CEPC Detector R&D Project

Contents

Introduction

This document introduces the CEPC detector R&D project for evaluation by the CEPC International Detector R&D Committee. It is a current snapshot of the on-going research projects, which is likely to evolve with time. The information should be kept confidential to the committee. It consists of eigth chapters. Chapter 1 describes the R&D of CEPC vertex detectors. Chapter 2 presents the tracking system. Chapter 3 presents the calorimeter options. Chapter 4 introduces muon detectors. Chapter 5 outlines the R&D of the detector solenoid. The challenging design of the interaction region is described in Chapter 6, together with the beam backgrounds and plans for the luminosity measurement. Chapter 8 presents detector related software and computing development.

Project Schedule

CEPC detector R&D project schedule at Level-3 work breakdown structure.

PBS	Task Name	Start	Finish
	CEPC Detector R&D Project	**2020/5/7**	**2026/12/31**
1	**Vertex**	**2020/5/7**	**2023/12/29**
1.1	Vertex Prototype	2020/5/7	2023/12/29
1.2	ARCADIA CMOS MAPS	2020/5/7	2021/12/31
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3.1.2	PFA Sci-ECAL Prototype	2020/5/7	2024/12/31
3.2	**HCAL Calorimeter**	**2020/5/7**	**2023/4/28**
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3.2.2	PFA Sci-AHCAL Prototype	2020/5/7	2023/4/28
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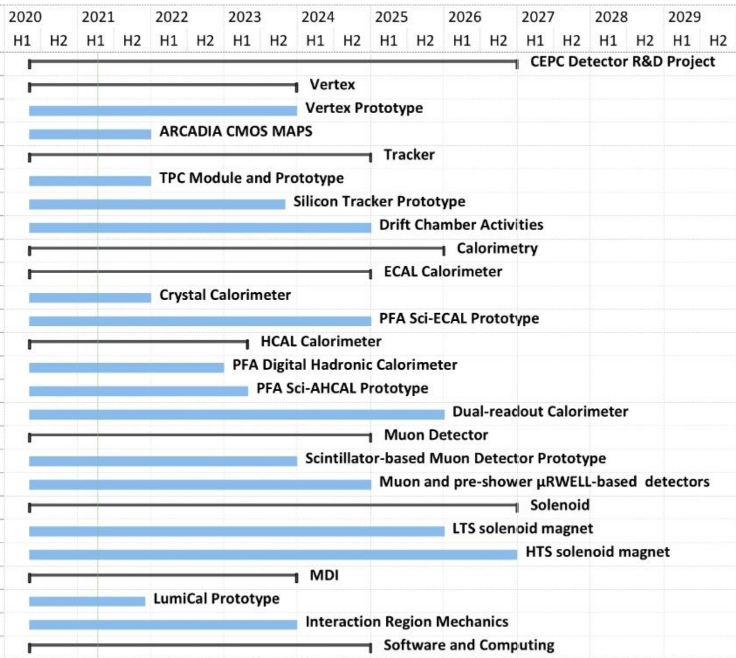
4	**Muon Detector**	**2020/5/7**	**2024/12/31**
4.1	Scintillator-based Muon Detector Prototype	2020/5/7	2023/12/29
4.2	Muon and pre-shower μRWELL-based detectc	2020/5/7	2024/12/31
5	**Solenoid**	**2020/5/7**	**2026/12/31**
5.1	LTS solenoid magnet	2020/5/7	2025/12/31
5.2	HTS solenoid magnet	2020/5/7	2026/12/31
6	**MDI**	**2020/5/7**	**2023/12/29**
6.1	LumiCal Prototype	2020/5/7	2021/12/1
6.2	Interaction Region Mechanics	2020/5/7	2023/12/29
8	**Software and Computing**	**2020/5/7**	**2024/12/31**



1 Vertex

1.1 Vertex Prototype

Document Responsible:	Ouyang Qun, Joao Guimaraes da Costa
Last saved by Joao Guimaraes da Costa on	4/11/2022 3:04:00 PM
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Change history

Revision	When	What changed and why
1	12/12/2019	First draft
2	5/5/2020	Completed the information
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iv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
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1.1 Vertex Prototype: Project Objectives

The project is to build a full-size prototype for CEPC vertex detector. The prototype should fulfill the CEPC requirement, especially the requirement on spatial resolution, time stamping precision, material budget, power consumption, as well as readout data throughput in Higgs runs, Z pole runs and WW threshold scan runs.

1.1 Vertex Prototype: Sub-projects Description

Project ID	Title	Description
1.1.1	Pixel sensor R&D	Sensor R & D for CEPC vertex detector
1.1.1.1	CMOS pixel sensor R&D	Baseline sensor R & D: Monolithic sensor with CMOS imaging technology
1.1.1.1.2	MOST1 CMOS sensor	CMOS R&D with Rolling-shutter readout, supported by the first CEPC grant from Ministry of Science and Technology (MOST1). Aim to develop high resolution and low power consumption pixel sensor.
1.1.1.1.1	Full size CMOS sensor	Full size CMOS pixel sensor using priority readout (FEI3-like and ALPIDE-like) with full functionality to be used in a pixel vertex detector. It is designed to obtain 25ns time stamp and fast readout pixel sensor.
1.1.1.2	SOI pixel sensor R&D	Alternative sensor R & D: Aim to Develop high resolution and fast readout pixel sensor with 3D connection technology and SOI technology
1.1.2	Low-mass ladder	Build low-mass Ladder to satisfy CEPC requirements, including the support structure prototyping and ladder assembly with automatic robot.
1.1.3	Readout electronics and DAQ	Readout electronics and data acquisition for ladder and vertex detector. Design data acquisition system to handle data transmission rate in Higgs runs, Z pole runs and WW threshold scan runs.
1.1.4	Detector Layout optimization	Use MC simulation to optimize the layout of vertex detector
1.1.5	Mechanical structure	Build a full-size low-mass mechanical structure for pixel detector
1.1.6	Detector integration	Install ladders on vertex detector structure, and integrated them into one system.
1.1.7	Detector test	Commissioning the detector system and perform beam test and study radiation hardness of the detetor.

1.1 Vertex Prototype: CEPC Relationship

The project aims to build a full-size prototype for CEPC vertex detector in barrel region and verify the performance in terms of spatial resolution, time stamping precision, material budget, readout data throughput. For short term, this is standalone vertex prototype R & D project. In longer term, this prototype should be integrated with beam pipe structure and incorporated into machine-detector interface R & D.

1.1 Vertex Prototype: Project Schedule

Project ID	Title	Schedule
1.1.1	Pixel sensor R&D	
1.1.1.1	CMOS pixel sensor R&D	
1.1.1.1.1	Full size CMOS sensor	2020: complete R & D for small-size full-functionality CMOS sensor using priority readout (FEI3-like and ALPIDE-like) 2021: complete R & D for full-size full-functionality sensor.
1.1.1.1.2	MOST1 CMOS sensor	2020-2021: test engineering-run CMOS sensors with Rolling-shutter readout, verify its power consumption lower than 100 mW/cm^2 and spatial resolution better than 5μm.
1.1.1.2	SOI pixel sensor R&D	2021: develop high resolution SOI sensor 2023: use 3D connection technology to inter-connect the high resolution SOI sensor and fast readout chip
1.1.2	Low-mass ladder	2020: first prototype of low-mass support structure of the Ladder. 2022: Assemble the first ladder prototype with full-size sensor
1.1.3	Readout electronics and DAQ	2021：complete readout system for one ladder 2022: Readout system for vertex detector prototype
1.1.4	Detector Layout optimization	2020: finish the optimization of detector layout with CEPC MC simulation
1.1.5	Mechanical structure	2021: Build a full-size low-mass mechanical structure for pixel detector.
1.1.6	Detector integration	By the end of 2022: complete the detector integration
1.1.7	Detector test	2021: radiation hardness tests of single sensor, verify it can survive 1MRad total ionization does irradiation 2022: beam tests of single ladder 2023: beam tests of full-size prototype, verify its spatial resolution better than 5μm.

1.1 Vertex Prototype: Funding Availability

The project is mainly supported by Ministry of Science and Technology(MOST).
The first CEPC grant from MOST (MOST1) is mainly to develop monolithic active pixel sensors with CMOS imaging technology and its frontend electronics for CEPC application. This sensor R & D is also supported by National Nature Science Foundation of China and IHEP innovation grant.
The second CEPC grant from MOST (MOST2) supports the R & D for a full-size CEPC vertex detector prototype.
Further, the alternative sensor development with SOI and National Nature Science Foundation of China.

1.1 Vertex Prototype: Leadership Arrangement

Funding agency	Project ID	objectives of the project	anticipated schedule	funding available(MRMB)/ leadership arrangements	CEPC-specific development
MOST1	1.1.1.1.2 MOST1 CMOS sensor	CMOS pixel	2016-2021	5.0/IHEP+CCNU	Aim to develop high resolution and low power consumption pixel sensor
MOST2	1.1 Vertex prototype	Full-size vertex detector prototype	2018-2023	12.0/IHEP+SDU +NWPU+NJU	Aim to build a full-size vertex detector prototype with 25ns time stamp and fast readout pixel sensor
NSFC	1.1.1.1.2 MOST1 CMOS sensor	CMOS pixel	2016-2022	1.1/IHEP	Aim to optimize the pixel sensing front-end
NSFC	1.1.1.2 SOI pixel sensor R&D	SOI pixel	2016-2023	4.0/IHEP	Aim to develop high resolution and fast readout pixel sensor with 3D connection technology
IHEP	1.1.1.1.2 MOST1 CMOS sensor	CMOS pixel	2015-2018	1.0(finished)	Aim to explore the CMOS process with optimization of sensing diode

1.1 Vertex Prototype: Manpower Resources

	objectives of the project	CEPC-specific development	Manpower resources		
			Faculty/ FTE	Engineer / FTE	Student/ FTE
MOST1	CMOS pixel	Aim to develop high resolution and low power consumption pixel sensor	5	1	3
MOST2	Full-size vertex	Aim to build a full-size vertex detector prototype with 25ns time stamp and fast	14	2	13

	detector prototype	readout pixel sensor			
NSFC	CMOS pixel	Aim to optimize the pixel sensing front-end	0.5		0.5
NSFC	SOI pixel	Aim to develop high resolution and fast readout pixel sensor with 3D connection technology	1.5	0.5	0.7
IHEP	CMOS pixel	Aim to explore the CMOS process with optimization of sensing diode			

1.2 ARCADIA CMOS MAPS

Document Responsible:	Manuel Rolo
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Change history

Revision	When	What changed and why
1	29/04/2020	First draft
2	11/01/2021	Updates the status and schedule of the project

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1.2 ARCADIA CMOS MAPS: Project Objectives

Since about two decades, the HEP community has actively worked on the development of monolithic active pixel sensors. MAPS offer significant advantages at the price of a reduced signal-over-noise ratio, essentially due to the reduction of the sensitive layer to the low resistivity epitaxial layer. Typically, these solutions are embodied in a silicon detector with thickness not exceeding 20 µm, even in the "opto" technologies, and charge collection by diffusion.

Several solutions have been proposed to overcome this initial limitation. The ARCADIA (Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays) collaboration is targeting the integration of pixel arrays on high resistivity fully depleted substrates, with the following main features:

- active sensor thickness in the range 50 µm to 500 µm;
- operation in full depletion with fast charge collection only by drift;
- small charge collecting electrode for optimal signal-to-noise ratio;
- scalable readout architecture with ultra-low power capability;
- compatibility with standard CMOS fabrication processes.

The main goal of the project, started in 2019 with a timescale of 3 years, is the design, production and commissioning of an array of 512x512 pixels with a pitch of 25 x 25 µm2 (total matrix area 1.28x1.28 cm2), embedded electronics performing sparsified readout and power consumption at the level of 20 mW/cm2.   This test vehicle is expected the be a viable prototype for applications at the next generation lepton colliders.

The reticle for the first tape-in, sent to foundry during Q3-2020, featured 800 mm^2 of innovative sensor and electronics designs, including full-scale system-grade demonstrators and test features exploring pixel pitches down to 10 um.

The project has been retained for funding within a competitive call by INFN-CSN5, with a budget around 1 MEUR. The extension of the R&D proposed for the ARCADIA program was included on WP5 of the recently approved AIDAinnova H2020-INFRAINNOV-2020-2 EU project.

1.2 ARCADIA CMOS MAPS: Sub-projects Description

Project ID	Title	Description
1.2.1	Sensor&Technology	Simulation and design of CMOS sensors
1.2.2	CMOS IP & Chip Design	Design of CMOS IP Cores and MAPS Chip Integration
1.2.3	Data Acquisition	Development of DAQ HW/FW/SW for the full-chip ARCADIA-MD1 MAPS

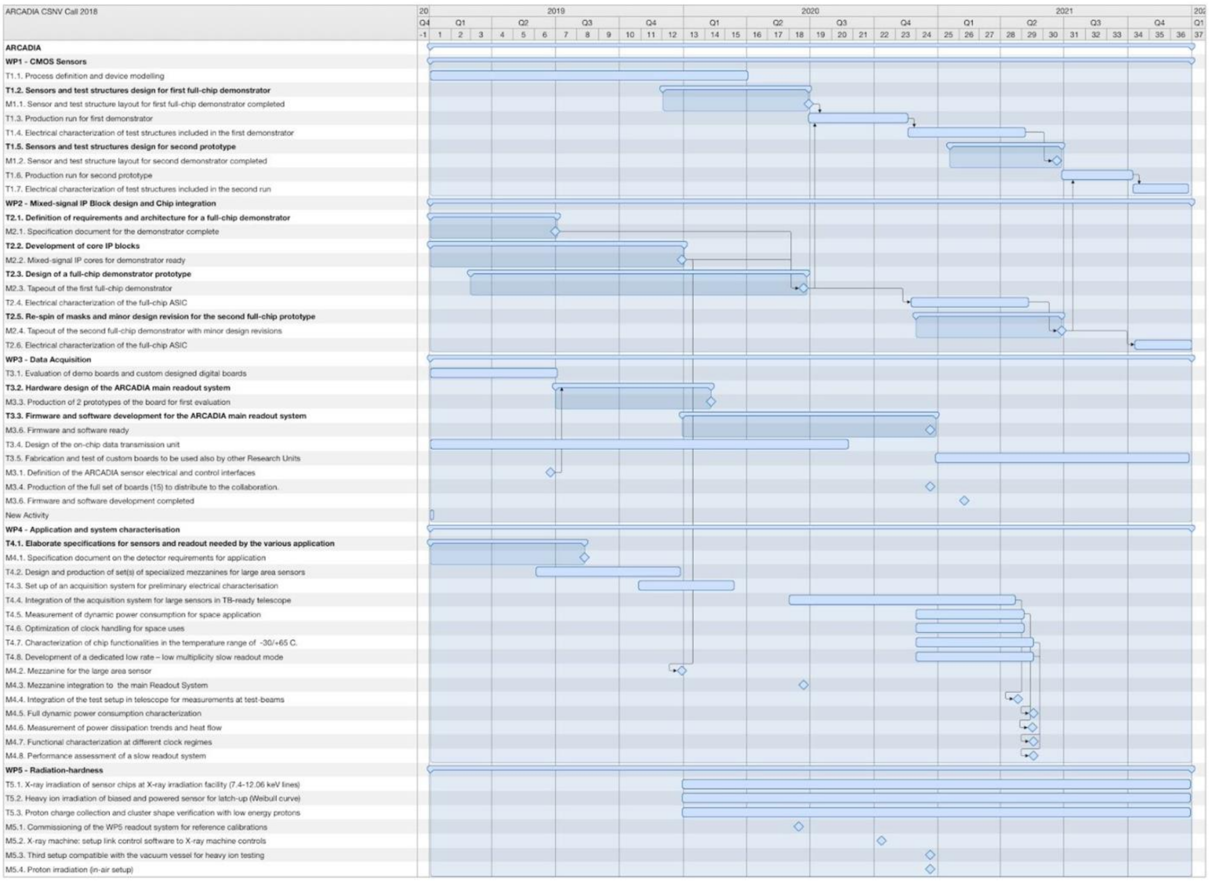
1.2.4	Application and System	Characterisation and system-grade validation, test beam and data reconstruction
1.2.5	Radiation Hardness	Radiation hardness characterisation
1.2.6	Space Applications	Characterisation and qualification for space applications

1.2 ARCADIA CMOS MAPS: CEPC Relationship

Reconstructing with the highest precision the perigee parameters of charged particle trajectories in a dense environment is essential for flavour tagging and secondary vertex reconstruction, fundamental tools in the exploitation of the physics program at current and future accelerators. This can only be made possible by using pixel detectors in the layers closer to the interaction point, as long as high spatial resolution, speed, low power and radiation & fault tolerance can be guaranteed.

1.2 ARCADIA CMOS MAPS: Project Schedule

The plan of the activities over the three year INFN project, started officially on January 1st, 2019, are summarized in the following Gantt chart:



At the time of writing (January 2021) the project is keeping track. The first engineering run featuring full-scale MAPS was sent for fabrication and the design and verification teams are working on a second engineering run scheduled for June 2021. The Collaboration collected laser, source and microbeam data from pseudo-matrixes and 2x2mm^2 small-scale MAPS available from previous silicon productions, demonstrating the ability to fully deplete the CMOS sensors in 100 and 300µm thick substrates.

1.2 ARCADIA CMOS MAPS: Funding Availability

The total cost of the project has been estimated to be 950 kEUR, largely dominated by the CMOS maskset and production runs. The full budget has been granted after the project was retained for funding, following a selection based on independent evaluators and a final discussion with a panel of INFN referees. Additional external funding, up to 400 kEUR, were secured by the Collaboration at the end of 2019 and will allow for extra silicon fabrication, back-end and stitching R&D.

1.2 ARCADIA CMOS MAPS: Leadership Arrangement

The management board of the ARCADIA project includes experts on CMOS and Sensor design, DAQ development, radiation hardness and application of innovative silicon tracker and sensors to frontier detectors in HEP, medical and space applications: Manuel Rolo (PI), Lucio Pancheri, Alessandro Gabrielli, Romualdo Santoro, Jeffery Wyss, Roberto Iuppa, Gianluca Traversi, Massimo Caccia.

1.2 ARCADIA CMOS MAPS: Manpower Resources

A total of 7 INFN Divisions contribute to the ARCADIA program, and the Collaboration active participants list is 55 people, mostly staff INFN and University Associates. The allocated manpower corresponds to an average value of 15 FTE/year, with about 3 FTE/year funded on the project budget.

2. Tracker

2.1 TPC modules and prototype

Document Responsible:	Qi Huirong
Last saved by Joao Guimaraes da Costa on	4/11/2022 3:04:00 PM
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Change history

Revision	When	What changed and why
1	12/12/2019	First draft v1.0
2	04/29/2020	Second draft v2.0
3	05/07/2020	Second draft with new schedules v2.1
4	01/06/2021	Third draft
5	01/11/2021	V6.0 draft
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2.1.1 TPC modules and prototype: Project objectives

Time Projection Chambers (TPCs) have been extensively studied and used in many fields, especially in particle physics experiments, including STAR and ALICE. Their low material budget and excellent pattern recognition capability make them ideal for three dimensional tracking and identification of charged particles. The TPC detector will operate in continuous mode on the circular machine. To fulfill the physics goals of the future circular collider and meet Higgs/Z run, a TPC with excellent performance is required. MPGDs with outstanding single-point accuracy and excellent multi-track resolution are needed. We have proposed and investigated the ions controlling performance of a novel configuration detector module. The aim of this study is to suppress ion backflow (IBF) continually.

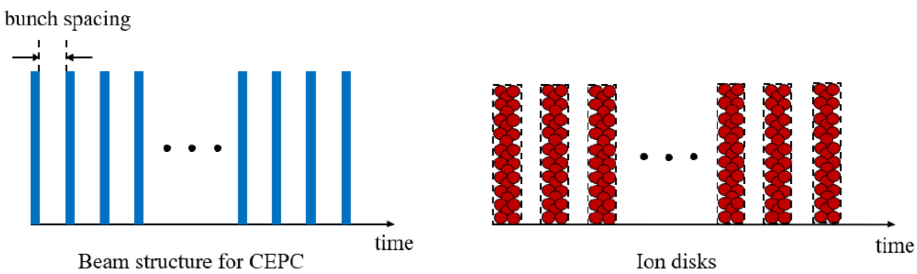

Fig. 1 The beam structure of CEPC with the specific bunch spacing for the Higgs, W and Z bosons (Left) and the structure of ion disk with equal spacing and thickness (Right).

The CEPC is a circular electron-positron collider with a 100 km circumference and two interaction points (IP). In the CEPC CDR,5 the bunch spacing as Fig. 1 (Left) of the Higgs, W and Z bosons is approximately 760ns, 200ns and 25ns, respectively. On the one hand, the CEPC beam structure will cause the subsequent ion disk as Fig. 1 (Right).

Nevertheless, IBF×Gain has the limitation ratio from the detector R&D at high gain. The new idea for pixel TPC is being considered as the option to take the place of the traditional MPGDs. Its gain is less than 2000, and there is almost no IBF×Gain. It can handle the massive data rates during CEPC Z running. The pixel occupancies are low, and the pattern recognition will have no problem to separate events and find the tracks. If CEPC produces close to one trillion or not one million Z bosons, the technology of TPC needs to be adopted. Moreover, the pixel TPC needs to be considered under a higher luminosity. Pattern recognition will be no problem. The occupancies in the pixel plane are low. The time between the Z interactions is large 120μs. The time will be measured by each pixel. The resolution is dominated by longitudinal diffusion. It amounts to less than about 20 nsec. Different Z events can be easily separated in time.

2.1.2 TPC modules and prototype: Sub-projects description

Project ID	Title	Description
2.1.1	Pads TPC module	The continuous IBF suppression TPC module for the circular collider's beam structure using the traditional pads readout
2.1.2	Pixel TPC module	Pixel TPC module with low gain, IBF study for the circular collider, Rates and occupancies, Cost estimation
2.1.3	Minimum module boundary distortion	Minimum module(even without) adjacent modules boundary distortion
2.1.4	Low material budget of the chamber and readout board	Low material budget to satisfy CEPC requirements, Field cage and connector and barrel, Low-mass mechanical structure for TPC detector, Stability and strong supporting
2.1.5	TPC prototype R&D	High space resolution with MPGD, continue IBF suppression detector module
2.1.6	FEE electronics	Low power consumption R&D for FEE electronics and ASIC chips
2.1.7	Calibration and alignment	266nm UV laser beams to calibration and alignment study with TPC prototype
2.1.8	Cooling system	CO_2 cooling for the readout to reach below 25^o
2.1.9	HV and low power supply	Low power crate, connector, cable and HV system
2.1.10	Data analysis and software	With the common raw data analysis framework and software of LCIO, Marlin TPC, Kalman filter reconstruction, DAQ and LabView software to run and display

2.1.3 TPC modules and prototypee: CEPC Relationship

The preliminary baseline design of CEPC detector is a PFA concept, with a superconducting solenoid of 2.0-3.0 Tesla surrounding the inner silicon detector, TPC tracker detector and the calorimeters system. In order to accommodate the CEPC collision environment, some necessary changes have been made to the Machine Detector Interface (MDI) and sub-detector design. The CEPC design, for instance, has a significantly shorter focal length L* of 1.5-2.0m than that of the ILC design (3.5m), which indicates that the final focusing magnet QD0 will be placed inside the CEPC detector. In addition, unlike the ILC detector, the CEPC detector will operate in continuous mode, which imposes special considerations on power consumption and subsequent cooling of the sub-detectors.

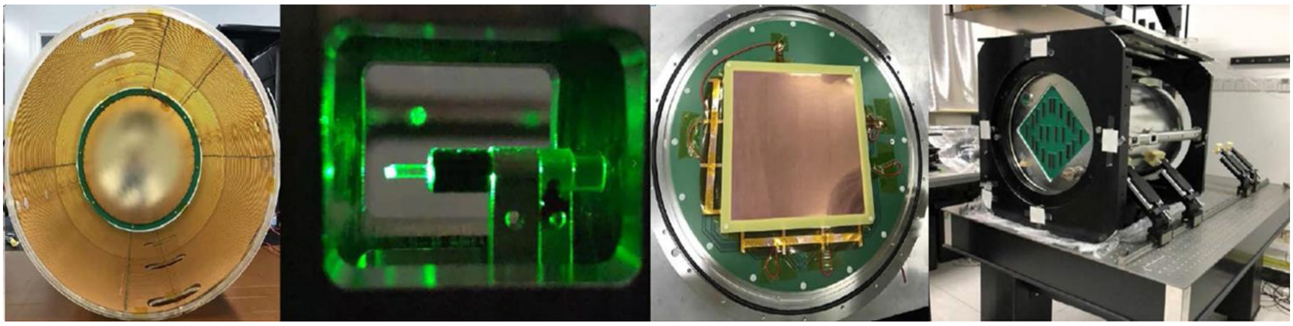

Fig. 2 TPC prototype integrated with 266nm UV calibration system

The CEPC CDR and updated parameters are updated. According to this update parameters, the luminosity increase factor for Higgs and Z(2T) are 1.8 and 3.2 respectively from CEPC CDR to Updated parameters. The conditions for CEPC running High(est) luminosity CEPC L = 32×10^{35} $cm^{-2}s^{-1}$ at 2 T from CDR. CEPC Ring length 100 km with 12 000 bunches and a hadronic Z rate of <32 k Hz (cross section 32 nb). Beam structure rather continuous 25 ns spacing. Note that this Luminosity gives about 60-185 Gega Zs per running year. Time between Z interactions 200-70 μs and TPC drift time will take 30 μs, so events are separated in the TPC. Running at the Z with high luminosities and high rates is however problematic for current gaseous detector pad technologies. Tracks will overlap in the read-out plane and the occupancy at low radii will become higher. Under high-luminosity operation, CEPC will produce close to one trillion Z bosons, 100 million W bosons and over one million Higgs bosons to provide precision measurements of their properties. Additionally, it is an excellent opportunity to search for Beyond the Standard Model (BSM) physics. Correspondingly, TPC as a tracker detector needs to meet perfect position resolution and high count rate. The main problem is how to evaluate and solve space charge effects and distortions caused by positive ion backflow. The following subsections will give brief details about the evaluation of space charge effects in CEPC TPC.

Aiming for the CDR and TDR of the CEPC project, two-phase funding scheme is proposed by the funding agency, the Ministry of Science and Technology (MOST) of China. To launch the project, the MOST funded the CEPC accelerator and detector R&D project for phase-I period of 2016-2021. Among sub-detectors, the feasibility study of the TPC tracker detector was initiated for the purpose to identify feasible technology options and to gain expertise to build the detector units which meet the basic requirements of the CEPC detector design. The specific research goals of this MOST project are described as following.

2.1.4 TPC modules and prototype: Project schedule

TPC module R&D schedule

From 2016-2021, we will finish that some simulations and estimations of TPC readout module with IBF suppression function in TPC module R&D group, and we will do that some simulations and estimations of TPC technology at Tera/Mega Z according to the update new parameters from CEPC update CDR. We will setup and finalize TPC module and TPC smaller prototype at IHEP, the experiment of the resolution and IBF/Electron transmission will be done.

Concerning the pixel TPC R&D and LCTPC Collaboration, we cooperate with Nikehf staffs of Prof. Peter Kurit and Kees who in charge of simulation. The preliminary study of IBF with the low gain is started.

TPC Prototype R&D schedule

From 2020-2021, we will finish that some simulations and estimations of TPC prototyupe at Tera/Mega Z according to the update new parameters from CEPC update CDR in TPC prototype R&D group, We will setup and finalize TPC smaller prototype at IHEP according to the beam test schedules, we will want to study TPC prototype in 1.0T magnetic field. Aimed to the minimum (even without) adjacent modules boundary distortion, the resistive anodes modules and the prototype with it will be developed.

Concerning TPC R&D and LCTPC Collaboration, we will cooperate with some staffs in KEK, DESY, Saclay who in charge the software packages and data analysis.

2.1.5 TPC modules and prototype: Funding Availability

In MOST's project of CEPC R&D, I have finished to arrange TPC review and got the very positive comment. The detector, FEE electronics and DAQ system with 1280 channels has been done for TPC R&D. Some update experimental studies of the UV laser beam in TPC prototype will be done and analyzed. The radioactive tolerant (larger than 3Mrad) of the low power consumption ASIC chips have been tested and the performance are stable. In National Natural Science Foundation of NO.11975256 and NO. 11675197, the continuous ion backflow suppression TPC module has been measured and all the recommendation parameters of the lower IBF ratio, the gain requirements, the high voltages will be studied.

2.1.6 TPC modules and prototype: Leadership arrangement

Full time group and staff of Qi Huirong are from IHEP, CAS. He is involved in the related filed of IBF study, the TPC model and TPC prototype R&D from 2016. In this group, Zhang Jian is an engineer for TPC R&D in charge of the design and mechanic study. There are two students of Yuan Zhiyang and Chang Yue.

Half full time group and staff of Deng Zhi are from Tsinghua University. He is involved in the related filed of FEE study, the TPC model and TPC prototype R&D from 2016. In this group, Deng Zhi is a professor for TPC FEE ASIC chips R&D in charge of the design and test study. There are some students of Liu Wei, Cai Yiming and Huang Yuyan.

2.1.7 TPC modules and prototype: Manpower resources

FTE staffs from IHEP

In this group, Zhang Jian is an engineer for TPC R&D in charge of the design and mechanic study. There are two students of Yuan Zhiyang and Chang Yue.

FTE staff from Tsinghua

In this group, Deng Zhi is a professor for TPC FEE ASIC chips R&D in charge of the design and test study. There are some students of Liu Wei, Cai Yiming and Huang Yuyan.

Type	Average FTE Expected
Faculty	3
Students	**4**
Engineers	1

2.2 Silicon Tracker Prototype

Document Responsible:	Harald Fox, Meng Wang
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	**When**	**What changed and why**
1	28/12/2019	First draft
2	11/05/2020	Adding Italian groups; updated schedule
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2.2 Silicon Tracker Prototype: Project Objectives

The project objective is to define a Silicon Tracker that fits the detector requirements outlined by the CDR document, in particular the detector resolution, timing and material budget.

2.2 Silicon Tracker Prototype: Sub-projects Description

Project ID	Title	Description
2.2.1	CMOS pixel sensor and strip sensors	Full size CMOS pixel sensor with full functionality to be used in a silicon tracker detector
2.2.2	Readout electronics & DAQ	Data throughput and 680ns / 25ns readout of the detector
2.2.3	Low-mass staves	Low-mass support and cooling structure for sensors
2.2.4	Mechanical structure	Low-mass mechanical support structure
2.2.5	Module building	Pick and Place options for automatic building
2.2.6	Detector simulation	Investigate the overall detector design based on physics benchmark processes.
2.2.7	System test	Test of full system, including beam tests
2.2.8	System integration	Integration of all systems into a complete detector

We envisage a number of prototypes to study electrical/DAQ, mechanical and thermal properties. Mechanical properties need to be studied for short staves, long staves and the support structure. For the overall design, one will also need to consider the interplay between vertex detector and tracker barrels and disks.

2.2.1 CMOS pixel sensor. Given the aggressive time scale there is little time for the development of new sensor technology. Thus a monolithic silicon CMOS sensor based on already existing technology is selected as baseline, with adaptations to CEPC and improvements being developed.

2.2.1.1 ATLASPix3/ARCADIA/FCEPCPix1. A working baseline sensor is ATLASPix3 with a pixel size of 50 x 150 µm and 25 ns readout. This sensor achieves the required spatial resolution and efficiency (> 99%) with a state-of-the-art power consumption. Another sensor fulfilling the requirements as well is for example MuPix.

Another candidate sensor is the ARCADIA chip which implements 25 x 25 µm pixels with peripheral readout, achieving an extremely low power consumption. This sensor concept and the associated foundry allow for stitching of sensors, high-resistive wafers and back-side processing.

Characterisation of considered sensors have included laser measurements, radioactive sources and beam tests. Further tests will include small-spot laser measurements, irradiation programmes and further beam tests in addition to further lab measurements. Lancaster, IHEP, Bristol, KIT, Como, Milano and Torino are interested in evaluating bulk sensor properties.

There will be an engineering run of an updated sensor design in April 2020 (FCEPCPix1), evolving ATLASPix3 in order to accommodate data aggregation (to reduce the number of data links required), optimise the pixel geometry to 25 x 200 – 300 µm improving pT resolution by halving the r-phi pitch, and test improved dE/dx capabilities. Similarly ARCADIA is being developed further, in particular an engineering run with full pixel matrix is planned.

KIT, Liverpool and Torino are chip design institutes working on sensor designs and the related chip testing.

2.2.1.2 FCEPC40Pix. It is desirable to be able to produce the monolithic CMOS tracker sensor in China. Therefore the possibility of a port of a relevant chip design to a Chinese fab (e.g. SMIC or HHGrace) will be explored. Processes with smaller feature sizes will also be investigated as they could offer both smaller pixels (better resolution) and lower power consumption. Based on development and testing cycles any significant new development and port to a new process could take up to 6 years. KIT, IHEP, NWPU and HITWH are interested in this development.

2.2.1.3 Pixel sensor development. Some sensor developments should be evaluated in addition to the baseline efforts, e.g. SUPix, which is a sensor developed at Shandong University that will be pursued as a first-principles generic CEPC sensor (rather than a sensor adapted to CEPC). NWPU is another institute that has experience with both, MAPS and Chinese foundries.

2.2.1.4 The silicon strip option is based on the possibility to use a reduced set of masks from a commercial CMOS process to implant strip diodes and top-level metal lines for readout on commercially available high-resistivity substrates used for RF application. The reticle size for commercial CMOS processes is limited to about 20x30 mm^2 area, but large are detectors can be achieved by stitching the reticle. This production process may be competitive with the traditional processing of a wafer-size mask on detector-grade silicon substrate, for which it is difficult to find reliable manufacturers for large size production. Some strip detectors are being produced by LFoundry as a byproduct of a larger production of passive pixel detector by the ATLAS Collaboration. They use the 150 nm process and will be available in January 2020. Besides the possibility to achieve a large production size at reasonable costs, using a CMOS process may allow both the integration of further features, like a multiplication layer aiming at achieving good timing resolution, or integrating the readout electronics, providing monolithic strip sensors. Como and Milano in particular are interested in developing this option.

2.2.1.4 Sensor powering. Any chip technology needs to adopt either serial powering or DC-DC conversion as part of its powering scheme to reduce the material budget otherwise necessary to accommodate the massive low voltage supply currents.

2.2.2 Readout Electronics & DAQ. For the purposes of the CMOS tracker, the readout electronics/DAQ comprises the data and power bus cable (often envisaged to be a flexible PCB ("flex"), an opto-conversion (and aggregation) stage at the end-of-stave/structure and a prototype DAQ system that will evolve into a counting room design.

2.2.2.1 Stave Flex. There is an existing "module flex" design effort for ATLASPix3, based on a 2×2 sensor matrix (quad module) produced by Milano and using industry standard copper-on-Kapton technology. This will be used for an electrical prototype testing the readout. USTC, RAL, Liverpool, Edinburgh and Milano are interested in the flex design.

2.2.2.2 GECCO/YARR/CaRIBou. The powerful and scalable RD53 YARR readout system is based on cost-efficient off-the-shelf PC components and will be used to test individual chips and quad modules, and can be scaled up to read out full stave prototypes. Thanks to its modular nature, its suitability for the final off-detector DAQ will be studied with the upgraded version. This is the baseline option and Lancaster and Edinburgh are interested in developing the YARR readout. In the short term the GECCO readout system used by KIT is available for sensor testing. The CaRIBou readout system has been developed for various sensor developments and has implemented

ATLASPix3. It can also use FELIX as a backend. We will investigate all three readout options. Almost all participating institutes are interested in developing the readout and hosting a system on site.
2.2.2.3 FELIX. There is also experience in various groups in China and the UK, such as USTC and RAL, with the FELIX readout system, which is the envisaged ATLAS DAQ system for the whole detector based on high-end custom FPGA-PCIe-cards.
2.2.2.5 End-of-stave electronics. Depending on the chip that is being used, data will be aggregated at the end of the stave. In either case there will be an opto-conversion for a low mass single connection to the readout. (USTC & SJTU, RAL)
2.2.3 Low Mass Staves. Both ATLAS and ALICE use a carbon fibre truss structure for support of the flex and sensors, with ALICE having the lower material budget. The driving factor is cooling, where the requirements for ALICE are lower as they do not require 25ns readout. First FEA analyses of a stave with cooling pipes look promising.
2.2.3.1 Ti-Pipes with bi-phase CO_2. There is considerable expertise within the UK groups (especially Lancaster, Liverpool, Sheffield and RAL) with Ti-pipes and bi-phase CO_2 coolant developed for the ATLAS experiment. This will be pursued as the baseline option.
2.2.3.2 ALICE-style low pressure water-cooling will be investigated as an alternative, in particular with view of the material budget.
2.2.3.3 Micro-channel cooling can provide highly efficient cooling with low material budget. This option will be studied in parallel. Liverpool and Pisa are interested in developing this option.
2.2.3.4 End-of-stave cooling is another option that should be investigated.
2.2.3.5 Air-cooling is one of the options that should be investigated, depending on the overall size of the tracker, the expected power consumption of the sensor and the compactness of the detector layout.
2.2.3.6 The ALICE, ATLAS and CMS truss structures will be evaluated in detail for an updated design to minimise the material requirement. Liverpool, Pisa, Daresbury and Lancaster are interested in the design and prototyping of this structure.
2.2.4 Mechanical Structure. We envisage a carbon fibre based support structure for the overall system. In particular Liverpool and Pisa are interested in this investigation.
2.2.5 Module Building. Depending on the detector option a Full Silicon Tracker can have an active area of over $100m^2$. We will be looking into industrial scale building options for detector staves. There is experience in the UK, Italy and China with the ALICIA pick and place robot. Options to extend this to CEPC will be investigated.
2.2.6 Detector Simulation. The design of the tracker is driven by physics requirements. In particular the impact of the material budget on benchmark physics processes will be investigated (Edinburgh, Warwick, Lancaster). The usage of dE/dx for particle ID and heavy flavour object tagging will also be studied. The number of layers will be a limiting factor. Whilst it is possible to provide dE/dx with the existing sensor and electronics, a cost/benefit analysis will be performed.
2.2.7 System Test. Evaluating a full stave(let) with cooling, a number of sensors, a stave flex/power bus and full speed readout of all modules will be performed on its own, with cosmics and possibly with a beam. Interested institutes are Bristol, Daresbury, RAL, IHEP, Lancaster, Edinburgh and USTC.
2.2.8 Integration. Detector integration of staves, support structure, DAQ and services.

2.2 Silicon Tracker Prototype: CEPC Relationship

This project makes heavily use of the ATLAS and ALICE experience in China, Italy and the UK. There is also overlap with the LHCb upgrade R&D in China and the UK. The R&D is useful for any collider with up to 25ns BX timing, but given the proposed timescale the R&D is aimed primarily at the CEPC.

2.2 Silicon Tracker Prototype: Project Schedule

The project schedule depends on the available funding.

- November 2020: Evaluate sensor options. Start physics simulations.
- November 2020: First prototype stavelet based on ATLASPix3 with quad modules mounted on carbon fibre with established readout.

- May 2021: Electrical and mechanical prototypes. One long stave. First simulation results.
- November 2021: Testing of CEPC sensor minis
- December 2021: Physics simulation informs the first overall detector design, prototype with 4 layers, prototype ladder finished.

- May 2022: Decision on detector readout system; Scale up of readout system
- October 2022: Mechanicial prototype of large support structure
- November 2022: Testing of production CEPC sensors

- May 2023: Comissioning of large scale testing system of prototypes and production ladders
- October 2023: Medium scale cooling prototype
- November 2023: Prototypes and large scale structures with CEPC sensors

2.2 Silicon Tracker Prototype: Funding Availability

There is no dedicated CEPC funding available at this time. All activities are funded by group budgets. R&D activities are derived from ATLAS, ALICE or LHCb developments where all sides profit from a parallel development.

Dedicated funding is needed and will be sought, while project approval would be helpful in doing so.

2.2 Silicon Tracker Prototype: Leadership Arrangement

WANG Meng, Shandong University
Harald FOX, Lancaster University
Groups involved:
Hongbo Zhu & Jianchun Wang, IHEP; Xin Chen, Tsinghua; Changqing Feng, USTC; Yann Hu, NWPU; Weihao Wu, SJTU/TD Lee; Chenxu Wang, Harbin Institute of Technology; Yanyan Gao, Edinburgh; Tim Jones, Liverpool; Jaap Velthuis, Bristol; Jens Dopke, RAL; Roy Lemmon, Daresbury; Trevor Vickey, Sheffield; Bill Murray, Warwick; Ivan Peric, KIT (Karlsruhe, Germany); Massimo Caccia, Como; Attilio Andreazza, Milano; Franco Bedeschi, Pisa; Manuel Da Rocha Solo, Torino.

2.2 Silicon Tracker Prototype: Manpower Resources

Type	Average FTE Expected
Faculty	50
Postdoc	0
Students	4
Engineers	5

Note: As the experiment has not been approved and hence is not being funded, present activities are mainly restricted to academic time at the 10-20% level and student projects, with occasional expert involvement from PostDocs and engineers. Once the experiment is approved and funded, and other funded projects are wrapping up, involvement can rapidly be increased.

2.3 Drift Chamber Activities

Document Responsible:	Franco Grancagnolo Mingyi Dong Linghui Wu
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	When	What changed and why
1	13/12/2019	First draft
2	28/04/2020	Update on funding availability
3	05/01/2021	Update on scheduling and funding
4	06/04/2022	Update on the drift chamber for the CEPC 4th detector conceptual design
5	08/04/2022	Update on IDEA drift chamber
		< Add further lines to table as required >

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iii. Don't change field directly, instead modify the document options, under File→ Properties (or similar)
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   - The project name should be changed in Document:Summary: Subject.

iv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

v. Finally, remember to update the *Change History*.

2.3 Drift Chamber Activities: Project Objectives

The proposed Cluster Counting/Timing technique, which consists in measuring the arrival times on the sense wires of each individual ionization cluster generated in a drift cell, offers the possibility of greatly improving both the momentum resolution and the particle identification capabilities of this kind of gas sampling detectors (separation powers of better than a factor two with respect to the traditional method of dE/dx have been demonstrated experimentally). The drift chamber proposed for the IDEA detector exploits the peculiarities of such a tracking system.

The technique is also being studied for the drift chamber of the CEPC 4th conceptual detector. A drift chamber between the silicon inner tracker (SIT) and silicon external tracker (SET) is expected to provide excellent particle identification on charged hadrons for flavor physics and jet study, and also benefit the tracking.

The objectives of the R&D projects are relative to the four different tasks listed as follows.

2.3 Drift Chamber Activities: Sub-projects Description

Project ID	Title	Description
2.3.1	Development of new wire materials.	Find suitable proposals for new wire materials together with the corresponding technologies for anchoring the wires to the endplates.
2.3.2	Development of a DAQ board specific to Cluster Counting/Timing for data reduction and pre-processing of drift chamber signals sampled at high rates.	Implement, within a single FPGA board, peak finding algorithms on a large number of analog to digital conversion channels (128 being the ultimate goal), for parallel pre-processing, to reduce costs and system complexity, and to gain on flexibility in determining proximity correlations among hit cells for track segment finding and triggering purposes.
2.3.3	Construction of a full length drift chamber prototype.	Full mechanical test of the proposed innovative technologies on the new types of wires and of the new concepts for the design of the drift chamber wire structure placed inside a light gas-tight envelope.
2.3.4	Simulation and prototype studies on the PID performance of the drift chamber in the CEPC 4th conceptual detector	Simulation study of the PID performance for optimizing the design of the drift chamber. Prototype test for validating the cluster counting technique.
2.3.5	Beam test of drift tubes, aimed at optimizing cluster counting algorithms, and relative analysis and at measuring the cluster density in the relativistic rise region	Test of different size drift tube equipped with different diameter sense wires exposed to a muon beam of 165 GeV/c. Data taken in Nov. 2021. Development of dedicated peak counting algorithms. Definition of the parameters for a beam test during summer 2022 to study particle identification in the relativistic rise region.

2.3 Drift Chamber Activities: CEPC Relationship

The first three activities are strictly (almost exclusively) related to the design of the central tracking chamber of the IDEA detector, for both the CEPC and the FCC-ee.

The fourth activity is related to the design of the drift chamber of the CEPC 4th detector.

2.3 Drift Chamber Activities: Project Schedule

Project 2.3.1 has received funds from INFN CSN1. Activity was expected to start in 2020 and to be completed by the end of 2022. In the meantime, we are currently engaged in tests of light polymeric fibers and Carbon monofilaments and in different technologies for anchoring such wires to the endplates. Because of the unexpected situation due to the COVID-19, this project will suffer a delay, currently estimated in approximately 9 months.
Most of the activity and of the successful results were obtained in strict collaboration with colleagues from Budker Institute of Nuclear Physics at Novosibirsk, Russia. The current world political situation imposes a temporary halt to this project, however, we are in the process of finding a different strategy for pursuing the sought objectives. Clearly, the time scale of this project will need to be readjusted accordingly.

Project 2.3.2 has received funding from INFN/CSN1 for the design of a FPGA board with two RO channels, which should be completed by the end of 2020. Here again, we expect a six months delay due to the COVID-19. Moreover, in the framework of the AIDAinnova project, we have been funded for the extension of this FPGA board from 2 to 4 channels, to be completed by the middle of 2024.
A simple cluster counting algorithms has been implemented on the FPGA (Electronics Engineering Master Thesis) to compare different models of data processing and storage. ”Slow" signals on a single channel ADC have been used for these tests. A comparison of different models has shown that creating a buffer inside the FPGA (even with a faster external memory) worsens the peak finding efficiency and the most efficient model is to have small buffers and to send the peak information directly.
We have started a collaboration with engineers from CAEN, who will provide us with their latest developed digitizer for implementing our peak finding algorithms and testing their architecture as a possible implementation of our final board.
We have initiated also an exchange program with Nalu Scientific for the test of a new, compact, high performance, digitizer equipped with the ASOC V3 chip. An evaluation board is being delivered to us.
A post-doc position and a support fellowship for a perspective PhD student have been granted by INFN and will start, respectively, in fall 2022 and in spring 2022.

Project 2.3.3 is staged in three different steps.

The first one includes the construction of small drift tube prototypes to test the new wire types and the RO scheme with FPGA board prototype of project 2.3.2. For this step, we have received funds from INFN CSN1. We expect to complete these prototypes by the middle of 2022.

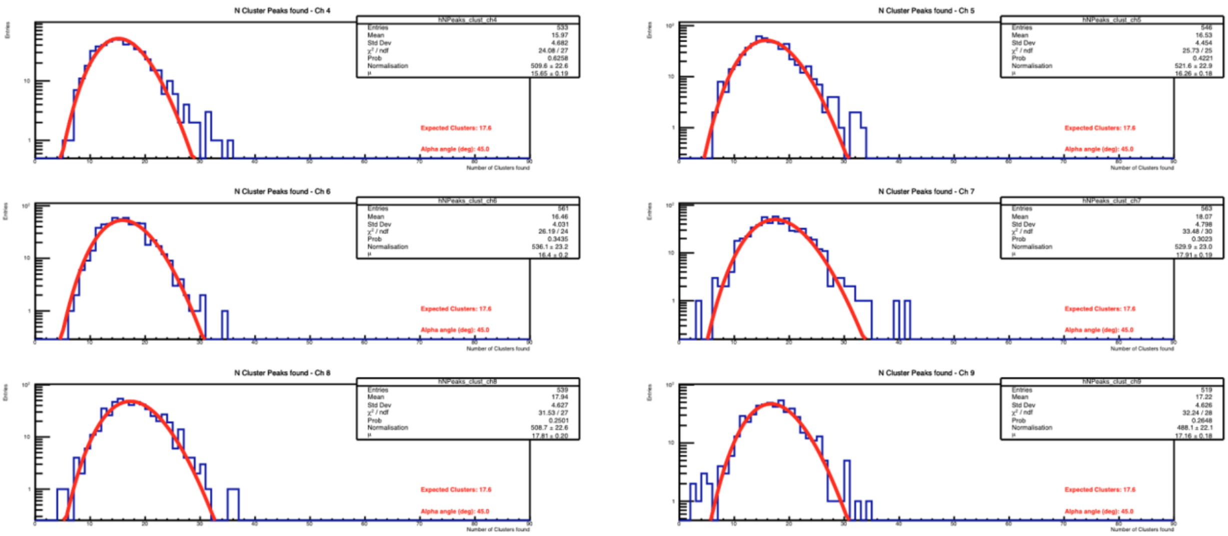
The second step, which is supposed to start during spring 2020, with funds secured by the already financed CREMLINplus program, foresees the construction of a drift chamber for the CMD-3 experiment at the Budker Institute for Nuclear Physics at Novosibirsk, Russia. This chamber will

exploit the same technology, including the new concept for the wire support structure, as the CEPC/FCCee prototype and, therefore, will act as a full system test of the IDEA drift chamber, except for the reduced dimensions. Commissioning of this chamber will occur at during 2024. Once more, due to the unexpected COVID-19 situation, this step will suffer a delay of approximately 9 months.
The current world political situation imposes a necessary modification of our initial plans. We are in the process of converting the funded CREMLINplus program into a new program EURIZON, no longer addressed to collaborations with Russian Institutes and with the objective of building a drift chamber prototype for the next generation of lepton colliders: FCC-ee and CEPC.
In summary, the second step of project 2.3.3 has been canceled and, hopefully, the secured funds will be addressed to the fulfillment of the third step.

The third, more ambitious step concerns the construction of a full-scale prototype, 4 m long, to fully demonstrate the mechanical and electrostatic stability of the proposed solutions, together with the capability of data reduction and pre-processing of the multichannel RO board. Funds for this step will need to be secured.

Project 2.3.4 has received the Science and Technology Innovation Project fund from IHEP, which aims to support the R&D efforts for the drift chamber in the CEPC 4th conceptual detector. Both simulation study and prototype test will be carried out. A waveform-based full simulation chain will be developed, which includes realistic waveform generation with electronics and noise effects and waveform analysis by utilizing effective cluster counting algorithms. The design of the drift chamber will be optimized based on the simulation study. A prototype including electronics boards will be designed and developed to validate the cluster counting technique and further optimize the design of the drift chamber.

Project 2.3.5 An ambitious test campaign has started on different configurations of drift cells to establish the optimal operating parameters for an efficient application of the cluster counting/timing techniques, aimed at separating particles in the relativistic rise region up to the Fermi plateau. A first test has been performed in Nov. 2022 at the H8 beam line of CERN, Geneva, Switzerland, with beams of muons of different momenta, to cover up a range of as wide as available, impinging on an experimental setup constituted of drift tubes of different size, instrumented with sense wires of different diameter and supplied with different gas mixtures, in order to establish the limiting parameters for an efficient cluster counting with respect to gas gain saturation, cluster density and space charge effects. Essential tool for demonstrating the ability to efficiently count clusters is a proper peak finding algorithm to isolate the ionization electrons in the digitized signals coming from the drift tubes.
The expected number of ionization electrons, found by the algorithm, follows a Landau distribution. The association of electrons in clusters is then performed according to their relative time delay (electrons belonging to the same primary cluster are separated in time by no more than the spread due to their diffusion, which, in our configuration, amounts to about 2.5 ns). The distributions of the number of clusters must then follow a Poisson distribution, as shown in the following figure.



Poisson fits to the distribution of the number of clusters in 6 different 1 cm drift tubes.

We are currently in the process of defining the optimal parameters for a beam test during summer 2022 to study in detail the particle identification in the relativistic rise region.

2.3 Drift Chamber Activities: Funding Availability

During 2019, we have been funded from INFN-CSN1 with 4.5 keuro for the first phase of project 2.3.2 and, for the years 2021-2024, 70 keuro for its continuation from the AIDAinnova project.

During 2020, we have been funded from INFN-CSN1 with 16.5 keuro for studies on new wire materials and for small drift tubes prototypes.

During 2021 and 2022, we have received funds from INFN-CSN1 for about 30.0 keuro.

We are in the process of converting the funds assigned under CREMLINplus (364 keuro) in funds for EURIZON for realizing Projects 2.3.1, 2.3.2 and 2.3.3.

We are going to ask for support for the beam test of summer 2022.

We can count on adequate support for travel to China according to the MISE-FEST agreement.

IHEP group has been funded from IHEP (Science and Technology Innovation Project) with 1.5 million RMB for years of 2022-2024.

2.3 Drift Chamber Activities: Leadership Arrangement

Leading institute for the first three projects will be INFN-Lecce (coordinated by F. Grancagnolo). Given the geographic proximity, INFN-Bari (coordinated by N. De Filippis) will actively participate in all phases of the R&D, although common tasks will be clearly differentiated and each unit will autonomously contribute to the whole project.

Significant support will be given by the industrial companies EnginSoft (coordinated by M. Perillo), for what concerns simulations and finite element analysis of the mechanical structures, and by CAEN (coordinated by A. Iovene) for what concerns industrialization of the different versions of RO boards.

Leading institute for the fourth project is IHEP (coordinated by Mingyi Dong and Linghui Wu)

2.3 Drift Chamber Activities: Manpower Resources

For each of the 4 years of the R&D program

Type	Average FTE Expected
10 Faculty	2.5
3 Postdoc	2.4
3 PhD Students	1.8
4 Engineers	0.8

For IHEP 3 years of the R&D program

Type	Average FTE Expected
9 Faculty	2.7
3 PhD Students	1.6
2 Engineers	0.6

3. Calorimetry

3.1 ECAL Calorimeter

3.1.1 Crystal Calorimeter

Document Responsible:	Yong Liu
Last saved by Yong Liu on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	When	What changed and why
1.1	18/12/2019	First draft using the universal .docx template
2	06/05/2020	Updated objectives, funding situations and person power
3	06/01/2021	Updates on the wording, objectives/timelines and taskforce
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iv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **3.1.1 Crystal Calorimeter**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
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3.1.1 Crystal Calorimeter: Project Objectives

A novel highly granular crystal electromagnetic calorimeter (ECAL) has been recently proposed in the context of the particle-flow oriented detector design for future lepton colliders, firstly raised and discussed in the CEPC Topical Workshop on Calorimetry in March, 2019. One major motivation is to achieve an optimal intrinsic energy resolution using the homogeneous calorimetry design with scintillation crystals while maintaining the capability to the particle-flow algorithms (PFA) for precision measurements of jets with finely segmented detector cells. One major physics motivation is to be sensitive to low-energy photons, which can help the electron energy measurements (with Bremsstrahlung corrections) to improve Higgs recoil mass measurements. Another motivation is to be able to trigger on single photons, which can play an essential role in the flavor physics programs (at the Z-pole) as well as searches for new physics.

3.1.1 Crystal Calorimeter: Sub-projects Description

Project ID	Title	Description
3.1.1.1	Performance with jets in Particle-Flow Algorithms (e.g. CEPC full simulation)	• To study the PFA performance of the crystal ECAL option for precision measurements of jets; • To optimize crystal segmentations to achieve a reasonable balance among performance, power consumption and cost; • To study the PFA performance in a new detector option with the superconducting magnets positioned between ECAL and HCAL; • To study how to make good use of the timing information to improve the PFA performance.
3.1.1.2	Performance with single particles (simulation and hardware)	• To study the two major designs of crystal readout, including the double-ended readout of long crystals, using timing information at two ends to determine hit positions, and single-ended readout of short crystals; to develop digitizers and reconstruction algorithms in order to compare the performance, e.g. separation of closing-by incident particles; • To evaluate the performance of hadronic showers with different ECAL options and an HCAL option; • To study how to utilize the timing information of showers for the particle identification, shower separation, response compensation, etc.; • To explore potentials of detecting Cherenkov photons with a crystal-SiPM detector unit and study the performance of the “dual-gated” readout scheme.

3.1.1.3	Impacts of upstream materials and ECAL services (simulation)	• To study the impact from materials in the tracker system to the crystal ECAL performance and compare between tracker options; • To evaluate the impact to the crystal ECAL performance from the cooling plates between sensitive layers.
3.1.1.4	Studies of photo-sensors (e.g. SiPM) and front-end electronics for readout (hardware and simulation)	• To quantify the requirements on the SiPM and electronics, including the MIP calibration, the dynamic range, timing and study possible solutions to mitigate non-linearity effects; • To develop test stands to characterize SiPM and crystals, and to validate simulation models; • To cooperate with an electronics team at the University of Heidelberg and perform studies on the low-power front-end electronics dedicated to the SiPM readout developed within the CALICE collaboration.
3.1.1.5	Calibration and monitoring schemes	• To identify a calibration scheme for SiPMs, crystals and readout electronics; • To estimate required calibration precision, long-term stability and their impacts to the ECAL performance (e.g. energy resolution).
3.1.1.6	Development of a small-scale crystal calorimeter prototype	• To construct a small prototype with a matrix of crystal bars photo-sensors and front-end electronics; • To perform cosmic-ray calibration and beam tests for the prototype to evaluate the performance of the prototype, including energy linearity, energy resolution, positioning resolution, etc..
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3.1.1 Crystal Calorimeter: CEPC Relationship

This crystal calorimeter option has been proposed for applications in the future lepton colliders, including the CEPC. Till now the major task force working on the R&D is from the CEPC community.

3.1.1 Crystal Calorimeter: Project Schedule

The Project ID 3.1.1.1 addresses key questions on the PFA performance based on a common software framework for future lepton colliders (e.g. CEPCSW). It is expected to perform PFA performance studies in the scale of next few years at the same time when the software evolves.

The Project ID 3.1.1.2 and 3.1.1.4 have been focused since 2019, where several items were finished within 2020. Through the exercises in these two projects, it is expected to develop software tools and accumulate knowledge essential to the address the challenges in Project ID 3.1.1.1. The outcome of the Project ID 3.1.1.4 will also help the Project ID 3.1.1.6.
Major objectives in the Project ID 3.1.1.3, 3.1.1.5 and 3.1.1.6 are expected to achieve major progress in the next two years, depending on the person power situation.

3.1.1 Crystal Calorimeter: Funding Availability

The R&D programs are supported by a grant from the CAS Center of Excellence in Particle Physics and a starting funding program of Dr. Yong Liu (IHEP) during 2019-2022.

3.1.1 Crystal Calorimeter: Leadership Arrangement

The China and US teams will continue to work closely.
In China, Dr. Yong Liu (IHEP) coordinates the work on the design, hardware development and simulation closely related to hardware. Dr. Manqi Ruan (IHEP) coordinates the efforts on the performance studies of full detector simulation and performance.
In the US, Prof. Christopher Tully (Princeton University) plays a leading role in efforts of the crystal calorimeter design and optimization. They primarily focus on the dual-readout capability and performance of the crystal ECAL, a practical mechanical support, as well as on the PFA optimization. There are several other people working on relevant generic detector R&D such as Sarah Eno, who we are in correspondence with.

3.1.1 Crystal Calorimeter: Manpower Resources

The situation of person power at IHEP is listed as following.
Faculty members: Dr. Chunxiu Liu (0.1 FTE), Dr. Yong Liu (0.4 FTE), Prof. Junguang Lv, (0.3 FTE), Dr. Manqi Ruan (0.3 FTE), Dr. Shengsen Sun (0.1 FTE), Dr. Linghui Wu (0.1 FTE);
PhD students: Fangyi Guo (0.5 FTE), Yuexin Wang (0.5 FTE);
Master student: Baohua Qi (0.5 FTE).

Type	Average FTE Expected
Faculty	1.3
Postdoc	0
Students	1.5
Engineers	0

3.1.2 PFA Sci-ECAL Prototype

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Revision number:	1

Change history

Revision	When	What changed and why
1	12/12/2019	First draft
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ix. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **3.1.2 PFA Sci-ECAL Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
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3.1.2 PFA Sci-ECAL Prototype: Project Objectives

(1) To optimize the conceptual design of a highly-granular electromagnetic calorimeter CEPC using the Tungsten + scintillator (readout with SiPM) technology.
(2) To optimize the way of the scintillator strip coupling to SiPM in an active cell of the calorimeter.
(3) To develop SiPM readout electronics and then build a prototype for the Sci-W calorimeter that has the SiPM readout electronics embedded in the detector. Key parameters for the prototype are 22cm*22cm for transverse area, $24X_0$ for thickness, and 5mm*5mm for effective cell size.
(4) To validate the Sci-W ECAL design by testing and characterizing the prototype with cosmic rays and high-energy particle beams.

3.1.2 PFA Sci-ECAL Prototype: Sub-projects Description

Project ID	Title	Description
3.1.2.1	Design optimization	Optimization of key parameters in the CEPC Sci-W ECAL conceptual design and in some technical and engineering aspects
3.1.2.2	Readout electronics	Development of SiPM readout electronics based on the SPIROC chip for a Sci-W ECAL prototype
3.1.2.3	ECAL prototype	Construction of a Sci-W ECAL prototype that has readout electronics embedded in the detector.

3.1.2 PFA Sci-ECAL Prototype: CEPC Relationship

This project is part of the phase-1 CEPC R&D project funded by the Ministry of Science and Technology of China. The outcome from this project has already contributed to the CEPC CDR released last year. This project also constitutes a major detector R&D program for the CEPC Sci-W ECAL.

3.1.2 PFA Sci-ECAL Prototype: Project Schedule

This is a five-year R&D project which has entered its last year. The first three objectives have been met and a full-size and fully-intergraded Sci-ECAL prototype has been built. We are now in the process of commissioning the prototype with cosmic rays at USTC. The prototype will be eventually packaged and shipped to DESY for a two-week beam test in the near future. The remaining part of the project will be dedicated to the beam test and data analysis.

3.1.2 PFA Sci-ECAL Prototype: Funding Availability

This project is mainly funded by the Ministry of Science and Technology of China. It has also received funds from two projects funded by the National Science Foundation of China. The total budget available for this project is about 3 M Chinese Yuan.

3.1.2 PFA Sci-ECAL Prototype: Leadership Arrangement

This is a joint project between University of Science and Technology of China and Institute of High Energy Physics, Chinese Academy of Sciences. The leadership of this project is also shared between the two institutes:
Yunlong Zhang, Jianbei Liu, University of Science and Technology of China (USTC)
Yong Liu, Institute of High Energy Physics, Chinese Academy of Sciences (IHEP)

3.1.2 PFA Sci-ECAL Prototype: Manpower Resources

Yunlong Zhang, USTC, Faculty, 0.3
Zhongtao Shen, USTC, Faculty, 0.3
Shubin Liu, USTC, Factulty, 0.1
Jianbei Liu, USTC, Faculty, 0.3
Yazhou Niu, USTC, Student, 1.0
Shensen Zhao, USTC, Student, 1.0

Yong Liu, IHEP, Faculty, 0.3
Zhigang Wang, IHEP, Faculty, 0.3
Mingyi Dong, IHEP, Faculty, 0.3
Bing Zhao, IHEP, Student, 0.5

3.2 HCAL Calorimeter

3.2.1 PFA Semi-Digital Hadronic Calorimeter

Document Responsible:	Haijun Yang, Imad Laktineh Shikma Bressler
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	When	What changed and why
1	12/18/2019	First draft
2	5/6/2020	Second revision, add R&D and construction of RPC and RWELL
3	1/13/2021	Third revision, add manpower and some minor modifications

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3.2.1 Semi-Digital Hadronic Calorimeter : Project Objectives

High-granularity hadronic calorimeter concept is to play an essential role in PFA-based experiments such as CEPC. It allows to separate the deposits of charged and neutral hadrons and to precisely measure the energy of the neutrals. Although the contribution of the neutrals to the jet energy, around 10% on average, the performance is dominated by confusion of energy separation between charged and neutral hadrons, topological pattern recognition and energy information are important for correct track cluster assignment. High-granularity hadronic calorimeter is thus needed to achieve excellent jet energy resolution.

HCAL are sampling calorimeters with steel as absorber and scintillator tiles or gaseous devices with embedded electronics for the active part. The steel was chosen due to its rigidity which allows to build self-supporting structure without auxiliary supports (dead regions). The active detector element has very finely segmented readout pads, with 1cm 1cm cell size. For the entire HCAL, with ~100 m^3 total volume, the total number of channels will be 4 10^7which is one of the biggest challenges for the HCAL system. A simple hit counting is already a good energy measurement for hadrons. In a Semi-DHCAL, each readout channel is used to register a 'hit', instead of measure energy deposition, as in traditional HCAL. In this context, gas detectors (such as RPC, RWELL, RPWELL) become excellent candidates for the active element of a SDHCAL.
The objectives of the R&D projects are relative to four tasks listed in the following subsections.

3.2.2 Semi-Digital Hadronic Calorimeter : Sub-projects Description

Project ID	Title	Description
3.2.1	Sensitive detector R&D and construction	• To carry out R&D of sensitive detector RPC and RWELL/RPWELL • To construct large size RPC and RWELL/RPWELL • To design and construct readout electronics
3.2.2	Performance with jets in PFA and optimization	• To study performance of SDHCAL option for precision measurements of jets with PFA; • To provide comparisons with Analog HCAL (e.g. based on scintillator with SiPM), and also with different gaseous detector options; (e.g. energy resolution, cost budget); • To optimize PCB cell size to achieve descent jet energy performance with reduced power and cost.
3.2.3	Test Beam and performance study	• To involve the test beam and related data analysis to better understand performance of SDHCAL technological prototype.

		• To evaluate the performance of SDHCAL and ECAL using joint test beam data.
3.2.4	Active Cooling of SDHCAL (hardware and simulation)	• To establish thermal simulation program to optimize active cooling design • To develop small-scale prototypes with active cooling system, to evaluate its performance and validate simulation results.
3.2.5	Performance with timing information	• To study how additional timing information in hadronic showers can be made to improve particle identification, shower separation for PFA study. • To design and build a few modules of MRPC with good timing resolution (~100ps) • To make feasibility study of building a 5D HCAL prototype which include 3D position, amplitude, and timing. (part of AIDAnova project)

3.2.3 Semi-Digital Hadronic Calorimeter : CEPC Relationship

This R&D on Semi-Digital Hadronic Calorimeter based on gaseous detector (eg. RPC, RWELL, RPWELL) is an essential part of the PFA based HCAL R&D program in the context of CALICE collaboration, especially for the high granularity HCAL to be designed for future lepton colliders such as ILC, CEPC and FCC-ee etc.   This R&D effort is common for future lepton colliders.

3.2.4 Semi-Digital Hadronic Calorimeter : Project Schedule

Task 3.2.1 should be completed by 2021. Intermediate milestone will be the construction of large size RPC and RWELL/RPWELL detectors.
Task 3.2.2-3 should be completed by 2022, construction of a small prototype for test beam.
Task 3.2.4 should be completed by 2022.
Task 3.2.5 is part of AIDA2020 project, shall meet the schedule of AIDA2020.

3.2.5 Semi-Digital Hadronic Calorimeter : Funding Availability

Currently, CEPC detector R&D are supported by
- one MOST key project (2016-2021, ~2M RMB)
- one NSFC joint project (2019-2022) between China (~1.75M RMB) and Israel (~1.8M RMB).

We also received significant funding from another European project, Cremlin+.

3.2.6 Semi-Digital Hadronic Calorimeter : Leadership Arrangement

Haijun Yang SJTU, Shanghai, China
Imad Laktineh IPNL, Lyon, France
Shikma Bressler Weizmann Institute of Sciences, Israel

3.2.1.7 Semi-Digital Hadronic Calorimeter : Manpower Resources

Type	Average FTE Expected
Faculty	2.1
Postdoc	1.75
Students	2.55
Engineer	0.25

Domestic Institutes:

* Prof. Haijun Yang (SJTU), Faculty, FTE: 0.3
* Prof. Jianbei Liu (USTC), Faculty, FTE: 0.3
* Prof. Jun Guo (SJTU), Faculty, FTE: 0.2
* Prof. Weihao Wu(SJTU), Faculty, FTE: 0.3
* Dr. Francois Lagarde(SJTU), Postdoc, FTE: 0.5
* Dr. Yanyun Duan(SJTU), Postdoc, FTE: 0.5
* Daojin Hong(USTC), PhD student, FTE: 0.5
* Qiuping Sheng(SJTU), PhD student, FTE: 0.5
* Xi Wang(SJTU), PhD student, FTE: 0.5
* Yifan Zhu(SJTU), PhD student, FTE: 0.3

International Institutes:

* Prof. Imad Laktineh (IP2I, Lyon), Faculty, FTE: 0.2
* Prof. Gerald Grenier (IP2I,Lyon), Faculty, FTE:0.1
* Prof. Laurent Mirabito (IP2I, Lyon), CNRS, FTE:0.1
* Prof. Shikma Bressler (Weizmann, Israel), Faculty, FTE: 0.3
* Prof. Enrique Kajomovitz (IIT, Israel), Faculty, FTE: 0.3
* Luca Moleri (postdoctoral fellow - 0.5 FTE)
* Abhik Jash (postdoctoral fellow - 0.25 FTE)
* Dan Shaked-Renous (PhD student - 0.5 FTE)
* Darina Zavazieva (PhD student - 0.5 FTE)
* Gil Cohen (leading technician - 0.25 FTE)

CEPC Detector R&D Project

3.2.2 PFA Sci-AHCAL Prototype

Document Responsible:	Jianbei Liu
Last saved by Microsoft Office User on	4/11/2022 3:04:00 PM
Revision number:	1

Change history

Revision	When	What changed and why
1	12/12/2019	First draft
		< Add further lines to table as required >

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ix. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **3.2.2 PFA Sci-AHCAL Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
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3.2.2 PFA Sci-AHCAL Prototype: Project Objectives

(1) To optimize the conceptual design of a highly-granular hadronic calorimeter for CEPC using the iron + scintillator (readout with SiPM) technology. Important design parameters to be optimized include cell size, number of sampling layers, total thickness of absorber, thickness of scintillator tile serving as the active medium of the calorimeter.
(2) To develop techniques and devices for production, wrapping and quality-control of scintillator titles on a large scale, and for assembling of active layers of the calorimeter.
(3) To develop a SiPM calibration circuit and readout electronics embedded in the calorimeter.
(4) To build a large-size prototype for the CEPC hadronic calorimeter that could fully contain hadronic showers with energy up to 100 GeV.
(5) To validate the Sci-Fe HCAL design by testing and characterizing the prototype with cosmic rays and high-energy particle beams.

3.2.2 PFA Sci-AHCAL Prototype: Sub-projects Description

Project ID	Title	Description
3.2.2.1	Design optimization	Optimization of key parameters in the CEPC Sci-Fe HCAL conceptual design
3.2.2.2	Production and assembling techniques and devices	Development of techniques and devices for massive production of scintillator tiles and assembling of scintillator tile layers.
3.2.2.3	SiPM calibration circuit and readout electronics	Development of a SiPM calibration circuit based on LED and SiPM readout electronics that works in a continuous mode.
3.2.2.4	HCAL prototype	Construction of a Sci-Fe HCAL prototype with readout electronics embedded. Characterization of the prototype with high-energy particle beams.

3.2.2 PFA Sci-AHCAL Prototype: CEPC Relationship

This project is one of the three tasks of the phase-2 CEPC R&D project funded by the Ministry of Science and Technology of China. The central goal of this project is to validate the Sci-Fe calorimeter technology option for its application to CEPC. So it lies along with a few other detector R&D projects at the heart of the ongoing CEPC detector R&D activities.

3.2.2 PFA Sci-AHCAL Prototype: Project Schedule

This is a five-year R&D project which was launched in July 2018. The yearly milestones set for the project are as follows:
1st year: complete the design of the detection cell of the CEPC Sci-Fe HCAL
2nd year: complete the detector design of the HCAL prototype, finish mass production and wrapping of scintillator tiles .

3rd year: finish assembling all active layers for the HCAL prototype and the mechanical design of the prototype.
4th year: complete the construction of the HCAL prototype and its integration with readout electronics and DAQ.
5th year: complete the commissioning and beam test of the prototype

3.2.2 PFA Sci-AHCAL Prototype: Funding Availability

This project is fully funded by the Ministry of Science and Technology of China. It will also receive resource from an international project jointly funded by the National Science Foundation of China and Israel Science Foundation. The total budget available for this project is about 10 M Chinese Yuan.

3.2.2 PFA Sci-AHCAL Prototype: Leadership Arrangement

The institutes being involved in this project include University of Science and Technology of China (USTC), Institute of High Energy Physics, Chinese Academy of Sciences (IHEP), and Shanghai JiaoTong University (SJTU), while USTC is the leading institute with Jianbei Liu being the PI of the project. The representatives of the other two institutes are Yong Liu for IHEP and Haijun Yang for SJTU. They work together closely with the PI to coordinate the whole project.

3.2.2 PFA Sci-AHCAL Prototype: Manpower Resources

Yunlong Zhang, USTC, Faculty, 0.3
Zhongtao Shen, USTC, Faculty, 0.3
Shubin Liu, USTC, Factulty, 0.1
Jianbei Liu, USTC, Faculty, 0.3
Yukun Shi, USTC, Student, 1.0
Anshun Zhou, USTC, Student, 1.0
Hao Liu, USTC, Student, 1.0

Yong Liu, IHEP, Faculty, 0.3
Boxiang Yu, IHEP, Faculty, 0.3
Jiecheng Jiang, IHEP, Student, 1.0

Haijun Yang, SJTU, Faculty, 0.3
Shu Li, SJTU, Faculty, 0.2
Weihao Wu, Faculty, 0.2
Yanyun Duan, Postdoc, 0.8

CEPC Detector R&D Project

3.3 Dual-readout Calorimeter

Document Responsible:	Roberto Ferrari
Last saved by Roberto Ferrari on	17/12/19 08:00:00 PM
Revision number:	1

Change history

Revision	When	What changed and why
1	17/12/2019	First draft
2	30/03/2020	Update on funding status and planning
3	10/01/2021	Update

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iv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **3.3 Dual-readout Calorimeter**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

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3.3 Dual-readout Calorimeter: Project Objectives

The 20-year-long experimental research program on dual-readout calorimetry of the DREAM/RD52 collaboration has yielded a technology that is mature for application at CEPC. The results show that the parallel, independent, readout of scintillation and Čerenkov light, makes it possible to cancel the effects of the fluctuations of the electromagnetic fraction in hadronic showers, heavily affecting the energy resolution of the present calorimetry technologies. In conjunction with high-resolution em and hadronic energy measurements, excellent standalone particle-ID capability was demonstrated as well.

Those results strongly support the conviction that a matrix of alternating scintillating and clear fibres, inserted in copper or lead strips and readout by Silicon PhotoMultipliers (SiPMs), will be able to provide performance more than adequate for the physics program at the CEPC collider. A pointing geometry may allow for unprecedented transverse sampling granularity. Photon pairs could be identified and reconstructed down to a separation of less than 1 cm. Moreover, timing measurements should provide the capability to reconstruct the longitudinal shower development position. A 100 ps time resolution should result in a position resolution of about 5 cm.

The objectives of the R&D projects are relative to five tasks listed as follows.

3.3 Dual-readout Calorimeter: Sub-project Description

Project ID	Title	Description
3.3.1	Mechanics	In order to arrive to an executive design and engineering drawings of a realistic detector, the following issues need to be clarified: a) dimensions and construction method of the building elements of the absorber structure; b) the procedure for the assembly of single towers; c) the definition of a sensible breakdown of a full coverage 4π geometry. All depends on the choice of the absorber material, one among brass and iron being, at present, the baseline. The gluing of capillary tubes seems to be a viable solution for the construction of O(10×10 cm^2) modules and an R&D programme in this direction is ongoing, with fundings from INFN, University of Sussex and RBI. A 1 m long single (brass) module will be built, in the next months, to be tested at DESY. A beam period was allocated at the end of 2020 but, following the COVID-19 crisis, the schedule needs to be revised as soon as possible. In parallel, a 3-year R&D project will be submitted during next year for the construction of a "hadronic-size" prototype as well as for addressing the issues related to the construction of projective modules (including engineering drawings of a possible 4π detector). In February 2020, the National Research Foundation of Korea (NRF) granted a 5-year funding of about 2M USD for building a full-scale "hadronic-size" projective prototype..
3.3.2	Fibres and optical elements	The fibre selection needs to target the proper tuning of light collection yield and attenuation-length properties. Since scintillating and Čerenkov light production processes have yields that differ by orders of magnitude, the transmission chain critically needs to tackle possible optical cross-talk of scintillation in Čerenkov signals. A suitable choice of core material, numerical aperture (i.e. cladding

		structure) and light filtering, properly matched with the sensor PDE, should allow to obtain a yield of ~100-400 p.e./GeV, with manageable attenuation-length effects. Qualification of fibres, optical coupling and light sensors will be part of the R&D plans.
3.3.3	Light sensors and readout electronics	A SiPM-based readout provide several advantages: no fibres sticking out (i.e. no tail oversampling), operation in magnetic field, larger light yield with respect to standard PMTs, very high readout granularity. On the other hand, being digital detectors, SiPMs may show saturation, non-linearity, after pulsing, cross-talk. The R&D program will address these points with a market survey of sensors and front-end ASICs. The large dynamic range (a single fibre collects O(10%) of the em shower signals) requires high-density sensors (small cell size). This is a requirement also in the case that we need to guarantee a linear response. Indeed, to reduce the huge number of readout elements, the analog grouping of sensor outputs will be exploited, making impossible to apply non-linearity corrections. A readout chain based on modular (innovative) elements will be tested with specific efforts for the assessment and optimisation of the timing performance. The possibility of using a sampling ASIC is also being considered. In this context, the collaboration with CAEN and, as far as possible, with other producers, will be carried on. Hamamatsu SiPMs, with 15 μm cell pitch, and the CAEN DT5550W readout system, based on the Citiroc1A ASIC, are the baseline choices for the 2020 prototype.
3.3.4	Simulations and detector performance	A complex (Geant4) simulation programme is being pursued in order to assess both the standalone and the combined performance of dual-readout calorimeter implementations. Square (testbeam) modules, according to real and possible prototypes, have been and will be simulated for comparison with data. At the same time, simulations of a 4π detector will be carried on in order to estimate at best the possible performance in a real experiment concerning: 1. Energy resolution for electrons, gammas, single hadrons and hadronic jets both standalone and with a preshower detector; 2. Angular and position resolution, in particular for the identification and separation of the two photon showers from π^0 decays; 3. Reconstruction of the longitudinal shower development position through timing measurements; 4. Particle identification of single e, π, μ, γ, both isolated and within jets; 5. Identification and reconstruction of final states from hadronic τ-decays; 6. Identification and reconstruction of final states from Z/W/H→jj, H→ZZ*/WW*→4j, H→γγ, Z/H→ττ decays.
3.3.5	Data selection and processing with deep-learning algorithms	Development of deep-learning algorithms (over convolutional neural networks) exploiting timing information, for online and offline data selection and processing. The performance assessment will concern the same final states as in task 3.3.4.

3.3 Dual-readout Calorimeter: CEPC Relationship

This R&D on dual-readout calorimetry is an integral part of the program for the calorimeter system of the IDEA detector concept. IDEA is included in the CDRs of both high-energy circular e^+e^- colliders presently under discussion: CEPC in China and FCC-ee at CERN. The R&D is the same for both colliders.

3.3 Dual-readout Calorimeter: Project Schedule

In the present planning for the fibre-sampling calorimetry, all the tasks are meant to be completed by 2025. The prototype under preparation is presently planned to be tested at DESY in the next month. Nevertheless, due to the COVID-19 emergency, no solid statement on the dates can be done. The test beam period is expected to be postponed (probably to summer or autumn 2021). Further planning, including the schedule for the hadronic-size prototype, will need to be reassessed as soon as possible. At present, the delay is meant to be of the order of months. On the other hand, the schedule strongly depends on the amount of funding and resources that will be secured.

3.3 Dual-readout Calorimeter: Funding Availability

The first stage of the project (the 2020 prototype) has received funding from INFN CSN1 (~40 k€), from RBI (about 15 k€) and from the University of Sussex (about 5 k€). RBI has retired in late 2020 from the collaboration due to lack of manpower and funds. Small amount of funding from University grants has also been made available.

A request of about 100 k€ has been also presented for the AIDA++ proposal, mainly thought to be used for hiring young manpower.

About the building of a hadronic-size prototype, a request will be submitted for EU grants and to European funding agencies in 2021 (INFN, Royal Society).

In South Korea, a R&D fund of about 2M USD has been granted, from March 2020 over 5 years, by the Korea National Research Foundation (NRF) for building a full-hadronic-scale projective prototype, addressing the main engineering, operating and readout issues. Additional soft funding is also available for simulation study to support postdoc positions and graduate students in each institute.

3.3 Dual-readout Calorimeter: Leadership Arrangement

Project leader: Roberto Ferrari INFN Pavia
Technical coordinator: Romualdo Santoro Università dell'Insubria Como and INFN Milano

Group leaders/contacts:
Hwidong Yoo South Korea Consortium (Kyungpook National University, Korea University, University of Seoul, Yonsei University, includes also Iowa State University)
Romualdo Santoro Università dell'Insubria Como and INFN Milano
Gabriella Gaudio INFN Pavia
Franco Bedeschi INFN Pisa
Stefano Giagu Università di Roma "La Sapienza" and INFN Roma 1
Paolo Giacomelli INFN Bologna
Iacopo Vivarelli University of Sussex

3.3 Dual-readout Calorimeter: Manpower Resources

Type	Average FTE Expected
Faculty	4.2
Postdoc	2.2[1]
Students	6.8[1]
Engineers	1.3[2]

1. The number for students and postdoc includes positions that will be funded within the R&D project (i.e. for which at present funds are not guaranteed).
2. The number of engineers includes technical manpower from institute workshops that are not engineers but are nevertheless actively participating to the design efforts.

CEPC Detector R&D Project

4. Muon Detector

4.1 Scintillator-based Muon Detector Prototype

Document Responsible:	Xiaolong Wang, Liang Li
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	1

Change history

Revision	When	What changed and why
1	12/17/2019	First draft
1	1/9/2021	Update the situation on R&D performed and expected manpower, and section for readout system
		< Add further lines to table as required >

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xiv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

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4.1 Scintillator-based Muon detector Prototype: Project Objectives

A simple structure of Scintillator + WLS fiber + SiPM is proposed for CEPC muon detector. Organic scintillator can be produced massively according to the geometry of the detector, and the required spatial resolution can be achieved by changing the width of the scintillator strip. Multiple hits in the muon detector with a good spatial resolution is used for muon identification. High density of scintillator and the dE/dx offer large output of scintillation photons, some of which are captured by WLS fiber and then guided to SiPM. Similar to TOF, a good time resolution and a narrow time window is possible for muon hits.

The objectives of R&D can be divided in to (1) procurement and testing of Scintillator strips and SiPMS; (1) improvement on light output and collection with high signal-to-noise ratio; (2) time/spatial resolution measurement benchmark and improvement; (3) radiation hardness test; (4) prototype detector arrays for detecting muon tracks from cosmic rays; (5) the electronic readout system including frond-end and back-end.

4.1 Scintillator-based Muon detector Prototype: Sub-projects Description

Project ID	Title	Description
4.1	SiPMs and Scintillator strips procurement	High Gain SiPMs and high light output and short decay time scintillator strips procurement and Q/C testing. This can be studied with some MPPCs from HAMAMATSU and some scintillators purchased in China. The specific MPPC of interest is one kind SiPM used comprehensively in Belle II and T2K experiments. More studies with different kinds of SiPMs should be performed to find the best SiPM for CEPC. We also need to study SiPM performance and trying to improve the quality of the scintillator strips.
4.2	WLS fiber and optical couplings	Improve photon collection efficiency with WLS fiber and couplings to SiPM. This is about how to improve the photon collections for a large muon hit signal. The type of WLS fiber, the couplings between fiber and scintillator, between fiber and SiPM should be studied carefully.
4.3	Time/spatial resolution measurements	Signal detection performance benchmark and improvement. This is to do a complete test of experimental setup and perform the (injected) signal efficiency and time/spatial resolution measurements. Simple readout electronics for testing will also be studied.
4.4	Radiation Hardness of SiPM and scintillator	Study the performance of SiPM and scintillator after the projected radiation level for CEPC. This should be performed by MC simulation and beam testing. The noises of SiPM and scintillator, and the gain reduce of SiPM should be studied.
4.5	Prototype construction: Multi-	Several layers of scintillator modules constructed to build a detection array for cosmic rays test.

	layer detectors	This is the prototype study. Sensitive detector channels of scintillator+fiber+SiPM setup will be constructed to build a single module, and several layer of modules will be then combined to build an array. DAQ system with the test stand will also be built and integrated with readout electronics. Studies with cosmic ray should be performed, especially reconstruction the cosmic ray tracks with high efficiency.
4.6	Electronic readout: frond-end and back-end	Fond-end: pre-amplifier and pulse shaping with low pedestal noise are required. Back-end: digitization for multiple channels, high sampling rate, data transmission and trigger.

4.1 Scintillator-based Muon detector Prototype: CEPC Relationship

The activities are a part of ongoing CEPC muon detector R&D. Scintillator-based muon detector is one of the highly considered CEPC muon detector options.

4.1 Scintillator-based Muon detector Prototype: Project Schedule

Project 4.1 can be completed soon after sufficient funding is secured, hopefully by end of 2020.
Project 4.2 can be completed after 4.1, hopefully also by end of 2020.
Project 4.3 can be completed after 4.1 and 4.2, hopefully by end of 2021.
Project 4.4 can be completed by end of 2022.
Project 4.5 can be completed by end of 2023 once sufficient funding is secured.

We have got some materials for R&D: 1) MPPCs: we purchased some Hamamatsu MPPCs in 2018, and KEK is donating Fudan some spare MPPCs for Belle II. 2) scintillator: we purchased some from a Chinese company in 2019. 3) WLS fibres from Saint-Gobain and Kurary. 4) Front-End readout for KLM. So that Project 4.1 is partially done, and we are doing study with setups. We also performed Geant4 simulation on iron layers and scintillator layers to get spatial resolution and time resolution. Currently, we are working on a DAQ system with VME for further study on ADC and TDC, which can be used for Project 4.5 as well in the future.

R&D on the readout system, including both front-end and back-end, should start recently. The requirements of stintillator-based muond detector, including data rate, pulse shaping, and time resolution should be investigaged. Function of trigger should be included. The design of the readout system, testing and optimization should be carried out in the coming years.

4.1 Scintillator-based Muon detector Prototype: Funding Availability

We have limited funding support from Fudan University (mostly for Belle II experiment upgrade R&D , which can cover a small portion of 4.1 and 4.2) and Shanghai Jiao Tong University (mostly for CEPC Phase-I general software simulation and performance studies).
We are in short of R&D funding and we are requesting 600K CNY to complete 4.1-4.4 and prototype building (4.5). There should be additional budget for the R&D of readout system.

4.1 Scintillator-based Muon detector Prototype: Leadership Arrangement

Leaders: Xiaolong Wang (Fudan University) and Liang Li (Shanghai Jiao Tong University).
Leading institute for this project will be Fudan University with strong contributions from Shanghai Jiao Tong University on all sub-projects. Significant participations are also expected to come from Institute of High Energy Physics at Beijing. The University of Shanghai for Science and Technology has strong interest in the readout system.

4.1 Scintillator-based Muon detector Prototype: Manpower Resources

Type	Average FTE Expected
5 Faculty	1.2
TBA Postdoc	TBA
5 Students	2.1
1 Engineer	0.2

CEPC Detector R&D Project

4.2 Muon and pre-shower µRWELL-based detectors

Document Responsible:	Paolo Giacomelli
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	When	What changed and why
1	17/12/2019	First draft
2	28/04/2020	Second draft added simulation task and INFN Torino
3	07/01/2021	Third draft with addition of front-end electronics task

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xix. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
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4.2 Muon and pre-shower detector : Project Objectives

The µRWELL technology, developed at LNF-INFN (*"The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD", G. Bencivenni et al 2015_JINST_10_P02008*), has been identified as a very promising technology to realize both the muon apparatus as well as the pre-shower. The muon detector will provide complete coverage for detecting very penetrating particles, most of them being muons, having traversed the calorimeter. The µRWELL based pre-shower system is used to identify and measure electromagnetic showers initiated in the material of the solenoid before reaching the calorimeter. The information from the pre-shower is essential to recover a good energy resolution from the dual readout calorimeter. µRWELL detectors can obtain a position resolution of the order of 50-60 um with a time resolution of about 5 ns. The muon detector does not need such a precise position resolution and µRWELL detectors with a larger strip pitch than what will be used for the pre-shower will be employed. For both the muon detector and the pre-shower system a modular structure of µRWELL detectors of dimensions of about 50x50cm^2 is envisaged. These detector dimensions should be a good compromise between the industrial engineering and production and the large overall dimensions to be covered, especially for the muon detector.

The objectives of the R&D projects are relative to the four different tasks listed in the following section.

We also anticipate that the simulation studies will be used to optimize the overall detector design.

4.2 Muon and pre-shower detectors : Sub-projects Description

Project ID	Title	Description
4.2.1	Industrialization of large size µRWELL detectors with bi-dimensional readout	The µRWELL technology has been extensively characterized in laboratory measurements and has undergone several beam tests and is now a rather mature detector technology. Its characteristic of high space and good time resolution, high efficiency and high gain with a single amplification stage have been clearly demonstrated. The purpose of this task is to optimize the engineering design of the detector and bring the technology and know-how to industry for a future mass production. For this purpose, we have started a collaboration with the ELTOS company in Arezzo, Italy, more than 2 years ago. The ELTOS company is specialized in PCB production and has already produced the anodes and cathodes of several µRWELL prototypes in the past. The next step was to perform the coupling of the µRWELL kapton foil with the well scheme with the anode PCB. Eltos has already achieved this step for several small size (10x10 cm^2) µRWELL prototypes with the original layout with a single resistive layer. Several other layouts of µRWELL detectors, up to dimensions of about 40x50 cm2, have been produced and tested subsequently. From the original single resistive layer, dubbed "low rate" version, capable of particle rates up to about 30-50 kHz/cm^2, we have then also developed newer high-rate designs that allow higher particle rates, up to about 10 MHz/cm^2. The high-rate layouts employed have proved effective but unfortunately of difficult industrialization. For this reason, and the fact that the low rate version is highly sufficient for the particle rates expected at the CEPC, we decided to continue the development of the low rate layout. This is layout that we would now like to fully co-develop and produce with ELTOS. The next step we want to achieve is the production of larger size

		detector prototypes, ~50x50 cm^2, with strip length of 50 cm, at affordable and competitive costs.
4.2.2	R&D on DLC sputtering and optimization of the resistive coating	The Diamond Like Carbon (DLC) sputtering technique is what has been used until now to produce the resistive layer of the µRWELL kapton foils. All the recent µRWELL detector prototypes we have built employ this technique for their resistive layer. The DLC resistive layer is responsible for the avalanche quenching and the charge distribution at the anode. Testing detectors with different resistivity will allow to optimize the chamber and readout design. For each IDEA's system (i.e., muon and pre-shower) five detectors, with resistivity ranging from 10 to 200 MOhm/square, will be tested. This will be the first systematic DLC resistivity scan with m-RWELL detectors; the test will give precious information about performance and data size of the different configurations; the data will also be used to tune our simulation for further design optimization. We are discussing with CERN the possibility of acquiring a dedicated sputtering machine that would allow to make DLC depositions up to Kapton surfaces of 60x200 cm^2.
4.2.3	Bi-dimensional readout	We have recently built two small µRWELL detectors, 10x10 cm^2, with two readout layers with a strip design, the first layer placed at 90° degrees with respect to the following one, in order to be able to read the x and y coordinates independently. The next step will be to optimize the design of such a detector to achieve a similar signal size and resolution for both coordinates. The following step will be to increase the size of the detectors with bi-dimensional readout up to the size that we want to employ for IDEA of about 50x50 cm^2. The strip pitch is what determines mostly the possible spatial resolution of a µRWELL detector. For the pre-shower system we need a spatial resolution, in both x and y coordinates, of the order of (or better than) 100 µm. The strip pitch envisaged is therefore of 400 µm. For the muon system the requirement of spatial resolution can be relaxed and the envisaged strip pitch is 1.0-1.5 mm.
4.2.4	Front-end electronics	The IDEA muon detector would have, taking into account the considered strip pitch of the detectors, between 4 and 6 million channels. It is therefore extremely important to develop a custom-made front electronics, based on a dedicated ASIC, in order to significantly reduce the electronics costs. The BESIII experiment at BEPCII at IHEP has developed a custom-made ASIC, called TIGER, for the front-end of their cylindrical GEM-based tracker. Since the signals produced by a µRWELL detector are rather similar to the ones produced by a GEM, we will equip a large area (~40x50 cm^2) µRWELL with a TIGER-based readout. The µRWELL detector will have a strip pitch similar to the one we want to employ for the IDEA muon detector and strips length about half the length of the IDEA ones. This makes for a test-bench for the TIGER very similar to the final muon detector configuration. From tests with the TIGER with a cosmic bench and possibly later on a muon test beam, we will derive the information needed to develop a dedicated ASIC for the µRWELL.
4.2.5	Simulation and tracking algorithm of a µRWELL-based muon detector	Implementation of this detector in a fast simulation context to study physics potential for tracks tagging and long lived particles identification. Development of a full simulation model in Geant4 to study more realistic performance and optimization of detector design.

4.2 Muon and pre-shower detectors : CEPC Relationship

This R&D on µRWELL detectors is an integral part of the needed R&D program for the muon and pre-shower systems of the IDEA detector concept. IDEA has been proposed an accepted by both very large circular e^+e^- colliders proposed: CEPC in China and FCC-ee at CERN. The R&D is the same for both colliders.

4.2 Muon and pre-shower detectors : Project Schedule

Task 4.2.1 should be completed by 2024. Intermediate milestones will be the construction of smaller size µRWELL prototypes.
Task 4.2.2 should be completed by 2022.
Task 4.2.3 is a prerequisite for the completion of Task 4.2.1. It is scheduled to be completed towards the end of 2022-23.
Task 4.2.4 will in start in 2021 and is scheduled to be finished by 2024.
Task 4.2.5 will run in parallel to the other three tasks until 2024. First results will however be available already in 2021.

4.2 Muon and pre-shower detectors : Funding Availability

Task 4.2.1 will receive significant funding within the framework of the AIDAinnova project, specifically for the pre-shower and muon detector of IDEA. The funding, that will be available from April 2021 for a period of 4 years, is around 120 keuro.

Task 4.2.2 has received some funding (8 keuro) from INFN CSN1 as co-funding of the RD51 project at CERN. It has also received funding (25 keuro) from INFN CSN1 for the construction of 2 sets of 5 medium size µRWELL prototypes each with a different value of the resistivity of the DLC coating by the end of 2021.

For task 4.2.3 we envisage to ask for dedicated funding from INFN CSN1 in 2022 and in 2023.

For Task 4.2.4 we have received in 2020 funding from INFN CSN1 (20 keuro) for building a large-size detector equipped with the TIGER readout. This step will be a pre-requisite for later developing a µRWELL-dedicated ASIC. For this purpose, we will receive a funding of 100 keuro also coming from the AIDAinnova project. Completion of this task is expected by the end of 2024.
Task 4.2.5 will receive a funding of 40 keuro from the AIDAinnova project, for the development of an advanced machine-learning based track reconstruction algorithm for µRWELL detectors.

We also received significant funding from another European project, Cremlin+, to build a cylindrical µRWELL detector to serve as the main tracker for the proposed Super Charm-Tau Factory of the Budker Institute for Nuclear Physics in Novosibirsk, Russia, to be developed and tested by groups from INFN Frascati and Ferrara.

4.2 Muon detector : Leadership Arrangement

Paolo Giacomelli INFN Bologna
Gianluigi Cibinetto INFN Ferrara

Gianni Bencivenni LNF
Manuel Rolo INFN Torino

4.2 Muon and pre-shower detectors : Manpower Resources

Type	Average FTE Expected
Faculty	2.0
Postdoc	1.5
Students	1.0
Engineers	0.3

Four INFN sections are involved in this R&D: Bologna, Ferrara, LNF and Torino.
Bologna can count on an undergraduate and a PhD student, and three faculty members.
Ferrara can count on 3 PostDocs, 1 PhD student and two faculty.
LNF can count on 1 PhD student and three faculty members.
Torino can count on 1-2 faculty.

CEPC Detector R&D Project

5. Solenoid

5.1 LTS solenoid magnet

Document Responsible:	Zhu Zian
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Revision number:	2

Change history

Revision	When	What changed and why
1	12/12/2019	First draft
2	06/01/2021	Very thin solenoid required
		< Add further lines to table as required >

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xxiv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

xxv. Finally, remember to update the *Change History*.

5.1 LTS solenoid magnet: Project Objectives

The proposed 3 tesla solenoid with a 6.8 m diameter bore for CEPC detector magnet, can be reached by adopt a self-supporting aluminum stabilized low temperature NbTi superconductor.

During the past three years, we have developed a 1.5 km long superconducting Rutherford cable with 16 strands of NbTi wire embedded in pure aluminum stabilizer, which has achieve a critical current 50 kA at 3 tesla background magnetic field. The final conductor for CEPC detector magnet is a 32 strands of NbTi wire Rutherford cable inserted in pure aluminum stabilizer and together with aluminum alloy reinforcement, with critical current of 60 kA at 4 tesla background field and residual resistance ratio (RRR) of 400. Meanwhile the measurement of the material properties and the tensile stress of the cable will be a necessary part for the structural simulation of the solenoid coil and the conductor development. The total required cable length of the detector solenoid is around 30 km. We will built a winding model by using dummy conductor to study the inner winding technique of large diameter solenoid, and to improve its automation performance. A 1:10 scale superconducting model is necessary for the cooling, quench behavior study, and study of the electrical connecting between the several coil segments.

We also analyze iron yoke structure configuration that will be needed in order to optimize the overall detector design and MDI design.

The objectives of the detector magnet R&D projects are relative to the four different tasks listed as follows.

5.1 LTS solenoid magnet: Sub-projects Description

Sub-project ID	Title	Description
5.1.1	Development of special low temperature superconductor	A 32 strands of NbTi wire Rutherford cable inserted in pure aluminum stabilizer and together with aluminum alloy reinforcement, Ic > 60 kA@4T
5.1.2	Study of cooling method for large size thin solenoid magnet	Thermosyphon or forced two phase helium flow will be used. In order to study the phase transition process of helium in the circuit, the changes of the temperature distribution and the density distribution over the time, a 1:10 scale circuit will be established for simulation and experiment.
5.1.3	Study of large size coil winding techniques	The model study is necessary for the large detector magnet, to develop the inner winding technique and to improve automatic performance for the 6.8 m coil of inner diameter by using dummy conductor.
5.1.4	Construction of superconducting coil prototype	A 1:10 prototype built to study the coil cryogenics and quench protection, the electrical joint of the cable, and verify the electromagnetic structure and force inside the coil.
		< Add further lines to table as required >

5.1 LTS solenoid magnet: CEPC Relationship

All four activities are strictly (almost exclusively) related to the design of the solenoid magnet of the CEPC detector.

5.1 LTS solenoid magnet: Project Schedule

Project 5.1.1 got funding from the IHEP innovation fund for LTS conductor development which should be completed by the end of 2021.

Project 5.1.2 and 5.1.3 has received funding from CAS Center for Excellence in Particle Physics for the design of large diameter superconducting coil, which should be completed by the end of 2021.

Project 5.1.4 is being requesting funds, activity is expected to start in 2022. We expect completion of the project by the end of 2025.

5.1 LTS solenoid magnet: Funding Availability

We have received from CAS Center for Excellence in Particle Physics 3M CNY for the first phase of this project, and another 1.5M CNY from the IHEP innovation fund for key technology of large diameter superconducting coil, part of the fund is for HTS conductor development and part for LTS conductor development.

We are missing the funds needed for the construction of the 1/10 scale prototype of the superconducting coil described in the fourth step of project 5.1.4.

5.1 LTS solenoid magnet: Leadership Arrangement

Leading institute for the LTS solenoid magnet project will be Institute of High Energy Physics, CAS (coordinated by Zhao Ling).

Significant support will be given by the industrial companies, Toly Electric Works Co. LTD at Wuxi (coordinated by Liao He'an) for what concerns aluminum stabilized superconductor, and by Keye Company at Hefei (coordinated by Zhu Zhiliang) for what concerns industrialization of the large size coil windings.

5.1 LTS solenoid magnet: Manpower Resources

Type	Average FTE Expected
3 Faculty	2
0 Postdoc	0
2 Students	1
1 Engineer	0.5

CEPC Detector R&D Project

5.2 HTS solenoid magnet

Document Responsible:	Zhu Zian
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Revision number:	2

Change history

Revision	When	What changed and why
1	12/12/2019	First draft
2	06/01/2021	Very thin solenoid required
		< Add further lines to table as required >

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xxix. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

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5.2 HTS solenoid magnet: Project Objectives

A large HTS solenoid concept is proposed by IHEP team for the CEPC detector, with the calorimeter located outside of the solenoid, which requires a very thin solenoid.

The HTS solenoid is supposed to use YBCO stacked-tape cable as the conductor. The radiation length of single YBCO tape coated with 10 μm copper is about 0.004 X0, we can get a thinner solenoid by using HTS compare to LTS. Therefore, the YBCO stacked-tape cable and the cryogenics are brought into R&D. Up to 20% additional reduction in the overall thickness may be achieved with more R&D and engineering.

The objectives of the detector magnet R&D projects are relative to the four different tasks listed as follows.

5.2 HTS solenoid magnet: Sub-projects Description

Sub-project ID	Title	Description
5.2.1	Development of HTS conductor	Develop aluminum stabilized ReBCO stacked tape cable, the tapes are embedded in a pure aluminum, cable length > 200 m, current > 6 kA at 20 K. We also consider other HTS cables if they are suitable for large detector magnet.
5.2.2	Development of 20 K cooling for HTS coil	Explore the cooling mechanism and heat conductivity structure at 20 K, study the stability and quench behavior at this temperature.
5.2.3	Development of thin cryostat	Study the cryostat structure with thin and less material to make particles more easily penetrate to reach the calorimeter.
5.2.4	Construction of 1:10 superconducting coil prototype	Develop the prototype of large HTS magnet, study the winding process, cable joint, quench protection and so on, with an inner diameter 2m, 4.2K liquid helium cooling, stack cable 4mm width 20 layers.
		< Add further lines to table as required >

5.2 HTS solenoid magnet: CEPC Relationship

All four activities are strictly (almost exclusively) related to the design of the solenoid magnet of the CEPC detector.

5.2 HTS solenoid magnet: Project Schedule

<u>Project 5.2.1 and 5.2.4</u> got funding from the Chinese Academy of Sciences Foundation for original innovation project from 0 to 1, research focus on the key technology of high temperature superconducting magnet for large detector in the future. It was expected to complete the project by the end of 2024.

Project 5.2.2 and 5.2.3 have to get new funding support, activity is expected to start in 2023, we expect to master all aspects of the technology of large-scale HTS detector magnet and complete the project by the end of 2026.

5.2 HTS solenoid magnet: Funding Availability

We have obtained 3M CNY from the Chinese Academy of Sciences Foundation for original innovation project from 0 to 1, for the key technology of high temperature superconducting magnet for large detector in the future, mainly focus on the research described in the first and second step of project 5.2.1 and 5.2.2.

We are missing the funds needed for the low material cryostat study described in the third and fourth step of project 5.2.3 and 5.2.4.

5.2 HTS solenoid magnet: Leadership Arrangement

Leading institute for the HTS solenoid magnet project will be Institute of High Energy Physics, CAS (coordinated by Ning Feipeng).

Significant support will be given by the industrial companies, Toly Electric Works Co. LTD at Wuxi (coordinated by Liao He'an) and Shanghai Superconductor Technology Co. Ltd at Shanghai (coordinated by Zhu Jiamin) for what concerns high temperature superconducting cable development. Cooperation partners for simulations and finite element analysis of the cable and coil are under investigation.

5.2 HTS solenoid magnet: Manpower Resources

Type	Average FTE Expected
3 Faculty	1.5
0 Postdoc	0
2 Students	1
1 Engineer	0.5

CEPC Detector R&D Project

6. MDI

6.1 LumiCal Prototype

Document Responsible:	Suen HOU
Last saved by on	04/11/2022 3:04:00 PM
Revision number:	2

Change history

Revision	When	What changed and why
1	12/29/2019	First draft based on 2019 workshop materials
2	01/08/2021	Design match to the beampipe and vacuum flange

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xiv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1Vertex Prototype**.If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

xv. Finally, remember to update the *Change History*.

6.1LumiCal Prototype: Project Objectives

The luminosity of electron-positron collisions can be measured *with high statistics and precision* through the *Bhabha* scattering process $e^+e^- \rightarrow e^+e^-$ with the scattered electrons detected in forward direction. At CEPC, the luminosity measurement is aimed for a precision of 10^{-4} at the Z-pole, which corresponds to the spatial resolution of 1 mRad on the fiducial edges for the Bhabha angular distribution.

Bhabha events are detected for 1) elastic scattering of beam particles back-to-back in the center-of-mass frame, 2) energies of each particles consist with beam energy. The challenge to the luminosity detector is to identify electrons with the spatial resolution in θ-angle reaching 1 mRad. The readout electronics readout is also required to sustain radiation damage and the high event rate at beam crossing interval of 32 ns.

The design of Luminosity Calorimeter (LumiCal) has been studied with GEANT simulation for a sandwiched Silicon-Tungsten assembly with upstream silicon wafers surrounding beam-pipe. The measurables on electron impact position and lateral shower profiles are evaluated. We envision that the silicon wafers of LumiCal is positioned surrounding the beam-pipe within the inner tracker volume. The detector design and an event display are illustrated in Fig. 1.

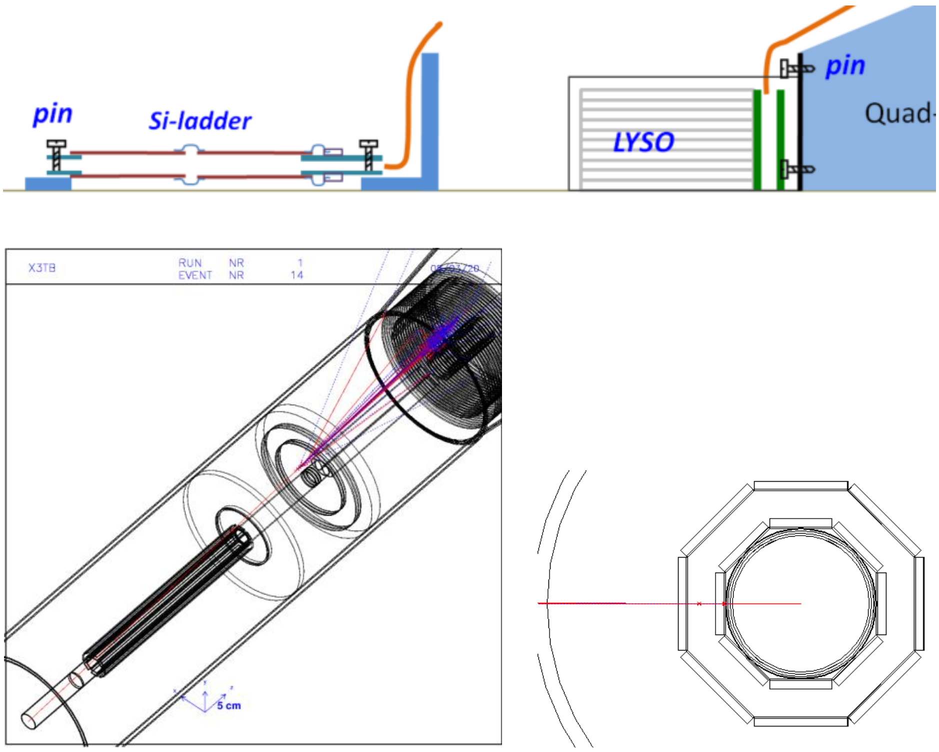

Figure 1: The top drawing illustrates the LumiCal detector design with silicon wafers and LYSO crystal calorimeter. The event display below is shown for a 50 GeV electron in GEANT simulation with the beam-pipe of 1 mm thick Al tube, flange layers at z=520 mm and z=700 mm. The LumiCal Si-wafers include two octagon rings at z=150-520 mm, disks of circular wafers on beam pipe flanges, and a Si-W calorimeter with front face at z=1000 mm.

6.1 LumiCal Prototype: Sub-projects Description

Project ID	Title	Description
6.1.1	Silicon Strip detector	Assembly of single sided Si-Strip sensor in 50 or 100 µm pitch, with AVP25 readout ASIC.
6.1.2	Crystal calorimeter	LYSO crystal in strip (>50mm) of diameter as small as 2x2 mm^2 with SiPM readout electronics

6.1LumiCal Prototype: CEPC Relationship

The LumiCal prototyping is proposed for fabrication of detector modules and readout electronics. The detector modules of interests are the Silicon Strip wafer assembled with, for example, the APV25 readout chip and the LYSO crystal with SiPM readout electronics.

1) Single-side silicon wafer assembly for beam test: Assembly of silicon sensor directly available from manufacturers with the strip pitch of 50 µm or 100 µm. The readout chip could be the AVP25 with ADC of >8 bits and the signal-to-noise ratio of better than 10. The charge collection of Si-strip sensors shall be investigated in beam tests for the scenario that the electrons traverse at very low angle (<100 mRad) to the wafer surface. The traversing distance is up to 1 mm for a wafer thickness of 300 µm. The charge collection by the continuous strips over the passage of the track is illustrated in Fig. 2. The analysis mechanism for the impact position shall be demonstrated.

The assembly of Si-strip detector will be conducted at the IHEP detector shop, or elsewhere capable for detector alignment and fine-pitch wire bonding. Alignment will be practiced for a few micron precision.

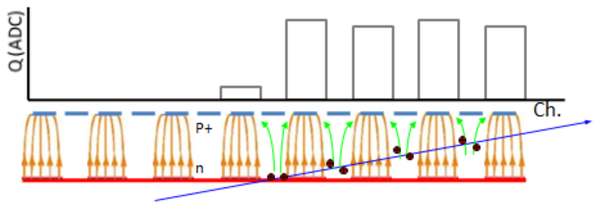

Figure 2: Beam test with silicon wafer is illustrated for the incident of a low angle charged particle. The impact position and angle is measured by the collected ionization charges by readout strips or pads on the edge where the particle enter and exit the wafer.

2) fine-strip LYSO crystal with SiPM readout: We have purchased LYSO crystal strips of dimension 2x3x50mm^3 for assembly of a small calorimeter array suitable for measuring cosmic ray track and for study in beam tests. The Hamamatsu SiPM and front-end test kits are purchased. The R&D will be conducted for characteristics of LYSO crystal and electronics. The advantage with a Crystal Calorimeter for LumiCal is for the compactness of electronics saving the service volume. The length in z may be a concern for shower containment, which will be optimized with the beam-pipe layout.

The readout chain is planned to first making a DAQ board using commercial ADC chips. The ASIC design of a customized readout chip is scheduled to started in mid-2021. The purpose is for a fast shaper with flash ADC suitable for high speed readout suitable for processing large data quantity with event rate of 1k Hertz at LumiCal.

6.1LumiCal Prototype: Project Schedule

The prototype silicon detector will be assembled with components collected off-the-shelf in 2020. Depending on the components available, the detector circuit board will be prepared for assembly at Silicon bonding facility at IHEP. We shall have installed a complete readout chain for a prototype Si-strip detector.

The laboratory setup for tests of LYSO with SiPM can be quickly assembled with the Hamamatsu front-end test kits and digital oscilloscope. The ASIC design implementing signal input, ADC and TDC for digitized output, will require longer schedule, with the first version of design ready in late 2021.

6.1LumiCal Prototype: Funding Availability

The funding requirement includes items for

1. Silicon wafer, AVP25 chips, Belle II DAQ modules
2. Scintillation crystal and SiPM components
3. SiPM readout chip, ASIC submission to CMOS of .25 um or .13 technology

The total budget is estimated for 1000k RMB. The Academia Sinica group has an annual budget of 200k RMB for the detector R&D. A small amount of LYSO and SiPM components are purchased. The fabrication of Silicon wafer and SiPM readout modules will depend on mutual agreement with the IHEP groups.

6.1LumiCal Prototype: Manpower Resources

Type	Average FTE Expected
Faculty	1 FTE
Postdoc	1 FTE
Students	2 FTE
Engineers	1 FTE

CEPC Detector R&D Project

6.2 Interaction Region Mechanics

Document Responsible:	Haijing Wang
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	3

Change history

Revision	When	What changed and why
1	18/12/2019	First draft
2	6/5/2020	Second draft
3	14/1/2021	Third draft
		< Add further lines to table as required >

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- The project name should be changed in Document:Summary: Subject.

iv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

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6.2 Interaction Region Mechanics: Project Objectives

The proposed R&D topics are aimed to address several critical mechanical issues around the complicated interaction region. They include a prototype Beryllium beampipe with a wall thickness down to 0.15 mm, which is necessary to minimize the material budget between the interaction point and the first vertex detector layer. A reliable welding technique to connect the central Beryllium beampipe and the forward Aluminum beampipe will be explored. At the same time, it is desirable to develop a reliable scheme to install all the sensitive detector and machine components in the complex interaction region. The remote vacuum connection method will be considered for the challenging installation. Both detector and machine components, including the superconducting magnet, must be supported with required precision, rigidity and excellent long-term stability.

6.2 Interaction Region Mechanics: Sub-projects Description

Project ID	Title	Description
6.2.1	Beryllium beampipe prototype	To machine a short Beryllium beampipe with a wall thickness of down to 0.15 mm, and explore reliable welding between thin Beryllium and Aluminum
6.2.2	Installation scheme	To develop a feasible scheme to install the detector and machine components around the interaction region with required precision and reliability
6.2.3	Remote vacuum connection methods	To develop new methods for the remote vacuum connection and verify the critical technologies with prototyping
6.2.4	Supporting structure of SC magnets	To design a stable supporting structure for the superconducting magnet that can fit into the limited space around the interaction region

6.2 Interaction Region Mechanics: CEPC Relationship

The proposed R&D topics on mechanics in the interaction region are aimed to address several most challenging machine detector interface issues of the CEPC project. A thin central beampipe will be crucial to minimize the material in front of the vertex detector and have direct impacts on the tracking and vertexing performance. Reliable supporting structure of SC magnets and installation scheme of detector and machine components are critical for the operation performance.

6.2 Interaction Region Mechanics: Project Schedule

6.2.1: Beryllium beampipe prototype
2021: Development of the technique for welding between thin Beryllium and Aluminum pipes
2022: Prototyping a short Beryllium beampipe with a wall thickness down to of 0.15mm

2023: Prototype Beryllium beampipe with cooling structure

6.2.2-6.2.4: supporting structure and installation scheme
2021: Design of a supporting system for the superconducting magnets; Exploration of the remote vacuum connection method;
2022: Development of the remote vacuum connection method and prototyping in collaboration with industrial partners;
2023: Development of an installation scheme for the interaction region, with joint efforts from both machine and detector groups

6.2 Interaction Region Mechanics: Funding Availability

There is very limited funding support on the listed research topics for the moment. Bids for funding was already sent to NSFC and other funding agencies. It is planned to start the design effort concentrating on the feasibility studies and will starting the prototyping work when funding becomes available. Some of the initial costs will be covered by IHEP's own funding.

6.2 Interaction Region Mechanics: Leadership Arrangement

Haijing Wang (IHEP) and Quan Ji (IHEP) are representatives from the accelerator and detector working groups, respectively and they will jointly lead the R&D efforts. They will also promote the collaboration with industrial partners under the CEPC CIPC framework.

6.2 Interaction Region Mechanics: Manpower Resources

Type	Average FTE Expected
Faculty	0.5
Postdoc	0.25
Students	1.5
Engineers	2

CEPC Detector R&D Project

8. Software and computing

Document Responsible:	Li Weidong, Ruan Manqi, Sun Shengseng, Li Gang
Last saved by on	4/11/2022 3:04:00 PM
Revision number:	1.2

Change history

Revision	When	What changed and why
1	12/22/2019	First draft
2	05/07/2020	
3	01/08/2021	Update the project and schedules
		< Add further lines to table as required >

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xxxiv. In Section *Project Objectives* provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **1.1 Vertex Prototype**. If this project includes identifiable sub-projects you can indicate them in the *Sub-projects Description* Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.

xxxv. Finally, remember to update the *Change History*.

8. Software and computing: Project Objectives

A software and computing framework with well top design and various key algorithms/software tools are essential for high energy experiments. The CEPC software and computing project aims to provide a complete software chain for detector R&D, physics study, and future operation. Besides maintaining the existing CEPC software developed from the ILCSoft, the project is developing new CEPC software based on the Gaudi and the EDM4HEP, which also includes many new modern software techniques and packages, such as DD4HEP, ACTS, and so on. The software is going to support both full and fast simulation and provide a unified reconstruction and analysis toolkit, which also support flexible switch between fast and full simulation for sub-detectors. The new software is going to support both single thread, multi-thread computing, as well as Heterogeneous computing to make use of various potential computing resources.

8. Software and computing: Sub-projects Description

Project ID	Title	Description
8.1	Core Software	
8.1.1	Event Data Model	In Key4HEP, EDM4hep is the common event data model that describes the event data in different processing steps as well as the relationships between them. Customized EDM classes will be added according to CEPC requirements. In order to read M.C. data produced by iLCSoft, we have implemented K4LCIOReader which can convert LCIO data to EDM4Hep objects on the fly.
8.1.2	Detector Description	A unified detector description will be adopted by the simulation and reconstruction to keep the consistencies. The DD4hep-based geometry service has been implemented to provide a unified way to retrieve the detector geometry data. Standard geometry management policies are released to support the development of Reference Detector, including Drift Chamber and Long bar ECAL.
8.1.3	Simulation Framework	A simulation framework has been implemented to integrate Gaudi and Geant4. The simulation software will be enhanced by enabling more realistic simulation. The non-uniformity of magnetic field will be considered. The beam-related and electronics noises will be added to physics signals at the MC hit level. Various types of fast simulation tools will be provided such as Delphes and fast ECAL simulation tools etc. Simulated data corresponding to different detector configurations will be produced for optimizing the detector design.
8.1.4	Analysis Framework	A ROOT based analysis framework will be developed based on the declarative analysis. The performance of the ROOT based analysis software framework will be tuned to achieve good

		scalability for any analysis running on a multi-core server and a large computing cluster respectively. Event selection for online data reduction will be studied by developing event selection steering software and reusing software components developed in the offline environment.
8.1.5	Parallelization	Parallelization in different levels will be fully supported, including inter-event level and intra-event level. The thread safety of EDM4hep and data I/O will be tested with GaudiHive and the performance will be optimized. Parallelized simulation of dE/dx or dN/dx in the gaseous detector will be prototyped as a possible application scenario for parallel computing. To take advantage of machines with many cores, both simulation and reconstruction algorithms will be migrated to run as fully multi-threaded applications. In order to use GPU, FPGA etc more efficiently, the framework software will provide a unified and straightforward way to offload time consuming calculations to any kind of accelerator.
8.1.6	Machine Learning	The interfaces will be developed to integrate TensorFlow/PyTorch tools with the CEPCSW to support various machine learning applications, such as ECAL fast simulation with GANS, Jet/Falvor tagging as well as signal/background discrimination.
8.1.7	Database	The database service will be developed to manage static metadata of detector geometry files and to provide coherent access to geometry data, and the conditions data management system will be designed to manage conditions data which are varying with time and come from calibration, detector monitoring and running.
8.1.8	Validation	The validation platform will be built for software validation tasks including automatic compiling, unit testing and physics validation etc. It will be setup based on the Github action system with runners based on Jenkins and Kubernetes, a central database recording the test results and a message queue synchronizing test jobs. To provide user-friendly interface, a web-based validation dashboard will also be developed.
8.2	Generators(in terface)	The integration of generator interface with Gaudi framework has been done by using the Gaudi Tools. The generator interfaces already support different types, such as particle gun, LCIO reader, HepMC reader etc. New generator tools could be implemented when new physics generators are requested.
8.3	Simulation	

	and Reconstruction	
8.3.1	Silicon detector	Continue to optimize the geometry, digitization, tracking and fitting software for silicon tracker in CEPCSW, based on implemented CEPCv4 silicon trackers and migrated reconstruction from Marlin. New type of silicon modules more realistic for CEPC design are considered to be implemented, and then mechanics support, cooling and electronics are also will be implemented step by step. At the same time, detail digitization will be implemented, and effect of background, noise, non-uniform magnetic field and mechanical alignment on performance will be studied. For the tracking algorithm, the tracking packing ConformalTracking will be migrated, and developing a new tracking algorithm using machine learning techniques to look for possible way to improve the tracking performance is in plan. For the fitting, DDKalTest will be implemented to improve geometry interface from Gear to DD4hep. Combining fitting for silicon tracker and drift chamber will be developed. In the developing procedure, Key4hep will be an important station to keep toughing, benefitting and feedback.
8.3.2	TPC	The TPC geometry, simple digitization and tracking algorithms has been implemented into CEPCSW. The full reconstruction chain for TPC and silicon trackers has been completed, and the full simulation and reconstruction chain in CEPCSW is being validated. Software architecture will be optimized, such as reorganizing the common constants and common tools used in tracking and refining the structure of GaudiAlgorithm ClupatraAlg. More realized TPC digitization and optimization of tracking after mixing background will be performed. Another tracking algorithm ArborTracking will be implemented and compared. Correction on the energy lose and multi-particle scattering for gas in Kalman filter will be investigated. Once the reconstruction has good shape, tracking based alignment will enter the agenda. After ACTS and GenFit are implemented into CEPCSW, they will be considered to apply onto TPC reconstruction processor. Finally, performance study on benchmark physics channels will be performed. Software and design are both optimized as far as possible.
8.3.3	Drift Chamber	Develop the two drift chamber simulation in CEPCSW. Realize a simple drift chamber digitization by get the POCA and dE/dx of

		hit in cell. Develop the track fitting algorithm according to MC truth position. Implement a track seeding algorithm based on truth information. Realize a dummy dE/dx reconstruction algorithm by doing a hit level sample from empirical model. Simulation of CRD detector including silicon, drift chamber and ECAL. Do Garfield simulation on the cluster counting method is performed. Develop the track fitting combined DC and silicon measurement in CEPCSW. Integrate a track level dN/dx simulation from Garfield in CEPCSW to study the PID performance. Optimize the tracker through fast simulation. Optimize the tracker by study the resolution of momentum, impact parameter, and dE/dx(dN/dx) in CEPCSW. Optimize the design with benchmark physics channels in CEPCSW.
8.3.4	Calorimetry	Porting simulation and digitization of ECAL into CEPCSW with EDM4hep based calorimetry hit objects and MC truth information and integrated with DDG4 for detector description. Simulation and digitization algorithms for a long crystal bar solution for ECAL have been developed and a preliminary result has been obtained. Feasibility research on long crystal bar solution for ECAL is in processing, the ghost ambiguity rejection is the key point. Porting simulation and digitization of HCAL in baseline detector design to CEPCSW will be implemented. Optimization of reconstruction of long crystal bar for ECAL to improve the precision of 3D cluster finding, especially with multiple particles incidented into one super module. Extraction of the jet energy resolution, and the limitation of detector and physics reach based on the long crystal bar solution for ECAL will be implemented. Development and upgrade of PFA algorithms is in the plan to improve the performance of long crystal bar solution for ECAL.
8.3.5	Muon detector	The CEPCv4 coil, yoke and muon detector will be implemented into CEPCSW as comparison at first, and then new design of muon detector for TDR will be described based on DD4hep description. Pandora and Arbor are considered as muon identification using the muon detector as the first attempt. The more developing and optimization will be investigated.
8.3.6	ACTS	The standalone ACTS implementation of two trackers is going to be integrated into the CEPCSW, then the optimization of silicon tracker will be the driver of the development. A new propagator algorithm to achieve the balance between speed and precision is going to be developed. A new seeding and pattern recogniation

		algorithms are also in the agenda.
8.3.7	PFA	In the past year, Pandora from Marlin was ported into CEPCSW. The single γ and electron events were used to check its ECAL and ECAL+Tracker reconstruction performance and the results looks good. Besides, the Pandora was put into Key4HEP project. In the next year, the main work for Pandora will be checking its reconstruction performance for hadrons and jets. Moreover, optimizing the Pandora reconstruction algorithms for different detector designs will also be considered. After that, there are some future plans, such as optimizing the Pandora client to make it more flexible to read geometry information, improving the Pandora reconstruction performance by using machine learning techniques, working with Key4HEP to optimize the PandoraSDK and making it more efficient. The clustering of Arbor has been ported into CEPCSW. In the next year, the whole reconstruction will be ported and it will be validated using the single particle performance and Boson mass resolution. For future plans, the ArborPFA will be integrated into Key4HEP project, the performance will also be improved.
8.4	Analysis tools	A a full covariance fast simulation module combined with the analysis framework is being developed. Next plan is migrating the analysis framework from the IlcSoft to CEPCSW, which depends on the EMD development. The vertex finding, jet-clustering, and flavor tagging package will also be interfaced the CEPCSW, more machine learning approaches will be tried to improve the performance. Implementing the CEPC plot style macros into the analysis framework and the CEPCSW. Integration of the CEPC statistical combination package in the CEPCSW will be realized in near future.
8.5	Visualization	In the next year, the Druid package will be ported into the CEPCSW and tuned according to the detector design.
8.6	Computing	The basic Grid Infrastructure has been set up for CEPC: The VOMS(VO Management System) service was deployed for CEPC VO. The IHEP Grid Computing Element and Storage Element prototype was built up and successfully tested using HTCondorCE with more than 500 CPU cores. The CVMFS server was deployed CEPC software in distributed environment. The distributed computing infrastructure (DCI) prototype is built up based on DIRAC. Available CPU and storage resources are being

		integrated in the infrastructure. The production system prototype will be built up to allow massive production MC jobs to automatically submit, schedule and run in DCI. User job submission and management system will be considered to support user analysis. Also metadata system and data transfer system should be designed and built to share data among sites. Data challenges, tuning, performance study and optimization in real user cases need to be done before production. After in production, a complete monitoring system is needed to ease operations. The issues such as improvements with parallel computing, upgrading with WLCG evolutions needed to be considered.

8. Software and computing: CEPC Relationship

Software and computing projects play an essential role, which interplay with detector, accelerator, and physics study. A framework and complete toolkit with good top design, wide collaboration among different experiments and industry will make CEPC a fruitful and successful experiment.

Physics performance. Physics is the ultimate goal of any experiment. CEPC is going to focus on Higgs, electroweak precision measurements to test SM, as well as lots of QCD and flavor physics topics. Software and computing is supporting this kind of study by providing complete simulated samples with the software chain including generation, detector simulation, reconstruction, and analysis. It should be reliable and fast, so the physics performance could be evaluated according the experiment design quickly.

Detector design and optimization. Detector design depends many factors, such as physics performance, background, and other constraints. Full simulation and realistic digitization

New technology. High energy experiment could and should benefits from the development of artificial intelligence and data science.

8. Software and computing: Project Schedule

2020:

Core software

The Gaudi was adopted as the underlying software framework, based on which CEPCSW was developed. The DD4hep-based geometry service was implemented to provide a unified way to retrieve the detector geometry data. The EDM4Hep was used as the event data model to describe the event data in different processing steps as well as the relationships between them. The K4LCIOReader was implemented to convert LCIO data to EDM4Hep objects, which made it possible to read M.C. data produced by iLCSoft. The Geant4 was integrated to the CEPCSW with the help of newly developed integrating modules. The environment for software developing was established by using tools such as Boost, Python, GitHub, CMake, Spack, and CVMFS etc. in the CentOS operating system.

Detector simulation and reconstruction

Tracking algorithms for Silicon Trackers and TPC detector were ported to the new framework and consistent tracking performances were obtained. Realize the drift chamber geometry and simulation and digitization. Make track seed through MC truth information. Integrate Genfit framework in CEPCSW for the track fitting of tracker. Pandora-based PFA from Marlin was ported into CEPCSW for particle reconstruction. Porting simulation and digitization of ECAL into CEPCSW with EDM4hep based calorimetry hit objects and MC truth information and integrated with DDG4 for detector description. Development of simulation and digitization algorithms for a long crystal bar solution for ECAL.

Computing

The basic Grid Infrastructure was set up for CEPC: The VOMS(VO Management System) service was deployed for CEPC VO. The IHEP Grid Computing Element and Storage Element prototype was built up and successfully tested using HTCondorCE with more than 500 CPU cores. The CVMFS server was set up to successfully deploy CEPC software in distributed environment.

2021:

Core software

The simulation software will be enhanced by enabling more realistic simulation. The simulation will use the non-uniformity of magnetic field,and also beam-related and electronics noises will be added to physics signals at the MC hit level. Various types of fast simulation tools will be provided such as Delphes and fast ECAL simulation tools etc. Simulated data corresponding to different detector configurations will be produced for optimizing the detector design. The thread safety of EDM4hep and data I/O will be tested with GaudiHive and performance will be optimized. Parallelized simulation of dE/dx or dN/dx in the gaseous detector will be prototyped as a possible application scenario for parallel computing . The prototype of validation platform will be setup to demonstrate the process of automatic compiling and unit testing triggered by source code commitment.

Detector simulation and reconstruction

Tracking and fitting performance for silicon tracker and TPC will be studied and optimized, through improving the architecture of reconstruction software, implementing more realitic detector modules and comparing more algorithms. The effect of noise and background on silicon and TPC tracker will be implemented into performance study. Besides the CDR baseline, track fitting with the combination of silicon and drift chamber measurements will also be performed. Realize the dN/dx samping with the sampling tool and study the performance of PID with cluster counting method in CEPCSW. Optimize tracker with fast simulation tools. Get the CRD physics performance in CEPCSW. Check particles and jet reconstruction performance using PFA algorithm such as Pandora and optimize the reconstruction algorithms for different detector designs. Feasibility research on long crystal bar solution for ECAL, the ghost ambiguity rejection is the key point. Porting simulation and digitization of HCAL in baseline detector design to CEPCSW.

Interfacing the FastJet package and migrating LCFIplus, the vertex finding, jet-clustering, and flavor-tagging tool in the CEPSW. To support alternative ML-based jet classification algorithms, which will be studied and implemented in CEPCSW. The core software will integrated with ACTS to take advantage of its modern, parallelizable, efficient and fast track and vertexing reconstruction software.

Computing
The distributed computing infrastructure prototype is built up based on DIRAC. Available CPU and storage resources are being integrated in the infrastructure.

2022:

Core software
To take advantage of machines with many cores, both simulation and reconstruction algorithms will be migrated to run as fully multithreaded applications. The database service will be developed to manage metadata of detector geometry files and to provide coherent access to geometry data. For machine learning, the interface will be developed to integrate TensorFlow/PyTorch tools with the CEPCSW to support various machine learning applications. A software prototype will be developed based on ROOT RDataFrame to support declarative analysis. According to data format of the beam test, new interfaces will be developed for reading the test beam data and performing analysis on test beam data in the CEPCSW. The software validation platform will be fully functioning by adding database to store unit testing results, synchronizing message queue, and validation algorithms, and a web-based validation dashboard will be provided.

Detector simulation and reconstruction and physics analysis
More silicon tracking optimization will be considered, and try to develop tracking algorithm based on machine learning technique. For TPC, correction on the energy lose and multi-particle scattering for gas in Kalman filter will be optimized.
On ACTS, the new propagator method will be development to balance the speed and precision. Optimization of reconstruction of long crystal bar for ECAL to improve the precision of 3D cluster finding, especially with multiple particles incidented into one super module. Extraction of the jet energy resolution dependence, and the limitation of detector and physics reach. Development and upgrade of PFA algorithms to improve the performance of long crystal bar solution for ECAL.

Computing
The production system prototype will be built up to allow massive production jobs to automatically submit and run.

2023 and 2024:

Core software

The complete chain of data production from event generator, detector simulation, digitization, event reconstruction and physics analysis will be established by fully utilizing Key4hep software stack. In order to use GPU, FPGA and TPU etc. more efficiently, the framework software will provide a unified and straightforward way to offload time consuming calculations to any kind of accelerator. The performance of ROOT based analysis software framework will be tuned to achieve good scalability for any analysis running on a multi-core server and a large computing cluster respectively. Event selection for online data reduction will be studied by developing event selection steering software and reusing software components developed in the offline environment.

Computing

The User job submission and management system prototype will be developed to allow users easily used. The data transfer system prototype will be developed to allow data sharing between sites.

8. Software and computing: Funding Availability

There is no dedicated funding for software.

8. Software and computing: Leadership Arrangement

IHEP: LI Weidong, Sun Shengseng, Ruan Manqi, Li Gang

Others: Huang Xingtao(SDU)

8. Software and computing: Manpower Resources

Type	Average FTE Expected
Faculty	7
Postdoc	2
Students	**3**
Engineers	0