CEPC Detector R&D Project

1.1 Vertex Prototype

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| Document Responsible: | Qi Huirong |
| Last saved by on |  |
| Revision number: | 3 |
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Change history

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| **Revision** | **When** | **What changed and why** |
| 1 | 12/12/2019 | First draft v1.0 |
| 2 | 4/29/2020 | Second draft v2.0 |
| 3 | 5/07/2020 | Second draft with new schedules v2.1 |
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Readme first

1. Please do not delete or modify this section or its structure.
2. Only change text enclosed by (and including) angled brackets “< … >”.
3. Don’t change field directly, instead modify the document options, under File🡪 Properties (or similar)
   * Enter name of person that wrote the document in Document:Summary: Author
   * The project ID number, should follow the rules provided to you earlier. The number should be changed in Document:Custom: PBS.
   * The project name should be changed in Document:Summary: Subject.
4. In Section [*Project Objectives*](#ProjectObjectives) 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*](#SubprojectsDescription) Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
5. Finally, remember to update the [*Change History*](#ChangeHistory).

2.1.1 TPC Module 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 760 ns, 200 ns and 25 ns, 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 120 μs. 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 Module Prototype: Sub-projects Description

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| **Project ID** | **Title** | **Description** |
| 2.1.1 | IBF TPC module | The continuous IBF suppression TPC module for the circular collider’s beam structure |
| 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 | Low material budget TPC | Low material budget to satisfy CEPC requirements |
| 2.1.4 | TPC prototype R&D | High space resolution with MPGD, IBF detector module and calibration using UV system |
| 2.1.5 | Chamber R&D | Field cage and connector and Barrel, Low-mass mechanical structure for TPC detector |
| 2.1.6 | FEE electronics | Low power consumption R&D for FEE electronics and ASIC chips |
| 2.1.7 | Calibration system | 266nm UV laser beams to calibration and alignment study with TPC prototype |
| 2.1.8 | Mechanical structure | Stability and strong supporting |
| 2.1.9 | Cooling | CO2 cooling for the readout |
| 2.1.10 | HV and low power | Low power Crate, connector, cable and HV system |
| 2.1.11 | Data analysis and software | With LCTPC and ILD common raw data analysis framework and software of LCIO, Marlin TPC, Kalman filter reconstruction |
| 2.1.12 | Online display interface and track display | With DAQ and LabView software to run and display |

2.1.3 TPC Module Prototype: 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. The TPC smaller 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 = 32×1035 cm-2s-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 Module 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.

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

2.1.5 TPC Module Prototype: Funding Availability

MOST R&D

CEPC R&D – TPC /2017.6-2022.6

TPC prototype R&D/IHEP/1.2M RMB

TPC ASIC chip R&D/Tsinghua/1.1M RMB

NSFC R&D

Key Program

2017.1-2020.12 TPC calibration R&D /IHEP/1.2M RMB

2017.1-2020.12 TPC calibration R&D /Tsinghua/1.9M RMB

General Program

2018.1-2021.12 TPC module R&D/IHEP/0.6M RMB

2020.1-2023.12 TPC R&D/IHEP/0.6M RMB

2.1.6 TPC Module 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 Module 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.

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