CEPC Detector R&D, Collaboration and Future

João Guimarães da Costa

(for the Physics and Detector Working Group)

中国科学院高能物理研究所

Institute of High Energy Physics
Chinese Academy of Sciences

International Advisory Committee Meeting
October 31, 2022

CEPC action plan since CDR

Public release: November 2018

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

arXiv: 1809.00285

The CEPC Study Group
August 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

arXiv: 1811.10545

The CEPC Study Group
October 2018

Download from: http://cepc.ihep.ac.cn/

Since 2019

Cement project with R&D towards:

Detector technologies development and establishment of seeds for International Collaborations

Identify challenges and devise solutions

CEPC TDR Parameters (upgrade version)

Main Parameters: High luminosity

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	**50**			
Energy [GeV]	**120**	**80**	**45.5**	**180**
Bunch number	415	2161	19918	59
Emittance (εx/εy) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (σx/σy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Beam-beam parameters (ξx/ξy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF frequency [MHz]	650			
Luminosity per IP[10^{34}/cm^2/s]	**8.3**	**27**	**192**	**0.83**

Increase relative to CDR: x 2.8 x 2.7 x 6

CEPC Physics Program

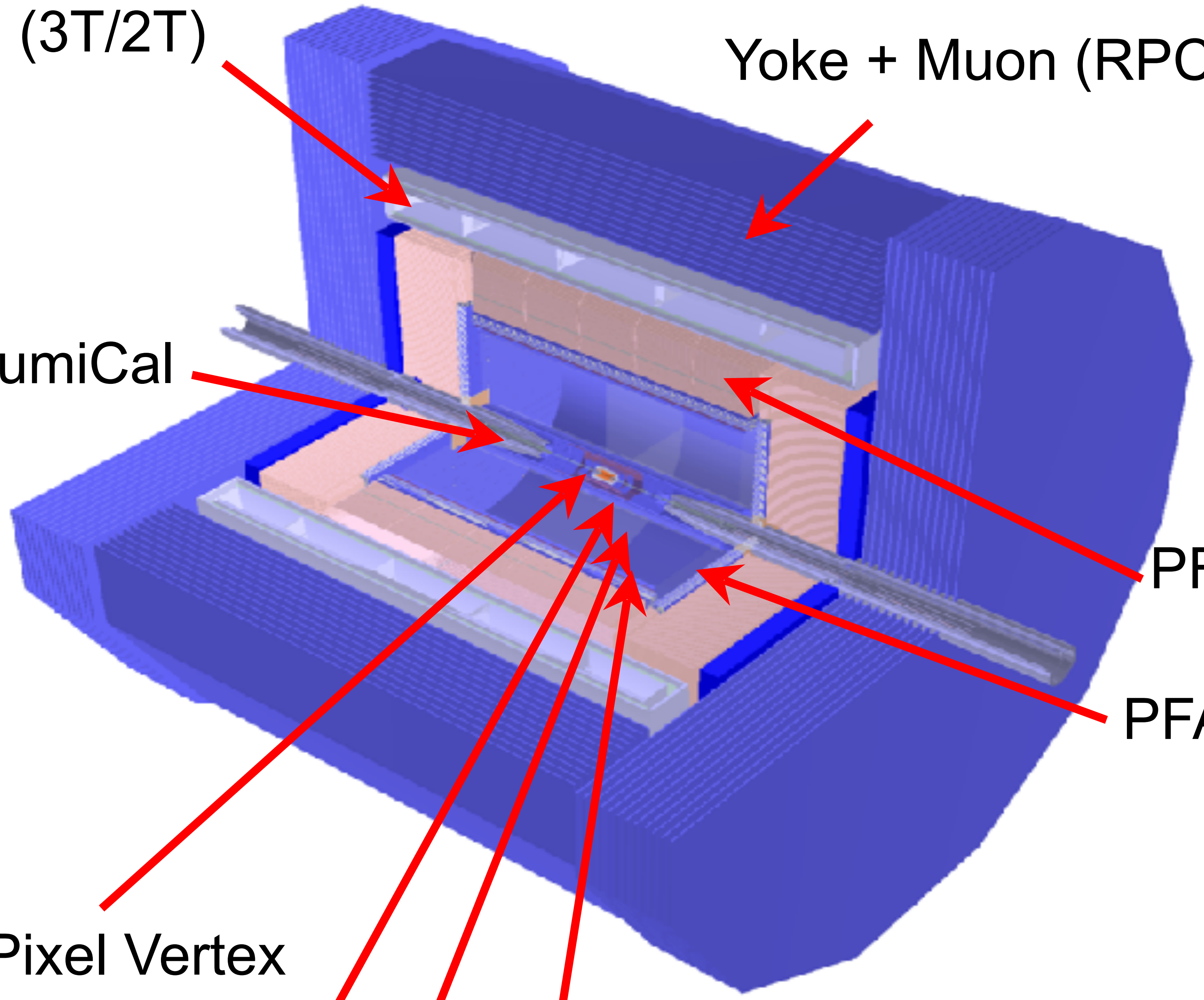
CEPC Operation mode		ZH	Z	W^+W^-	ttbar
		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	L / IP [$\times 10^{34}$ $cm^{-2}s^{-1}$]	3	32	10	-
	[ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run time [years]		10	2	1	5
Latest (50MW)	L / IP [$\times 10^{34}$ $cm^{-2}s^{-1}$]	8.3	192	27	0.83
	[ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	4×10^6	4×10^{12}	5×10^7	5×10^5

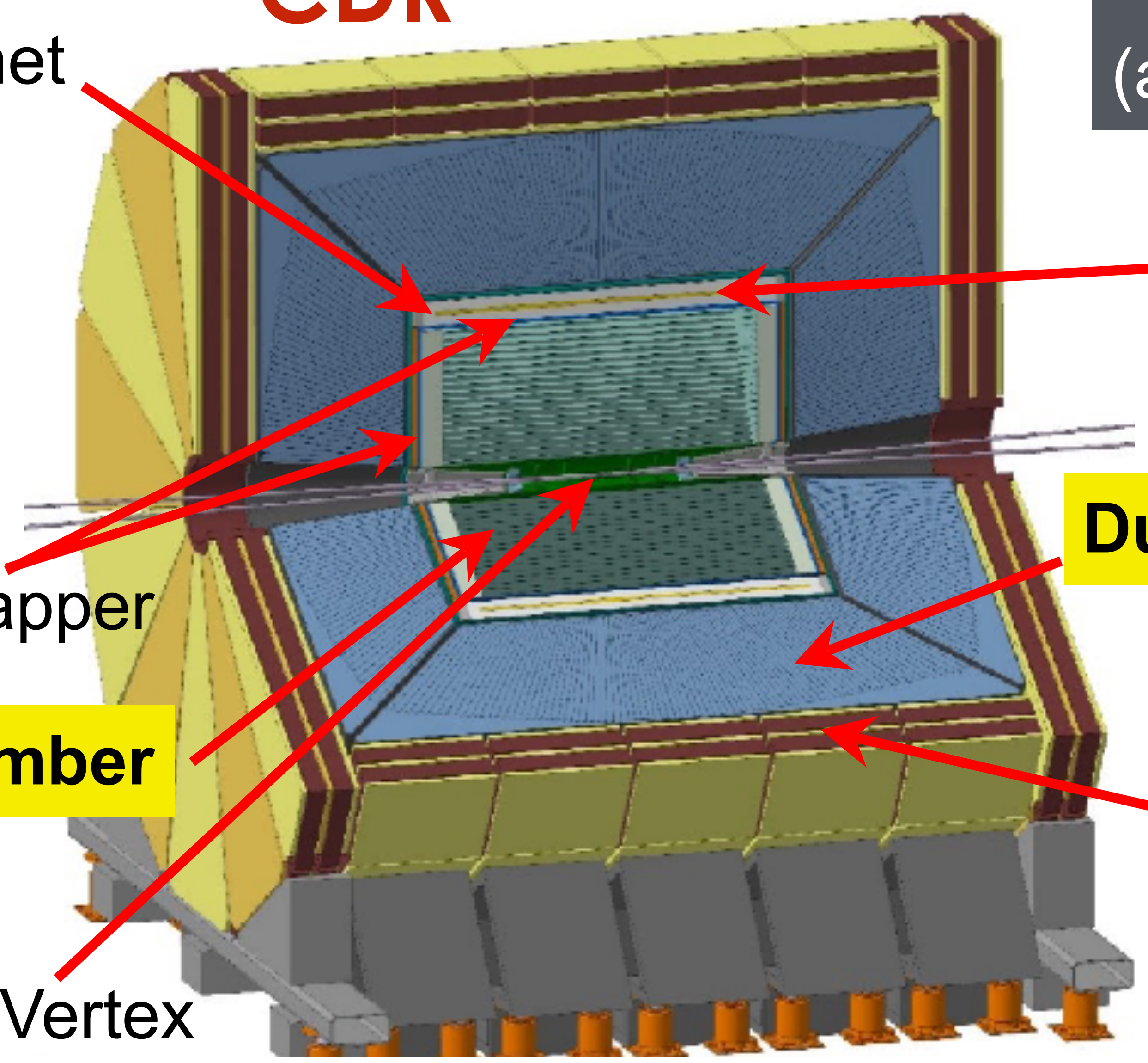
Large physics samples: ~10^6 Higgs, ~10^{12} Z, ~10^8 W bosons, ~10^6 top quarks

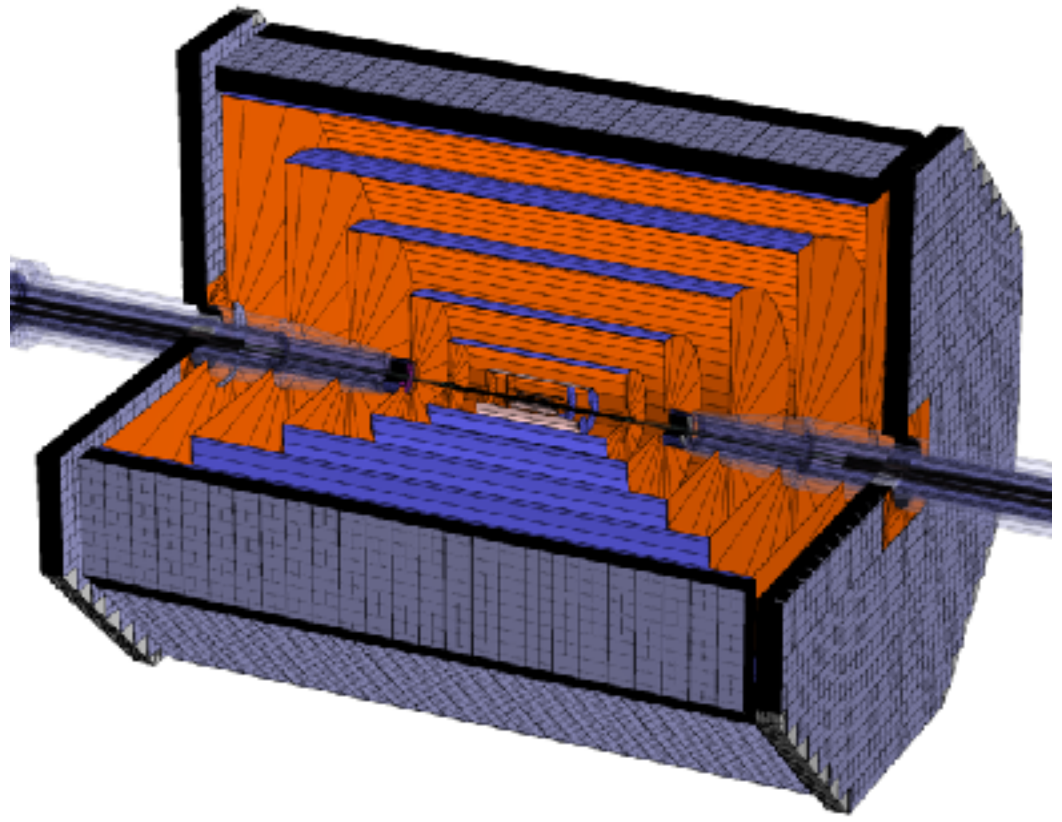
Physics potential similar to FCC-ee, ILC, CLIC

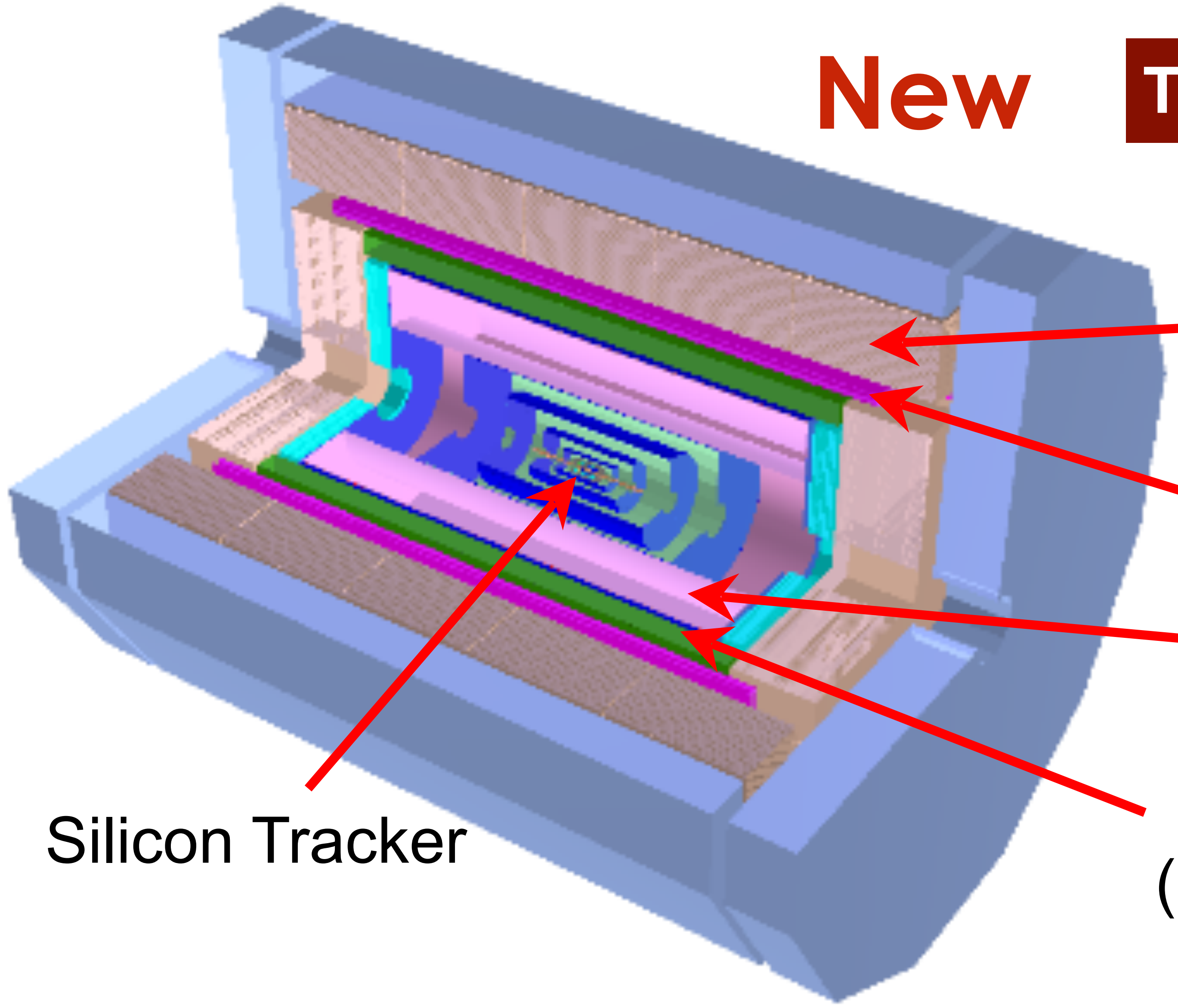
Detector R&D progress

CEPC Detector Concept Designs







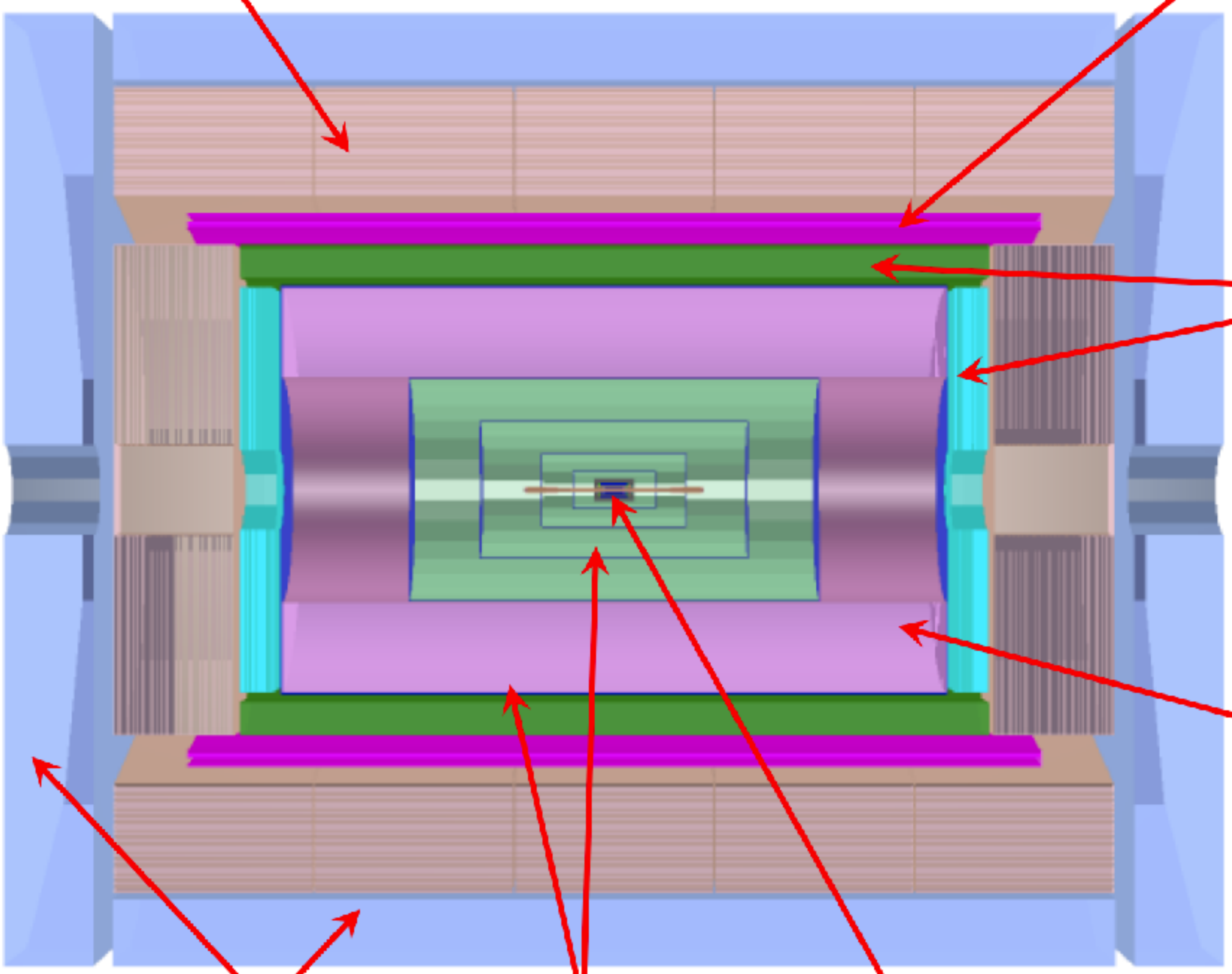


The 4th Conceptual Detector Design

Scint Glass PFA HCAL

Advantage: Cost efficient, high density

Challenges: Light yield, transparency, massive production.



Solenoid Magnet (3T / 2T) Between HCAL & ECAL

Advantage: the HCAL absorbers act as part of the magnet return yoke.

Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Crystal ECAL

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

A Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

Challenges: sufficient PID power; thin enough not to affect the moment resolution.

Detector R&D Breakdown

Total of 103 sub-tasks identified

1. Vertex
   1.1. Pixel Vertex Prototype
   1.2. ARCADIA/LFoundry CMOS
2. Tracker
   2.1. TPC
   2.2. Silicon Tracker
   2.3. Drift Chamber
3. Calorimeter
   3.1.ECAL Calorimeter
      3.1.1. Crystal Calorimeter
      3.1.2. Scintillator-Tungsten
   3.2. HCAL PFA Calorimeter
      3.2.1. DHCAL
      3.2.2. Sci AHCAL
   3.3. DR Calorimeter
4. Muon Detectors
   4.1. Muon Scintillator Detector
   4.2. Muon and pre-shower MuRWell Detectors
5. Solenoid
   5.1. LTS Solenoid
   5.2. HTS Solenoid
6. MDI
   6.1. LumiCal Prototype
   6.2. Mechanics
7. TDAQ
8. Software and Computing

Det	Technology
Pixel Vertex	JadePix
	TaichuPix
	Arcadia
	CPV(SOI)
	Stiching
Tracker & PID	TPC
	CEPCPix
	Drift chamber
	PID DC
	LGAD
	Silicon Strip

Det	Technology
Calorimeter	Crystal ECAL
	Si+W ECAL
	Scint+W ECAL
	Scint AHCAL
	ScintGlass AHCAL
	RPC SDHCAL
	MPGD SDHCAL
	DR Calorimeter
Muon	Scintillation Bar
	RPC
	μ-Rwell
Lumi	SiTrk+Crystal ECAL
	SiTrk+SiW ECAL

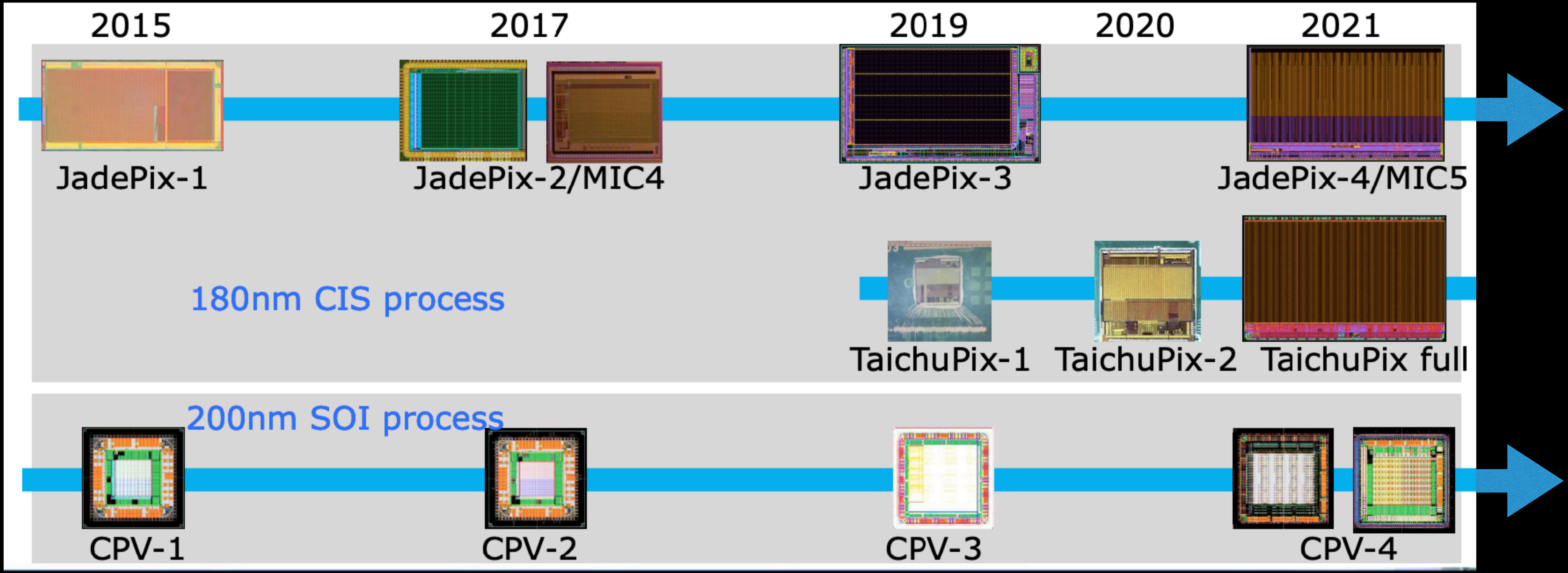
Prototypes under evaluation

Sub-detector	Specification	Requirement	CEPC prototype
Pixel detector	Spatial resolution	$\sim 3\ \mu m$	$3 - 5\ \mu m$ [14–16]
TPC/drift chamber	dE/dx (dN/dx) resolution	$\sim 2\%$	$\sim 4\%$ [19–21]
Scintillator-W ECal	Energy resolution Granularity	$< 15\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2\ \mathrm{cm}^2$	Prototype built to be measured $0.5 \times 0.5\ \mathrm{cm}^2$
4D crystal ECal	EM energy resolution 3D Granularity	$\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2 \times 2\ \mathrm{cm}^3$	Prototyping [25] $\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2 \times 2 \times 2\ \mathrm{cm}^3$
Scintillator-Steel HCal	Support PFA, Single hadron σ_E^{had}	$< 60\%/\sqrt{E(\mathrm{GeV})}$	Prototyping
Scintillating glass HCal	Support PFA Single hadron σ_E^{had}	$\sim 40\%/\sqrt{E(\mathrm{GeV})}$	Prototyping $\sim 40\%/\sqrt{E(\mathrm{GeV})}$
Low-mass Solenoid magnet	Magnet field strength Thickness	$2\ \mathrm{T} - 3\ \mathrm{T}$ $< 150\ \mathrm{mm}$	Prototyping

PFA calorimeter

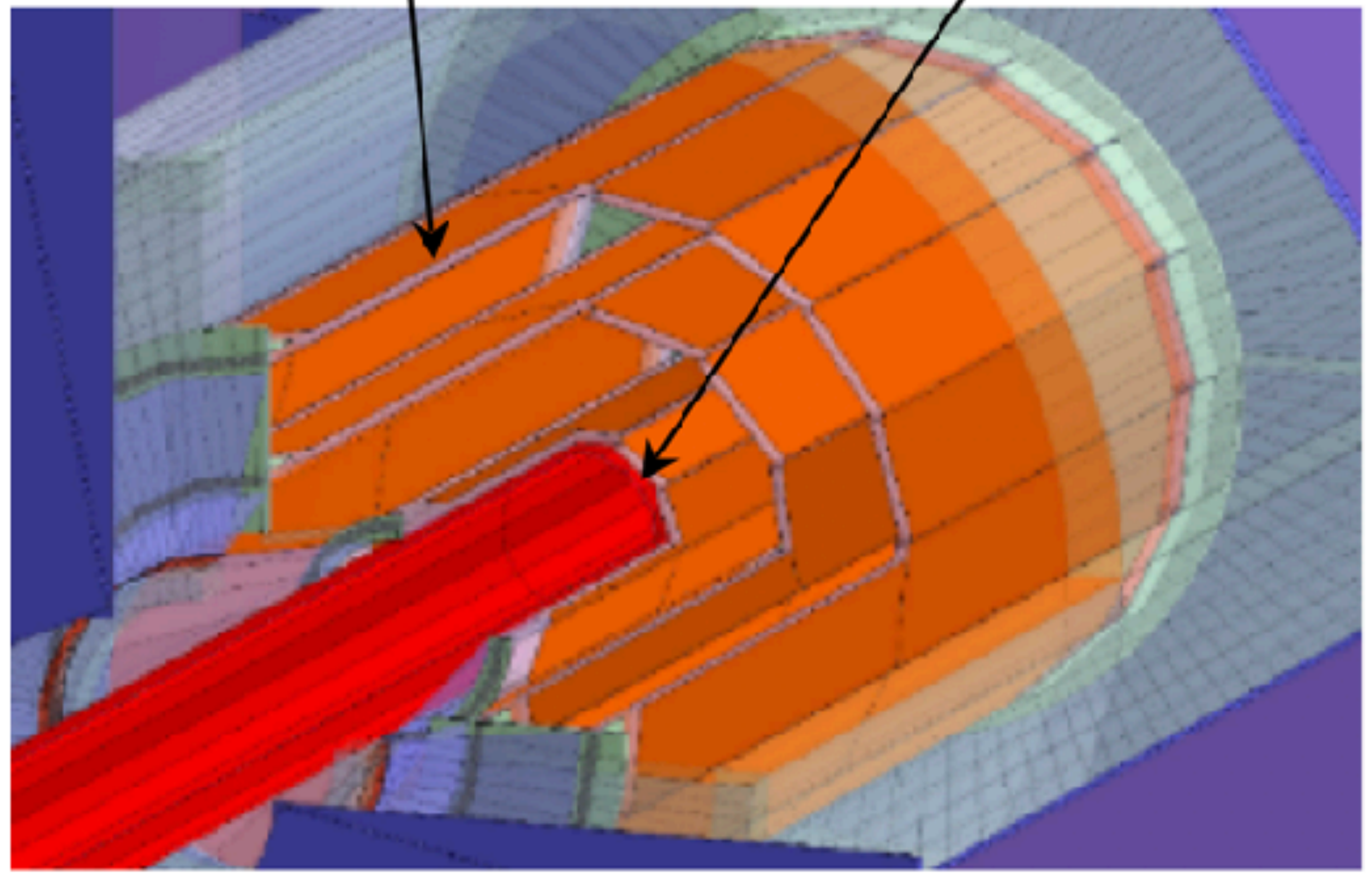
CEPC Vertex detector R&D

- CEPC Vertex detector sensor R&D timeline
  - Based on Tower Jazz CIS 180nm process (Jadepix , TaichuPix)
  - Based SOI 200nm process (CPV chip)



CEPC R&D: Silicon Pixel Sensors

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

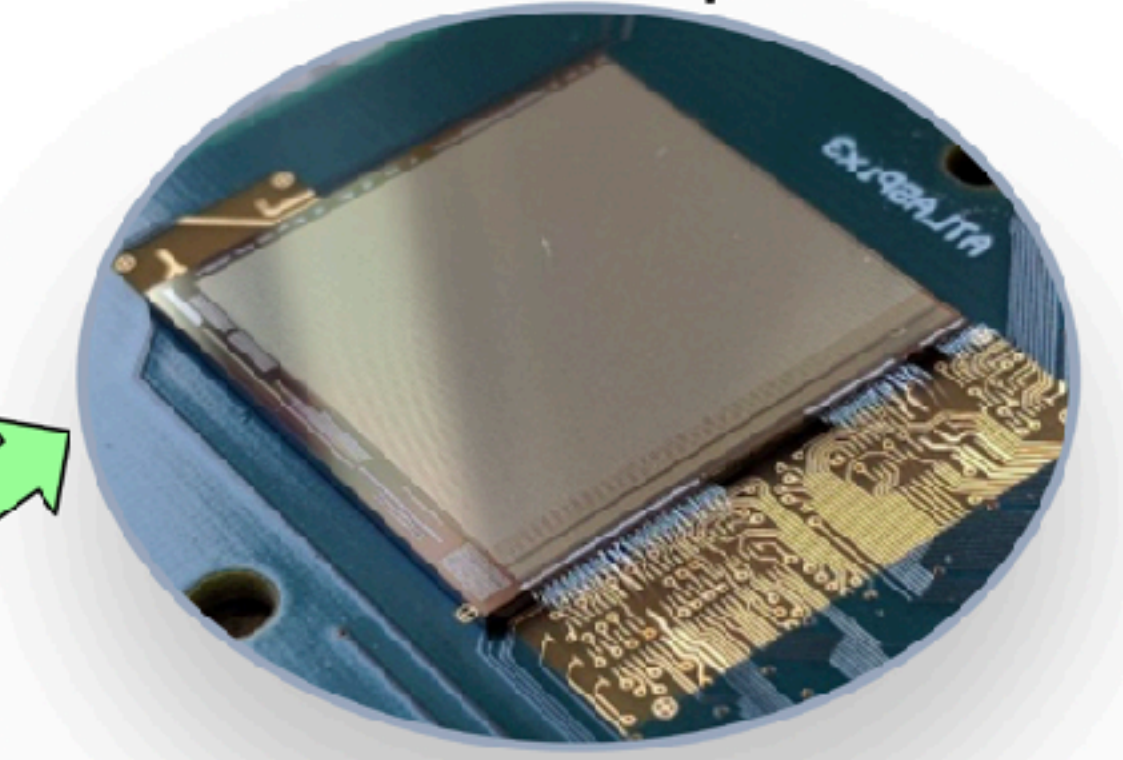
CDR design specifications

- Single point resolution ~ 3μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)

Silicon pixel sensor develops in 5 series:
JadePix, TaichuPix, CPV, Arcadia, CEPCPix

Develop **CEPCPix** for a CEPC tracker based on **ATLASPix3** **CN/IT/UK/DE**

TSI 180 nm HV-CMOS process

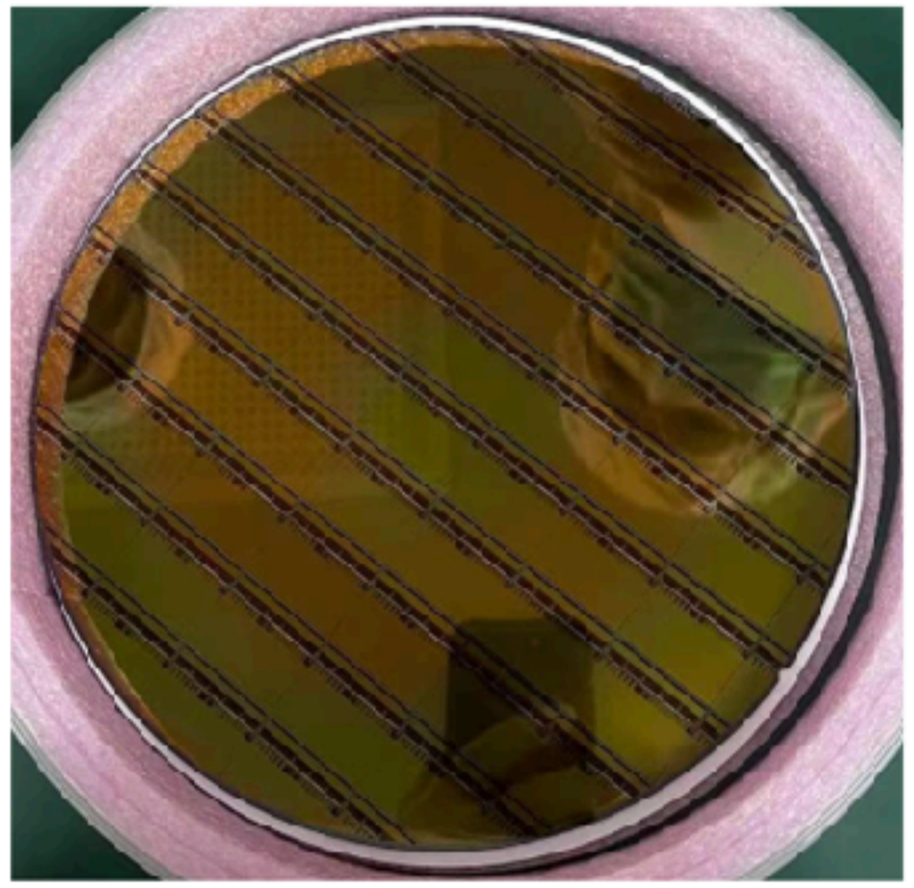


JadePix-3 Pixel size ~16×23 μm²

Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm²

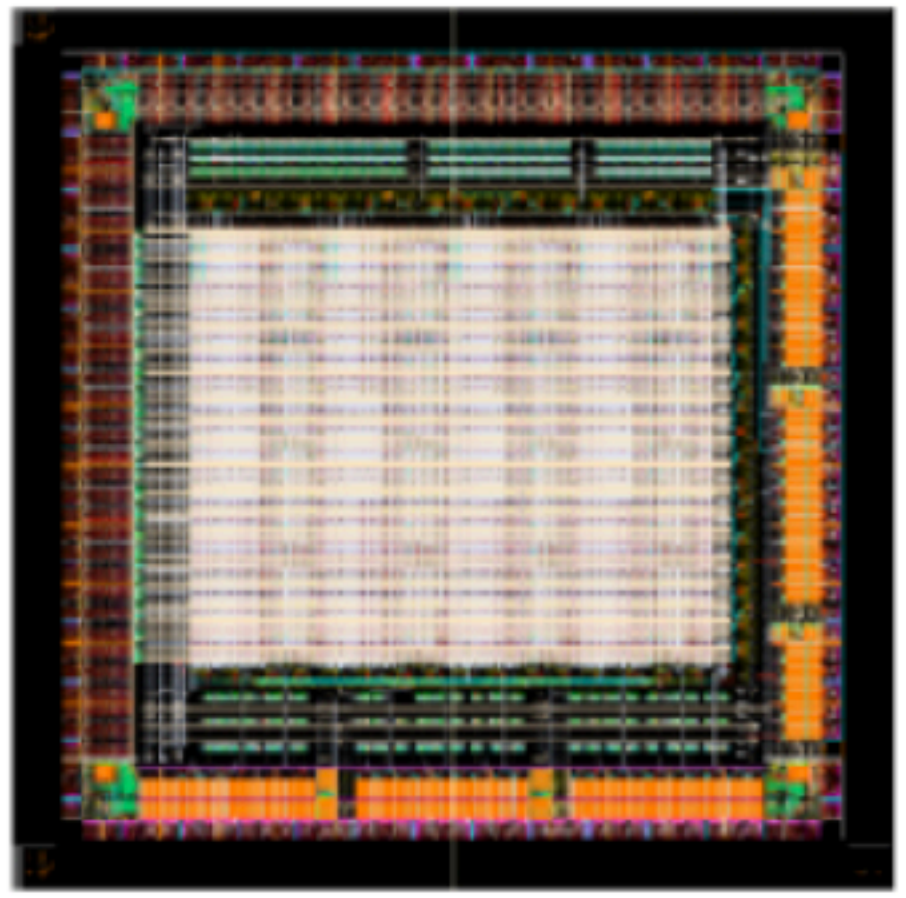
MOST 1

TaichuPix-3, FS 2.5x1.5 cm²
25×25 μm² pixel size

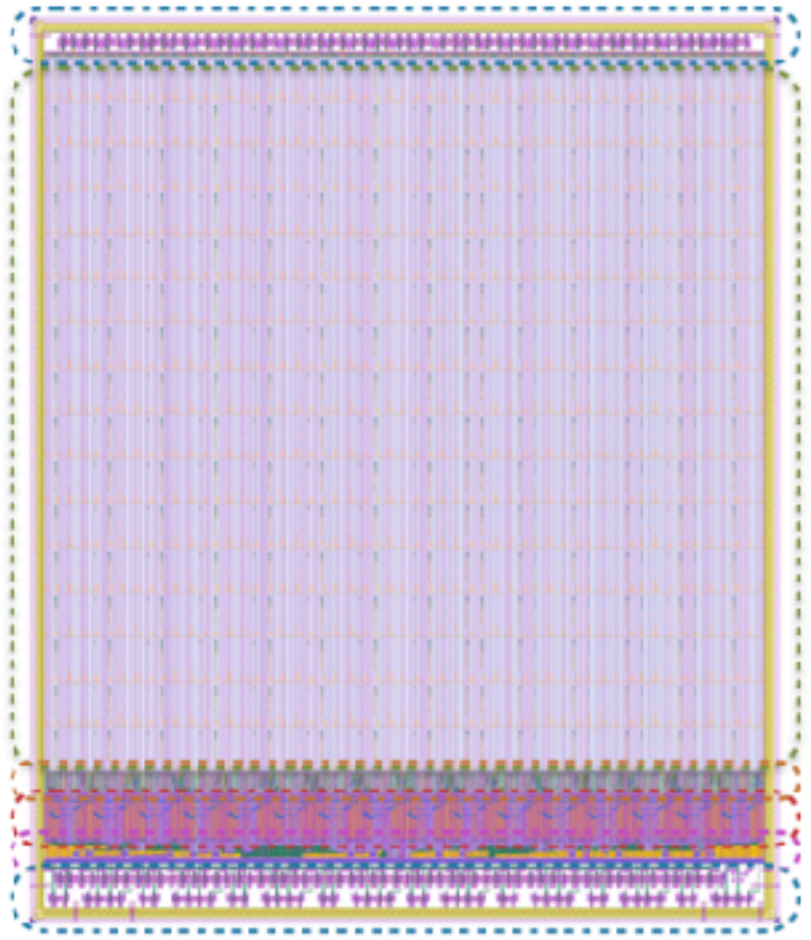


MOST 2

CPV4 (SOI-3D), 64×64 array
~21×17 μm² pixel size



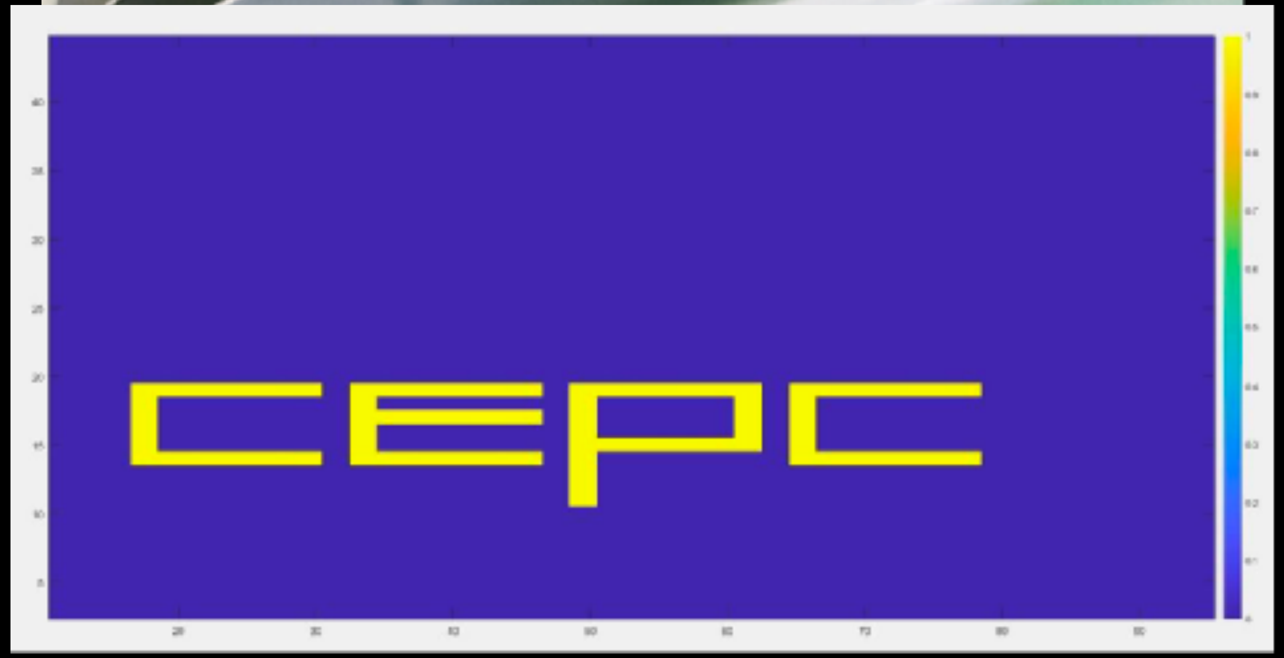
Arcadia by Italian groups
for IDEA vertex detector
LFoundry 110 nm CMOS



CEPC R&D: Vertex Detector Prototype

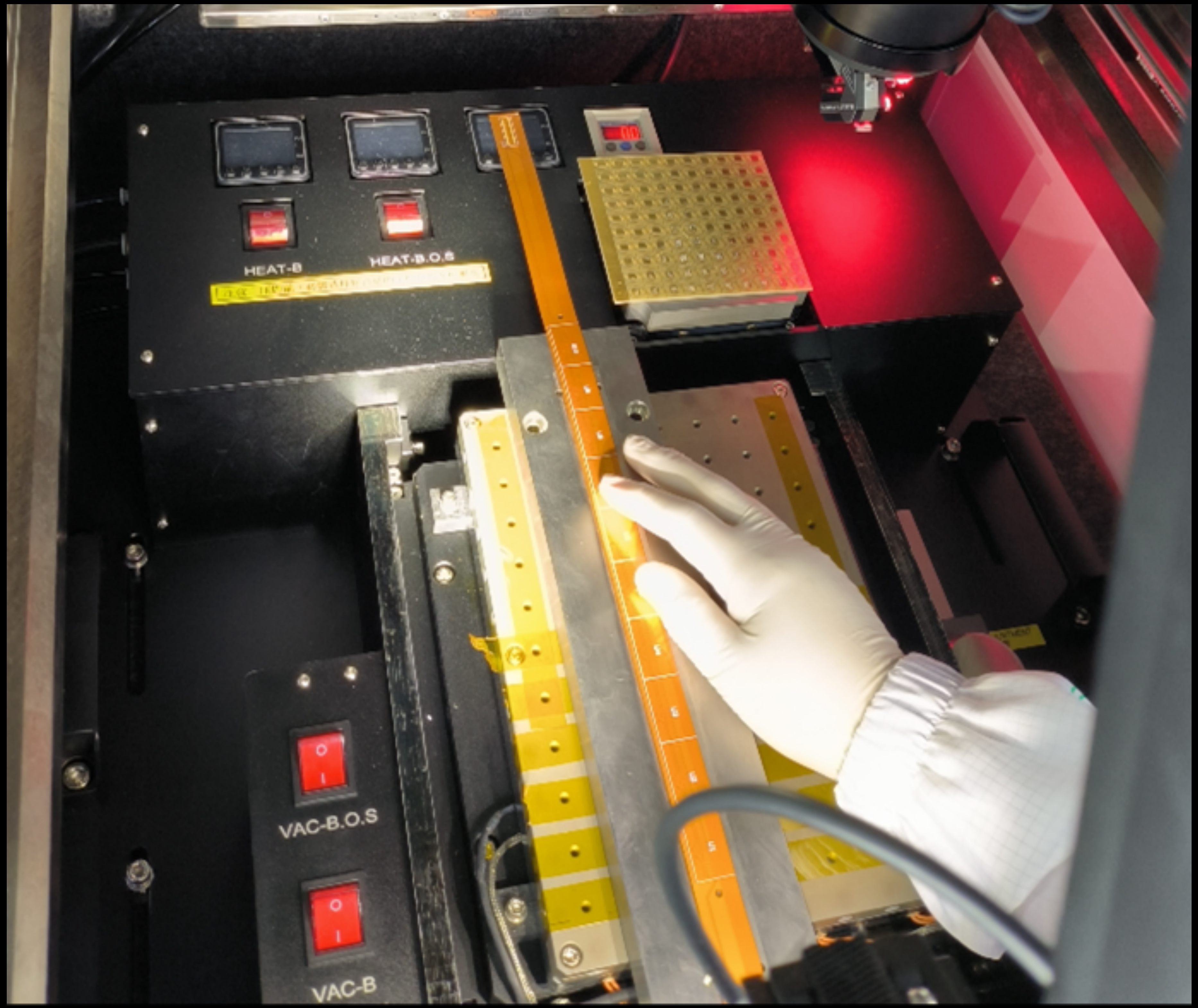
Low-mass vertex detectors require sensors with:
- integrated readout electronics
- low power consumption

TaichuPix3 chips at IHEP



Chip working well

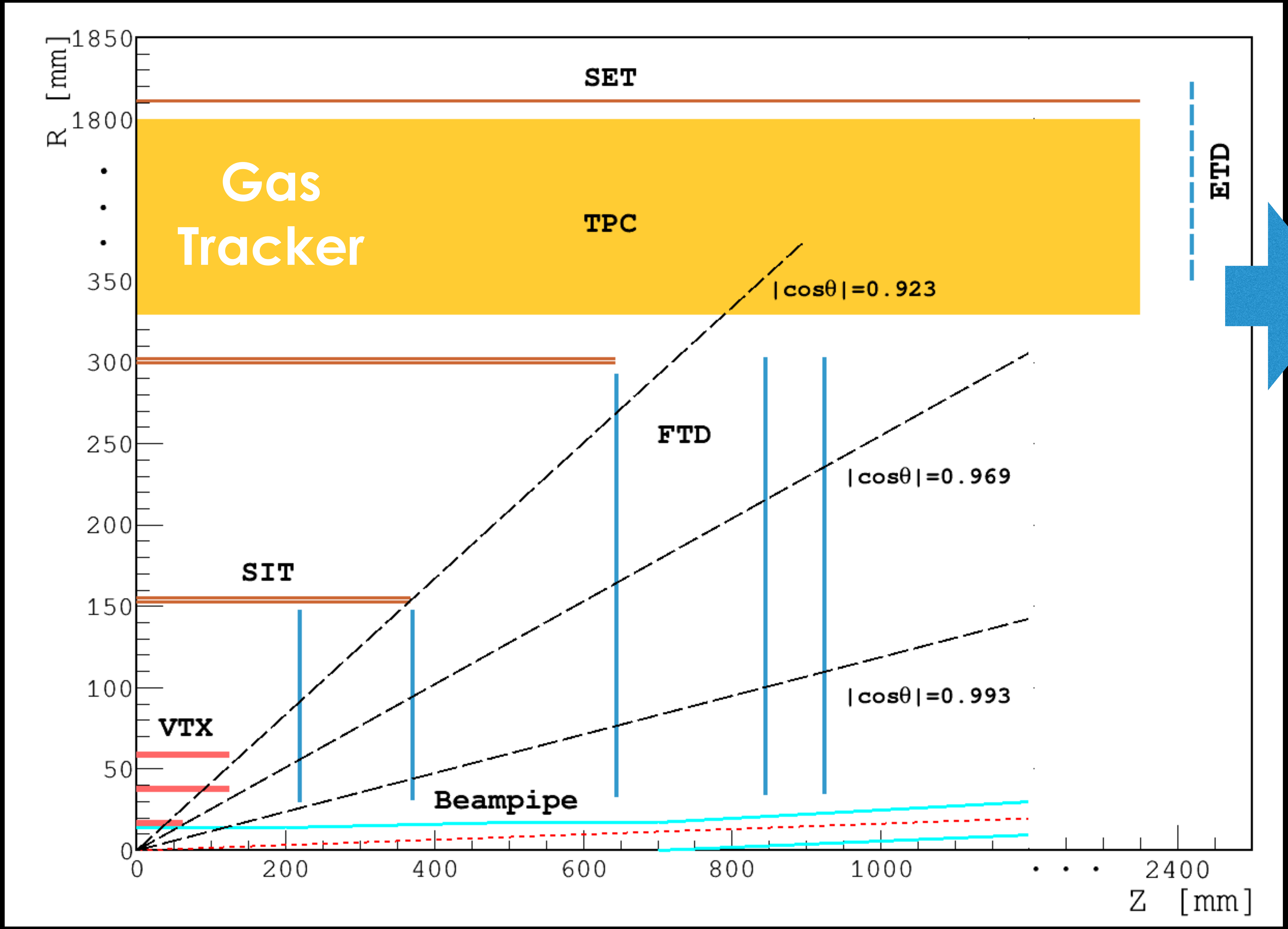
Ladder wire bonding preparations



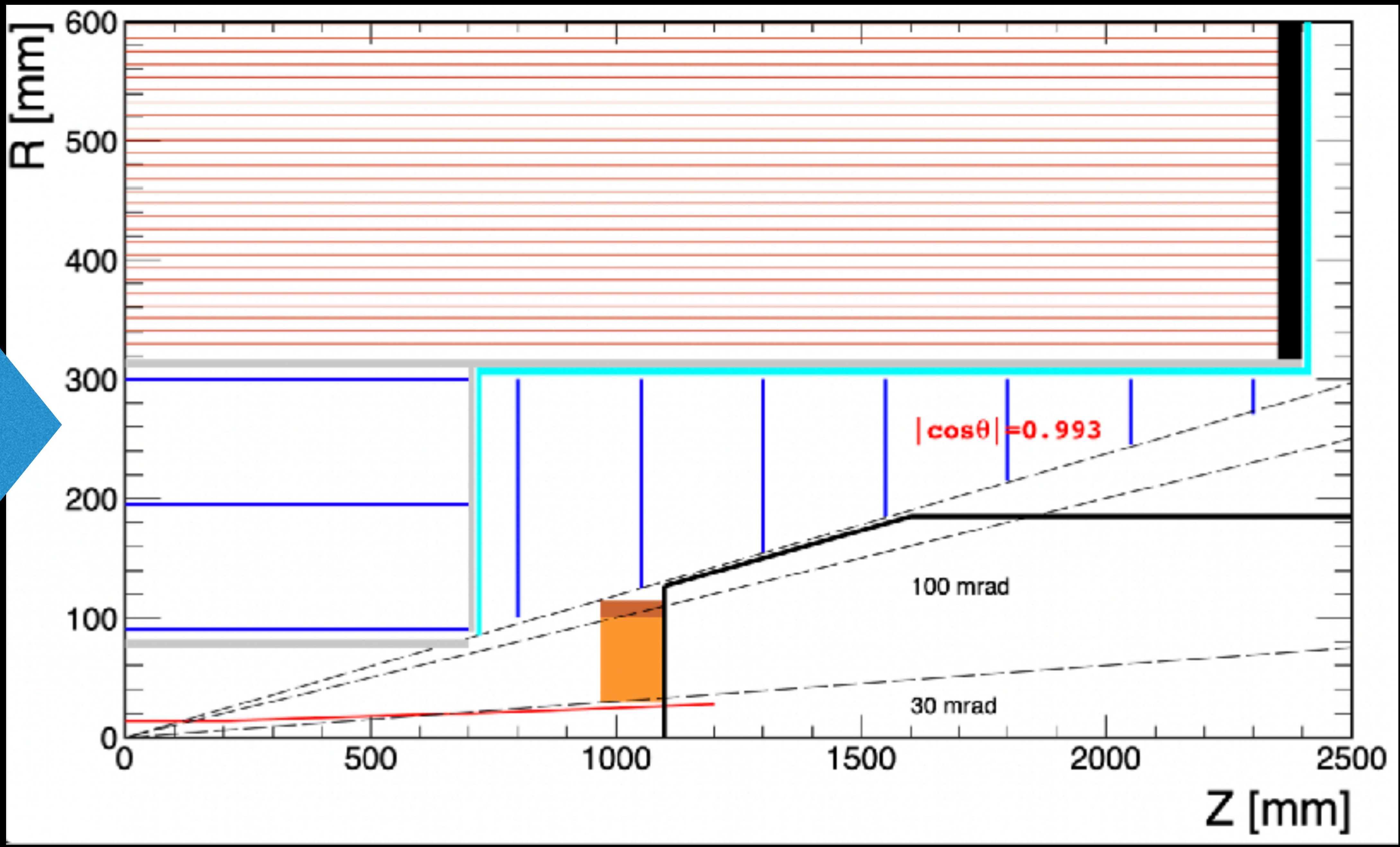
Assembly tooling designed

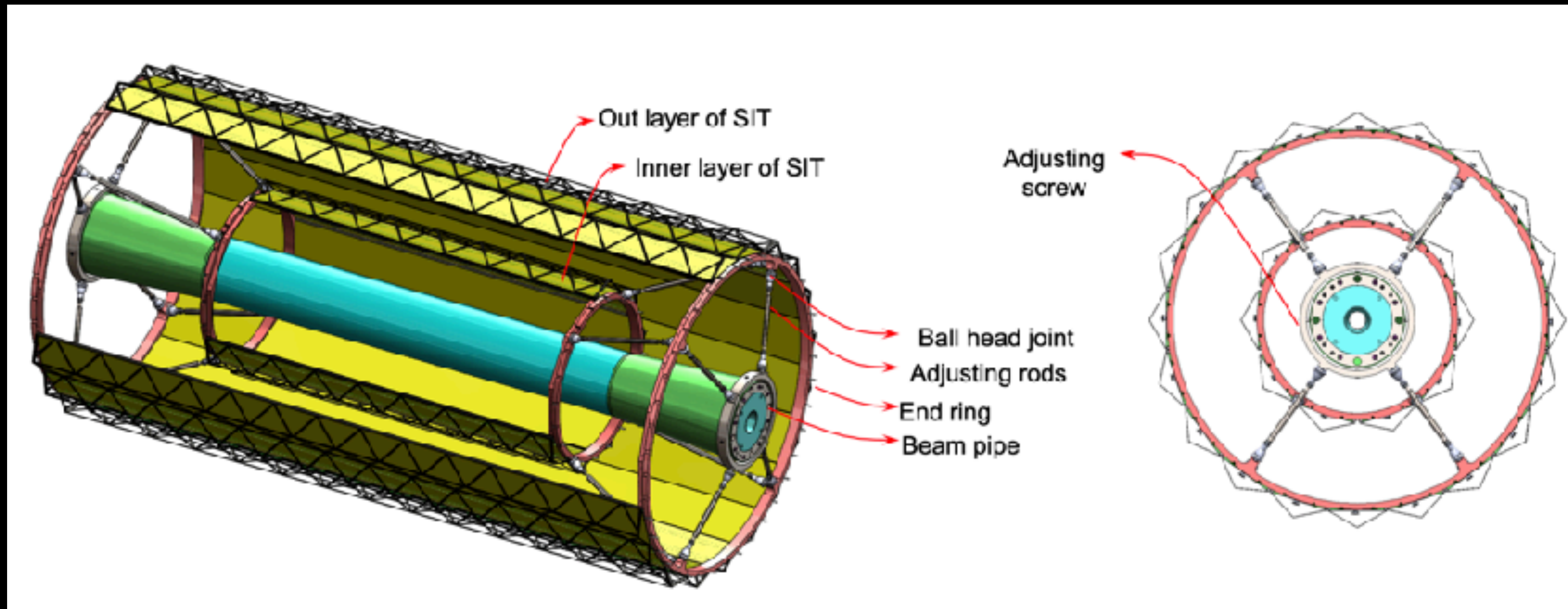
Full vertex detector prototype test beam planned for DESY December 2022

CEPC R&D: Silicon Tracker design



Optimization: tracker layout taskforce





Silicon tracker demonstrator with international partners

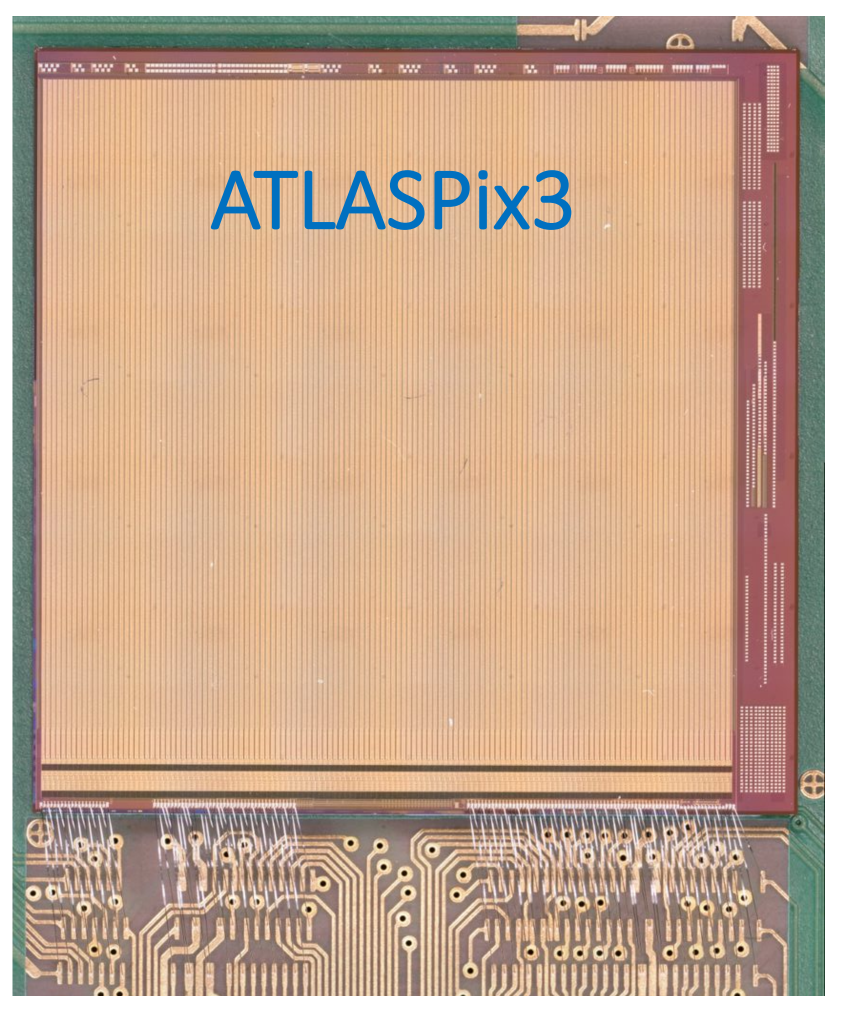
HV-CMOS Tracker Demonstrator

International collaboration

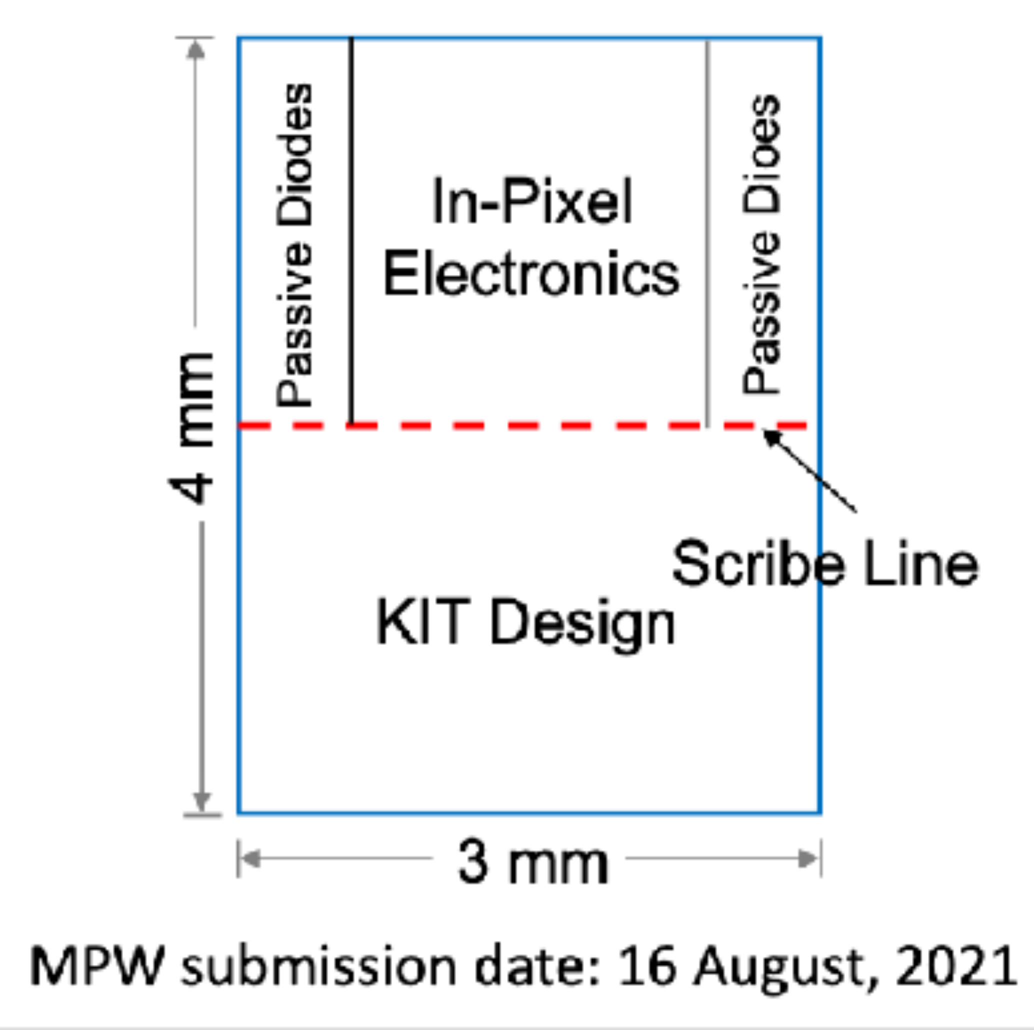
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of South China
- **Italy**
  - INFN Sezione di Milano, Università di Milano e Università dell'Insubria
  - INFN Sezione di Pisa e Università di Pisa
  - INFN Sezione di Torino e Università di Torino
- **Germany**
  - Karlsruhe Institute of Technology
- **UK**
  - University of Bristol
  - STFC – Daresbury Laboratory
  - University of Edinburgh
  - Lancaster University
  - University of Liverpool
  - Queen Mary University of London
  - University of Oxford
  - University of Sheffield
  - University of Warwick

Test beam at DESY in April 2022

Start by using components developed for other projects



smaller pixel size (25×150 μm²)

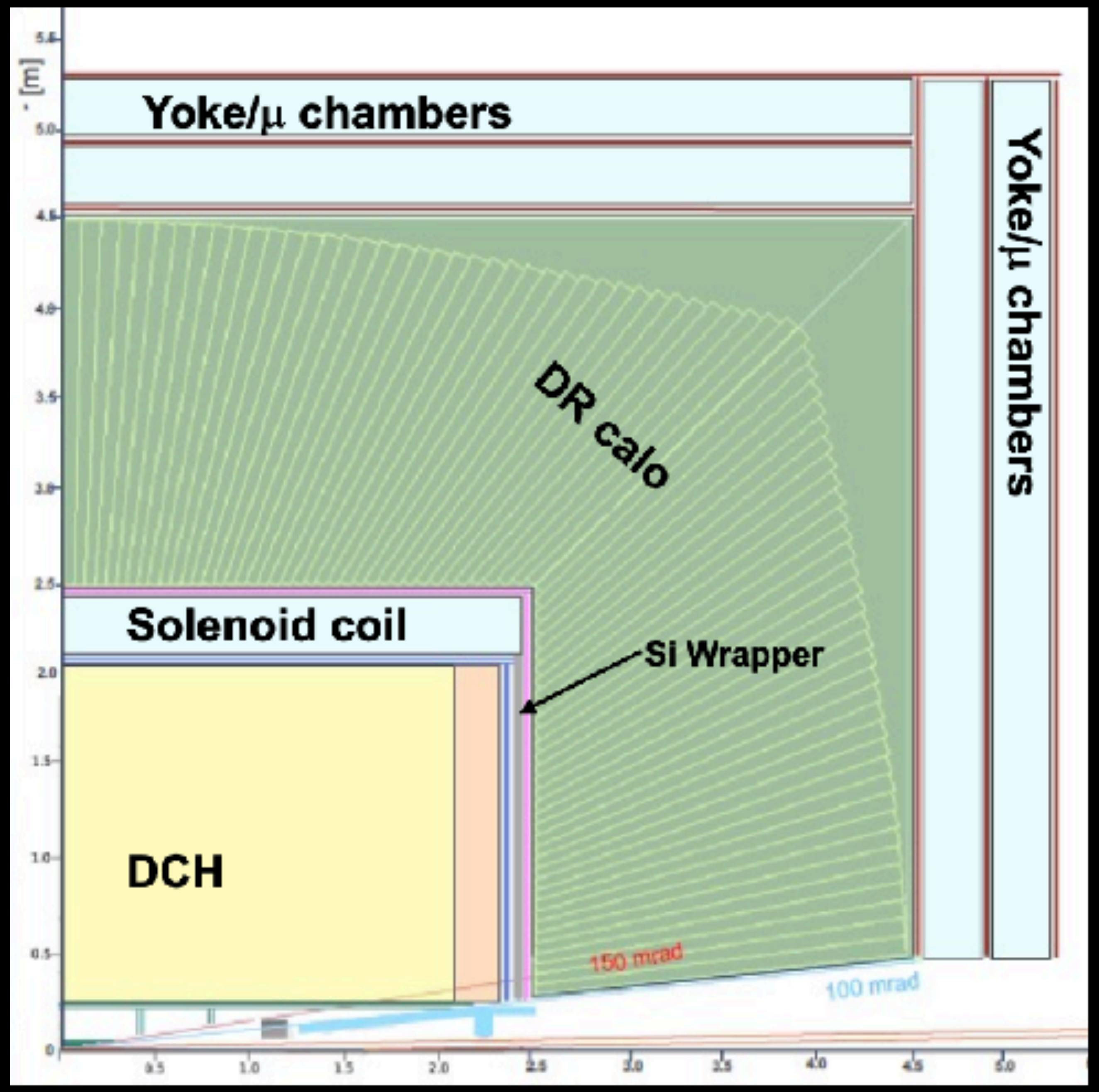


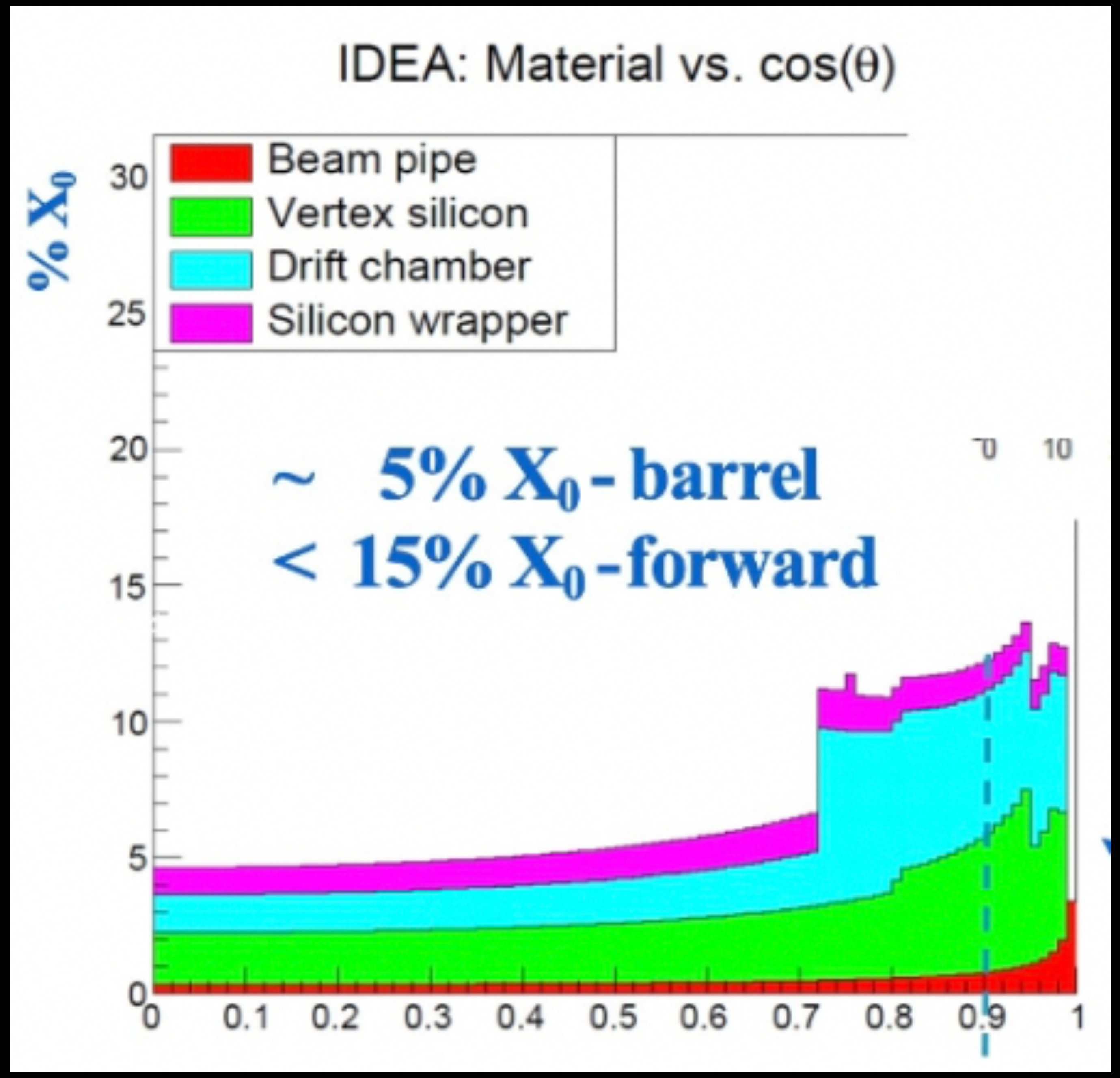
Migrate to a new process: HLMC 55 nm HV-CMOS

Possibility of producing in chinese foundry

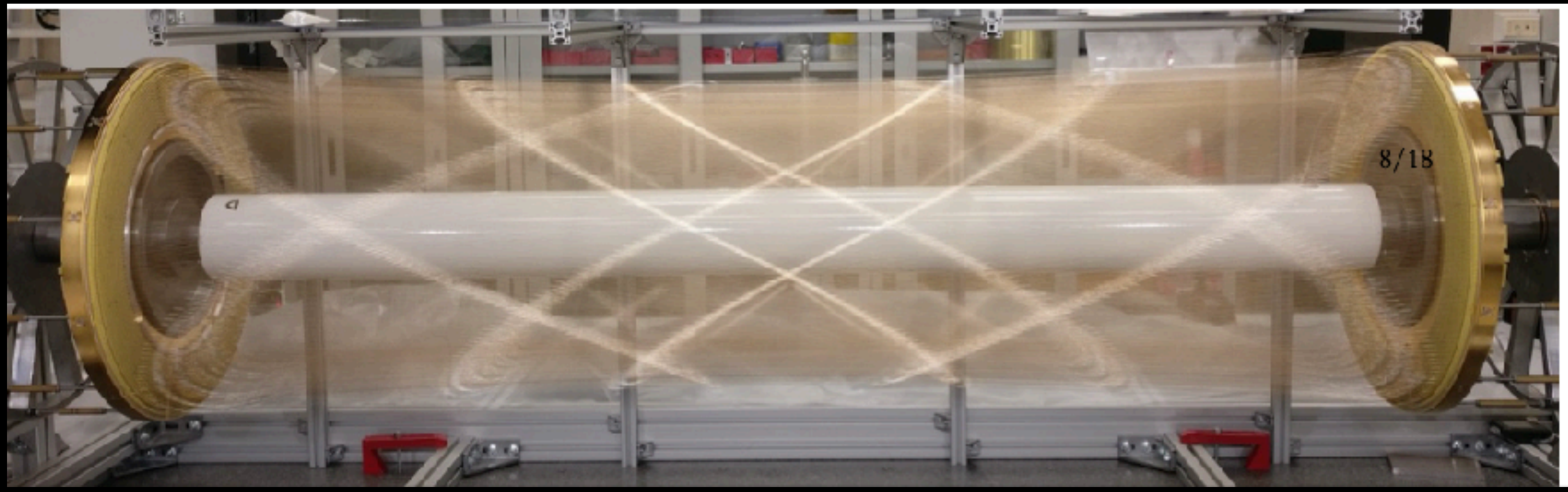
Drift Chamber

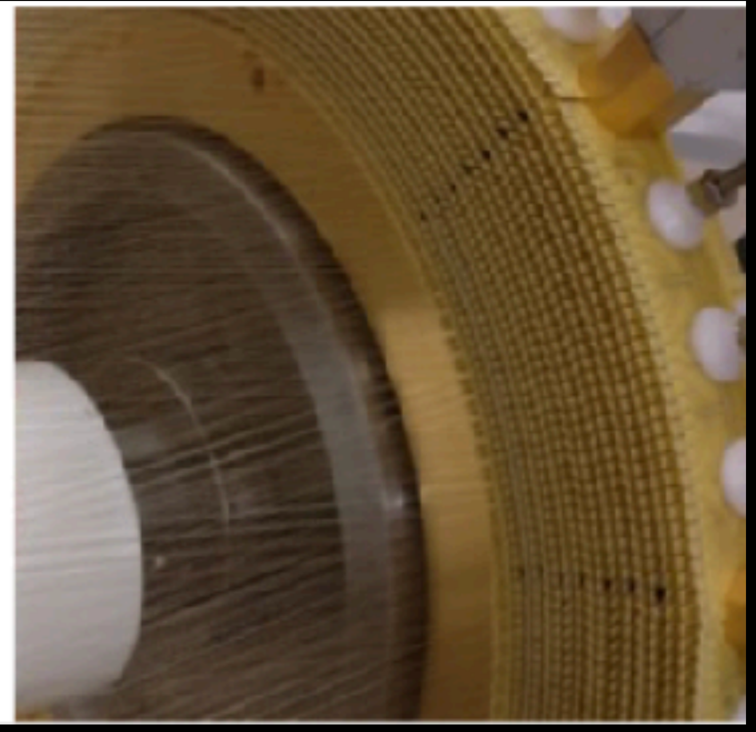
IDEA Drift Chamber





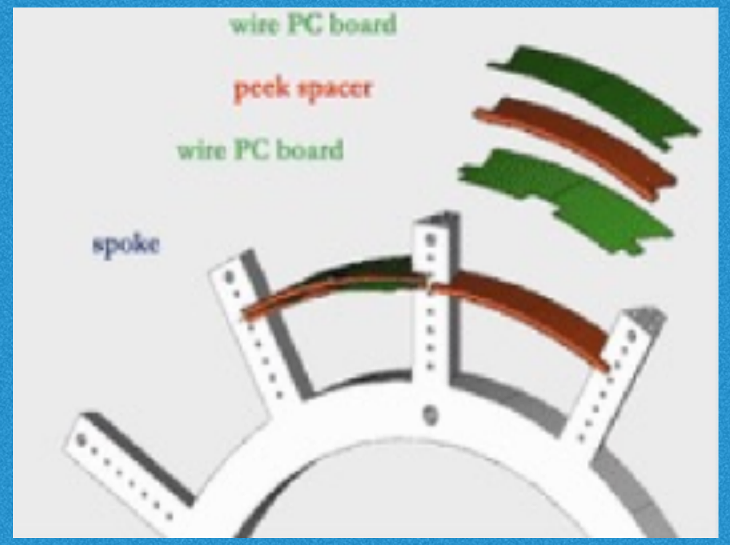
Design based on MEG-II drift chamber



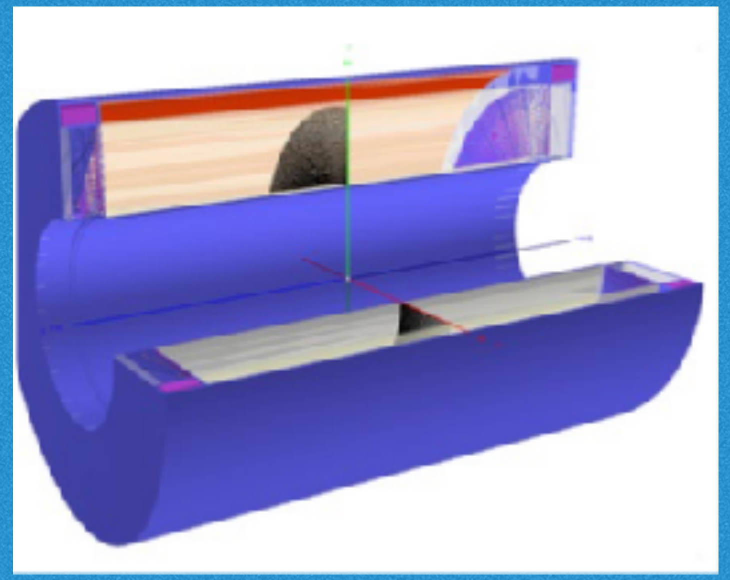


On-going work

Mechanical design



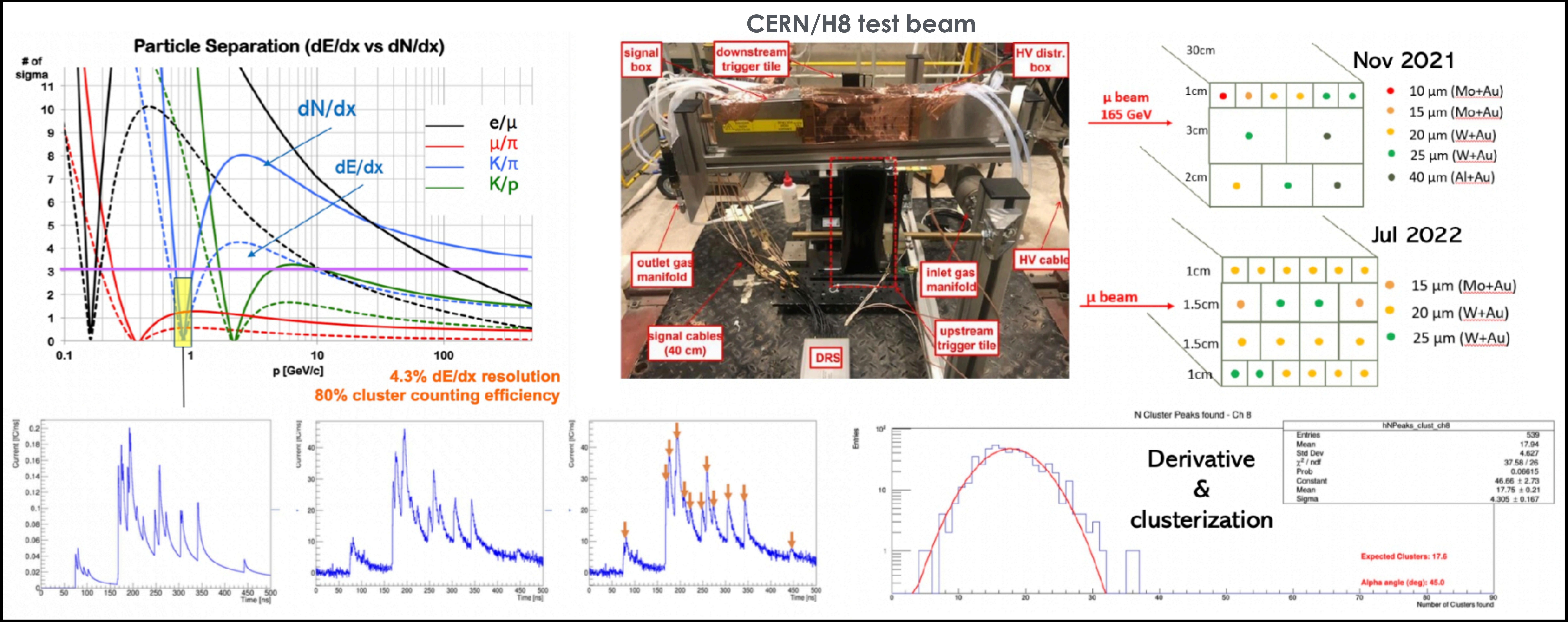
Geant4 simulation



Particle identification studies

CEPC R&D: Particle Identification—Drift Chamber (dN_{cl}/dx)

Cluster counting potentially a factor ~2 better than dE/dx, but requires fast electronics and good counting algorithms



- Essential to have a high efficiency and accurate counting of clusters
- Multiple peak finding algorithm are developed & tested
- Test beam result seems matched the expectation

Collaboration on Drift Chamber and Tracking - Regular meetings

Cluster counting regular meeting

September 2022
- Sep 15 Meeting on cluster counting in drift chambers

July 2022
- Jul 28 Meeting on cluster counting in drift chambers

May 2022
- May 05 Meeting on cluster counting in drift chambers

April 2022
- Apr 07 Meeting on cluster counting in drift chambers

March 2022
- Mar 17 Meeting on cluster counting in drift chambers

February 2022
- Feb 18 Meeting on cluster counting in drift chambers

- Called by:
  - Franco and Linghui
- Participants from:
  - IHEP
  - INFN
  - Shandong University
  - Jilin University
  - BINP

Tracker layout optimization discussion

- Called by:
  - Gang and Linghui
- Participants from:
  - IHEP
  - Lancaster University
  - Jilin University
  - Shandong University
  - Nanjing University

October 2022
- Oct 21 CEPC Drift Chamber Meeting

September 2022
- Sep 23 CEPC Drift Chamber Meeting
- Sep 16 CEPC Drift Chamber Meeting
- Sep 02 CEPC Drift Chamber Meeting

August 2022
- Aug 26 CEPC Drift Chamber Meeting
- Aug 19 CEPC Drift Chamber Meeting
- Aug 12 CEPC Drift Chamber Meeting

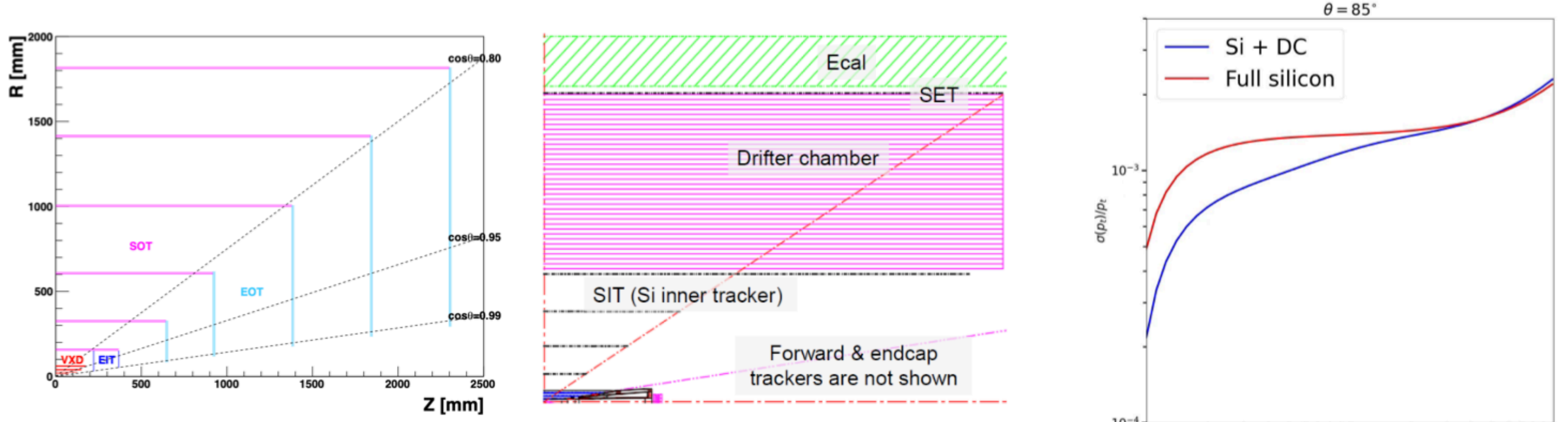
July 2022
- Jul 22 CEPC Drift Chamber Meeting
- Jul 15 CEPC Drift Chamber Meeting
- Jul 08 CEPC Drift Chamber Meeting

June 2022
- Jun 24 Tracker Discussion
- Jun 10 Tracker Discussion

May 2022
- May 27 Tracker Discussion
- May 20 Tracker Discussion
- May 13 Tracker Discussion
- May 07 Tracker Discussion

CEPC tracking with drift chamber: 4th detector

Silicon inner tracker, silicon external tracker for precise measurement provide high resolution and still low Si-system budget



Full Silicon Tracker (FST) from CDR

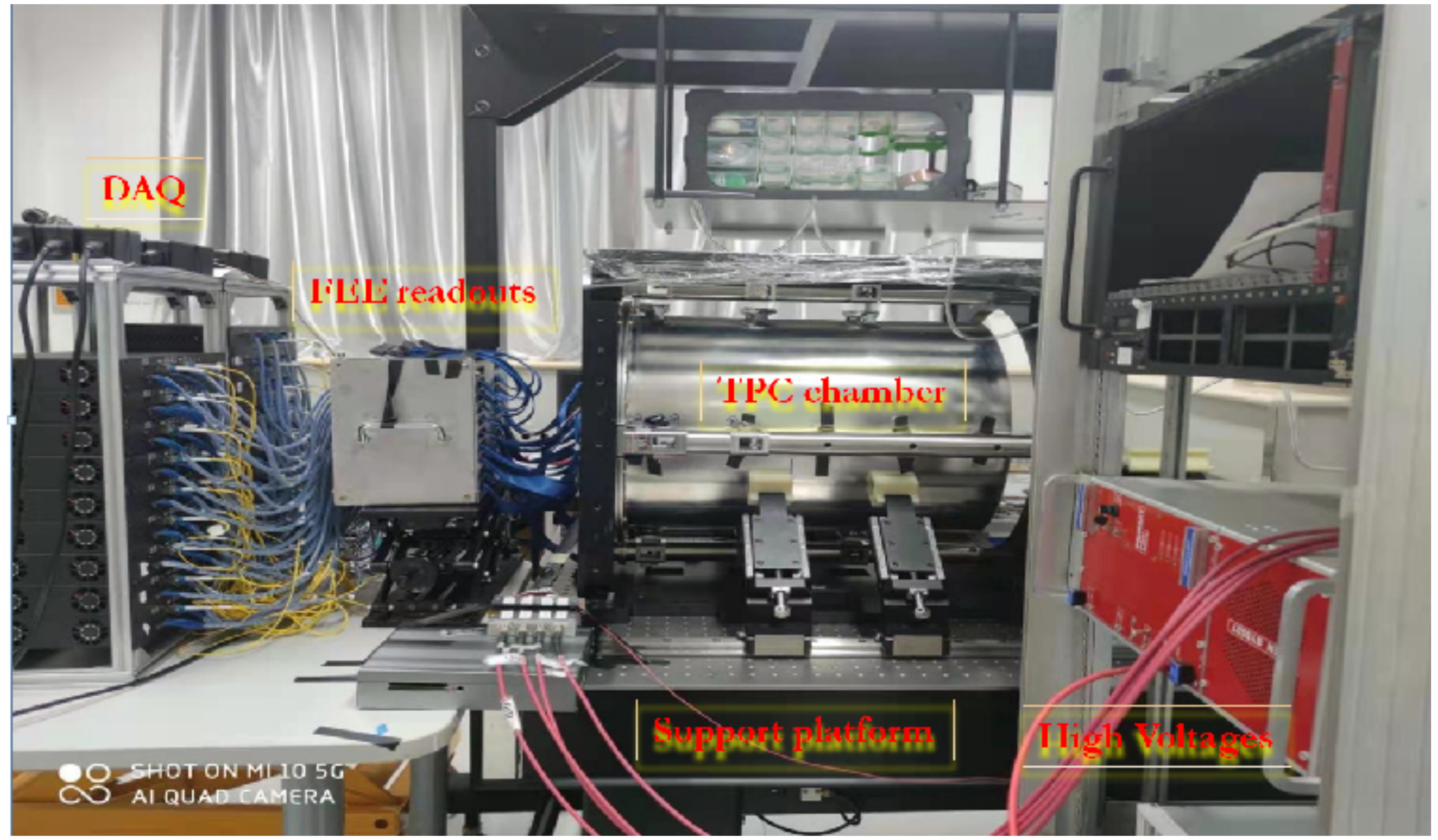
Si + DC

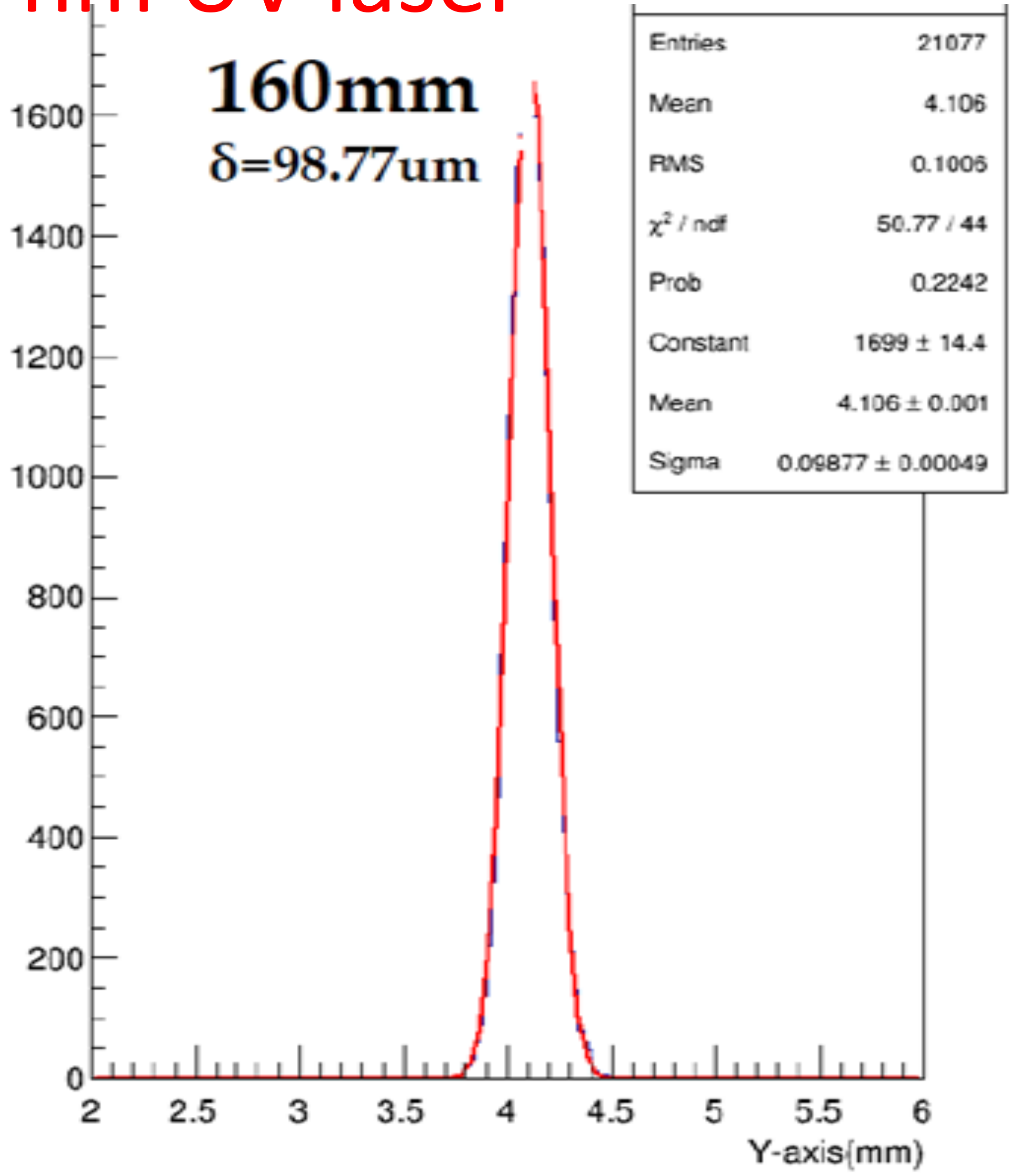
Si + DC design gives better momentum resolution than full Silicon design ~ Pt < 50 GeV/c

CEPC TPC detector R&D

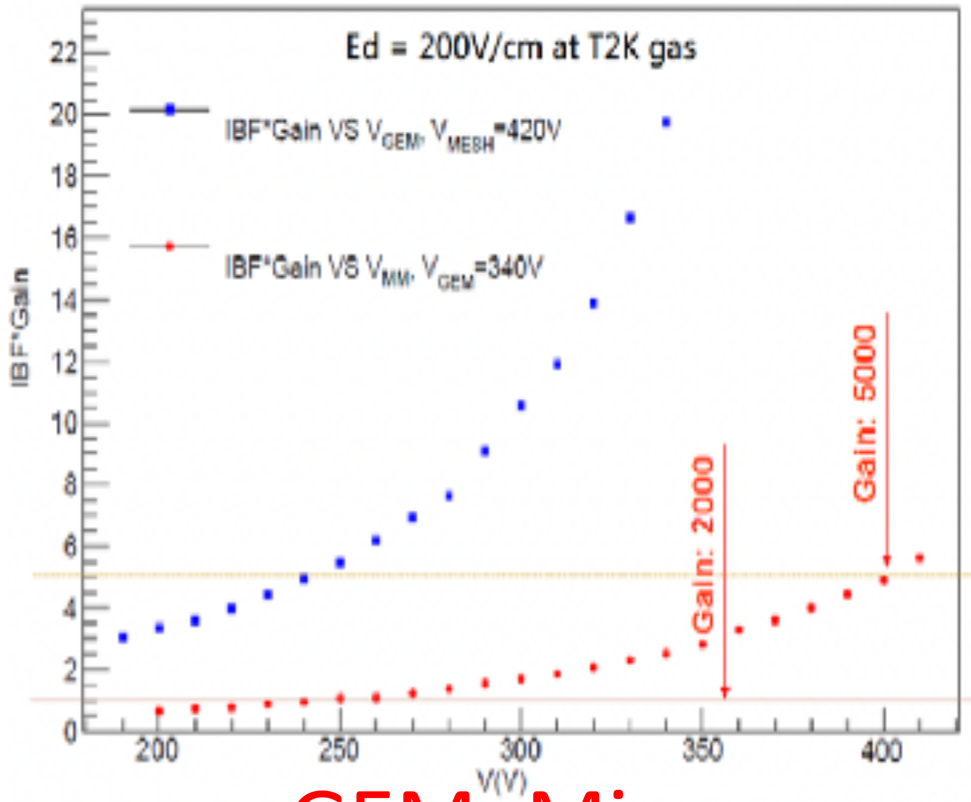
- CEPC TPC detector prototyping roadmap:
  - From TPC module to TPC prototype R&D for beam test
  - Low power consumption FEE ASIC R&D (reach **<5mW/ch** including ADC)
- Achievement by far:
  - Supression ions hybrid GEM+Micromegas module
    - IBFxGain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of **$\sigma_{r\phi}$≤100 μm** by TPC prototype
  - dE/dx for PID: **<4%** (as expected for CEPC baseline detector concept)

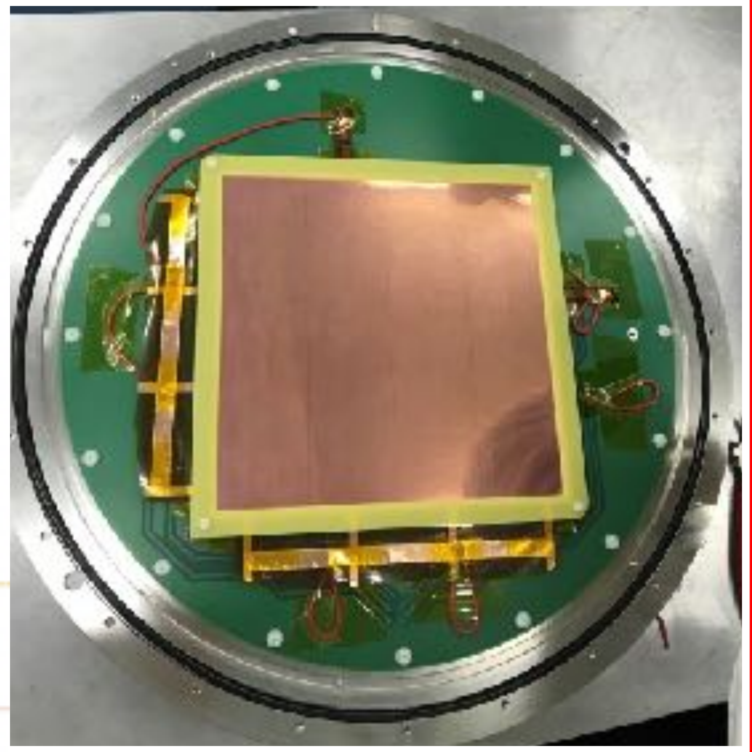
TPC prototype with integrated 266 nm UV laser



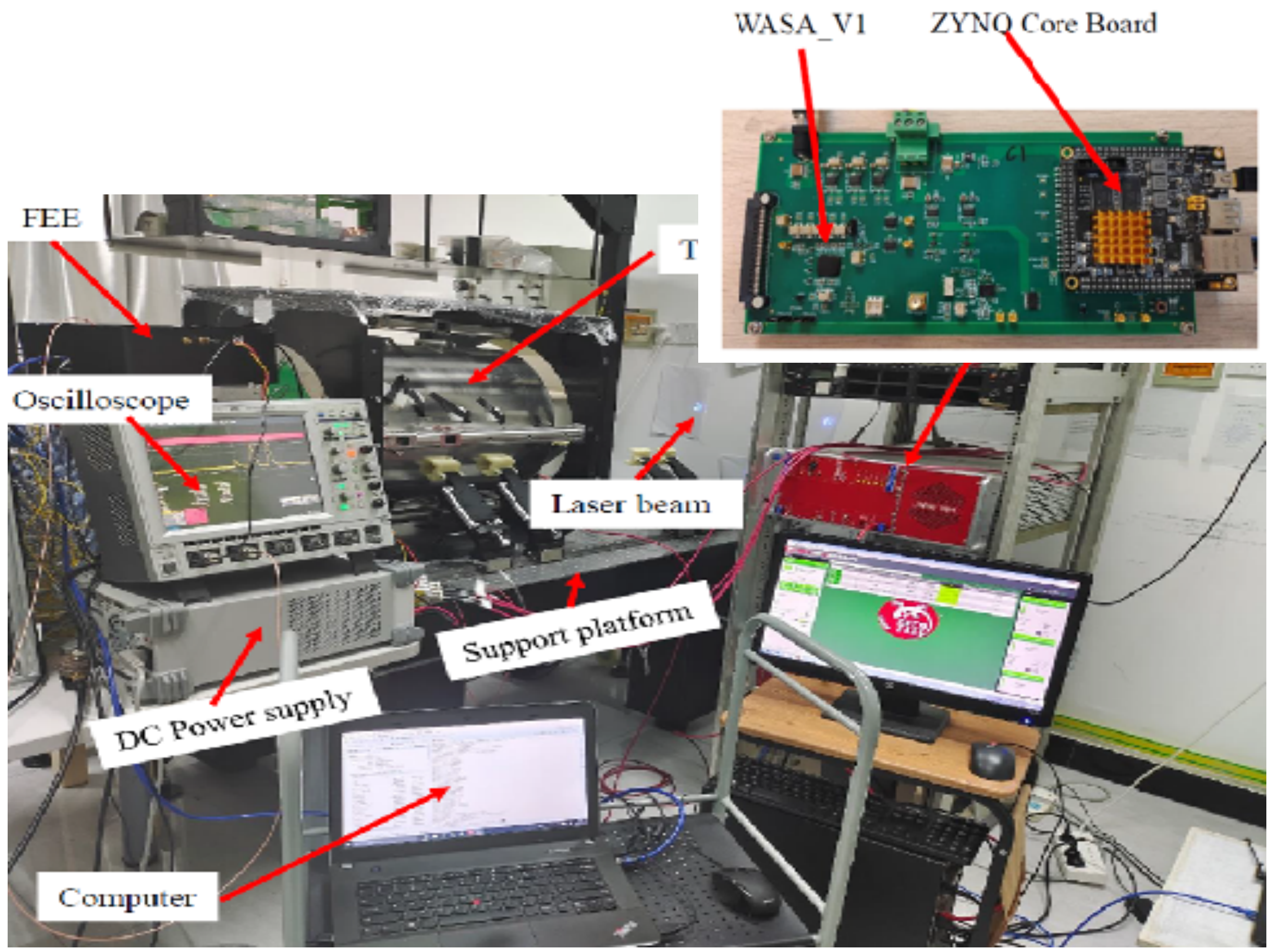


Achievement





GEM+Micromegas module R&D

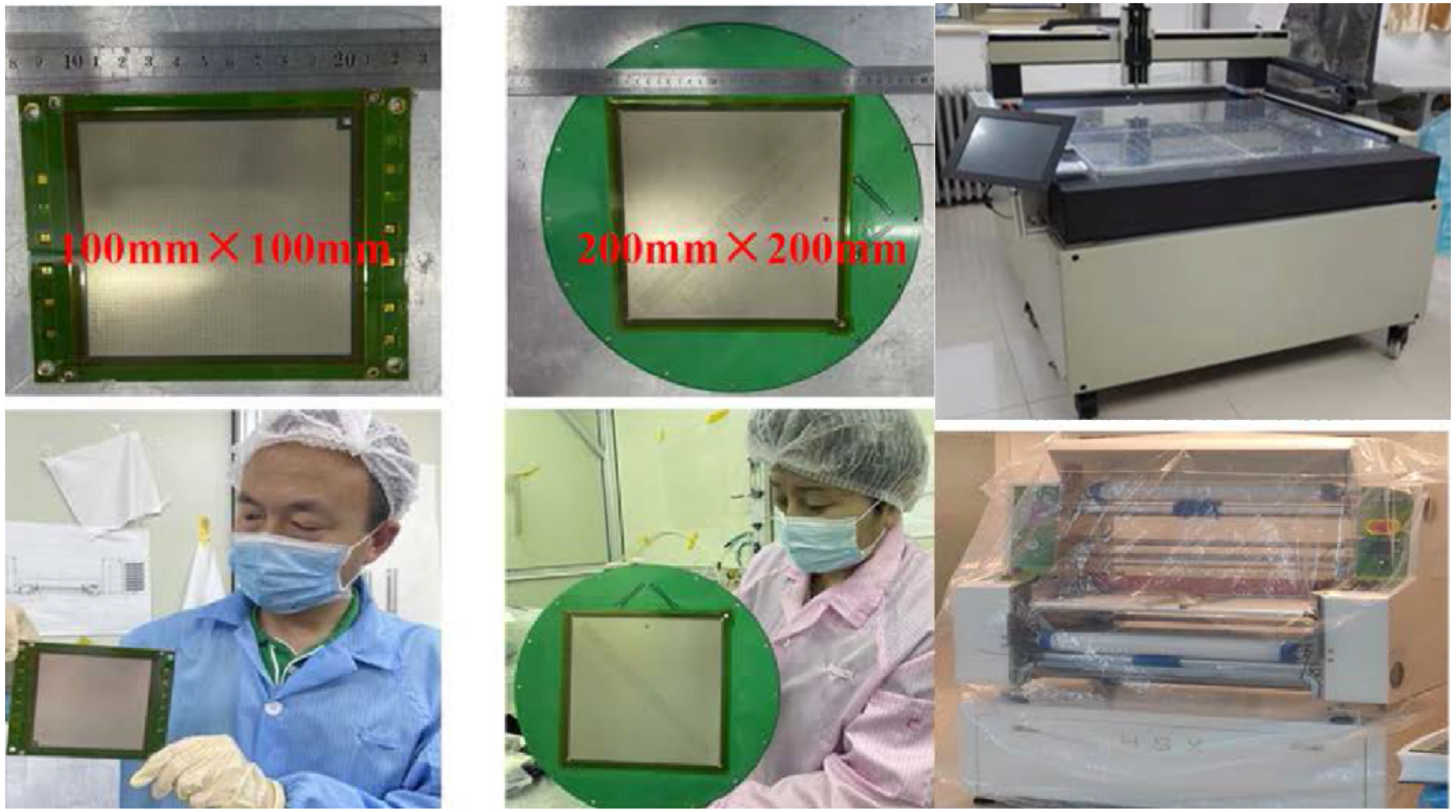


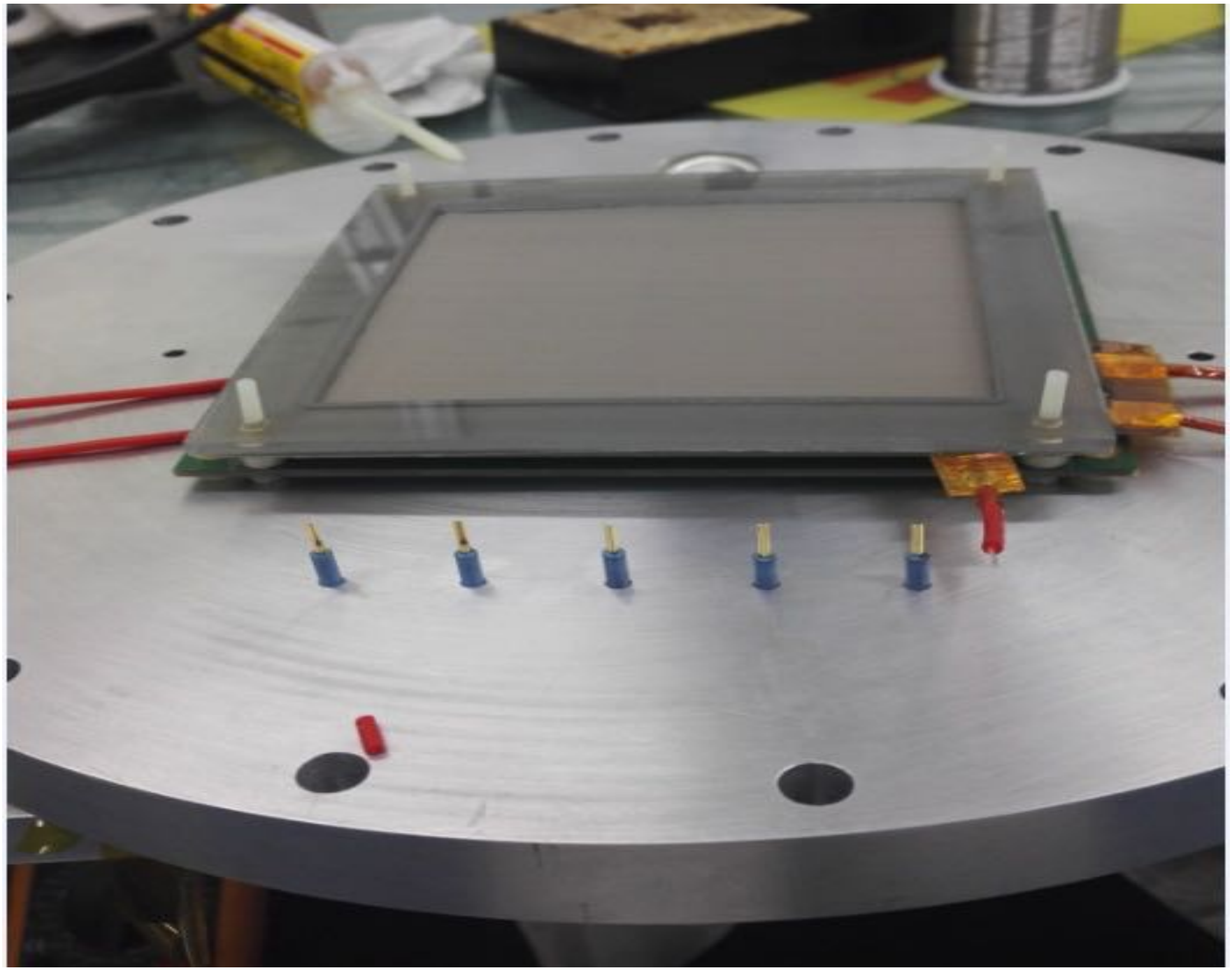
Low power consumption readout

CEPC TPC detector R&D

- Highlights of CEPC TPC detection technology R&D
  - Pad readout towards pixelated readout TPC to increased PID to 2-3%
  - Massive production and assemble MPGD lab has been setup at IHEP
  - Very activate international collaboration with LCTPC and RD51

Publications by TPC group:
https://doi.org/10.1016/j.nima.2022.167241
https://doi.org/10.1109/NSS/MIC44867.2021.9875566
https://doi.org/10.1088/1748-0221/15/09/C09065
https://doi.org/10.1088/1748-0221/15/05/P05005
https://dx.doi.org/10.1142/S0217751X20410146
https://doi.org/10.1088/1674-1137/41/5/056003
https://doi.org/10.1088/1748-0221/15/02/T02001





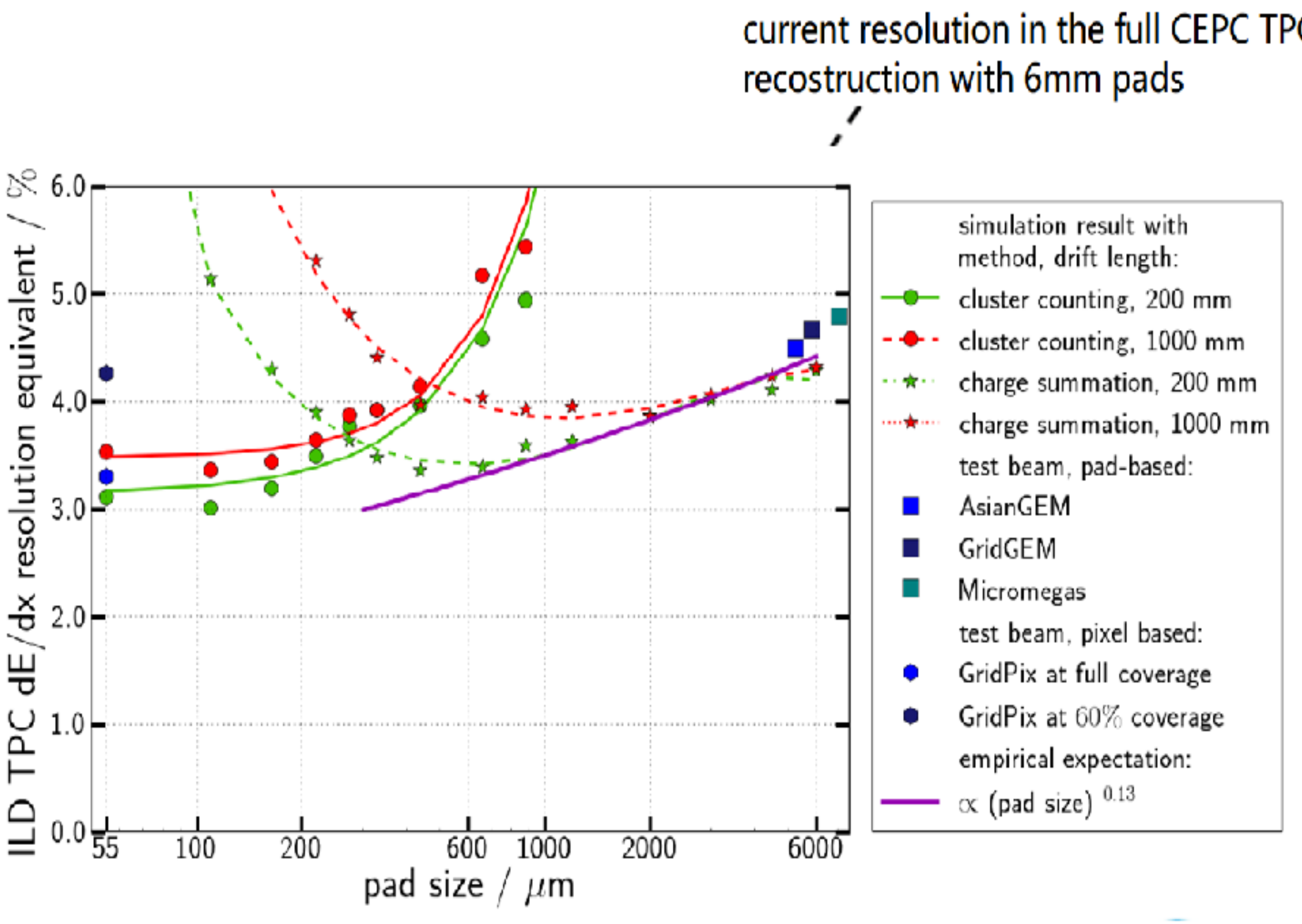
Pixelated readout TPC for dN/dx

Current full CEPC TPC reconstruction: 6 mm pads → ~4.8% dE/dx resolution

6mm → 1mm: 15% improved resolution via the charge summation (dE/dx)

6mm → 0.1mm: 30% improved resolution via the cluster counting (dN/dx)

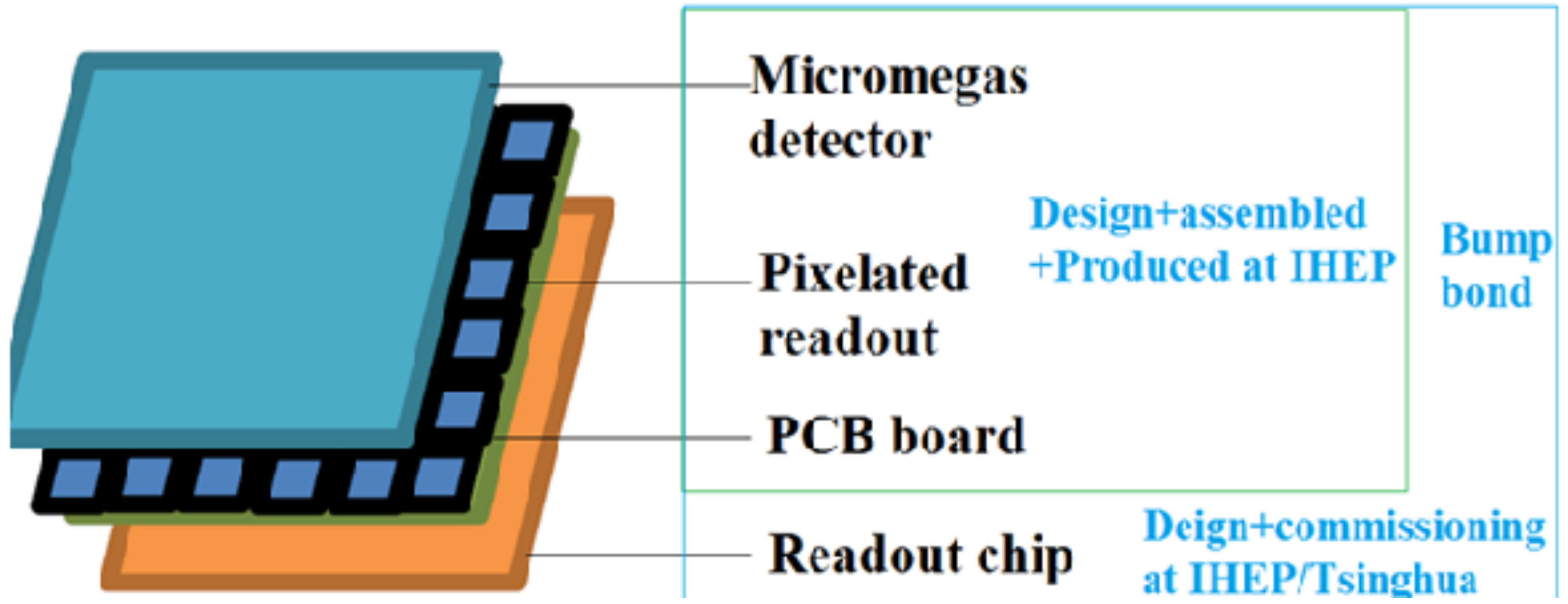
High readout granularity VS the primary cluster size optimization ongoing at IHEP



Pad size of about 300μm can record ~1 primary cluster along track length with T2K gas

- **Realization of pixelated technology collaborated with Tsinghua**

Bump bond pixelated readout with Micromegas detector	Module size	To be addressed by R&D
• **≥300 μm×300 μm** • Developed the readout chip by Tsinghua University • Developed the Micromegas detector sensor at IHEP • Development of the new module and prototype in the end of 2022	$1\text{-}2\ cm^2$	• Research on pixelated readout technology realization • Optimization of cluster profile and pad size • Study of the ‘dN_{cl}+dx’
	$100\ cm^2$	• Study the distortion using UV laser tracks and UV lamp to create ions disk • In-situ calibration with UV Laser system • Study of the ‘$dE/dx+dN_{cl}/dx$’

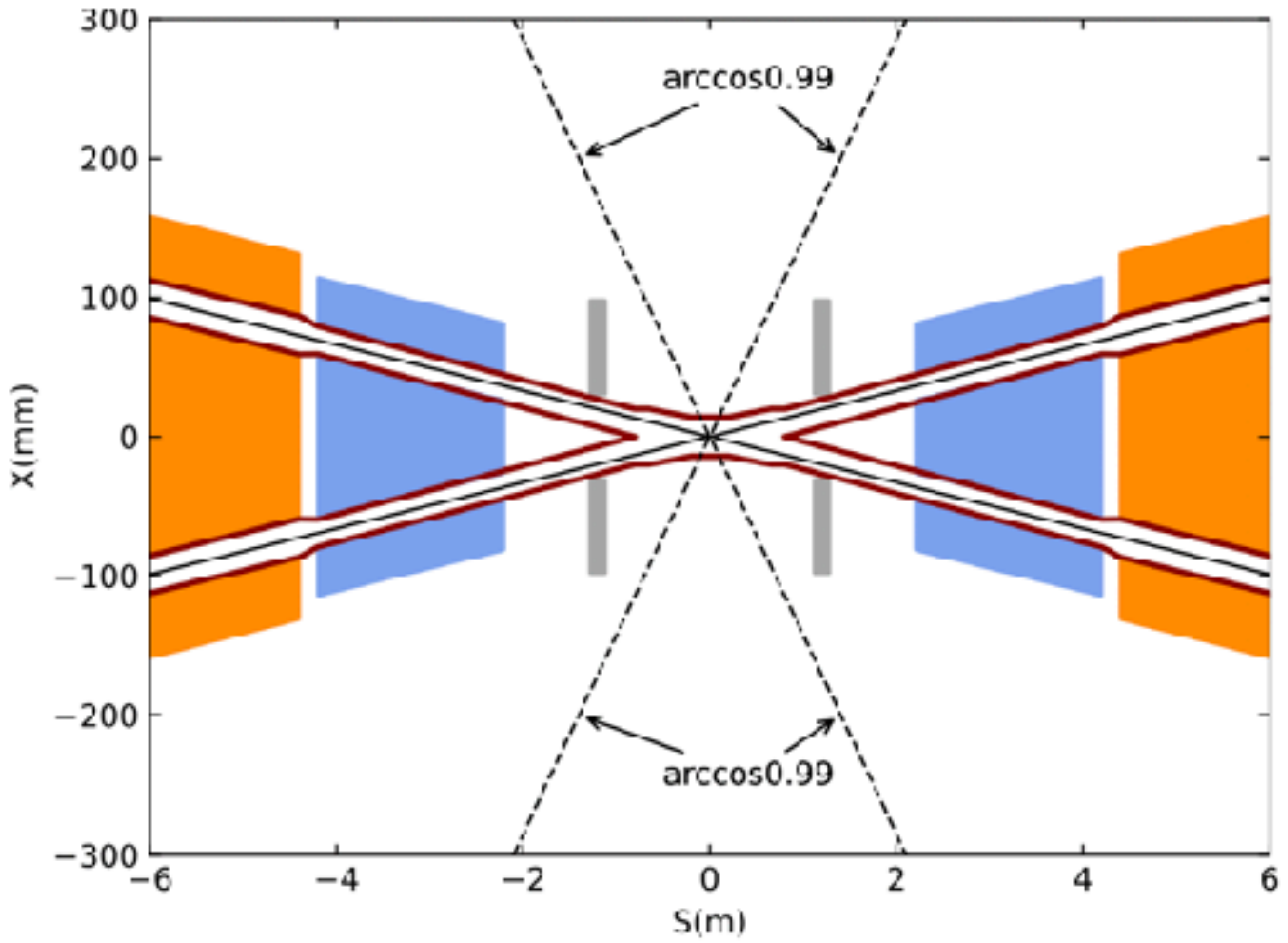


Tsinghua University
University

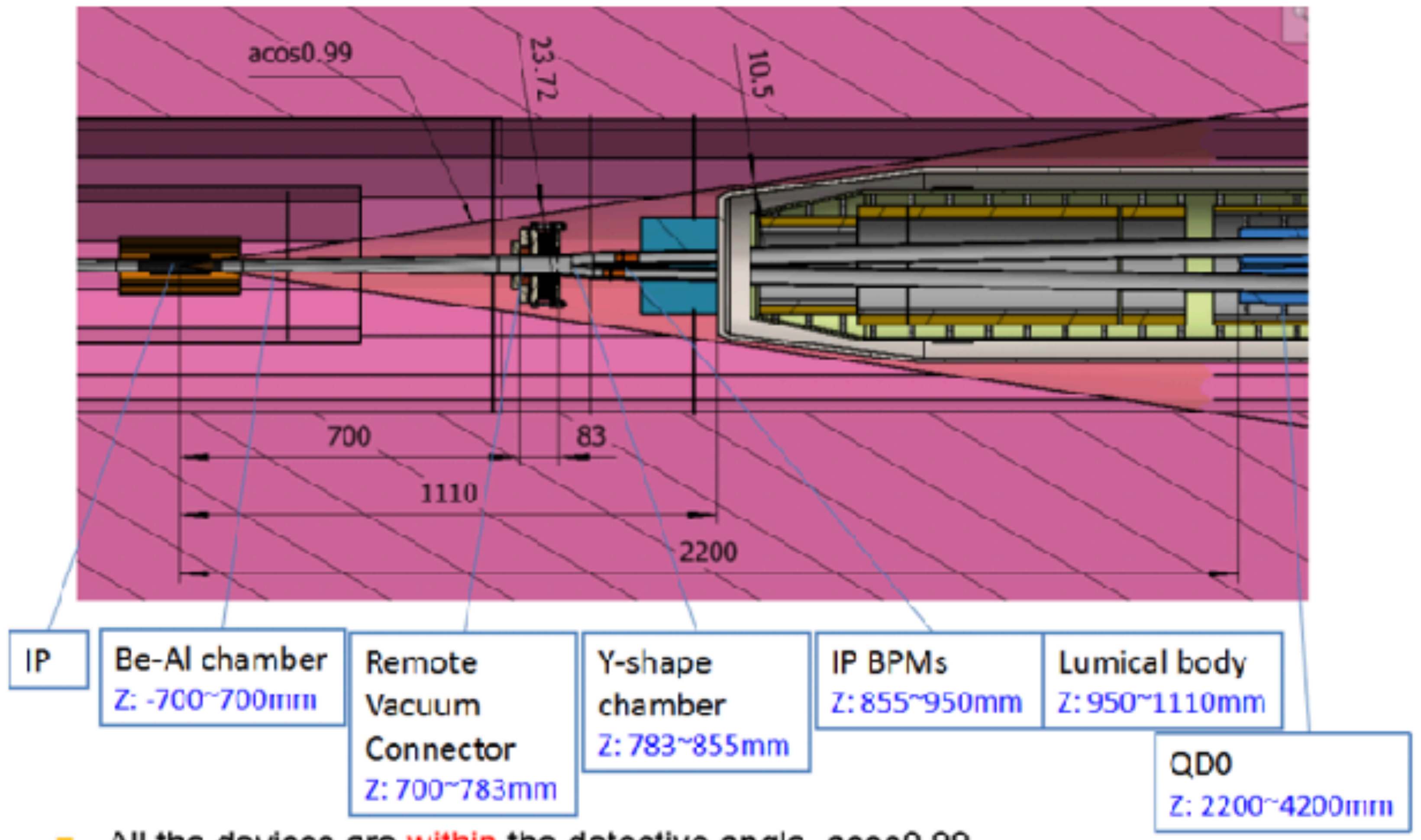
25

CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad
Focal length: 2.2 m



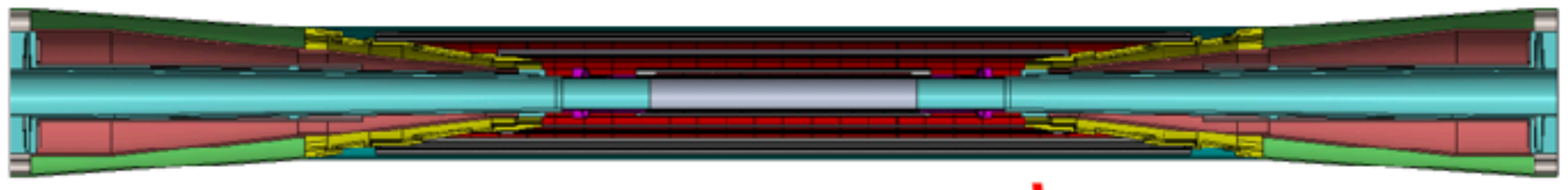
Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets



- All the devices are within the detective angle, acos0.99.

2021 Workshop on CEPC Detector & MDI Mechanical Design, Oct.22-23
https://indico.ihep.ac.cn/event/14392/

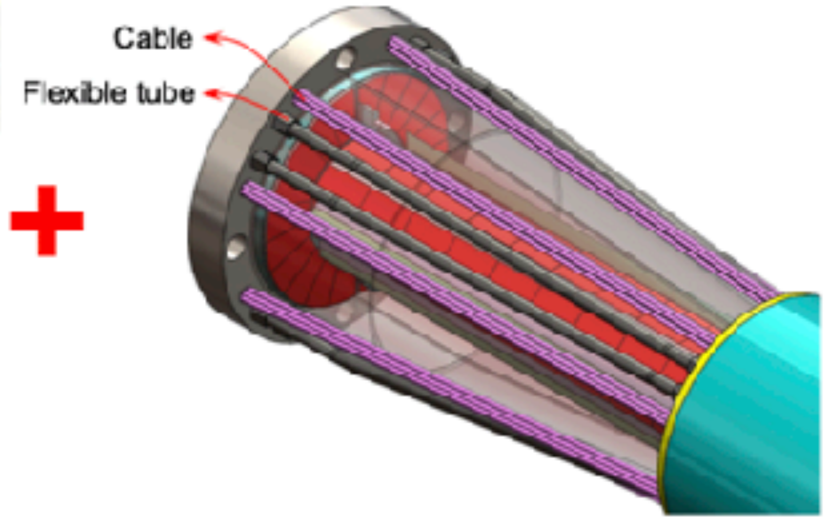
Beam Pipe
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

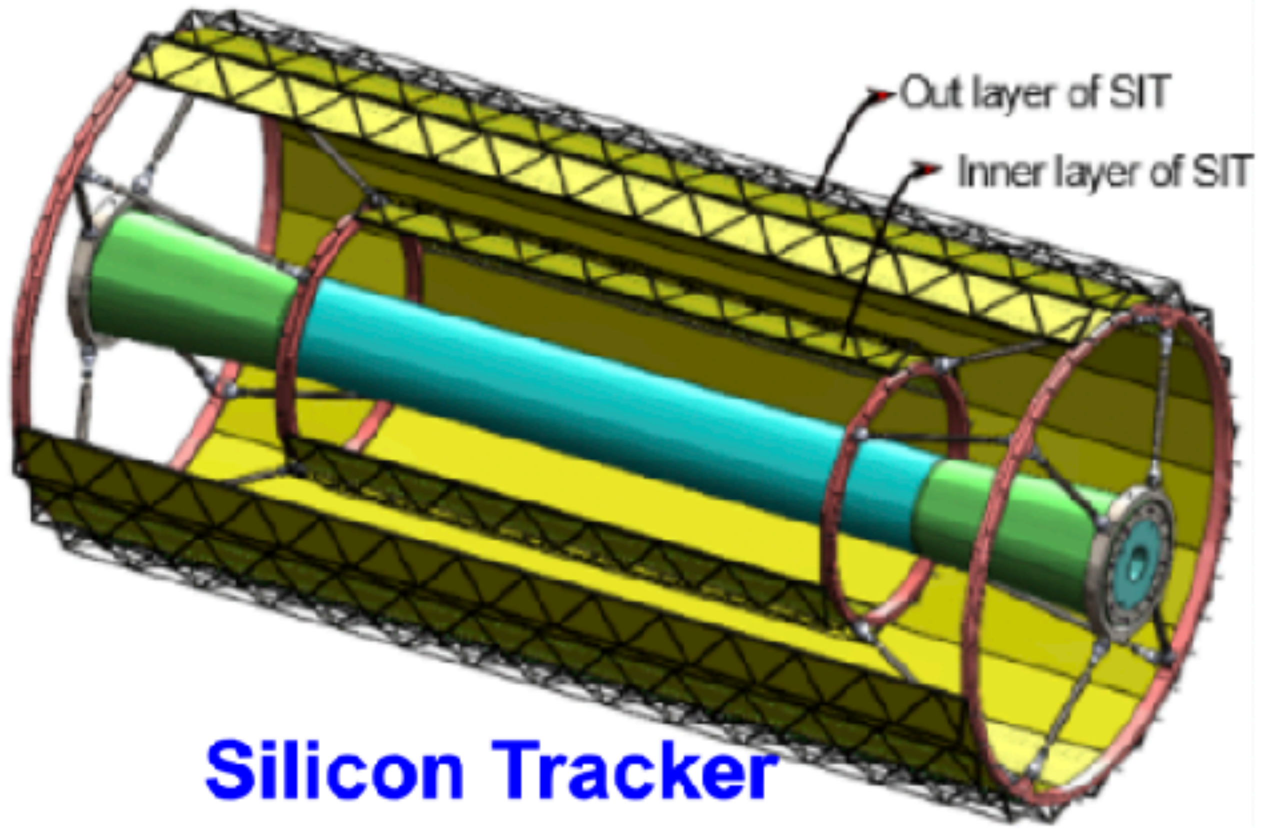


Vertex

+

LumiCal Tracker





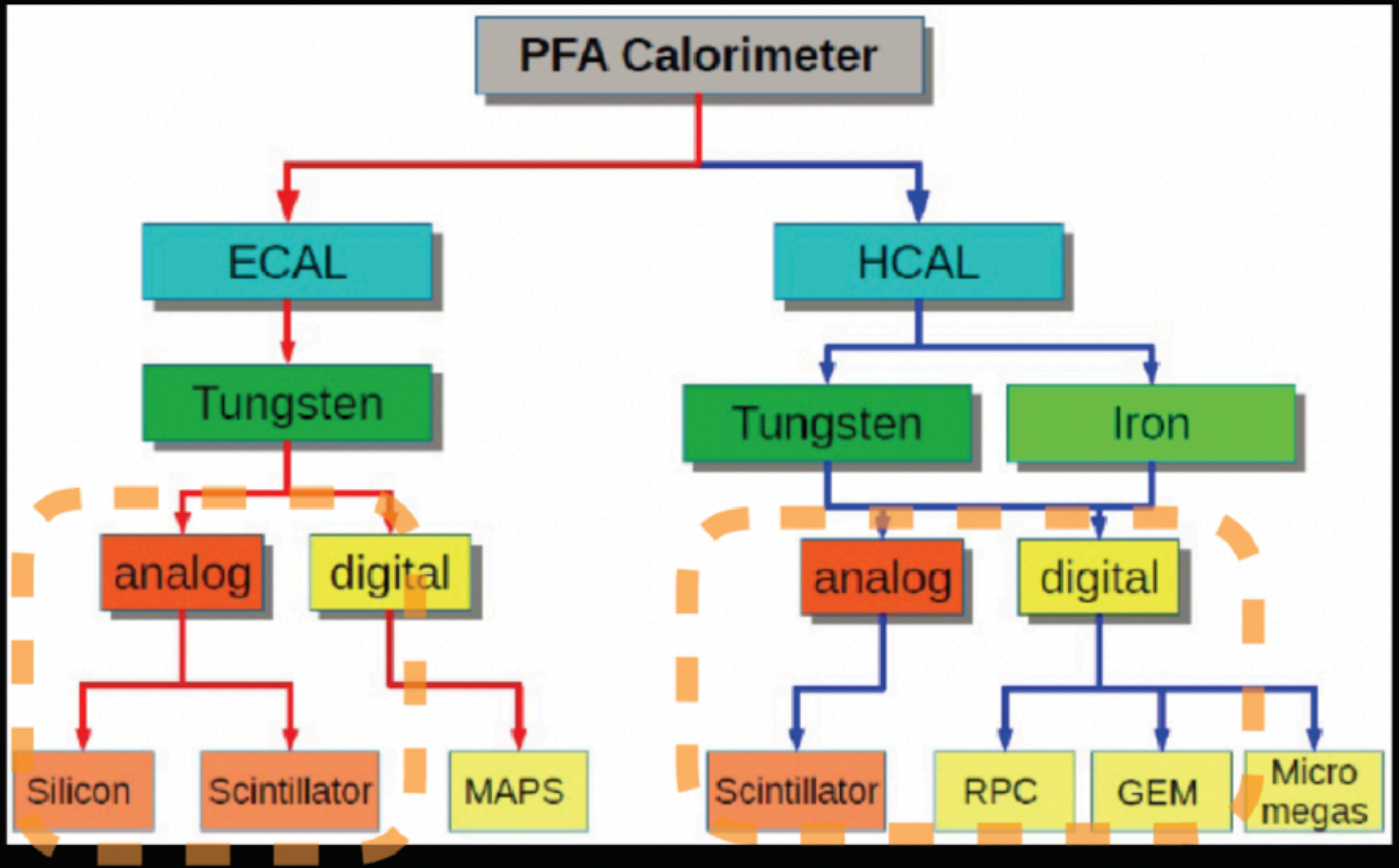
Silicon Tracker

Workshop on CEPC Central Beampipe and Beryllium Application
May 6, 2022, https://indico.ihep.ac.cn/event/16173/

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding

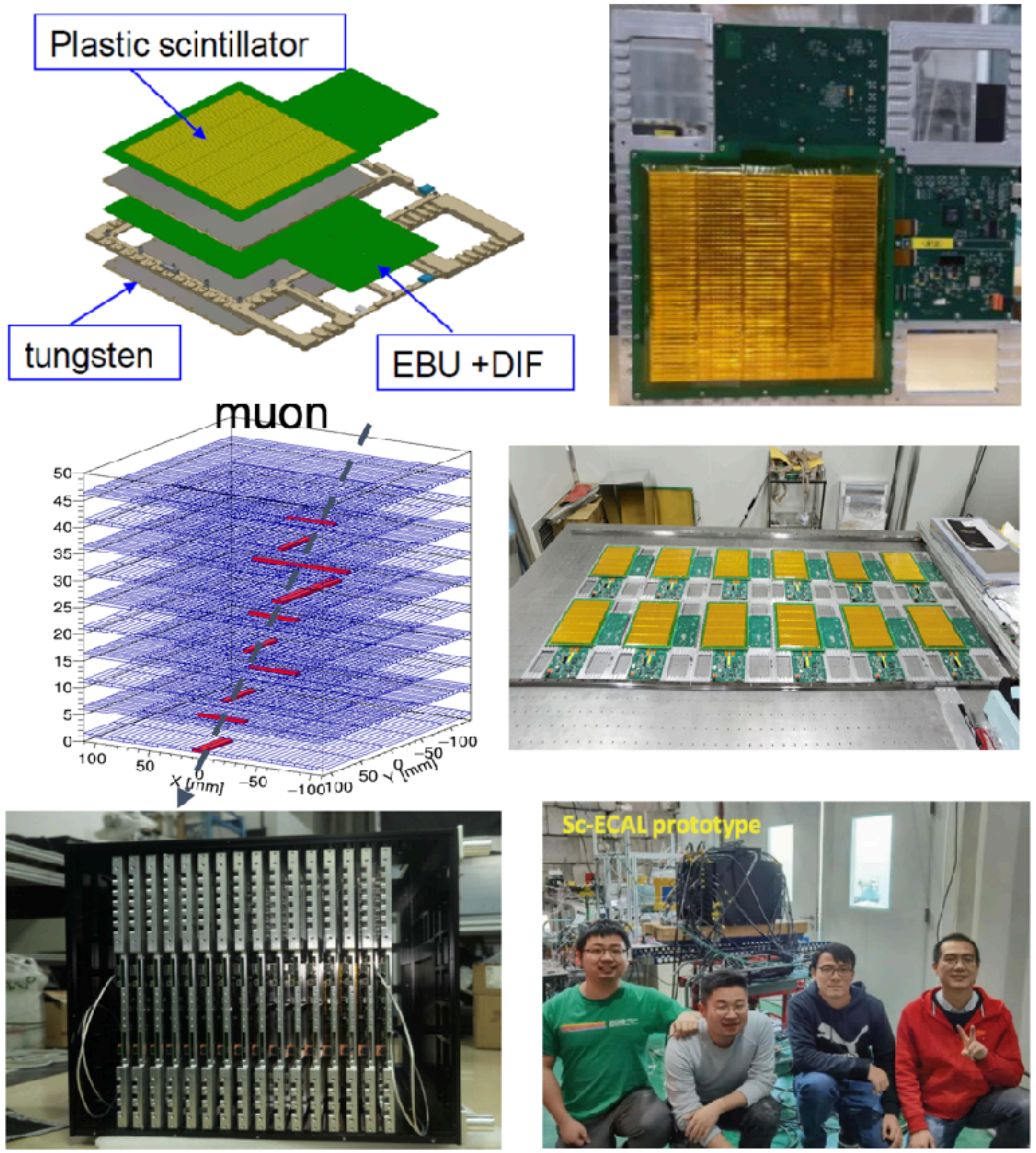


High Granularity		
	Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
	Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)

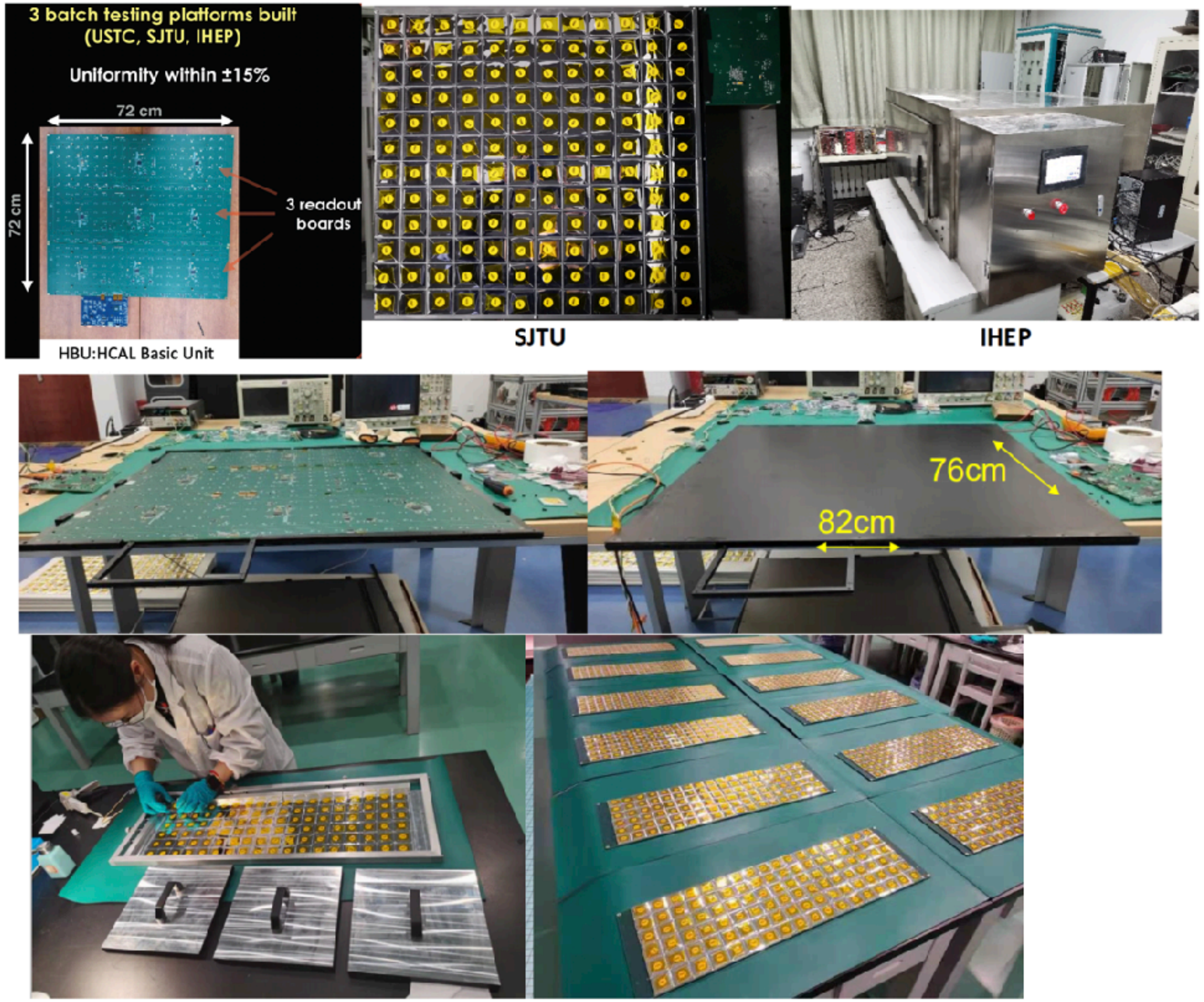
Newer Options		
	Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

CEPC R&D: Scintillating Calorimeters (ECAL, AHCAL)

Scintillator-W ECAL Prototype



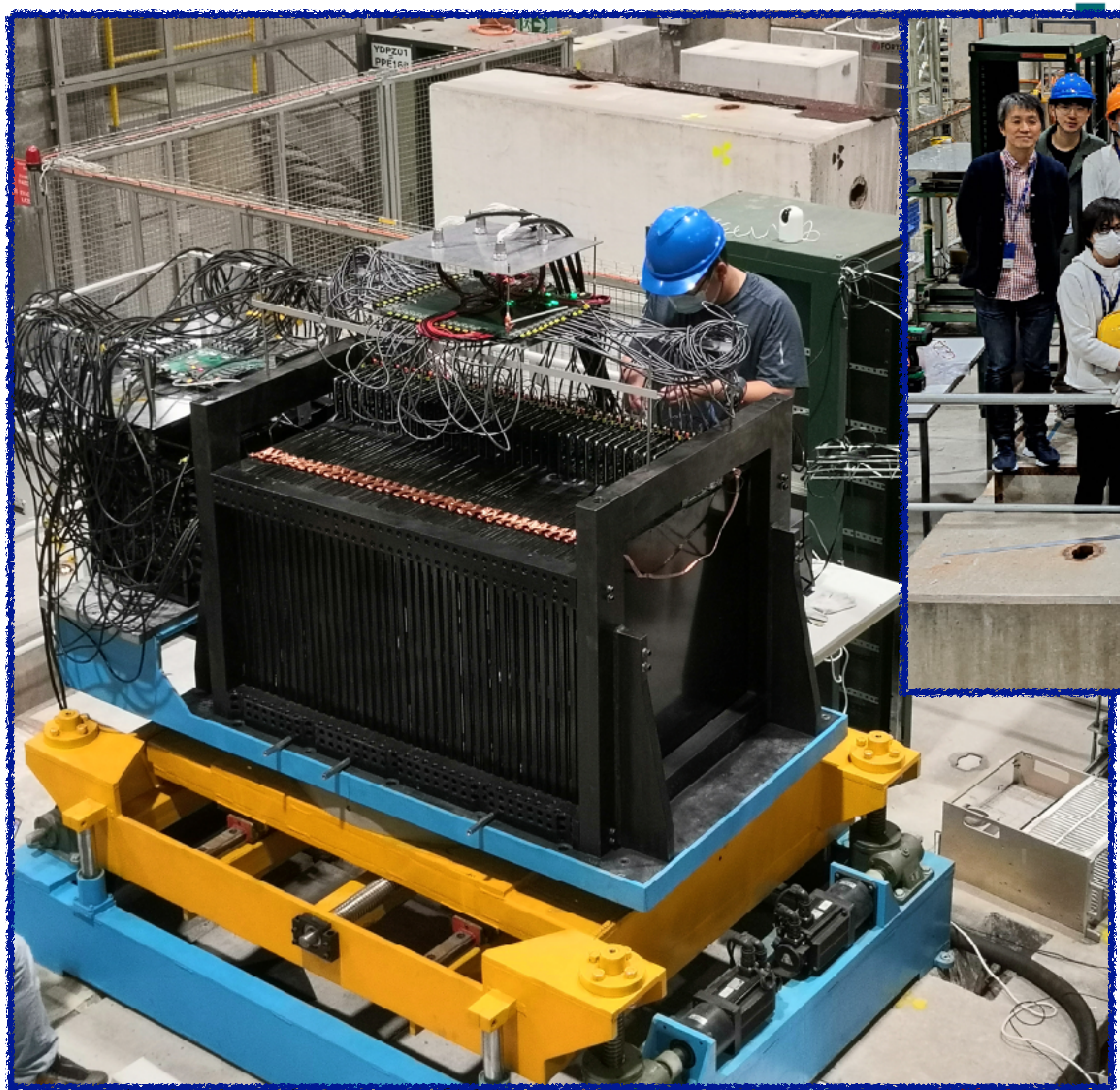
Scintillator + SiPM AHCAL Prototype

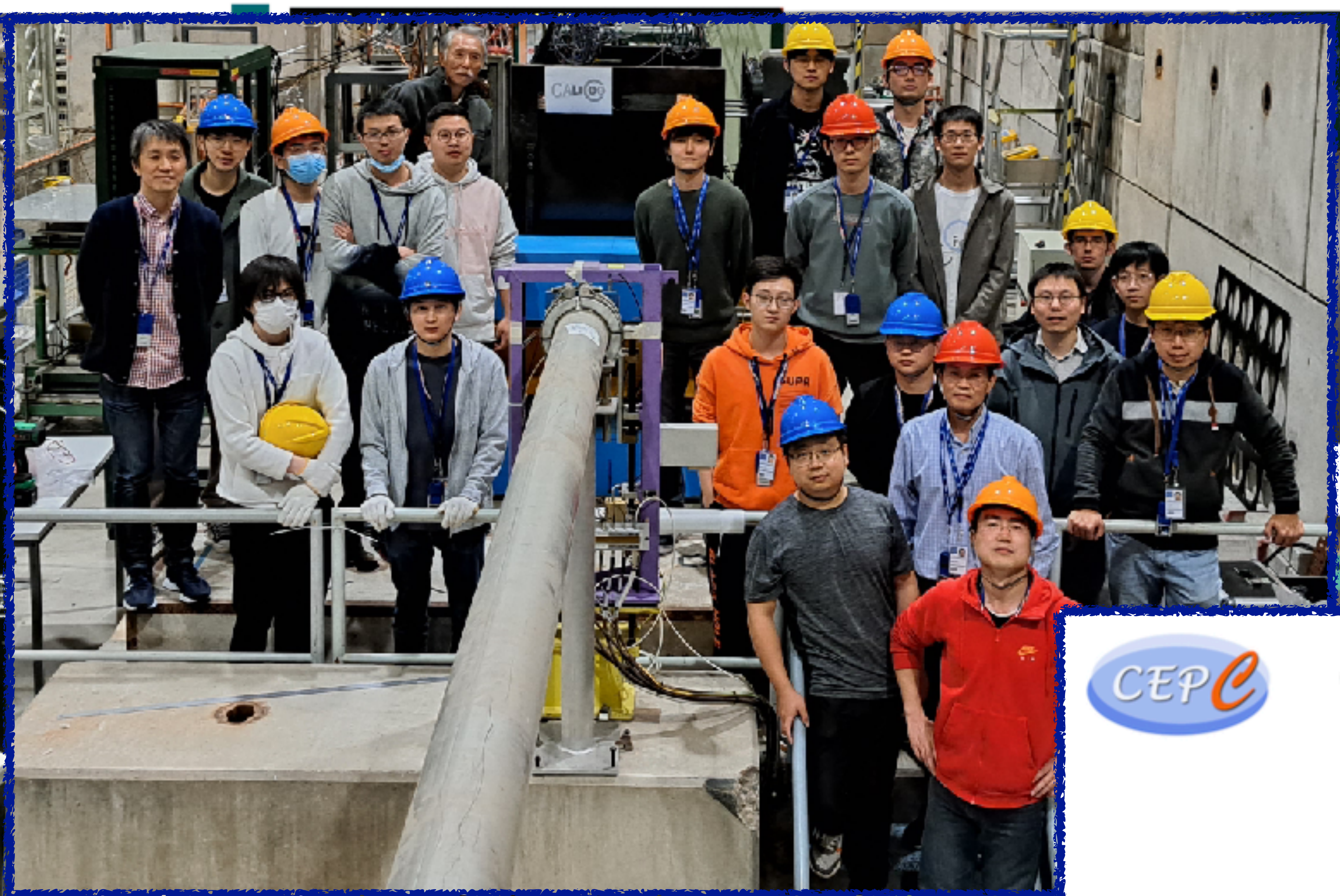


Test beam at CERN SPS on-going, together with CALICE

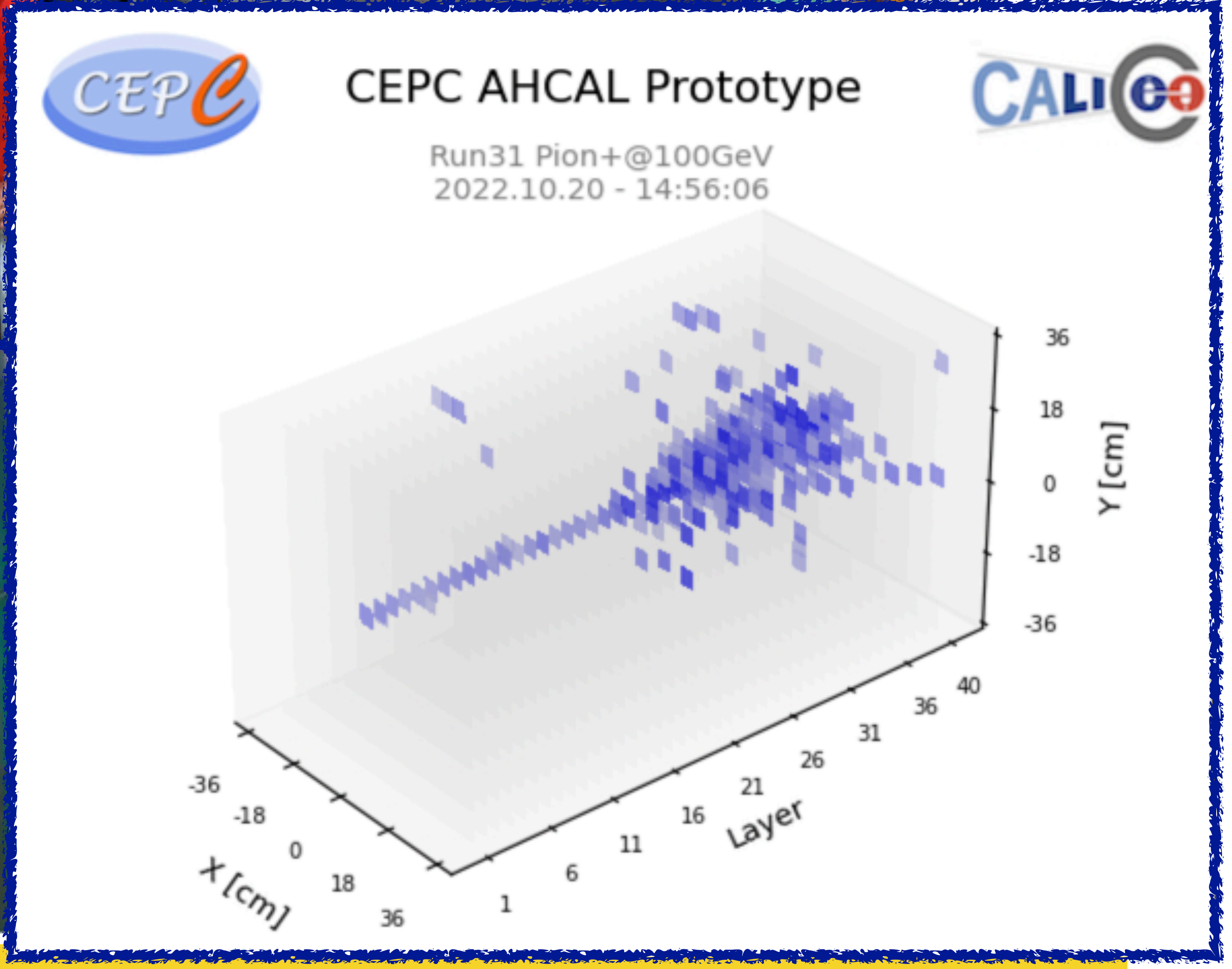
CEPC R&D: Scintillating Calorimeters (ECAL, AHCAL)

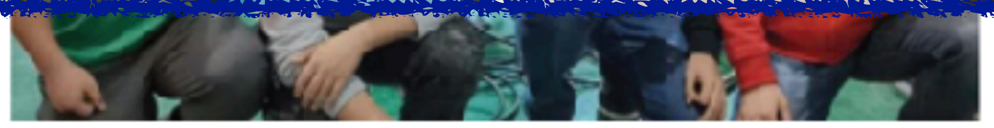
Combined ScW-ECAL and AHCAL test beam





IHEP



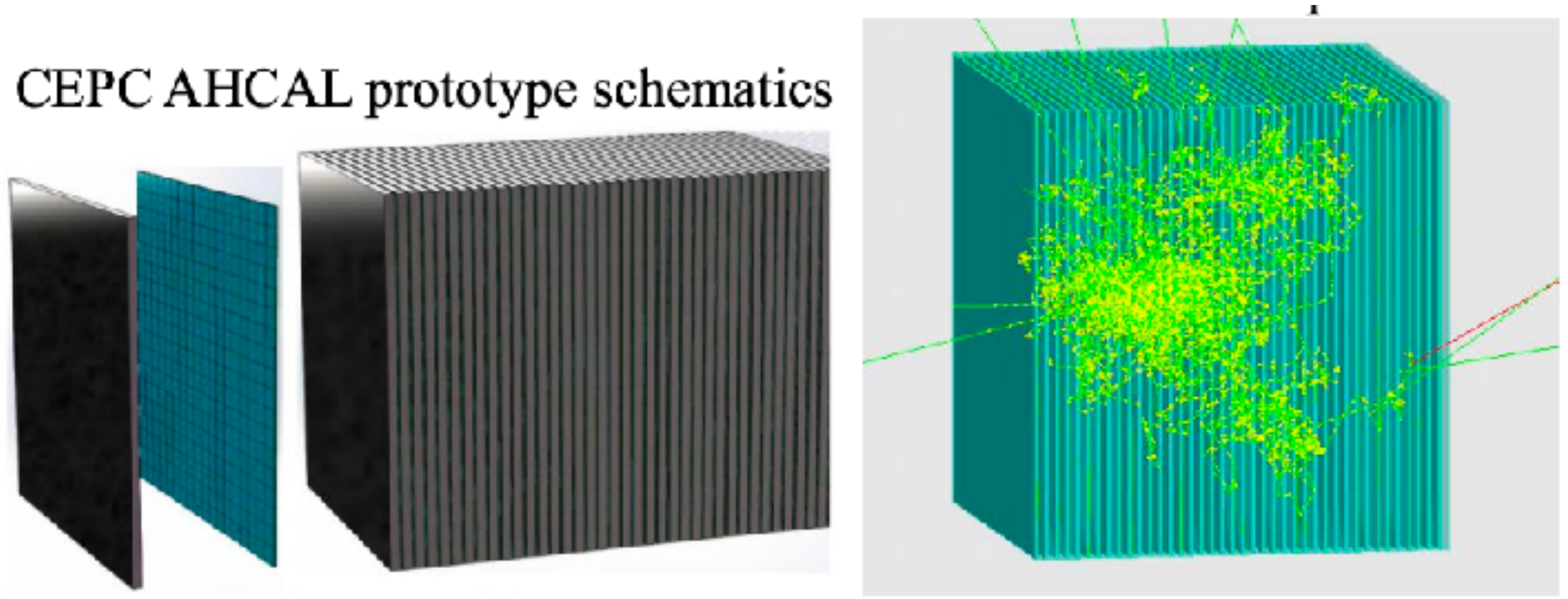


Test beam at CERN SPS on-going, together with CALICE

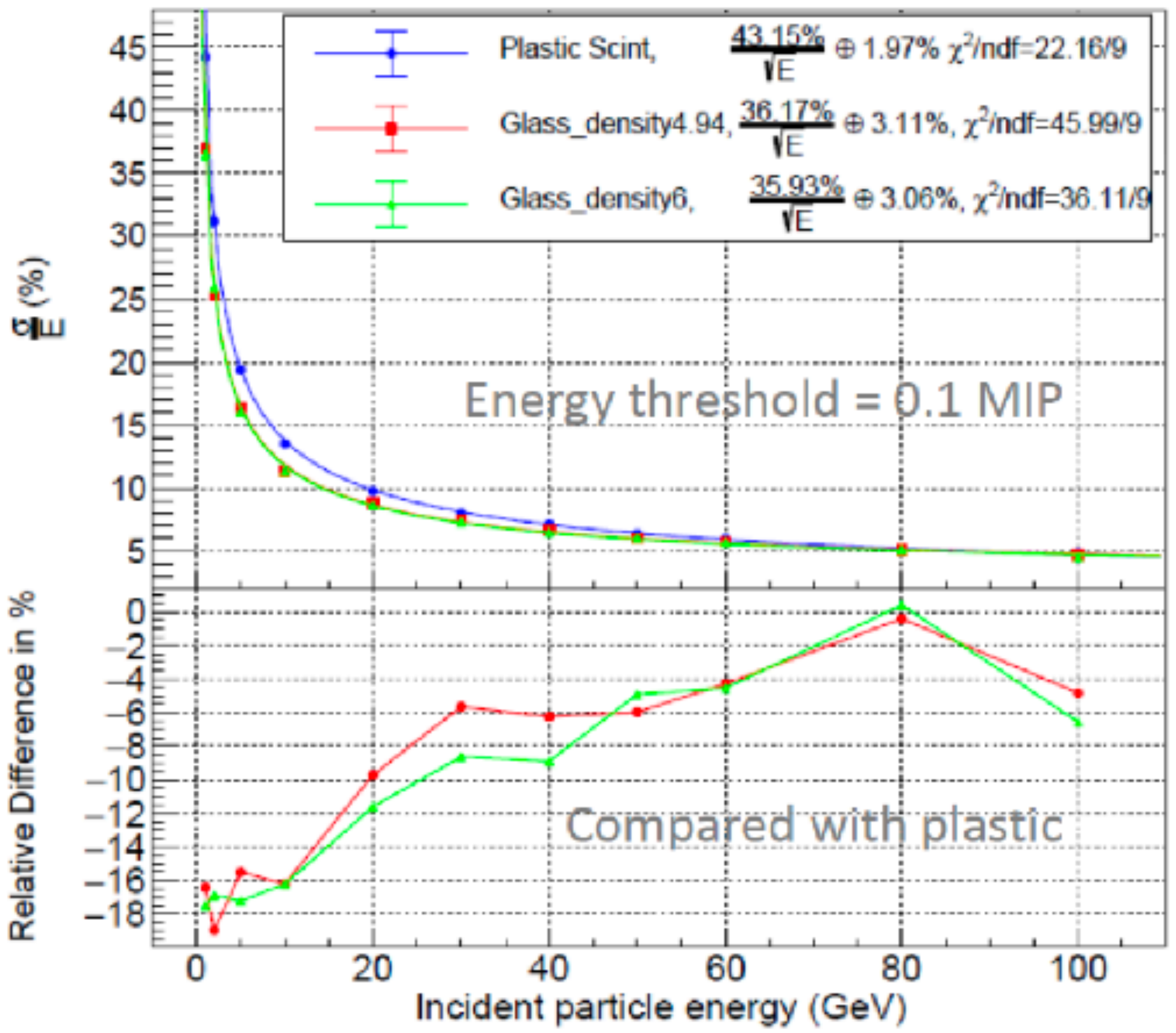
CEPC R&D: New HCAL with Scintillating Glass Tiles

- **CEPC detector: highly granular calorimeter + tracker**
  - Boson Mass Resolution (BMR) ~4% has been realized in baseline design
  - Further performance goal: BMR 4%→3%
- **New Option: Glass Scintillator HCAL (GS-HCAL)**
  - Higher density provides higher sampling fraction
  - Doping with neutron-sensitive elements: improve hadronic response (Gd)
  - More compact HCAL layout (given 4~5 nuclear interaction lengths in depth)

Design similar to baseline AHCAL

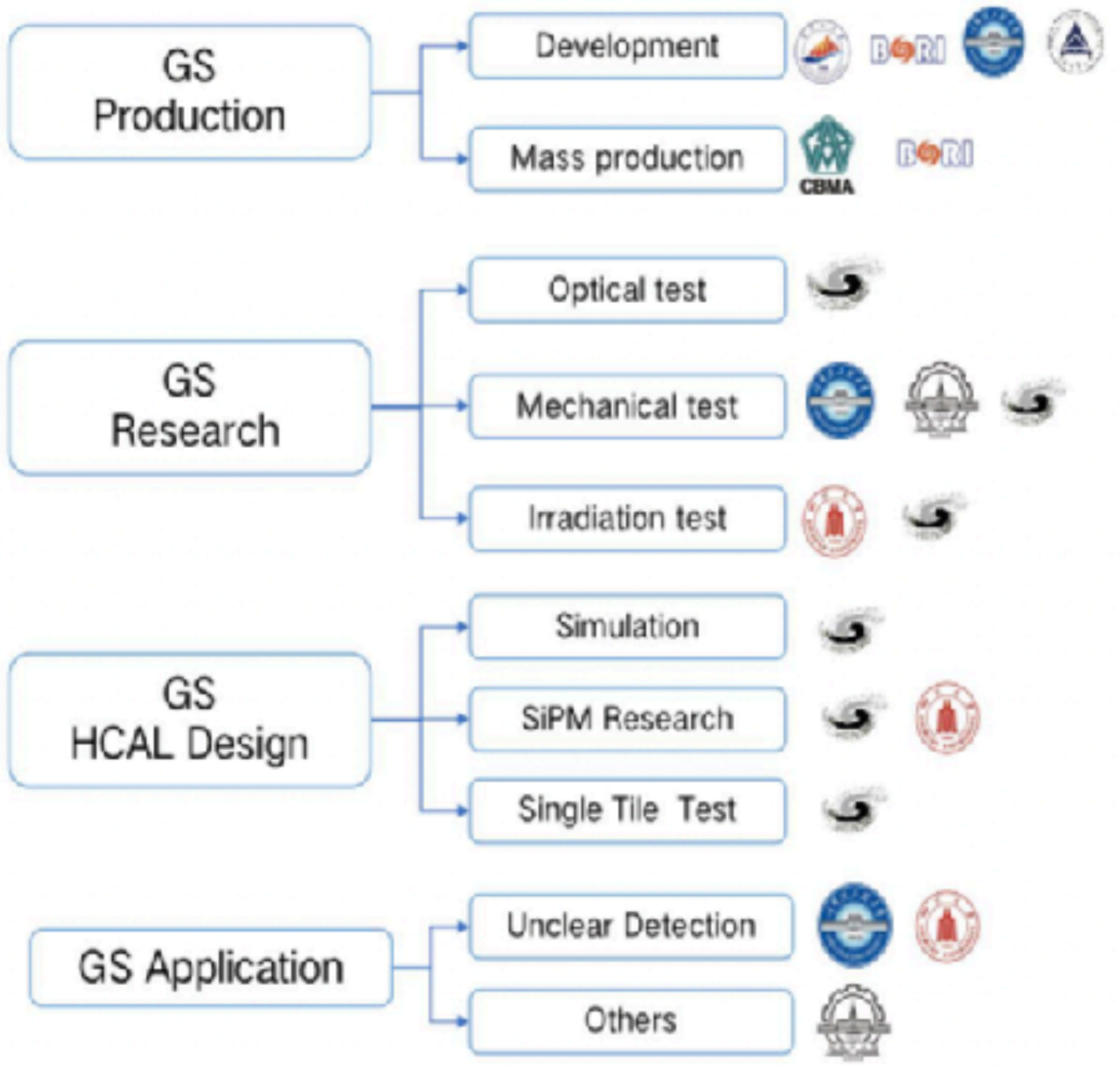


Key parameters	Value	Remarks
Tile size	~30×30 mm^2	Reference CALICE-AHCAL, granularity, number of channels
Tile thickness	~10 mm	Energy resolution, Uniformity and MIP response
Density	**6-7 g/cm^3**	More compact HCAL structure with higher density
Intrinsic light yield	**1000-2000 ph/MeV**	Higher intrinsic LY can tolerate lower transmittance
Transmittance	~75%	
MIP light yield	~150 p.e./MIP	Needs further optimizations: e.g. SiPM type, SiPM-glass coupling
Energy threshold	~0.1 MIP	Higher light yield would help to achieve a lower threshold
Scintillation decay time	~100 ns	Mitigation pile-up effects at CEPC Z-pole (91 GeV)
Emission spectrum	Typically 350-600 nm	To match SiPM PDE and transmittance spectra



Better energy resolution than scintillator

CEPC R&D: New HCAL with Scintillating Glass Tiles



中国科学院高能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences

Jinggangshan University 井冈山大学

Beijing Glass Research Institute 北京玻璃研究院

China Building Materials Academy 中国建筑材料研究院

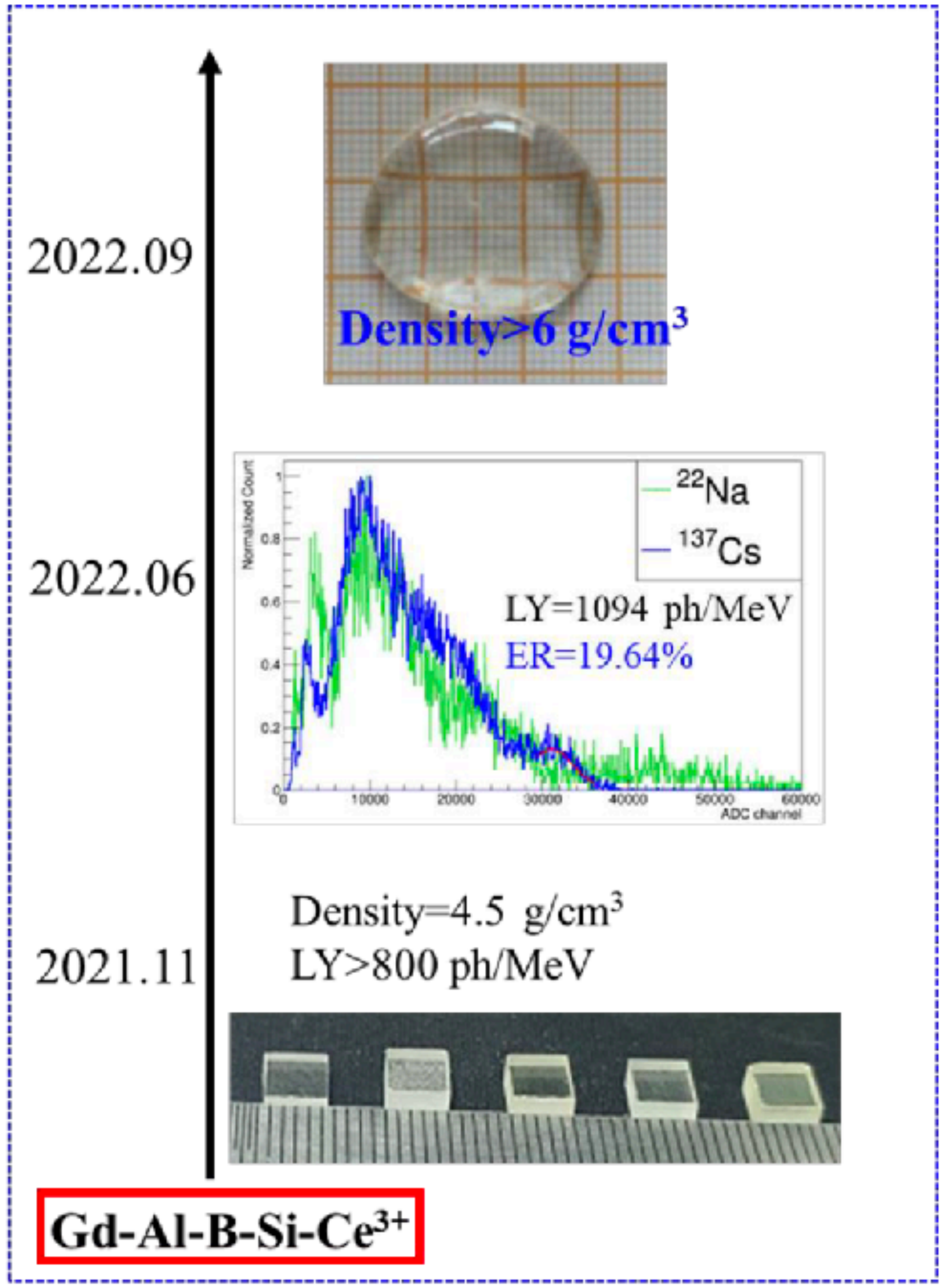
China Jiliang University 中国计量大学

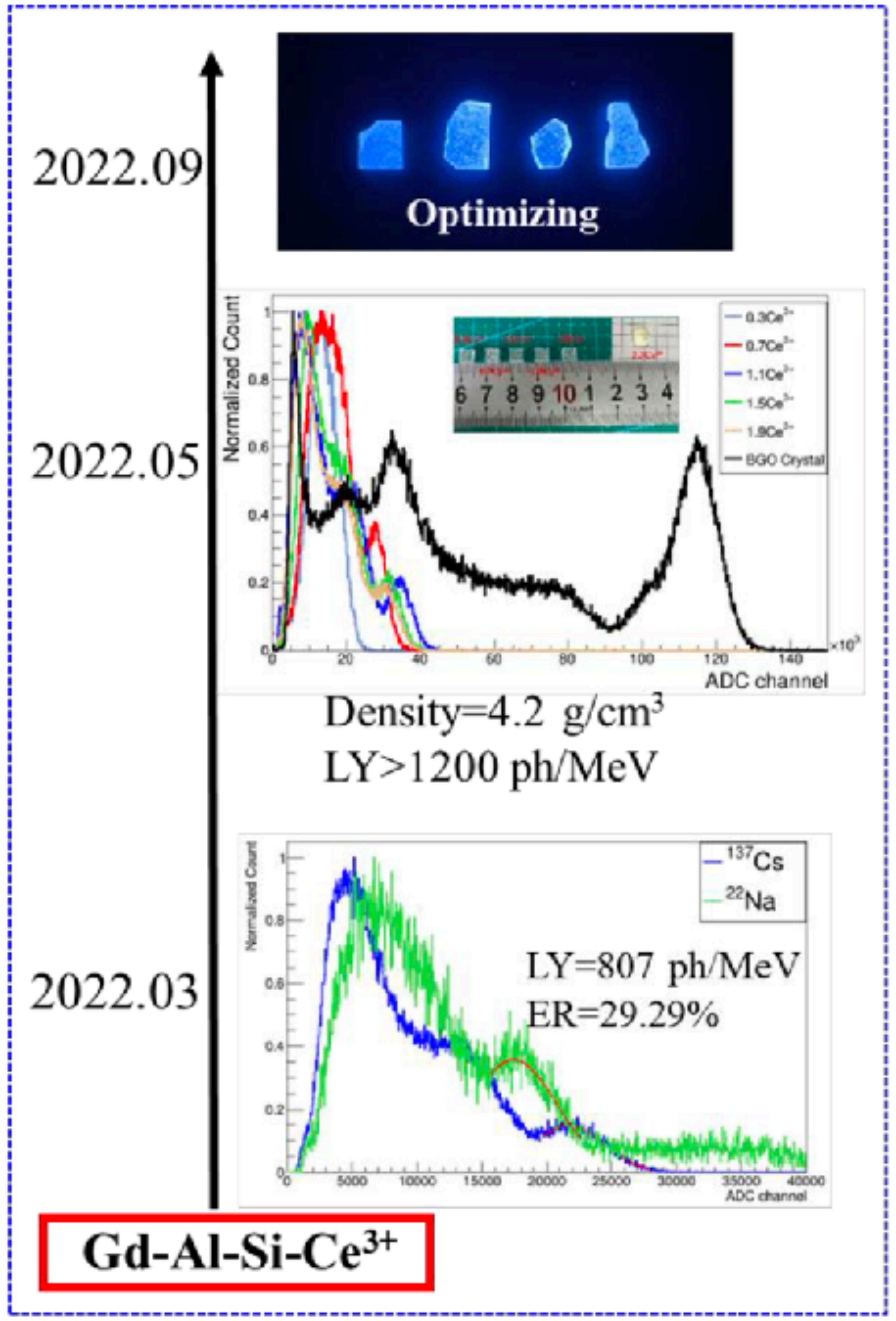
Harbin Engineering University 哈尔滨工程大学

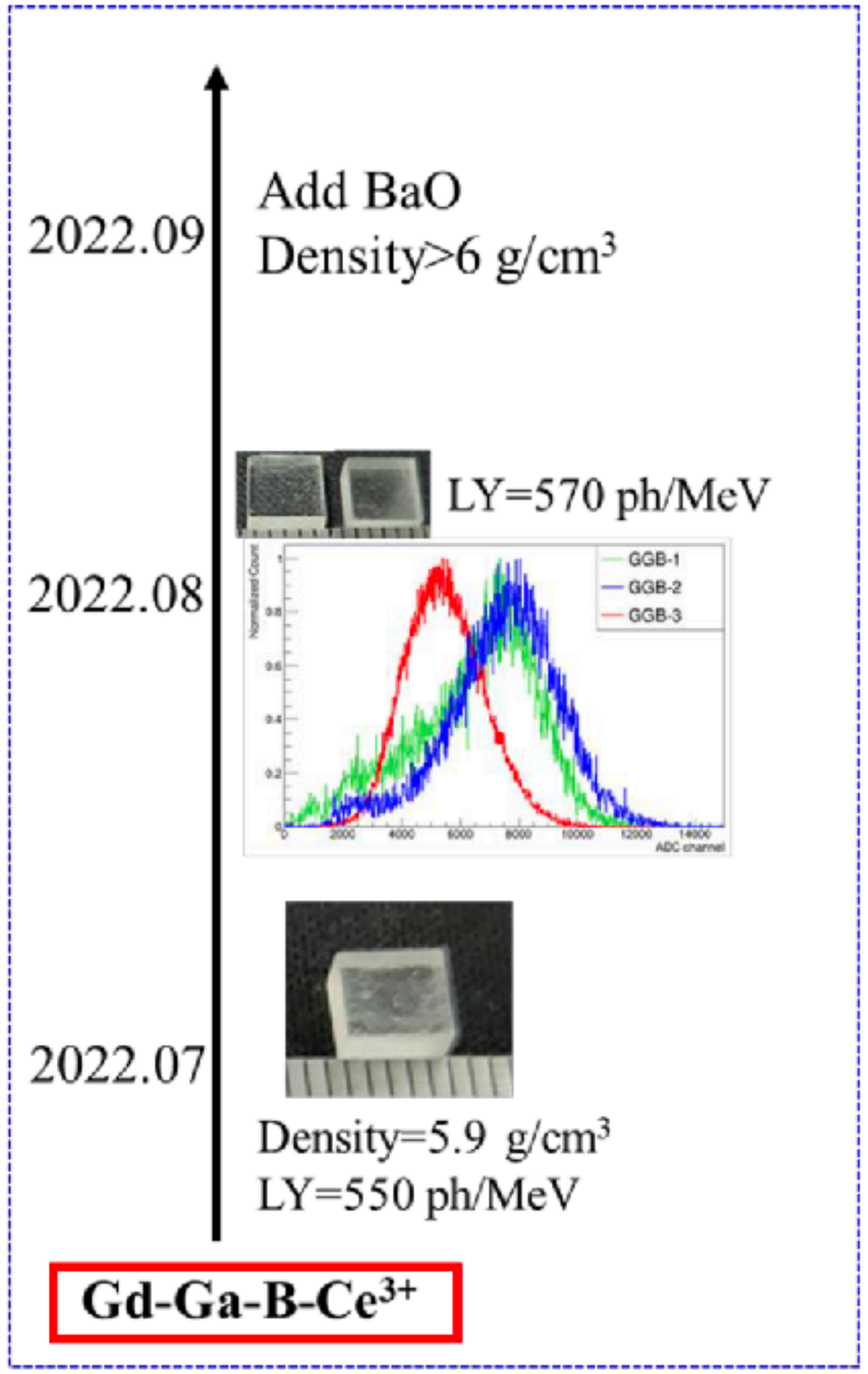
Harbin Institute of Technology 哈尔滨工业大学

Sichuan University 四川大学

Different types of glass have been investigated







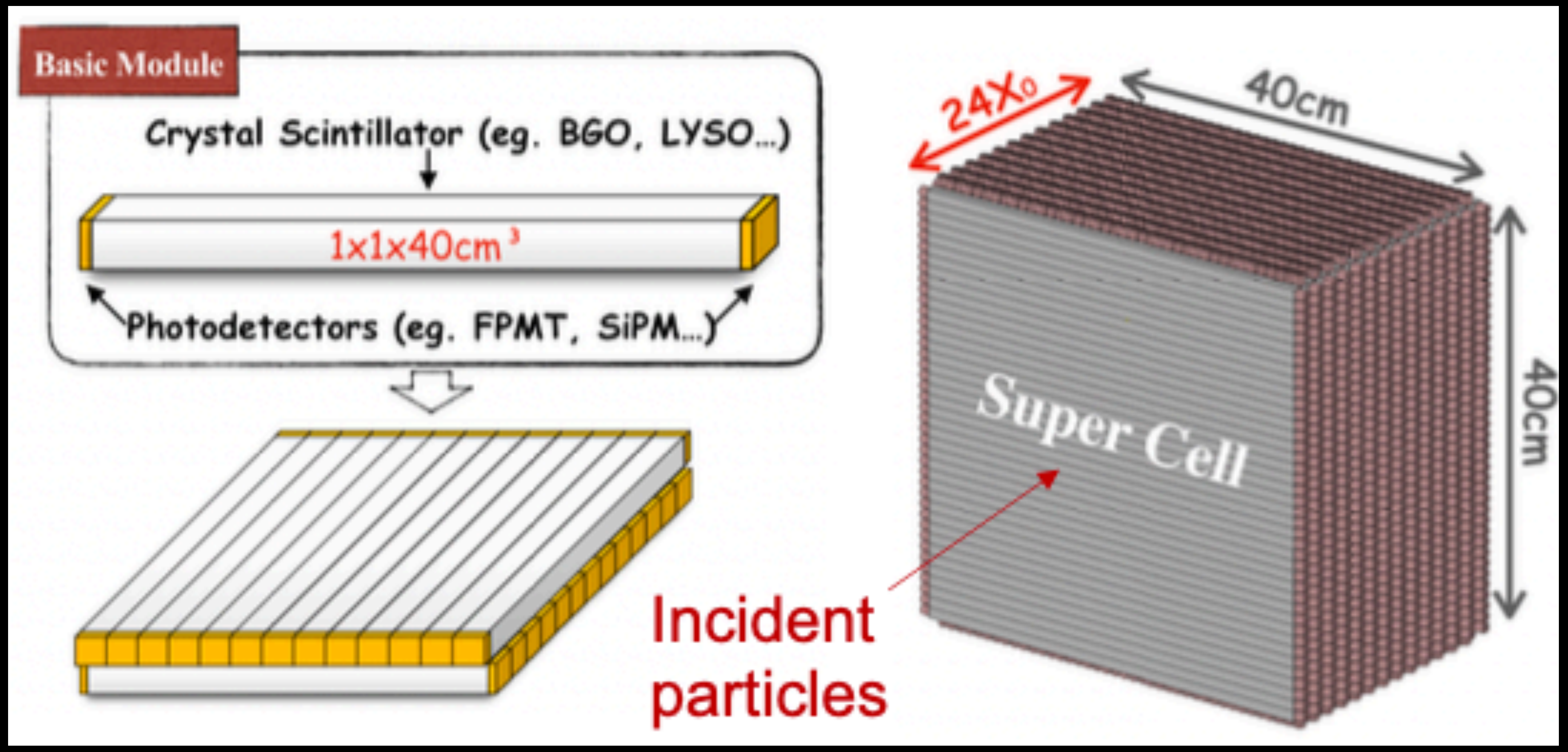
Glass scintillator of high density and light yield:

5.2 g/cm³ & 800 ph/MeV—Gd-B-Si-Ce^{3+} glass

5.9 g/cm³ & 550 ph/MeV—Gd-Ga-B-Ce^{3+} glass

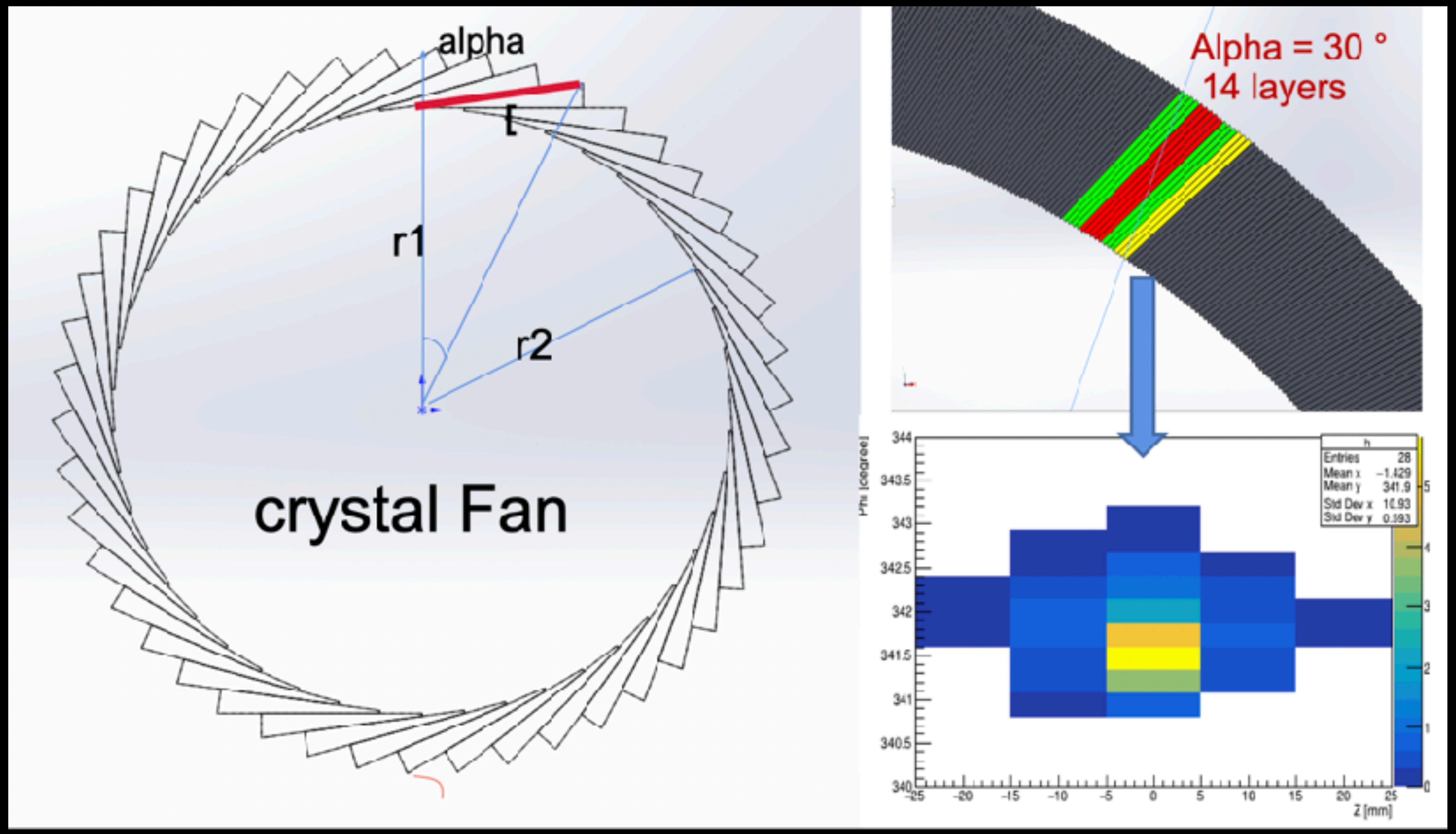
CEPC R&D: High Granularity Crystal ECAL

New segmented ECAL designs based on crystals



- Long bars: 1 × 40 cm
  - Super-cell: 40 × 40 cm cube
- Double-sided readout
  - Timing at both sides, gives position along bar
- Key concerns:
  - Ambiguities in separation of close showers
  - Impact on Jet Energy Resolution (JER)

Crystal Fan Design

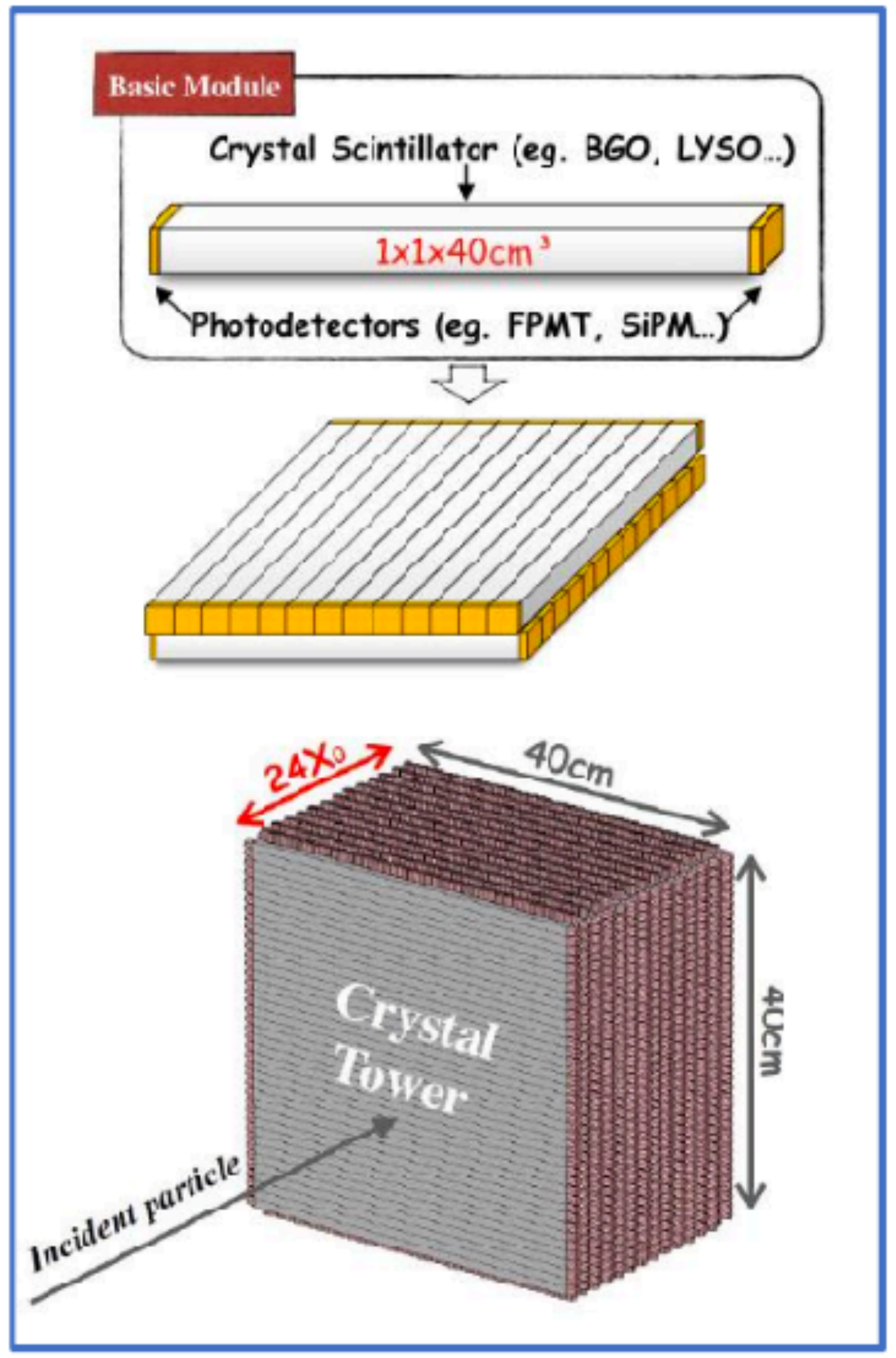


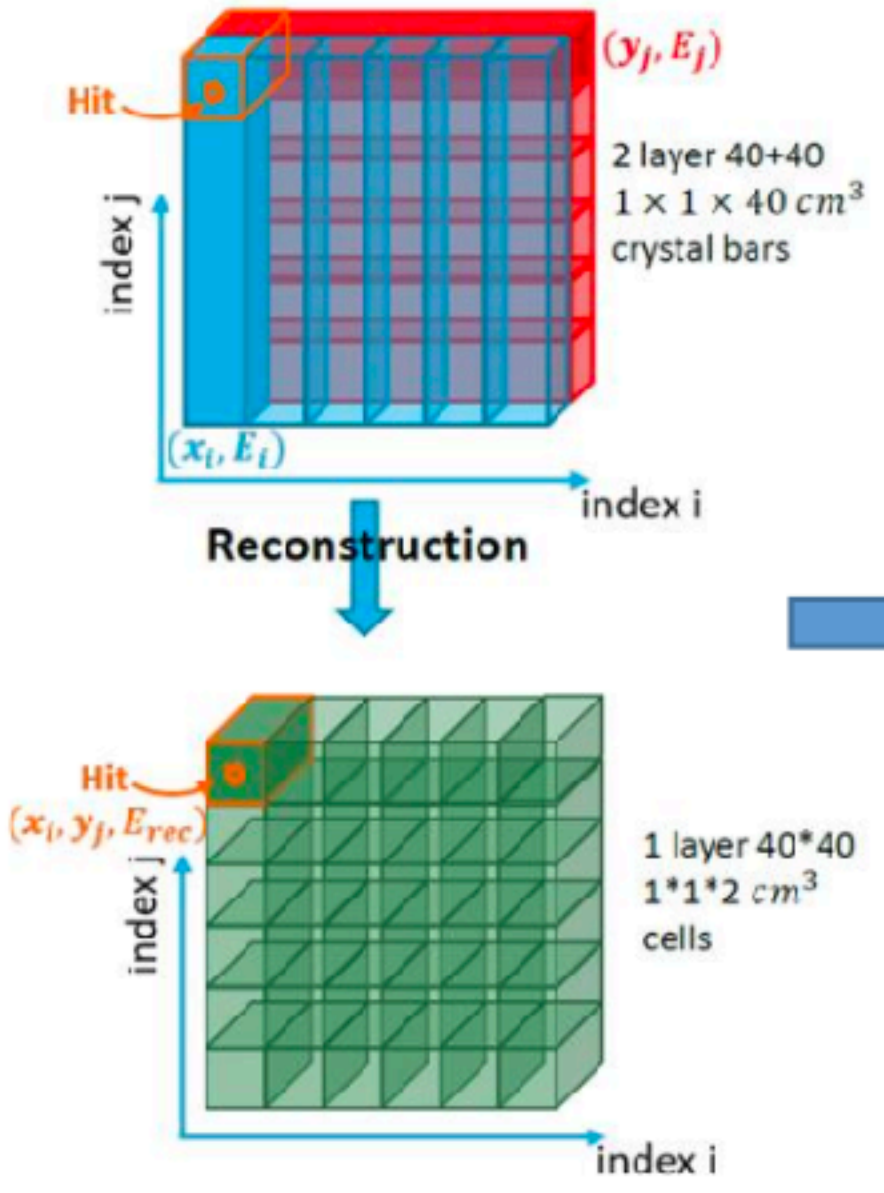
- Fine segmentation in Z, ϕ and r
  - Resolutions (mm) : Z ~ 1 ; ϕ ~ 2; r ~ 8
  - Reduced readout electronics channels

Dual Readout Crystal Calorimeter also being consider by USA and Italian colleagues

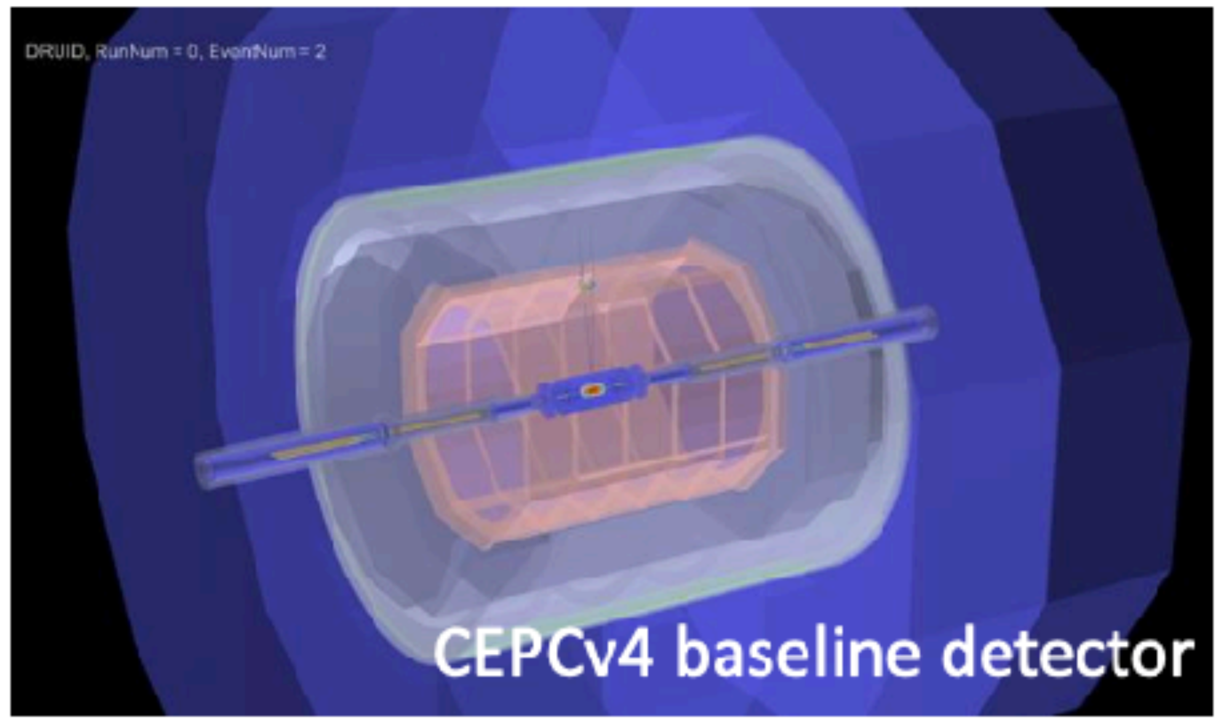
CEPC R&D: High Granularity Crystal ECAL

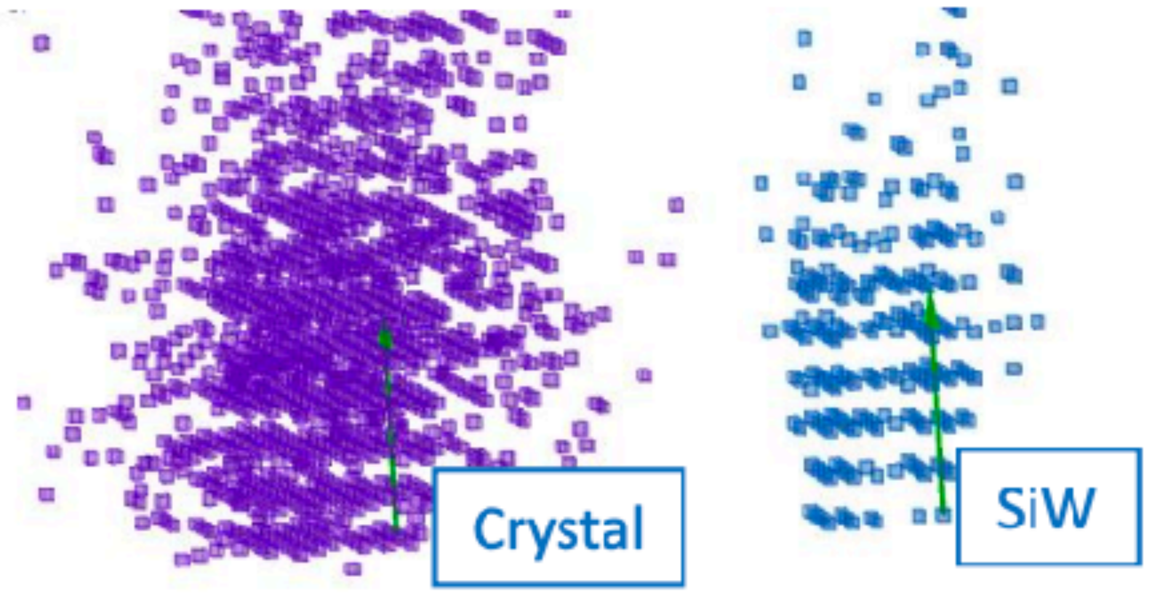
Hardware design → Simulation and validation → Performance evaluation



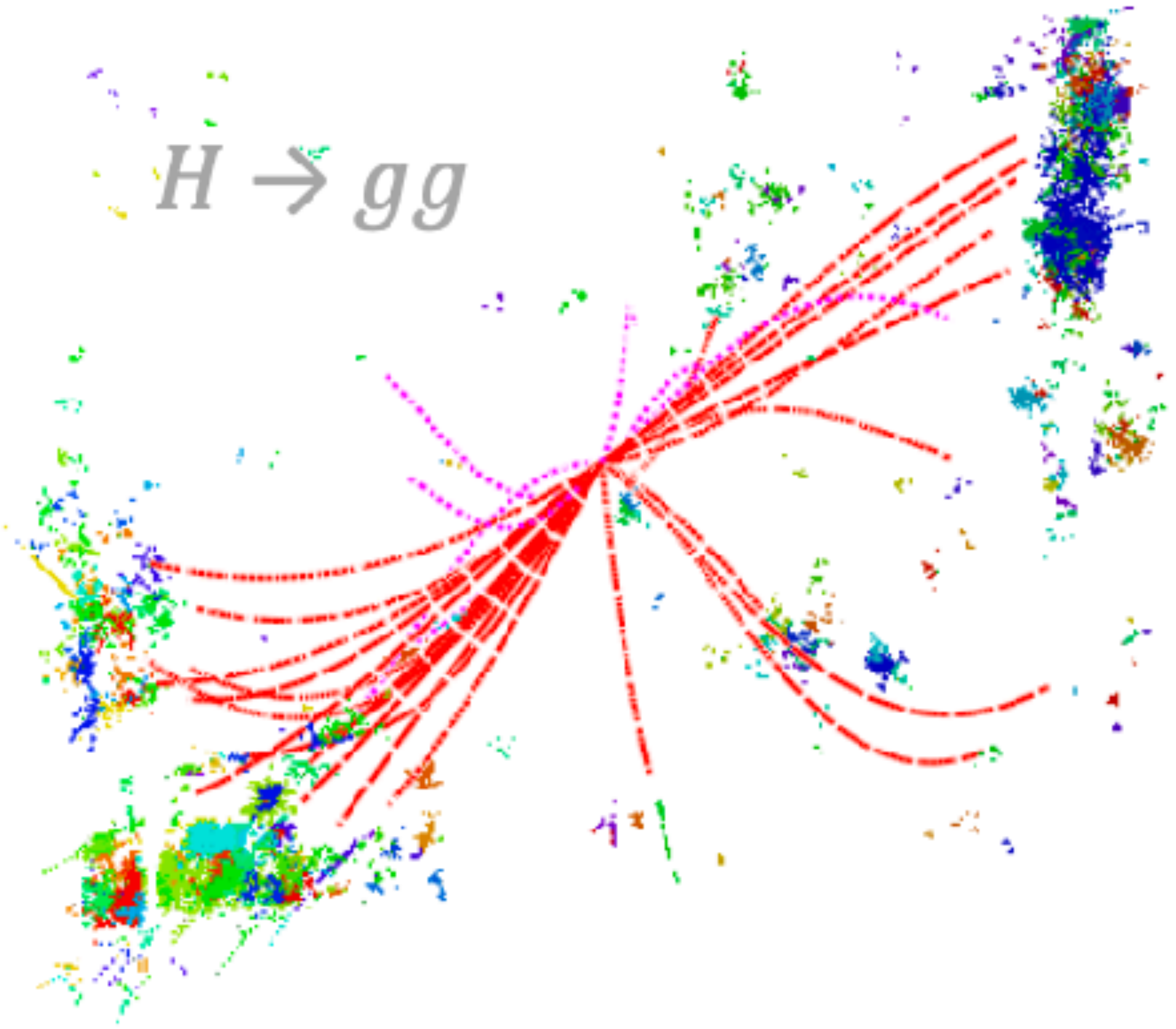


Crossed long bar design:
$1 \times 1 \times 2$ cm^3 granularity
after reconstruction





Shower profile of 5 GeV photons:
significant increase of #hit due to a larger
Molière radius: 2.26 cm (BGO) vs 0.93 (W)



Performance study with multiple
jets events of Higgs decay

Hardware development: crossed long crystal bars

- New reconstruction software for long bars
- Optimizations of the Arbor-PFA for crystal ECAL

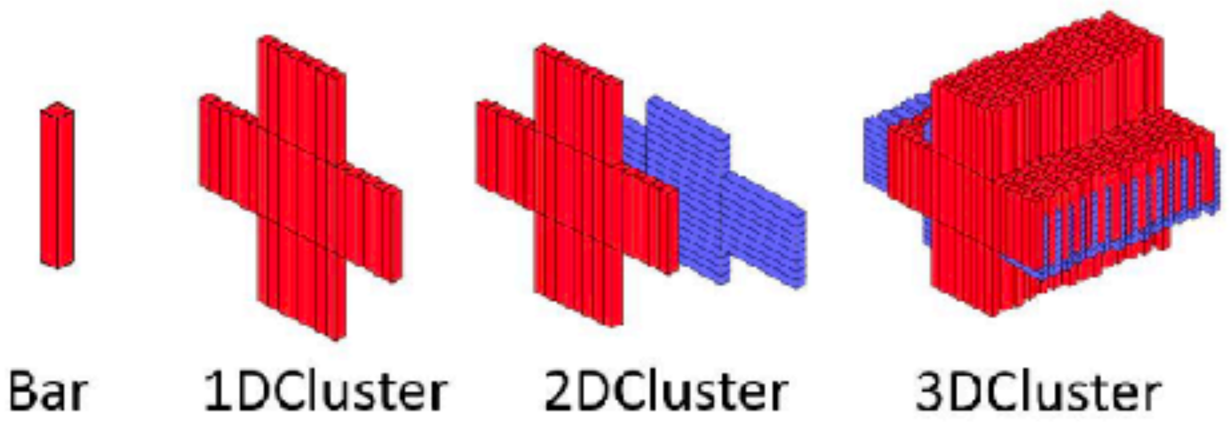
Physics performance evaluation with Higgs benchmarks

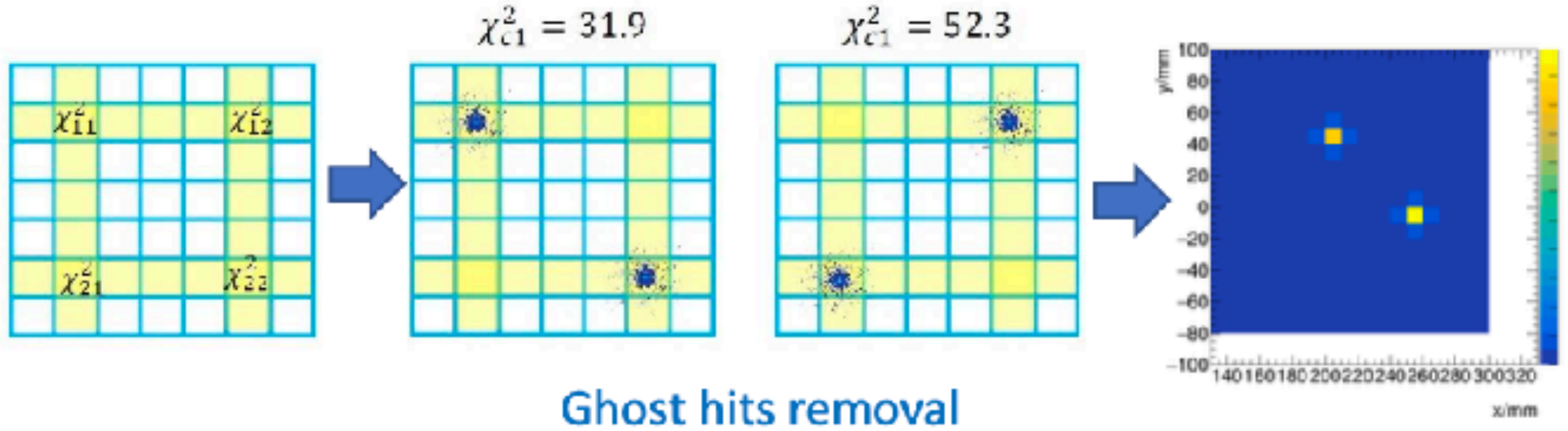
Goal: Intrinsic energy resolution: $\sim 3\%/\sqrt{E}$ ~1%

CEPC R&D: High Granularity Crystal ECAL

Reconstruction algorithms

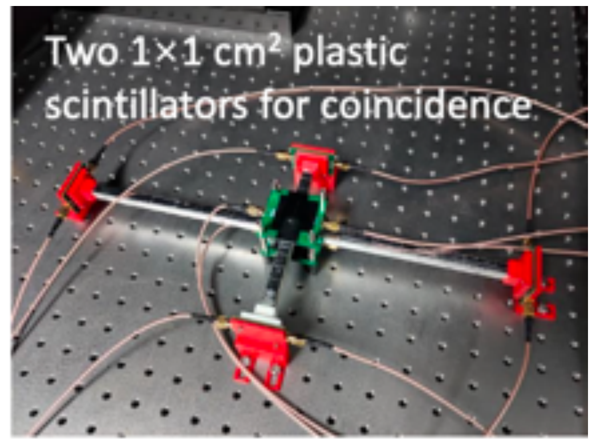
Basic principles of clustering algorithm

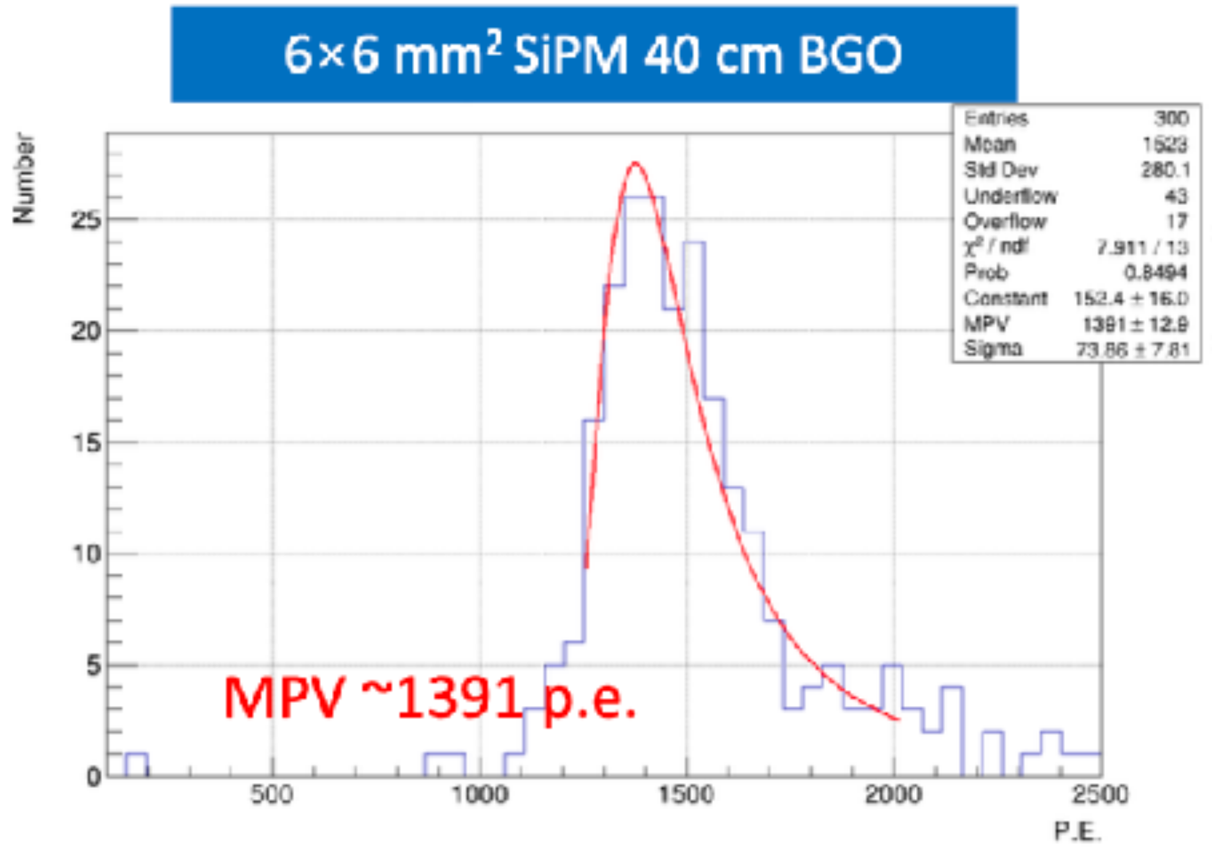




Ghost hits removal

Cosmic ray test

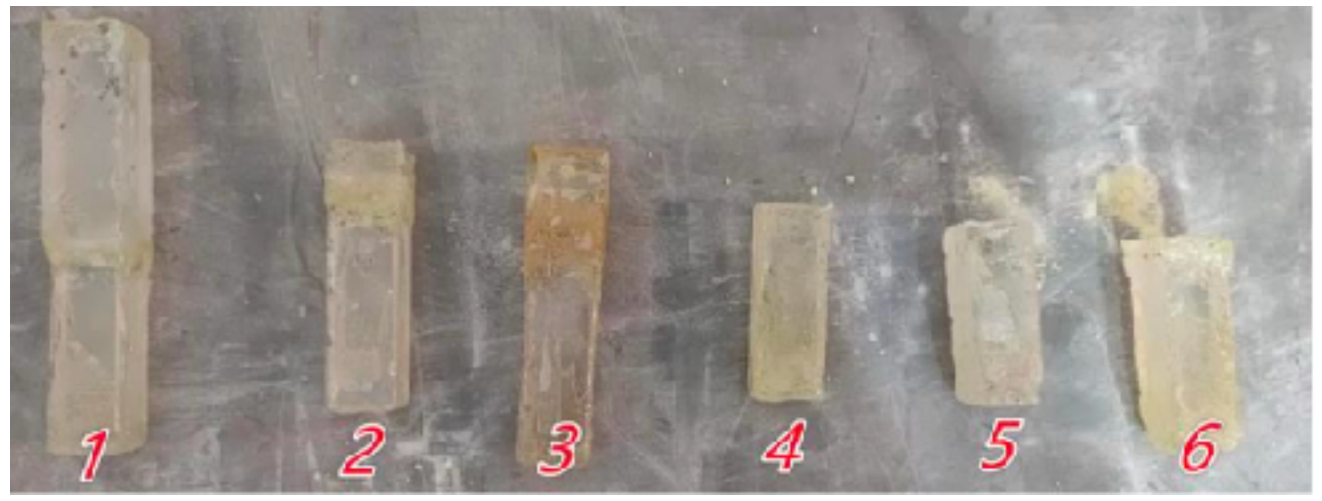




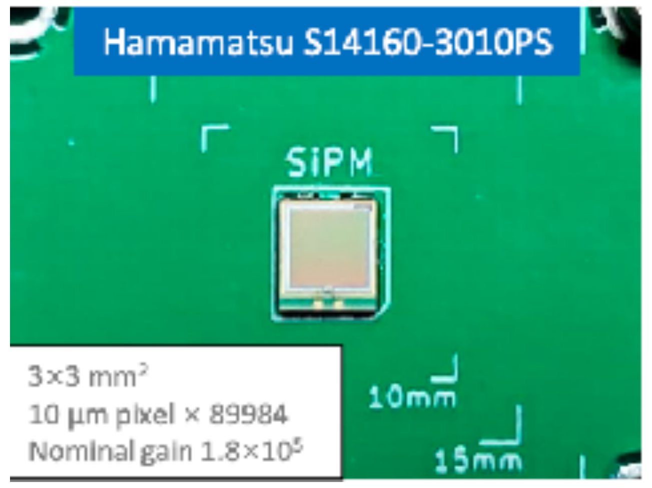
good enough light yield

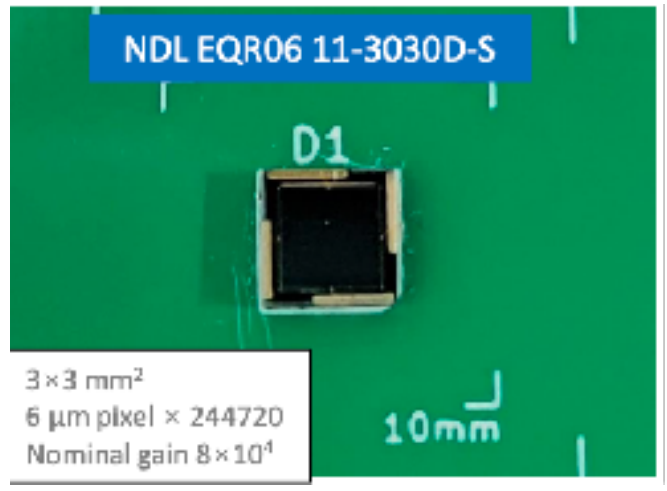
Study of crystal-SiPM units

BGO crystals

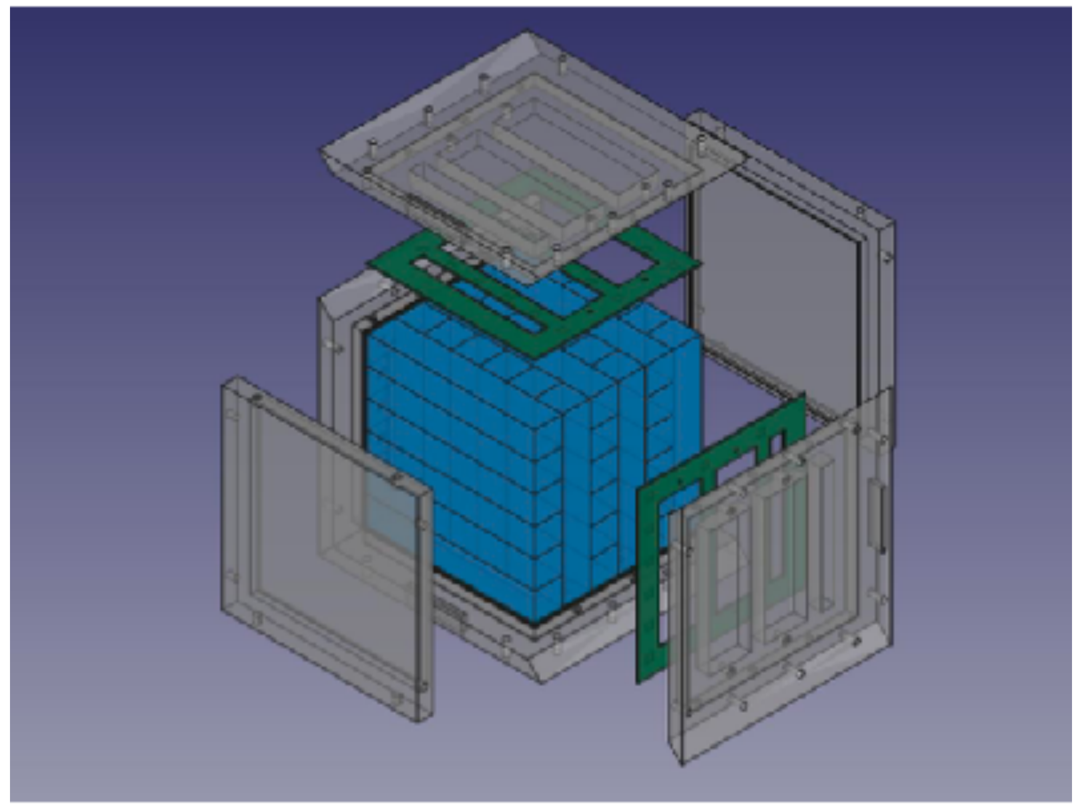


Large dynamics SiPMs





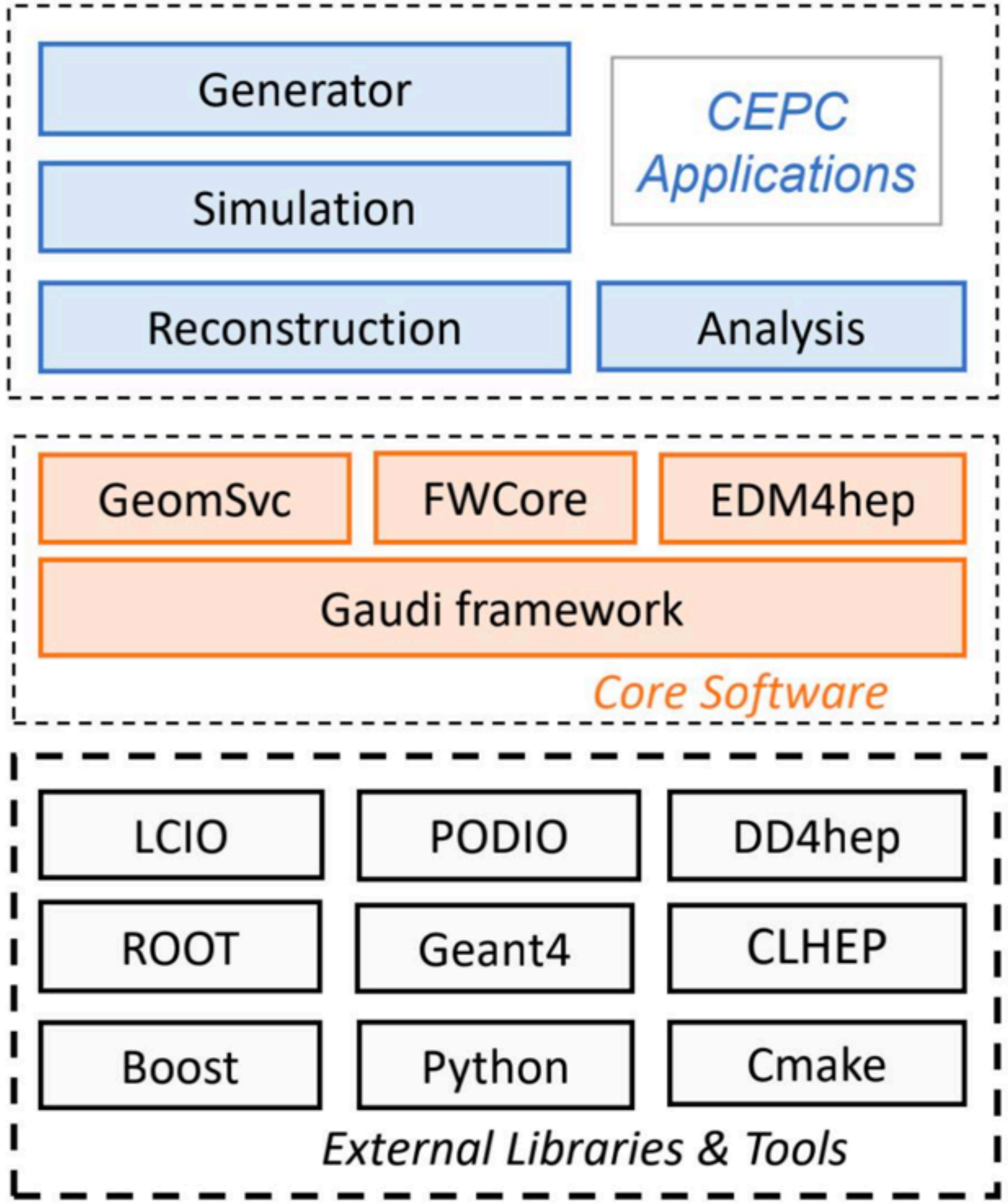
Mechanical structure



CEPC Software

Key4hep is the foundation of CEPC software

- Based on Key4HEP
- Reuse and extend existing components
  - Gaudi, EDM4hep, DD4hep, …
- Implement the specific components for CEPC
  - Geometry, generator, simulation and reconstruction algorithms, etc.
- Provide ready-to-work environment to algorithm developers and physicists
  - Porting algorithms from iLCSoft to CEPCSW
  - Integrate/develop more algorithms and features

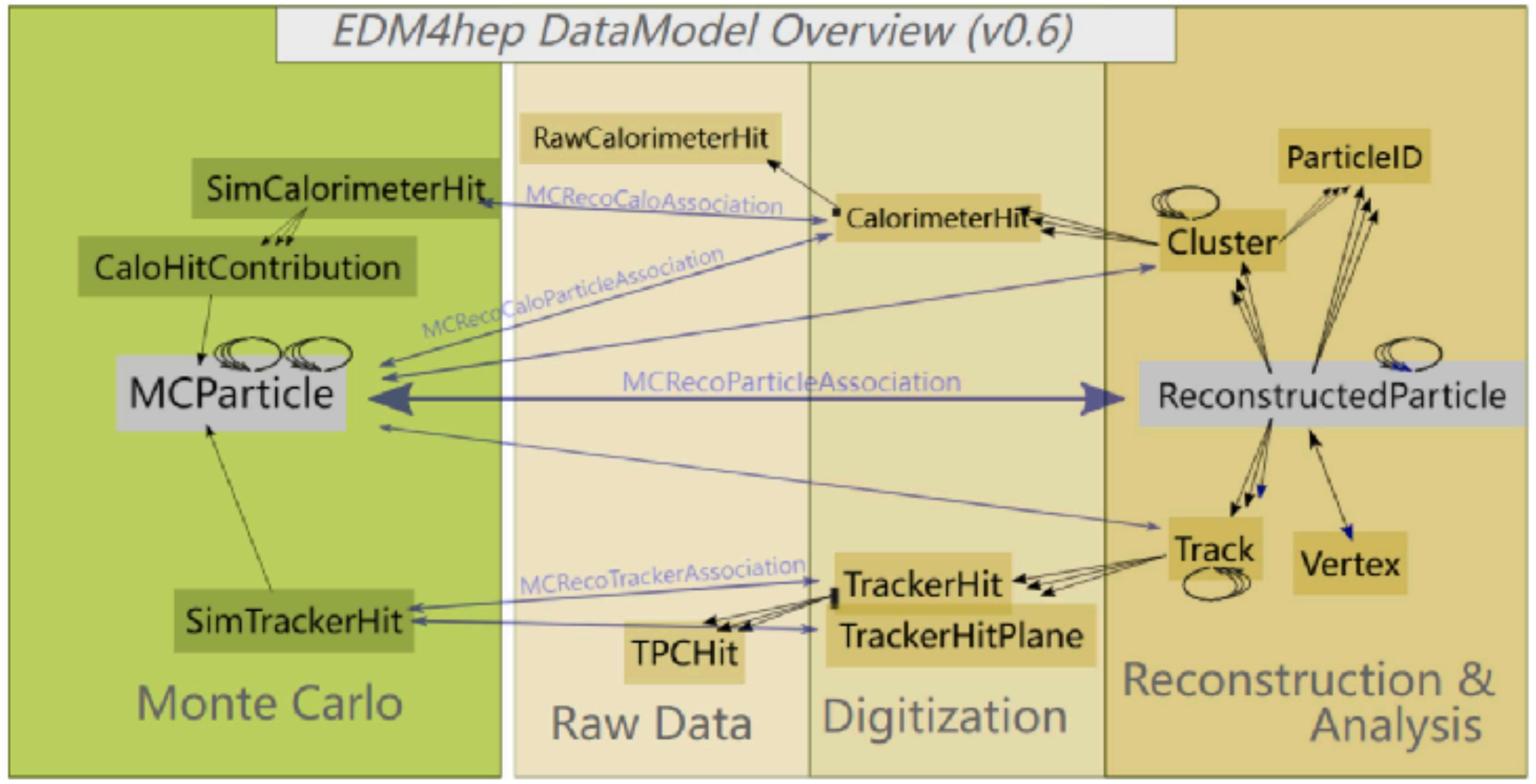


https://github.com/cepc/CEPCSW

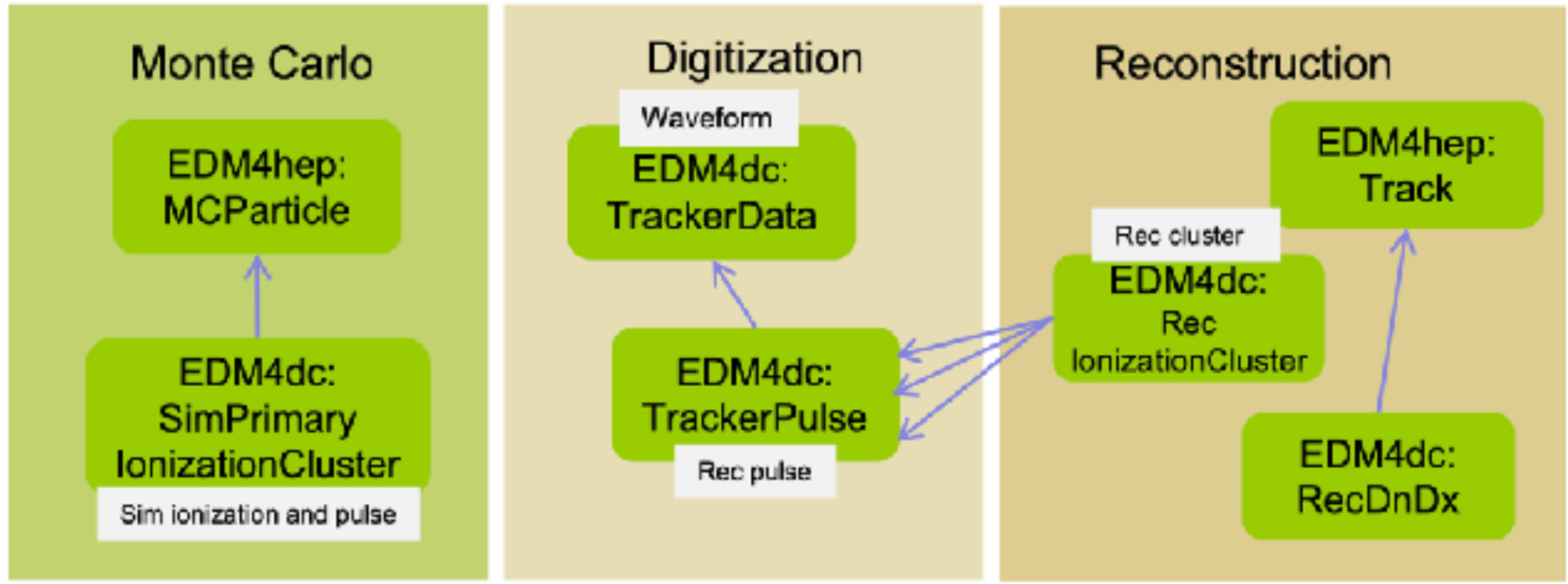
CEPC Software

Common Event Data Model: EDM4hep

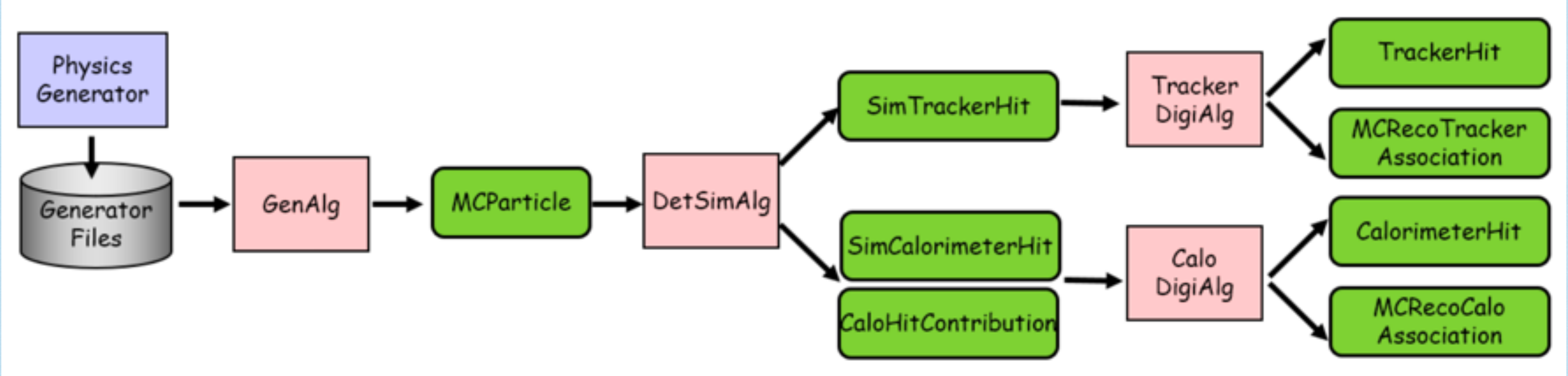
CEPC uses EDM4hep, the common EDM that can be used by all communities in the Key4hep project: ILC, CLIC, FCC-ee & FCC-hh



Extensions to EDM4Hep for cluster counting



CEPC simulation using EDM4hep



Detector description using DD4hep

Reconstruction work done for:

- Silicon tracking
- TPC software
- Drift chamber tracking and cluster counting
- Calorimeter

International Collaboration

Snowmass — Letters of Intent

14 CEPC-Related Detector LoI submitted

https://indico.ihep.ac.cn/event/12410/

Detector R&D

Conveners: Joao Guimaraes Costa, WANG Jianchun, Mr. Manqi Ruan (IHEP)

15:00 **CEPC Detectors Overview LoI** *1'*

CEPC Detector Overview LOI
SNOWMASS21-EF1_EF4-IF9_IF0-260.pdf

Speakers: Joao Guimaraes Costa, Mr. Manqi Ruan (IHEP), WANG Jianchun

Material: Paper Slides

15:02 **IDEA Concept** *1'*

Speaker: Franco Bedeschi (INFN-Pisa)

Material: Paper

15:03 **Dual Readout Calorimeter** *1'*

Speaker: Roberto Ferrari (INFN)

Material: Paper

15:04 **Drift Chamber** *1'*

Speaker: Franco Grancagnolo

Material: Paper

15:06 **mu-RWELL (muons, preshower)** *1'*

Speaker: Paolo Giacomelli (INFN-Bo)

Material: Paper

15:08 **Time Detector LoI** *1'*

Speaker: Prof. Zhijun Liang (IHEP)

Material: Slides

15:09 **Key4hep** *1'*

Speakers: Dr. Weidong Li (高能所), Dr. Tao LIN (高能所), Prof. Xingtao Huang (Shandong University), Wenxing Fang (Beihang University)

Material: Slides

15:10 **PFA Calorimeter** *1'*

Speakers: Haijun Yang (Shanghai Jiao Tong University), Dr. Jianbei Liu (University of Science and Technology of China), Dr. Yong Liu (Institute of High Energy Physics)

Material: Slides

15:11 **High Granularity Crystal Calorimeter** *1'*

Speaker: Dr. Yong Liu (Institute of High Energy Physics)

Material: Paper Slides

15:12 **Muon Scintillator Detector** *1'*

Speaker: Dr. Xiaolong Wang (Institute of Modern Physics, Fudan University)

Material: document

15:13 **Vertex LoI** *1'*

Speaker: Prof. Zhijun Liang (IHEP)

Material: Slides

15:15 **MDI LoI** *1'*

Speaker: Dr. Hongbo ZHU (IHEP)

Material: Slides

15:16 **TPC LoI** *1'*

Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)

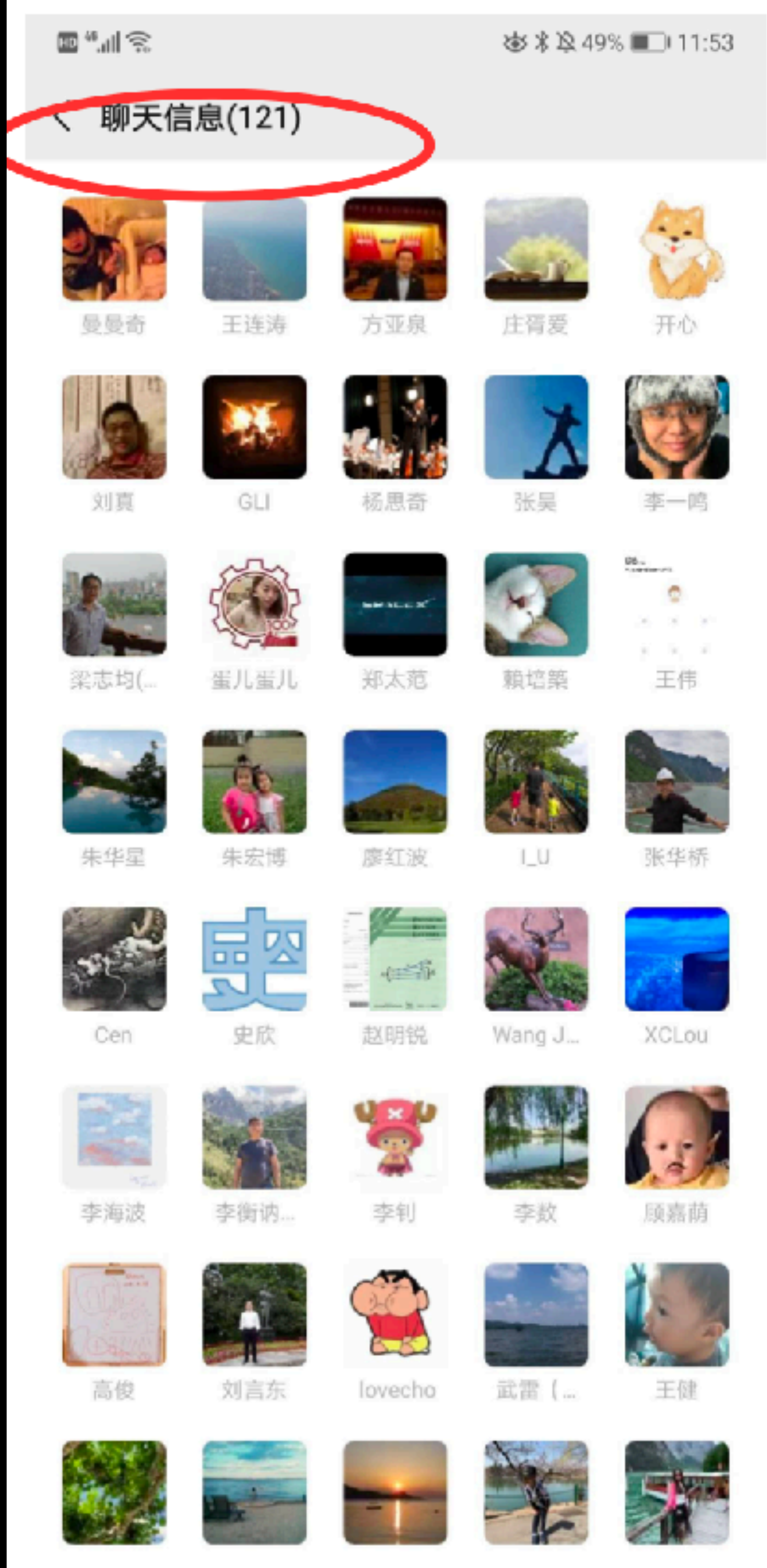
Material: Slides

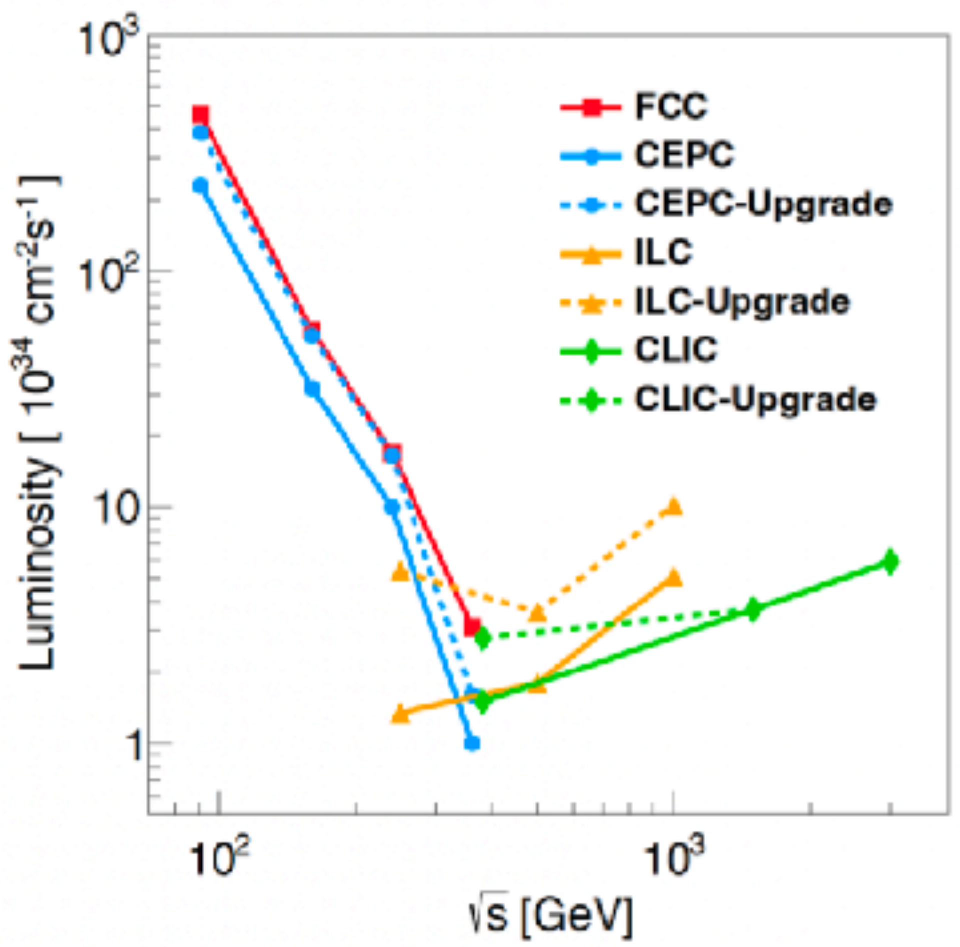
15:17 **Solenoid R&D LoI** *1'*

Speaker: Dr. Feipeng NING (IHEP)

Material: Slides

CEPC Physics at Snowmass





CEPC input to the Snowmass 2021 - Physics cases

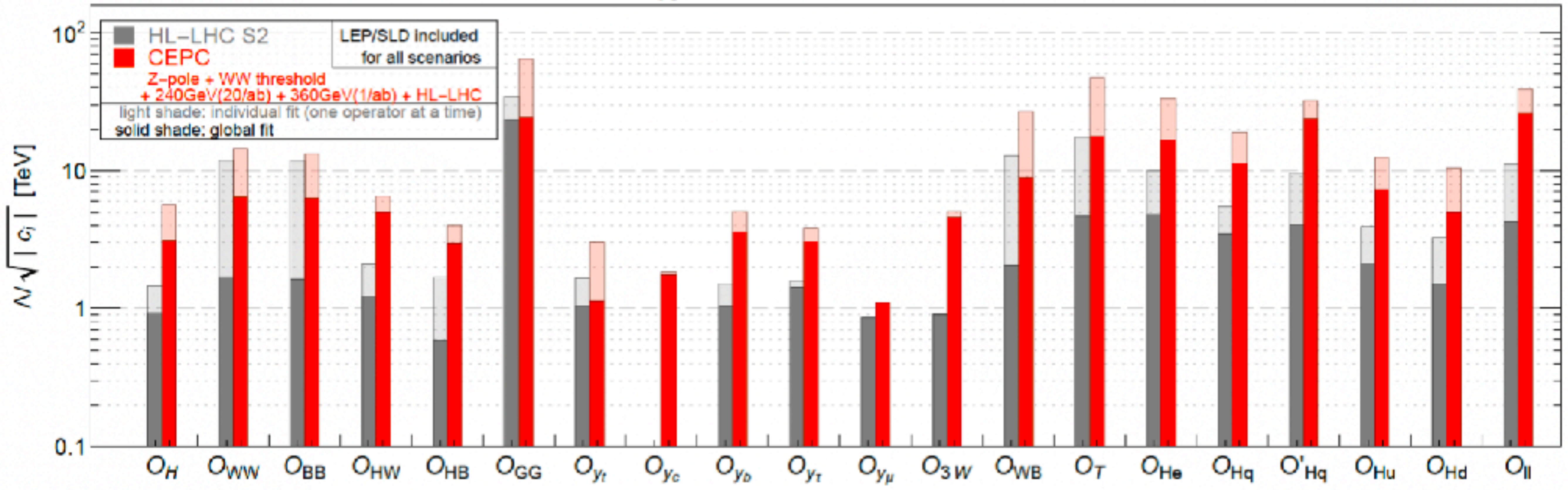
CEPC Physics Study Group

(Dated: March 28, 2022)

ABSTRACT

The Circular Electron Positron Collider (CEPC) is a large-scale future collider facility that can serve as a factory of the Higgs boson, the W boson and the Z boson, and is upgradable to be also a top-quark factory. This document provides the latest nominal operation scenario and particle yields, and report briefly the physics potential studies. This submission is for the consideration by the Snowmass process.

95% CL reach from SMEFT fit



- Covers Higgs, EW, Flavor, NP, etc.
- Updated to the latest(TDR) beam parameters,
- Strong collaboration with theory/pheno community + clear requirement for the detector design

Essential International Partners:

- International partnership in the detector prototypes
  - PFA calorimeter: with CALICE Collaboration
  - TPC: with LC-TPC Collaboration
  - Drift chamber: with Italian colleague from IDEA
  - Silicon tracker: with UK/Germany/Italian colleague
  - Silicon vertex: with French/Spanish colleague
  - Key4hep software development

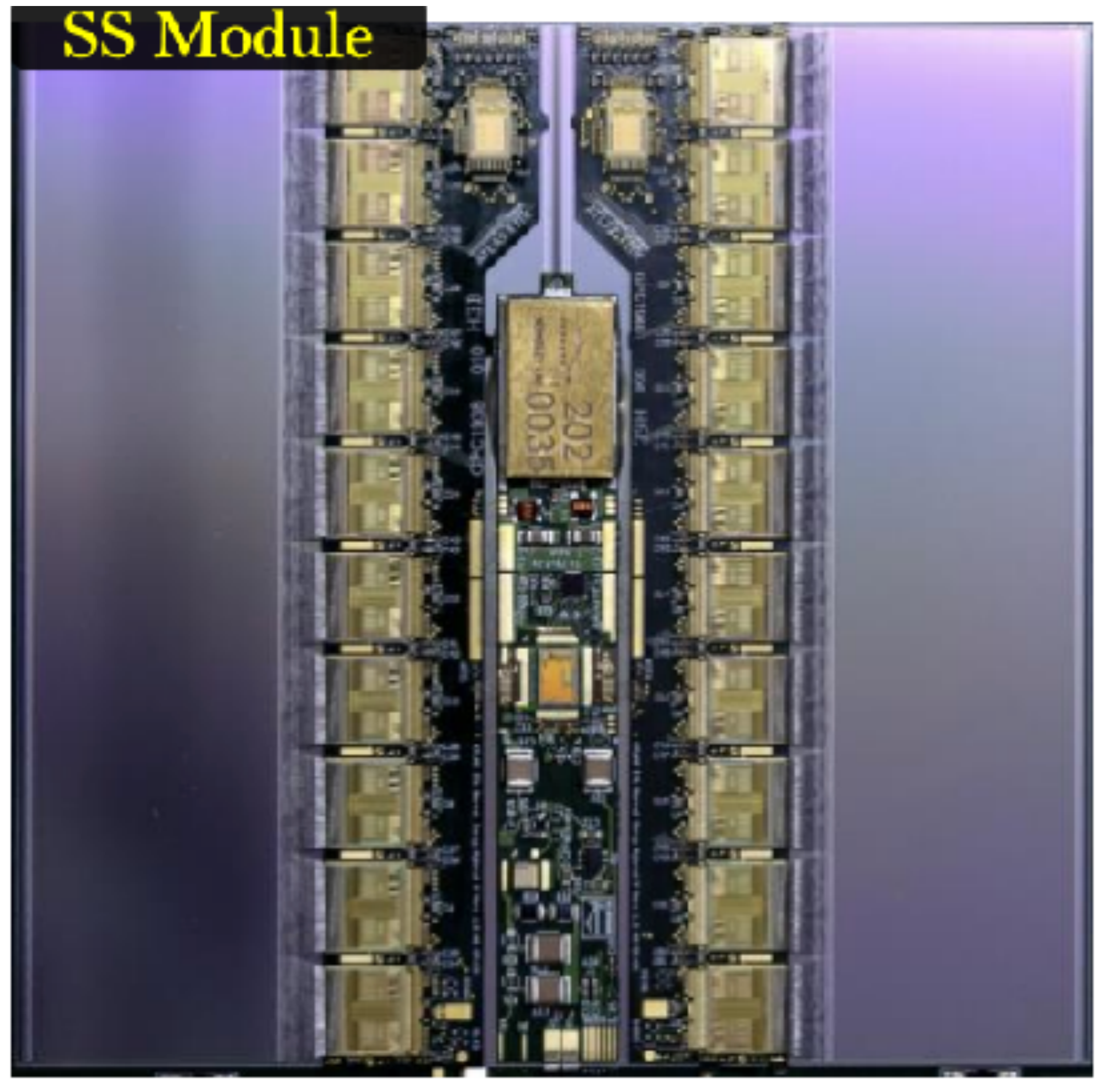
  - CERN and DESY for test beams among other

CEPC Team participation in HL-LHC upgrade

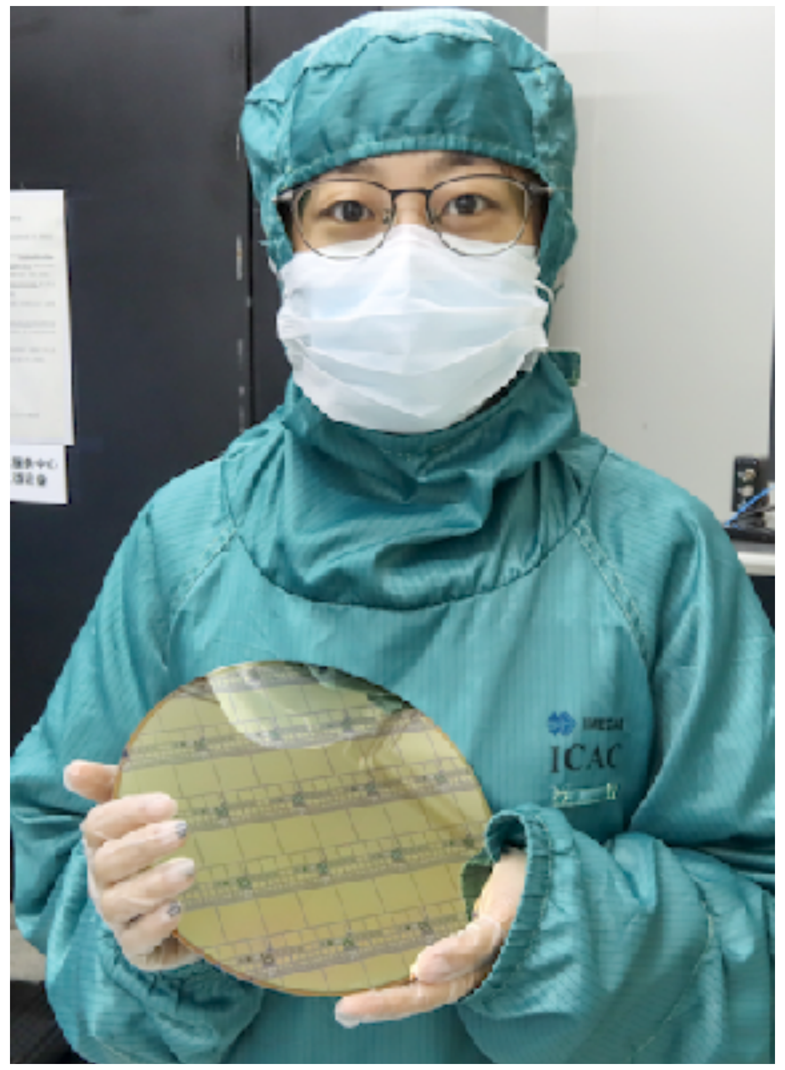
Example: Silicon-based detector upgrades

LHC upgrade Project	Contribution	IHEP member Leadership
ATLAS high granularity timing detector (HGTD)	~44% modules and ~34% sensors (~4000 modules, ~4000 sensors by Chinese foundry)	Project leader Coordinators in Sensors/ modules
LHCb UT tracker upgrade	System design, test and integration	Deputy project leader
ATLAS ITK strip detector upgrade	~10% modules in Barrel (1000 modules)	Coordinator in China/UK cluster
CMS HGcal	~ 20% modules (~100 m^2 area) silicon module	

ATLAS ITK strip upgrade
Module prototyping

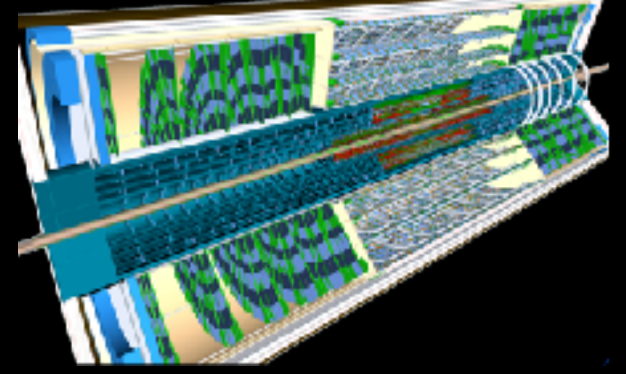


ATLAS HGTD
Sensor developed by IHEP



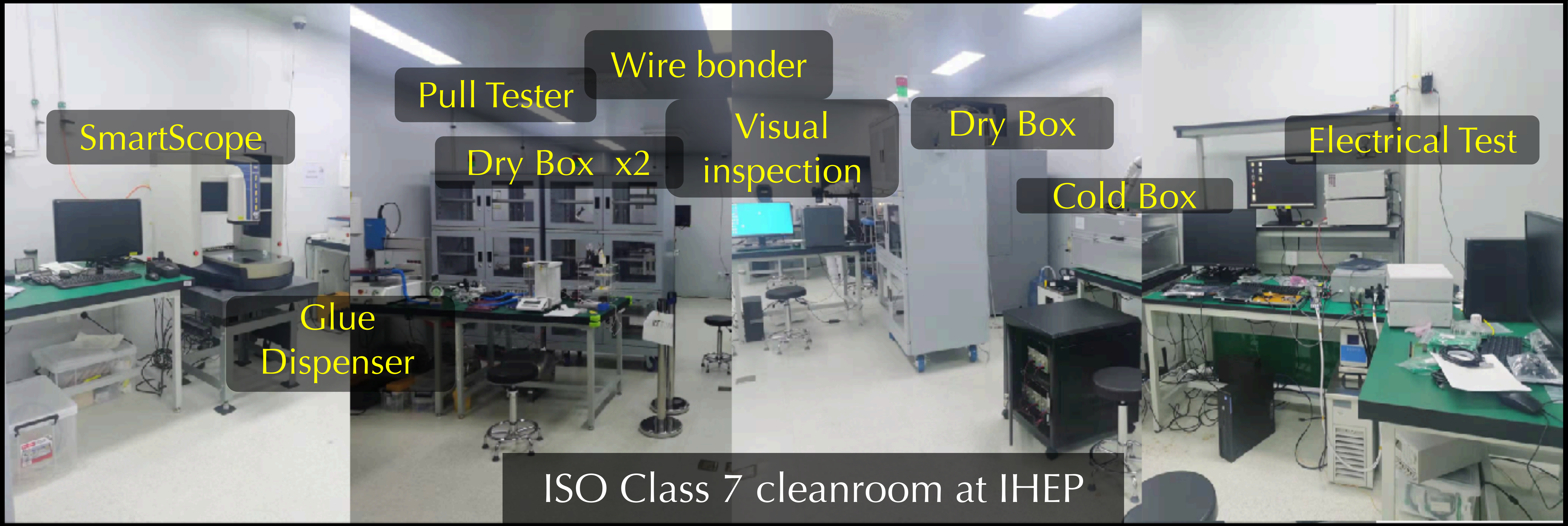
CMS HGcal
module prototyping

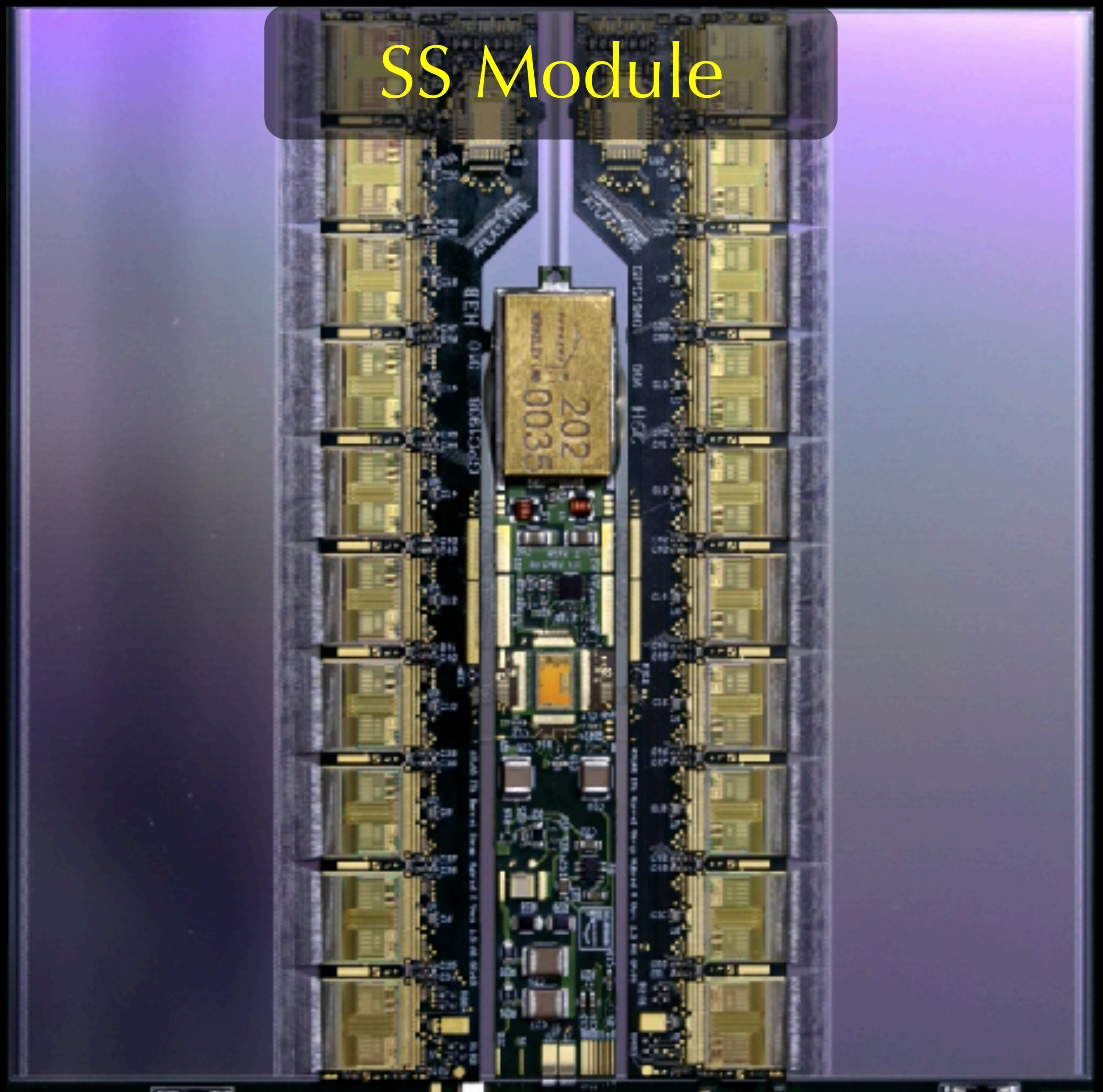
ATLAS Silicon Tracker (ITk Strips)



China (IHEP/THU) responsible for 10% barrel ATLAS ITk strip module production (>1000, 10 m²)

- Work done in collaboration with Rutherford Labs, UK — China/UK cluster responsible for 50% of barrel production — IHEP participating in the management team
  - Site has passed pre qualifications and a total of 15 pre-production modules have been produced
- Carried out irradiation study for readout ASICs and sensors
  - Possibly will use the proton beam at CSNS as irradiation site for quality assurance for ASICs and Sensors
- Contribute to the inner tracker system integration and test in the future
  - Two FTEs from IHEP based at RAL responsible for module production and stave loading

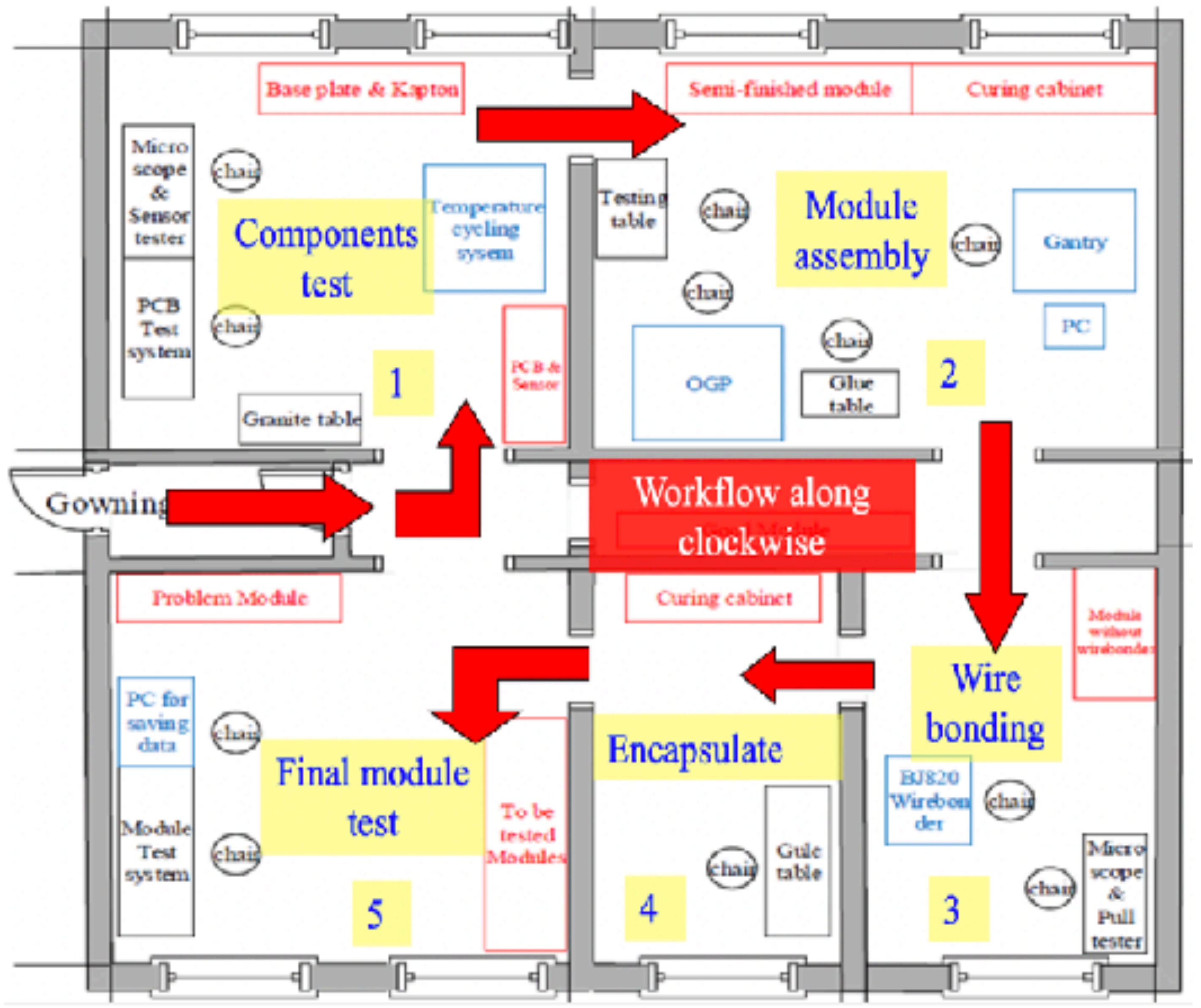


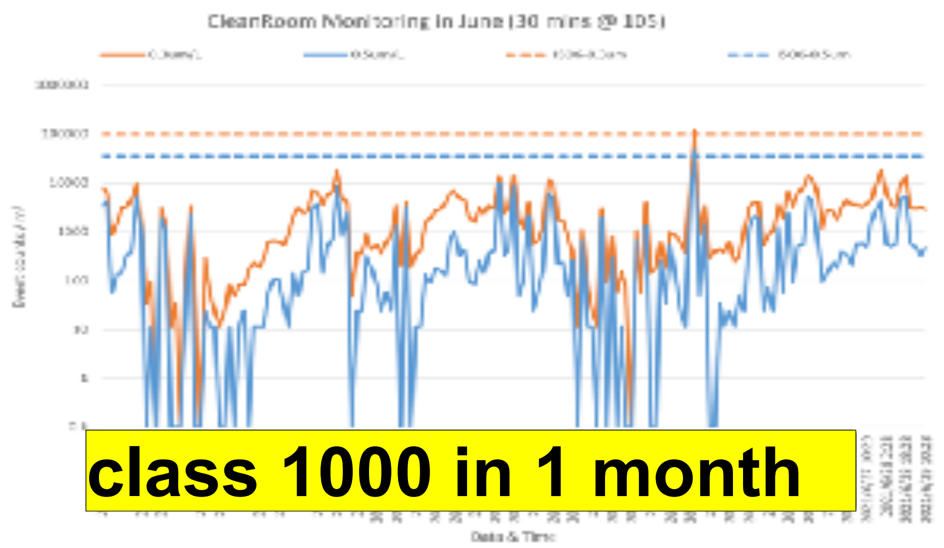


CMS High Granularity Calorimeter at IHEP

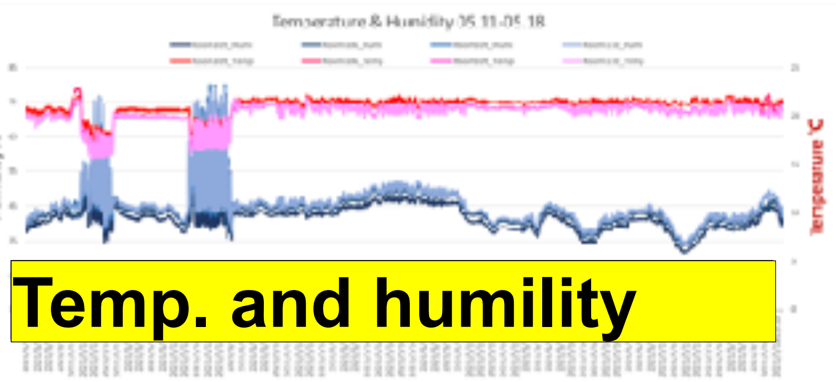
- Hosting a HGCal silicon Module Assemble Center at IHEP
  - Plan prod.: ~5000 modules, >100 m² silicon (on average of 6 MACs)
- Cleanroom, equipment, assemble procedures settled

Clean room

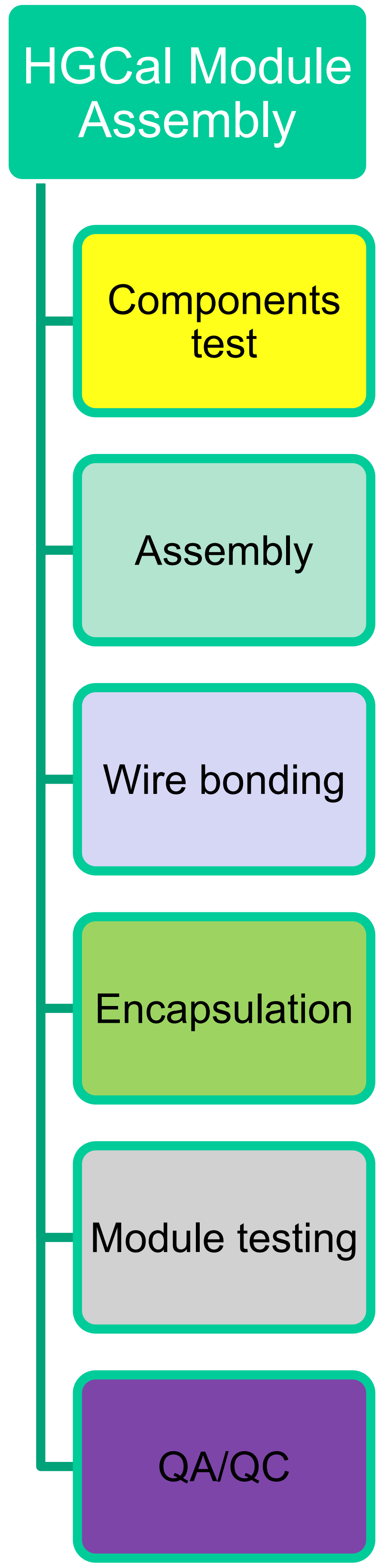


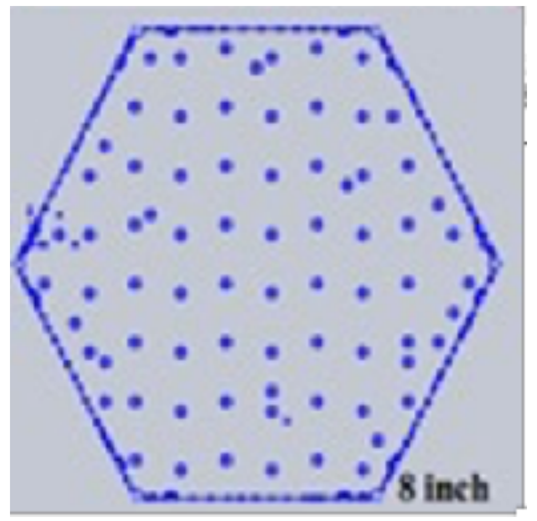


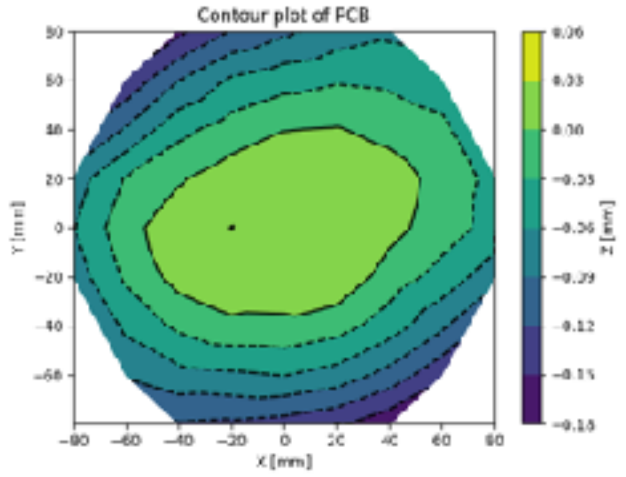
class 1000 in 1 month

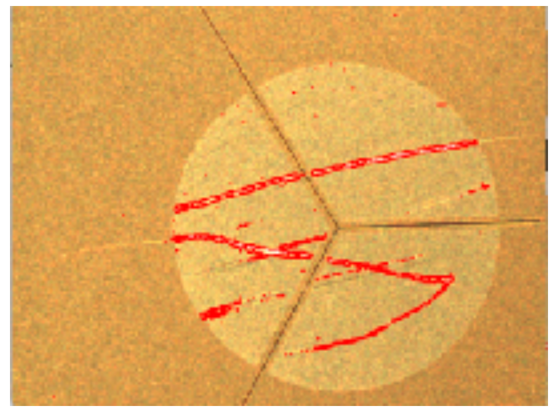


Temp. and humility









CMS High Granularity Calorimeter at IHEP

- Produced 7 modules (8 inch)
  - All have good noise level (pass lab tests)
  - 2 at CERN, tested using SPS beams
  - 4 at Fermilab for cassette tests
- Passed HGCal MAC Site qualification
  - Pre-production ~2023

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
COMPACT MUON SOLENOID COLLABORATION
URL : http://cms.cern

Dr. Karl Gill
CMS HGCAL Project Manager
Principal Applied Physicist
CERN - EP Department
CH - 1211 GENEVA 23
Switzerland

Tel. +41 75 411 4712
E-mail Karl.Aaron.Gill@cern.ch

December 15, 2021

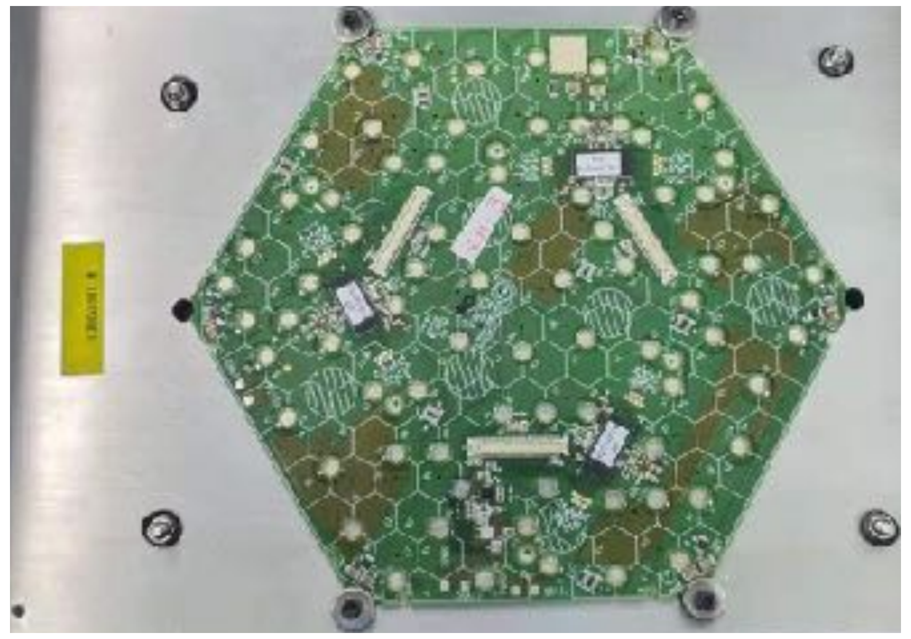
Subject: Certification of qualification the HGCAL Module Assembly Centre at IHEP, Beijing

To whom it may concern,

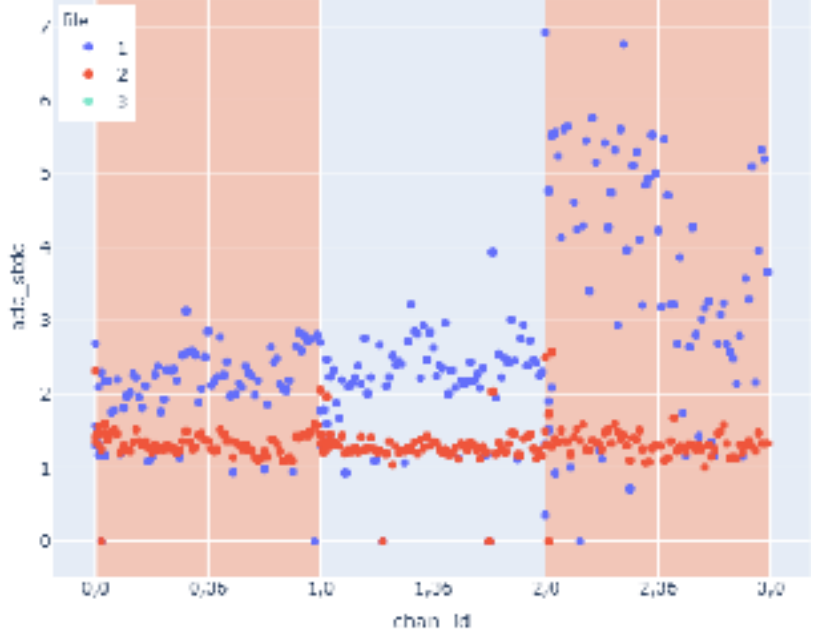
I am writing as Project Manager for the CMS endcap calorimeter upgrade project (HGCAL) to certify that the silicon module assembly center (MAC) at IHEP Beijing, led by Prof. Huaqiao Zhang, has been qualified for the HGCAL project as ready to move into the Pre-Series phase of construction.

HGCAL will replace several of the present CMS sub-detectors: the silicon/lead endcap pre-shower detector, the lead-tungstate crystal electromagnetic endcap calorimeter, and the plastic/brass endcap hadron calorimeter. HGCAL is a novel sampling calorimeter, based on a large-scale deployment of silicon modules (a grand total of approximately 26000 installed, plus 5% spares), positioned between dense layers of absorber. The silicon modules will be complemented with plastic scintillator tiles instrumented by silicon photomultipliers (SiPMs) in regions of the detector where particles arrive with lower intensity.

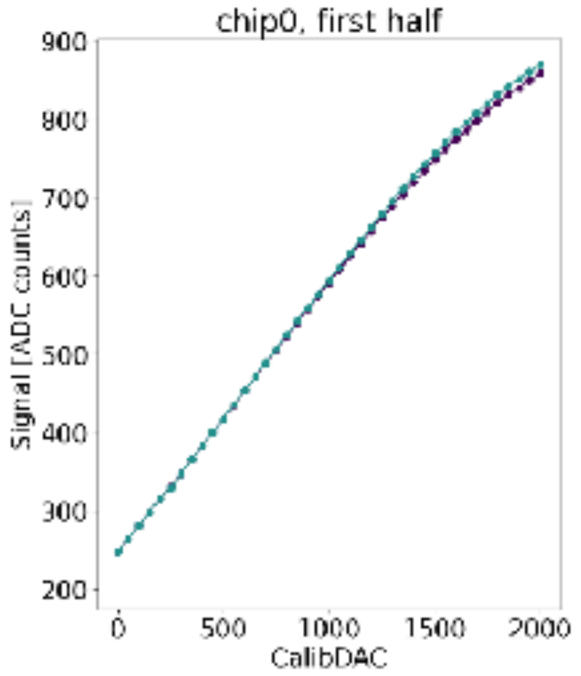
The qualification of the IHEP Beijing MAC has been completed on time to meet the corresponding project milestone. The MAC is set up in a Class 1000 clean room that is dedicated to this facility and all of the equipment for mass production of silicon modules for HGCAL has been installed in the clean room and commissioned. This equipment includes a gantry machine for automated module assembly, a wire-bonding machine, an optical inspection and coordination measurement machine, and a silicon module test-stand. The IHEP Beijing team has been trained in how to use the MAC equipment, and they have practiced extensively on dummy module components before moving onto using live components.



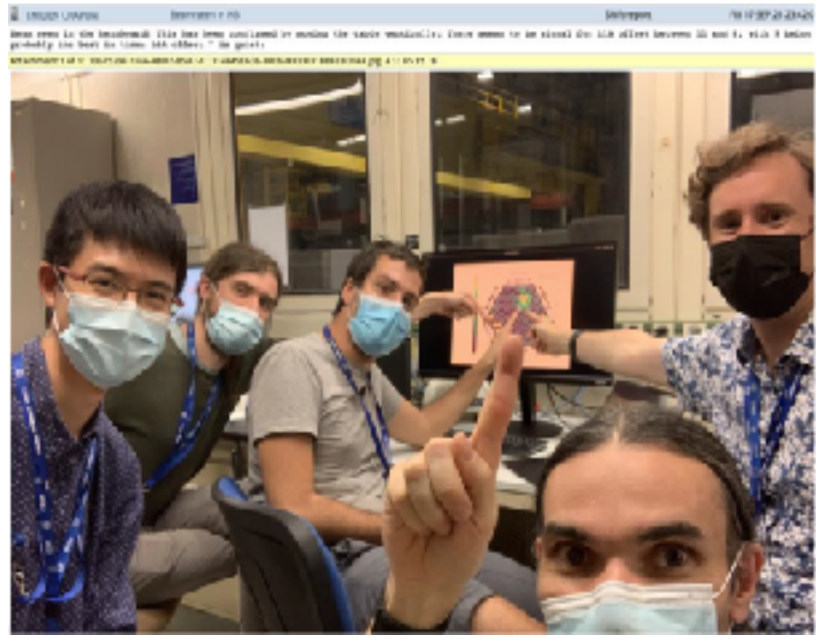
First 8 inch module at IHEP

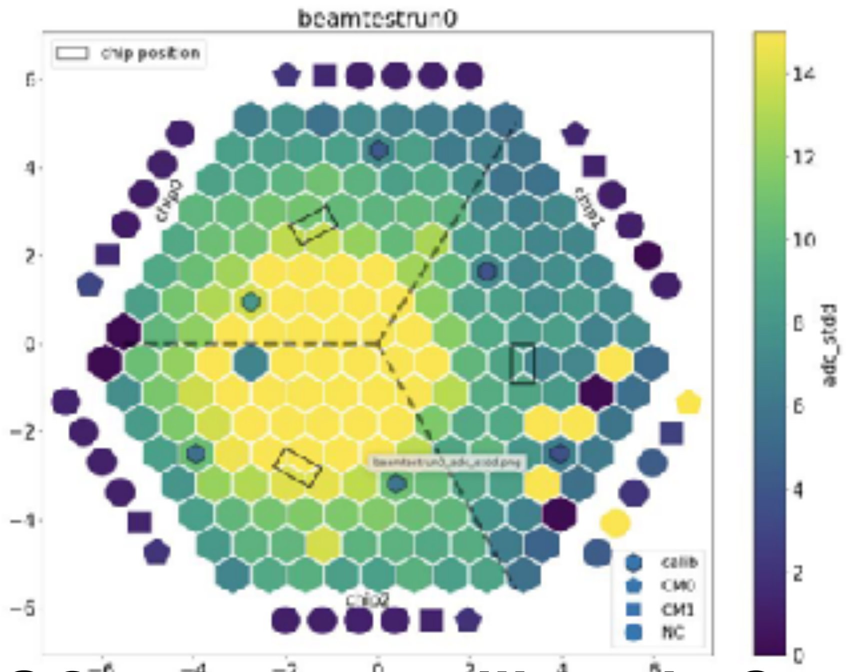


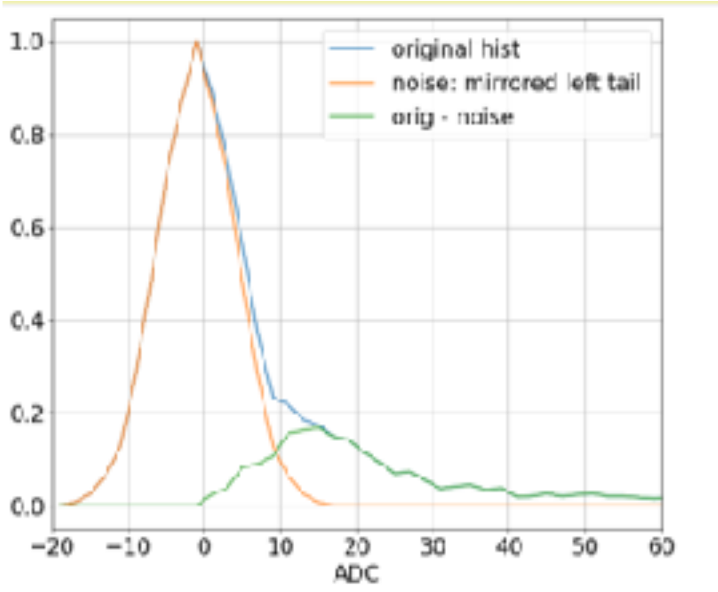
Noise before/aftter assembly



Charge injection





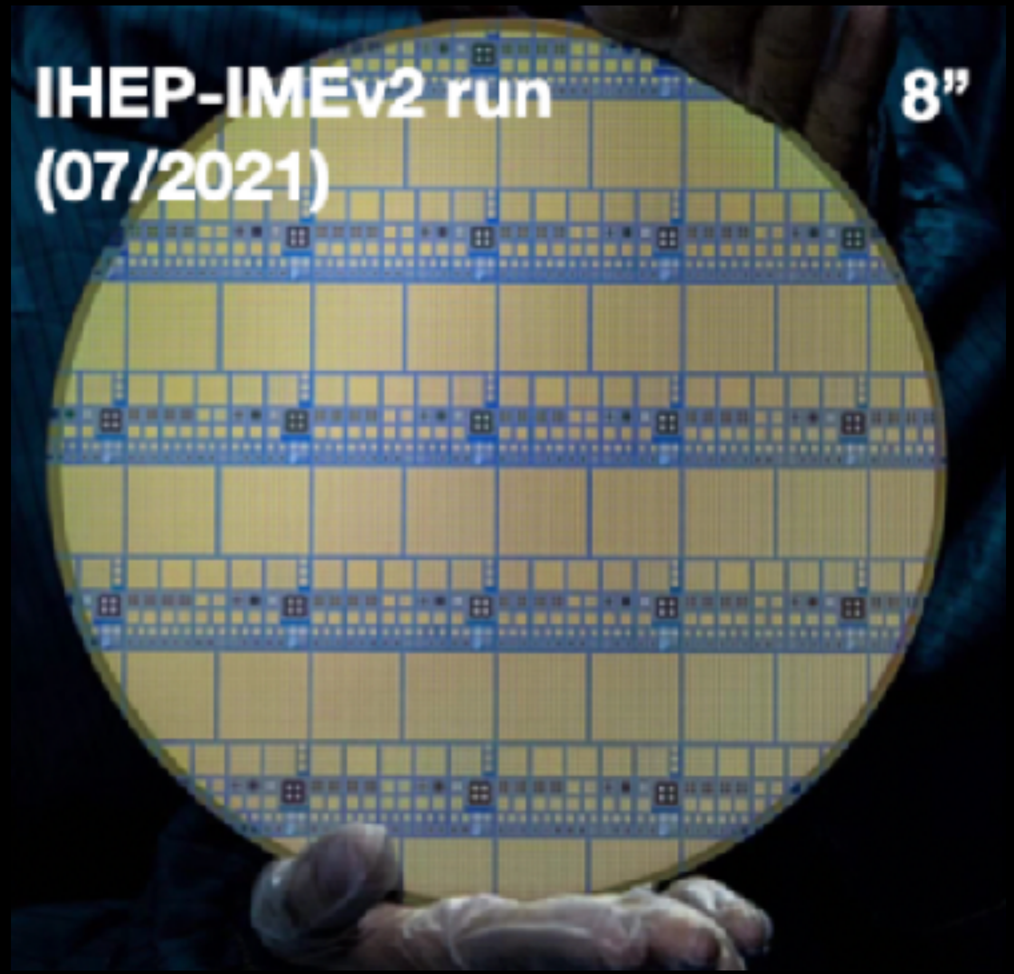


IHEP LD Module with HGCROCv2, 300mm silicon in September 2021 beam test

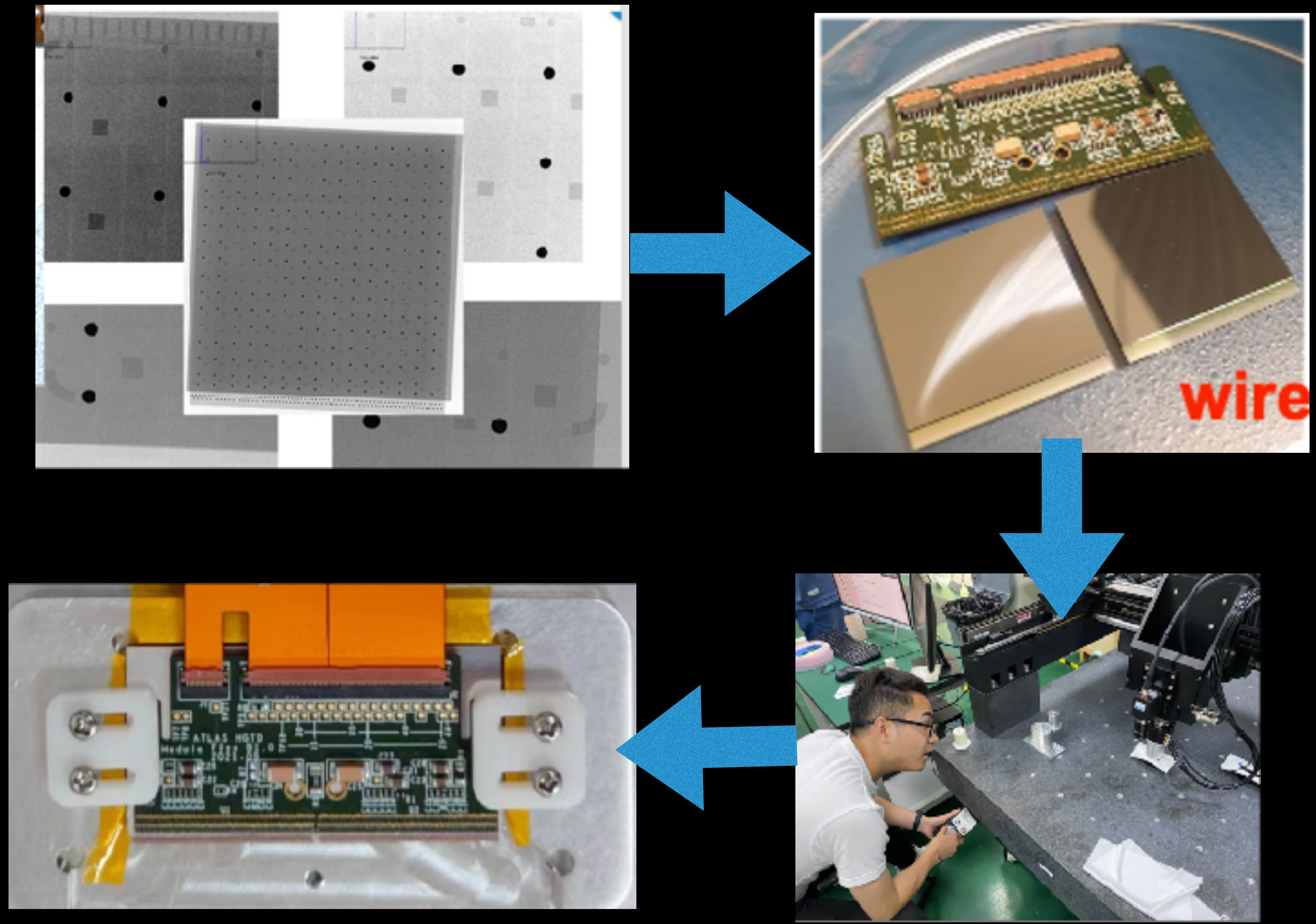
ATLAS Timing Detector (HGTD)

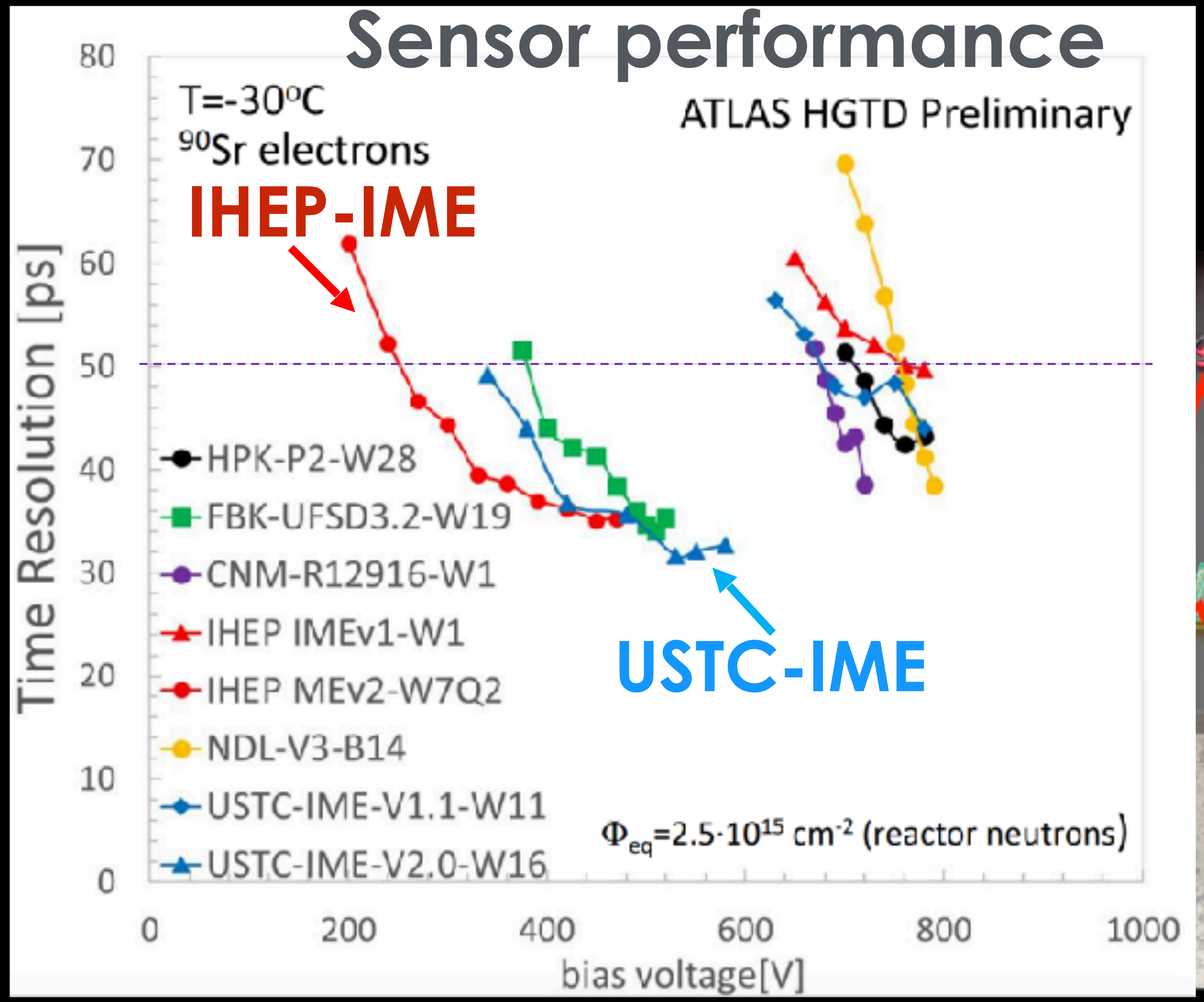
China is taking a leadership role in HGTD (IHEP, USTC, Nanjing, Shandong, Shanghai)

- 34% of LGAD sensors (IHEP-IME, USTC-IME)
- 100% module flex electronics
- 50% module hybridization
- 44% module assembly
- 50% module supports
- 33% flex cables
- 67% design/100% production peripheral electronics
- Low voltages power supplies

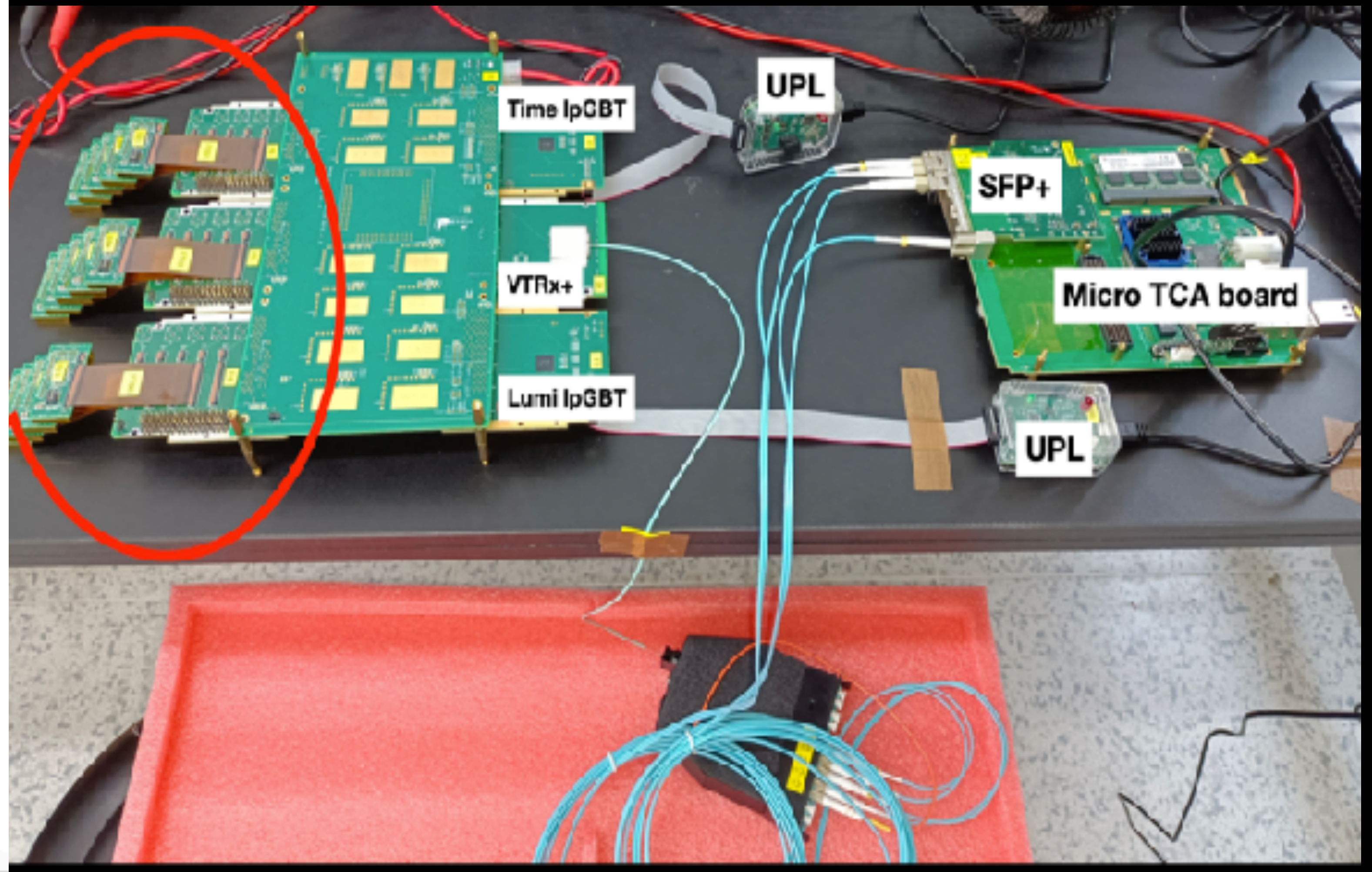


- Project leader
- HGTD risk and schedule coordinator
- L2 Sensors coordinator
- L2 Module coordinator
- L3 Module flex coordinator
- L2 software coordinator
- L3 Peripheral electronics coordinator
- L3 High Voltage coordinator
- HGTD Speakers committee Chair





Peripheral electronics testing



CEPC International Detector R&D Review Committee (IDRC)

Committee proposed by CEPC IAC

Initial Charge and Goals

Evaluate International proposals for detector R&D relevant to the CEPC

Independent organ to evaluate the importance and suitability of worldwide detector R&D proposals for CEPC and produce short report with findings.

Reviews and endorses the Detector R&D proposals from the international community, such that international participants can apply for funds from their funding agencies and make effective and sustained contributions

Later, this committee is expected to evolve to evaluate the Letters of Intent for the CEPC Detectors submitted by the proponents of the International Detector Collaborations

CEPC International Detector R&D Review Committee (IDRC)

Goals for original meeting, provided to committee:

Provide an overview of the on-going detector R&D linked to the CEPC

Solicit input regarding the directions one should take in the near future

Suggest: Short report with the opinion of the committee regarding the current R&D program and future directions

Outcome of original review: Report with main recommendation to produce:

1) Document with a coherent list of the on-going of R&D activities, such that the presence of gaps and overlaps can be determined and addressed — DONE
2) Updated CDR document within 12-18 months
3) A conservative full-detector concept, potentially deliverable on an aggressive time scale, should be specified by the CEPC Management and adopted as the baseline for the CDR update

We, the CEPC management and IAC, didn't agree with the production of another "CDR" document in this timescale, due to the large amount of resources required. Instead, the decision was to move forward with the R&D for a 4th detector

Key previous steps:

- IDRC expressed concern that the schedule presented to them (with detector TDRs in 2023) was not realistic and prompted the problematic recommendations
- Follow-up IDRC meeting in 2020, planned for Marseille, was cancelled due to COVID
- A document with the summary of on-going R&D activities was produced and sent to the IDRC chair, as requested by the IDRC

- **Since the last IAC meeting in 2021:**
  - An updated version of the document with the summary of R&D activities was produced and sent to the IDRC
  - Two attempts to organize a meeting in 2022 were made by the IDRC chair, but unfortunately it was not possible to secure the presence of enough committee members
  - Given the current international situation, the chair has suggested a modification to the committee charge that we would like to discuss

Document with summary of on-going R&D activities updated in early 2022

Contents

Suggestions and next steps:

Discussion with IDRC chair → suggestions on how to proceed

- Concern that, given the current international situation, effectively there are no proposals from international community specifically to work at CEPC and it is difficult to imagine such proposals will materialize in the near future, therefore, the charge to this committee is not actionable
  - Observation: This might not be exactly correct since most detector R&D work for FCC-ee directly applies to CEPC. It is possible that, for certain communities, getting the support of this International Committee would be advantageous — this seems to be the situation with our Italian colleagues

- Suggest to change the charge of the committee to become more technical covering a technical evaluation of all detector R&D being done towards the CEPC — hence, closer to the International Accelerator Review Committee charge

- Re-evaluate the committee membership in light of this new, more technical, charge, and in particular, investigate the availability of the current committee members to still serve in such committee

Given that this committee was created following an IAC recommendation, we would like to discuss these possible changes with you

Suggestions for a new charge:

- The IDRC will advise on matters related to the CEPC detector R&D, including the Machine-Detector Interface, and the compatibility of the detector technologies proposed with the high-luminosity operation of the accelerator at the Z, WW, ZH, and tt-bar production threshold energies.
- The IDRC will evaluate international proposals for detector R&D relevant to the CEPC, and produce a short report with its findings.
- The IDRC reports to the Project Director.
- Later, this committee is expected to evolve into an experimental committee (similar to LHCC) to evaluate the Letters of Intent for the CEPC Detectors submitted by the proponents of the International Detector Collaborations
- The committee should have external members including 2-3 IAC members.
- The committee should meet at least once a year and a report should be provided at the IAC meeting.

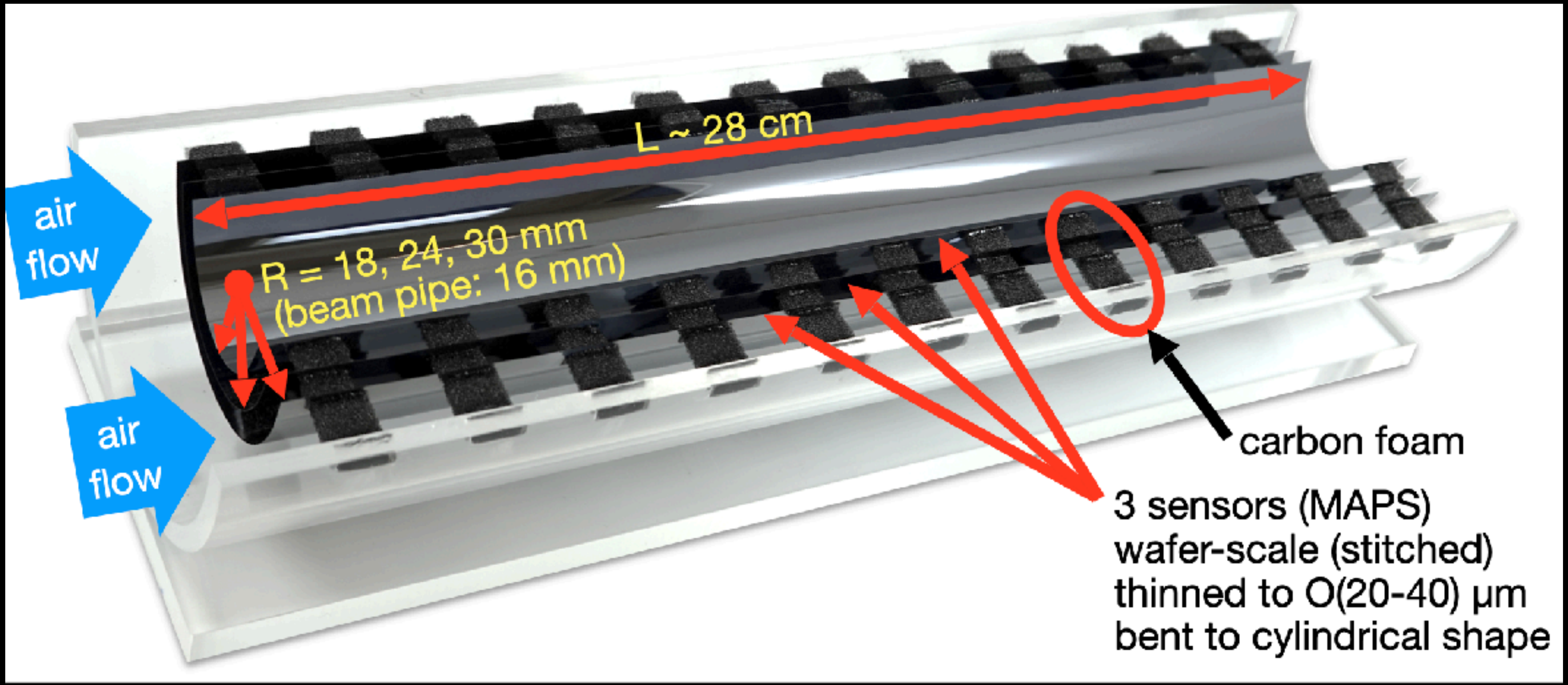
Current committee membership:

Dave Newbold, UK, RAL (chair)
Jim Brau, USA, Oregon
Brian Foster, UK, Oxford
Liang Han, China, USTC
Andreas Schopper, CERN, CERN
Steinar Stapnes, CERN, CERN
Hitoshi Yamamoto, Japan, Tohoku
Valter Bonvicini, Italy, Trieste
Ariella Cattai, CERN, CERN
Cristinel Diaconu, France, Marseille
Abe Seiden, USA, UCSC
Laurent Serin, France, LAL
Roberto Tenchini, Italy, INFN
Ivan Villa Alvarez, Spain, Santader
Harvey Newman, USA, Caltech
Marcel Stanitzki, Germany, DESY

Key R&D Issues Moving Forward

Some key R&D topics moving forward

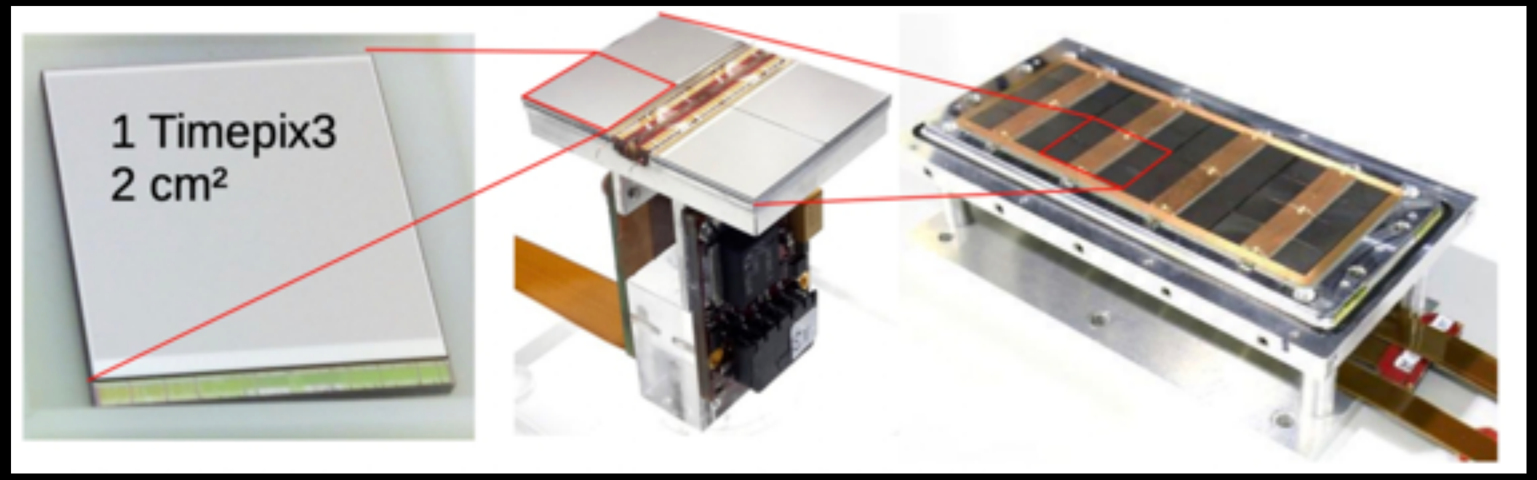
- **Machine Detector Interface**
- **Luminosity meter (LumiCal)** - continue integration in beampipe development
- **Silicon Vertex**
  - Continue to explore low-material budget solutions, cooling integration and performance optimization
  - Major issue: Sensor technology and availability in China
  - Curved silicon, as in ALICE ITS3, should be considered but it has lots of challenges that would need to be solved in a tight timescale



Some key R&D topics moving forward

Trade off: Transparency <—> reliability/resolution

- Tracker
  - Time Projection Chamber
    - Evaluate the Pixel TPC possibility



  - Drift Chamber
    - Demonstrate it can cope with the high increased rates at the Z pole? Enough resolution?
    - Demonstrate PID capabilities with cluster counting
    - Continue mechanical design and stability analysis
  - Full silicon tracker → still need manpower increase to exploit this option
    - Continue Silicon Tracker prototype collaboration
    - Need to add detector for particle identification — drift chamber is an option
    - Consider adding timing Silicon layer
      - AC-Coupled Resistive Silicon Detector (RSD)
      - Trench-isolated LGAD (TI-LGAD)

Some key R&D topics moving forward

- Calorimetry
  - Cost versus physics performance
  - ECAL
    - Finalize evaluation of the crystal calorimeter option
    - Cooling of PFA calorimeter versus performance
  - HCAL
    - Study glass hadronic calorimeter has an alternative to Scintillator option
    - Cooling and mechanics studies
  - Dual Readout
    - Demonstration using full size prototype

Some key R&D topics moving forward

- Calorimetry
  - Cost versus physics performance
  - ECAL
    - Finalize evaluation of the crystal calorimeter option
    - Cooling of PFA calorimeter versus performance
  - HCAL
    - Finalize evaluation of Scintillator Steel option
    - Study glass hadronic calorimeter has an alternative
    - Cooling and mechanics studies
  - Dual Readout
    - Demonstration using full size prototype

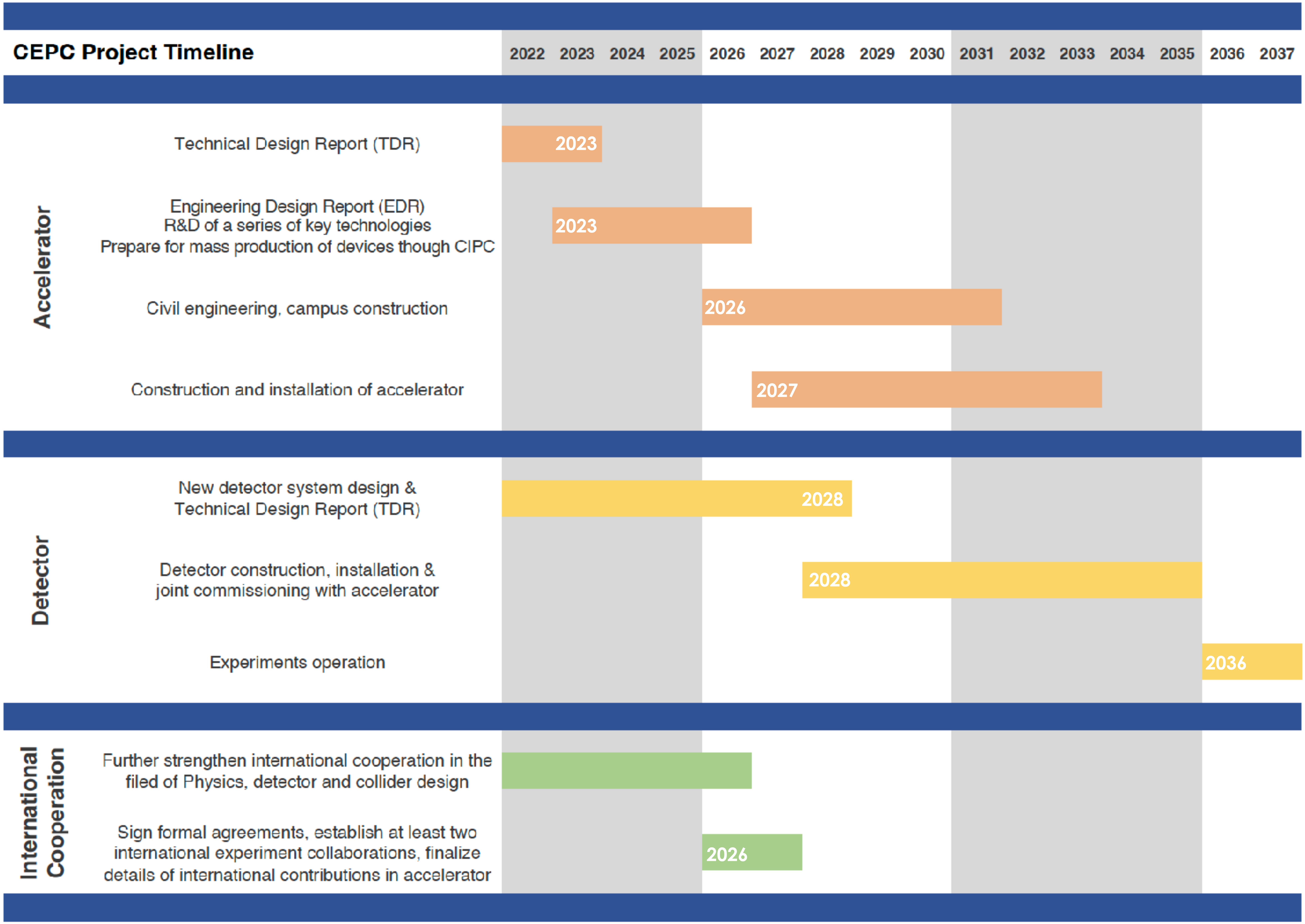
- Muon System optimization
  - Optimize number of layers
  - Optimize design for industrialization and cost

Optimization of detectors

Not an easy task without definite detectors/collaborations target

- Use a mixture of fast simulation and full simulation
- Need to consider engineering aspects
- Need to consider costing issues
  - balance between performance and eventual total detector cost

CEPC Project timeline



Final remarks

New ideas continue to be deployed while we also develop new tools

International collaboration has continue albeit the difficulties

Key detector technologies R&D continues and many have been put to prototyping

Several CEPC R&D detector projects reaching a successful conclusion
others are starting

International collaboration continues to be a main goal of the CEPC

Final detectors are to be defined by International Collaborations and they are likely to incorporate a mixture of the technologies discussed here

Still very important to expand international collaboration

Explore the CEPC and FCC-ee R&D synergies

The End

Extra Slides

Sub-detectors and Key techs

Table 3.2: All sub-detectors and the key technologies

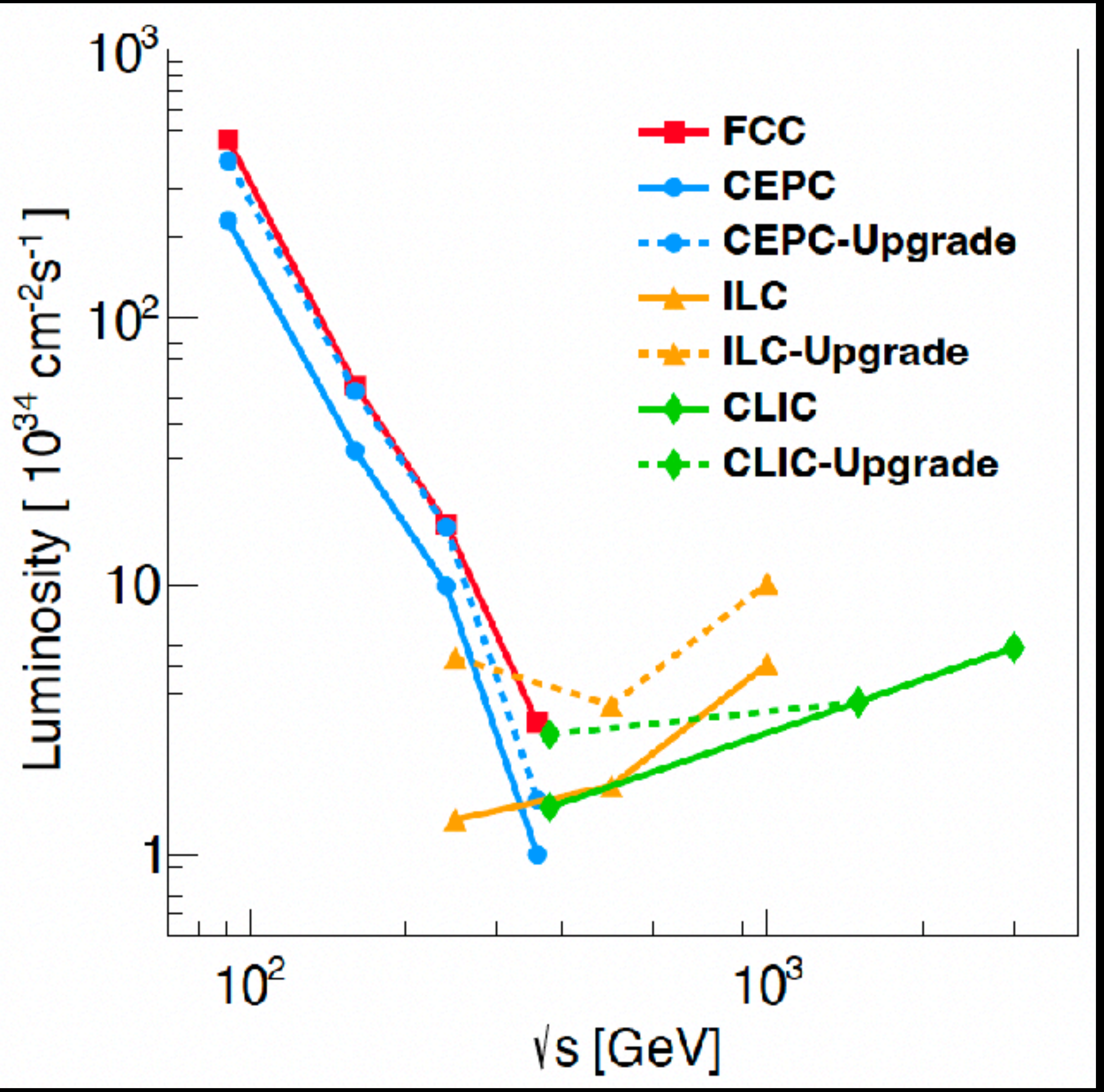
Sub-detector	Key technology	Key Specifications
Silicon vertex detector	Spatial resolution and materials	$\sigma_{r\phi} \sim 3\ \mu\text{m}$, $X/X_0 < 0.15\%$ (per layer)
Silicon tracker	Large-area silicon detector	$\sigma(\frac{1}{p_T}) \sim 2 \times 10^{-5} \oplus \frac{1\times10^{-3}}{p\times\sin^{3/2}\theta}(\text{GeV}^{-1})$
TPC/Drift Chamber	Precise dE/dx (dN/dx) measurement	Relative uncertainty 2%
Time of Flight detector	Large-area silicon timing detector	$\sigma(t) \sim 30$ ps
Electromagnetic Calorimeter	High granularity 4D crystal calorimeter	EM energy resolution $\sim 3\%/\sqrt{E(\text{GeV})}$ Granularity $\sim 2 \times 2 \times 2\ \text{cm}^3$
Magnet system	Ultra-thin High temperature Superconducting magnet	Magnet field $2-3$ T Material budget $< 1.5X_0$ Thickness < 150 mm
Hadron calorimeter	Scintillating glass Hadron calorimeter	Support PFA jet reconstruction Single hadron $\sigma_E^{had} \sim 40\%/\sqrt{E(\text{GeV})}$ Jet $\sigma_E^{jet} \sim 30\%/\sqrt{E(\text{GeV})}$

CEPC TDR Parameters (upgrade version)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

Higher SR power of 50MW: Luminosity increase ~66%.

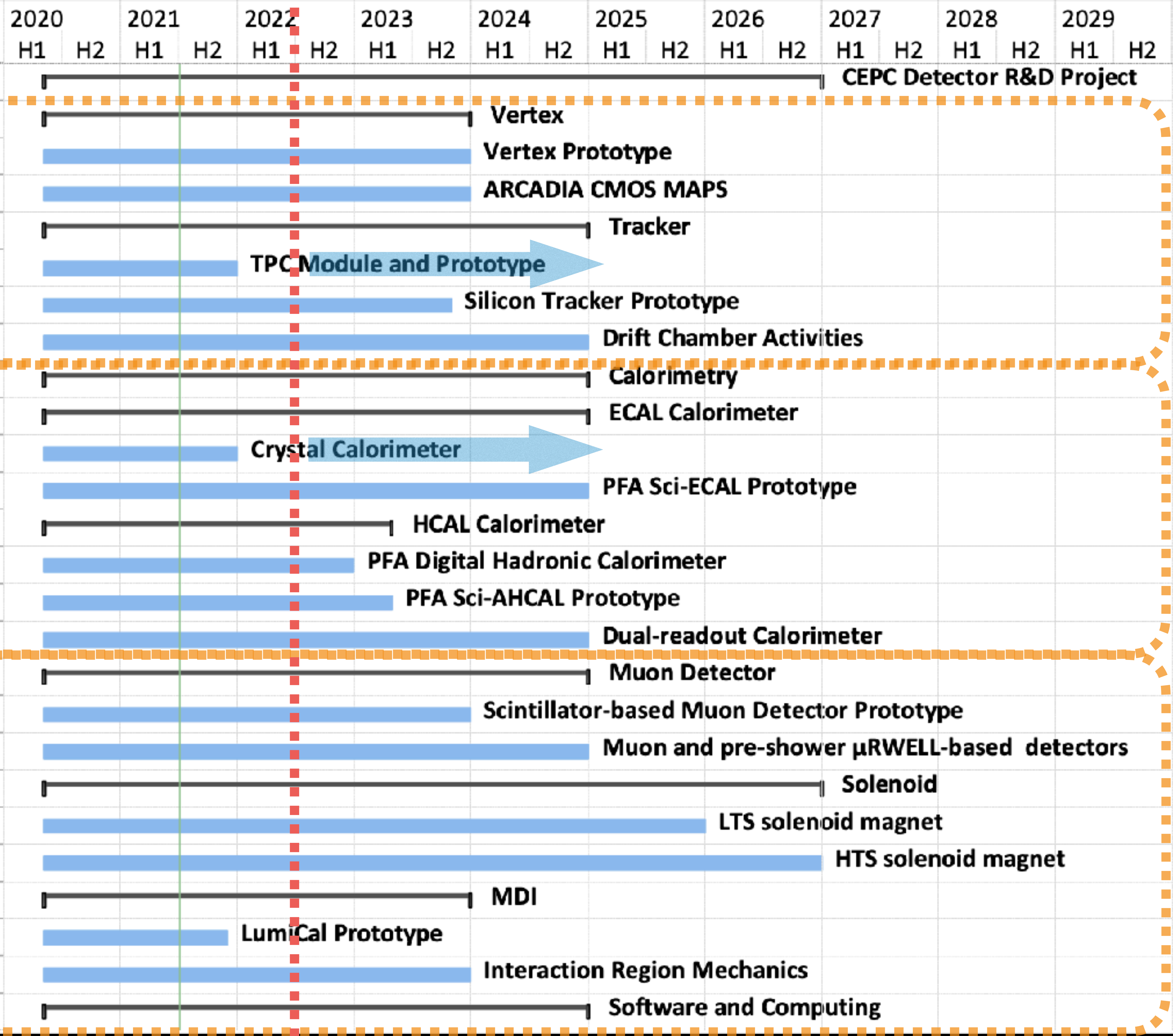
CEPC accelerator white paper for Snowmass21, arXiv:2203.09451



Detector

Projects overview: R&D schedule

PBS	Task Name	Start	Finish	Duration
	CEPC Detector R&D Project	**2020/5/7**	**2026/12/31**	**1736 days**
1	**Vertex**	**2020/5/7**	**2023/12/29**	**952 days**
1.1	Vertex Prototype	2020/5/7	2023/12/29	952 days
1.2	ARCADIA CMOS MAPS	2020/5/7	2023/12/29	952 days
2	**Tracker**	**2020/5/7**	**2024/12/31**	**1214 days**
2.1	**TPC Module and Prototype**	**2020/5/7**	**2021/12/31**	**432 days**
2.2	**Silicon Tracker Prototype**	**2020/5/7**	**2023/10/31**	**909 days**
2.3	**Drift Chamber Activities**	**2020/5/7**	**2024/12/31**	**1214 days**
3	**Calorimetry**	**2020/5/7**	**2024/12/31**	**1214 days**
3.1	**ECAL Calorimeter**	**2020/5/7**	**2024/12/31**	**1214 days**
3.1.1	Crystal Calorimeter	2020/5/7	2021/12/31	432 days
3.1.2	PFA Sci-ECAL Prototype	2020/5/7	2024/12/31	1214 days
3.2	**HCAL Calorimeter**	**2020/5/7**	**2023/4/28**	**777 days**
3.2.1	PFA Digital Hadronic Calorimeter	2020/5/7	2022/12/30	692 days
3.2.2	PFA Sci-AHCAL Prototype	2020/5/7	2023/4/28	777 days
3.3	**Dual-readout Calorimeter**	**2020/5/7**	**2024/12/31**	**1214 days**
4	**Muon Detector**	**2020/5/7**	**2024/12/31**	**1214 days**
4.1	Scintillator-based Muon Detector Prototype	2020/5/7	2023/12/29	952 days
4.2	Muon and pre-shower µRWELL-based detectc	2020/5/7	2024/12/31	1214 days
5	**Solenoid**	**2020/5/7**	**2026/12/31**	**1736 days**
5.1	LTS solenoid magnet	2020/5/7	2025/12/31	1475 days
5.2	HTS solenoid magnet	2020/5/7	2026/12/31	1736 days
6	**MDI**	**2020/5/7**	**2023/12/29**	**952 days**
6.1	LumiCal Prototype	2020/5/7	2021/12/1	410 days
6.2	Interaction Region Mechanics	2020/5/7	2023/12/29	952 days
8	**Software and Computing**	**2020/5/7**	**2024/12/31**	**1214 days**



Projects overview: FTE

PBS	Task Name	Team
	CEPC Detector R&D Project	
1	Vertex	
1.1	Vertex Prototype	China+ international collaborators
1.2	ARCADIA CMOS MAPS	INFN
2	Tracker	
2.1	TPC Module and Prototype	IHEP, Tsinghua
2.2	Silicon Tracker Prototype	China, UK, INFN
2.3	Drift Chamber Activities	INFN, Novosibirsk
3	Calorimetry	
3.1	ECAL Calorimeter	
3.1.1	Crystal Calorimeter	IHEP, USA, INFN
3.1.2	PFA Sci-ECAL Prototype	USTC, IHEP
3.2	HCAL Calorimeter	
3.2.1	PFA Digital Hadronic Calorimeter	SJTU, IPNL, Weizmann, IIT, USTC
3.2.2	PFA Sci-AHCAL Prototype	USTC, IHEP, SJTU
3.3	Dual-readout Calorimeter	INFN, Sussex, Zagreb, South Korea
4	Muon Detector	
4.1	Scintillator-based Muon Detector	Fudan, SJTU
4.2	Muon and pre-shower µRWELL-	INFN, LNF
5	Solenoid	
5.1	LTS solenoid magnet	IHEP+Industry
5.2	HTS solenoid magnet	IHEP+Industry
6	MDI	
6.1	LumiCal Prototype	AC, IHEP, Vinca
6.2	Interaction Region Mechanics	IHEP
8	Software and Computing	IHEP, SDU, CERN, INFN