TDR
Introduction Chapter

Tuesday CEPC TDR Meeting
May 27, 2025

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Outline

- Keeping track of modifications
- Common structure for chapters
- Format issues
  - Tables
  - Significant digits/figures
  - Figure style and formatting
    - Comparison with CDR
- Symbols consistency and glossary
- Other observations
  - New chapters (16, 17 and 18?)
- Personal evaluation of current situation
  - Magnet Chapter
    - Detailed comments based on May 14 version

Keeping track of modifications

- Need to receive feedback on WeChat
  - Most people typically do not recognize the requests being made and don’t provide feedback if they are working on it

- **Shared document from Zhaoru on WeChat**
  - https://docs.qq.com/sheet/DQkxVTmhpRkdhQUJq?tab=000001&_t=1748241620462&nlc=1
  - Please feel your input now, and keep it updated as we move along
  - Information will be added by myself as well to give feedback on the parts that have been processed
    - Will indicate timeline for reading next chapters

- Evaluating how to keep comments and feedback stored
  - IHEPbox, IHEPdocs

Summary of status

As evaluated by the chapter editors

Chapter	Overall Complete (%)	Chapter structure	Tables		Figures	
			Unified format	Significant digits 有效数字	Change to pdf format	Enlarge the font size in figure
Executive summary						
1 Introduction						
2 Concept of CEPC Reference Detector						
3 MDI and Luminosity	90%	100%				
4 Vertex Detector	90%	100%	90%	95%	50%	70%
5 Silicon Trackers	100%	100%				
6 Pixelated Time Projection Chamber						
7 Electromagnetic calorimeter	95%	100%	95%	95%	50%	95%
8 Hadronic calorimeter	90%	100%	90%	90%	50%	80%
9 Muon Detector						
10 Detector magnet system	100%					
11 Readout Electronics	100%	100%	90%	90%	50%	80%
12 Trigger and Data Acquisition						
13 Offline software and computing	100%	100%	100%	100%	90%	90%
14 Mechanics and integration	100%					
15 Detector and physics performance						
16 Timeline and Future Plans						
17 Detector Costing						

Chapter Structure

Chapter X:				
X.	**1**	**Overview**		What are we going to build? Design, expected performance ("requirements")
X.	**2**	**Detailed Design**		
X.	**2.**	**1**	**Detailed design**	
X.	**2.**	**2**	**Challenges and critical R&D**	
X.	**3**	**Key Technologies to address challenges**		
X.	**4**	**R&D and prototypes**		
X.	**5**	**Simulation and Performance**		
X.	**6**	**Alternative Solutions**		Can be either backup or more advanced solution (demonstrate backup solutions are in hand and that their possible selection still meet the requirements)
X.	**7**	**Summary and Future Plan**		
X.	**8**	**(Cost table and justification)**		Eventually to be moved to a common chapter

- Sections should not have more than 4 numbered subsection levels x.y.z.w
- If using AI, editors need to read the AI output and finalize the text themselves. Cannot blindly use AI output. Also, AI usage should be minimized to correct english, NOT write sections from scratch
- Captions should be long and describe plot, not just a title

Outcome of IDRC Review - Recommendations

exploiting the CEPC's physics potential if the project is approved. While the presentations were excellent, the Ref-TDR requires further editing before it can be released publicly. The IDRC issues the following general recommendations:

- **Appoint an overall editor** to enhance the document's coherence, eliminate duplications, and ensure consistency across chapters.
- **Restructure chapters** to focus clearly on the baseline design for each detector component, including specific details showing that the required physics performance can be achieved. Clearly outline the R&D and prototyping still needed to demonstrate the feasibility of the selected baseline technologies.
- **Describe backup solutions** in detail, showing that they are available and could meet performance requirements if needed. The proposed use of HTS cables for the superconducting magnet, for instance, will require significant additional R&D.
- **Significantly shorten discussions** of alternative technologies.
- **Eliminate descriptions** of the basic working principles of well-established technologies.

TDR Index

Contents

Format Issues

Table styles

- Many different styles were present → should to make it as uniform as possible
  - Think about how to better display the information
  - Tables with many small numbers might not convey very useful information → sometimes it is better to split into multiple tables

Proposal that you should implement

Table 7.7: Deformation and stress in various directions of the composite frame under self-weight

Parameter	Values for T700	Reference Value/Range
Deformation (mm)	0.025 mm	Row 1, Cell 3
Fiber direction stress (MPa)	2.3/-5.6	1600/-900
Lateral stress (MPa)	0.12/-0.12	22/-120
In-plane shear stress (MPa)	0.18	20

But don’t do it blindly

Adjust text or format to make reasonable tables

Table 4.9: Estimates of power consumption of the Left-End Block (LEB). All values are for 27 °C temperature and 1.2 V power supply voltage.

Components	Clock Block	Data Aggregat	Data Encoder	Serializer	Slow&Power control	LEB Total
Power [mW]	36	120	80	32	80	348

x x

Table styles

Table 5.11: Estimation of the OTK stave material contributions

Estimation of OTK stave material contributions					
Functional unit	Component	Material	Thickness [µm]	X_0 [cm]	Radiation Length [% X_0]
Sensor Module	PCB metal layers	Cu		1.436	0.200
	PCB Insulating layers	Polyimide		28.41	0.070
	Sensor	Silicon	300	9.369	0.320
	Glue		100	44.37	0.023
	Other electronics				0.100
Structure	Carbon fiber facesheet	Carbon fiber	300	26.08	0.115
	Cooling tube wall	Titanium	200	3.560	0.169
	Cooling fluid	Water		35.76	0.105
	Graphite foam+Honeycomb	Allcomp+Carbon fiber	6000	186	0.322
	Carbon fiber facesheet	Carbon fiber	300	26.08	0.115
	Glue	Cyanate ester resin	200	44.37	0.045
Total					1.584

Text is too small

Split row titles into two rows:

- one row with name
- one row with unit

- Tables **cannot** be screenshots or images of tables
  - Likely this happens to tables that we didn't produce ourselves → make sure to reference all such cases
  - Still, please reproduce the tables properly into the document

Significant figures/digits (有效数字)

- Significant digits in a number represent the significance we know that value with.
  - Don’t use more digits than what represents our knowledge. Too many figures makes text and tables difficult to read and scientifically incorrect

Table 6.7: K/π separation powers for ML-based and traditional algorithms. The ML-based algorithm has a rough 10% improvement for momentum range from 5.0 to 20.0 GeV/c.

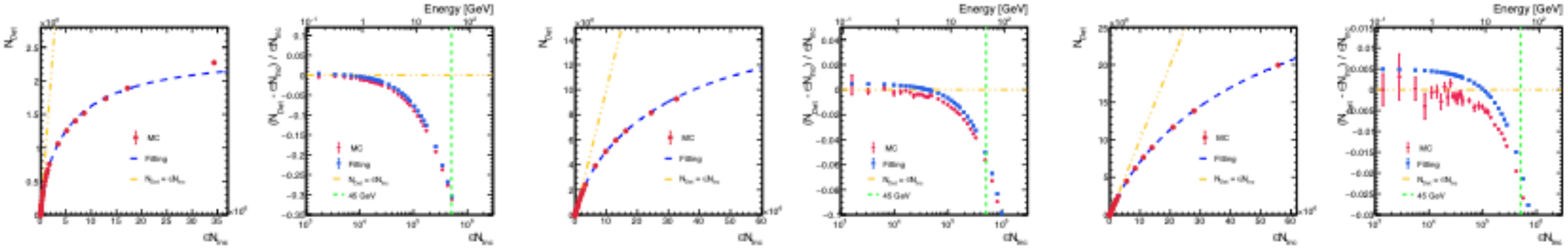
	Momentum (GeV/c)						
	5.0	7.5	10.0	12.5	15.0	17.5	20.0
ML alg.	4.605σ	4.688σ	4.471σ	4.198σ	3.844σ	3.523σ	3.200σ
Traditional alg.	4.259σ	4.332σ	4.125σ	3.891σ	3.590σ	3.346σ	2.955σ

Figures style, formatting and files

- **Images, plots and figures in the TDR need to be of the highest quality**
  - File format need to be scalable (pdf or eps) - not png and definitively not jpeg
    - Some high quality png and jpeg might work but it is not guaranteed because they are not scalable, it depends how their dimensions are changed and ultimately edited
    - **Change all figures to PDF as much as possible**
    - Some plots in jpeg format really look bad
- All text inside the figures needs to be readable.
  - If text is too small either:
    - Increase the text
    - Increase the size of the figure
    - Remove the figure (if the text cannot be read, probably the figure is not important)
- Figures should be large and easily understandable
- Don't make ridiculously small plots

Figures style, formatting and files

- These are ridiculously small plots



(a) (b) (c)

Figure 7.40: Simulated responses of SiPMs to BGO (1.5×1.5×40 cm^3) scintillation light: (a) HAMAMATSU S14160-3010PS, (b) NDL EQR10 11-3030D-S, and (c) NDL EQR06 11-3030D-S. In the figures, the red points represent the simulation results, the blue dashed line corresponds to the fitting functions [16].

Figures style, formatting and files

- A little larger but still unacceptable

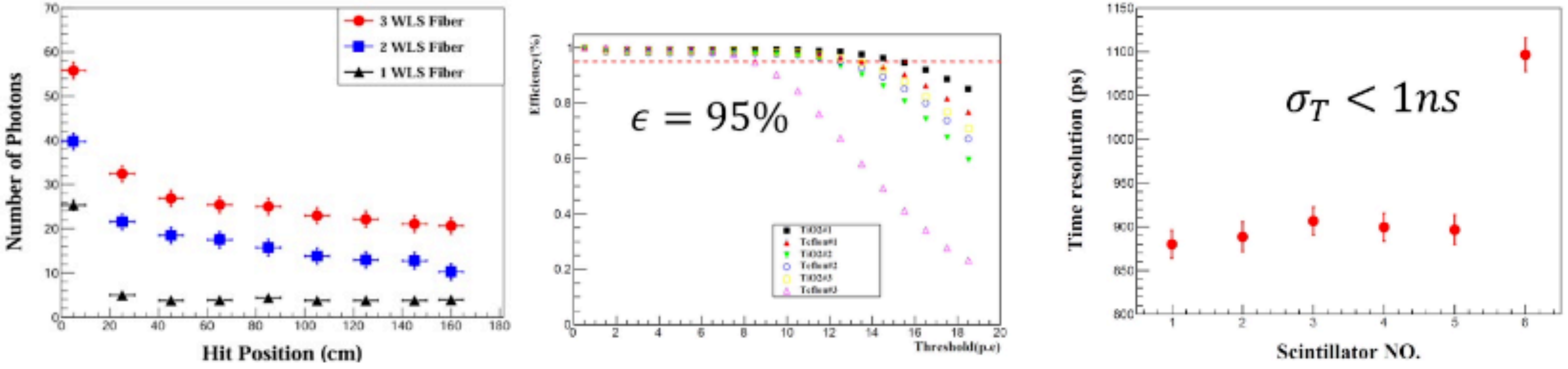
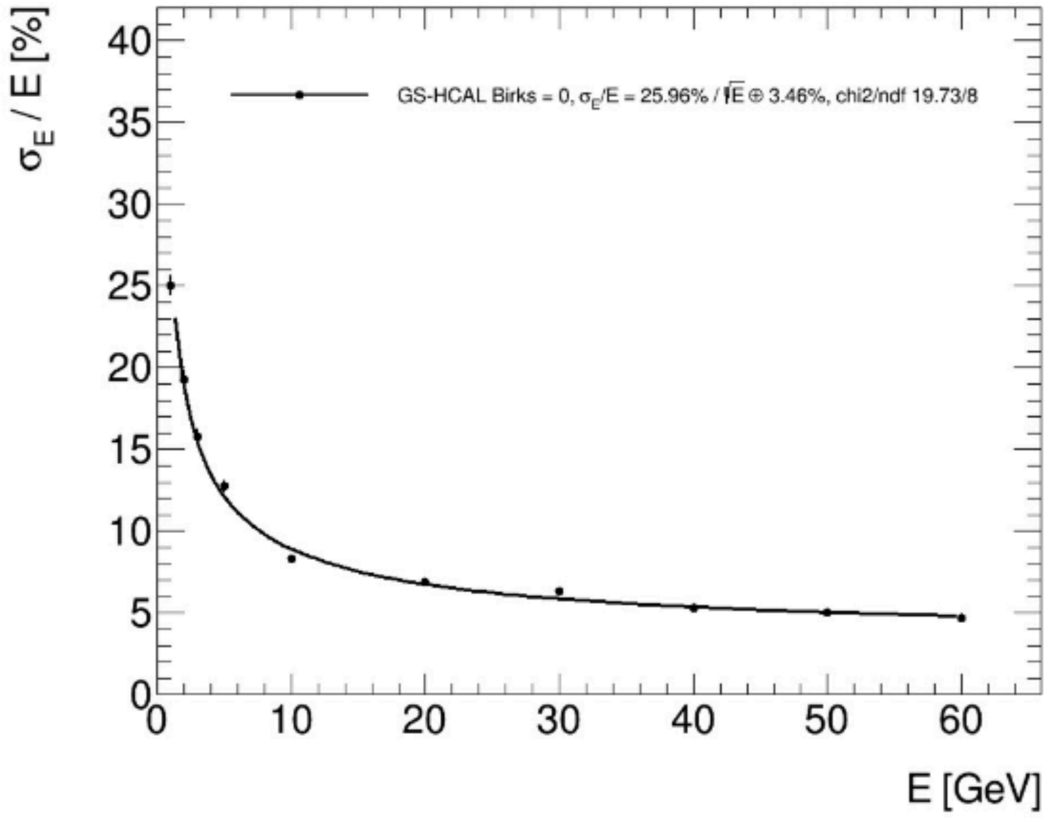


Figure 9.7: The performance of the new scintillators with a hole in the cosmic ray test. The left plot shows the N_{pe} of the photon collection. The middle plot shows the efficiency, and the right one shows the time resolution.

- It seems like one technique used to reduce the number of pages was to reduce the size of the plots!!
  - This was not what anyone had in mind :-)
- Please revert back to larger figures and **reduce the text!**

Figures style, formatting and files

- More tiny font figures



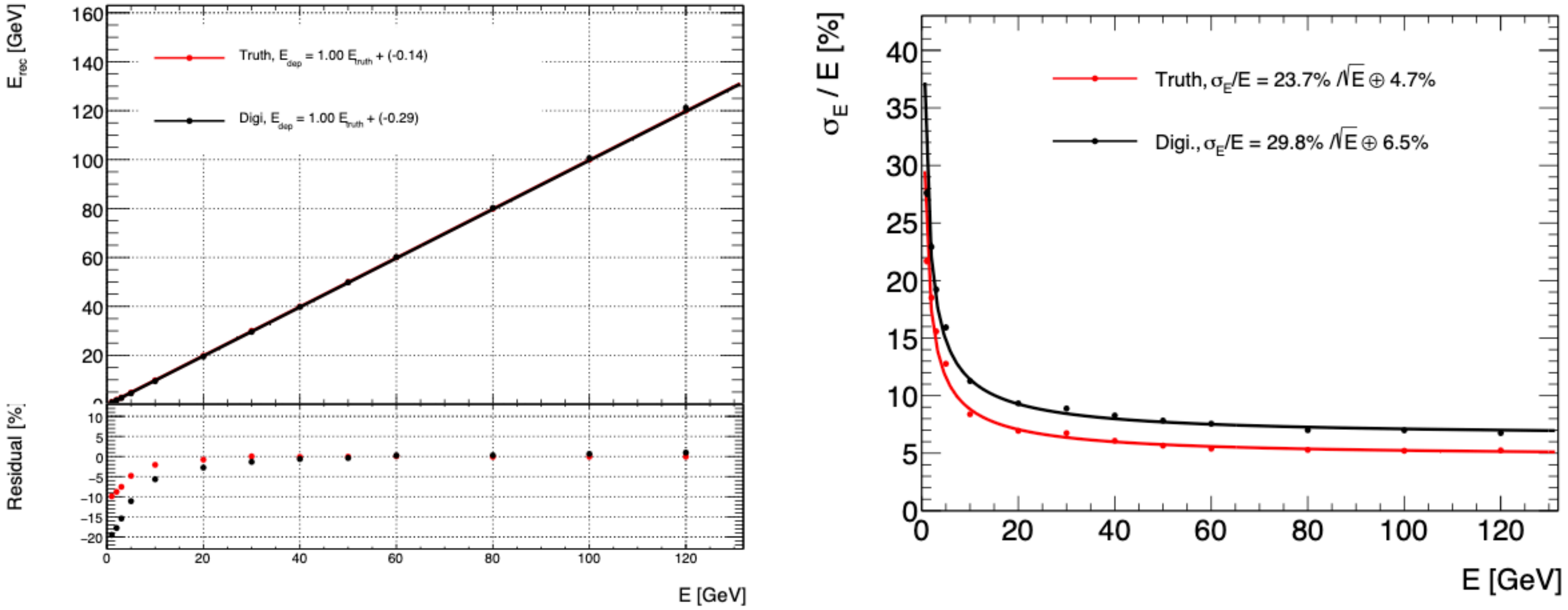


Figure 8.40: Energy linearity and energy resolution of GS-HCAL with the digitization model.

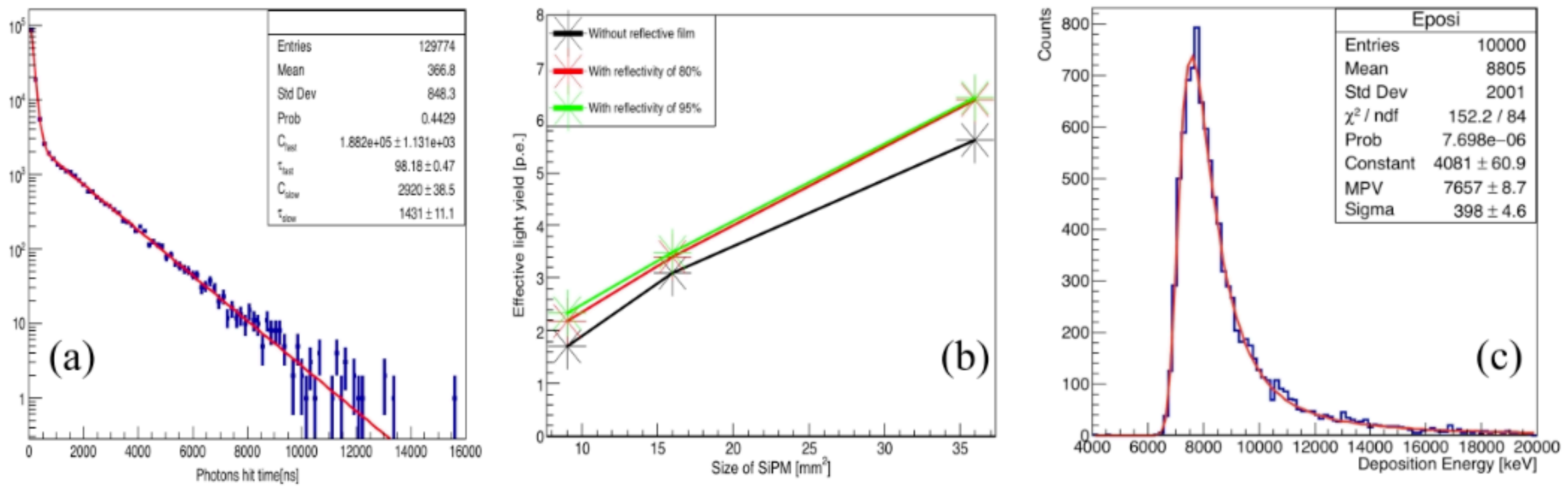


Figure 8.30: The results checked to validate the physical process in simulation, (a) Signal decay time (fast and slow components), (b) Effect of wrapping film with different reflectivity, (c) Muon deposited energy in GS cell (10mm thick).

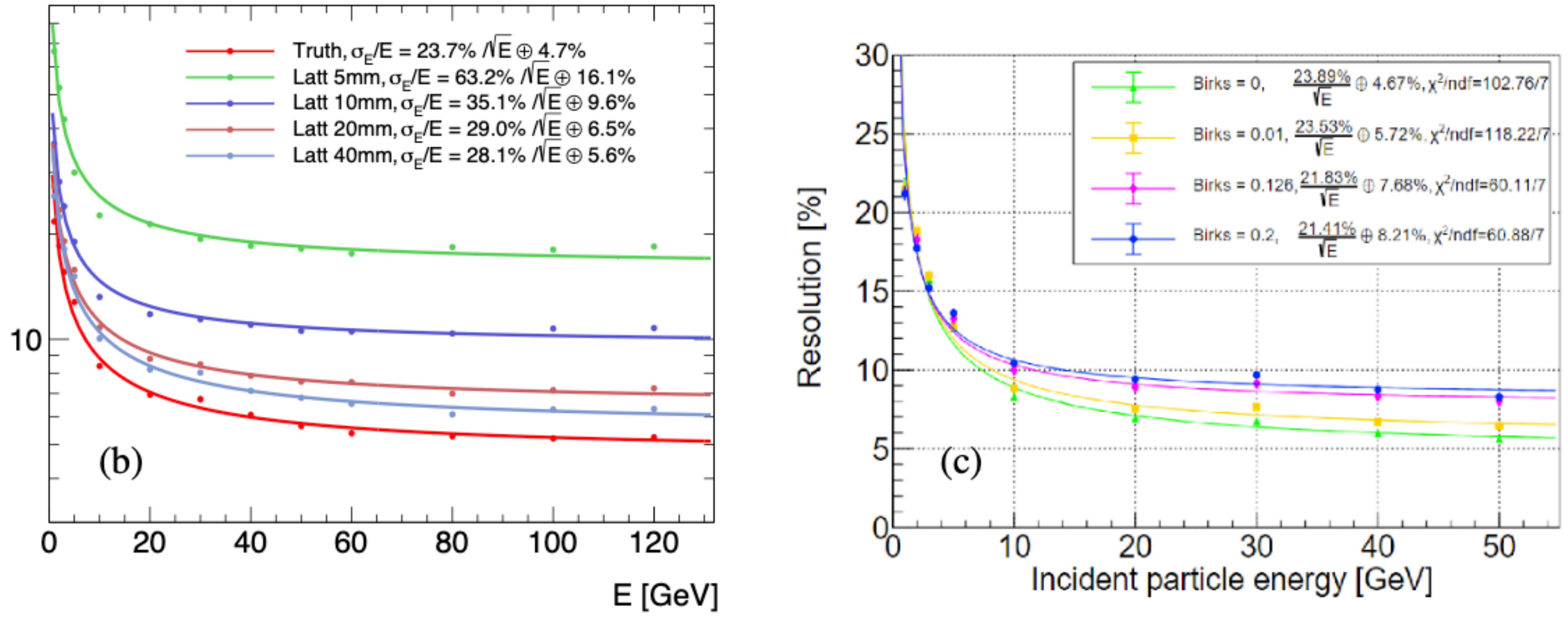


Figure 8.42: The simulated energy resolution with varies of (a) light yield and energy threshold, (b) glass scintillator attenuation lengths, (c) Birk's constants.

Figures style, formatting and files

- Template for plot making
  - Will suggest a baseline template for plots
  - Try to keep plots as consistent as possible
  - It is understood that needs to be some exceptions

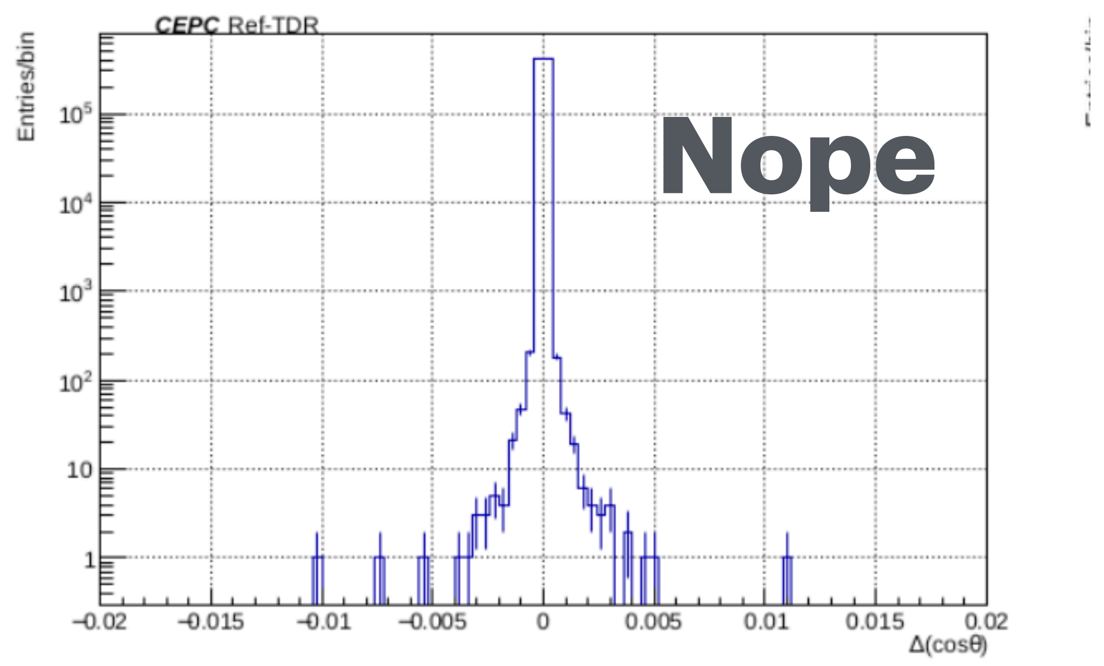
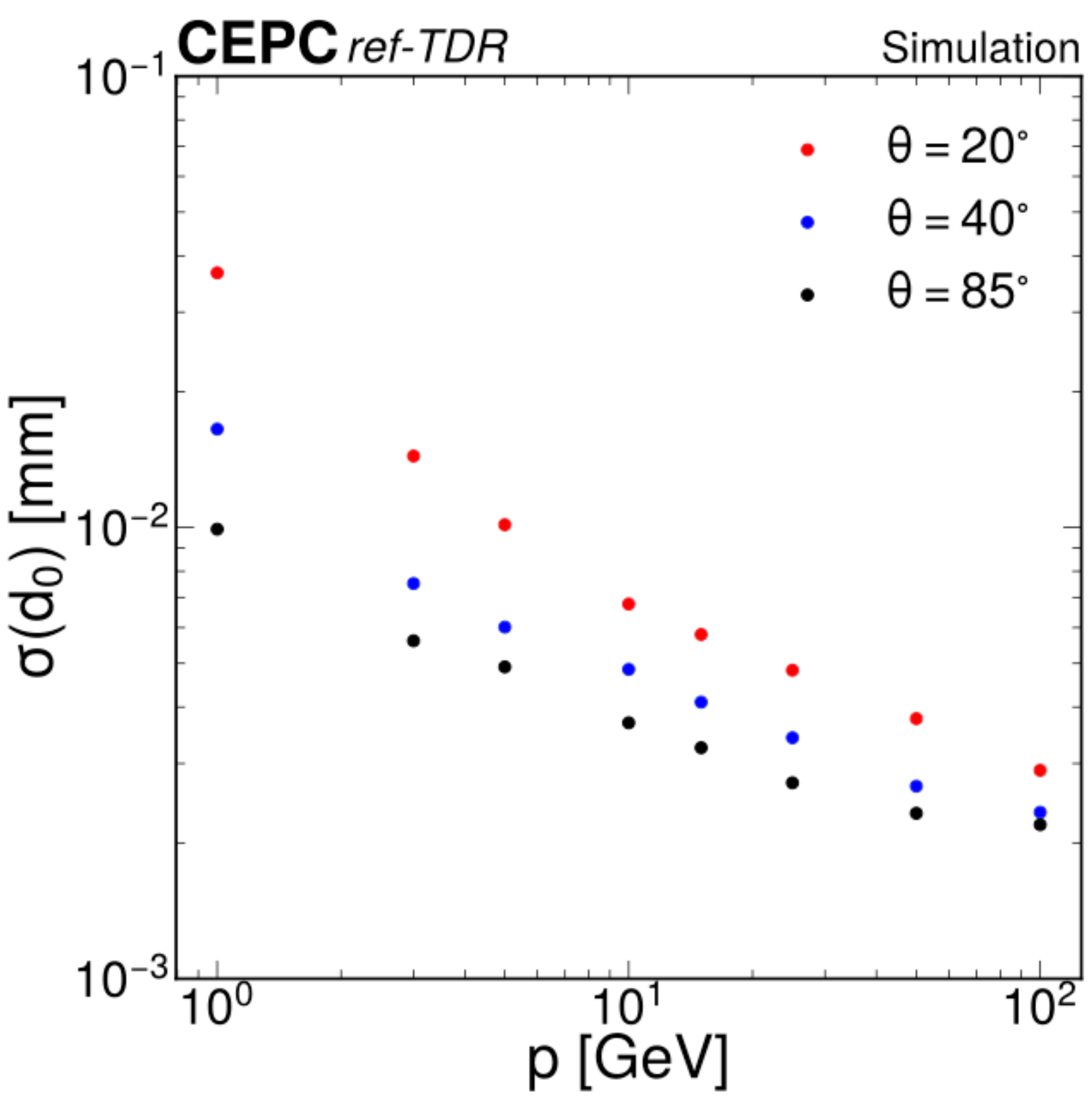
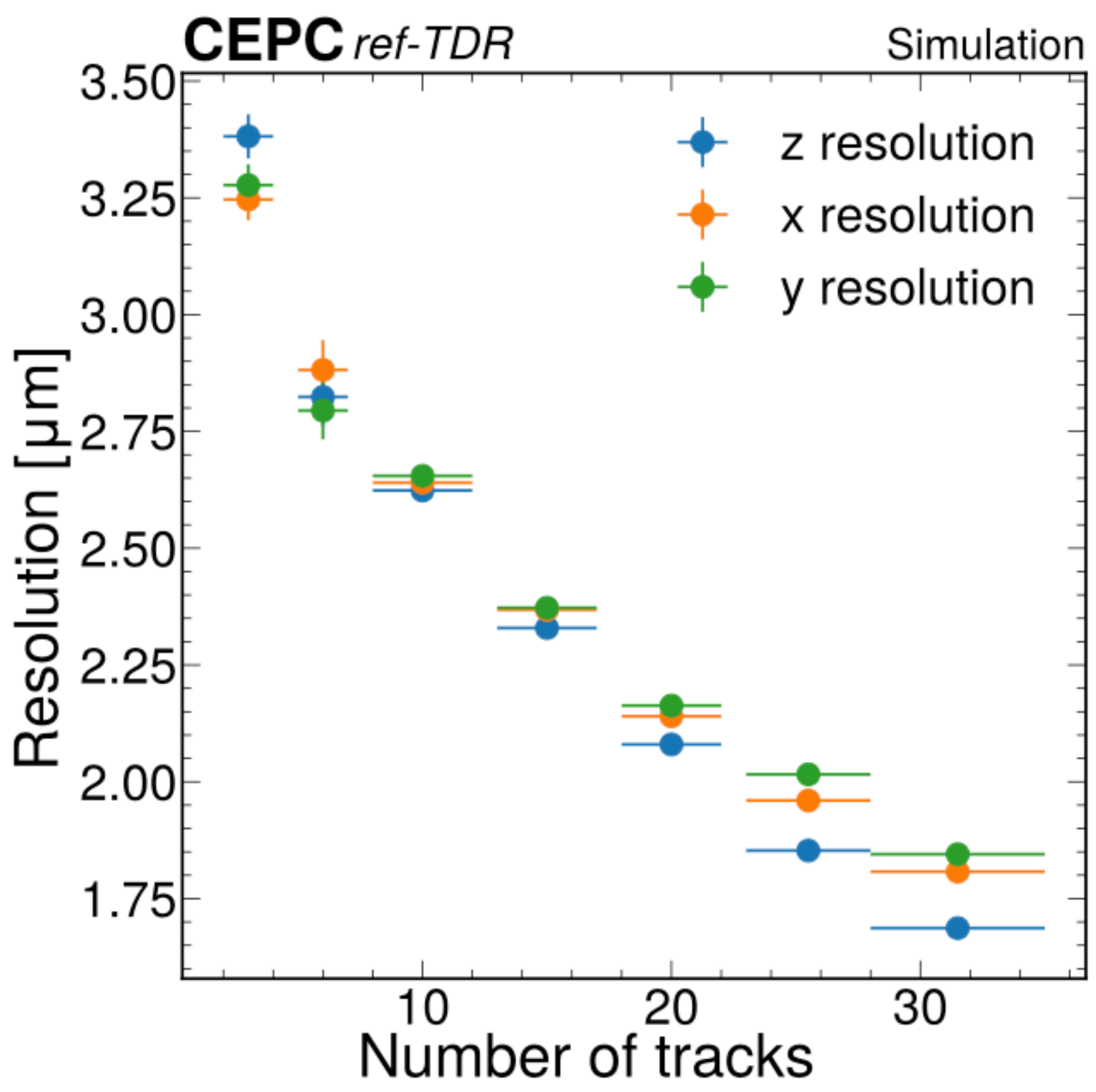
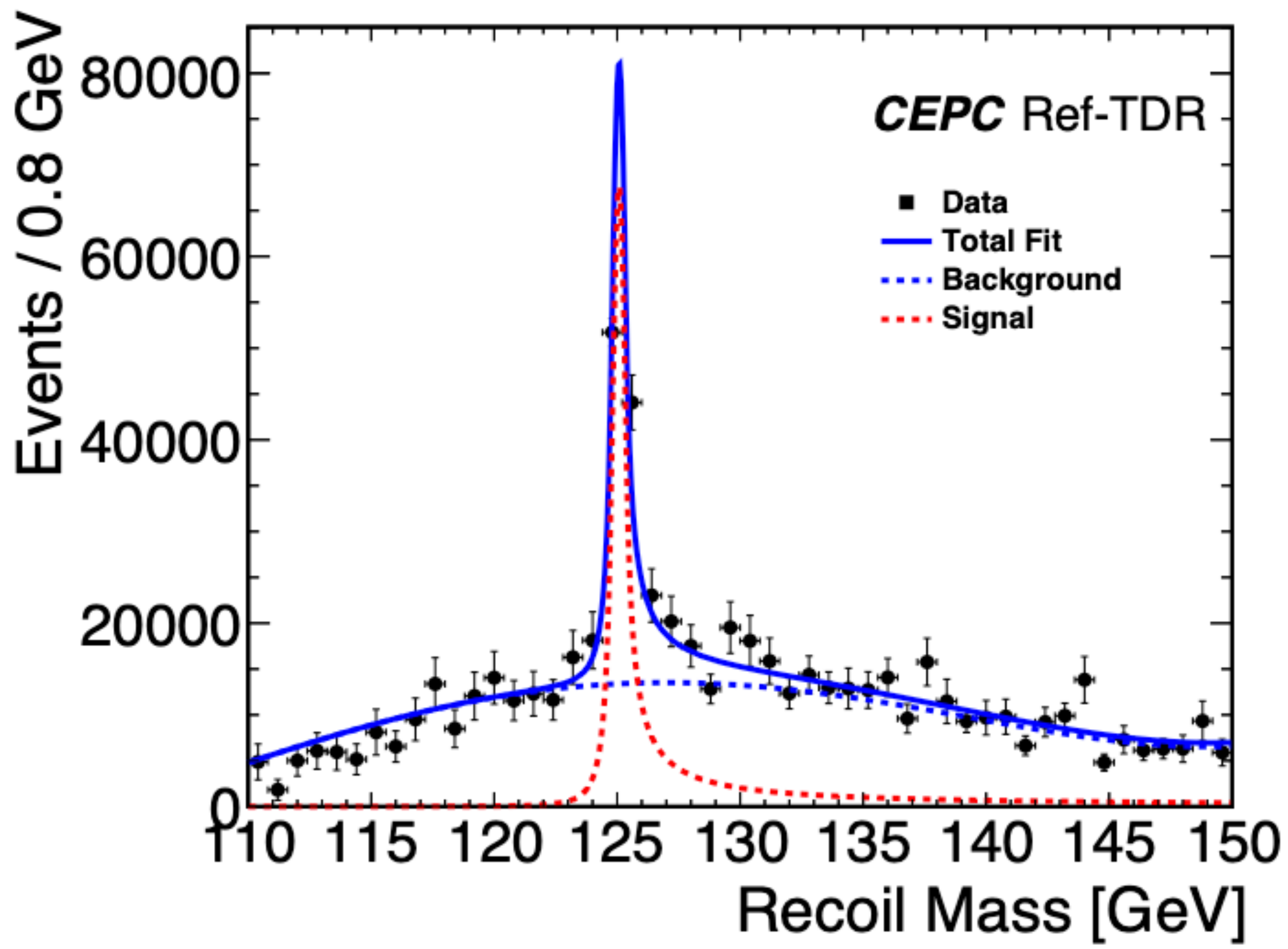


Figure 15.28: (Left) The difference between the μ^- cos(θ)
function of the angular resolution of PFOs. (Right) The differ

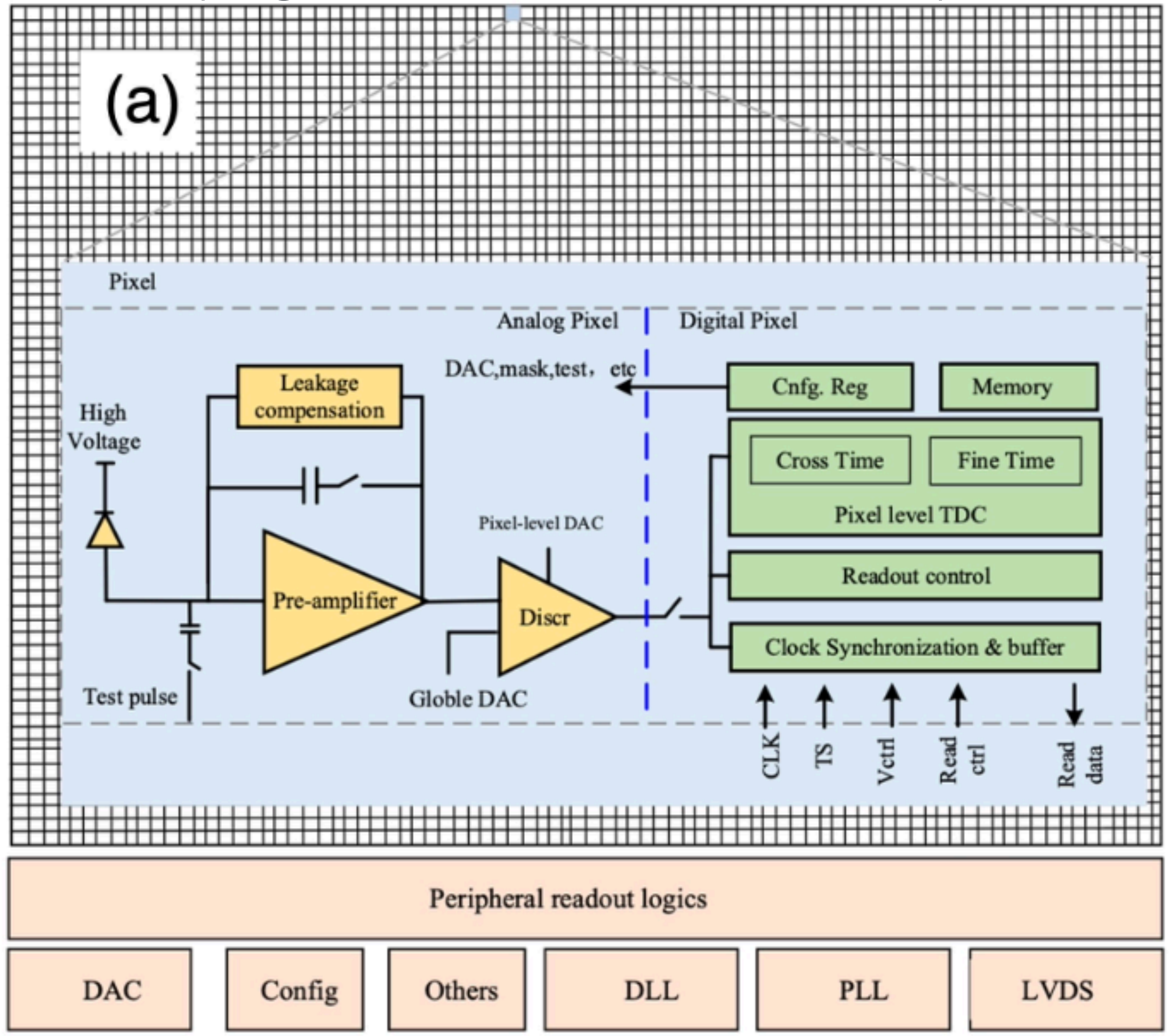


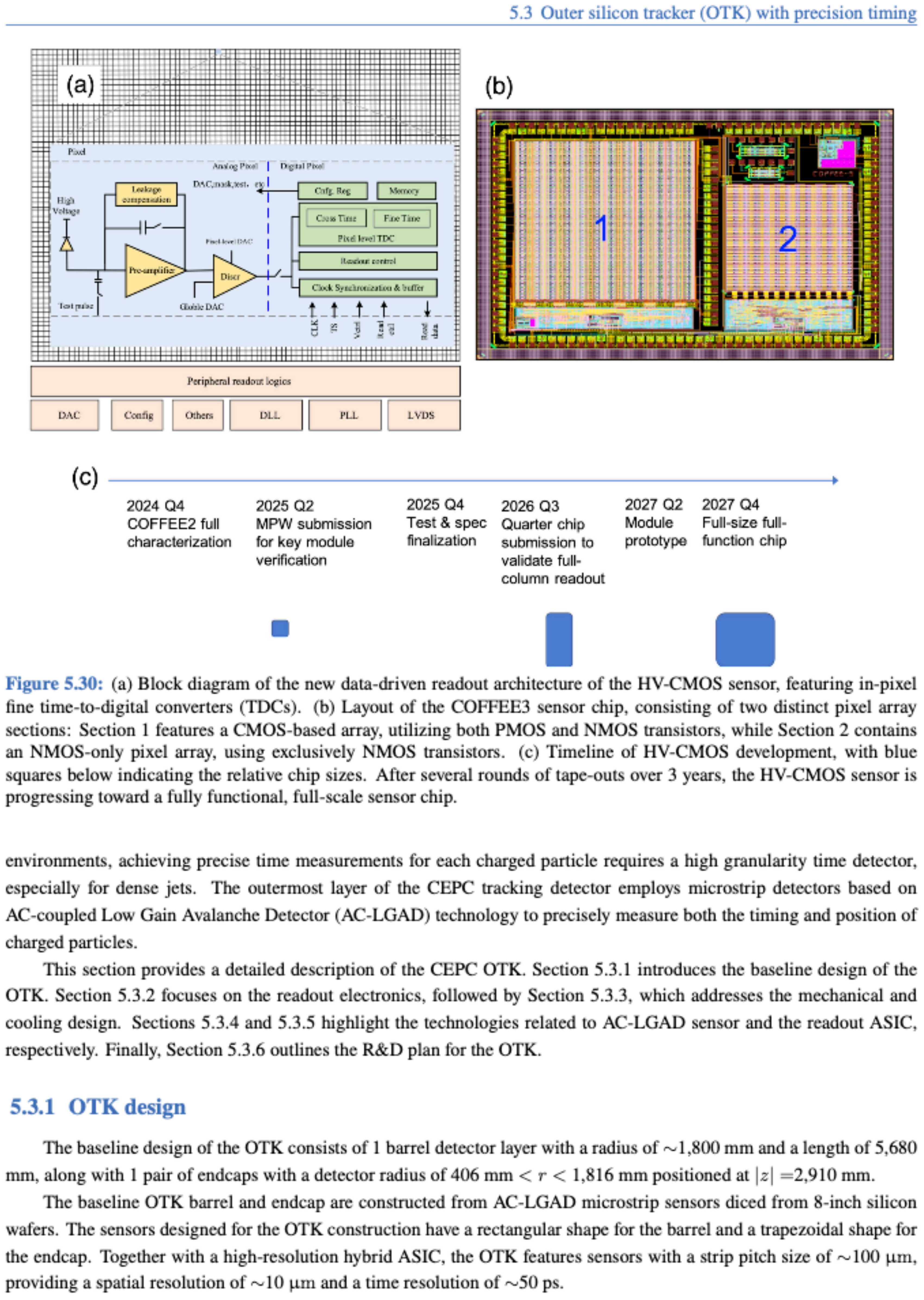




Figures style, formatting and files

- Example of a figures that requires either to be displayed larger, or be simplified with larger text, or removed
  - This size is 1/2 page size, but this figure is in the TDR as <1/6th of a page → not readable in the printed version





5.3 Outer silicon tracker (OTK) with precision timing

Figure 5.30: (a) Block diagram of the new data-driven readout architecture of the HV-CMOS sensor, featuring in-pixel fine time-to-digital converters (TDCs). (b) Layout of the COFFEE3 sensor chip, consisting of two distinct pixel array sections: Section 1 features a CMOS-based array, utilizing both PMOS and NMOS transistors, while Section 2 contains an NMOS-only pixel array, using exclusively NMOS transistors. (c) Timeline of HV-CMOS development, with blue squares below indicating the relative chip sizes. After several rounds of tape-outs over 3 years, the HV-CMOS sensor is progressing toward a fully functional, full-scale sensor chip.

environments, achieving precise time measurements for each charged particle requires a high granularity time detector, especially for dense jets. The outermost layer of the CEPC tracking detector employs microstrip detectors based on AC-coupled Low Gain Avalanche Detector (AC-LGAD) technology to precisely measure both the timing and position of charged particles.

This section provides a detailed description of the CEPC OTK. Section 5.3.1 introduces the baseline design of the OTK. Section 5.3.2 focuses on the readout electronics, followed by Section 5.3.3, which addresses the mechanical and cooling design. Sections 5.3.4 and 5.3.5 highlight the technologies related to AC-LGAD sensor and the readout ASIC, respectively. Finally, Section 5.3.6 outlines the R&D plan for the OTK.

5.3.1 OTK design

The baseline design of the OTK consists of 1 barrel detector layer with a radius of ∼1,800 mm and a length of 5,680 mm, along with 1 pair of endcaps with a detector radius of 406 mm $< r <$ 1,816 mm positioned at $|z|$ =2,910 mm.

The baseline OTK barrel and endcap are constructed from AC-LGAD microstrip sensors diced from 8-inch silicon wafers. The sensors designed for the OTK construction have a rectangular shape for the barrel and a trapezoidal shape for the endcap. Together with a high-resolution hybrid ASIC, the OTK features sensors with a strip pitch size of ∼100 µm, providing a spatial resolution of ∼10 µm and a time resolution of ∼50 ps.

Figures style, formatting and files

- The detector concept picture in the TDR
  - Two pictures side by side…. some text impossible to read, impossible to understand each component
    - Quality of the file is also very poor

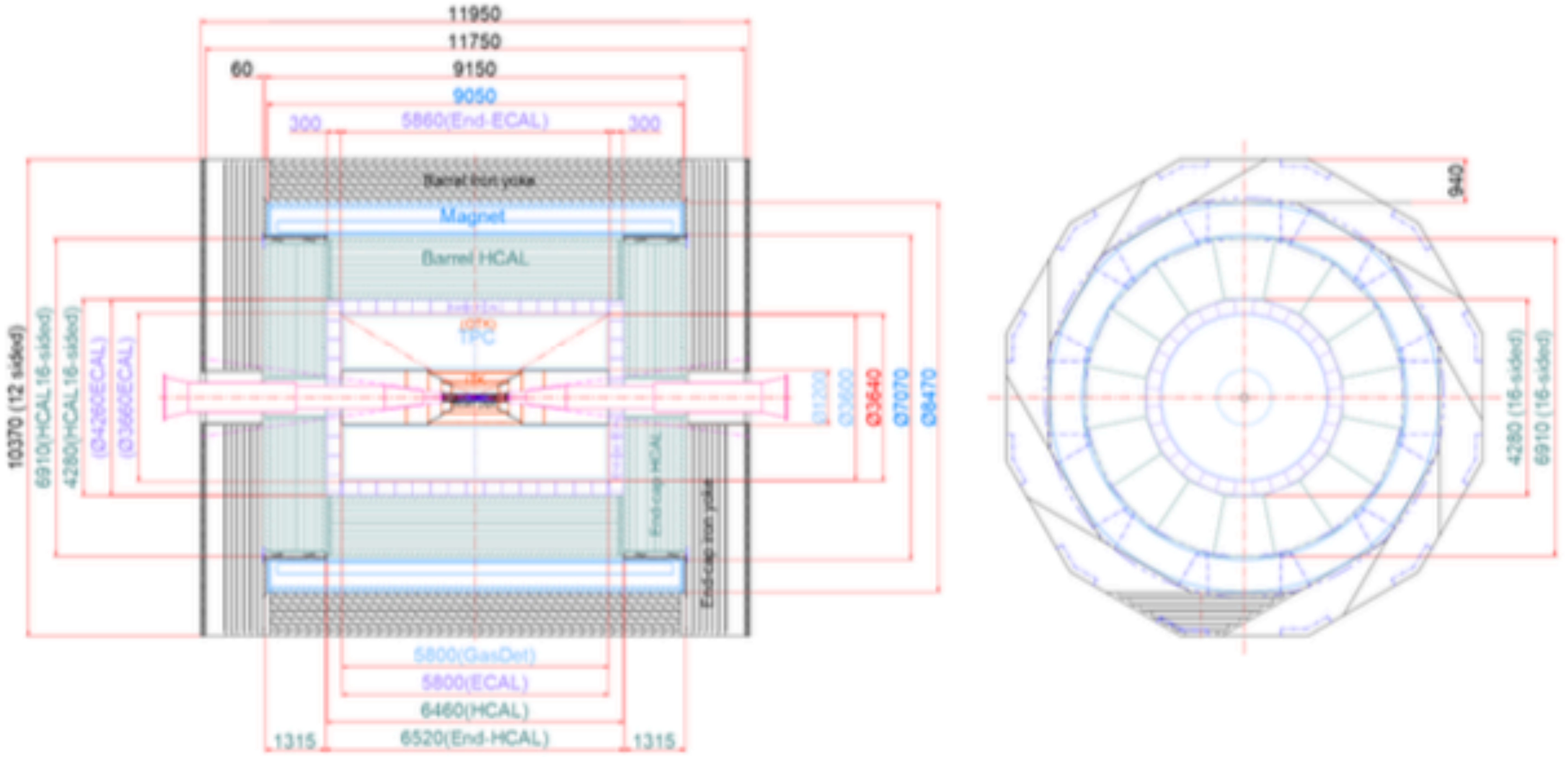
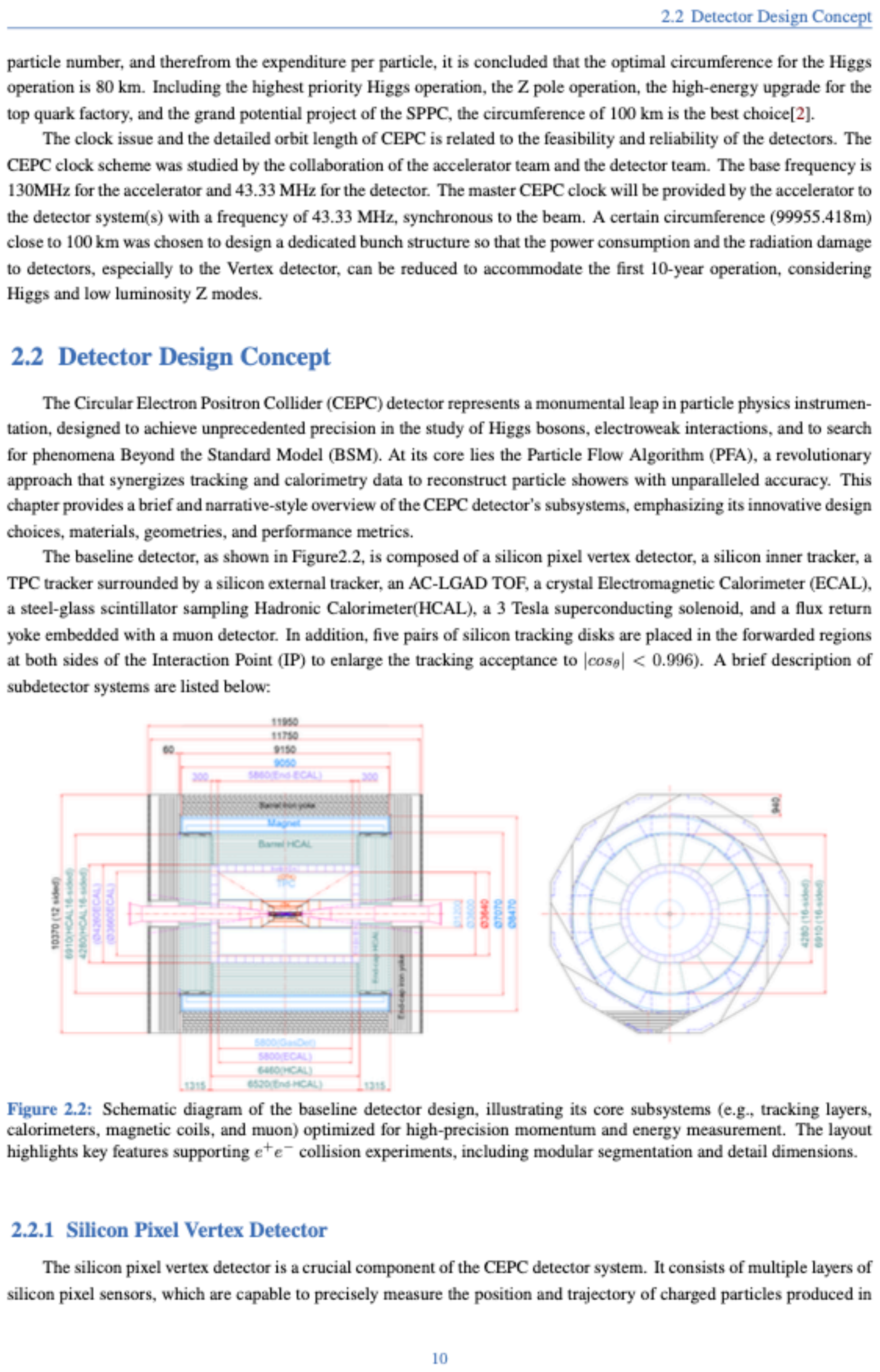


Figure 2.2: Schematic diagram of the baseline detector design, illustrating its core subsystems (e.g., tracking layers, calorimeters, magnetic coils, and muon) optimized for high-precision momentum and energy measurement. The layout highlights key features supporting e^+e^- collision experiments, including modular segmentation and detail dimensions.



2.2 Detector Design Concept

particle number, and therefrom the expenditure per particle, it is concluded that the optimal circumference for the Higgs operation is 80 km. Including the highest priority Higgs operation, the Z pole operation, the high-energy upgrade for the top quark factory, and the grand potential project of the SPPC, the circumference of 100 km is the best choice[2].

The clock issue and the detailed orbit length of CEPC is related to the feasibility and reliability of the detectors. The CEPC clock scheme was studied by the collaboration of the accelerator team and the detector team. The base frequency is 130MHz for the accelerator and 43.33 MHz for the detector. The master CEPC clock will be provided by the accelerator to the detector system(s) with a frequency of 43.33 MHz, synchronous to the beam. A certain circumference (99955.418m) close to 100 km was chosen to design a dedicated bunch structure so that the power consumption and the radiation damage to detectors, especially to the Vertex detector, can be reduced to accommodate the first 10-year operation, considering Higgs and low luminosity Z modes.

2.2 Detector Design Concept

The Circular Electron Positron Collider (CEPC) detector represents a monumental leap in particle physics instrumentation, designed to achieve unprecedented precision in the study of Higgs bosons, electroweak interactions, and to search for phenomena Beyond the Standard Model (BSM). At its core lies the Particle Flow Algorithm (PFA), a revolutionary approach that synergizes tracking and calorimetry data to reconstruct particle showers with unparalleled accuracy. This chapter provides a brief and narrative-style overview of the CEPC detector's subsystems, emphasizing its innovative design choices, materials, geometries, and performance metrics.

The baseline detector, as shown in Figure2.2, is composed of a silicon pixel vertex detector, a silicon inner tracker, a TPC tracker surrounded by a silicon external tracker, an AC-LGAD TOF, a crystal Electromagnetic Calorimeter (ECAL), a steel-glass scintillator sampling Hadronic Calorimeter(HCAL), a 3 Tesla superconducting solenoid, and a flux return yoke embedded with a muon detector. In addition, five pairs of silicon tracking disks are placed in the forwarded regions at both sides of the Interaction Point (IP) to enlarge the tracking acceptance to $|cos_\theta| < 0.996$). A brief description of subdetector systems are listed below:

Figure 2.2: Schematic diagram of the baseline detector design, illustrating its core subsystems (e.g., tracking layers, calorimeters, magnetic coils, and muon) optimized for high-precision momentum and energy measurement. The layout highlights key features supporting e^+e^- collision experiments, including modular segmentation and detail dimensions.

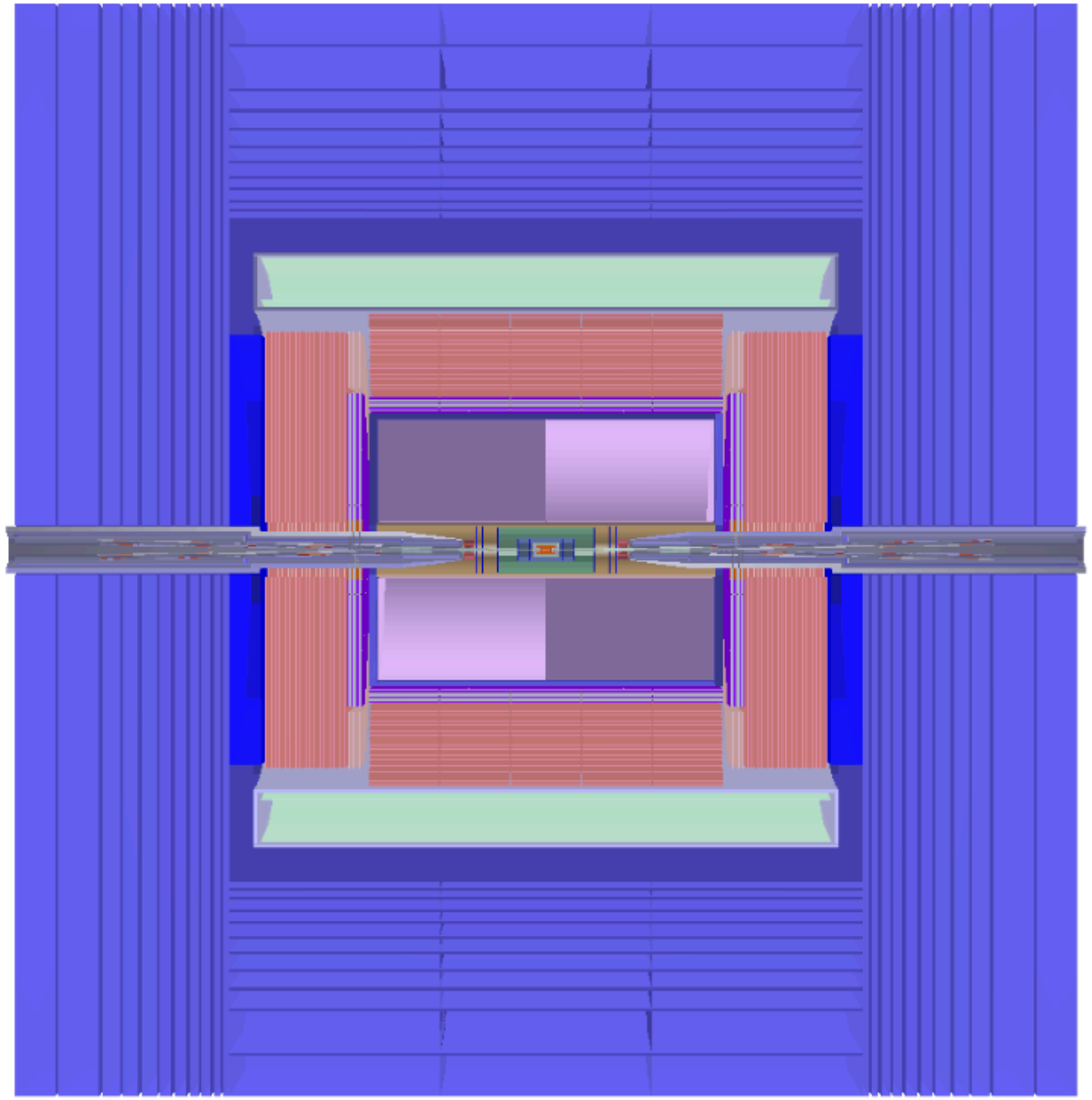
2.2.1 Silicon Pixel Vertex Detector

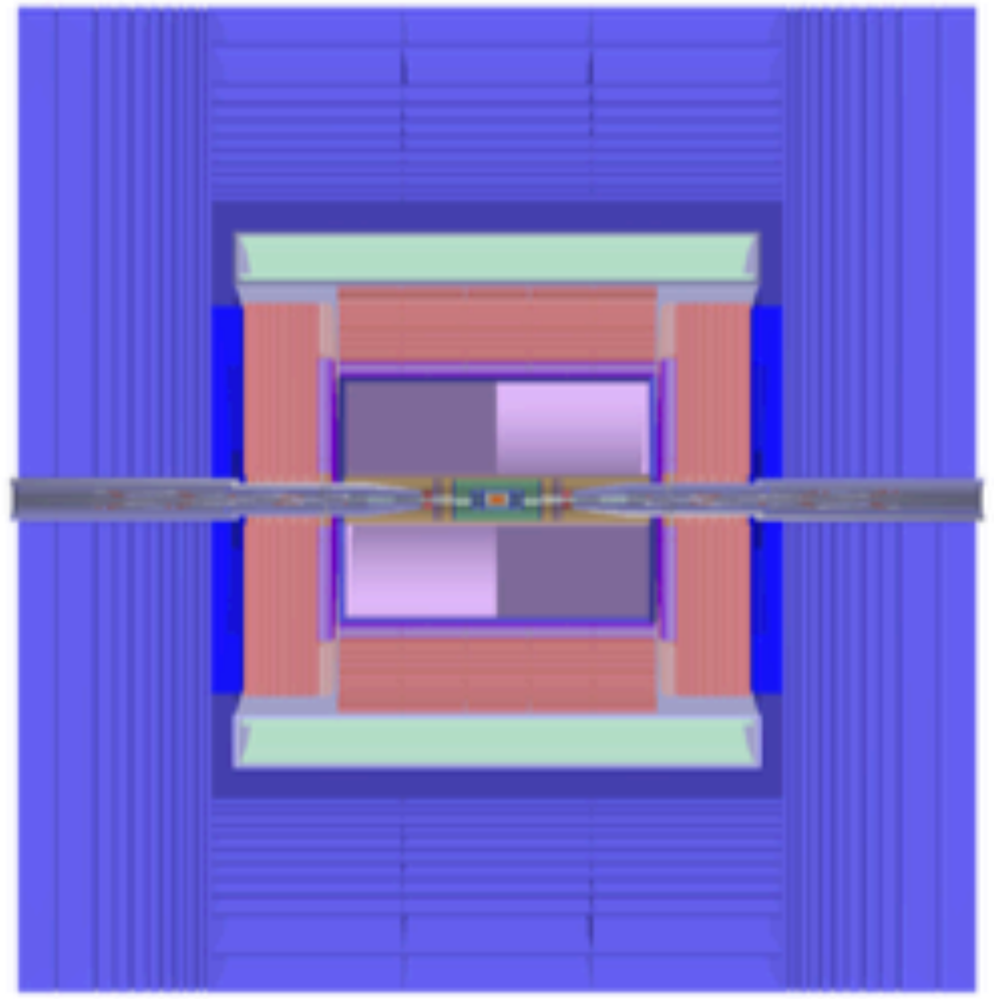
The silicon pixel vertex detector is a crucial component of the CEPC detector system. It consists of multiple layers of silicon pixel sensors, which are capable to precisely measure the position and trajectory of charged particles produced in

10

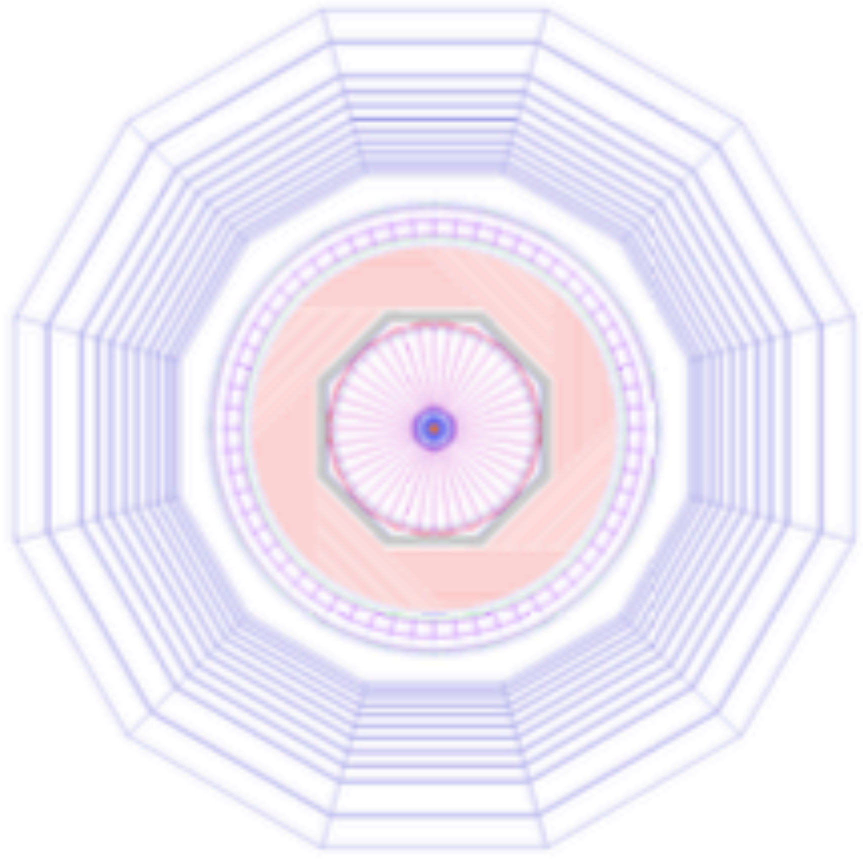
Figures style, formatting and files

- The detector concept picture in the CDR
  - One full page (still not perfect but visible) → we did had a lot of steel :-)





(a)



(b)

Figure 3.8: The (a) r–z and (b) r–ϕ view of the baseline detector concept. In the barrel from inner to outer, the detector is composed of a silicon pixel vertex detector, a silicon inner tracker, a TPC, a silicon external tracker, an ECAL, an HCAL, a solenoid of 3 Tesla and a return yoke with embedded a muon detector. In the forward regions, five pairs of silicon tracking disks are installed to enlarge the tracking acceptance (from $|\cos(\theta)| < 0.99$ to $|\cos(\theta)| < 0.996$).

Figures need to take whatever size is required to express the message

Comparing the CDR with the TDR

CDR

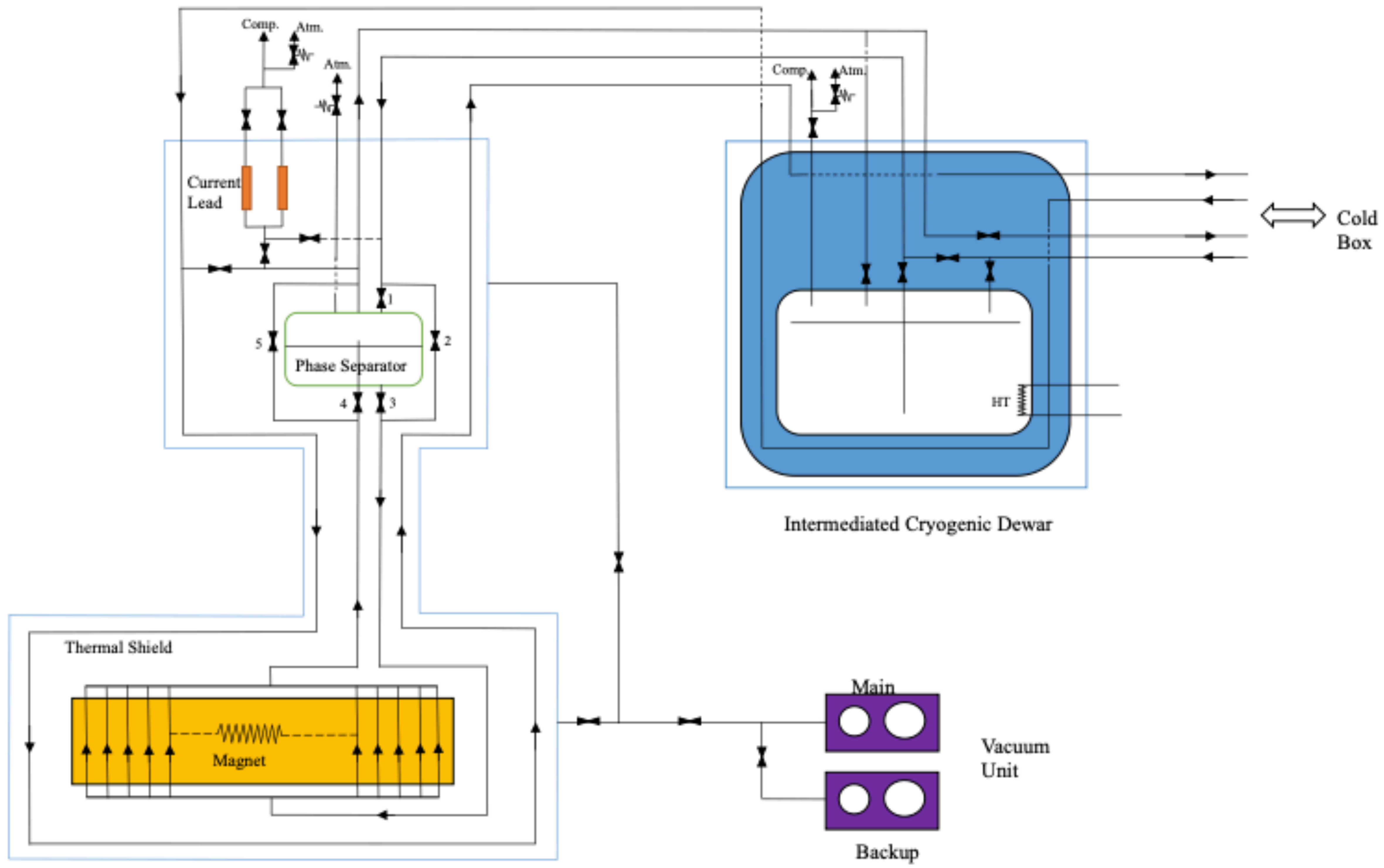


Figure 6.5: Thermosiphon cooling circuit. The CEPC detector magnet cryogenic system is composed of two sub-system: the external system and the inner system. The external system includes cold box and intermediate Dewar; the inner system includes coil cooling circuit and phase separator. The cryogenic sequences include cooling down, normal operation, energy dump and warming up. The first operation mode is the cooling down process by forced flow helium from 300 K to 100 K and to 4.5 K. The second operation mode is the normal operation process in thermosiphon flow condition, which is the main working mode for the magnet. The third one is the energy dump process, which is divided into fast discharge, slow discharge and post quench re-cooling. The last operation mode is the warming up.

TDR

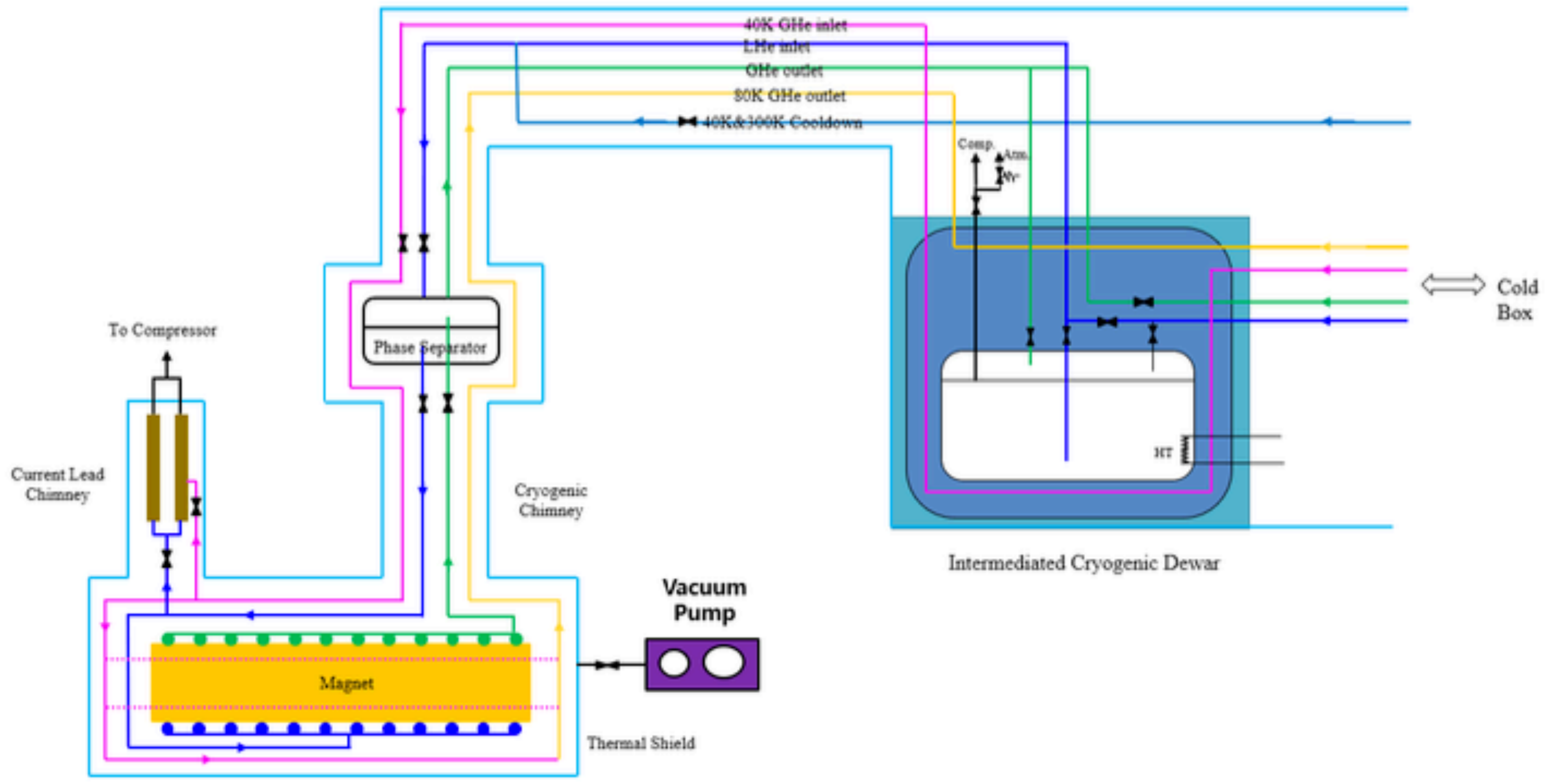


Figure 10.51: Coil cryogenic circuits

Provide proper captions

(still **tiny** font and symbols…
there are valves in this picture)

Family photos are not acceptable

Avoid group photos with accomplishments... they are not scientific or technical

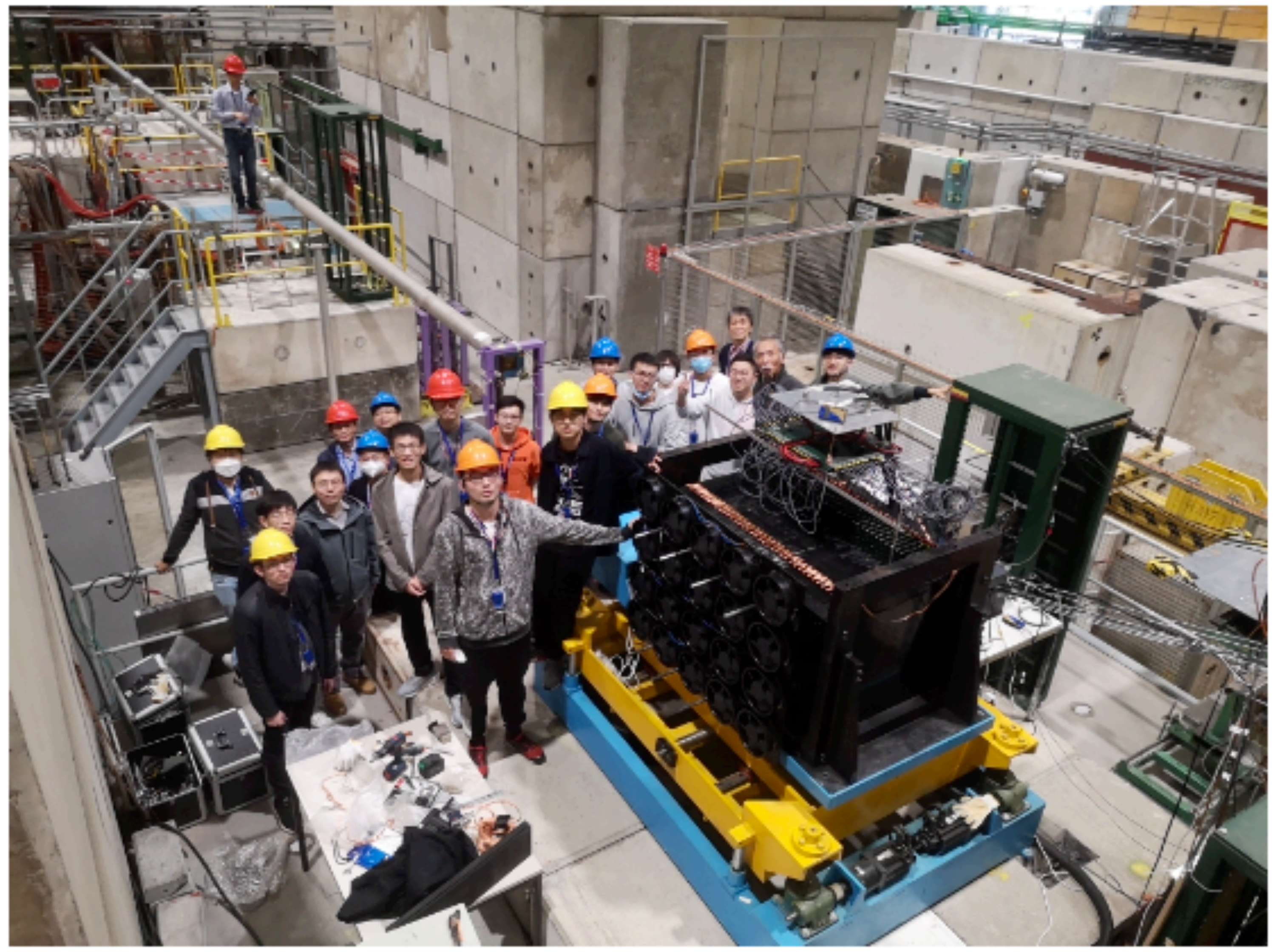


Figure 8.51: AHCAL prototype at CERN beamline with a group of colleagues from China, Japan and Israel.

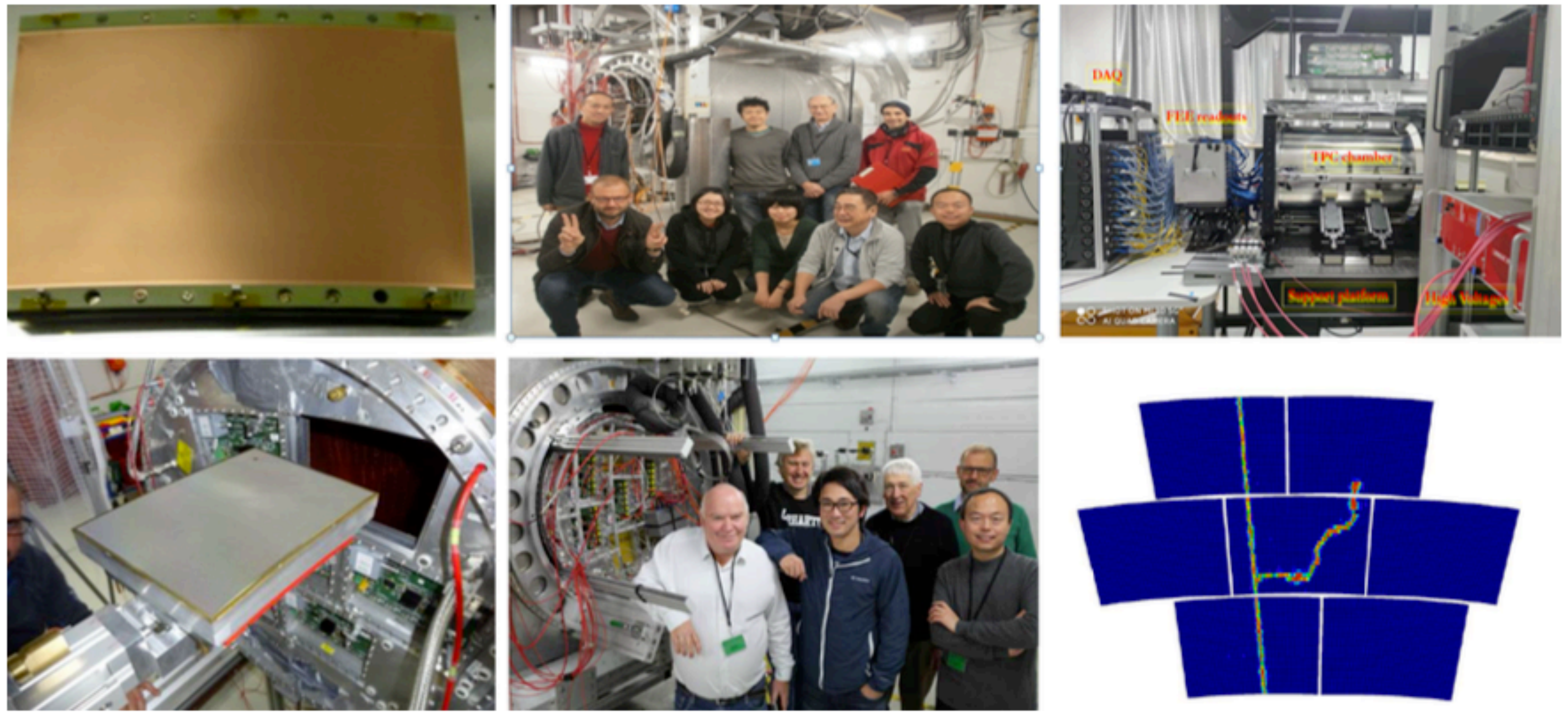


Figure 6.20: Beam tests of TPC prototype at DESY in LCTPC international collaboration, the performance of the prototype was evaluated in a beam test using 5 GeV electrons from several R&D groups in the collaboration.

In particular if these pictures include some of our reviewers! These people didn't consent to be in the TDR

Six images collected in one figure without explanations is not scientific. Pictures should have a technical purpose to be included in the TDR → either explain explicitly what is the image, or remove it

Test beams work can be expressed in words, results and papers, ... not group pictures

Figures style, formatting and files

- There are some “strange figure”
  - Figures need to be scientific and technical in nature

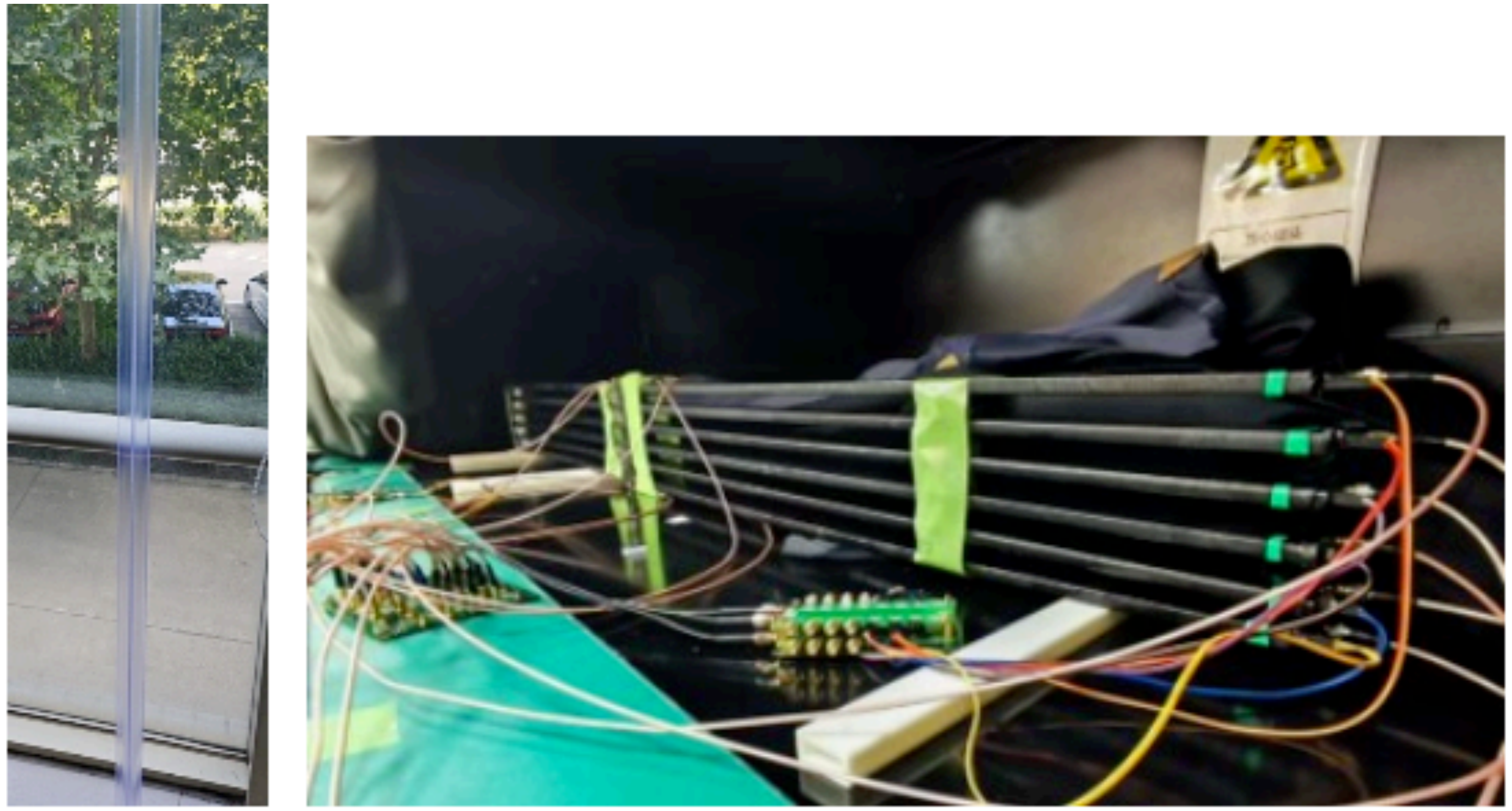


Figure 9.6: The new scintillator strip with a hole for embedding WLS fiber and the cosmic ray test. The left picture shows a strip without a coating reflection layer. The right picture shows the cosmic ray test on six strips with a length of 1.65 m.

There is a **parking lot** in this picture that seems to be taken from a balcony without any explanation

Better to **remove ALL such pictures**, otherwise 1) improve picture; 2) explain technical and scientific value

Other format issues

- **Symbol and format consistency**
  - Need to use the power of Latex to make sure the symbols and other format issues are kept uniform throughout the document
    - New Latex style file provided that ALL chapter editors should use: **cepcphysics.sty**
      - This guarantees that:
        - Particle names: H, Z, W, etc... are used consistently... they are NOT now
        - Units: GeV, keV, TeV are used correctly
        - Also, variables like p_T, Missing ET, ET, etc...
        - Journal names
      - We will work with you to add more symbols specific to the CEPC into this file → fill free to add and let us know
- **Glossary**
  - Latex provides tools to create glossaries → avoid repetitive definition of names and provides a list of symbols at the end
  - Done for the CDR at the last minute, as requested by reviewers at the time
    - Will implement this and let you know what to do (with help from Zhaoru)

Glossary from CDR

Glossary

CP Charge-Parity 57, 58

ADC Analog-to-Digital Convert 155

AFE Analog Front-End 155

AHCAL Analog HCAL 194, 208

ALP Axion-Like Particle 29, 33

ASIC Application Specific Integrated Circuits 155

ASU Active Sensor Unit 200

ATCA Advanced Telecommunications Computing Architecture 269

BAU Baryon Asymmetry of the Universe 51, 57

BE Back-end Electronics 206

BMR Boson Mass Resolution 124

BSM Beyond the Standard Model 297

CDR Conceptual Design Report 1, 2, 116, 388

CEPC Circular Electron Positron Collider 1

CMOS Complementary Metal-Oxide-Semiconductor 146

CPS CMOS Pixel Sensors 167

DAQ Data AcQuisition 267

DCH Drift CHamber 175

DEPFET Depleted P-channel Field Effect Transistor 147

DHCAL Digital HCAL 194

DLC Diamond Like Carbon 262

DM Dark Matter 35

DR Dual Readout 224

DSP Digital Signal Processors 155

EB Event Builder 272

EBM Event Building Manager 272

ECAL Electromagnetic Calorimeter 130, 300, 304

EDM Electric Dipole Moment 333

EEC Energy-Energy Correlation 65

EFT Effective Field Theory 10

EIT Endcap Inner Tracker 170

EOT Endcap Outer Tracker 170

EQR SiPM SiPM with Epitaxial Quenching Resistors 222

ETD Endcap Tracking Detector 165

EW ElectroWeak 315

EWPT ElectroWeak Phase Transition 20, 21

EWSB ElectroWeak Symmetry Breaking 20

FE Front-End 206

FEA Finite Element Analysis 250, 251, 256

FPGA Field-Programmable Gate Array 222, 253

FST Full-Silicon Tracker 115

FTD Forward Tracking Detector 165

FV Fiducial Volume 290

GEM Gas Electron Multiplier 153, 160, 161

GEM-MM hybrid Gas Electron Multiplier and Micro-Mesh Gaseous Structure 153, 160, 161, 162, 163

Summary of status

- https://docs.qq.com/sheet/DQkxVTmhpRkdhQUJq?tab=000001&_t=1748241620462&nlc=1

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10 Detector magnet system	100%					
11 Readout Electronics	100%	100%	90%	90%	50%	80%
12 Trigger and Data Acquisition						
13 Offline software and computing	100%	100%	100%	100%	90%	90%
14 Mechanics and integration	100%					
15 Detector and physics performance						
16 Timeline and Future Plans						
17 Detector Costing						

Other Issues

Other observations

- Each chapter should have an **introduction before the first section**
  - The introduction should be short 2-3 paragraphs are enough
    - Introduce the relevance of the chapter within the context of the detector TDR
    - Explain what is covered in the chapter and how that is split throughout the sections
- **Very good example from Chapter 13**

Chapter 13 Offline software and computing

The development of the CEPC software (CEPCSW) [1] is based on several foundational HEP software packages, including the Gaudi [2] software framework for event processing, EDM4hep [3] for the event data model, DD4hep [4] for detector description, Geant4 [5] for simulation, and ROOT [6] for data analysis. A key aspect of this endeavor is the development of CEPC-specific software, designed to meet the experiment's unique requirements. The core software will be introduced in Section 13.1, while the applications for simulation, reconstruction, analysis, and visualization will be described in Sections 13.2, 13.3, and 13.4, respectively.

To tackle the growing complexity of data processing tasks, emerging technologies are being actively explored. Research and development efforts focus on areas such as concurrent computing, machine learning, and quantum computing, which will be discussed in Section 13.5.

Grid computing technology, successfully implemented in the LHC experiments, connects computing and storage resources distributed across laboratories worldwide, facilitating the processing and analysis of EB-level data. Leveraging this technology, we have established a distributed computing infrastructure (DCI) to support detector R&D activities. On this prototype, the latest Grid computing technologies are being investigated and evaluated to ensure robust support for the experiment's future operations. These aspects will be discussed in Sections 13.7 and 13.10.

In the current project, the software and computing team is responsible for providing the core software, including the framework, various services, data management, and computing systems. The development of detector-specific algorithmic code for simulation, calibration, and reconstruction is a shared responsibility between the software and computing team and the sub-detector teams. Close collaboration with the Physics Group ensures the smooth development of global event-reconstruction code and software tools for physics analysis.

Examples from CDR

DETECTOR MAGNET SYSTEM

The CEPC detector magnet is an iron-yoke-based solenoid to provide an axial magnetic field of 3 Tesla at the interaction point. A room temperature bore is required with 6.8 m in diameter and 8.3 m in length. This chapter describes the conceptual design of the magnet, including the design of field distribution, solenoid superconducting coil, cryogenics, quench protection, power supply and the yoke. In the end of this chapter, the R&D Section 6.5 brings up other concept options and some reach projects. The compensating magnets designed to minimize the disturbance from the detector solenoid on the incoming and outgoing beams are briefly discussed in Section 9, and in more detail in the CDR accelerator volume, Chapter 9.2 [1].

6.1 MAGNETIC FIELD DESIGN

TRACKING SYSTEM

The CEPC physics program demands a robust and high performance charged particle tracking system. Charged particles are used directly in physics analyses; they are input to determine primary and secondary vertices; and they are crucial input to particle flow calorimetry.

The tracking system has two major components. The vertex detector has excellent spatial resolution and is optimized for vertex reconstruction. The main tracker is optimized for tracking efficiency and resolution required for the CEPC physics program.

This Chapter introduces all tracking system options of the detector concepts discussed in this report. Section 4.1 describes the CEPC baseline vertex detector and the inner tracker. An outer tracking system, composed of a Time Projection Chamber (TPC), a silicon external tracker and a forward tracking detector, is discussed in Section 4.2. This system, together with the vertex detector and the inner tracker from Section 4.1, composes the tracking system of the baseline detector concept which is represented in Figure 4.1. Section 4.3 discusses in some detail the option of a full-silicon tracker that could substitute the tracking system of the CEPC baseline detector concept. Finally, in Section 4.4 a Drift Chamber Tracker is proposed as an option for the CEPC main outer tracker. This chamber, together with a layer of silicon microstrip detectors that surrounds it in both barrel and forward/backward regions, and the inner vertex detector, constitute the tracking system of the CEPC alternative detector concept.

4.1 VERTEX DETECTOR

MUON DETECTOR SYSTEM

For the baseline detector concept, muons are identified primarily in the the PFA-oriented calorimeters and their momenta are measured in the tracking system. An outermost muon detector system is envisioned to provide redundancy, aid muon identification in busy environments and reduce backgrounds. Embedded in the solenoid flux return yoke, the detector is designed to identify muons with high standalone efficiency ($\geq 95\%$) and purity for muon p_T down to ~ 3 GeV over the largest possible solid angle. While the design is driven by the identification, the muon detector could provide standalone measurements of the muon momenta as well.

The muon detector will significantly improve the identification of muons produced inside jets such as those from B hadron decays. Moreover, the detector can compensate for leaking energetic showers and late showering pions from the calorimeters, which could help to improve the jet energy resolution [1]. It can also aid in searches for long-lived particles that decay far from the IP, but still inside the detector.

This Chapter presents design considerations and technology options for the CEPC muon detector. Section 7.1 introduces the conceptual design. Both the Resistive Plate Chamber (RPC) and an innovative type of Micro Pattern Gas detector (MPGD), the μ-RWELL detector, are being considered. The main difference between the two technologies lies in the position resolution and the cost. Details are presented in Section 7.2 for the RPC technology and in Section 7.3 for the μ-RWELL technology. Though not described here, other gas detectors such as Gas Electron Multiplier (GEM), MicroMegas and Monitored Drift Tubes (MDT) are also possible options. Section 7.4 briefly describes the future R&D program.

CALORIMETRY

A calorimetry system is employed in the CEPC detectors to provide hermetic coverage for high-resolution energy measurements of electrons, photons, taus and hadronic jets. Section 5.1 provides an overview of the calorimetry systems being considered. Two distinct approaches are being pursued: particle-flow and dual-readout calorimeters. The current baseline detector concept adopts the particle flow approach. Section 5.2 introduces design considerations for these calorimeters. It is followed by the description of the corresponding particle flow oriented electromagnetic calorimeter (ECAL) in Section 5.3, and hadronic calorimeter (HCAL) in Section 5.4. Different technology options are described in both cases. The technology options that have been integrated into the full detector simulation are silicon-tungsten for the ECAL and steel-GRPC for the HCAL. The dual-readout calorimeter concept, described in Section 5.5, is an integral part of IDEA, the alternative detector concept for the CEPC.

5.1 OVERVIEW

Please check the CDR, specially for your chapter, for some guidance regarding style and formatting

Not suggesting to copy content!!

Summary of status: Chapter Introduction

Chapter	Introduction	Quality (first impressions)
Executive summary		
1 Introduction	Yes	Poor, needs expansion
2 Concept of CEPC Reference Detector	No	
3 MDI and Luminosity	No	
4 Vertex Detector	No	
5 Silicon Trackers	Yes	OK, but needs expansion to cover sections
6 Pixelated Time Projection Chamber	No	
7 Electromagnetic calorimeter	Yes	Good
8 Hadronic calorimeter	No	
9 Muon Detector	No	
10 Detector magnet system	Yes	Not the right level of detail. Needs to expand to cover sections
11 Readout Electronics	No	
12 Trigger and Data Acquisition	Yes	Perhaps too long, needs to expand to cover sections
13 Offline software and computing	Yes	Very good → Excellent :-)
14 Mechanics and integration	Yes	Needs to expand to cover sections
15 Detector and physics performance	No	
16 Timeline and Future Plans		
17 Detector Costing		

Other observations

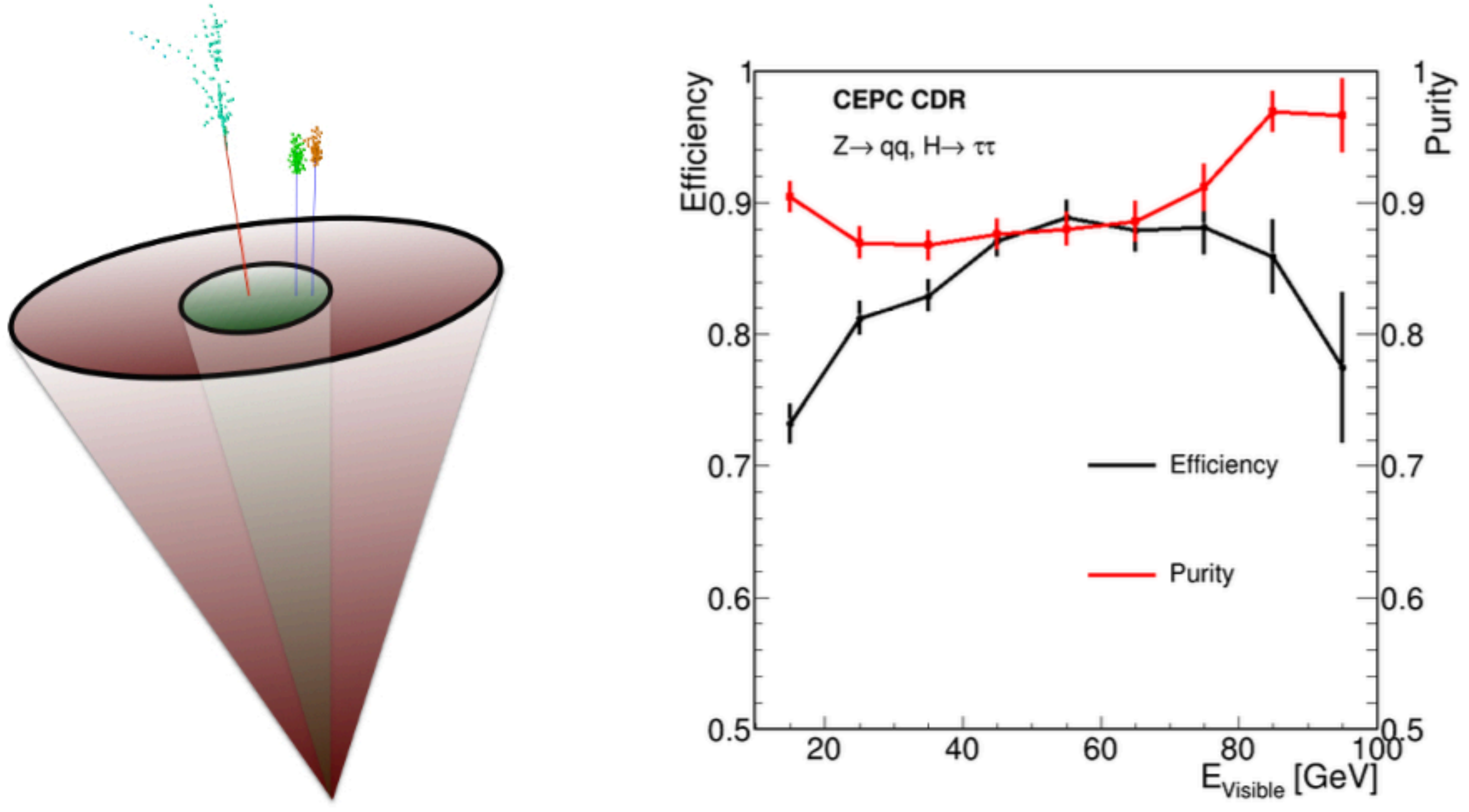
- Many chapters **repeat introduction to CEPC** or to the CEPC physics
  - Assume that those items are already covered → point to us if some aspects need to be clarified before your chapter
- Some **repetition or discussions about other detectors**
  - Should avoid repetitions and check with other chapter editors (and me) if some overlap is needed
- Handling of **Calorimeter and Tracking** optimization and performance is tricky
  - CDR and other TDRs have one chapter for each Calorimetry and Tracking, not individual chapter for each sub-detector
  - Solution:
    - Chapter 2 should justify in more detail the choices for the calorimeters and tracking and how things fit together — no other better place
    - Chapter 15 needs to cover the integrated **object** performance covering tracking and calorimetry

Other observations

- Tau physics is an essential components of CEPC physics, either:
  - Flavor physics at the Z pole
  - New physics
- Just like for the CDR… we are getting to the end of the TDR without any tau performance
  - In the CDR, we added them urgently at the end…. pushed by colleagues/reviewers
  - Should not wait for that extreme for the TDR

Showing less in the TDR than in the CDR seems very undesirable

Suggest to work on this urgently to add it to the TDR



(a) (b)

Figure 10.10: (a) Illustration of the τ-lepton identification and (b) the efficiency and purity as functions of the visible energies of the τ-lepton candidates. Both the efficiency and purity are determined from $e^+e^- \to ZH \to q\bar{q}\tau^+\tau^-$ events at $\sqrt{s} = 240$ GeV.

Other observations

- **Chapter 16: Timeline and Future Plans**
  - Project Timeline
  - Detector Systems Further R&D and Alternative Solutions
    - Tracking System (Vertex, Silicon Tracker, Outer Tracker, TPC)
    - Calorimetry (ECAL, HCAL)
    - Magnet System
    - Muon System
    - Readout Electronics, Trigger and Data Acquisition
    - Machine Detector Interface
    - Detector Integration and Installation
  - Extended Studies of Physics Potential
  - Software, Computing and Detector Performance Improvements
- **Chapter 17: Reference Detector Cost**
  - We can decide later if it is included in the final version and how it is included
- **Chapter 18: 2-page Summary Chapter?**

SUMMARY

The discovery of the Higgs boson in 2012 at the LHC opened up the physics case for a circular electron-positron collider operating near the Higgs-strahlung threshold at $\sqrt{s} \sim$ 240 GeV. The CEPC accelerator and detectors, described in these two volumes of the Conceptual Design Report, will deliver milestone physics results at a relevant timescale. The design is based on achievable technology, while keeping the construction cost and power consumption affordable. The CEPC Higgs measurements will by far surpass the precision of those achievable at the LHC. The ability to run the CEPC at the Z-pole and WW threshold energies will allow extremely precise measurements of the W and Z bosons. These measurements will provide stringent tests of the underlying fundamental physics principles of the SM. Together with the Higgs measurements, they will be instrumental in the exploration of new physics beyond the SM.

The CEPC accelerator operations in rather different conditions required for the CEPC physics program place demanding requirements on its detectors. The detector concepts proposed here to meet those requirements are based on complementary strategies and technologies. Together they demonstrate the capability of delivering the detector performance essential for the physics program. Further advances in the state-of-art detector technologies from now, through the Technical Design Report, and until the detector construction, are expected to make these capabilities even more feasible.

All detector concepts proposed realize the need for high-granularity calorimeters and high-precision tracking, albeit using different technologies. Two different calorimetry approaches are presented: a particle flow approach utilizing the detailed particle shower information for the jet reconstruction; or a dual-readout approach with a combined, homogeneous, detector capable of measuring simultaneously both electromagnetic and hadronic particle showers. The magnetic field strength of the detector solenoid is another differen-

tiating factor. It will need to be carefully chosen to maximize the physics output of the CEPC, balancing between the maximum luminosity achievable for the Z-pole operation and the need for high precision track momentum measurements.

While only the CEPC baseline detector concept has been studied in detail through realistic simulation, different options presented are expected to have similar capabilities. The performance results summarized in Chapters 10 and 11 demonstrate that it is possible to achieve the physics goals of the CEPC. In the coming years, the detector simulation studies will be enhanced to address specific issues requiring further optimization, while physics activities will be broadened to include flavor and QCD physics as well as new physics processes.

The detector R&D has started and will expand both in China and abroad. The international particle physics community is expected to coalesce into two collaborations to further develop the detector designs that will eventually evolve into the two experiments at the CEPC. The ultimate designs will not necessarily be the concepts proposed in this CDR, but will likely incorporate many of the detector technologies described here.

The CEPC has been identified as the top priority for the next high-energy physics (HEP) project in China by the HEP Division of the Chinese Physical Society. It has received strong supports from particle physicists at home and abroad. A significant amount of R&D funds has been received from the Chinese government for the 5-year R&D plan as described in both volumes of this CDR. During the past several years, a core team of accelerator physicists and engineers has been formed to steer the CEPC accelerator project from the R&D, through the final design, to the construction and operation. A number of candidate sites have been identified and the final site will be selected after the project receiving government approval. The particle physics community in China is steadily growing, in part through participations in both domestic and international HEP projects. The technological knowledge acquired through these participations will be invaluable for the design, construction, and operation of the CEPC detectors.

For a project of this scale, international collaboration is a key for its success. IHEP has a long history collaborating with other laboratories and universities both domestically and internationally. This CDR itself is the result of collaborative work by particle physicists around the world. The work presented has also benefited from the tools and methodologies developed in the frameworks for other international HEP programs, such as the ILC. Many of the concepts and technologies proposed for the CEPC detectors are evolutions from the ILC detector designs, adapted for a circular collider. Moreover, the detector technologies proposed benefit greatly from the R&D performed for the ILC, the HL-LHC and others.

This project aims to grow into a truly worldwide endeavor, with international collaboration for both the accelerator and the detectors. A CEPC International Advisory Committee consisting of two dozen world renowned HEP physicists meets once a year in Beijing to offer valuable advices about the project. The collaboration with several other proposed future collider projects – the ILC, CLIC and FCC – includes visitor exchanges, jointly organized workshops (e.g., the ICFA eeFACT workshop series on high luminosity circular e^+e^- colliders), and accelerator schools.

The Chinese government has announced an ambitious plan to establish several large international scientific research centers in China in the coming decade. The CEPC is a strong and viable candidate. The Chinese particle physics community together with

Other observations

- **Chapter 16: Timeline and Future Plans**
  - Project Timeline
  - Detector Systems Further R&D and Alternative Solutions
    - Tracking System (Vertex, Silicon Tracker, Outer Tracker, TPC)
    - Calorimetry (ECAL, HCAL)
    - Magnet System
    - Muon System
    - Readout Electronics, Trigger and Data Acquisition
    - Machine Detector Interface
    - Detector Integration and Installation
  - Extended Studies of Physics Potential
  - Software, Computing and Detector Performance Improvements
- **Chapter 17: Reference Detector Cost**
  - We can decide later if it is included in the final version and how it is included
- **Chapter 18: 2-page Summary Chapter?**

A slightly different proposal from Jianchun:

Quick personal understanding of status

Chapter	Introduction	Quality (first impressions)
Executive summary	OK	Can be improved but good enough for now
1 Introduction	50%	Should follow the description in backup. More details overall and references
2 Concept of CEPC Reference Detector	50%	Expand to include justification for the concept and tracker and calorimeter integration
3 MDI and Luminosity	?	Need to read
4 Vertex Detector	80%	Does not follow proposed structure. Needs improvements
5 Silicon Trackers	80%	Too wordy. Introduction does not follow structure. Need re-ordering. Optimization. Figures
6 Pixelated Time Projection Chamber	70%	Does follow structure. Seems to need work
7 Electromagnetic calorimeter		Does not follow structure. Overview should cover baseline design
8 Hadronic calorimeter	?	Totally re-written, much improved → need to read in detail
9 Muon Detector		Does not follow structure. Text can likely be further reduced
10 Detector magnet system	70%	Comments already provided. Needs more work overall.
11 Readout Electronics		Some too small figures. Does not follow structure. Likely diving into too much details
12 Trigger and Data Acquisition		Looks good. Needs to reference to detectors. Not sure it does
13 Offline software and computing	95% ?	Looks good but need to check details. A bit long
14 Mechanics and integration		Much improved relative to last version
15 Detector and physics performance		Object performance still not clear. Needs work
16 Timeline and Future Plans		
17 Detector Costing		

The end

Introduction Chapter Outline

- Overview of the context for the CEPC, link to the accelerator TDR, and overview of full TDR document
- Chapter 1.1: Physics Case (~5 pages)
  - Higgs, electroweak, QCD physics, flavor physics, new physics searches, outlook for top physics at upgraded
- Chapter 1.2: Collider and Experimental Environment
  - Operation modes (do we talk about upgrades?)
- Chapter 1.3: Detector concept and TDR organization
  - Detector challenges
- Chapter 1.4: Performance and physics benchmarks
  - Summary table of physics benchmarks, reference chapter
- Chapter 1.5: Future plans and outlook (2 paragraphs)

Chapter 1.1: Physics Case

- CEPC precision frontier
- Higgs boson and electroweak symmetry breaking
  - Naturalness
  - Electroweak phase transition
- Exploring new physics
  - Exotic Higgs boson decays, Exotic Z boson decays, Dark matter and hidden sectors, Neutrino connection, Extended Higgs sector
- QCD precision measurement
  - Precision α_s determination, Jet rates at CEPC, Non-global logarithms, QCD event shapes and light quark Yukawa coupling
- Flavor Physics with the Z factory of CEPC
  - Rare B decays, Tau decays, Flavor violating Z decays

Introduction Chapter Goals

- Overview of the full TDR document
- Overview of the current context for the CEPC
- Brief Physics Case → mostly references to the White Papers
- Collider and Experimental Environment
- Brief introduction of the detector concept and explanation about the R&D stages and extensions
- Brief summary of performance and physics benchmarks
- Future plans and outlook (2 paragraphs)

Suggest to change name of chapter from "Physics Goal and Requirements" to simply "Introduction"

In addition, we need a brief Executive Summary

Summary of status

Chapter	Overall Complete (%)	Chapter structure	Tables		Figures	
			Unified format	Significant digits 有效数字	Change to pdf format	Enlarge the font size in figure
Executive summary						
1 Introduction						
2 Concept of CEPC Reference Detector						
3 MDI and Luminosity	90%	100%				
4 Vertex Detector	90%	100%	90%	95%	50%	70%
5 Silicon Trackers	100%	100%				
6 Pixelated Time Projection Chamber						
7 Electromagnetic calorimeter	95%	100%	95%	95%	50%	95%
8 Hadronic calorimeter	90%	100%	90%	90%	50%	80%
9 Muon Detector						
10 Detector magnet system	100%					
11 Readout Electronics	100%	100%	90%	90%	50%	80%
12 Trigger and Data Acquisition						
13 Offline software and computing	100%	100%	100%	100%	90%	90%
14 Mechanics and integration	100%					
15 Detector and physics performance						
16 Timeline and Future Plans						
17 Detector Costing						