Progress of the CEPC detector R&D

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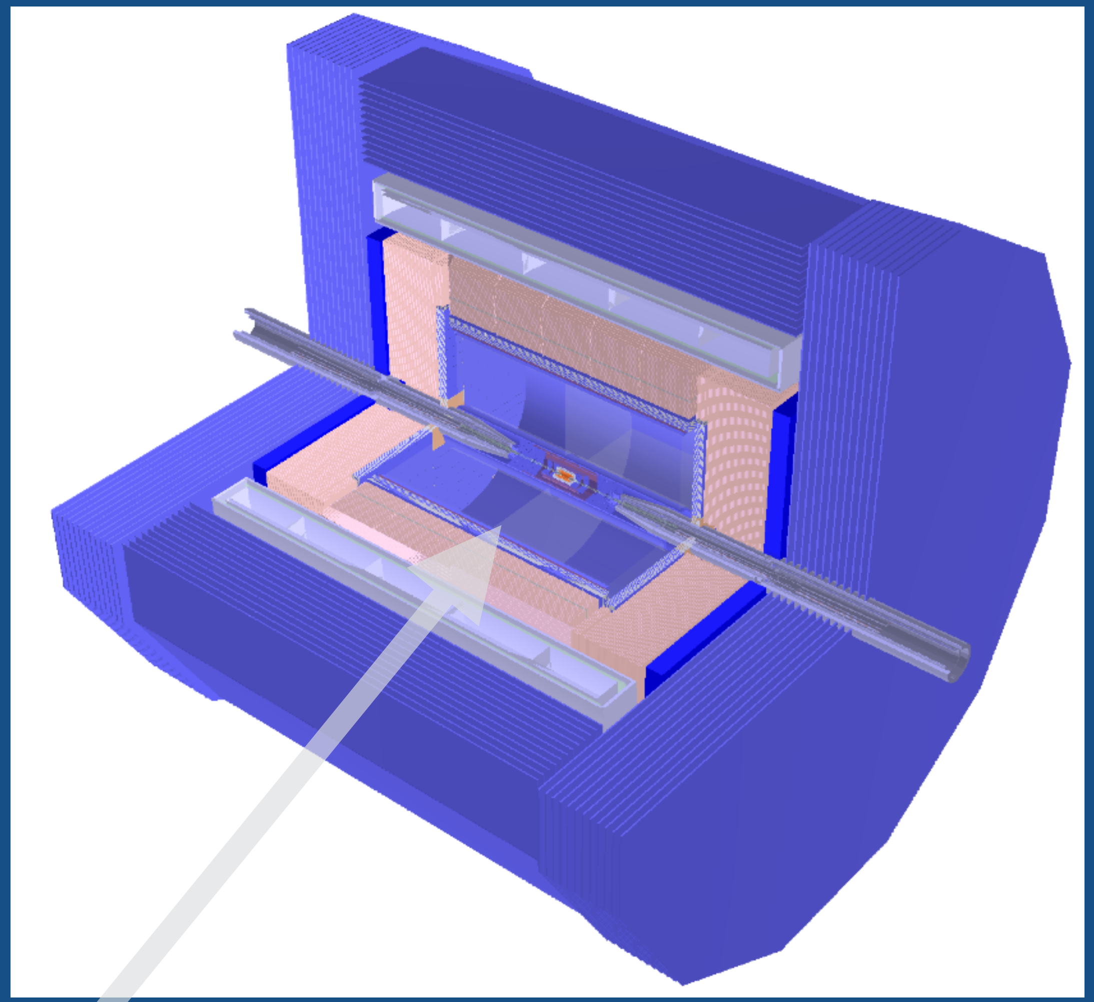
Joint Workshop of the CEPC Physics, Software and New Detector Concept
Yangzhou, April 14, 2021

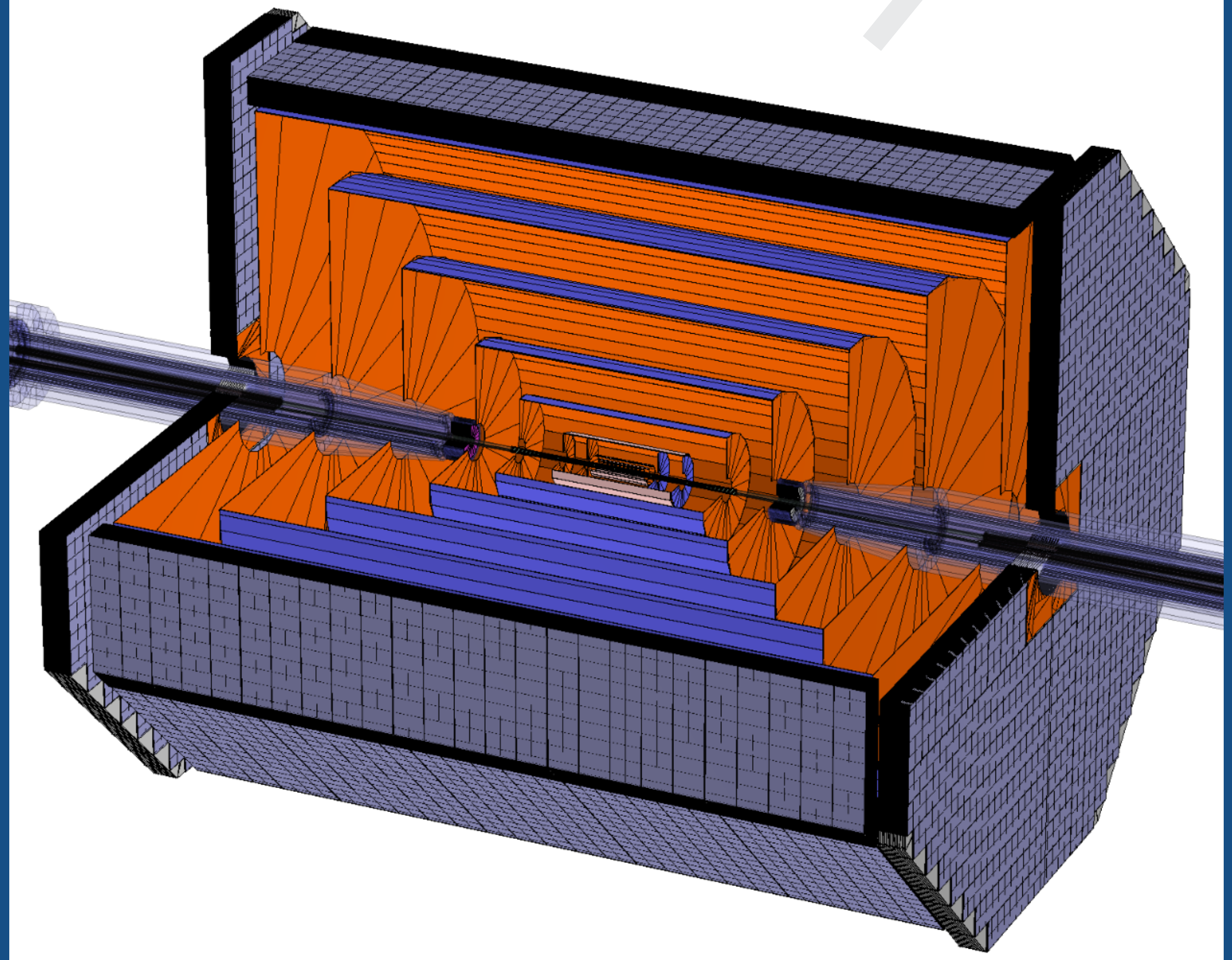
CEPC Detector Concepts studied for CDR

2 interaction points

Particle Flow Approach

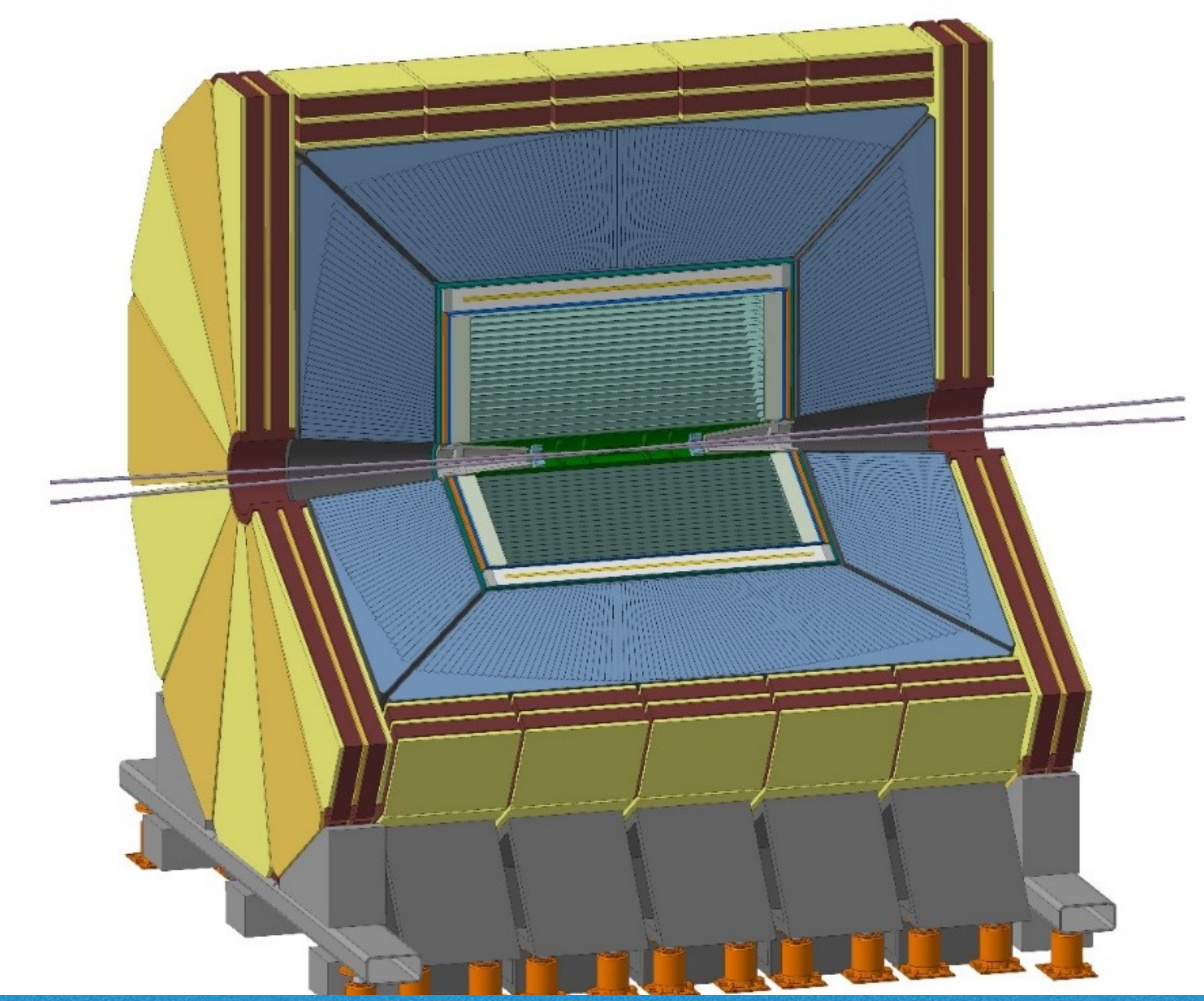
High magnetic field concept (3 Tesla)





Full silicon tracker concept

Low magnetic field concept (2 Tesla)



IDEA Concept

also proposed for FCC-ee

Final two detectors WILL be a mix and match of different options

CEPC Detector Concepts studied

2 interaction points

Particle Flow Approach

High
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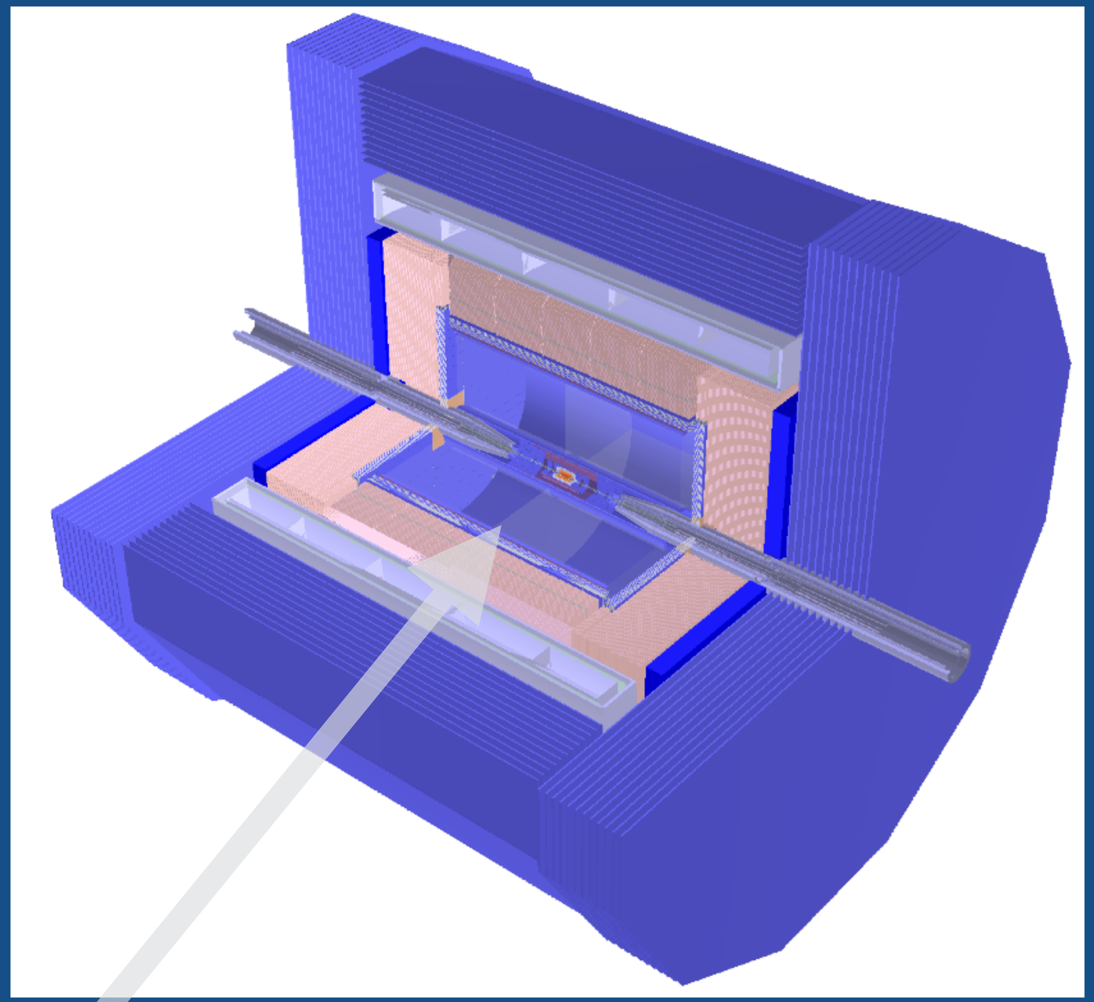
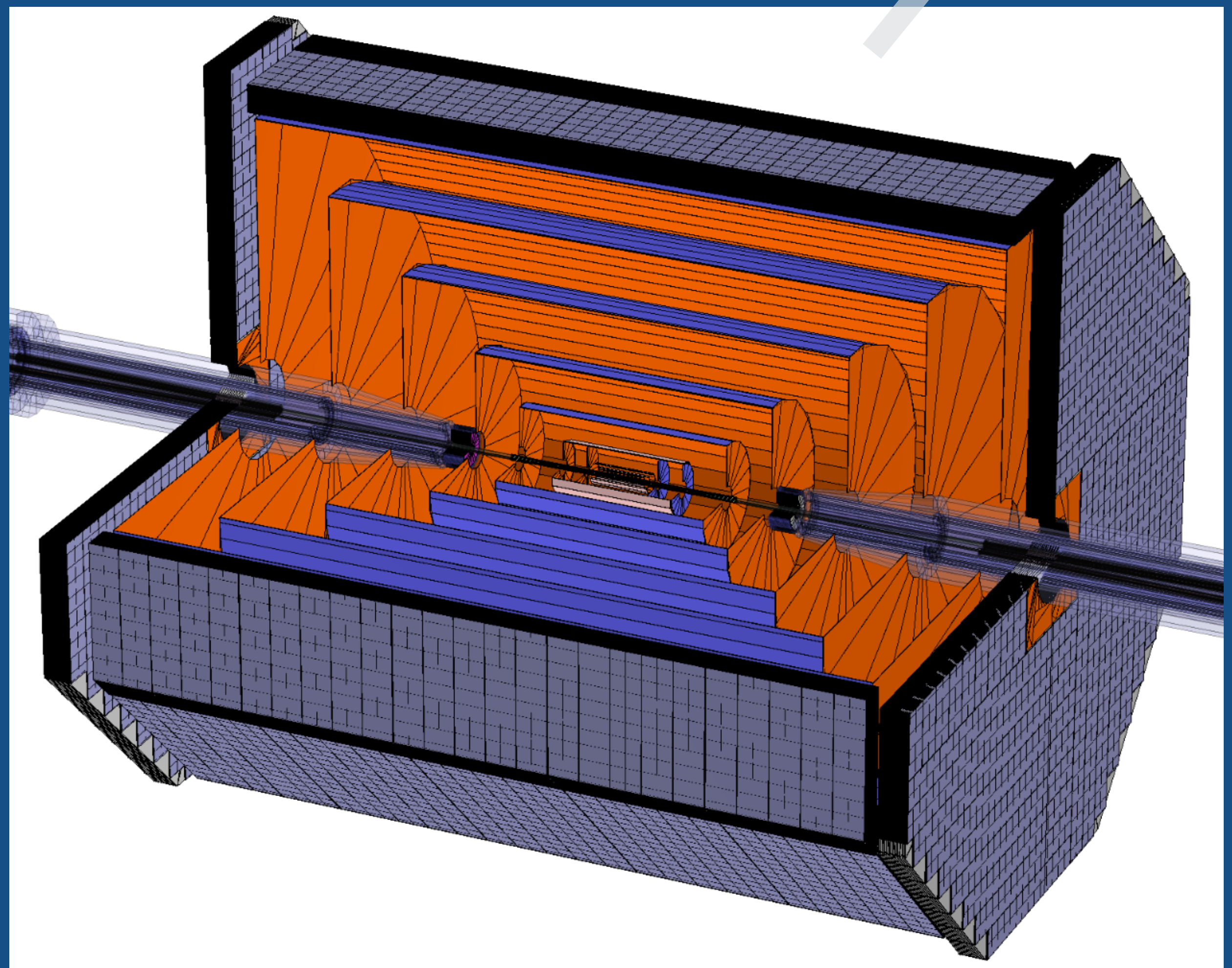
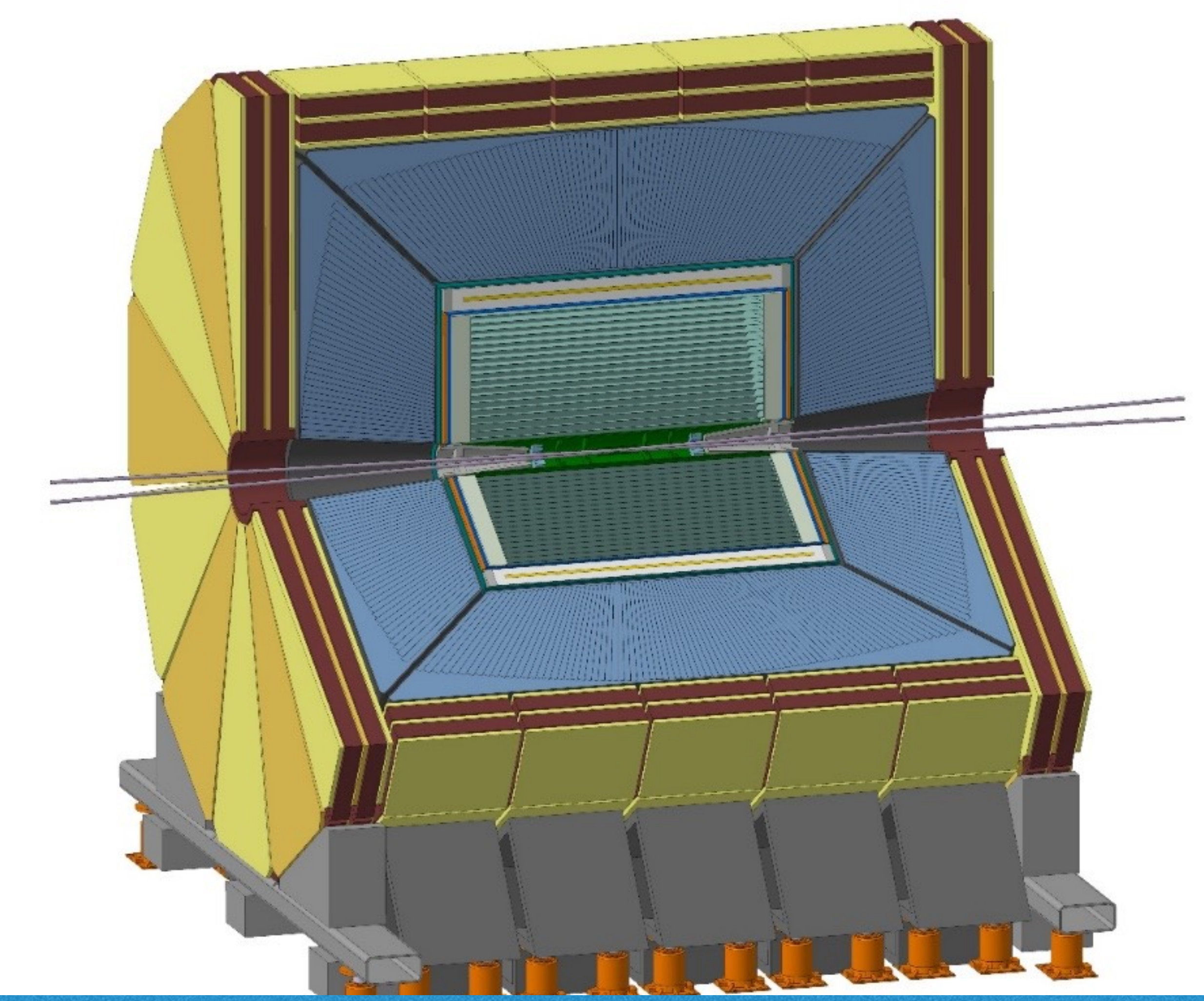




Full silicon
tracker
concept

Low
magnetic field
concept
(2 Tesla)



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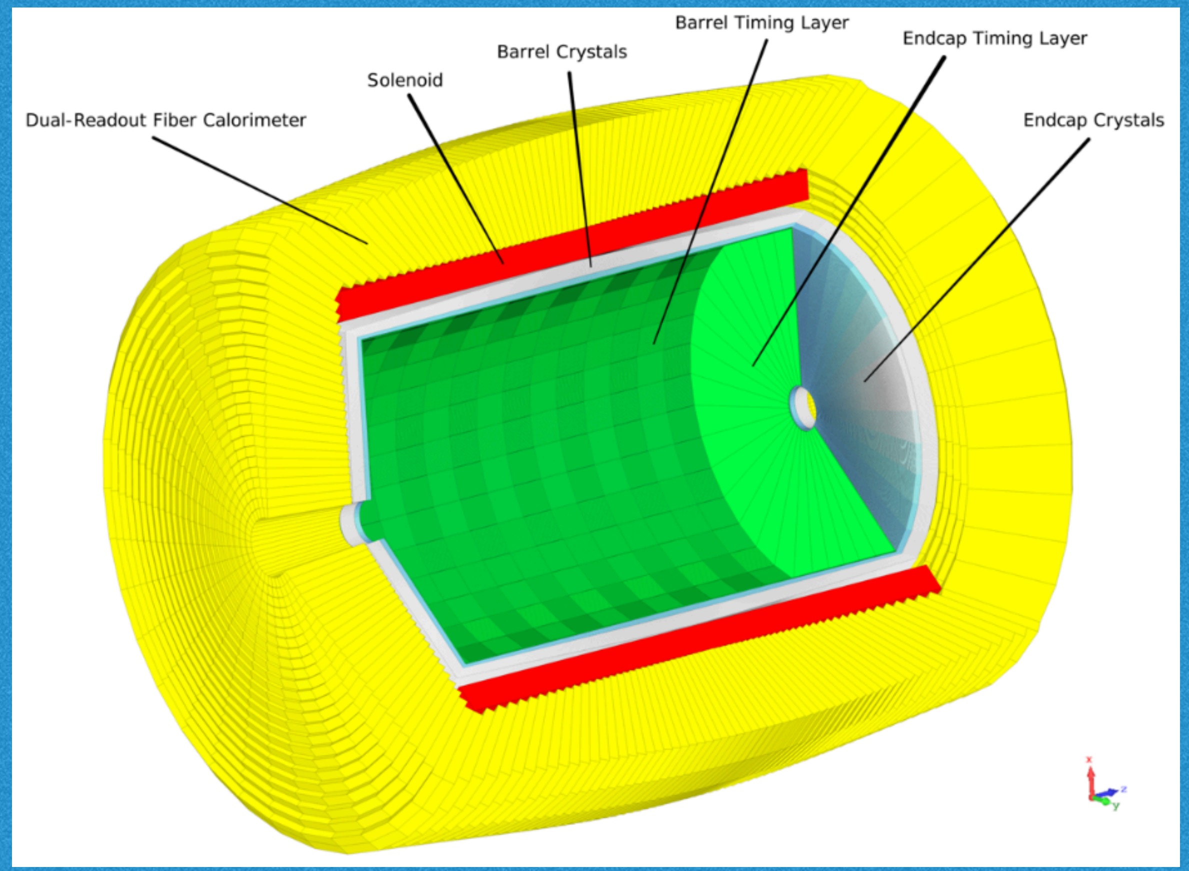


Crystal Calorimeter
based detector
(2-3 Tesla)

News reported at this workshop

Final two detectors WILL be a mix and match of different options

Detector R&D Major R&D Breakdown

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

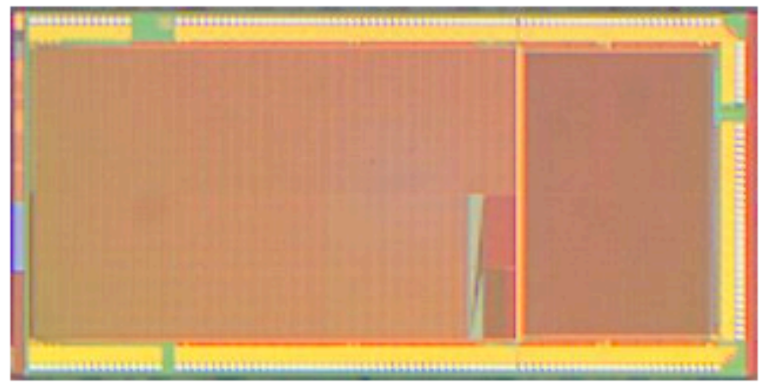
Total of 103 sub-tasks identified

CEPC CMOS Pixel Sensor Development

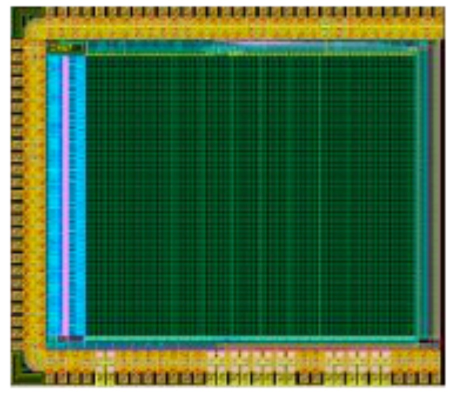
	JadePix1 (2015)	JadePix2 (2017)	MIC4	JadePix3 (2019)
Architecture	Roll. Shutter + Analog output →	Roll. Shutter + In pixel discri.	Data-driven r.o. + In pixel discri.	Roll. shutter + end of col. priority encoder
Pitch (μm²)	33 × 33 /16 × 16	22 × 22	25 × 25 →	16 × 26 16 × 23.11
Power con. (mW/cm²)	--	--	150 →	~ 55*
Integration time (μs)*	--	40-50	~3	~100
Prototype size (mm²)	3.9 × 7.9 (36 individual r.o)	3 × 3.3	3.1 × 4.6 →	10.4 × 6.1
Main goals	Sensor optimization	Small binary pixel	Small pixel + Fast readout+ nearly full functional	Smaller pixel + Low power + fully functional

* Assuming a matrix of 512 × 1024 pixels

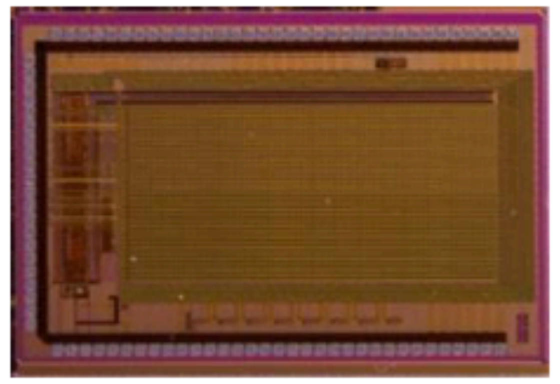
All prototypes in TowerJazz 180 nm process



JadePix1 (IHEP)



JadePix2 (IHEP)



MIC4 (CCNU & IHEP)

JadePix3 (IHEP, CCNU, Dalian Minzu Unv., SDU)

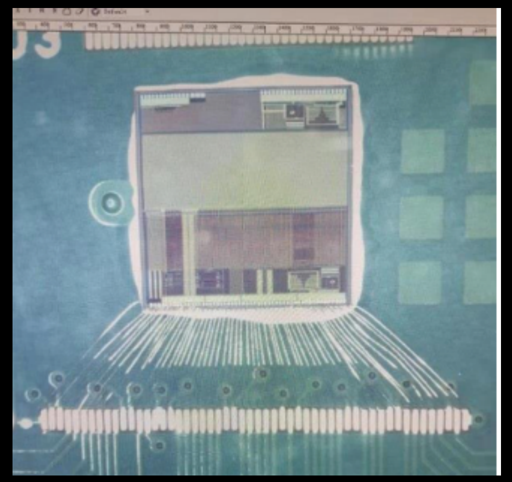
TaichuPix-1 TaichuPix-2

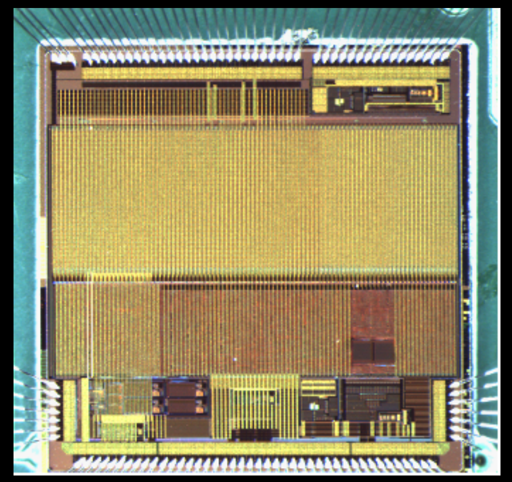
FE-I3-like and ALPIDE-like pixel

Pitch: 25/24 × 25 μm²

Power: 100-150 mW/cm²

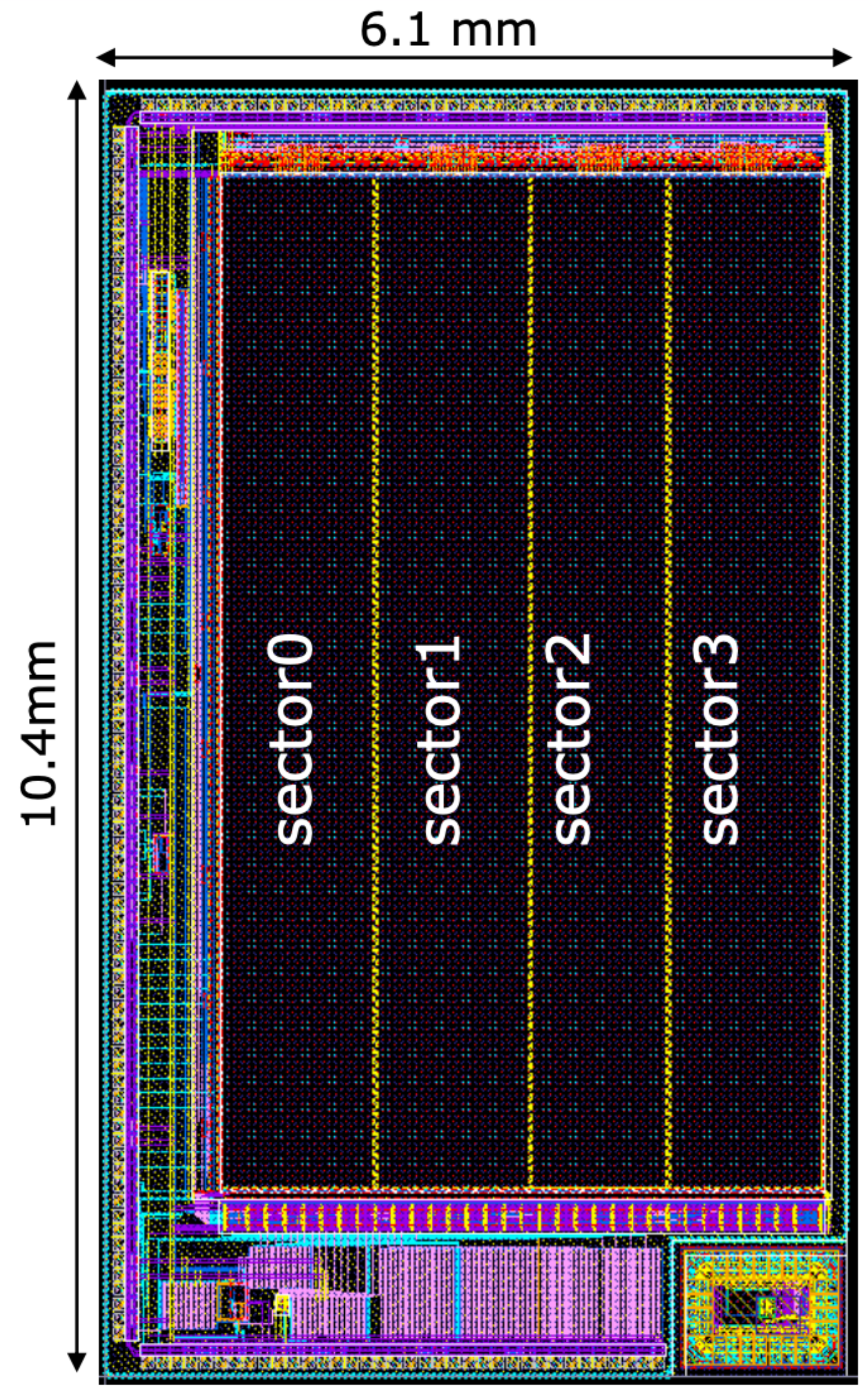
Size: 5 × 5 mm²





IHEP, SDU, NWPU, IFAE & CCNU

CEPC CMOS Pixel Sensor Development: JadePix3



- **Rolling shutter** to avoid heavy logic and routing in the column-wise
  - Shrink the pixel size by ~ 7 μm
- **Full-sized** in the φ direction
  - Matrix coverage: 16 μm * 512 rows = 8.2 mm
  - Matrix readout time: 192ns/row * 512 rows = **98.3 μs/frame**
- **Extensible** in the z direction
  - 48 columns * 4 sectors

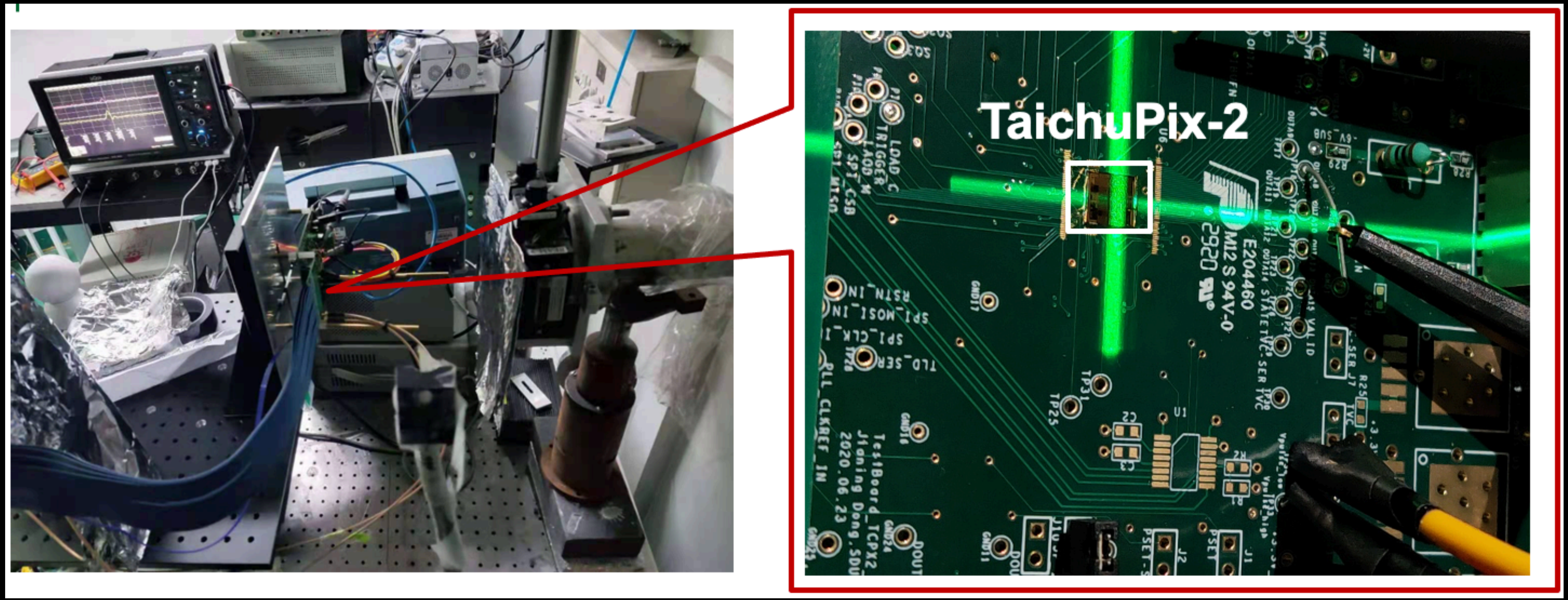
Sector	Diode	Analog	Digital	Pixel layout
0	2 + 2 μm	FE_V0	DGT_V0	16×26 μm²
1	2 + 2 μm	FE_V0	DGT_V1	16× 26 μm²
2	**2 + 2 μm**	**FE_V0**	**DGT_V2**	**16× 23.11 μm²**
3	2 + 2 μm	FE_V1	DGT_V0	16×26 μm²

Recent measurements:

- Performance consistent with the design targets
  - Low threshold and noise
  - Single point resolution 3 ~ 5 μm , obtained with laser
  - Low power < 100 mW/cm² , when extrapolated to FS sensor
  - Integration time < 100 μs

MOST project goals achieved

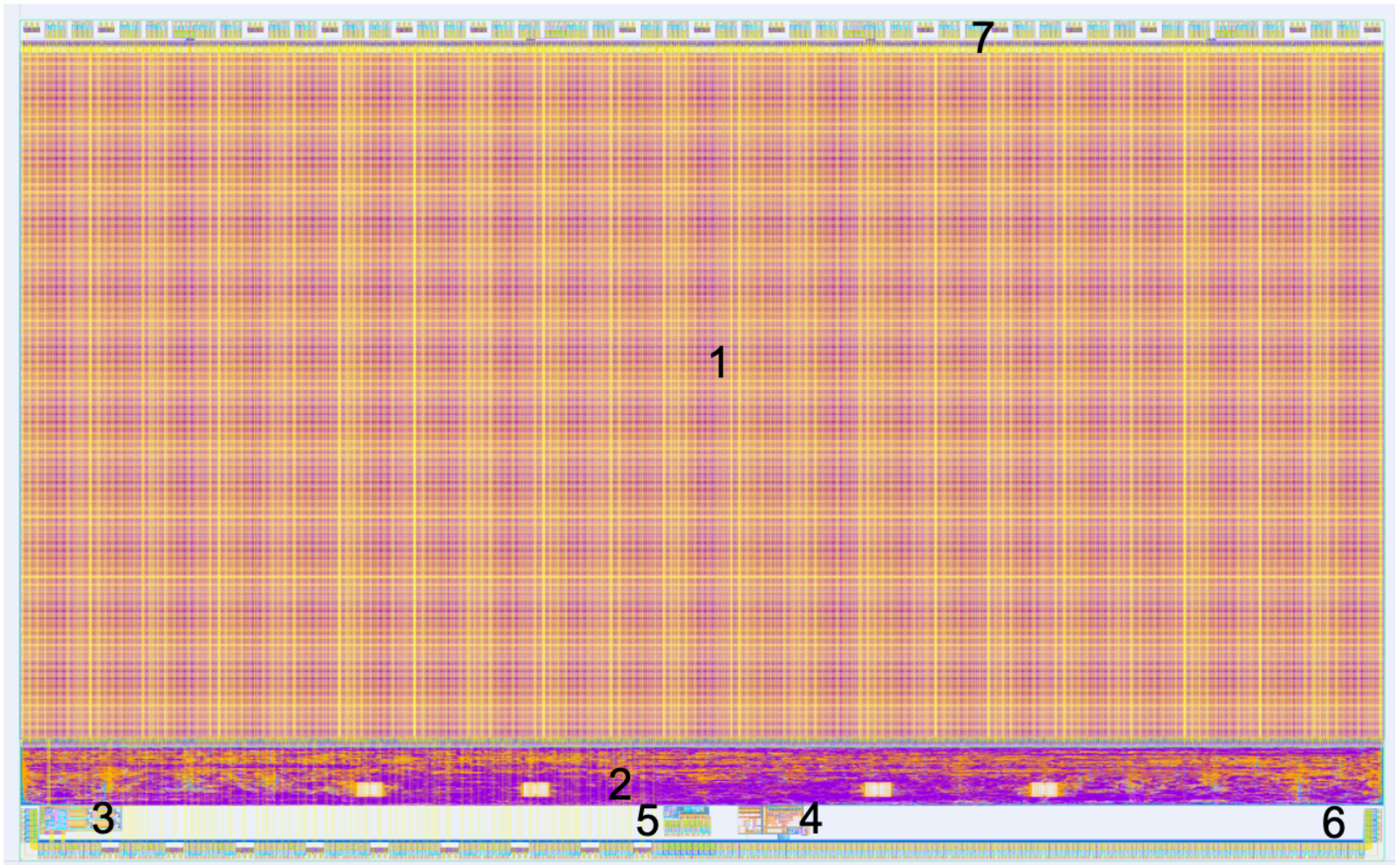
CEPC CMOS Pixel Sensor Development: TaichuPix



TaichuPix-2 irradiated at BSRF 1W2B beamline (6 keV X-ray)

Good chip function and noise performance proved up to 2.5 Mrad, and no deterioration observed up to 30 Mrad TID

MOST project goals achieved



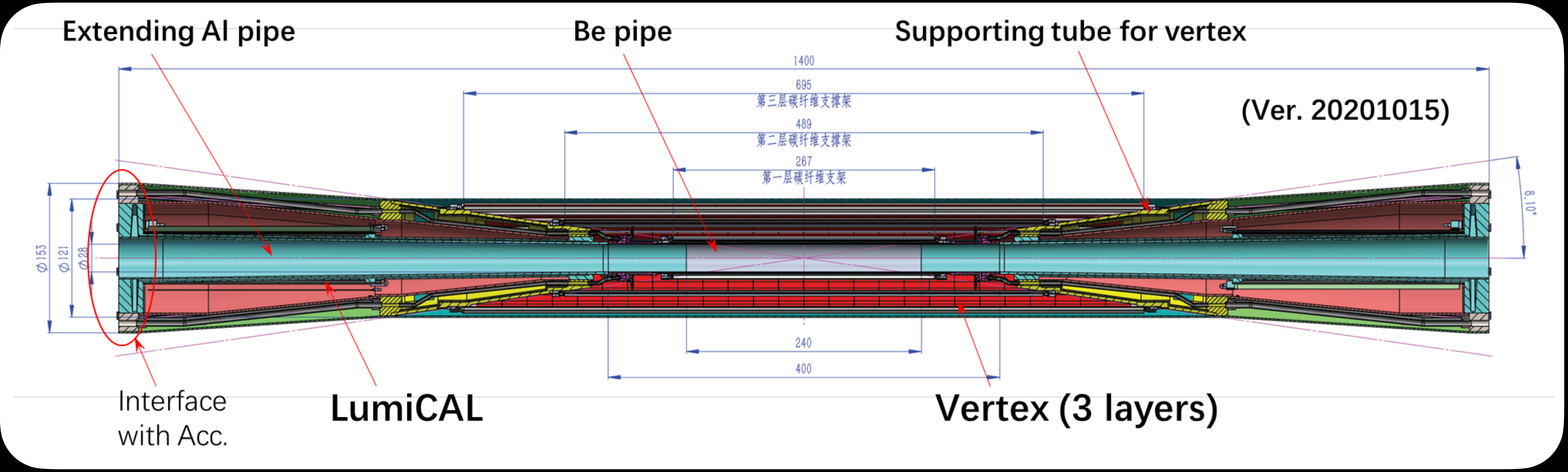
1. Pixel array 1024*512
2. Periphery
3. DAC & Bias generation
4. Data interface
5. LDO (test blocks)
6. Chip inter-connection features
7. Scribe-able top power connection features

Full size chip ready to submit next month

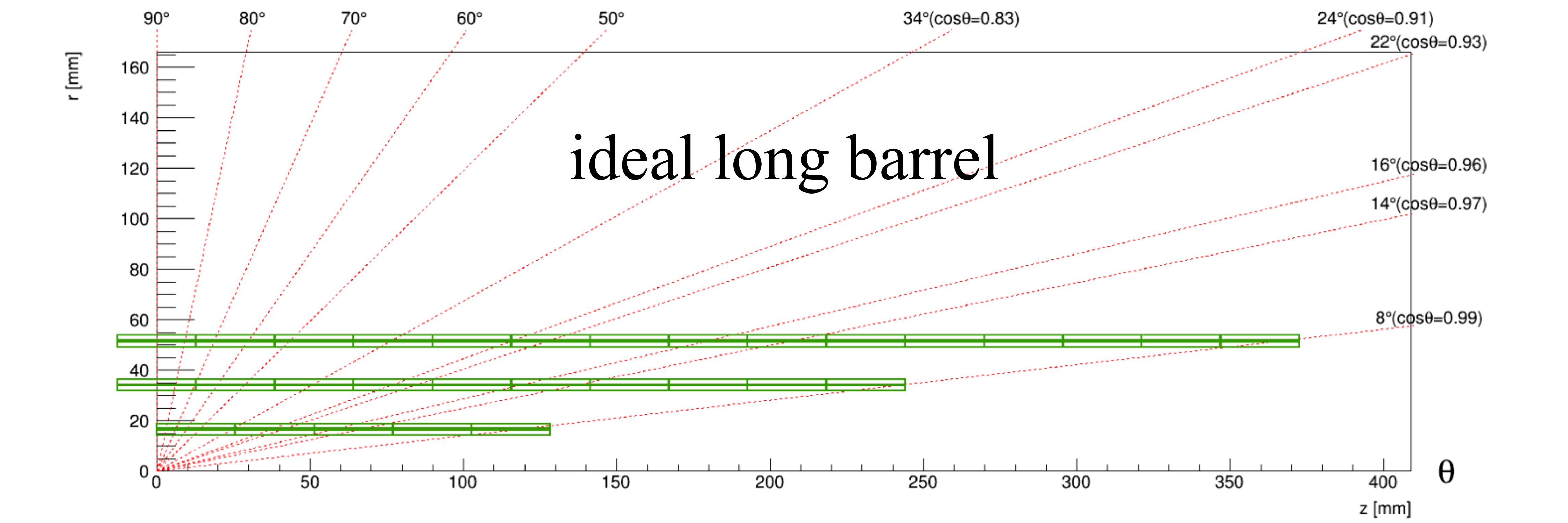
Engineering run for Pixel Vertex detector prototype

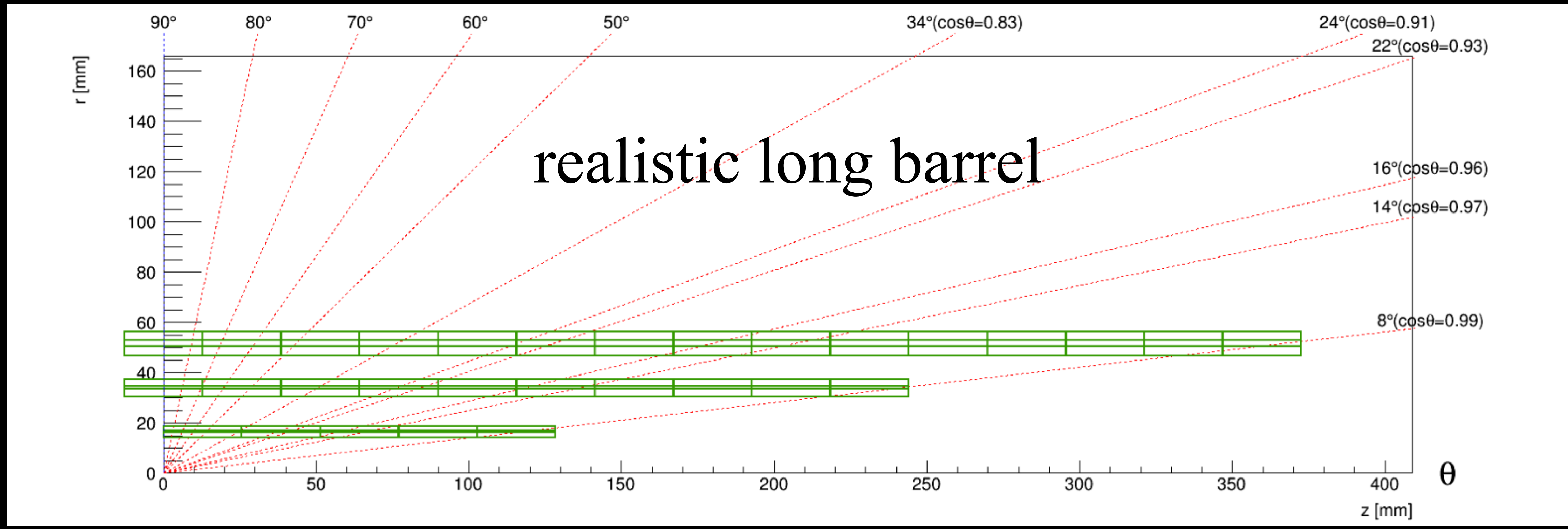
Trigger mode: <100 mW/cm^2
Triggerless mode: 150 mW/cm^2

Pixel Vertex Detector Optimization: Long Barrel Design



- **Positives:**
  - Better solution for air cooling
  - Simple structure
- **Negatives:**
  - Possible vibration of long ladder
  - Stiffer ladder support
  - More readout copper in center





2-layer flex

	Thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

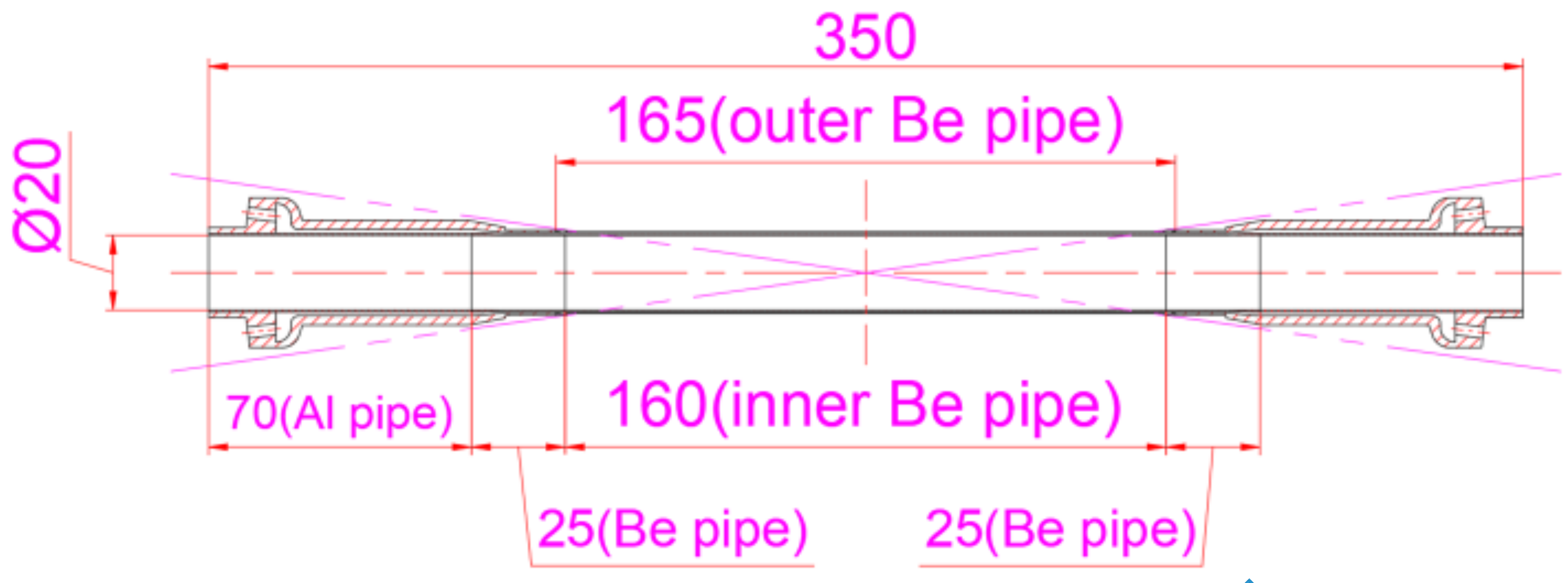
4-layer flex

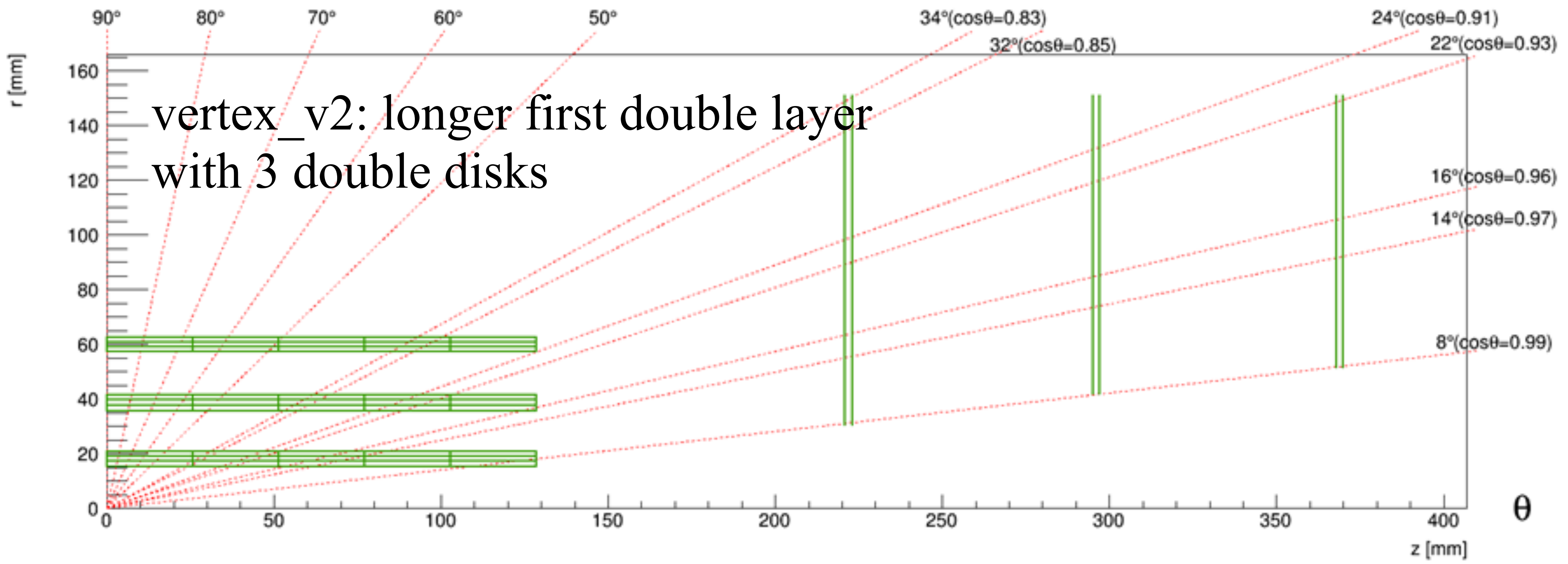
	thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
kapton+adhesive	50um	50
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

Pixel Vertex Detector Optimization:

New beampipe 20mm diameter

Detailed structure of the central beryllium pipe





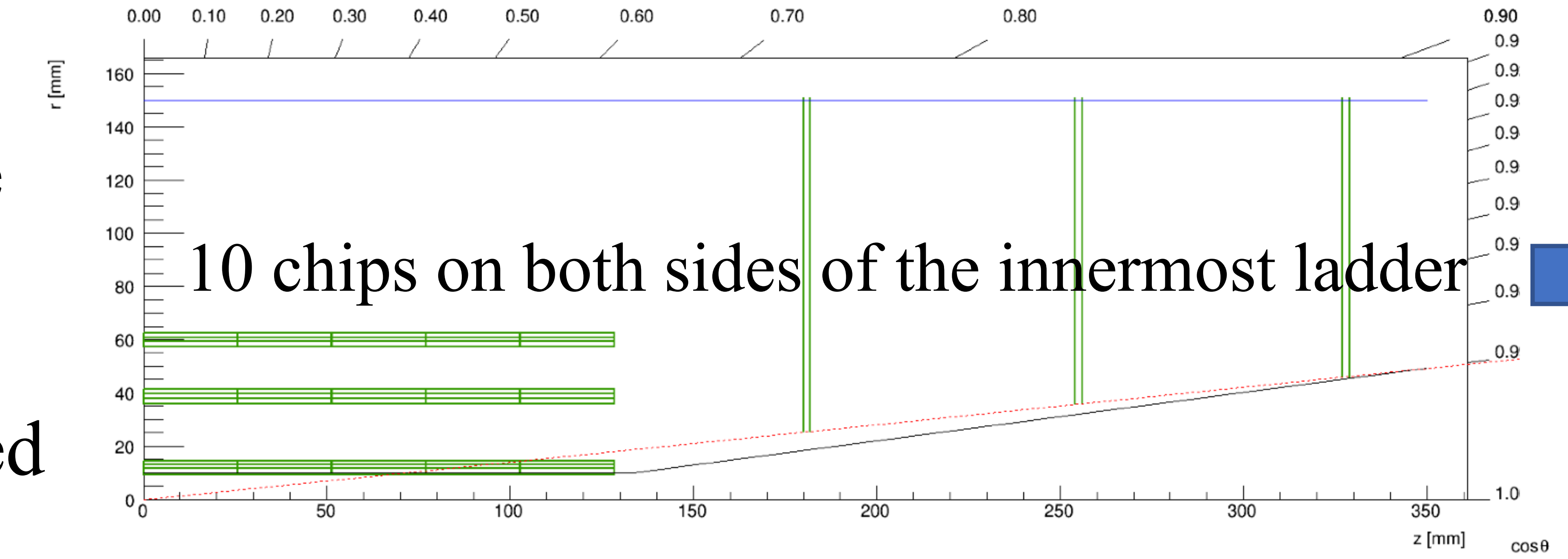
According to processing capacity:

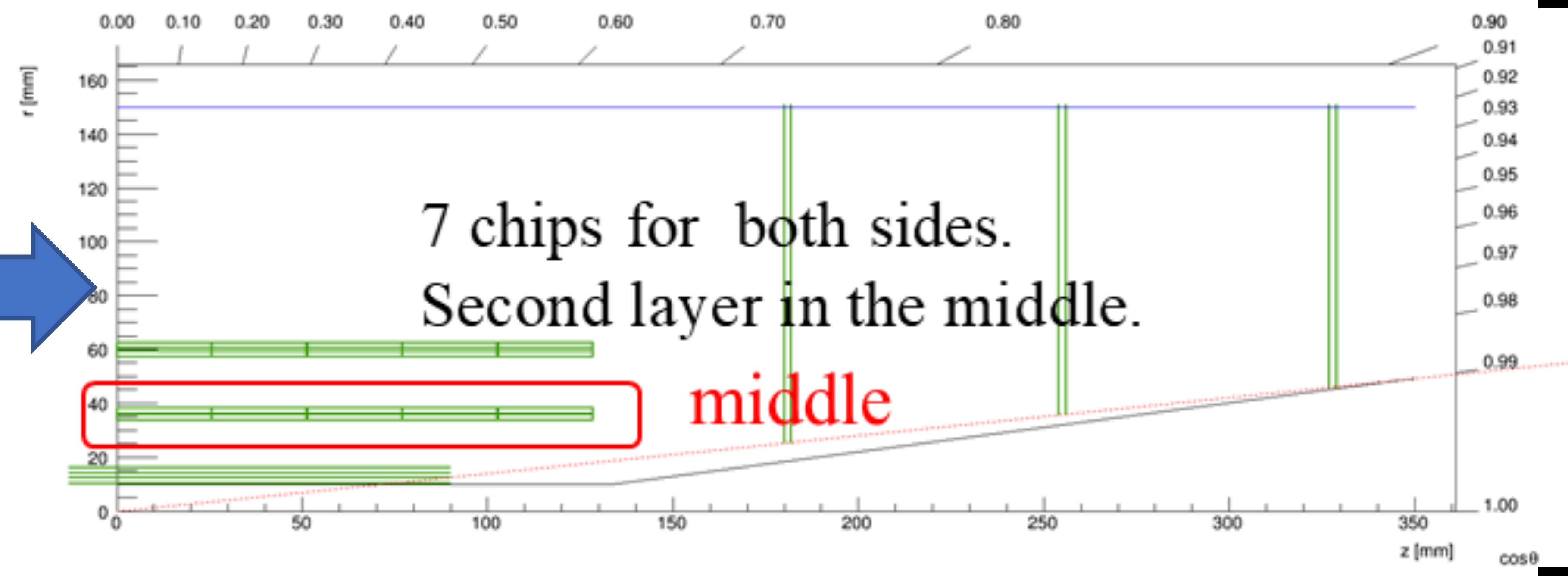
Inner Be pipe: 0.20mm thick, 210(25+160+25)mm long

Outer Be pipe: 0.15mm thick, 165mm long

Innermost layer will be inside the boundary line, which defines the vertex detector coverage.

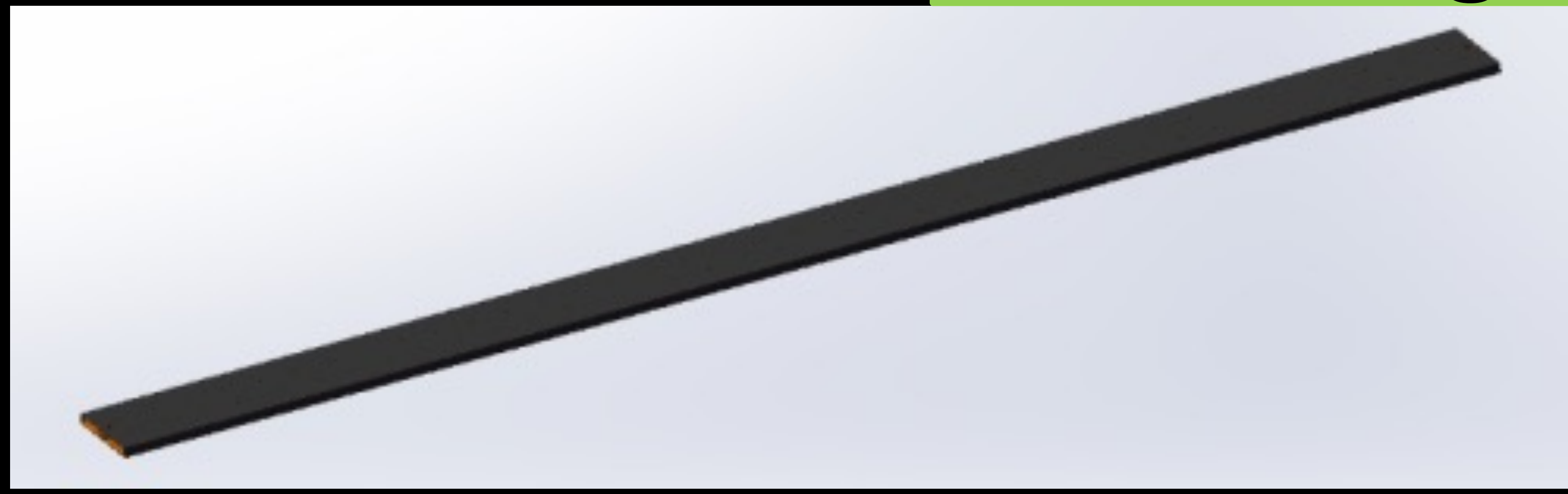
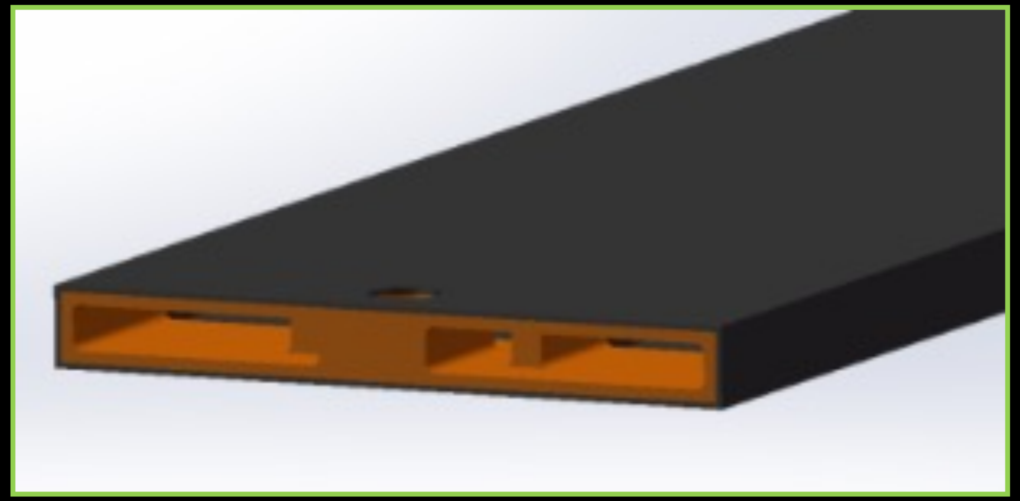
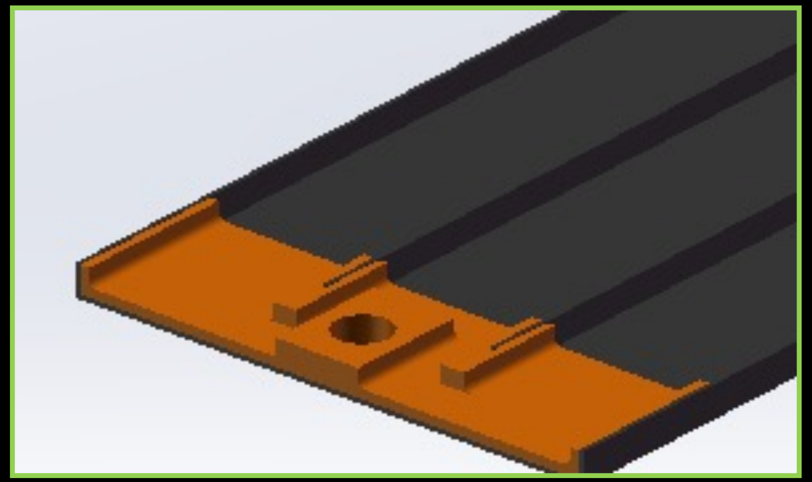
Shorter innermost layer is required



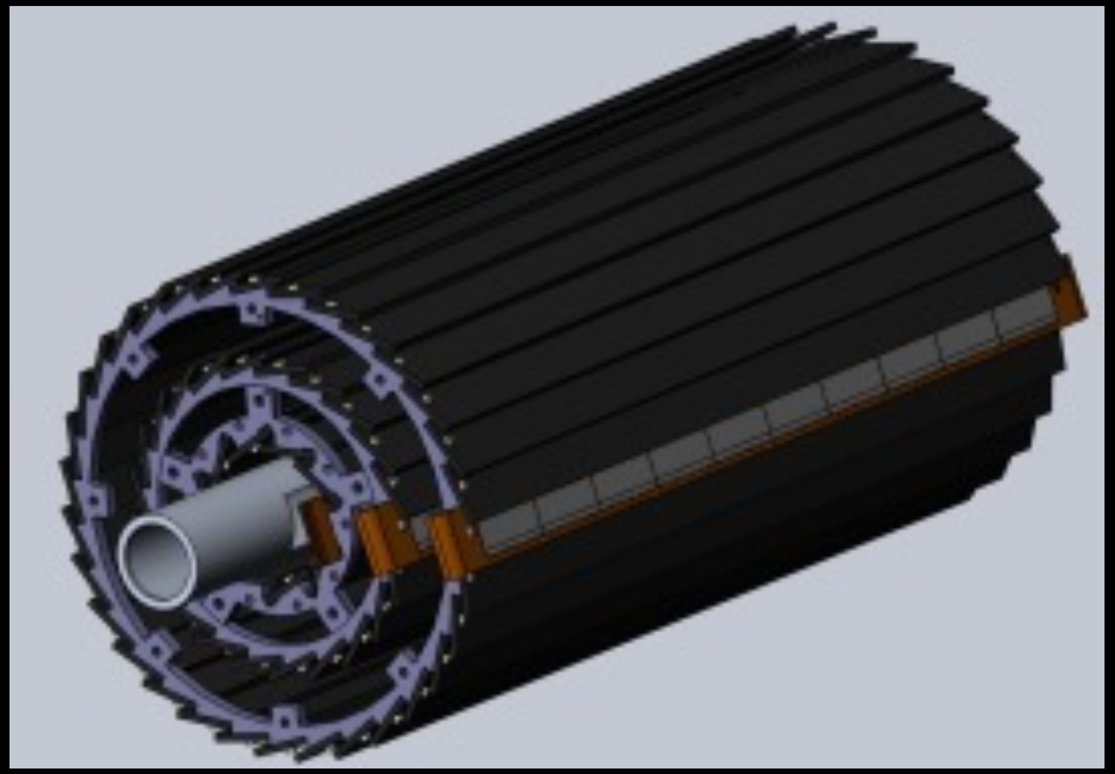
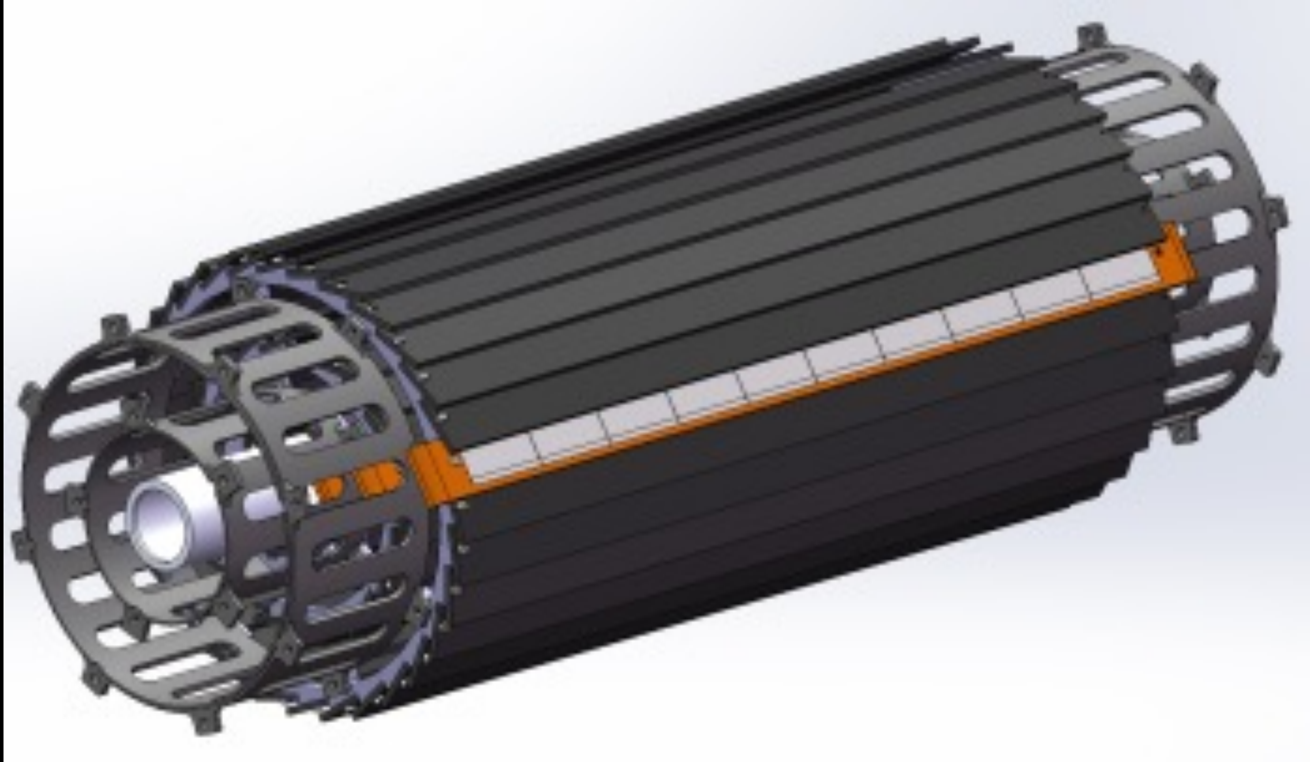
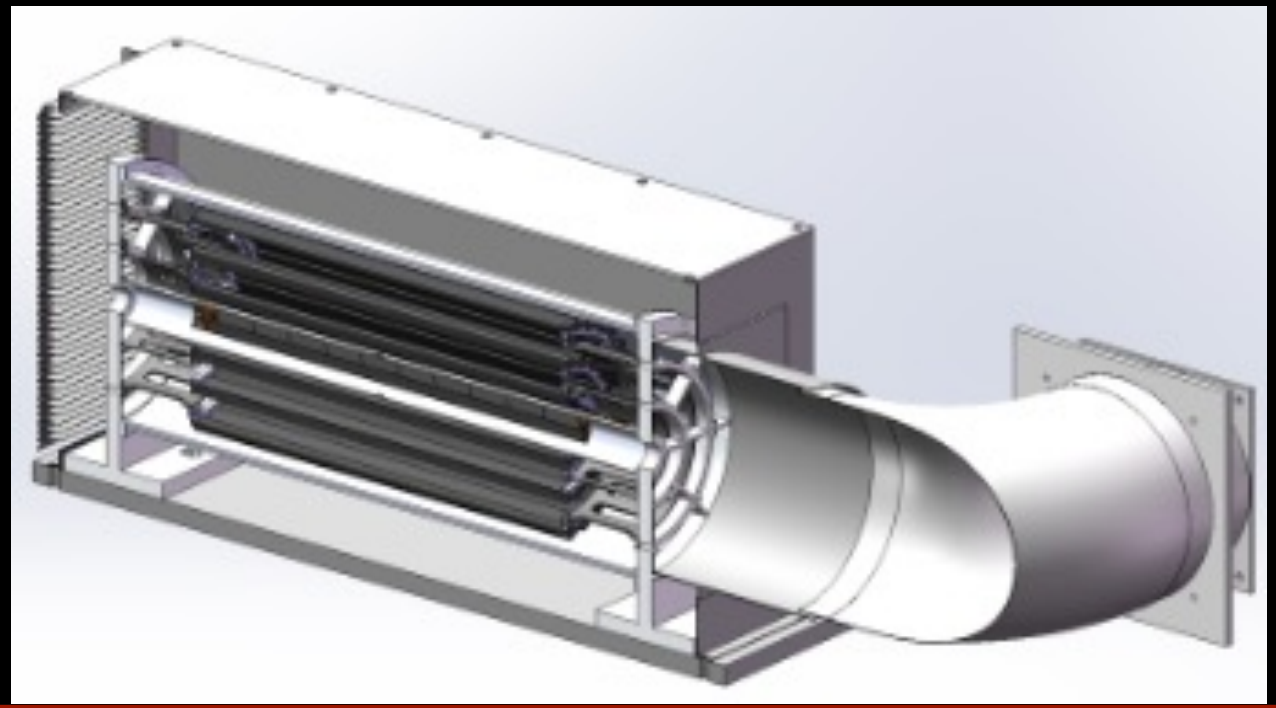


Pixel Vertex Detector Prototype: Mechanics

The design model of ladder support

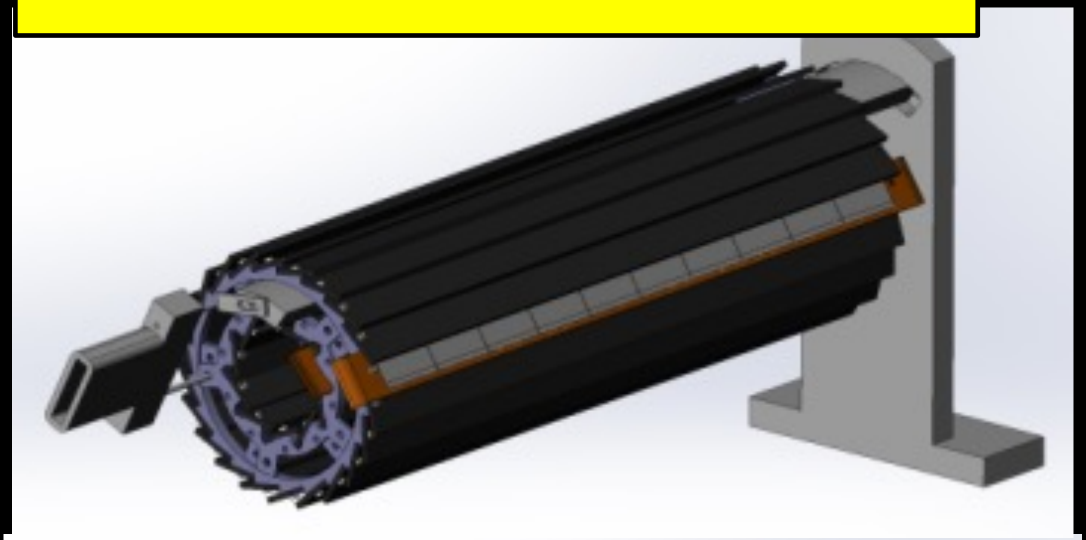
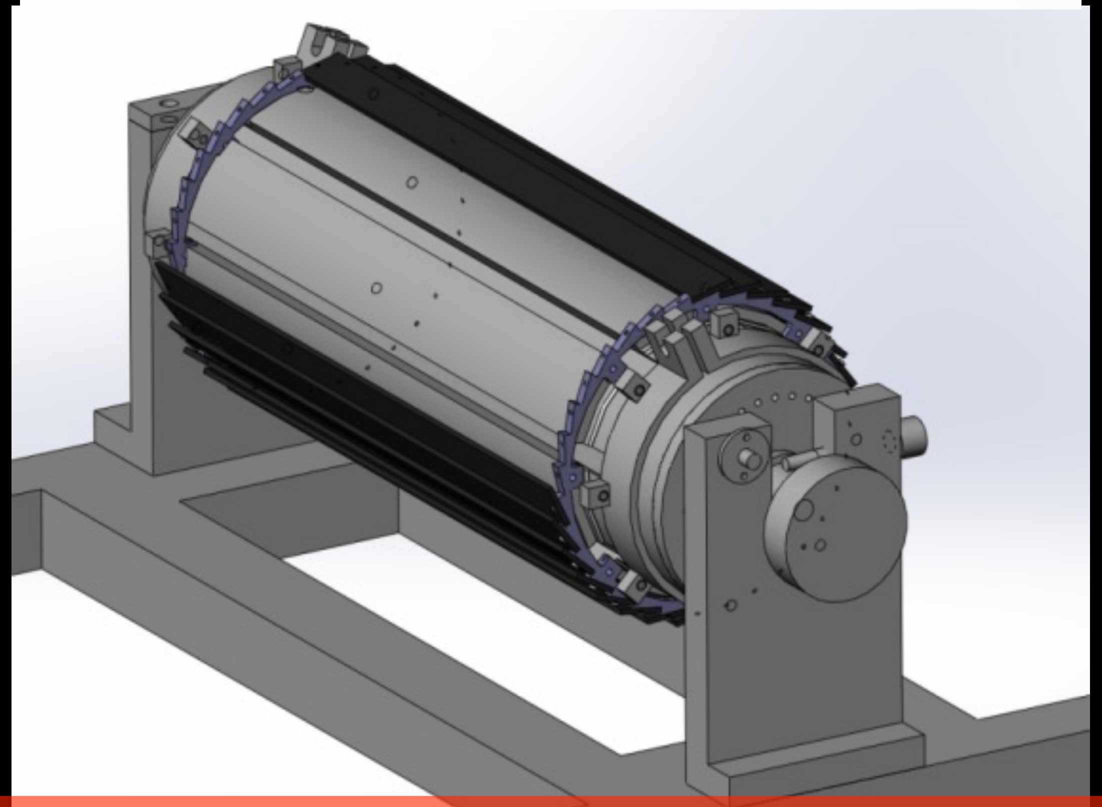





Vertex Detector Structure

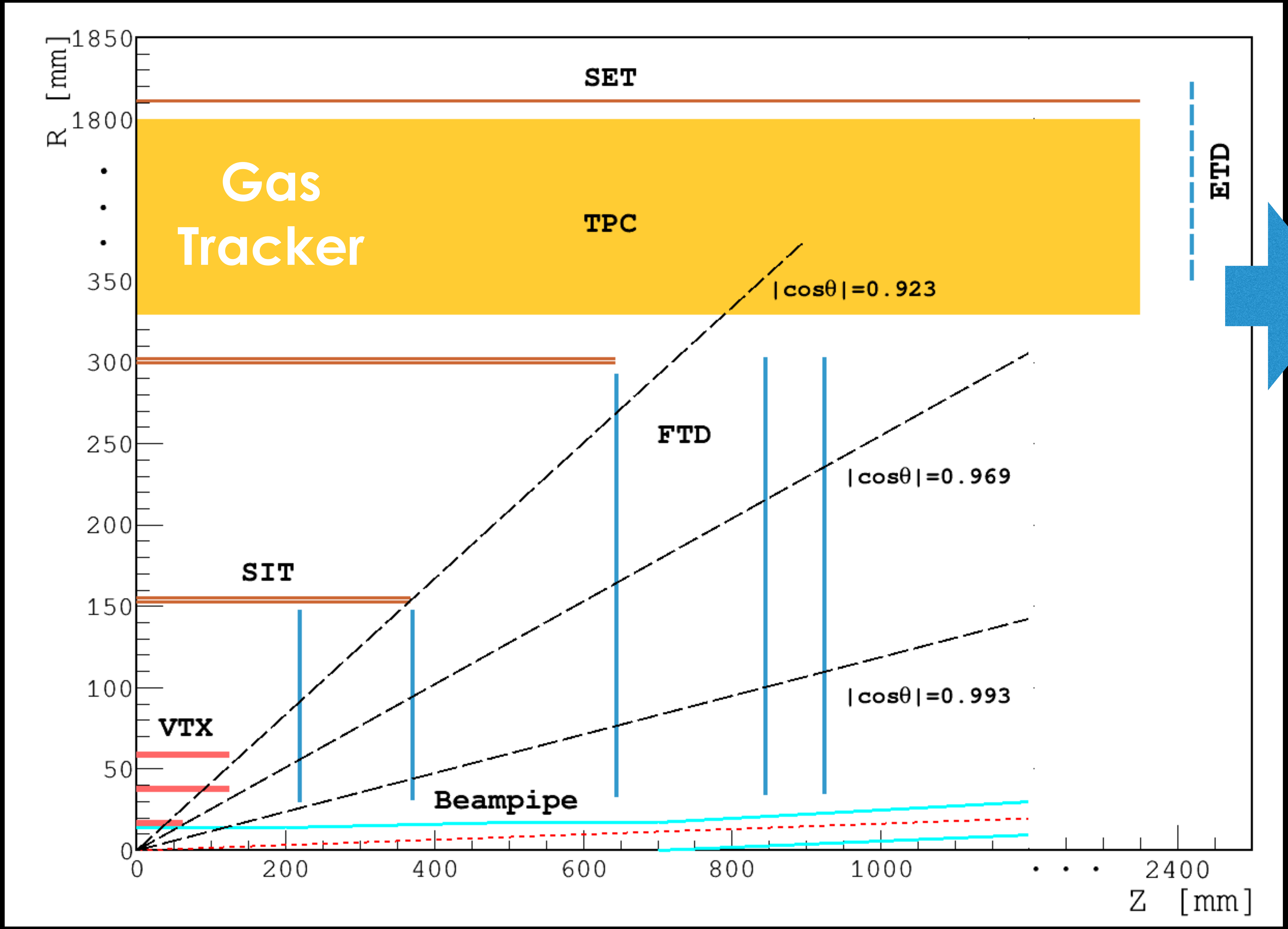
Assembling Tooling

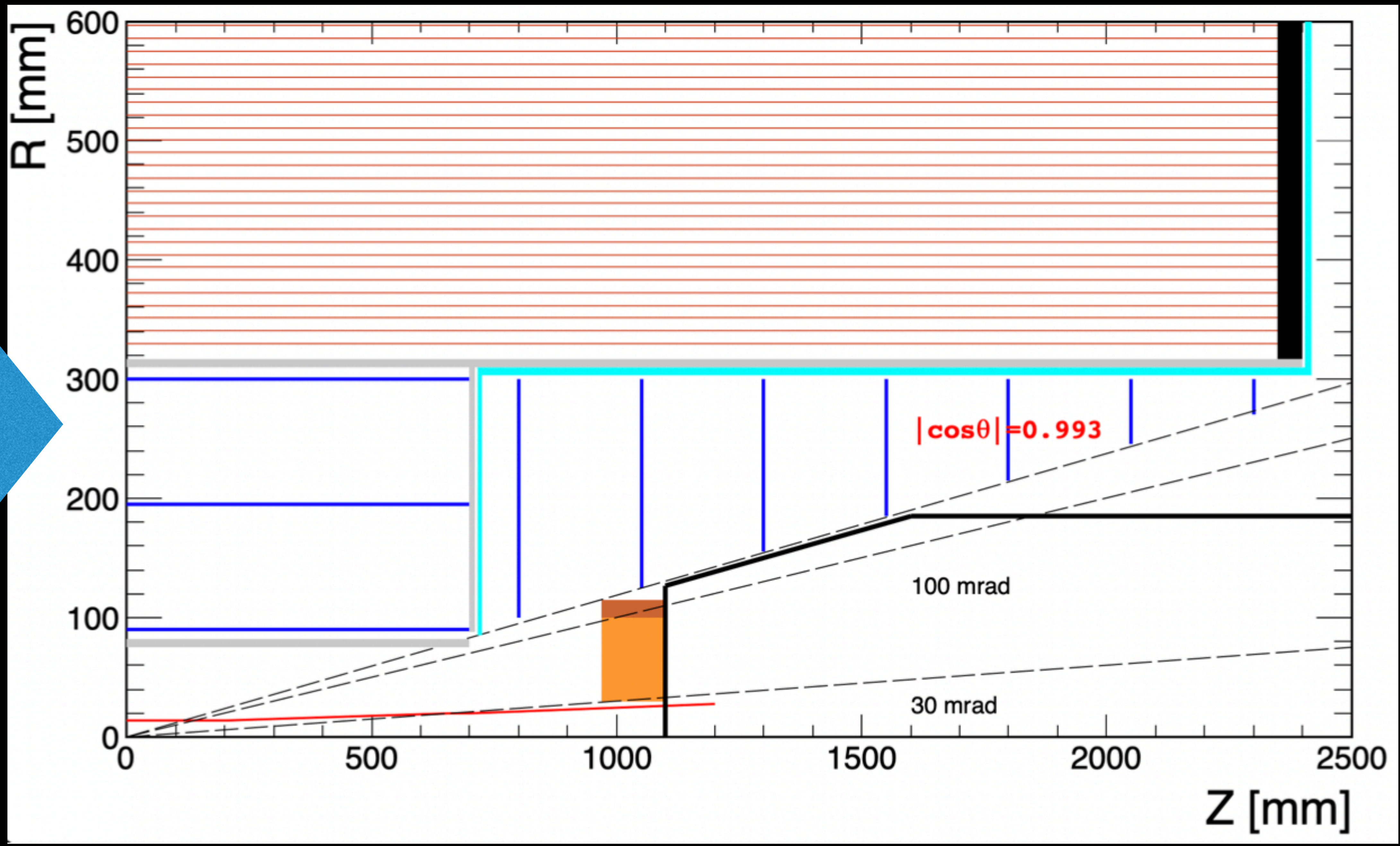
Inner and middle barrels combination and customized tool

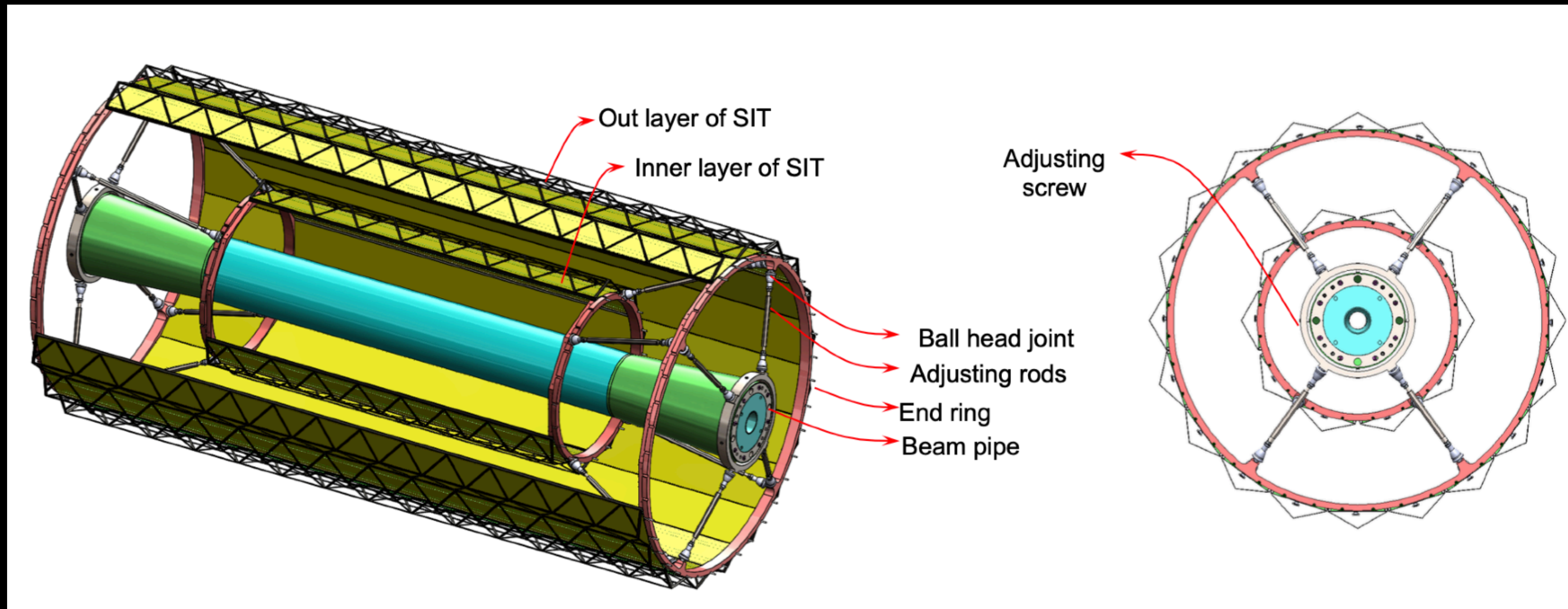



Silicon Tracker design

Optimization: tracker layout taskforce







Silicon tracker demonstrator with international partners

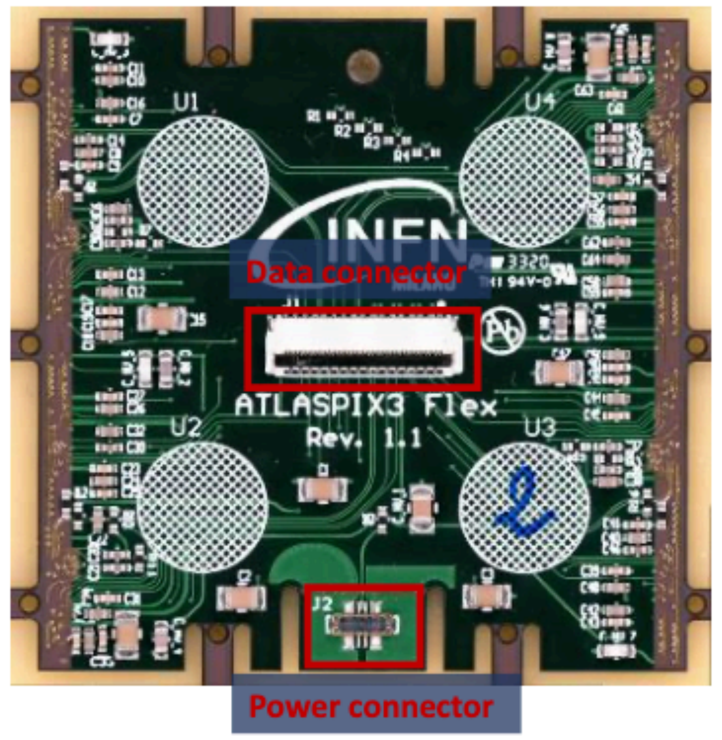
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of 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

International group led by H.Fox (Lancaster) and M.Wang (SDU)

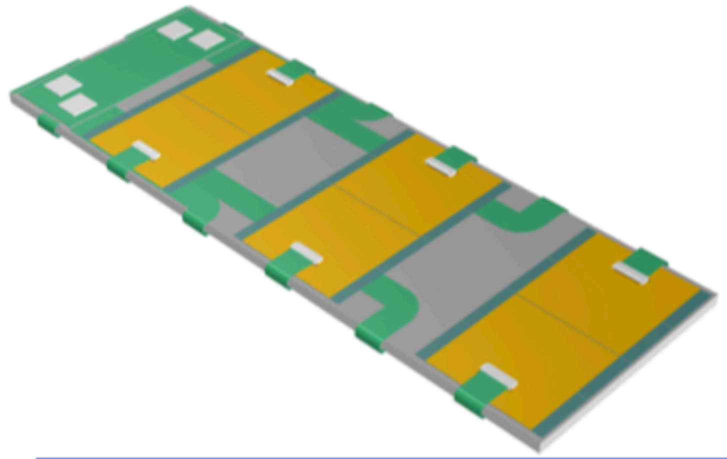
Start by using components developed for other projects

DEMONSTRATOR (SHORT STAVE)

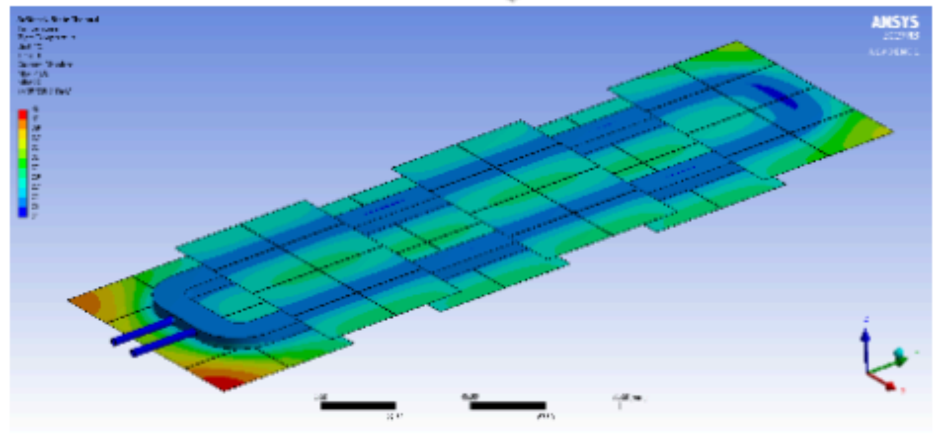
QuadModule Concept

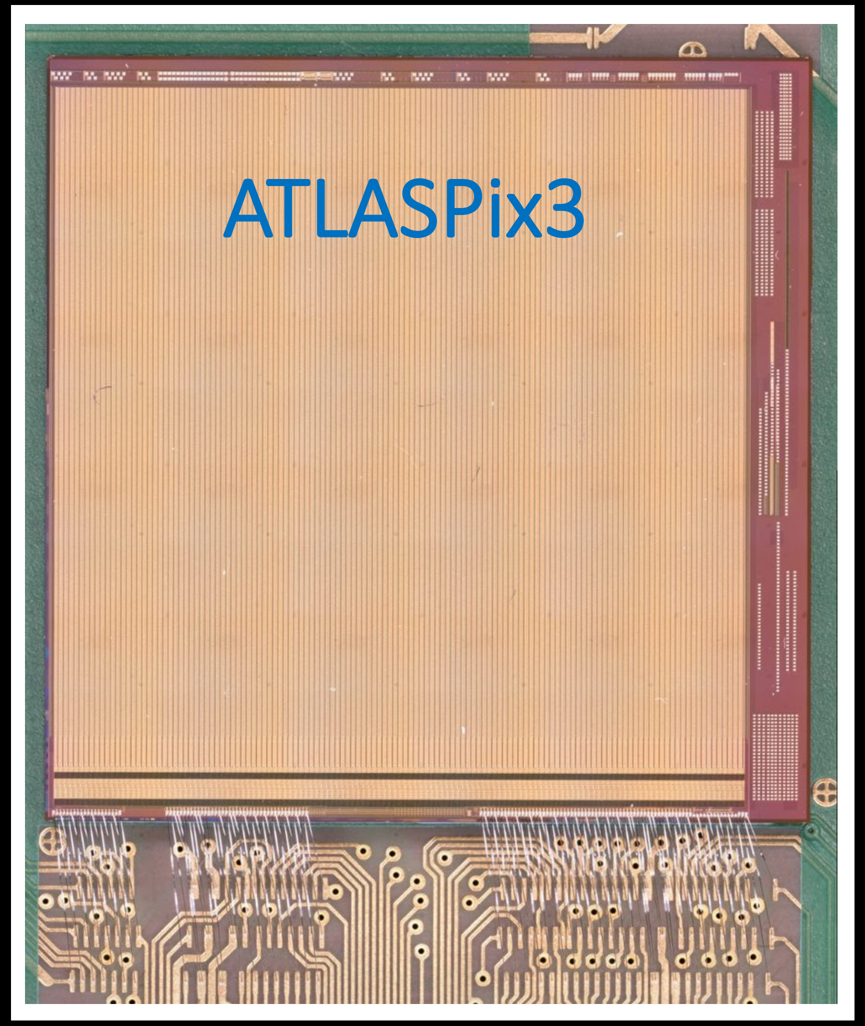


- Multiple modules on light composite support
  - Alternate tile pattern for hermeticity
  - Aggregation of data/optical conversion at the end-of-stave; serial powering

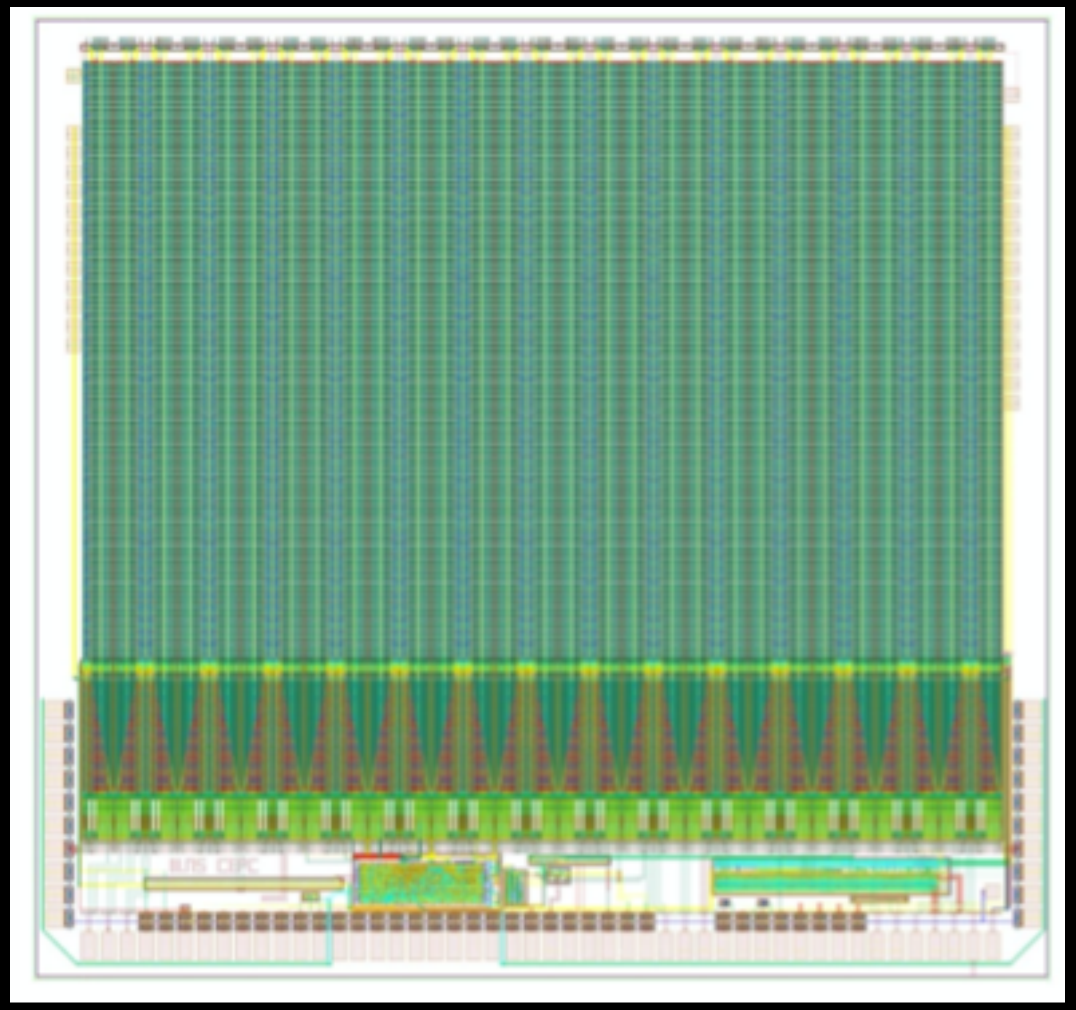


- Readout unit based on 4 chips
  - Shared services among 4 sensors by common power connections and configuration lines
  - Benefits of in-chip regulators to reduce connections



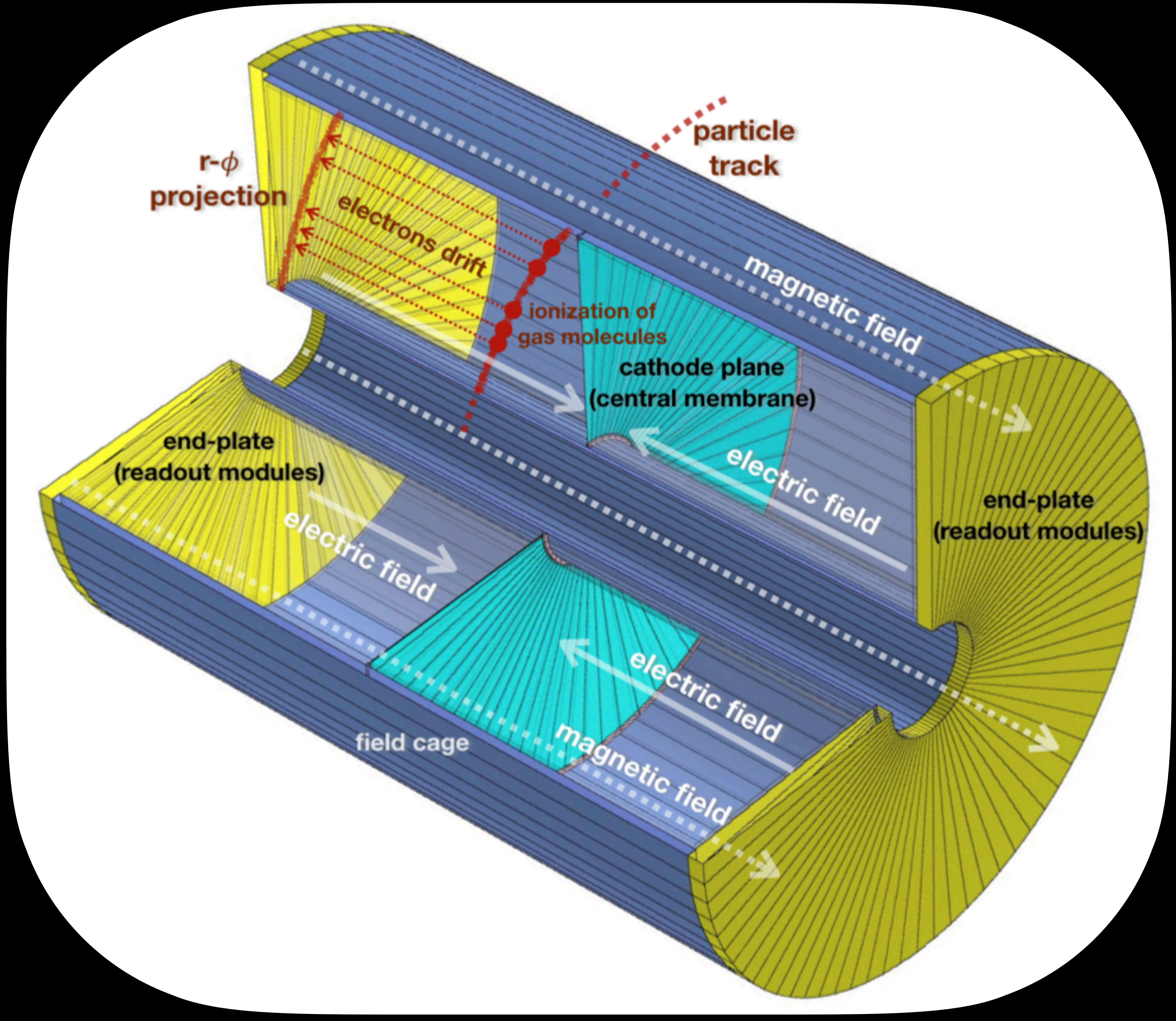


smaller pixel size ($25\times165\ \mu m^2$)

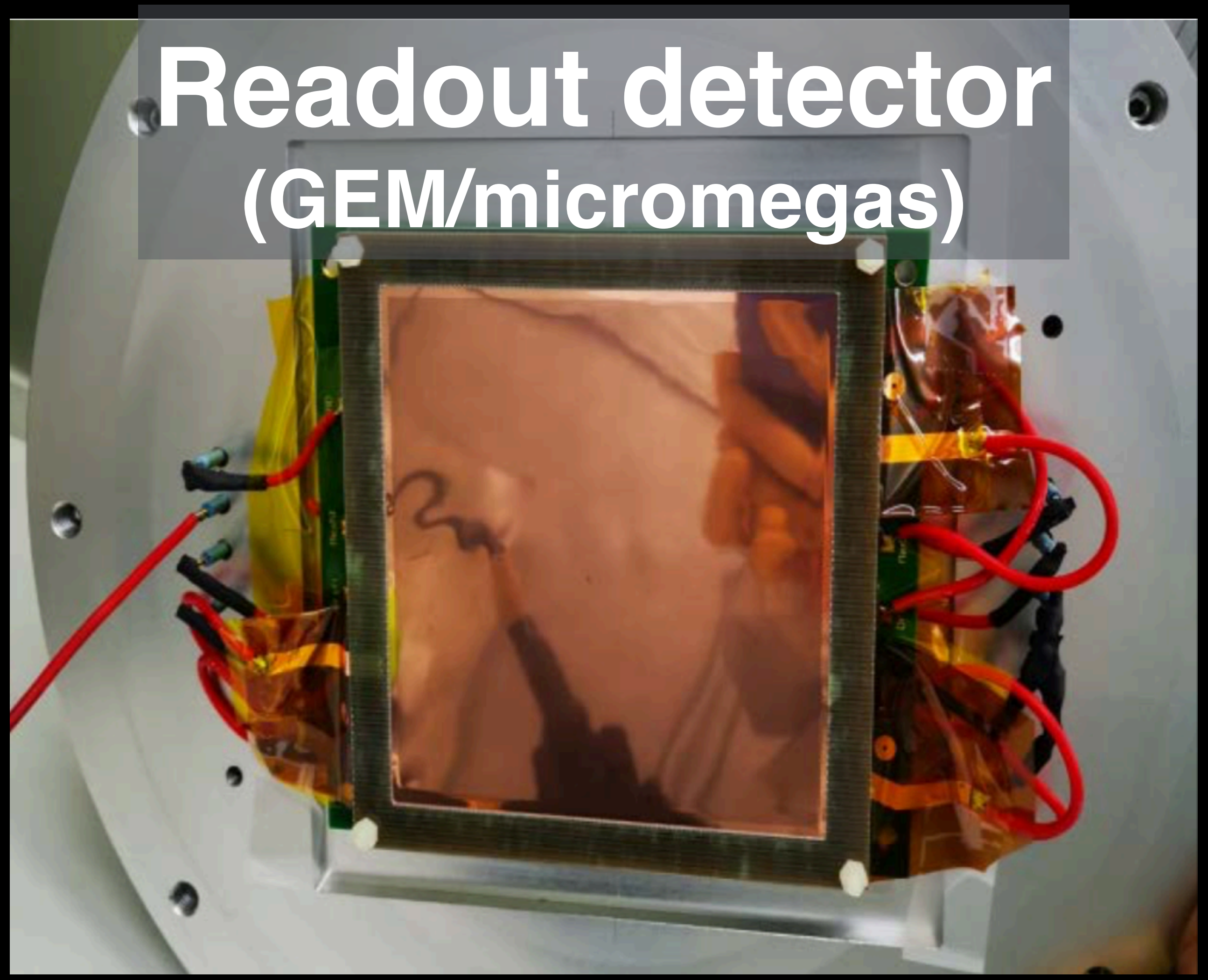


Migrate to a Chinese foundry if possible

Time Projection Chamber at CEPC

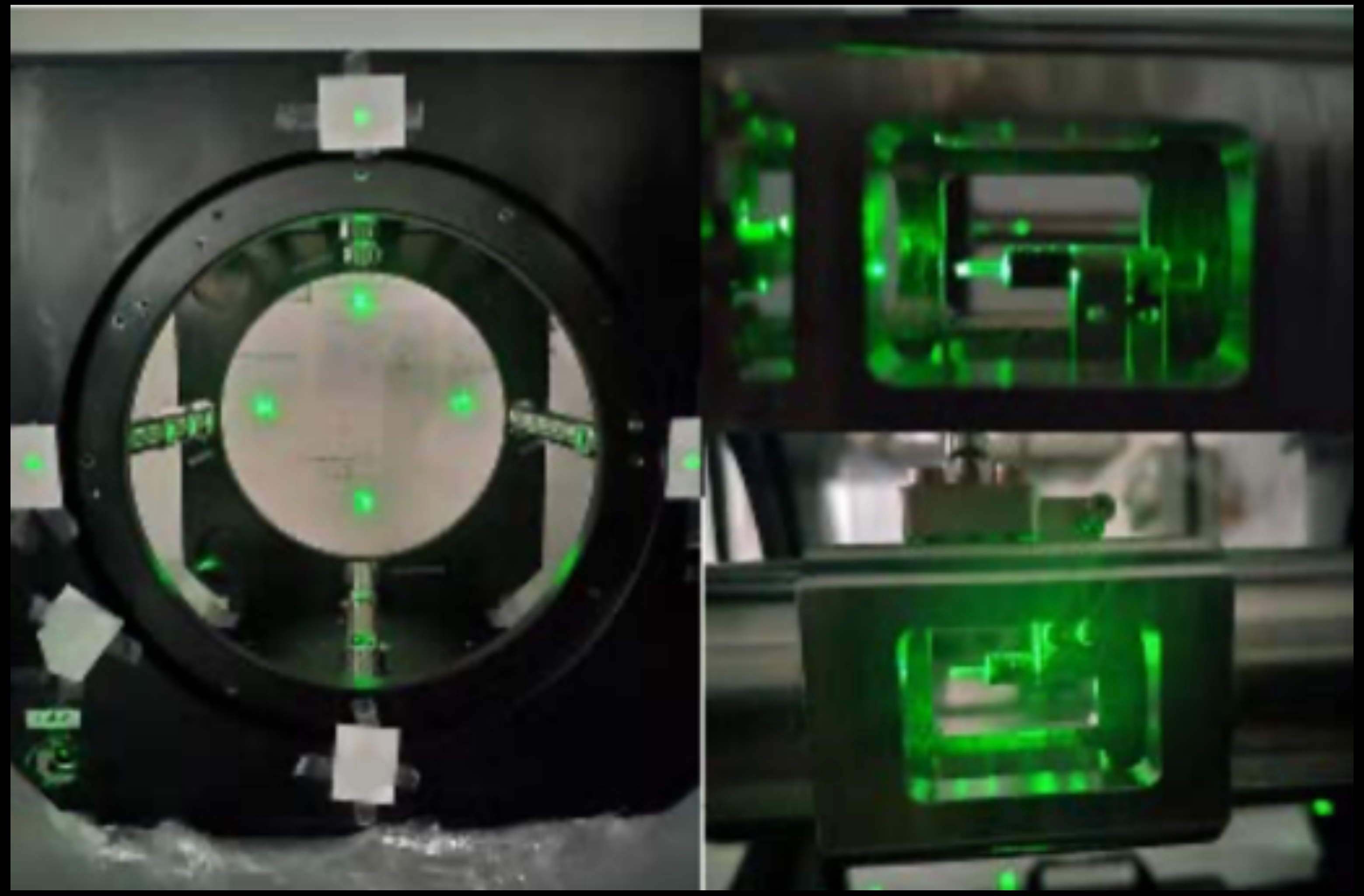


- TPC is the baseline central tracker option in CEPC CDR
  - TPC limitations at high luminosity
  - Ion back flow in chamber



(Pixel readout also being considered as an option for a circular collider)

- Calibration and alignment using UV lasers

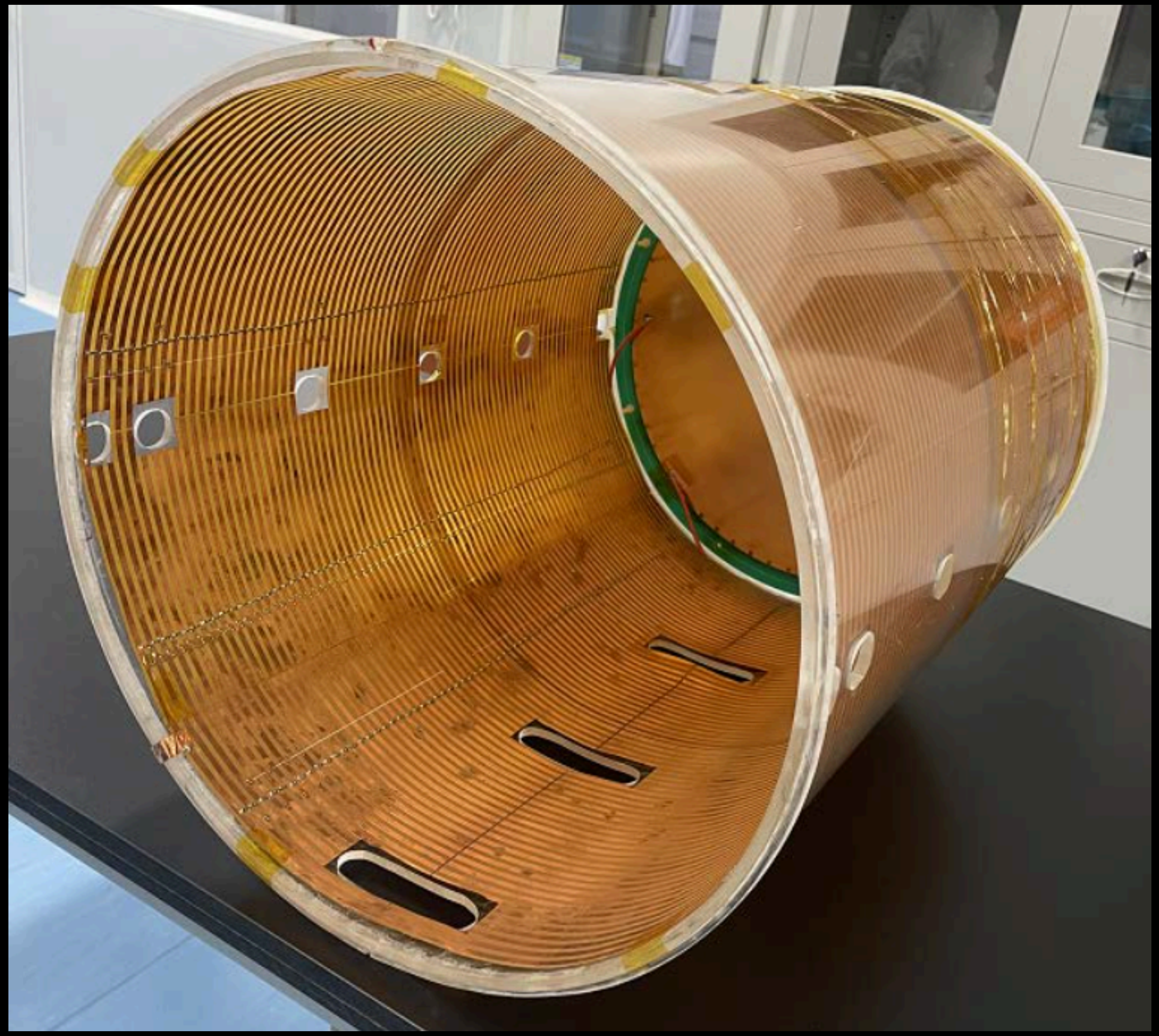


- Lower power FEE ASIC chip development

TPC Prototype

Drift Chamber

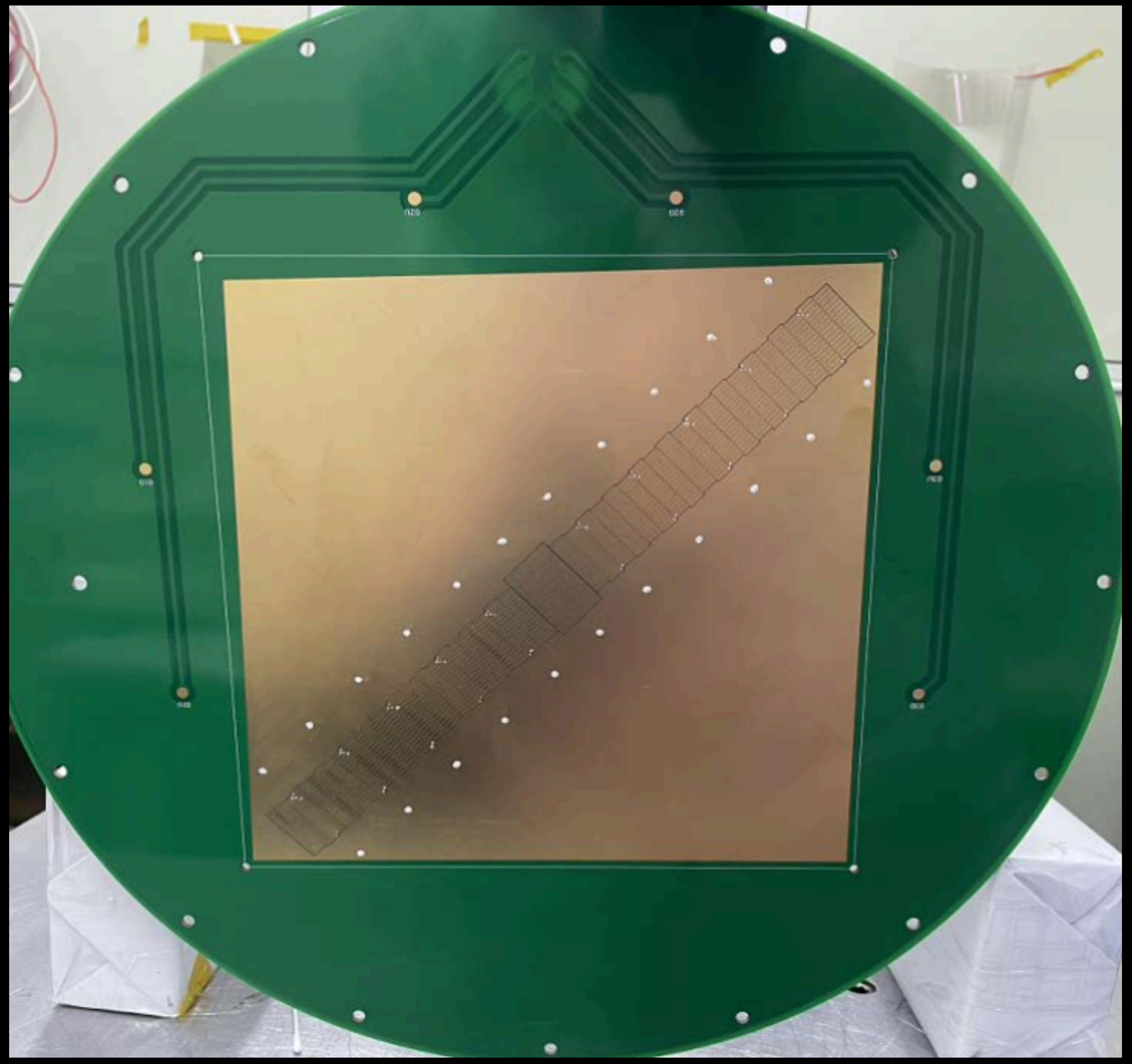
New high-voltage field cage



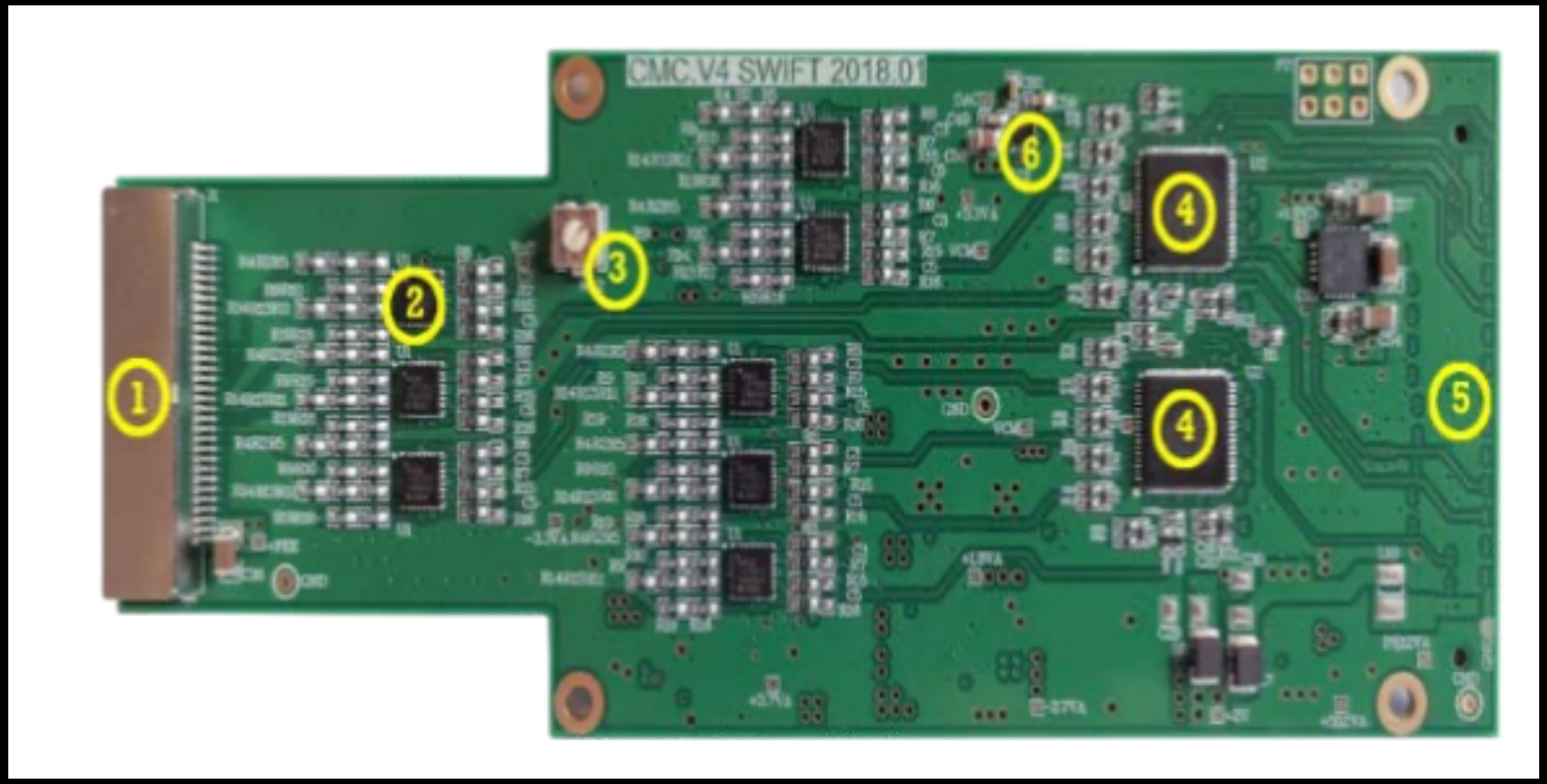
>300V/cm

New, larger, readout board

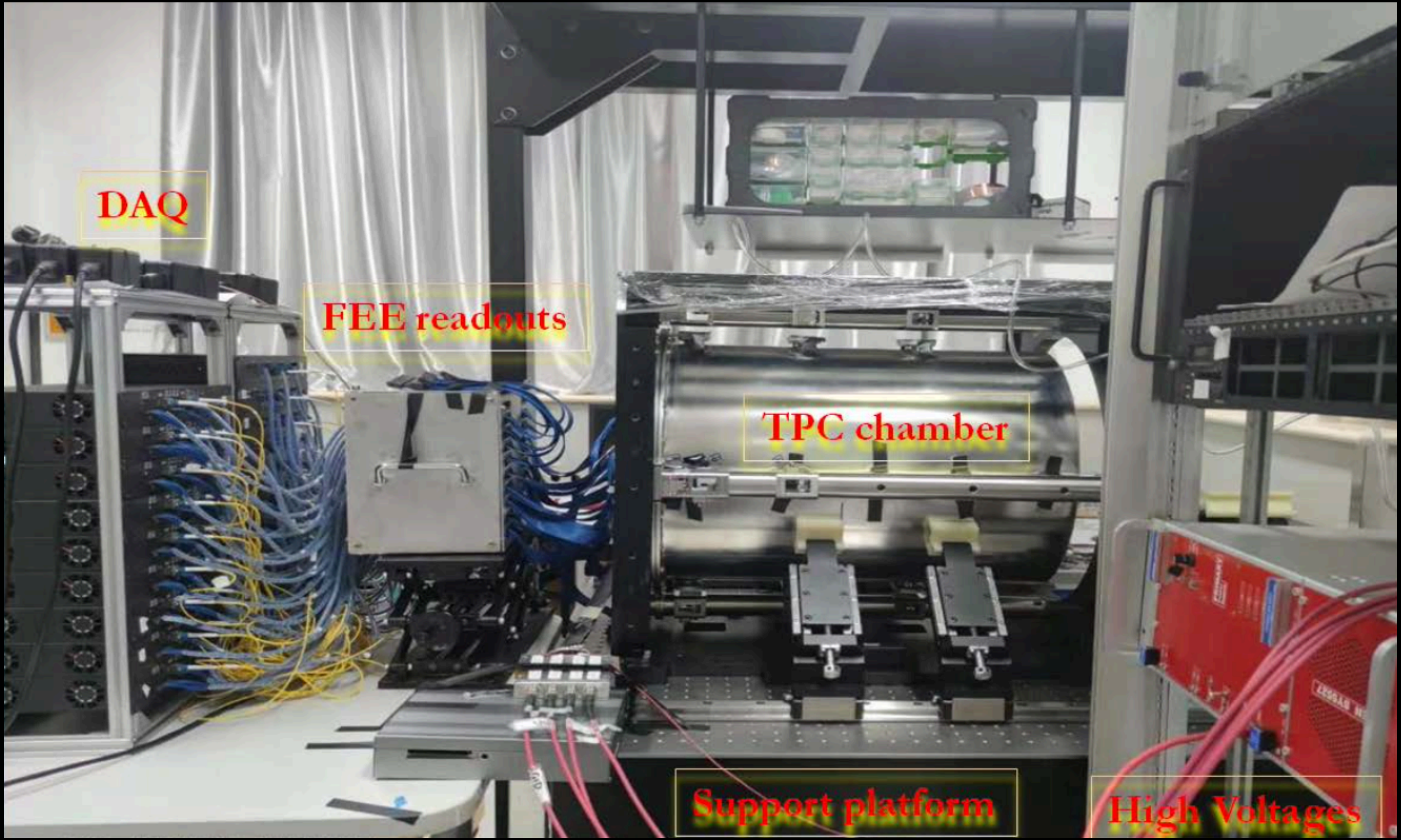
larger area



New ASIC and readout electronics



TPC Prototype under test



UV laser results indicate a resolution of 200 μm to 350 μm, depending on distance
More studies are ongoing and the update analyzing will been done

Drift Chamber Option - IDEA Concept

Lead by Italian Colleagues

Low-mass cylindrical drift chamber

Follows design of the KLOE and MEG2 experiments

- Length: 4 m
- Radius: 0.35- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

- Spatial resolution: < 100 μm
- Max drift time: ~350 nsec
- Cells: 56,448

Layers: 14 SL × 8 layers = 112

Cell size: 12 - 14 mm

New DAQ board: dual channel

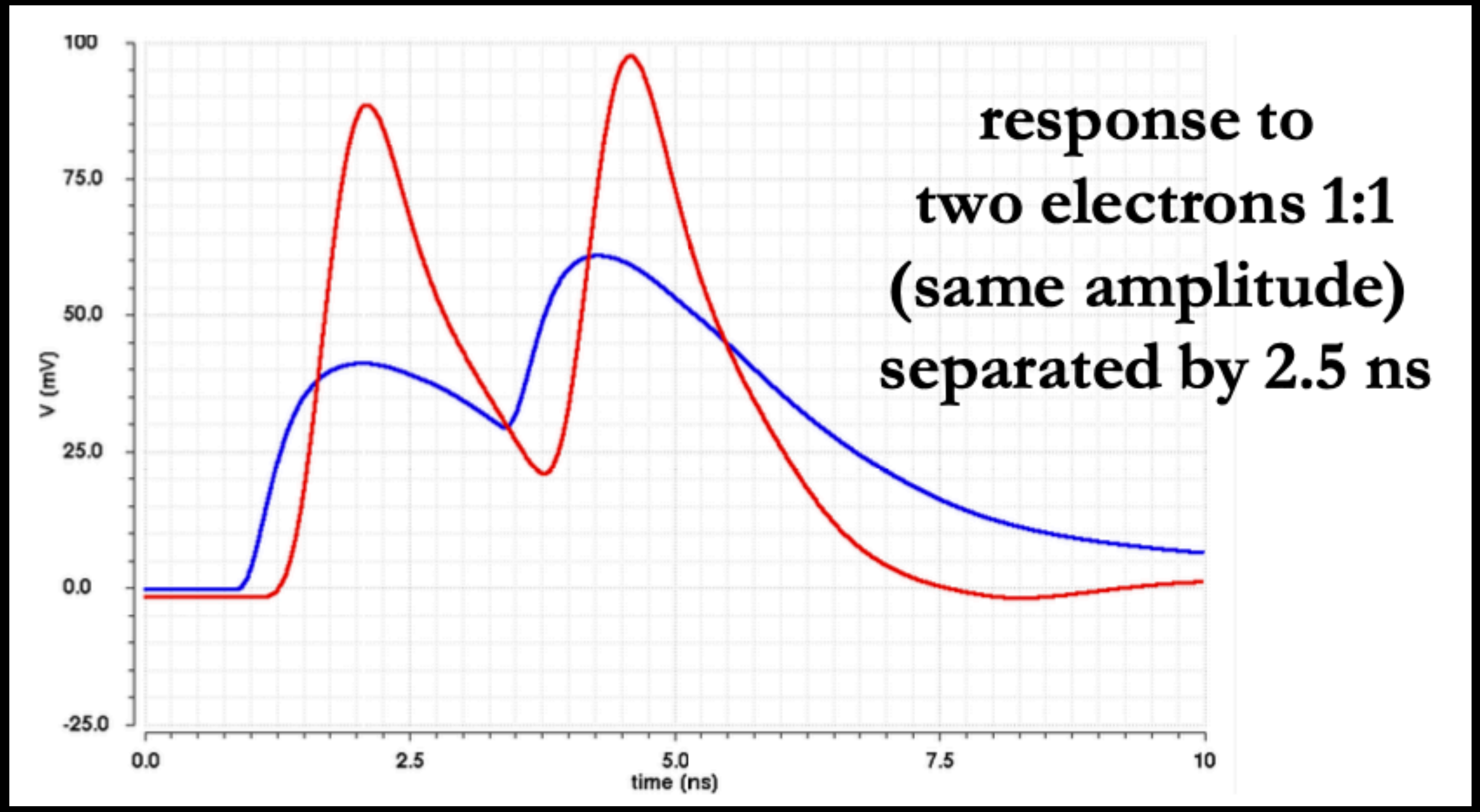
- increase resolution and signal-to-noise ratio
- improve peak finding algorithm


Xilinx Kintex UltraScale FPGA KCU105 Evaluation Kit
chosen to be compatible with CAEN digitizer boards

AD9689 - 2000EBZ (dual channel)
sufficient resolution and transfer capabilities

Front-end ASIC

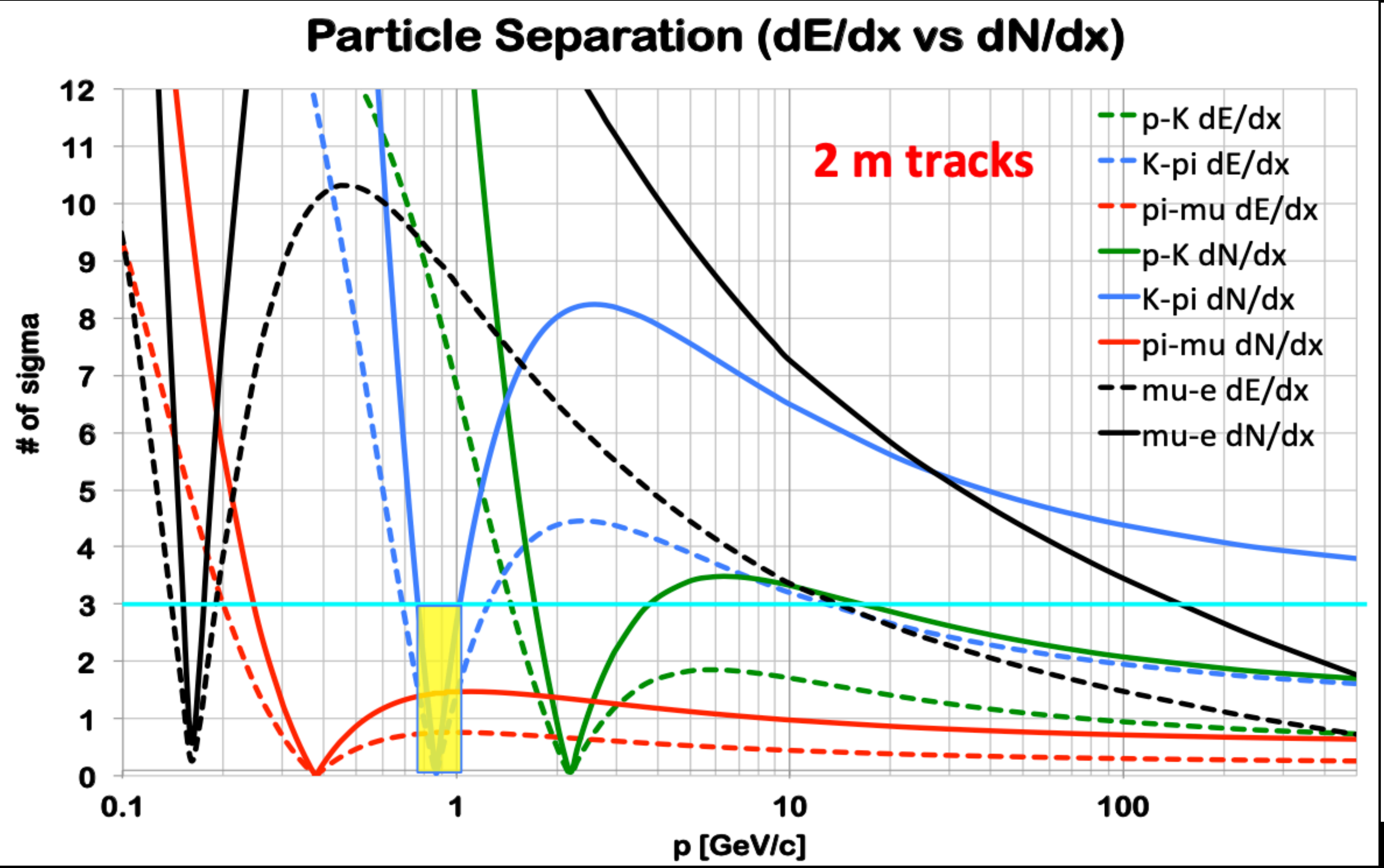
a two stage amplifier for cluster counting/timing



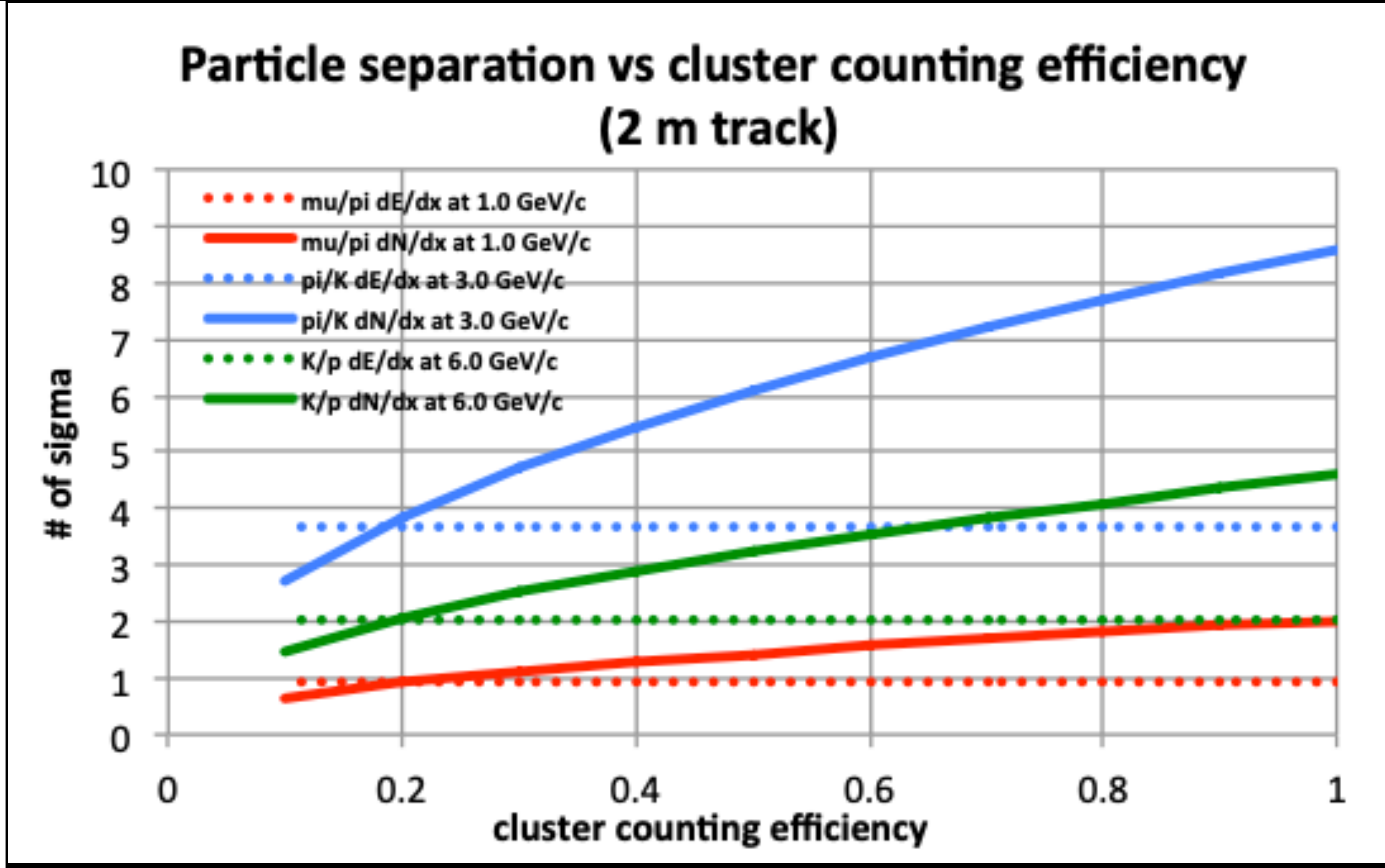
Drift Chamber Considerations: dE/dx vx dN_{cl}/dx

Expected from analytical calculation of IDEA chamber

80% cluster counting efficiency



4.3% dE/dx resolution



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

- Depends on the √ of the track length
- Potentially can get same resolution as dE/dx with 4x smaller track ==> 0.5 meter drift chamber

Work on-going in Italy and IHEP

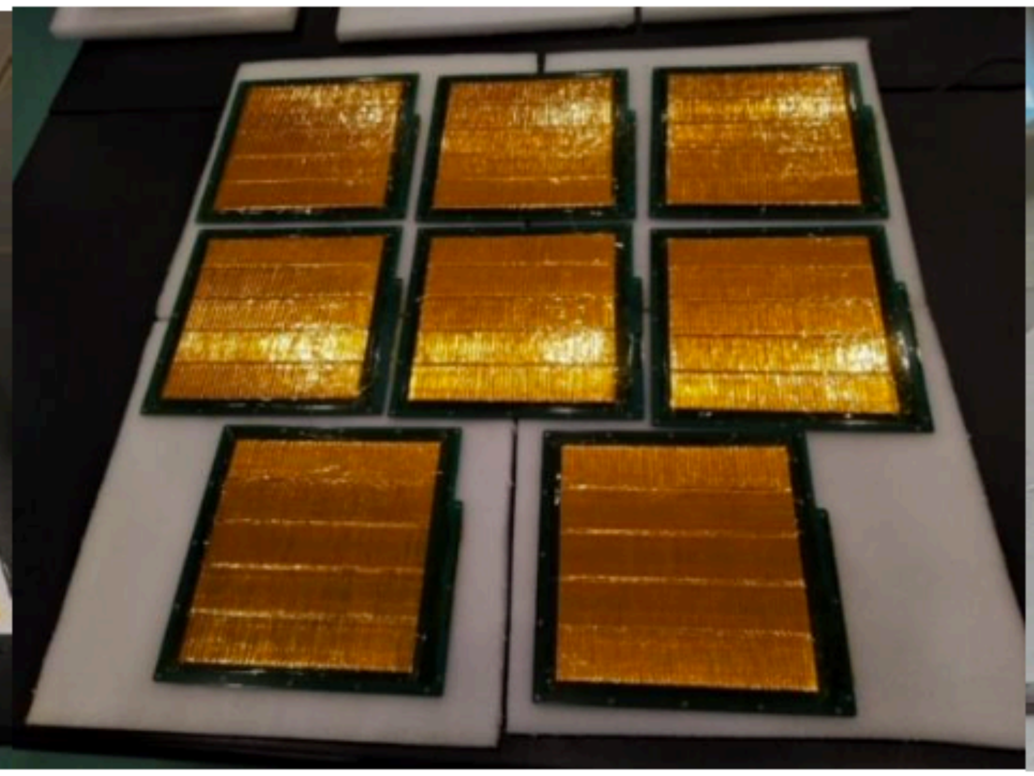
Scintillator ECAL Prototype

Scintillator-Tungsten Sandwich ECAL

scintillator strips

Ecal Basic Unit (EBU)

Super-layer: two EBU and absorber layers integrated



- Energy resolution $< 16\%/\sqrt{E}$, position resolution $< 10mm \times 10mm$
- One EBU: 210 sensitive cells of scintillator strip coupling with SiPM
  - Scintillator strips : $2mm \times 5mm \times 45mm$
  - SiPM (HPK) : S12571-010P (24 layers) and S12571-015P (8 layers)
- Super-layers: two alternate of EBU and absorber layers integrated
- Complete Sc-ECAL prototype has been fabricated
  - Transverse dimension : $226\ mm \times 222\ mm$
  - Radiation length : $22\ X_0$

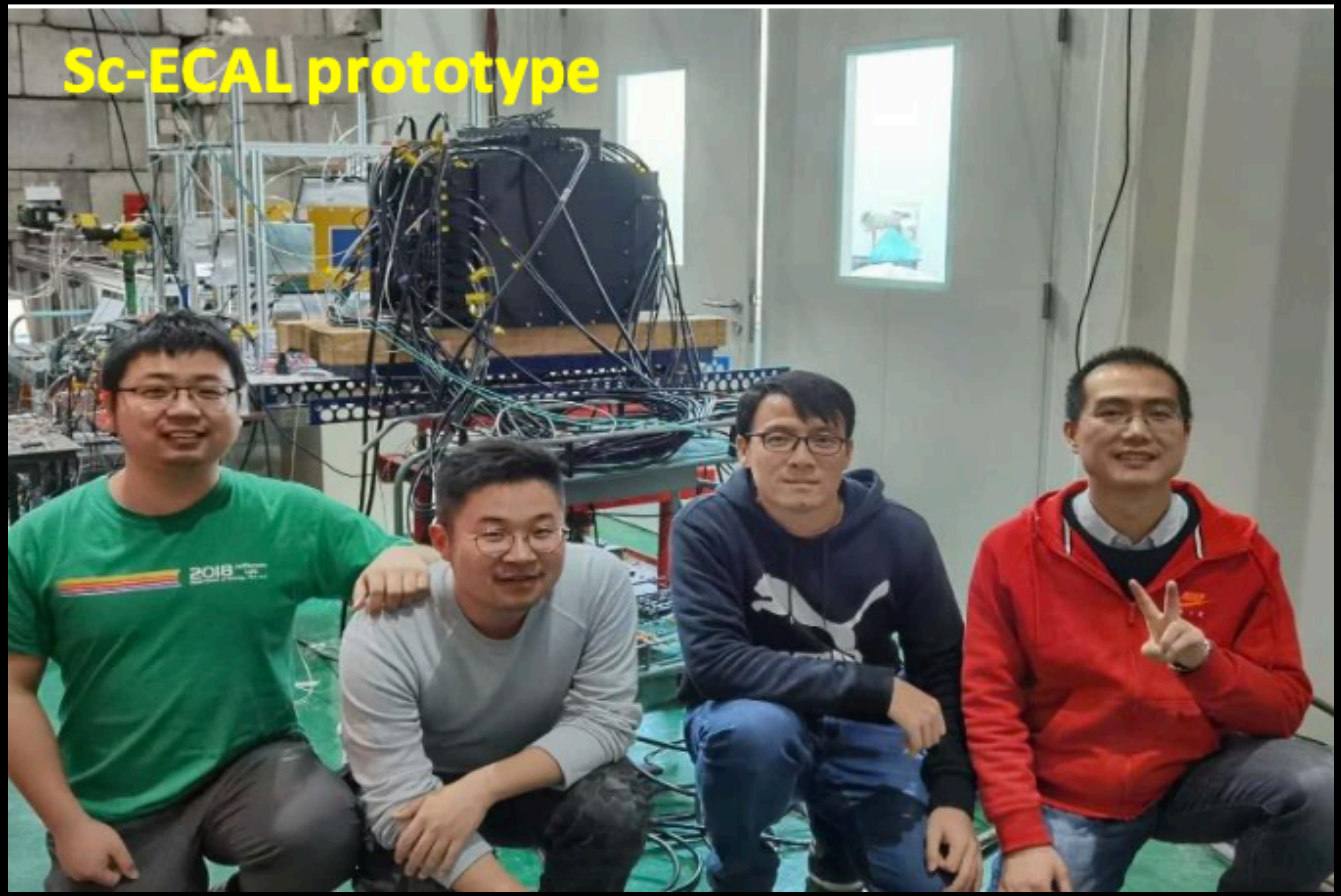
Sc-ECAL prototype

2

Test beam at IHEP earlier this year

Scintillator ECAL Prototype: testing

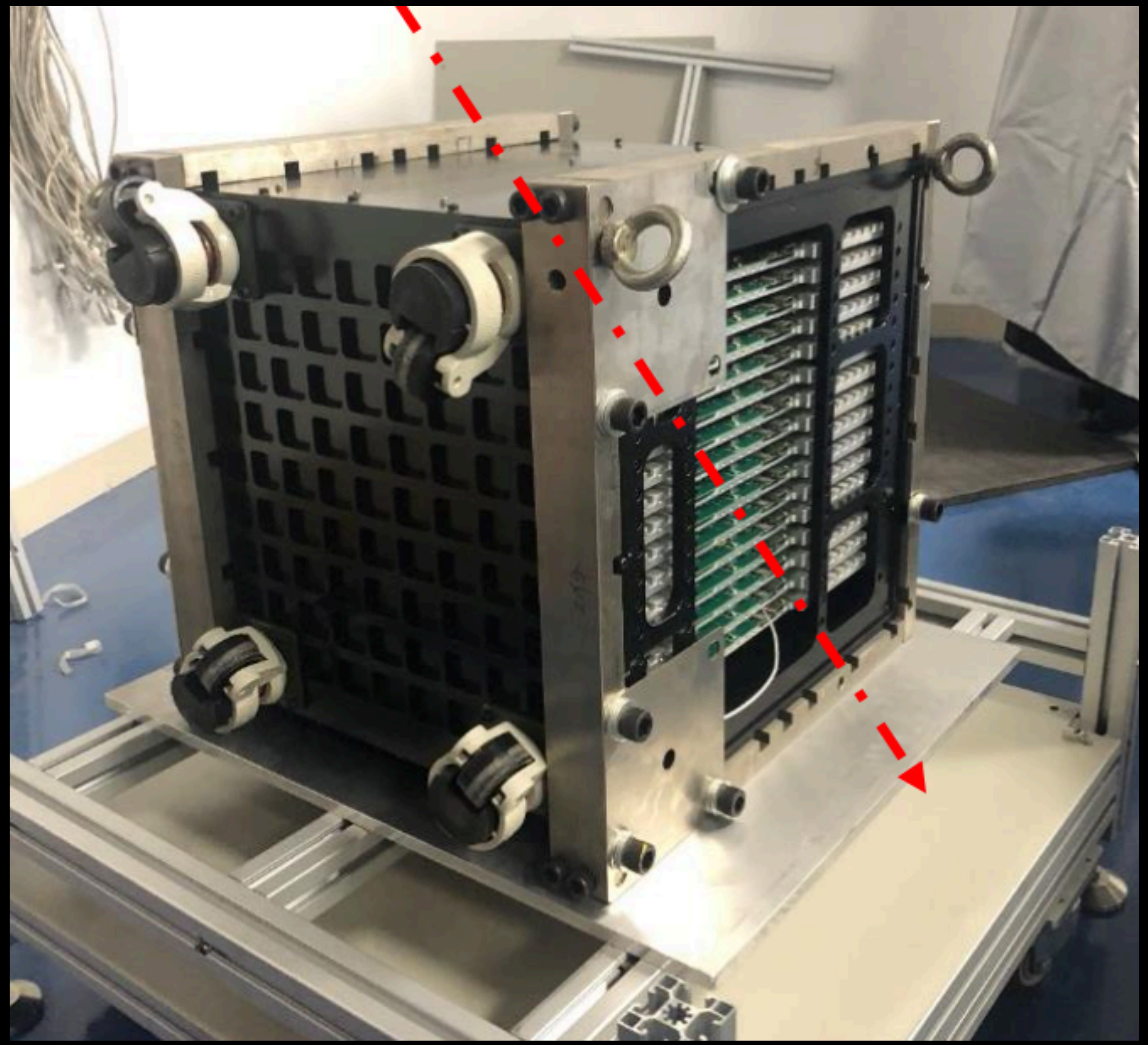
Test beam at IHEP



- IHEP E3 beam line: secondary particle beam
  - Mixed with proton/pion: proton dominate
  - Momentum : 300 MeV-1.2GeV
  - Event rate: less than 100 per minute

Total 12 thousands events collected

Cosmic ray tests



Position resolution better than 3mm, better than required by MOST project for CEPC ScECAL

Correction of incident angle and temperature effect on the ADC measurement implemented

Further analysis on-gong

Two Hadronic Particle Flow Calorimeters

Linearity: $\pm 3\,\%$ **Resolution:** $\frac{60\,\%}{\sqrt{E(\mathrm{GeV})}} \oplus 3\,\%$ **BMR:** $< 4\,\%$

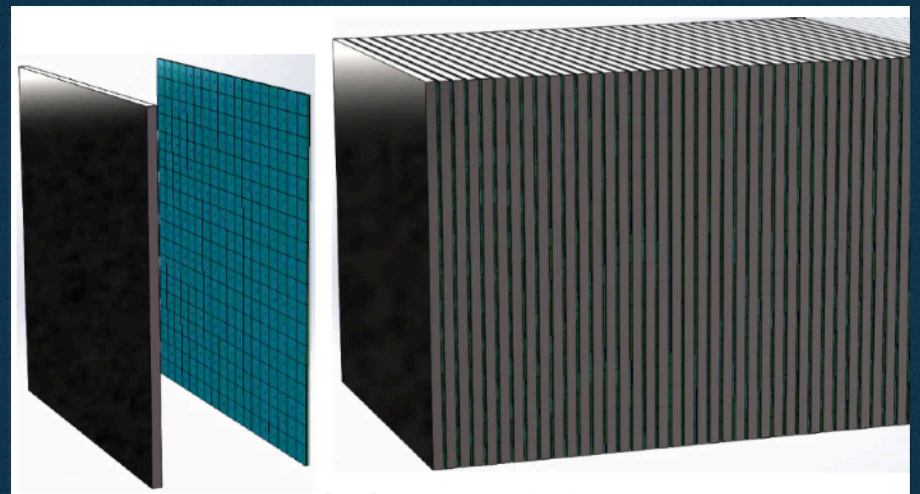
AHCAL
Scintillator and SiPM

40 layers of 20 mm stainless steel
+ 3 mm scintillator
+ 2 mm PCB

Transverse size: 72 × 72 cm^2

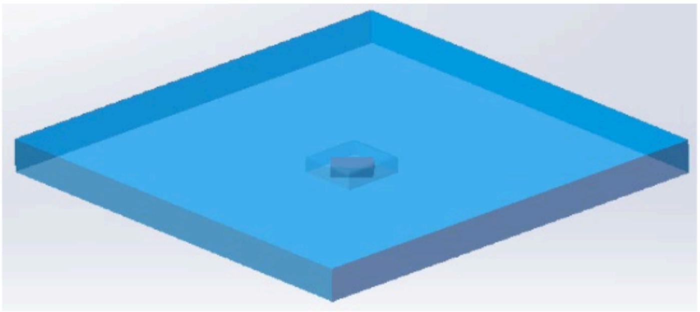
Length: 1.3 m

Prototype



Single layer and detector part

Cell size: 4 × 4 cm^2



SDHCAL
Glass RPC

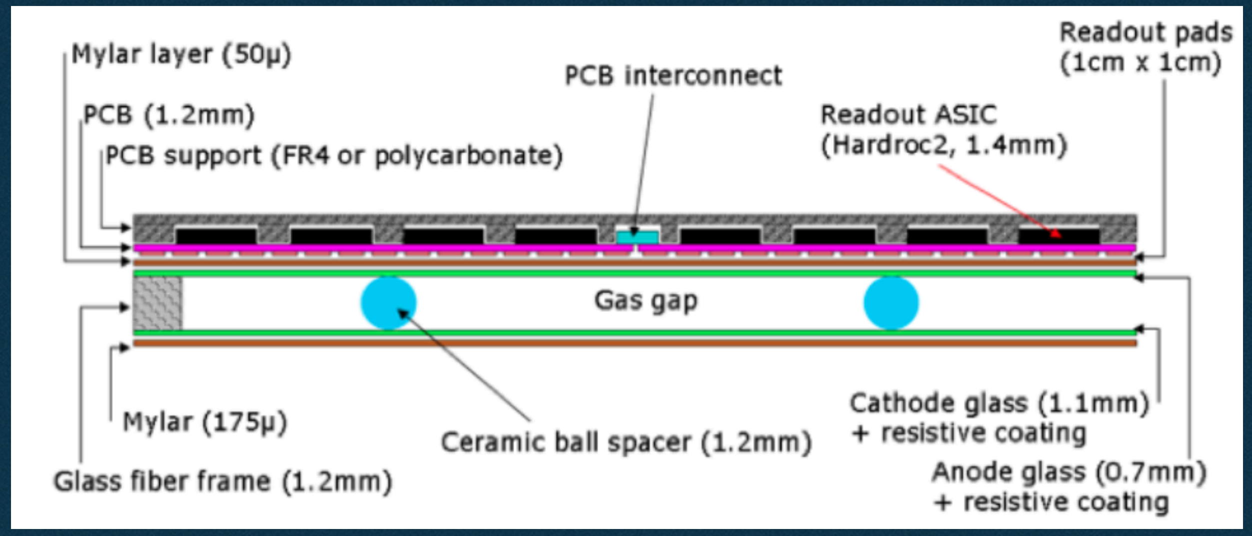
48 layers of 17.5 mm stainless steel
+ 6 mm RPC and electronics

Transverse size: 100 × 100 cm^2

Length: 1.3 m

CALICE prototype

Cell size: 1 × 1 cm^2

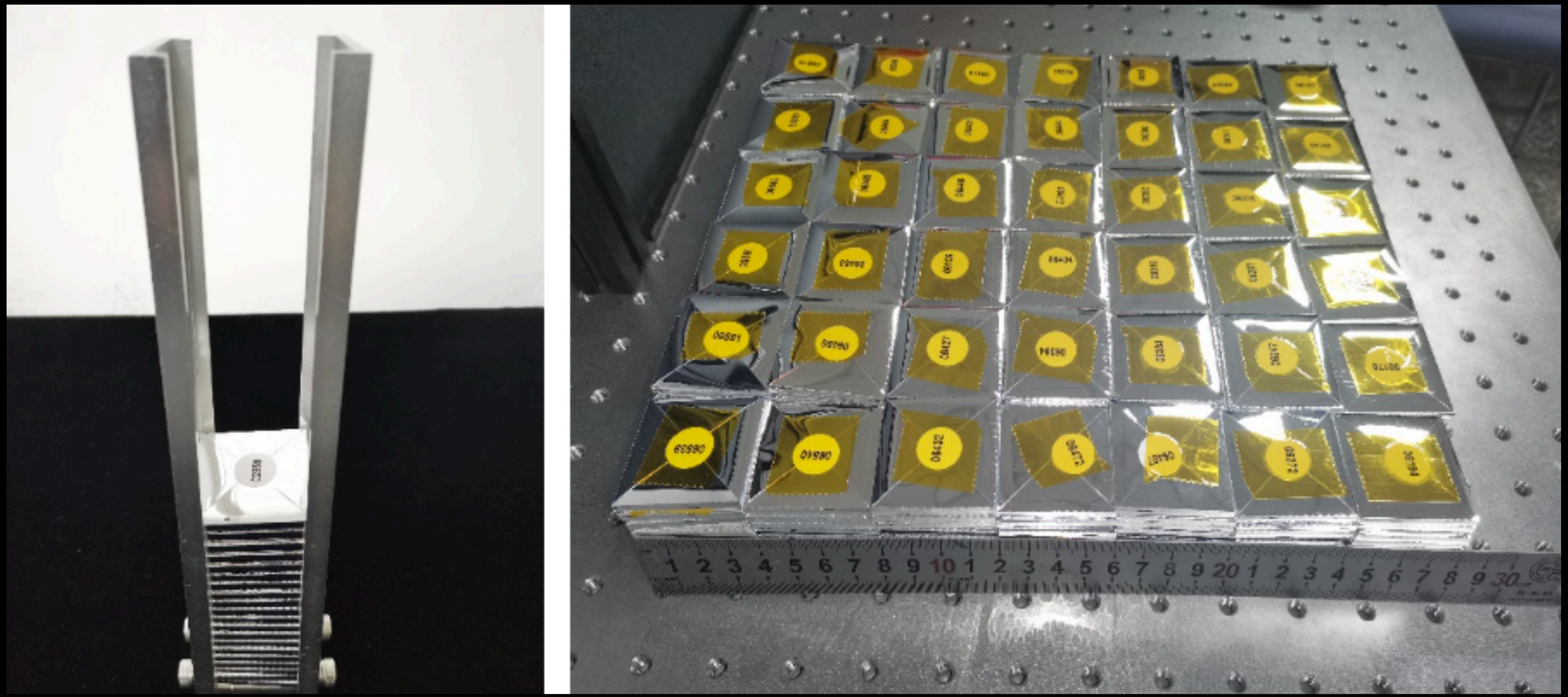


AHCAL: Scintillator and SiPM HCAL Prototype

16000 scintillators have been produced using the injection molding technique

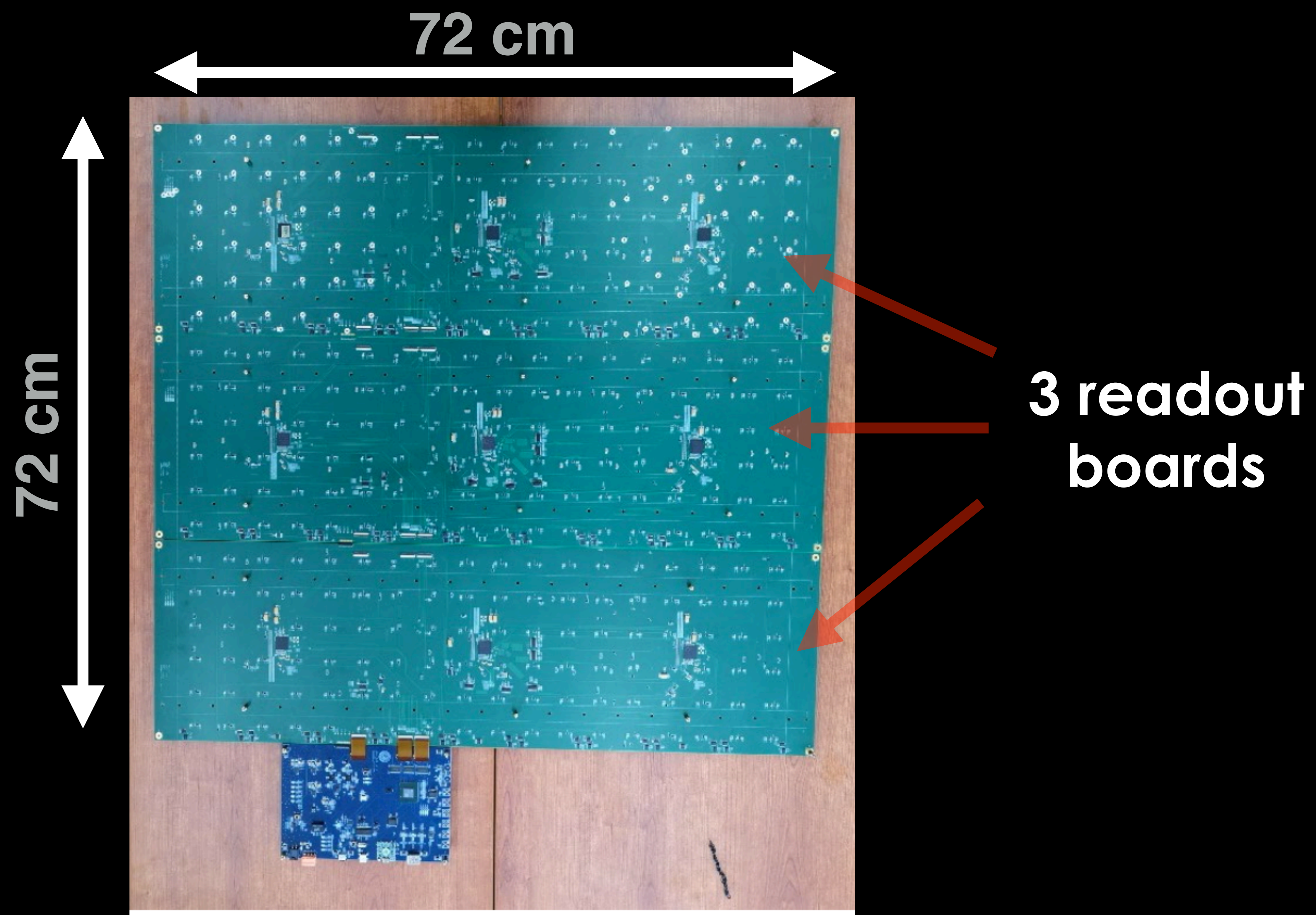
The light yield of each scintillator is about 40 p.e., tested by NDL-22-1313-15S

Automatic wrapping and labelling
100 scintillators take 75 min



3 batch testing platforms built (USTC, SJTU, IHEP)

Uniformity within ±15%

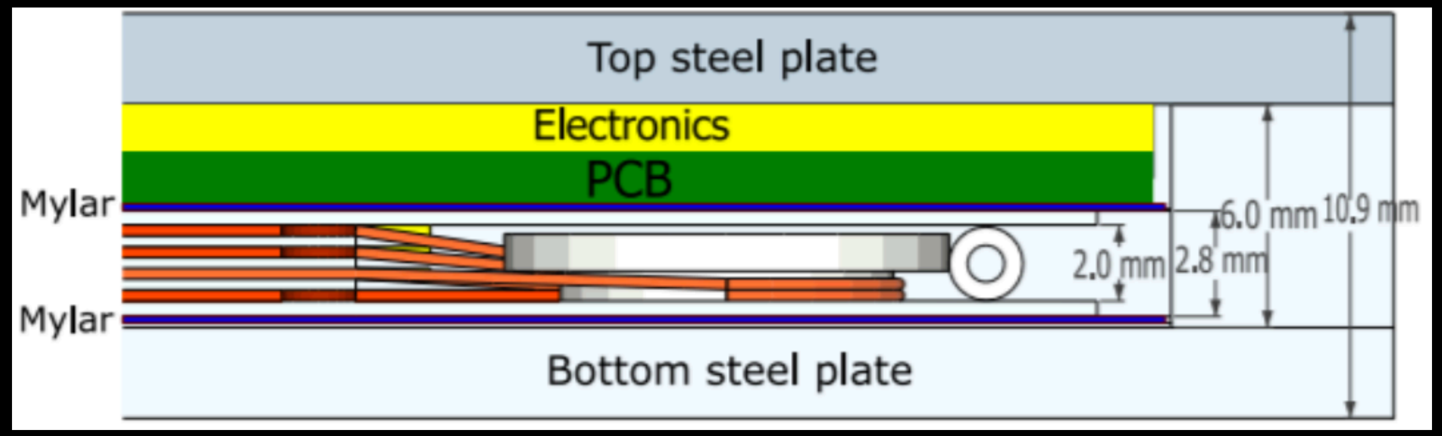


HBU:HCAL Basic Unit

SDHCAL: Glass RPC

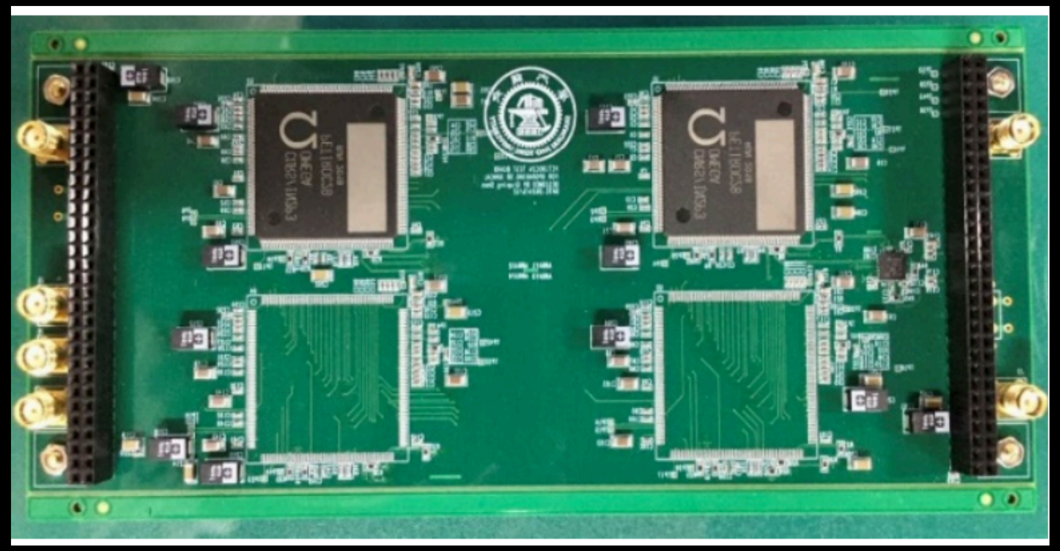
SJTU group has built:
50cm x 35cm, 100cm x 100cm RPCs

Multigap Resistive Plate Chambers (MRPC)



Fast timing readout electronics for MRPC designed and manufactured

Using PETIROC chip from OMEGA group



Test platform have been constructed. The DAQ system is under development.

New Ideas: Crystal Calorimeters

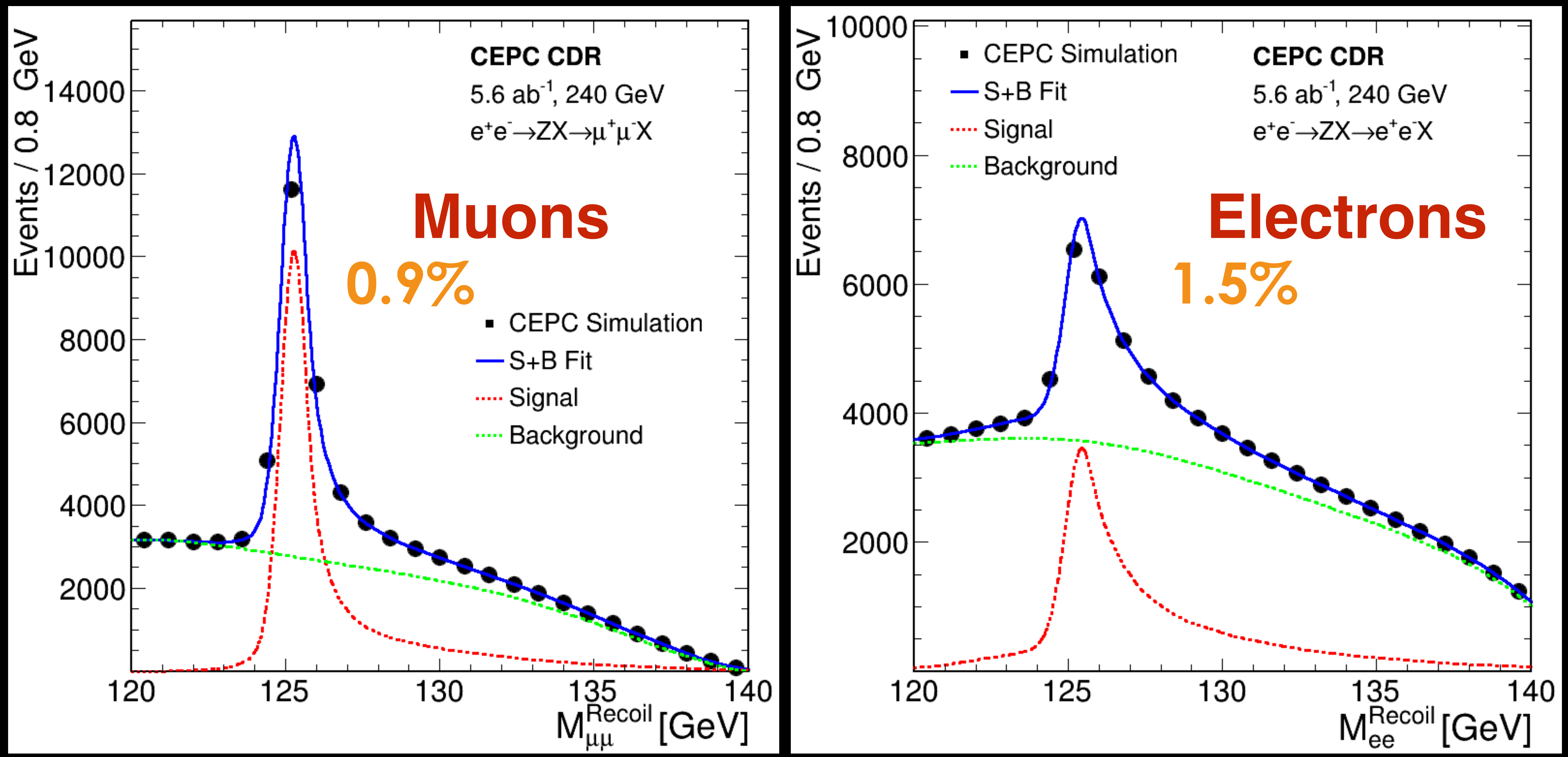
Concern: Electromagnetic resolution of PFA calorimeter not optimal

Physics motivations:

- Electrons' Bremsstrahlung: energy recovery
- Improve angular resolution, and gamma counting
- Recoil photons: new physics and neutrino counting

Resolution: $$\frac{3\,\%}{\sqrt{E(GeV)}} \oplus 1\,\%$$

Z boson recoil mass

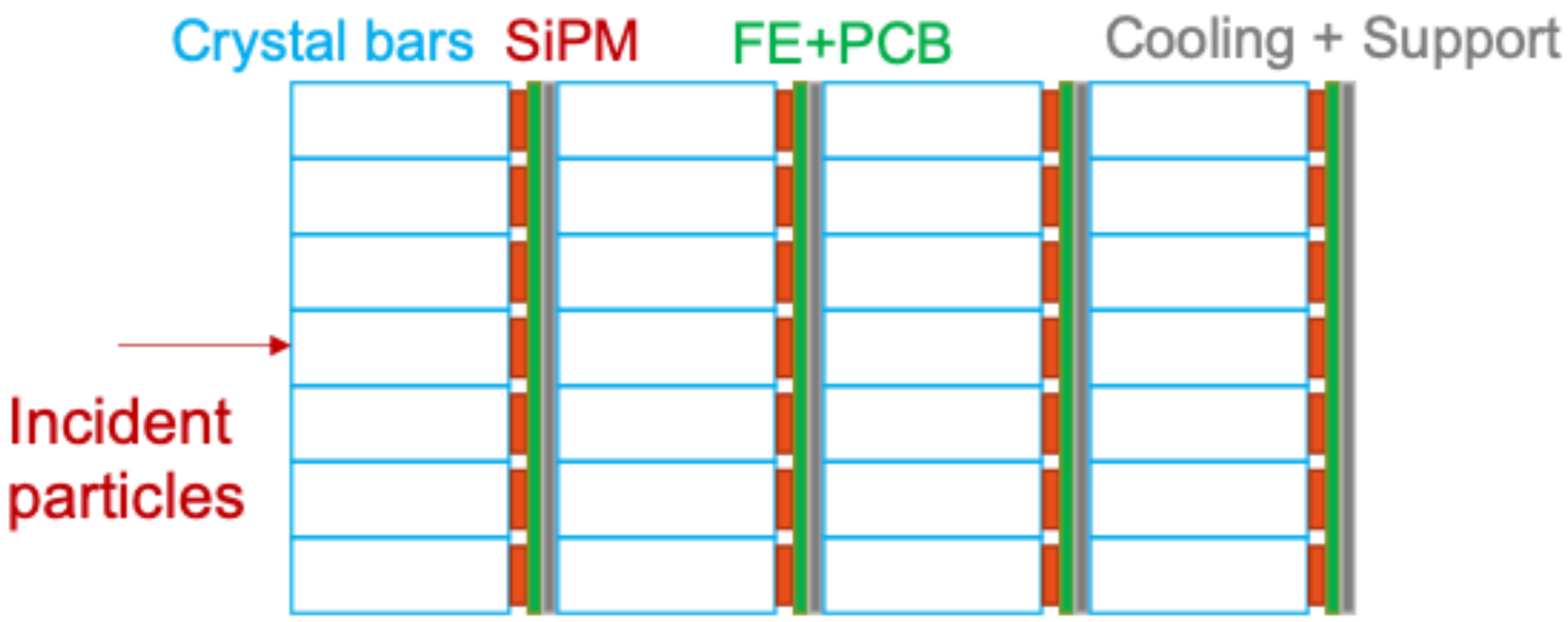


New Ideas: Crystal Calorimeters

Yong Liu

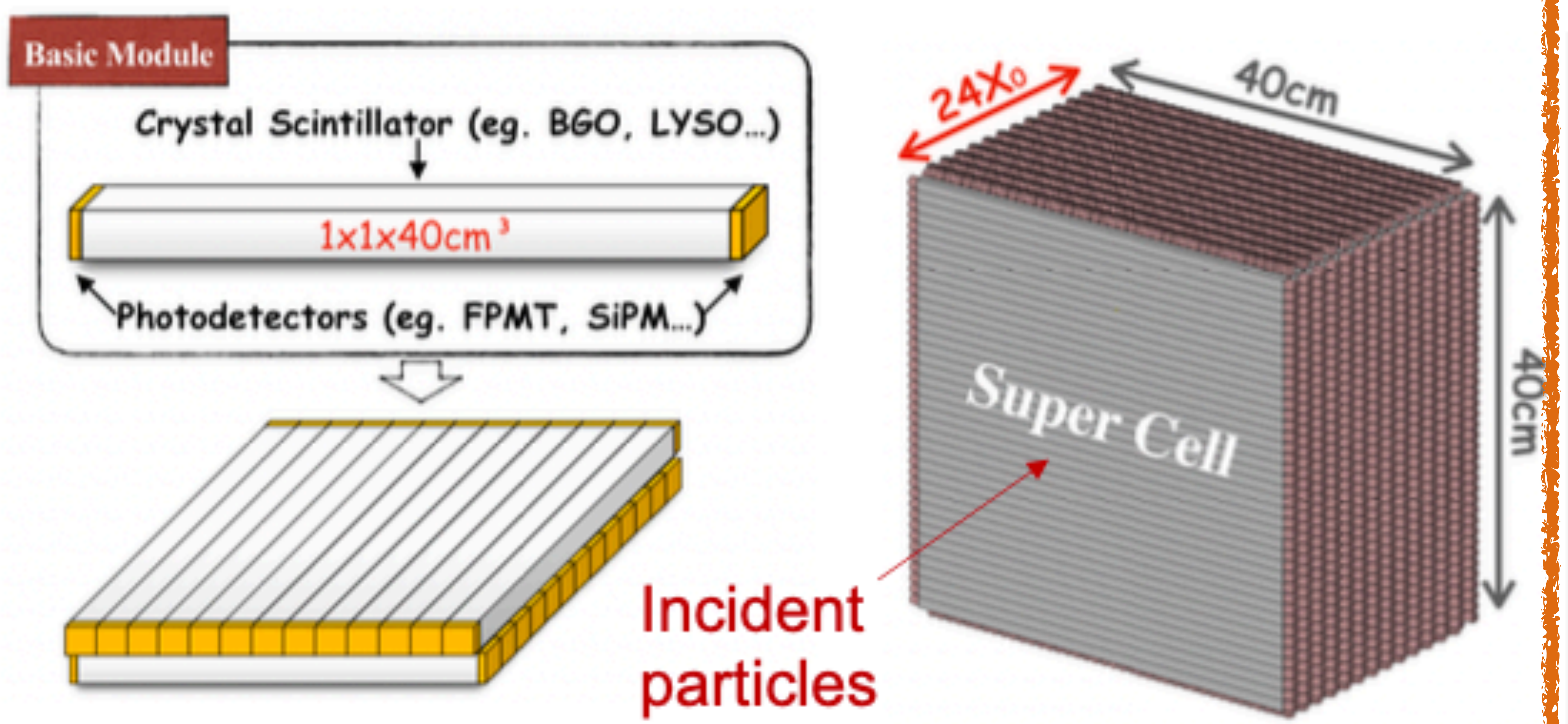
Two new segmented ECAL designs based on crystals

Design 1



- Longitudinal segmentation
- Fine transverse segmentation
  - 1×1cm or 2×2cm cells
- Single-ended readout with SiPM
- Potentials with PFA

Design 2



- Long bars: 1×40cm, double-sided readout
  - Super cell: 40×40cm cube
- Crossed arrangement in adjacent layers
- Significant reduction of #channels
- Timing at two sides: positioning along bar

Crystals: LYSO:Ce, PbWO, BGO? **SiPM: HPK, NLD?**

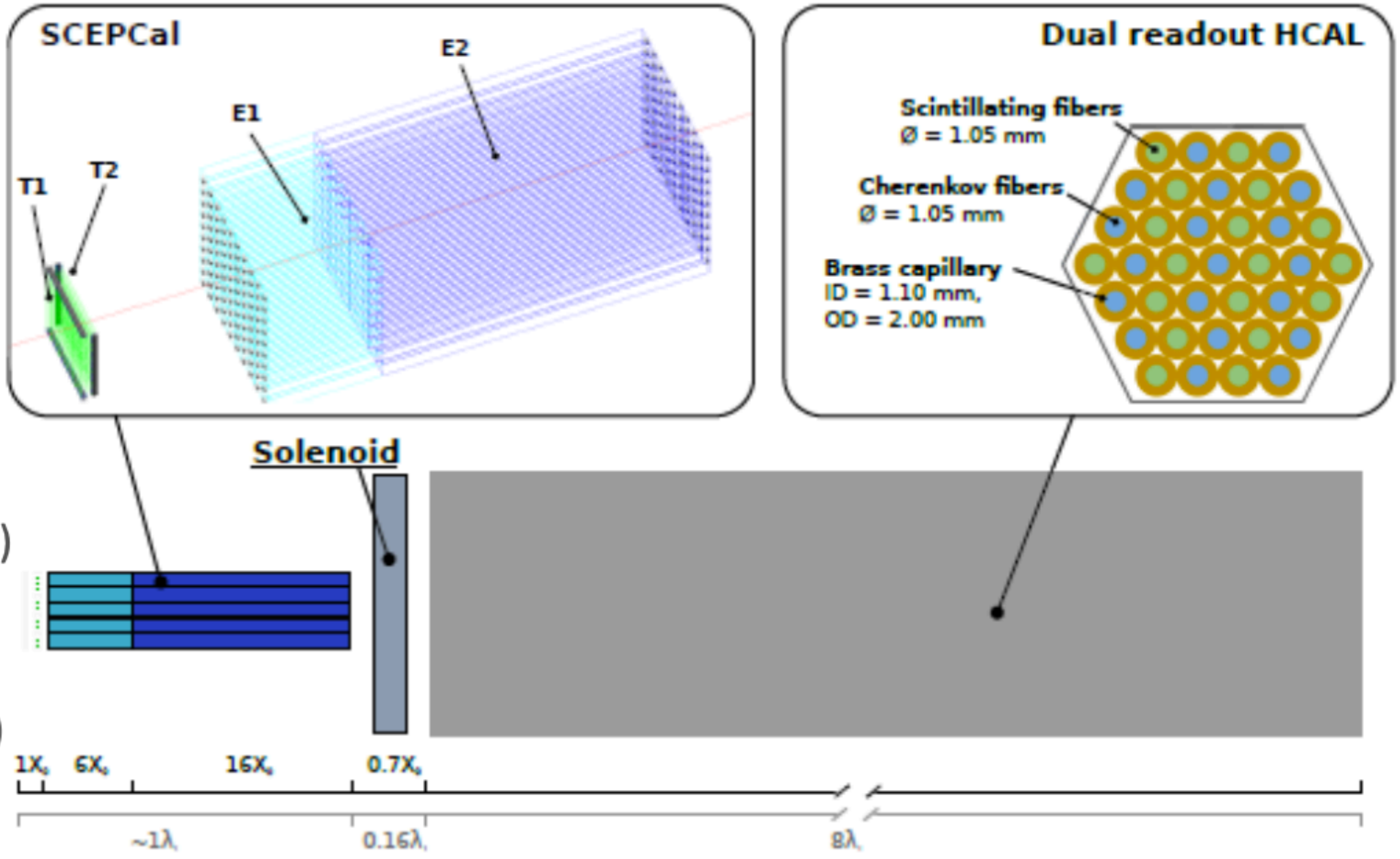
Need to control cost

Being incorporated into CEPC Software

Dual Readout Crystal Calorimeter

Drawing from the pioneering work of RD52, but upgrading for new developments in inexpensive, high-QE, tailored-wavelength sipmms See: https://arxiv.org/abs/2008.00338 Also see Snowmass LOI: SNOWMASS21-IF6-008.pdf

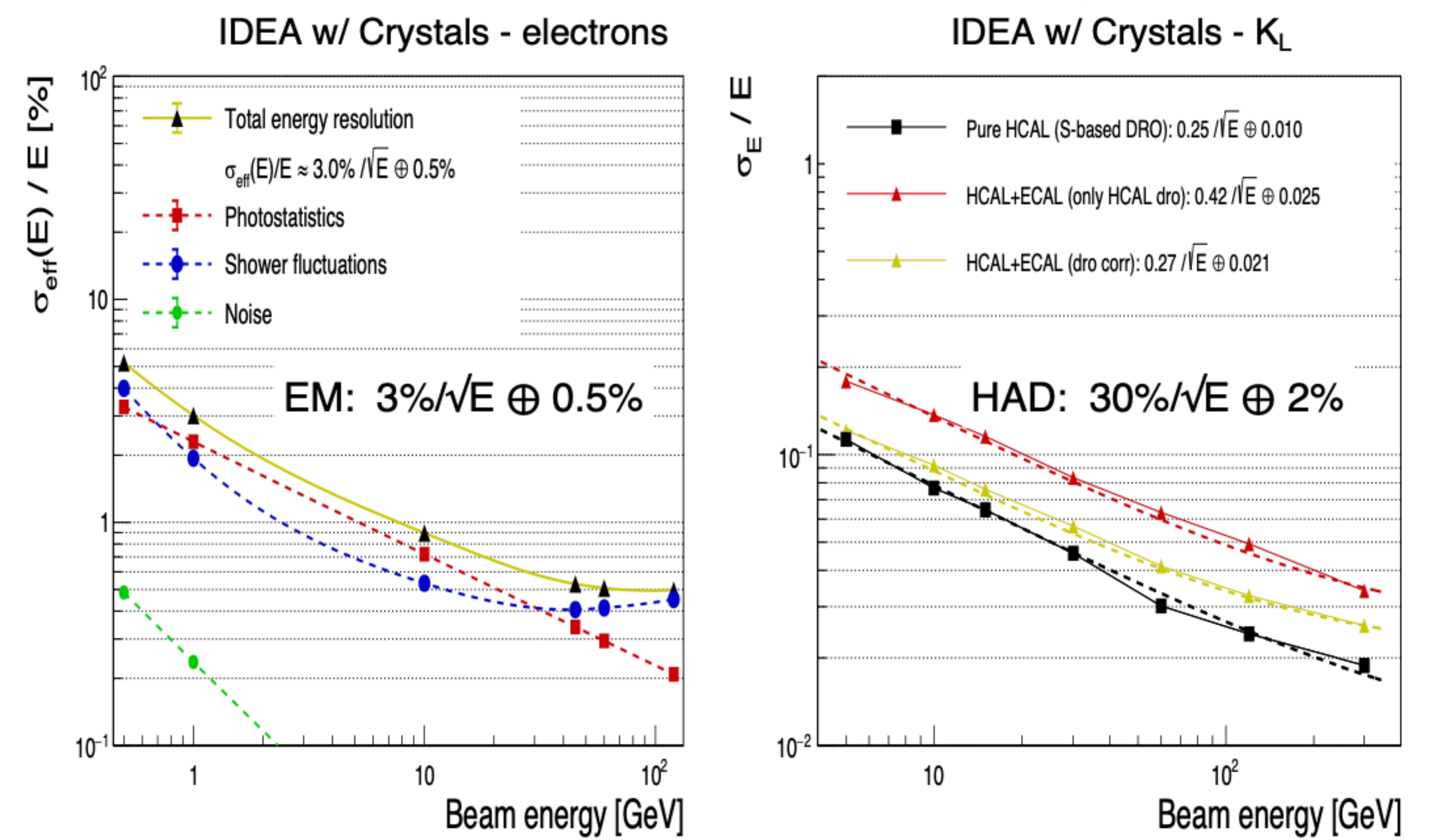
- **Timing layer** $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x54 mm^3 active cell
  - 3x3 mm^2 SiPMs (15-20 um)
- **ECAL layer** $\sigma_E/E \sim 3\%/\sqrt{E}$
  - PbWO crystals
  - Front segment ($\sim 6X_0$, $\sim 0.2\lambda$, ~50 mm)
  - Rear segment ($\sim 16X_0$, $\sim 0.7\lambda$, ~140 mm)
  - 10x10 mm^2 crystal
  - 5x5 mm^2 SiPMs (10-15 um)
  - 3 SiPMs (one on entrance, two on exit)
- Thin solenoid between ECAL and HCAL
- IDEA HCAL



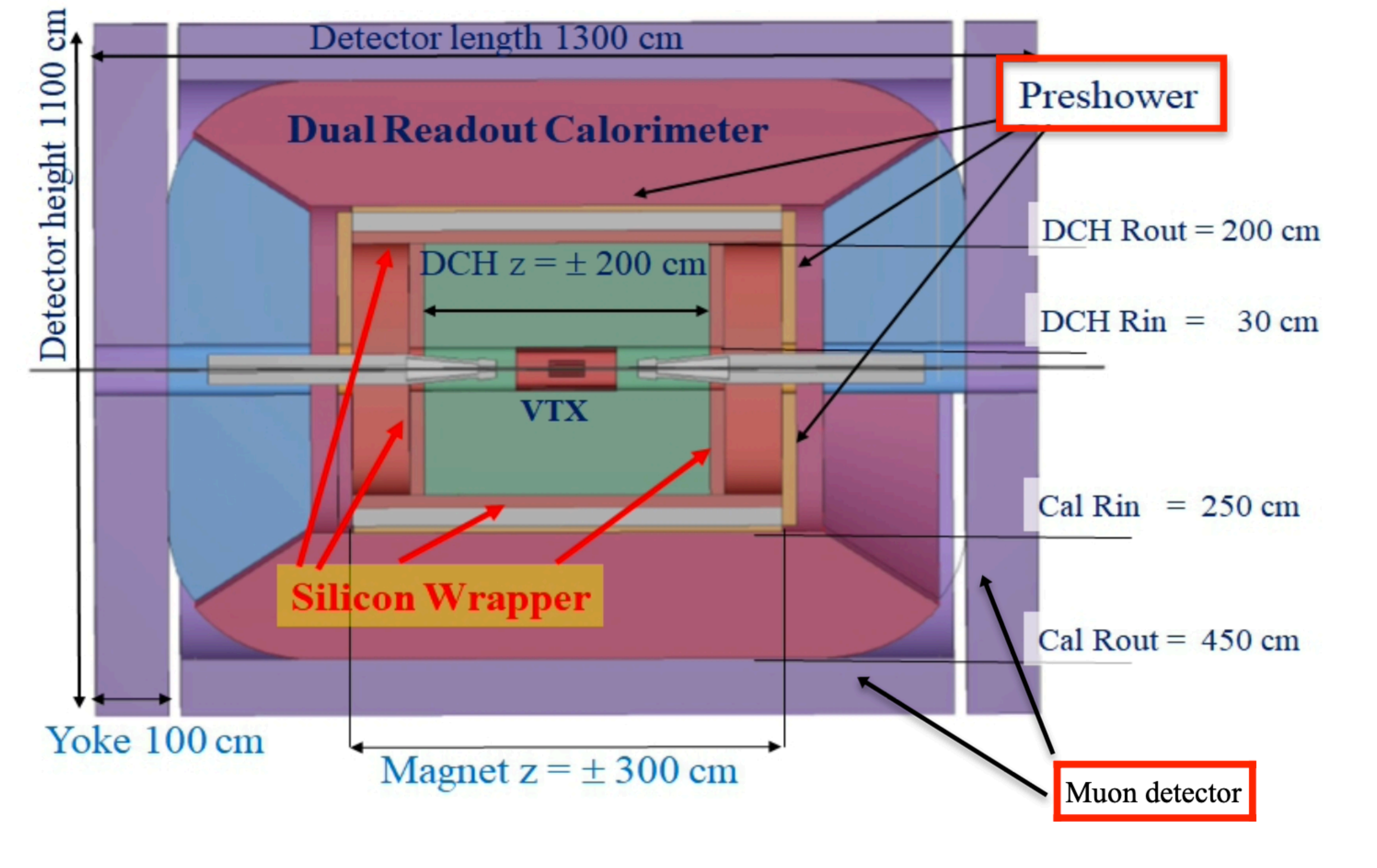
CMS ECAL crystals are 22x22x230 mm

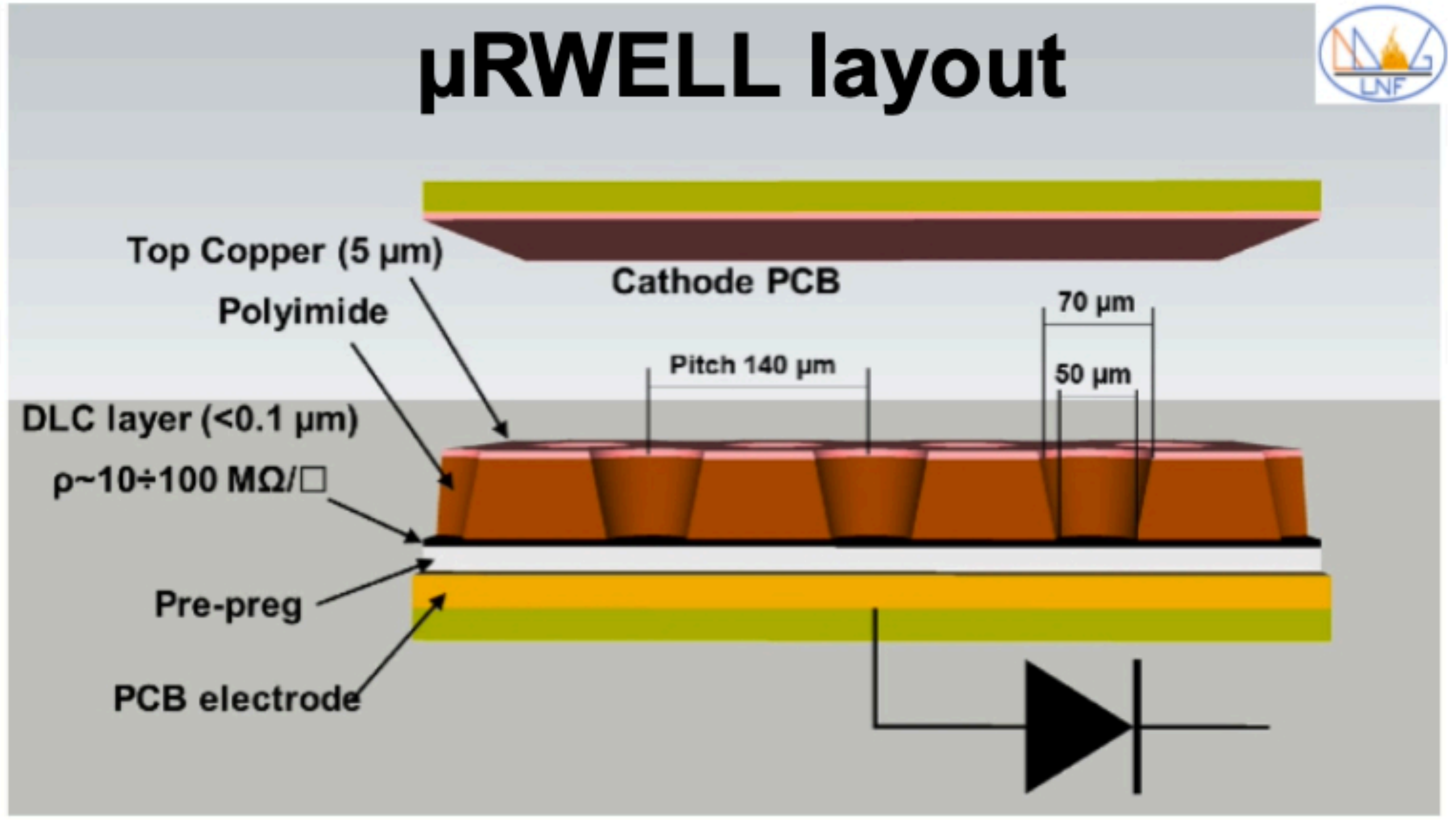
Dual Readout Crystal Calorimeter

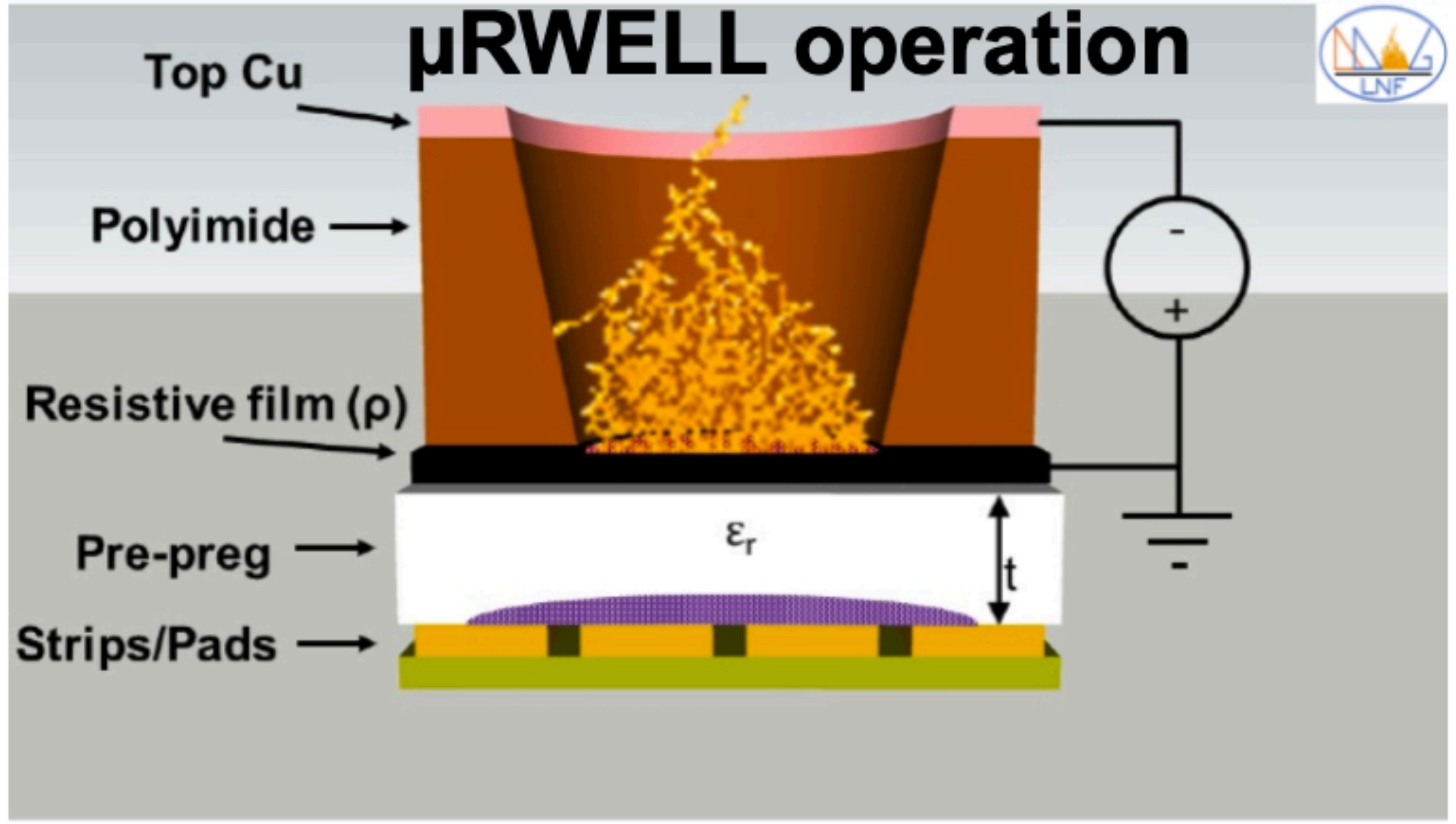
Photon and Neutral Hadron Energy Resolutions



IDEA Detector: μ-RWELL technology





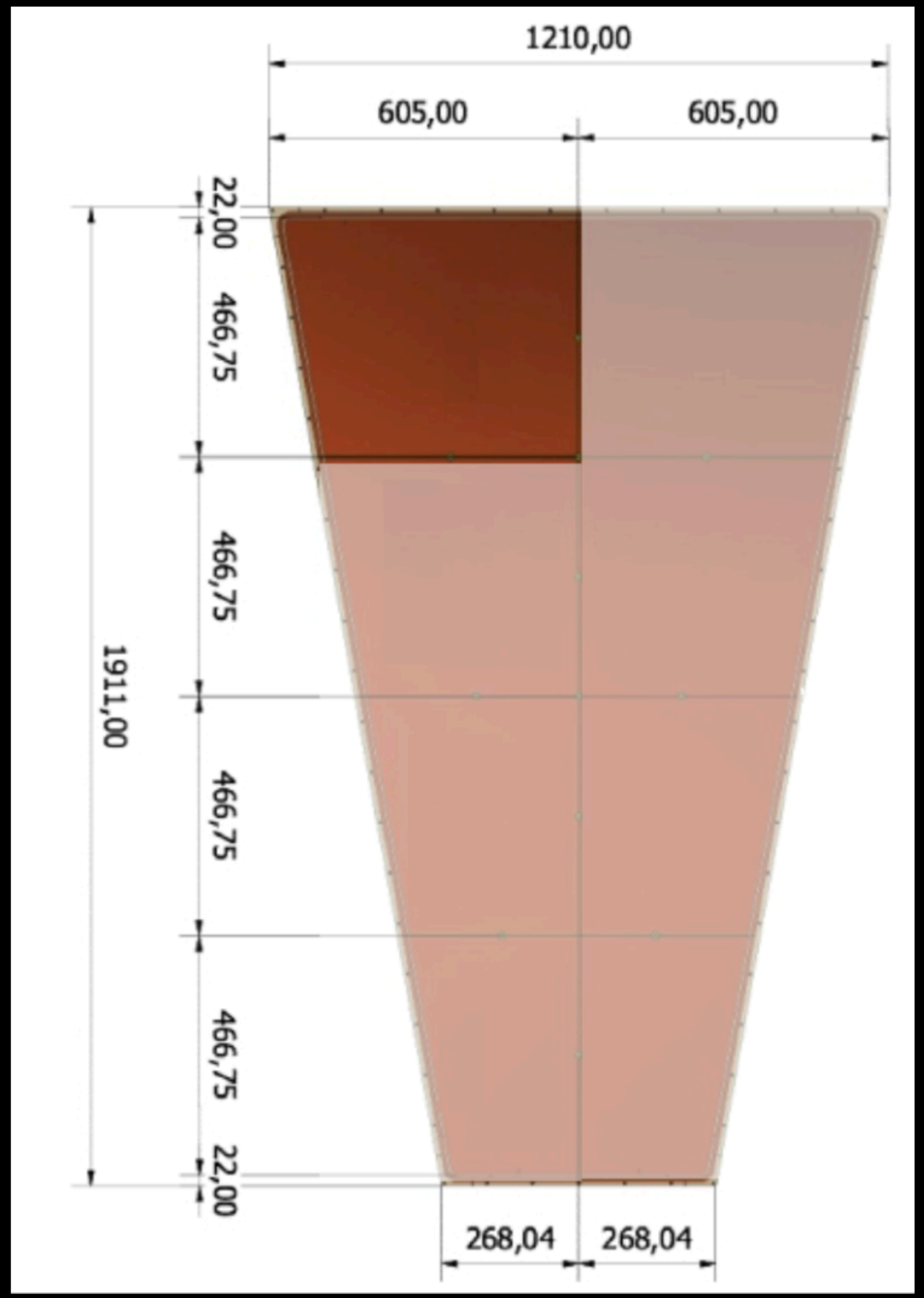


	Pixel size (mm)	Area (m²)	Channels
Pre-shower	0.4 × 500	120	570 k
Muon detector	1.5 × 500	2800	4 M

IDEA Detector: μ-RWELL technology

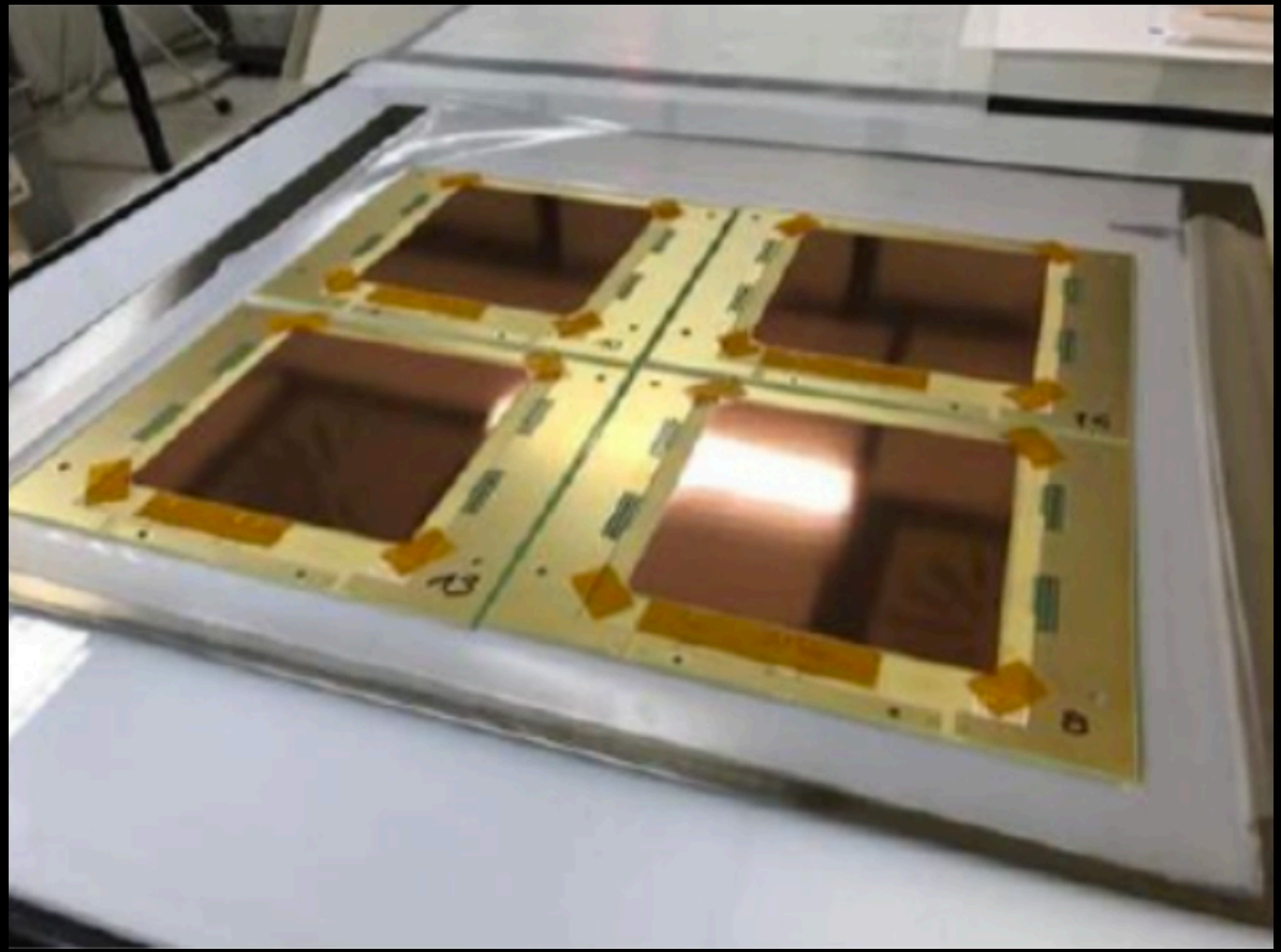
- How to optimize the detector design to the CEPC physics program?
- How to reduce the input FEE capacity in the muon system?
- How to built more than 3000 m^2 of μRWELL detectors?

First large area μRWELL (produced at CERN)



TIGER-GEMROC technology developed by INFN within the CGEM-IT BESIII frame

A second large area μRWELL of 500 x 500 mm^2 to be developed with ELTOS, an Italian company



μRWELL detailed simulation is on-going

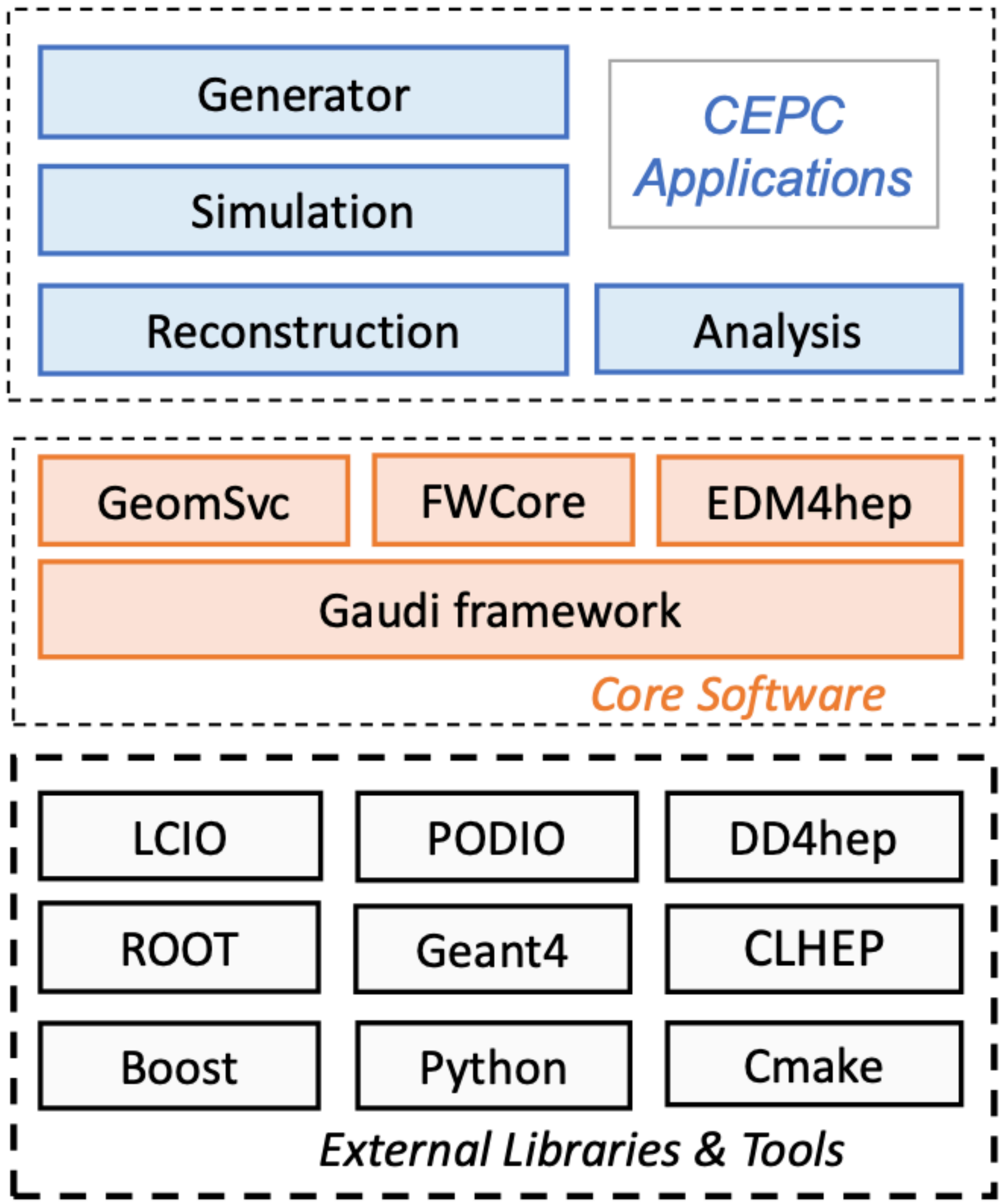
Description to be included in DD4HEP framework within Key4HEP environment

Goal by 2024: Optimize engineering mass construction with the ELTOS Develop new specific ASIC, and complete simulation/reconstruction

CEPC Software migration to key4hep

CEPCSW: the first application of Key4hep

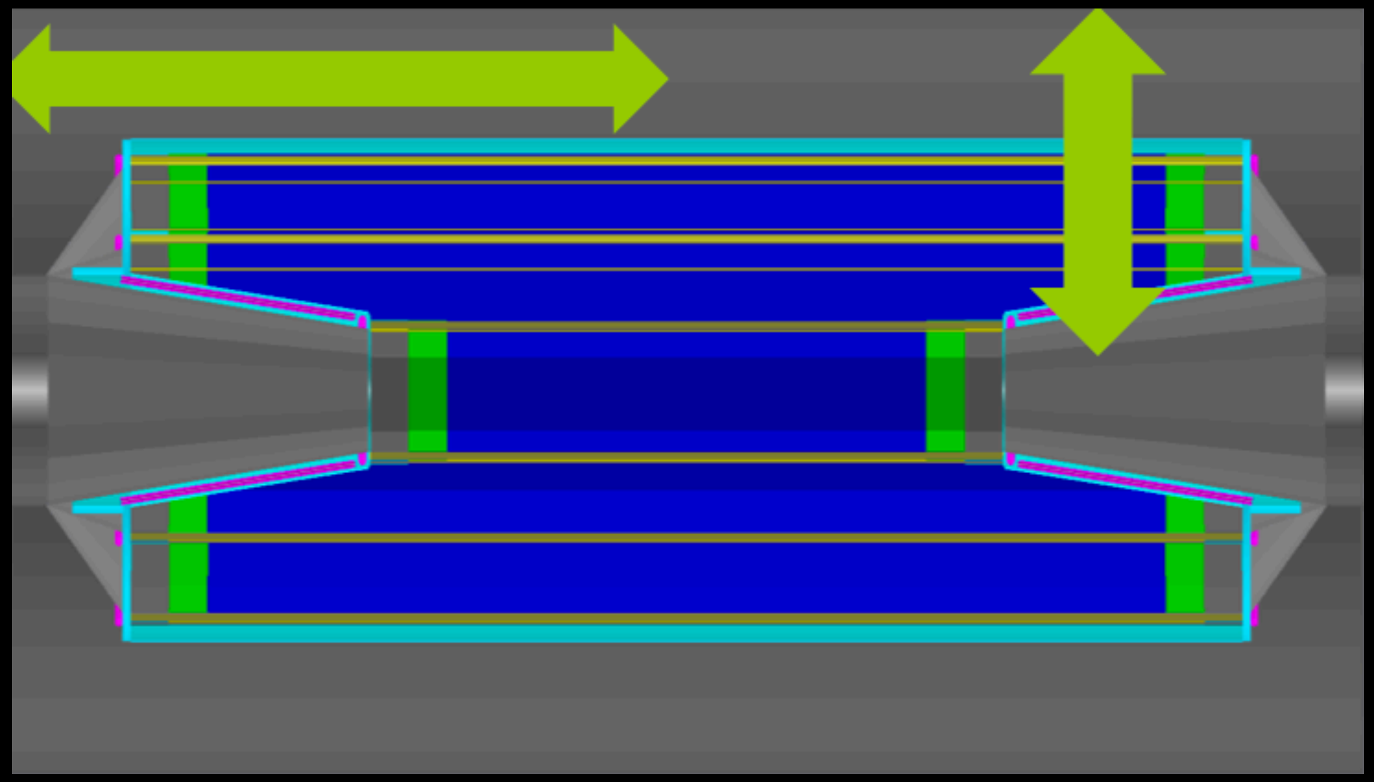
- Architecture of CEPCSW
  - external libraries
  - core software
  - CEPC applications for simulation, reconstruction and analysis.
- Core software
  - Gaudi framework: defines interfaces of all the software components and controls the event loop.
  - EDM4hep: generic event data model.
  - FWCore: manages the event data.
  - GeomSvc: DD4hep-based geometry management service.
- CEPCSW is already included in Key4hep software stack.

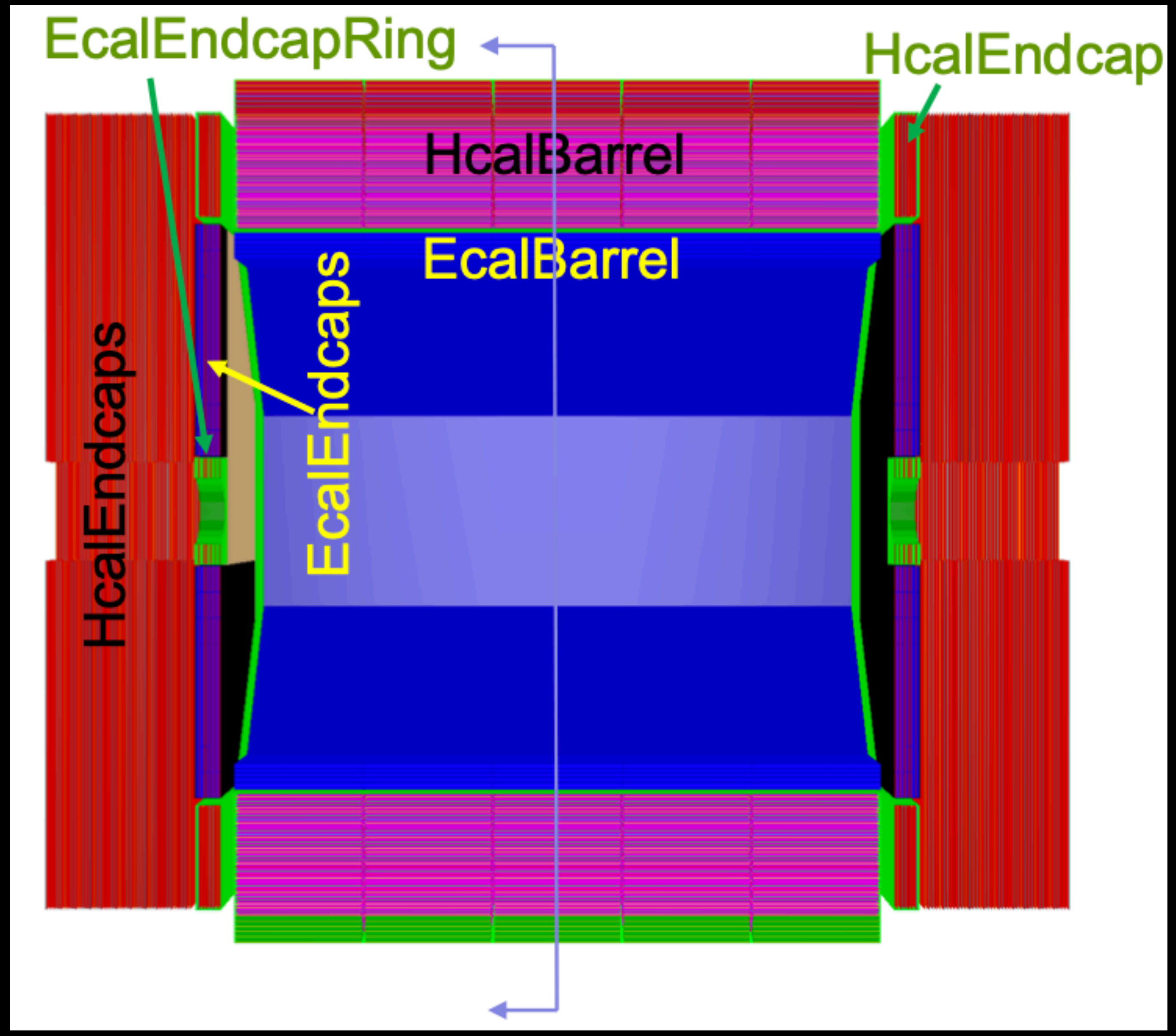


https://github.com/cepc/CEPCSW

Xingtao Huang: https://indico.ihep.ac.cn/event/11444/session/12/contribution/169/material/slides/0.pdf 14

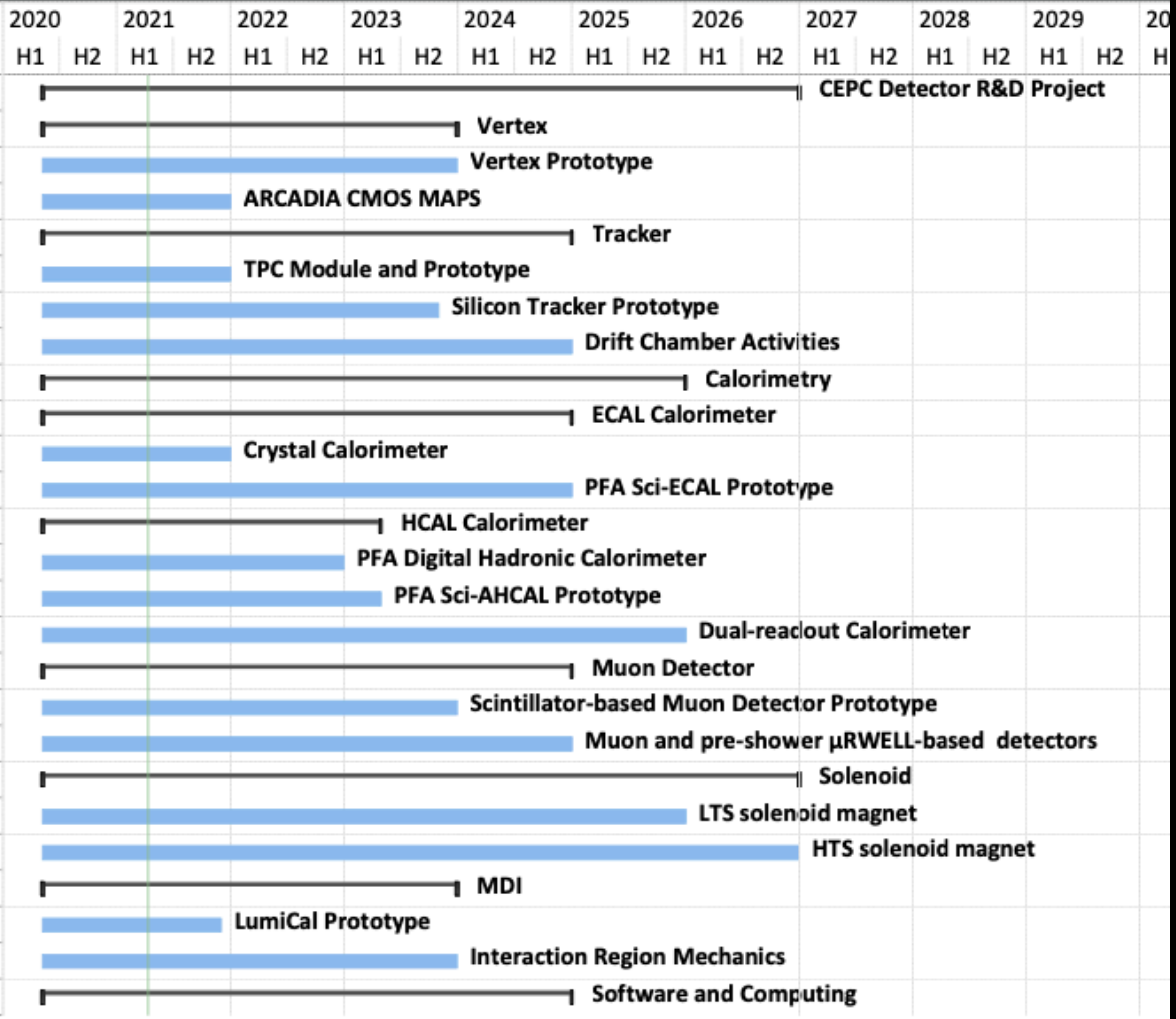
CEPC_v4 reference detector





Projects overview: R&D schedule

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



Projects overview

Total subtasks: 103

17 documents, total: 85 pages

PBS	Task Name	Page	Subtask	Context	Team	Document Responsible
	CEPC Detector R&D Project					
1	**Vertex**					
1.1	**Vertex Prototype**	5	9	CEPC	China+ international collaborators	Zhijun, Ouyang
1.2	**ARCADIA CMOS MAPS**	6	6	Generic	INFN, Italy	Manuel Rolo
2	**Tracker**					
2.1	**TPC Module and Prototype**	6	10	CEPC	IHEP, Tsinghua	Huirong
2.2	**Silicon Tracker Prototype**	6	8	Generic	China, UK, Italy	Harald Fox, Meng Wang
2.3	**Drift Chamber Activities**	4	3	FCC-ee/CEPC	INFN, Novosibirsk	Franco Grancagnolo
3	**Calorimetry**					
3.1	**ECAL Calorimeter**					
3.1.1	Crystal Calorimeter	4	6	CEPC	IHEP, Princeton + others	Yong Liu
3.1.2	PFA Sci-ECAL Prototype	3	3	CEPC	USTC, IHEP	Jianbei Liu
3.2	**HCAL Calorimeter**					
3.2.1	PFA Digital Hadronic Calorimeter	4	5	CEPC	SJTU, IPNL, Weizmann, IIT, USTC	Haijun Yang, Imad Laktineh, Shikma Bressler
3.2.2	PFA Sci-AHCAL Prototype	4	4	CEPC	USTC, IHEP, SJTU	Jianbei Liu
3.3	**Dual-readout Calorimeter**	5	5	FCC-ee/CEPC	INFN, Sussex, Zagreb, South Korea	Roberto Ferrari
4	**Muon Detector**					
4.1	Scintillator-based Muon Detector	4	6	CEPC	Fudan, SJTU	Xiaolong Wang, Liang Li
4.2	Muon and pre-shower µRWELL-	5	5	FCC-ee/CEPC	INFN, LNF	Paolo Giacomelli
5	**Solenoid**					
5.1	LTS solenoid magnet	4	4	CEPC	IHEP+Industry	Zhu Zian
5.2	HTS solenoid magnet	4	4	CEPC	IHEP+Industry	Zhu Zian
6	**MDI**					
6.1	LumiCal Prototype	5	2	ILC/CEPC	AC, IHEP	Suen Hou
6.2	Interaction Region Mechanics	4	4	CEPC	IHEP	Hongbo Zhu
8	**Software and Computing**	11	19	CEPC	IHEP, SDU	Li Weidong, Ruan Manqi, Sun Shengseng, Li Gang

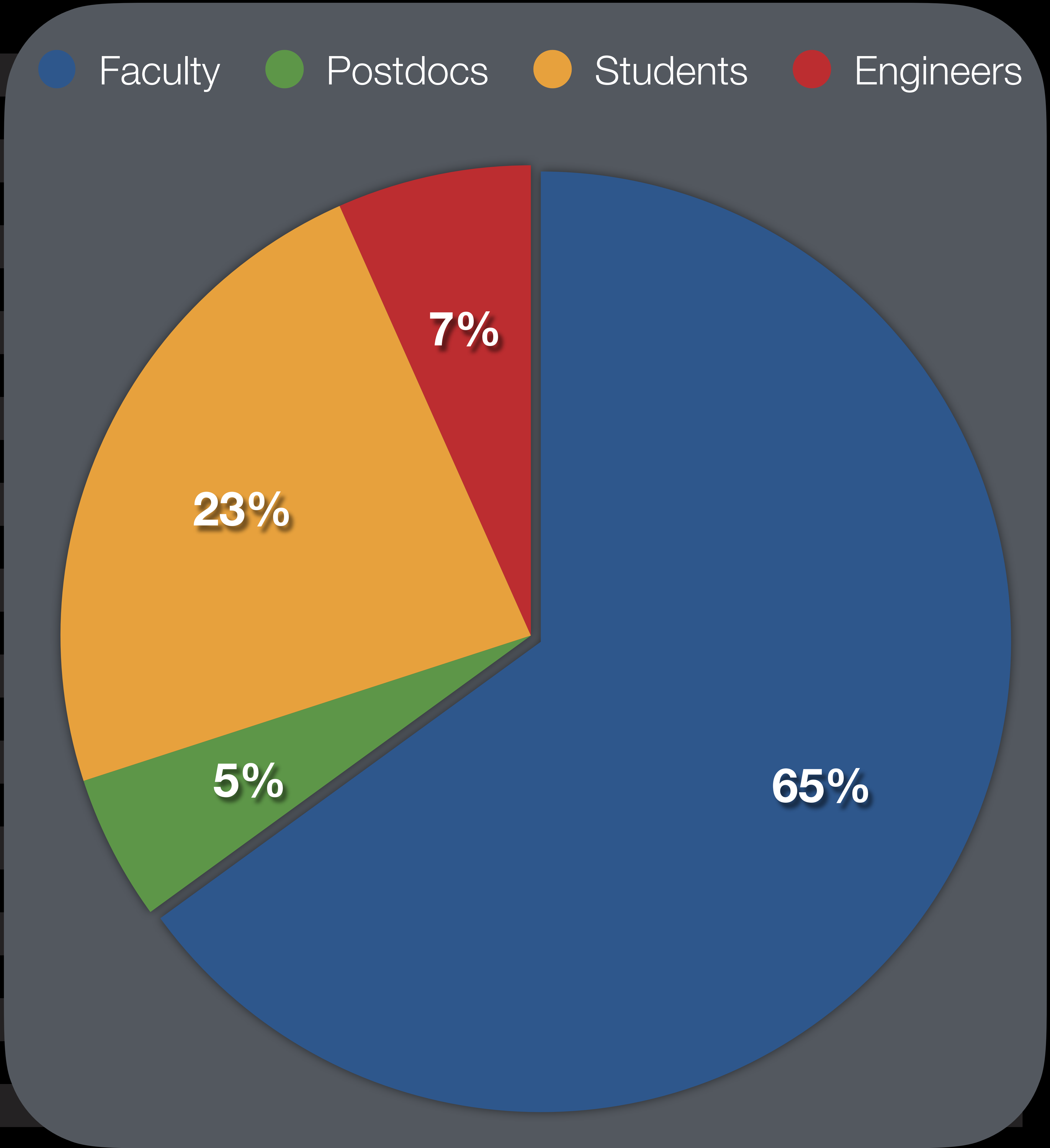
Projects overview: FTE

PBS	Task Name	Team	Faculty	Postdoc	Students	Engineers
		Total:	156	12	56	16
	CEPC Detector R&D Project					
1	Vertex					
1.1	Vertex Prototype	China+ international collaborators	21		17.2	3.5
1.2	ARCADIA CMOS MAPS	INFN, Italy	55 people, mostly staff INFN and University Associates			
2	Tracker					
2.1	TPC Module and Prototype	IHEP, Tsinghua	3		4	1
2.2	Silicon Tracker Prototype	China, UK, Italy	50		4	5
2.3	Drift Chamber Activities	INFN, Novosibirsk	2.5	2.4	1.8	0.8
3	Calorimetry					
3.1	ECAL Calorimeter					
3.1.1	Crystal Calorimeter	IHEP, Princeton + others	1.3		1.5	
3.1.2	PFA Sci-ECAL Prototype	USTC, IHEP	1.9		2.5	
3.2	HCAL Calorimeter					
3.2.1	PFA Digital Hadronic Calorimeter	SJTU, IPNL, Weizmann, IIT, USTC	2.1	1.8	2.6	0.3
3.2.2	PFA Sci-AHCAL Prototype	USTC, IHEP, SJTU	2.3	0.8	4	
3.3	Dual-readout Calorimeter	INFN, Sussex, Zagreb, South Korea	4.2	2.2	6.8	1.3
4	Muon Detector					
4.1	Scintillator-based Muon Detector	Fudan, SJTU	1.2		2.1	0.2
4.2	Muon and pre-shower µRWELL-	INFN, LNF	2	1.5	1	0.3
5	Solenoid					
5.1	LTS solenoid magnet	IHEP+Industry	2	0	1	0.5
5.2	HTS solenoid magnet	IHEP+Industry	1.5	0	1	0.5
6	MDI					
6.1	LumiCal Prototype	AC, IHEP	1	1	2	1
6.2	Interaction Region Mechanics	IHEP	0.5	0.3	1.5	2
8	Software and Computing	IHEP, SDU	7	2	3	0

Projects overview: FTE

Total: 156 12 56 16

PBS	Task Name	Team				
	CEPC Detector R&D Project					
1	**Vertex**					
1.1	**Vertex Prototype**	China+ international collaborators				
1.2	**ARCADIA CMOS MAPS**	INFN, Italy				
2	**Tracker**					
2.1	**TPC Module and Prototype**	IHEP, Tsinghua				
2.2	**Silicon Tracker Prototype**	China, UK, Italy				
2.3	**Drift Chamber Activities**	INFN, Novosibirsk				
3	**Calorimetry**					
3.1	**ECAL Calorimeter**					
3.1.1	Crystal Calorimeter	IHEP, Princeton + others				
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				
6.2	Interaction Region Mechanics	IHEP				
8	**Software and Computing**	IHEP, SDU	7	2	3	0



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

Final remarks

Now considering new ideas and developing new tools

Need more time to explore alternatives and test these ideas

Key detector technologies R&D continues and are put to prototyping

Several CEPC R&D detector projects reaching a successful conclusion

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

Extra slides

Updated Parameters of Collider Ring since CDR

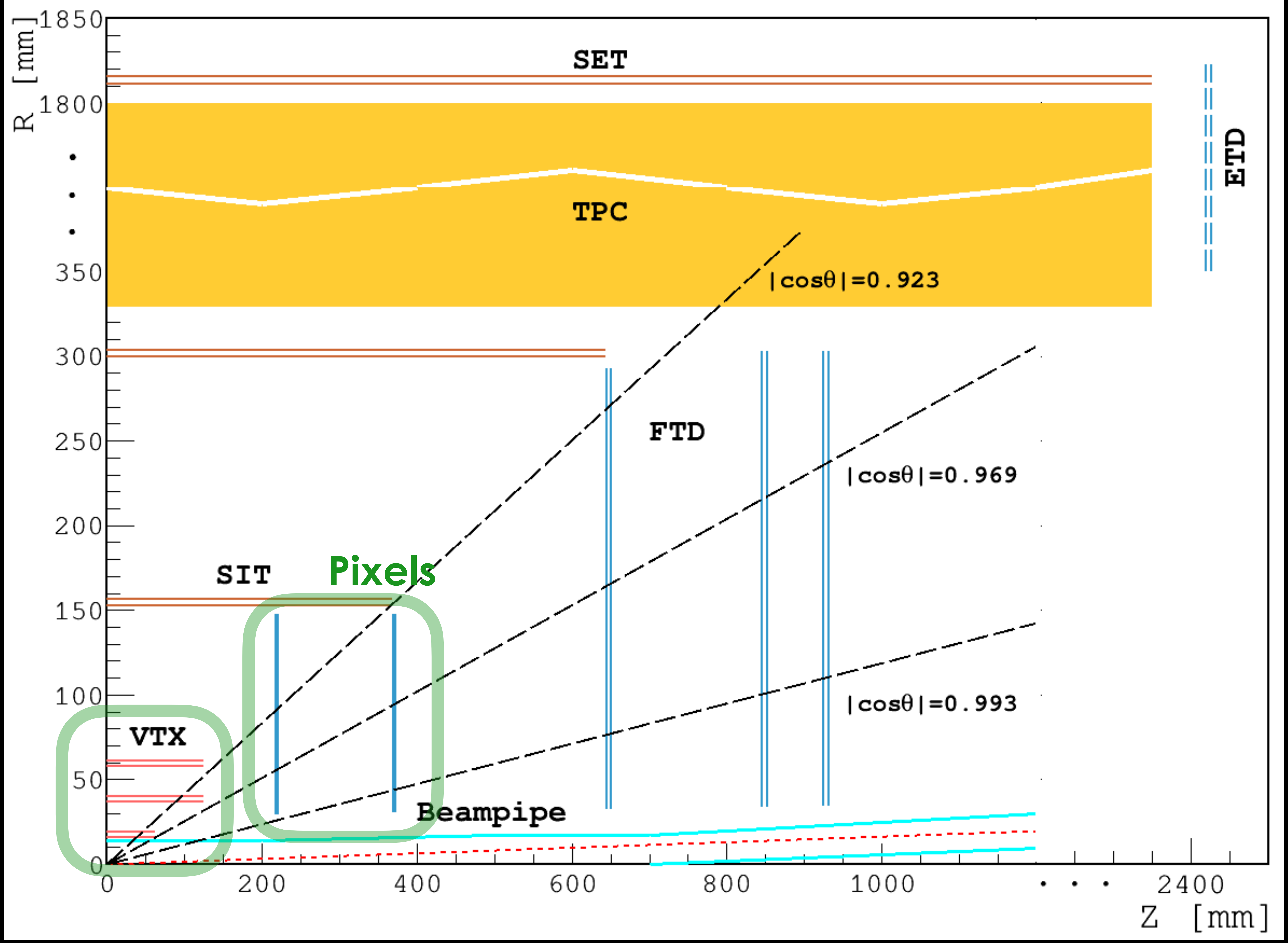
	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.8	0.036	-
Number of particles/bunch N_e (10^{10})	15.0	16.3	8.0	16.1
Bunch number (bunch spacing)	242 (0.68μs)	214 (0.7 μs)	12000	10870 (27ns)
Beam current (mA)	17.4	16.8	461.0	841.0
Synchrotron radiation power /beam (MW)	30	-	16.5	30
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.33/0.001	0.2/0.001	0.15/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.00[illegible]	0.68/0.0014	0.18/0.0016	0.52/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	15.0/0.037	6.0/0.04	8.8/0.04
Bunch length σ_z (mm)	[illegible]	[illegible]	[illegible]	[illegible]
Lifetime (hour)	0.67	0.35	2.1	[illegible]
Luminosity/IP L (10^{34} cm^{-2}s^{-1})	2.93	5.0	32.1	101.1

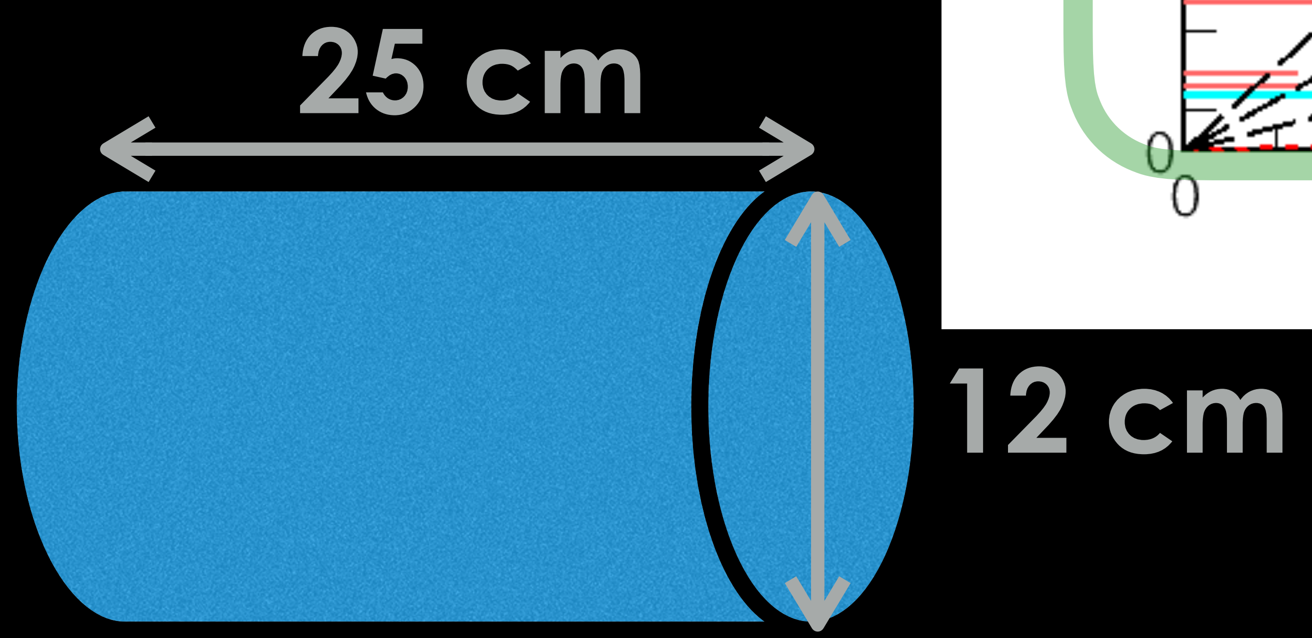
These luminosity increases have not yet been absorbed into physics and detector studies

Luminosity increase factor: × 1.8 × 3.2

Tracker Detector - PFA Detector

Tracker material budget/layer: ~0.50-0.65% X/X_0





Required resolution

$\sigma_{SP} < 7$ µm

Sensor technology

1. Microstrip sensors double layers:
   stereo angle: 5°-7°
   strip pitch: 50 µm
2. Large CMOS pixel sensors (CPS)

HV-CMOS research on-going: SUPIX-1 / -2 sensor prototypes

Power and Cooling

1. DC/DC converters
2. Investigate air cooling

Total Silicon area ~ 68 m²

Extensive opportunities for international participation

CEPC CDR: Particle Flow Conceptual Detector

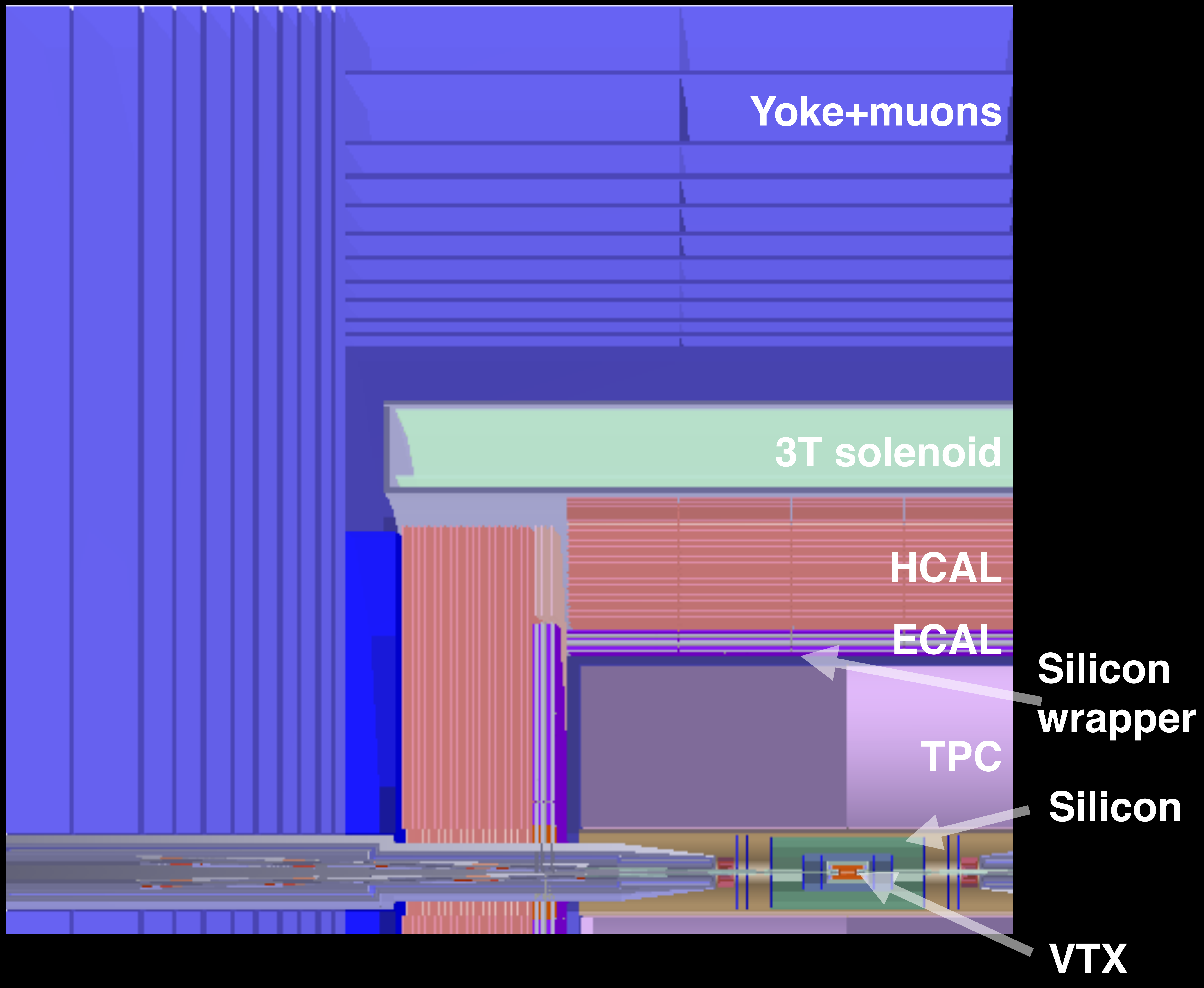
Major concerns being addressed

1. MDI region highly constrained
L* = 2.2 m
Compensating magnets

2. Low-material Inner Tracker design

3. TPC as tracker in high-luminosity Z-pole scenario

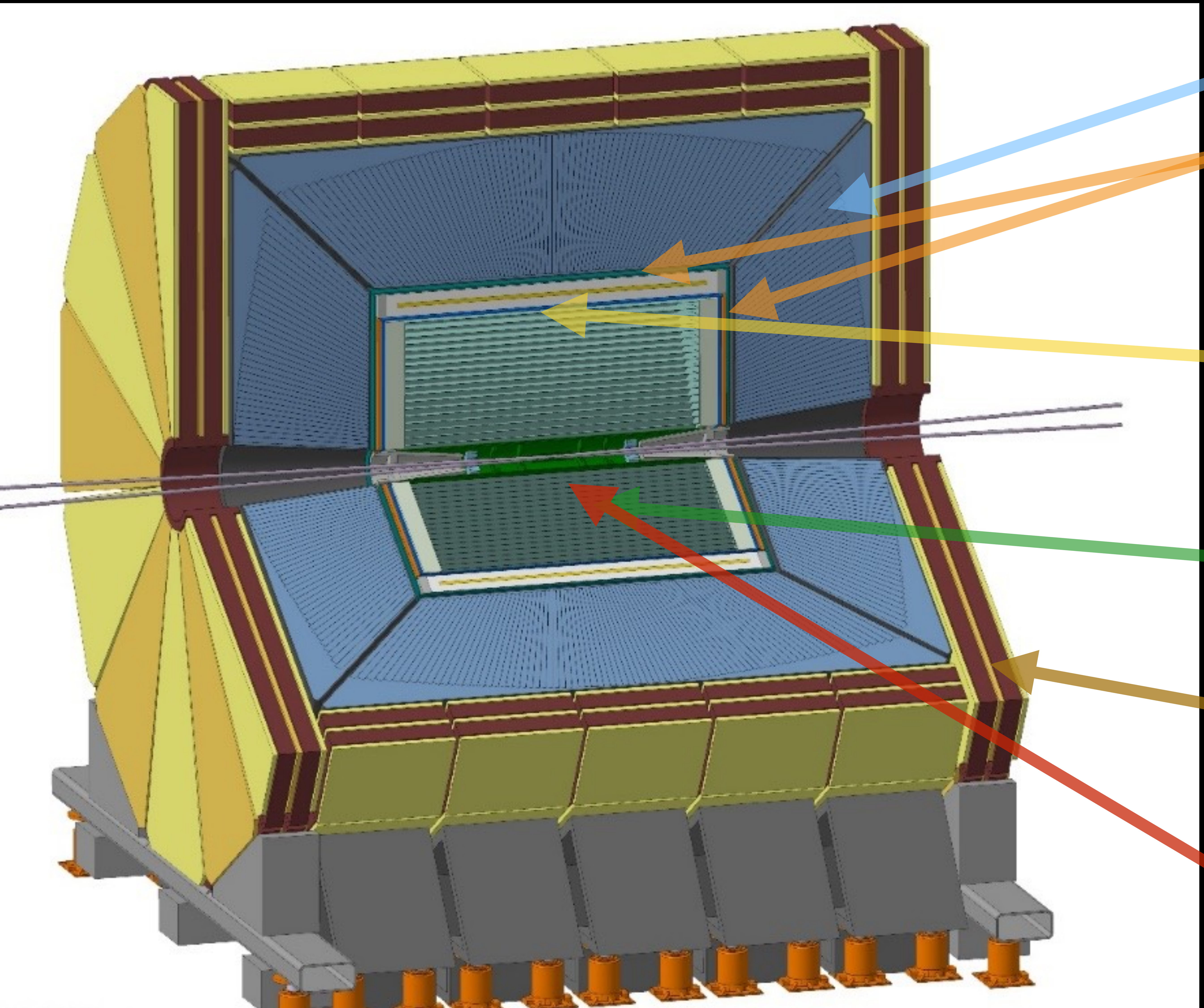
4. ECAL/HCAL granularity needs
Passive versus active cooling
Electromagnetic resolution



Magnetic Field: 3 Tesla

CEPC CDR: IDEA Conceptual Detector (CEPC + FCC-ee)

Inspired on work for 4th detector concept for ILC



Calorimeter outside the coil

* Dual-readout calorimeter: 2 m/8 λ_{int}
* Preshower: ~1 X_0

Magnet: 2 Tesla, 2.1 m radius

Thin (~ 30 cm), low-mass (~0.8 X_0)

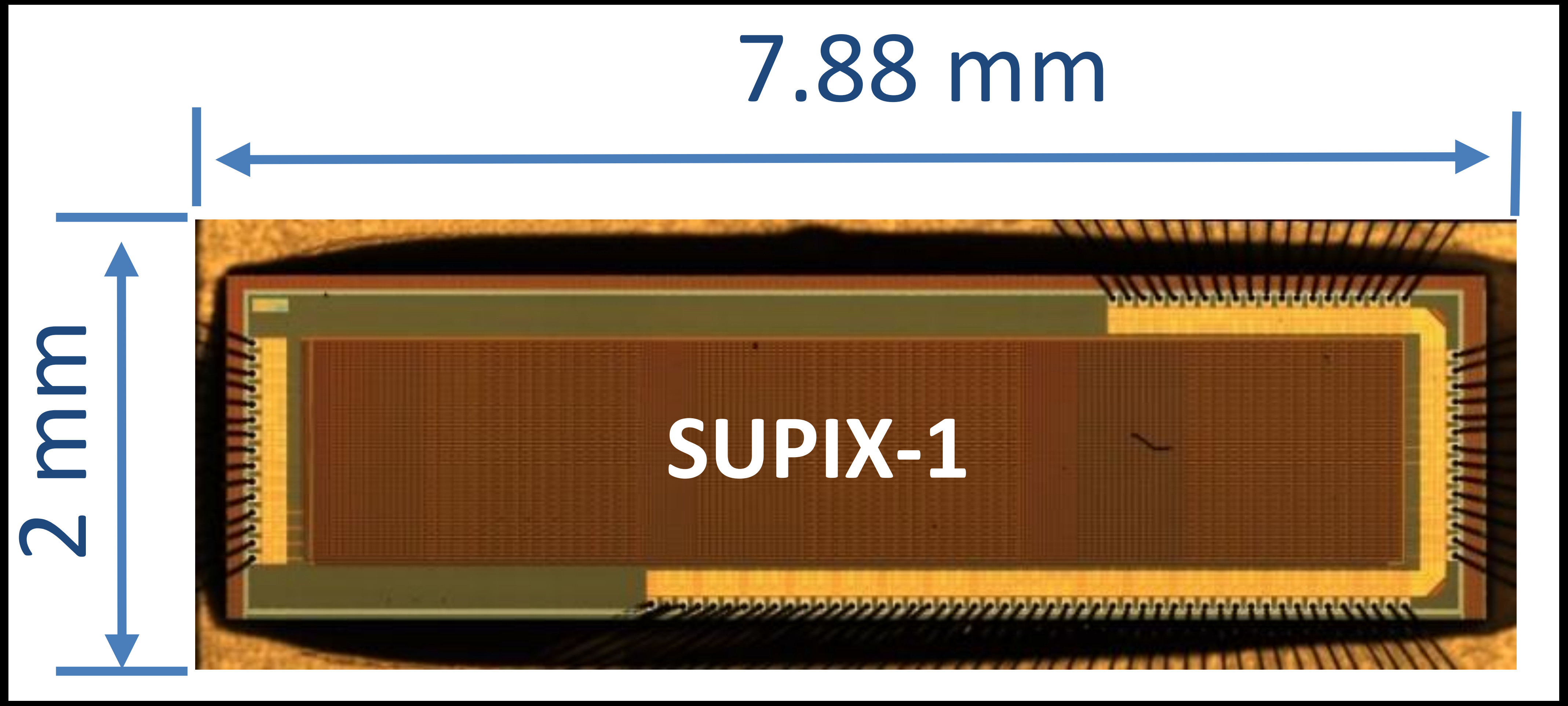
* Drift chamber: 4 m long; Radius ~30-200 cm, ~ 1.6% X_0 , 112 layers
* (yoke) muon chambers

Vertex: Similar to CEPC default

CMOS Large-Pixel Sensors for Tracker

SUPIX1 (Shandong University PIXel)

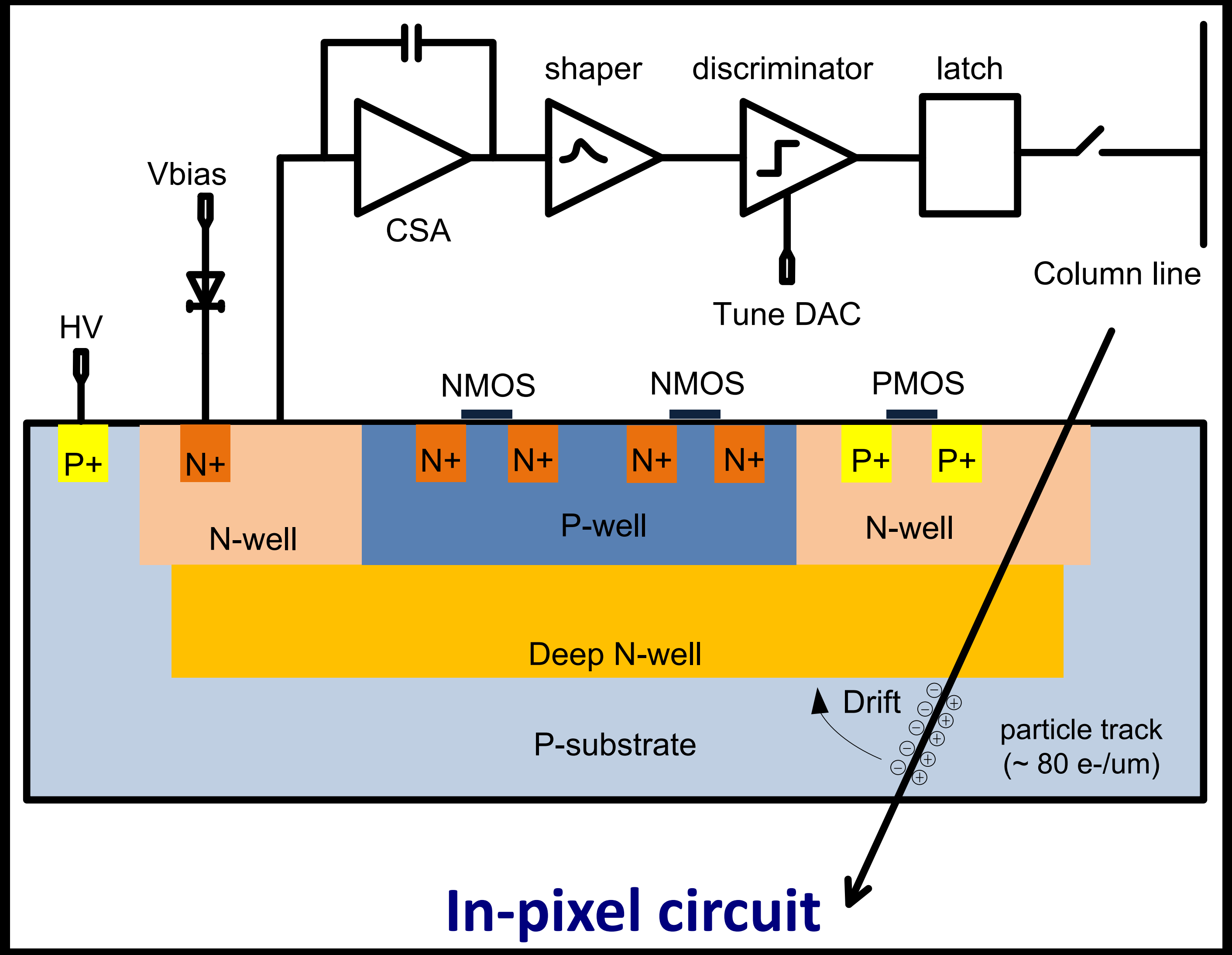
Produced and under test



- Matrix: 64 × 16
- Rolling shutter readout mode
- 16 parallel analog outputs
- Sensitive area: 2 × 7.88 mm²

SUPIX2

Submitted to SMIC in November



- Matrices: 32 × 16
- Rolling shutter readout mode
- 16 parallel analog outputs
- Pixel sizes: 60×60 μm², 60×180 μm²

MDI Assembly and Installation

Engineering studies started

Different scenarios under study

Silicon tracker assembly pushed from one side

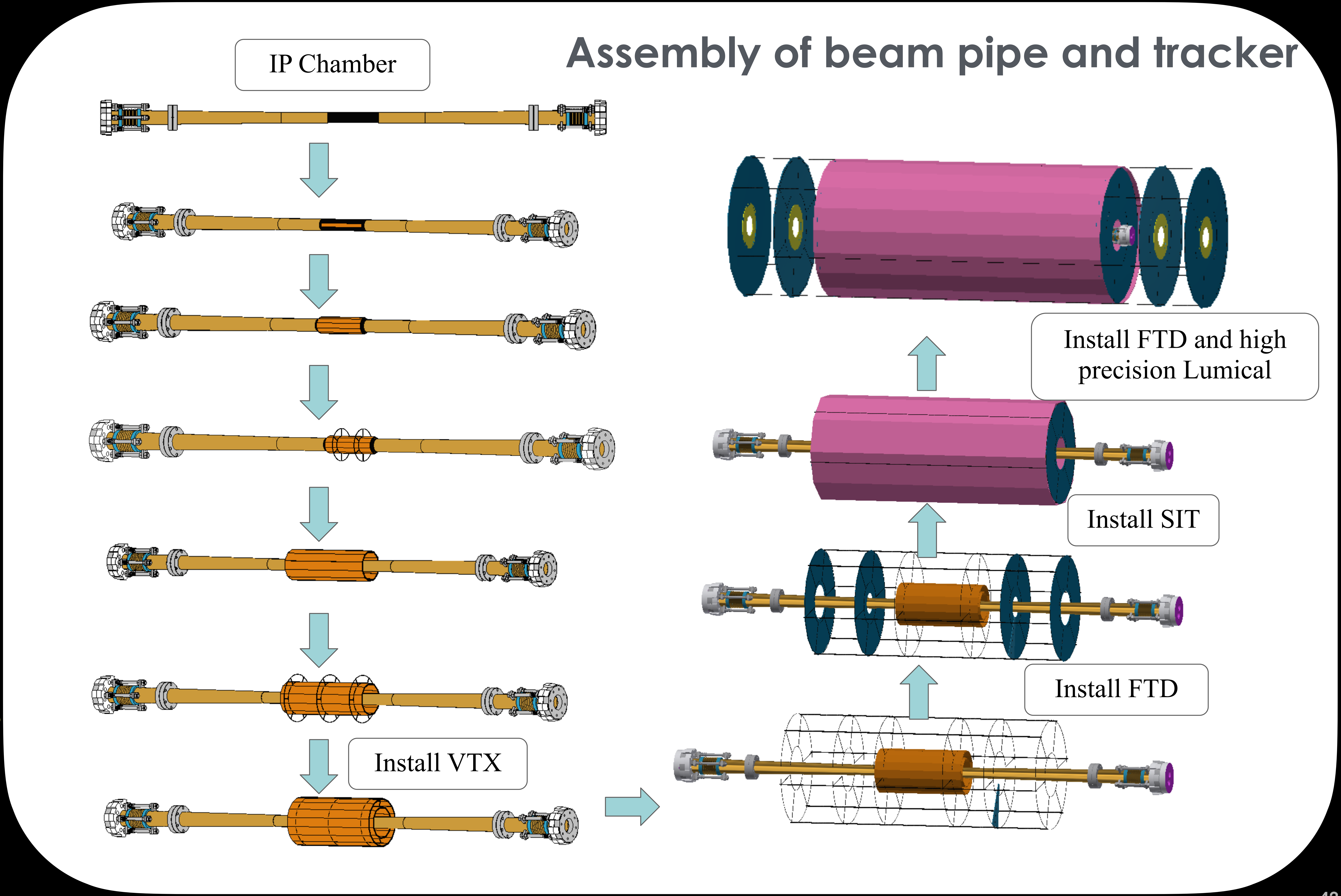
Vacuum connections closed remotely

MDI Assembly and Installation

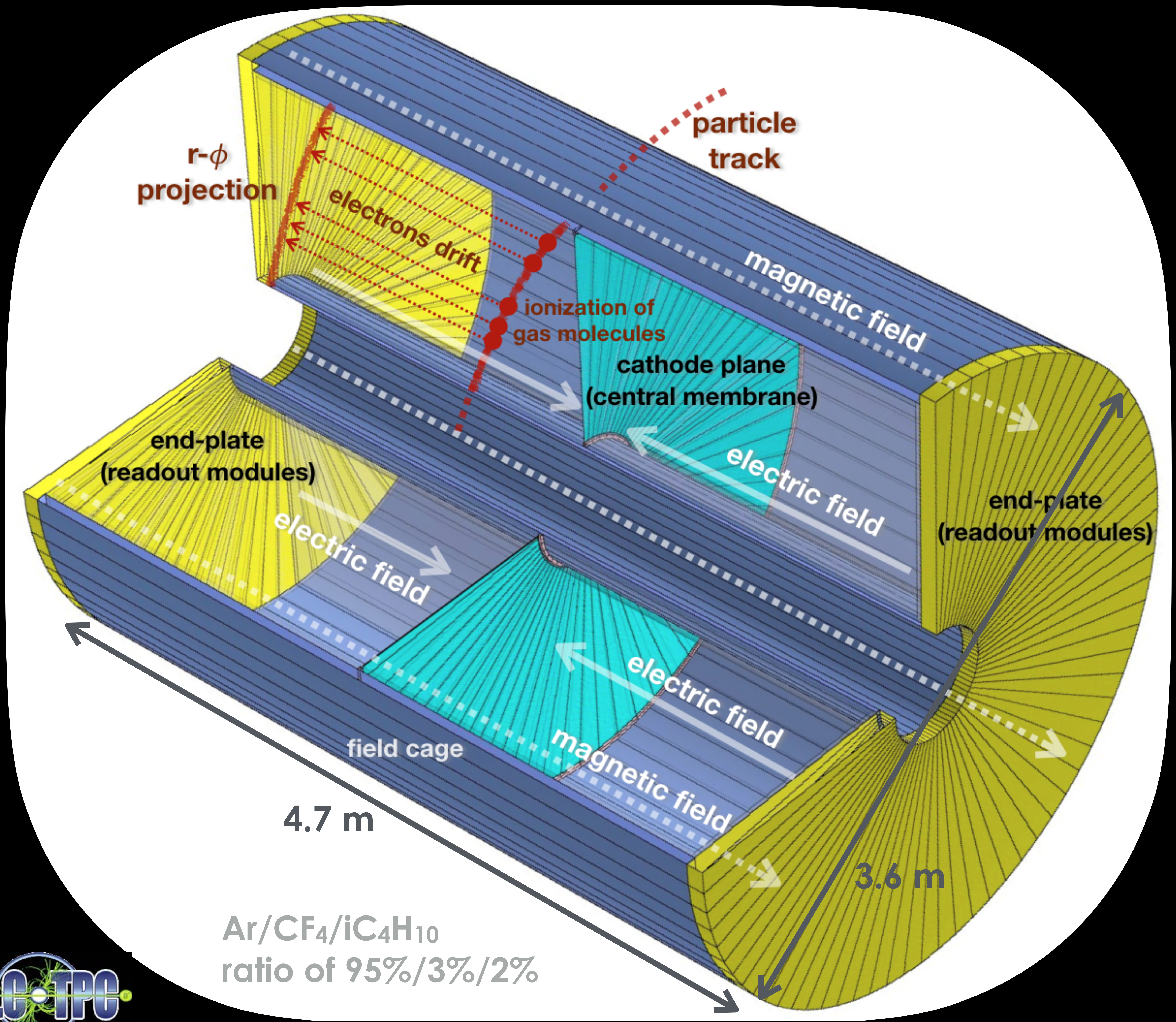
Engineering studies started

Different scenarios under study

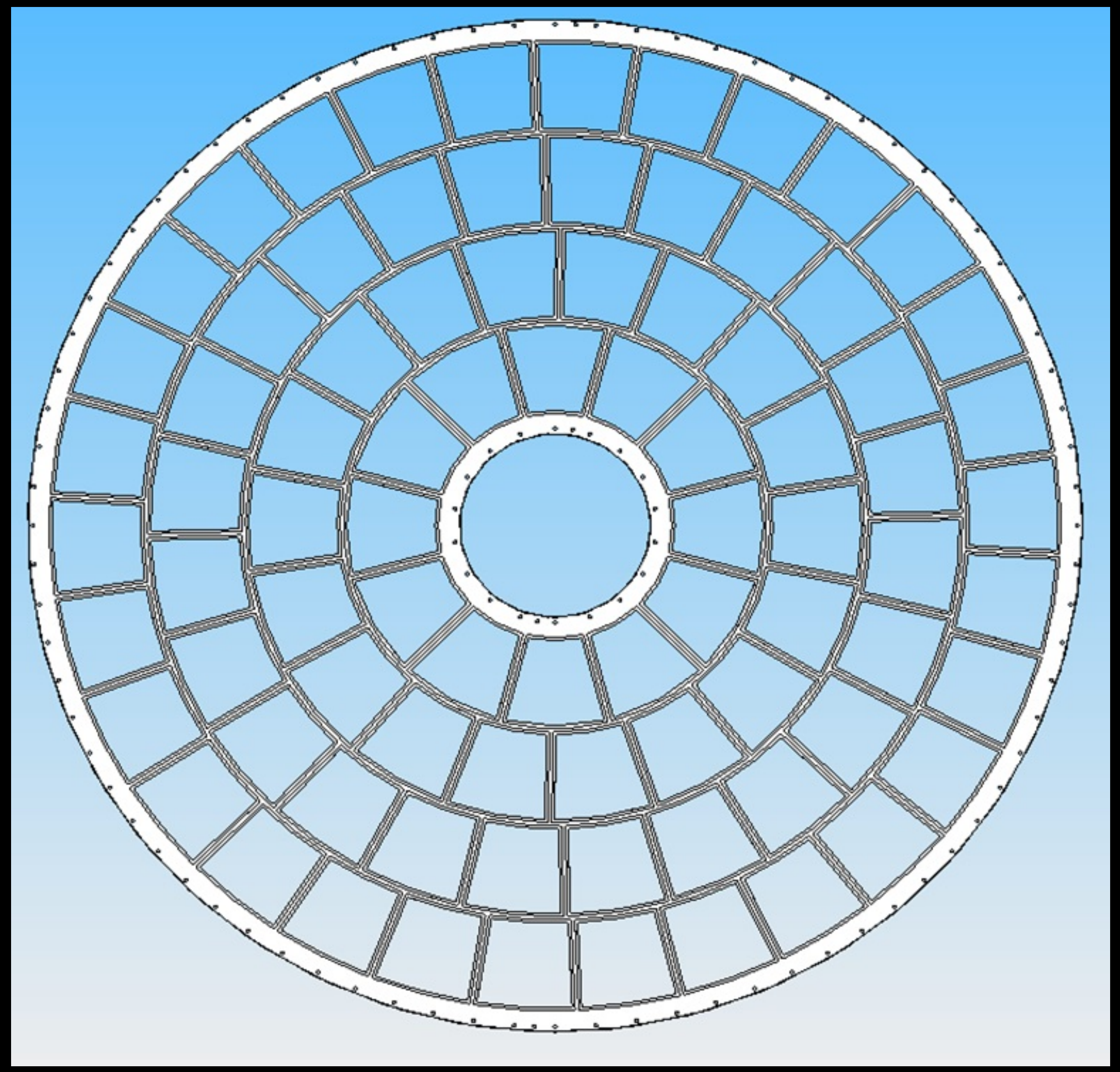
Needs close collaboration between detector designers and MDI engineers



Time Projection Chamber (TPC)



- **Allows for particle identification**
- **Low material budget:**
  - <1% X_0 in r
  - 10% X_0 for readout endcaps in Z

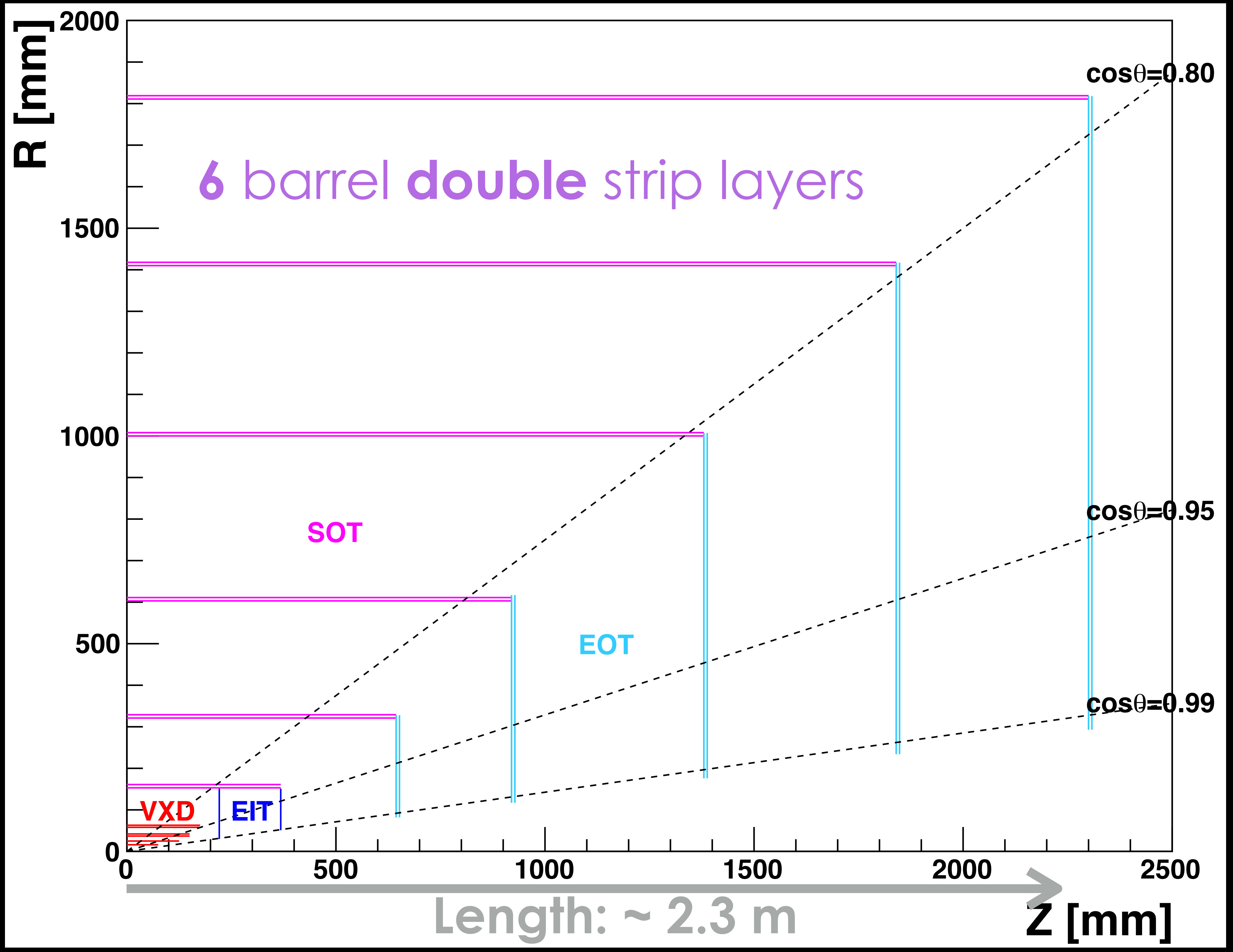


Readout by: Micro-Pattern Gas Detector (MPGD)

Full Silicon Tracker Concept

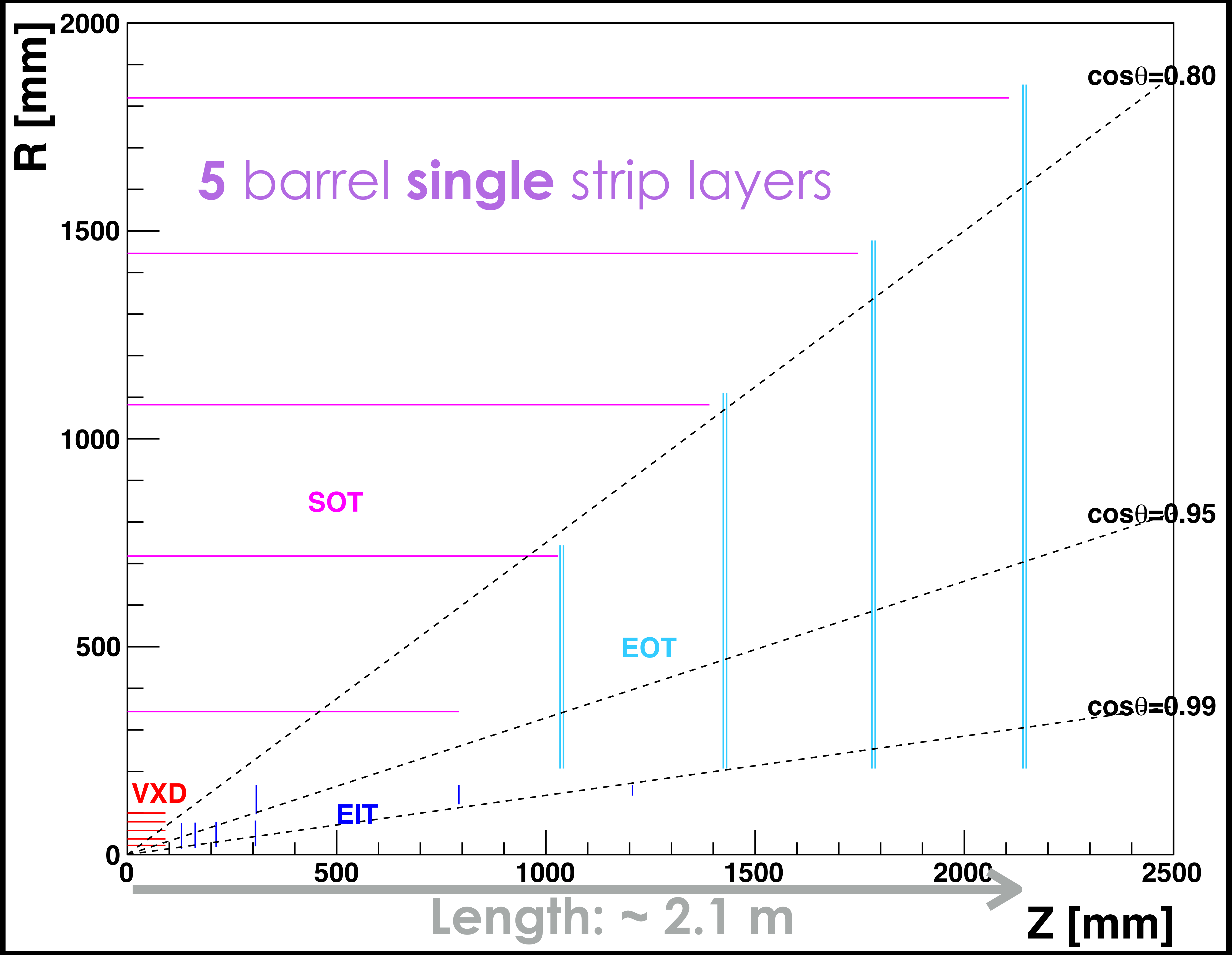
Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



Radius ~ 1.8 m

FST2 layout: Rad length up to 10%



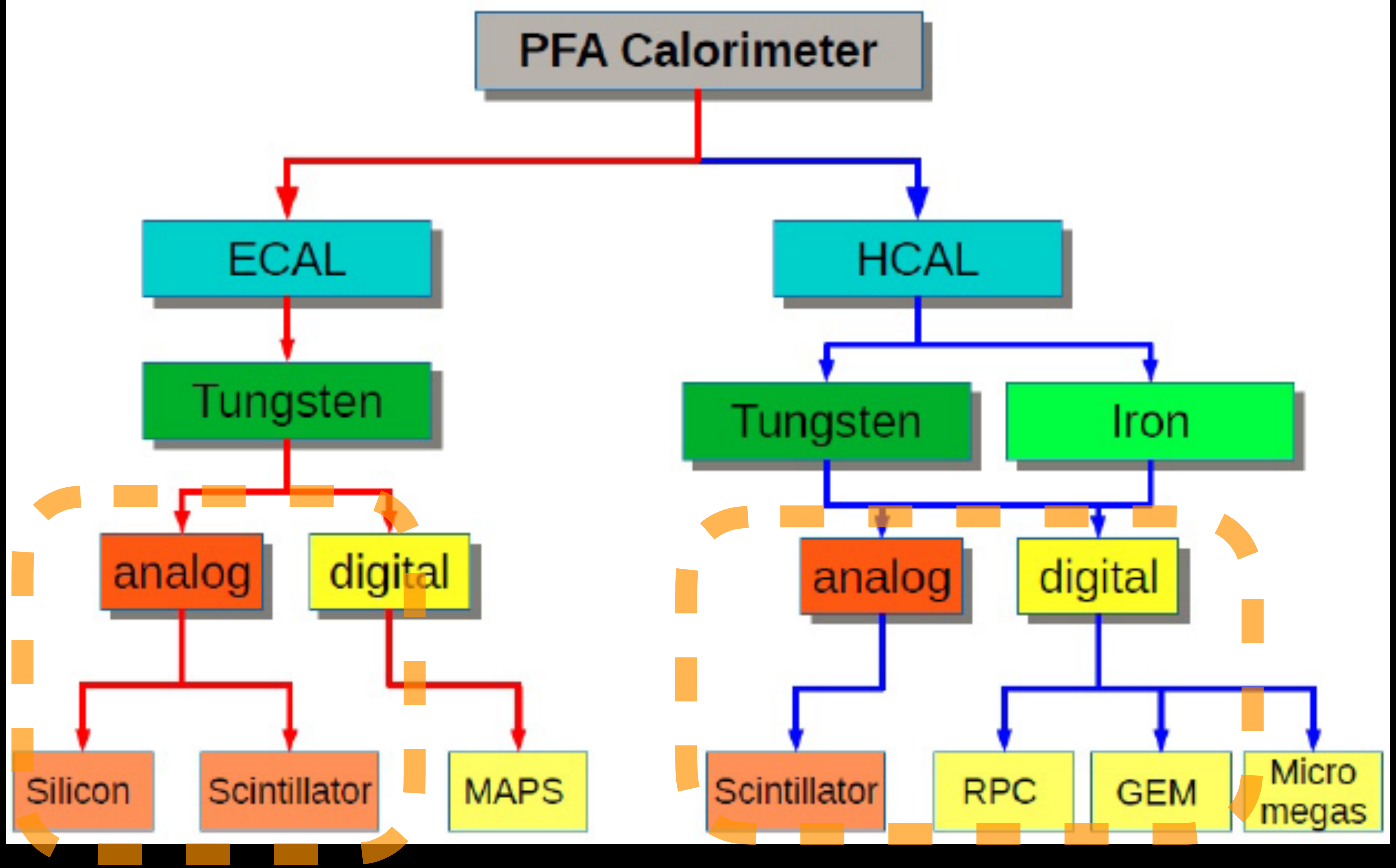
Proposed by Berkeley and Argonne

Drawbacks: higher material density and limited particle identification (dE/dx)

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

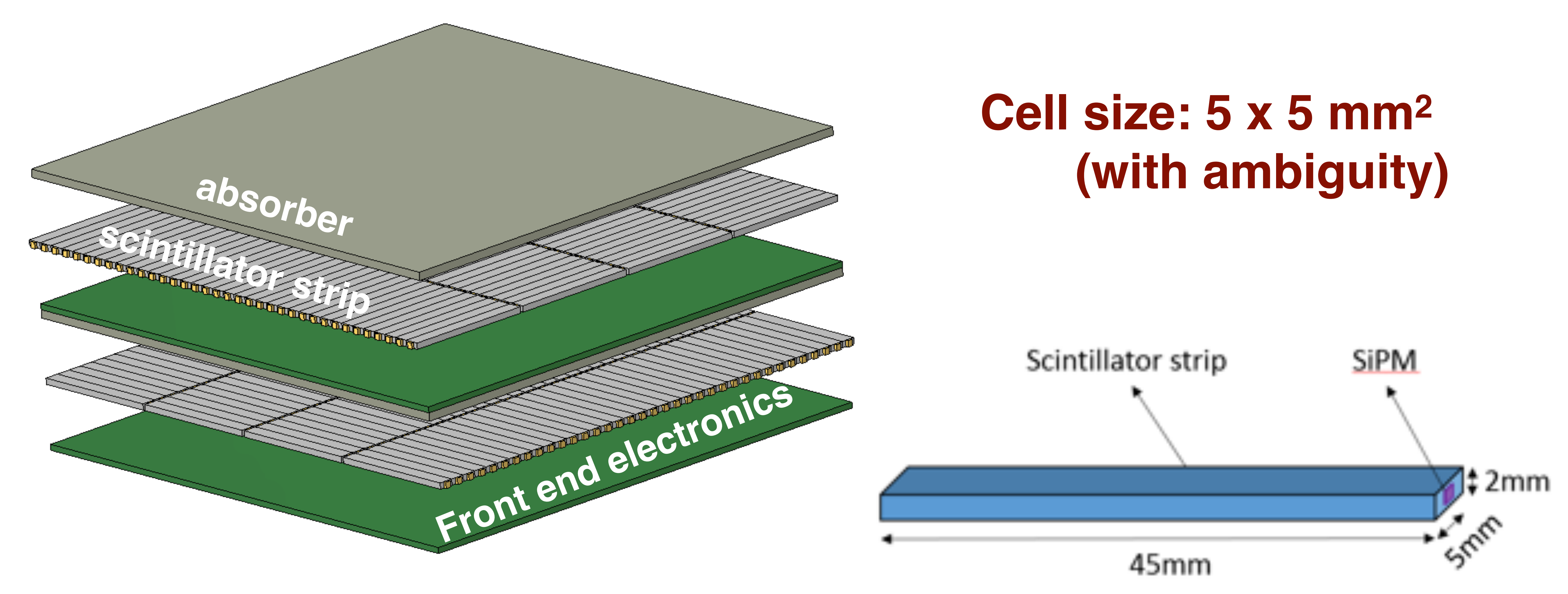
Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

ECAL Calorimeter — Particle Flow Calorimeter

Scintillator-Tungsten Sandwich ECAL

Crucial parameters
- Absorber thickness: 24 X_0
- Layer number: 30 layers
- Cell size: < 10 mm × 10 mm

Superlayer (7 mm) is made of:
- 3 mm thick: Tungsten plate
- 2 mm thick: Scintillator 5 x 45 mm²
- 2 mm thick: Readout/service layer

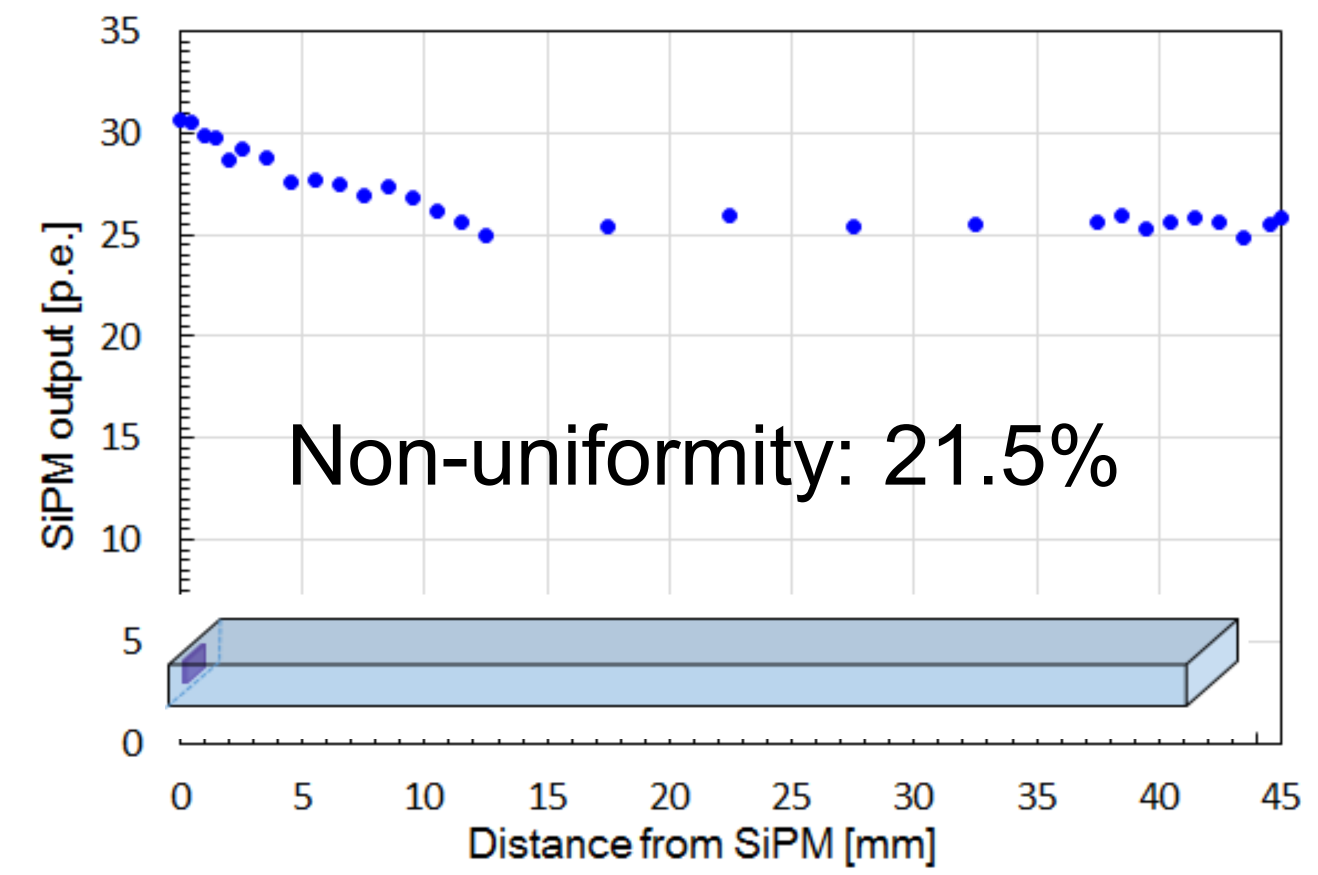


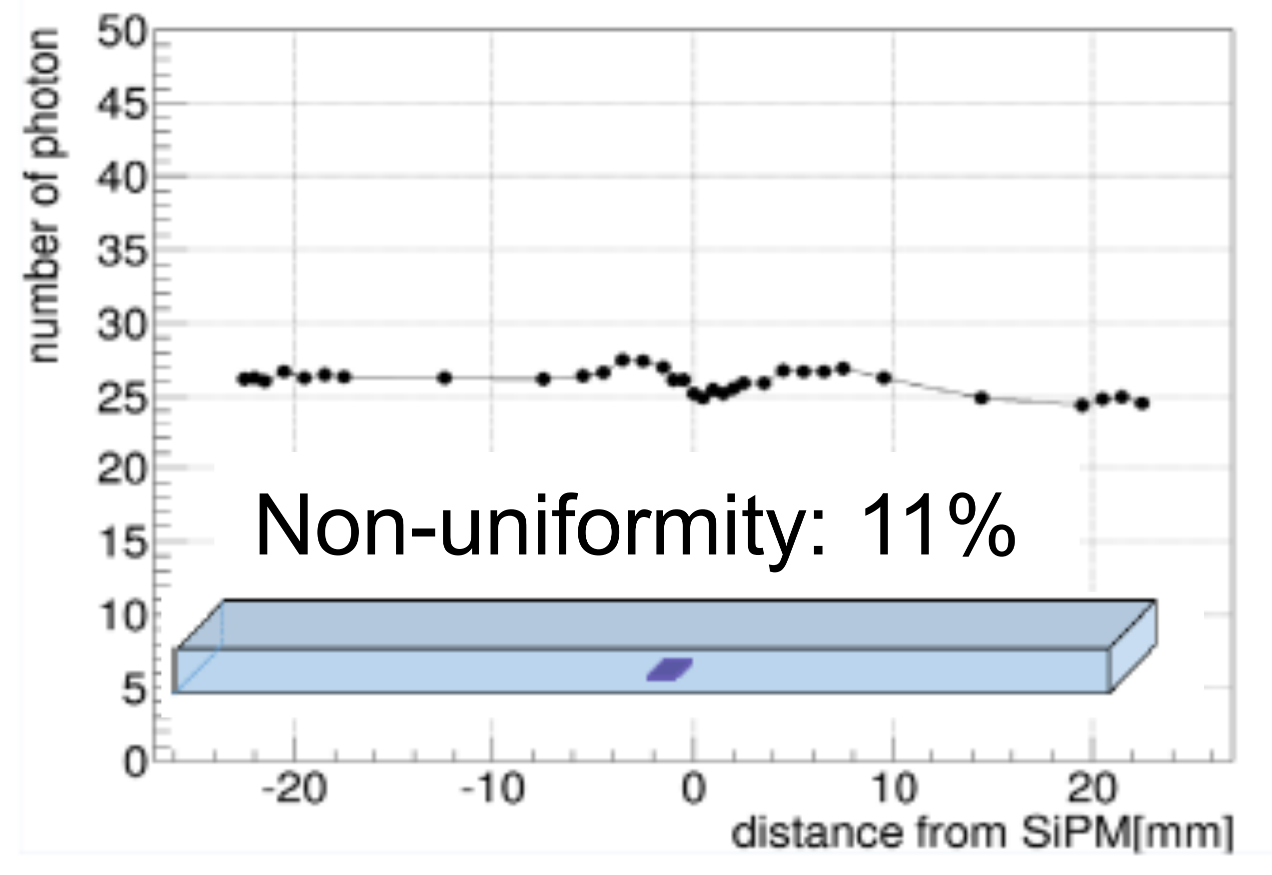
SiPM studies

Determined the optimal dynamic range of SiPM for both Sci-ECAL and AHCAL

1. SiPM with more than 10000 pixels are not required

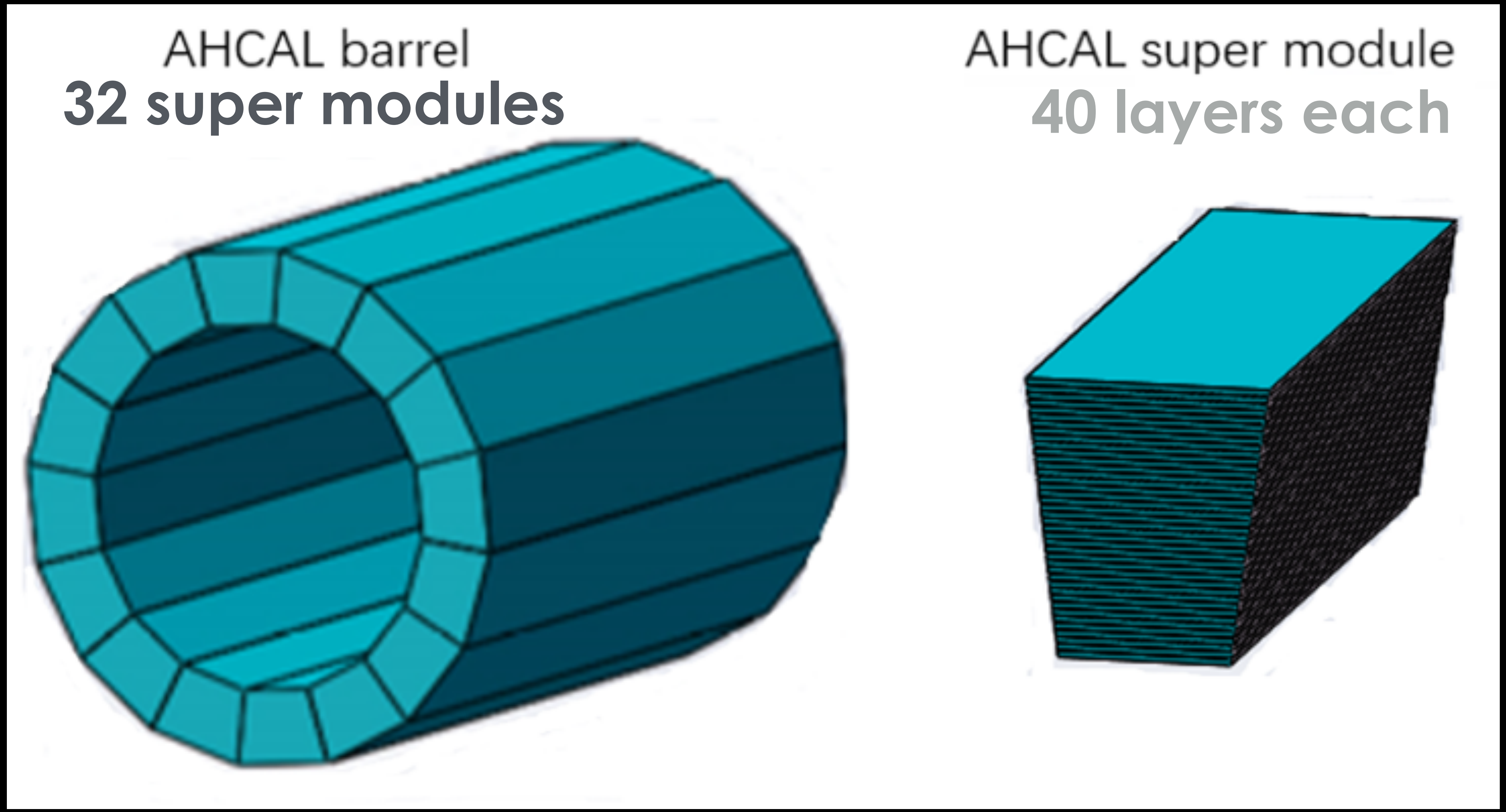
2. SiPM to be located in center of strip

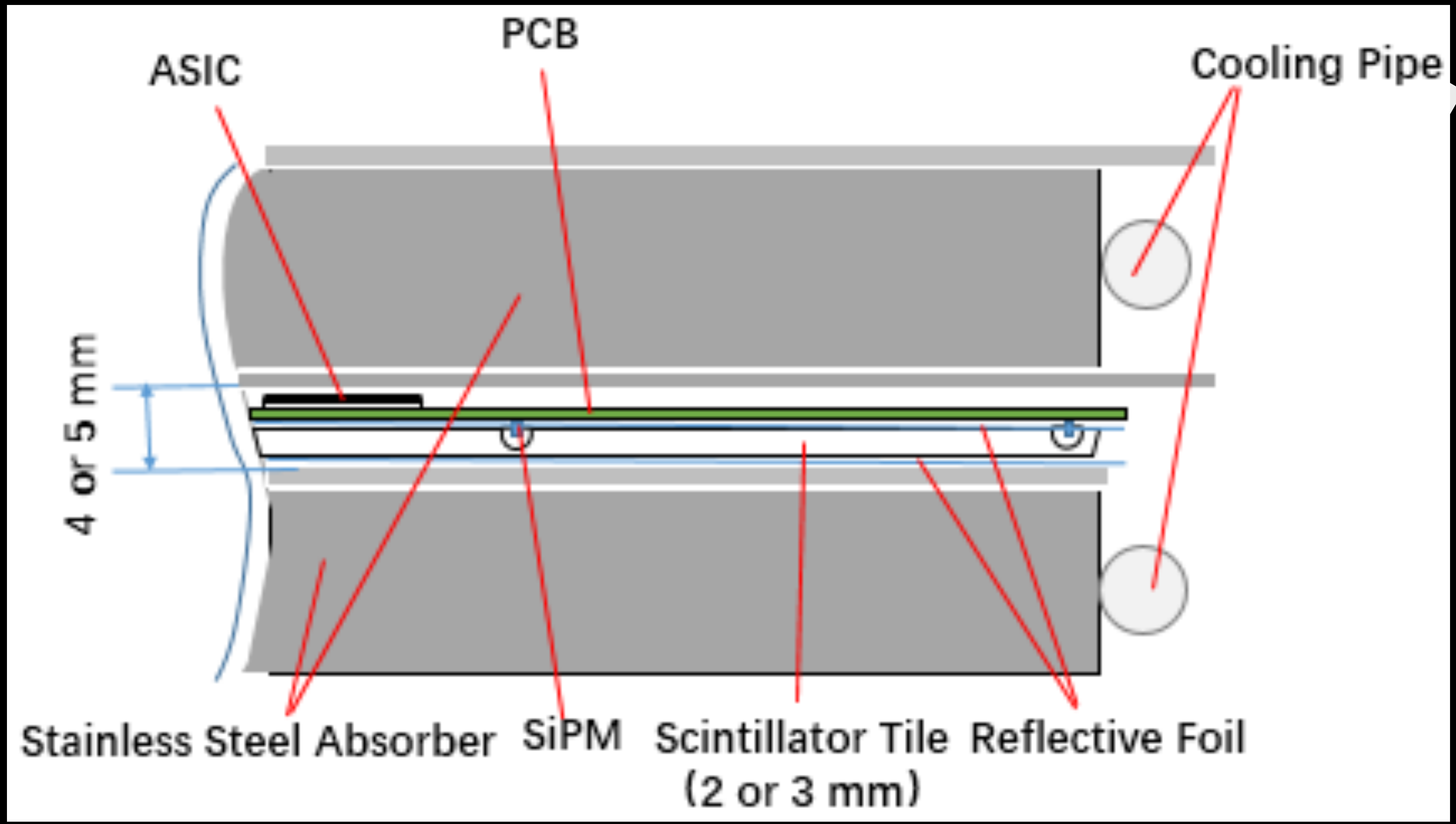


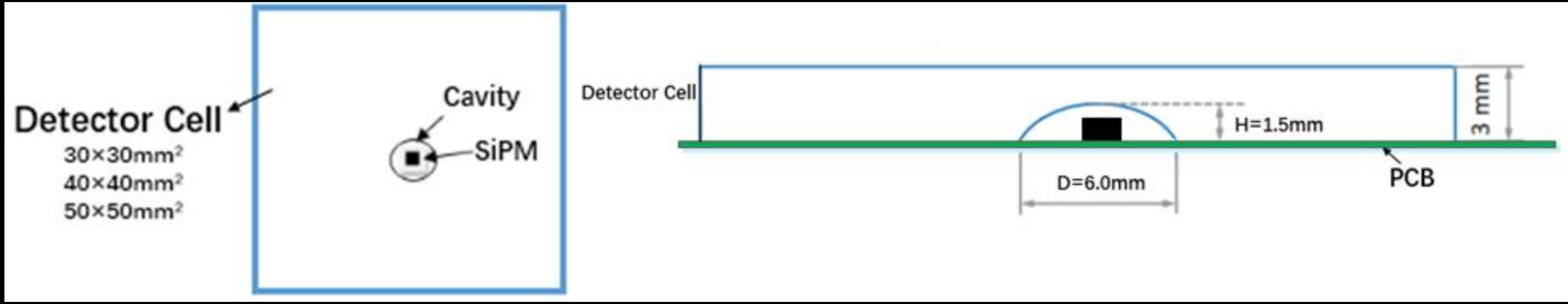


HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)





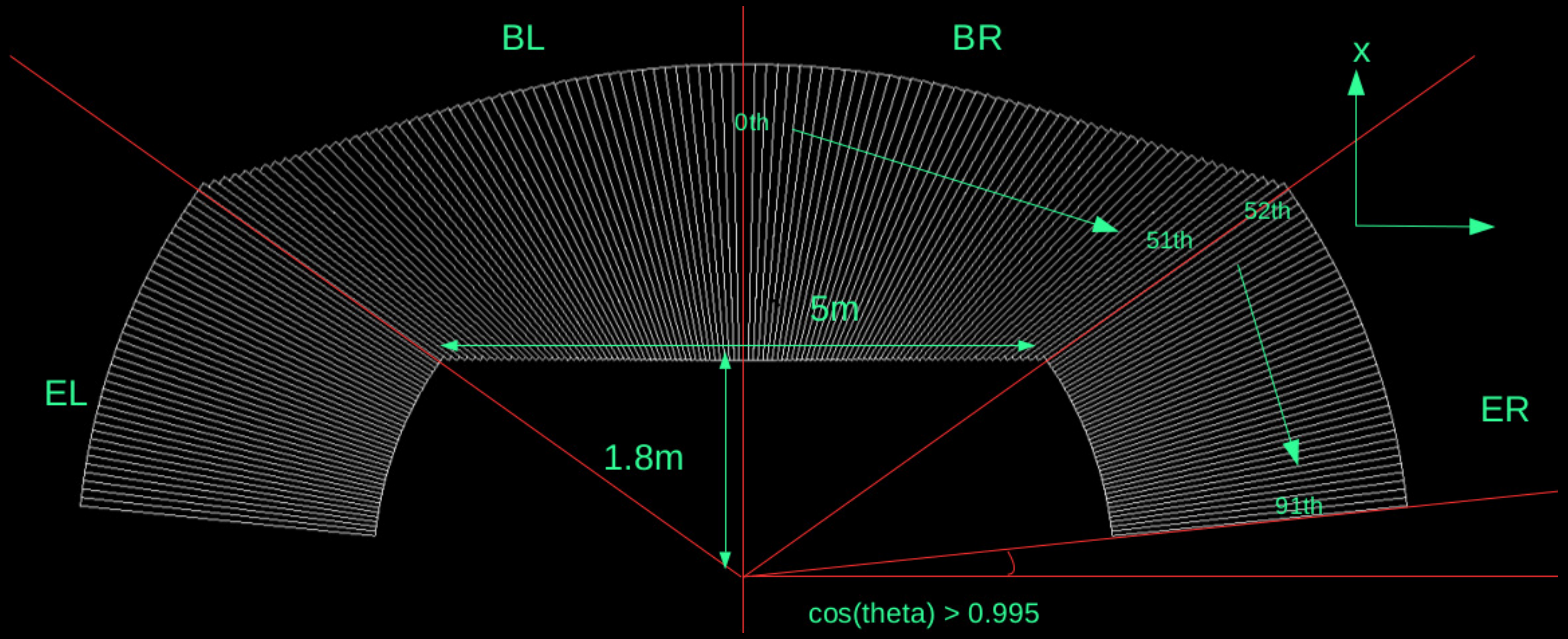


Readout channels:
~ 5 Million (30 x 30 mm^2)
~ 2.8 Million (40 x 40 mm^2)

Dual Readout Calorimeter

Lead by Italian colleagues: based on the DREAM/RD52 collaboration

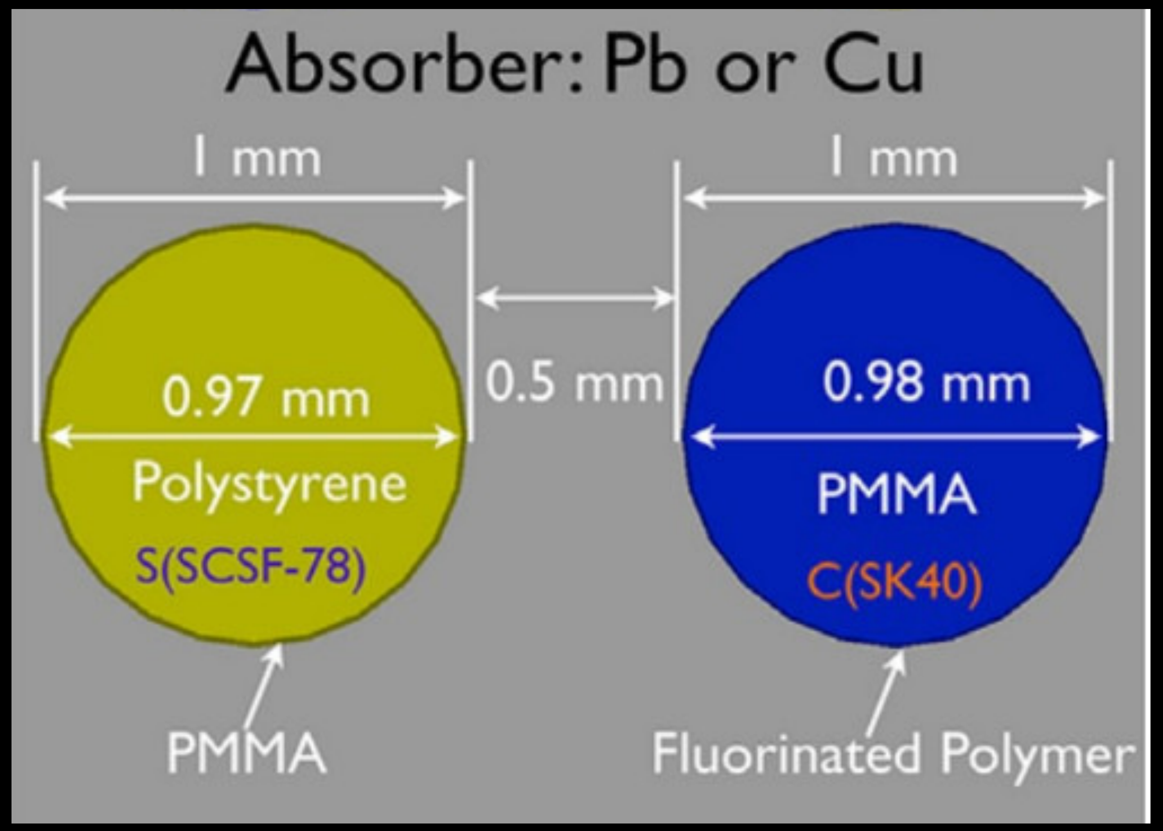
Projective 4π layout implemented into CEPC simulation
(based on 4th Detector collaboration design)



Covers full volume up to |cos(θ)| = 0.995
with 92 different types of towers (wedge)

4000 fibers (start at different depths
to keep constant the sampling fraction)

Performance in G4 simulation:
EM resolution: 10.3%/√E + 0.3%
Had resolution : ~34%/√E

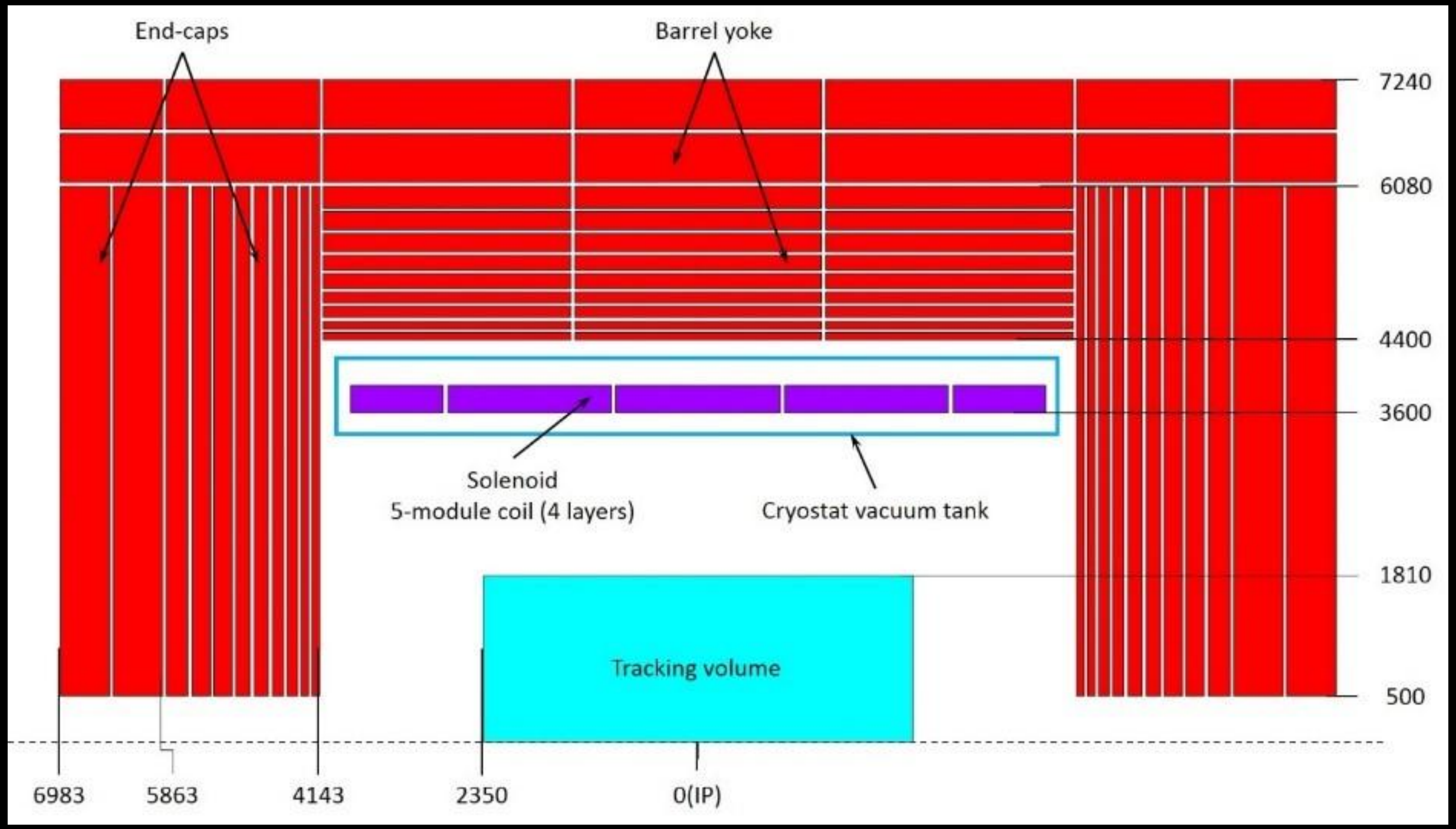


Studying different readout schemes
PMT vs SiPM

Several prototypes from RD52 have been built

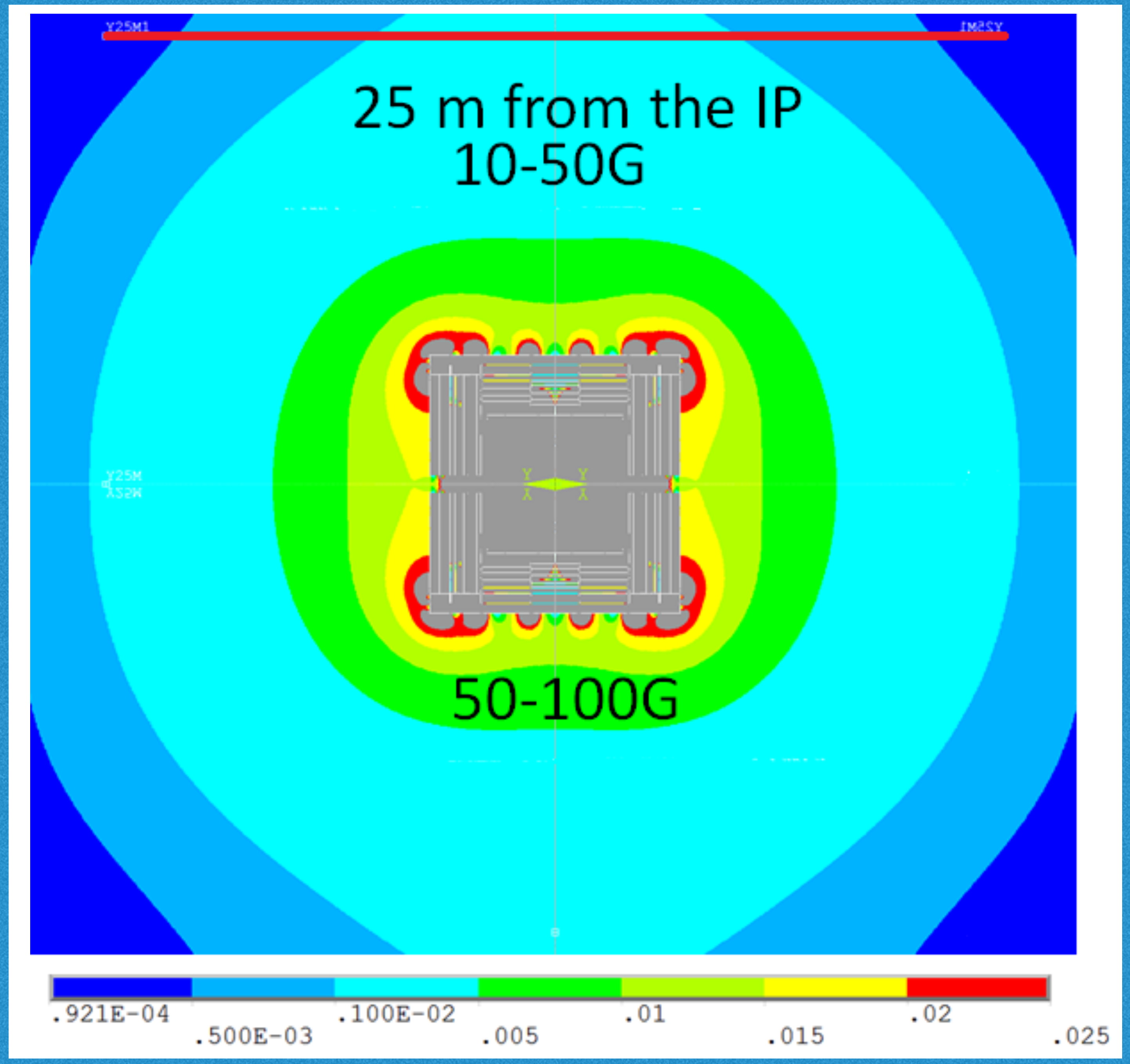
Superconductor solenoid development

3 Tesla Field Solenoid

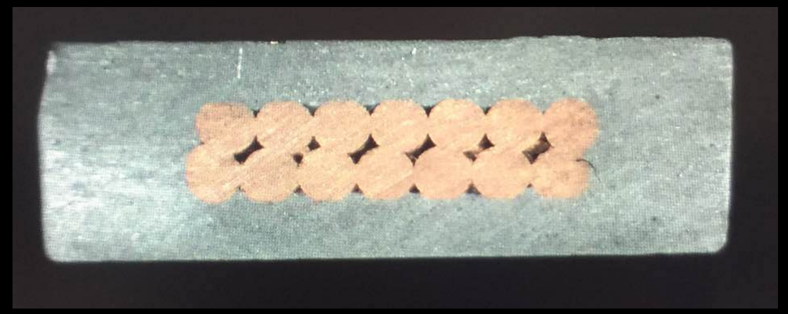


Operating current	15.8 A	Cable length	30.1 km

Stray field map of magnet



Default is NbTi Rutherford SC cable (4.2K)
High-Temperature SC cable is also being considered (YBCO, 20K)



Design for 2 Tesla magnet presents no problems

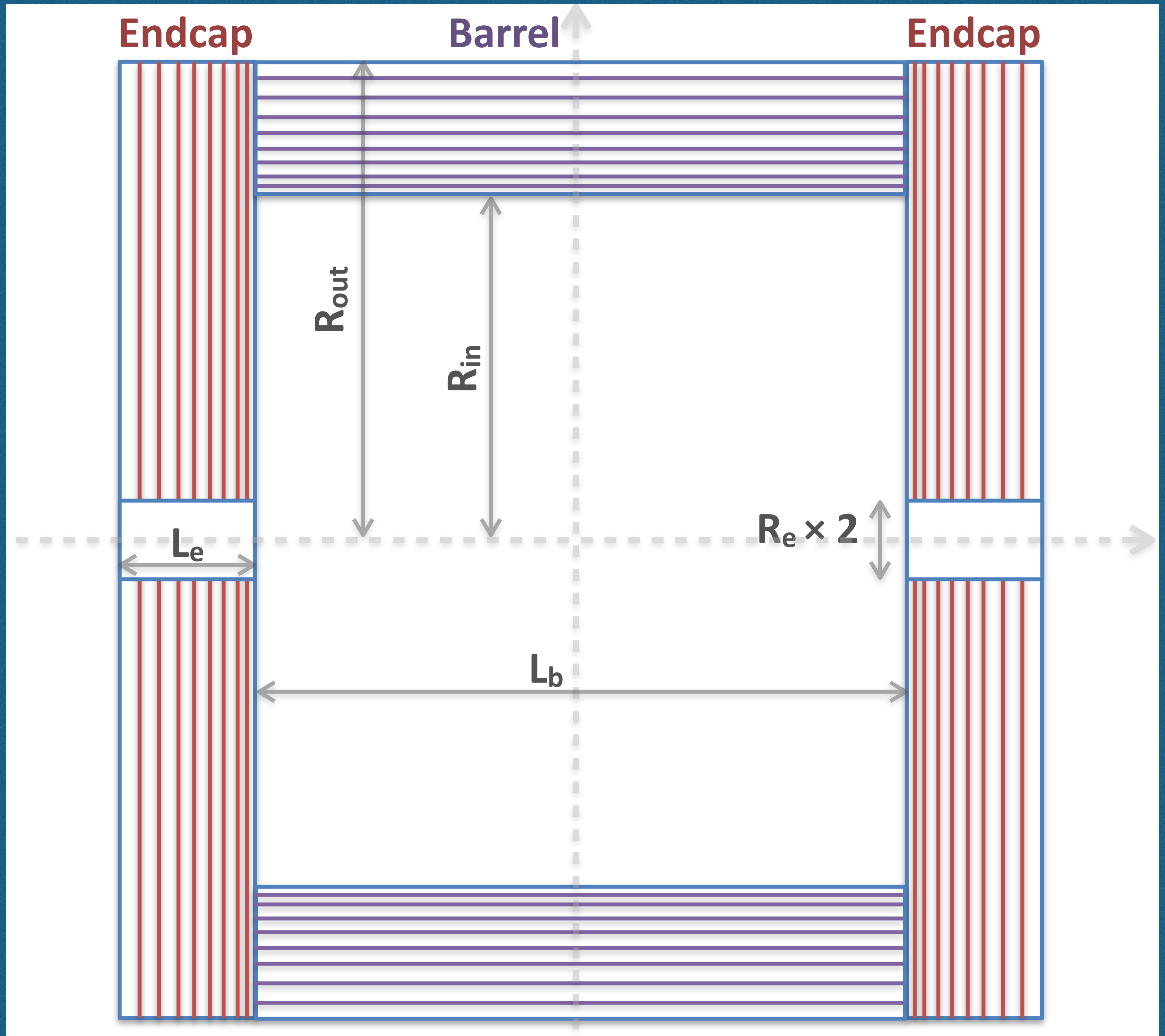
Thin HTS solenoid being designed for IDEA concept

Double-solenoid design also available

Muon Detector System

Baseline Muon detector

- 8 layers
- Embedded in Yoke
- Detection efficiency: > 95%

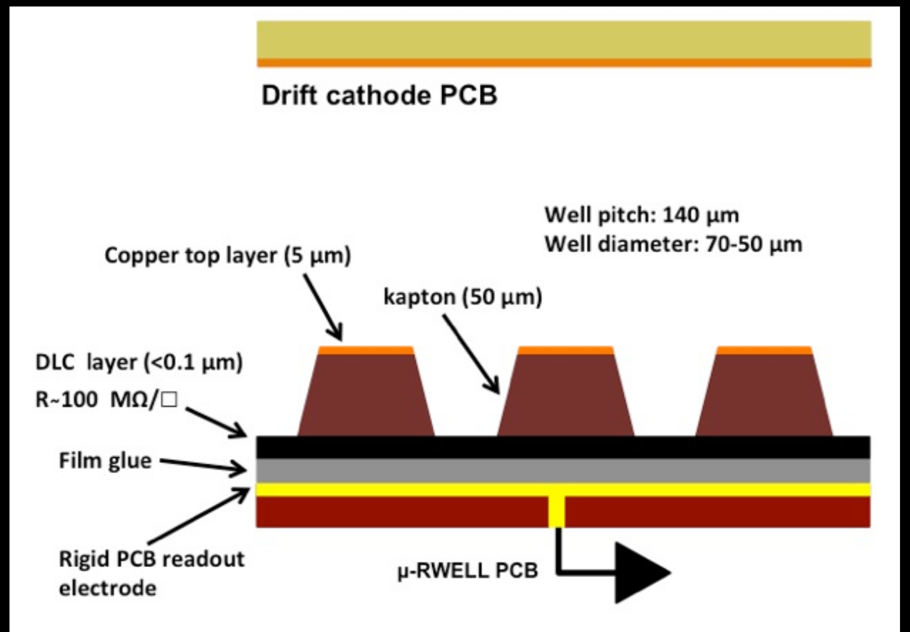


Baseline: Bakelite/glass RPC

Other technologies considered

Monitored Drift Tubes
Gas Electron Multiplier (GEM)
MicroMegas

New technology proposal (INFN): µRwell



Better resolution (200-300 µm) at little extra cost (?)

Muon system: open studies

Good experience in China on gas detectors but currently little strong direct R&D on CEPC — rather open for international collaboration

- **Layout optimization**:
  - Visit the requirements for number of layers
    - Implications for exotic physics searches
  - Use as a tail catcher / muon tracker (TCMT)
    - Jet energy resolution with/without TCMT
- **Detector industrialization**