CEPC Detector R&D, Collaboration and Future

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International Advisory Meeting Committee
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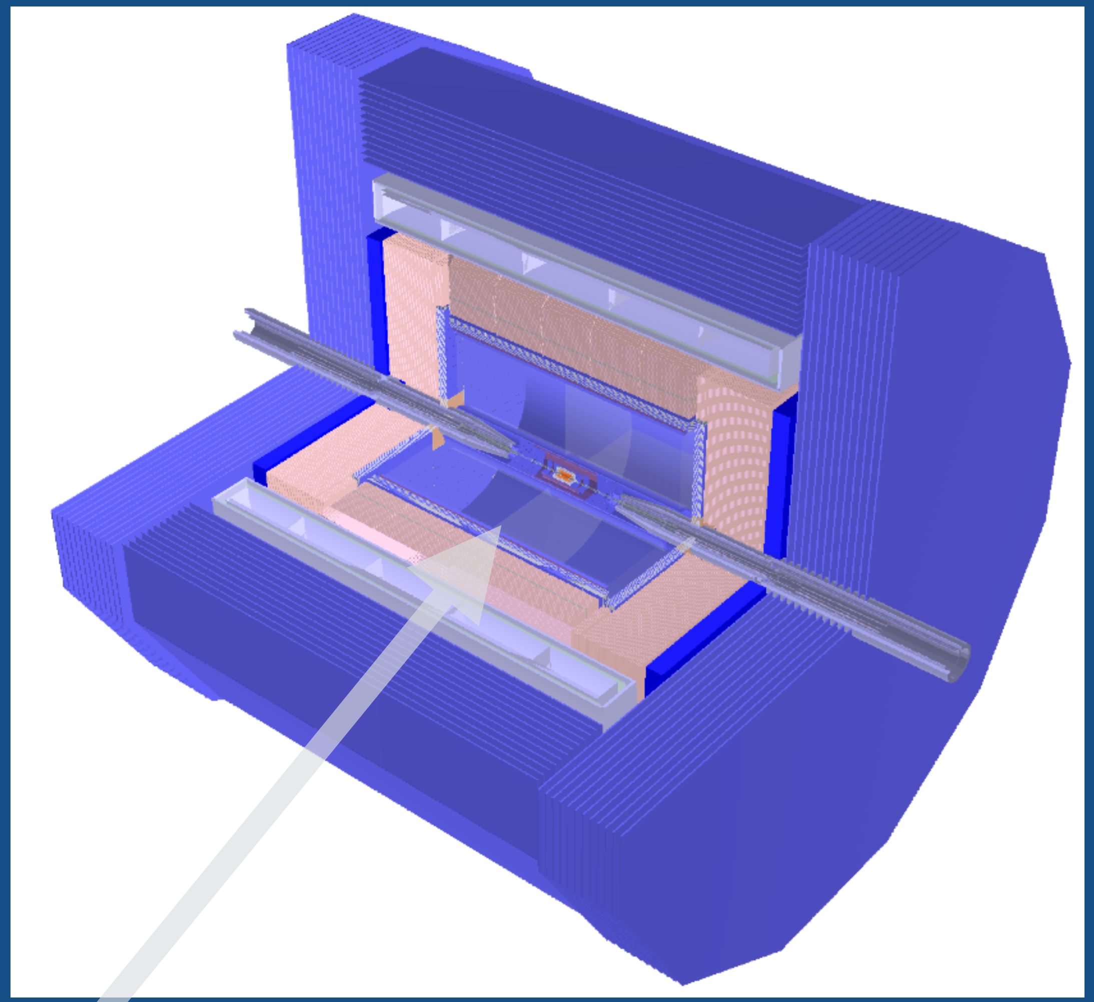
Detector R&D progress

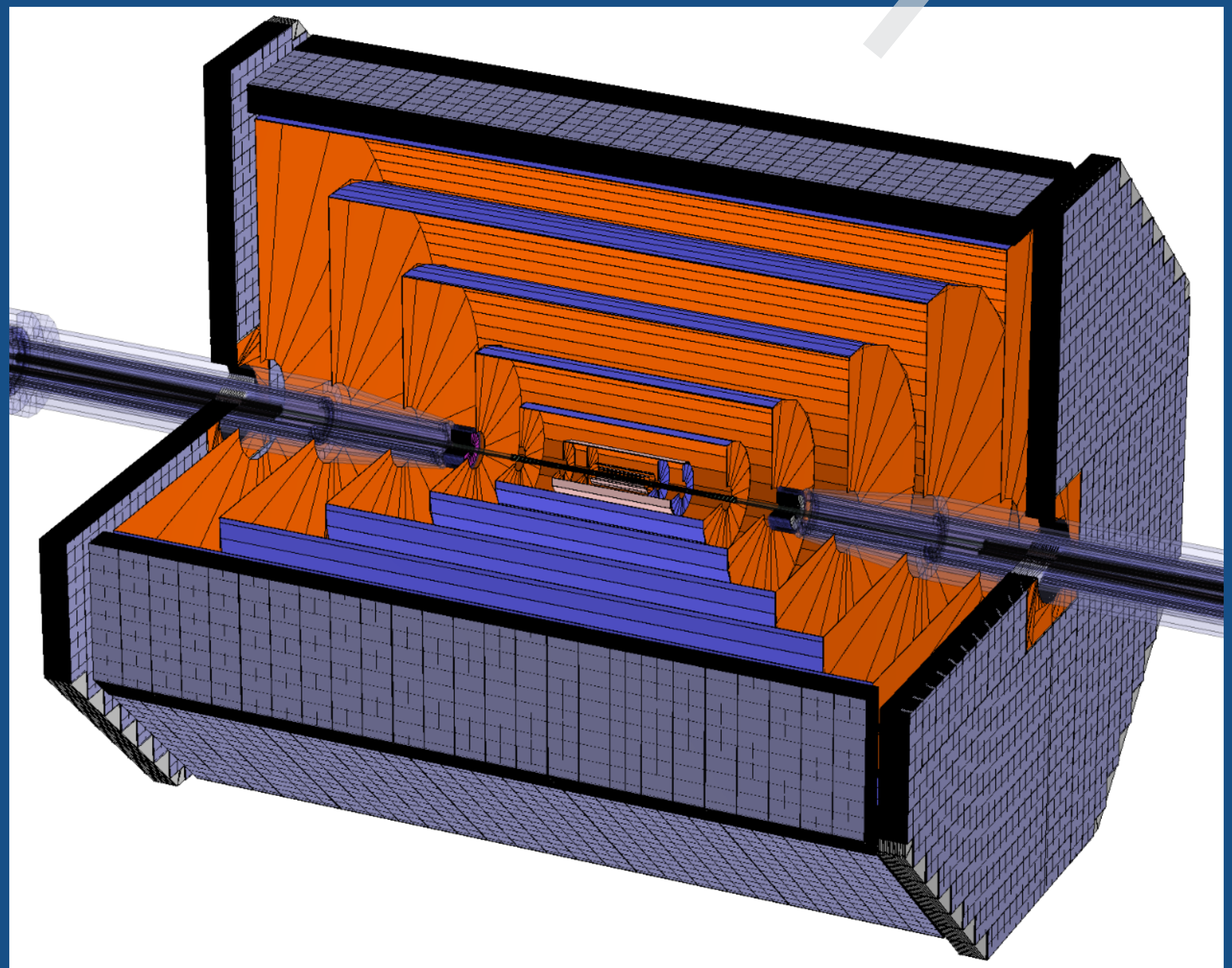
CEPC Detector Concepts studied

2 interaction points

Particle Flow Approach

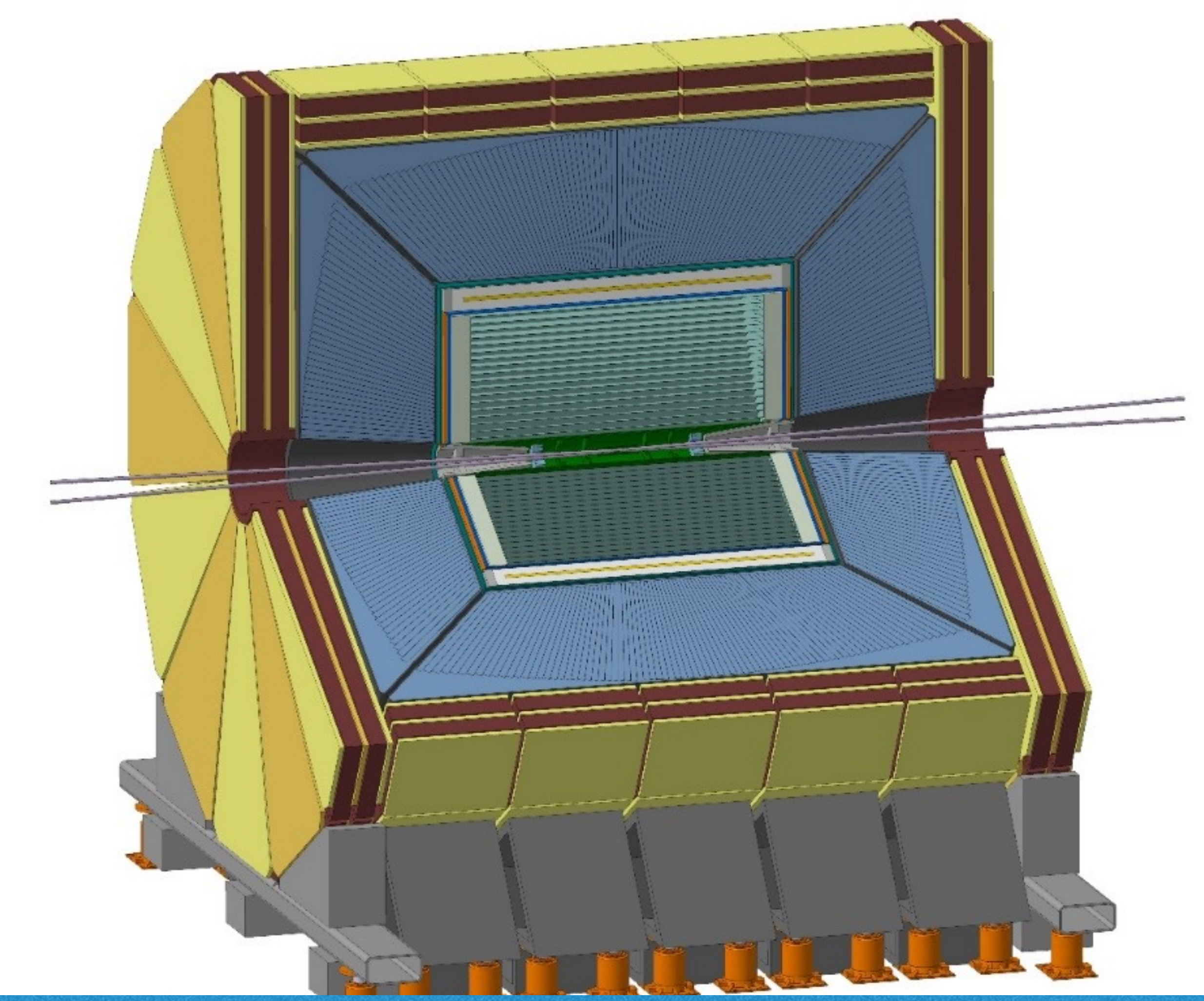
High
magnetic field
concept
(3 Tesla)





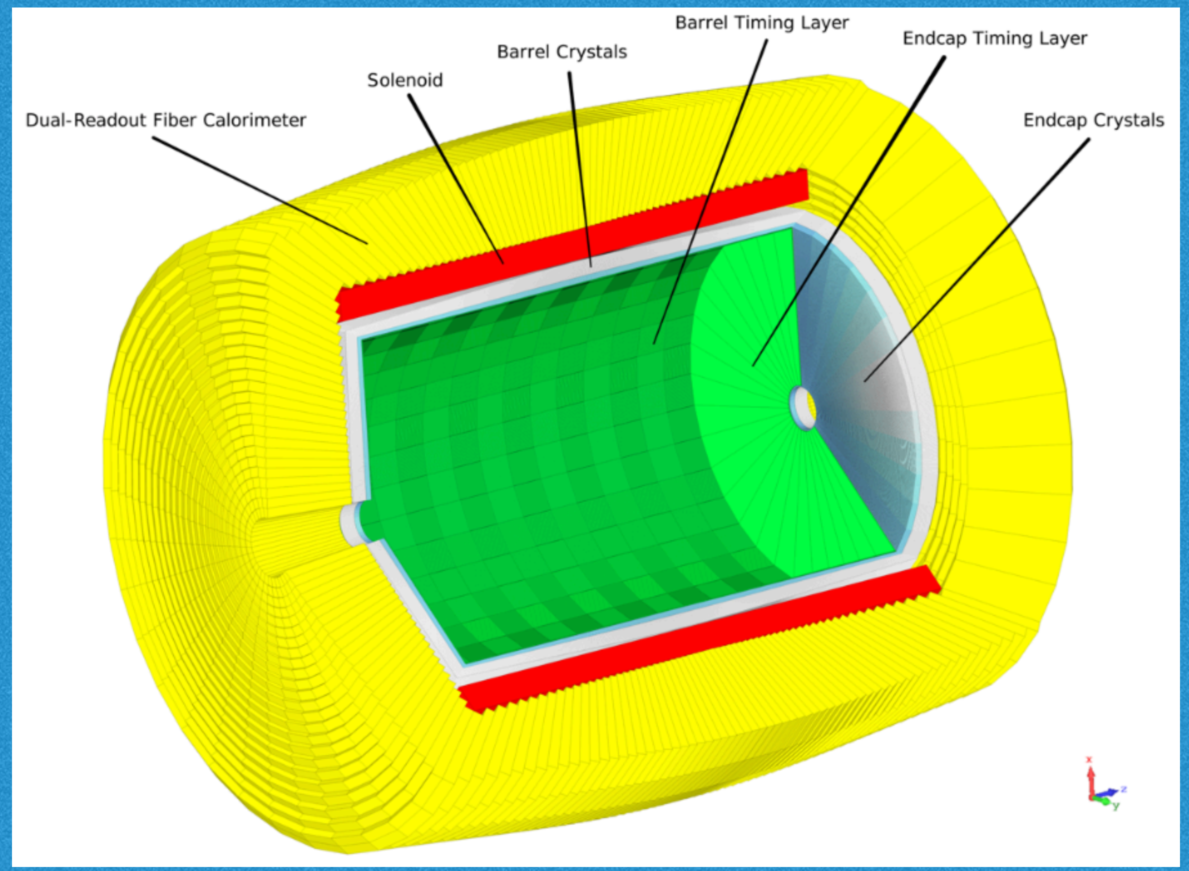
Full silicon
tracker
concept

Low
magnetic field
concept
(2 Tesla)



IDEA Concept

also proposed for FCC-ee



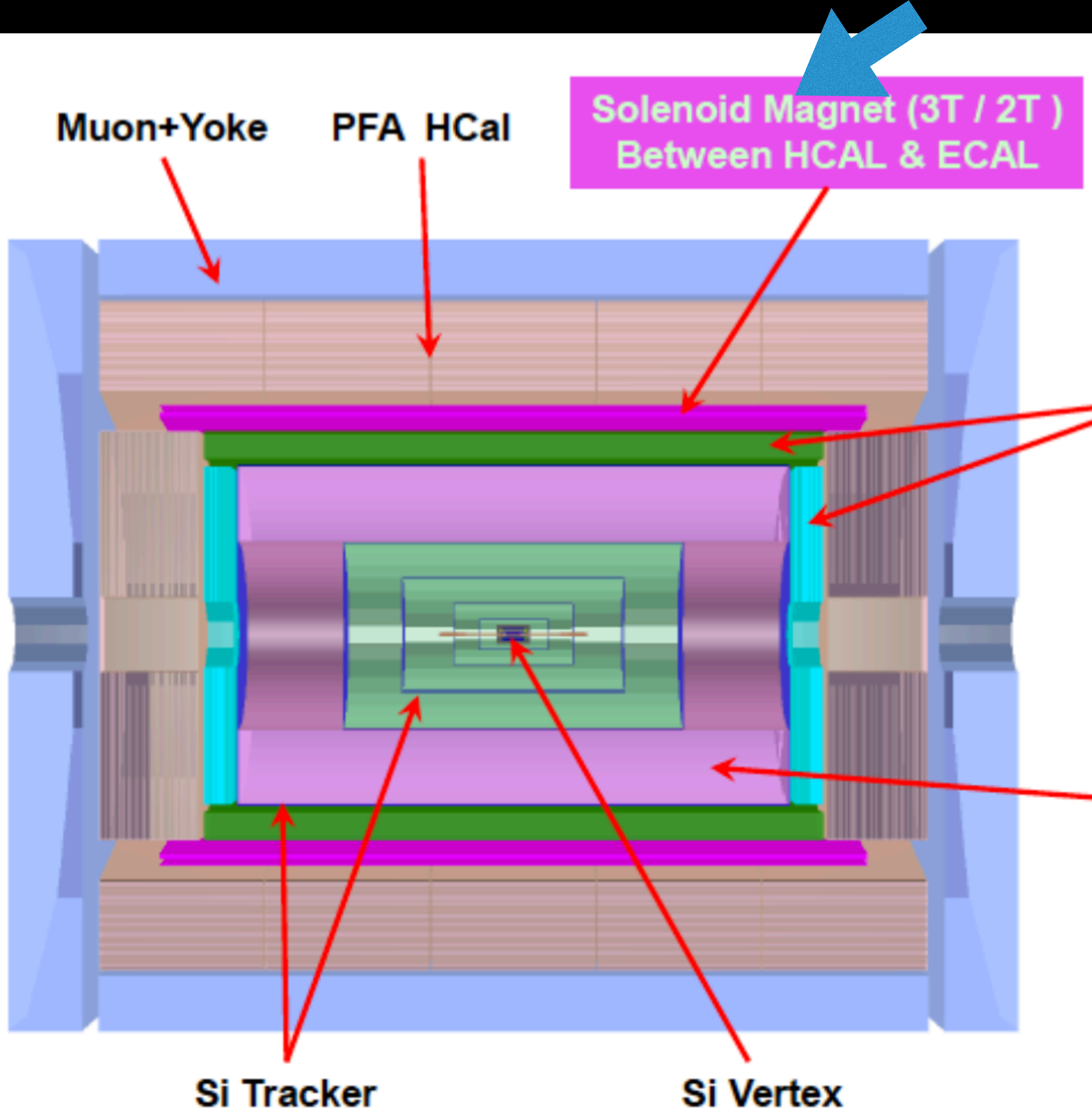
Crystal Calorimeter
based detector
(2-3 Tesla)

4th Concept

News reported at this meeting tomorrow

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

The 4th conceptual detector design



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

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

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

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

Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

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

See Jianchun's talk on Tuesday for details

Updated Parameters of Collider Ring since CDR

	Higgs		Z (2T)	
	CDR	For TDR	CDR	For TDR
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.8	0.036	0.037
Number of particles/bunch N_e (10^{10})	15.0	14	8.0	14
Bunch number (bunch spacing)	242 (0.68μs)	249 (0.7 μs)	12000	11951 (27ns)
Beam current (mA)	17.4	16.7	461.0	803.5
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	0.13/0.0009
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.64/0.0013	0.18/0.0016	0.27/0.0014
Beam size at IP σ_x/σ_y (μm)	[illegible]	[illegible]	[illegible]	[illegible]
Bunch length σ_z (mm)	3.26	[illegible]	8.5	[illegible]
Lifetime (hour)	0.67	0.30	2.1	1.3
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	[illegible]	[illegible]	[illegible]	115

These luminosity/rate increases have not yet been absorbed into physics and detector studies, although considerations about it have started

Luminosity increase factor: × 1.8 × 3.6

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

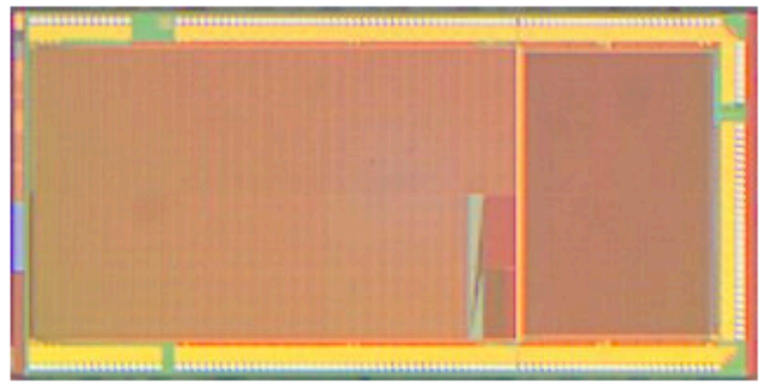
Total of 103 sub-tasks identified

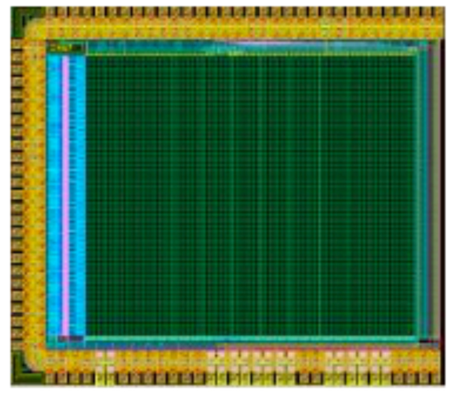
CEPC CMOS Pixel Sensor Development

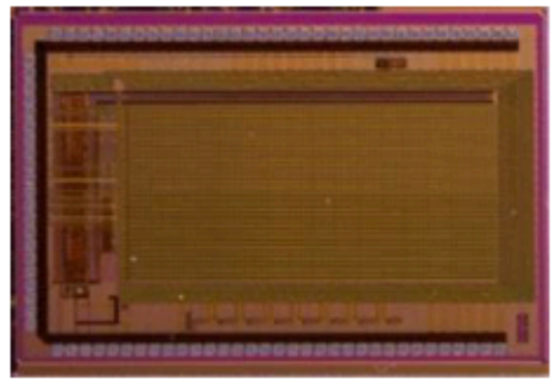
	JadePix1 (2015)	JadePix2 (2017)	MIC4 (2017)	JadePix3 (2019)
Architecture	Roll. Shutter + Analog output	Roll. Shutter + In pixel discri.	Data-driven r.o. + In pixel discri.	Roll. shutter + end of col. priority encoder
Pitch (μm^2)	33 × 33 /16 × 16	22 × 22	25 × 25	16 × 26 16 × 23.11
Power con. (mW/cm^2)	--	--	150	~ 55*
Integration time (μs)*	--	40-50	~3	~100
Prototype size (mm^2)	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)

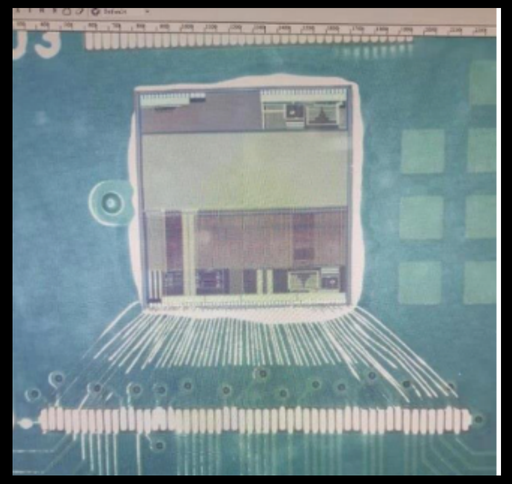
TaichuPix-1 TaichuPix-2

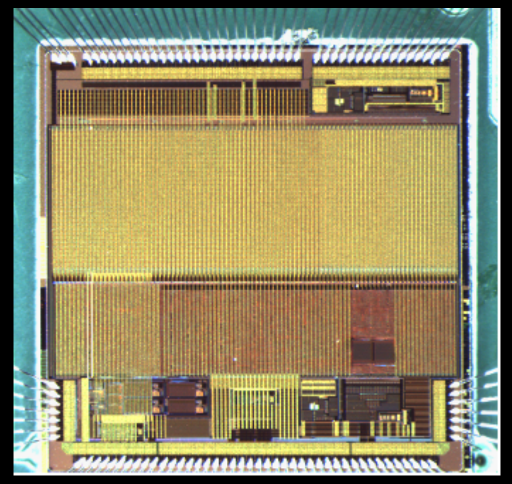
FE-I3-like and ALPIDE-like pixel

Pitch: 25/24 × 25 μm^2

Power: 100-150 mW/cm^2

Size: 5 × 5 mm^2





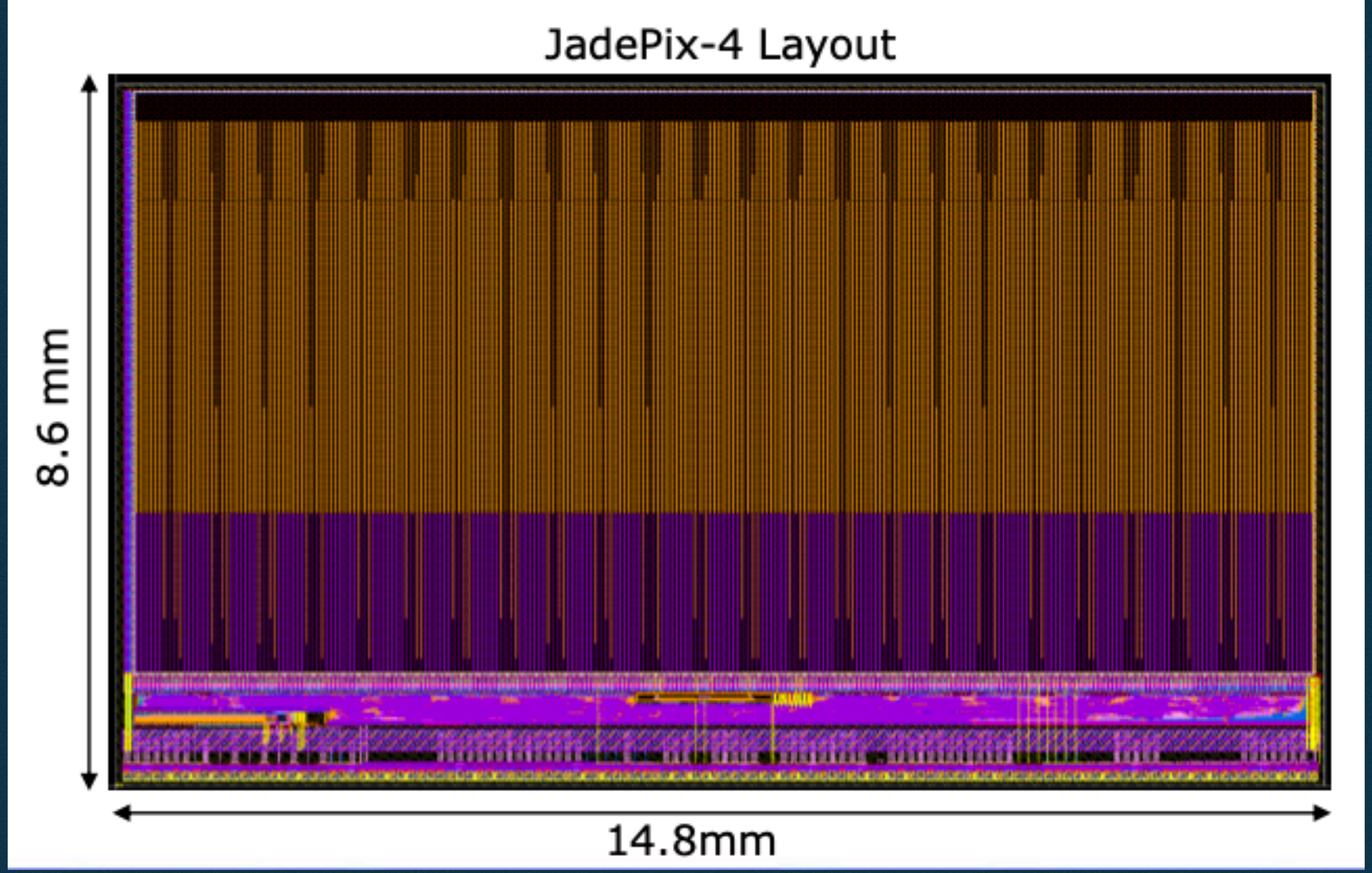
IHEP, SDU, NWPU, IFAE & CCNU

CEPC CMOS Pixel Sensor Development: JadePix3→ JadePix4

- JadePix3 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

JadePix4



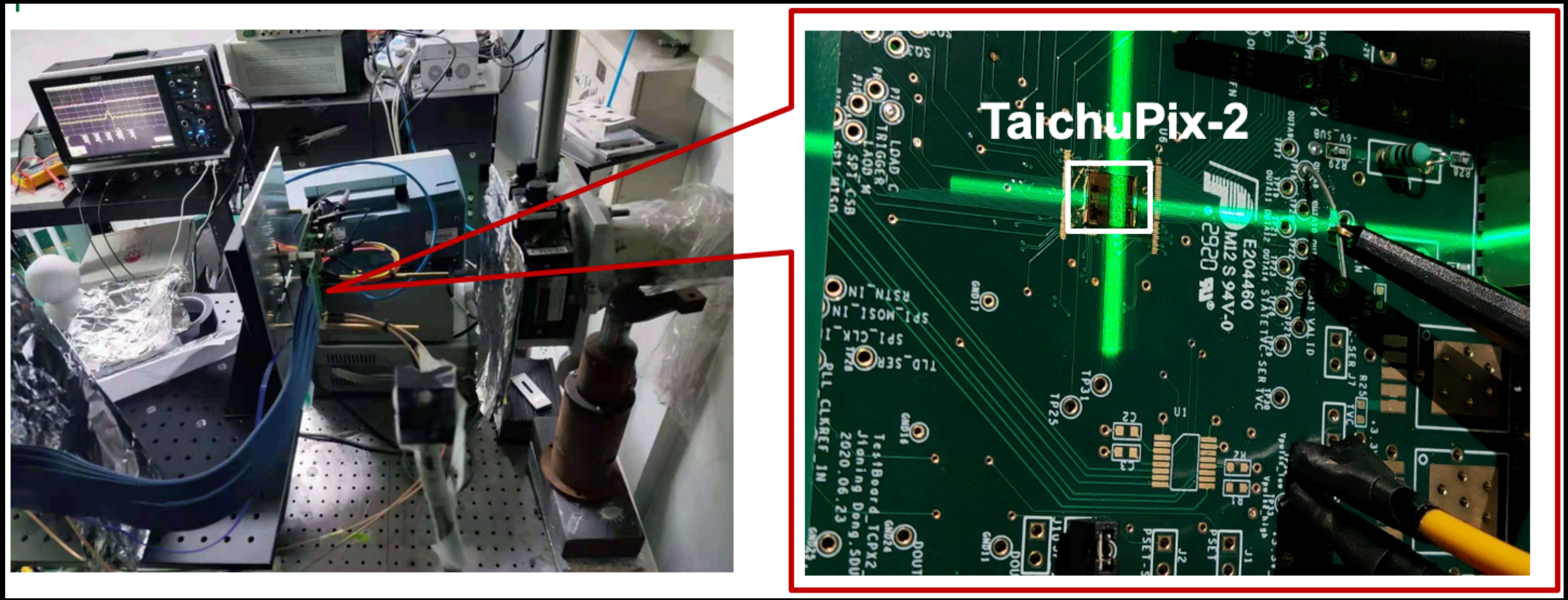
TowerJazz 180 nm

	JadePix-3	JadePix-4/MIC5
Pixel size	16 μm × 23.1 μm	20 μm × 29 μm
Integration time	98.3 μs	~ 1 μs
Average power	< 100 mW/cm²	< 100 mW/cm²
Pixel array	512 row × 192 col.	356 row × 498 col.
Mask area	10.4 mm × 6.1 mm	14.8 mm × 8.6 mm

Submitted to a shared engineering run two weeks ago

CEPC CMOS Pixel Sensor Development: TaichuPix

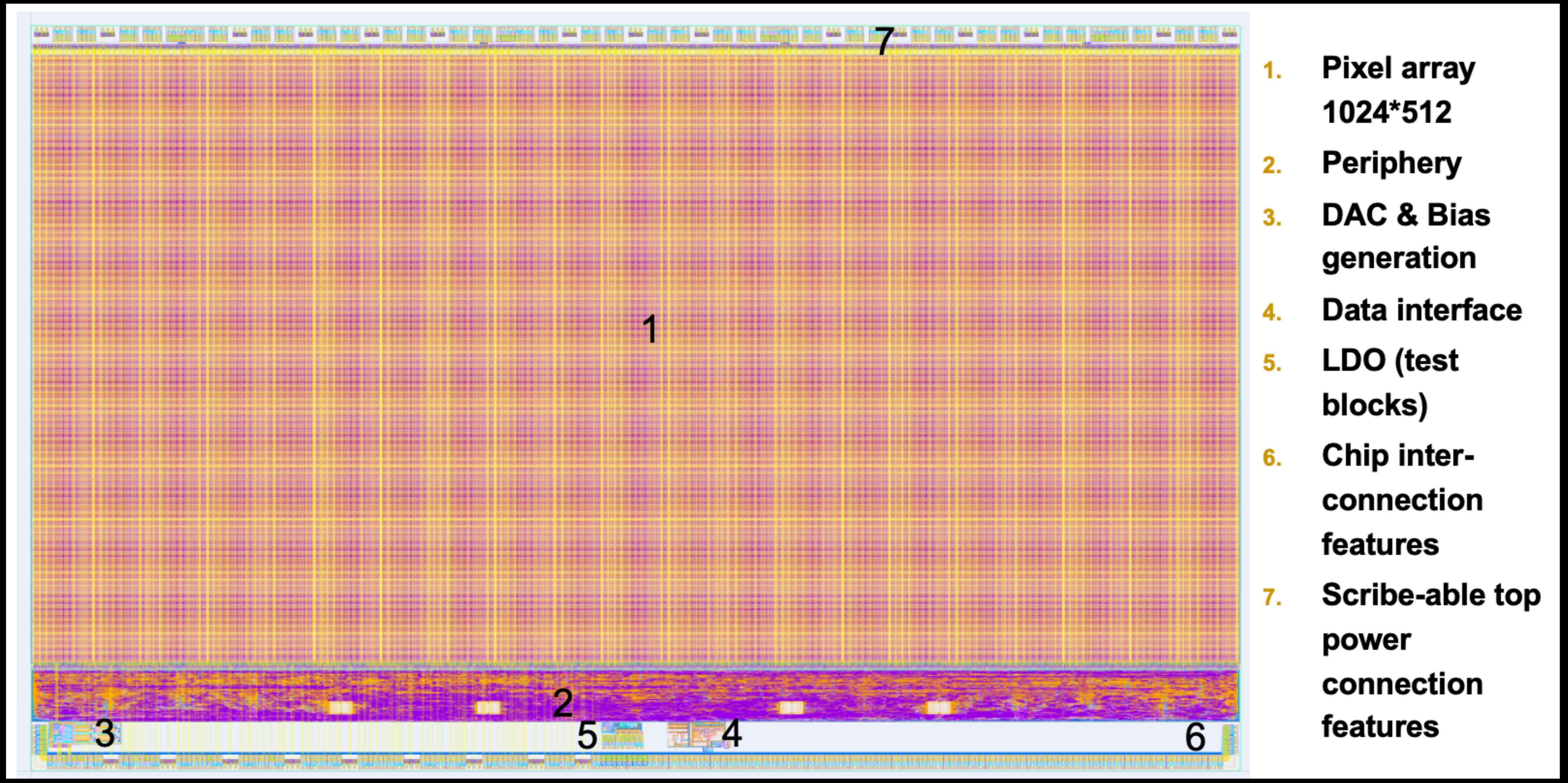
Full size sensors for prototype



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



Full size chip submitted this weekend

Engineering run for Pixel Vertex detector prototype

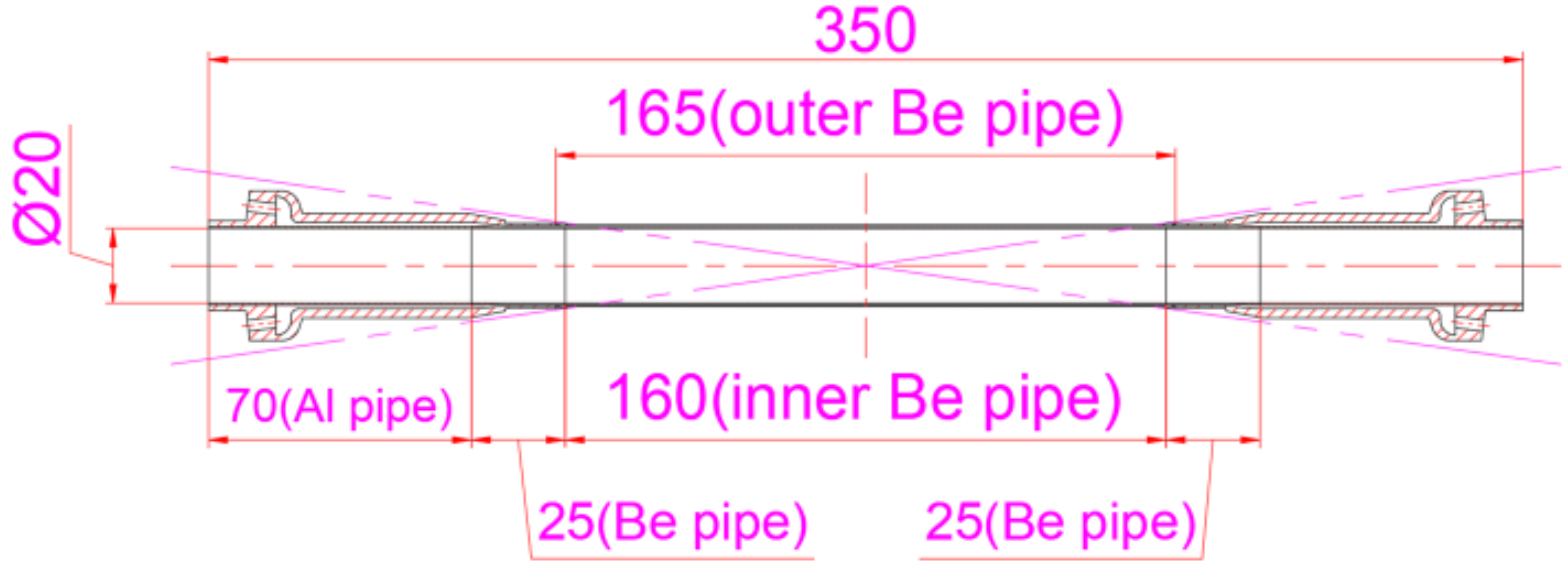
Trigger mode: <100 mW/cm^2

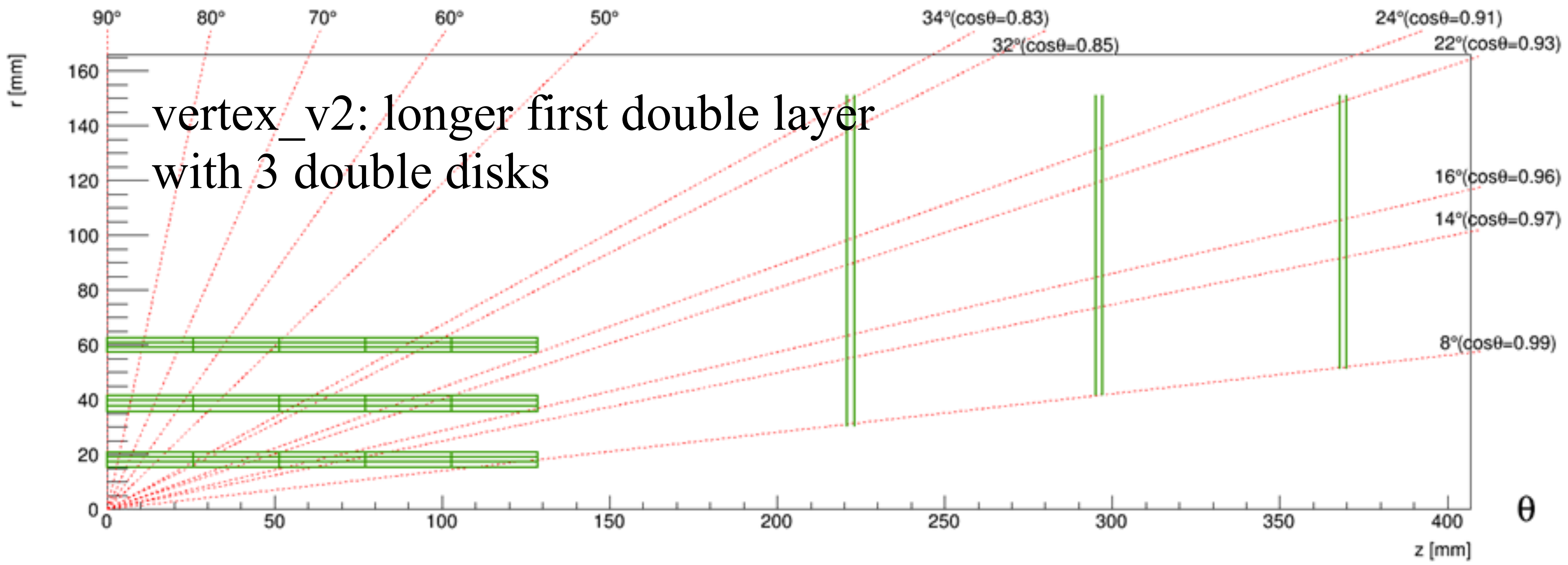
Triggerless mode: 150 mW/cm^2

Pixel Vertex Detector Optimization:

New beampipe 20mm diameter

Detailed structure of the central beryllium pipe

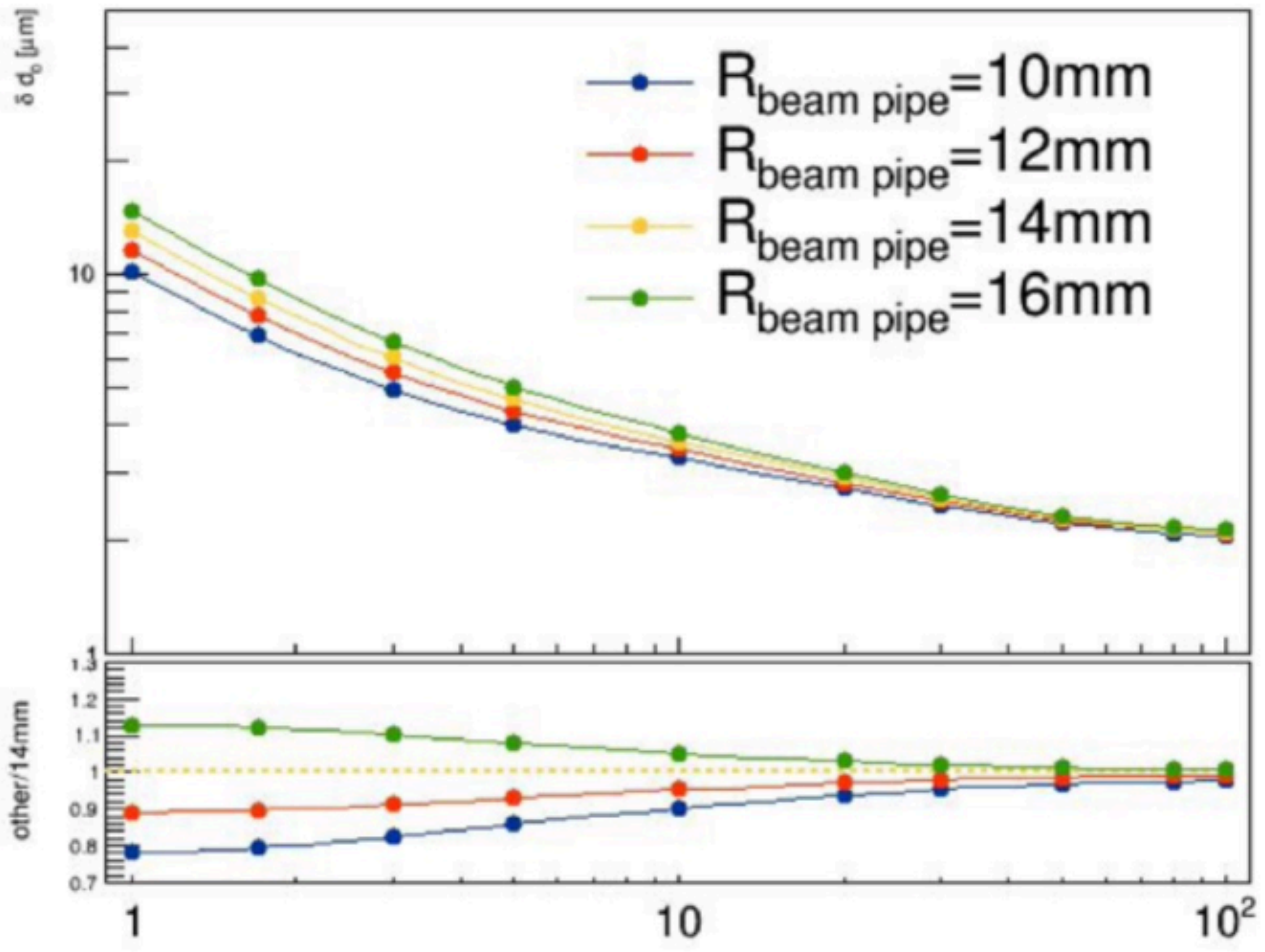


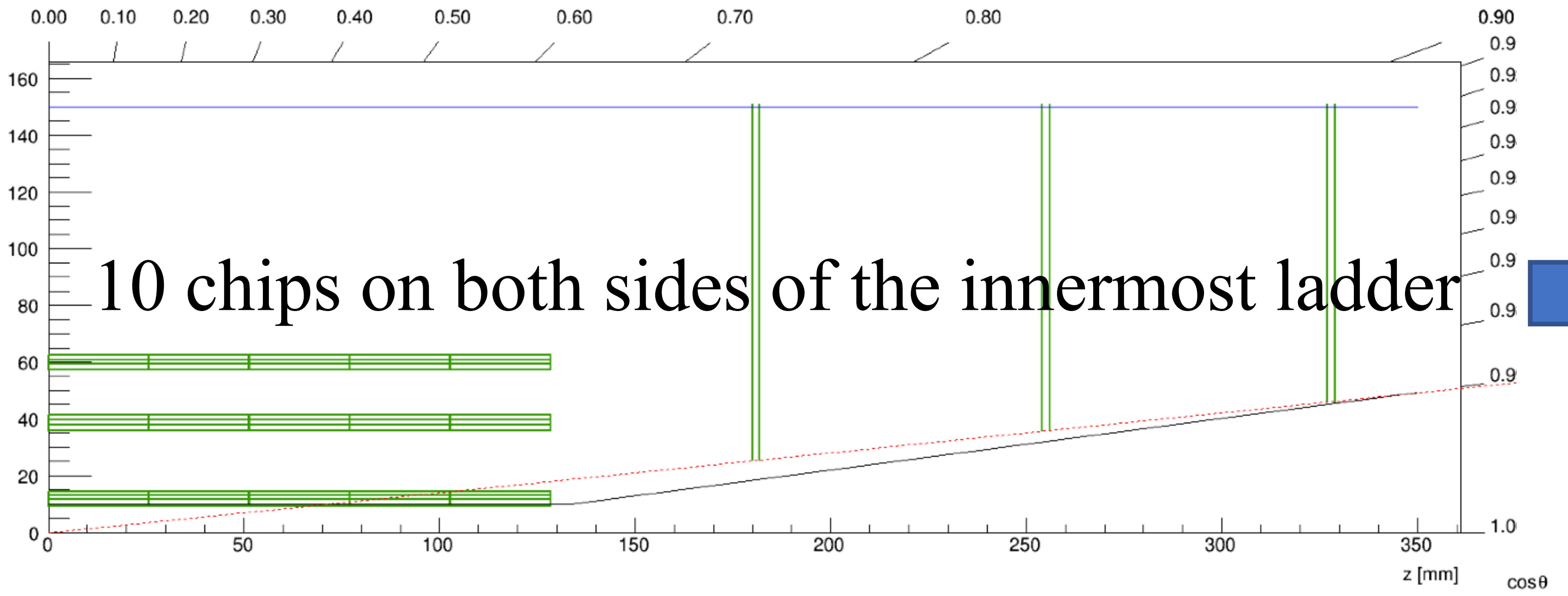


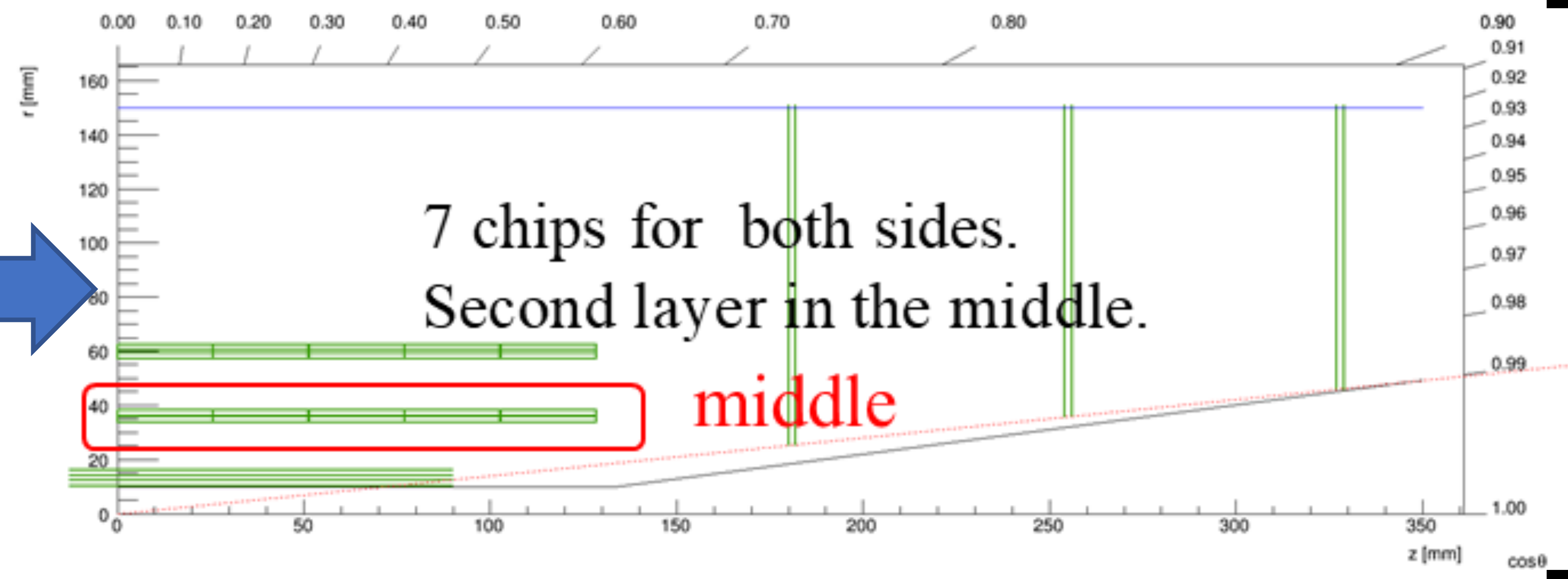
According to processing capacity:

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

Outer Be pipe: 0.15mm thick, 165mm long

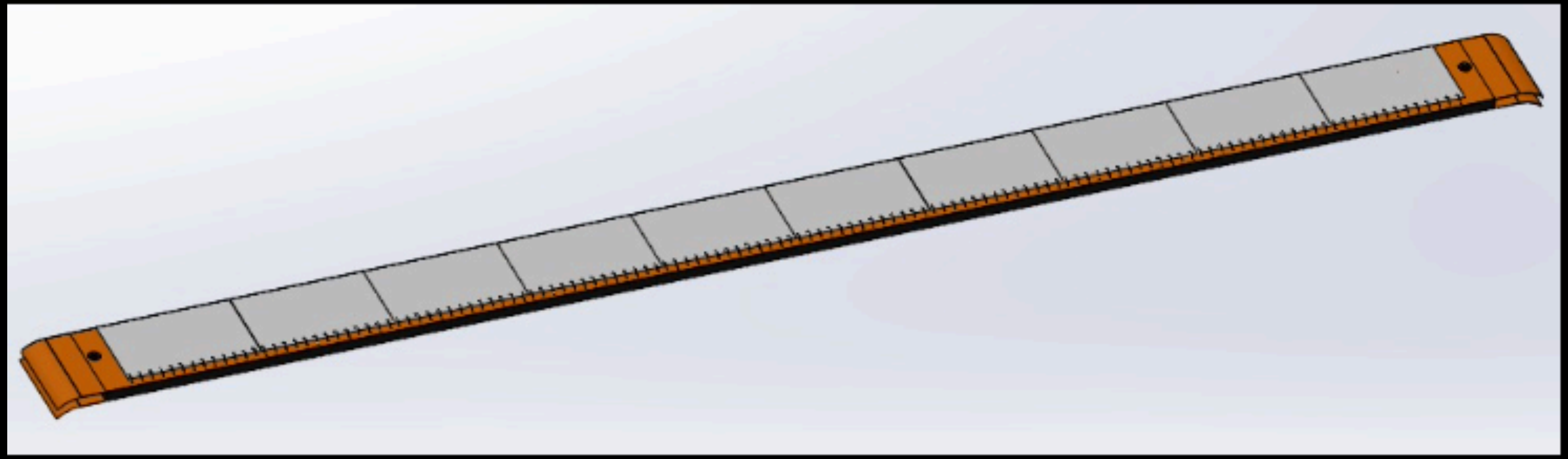




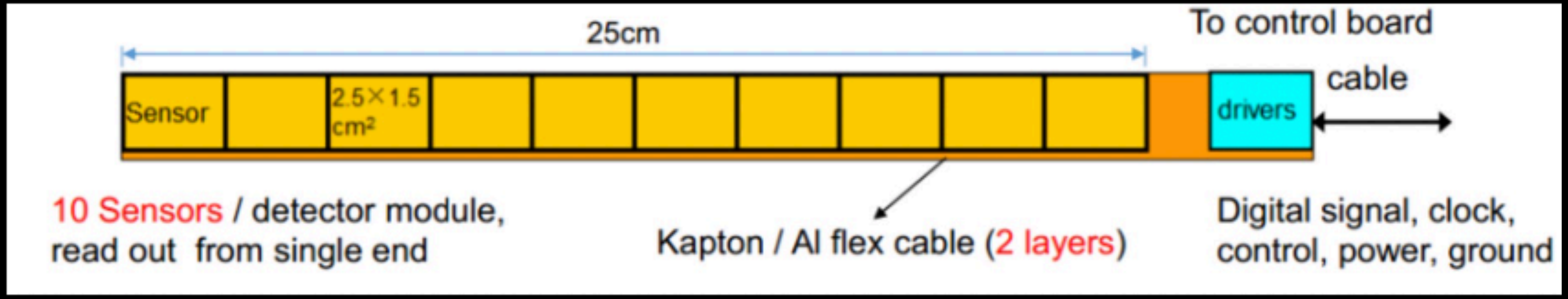


Pixel Vertex Detector Prototype

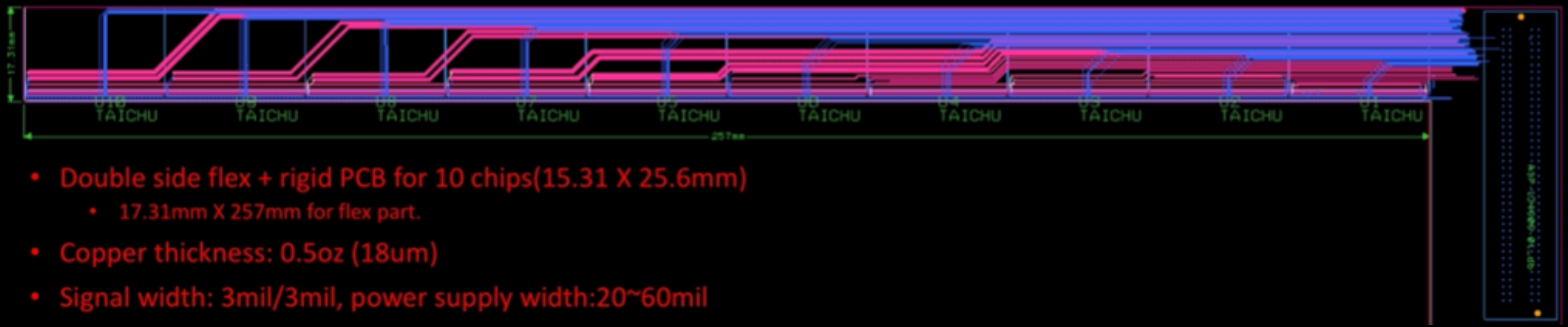
3D model of the ladder



Schematic of ladder electronics



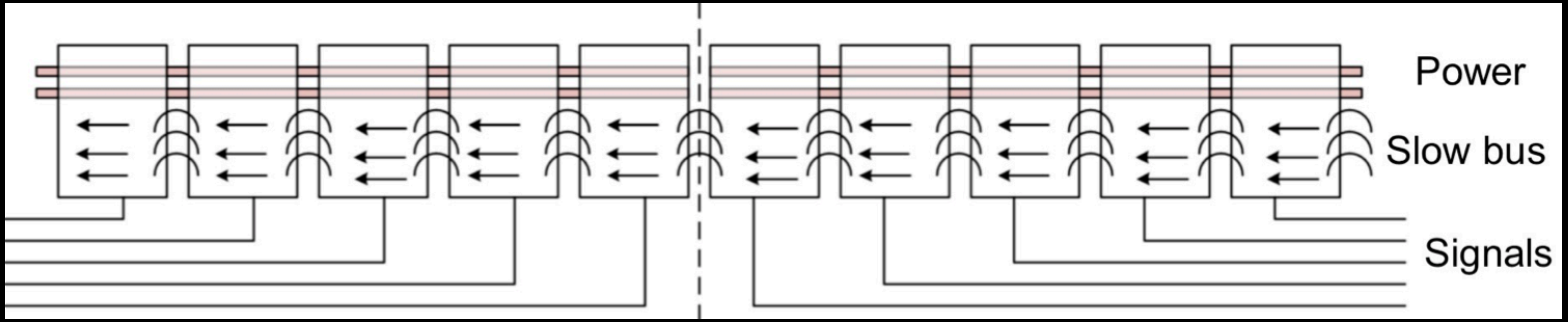
Design of Flexible PCB prototype



Profile of flexible PCB

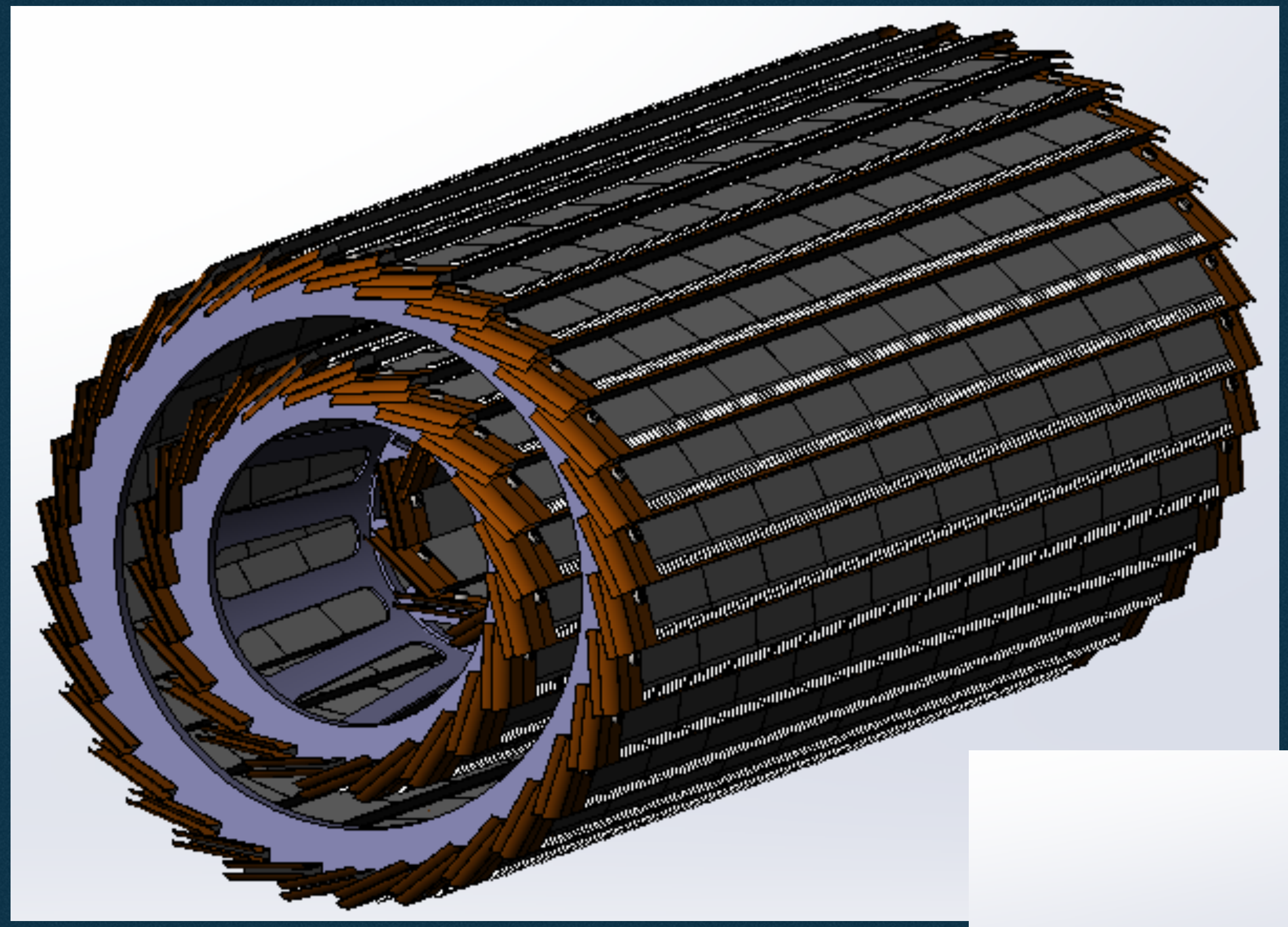
	Achieved Thickness (μm)	Optimization goals (μm)
Polyimide	25	12
Adhesive	28	15
Plating Cu	17.8	17.8
kapton	50	50
Plating Cu	17.8	17.8
Adhesive	28	15
Polyimide	25	12

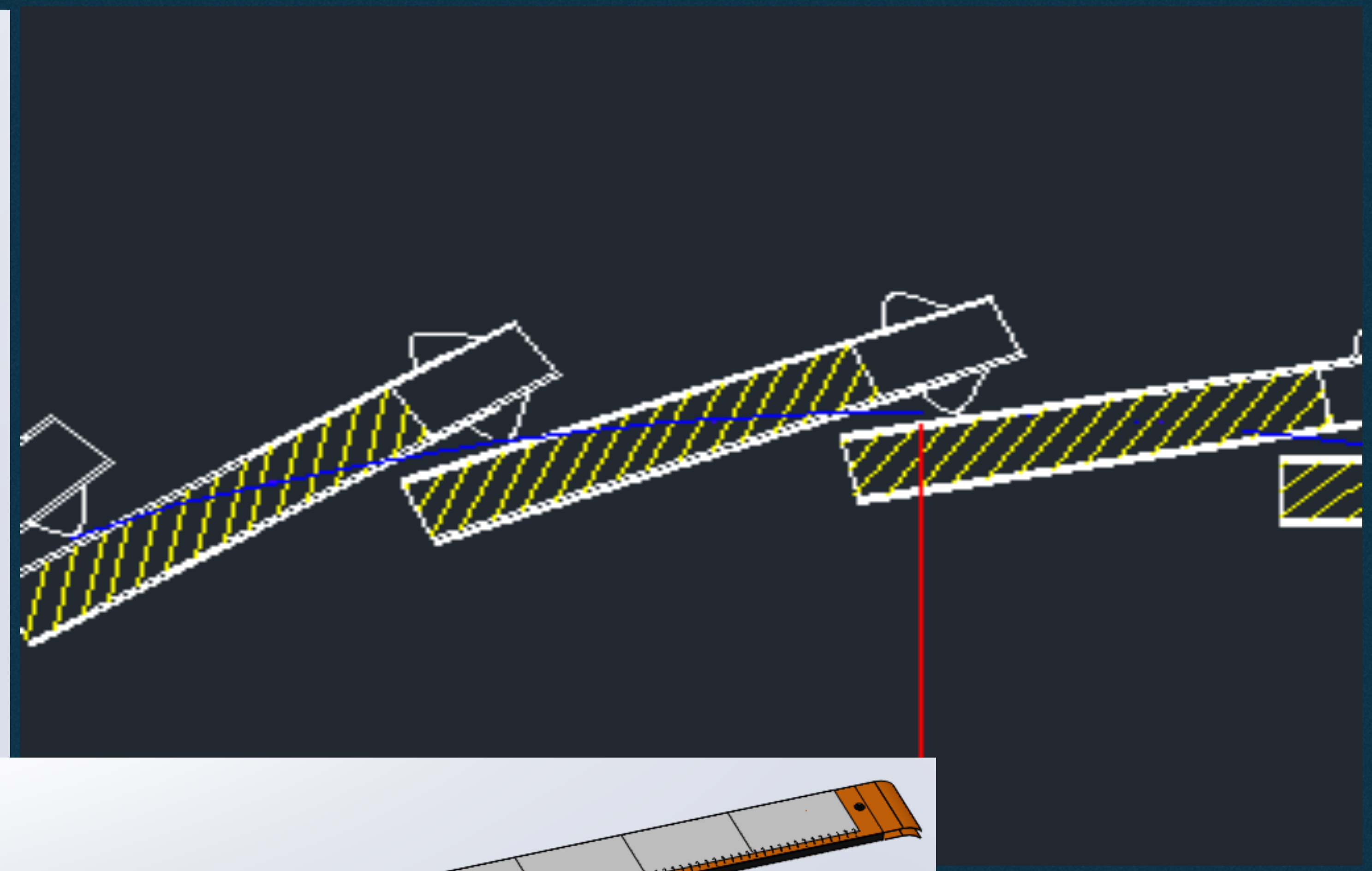
New idea: Taichupix design includes inter-chip connections

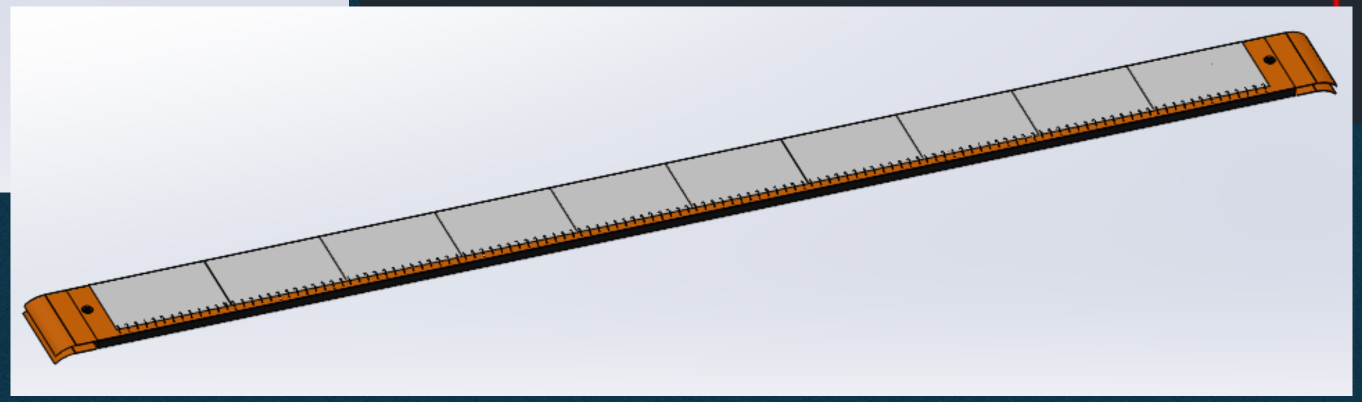


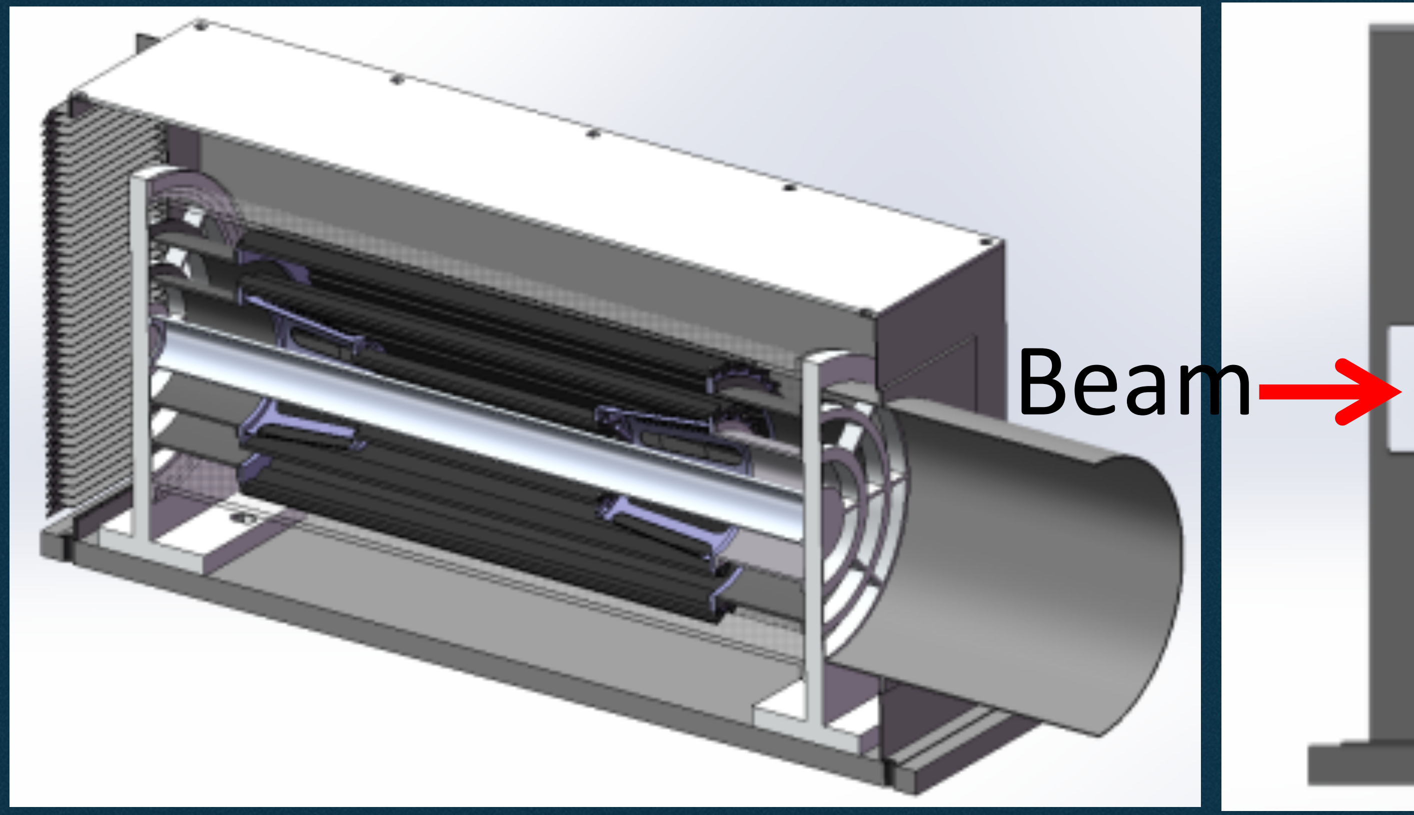
Pixel Vertex Detector Prototype

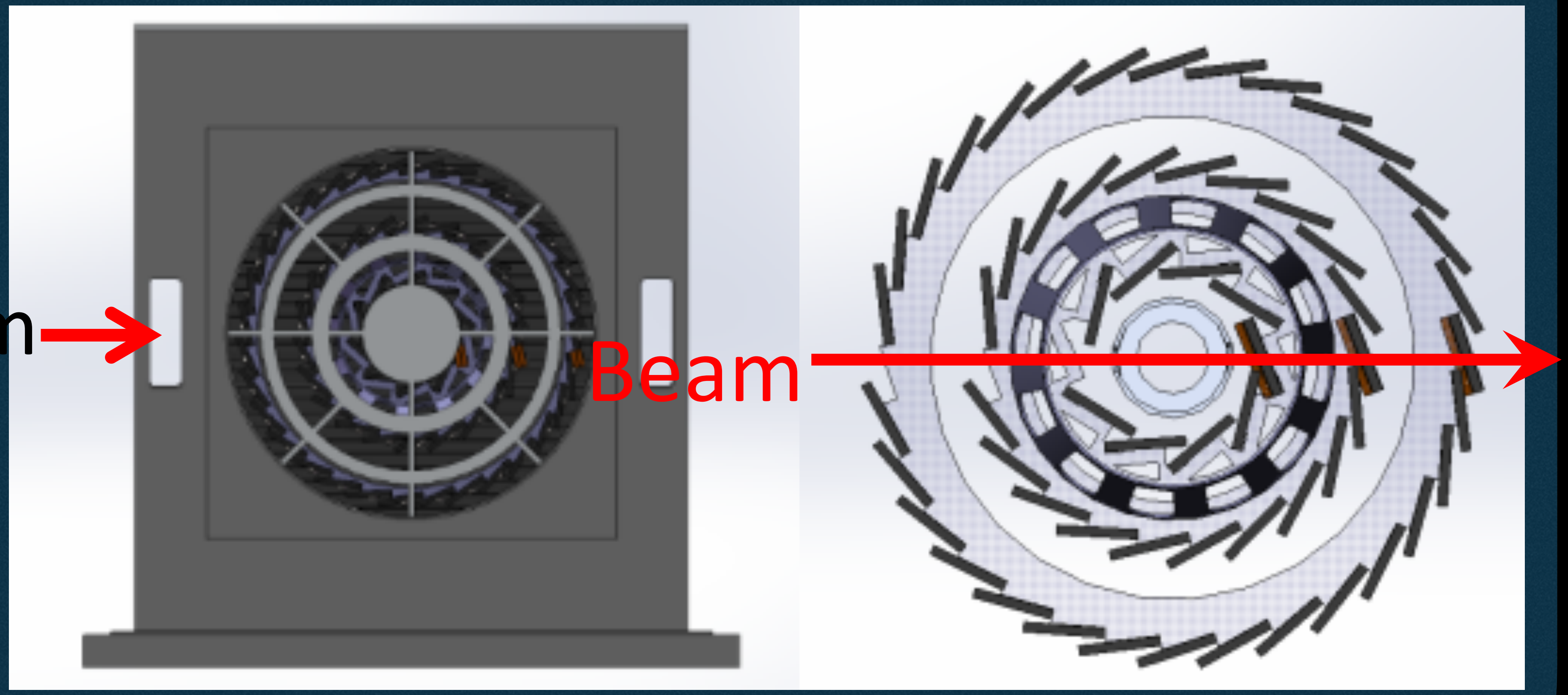
Detailed engineering design on-going





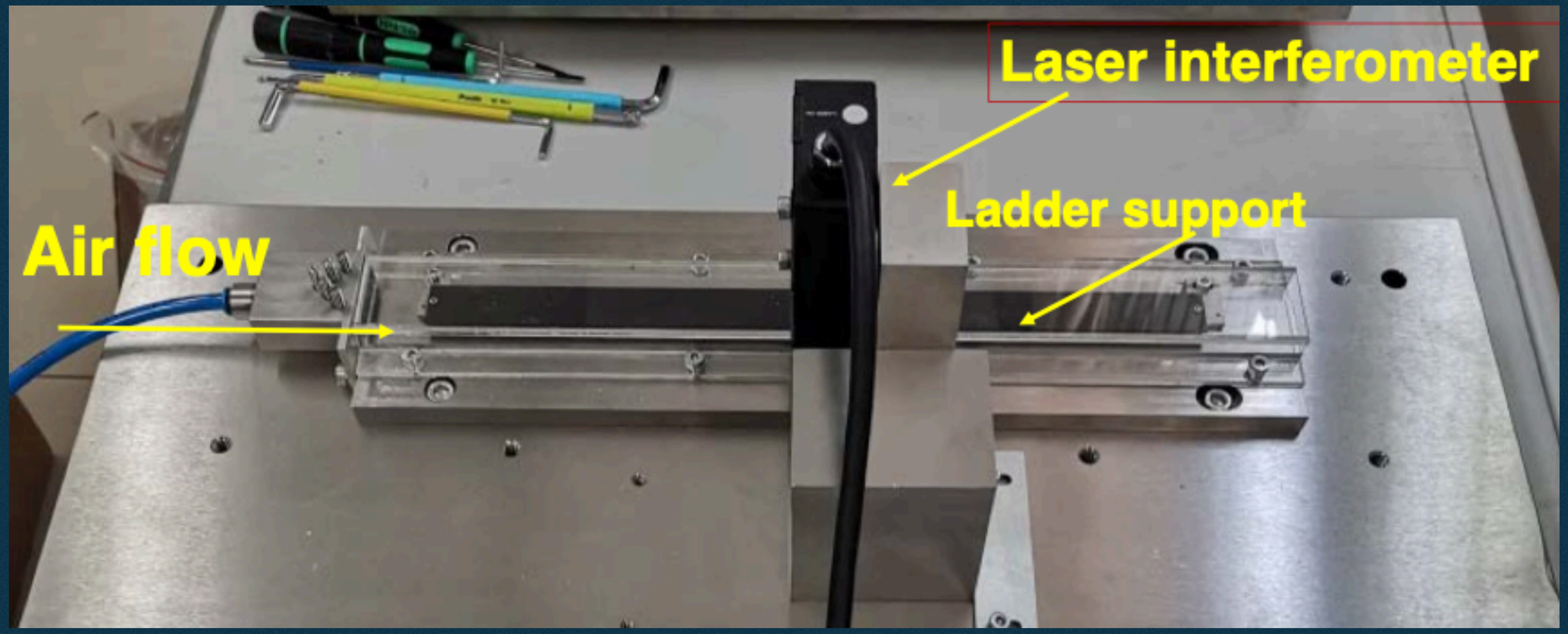






Air cooling testing

Max temperature of ladder (℃) (air temperature 5 ℃)					
Air speed (m/s) / Power Dissipation (mW/cm2)	5	4	3	2	1
100	19.6	21.8	25.0	*30.6*	*43.4*
150	26.9	30.1	35	*43.4*	*62.6*
200	34.2	38.6	45.1	*56.2*	*81.8*

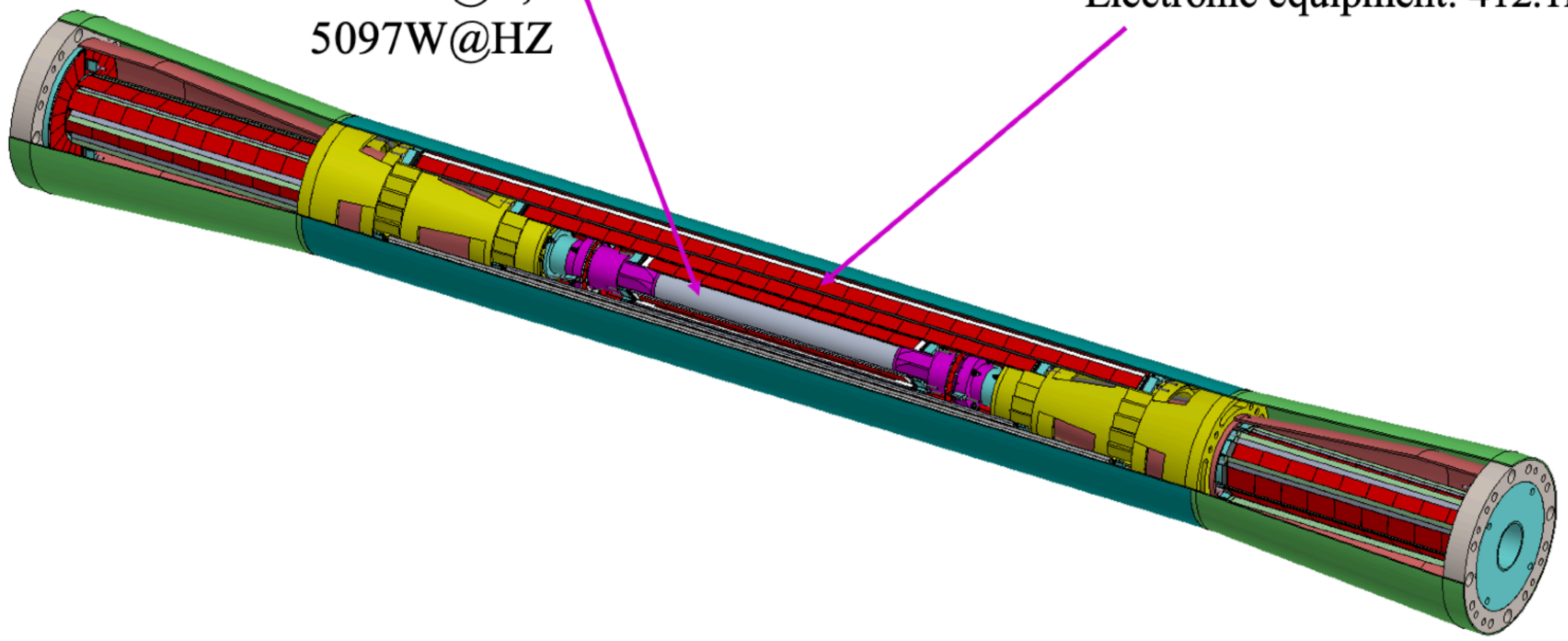


2 μm vibrations
using compressed air for cooling

Integration of vertex detector and beampipe

Beam pipe:
- High-order mode heat
- Uniformly distributed
- Total heat load: 1692W@Z; 5097W@HZ

Vertex detector:
- chips: 50mW/cm^2
- Electronic equipment: 412.1mW/cm^2

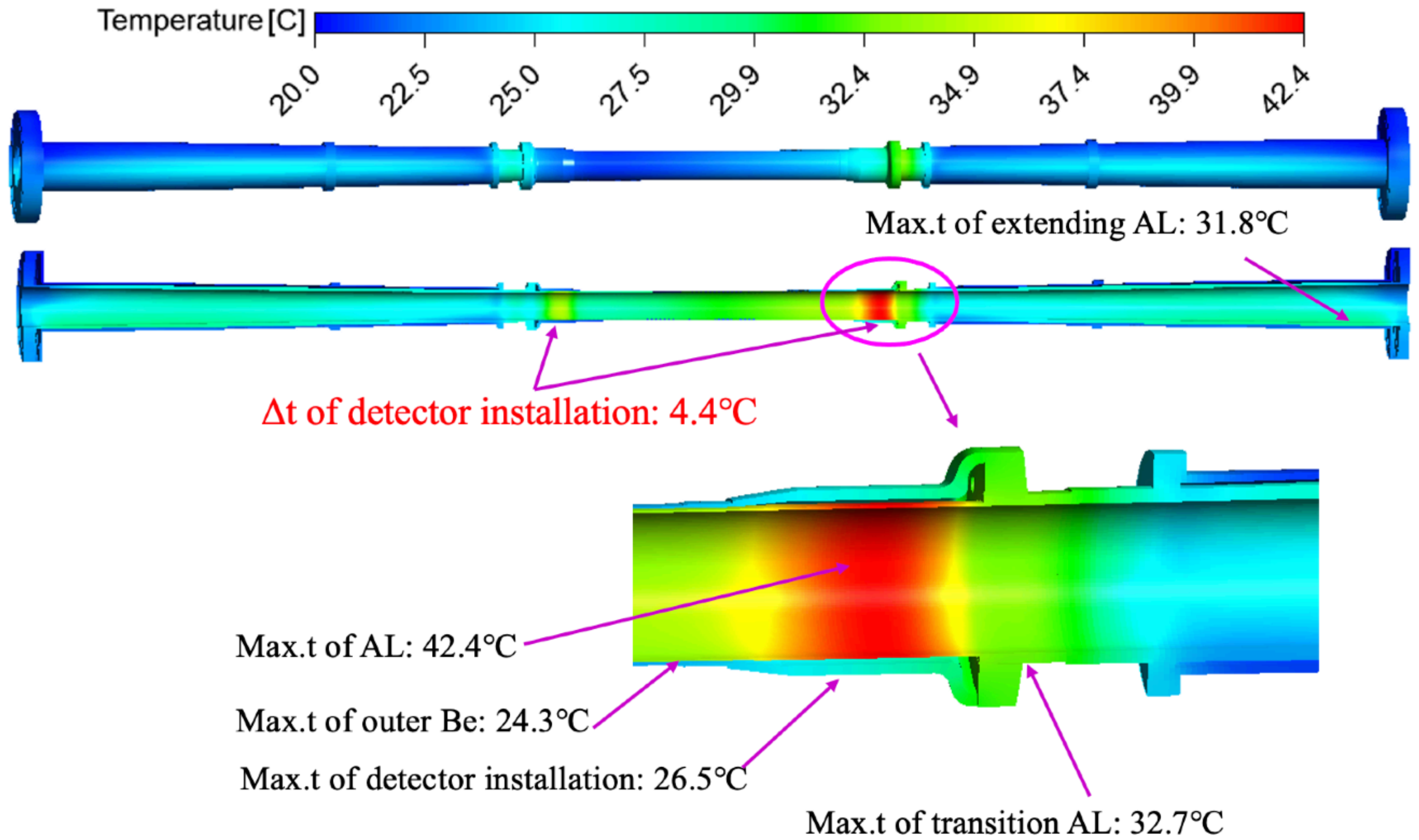


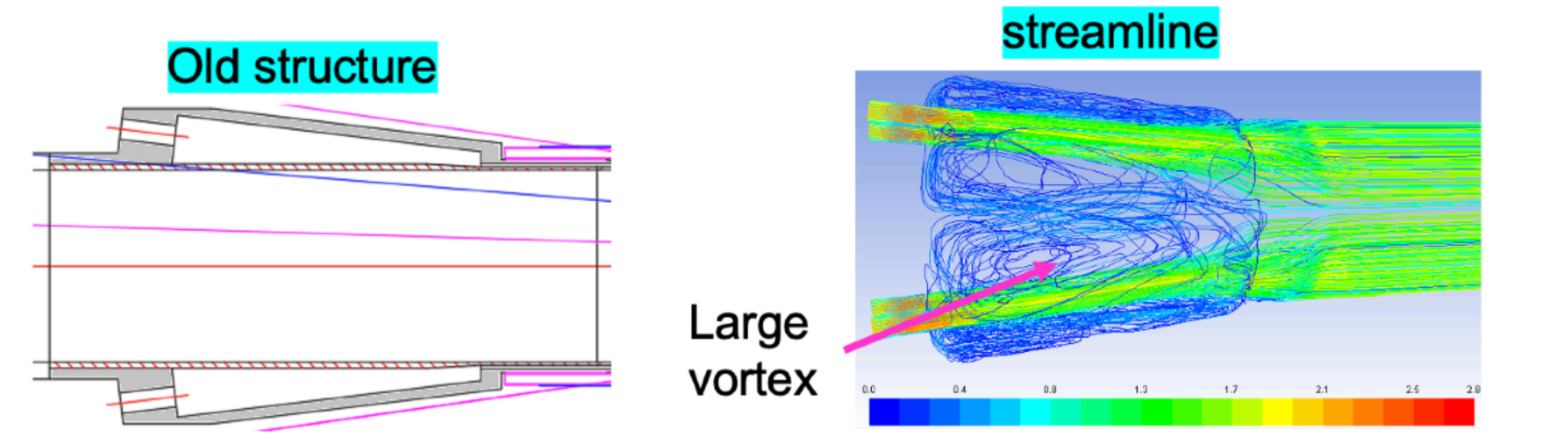
(1) Results of paraffin cooling in Z mode(1692W)

Paraffin flow parameters:
Flow rate: 1.7L/min
Inlet velocity: 1m/s
Velocity in ring pipe: 0.6m/s
Inlet temperature: 20℃

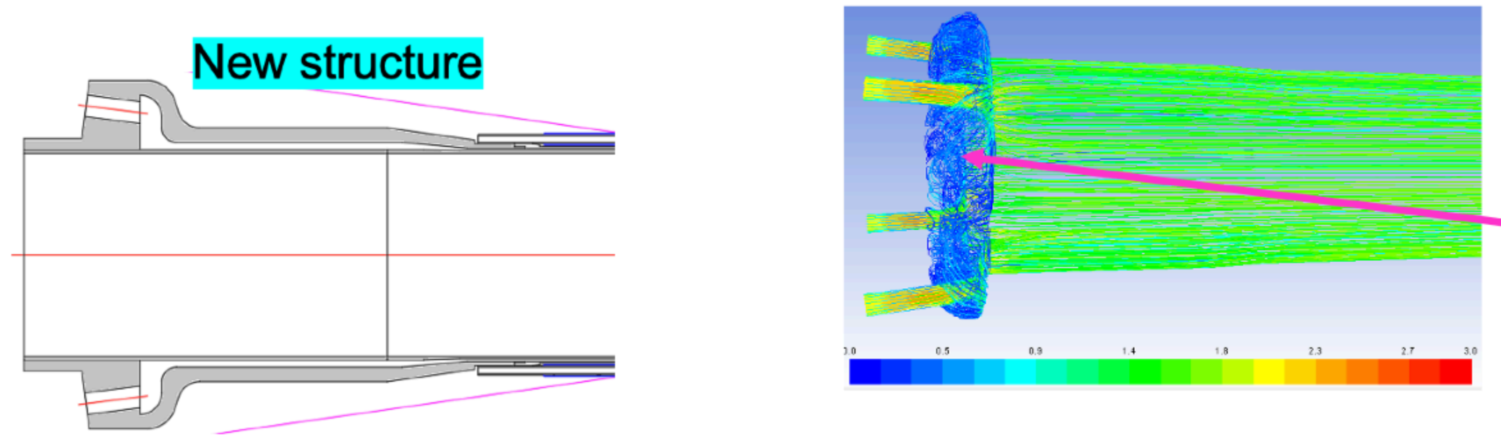
Δp of paraffin: 23.3kPa
Δp of water: 14.8kPa

✓ Cooling well!





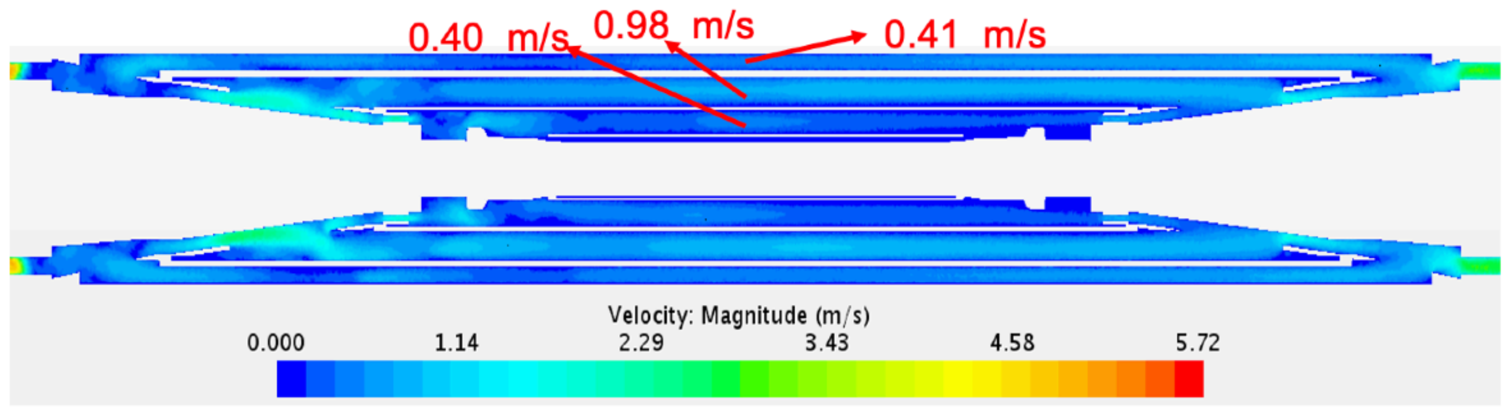
- ✓ More stable flow
- ✓ Better heat exchange
- ✓ Pressure drop increases



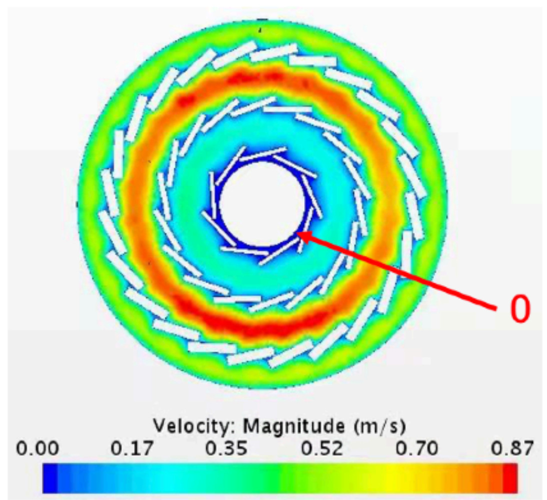
The vortex is compressed to make the flow more stable.

(2) Velocity distribution

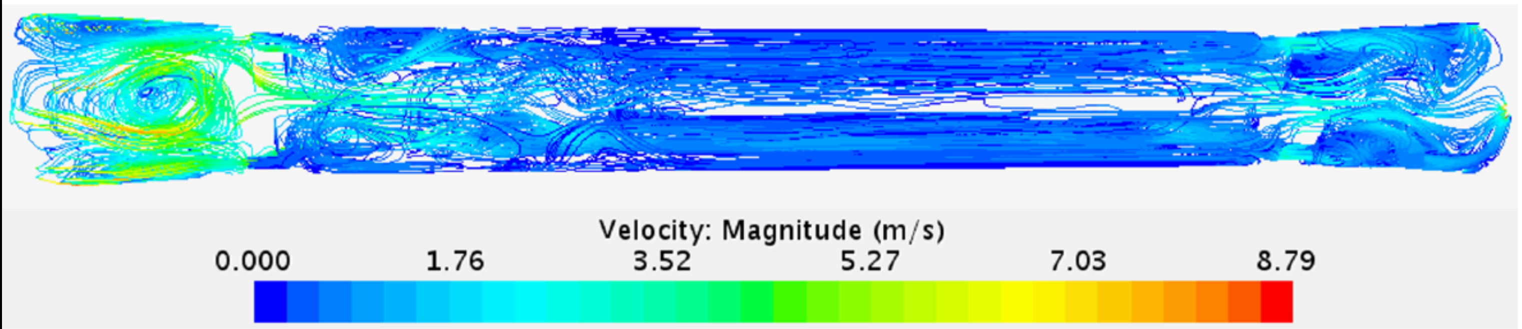
✓ The average velocity in detector cavity is very low.



Velocity distribution



Velocity distribution (cross section)



Streamline

Work will continue with new beampipe and VTX designs

MDI: CEPC beam background estimations

Backgrounds on first layer of Vertex Detector

Safety factor 10

Background	Hit Density($cm^{-2} \cdot BX^{-1}$)			TID($Mrad \cdot yr^{-1}$)			1 MeV equivalent neutron fluence ($n_{eq}\times10^{12} \cdot cm^{-2} \cdot yr^{-1}$)		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
Pair production	1.8	1.2	0.4	0.50	2.1	5.6	1.0	3.8	10.6
Beam Gas	0.4	0.4	0.2	0.36	1.3	4.1	1.0	3.6	11.1
Beam Thermal Photon	0.1	0.1	0.03	0.07	0.3	0.8	0.2	0.7	1.9
Total	2.3	1.7	0.63	0.93	3.7	10.5	2.2	8.1	23.6
Lifetime	-			31.21			70.7		
Total_oCDR	2.4	2.3	0.25	0.93	2.9	3.4	2.1	5.5	6.2

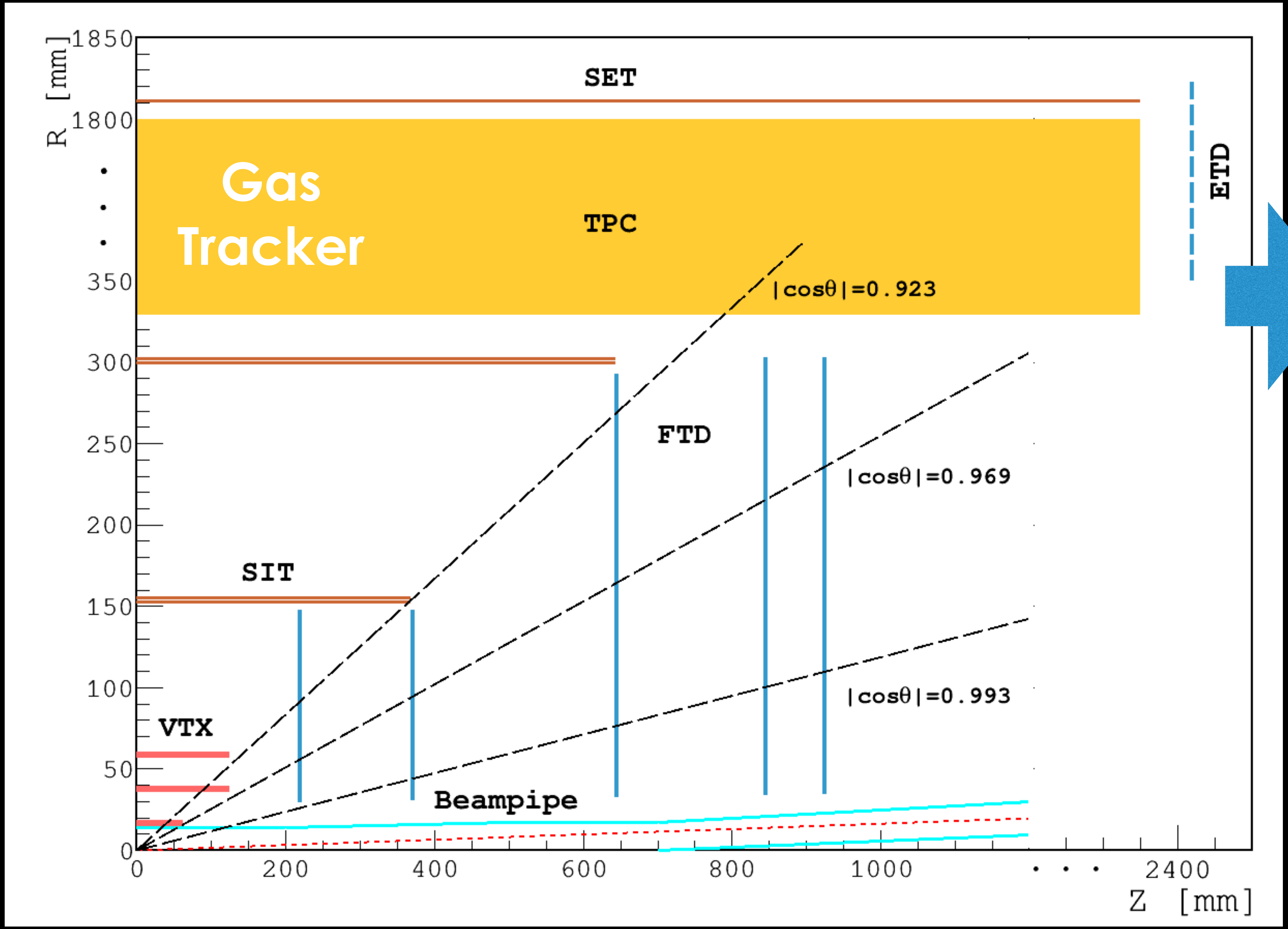
New

Previous results

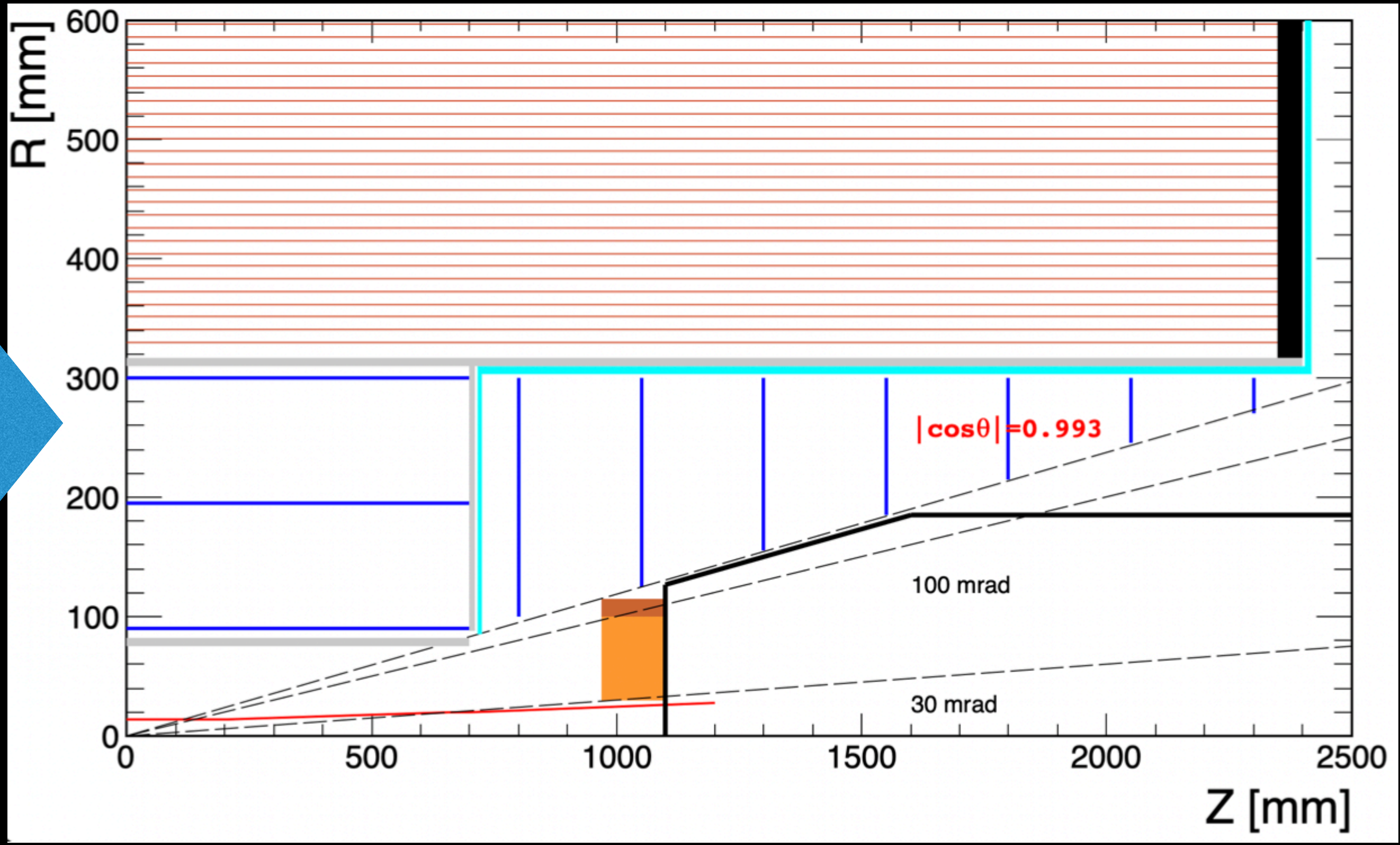
Backgrounds re-estimated with better MDI description and simulation tools

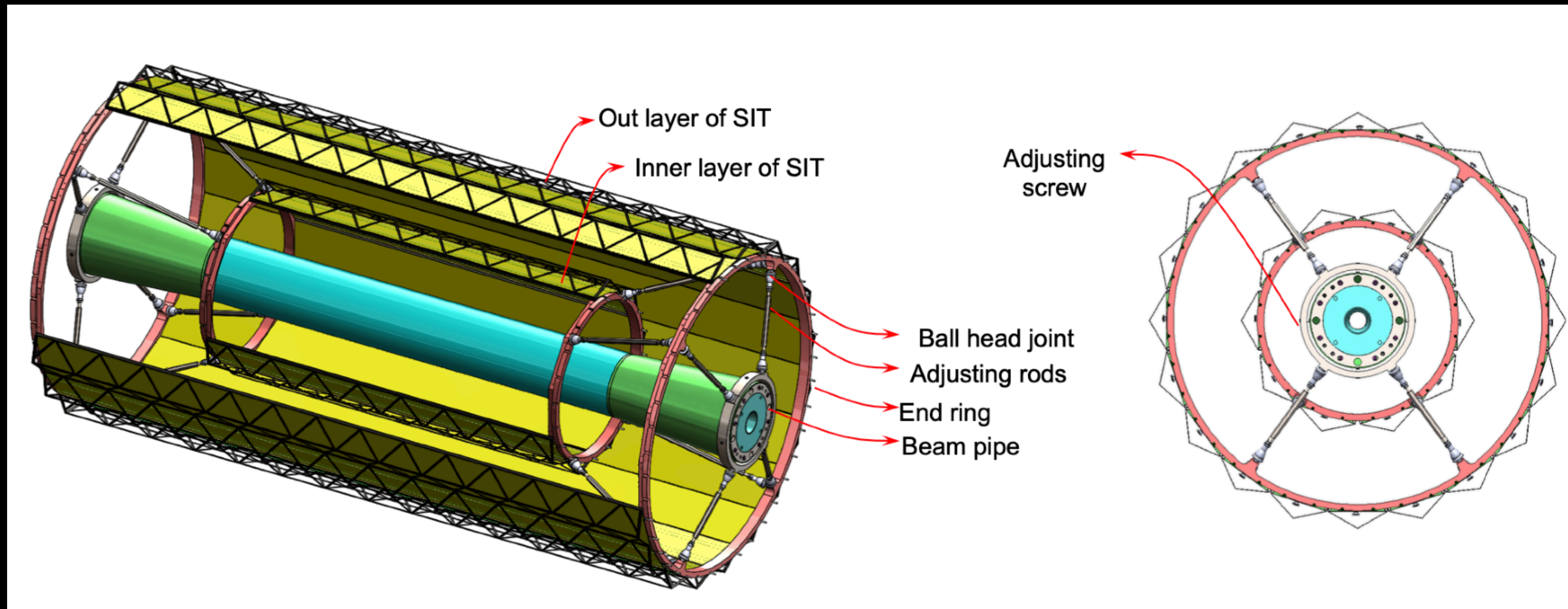
Integration of the updated luminosity values will be next step

Silicon Tracker design



Optimization: tracker layout taskforce



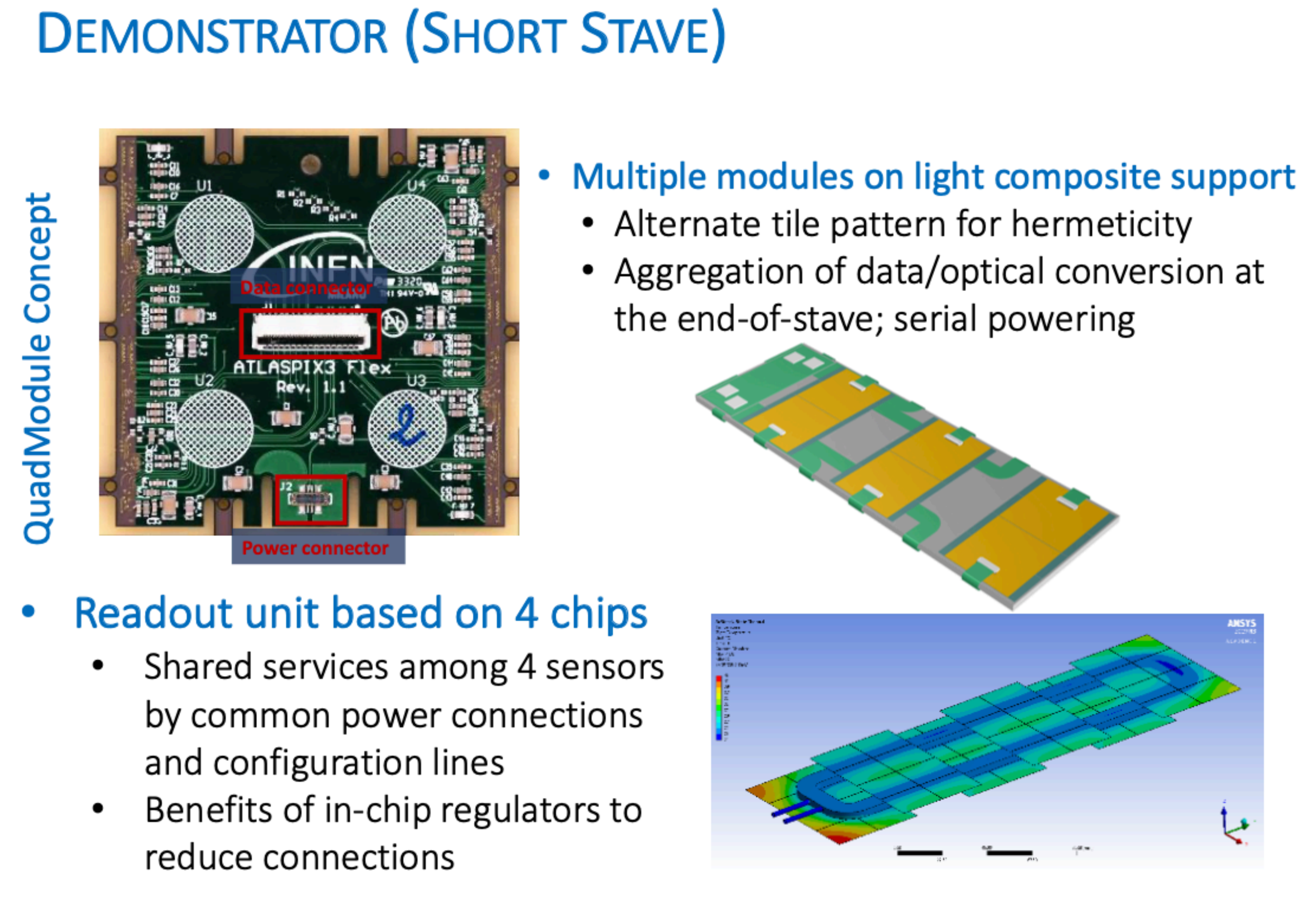


Silicon tracker demonstrator with international partners

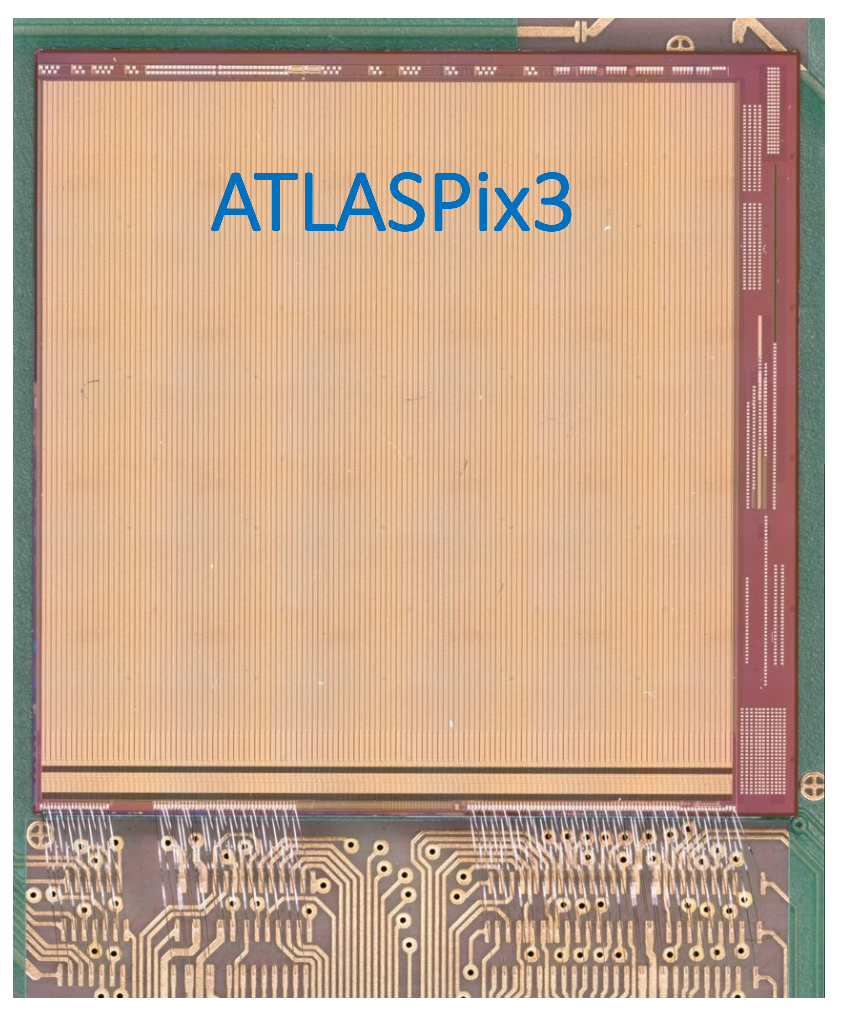
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of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

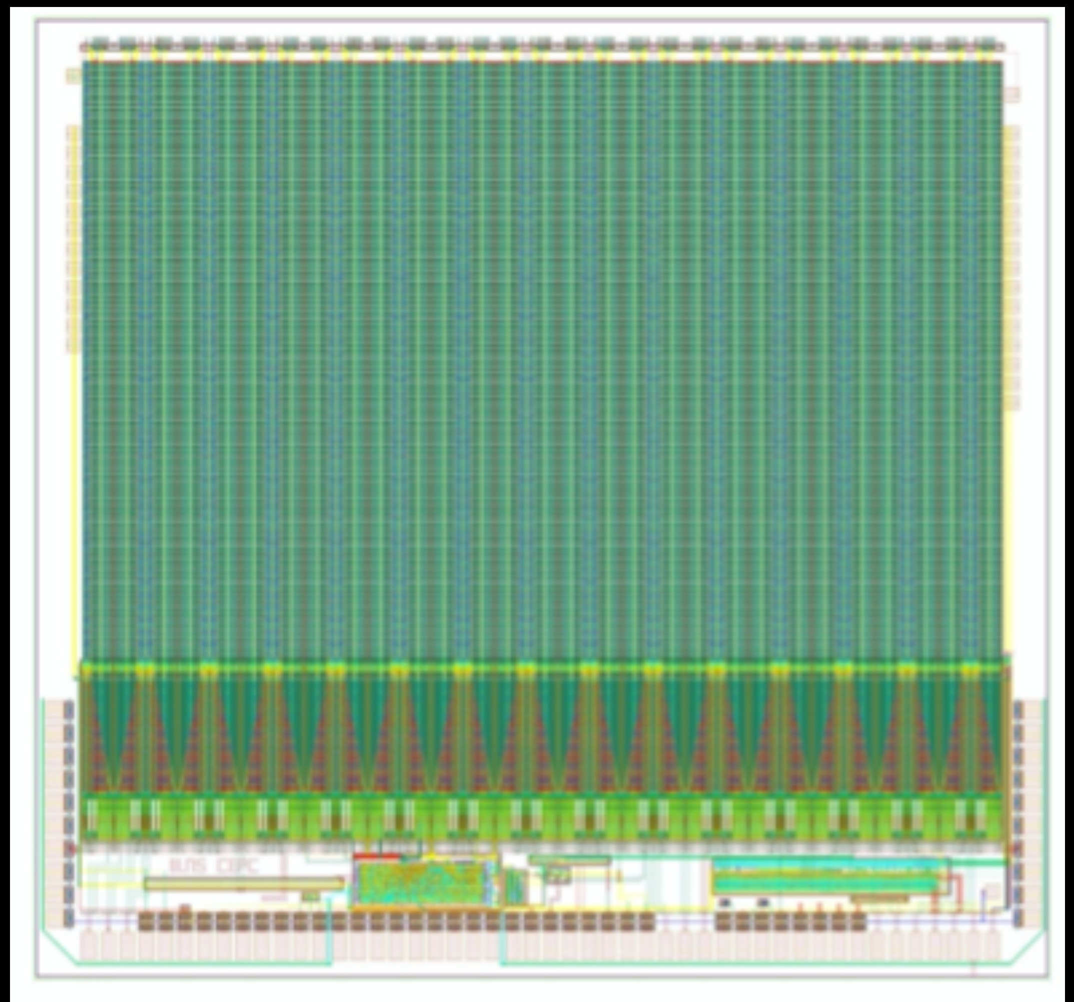
International group led by H.Fox (Lancaster) and M.Wang (SDU)

Start by using components developed for other projects



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

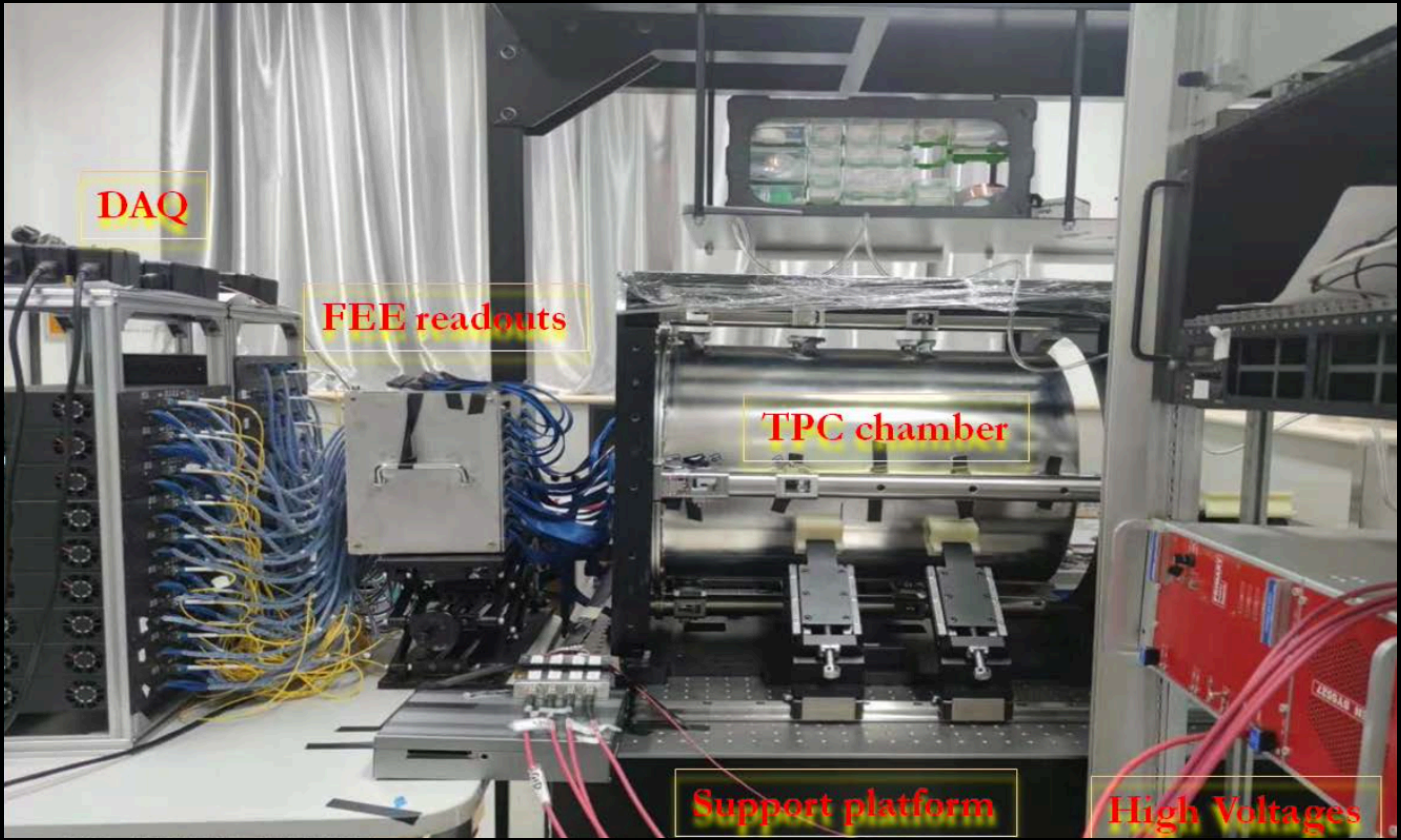




Migrate to a Chinese foundry if possible

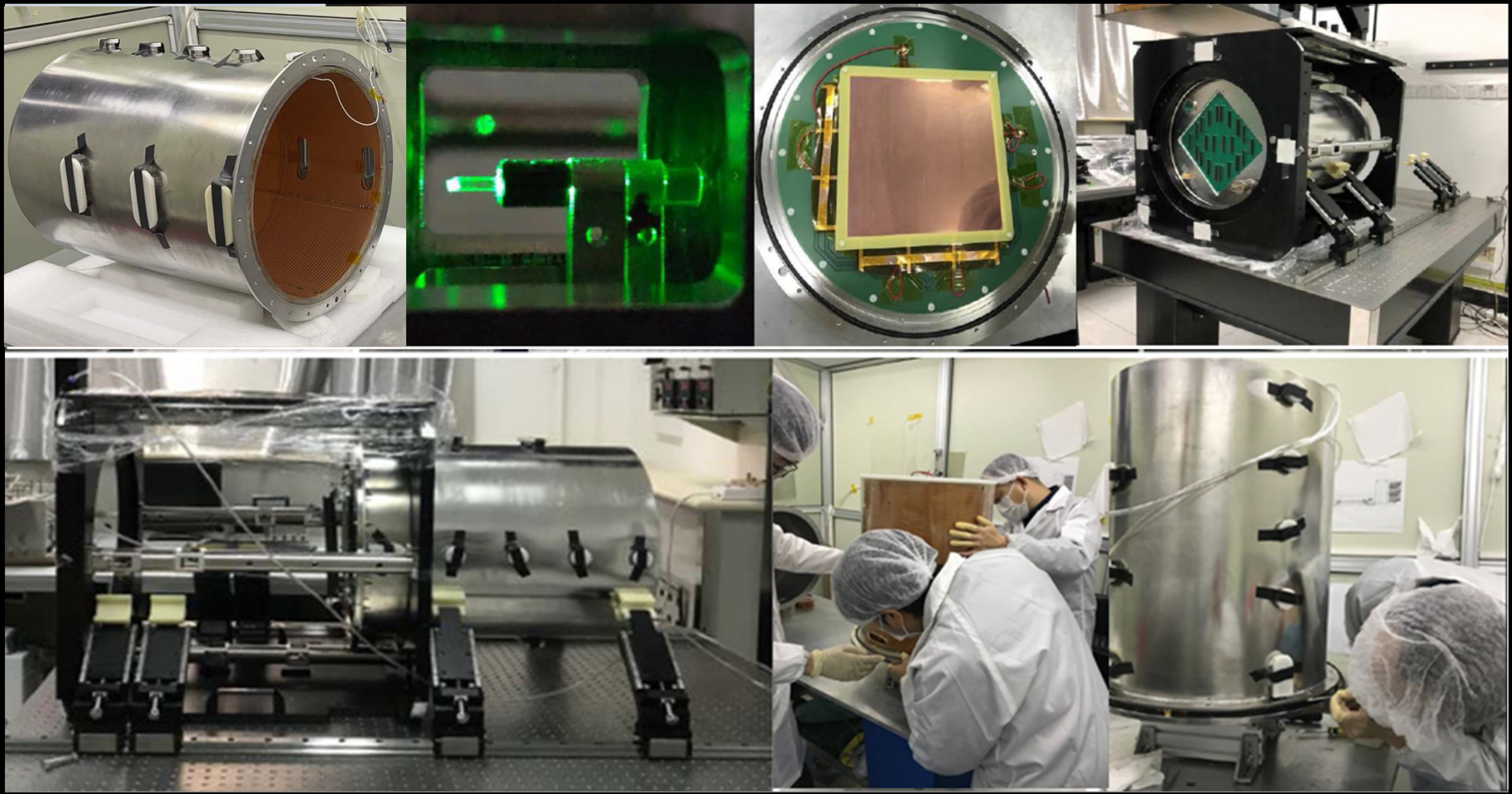
CEPC TPC Prototype under test

Prototype complete, achieving MOST1 project goals



TPC Prototype

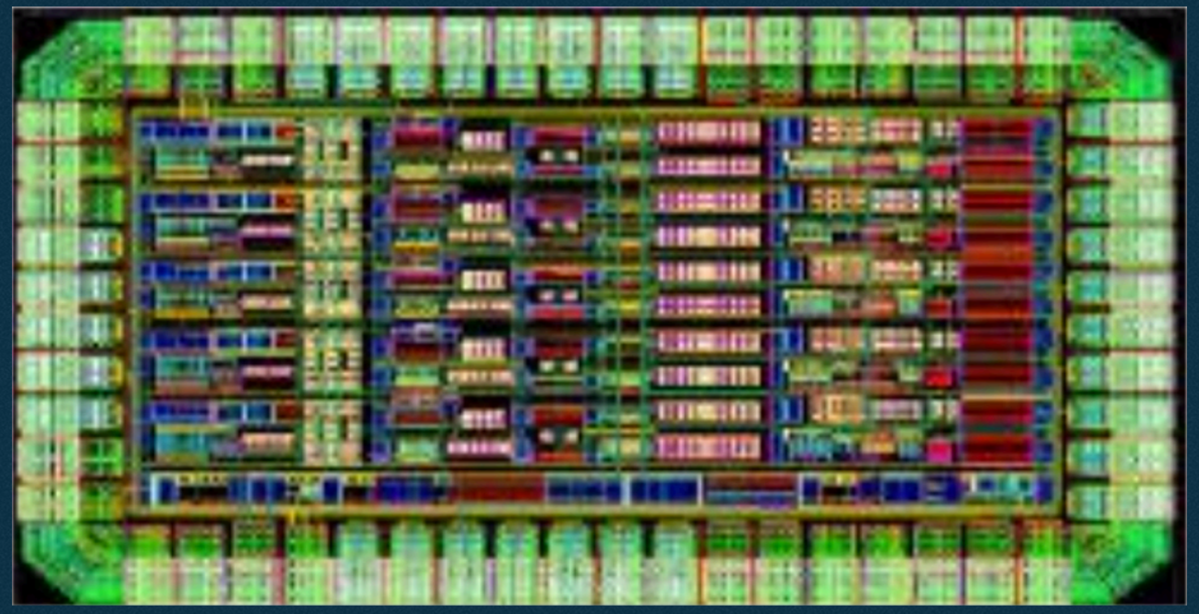
- **500 mm** drift length with **20kV** high voltage
- GEM detector at endplate with **200 mm^2**
- Calibrated with **266nm UV** laser tracks into that the chamber



Lower power FEE ASIC chip developed

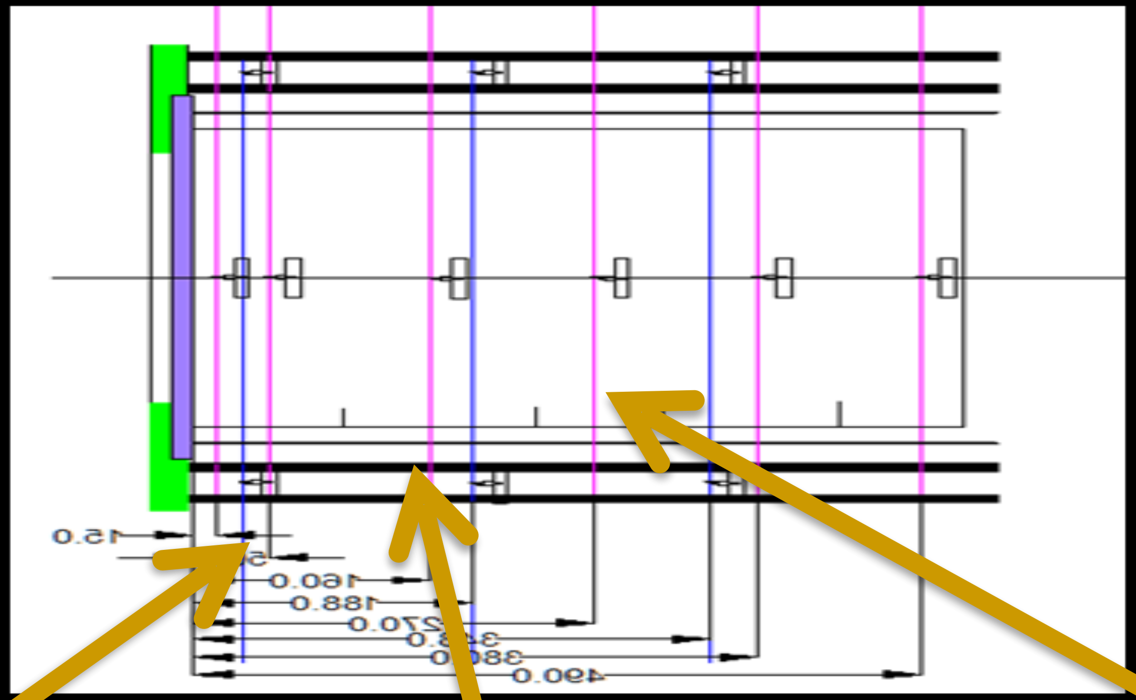
65 nm CMOS ASIC

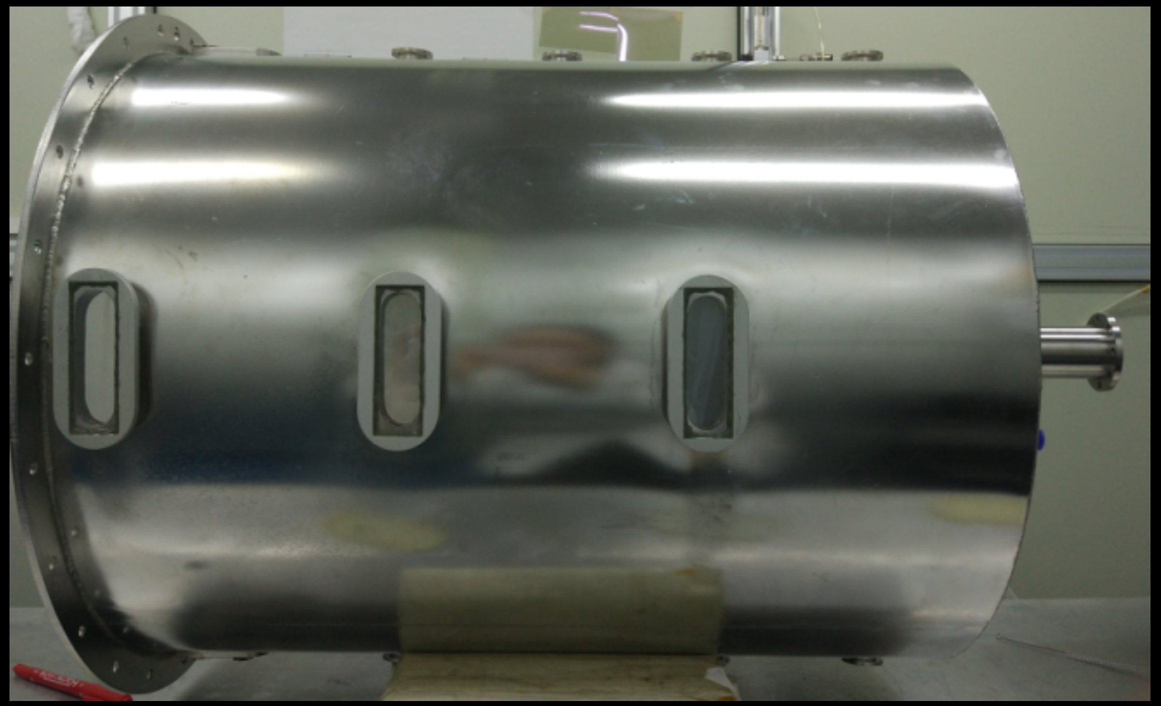
Power < 2.5 mW/ch

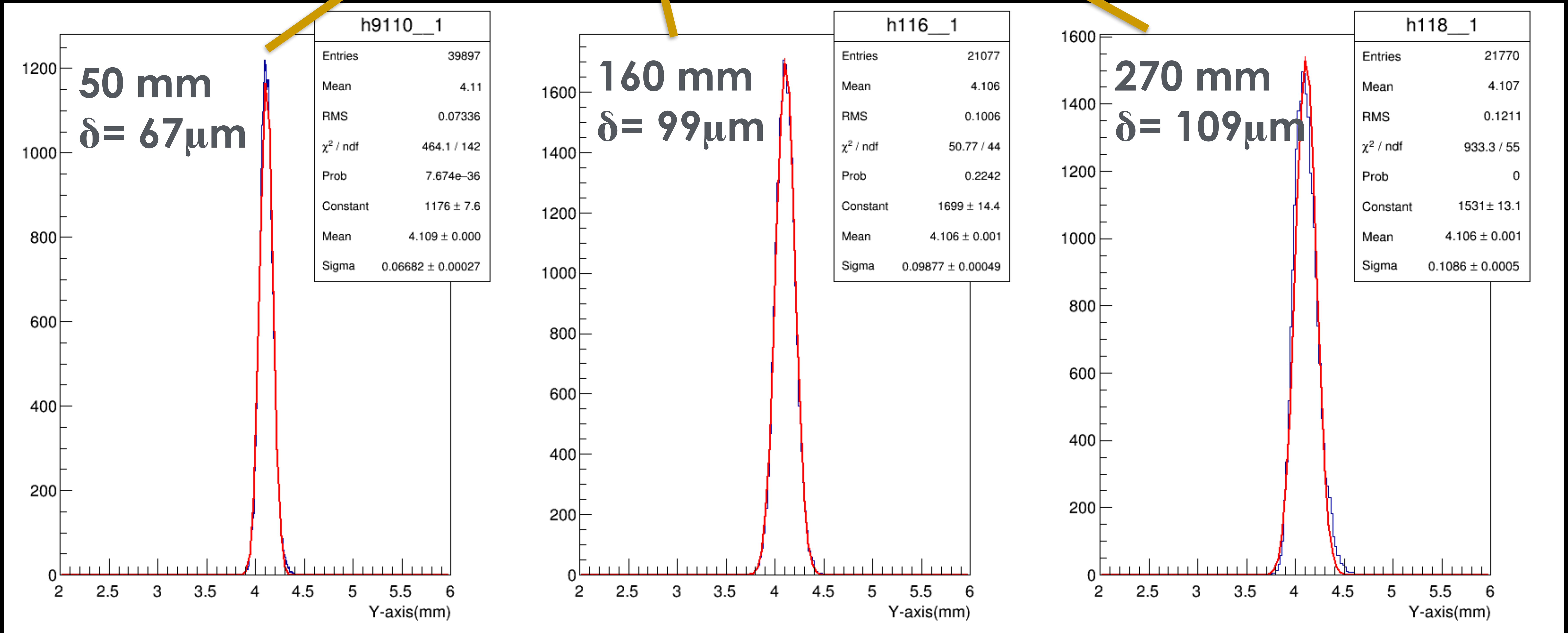


TPC Prototype Test Results

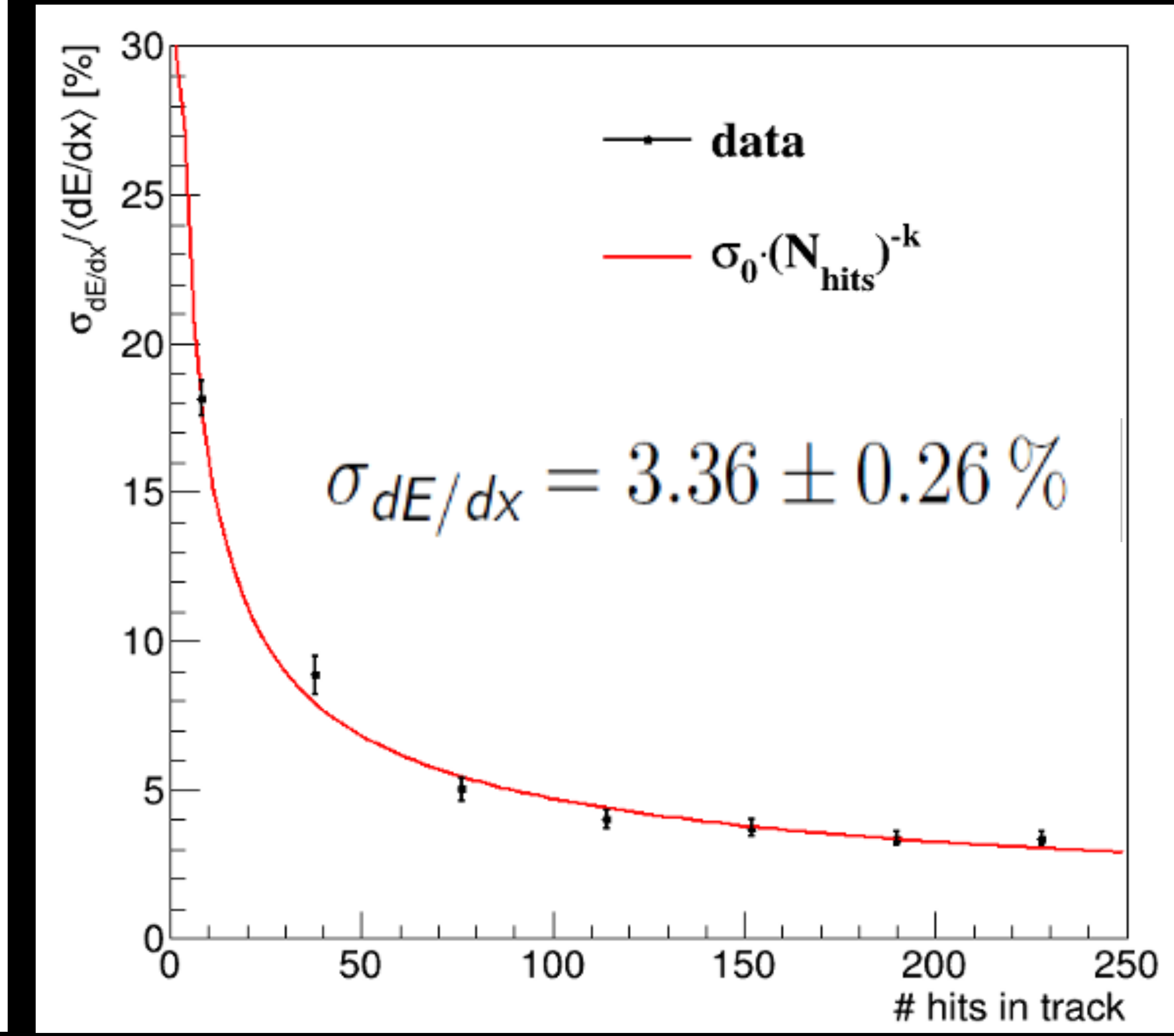
Readout







PID analysis



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)

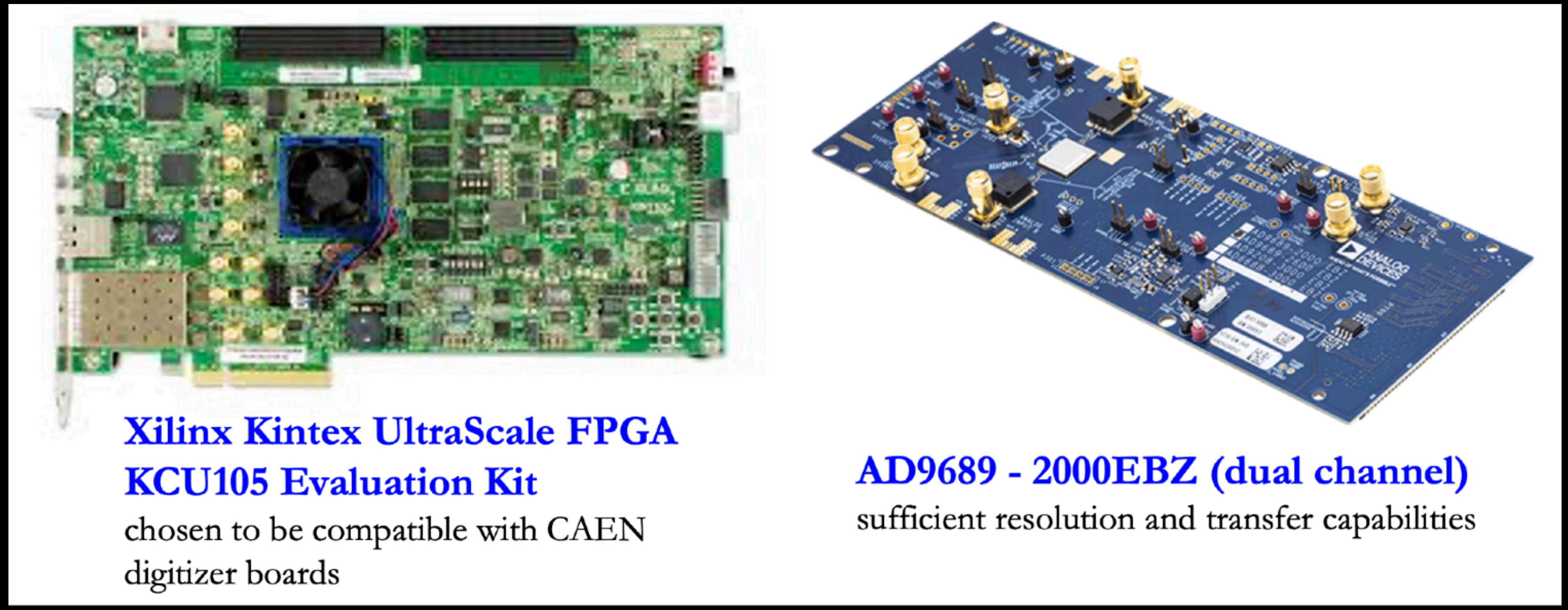
- Spatial resolution: < 100 µm
- Max drift time: ~350 nsec
- Cells: 56,448

Layers: 14 SL × 8 layers = 112

Cell size: 12 - 14 mm

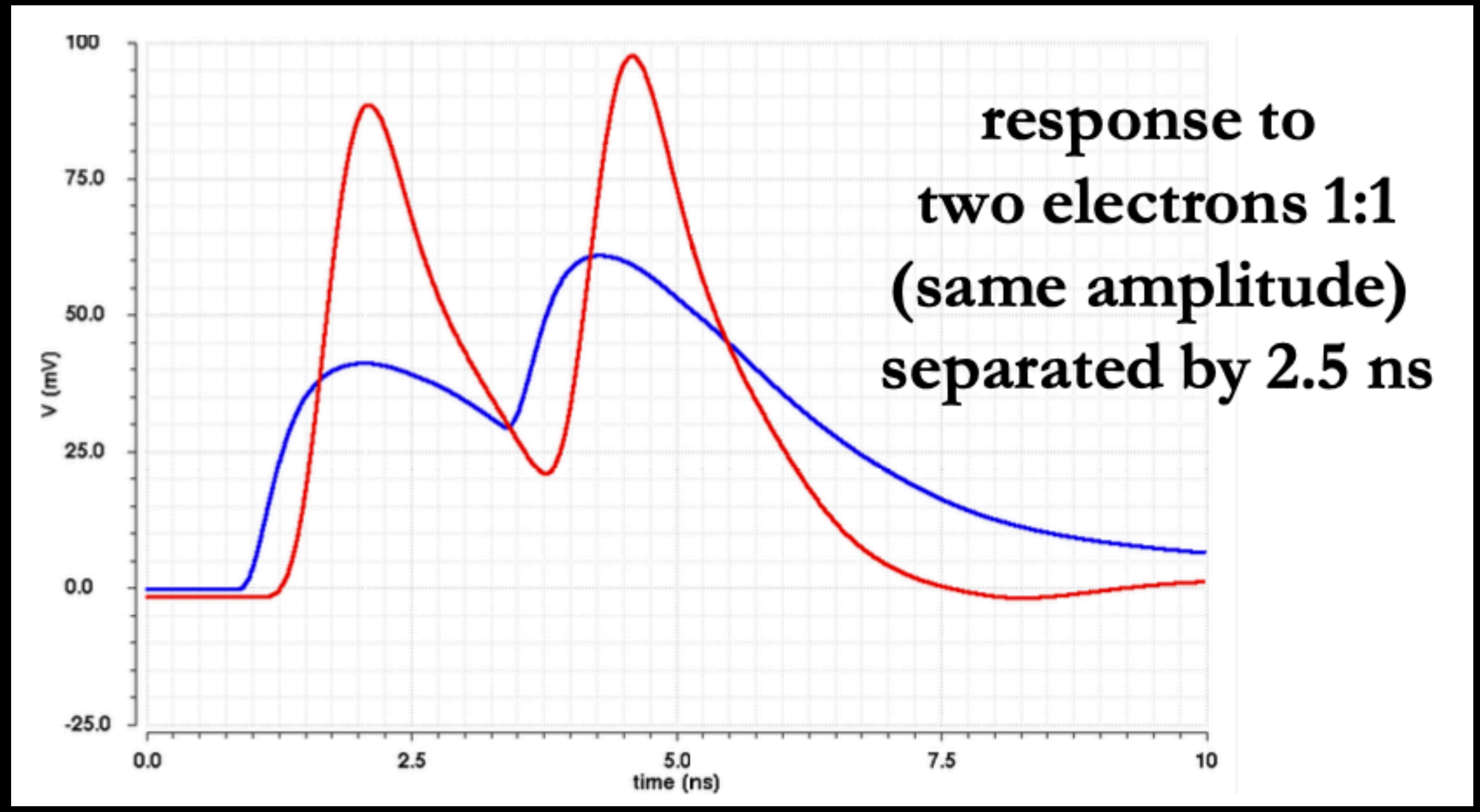
New DAQ board: dual channel

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

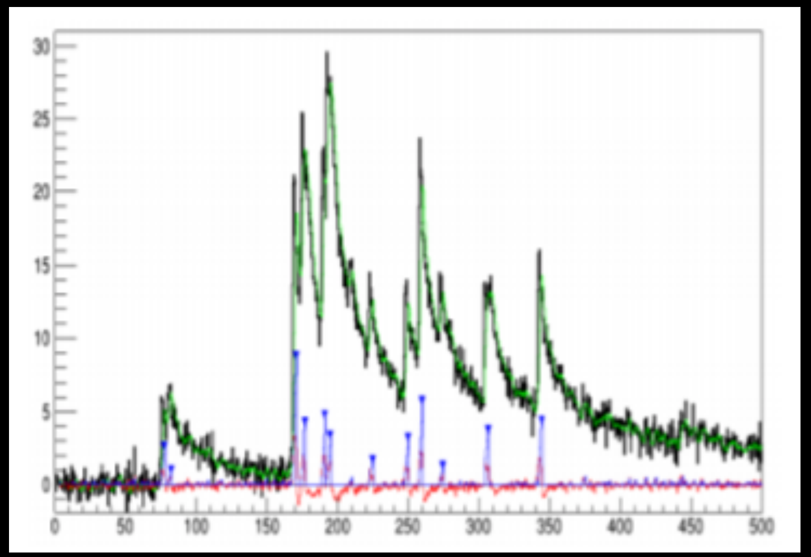


Front-end ASIC

a two stage amplifier for cluster counting/timing



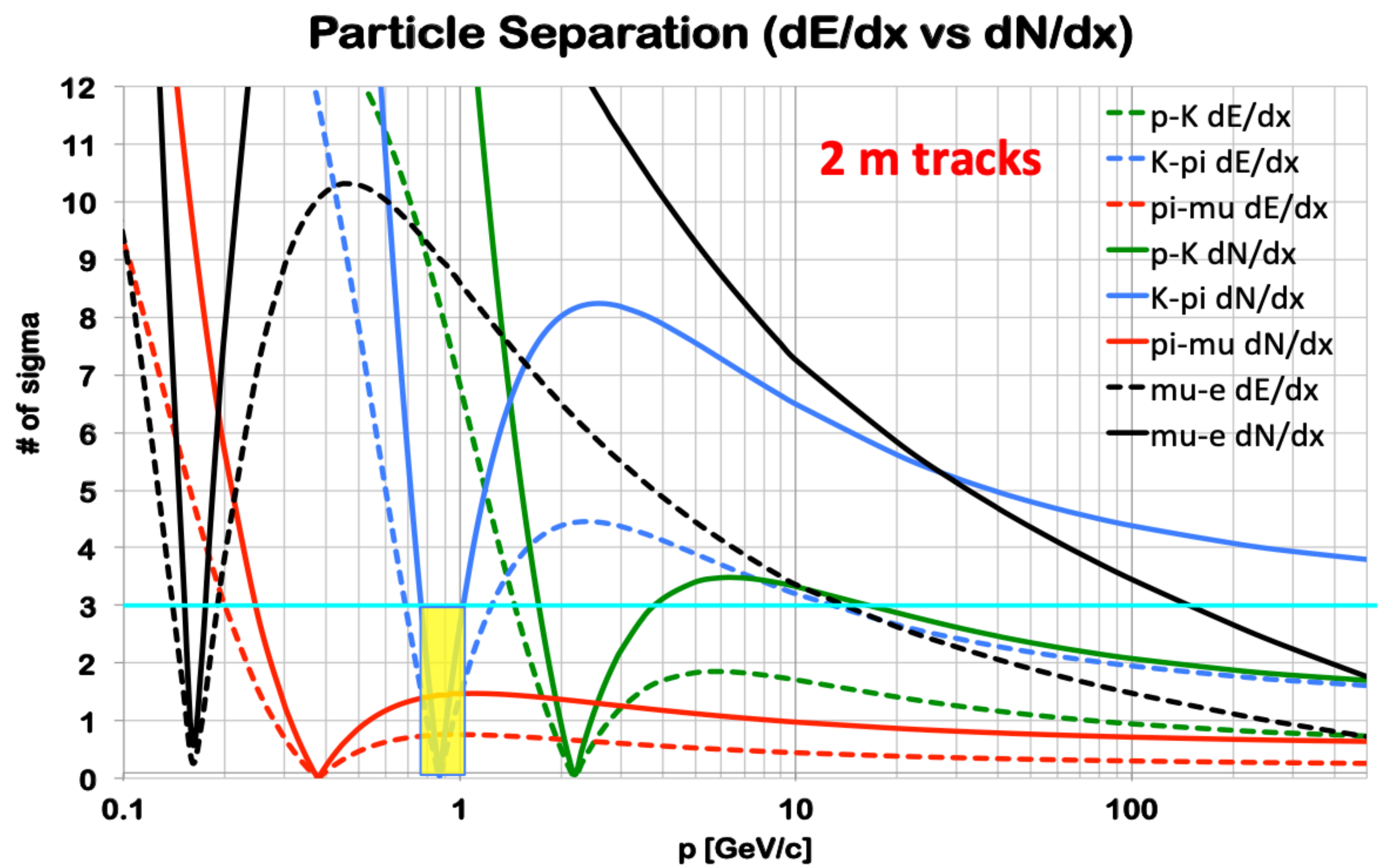
Drift Chamber Considerations: dE/dx vx dN_{cl}/dx

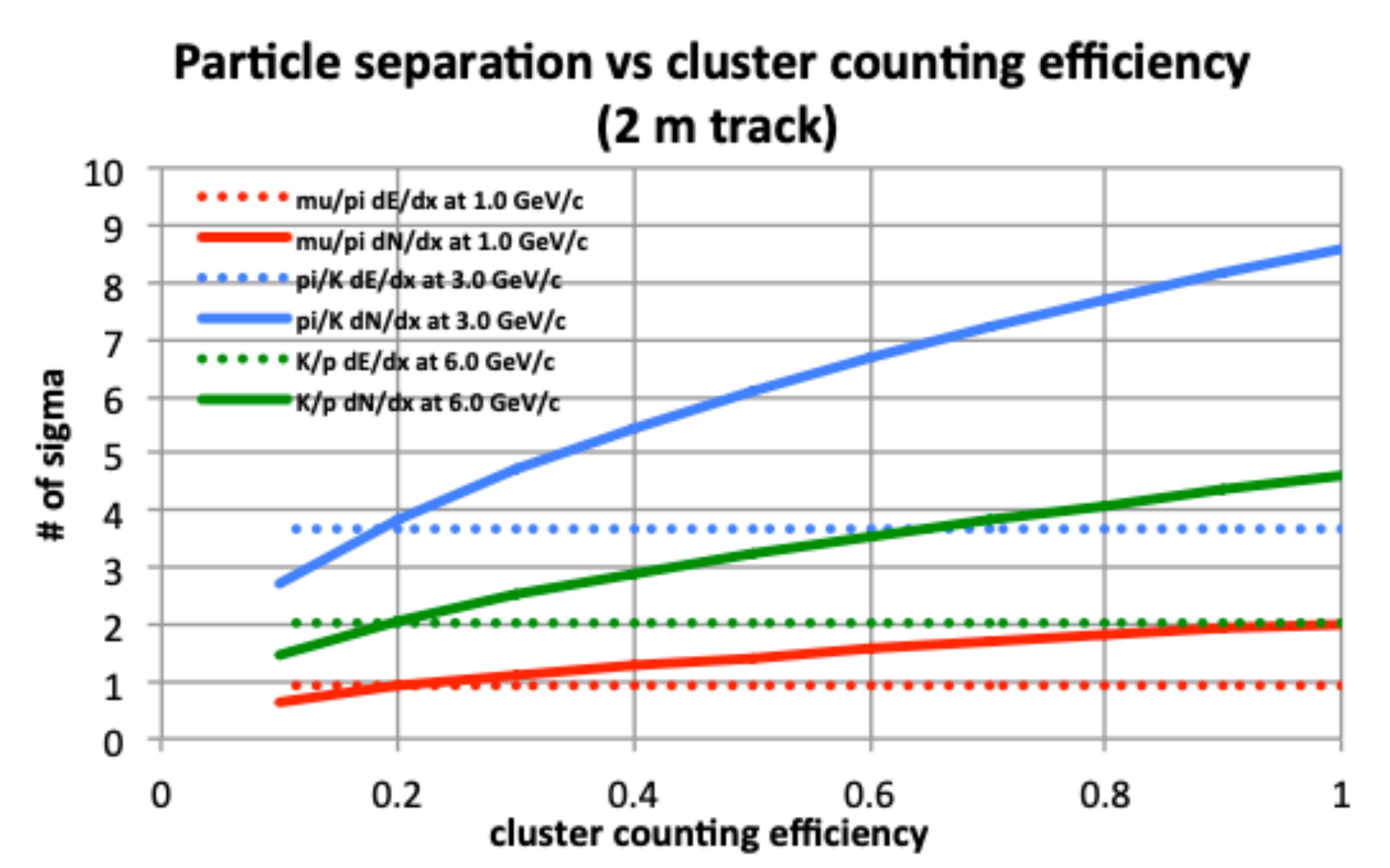


Expected from analytical calculation of IDEA chamber

80% cluster counting efficiency

4.3% dE/dx resolution



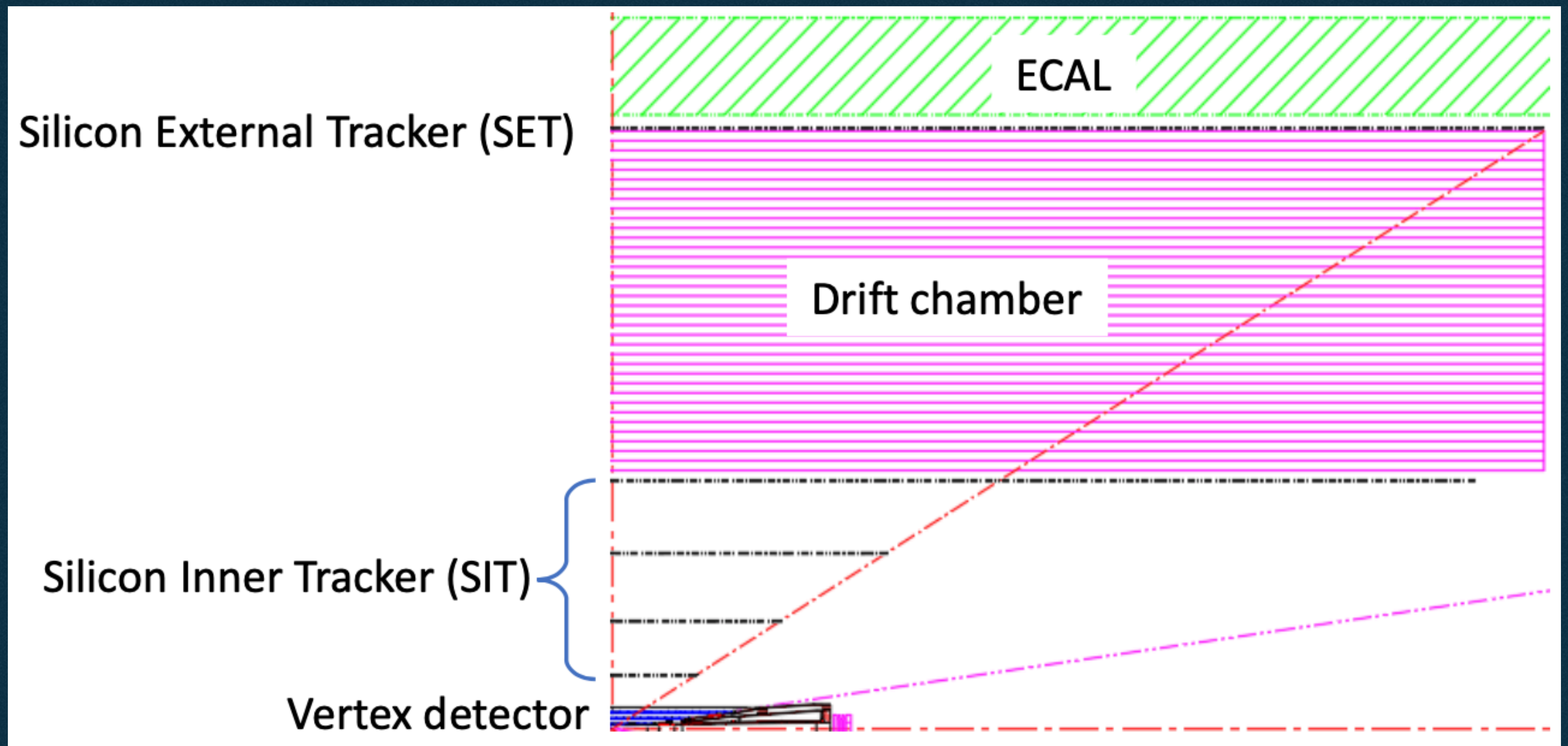


Cluster counting potentially a factor 2 better than dE/dx, but requires fast electronics and good counting algorithms

- 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

Drift Chamber research at IHEP



Drift chamber radius > 1m :
- K/π separation up to 20 GeV/c
- PID efficiency > 90%, for K/π up to 20 GeV/c

Preliminary

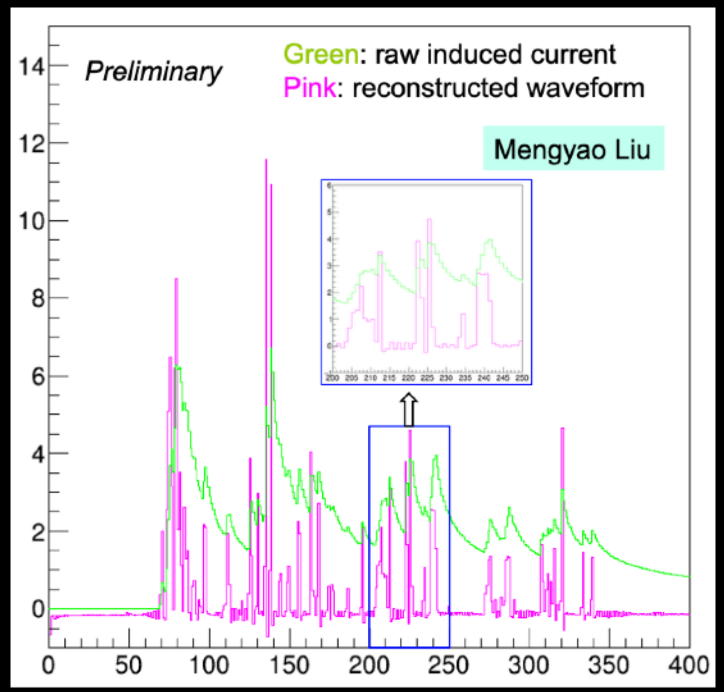
Optimization of drift chamber for PID

Garfield++(Heed): Simulates in deep detail the ionization processes in the gas

GEANT4: Does not simulate the ionization clustering process → essential for cluster counting

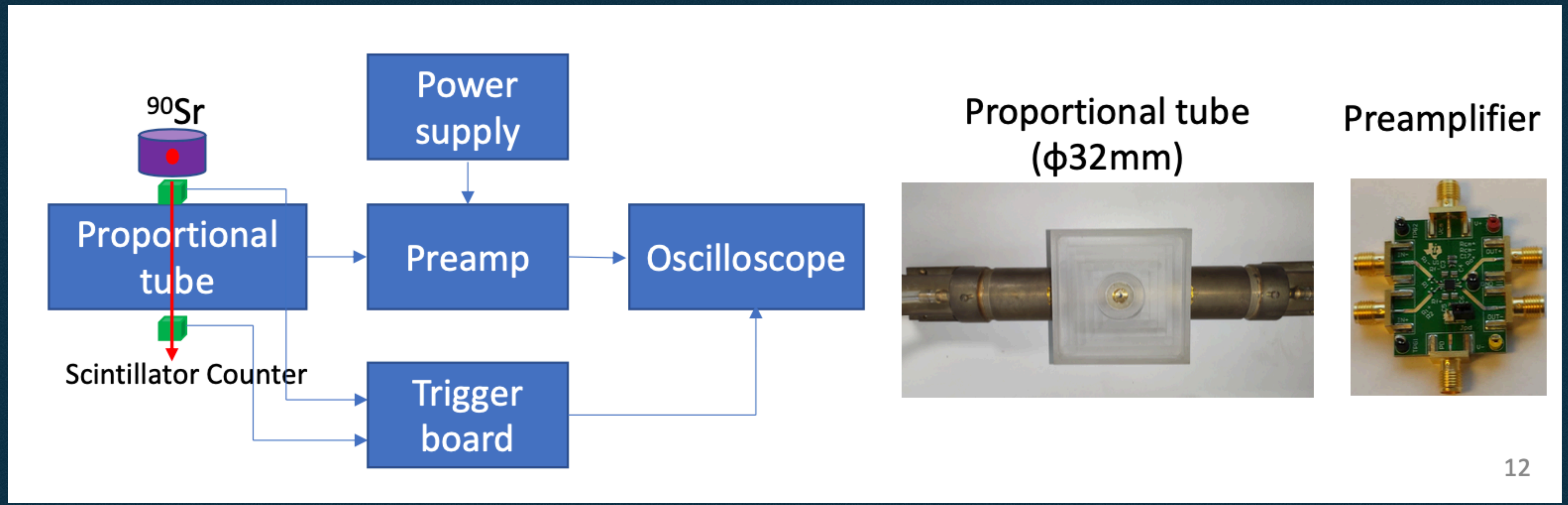
(dE/dx and with dN_{cl}/dx separation in GEANT4 is worse by 20%)

Combine both



Preliminary version of software developed and incorporated into key4hep/EDM4hep

Prototype to verify simulation results



Collaboration on Drift Chamber and Tracking - Regular meetings

Cluster counting regular meeting

CEPC » Physics and Detector Meetings » Tracker » Drift Chamber

Drift Chamber

October 2021

- 15 Oct Meeting on cluster counting in drift chambers

September 2021

- 30 Sep Meeting on cluster counting in drift chambers
- 16 Sep Meeting on cluster counting in drift chambers

July 2021

- 15 Jul First meeting on cluster counting in drift chambers

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

Tracker layout optimization discussion

CEPC » Physics and Detector Meetings » Physics and Simulations » Tracking

Tracking

October 2021

- 29 Oct Tracker Discussion New!
- 15 Oct Tracker Discussion

September 2021

- 24 Sep Tracker Discussion
- 17 Sep Tracker Discussion
- 10 Sep Tracker Discussion

August 2021

- 27 Aug Tracker Discussion
- 20 Aug Tracker Discussion
- 13 Aug Tracker Discussion

• • •

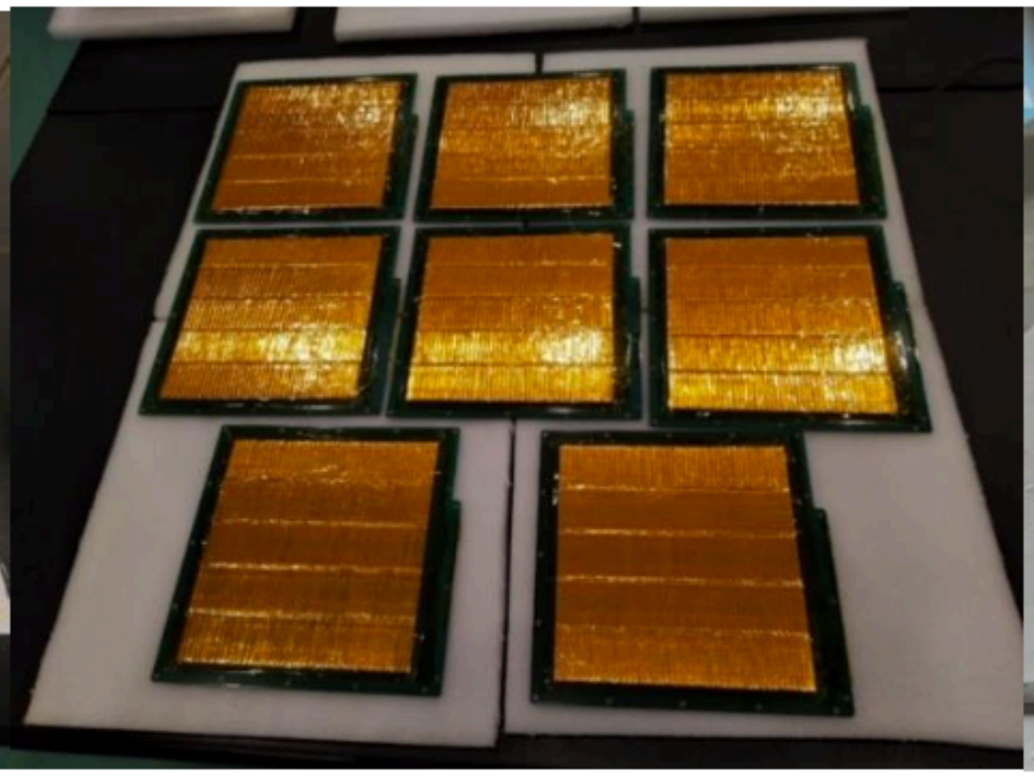
- Called by:
  - Gang and Linghui
- Participants from:
  - IHEP
  - Lancaster University
  - Jilin University
  - Shandong University
  - Nanjing University

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 : $22\ X_0$

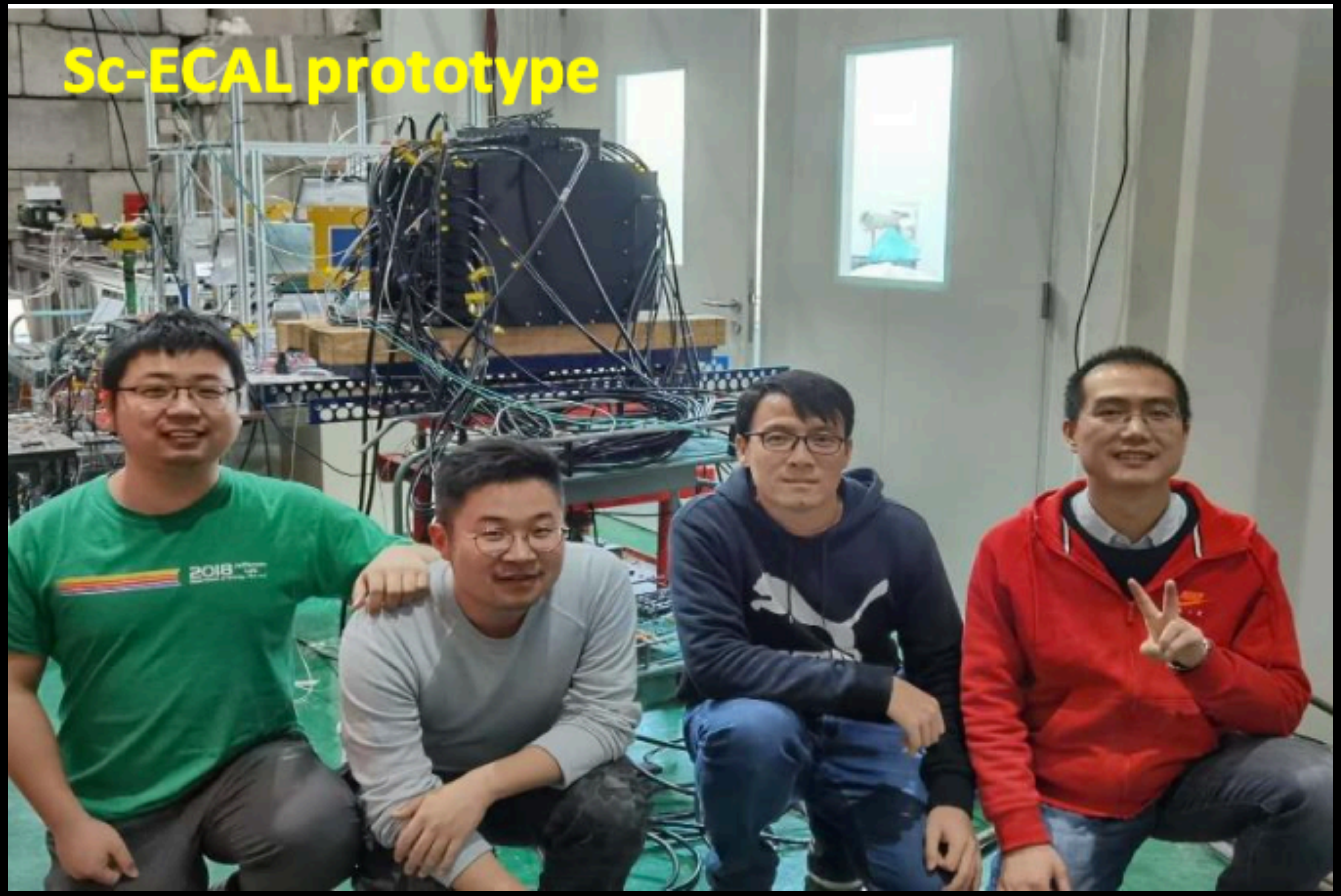
Sc-ECAL prototype

2

Test beam at IHEP earlier this year

Scintillator ECAL Prototype: testing

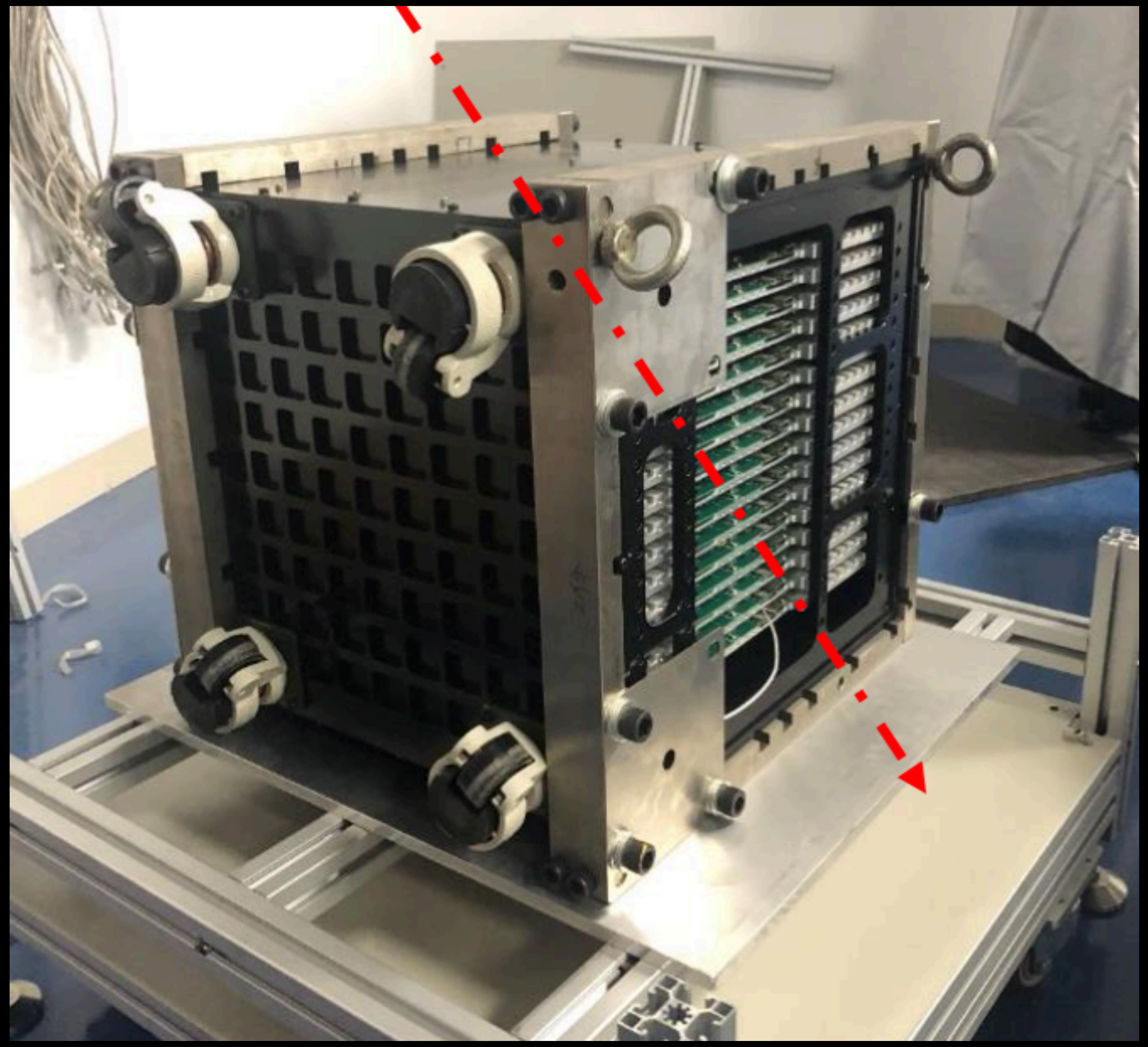
Test beam at IHEP



- 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 2 mm, better than required by MOST project for CEPC ScECAL

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

Satisfied MOST1 project requirements

Two Hadronic Particle Flow Calorimeters

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

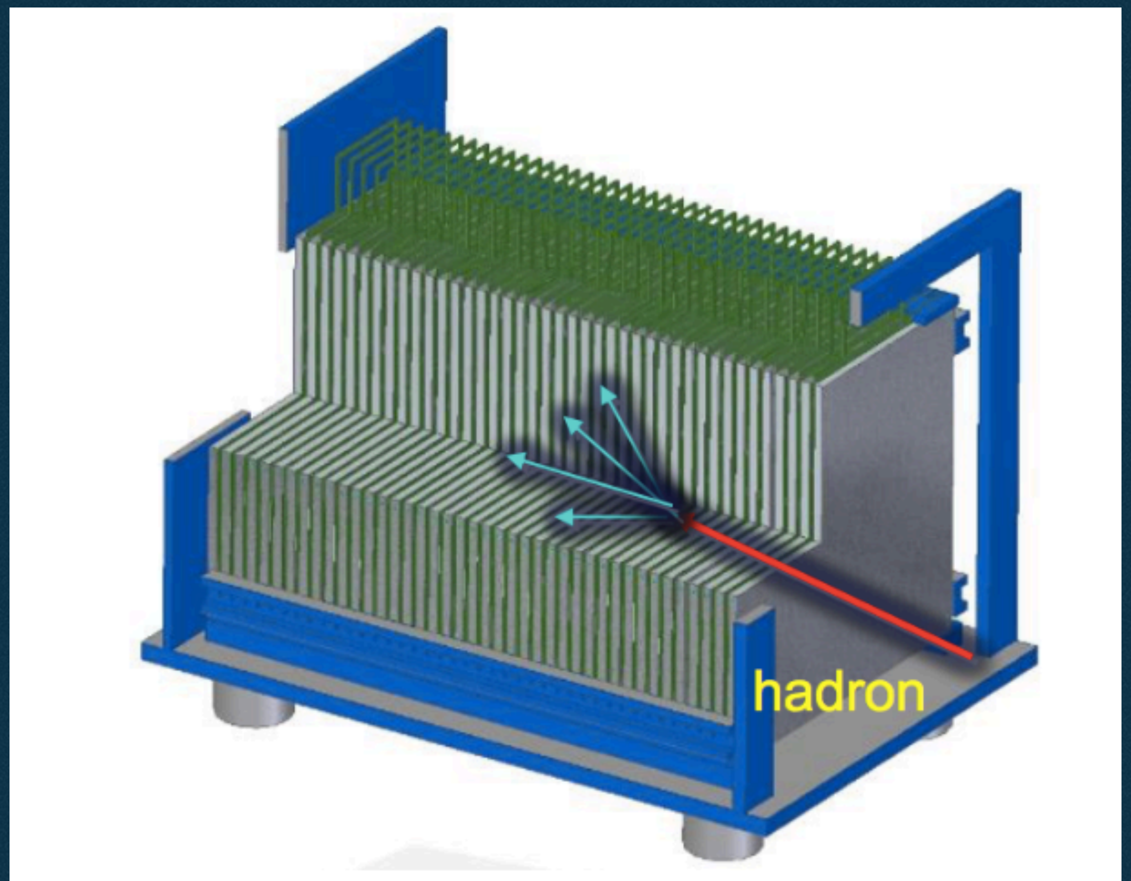
AHCAL
Scintillator and SiPM

Prototype

40 layers of 20 mm stainless steel
+ 3 mm scintillator
+ 2 mm PCB
Transverse size: 72 × 72 cm^2
Length: 1.3 m

Cell size: 4 × 4 cm^2

To be finalized next year

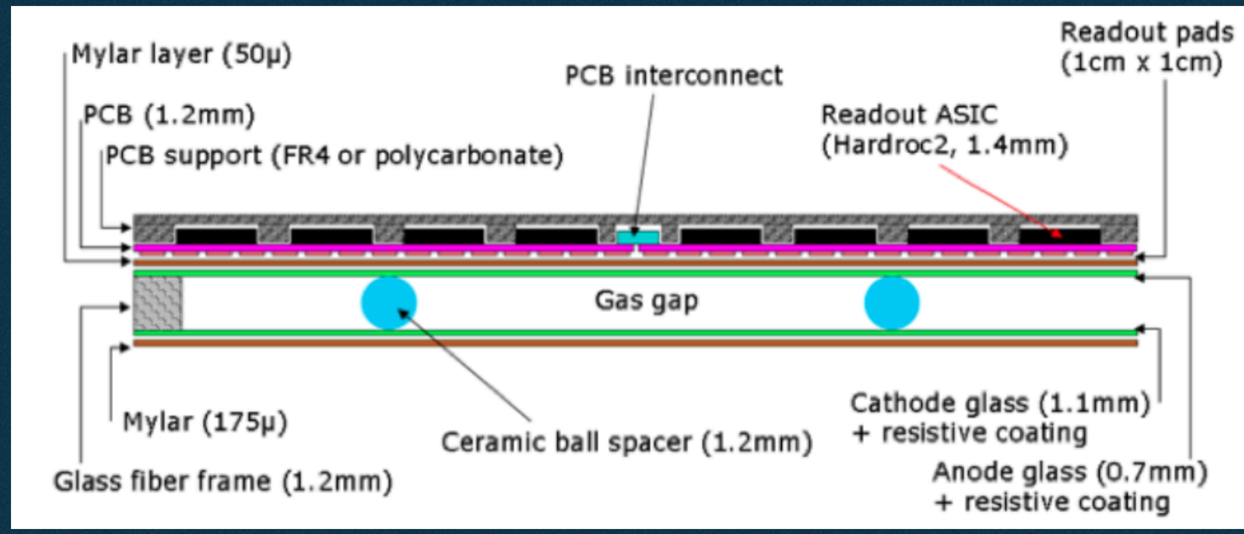


SDHCAL
Glass RPC

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

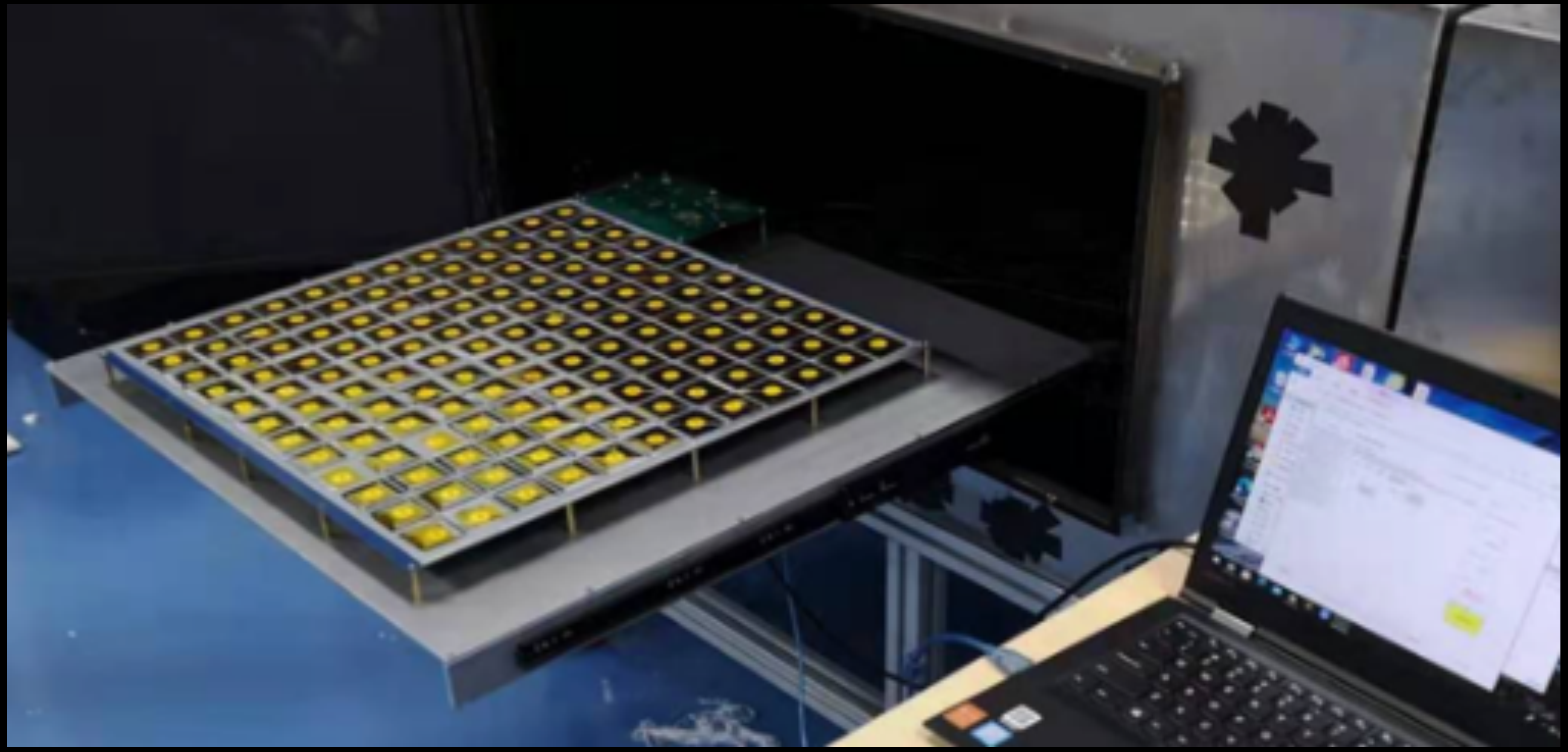


AHCAL: Scintillator and SiPM HCAL Prototype

16k scintillators have been produced
~15k wrapped and tested
> 14k pass requirements

NDL and HPK SiPM being tested/used

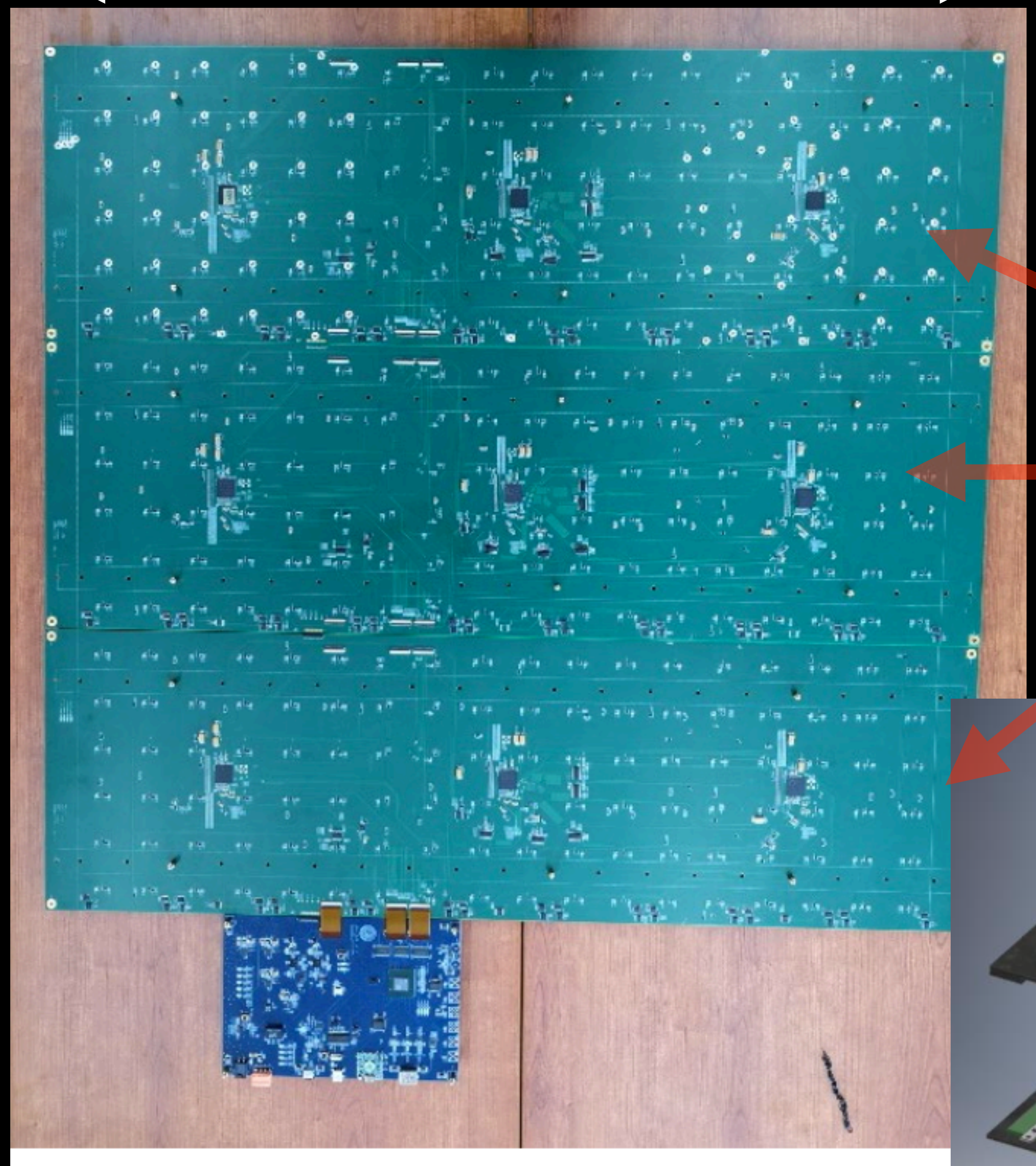
Uniformity within ±15%



Collaboration: USTC, SJTU, IHEP

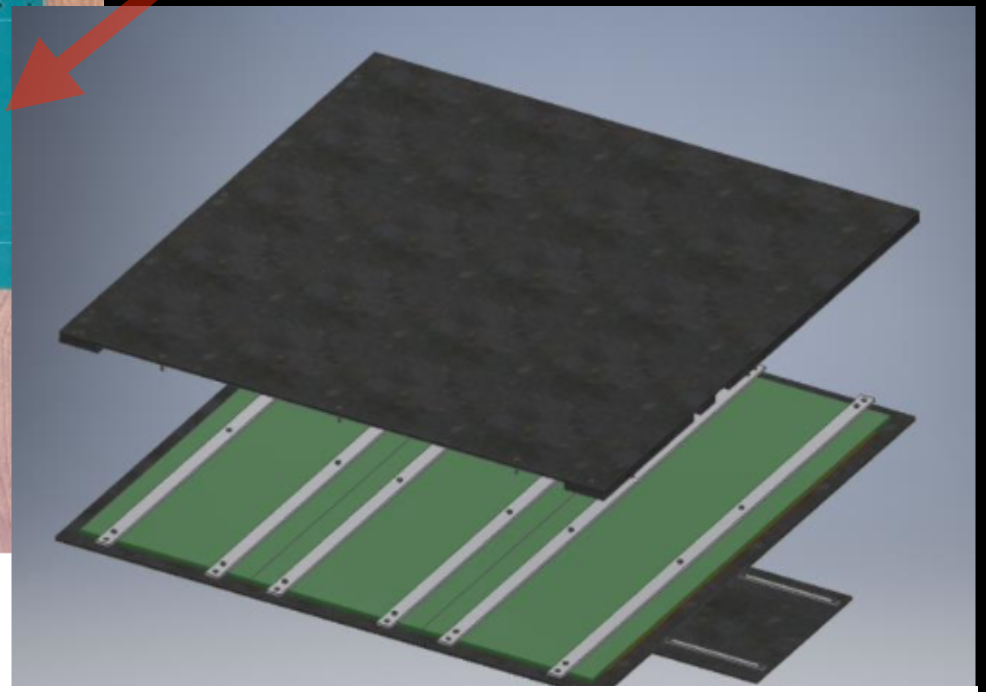
72 cm

72 cm

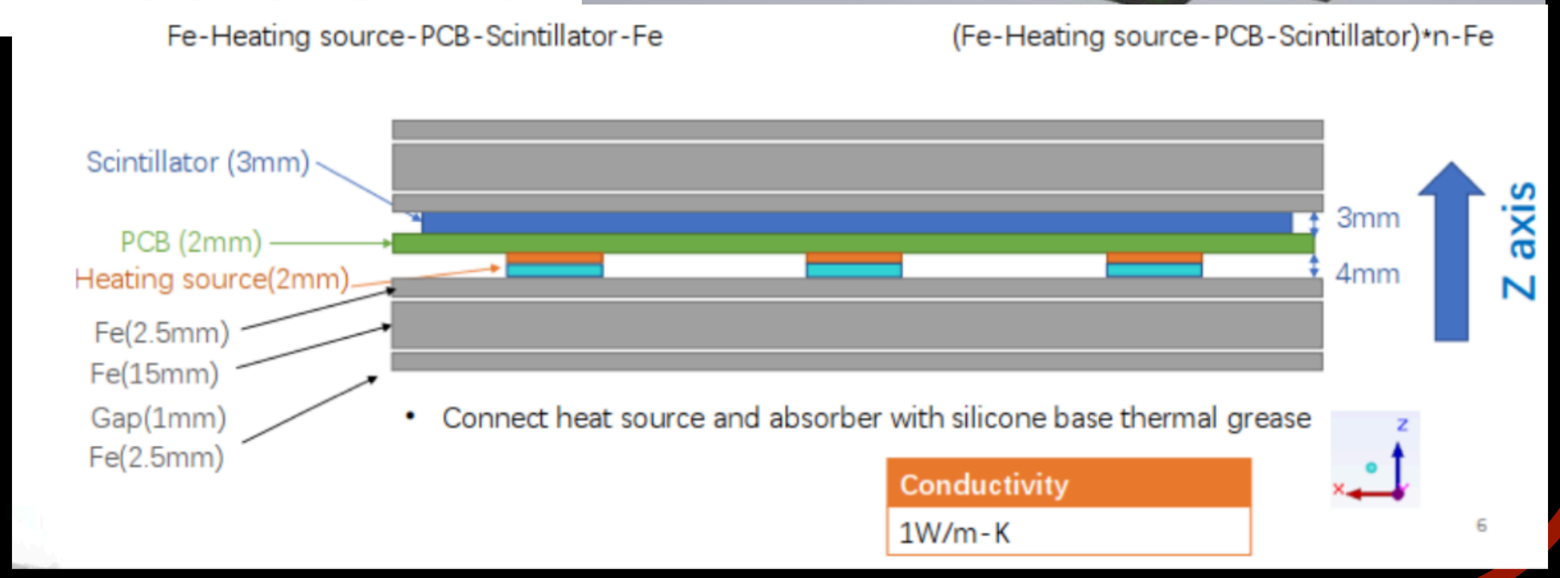


HBU:HCAL Basic Unit

3 readout boards



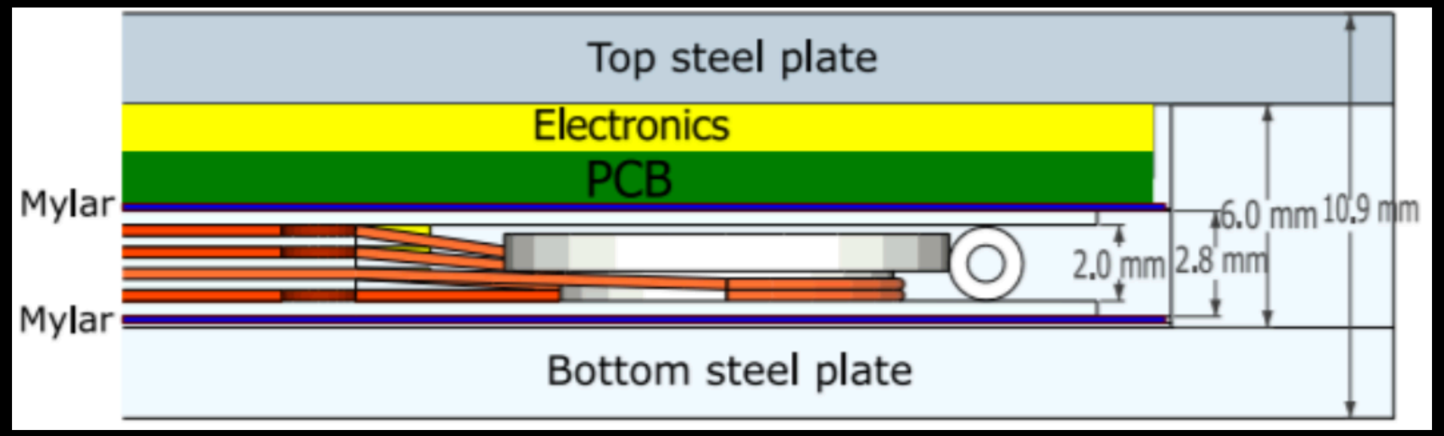
Cooling simulation



SDHCAL: Glass RPC

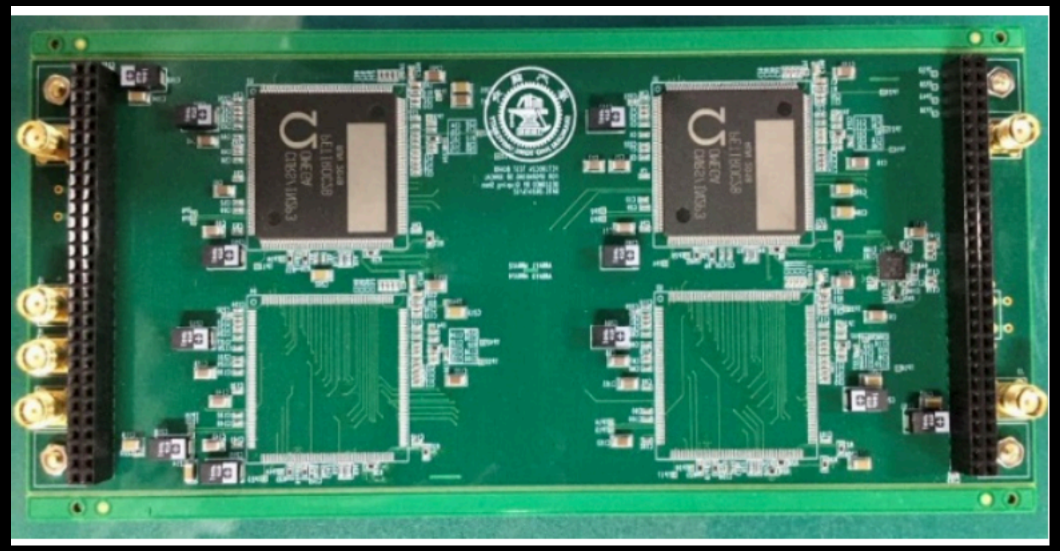
SJTU group has built:
50cm x 35cm, 100cm x 100cm RPCs

Multigap Resistive Plate Chambers (MRPC)



Fast timing readout electronics for MRPC designed and manufactured

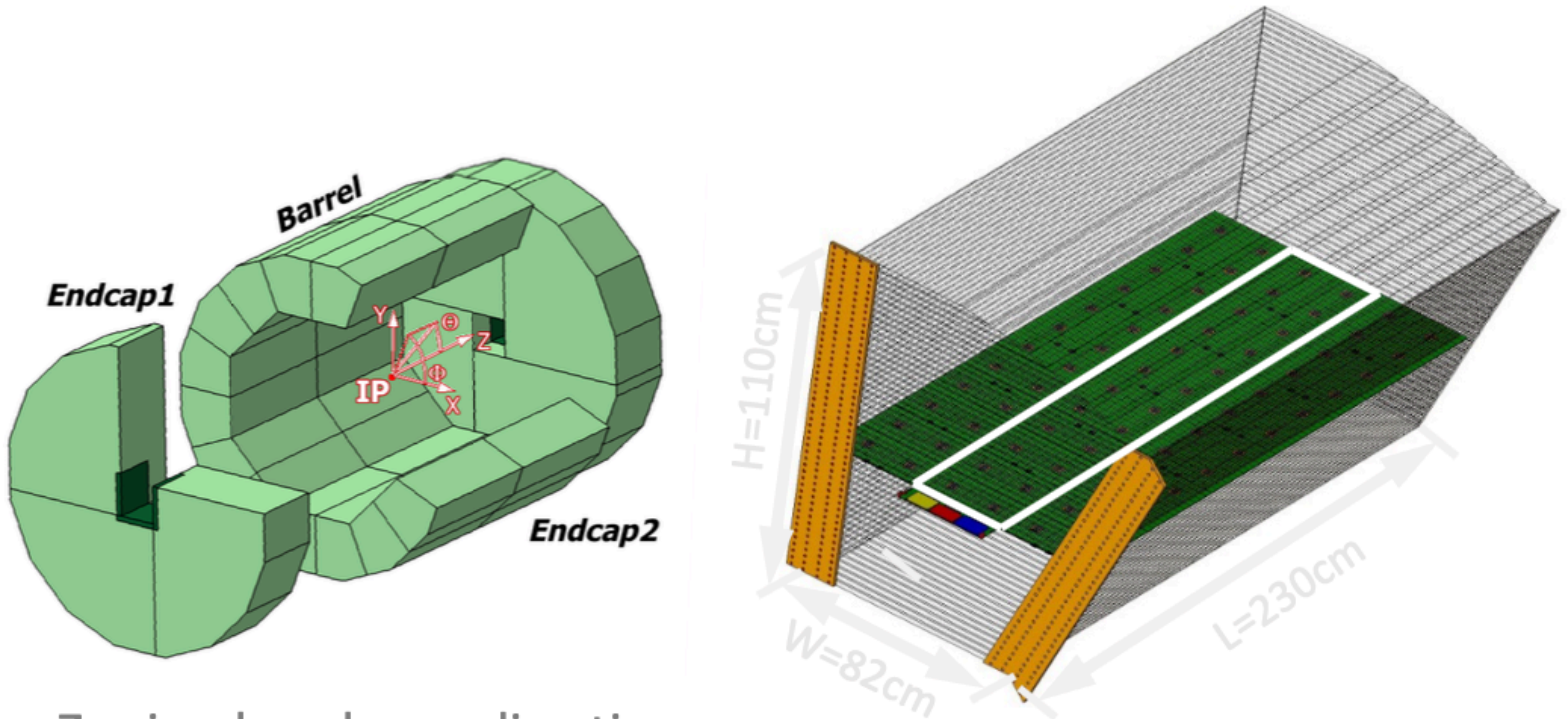
Using PETIROC chip from OMEGA group



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

HCAL Mechanical layouts

HCAL Layout 1

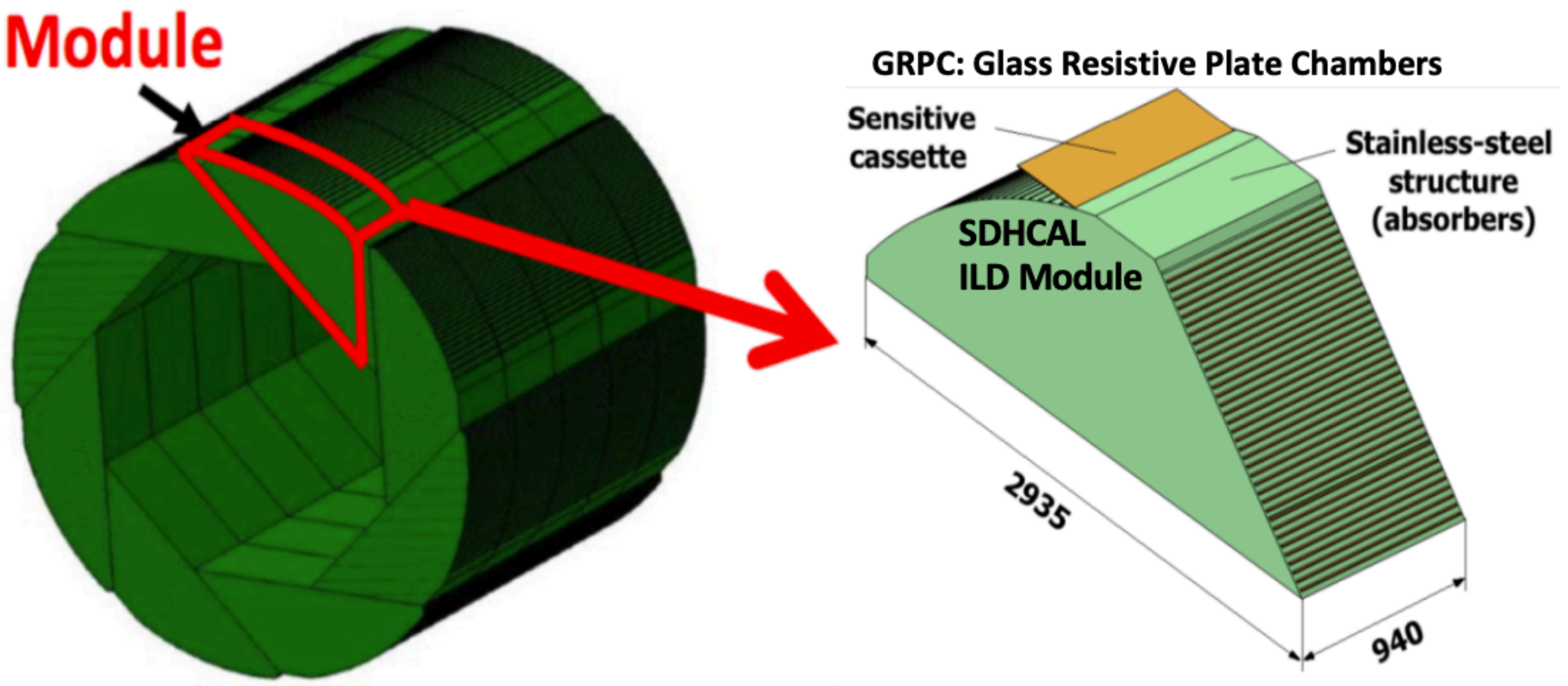


Z-axis: along beam direction

Symmetric Layout

+ Similar module sizes: friendly for QA/QC
? Projectile cracks from IP (z, φ): possible impacts to performance
Simulation studies show negligible effects (results in backup slides)
– Difficulty for installation and maintenance from each side (along z)
  – Extra challenge for longer barrel HCAL designs (8-9m long); **ILD 4.7m**

HCAL Layout 2



Asymmetric/spiral Layout

+ Avoid projectile cracks from IP along (z, φ)
+ Handy for installation and maintenance (along outer radius)
– Very different module sizes: challenges for QA/QC

Technical challenges for both layouts:
(1) production/assembly of long modules: 2~4m in Layout 1; ~3m in Layout 2
(2) active cooling system and its integration with mechanics

→ Ongoing R&D efforts to address the challenges (next pages)
(1) ~2m long AHCAL slabs (DESY); ~1x2m RPC+PCB (Lyon)
(2) Simulation studies of an active cooling system (SJTU)

New Ideas: Crystal Calorimeters

Concern: Electromagnetic resolution of CDR PFA calorimeter not optimal

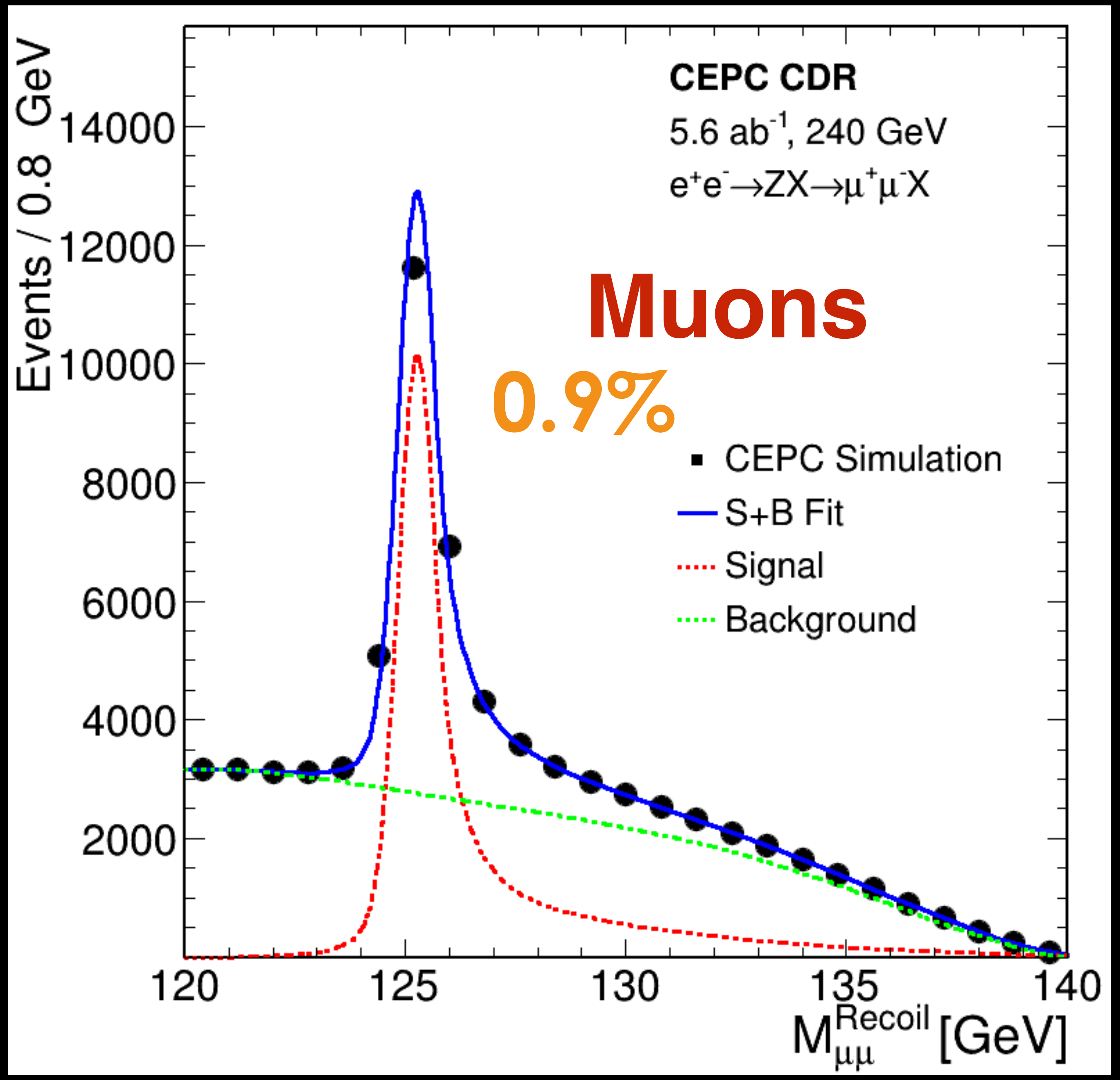
Physics motivations:

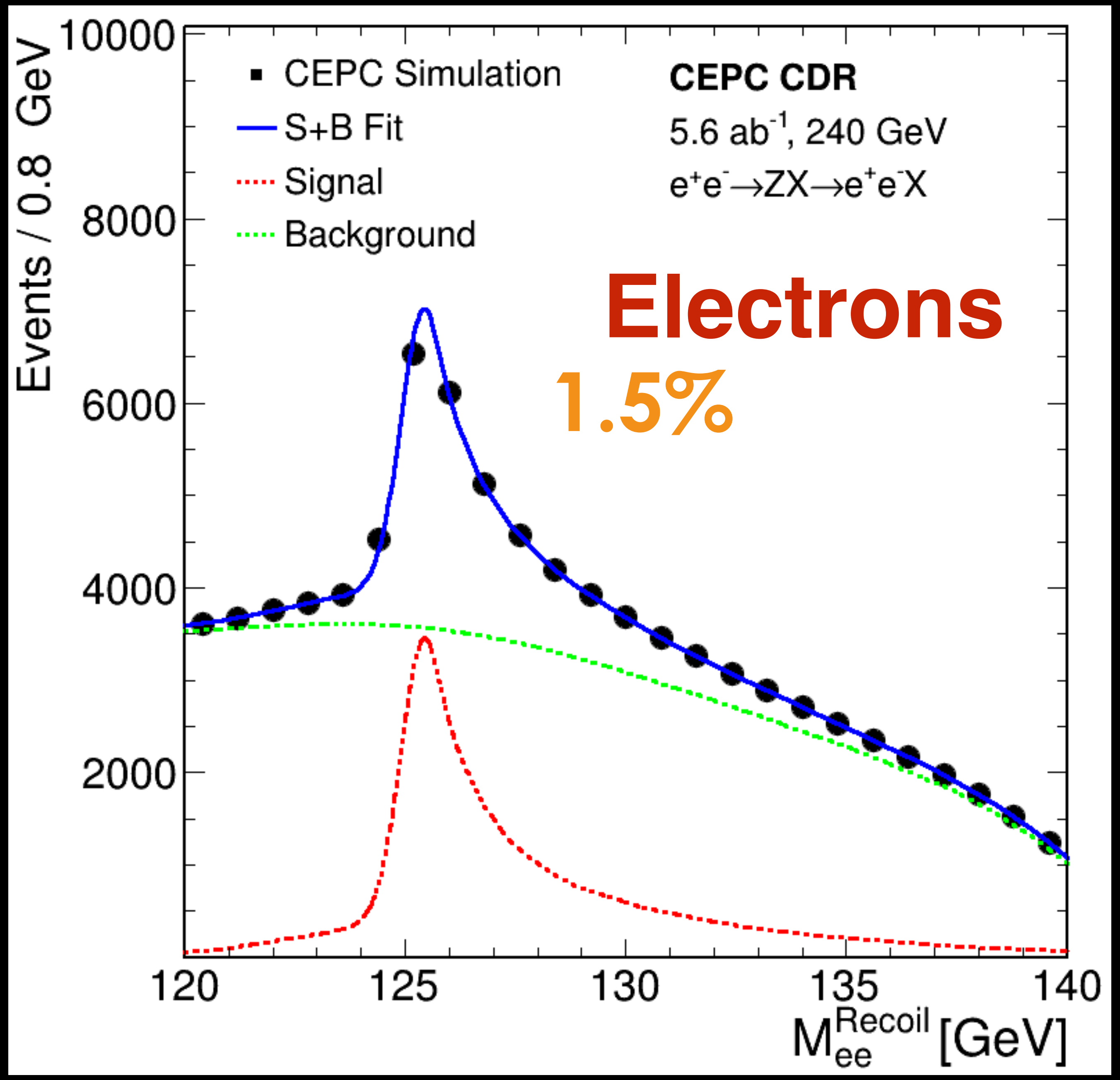
- Electrons' Bremsstrahlung: energy recovery
- Improve angular resolution, and gamma counting
- Recoil photons: new physics and neutrino counting

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

Z boson recoil mass

~70% worse resolution in electron channel compared to muons

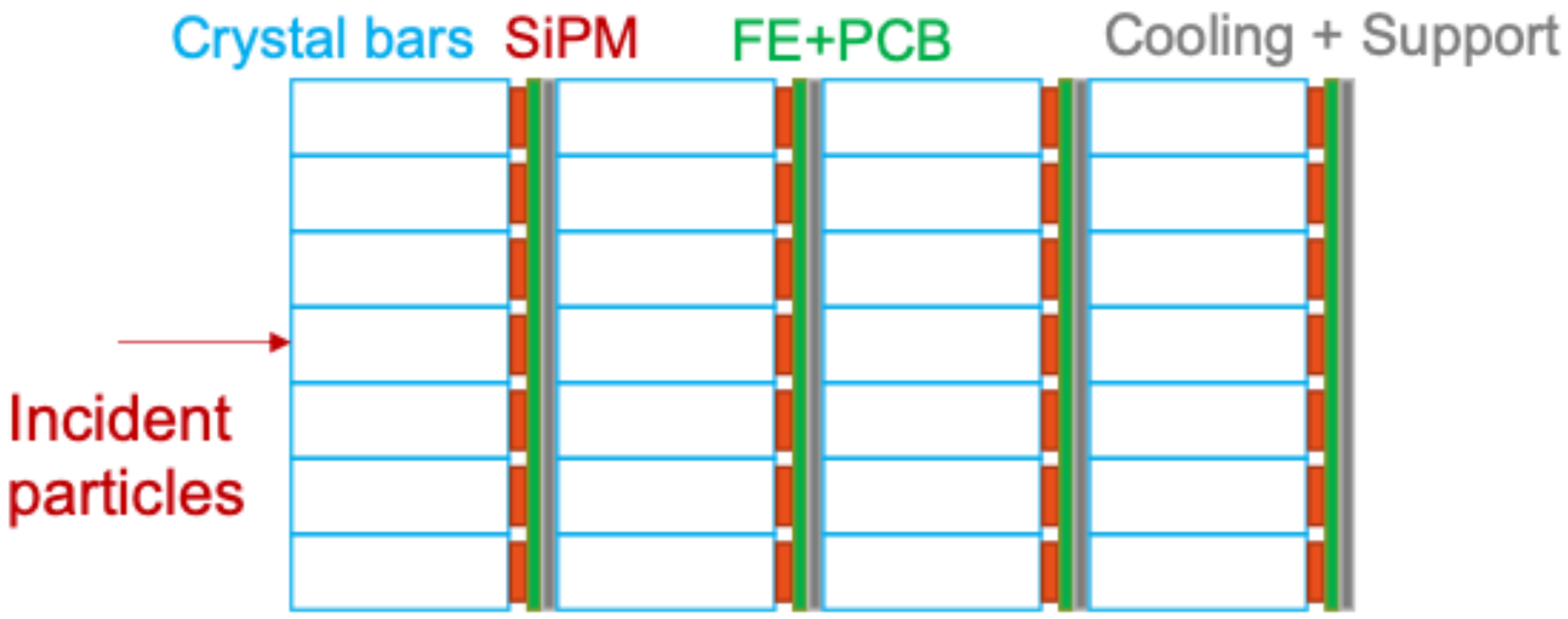




Crystal Calorimeters

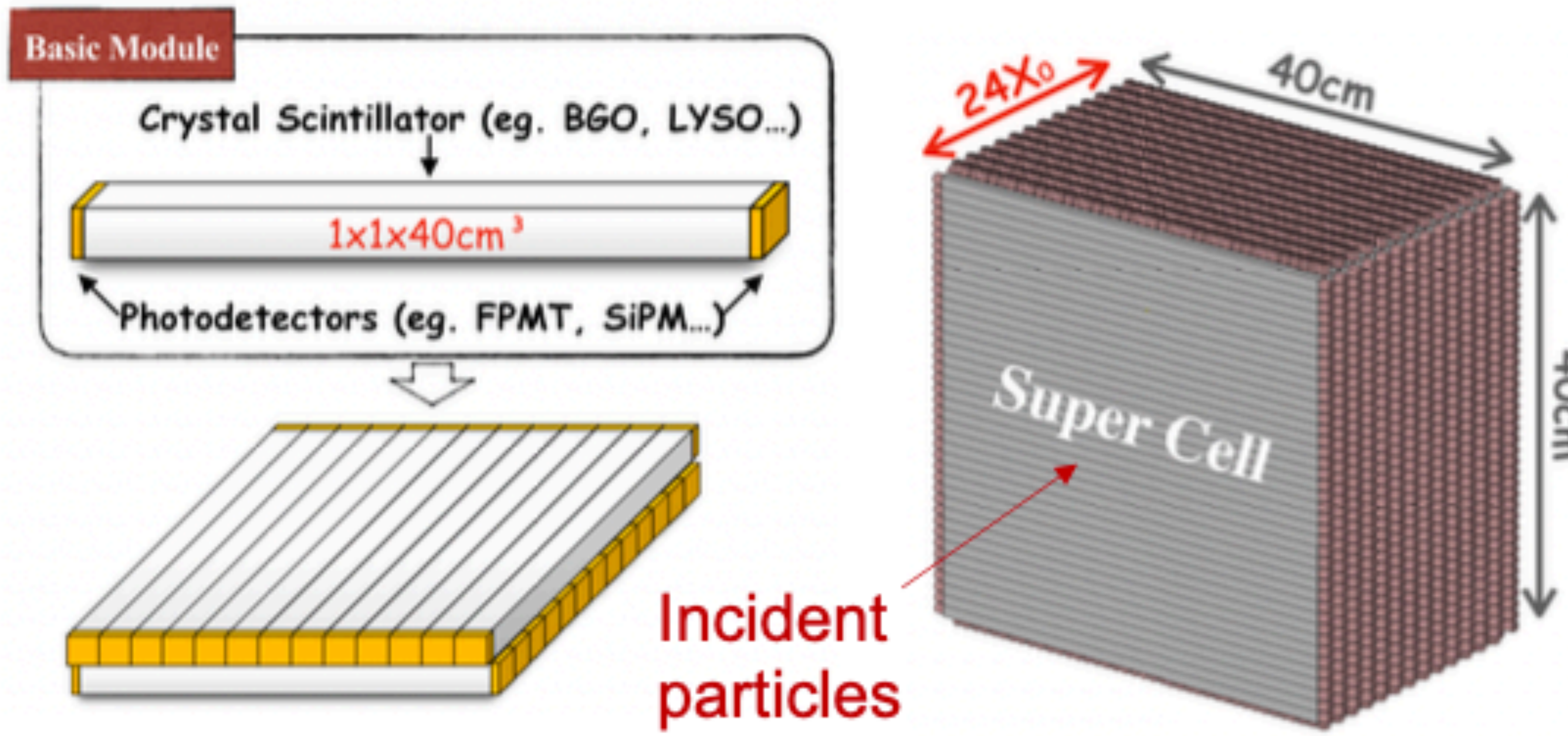
Two segmented ECAL designs based on crystals

Design 1: Short bars



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

Design 2: Long bars



- 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

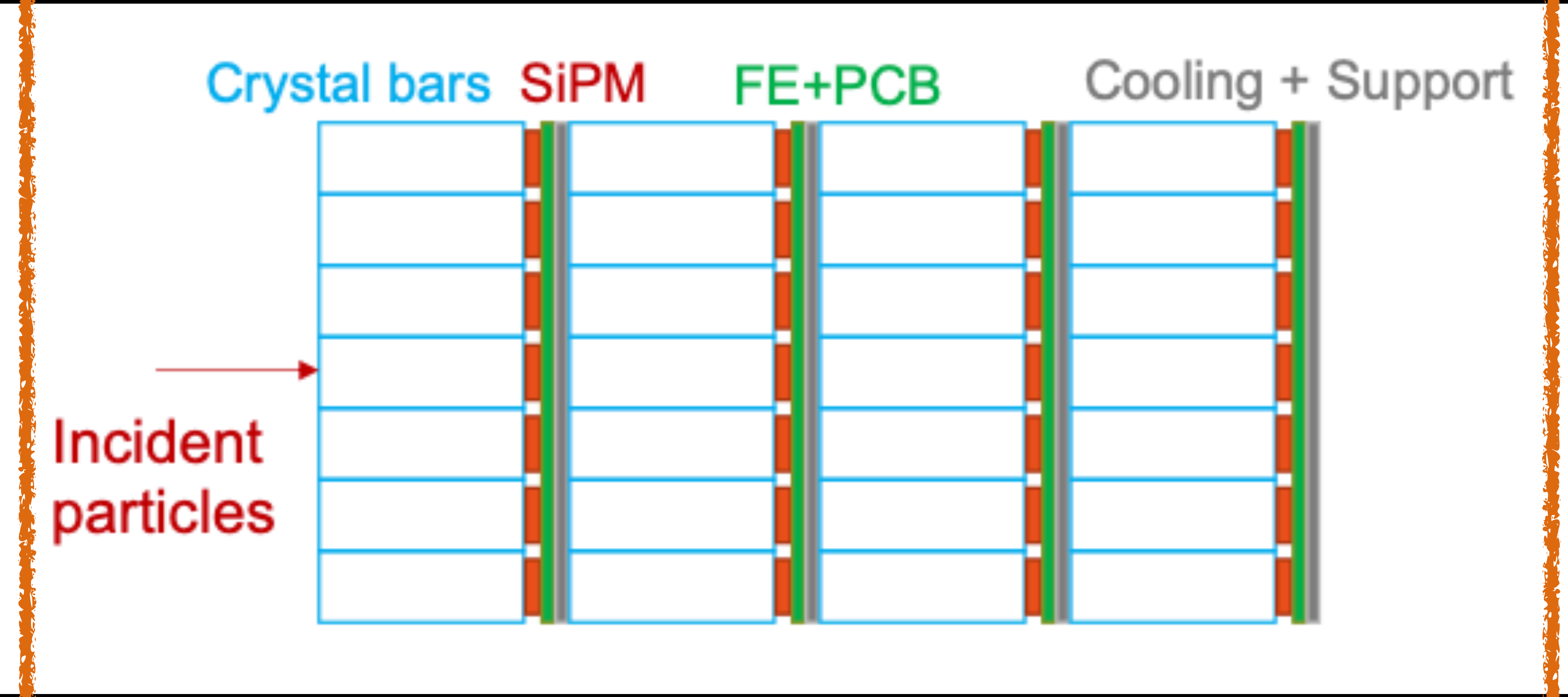
Crystals: LYSO:Ce, PbWO, BGO?

SiPM: HPK, NLD?

Crystal Calorimeters

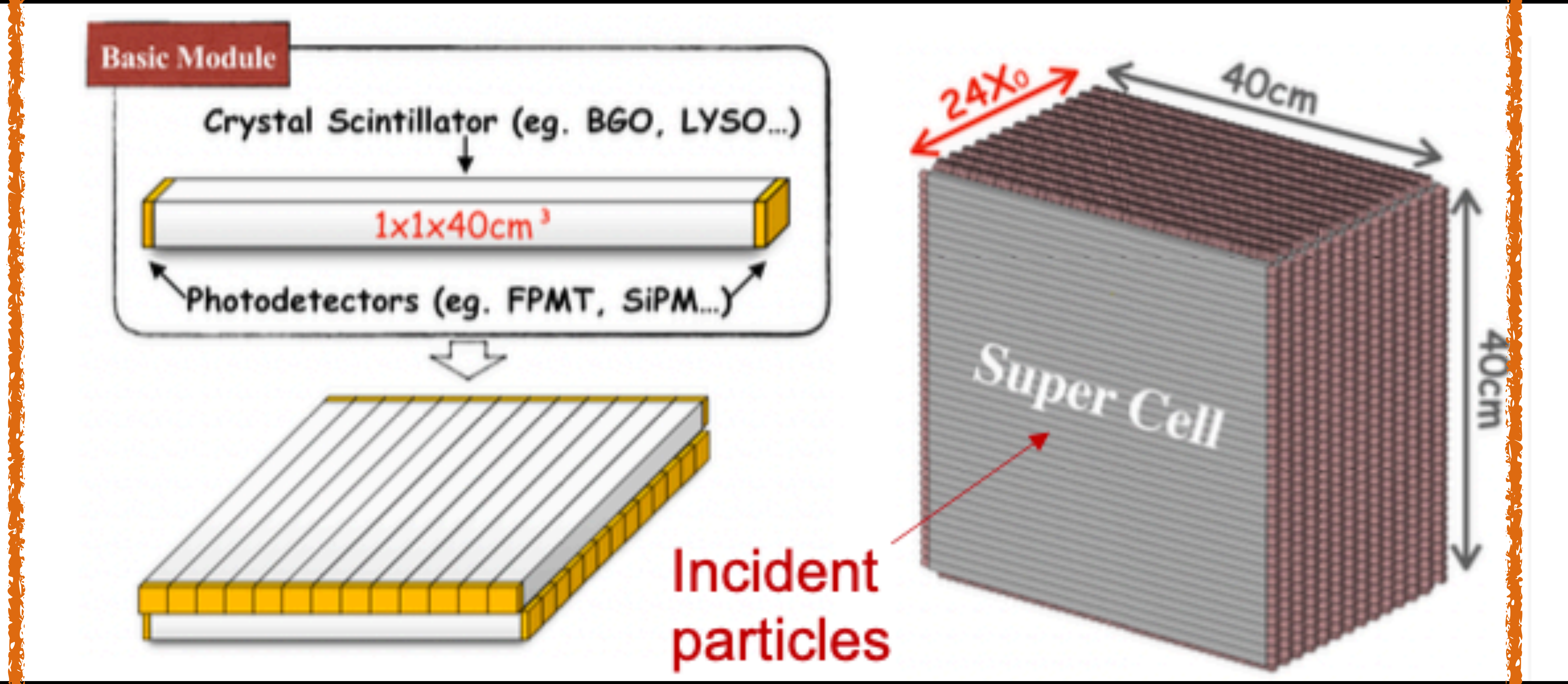
Two segmented ECAL designs based on crystals

Design 1: Short bars



Focus on PFA performance studies:
- Crystal cubes (ideal granularity) for physics benchmarks
- Studied within existing CEPCv4 PFA (ArborPFA)

Design 2: Long bars



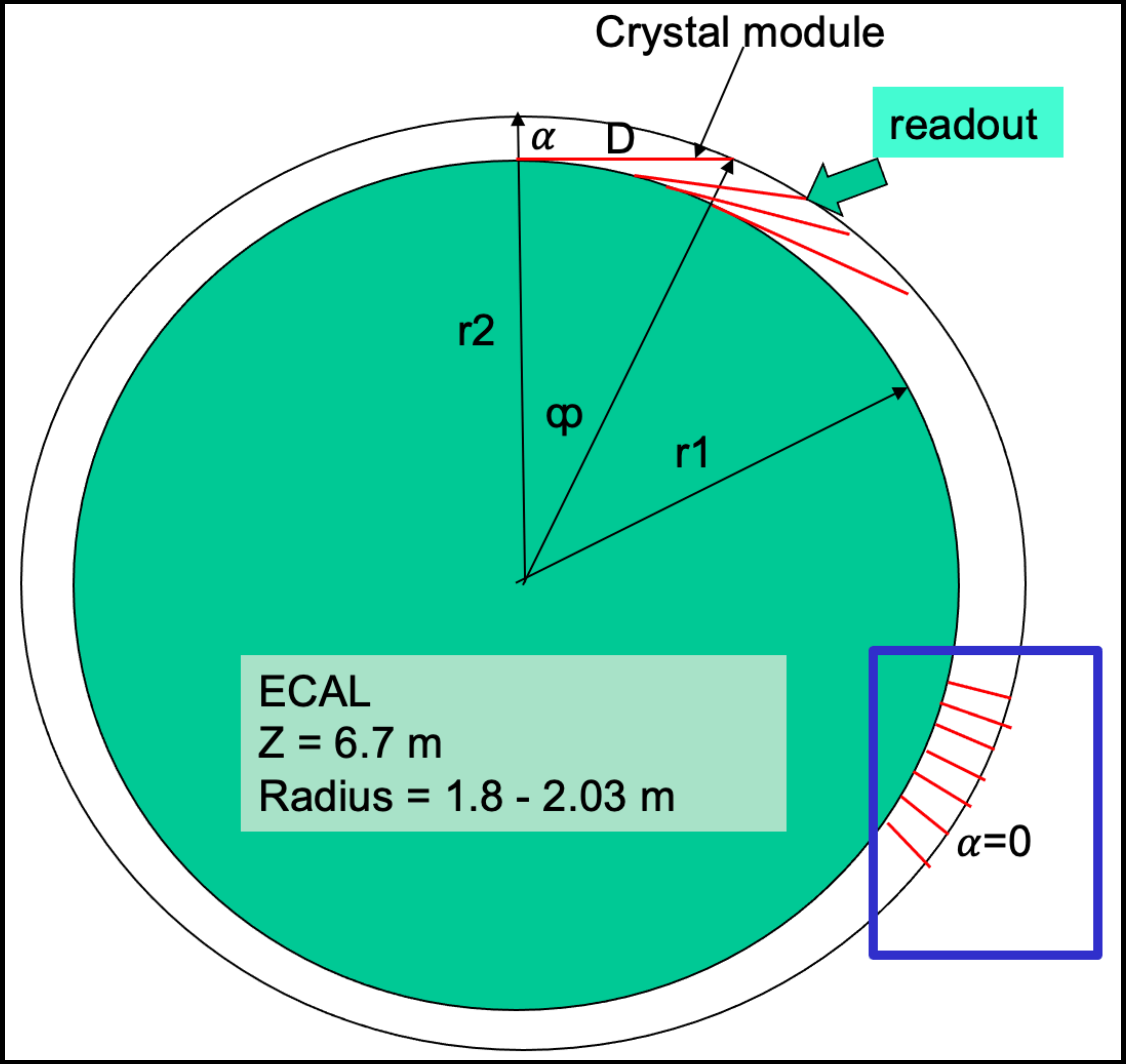
Focus on new reconstruction algorithm development

Key issue:
- Separation capability of multiple incident particles (resolving "ghost hits")
- Impacts PFA performance

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

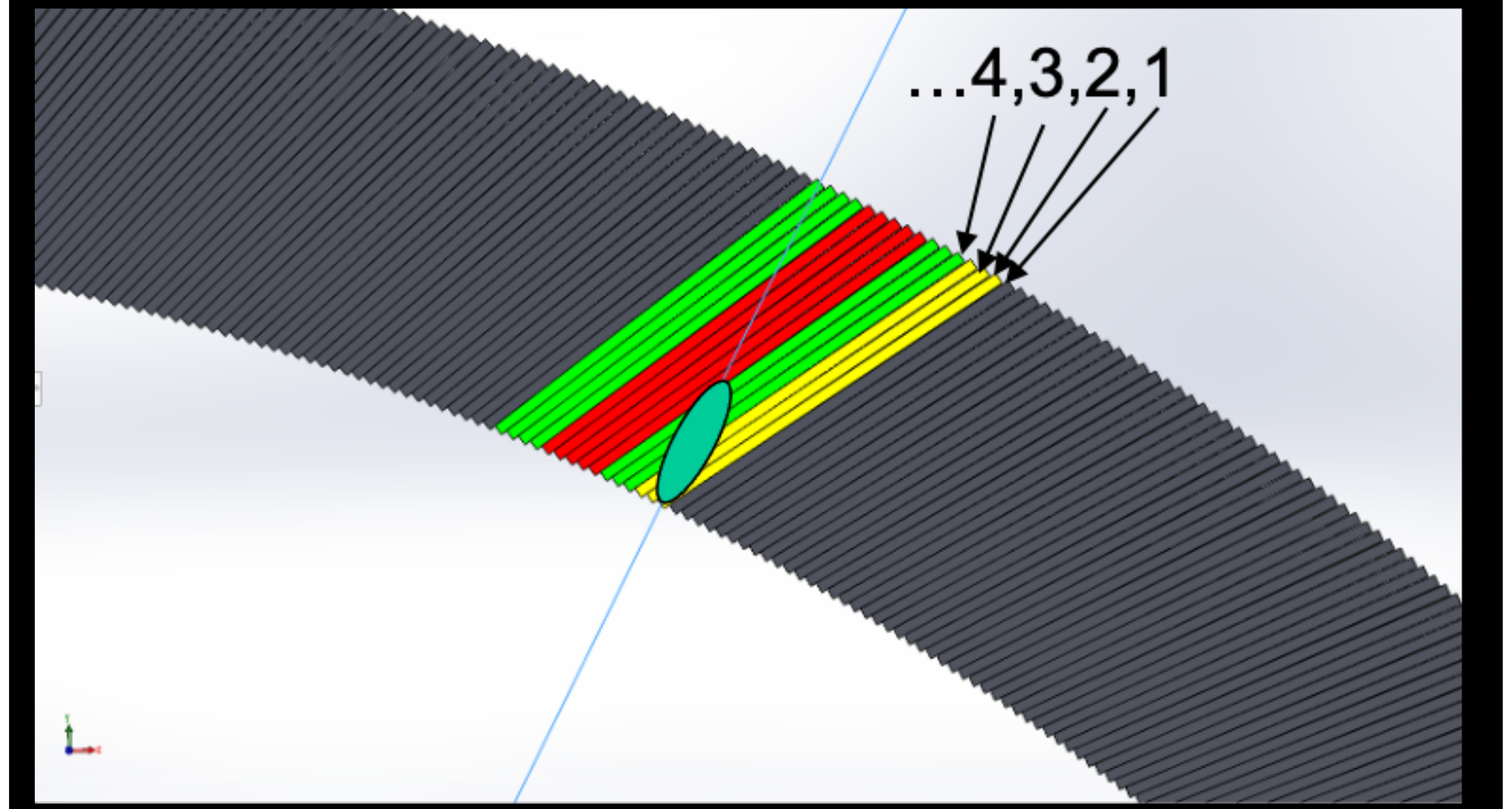
Being incorporated into CEPC Software

New Crystal Layout Possibility



- Take α = 0 degrees
  - D = 0.230 m

- Take α = 30 degrees
  - D = 0.260 m
  - φ = 0.064 (3.7degree)
  - Each z segmentation: 1368 crystals



φ →, Z ↓

-	-	1	2	3	4	5	6	-	-
0	0	0	0	1	0	0	0	0	0
0	0	0	0	3	1	0	0	0	0
0	0	1	5	9	7	4	1	0	0
0	0	0	2	5	3	1	0	0	0
0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

- + Provides depth information
- + Readout outside of ECAL calorimeter

Dual Readout Calorimetry - International Collaboration

Korea

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Sanghoon Lim (PNU)
Prof. Hwidong Yoo (YU)

KiSTi www.kisti.re.kr

Taiwan

Prof. Rong-Shyang Lu
Prof. Chia Ming Kuo

Japan

Prof. Yuji Enari (Active from 2021)

USA

Prof. Sarah Eno
Prof. Chris Tully
Prof. Richard Wigmans
Prof. John Hauptman

Europe

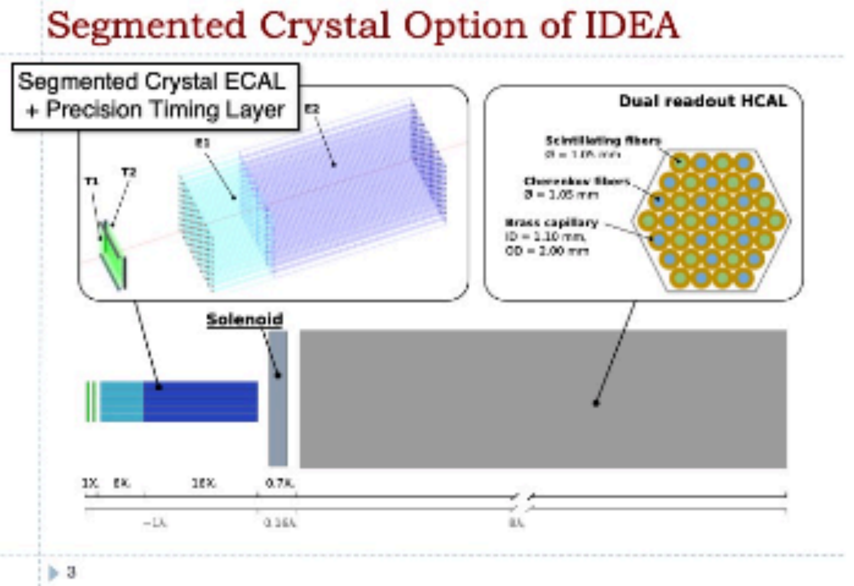
INFN
Prof. Paolo Giacomelli (Bologna)
Prof. Romualdo Santoro (Insubria)
Prof. Roberto Ferrari (Pavia)
Prof. Franco Bedeschi (Pisa)

University of Sussex
Prof. Iacopo Vivarelli

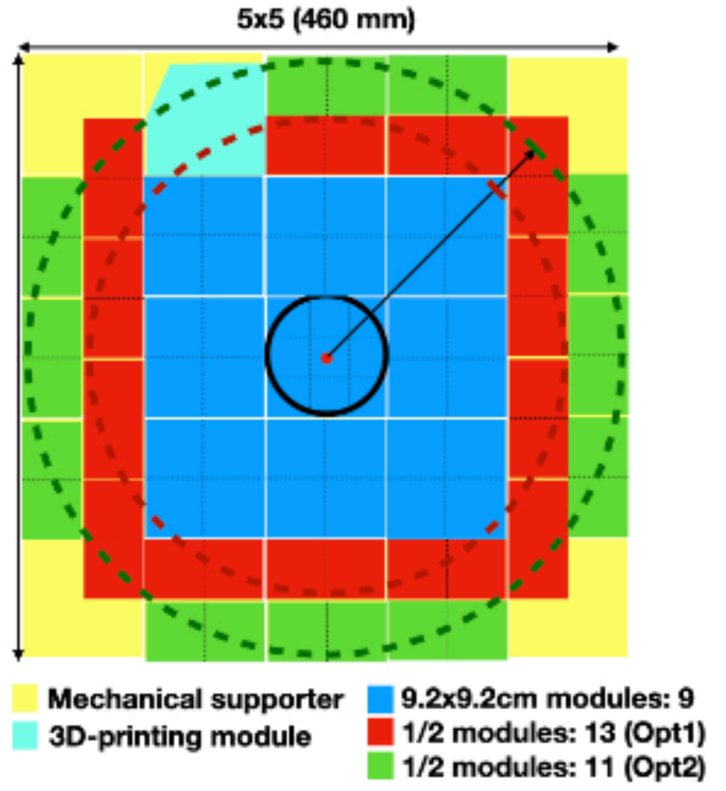
Prof. Valery Chmill

FCC — DREAM FOR FUTURE — CEPC

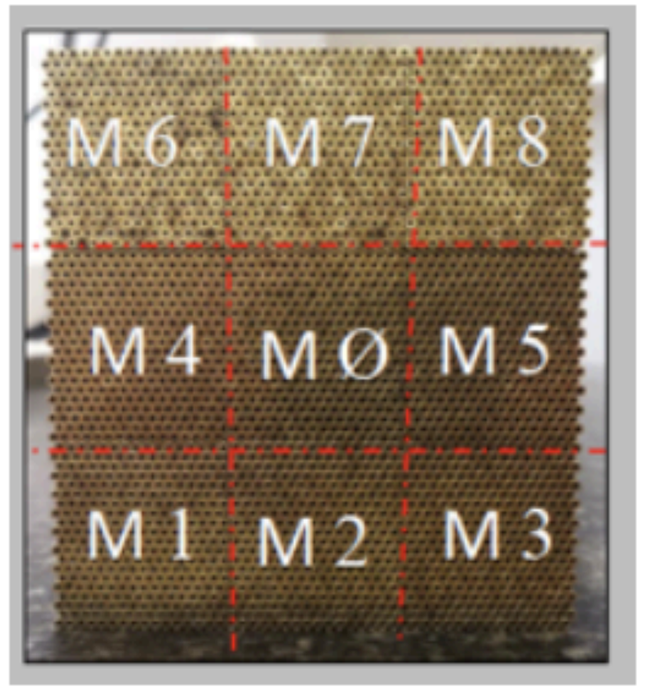
DRC with crystal



Full-size prototype detector



Bucatini prototype



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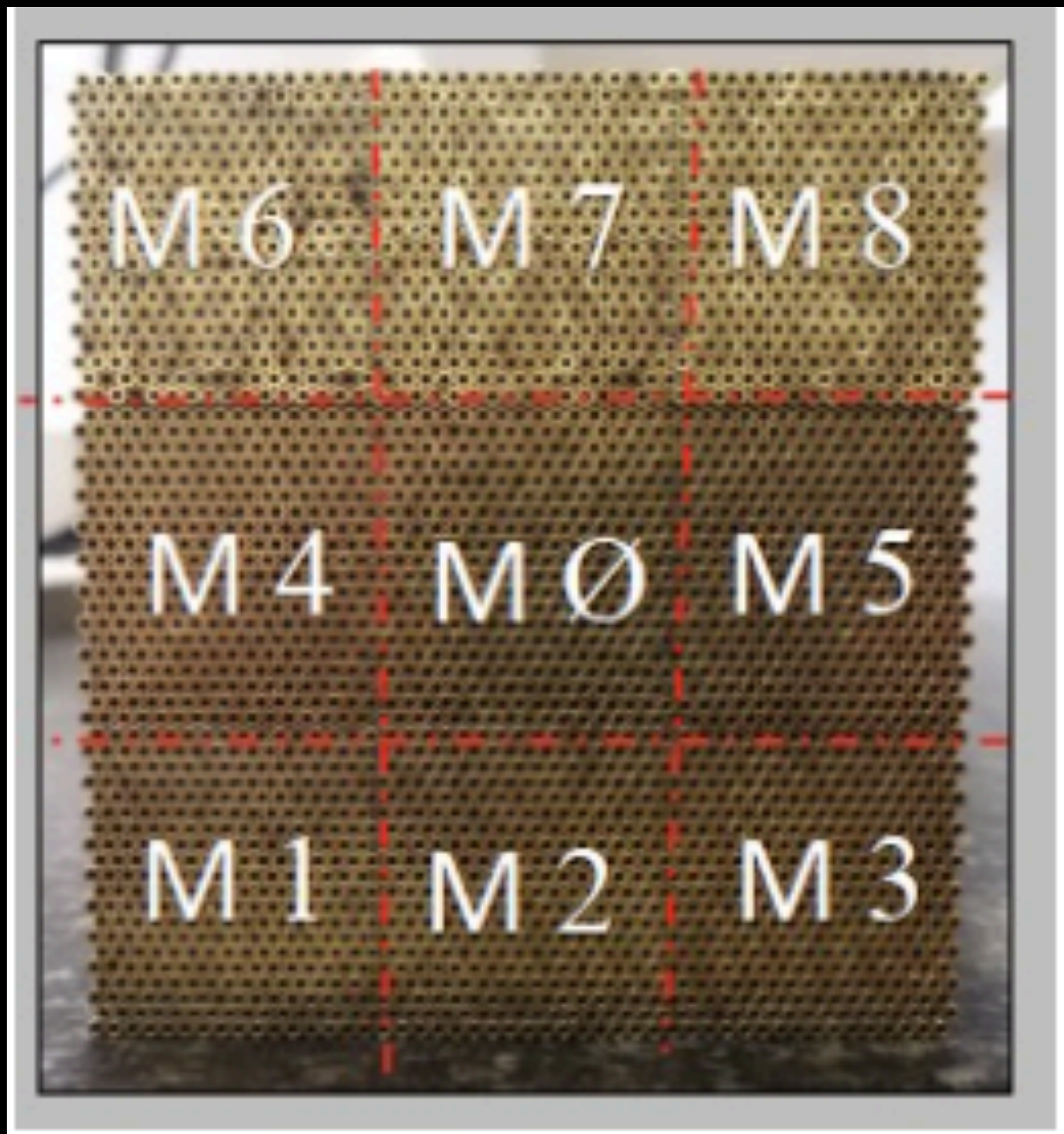
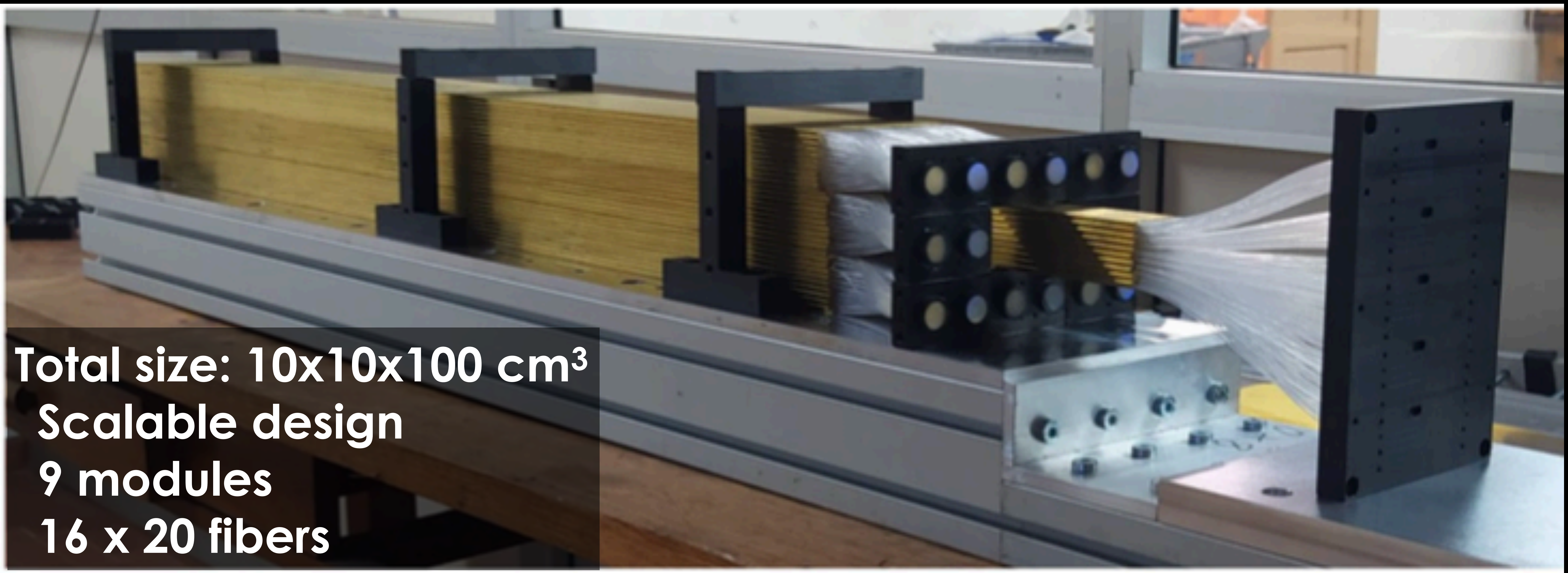
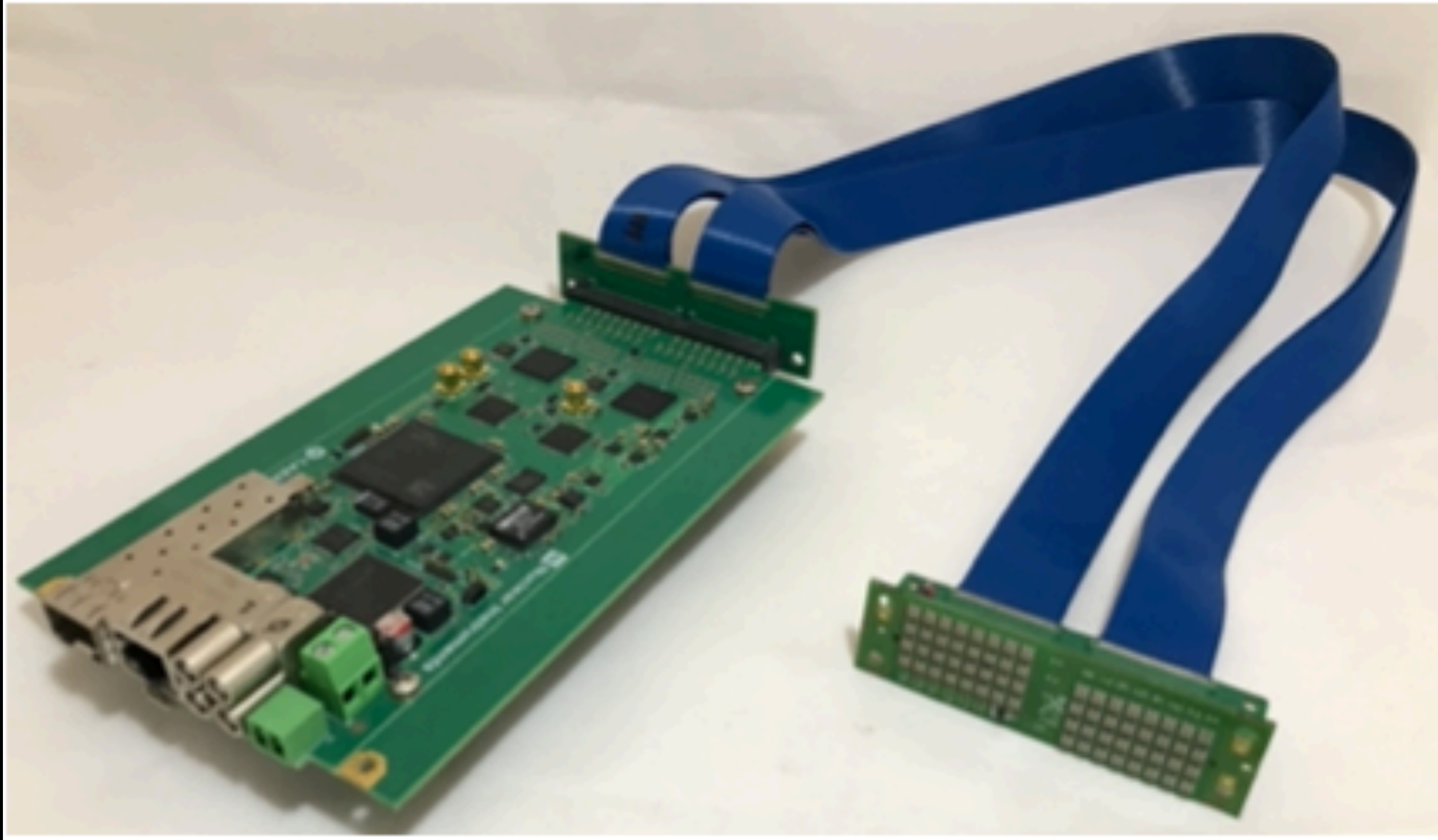
IDEA Dual Readout Calorimeter prototype - test beam

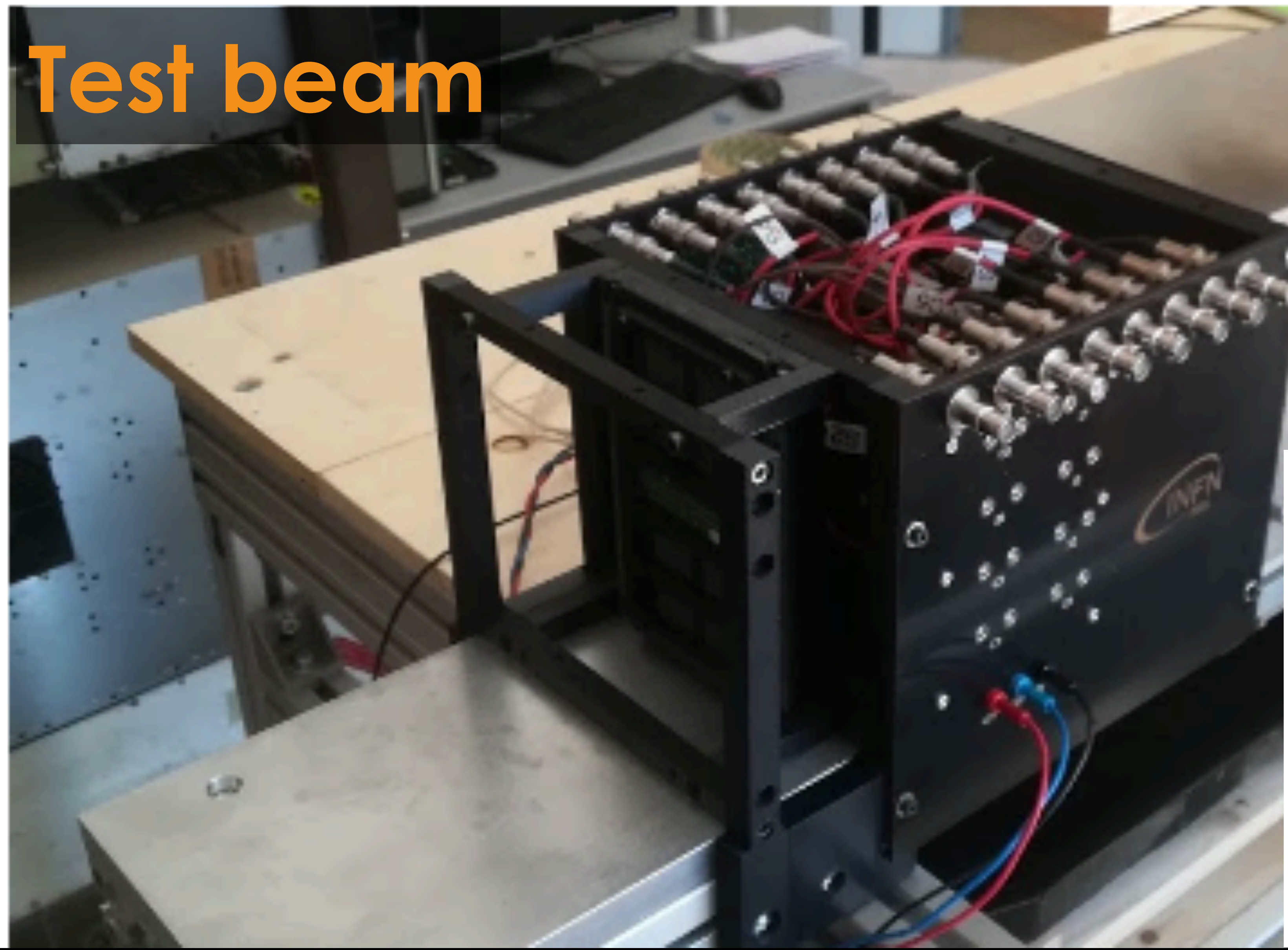




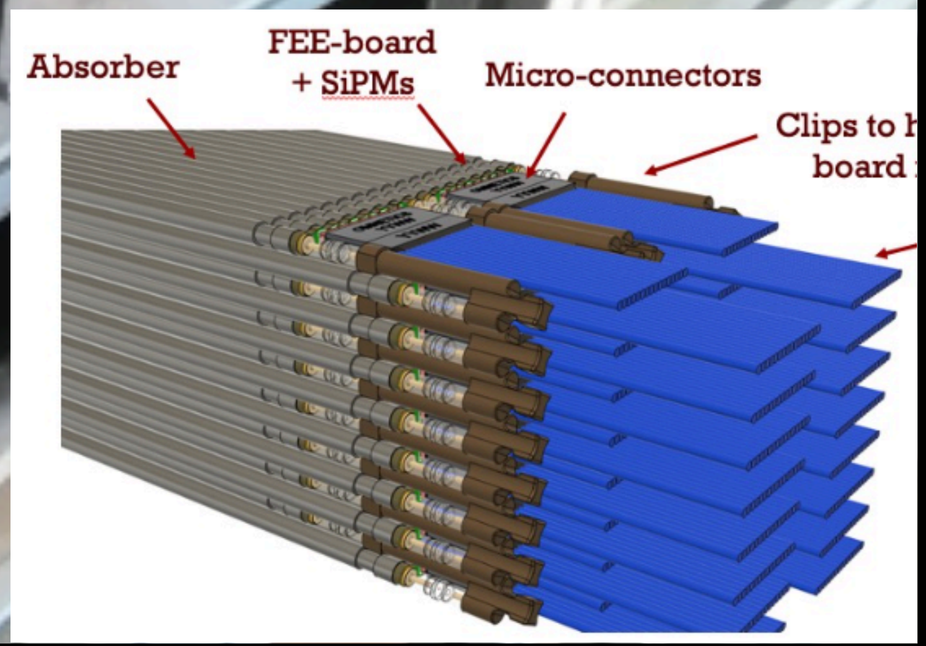
Total size: 10x10x100 cm^3
Scalable design
9 modules
16 x 20 fibers



Test beam



SiPM readout



Dual-Readout Calorimetry research in Korea

Primary goal: build a prototype detector for the detector design of CEPC experiment

- **5 year (2020.Mar. - 2025.Feb.) R&D funding** supported by Korea NRF ($~0.4M/year, total **$~2M** for 5 years) => 2nd year in this program
- Contain almost (97.5%) full hadronic shower energy
- Demonstrate engineering aspects for full geometry detector

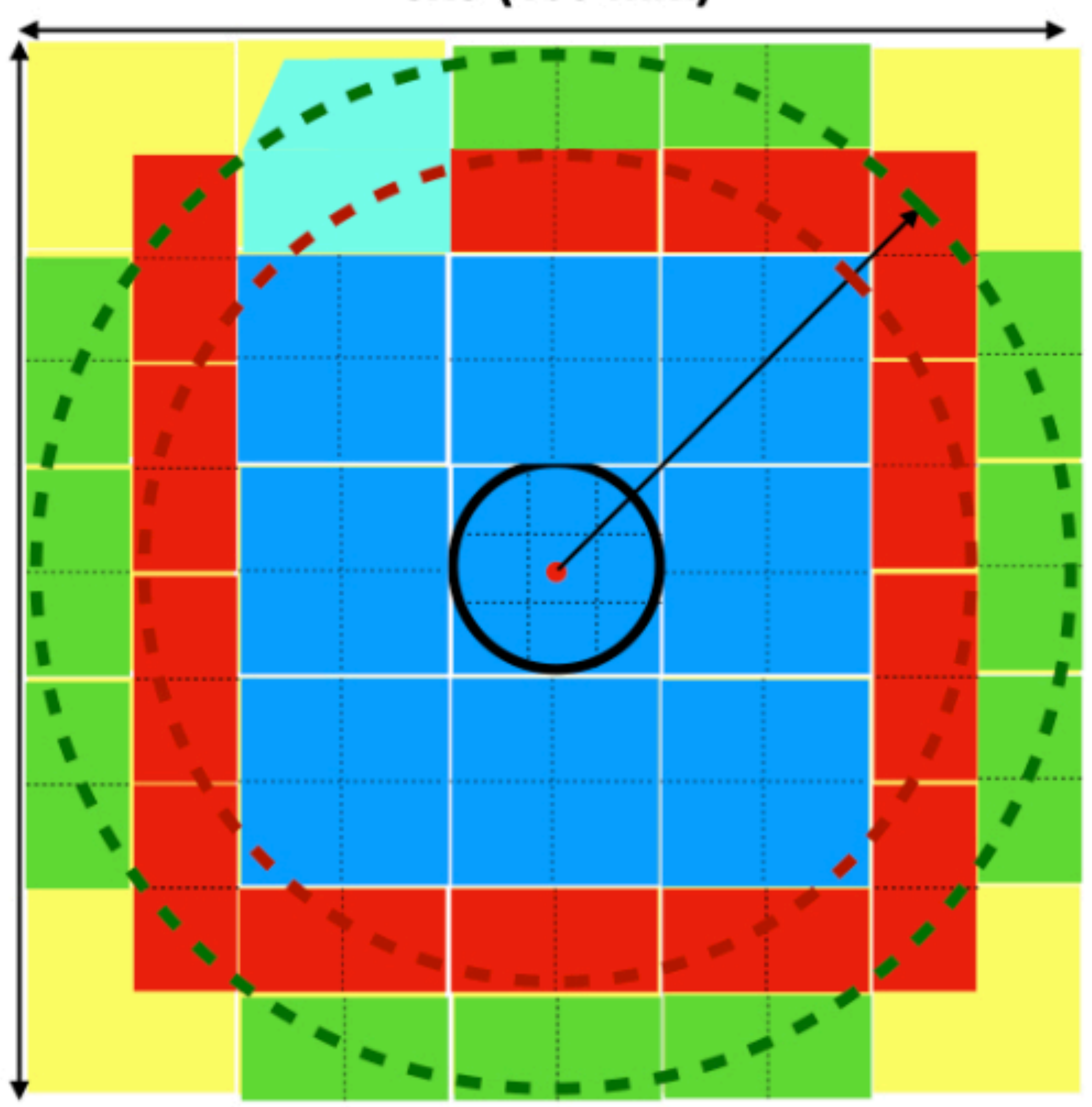
- Secondary goal: train next generations as experts of the (DRC) detector

WE ARE HERE

2017-9	2020-1	2022-5	TBD
Design	R&D	Prototype	Production

Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD

Prototype Detector (2025)



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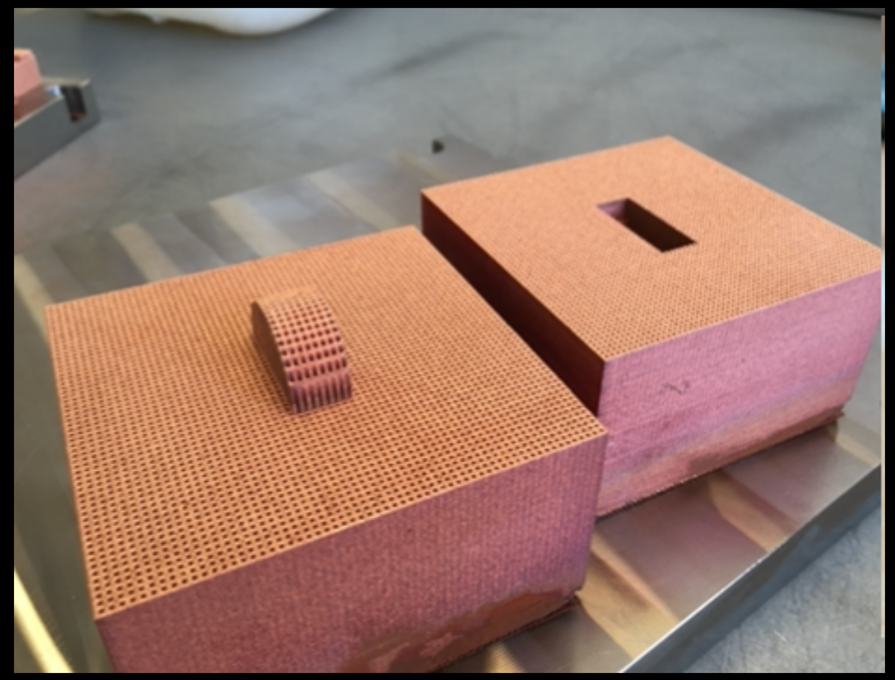
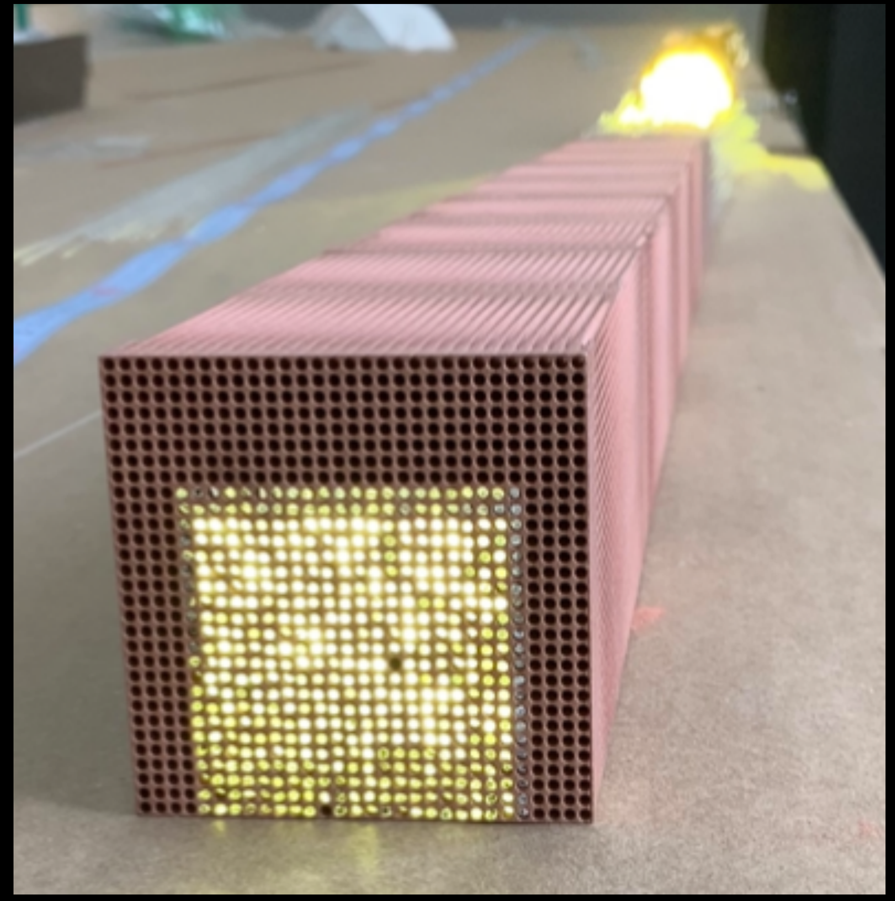
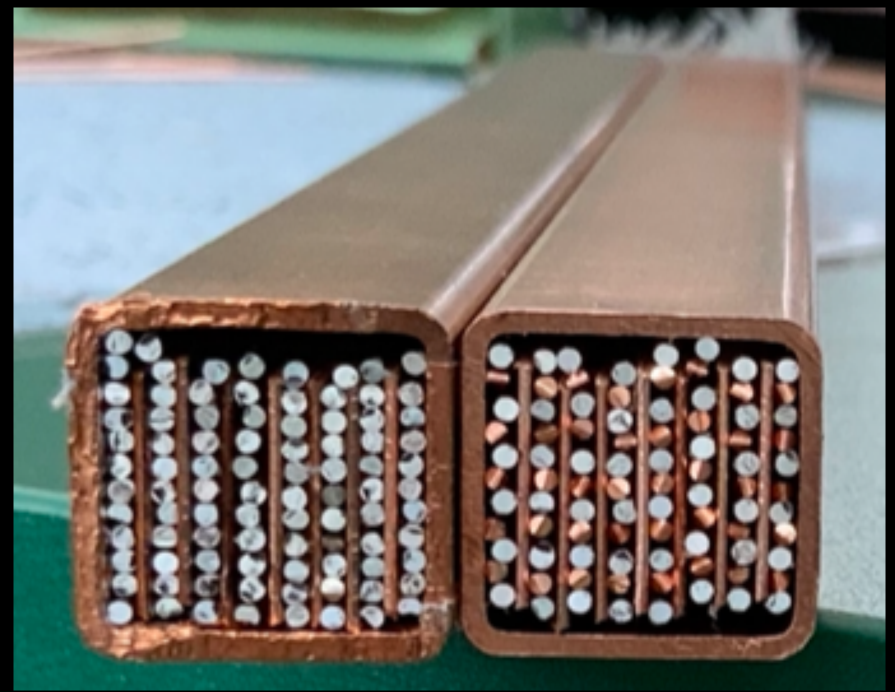


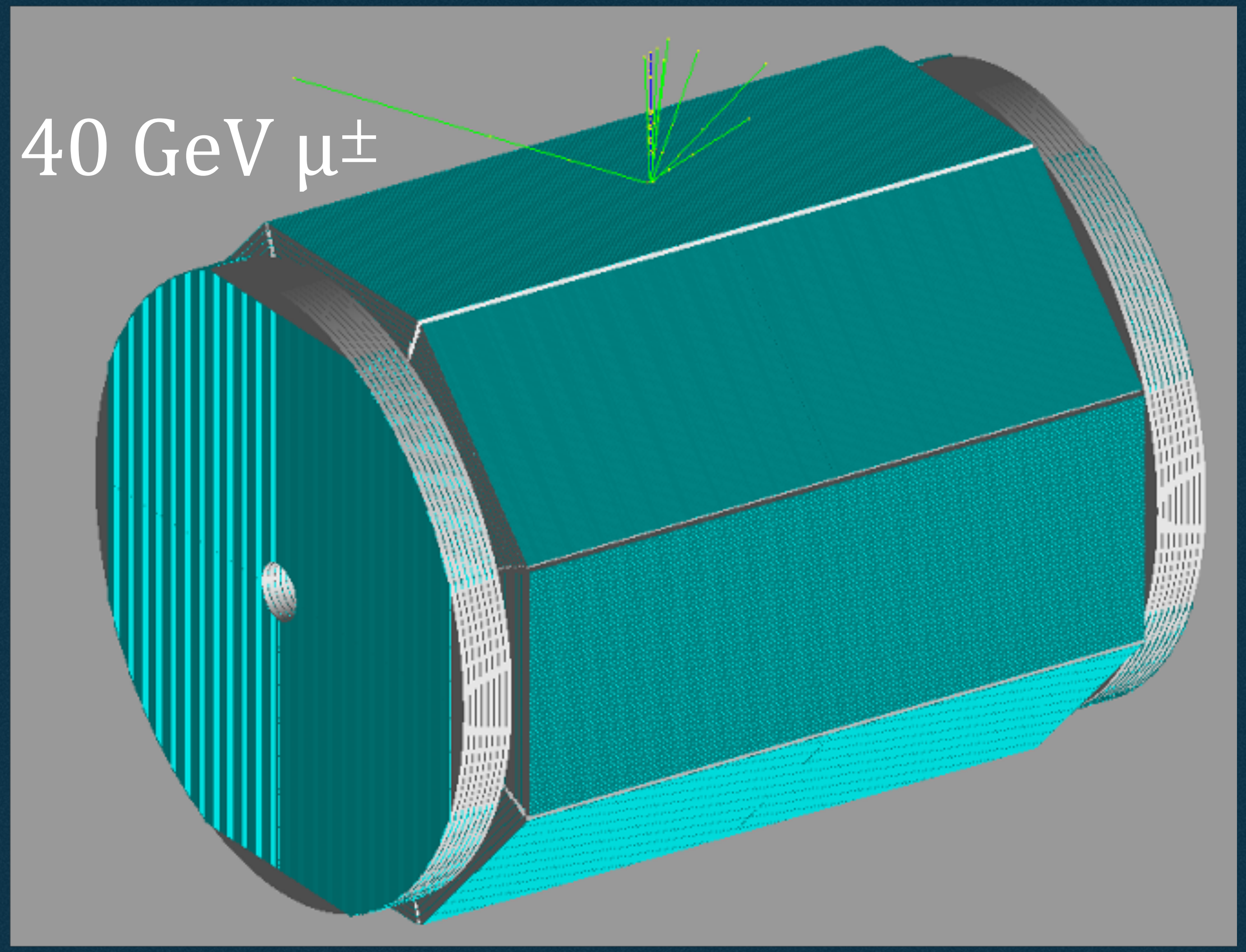


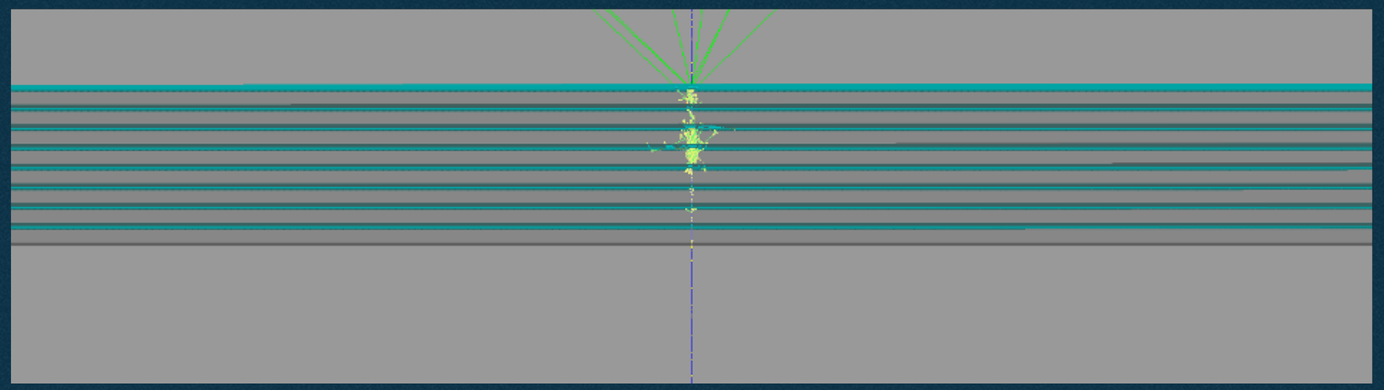


CEPC Muon Detector: Scintillator-based

How many layers of muon detector are necessary?

Implementation in G4 simulation started



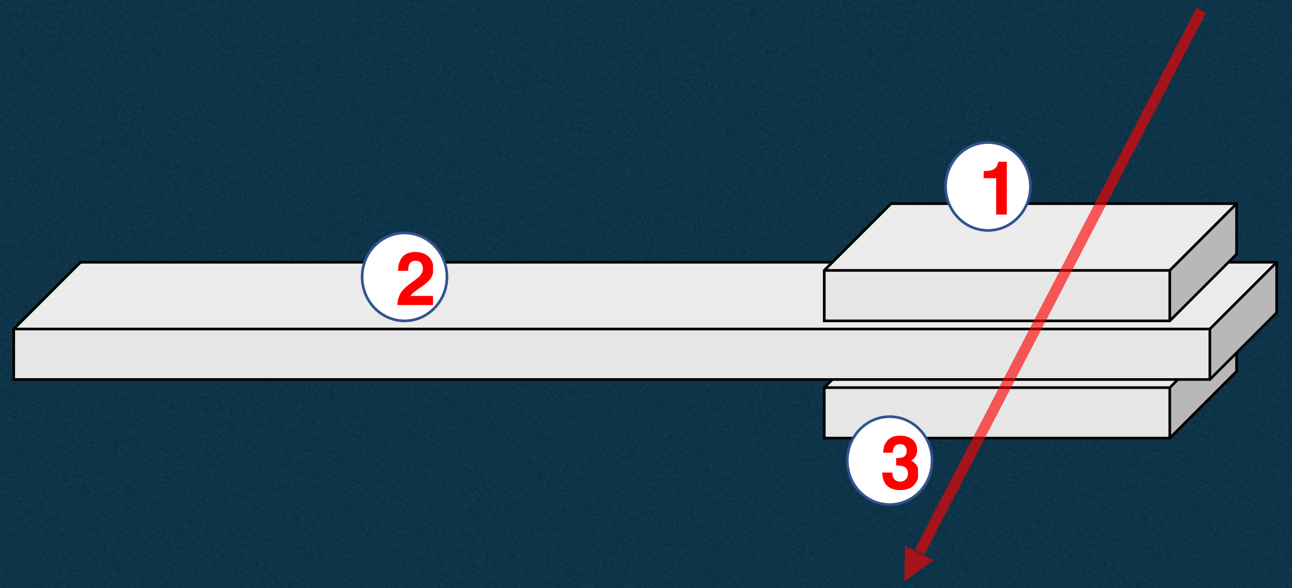


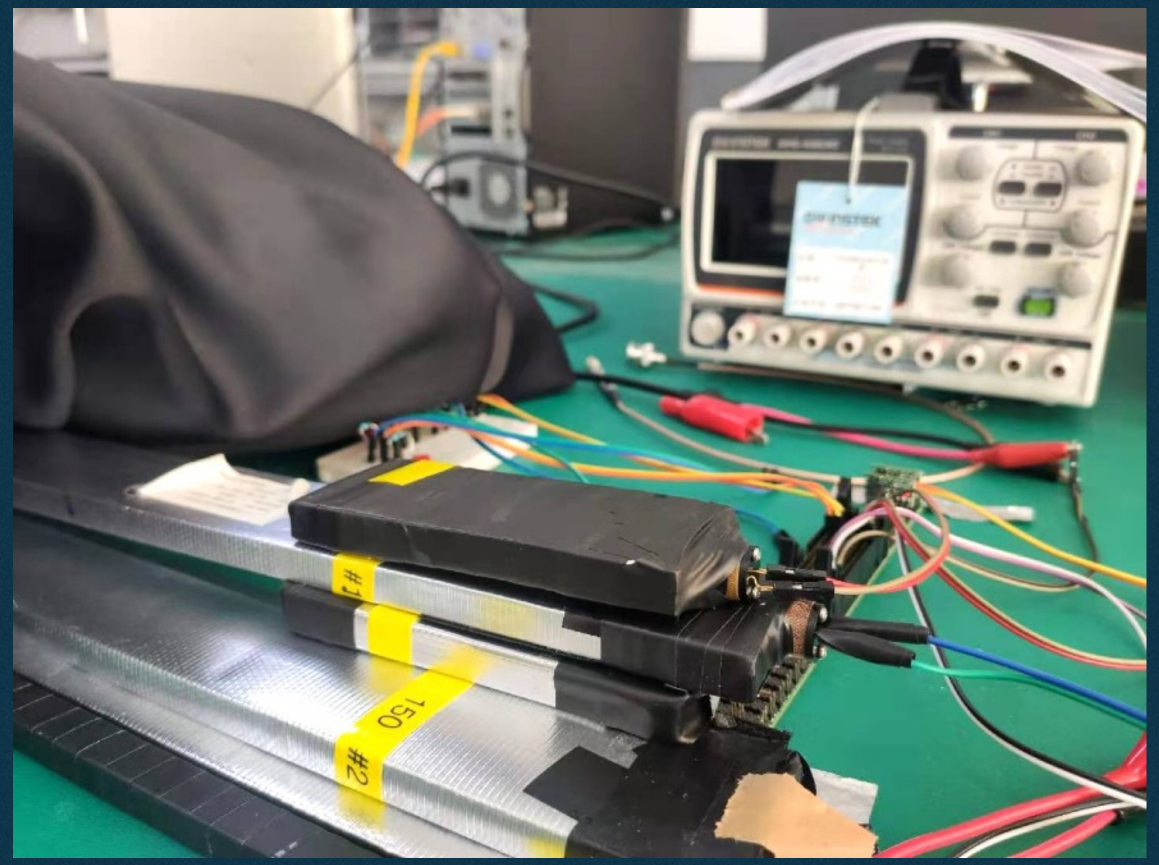
Results expected soon

R&D on scintillators and SiPM

Integrating BELLE II Muon detector knowledge

- Made in China: scintillator+SiPM (NDL)
- New FEE designed
- Good efficiency: >90%
- Time resolution: < 2ns





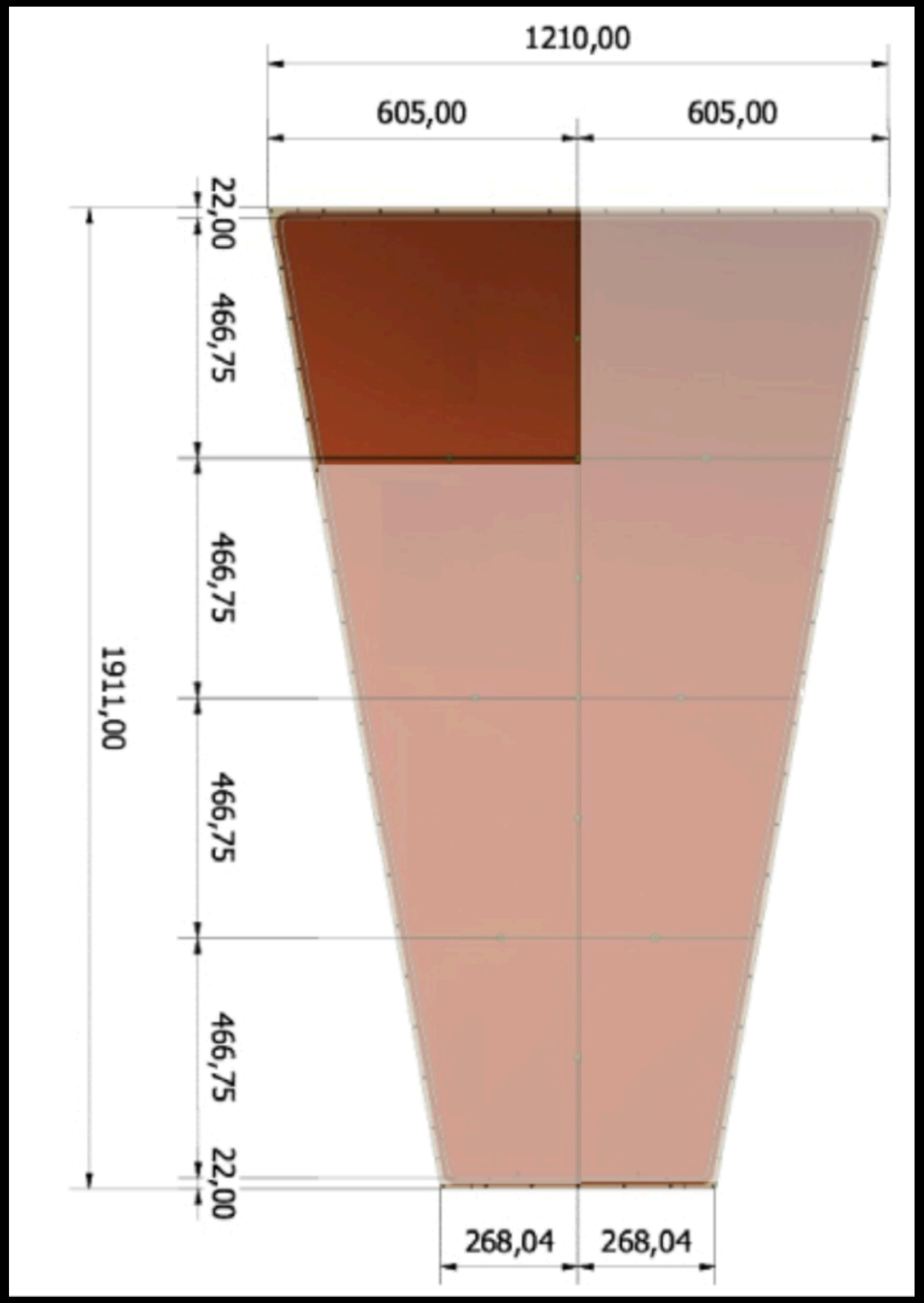
Cosmic ray test stand

IDEA Detector: μ-RWELL technology

Lead by Italian Colleagues

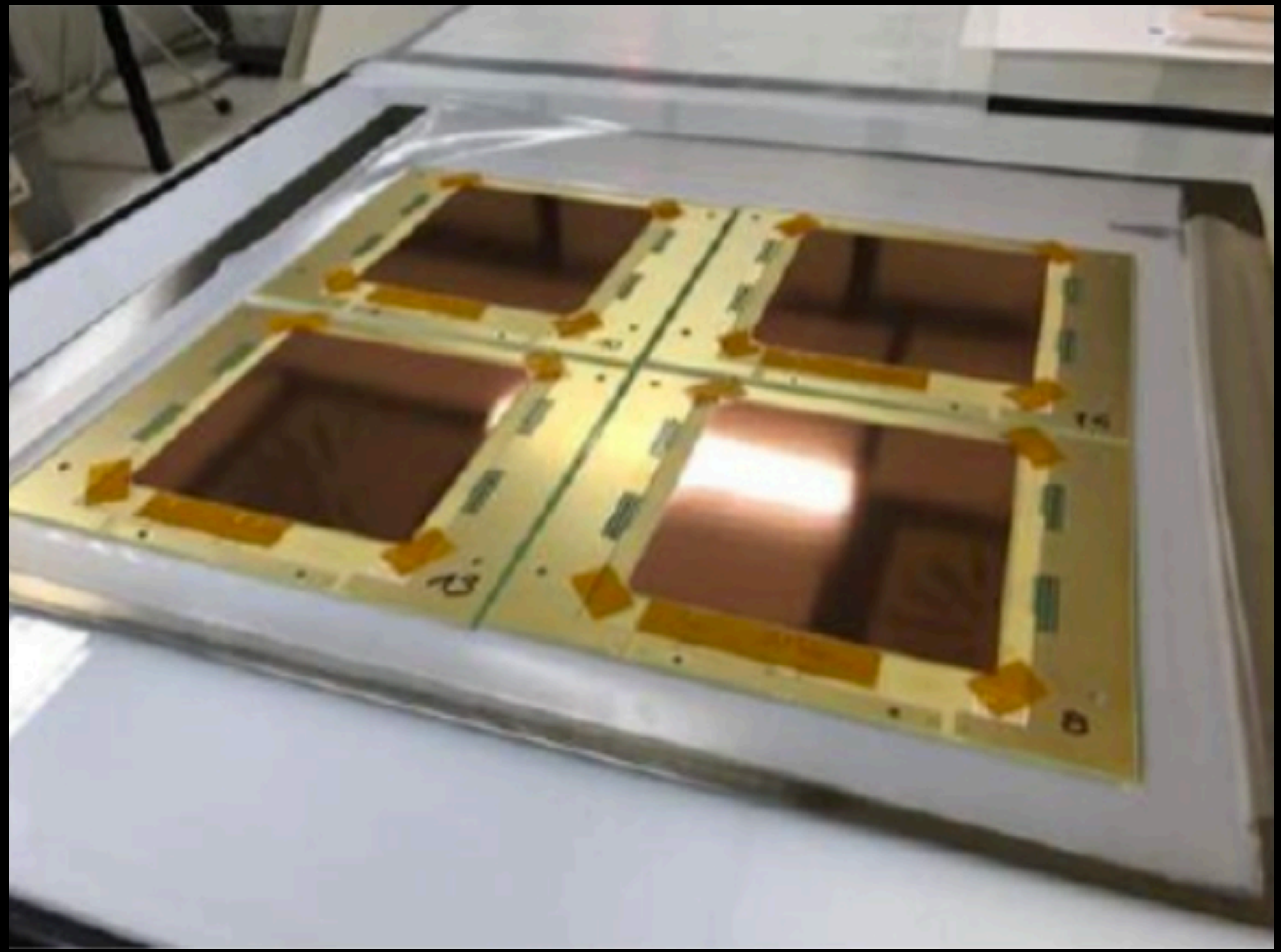
- How to optimize the detector design to the CEPC physics program?
- How to reduce the input FEE capacity in the muon system?
- How to built more than 3000 m² of μRWELL detectors?

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 mm² to be developed with ELTOS, an Italian company



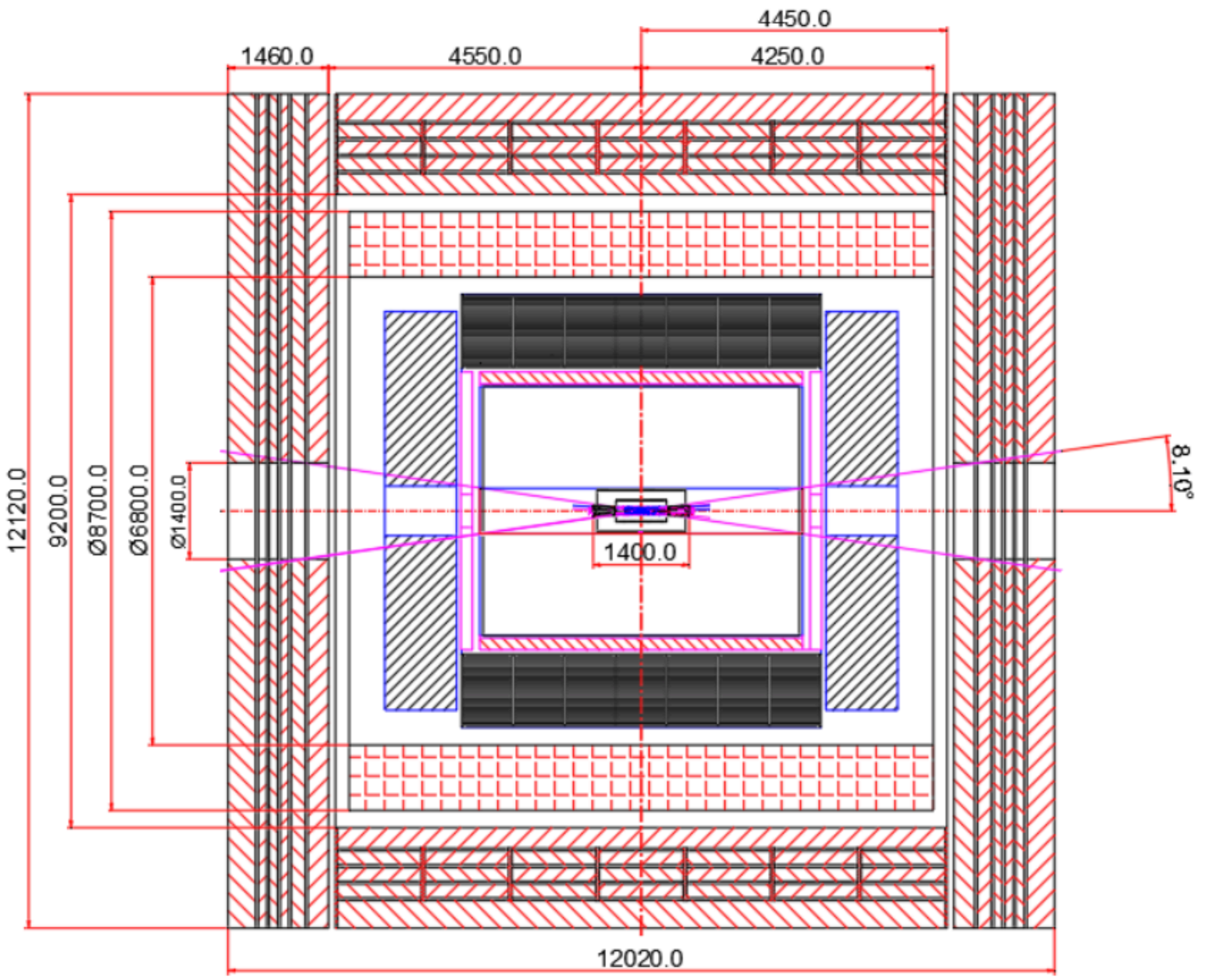
μRWELL detailed simulation is on-going

Description to be included in DD4HEP framework within Key4HEP environment

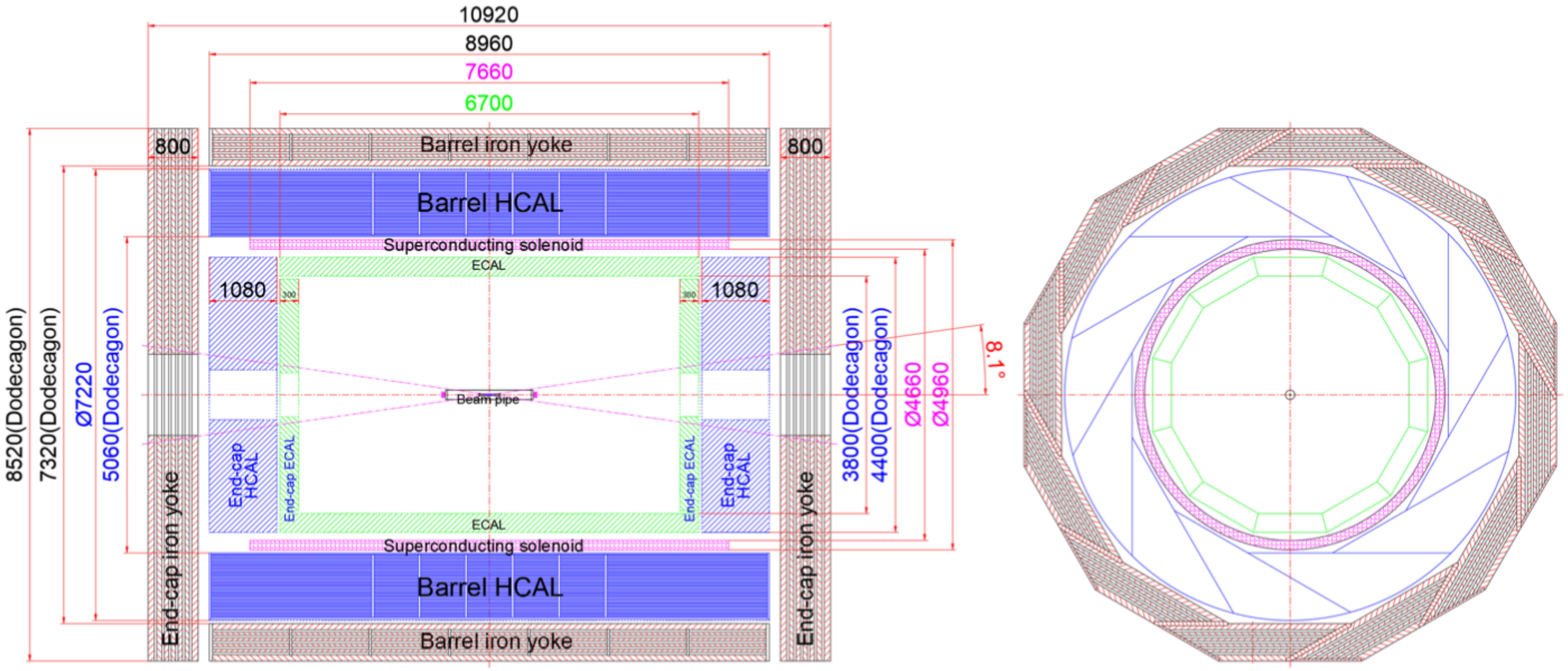
Goal by 2024: Optimize engineering mass construction with the ELTOS Develop new specific ASIC, and complete simulation/reconstruction

CEPC Mechanical Design

CEPC detector layout is evolving: several options proposed



A detector layout in the Mechanics Workshop 2020 by Quan Ji (IHEP)



A new detector layout in the Yangzhou Joint Workshop 2021 by Quan Ji (IHEP)

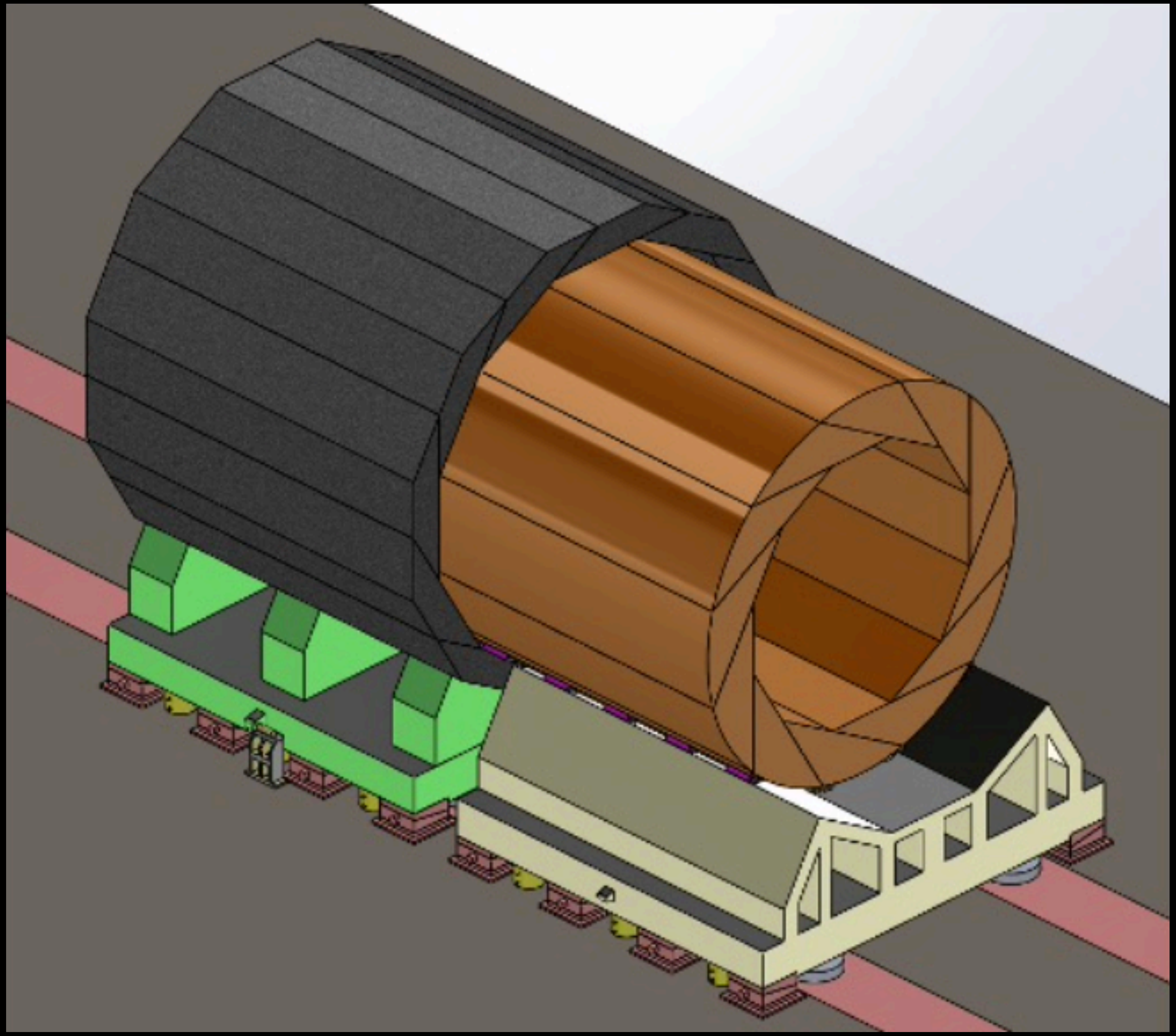
Detailed studies need to be based on a specific design: currently evolving away from the CDR baseline towards the 4th concept design

Detector Installation

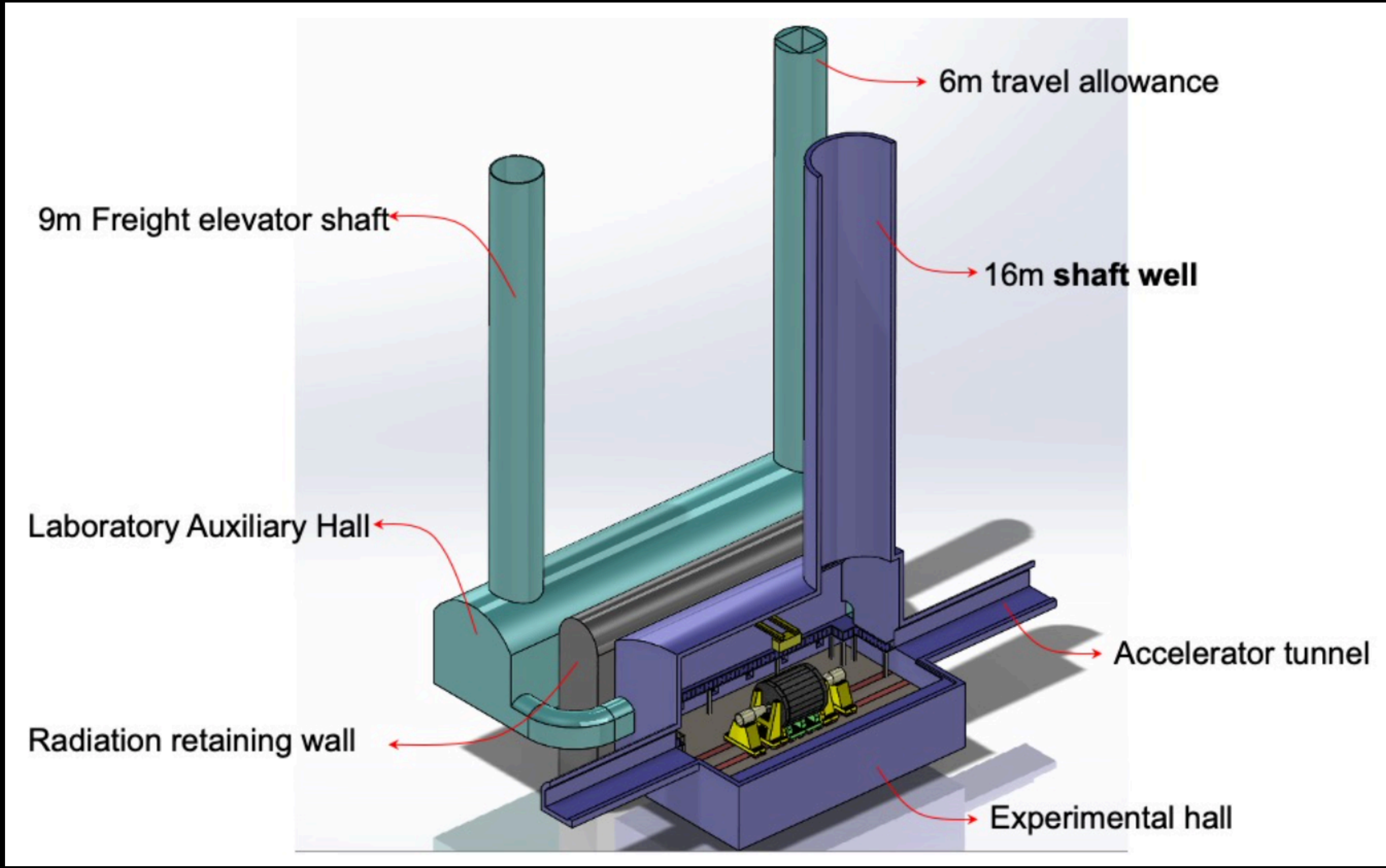
Studies about installation of detector have started

Detector Installation

Studies about installation of detector have started



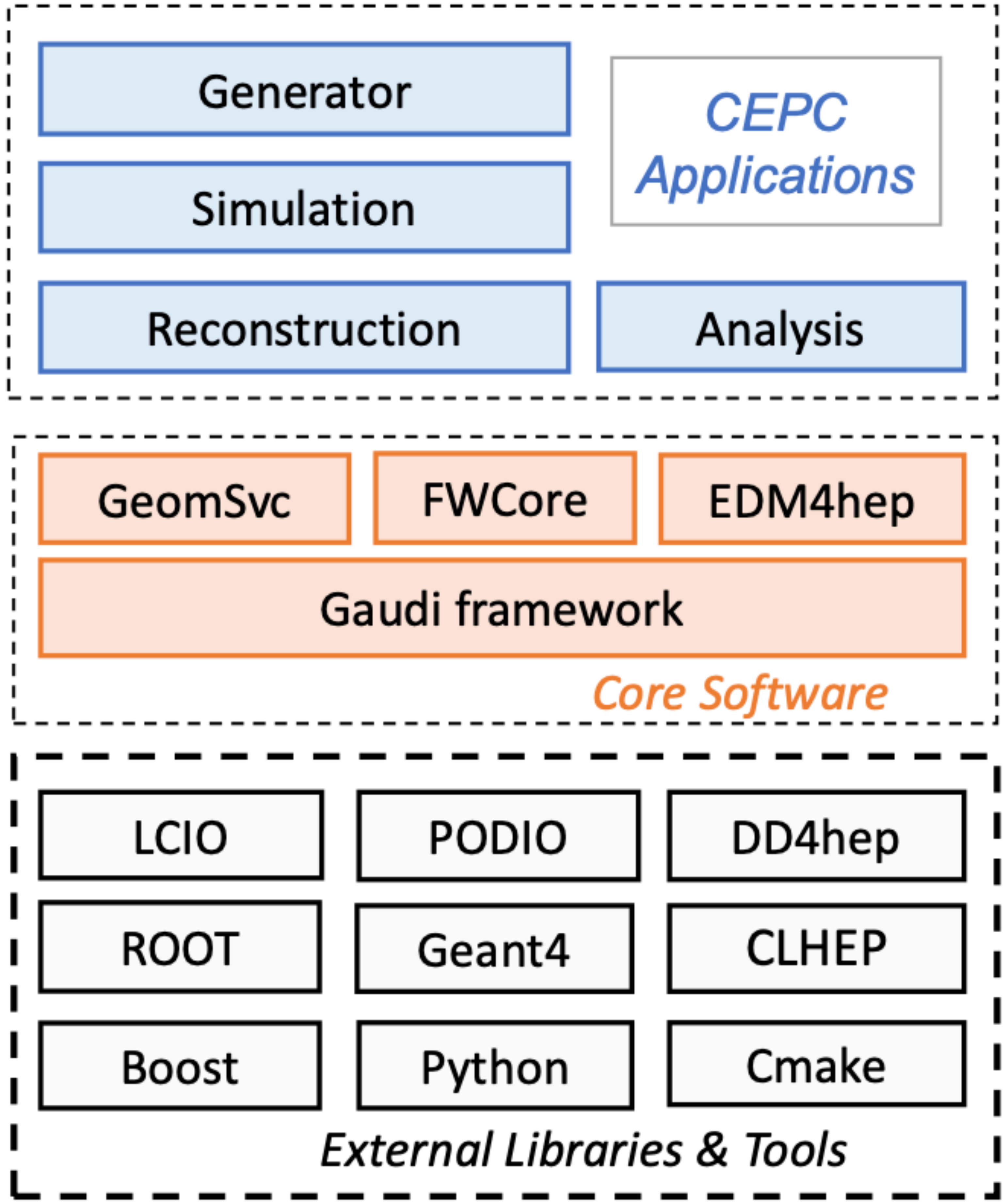
Technical challenges on HCAL (1200 Tons) installation



CEPC Software migration to key4hep

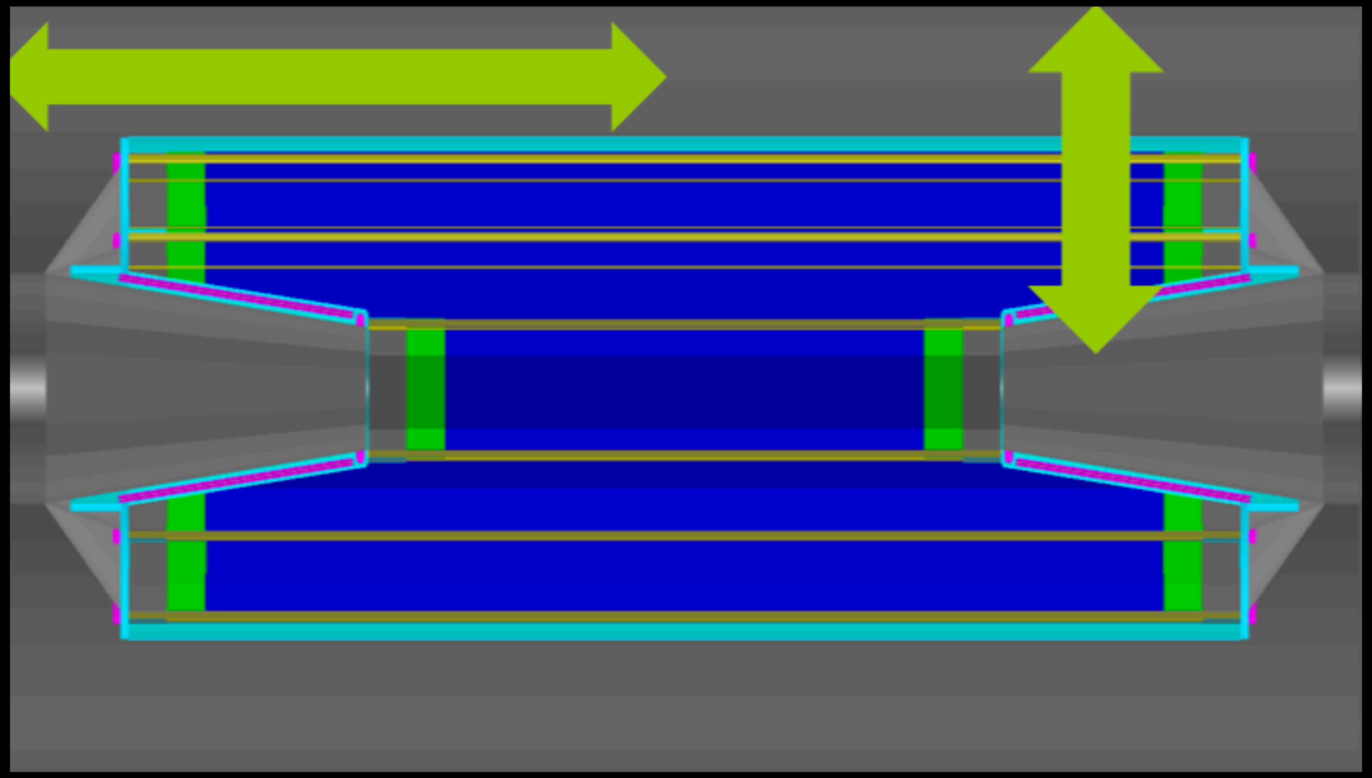
CEPCSW: the first application of Key4hep

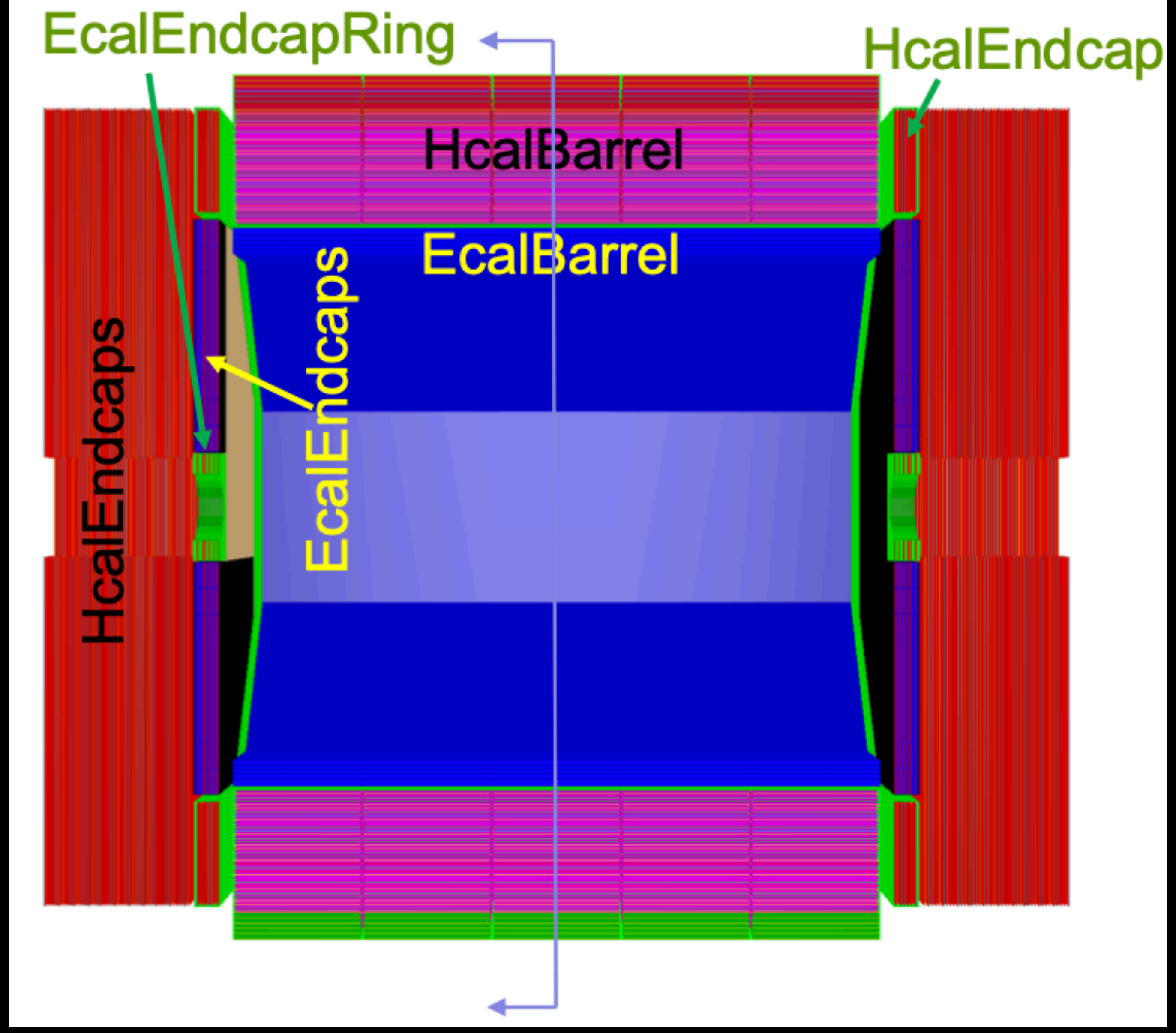
- Architecture of CEPCSW
  - external libraries
  - core software
  - CEPC applications for simulation, reconstruction and analysis.
- Core software
  - Gaudi framework: defines interfaces of all the software components and controls the event loop.
  - EDM4hep: generic event data model.
  - FWCore: manages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



https://github.com/cepc/CEPCSW

CEPC_v4 reference detector





See talk by Weidong tomorrow

CEPC Software Plans

- Core software
  - Moving towards multithreading based on the Intel TBB (Threading Building Blocks)
  - Providing user-friendly interfaces to machine learning libraries like TensorFlow and PyTorch
  - Development of data analysis software using ROOT RDataFrame
  - Deployment of the automated validation platform to support continuous integration
- Simulation software
  - Updating geometry information according detector design
  - Adding beam-related backgrounds
  - Providing more realistic simulation of digitization process
- Reconstruction software
  - Performance optimization of tracking algorithms in silicon and TPC trackers
  - Development of pattern recognition algorithms for the drift chamber
  - Improving the performance of 3D cluster identification in the long crystal bar ECAL
- Computing
  - The data production prototype will be built to facilitate massive Monte Carlo production

International Collaboration and Future

Projects overview

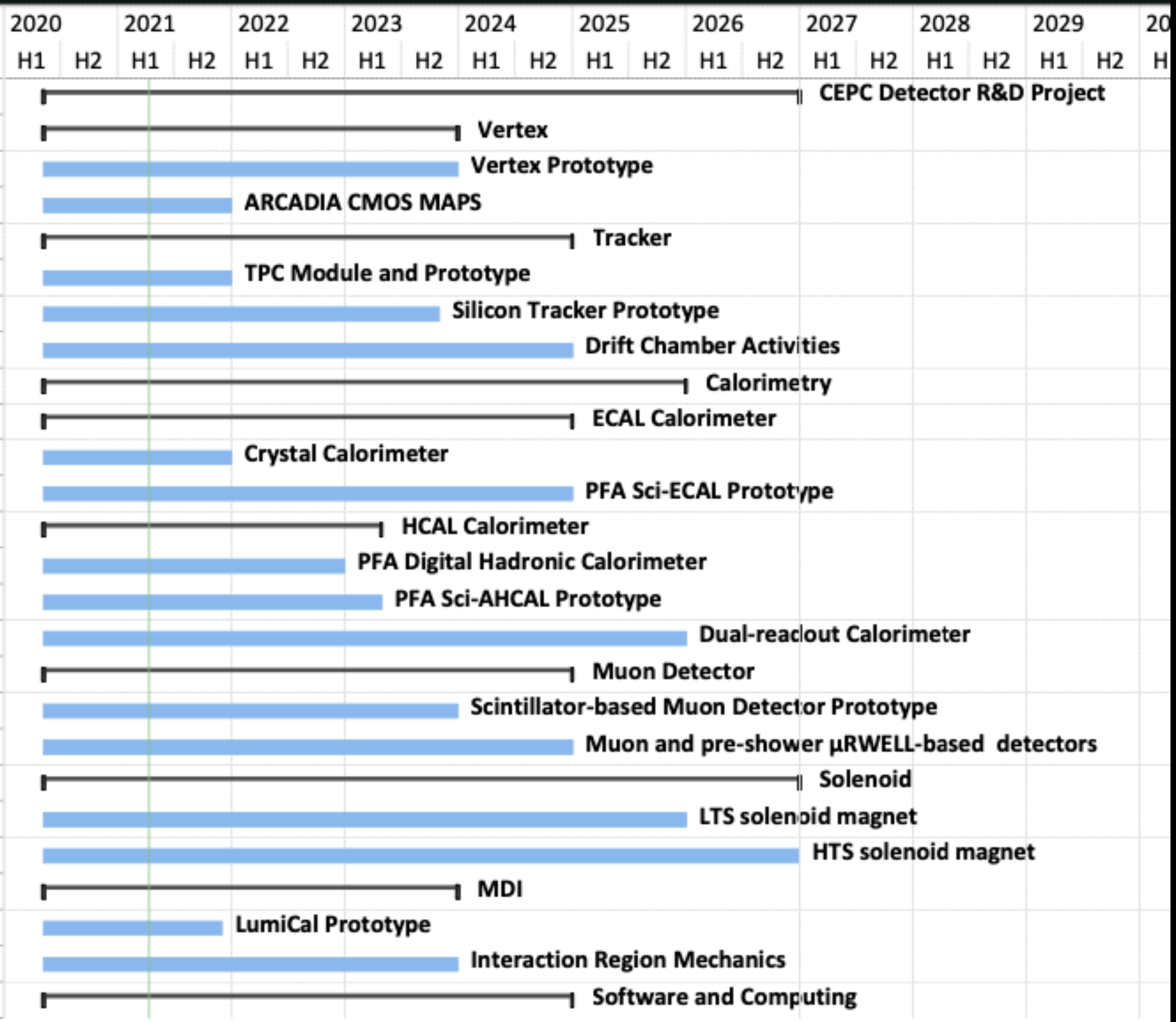
Total subtasks: 103

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, Vinca	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: 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: 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, Vinca	1.5	1.5	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
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5.1	LTS solenoid magnet	IHEP+Industry
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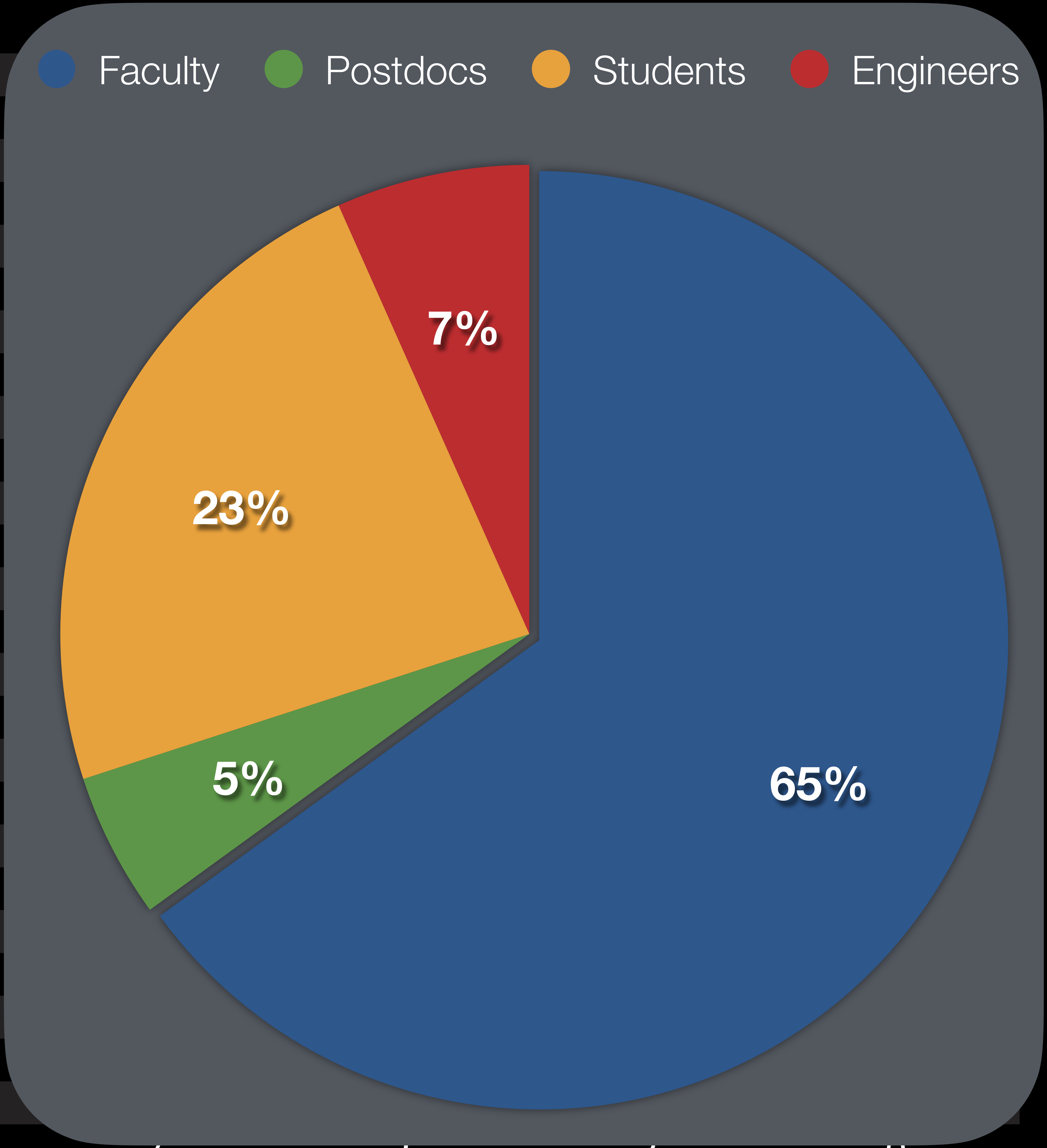
6	**MDI**	
6.1	LumiCal Prototype	AC, IHEP, Vinca
6.2	Interaction Region Mechanics	IHEP
8	**Software and Computing**	IHEP, SDU



Snowmass — Letters of Intent

14 CEPC-Related Detector LoI submitted

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

Detector R&D

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

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

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

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

Material: Paper | Slides

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

Speaker: Franco Bedeschi (INFN-Pisa)

Material: Paper

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

Speaker: Roberto Ferrari (INFN)

Material: Paper

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

Speaker: Franco Grancagnolo

Material: Paper

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

Speaker: Paolo Giacomelli (INFN-Bo)

Material: Paper

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

Speaker: Prof. Zhijun Liang (IHEP)

Material: Slides

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

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

Material: Slides

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

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

Material: Slides

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

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

Material: Paper | Slides

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

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

Material: document

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

Speaker: Prof. Zhijun Liang (IHEP)

Material: Slides

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

Speaker: Dr. Hongbo ZHU (IHEP)

Material: Slides

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

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

Material: Slides

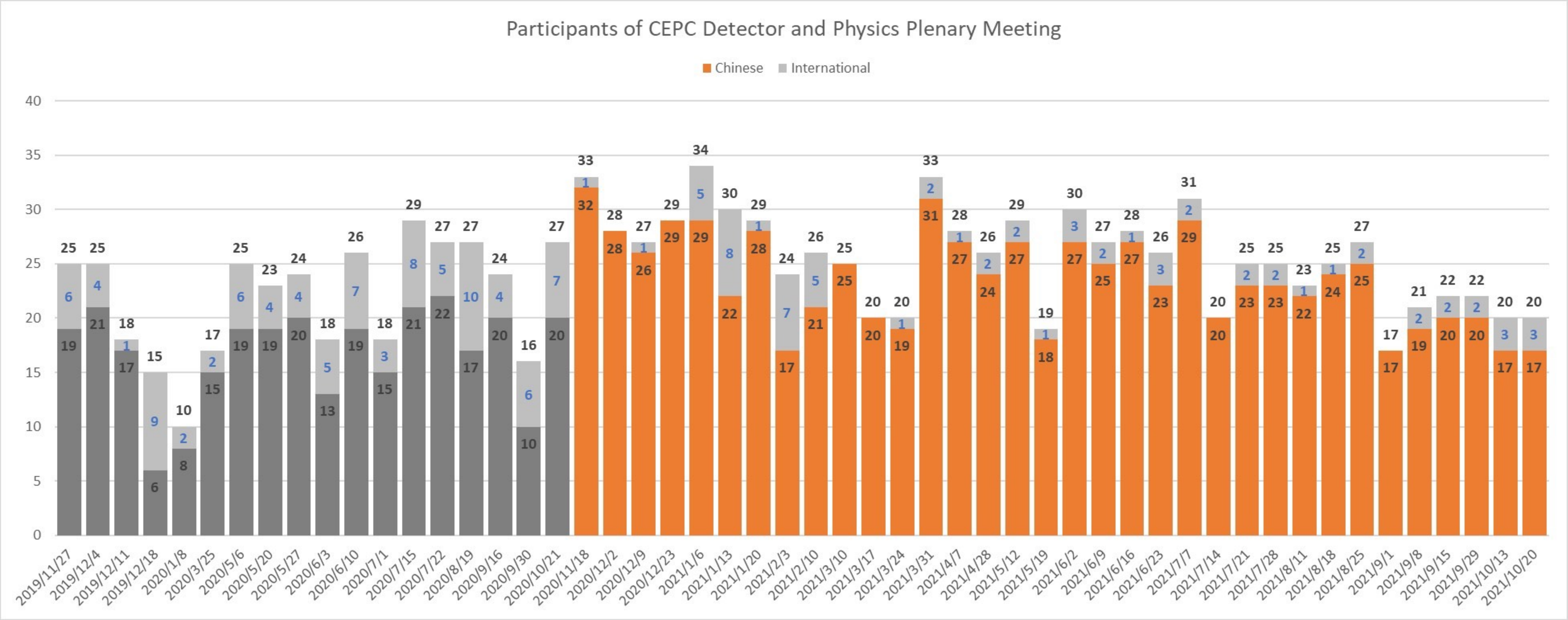
15:17 **Solenoid R&D LoI** *1'*

Speaker: Dr. Feipeng NING (IHEP)

Material: Slides

CEPC Physics and Detector Meetings

https://indico.ihep.ac.cn/category/214/



Reduction of the International Participation at the Plenary Meetings

CEPC Day meeting every month

Key R&D Issues Moving Forward

Updated Parameters of Collider Ring since CDR

	ttbar	Higgs	W	Z
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	0.10/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	1.7/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Longitudinal tune Qs	0.078	0.049	0.062	0.035
Beam lifetime (bhabha/beamstrahlung)[min]	81/23	39/40	60/700	80/18000
Beam lifetime total [min]	18	20	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

× 1.8 × 3.6

Evaluate impact of luminosity/rate increases

Evaluate requirements from ttbar upgrade run

Some key R&D topics moving forward

- Machine Detector Interface
- Luminosity meter (LumiCal) - continue integration in beampipe development
- Silicon Vertex
  - Continue to explore low-material budget solutions, cooling integration and performance optimization
  - Sensor technology and availability in China

Some key R&D topics moving forward

- Machine Detector Interface
- Luminosity meter (LumiCal) - continue integration in beampipe development
- Silicon Vertex
  - Continue to explore low-material budget solutions, cooling integration and performance optimization
  - Sensor technology and availability in China
- Tracker

Trade off: Transparency <—> reliability/resolution

  - Time Projection Chamber
    - Conclude feasibility study for high-rate CEPC operation (Ion back flow/field distortion)
    - Follow up on the Pixel TPC possibility
  - Drift Chamber
    - Can it cope with the high increased rates at the Z pole? Enough resolution?
    - Demonstration of PID capabilities
    - Mechanical design and stability analysis
  - Full silicon tracker → still need manpower increase to exploit this option
    - Continue Silicon Tracker prototype collaboration
    - Need to add detector for particle identification

Some key R&D topics moving forward

- Calorimetry
  - Cost versus physics performance
  - ECAL
    - Finalize evaluation of the crystal calorimeter option
    - Cooling of PFA calorimeter versus performance
  - HCAL
    - Finalize production of Scintillator HCAL prototype
    - Cooling and mechanics studies
  - Dual Readout
    - Demonstration using full size prototype

Some key R&D topics moving forward

- Calorimetry
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  - HCAL
    - Finalize production of Scintillator HCAL prototype
    - Cooling and mechanical studies
  - Dual Readout
    - Demonstration using full size prototype
- Muon System optimization
  - Optimize number of layers
  - Optimize design for industrialization and cost

Optimization of detectors

Not an easy task without definite detectors/collaborations target

- Use a mixture of fast simulation and full simulation
- Need to consider engineering aspects
- Need to consider costing issues

See talk on 4th Concept Detector
by Jianchun tomorrow

Final remarks

Now considering new ideas and developing new tools

Need more time to explore alternatives and test these ideas

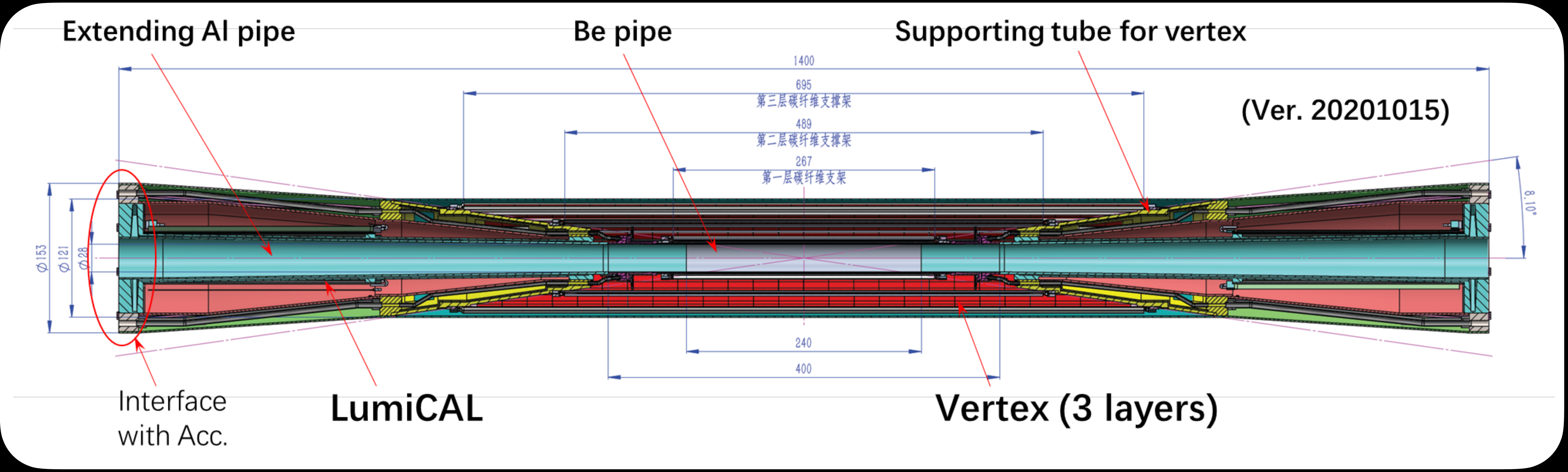
Key detector technologies R&D continues and are put to prototyping

Several CEPC R&D detector projects reaching a successful conclusion

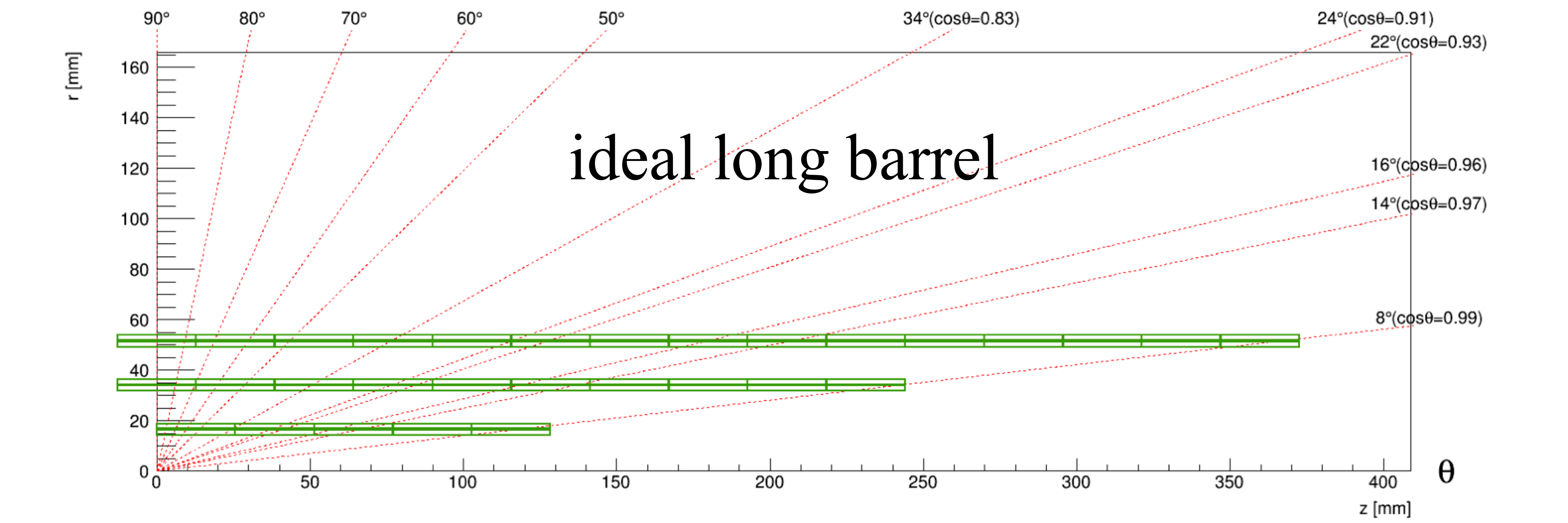
Final detectors are to be defined by International Collaborations and they are likely to incorporate a mixture of the technologies discussed here

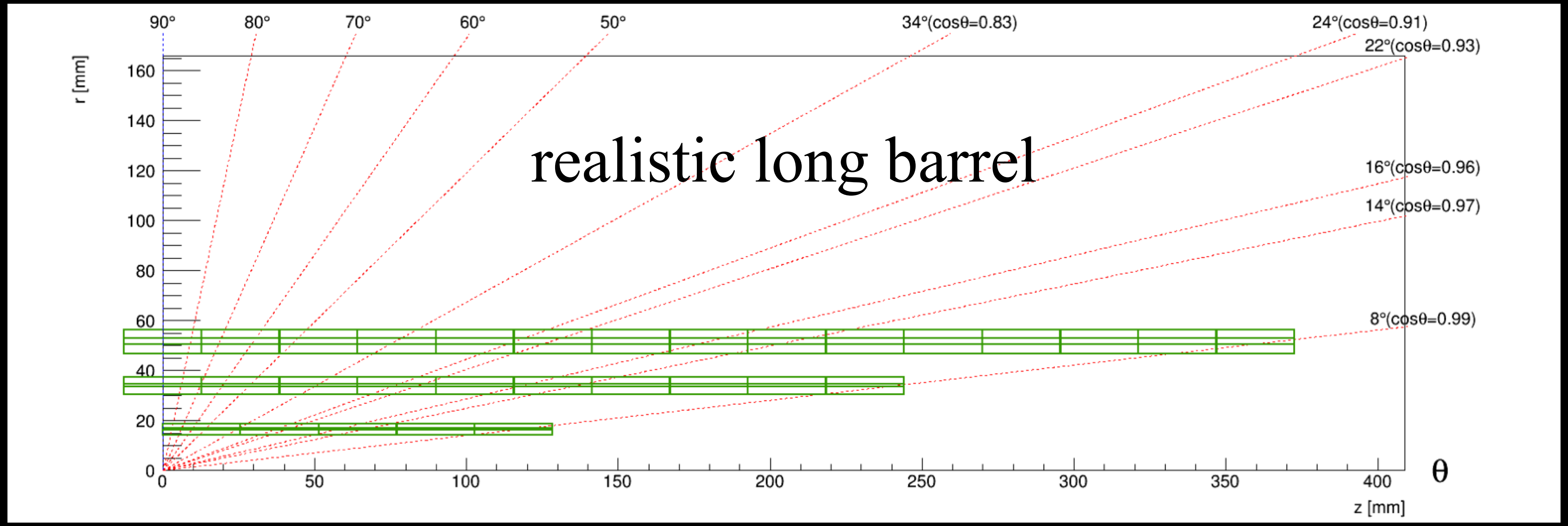
Still important to expand international collaboration

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

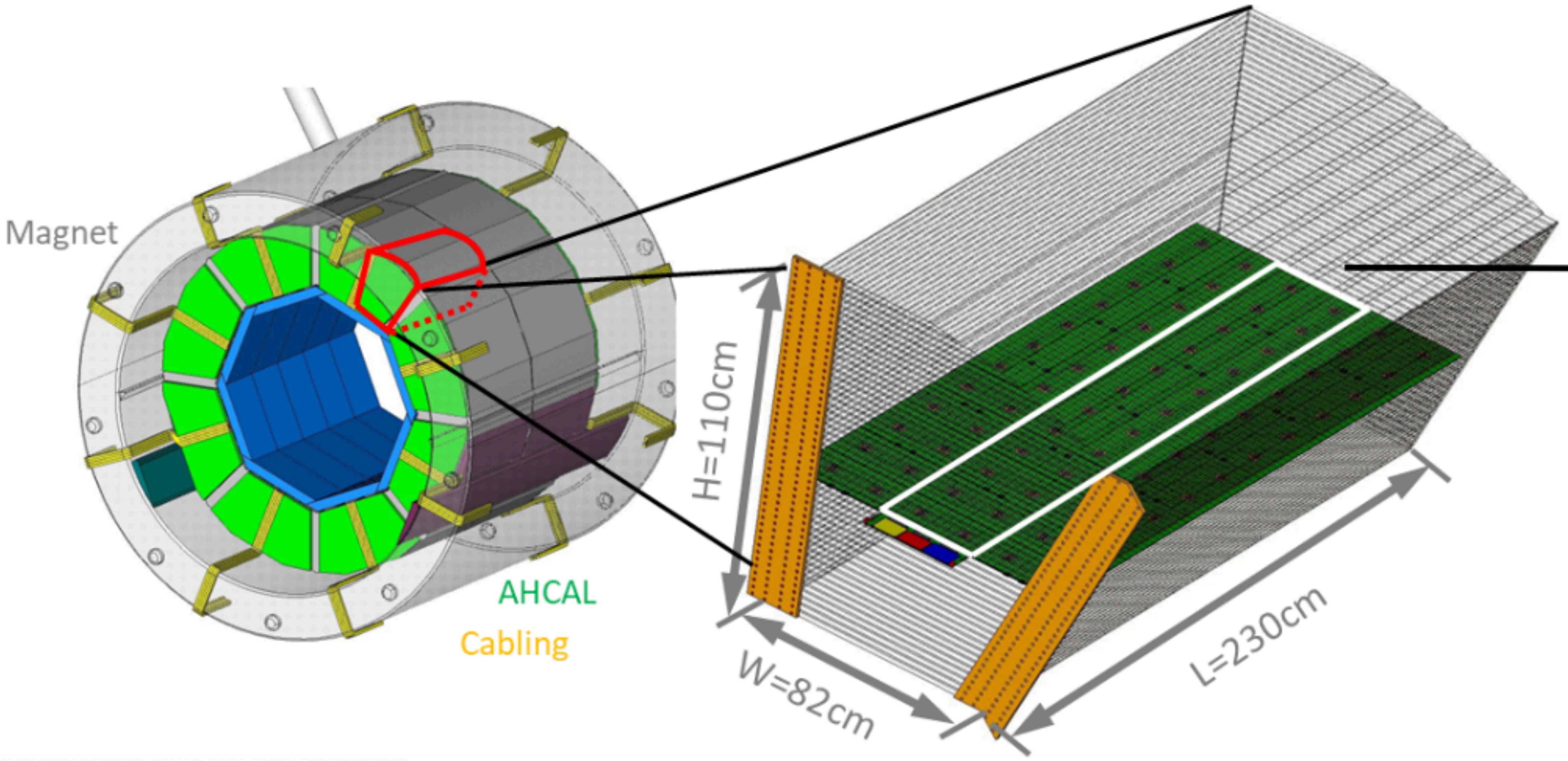
4-layer flex

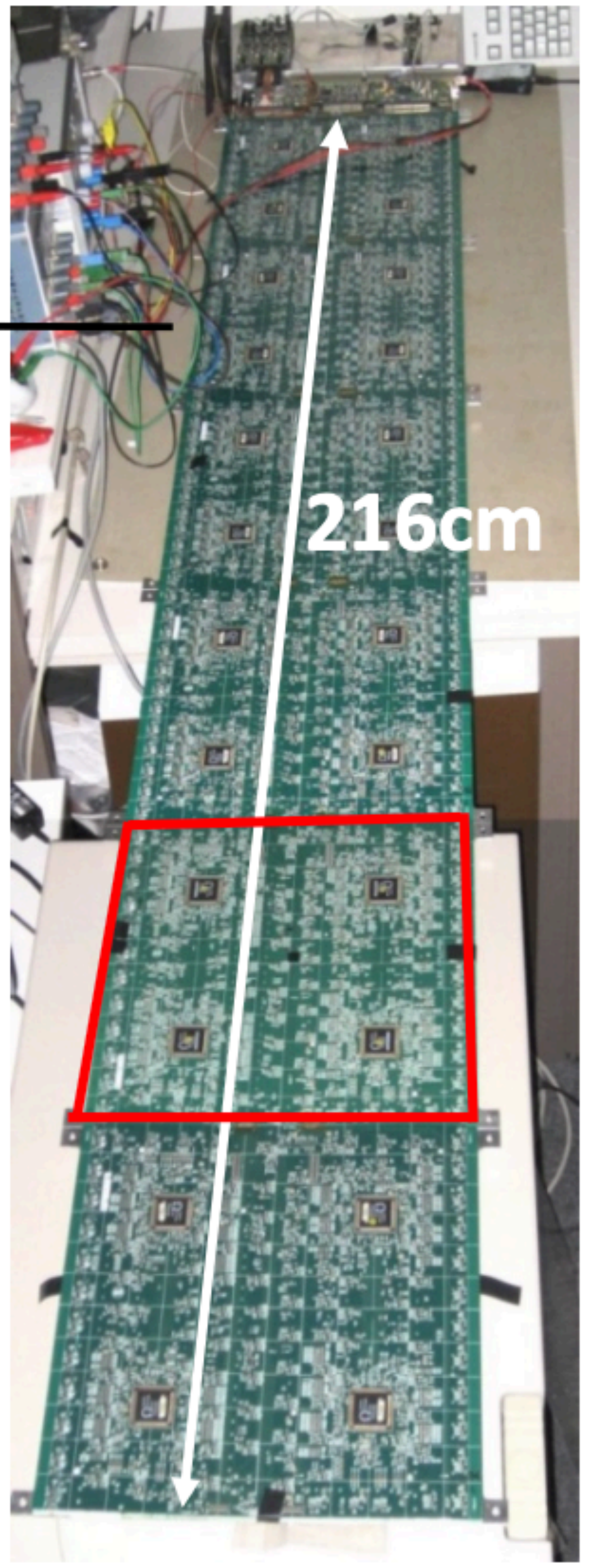
	thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
kapton+adhesive	50um	50
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

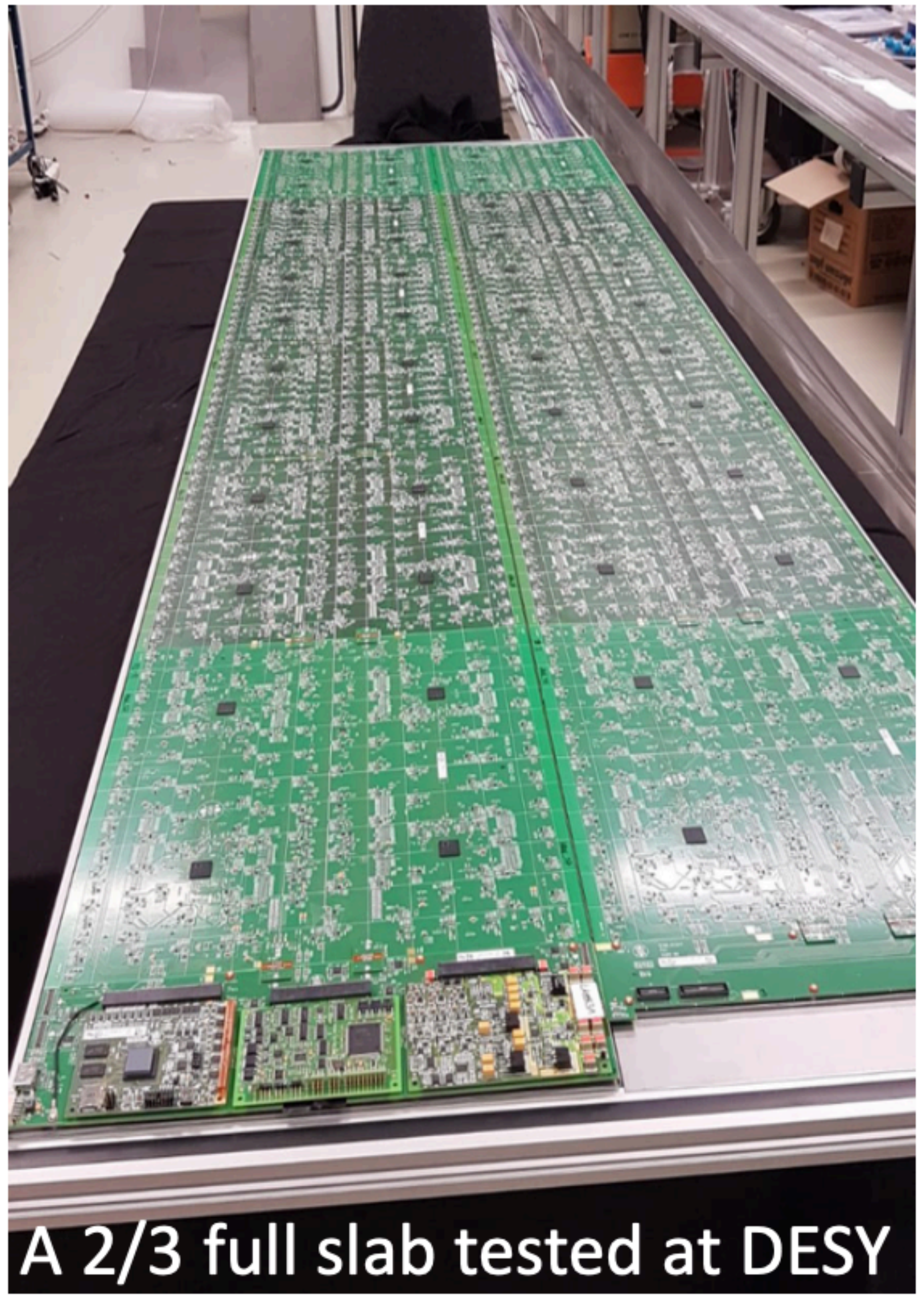
HCAL: Mechanics and Cooling

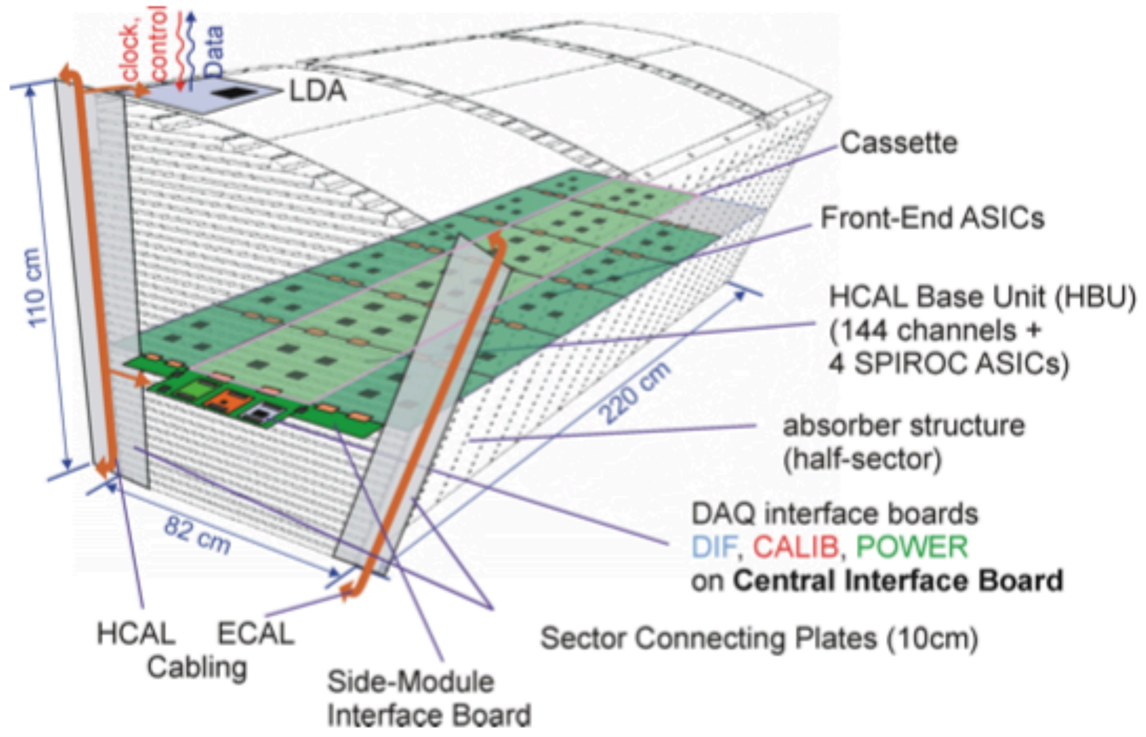
HCAL modules for the final detector

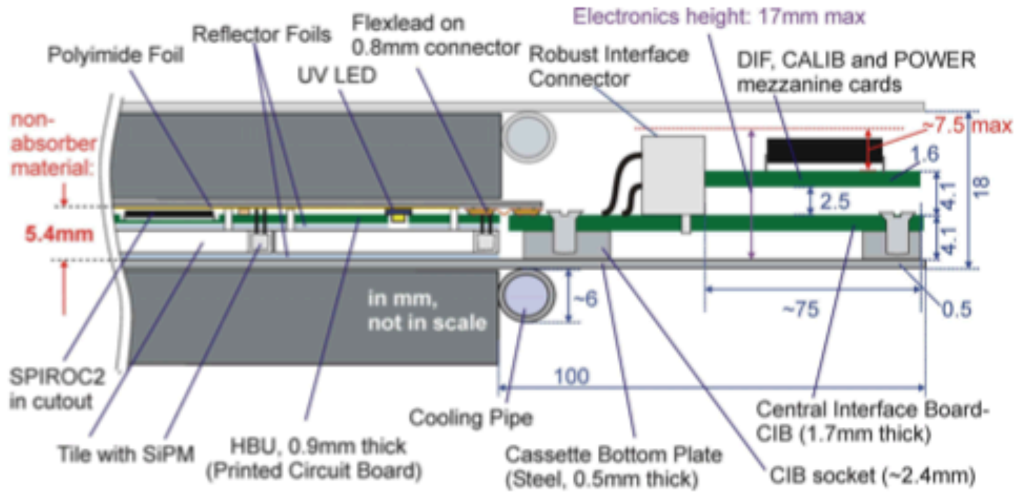
- Ongoing R&D efforts within CALICE to realise large-scale modules
  - Analog HCAL option: "SiPM-on-Tile" technology with steel plates
  - Efforts to test full-sized layers at DESY: aim for <u>1.1x2.2m² full slabs</u> at ILD

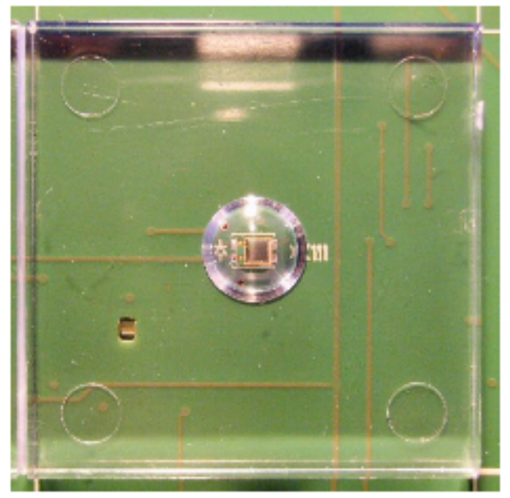





A 2/3 full slab tested at DESY



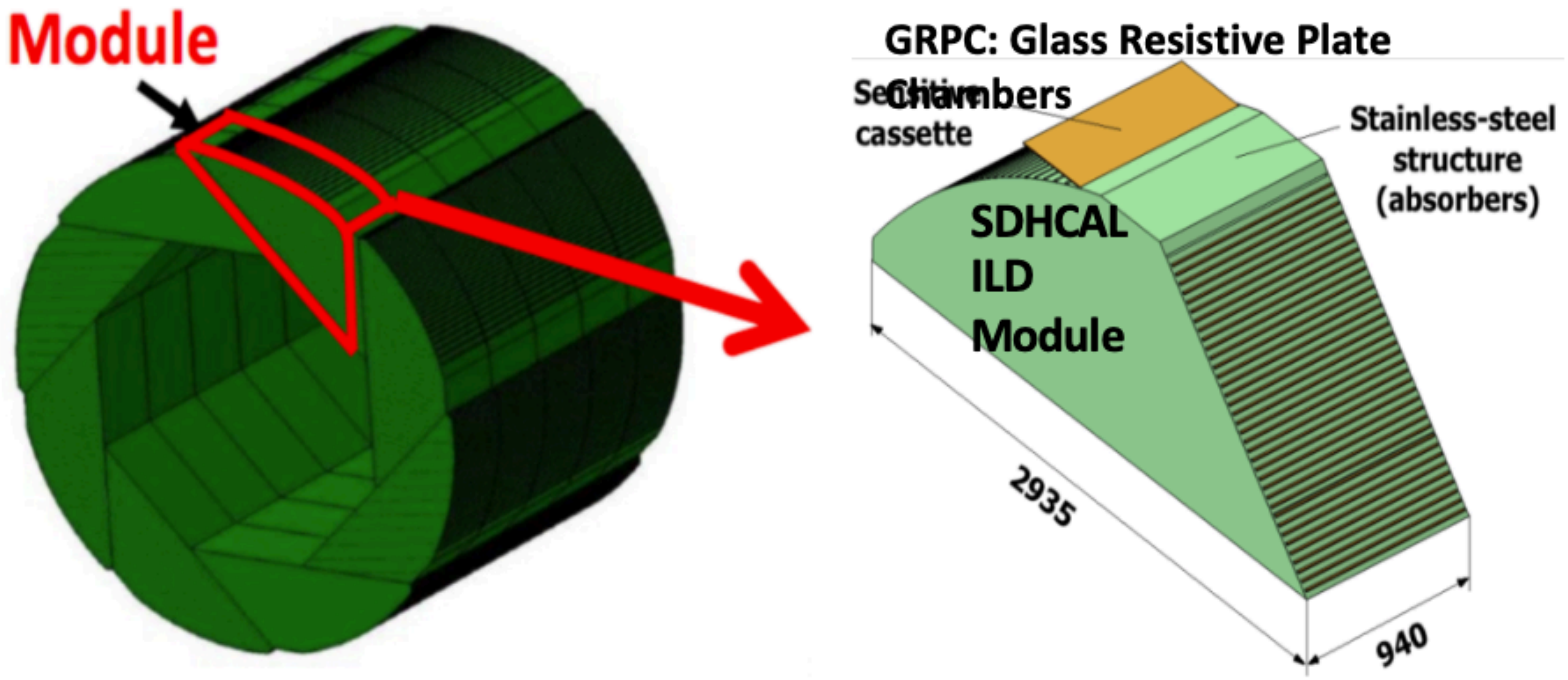




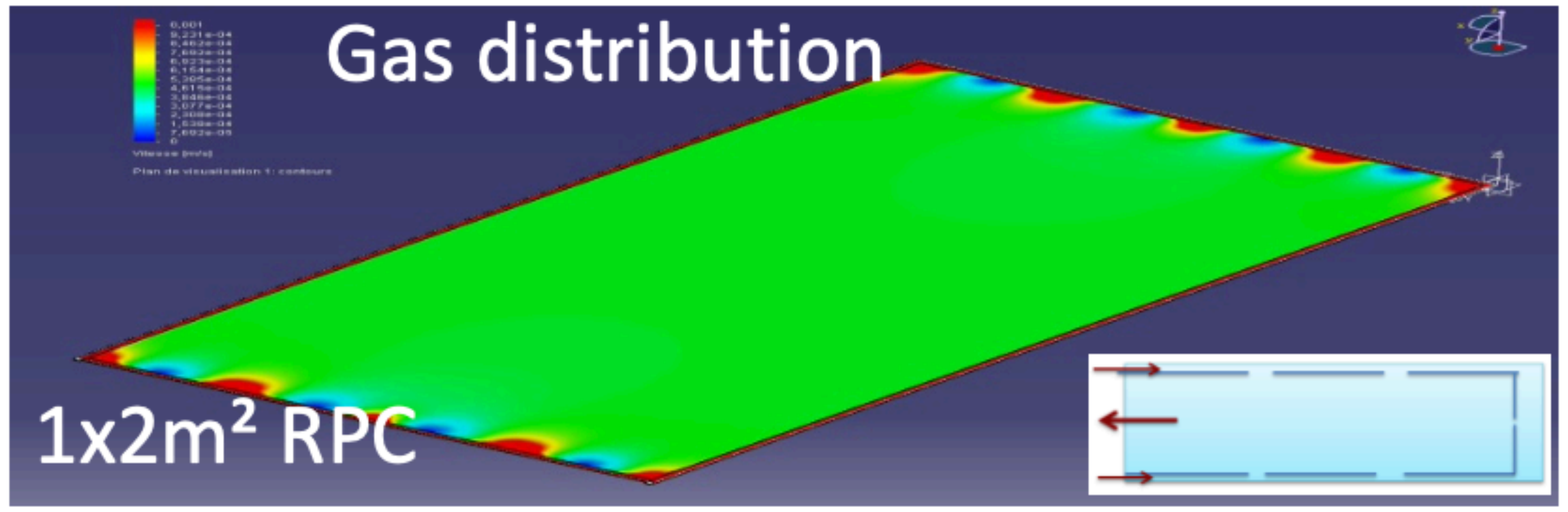
HCAL: Mechanics and Cooling

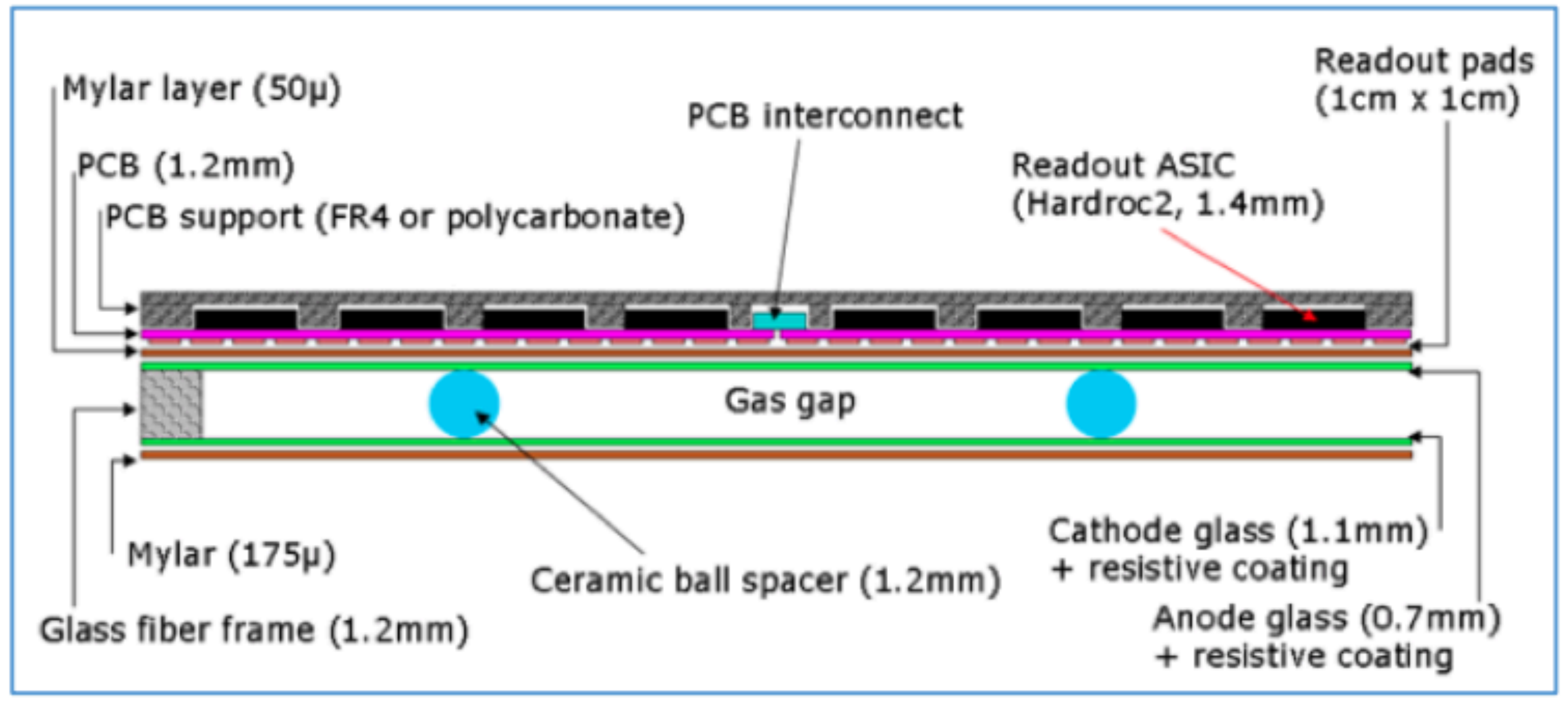
HCAL modules for the final detector

- Ongoing R&D efforts within CALICE to realise large-scale modules
  - Semi-digital HCAL option: large-scale RPC technology with steel plates
  - Efforts to build full-sized layers at Lyon: aim for full <u>1x3m² slabs</u>



Assembled 1x2m² large RPC, 1x0.33m² PCBs

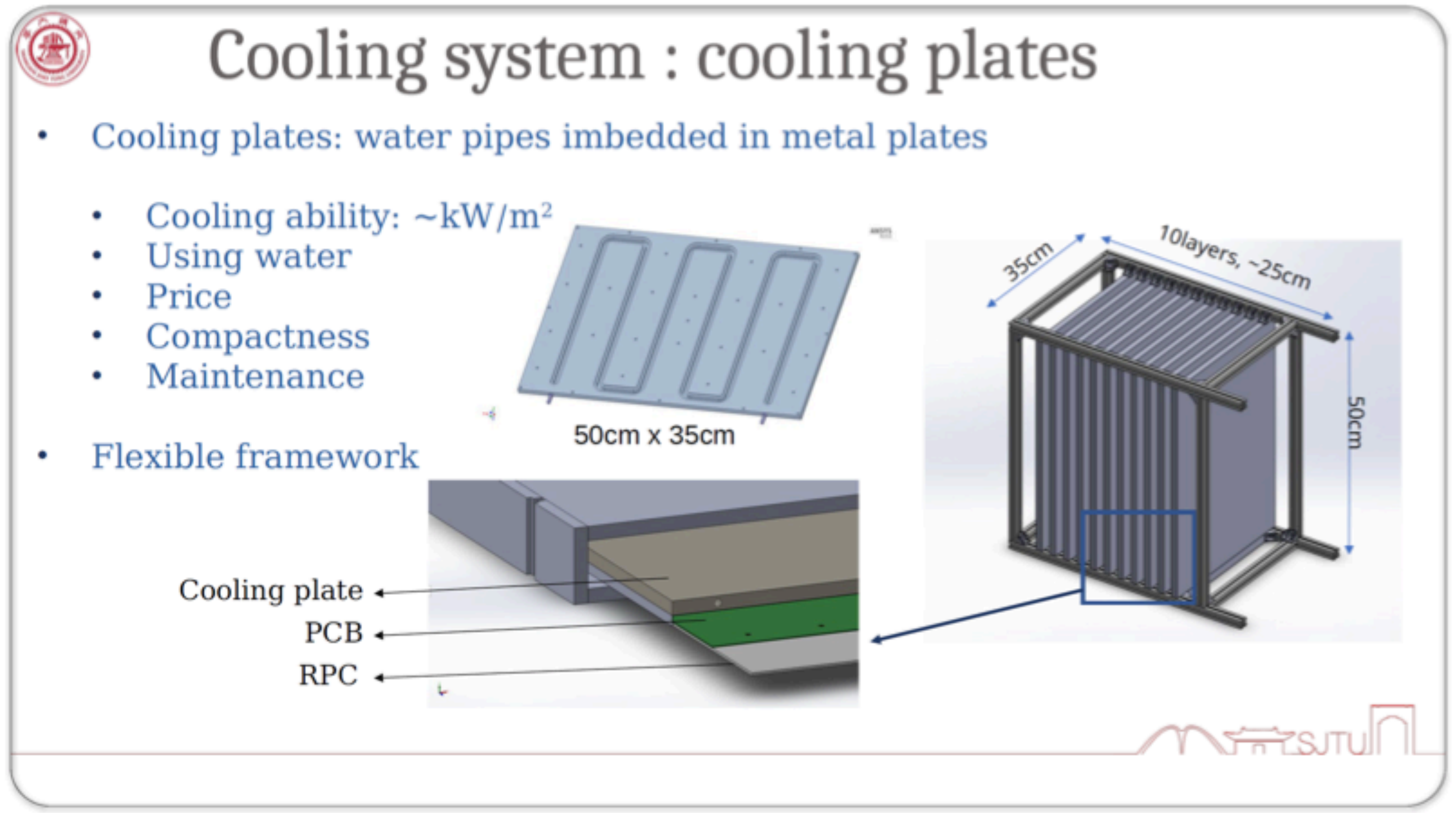


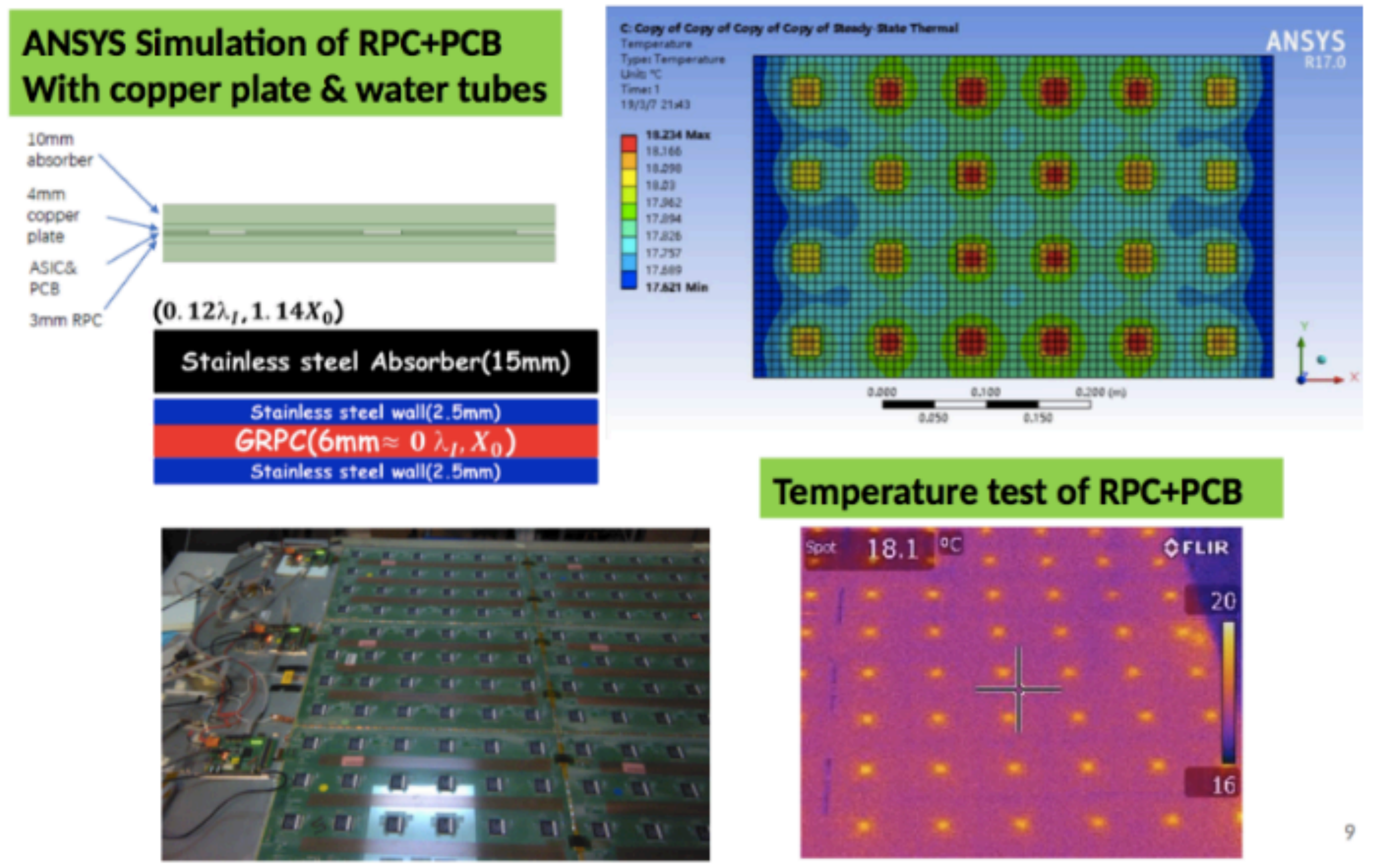


HCAL: Mechanics and Cooling

HCAL Active Cooling Studies

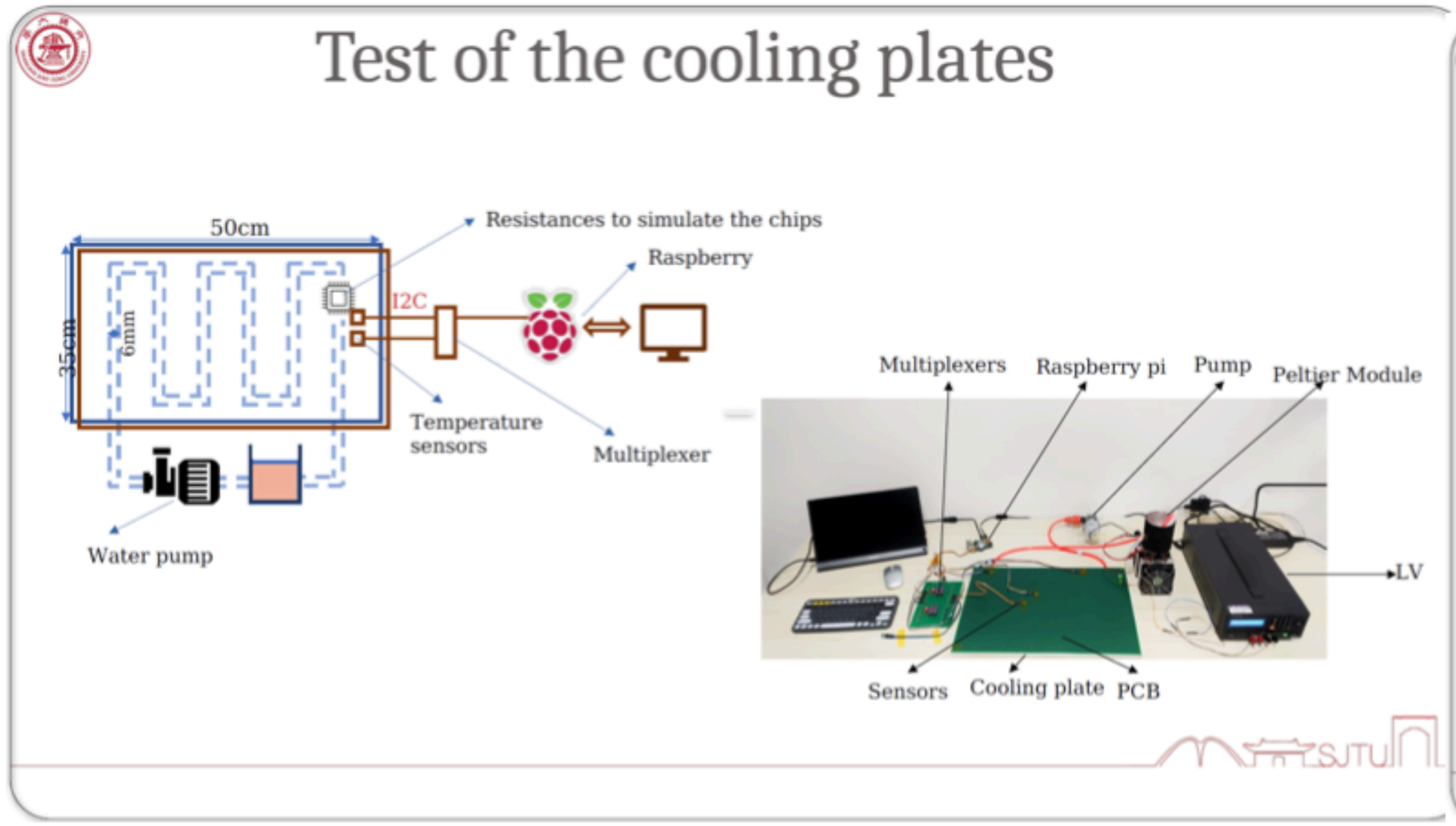
- Active cooling studies for SDHCAL at SJTU and Lyon
- Ongoing cooling studies for AHCAL prototype: different ASICs (SPIROC2E) and lower granularity

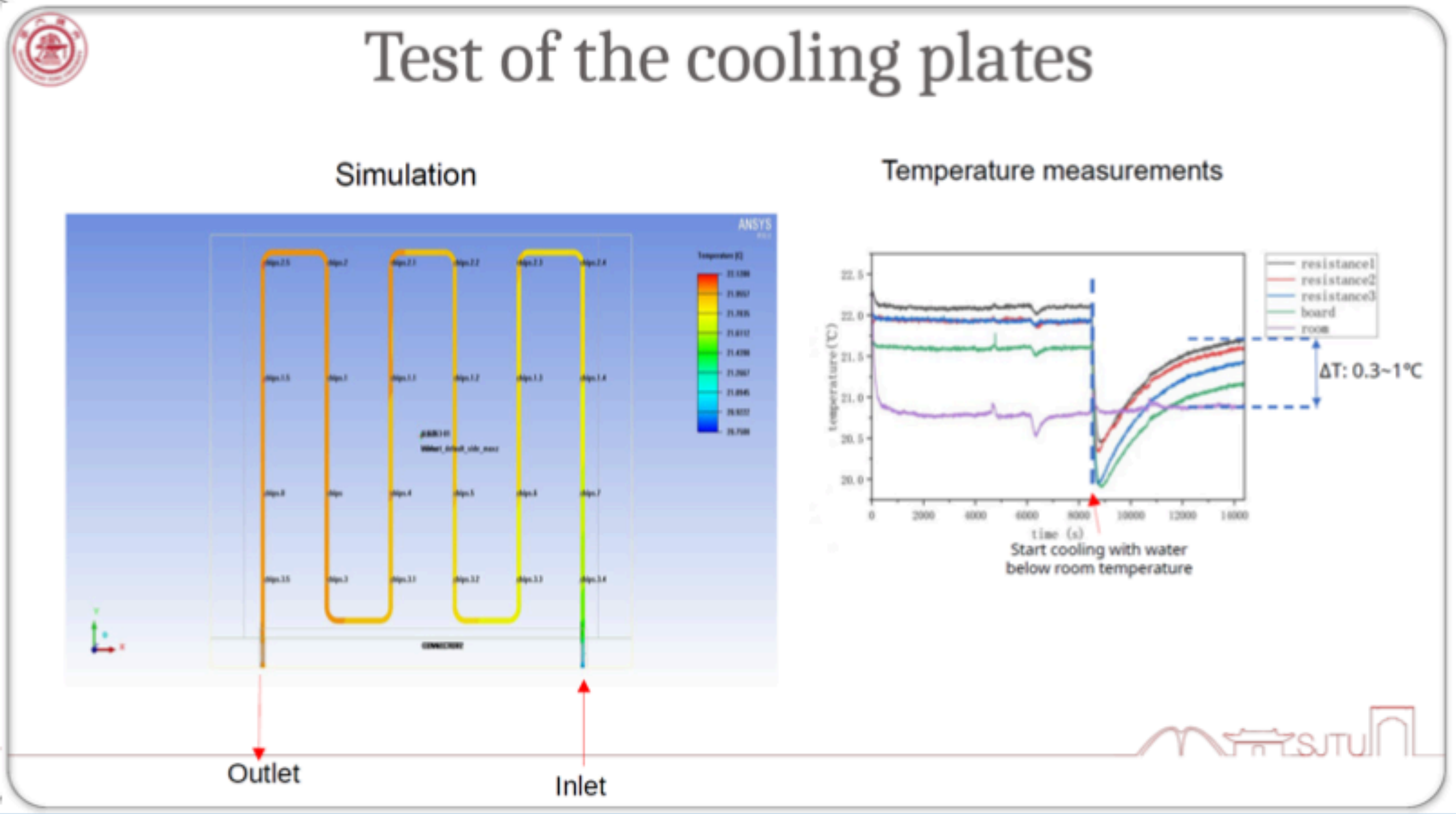


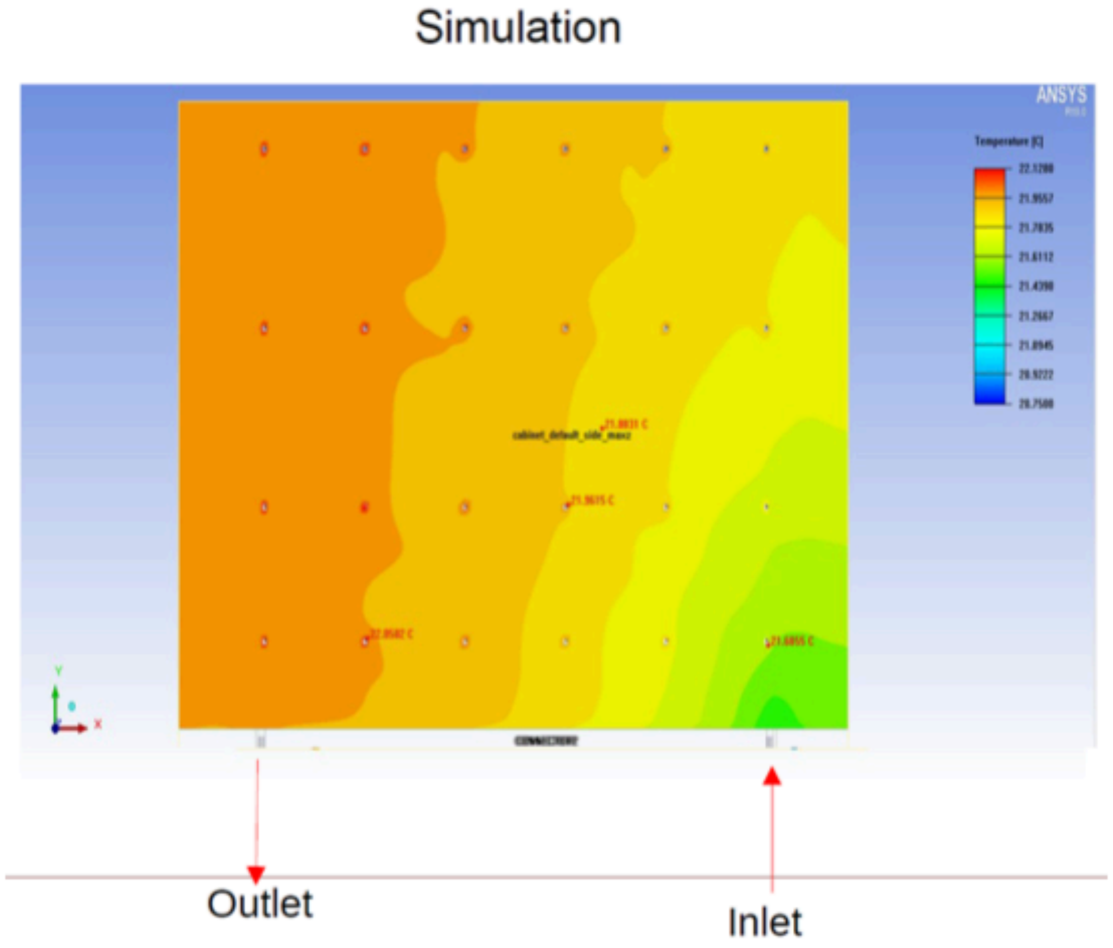


Synergies with the CEPC MOST-2 AHCAL prototype construction (40 layers, 72cmx72cm per layer)

[SDHCAL Electronics, Gas Flow and Cooling](#) at [CALICE Collaboration Meeting Mar. 2021](#)

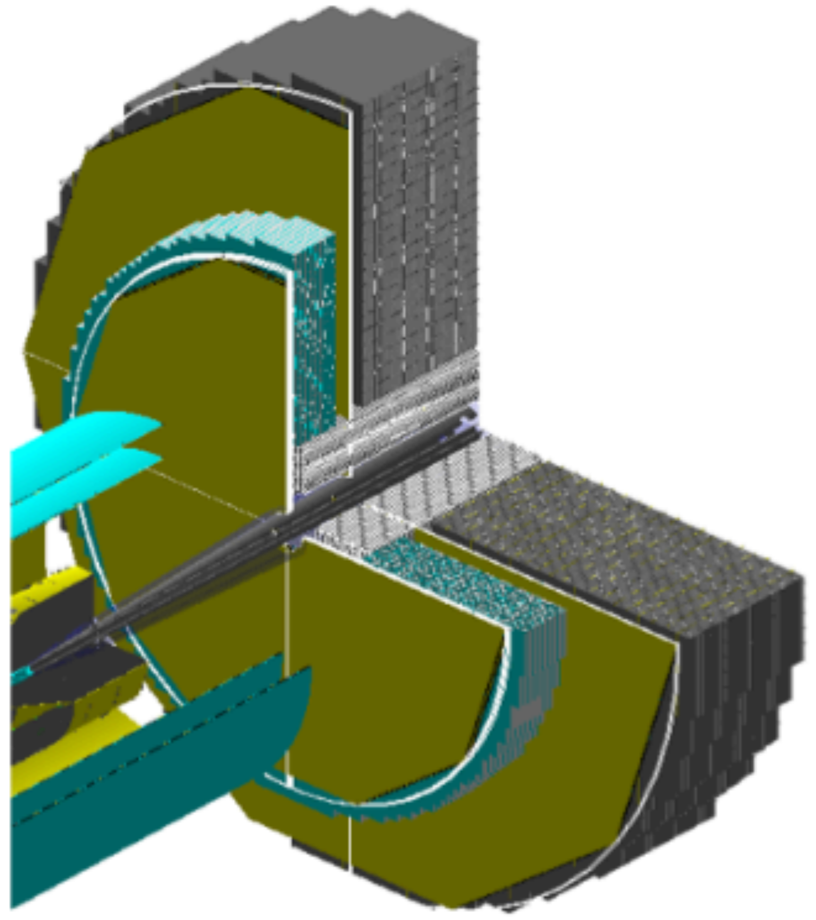




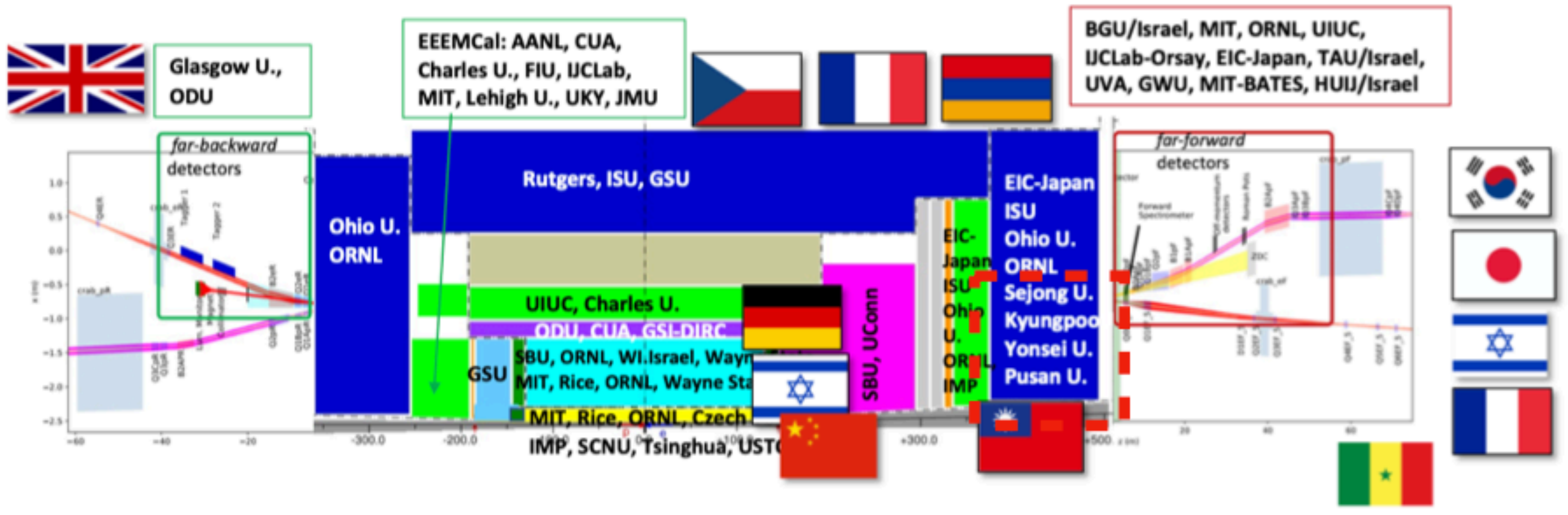


Dual readout calorimeter: Forward Detector Design for EIC

- Initial design and feasibility study is on-going
  - DRC pre-desing is implemented in Fun4All framework
  - Absorber type: Cu vs. W



ECCE International Interests



Polarized Beam and polarimetry: MIT, UNH, SBU

Electronics: Columbia, ORNL

DAQ/Trigger: ISU, CU Boulder, OU, ORNL, SBU, UConn, LLNL

Artificial Intelligence: MIT, CNU, Brunel U.

CENTRAL

Tracking:
- Silicon: China, Czech Republic, Japan

Calorimetry
- PWO and SciGlass: Czech Republic, Armenia, France
- Forward Calo/Dual Readout: China, Japan, South Korea

Particle ID
- DIRC: GSI/Germany

FAR FORWARD – FAR BACKWARD
- Roman pots: France
- Off momentum: Israel
- ZDC: Japan
- Luminosity monitors: Israel
- Low Q2 tagger: UK