Preparing for the Detector TDR Phase

João Guimarães da Costa

(for the Physics and Detector Working Group)

中国科学院高能物理研究所

Institute of High Energy Physics
Chinese Academy of Sciences

The 2019 International Workshop on the High Energy Circular Electron Positron Collider
Beijing, November 20, 2019

Key Technology Demonstration and Detector R&D phase

Detector Technical Design Report (TDR)

Key Technology Demonstration and Detector R&D phase

2 International Detector Collaborations to be established

Detector Technical Design Report (TDR)

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The Detector Technical Design Report (TDR) is not of the responsibility of the current CEPC Working Group

This is to be taken by the International Collaborations that will be formed circa 2022-23

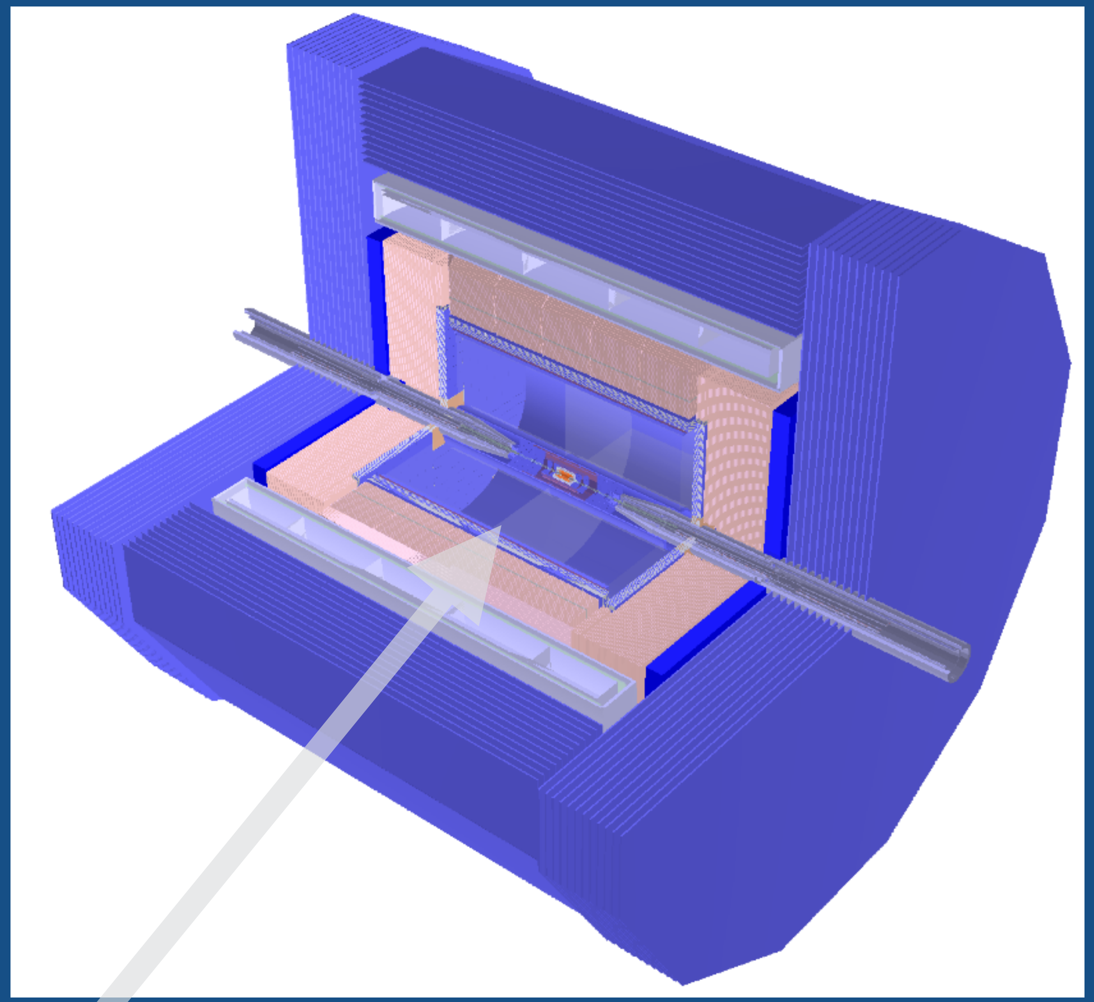
Our job is to promote detector R&D in key technologies applicable to circular e^+e^- collisions:

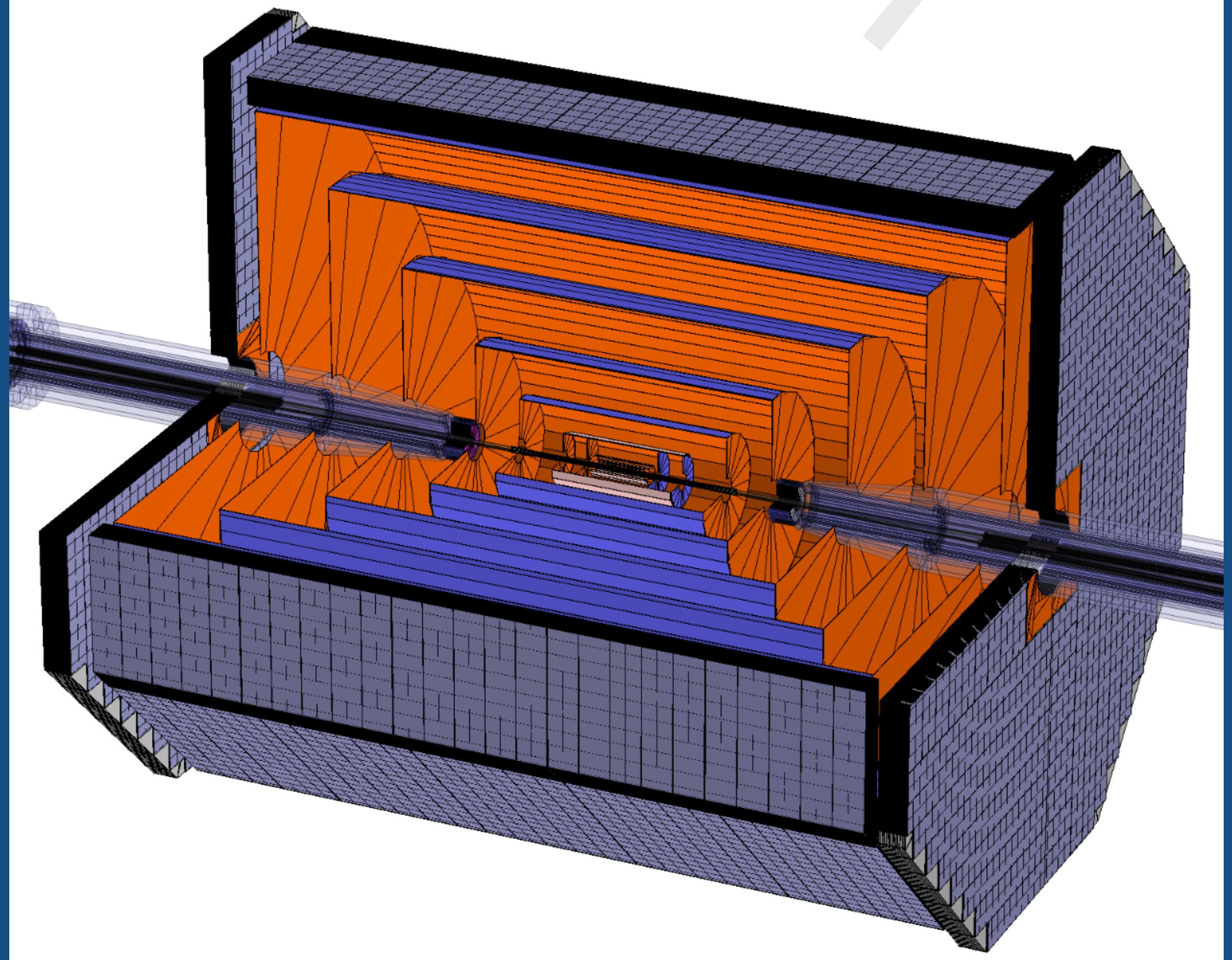
- Taking into account the CEPC timescale
- Keeping an open mind to more challenging emerging technologies

CEPC: These are NOT detector collaborations

Particle Flow Approach

High magnetic field concept (3 Tesla)

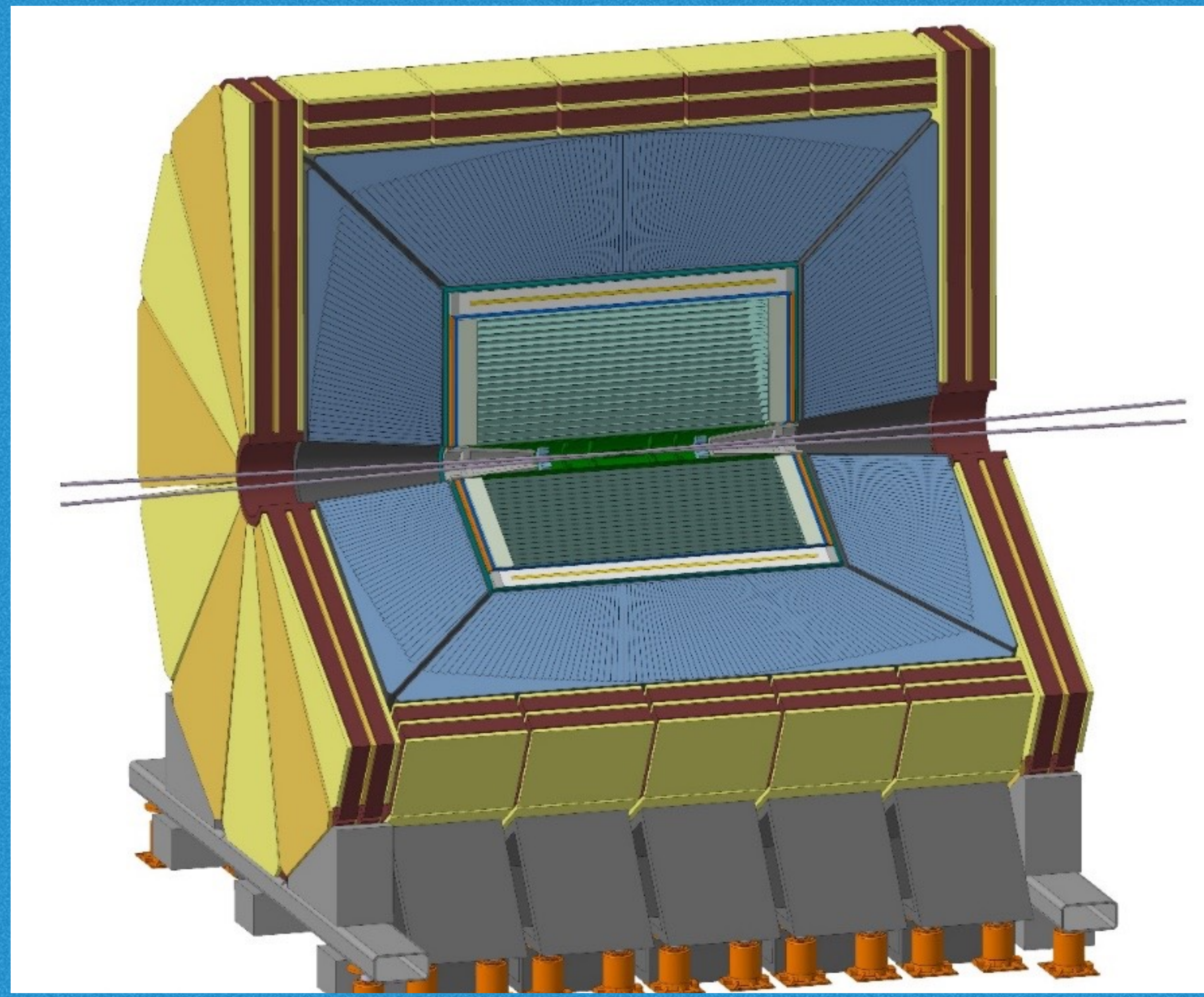




Full silicon tracker concept

CEPC plans for 2 interaction points

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

The Next Steps in the Detector R&D Program

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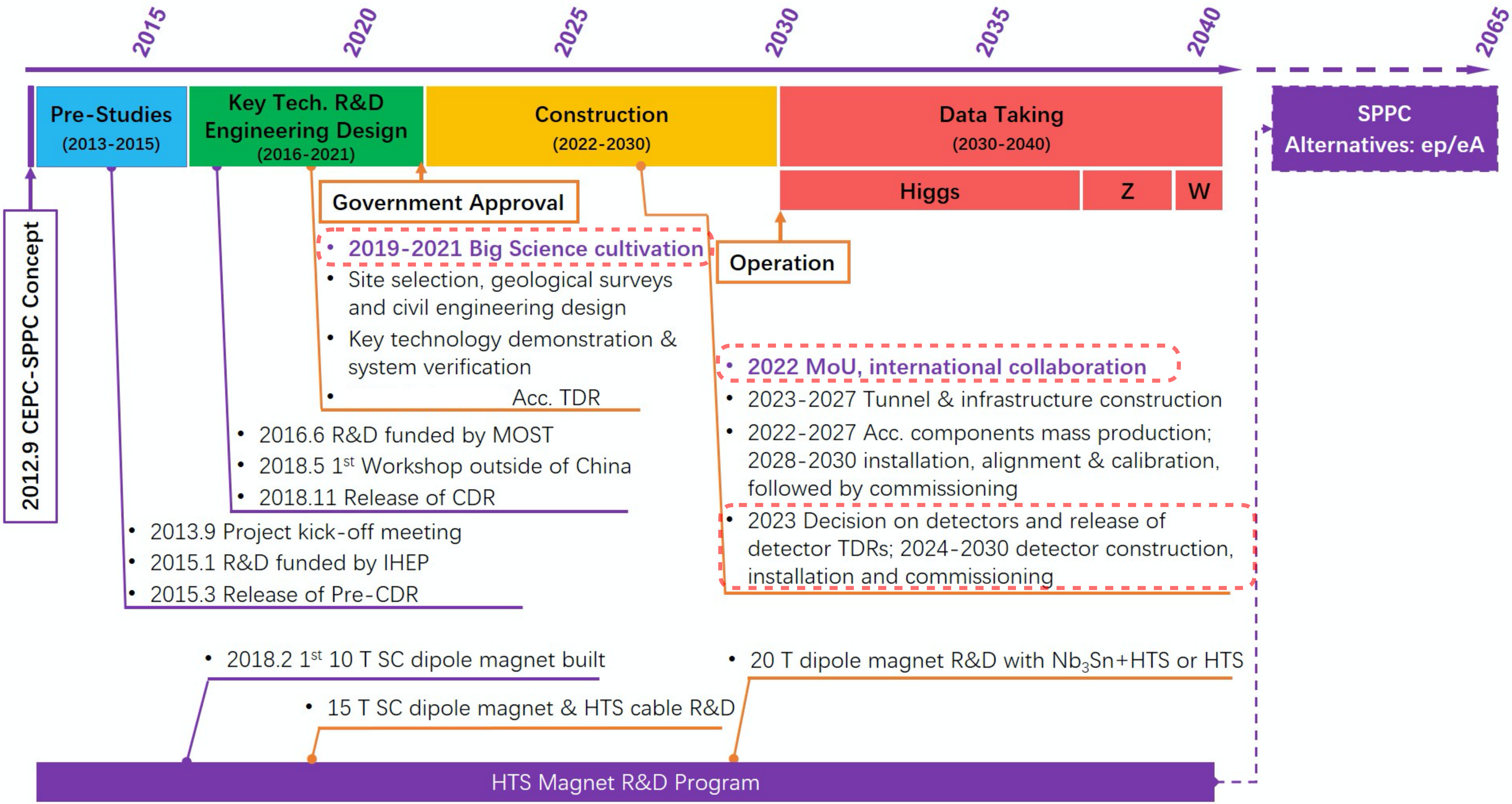
CEPC Project Timeline



CEPC Project Timeline

CEPC International Detector R&D Review Committee (IDRC)

Committee proposed by CEPC IAC

Detector R&D Committee that reviews and endorses the **Detector R&D proposals** from the **international community**, such that the international participants could apply for funds from their funding agencies and make effective and sustained contributions.

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

Evaluate the quality of the research proposed independently of the CEPC project management, and therefore unbiased regarding internal institutional or personal interests

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Later, this committee is expected to evolve to

evaluate the Letters of Intent for the CEPC Detectors

submitted by the proponents of the International Detector Collaborations

(Expected timescale 2022-23)

CEPC International Detector R&D Review Committee (IDRC)

Committee: 16 members

Dave Newbold, UK, RAL (chair)
Jim Brau, USA, Oregon
Valter Bonvicini, Italy, Trieste
Ariella Cattai, CERN, CERN
Cristinel Diaconu, France, Marseille
Brian Foster, UK, Oxford
Liang Han, China, USTC
Andreas Schopper, CERN, CERN

Steinar Stapnes, CERN, CERN
Hitoshi Yamamoto, Japan, Tohoku
Harvey Newman, USA, Caltech
Abe Seiden, USA, UCSC
Laurent Serin, France, LAL
Roberto Tenchini, Italy, INFN
Ivan Villa Alvarez, Spain, Santader
Marcel Stanitzki, Germany, DESY

First meeting happened yesterday afternoon

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Organizational Meeting:

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

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

Committee will provide a short report with an opinion regarding the current R&D program and future directions

Highlights for discussion at IDRC Meeting

Machine Detector Interface *5'*
Speaker: Dr. Hongbo ZHU (IHEP)
Material: Slides

Luminometer *5'*
Speaker: Suen Hou (高能所)
Material: Slides

Silicon vertex detector *5'*
Speakers: Prof. Qun OUYANG (IHEP), Prof. Zhijun Liang (IHEP)
Material: Slides

Silicon tracker *5'*
Speakers: Prof. Meng Wang (Shandong University), Dr. Hongbo ZHU (IHEP)
Material: Slides

Time Projection Chamber *5'*
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
Material: Slides

Drift Chamber *5'*
Speakers: Franco Grancagnolo, Franco Bedeschi (INFN-Pisa)
Material: Slides

Electromagnetic Calorimetry *5'*
Speakers: Dr. Yong Liu (Institute of High Energy Physics), Dr. Jianbei Liu (University of Science and Technology of China)
Material: Slides

Hadronic Calorimetry *5'*
Speakers: Haijun Yang (Shanghai Jiao Tong University), Dr. Jianbei Liu (University of Science and Technology of China)
Material: Slides

Dual Readout Calorimeter *5'*
Speakers: Dr. gabriella gaudio (INFN-PV), Franco Bedeschi (INFN-Pisa), Prof. Sehwook Lee (Kyungpook National University)
Material: Slides

Solenoid Magnet *5'*
Speaker: Dr. Feipeng NING (IHEP)
Material: Slides

Muon detector *5'*
Speaker: Paolo Giacomelli (INFN-Bo)

Software *5'*
Speaker: Dr. Weidong Li (高能所)
Material: Slides

Trigger and DAQ *5'*
Speaker: Mr. Jingzhou ZHAO Jingzhou (高能所)

Key issues in the short term

CEPC Running Program and Datasets for CDR

Operation mode	Z factory	WW threshold scan	Higgs factory
$\sqrt{s}$ (GeV)	91.2	158 – 172	240
Running time (years)	2	1	7
L (10^{34} cm^{-2}s^{-1}) per IP	17 – 32	10	3
Integrated Luminosity (ab^{-1})	8 – 16	2.6	5.6
Higgs yield	–	–	10^6
W yield	–	10^7	10^8
Z yield	10^{11-12}	10^8	10^8

2 IPs

3 Tesla vs 2 Tesla Solenoid

CDR studies assume 2 Interaction Points

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	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
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	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	17.1/0.042	6.0/0.04	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	0.67	0.22	2.1	1.8
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	5.2	32.1	101.6

Luminosity increase factor: × 1.8 × 3.2

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

Luminosity increase factor: × 1.8 (Higgs), × 3.2 (Z)

Re-evaluation of physics requirements

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

under discussion → started at this meeting → aim at workshop in Hong Kong

Software and Reconstruction algorithms

After the CDR it is a good time to re-evaluate our software tools

Developing a Common Software Stack

Simulation Software

Based on standard tools

Root data format
DD4hep
Geant4

New hit-based Fast Simulation

FATRAS
(Fast ATLAS TRAck Simulation)

Reconstruction Software

Considering new tracking tool

ACTS
(A Common Tracking Software)

Porting of PFA tools:
Pandora and Arbor

Developing other algorithms:
vertex, long-lived charged particles,
particle identification in jets

Workshop in Bologna (June 12-13) (FCC, CEPC, ILC) kicked-off collaboration:
https://agenda.infn.it/event/19047/

Converged to a Turnkey Software Stack (Gaudi)

See Weidong's talk next

Overview

Program: January 7-25, 2019
Conference: January 21-24, 2019

- Detector Mini-workshop:
  Software and Physics Requirements for e+e- Colliders- Jan 16, 17
  - Joint workshop CEPC/FCC-ee + others
  - Day 1: Software framework
  - Day 2: Physics requirements

Optimization of detectors

Not an easy task without definite target detectors/collaborations

Work needs to be shared and co-ordinated at common Detector Plenary Meeting

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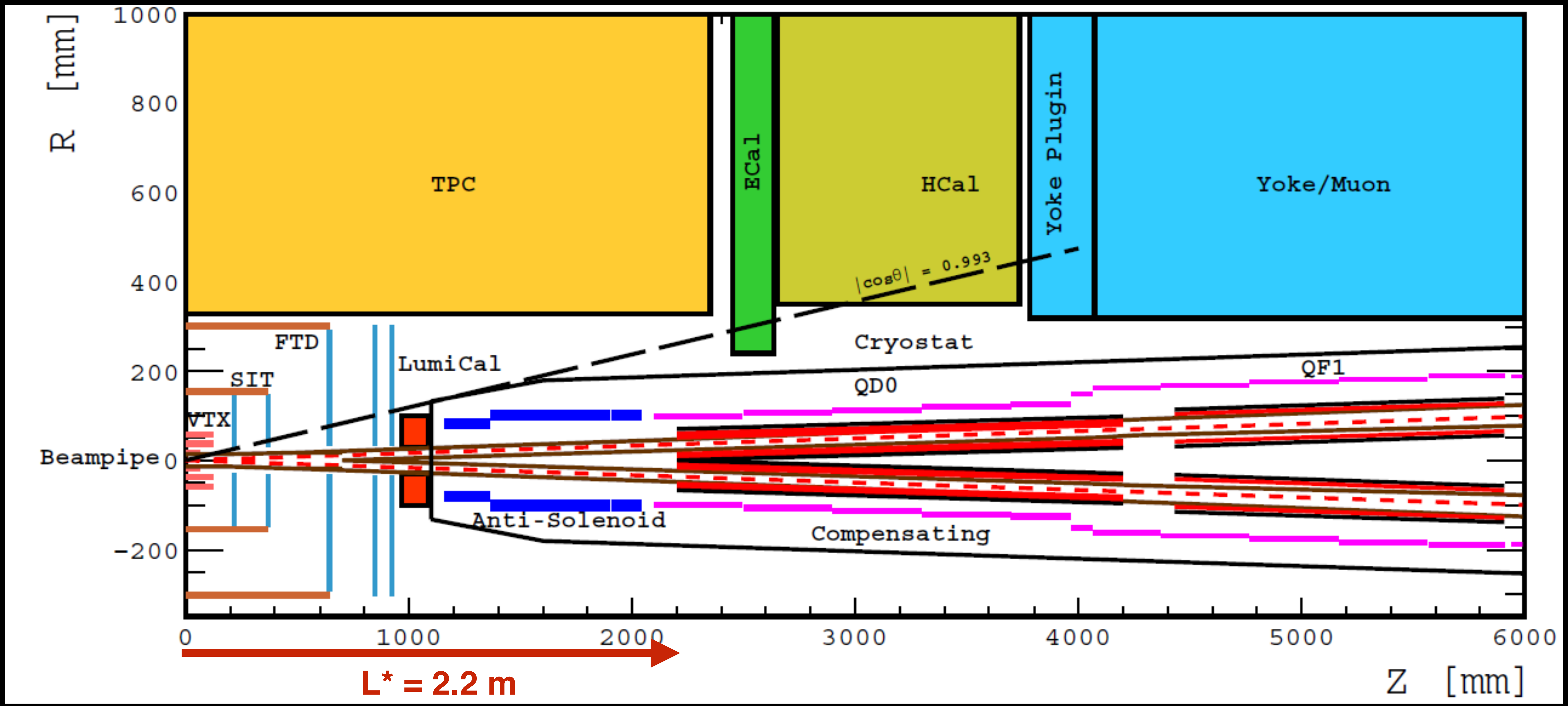
- Need to consider costing issues

Machine–detector interface (MDI) in circular colliders

High luminosities → **Final focusing quadrupoles (QD0) need to be very close to IP**

Head-on collision crossing angle: **33 mrad**

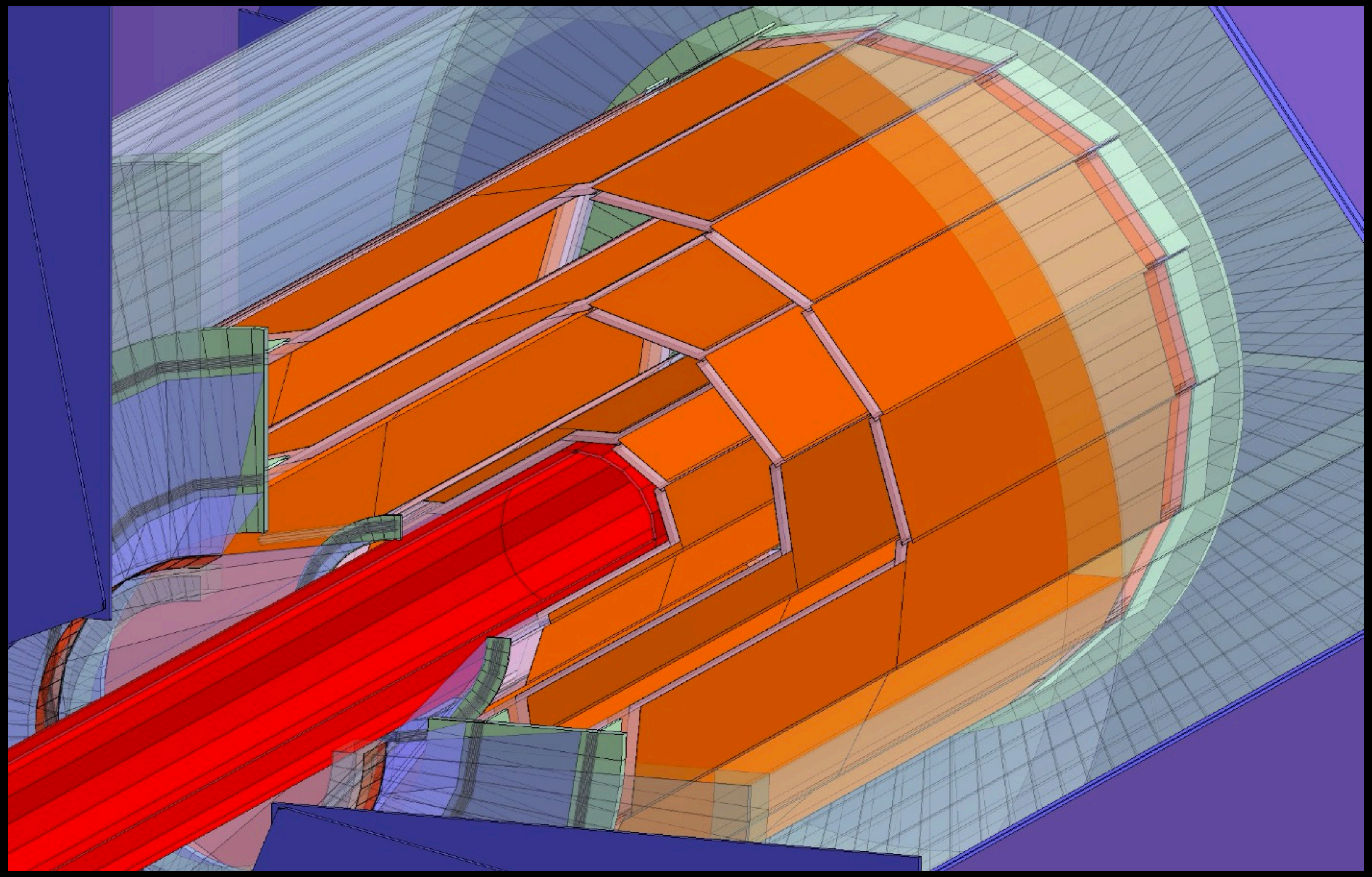
Detector acceptance: > ± 150 mrad



Cooling of beampipe needed → increases material budget near the interaction point (IP)

Baseline Pixel Detector Layout

3-layers of double-sided pixel sensors



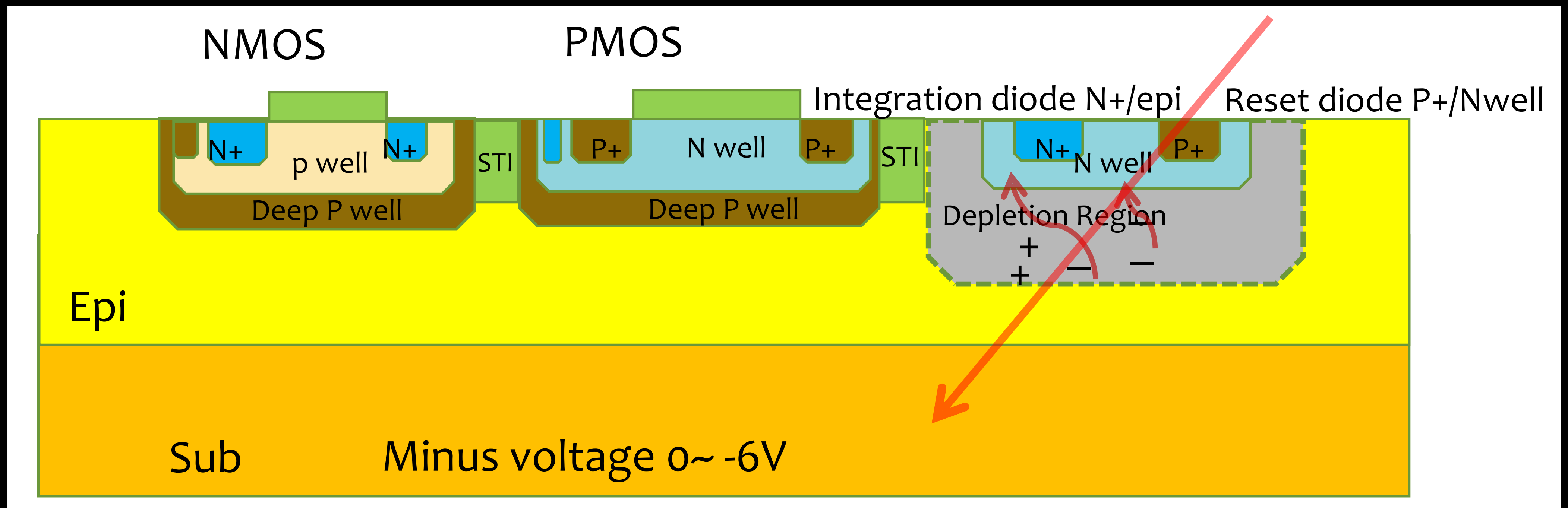
- ILD-like layout
- Innermost layer: σ_{SP} = 2.8 μm
- Polar angle θ ~ 15 degrees

Low material budget
~ 0.15%X_0 per layer

		$R(mm)$	$\lvert z\rvert(mm)$	$\lvert cos\theta\rvert$	$\sigma(\mu m)$	$Readout\ time(us)$
Ladder 1	Layer 1	16	62.5	0.97	2.8	20
	Layer 2	18	62.5	0.96	6	1-10
Ladder 2	Layer 3	37	125.0	0.96	4	20
	Layer 4	39	125.0	0.95	4	20
Ladder 3	Layer 5	58	125.0	0.91	4	20
	Layer 6	60	125.0	0.90	4	20

Implemented in GEANT4 simulation framework (MOKKA)

CMOS pixel sensor (MAPS)



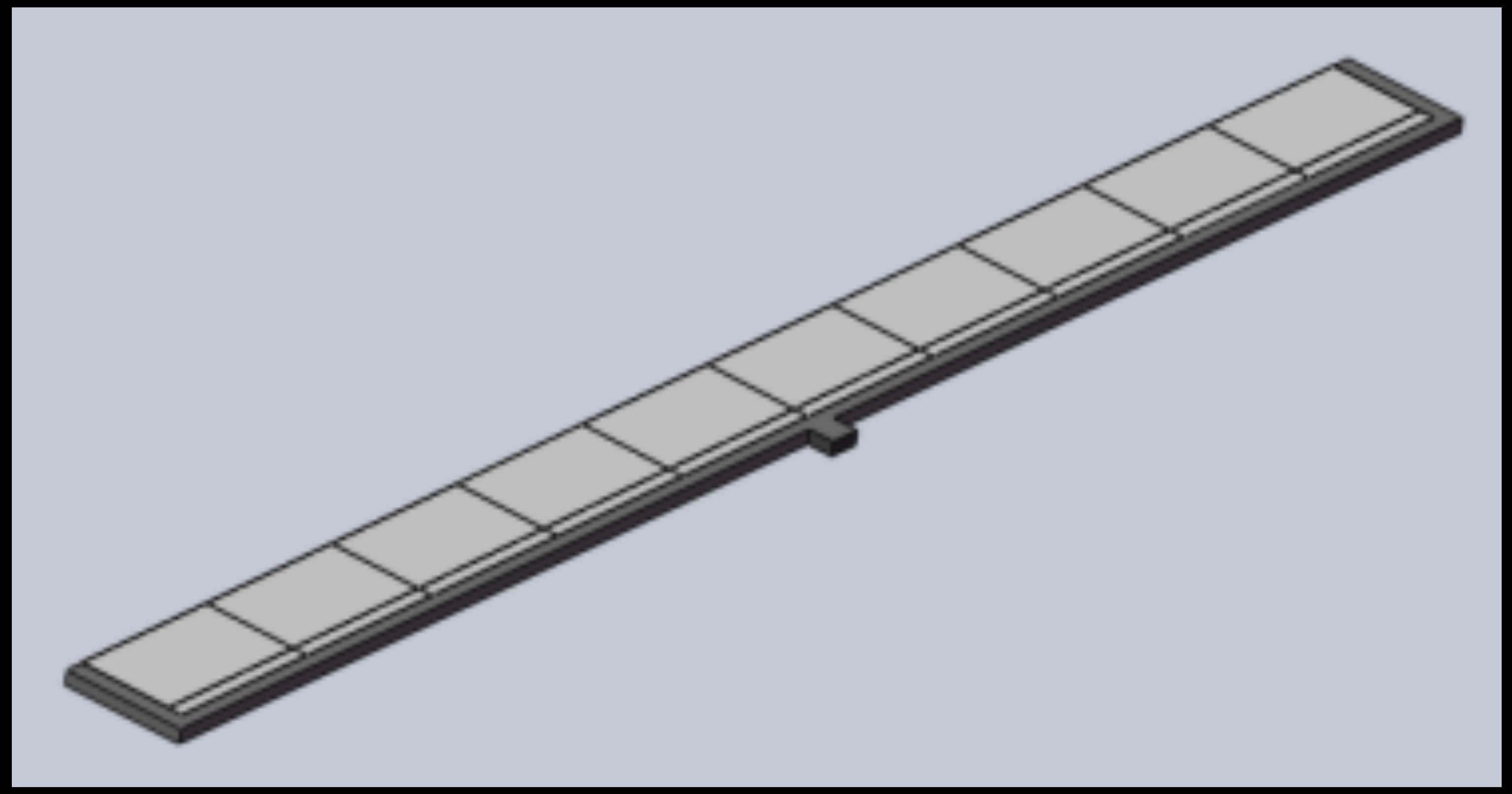
Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process:
- low material budget,
- low power consumption,
- low cost …

Pixel Vertex Detector Prototype

- **Full size prototype to be built and tested 2023**

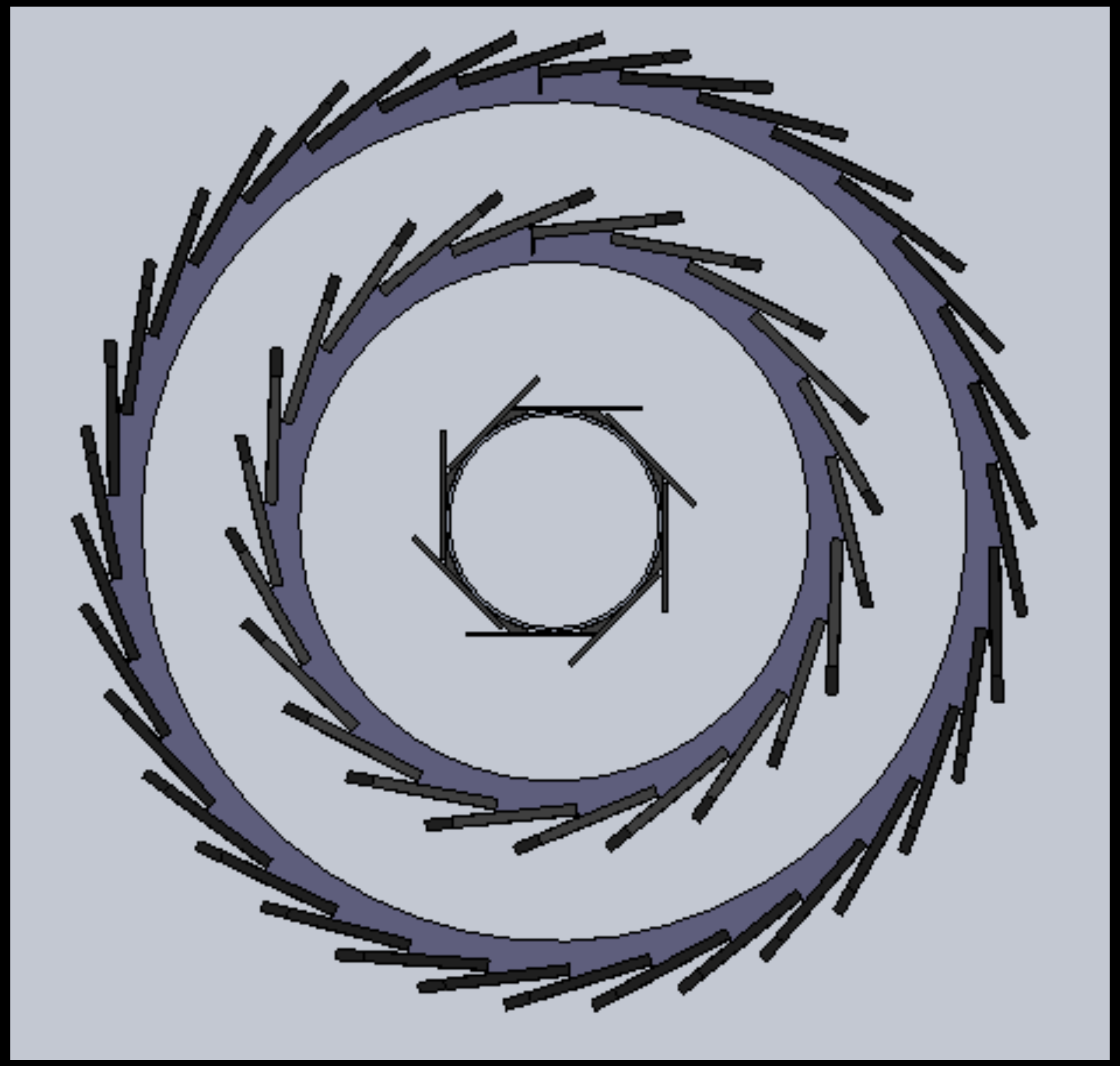
  Explore light material construction

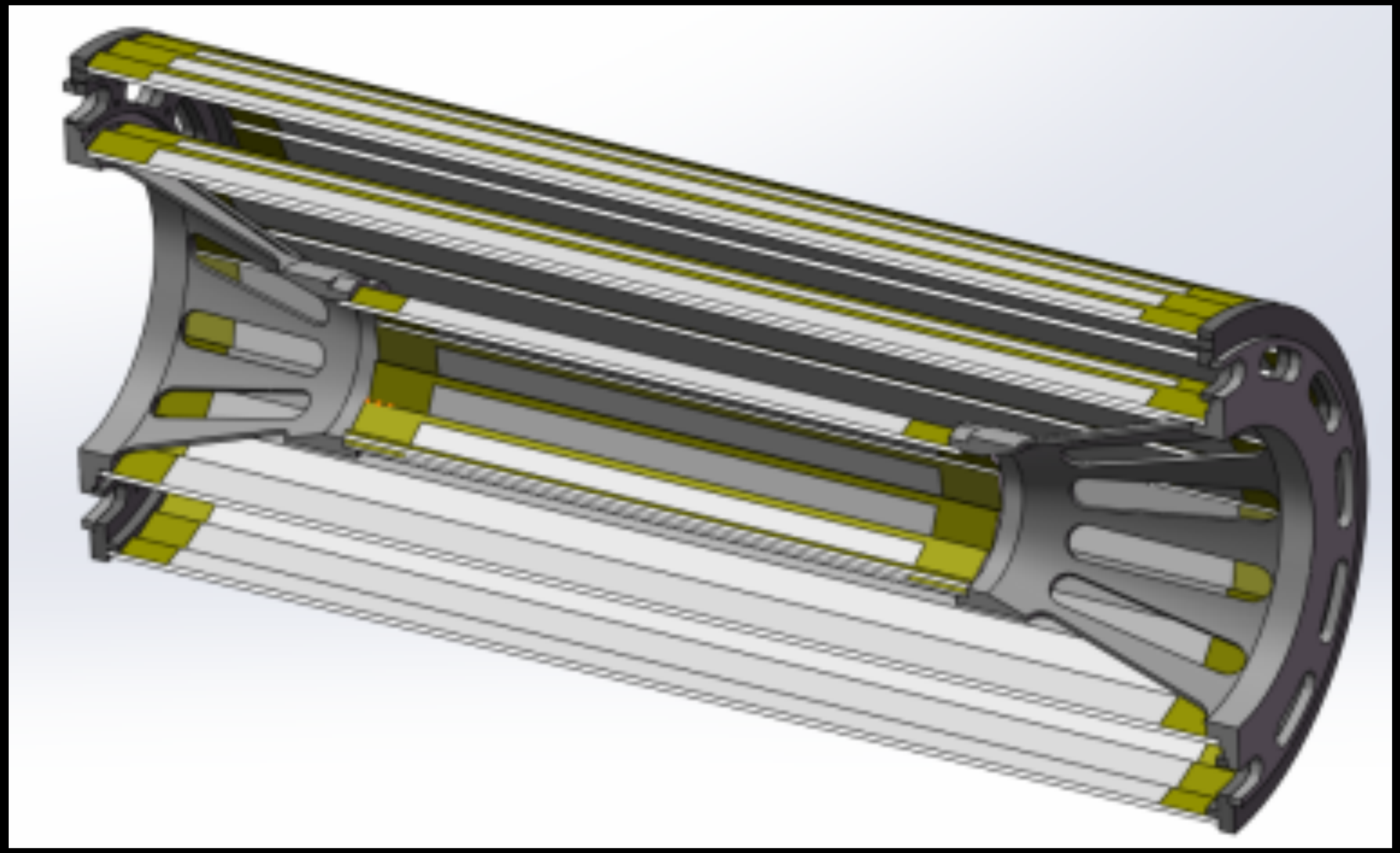
  Full size chip



- **Detector layout optimization required**

  Engineering design started (including cabling, cooling, installation)





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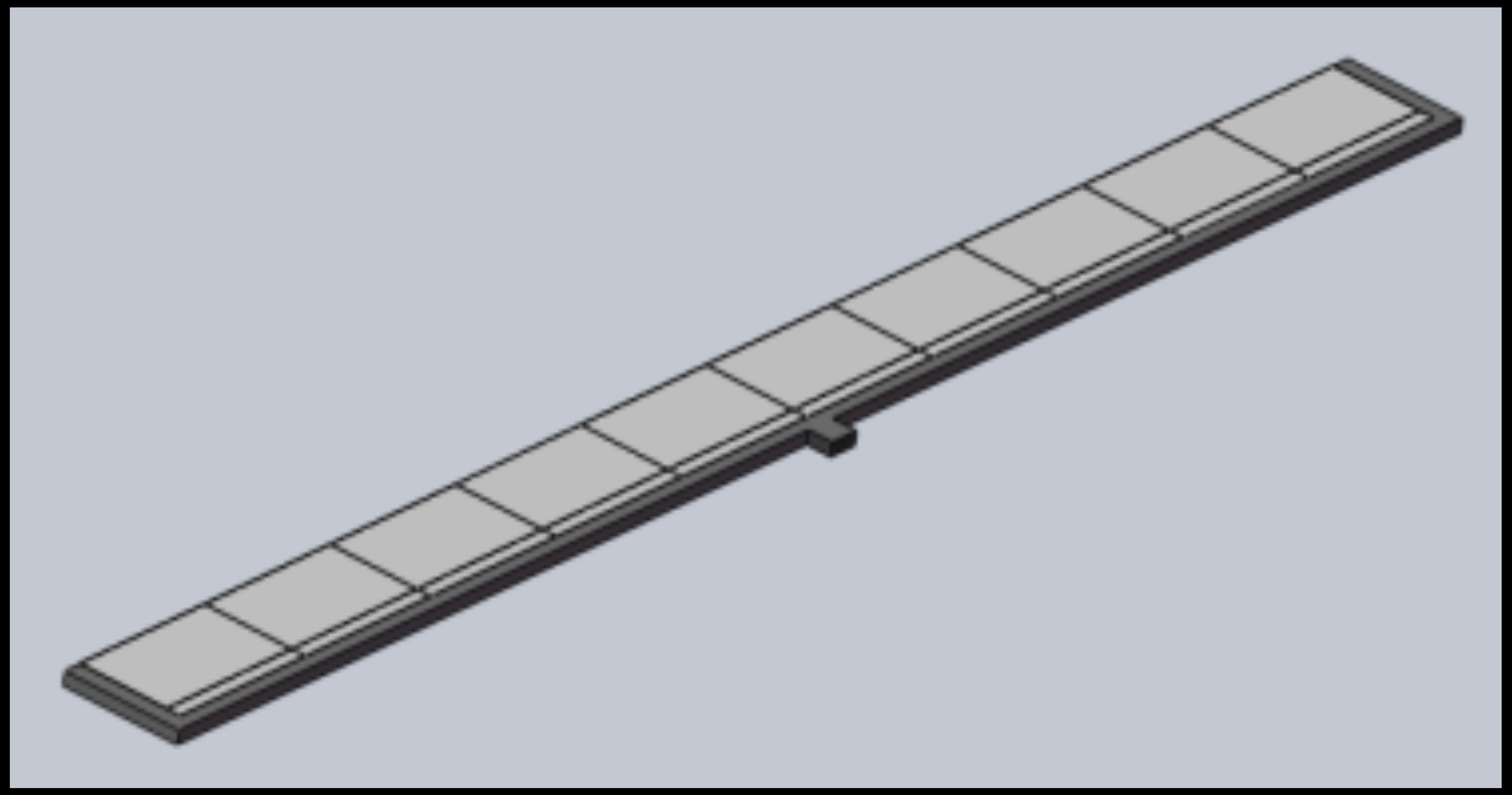

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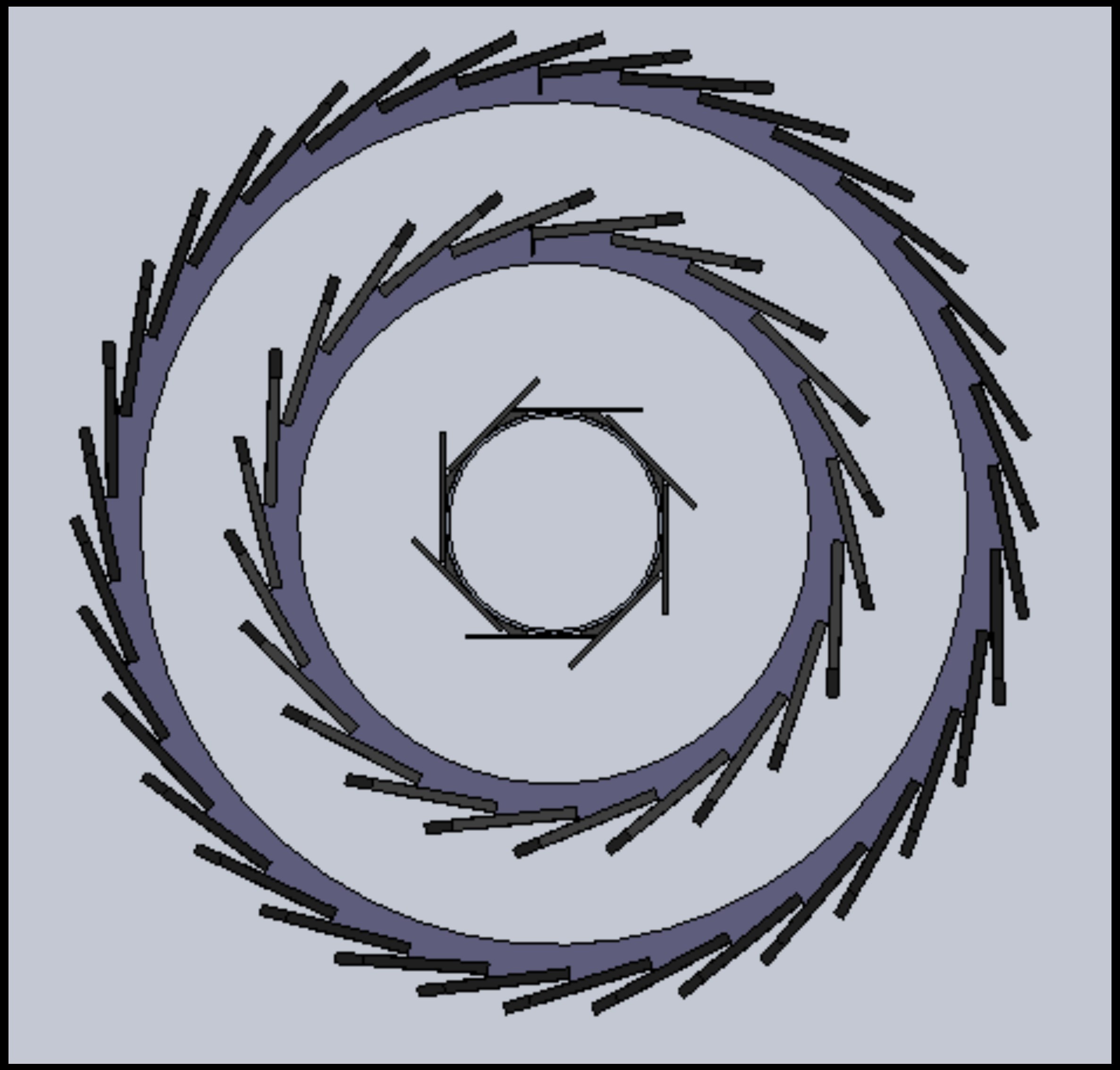
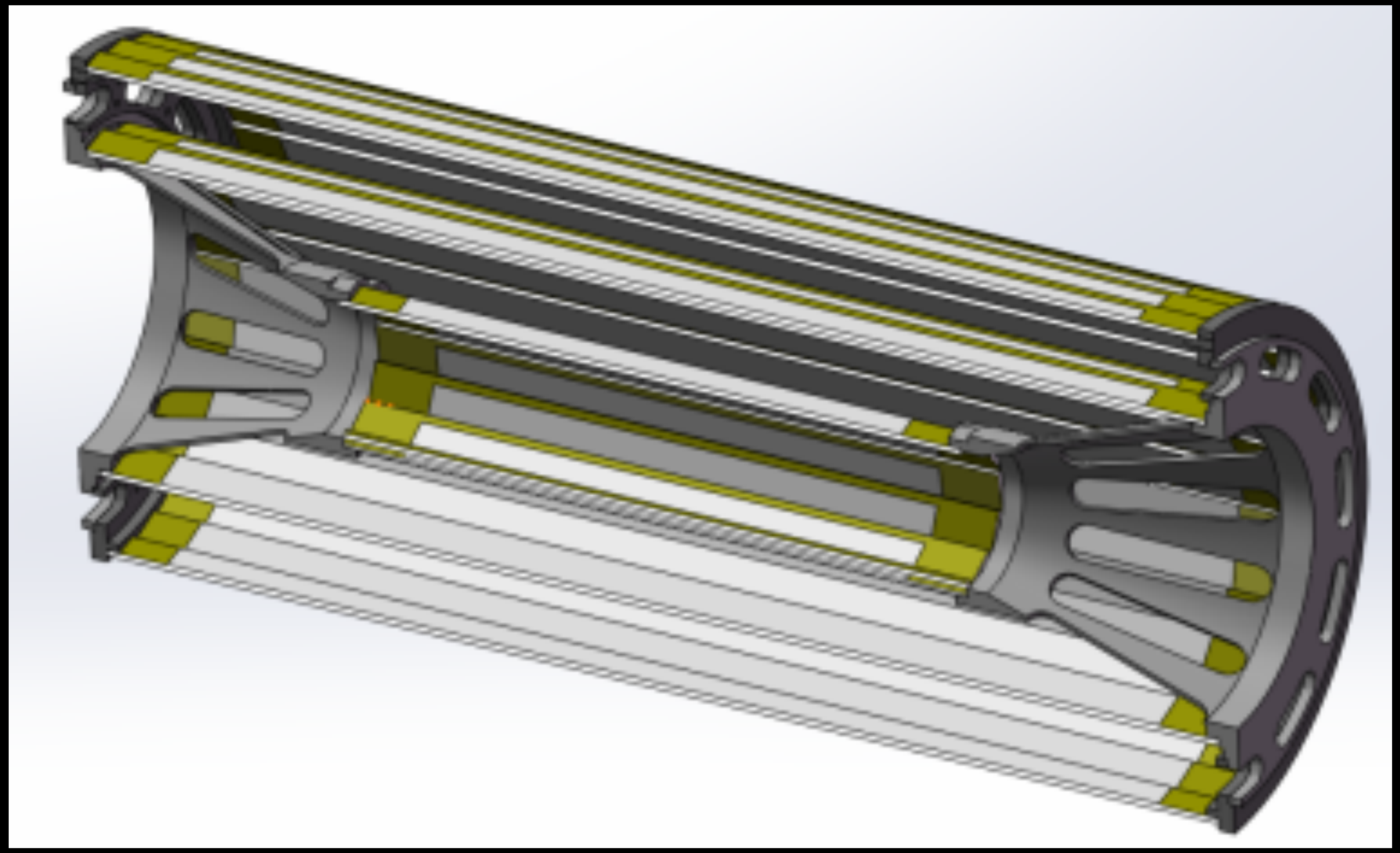
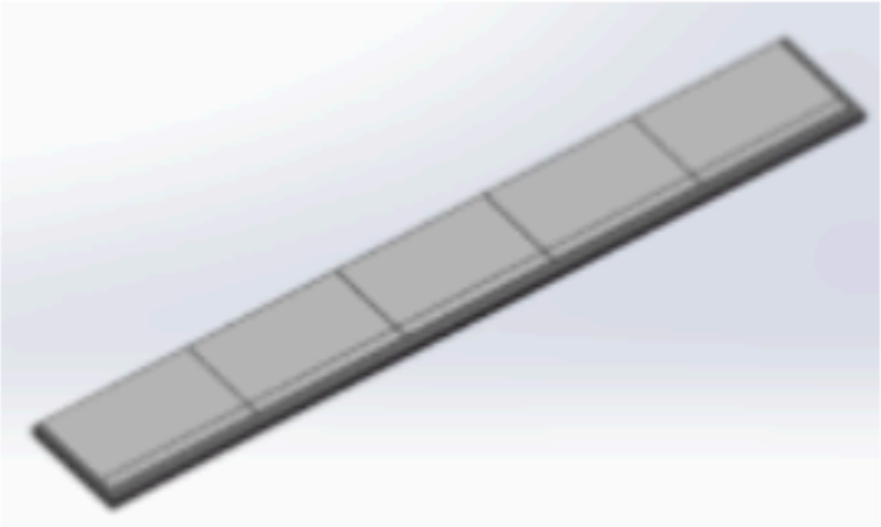


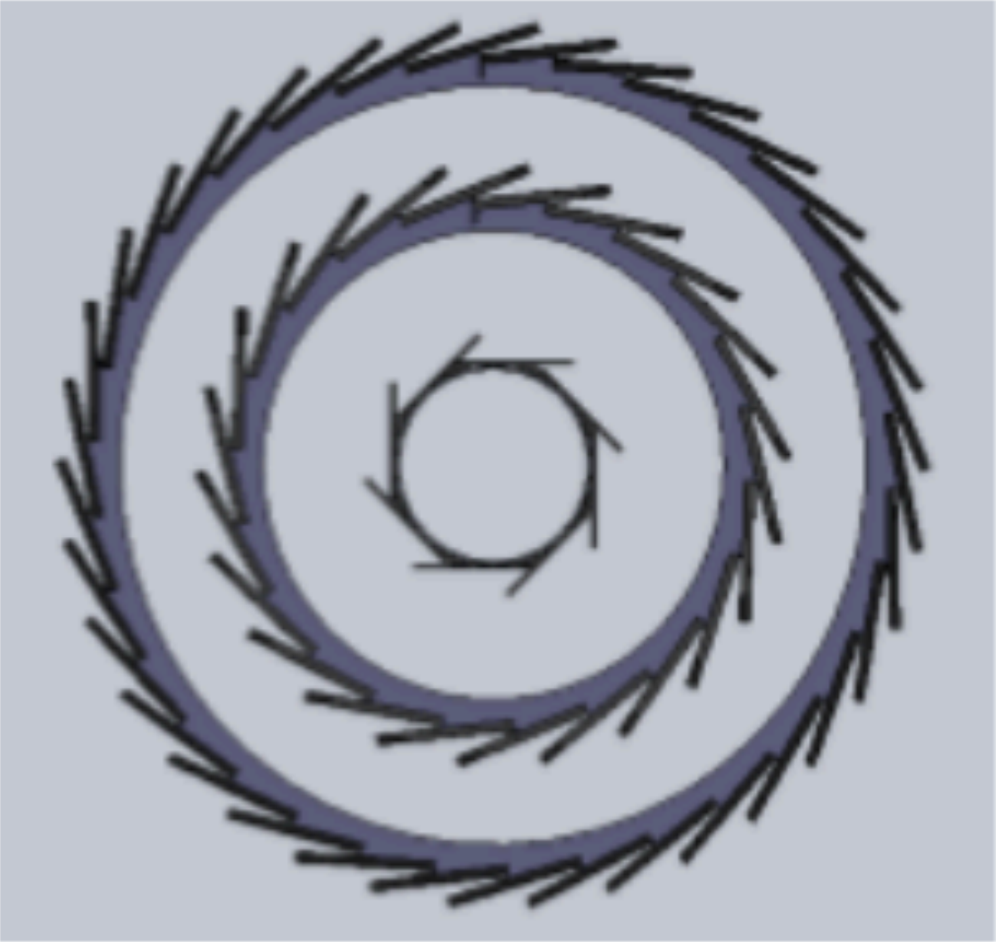


Effort needs to be integrated with MDI engineering design

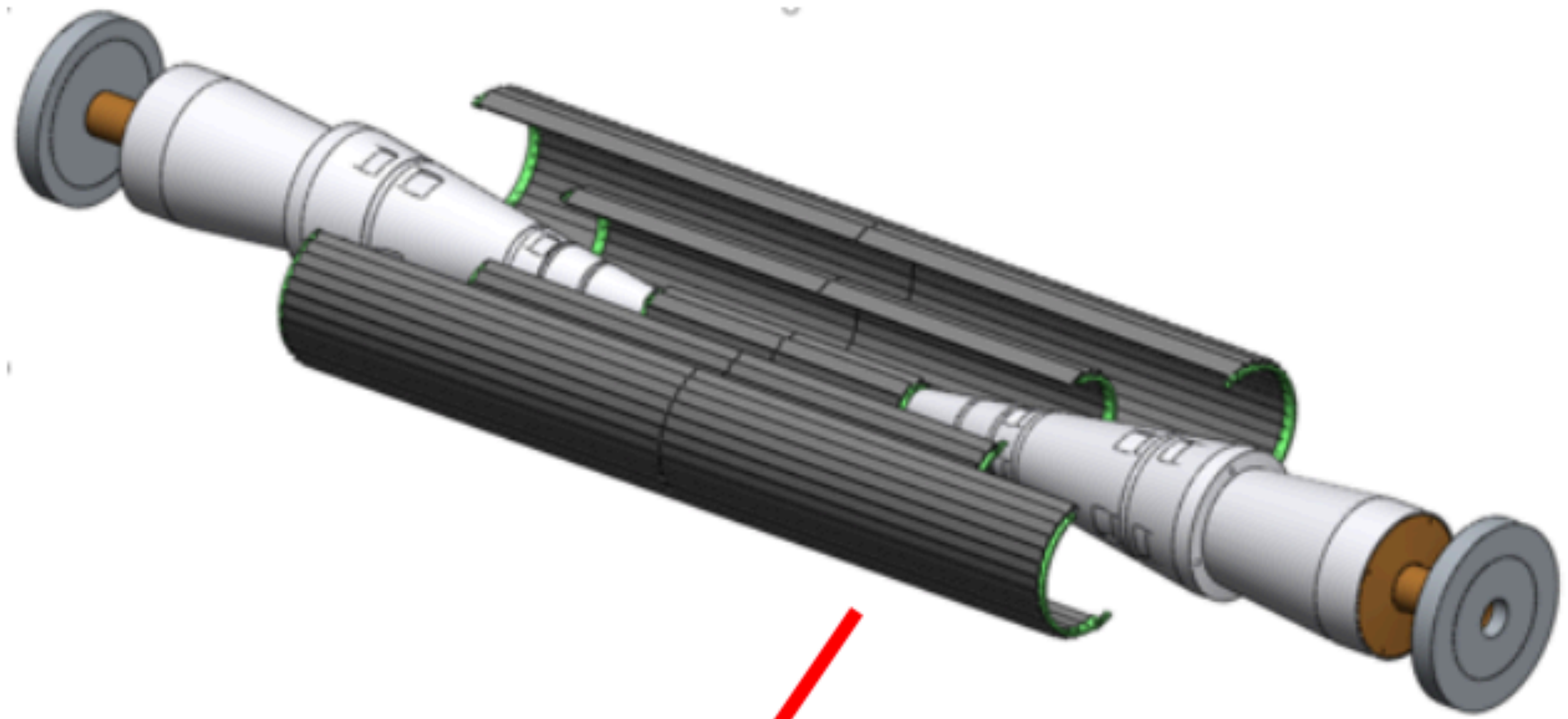
Silicon vertex supporting structure



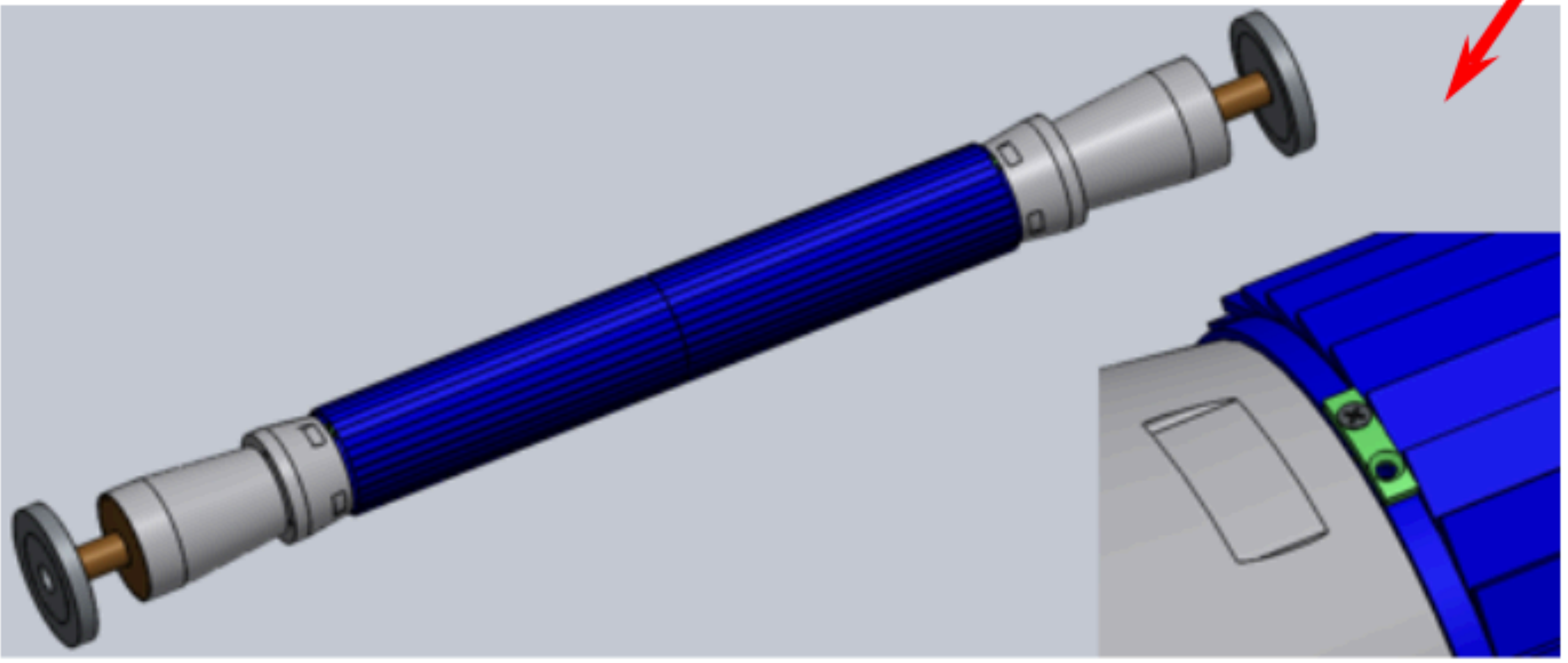
Detection unit



Ring arrangement

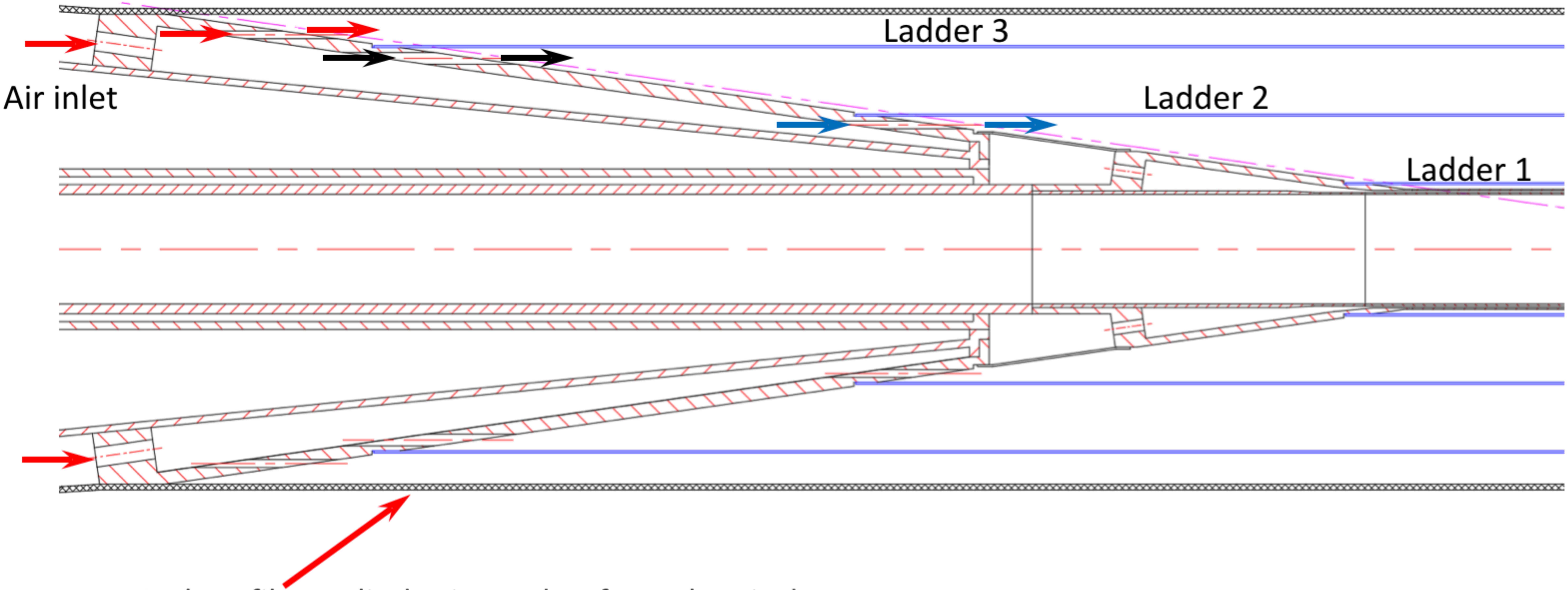


Half ring structure



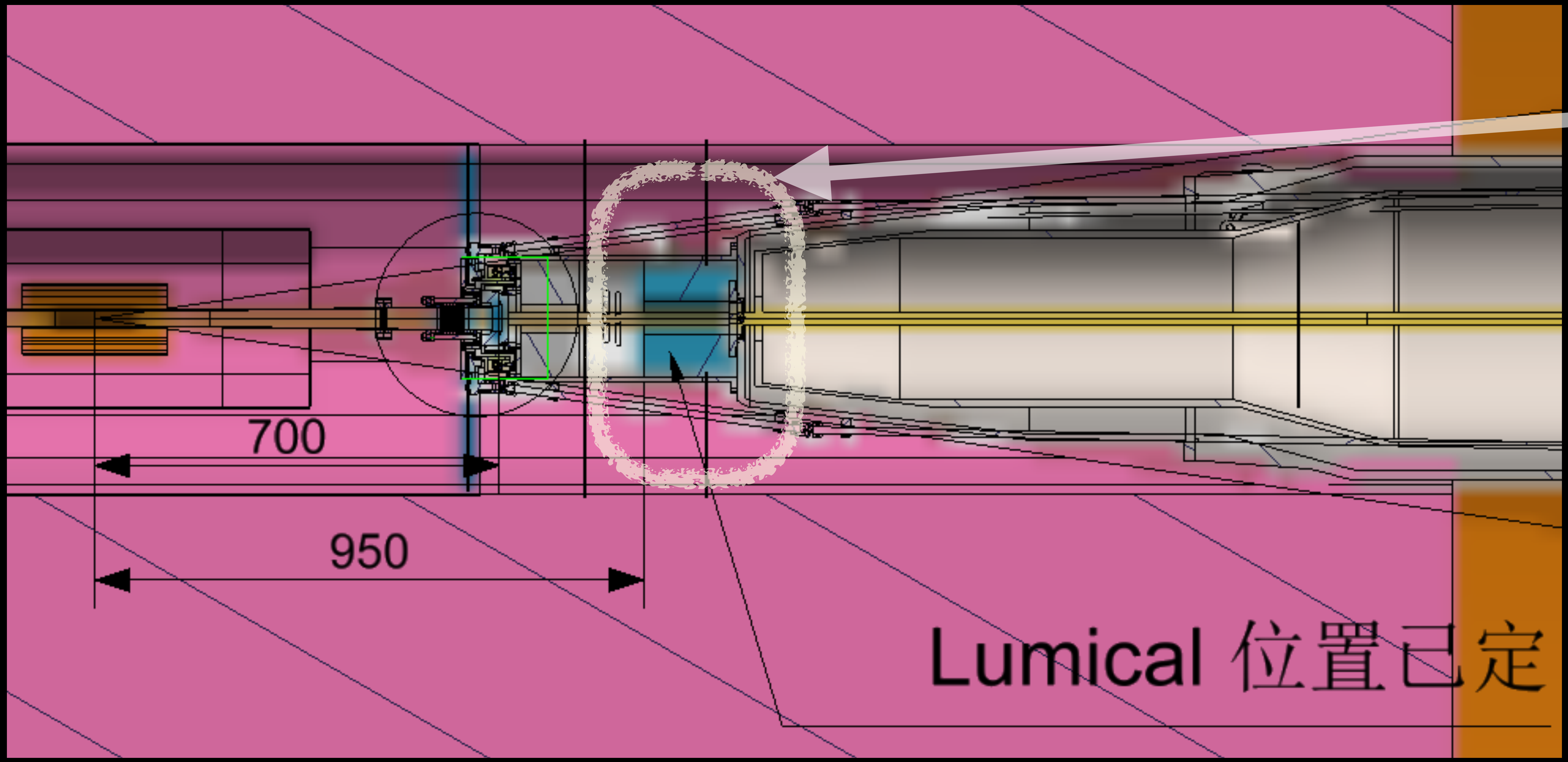
Silicon vertex supporting structure

1) Silicon Vertex Detector --- air cooling design



Carbon fiber cylinder is used to form the air duct.

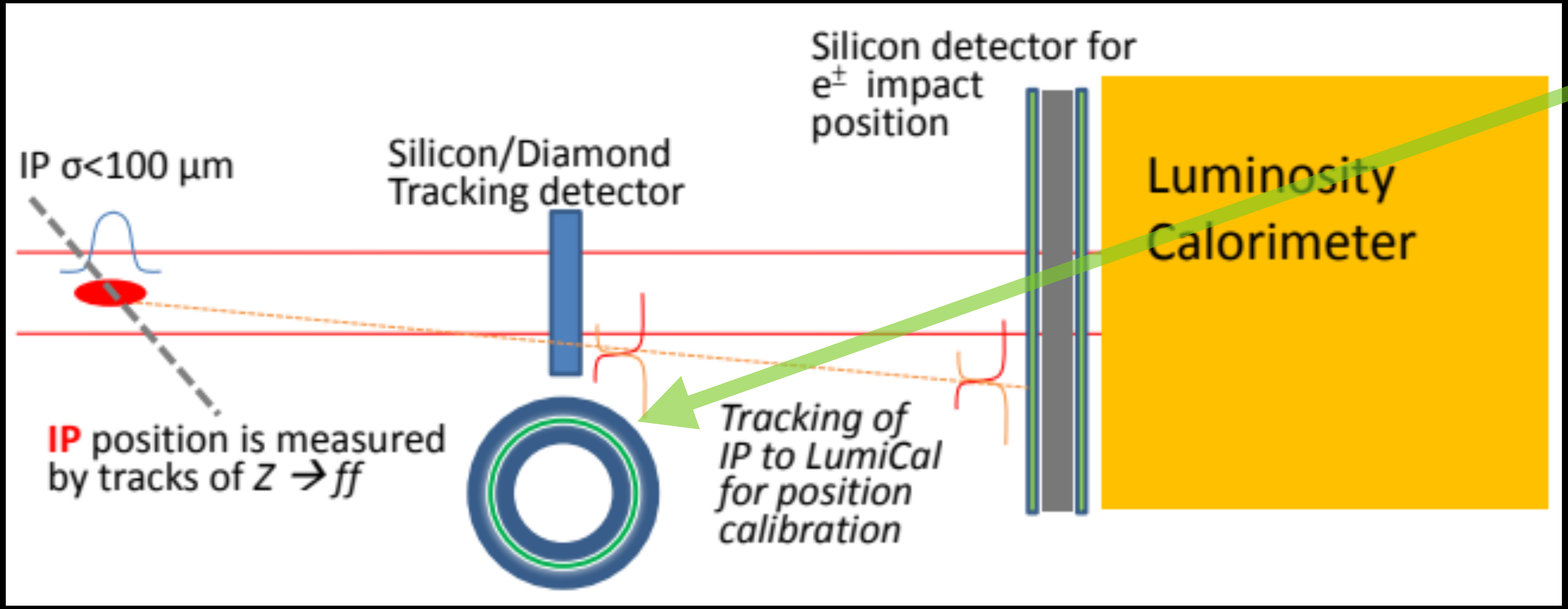
LumiCal



Si-W Calorimeter: ~ 20 X_0, ~10 kg

Located behind flange

Large amount of material impossibilities precise energy and position measurements



Ameliorate situation by adding a silicon/diamond tracking ring

Working on new idea whereas LumiCal is attached to the inner tracker structure/beampipe

Moving the LumiCal into the beampipe structure

LumiCal,20kg

LumiCal,20kg

Weight： about 13+20+20=53Kg

(does not include vertex and Carbon fiber cylinder weight)

Some key R&D topics

- Machine Detector Interface
- Luminosity meter (LumiCal)
- Silicon Vertex (material budget versus resolution versus cooling)
  - Services design and integration

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Transparency <—> reliability/resolution

  - Time Projection Chamber
    - Ion back flow and field distortion is a major problem to operate at the Z pole and 2 Tesla
  - Drift Chamber
    - Can it cope with the high rates at the Z pole? Enough resolution?
  - Full silicon tracker
    - Are we adding too much material?
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    - What about particle identification? Does it really matter?
- Do we really need a 3 Tesla solenoid? Why?
  - Trade-off of luminosity versus resolution and particle identification needed?
  - Can the same physics goals be achieved some other way?

Some key R&D topics

- Calorimetry
  - ECAL, HCAL, DR
    - cost versus physics performance
    - Cooling of PFA calorimeter? versus performance?
    - PFA ECAL photon resolution rather poor
      - Do we need to improve it for physics purposes?
      - Does it make sense to pay for such expensive detector with poor photon resolution
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  - Why so many muon layers?
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no need to rush for another document based on full simulation and detailed studies

First, integrate better detector and physics performance people to study different options

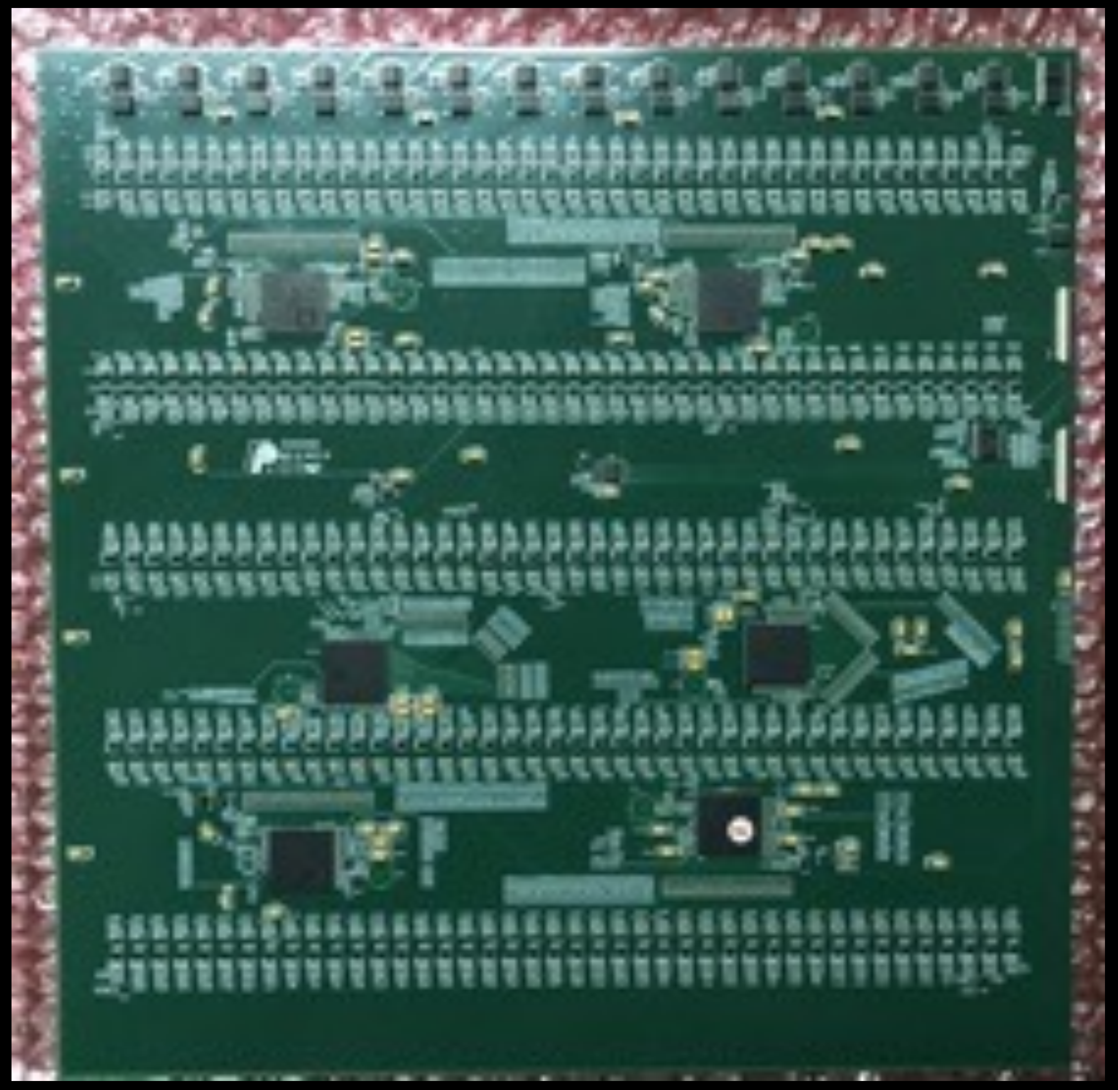
Building prototypes

ECAL Calorimeter — Particle Flow Calorimeter

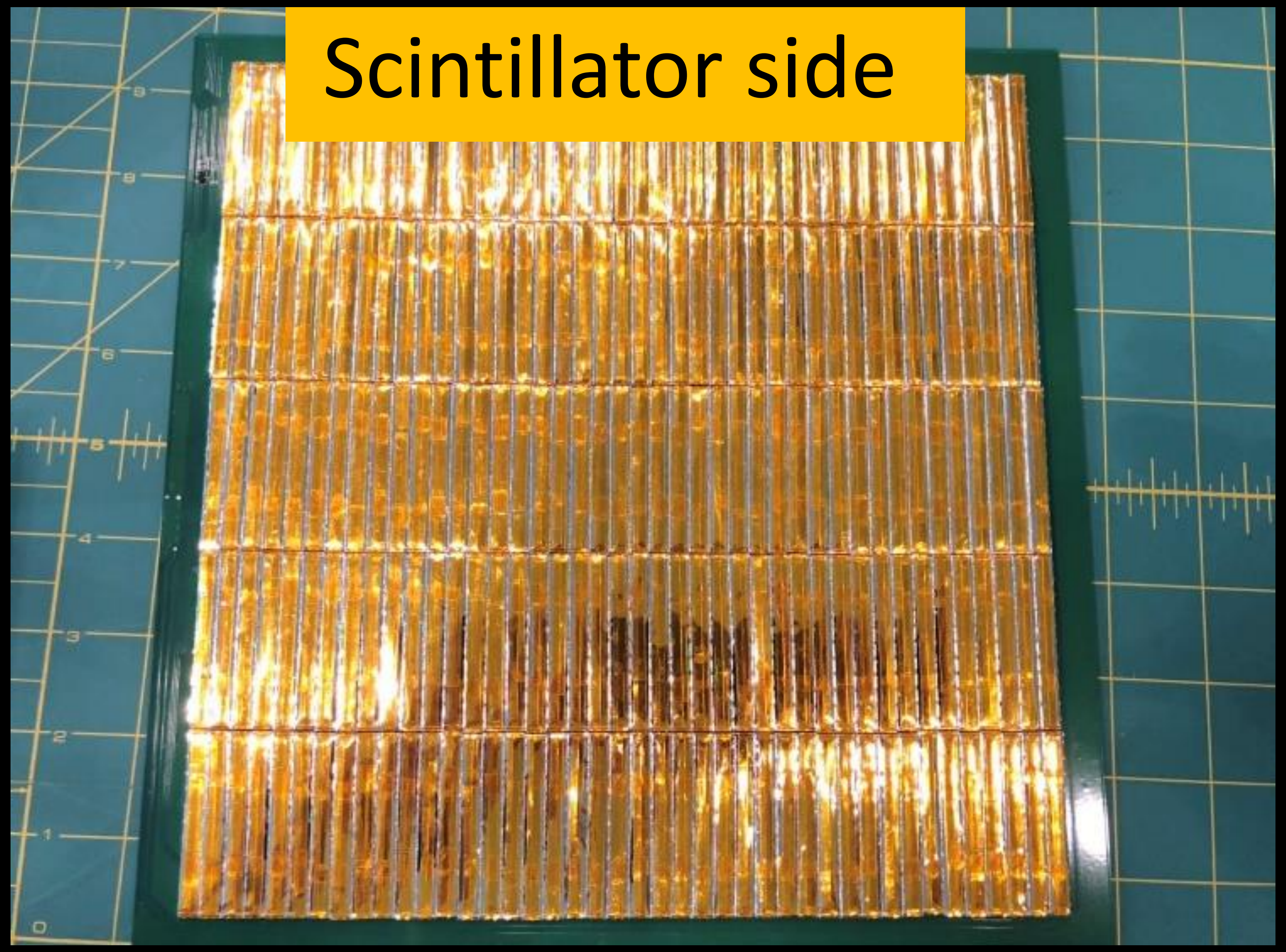
Scintillator-Tungsten Sandwich ECAL

Prototype to be built and lab test by August 2020
Test beam at DESY to follow

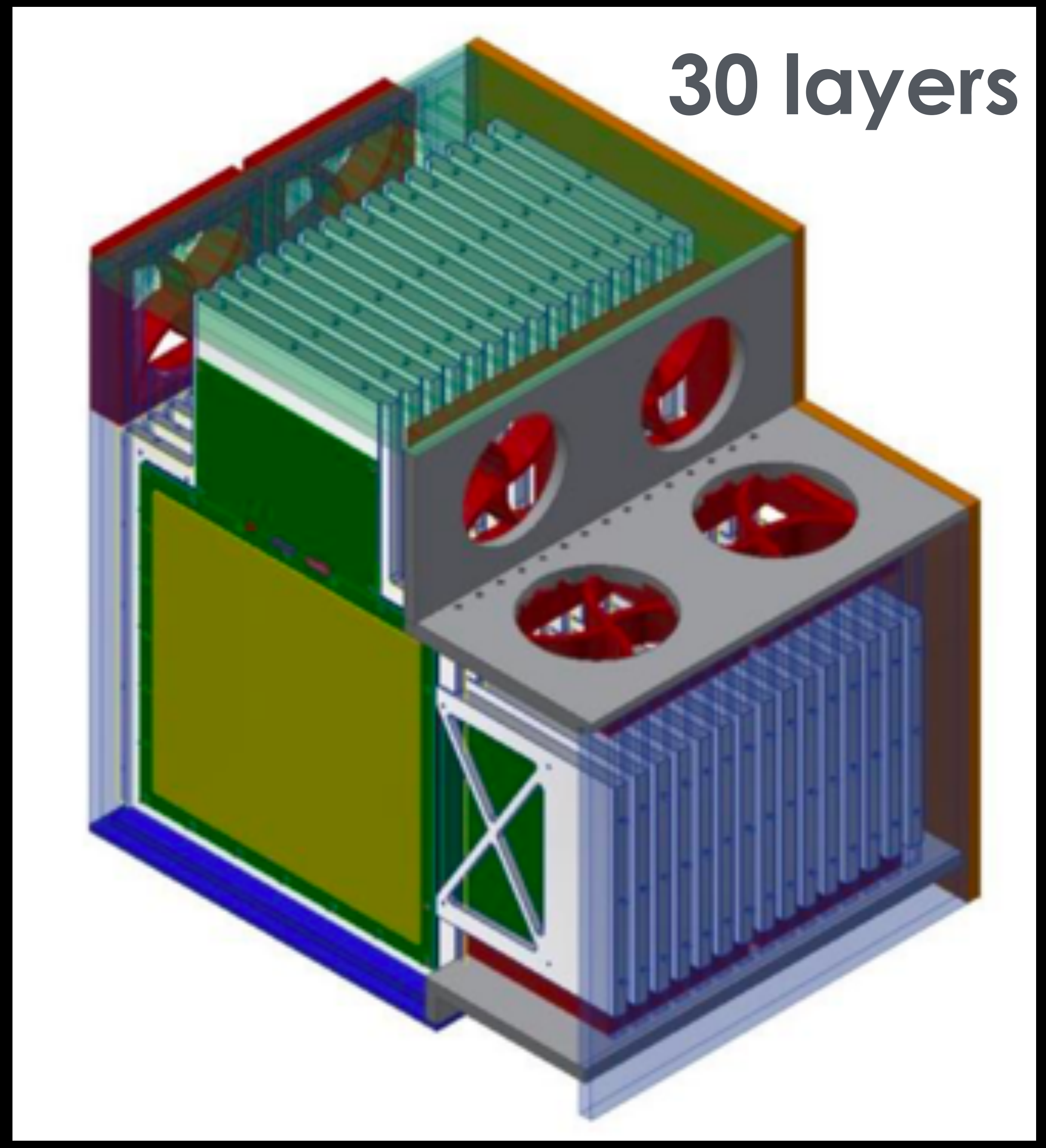
Designed and developed new version of front-end PCB with SPIROC-2e chips



Mass production of scintillator strips and wrapping established



Mechanical and structural design of the prototype

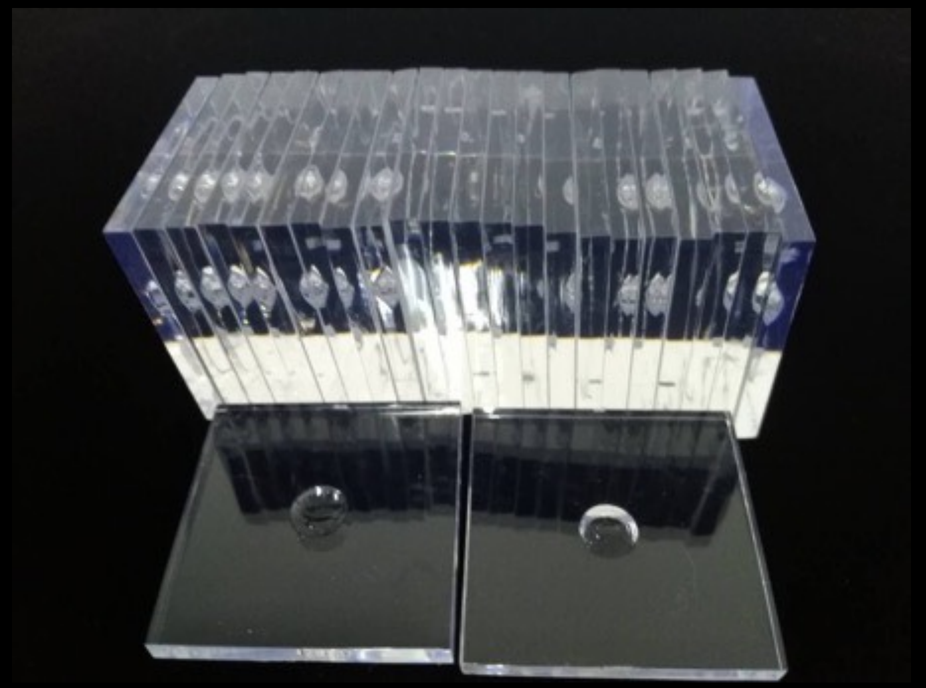


active area: ~ 25 x 25 cm^2

Essential collaboration with Japanese Sci-ECal group established: Prototype will be joint effort

HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)

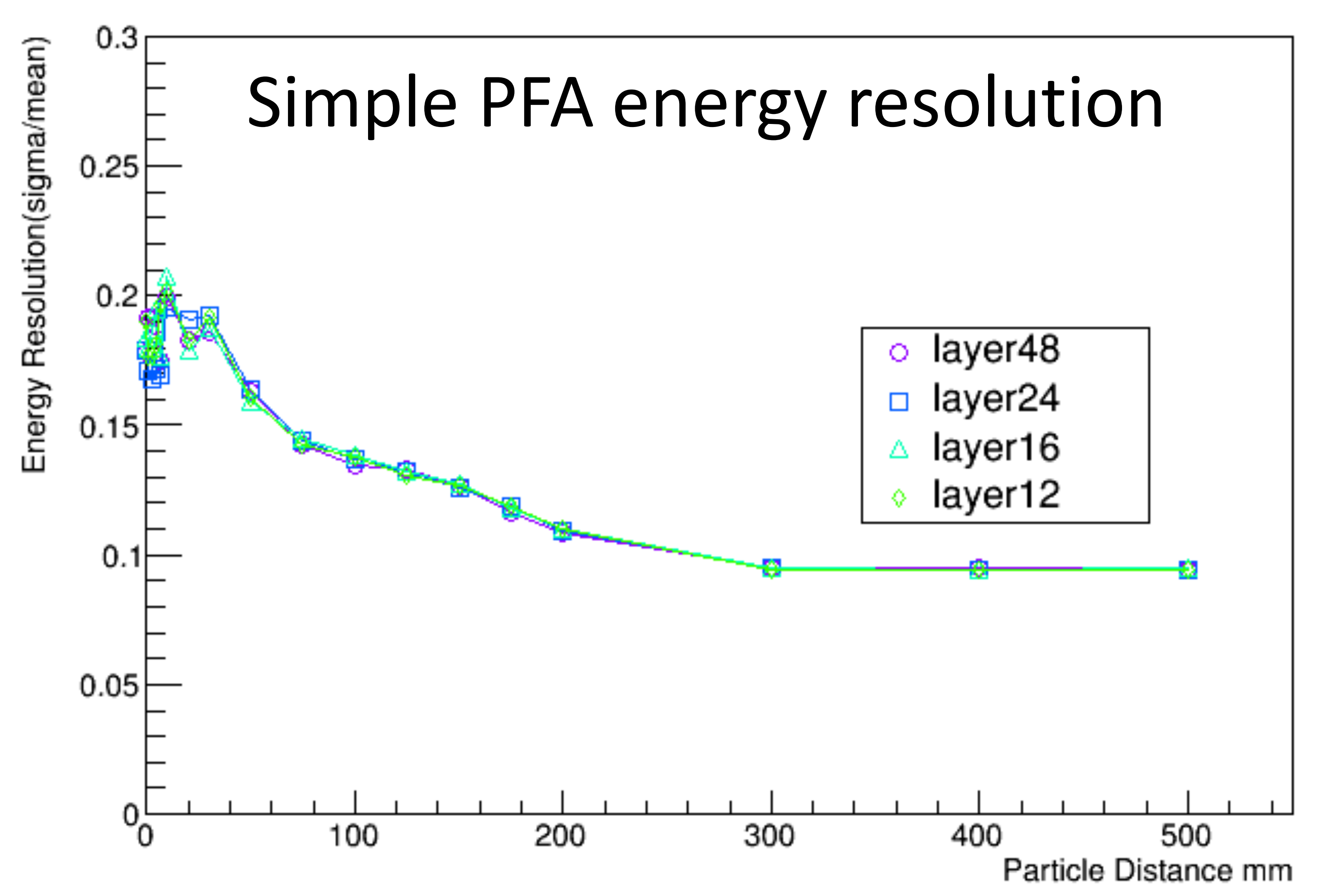


Prototype to be built and tested by 2023

aim: 0.5 × 0.5 m^2 , 35 layer (4λ), 30×30 mm^2 module

Design optimization advanced: sampling fraction, number of readout layers, cell-size, transversal area

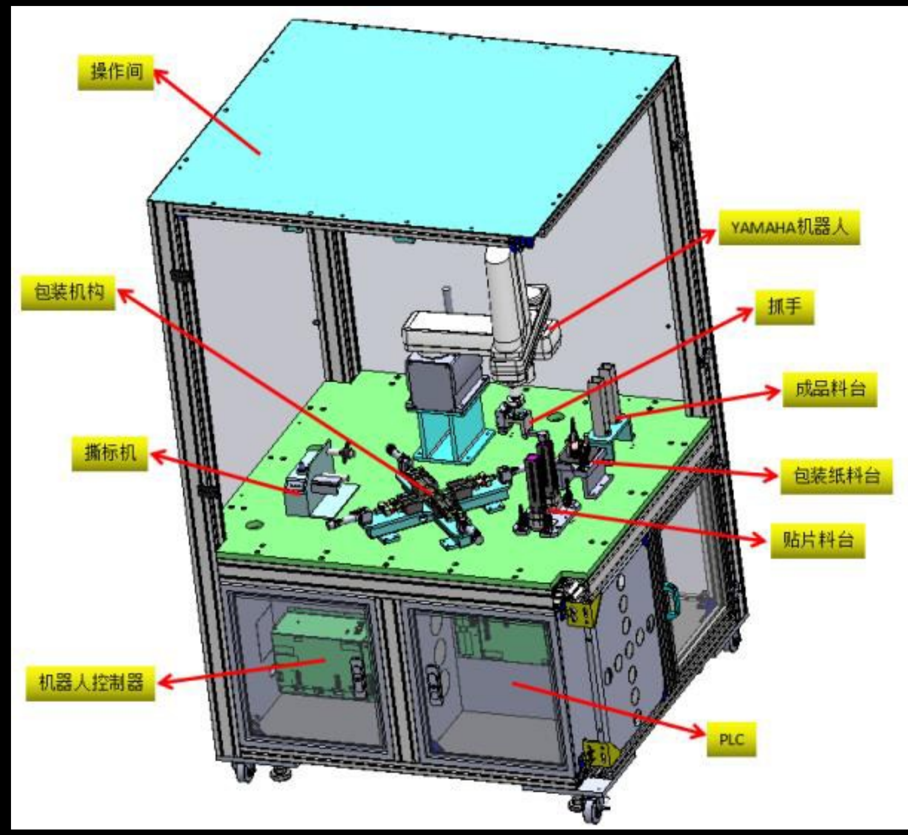
AHCAL PFA energy resolution stable down to 12 layers



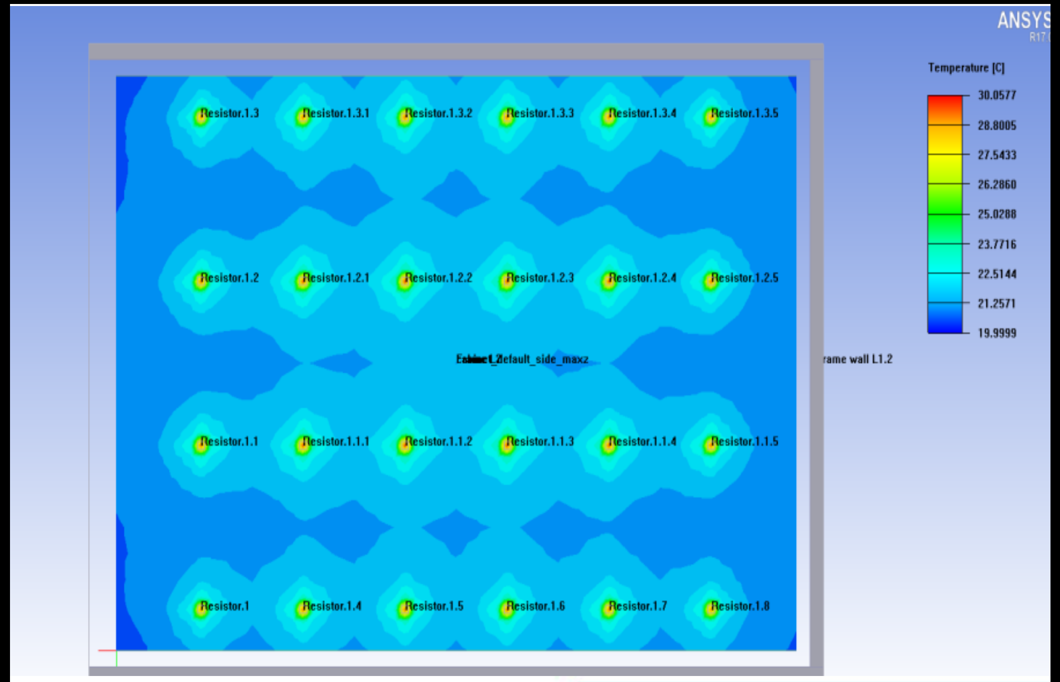
Progress in a few key technical aspects

Scintillator tile manufacturing and wrapping

Automatic wrapping machine mostly finalized

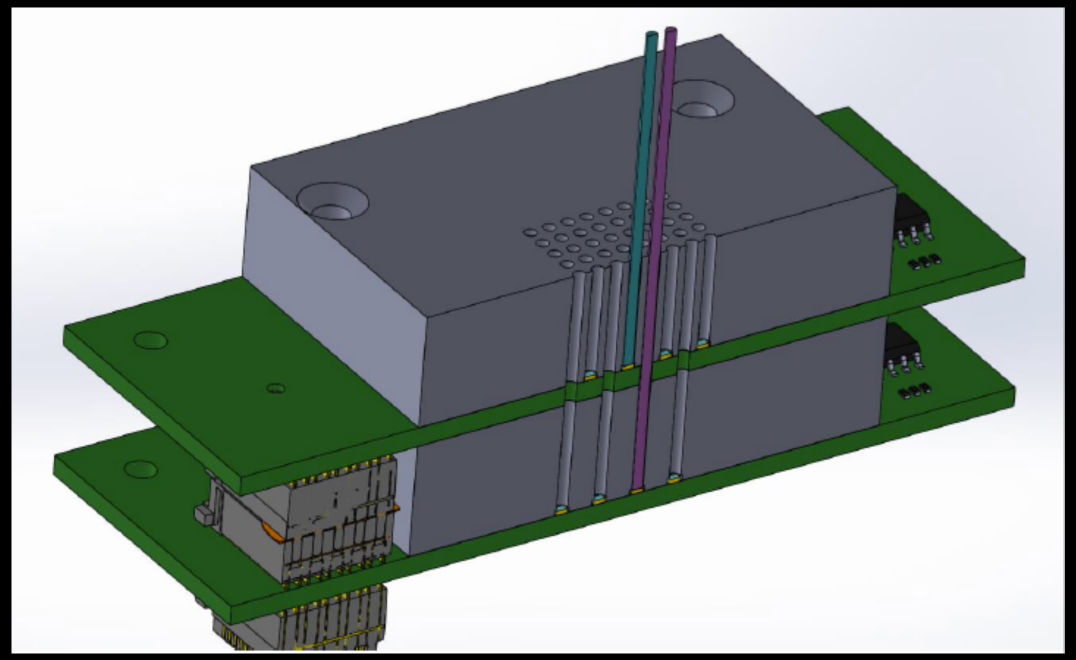


Cooling studies started



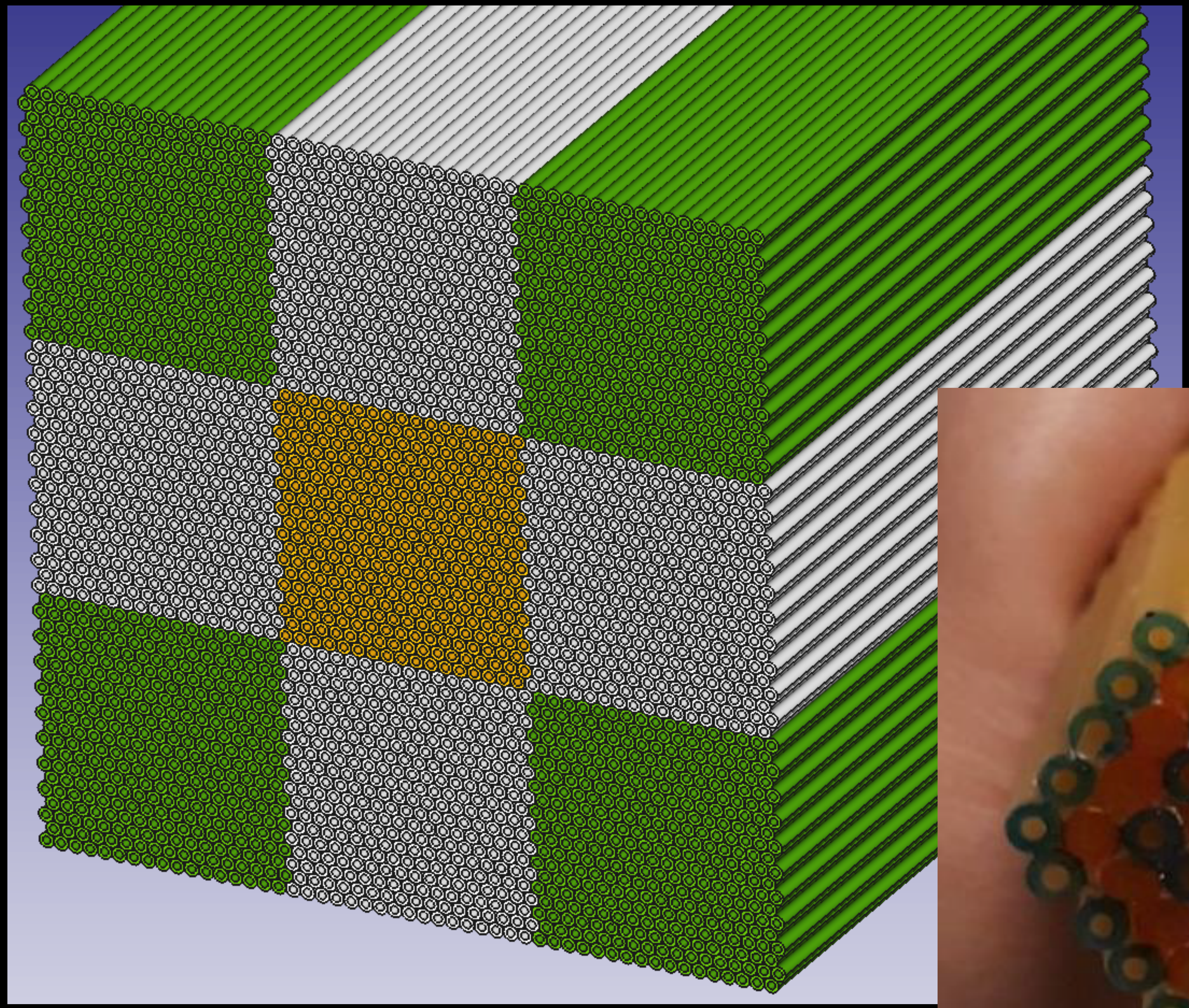
Dual Readout Calorimeter

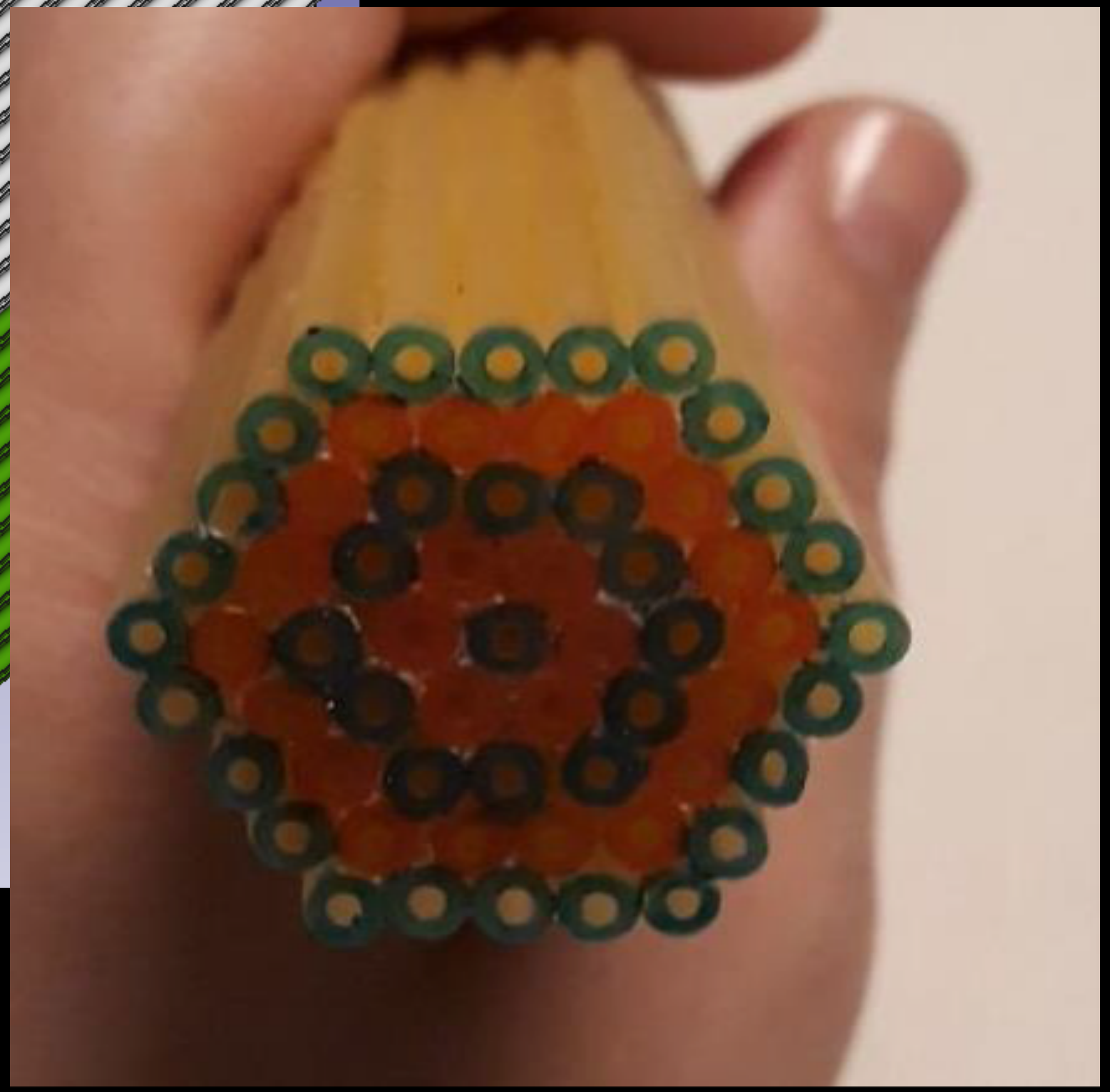
SiPM Readout: RD 52 Test Beam



Using timing for longitudinal "segmentation" information

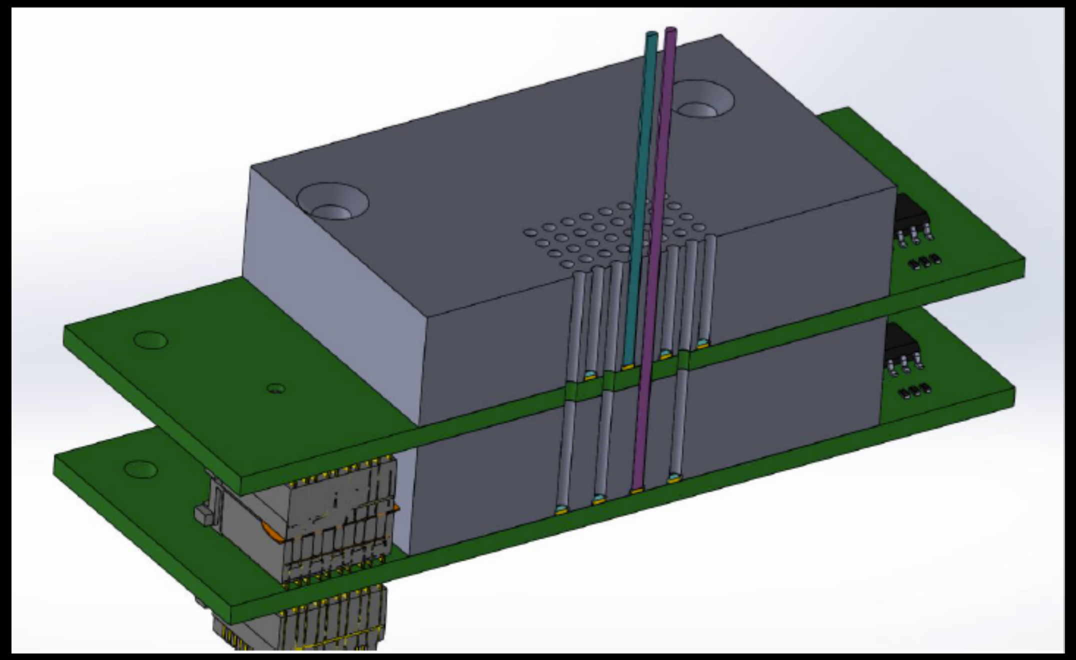
Testing new mechanical options
Prototype in progress 10x10x100 cm^3



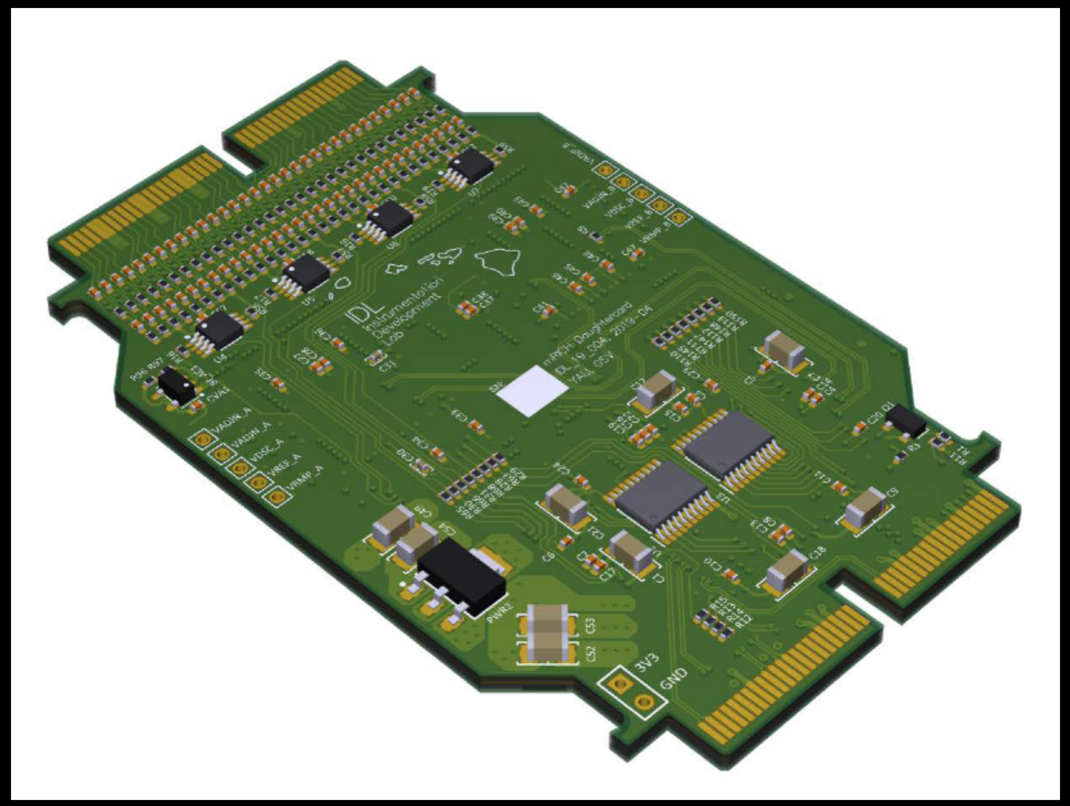


Dual Readout Calorimeter

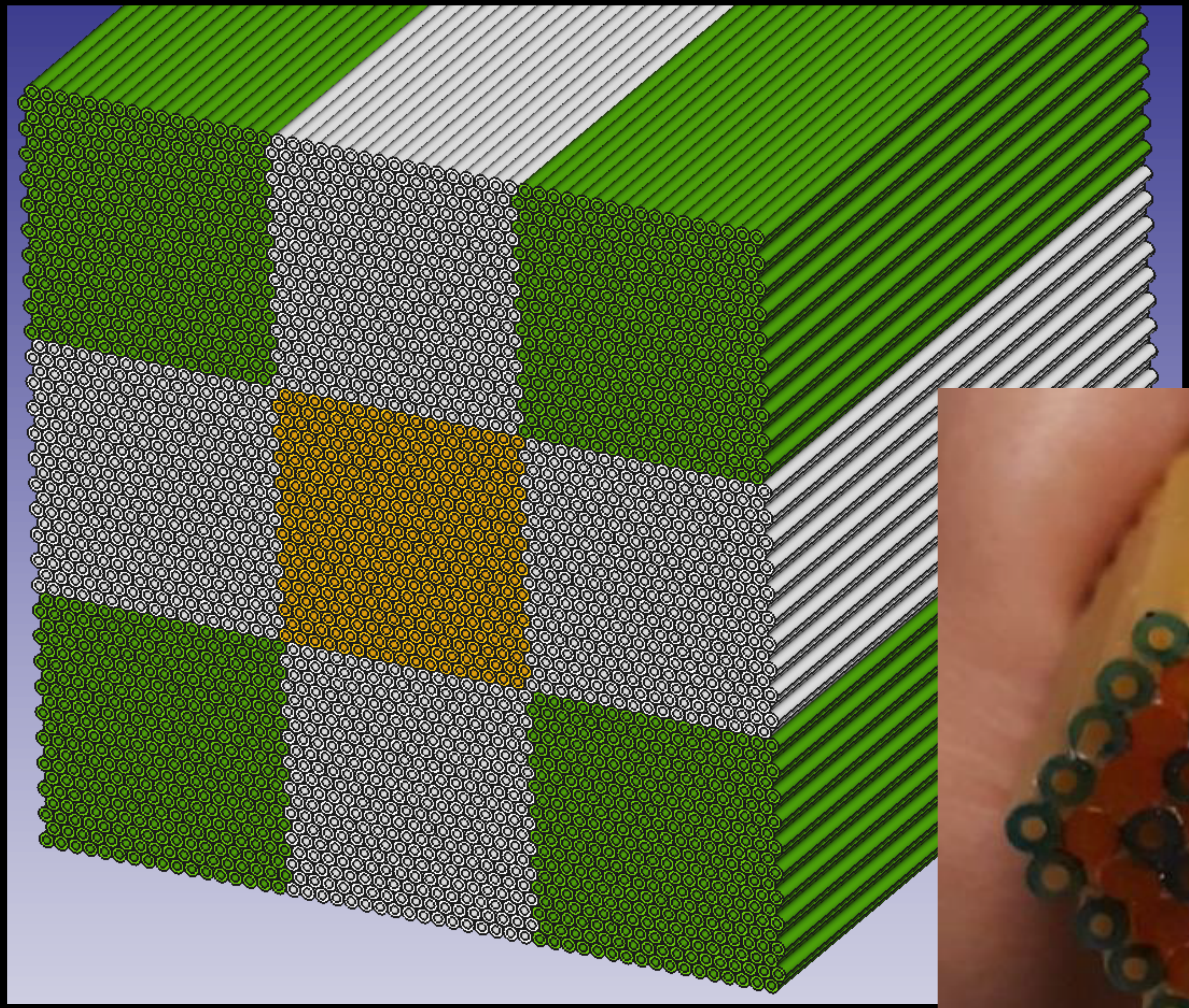
SiPM Readout: RD 52 Test Beam

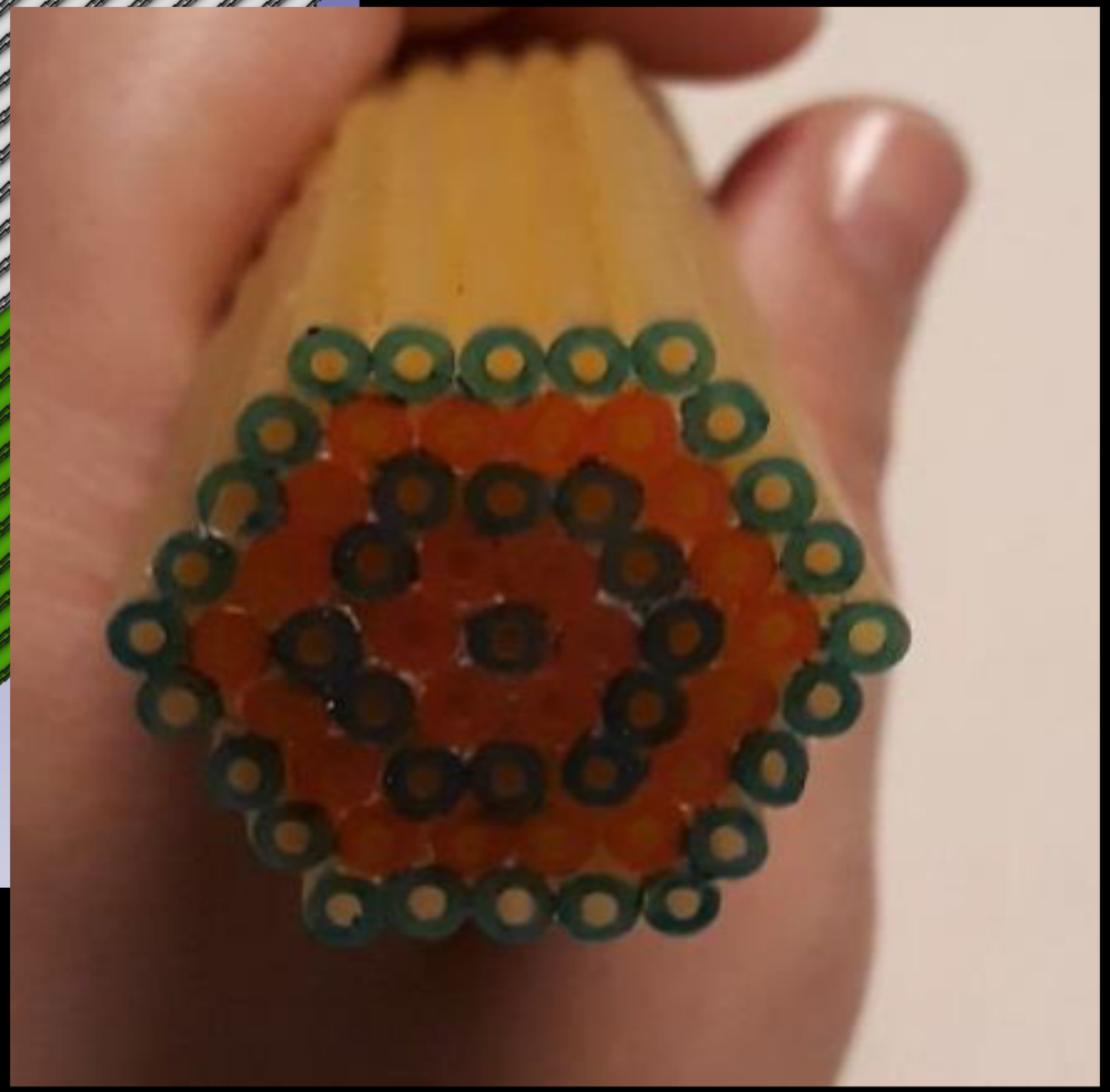


Using timing for longitudinal "segmentation" information

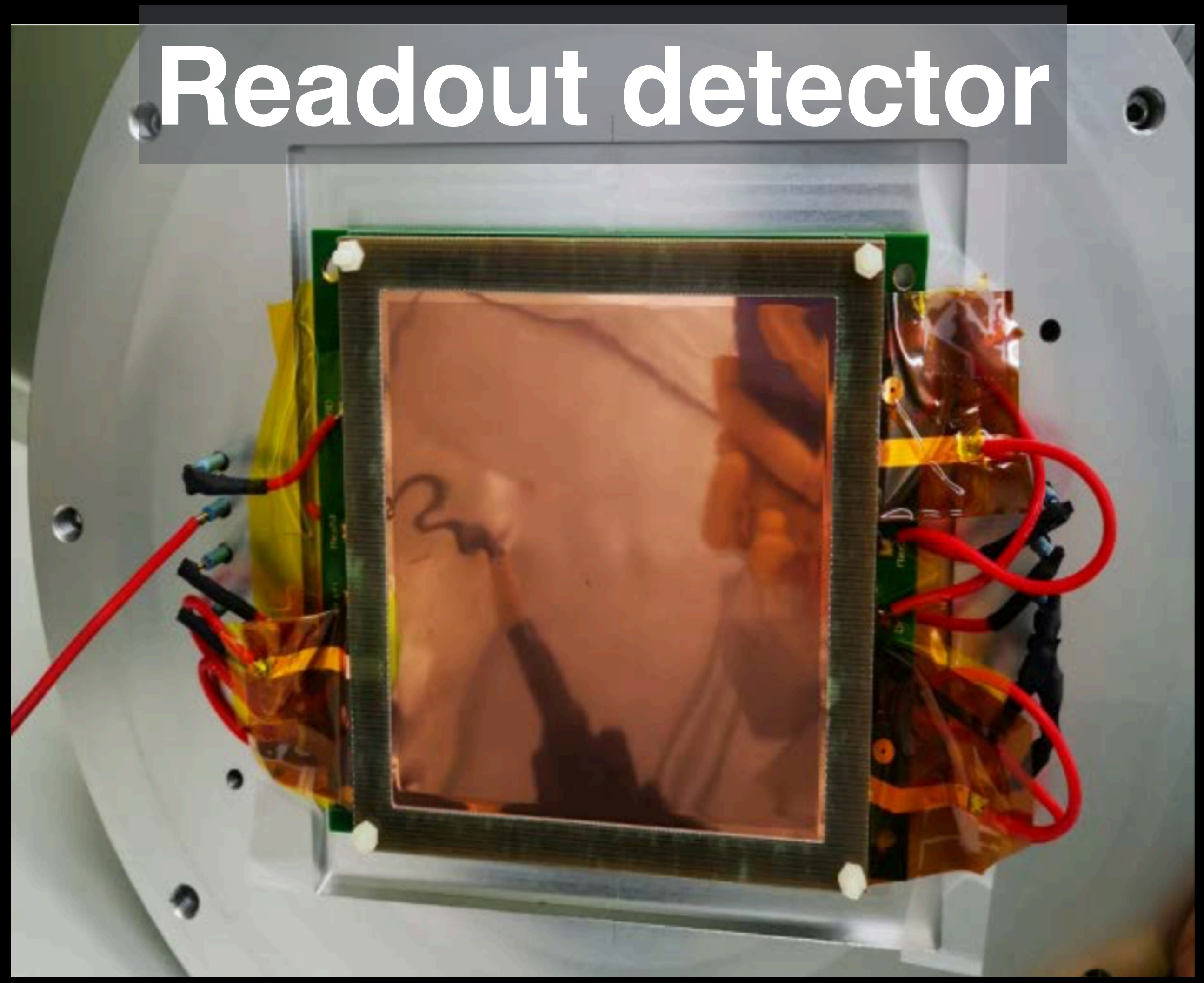


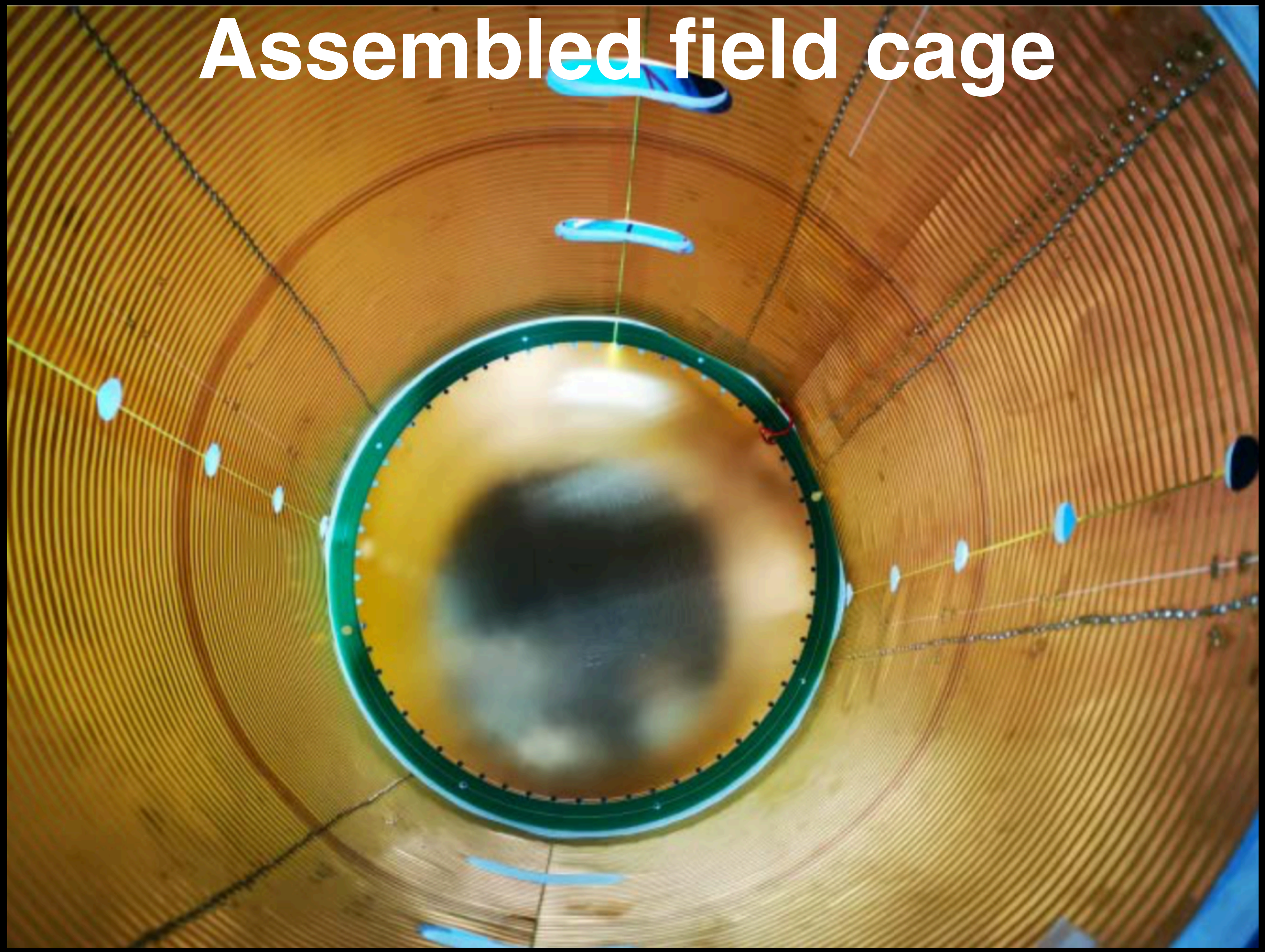
Testing new mechanical options
Prototype in progress 10x10x100 cm^3



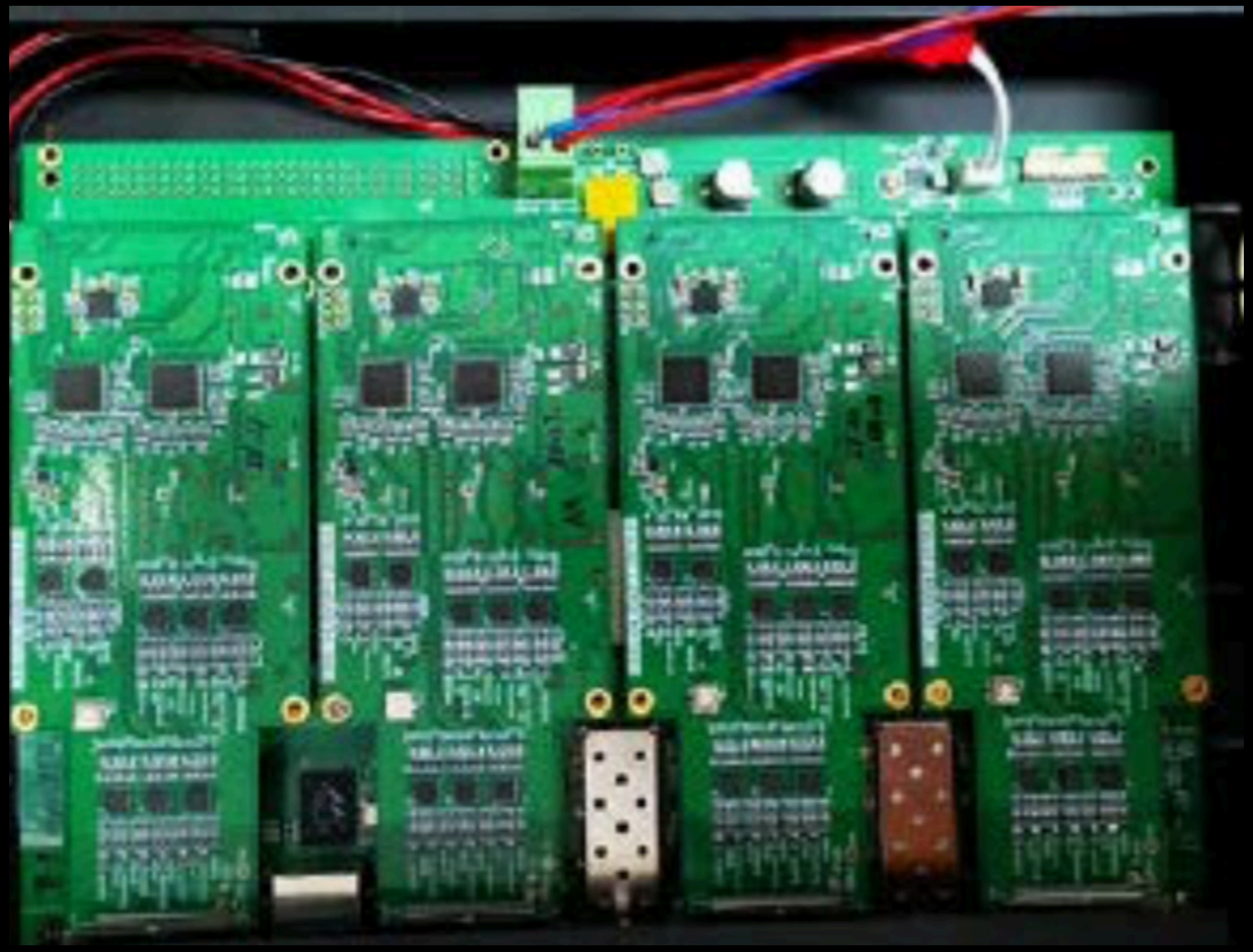


TPC Prototype





Readout electronics and DAQ



Expanding the Detector Collaboration

Released
November 2018

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

CEPC

Conceptual Design Report

Volume II - Physics & Detector

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

The CEPC Study Group
October 2018

405 pages

CEPC CDR, Vol. 1 and Vol. 2 — authorship

1149 authors from 222 institutions

29% from foreign institutions

24 countries

Australia	3
Belgium	3
Canada	3
Denmark	1
France	18
Germany	11
Indian	1
Israel	4
Italy	95
Japan	6
Korea	14
Mexico	1
Morocco	1
Netherlands	1
Pakistan	2
Russia	11
Serbia	6
South Africa	2
Spain	5
Sweden	2
Switzerland	9
UK	16
US	119

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Zhijun Liang	11	IHEP
Fulvio Piccinini	11	Univ. of Pavia, INFN
Xin Shi	12	IHEP

Particle Flow Calorimeter Collaborations

- **CEPC HCAL:**
  - **Imad Laktineh**, IPNL, University of Lyon, France (SDHCAL based on GRPC)
  - **Shikma Bressler**, Weizmann Institute of Science, Israel (SDHCAL based on RPWELL)
  - **Enrique Kajomovitz**, Israel Institute of Technology, Israel (SDHCAL based on RPWELL)
  - **Hans-Christian Schultz-Coulon and Wei Shen**, University of Heidelberg, Germany (Scintillator+Steel HCAL)

- **CEPC ECAL:**
  - **Vincent Boudry, Jean-Claude Brient**, LLR, France (Silicon+W ECAL)
  - **Tohru Takeshita, Shinshu University**, Japan (Scintillator+SiPM ECAL)
  - **Wataru Ootani**, University of Tokyo, Japan (Scintilator+W ECAL)
  - **Christoph Tully**, Princeton University, USA (Crystal ECAL)
  - **Sarah Eno**, University of Maryland, USA (Crystal ECAL)

  - **Christophe de la taille**, CNRS/IN2P3 Micro-Electronics Design Lab, Ecole Polytechnique Palaiseau, France (Readout electronics)

Silicon Vertex Detector

- CMOS pixel sensor development:
  - Marc Winter, Christine Hu-Guo, IPHC Strasburg, France
  - Sebastian Grinstein, Raimon Casanova, IFAE, Barcelona, Spain
  - ALICE, indirectly through CCNU

- SOI pixel sensor development
  - KEK, Japan

- Vertex Detector Prototype (MOST2):
  - CMOS Pixel Sensor development
    - Barcelona, IFAE
  - Mechanics and services
    - Liverpool, Oxford, RAL, QMU (UK)
    - Univ. Massachusetts (USA)

Trackers

- Time Projection Chamber
  - Paul Colas, Aleksan Roy, Stephan Anne., CEA-Saclay IRFU group, France (FCPPL)
  - Keisuke Fujii's group, KEK, Japan
  - Joined LC-TPC in Dec 2016
    - DESY test beam in 2018

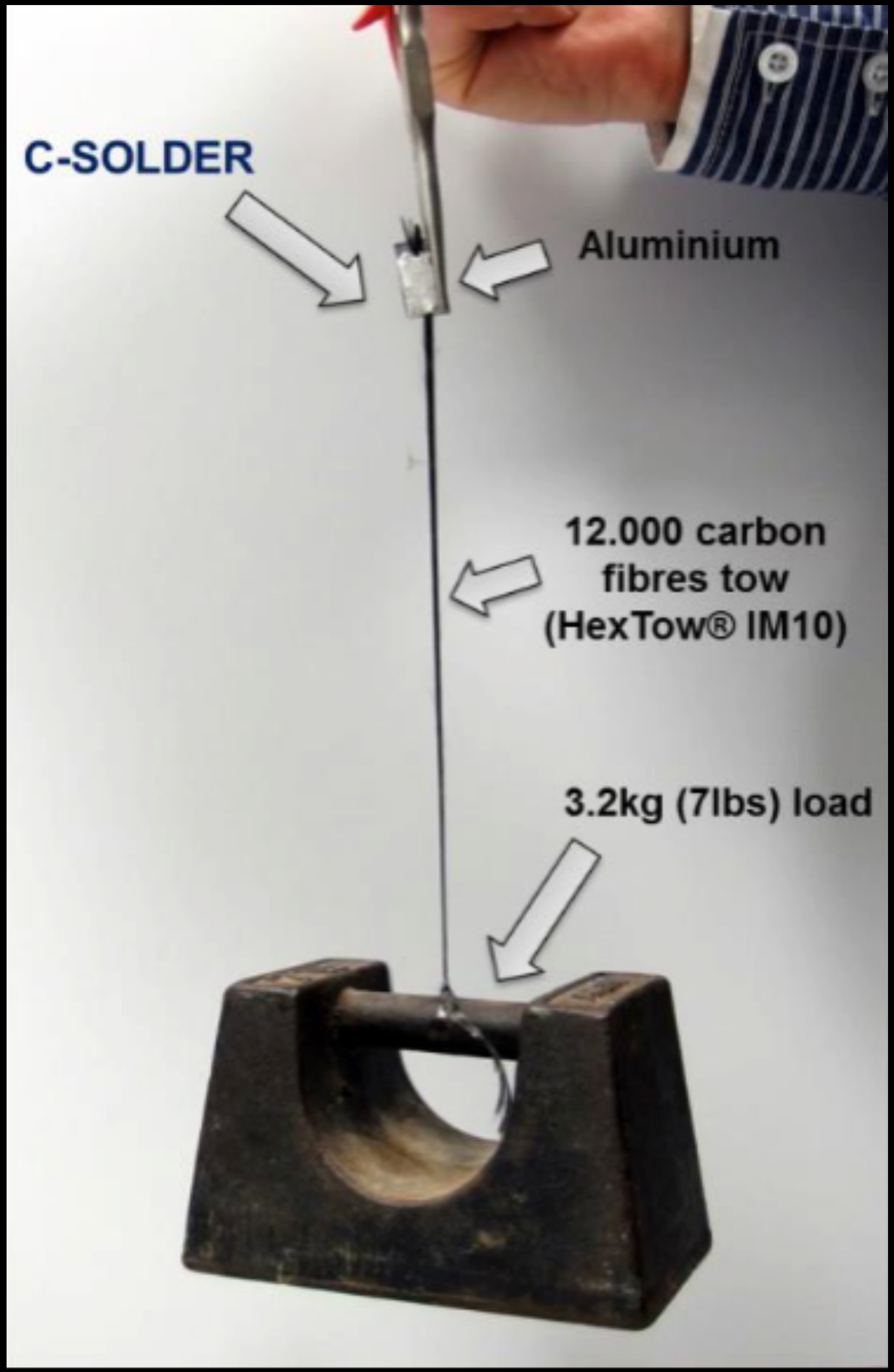
- Silicon Tracker
  - Full Silicon Tracker Design
    - Weiming Yao, Berkeley (USA)
    - Sergei Chekanov, Argonne (USA)
  - Tracker Demonstrator
    - Harald Fox (Lancaster), Yanyan Gao (Edinburgh), Roy Lemmon (Daresbury), Tim Jones (Liverpool)
    - Ivan Peric (KIT)
    - Based on ALICE and ATLAS technology

2020: Silicon

- Active pixel detectors (INFN: Milano, Torino)
  - SEED and ARCADIA (1 M€ INFN grant)
    - Low power, high resolution, stitching
    - First prototypes by late 2020 → test on beam
  - DAQ development for test beam
    - Potential collaboration with China (FEST grant supports travel to China)
- Active and passive CMOS for Si wrapper (INFN: Milano)
  - Continuation of ATLAS phase 2 upgrade work
- EU grants:
  - FEST (travel 4 yr), AIDA++ (applied)
- International collaboration:
  - UK-Oxford, ETH, Zurich university, (IHEP-China?)

2020: Drift Chamber

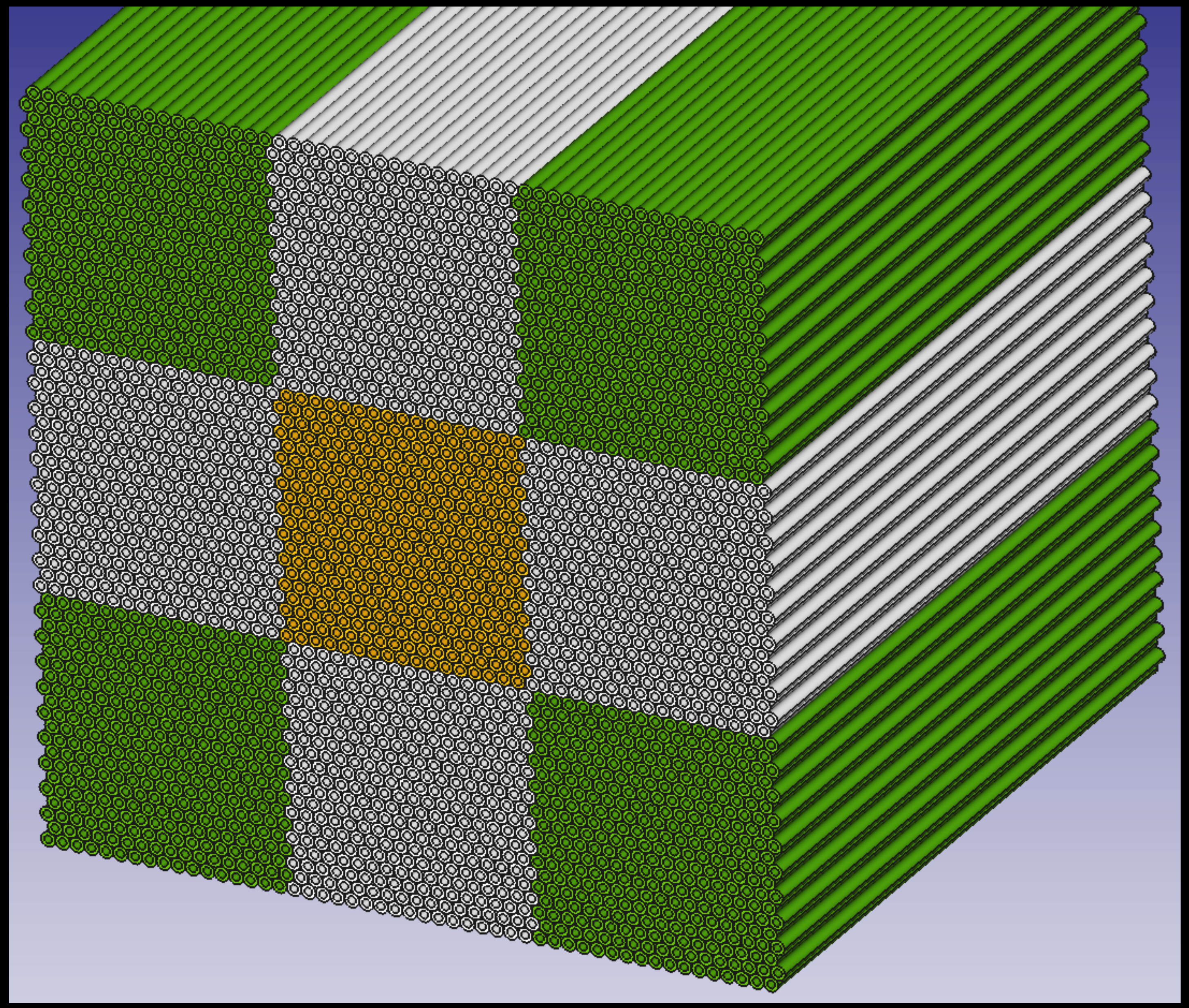
- Drift chamber (INFN: Lecce, Bari)
  - Full length prototype
    - C-fiber wires
    - Cluster counting electronics
    - Non-flammable gases
- EU grants:
  - CREMLIN2, AIDA++ (Applied)
- International collaboration:
  - (BINP, Novosibirsk)



2020: DR calorimeter

- Full EM containment prototype (INFN: Pavia, Milano, Pisa)
  - 10 cm x 10 cm x 100 cm
    - Mechanics with metal capillaries 2 mm OD, 1.1 mm ID
    - 9 towers. Central tower read out with SiPM. Remaining with PMT.
    - Alpha-tester compact CAEN electronics (FERS system)

- EU grants:
  - AIDA++ (applied)
- Cofunded by INFN, UK, Croatia
- International collaboration:
  - UK: University of Sussex, RBI - Croatia, South Korea



2020: μRwell chambers

- Development of large area chambers with industrial partners ELTOS and TECHTRA (INFN: Bologna, Ferrara, Frascati)
  - μRwell technology
  - Test μRwell 2D readout
  - R&D on DLC+Cu sputtering with USTC (China)
- EU grants:
  - ATTRACT, CREMILN2, AIDA++(Applied)
- International collaboration:
  - USTC – China, BINP-Novosibirsk

ATLAS Detector Involvement

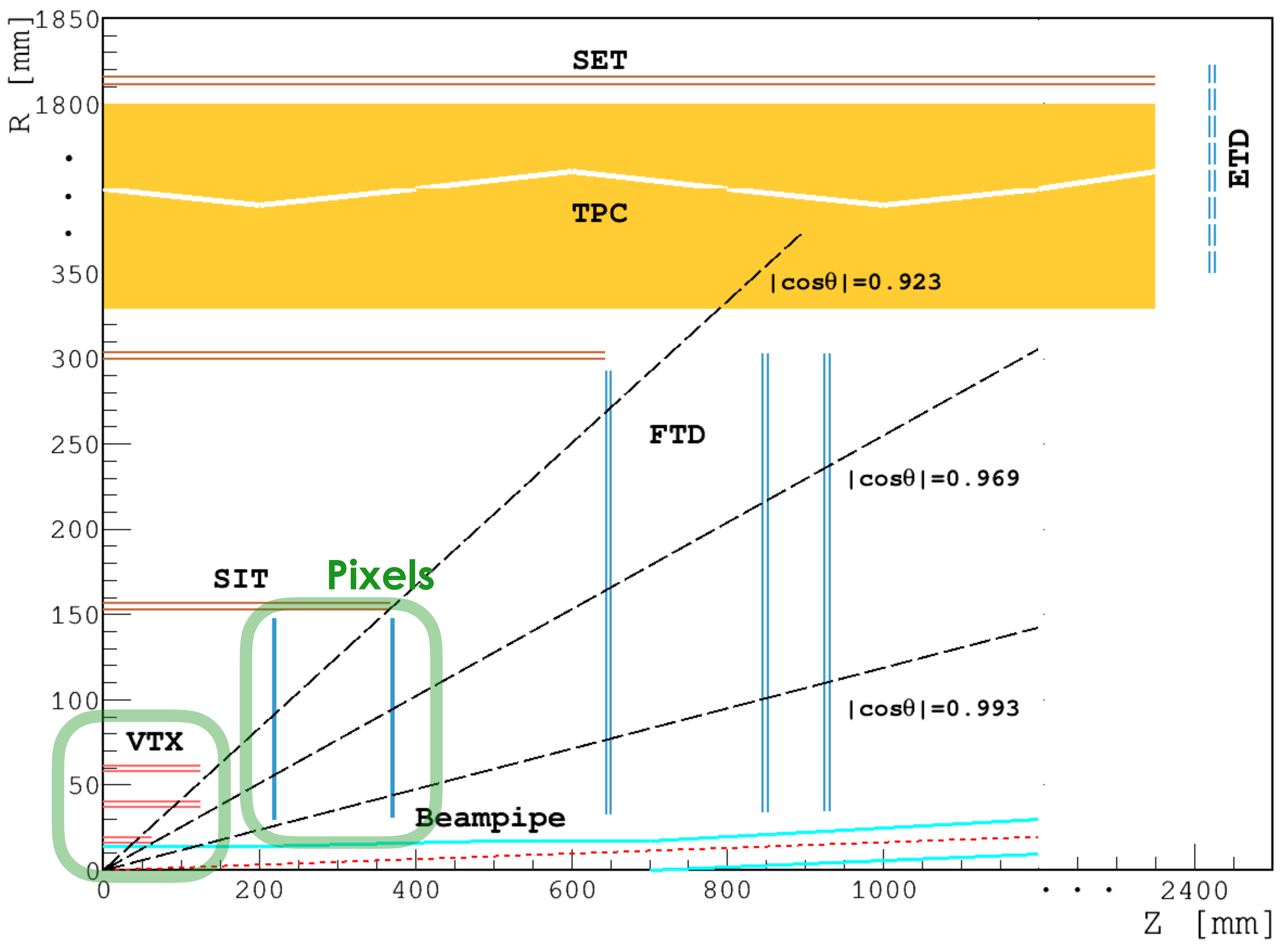
Number of institutions involved in Phase II Upgrades in ATLAS

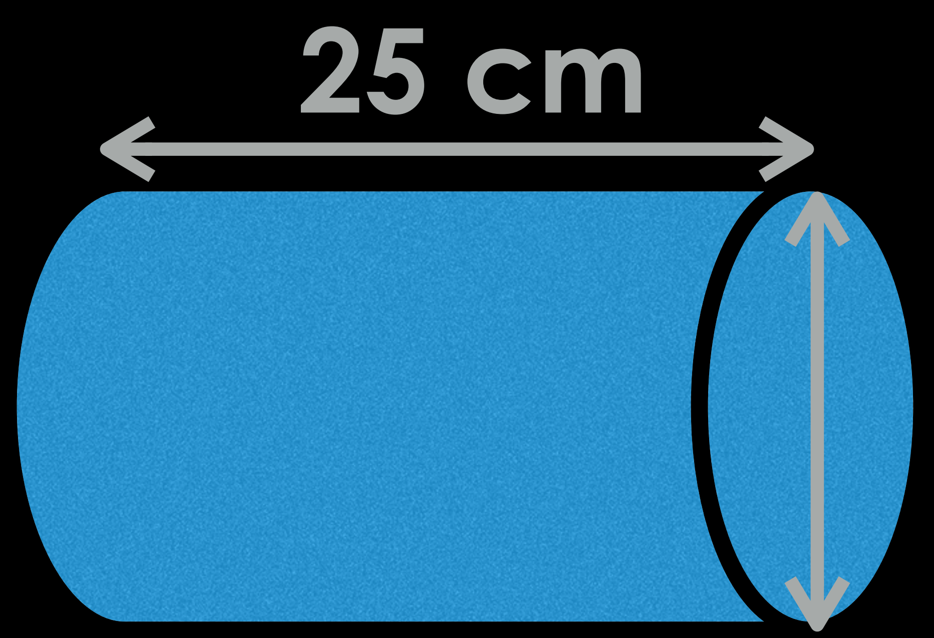
	Institutions
ITK Pixel	65
ITK Strip	62
Muon	60
Tile Calorimeter	34
LAr Calorimeter	29
Trigger/DAQ	101
New Small Wheel	59
HGTD	18

Expanding the collaboration is essential!!

Tracker Detector – PFA Detector

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





Total Silicon area ~ 68 m²

Required resolution
σ_{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

Extensive opportunities for international participation

Integrated optimization effort needed

CEPC Detector Working Group Exists

Need to better integrate:

Detector and physics performance people

International Colleagues

Plenary meetings, Wednesday, 3 pm Beijing time

Aiming for a document sometime before collaborations are proposed is reasonable (end of 2021?)

Final remarks

CEPC CDR: http://cepc.ihep.ac.cn/

CEPC Detector CDR completion was a major milestone for the CEPC project

Two significantly different detector concepts developed

High-magnetic field (3 Tesla)
PFA-oriented — with TPC or full-silicon tracker

Low-magnetic field (2 Tesla)
Drift chamber and dual readout calorimeter

Now is time to explore alternatives and test new ideas
Work needs however to be coherent and organized

From 2019 - 2022, R&D towards CEPC Detector Collaborations

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

Need to coordinate with engineers to study real detector feasibility

Need to expand international collaboration

Big Science Cultivation project starting —> Key technology demonstration

2023: Decision on Experimental Detectors and TDR

CEPC CDR: Particle Flow Conceptual Detector

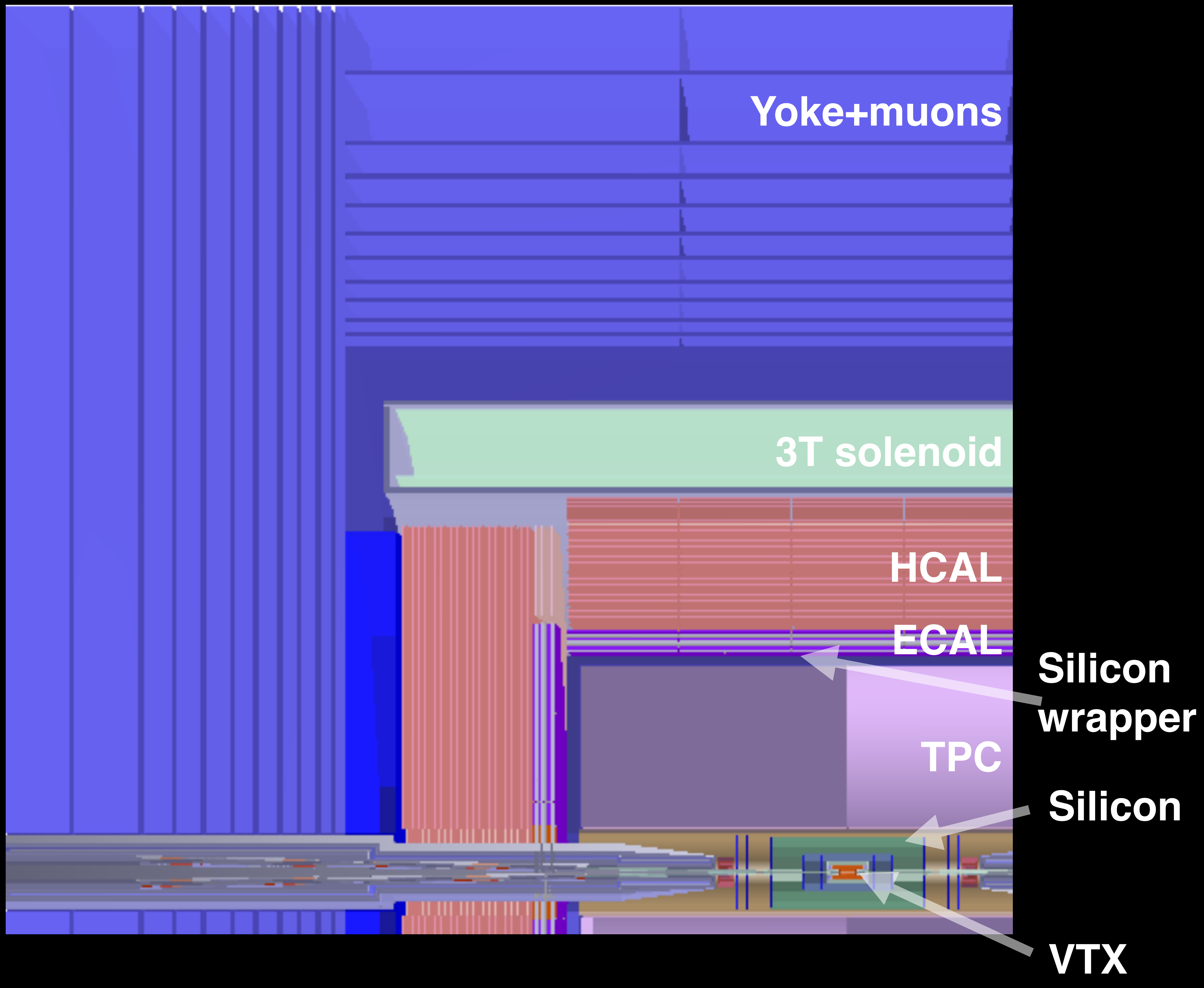
Major concerns being addressed

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

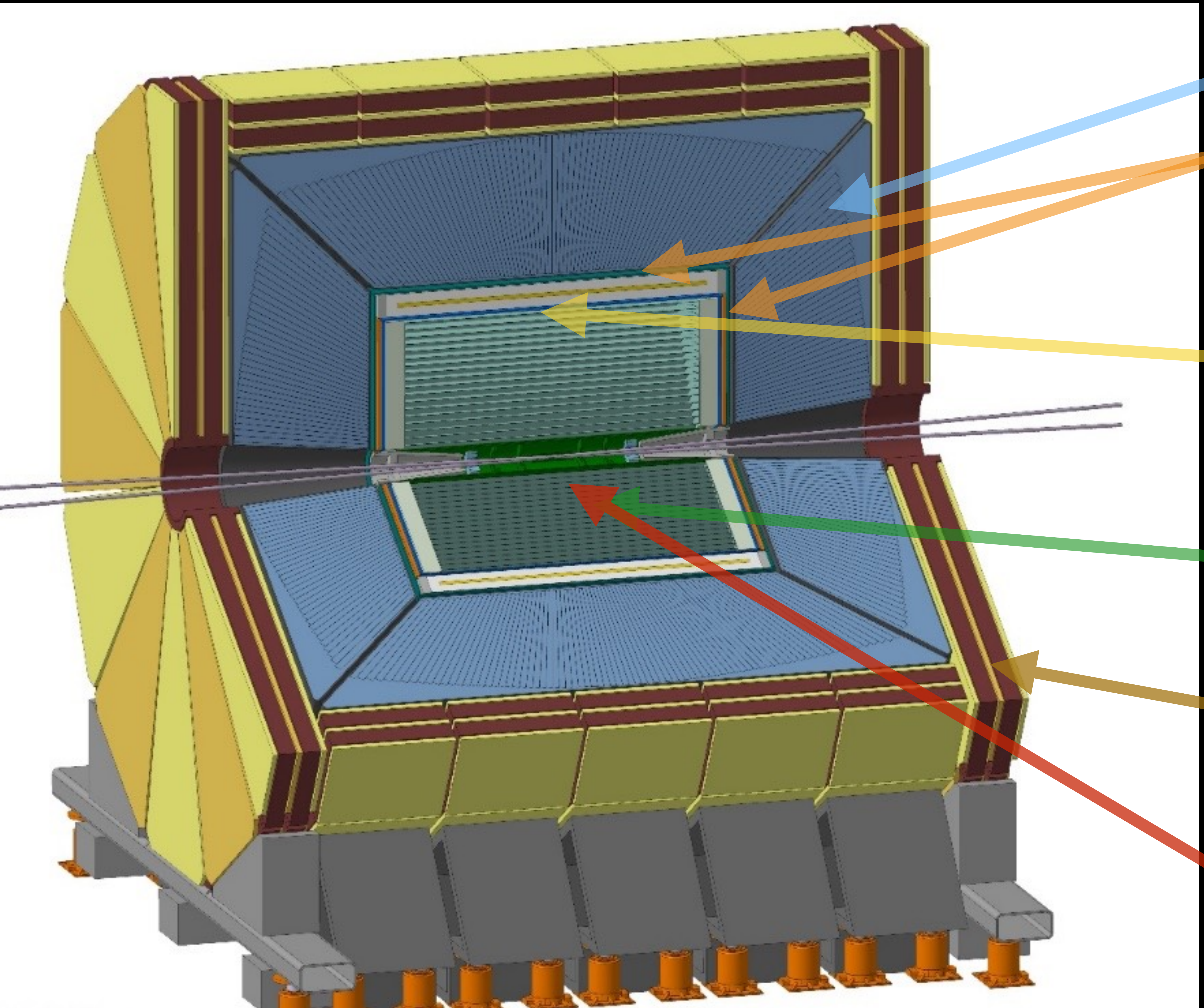
4. ECAL/HCAL granularity needs
   Passive versus active cooling
   Electromagnetic resolution



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

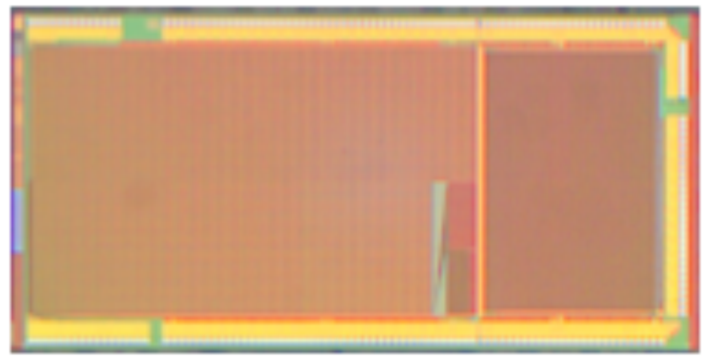
Thin (~ 30 cm), low-mass (~0.8 X_0)

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

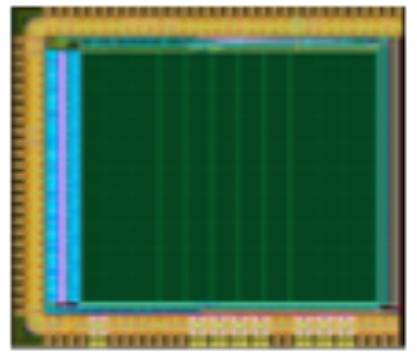
Vertex: Similar to CEPC default

DEVELOPED CMOS PIXEL SENSOR PROTOTYPES FOR CEPC

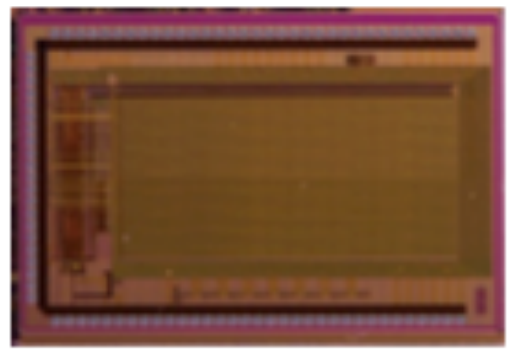
Prototype	Pixel size (μm^2)	Readout time	Power Consumption	In-pixel circuit	R/O architecture	Main goals	Status
JadePix1	33 × 33 16 × 16	~100 μs	~ 100 mW/cm^2	SF/amplifer, analog output	Rolling shutter	Sensor optimization	Lab. and beam test finished
JadePix2	22 × 22	~100 μs	< 100 mW/cm^2	amp., discriminator, binary output	Rolling shutter	Small pixel, Power < 100 mW/cm^2	Electrical functionality verified
MIC4	25 × 25	~10 μs	<26mW/cm^2	Low power front-end, address encoder	Data-driven, Asynchronous	Small pixel, fast readout for ZH run	Electrical functionality verified
JadePix3	16 × 26 16 × 23.11	~10 μs	<26mW/cm^2	Low power front-end, binary output	Rolling shutter with end of col. priority encoder	Small pixel, low power	In fabrication
Taichu-1	25×25	~50ns	100~200 mW/cm^2	binary output	Data-driven, Priority encoder	Full Functionalities Fast readout for Z pole	Fabricated, To be tested



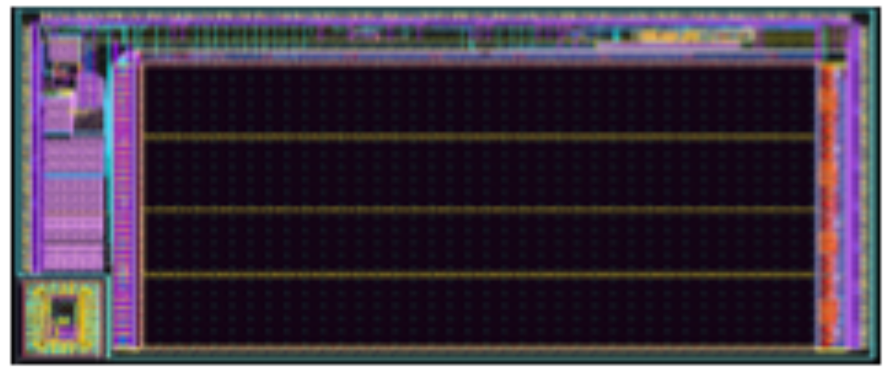
JadePix1 (IHEP)
3.9 × 7.9 mm^2



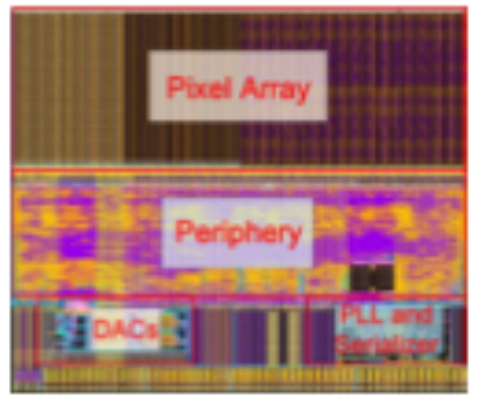
JadePix2 (IHEP)
3 × 3.3 mm^2



MIC4 (CCNU & IHEP)
3.2 × 3.7 mm^2



JadePix3
IHEP, CCNU, Dalian Minzu Unv., SDU
6.1 × 10.4 mm^2



Taichu-1
IHEP, SDU, NWPU, IFAE & CCNU
5 × 5 mm^2

TowerJazz CIS 0.18 μm

New large CMOS Pixel Sensor for Vertex Prototype

TaichuPix1

None of the existing CMOS sensors can fully satisfy the requirement of the high-rate CEPC Vertex Detector (operating at the Z pole)

- **Evolution from previous design**
  - **Aiming at full-size sensor by 2021**

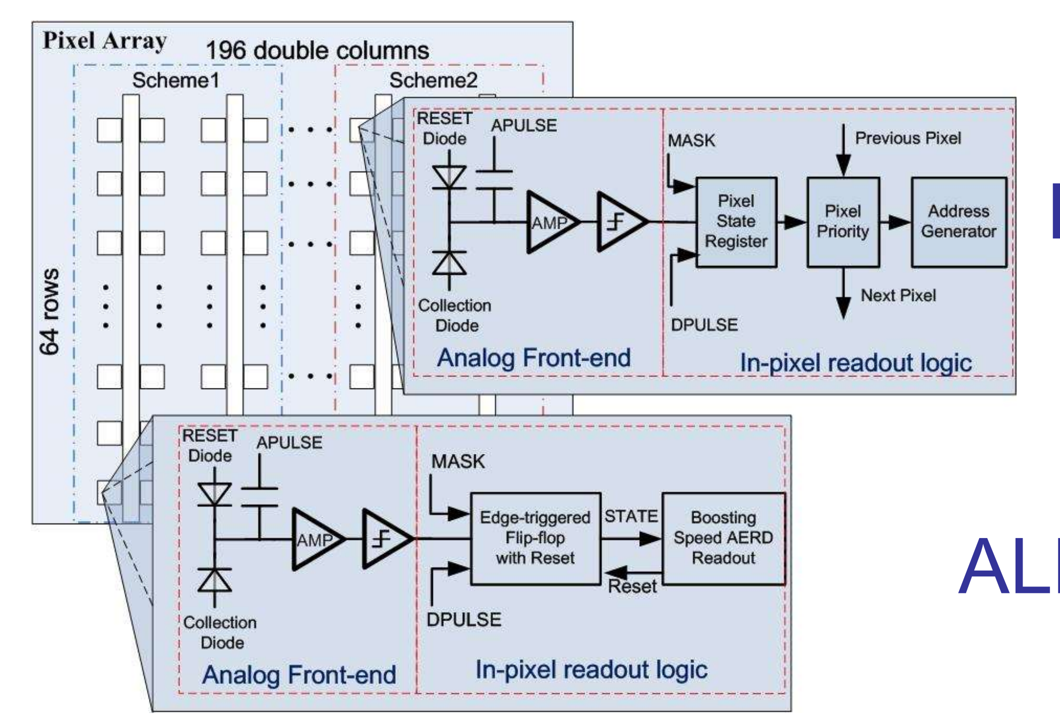
TowerJazz CIS 0.18 μm

For Vertex	Specs	For High rate Vertex	Specs	For Ladder Prototype	Specs
Pixel pitch	< 25 μm	Hit rate	120 MHz/chip	Pixel array	512 row×1024 col
TID	> 1 Mrad	Date rate	3.84 Gbps --triggerless ~110 Mbps --trigger	Power Density	< 200 mW/cm² (air cooling)
		Dead time	< 500 ns --for 98% efficiency	Chip size	~1.4 cm×2.56 cm

Collaboration with Barcelona, IFAE (Engineer plus student)

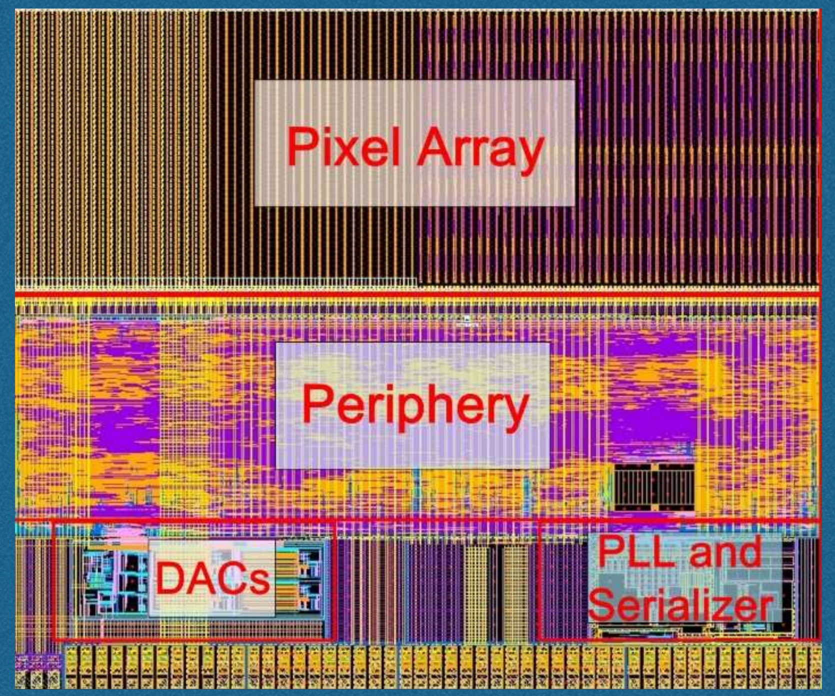
First MPW chip back this month

Full functionality implemented
Two readout architectures



FE-I3-like Pixel

ALPIDE-like Pixel



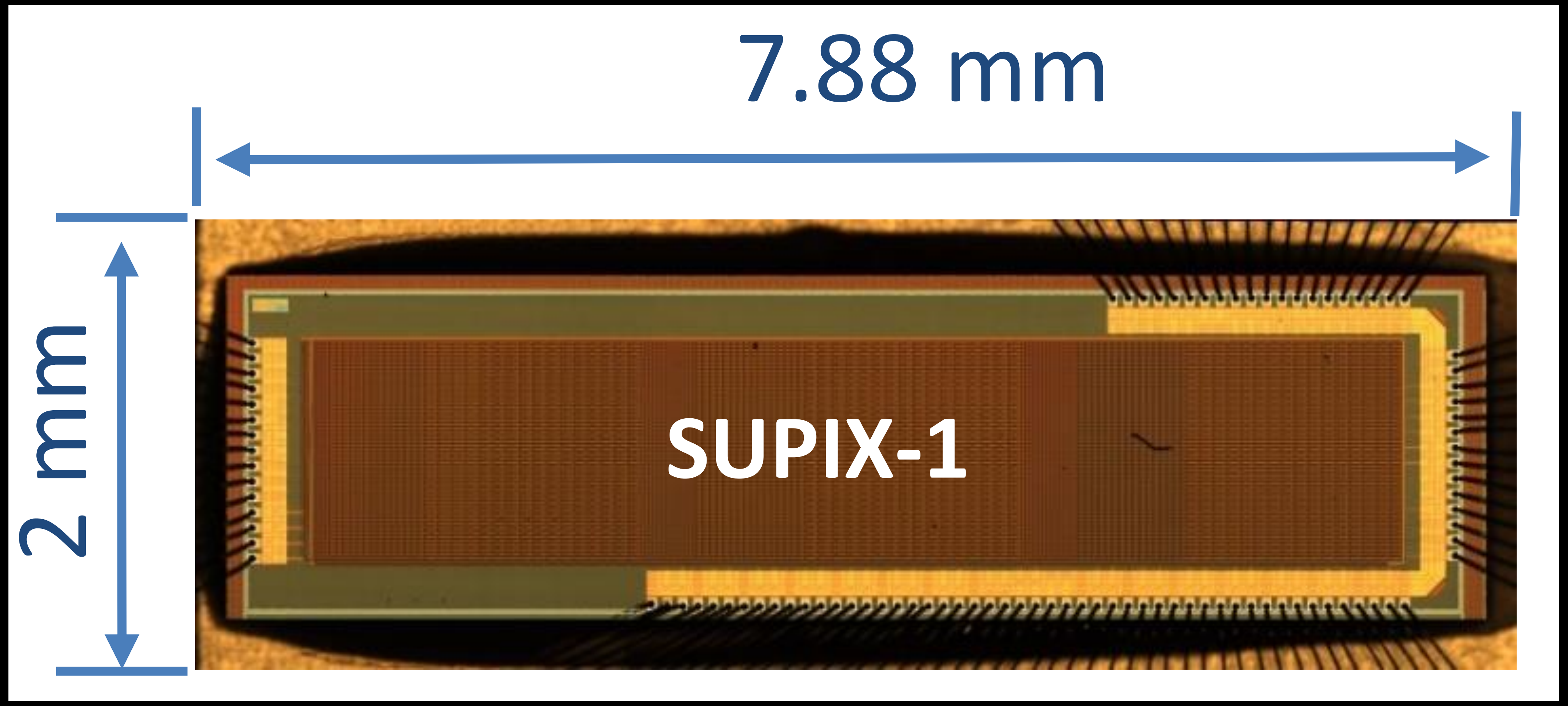
Chip size:
5 mm × 5 mm

Pixel size:
25 μm × 25 μm

CMOS Large-Pixel Sensors for Tracker

SUPIX1 (Shandong University PIXel)

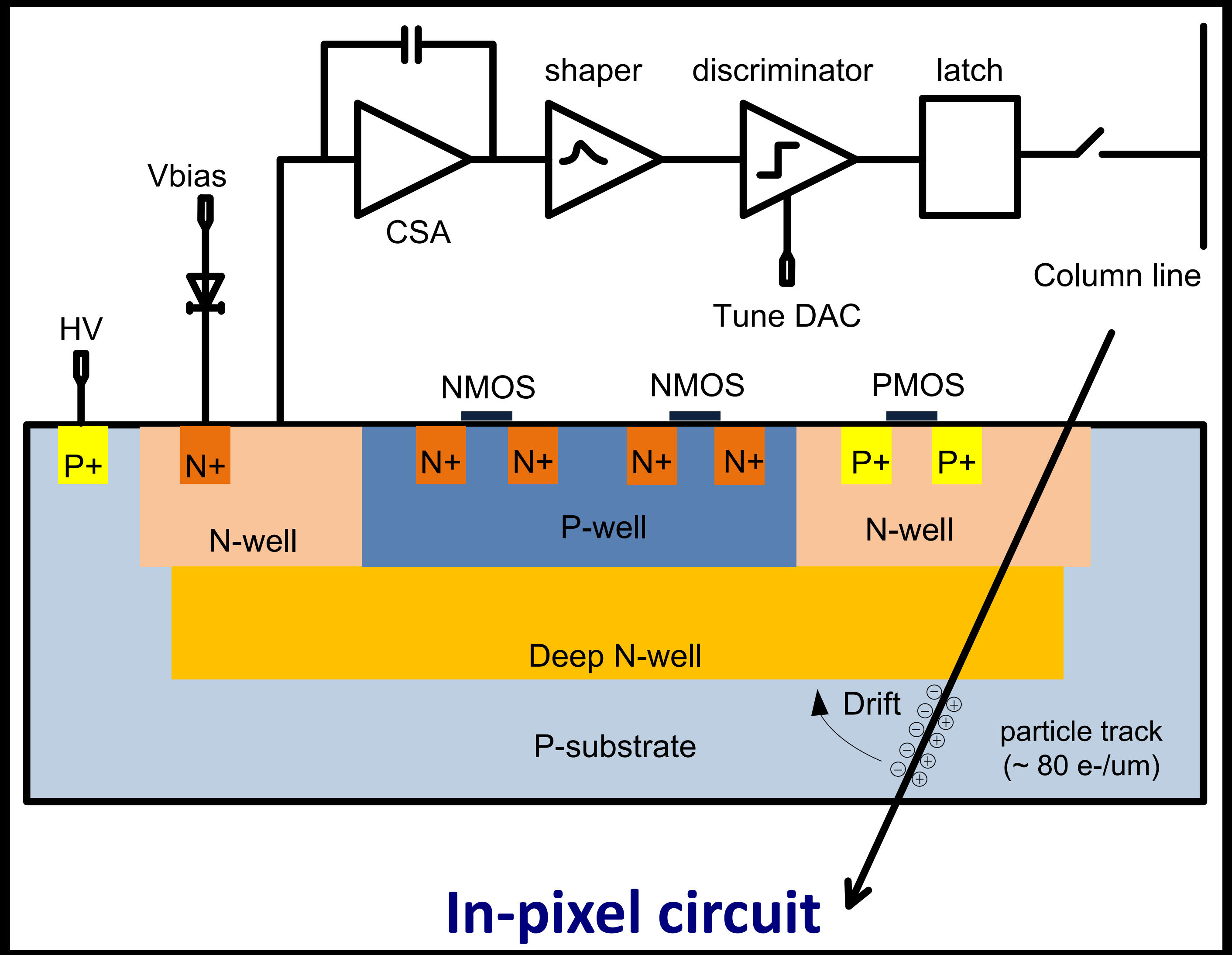
Produced and under test



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

SUPIX2

Submitted to SMIC in November



- Matrices: 32 × 16
- Rolling shutter readout mode
- 16 parallel analog outputs
- Pixel sizes: 60×60 μm^2, 60×180 μm^2

MDI Assembly and Installation

Engineering studies started **Different scenarios under study**

Silicon tracker assembly pushed from one side

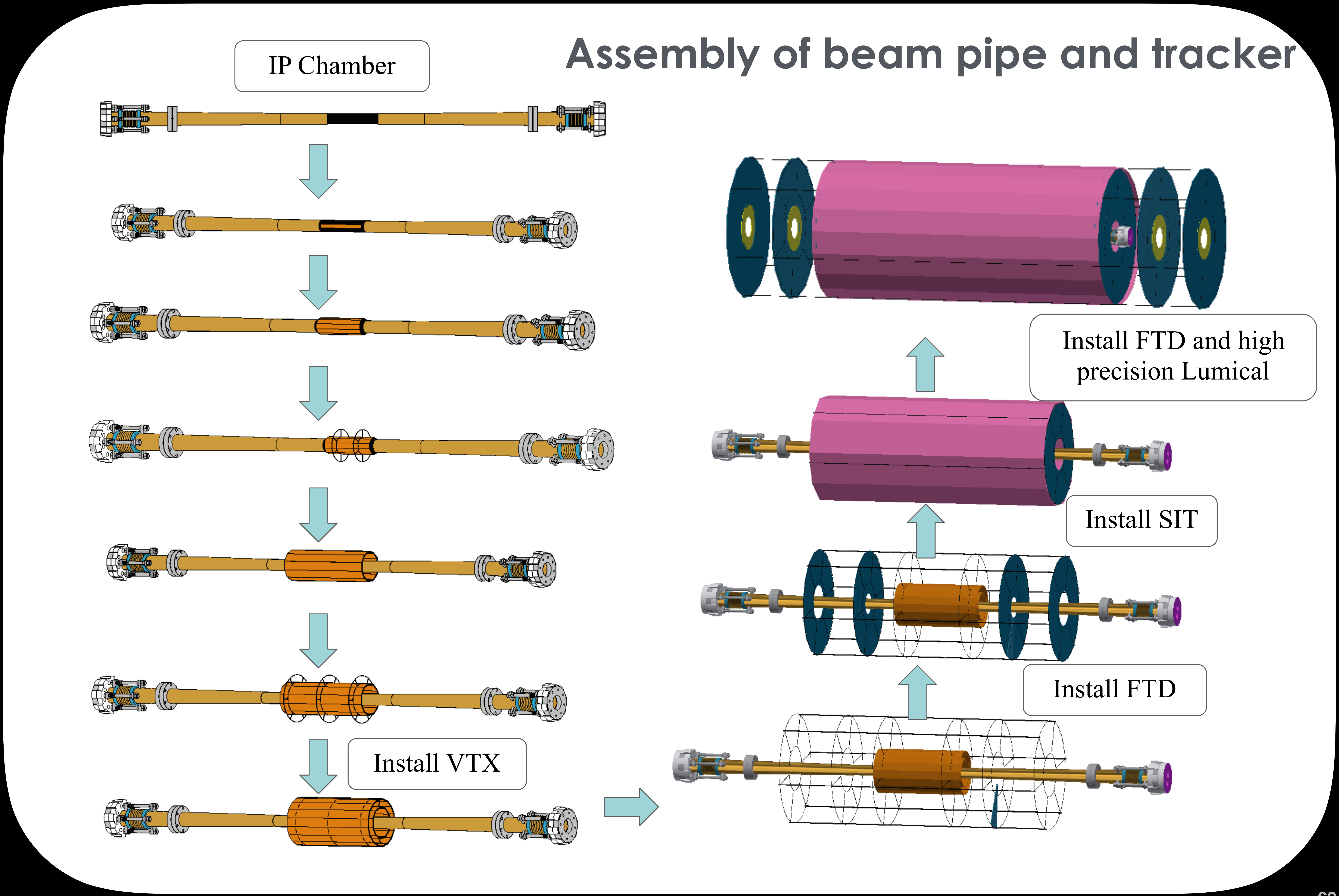
Vacuum connections closed remotely

MDI Assembly and Installation

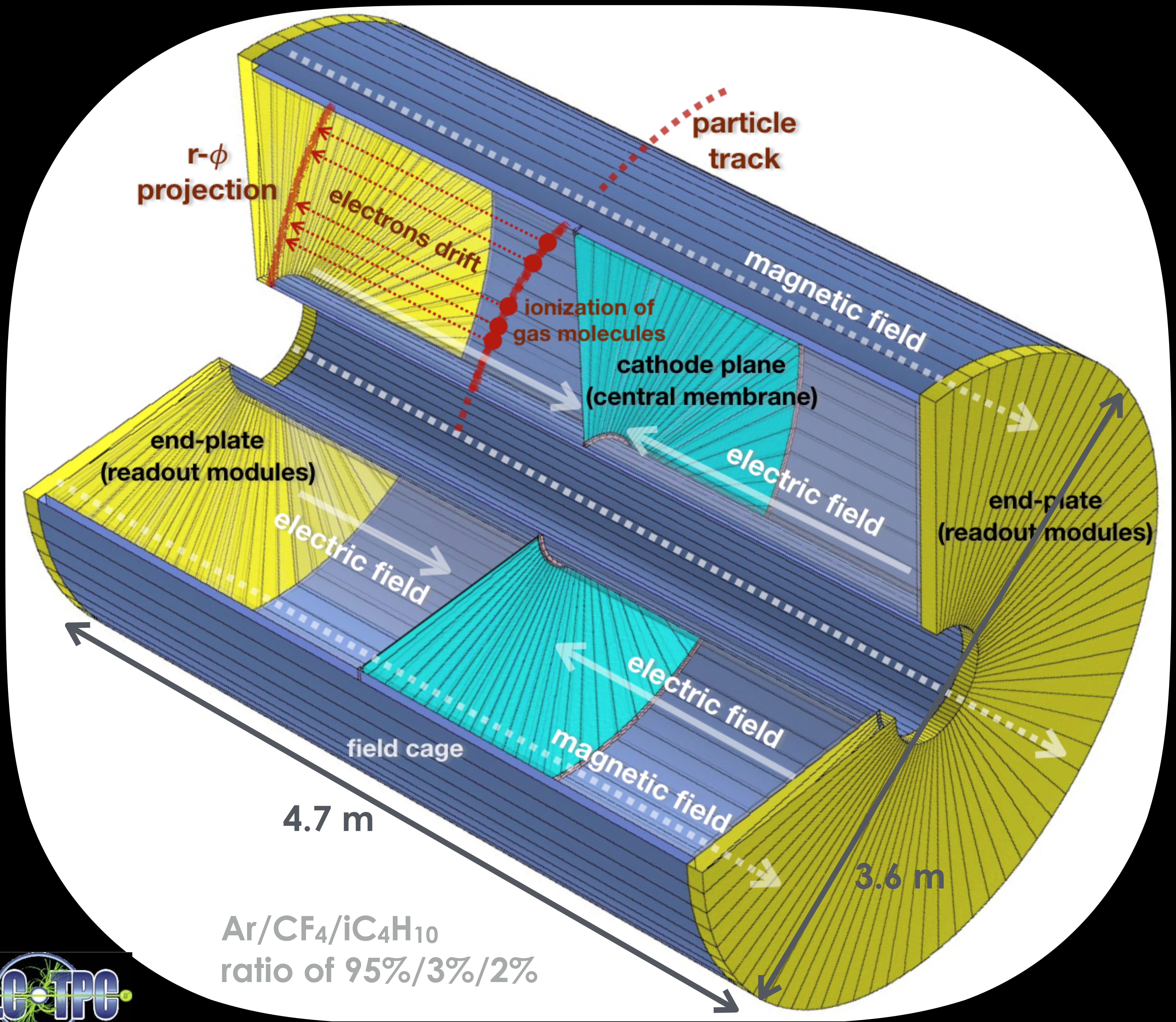
Engineering studies started

Different scenarios under study

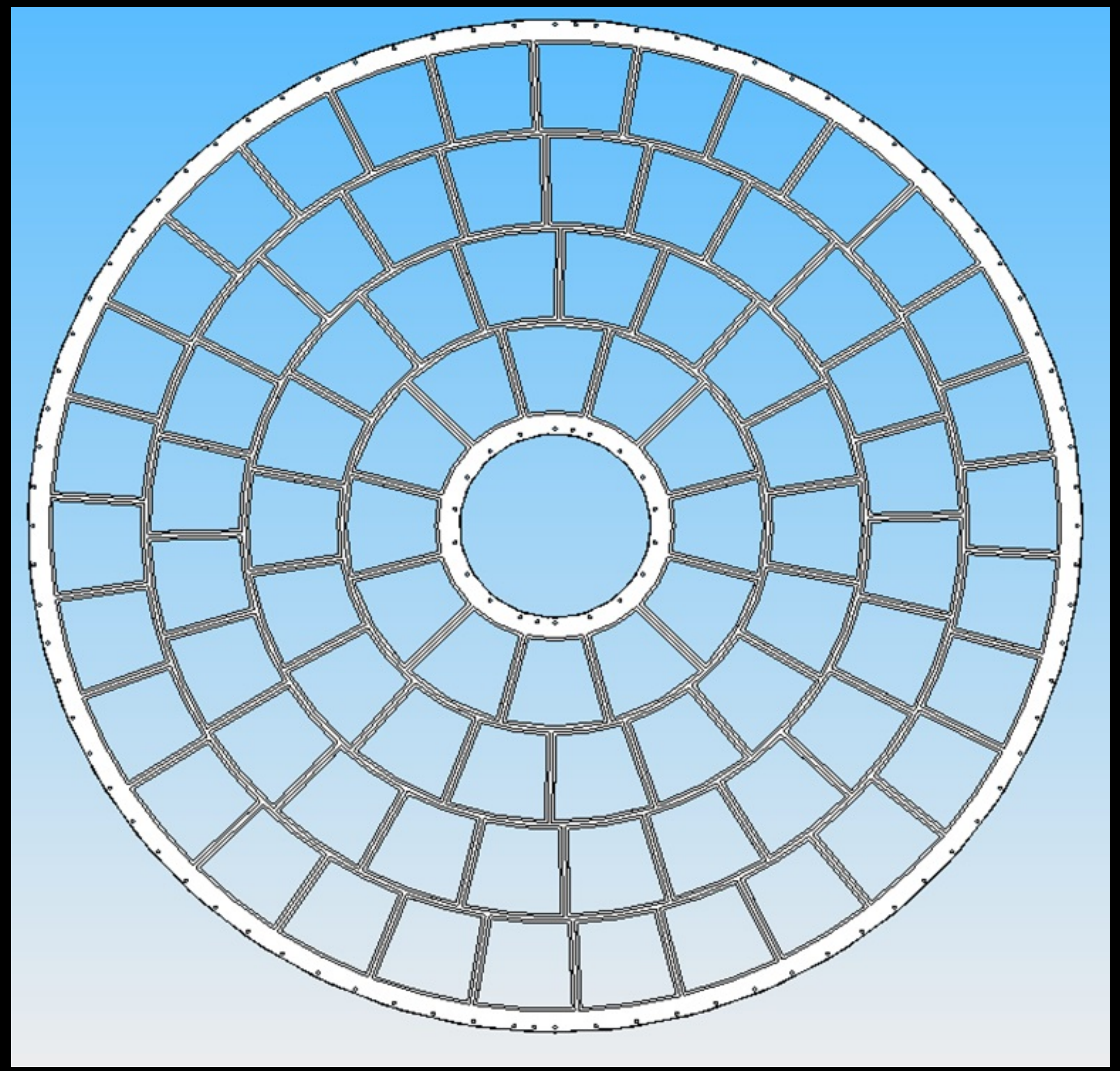
Needs close collaboration between detector designers and MDI engineers



Time Projection Chamber (TPC)

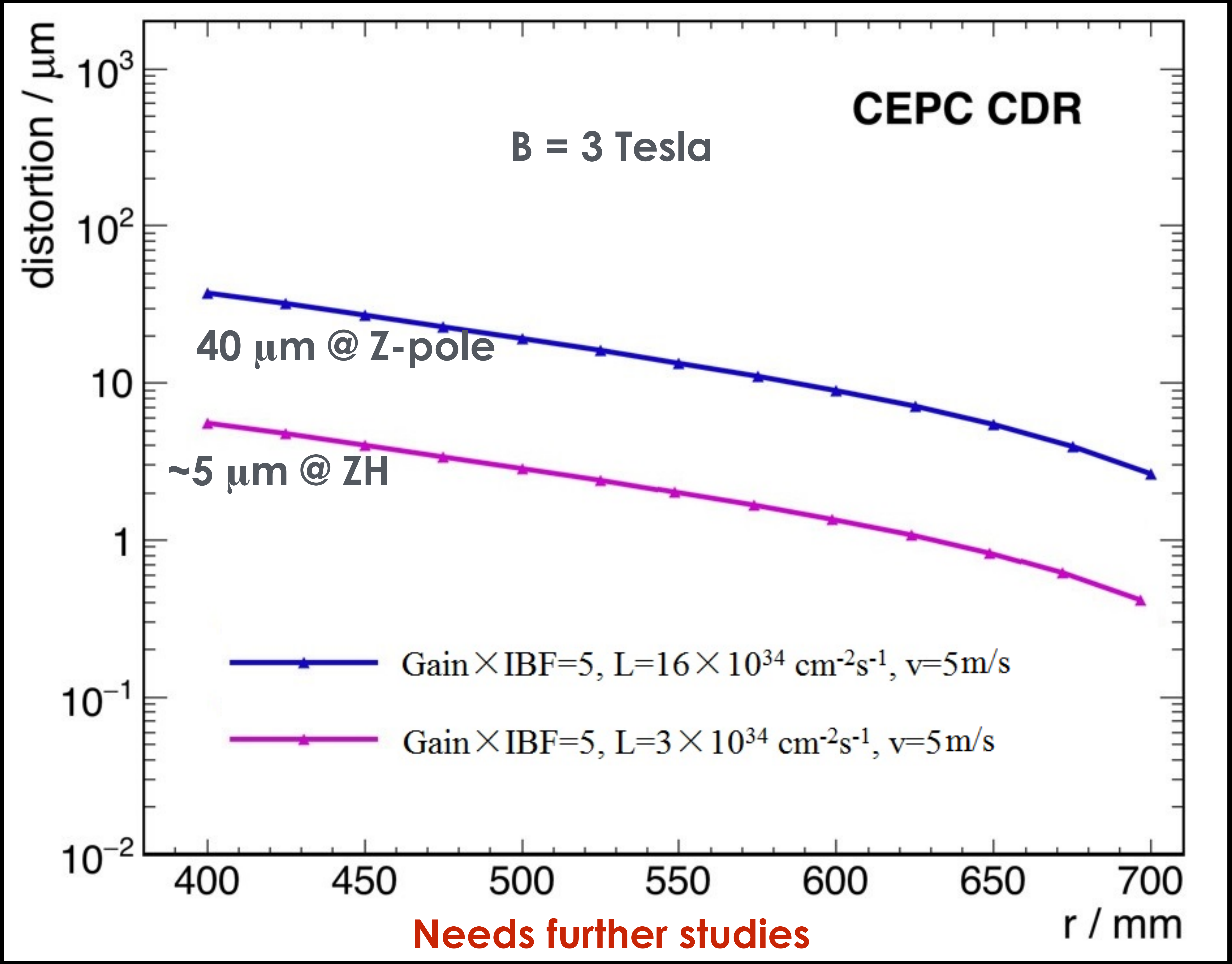


- **Allows for particle identification**
- **Low material budget:**
  - <1% X_0 in r
  - 10% X_0 for readout endcaps in Z



Readout by: Micro-Pattern Gas Detector (MPGD)

Time Projection Chamber (TPC) – Challenges



- Position resolution: ~100 μm in rϕ
- dE/dx resolution: 5%

- 3 Tesla magnetic field —> reduces diffusion of drifting electrons
- Problem: Ion Back Flow —> track distortion

Assumes, for each primary ionization,
5 ions backflow from
readout into main gas system

Hybrid: GEM and Micromegas readout

Mini-workshop, Hong Kong, IAS Jan 2019: http://iasprogram.ust.hk/hep/2019/workshop_cc.php

Drift Chamber Option – IDEA Concept

Lead by Italian Colleagues

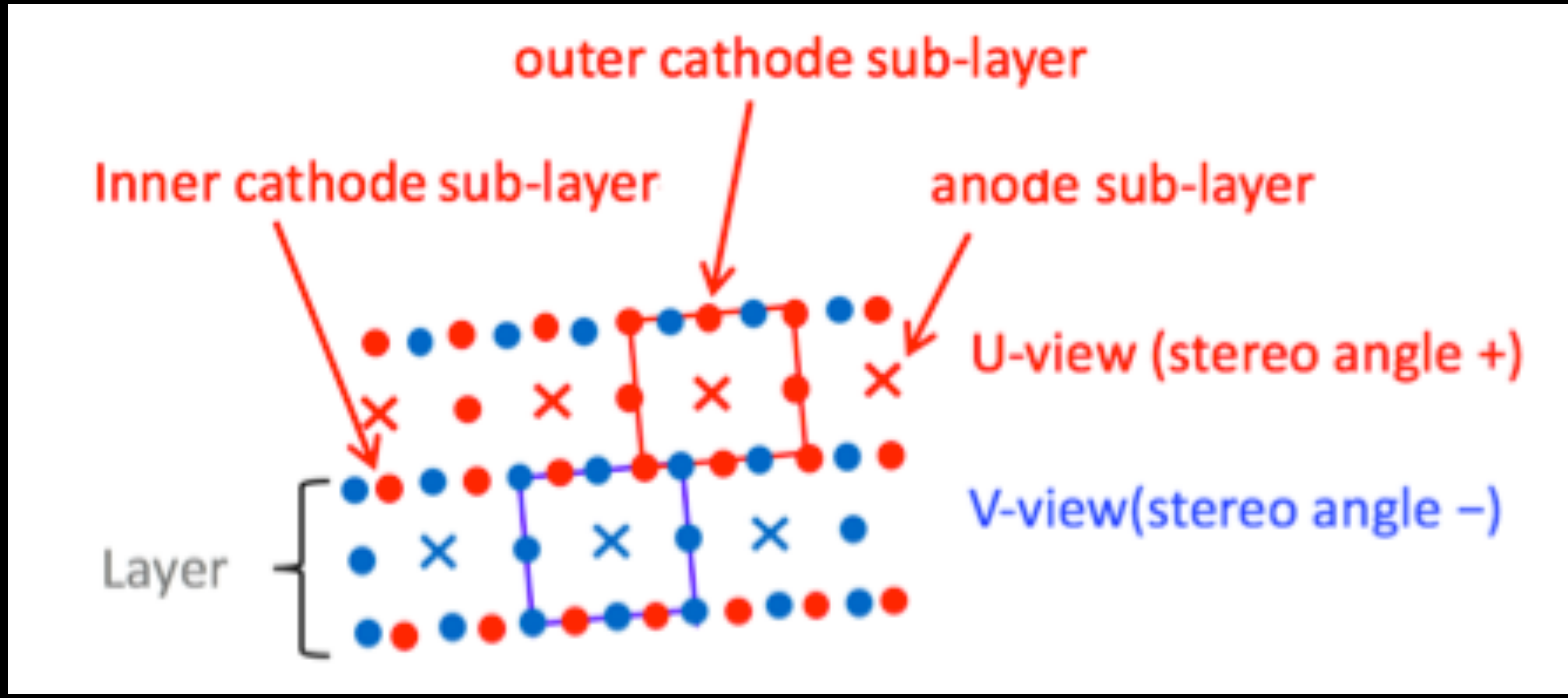
Low-mass cylindrical drift chamber

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)

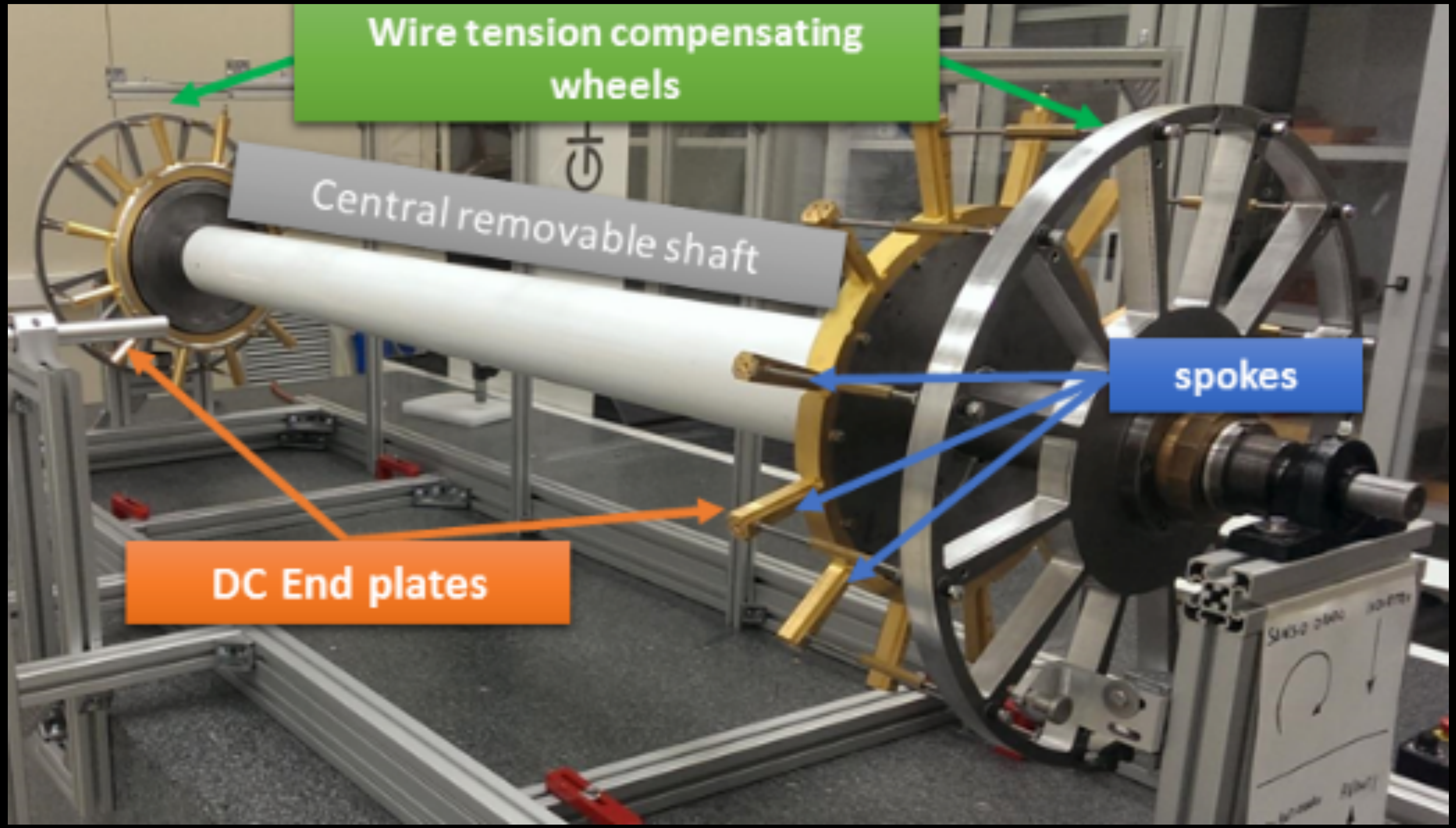
- Spatial resolution: < 100 μm
- Max drift time: ~350 nsec
- Cells: 56,448

Layers: 14 SL × 8 layers = 112
Cell size: 12 - 14 mm



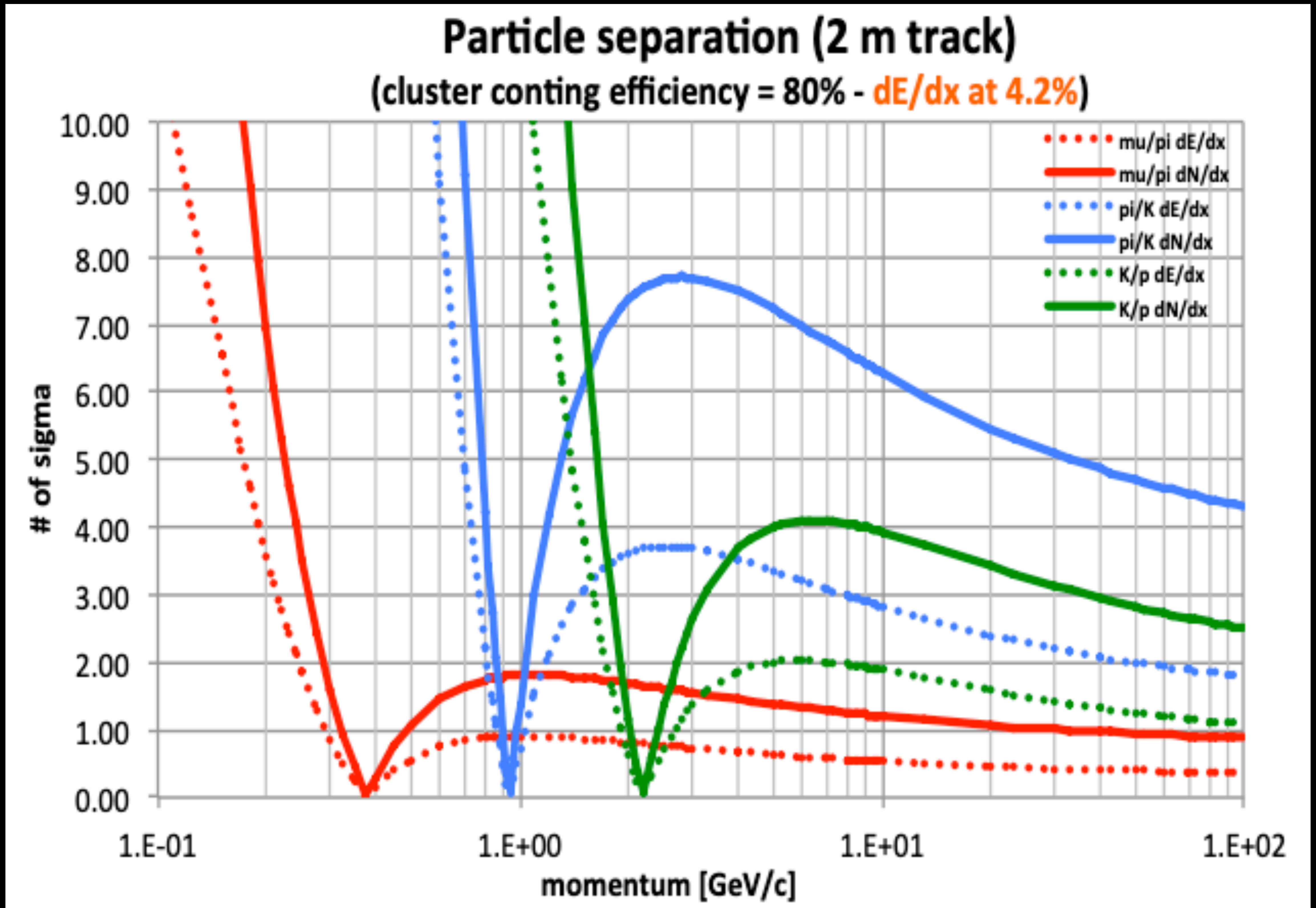
Stereo angle: 50-250 mrad

MEG2 chamber (naked)



Drift Chamber Considerations

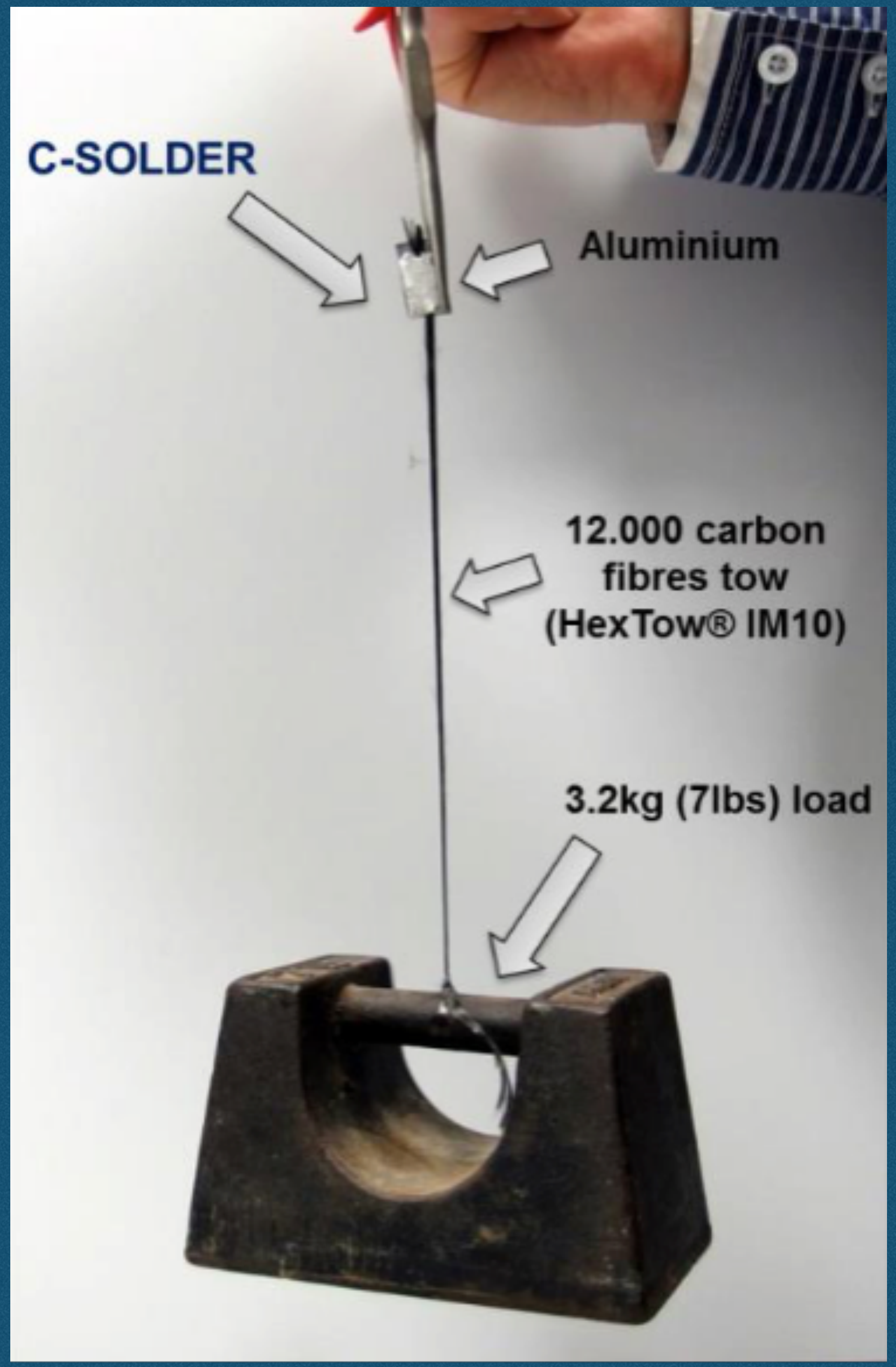
Particle Identification



Wire tension, 25 g, $T > 0.32$ N

Aluminium and Tungsten wires marginal

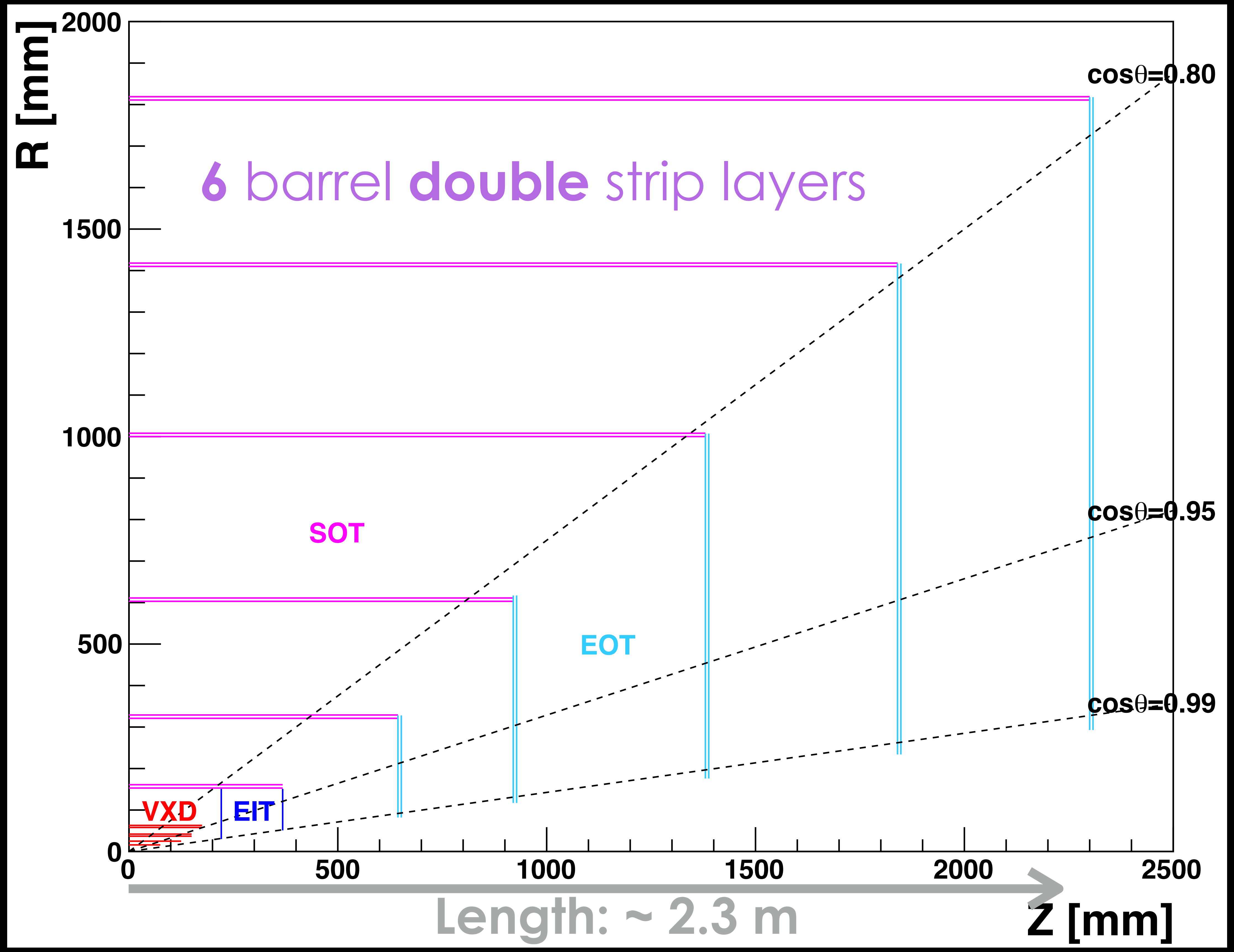
Exploring 35 μm Carbon monofilaments



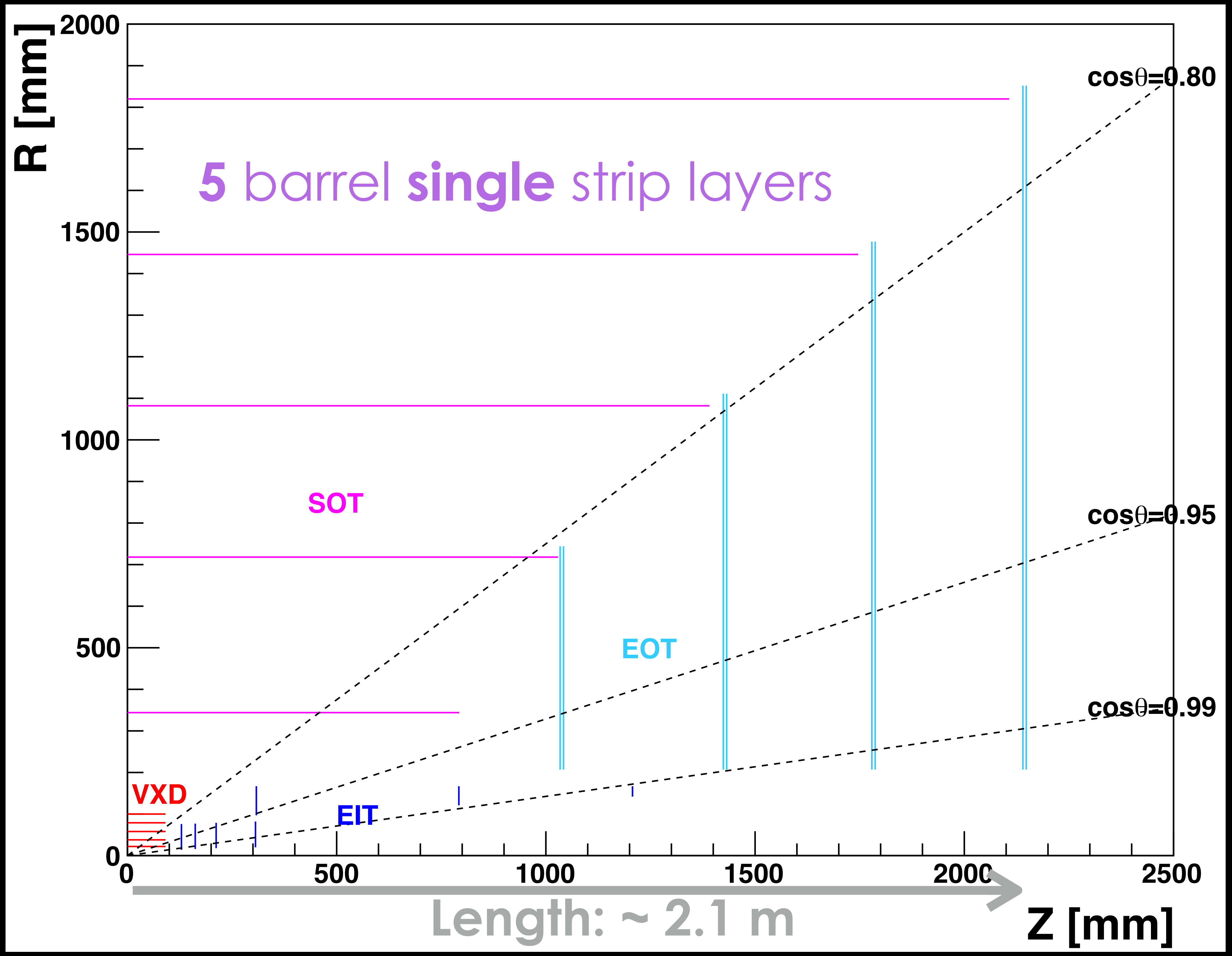
Full Silicon Tracker Concept

Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



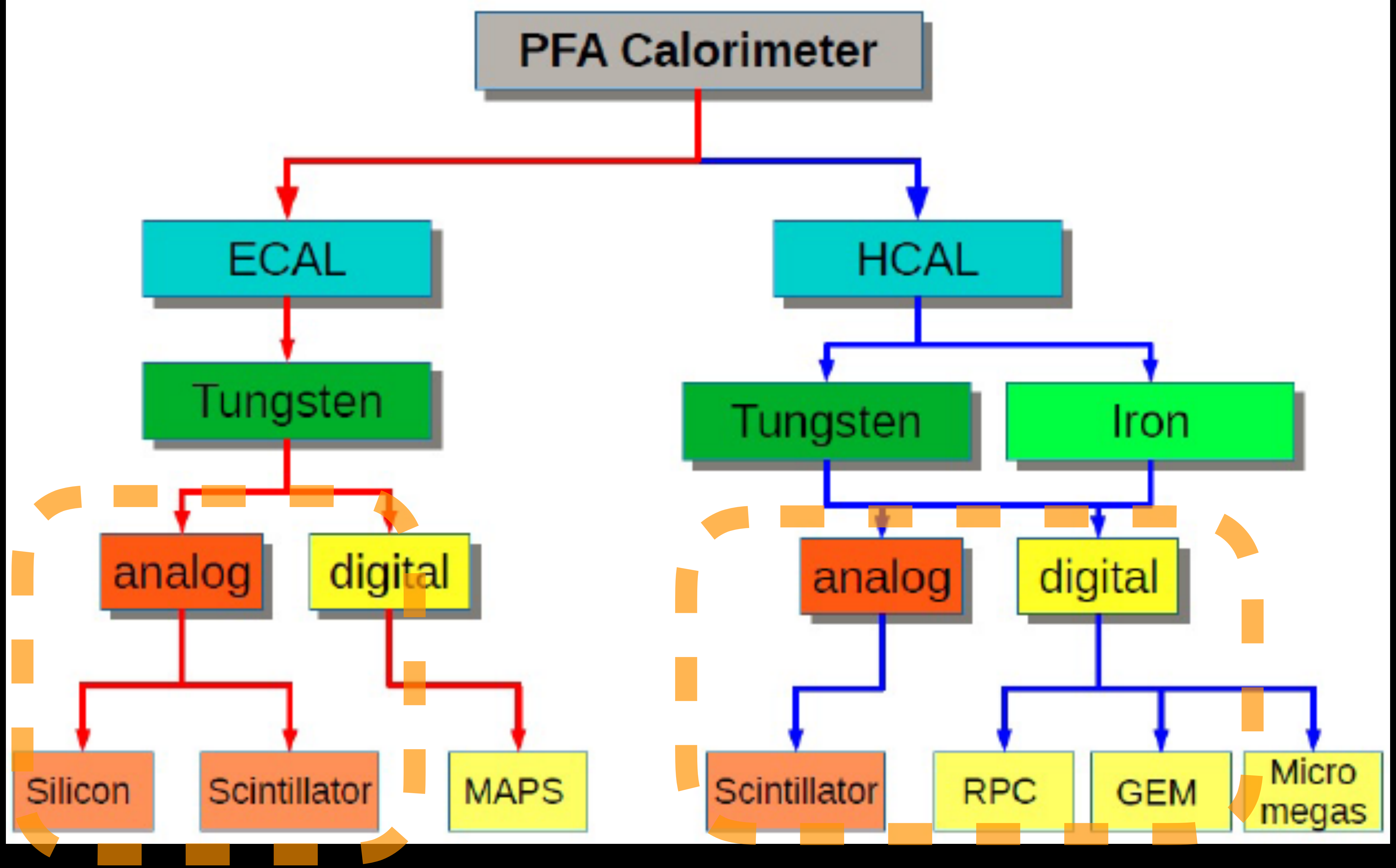
FST2 layout: Rad length up to 10%



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

Calorimeter for ILC

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)

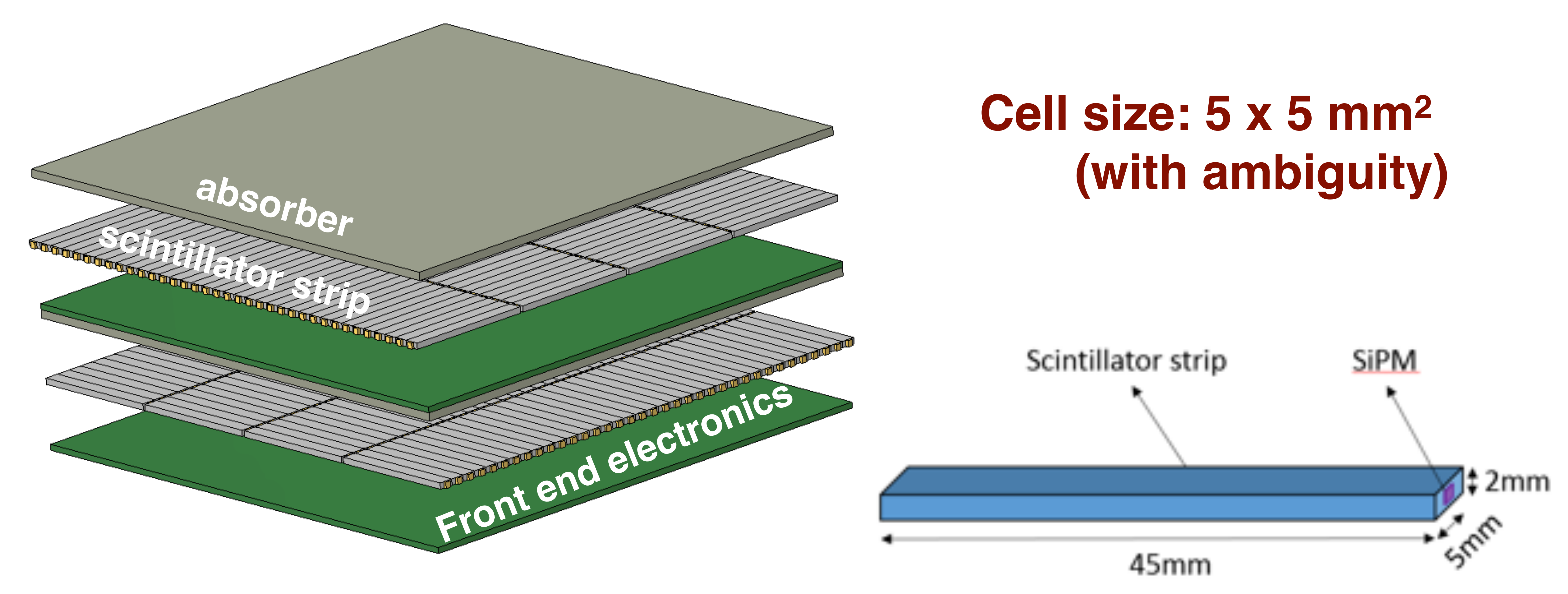
Newer Options

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



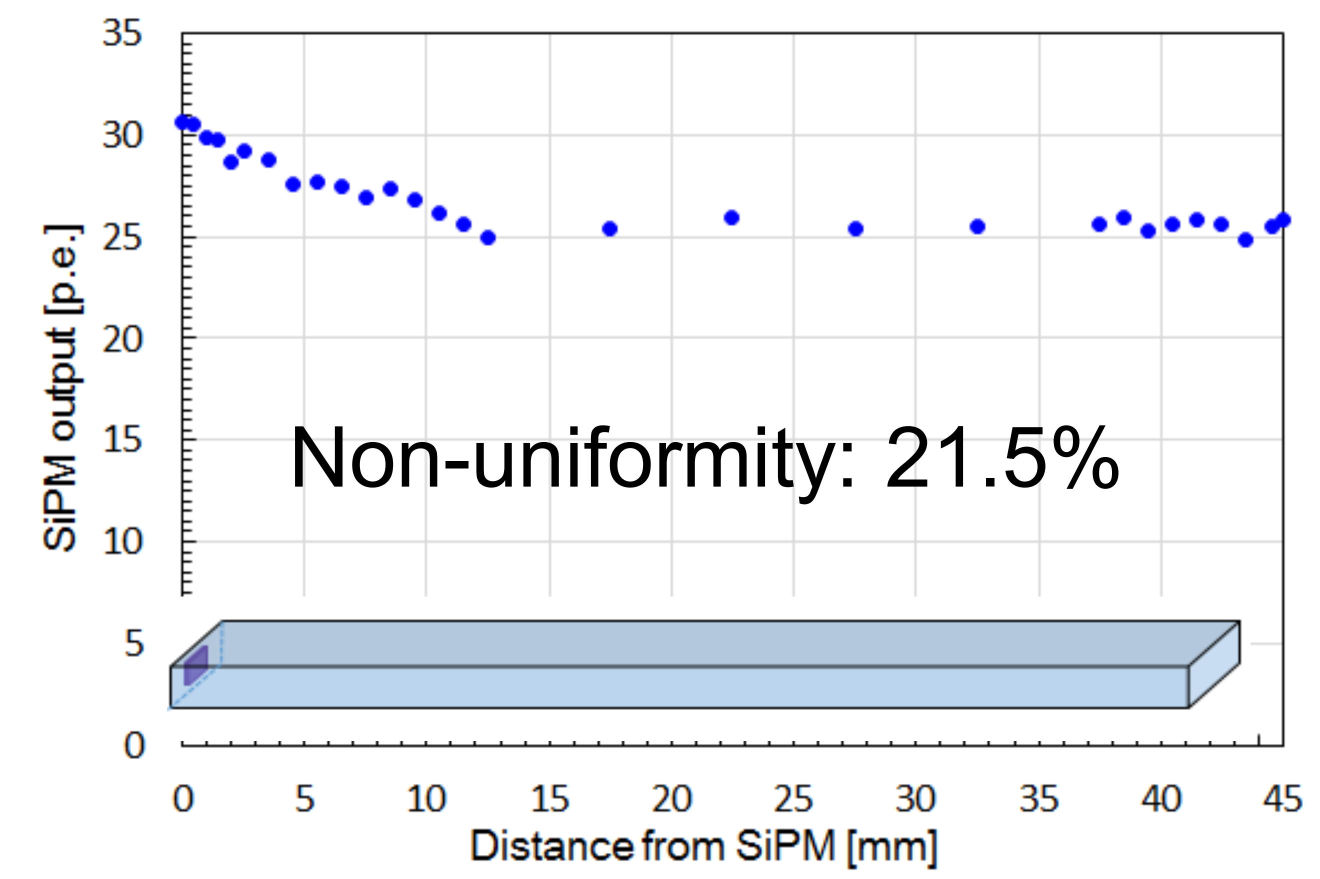
Superlayer (7 mm) is made of:
- 3 mm thick: Tungsten plate
- 2 mm thick: Scintillator 5 x 45 mm²
- 2 mm thick: Readout/service layer

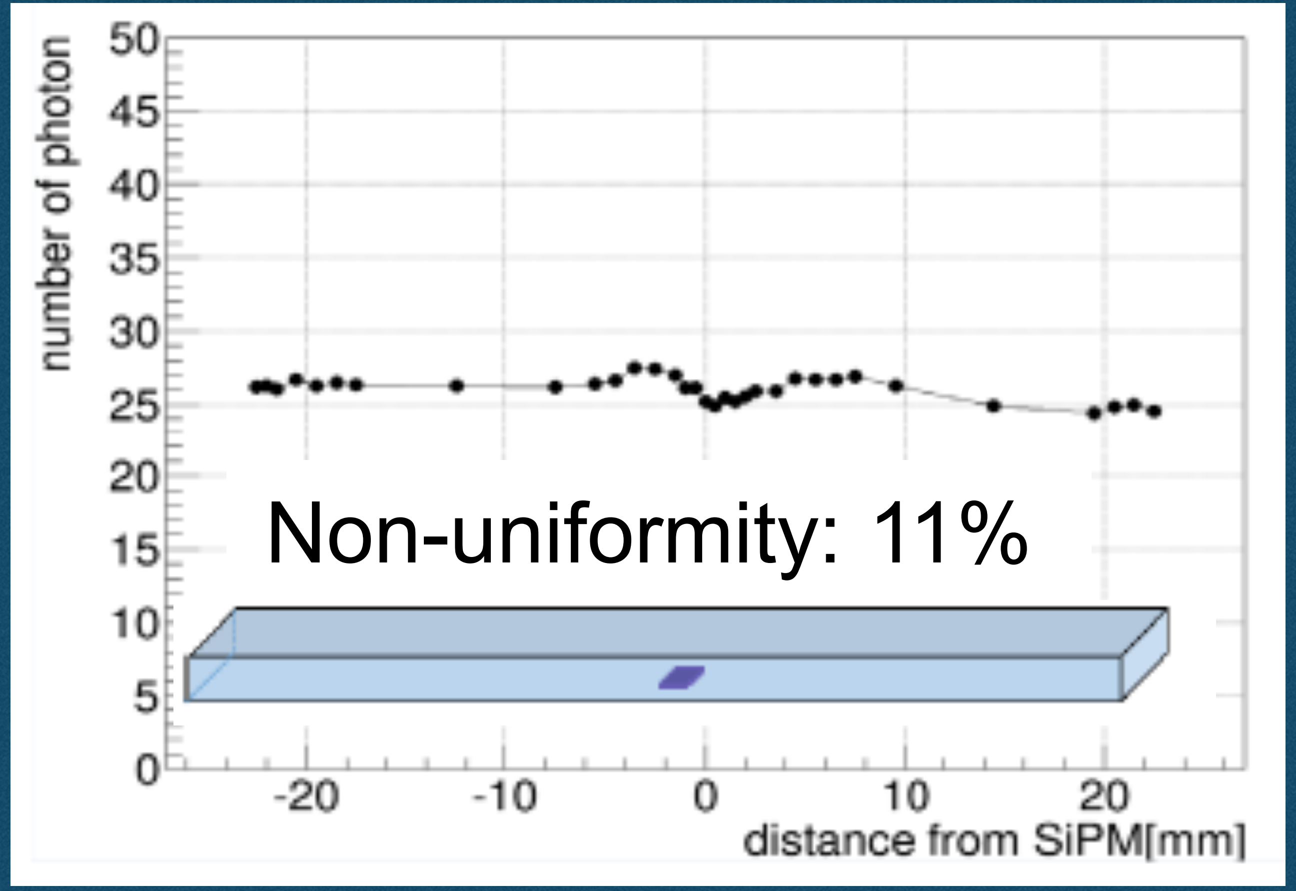
SiPM studies

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

1. SiPM with more than 10000 pixels are not required

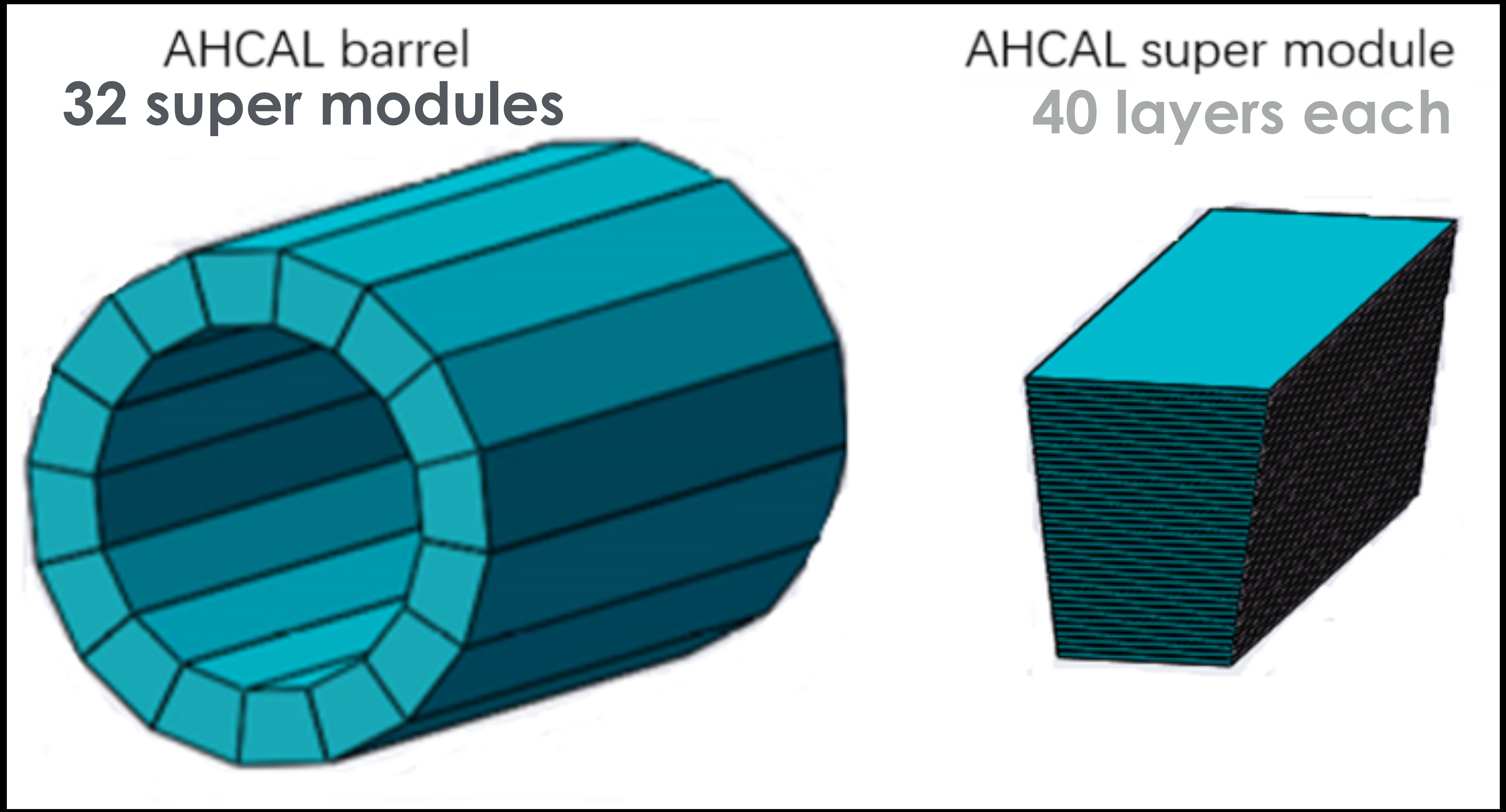
2. SiPM to be located in center of strip

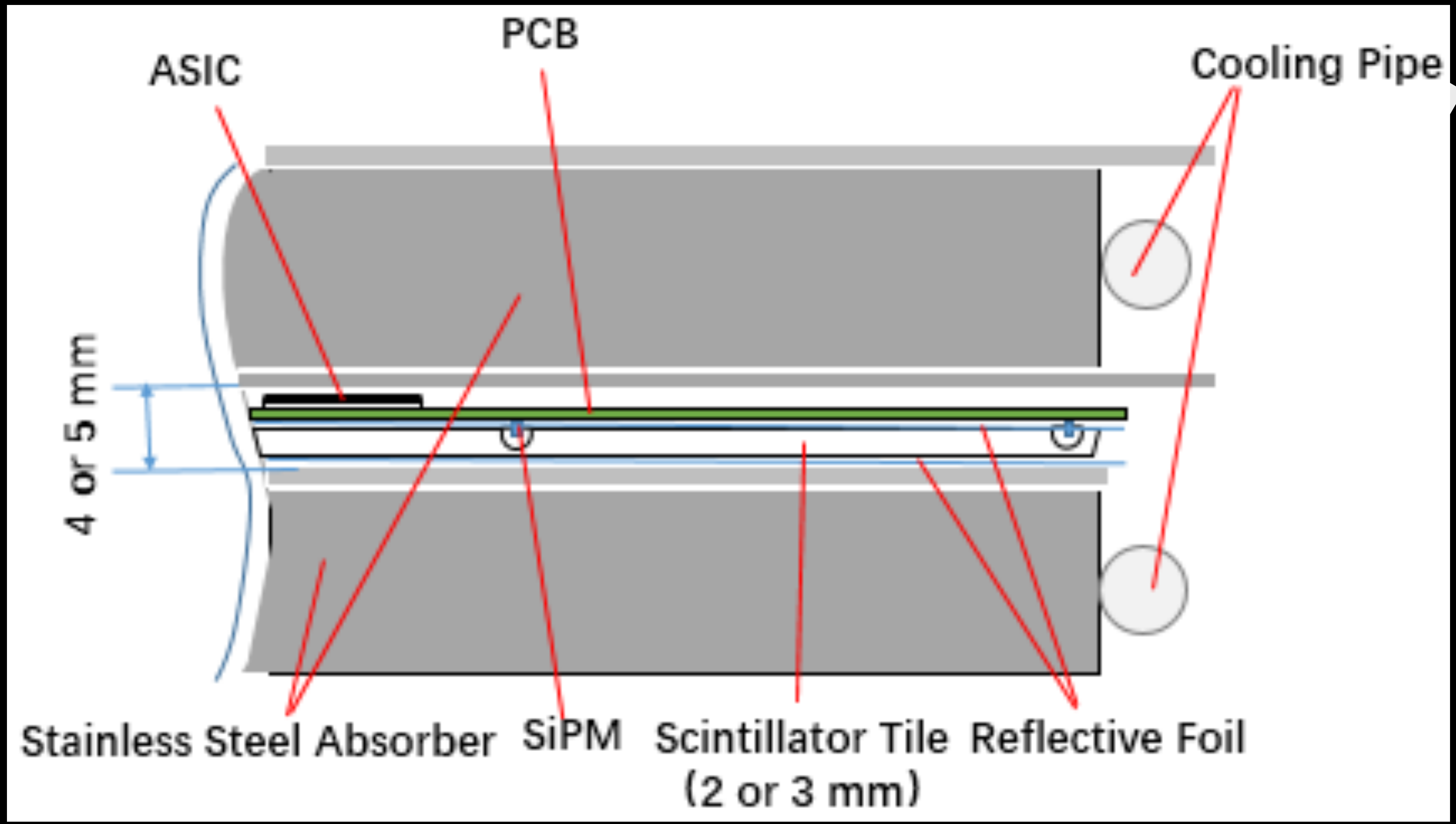


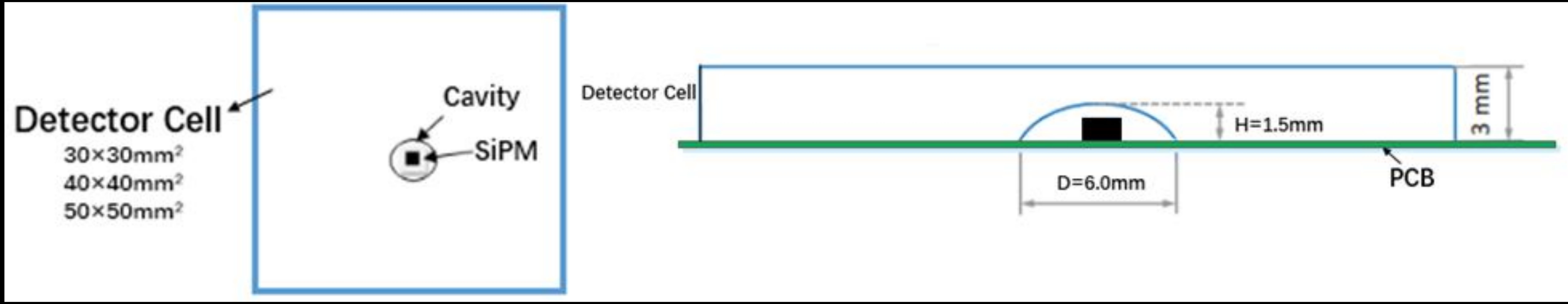


HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)







Readout channels:

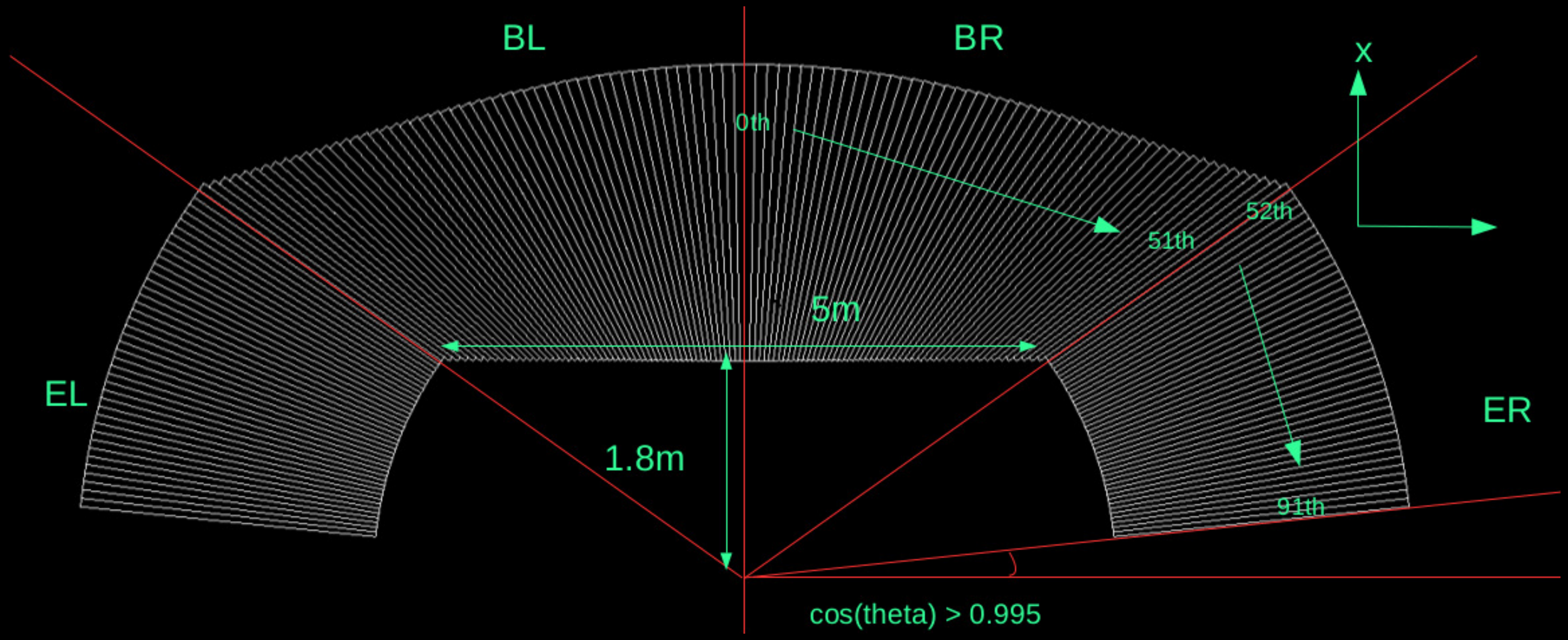
~ 5 Million (30 x 30 mm²)

~ 2.8 Million (40 x 40 mm²)

Dual Readout Calorimeter

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

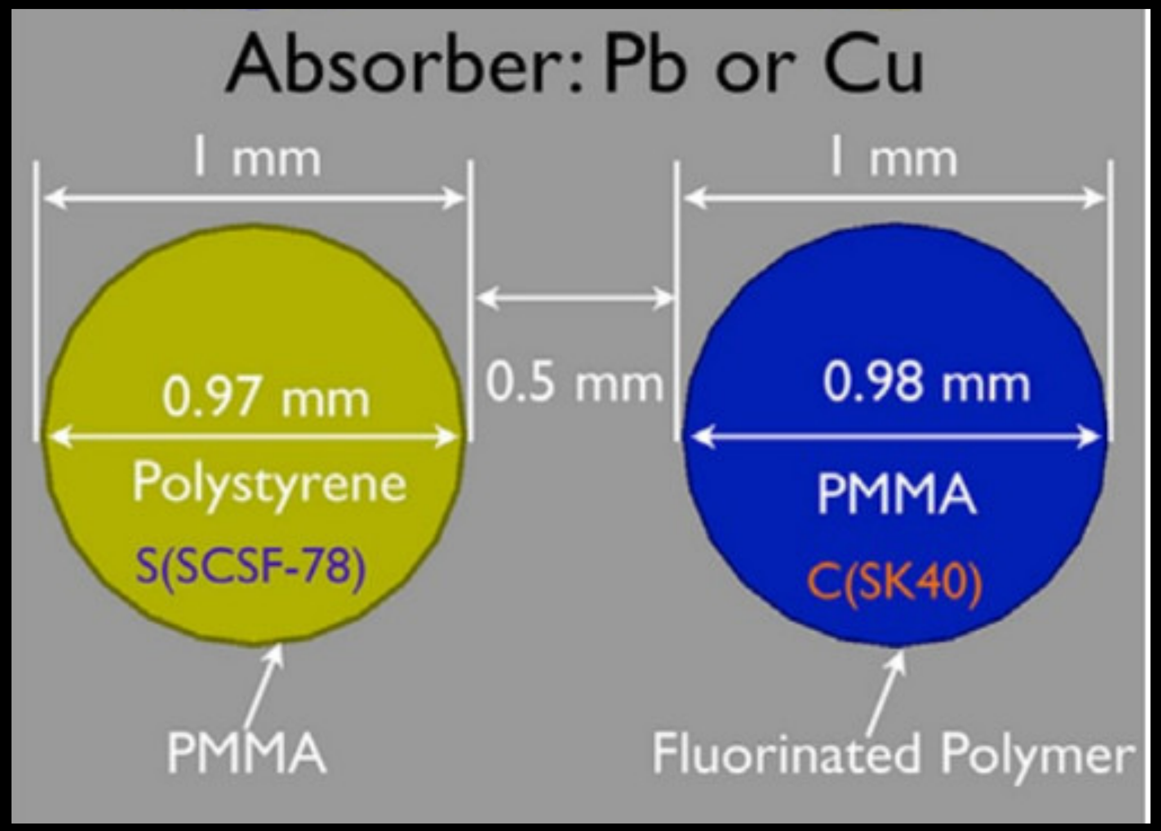
Projective 4π layout implemented into CEPC simulation
(based on 4th Detector collaboration design)



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

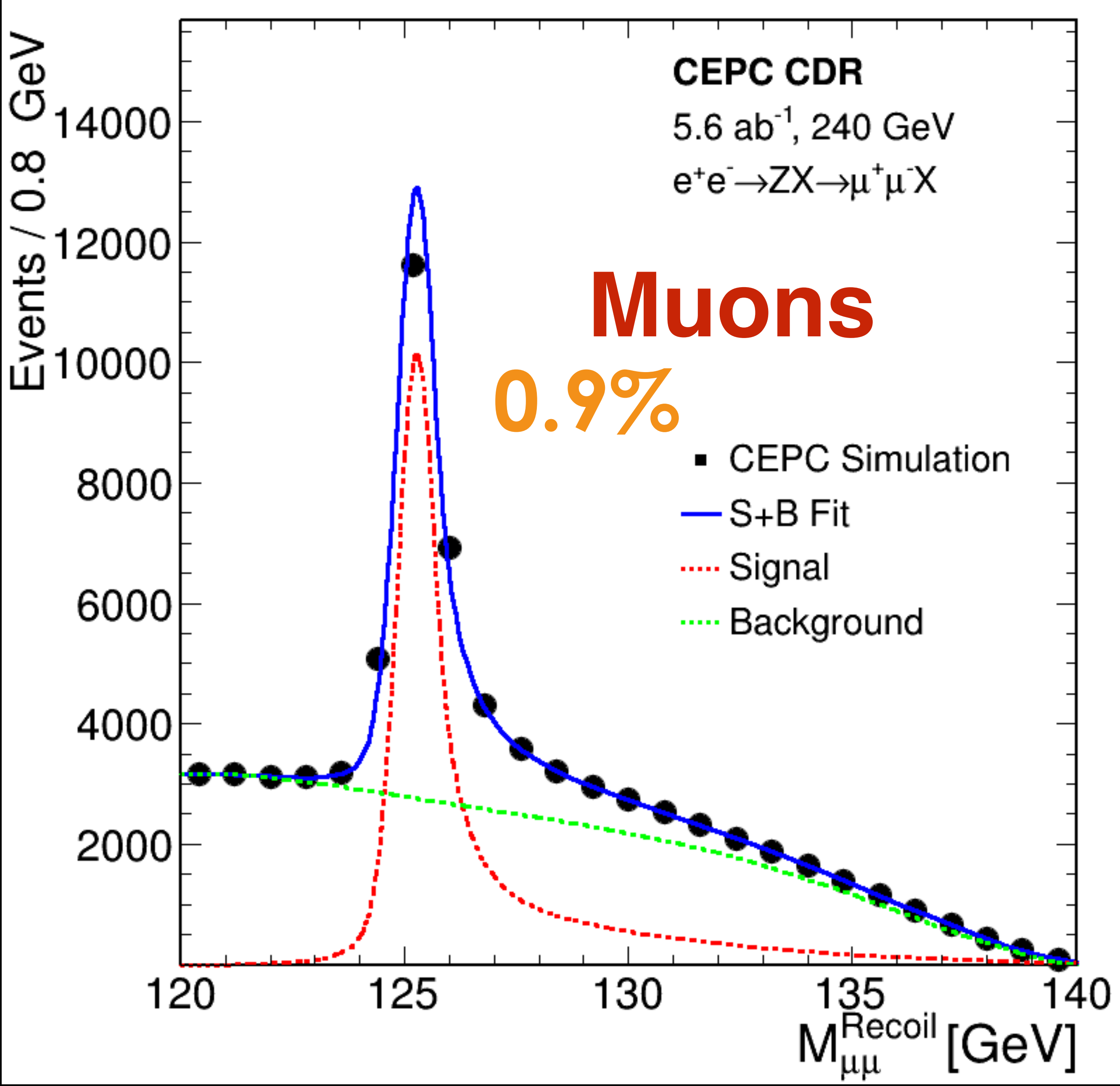
New Ideas: Crystal Calorimeters

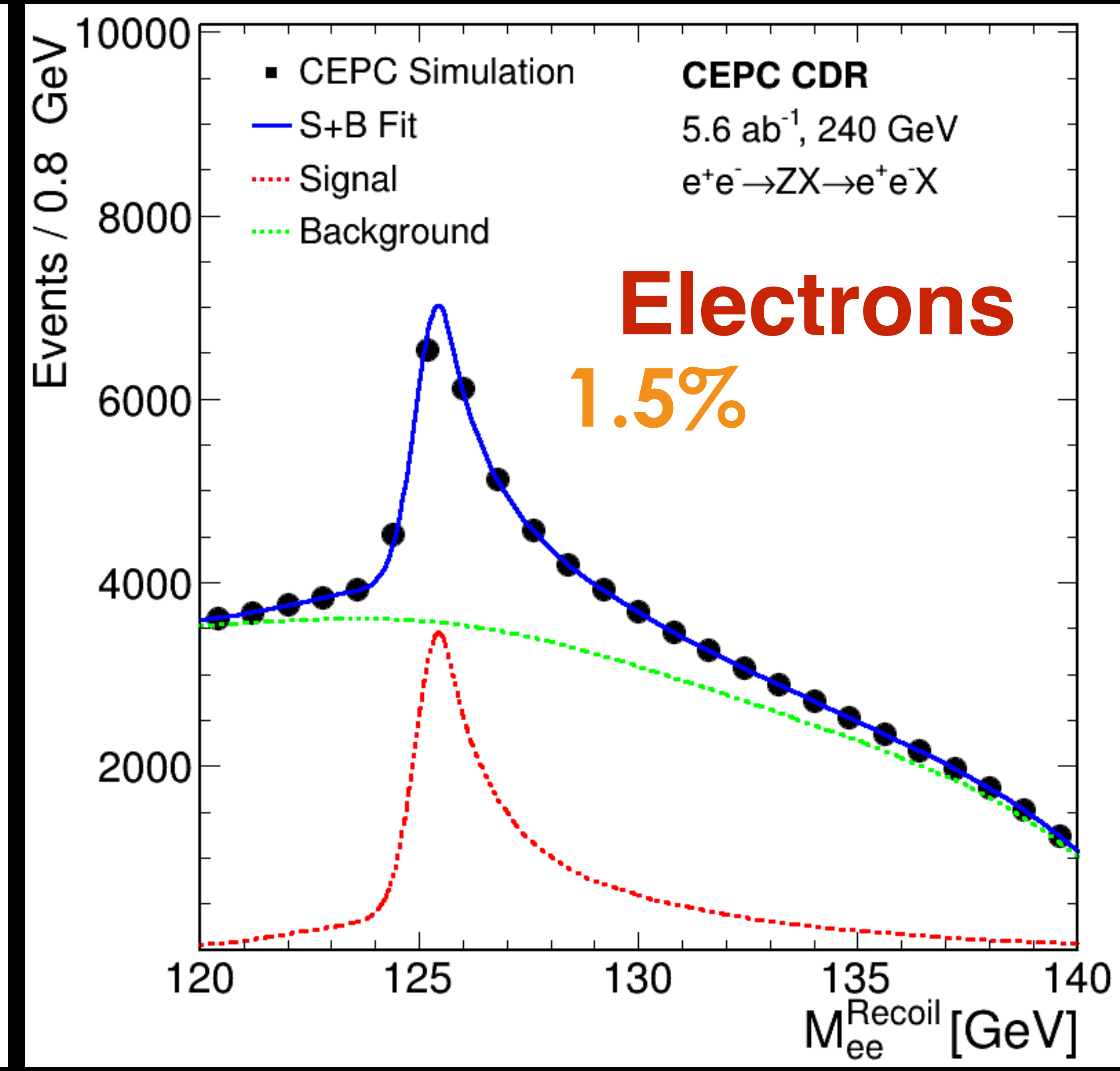
Topical Workshop on CEPC Calorimetry at IHEP • March 11-14, 2019
https://indico.ihep.ac.cn/event/9195/

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

Z boson recoil mass



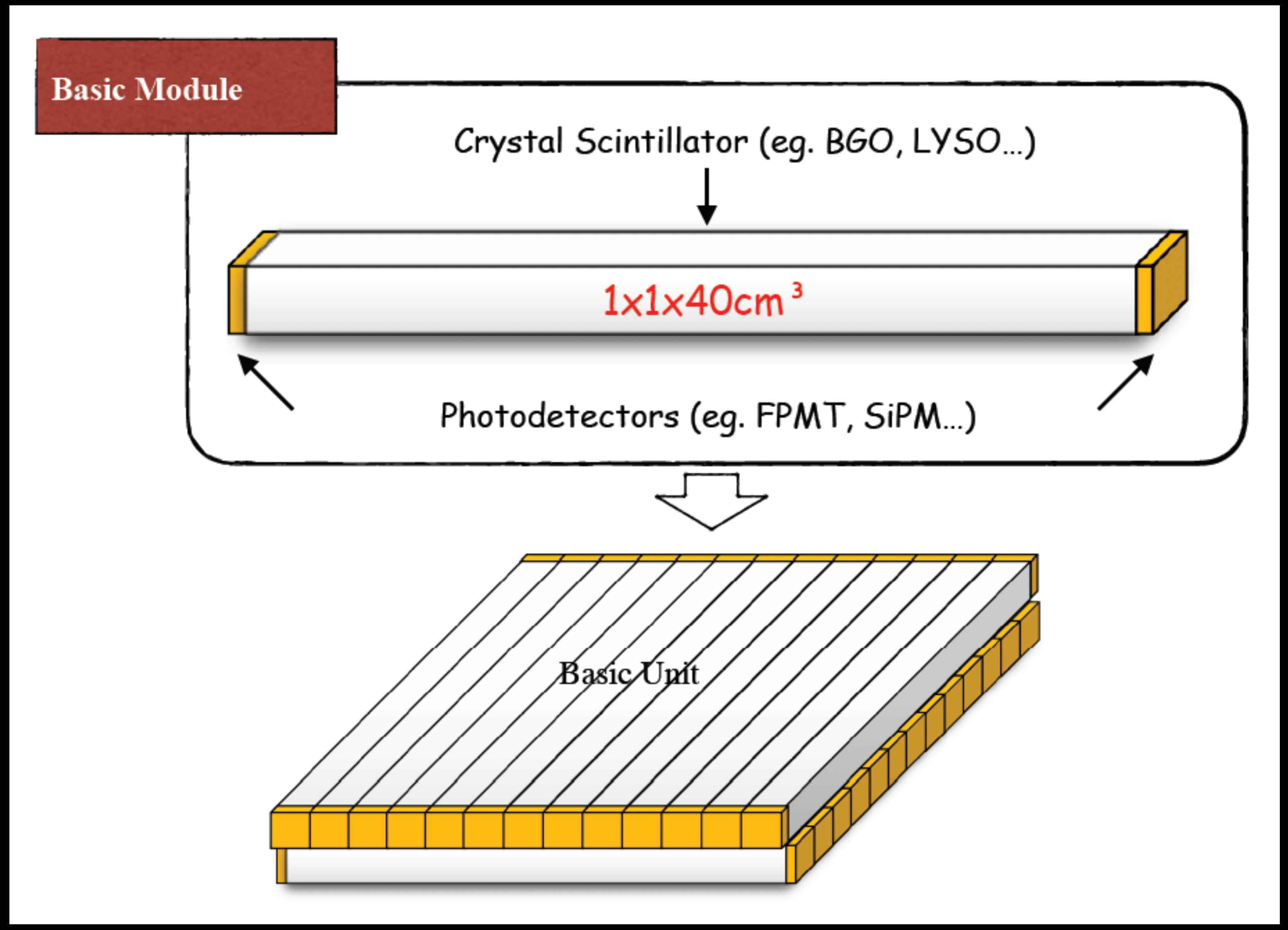


New Ideas: Crystal Calorimeters

Three new segmented calorimeter proposals based on crystals

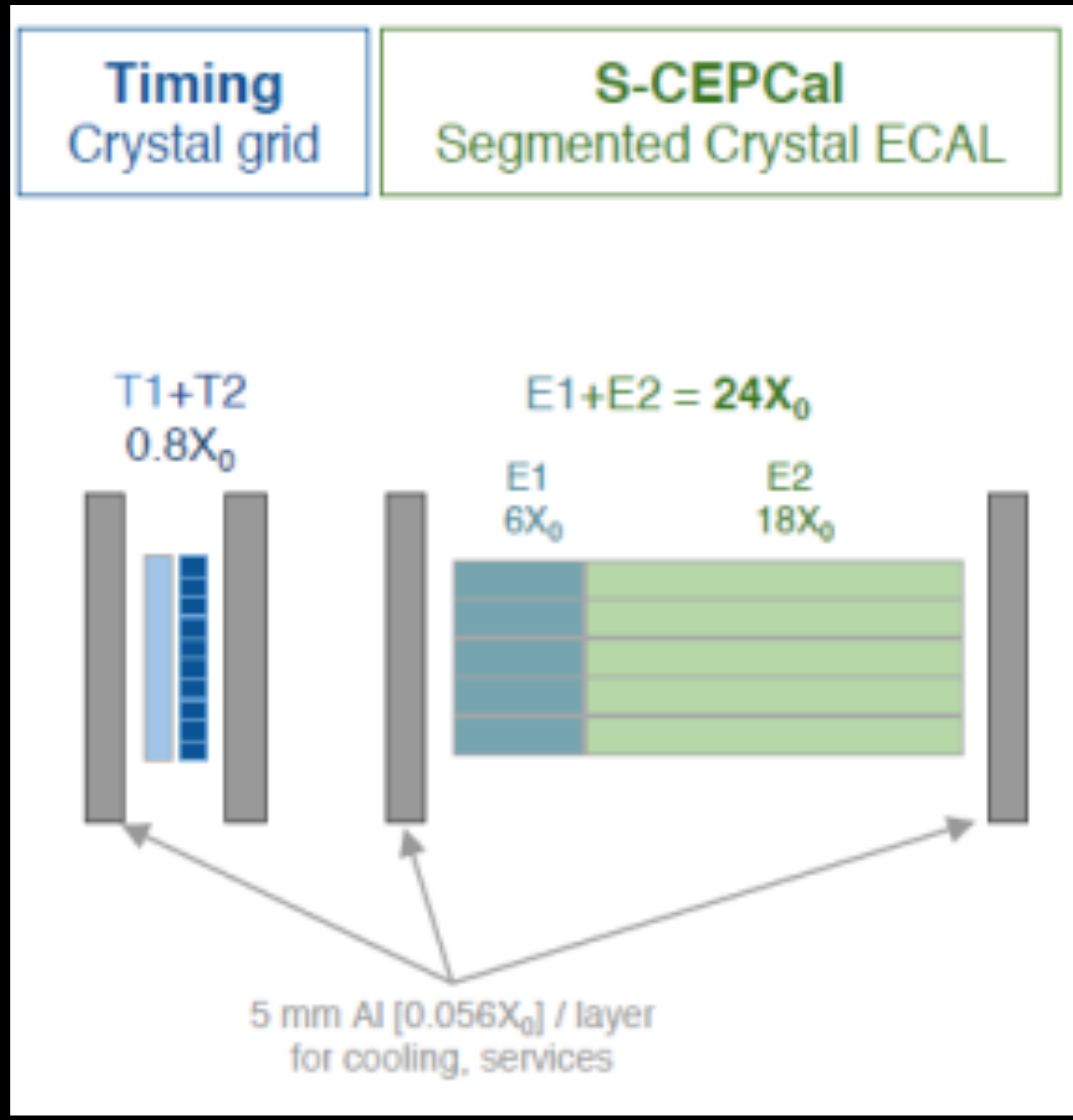
Long crystal bars with optical readout at both ends

Yuexin Wang (IHEP), et al



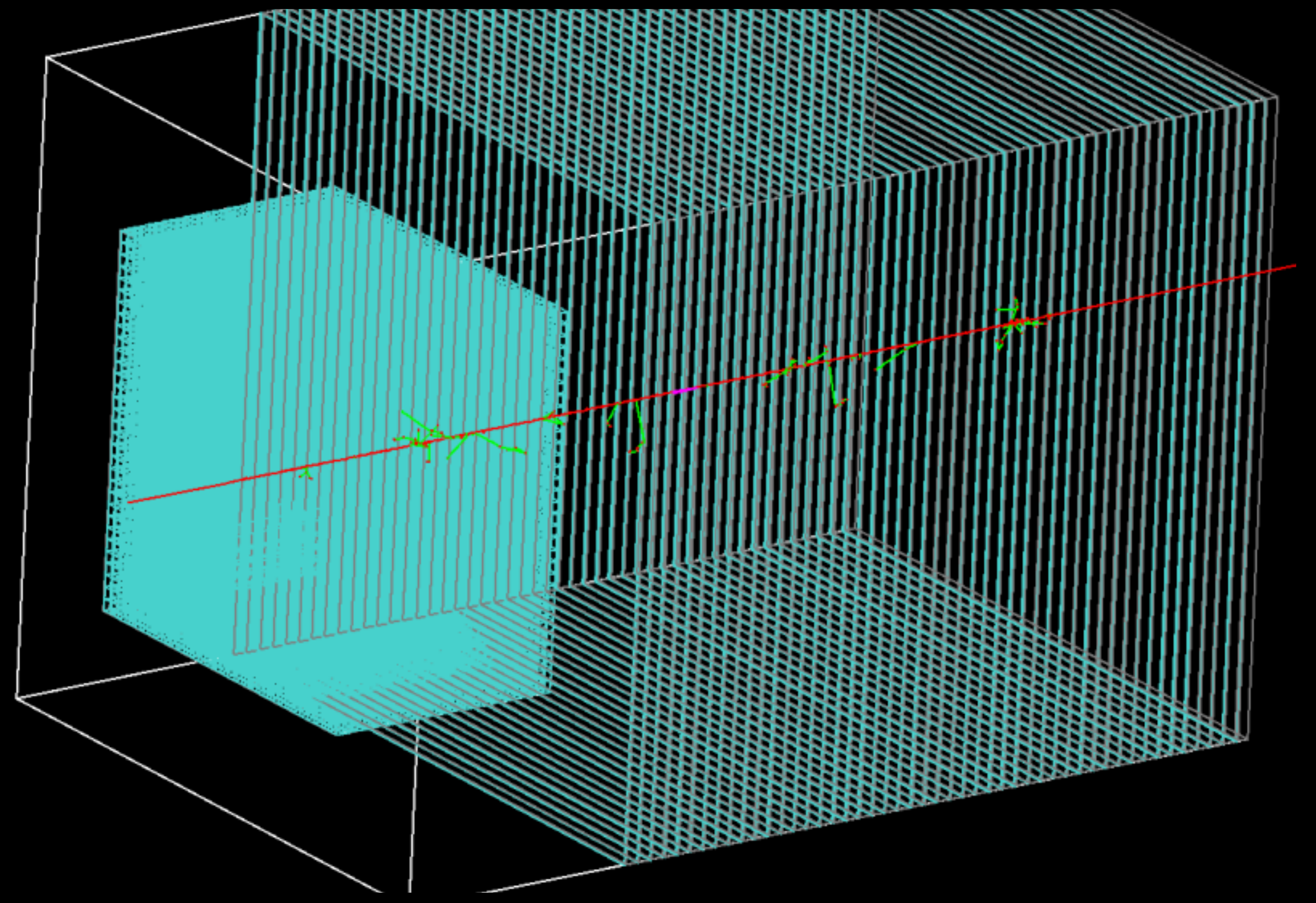
Long crystal bars with optical readout at single ends

Tully (Princeton), Eno (UMD), et al



Thin crystal tiles with optical readout at single ends

Yong Liu (IHEP), et al



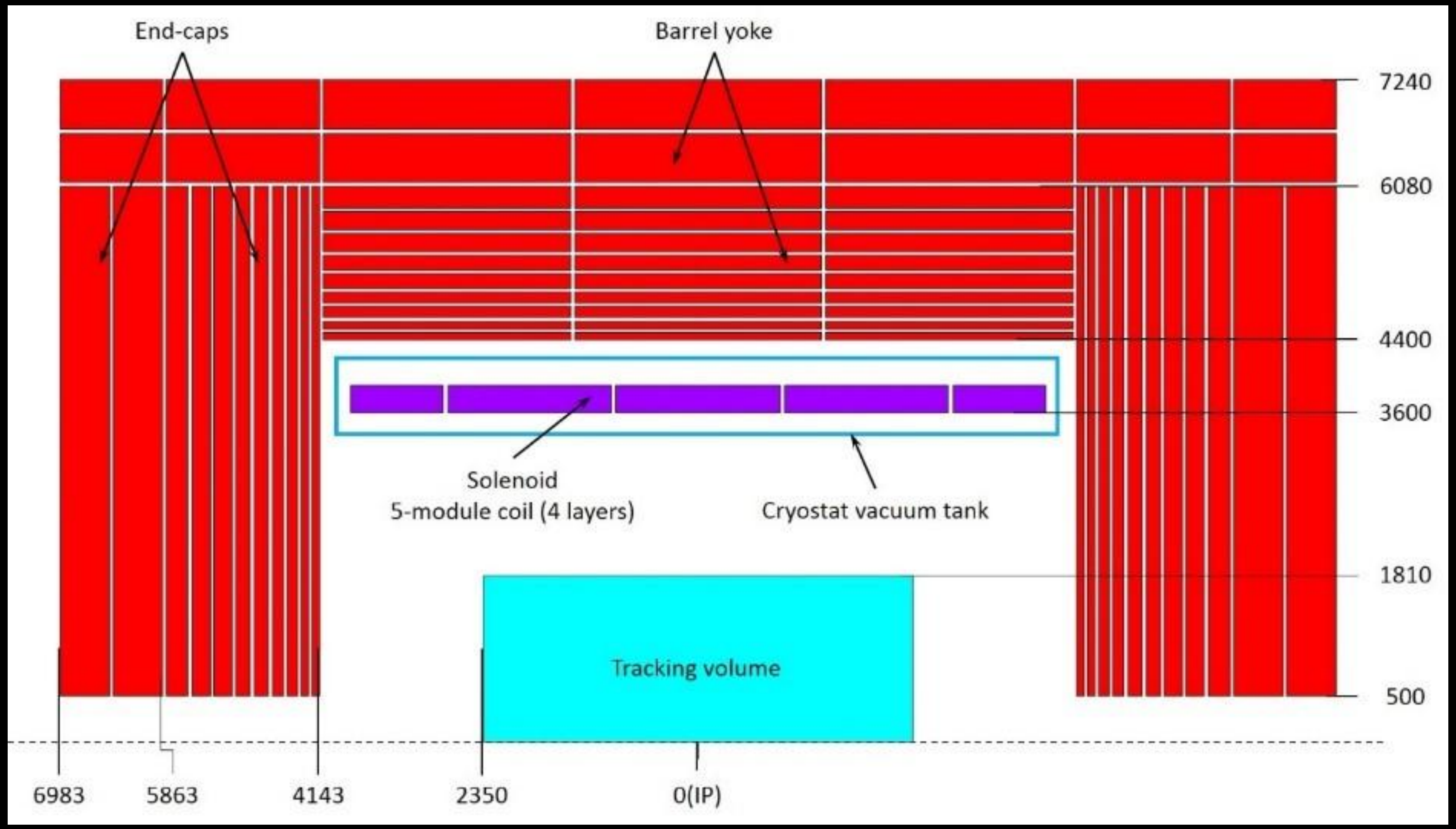
ECAL: 30 layers

Crystals: LYSO:Ce, PbWO, BGO

Cost is an issue

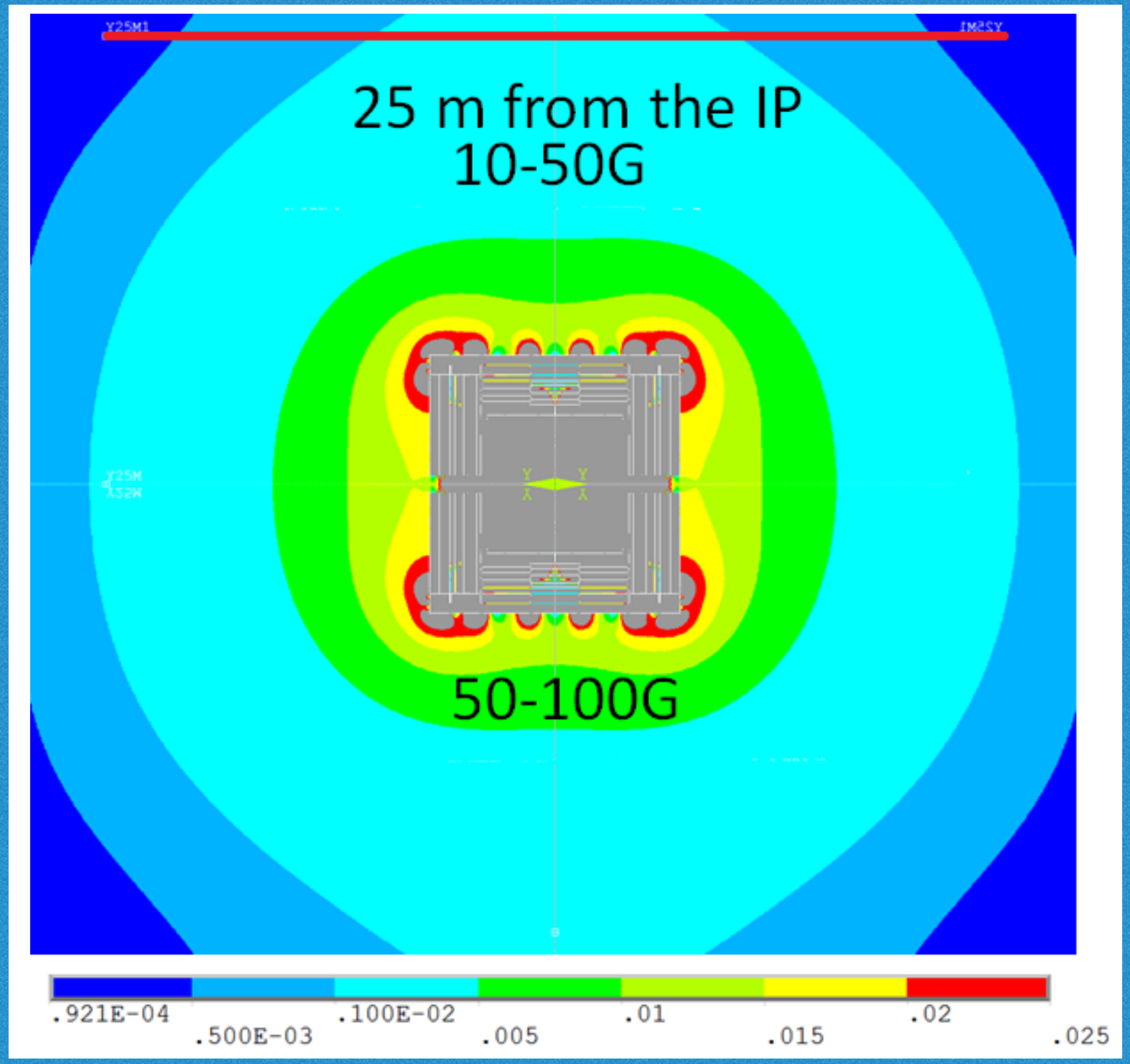
Superconductor solenoid development

3 Tesla Field Solenoid

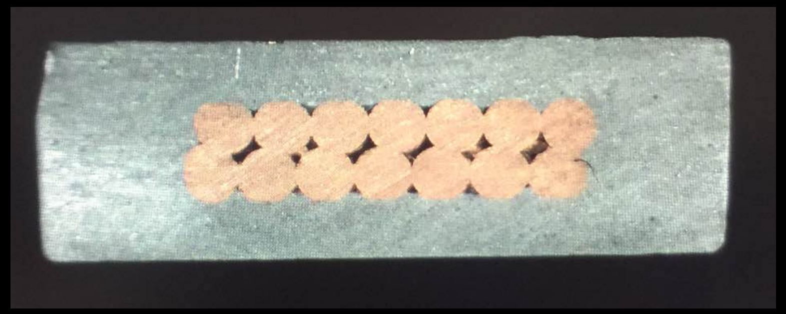


Operating current	15.8 A	Cable length	30.1 km

Stray field map of magnet



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



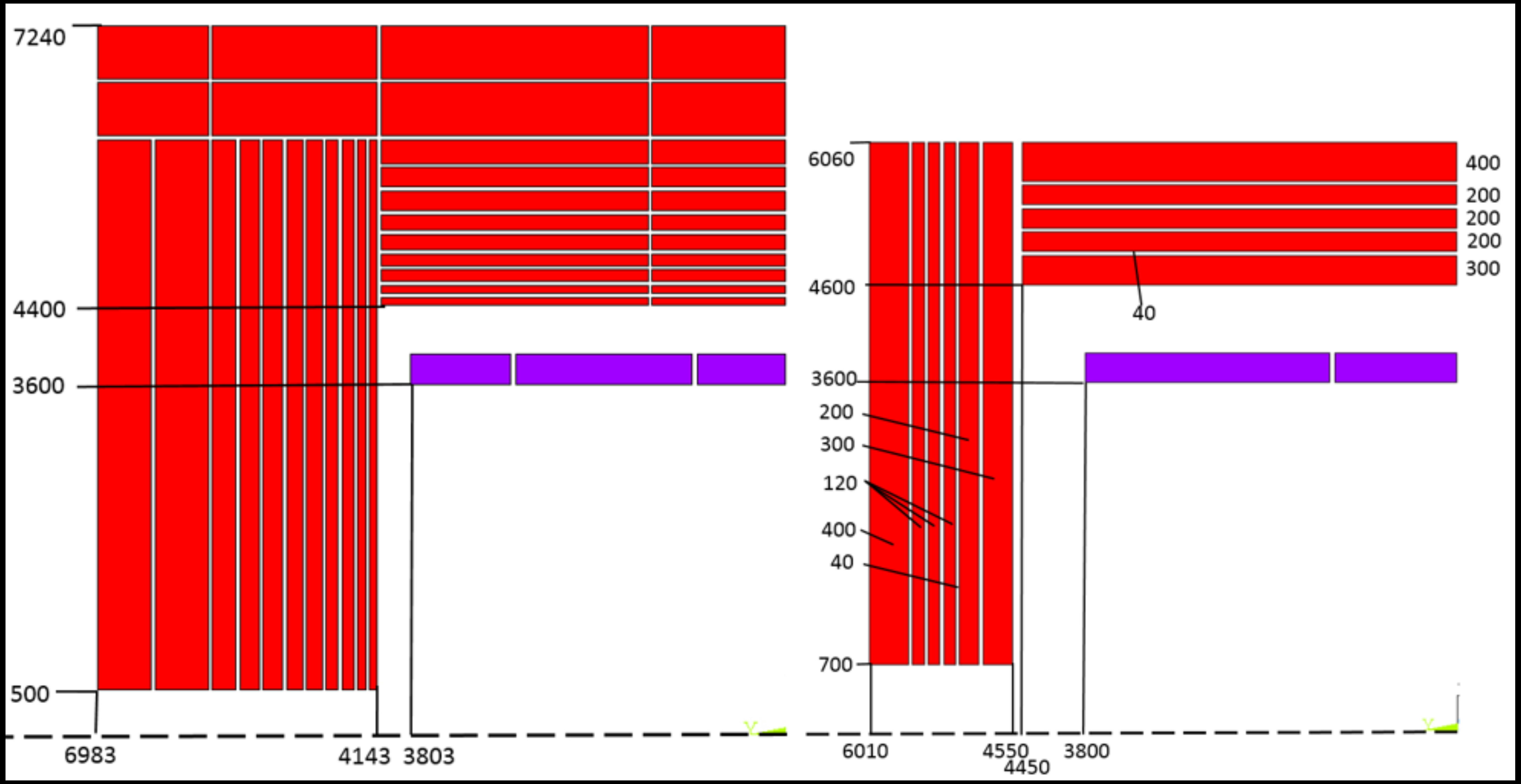
Design for 2 Tesla magnet presents no problems

Thin HTS solenoid being designed for IDEA concept

Double-solenoid design also available

Yoke Size Optimization

CDR　　　New Proposal



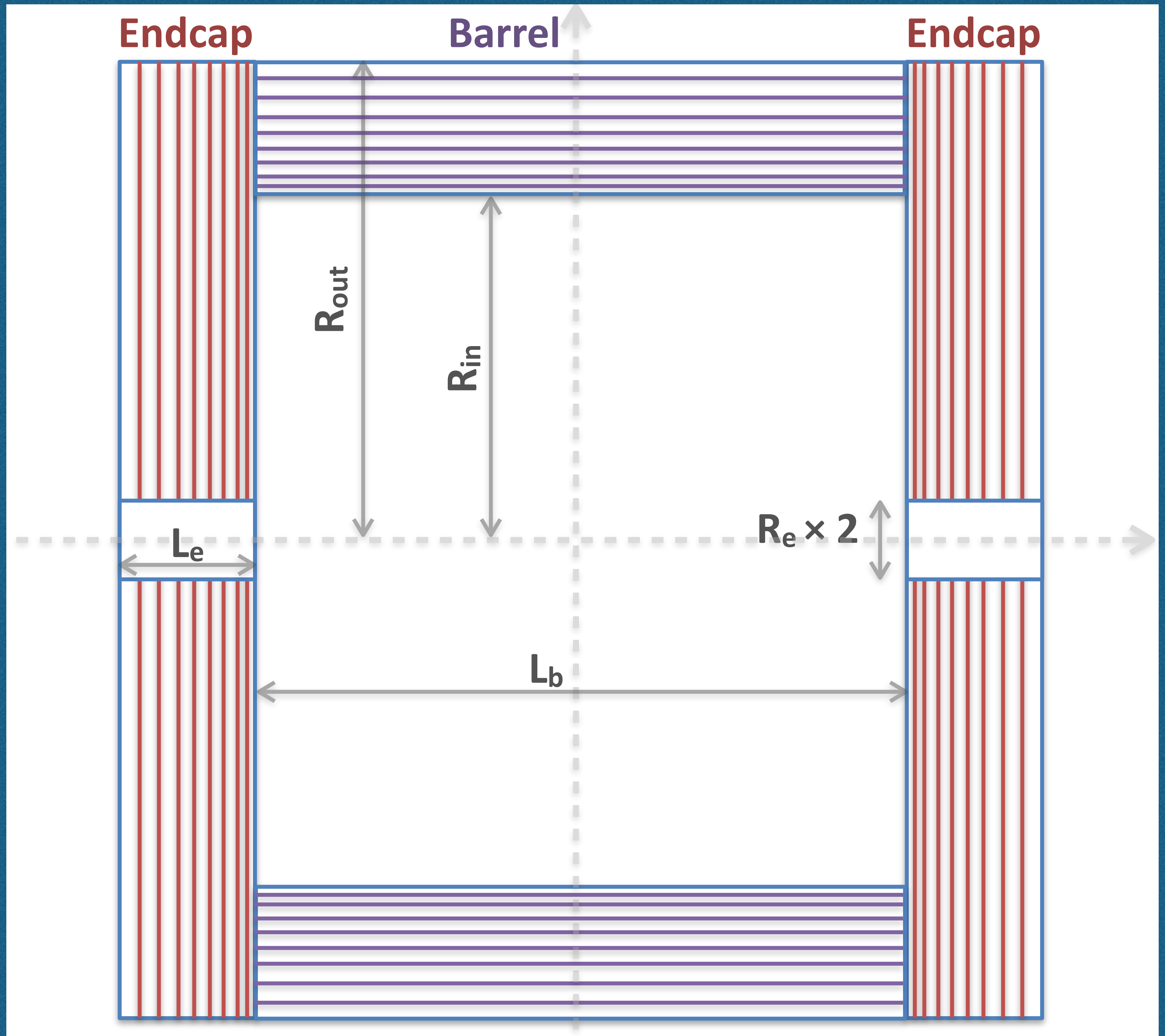
	CMS	CEPC original	CEPC New
Central field (T)	4	3	3
Operating current (A)	19600	15779	16796
Inner diameter of coil (mm)	6360	7200	7200
Length of coil (mm)	12480	7606	7600
Barrel yoke inner diameter (mm)	9180	8800	9200
Barrel yoke outer diameter (mm)	14000	14480	12120
Total length of yoke (mm)	20040	13966	12020
Weight of barrel yoke (t)	6000	5940	3137
Weight of each end cap (t)	2000	3316.6	1144
Total weight of yoke (t)	10000	12573	5425

Stray field similar to CMS but it will require shielding of Booster along a few hundred meters

Muon Detector System

Baseline Muon detector

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

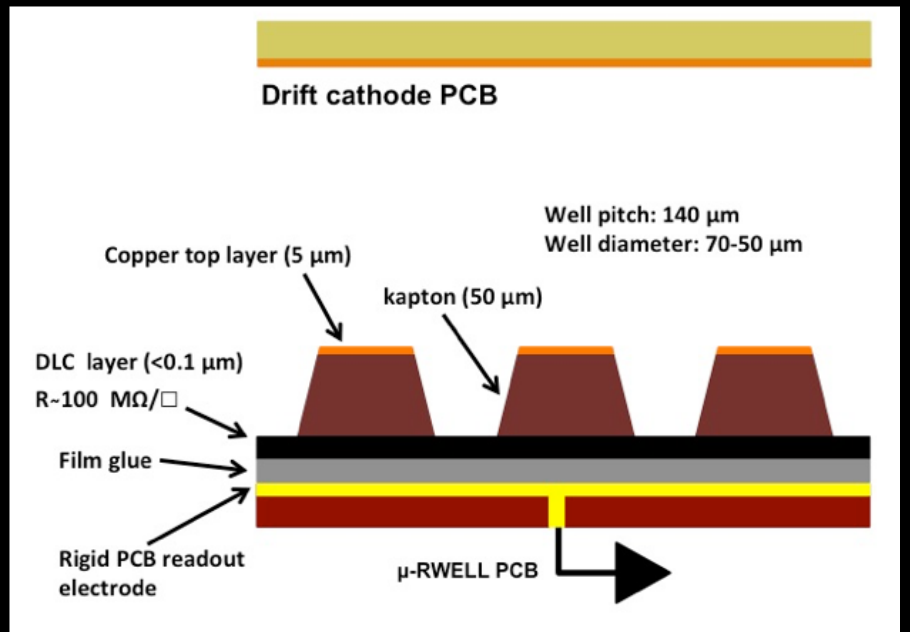


Baseline: Bakelite/glass RPC

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