The CEPC Detector
Highlights and R&D Program

João Guimarães da Costa
(IHEP, Chinese Academy of Sciences)

ICHEP CEPC Satellite meeting - Seoul
6 July 2018

Organization of the Physics and Detector Working Group

Conveners

Joao Barreiro Guimaraes Costa (IHEP)
Yuanning Gao (Tsinghua Univ.)
Shan Jin (Nanjing Univ.)

Machine Detector Interface	Vertex	Tracker	Calorimeter: ECal	Calorimeter: HCal	Calorimeter: Muons
Hongbo Zhu Sha Bai	Ouyang Qun Sun Xiangming Wang Meng	Qi Huirong Yulan Li	Hu Tao	Liu Jianbei Yang Haijun	Li Liang Zhu Chengguang

Physics analysis and detector optimization

Ruan Manqi
Li Gang
Li Qiang
Fang Yaquan

http://cepc.ihep.ac.cn/~cepc/cepc_twiki/index.php/Physics_and_Detector

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This talk

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Next talk by Manqi

http://cepc.ihep.ac.cn/~cepc/cepc_twiki/index.php/Physics_and_Detector

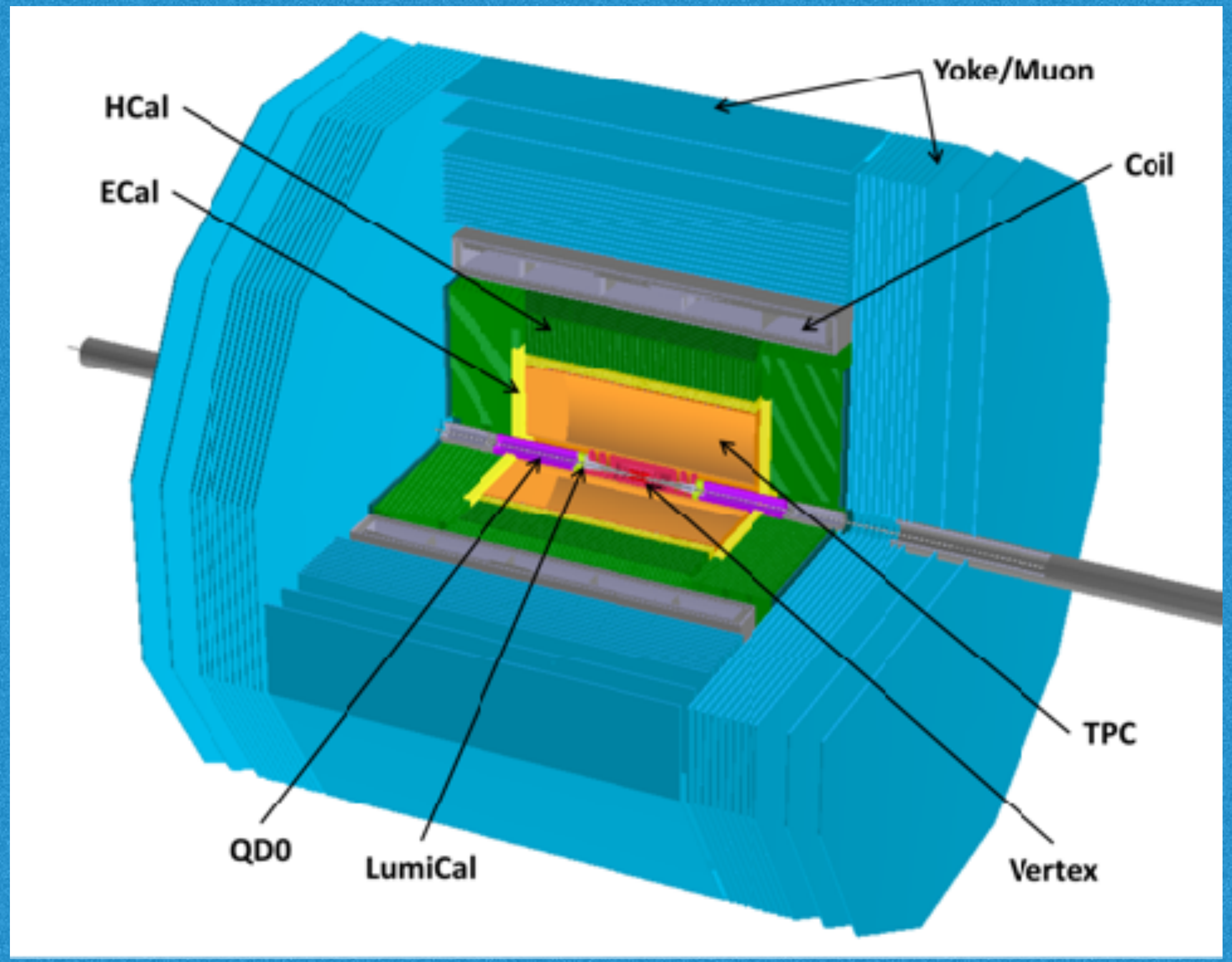
Main Parameters of Collider Ring

	Higgs	W	Z（3T)	Z（2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Crossing angle at IP (mrad)	16.5×2			
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Bunch length σ_z (mm)	3.26	5.9	8.5	
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

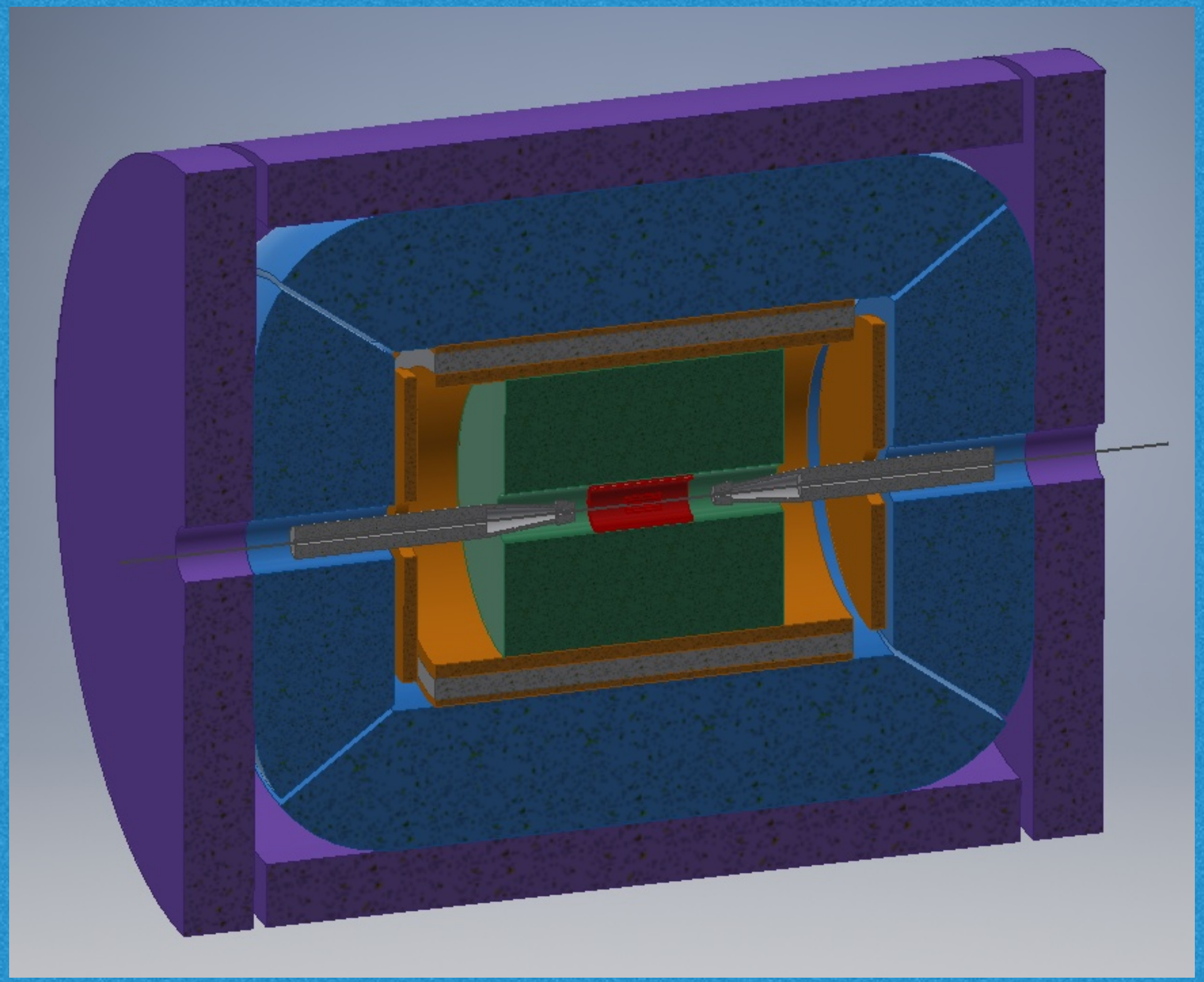
Detector Conceptual Designs

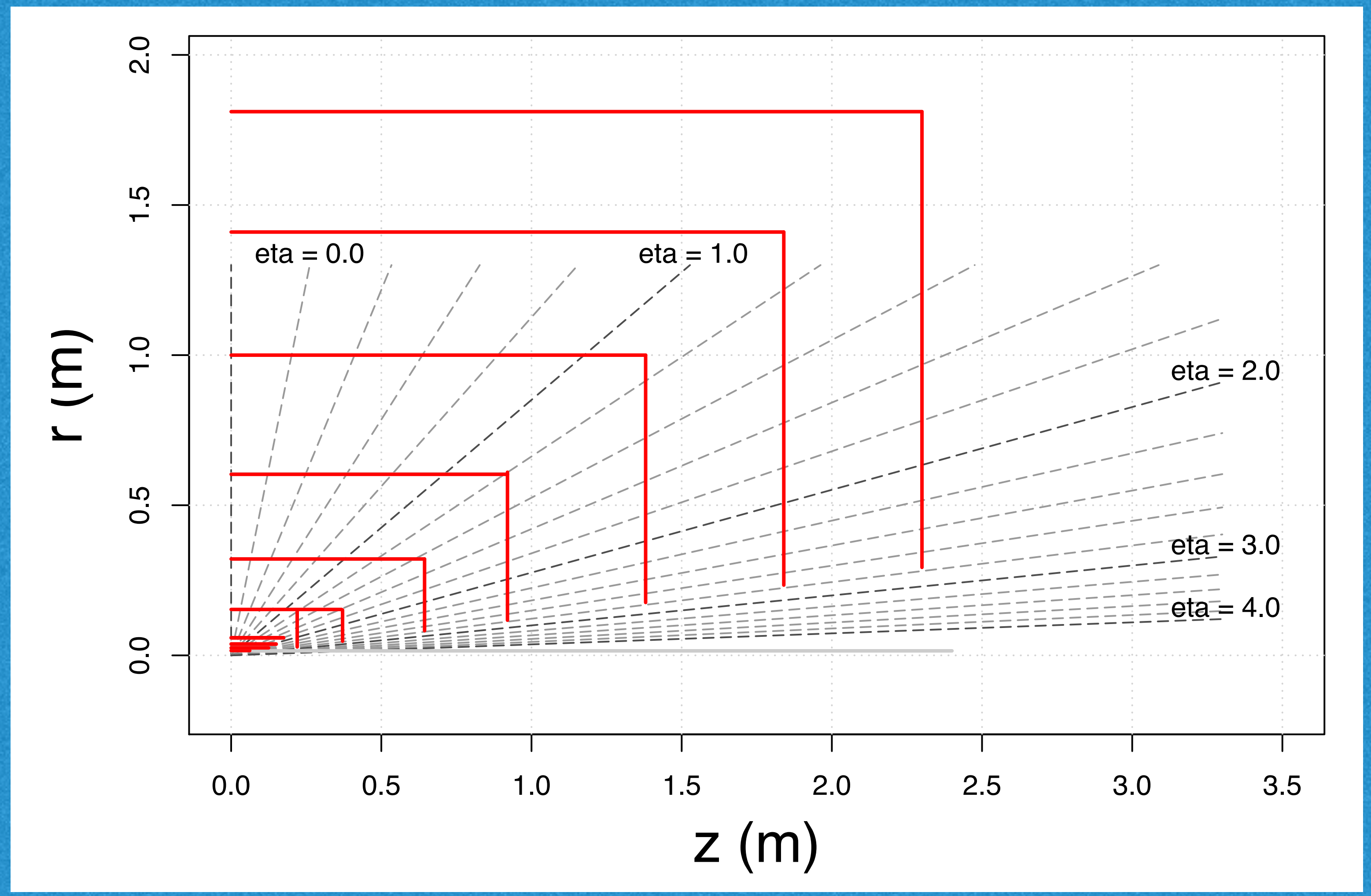
CEPC plans for 2 interaction points

Baseline detector (3 Tesla)
ILD-like
(similar to pre-CDR)



Low magnetic field concept (2 Tesla)

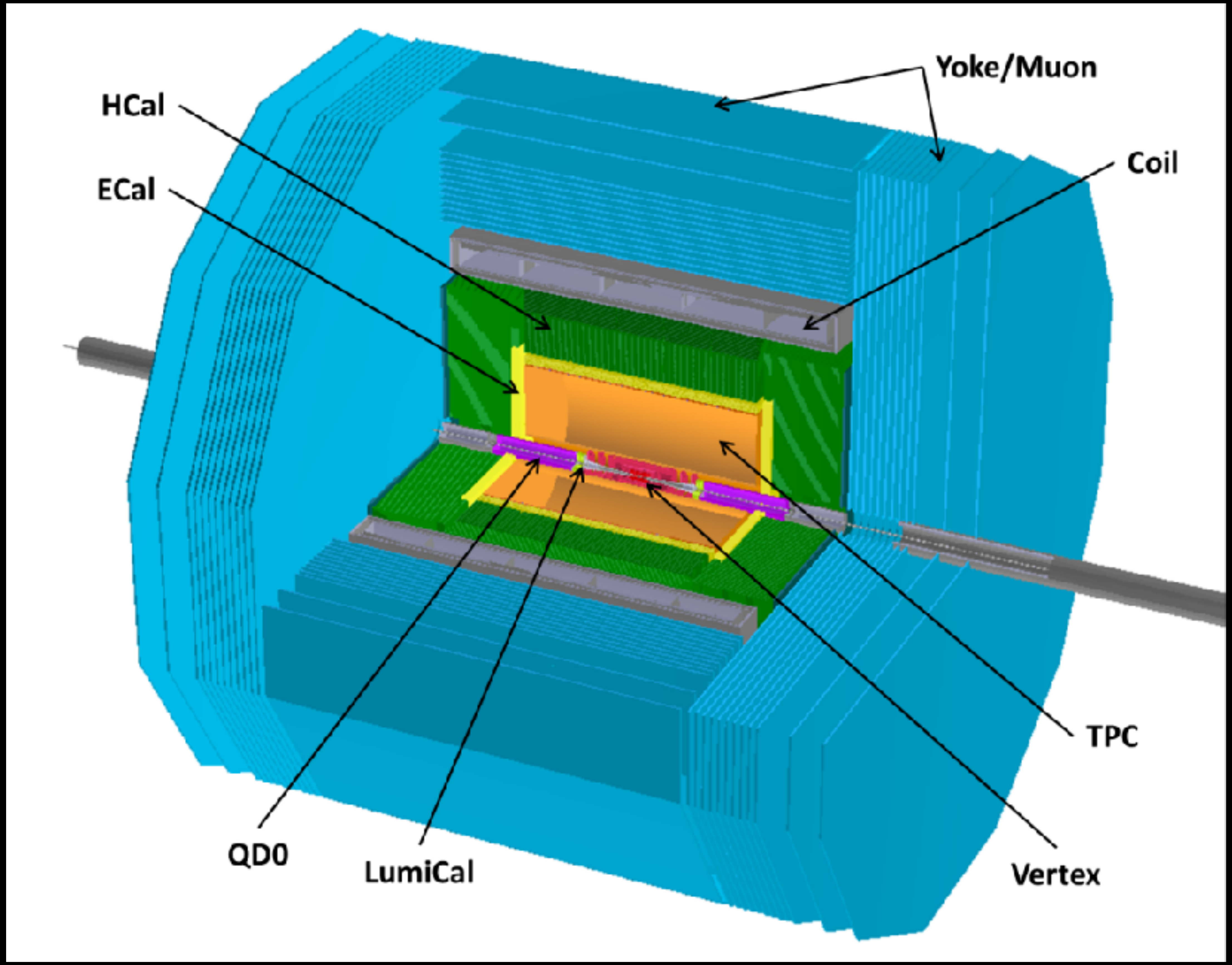


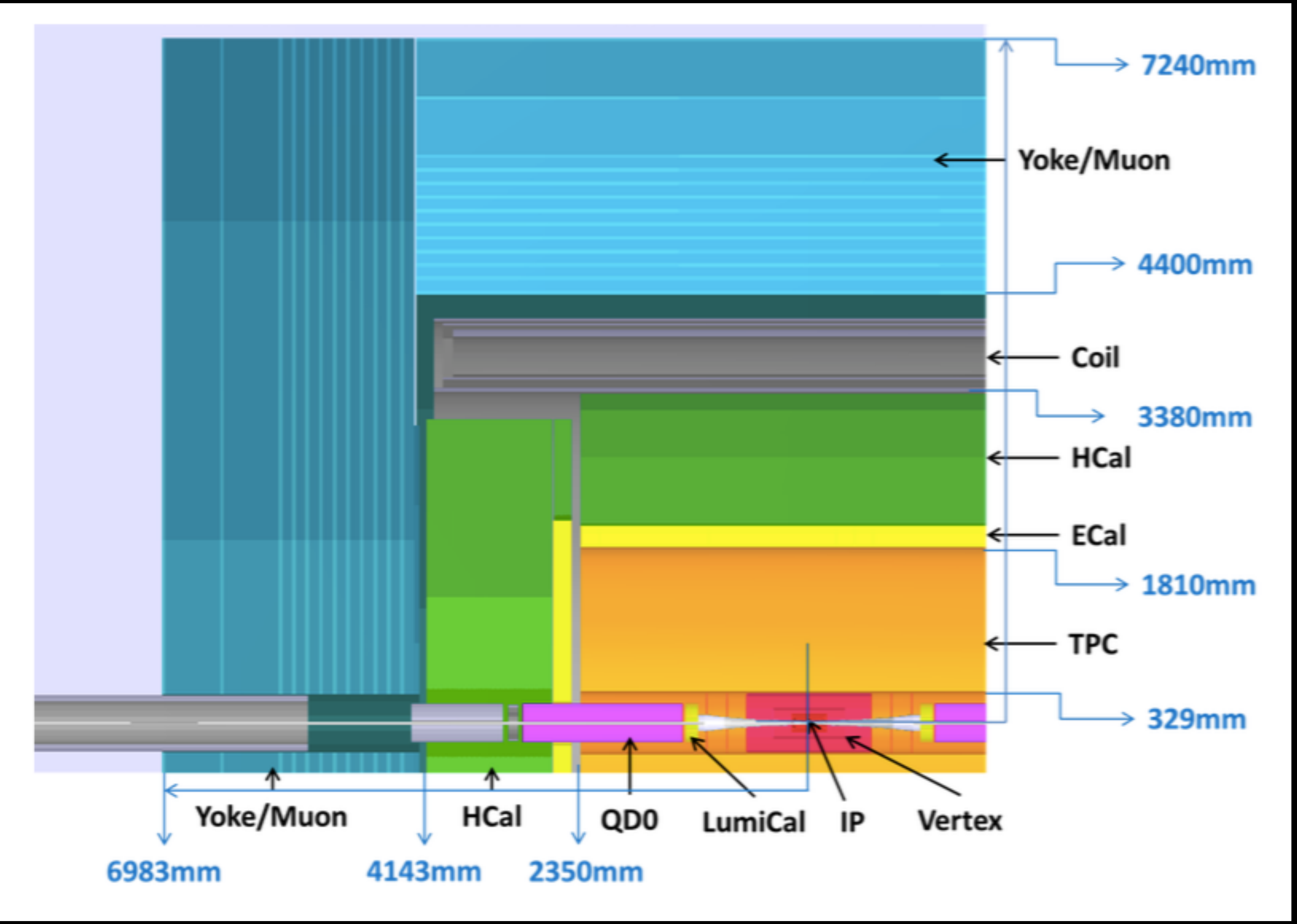


Full silicon tracker concept

Final two detectors likely to be a mix and match of different options

CEPC baseline detector: ILD-like





Magnetic Field: 3 Tesla — changed from preCDR

- **Impact parameter resolution**: less than 5 μm ⟵ Flavor tagging
- **Tracking resolution**: $\delta(1/P_t) \sim 2\times10^{-5}\ (\mathrm{GeV}^{-1})$ ⟵ BR(Higgs → μμ)
- **Jet energy resolution**: $\sigma_E/E \sim 30\%/\sqrt{E}$ ⟵ W/Z dijet mass separation

CEPC baseline detector: ILD-like: Design Considerations

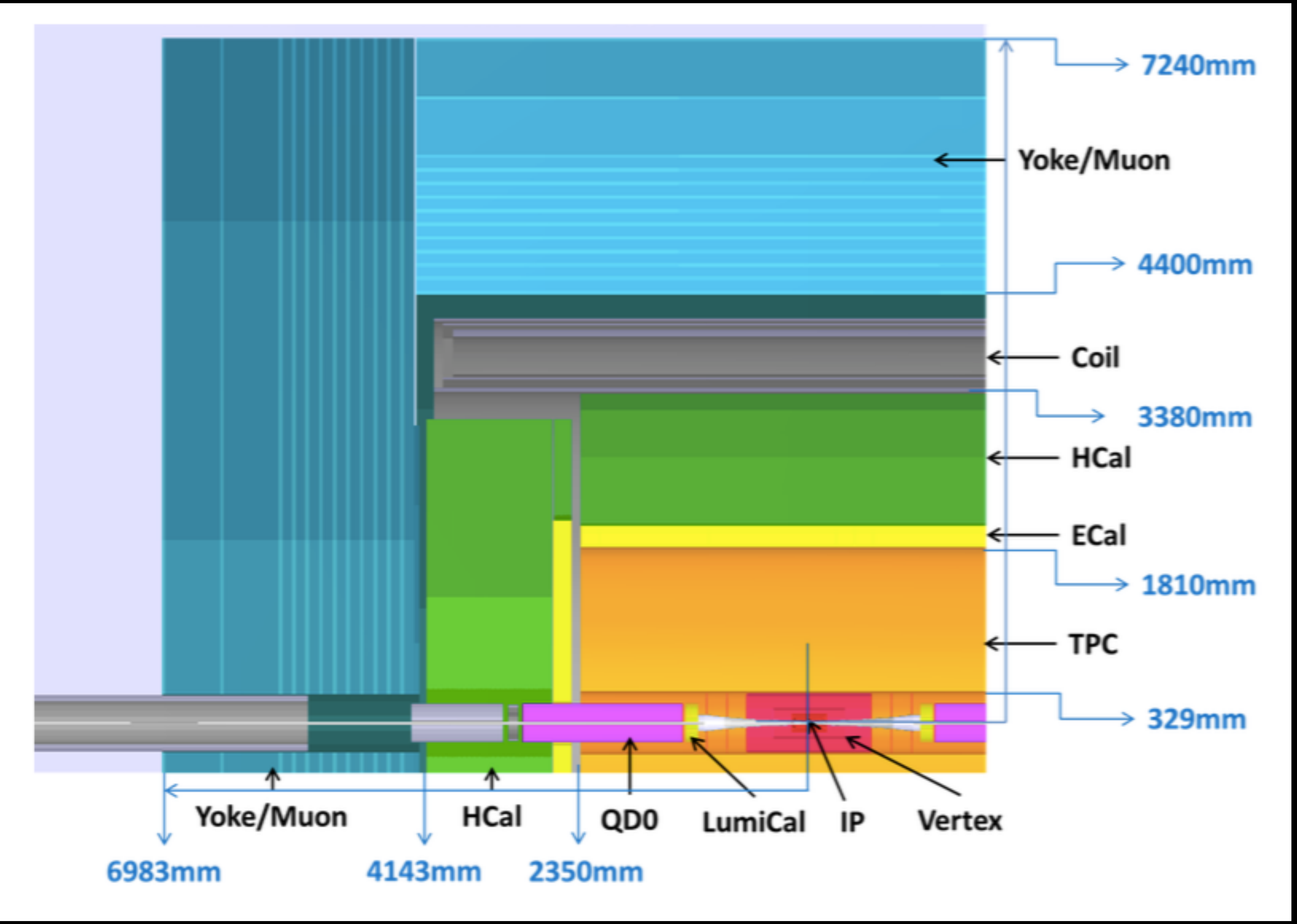
Major concerns being addressed

1. MDI region highly constrained
L* increased to 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



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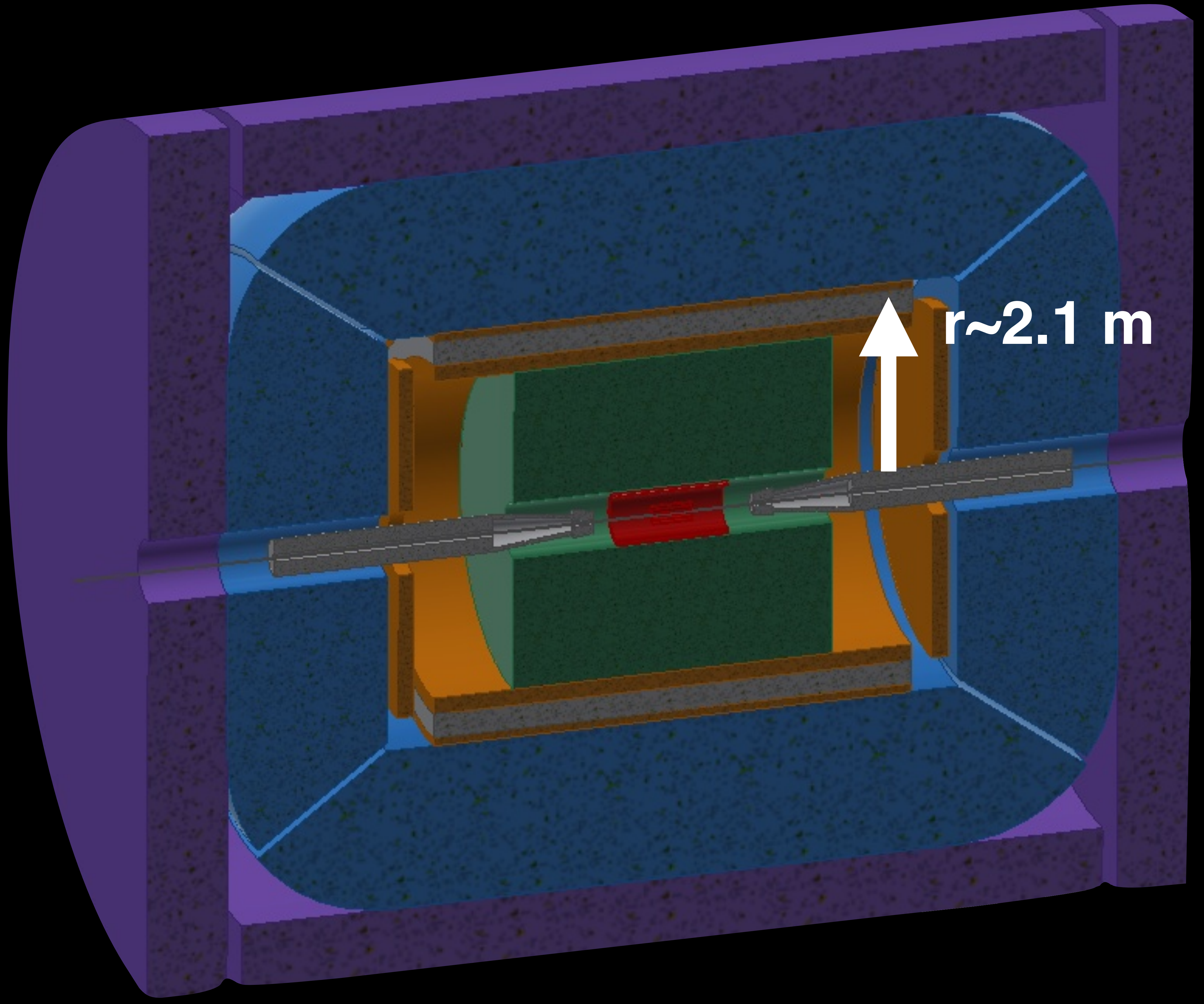
Low magnetic field detector concept

Proposed by INFN, Italy colleagues



Similar to Concept Detector for FCC-ee

Collaboration with China

Magnet: 2 Tesla, 2.1 m radius
Thin (~ 30 cm), low-mass (~0.8 X_0)

Vertex: Similar to CEPC default

* **Drift chamber: 4 m long; Radius ~30-200 cm**

Preshower: ~1 X_0

* **Dual-readout calorimeter: 2 m/8 λ_{int}**

* **(yoke) muon chambers**

Integrated test beam
September 2018
Looking for helpers

Interaction region: Machine Detector Interface

One of the most complicated issue in the CEPC detector design

Full partial double ring

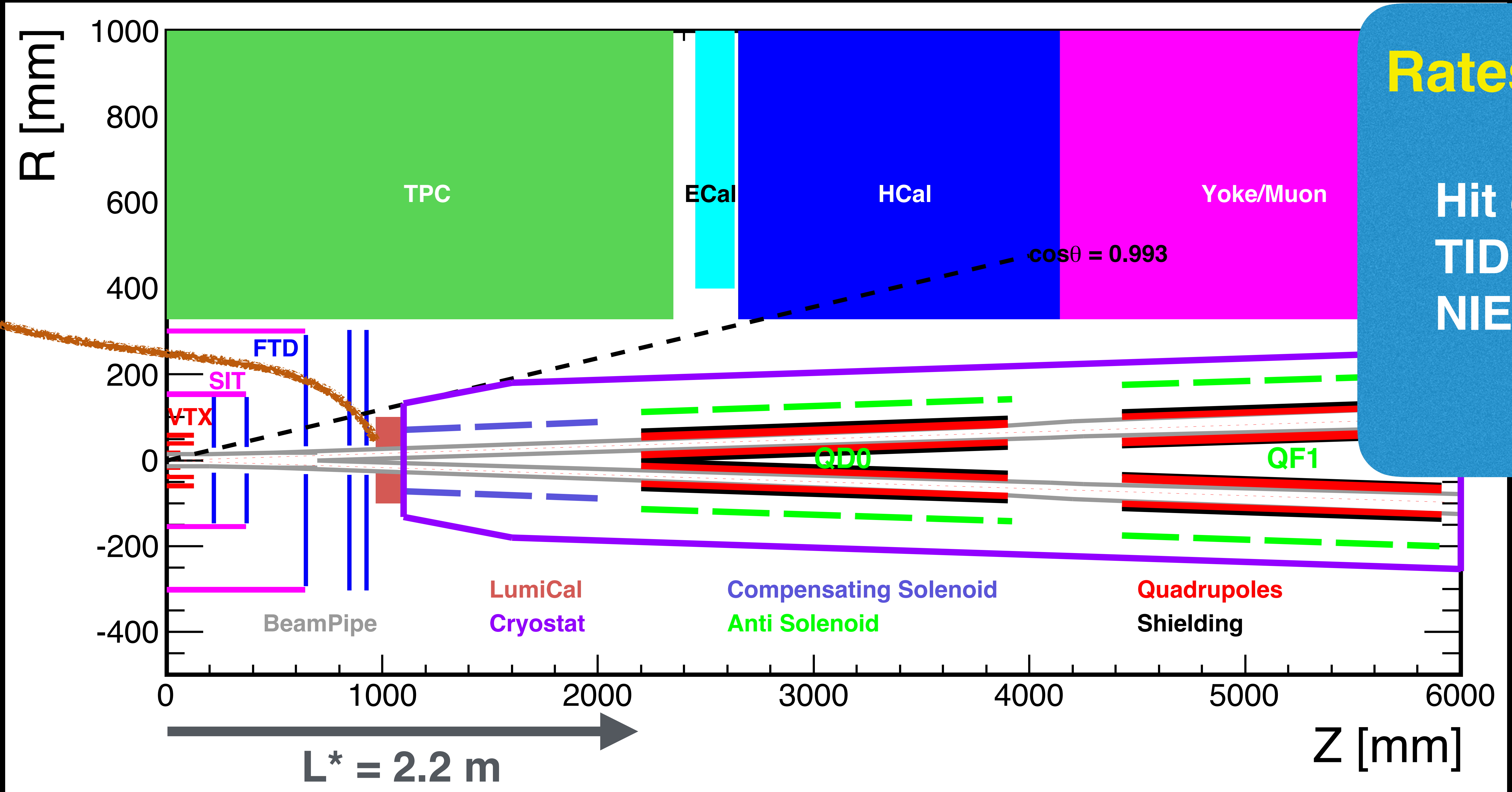
Updated baseline parameters:

- Head-on collision changed to crossing angle of **33 mrad**
- Focal length (**L***) increased from 1.5 m to **2.2 m**
- Solenoid field reduced from 3.5 T to **3 T**

LumiCal

Lumi unc: 1×10^{-3}

(studies lead by Vinca and Academia Sinica)



Rates at the inner layer (16 mm):

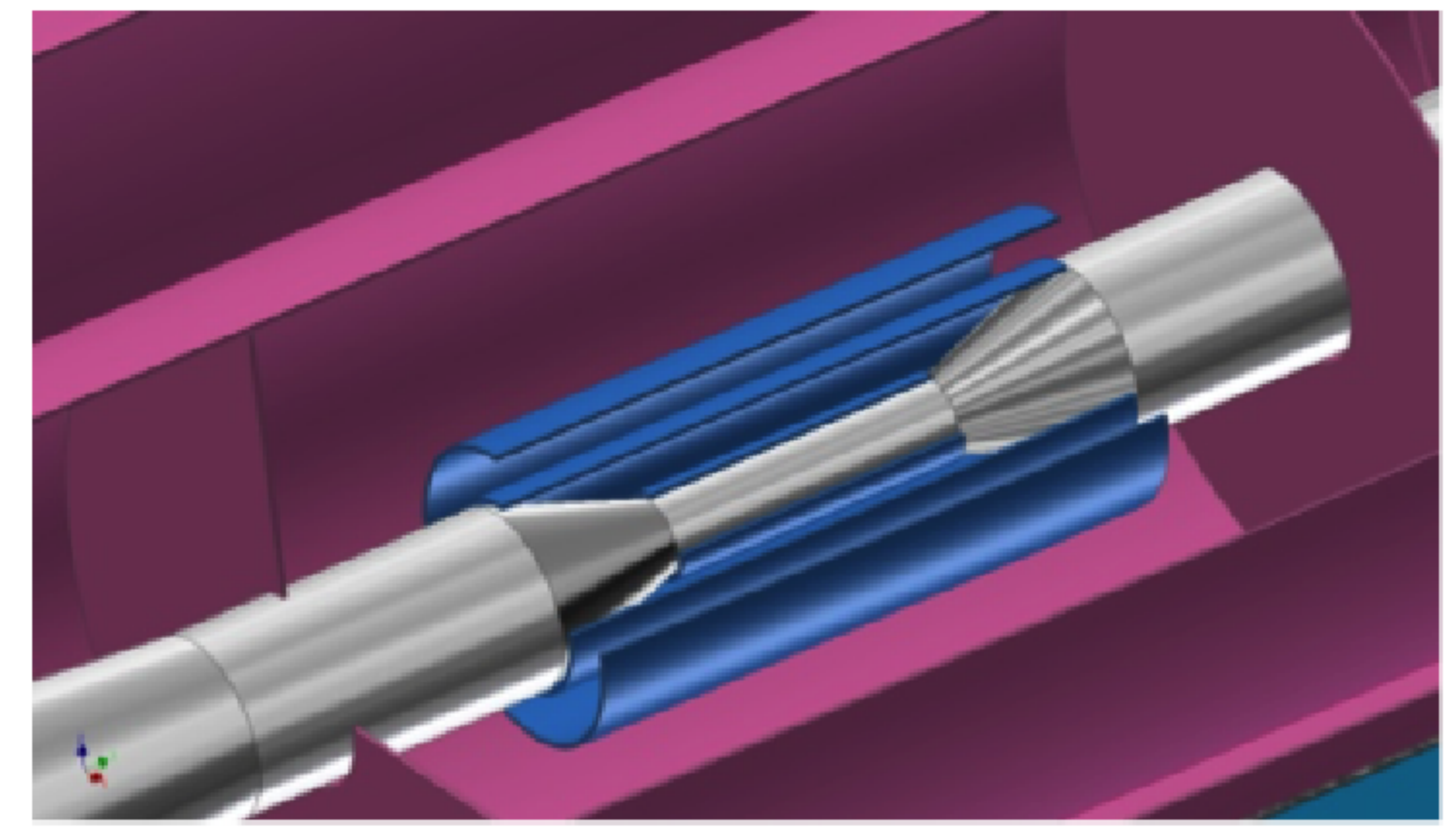
Hit density: ~2.5 hits/cm²/BX
TID: 2.5 MRad/year
NIEL: 10^{12} 1MeV n_{eq}/cm²

(Safety factors of 10 applied)

Challenging engineering design

Baseline Pixel Detector Layout

3-layers of double-sided pixel sensors

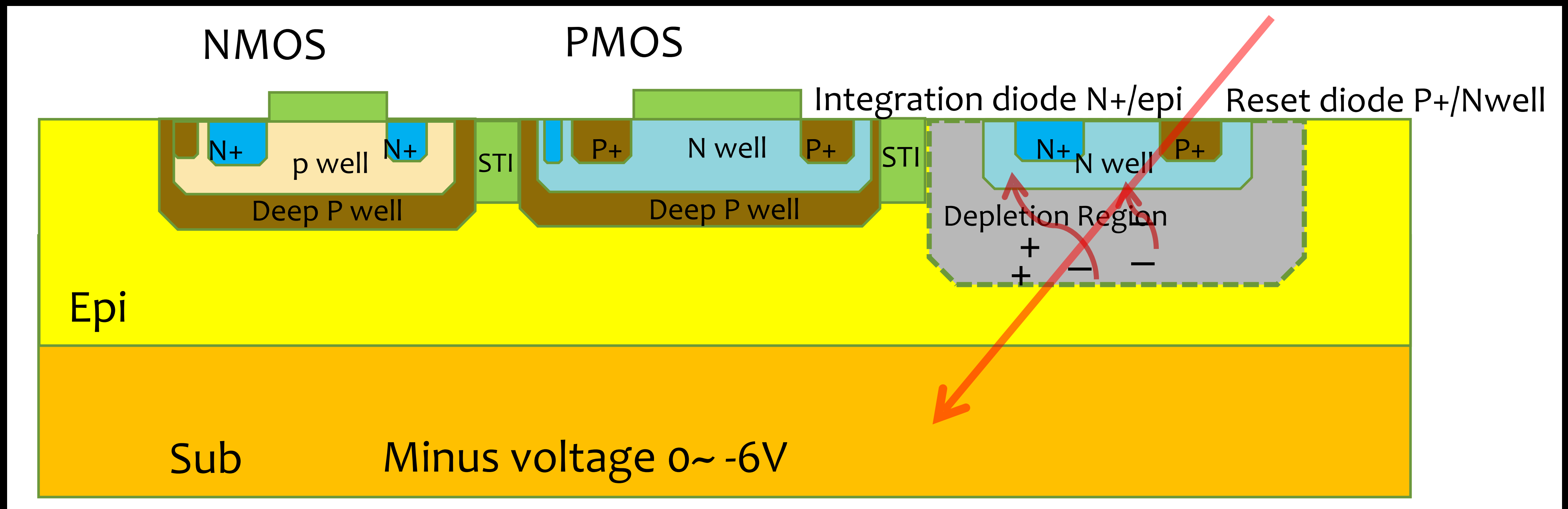


- ILD-like layout
- Innermost layer: σ_{SP} = 2.8 μm
- Polar angle θ ~ 15 degrees
- Material budget ≤ 0.15%X_0/layer

Implemented in GEANT4 simulation framework (MOKKA)

		$R(mm)$	$\|z\|(mm)$	$\|cos\theta\|$	$\sigma(\mu m)$	$Readout\ time(us)$
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

CMOS pixel sensor (MAPS)

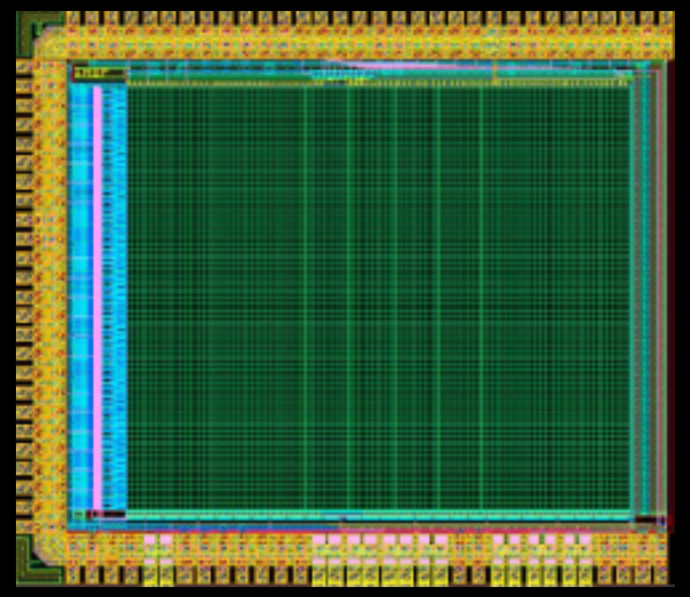


Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process:
- **low material budget,**
- **low power consumption,**
- **low cost …**

Current R&D activities

- **Initial sensor R&D targeting:**

	Specs	Observations
Single point resolution near IP:	< 3-5 μm	Need improvement
Power consumption:	< 100 mW/cm^2	Need to continue trying to lower by a factor of 2
Integration readout time:	< 10-100 μs	Need 1 μs for final detector
Radiation (TID)	1 MRad	Need 2.5× higher /year



New

- **Sensors technologies:**

	Process	Smallest pixel size	Chips designed	Observations
CMOS pixel sensor (CPS)	TowerJazz CIS 0.18 μm	22 × 22 μm^2	2	Founded by MOST and IHEP
SOI pixel sensor	LAPIS 0.2 μm	16 × 16 μm^2	2	Funded by NSFC

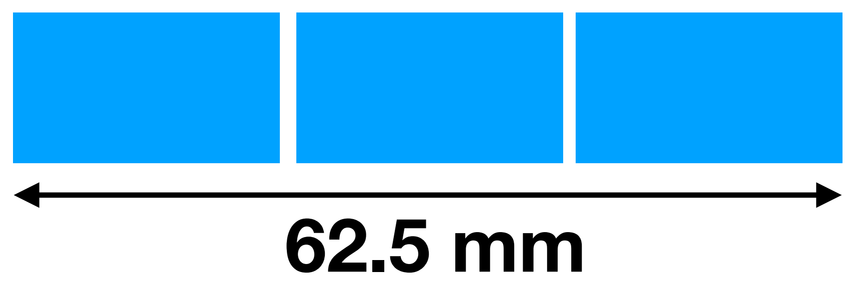
- Institutions: CCNU, NWTU, Shandong, Huazhong Universities and IHEP (IPHC in Strasbourg, KEK)
- New project: Full size CMOS sensor for use in real size prototype

Silicon Vertex Detector Prototype – MOST (2018–2023)

- Design full size CMOS sensor with high resolution and good radiation hardness

Double sided ladder

Layer 1 (11 mm x 62.5 mm)
Chip size: 11 mm X 20.8 mm



3 X 2 layer = 6 chips

Double sided ladder

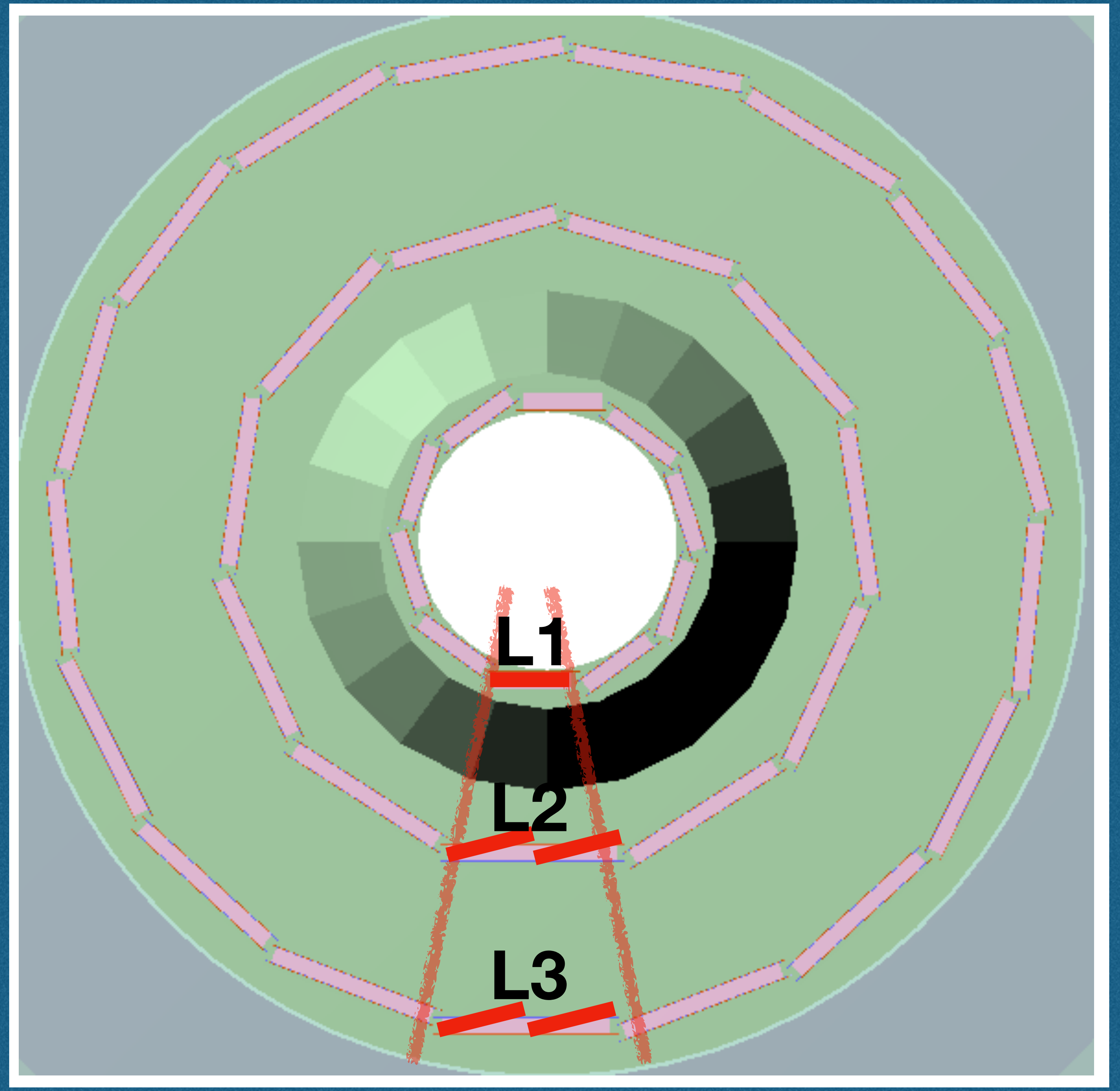
Layers 2 and 3 (22 mm x 125 mm)
Chip size: 11 mm X 20.8 mm

6 X 2 layer = 12 chips

Mechanical prototype

with subset of ladders instrumented/readout

Requires study/simulation of new layout



Minimal goals:

- 3-layer prototype
- Sensor:
  - 1 MRad TID sensor
  - 3-5μm SP resolution

Integrated electronics readout

Design and produce light and rigid support structures

Extended goals if manpower and support available

International Collaboration

Liverpool Univ.
Oxford Univ.
Barcelona Univ.
University of Mass
RAL
others…..

Silicon Tracker Detector – Baseline

SET: r = ~1.8 m

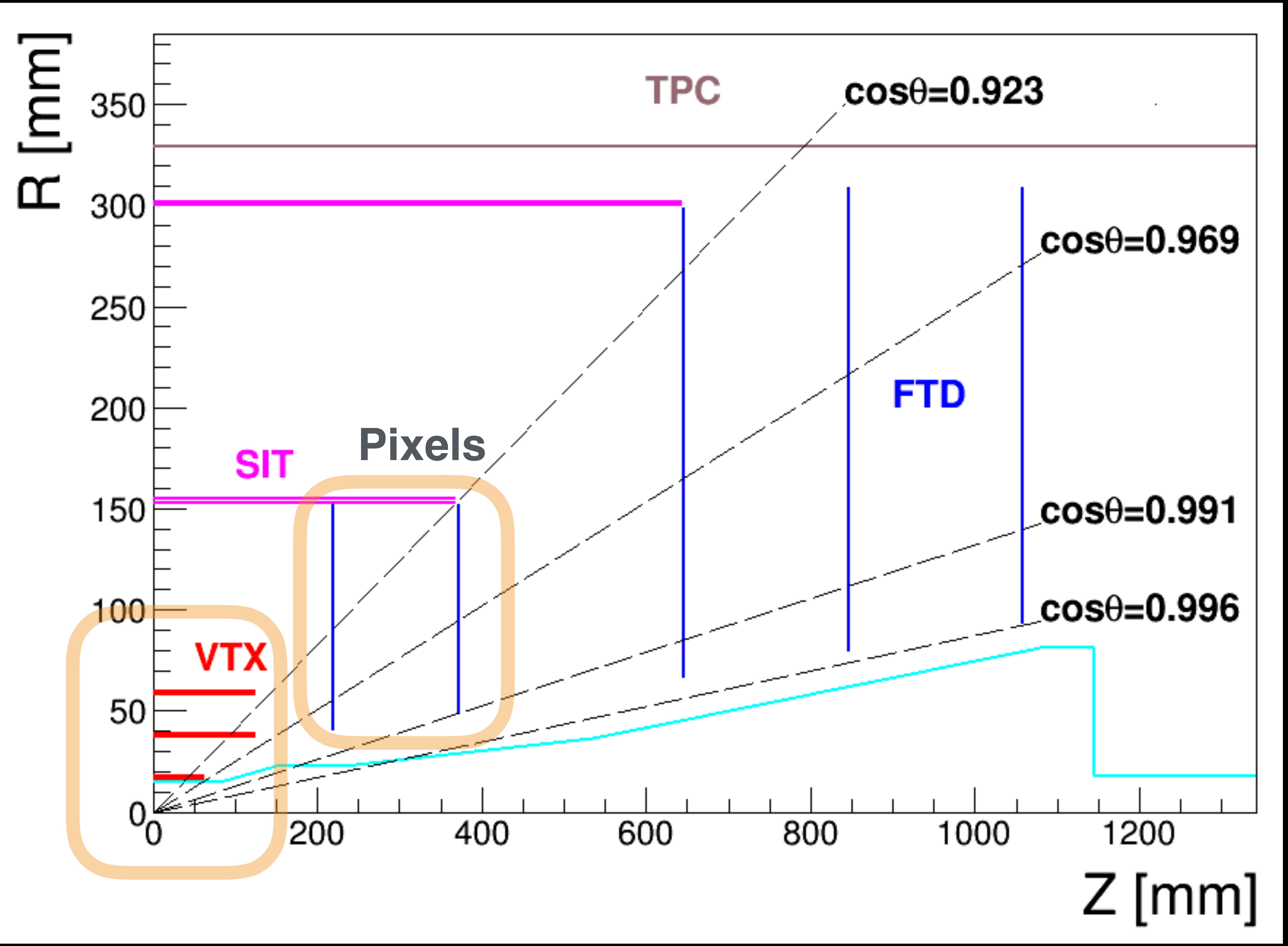
TPC

SIT

VTX

Not much R&D done so far

Tracker material budget/layer: ~0.50-0.56% X/X_0



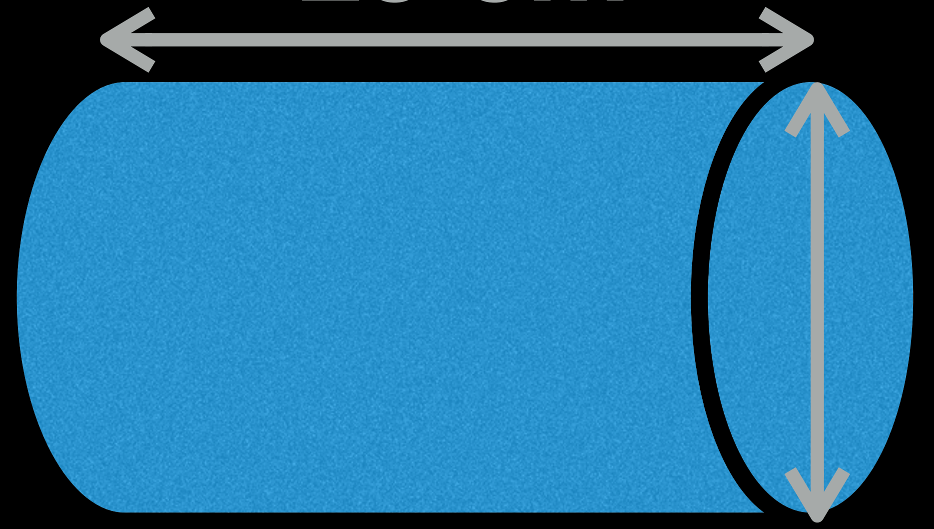
Sensor technology

1. Microstrip sensors
2. Large CMOS pixel sensors (CPS)

Power and Cooling

1. DC/DC converters
2. Investigate air cooling

ETD: z = ~2.4 m



Total Silicon area ~ 68 m²

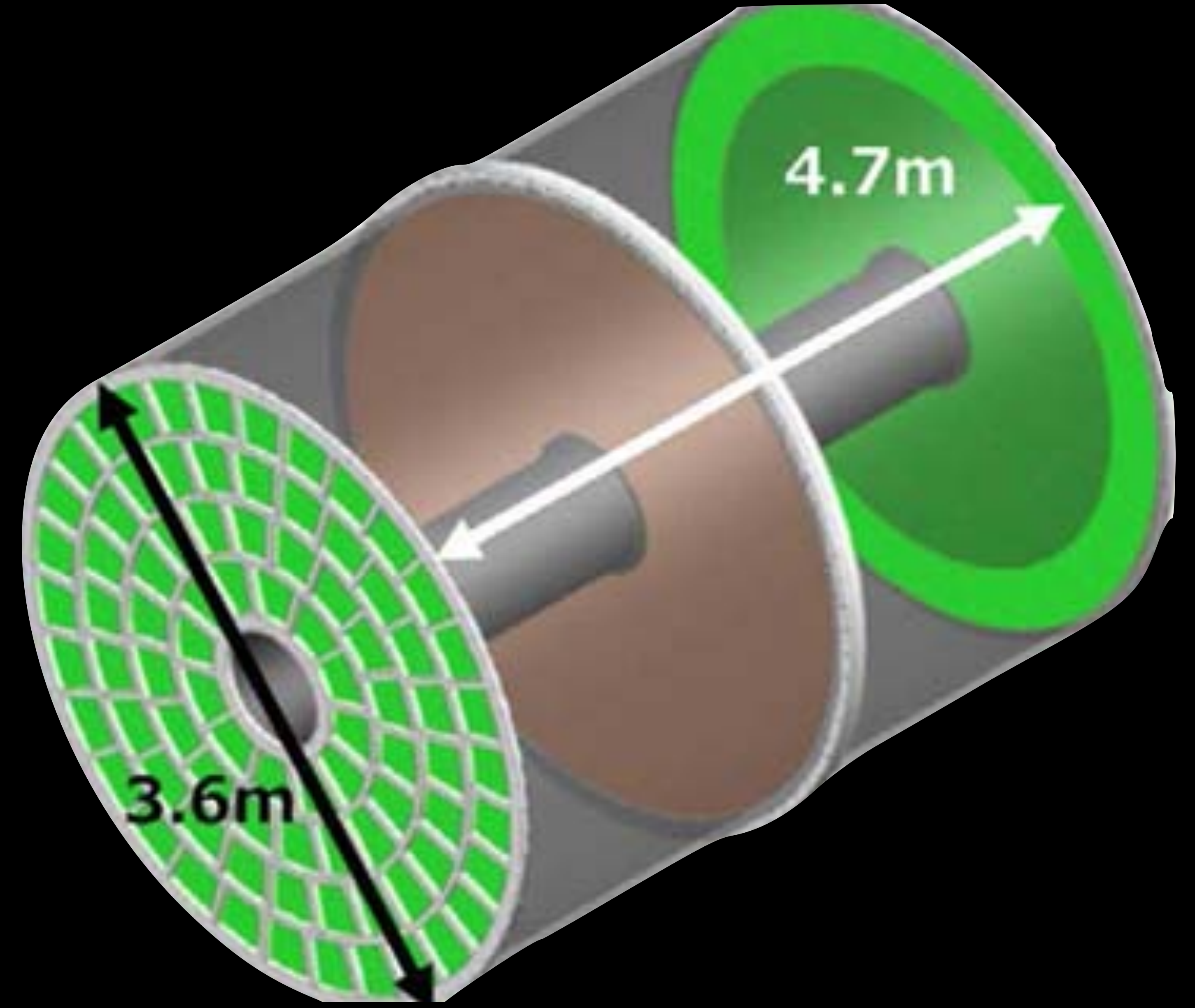
Extensive opportunities for international participation

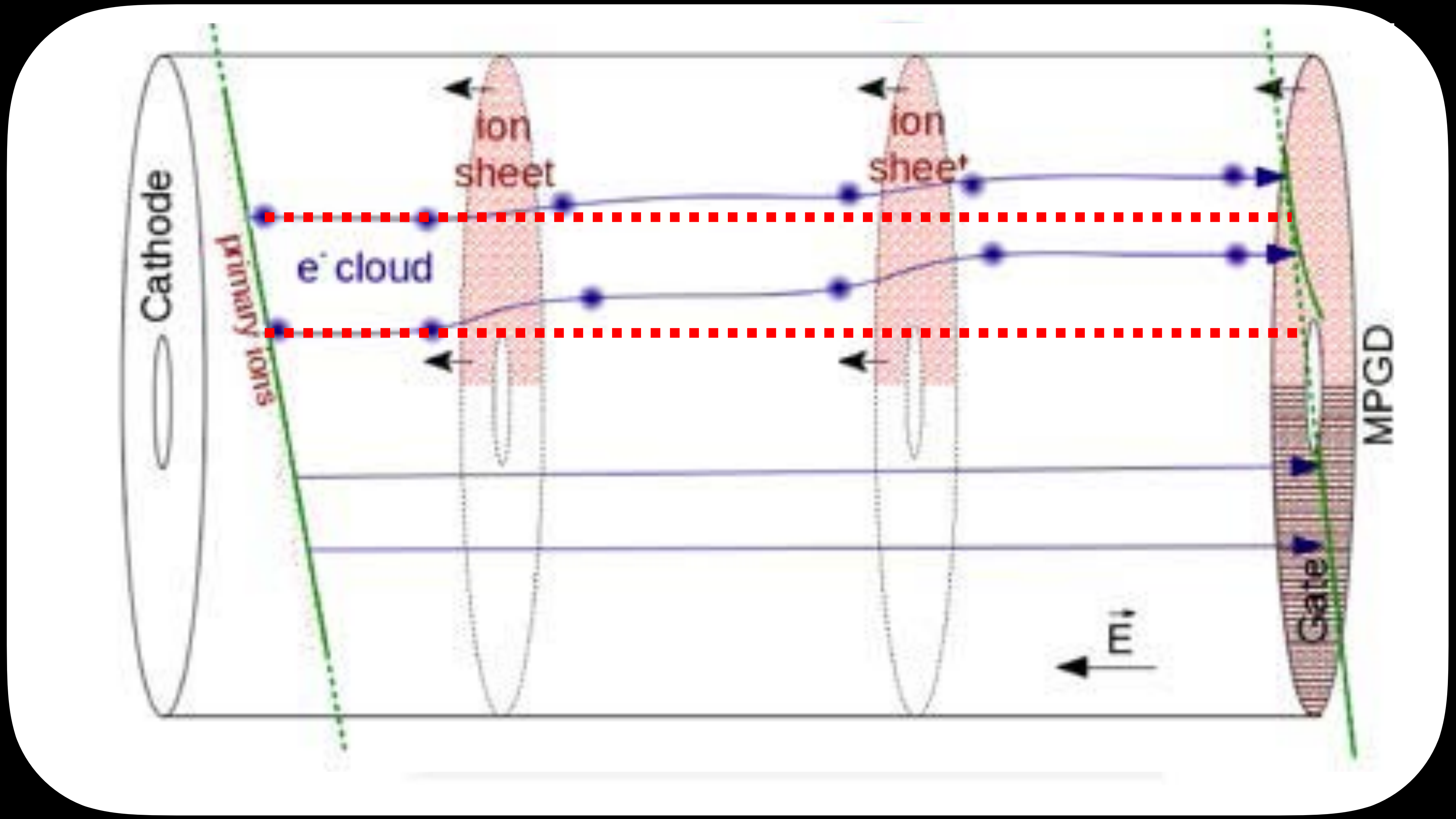
Time Projection Chamber (TPC)

- Allows for particle identification
- Low material budget:
  - 0.05 X_0 including outfield cage in r
  - 0.25 X_0 for readout endcaps in Z
- 3 Tesla magnetic field —> reduces diffusion of drifting electrons
- Position resolution: ~100 μm in rϕ
- dE/dx resolution: 5%
- GEM and Micromegas as readout
- **Problem**: Ion Back Flow —> track distortion

  Operation at $L > 2 \times 10^{34}$ cm^{-2} s^{-1} being studied

TPC detector concept





Prototype built

- R&D by IHEP, Tsinghua and Shandong
  - Funded by MOST and NSFC

Drift Chamber Option – IDEA proposal

Lead by Italian Colleagues

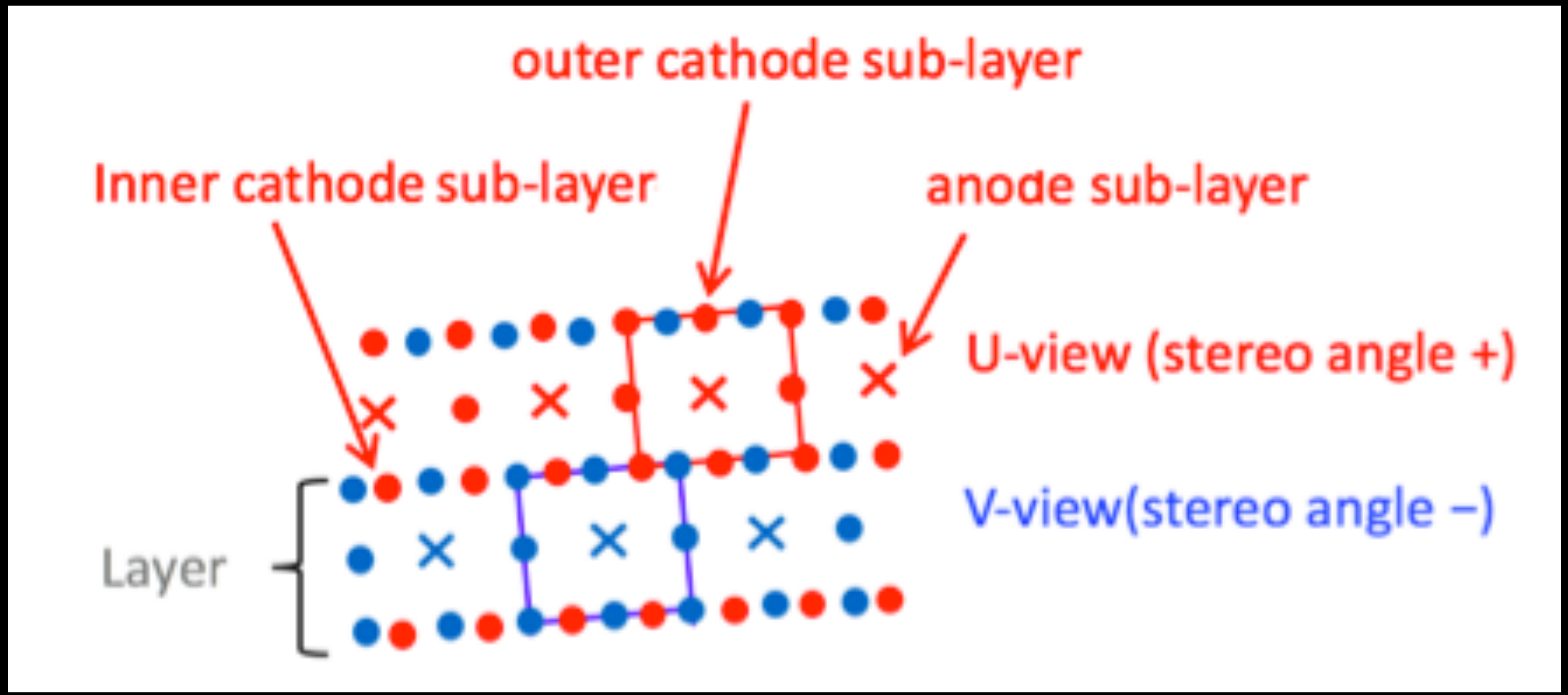
Low-mass cylindrical drift chamber

Follows design of the KLOE and MEG2 experiments

- Length: 4 m
- Radius: 0.3- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

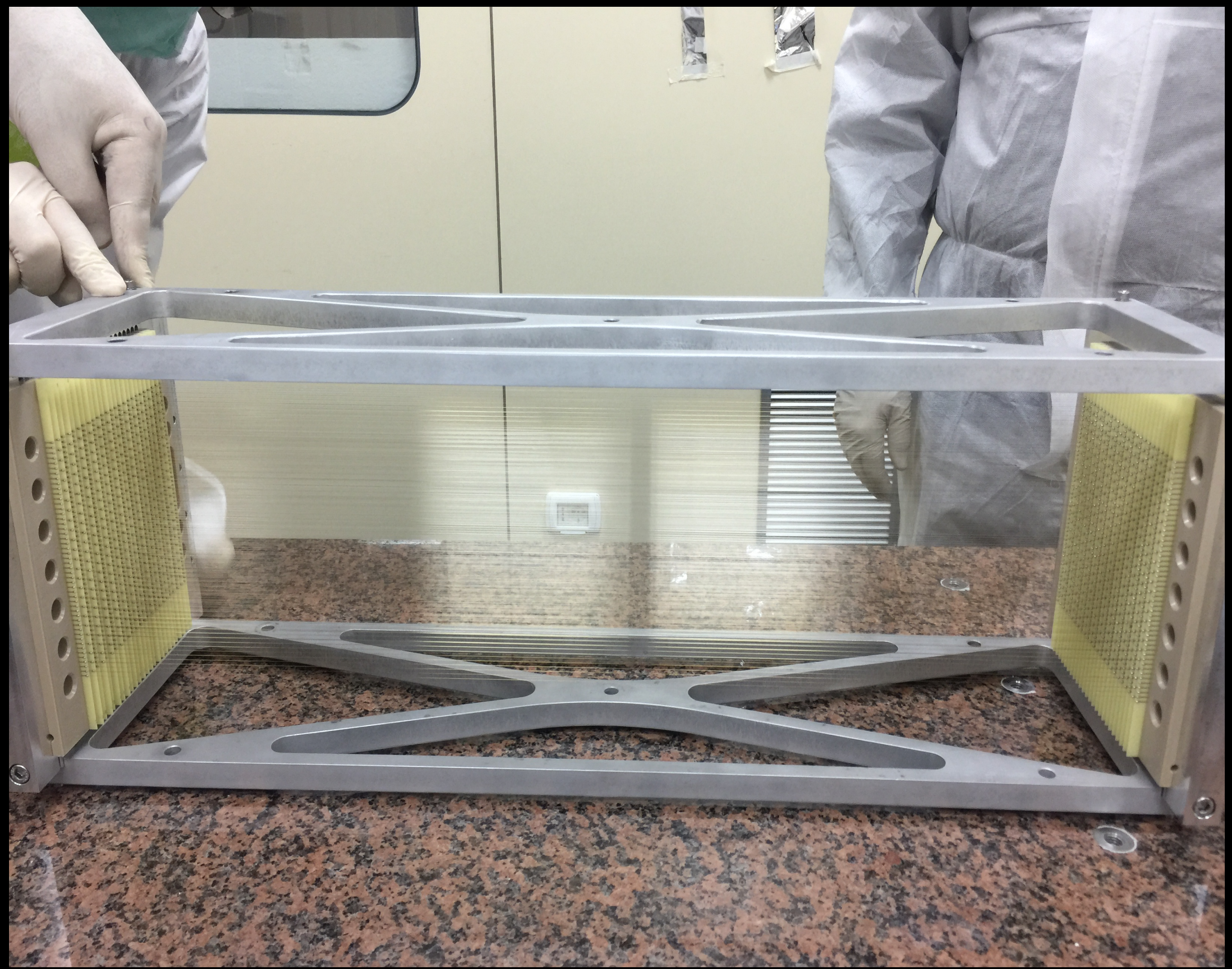
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

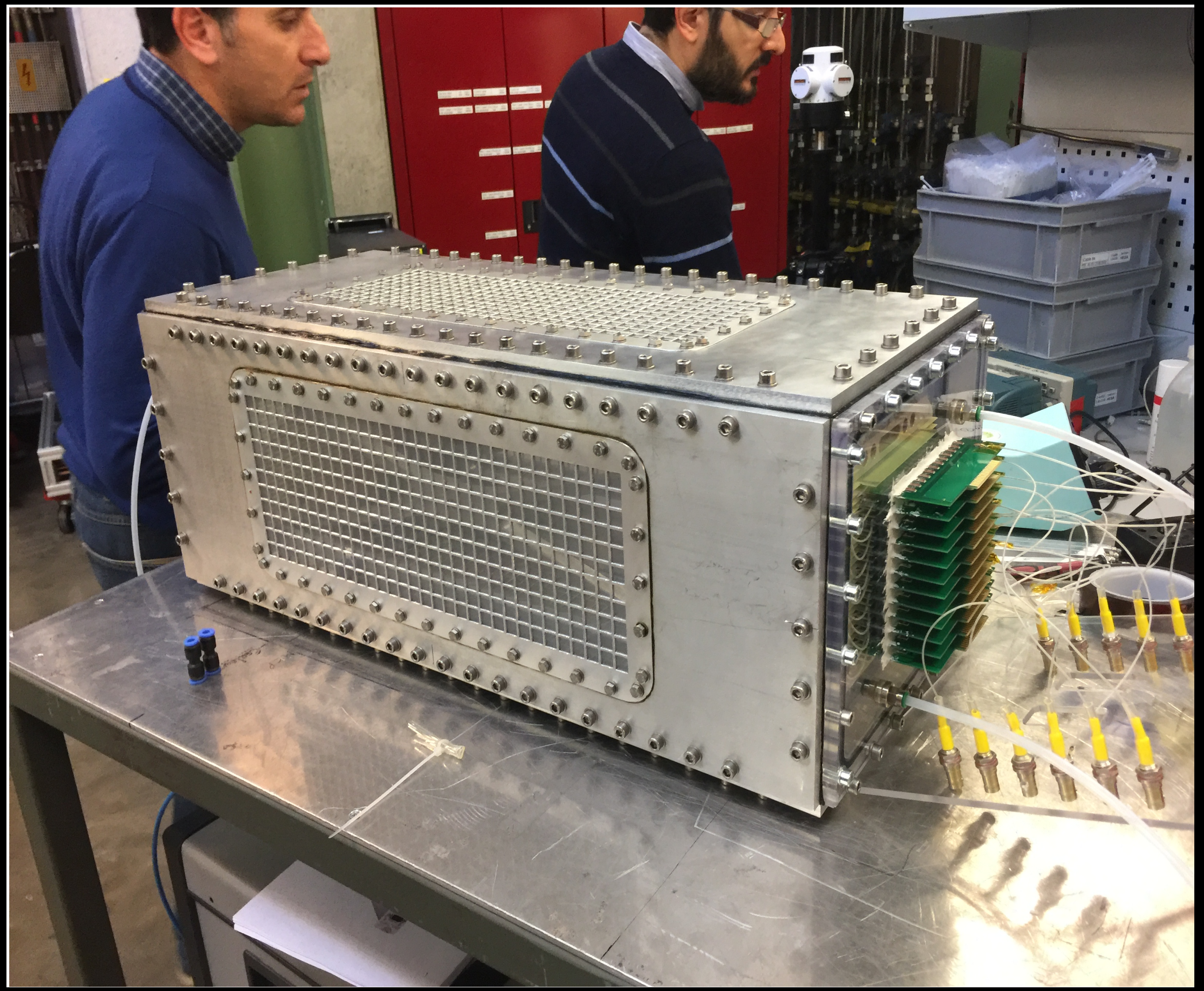
Layers: 14 SL × 8 layers = 112
Cell size: 12 - 14 mm



Stereo angle: 50-250 mrad

MEG2 prototype being tested

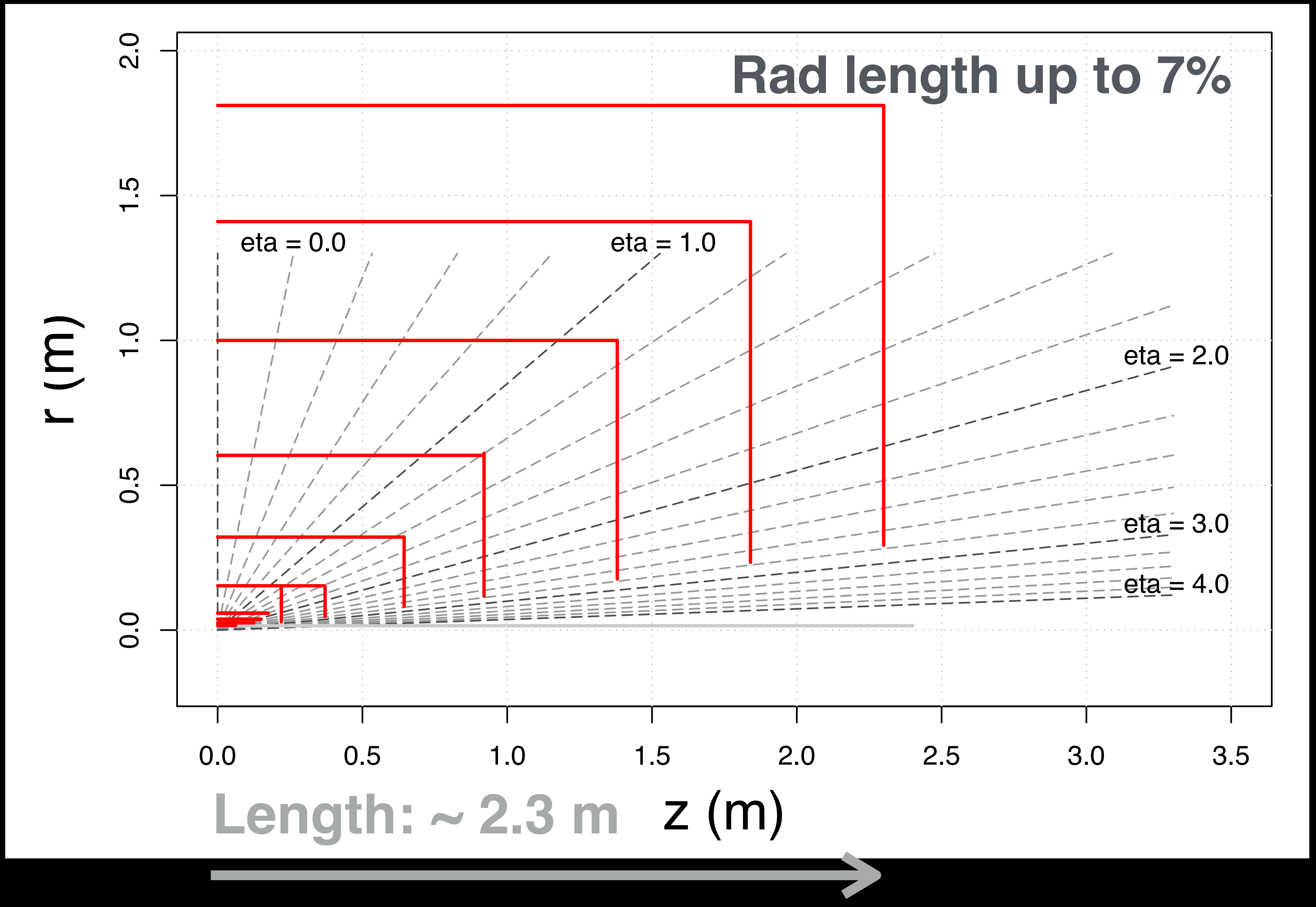




Full silicon tracker concept

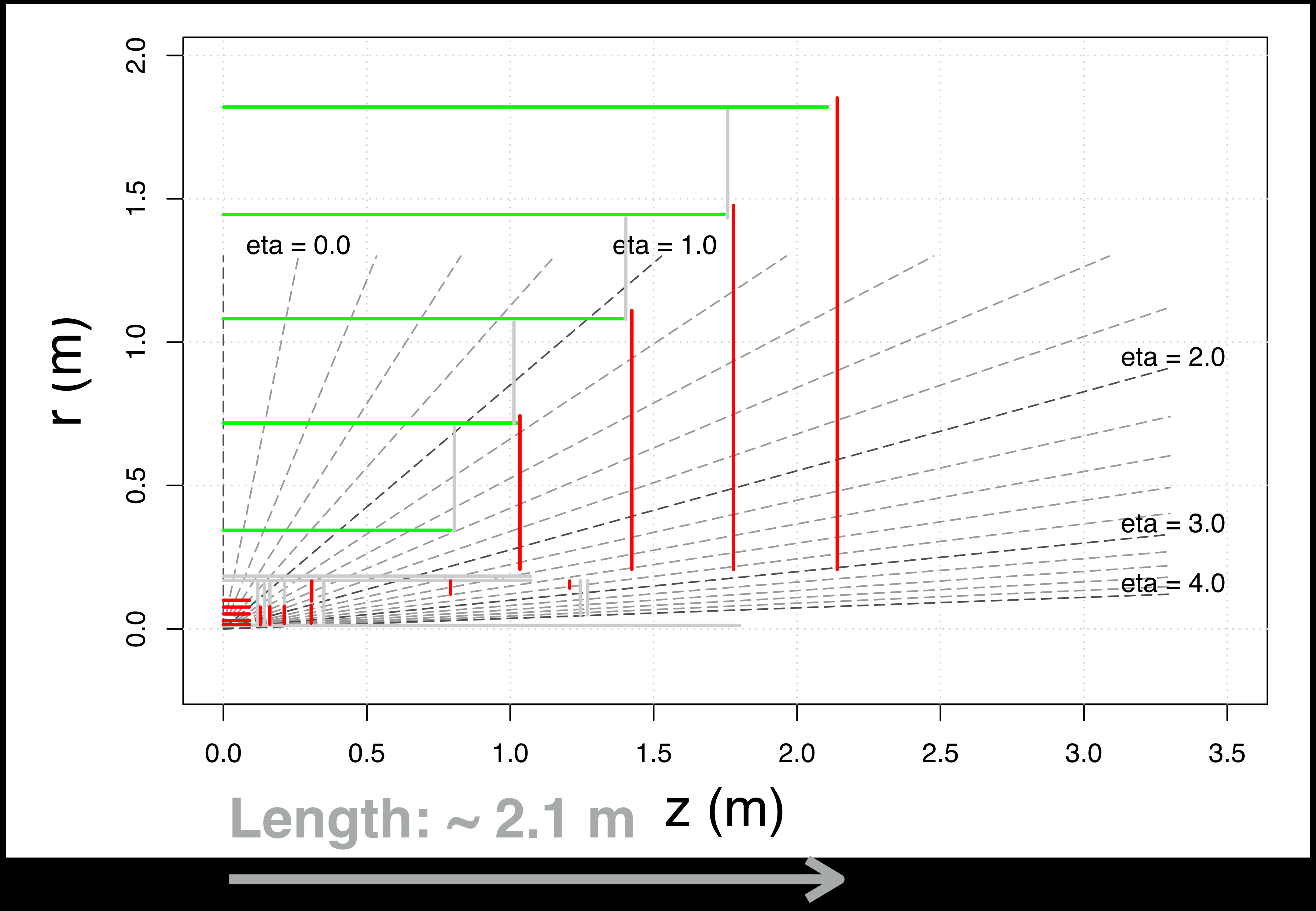
Replace TPC with additional silicon layers

CEPC-SID:
6 barrel double strip layers
5 endcap double strip layers



Radius ~ 1.8 m

SIDB: SiD optimized
5 barrel single strip layers
5 endcap double strip layers



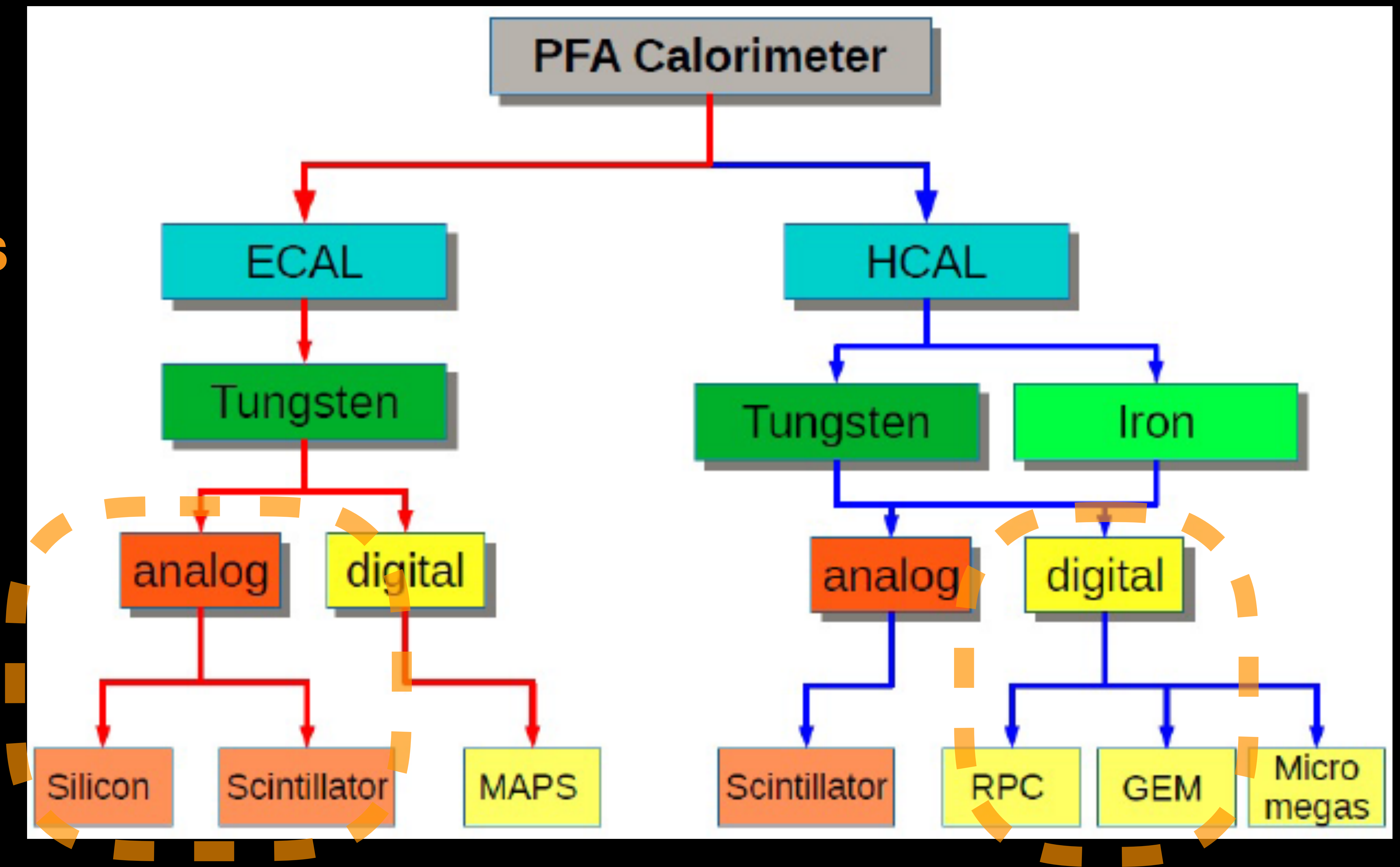
Collaboration with Argonne and Berkeley

Drawbacks: higher material density, less redundancy 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



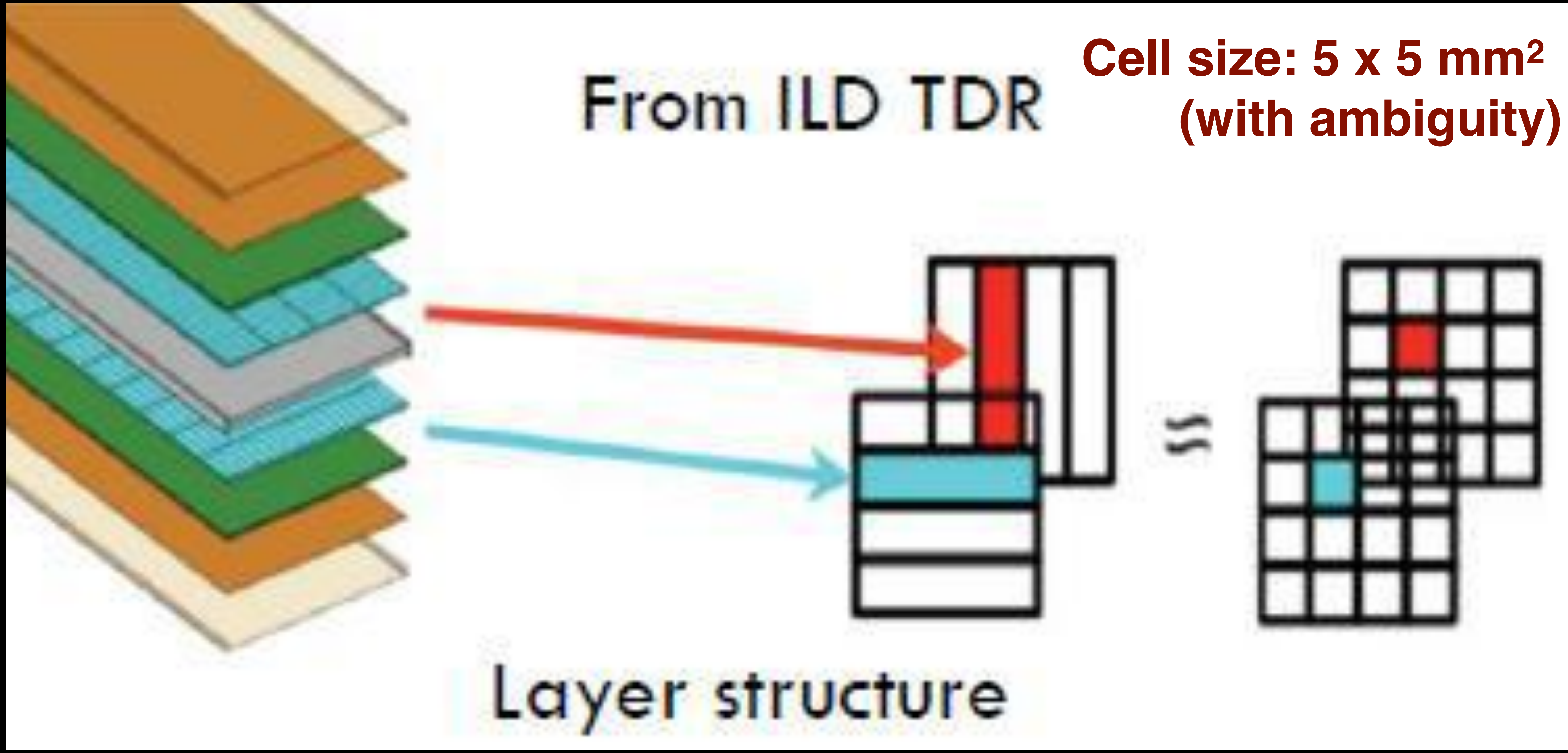
Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) (*) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	(*) SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) (*) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)
New →	(*) Dual readout calorimeters (INFN, Italy + Iowa, USA)

ECAL Calorimeter — Particle Flow Calorimeter

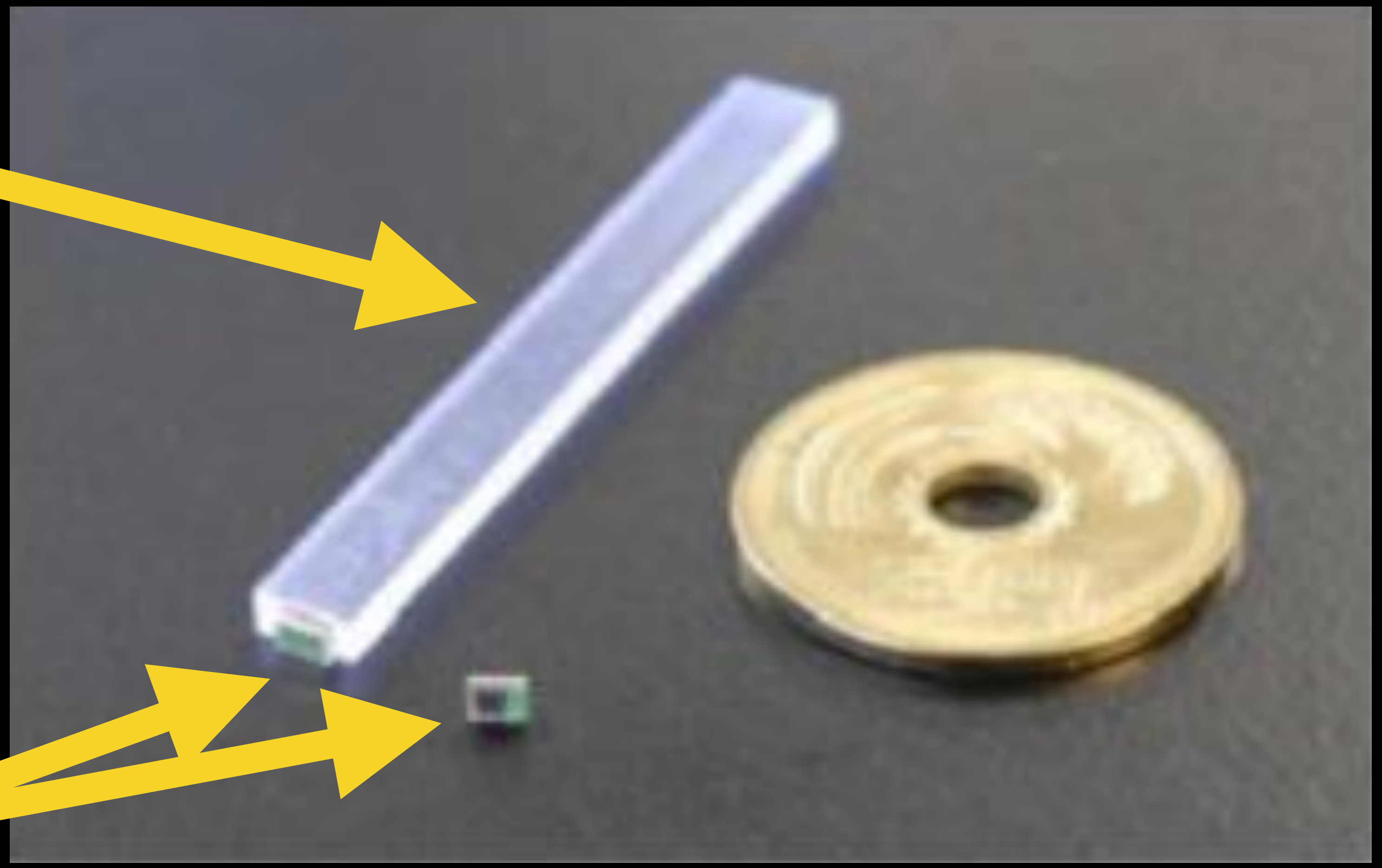
Scintillator-Tungsten Sandwich ECAL

Superlayer (7 mm) is made of:

- 3 mm thick: Tungsten plate
- 2 mm thick: 5 x 45 mm^2
- 2 mm thick: Readout/service layer



Plastic scintillator
5 x 45 mm^2 (2 mm thick)



SiPM

R&D on-going:

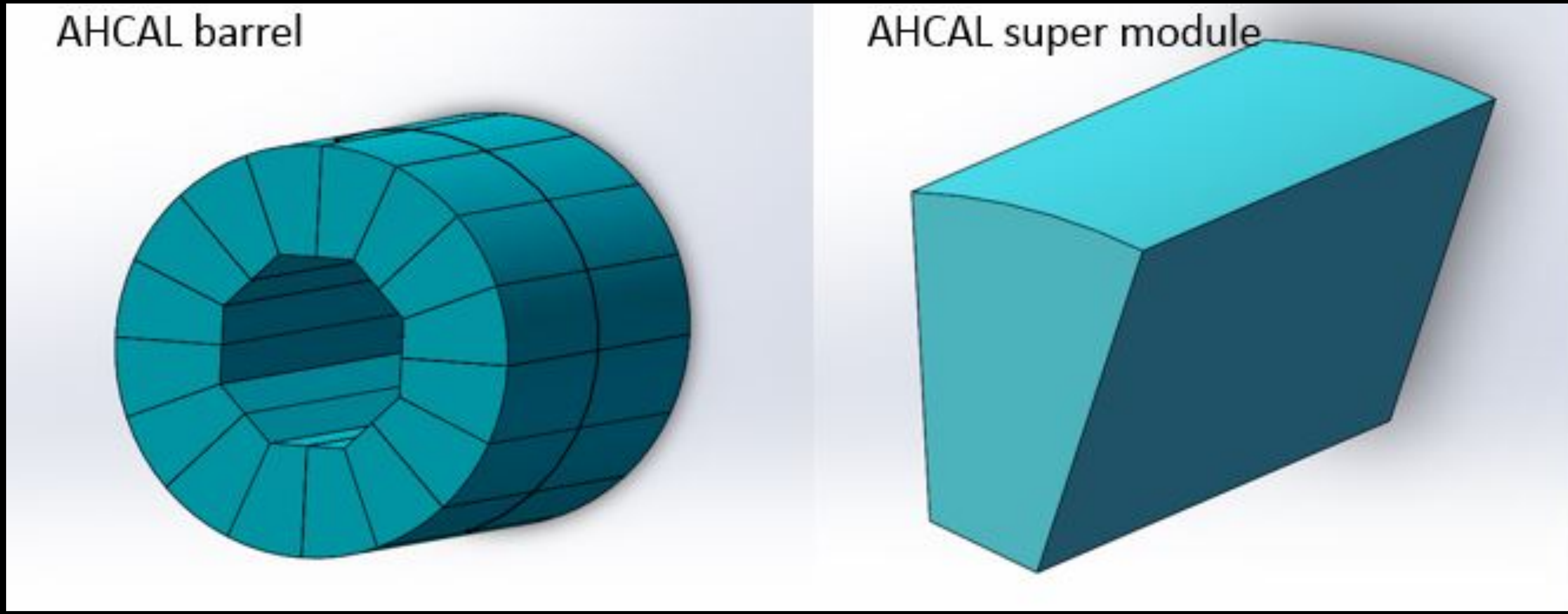
- SiPM dynamic range
- Scintillator strip non-uniformity
- Coupling of SiPM and scintillator

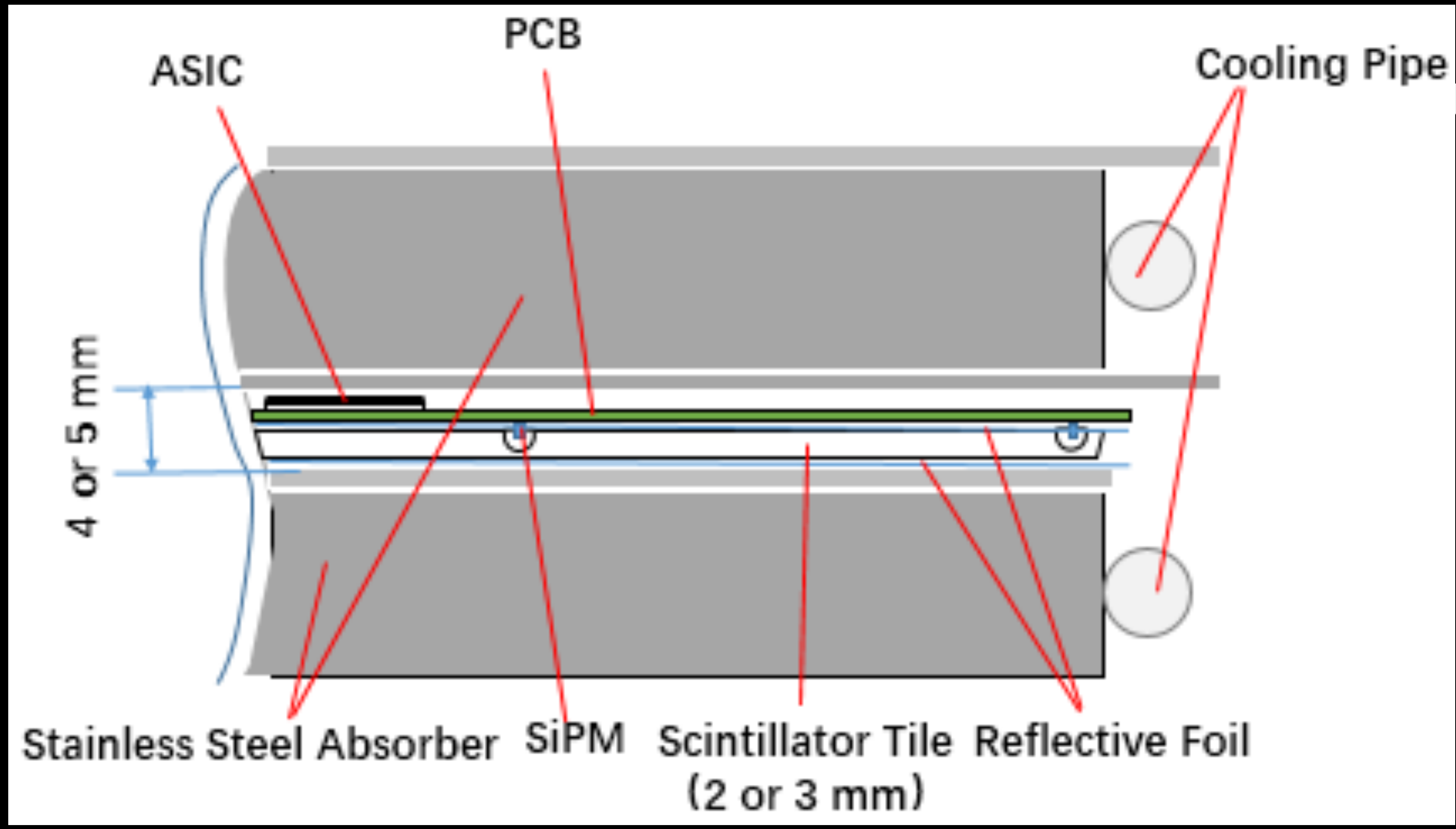
Mini-prototype tested on testbeam at the IHEP

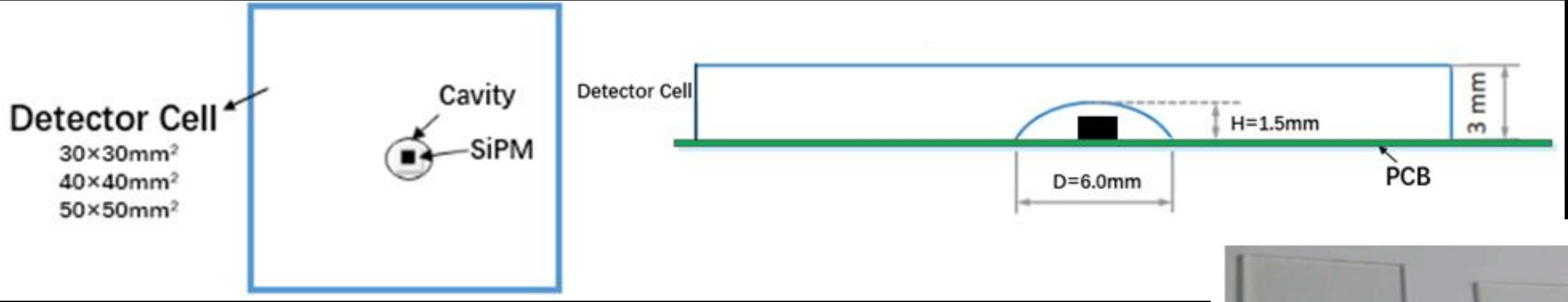
HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)

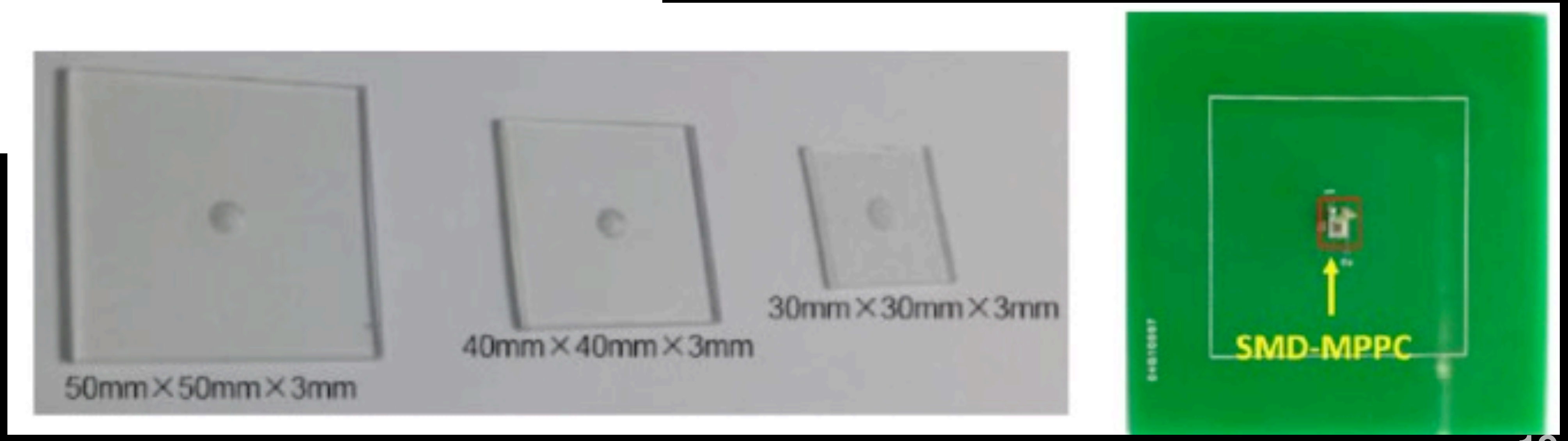
32 super modules **40 layers**







Readout channels:
~ 5 Million (30 x 30 mm²)
~ 2.8 Million (40 x 40 mm²)



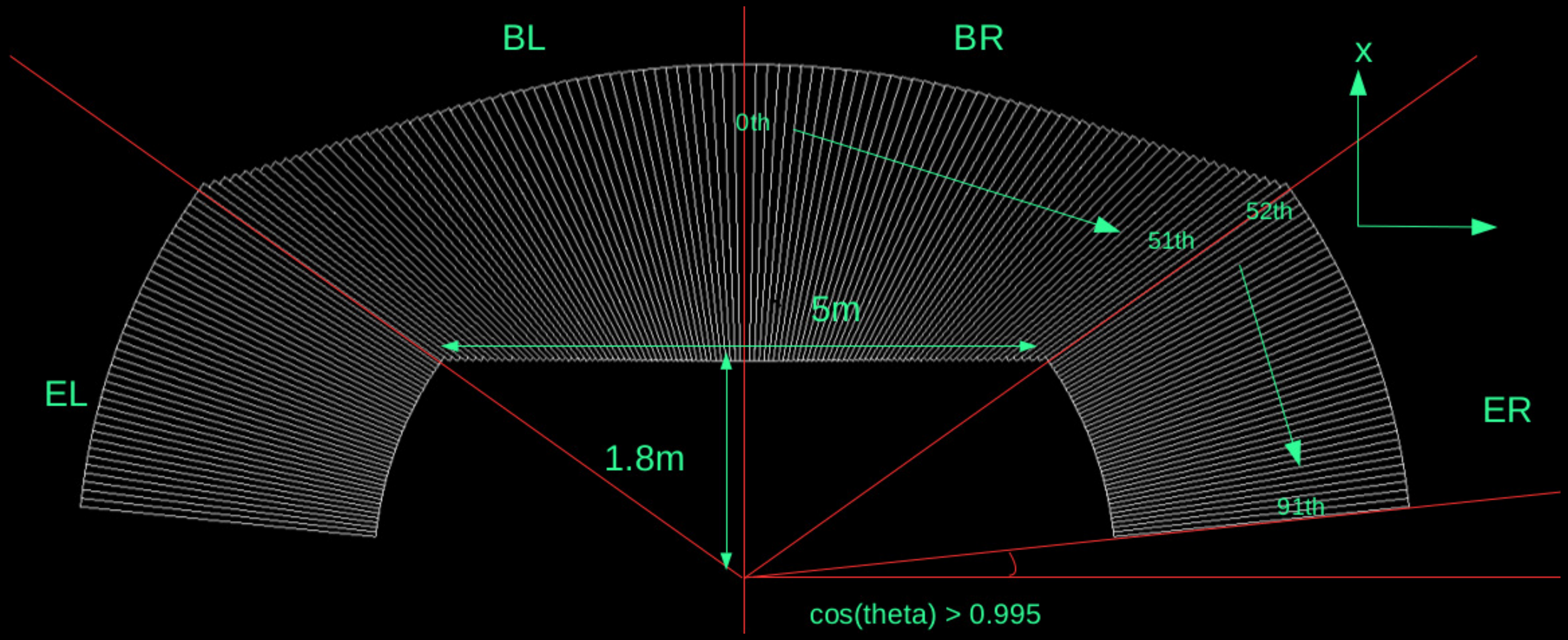
Prototype to be built: MOST (2018-2023)

0.5×0.5 m², 35 layer (4λ), 3×3 cm² module

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)

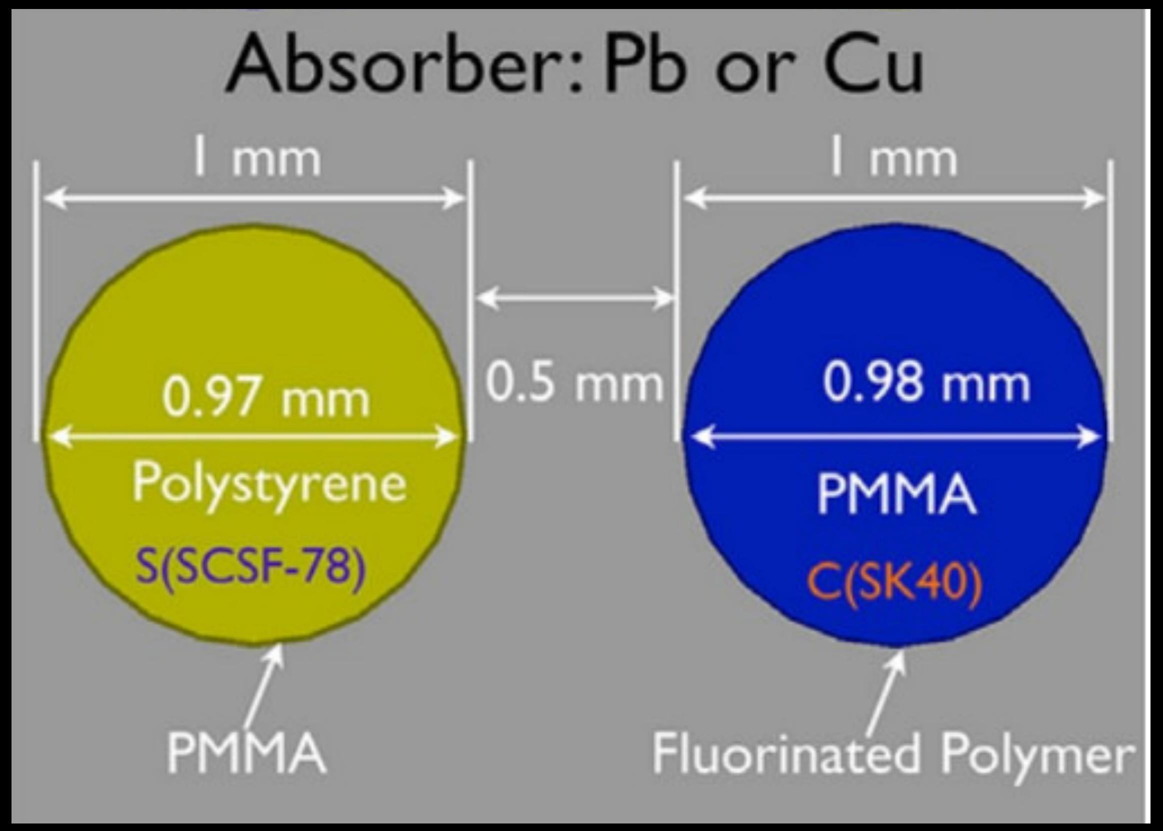


Covers full volume up to |cos(θ)| = 0.995

with 92 different types of towers (wedge)

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

Expected resolution:
EM: ~10%/sqrt(E)
Hadronic: 30-40%/sqrt(E)

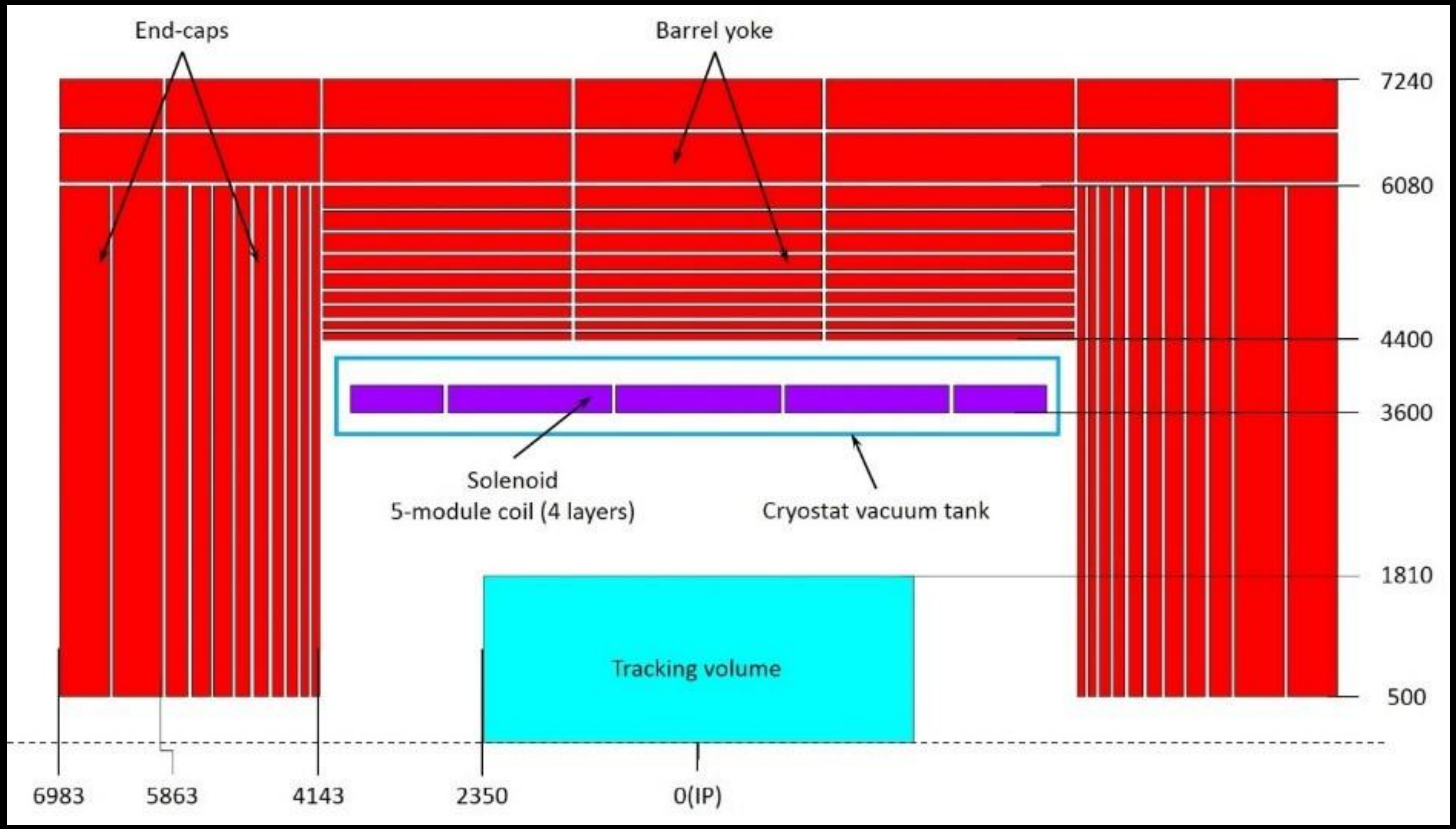


Studying different readout schemes
PMT vs SiPM

Several prototypes from RD52
have been built

Superconductor solenoid development

Updated design done for 3 Tesla field (down from 3.5 T)



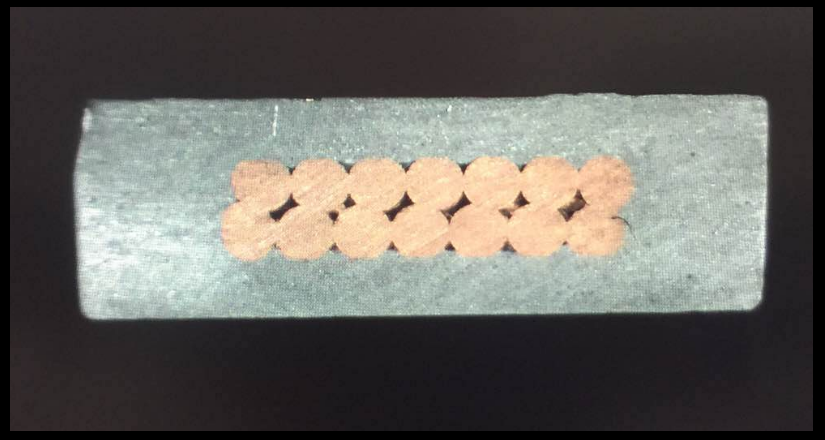
Main parameters of solenoid coil

Central magnetic field	3 T
Operating current	15779 A
Stored energy	1.3 GJ
Inductance	10.46 H
Coil radius	3.6-3.9 m
Coil length	7.6 m
Cable length	30.35 km

Design for 2 Tesla magnet presents no problems

Double-solenoid design also available

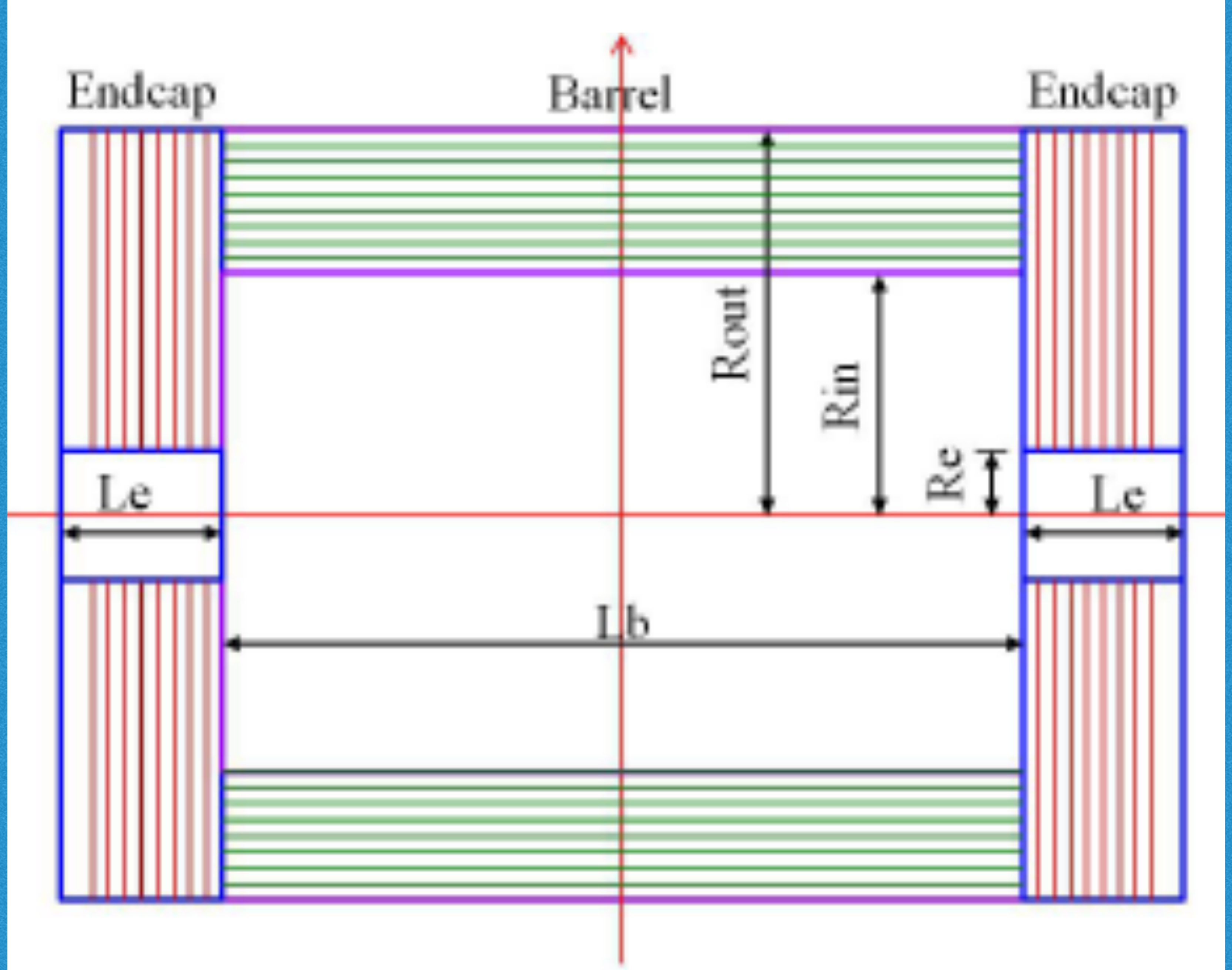
Default is NbTi Rutherford SC cable (4.2K)
Solutions with High-Temperature SC cable also being considered (YBCO, 20K)



Muon detector

Baseline Muon detector

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

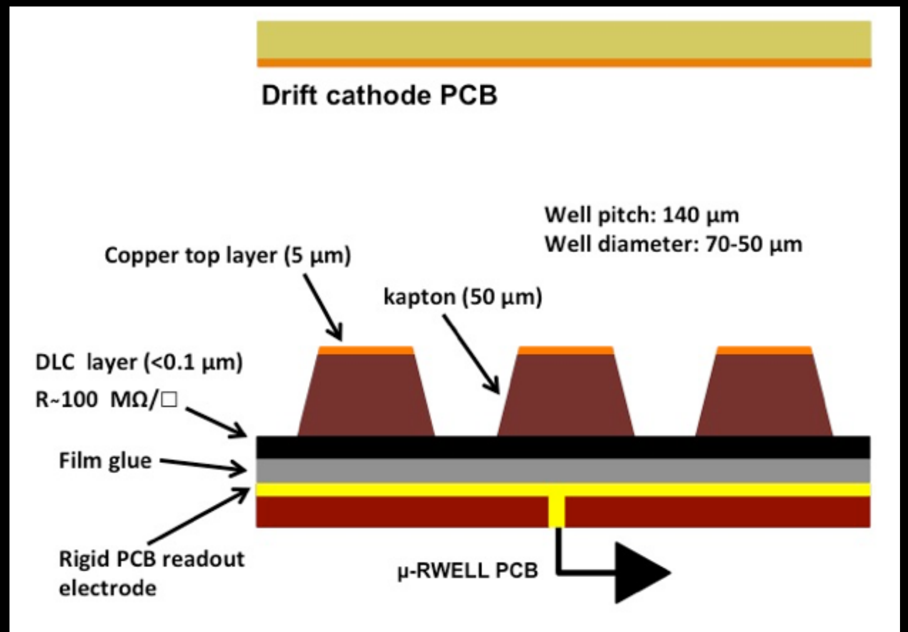


Technologies considered

Monitored Drift Tubes
Resistive Plate Chambers (RPC)
Thin Gap Chambers (TGC)
Micromegas
Gas Electron Multiplier (GEM)
Scintillator Strips

Baseline: Bakelite/glass RPC

New technology proposal (INFN): μRwell



Muon system: open studies

Good experience in China on gas detectors but currently no strong direct work on CEPC — rather open for international collaboration

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

Funding Support for Detector R&D

Multiple funding sources

- Ministery of Sciences and Technology (MOST)
- National Science Foundation of China
  - Major project funds
  - Individual funds
- Industry cooperation funds
- IHEP Seed Funding
- Others

Detector	Funding (M RMB)
Silicon	18.2
TPC	7.0
Calorimeter	21.3
Magnet	8.7
Total	55.2

Currently secured funding

Conceptual Design Report (CDR) – Status

Pre-CDR completed in 2015

- No show-stoppers
- Technical challenges identified → R&D issues

(http://cepc.ihep.ac.cn/preCDR/volume.html)

Detector and Physics - Conceptual Design Report (CDR)

- Goal: A working concept on paper, including alternatives

Draft-0 released in November 2017

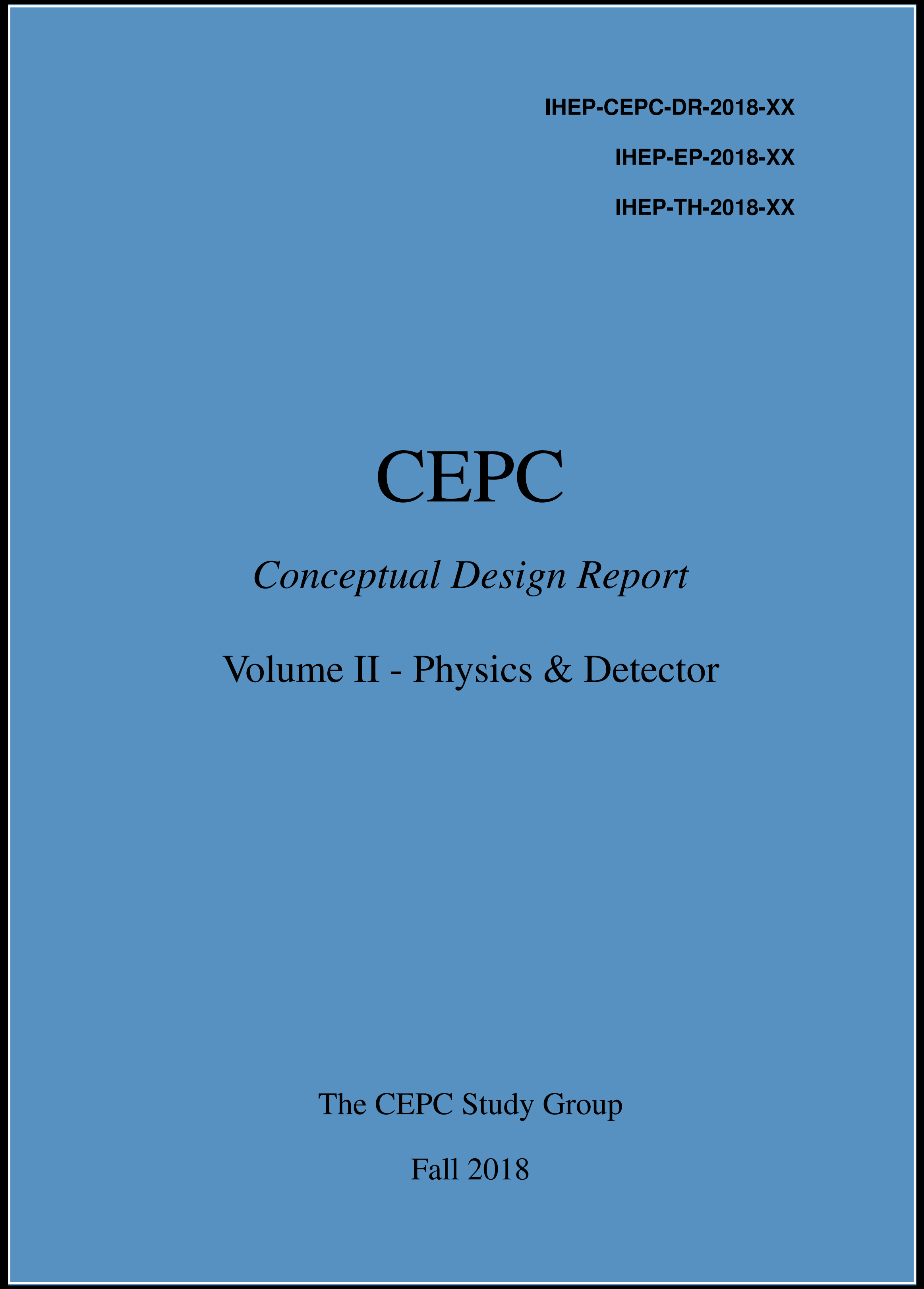
- Mini international review

Early fall 2018: Planned public release date

- Soon after CEPC accelerator CDR is released
- Accommodate new accelerator design parameters and solenoid magnetic field

Still

- Opportunities for people to contribute editing, reviewing


IHEP-CEPC-DR-2018-XX
IHEP-EP-2018-XX
IHEP-TH-2018-XX

CEPC

Conceptual Design Report

Volume II - Physics & Detector

The CEPC Study Group

Fall 2018

Final remarks

- Significant work done towards the CEPC Detector CDR
  - Two significantly different detector concepts are emerging
    - High-magnetic field (3 Tesla): PFA-oriented — with TPC or full-silicon tracker
    - Low-magnetic field (2 Tesla): with drift chamber and dual readout calorimeter
- Key technologies are under R&D and put to prototyping:
  - Vertex detector, TPC, calorimeters, magnets
  - International colleagues getting more heavily involved, participating in CDR
    - e.g. Drift chamber, dual readout calorimeter and muon chamber
- CEPC funding adequate for required R&D program
  - Support from several sources in China: NSFC, MOST, etc
- International collaboration expanding
  - INFN, SLAC, Iowa State Univ., Belgrade, LLR, IPNL, LC-TPC, Liverpool, Oxford, Barcelona, etc…

CDR Expected final release: Early Fall 2018

From 2018-2022, CEPC TDR will be finished

Thank you for the attention!