The CEPC
Physics and Detector
Conceptual Design Report

International Workshop on High Energy Circular Electron Positron Collider

12 November 2018

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(for the CEPC Study Group)

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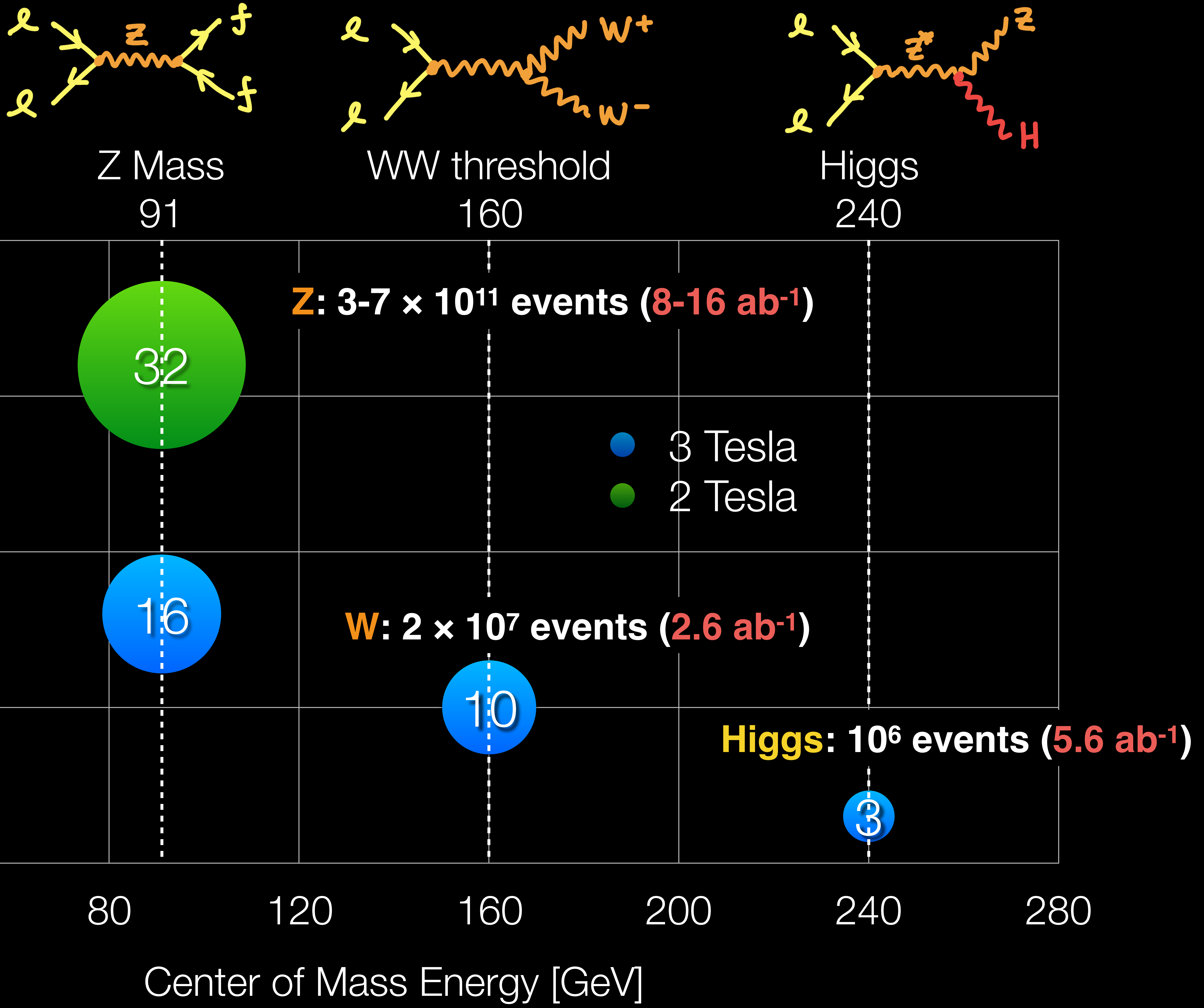
Institute of High Energy Physics
Chinese Academy of Sciences

The CEPC Program

100 km e^+e^- collider

2 IPs



IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

Can be downloaded from

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

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

Mini-Review of Preliminary CDR

https://indico.ihep.ac.cn/event/7384/

10-11 November, 2017

Reviewers:

- Alexandre Glazov (DESY),
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- Jianming Qian (Michigan),
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- Daniela Bortoletto (Oxford),
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IHEP-CEPC-DR-2018-XX
IHEP-EP-2018-XX
IHEP-TH-2018-XX

CEPC

Conceptual Design Report

Volume I - Physics & Detector

DRAFT-0

The CEPC Study Group

Spring 2018

Draft-0 preliminary chapters

- Chapter 3: Detector concepts (partial)
- Chapter 4: Vertex detector
- Chapter 5: Tracking system (TPC, silicon tracker, silicon-only concept, drift chamber)
- Chapter 6: Calorimeter (PFA and DR calorimeter options)
- Chapter 7: Magnet system
- Chapter 8: Muon system
- Chapter 10: MDI, beam background and luminosity measurement
- Chapter 11: Physics performance (partial)

Minutes and comments: https://indico.ihep.ac.cn/event/7384/material/slides/1.pdf

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. 2 — Physics and Detector

See Manqi's talk

IHEP-CEPC-DR-2018-02

IHEP-EP-2018-01

IHEP-TH-2018-01

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Conceptual Design Report

Volume II - Physics & Detector

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

The CEPC Study Group

October 2018

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

1143 authors from 221 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	9
Mexico	1
Morocco	1
Netherlands	1
Pakistan	2
Russia	11
Serbia	6
South Africa	2
Spain	5
Sweden	2
Switzerland	9
UK	16
US	118

Editorial Team: 41 people / 20 institutions

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The Physics Goals — Shopping List

(see Nathaniel Craig talk)

Chapter 2 - Physics Case

Input from:
Chapter 11
Physics Performance with Benchmark Processes

Physics requirements (from benchmark processes)

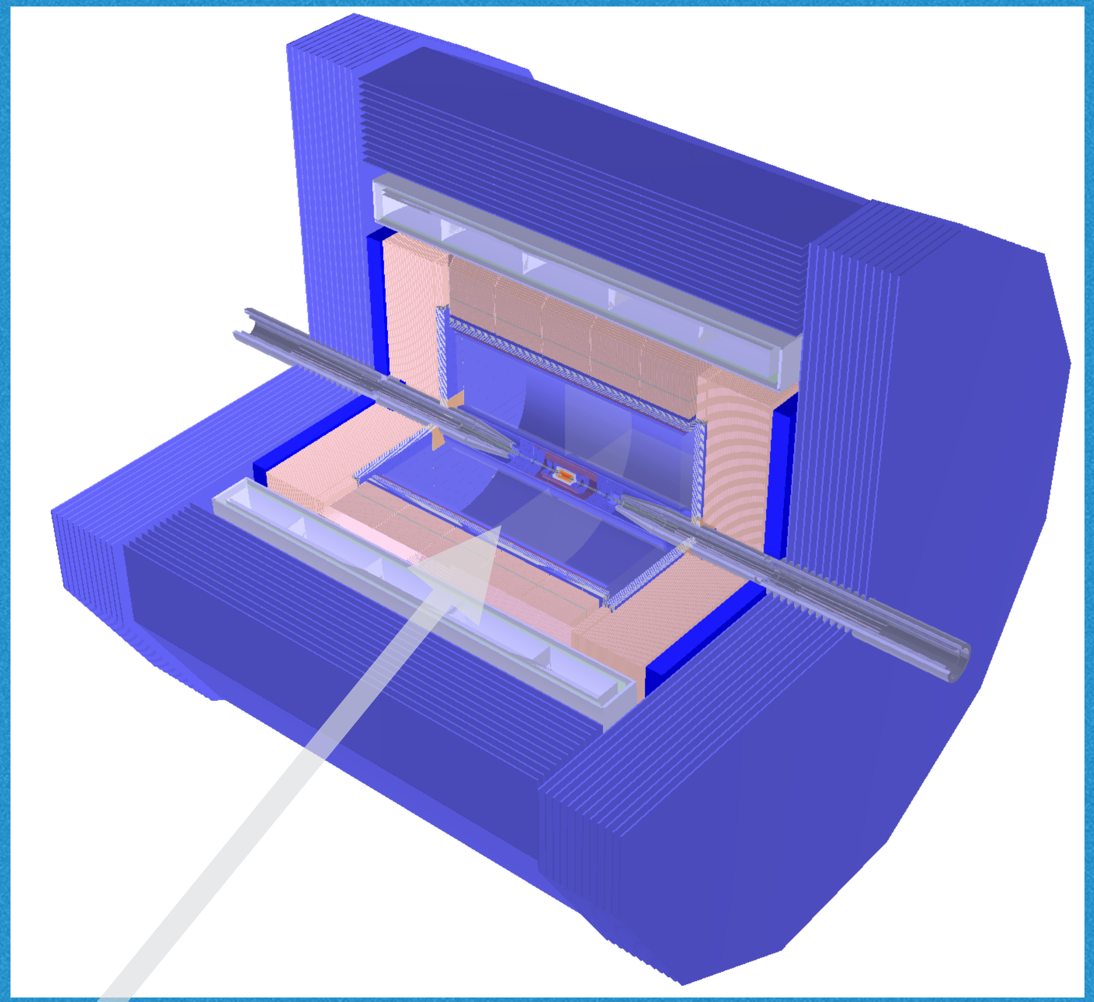
Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	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	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

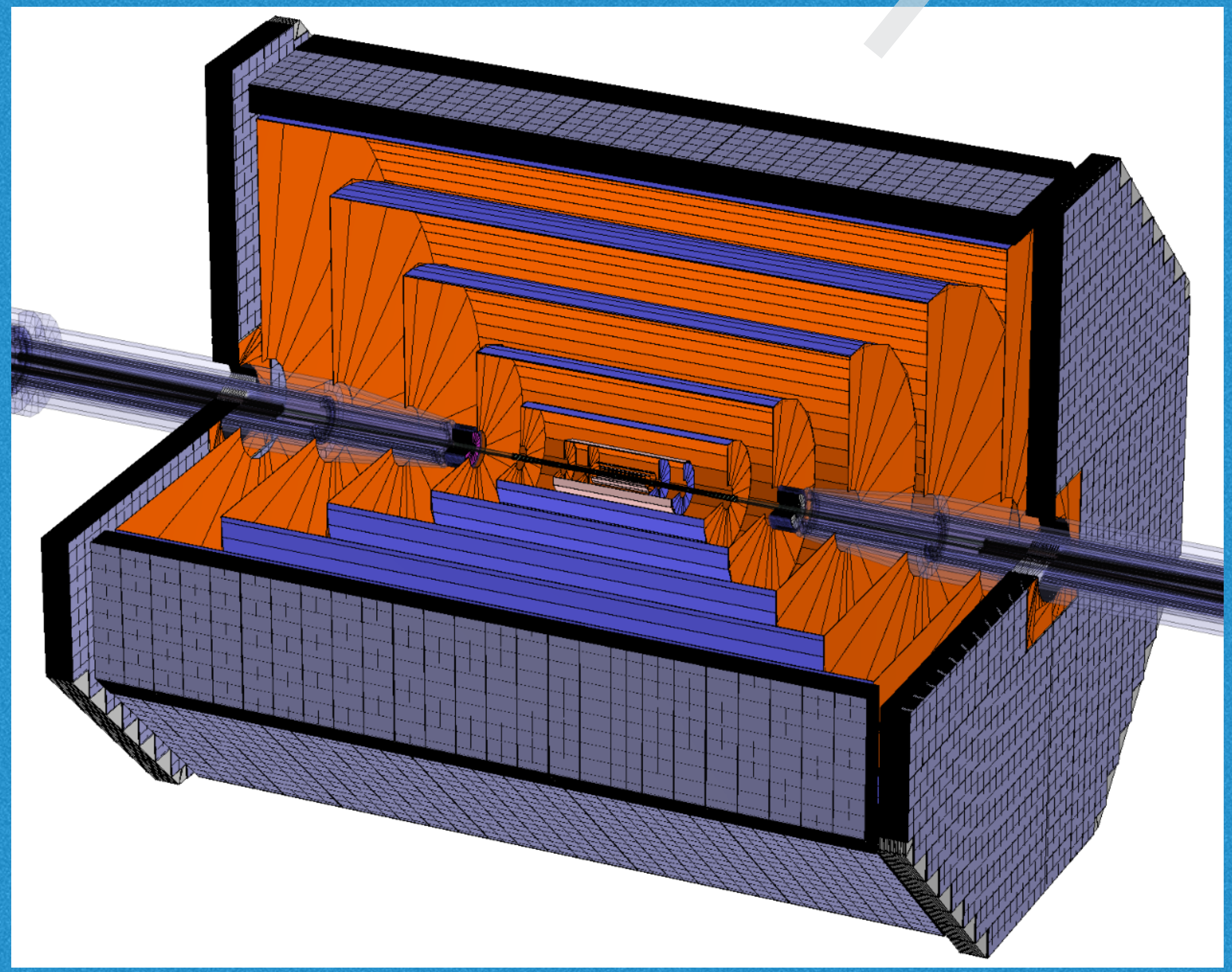
CEPC: 2.5 Detector Concepts

CEPC plans for 2 interaction points

Particle Flow Approach

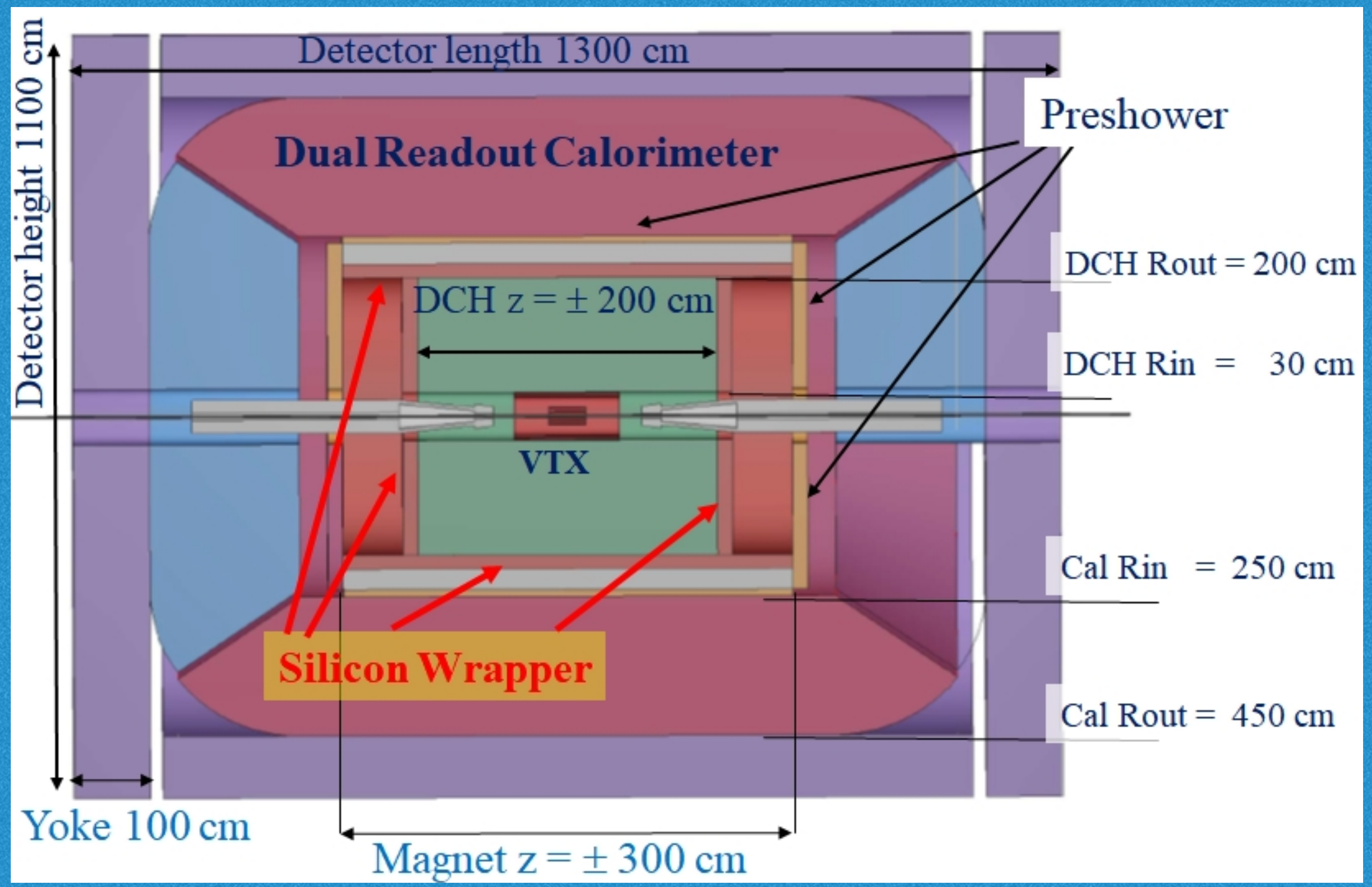
Baseline detector ILD-like (3 Tesla)





Full silicon tracker concept

Low magnetic field concept (2 Tesla)



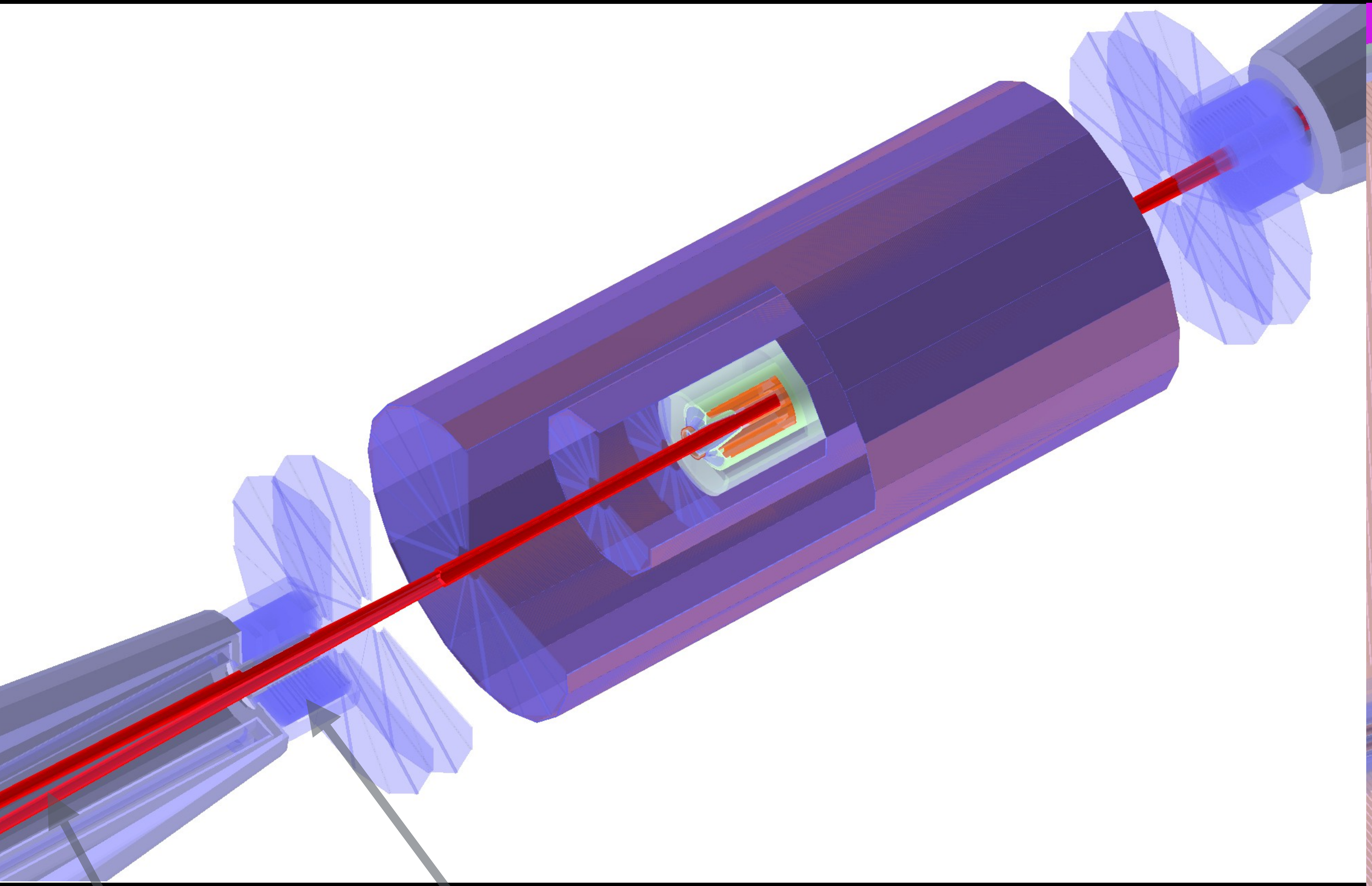
IDEA Concept

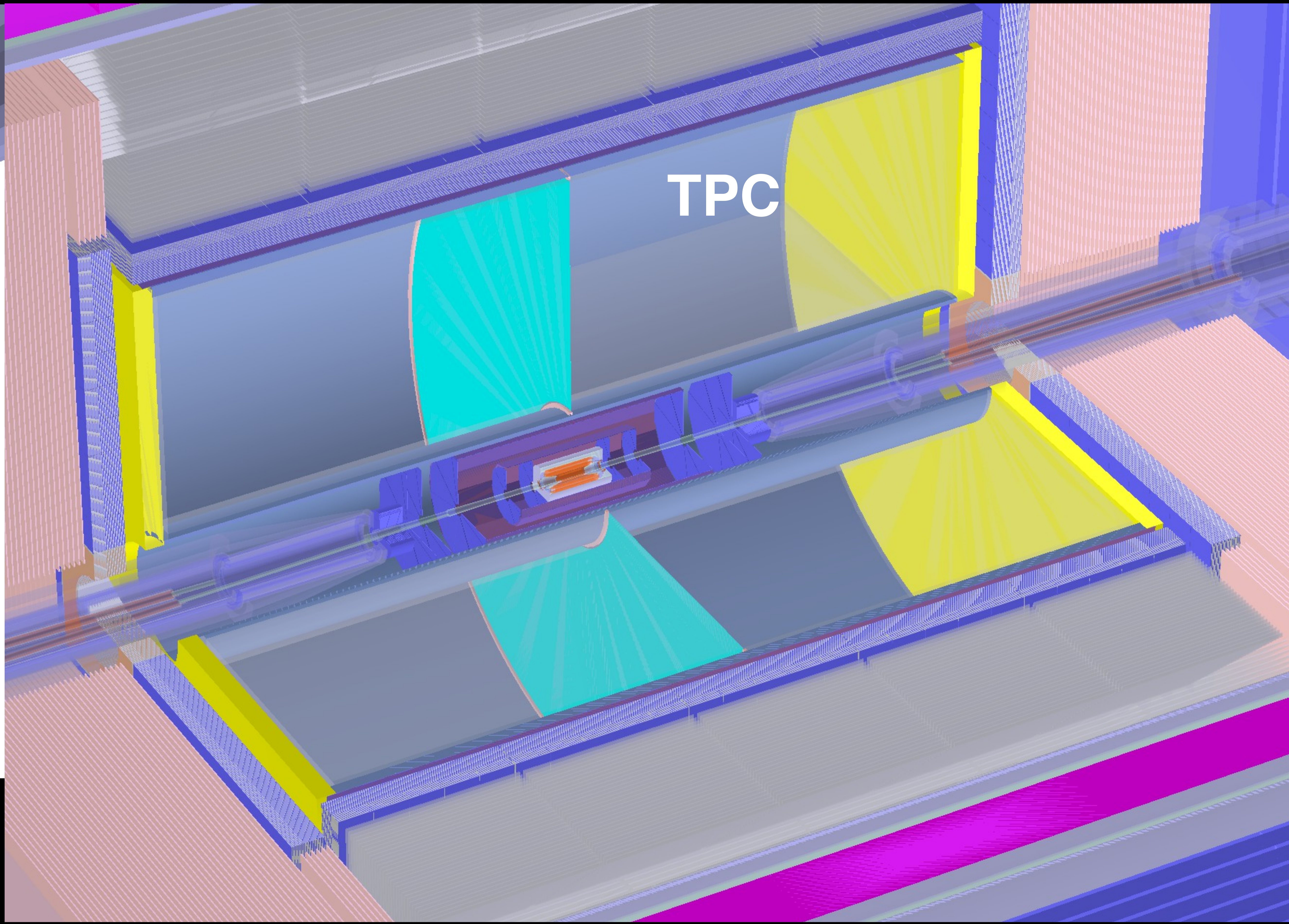
also proposed for FCC-ee

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

CEPC CDR–baseline detector

CEPC CDR baseline conceptual detector





MDI
Lumical
Beam pipes

L* = 2.2 m
Cross angle = 33 mrad

Interaction region: Machine Detector Interface

One of the most complicated issue in the CEPC detector design

Baseline parameters:

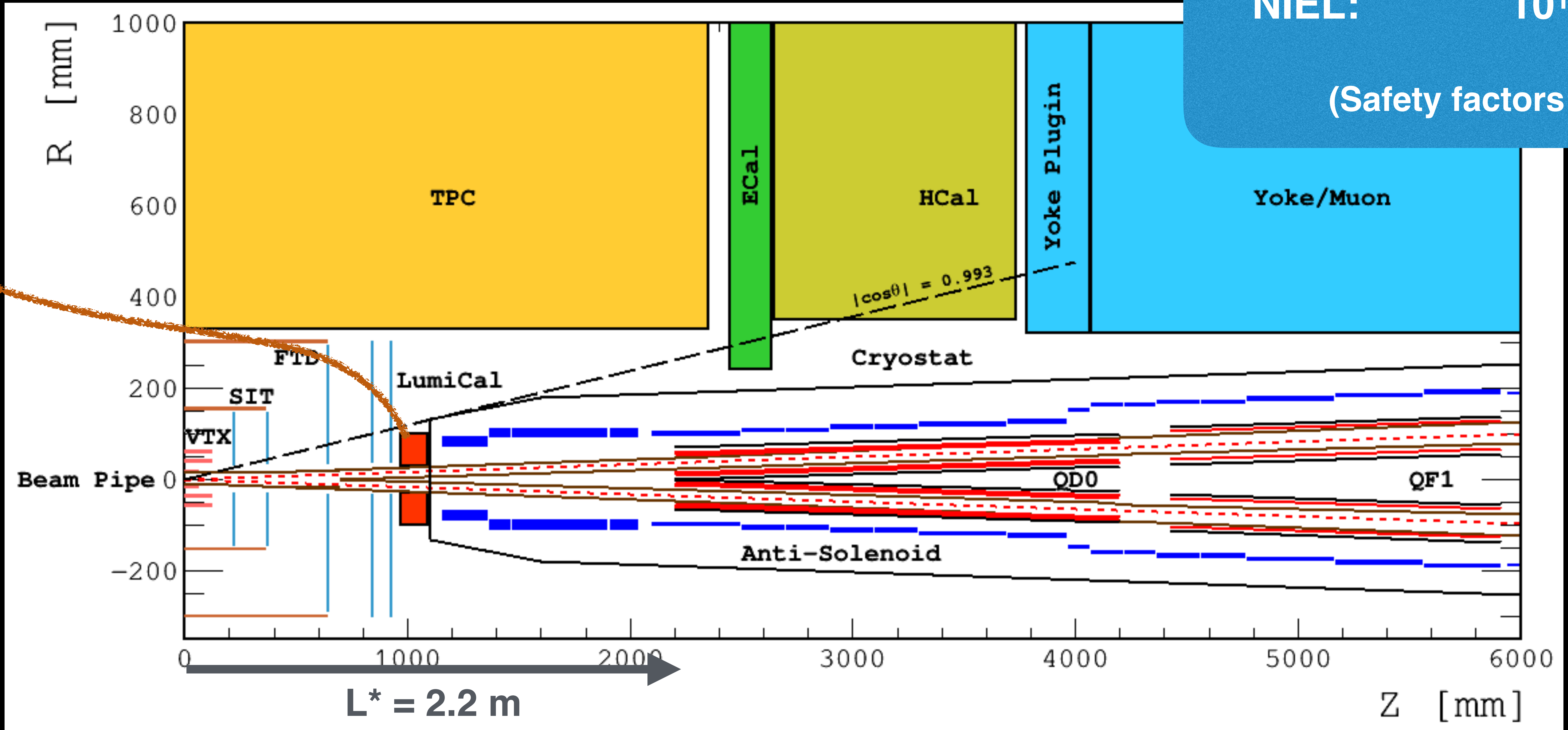
- Head-on collision crossing angle: **33 mrad**
- Focal length (**L***): **2.2 m**
- Solenoid magnetic field: **3 T**

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}/cm^2

(Safety factors of 10 applied)

LumiCal
Lumi unc: 1×10^{-3}
(studies lead by Vinca and Academia Sinica)

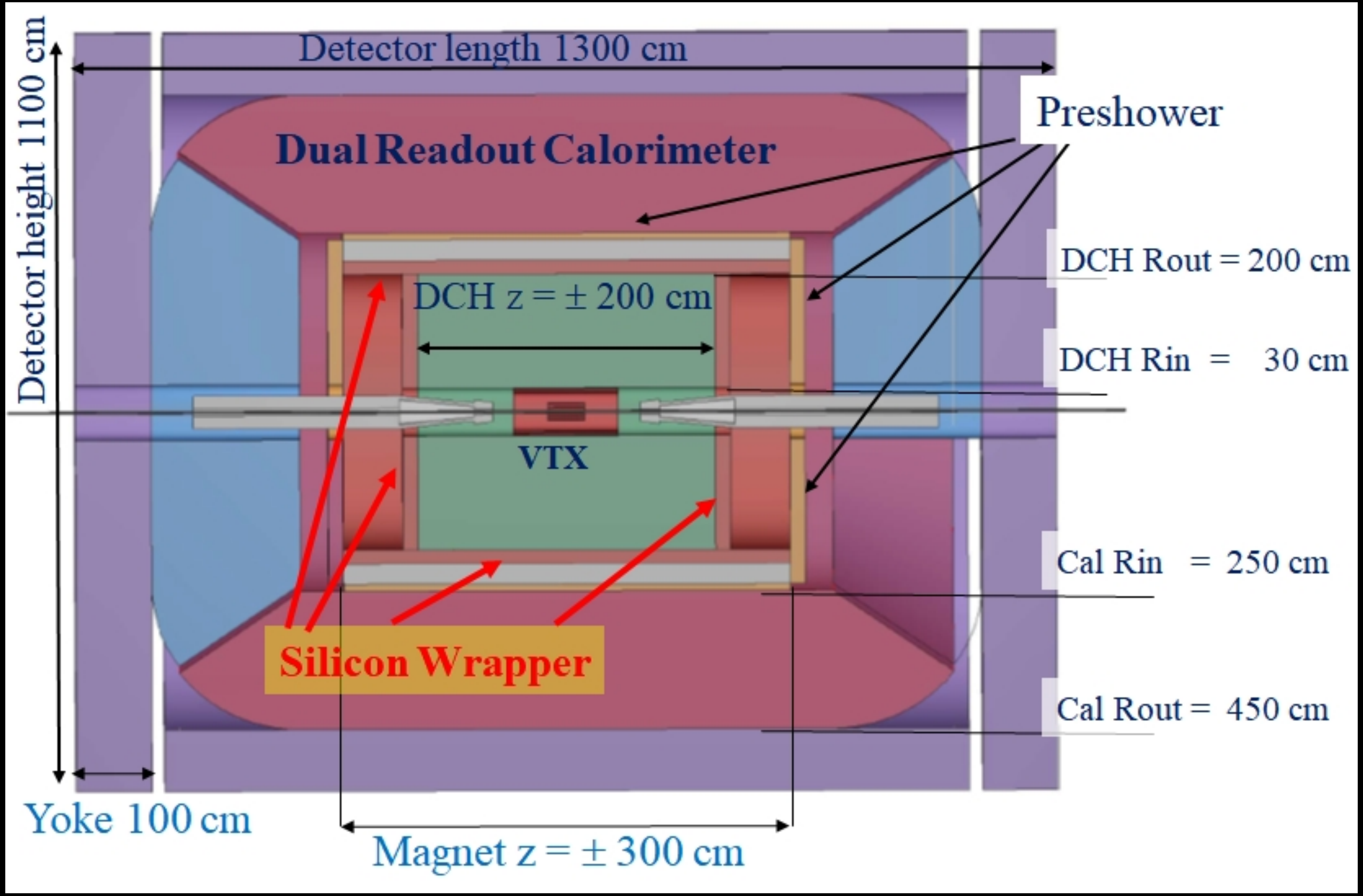


Challenging engineering design

CEPC CDR Alternative Conceptual Detector: IDEA

Inspired on work for 4th detector concept for ILC

Only concept with calorimeter outside the coil



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, ~ 1.6% X_0 , 112 layers**

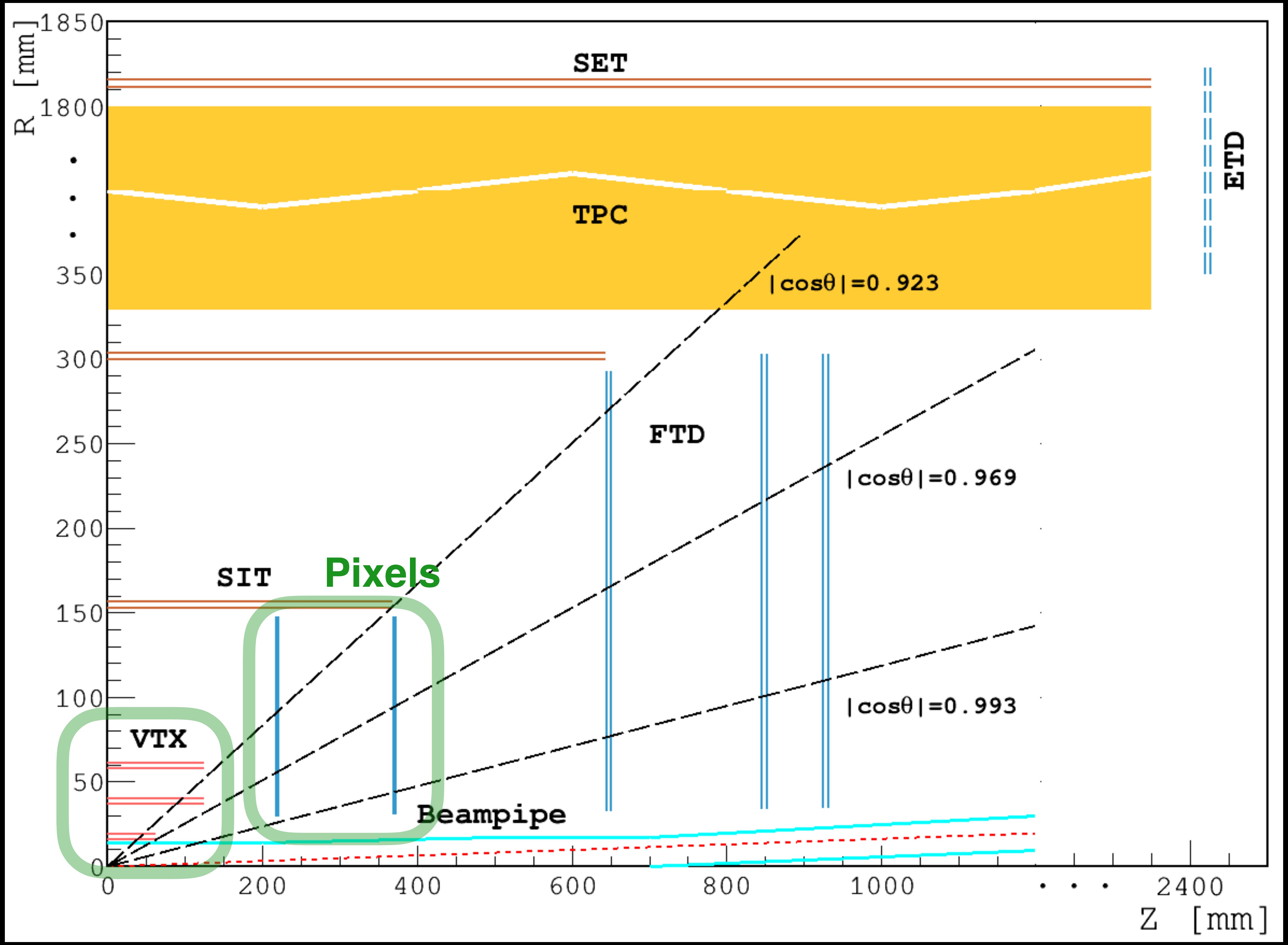
Preshower: ~1 X_0

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

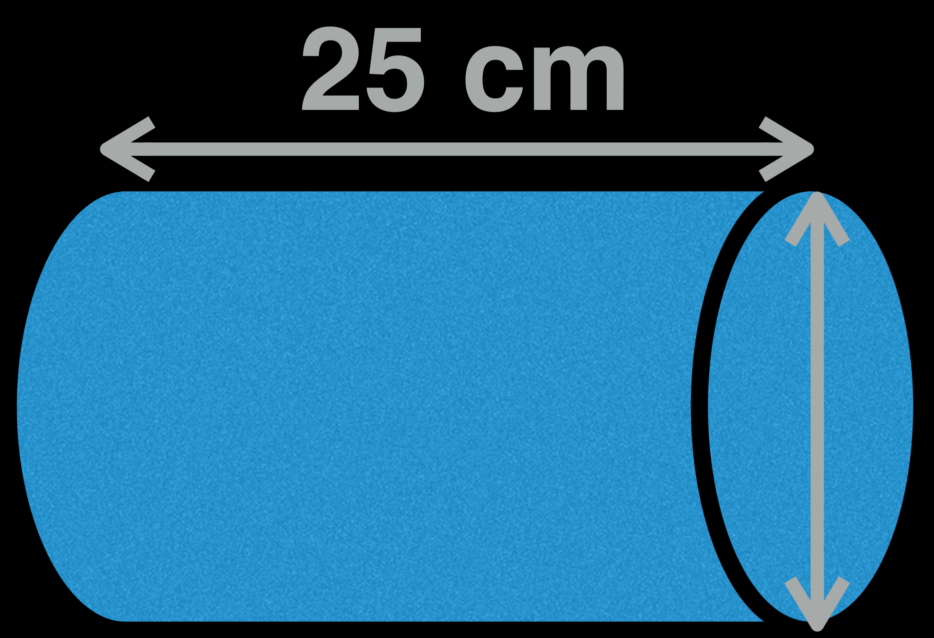
* **(yoke) muon chambers**

Tracker Detector – Baseline

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



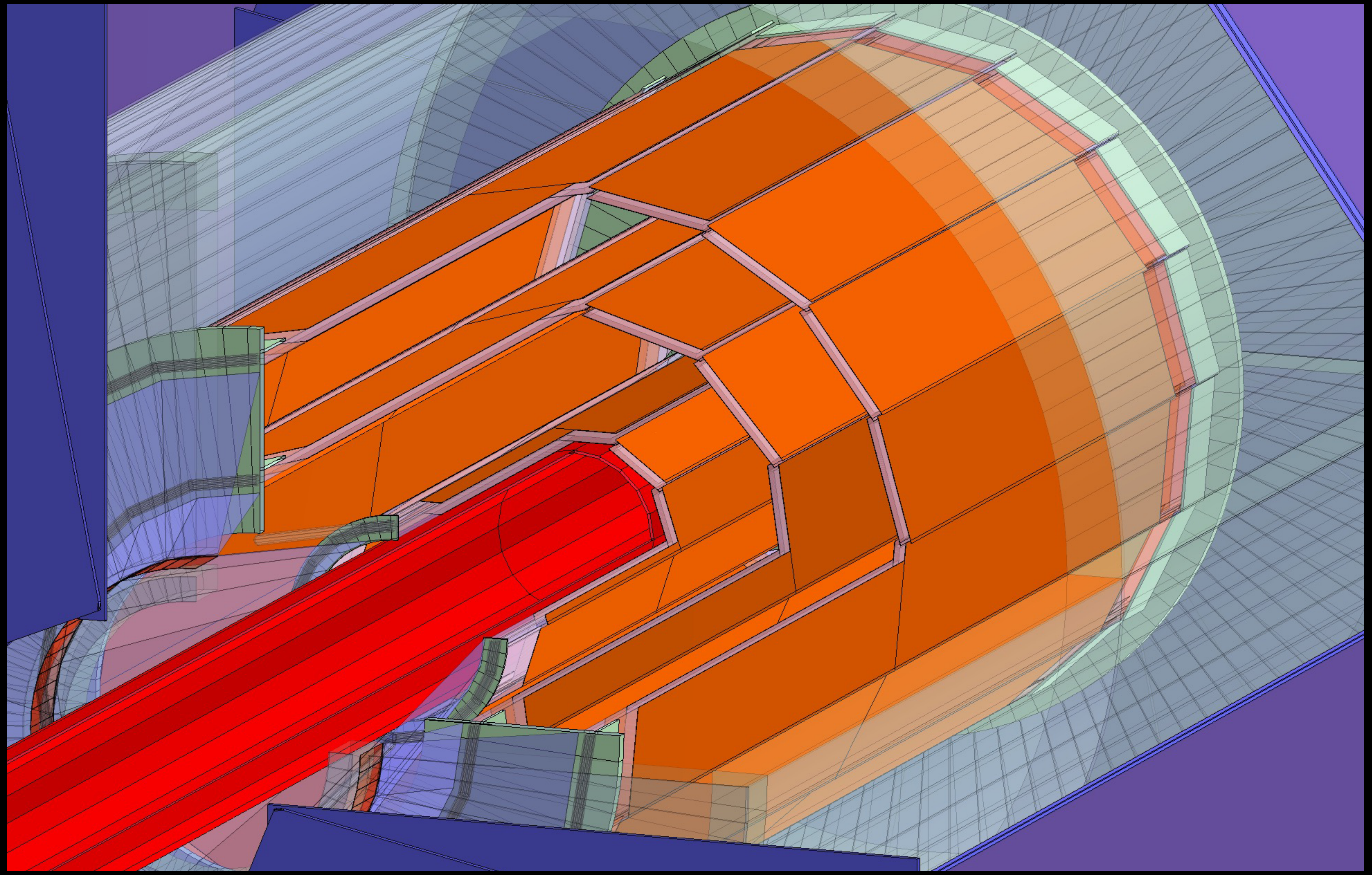
Microstrip sensors for most of tracker



Total Silicon area ~ 68 m^2

Baseline Pixel Detector Layout

3-ladders each with two layers of pixel sensors

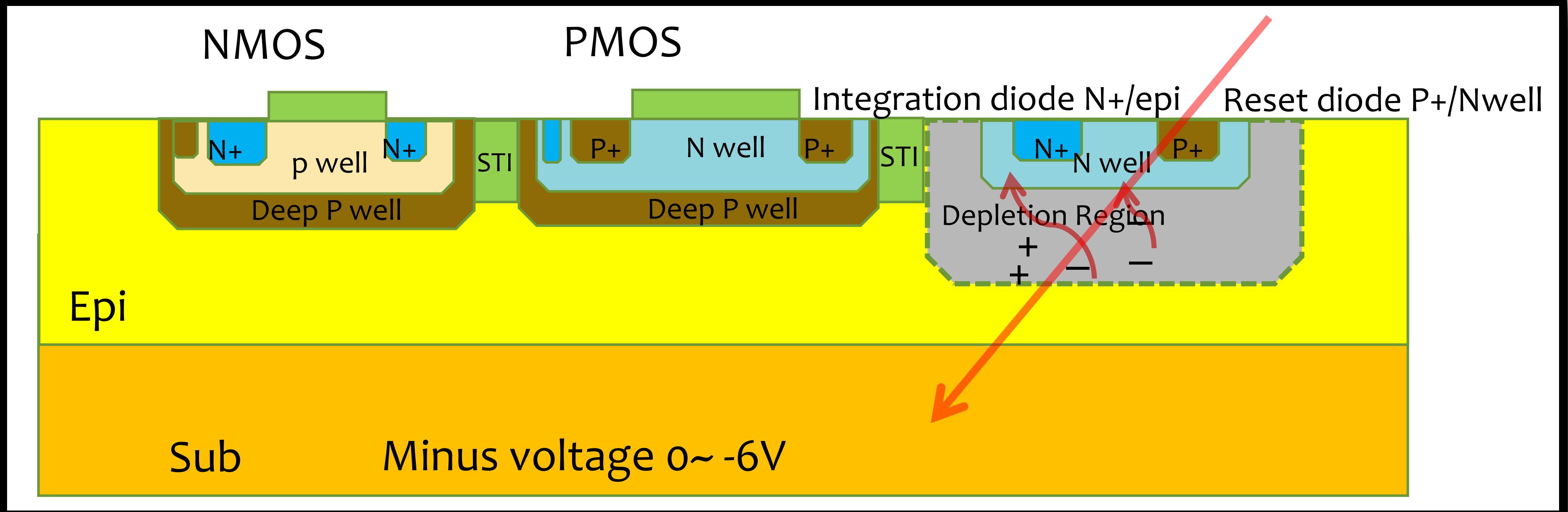


- ✦ Innermost layer: σ_{SP} = 2.8 μm
- ✦ Polar angle θ ~ 15 degrees
- ✦ Material budget ≤ 0.15%X_0/layer

Implemented in GEANT4 simulation framework (MOKKA)

		R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(μm)
Ladder 1	Layer 1	16	62.5	0.97	2.8
	Layer 2	18	62.5	0.96	6
Ladder 2	Layer 3	37	125.0	0.96	4
	Layer 4	39	125.0	0.95	4
Ladder 3	Layer 5	58	125.0	0.91	4
	Layer 6	60	125.0	0.90	4

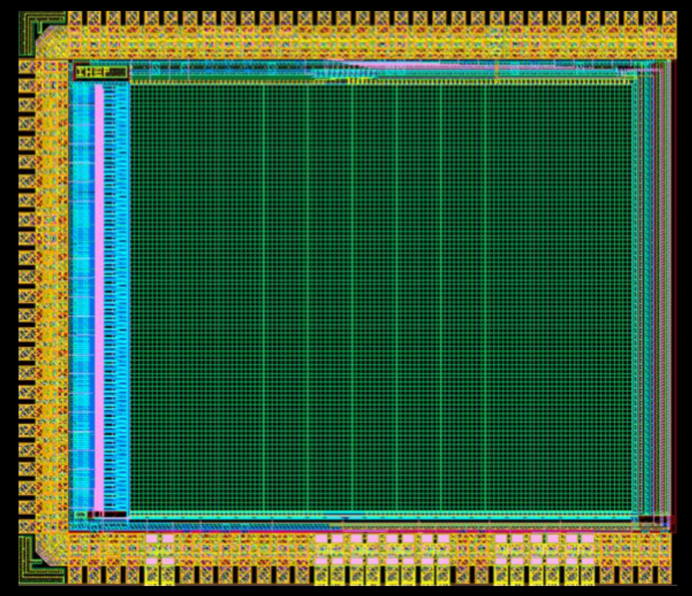
CMOS pixel sensor (MAPS)



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

R&D goals and activities

- **Sensor R&D targeting:**



	Specs	Observations
Single point resolution near IP:	< 3-5 μm	Need improvement
Power consumption:	< 100 mW/cm²	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)	> 2.5 MRad	Need 2.5× higher /year

- **Sensors technologies:**

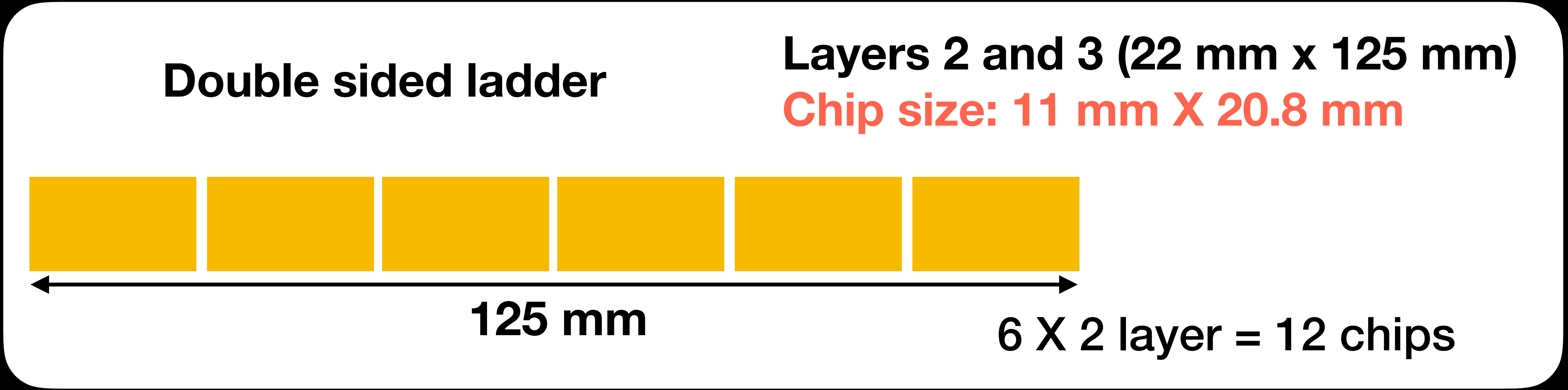
	Process	Smallest pixel size	Chips designed	Observations
CMOS pixel sensor (CPS)	TowerJazz CIS 0.18 μm	22 × 22 μm²	2	Founded by MOST and IHEP
SOI pixel sensor	LAPIS 0.2 μm	16 × 16 μm²	2	Funded by NSFC

  - Institutions: CCNU, NWTU, Shandong, Huazhong Universities and IHEP (IPHC in Strasbourg, KEK)

- **Full size prototype by 2023:**

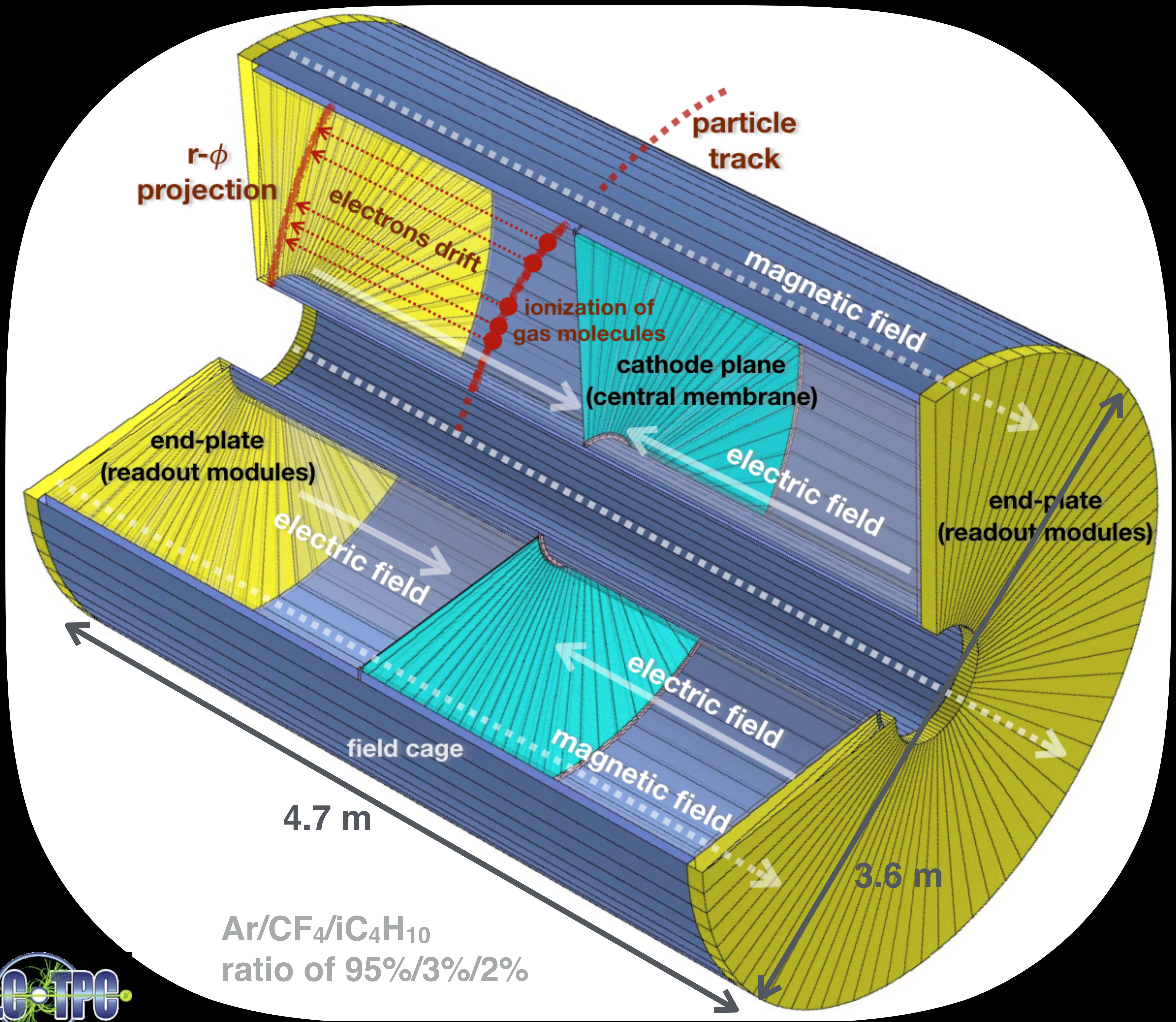
  Explore light material construction

  Full size chip



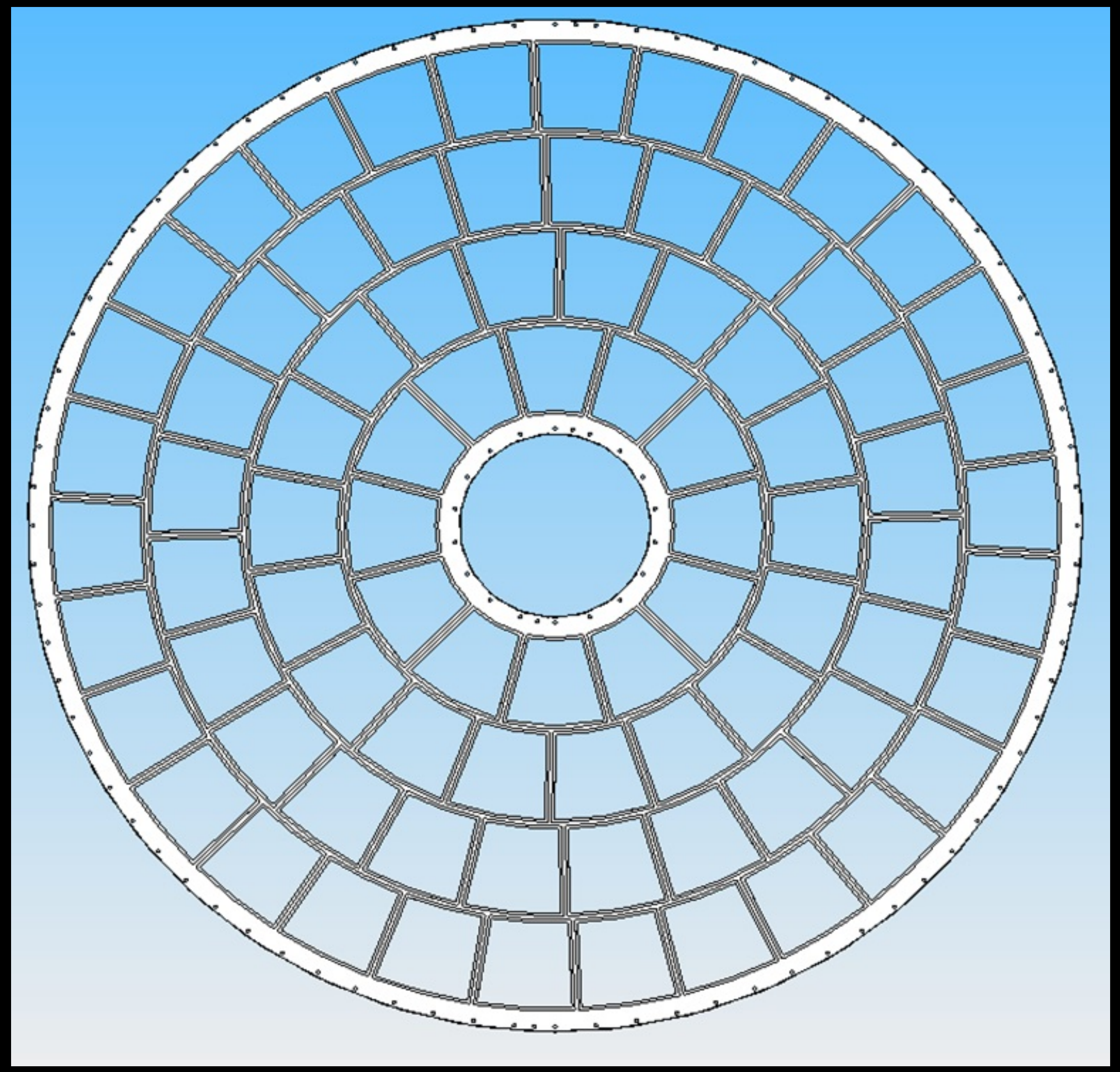
Time Projection Chamber (TPC)

TPC detector concept



$Ar/CF_4/iC_4H_{10}$
ratio of 95%/3%/2%

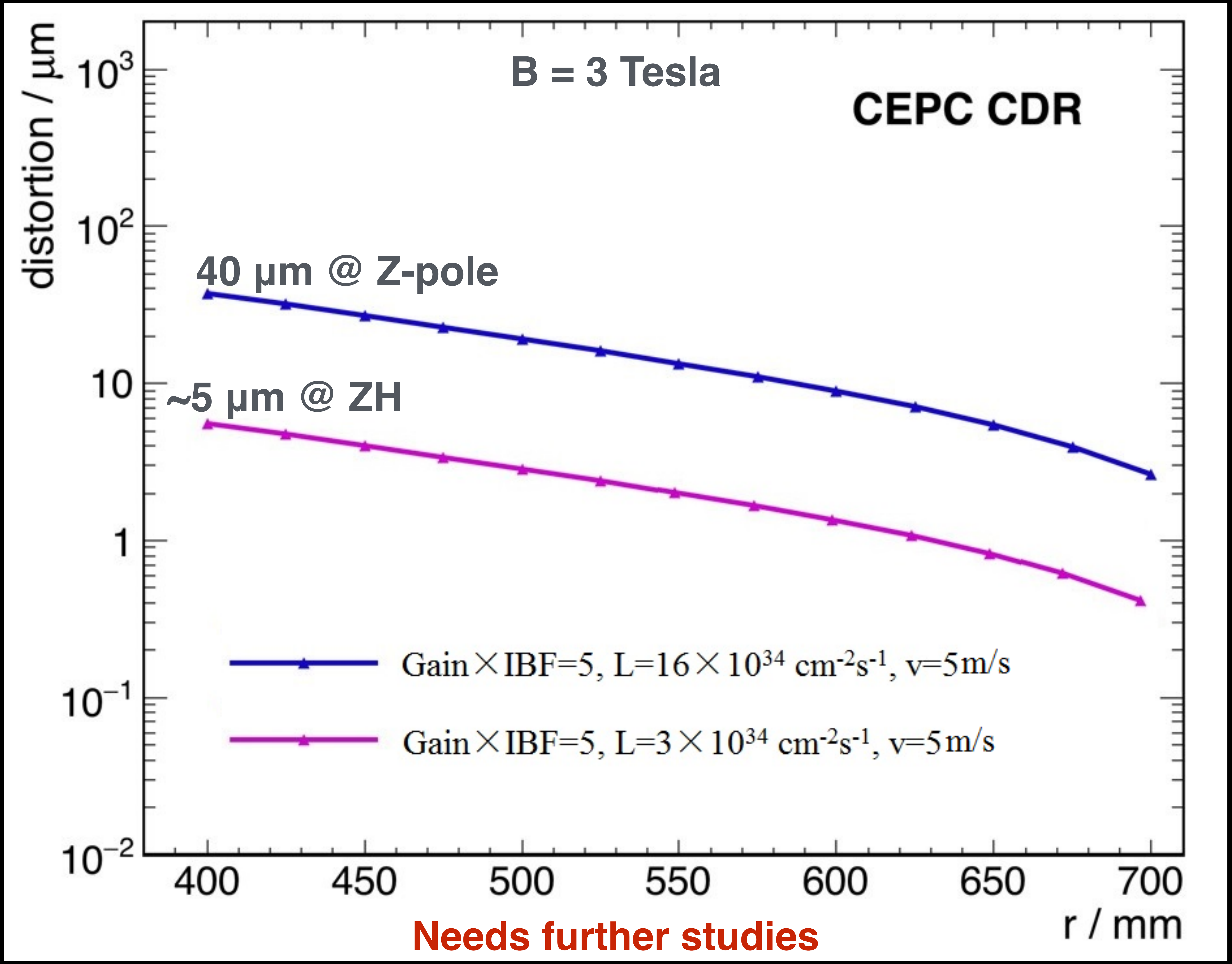
- **Allows for particle identification**
- **Low material budget:**
  - <1% X_0 in r
  - 10% X_0 for readout endcaps in Z



Readout by: Micro-Pattern Gas Detector (MPGD)

Time Projection Chamber (TPC)

TPC detector concept



- 3 Tesla magnetic field —> reduces diffusion of drifting electrons

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

- Problem: Ion Back Flow —> track distortion

Assumes 5 ions backflow from readout into main gas system per primary ionization

Hybrid: GEM and Micromegas readout

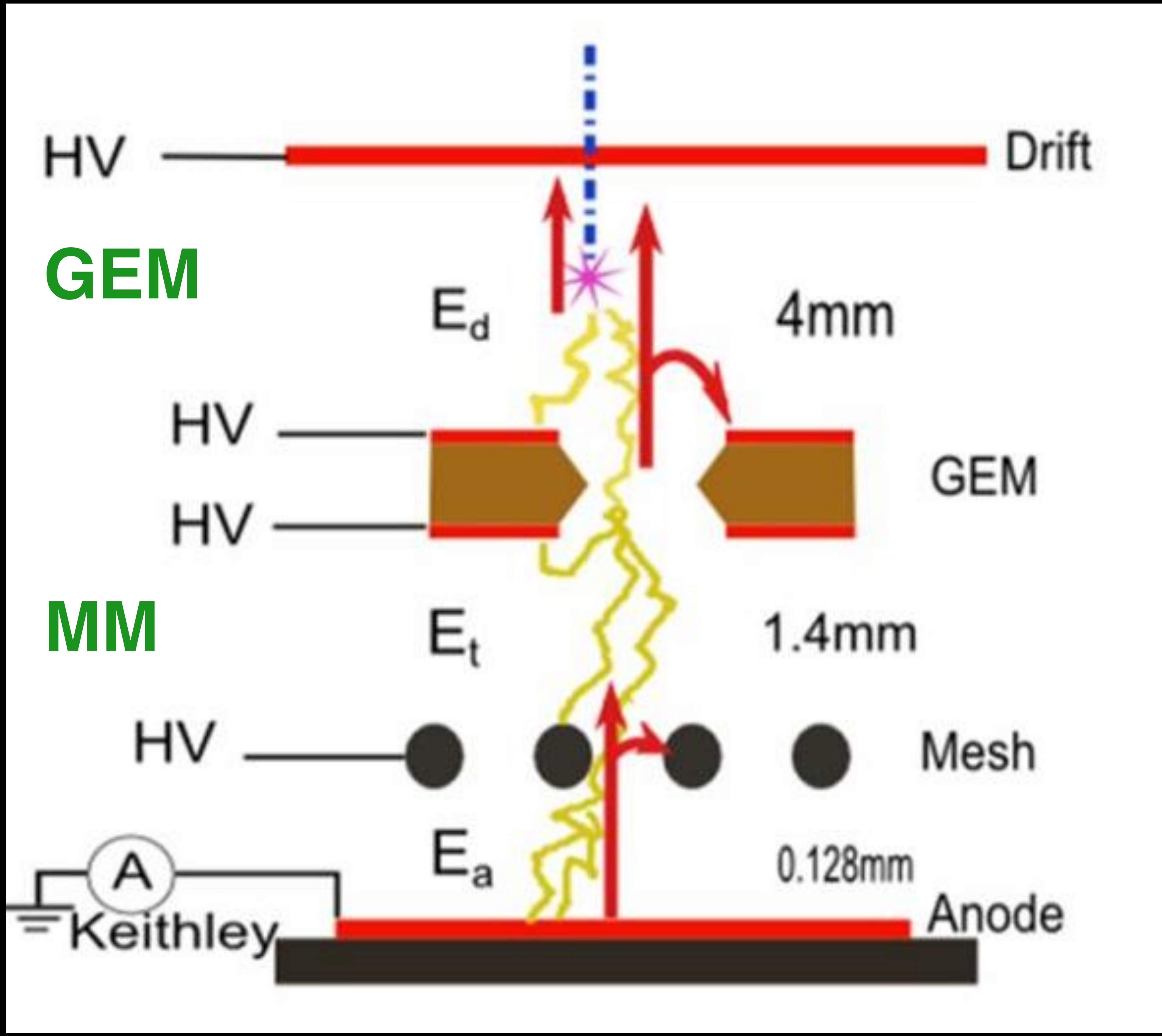
R&D on-going

Time Projection Chamber (TPC)

R&D by: IHEP, Tsinghua and Shandong

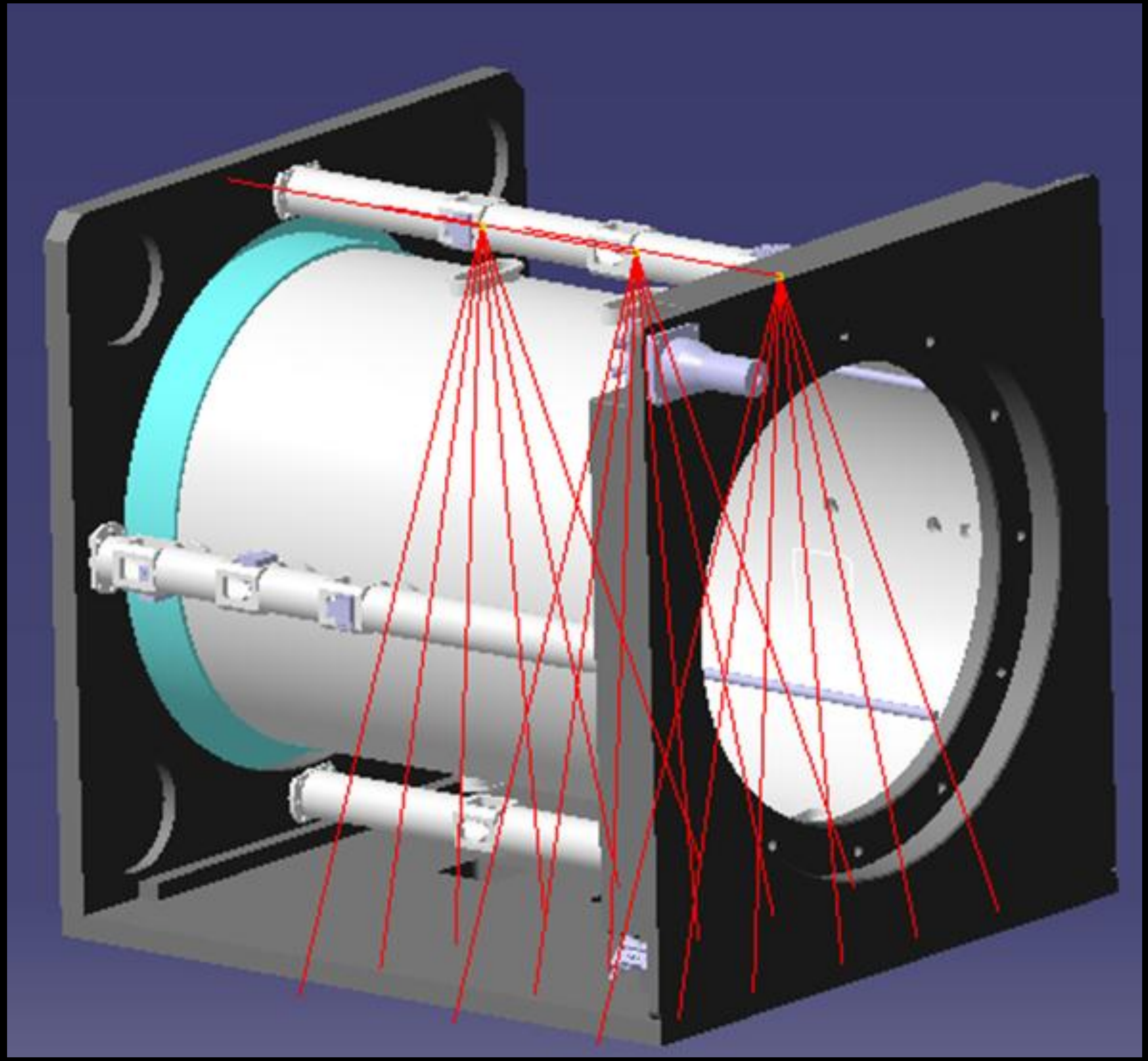
TPC detector concept

Hybrid: GEM and Micromegas readout



Small prototype built
R&D on-going

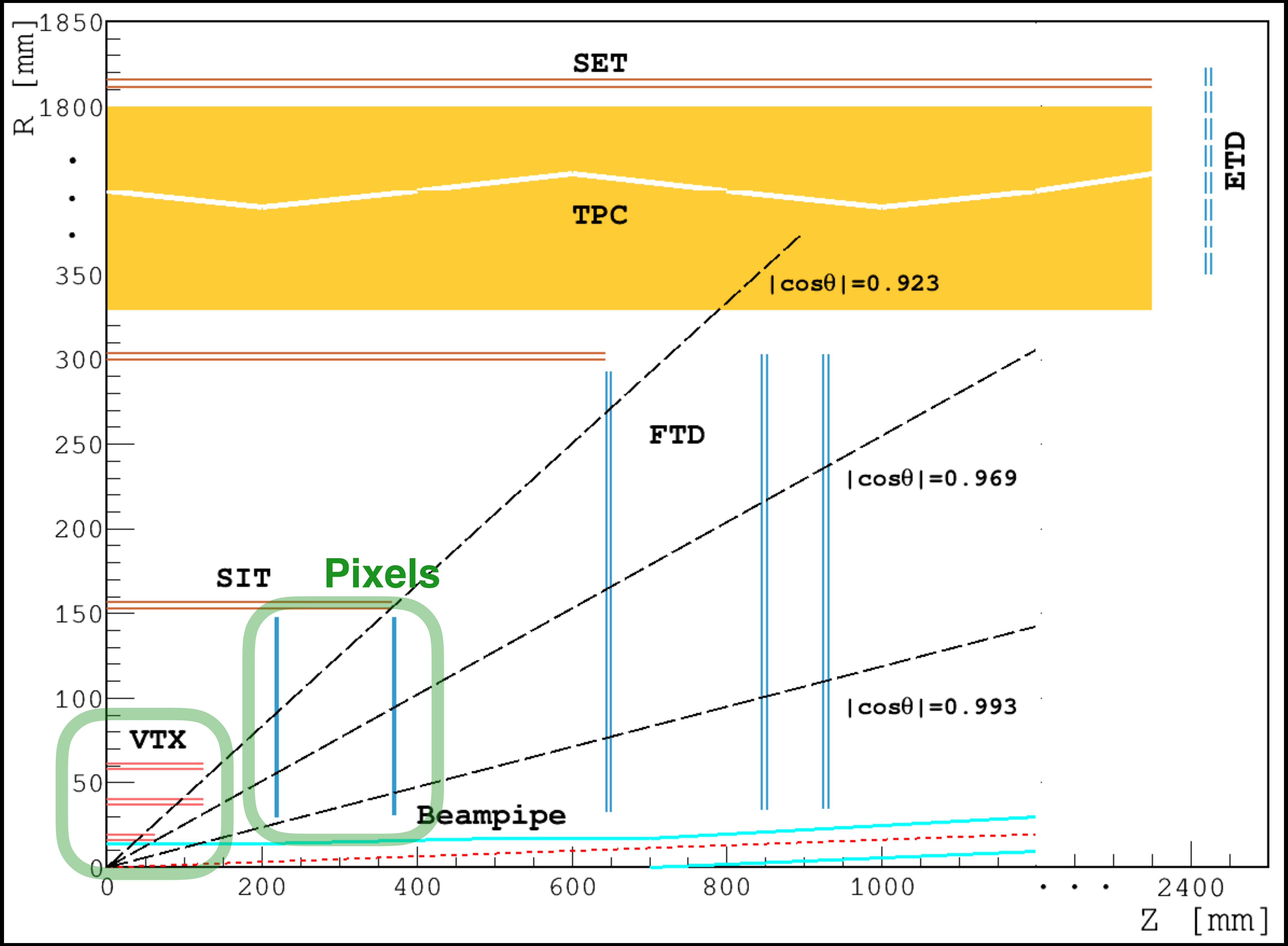
Laser calibration and alignment system



Small prototype with Nd:YAG laster built
R&D on-going

Silicon Tracker Detector – Baseline

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



Required resolution
$\sigma_{SP} < 7$ μm

Sensor technology

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

Power and Cooling

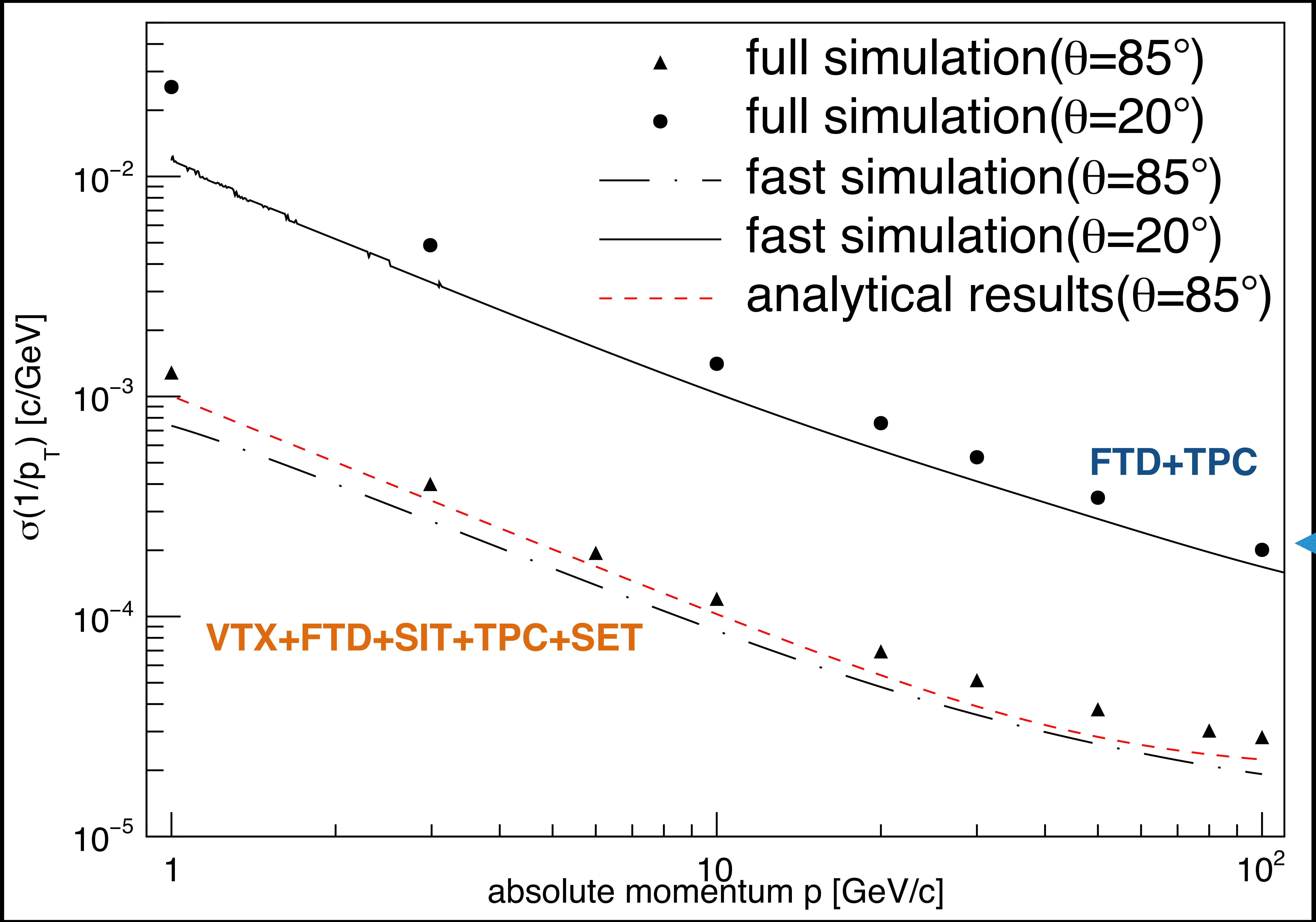
1. DC/DC converters
2. Investigate air cooling

Total Silicon area ~ 68 m^2

Extensive opportunities for international participation

Baseline Tracker Detector

Transverse momentum resolution for single muon tracks

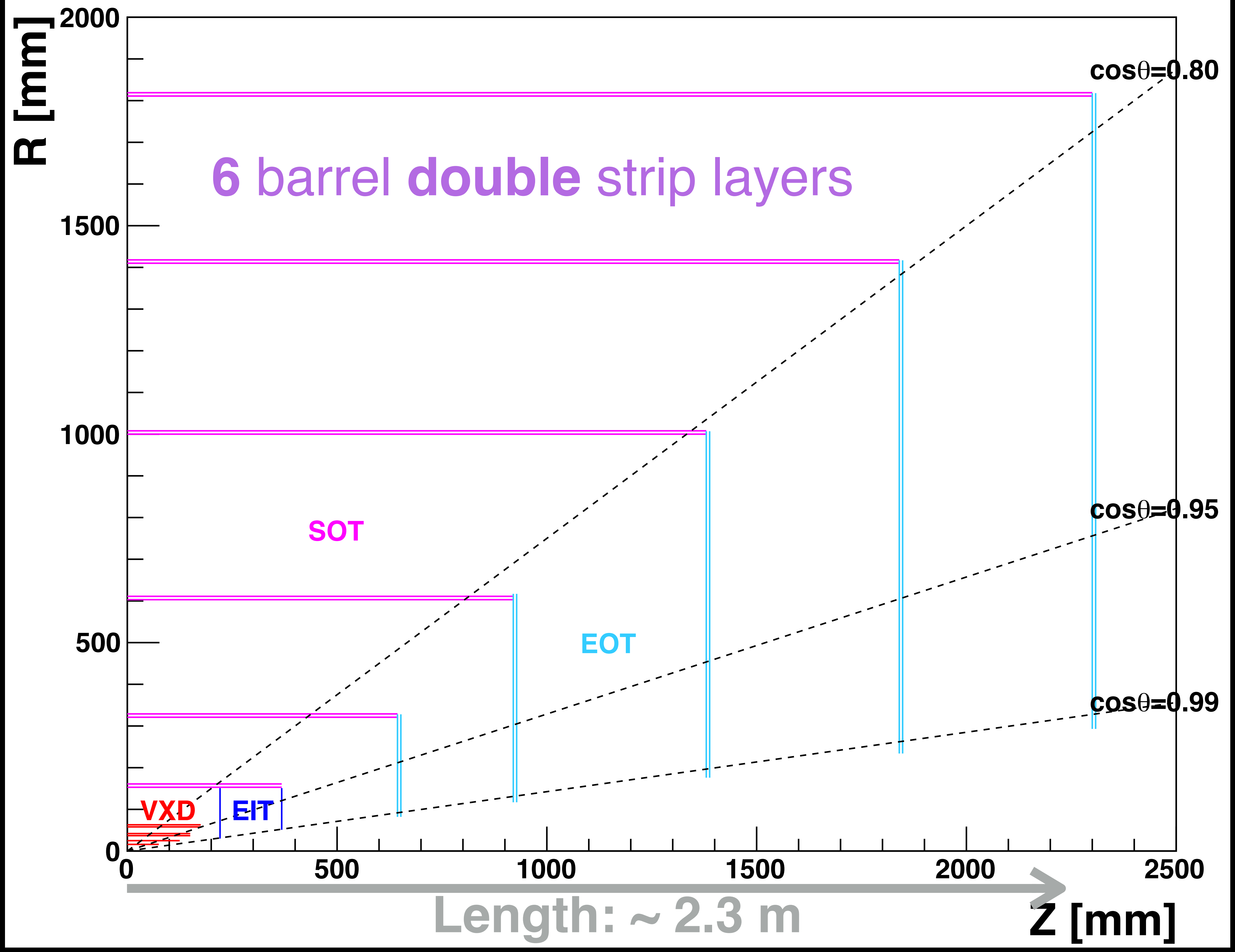


Inclusion of ETD should improve resolution

Full Silicon Tracker Concept

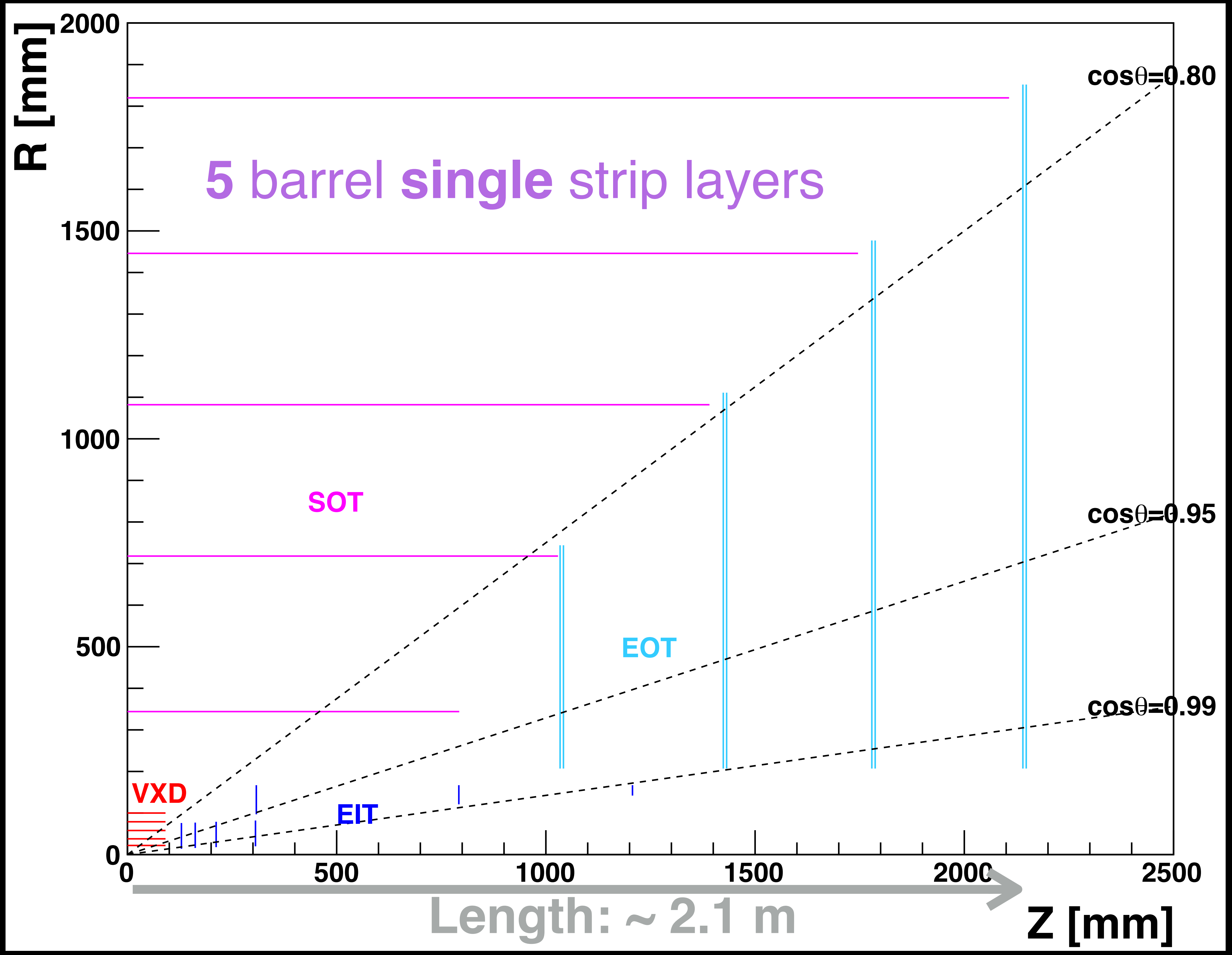
Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



Radius ~ 1.8 m

FST2 layout: Rad length up to 10%



Proposed by Berkeley and Argonne

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

Drift Chamber Option – IDEA Concept

Lead by Italian Colleagues

Low-mass cylindrical drift chamber

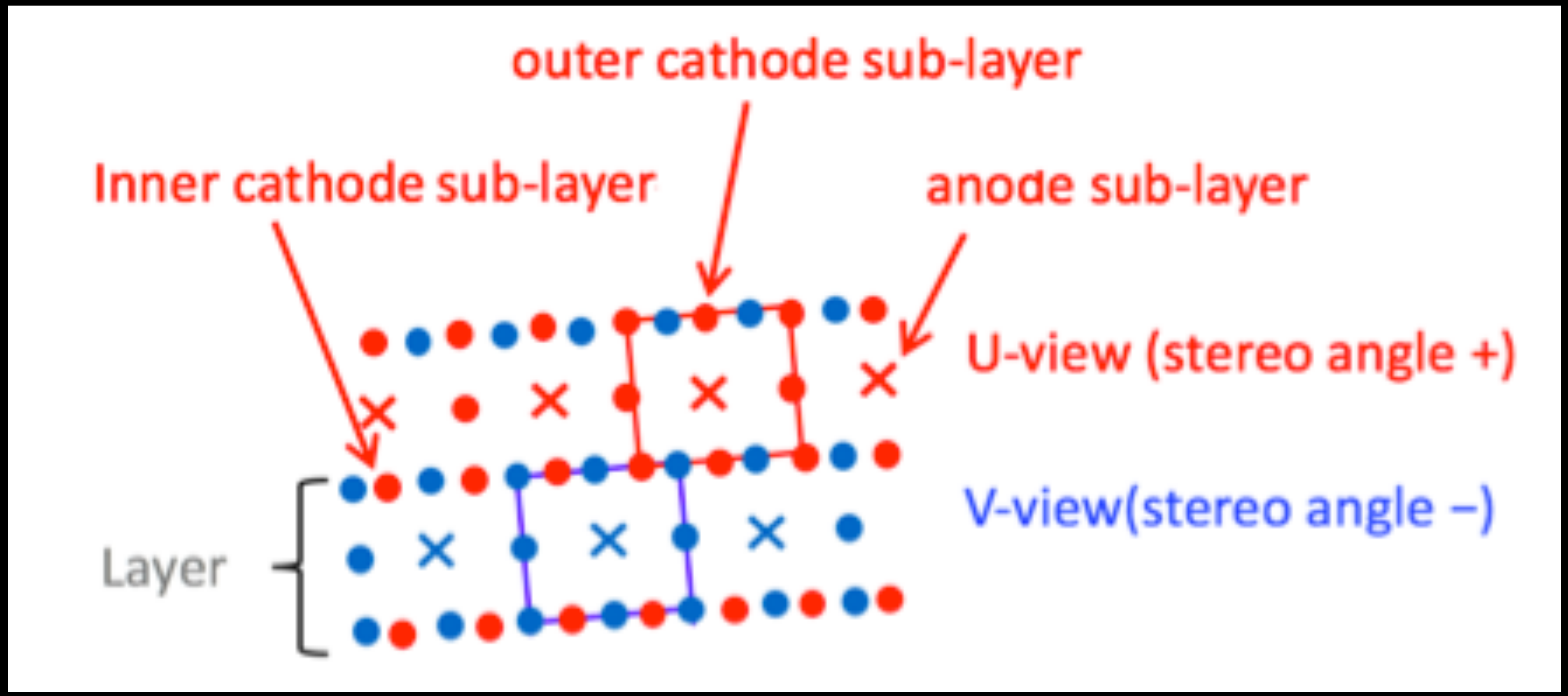
Follows design of the KLOE and MEG2 experiments

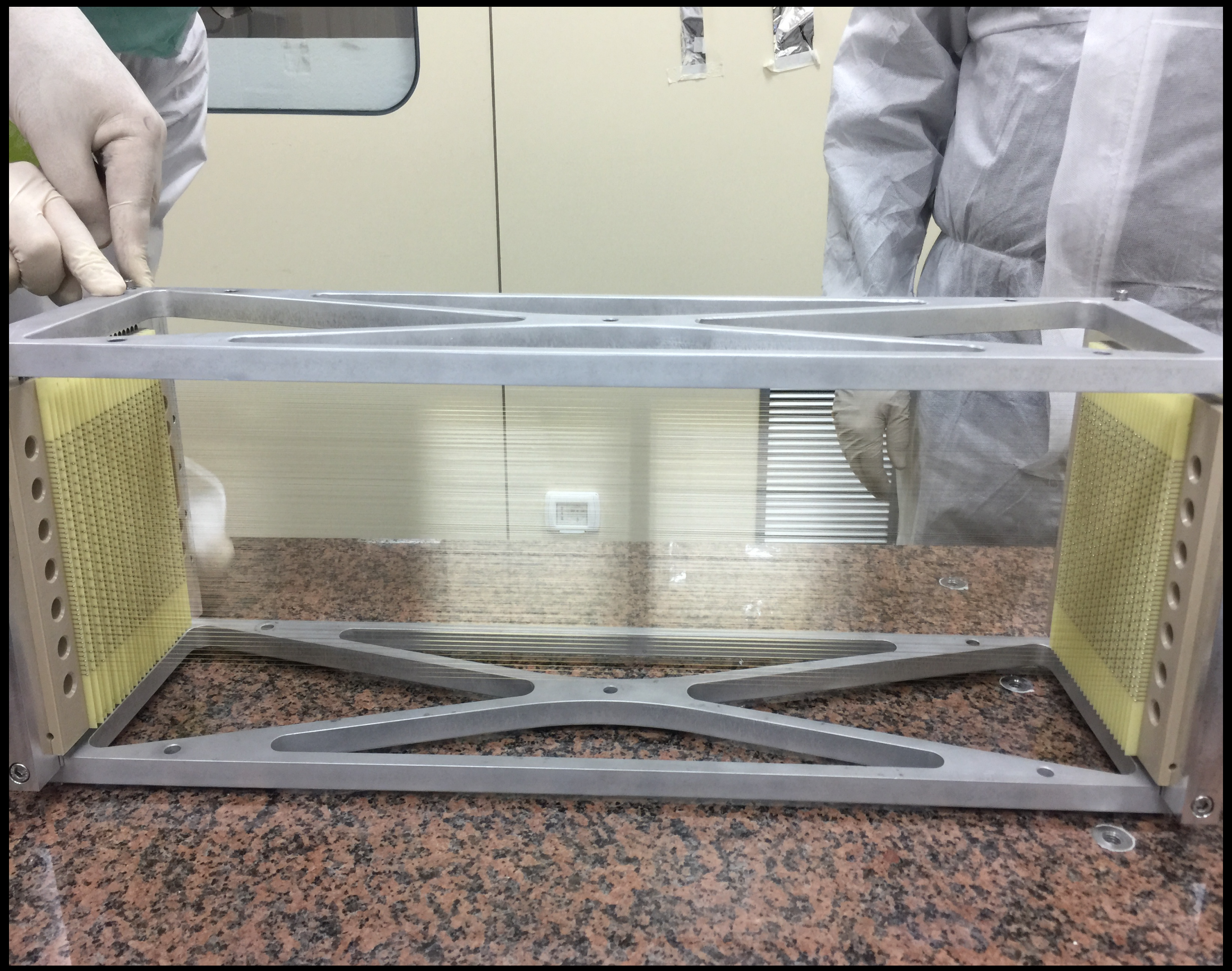
- Length: 4 m
- Radius: 0.3- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

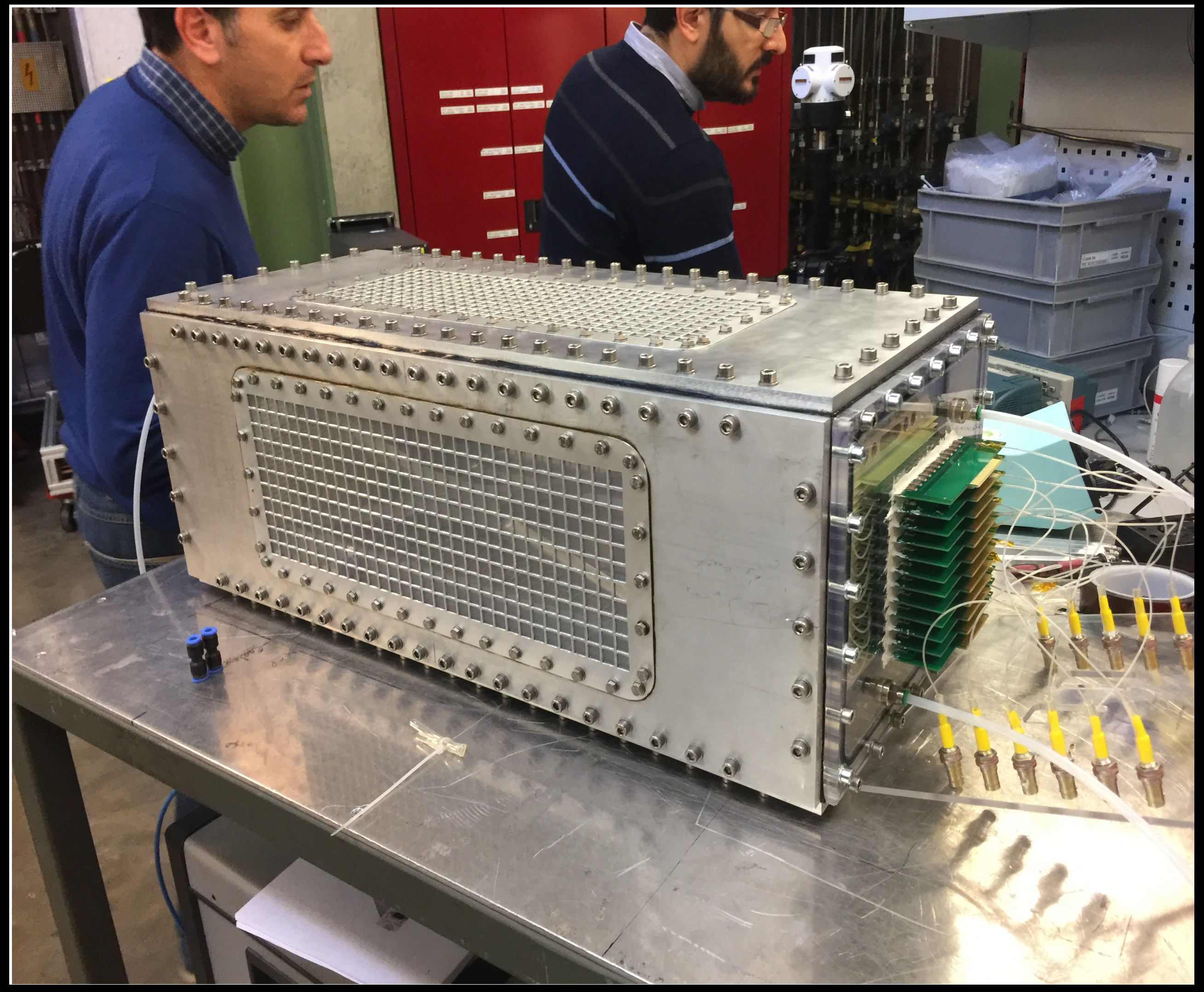
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

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

MEG2 prototype being tested





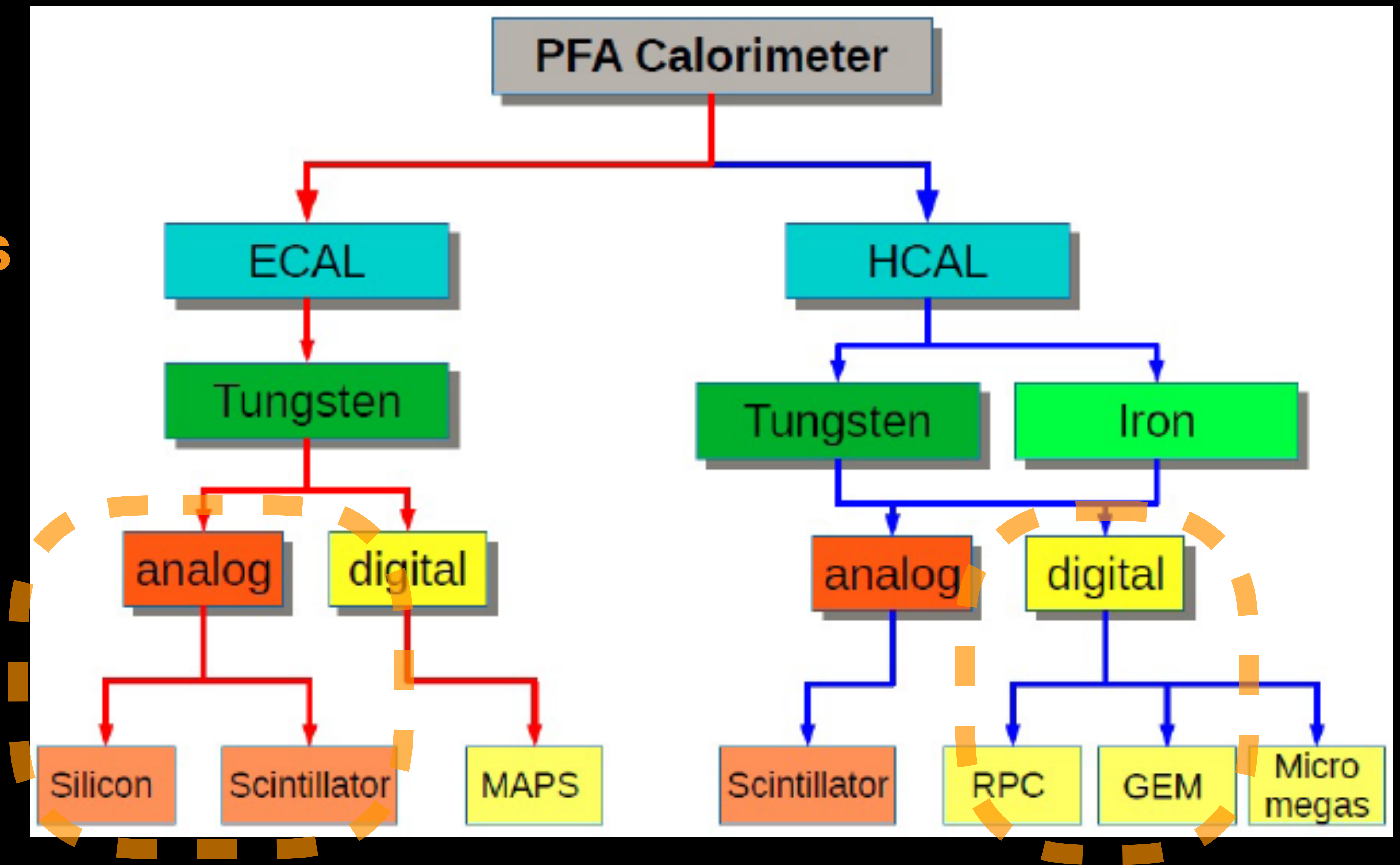


Stereo angle: 50-250 mrad

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding



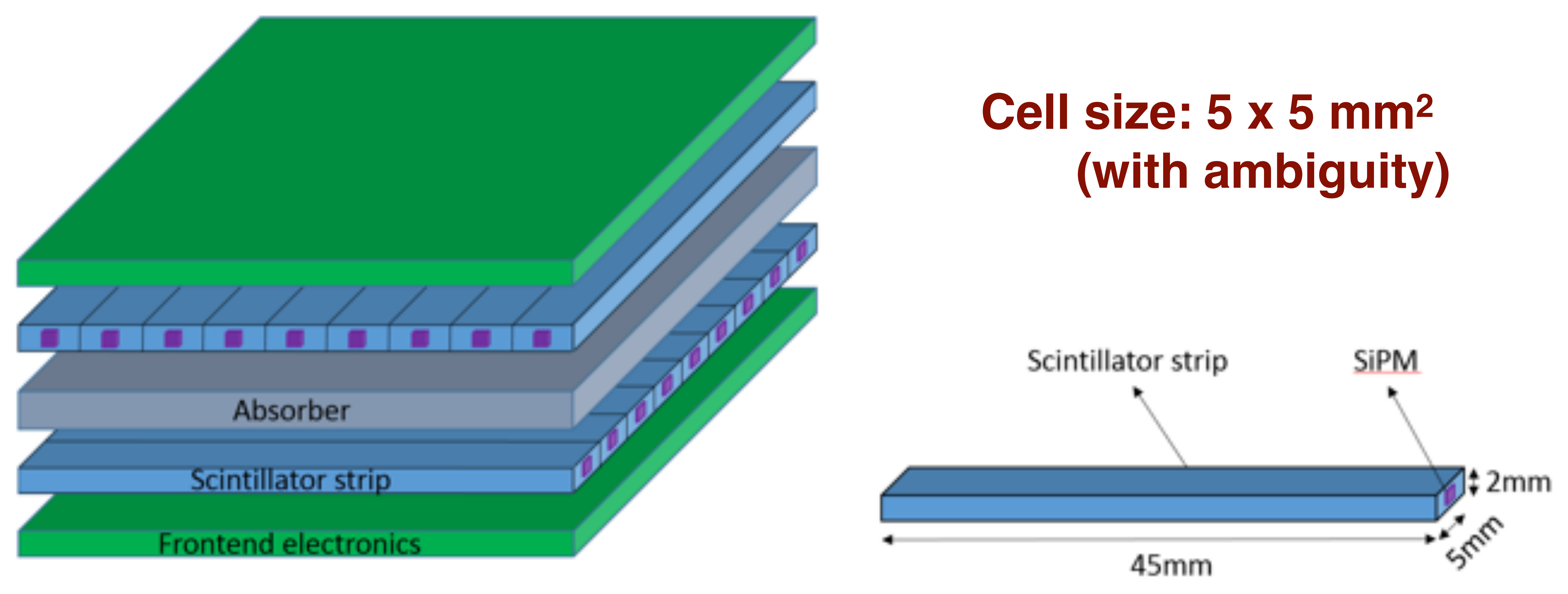
Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) (*) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	(*) SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) (*) HCAL with Scintillator+SiPM and Stainless Steel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

ECAL Calorimeter — Particle Flow Calorimeter

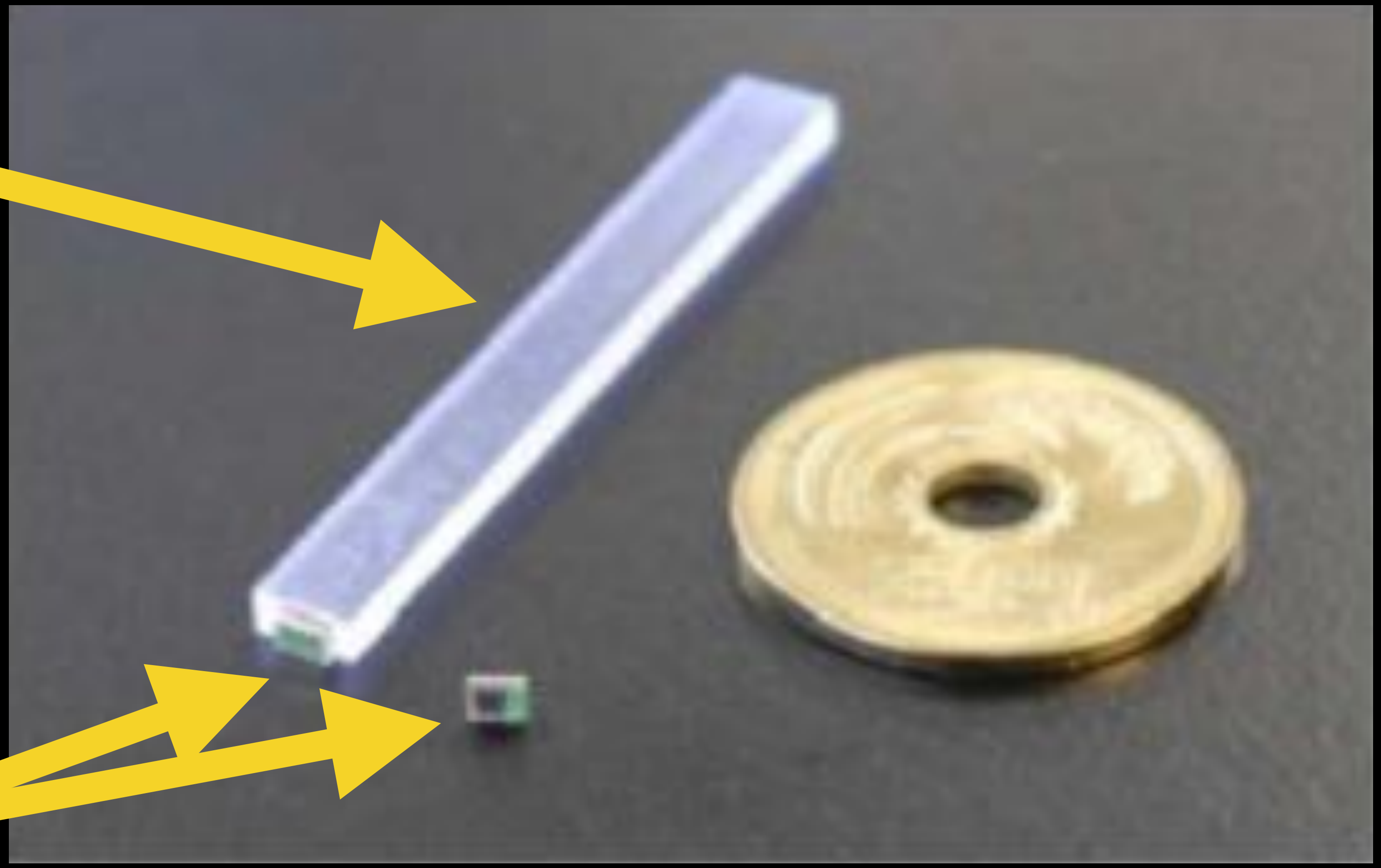
Scintillator-Tungsten Sandwich ECAL

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



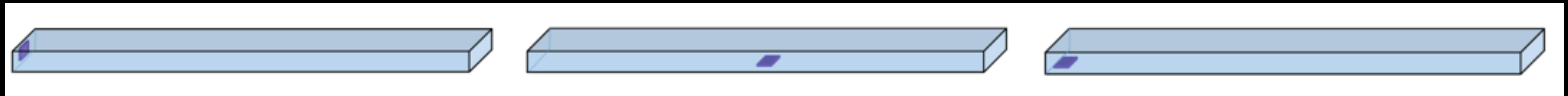
Plastic scintillator
5 x 45 mm^2 (2 mm thick)



SiPM

R&D on-going:

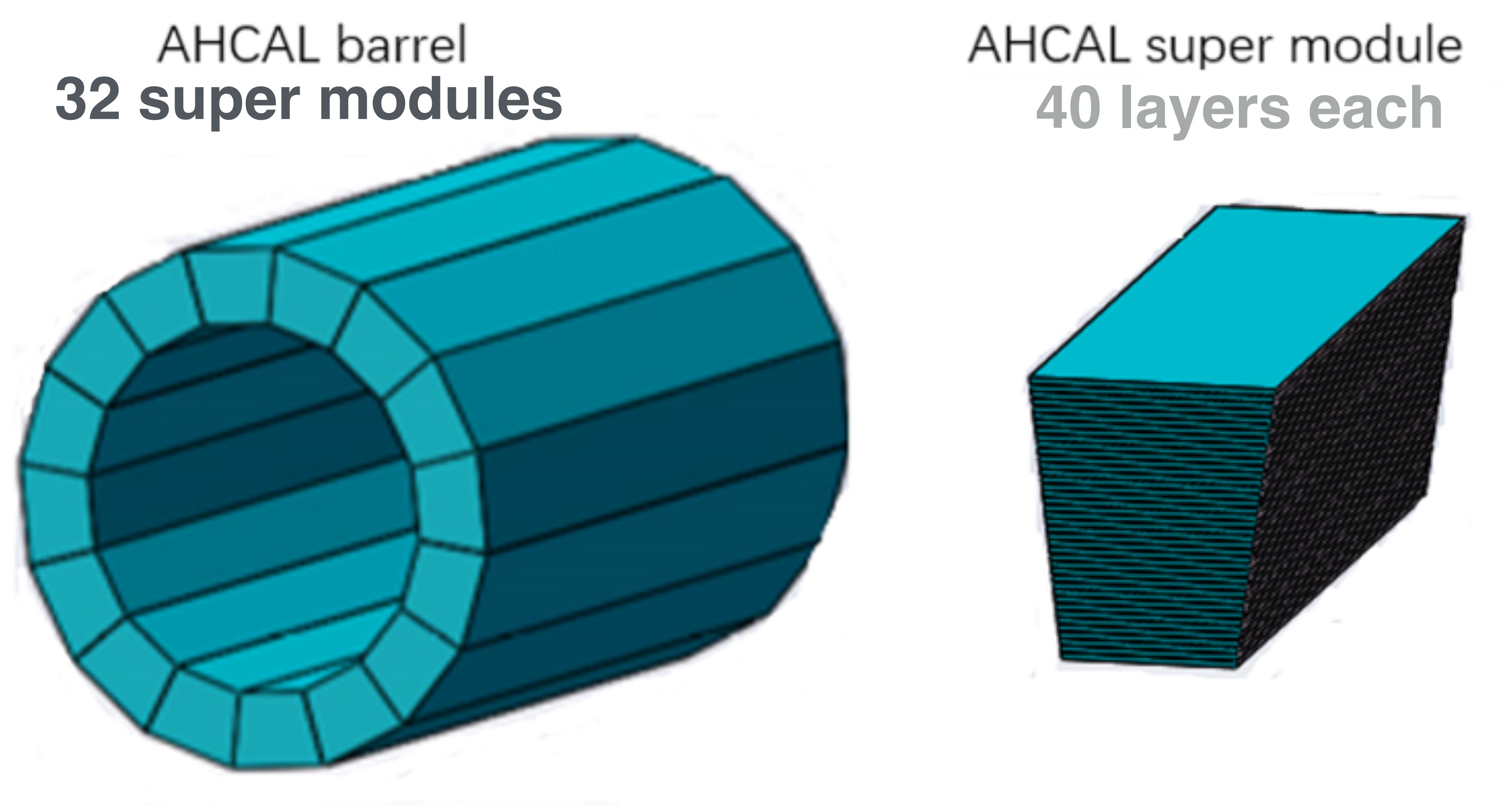
- SiPM dynamic range
- Scintillator strip non-uniformity
- Coupling of SiPM and scintillator

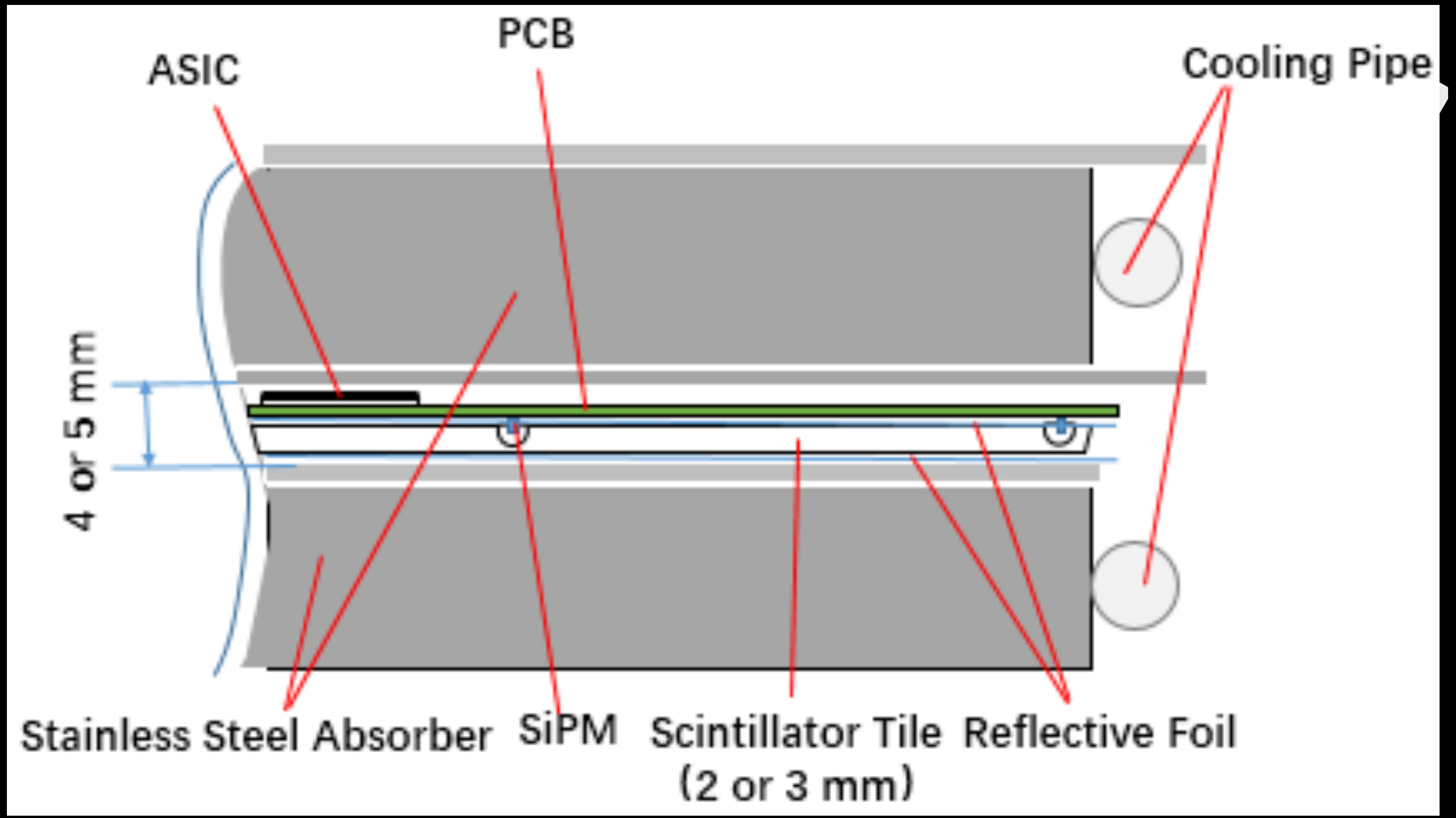


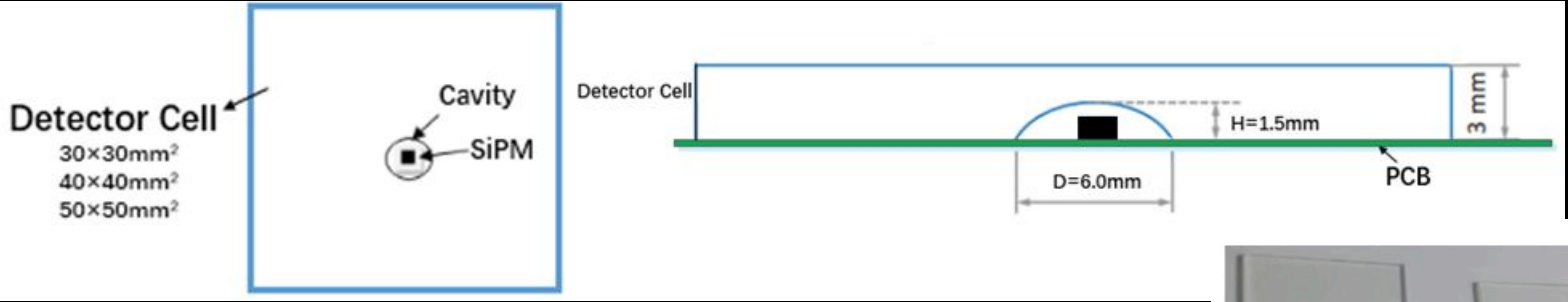
Mini-prototype tested on testbeam at the IHEP

HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)



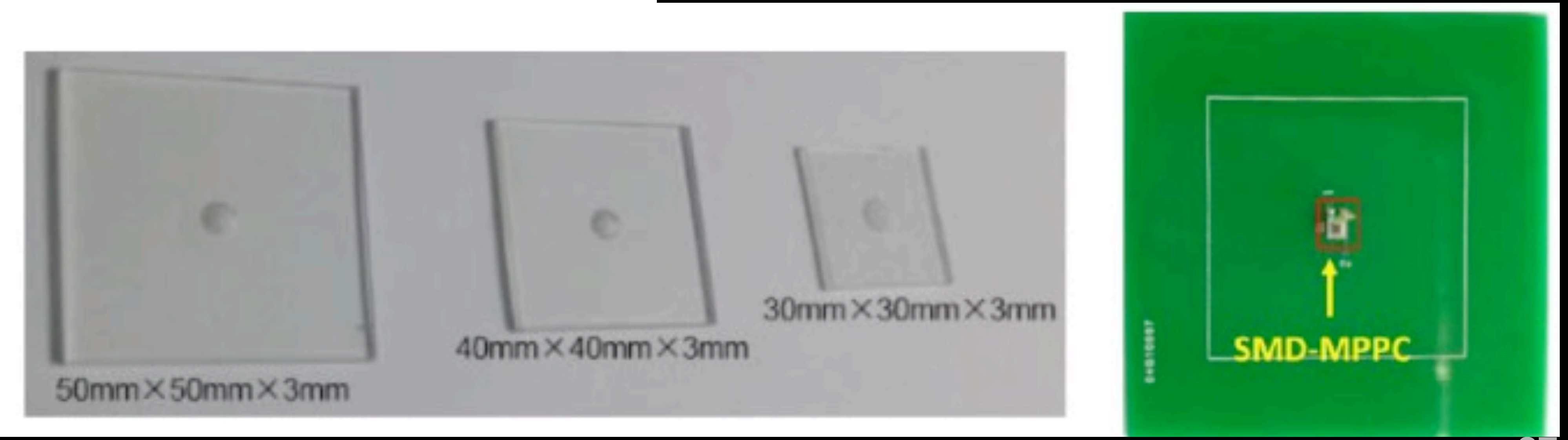




Readout channels:

~ 5 Million (30 x 30 mm²)

~ 2.8 Million (40 x 40 mm²)



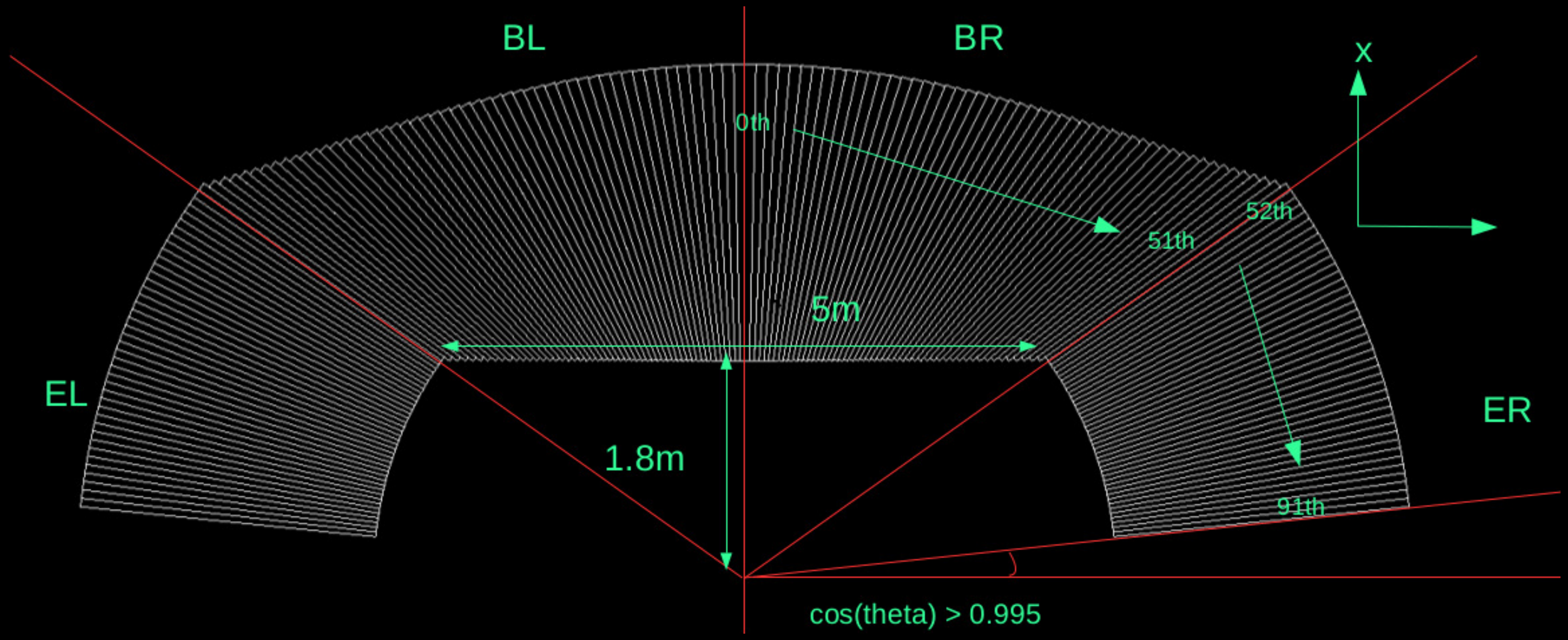
Prototype to be built: MOST (2018-2023)

0.5×0.5 m², 35 layer (4λ), 30×30 mm² 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)



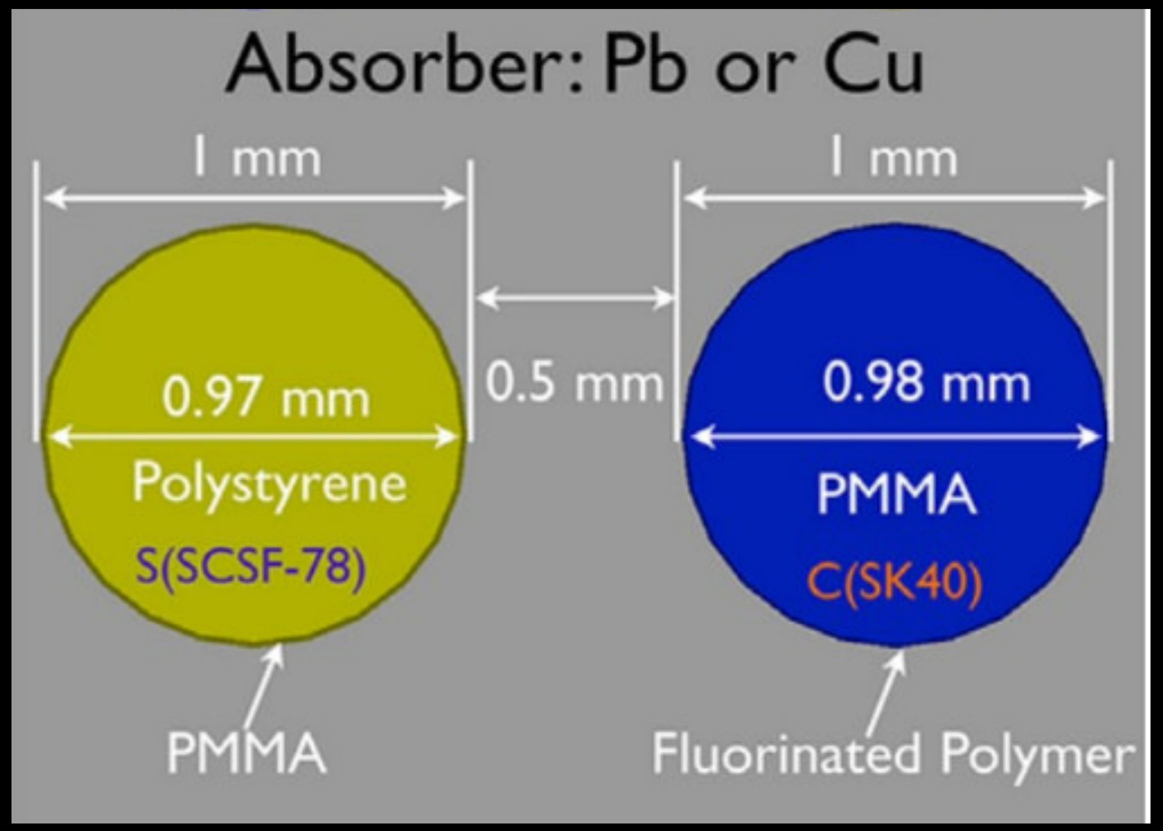
Covers full volume up to |cos(θ)| = 0.995

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)

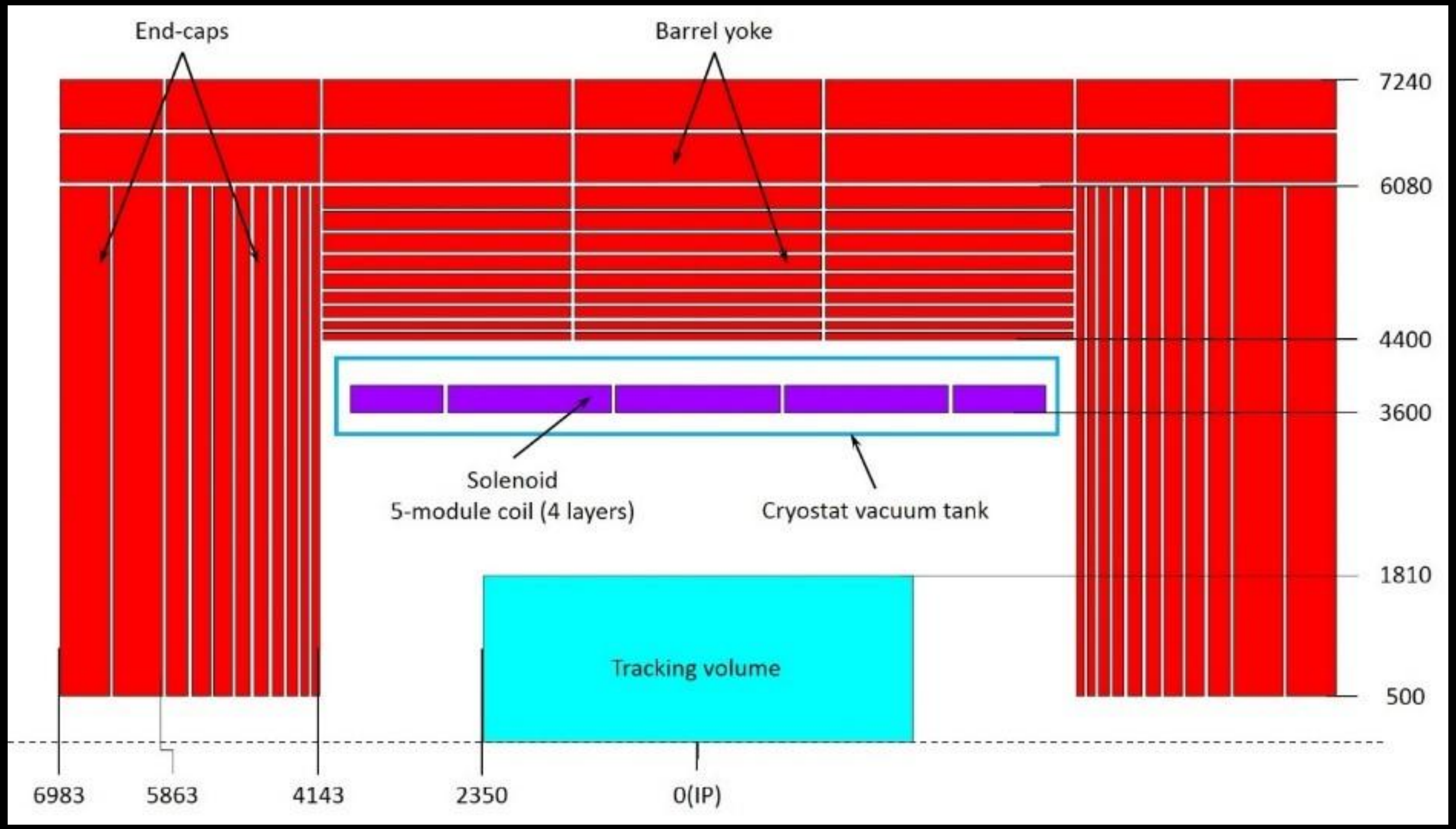


Studying different readout schemes PMT vs SiPM

Several prototypes from RD52 have been built

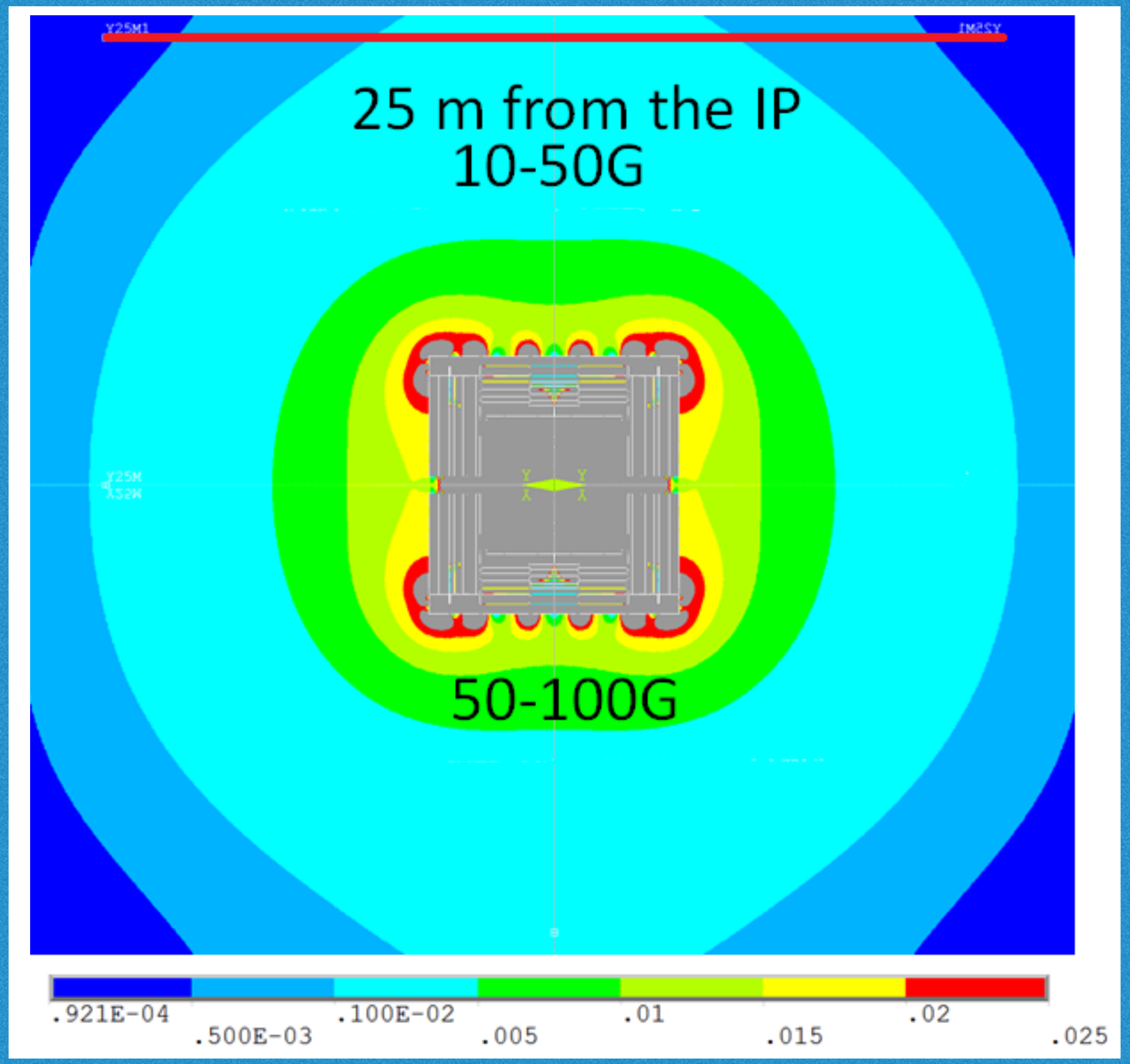
Superconductor solenoid development

3 Tesla Field Solenoid

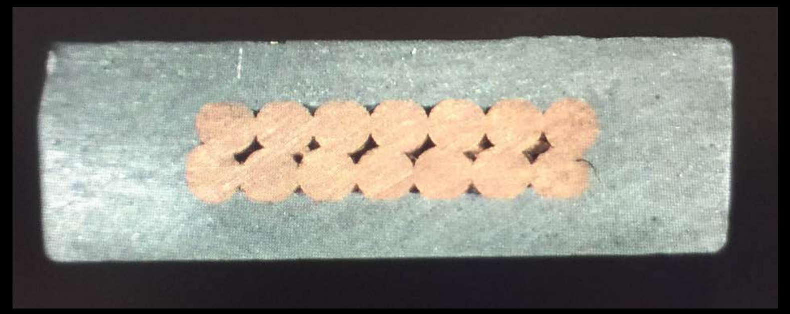


Operating current	15.8 A	Cable length	30.1 km

Stray field map of magnet



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



Design for 2 Tesla magnet presents no problems

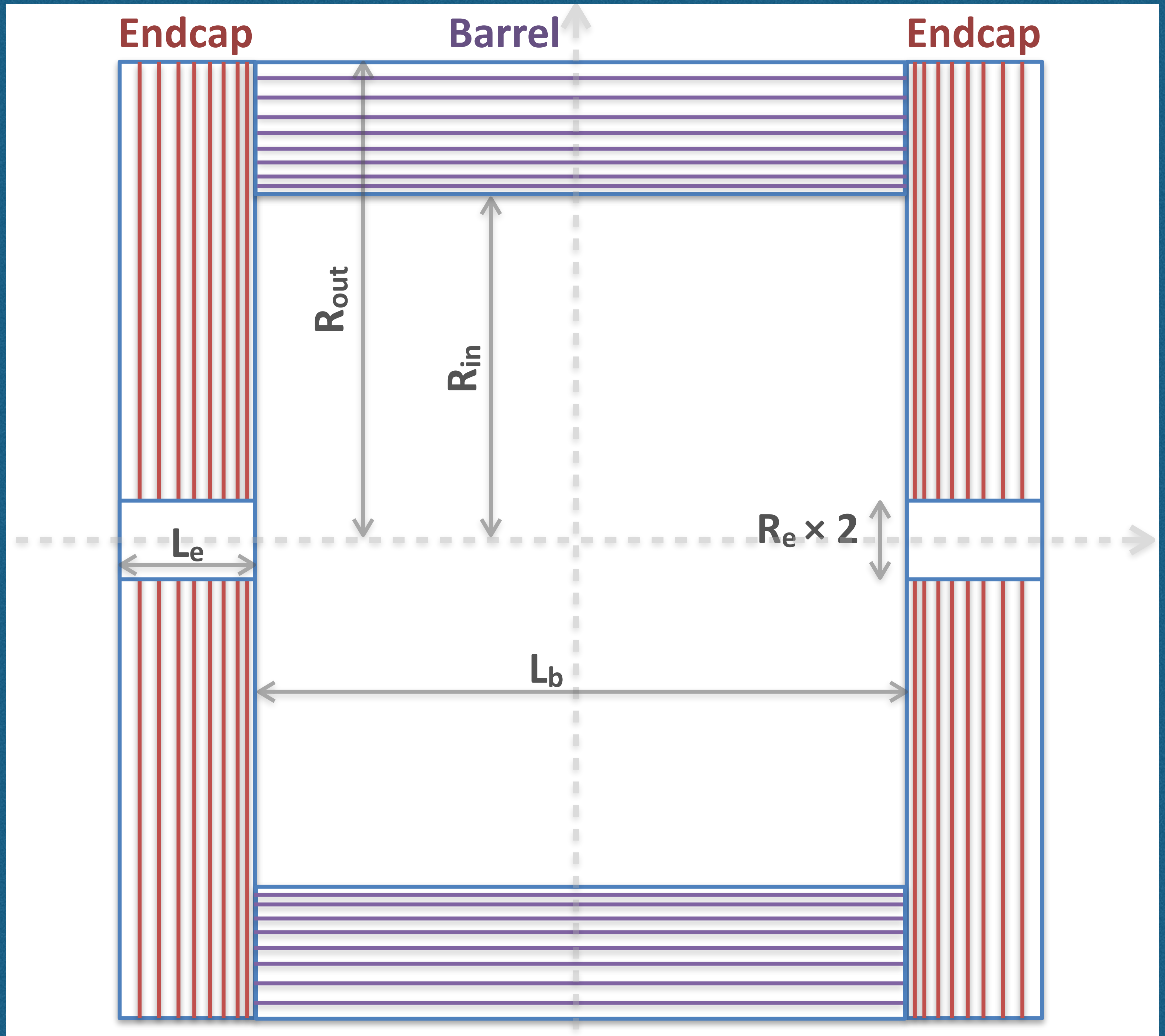
Thin HTS solenoid being designed for IDEA concept

Double-solenoid design also available

Muon Detector System

Baseline Muon detector

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

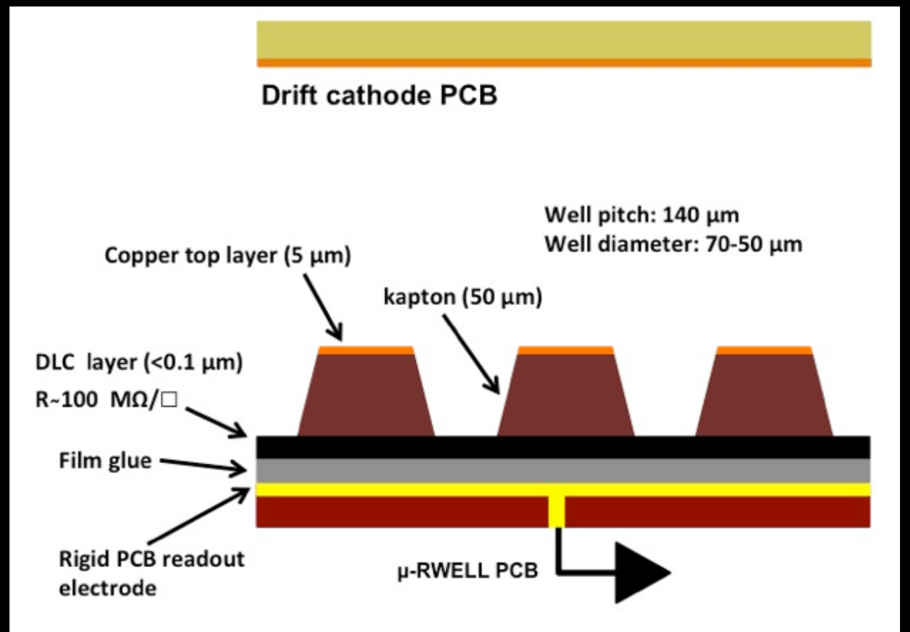


Baseline: Bakelite/glass RPC

Other technologies considered

Monitored Drift Tubes
Gas Electron Multiplier (GEM)
MicroMegas

New technology proposal (INFN): μRwell



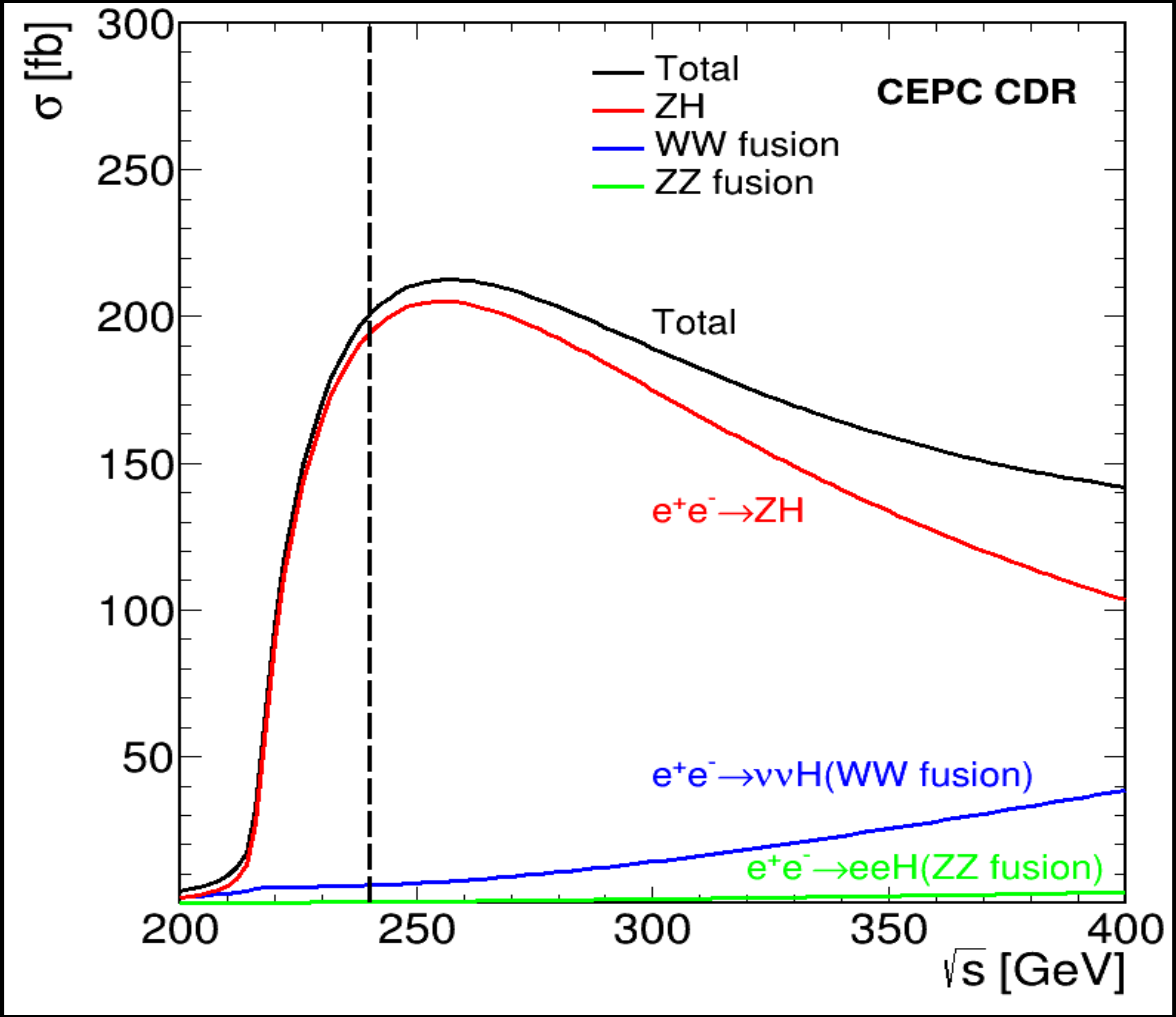
Better resolution (200-300 μm) at little extra cost (?)

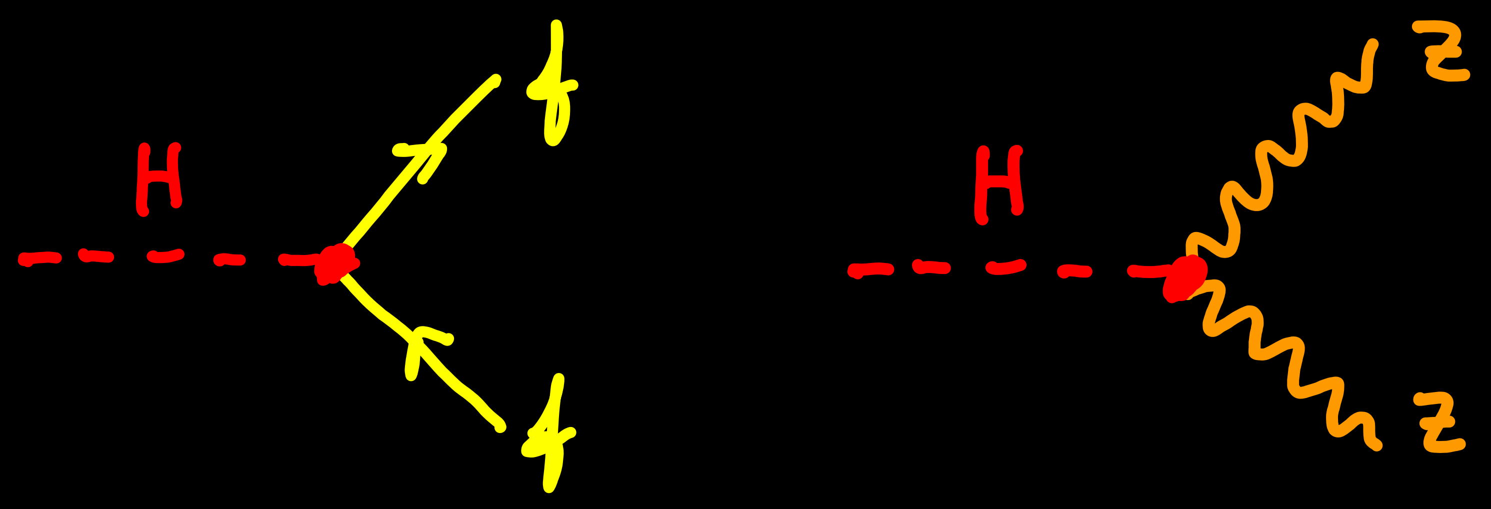
Muon system: open studies

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

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

Chapter 11: Physics Performance with Benchmark Processes





Events at 5 ab^{-1}

ZH: 10^6 events

ννH: 10^4 events

e^+e^-H: 10^3 events

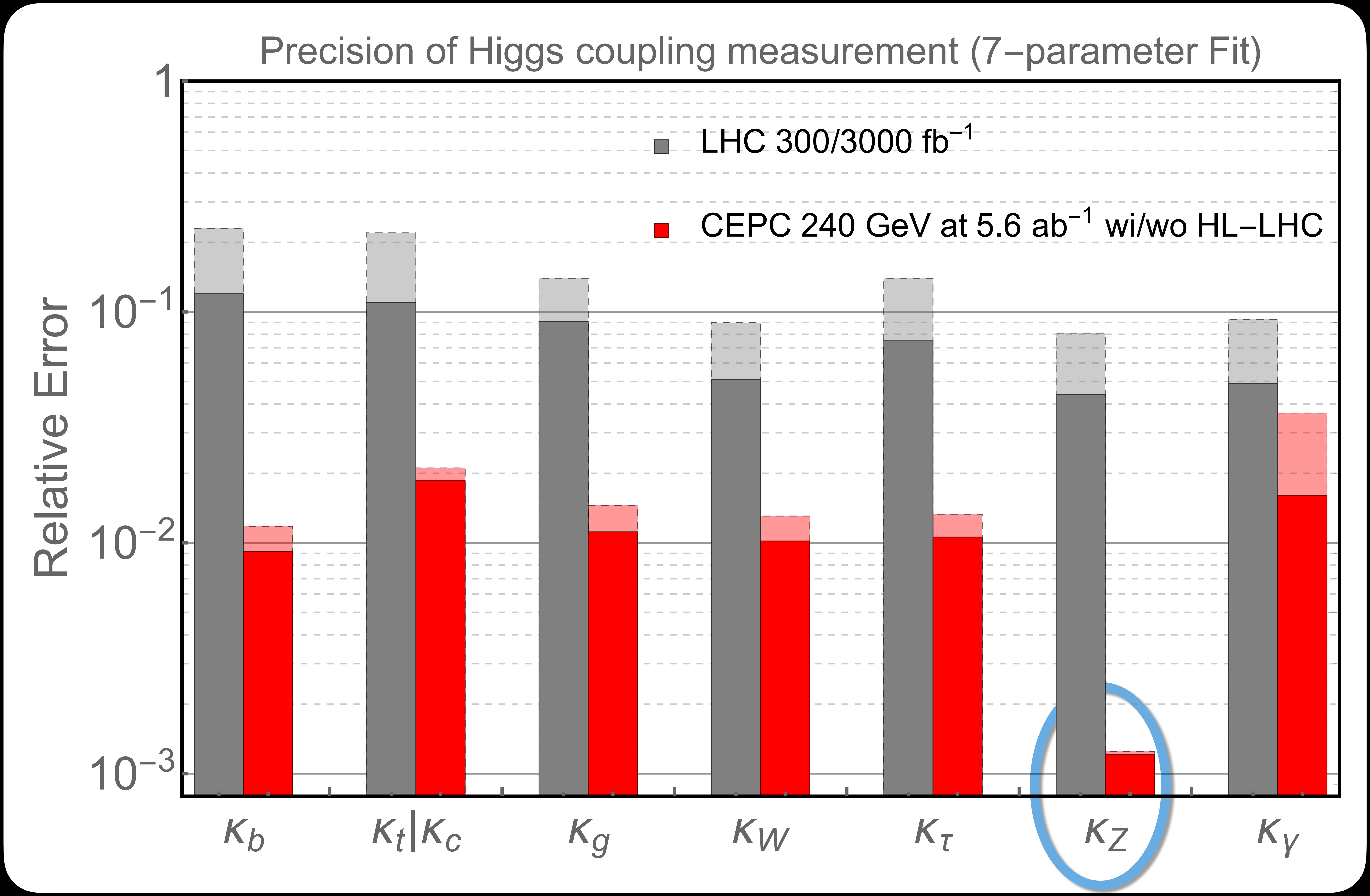
S/B
1:100-1000

Observables:
Higgs mass, CP, σ(ZH),
event rates (σ(ZH, ννH)*Br(H→X)),
Differential distributions

Extract:
Absolute Higgs width,
couplings

Higgs Couplings Measurement

Precision of Higgs couplings measurement compared to HL-LHC



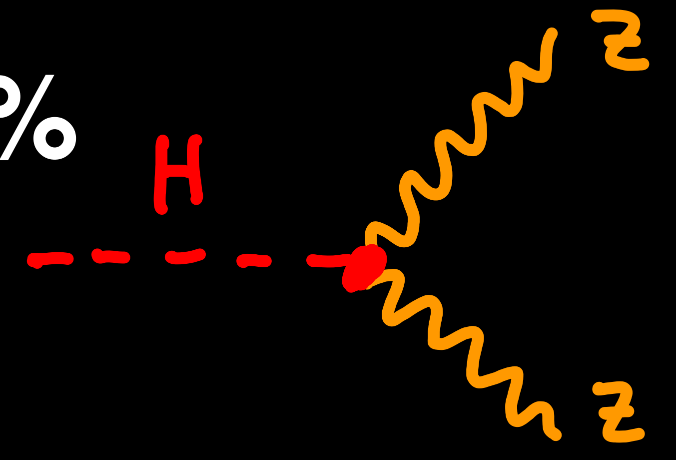
$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})}, \quad \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

HL-LHC

CEPC

~1% uncertainty

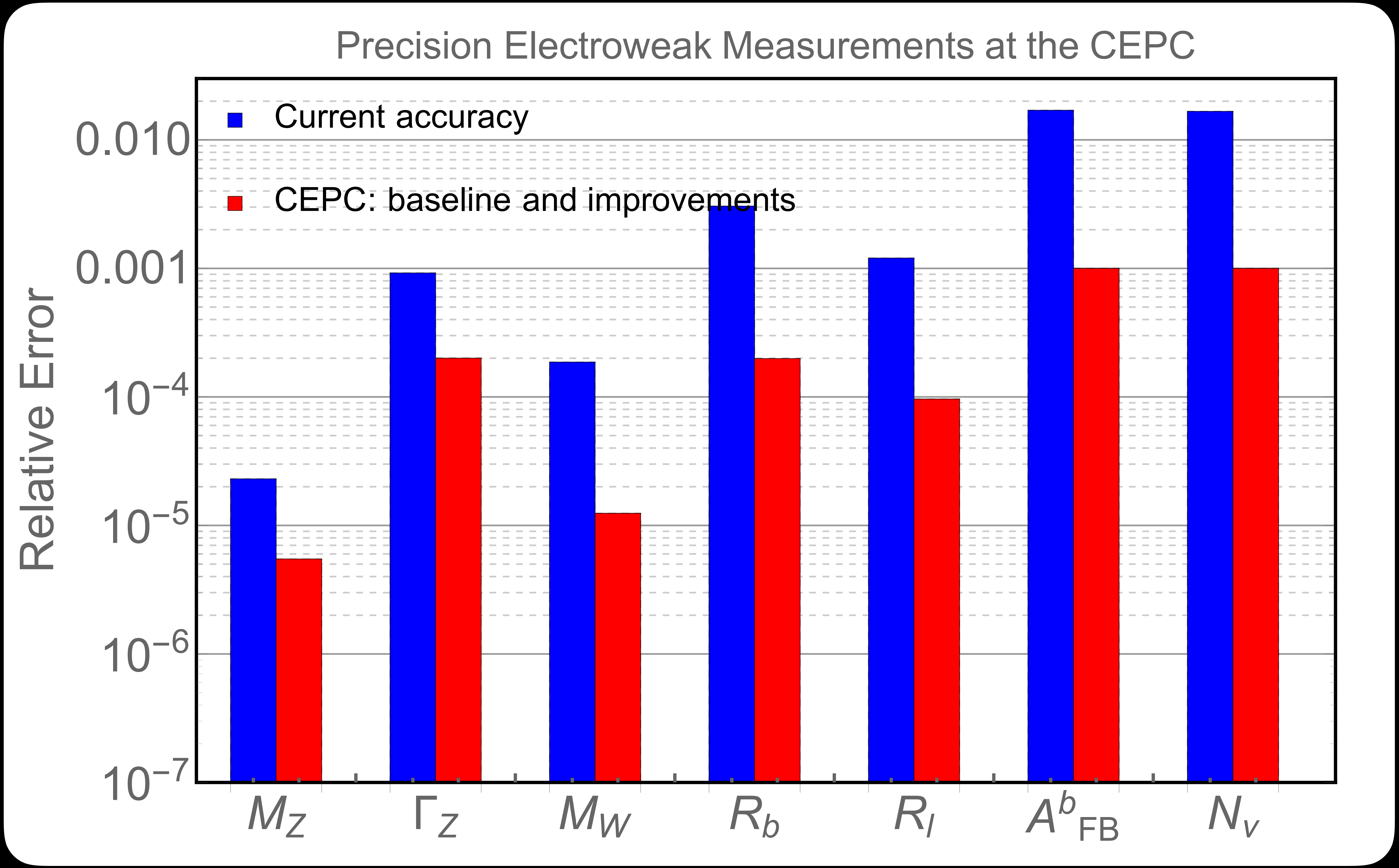
***K_Z* ~ 0.2 %**



ATL-PHYS-PUB-2014-016

Electroweak observables at CEPC

In addition: 2-year run at Z-pole and 1-year run at WW threshold



CEPC “optimistic” Schedule

- Design issues
- R&D items
- preCDR

- Design, funding
- R&D program
- Intl. collaboration
- Site study

- Seek approval, site decision
- Construction during 14th 5-year plan
- Commissioning

- **CEPC data-taking starts before the LHC program ends**
- **Possibly concurrent with the ILC program**

International Review of CEPC CDR – Vol.2

Beijing, September 13-15

International Review Committee (11 members):

- **Claudia Cecchi**, INFN Perugia, Italy
- **Mogens Dam**, Niels Bohr Institute, Copenhagen, Denmark
- **Sasha Glazov**, DESY, Hamburg, Germany
- **Christophe Grojean**, DESY Hamburg and Humboldt U. Berlin, Germany
- **Liang Han**, University of Science and Technology, China
- **Tao Han**, University of Pittsburgh, USA
- **Bill Murray**, Warwick University and RAL, UK
- **Maxim Perelstein**, Cornell University, USA
- **Marcel Stanitzki**, DESY, Hamburg, Germany
- **Marcel Vos (chair), IFIC UV/CSIC, Valencia, Spain**
- **Hitoshi Yamamoto**, Tohoku University, Sendai, Japan

Several other members of the HEP community provided comments and input for which we are thankful

International Review of CEPC CDR – Vol.2

Beijing, September 13-15

The review committee congratulates the CEPC study team with the successful completion of the conceptual design report (CDR). The document provides a complete, and very readable, description of the project. The scientific goals presented in the report are well motivated and aligned with the priorities of the international high-energy physics community. The report also presents a conceptual design for the CEPC experiments, with plausible solutions to address the main challenges. We believe that the studies reported in the CDR fully achieved the goals appropriate at this stage of the project, and we strongly encourage the CEPC team to proceed with the preparation of the technical design report.

。。。。。

Several challenges are identified, where more work is needed towards a technical design report.

。。。。。。。

59 recommendations for TDR follow

Final remarks

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

- CEPC Detector CDR completion is a major milestone for the CEPC project
  - Two significantly different detector concepts are included
    - 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

From 2018-2022, R&D towards CEPC TDR

- Key technologies are under R&D and put to prototyping:
  - Vertex detector, TPC, calorimeters, magnets
  - International colleagues getting more heavily involved (about 300 foreign CDR authors)
    - e.g. Drift chamber, dual readout calorimeter, vertex detector and muon chamber
      - INFN, SLAC, Iowa State Univ., Belgrade, LLR, IPNL, Liverpool, Oxford, Barcelona, etc…
- CEPC funding in China adequate for required R&D program
- Seeking international nominations for new Detector Subgroup structure
  - Move into 2 international collaborations as soon as possible

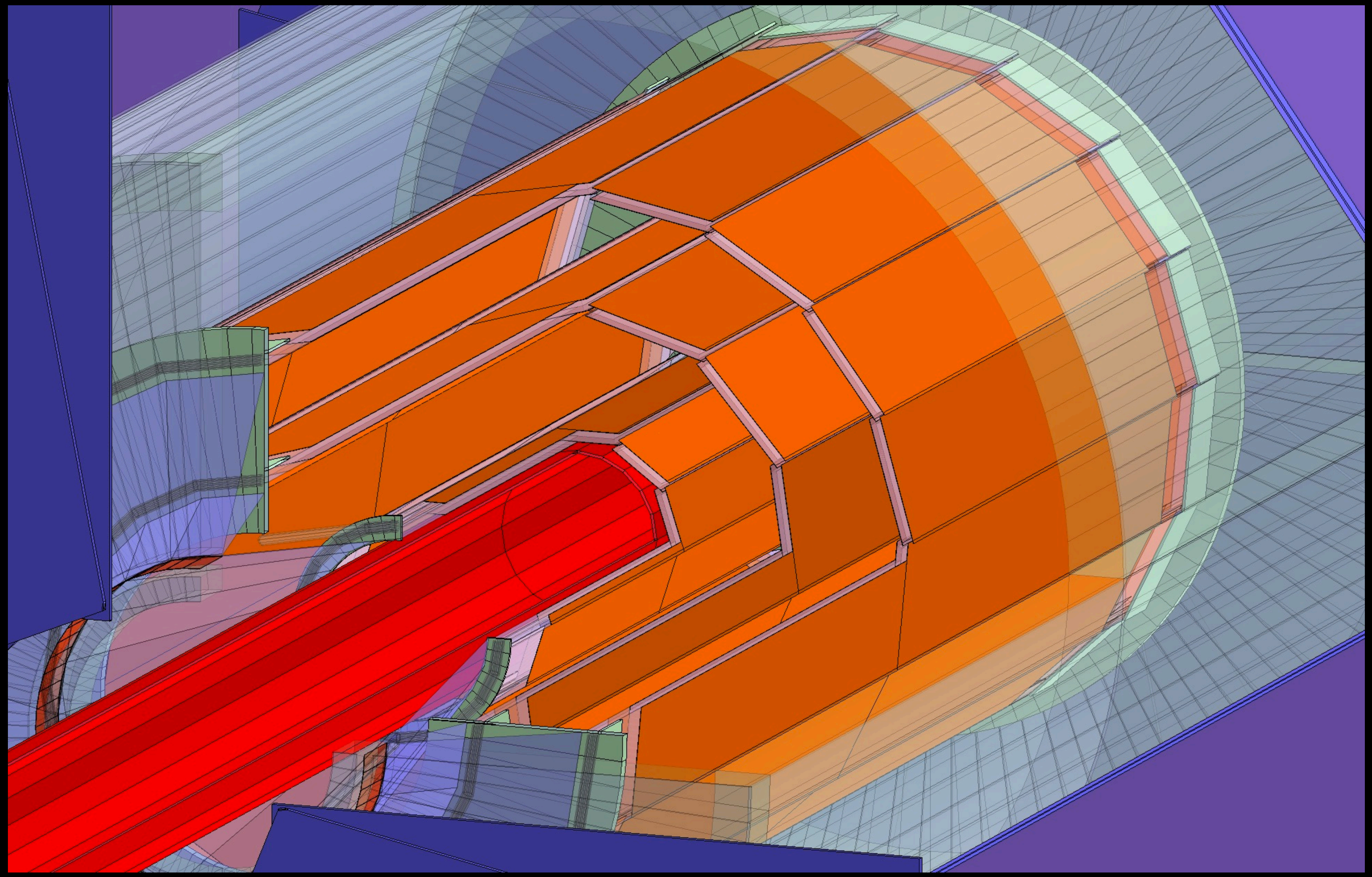
Concepts parameter comparison

Concept	ILD	CEPC baseline	IDEA
Tracker	TPC/Silicon	TPC/Silicon or FST	Drift Chamber/Silicon
Solenoid B-Field (T)	3.5	3	2
Solenoid Inner Radius (m)	3.4	3.2	2.1
Solenoid Length (m)	8.0	7.8	6.0
L* (m)	3.5	2.2	2.2
VTX Inner Radius (mm)	16	16	16
Tracker Outer Radius (m)	1.81	1.81	2.05
Calorimeter	PFA	PFA	Dual readout
Calorimeter λ_I	6.6	5.6	7.5
ECAL Cell Size (mm)	5	10	-
ECAL Time resolution (ps)	-	200	-
ECAL X_0	24	24	-
HCAL Layer Number	48	40	-
HCAL Absorber	Fe	Fe	-
HCAL λ_I	5.9	4.9	-
DRCAL Cell Size (mm)	-	-	6.0
DRCAL Time resolution (ps)	-	-	100
DRCAL Absorber	-	-	Pb or Cu or Fe
Overall Height (m)	14.0	14.5	11.0
Overall Length (m)	13.2	14.0	13.0

Challenges in vertex detectors

Vertex detector design
driven by needs of flavor tagging

- Extremely accurate/precise
- Extremely light



Large surfaces: ~ 1 m^2

Single point resolution
$\sigma < 3 - 5$ μm
→ Pixel pitch
~ 16 – 25 μm

Low material budget
$< 0.1 — 0.3\% X_0$ per layer
→ Thin sensors and ASICs
Light-weight support
→ Power pulsing (LC)
Air cooling
↓
Low power dissipation
≤ 50 mW/cm^2

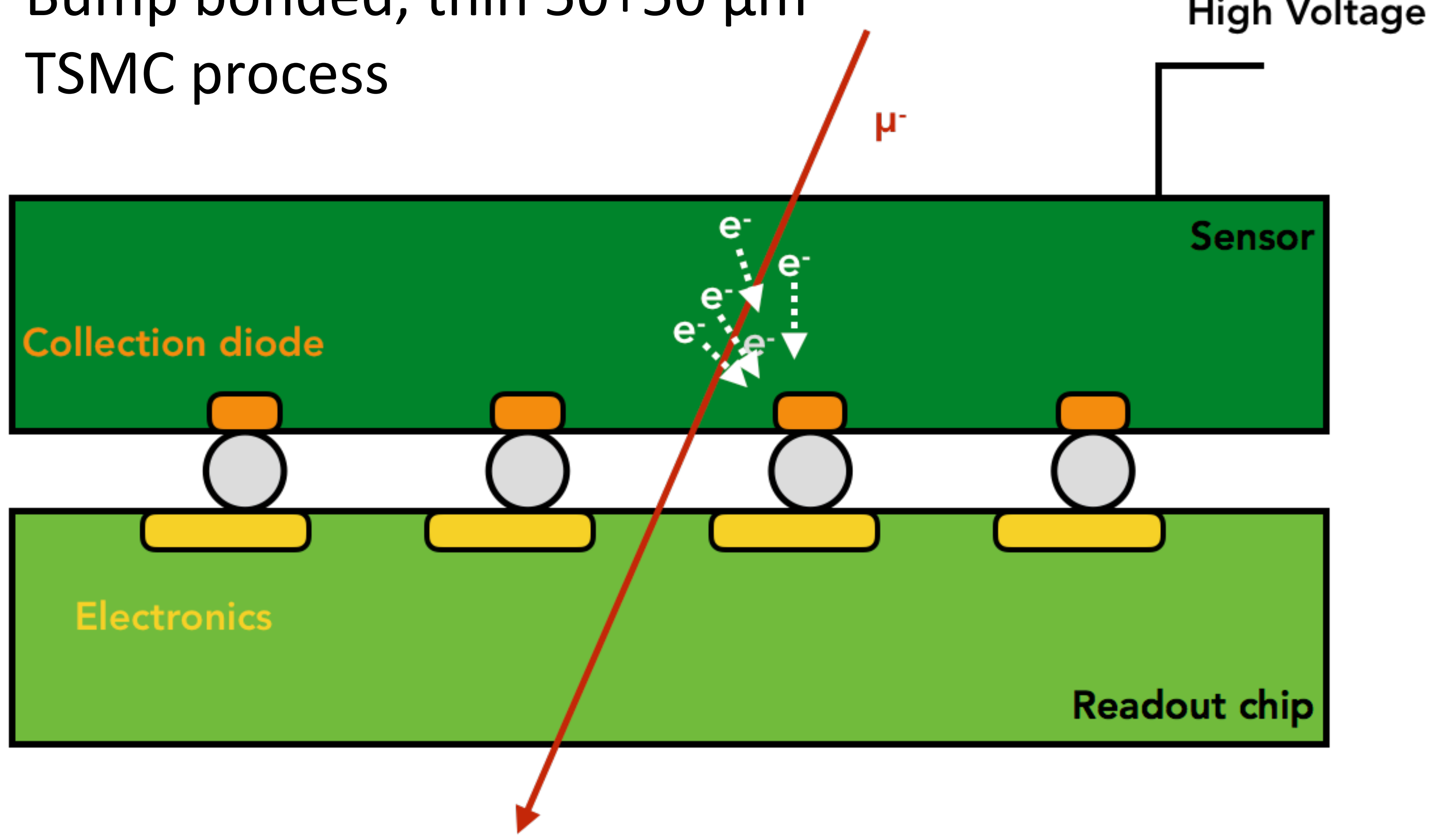
Time stamping
~10 ns (CLIC)
~300 ns — μs (ILC/CC)

Circular colliders: continuous operation → more cooling → more material

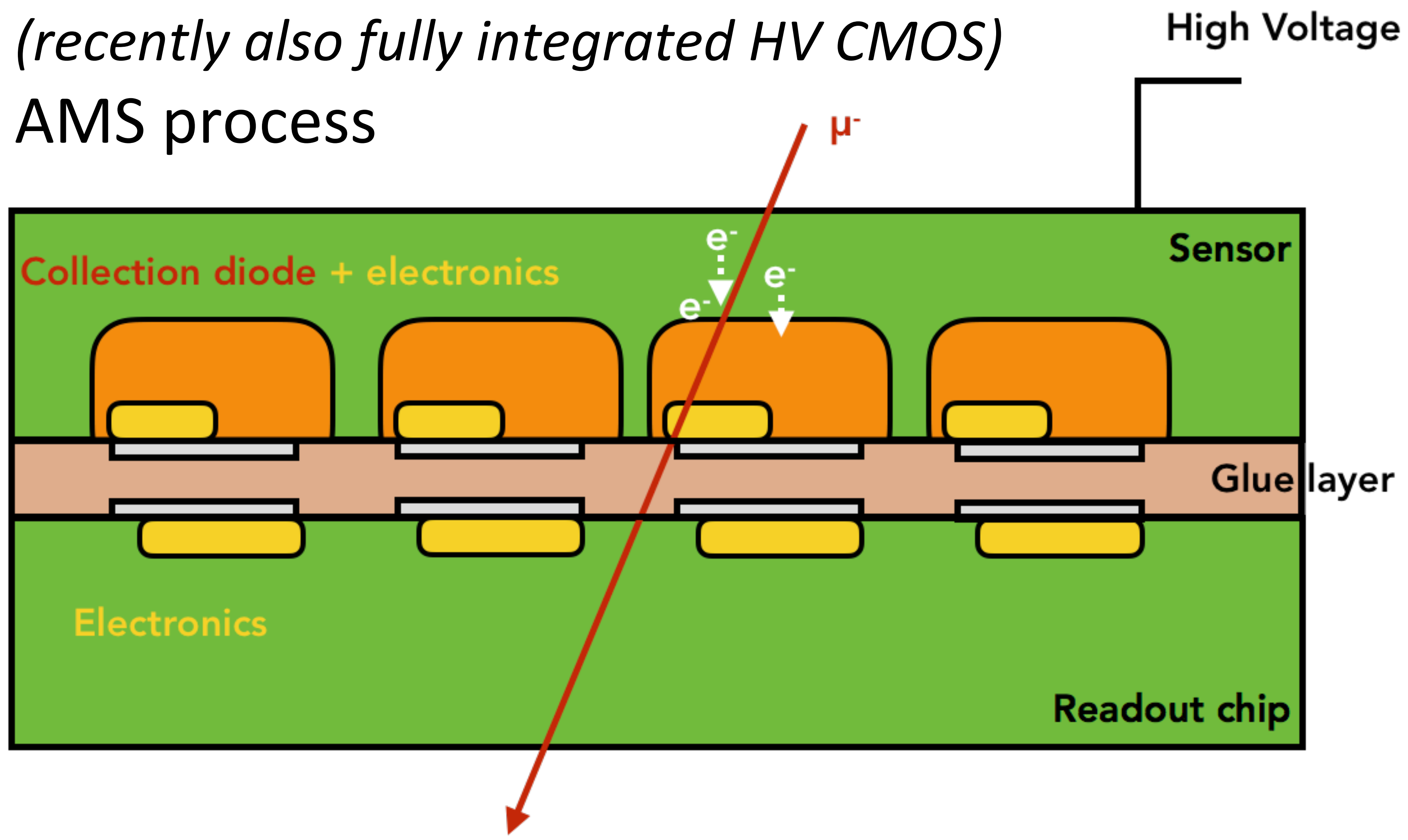
Silicon pixel-detector technologies

CLICpix
HV-CMOS
hybrid

Hybrid: Si sensor + ASIC (65 nm)
Bump bonded, thin 50+50 μm
TSMC process

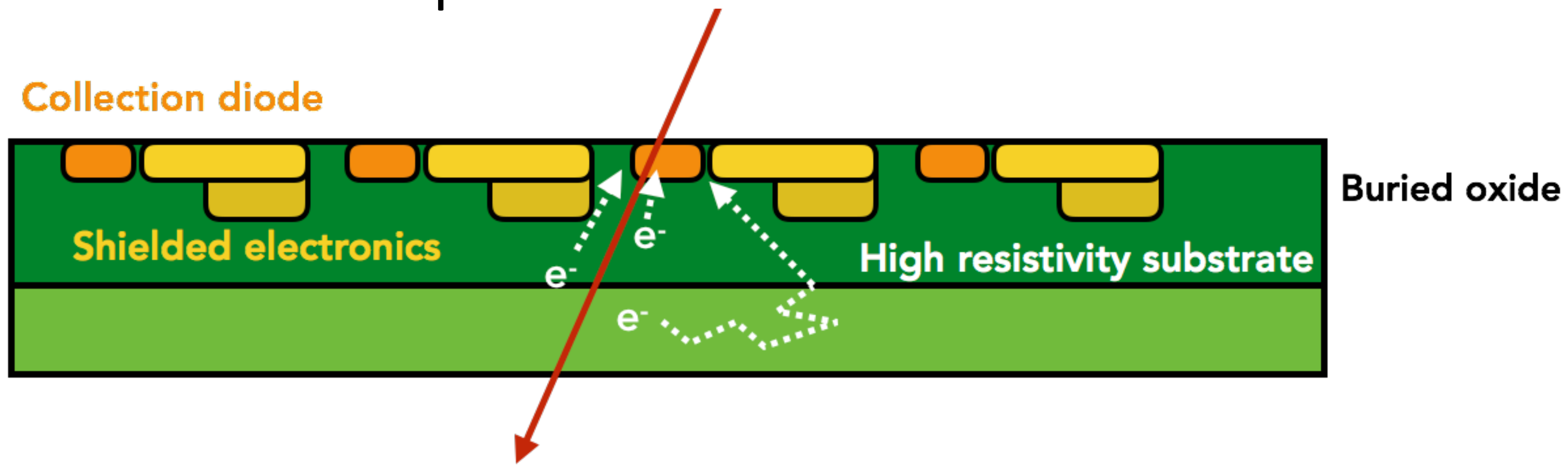


Hybrid: HV CMOS active sensor + ASIC (65 nm)
Capacitive coupling (glue)
(recently also fully integrated HV CMOS)
AMS process

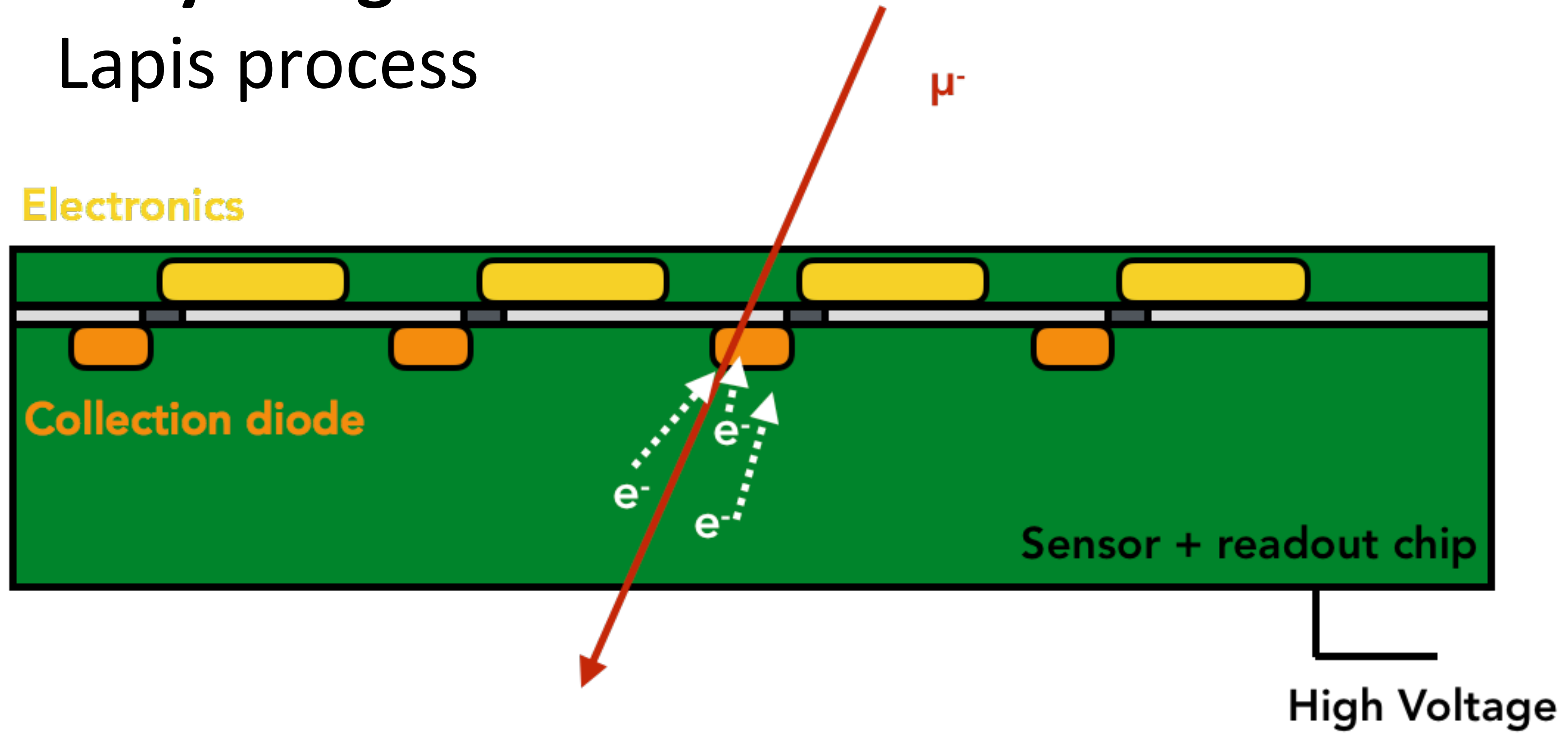


MAPS
HV-CMOS
HR-CMOS
Mimosa CPS

Fully integrated: HR CMOS
TowerJazz process



Fully integrated: SOI
Lapis process



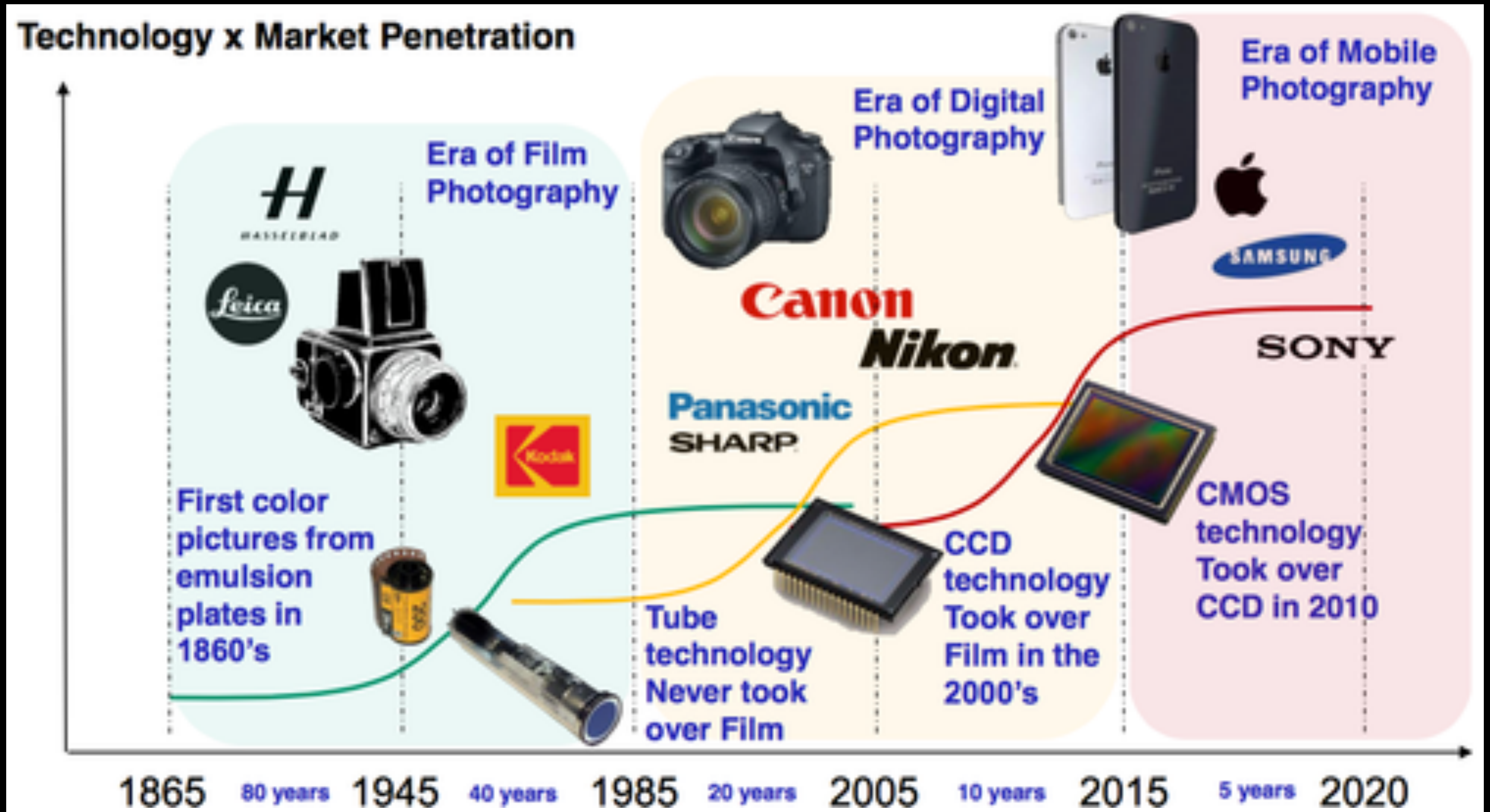
SOI
Silicon
-On
-Insulator

Systematics R&D studies have focused on Pixel implementation, with Pixel sizes around 25×25 μm^2
Studies equally valid for the main tracker, even though it will have larger cell sizes

Monolithic Active Pixel Sensor (MAPS)

Fully Integrated CMOS Technology

- CMOS Image Pixel Sensors —> benefit from industrialization
  - Commercial process (8” or 12” wafers)
  - Multiple vendors
  - Potentially cheaper interconnection processes available
  - Thin sensor (50-100 um) have less material



Early Generations

- Charge collection mainly by diffusion
- Timing limited by rolling-shutter readout (μs)

Recent advances

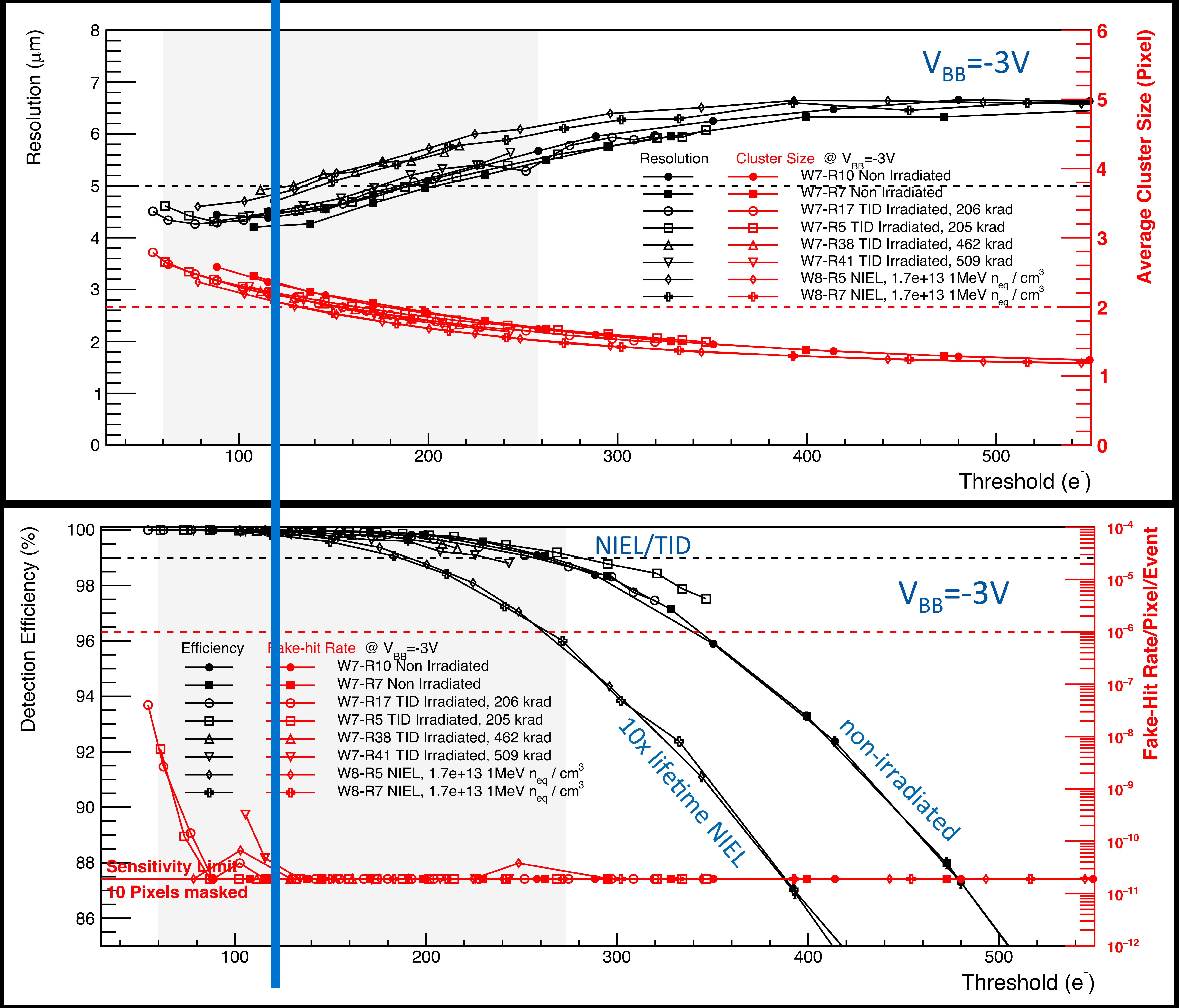
- Moving towards smaller feature size (TowerJazz 180 nm)
- Promising timing performance

Successfully deployed in HEP, with increasingly demanding requirements:

- Test-beam telescopes
- STAR @ RHIC
- CBM MVD @ FAIR
- ALICE ITS upgrade
- Baseline technology for ILD VTX, under study for CEPC and CLIC

ALPIDE CMOS Pixel Sensor

	ALPIDE
Pixel dimensions	26.9 μm × 29.2 μm
Spatial resolution	~ 5 μm
Time resolution	5-10 μs
Hit rate	~ 10^4/mm^2/s
Power consumption	< ~20-35 mW/cm^2
Radiation tolerance	300kRad 2×10^{12} 1 MeV n_{eq}/cm^2



Almost OK specifications

Need lower resolution

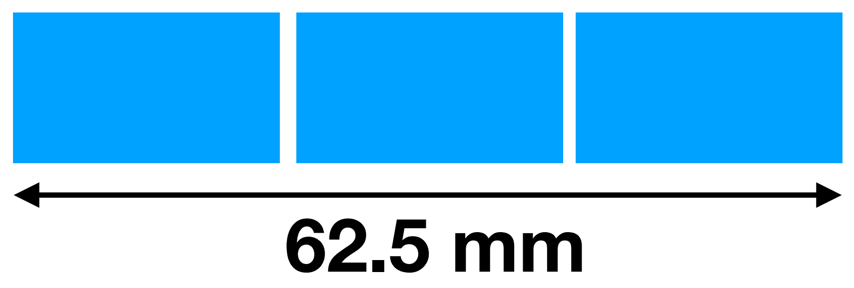
Higher radiation tolerance

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

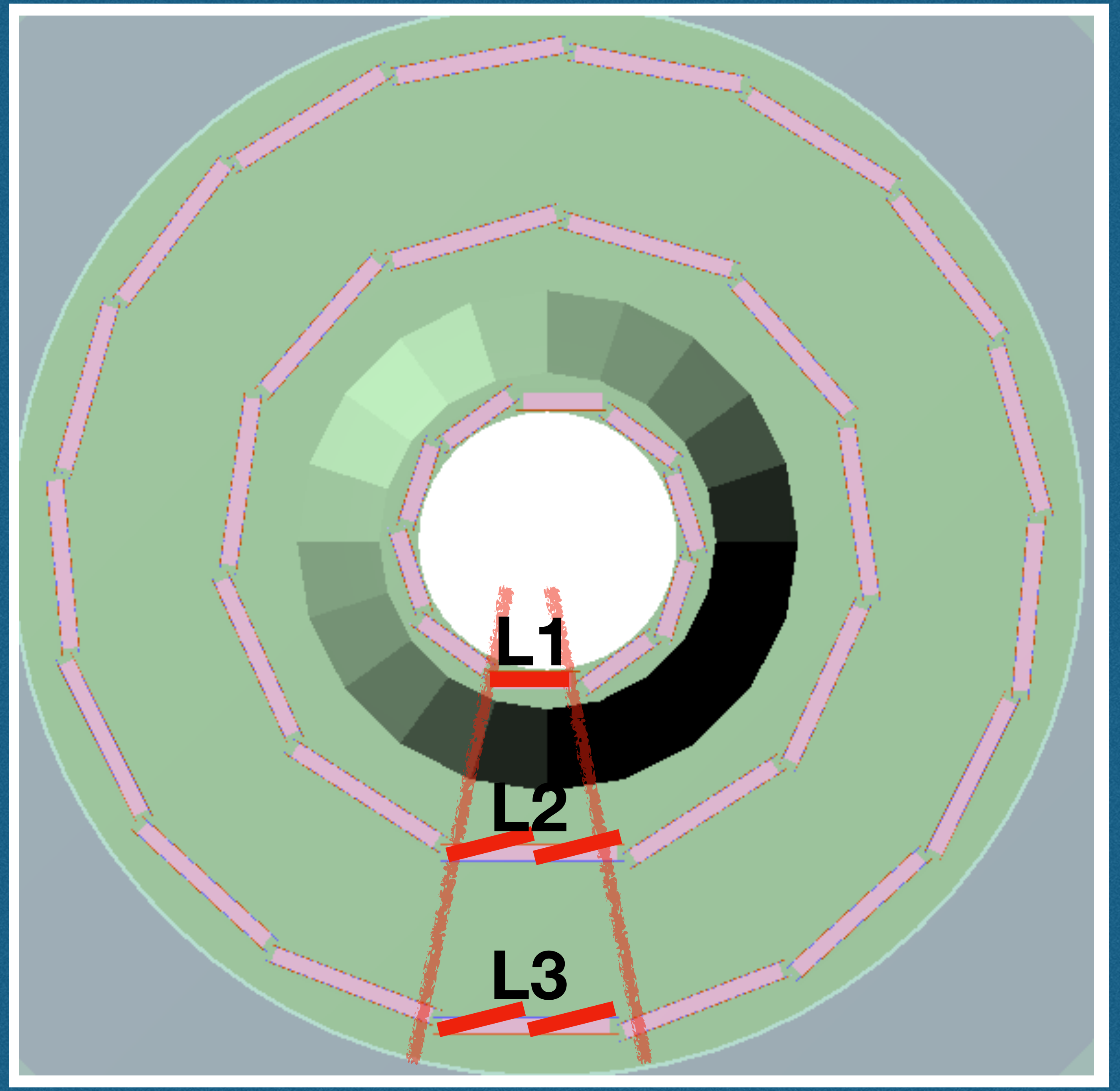
Layers 2 and 3 (22 mm x 125 mm)
Chip size: 11 mm X 20.8 mm

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

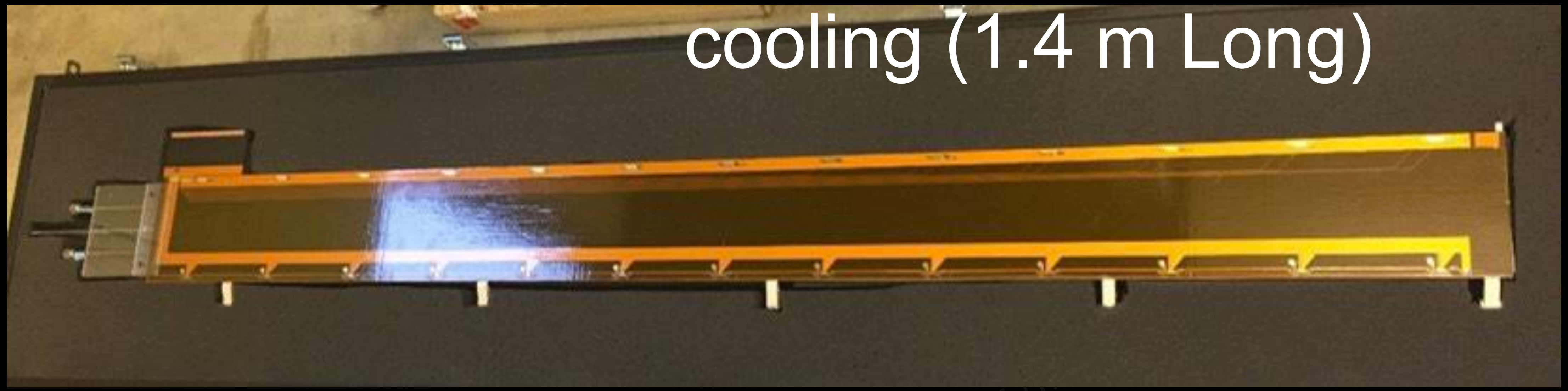
Extended goals if manpower and support available

International Collaboration

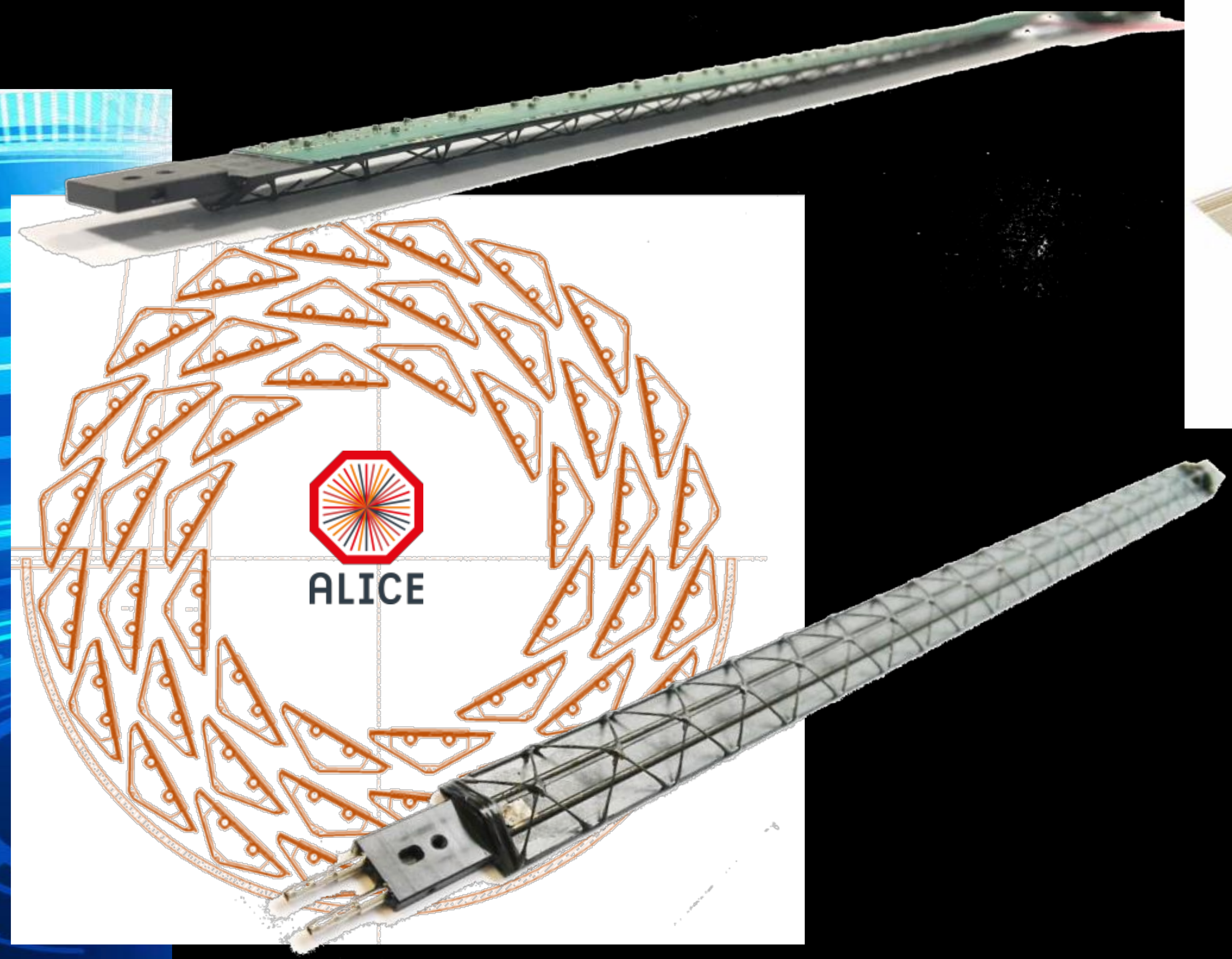
Liverpool Univ.
Oxford Univ.
Barcelona Univ.
University of Mass
RAL
others…..

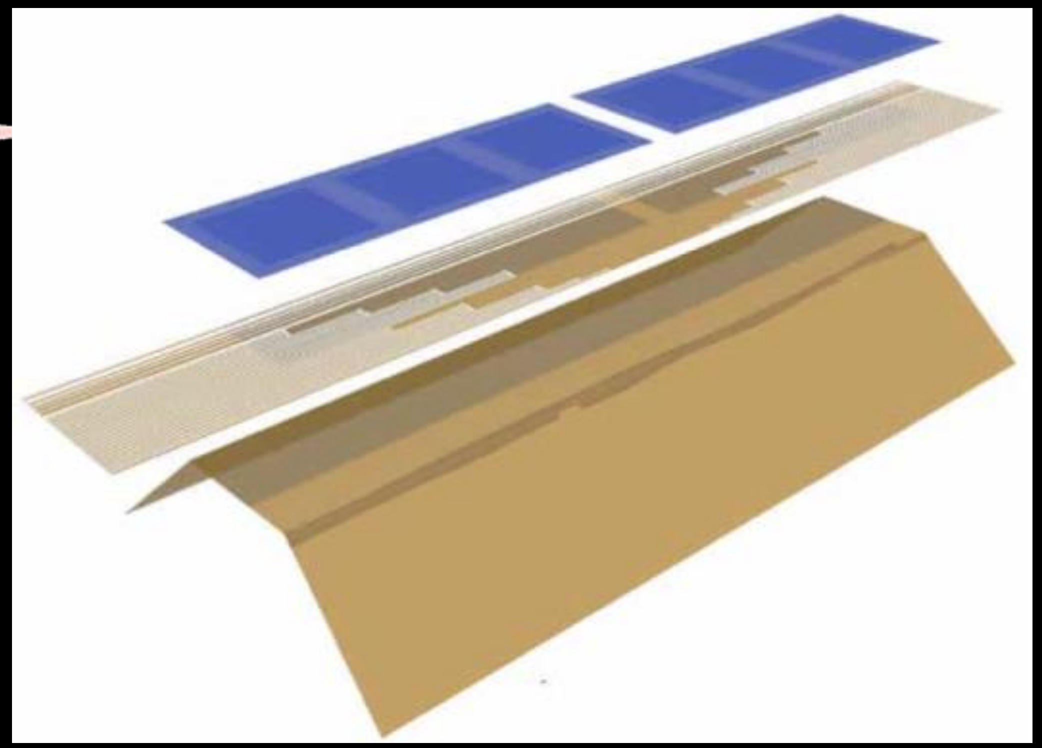
MATERIAL REDUCTION

ATLAS ITK module support structure with copper-Kapton co-cured tape and embedded CO2 cooling (1.4 m Long)



- Non conventional use of Carbon Fibre Reinforced Plastic (CFRP) materials for Vertex Detectors to match the requirement of minimum material budget, high rigidity, thermal management.



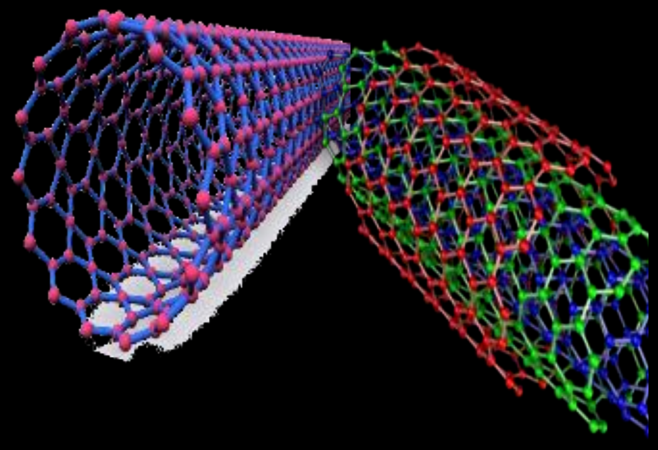


- 50 µm DMAPS
- 25 µm Kapton Flexprint
- 50 µm Kapton support frame
- < 1‰ Radiation length

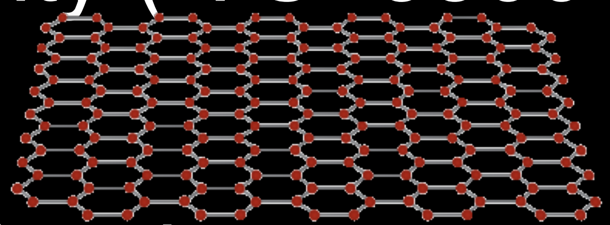
Carbon Nanotubes

Allotrope of carbon with a cylindrical nanostructure

Very high Therma Conductivity (TC=3500 W/mK)

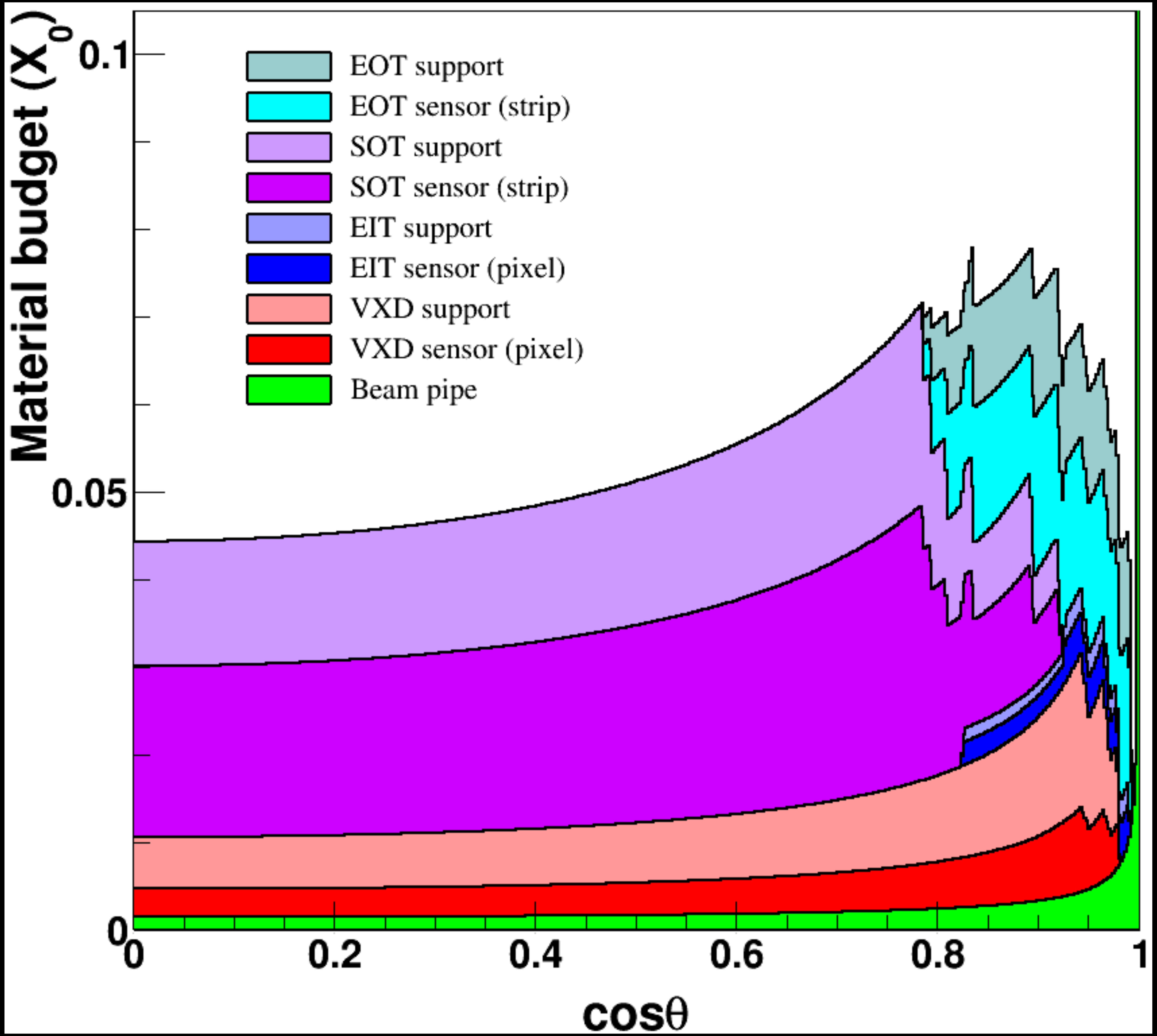


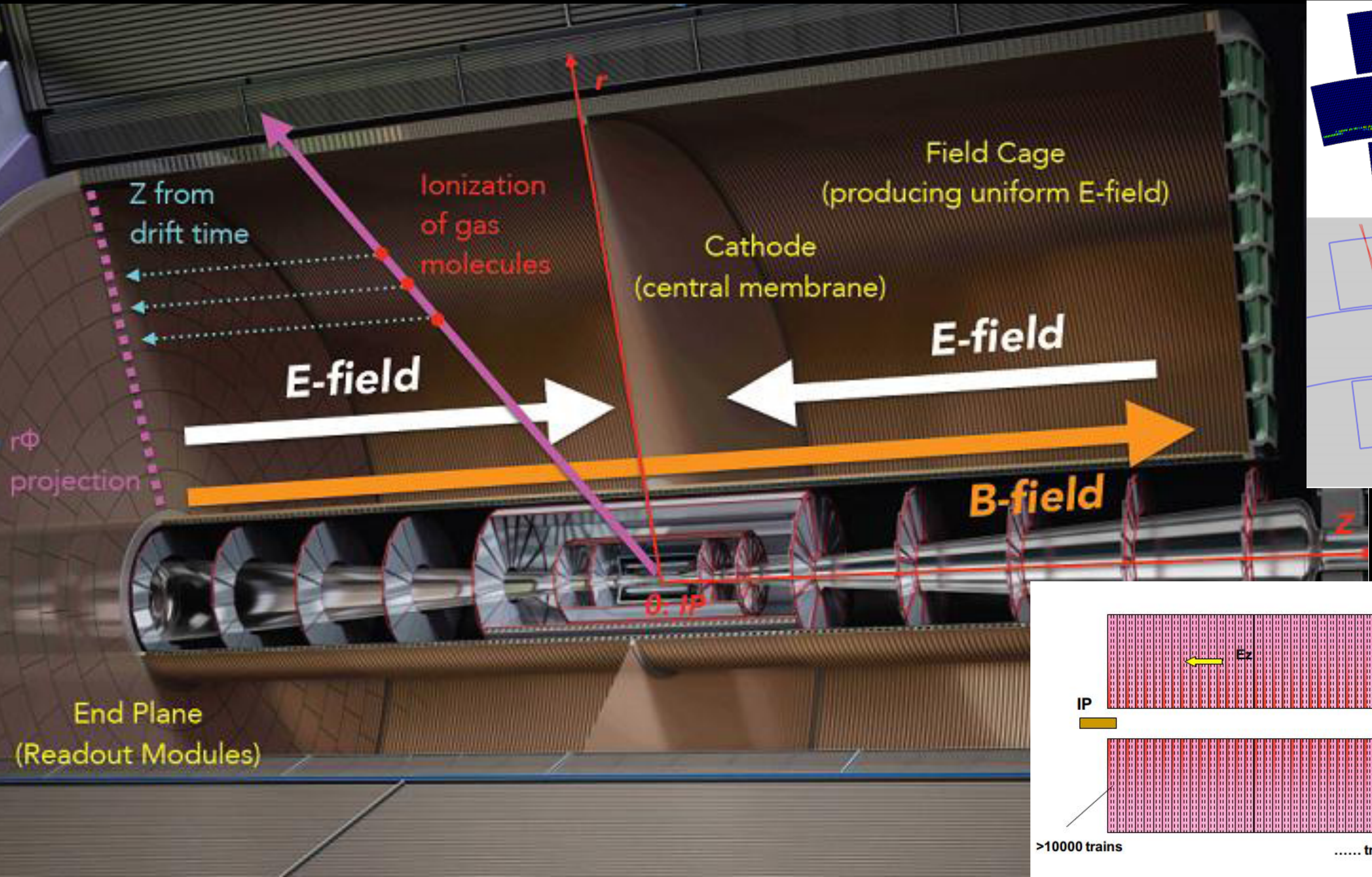
Graphene

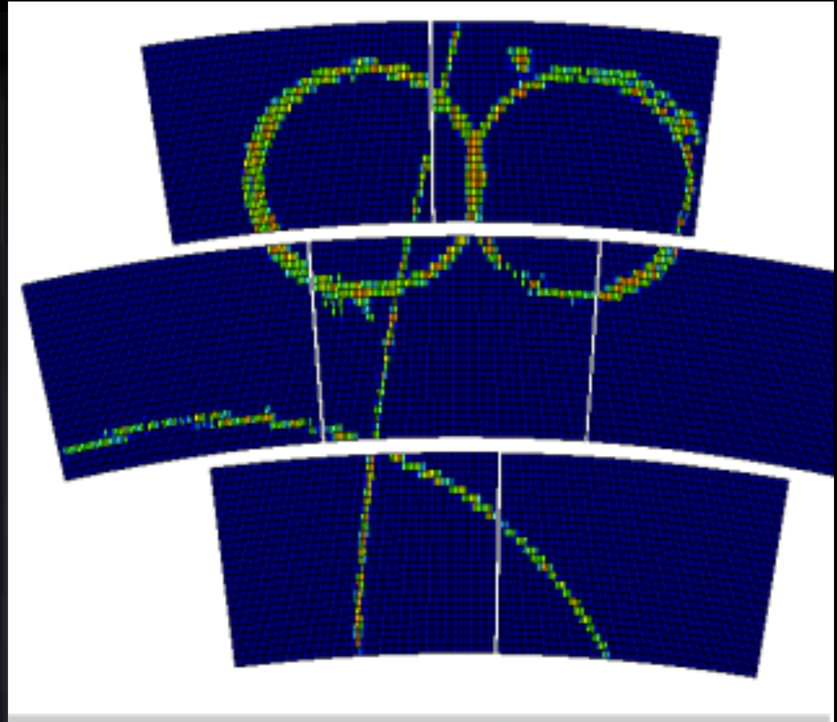


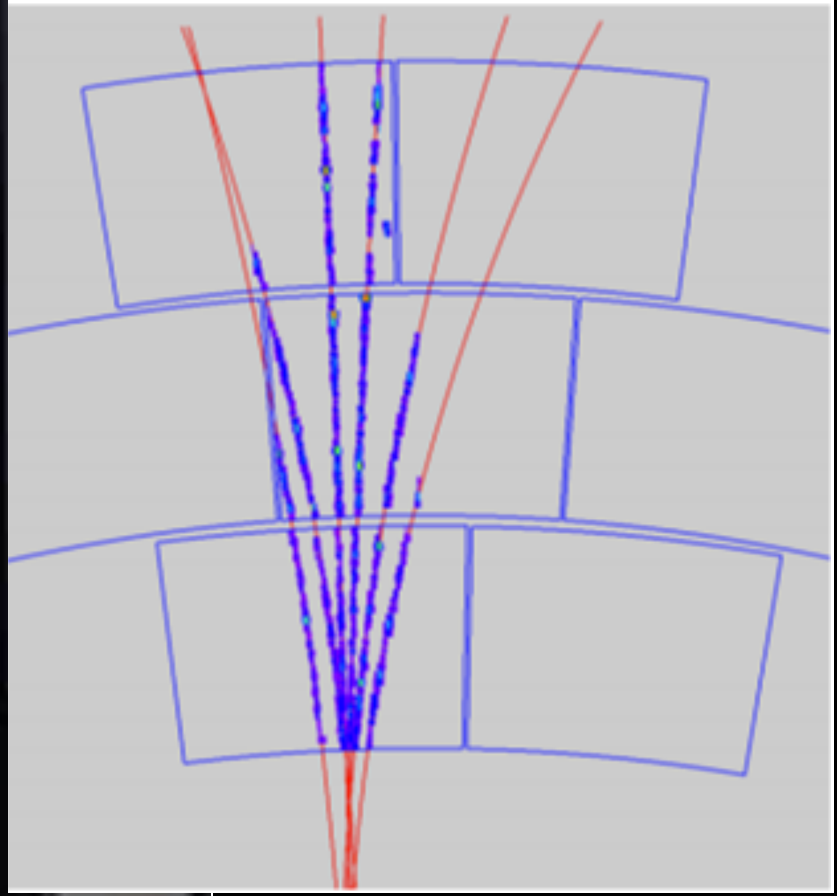
One atomic-layer thin film of carbon atoms in honeycomb lattice.
Graphene shows outstanding thermal performance, the intrinsic TC of a single layer is 3000-5000 W/mK

Full Silicon Tracker Concept




r
Z from
drift time
Ionization
of gas
molecules
Cathode
(central membrane)
Field Cage
(producing uniform E-field)
E-field
E-field
B-field
rΦ
projection
0: IP
Z
End Plane
(Readout Modules)
Ez
IP
z
>10000 trains
...... trains





Full Silicon Tracker Concept

VXD	FST R (m)	FST $\pm z$ (m)	FST2 R (m)	FST2 $\pm z$ (m)
Layer 1	0.016	0.078	0.022	0.091
Layer 2	0.025	0.125	0.038	0.091
Layer 3	0.037	0.150	0.058	0.091
Layer 4	0.038	0.150	0.079	0.091
Layer 5	0.058	0.175	0.100	0.091
Layer 6	0.059	0.175		

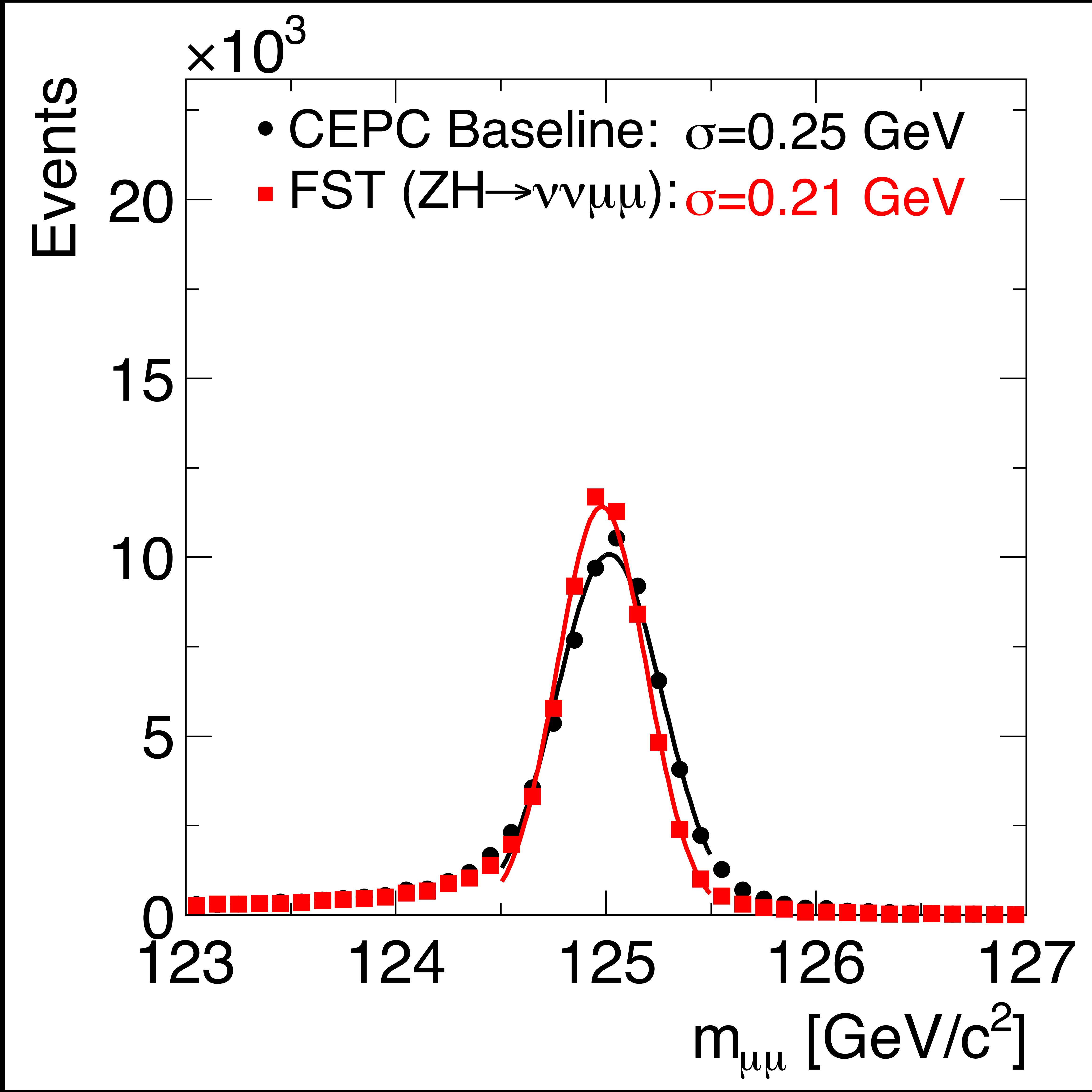
EIT	FST R_{in} (m)	FST R_{out} (m)	FST $\pm z$ (m)	FST2 R_{in} (m)	FST2 R_{out} (m)	FST2 $\pm z$ (m)
Disk 1	0.030	0.151	0.221	0.014	0.076	0.129
Disk 2	0.051	0.151	0.368	0.016	0.077	0.162
Disk 3				0.018	0.079	0.212
Disk 4				0.020	0.082	0.306
Disk 5				0.097	0.167	0.308
Disk 6				0.121	0.167	0.792
Disk 7				0.142	0.167	1.207

SOT	FST R (m)	FST $\pm z$ (m)	FST Type	FST2 R (m)	FST2 $\pm z$ (m)	FST2 Type
Layer 1	0.153	0.368	D	0.344	0.793	S
Layer 2	0.321	0.644	D	0.718	1.029	S
Layer 3	0.603	0.920	D	1.082	1.391	S
Layer 4	1.000	1.380	D	1.446	1.746	S
Layer 5	1.410	1.840	D	1.820	2.107	S
Layer 6	1.811	2.300	D			

EOT	FST R_{in} (m)	FST R_{out} (m)	FST $\pm z$ (m)	FST Type	FST2 R_{in} (m)	FST2 R_{out} (m)	FST2 $\pm z$ (m)	FST2 Type
Disk 1	0.082	0.321	0.644	D	0.207	0.744	1.034	D
Disk 2	0.117	0.610	0.920	D	0.207	1.111	1.424	D
Disk 3	0.176	1.000	1.380	D	0.207	1.477	1.779	D
Disk 4	0.234	1.410	1.840	D	0.207	1.852	2.140	D
Disk 5	0.293	1.811	2.300	D				

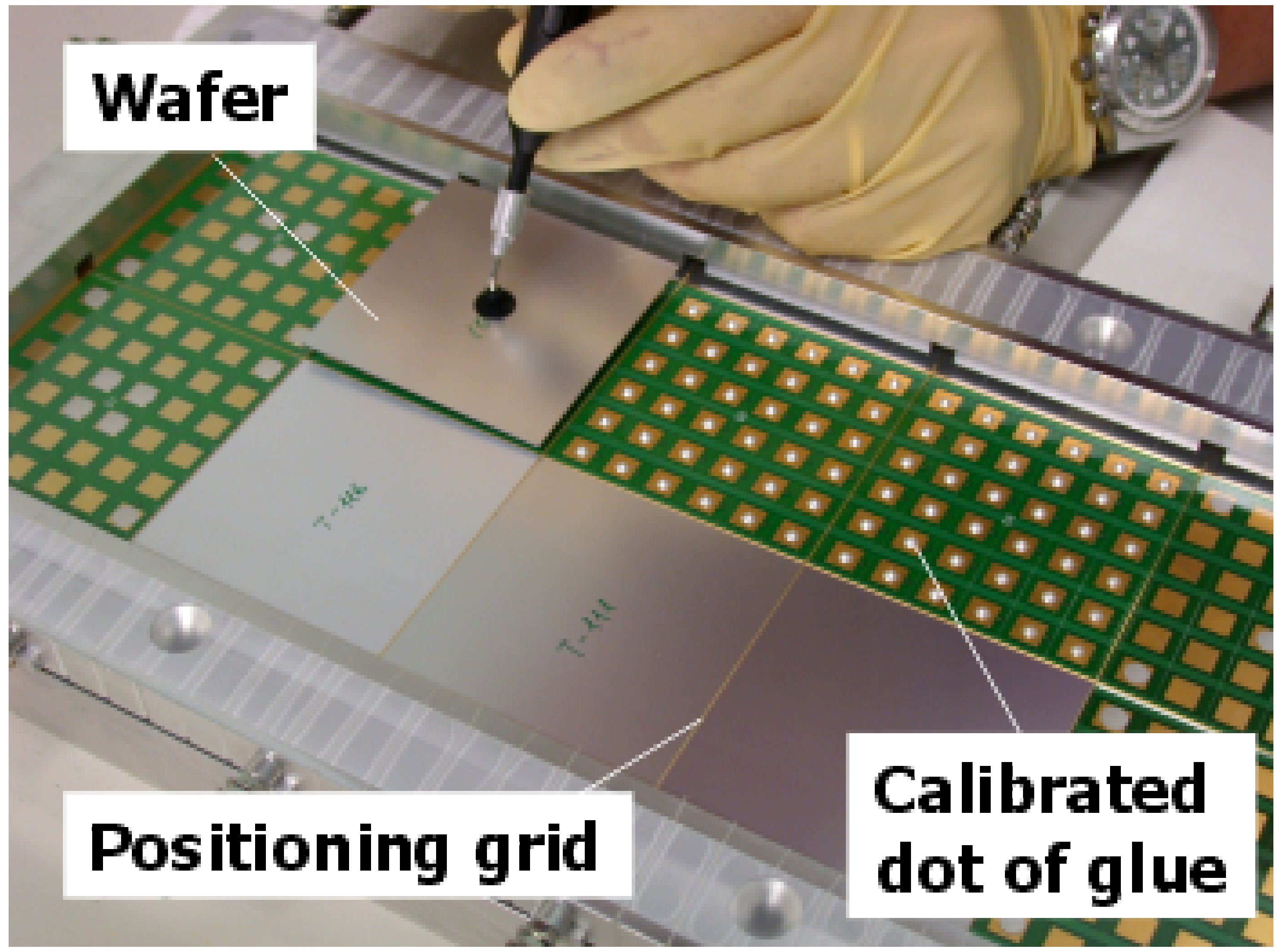
Full Silicon Tracker Concept

Comparison with CEPC TPC Baseline Tracker

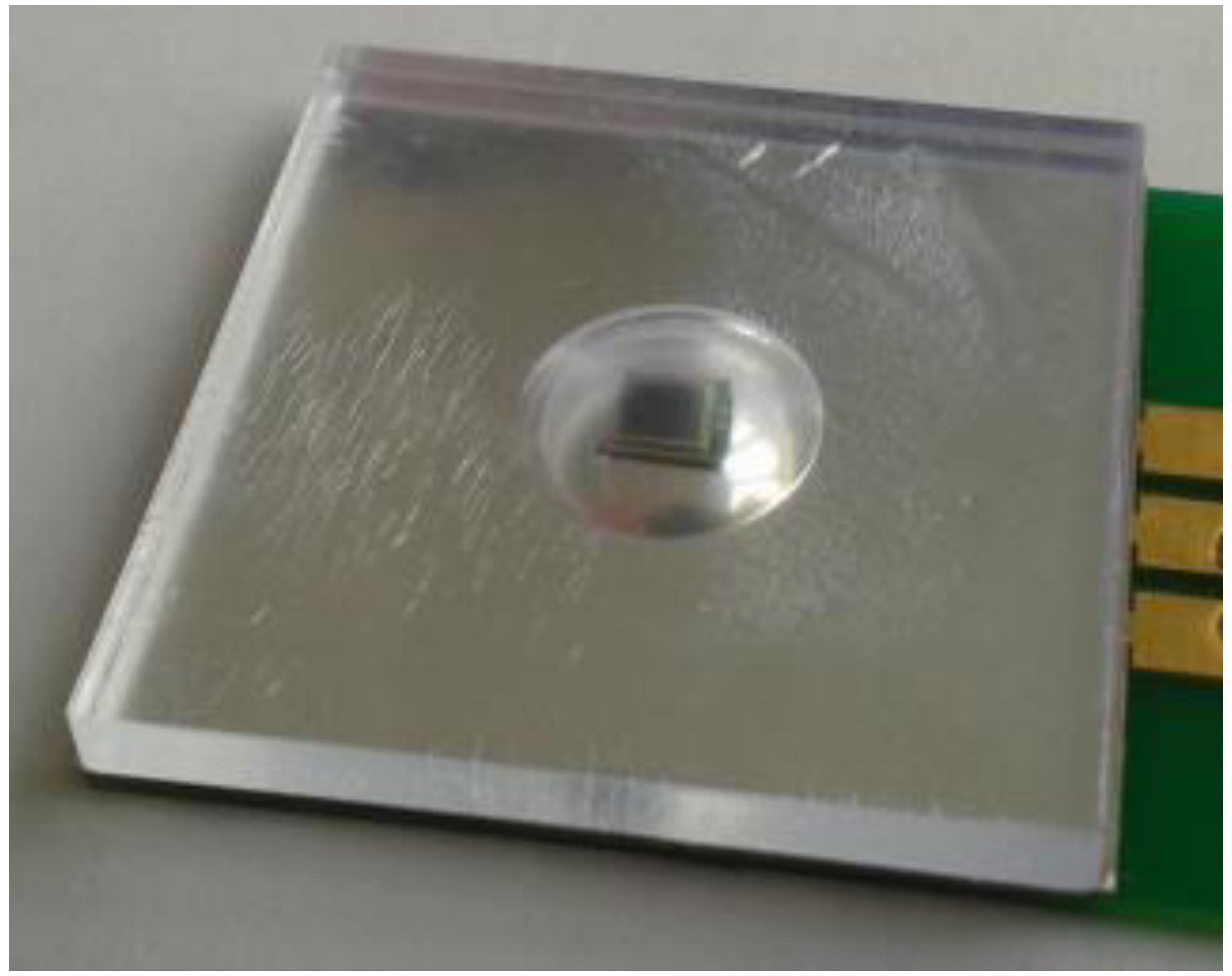


PFA calorimeter: active layer technologies

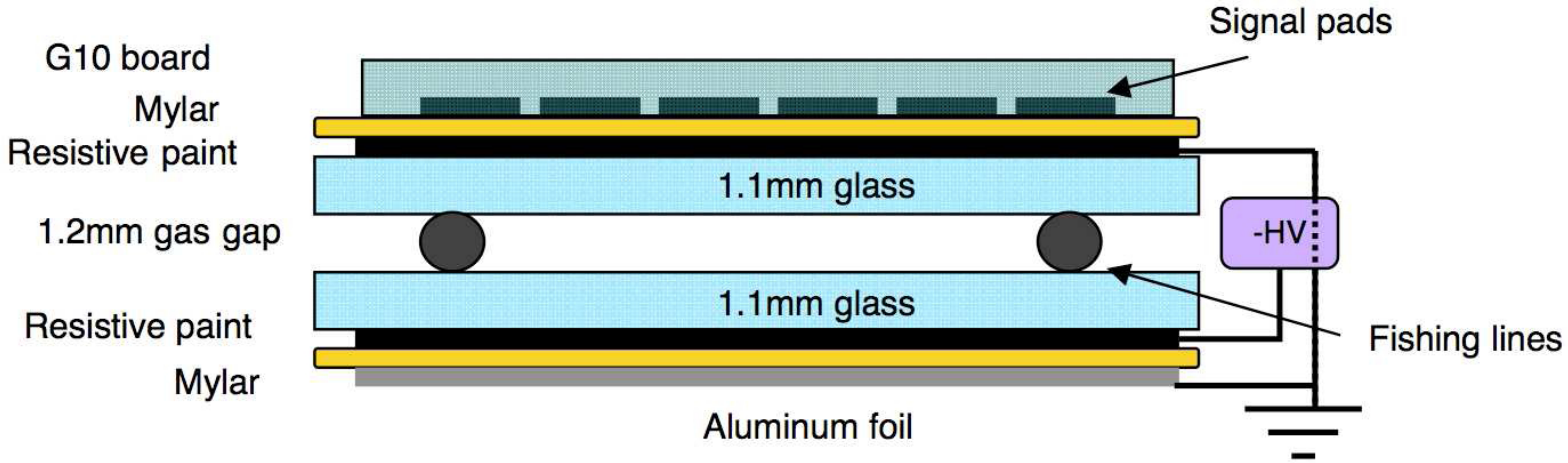
Silicon PIN diodes ($1 \times 1\,\mathrm{cm}^2$ in 6×6 matrices)



Scintillator tiles/strips (here $3 \times 3\,\mathrm{cm}^2$) + SiPMs

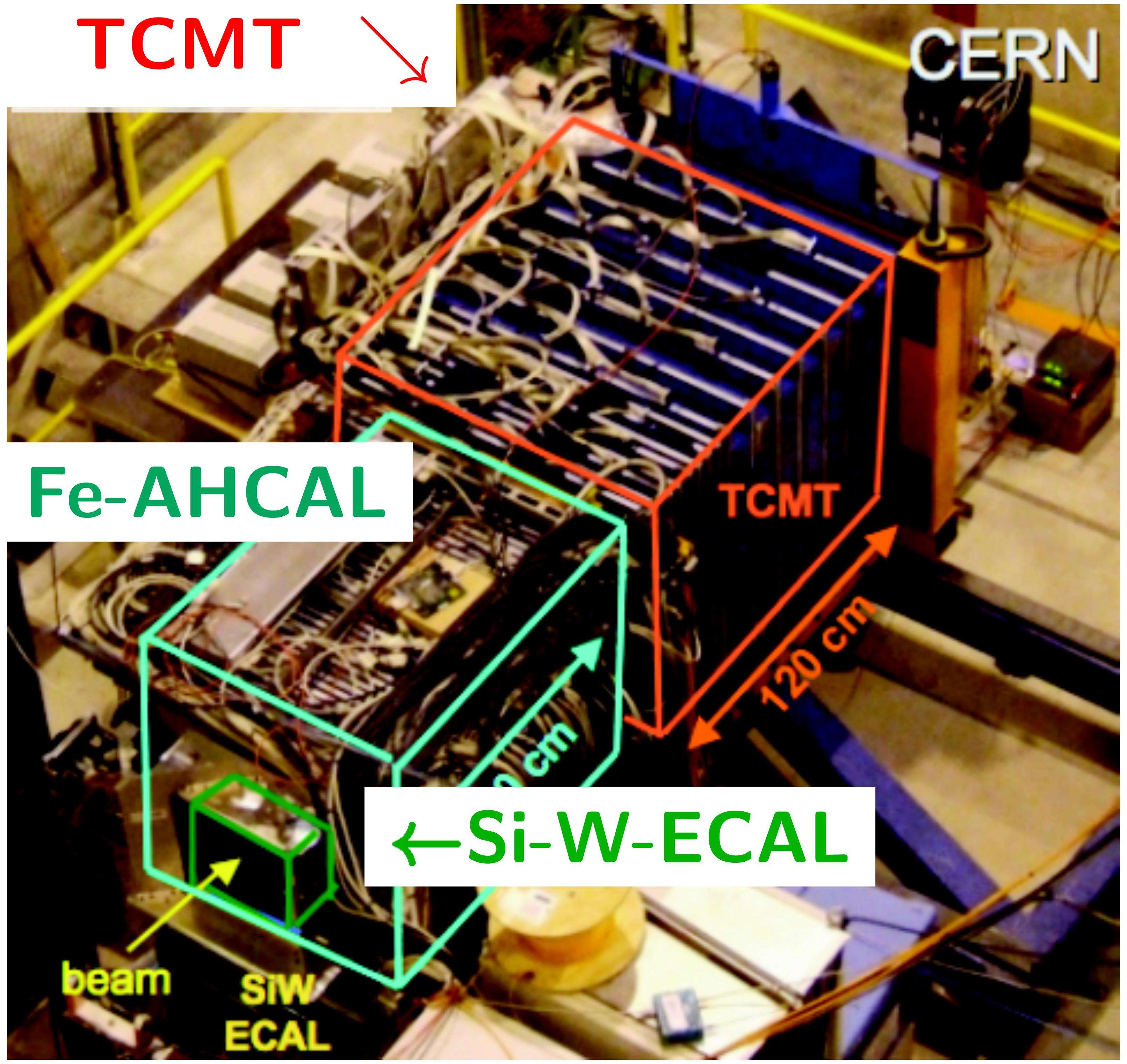


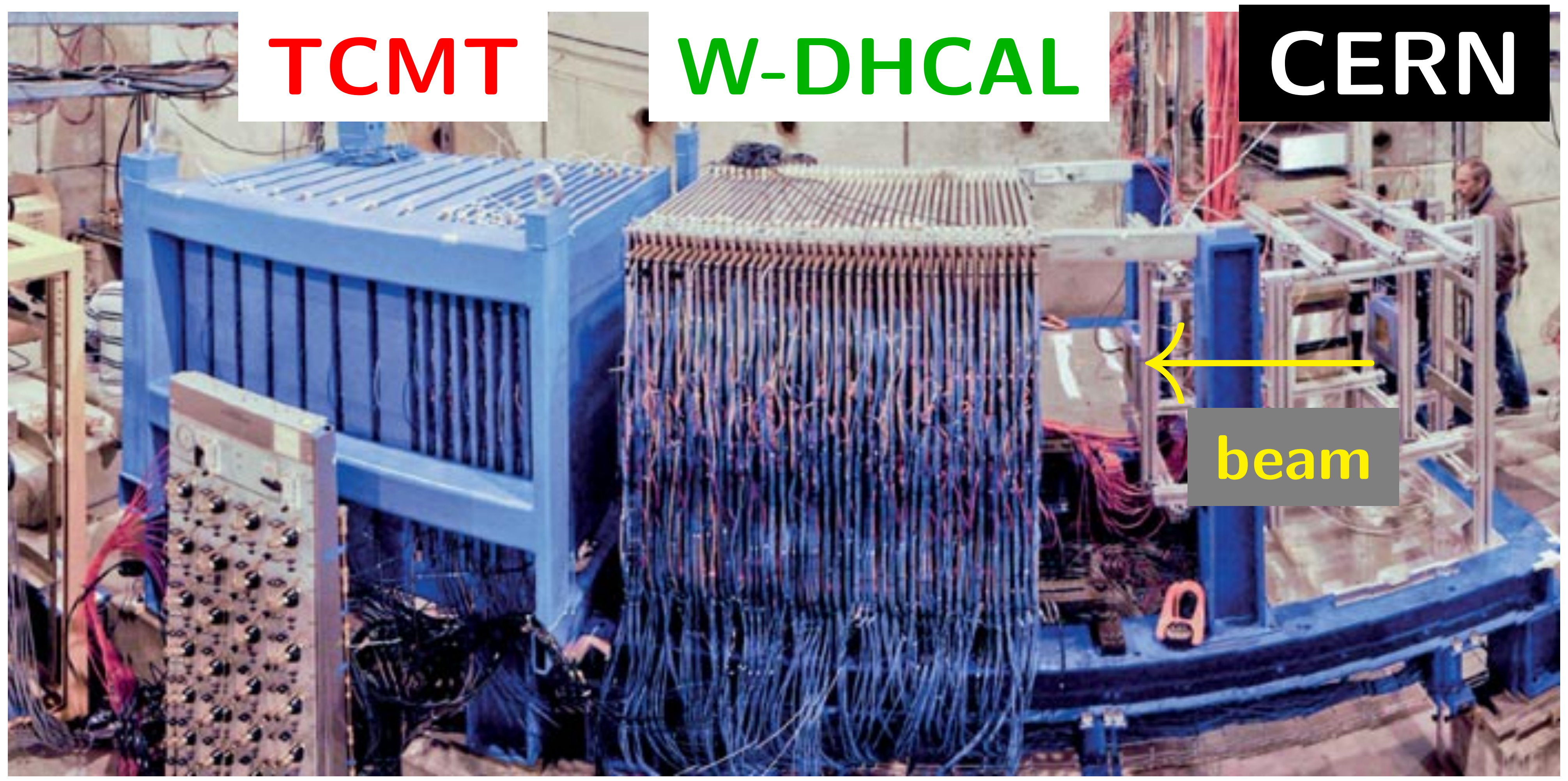
Resistive place chambers ($1 \times 1\,\mathrm{cm}^2$ signal pads)



CALICE collaboration

- Test beam experiments in 2006–2015 at DESY, CERN, FNAL
- First physics prototypes of up to $\sim 1\,\mathrm{m}^3$, $\sim 2\,\mathrm{m}^3$ including Tail Catcher Muon Tracker





AHCAL/Si-ECAL: ∼ 10 000 readout channels

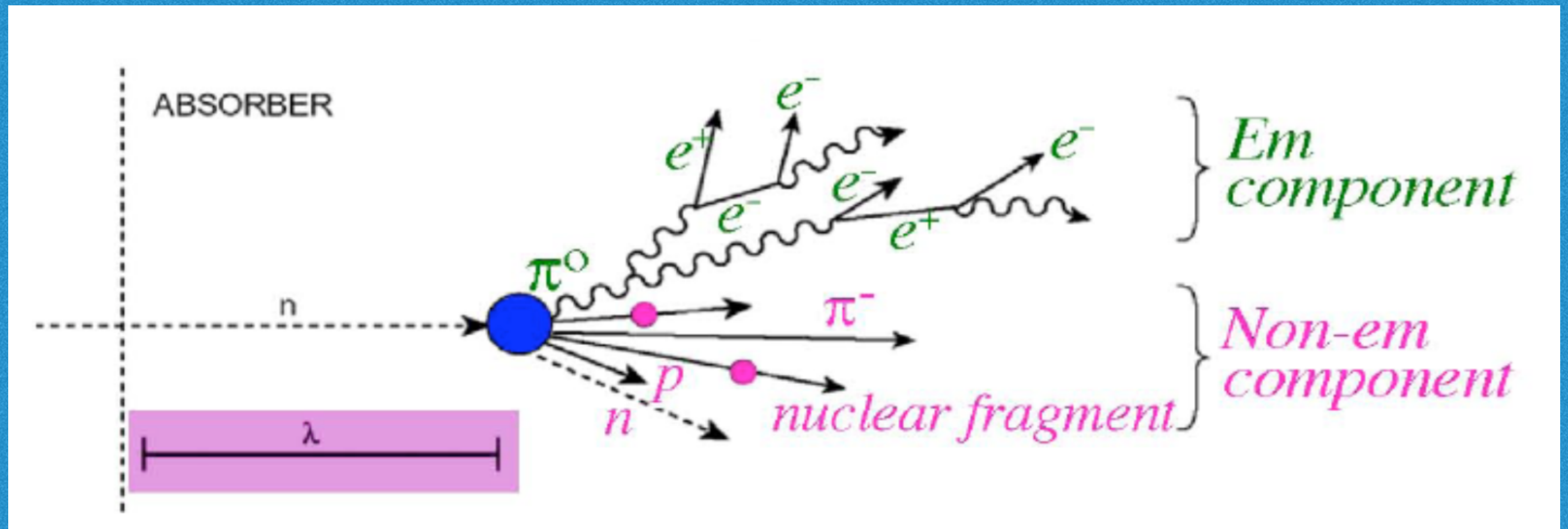
DHCAL: ∼ 500 000 readout channels

- Detector challenges:
  - Compact design of calorimeters
  - Calibration of all channels

Dual Readout Calorimeter

Based on the DREAM/RD52 collaboration

Dual readout (DR) calorimeter measures both:
- Electromagnetic component
- Non-electromagnetic component



Fluctuations in event-by-event calorimeter response affect the energy resolution

Measure simultaneously:

Cherenkov light (sensitive to relativistic particles)

Scintillator light (sensitive to total deposited energy)

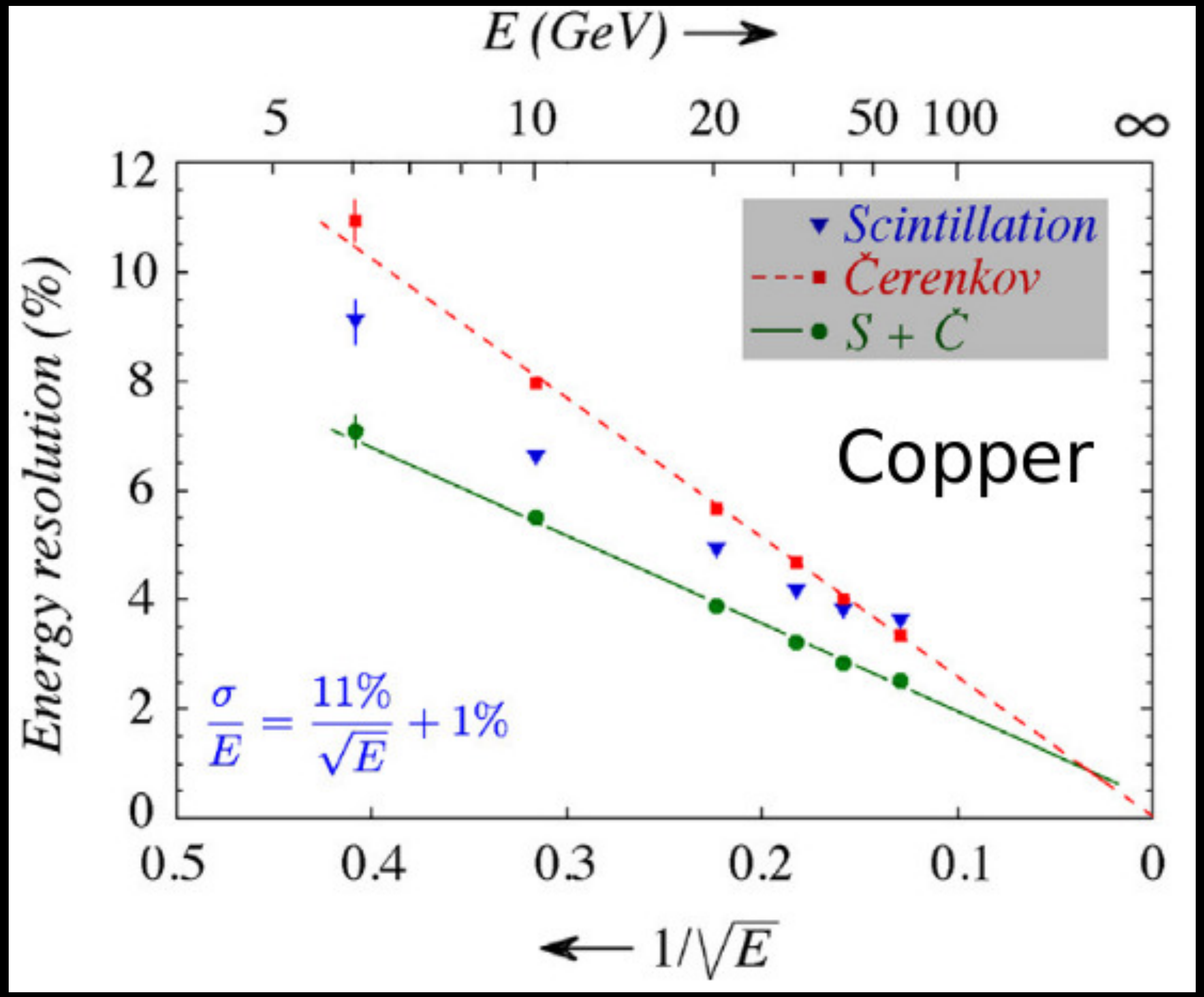
Expected resolution:

EM: ~10%/sqrt(E)

Hadronic: 30-40%/sqrt(E)

Several prototypes from RD52 have been built

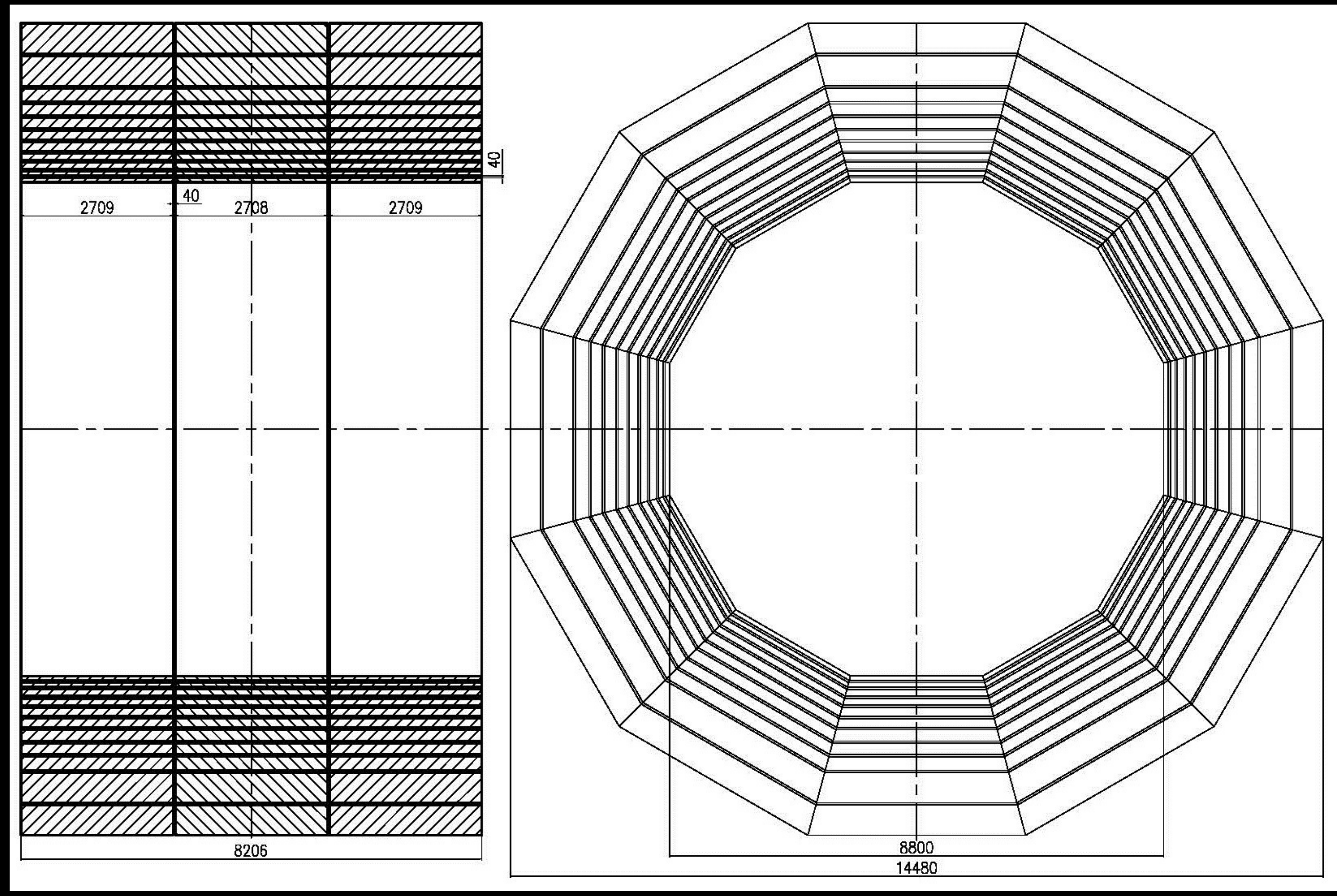
Energy resolution for electrons

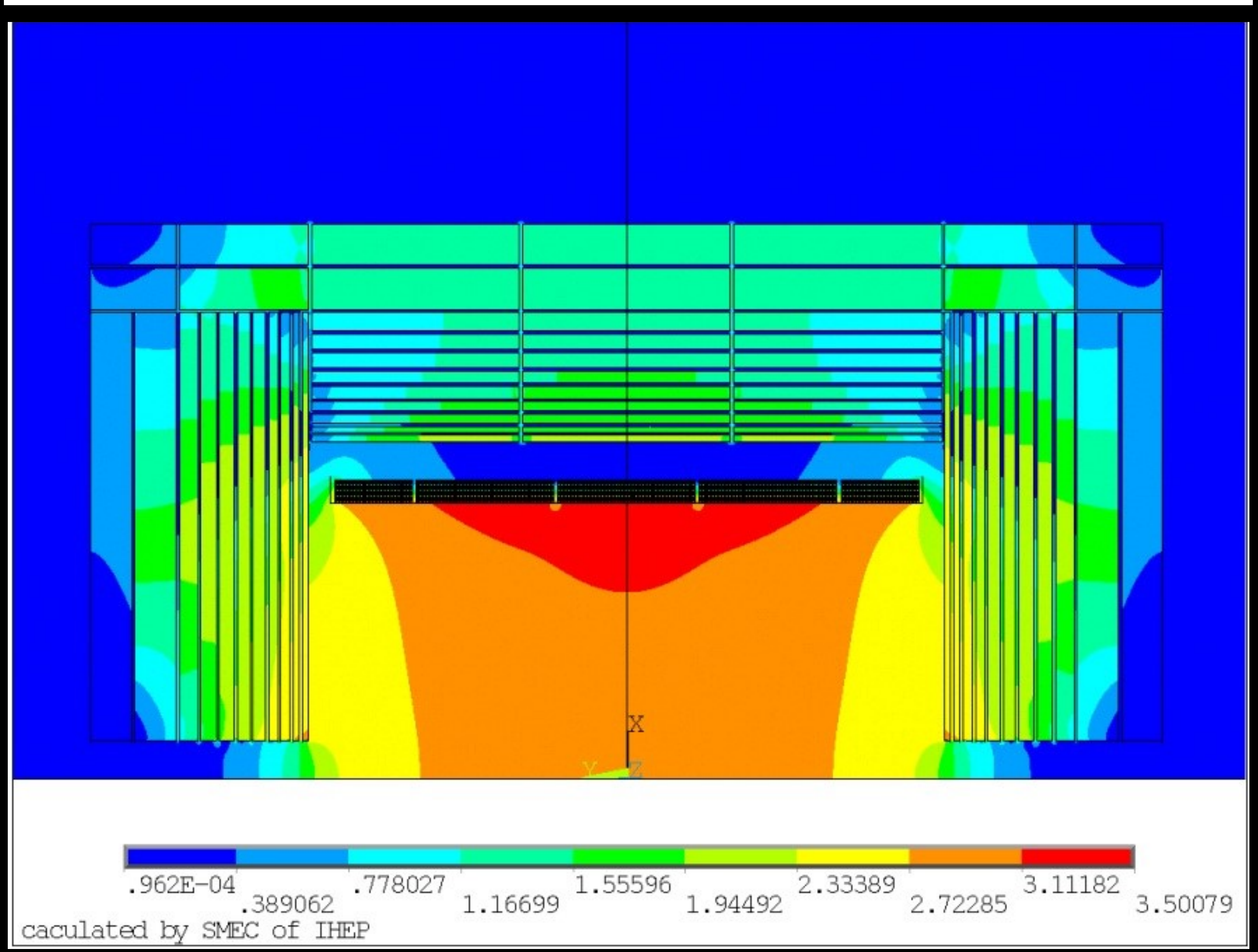


Superconductor solenoid development

Updated design done for 3 Tesla field

Default: Iron Yoke

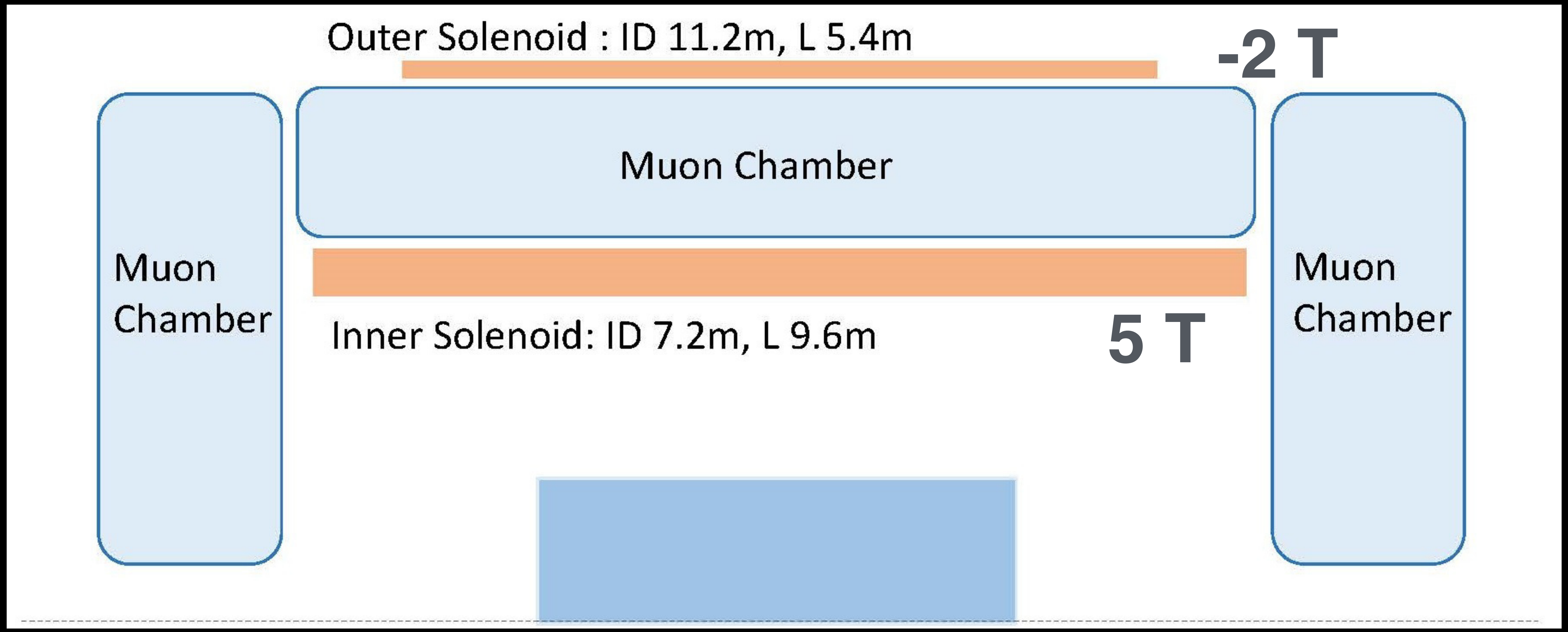




Concept improved by FCC studies

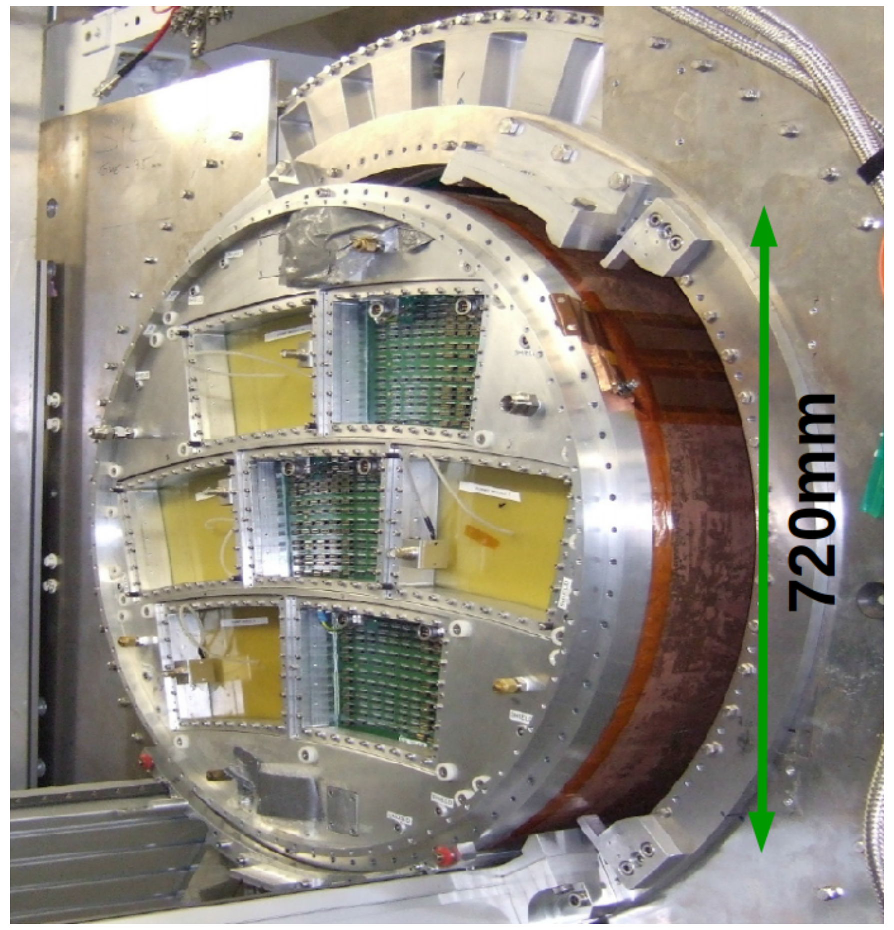
Dual Solenoid Scenario

Lighter and more compact



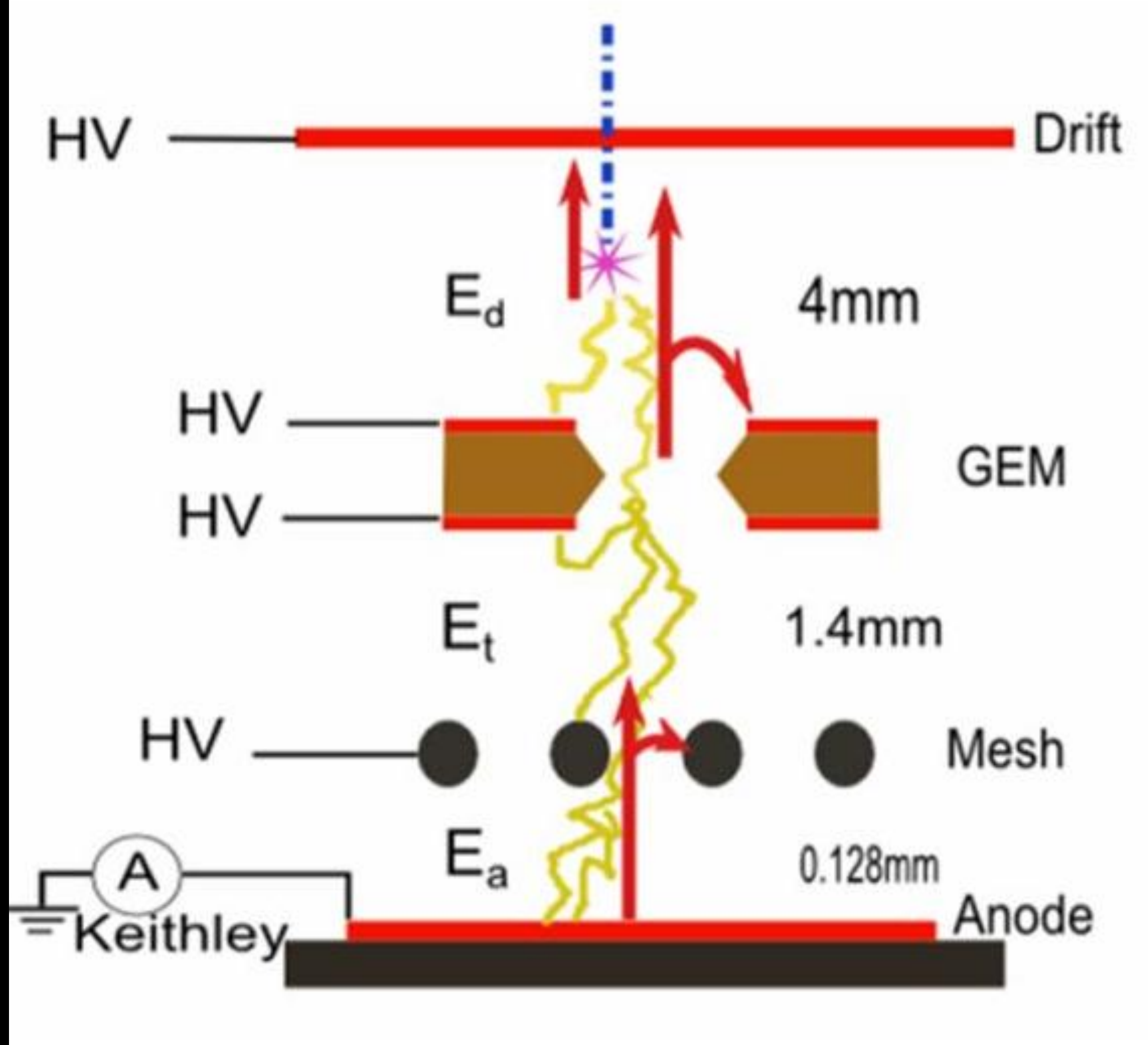
Time Projection Chamber: Ion back flow

Large TPC prototype

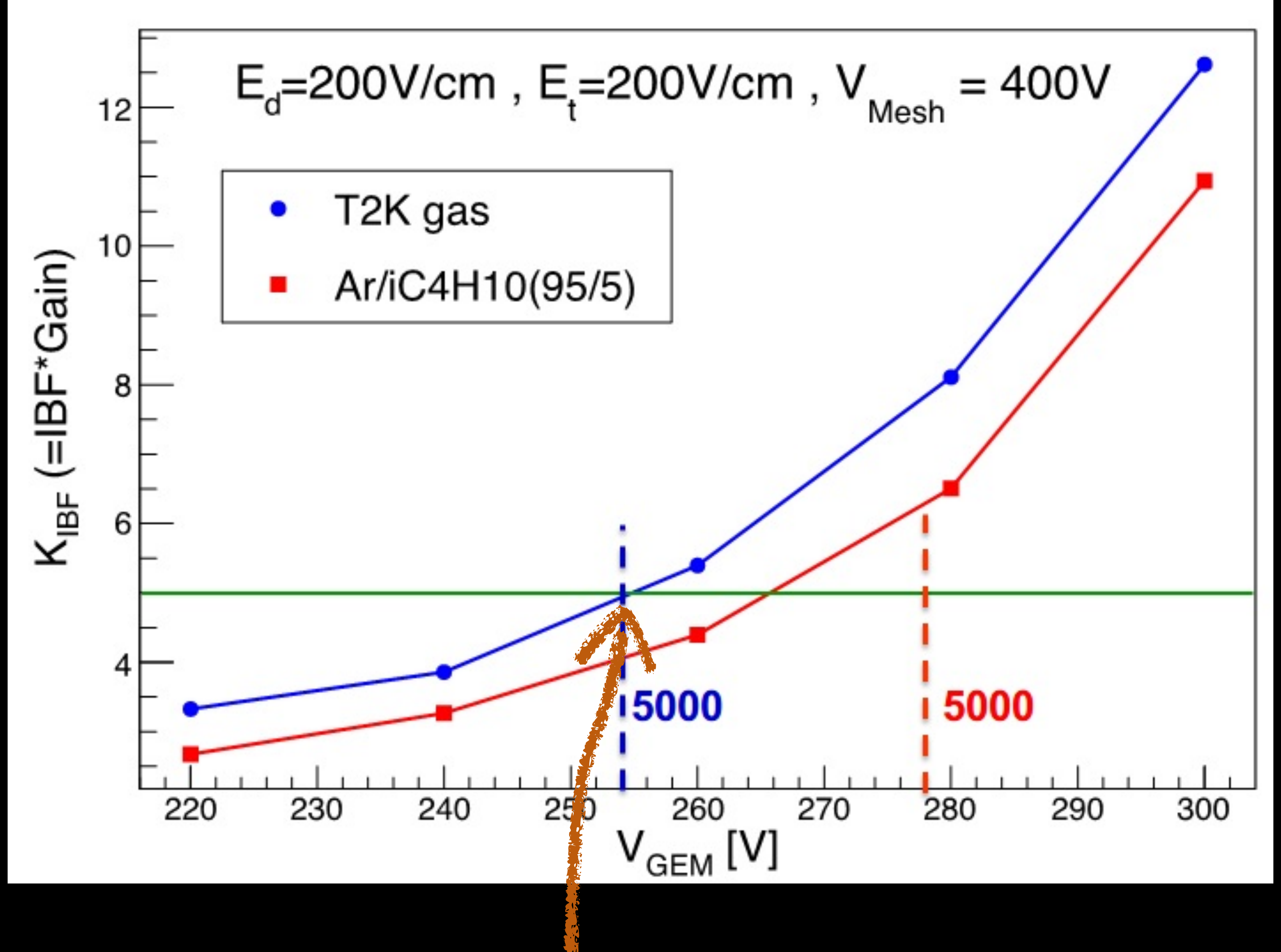


TPC readout with micro-pattern gaseous detectors (MPGDs)

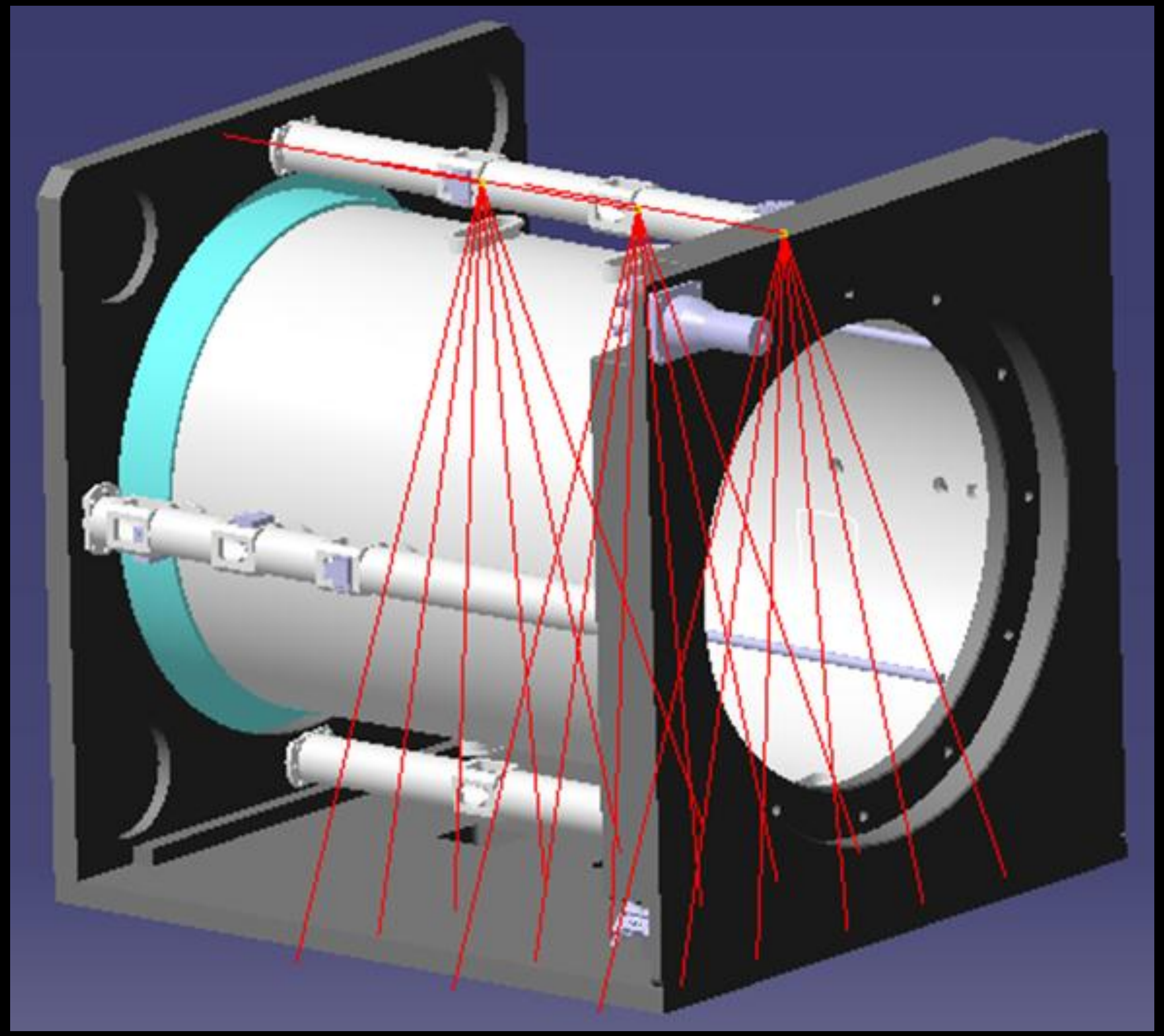
Readout module (GEM+MM)



Ion backflow



Laser calibration system



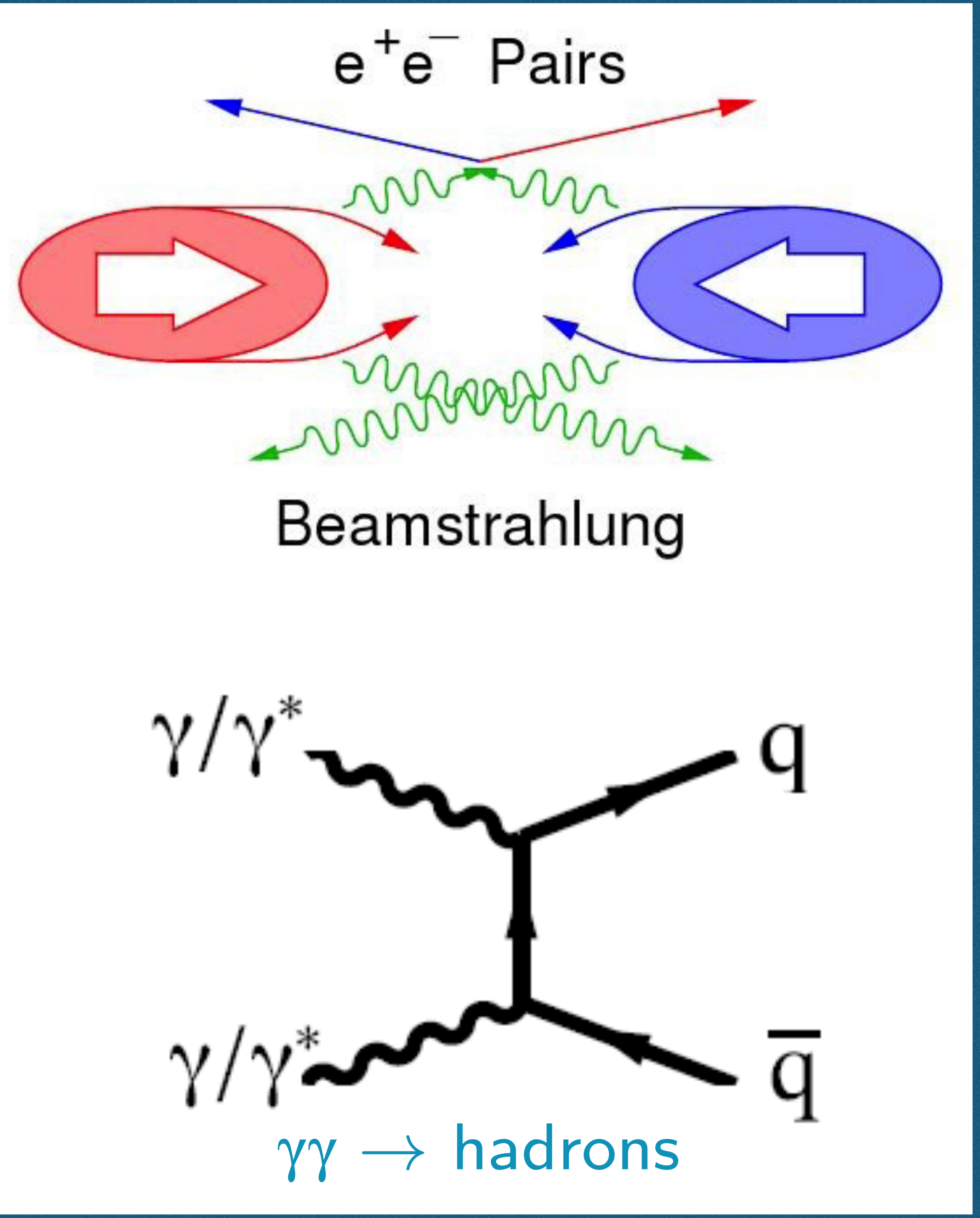
IBF: Ion Back Flow reduced to ~0.1%

Indication that TPC operation would be feasible at high-luminosity Z factory

Beam-induced backgrounds

Linear collider: Achieve high luminosities by using extremely small beam sizes

3 TeV CLIC: Bunch size: $\sigma_{x:y:z}$ = {40 nm; 1 nm; 44 µm} → beam-beam interactions



Main Backgrounds (p_T > 20 MeV, θ > 7.3°)

Incoherent e^+e^- pairs:

- 19k particles/bunch train at 3 TeV
- High occupancies
  → Impact on detector granularity

γγ → hadrons:

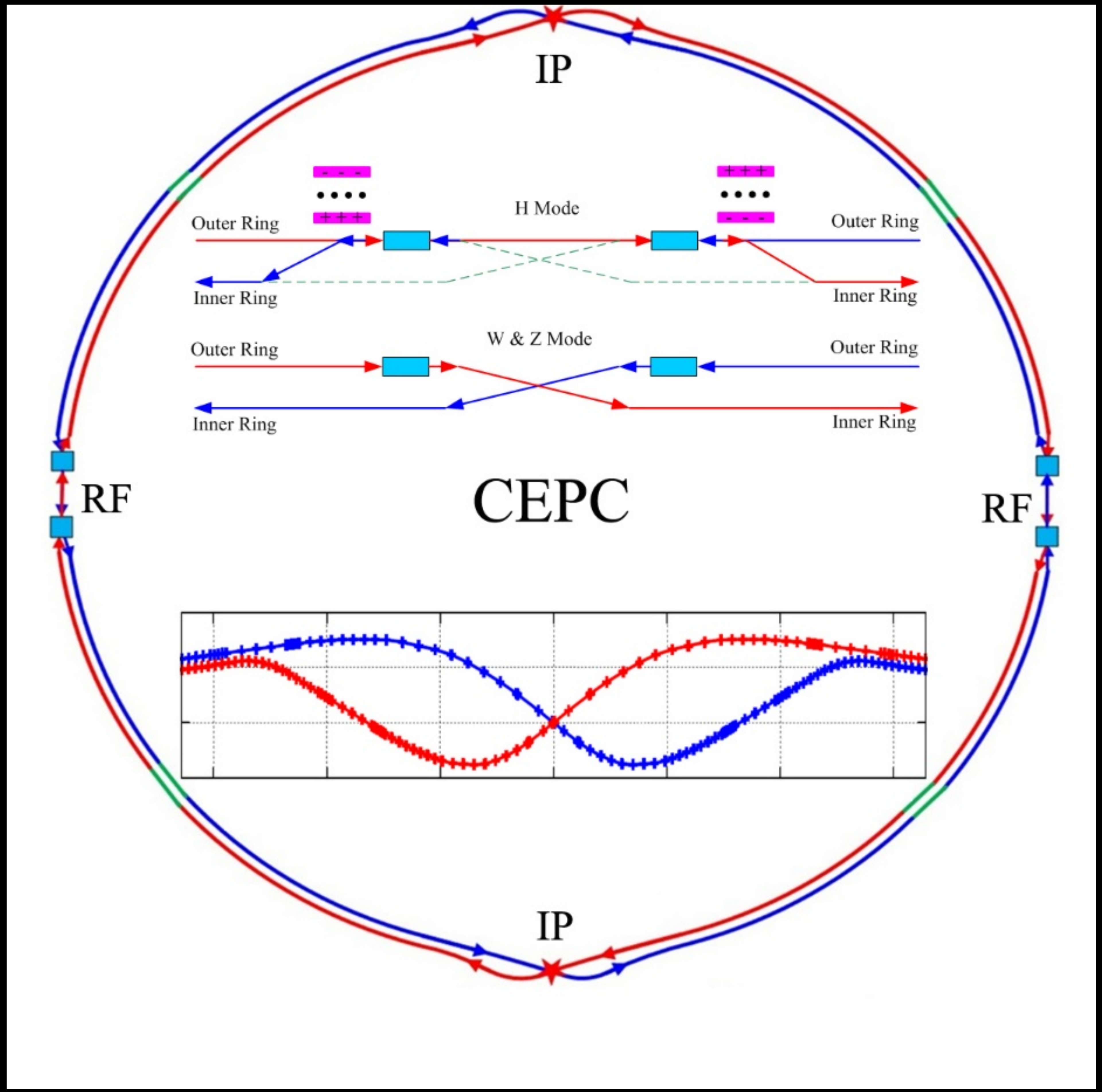
- 17k particles/bunch train at 3 TeV
- Main background in calorimeters and trackers
  → Impact on detector granularity and physics

Circular collider: same processes but to much low extent, plus synchrotron radiation

Synchrotron radiation in circular colliders (2)

Synchrotron radiation:

$$\sim \frac{E_{beam}^4}{M^4 \times r}$$



2.75 GeV/turn lost at LEP at E = 105 GeV
(0.09 GeV/turn at E = 45 GeV)

Property	FCC-ee (100 km)				CEPC (100 km)		
Beam energy (GeV)	**45.6**	**80**	**120**	**175**	**45.6**	**80**	**120**
Energy loss/turn (GeV)	0.03	0.33	1.67	7.55	0.036	0.34	1.73

High luminosities in circular colliders

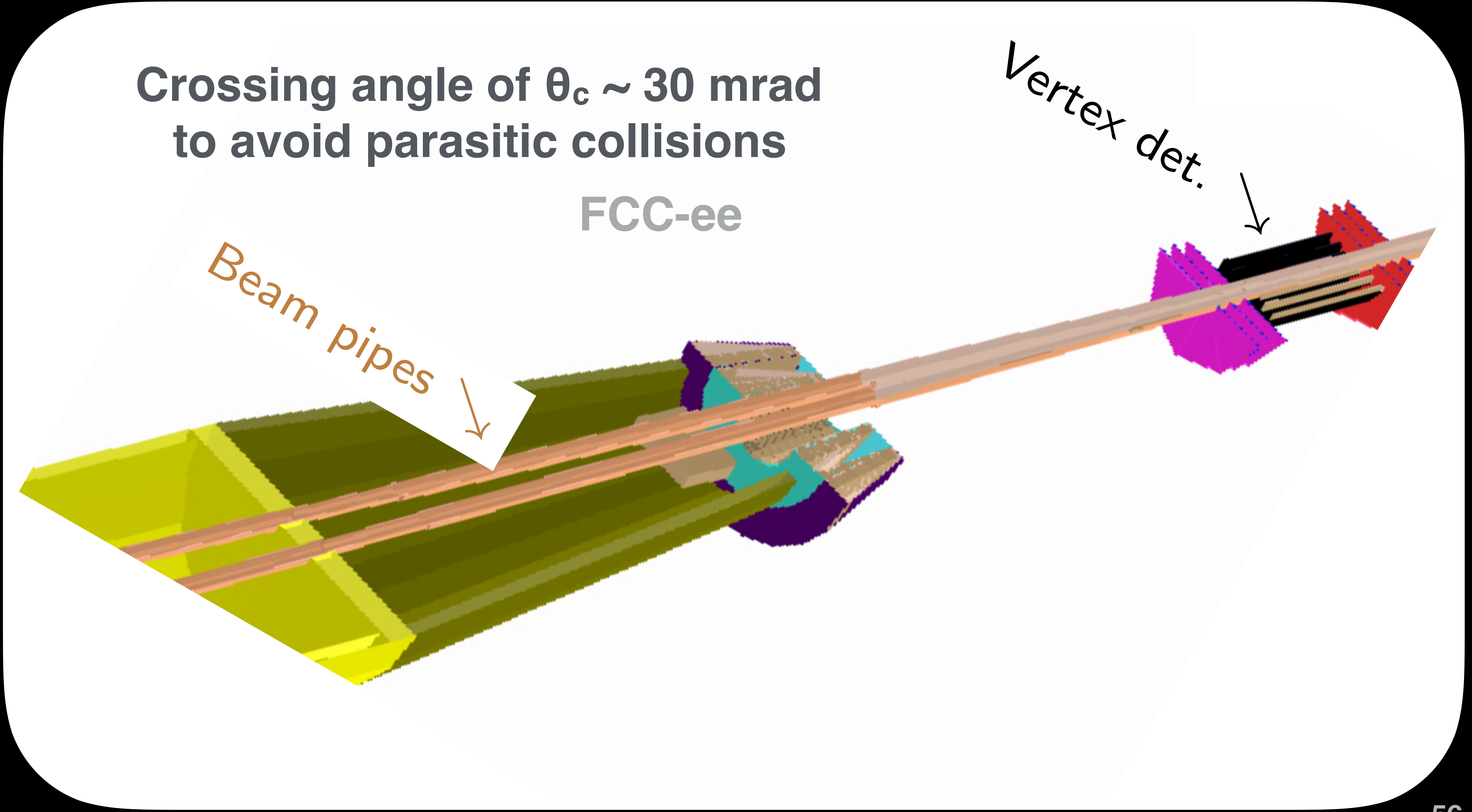
Property	FCC-ee (100 km)				CEPC (100 km)		
Beam energy (GeV)	**45.6**	**80**	**120**	**175**	**45.6**	**80**	**120**
Luminosity/IP ($10^{34} cm^{-2}s^{-1}$)	230	28	8.5	1.5	32	10	3
Bunches/beam	16640	2000	393	48	12000	1524	242
Bunch separation (ns)	20	160	830	8300	25	260	680

Luminosity up to ~ 10^{36} $cm^{-2}s^{-1}$

Large number of bunches

Consequences for detector design

Crossing angle at IP
Bunch separation impacts overall designs
No power pulsing of detectors



Machine-detector interface (MDI) in circular colliders

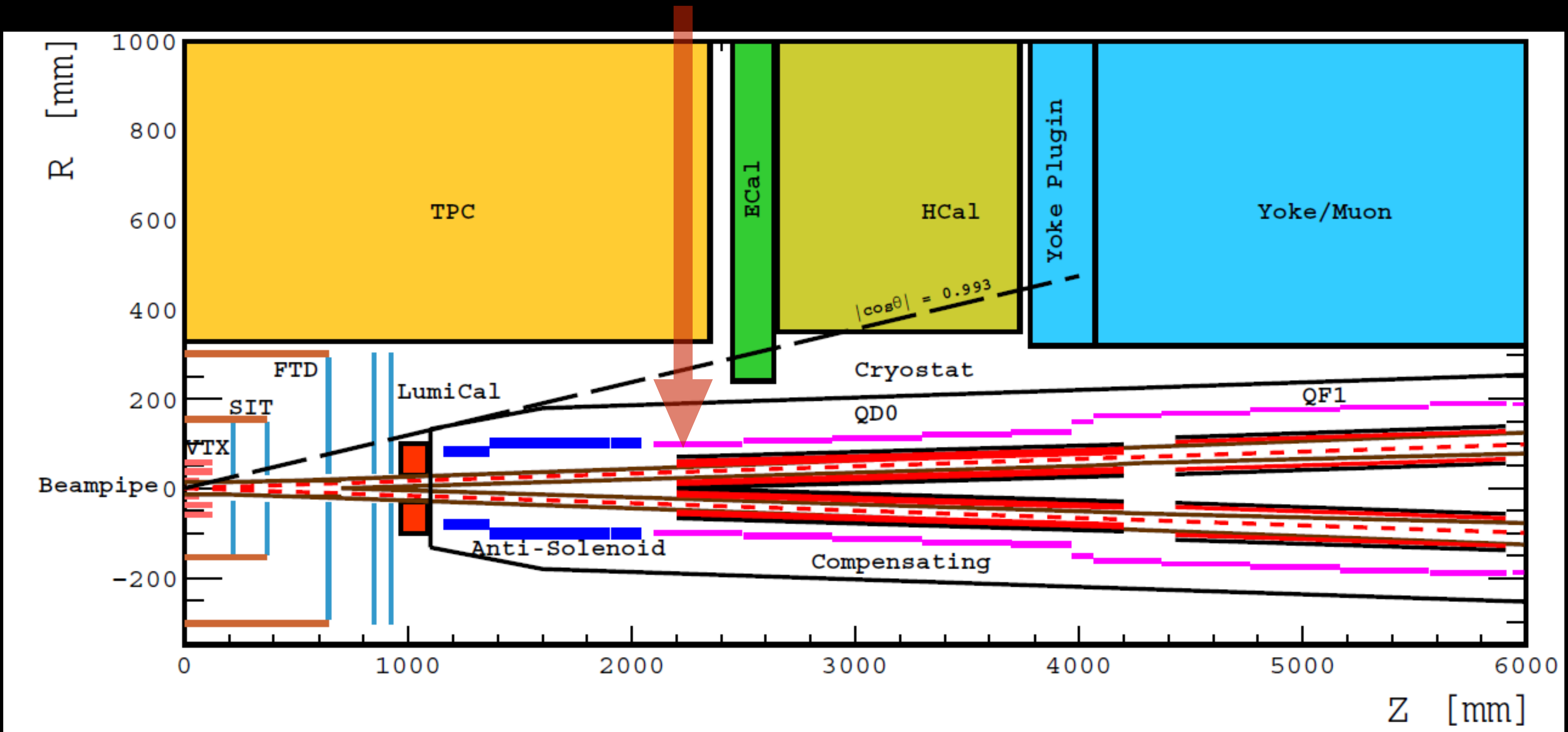
High luminosities ➡ **Final focusing quadrupole (QD0) needs to be very close to IP**

L* = 2.2 m at FCC-ee and CEPC

Detector acceptance:
> ± 150 mrad

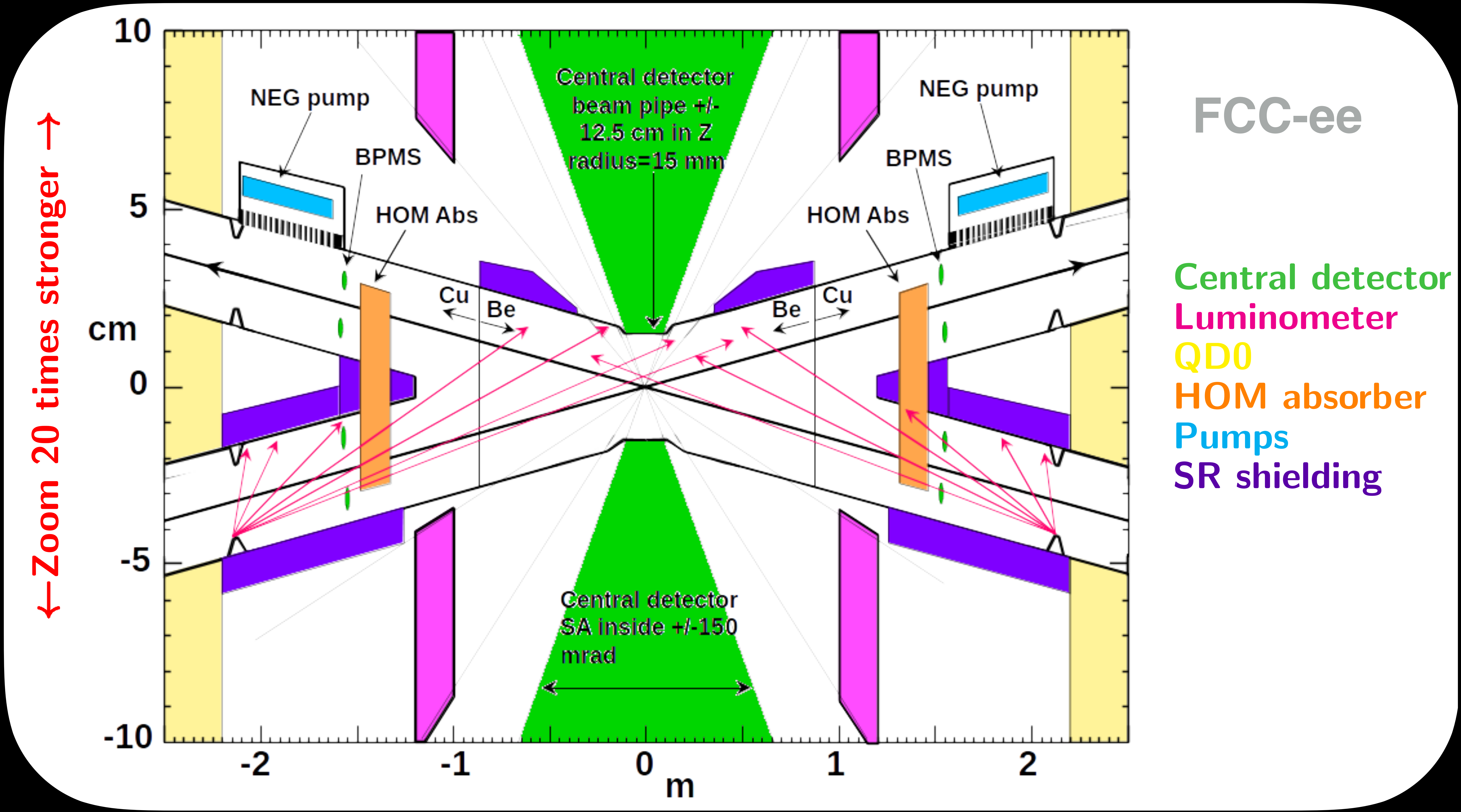
Solenoid magnetic field limited:
2-3 Tesla

due to beam emittance blow up



Synchroton radiation in circular colliders: Shielding

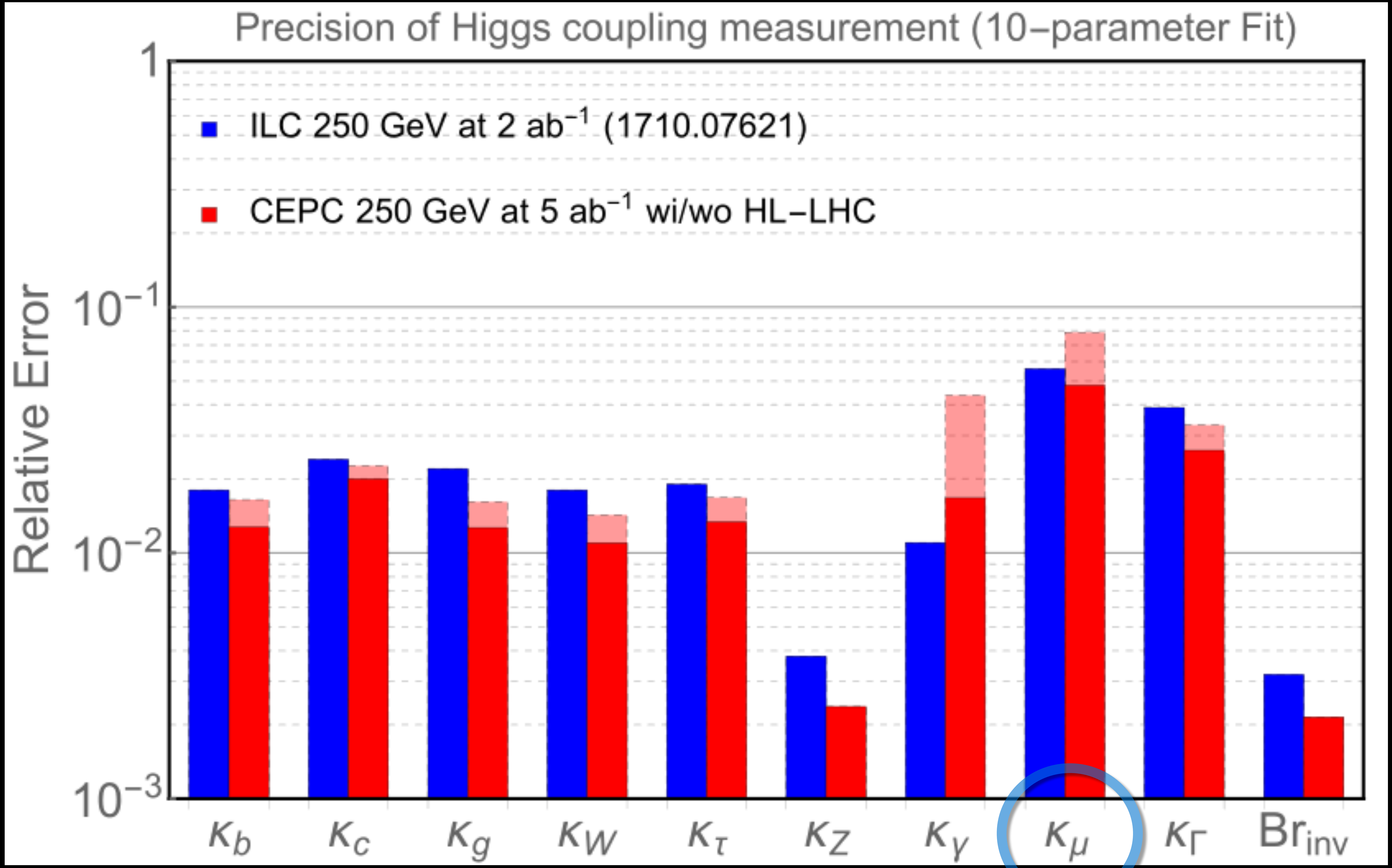
Shielding added to prevent synchrotron radiation/secondary radiation to enter the detector



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

Higgs Couplings Measurement

Precision of Higgs couplings measurement compared to ILC



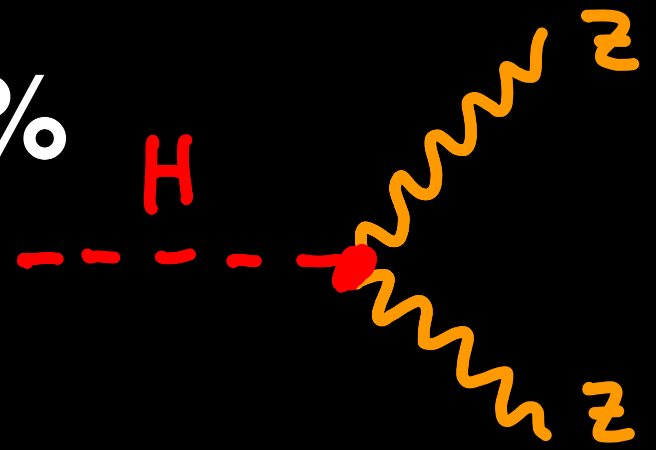
$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})}, \quad \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

ILC

CEPC

~1% uncertainty

$K_Z \sim 0.2$ %



ATL-PHYS-PUB-2014-016

Many BSM models impact Higgs couplings at percentage level

CEPC will be sensitive to these

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [38]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2	Type II 2HD [39]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [39]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [39]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Composite Higgs [40]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6	Little Higgs w. T-parity [41]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7	Little Higgs w. T-parity [42]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8	Higgs-Radion [43]	-1.5	- 1.5	+10.	-1.5	-1.5	-1.5	-1.0	-1.5
9	Higgs Singlet [44]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

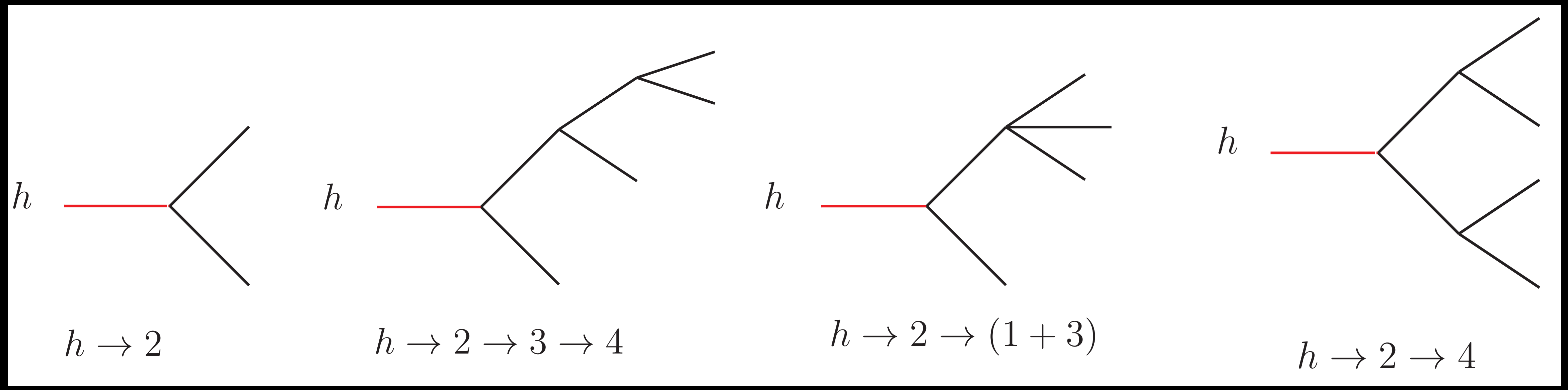
LHC not likely to be sensitive to these models even with full HL-LHC dataset

arXiv: 1710.07621

BSM Physics through Exotic Higgs Decays

General search for BSM

e^+e^- collider better than HL-LHC for MET+hadronic activity final states



Z. Liu, H. Zhang, LT Wang, 1612.09284

Electroweak observables at CEPC

Expect to have >10^{11} Z boson for electroweak precision physics

Observable	LEP precision	CEPC precision	CEPC runs	CEPC $\int \mathcal{L}dt$
m_Z	2.1 MeV	0.5 MeV	Z pole	8 ab^{-1}
Γ_Z	2.3 MeV	0.5 MeV	Z pole	8 ab^{-1}
$A_{FB}^{0,b}$	0.0016	0.0001	Z pole	8 ab^{-1}
$A_{FB}^{0,\mu}$	0.0013	0.00005	Z pole	8 ab^{-1}
$A_{FB}^{0,e}$	0.0025	0.00008	Z pole	8 ab^{-1}
$\sin^2\theta_W^{\text{eff}}$	0.00016	0.00001	Z pole	8 ab^{-1}
R_b^0	0.00066	0.00004	Z pole	8 ab^{-1}
R_μ^0	0.025	0.002	Z pole	8 ab^{-1}
m_W	33 MeV	1 MeV	WW threshold	2.6 ab^{-1}
m_W	33 MeV	2–3 MeV	ZH run	5.6 ab^{-1}
N_ν	1.7%	0.05%	ZH run	5.6 ab^{-1}

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

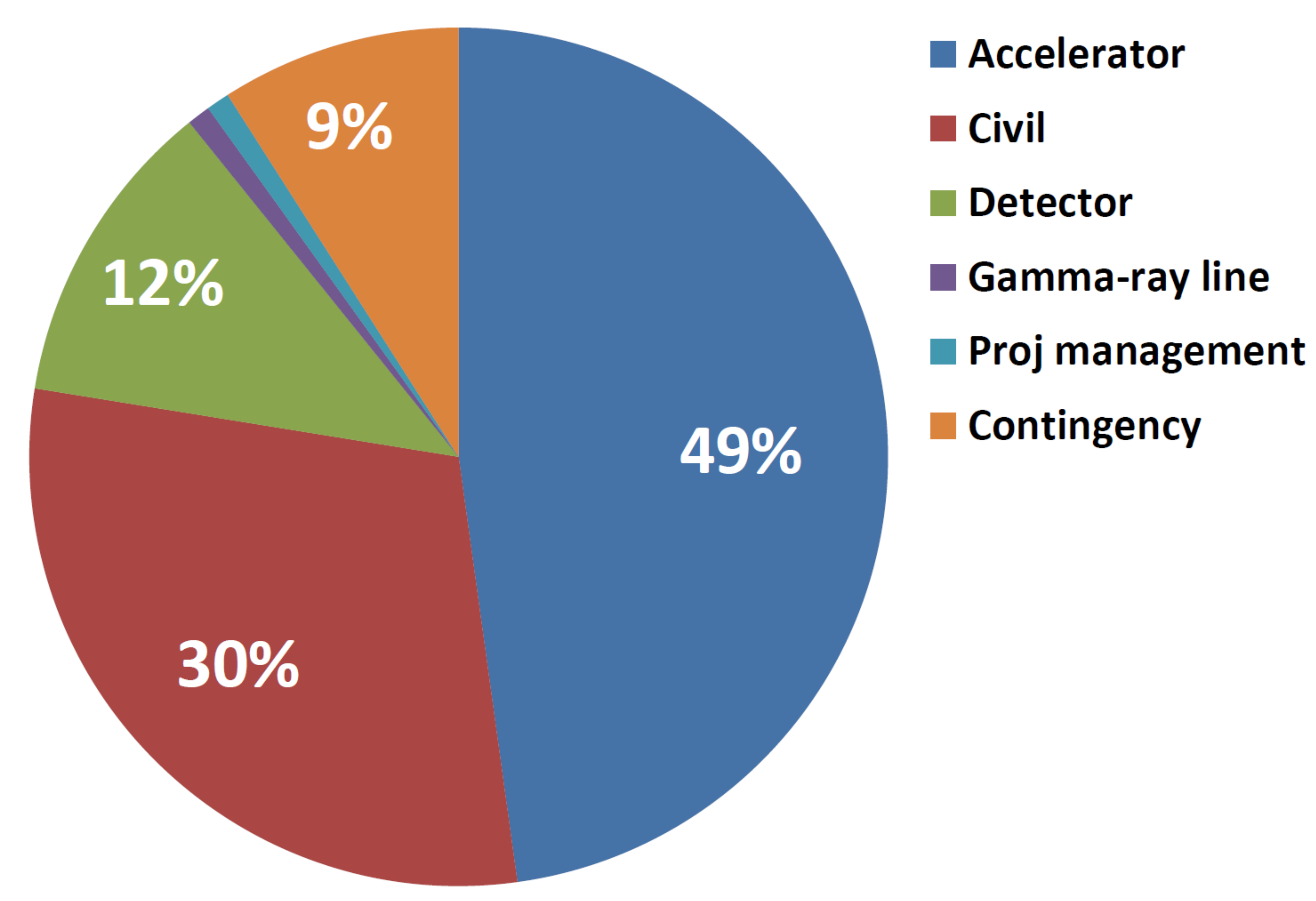
Currently secured funding

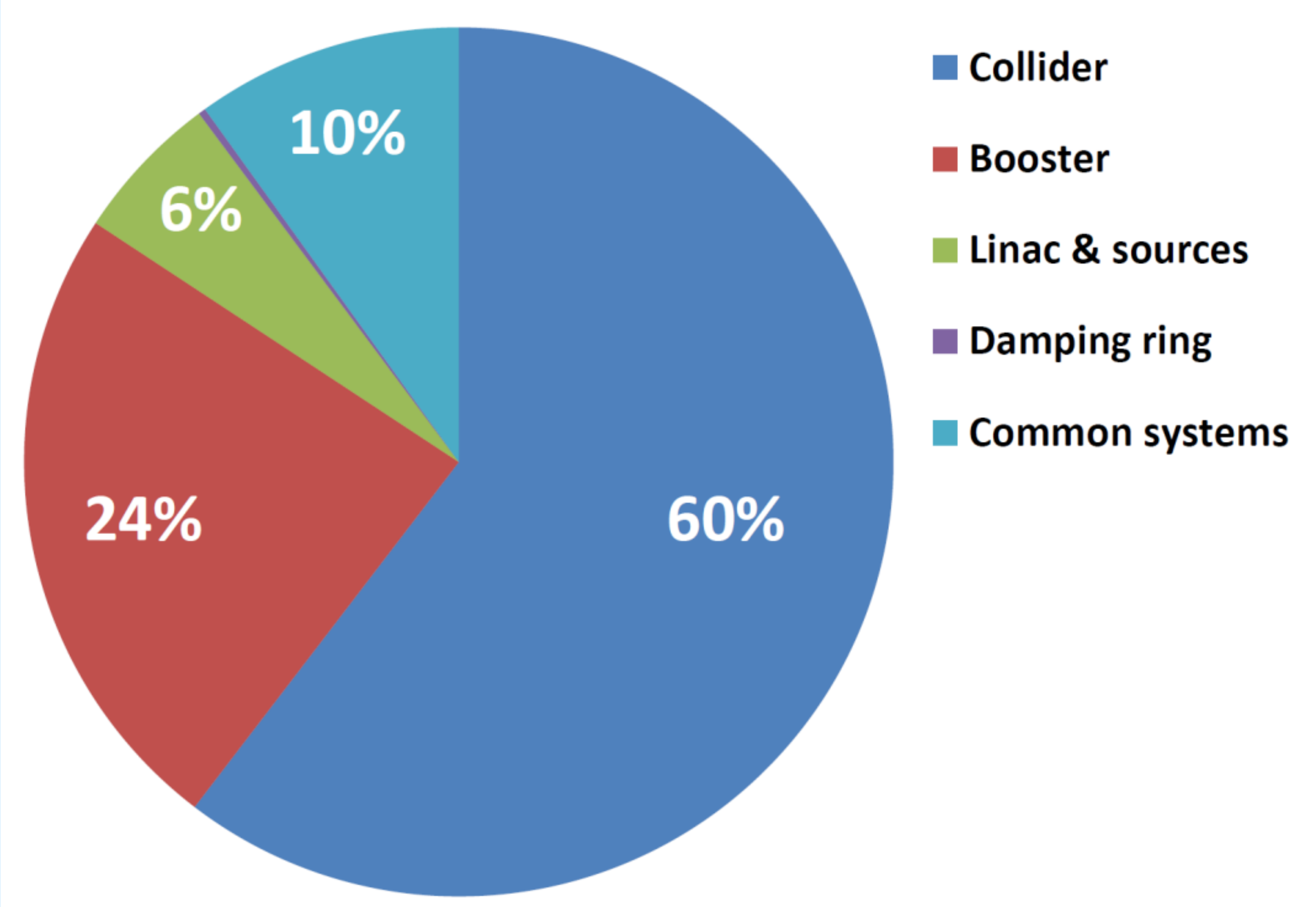
Cost of project

Cost of detectors not evaluated in detail and not part of the Conceptual Design Report

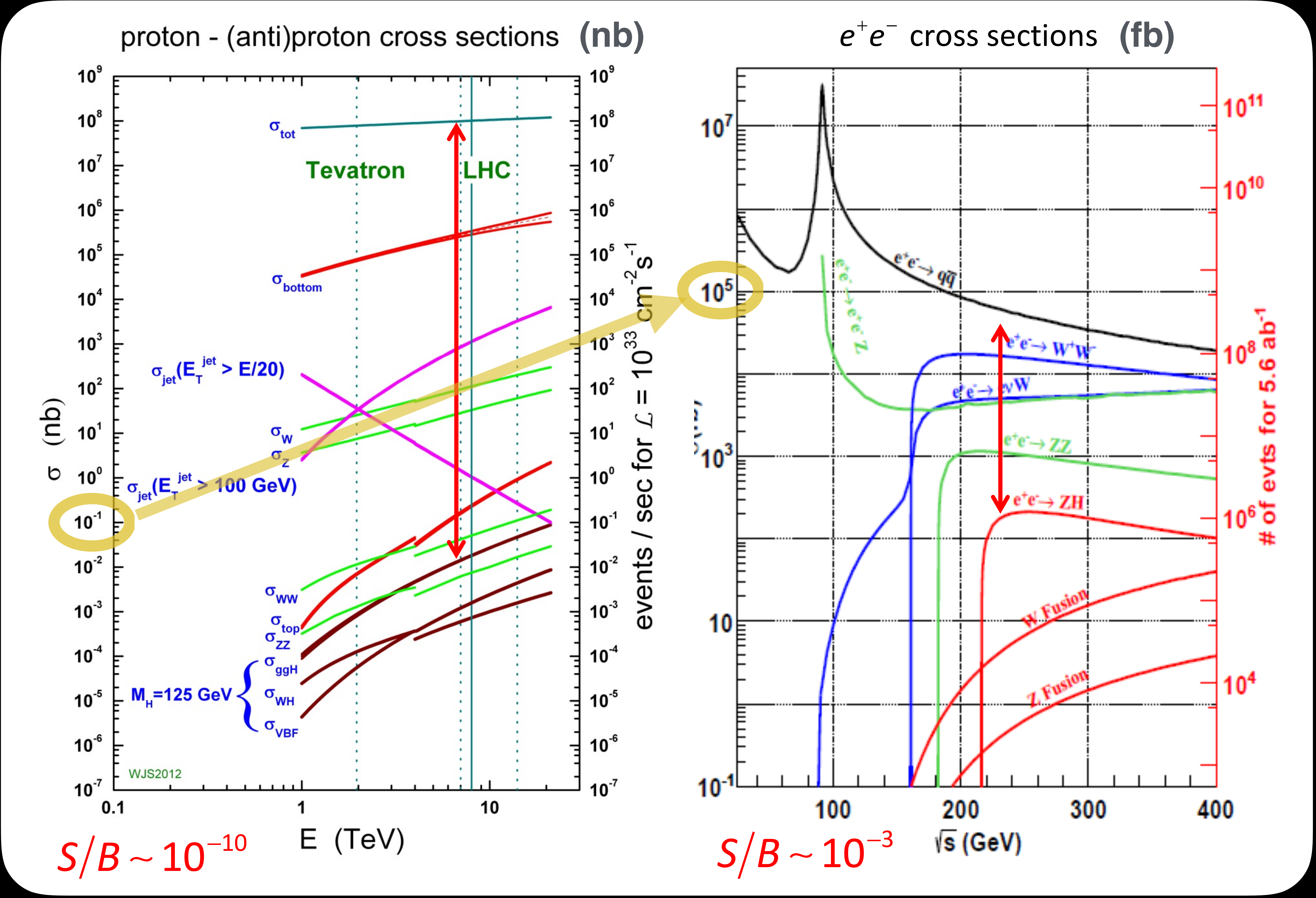
Careful costing estimates will be done moving forward towards the TDR

General evaluation of the relative cost of the project provided in the accelerator CDR





Cross sections: pp versus e+e−



In **pp collisions** interesting events need to be extracted from underneath a huge number of **background** events

S/B ~ 10^{-10}

In **ee collisions**

S/B ~ 10^{-3}

Generic detector requirements for high-energy e^+e^- colliders

Precision measurements

Require excellent momentum resolution and flavor tagging
- Low-mass vertex and tracking detectors, high granularity

Require excellent energy resolution
- Employ excellent calorimeters (particle flow, dual readout)

No major concerns about radiation hardness, unless for very forward detectors and inner most layer of vertex detector

Complementary subsystems

Subsystem	Measurement
Vertex detector	vertex position
	impact parameter → helps determine flavor
	track momenta of charged particles
Tracking detector	track momenta of charged particles
ECAL: electromagnetic calorimeter	energy of γ, $e^{\pm}$ and hadrons
HCAL: hadronic calorimeter	energy of hadrons (including neutrals)
Magnet system	bend charged particles → momentum measurement
Muon system	identify muons
Hermicity	missing energy (e.g. ν)
Luminosity detectors	luminosity