CEPC Physics and Detectors

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The CEPC Program

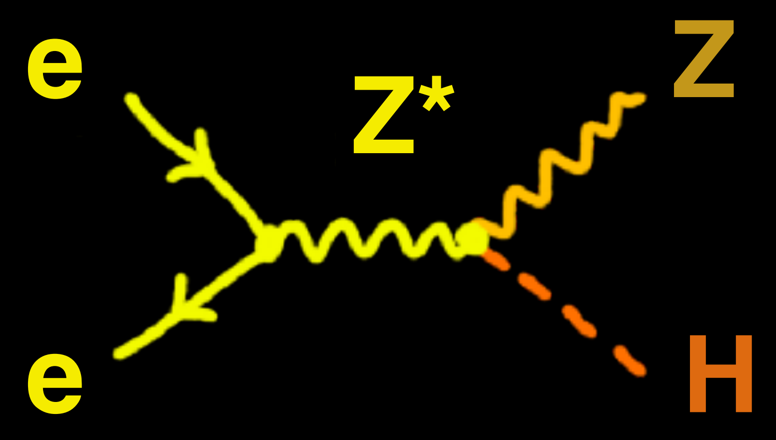
Accelerator Parameters	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Current main focus

CEPC: Electron-positron collisions at 91, 160, and 240 GeV)

Higgs factory (10^6 Higgs)

- Precision study of Higgs (m_H, couplings)
- Looking for hints of new physics
  - Higgs rare decays
- Similar & complementary to ILC



Z and W factory (10^{11} Z^0)

L (@ Z pole) > 16× 10^{34} $cm^{-2}s^{-1}$

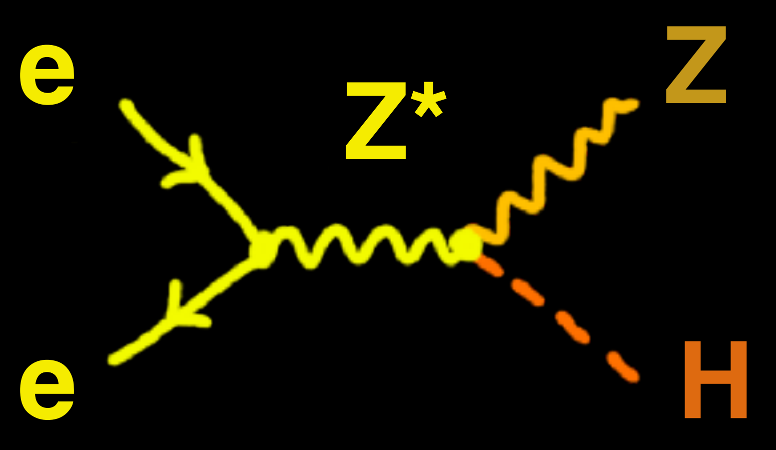
- Precision test of SM
- Search for rare decays

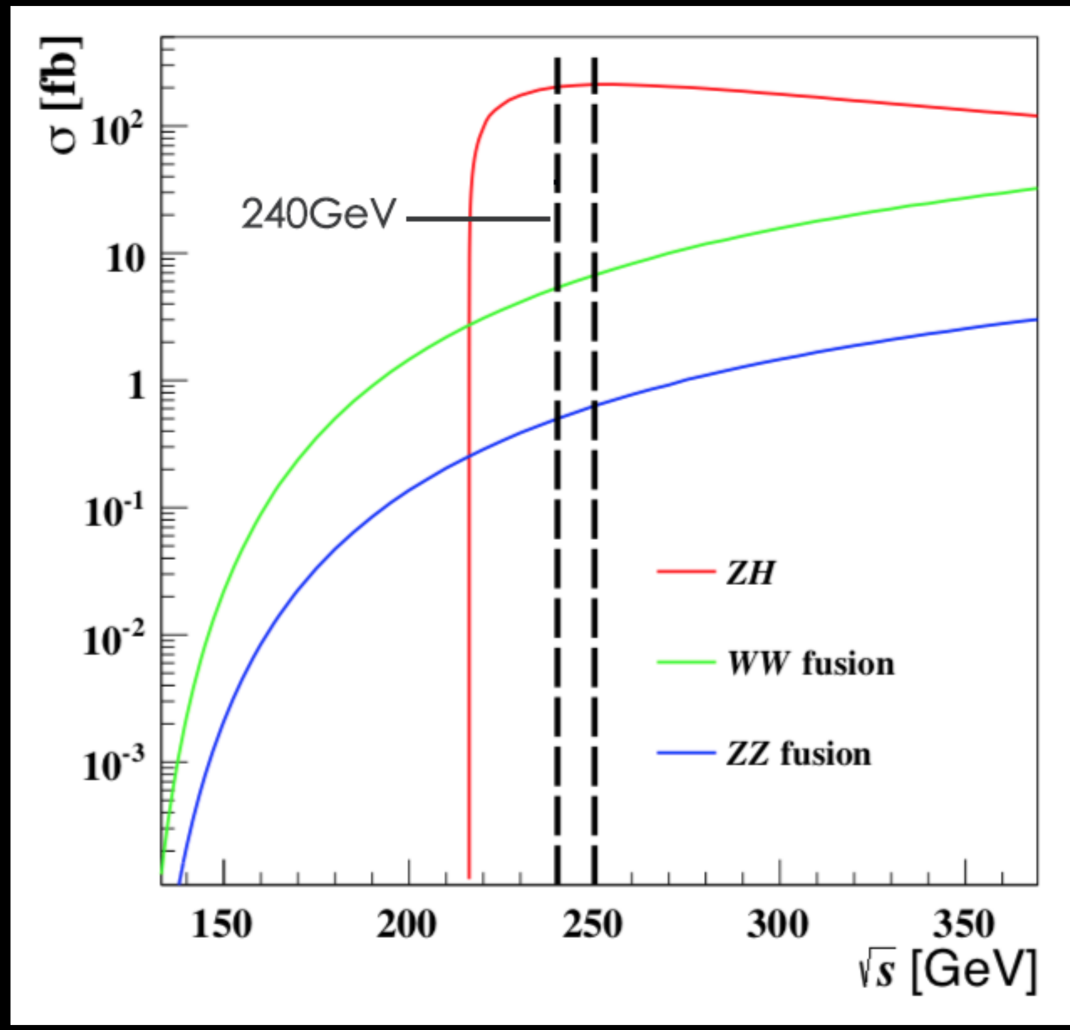
Flavor factory: *b*, *c*, *τ* and QCD studies

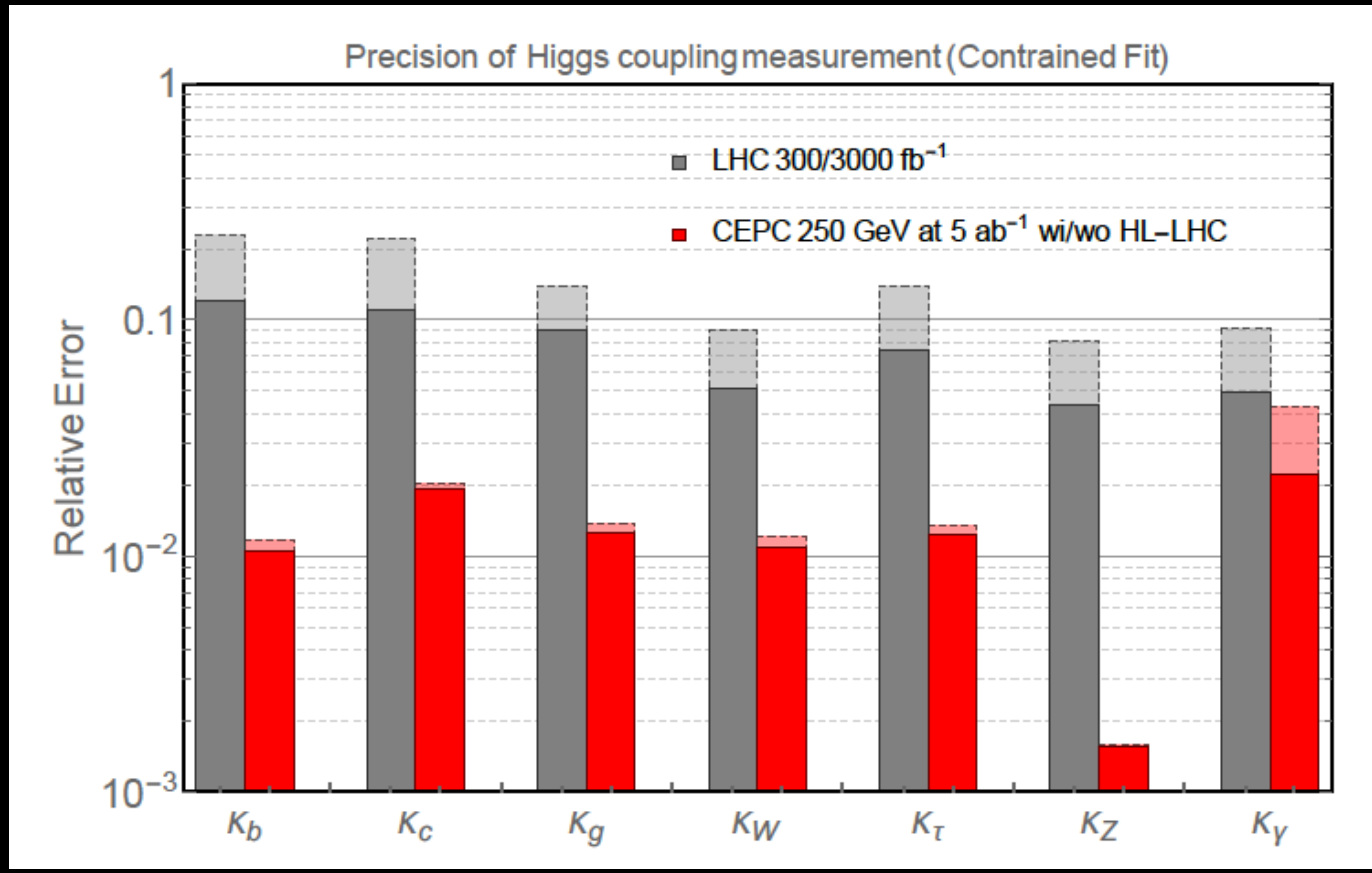
Precision Physics Overview

Higgs precision physics

Kaili Zhang, Yu Dan, Fangyi Guo, Tong Li, Yanyan Gao, Xin Shi, Bayju
Tomorrow







W and Z precision physics

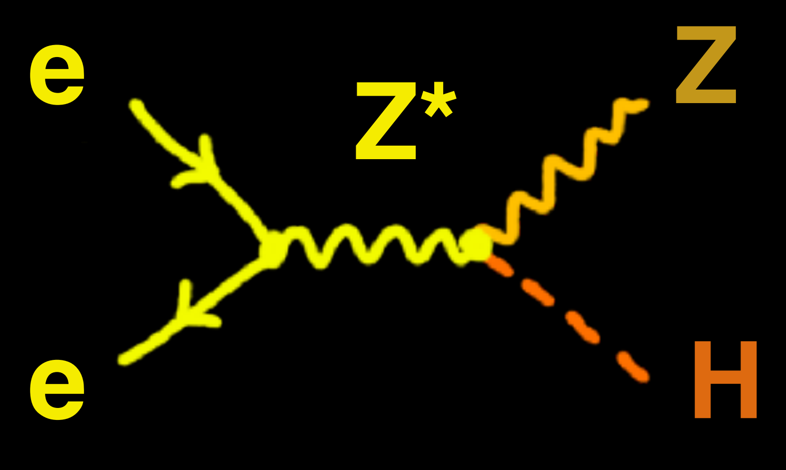
Zhijun Liang, Hengne Li, Peixun Shen
Tomorrow

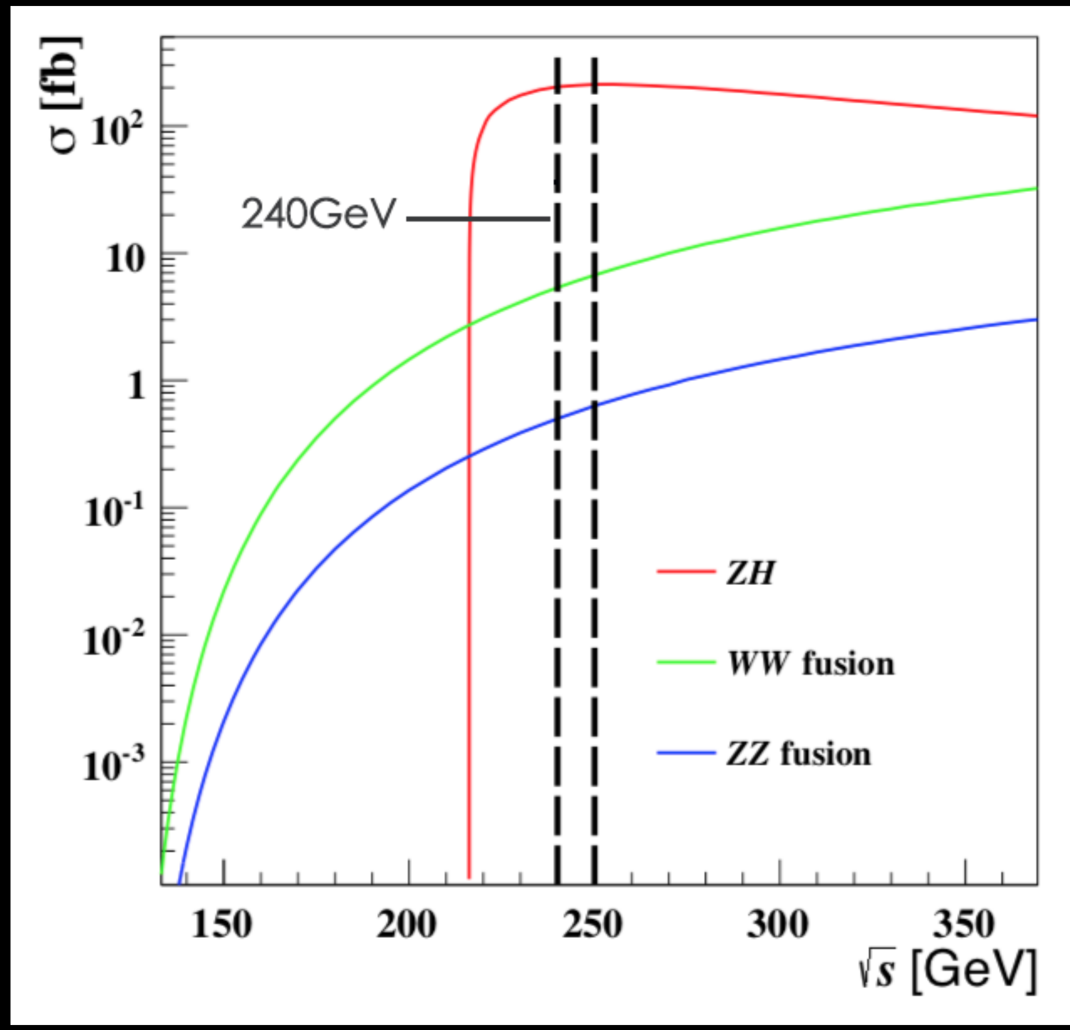
Observable	LEP precision	CEPC precision	CEPC runs	$\int \mathcal{L}$ needed in CEPC
m_Z	2 MeV	0.5 MeV	Z threshold scan runs	1ab^{-1}
m_W	33 MeV	2-3 MeV	WW threshold, ZH runs	5ab^{-1}
A^b_{FB}	1.7%	0.1%	Z threshold scan runs	1ab^{-1}
$\sin^2\theta^{\text{eff}}_W$	0.07%	0.01%	Z threshold scan runs	1ab^{-1}
R_b	0.3%	0.05%	Z pole	1ab^{-1}
N_ν	1.7%	0.05%	ZH runs	5ab^{-1}
R_μ	0.2%	0.01%	Z pole	1fb^{-1}

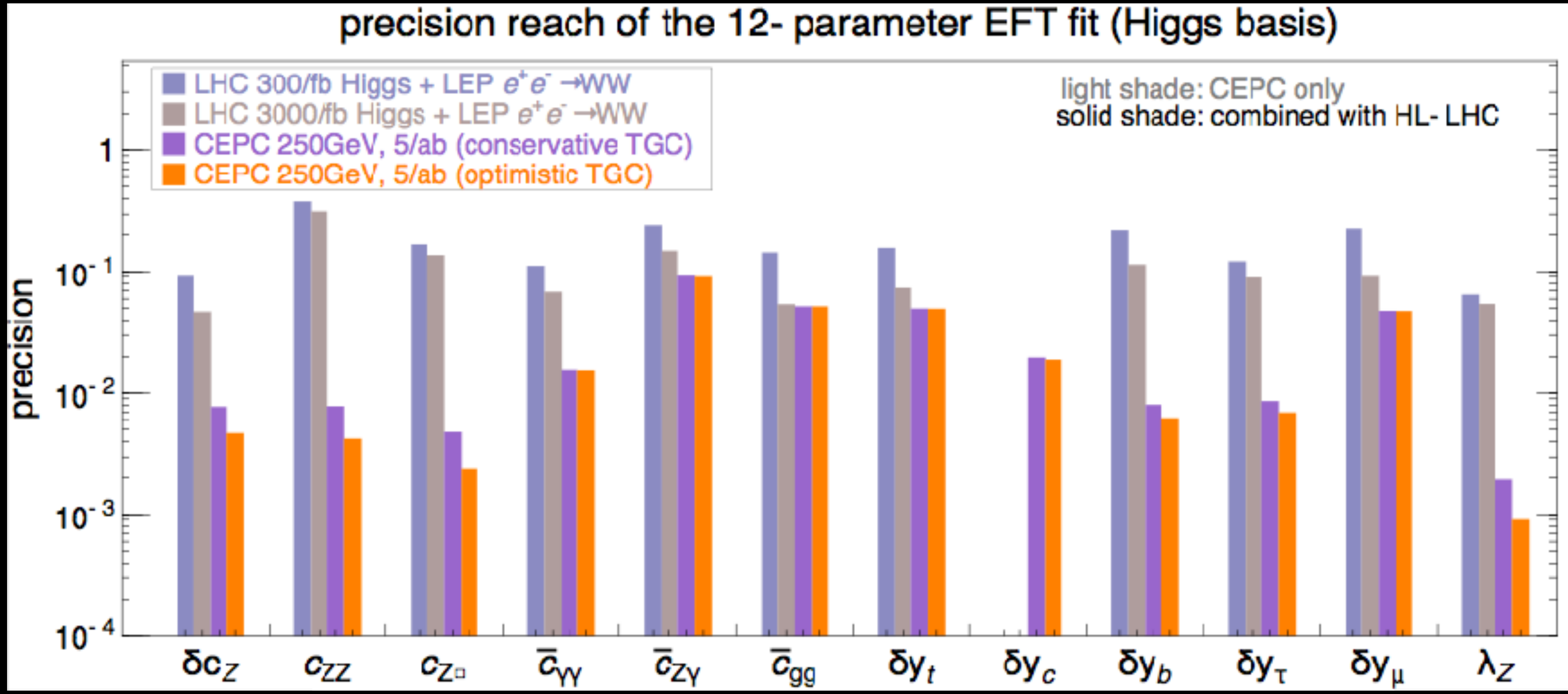
Precision Physics Overview

Higgs precision physics

Kaili Zhang, Yu Dan, Fangyi Guo, Tong Li, Yanyan Gao, Xin Shi, Bayju
Tomorrow







W and Z precision physics

Zhijun Liang, Hengne Li, Peixun Shen
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The physics case – theory overview

CEPC Conceptual Design Report: theory overview

April 8, 2018

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In the final editing phase

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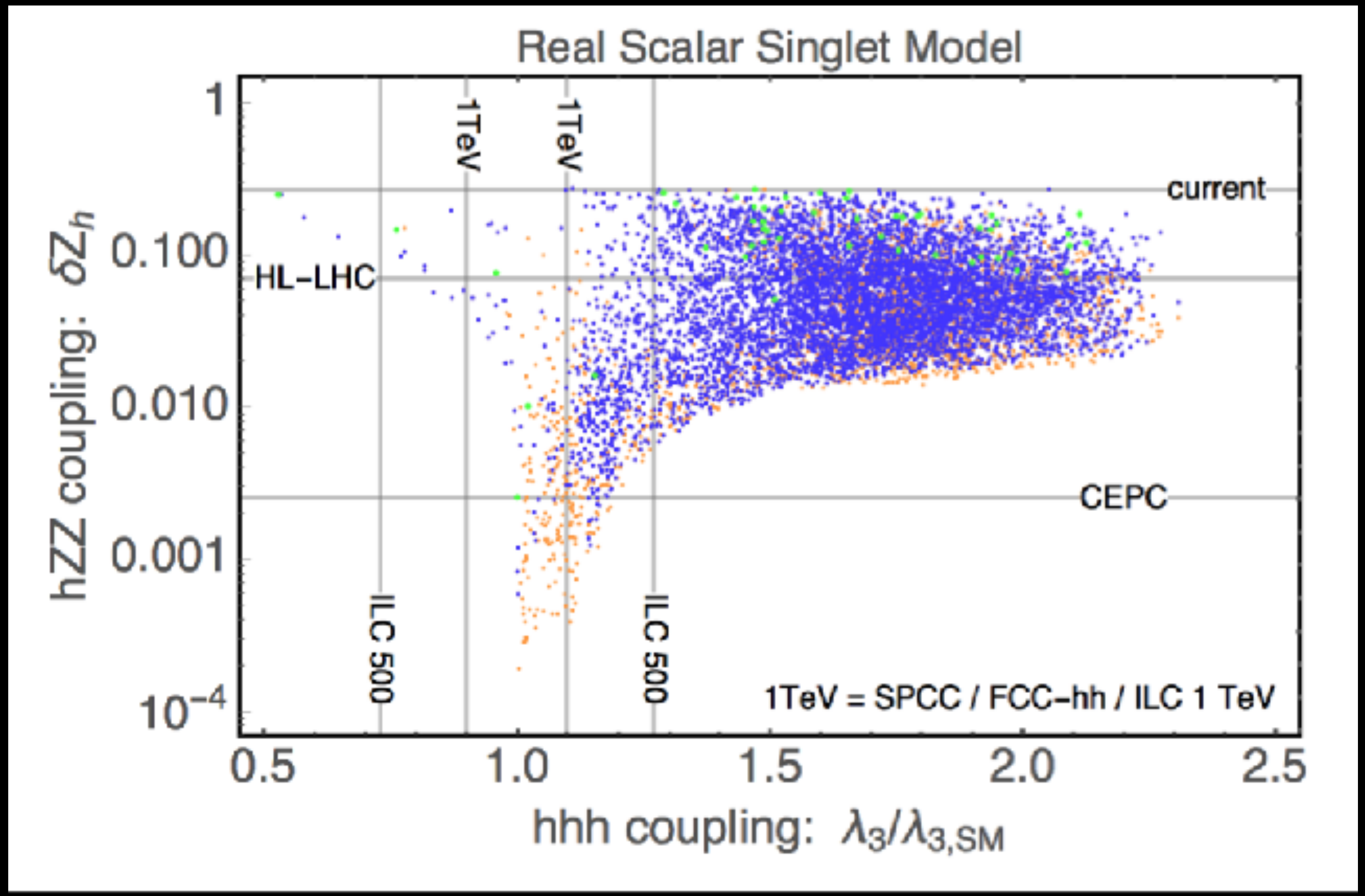
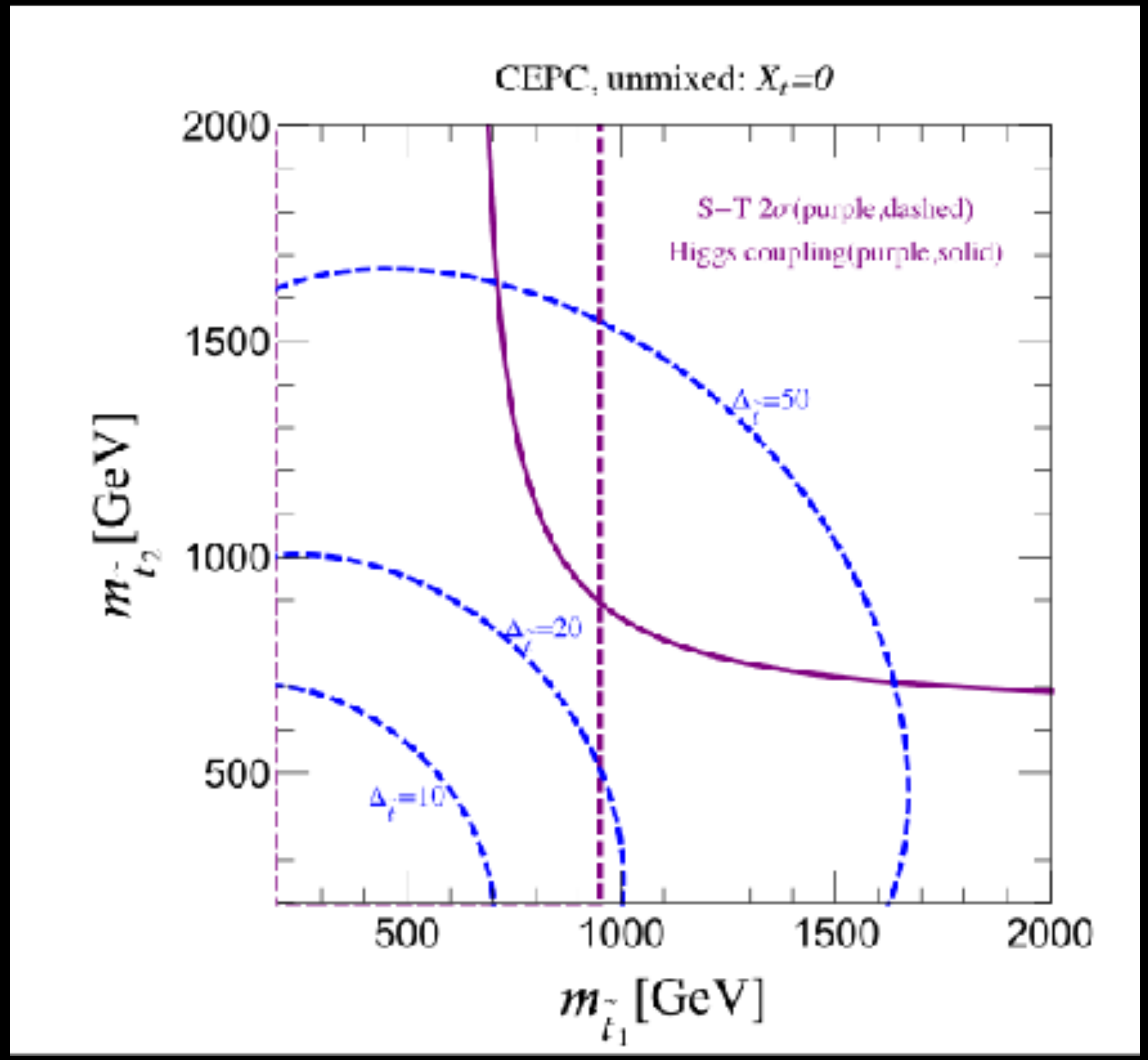
With many inputs and contributions from the International community

A few other physics highlights

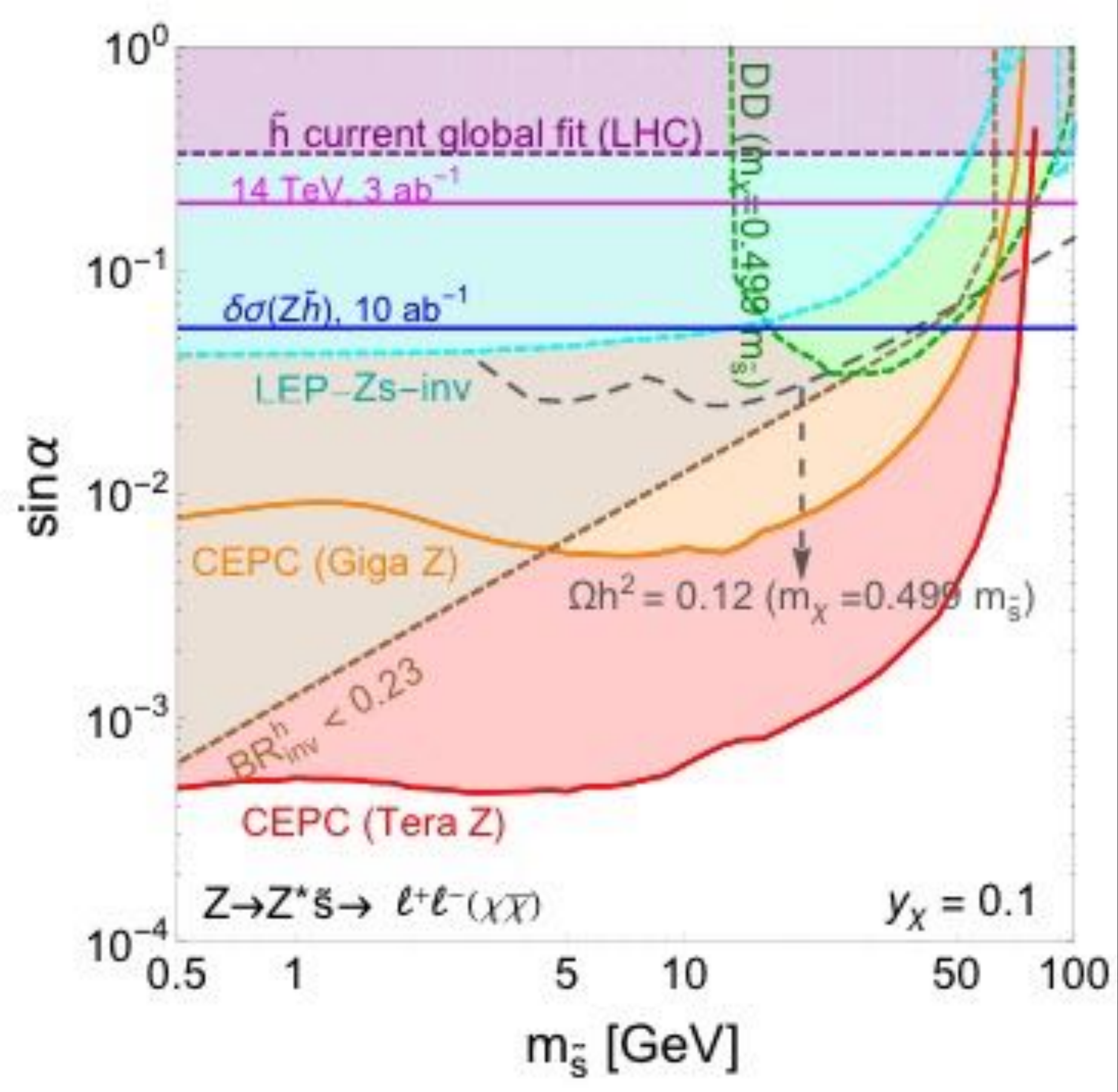
Is EWPT 1st order?

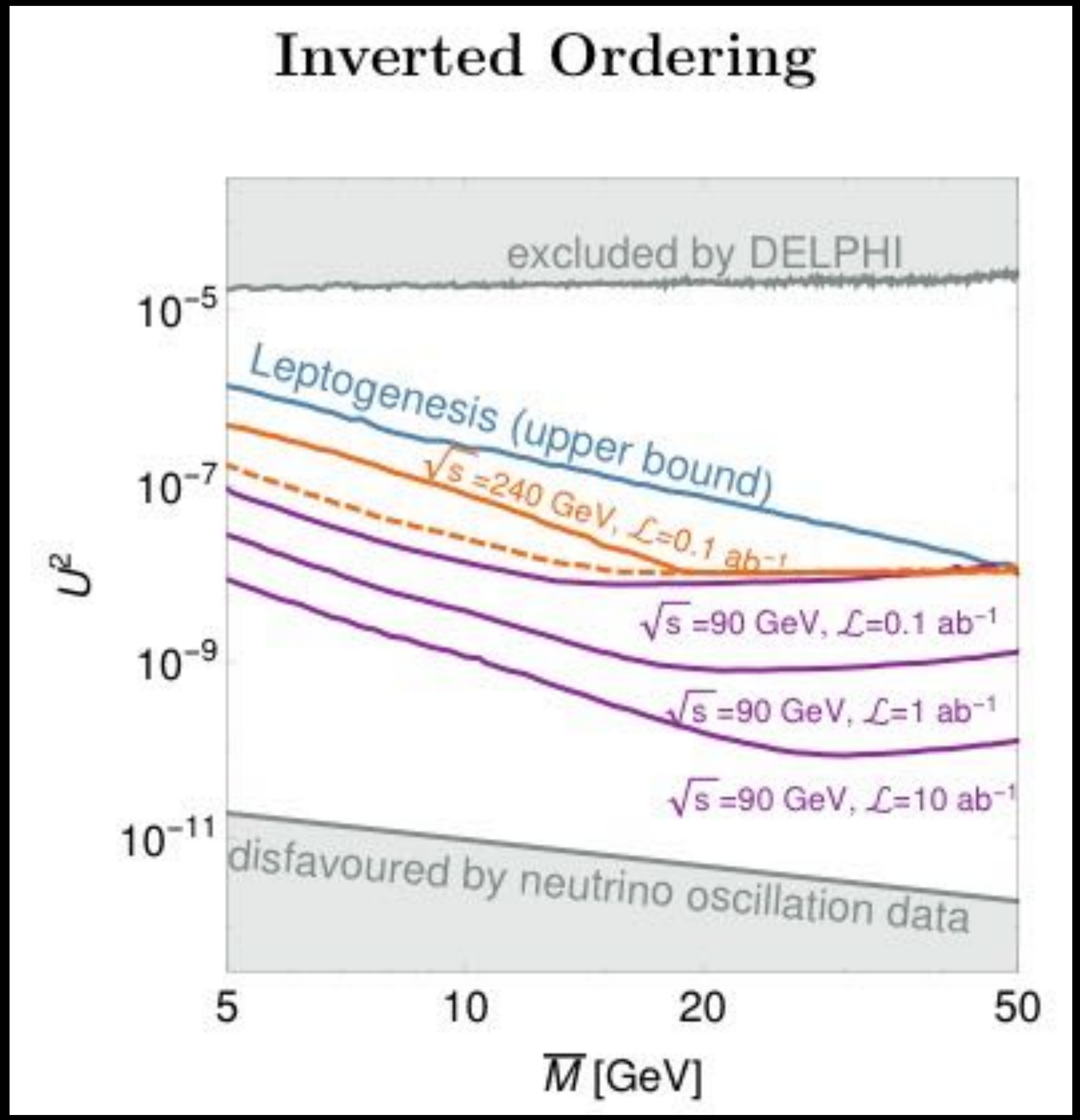




Naturalness

Dark sector search
With Z rare decay





Origin of neutrino mass

CEPC “optimistic” Schedule

- Design issues
- R&D items
- preCDR

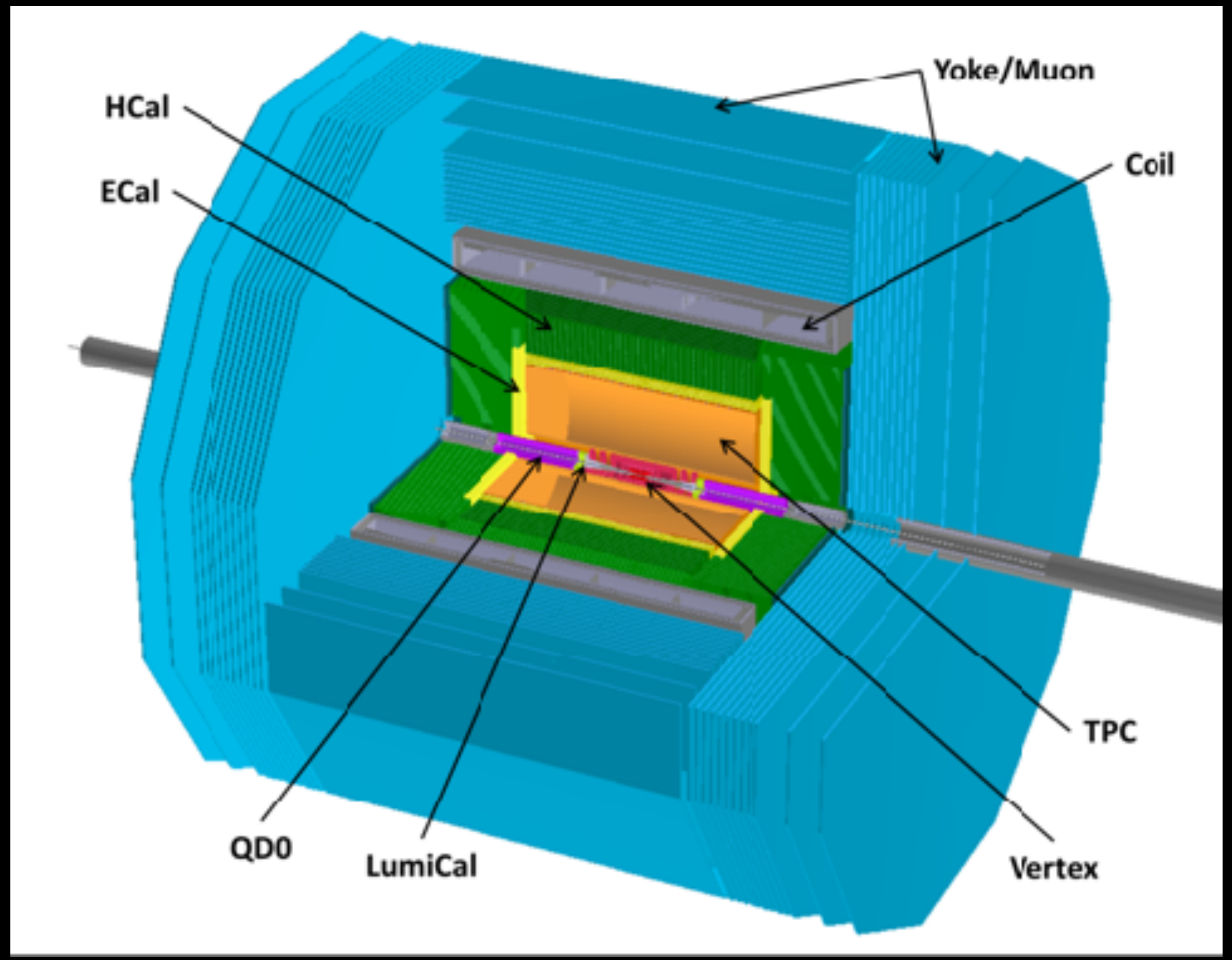
- Design, funding
- R&D program
- Intl. collaboration
- Site study

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

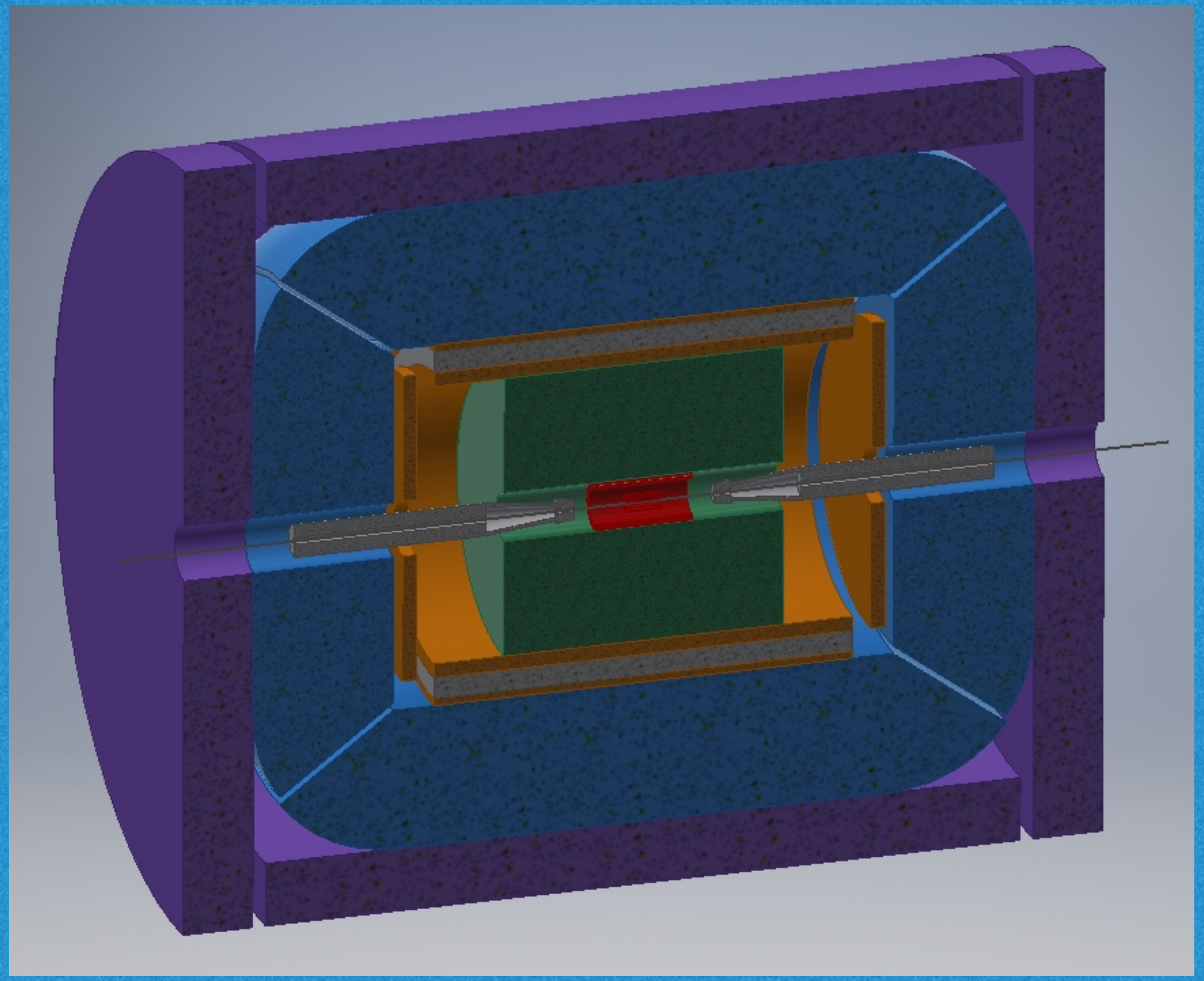
- CEPC data-taking starts before the LHC program ends
- Possibly concurrent with the ILC program

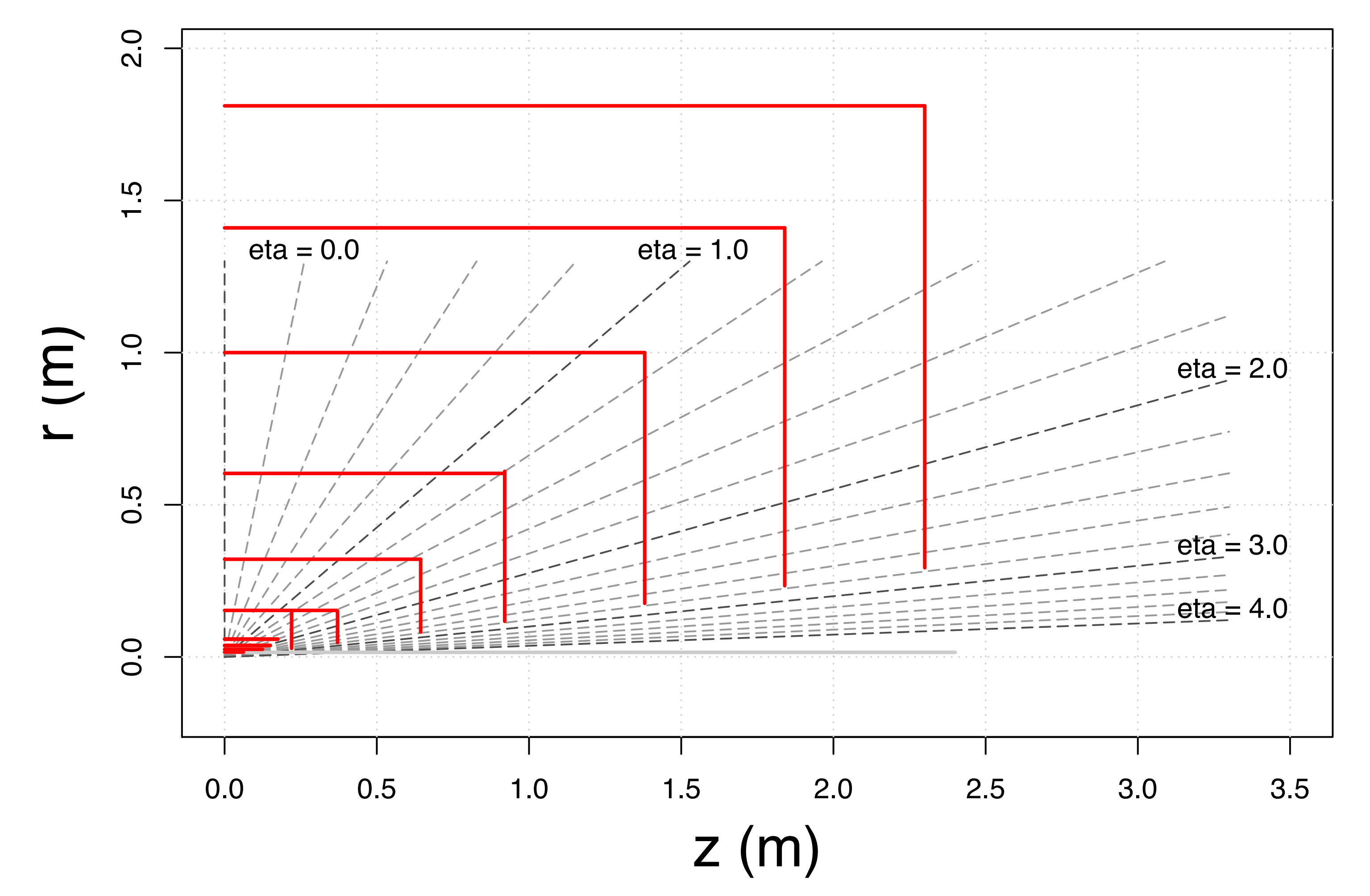
Detector Conceptual Designs (CDR)

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



Low magnetic field concept (2 Tesla)



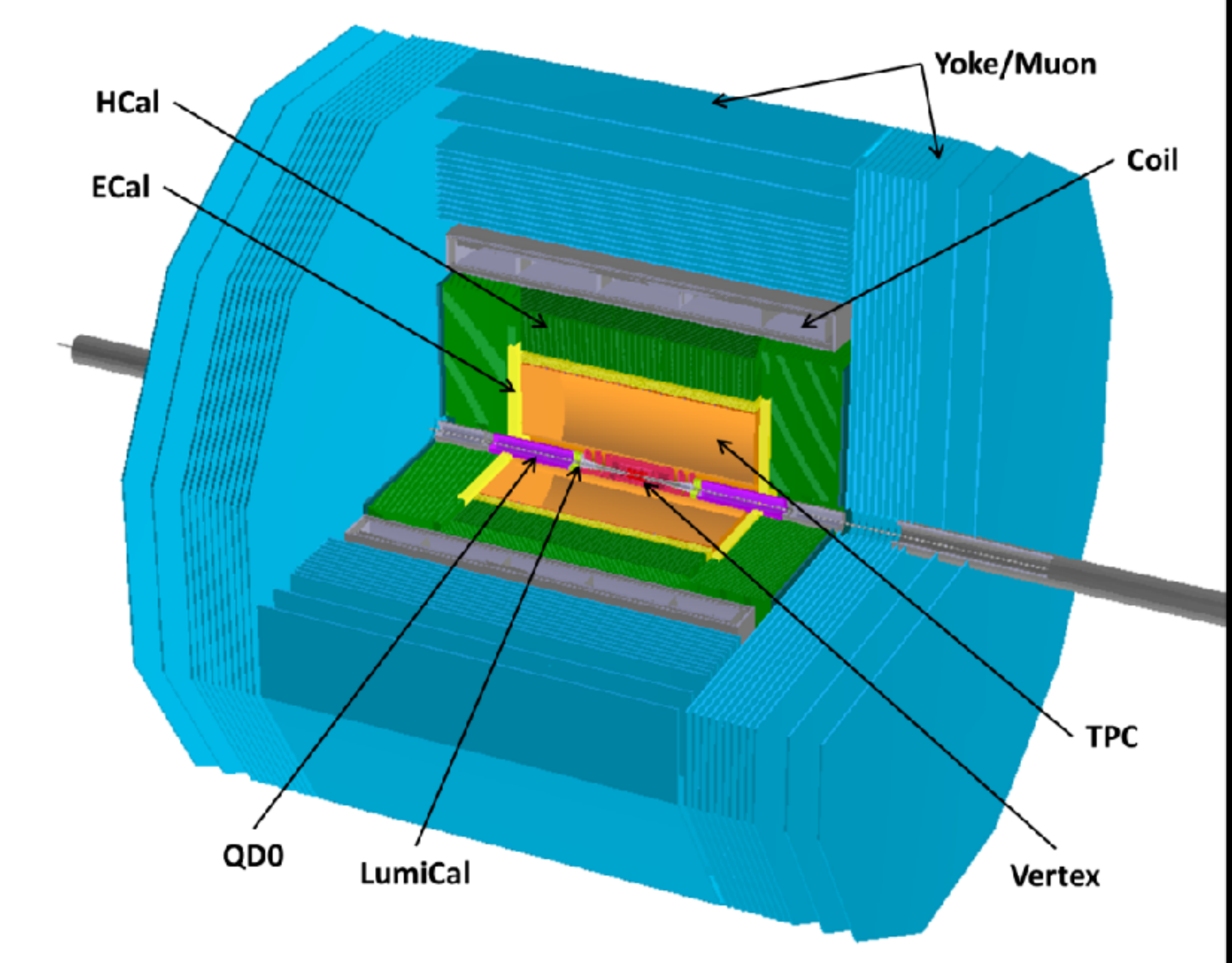


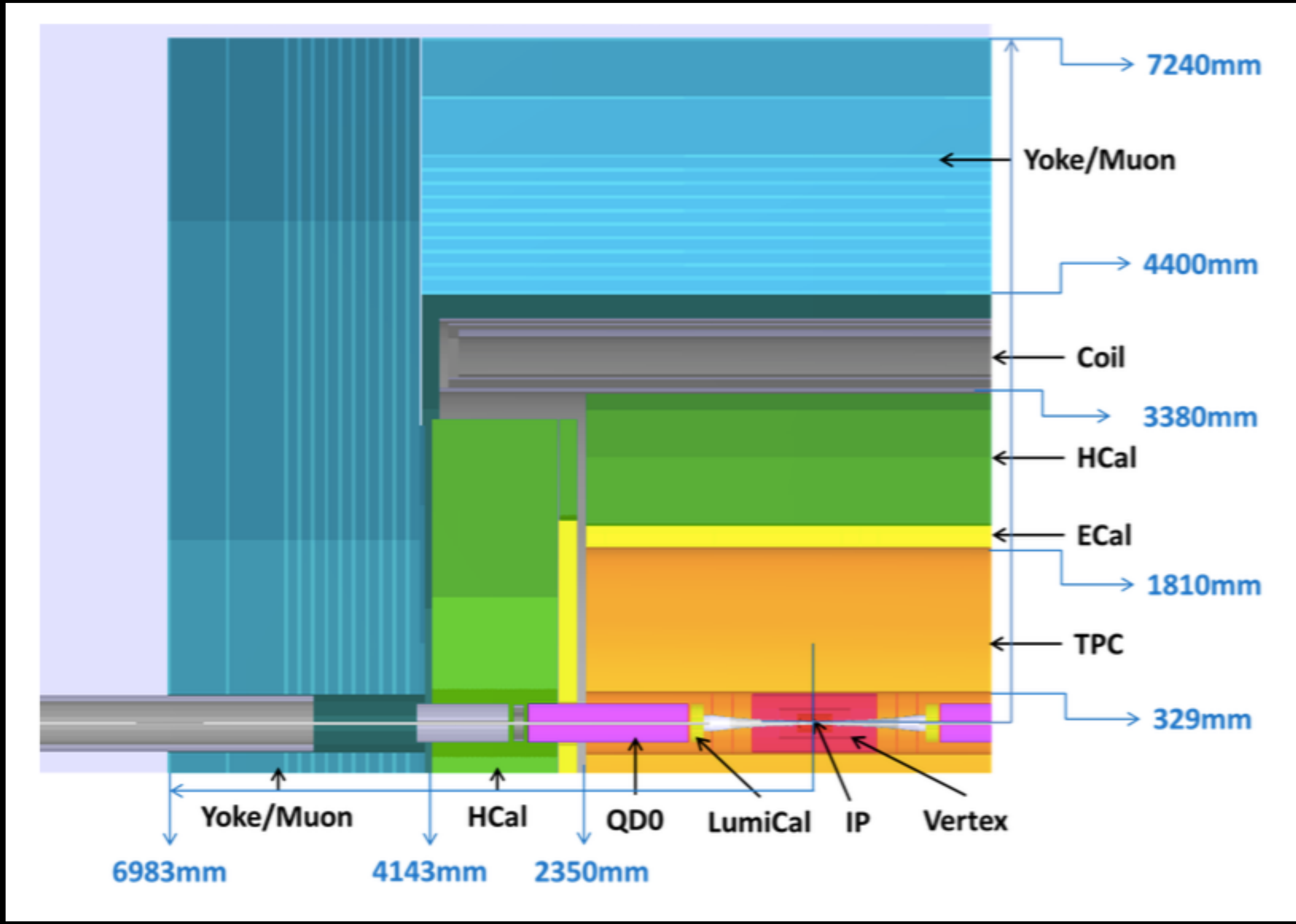
Full silicon tracker concept

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

CEPC baseline detector: ILD-like

Manqi Ruan
Tomorrow, 9:00 am





Magnetic Field: 3 Tesla — changed from preCDR

- **Impact parameter resolution**: less than 5 μm ⟵ Flavor tagging
- **Tracking resolution**: $\delta(1/Pt) \sim 2\times10^{-5}\ (GeV^{-1})$ ⟵ 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

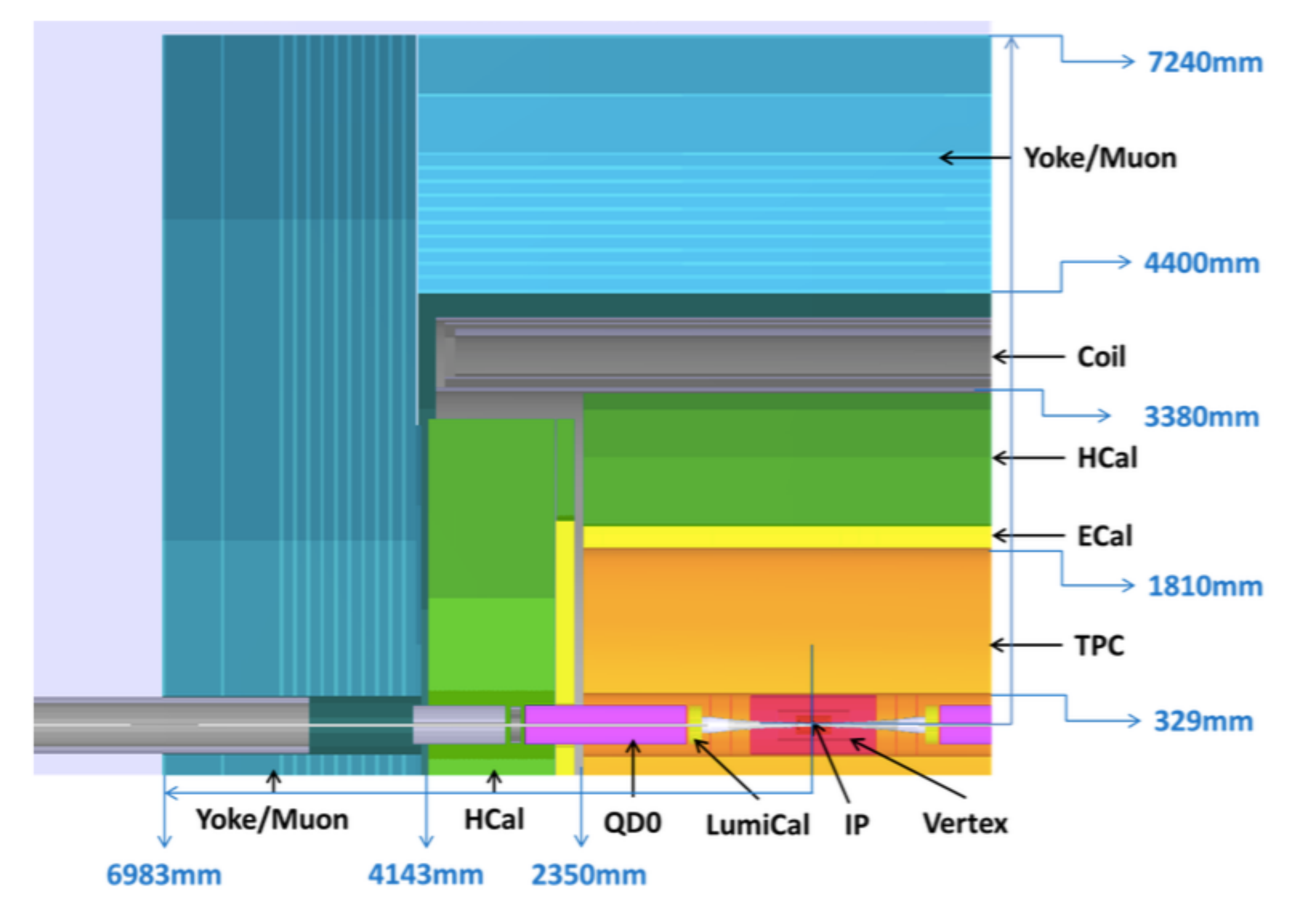
Major concerns being addressed

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



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

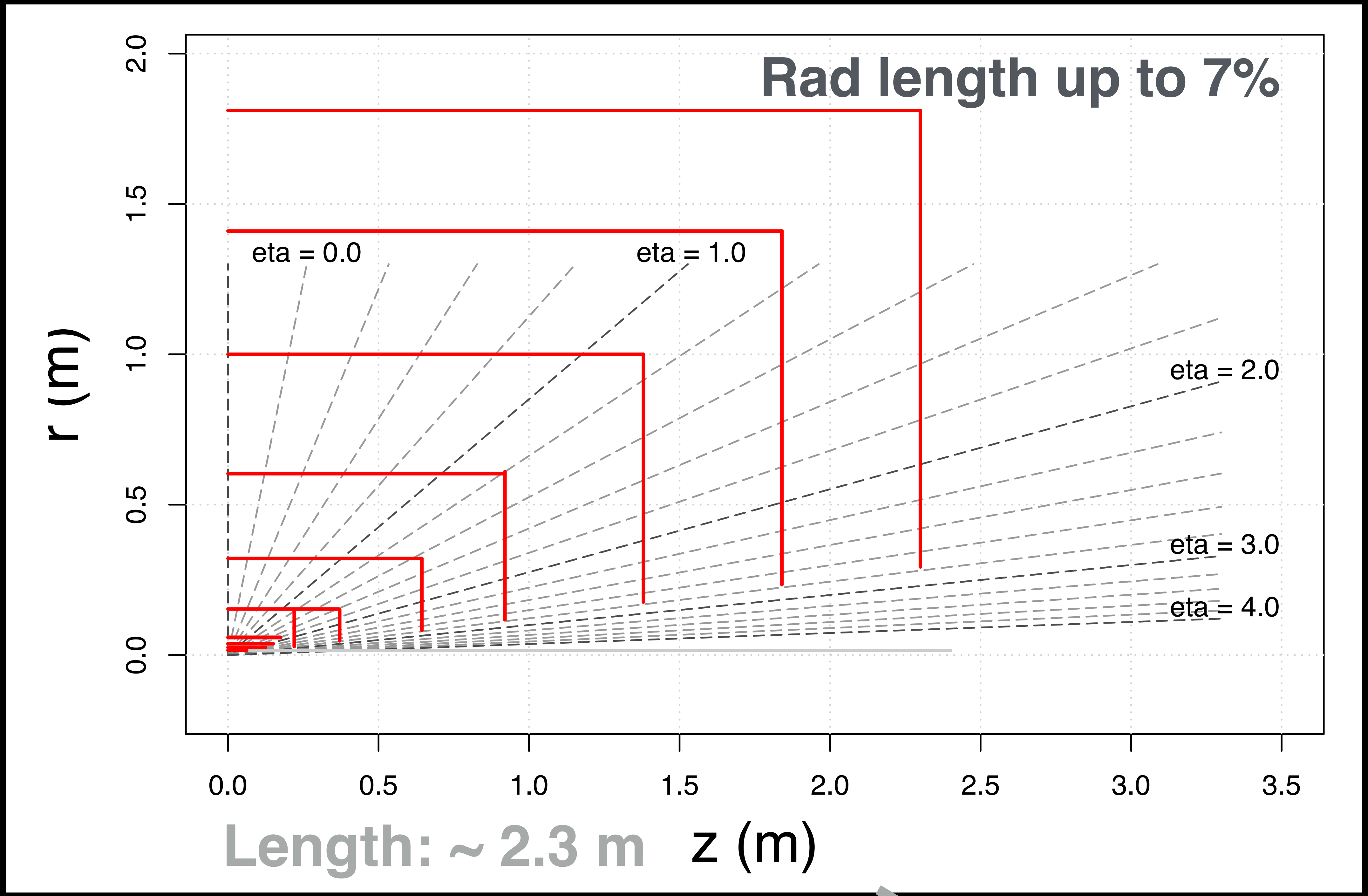
Full silicon tracker concept

Chengdong Fu
Tomorrow, 12:00 pm

Replace TPC with additional silicon layers

CEPC-SID:

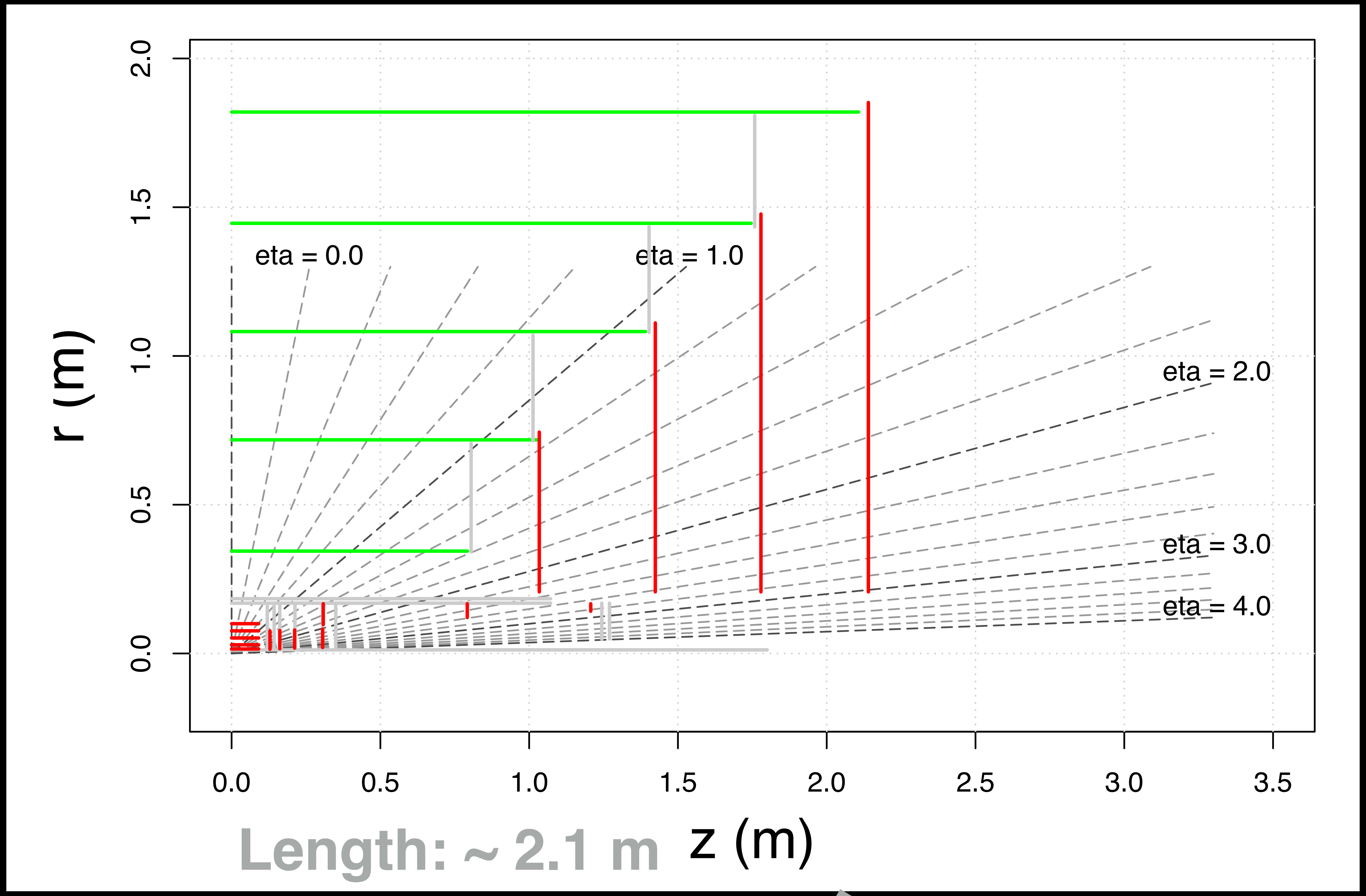
6 barrel double strip layers
5 endcap double strip layers



Radius
~ 1.8 m

SIDB: SiD optimized

5 barrel single strip layers
5 endcap double strip layers



ZH → ννμμ
Di-muon mass

$\sigma(m_{\mu\mu})$ = 0.21 GeV

$\sigma(m_{\mu\mu})$ = 0.26 GeV

TPC detector: $\sigma(m_{\mu\mu})$ = 0.24 GeV

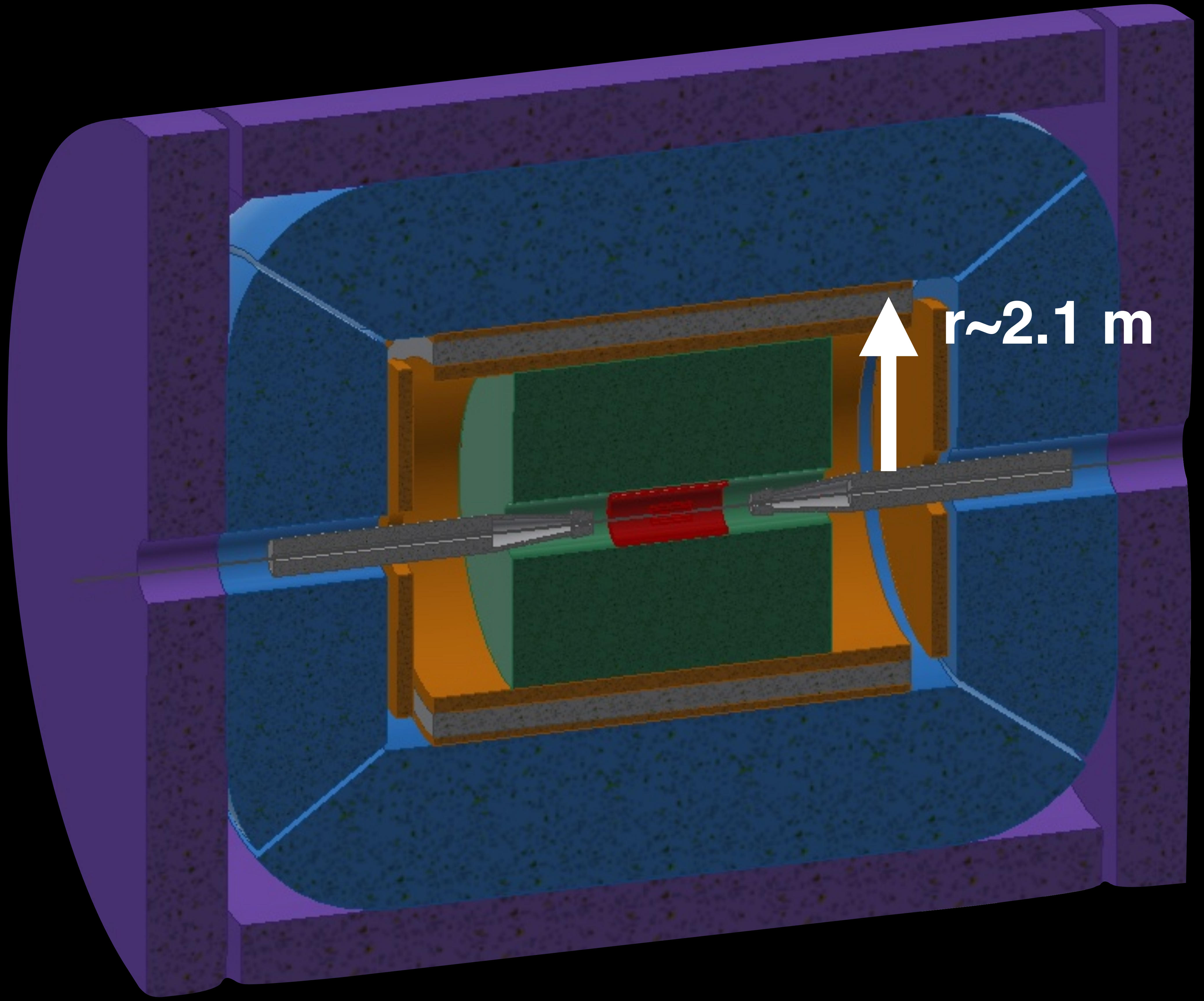
Preliminary

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

Low magnetic field detector concept

Massimo Caccia
Tomorrow, 9:24 am

Proposed by INFN, Italy colleagues



Similar to Concept Detector for CLIC

Open for collaboration within 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 into Conceptual Design Report

Dual readout calorimeter: Chapter 5

Drift chamber: Chapter 4

Muon detector (μRwell): Chapter 7

Interaction region: Machine Detector Interface

Sha Bai
Today, 3:00 pm

One of the most complicated issue in the CEPC detector design

Full partial double ring

Updated baseline parameters:

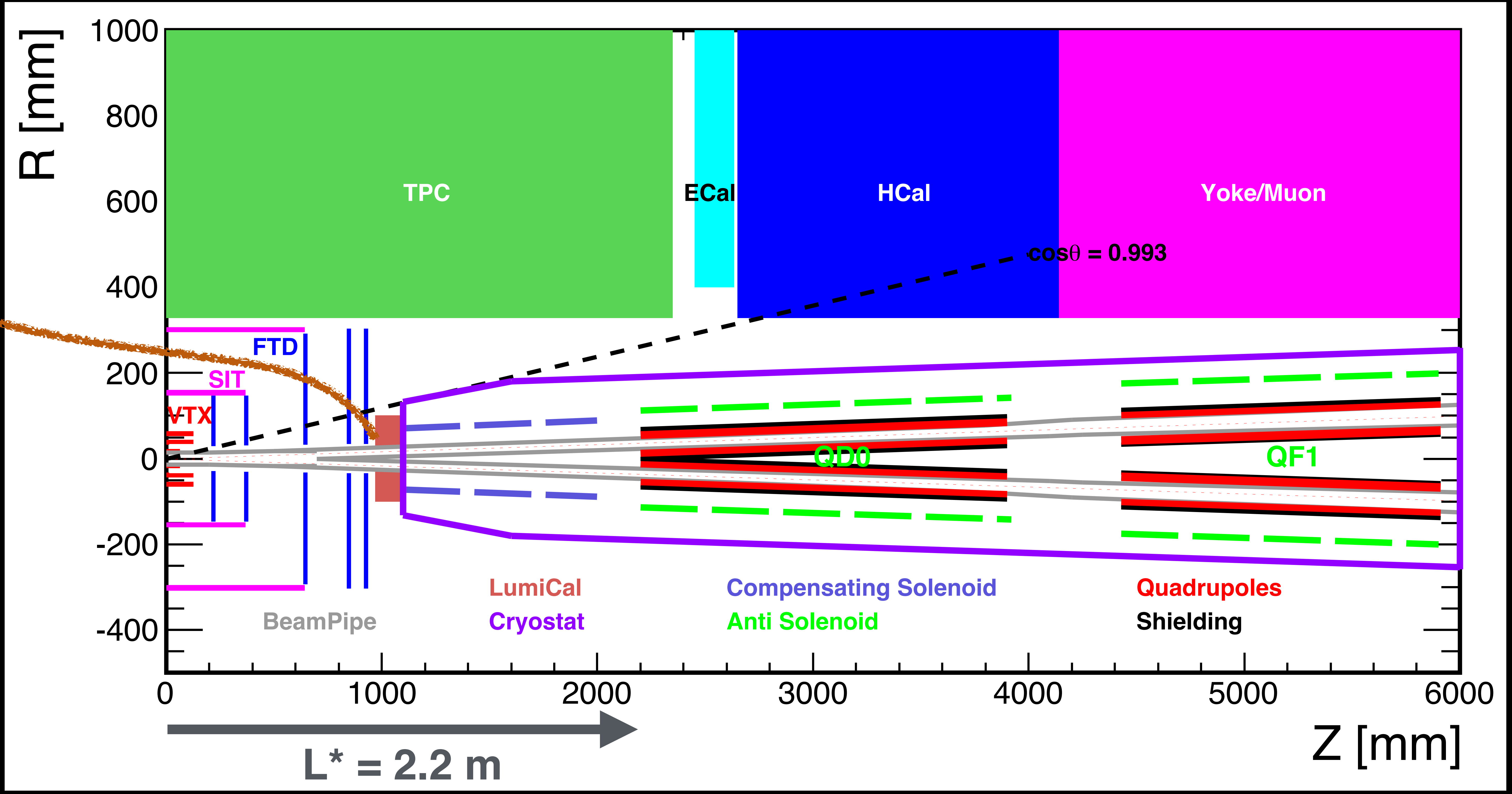
- Head-on collision changed to crossing angle of **33 mrad**
- Focal length (**L***) increased from 1.5 m to **2.2 m**
- Solenoid field reduced from 3.5 T to **3 T**

LumiCal

Lumi unc: 1 × 10^{-3}

(studies lead by Vinca and Academia Sinica)

Ivanka Bozovic
Tomorrow, 5:00 pm



Challenging engineering design

Magnet	Field Strength	Length	Inner Radius
QD0	136 T/m	1.73m	19 mm

Interaction region: Machine Detector Interface

Hongbo Zhu
Today, 4:00 pm

Machine induced backgrounds

- Radiative Bhabha scattering
- Beam-beam interactions
- Synchrotron radiation
- Beam-gas interactions

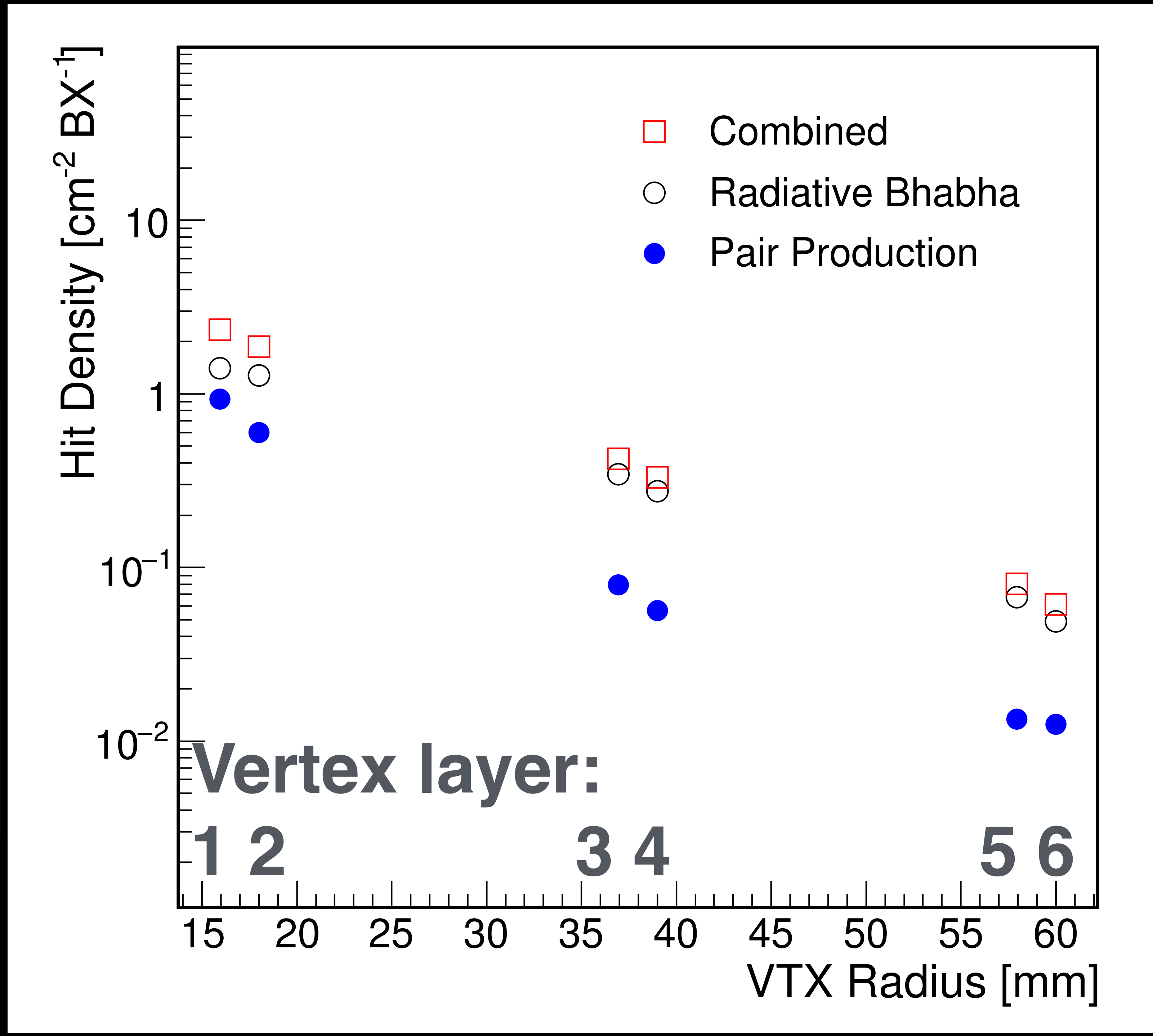
Studies for new configuration being finalized

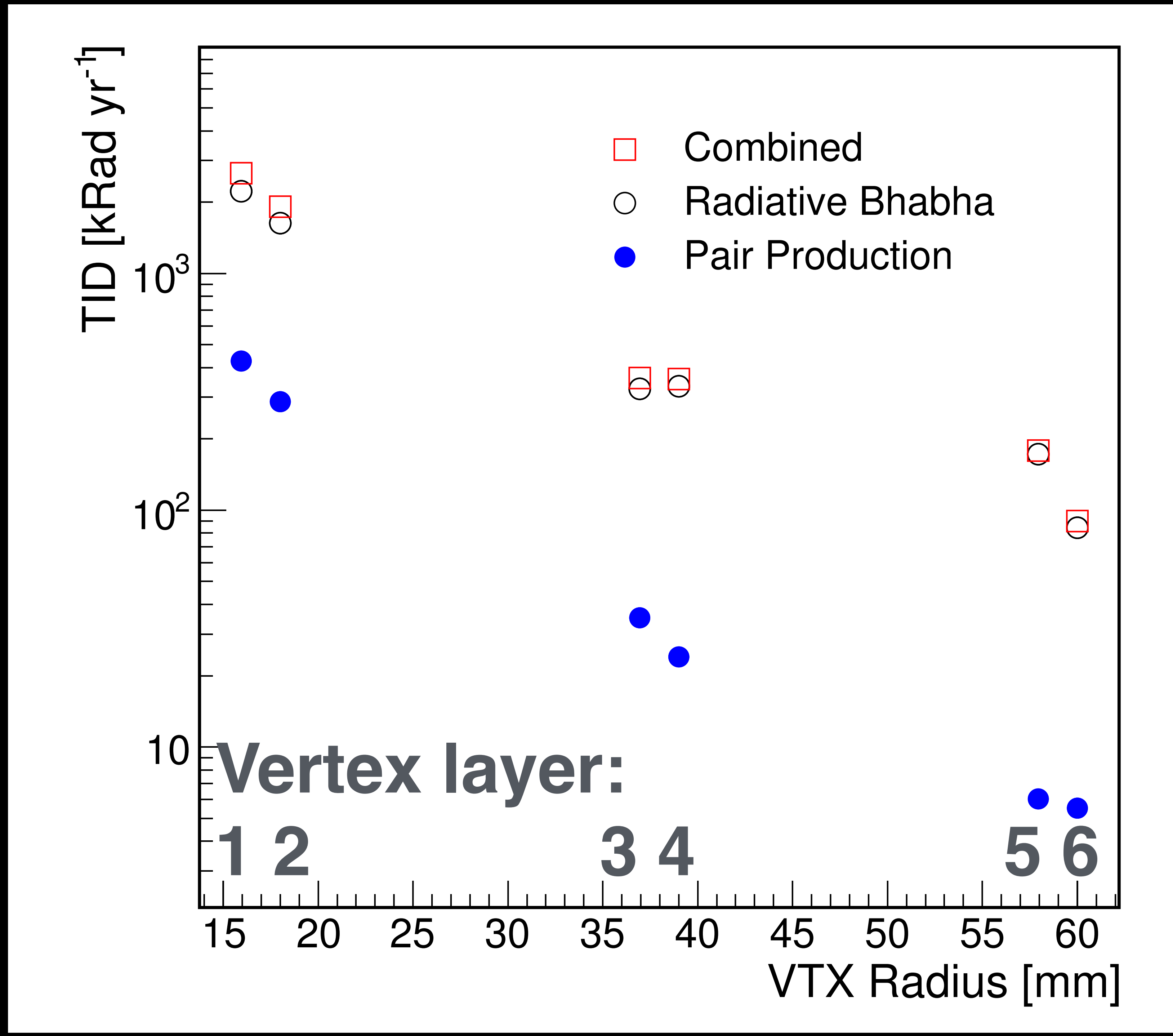
Higgs operation (E_{cm} = 240 GeV)

Rates at the inner layer (16 mm):

Hit density: ~2.5 hits/cm^2/BX
TID: 2.5 MRad/year
NIEL: 10^{12} 1MeV n_{eq}/cm^2

(Safety factors of 10 applied)





Vertex Detector Performance Requirements

Efficient identification of heavy quarks (b/c) and τ leptons

$$\sigma_{r\phi} = 5 \oplus \frac{10}{p(GeV)\sin^{3/2}\theta} (\mu m)$$

Intrinsic resolution of vertex detector

Resolution effects due to multiple scattering

Dominant for low-p_T tracks

	Specs	Consequences
Single point resolution near IP:	< 3 μm	High granularity
First layer close to beam pipe:	r ~ 1.6 cm	
Material budget/layer:	≤ 0.15%X_0	Low power consumption, < 50 mW/cm² for air cooling
Detector occupancy:	≤ 1%	High granularity and short readout time (< 20 μs)

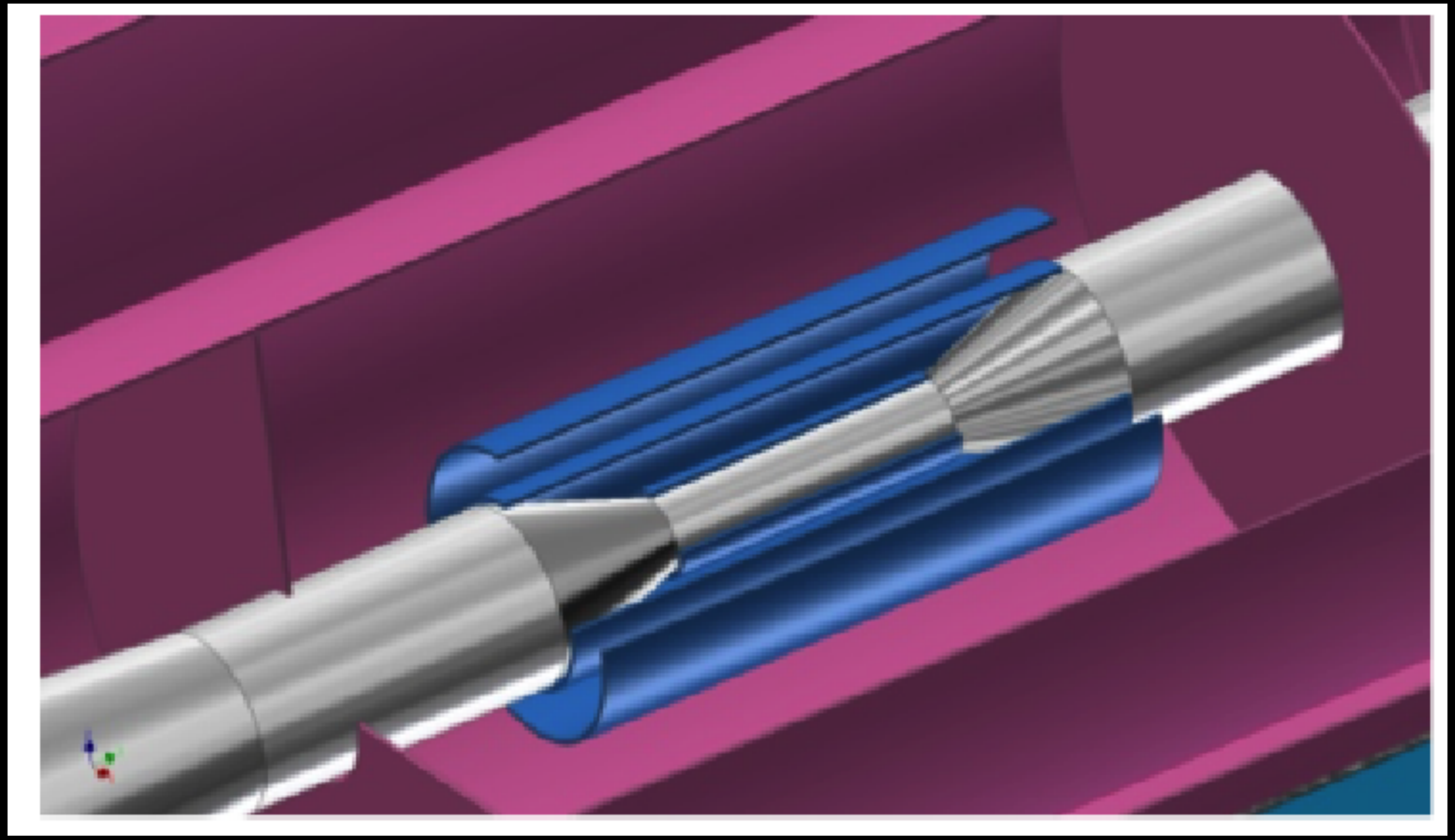
Continuous operation mode

Target: ✿ High granularity; ✿ Fast readout; ✿ Low power dissipation; ✿ Light structure

Baseline Pixel Detector Layout

Xin Shi, Zhou Yang
Tomorrow, 9:30, 10:00 am

3-layers of double-sided pixel sensors

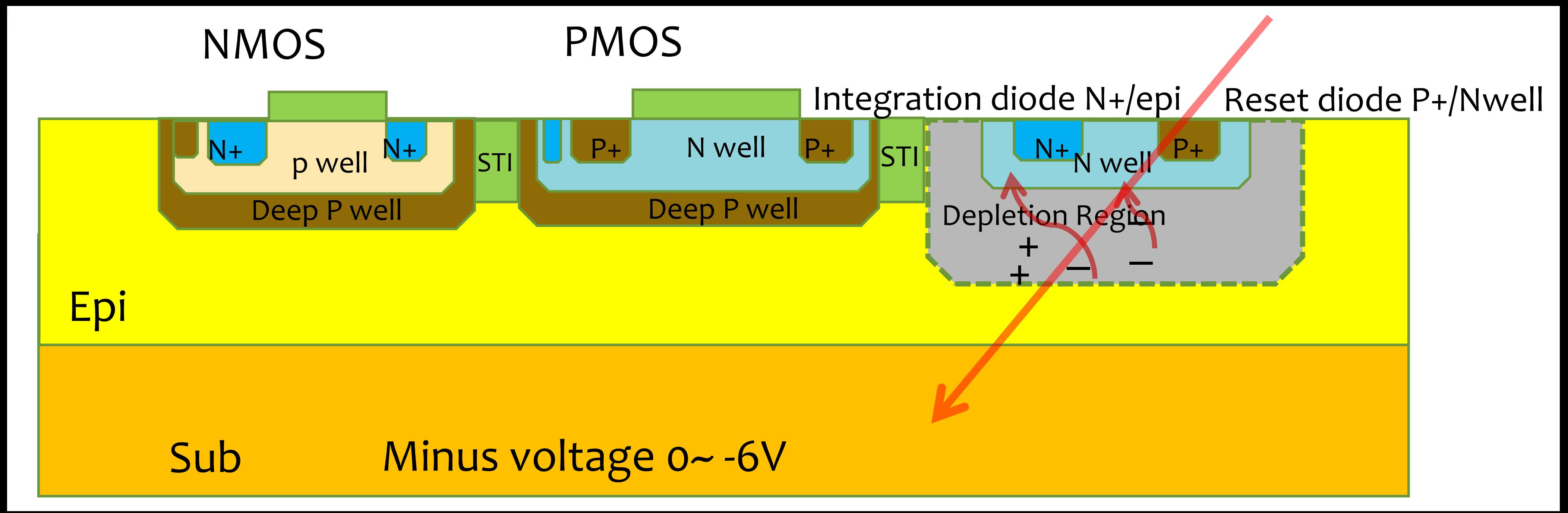


- ILD-like layout
- Innermost layer: σ_{SP} = 2.8 μm
- Polar angle θ ~ 15 degrees

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

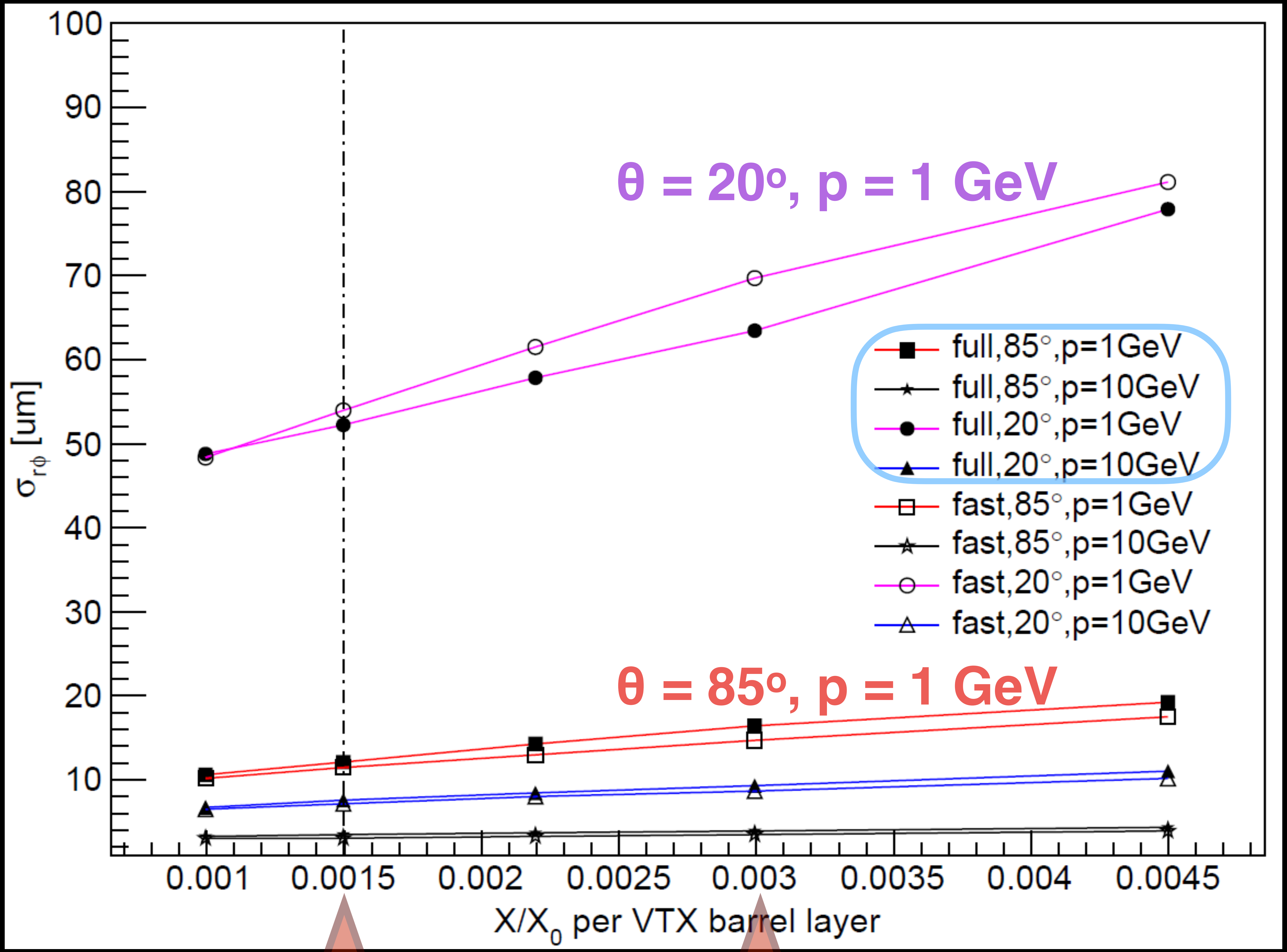
CMOS pixel sensor (MAPS)



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

Performance studies: Material budget

Transverse impact parameter resolution for single muons



Requirement

Baseline includes very small material budget for beam pipe, sensor layers and supports

$\leq 0.15\% X_0$ / layer

× 2 more material

⬇

20% resolution degradation

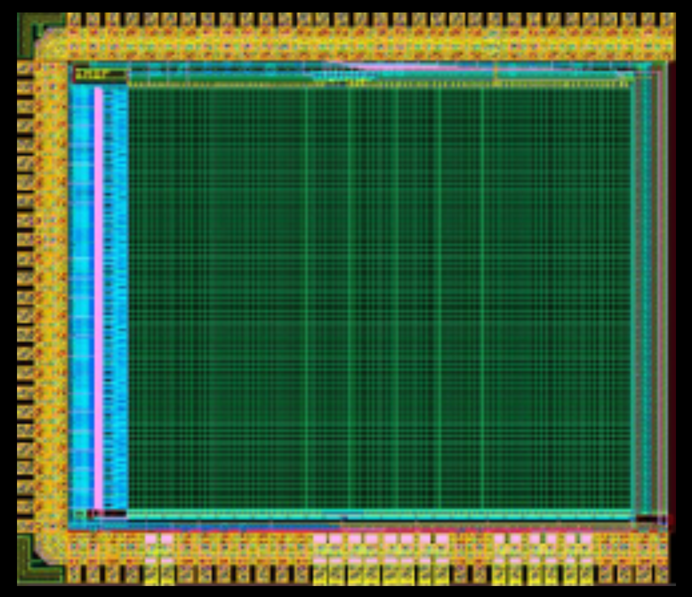
Impact parameter resolution goal achievable but only with low material budget

Current R&D activities

Xin Shi, Zhou Yang
Tomorrow, 9:30, 10:00 am

- Initial 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)	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 μm²	2	Founded by MOST and IHEP
SOI pixel sensor	LAPIS 0.2 μm	16 × 16 μm²	22	Funded by NSFC

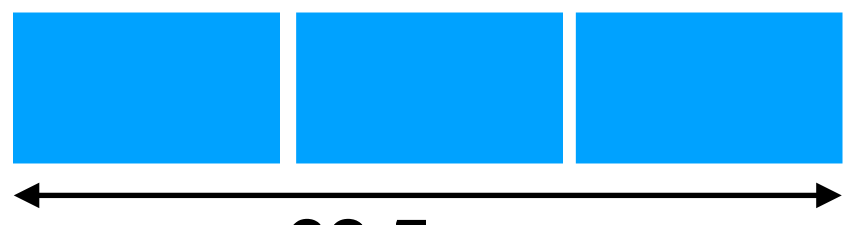
- Institutions: CCNU, NWTU, Shandong, Huazhong Universities and IHEP
- New project: Full size CMOS sensor for use in real size prototype

Silicon Vertex Detector Prototype - MOST (2018-2023)

- Design CMOS sensor with large area, 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

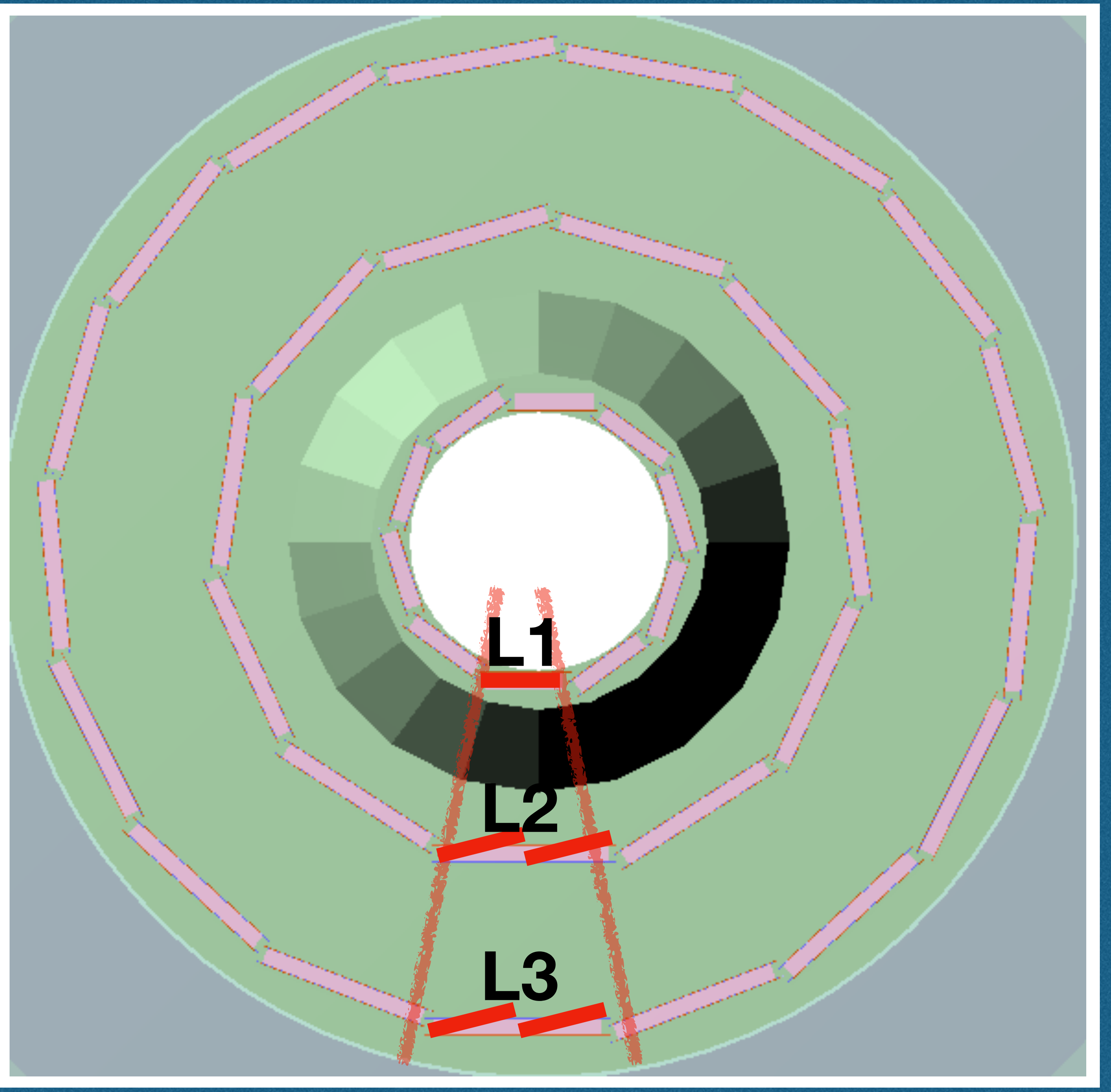
Layers 2 and 3 (22 mm x 125 mm)
Chip size: 11 mm X 20.8 mm

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.
Univ. of Mass
RAL
others.....

Silicon Tracker Detector – Baseline

SET: r = ~1.8 m

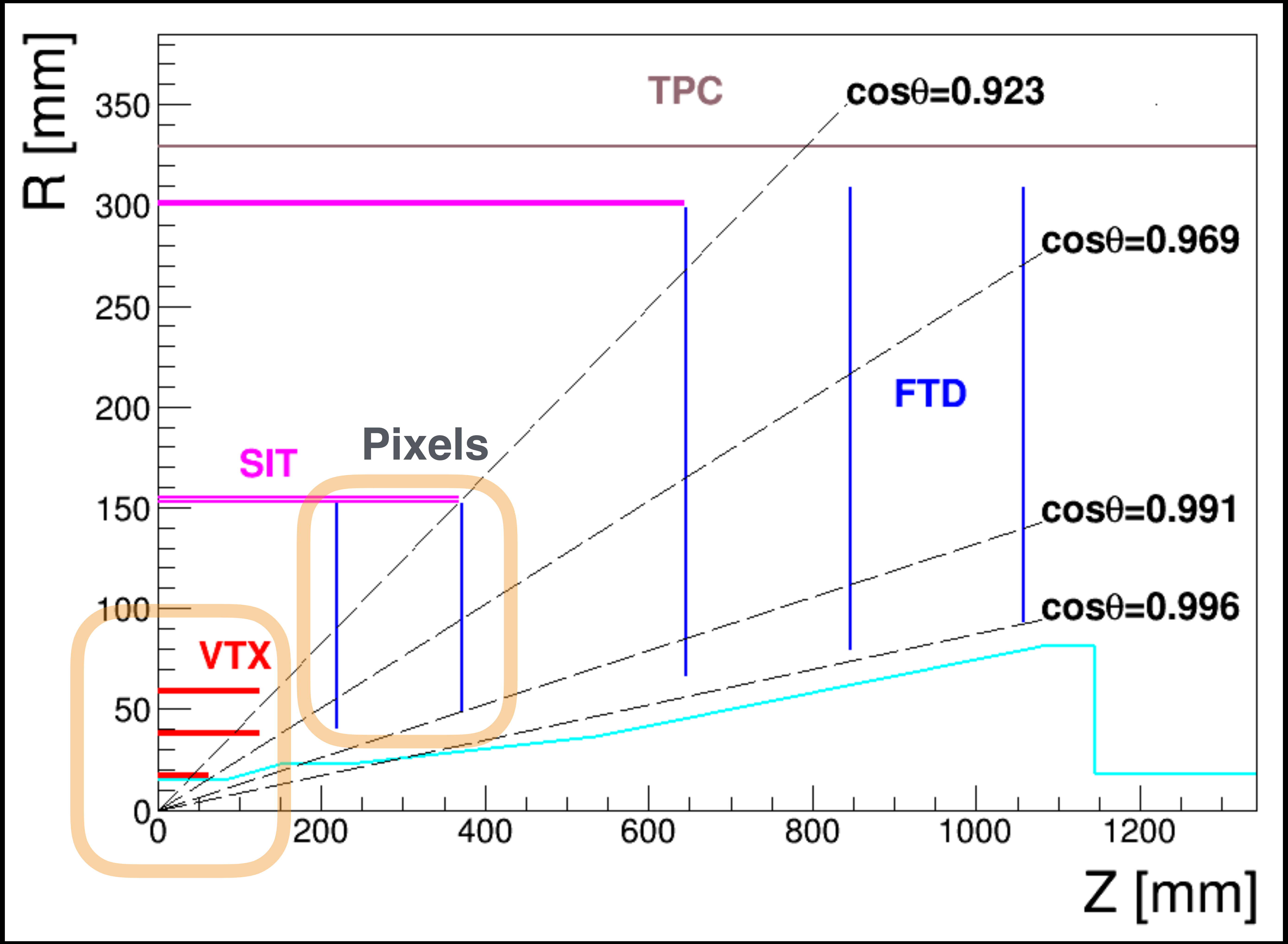
Not much R&D done so far

TPC

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

SIT

VTX



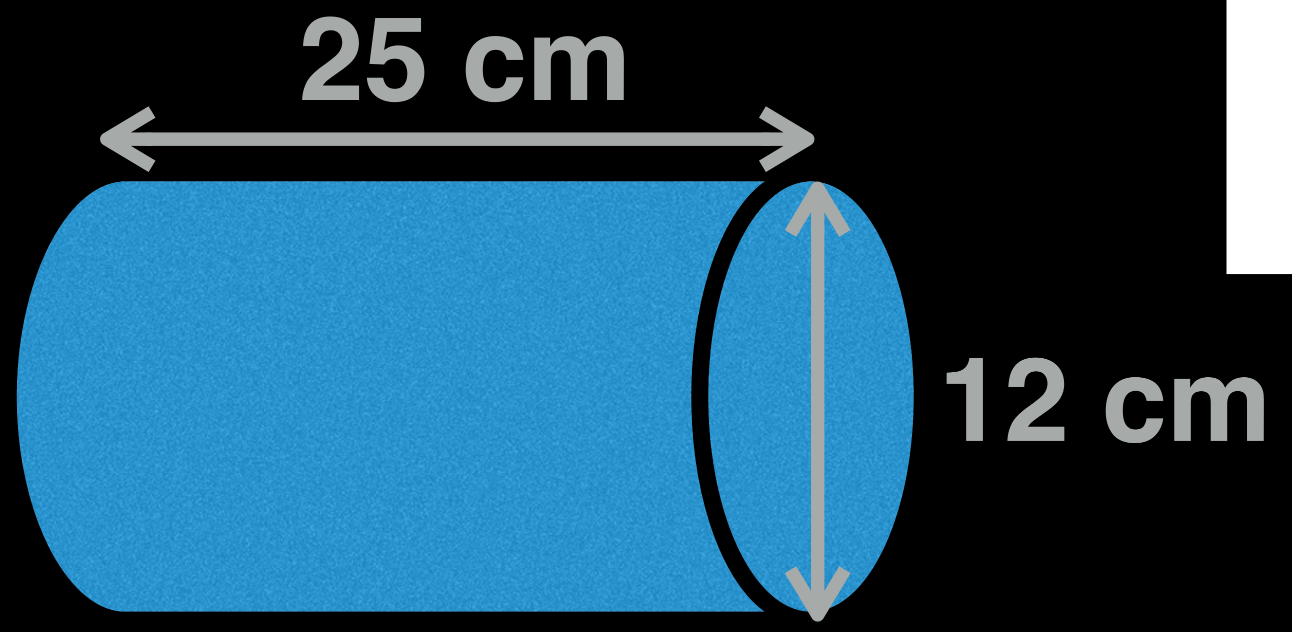
Sensor technology

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

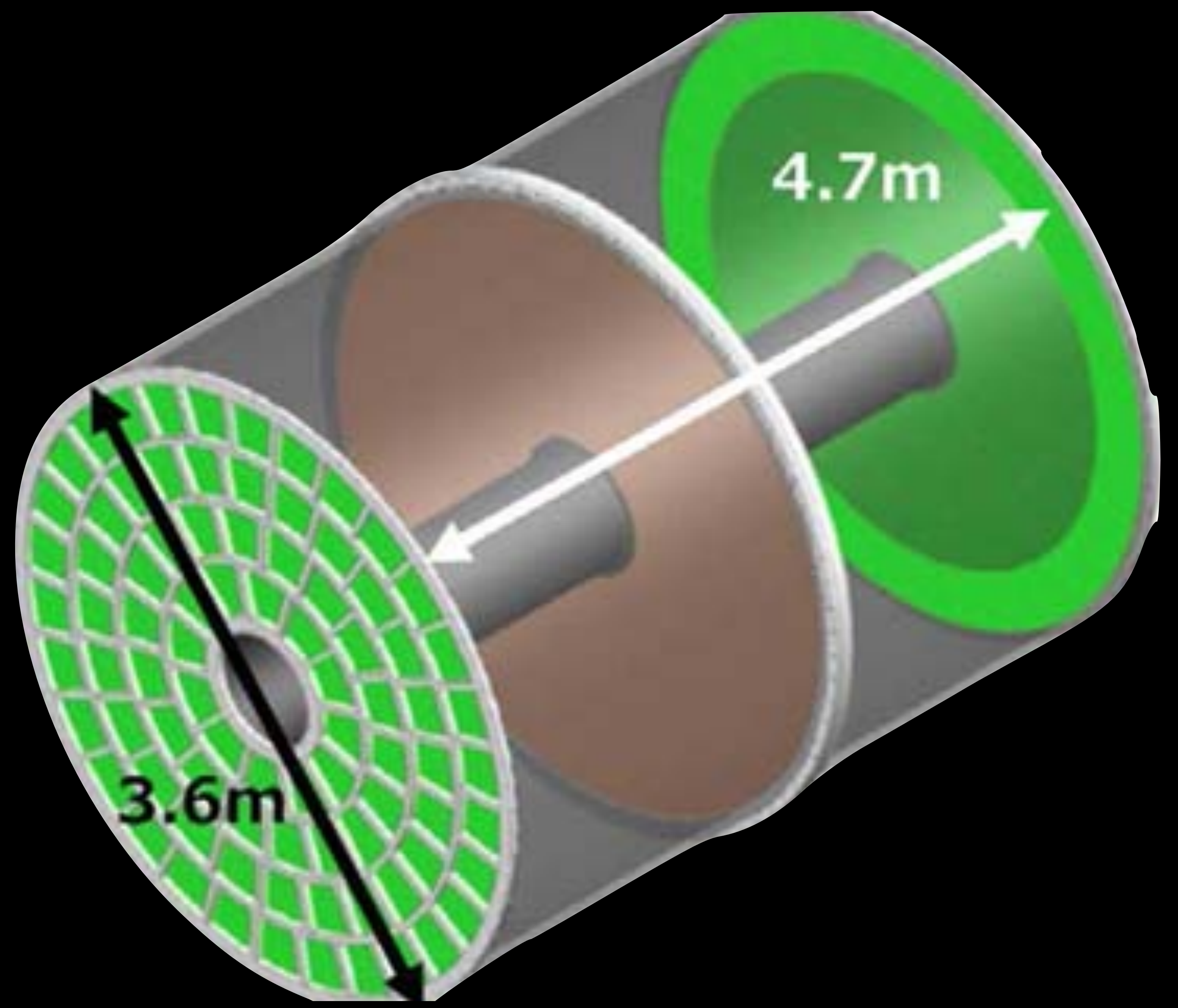
Time Projection Chamber (TPC)

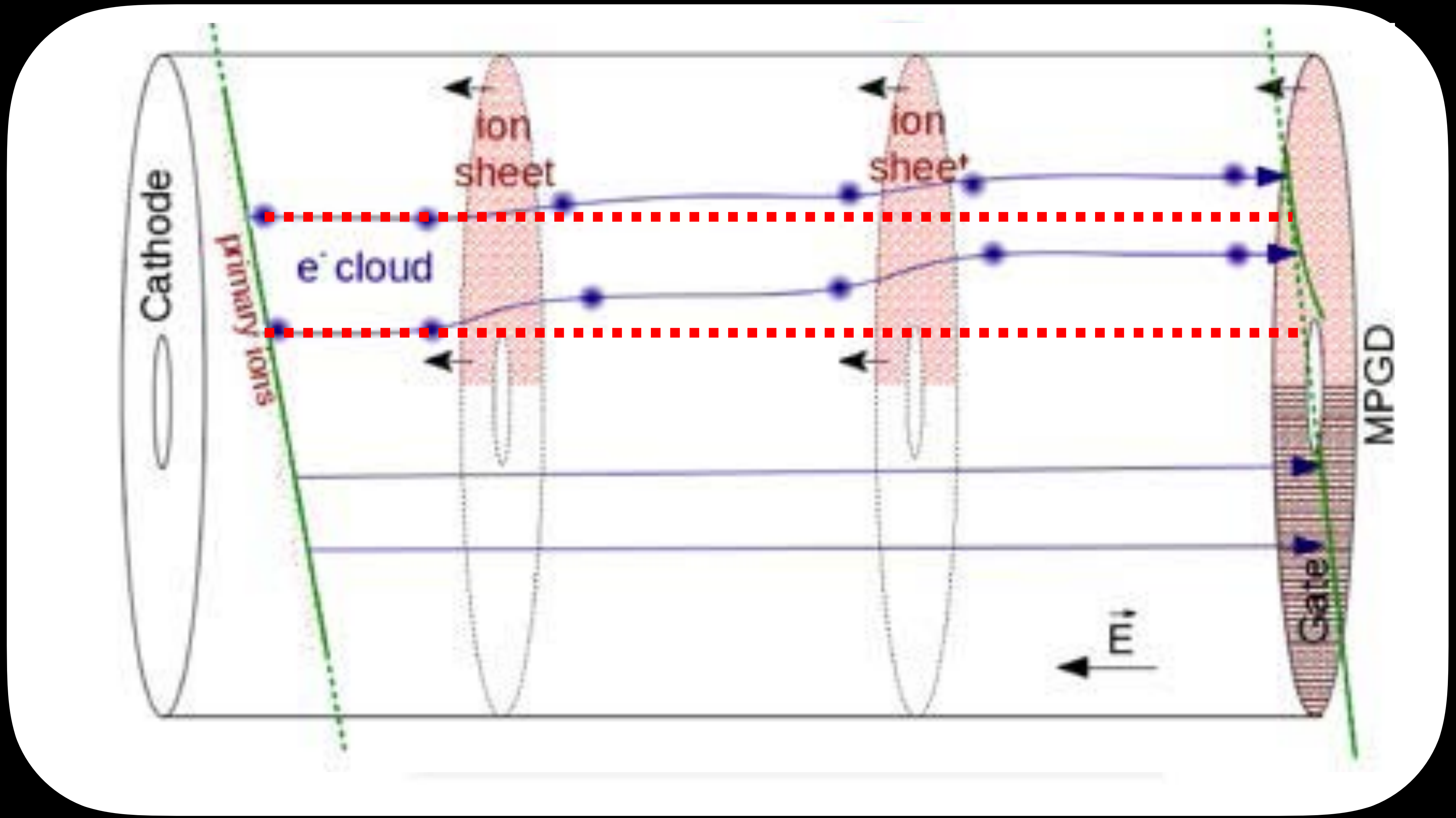
Huirong Qi
Tomorrow, 2:30 pm

TPC detector concept

- Allows for particle identification
- Low material budget: > 8% X_0 (without electronics and cables)
- 3 Tesla magnetic field —> reduces diffusion of drifting electrons
- Position resolution: ~100 μm in rϕ
- Systematics precision (<20 μm internal)
- GEM and Micromegas as readout
- Problem: Ion Back Flow —> track distortion

Operation at L > 2 × 10^{34} cm^{-2} s^{-1} ?





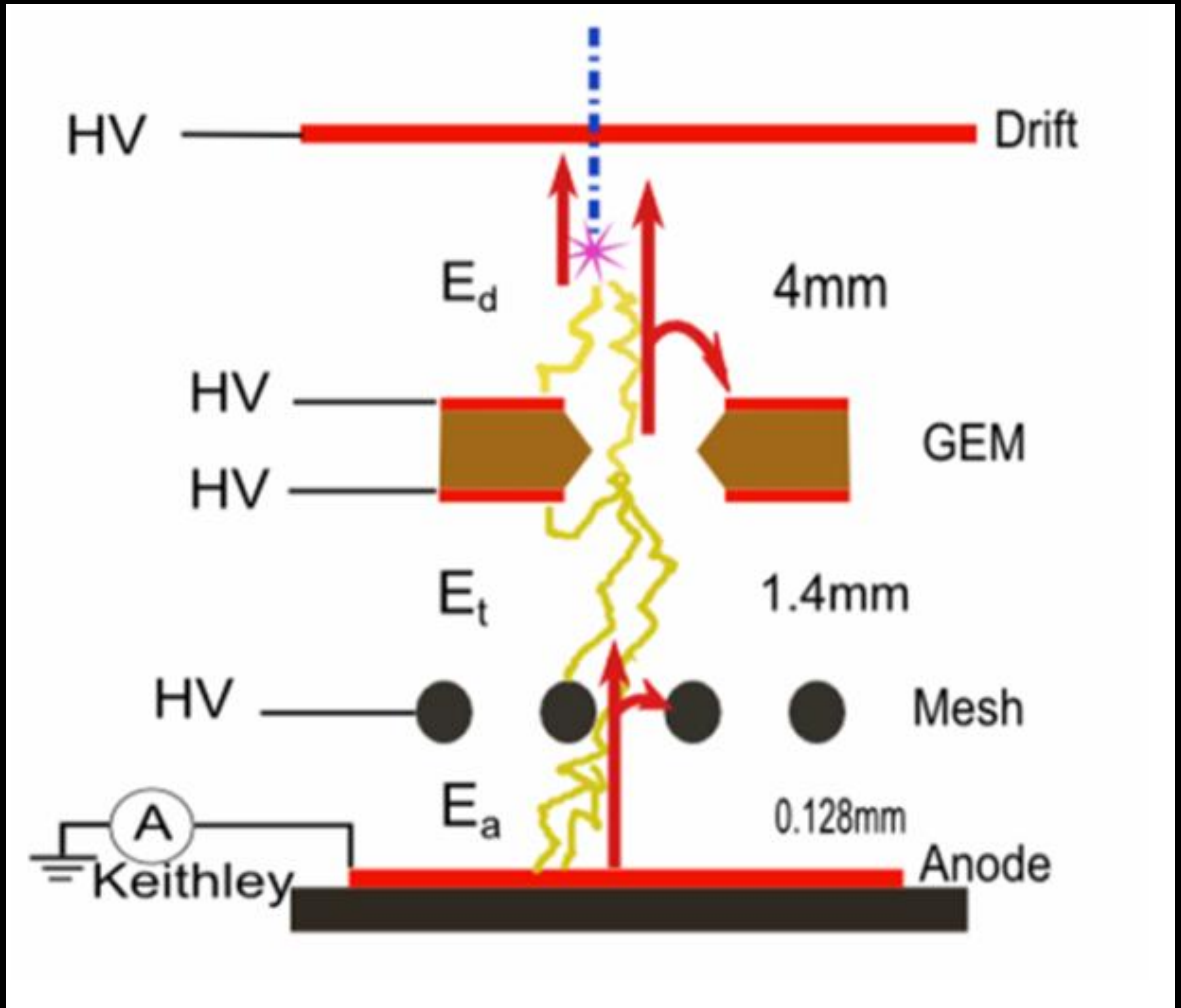
Manpower and activities

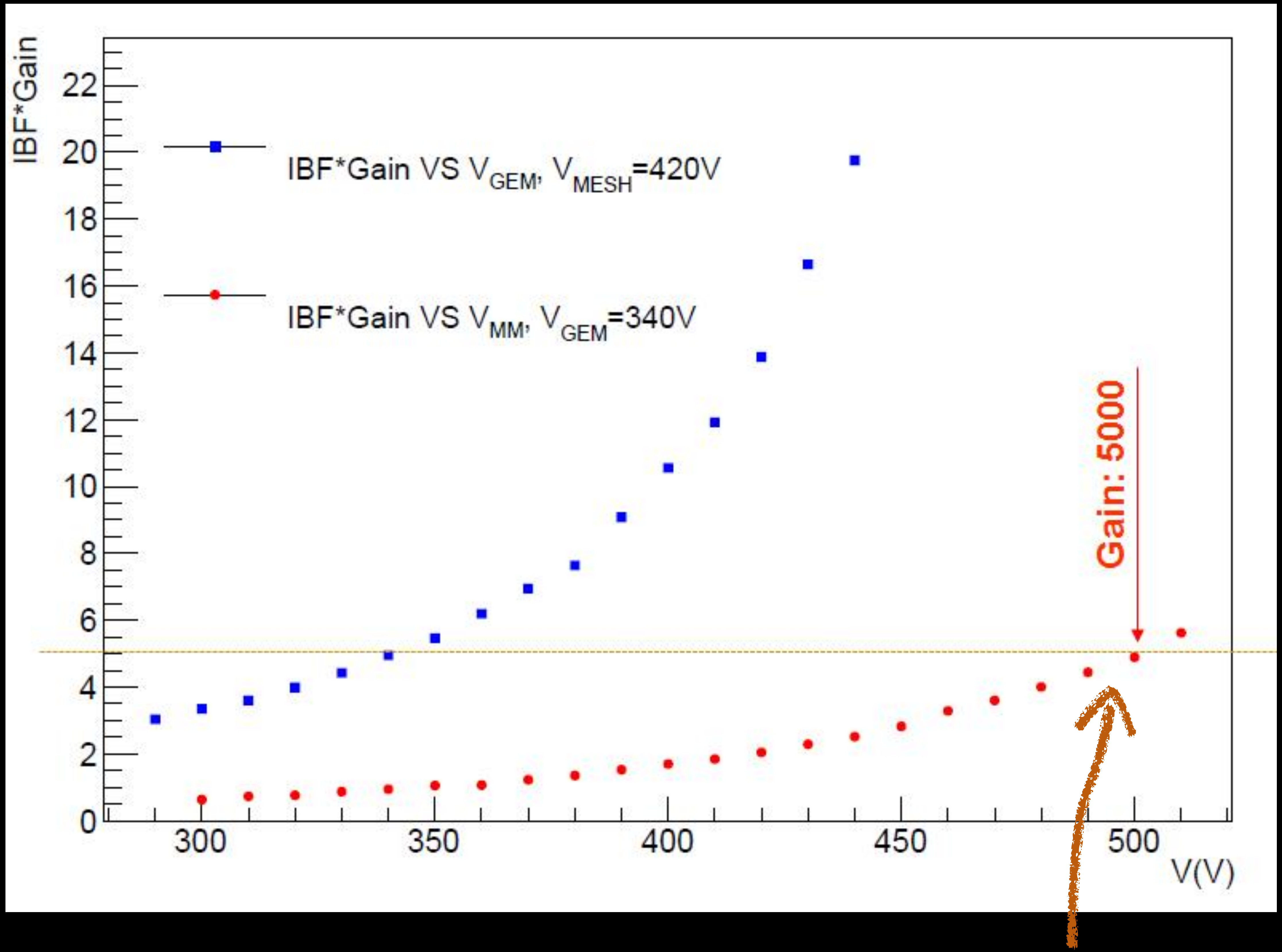
- TPC detector R&D @IHEP (2016~2020)
  - Funding from MOST and NSFC (~3.5 Million RMB)
- Electronics R&D @Tsinghua (2016~2020)
  - Funding from NSFC (~2.0 Million RMB)
- Inhabitation of IBF using graphene @Shandong Univ. (2016~2019)

Time Projection Chamber (TPC)

TPC readout with micro-pattern gaseous detectors (MPGDs)

New: Micromegas + GEM





IBF: Ion Back Flow reduced to 0.19%

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

Drift Chamber Option – IDEA proposal

Giovanni Tassielli
Tomorrow, 11:30 am

Lead by Italian Colleagues

Low-mass cylindrical drift chamber

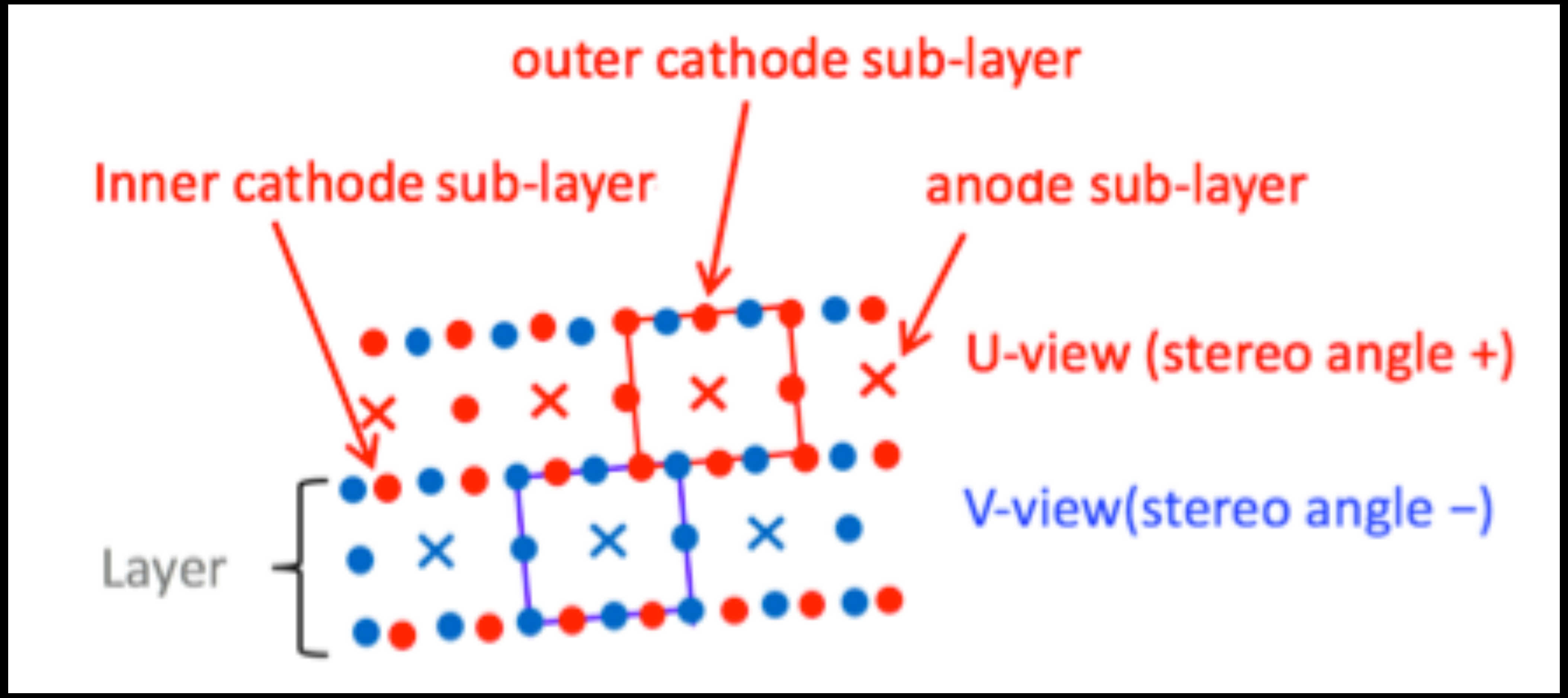
Follows design of the KLOE and MEG2 experiments

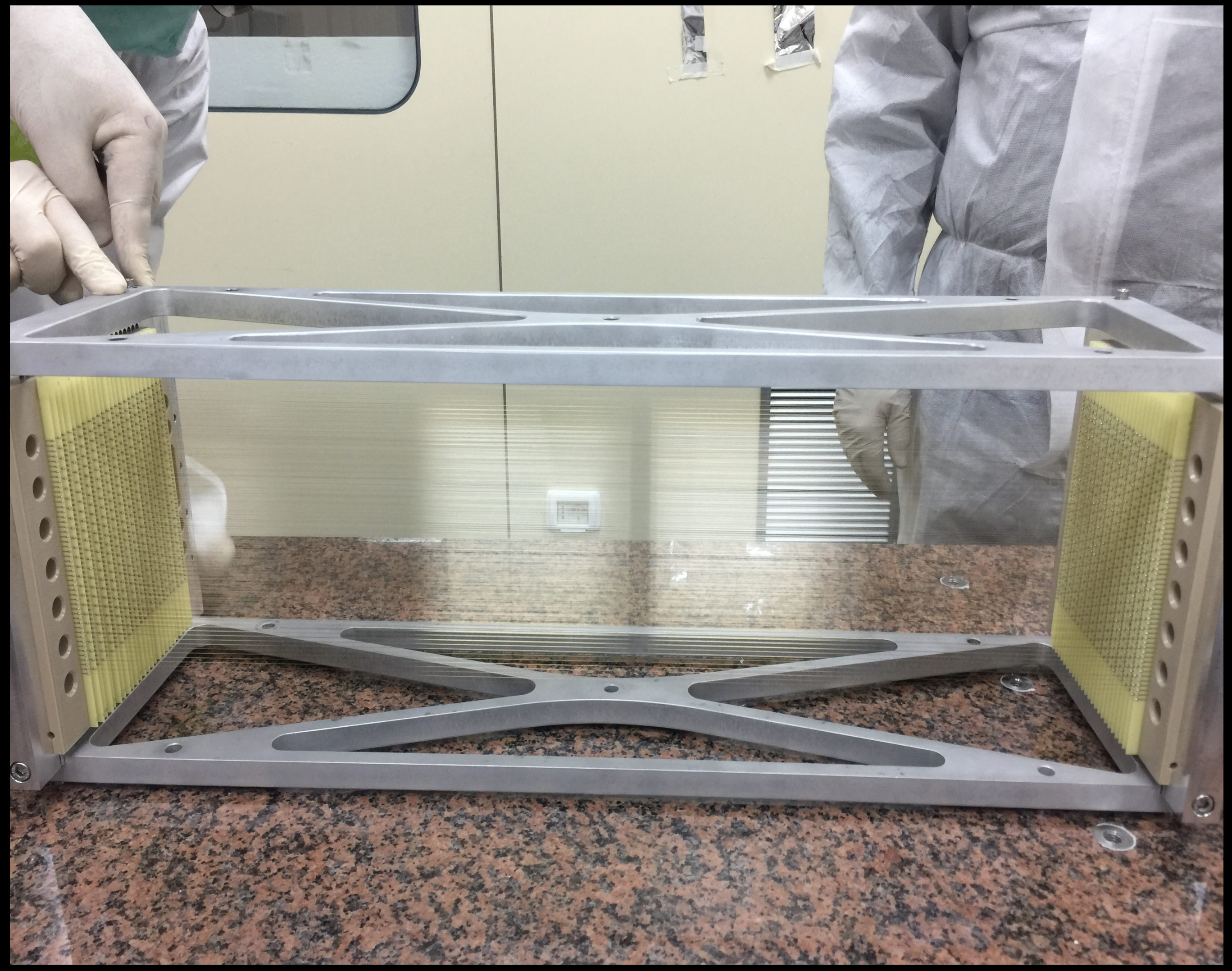
- Length: 4 m
- Radius: 0.3- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

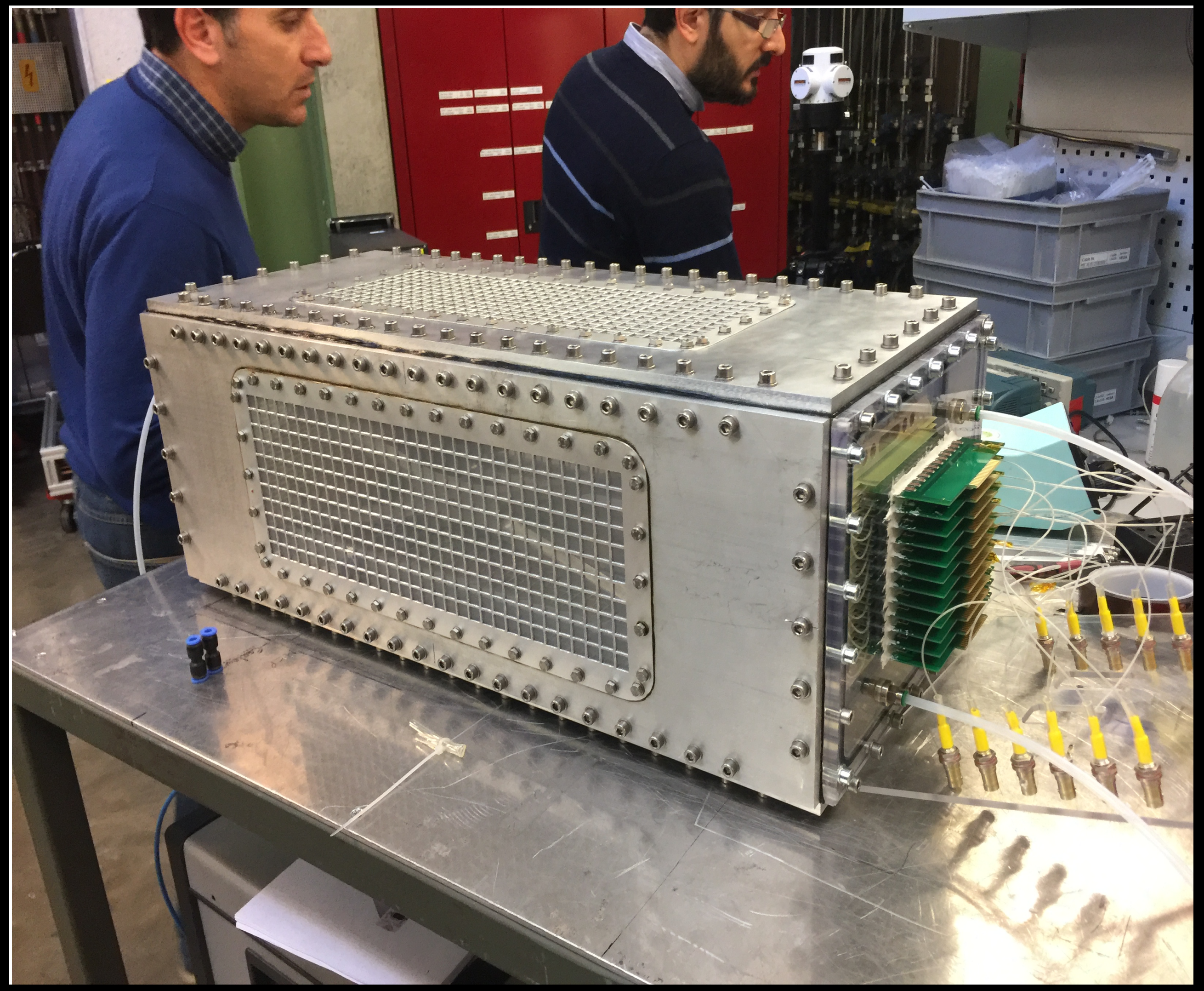
- Spatial resolution: < 100 µm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

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

MEG2 prototype being tested





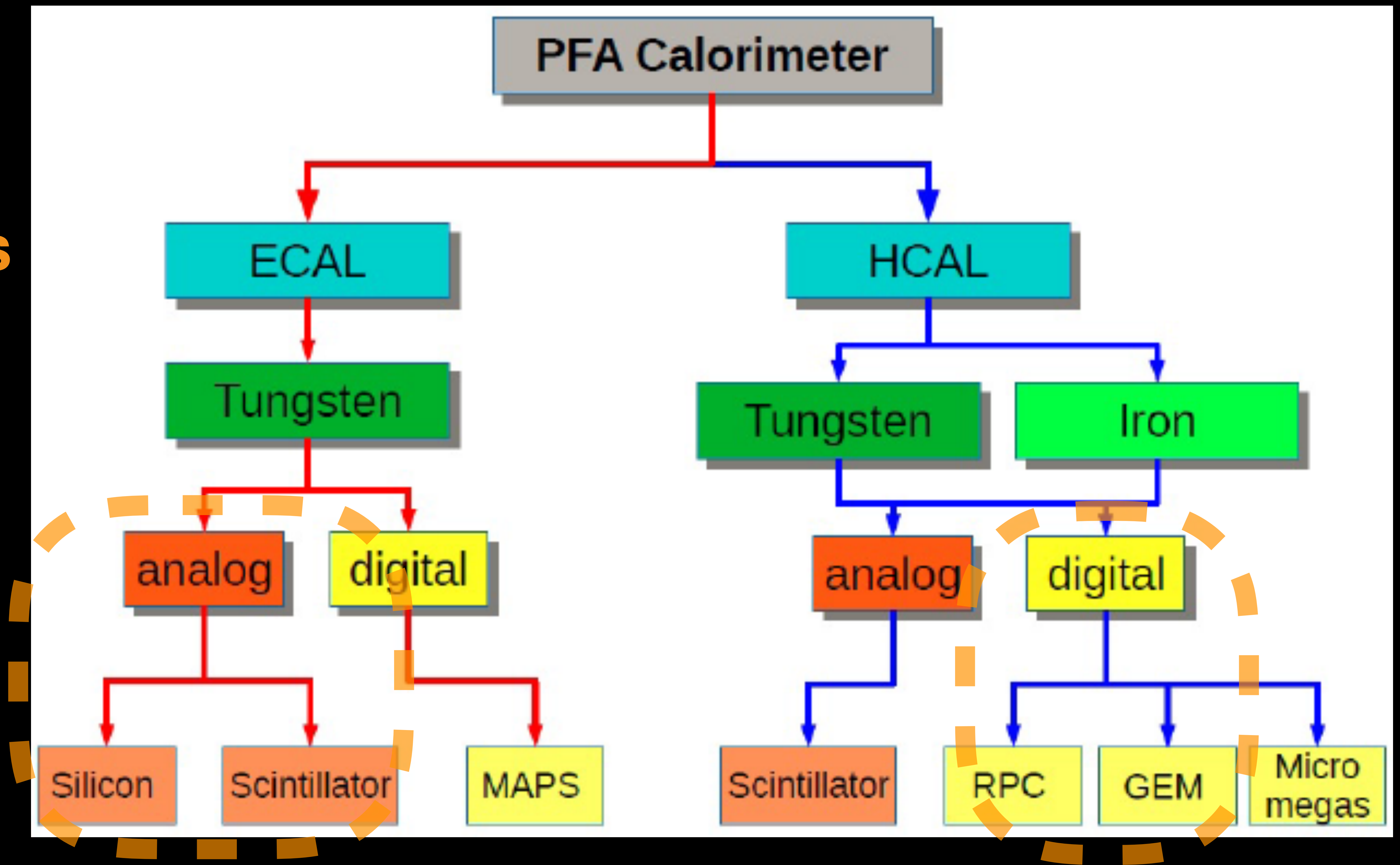


Stereo angle: 50-250 mrad

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

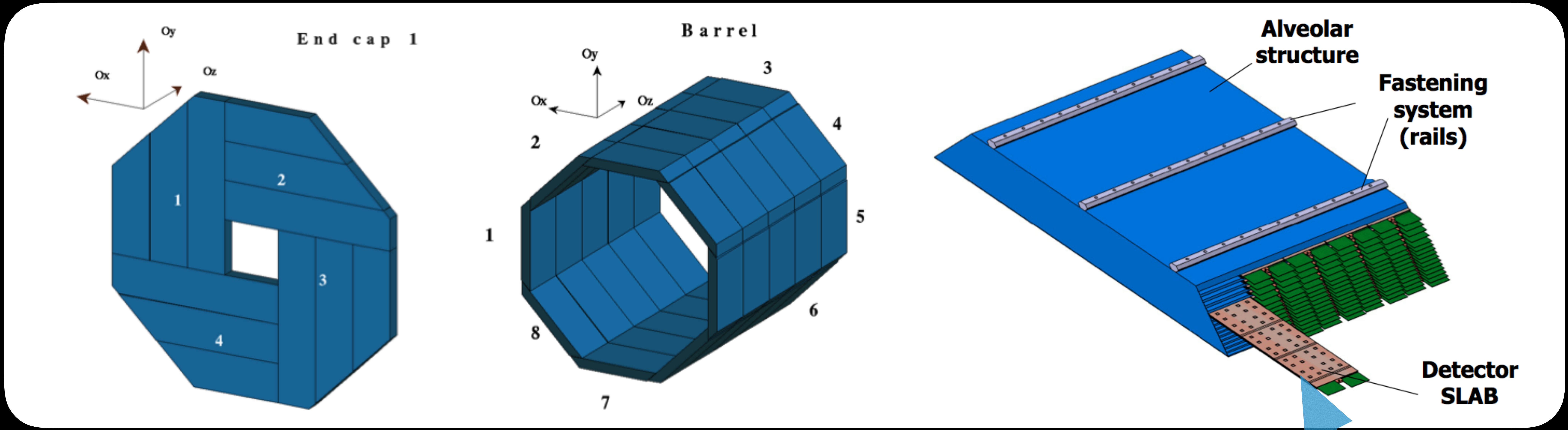
R&D supported by MOST, NSFC and IHEP seed funding



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)

Baseline ECAL Calorimeter — Particle Flow Calorimeter

Silicon-Tungsten Sandwich ECAL

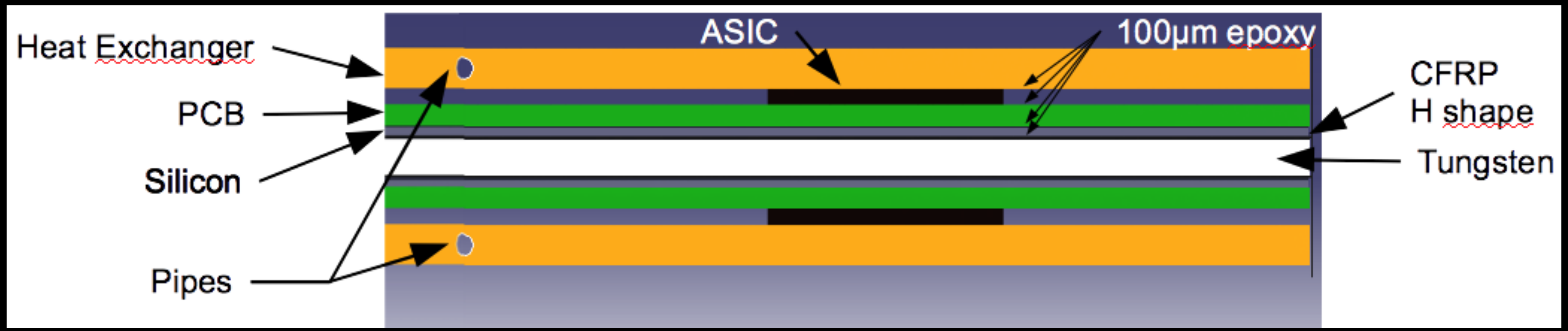


Cell size:

- 5 x 5 mm² - optimal for PFA
- 10 x 10 mm² - default
- 20 x 20 mm² - required for passive cooling

high granularity —> active cooling

CO_2 Active cooling



Sensor: high-resistivity silicon pin diodes

- Stability
- Uniformity
- Flexibility
- High S/N

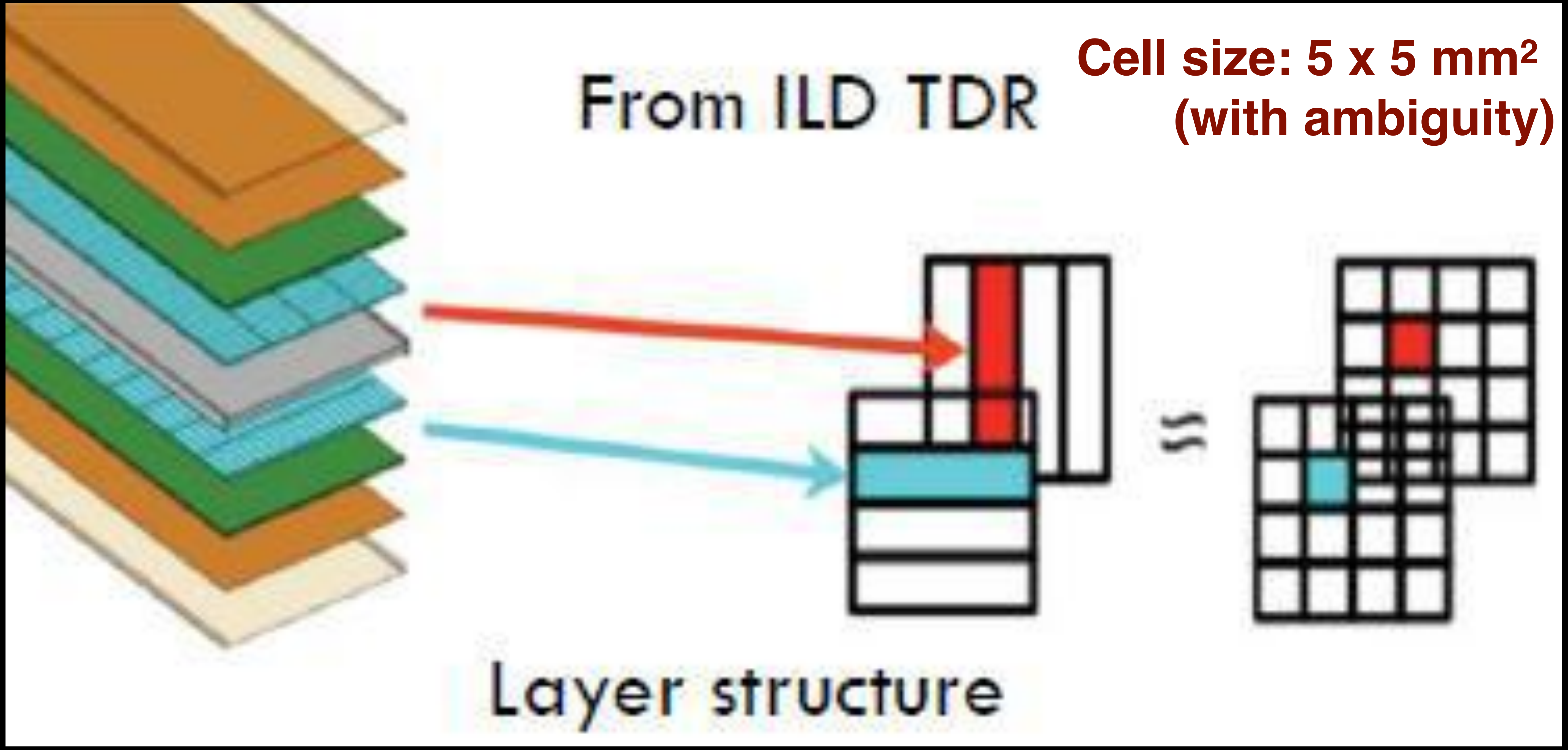
Preliminary simulation: ΔT ~ 2° C (HGCAL/ILD)

ECAL Calorimeter — Particle Flow Calorimeter

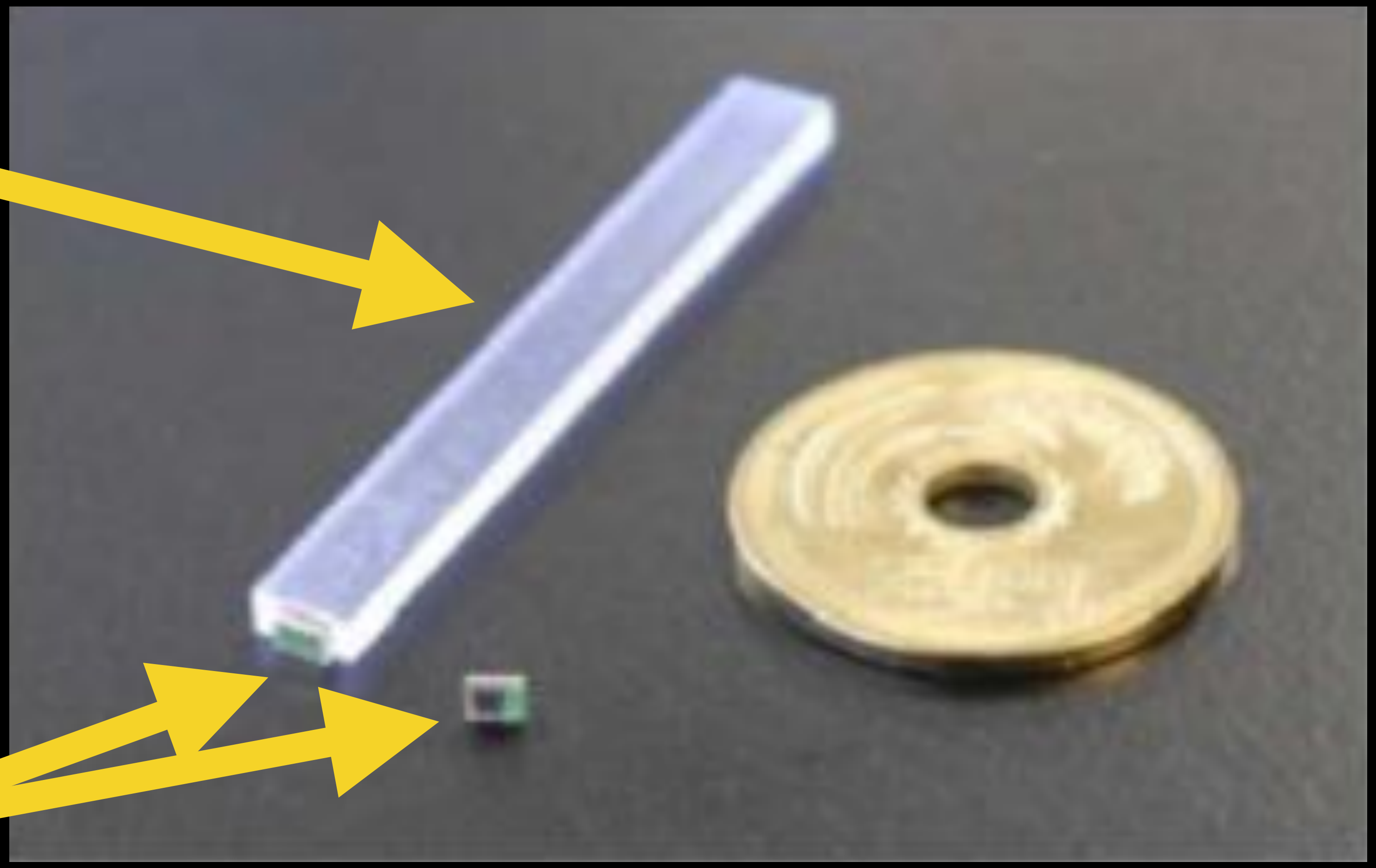
Scintillator-Tungsten Sandwich ECAL

Mingyi Dong, Hang Zhao
Tomorrow, 9:00, 9:30 am

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

Baseline HCAL Calorimeter — Particle Flow Calorimeter

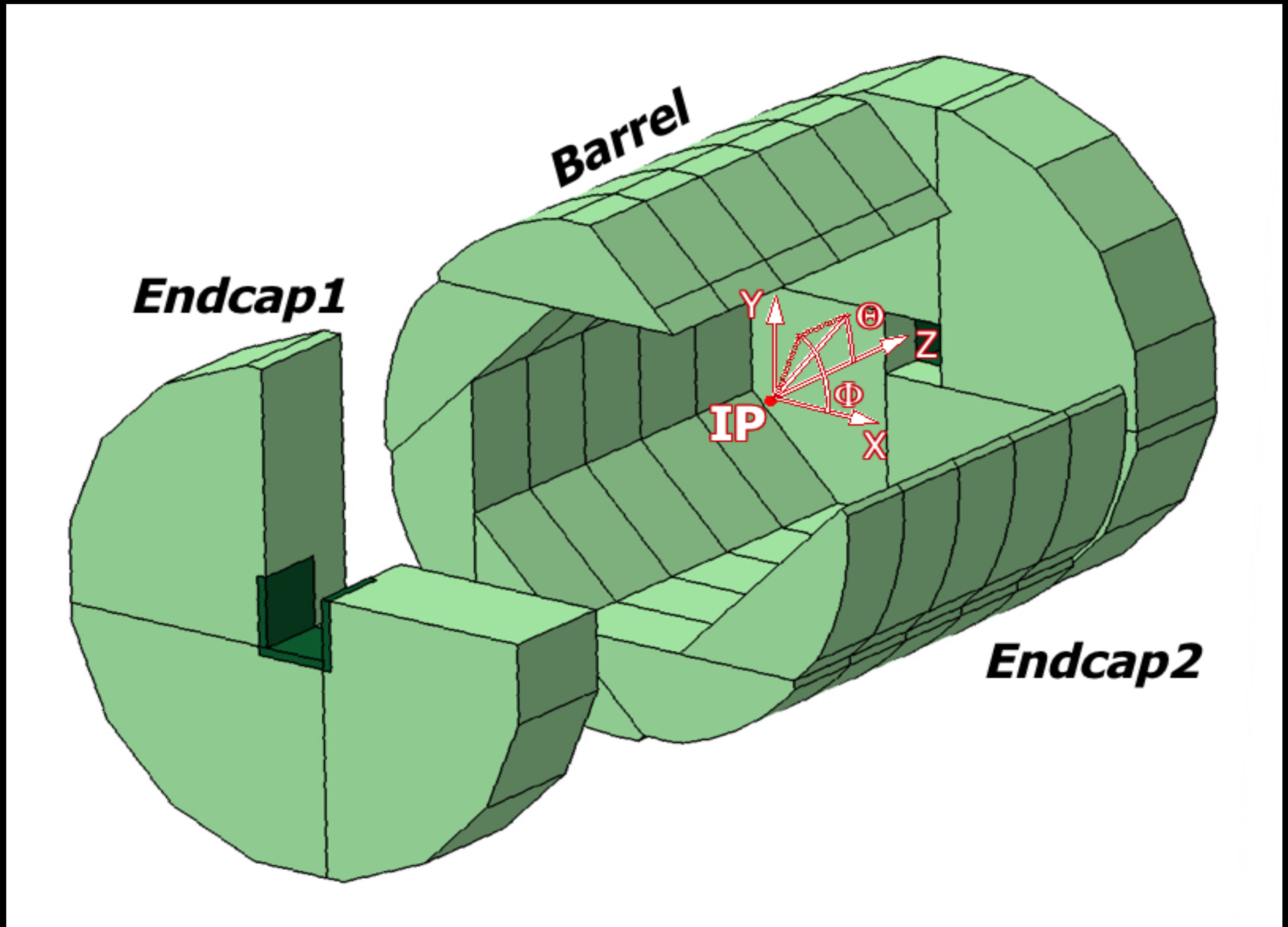
CALICE Calorimeter for ILC

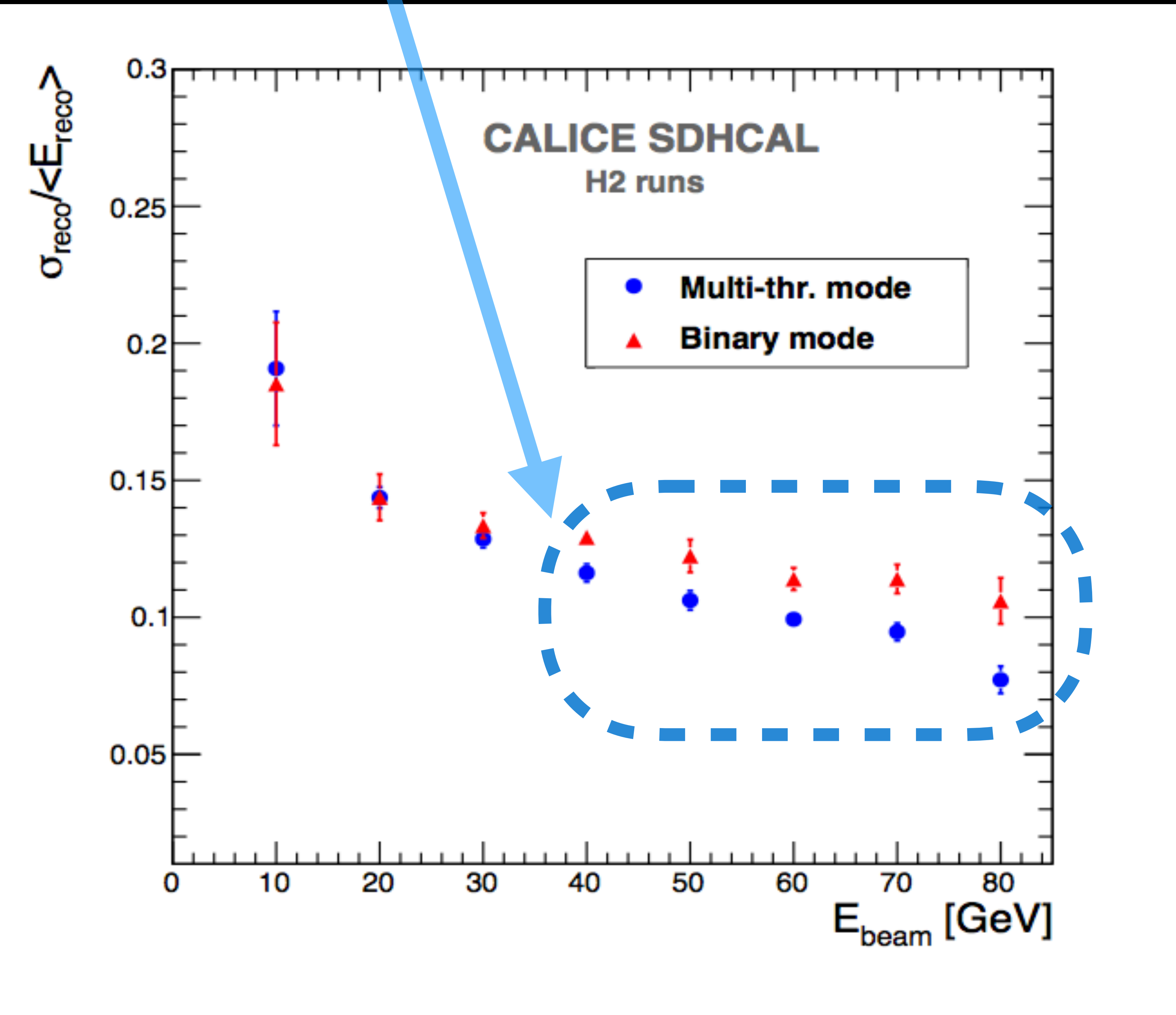
Semi-Digital HCAL

Boxyang Yu, Bing Liu
Tomorrow, 10:00, 10:30 am

SDHCAL: multiple thresholds per channel
Prevent saturations at E > 40 GeV

Self-supporting absorber (steel)





- Lateral segmentation: 1 x 1 cm^2
- Total number of channels: 4 x 10^7

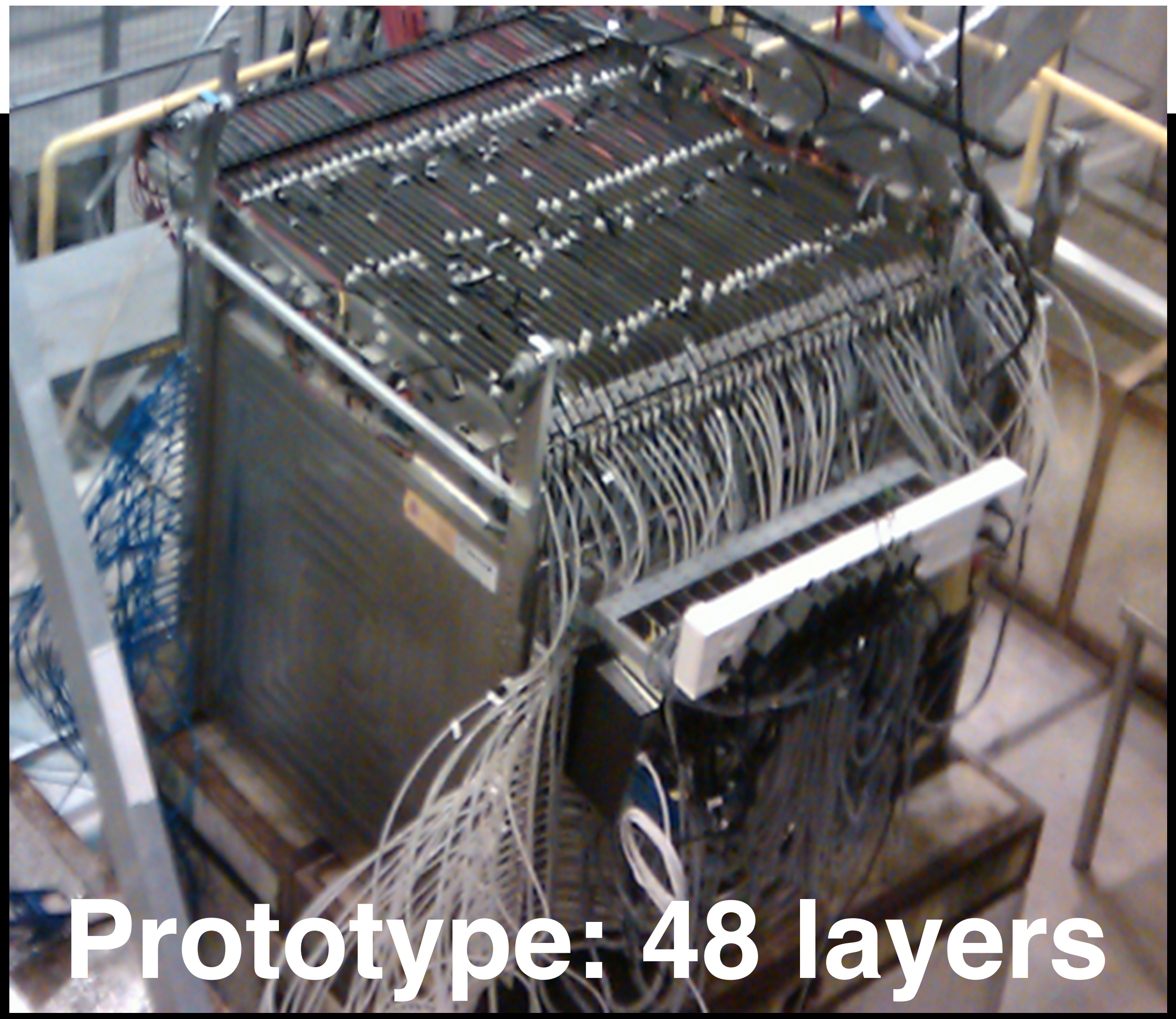
Challenges
- Power consumption —> temperature
- Large amount of services/cables

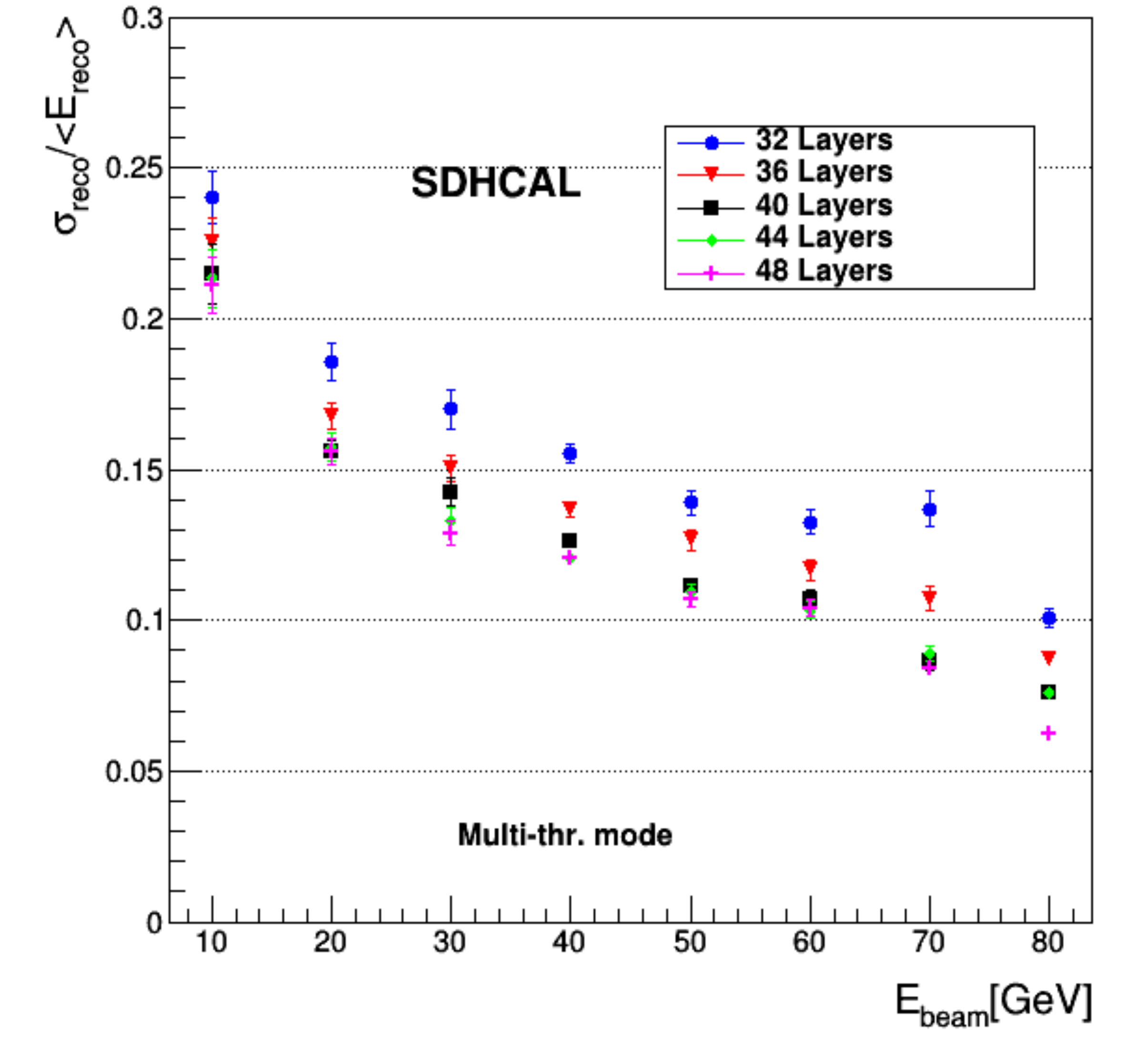
Baseline HCAL Calorimeter — Particle Flow Calorimeter

Semi-Digital gRPC HCAL

gRPC: Glass RPC

- Negligible dead zones
- Large size: 1 x 1 m²
- Cost effective





40 layers resolution similar to **48 layers**

6mm gRPC + 20mm absorber

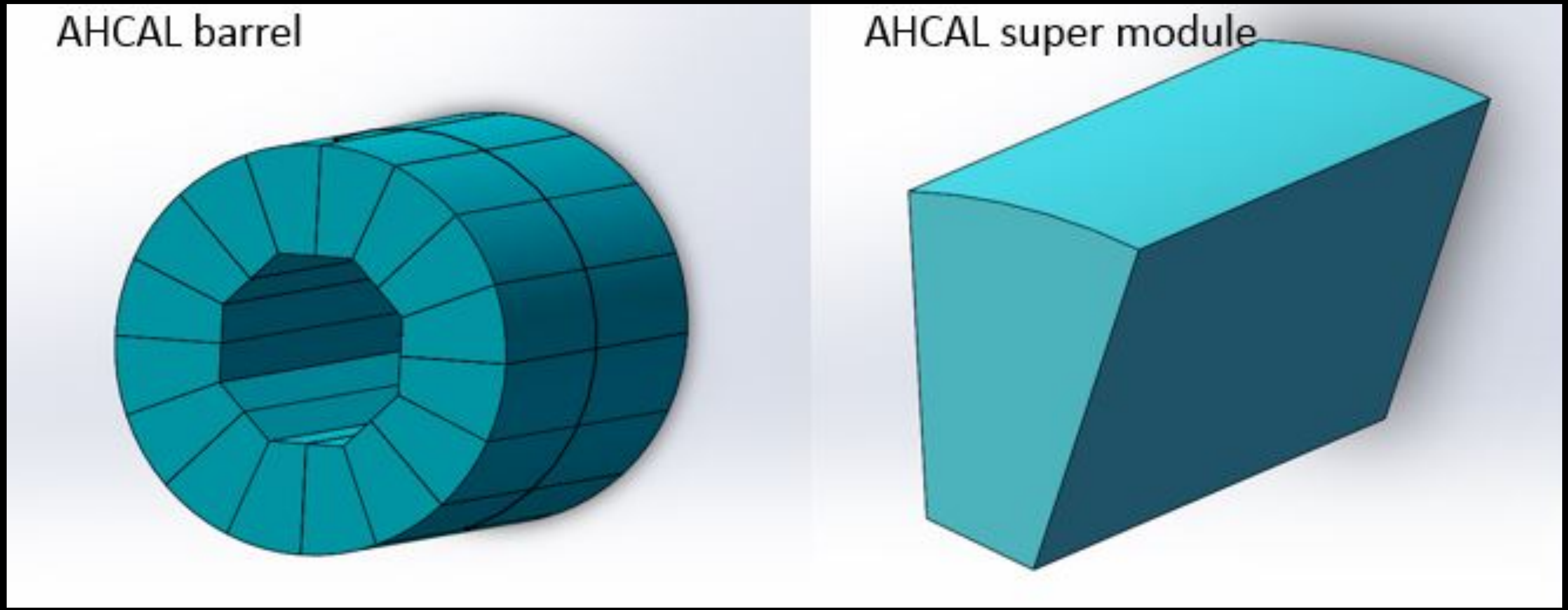
HCAL Calorimeter — Particle Flow Calorimeter

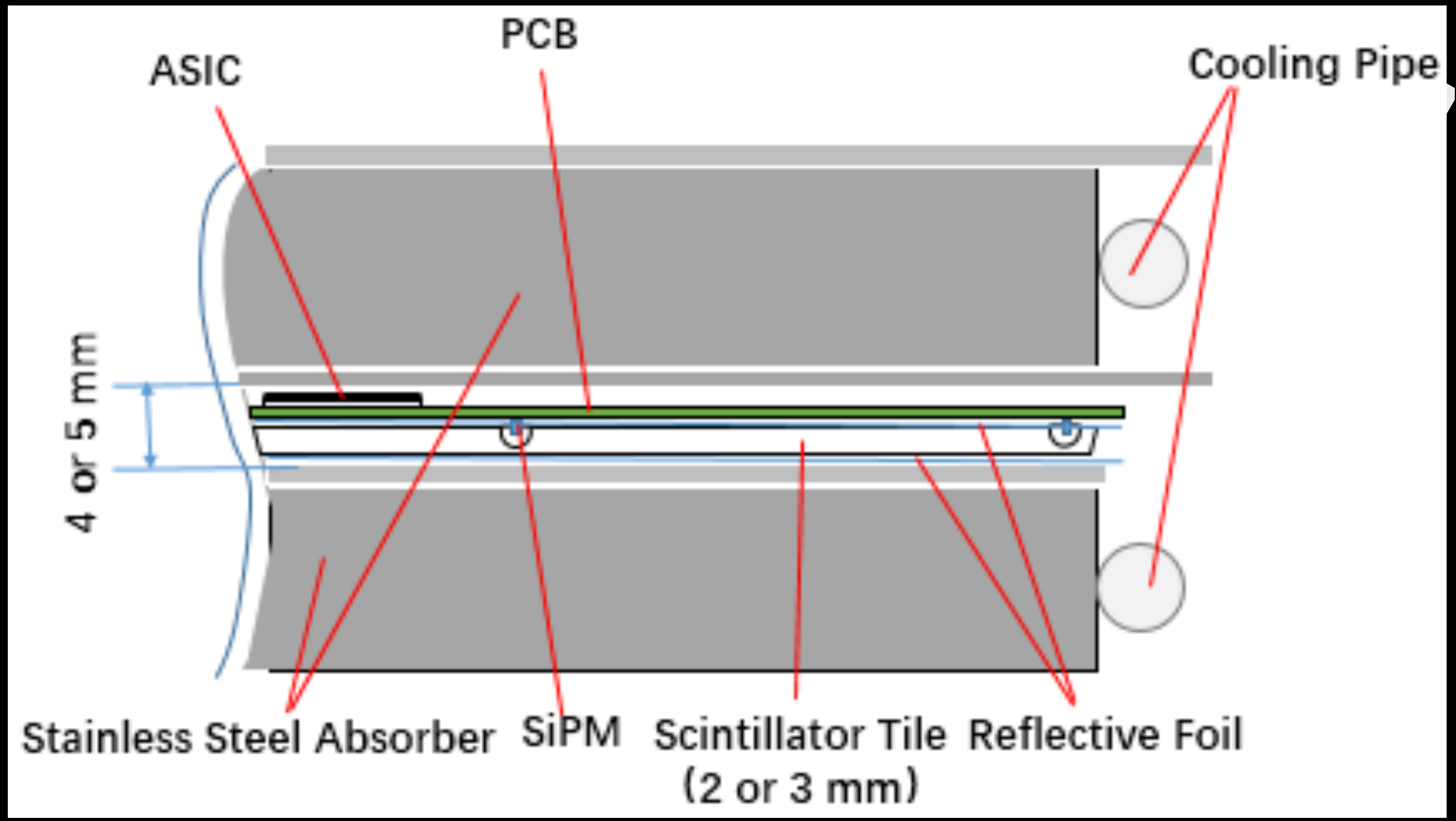
Scintillator and SiPM HCAL (AHCAL)

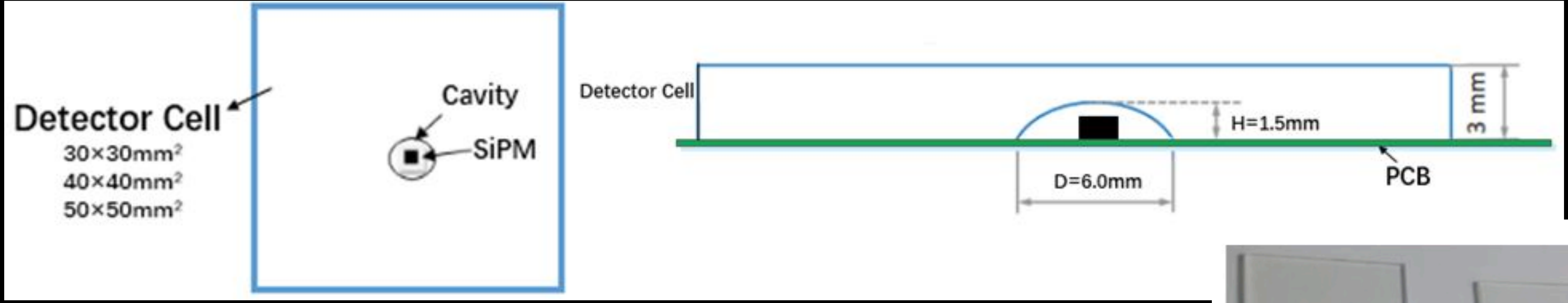
Boxyang Yu, Bing Liu
Tomorrow, 10:00, 10:30 am

32 super modules

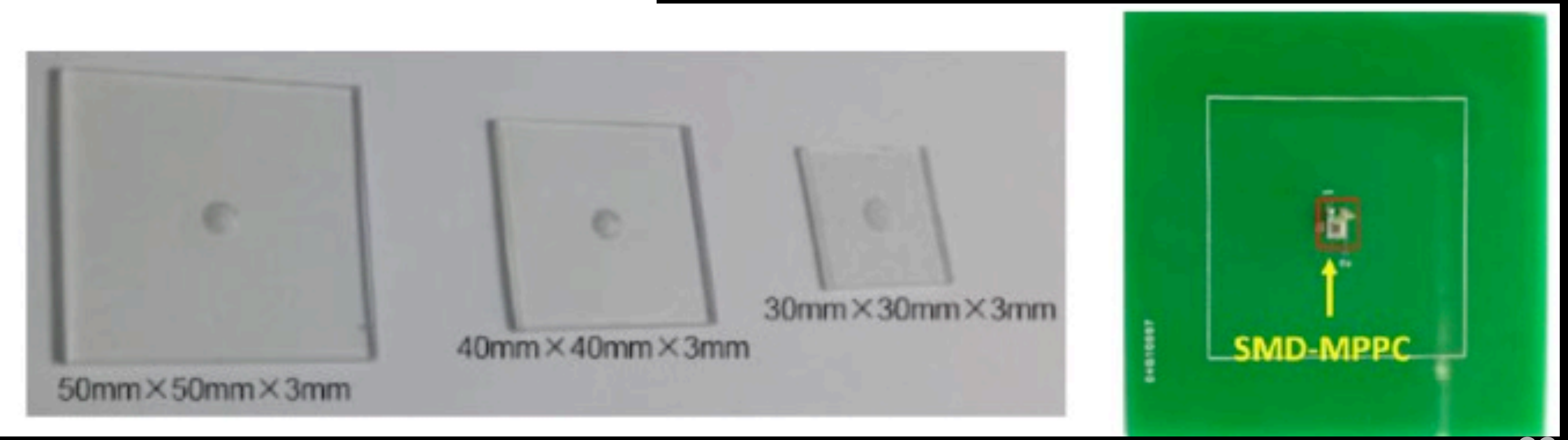
40 layers







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



Prototype to be built: MOST (2018-2022)

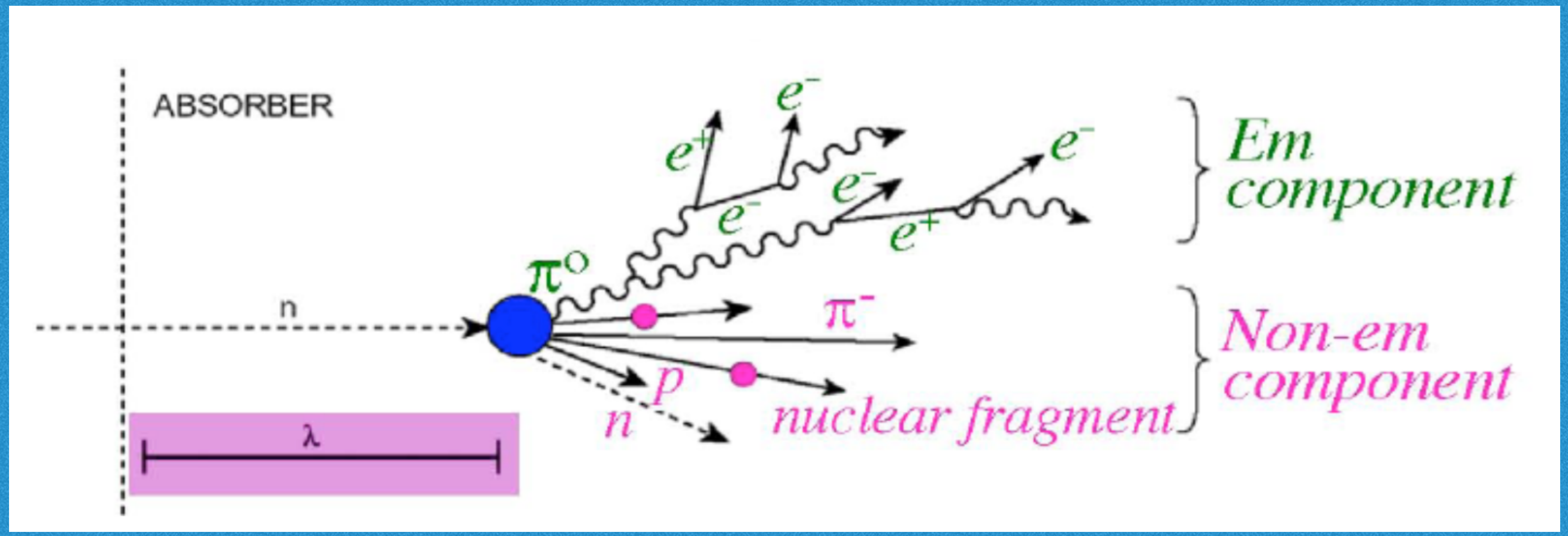
0.5×0.5 m², 35 layer (4λ), 3×3 cm² module

Dual Readout Calorimeter

Hauptman, Santoro, Ferrari
Tomorrow, 11:30, 12:00, 12:30 am

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

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



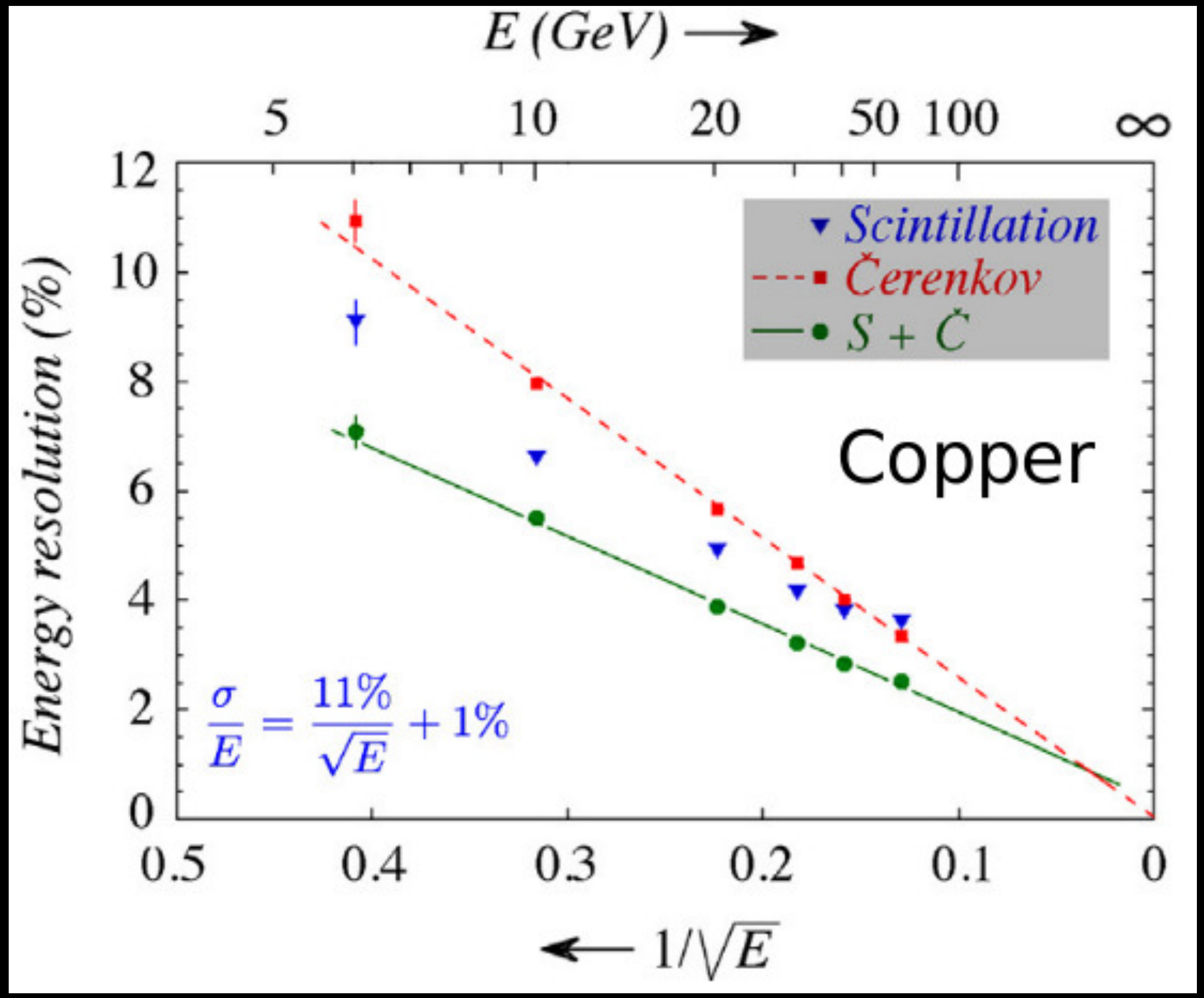
Fluctuations in event-by-event calorimeter response affect the energy resolution

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

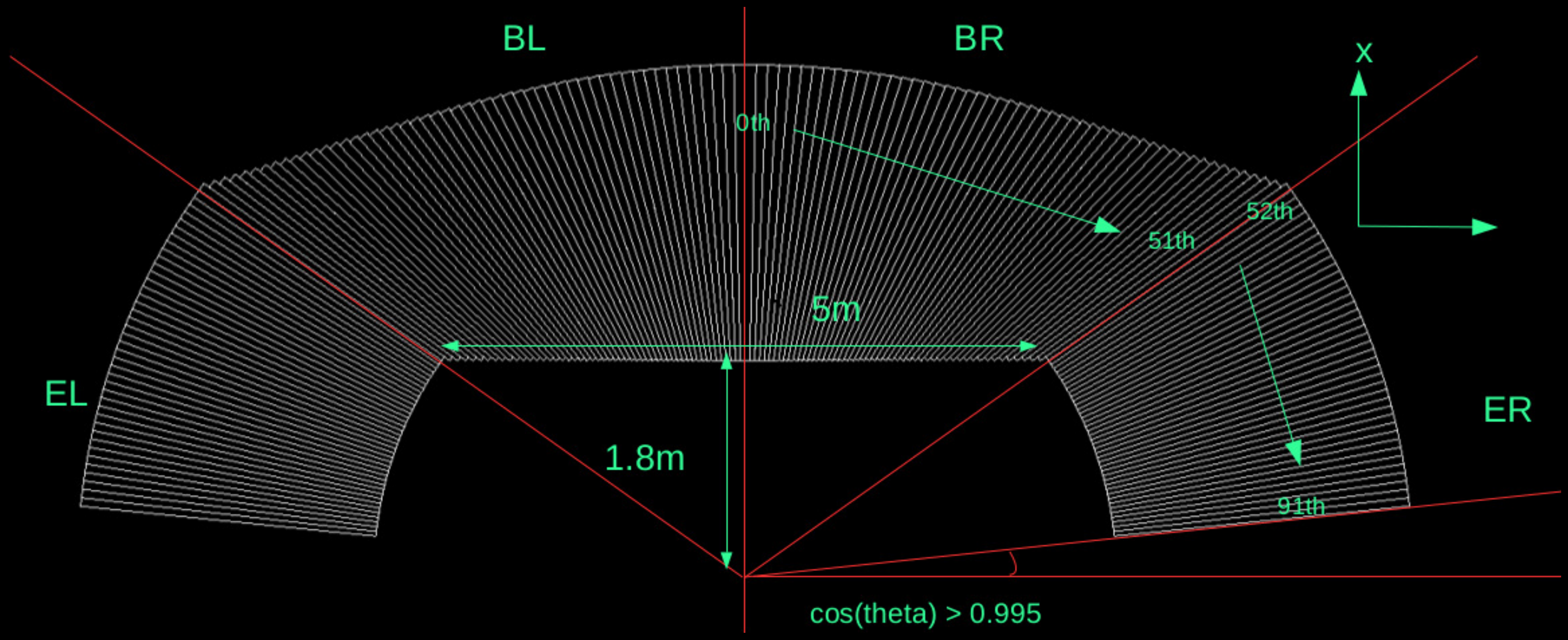


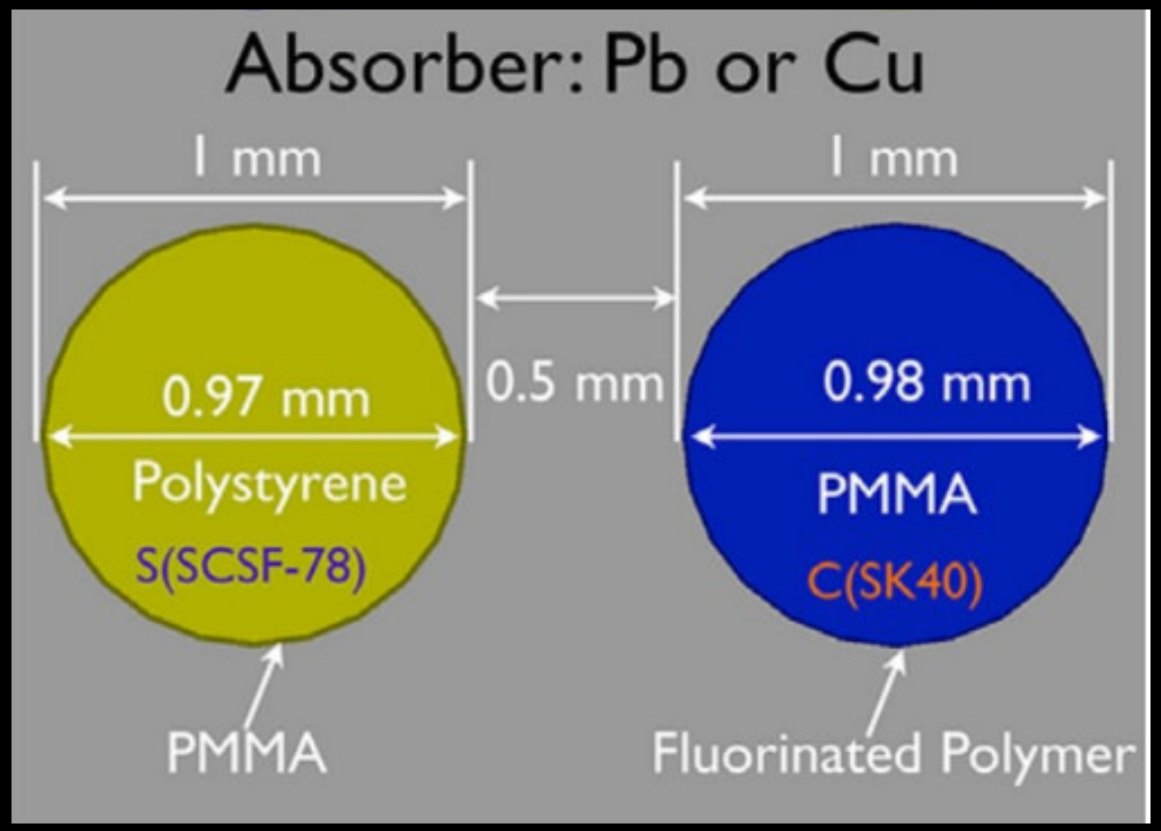
Dual Readout Calorimeter

Hauptman, Santoro, Ferrari
Tomorrow, 11:30, 12:00, 12:30 am

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)

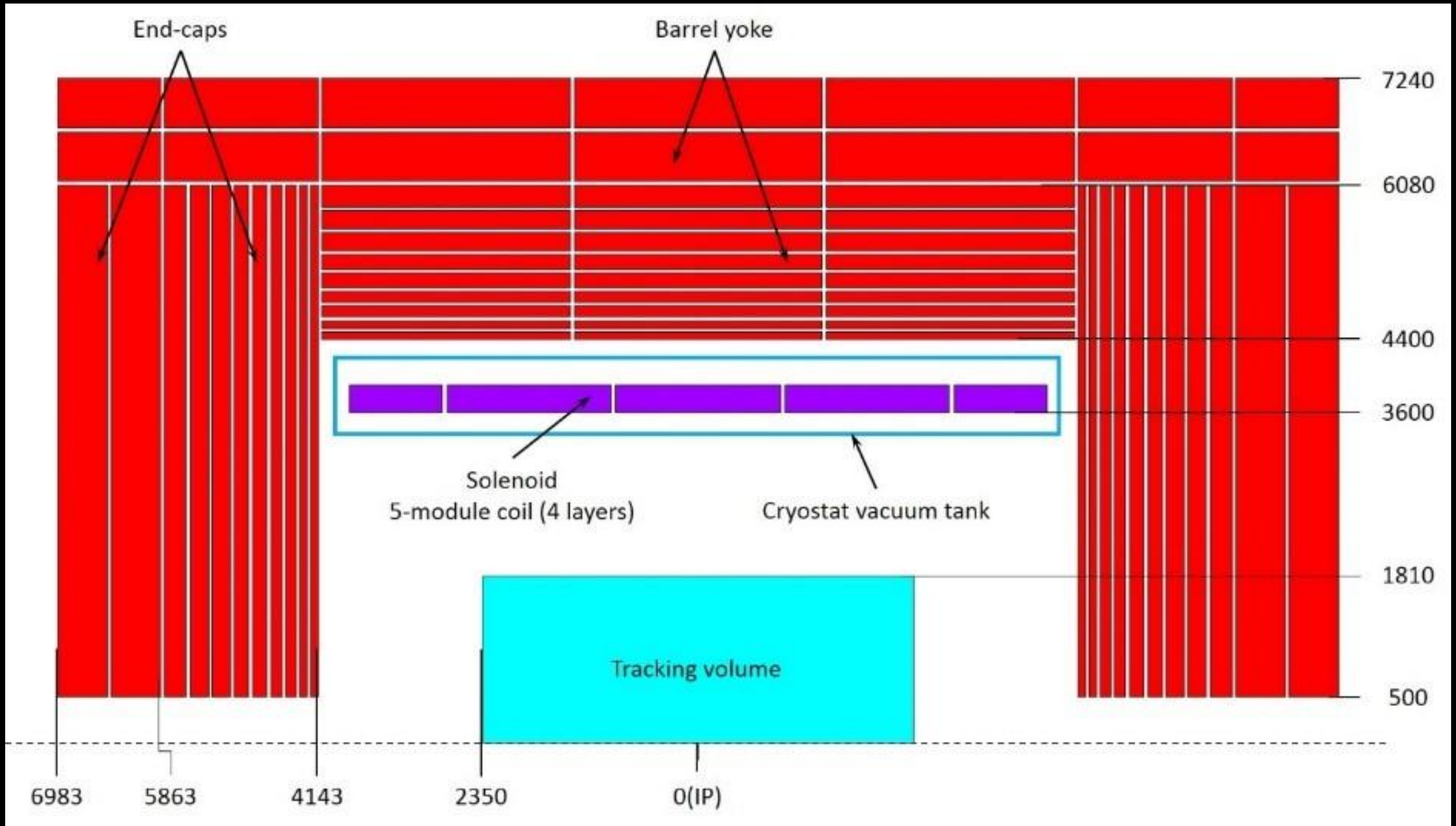
Studying different readout schemes
PMT vs SiPM

Preliminary results from simulation
to be shown at workshop

Superconductor solenoid development

Zian Zhu, Feipeng Ning
Tomorrow, 3:30, 4:00 pm

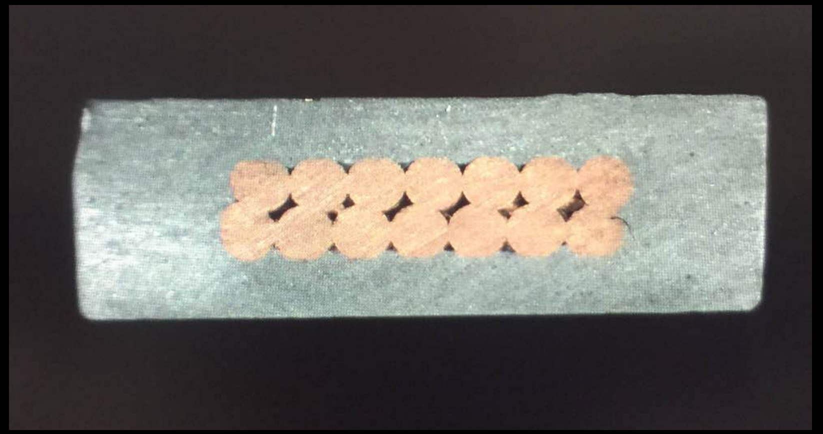
Updated design done for 3 Tesla field (down from 3.5 T)



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

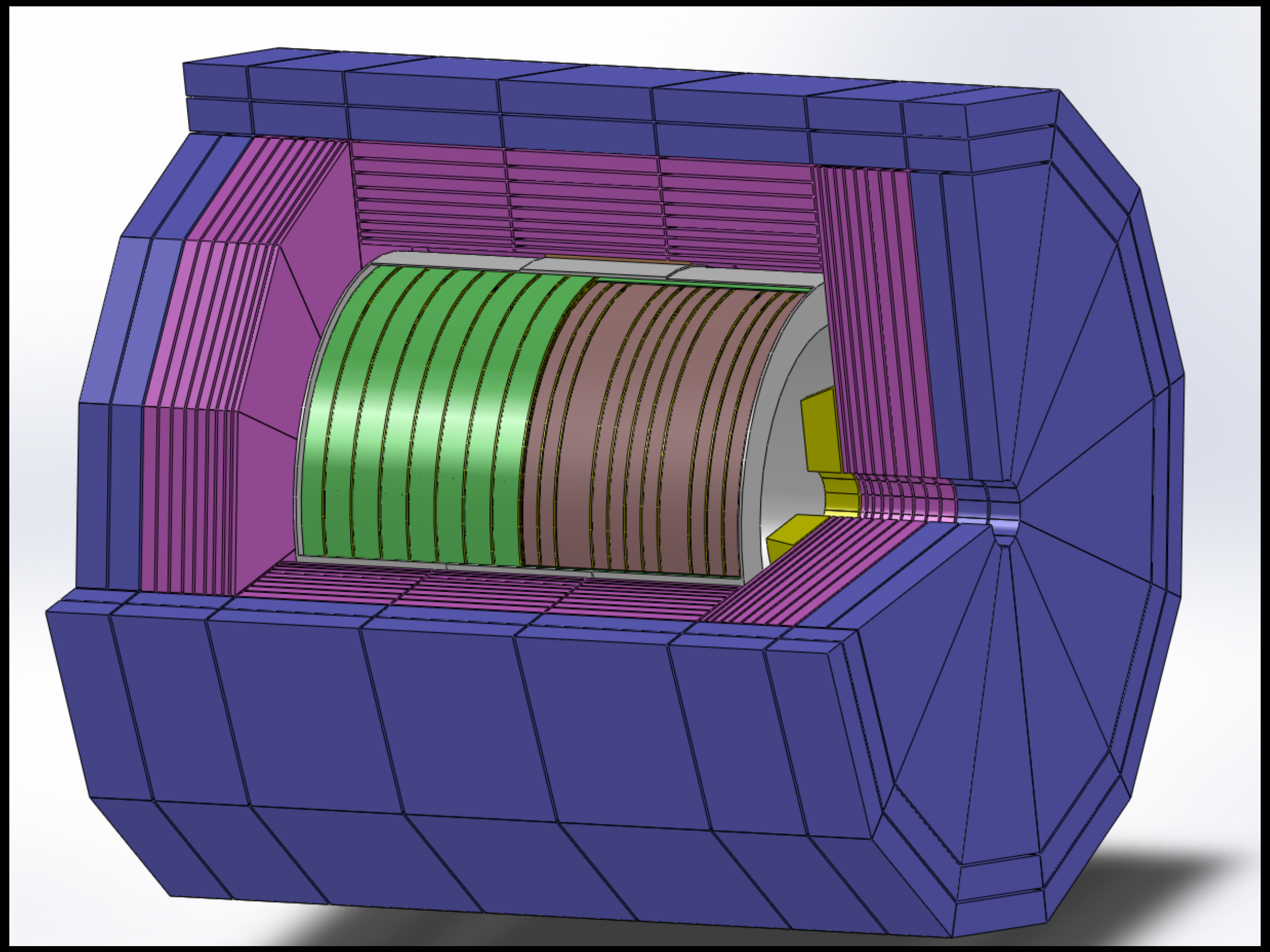


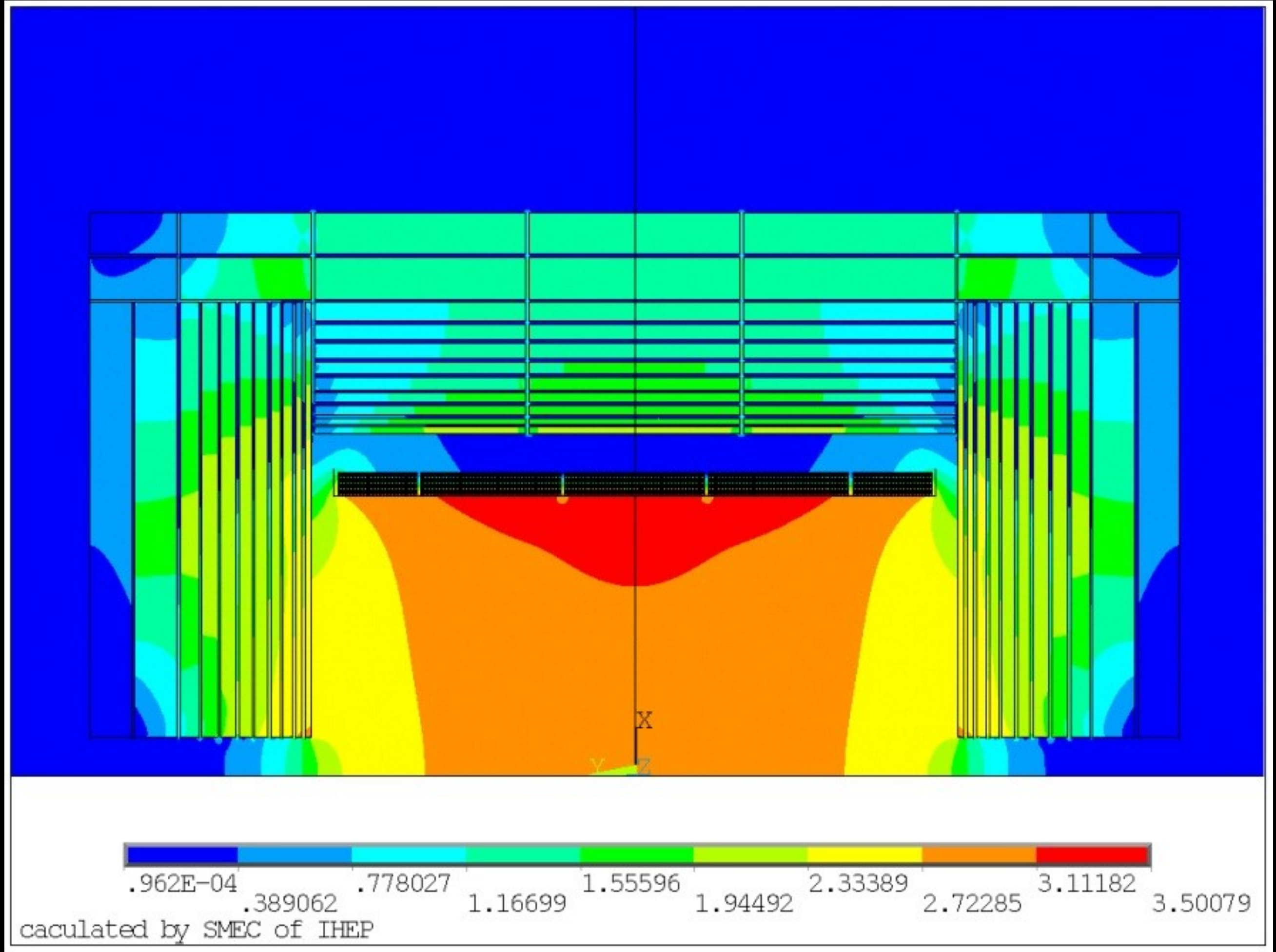
Default is NbTi Rutherford SC cable (4.2K)
Solutions with High-Temperature SC cable also being considered (YBCO, 20K)

Superconductor solenoid development

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

Default: Iron Yoke



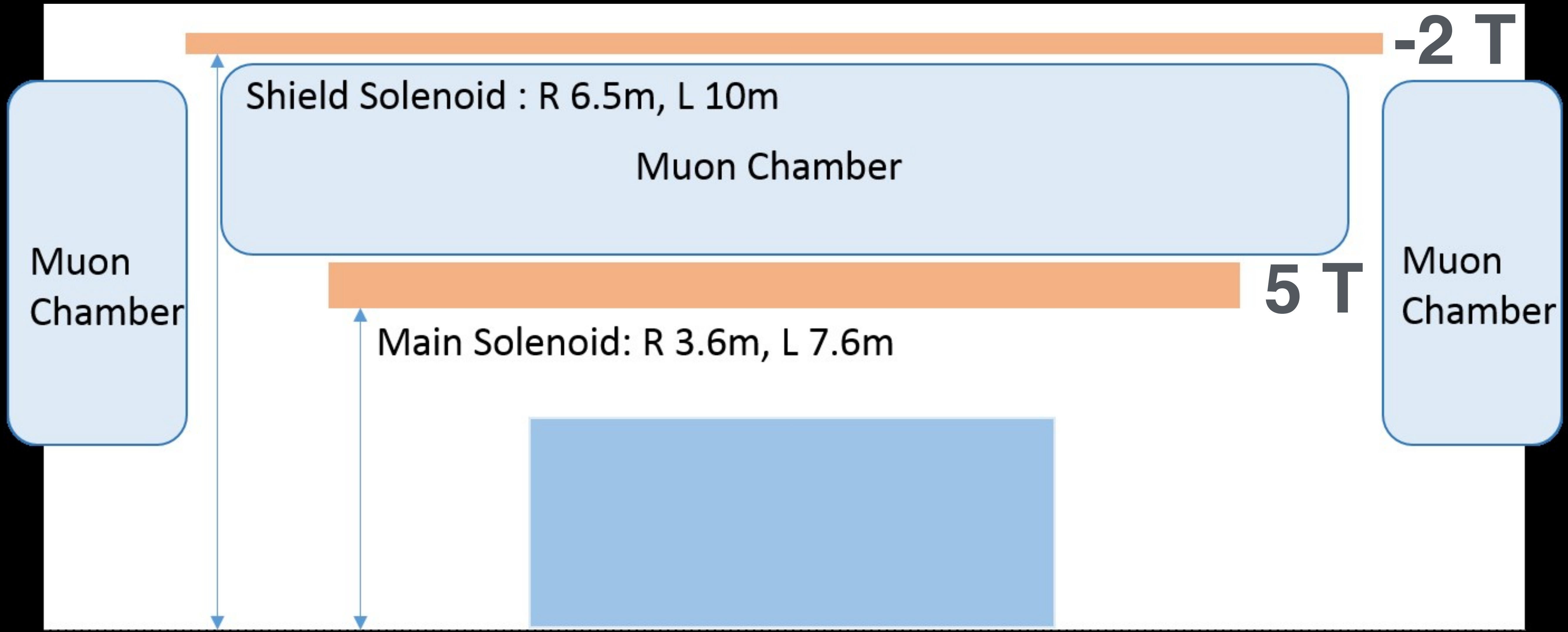


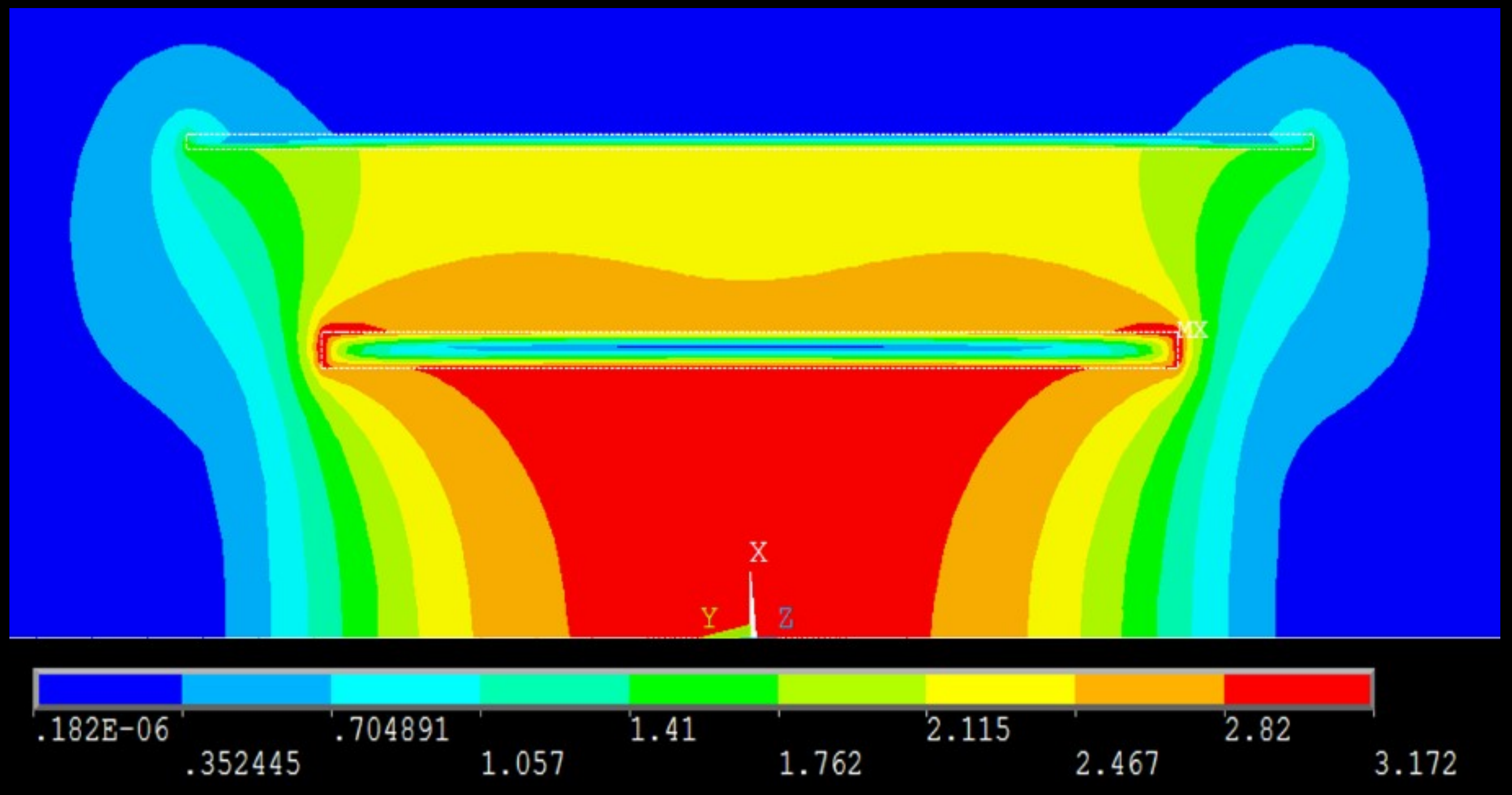
Non-uniformity 9.1%

Dual Solenoid Scenario

Lighter and more compact

Concept improved by FCC studies



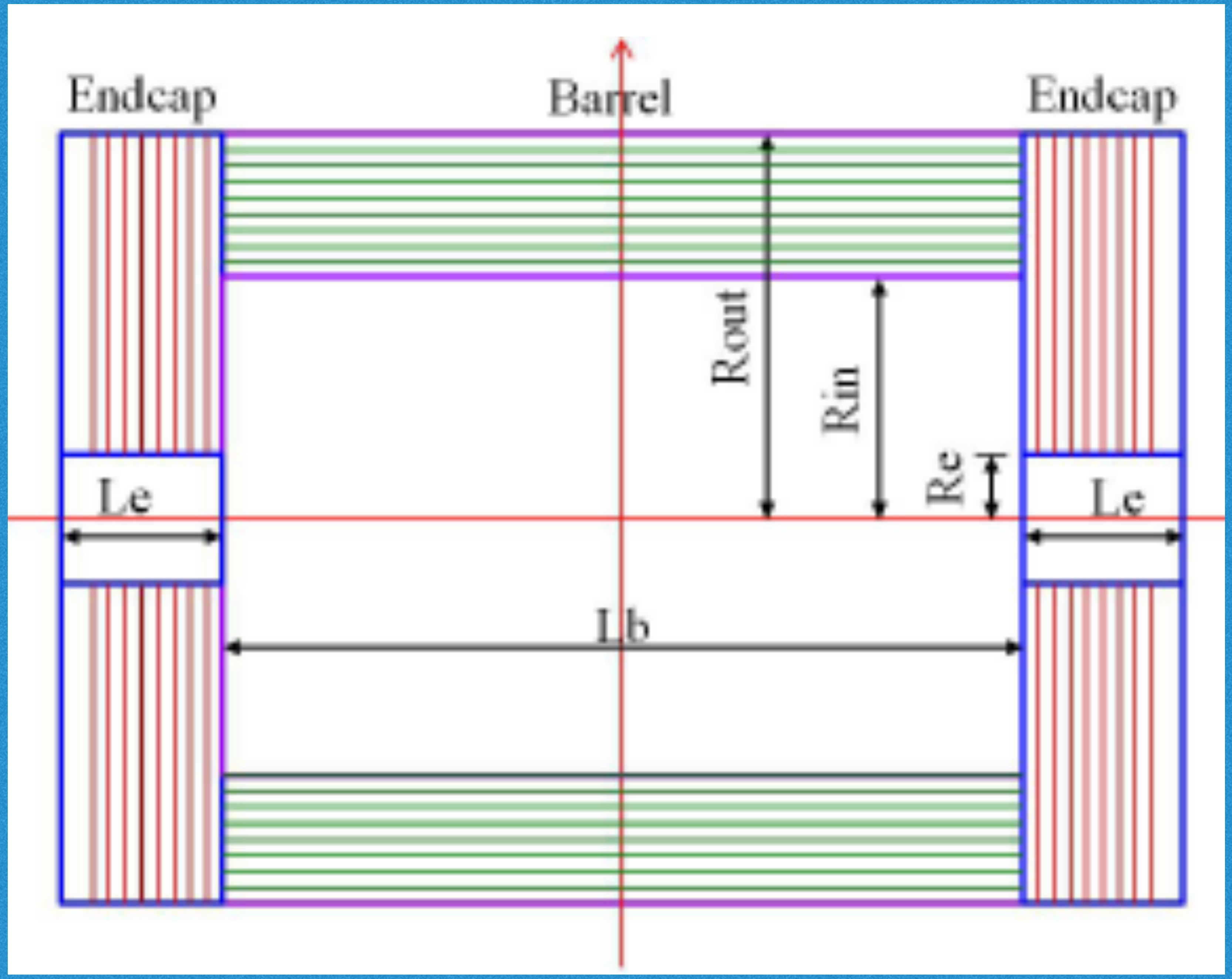


Muon detector

Giacomelli, Lener, Liang Li
Tomorrow, 5:00, 5:30, 6:00 pm

Baseline Muon detector

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

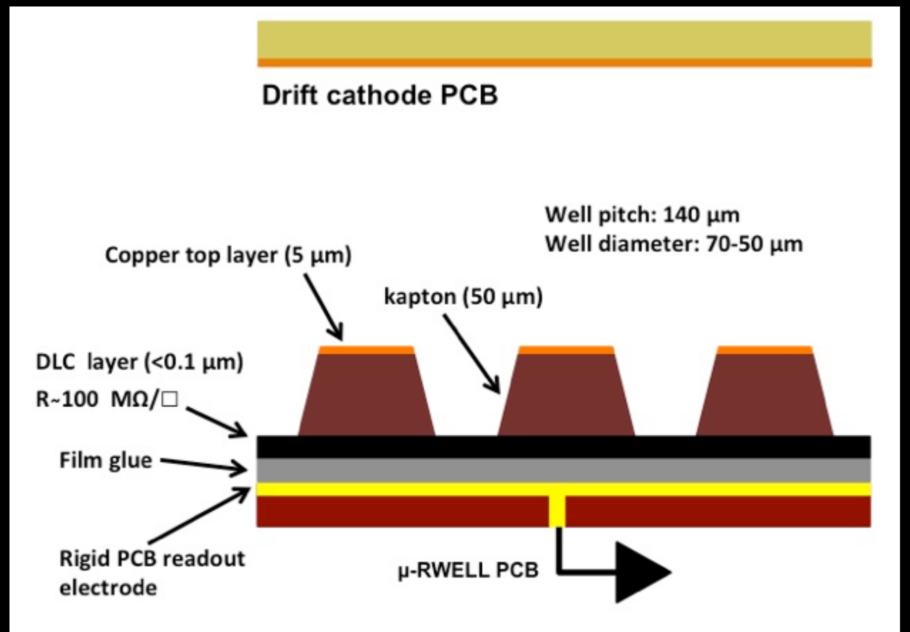


Technologies considered

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: µRwell



Muon system: open studies

Full simulation samples with full detector, integrated with yoke and magnet system

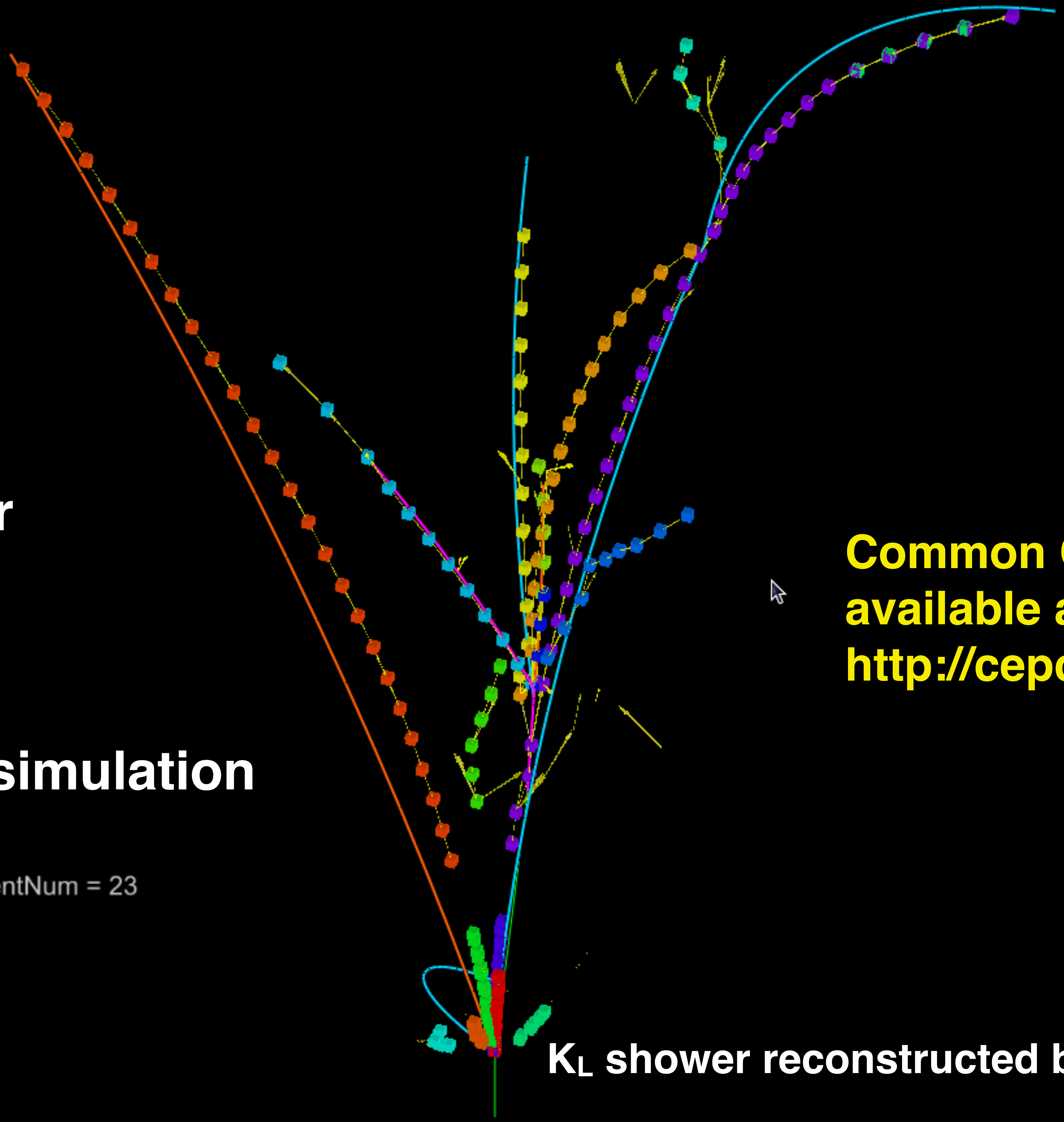
- **Further layout optimization:** N layers, thickness, cell size
- **Effect as a tail catcher / muon tracker (TCMT)**
  - **Jet energy resolution with/without TCMT**
- **Gas detectors:** Study aging effects, improve long-term reliability and stability
- **All detectors:** Improve massive and large area production procedures, readout technologies.

- **Exotics/new physics search study, e.g. long lived particles**

Optimization based on
particle flow oriented detector
and
full simulation Geant4

Some studies done with fast simulation

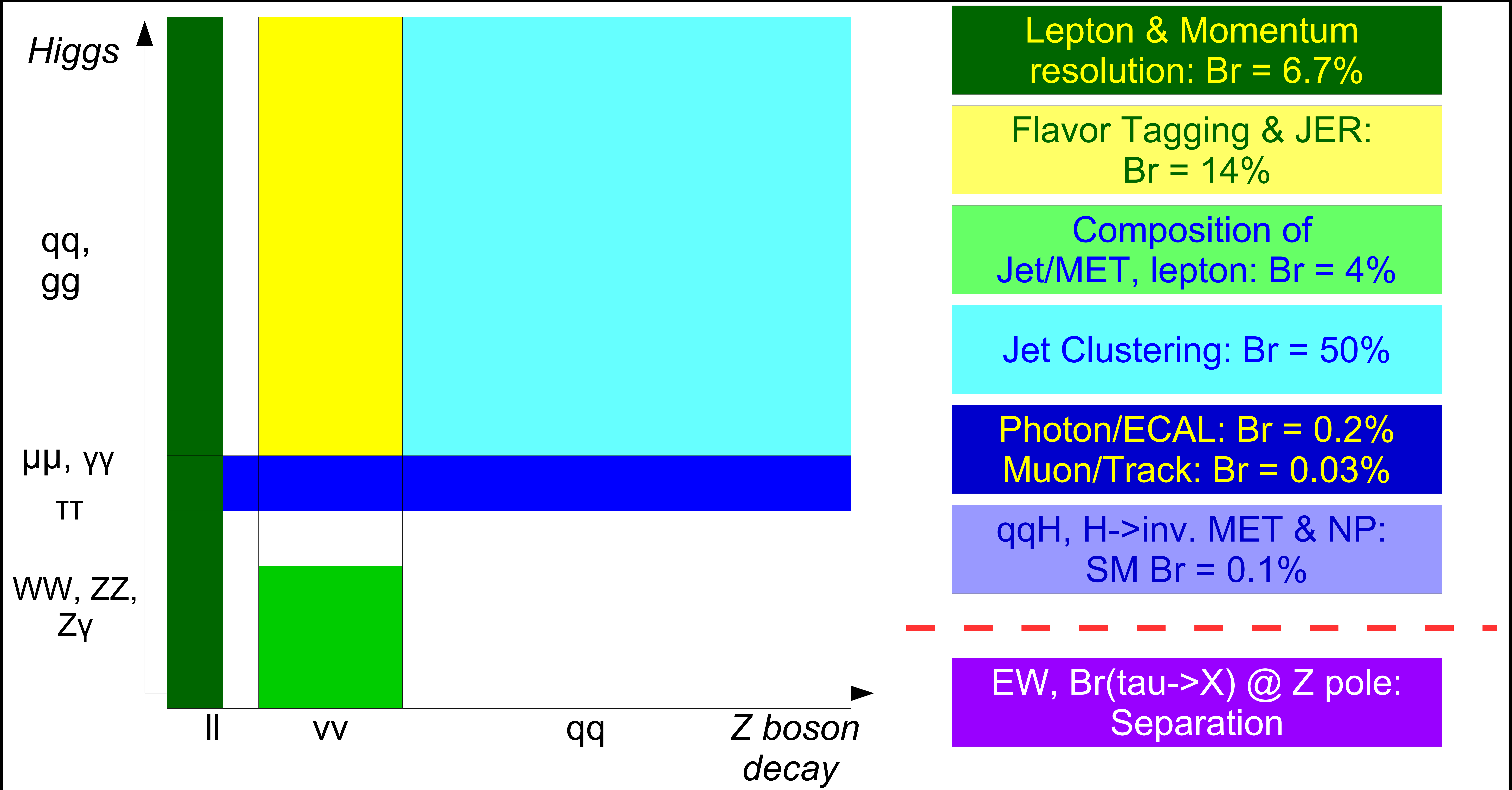
DRUID, RunNum = 0, EventNum = 23



K_L shower reconstructed by the Arbor algorithm

Common CEPC software tools
available at:
http://cepcsoft.ihep.ac/docs

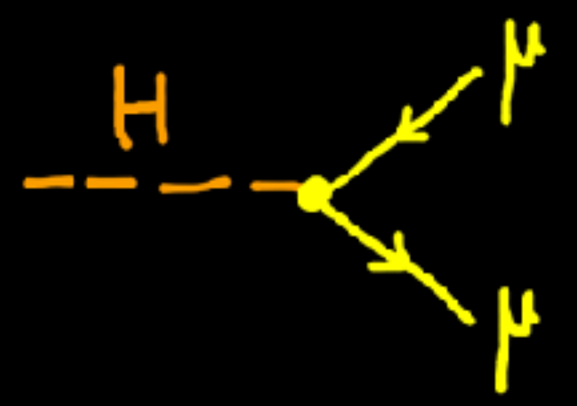
Detector optimization: Benchmark measurements

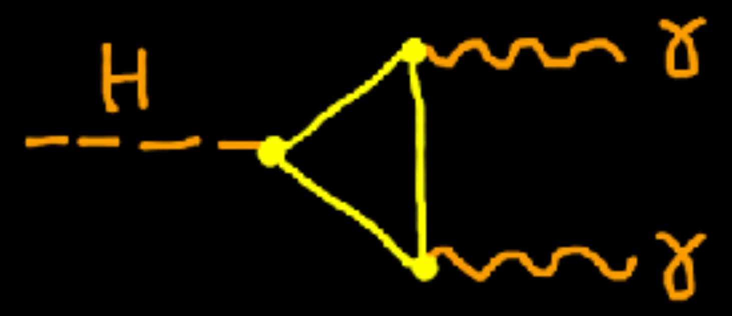


Results in CDR not fully updated for the 3 Tesla magnetic field and latest geometry

Detector optimization

	Optimized (CDR)	Comments
B Field	3 Tesla	Required from beam emmitance
TPC radius	1.8 m	Required by Br(H→μμ) measurement
TOF	50 ps	Pi-Kaon separation at Z pole
ECAL thickness	84 mm	Optimized for Br(H->γγ) at 250 GeV
ECAL cell size	10 mm	Maximum for EW measurements, better 5 mm but passive cooling needs 20 mm
ECAL num. layers	25	Depends on silicon sensor thickness
HCAL thickness	1 m	
HCAL num. layers	40	Optimized for Higgs at 250 GeV





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

Preliminary

- Draft-0 preliminary chapters available in November 2017
  - Chapter 2: Physics case
  - Chapter 3: Detector concepts (partial)
  - Chapter 4: Tracking system (vertex, silicon tracker, silicon-only, TPC, drift chamber)
  - Chapter 5: Calorimeter (PFA and DR calorimeter options)
  - Chapter 6: Magnet system
  - Chapter 7: Muon system
  - Chapter 8: Triger and DAQ
  - Chapter 9: MDI, beam background and luminosity measurement
  - Chapter 10: Physics performance and expectations (partial)

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

October 2018: Planned release date

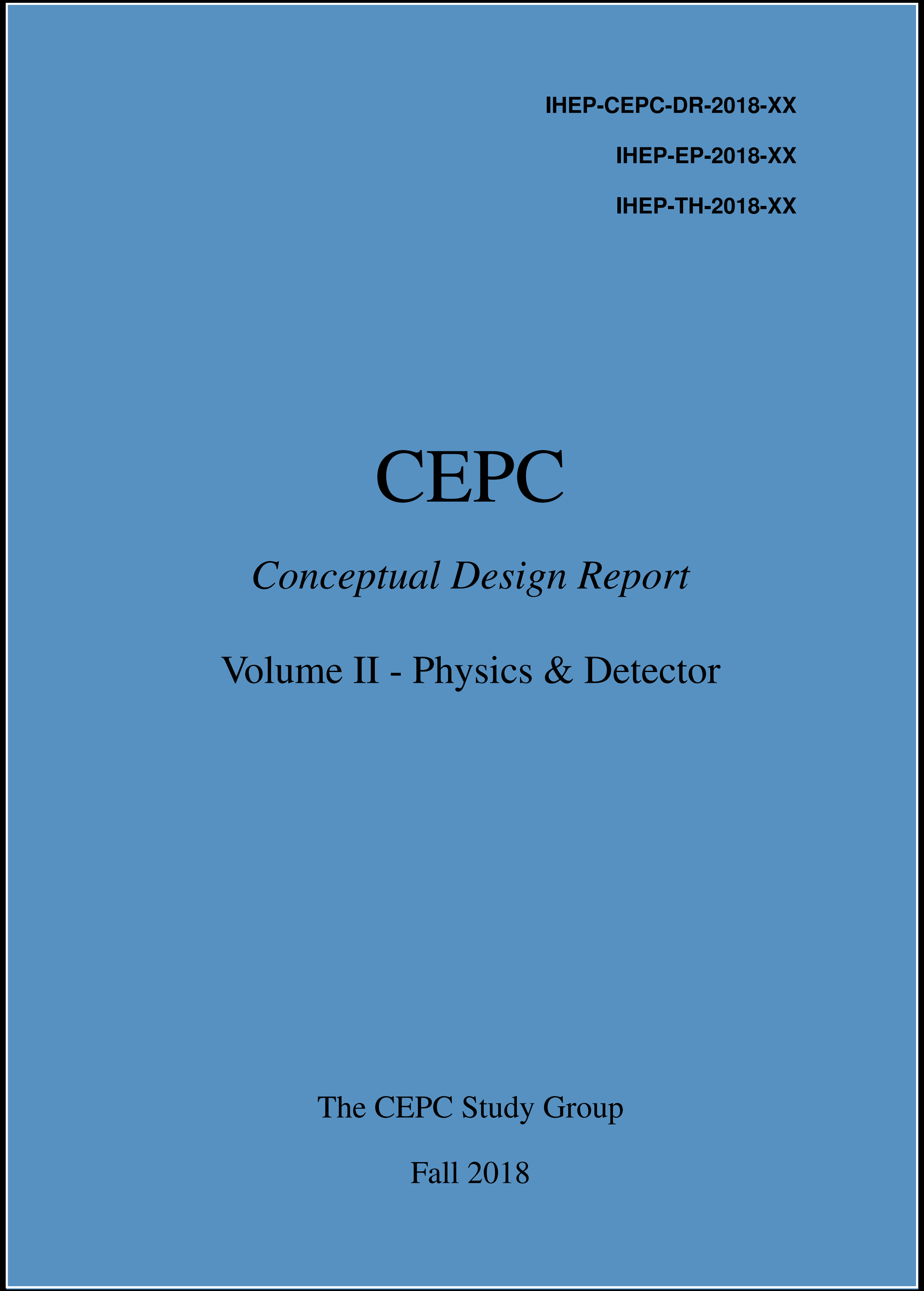
- Soon after CEPC accelerator CDR is released
- Delays to accommodate new accelerator design parameters and solenoid magnetic field

Still

- Plenty of opportunities for people to contribute
- Lots of room to make a serious impact

Weekly meetings:

- https://indico.ihep.ac.cn/category/324/



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 have emerged
    - High-magnetic field: with TPC or full-silicon tracker
    - Low-magnetic field: with drift chamber and dual readout calorimeter
  - Significant amount of R&D on-going in China
    - Vertex detector, TPC, calorimeters, magnets
    - Support from NSFC, MOST, etc
      - MOST (2018-2023) prototype projects approved
  - Colleagues from Italy heavily involved
    - Drift chamber, dual readout calorimeter and muon chambers
- International collaborations expanding
  - INFN, SLAC, Iowa State Univ., Belgrade, LLR, IPNL, LC-TPC, Liverpool, Oxford, Barcelona…
  - PFA calorimeter, TPC and vertex detector

CDR Expected final release:
Late 2018

Backup Slides

Accelerator Parameters

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
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	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Accelerator Parameters

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
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 current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	30	30	16.5	
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
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
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Bunch length σ_z (mm)	3.26	5.9	8.5	
Natural energy spread (%)	0.1	0.066	0.038	
Photon number due to beamstrahlung	0.29	0.35	0.55	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

Organization of the Physics and Detector Working Group

Conveners

Executive: **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	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

Ministry of Science and Technology – Funding Requests

- MOST 1 – Funding
  - SJTU, IHEP, THU, USTC, Huazhong Univ
  - Silicon pixel detector ASIC chip design
  - Time projection chamber detector
  - Electromagnetic and hadrons calorimeter
    - High-granularity ECAL
    - Large area compact HCAL
  - Large momentum range particle identification Cherenkov detector
- MOST 2 – funding
  - SJTU, IHEP, Shandong U. Northwestern Tech. University

Ministry of Science and Technology – Funding 1

- Vertex detector
  - Use 180 nm process
  - Carry out the pixel circuit simulation and optimization, in order to achieve a CPS design with a small pixel depletion type, and try to improve the ratio between signal and noise;
  - Focus on the small pixel unit design, reduce the power consumption and improve readout speed; time projection chamber detector
  - Parameters:
    - spatial resolution to be better than 5 microns
    - integrated time to be 10-100 microseconds
    - power consumption of about 100 mW/cm^2.

Ministry of Science and Technology – Funding 1

- **Time Projection Chamber**
  - Based on the new composite structure, read the positive ion feedback suppression, when the detector precision is better than 100 microns.
  - Study the effect of electromagnetic field distortion on position and momentum resolution.
  - Test the main performance indicators of the readout module in the 1T magnet field.
  - Low power readout electronics is planed to use advanced 65nm integrated circuit technology, to achieve high density and high integration of ASIC chip design, reduce circuit power consumption to less than 5mW / channel.
  - **Parameters:**
    - spatial resolution to be better than 5 microns
    - integrated time to be 10–100 microseconds
    - power consumption of about 100 mW/cm^2.

Ministry of Science and Technology – Funding 1

- **High granularity ECAL**
  - Technical selection based on SiPM readout electromagnetic calorimeter
  - Realizing ECAL readout unit granularity of $5\times5mm^2$
  - Develop small ECAL prototype;
  - Develop a set of active cooling system based on two-phase CO_2 refrigeration.
    - The thermal conductivity is greater than 30 mW/cm^2 in -20 degrees.
- **High granularity HCAL**
  - Decide technical design of digital calorimeter;
  - At a particle size of 1 cm x 1 cm, master the gas detector production process with thickness less than 6 mm; Produce the micro hole detector unit model with area of 1 m × 0.5 m. The overall gain uniformity of the detector is better than 20%. Counting rate is 1MHz/s; Produce the flat panel board with area of 1 m × 1 m
    - Detection efficiency is better than 95%.

Ministry of Science and Technology – Funding 1

- Particle Identification technology
  - Combine the advantages of THGEM and MicroMegas to achieve the detection of Cherenkov light with high sensitivity, low background, high count rate and anti-radiation
  - Make a prototype and test it
  - Parameters:
    - The photon angle resolution of the Cherenkov radiation is better than 2 mrad

Vertex Detector Performance Requirements

CDR: Chapter 4

Efficient identification of heavy quarks (b/c) and τ leptons

$$\sigma_{r\phi} = 5 \oplus \frac{10}{p(GeV)\sin^{3/2}\theta} \ (\mu m)$$

Intrinsic resolution of vertex detector

Resolution effects due to multiple scattering

Dominant for low-p_T tracks

	Specs	Consequences
Single point resolution near IP:	< 3 μm	High granularity
First layer close to beam pipe:	r ~ 1.6 cm	
Material budget/layer:	≤ 0.15%X_0	Low power consumption, < 50 mW/cm^2 for air cooling
Detector occupancy:	≤ 1%	High granularity and short readout time (< 20 μs)

Continues operation mode

Target: ✿ High granularity; ✿ Fast readout; ✿ Low power dissipation; ✿ Light structure

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/cm²	Need to continue trying to lower by a factor of 2
Integration readout time:	< 10-100 μs	Need 1 μs for final detector

- **Sensors technologies:**

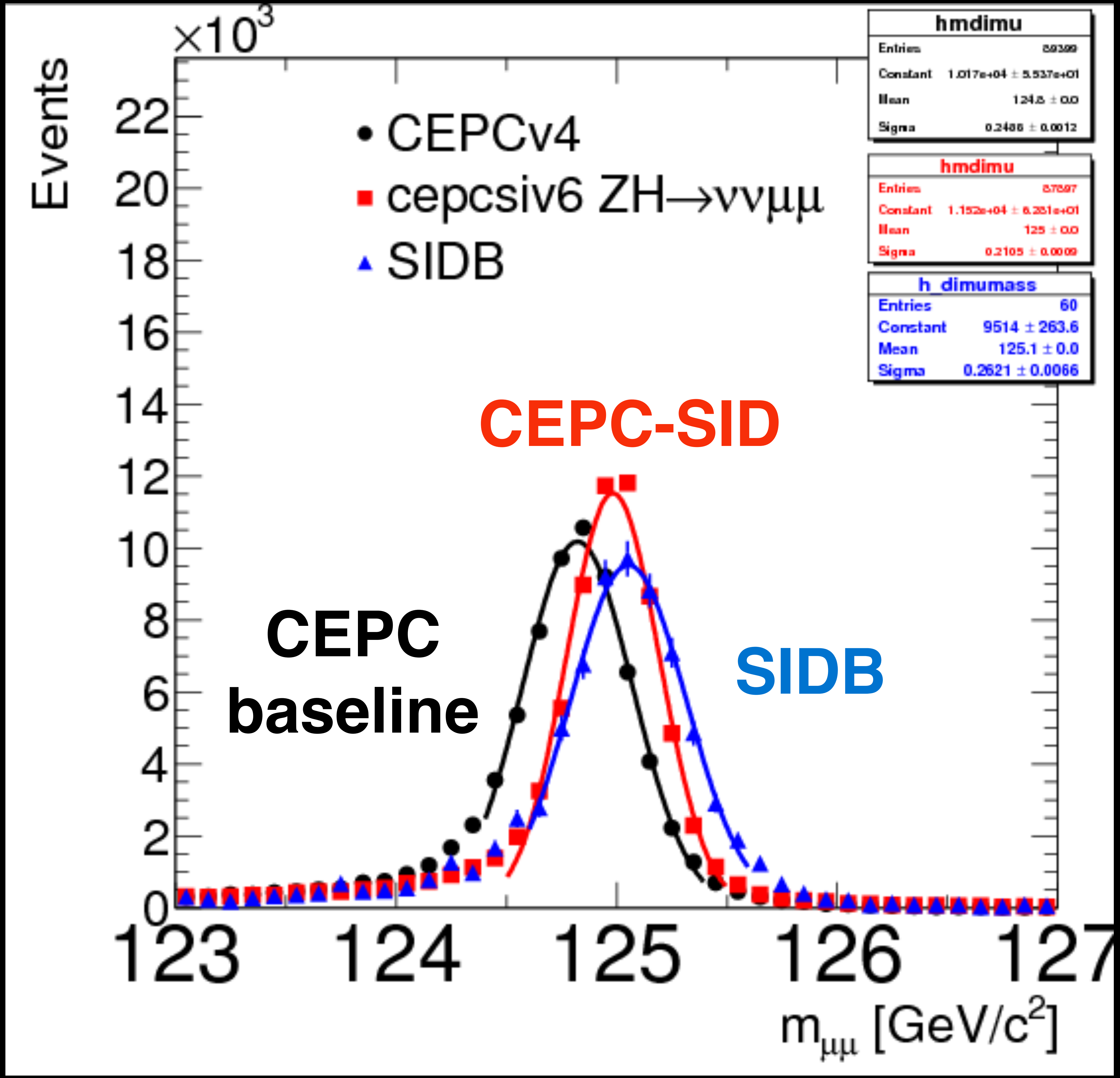
	Process	Observations
CMOS pixel sensor (CPS)	TowerJazz CIS 0.18 μm	Founded by MOST and IHEP
SOI pixel sensor	LAPIS 0.2 μm	Funded by NSFC

- Carry out the pixel circuit simulation and optimization, in order to achieve a CPS design with a small pixel depletion type, and try to improve the ratio between signal and noise;
- Focus on the small pixel unit design, reduce the power consumption and improve readout speed;

Full silicon tracker concept

Replace TPC with additional silicon layers

CEPC
Baseline
σ = 0.24 GeV



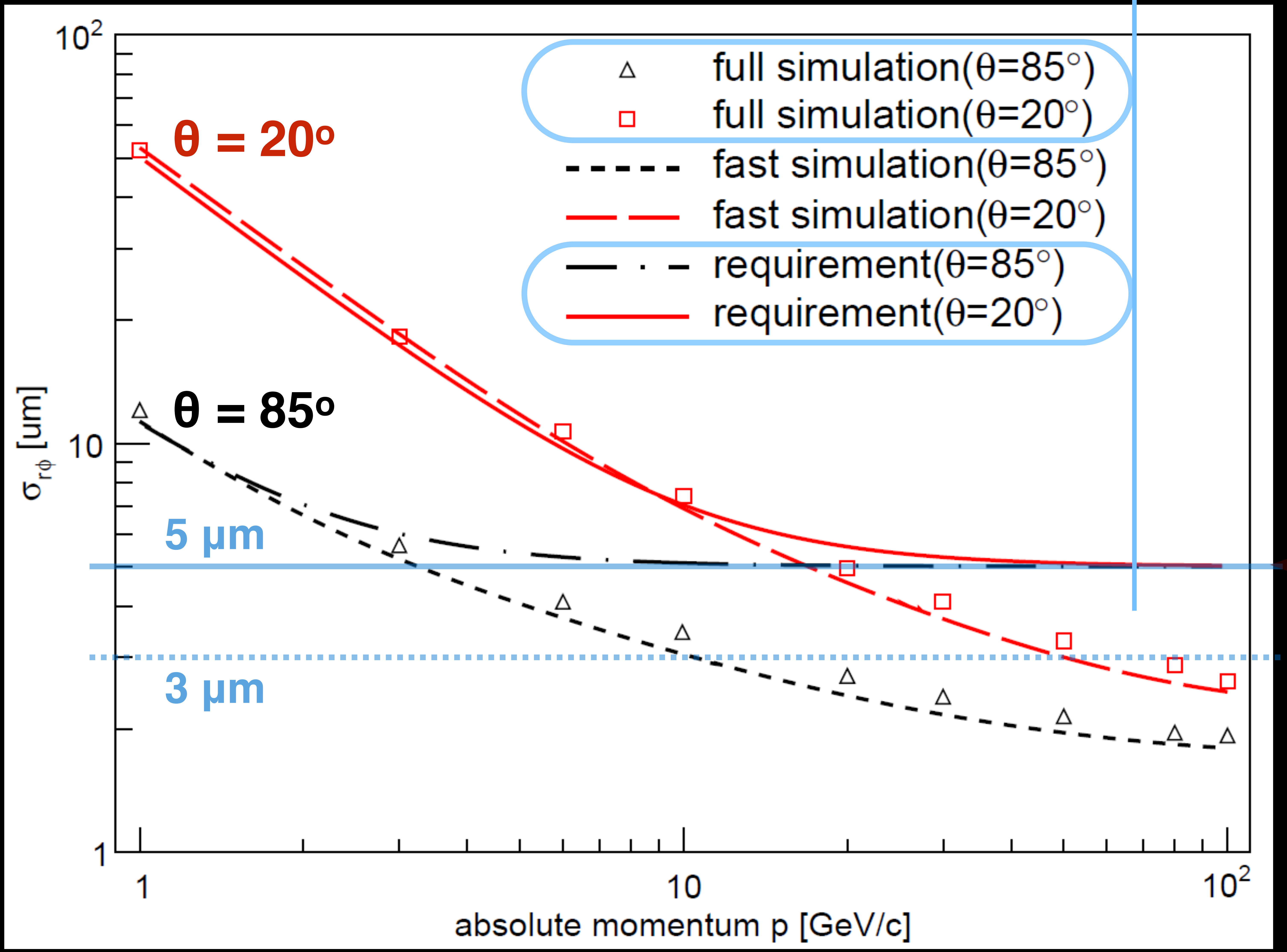
CEPC-SID: σ = 0.21 GeV

SIDB: σ = 0.26 GeV

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

Performance studies: Impact parameter resolution

Transverse impact parameter resolution for single muons

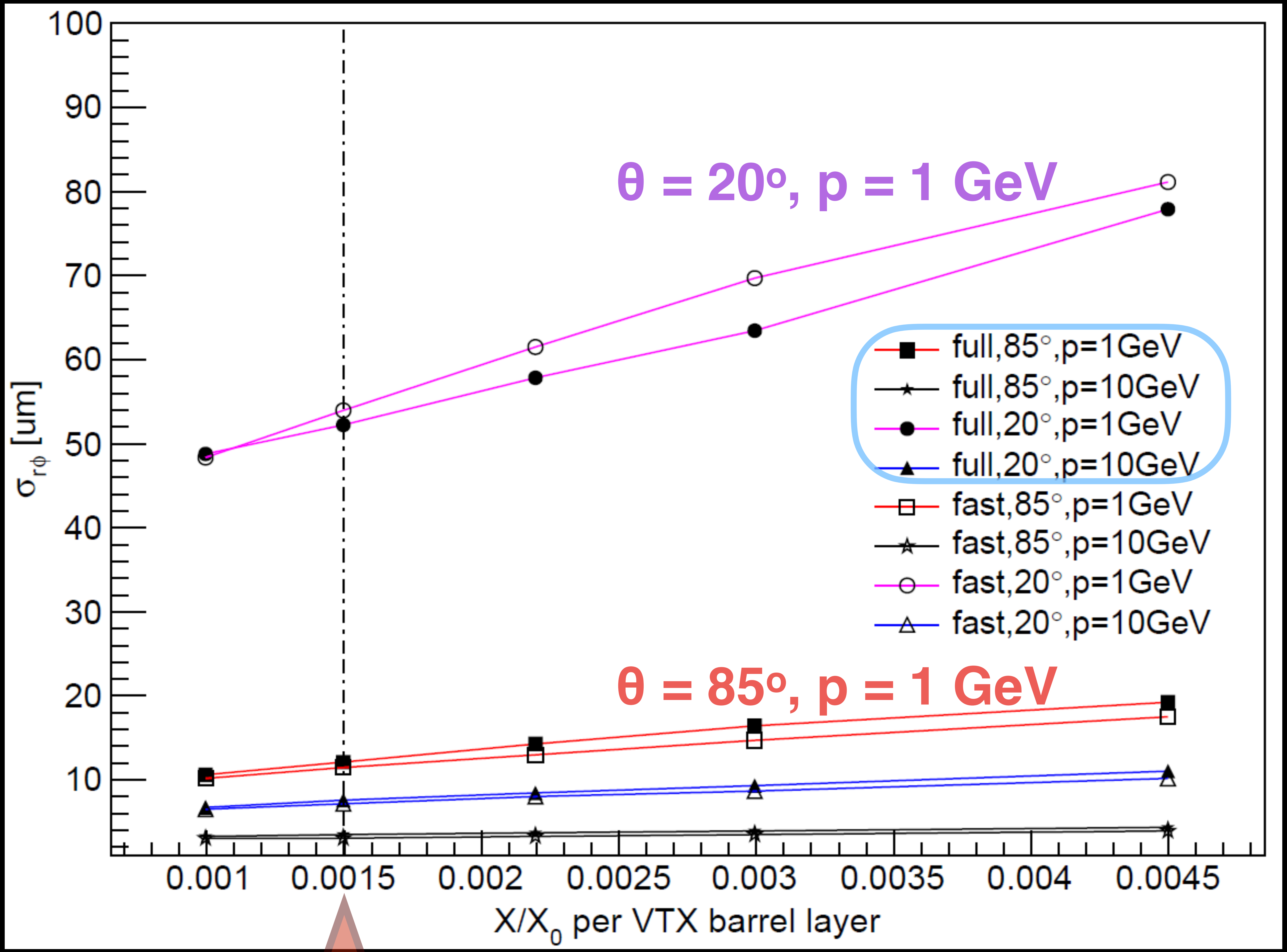


Requirement 5 µm

Impact parameter resolution goal achievable with current design

Performance studies: Material budget

Transverse impact parameter resolution for single muons



Requirement

Baseline includes very small material budget for beam pipe, sensor layers and supports
≤ 0.15%X_0

× 2 more material

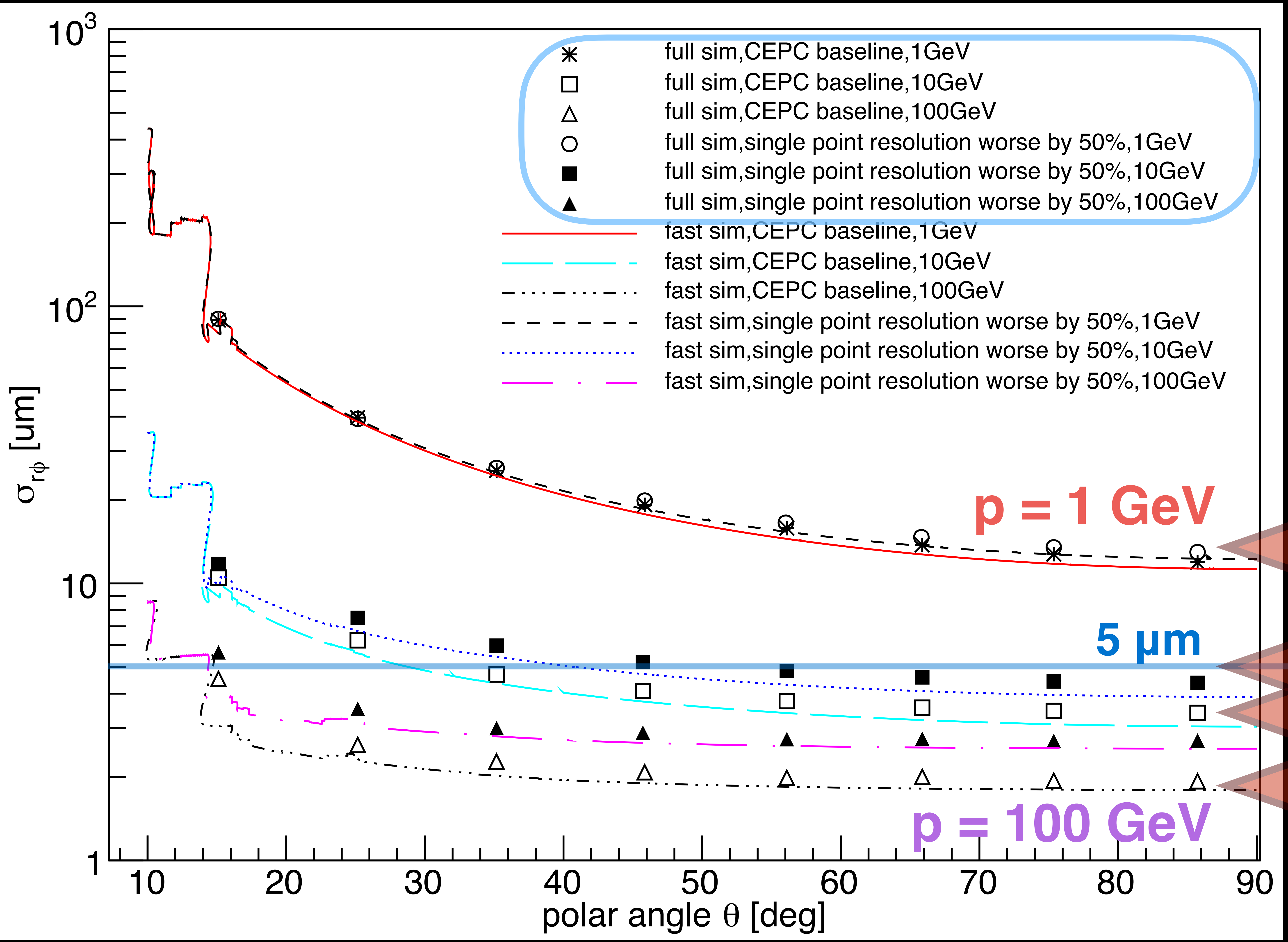
⬇

20% resolution degradation

Impact parameter resolution goal achievable but only with low material budget

Performance studies: Pixel size

Transverse impact parameter resolution for single muons



50% single point resolution degradation
⬇
50% impact parameter resolution degradation
(for high-pt tracks)

Minimum degradation for low-pt tracks (dominated by multiple scattering)

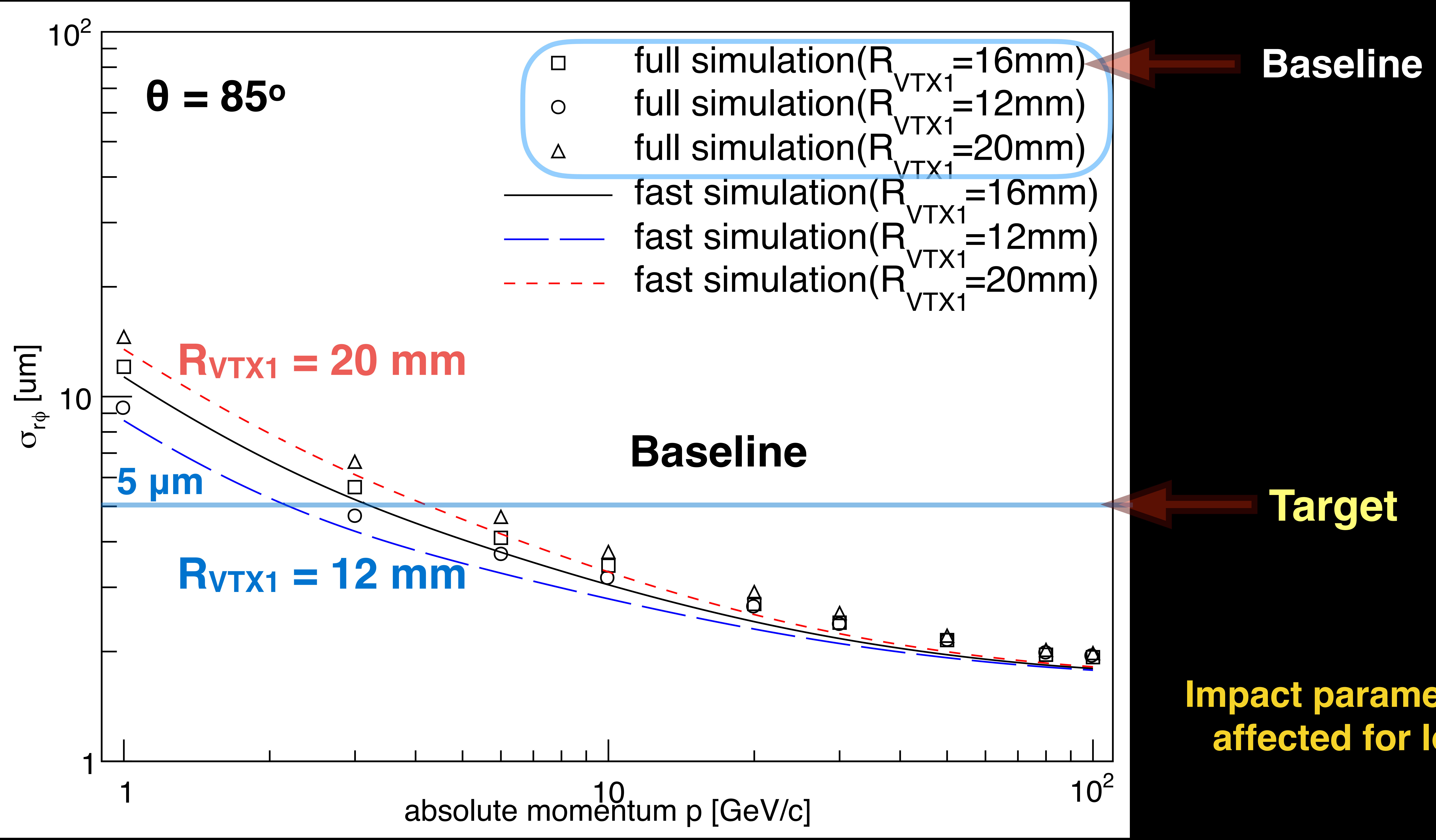
Target

Baseline p = 10 GeV

Baseline p = 100 GeV

Performance studies: Distance to IP

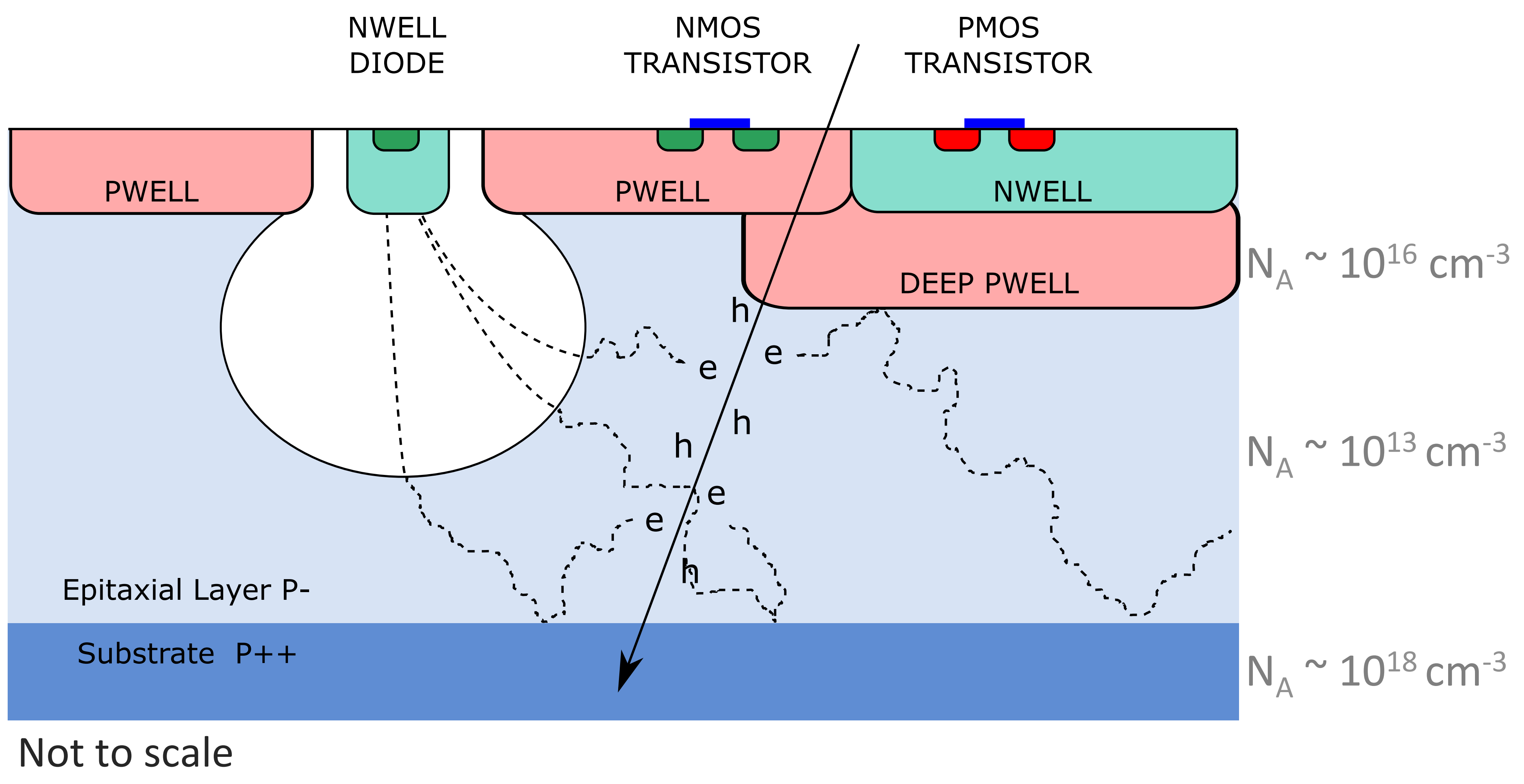
Transverse impact parameter resolution for single muons

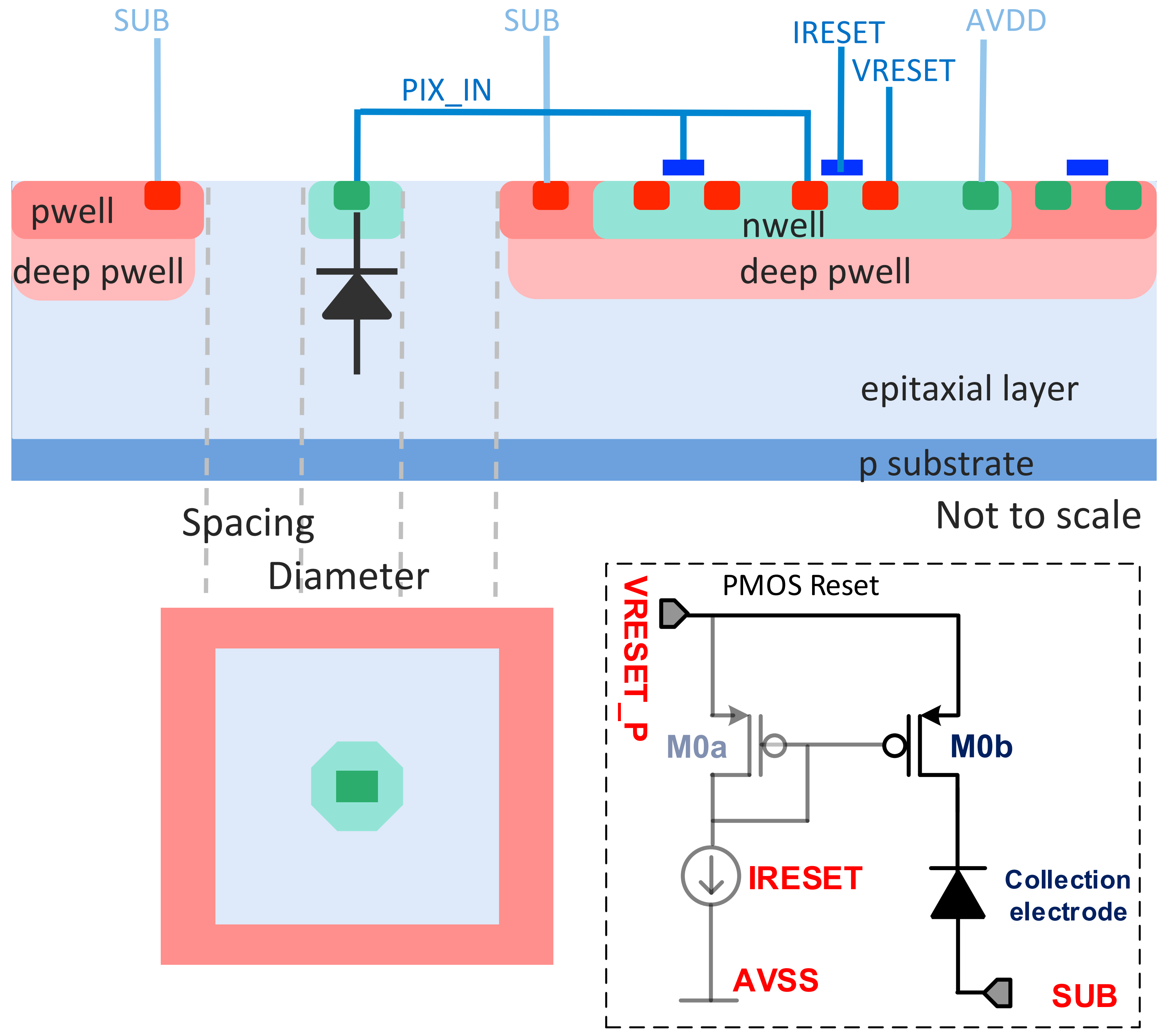


Impact parameter resolution affected for low-pt tracks

Standard Pixel Sensor imaging Process (TowerJazz)

CMOS 180nm
3 nm thin gate oxide, 6 metal layers





- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18 μm to 30 μm) on p-type substrate
- Deep PWELL shielding NWELL allowing PMOS transistors (full CMOS within active area)
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance (2fF) => large S/N
- Reverse bias can be applied to the substrate to increase the depletion volume around the NWELL collection diode and further reduce sensor capacitance for better analog performance at lower power

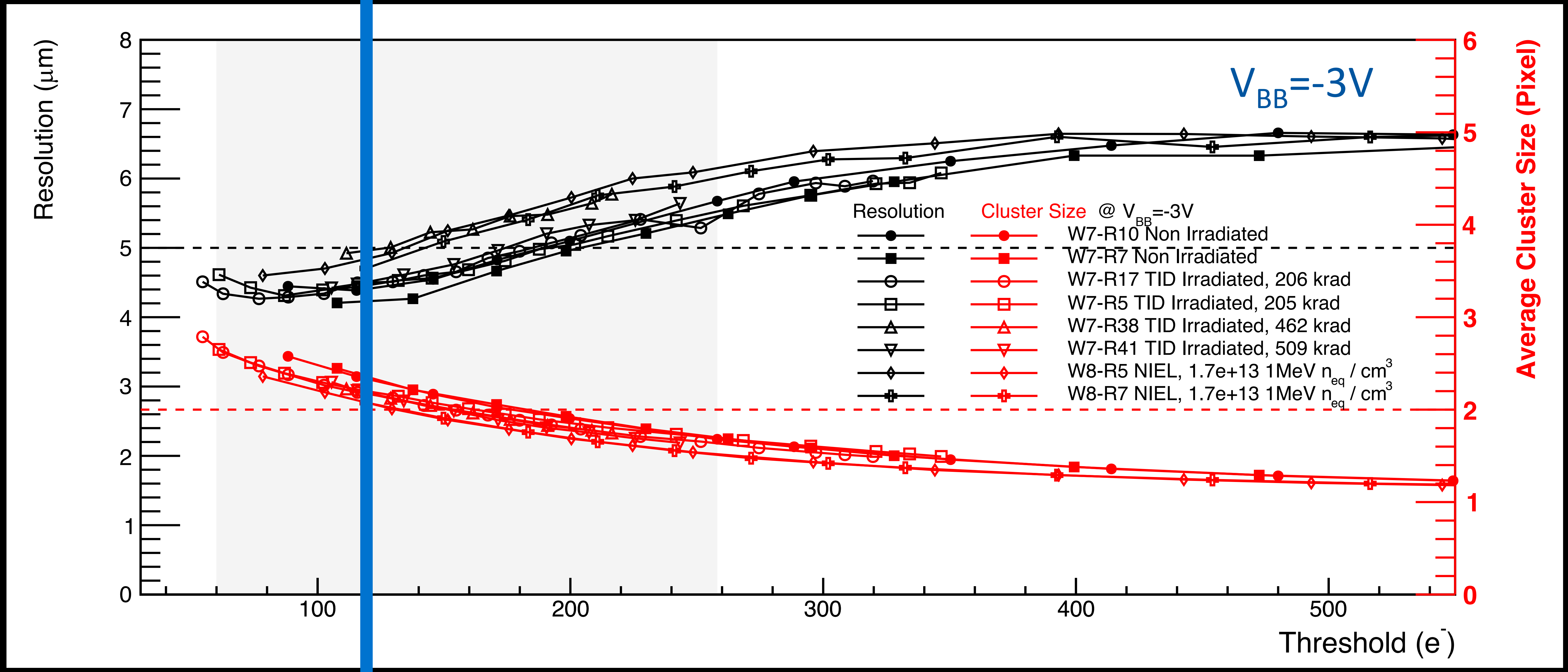
ALPIDE CMOS Pixel Sensor

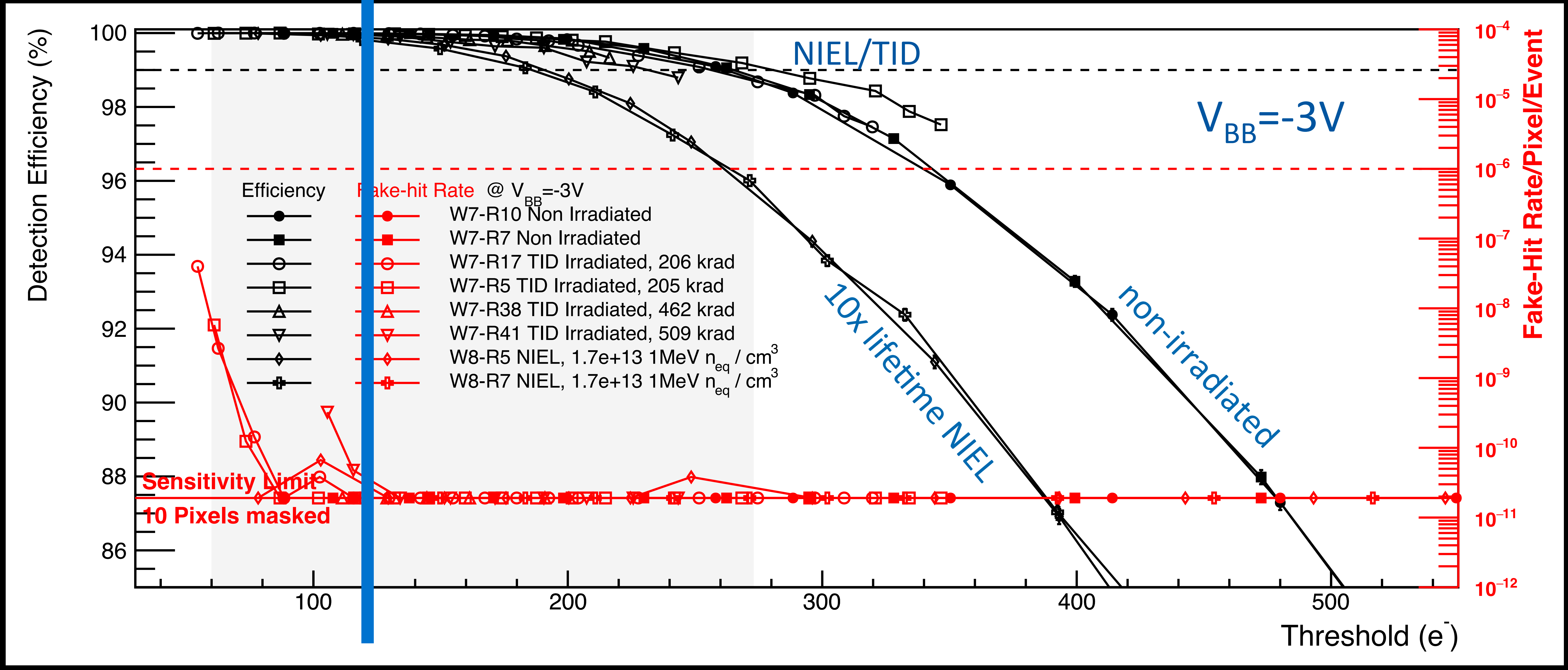
	ALPIDE
Pixel dimensions	26.9 μm × 29.2 μm
Spatial resolution	~ 5 μm
Time resolution	5-10 μs
Hit rate	~ 10^4/mm²/s
Power consumption	< ~20-35 mW/cm²
Radiation tolerance	300kRad 2×10^{12} 1 MeV n_{eq}/cm²

Almost OK specifications

Need lower resolution

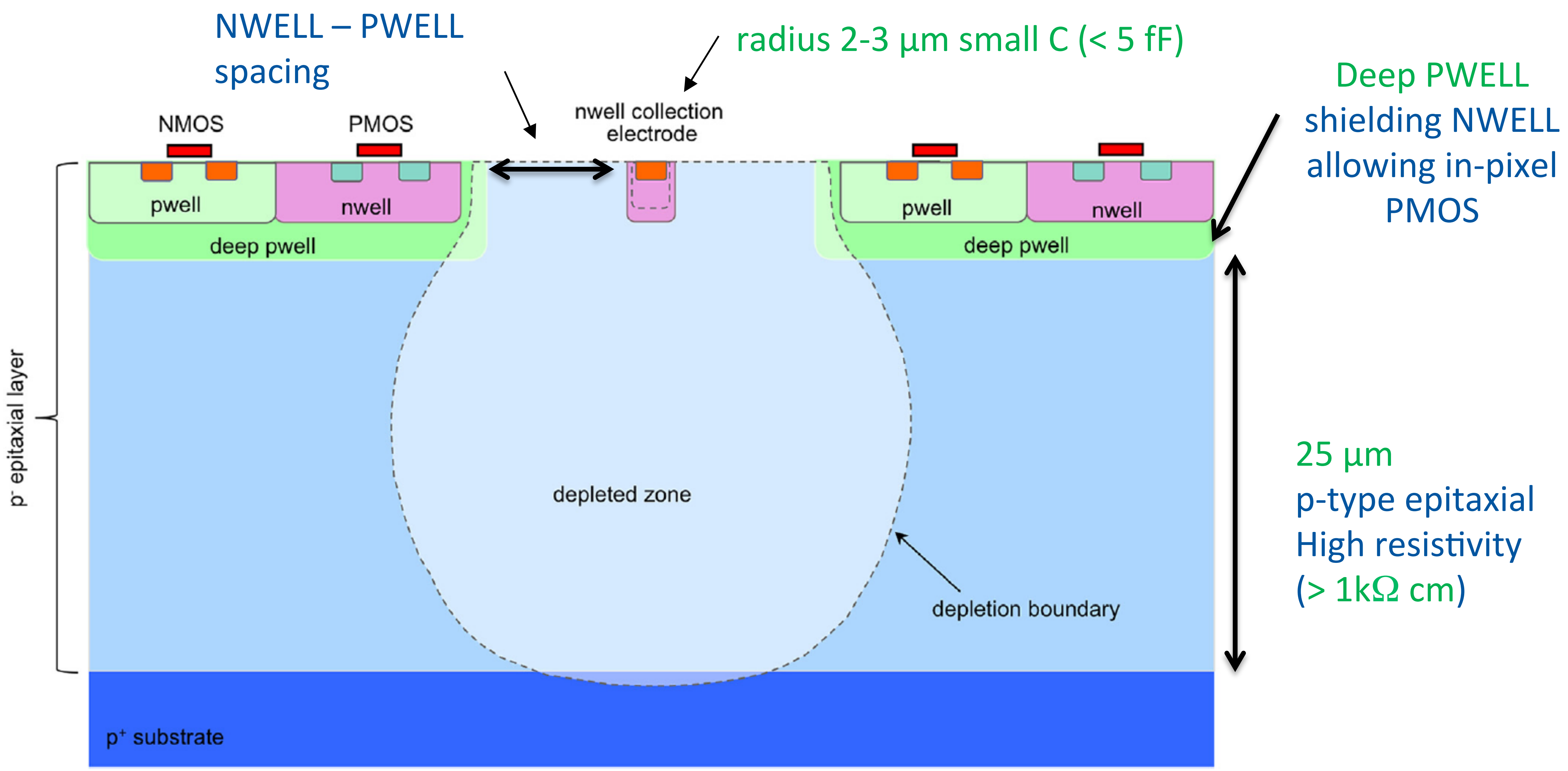
Higer radiation tolerance





ATLAS Modified TowerJazz process

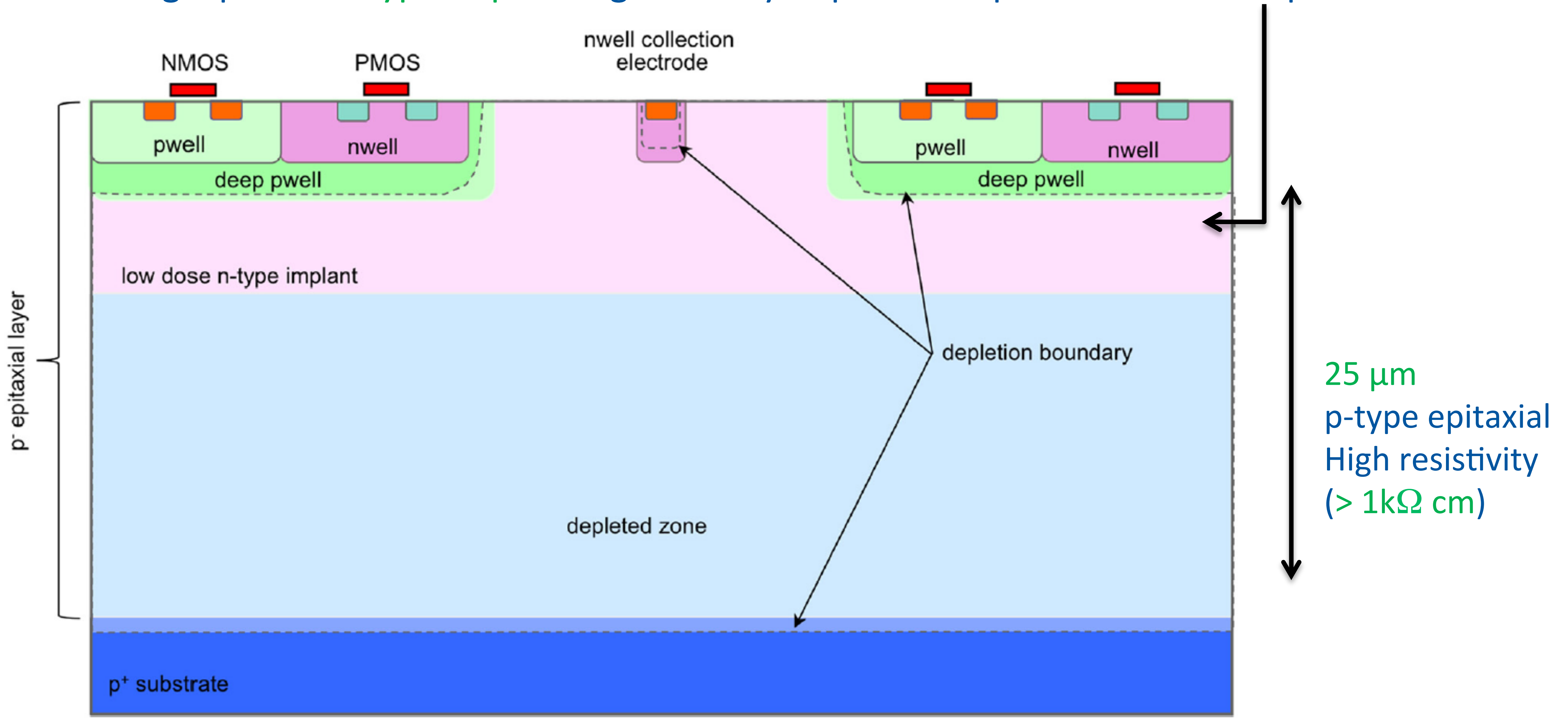
Standard process



- Reverse bias to increase depletion volume (-6 V, the sensor is not fully depleted)

Modified process

- Adding a planar n-type implant significantly improves depletion under deep PWELL



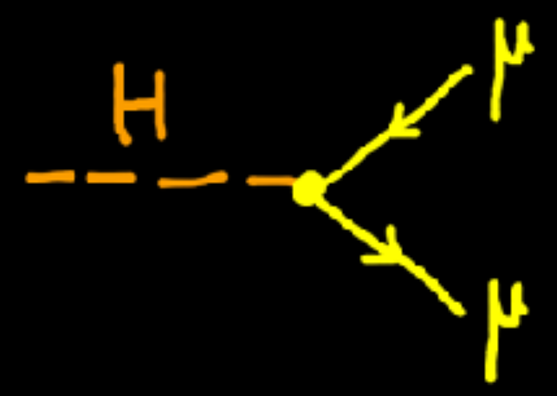
- Possibility to fully deplete sensing volume
- No significant circuit or layout changes required

W. Snoeys et al.
DOI 10.1016/j.nima.2017.07.046

Irradiation tests: 1×10^{15} n_{eq}/cm^2

Improvement of radiation tolerance by at least one order of magnitude

Optimization of TPC radius and B-field



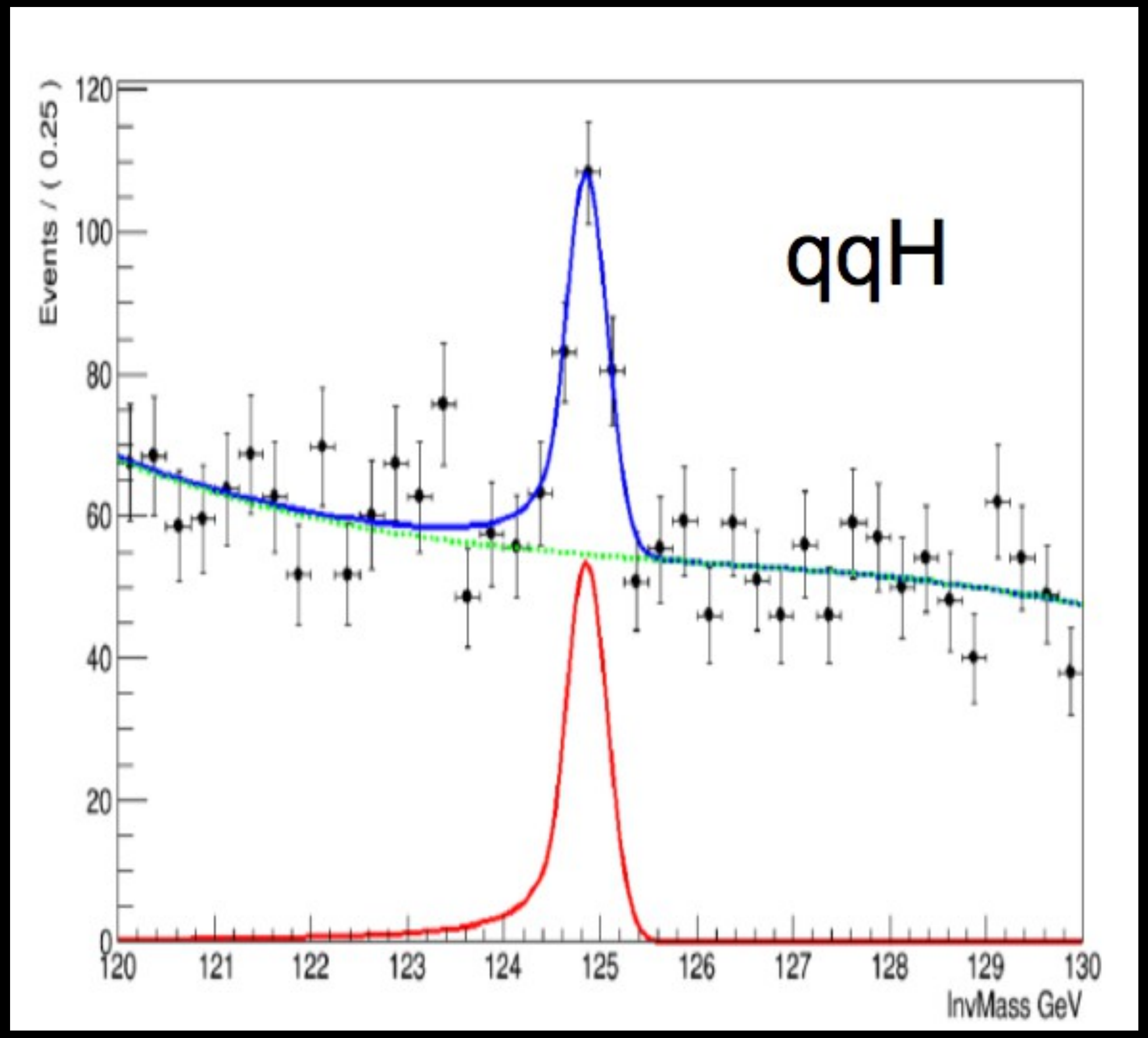
BR(H→μμ) measurement

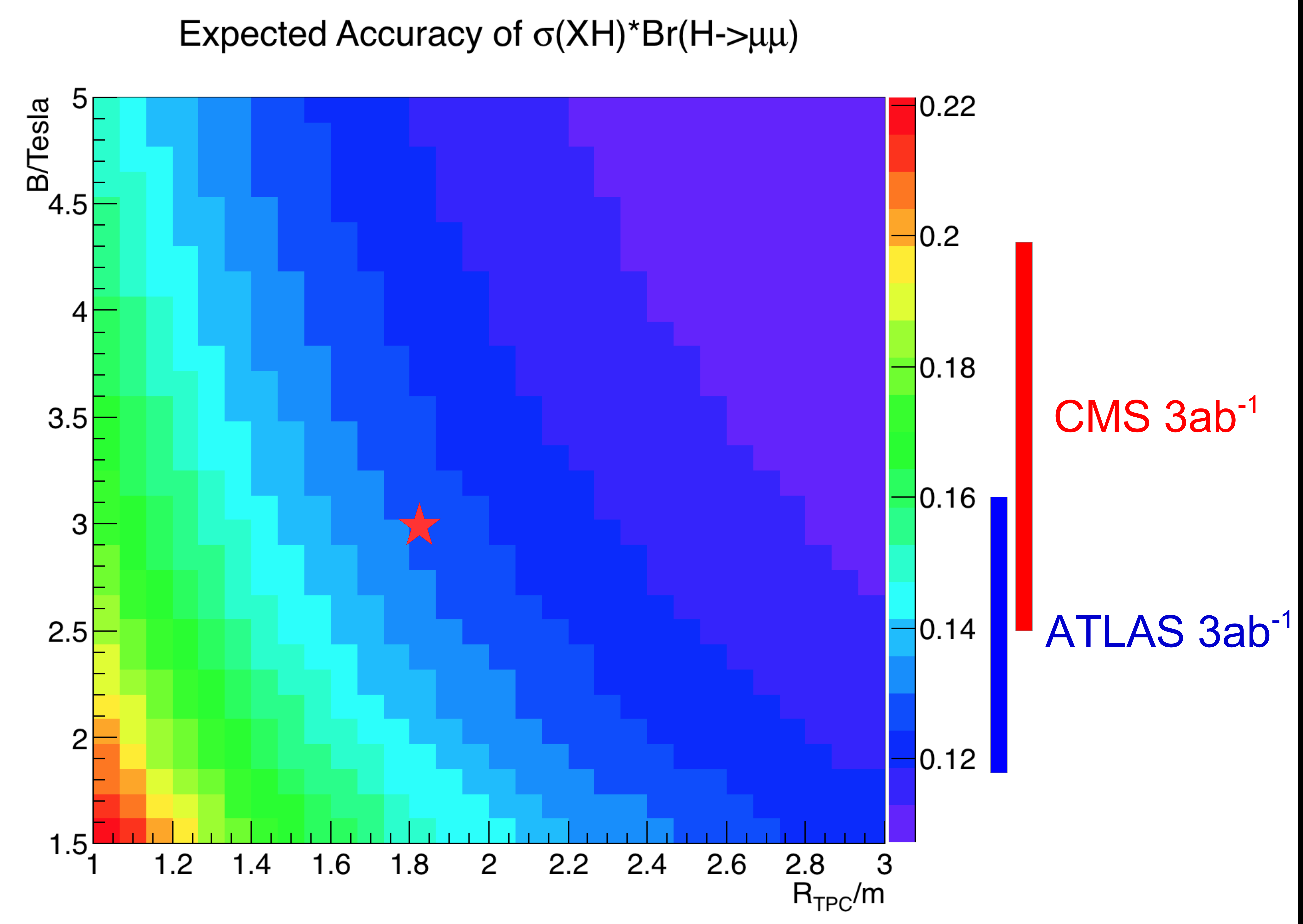
Detector cost sensitive to tracker radius, however:

- **simulation prefers TPC with radius >= 1.8 m,**
- **momentum resolution ($\Delta(1/P_T) < 2 \times 10^{-5}$ GeV^{-1})**

Better:

- **Separation and Jet Energy Resolution**
- **dE/dx measurement**
- **BR(H→ μμ) measurement**





★ *Default TPC Setting: B = 3 T & R_{out} = 1.8*

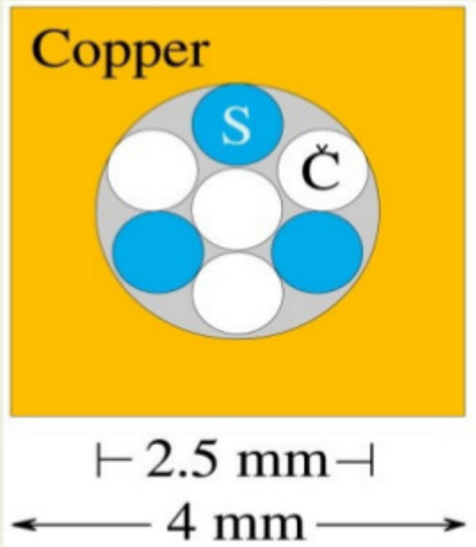
Dual Readout Calorimeter

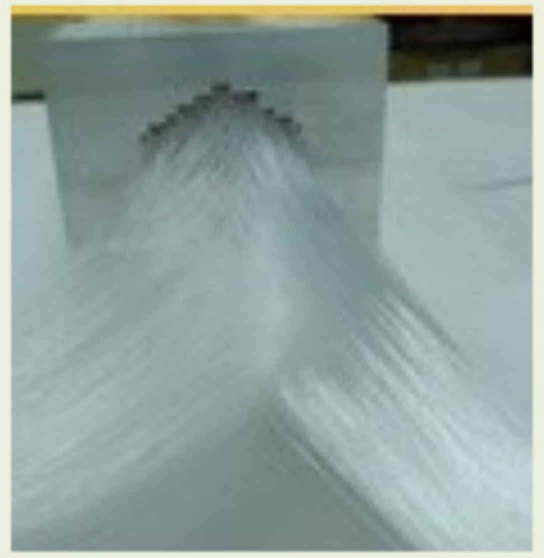
Hauptman, Santoro, Ferrari
Tomorrow, 11:30, 12:00, 12:30 am

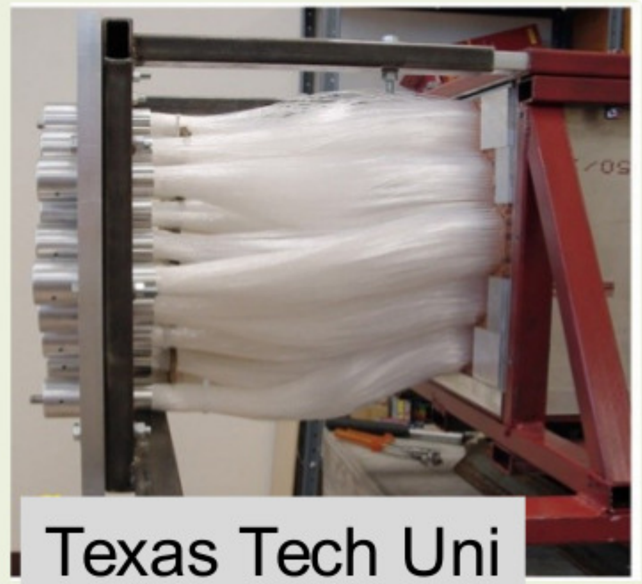
Lead by Italian colleagues: based on the DREAM/RD52 collaboration

2003 DREAM

Copper
2m long, 16.2 cm wide
19 towers, 2 PMT each
Sampling fraction: 2%



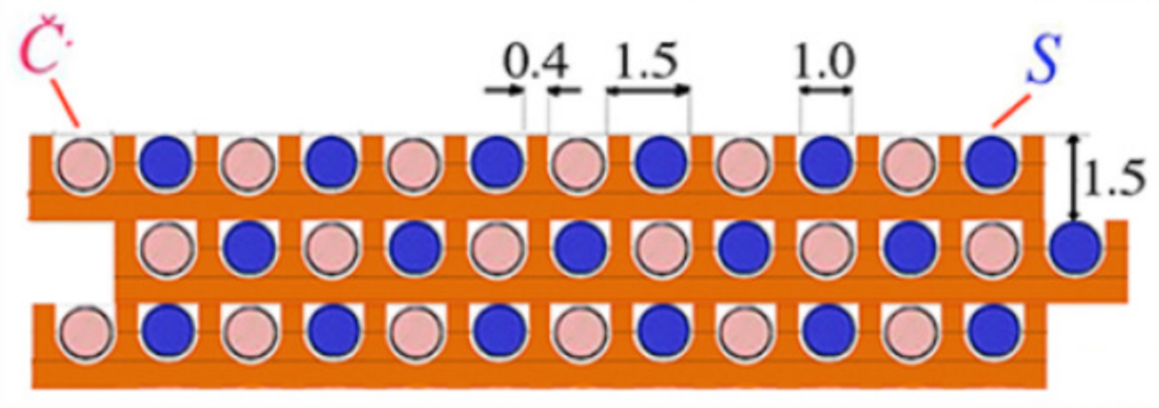




2012 RD52

Copper, 2 modules

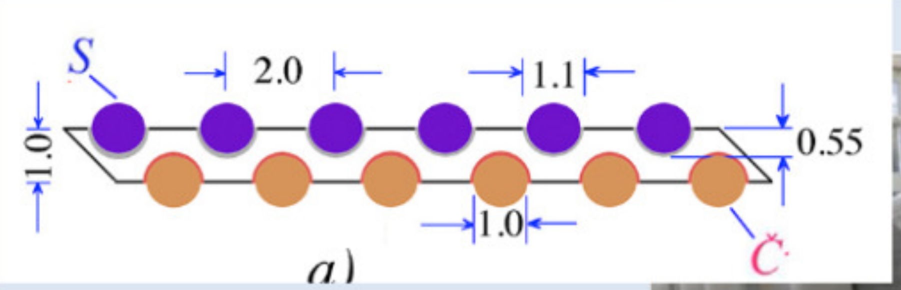
Each module: 9.3 * 9.3 * 250 cm³
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

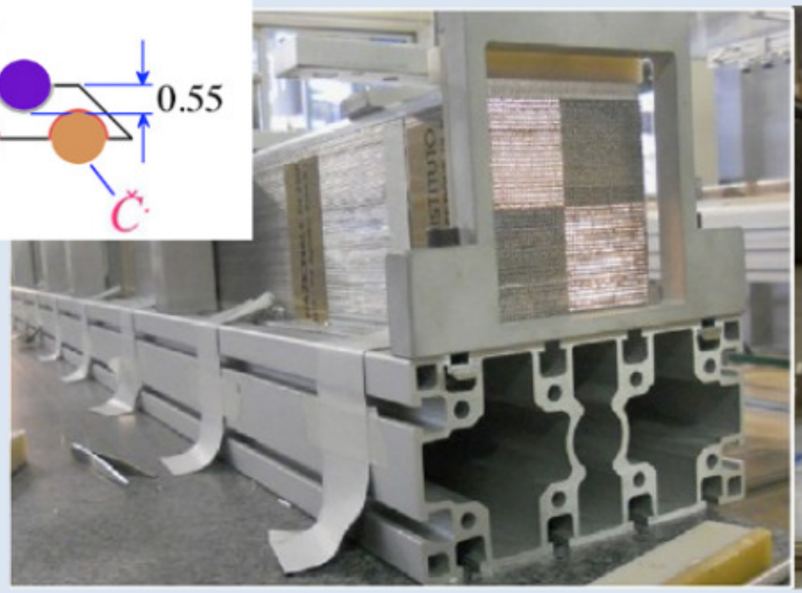


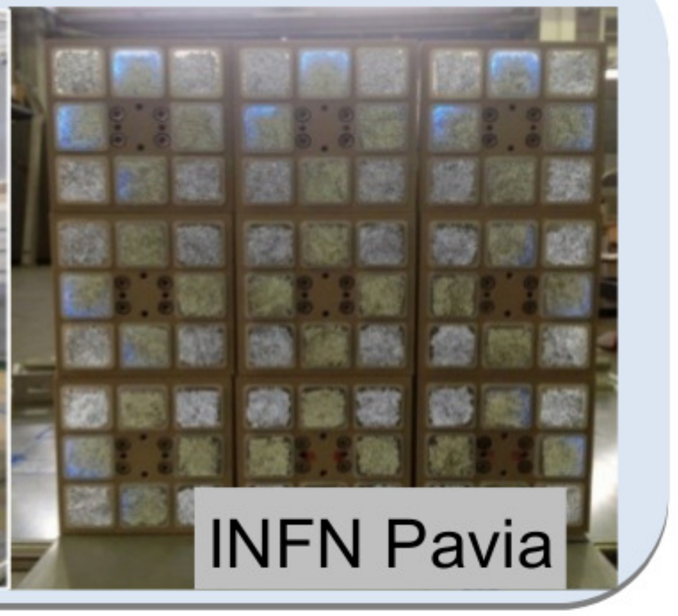
2012 RD52

Lead, 9 modules

Each module: 9.3 * 9.3 * 250 cm³
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 5%, 10 λ_{int}

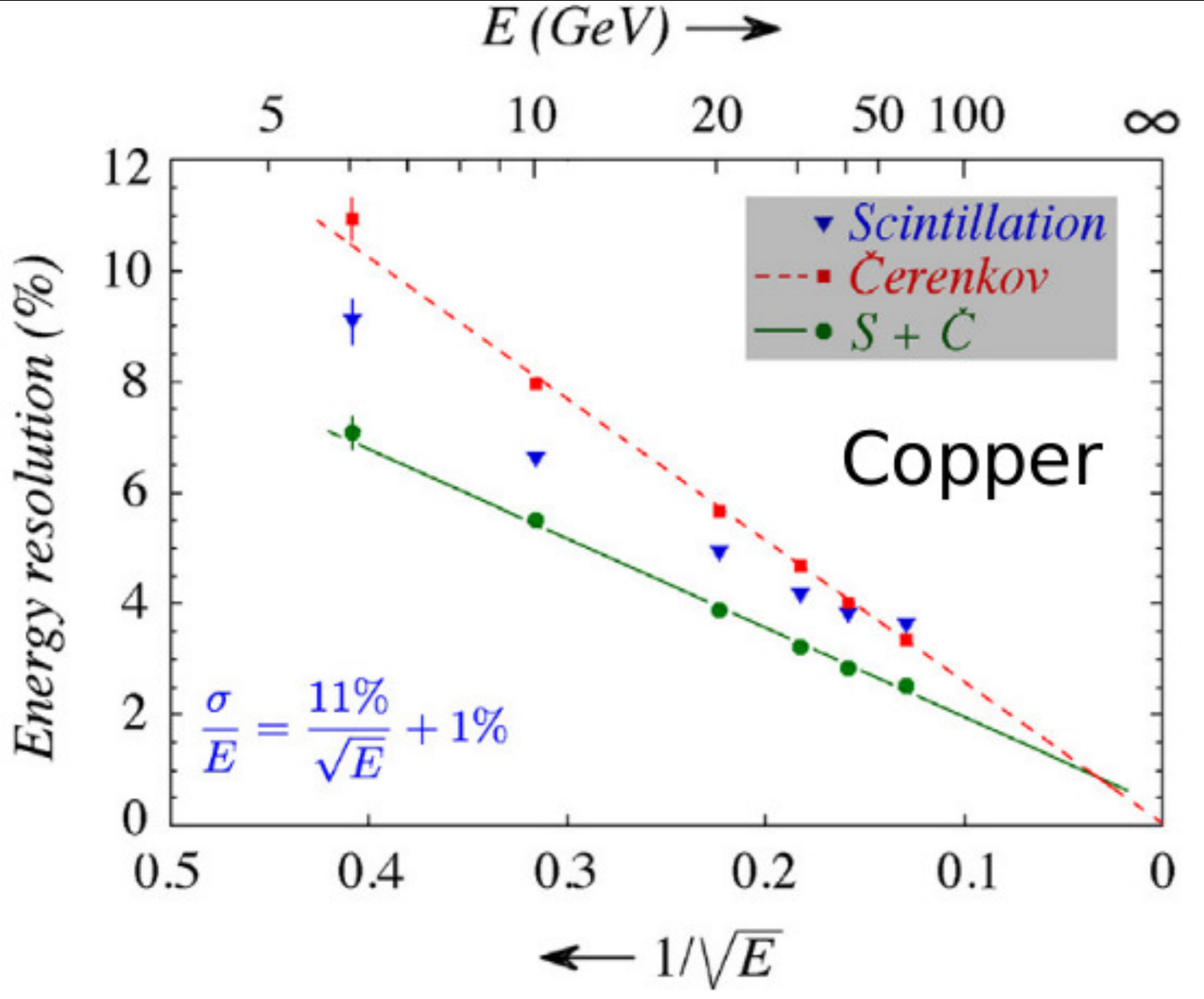






Expected resolution:
Electrons: 10.5%/sqrt(E)
Isolated pions: 35%/sqrt(E)

Energy resolution for electrons



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