The CEPC Detector Conceptual Design Report

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

International Workshop on High Energy Circular Electron Positron Collider
6 November 2017

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

Today: Draft–0 preliminary chapters available for discussion

Preliminary

- 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)

Conceptual Design Report (CDR) – Status

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Detector and Physics - Conceptual Design Report (CDR)

- Goal: A working concept on paper, including alternatives

- **Spring 2018: Planned release date**
  - Soon after CEPC accelerator CDR is released
- **From this workshop till publication:**
  - Plenty of opportunities for everyone to contribute
  - Lots of room to make a serious impact
- **Nov 10–11: Informal CDR Mini–review**
  - http://indico.ihep.ac.cn/event/7384/

More definite schedule available towards end of November

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

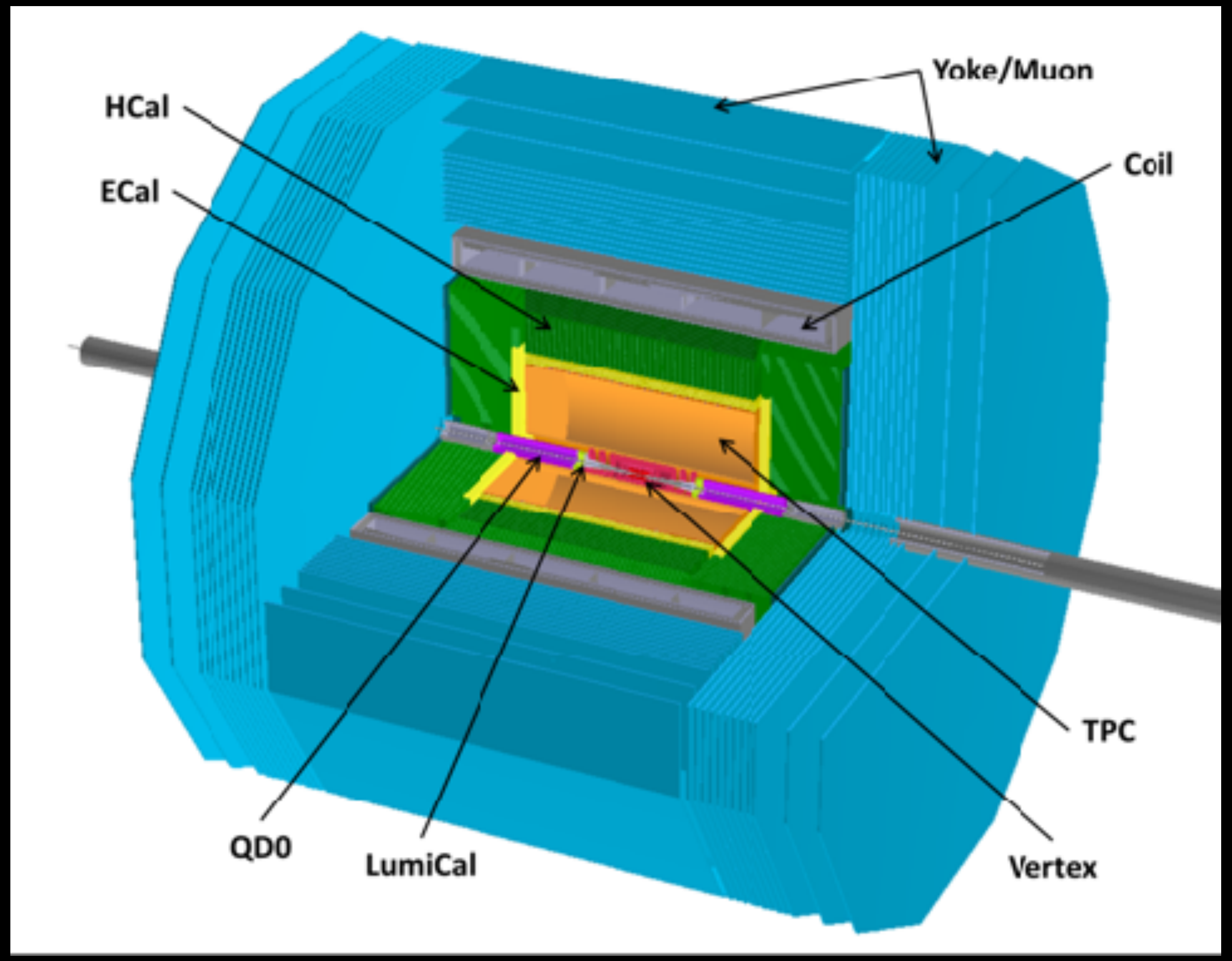
Detector and Physics Parallel Sessions

	Session	Chairs	CDR Chapter
Today, 16:00 (3-days)	Poster session (many CDR details will be provided)		"All"
Today, 16:30	I: Detector concepts and system aspects	Massimo Caccia JGC	3: Conditions and concepts 7: magnet
Tuesday, 8:00	II: Silicon vertex and tracker	Daniela Bortolleto Meng Wang	4: Vertex detector 5: Tracking system
Tuesday, 8:00	III: Gaseous detectors	Yuanning Gao Soeren Prell Charles Young	5: Tracking system 8: Muon system
Tuesday, 10:30	IV: Calorimeters	Roberto Ferrari Imad Laktineh Jianbei Liu	6: Calorimetry
Tuesday, 14:00	V: Simulation	Sasha Glazov Manqi Ruan	11: Physics performance
Tuesday, 16:30	VI: Physics, joint with theory	Patrizia Azzi Yaquan Fang	11: Physics performance
Tuesday, 16:30	MDI	Suen Hou Michael Sullivan	10: Interaction region

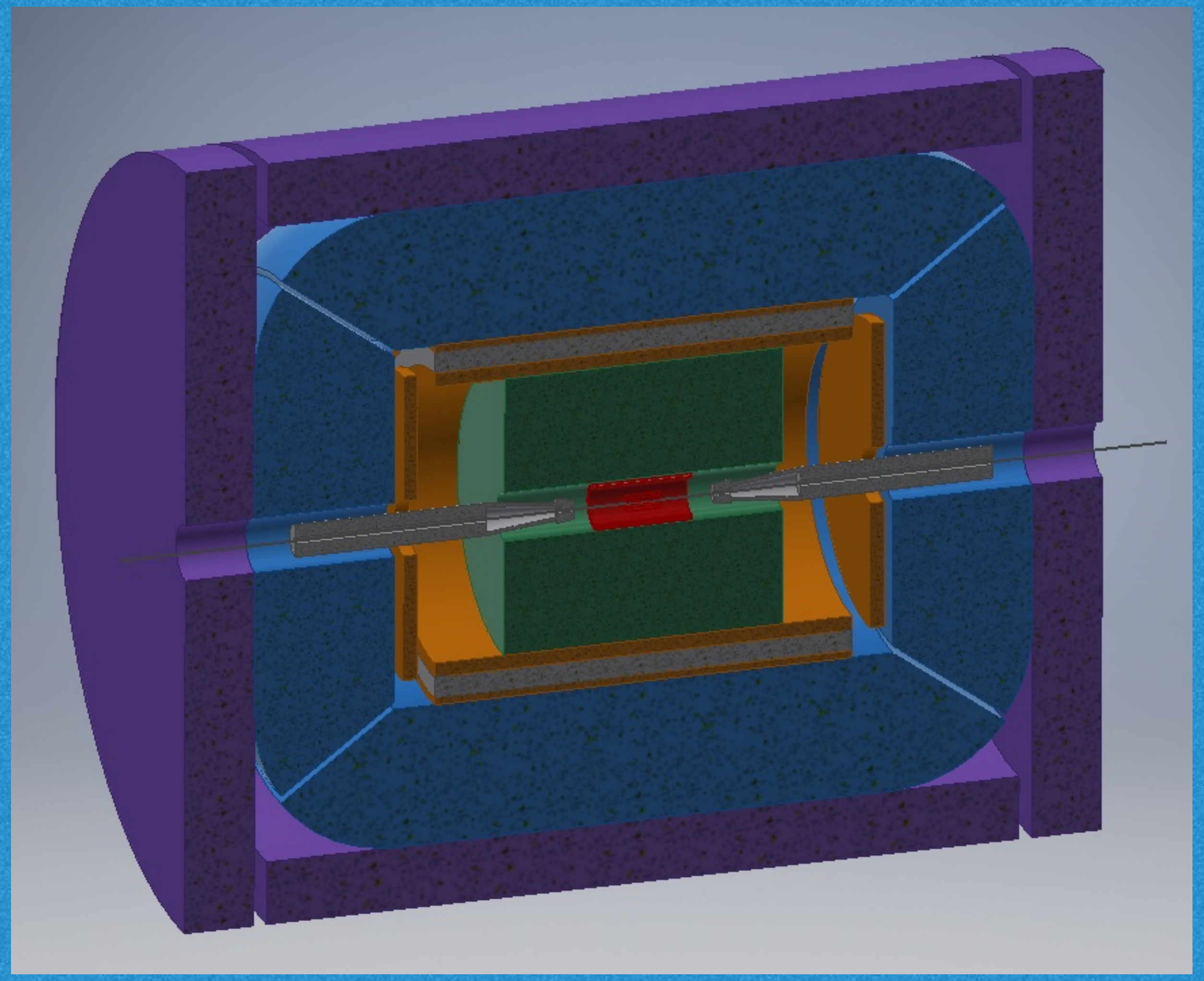
CDR Password: cdr2018-0draft

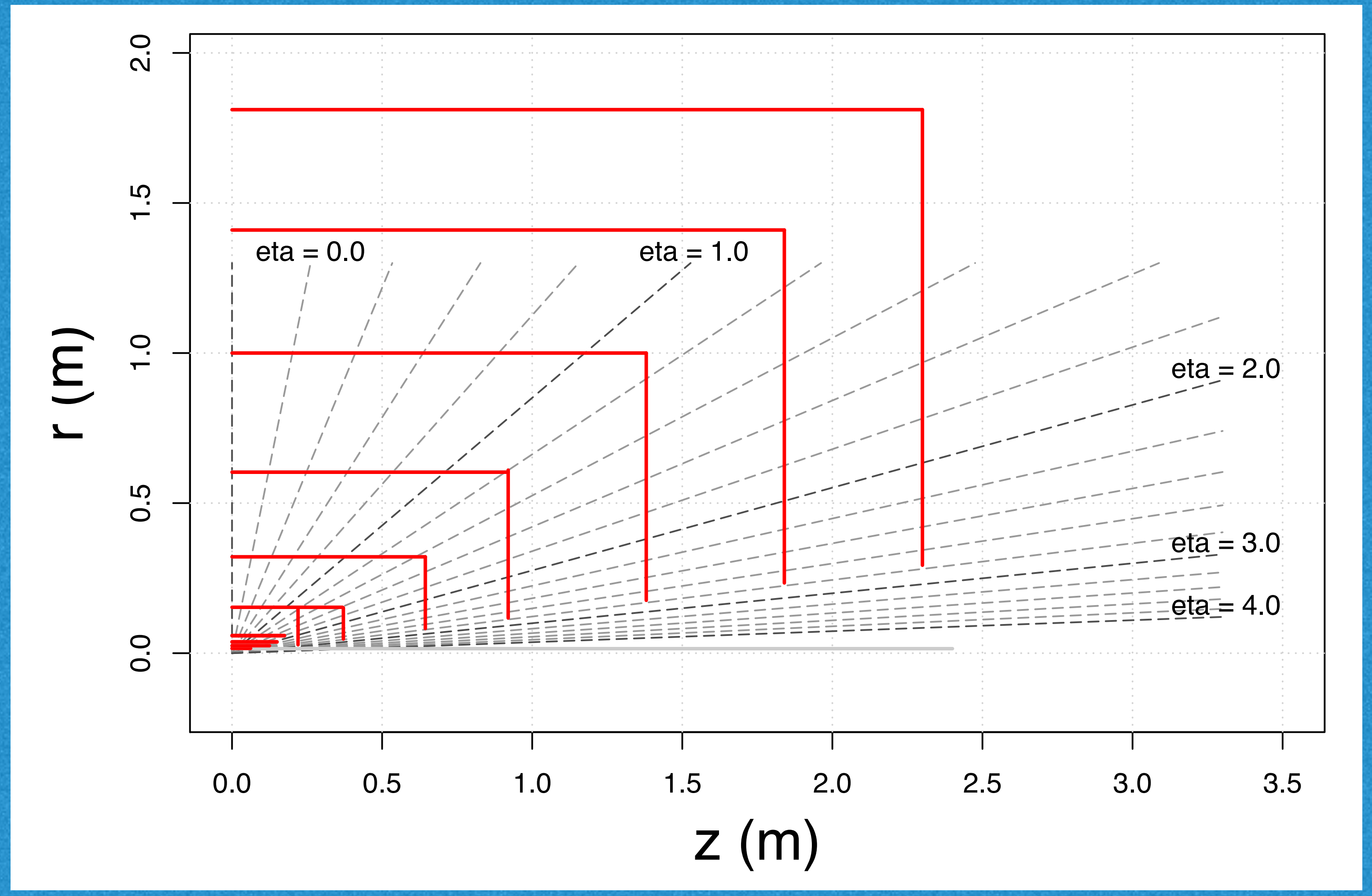
CDR Conceptual Designs

Baseline detector for CDR
ILD-like
(similar to pre-CDR)



Low magnetic field concept

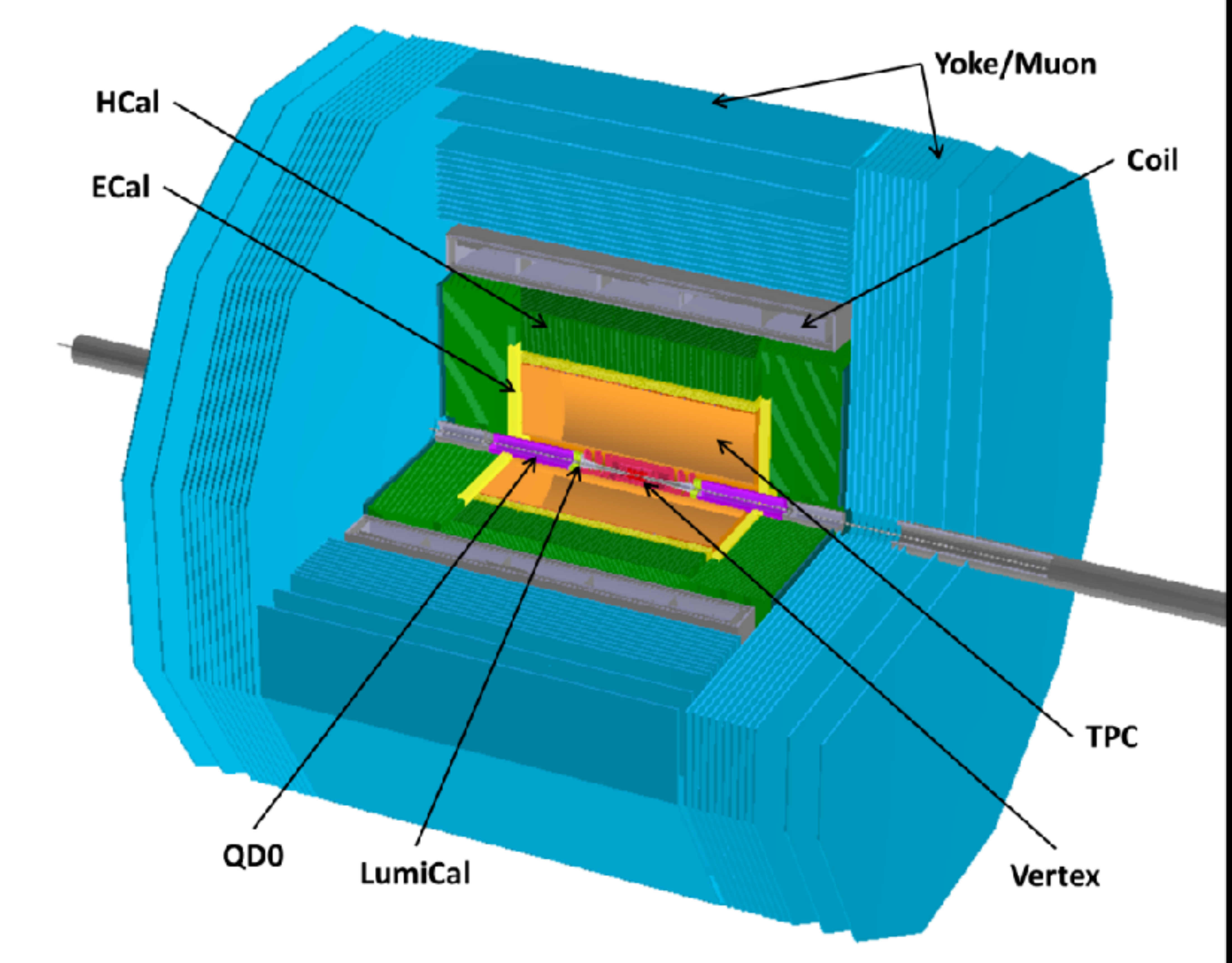


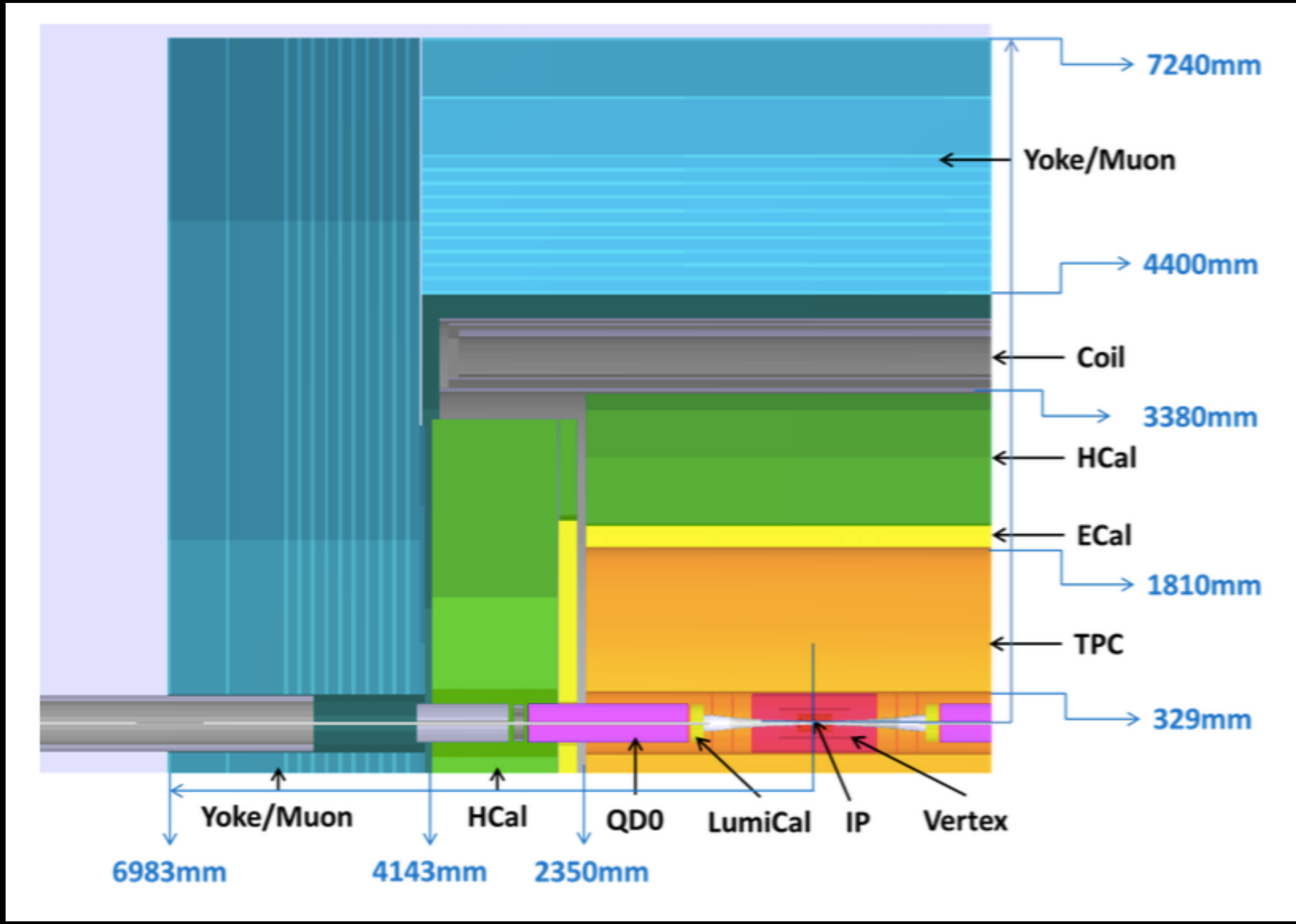


Full silicon tracker concept

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

CEPC baseline detector: ILD-like





Magnetic Field: 3 Tesla — changed from preCDR

- **Impact parameter resolution**: less than 5 μm ⟵ Flavor tagging
- **Tracking resolution**: $\delta(1/P_t) \sim 2\times10^{-5}\ (\mathrm{GeV}^{-1})$ ⟵ BR(Higgs → μμ)
- **Jet energy resolution**: $\sigma_E/E \sim 0.3/\sqrt{E}$ ⟵ W/Z dijet mass separation

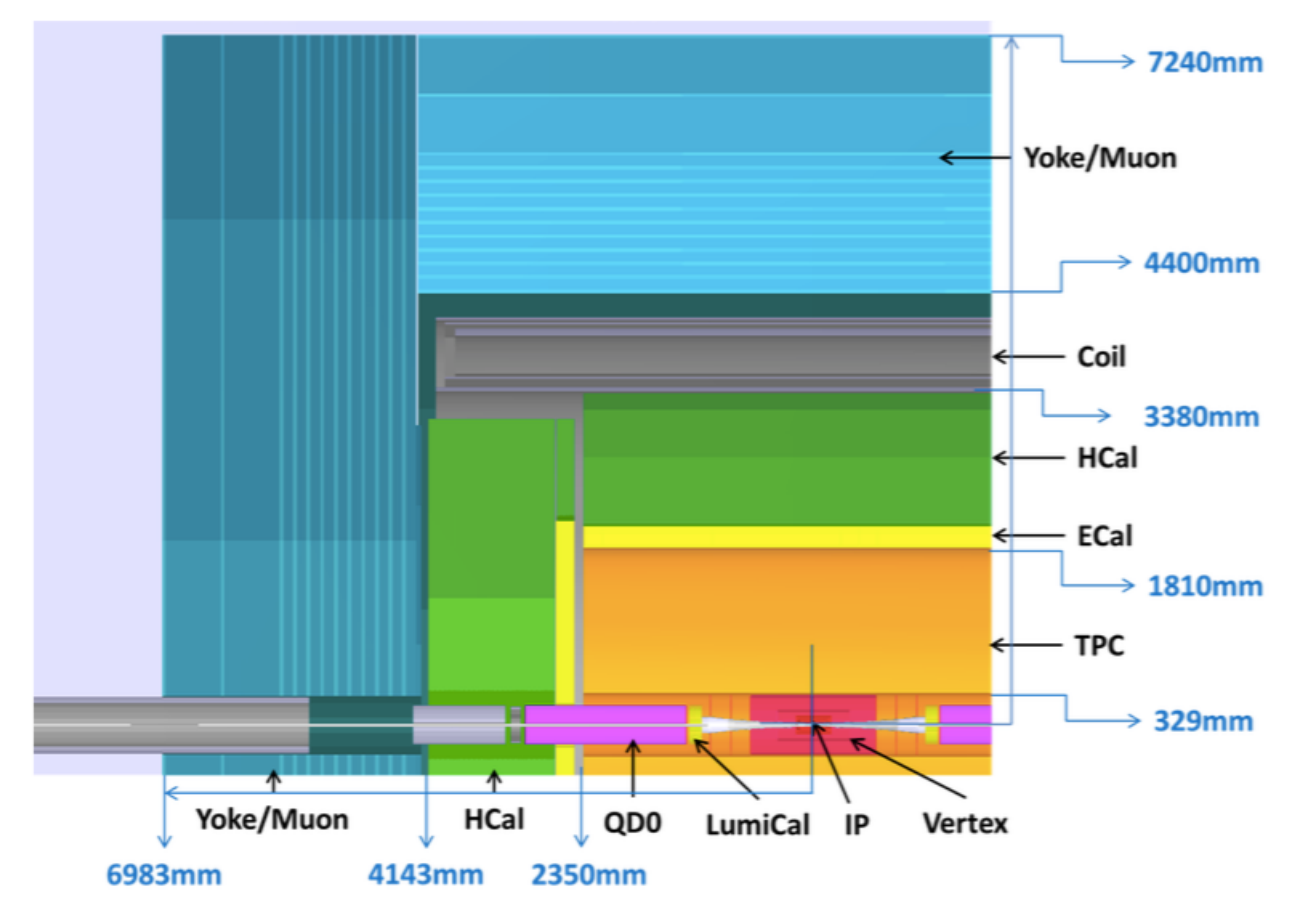
CEPC baseline detector: ILD-like: Design Considerations

Major concerns being addressed

MDI region highly constrained
L* increased to 2.2 m
Compensating magnets

TPC as tracker in high-luminosity Z-pole scenario

ECAL/HCAL granularity needs
Passive versus active cooling



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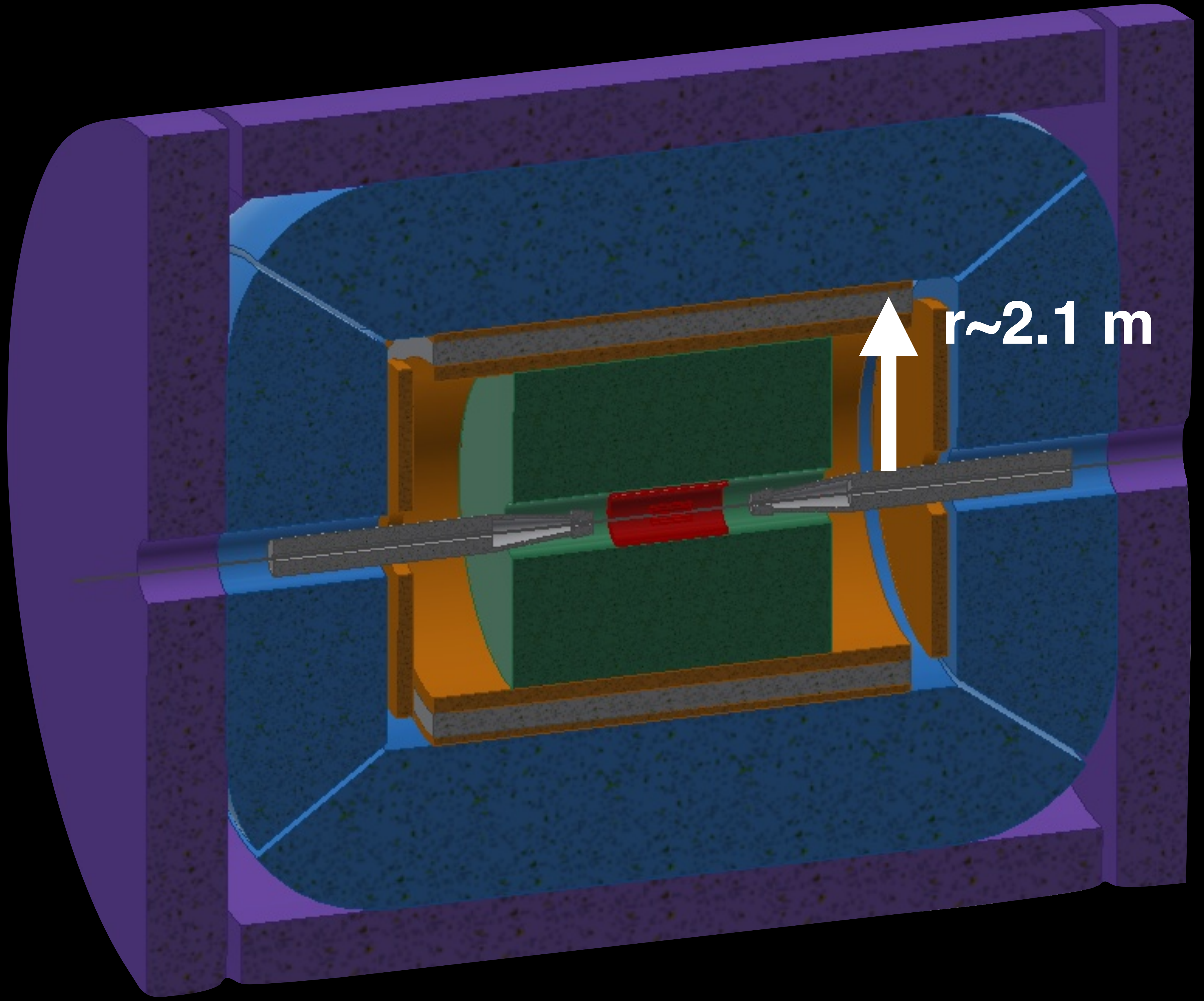
Low magnetic field detector concept

Session I: Franco Bedeschi
CDR: Section 3.3

Proposed by INFN, Italy colleagues



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

Beam pipe: radius 1.5 cm

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 6
Talk: Session IV - Roberto Ferrari

Drift chamber: Chapter 5
Talk: Session II - Franco Gancagnolo

Muon detector (μRwell): Chapter 8
Talk: Session IV - Paolo Giacomelli

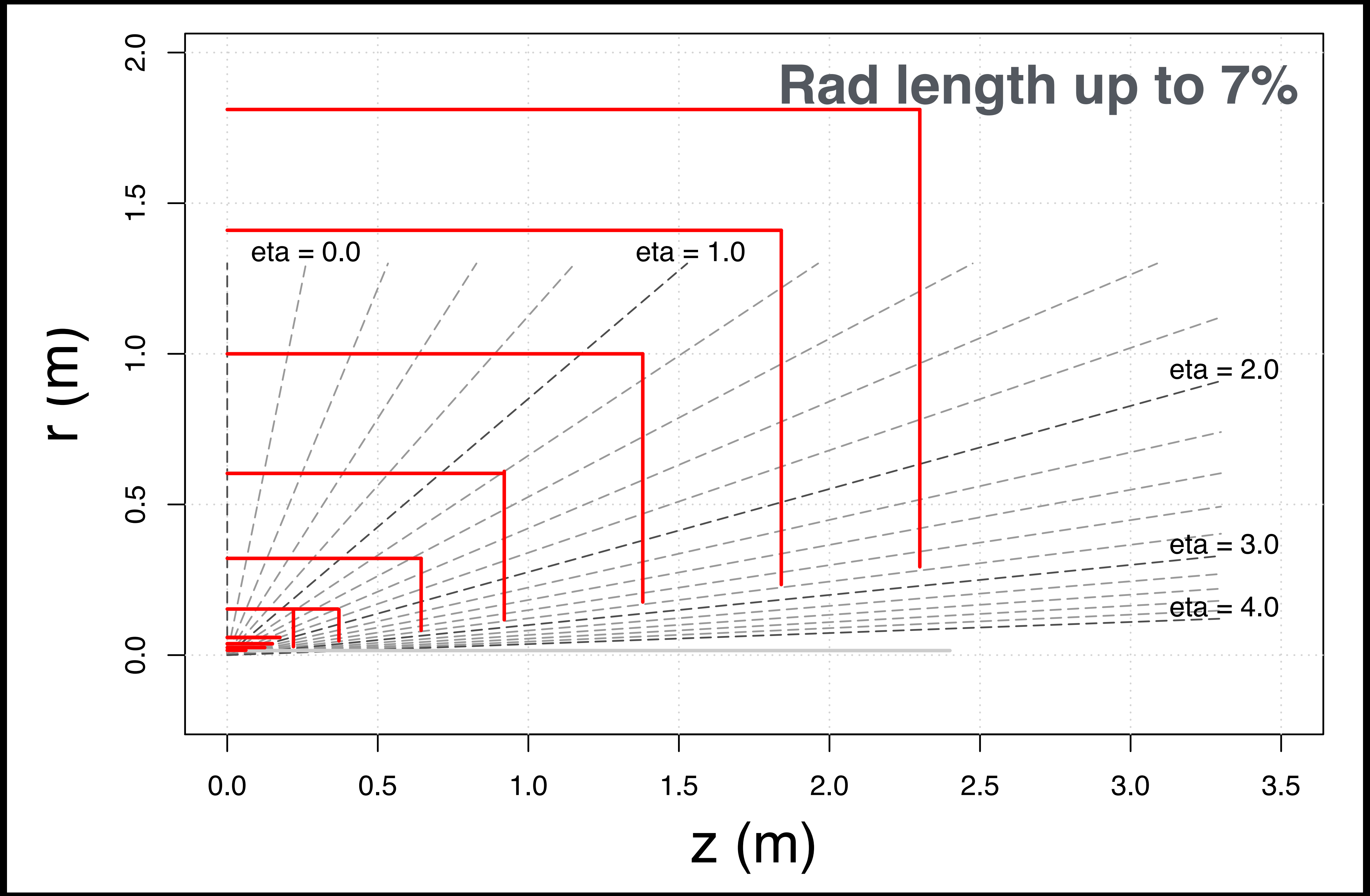
Full silicon tracker concept

Session I: Weiming Yao
CDR: Section 5.3

Replace TPC with additional silicon layers

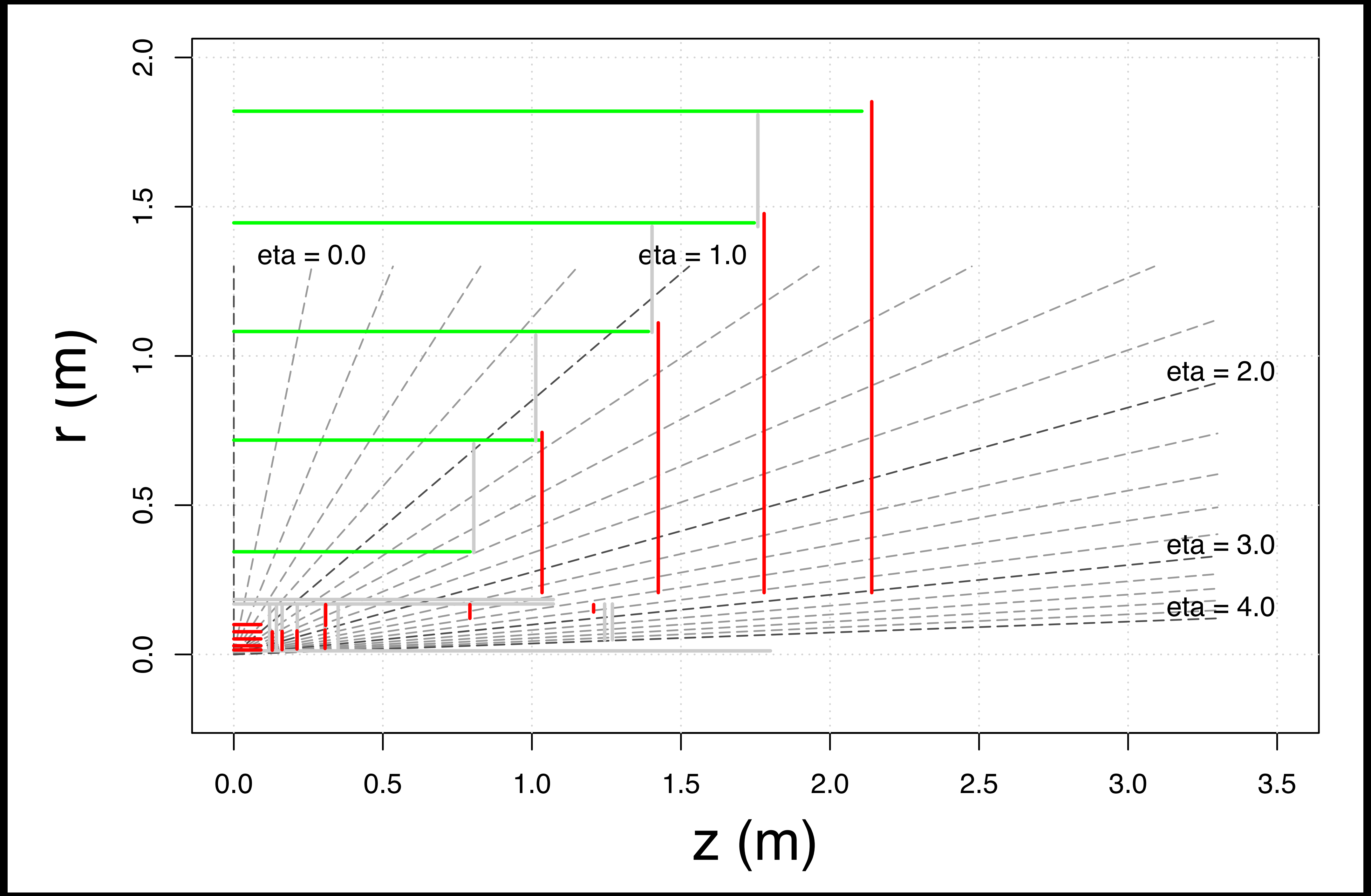
CEPC-SID:

6 barrel double strip layers
5 endcap double strip layers



SIDB: SiD optimized

5 barrel single strip layers
5 endcap double strip layers



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

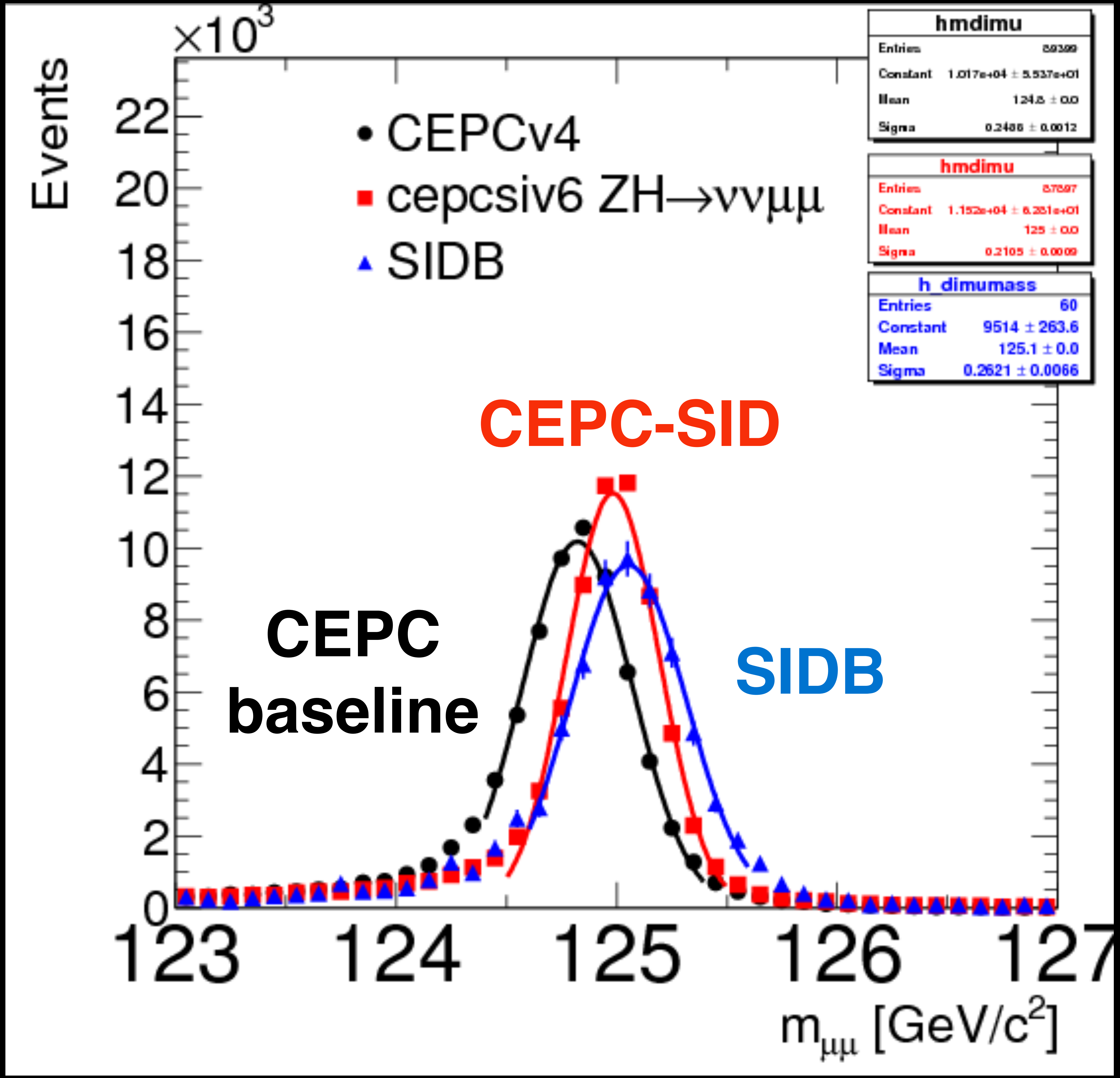
Full silicon tracker concept

Session I: Weiming Yao
CDR: Section 5.3

Replace TPC with additional silicon layers

ZH → ννμμ
Di-muon mass

CEPC
Baseline
σ = 0.24 GeV



CEPC-SID: σ = 0.21 GeV

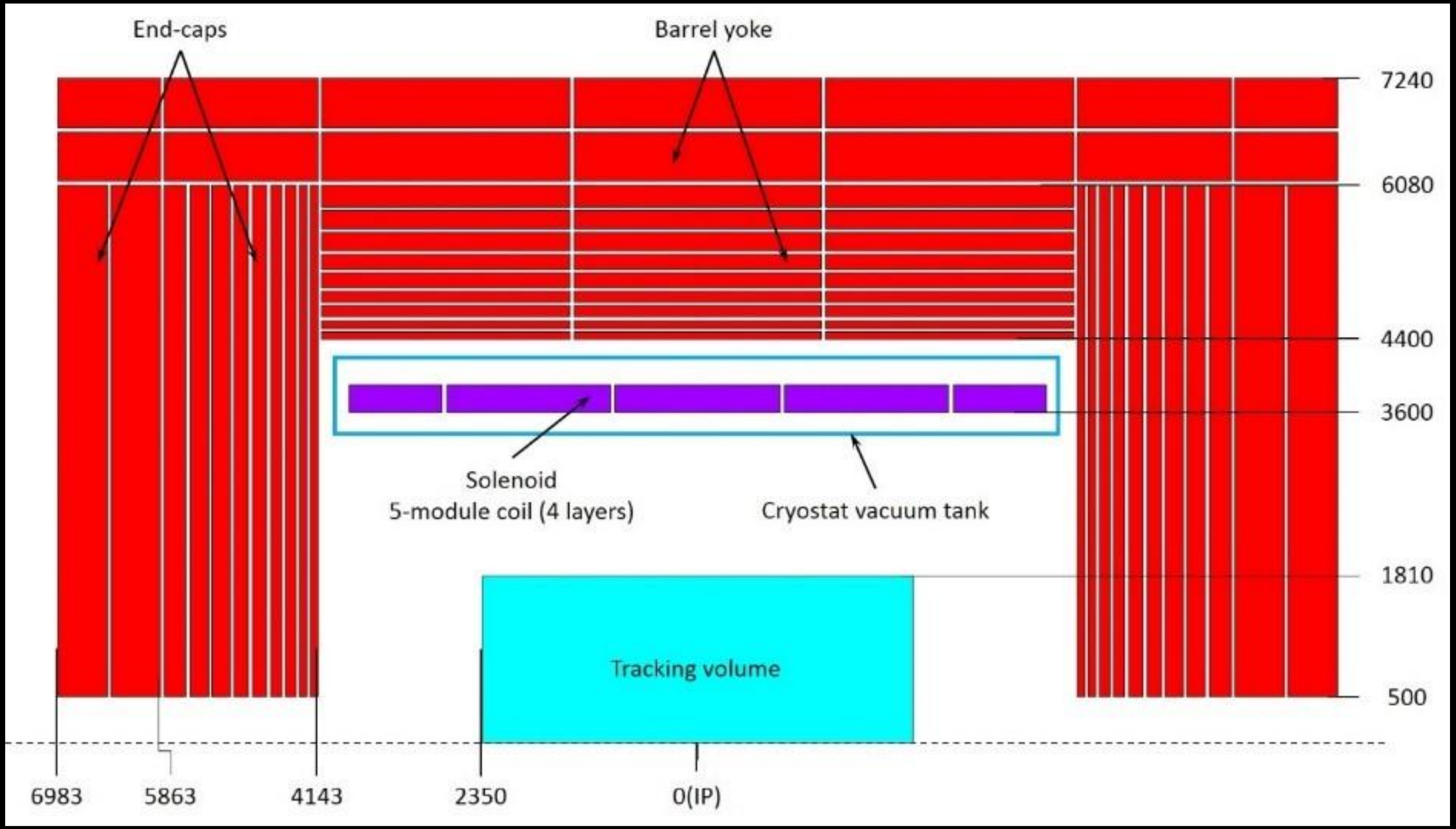
SIDB: σ = 0.26 GeV

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

Superconductor solenoid development

Session I: Zian Zhu
CDR: Chapter 7

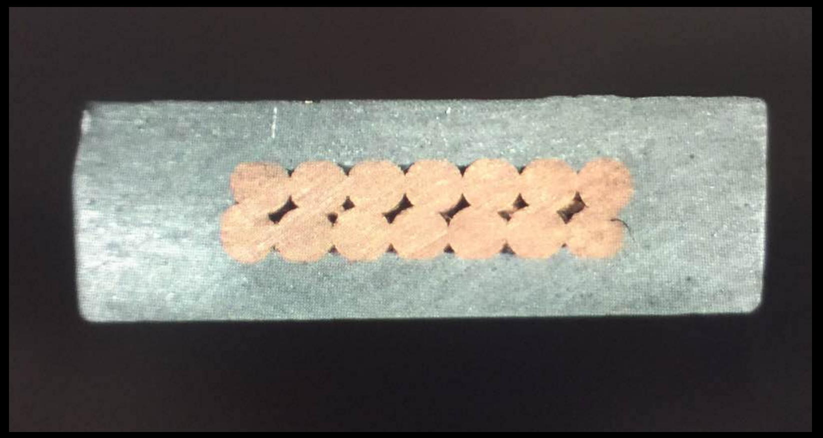
Updated design done for 3 Tesla field (down from 3.5 T)



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

Can consider design for 2 Tesla magnet, if needed



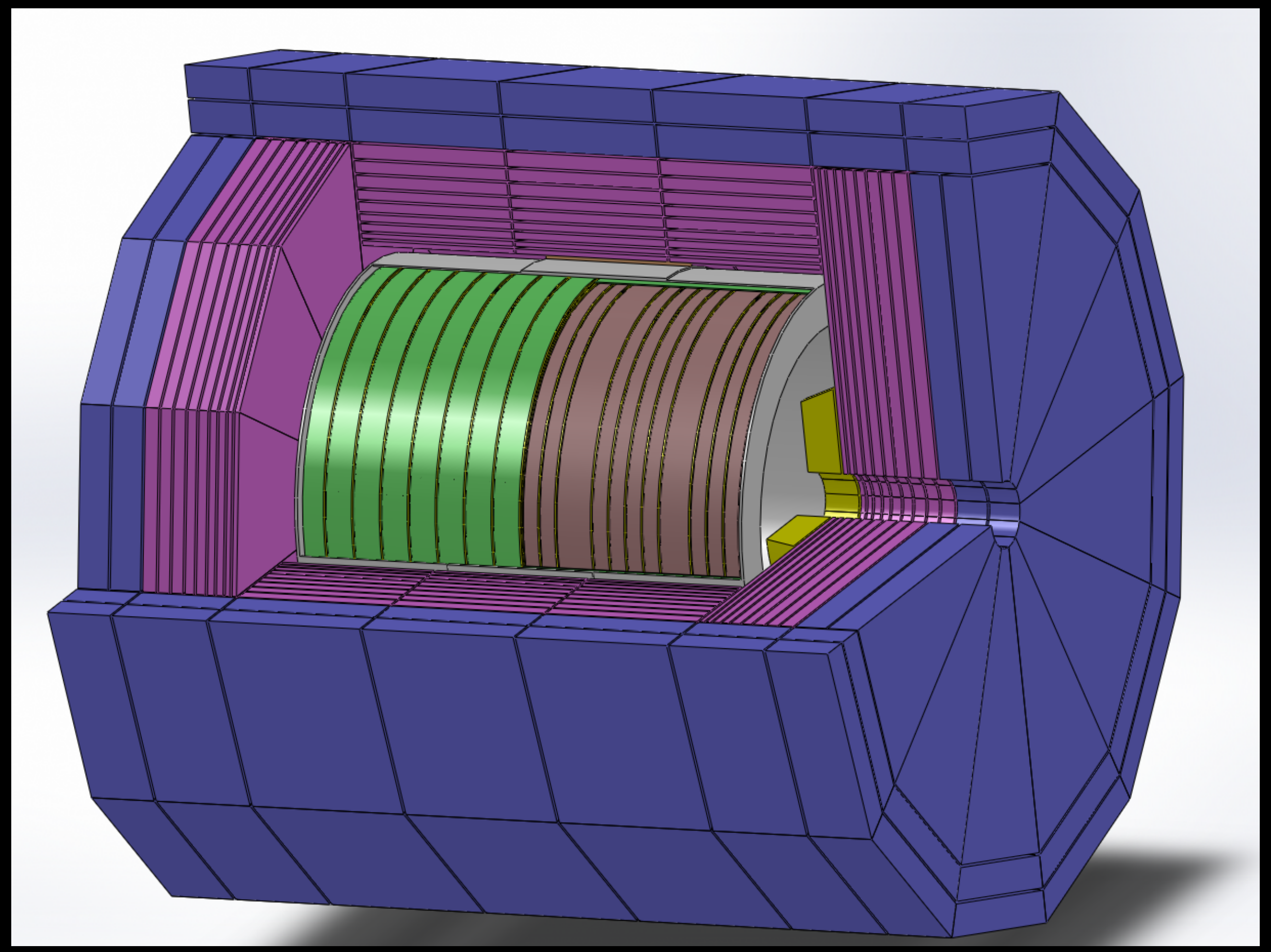
Default is NbTi Rutherford SC cable (4.2K)
Solutions with High-Temperature SC cable also being considered (YBCO, 20K)

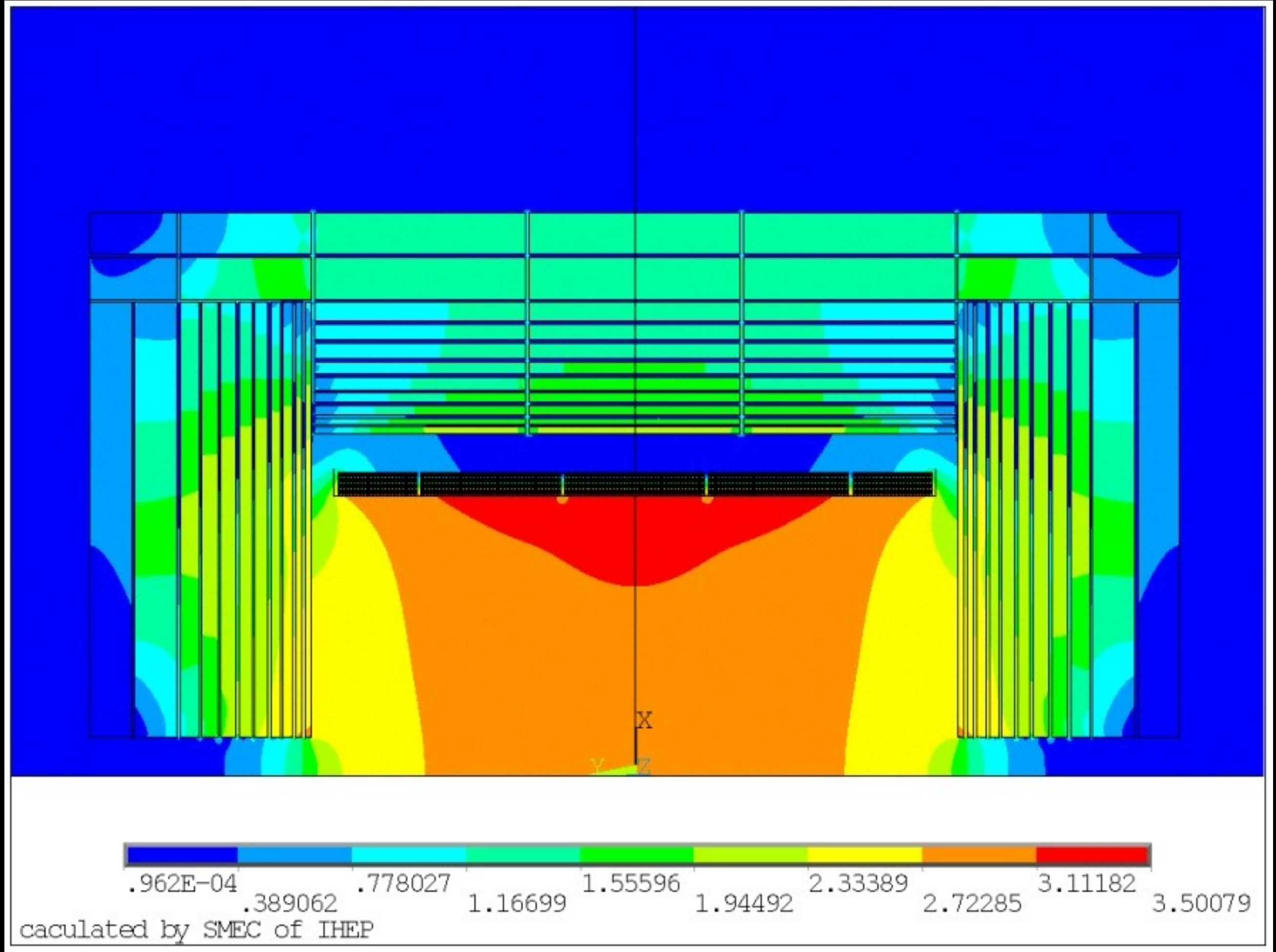
Superconductor solenoid development

Session I: Zian Zhu
CDR: Chapter 7

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

Default: Iron Yoke



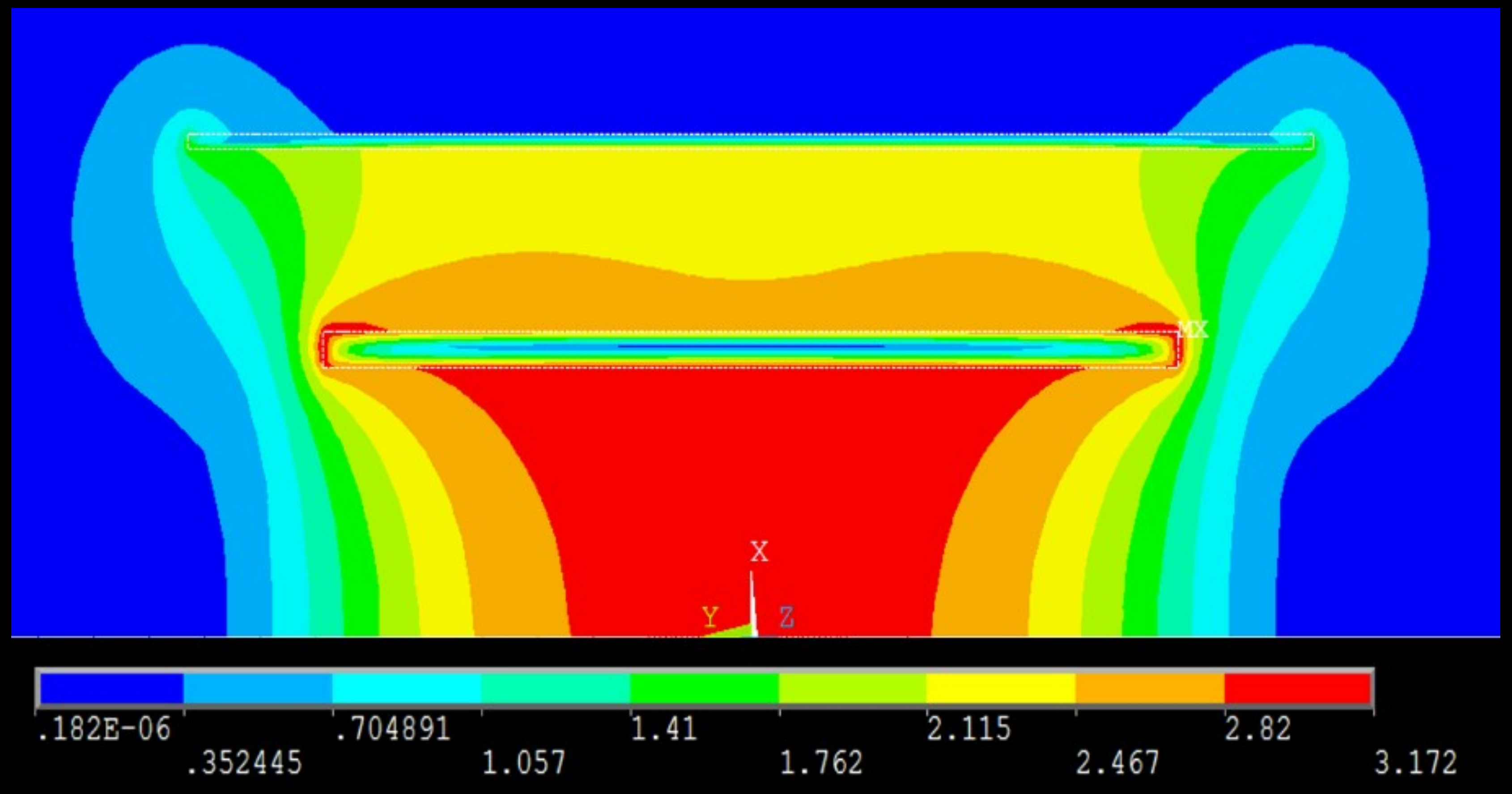


Non-uniformity	9.1%

Dual Solenoid Scenario

Lighter and more compact

Concept improved by FCC studies



Interaction region: Machine Detector Interface

Session MDI: Chenghui Yu
CDR: Chapter 10

One of the most complicated issue in the CEPC detector design

Full partial double ring

Updated baseline parameters:

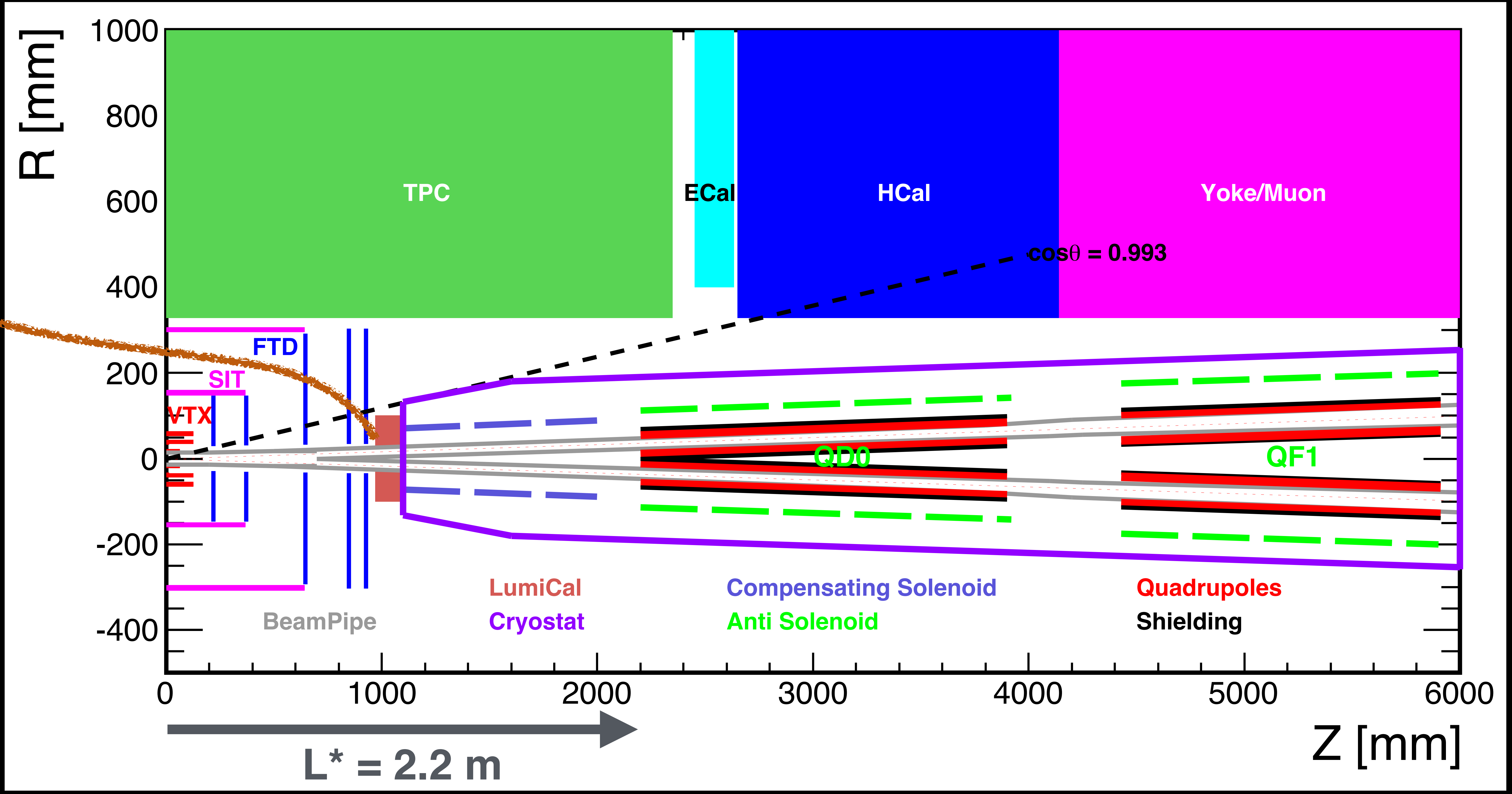
- Head-on collision changed to crossing angle of **33 mrad**
- Focal length (**L***) increased from 1.5 m to **2.2 m**
- Solenoid field reduced from 3.5 T to **3 T**

LumiCal

Lumi unc: 1 × 10^{-3}

Session MDI: Suen Hou
CDR: Chapter 10

(studies lead by Vinca and Academia Sinica)



Magnet	Field Strength	Length	Inner Radius
QD0	151 T/m	1.73m	19 mm

Interaction region: Machine Detector Interface

Session MDI: Hongbo Zhu
CDR: Chapter 10

Machine induced backgrounds

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

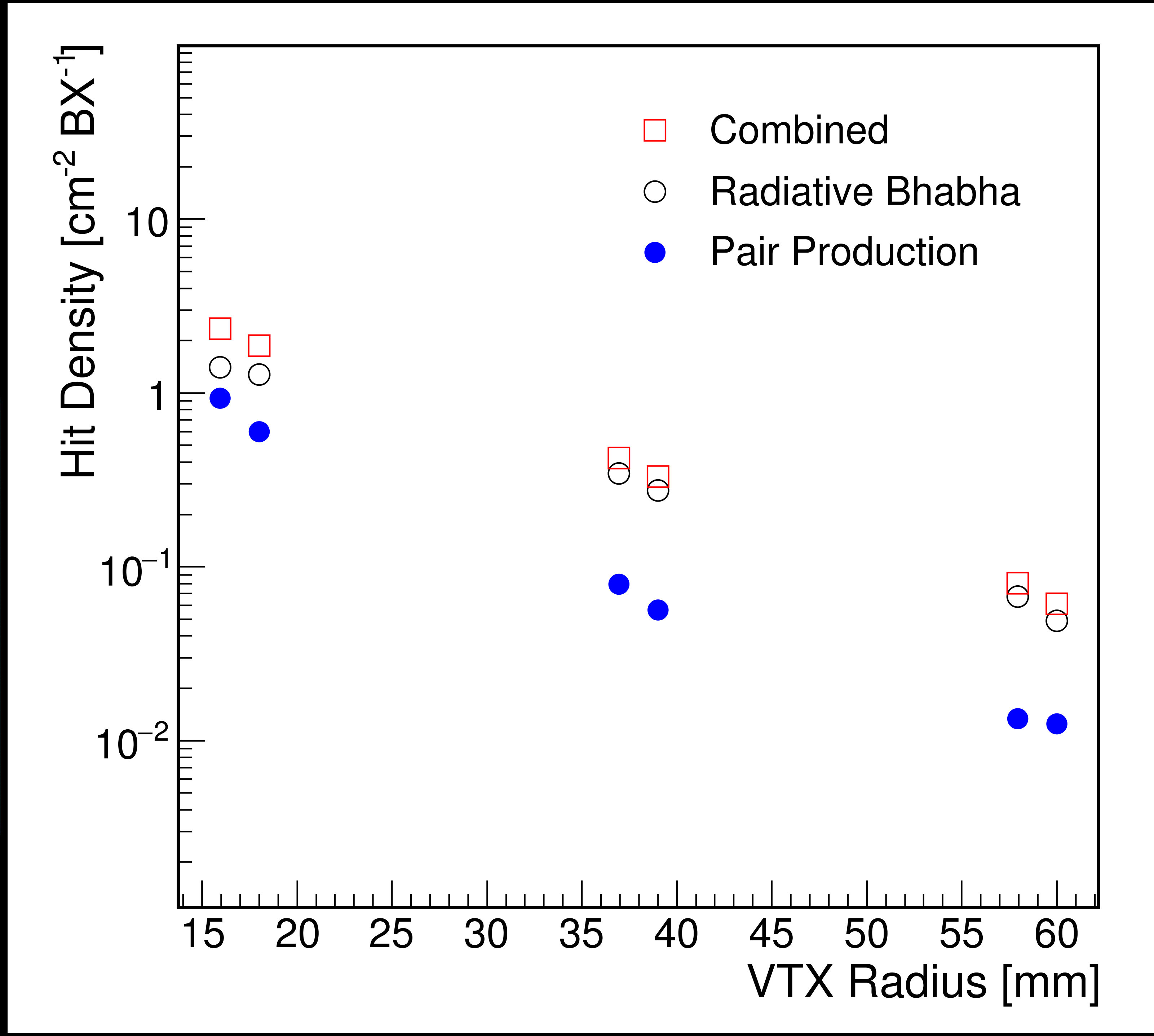
Studies for new configuration being finalized

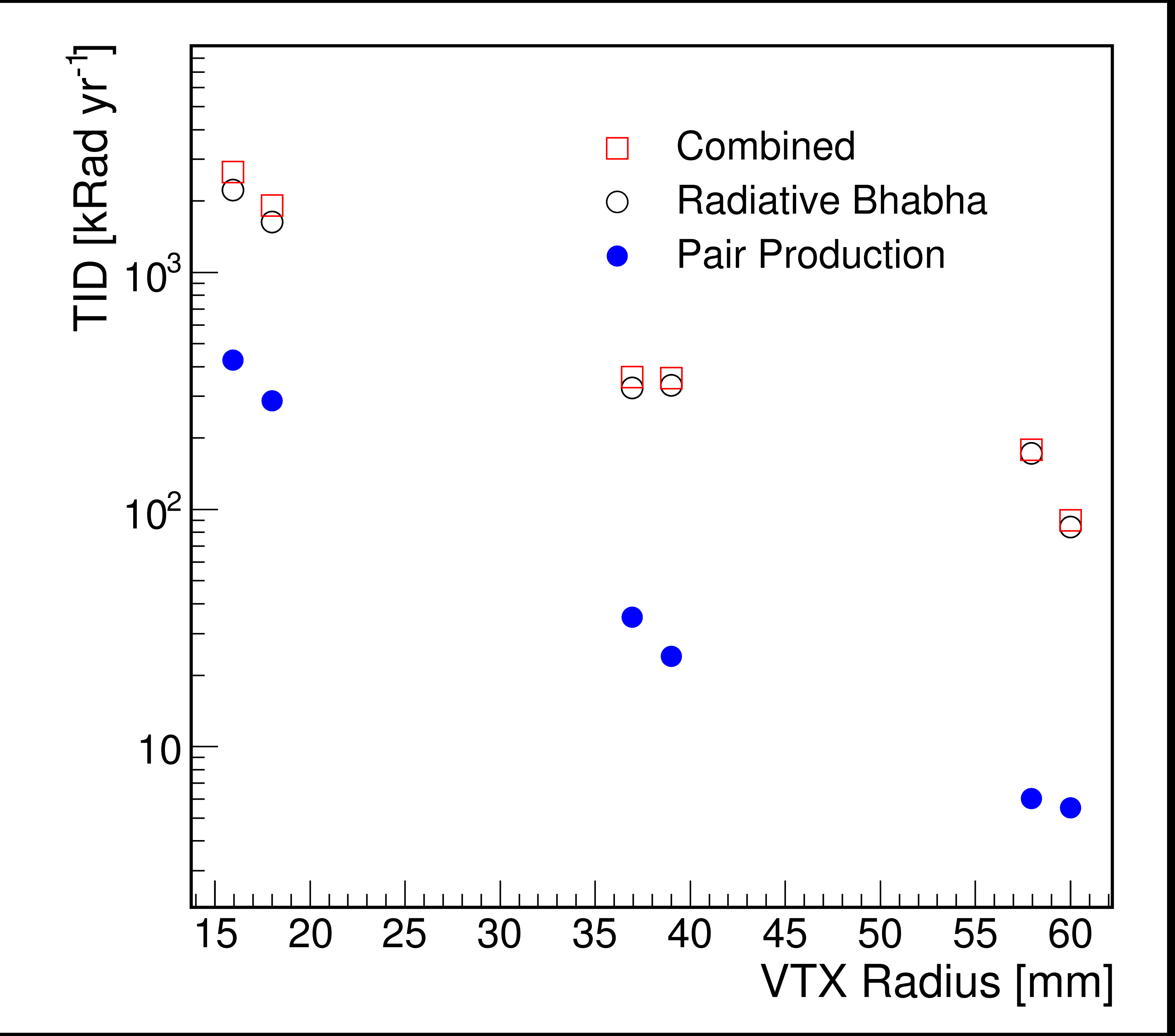
Higgs operation (E_{cm} = 240 GeV)

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)





Silicon Vertex Detector

Session II: Qun OUYANG
CDR: Chapter 4

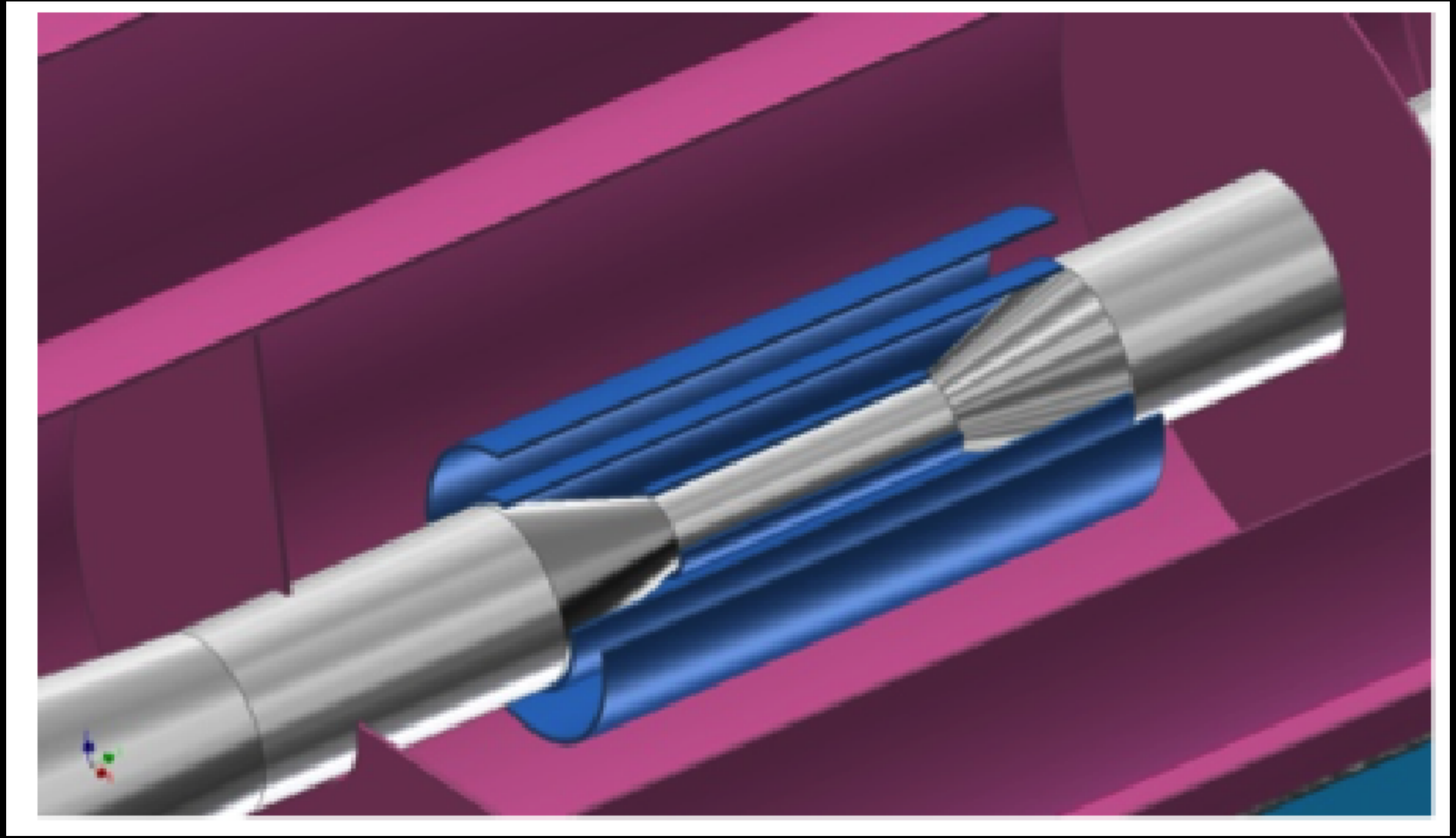
Requirements

- Single point resolution near the IP: ≤ 3 μm → high granularity
- Material budget: $\leq 0.15\%X_0$/layer → Low power dissipation, thinned
- Pixel occupancy: $\leq 1\%$ → High granularity and/or short readout time

Target:

★ High granularity
★ Fast readout
★ Low power dissipation
★ Light structure

3-layers of double-sided pixel sensors



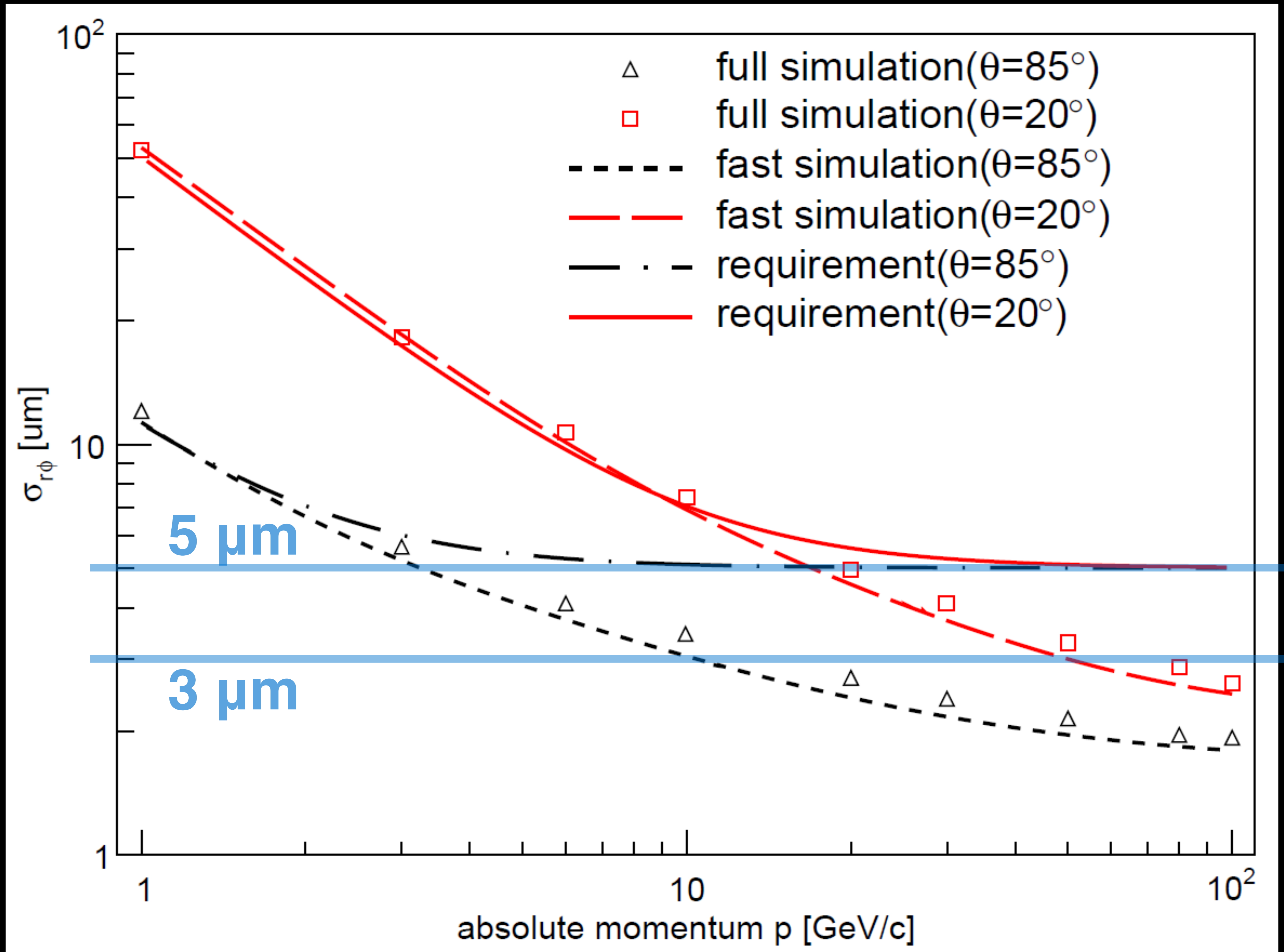
	$R(mm)$	$\|z\|(mm)$	$\|cos\theta\|$	$\sigma(\mu m)$	$Readout\ time(us)$
Layer 1	16	62.5	0.97	2.8	20
Layer 2	18	62.5	0.96	6	1-10
Layer 3	37	125.0	0.96	4	20
Layer 4	39	125.0	0.95	4	20
Layer 5	58	125.0	0.91	4	20
Layer 6	60	125.0	0.90	4	20

Table 4.1: Vertex detector parameters

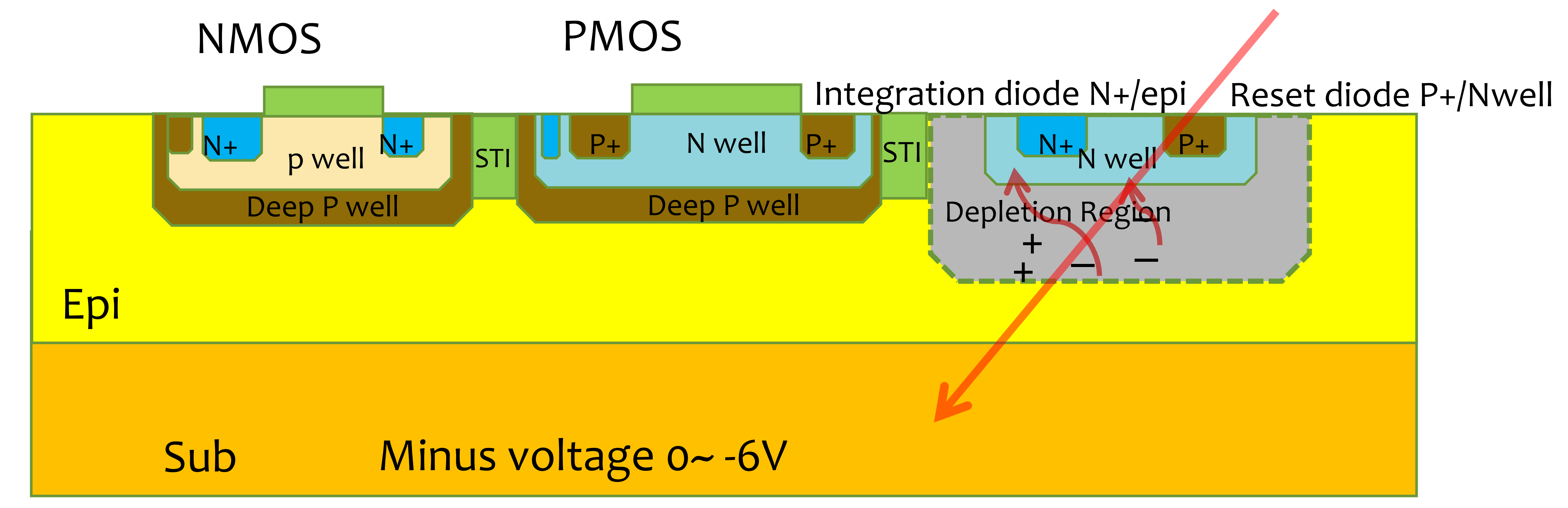
Silicon Vertex Detector

Session II: Qun OUYANG
CDR: Chapter 4

Transverse impact parameter resolution for single muon



CMOS pixel sensor (MAPS)



Integrated sensor and readout electronics on the same silicon bulk with **“standard” CMOS** process:

- low material budget,
- low power consumption,
- low cost …

Pixel sensor R&D

Session II: Qun OUYANG
CDR: Chapter 4

R&D by CCNU, Shandong, Huazhong universities and IHEP

1st CMOS sensor (CPS) test: modified versions of both mother board and daughter board finished

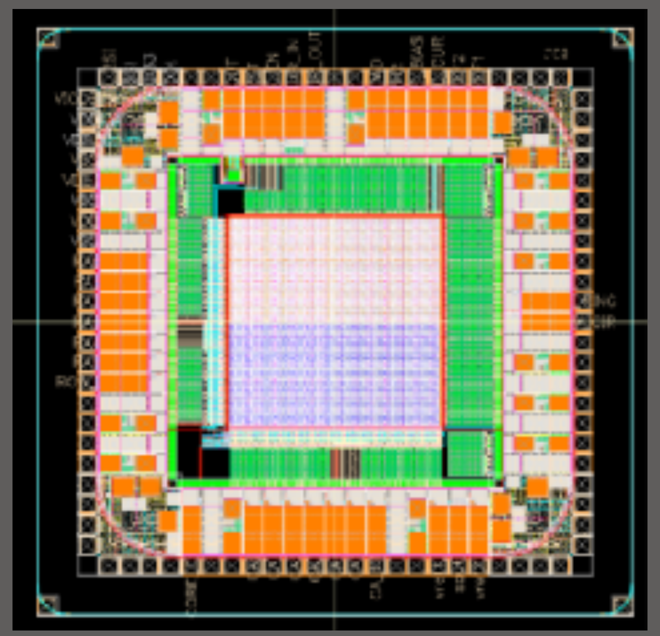
2nd CMOS sensor (CPS) submission: digital prototypes design at IHEP & CCNU
- First with in-pixel digitization; readout structure study
- Taped-out in May of 2017 (process: TowerJazz CiS 180nm)

	Rolling shutter mode		Global shutter mode	
In-pixel front-end	2 stage single end version	Differential version	Self designed +Digital processing	ALPIDE-like +Digital processing
Pixel size	22×22 um^2 33% ↓vs ASTRAL chip		25×25 um^2 20%↓vs ALPIDE chip	

Sensor size: 3-4 mm^2

1st Silicon-on-Insulator (SOI) sensor (CPV1) test: in progress

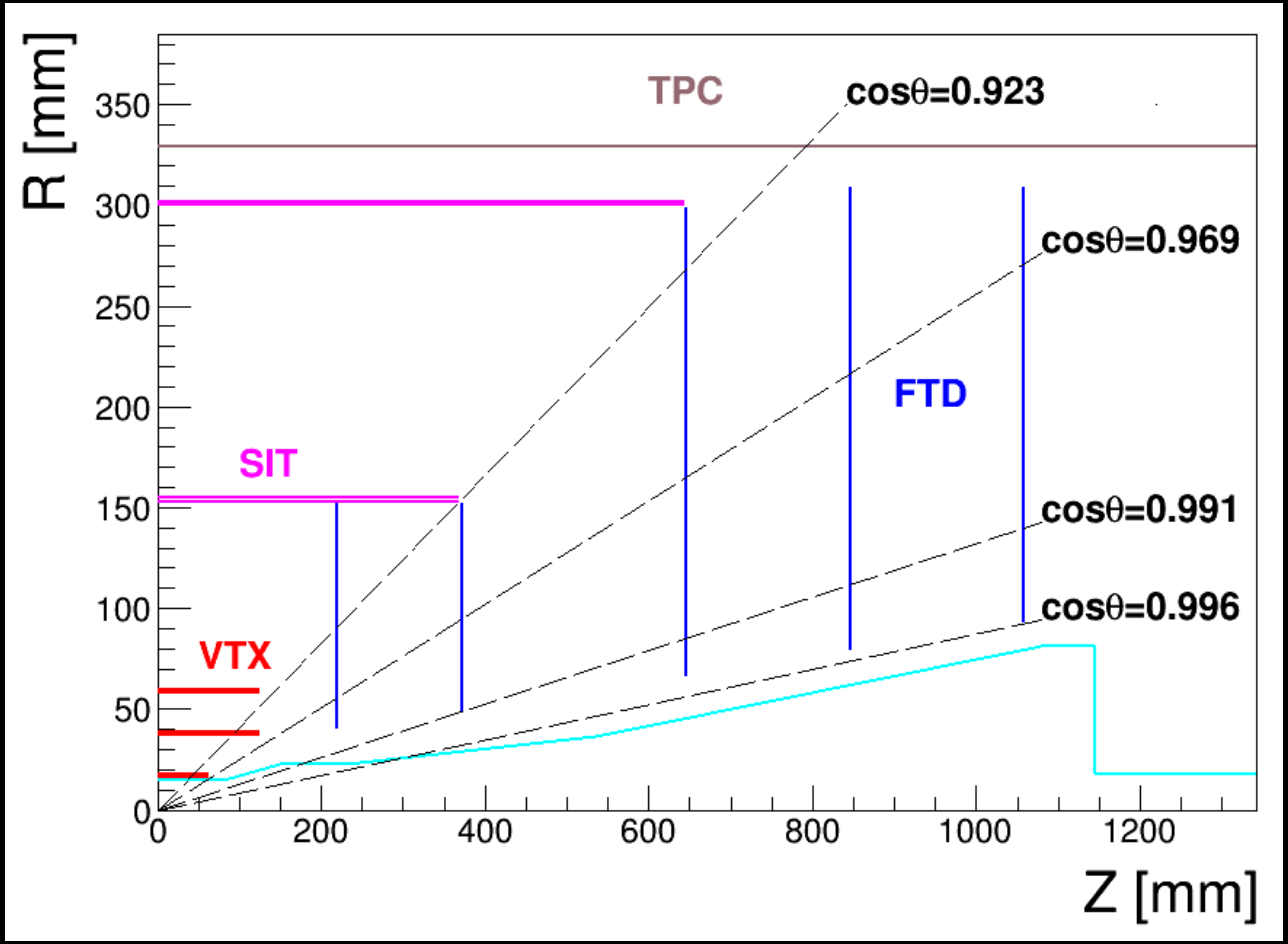
2nd SOI sensor (CPV2) design:
- Pixel size: 16 μm×16 μm
- Digital readout
- Thinning to 75 μm



Silicon Tracker Detector

Session II: Qun OUYANG
CDR: Chapter 5

SIT links
VTX with TPC



Not much R&D
done so far

Between TPC and calorimeter

- Barrel: SET (Silicon External Tracker), r = ~1.8 m
- Endcap: ETD (Endcap Tracking Detector), z = ~2.4 m

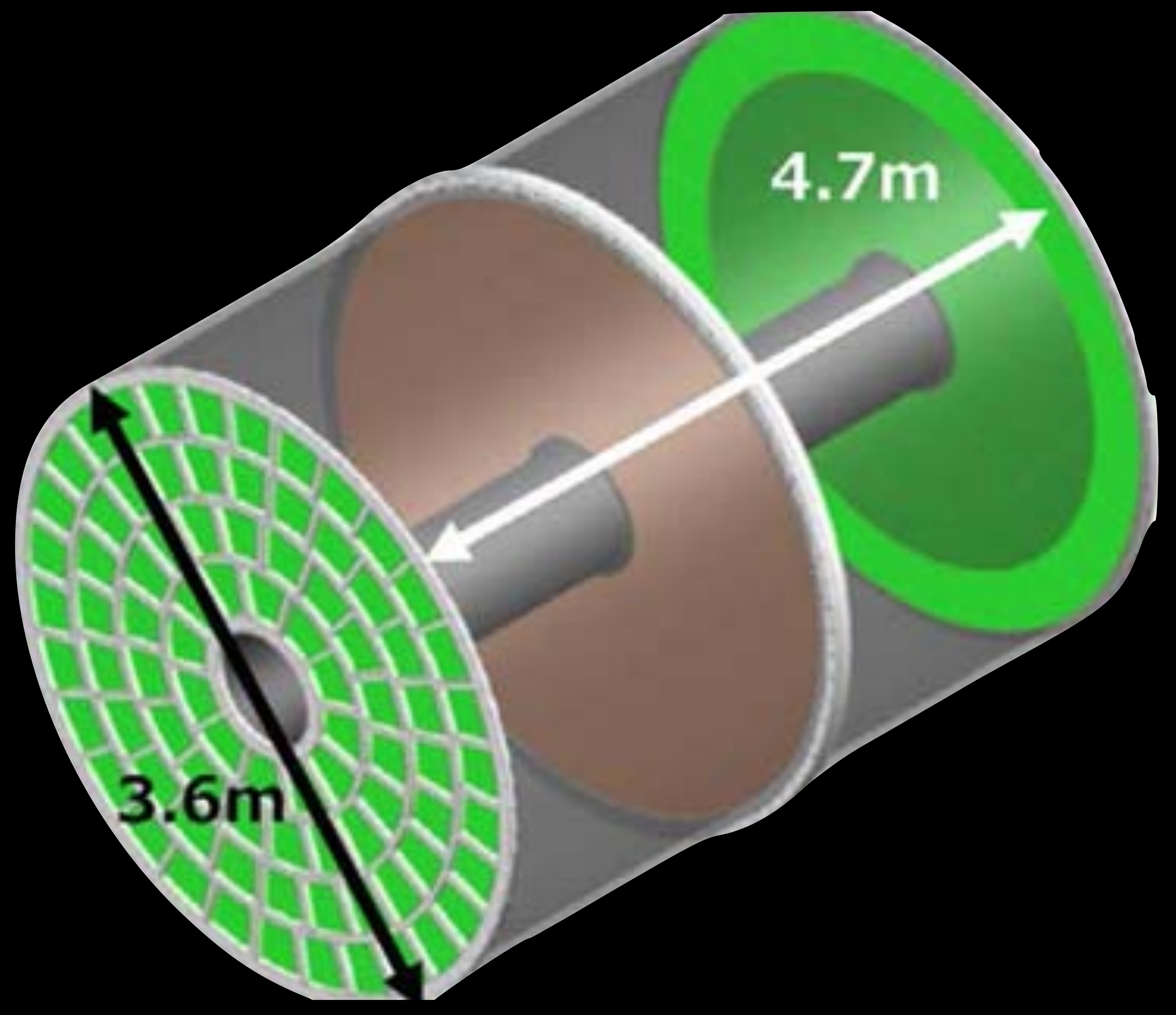
Time Projection Chamber (TPC)

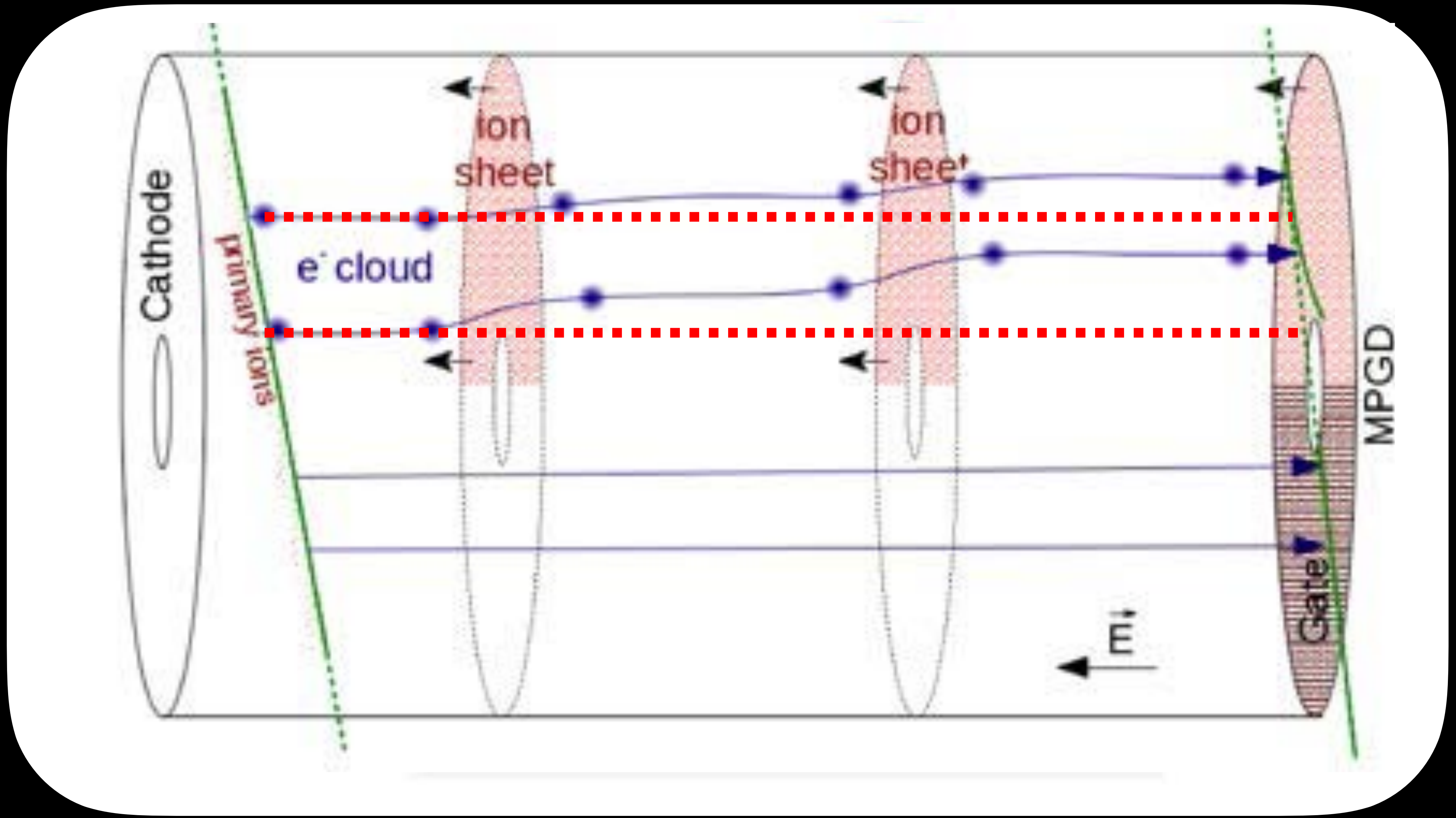
Session III: Huirong Qi
CDR: Chapter 5

TPC detector concept

- Allows for particle identification
- Low material budget
- 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} ?





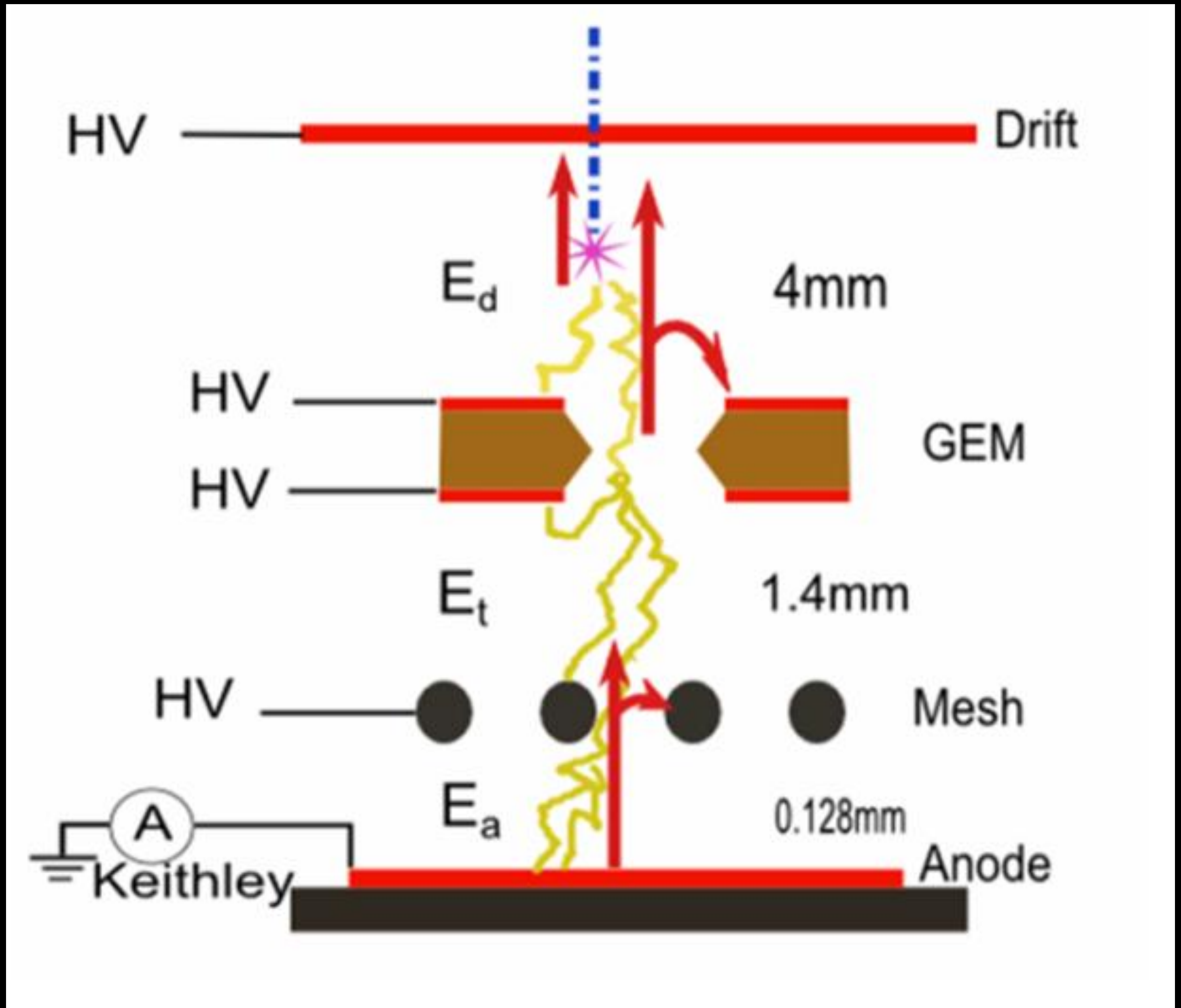
Manpower and activities

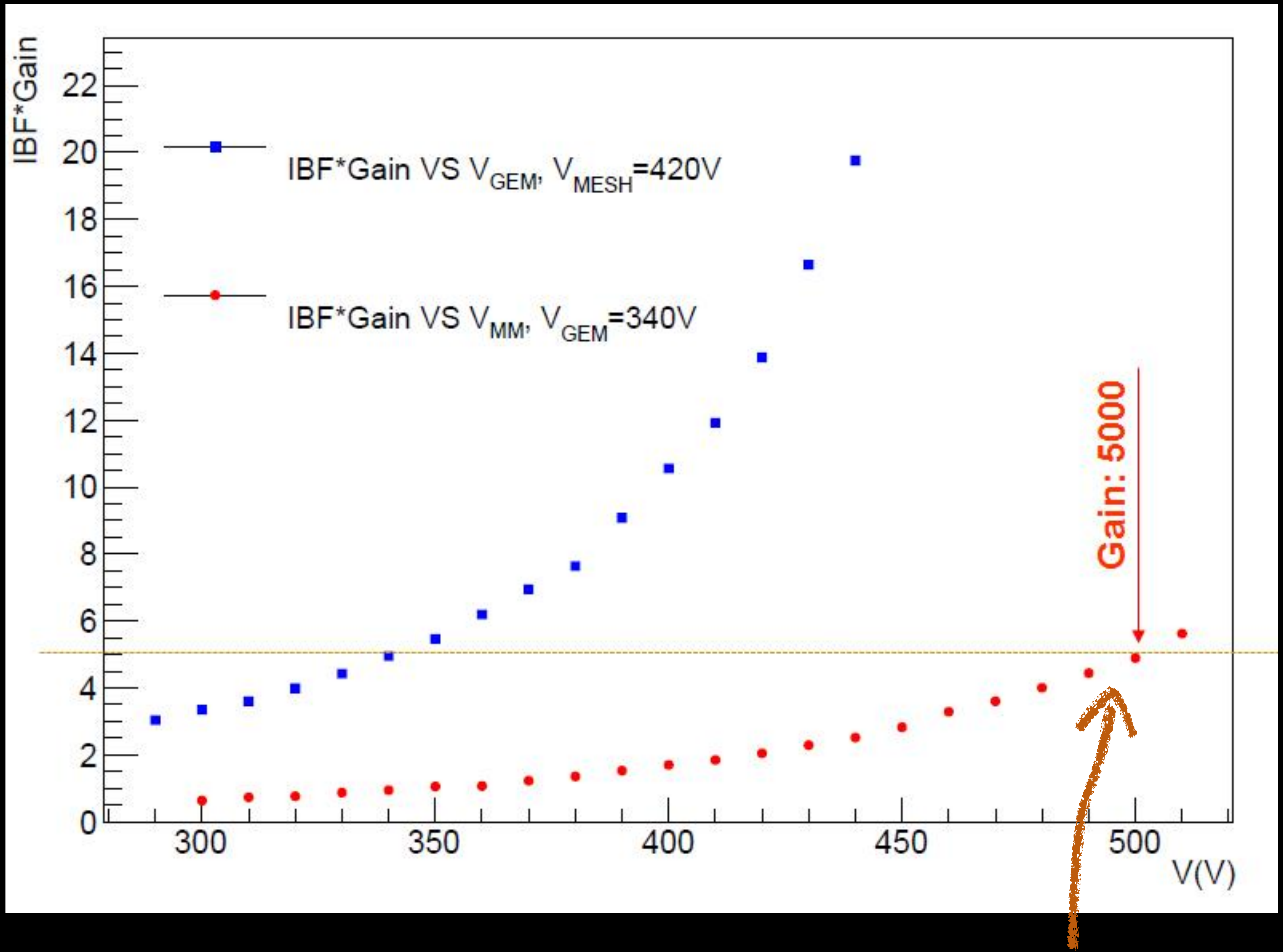
- TPC detector R&D @IHEP (2016~2020)
  - Funding from MOST and NSFC (~3.5 Million RMB)
- Electronics R&D @Tsinghua (2016~2020)
  - Funding from NSFC (~2.0 Million RMB)
- Inhabitation of IBF using graphene @Shandong Univ. (2016~2019)

Time Projection Chamber (TPC)

TPC readout with micro-pattern gaseous detectors (MPGDs)

New: Micromegas + GEM





IBF: Ion Back Flow reduced to 0.1%

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

Drift Chamber Option

Session III: Franco Grancagnolo
CDR: Chapter 5

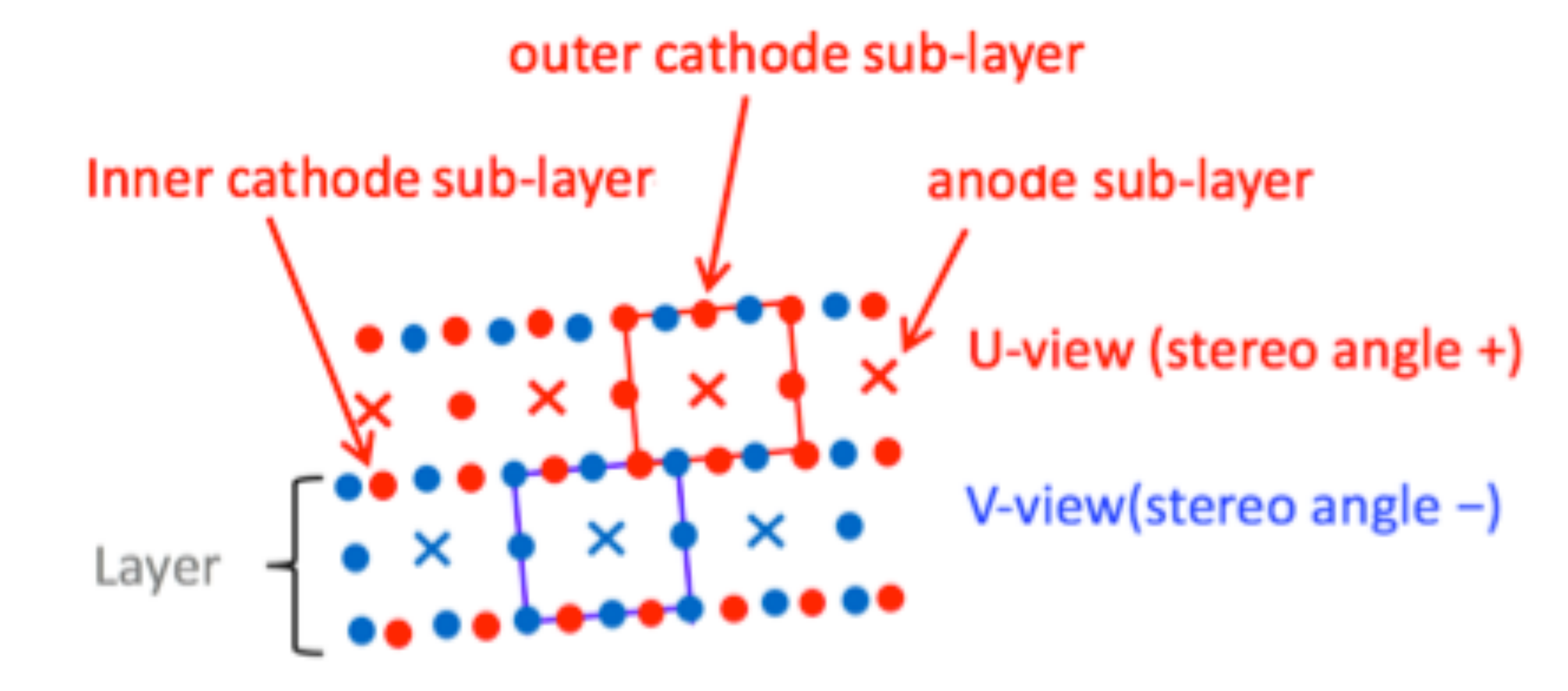
Lead by Italian Colleagues

Follows design of the KLOE and MEG2 experiments

- Length: 4 m
- Radius: 0.3- 2m
- Helium gas
- Material: aiming for 1% X_0

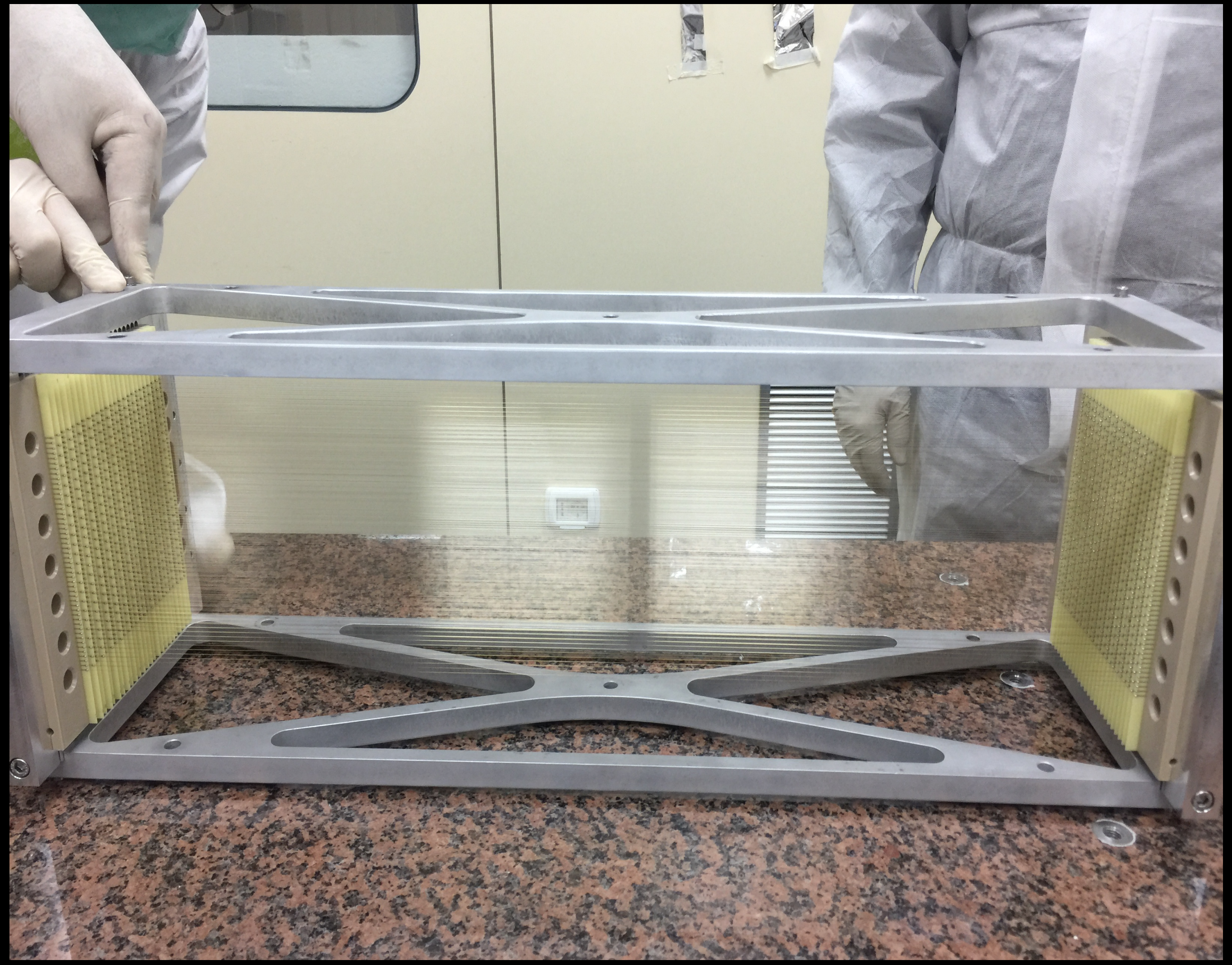
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: 150 nsec
- Material: aiming for 1% X_0

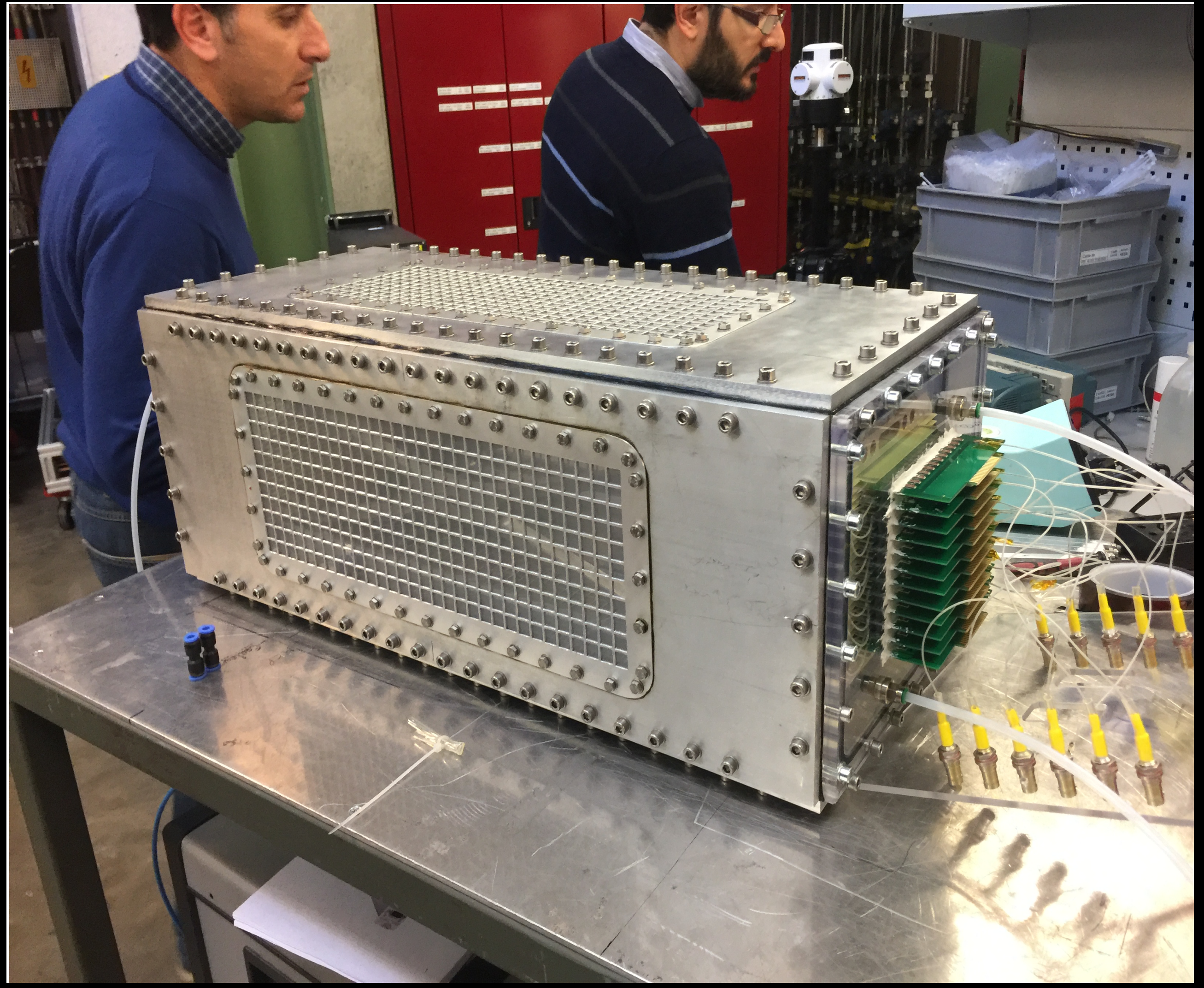
Layers: 14 SL × 8 layers = 112
Cell size: 12 - 14 mm



Stereo angle: 50-250 mrad

Prototype being tested



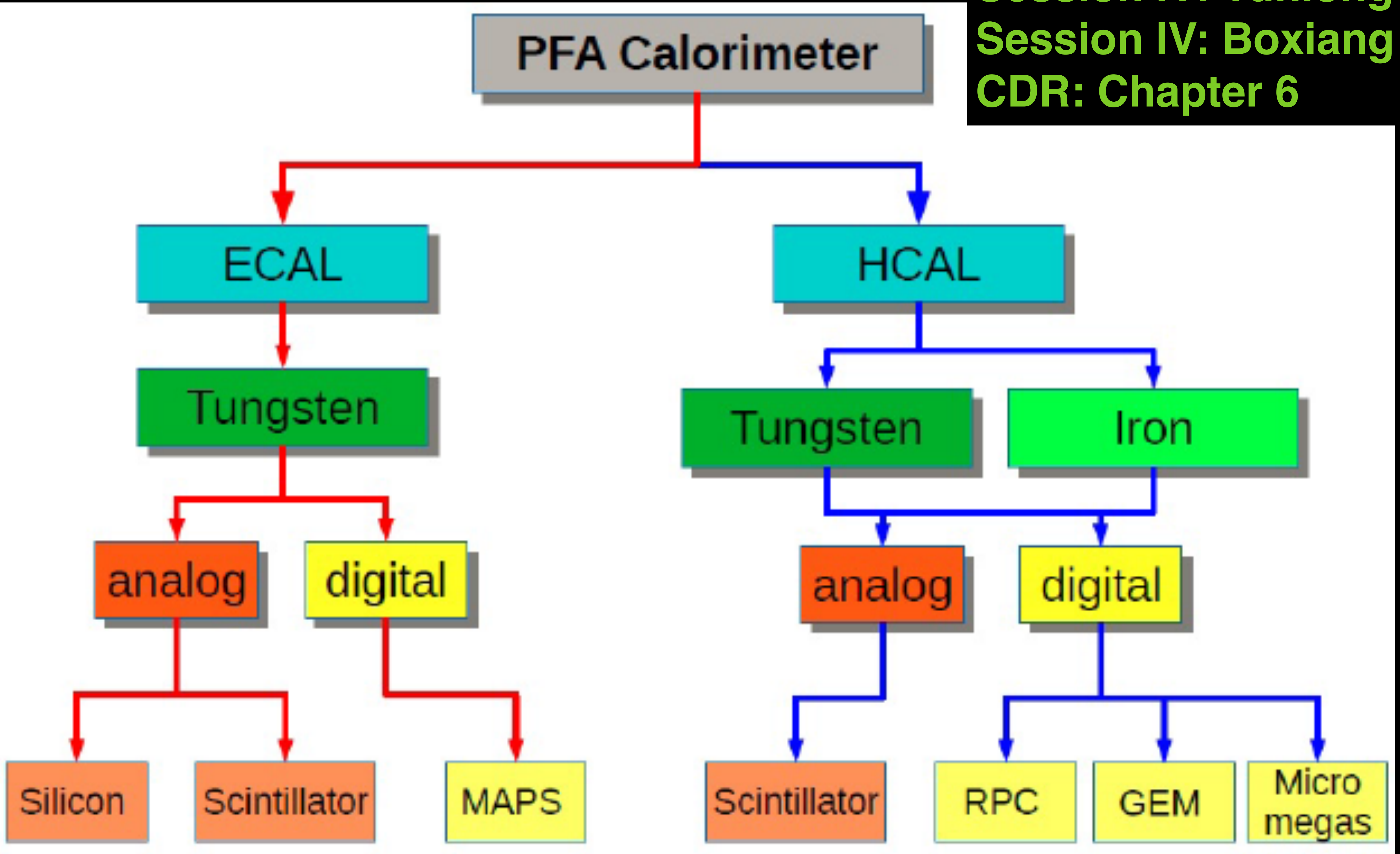


Calorimeter options

Session IV: Yunlong Zhang
Session IV: Boxiang Yu
CDR: Chapter 6

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) HCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP)
New →	Dual readout calorimeters (INFN, Italy + Iowa, USA)

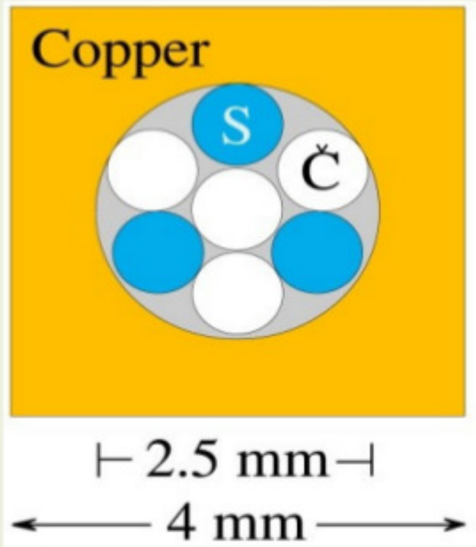
Dual Readout Calorimeter

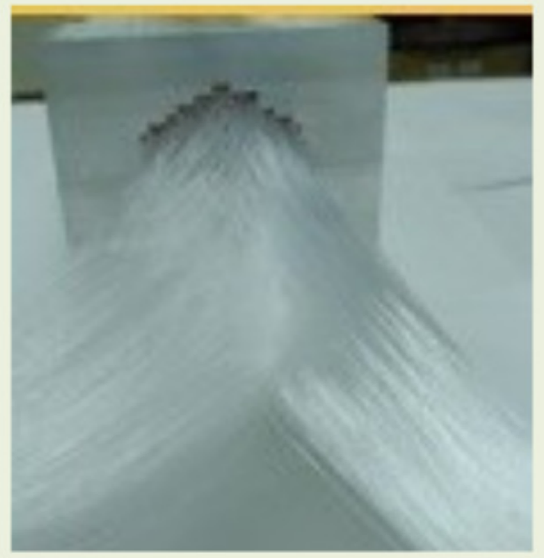
Session IV: Roberto Ferrari
CDR: Chapter 6

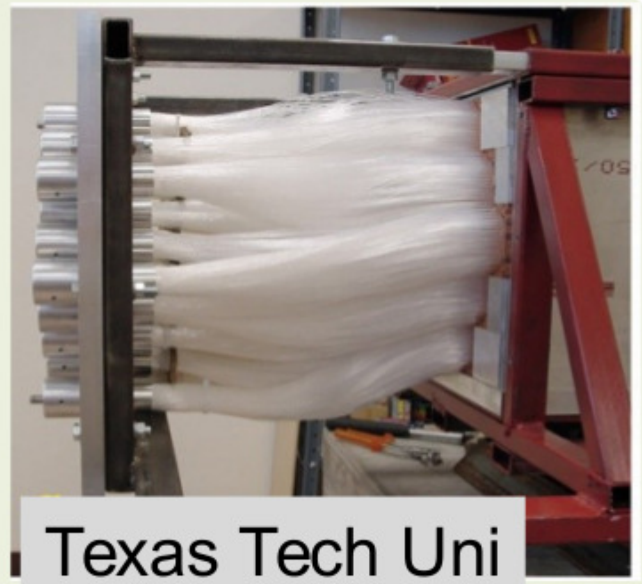
Lead by Italian colleagues: based on the DREAM/RD52 collaboration

2003 DREAM

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



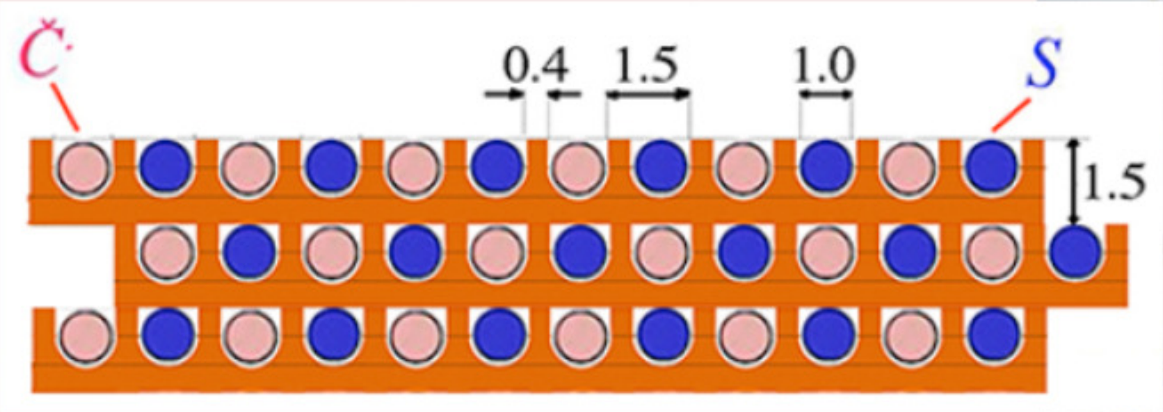




2012 RD52

Copper, 2 modules

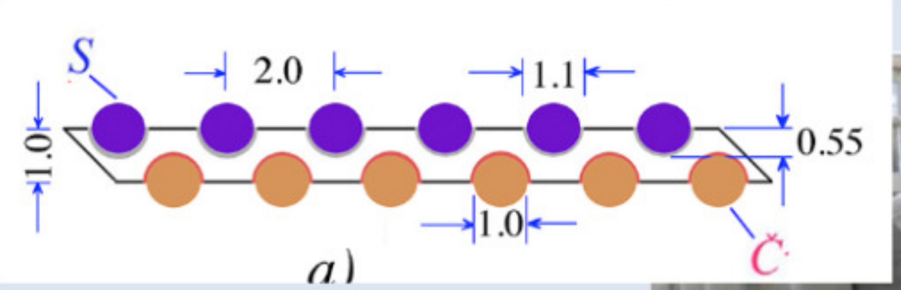
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

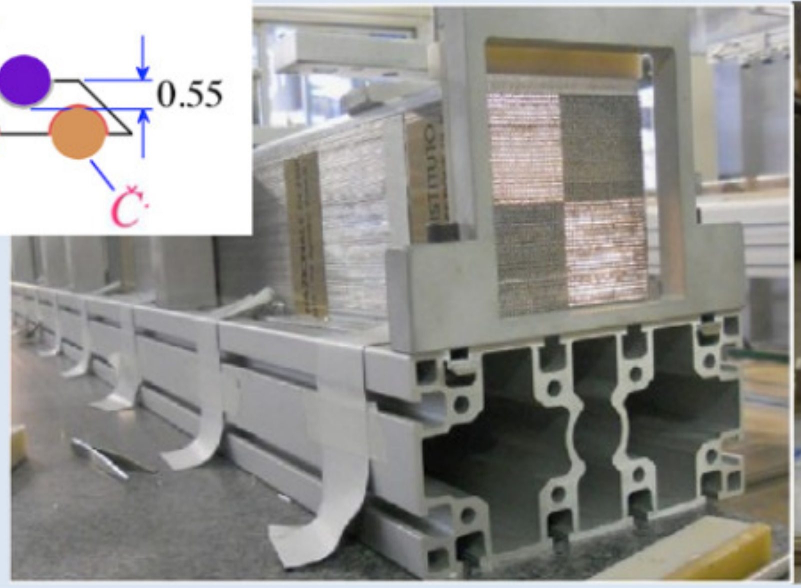


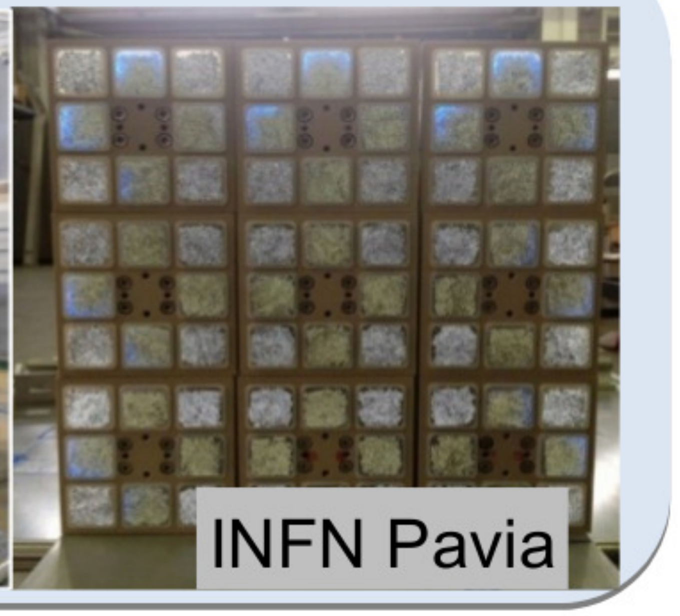
2012 RD52

Lead, 9 modules

Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 5%, 10 λ_{int}



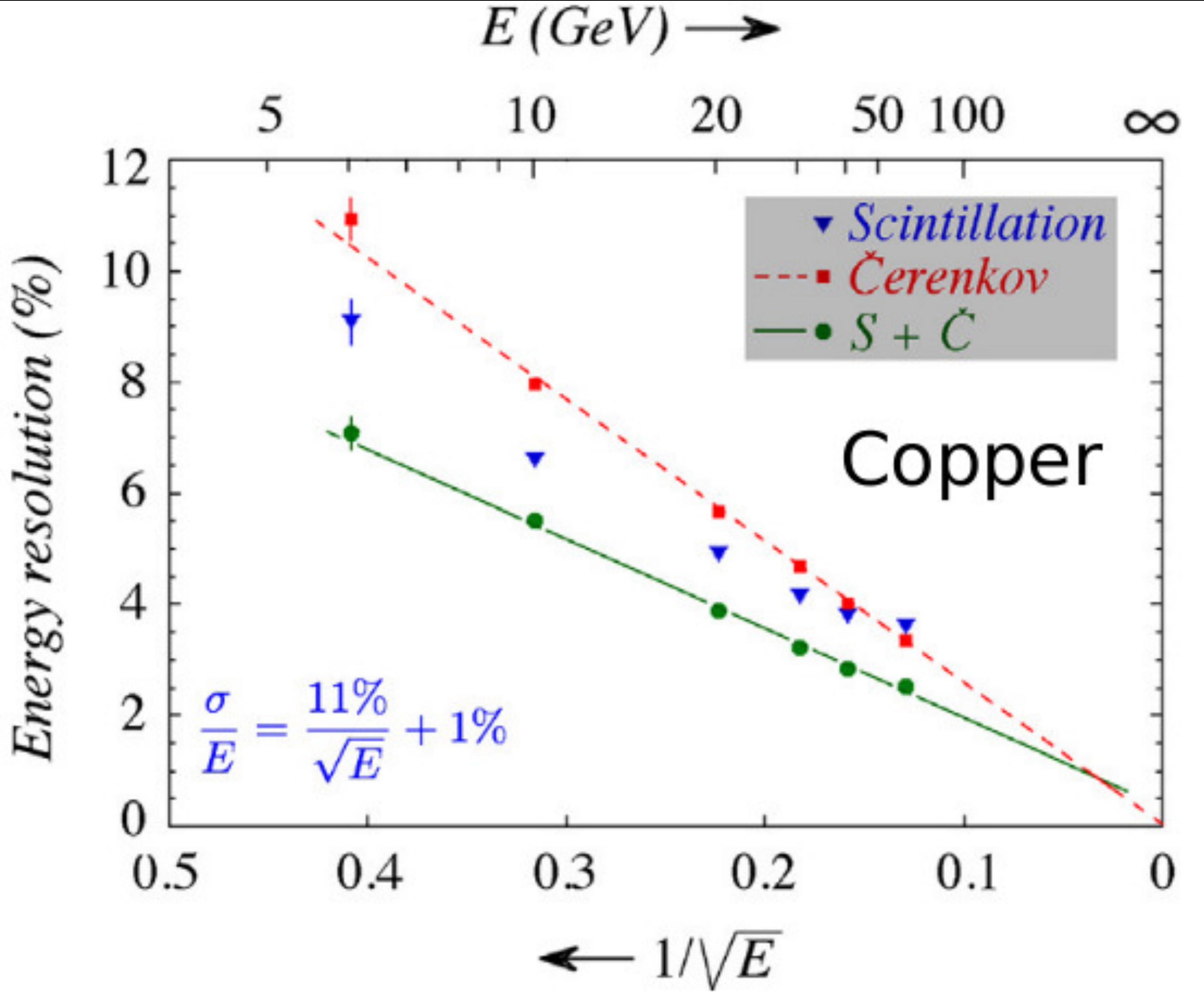




Expected resolution:

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

Energy resolution for electrons

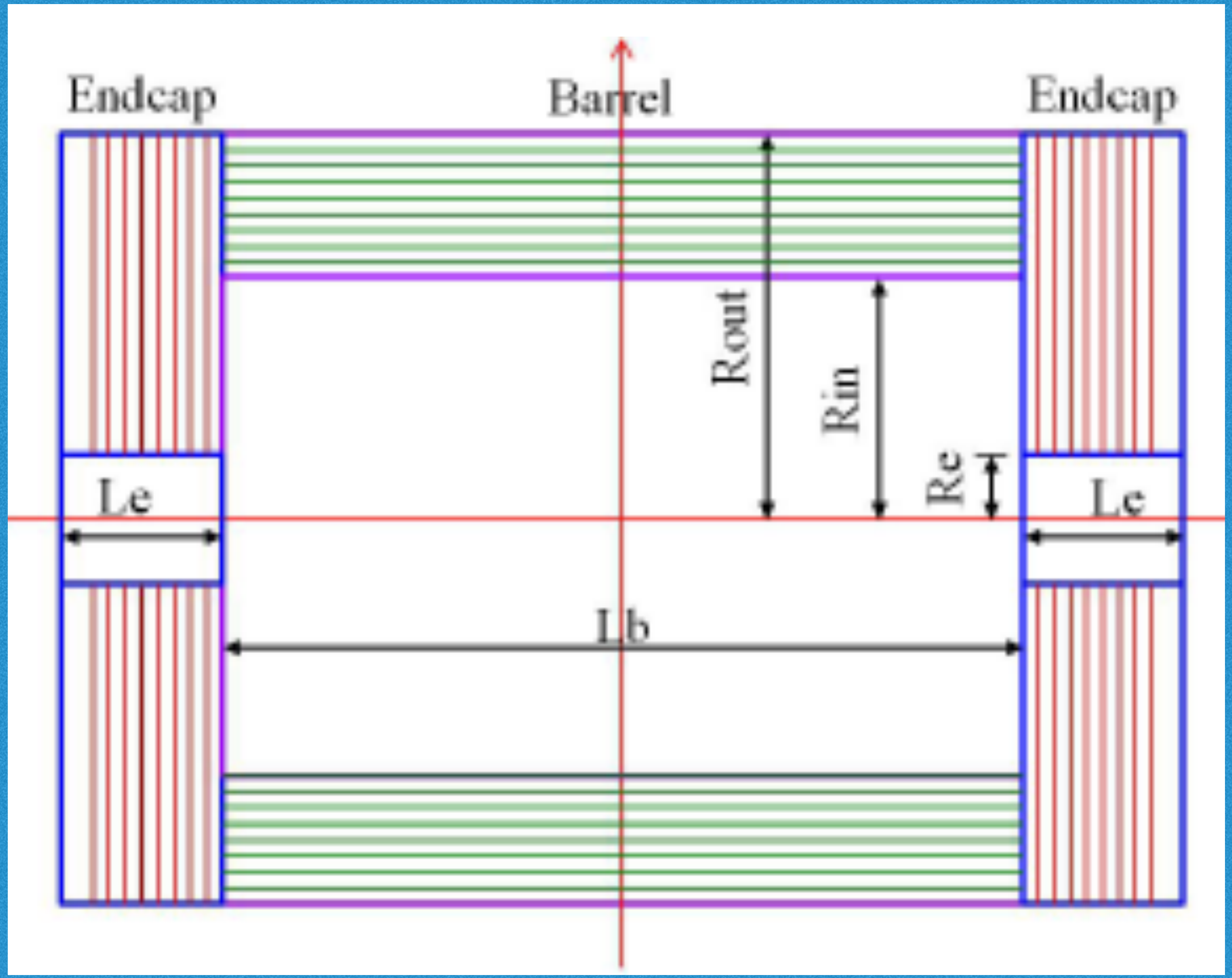


Muon detector

Session III: Liang Li
CDR: Chapter 8

Baseline Muon detector

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

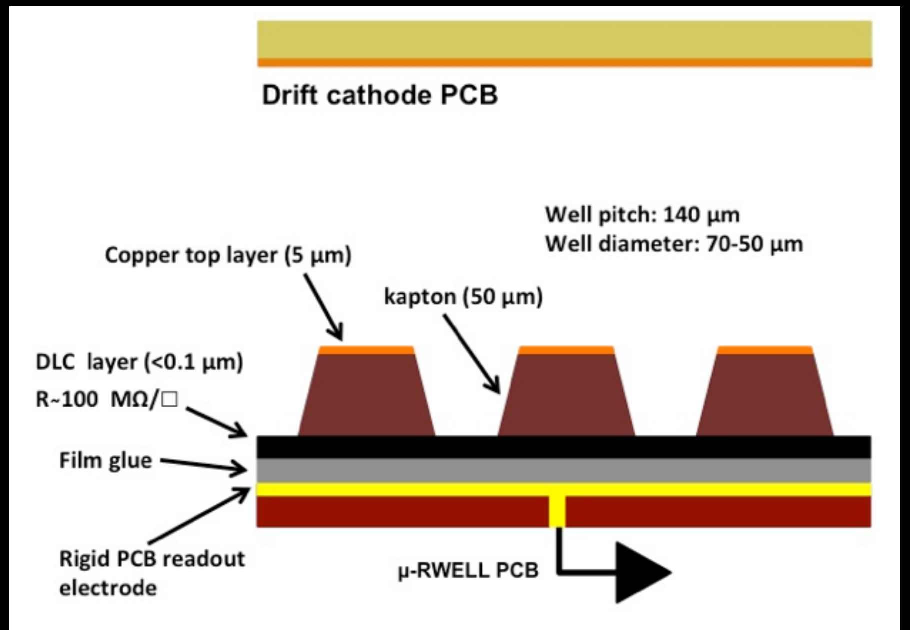


Technologies considered

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



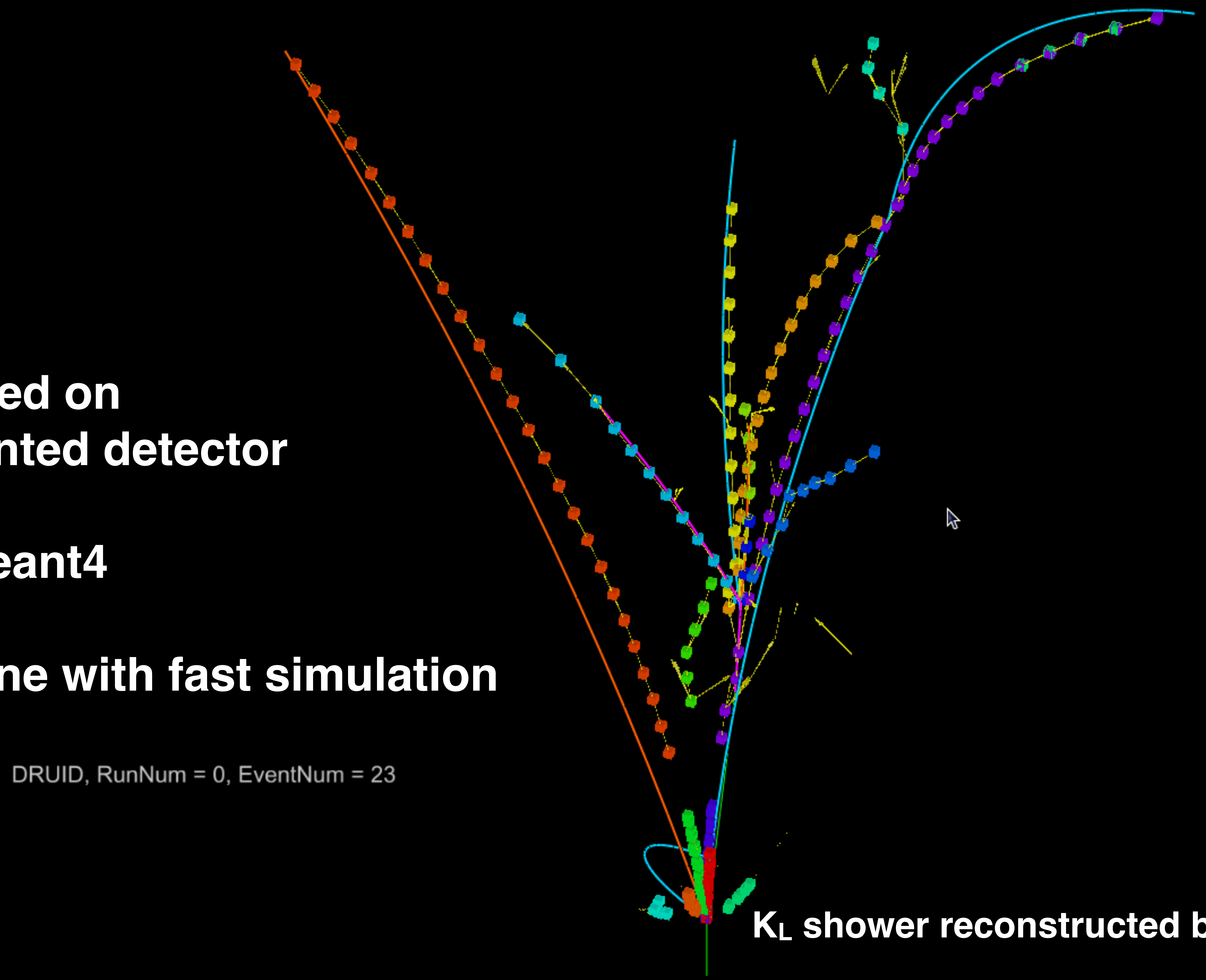
Muon system: open studies

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**

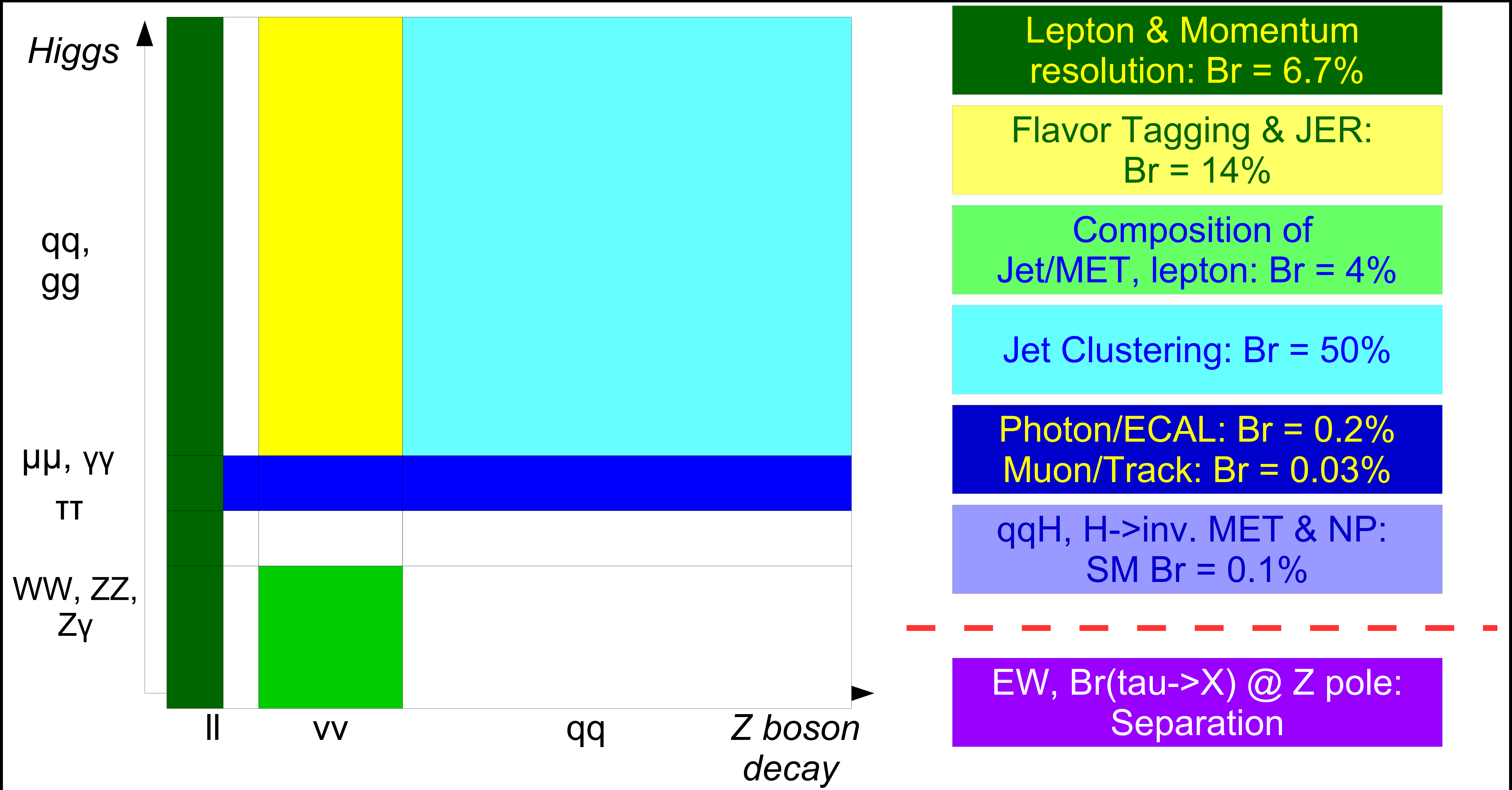
Optimization based on particle flow oriented detector and full simulation Geant4

Some studies done with fast simulation



K_L shower reconstructed by the Arbor algorithm

Detector optimization: Benchmark measurements



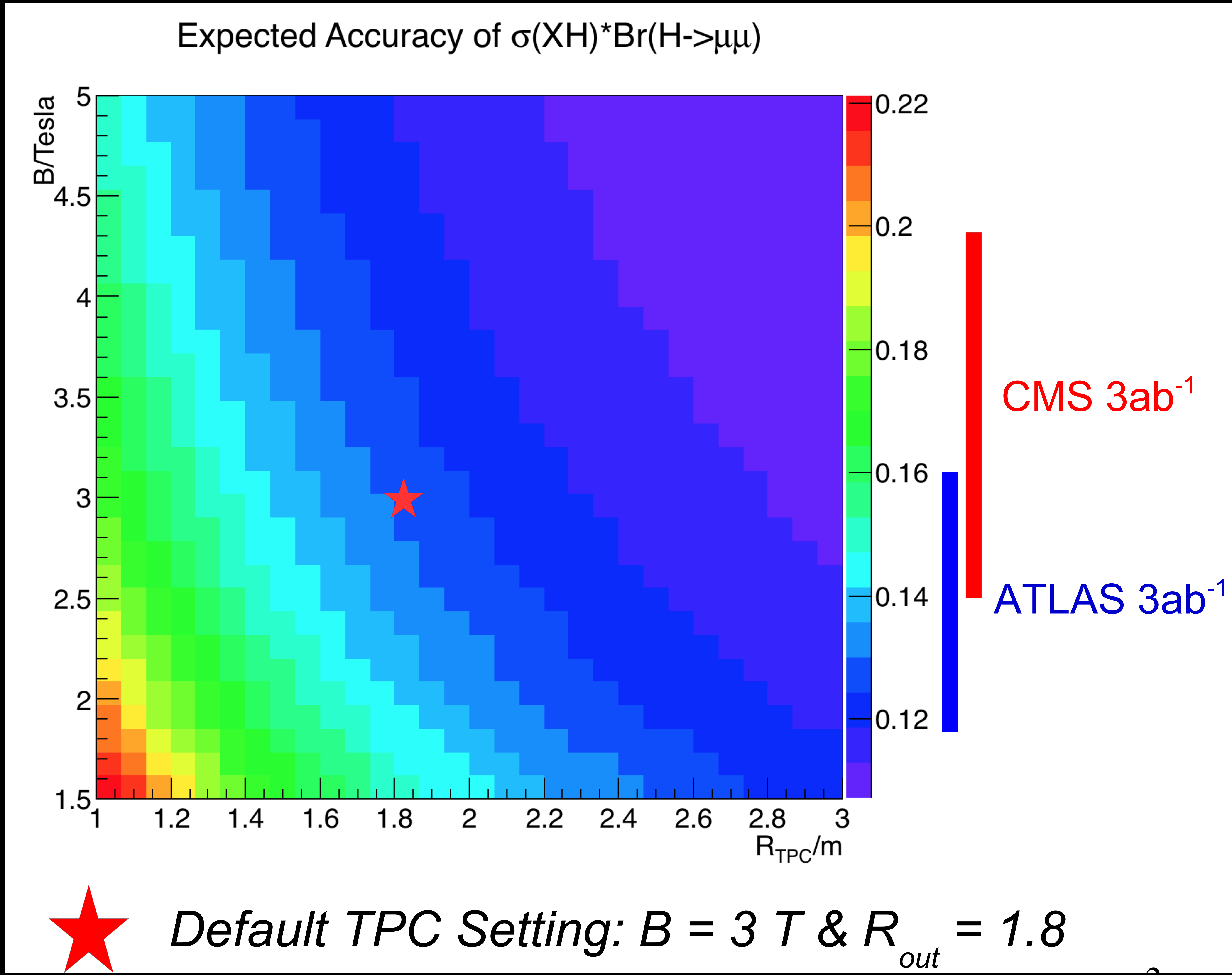
Results in CDR not fully updated for the 3 Tesla magnetic field and latest geometry

Detector optimization

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

Optimization of TPC radius and B−field

BR(H→μμ) measurement



Final remarks

- Work towards the CEPC Detector CDR is well advanced
  - Two significantly different concepts are emerging
    - 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
    - Still a lot of work to do, and newcomers are welcome
  - Colleagues from Italy heavily involved
    - Drift chamber, dual readout calorimeter and muon chamber
- International collaborations expanding
  - INFN, SLAC, Iowa State Univ., Belgrade, LLR, IPNL, LC-TPC,…

- Preliminary CDR draft-0 to be released at parallel sessions
  - CDR Password: cdr2018-0draft
  - Participation either as an author or a reviewer is very much appreciated

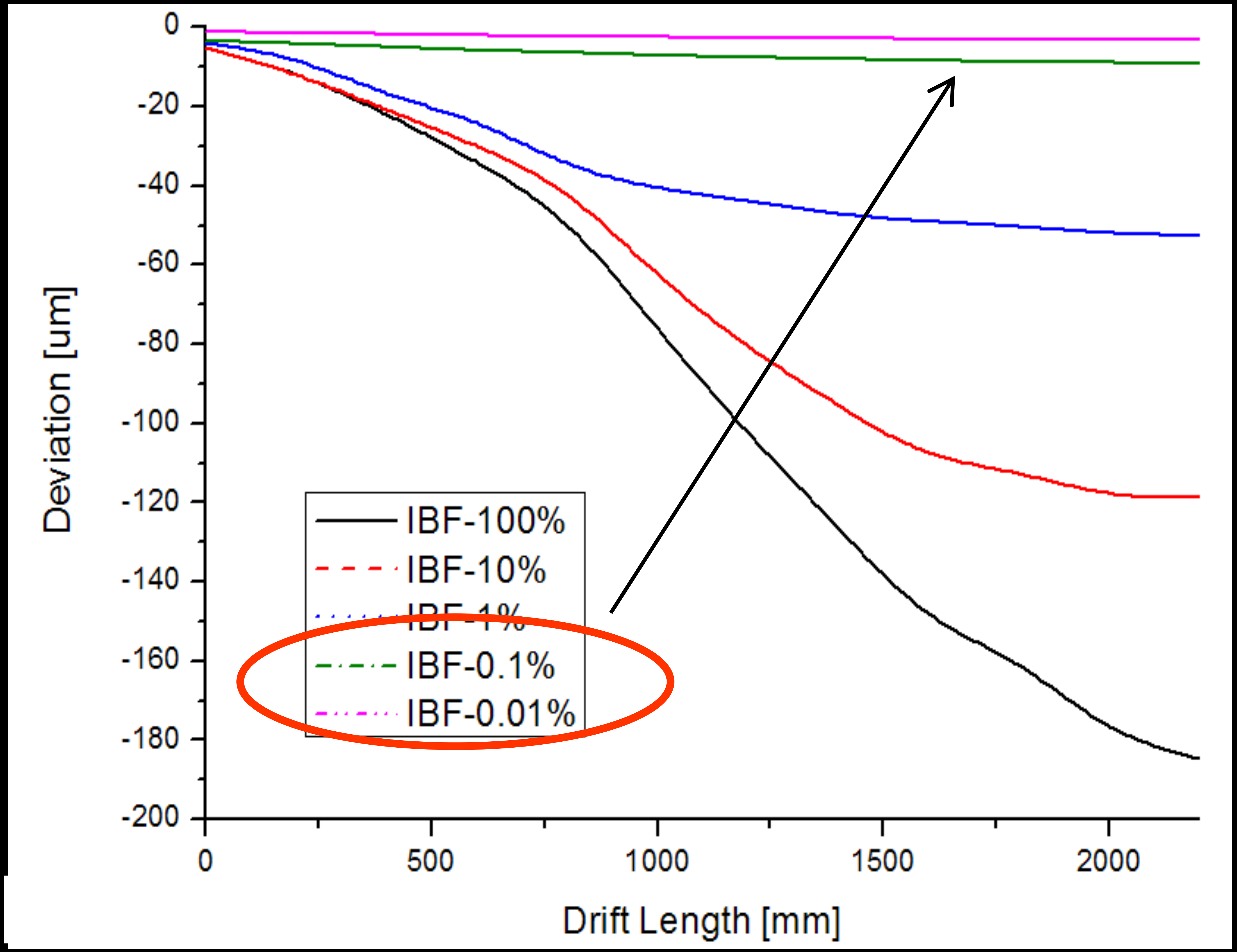
Expected final release: Spring 2018

Extra Slides

Ion Back Flow studies

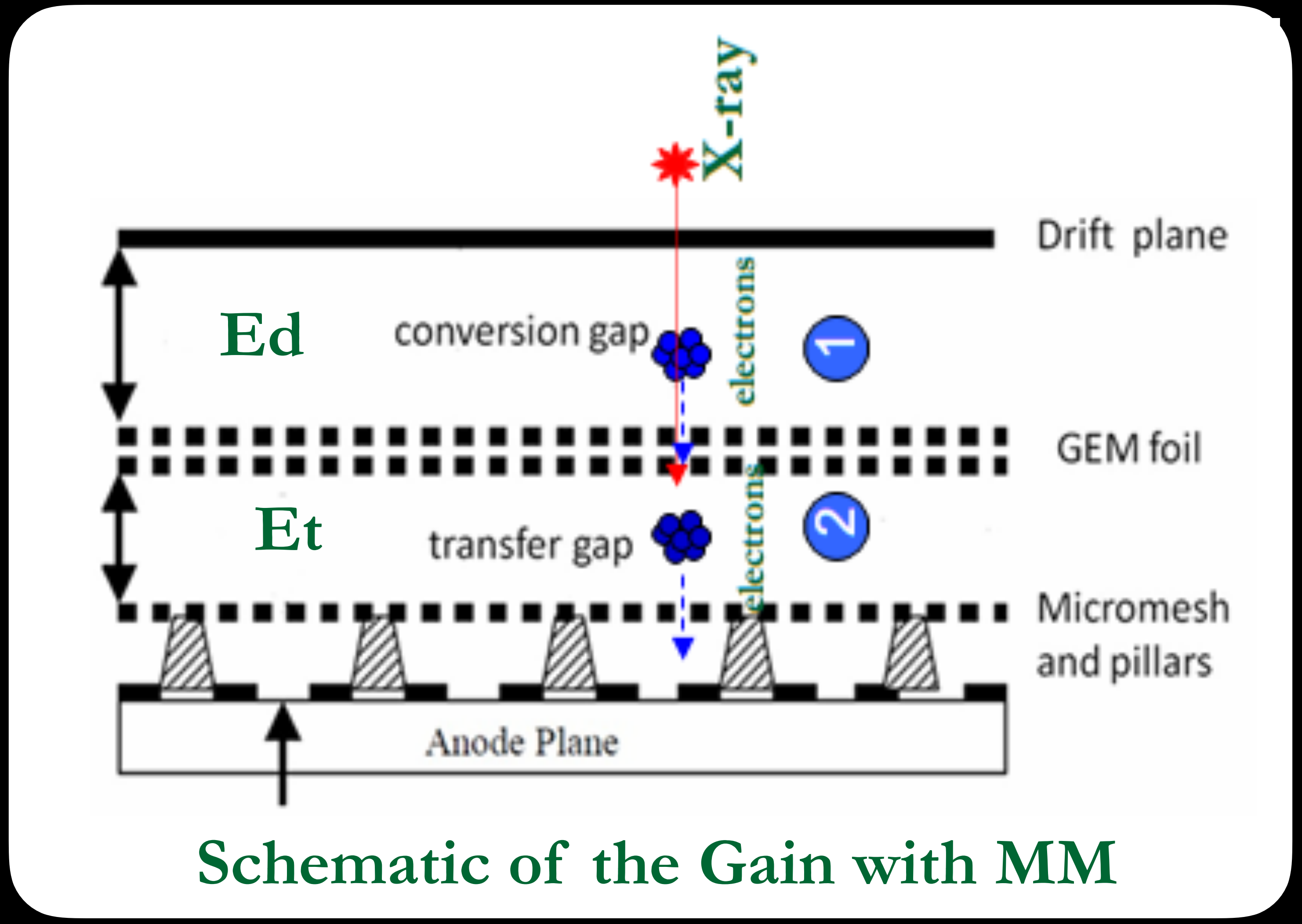
Simulation of Ion Back Flow
Z pole run @ $L = 10^{34}\ cm^{-2}s^{-1}$

Track distortions due to space charge effects of positive ions



Need IBF < 0.1%

Micromegas + GEM



Simulation and preliminary tests indicate this scheme can provide IBF ~ 0.1%

Simulation results to be published
Experiments and module R&D will continue

International collaboration with Saclay and LCTPC

Research supported by MOST and NSFC