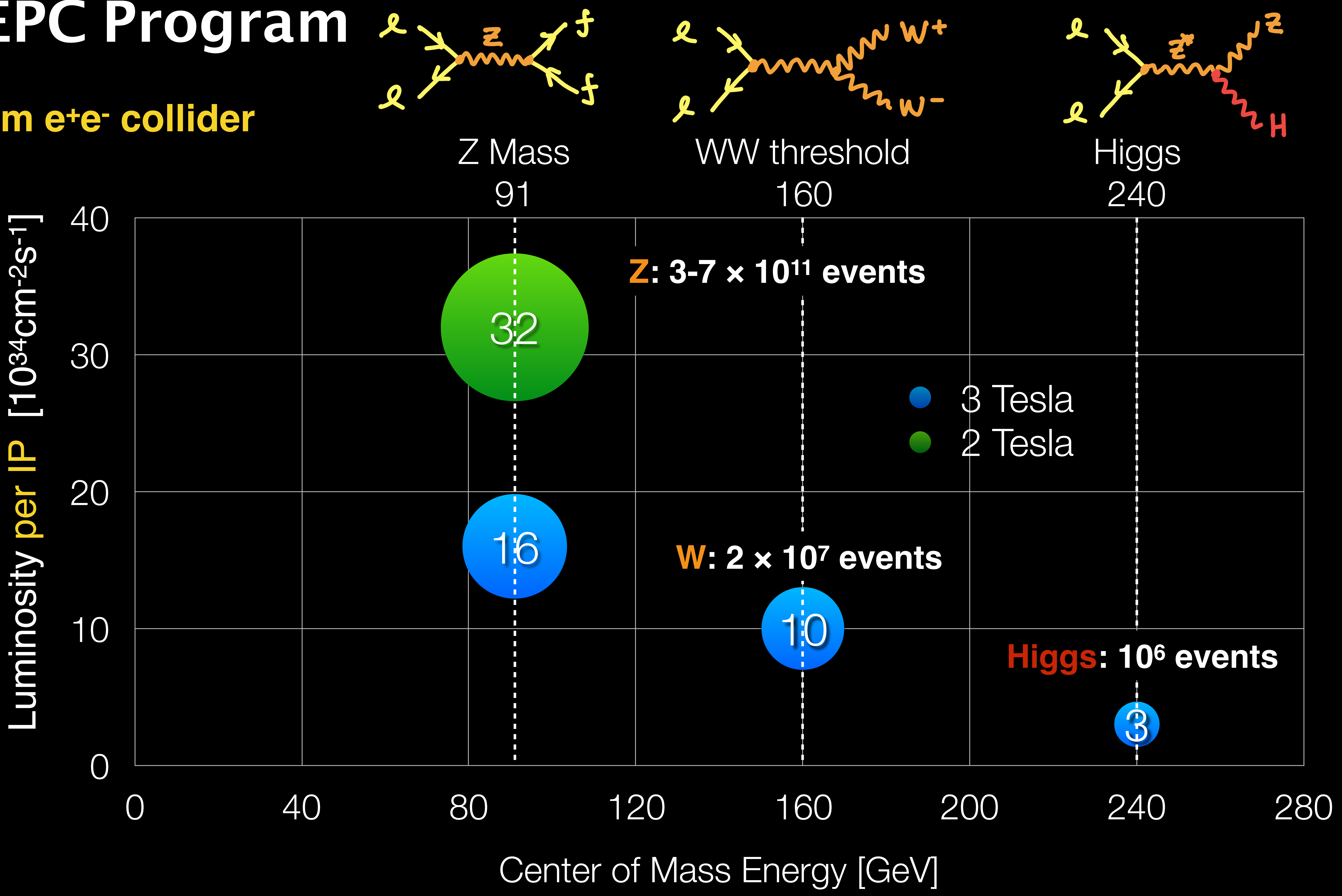
Overview of CEPC Physics and Detector CDR

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

CEPC Physics and Detector CDR International Review – Beijing
13 September 2018

The CEPC Program

100 km e^+e^- collider



Main Parameters of Collider Ring

	Higgs	W	Z（3T)	Z（2T)
Center-of-mass energy (GeV)	240	160	91	
Number of IPs	2			
Luminosity/IP (10^{34} $cm^{-2}s^{-1}$)	3	10	16	32
Number of years	7	1	2	
Total Integrated Luminosity (ab^{-1}) - 2 IP	5.6	2.6	8	16
Total number of particles	1×10^6	2×10^7	3×10^{11}	7×10^{11}

Current CEPC Organization

Since Sept. 2013

Institutional Board
YN GAO
J. GAO

Steering Committee
Y.F. WANG (IHEP),….

Project Director
XC LOU
Q. QIN
N. XU

Theory
HJ HE(TH)
JP MA(ITP)
XG HE(SJTU)

Accelerator
J. GAO (IHEP)
CY Long (IHEP)
SN FU (IHEP)

Detector
Joao Costa (IHEP)
S. JIN (NJU)
YN GAO (TH)

International Advisory Committee

Young-Kee Kim, U. Chicago (Chair)
Barry Barish, Caltech
Hesheng Chen, IHEP
Michael Davier, LAL
Brian Foster, Oxford
Rohini Godbole, CHEP, Indian Institute of Science
David Gross, UC Santa Barbara
George Hou, Taiwan U.
Peter Jenni, CERN
Eugene Levichev, BINP
Lucie Linssen, CERN
Joe Lykken, Fermilab
Luciano Maiani, Sapienza University of Rome
Michelangelo Mangano, CERN
Hitoshi Murayama, UC Berkeley/IPMU
Katsunobu Oide, KEK
Robert Palmer, BNL
John Seeman, SLAC
Ian Shipsey, Oxford
Steinar Stapnes, CERN
Geoffrey Taylor, U. Melbourne
Henry Tye, IAS, HKUST
Yifang Wang, IHEP
Harry Weerts, ANL

Organization of the Physics and Detector Working Group

Conveners

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

Machine Detector Interface
Hongbo Zhu
Sha Bai

Vertex
Ouyang Qun
Sun Xiangming
Wang Meng

Tracker
Qi Huirong
Yulan Li

Calorimeter

ECal	HCal	Muons
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

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

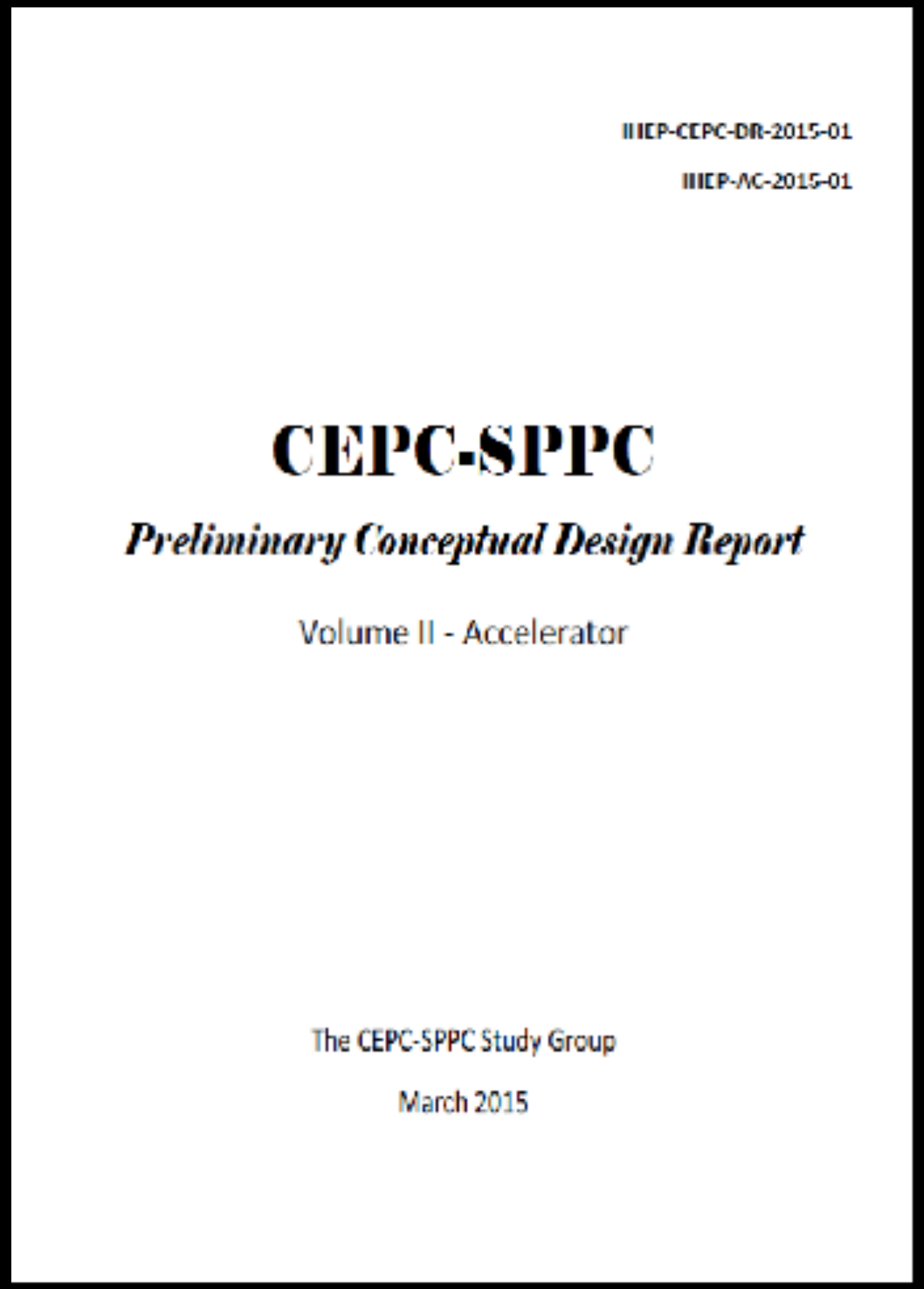
March 2015

CEPC CDR – Volume I: Accelerator Completed

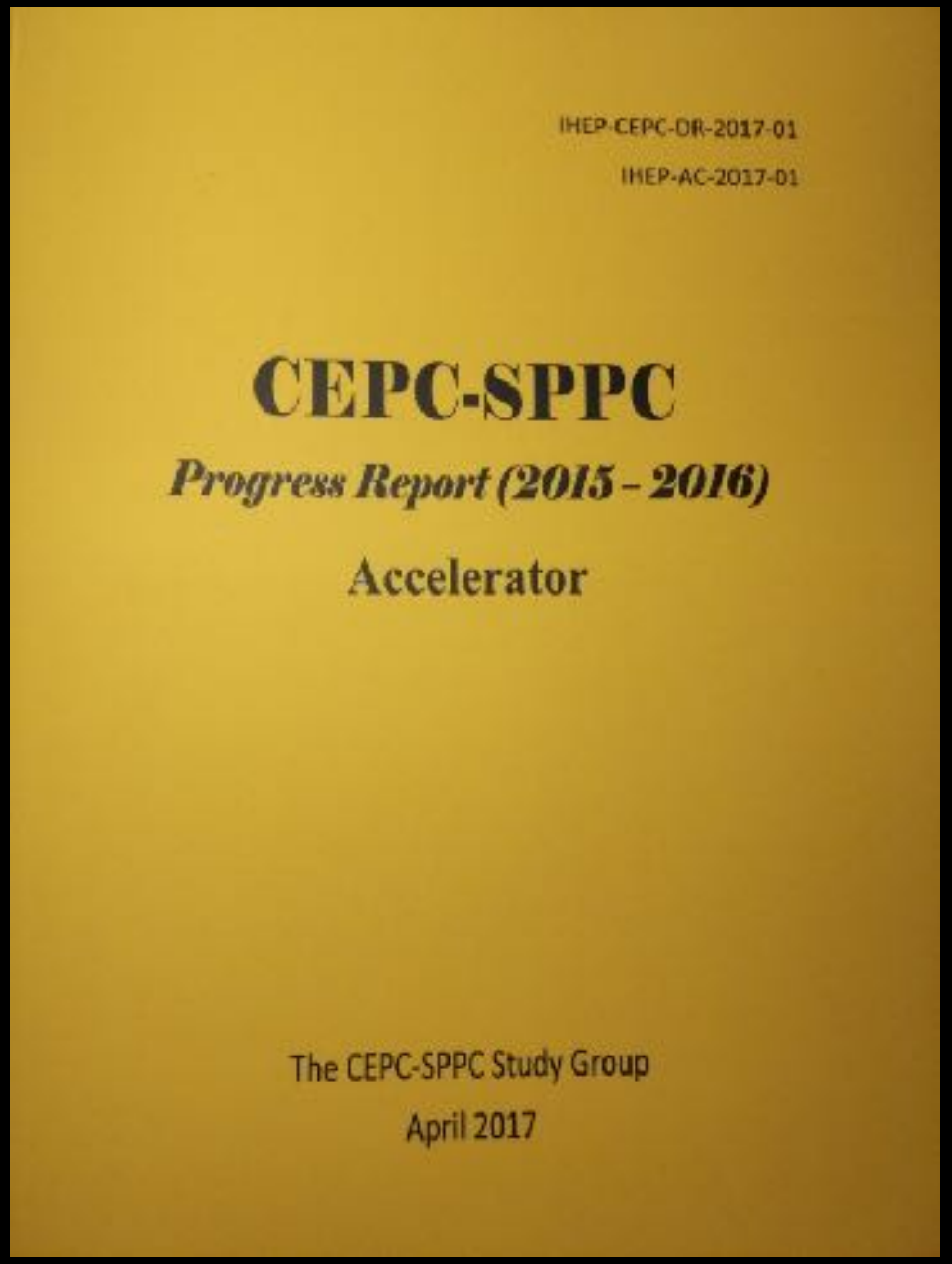
CEPC accelerator CDR completed in June 2018 (printed on Sept. 2018)

➡ Executive Summary
1. Introduction
2. Machine Layout and Performance
3. Operation Scenarios
4. CEPC Booster
5. CEPC Linac
6. Systems Common to the CEPC Linac, Booster and Collider
7. Super Proton Proton Collider
8. Conventional Facilities
9. Environment, Health and Safety
10. R&D Program
11. Project Plan, Cost and Schedule

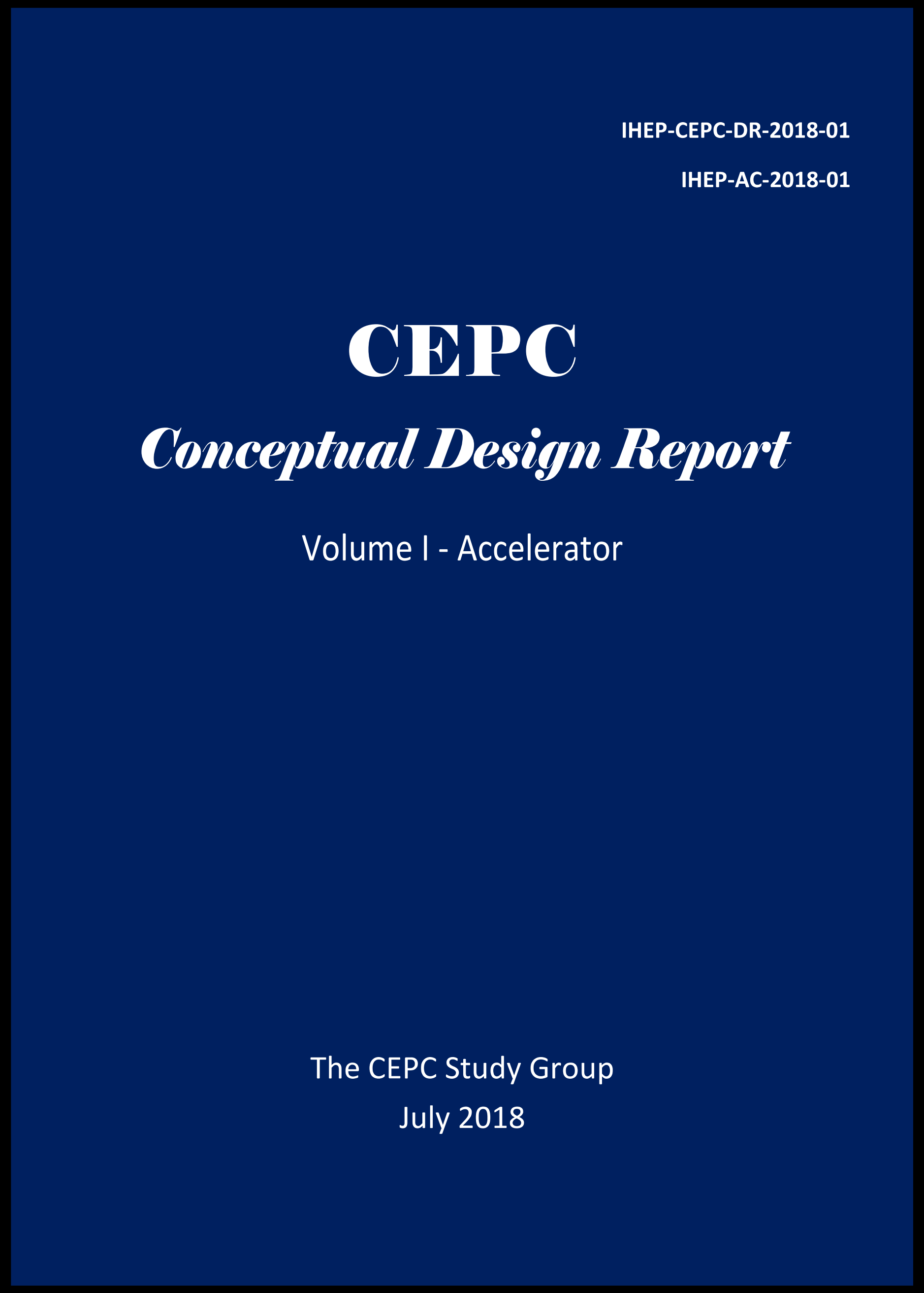
Appendix 1: CEPC Parameter List
Appendix 2: CEPC Technical Component List
Appendix 3: CEPC Electric Power Requirement
Appendix 4: Operation for High Intensity γ-ray Source
Appendix 5: Advanced Partial Double Ring
Appendix 6: CEPC Injector Based on Plasma Wakefield Accelerator
Appendix 7: Operation for e−p, e−A and Heavy Ion Collision
Appendix 8: Opportunities for Polarization in the CEPC
Appendix 9: International Review Report



March 2015



April 2017



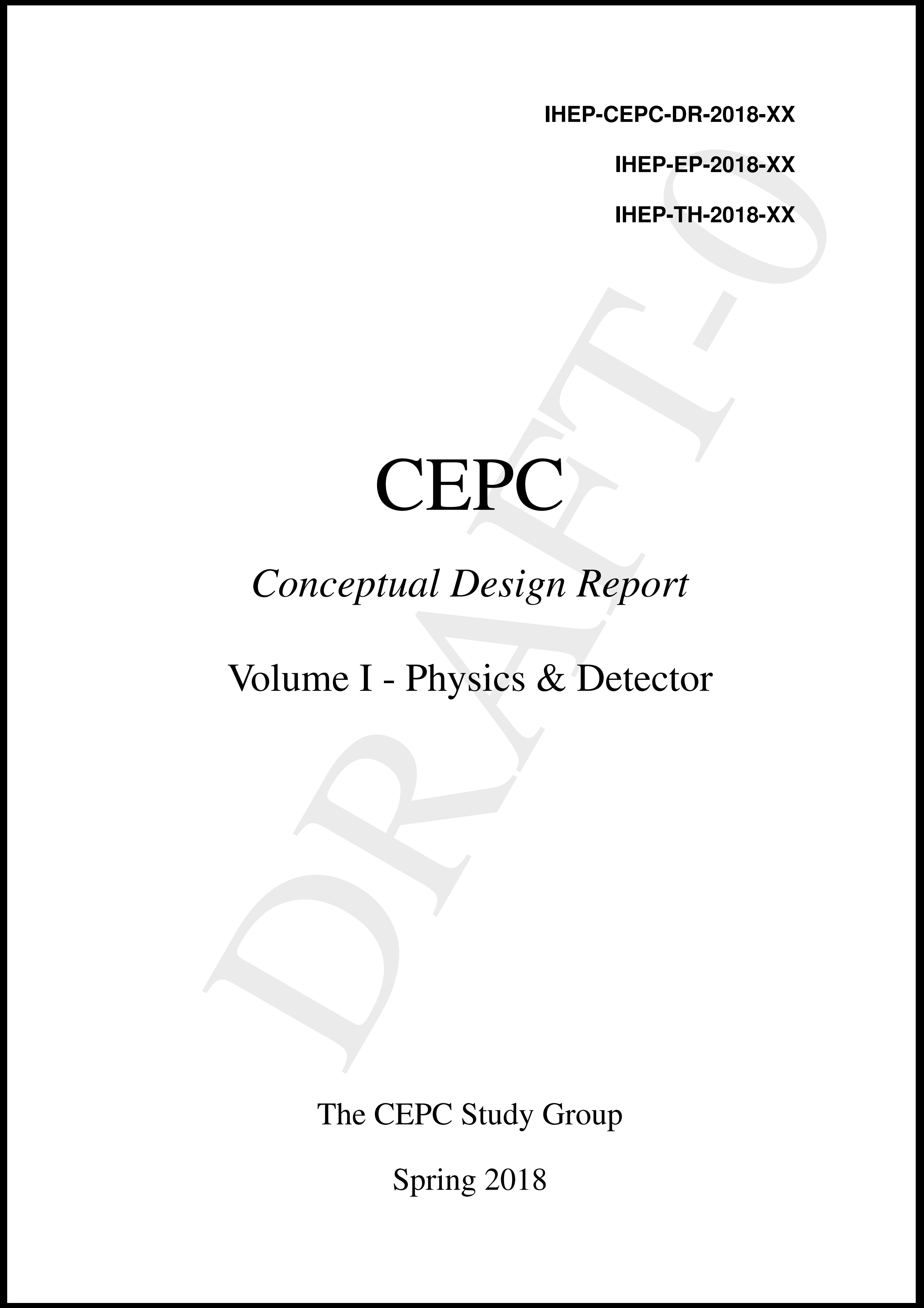
July 2018

CDR International Review June 28-30, 2018
Final CDR released on Sept. 2
arXiv:1809.00285

Mini-Review of Preliminary CDR

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

10-11 November, 2017


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

Reviewers:

Alexandre Glazov (DESY),

Charlie Young (SLAC),

Sebastian Grinstein (Barcelona),

Alberto Belloni (Maryland),

Jianming Qian (Michigan),

Walter Snoeys (CERN),

Daniela Bortoletto (Oxford),

Franco Grancagnolo (INFN)

- 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

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and
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13. Department of Physics, University of Michigan
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15. INFN - Sezione di Pavia and University of Pavia
16. INFN - Sezione di Pisa, Universita' di Pisa and Scuola Normale Superiore
17. INFN - Sezione di Bologna and University of Bologna
18. Vinca Institute of Nuclear Sciences, University of Belgrade
19. Institute of Physics, Academia Sinica, Taiwan

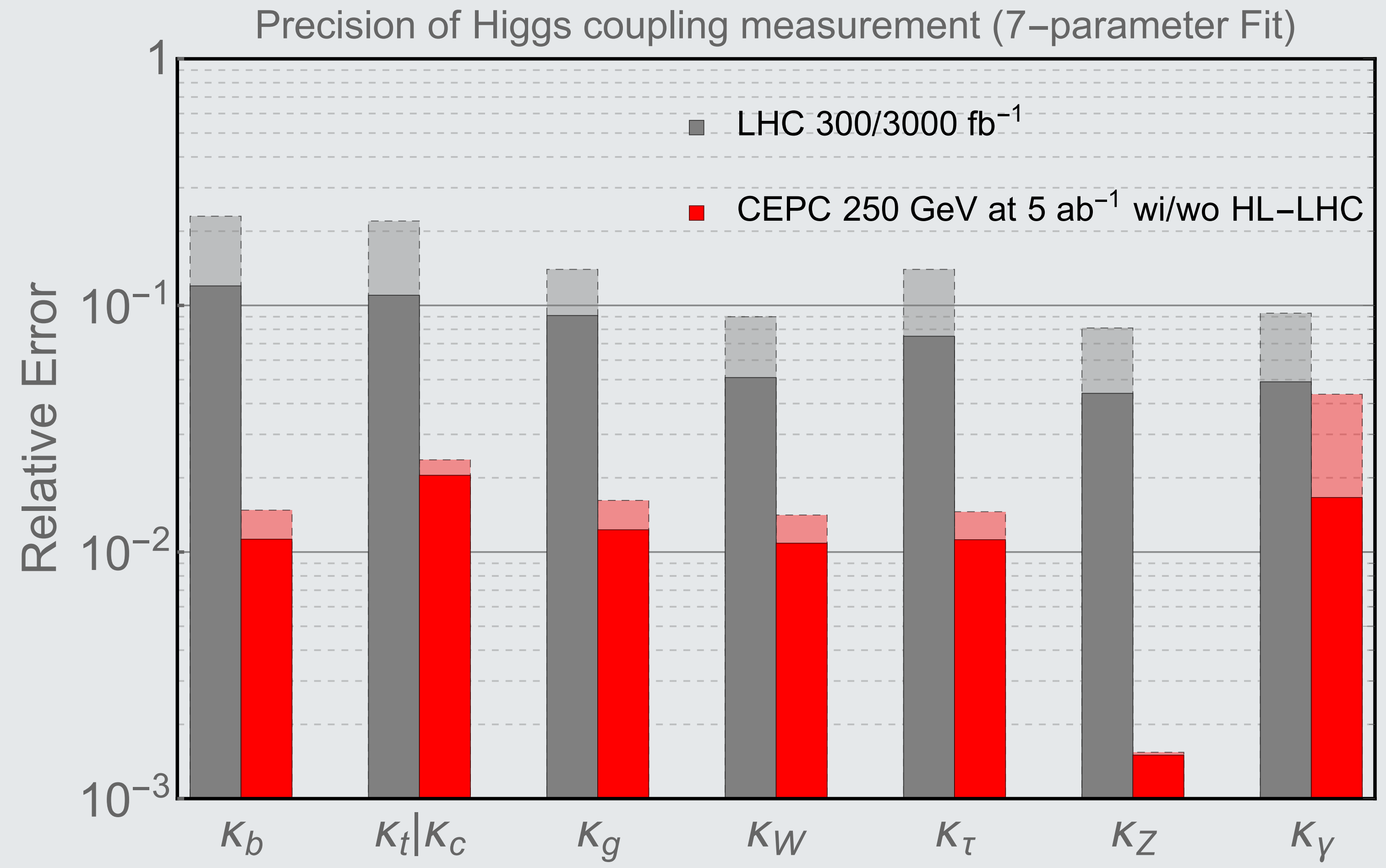
The Physics Goals — Shopping List

Chapter 2
Liantao's talk today

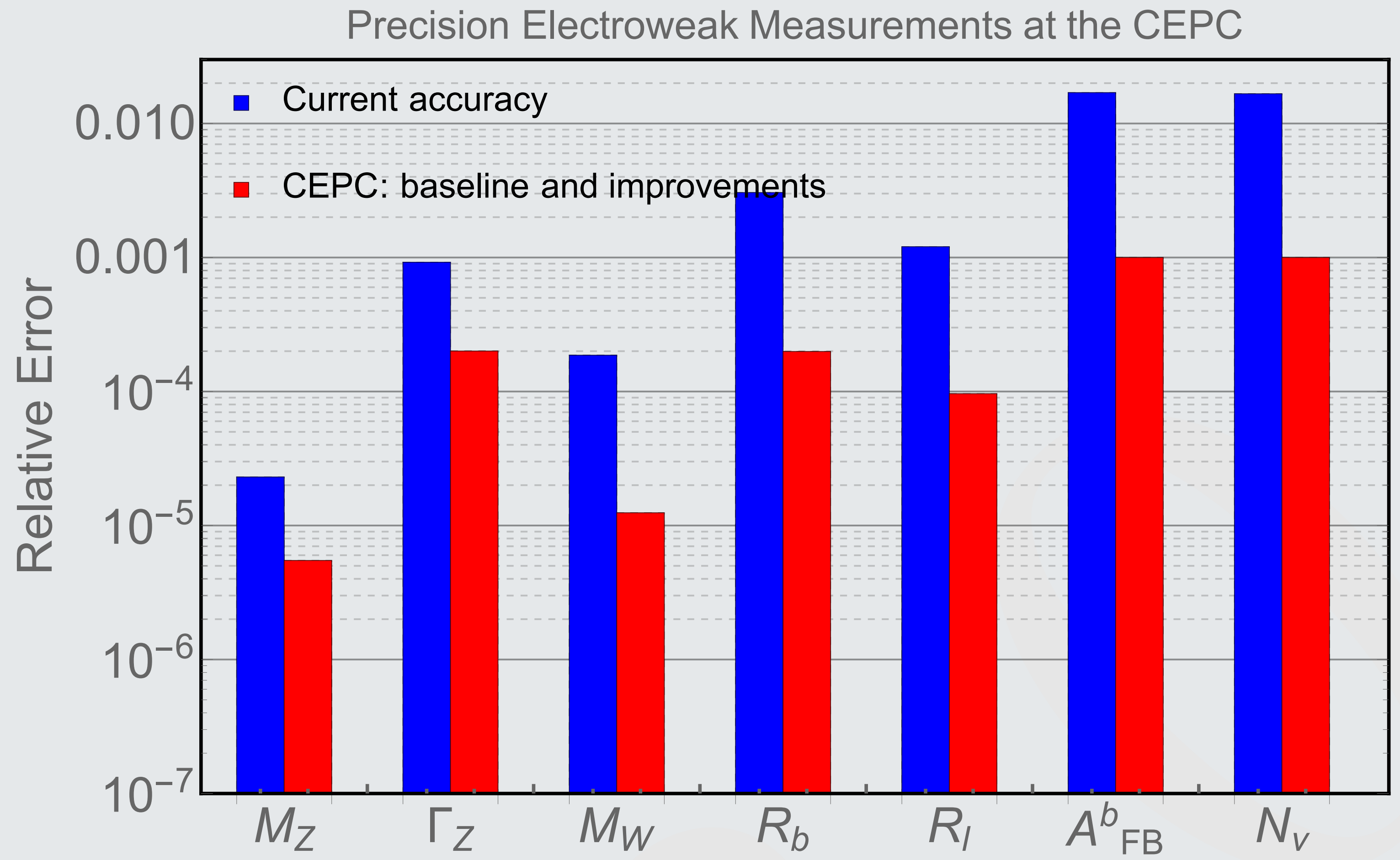
Chapter 11
Jianming and Zhijun's talk on Friday

Including detector performance

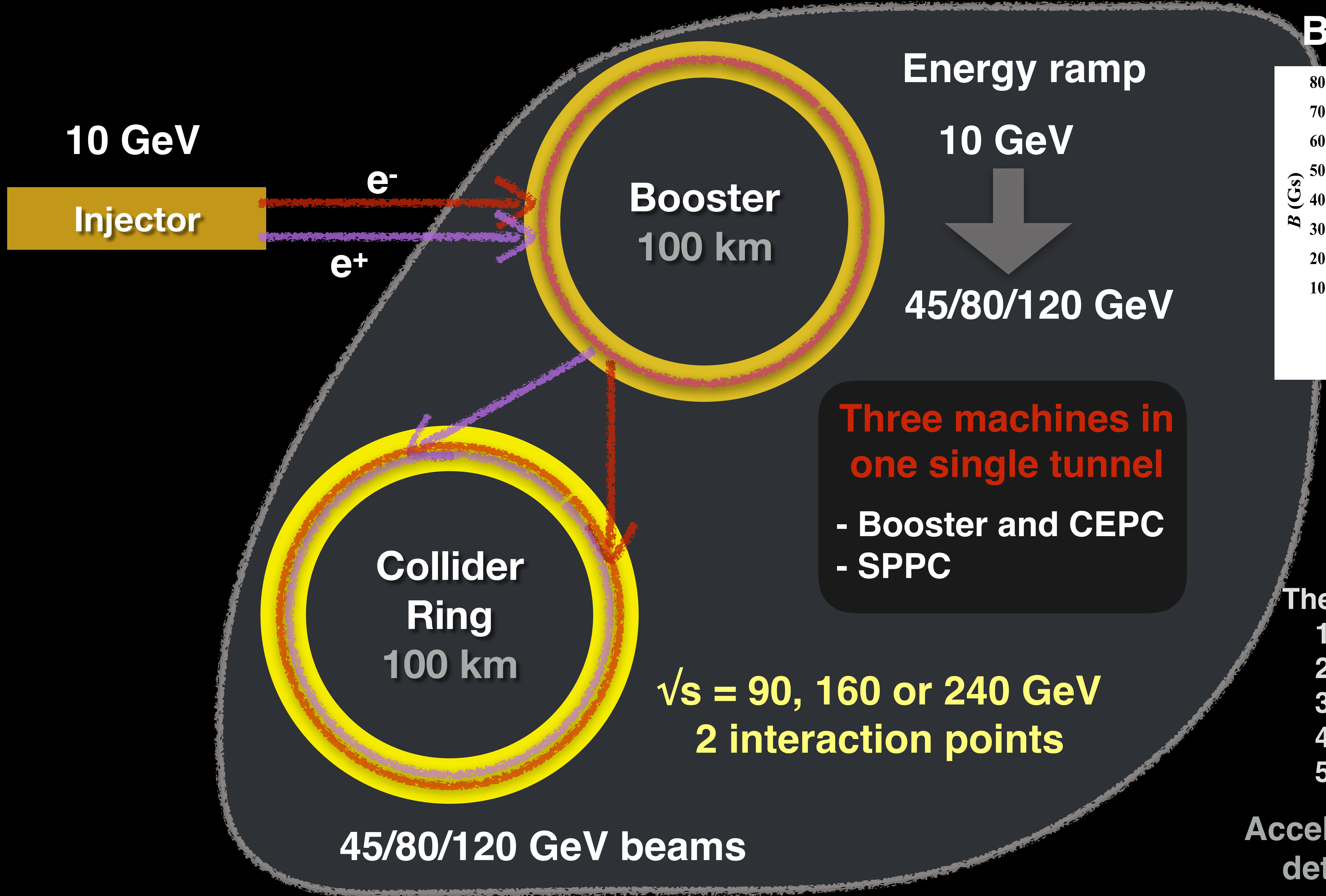
Higgs (HZ run)



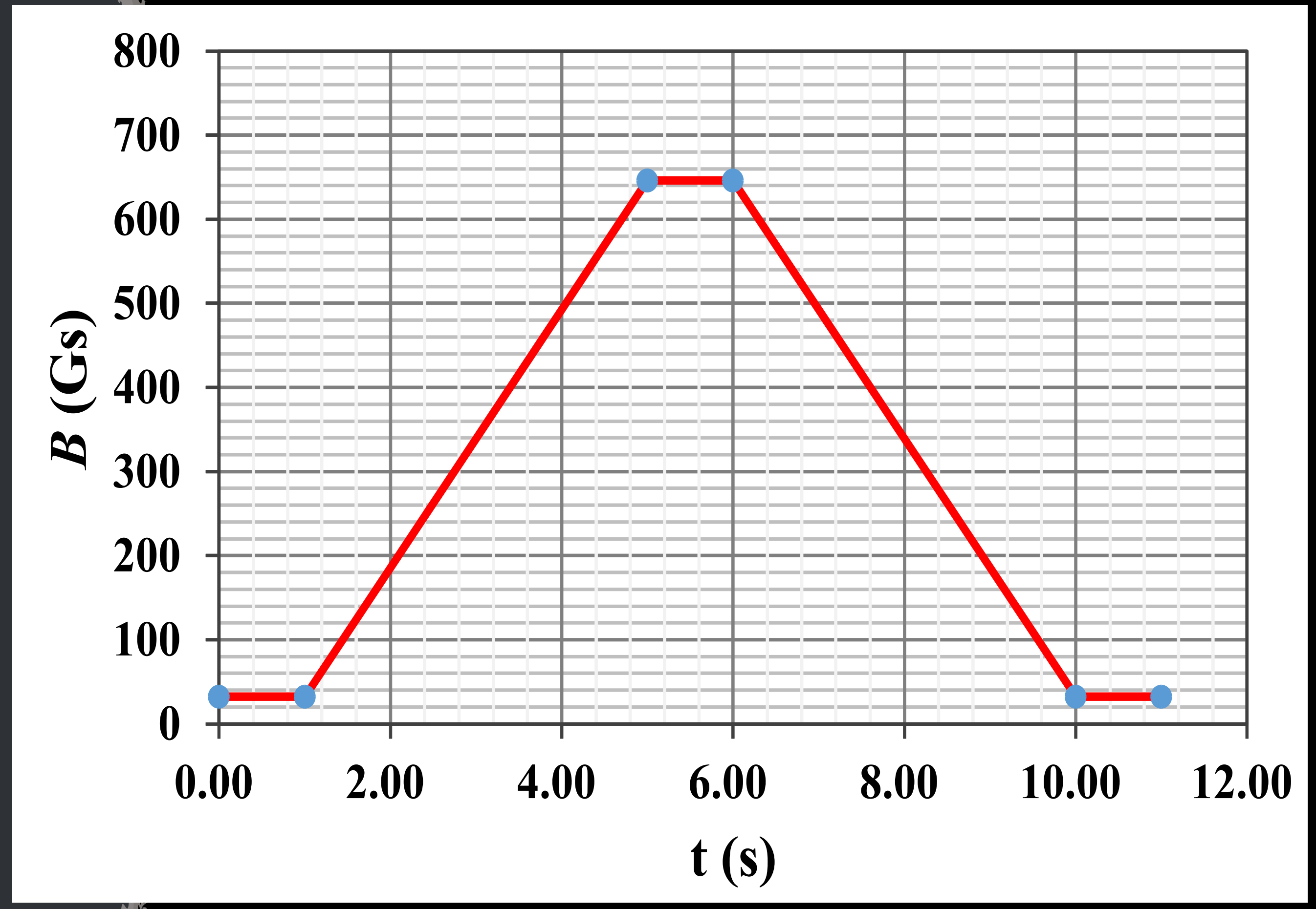
WW + Z runs



CEPC Accelerator Chain and Systems



Booster Cycle (0.1 Hz)



The key systems of CEPC:

1) Linac Injector
2) Booster
3) Collider ring
4) Machine Detector Interface
5) Civil Engineering

Accelerator CDR provides details of all systems

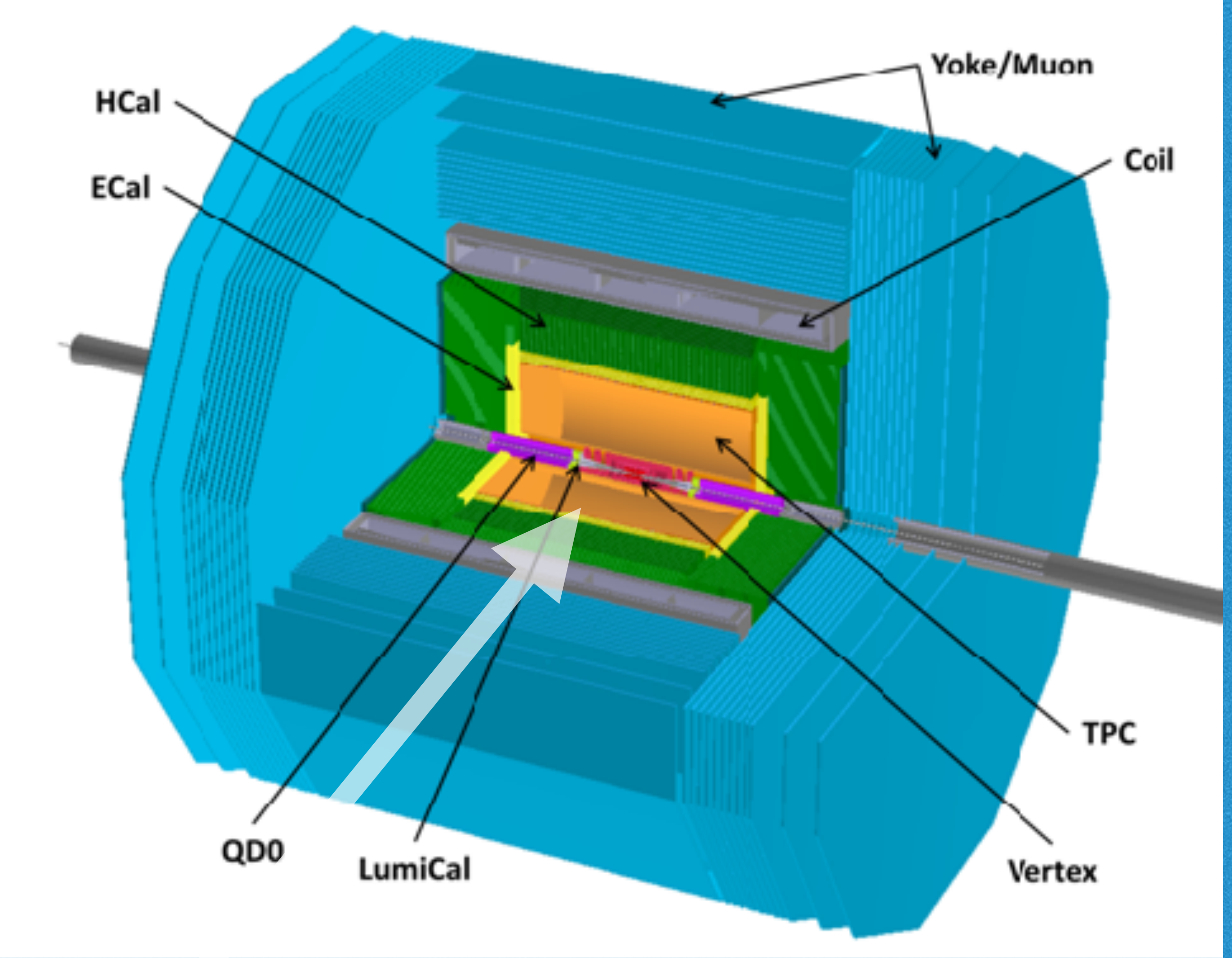
Detector Conceptual Designs

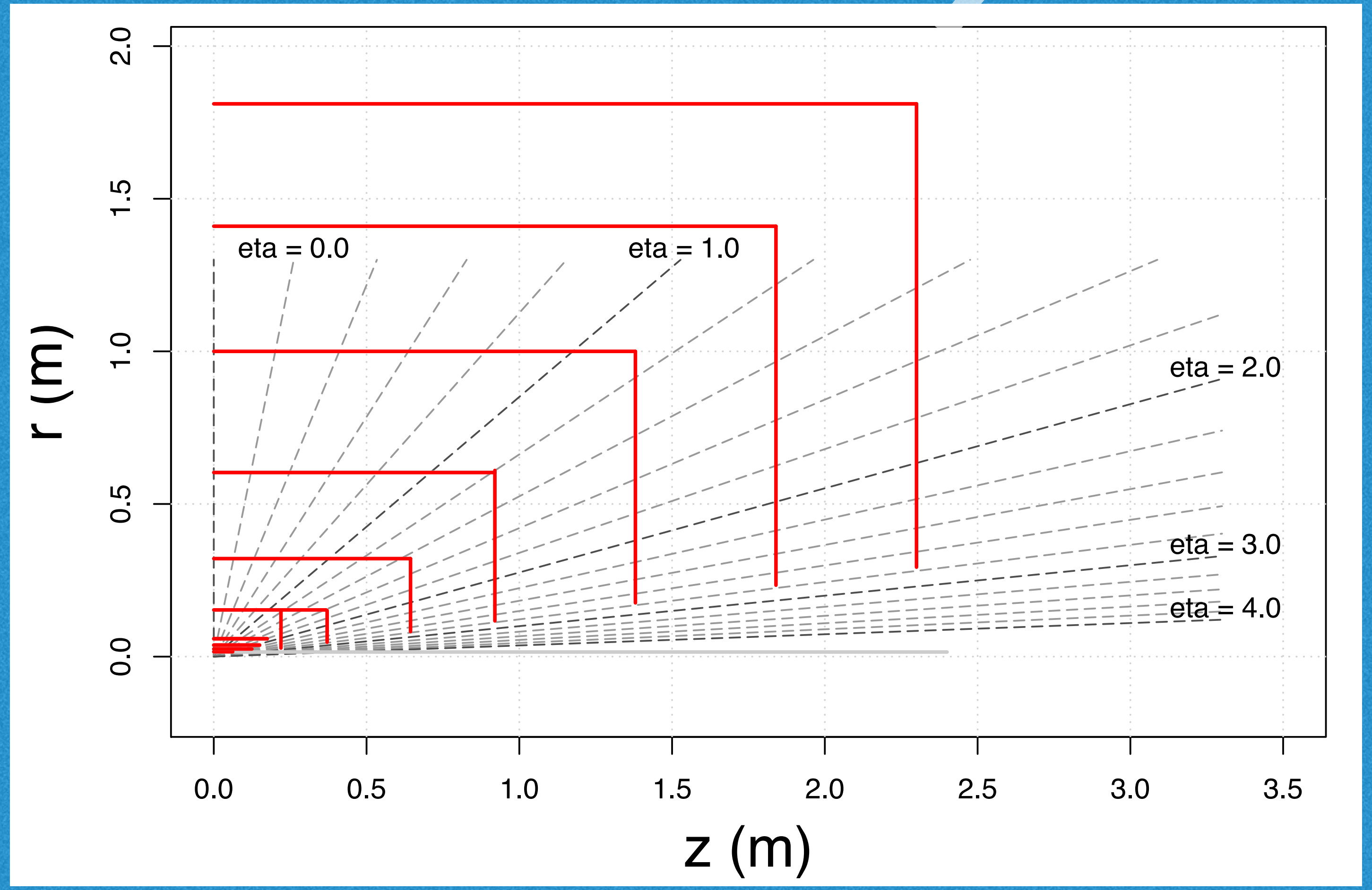
CEPC plans for
2 interaction points

Particle Flow Approach

Baseline detector
ILD-like
(3 Tesla)

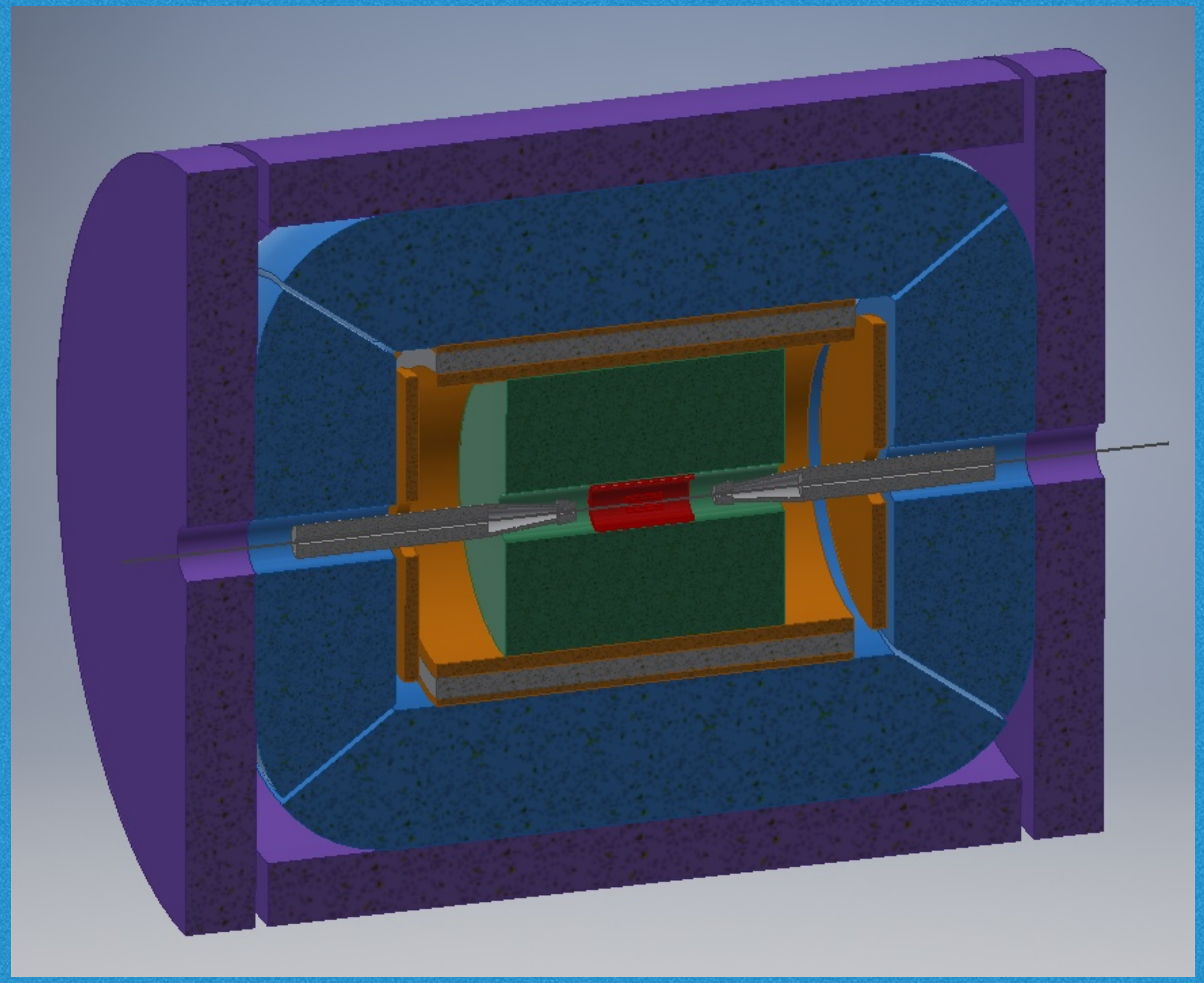
(similar to pre-CDR)





Full silicon tracker concept

Low magnetic field concept
(2 Tesla)



IDEA - also proposed for FCC-ee

Chapter 3
Gang and Franco's talk today

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

Committee Charge

The International Review Committee of the CEPC Physics and Detector Conceptual Design Report (CDR) is to consider the physics program goals of the CEPC and the detector concepts presented.

The committee is asked to assess if the CEPC physics program is well motivated and aligned with the worldwide program for the future of High Energy Physics, and if the detector concepts presented in the CDR, as a whole, are adequate to carry out the physics program, and if there is a sufficient understanding of the detector subsystems to start working towards the TDR and produce detectors on the CEPC timescale. The Committee is requested to suggest mitigating measures in case of potential technological concerns on specific detector subsystems.

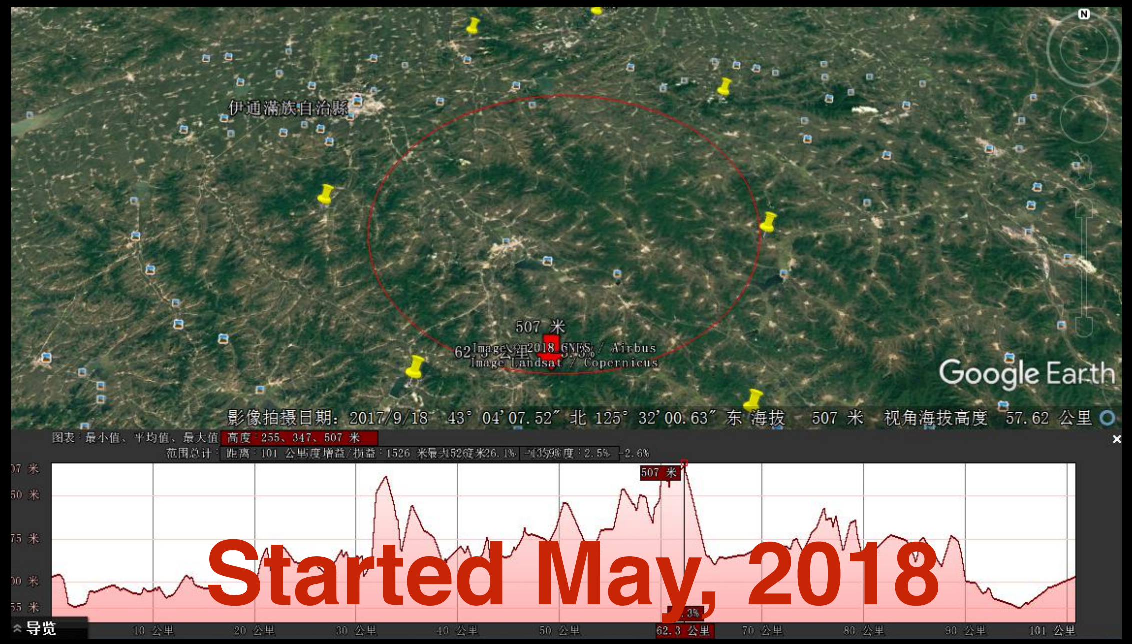
With regard to the site and cost no specific comments are solicited at this time.

The committee is invited to issue comments or suggestions on any aspect of this CDR draft beyond those specifically included in this charge.

It is requested that a committee report responsive to this charge be forwarded to the IHEP Director by September 27, 2018.

Site selection

Chuangchun, Jilin
吉林长春



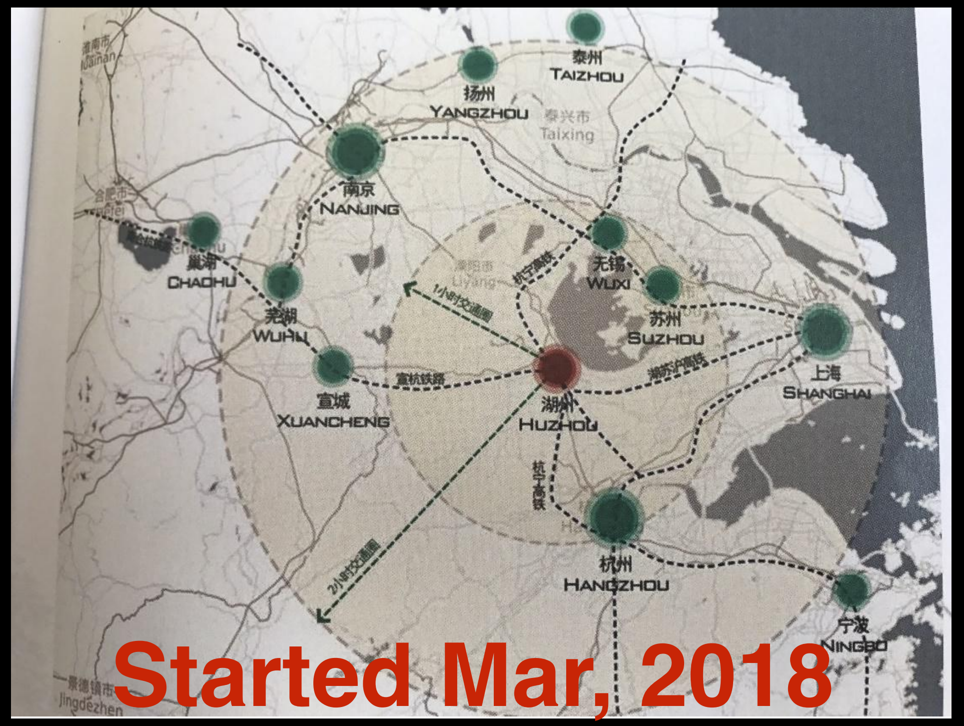
Huangling, Shanxi
陕西黄陵

Qinhuangdao, Hebei
河北秦皇岛

Xiong an, Hebei
河北雄安

Shenshan, Guangdong
深汕合作区

Huzhou, Zhejiang
浙江湖州



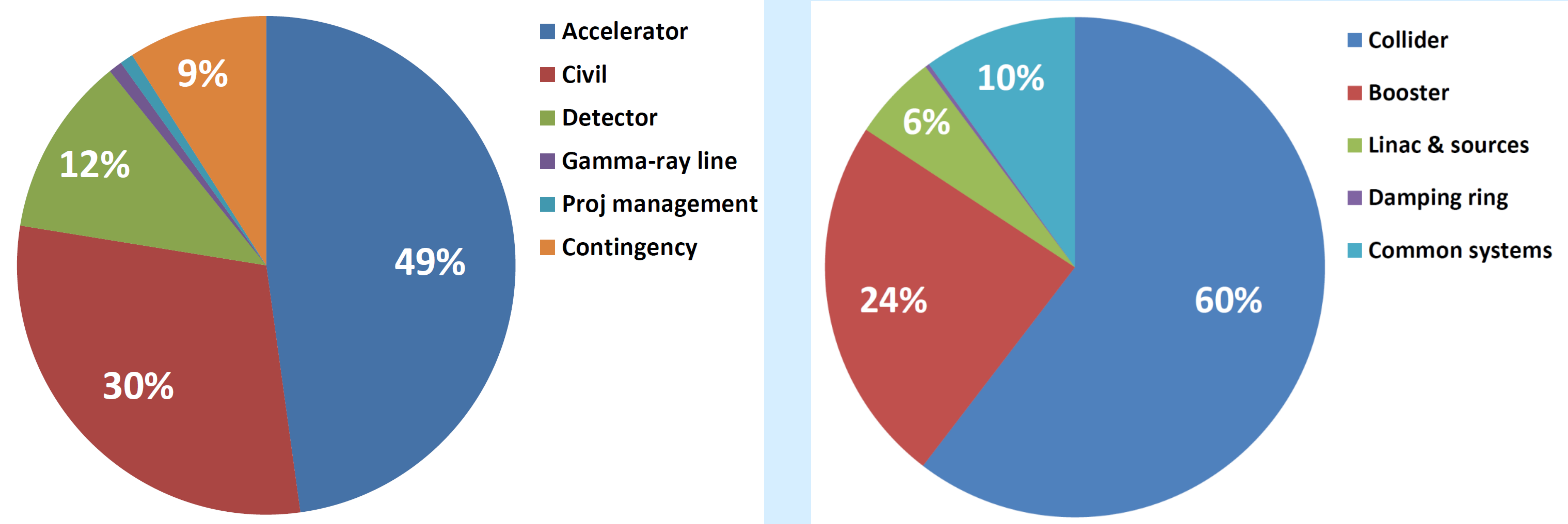
Considerations:
1. Available land
2. Geological conditions
3. Good social, environment, transportation and cultural conditions
4. Fit local development plan: mid-size city → + science city

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



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

CEPC Funding in recent years

IHEP seed money
11 M CNY/3 year (2015-2017)

R&D Funding - NSFC

Increasing support for CEPC D+RDby NSFC
5 projects (2015); 7 projects(2016)

CEPC相关基金名称（2015-2016）	基金类型	负责人	承担单位	
高精度气体径迹探测器及激光校正的研究 (2015)	重点基金	李玉兰/陈元柏	清华大学/高能物理研究所	Tsinghua IHEP
成像型电磁量能器关键技术研究(2016)	重点基金	刘树彬	中国科技大学	USTC
CEPC局部双环对撞区挡板系统设计及螺线管场补偿(2016)	面上基金	白莎	高能物理研究所	IHEP
用于顶点探测器的高分辨、低功耗SOI像素芯片的若干关键问题的研究(2015)	面上基金	卢云鹏	高能物理研究所	
基于粒子流算法的电磁量能器性能研究 (2016)	面上基金	王志刚	高能物理研究所	
基于THGEM探测器的数字量能器的研究(2015)	面上基金	俞伯祥	高能物理研究所	
高粒度量能器上的通用粒子流算法开发(2016)	面上基金	阮曼奇	高能物理研究所	
正离子反馈连续抑制型气体探测器的实验研究(2016)	面上基金	祁辉荣	高能物理研究所	
CEPC对撞区最终聚焦系统的设计研究(2015)	青年基金	王逗	高能物理研究所	
利用耗尽型CPS提高顶点探测器空间分辨精度的研究 (2016)	青年基金	周扬	高能物理研究所	
关于CEPC动力学孔径研究(2016)	青年基金	王毅伟	高能物理研究所	

Ministry of Sciences and Technology

2016: 36 M CNY

国家重点研发计划
项目申报书

项目名称： 高能环形正负电子对撞机相关的物理和关键技术研究
所属专项： 大科学装置前沿研究
指南方向： 高能环形正负电子对撞机预先研究
专业机构： 科学技术部高技术研究发展中心
推荐单位： 教育部
申报单位： 清华大学 （公章）
项目负责人： 高原宁

中华人民共和国科学技术部
2016 年 05 月 06 日

2018: ~31 M CNY

国家重点研发计划
项目申报书

项目名称： 高能环形正负电子对撞机关键技术研发和验证
所属专项： 大科学装置前沿研究
指南方向： 3.1 高能环形正负电子对撞机关键技术验证
专业机构： 科学技术部高技术研究发展中心
推荐单位： 中国科学院
申报单位： 中国科学院高能物理研究所 （公章）
项目负责人： Joao Guimaraes da Costa

中华人民共和国科学技术部
2018 年 02 月 26 日

~60 M CNY CAS-Beijing fund, talent program
~500 M CNY Beijing fund (light source)

Thanks to many different funding sources, CEPC team can carry out CEPC design, key-technology research and site feasibility studies

Funding Support for Detector R&D

Multiple funding sources

- Ministry 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

CEPC Workshops and international impact

Many international events have been hosted to discuss CEPC physics and carry out collaboration on key-technology research

260 attendees

30% from foreign institutions

55% attendance from abroad

Agenda

Thursday, 13 September 2018

08:30 - 09:00	Committee Executive Session		
09:00 - 13:30	Session 1		
	09:00	**Welcome** *5'*	
	09:05	**Overview of detector CDR (15'+10')** *25'*	Speaker: Joao Guimaraes Costa
	09:30	**Ch2: Physics Motivation (30'+20')** *50'*	Speaker: Liantao Wang (University of Chicago)
	10:20	**Coffee Break** *30'*	
	10:50	**Accelerator Overview (20'+15')** *35'*	Speaker: Dr. Yuan Zhang (IHEP, Beijing)
	11:25	**Ch 3: Physics Requirements and PFA Detector Concepts** *15'*	Speakers: LI Gang (EPC.IHEP), Dr. Gang LI (EPD, IHEP, CAS)
	11:40	**Ch 3: Alternative concept: IDEA** *10'*	Speakers: Franco Bedeschi (I), Franco Bedeschi (I)
	11:50	**Ch 3: Discussion** *20'*	
	12:10	**Lunch Box** *1h20'*	
13:30 - 16:00	Session 2		
	13:30	**Ch 9: MDI and beam backgrounds and luminosity (25'+20')** *45'*	Speakers: Dr. Hongbo ZHU (IHEP), Suen Hou (SINICA)
	14:15	**Ch 4.1: Vertex (20'+20')** *40'*	Speaker: Prof. Qun OUYANG (IHEP)
	14:55	**Ch 4.2.1: TPC (20'+20')** *40'*	Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
	15:35	**Coffee Break** *25'*	
16:00 - 16:30	Discussion with CEPC team *30'*		
16:30 - 18:00	Committee Executive Session		
18:00 - 20:00	Dinner(Committee only)		

Friday, 14 September 2018

08:30 - 10:40	Session 2: Continue		
	08:30	**Ch 4.2.2: Silicon (15'+15')** *30'*	Speaker: Prof. Meng Wang (Shandong University)
	09:00	**Ch 4.3: Full Silicon (15'+15')** *30'*	Speaker: Chengdong FU (IHEP)
	09:30	**Ch 4.4: Drift Chamber (20'+20')** *40'*	Speaker: Francesco Grancagnolo (INFN-Lecce)
	10:10	**Coffee Break** *30'*	
10:40 - 14:10	Session 3		
	10:40	**Ch 5.3: ECAL (20'+20')** *40'*	Speaker: Dr. Jianbei Liu (University of Science and Technology of China)
	11:20	**Ch 5.4: HCAL (20'+20')** *40'*	Speaker: Haijun Yang (Shanghai Jiao Tong University)
	12:00	**Lunch Box** *1h30'*	
	13:30	**Ch 5.5: Dual-Readout (20'+20')** *40'*	Speaker: Franco Bedeschi (I)
14:10 - 16:30	Session 4		
	14:10	**Ch 6: Magnet (20'+20')** *40'*	Speaker: Ms. Wei Zhao (IHEP)
	14:50	**Ch 7: Muon (25'+20')** *45'*	Speakers: Prof. Liang Li (Shanghai Jiao Tong University), Paolo Giacomel
	15:35	**Coffee Break** *20'*	
	15:55	**Ch 8: DAQ (15'+20')** *35'*	Speaker: Mr. Fei Li (IHEP, CAS, China)
16:30 - 17:10	Discussion with CEPC team *40'*		
17:10 - 18:10	Committee Executive Session		
18:10 - 20:10	Banquet(With CEPC team)		

Agenda

Saturday, 15 September 2018

09:00 - 10:55	Session 5	
	09:00	**Ch 10: Physics performance (20'+20')** *40'* Speaker: Mr. Manqi Ruan (IHEP)
	09:40	**Ch 11: Physics Analysis (25'+20')** *45'* Speakers: Jianming Qian (University of Michigan), Prof. Zhijun Liang (IHEP), Prof. Yaquan FANG Yaquan (IHEP)
	10:25	**Coffee Break** *30'*
10:55 - 11:25	Discussion with CEPC team *30'*	
11:25 - 12:00	Committee Executive Session	
12:00 - 13:30	Lunch Box	
13:30 - 16:00	Committee Executive Session	
16:00 - 16:30	Coffee Break	
16:30 - 17:30	Summary *1h0'*	

adjourn

Final remarks

* Detector designs at conceptual level, addressing potential drawbacks
  * Further R&D required towards TDR
  * Funding adequate for R&D but need to expand international collaboration

* Need to know if there are major technological road blocks that will prevents us from extracting the physics from CEPC

* International Collaborations with be formed in the coming years

* Next milestone: 2022 — CEPC TDR

Looking forward to you comments

CDR Contents – Draft v3.0

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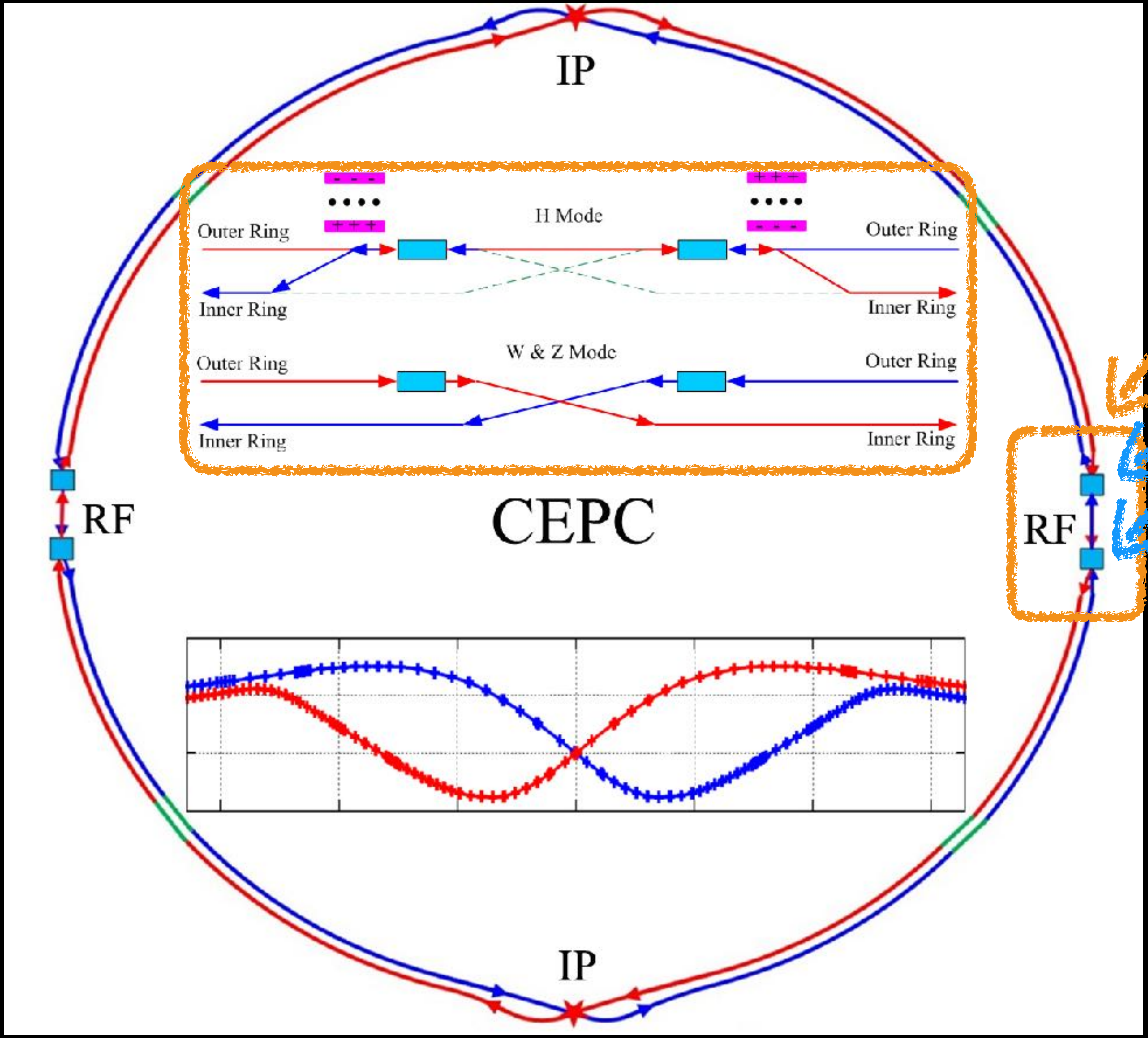
The CEPC Baseline Collider Design



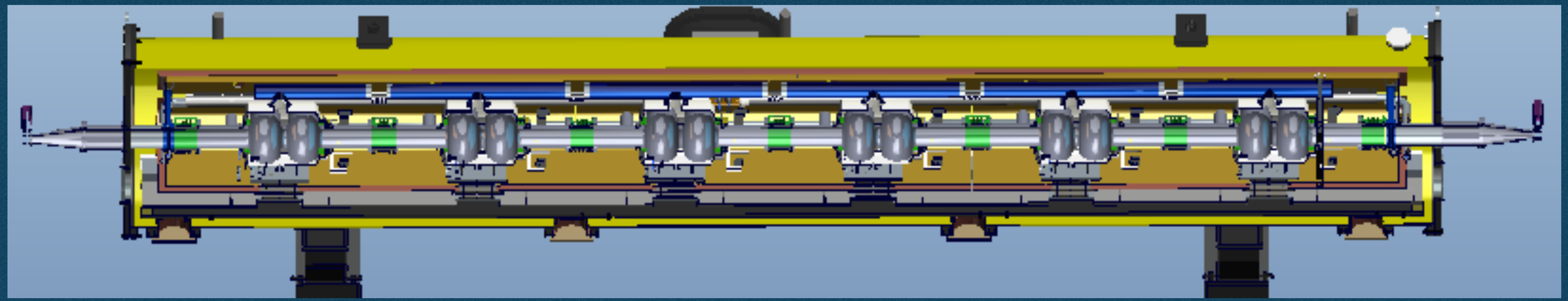
Double ring

Common RF cavities for Higgs

Two RF sections in total

Two RF stations per RF section

10 x 2 = 20 cryomodules

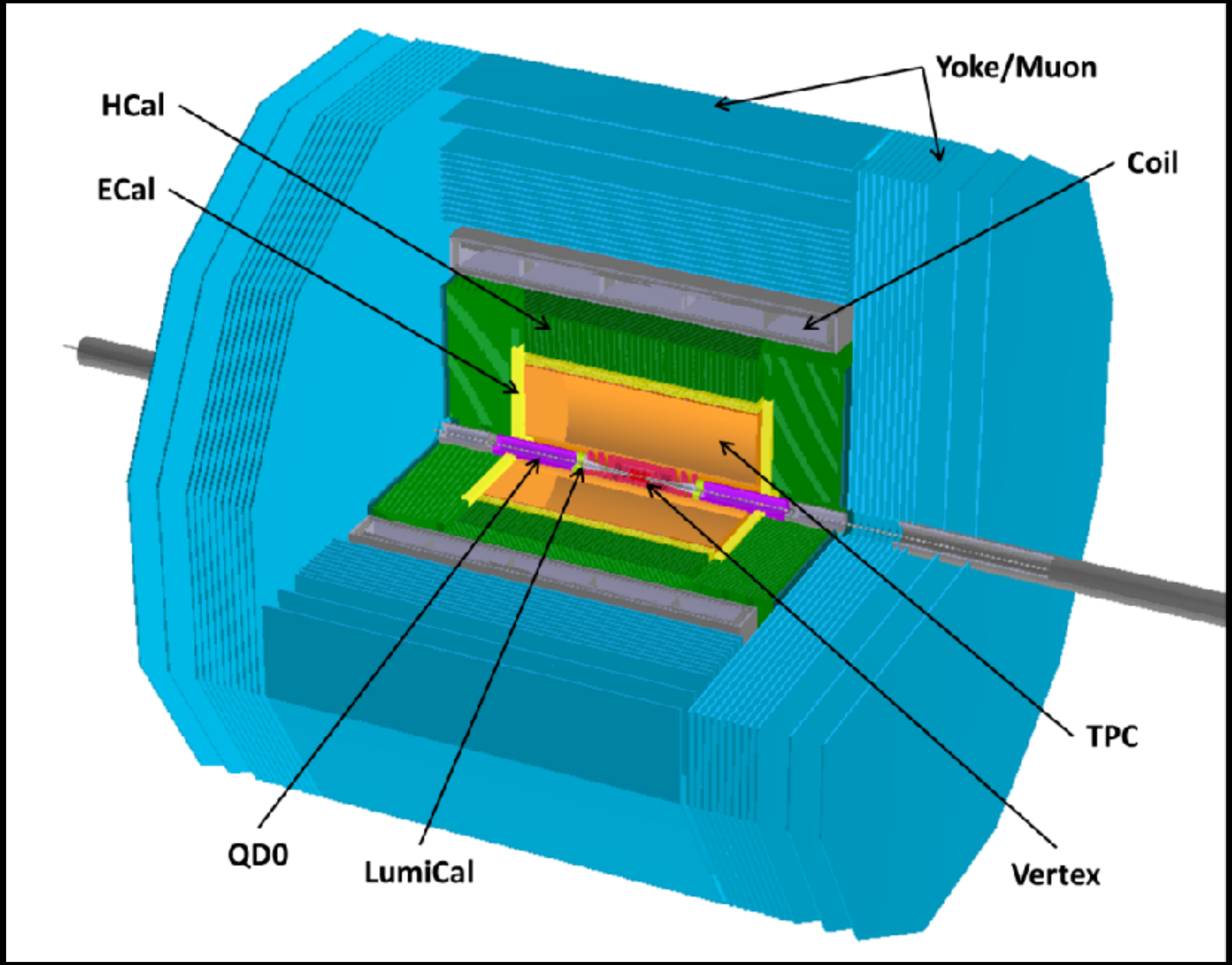


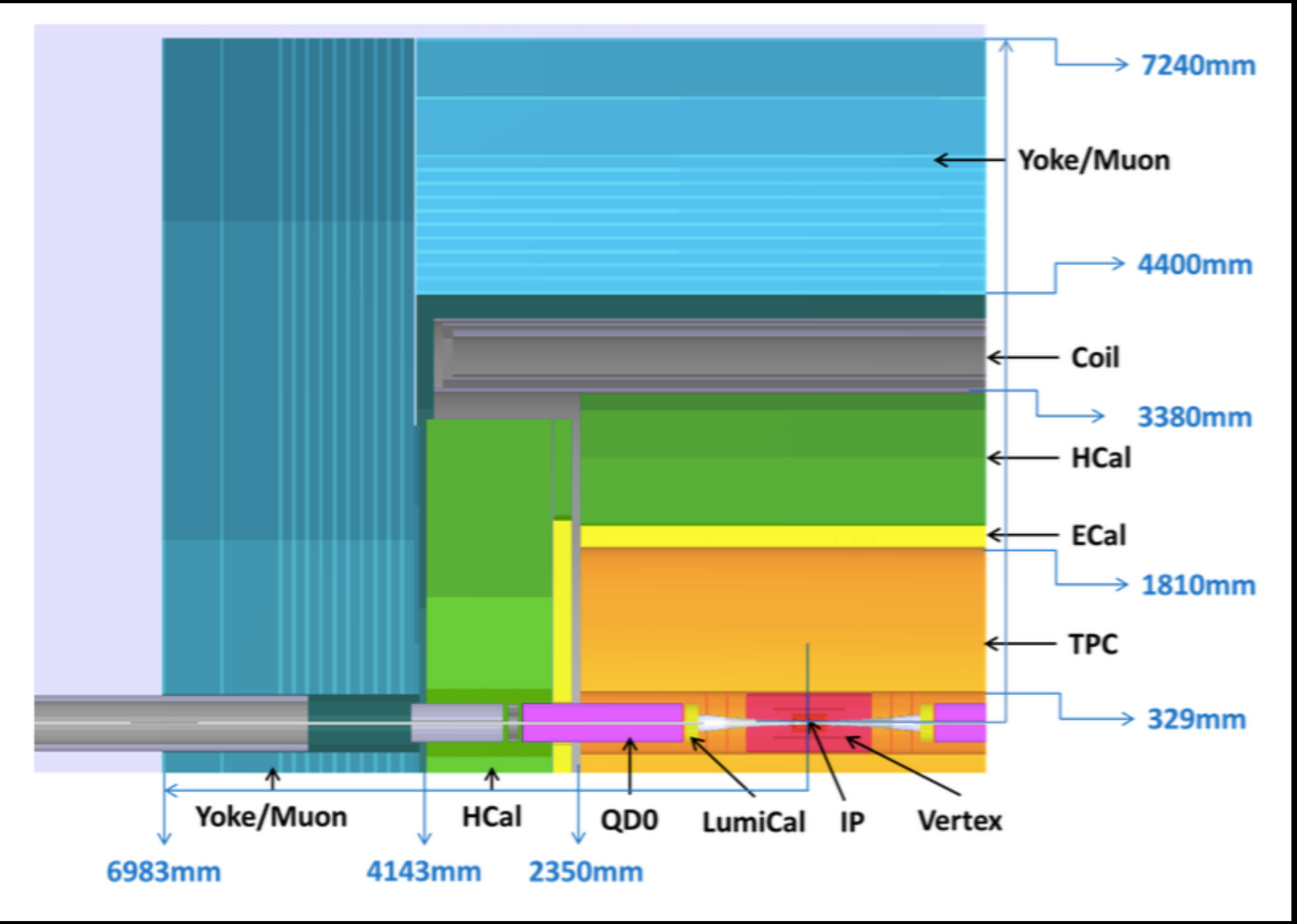
6 2-cell cavities per cryomodule

Main Parameters of Collider Ring

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Center-of-mass energy (GeV)	240	160	91	
Crossing angle at IP (mrad)	16.5×2			
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Beam size at IP σ_x / σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Bunch length σ_z (mm)	3.26	5.9	8.5	
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

CEPC baseline detector: ILD-like





Magnetic Field: 3 Tesla — changed from preCDR

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

CEPC baseline detector: ILD-like: Design Considerations

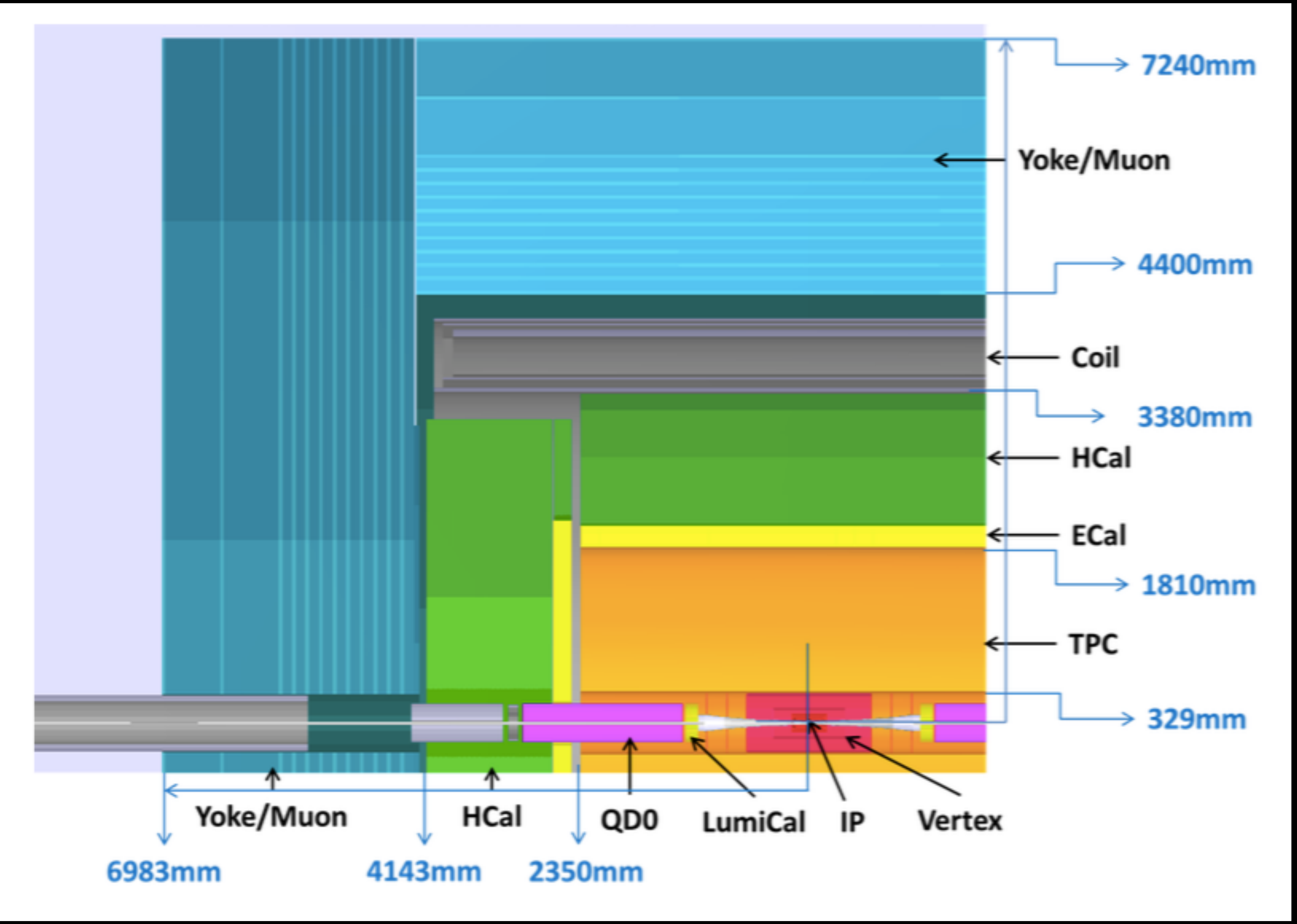
Major concerns being addressed

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

2. Low-material Inner Tracker design

3. TPC as tracker in high-luminosity Z-pole scenario

4. ECAL/HCAL granularity needs
Passive versus active cooling



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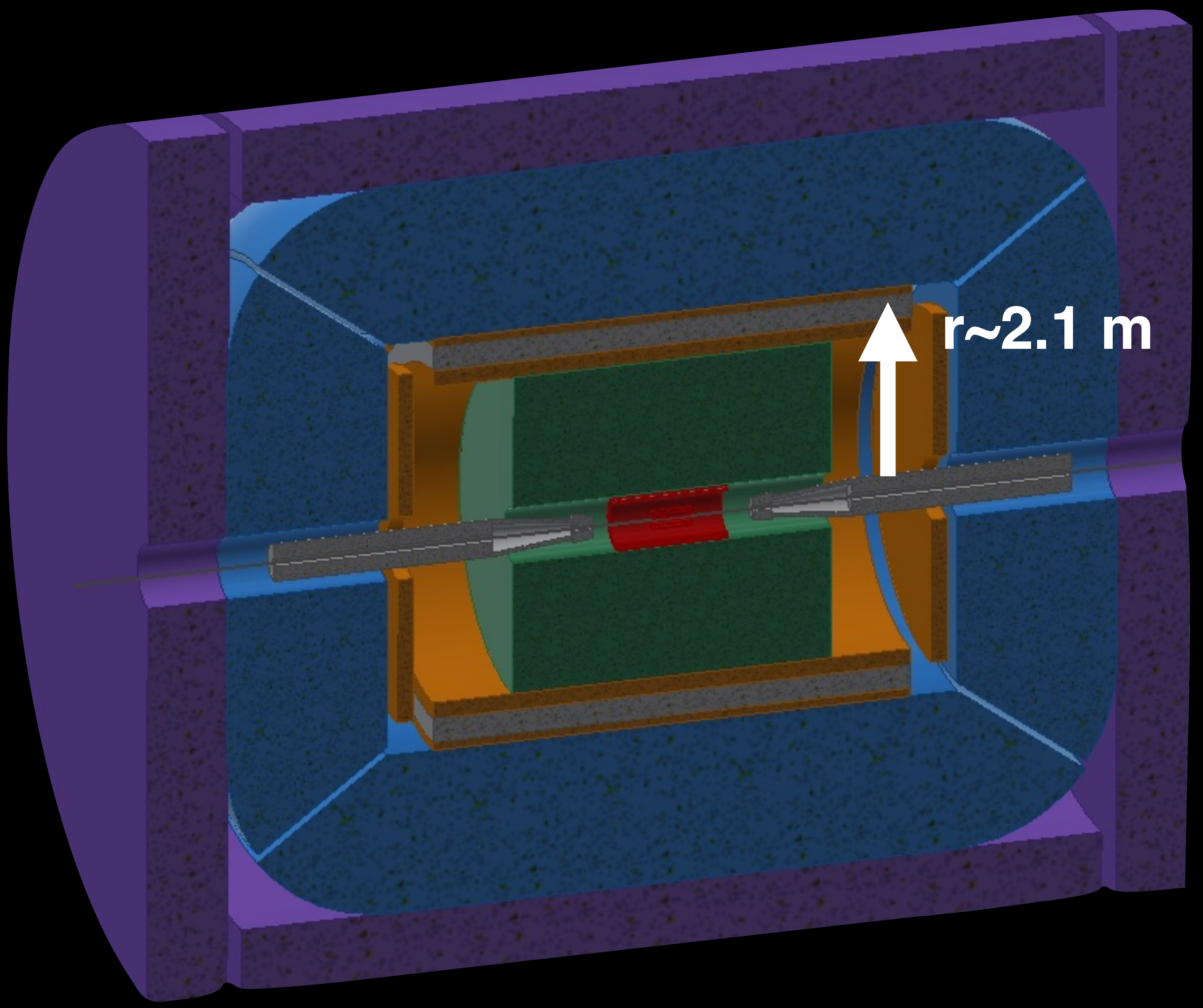
Low magnetic field detector concept

Proposed by INFN, Italy colleagues



Similar to Concept Detector for FCC-ee

Collaboration with China

Magnet: 2 Tesla, 2.1 m radius

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

Vertex: Similar to CEPC default

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

Preshower: ~1 X_0

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

*** (yoke) muon chambers**

Integrated test beam
September 2018
Looking for helpers

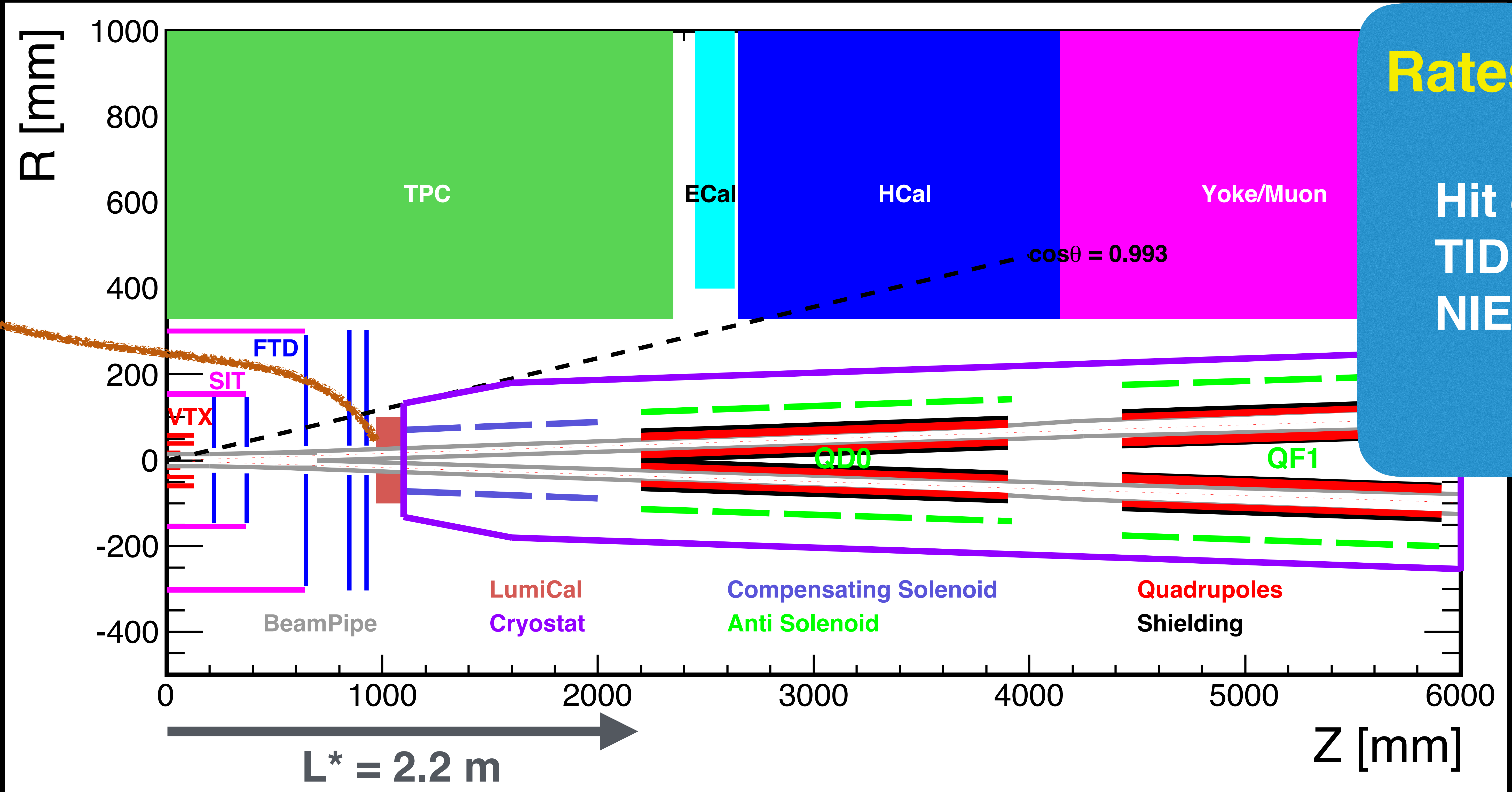
Interaction region: Machine Detector Interface

One of the most complicated issue in the CEPC detector design

Full partial double ring

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

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



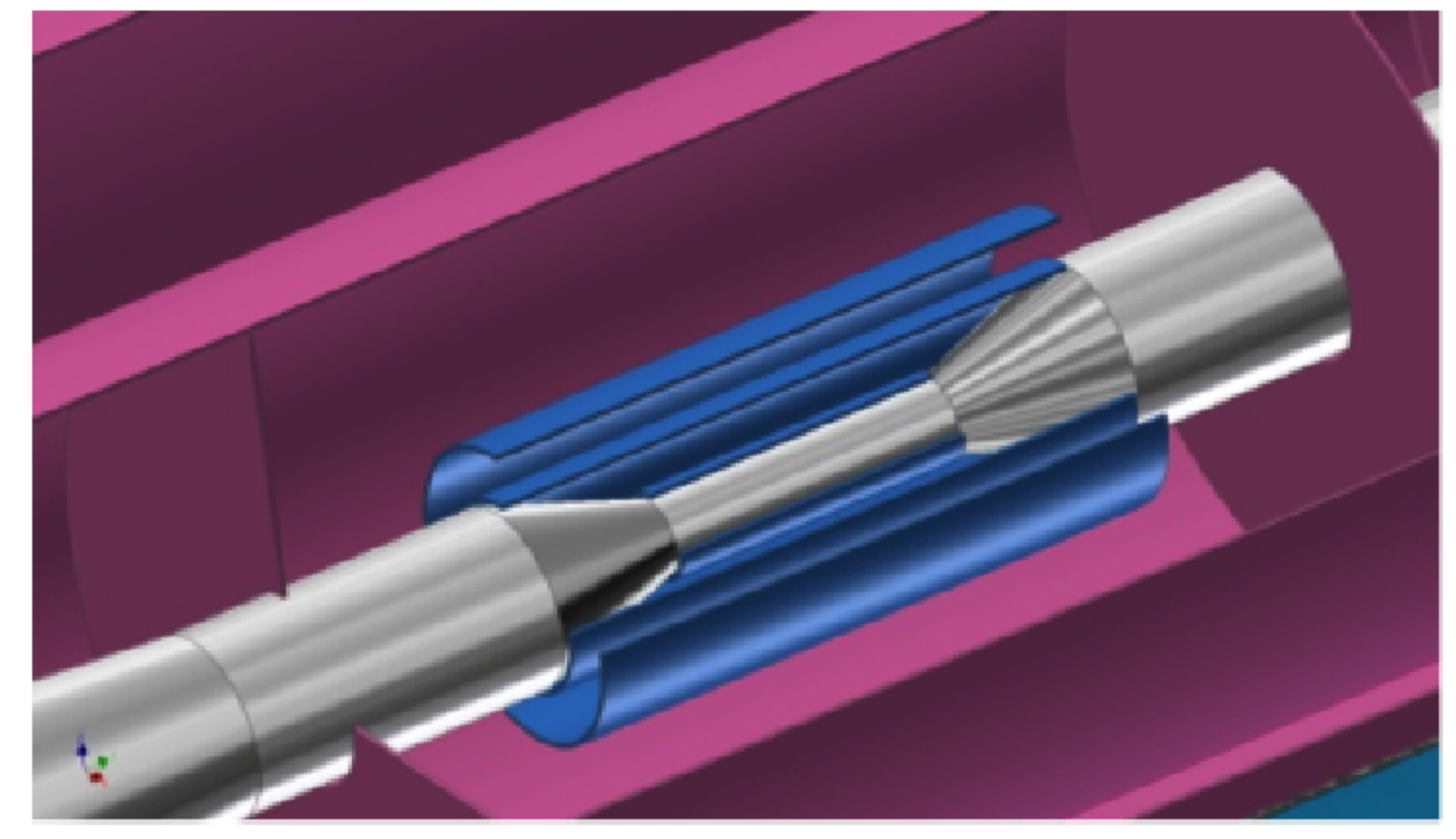
Rates at the inner layer (16 mm):
- Hit density: ~2.5 hits/cm²/BX
- TID: 2.5 MRad/year
- NIEL: 10^{12} 1MeV n_{eq}/cm²

(Safety factors of 10 applied)

Challenging engineering design

Baseline Pixel Detector Layout

3-layers of double-sided pixel sensors

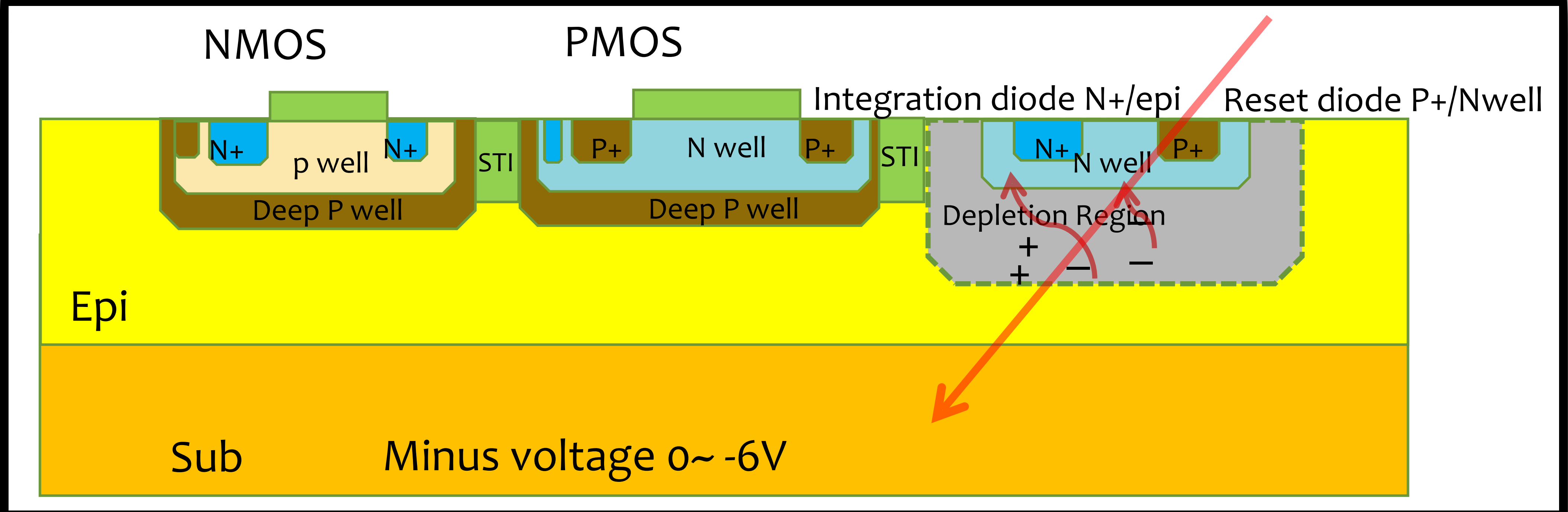


- ILD-like layout
- Innermost layer: σ_{SP} = 2.8 μm
- Polar angle θ ~ 15 degrees
- Material budget ≤ 0.15%X_0/layer

Implemented in GEANT4 simulation framework (MOKKA)

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

CMOS pixel sensor (MAPS)

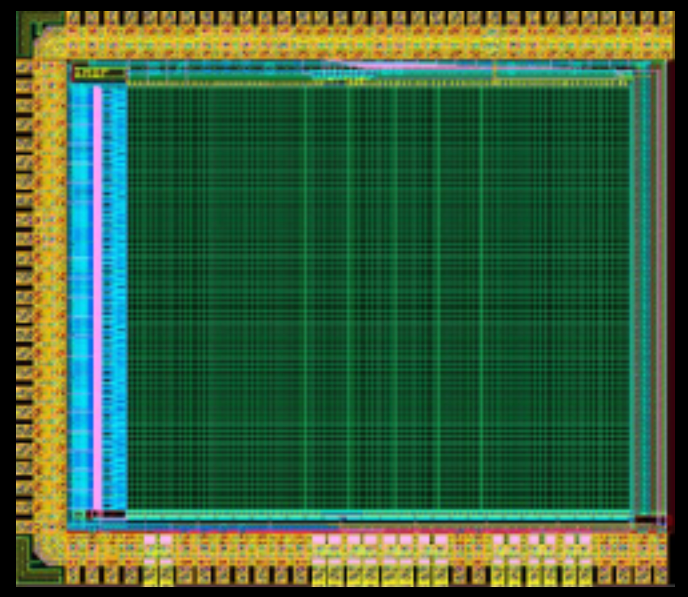


Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process:
- low material budget,
- low power consumption,
- low cost …

Current R&D activities

- Initial sensor R&D targeting:

	Specs	Observations
Single point resolution near IP:	< 3-5 μm	Need improvement
Power consumption:	< 100 mW/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



- 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

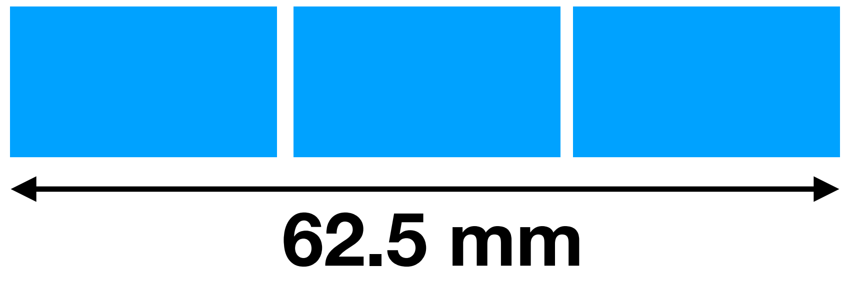
- Institutions: CCNU, NWTU, Shandong, Huazhong Universities and IHEP (IPHC in Strasbourg, KEK)
- New project: Full size CMOS sensor for use in real size prototype

Silicon Vertex Detector Prototype – MOST (2018–2023)

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

Double sided ladder

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



3 X 2 layer = 6 chips

Double sided ladder

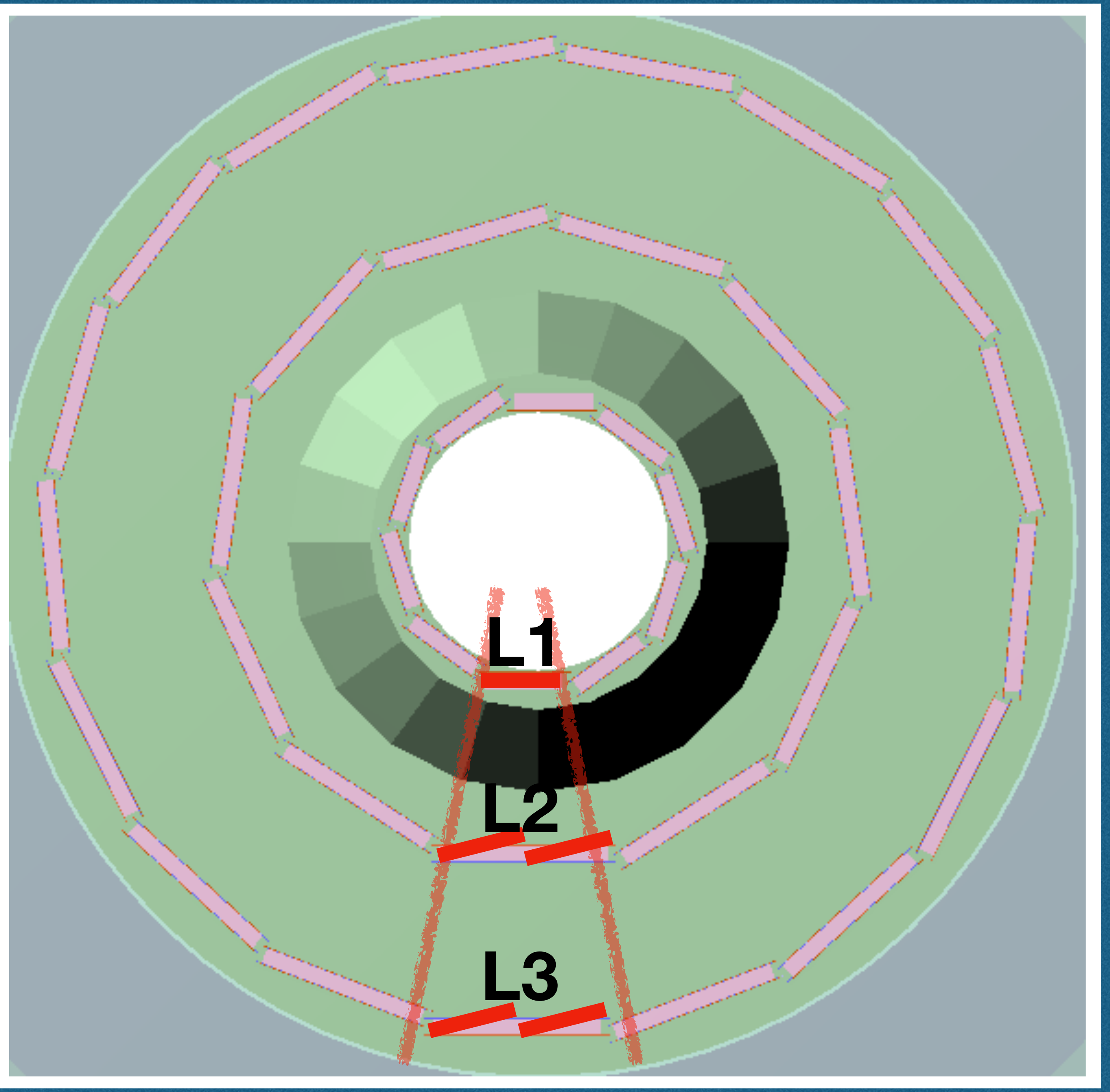
Layers 2 and 3 (22 mm x 125 mm)
Chip size: 11 mm X 20.8 mm

6 X 2 layer = 12 chips

Mechanical prototype

with subset of ladders instrumented/readout

Requires study/simulation of new layout



Minimal goals:

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

Integrated electronics readout

Design and produce light and rigid support structures

Extended goals if manpower and support available

International Collaboration

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

Silicon Tracker Detector – Baseline

SET: r = ~1.8 m

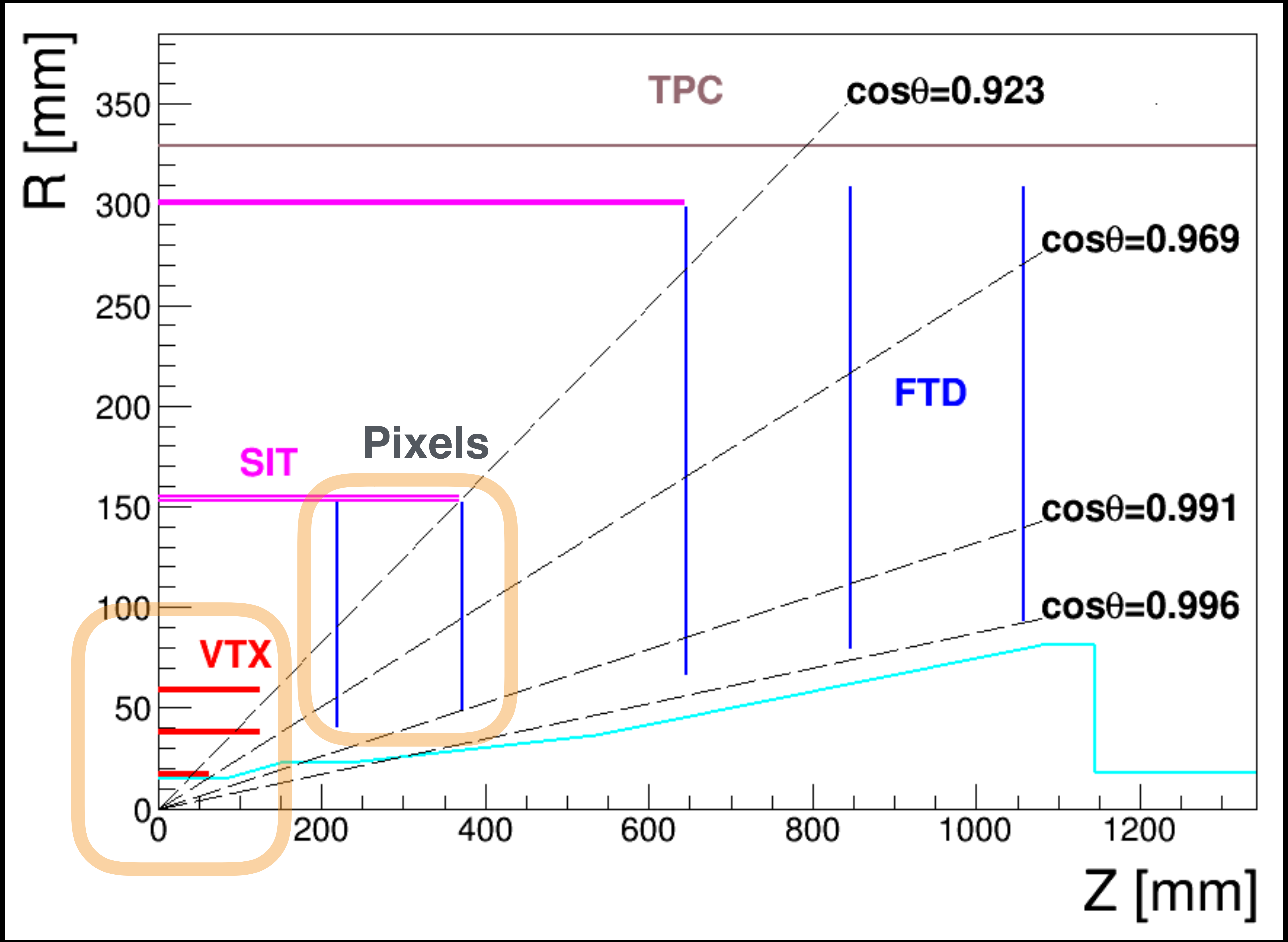
Not much R&D done so far

TPC

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

SIT

VTX



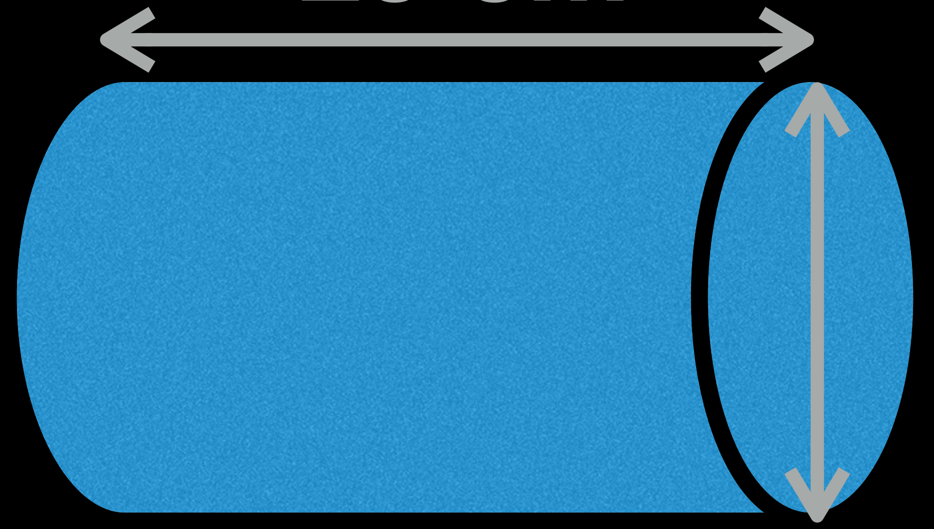
Sensor technology

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

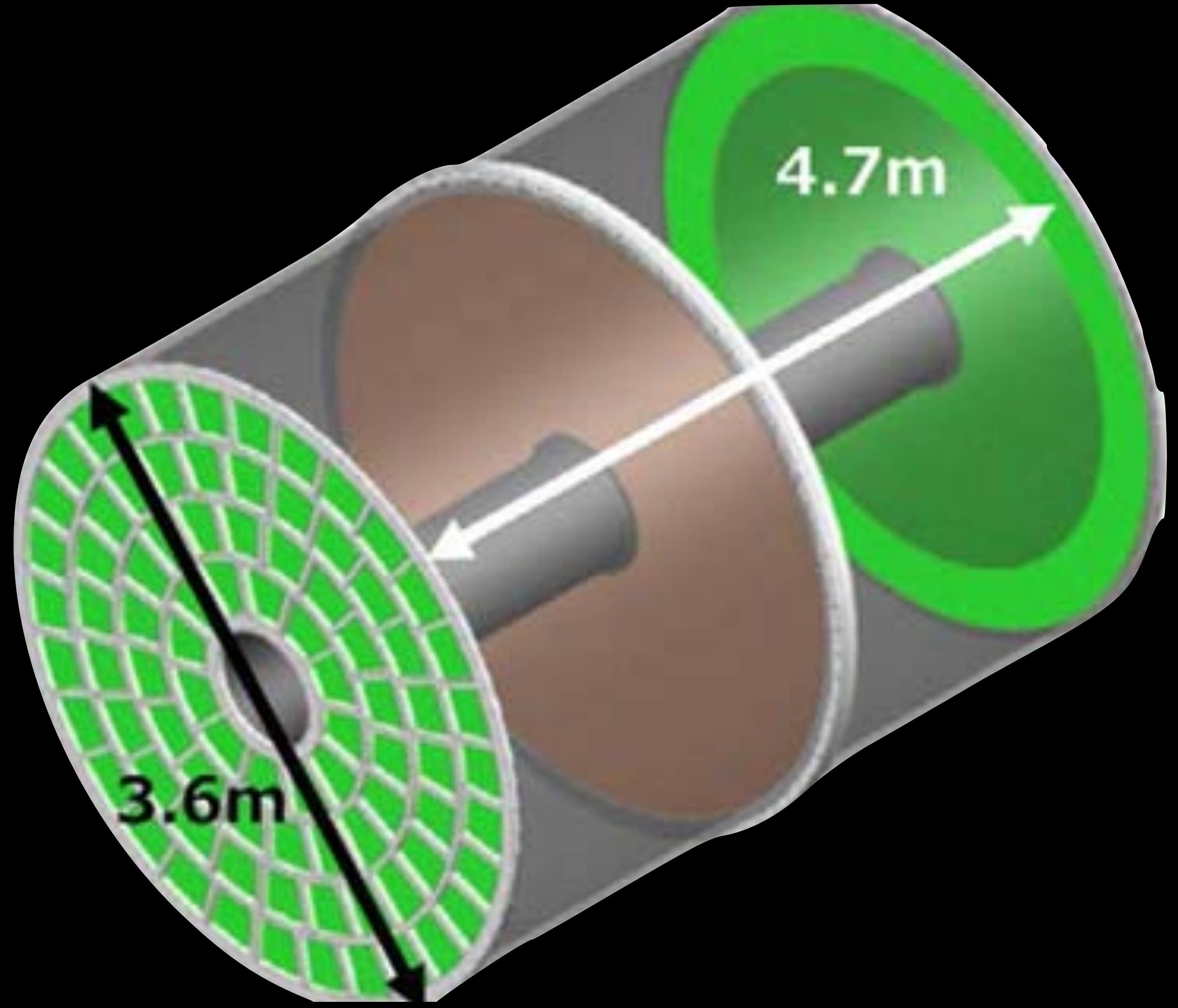
Extensive opportunities for international participation

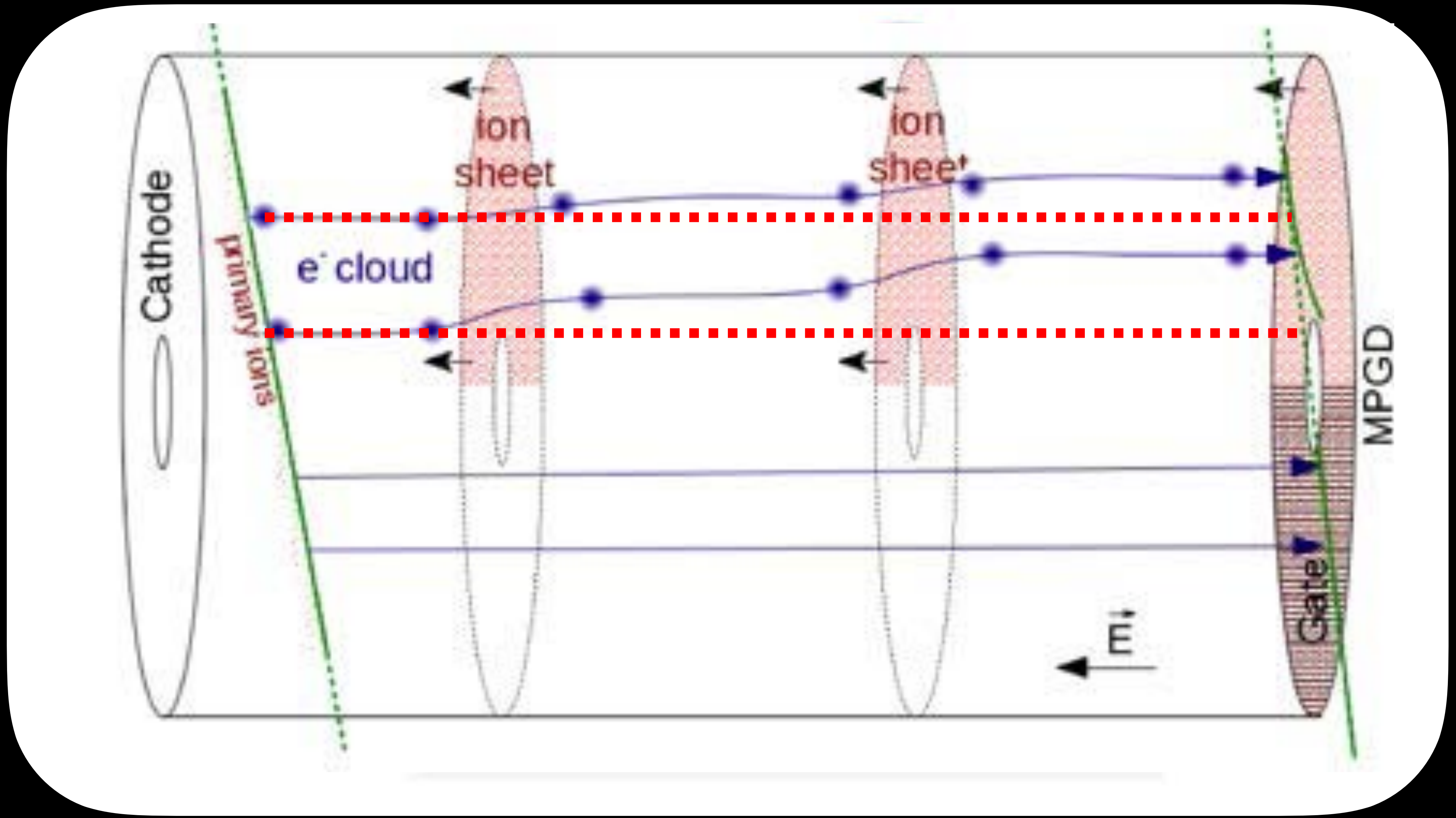
Time Projection Chamber (TPC)

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

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

TPC detector concept





Prototype built

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

Drift Chamber Option – IDEA proposal

Lead by Italian Colleagues

Low-mass cylindrical drift chamber

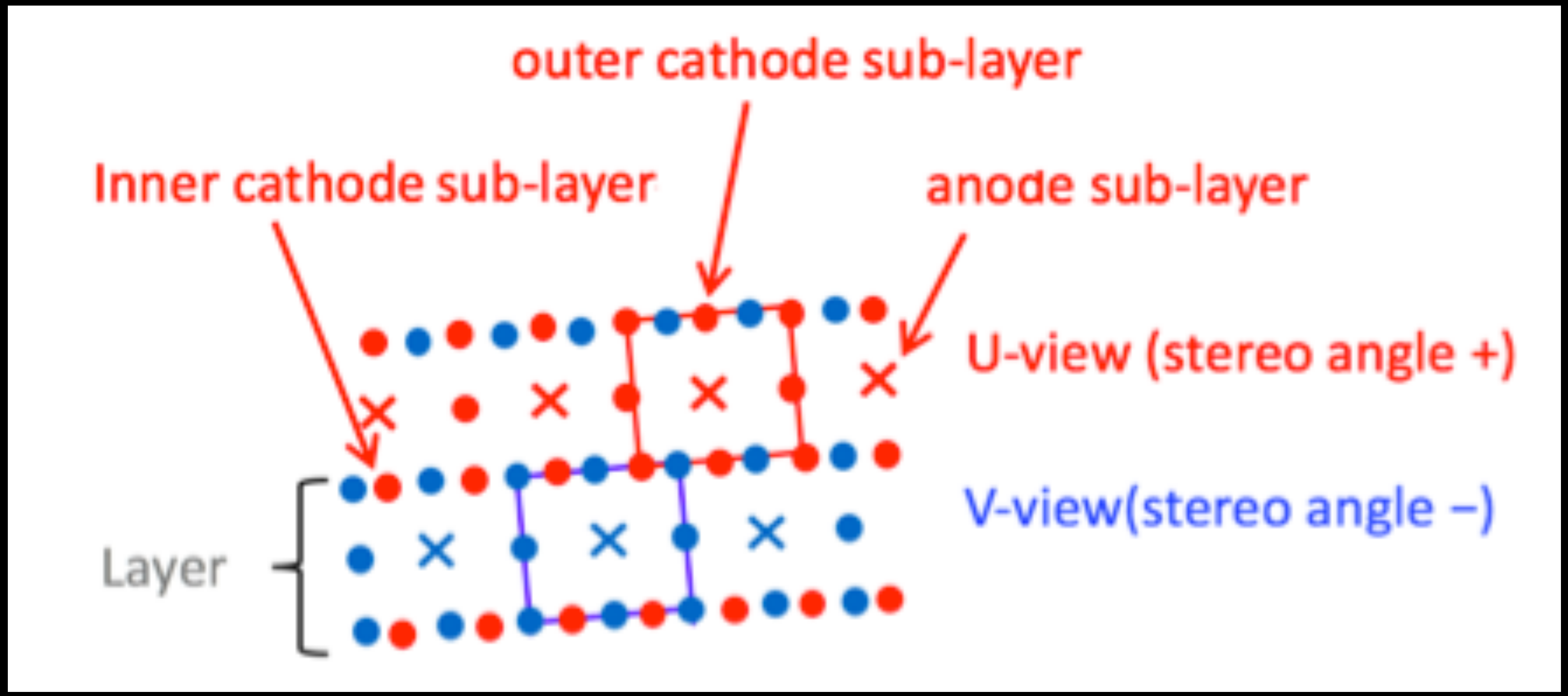
Follows design of the KLOE and MEG2 experiments

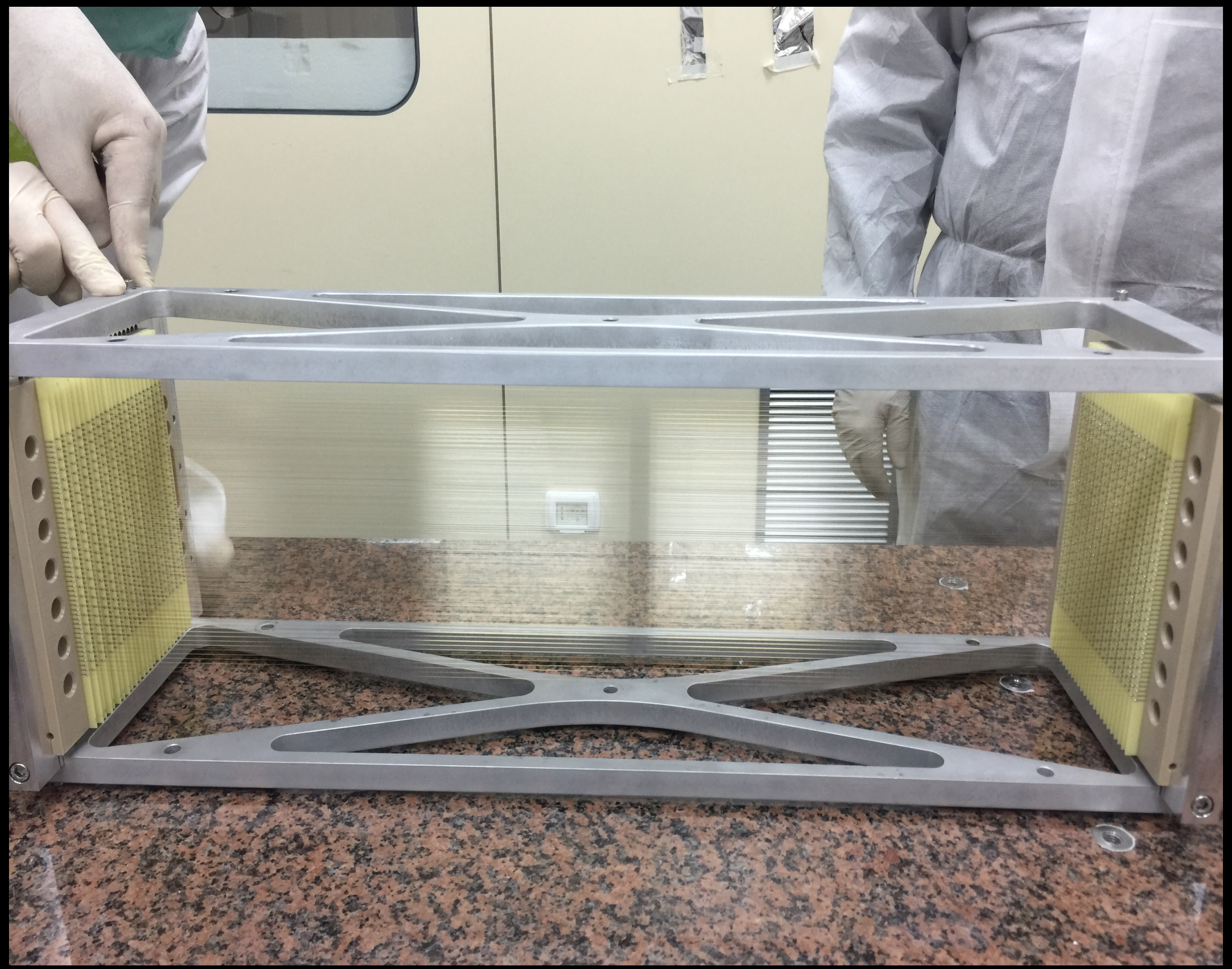
- Length: 4 m
- Radius: 0.3- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

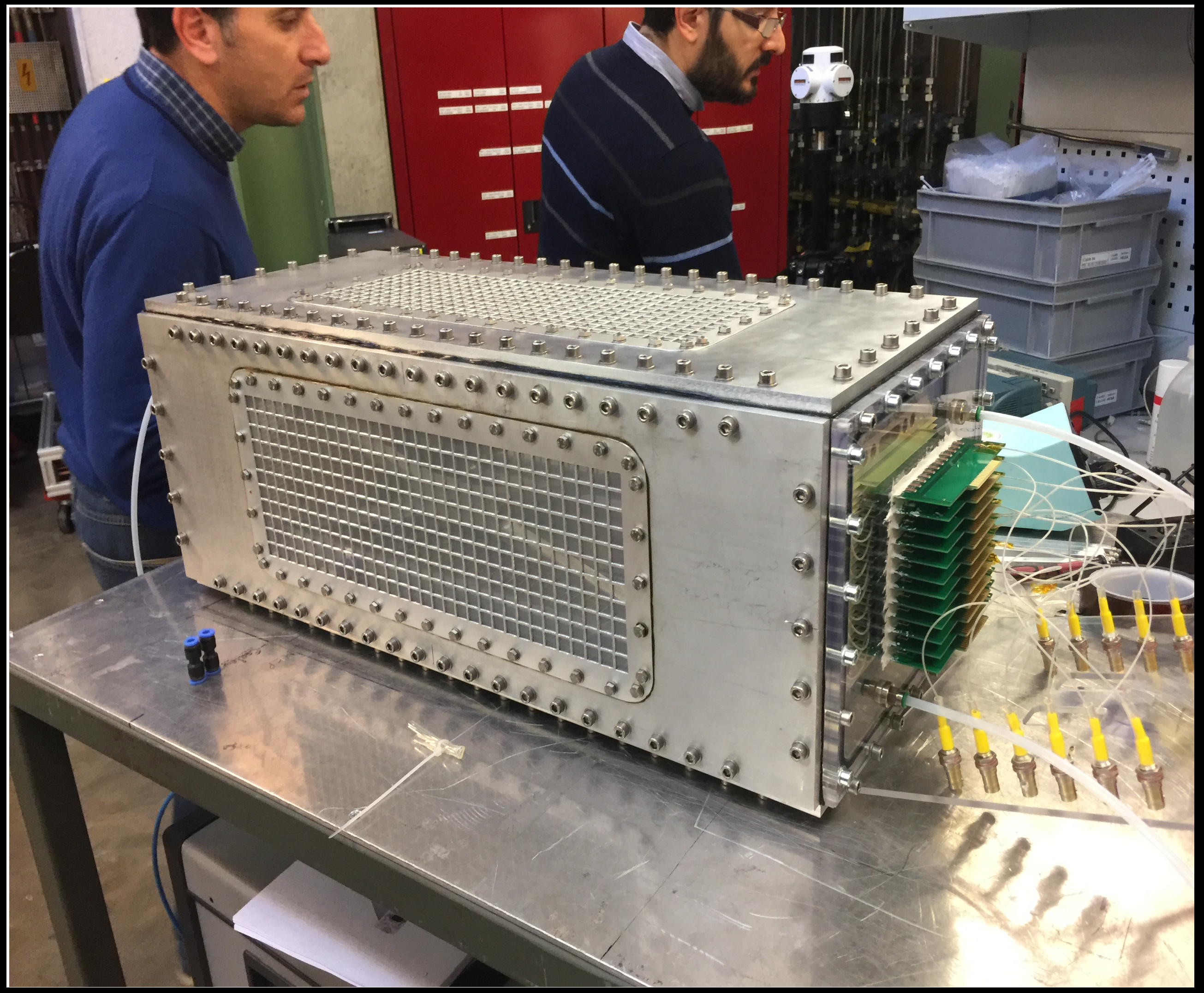
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

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

MEG2 prototype being tested







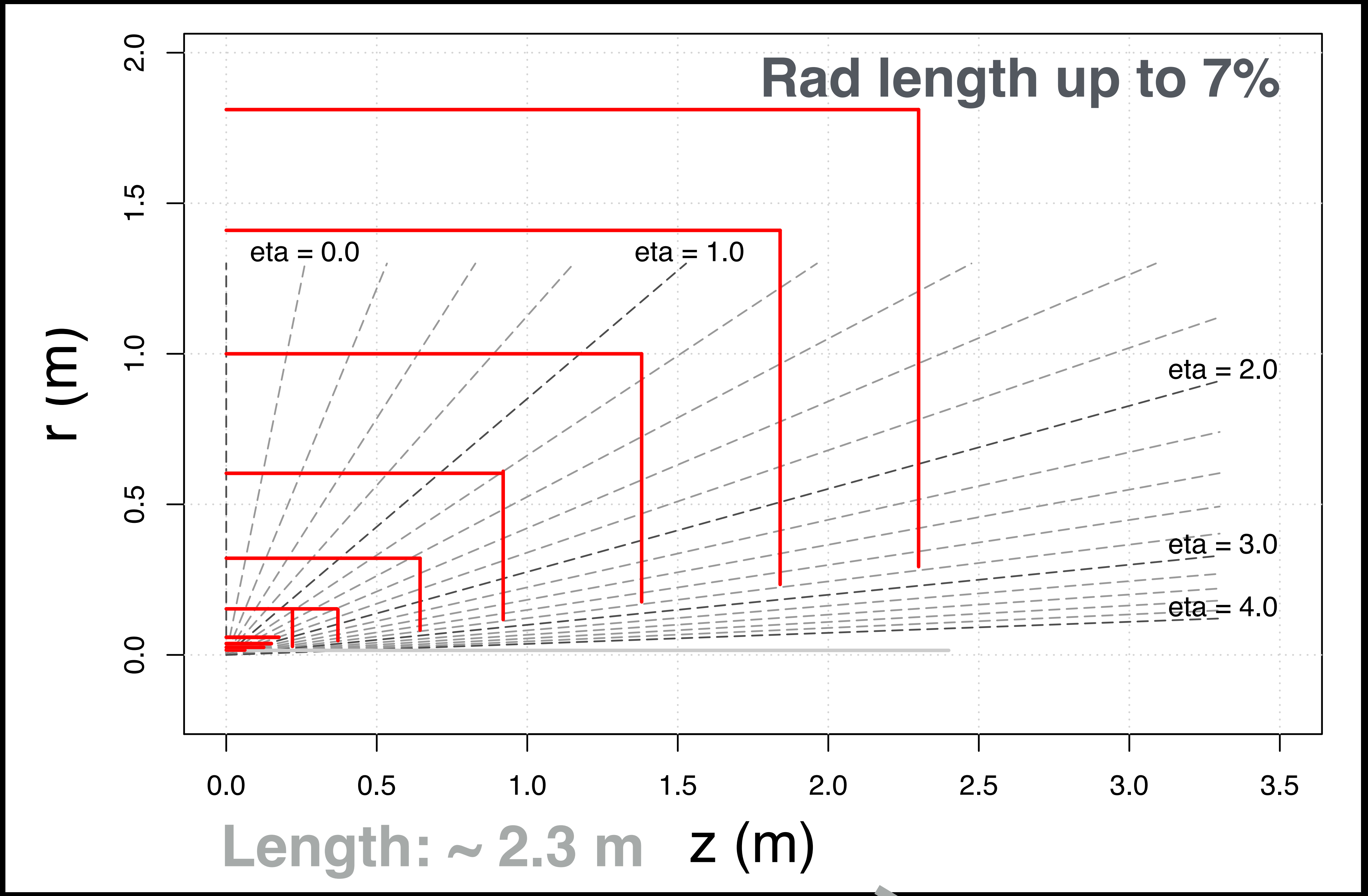
Stereo angle: 50-250 mrad

Full silicon tracker concept

Replace TPC with additional silicon layers

CEPC-SID:

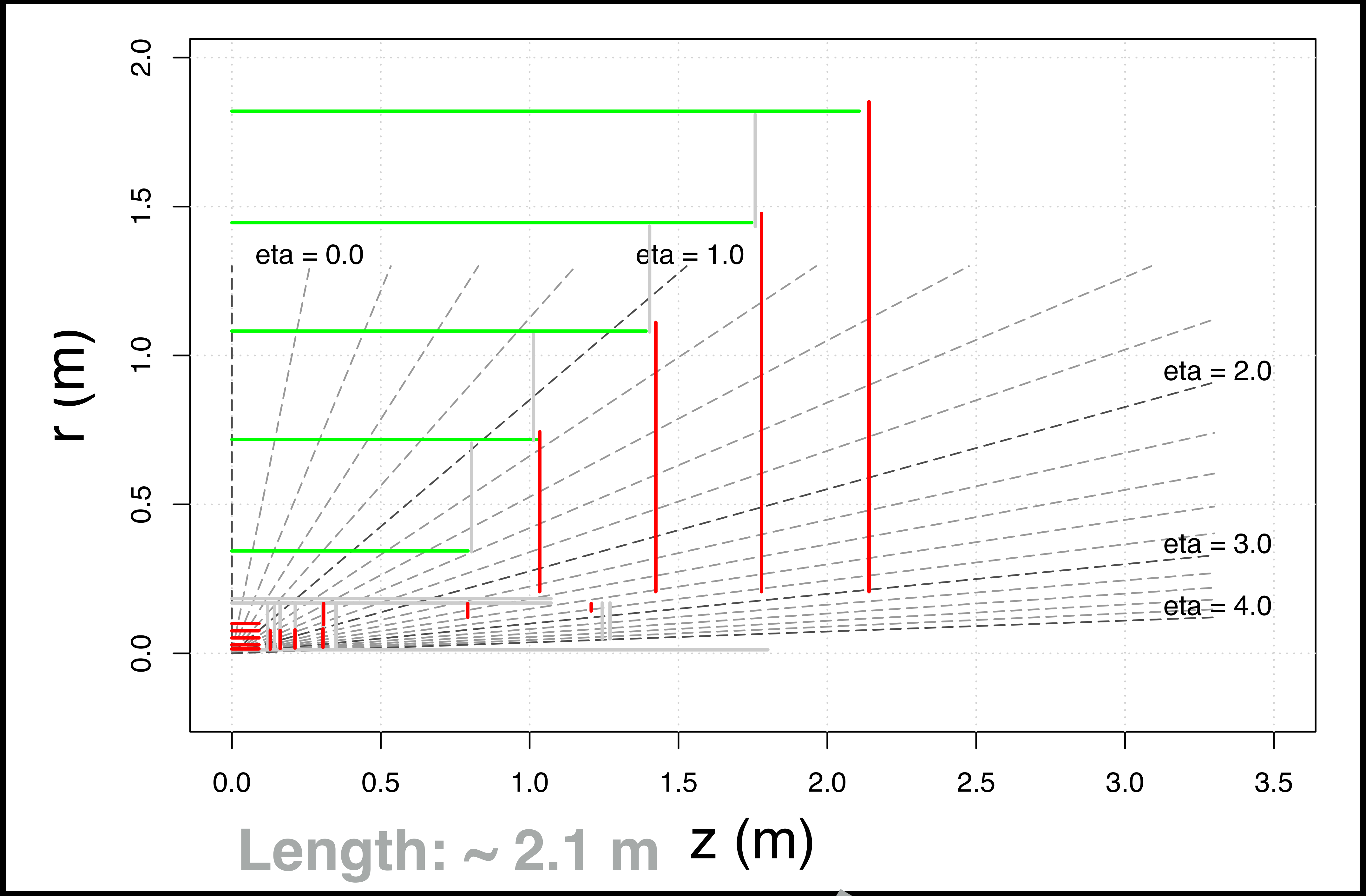
6 barrel double strip layers
5 endcap double strip layers



Radius ~ 1.8 m

SIDB: SiD optimized

5 barrel single strip layers
5 endcap double strip layers



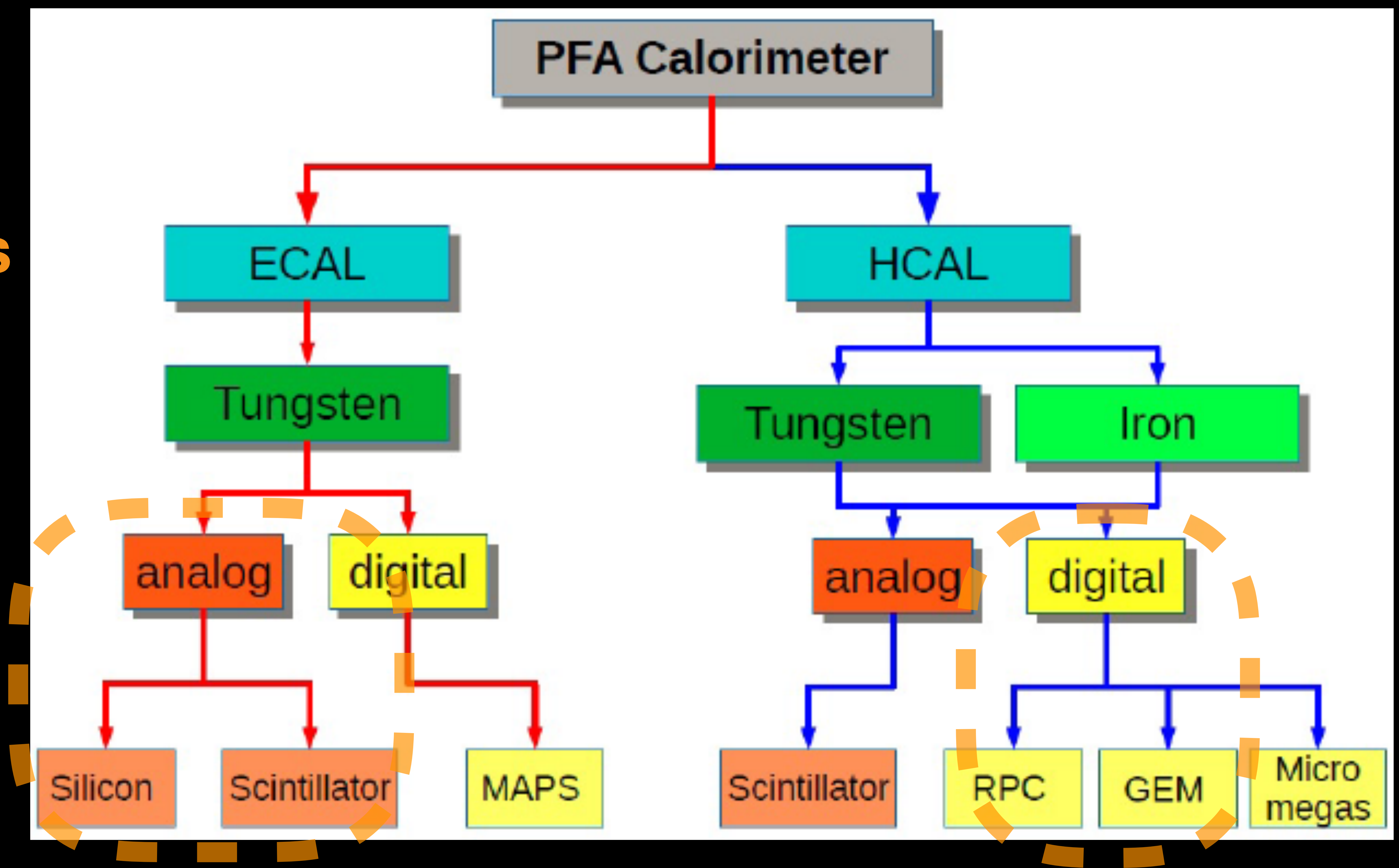
Collaboration with Argonne and Berkeley

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

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

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

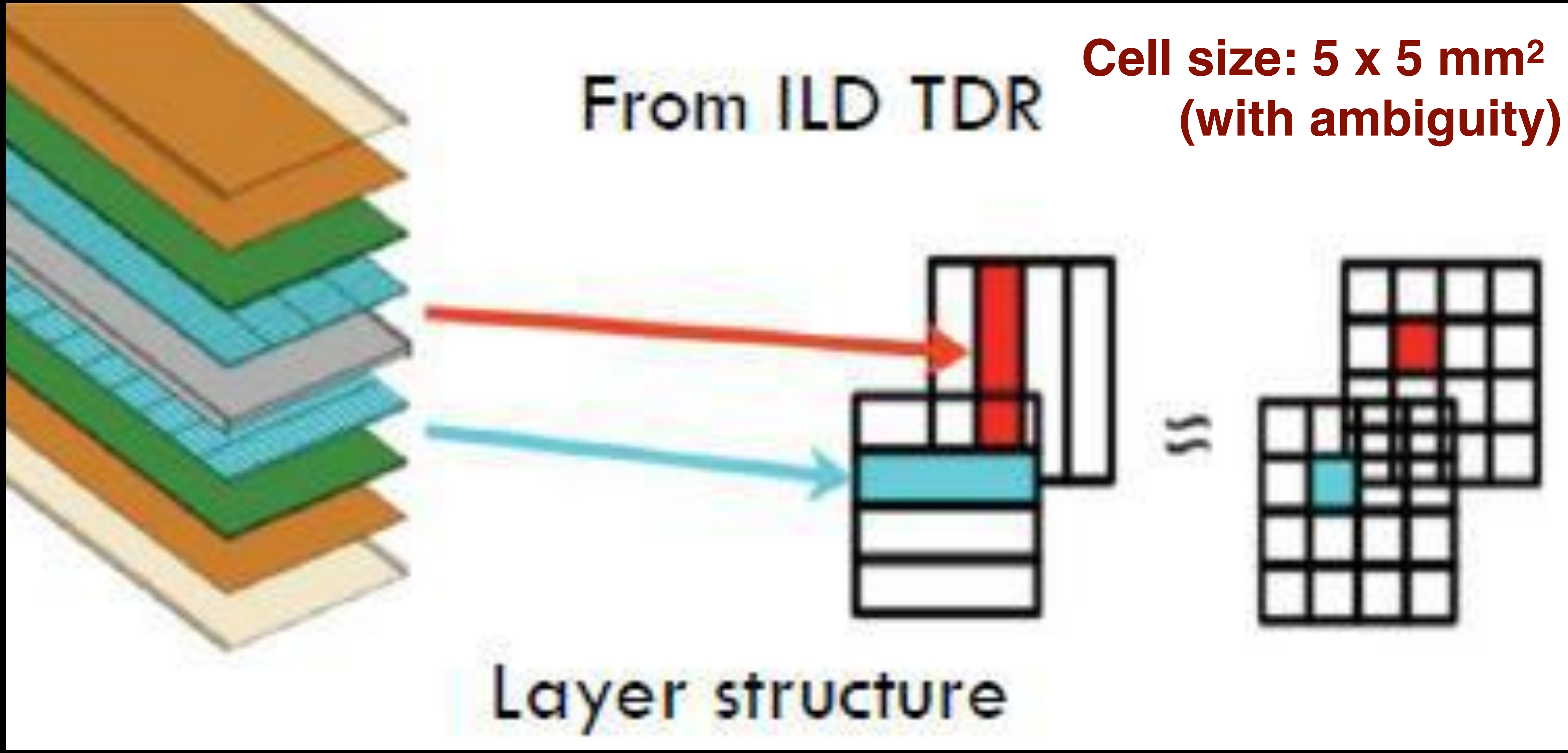


Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) (*) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	(*) SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) (*) HCAL with Scintillator+SiPM and Stainless Steel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

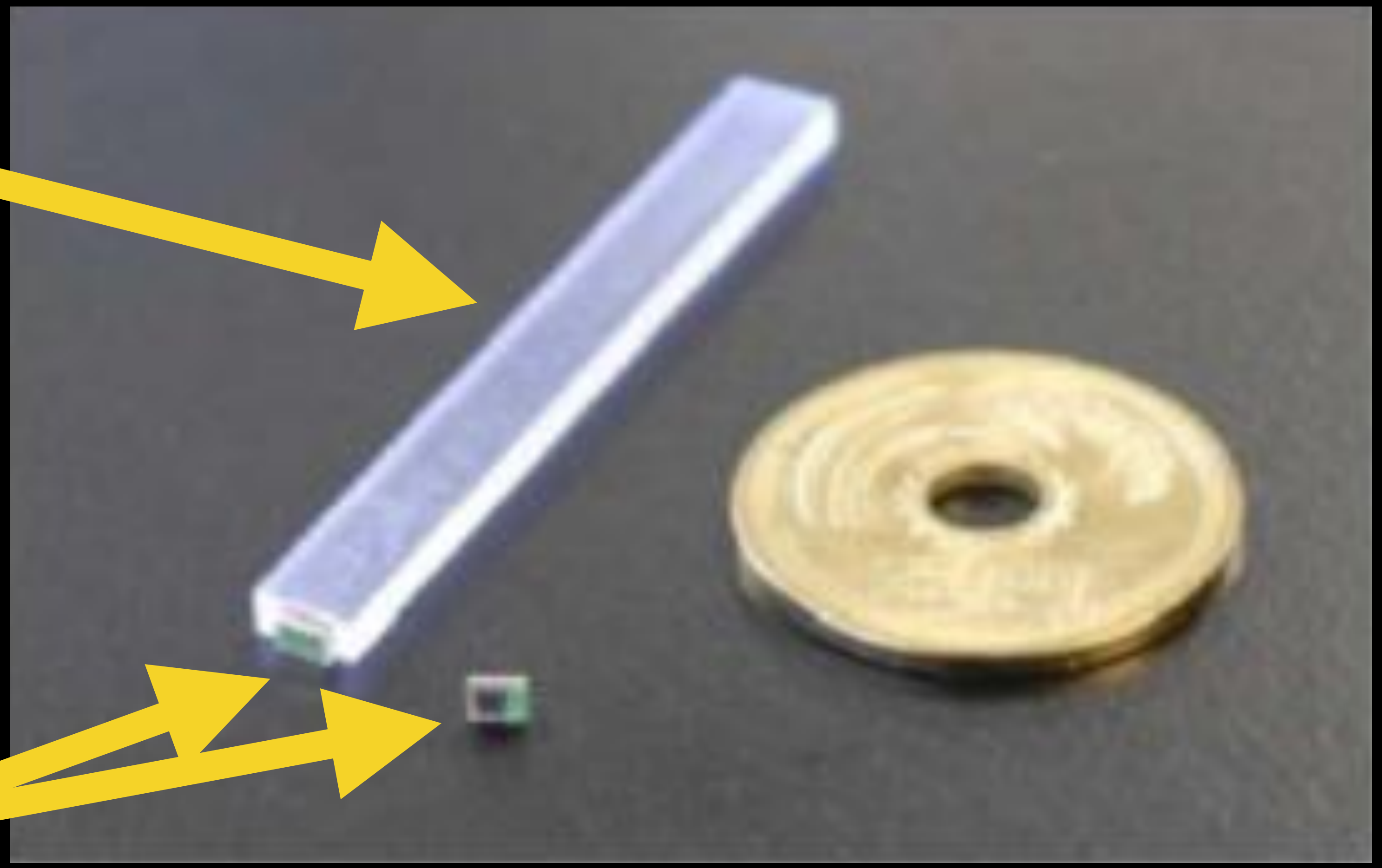
ECAL Calorimeter — Particle Flow Calorimeter

Scintillator-Tungsten Sandwich ECAL

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



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



SiPM

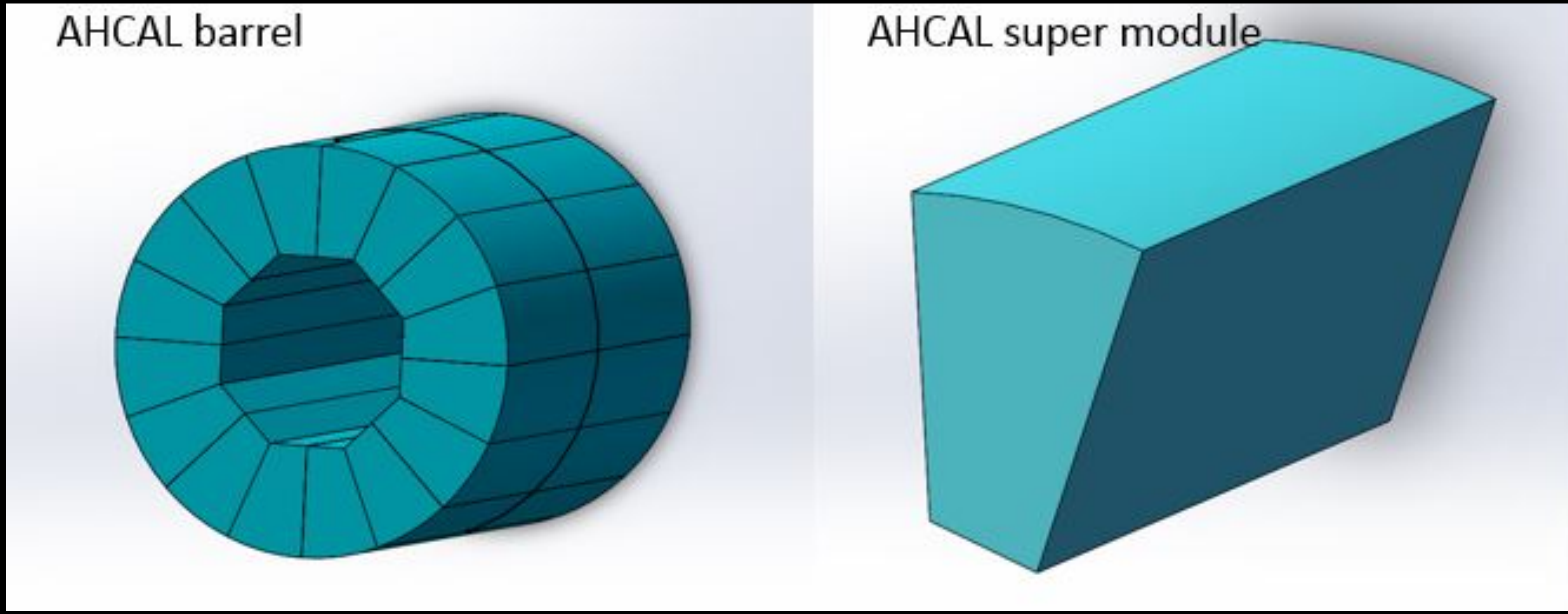
R&D on-going:
- SiPM dynamic range
- Scintillator strip non-uniformity
- Coupling of SiPM and scintillator

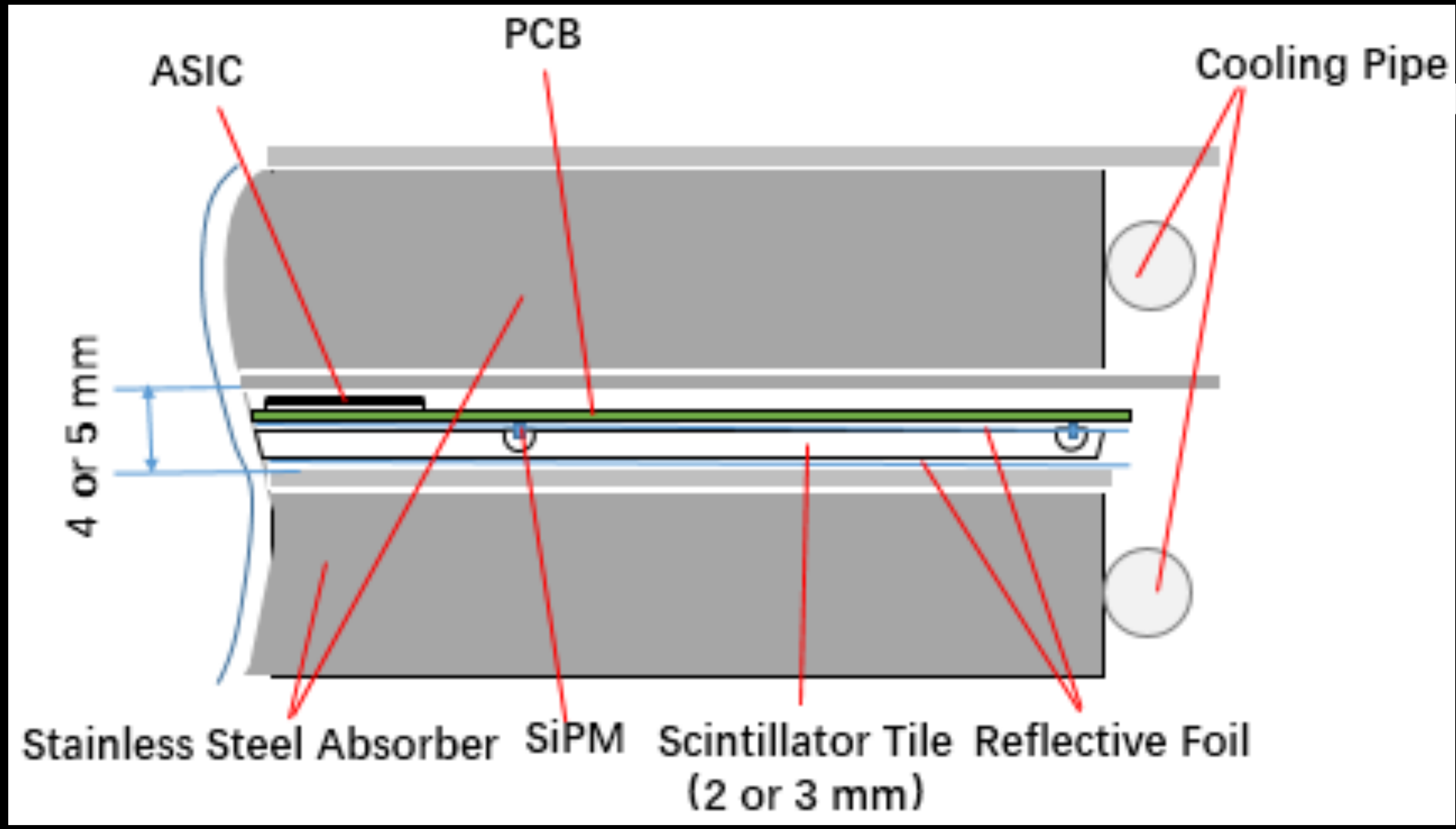
Mini-prototype tested on testbeam at the IHEP

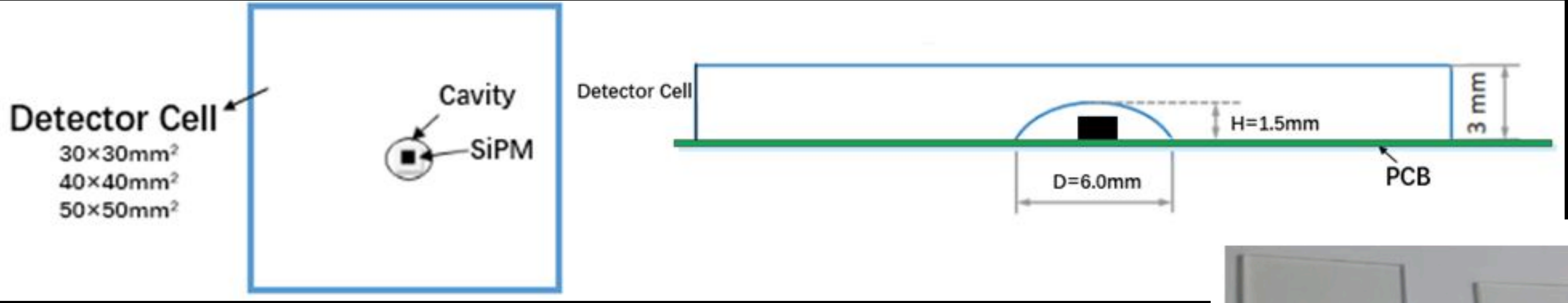
HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)

32 super modules **40 layers**



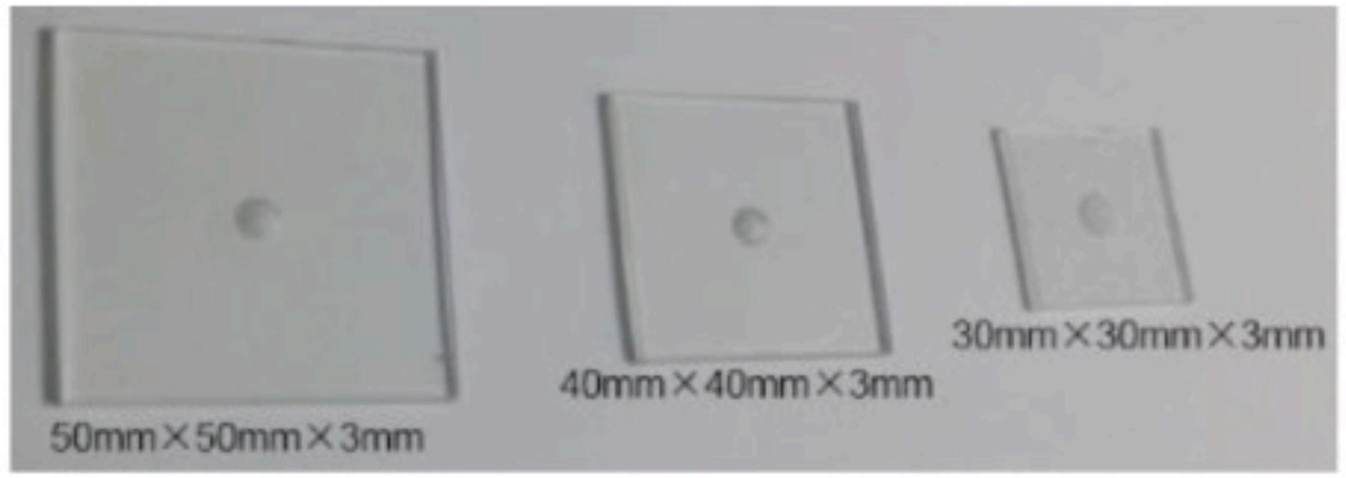


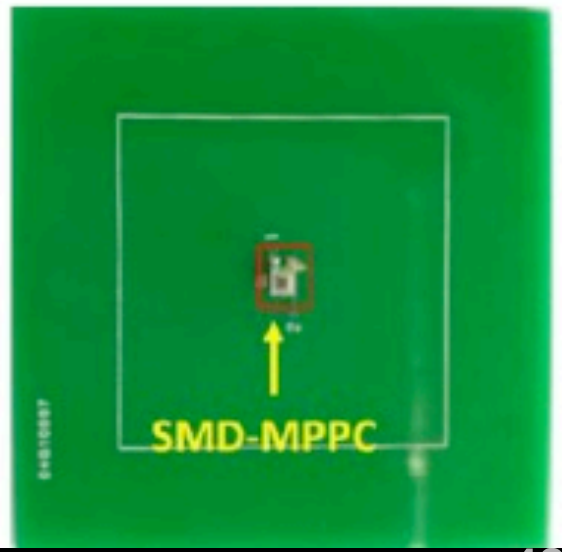


Readout channels:

~ 5 Million (30 x 30 mm²)

~ 2.8 Million (40 x 40 mm²)





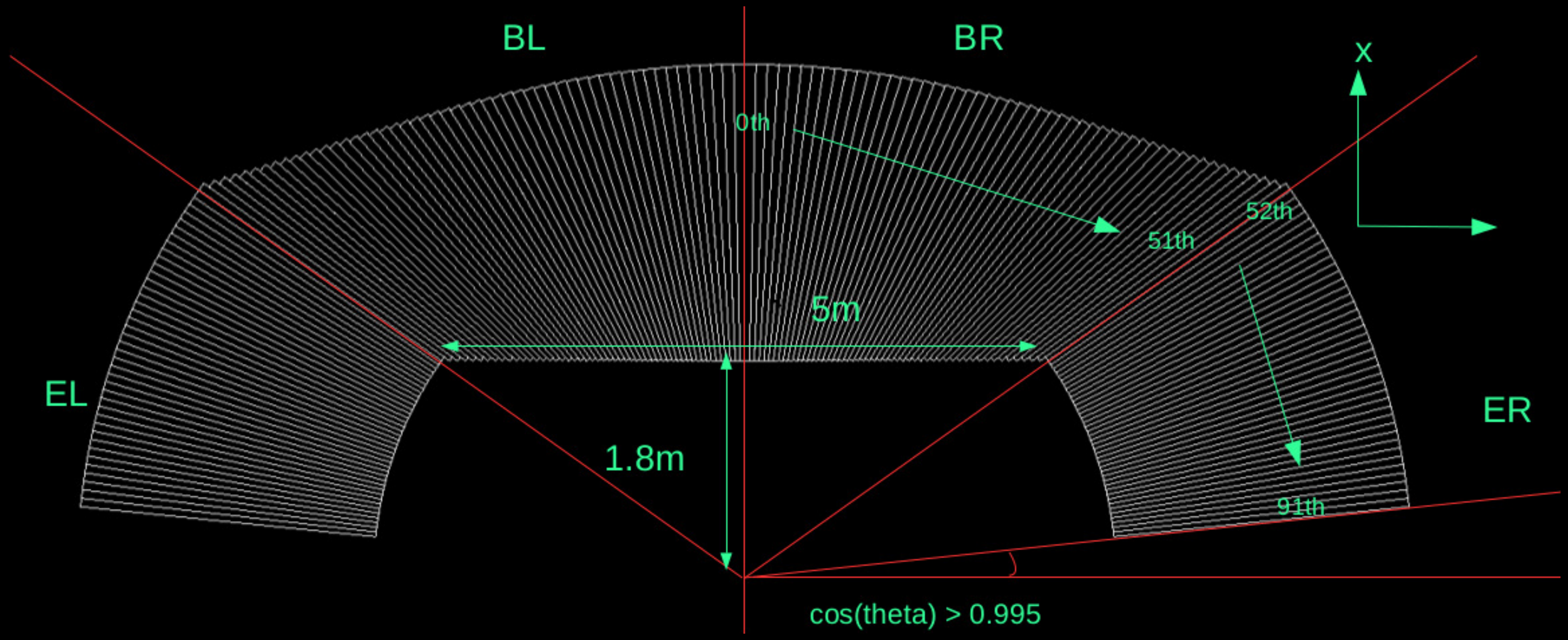
Prototype to be built: MOST (2018-2023)

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

Dual Readout Calorimeter

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

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

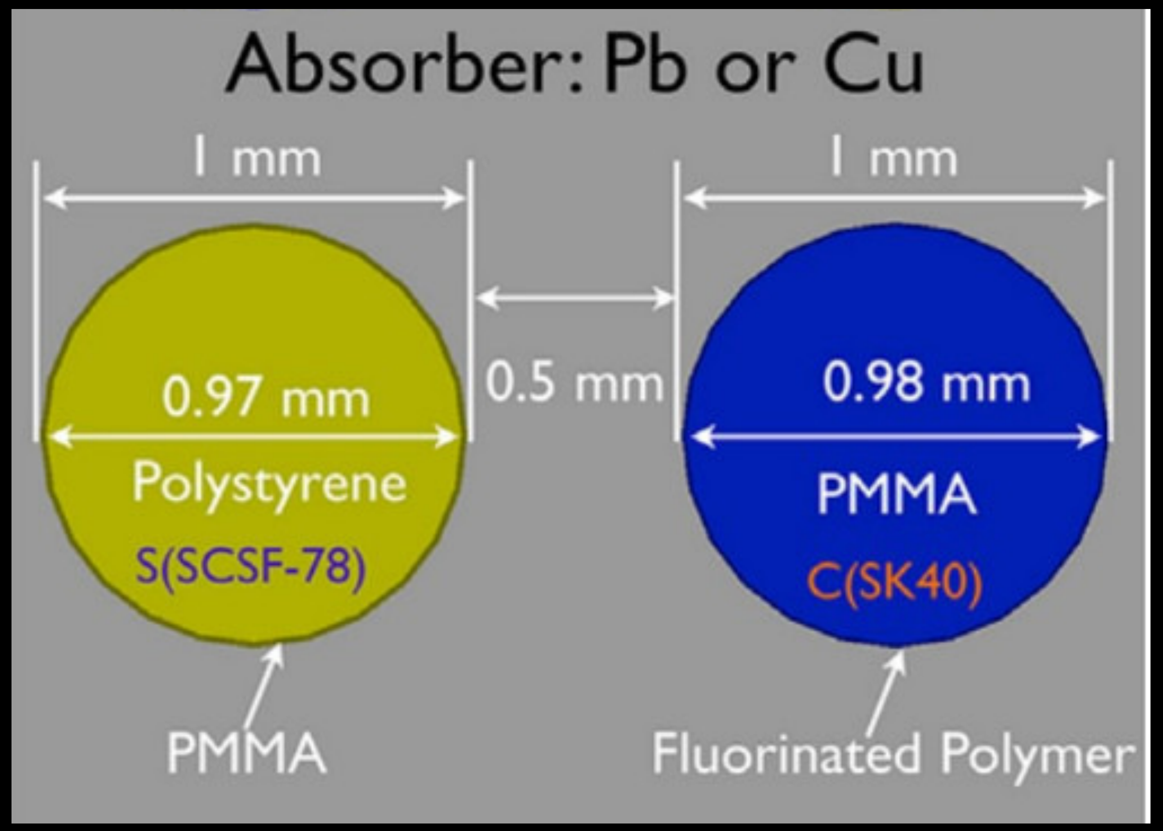


Covers full volume up to |cos(θ)| = 0.995

with 92 different types of towers (wedge)

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

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

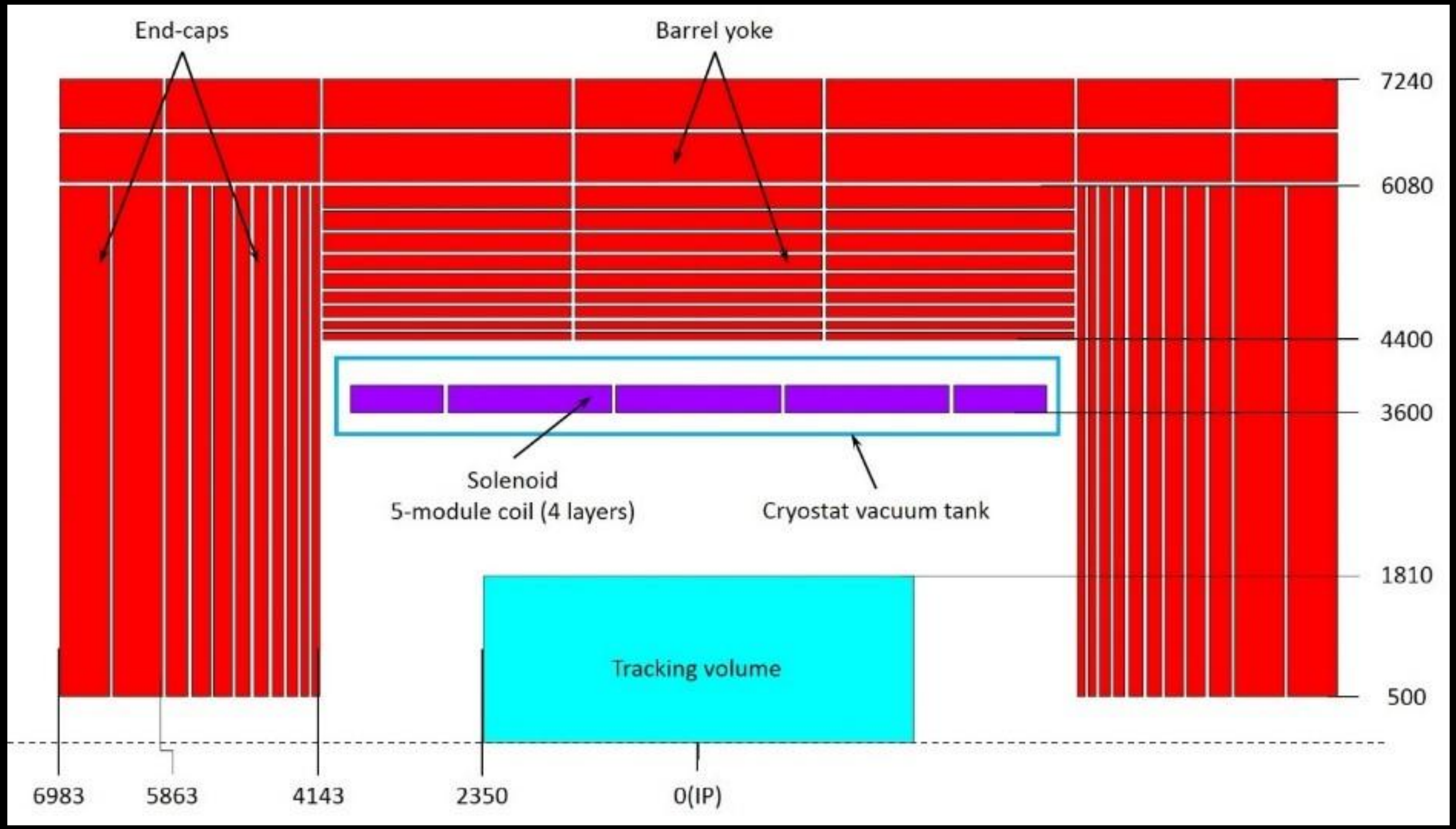


Studying different readout schemes PMT vs SiPM

Several prototypes from RD52 have been built

Superconductor solenoid development

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



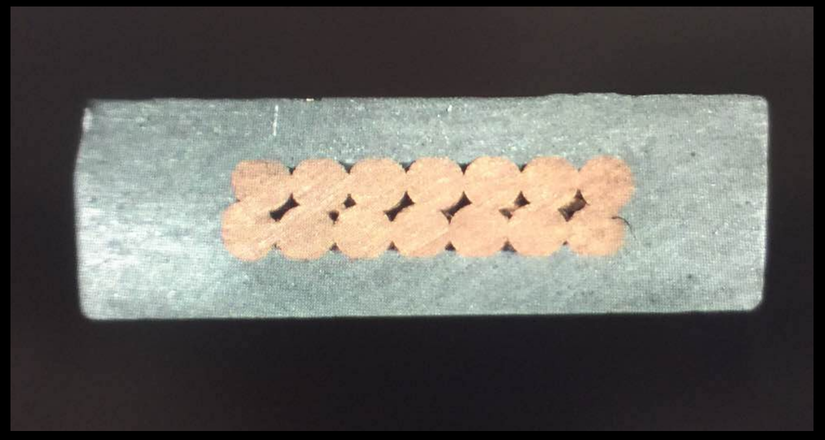
Main parameters of solenoid coil

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

Design for 2 Tesla magnet presents no problems

Double-solenoid design also available

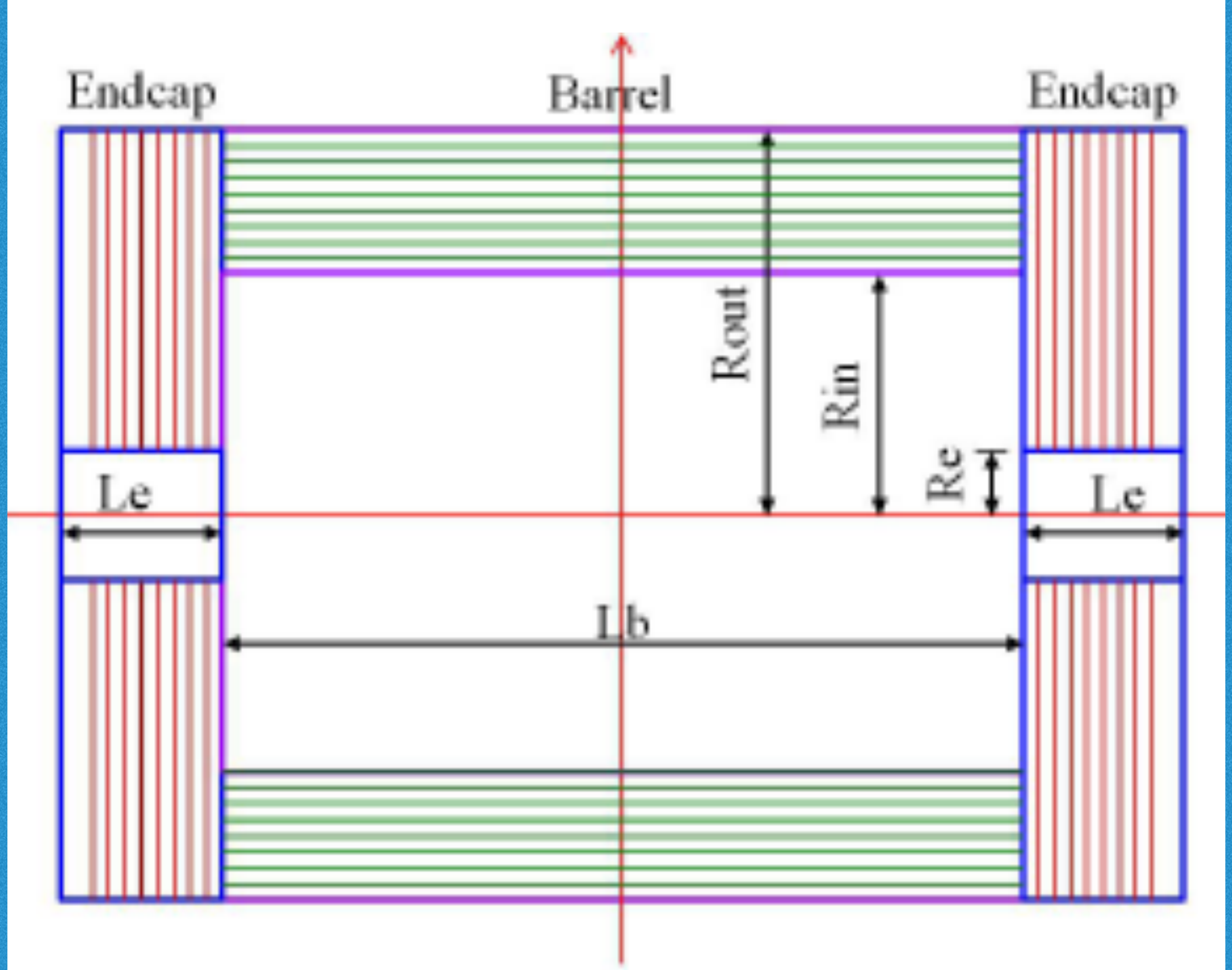
Default is NbTi Rutherford SC cable (4.2K)
Solutions with High-Temperature SC cable also being considered (YBCO, 20K)



Muon detector

Baseline Muon detector

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

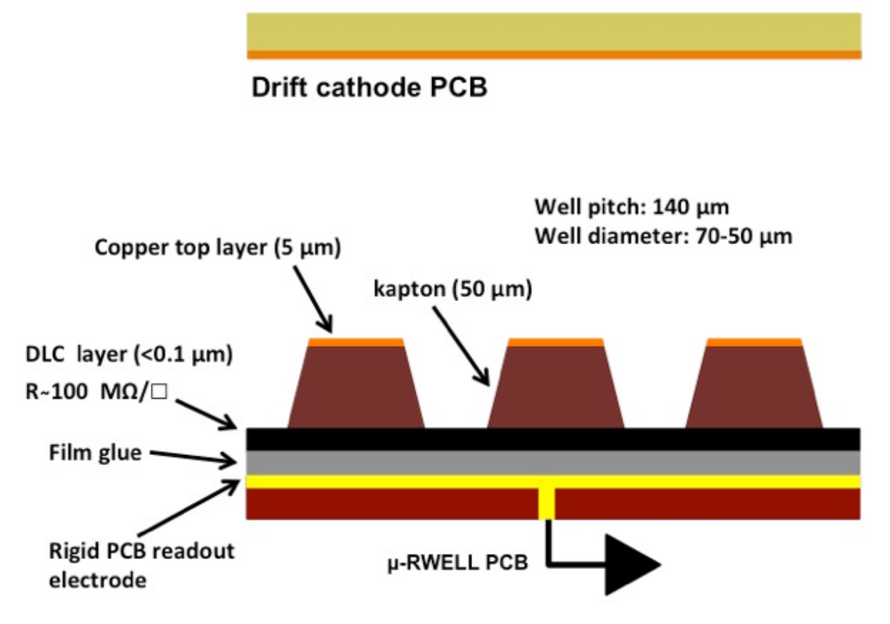


Technologies considered

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

Baseline: Bakelite/glass RPC

New technology proposal (INFN): μRwell



Muon system: open studies

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

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

Funding Support for Detector R&D

Multiple funding sources

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

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

Currently secured funding

Conceptual Design Report (CDR) – Status

Pre-CDR completed in 2015

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

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

Detector and Physics - Conceptual Design Report (CDR)

- Goal: A working concept on paper, including alternatives

Draft-0 released in November 2017

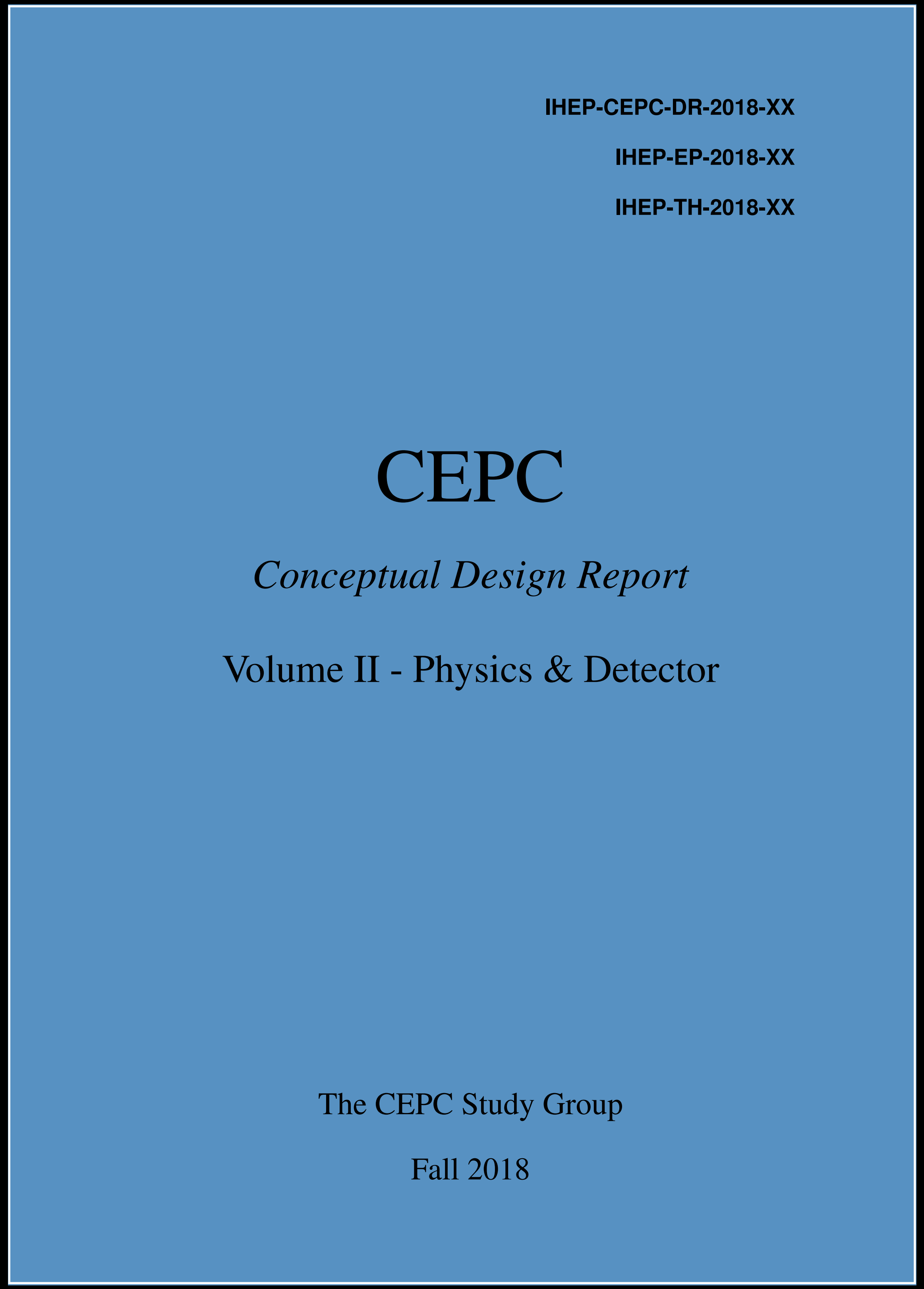
- Mini international review

Early fall 2018: Planned public release date

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

Still

- Opportunities for people to contribute editing, reviewing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IHEP-EP-2018-XX
IHEP-TH-2018-XX

CEPC

Conceptual Design Report

Volume II - Physics & Detector

The CEPC Study Group

Fall 2018

Final remarks

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

CDR Expected final release: Early Fall 2018

From 2018-2022, CEPC TDR will be finished

Thank you for the attention!

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- 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)

Main Parameters of Collider Ring

	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

Interaction region: Machine Detector Interface

Machine induced backgrounds

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

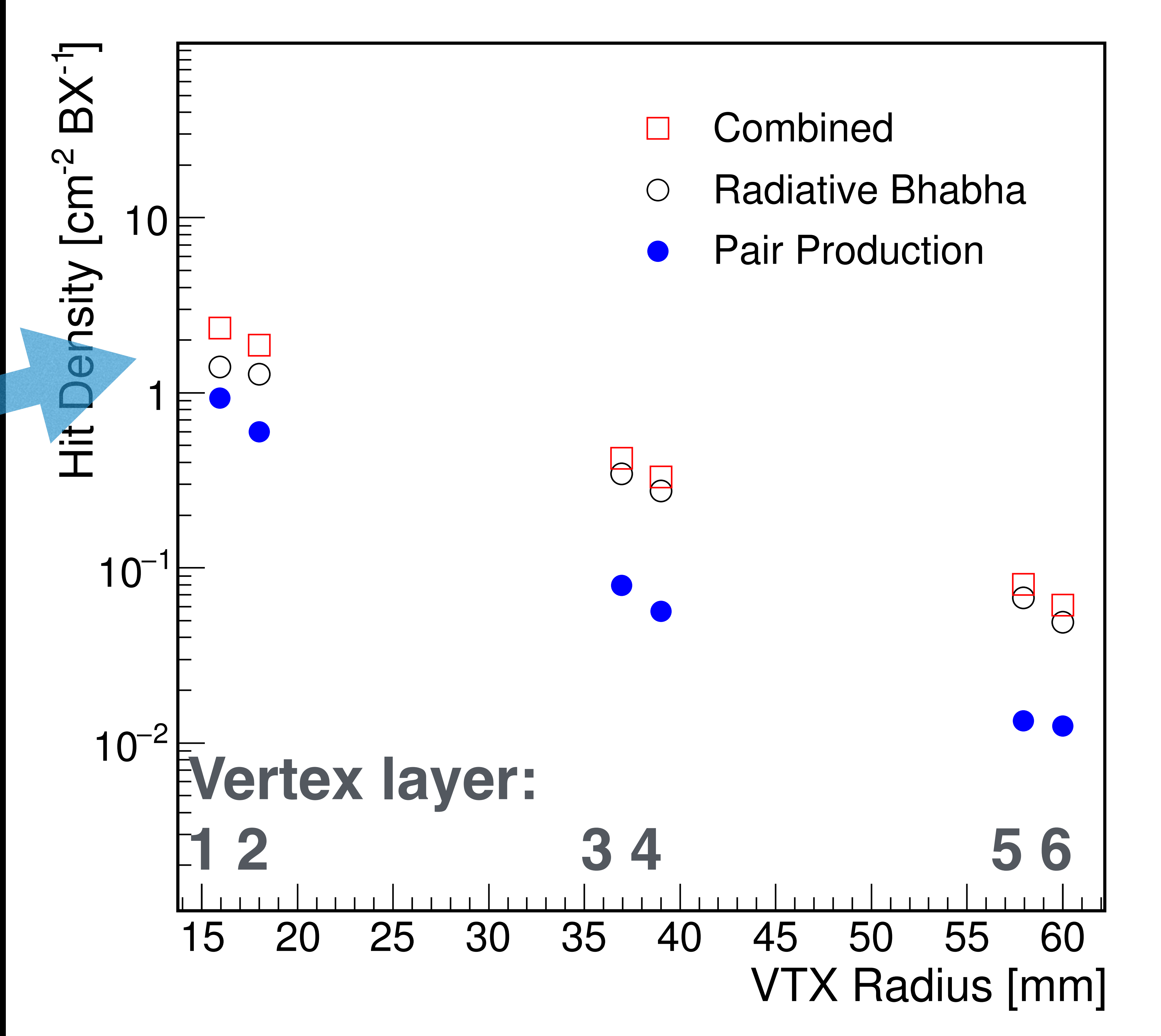
Studies for new configuration being finalized

Higgs operation
(E_{cm} = 240 GeV)

Rates at the inner layer (16 mm):

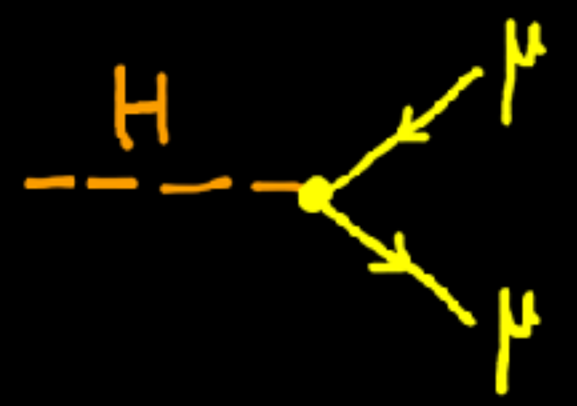
Hit density:	~2.5 hits/cm²/BX
TID:	2.5 MRad/year
NIEL:	10^{12} 1MeV n_{eq}/cm²

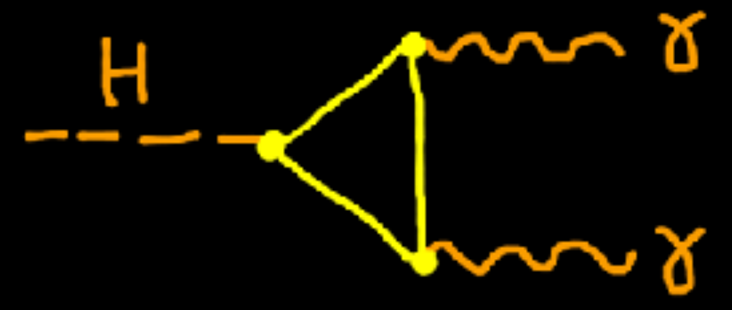
(Safety factors of 10 applied)



Detector optimization

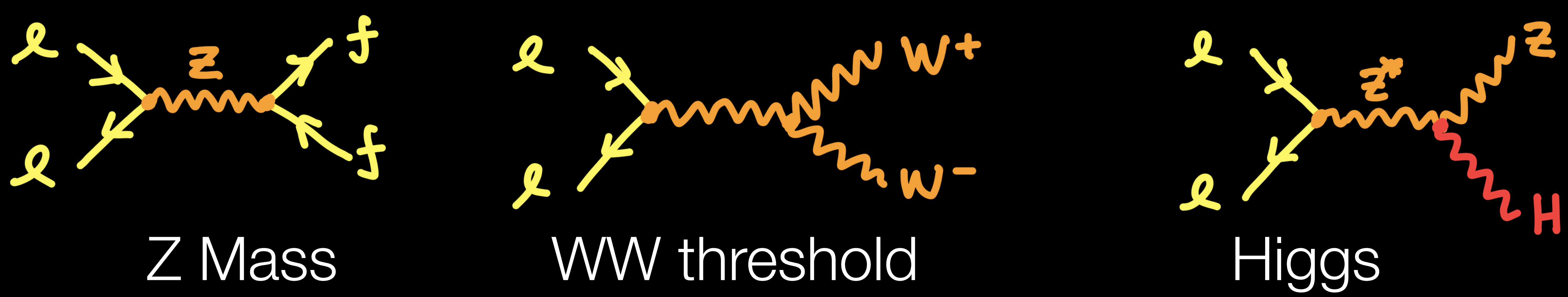
	Optimized (CDR)	Comments
B Field	3 Tesla	Required from beam emmitance
TPC radius	1.8 m	Required by $\mathrm{Br}(H\to\mu\mu)$ measurement
TOF	50 ps	Pi-Kaon separation at Z pole
ECAL thickness	84 mm	Optimized for $\mathrm{Br}(H\to\gamma\gamma)$ at 250 GeV
ECAL cell size	10 mm	Maximum for EW measurements,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

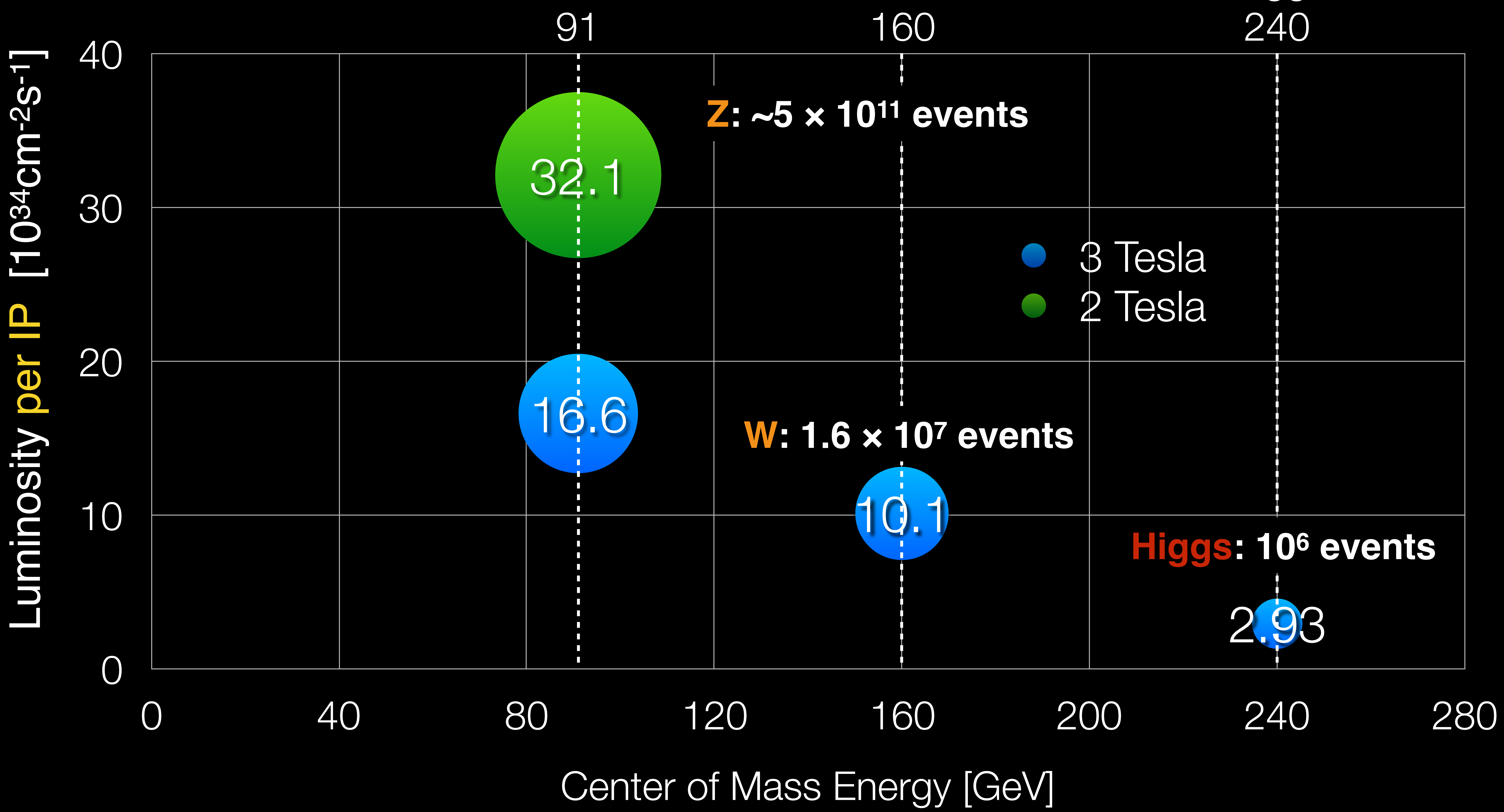




The CEPC Program

100 km e^+e^- collider





Current CEPC Organization

Since Sept. 2013

Institutional Board
YN GAO
J. GAO

Steering Committee
Y.F. WANG (IHEP),….

Project Director
XC LOU
Q. QIN
N. XU

Theory
HJ HE(TH)
JP MA(ITP)
XG HE(SJTU)

Accelerator
J. GAO (IHEP)
CY Long (IHEP)
SN FU (IHEP)

Detector
Joao Costa (IHEP)
S. JIN (NJU)
YN GAO (TH)

International Advisory Committee

Young-Kee Kim, U. Chicago (Chair)
Barry Barish, Caltech
Hesheng Chen, IHEP
Michael Davier, LAL
Brian Foster, Oxford
Rohini Godbole, CHEP, Indian Institute of Science
David Gross, UC Santa Barbara
George Hou, Taiwan U.
Peter Jenni, CERN
Eugene Levichev, BINP
Lucie Linssen, CERN
Joe Lykken, Fermilab
Luciano Maiani, Sapienza University of Rome
Michelangelo Mangano, CERN
Hitoshi Murayama, UC Berkeley/IPMU
Katsunobu Oide, KEK
Robert Palmer, BNL
John Seeman, SLAC
Ian Shipsey, Oxford
Steinar Stapnes, CERN
Geoffrey Taylor, U. Melbourne
Henry Tye, IAS, HKUST
Yifang Wang, IHEP
Harry Weerts, ANL

CEPC “optimistic” Schedule

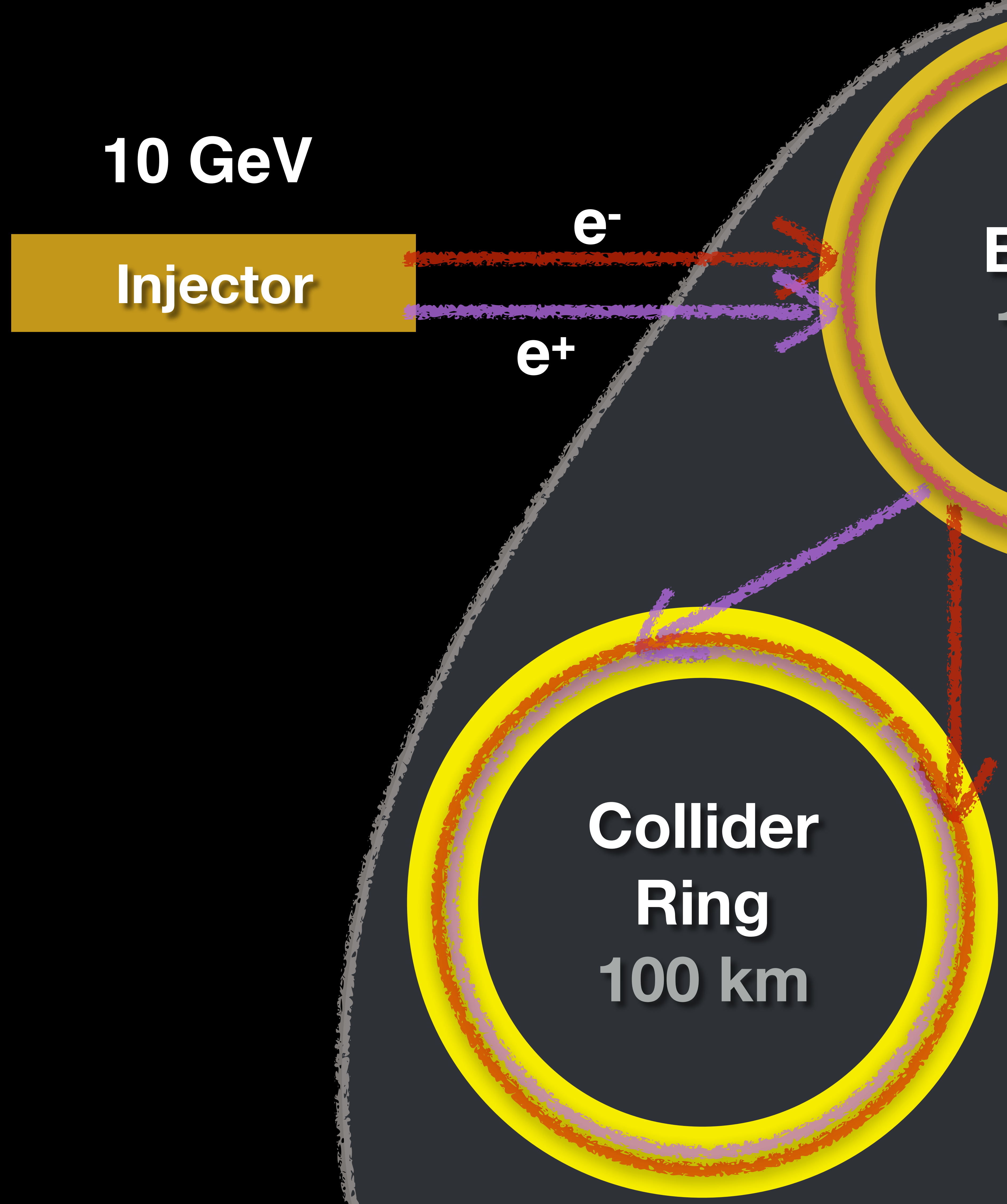
- Design issues
- R&D items
- preCDR

- 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

CEPC Accelerator Chain and Systems



Energy ramp

10 GeV

45/80/120 GeV

Three machines in one single tunnel

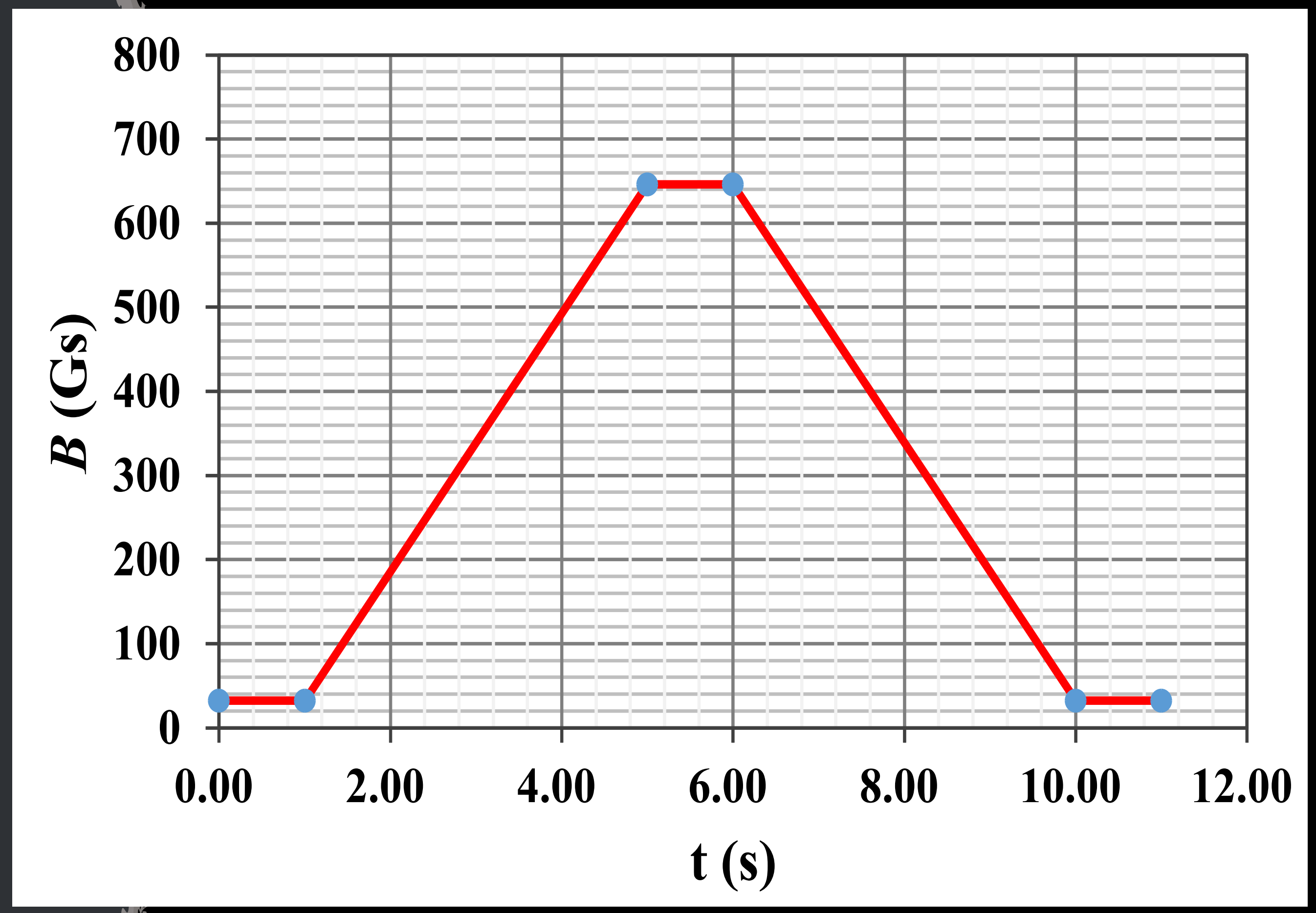
- Booster and CEPC
- SPPC

$\sqrt{s}$ = 90, 160 or 240 GeV

2 interaction points

45/80/120 GeV beams

Booster Cycle (0.1 Hz)



The key systems of CEPC:

1) Linac Injector
2) Booster
3) Collider ring
4) Machine Detector Interface
5) Civil Engineering

CDR provides details of all systems

CEPC Funding in recent years

IHEP seed money
11 M CNY/3 year (2015-2017)

R&D Funding - NSFC

Increasing support for CEPC D+RDby NSFC
5 projects (2015); 7 projects(2016)

CEPC相关基金名称（2015-2016）	基金类型	负责人	承担单位	
高精度气体径迹探测器及激光校正的研究 (2015)	重点基金	李玉兰/陈元柏	清华大学/高能物理研究所	Tsinghua IHEP
成像型电磁量能器关键技术研究(2016)	重点基金	刘树彬	中国科技大学	USTC
CEPC局部双环对撞区挡板系统设计及螺线管场补偿(2016)	面上基金	白莎	高能物理研究所	IHEP
用于顶点探测器的高分辨、低功耗SOI像素芯片的若干关键问题的研究(2015)	面上基金	卢云鹏	高能物理研究所	
基于粒子流算法的电磁量能器性能研究 (2016)	面上基金	王志刚	高能物理研究所	
基于THGEM探测器的数字量能器的研究(2015)	面上基金	俞伯祥	高能物理研究所	
高粒度量能器上的通用粒子流算法开发(2016)	面上基金	阮曼奇	高能物理研究所	
正离子反馈连续抑制型气体探测器的实验研究(2016)	面上基金	祁辉荣	高能物理研究所	
CEPC对撞区最终聚焦系统的设计研究(2015)	青年基金	王逗	高能物理研究所	
利用耗尽型CPS提高顶点探测器空间分辨精度的研究 (2016)	青年基金	周扬	高能物理研究所	
关于CEPC动力学孔径研究(2016)	青年基金	王毅伟	高能物理研究所	

Ministry of Sciences and Technology

2016: 36 M CNY

国家重点研发计划
项目申报书

项目名称：高能环形正负电子对撞机相关的物理和关键技术研究
所属专项：大科学装置前沿研究
指南方向：高能环形正负电子对撞机预先研究
专业机构：科学技术部高技术研究发展中心
推荐单位：教育部
申报单位：清华大学 （公章）
项目负责人：高原宁

中华人民共和国科学技术部
2016 年 05 月 06 日

2018: ~31 M CNY

国家重点研发计划
项目申报书

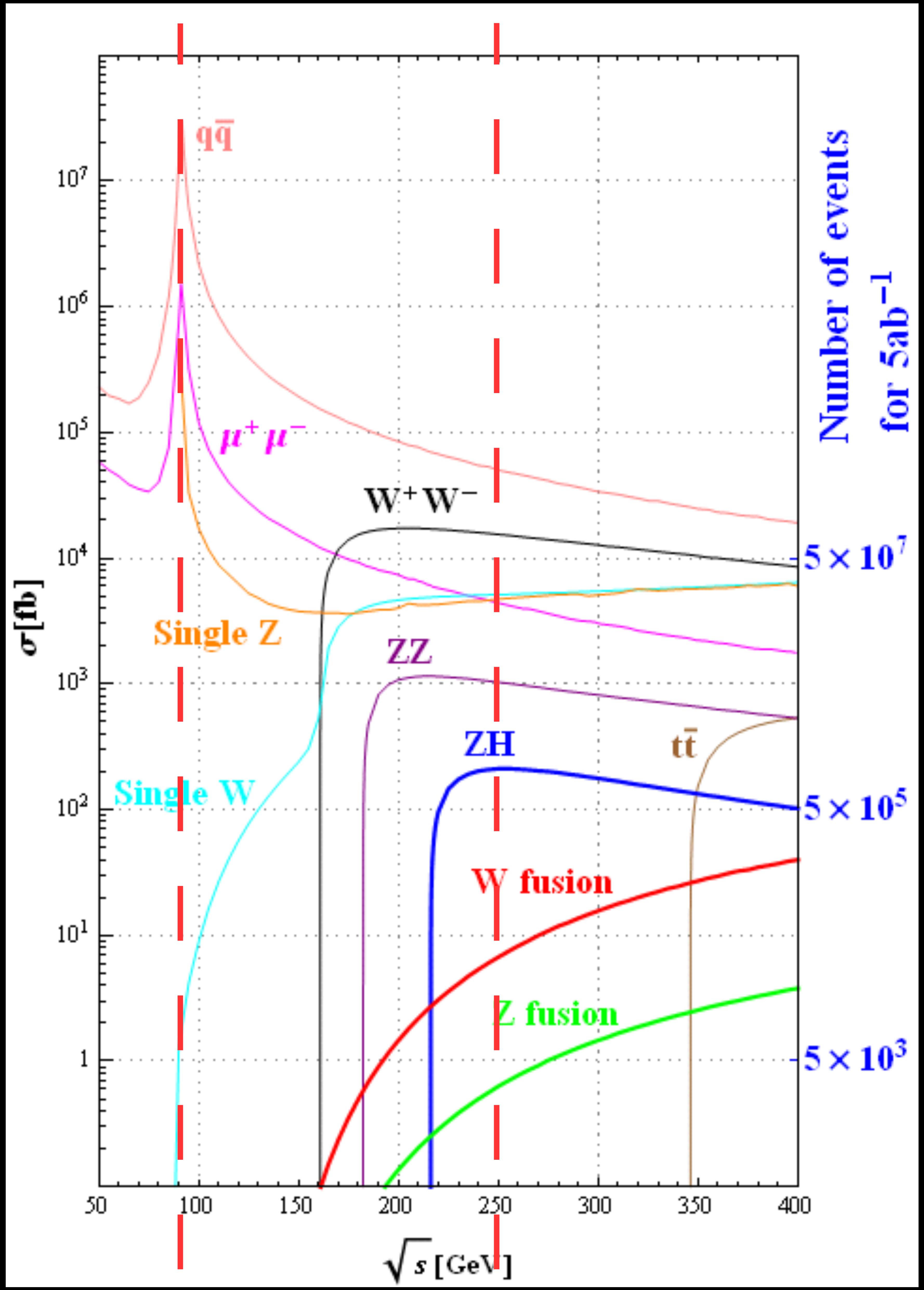
项目名称：高能环形正负电子对撞机关键技术研发和验证
所属专项：大科学装置前沿研究
指南方向：3.1 高能环形正负电子对撞机关键技术验证
专业机构：科学技术部高技术研究发展中心
推荐单位：中国科学院
申报单位：中国科学院高能物理研究所 （公章）
项目负责人：Joao Guimaraes da Costa

中华人民共和国科学技术部
2018 年 02 月 26 日

~60 M CNY CAS-Beijing fund, talent program
~500 M CNY Beijing fund (light source)

Thanks to many different funding sources, CEPC team can carry out CEPC design, key-technology research and site feasibility studies

Total e+e− cross sections



Running scenario

Particle type	Energy (c.m.) (GeV)	Luminosity per IP (10^{34} $cm^{-2}s^{-1}$)	Luminosity per year (ab^{-1}, 2 IPs)	Years	Total luminosity (ab^{-1}, 2 IPs)	Total number of particles
H	240	3	0.8	**7**	5.6	1×10^6
Z	91	32	8	**2**	16	0.7×10^{12}
W	160	12	3.2	**1**	3.2	1×10^7

Main Parameters of Collider Ring

	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**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
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
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.29	0.35	0.55	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
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	
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
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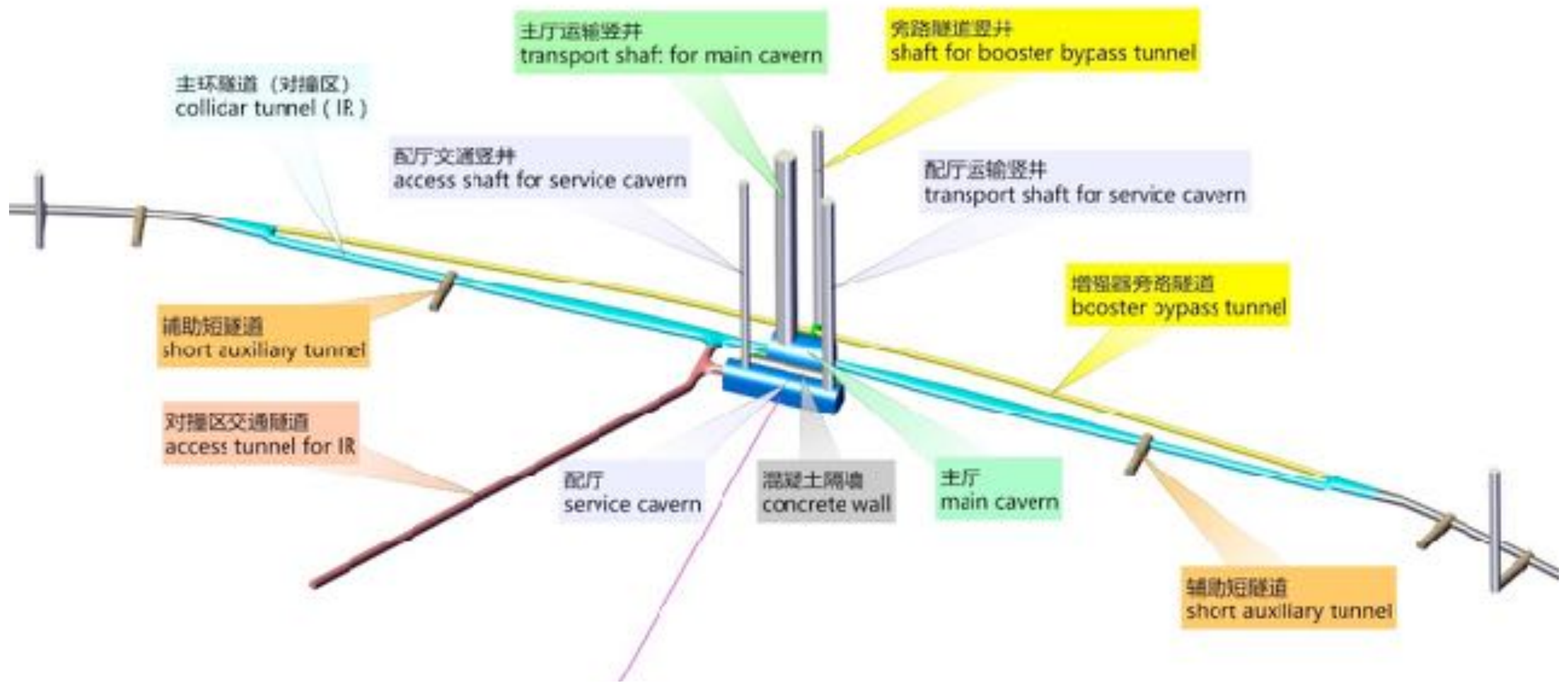
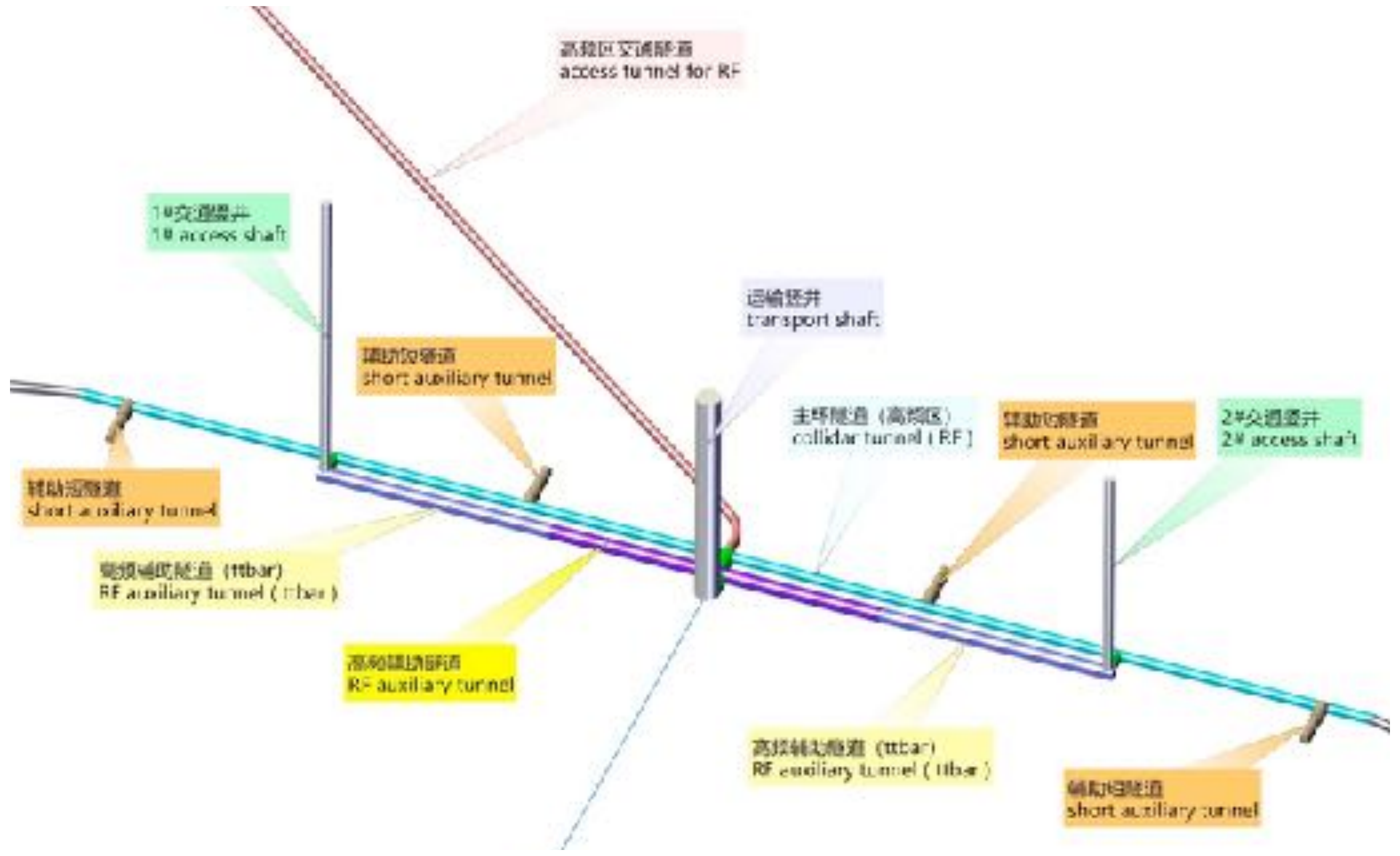
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

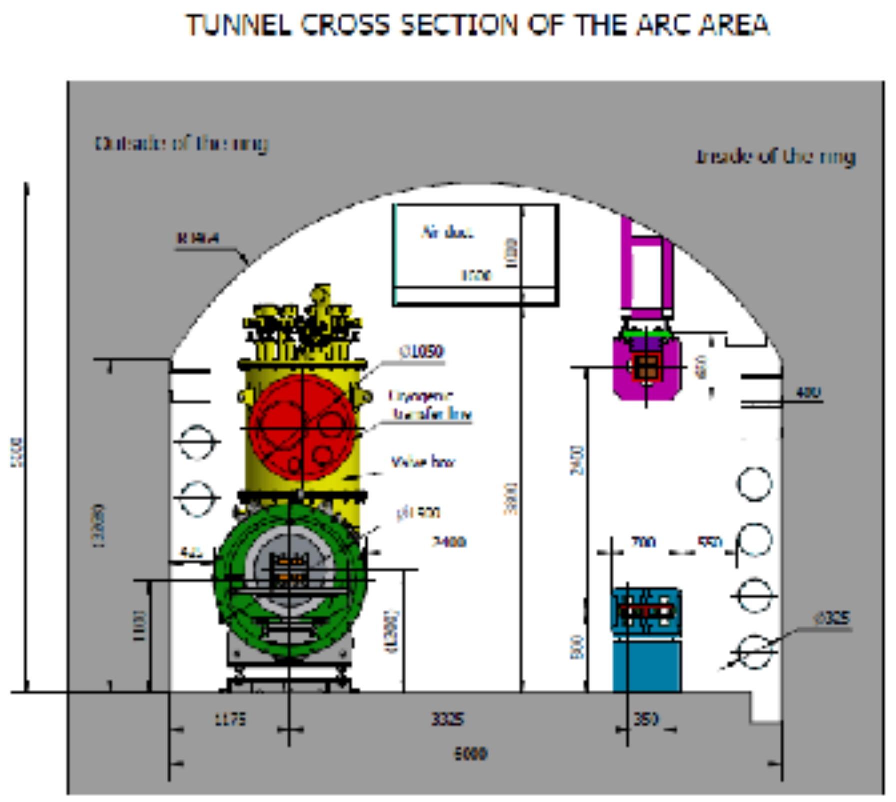
CEPC Civil Engineering Design and Implementation

CEPC Interaction Region

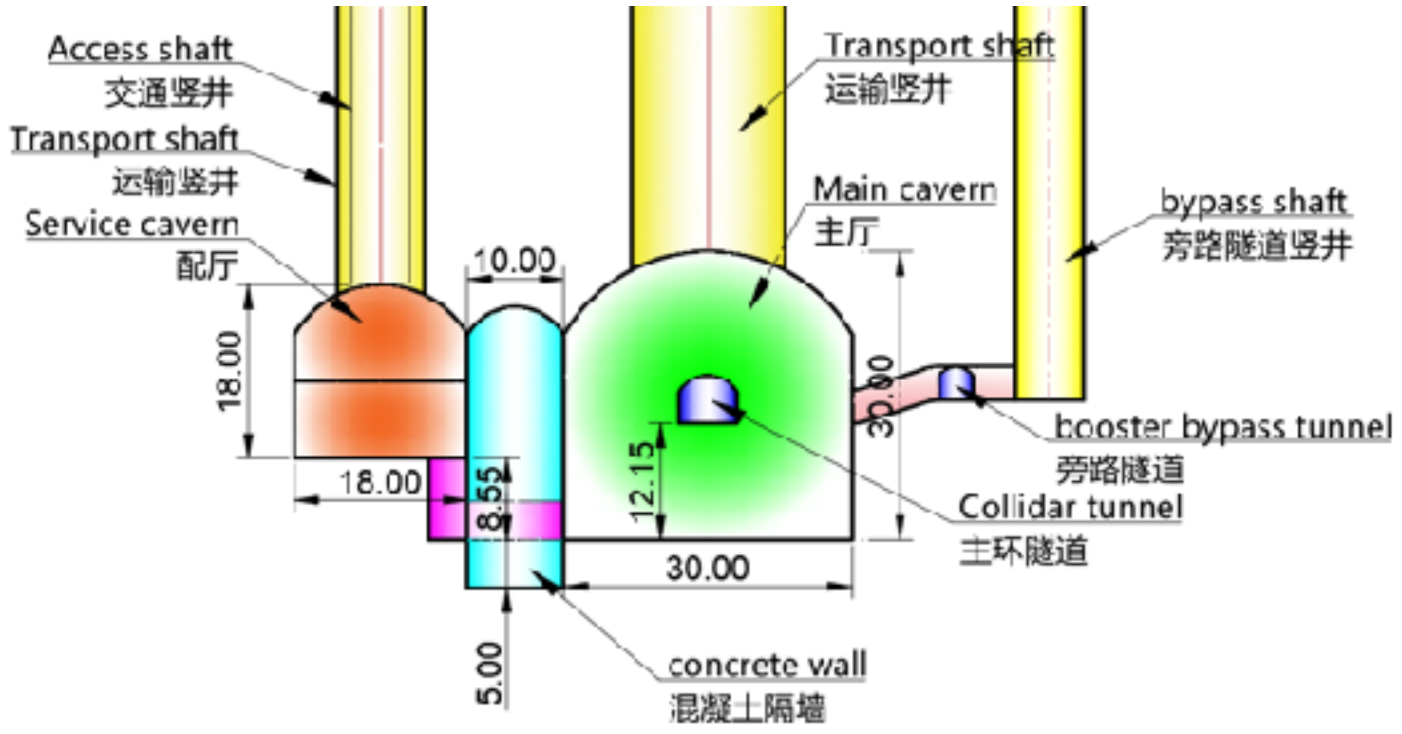


CEPC Injection Region

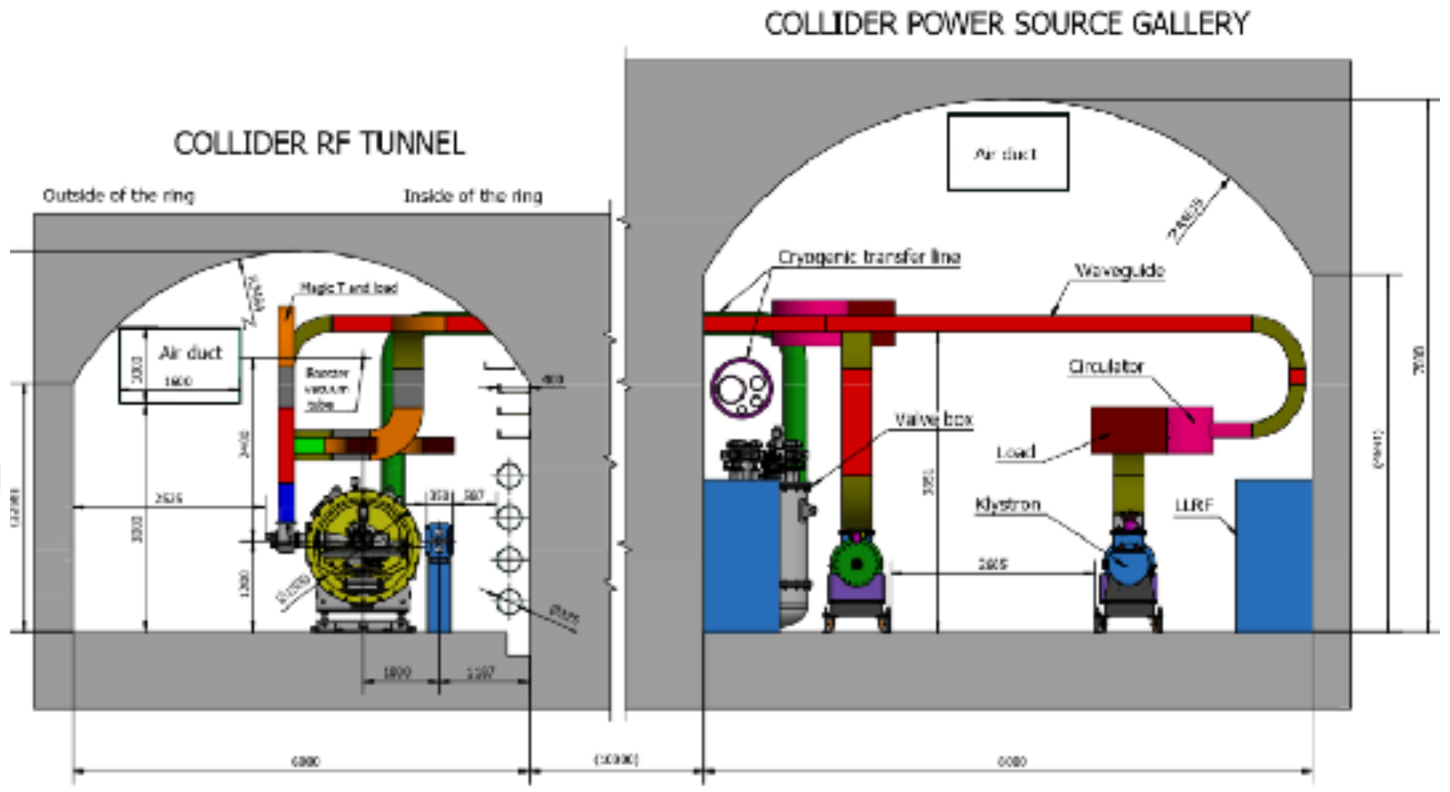




CEPC-SppC tunnel



CEPC Detector Hall



CEPC SCRF Gallary

Interaction region: Machine Detector Interface

Machine induced backgrounds

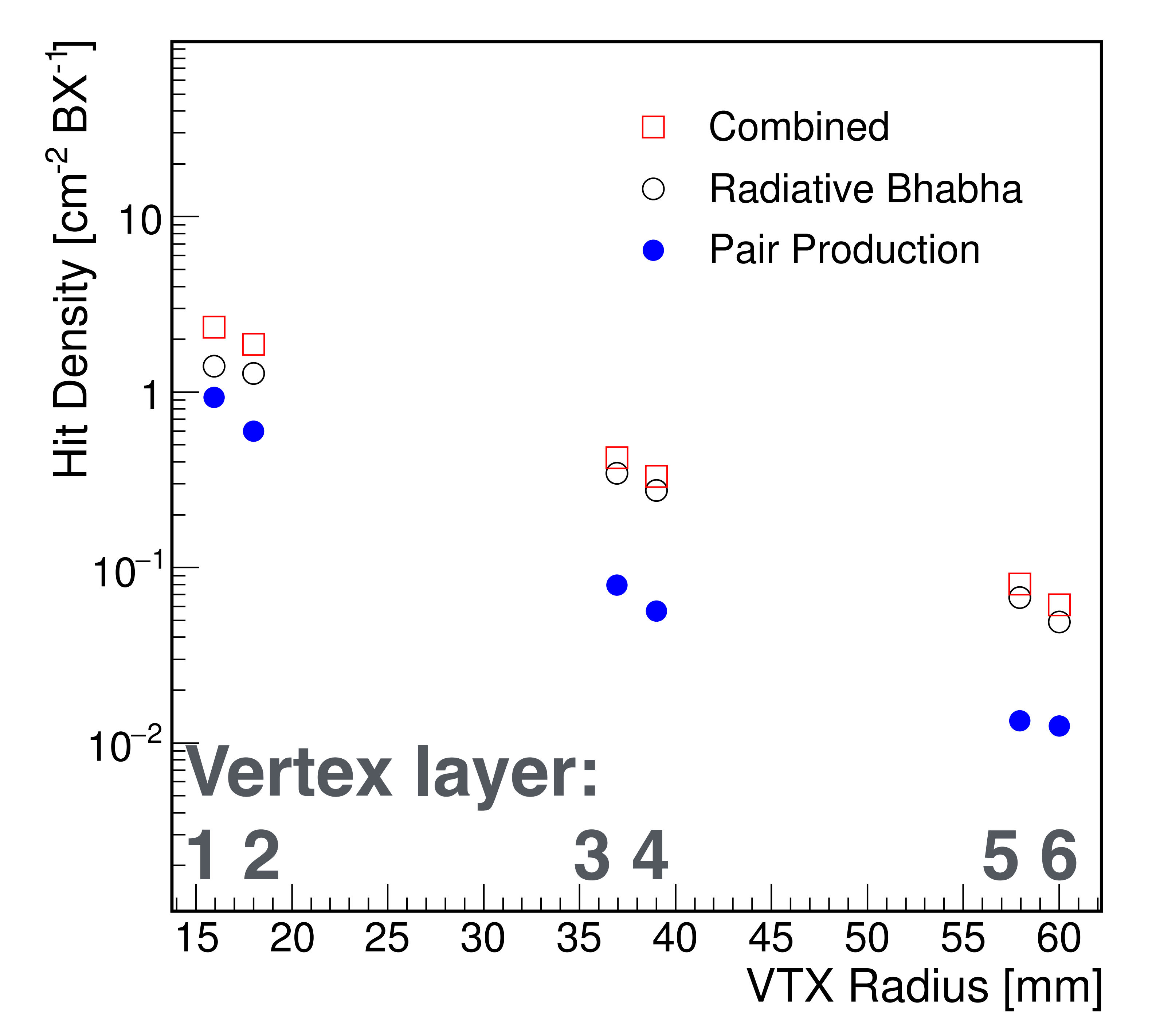
- Radiative Bhabha scattering
- Beam-beam interactions
- Synchrotron radiation
- Beam-gas interactions

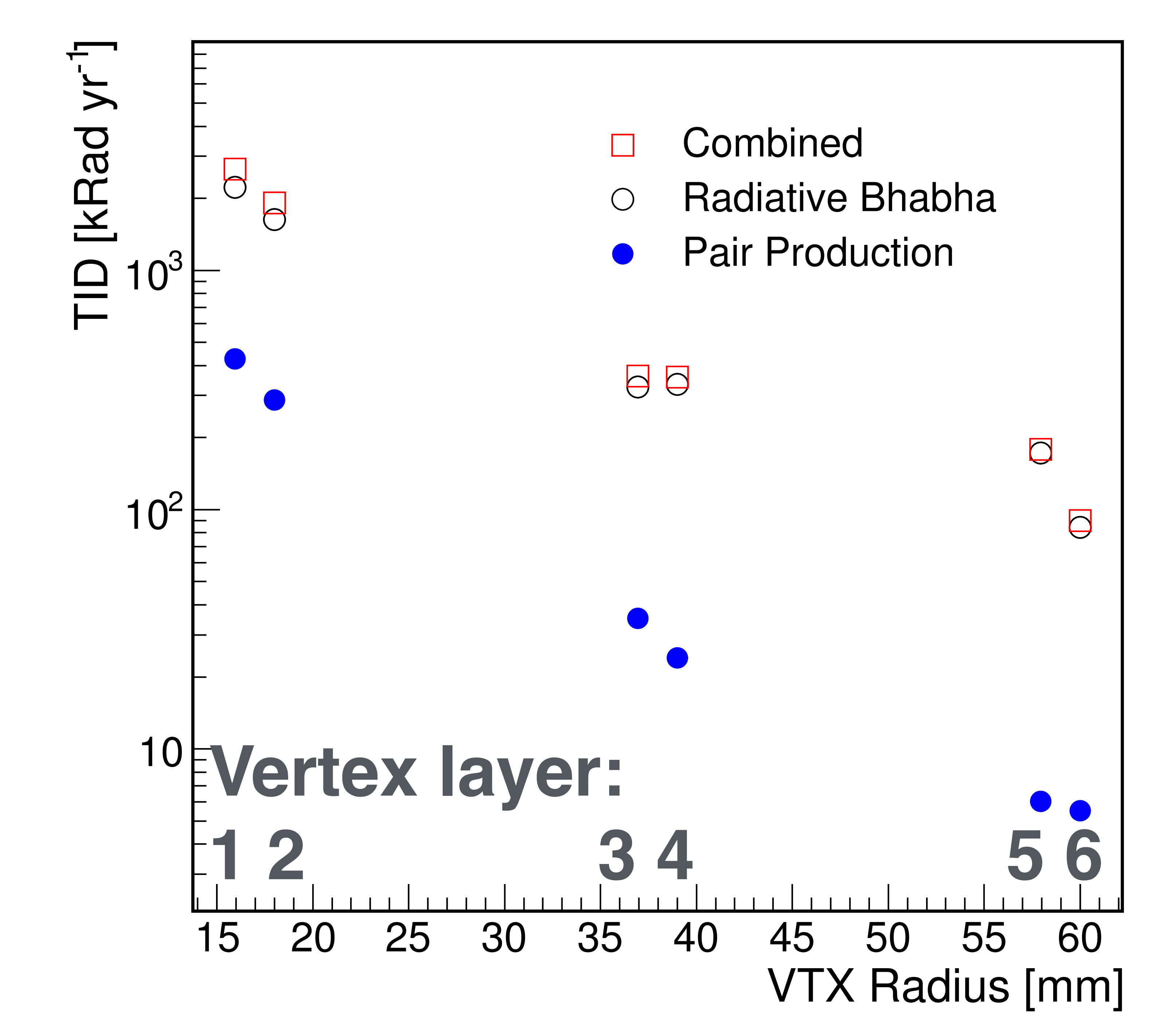
Studies for new configuration being finalized

Higgs operation
(E_{cm} = 240 GeV)

Rates at the inner layer (16 mm):
Hit density: ~2.5 hits/cm²/BX
TID: 2.5 MRad/year
NIEL: 10^{12} 1MeV n_{eq}/cm²

(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

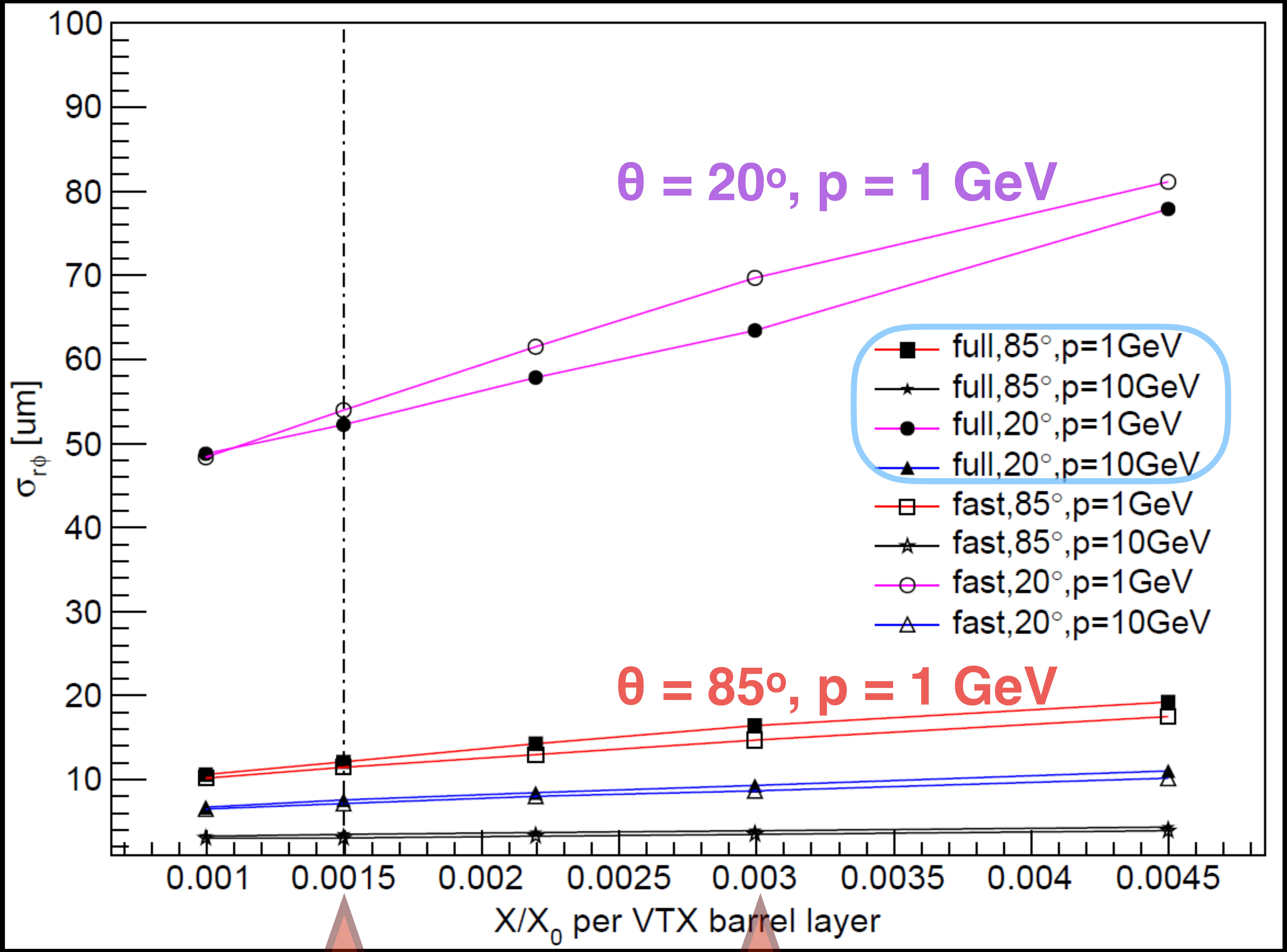
	Specs	Consequences
Single point resolution near IP:	< 3 μm	High granularity
First layer close to beam pipe:	r ~ 1.6 cm	
Material budget/layer:	≤ 0.15%X_0	Low power consumption, < 50 mW/cm² for air cooling
Detector occupancy:	≤ 1%	High granularity and short readout time (< 20 μs)

Continuous operation mode

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

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

Silicon Tracker Detector – Baseline

SET: r = ~1.8 m

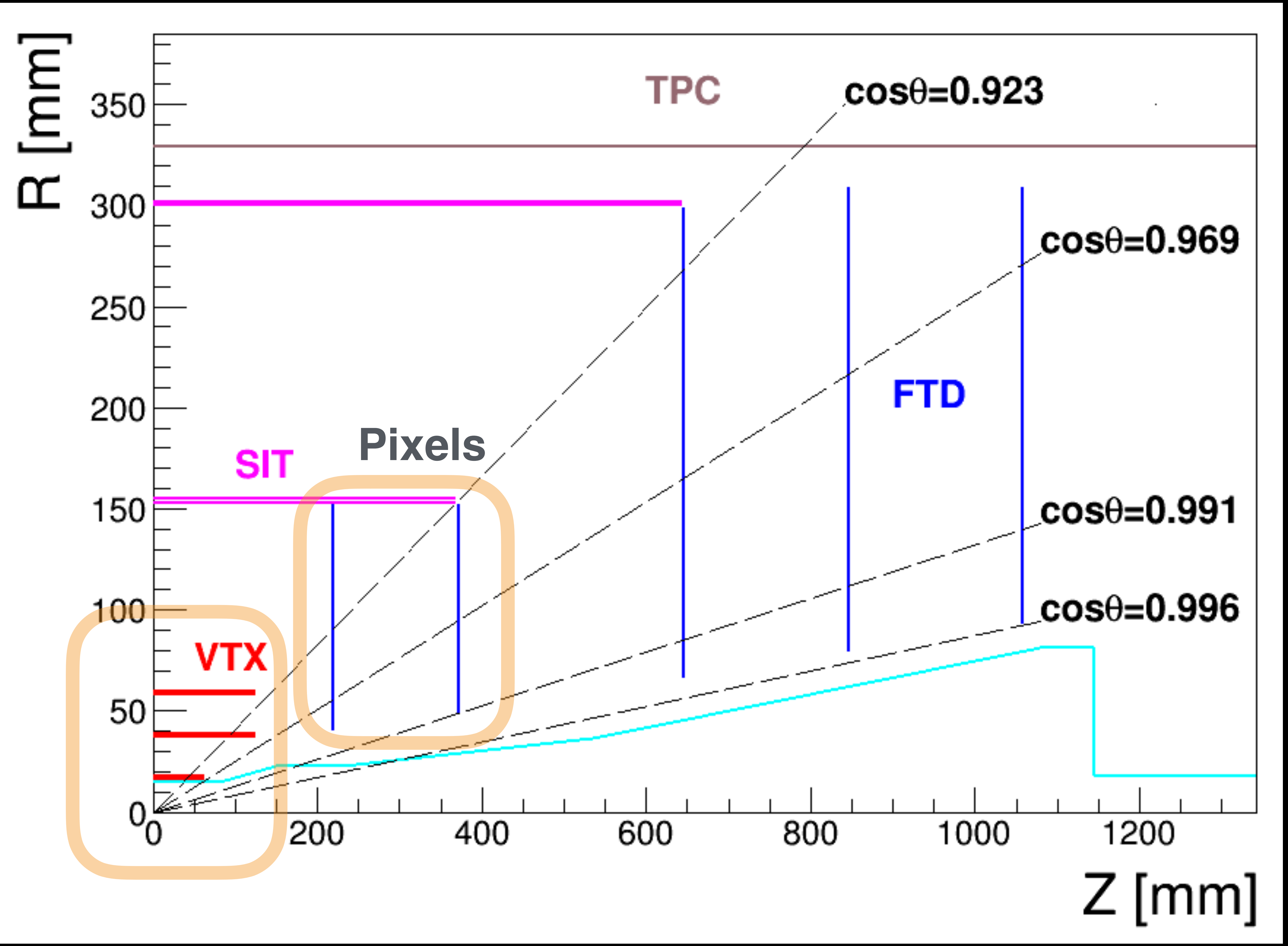
Not much R&D done so far

TPC

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

SIT

VTX



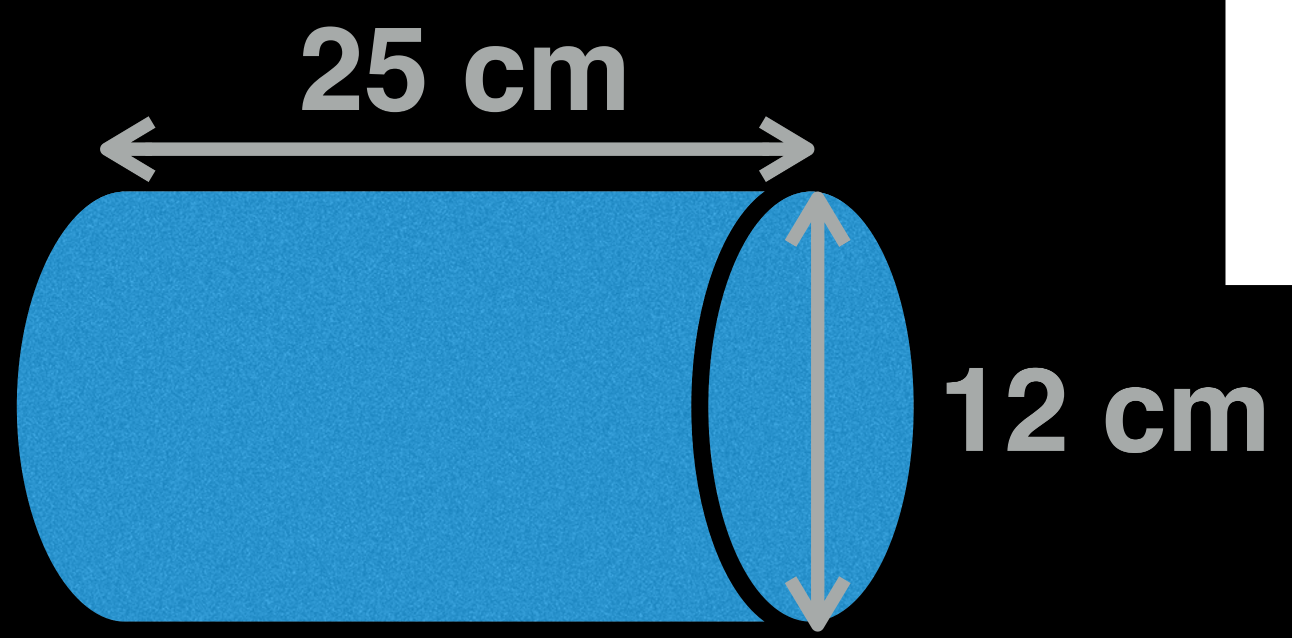
Sensor technology

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



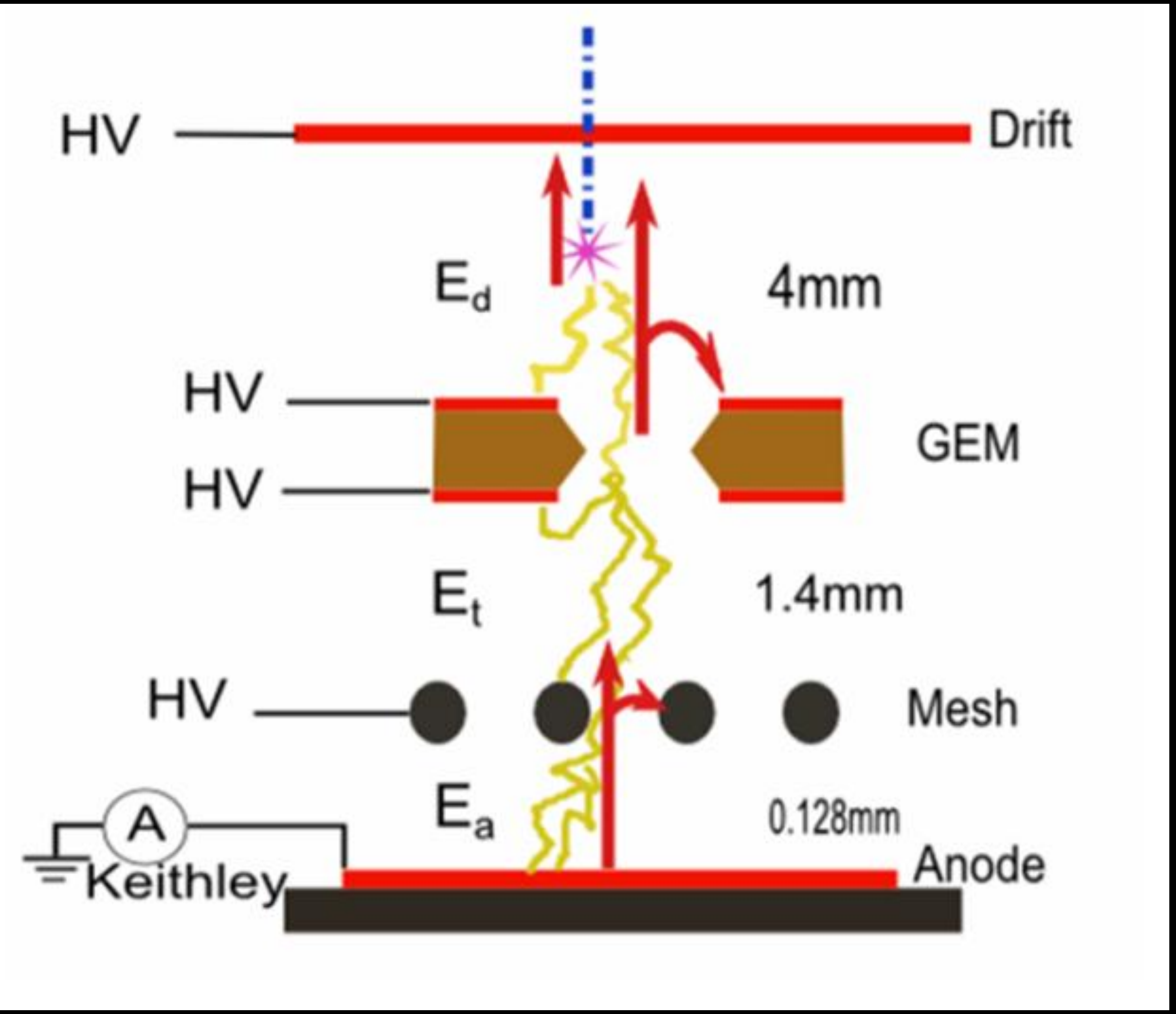
Total Silicon area ~ 68 m²

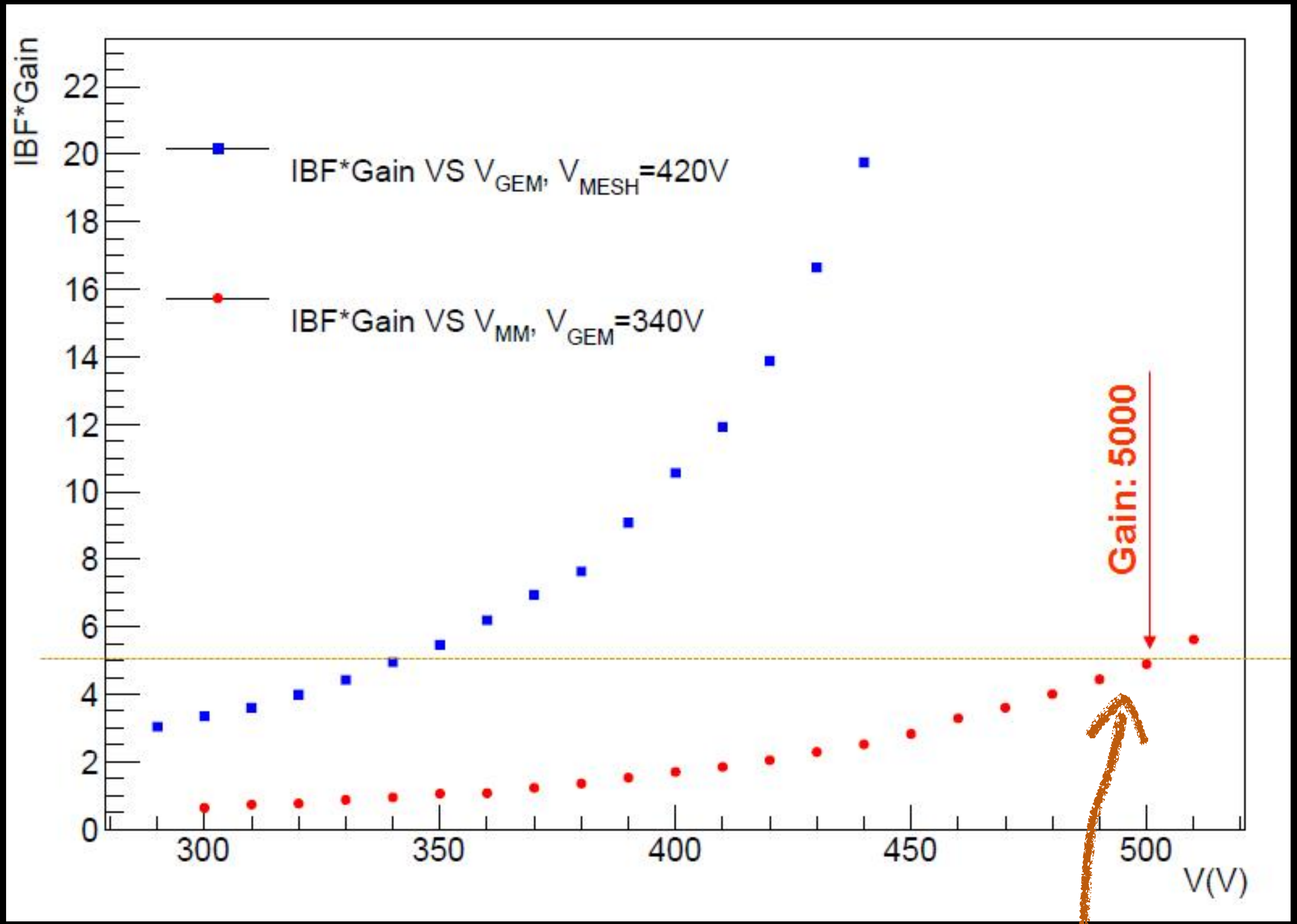
Extensive opportunities for international participation

Time Projection Chamber (TPC)

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

Lead by Italian Colleagues

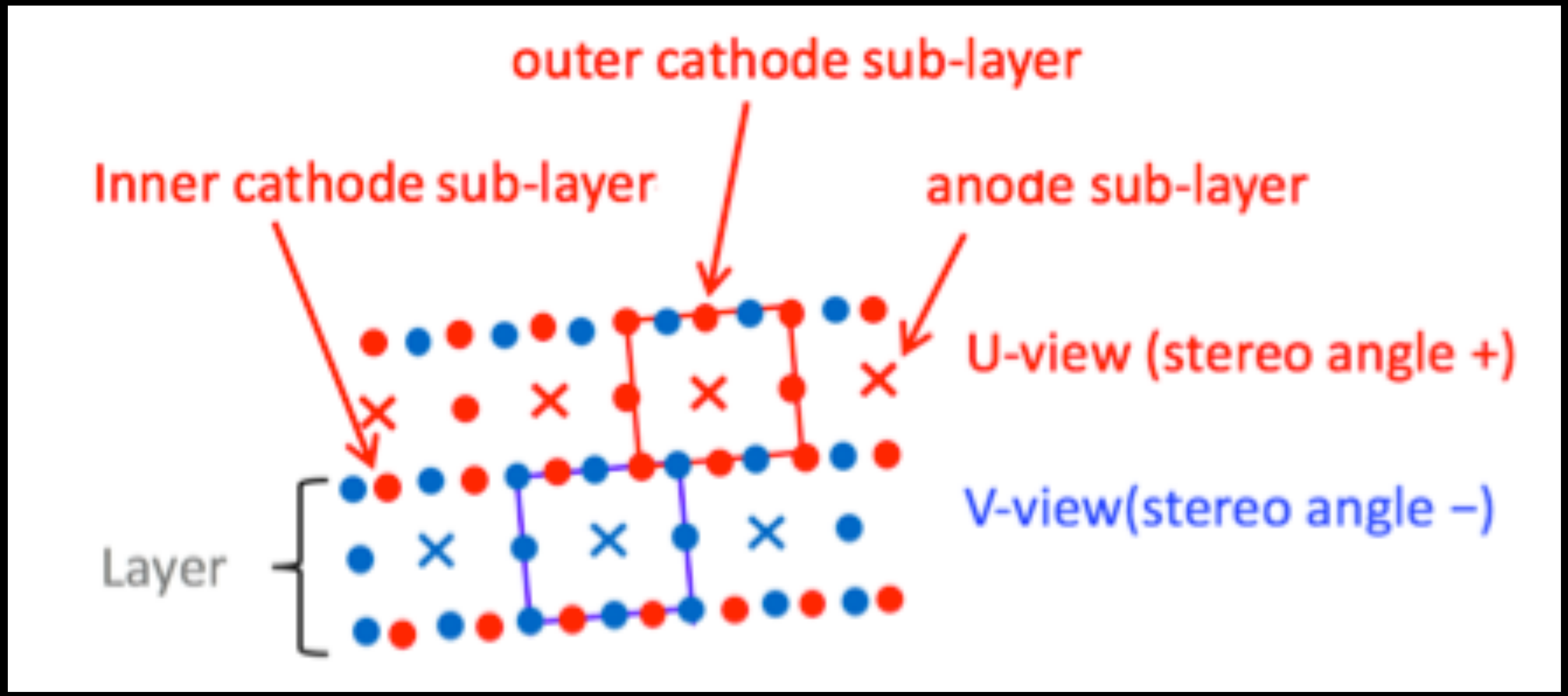
Low-mass cylindrical drift chamber

Follows design of the KLOE and MEG2 experiments

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

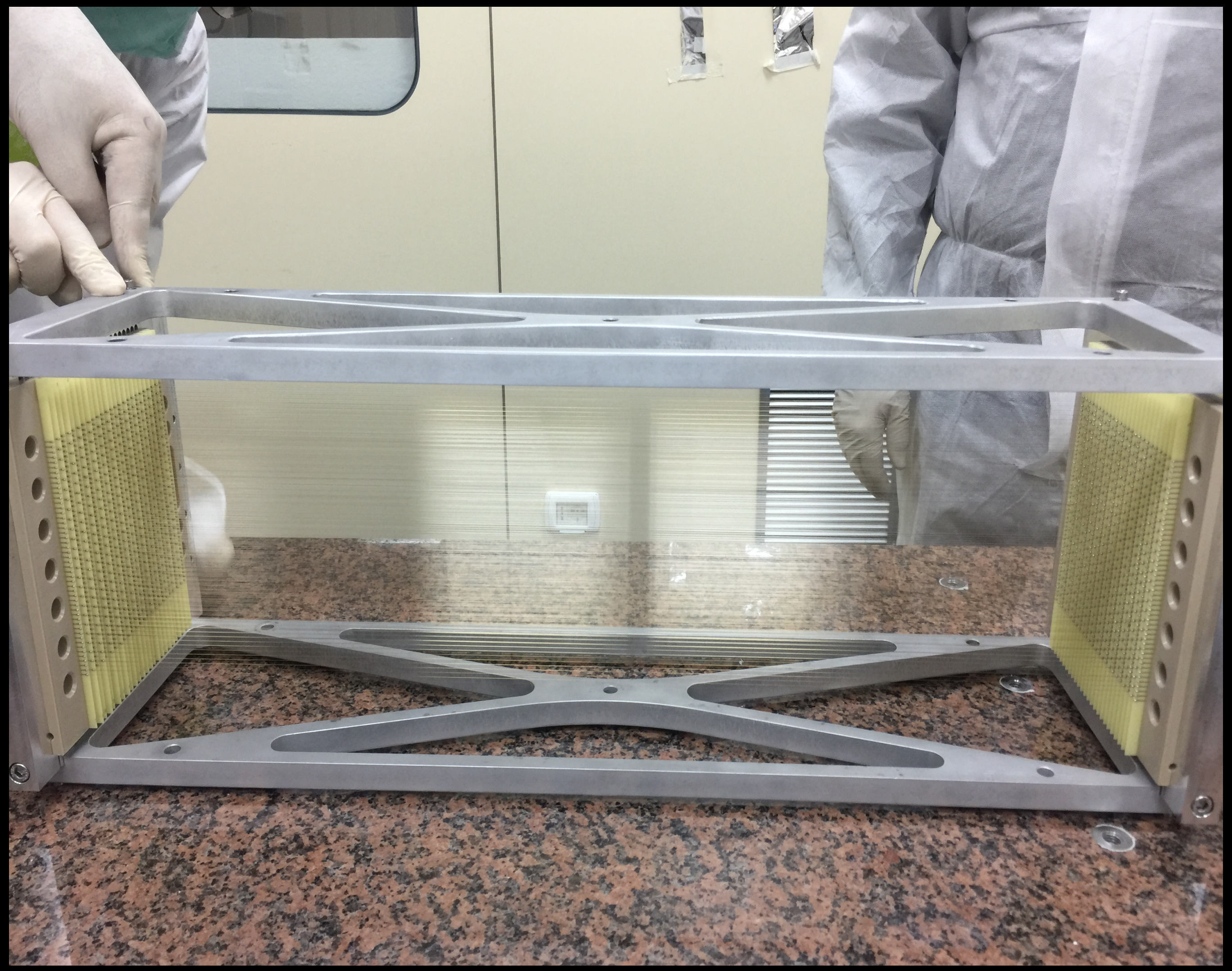
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

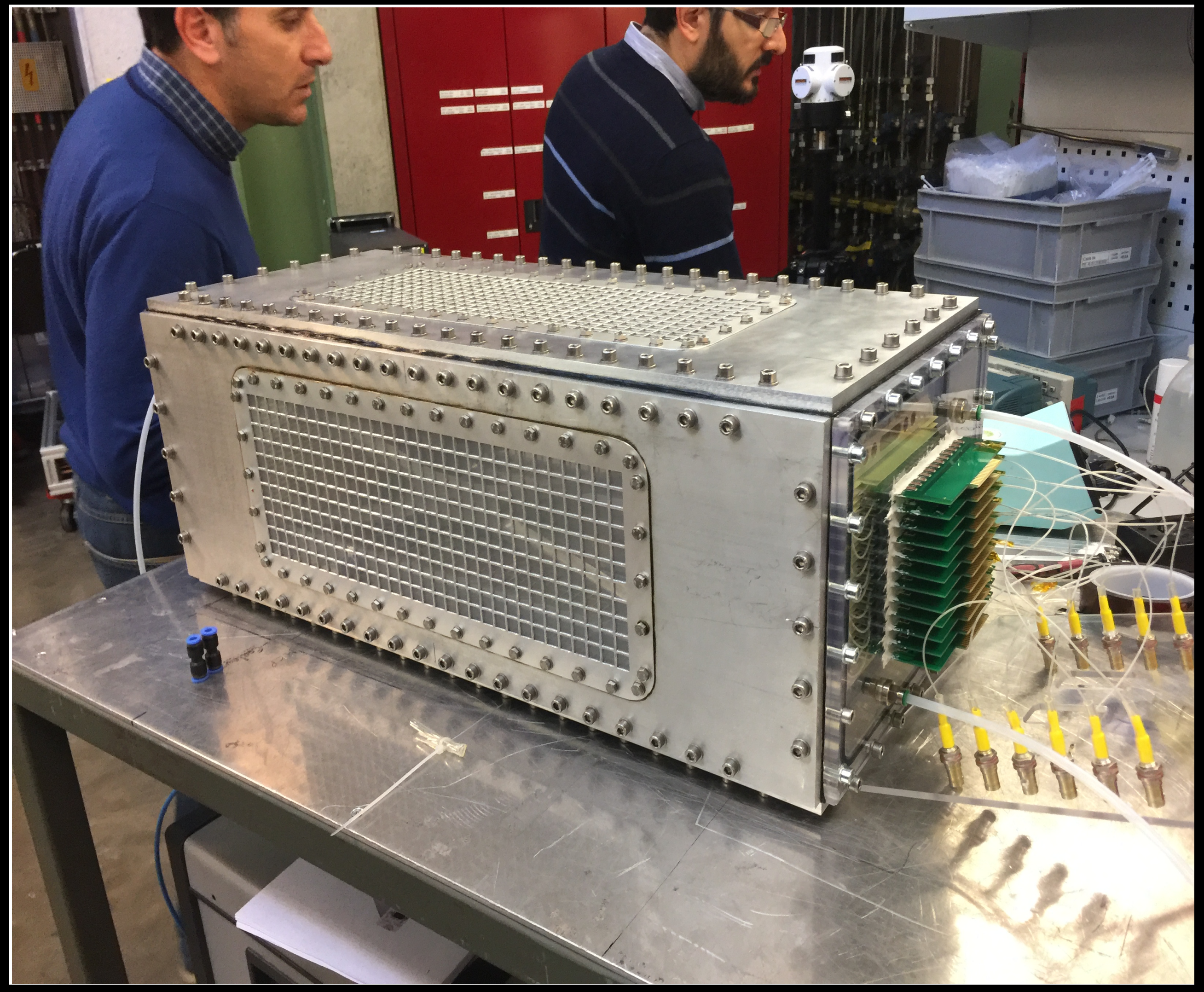
Layers: 14 SL × 8 layers = 112
Cell size: 12 - 14 mm



Stereo angle: 50-250 mrad

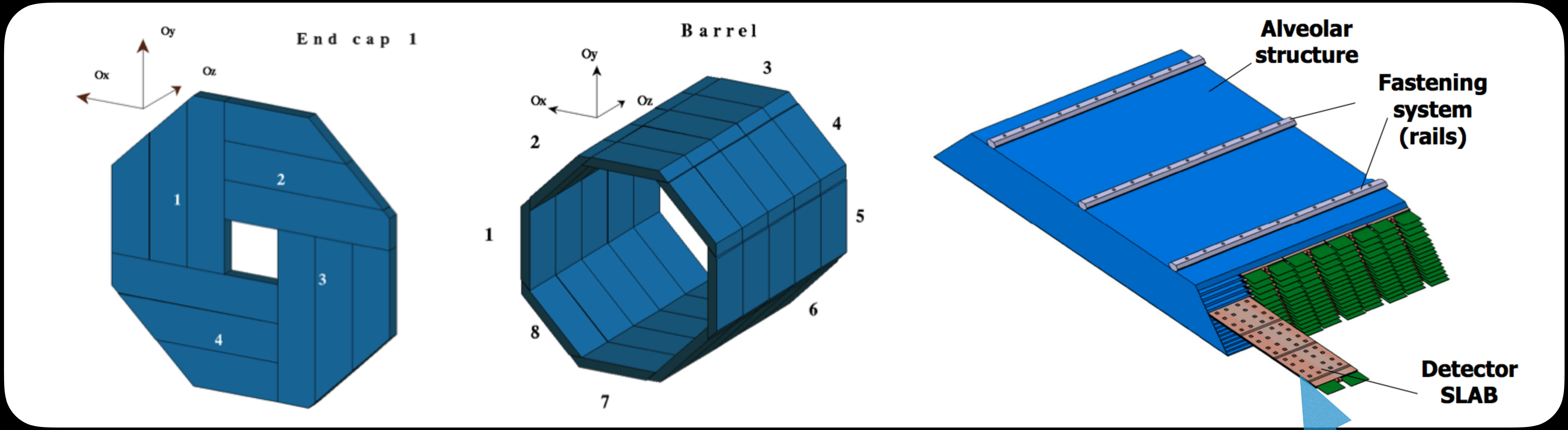
MEG2 prototype being tested





Baseline ECAL Calorimeter — Particle Flow Calorimeter

Silicon-Tungsten Sandwich ECAL



Cell size:

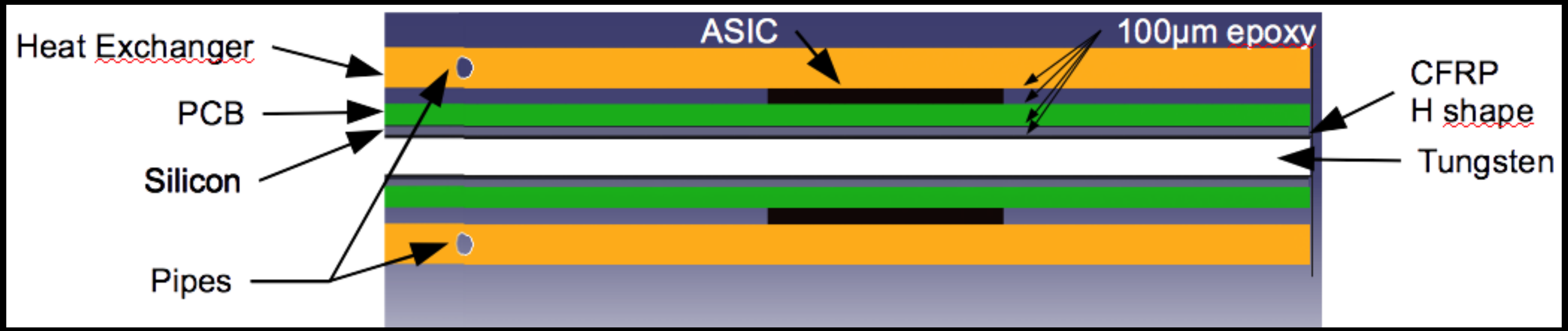
- 5 x 5 mm² - optimal for PFA
- 10 x 10 mm² - default
- 20 x 20 mm² - required for passive cooling

high granularity —> active cooling

Sensor: high-resistivity silicon pin diodes

- Stability
- Uniformity
- Flexibility
- High S/N

CO_2 Active cooling



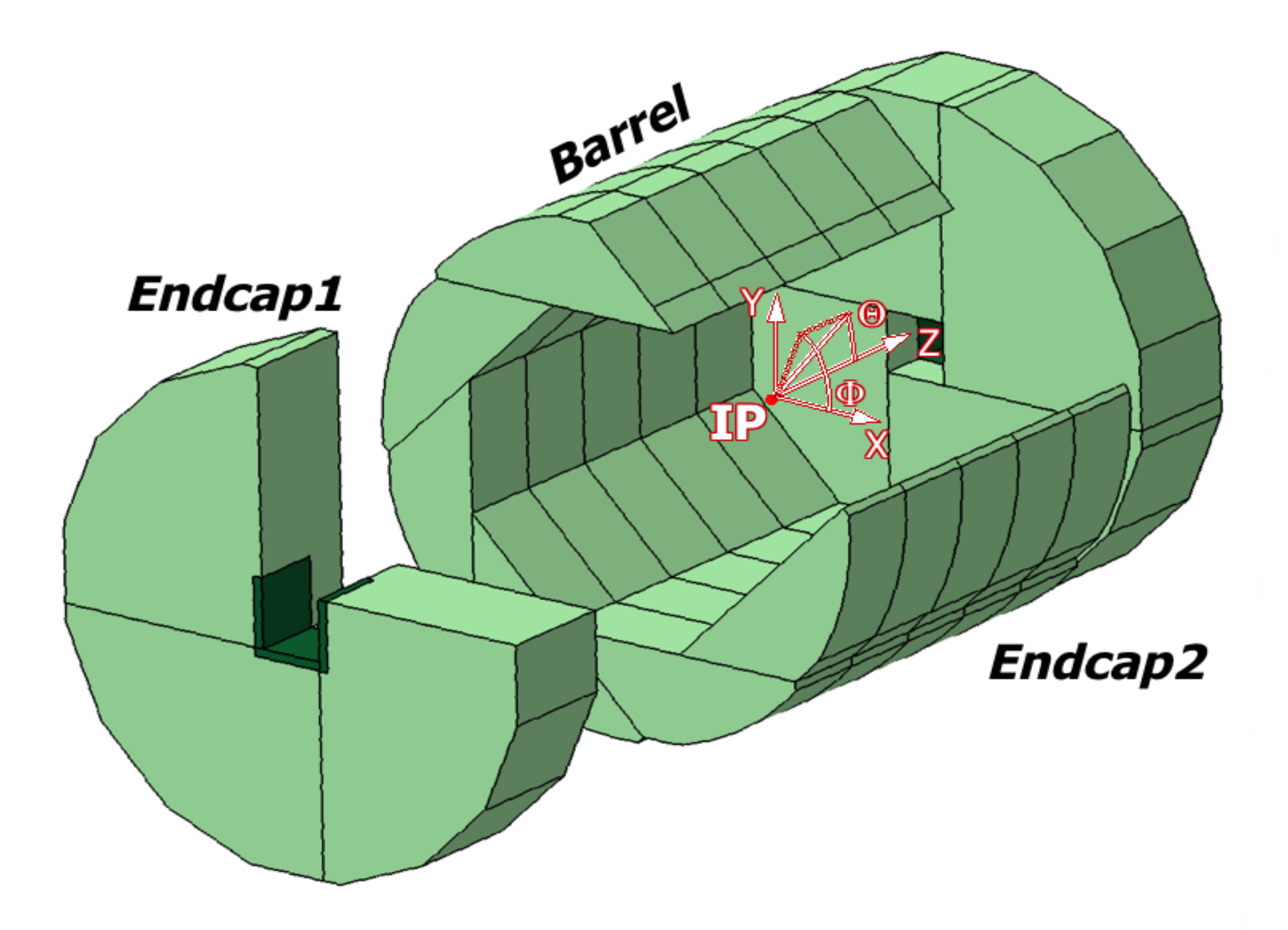
Preliminary simulation: ΔT ~ 2° C (HGCAL/ILD)

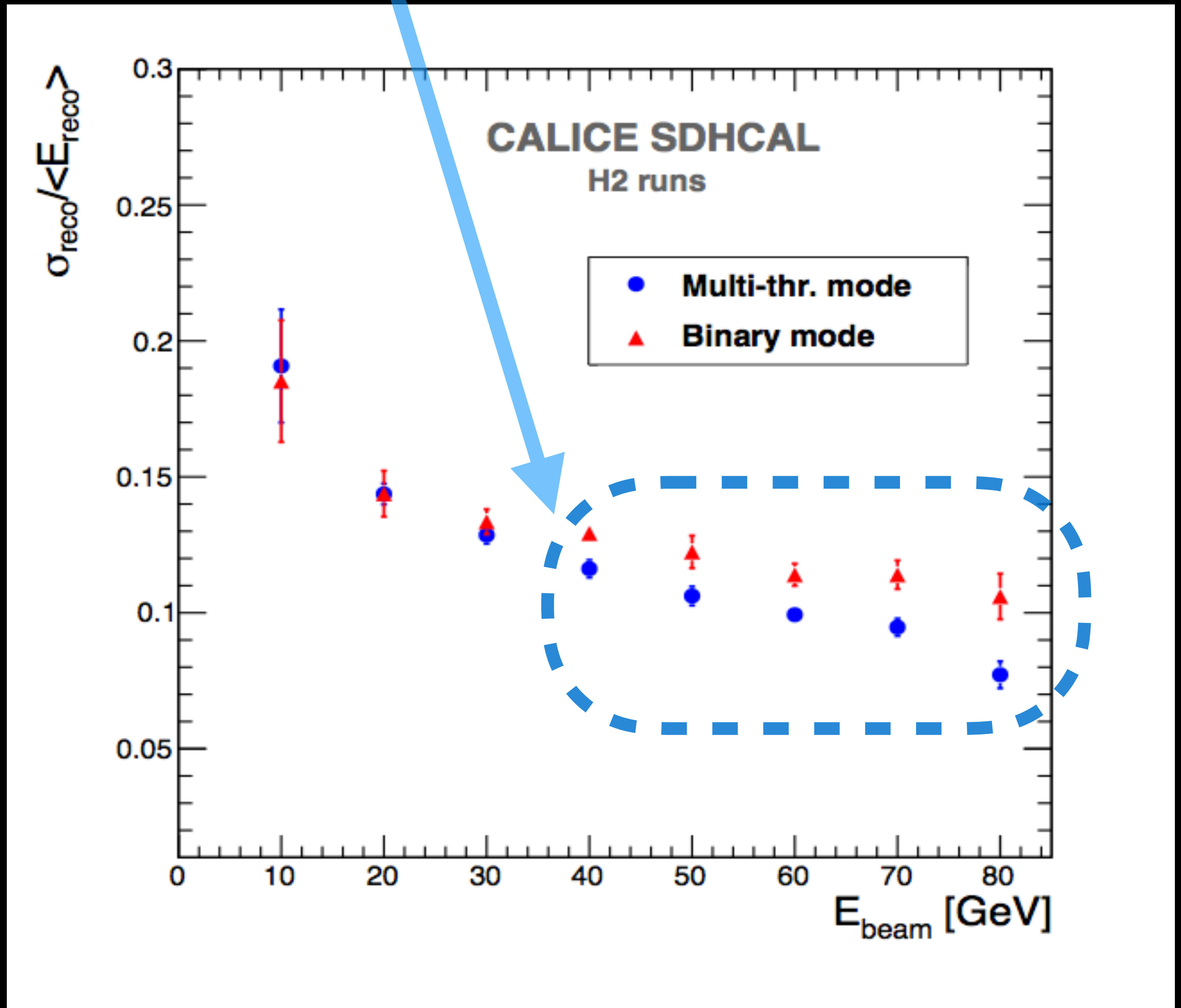
Baseline HCAL Calorimeter — Particle Flow Calorimeter

Semi-Digital HCAL

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

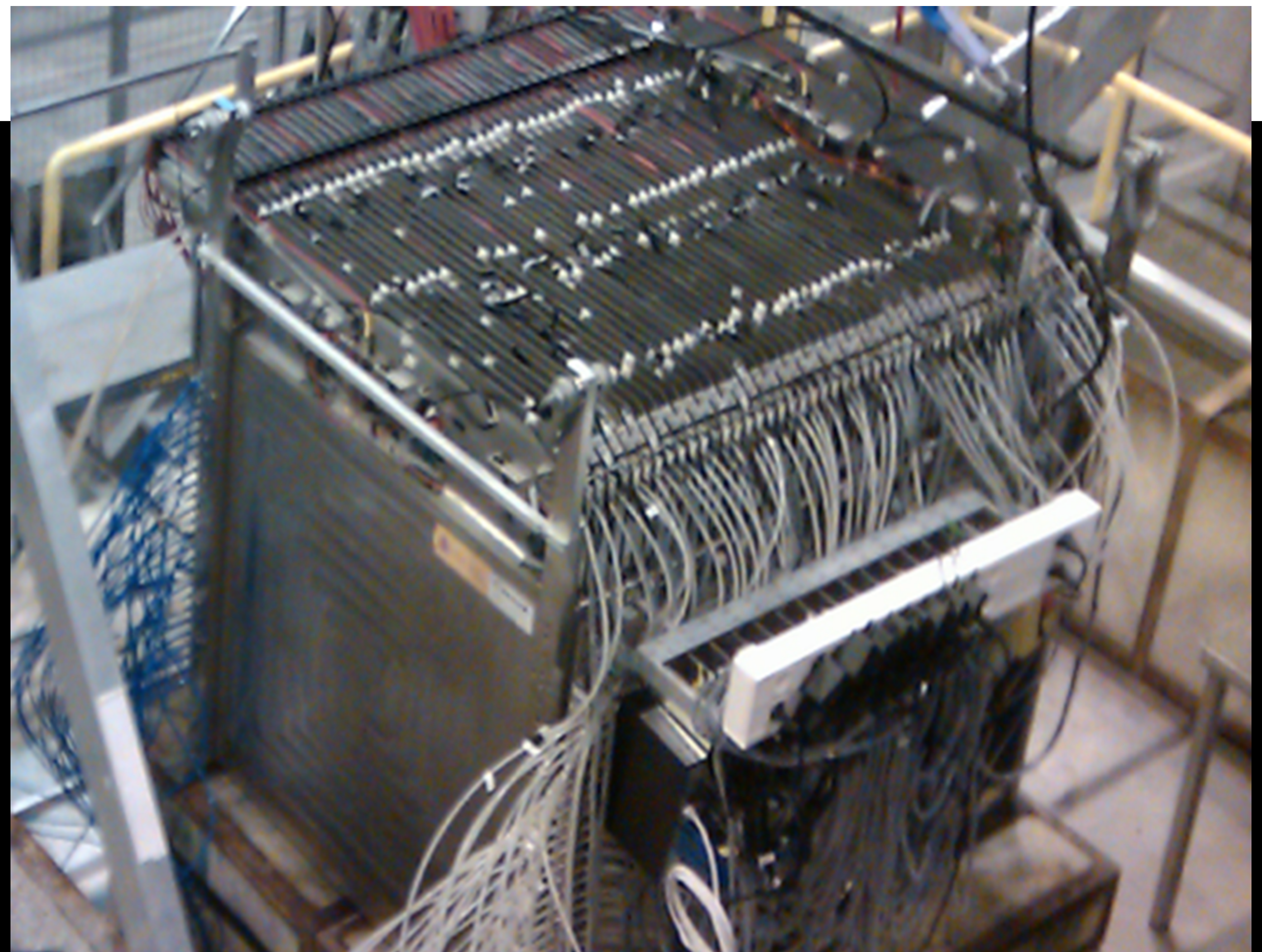
Challenges
- Power consumption —> temperature
- Large amount of services/cables

Baseline HCAL Calorimeter — Particle Flow Calorimeter

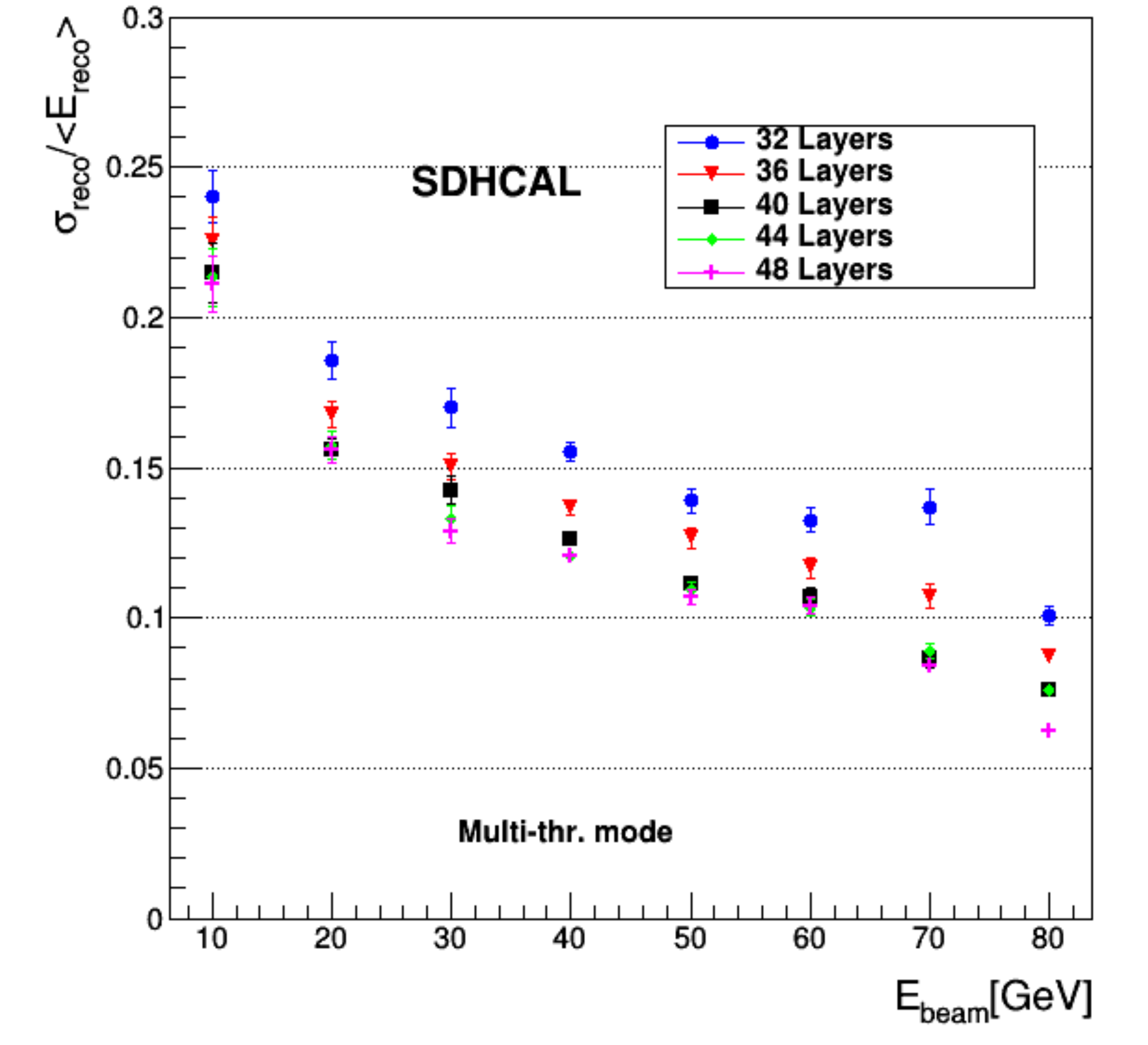
Semi-Digital gRPC HCAL

gRPC: Glass RPC

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



Prototype: 48 layers



40 layers
resolution similar to
48 layers

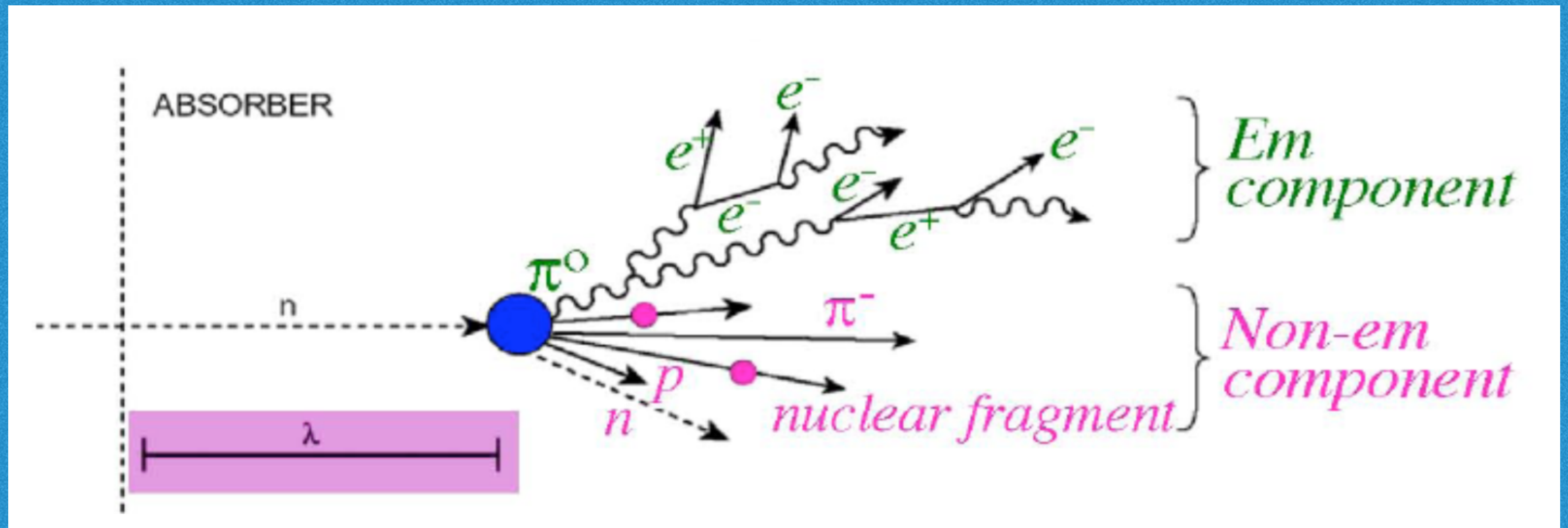
6mm gRPC + 20mm absorber

Dual Readout Calorimeter

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:

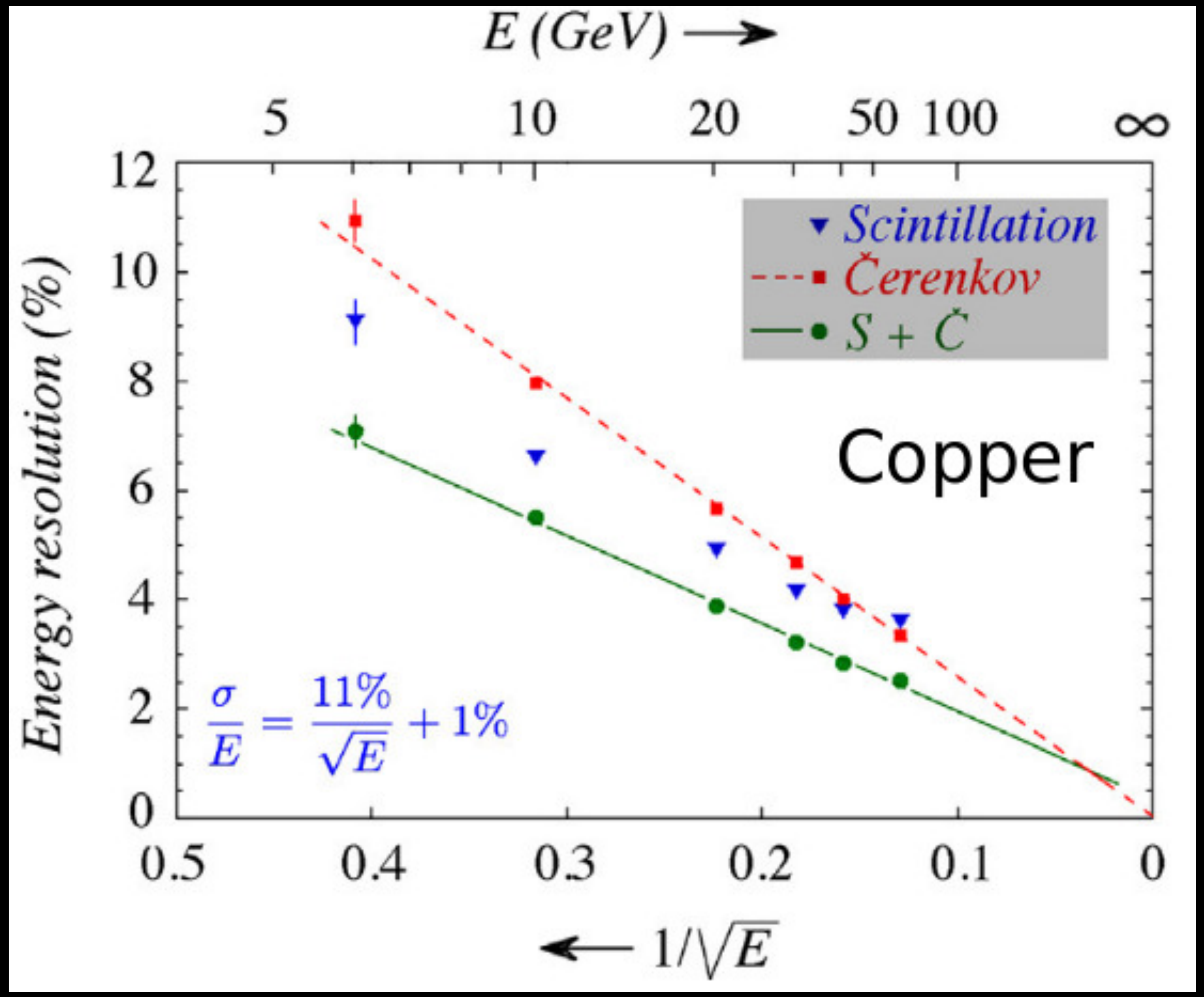
Cherenkov light (sensitive to relativistic particles)
Scintillator light (sensitive to total deposited energy)

Expected resolution:

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

Several prototypes from RD52 have been built

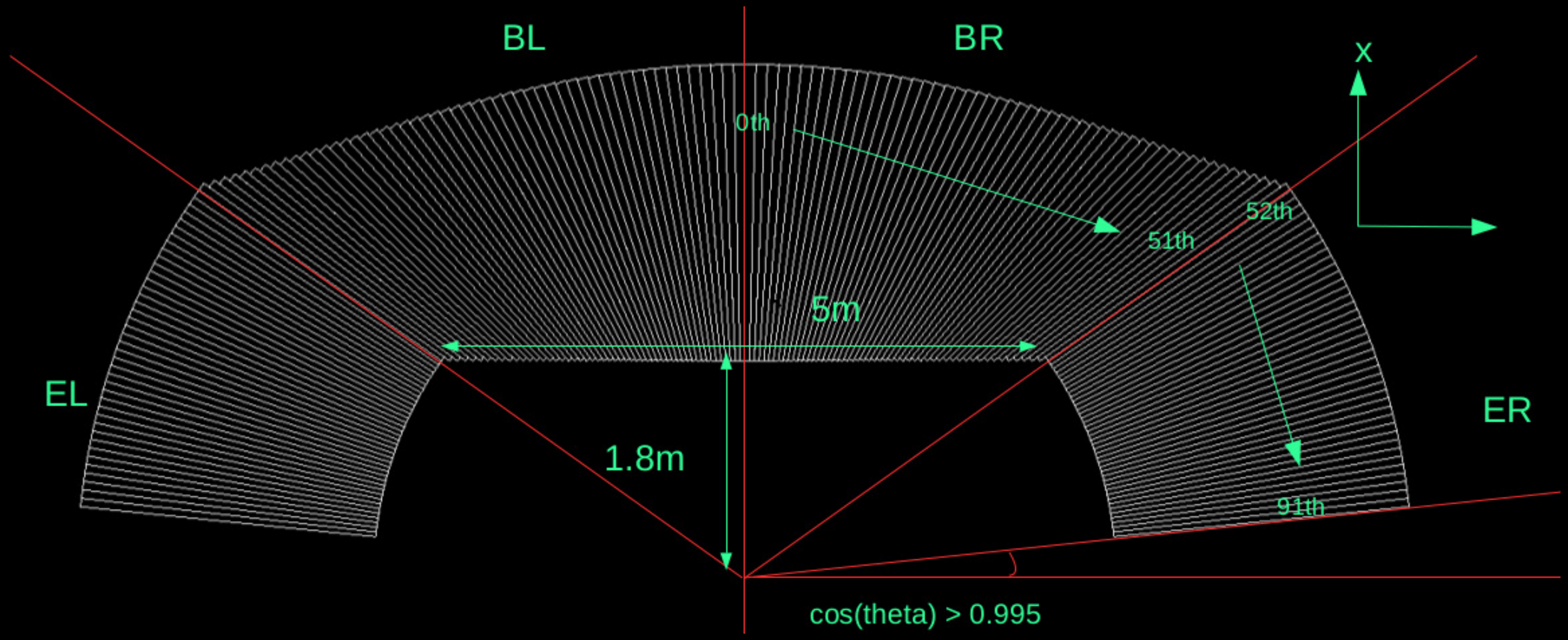
Energy resolution for electrons



Dual Readout Calorimeter

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

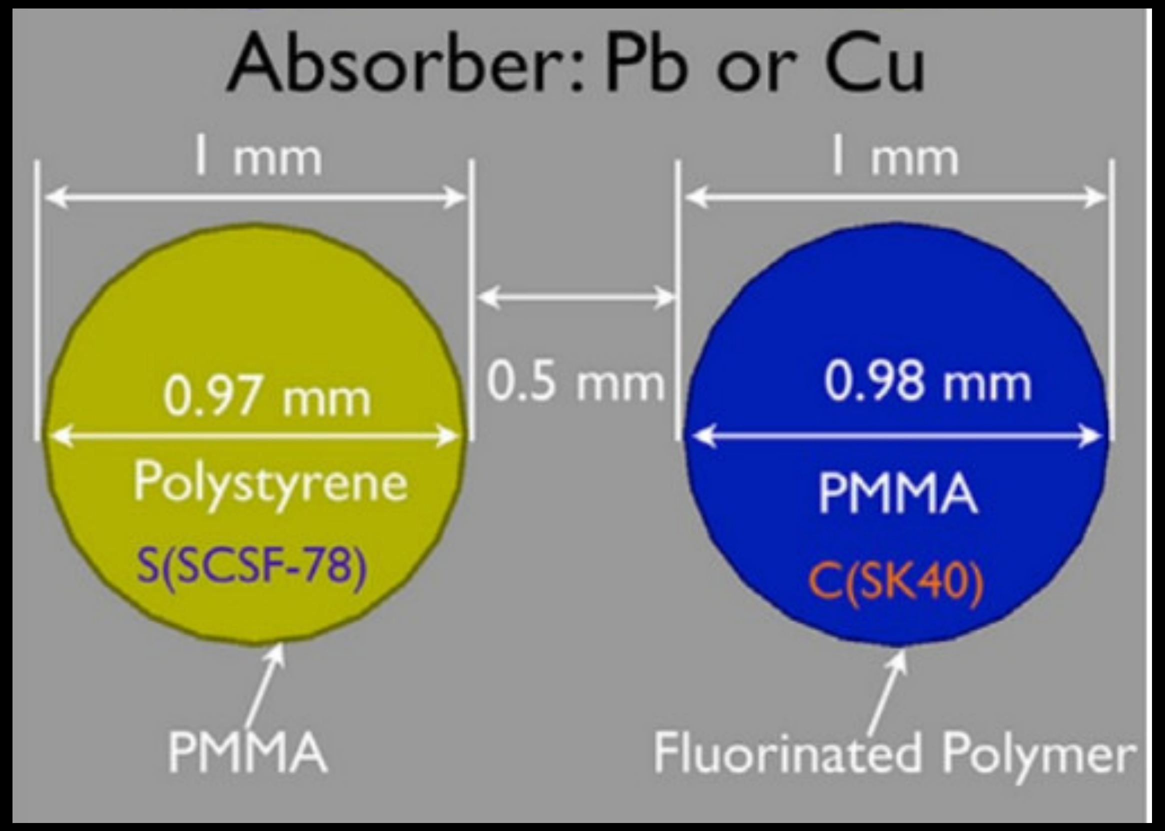
Projective 4π layout implemented into CEPC simulation
(based on 4th Detector Collaboration design)



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)

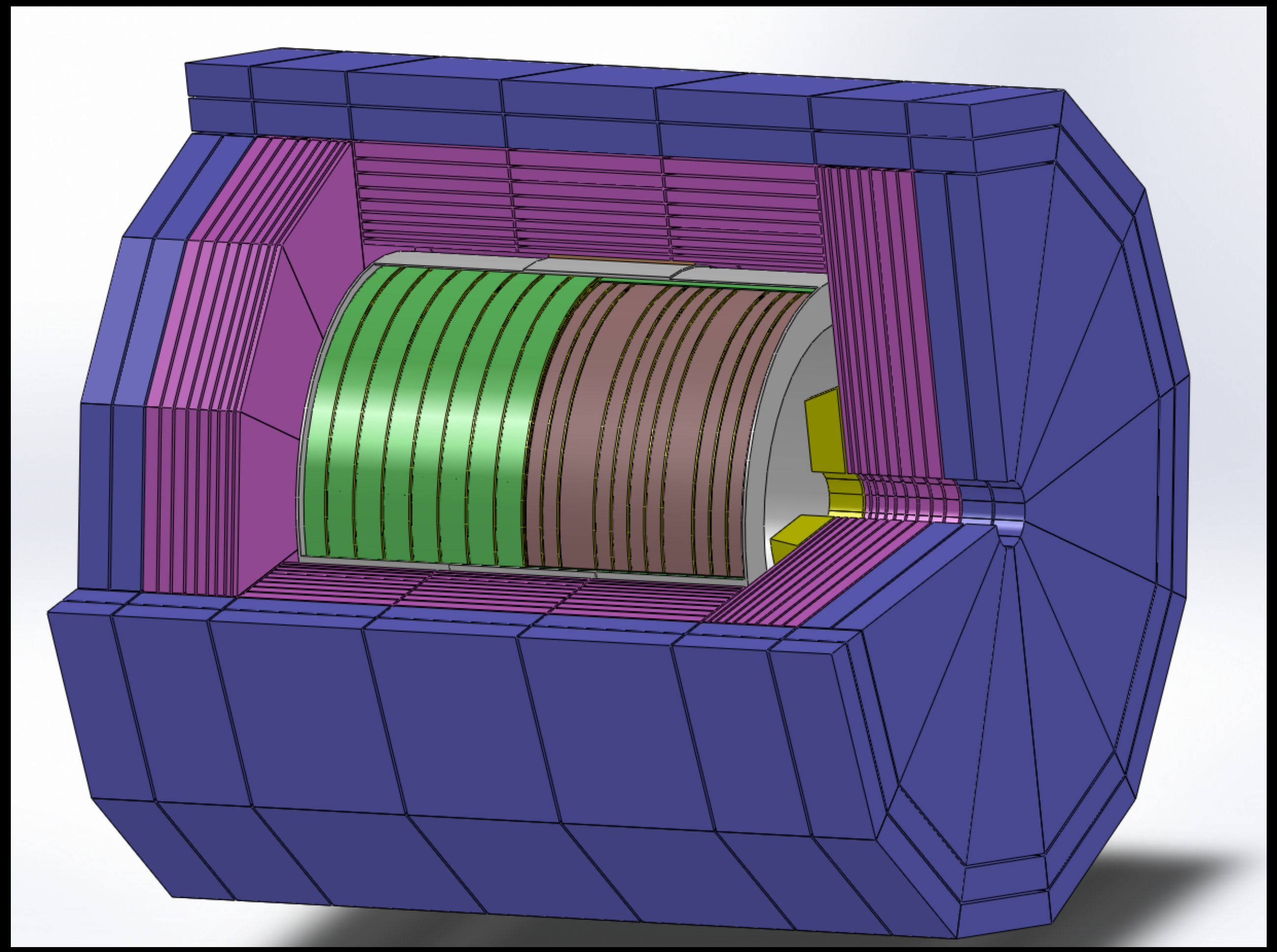


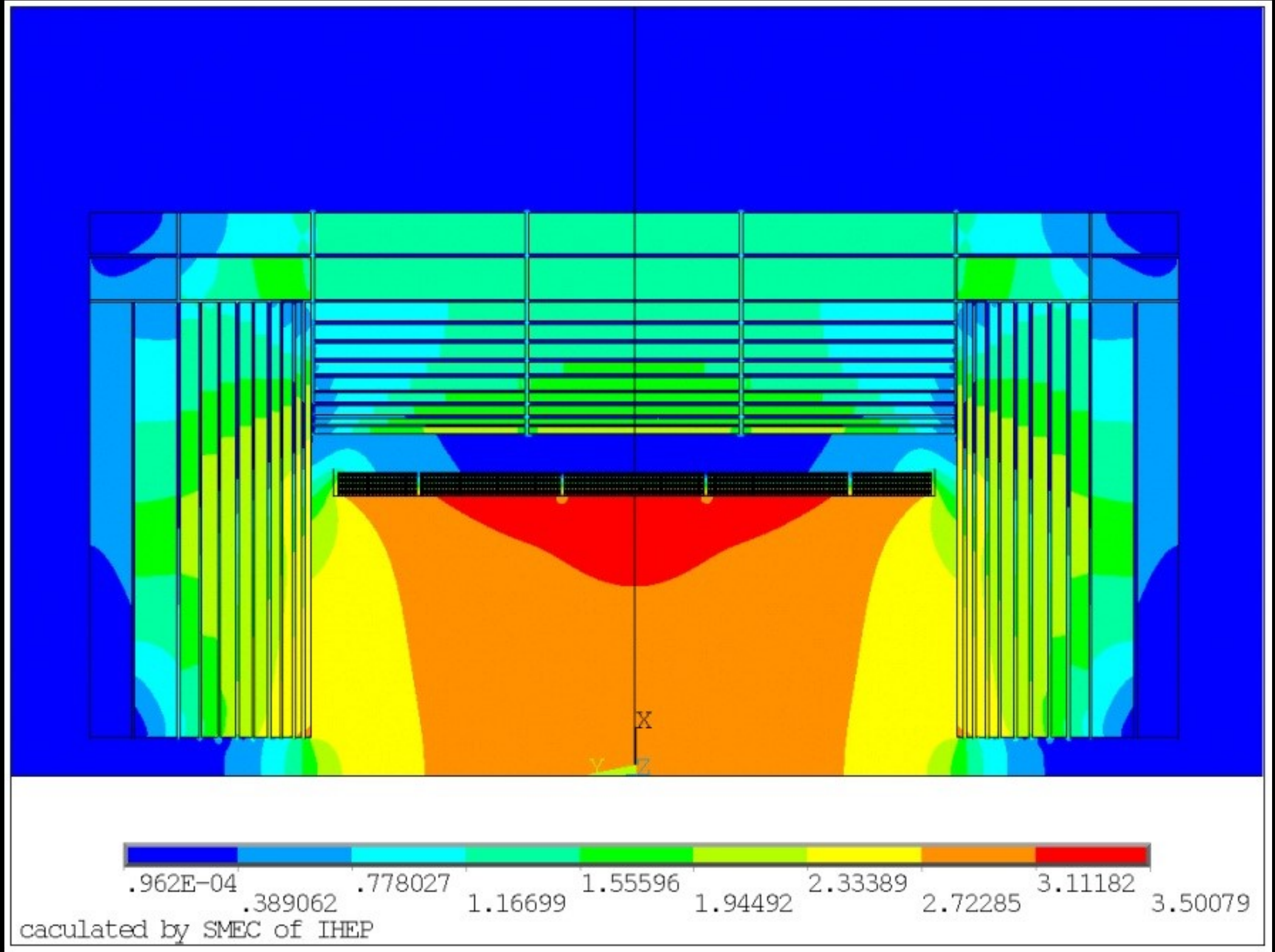
Studying different readout schemes
PMT vs SiPM

Superconductor solenoid development

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

Default: Iron Yoke



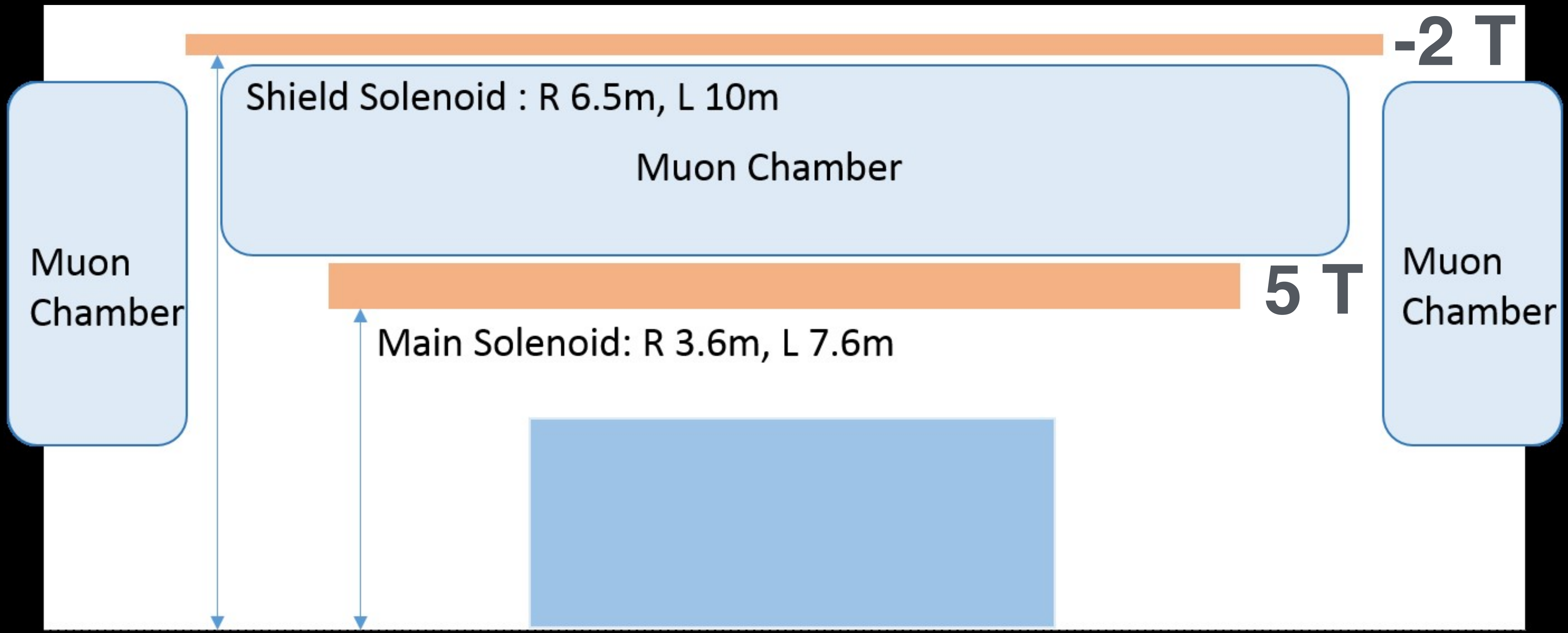


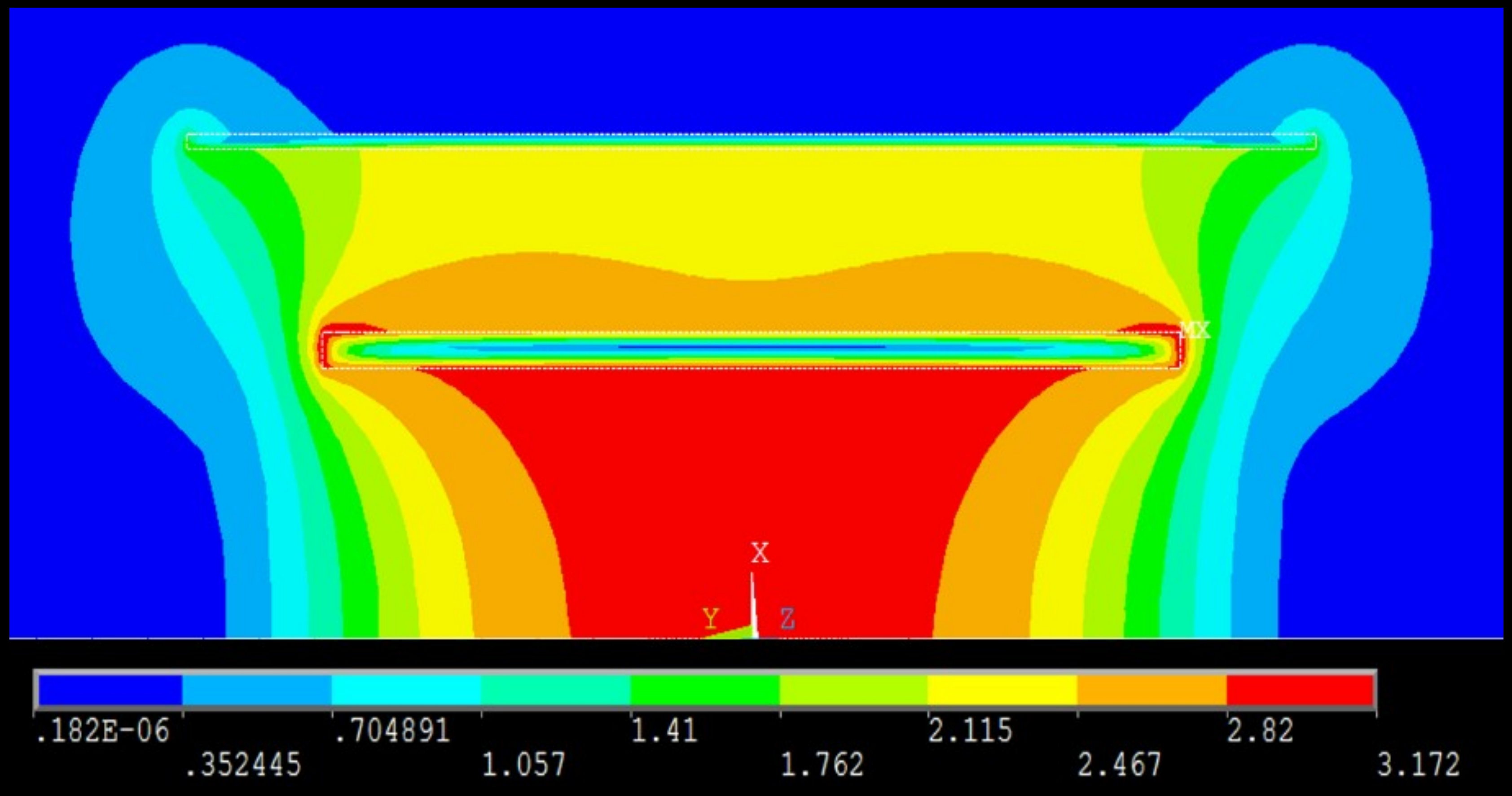
Non-uniformity	9.1%

Dual Solenoid Scenario

Lighter and more compact

Concept improved by FCC studies

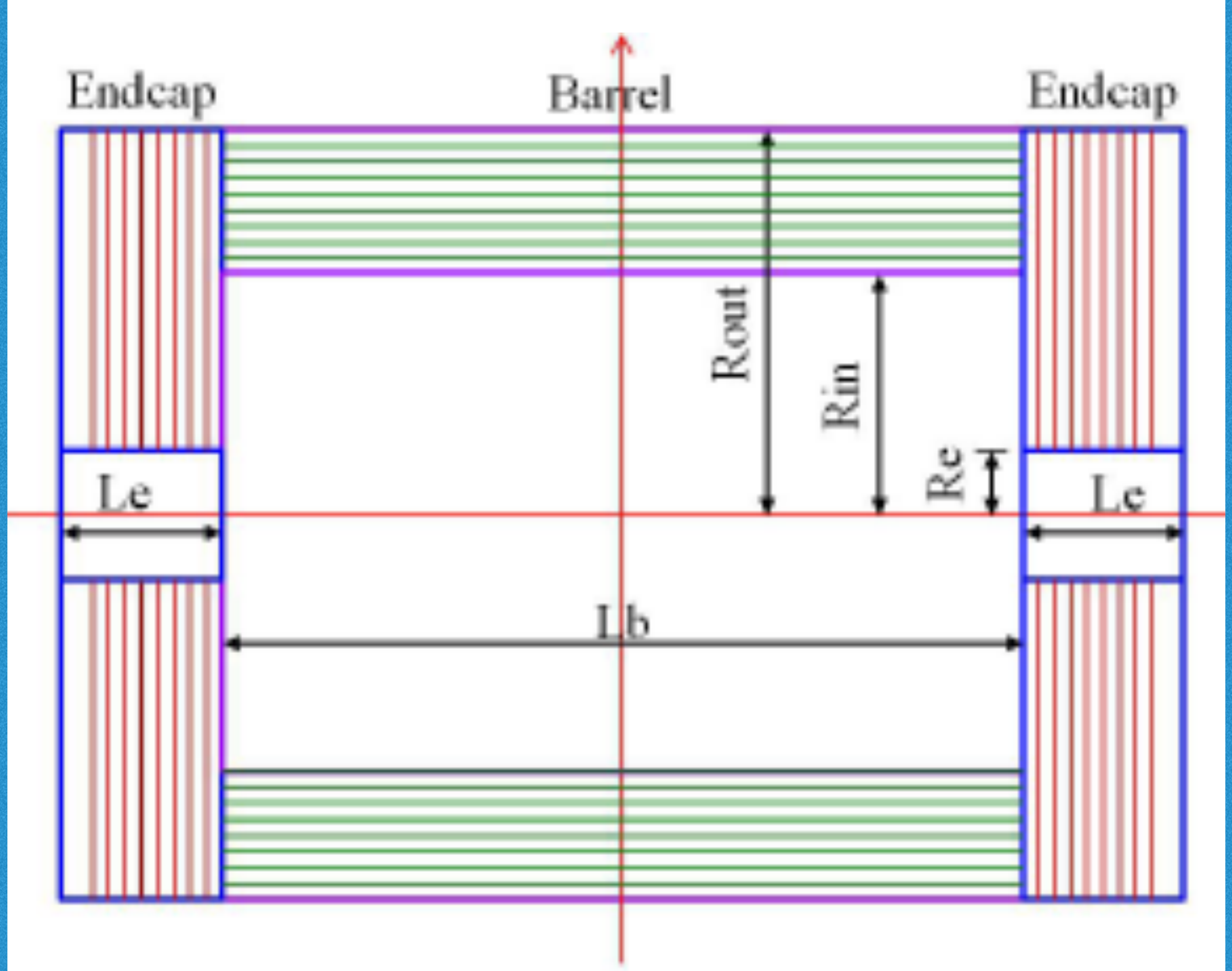




Muon detector

Baseline Muon detector

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

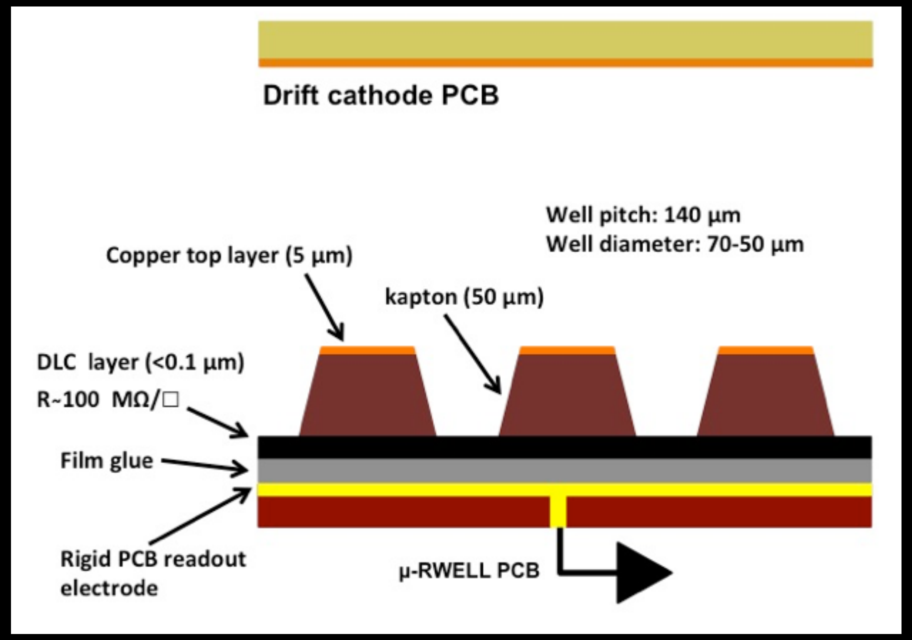


Technologies considered

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**

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%.

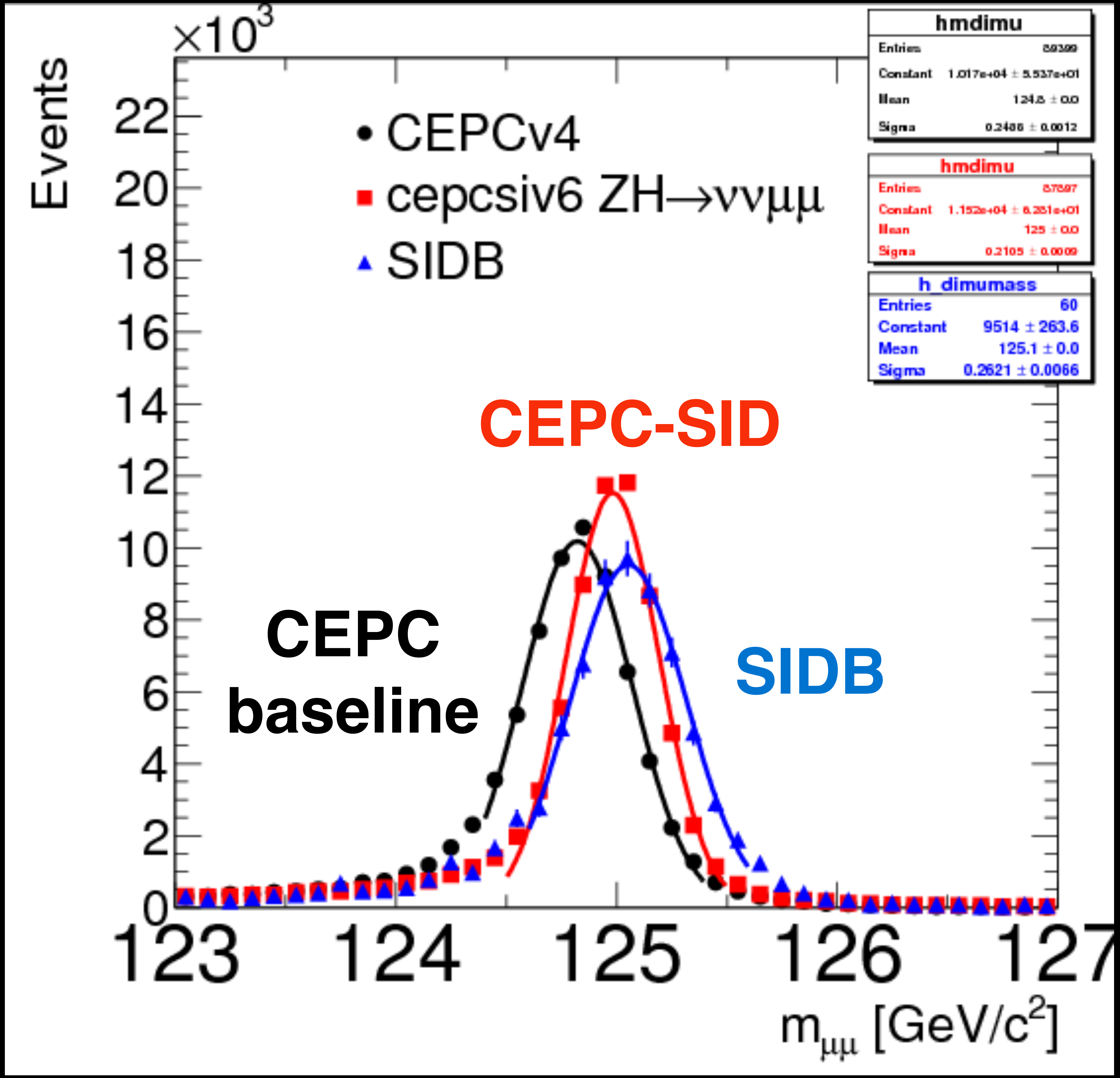
Ministry of Science and Technology – Funding 1

- 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

Full silicon tracker concept

Replace TPC with additional silicon layers

CEPC Baseline σ = 0.24 GeV



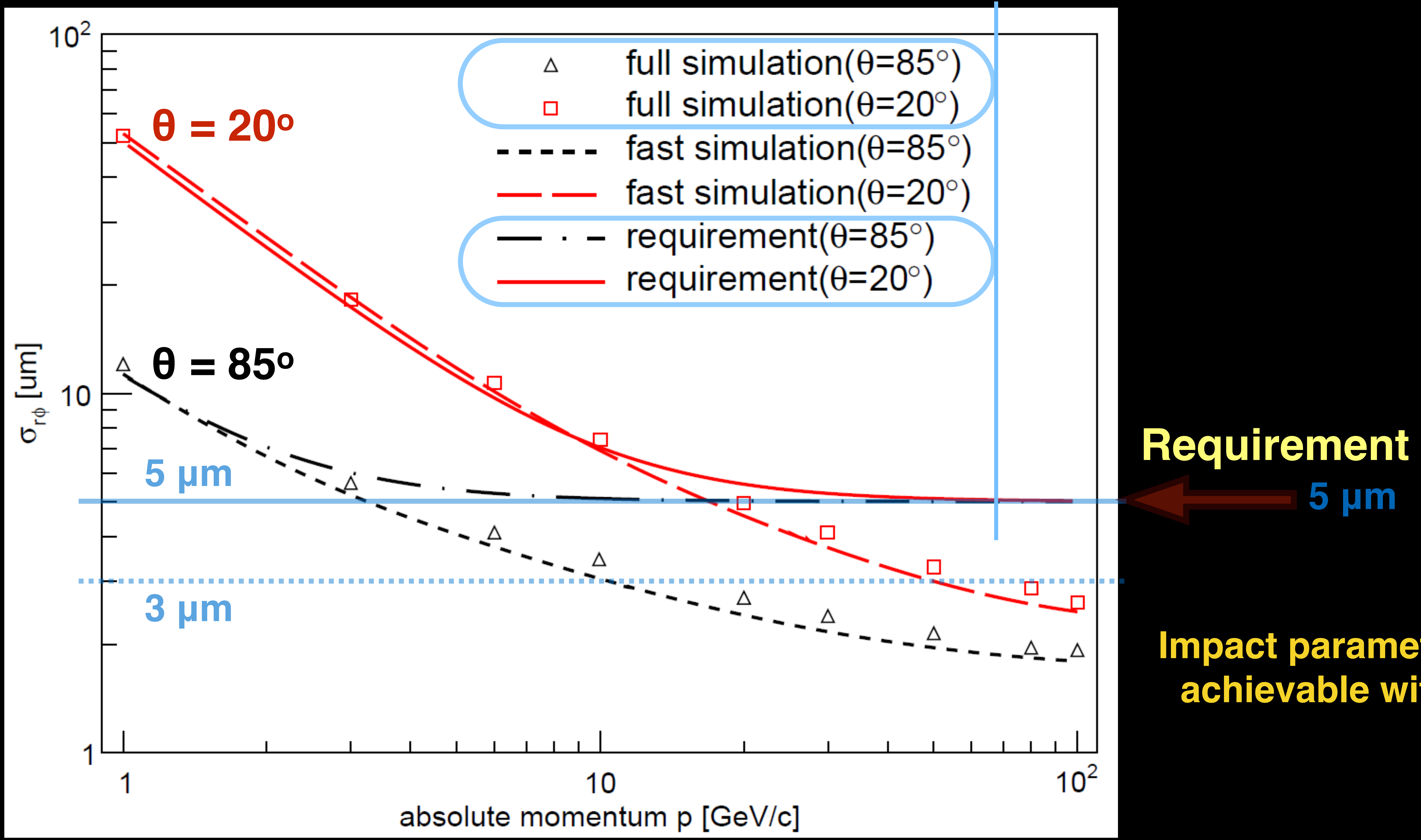
CEPC-SID: σ = 0.21 GeV

SIDB: σ = 0.26 GeV

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

Performance studies: Impact parameter resolution

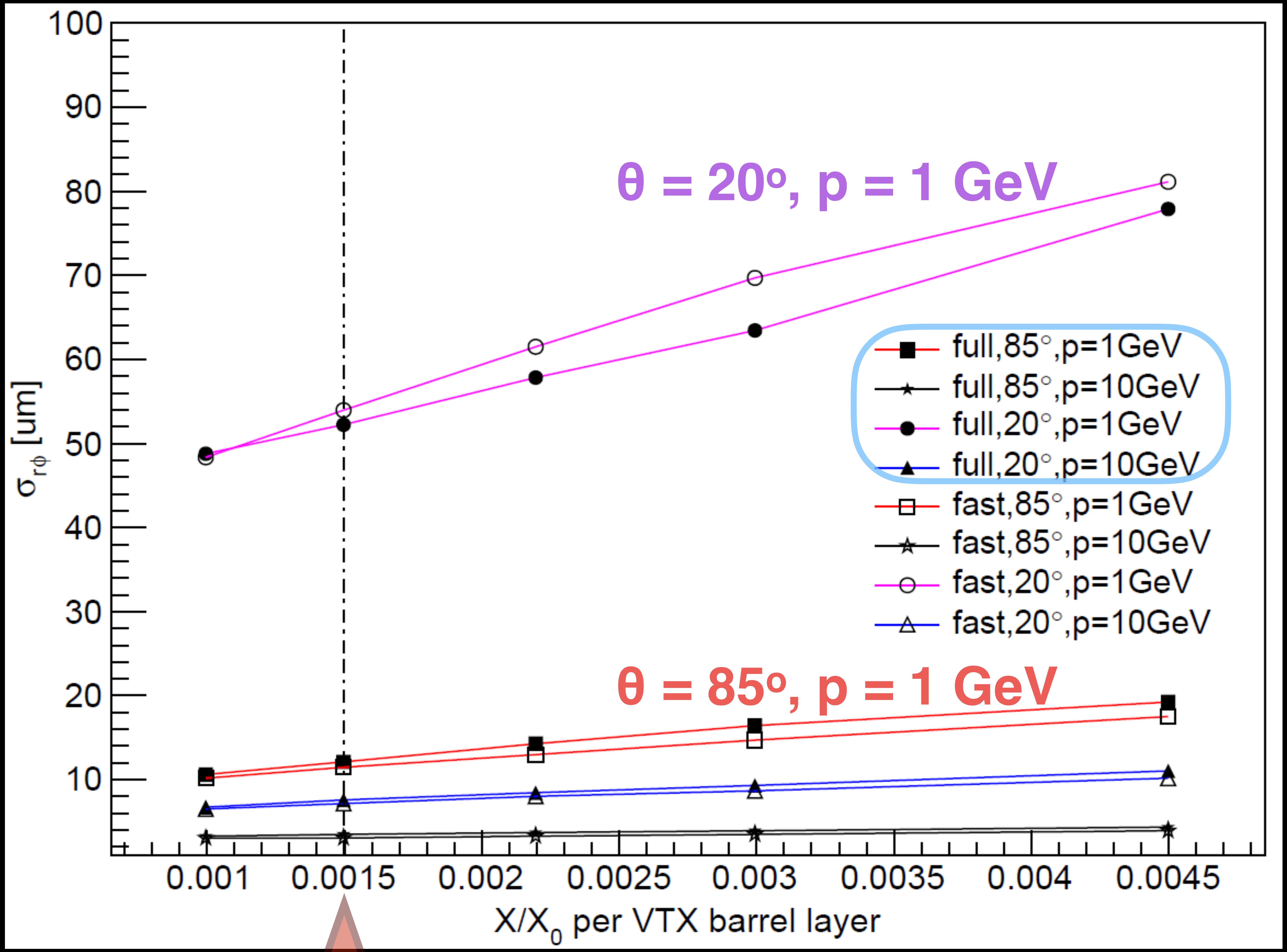
Transverse impact parameter resolution for single muons



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 $\leq 0.15\% X_0$

× 2 more material

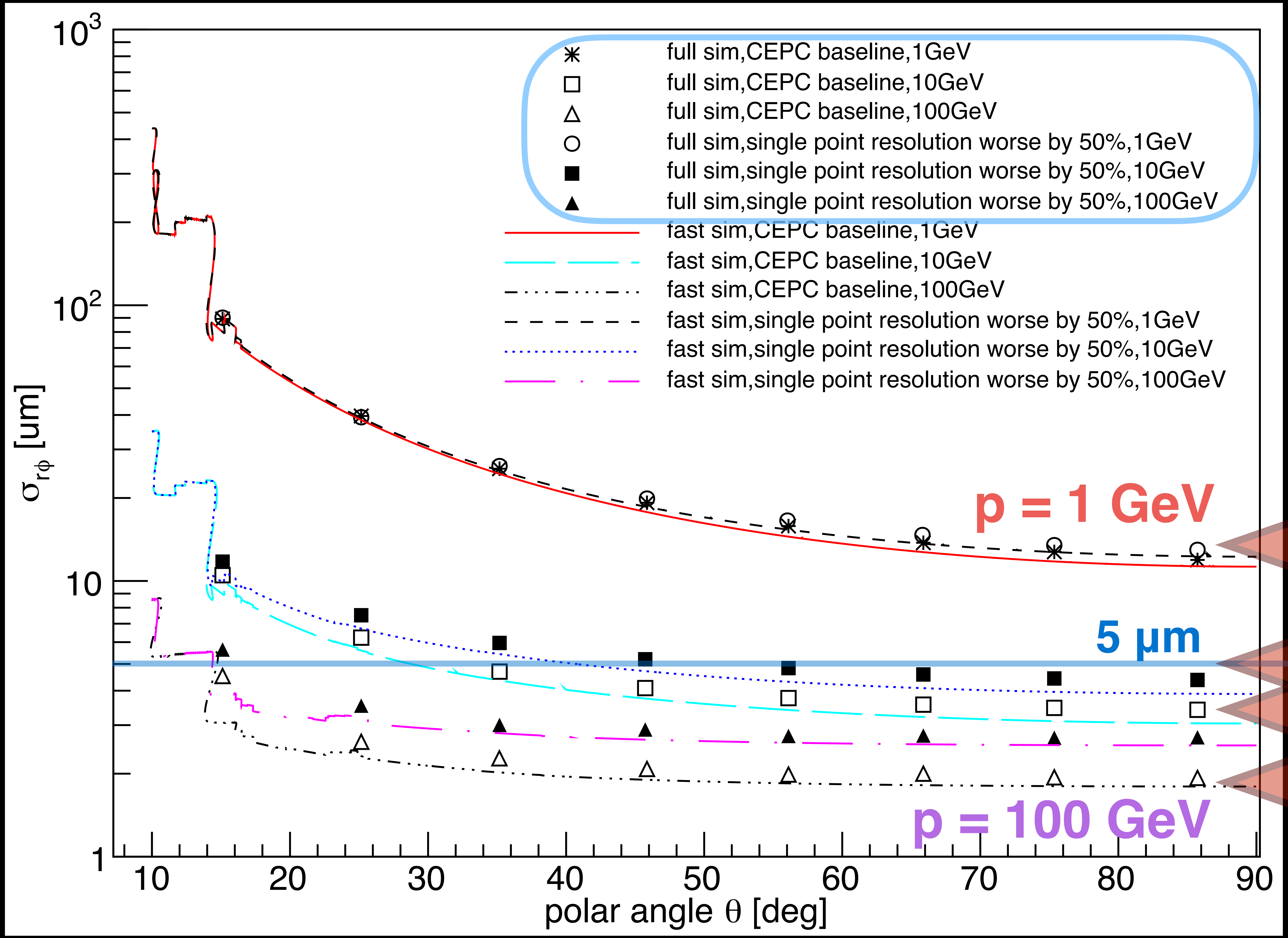
⬇

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)

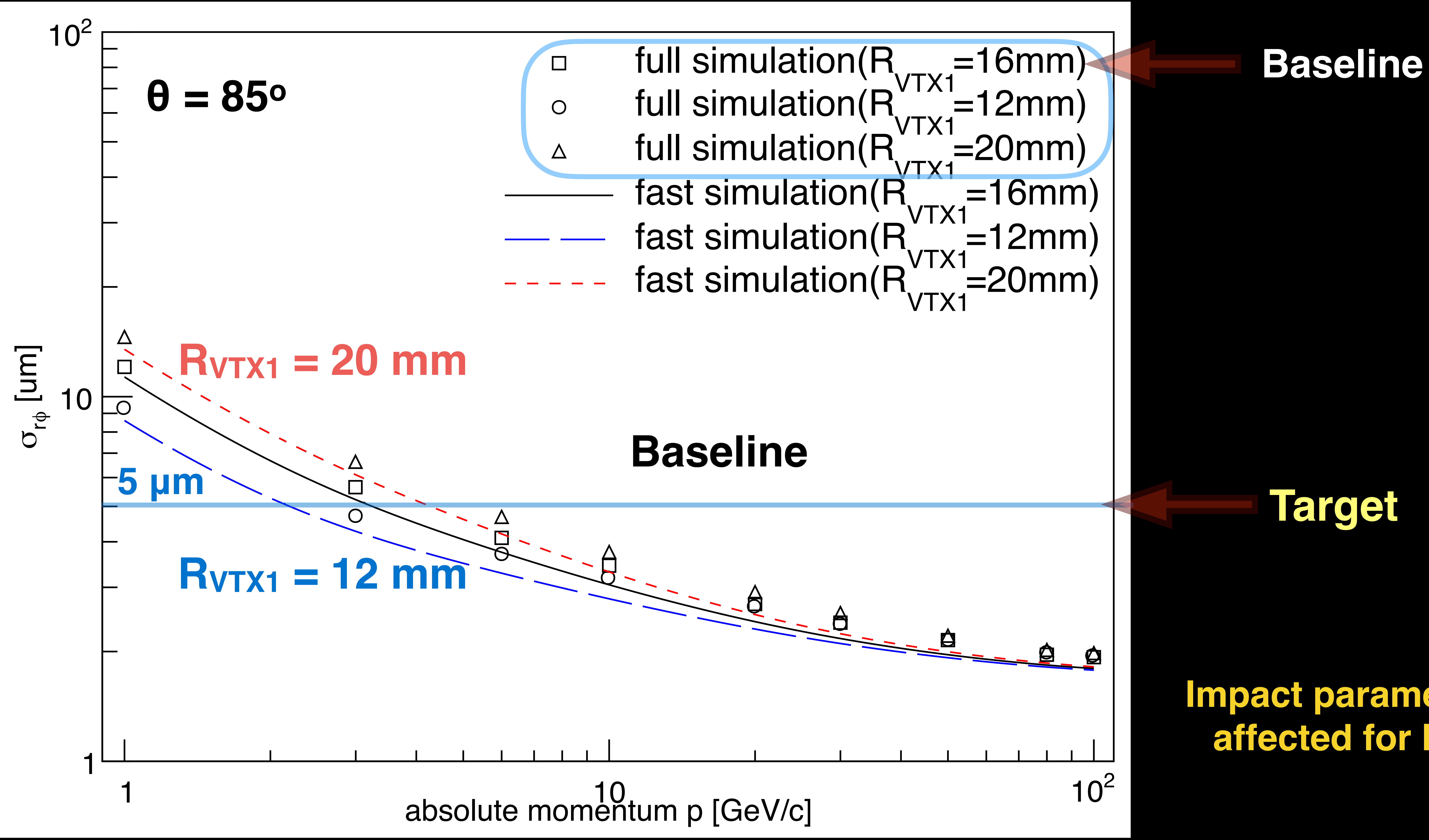
Target

Baseline p = 10 GeV

Baseline p = 100 GeV

Performance studies: Distance to IP

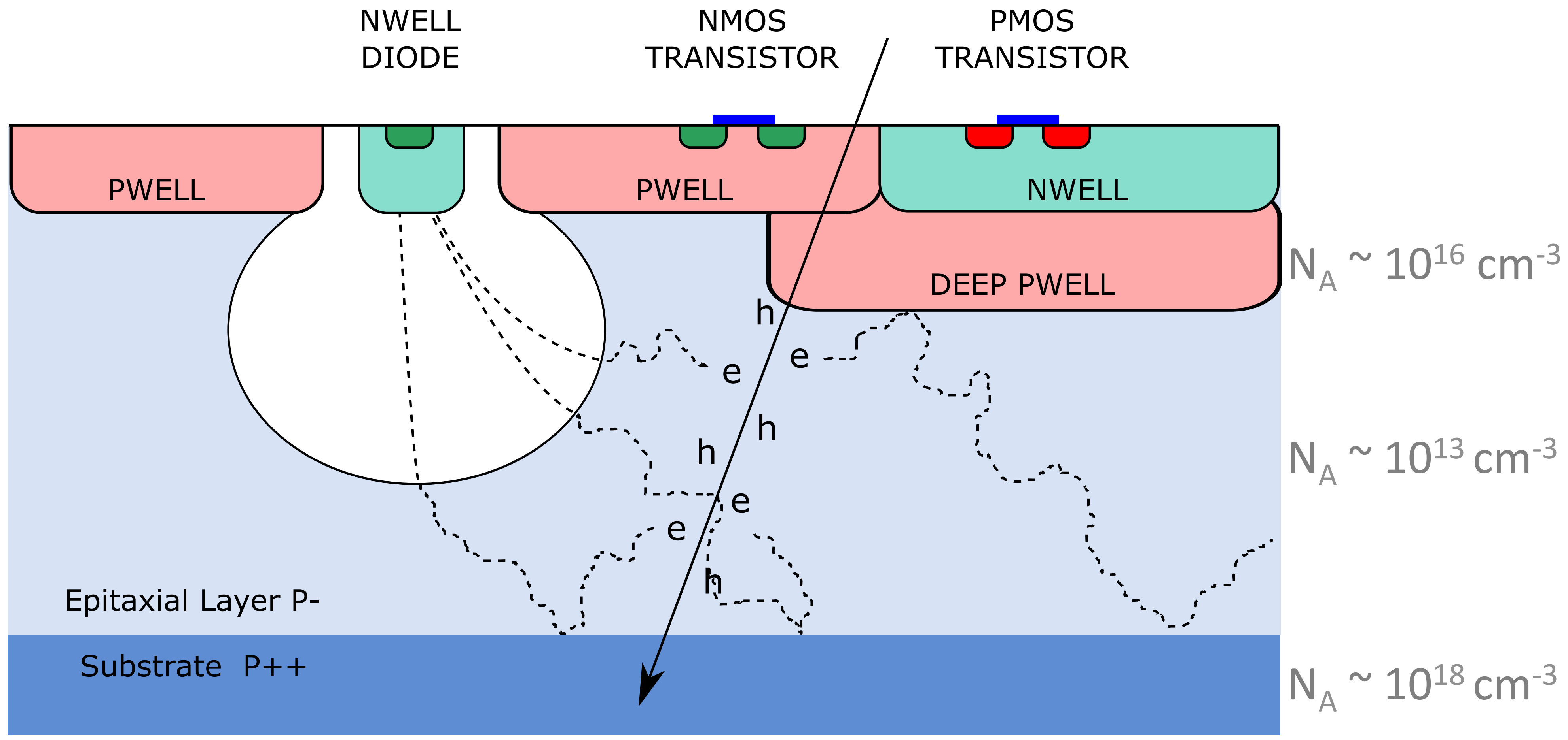
Transverse impact parameter resolution for single muons

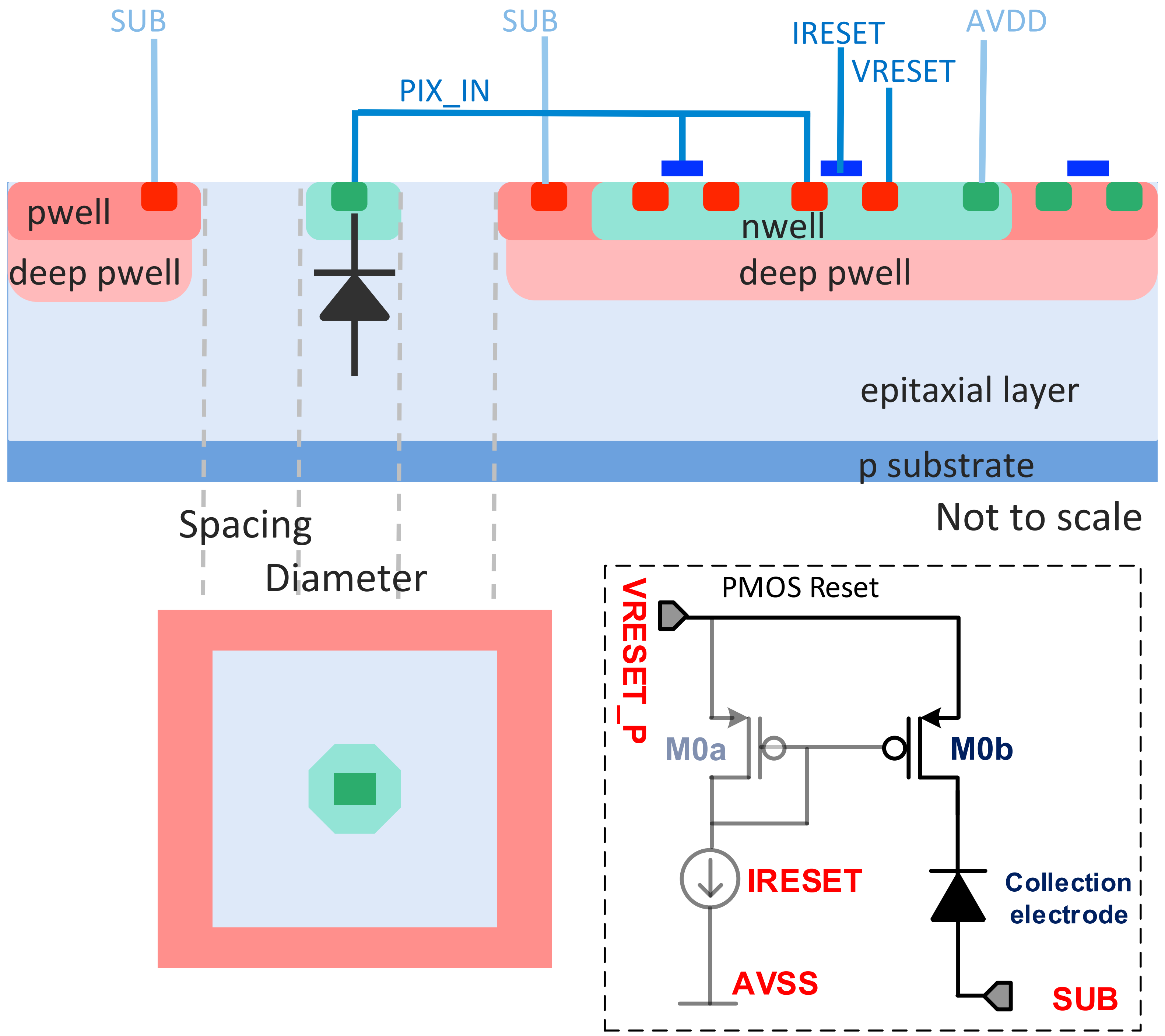


Impact parameter resolution affected for low-pt tracks

Standard Pixel Sensor imaging Process (TowerJazz)

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

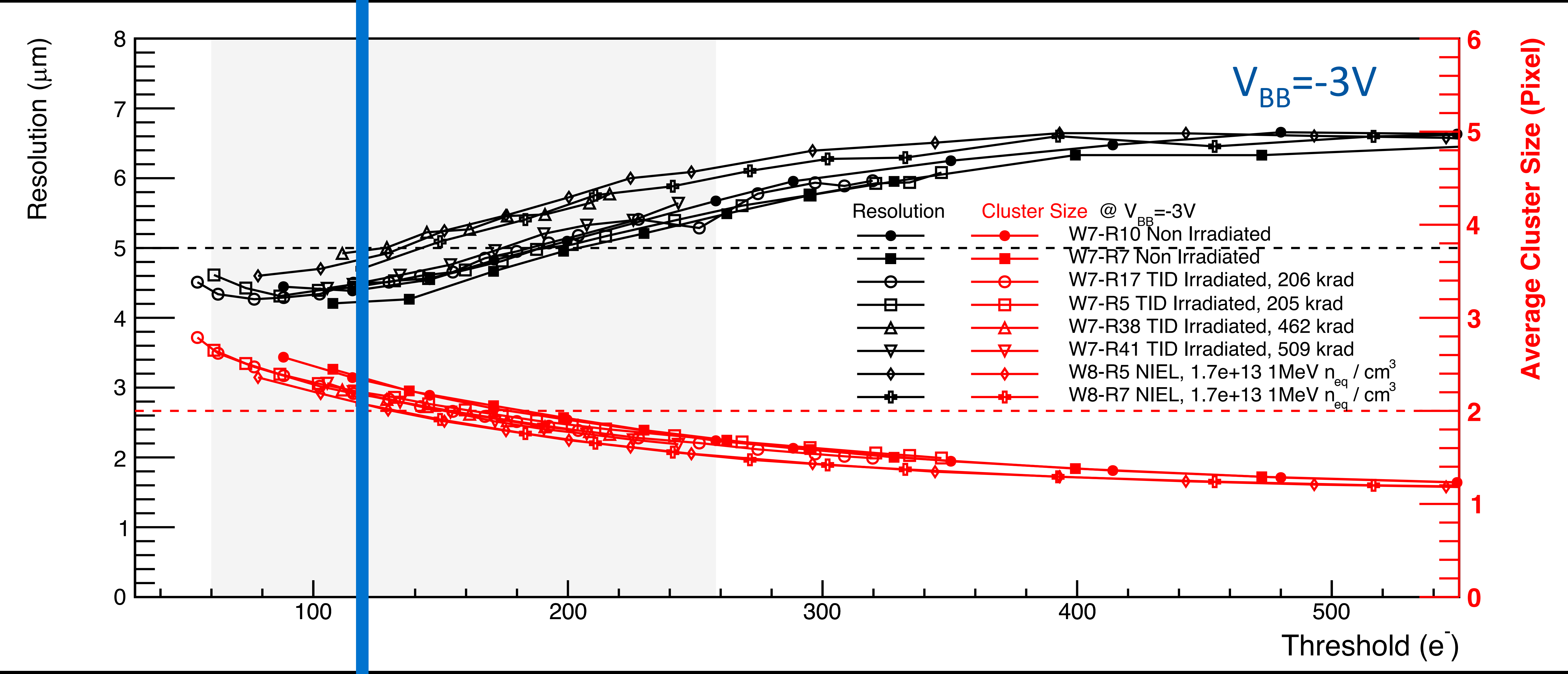


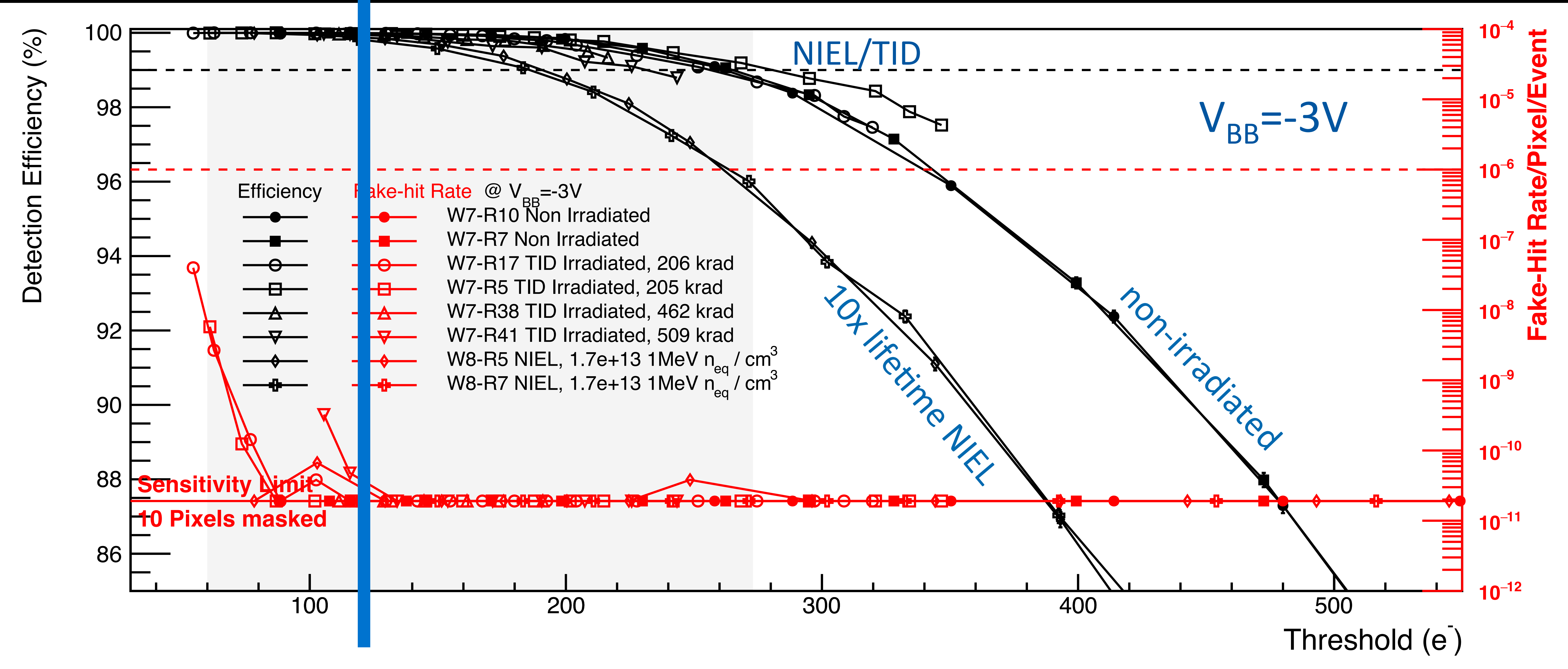


- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18 μm to 30 μm) on p-type substrate
- Deep PWELL shielding NWELL allowing PMOS transistors (full CMOS within active area)
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance (2fF) => large S/N
- Reverse bias can 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/mm^2/s
Power consumption	< ~20-35 mW/cm^2
Radiation tolerance	300kRad 2×10^{12} 1 MeV n_{eq}/cm^2





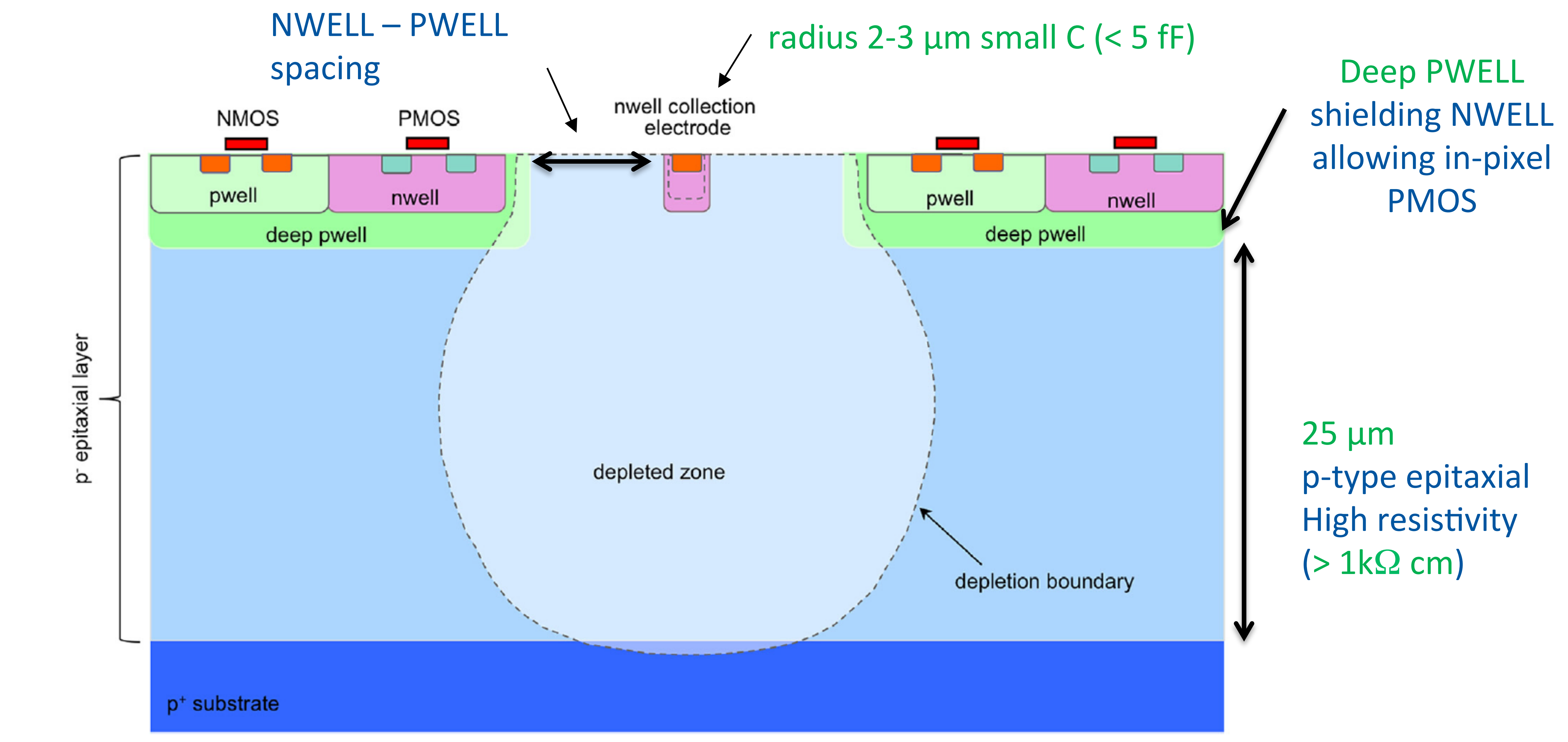
Almost OK specifications

Need lower resolution

Higer radiation tolerance

ATLAS Modified TowerJazz process

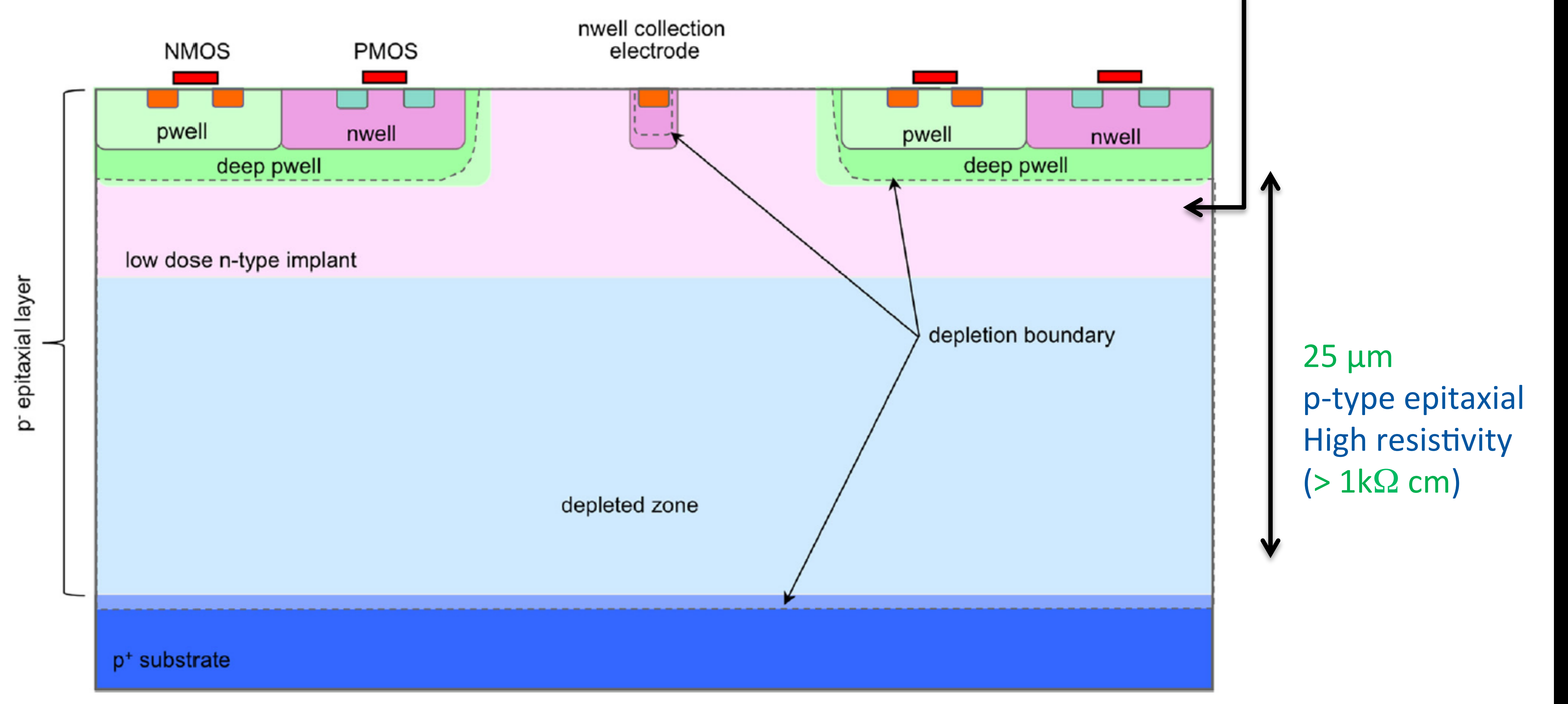
Standard process



- 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



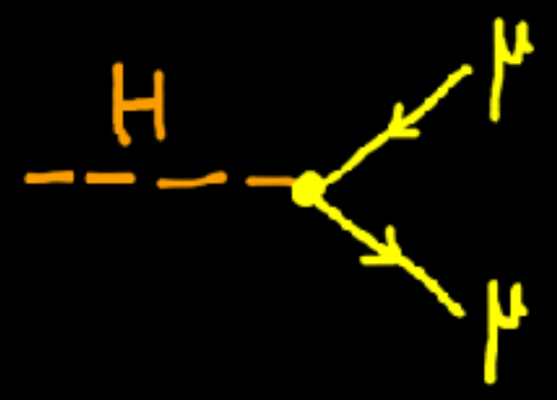
- Possibility to fully deplete sensing volume
- No significant circuit or layout changes required

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



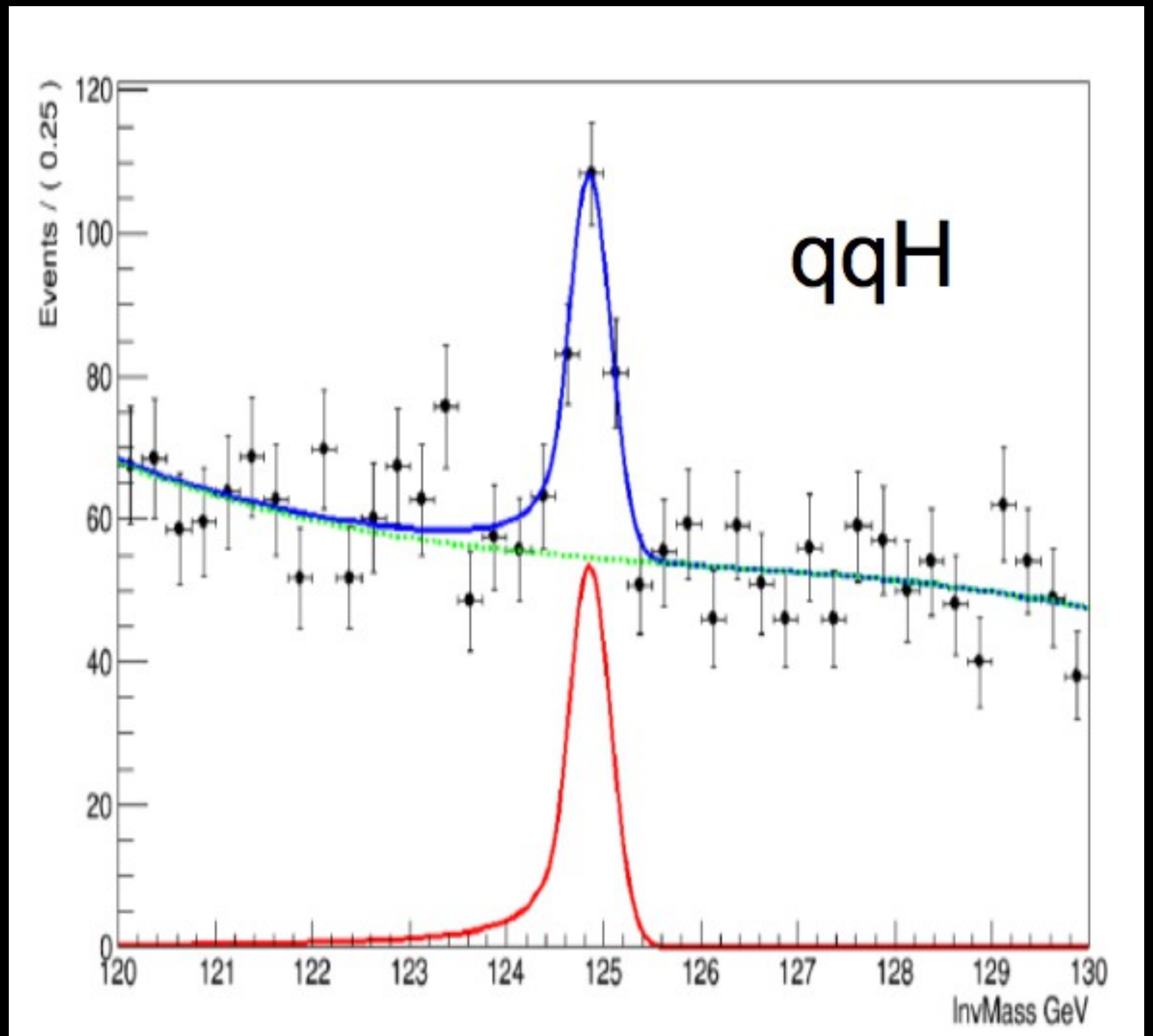
BR(H→μμ) measurement

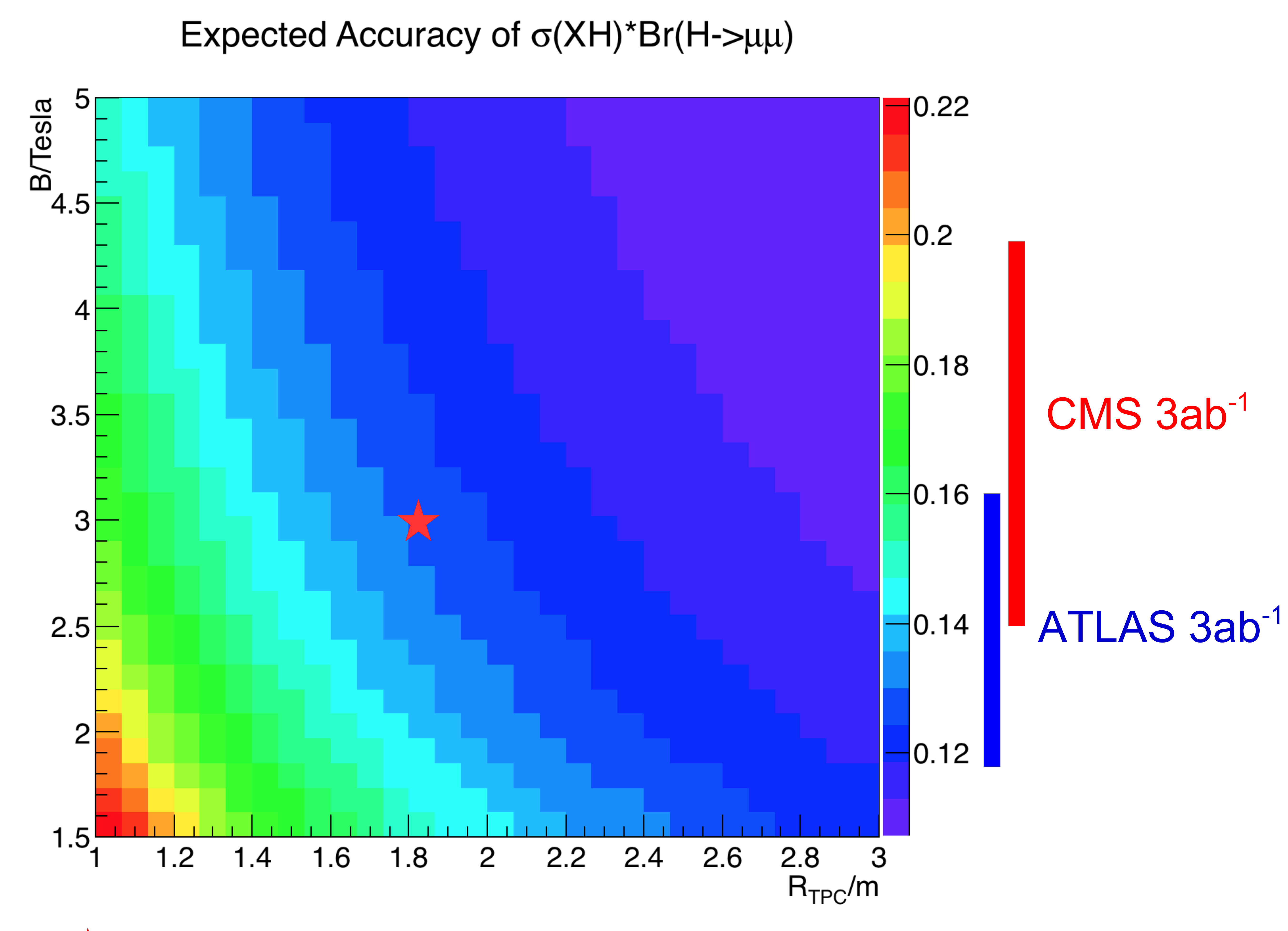
Detector cost sensitive to tracker radius, however:

- **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

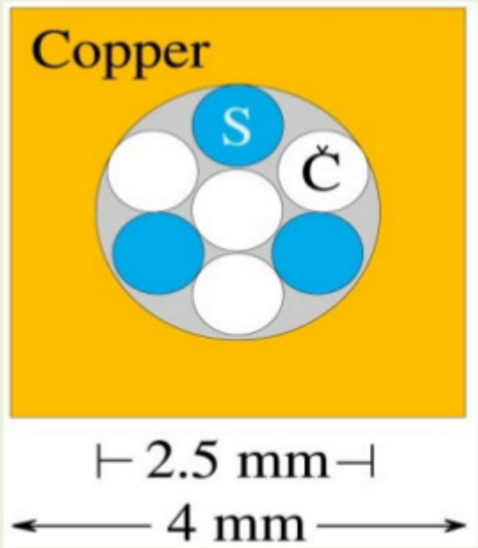
Dual Readout Calorimeter

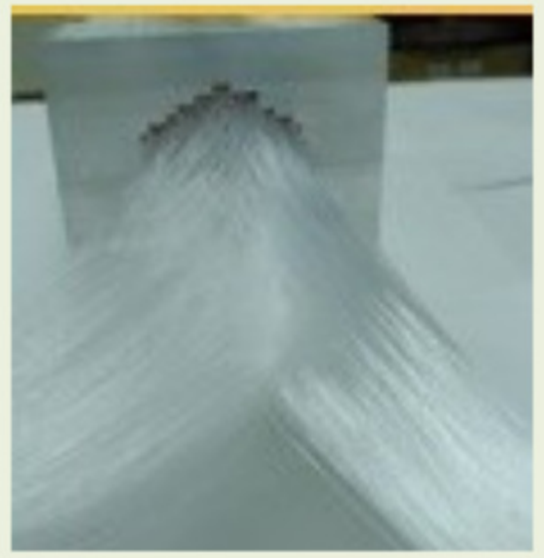
Hauptman, Santoro, Ferrari
Tomorrow, 11:30, 12:00, 12:30 am

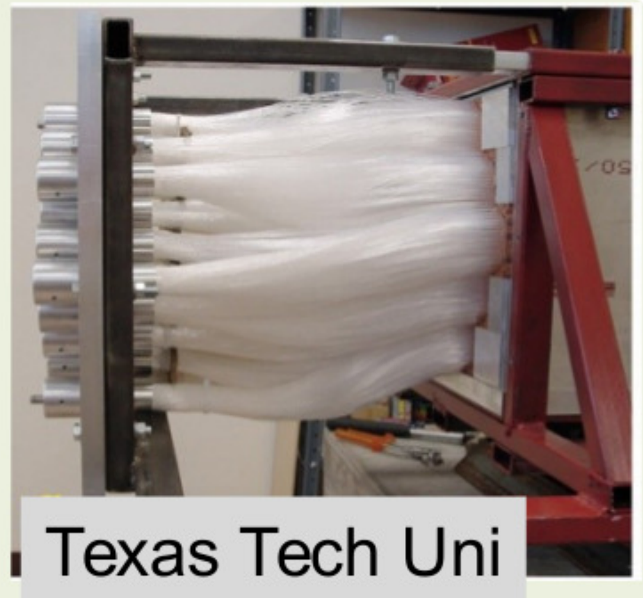
Lead by Italian colleagues: based on the DREAM/RD52 collaboration

2003
DREAM

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



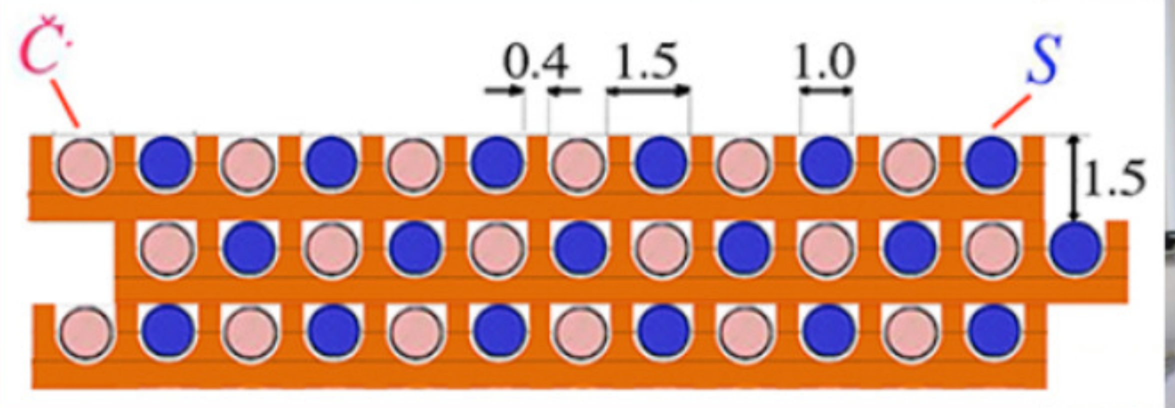




2012
RD52

Copper, 2 modules

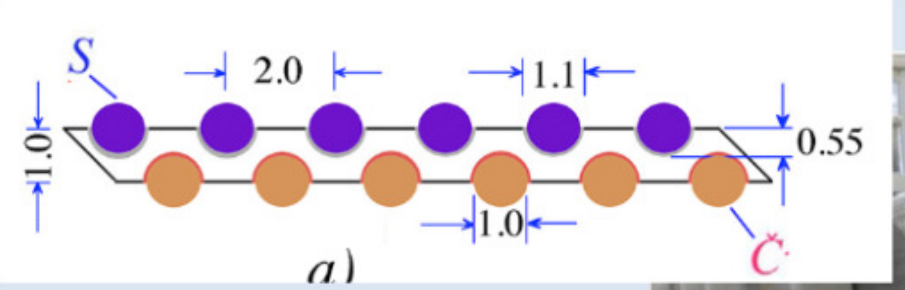
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

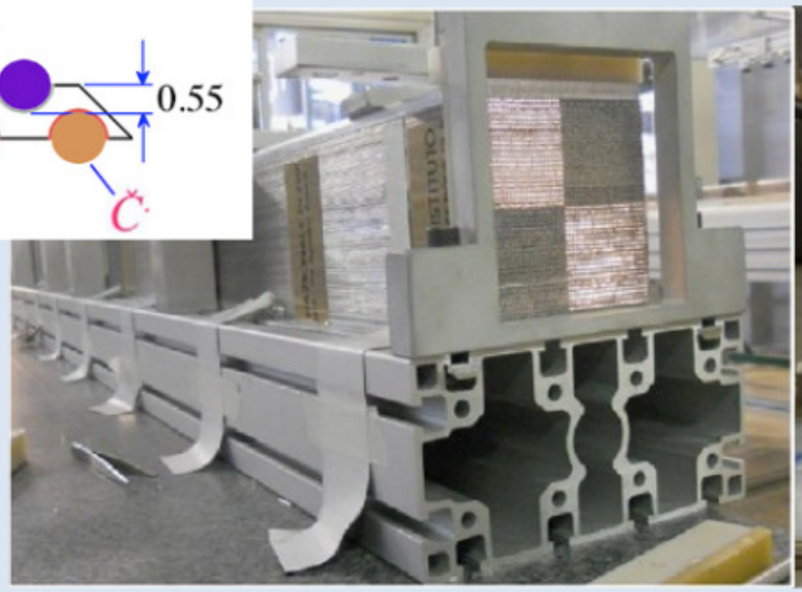


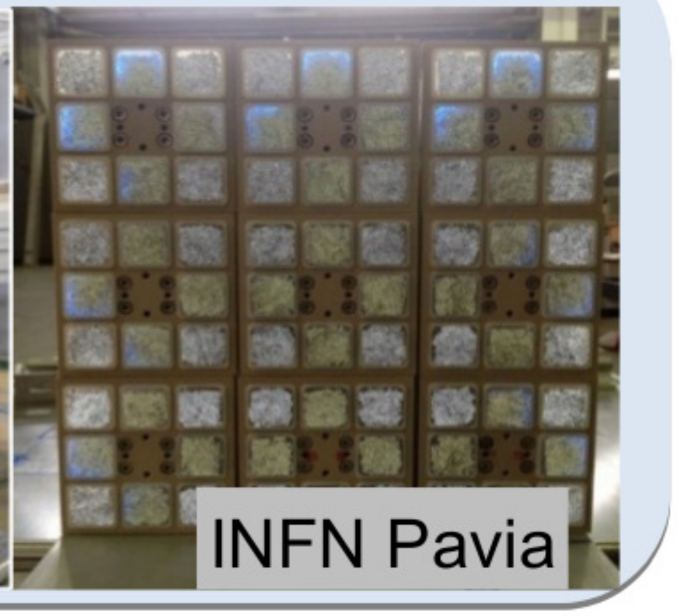
2012
RD52

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}



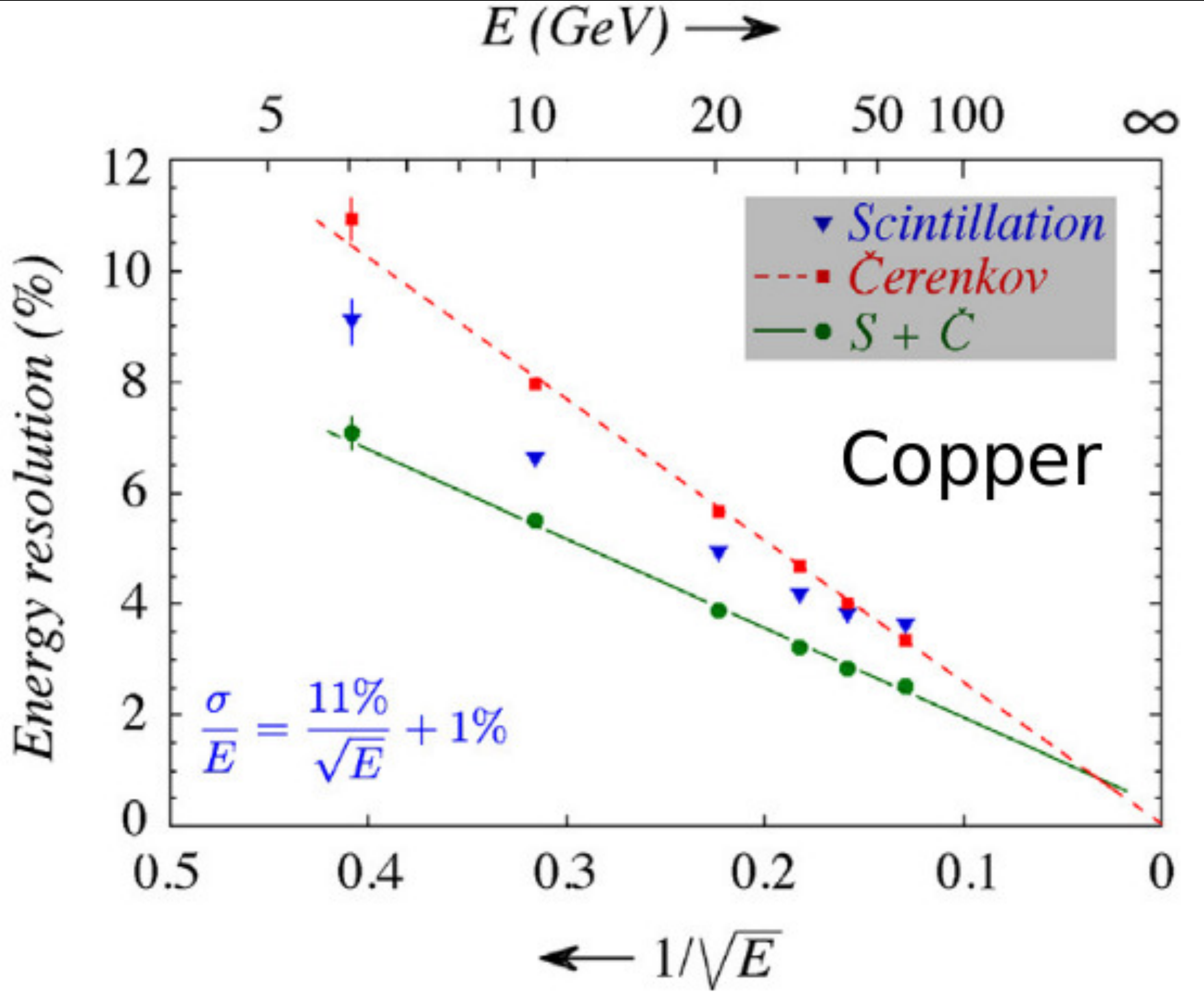




Expected resolution:

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

Energy resolution for electrons



Dual Readout Calorimeter

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