Circular Electron Positron Collider

Probing the Higgs Scale with a new Electron Collider in China

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Can be downloaded from
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Conceptual Design Report

Volume I - Accelerator

The CEPC Study Group

August 2018

IHEP-CEPC-DR-2018-02

IHEP-EP-2018-01

IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

The CEPC Study Group

October 2018

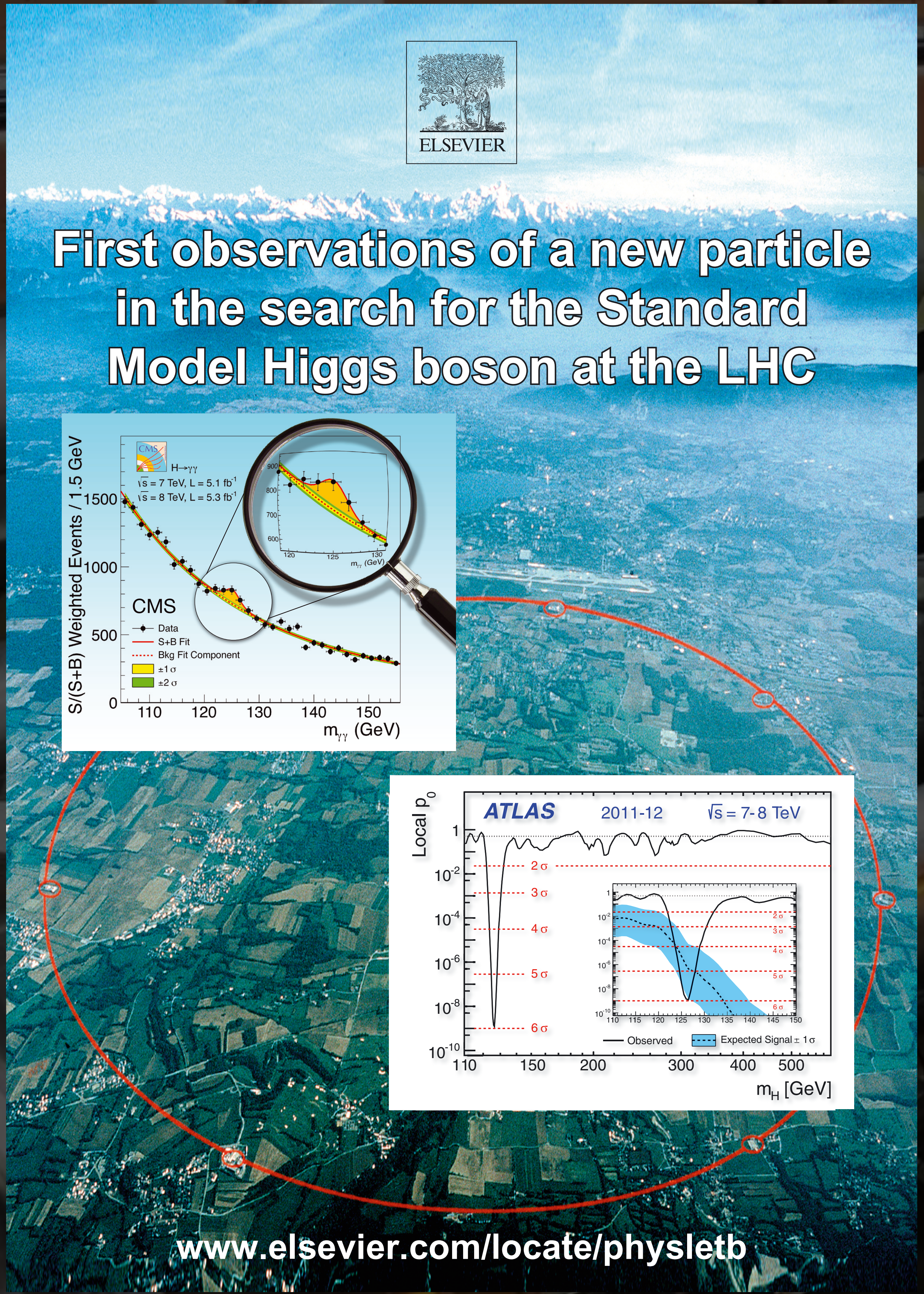
1143 authors
221 institutes (139 foreign)
26 countries

The Higgs Boson Discovery at LHC

Predicted in 1964, discovered in 2012! 48 year hunting!

An effort by **tens of thousands** scientists and engineers from all over the world

ATLAS & CMS Observation



2013 Nobel Prize

François Englert and Peter Higgs

Huge impact to humanity

Technology
Cultural
International Collaboration

What is the next step for HEP?

Higgs as a special probe

$$\mathscr{L}_{Higgs} = (D_\mu\phi)^\dagger(D^\mu\phi) - V(\phi^\dagger\phi) - \overline{\psi}_L\Gamma\psi_R\phi - \overline{\psi}_R\Gamma^\dagger\psi_L\phi^\dagger$$

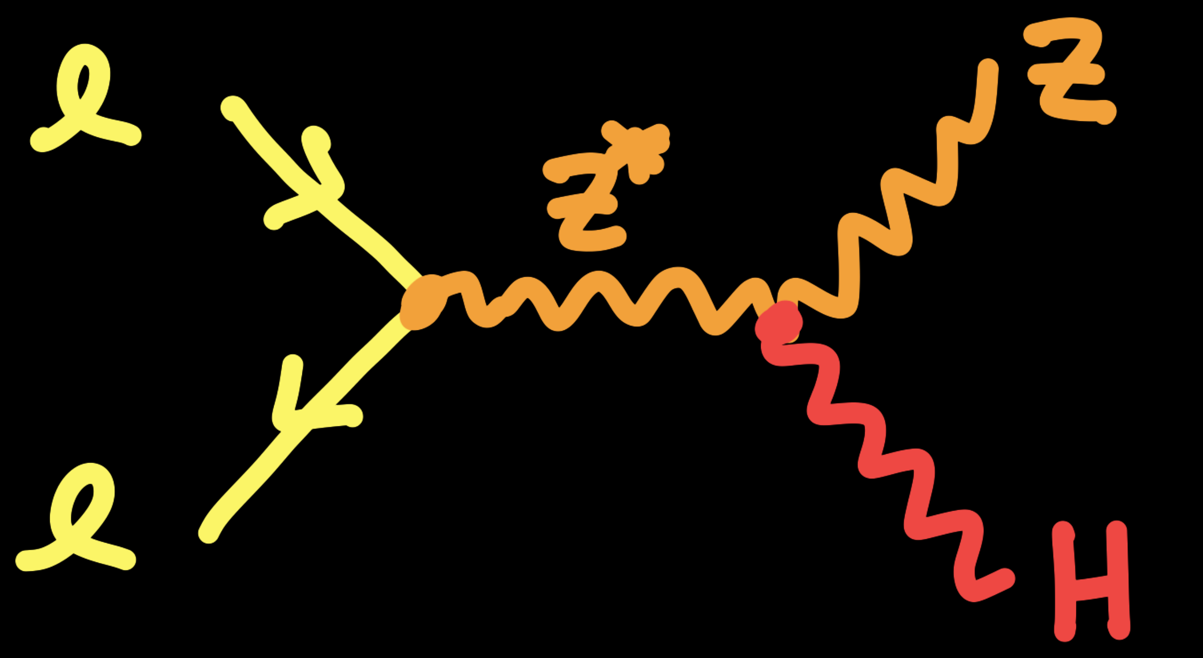
$$V(\phi^\dagger\phi) = -\frac{m_H^2}{2}\phi^\dagger\phi + \frac{1}{2}\lambda(\phi^\dagger\phi)^2$$

$$\lambda = \frac{m_H^2}{2v^2}$$

- Measure **Higgs properties** with highest precision
  - Many different couplings fixed by masses, yukawa hierarchy?
    - Have neutrinos a special role?
  - λ determines shape and evolution of the Higgs potential → cosmological implications
  - New **dark states**? → Portal to new physics beyond SM
  - Search for rare processes, through high-accuracy studies of SM cross sections

e^+e^- colliders offer clear advantages due to the potentially high accuracy of measurements

Revived e^+e^- Circular Colliders



Relatively low Higgs mass:
m_H = 125 GeV

LEP stopped taking data in 2000 limited by synchrotron energy loss
Center mass energy: √s = 209 GeV

Just a few GeV below the required energy to produce Higgs events copiously
√s = 240 GeV

Synchrotron energy loss

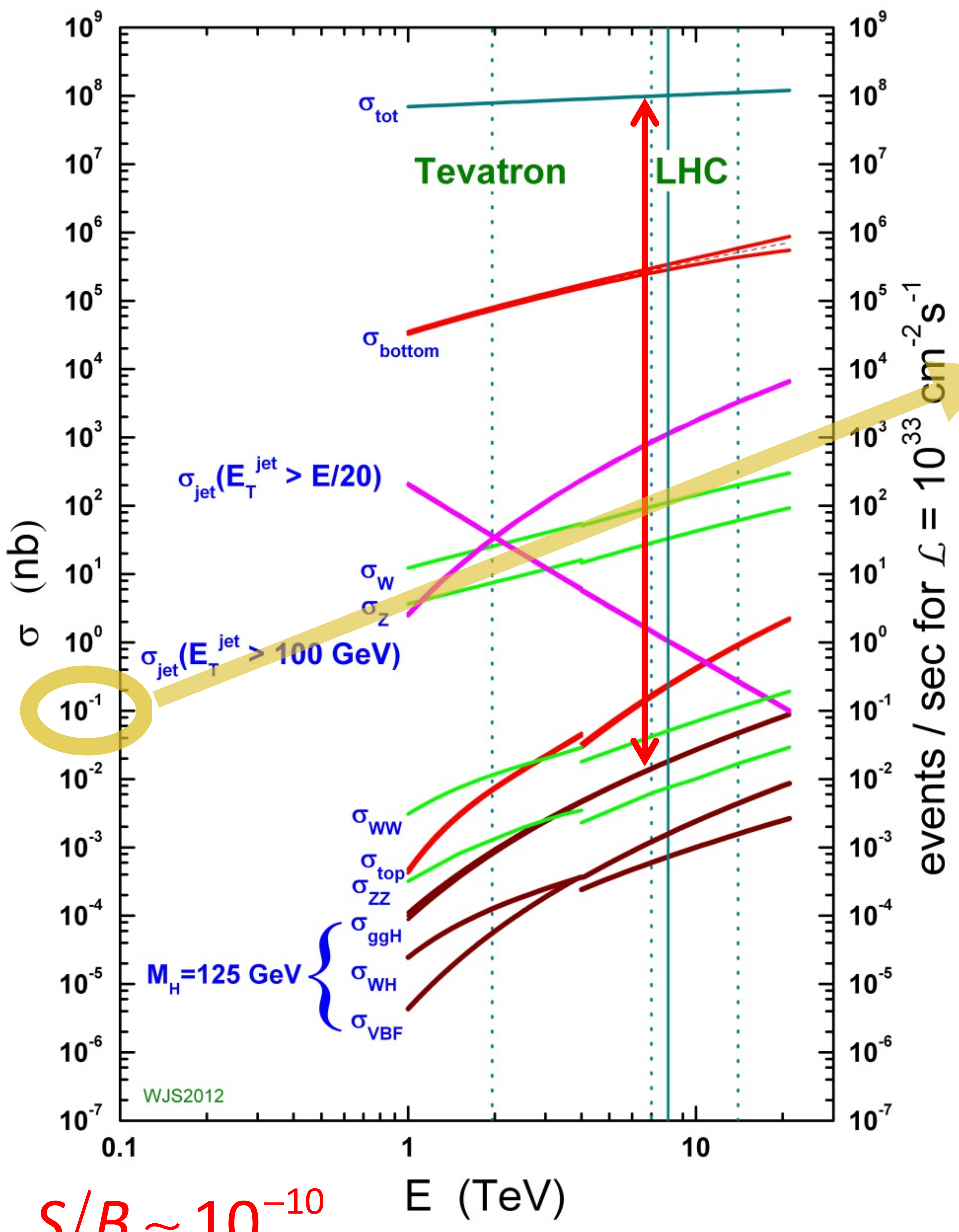
$$\frac{240\ \mathrm{GeV}}{209\ \mathrm{GeV}} \sim 1.14$$

$$\frac{E^4}{r} = \frac{1.14^4}{3.5} \sim 0.5$$

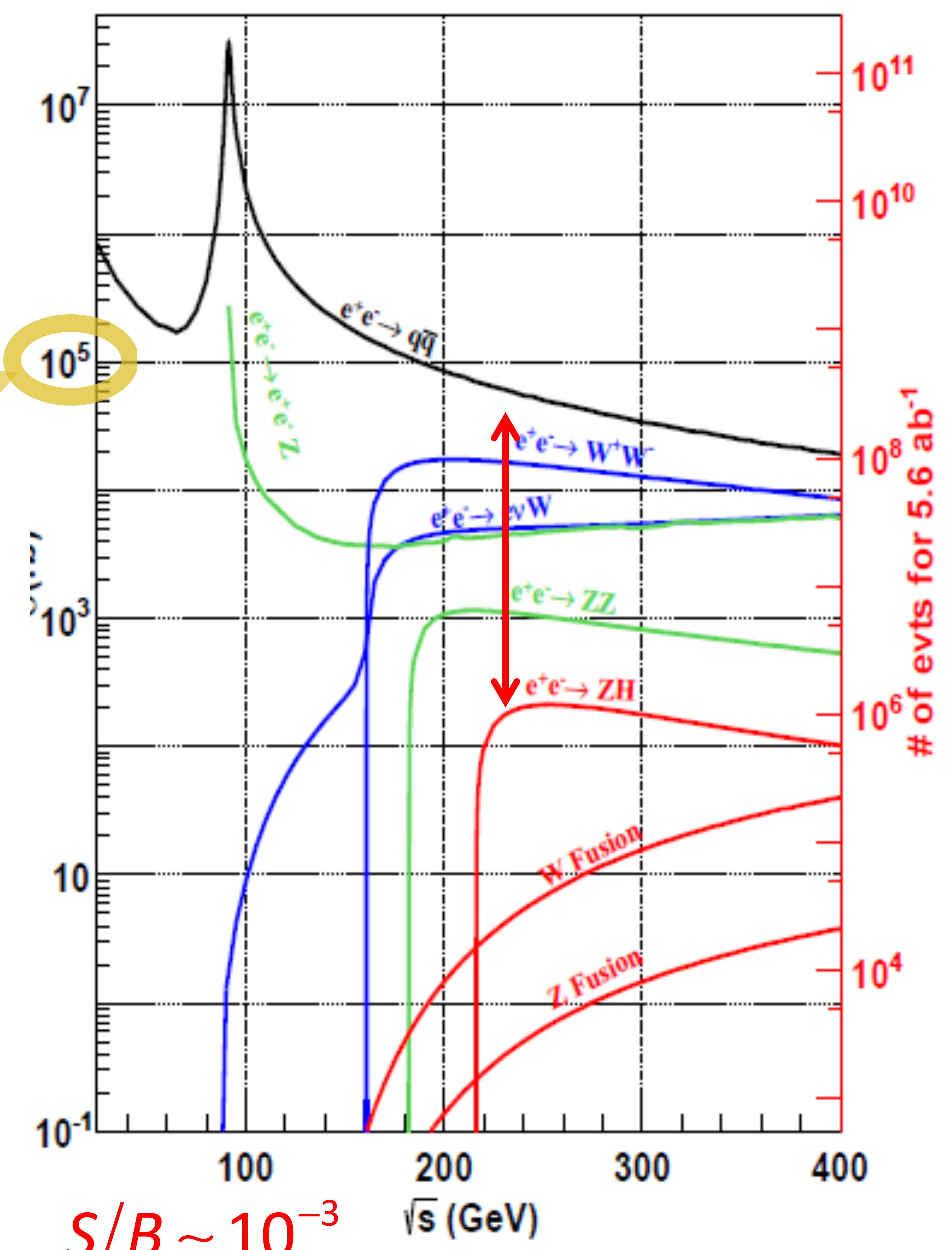
radius increased by 3.5×

~100 km accelerator adequate for Higgs studies

Cross sections: pp versus e^+e^-



$S/B \sim 10^{-10}$



$S/B \sim 10^{-3}$

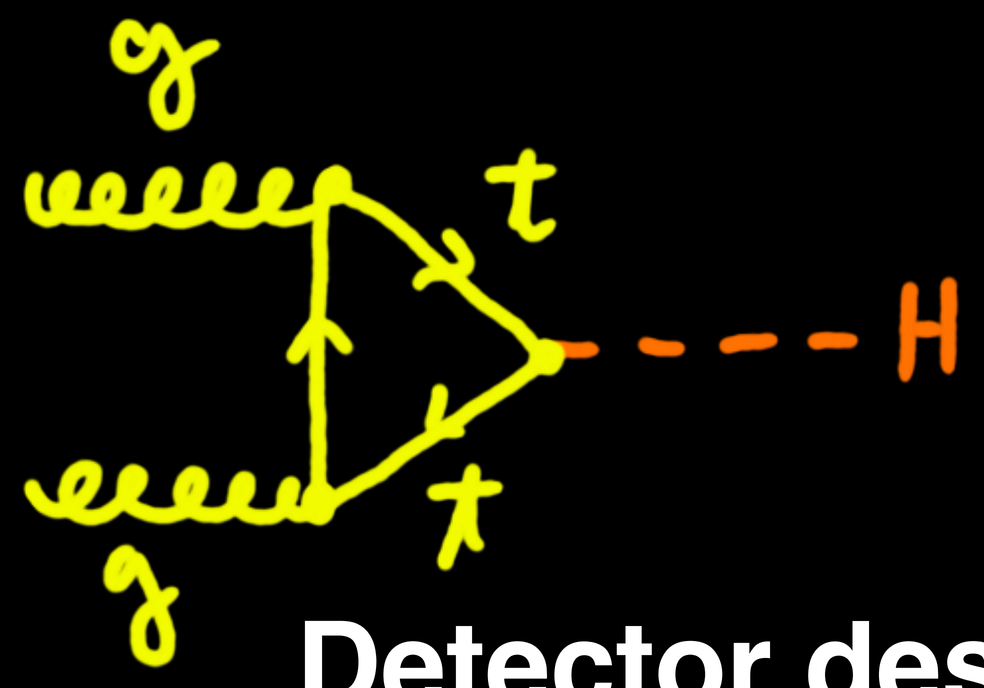
In **pp collisions** interesting events need to be extracted from underneath a huge number of **background** events

$S/B \sim 10^{-10}$

In **ee collisions**

$S/B \sim 10^{-3}$

Difference between e⁺e⁻ and pp environment

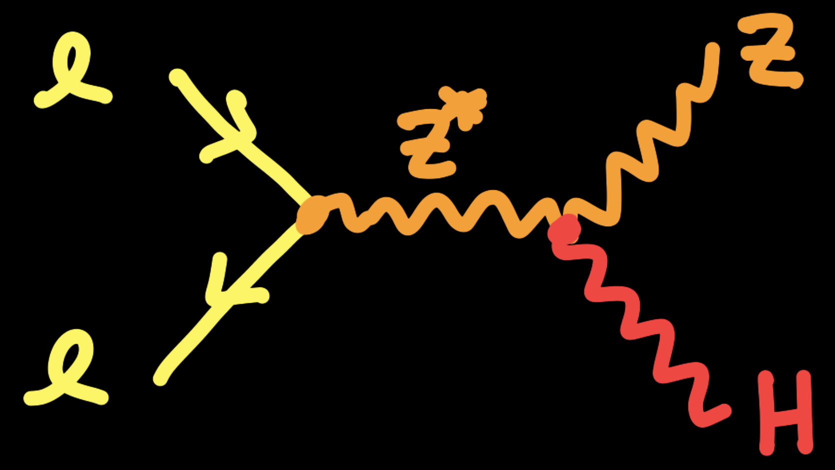


Detectors for hadron colliders

Large QCD backgrounds

Requires complex trigger system

Detector design focus on radiation hardness of many sub-detectors



Detectors for e^+e^- colliders

Cleaner e^+e^- collisions

Beam-induced backgrounds dominating source of radiation damage

Hadronic radiation damage only relevant in very forward detectors

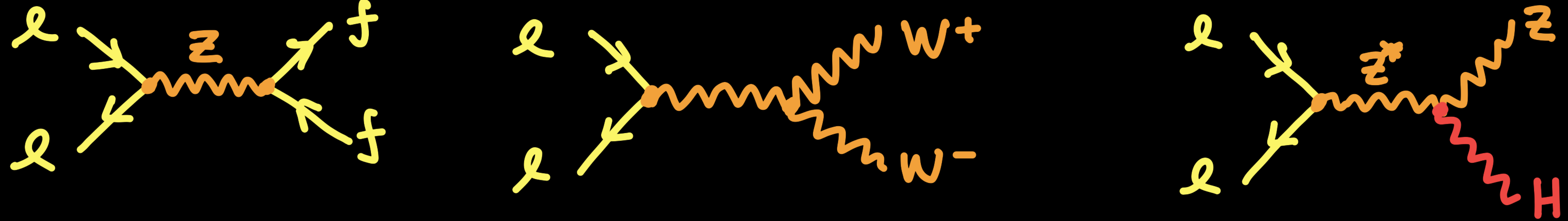
($\theta \sim 10$ mrad – 38 mrad)

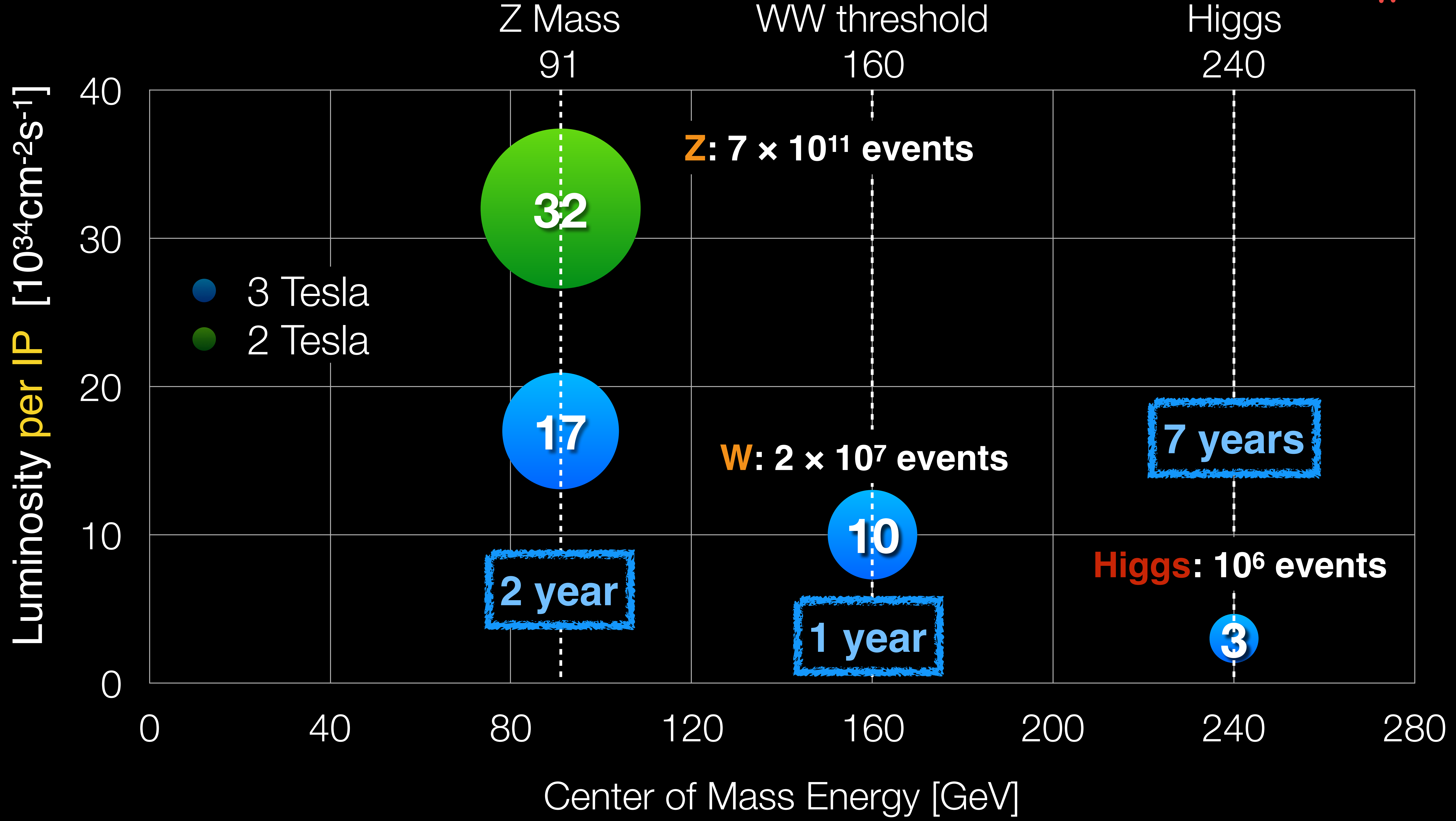
Well defined initial state (particle, energy, polarization?) ➡ Suitable for high-precision measurements

The Circular Electron Positron Collider (CEPC) Physics Program

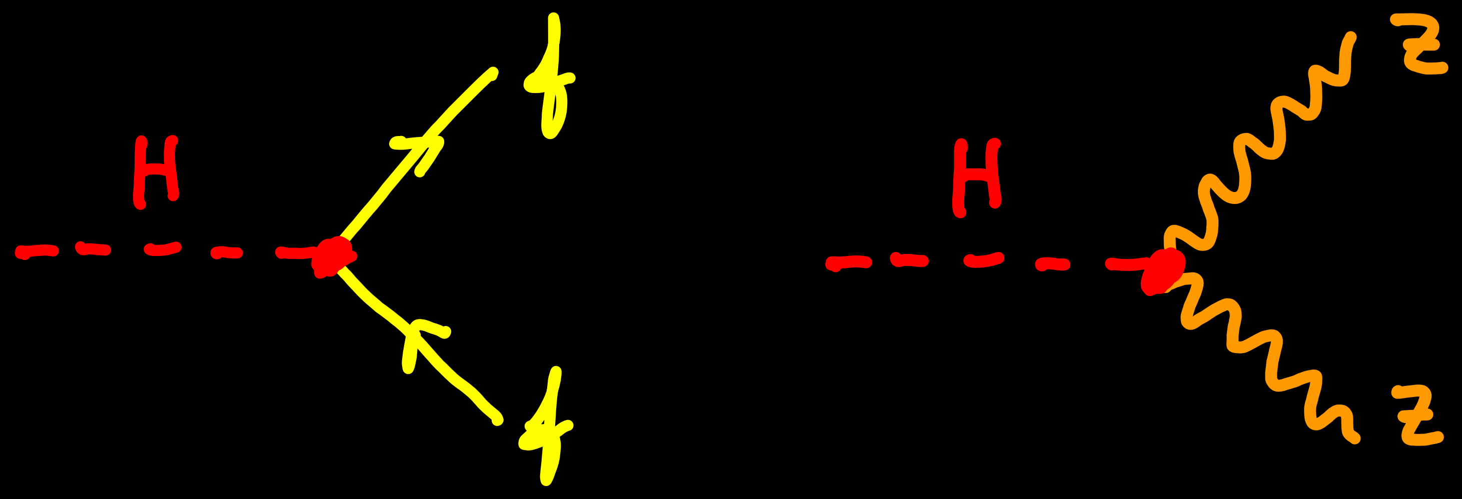
The CEPC Program

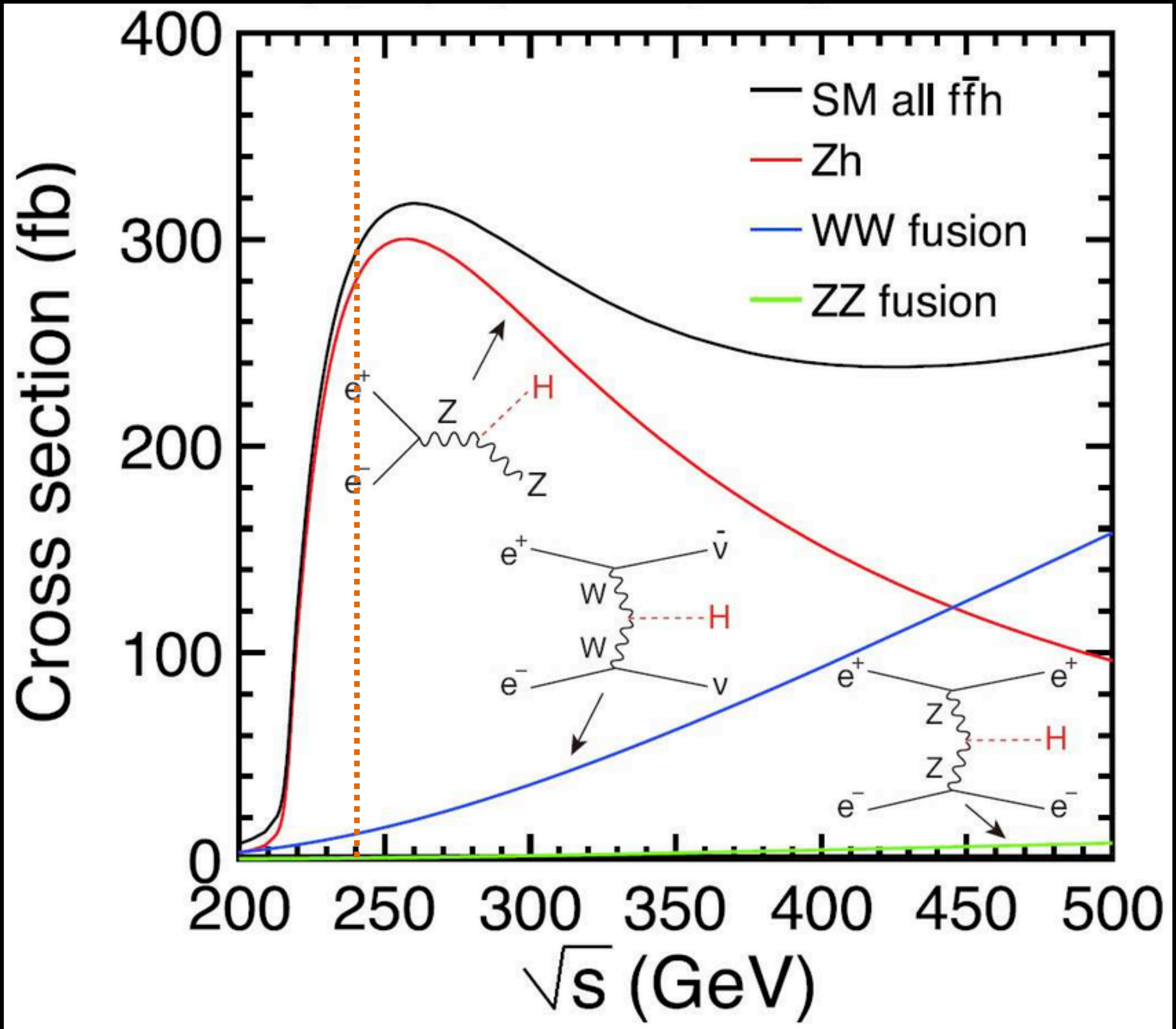
100 km e^+e^- collider





Higgs production in e+e− collisions





Events at 5 ab^{-1}

ZH: 10^6 events

vvH: 10^4 events

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

S/B
1:100-1000

Observables:

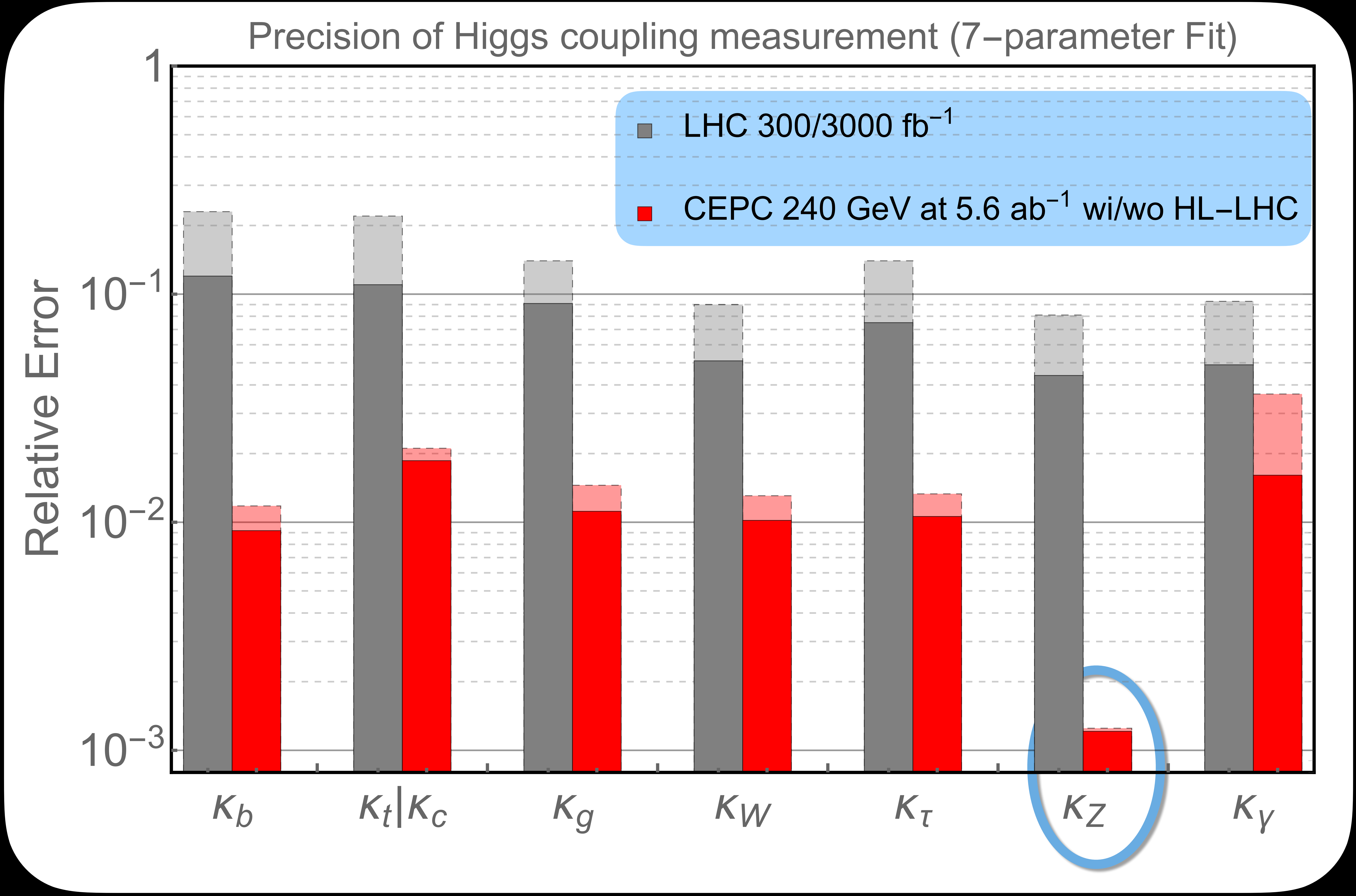
Higgs mass, CP, σ(ZH),
event rates (σ(ZH, vvH)*Br(H→X)),
Differential distributions

Extract:

Absolute Higgs width,
couplings

Higgs Couplings Measurement

Precision of Higgs couplings measurement compared to HL-LHC

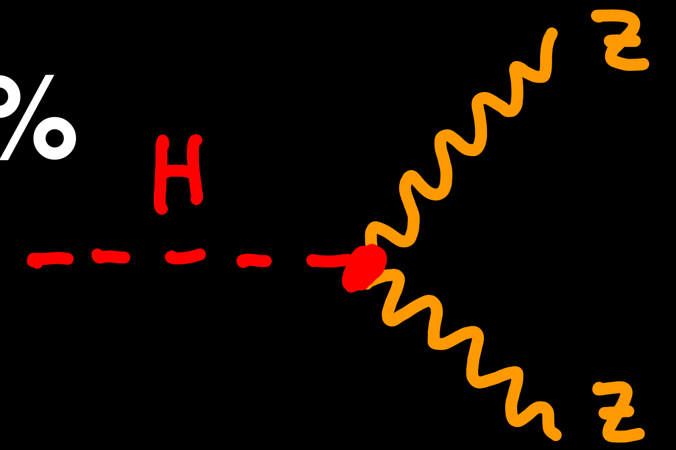


$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})}, \quad \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

HL-LHC

CEPC
~1% uncertainty

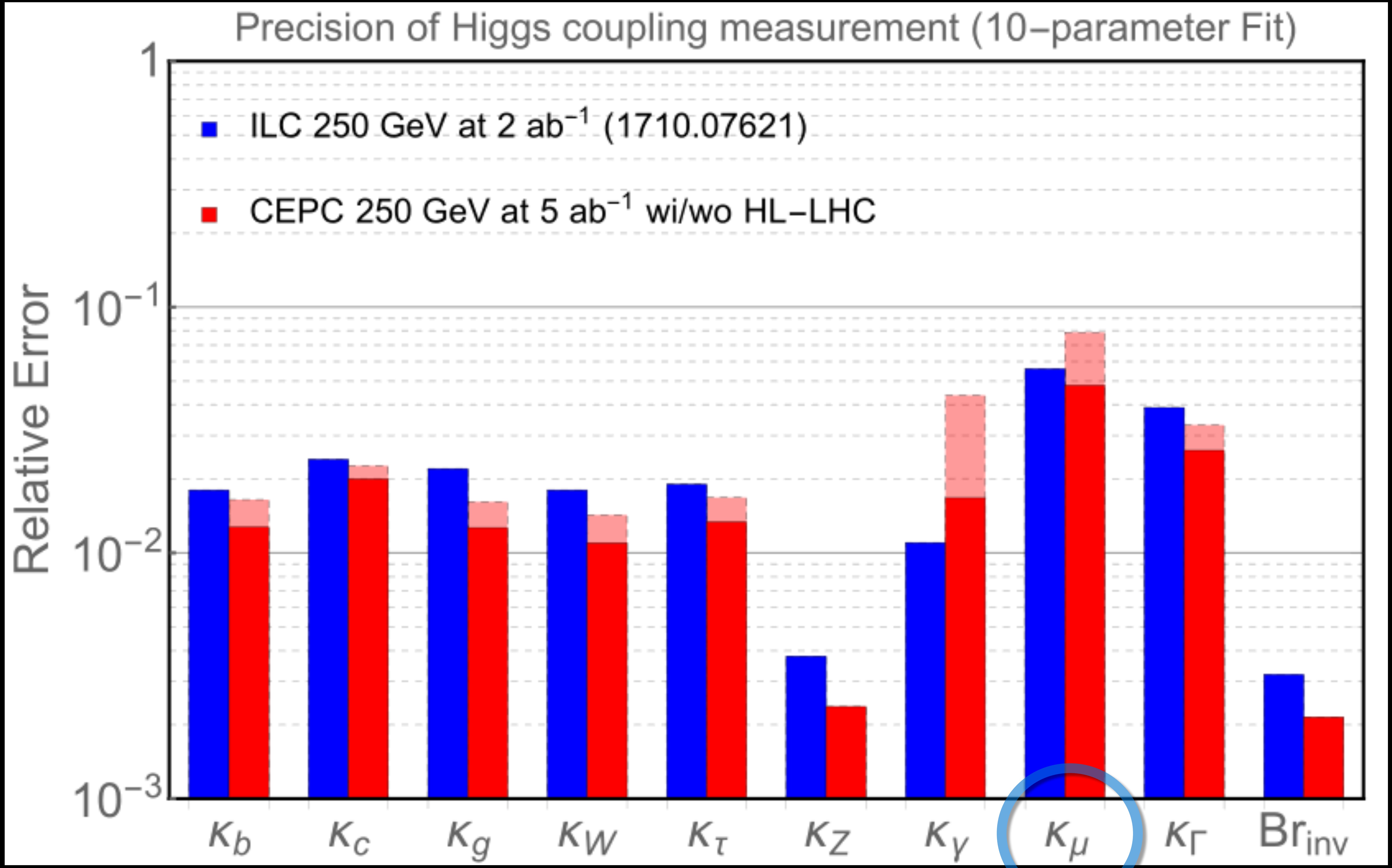
$\kappa_Z \sim 0.2$ %



ATL-PHYS-PUB-2014-016

Higgs Couplings Measurement

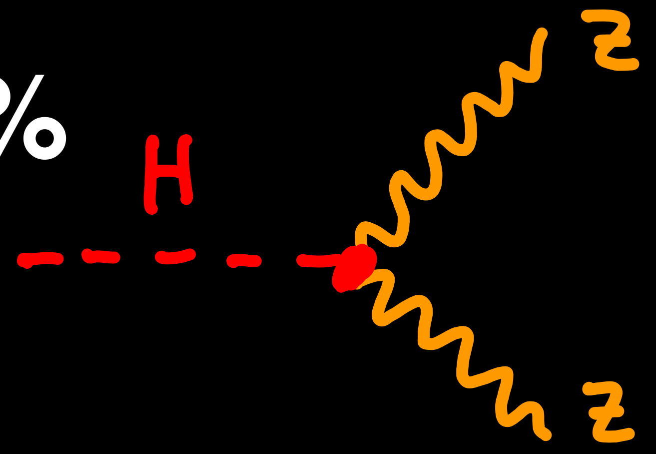
Precision of Higgs couplings measurement compared to ILC



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

ILC
CEPC
~1% uncertainty

$K_Z \sim 0.2\ \%$



1% precision → reach to new physics at 10 TeV

Many BSM models impact Higgs couplings at percentage level

CEPC will be sensitive to these

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

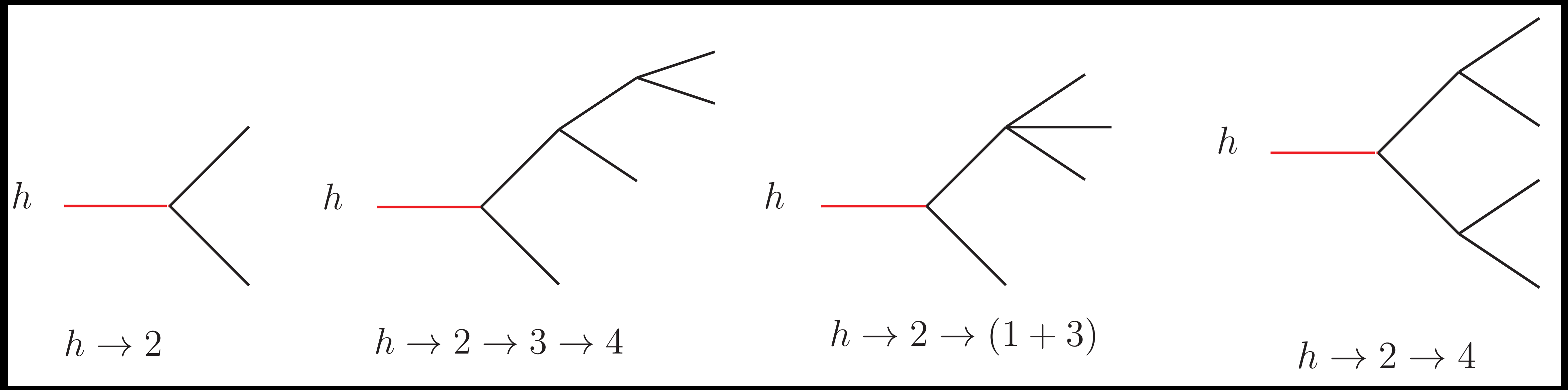
LHC not likely to be sensitive to these models even with full HL-LHC dataset

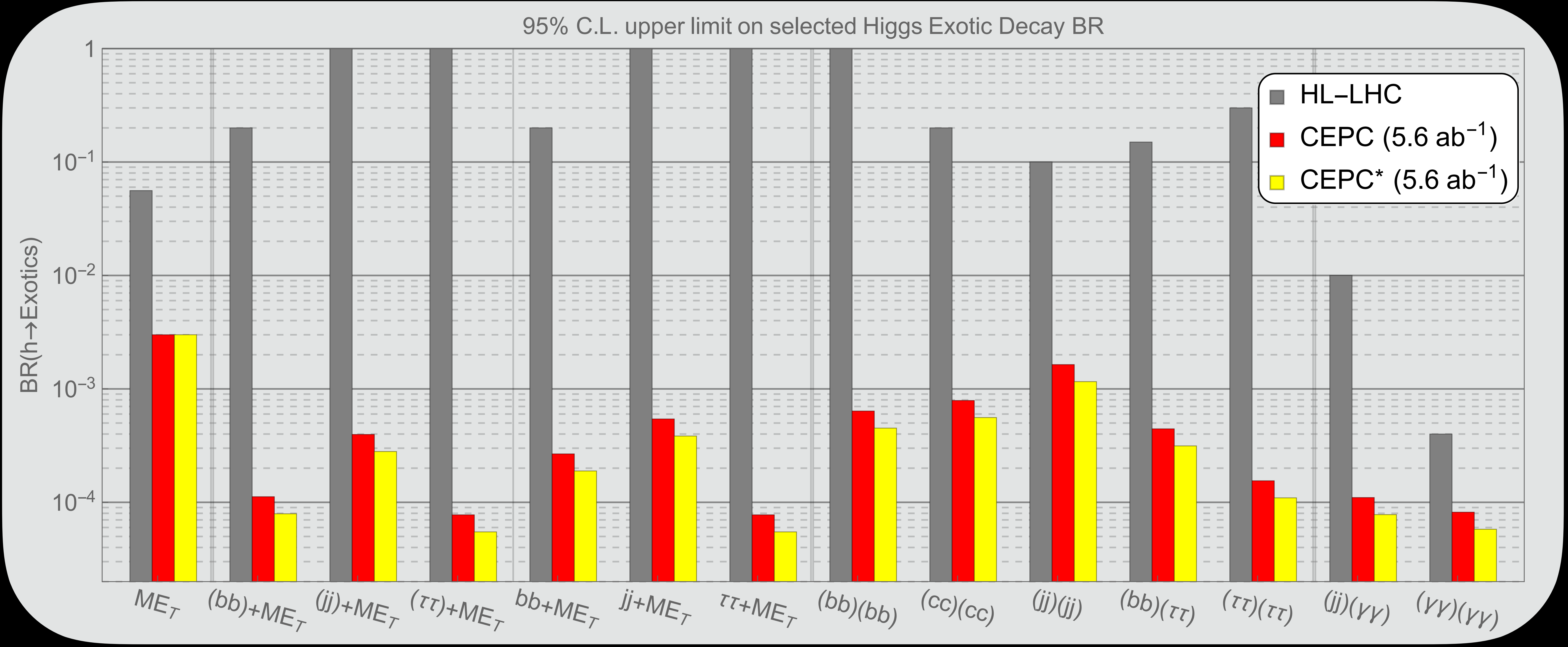
arXiv: 1710.07621

BSM Physics through Exotic Higgs Decays

General search for BSM

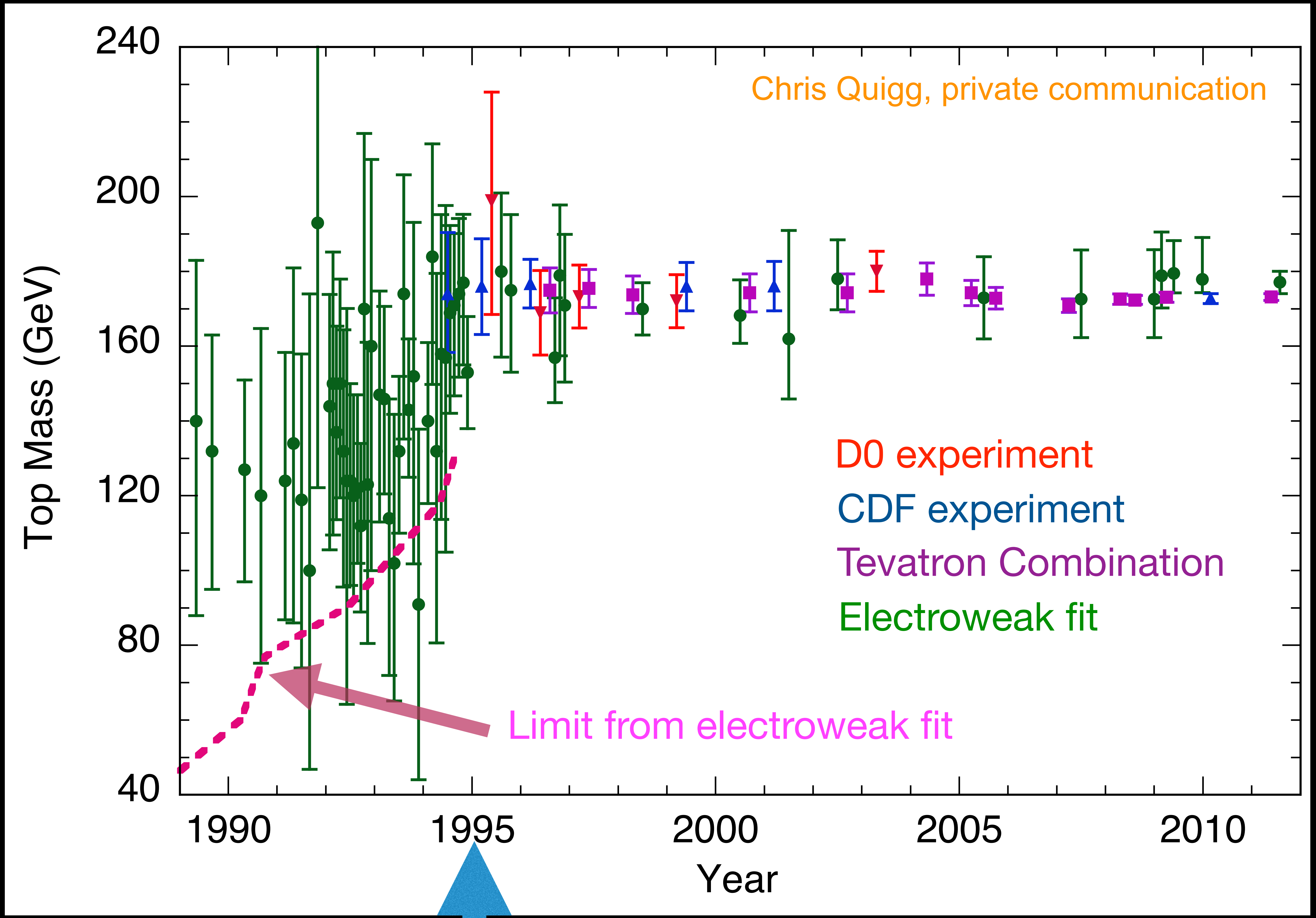
e^+e^- collider better than HL-LHC for MET+hadronic activity final states





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

Top Mass Prediction from Precision Electroweak data



Top discovery at Tevatron

M_{top} = 175 —> 173 GeV

Current world average:
m_{top} = 173.1 ± 0.6 GeV
(0.35%)

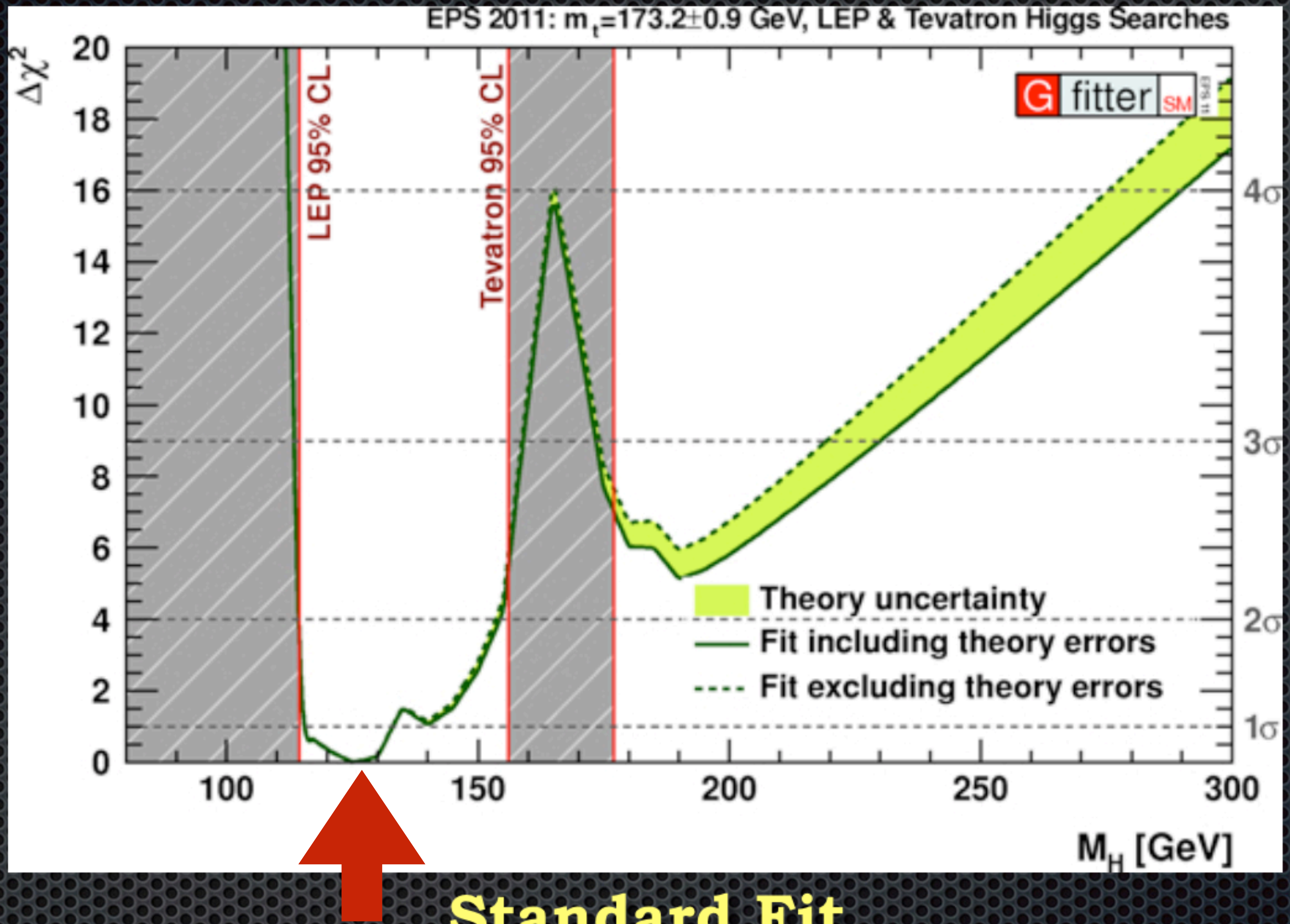
Higgs Mass Prediction from Precision Electroweak data

and some extra help!

PANIC 2011,
July 28, 2011

Overnight update

- Updated with EPS'01 results
  - Excludes direct searches from ATLAS and CMS from EPS



WARNING: Old Slide

Standard Fit

m_H (minimum)= 94.5 GeV, Range m_H = [71, 124], m_H < 166.5 GeV @ 95%

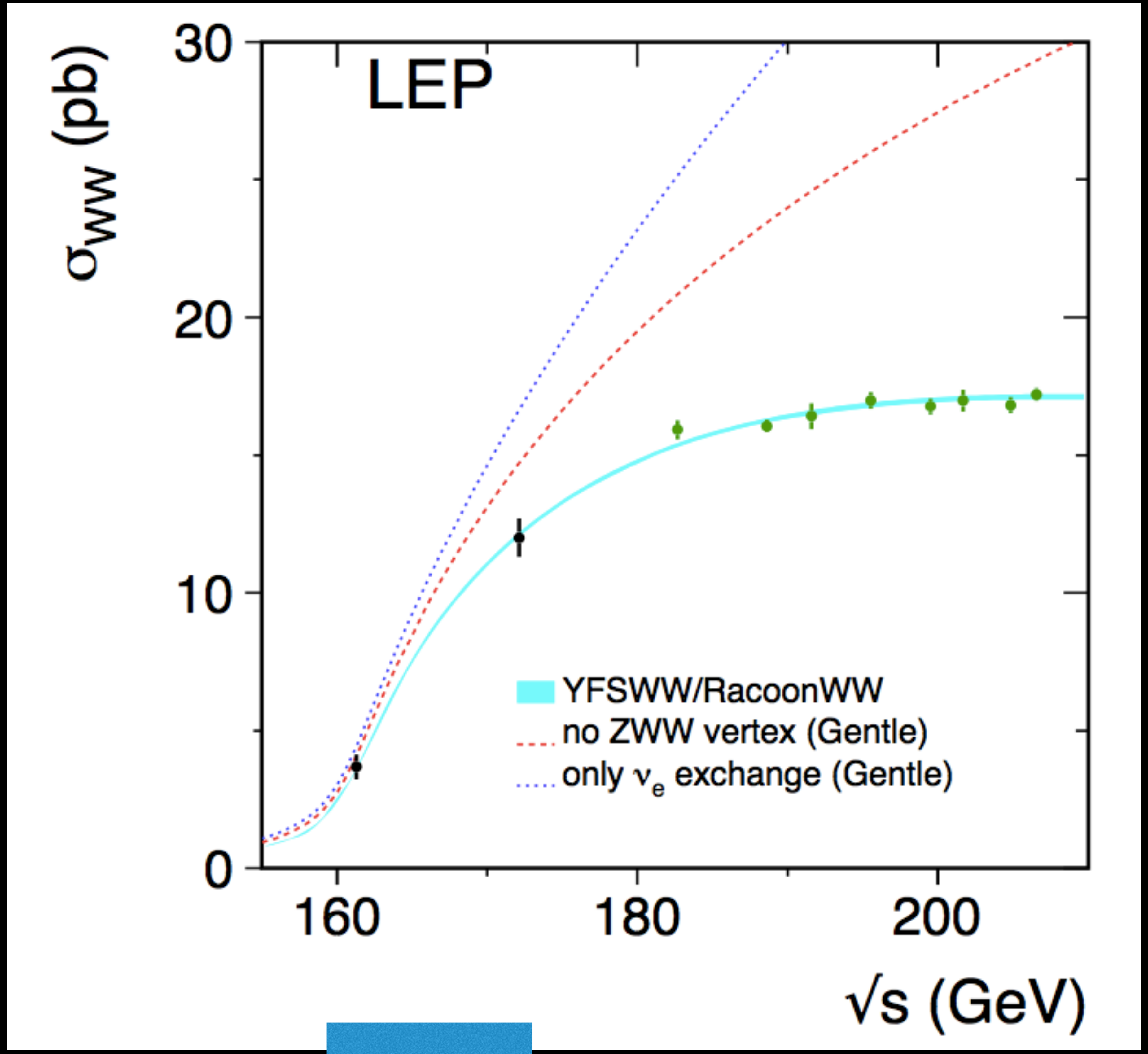
Complete Fit

m_H (minimum)= 125.2 GeV, Range m_H = [116, 133], m_H < 153.9 GeV @ 95%

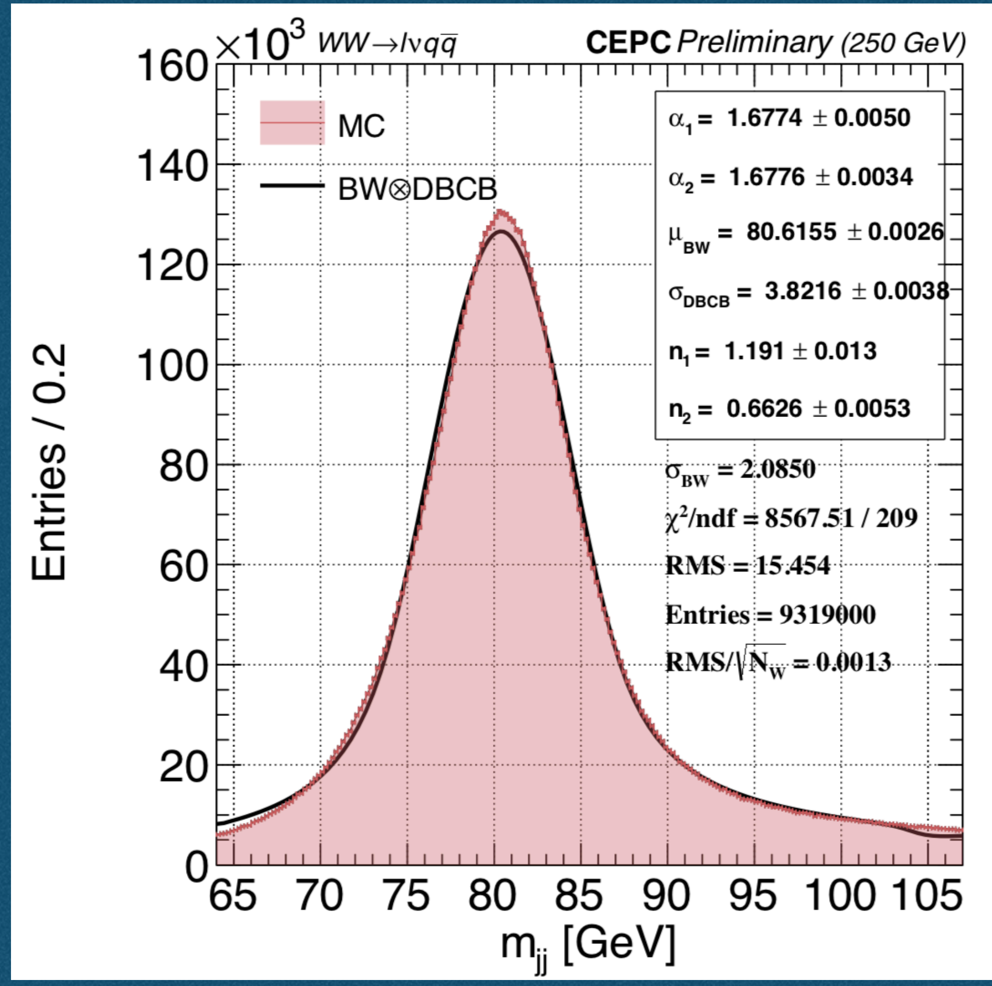
Thanks to Matthias Schott from the GFitter group

W mass measurement

2 methods to extract W mass



Direct measurement √s = 240 GeV
WW → lvqq , WW → qqqq

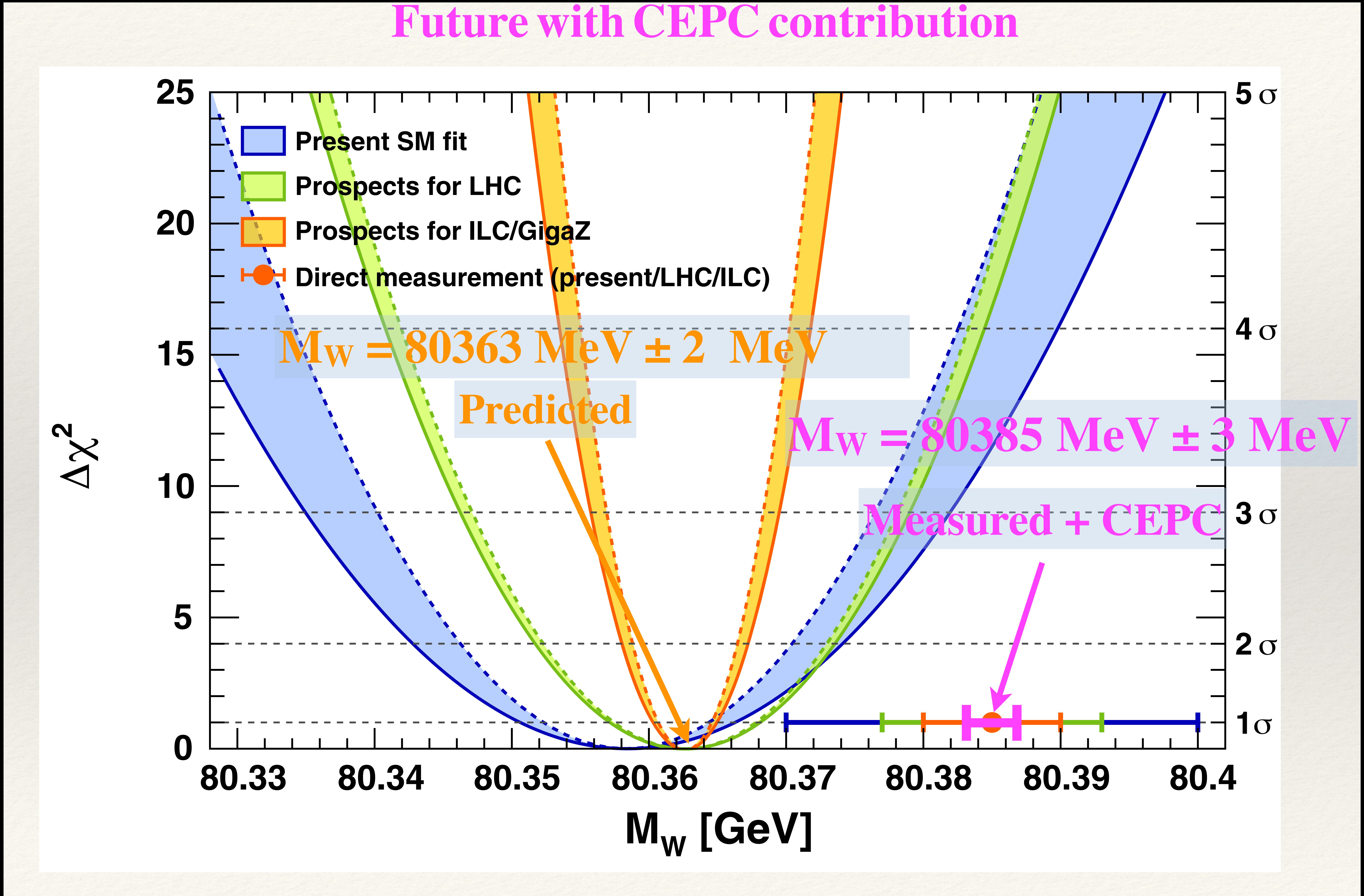


ΔM_W = 2-3 MeV

Energy scan threshold
Limiting factor is beam energy uncertainty: ΔE ~ 0.5 MeV

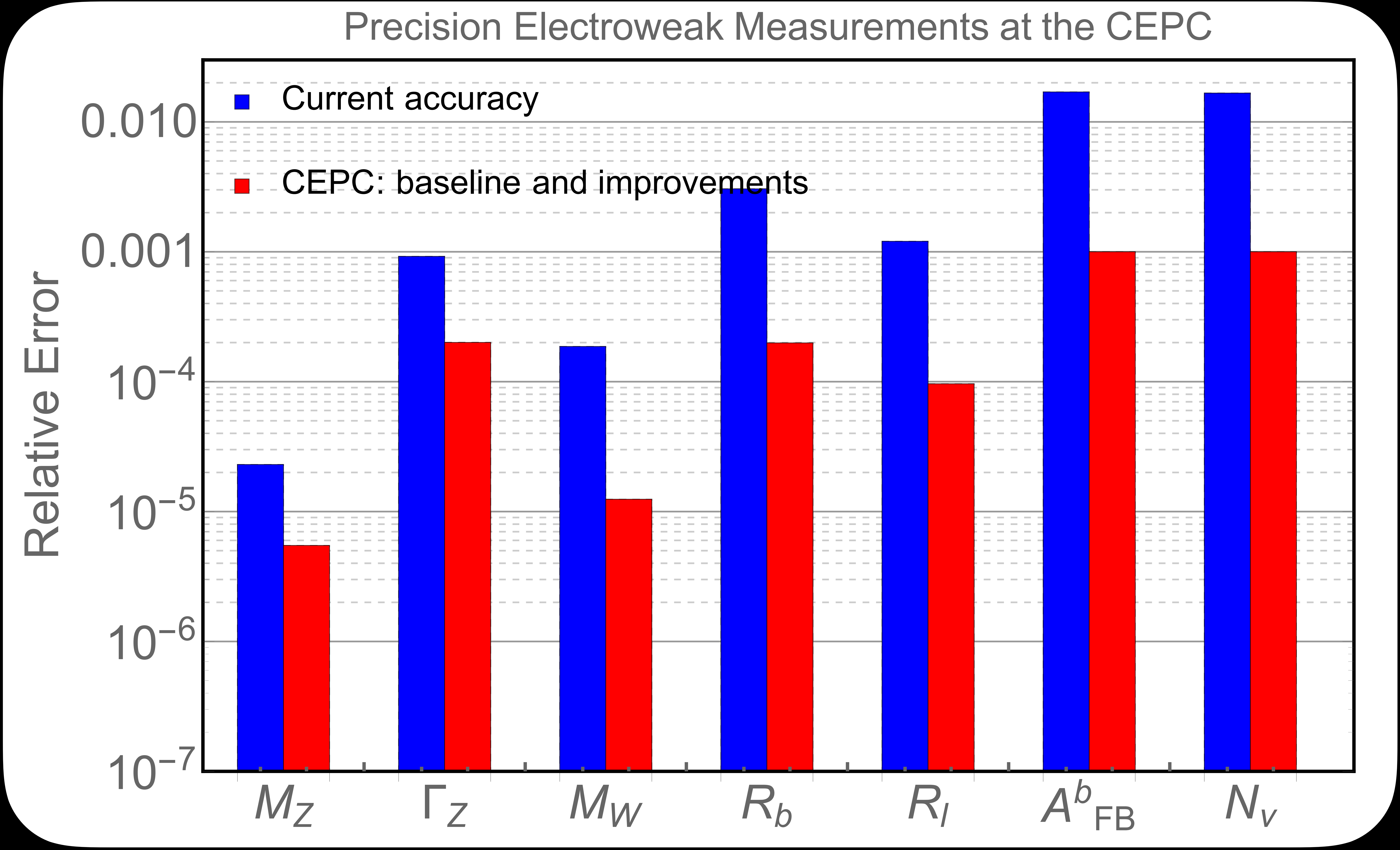
ΔM_W = 1 MeV

The W mass measurement



Electroweak observables at CEPC

Expect to have ~7×10[11] Z boson for electroweak precision physics



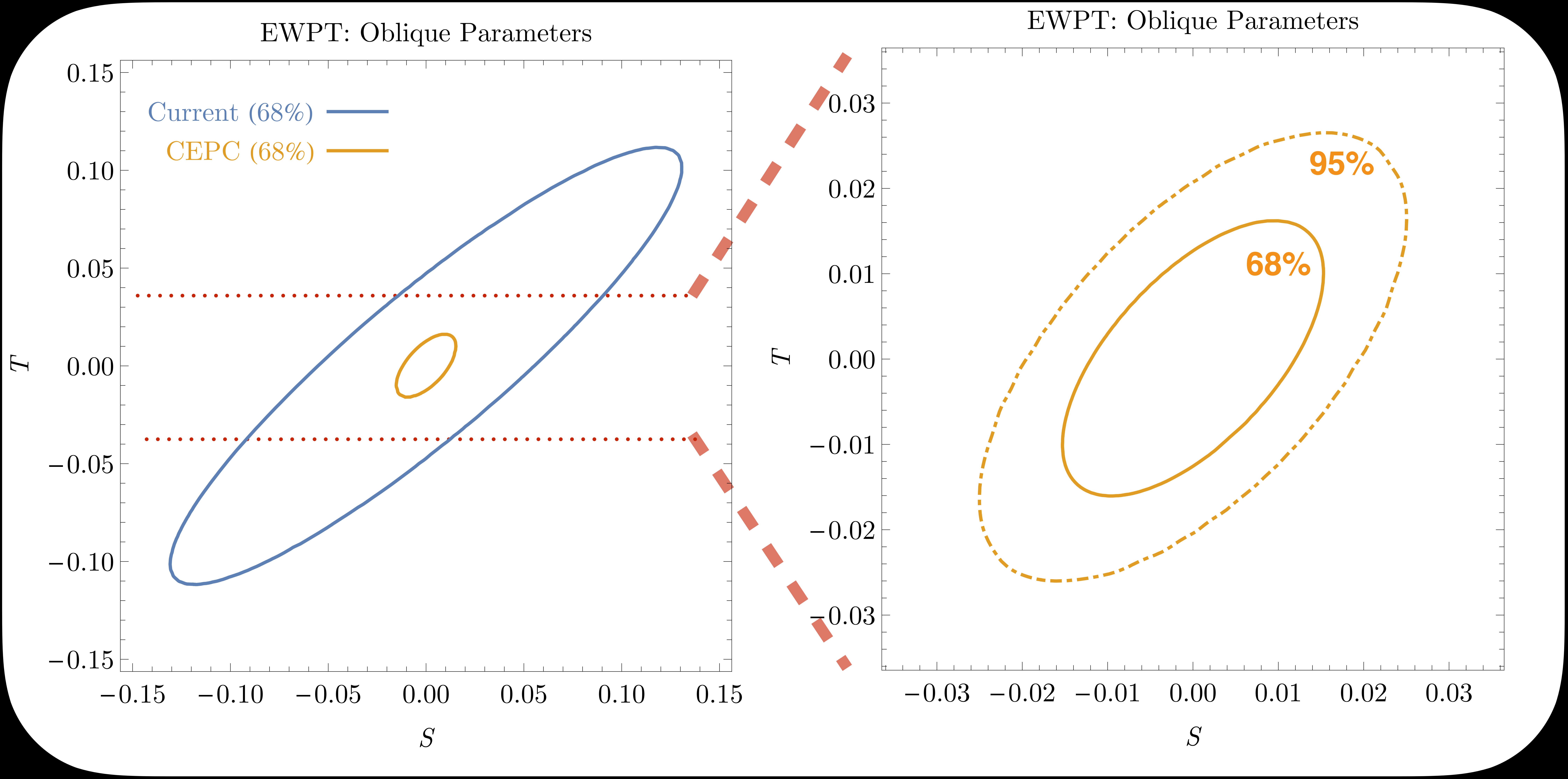
Electroweak observables at CEPC

Expect to have ~7×10¹¹ Z boson for electroweak precision physics

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

New physics from precision measurements

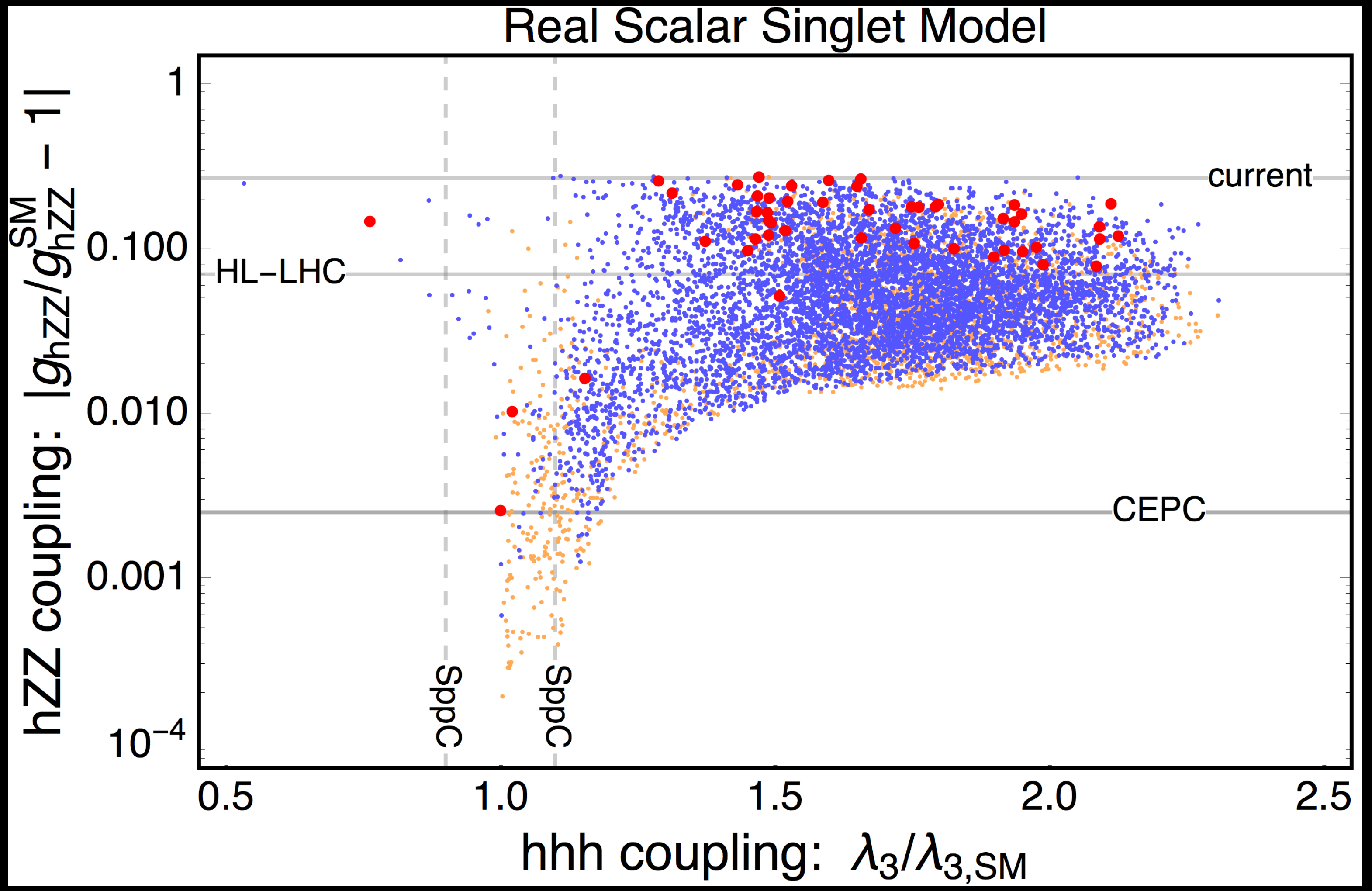
Probe New Physics scale up to O(10-100) TeV

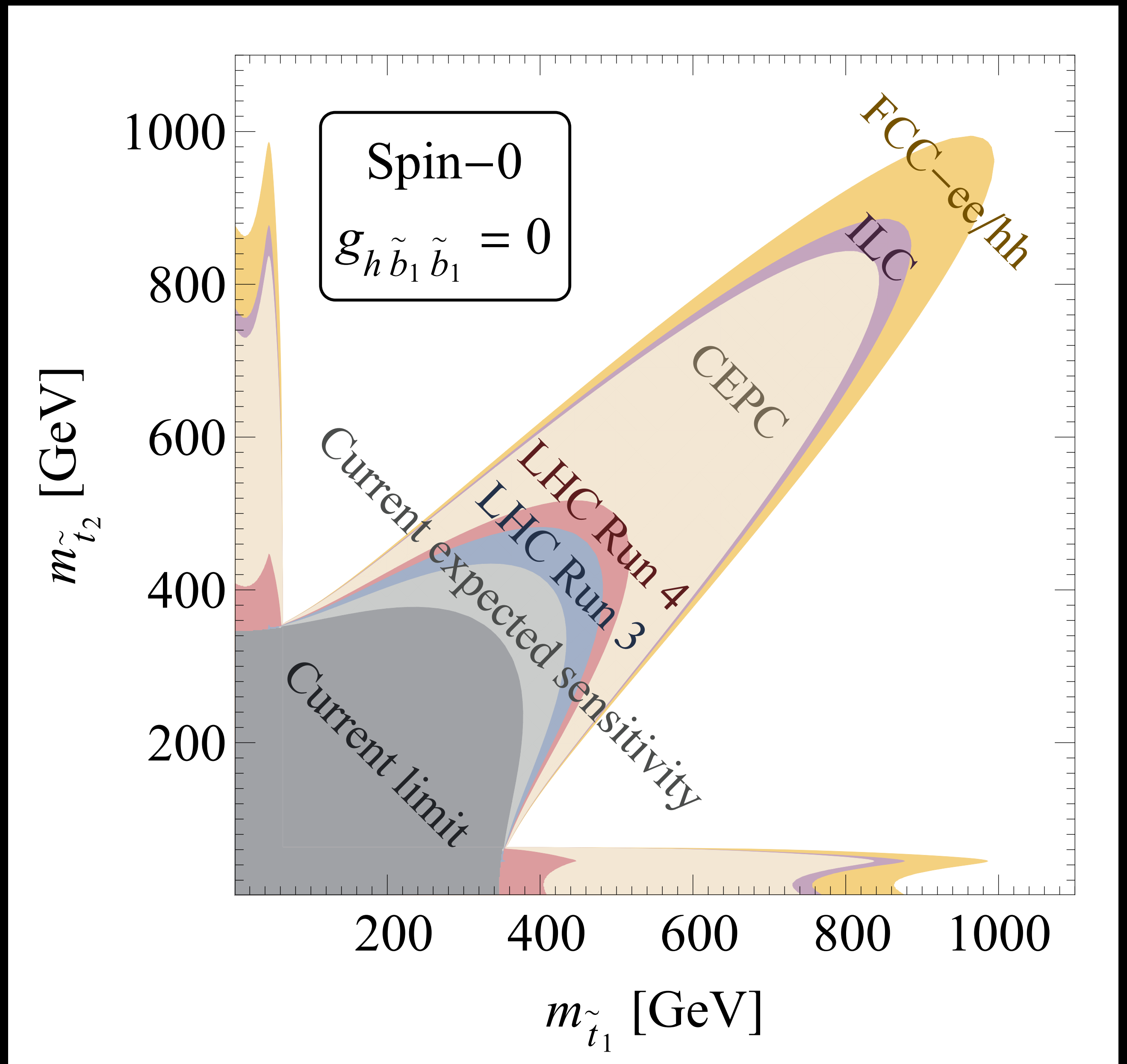


Expect small limit improvement from top mass measurement improvement

A few other physics highlights

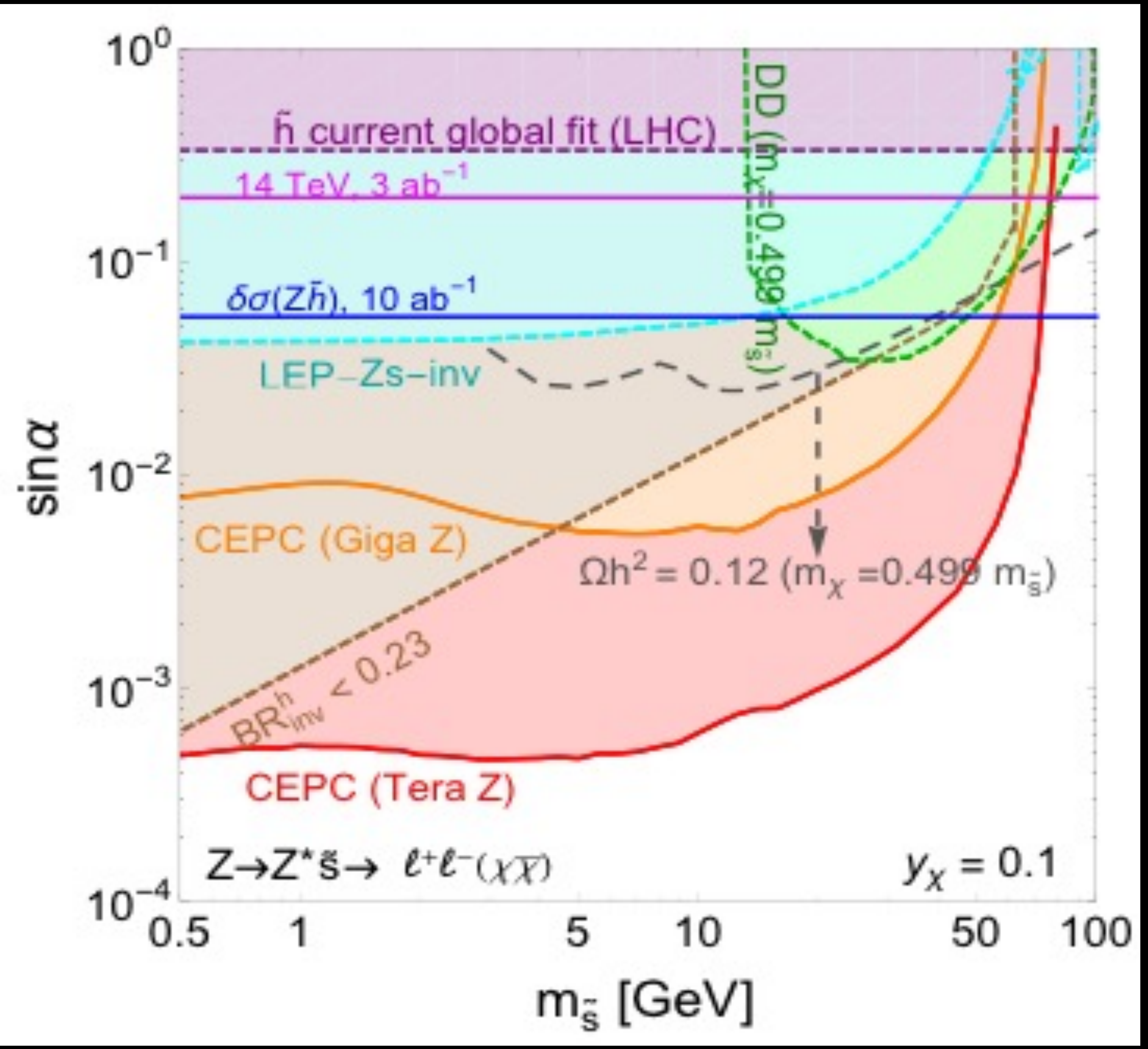
Is EWPT 1st order?

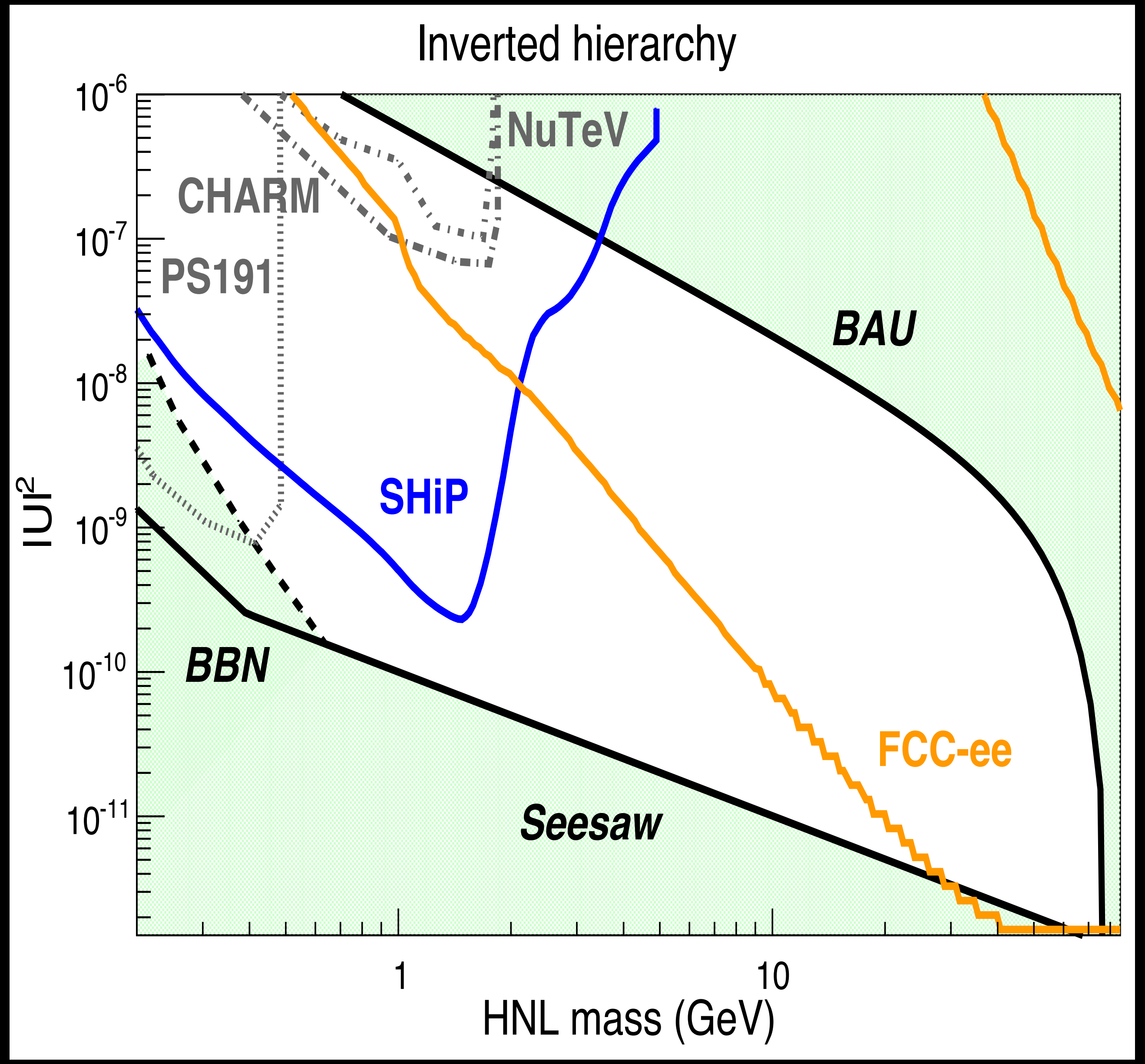




SUSY blind spots

Dark sector search
With Z rare decay



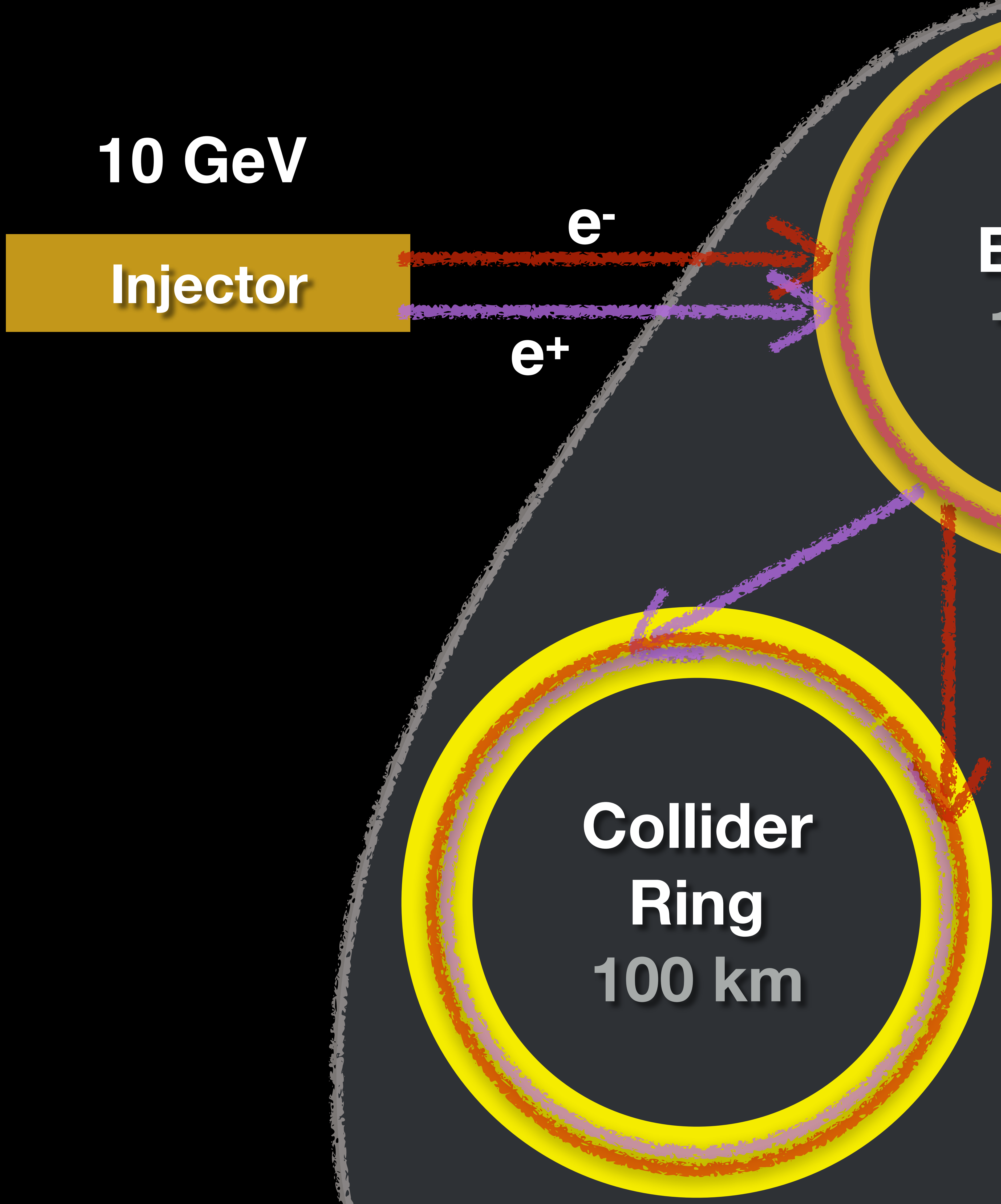


Right-handed neutrinos

Origin of neutrino mass

The tools to explore these questions

CEPC Accelerator Chain and Systems



Energy ramp

10 GeV

45/80/120 GeV

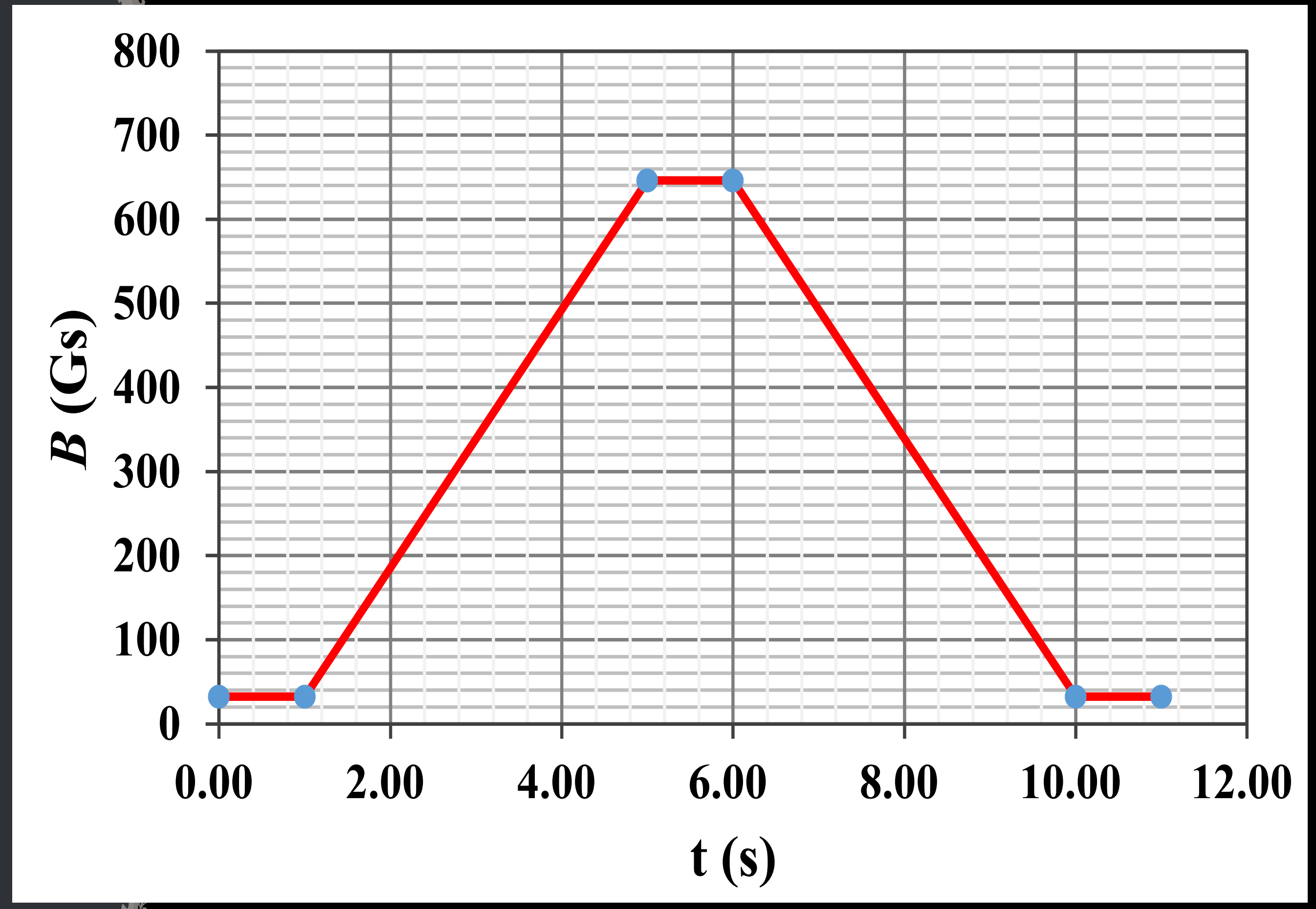
Three machines in one single tunnel

- Booster and CEPC
- SPPC

√s = 90, 160 or 240 GeV
2 interaction points

45/80/120 GeV beams

Booster Cycle (0.1 Hz)

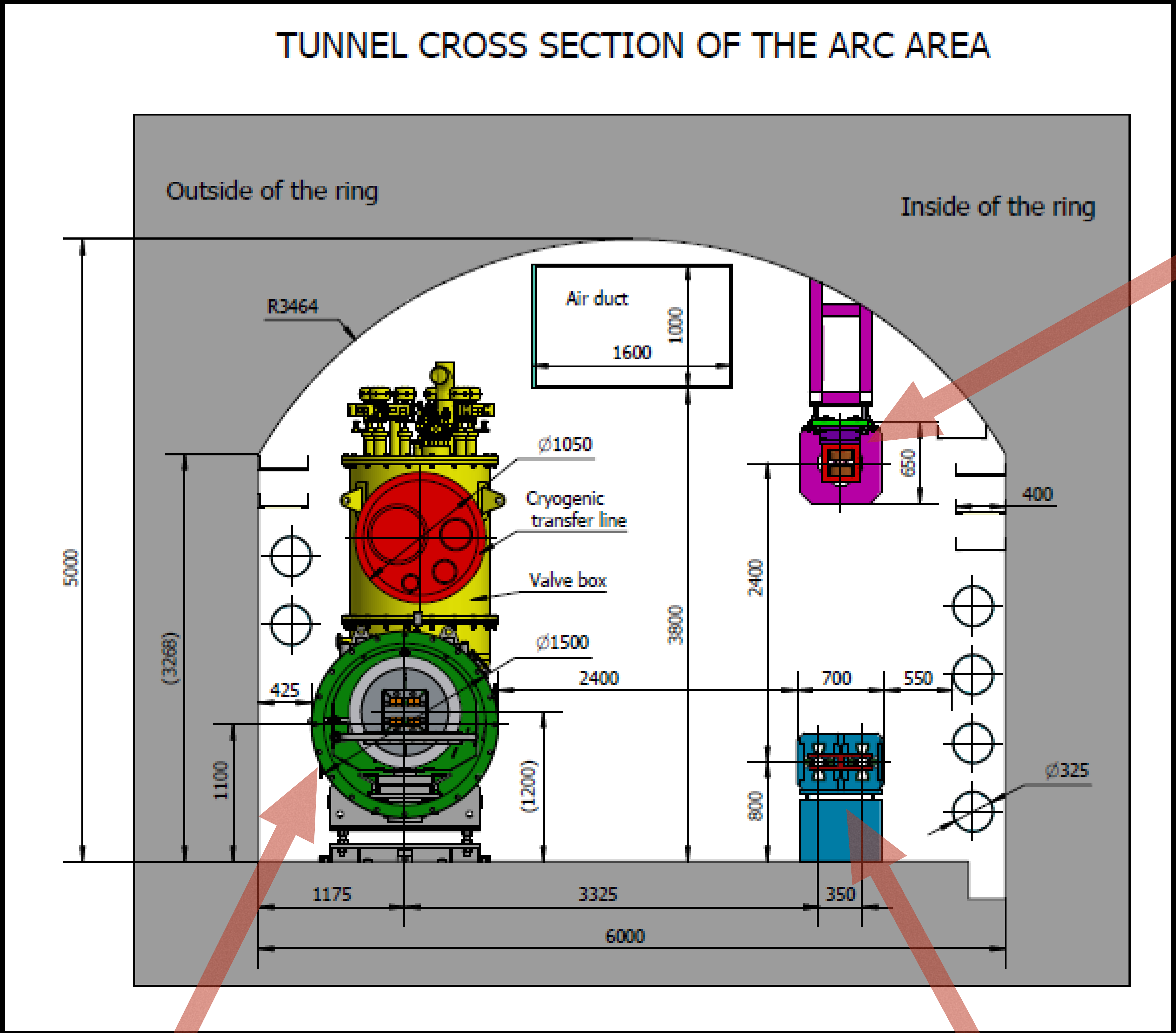


The key systems of CEPC:

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

CDR provides details of all systems

The 100k tunnel cross section

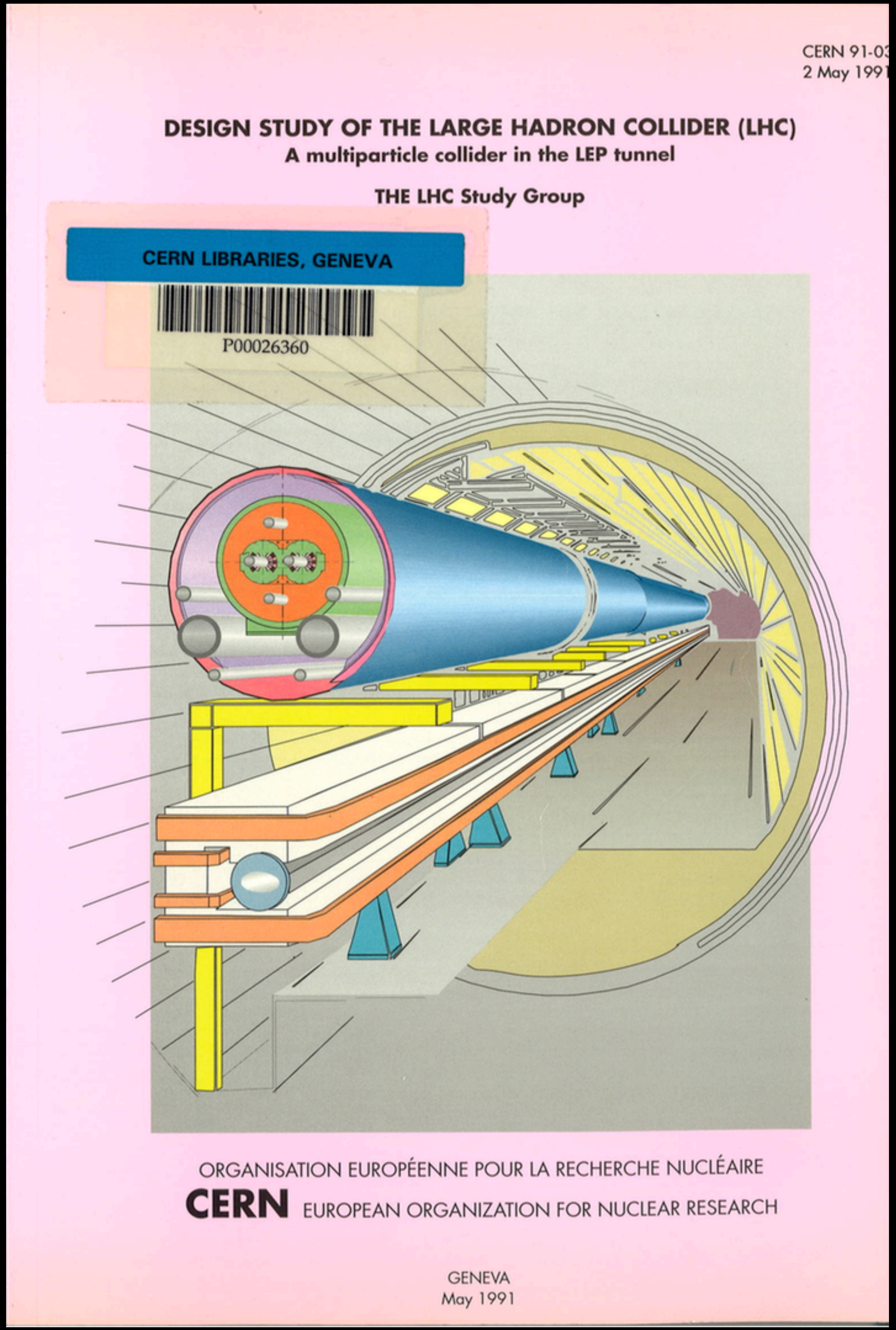


CEPC Booster

SPPC collider

CEPC collider

Proposed in Lausanne Workshop in 1984

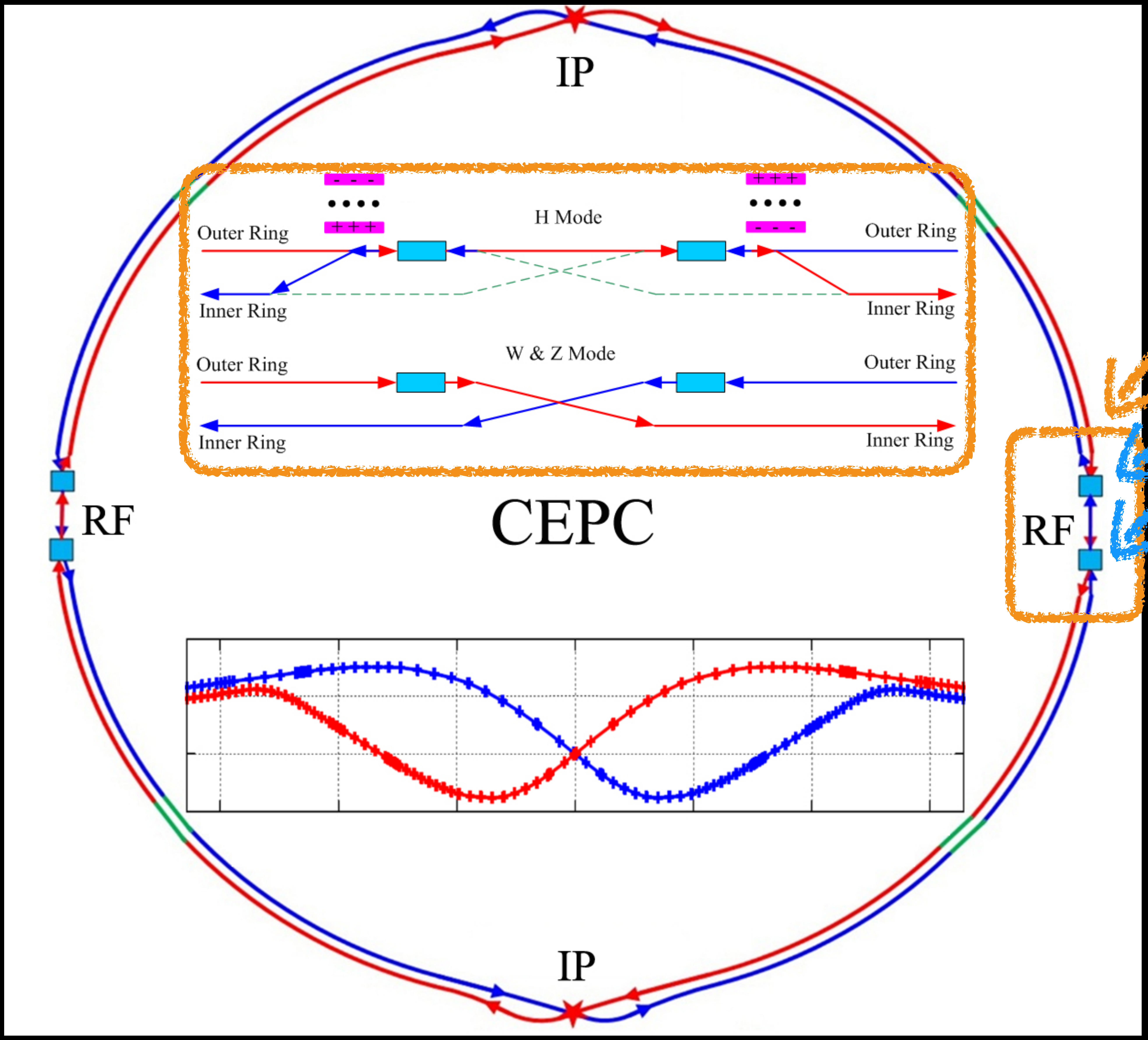


CEPC Civil Engineering Design very advanced

LEP tunnel internal diameter is 3.8 metres in the arcs

4.4 or 5.5 metres in the straight sections

The CEPC Baseline Collider Design



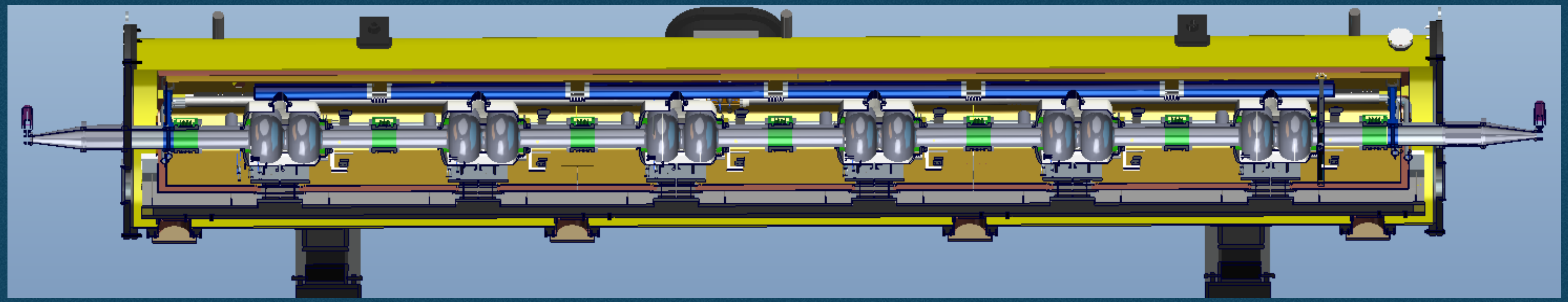
Double ring

Common RF cavities for Higgs

Two RF sections in total

Two RF stations per RF section

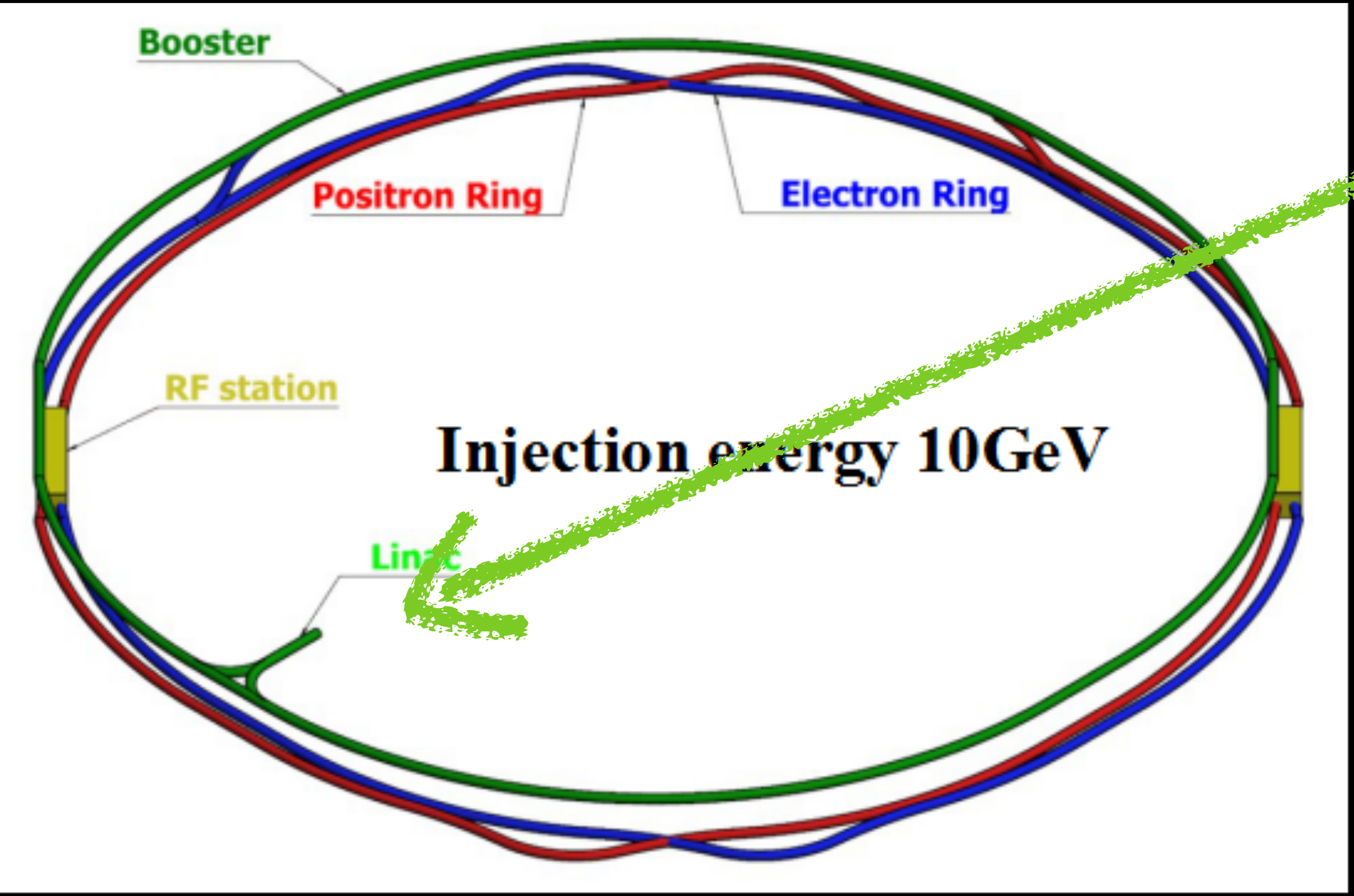
10 x 2 = 20 cryomodules



6 2-cell cavities per cryomodule

The CEPC Baseline Collider Design — Injection

Positron target



e+/e- beam energy:
10 GeV

Total beam transfer efficiency: **90%**

45 GeV Plasma Wakefield Accelerator considered as an alternative

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

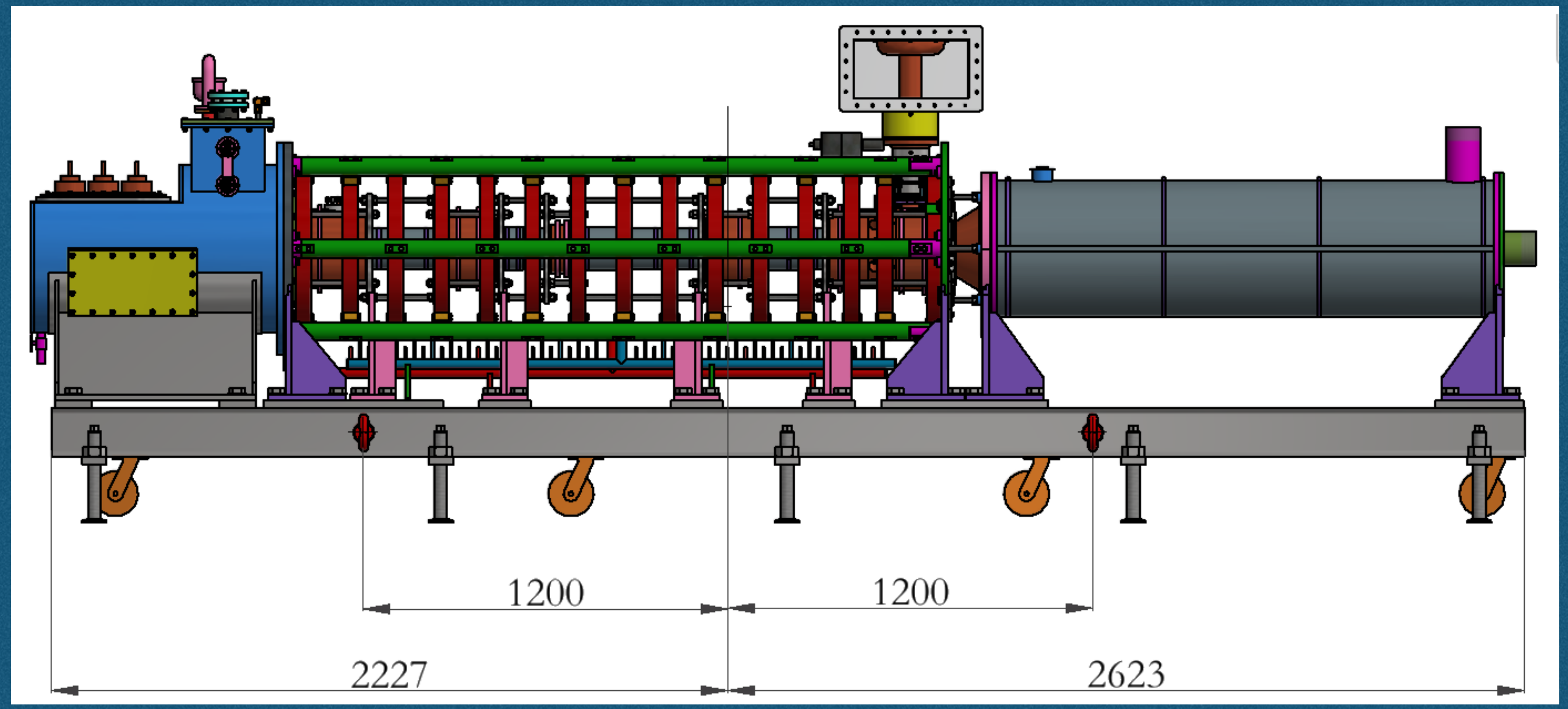
Accelerator key technologies R&D — prototypes

CEPC 650 MHz Cavity

Collaboration with Photon Source projects in Shanghai and Beijing (1.3 GHz cavities)

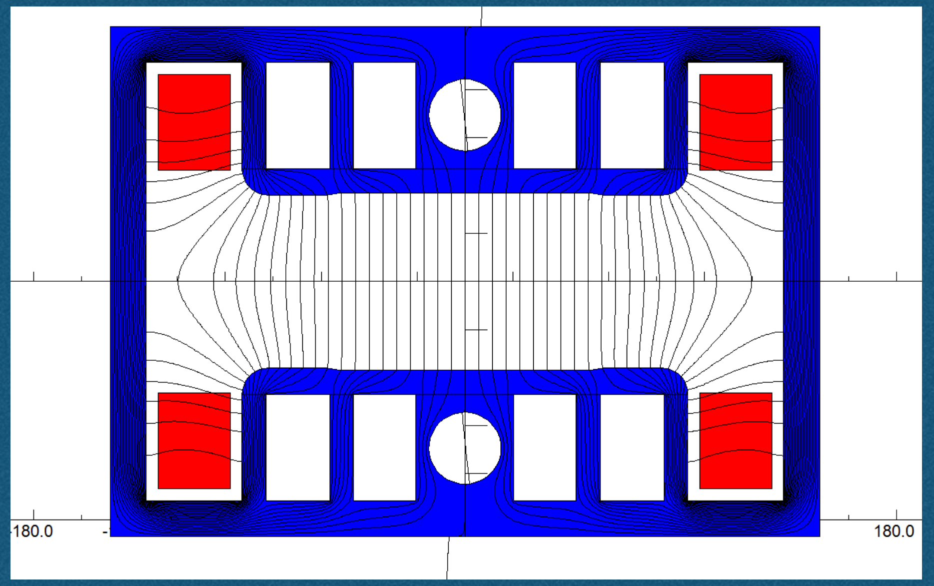
High Efficiency Klystron

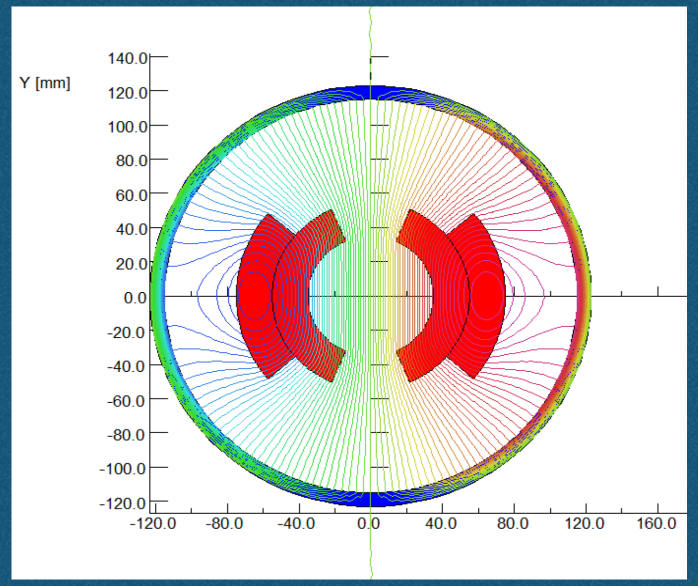
"High efficiency klystron collaboration consortium", including IHEP, Institute of Electronic) of CAS, and Kunshan Guoli Science and Tech.



3 high-efficiency klystron (up to 80%) prototypes to be built by 2021

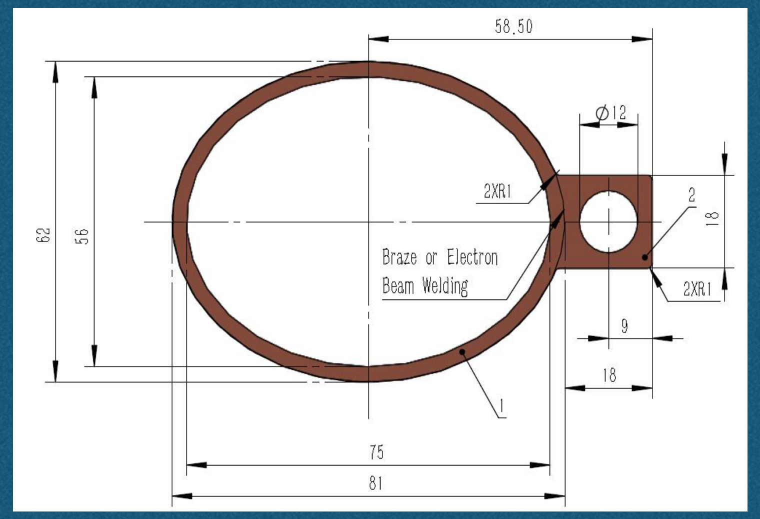
Booster low-field dipole magnets

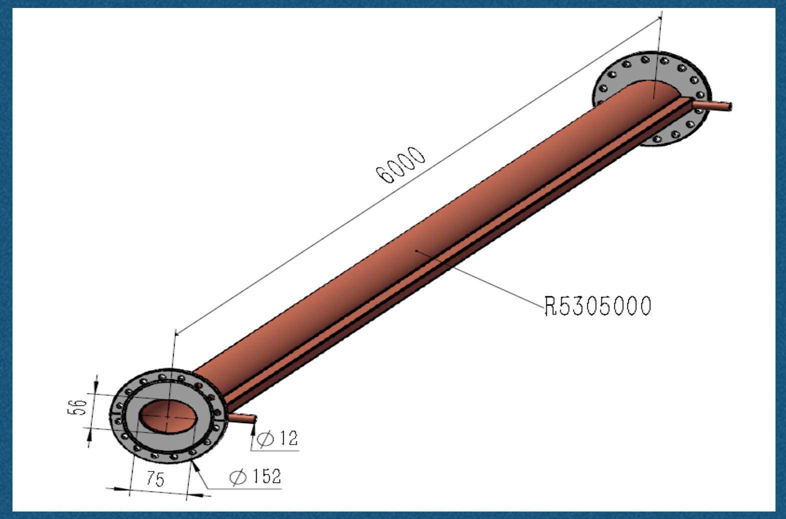


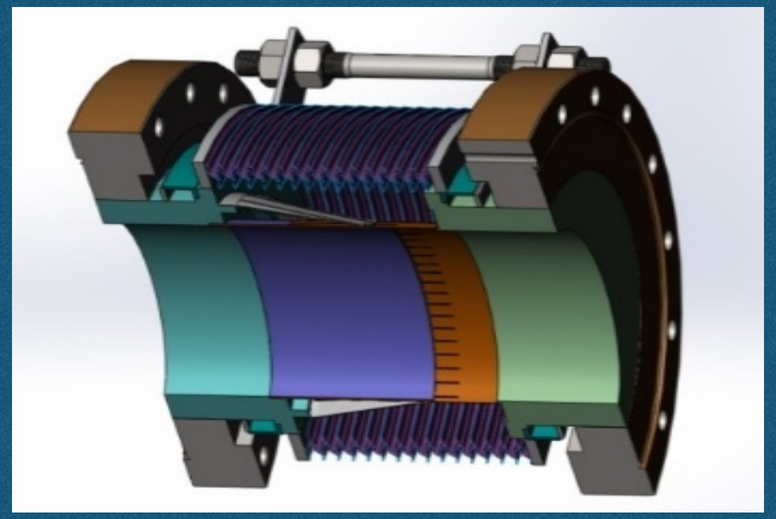


$L_{mag} = 5$ m, $B_{min} = 30$ Gs, Errors $<5\times10^{-4}$

Vacuum system R&D







- 6m copper vacuum chamber: pressure 2×10^{-10} torr
- Bellows module: allow thermal expansion, alignment

Detector requirements from physics

Momentum resolution :

- Higgs recoil mass, Higgs coupling to muons, smuon endpoint

$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \text{GeV}^{-1}$ for high-p_T

Impact parameter resolution:

- c/b-tagging, Higgs branching ratios

$\sigma_{r\phi} \sim a \oplus b/(p[\text{GeV}]\sin^{\frac{3}{2}}\theta)\ \mu m$

$a = 5$ µm, $b = 10\text{-}15$ µm

Jet energy resolution:

- Separation of W/Z/H in di-jet modes

$\sigma_E/E \sim 3.5\ \%$ for jets above 50 GeV

Large angular coverage

- Forward electron and photon tagging

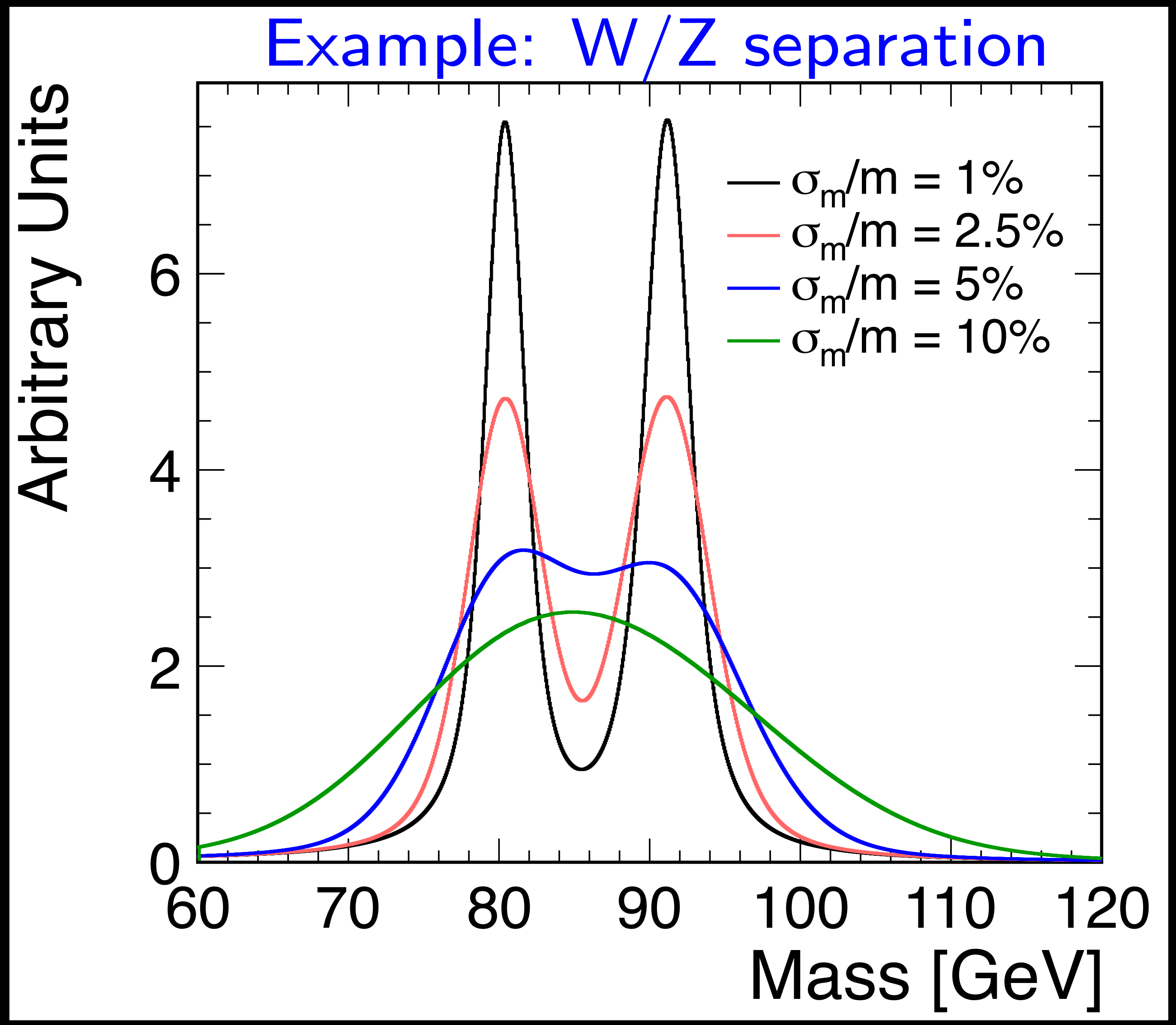
Requirements from beam environment

- Solenoid field, beam structure, beam induced backgrounds

Precision measurements:

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

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

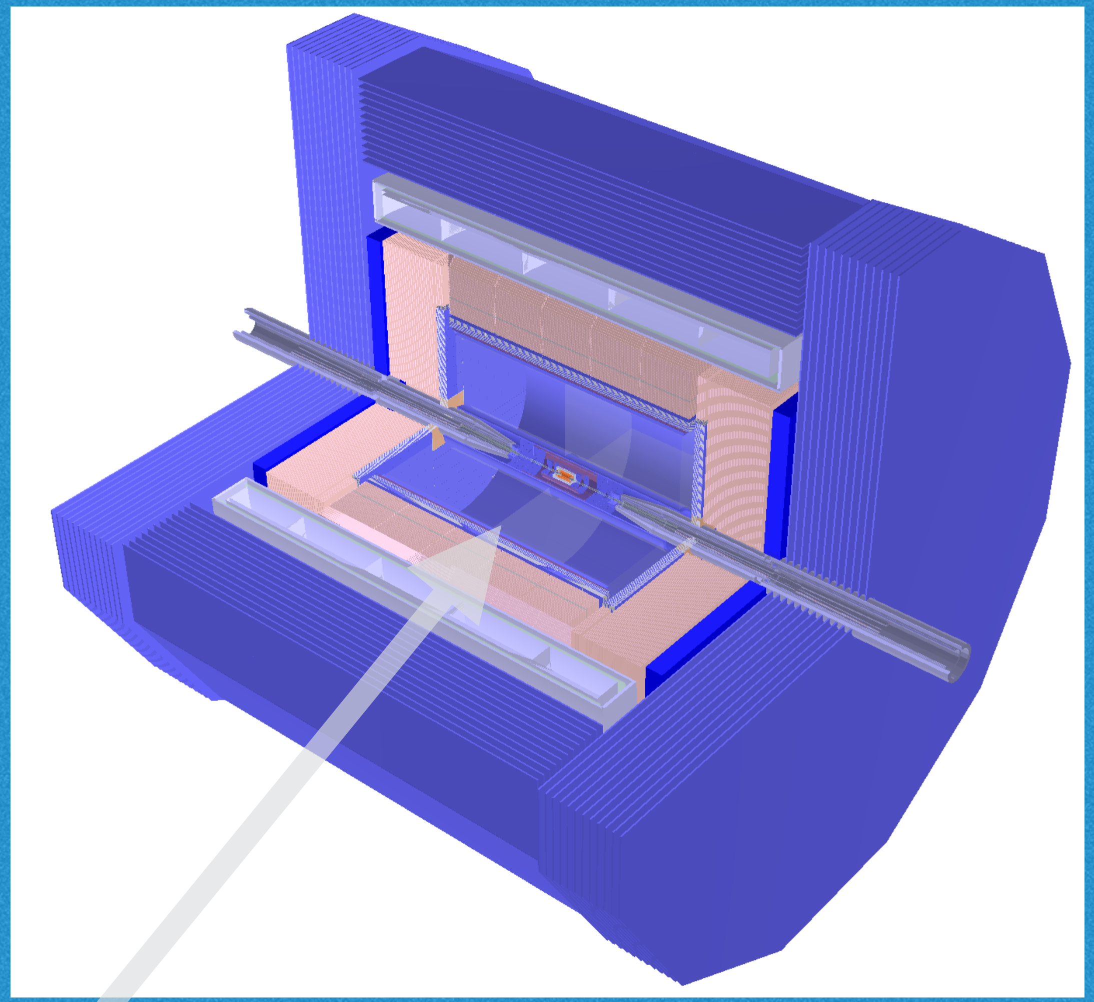


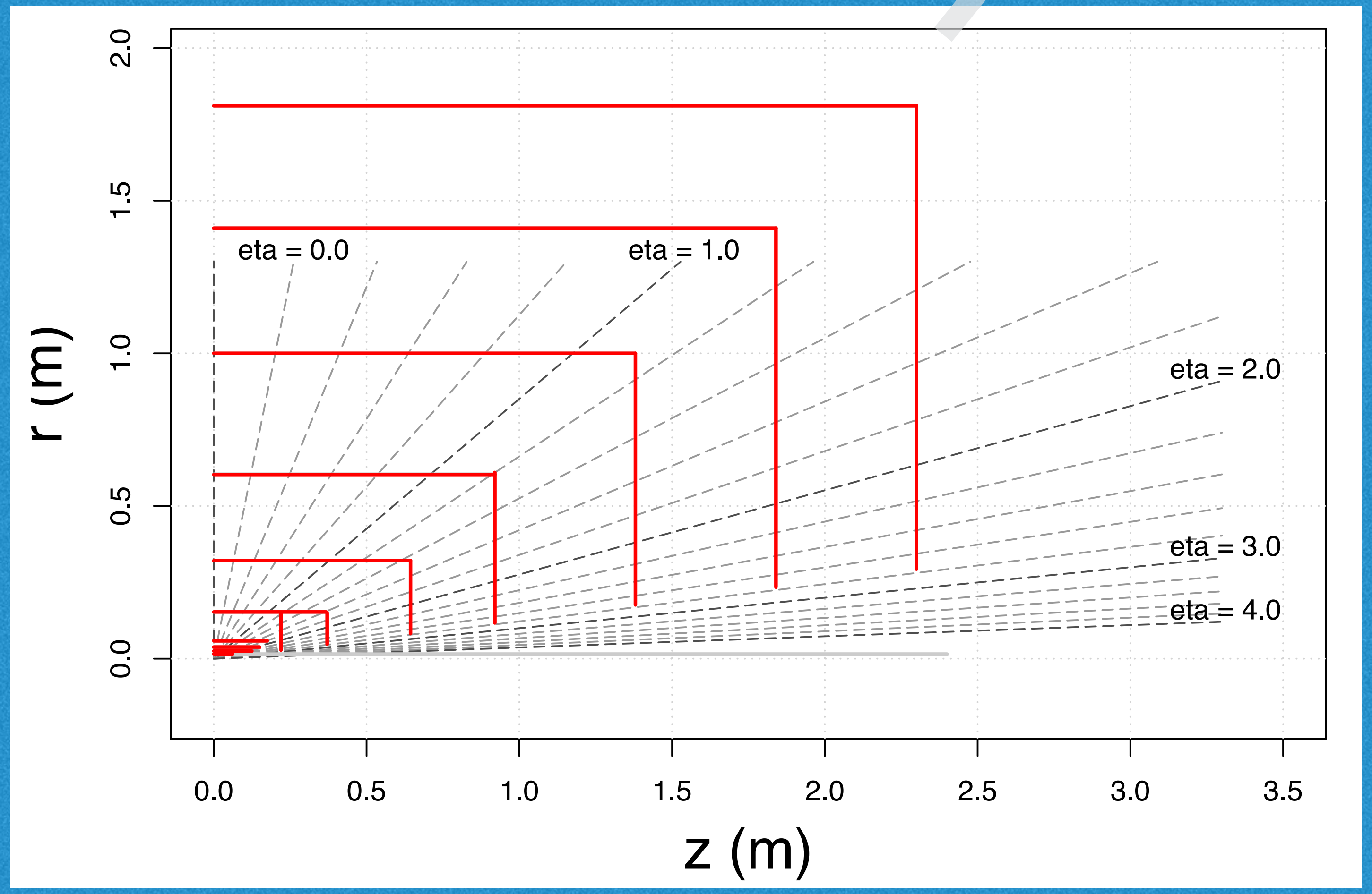
CEPC: 2.5 detector concepts

CEPC plans for
2 interaction points

Particle Flow Approach

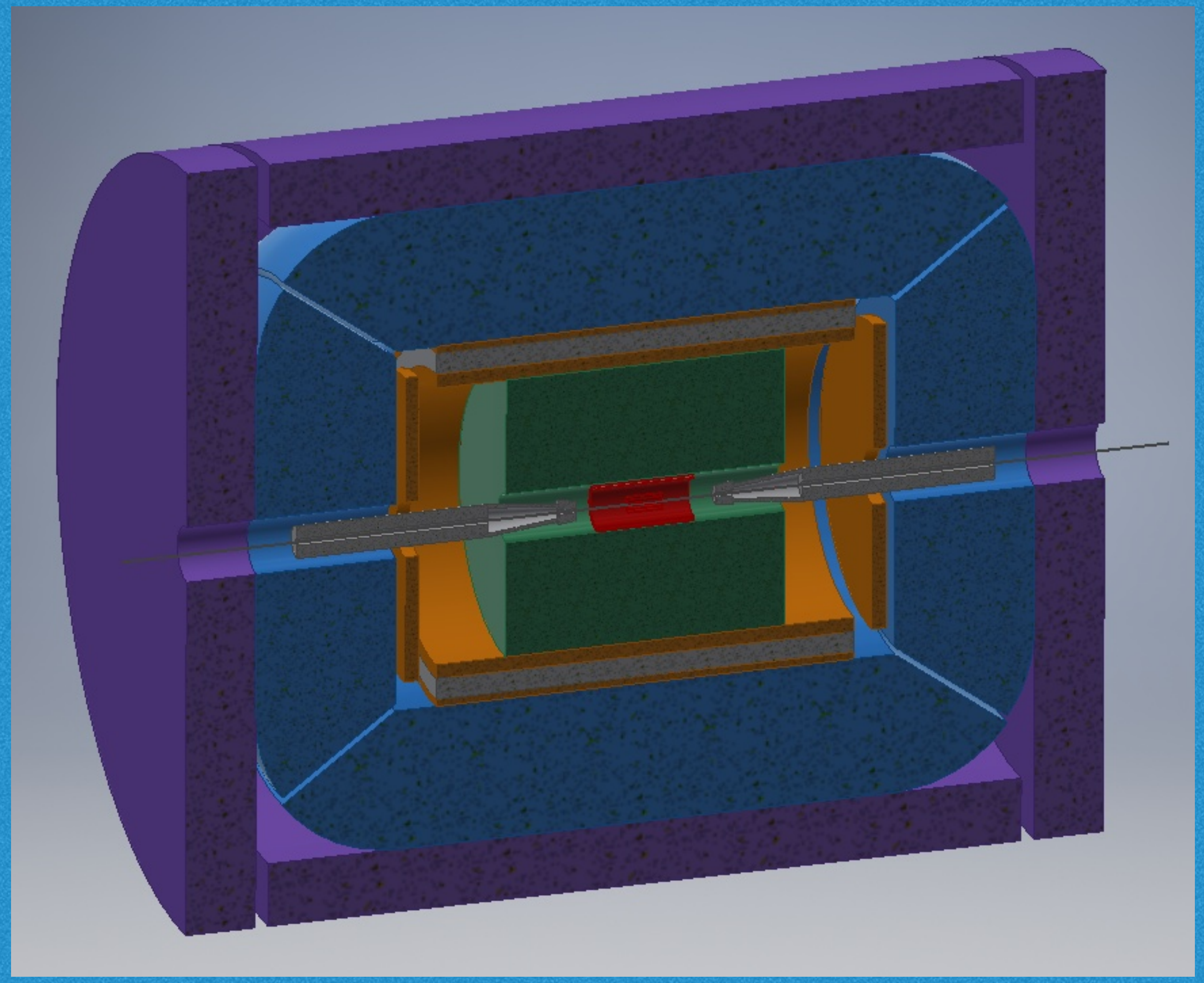
Baseline detector
ILD-like
(3 Tesla)





Full silicon
tracker
concept

Low
magnetic field
concept
(2 Tesla)



IDEA - also proposed for FCC-ee

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

CEPC baseline detector: ILD-like: Design Considerations

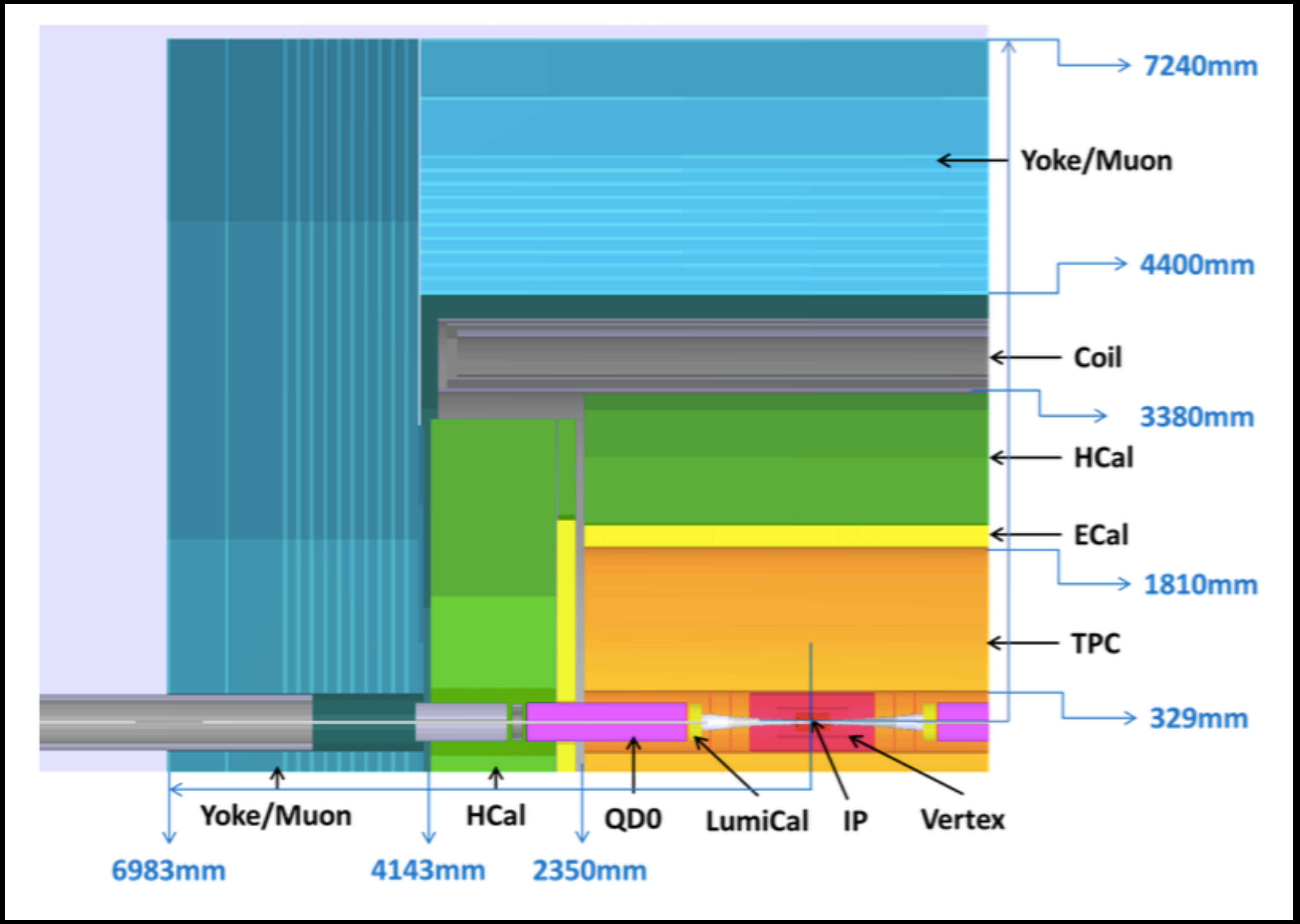
Major concerns being addressed

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

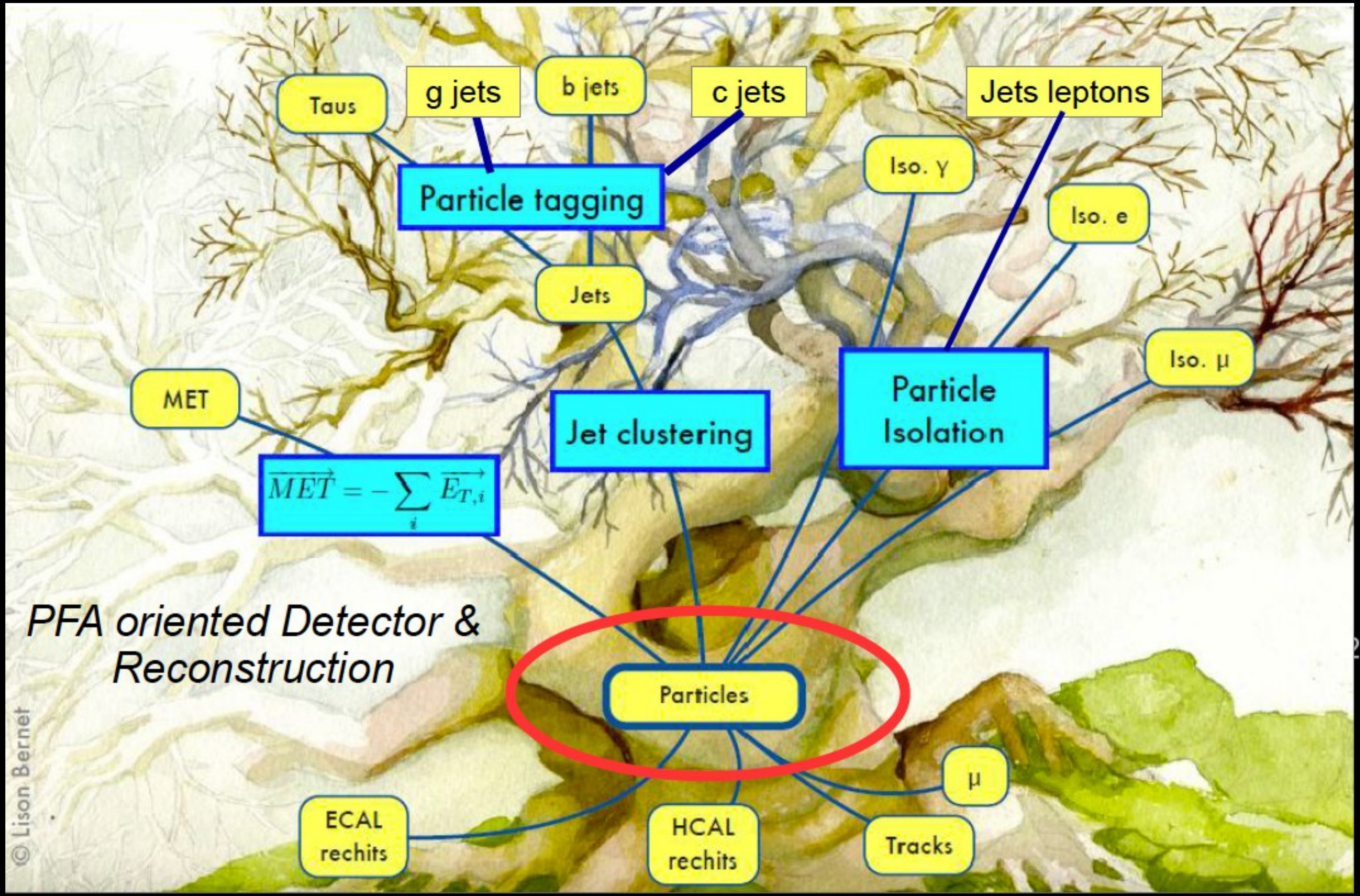


Magnetic Field: 3 Tesla — changed from preCDR

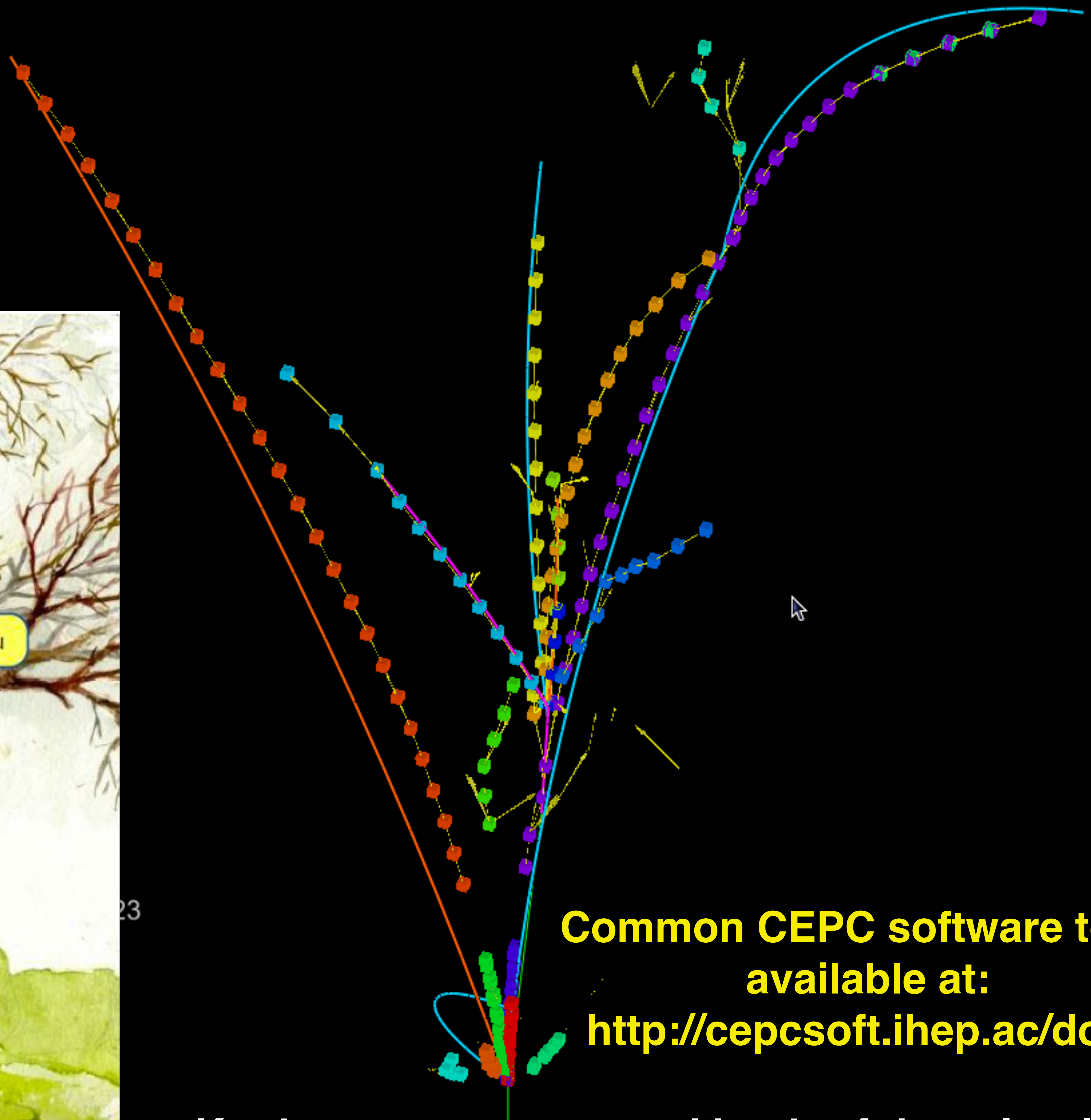
Detector optimization

Complete set of physics results in CDR

Optimization based on particle flow oriented detector and full simulation Geant4



Some studies done with fast simulation

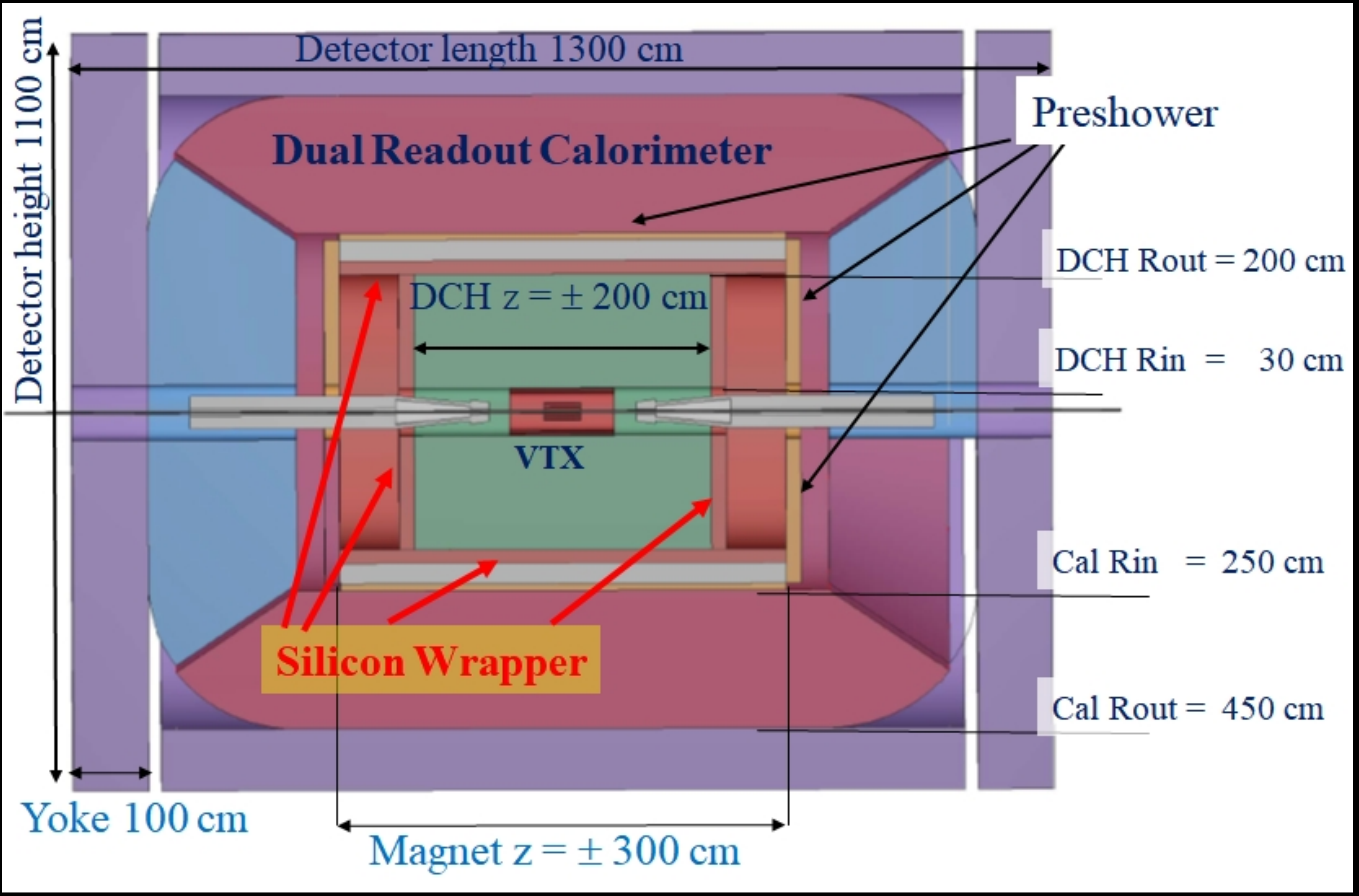


Common CEPC software tools available at: http://cepcsoft.ihep.ac/docs

K_L shower reconstructed by the Arbor algorithm

CEPC + FCC-ee: IDEA

Only concept with calorimeter outside the coil



Magnet: 2 Tesla, 2.1 m radius

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

Vertex: Similar to CEPC default

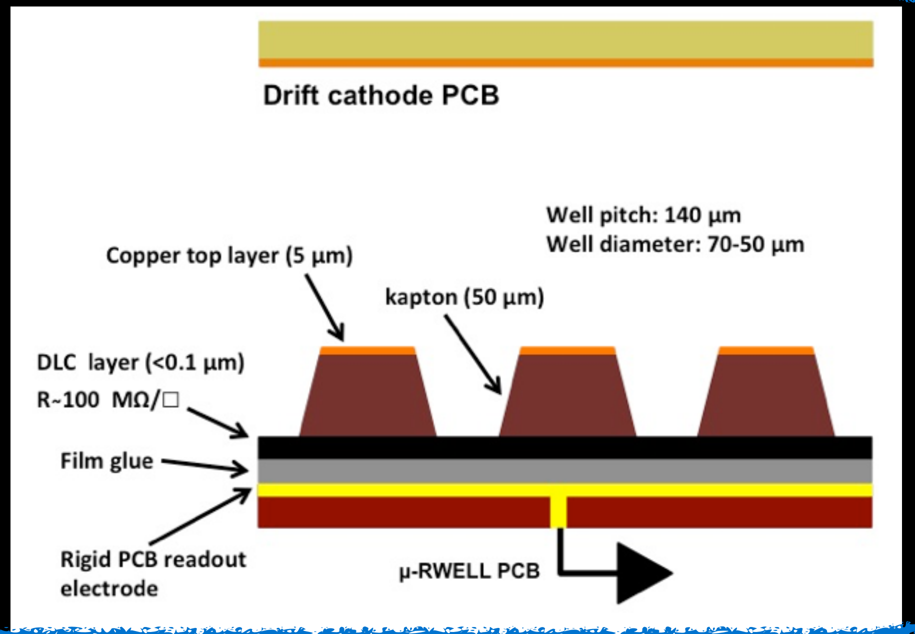
* **Drift chamber: 4 m long; Radius ~30-200 cm, ~ 1.6% X_0 , 112 layers**

Preshower: ~1 X_0

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

* **(yoke) muon chambers (MPGD)**

New technology proposal: µRwell



Proposed by INFN, Italy colleagues

Detector Challenges and R&D

Machine-detector interface (MDI) in circular colliders

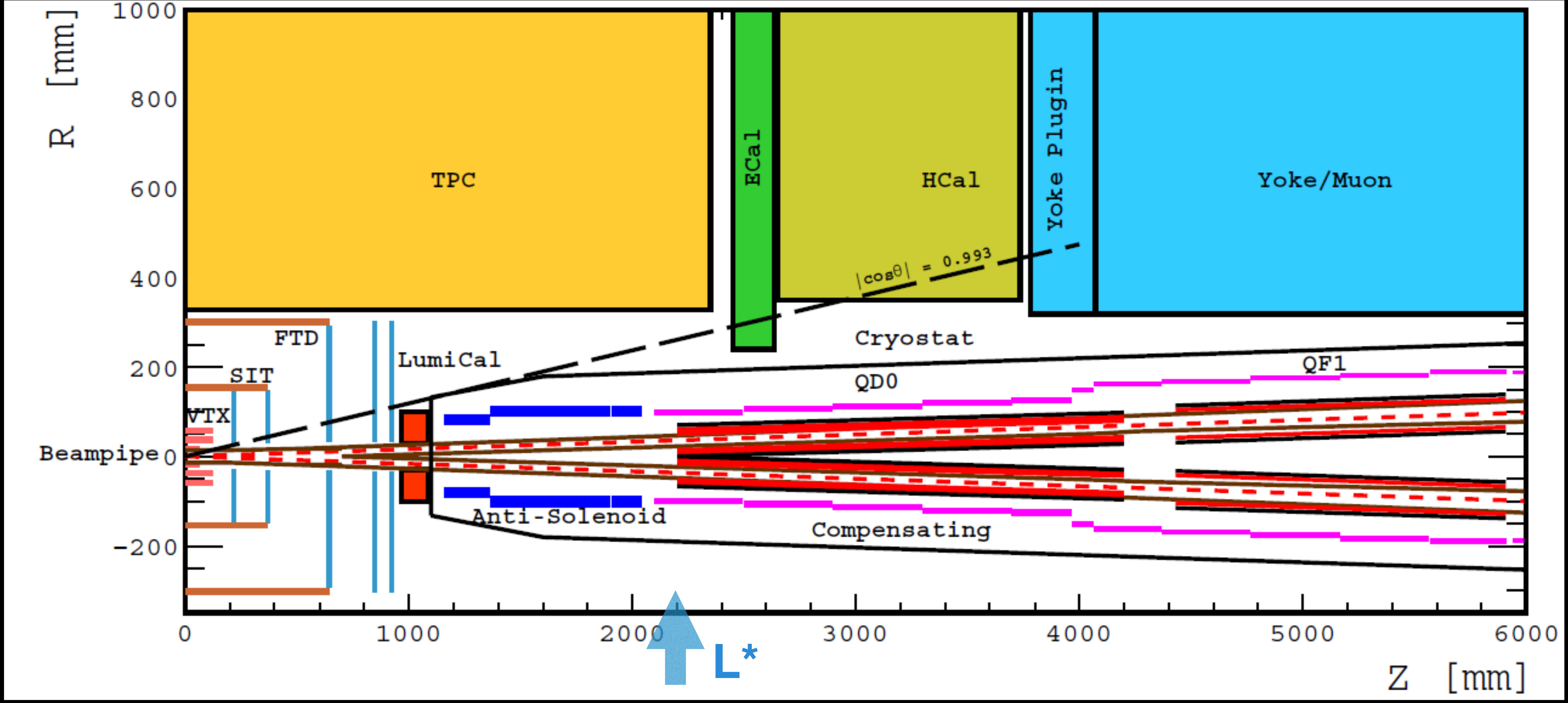
High luminosities → Final focusing quadrupole (QD0) needs to be very close to IP

$L^* = 2.2$ m at FCC-ee and CEPC

Detector acceptance:
$> \pm 150$ mrad

Solenoid magnetic field limited:
2-3 Tesla

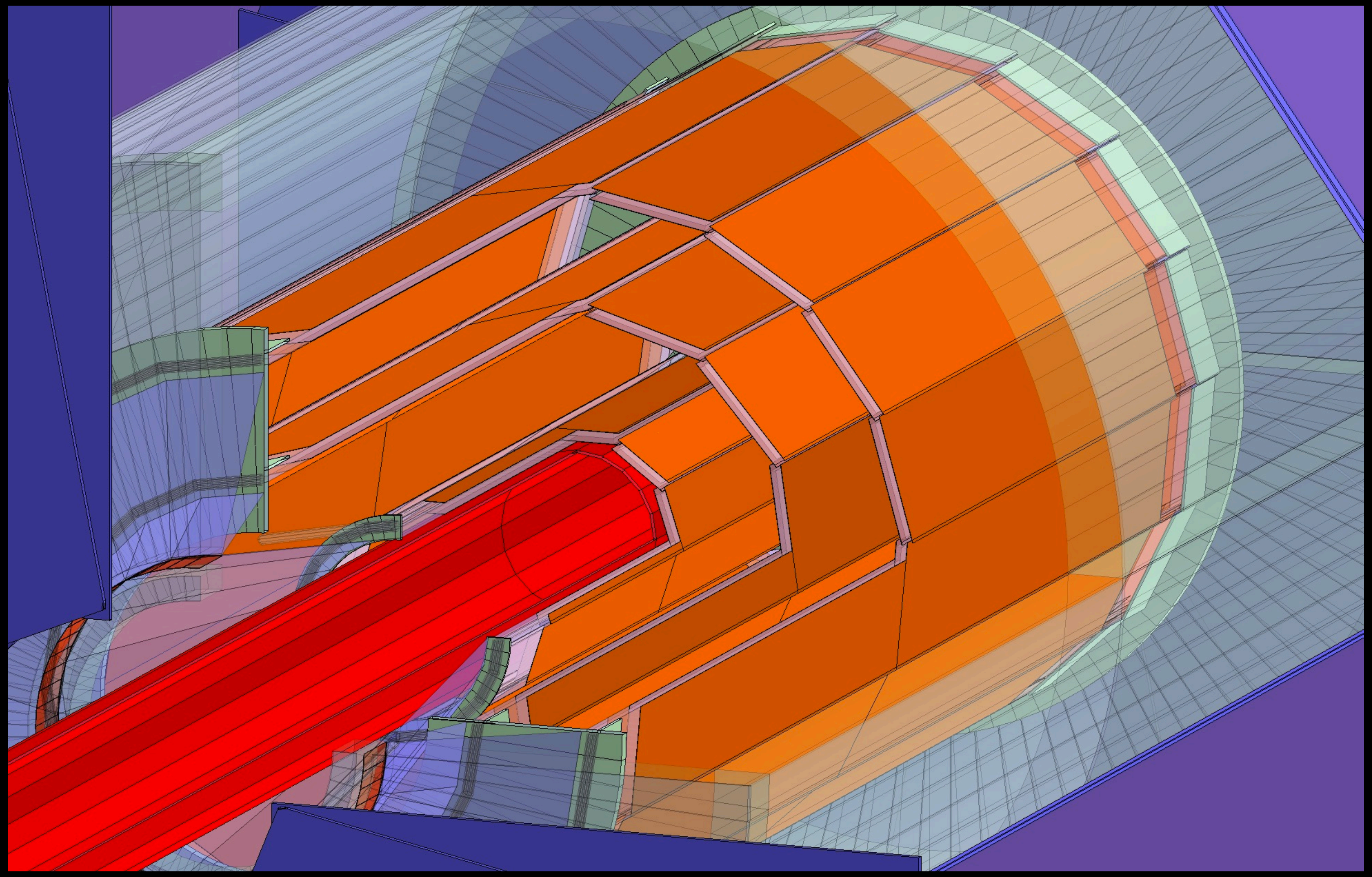
due to beam emittance blow up



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

Baseline Pixel Detector Layout

3-layers of double-sided pixel sensors



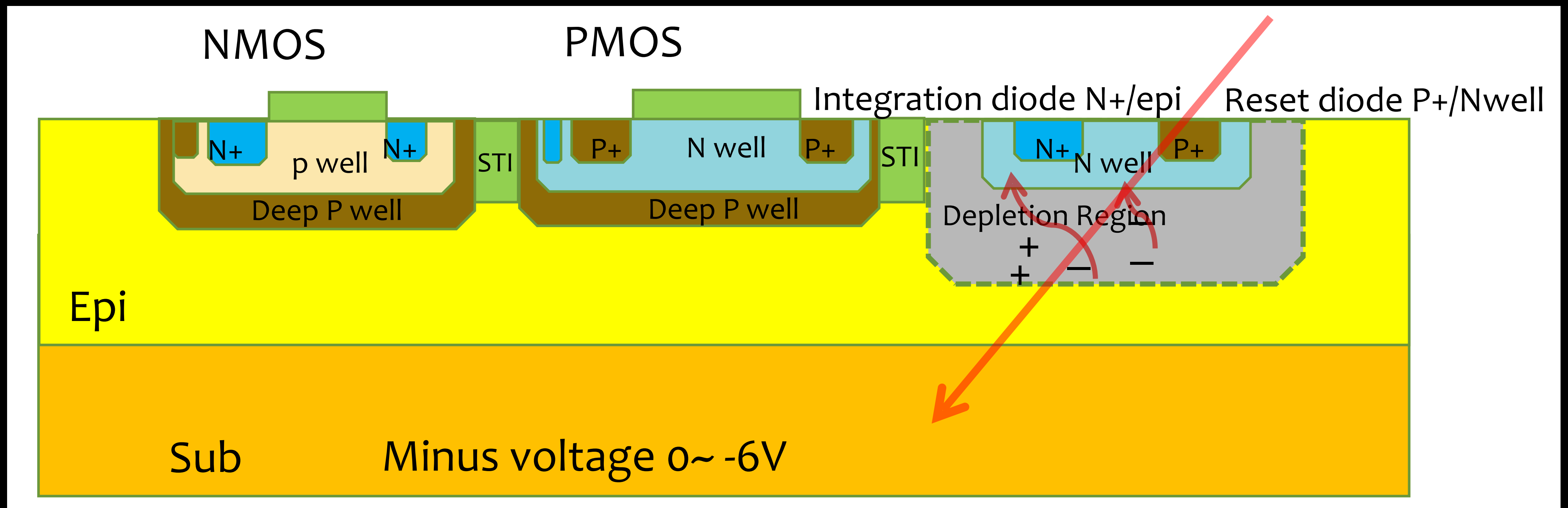
- ✦ ILD-like layout
- ✦ Innermost layer: σ_{SP} = 2.8 μm
- ✦ Polar angle θ ~ 15 degrees

Low material budget
~ 0.15%X_0 per layer

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

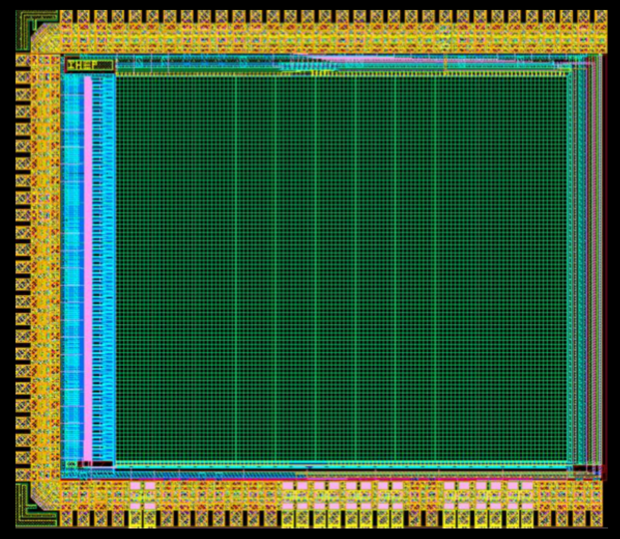
Implemented in GEANT4 simulation framework (MOKKA)

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



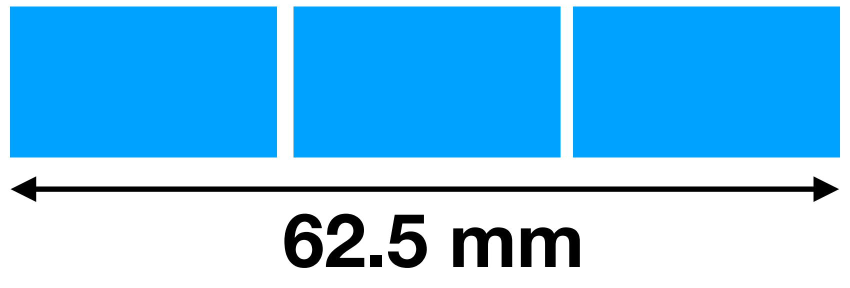
Initial Pixel sensor R&D:

	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

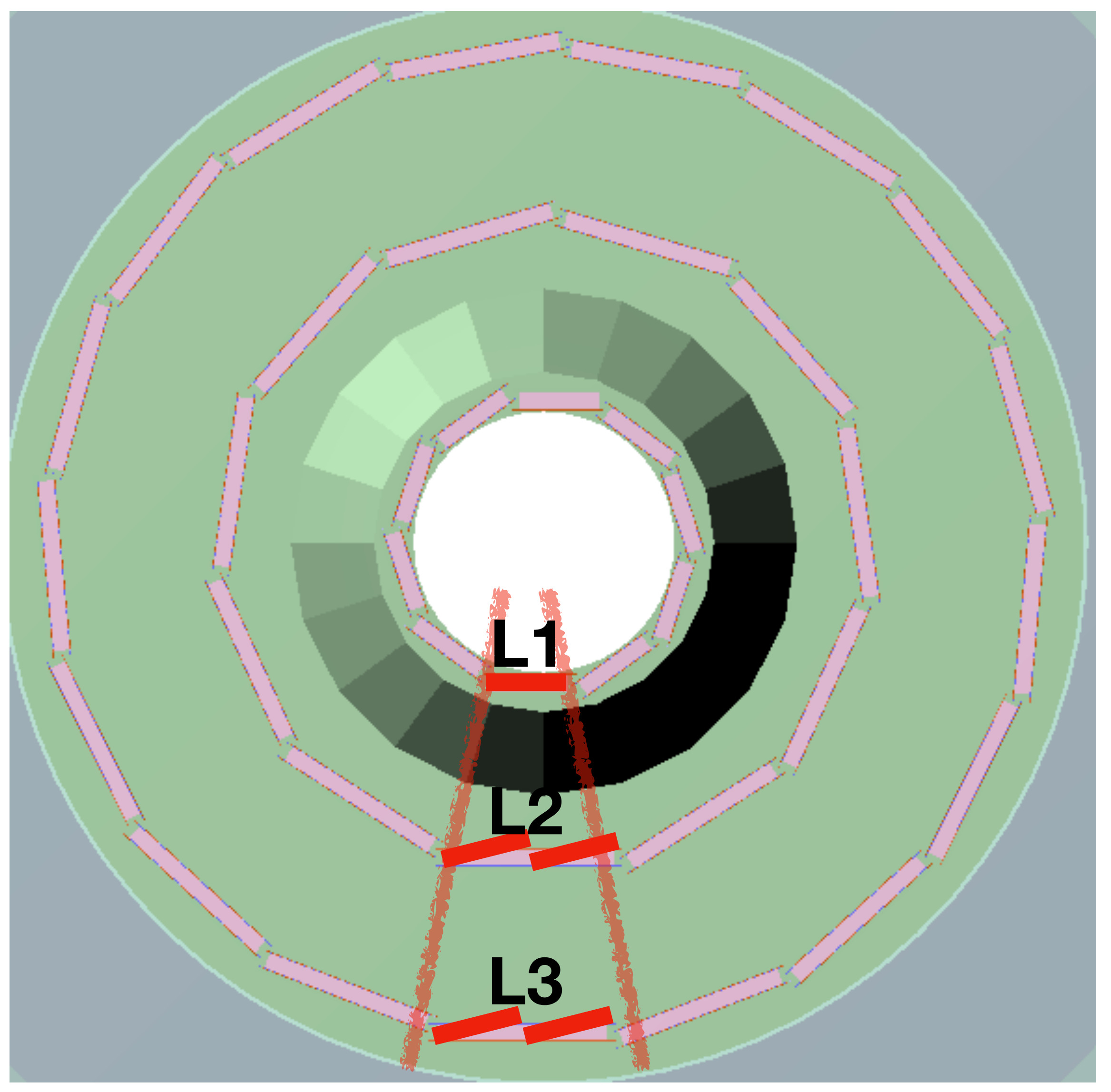
Pixel Detector prototype:

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



- Develop full size CMOS sensor for use in real size prototype, with good radiation hardness

Silicon Tracker Detector – Baseline

SET: r = ~1.8 m

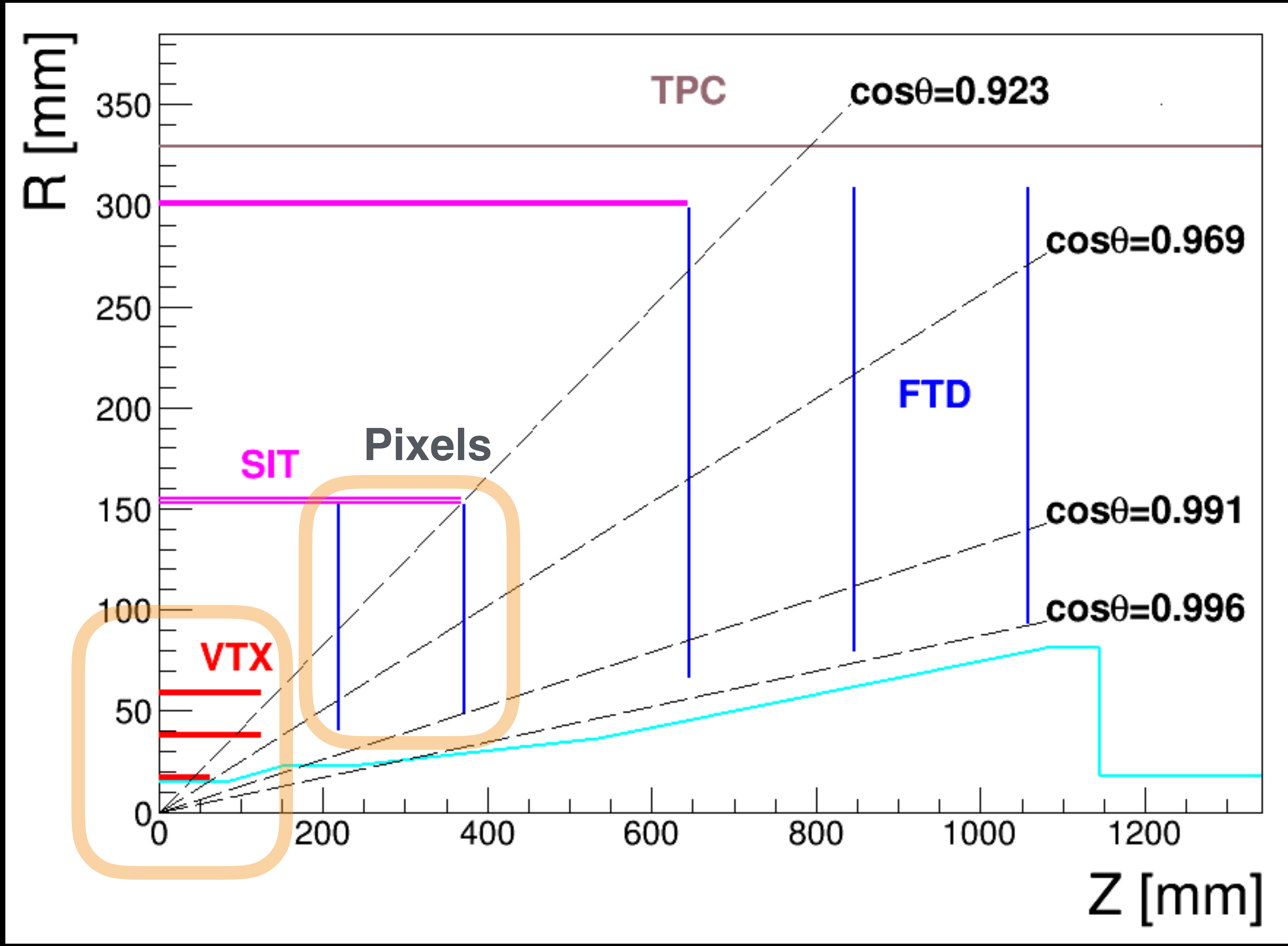
Not much R&D done so far

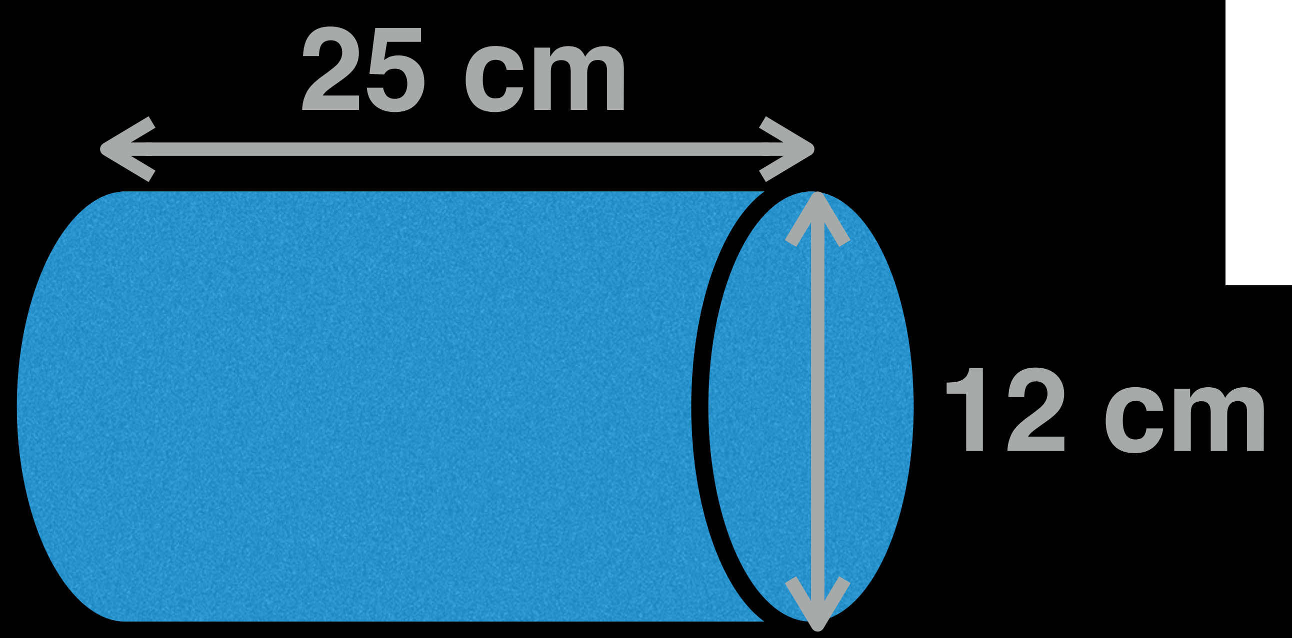
TPC

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

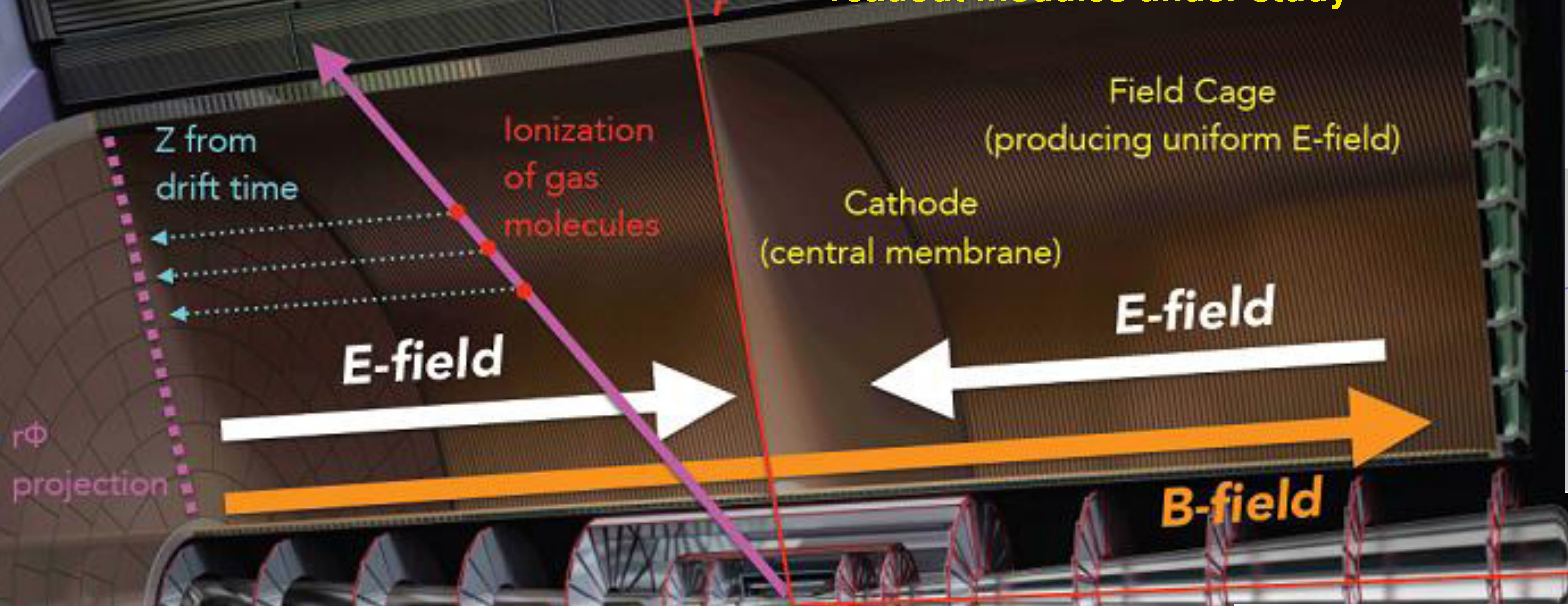
ETD: z = ~2.4 m

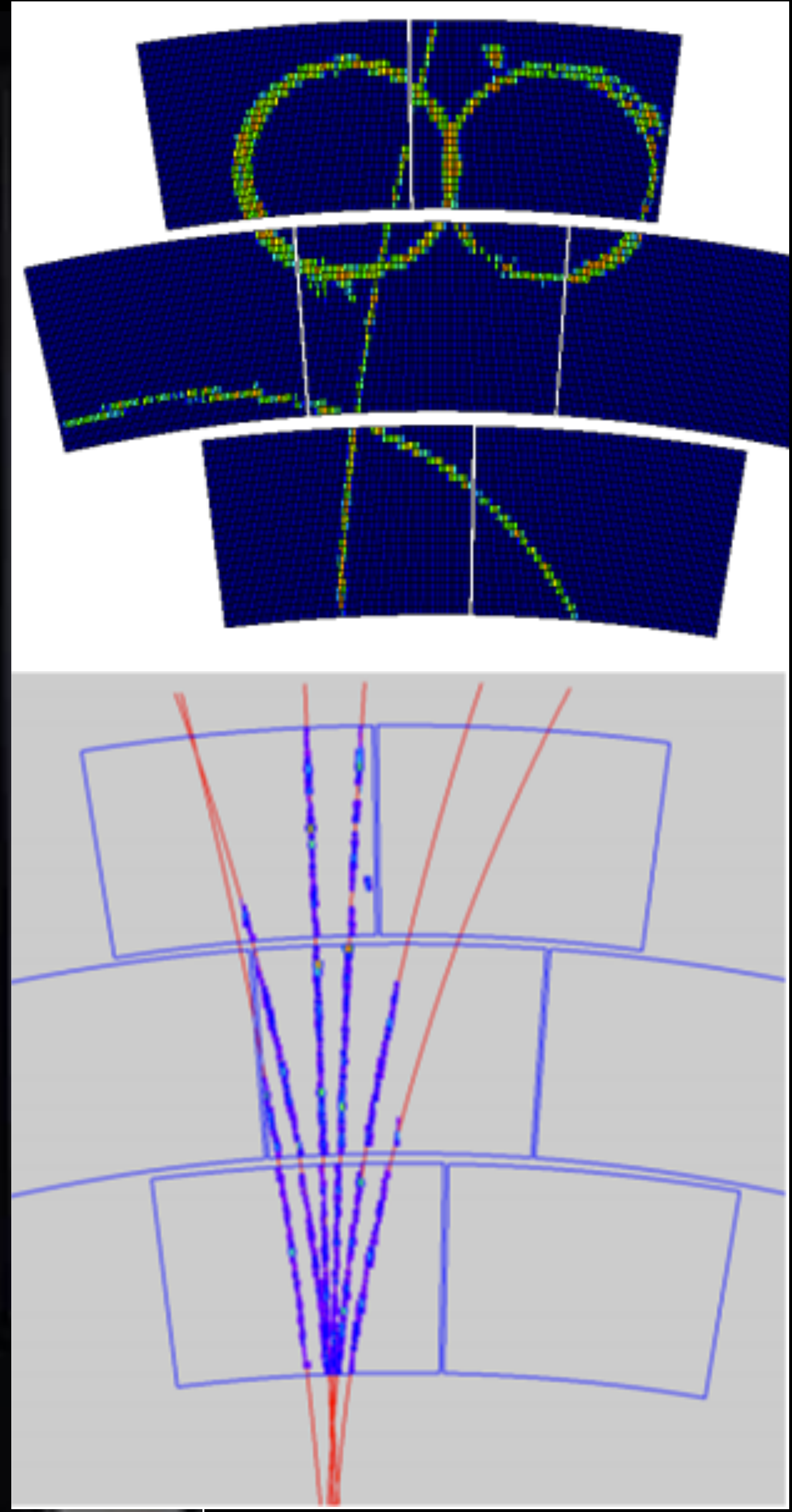
Total Silicon area ~ 68 m²

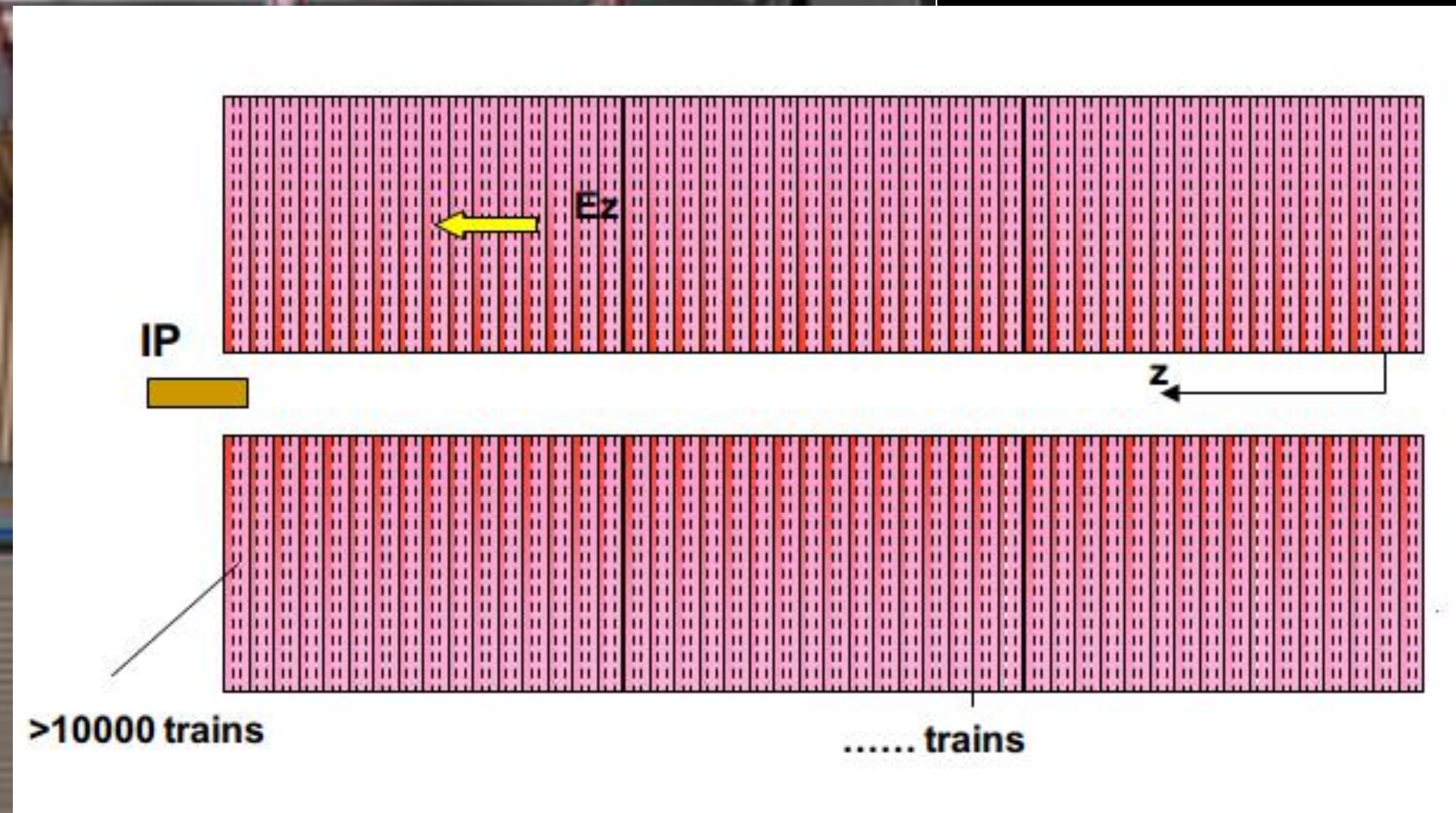
Extensive opportunities for international participation

Ion backflow → affects resolution

Solution: Gating concepts and new readout modules under study







Readout: Micro-pattern gas detectors

- Double/trip GEMs
- Resistive micromegas
- Integrated pixel readout

Particle flow calorimeters (ILC, CLIC, CEPC and FCC-ee)

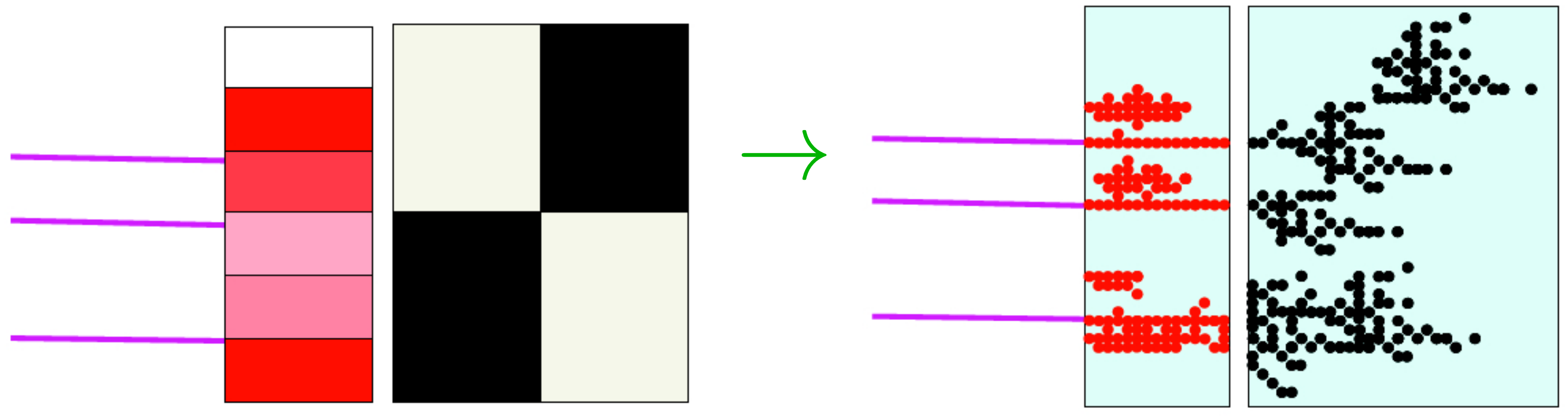
3%-4% jet energy resolution reachable with Particle Flow Analysis (PFA)

Average jet composition		Use best information
60% charged particles	→	60% tracker
30% photons	→	ECAL
10% neutral hadrons	→	HCAL

Full detector solution

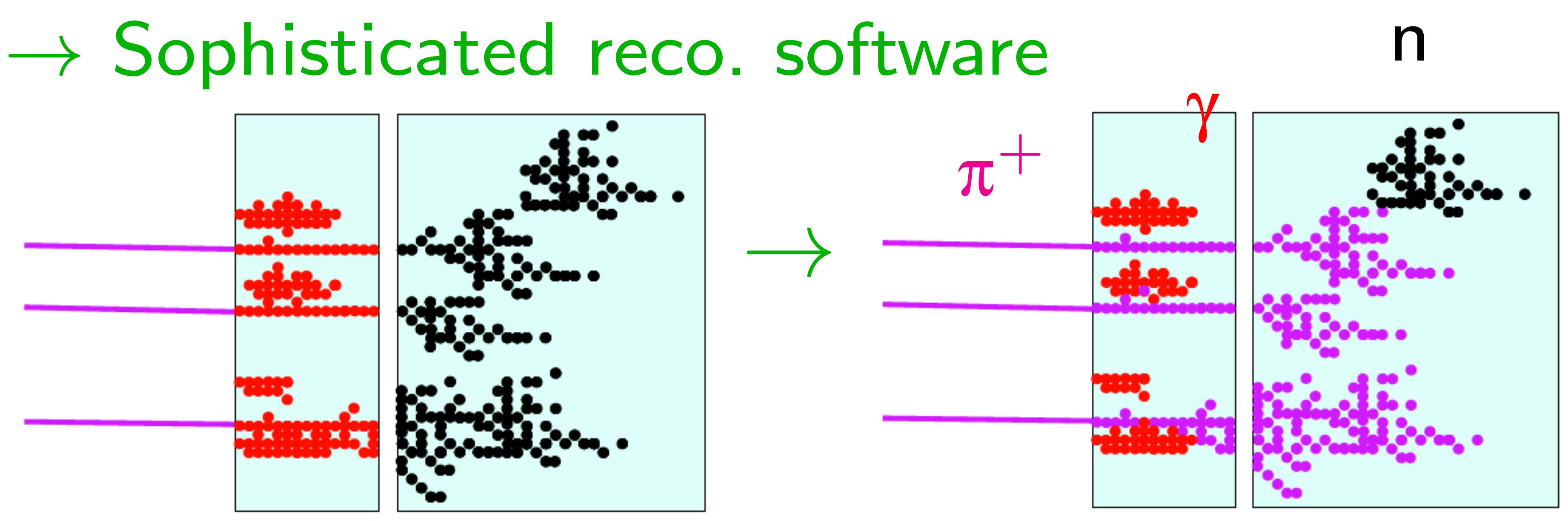
Particle Flow Analysis: Hardware + Software

- Hardware: Resolve energy deposits from different particles
  → High granularity calorimeters



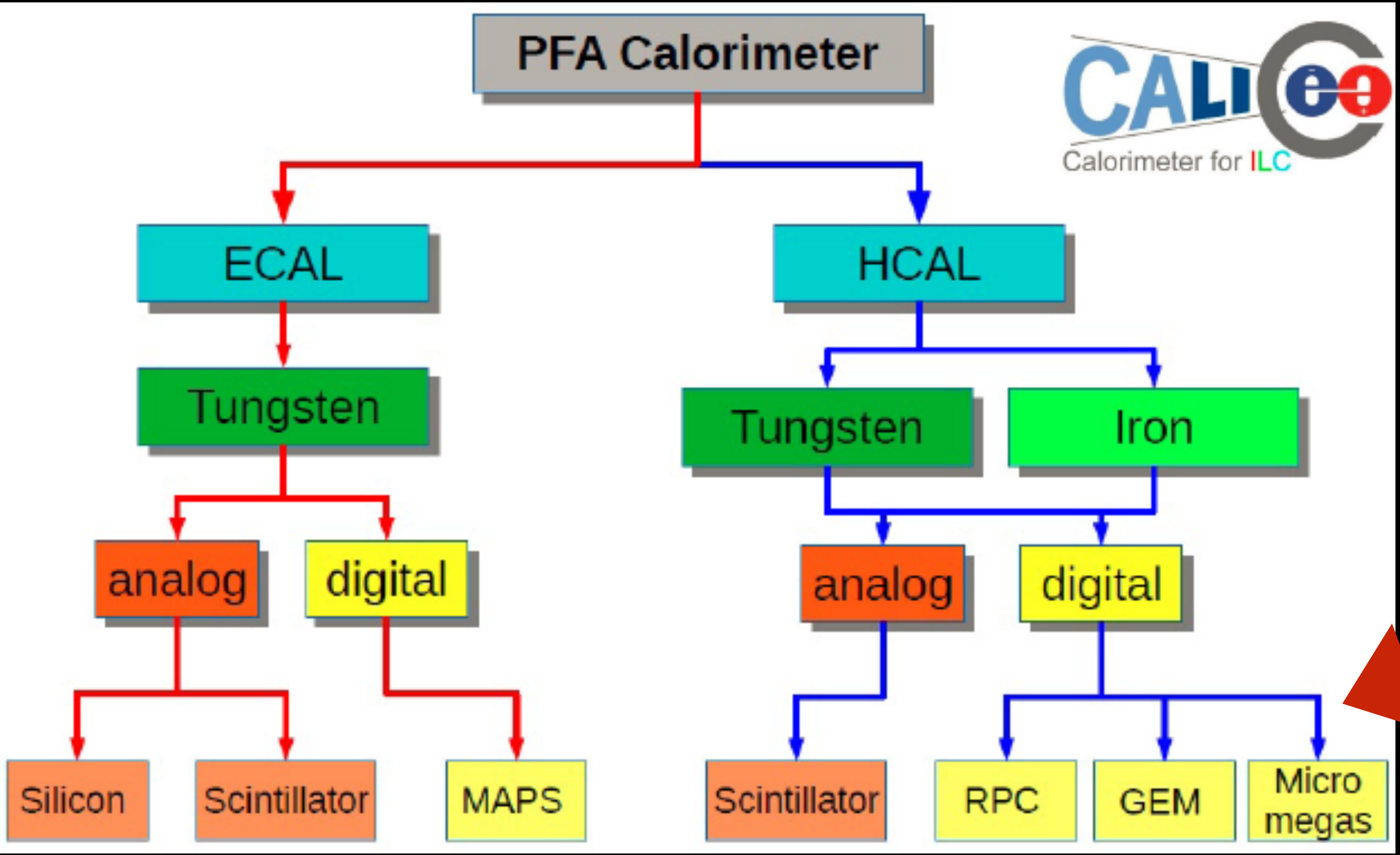
$E_{jet} = E_{ECAL} + E_{HCAL}$

- Software: Identify energy deposits from each individual particle
  → Sophisticated reco. software



$E_{jet} = E_{track} + E_{\gamma} + E_{n}$

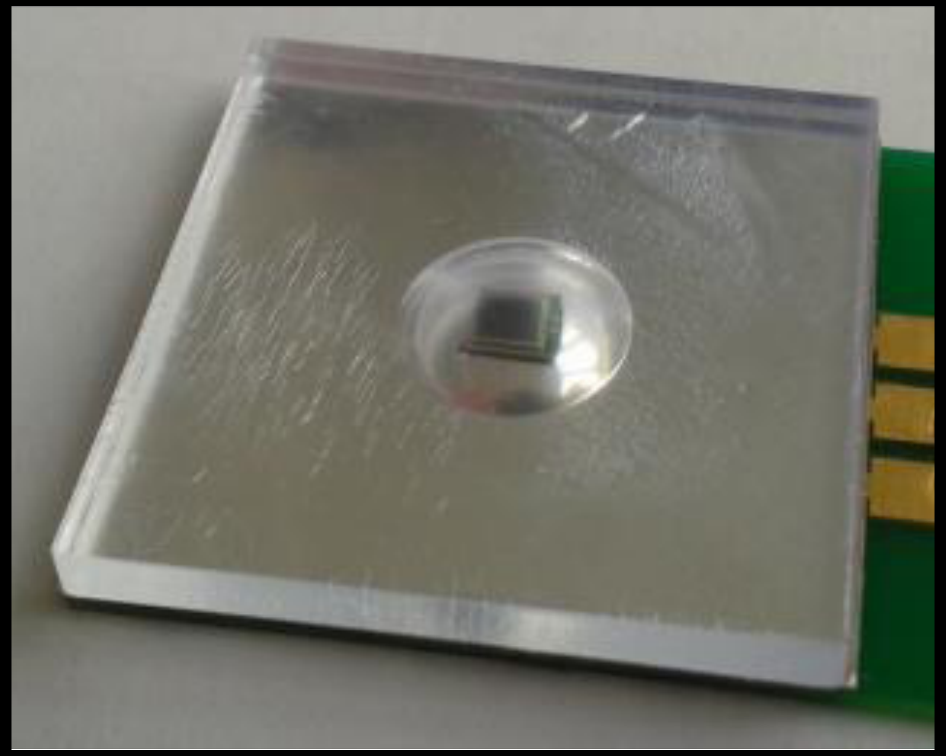
Particle Flow calorimeter options



Detector challenges:

- Compact design
- Calibration of channels
- Cooling
- Cost

Scintillator tiles/strips (here 3 × 3 cm^2) + SiPMs



Test beam experiments at DESY, CERN, FNAL: 2006 - 2015

First physics prototypes of up to ~1 m^3, ~ 2 m^3 (with Tail Catcher Muon Tracker)

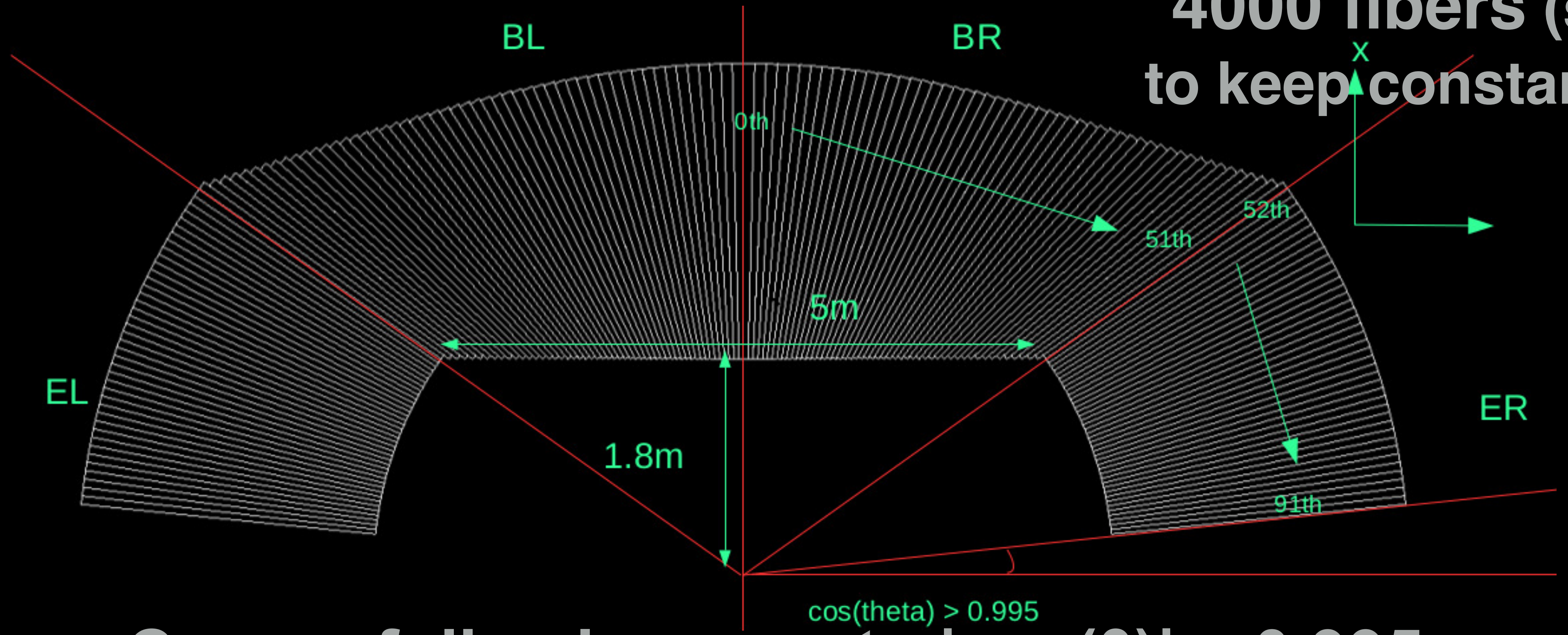
Studies started on a Crystal (LYSO:Ce + PbWO) ECAL (March 11 Workshop at IHEP)

Dual Readout Calorimeter

Based on the DREAM/RD52 collaboration

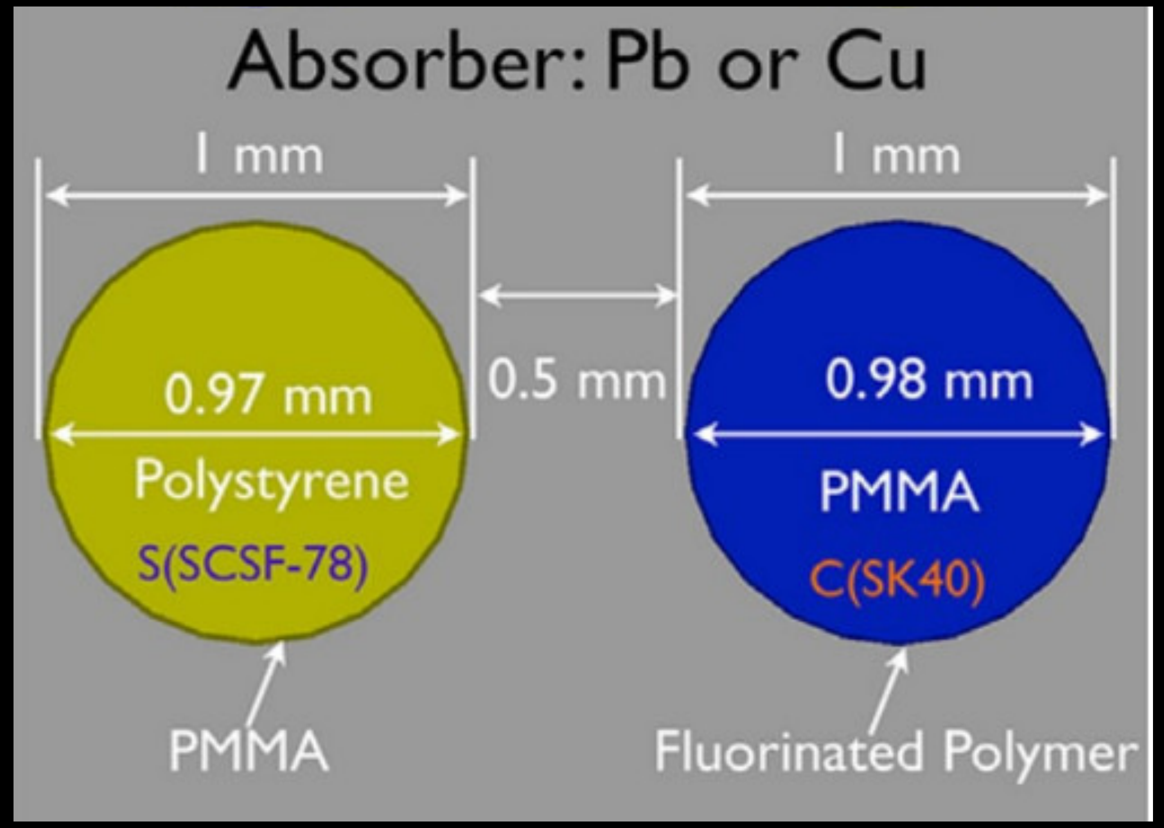
Projective 4π layout implemented into CEPC simulation
(based on 4th Detector Collaboration design)

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



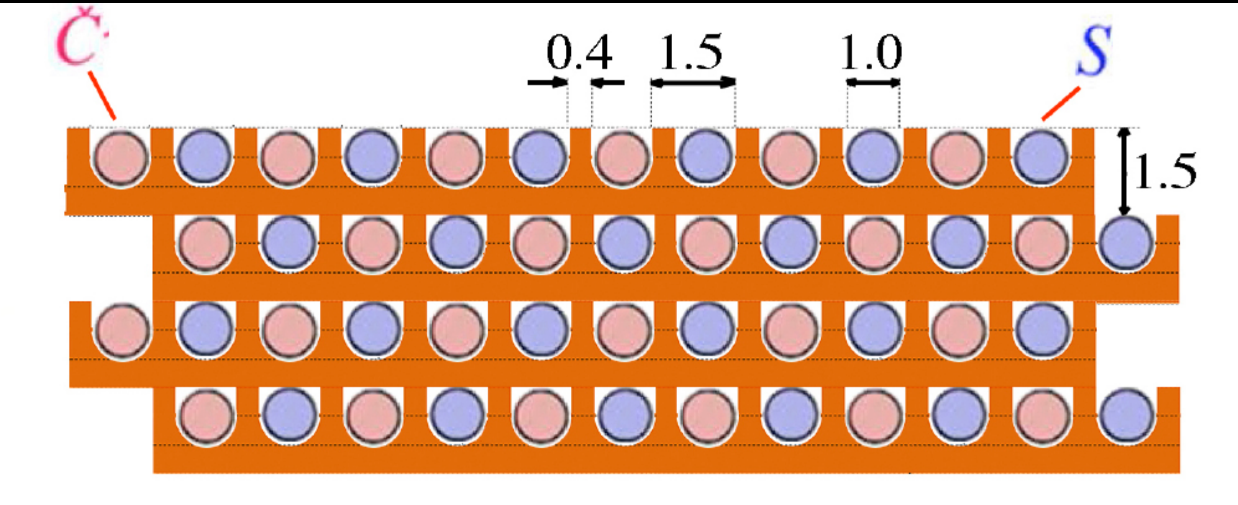
Covers full volume up to $|\cos(\theta)| = 0.995$

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



Demonstration in test beam experiments

Studying different readout schemes
PMT vs SiPM



Fiber pattern RD52

NEED: large size prototype that could contain full hadronic shower

How big is this project?

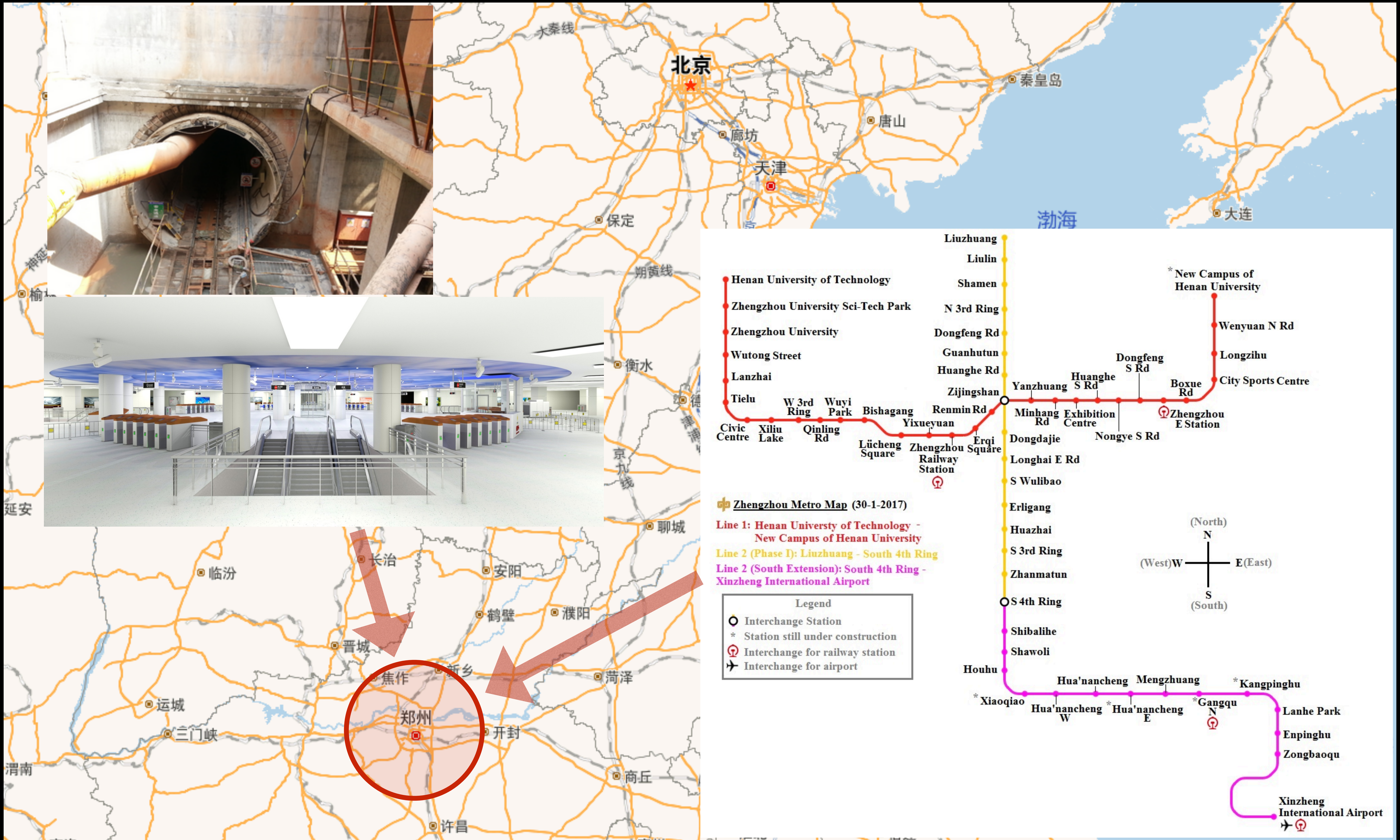
Similar tunneling projects…

Similar tunneling projects…

Similar tunneling projects…

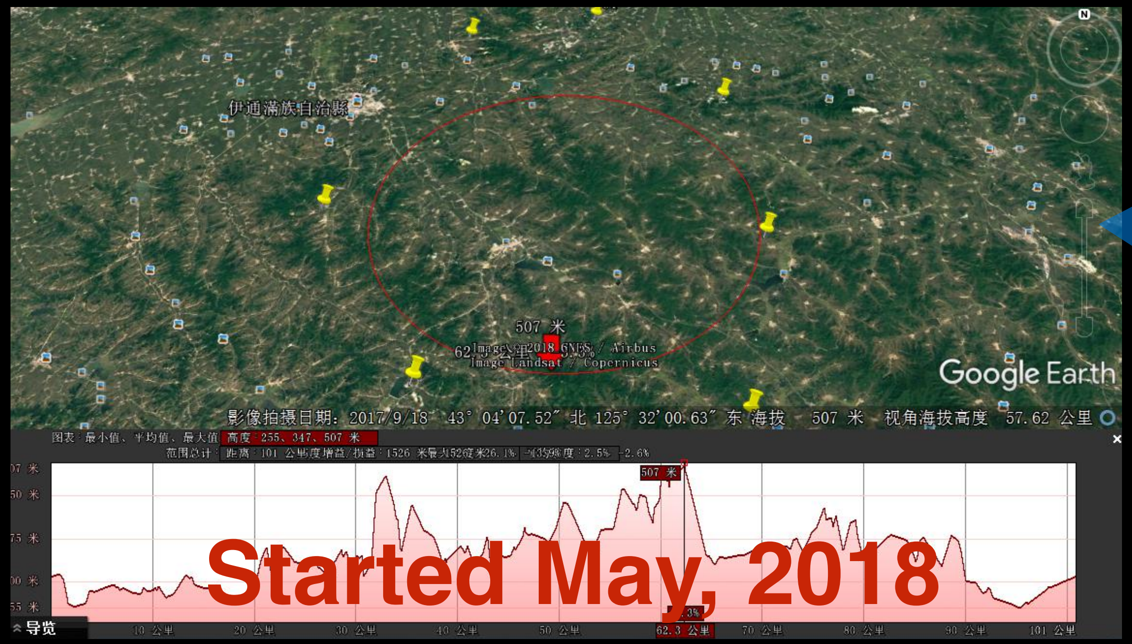
Subway in Zhengzhou

Length: 94 km
Stations: 57



Site selection

Chuangchun, Jilin
吉林长春



Huangling, Shanxi
陕西黄陵

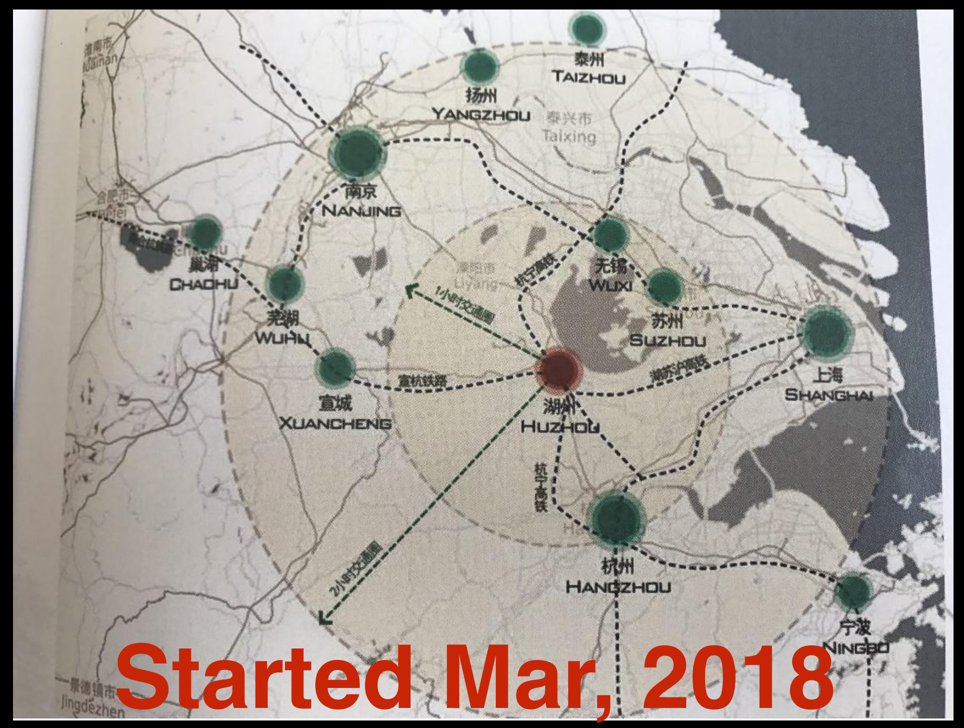
Considerations:
1. Available land
2. Geological conditions
3. Good social, environment, transportation and cultural conditions
4. Fit local development plan: mid-size city → + science city

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



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

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

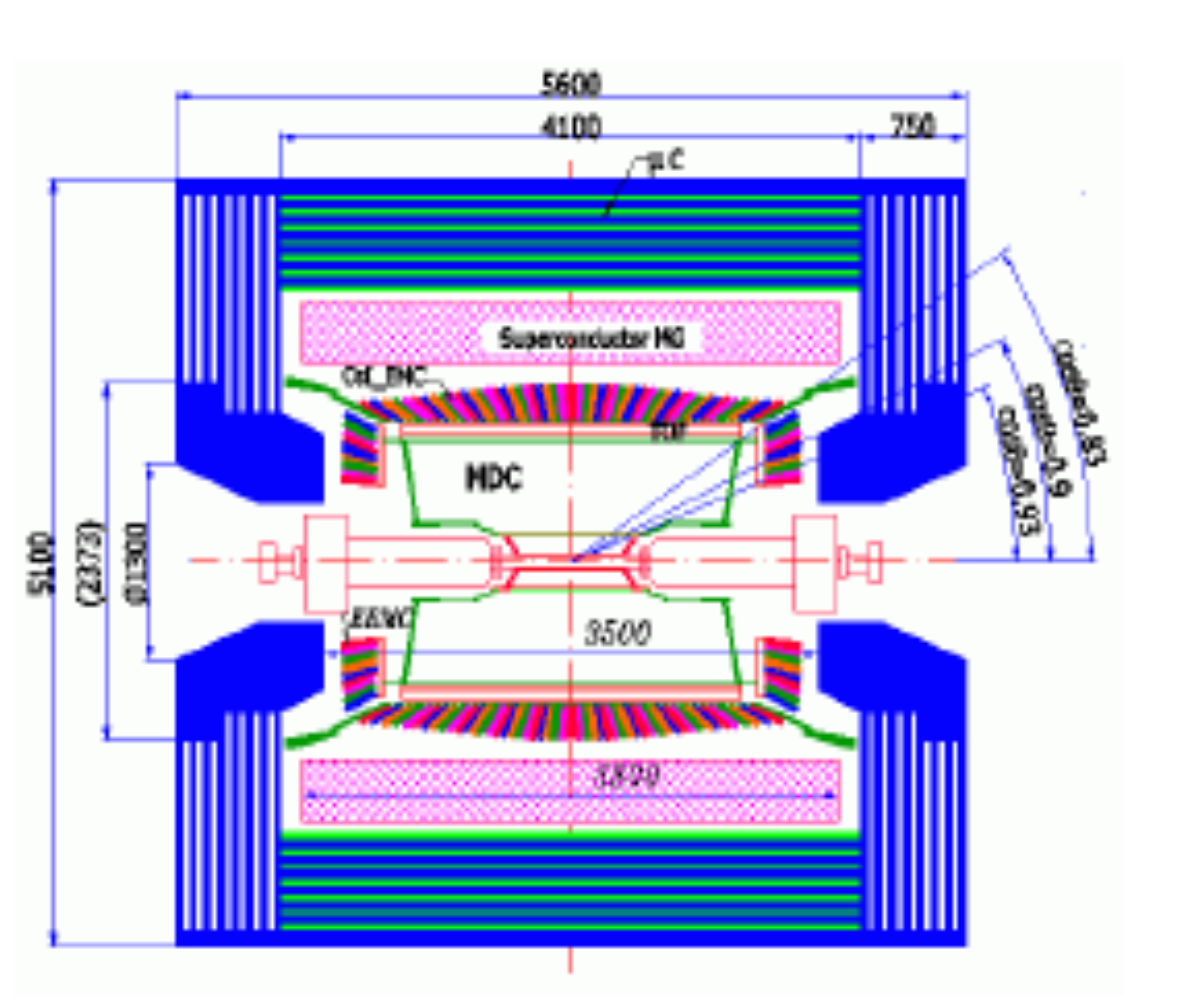
Can China do it?

International collaboration is a must for both accelerators and detector components, but….

China is experienced in e^+e^- colliders and detectors

BEPCII

BESIII



Big jump:
240 m ring → 100 km ring

A challenge smaller than 30 years ago when they started BEPC

BESIII Collaboration

Europe (16)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz, Univ. of Munster
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab, Ferrara Univ.
Netherland: KVI-CART/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center
UK: Oxford Univ., Univ. of Manchester

US (4)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Indiana

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Mongolia (1)

Institute of Physics and Technology

India (1)

Indian Institute of Technology

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(37)

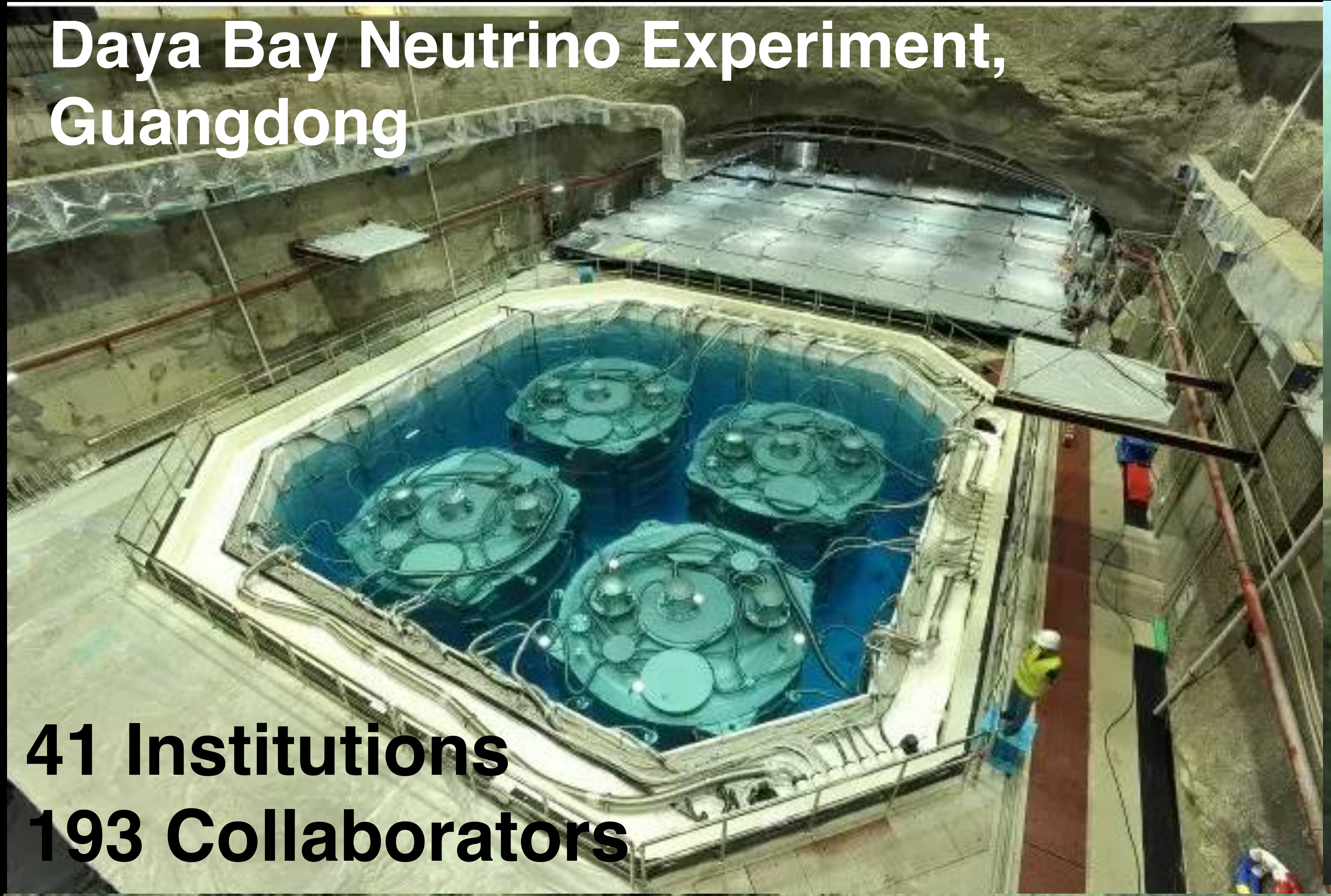
IHEP, CCAST, UCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll., Shanghai Jiaotong Univ.
Huazhong Normal Univ., Wuhan Univ., Xingyang Normal Univ.
Zhengzhou Univ., Henan Normal Univ., Hunan Normal Univ.
Peking Univ., Tsinghua Univ. , *Beijing Inst. of Petro-chemical Tech.*
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ., Univ. of Sci. and Tech. Liaoning
Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Jinan Univ., Fudan Univ.

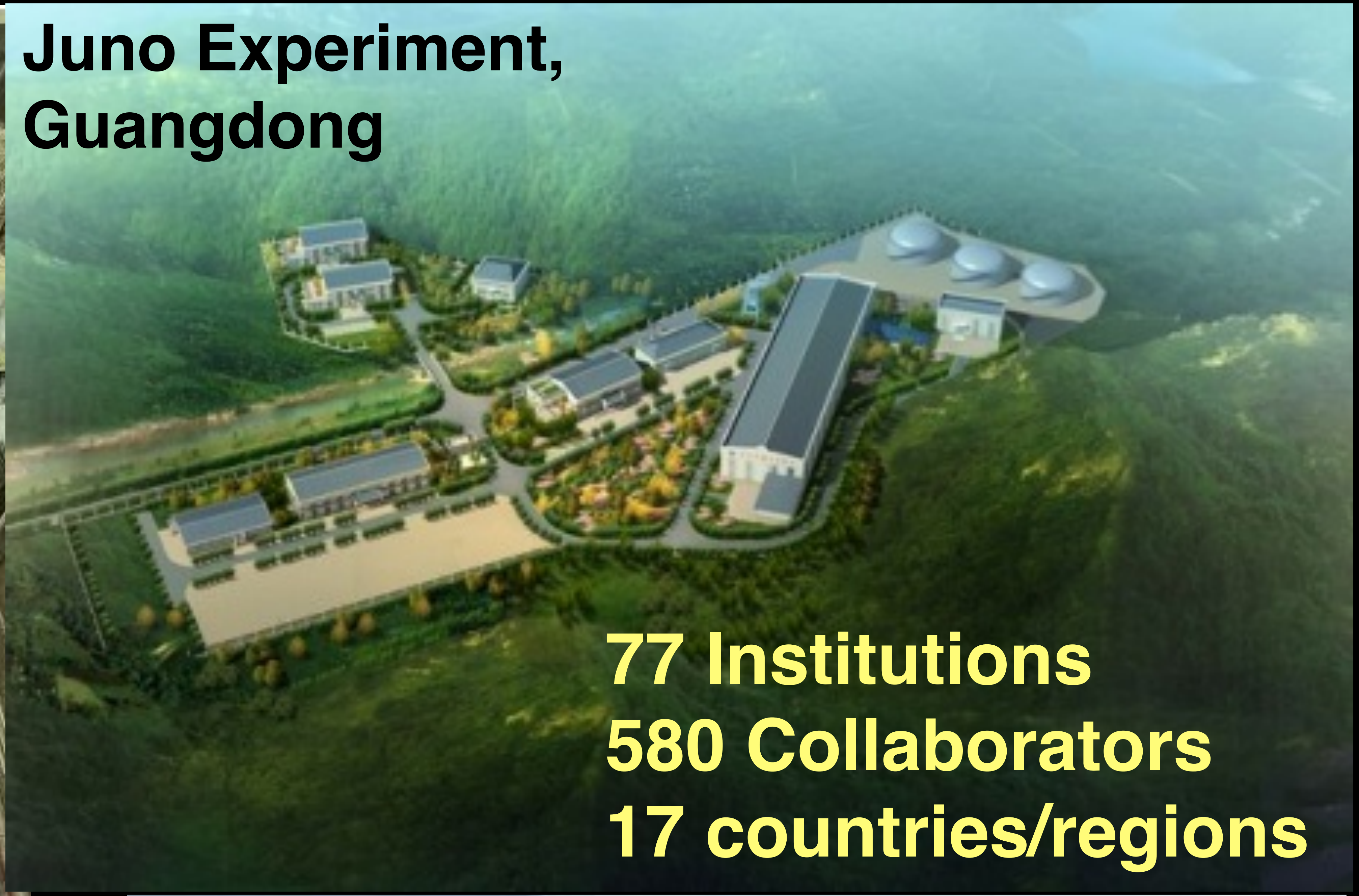
~ 450 members
from 64 institutions in 14 countries

3

Many other large scientific research projects with big construction

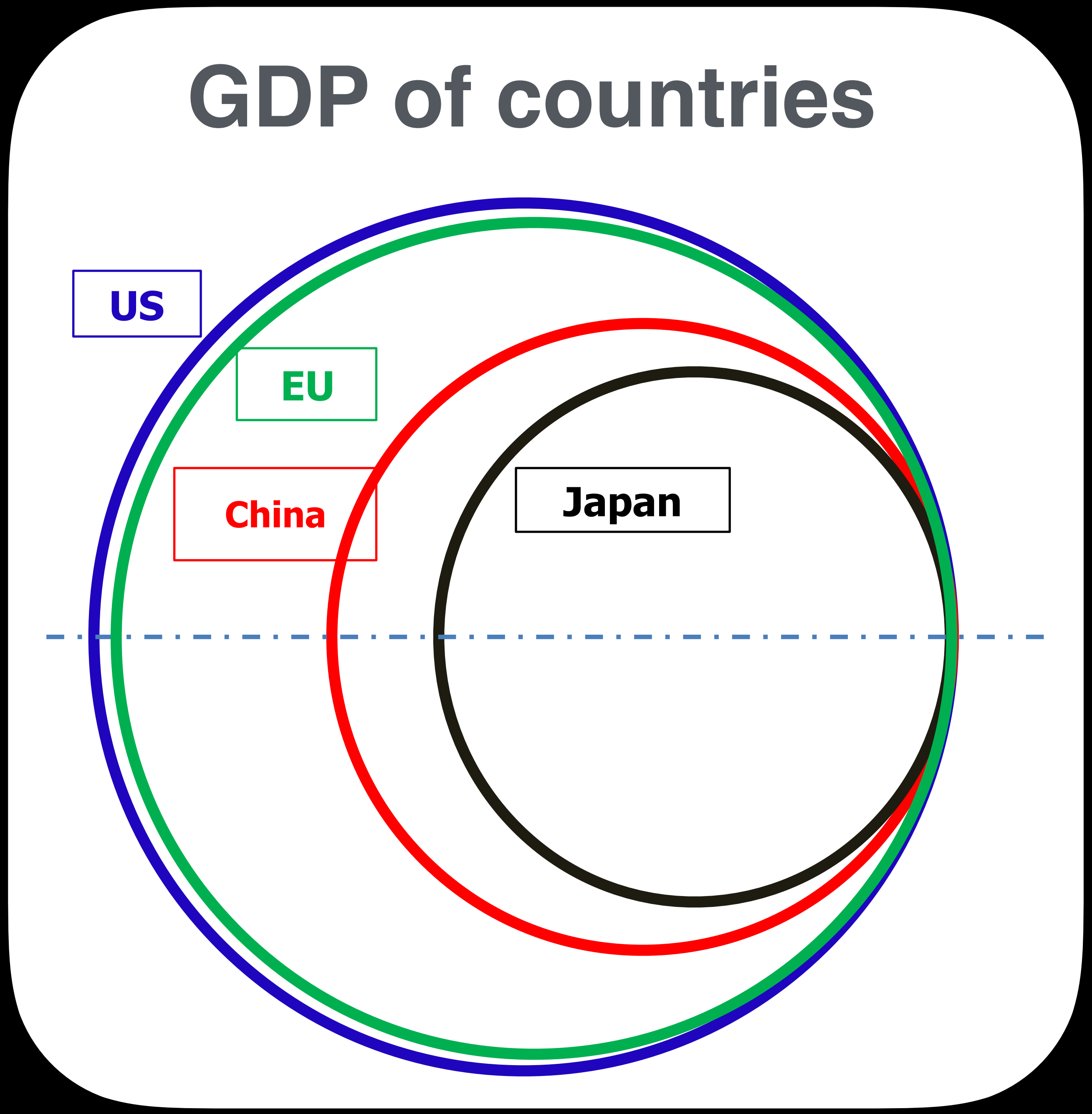
Chinese team can take responsibilities proportional to China's contributions



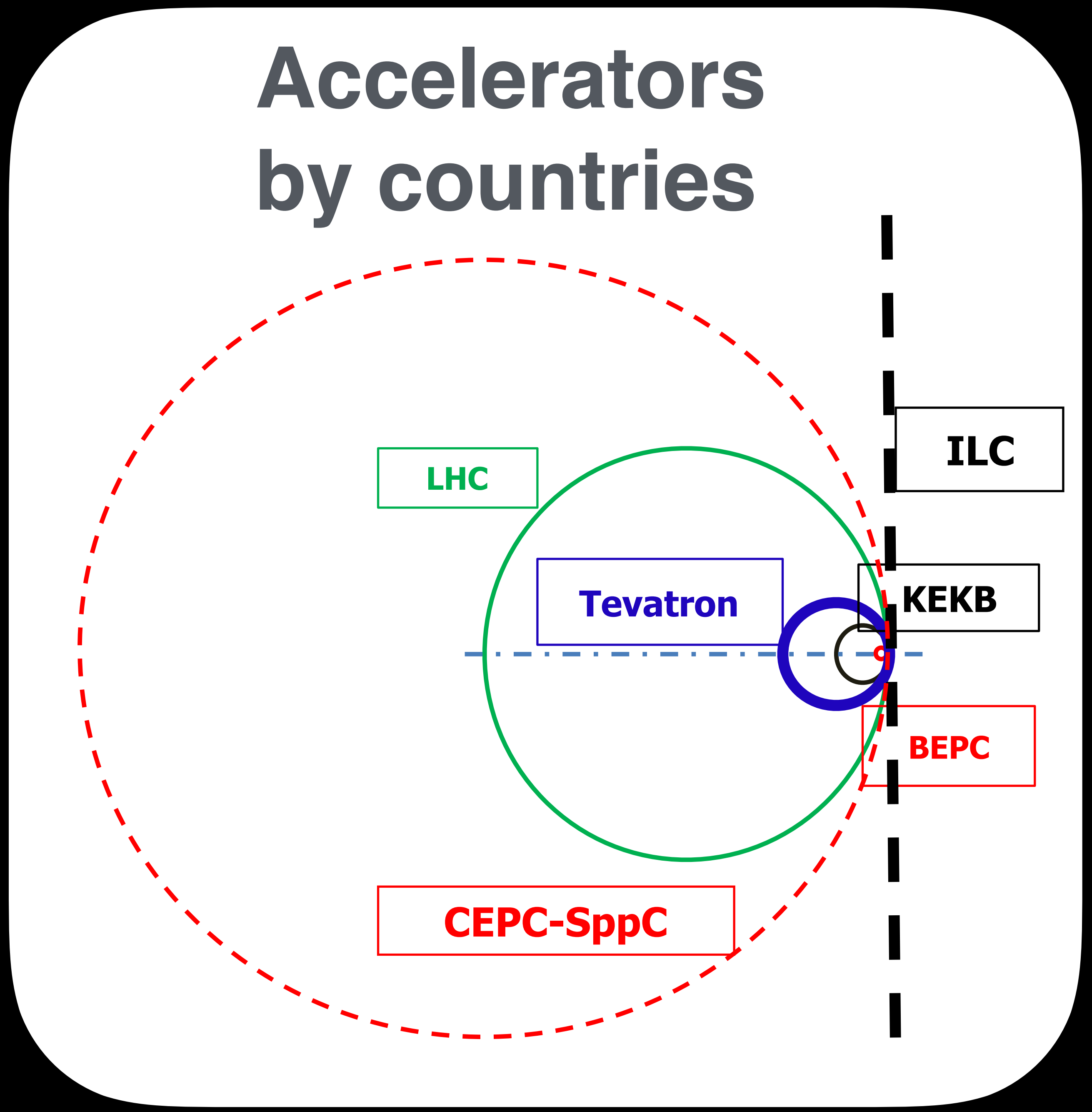


Perspective on the cost of future colliders

BEPC: Cost/4yrs/GDP of China 1984 ≈ 0.0001
SSC： Cost/10yrs/GDP of US 1992 ≈ 0.0001
LEP: Cost/8yrs/GDP of EU 1984 ≈ 0.0002
LHC： Cost/10yrs/GDP of EU 2004 ≈ 0.0003
ILC： Cost/8yrs/GDP of JP 2018 ≈ 0.0002
CEPC: Cost/8yrs/GDP of China 2020 ≈ 0.00005
SppC: Cost/8yrs/GDP of China 2036 ≈ 0.0001

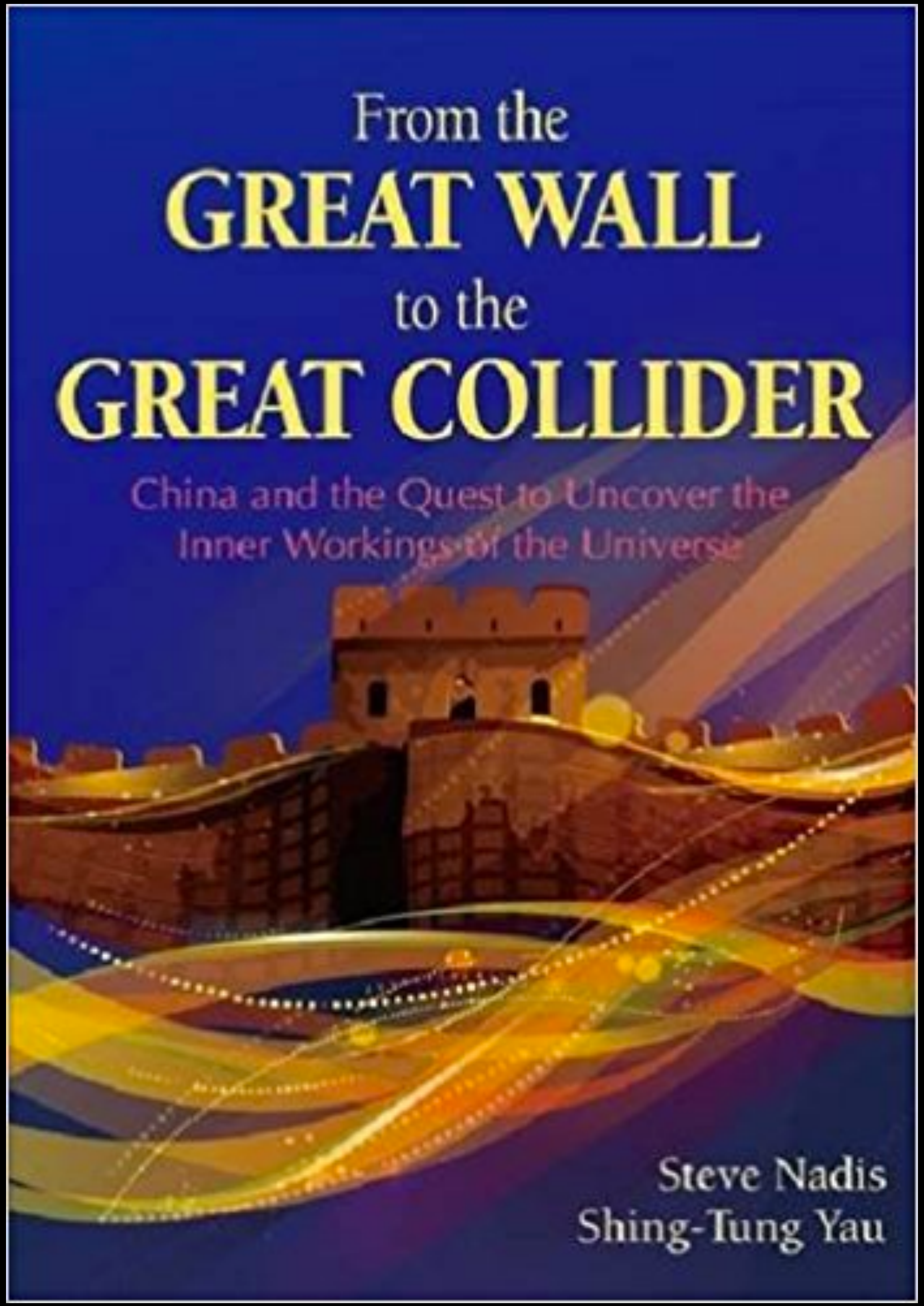


US
EU
China
Japan



From Y.Wang

Public Debate in China



Prof. Shing-Tung Yau

Harvard Professor
Field Medalist
Cabbibo-Yau Manifolds

Published book on CEPC/SPPC in 2016

Followed by International Meeting in Beijing

“A Super Collider Is Not for Today’s China”

Prof. Chen-Ning Yang

Tsinghua University Professor
Nobel Prize Winner
Yang-Mills Theory (the basis of SM)

Published article on WeChat platform

estimates cost of CEPC to be at least $20 billion and possibly ending as “a bottomless pit”

concerns over the science of CEPC as it is just out of “a guess of physicists”

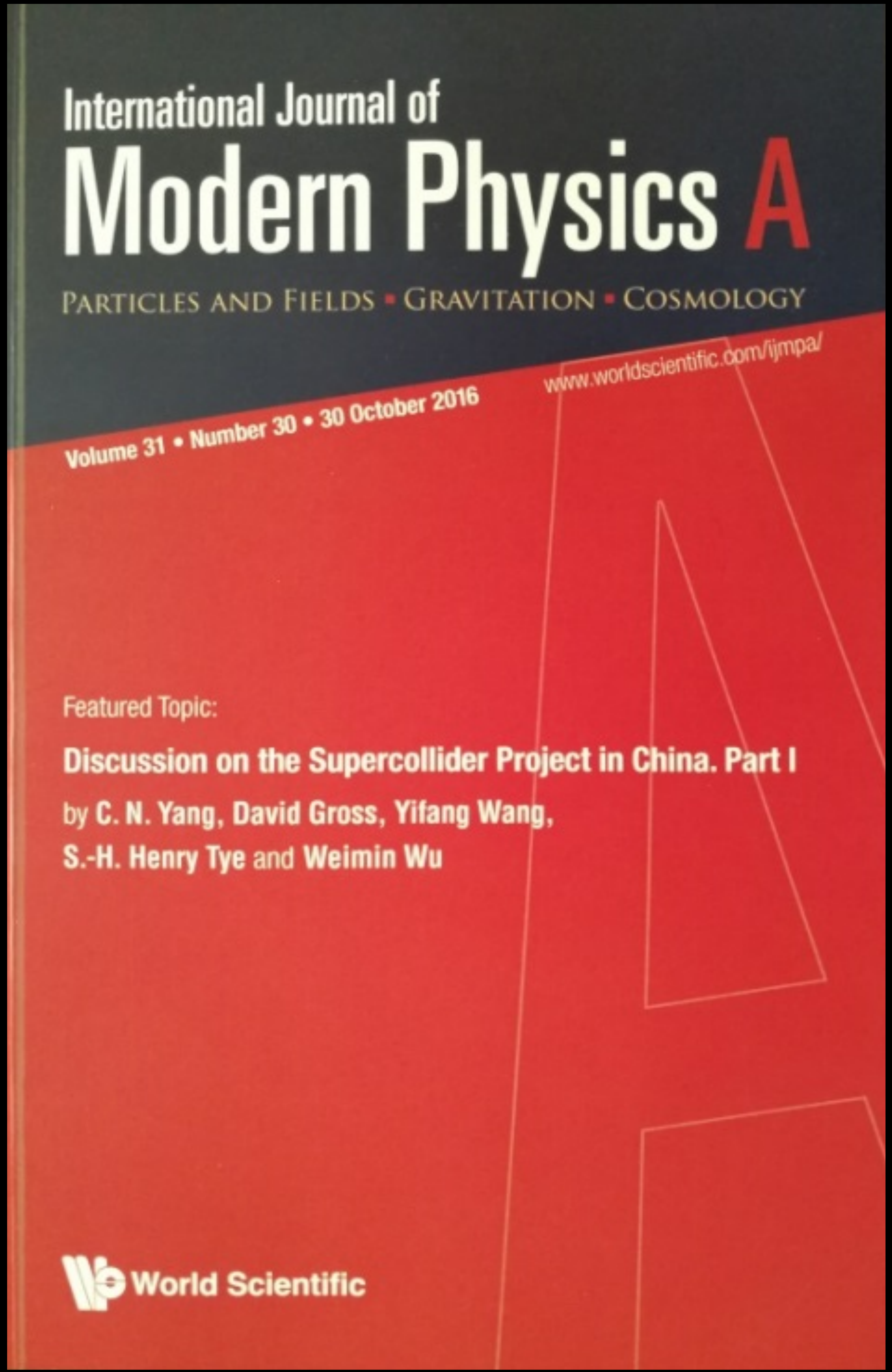
“Even if they see something with the machine, it’s not going to benefit the life of Chinese people any sooner,”

the Chinese cannot do it

Instant messaging application
> 1 billion accounts
> 860 million active users

Public debate in China

Public Debate exploded in main media and social media



Prof. Wang was joined in the discussion by

Yau, Anderson, Gross, Glashow, Weinberg, t Hooft', Hawking, ….

articles published by World Scientific

Most discussion happened in Chinese, on main TV, WeChat, and other platforms

I was told that even taxi drivers would discuss the issue!

CEPC web site

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

Chinese | Internal | Events | Contact Us

Circular Electron Positron Collider

HOME | ABOUT CEPC | ORGANIZATION | RESULTS | WHY SCIENCE | JOIN US | pre-CDR Author

Future High Energy Circular Colliders

The Standard Model (SM) of particle physics can describe the strong, weak and electromagnetic interactions under the framework of quantum gauge field theory. The theoretical predictions of SM are in excellent agreement with the past experimental measurements. Especially the 2013 Nobel Prize in physics was awarded to F. Englert and P. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".

After the discovery of the Higgs particle, it is natural to measure its properties as precise as possible, including mass, spin, CP nature, couplings, and etc., at the current running Large Hadron Collider (LHC) and future electron positron colliders, e.g. the International Linear Collider (ILC). The low Higgs mass of ~125 GeV makes possible a Circular Electron Positron Collider (CEPC) as a Higgs Factory, which has the advantage of higher luminosity to cost ratio and the potential to be upgraded to a proton-proton collider to reach unprecedented high energy and discover New Physics.

The CEPC input for the European Strategy

Accelerator

Accelerator Addendum

Physics and Detector

Physics and Detector Addendum

Recent Events

2019 CEPC International Workshop (EU Edition), University of Oxford, April, 2019

The Kick-off Meeting of MOST project "High Energy Circular Electron Positron Collider Key Technology Research and Validation" was held in IHEP

More...

CEPC Conceptual Design Report

CEPC CDR Volume I (Accelerator)

CEPC CDR Volume II (Physics and Detector)

More...

Panel Discussion on Fundamental Physics

CEPC meetings and international impact

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

European Edition

Workshop web site

http://www.physics.ox.ac.uk/confs/CEPC2019/index.asp

Next year: Marseille, France

The International workshop on the Circular Electron Positron Collider EU EDITION 2019

Oxford, April 15-17, 2019

http://www.physics.ox.ac.uk/confs/CEPC2019/

Scientific Committee:

Franco Bedeschi – INFN, Italy
Marica Biagini – INFN, Italy
Alain Blondel – University of Geneva, Switzerland
Daniela Bortoletto – University of Oxford, UK
Joao Guimaraes da Costa – IHEP, China
Jie Gao – IHEP, China
Hong-Jian He – SJTU, China
Eric Kajfasz – CPPM, France
Eugene Levichev – BINP, Russia
Shu Li – SJTU and TDLI, China
Jianbei Liu – USTC, China
Nadia Pastrone – INFN, Italy
Jianming Qian – University of Michigan, USA
Manqi Ruan – IHEP, China
Felix Sefkow – DESY, Germany
Chris Tully – Princeton University, USA
Liantao Wang – University of Chicago, USA
Meng Wang – Shandong University, China
Marcel Vos – CSIC, Spain

Local organizing committee:

D. Bortoletto – University of Oxford
P. Burrows – University of Oxford
B. Foster – University of Oxford
Y. Gao – University of Liverpool
B. Murray –University of Warwick/RAL
I. Shipsey –University of Oxford
G. Viehhauser – University of Oxford

UNIVERSITY OF OXFORD

Conclusions

The discover of the Higgs at 125 GeV makes e^+e^- machines an obvious next step

CEPC is the first Chinese Science project at such international scale

Tremendous progress so far {
- Conceptual Design Reports, R&D underway
- Large funding opportunity to start 2020

But, still many challenges to overcome

No need to wait for LHC

- If LHC finds nothing, a Higgs factory can give a first indication for new physics
- If LHC finds something, it is a new era:
  1. Higgs need(s) to be understood anyway
  2. A higher energy pp collider is needed

(An Higgs factory can give us time to develop technologies for 16-20 T magnets and SC cables)

Given the importance of the Higgs one of FCC-ee, ILC or CEPC should be built

We fully support a global effort even if not build in China

Thank you for the attention!

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	IHEP
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	IHEP
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	IHEP
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	IHEP
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	IHEP
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	IHEP
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	IHEP
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	IHEP

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)

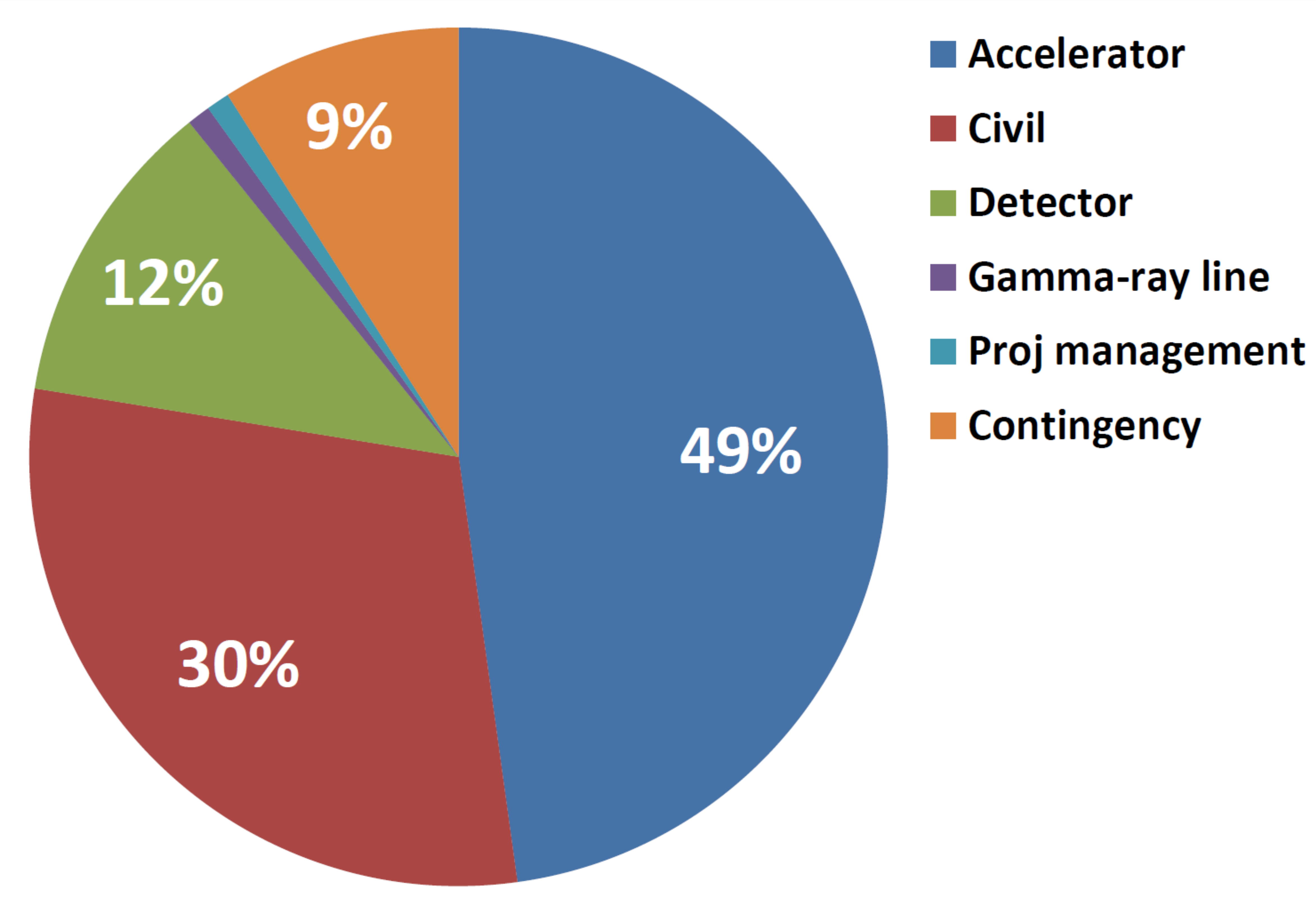
Thanks to many different funding sources, CEPC team can carry out CEPC design, key-technology research and site feasibility studies

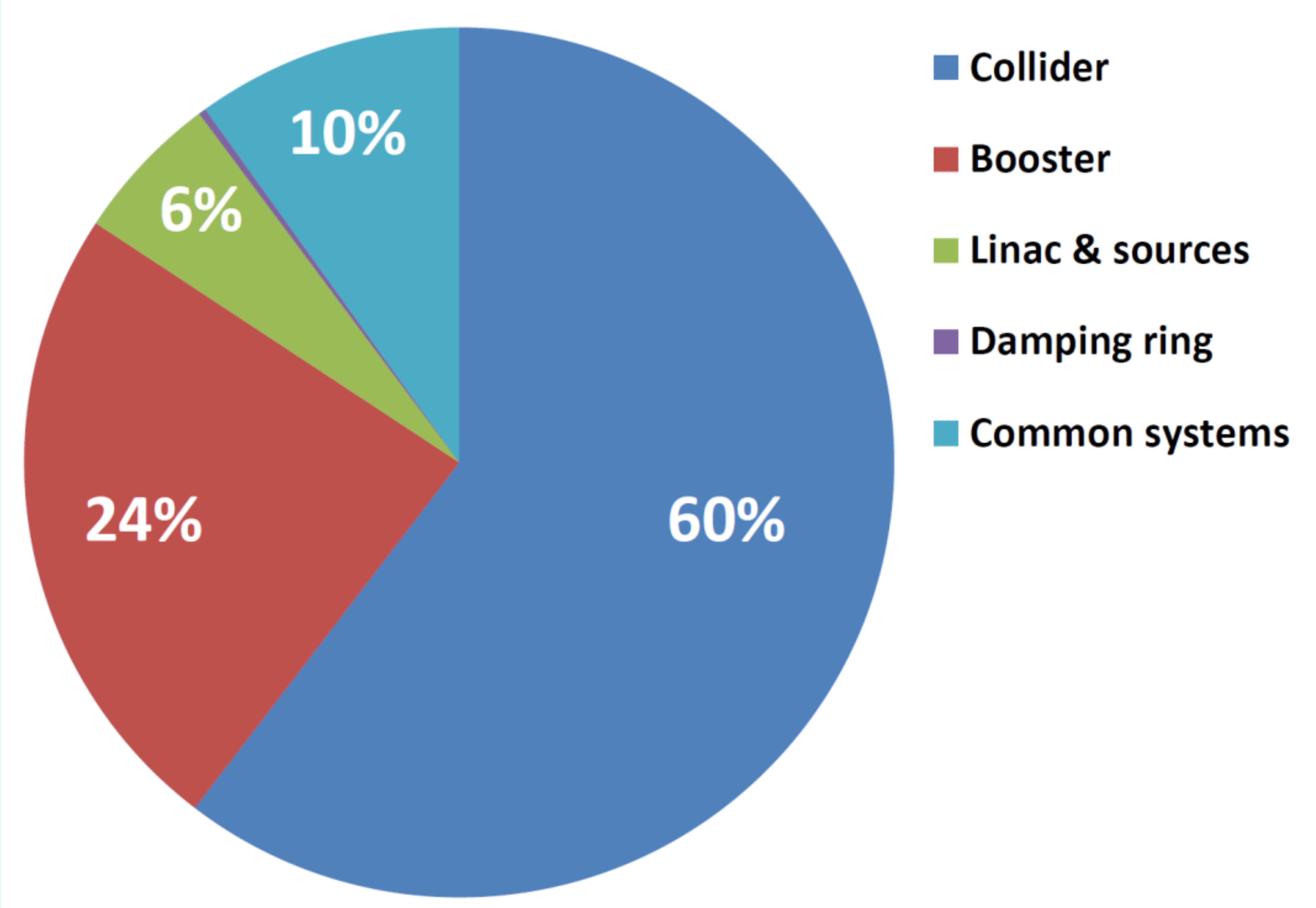
Cost of project

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





Cost Estimation of CEPC (Preliminary)

No.	Equipment name	Total price (M¥) (50 km)	Total price (M¥) (100 km)
1	Total	25,498	36,051
2	Accelerator	15,973	23,132
3	Detector	2,502	2,502
4	Synchrotron radiation device	326	326
5	Civil Construction	6,697	10,091
5.1	Civil engineering (Drilling and blasting method, ⦸ 6 m...)	2,793	4,138
5.2	Installation of electrical equipment	2,210	3,429
5.3	Installation of metal structure equipment	177	261
5.4	Temporary works	287	422
5.5	Independent cost	473	698
5.6	Unforeseen expenses (10%)	594	895
5.7	Other cost	163	247

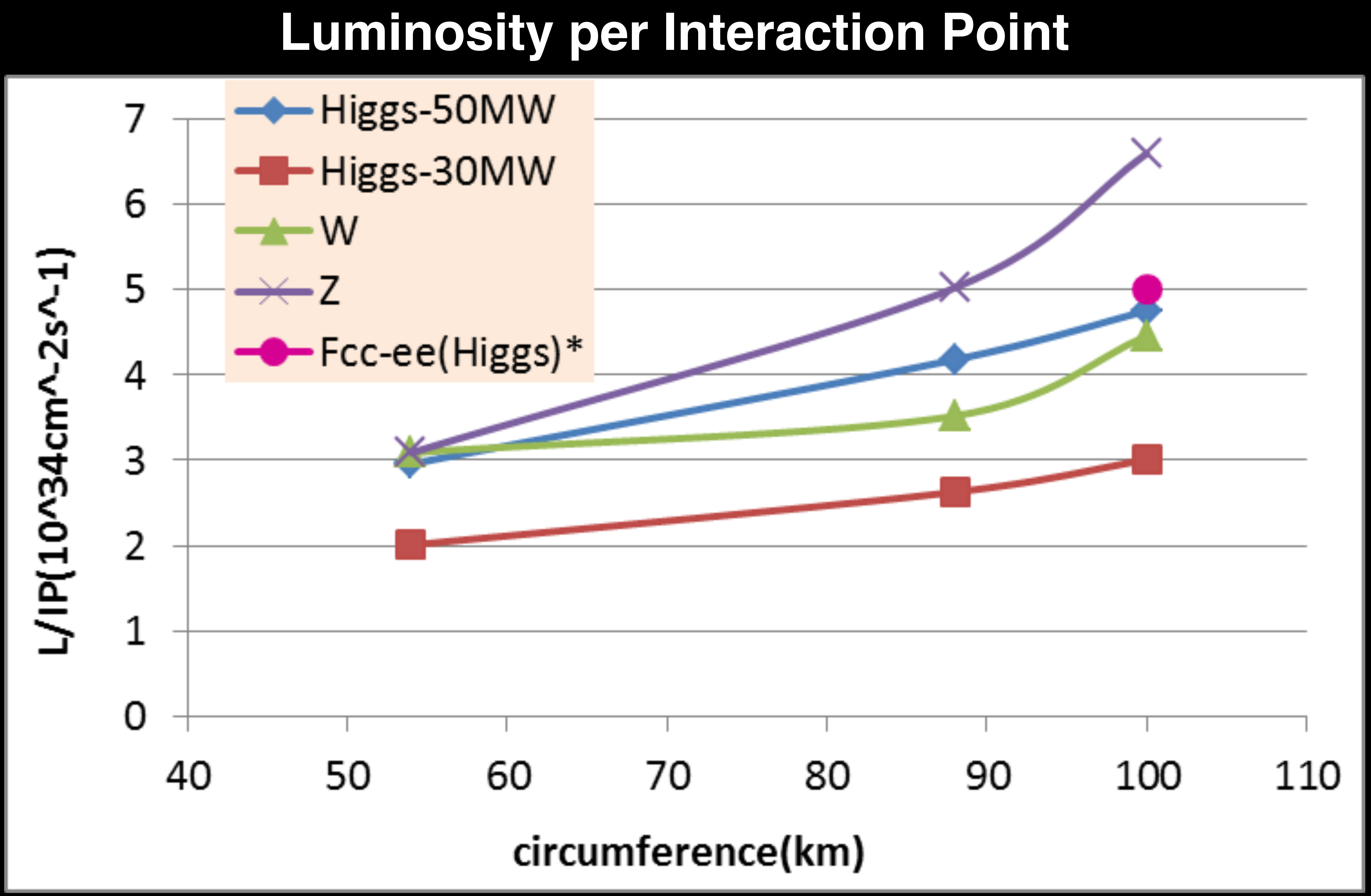
$1 US = 6.91 RMB(¥)

100 km CEPC cost:

< 40 Billion RMB(¥)

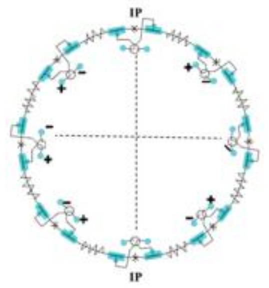
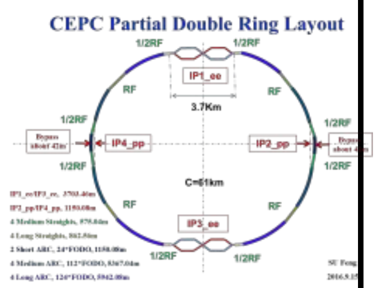
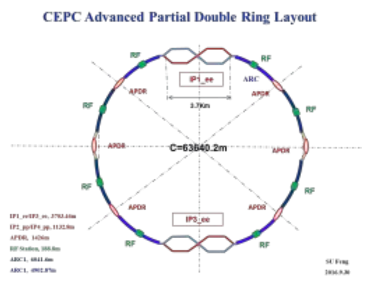
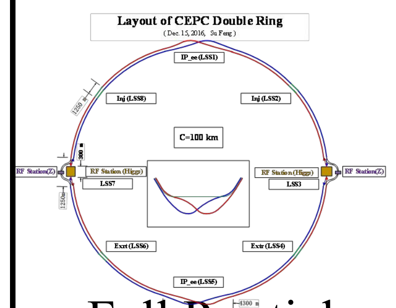
< 5.8 Billion $US

CEPC luminosity versus ring size



* Fabiola Gianotti, Future Circular Collider Design Study, ICFA meeting, J-PARC, 25-2-2016

CEPC configuration options comparison

Option	Pretzel	Sawtooth effect	Beam loading	Dynamic Aperture	Orbit Correction	H luminosity	Z-pole luminosity	AC power	SRF syetem compatible for H and Z
 Single Ring (SR)	Yes ★	Very high ★	Low ★★★★★	Very small ★	Very hard ★	Low ★★★	Very low ★	High ★	Difficult ★★★
 Partial Double Ring（PDR）	No ★★★★★	High ★★	Very High ★	Medium ★★★	Hard ★★	Medium ★★★	Medium ★★★	Low ★★★★★	Difficult ★★★
 Advanced Partial Double Ring （APDR）	No ★★★★★	High ★★★	High ★★★	Medium ★★★	Medium ★★★	Medium ★★★	High ★★★★	Low ★★★★★	Difficult ★★★
 Full Parrtial Double Ring（FPDR）	No ★★★★★	Vey Low ★★★★★	Low ★★★★★	Large ★★★★★	Easy ★★★★★	High ★★★★★	Very High ★★★★★	Low ★★★★★	Very good ★★★★★

Accelerator key technologies R&D

The key accelerator technologies are under studying with dedicated funds

- **Polarized electron gun**
  - ⇨ Super-lalce GaAs photocathode DC-Gun
- **High current positron source**
  - ⇨ bunch charge of ~3nC,
  - ⇨ 6Tesla Flux Concentrator peak magnetic field
- **SCRF system**
  - ⇨ High Q cavity - Max operation $Q_0 = 2\times10^{10}$ @ 2 K
  - ⇨ High power coupler - 300kW (Variable)
- **High efficiency CW klystron**
  - ⇨ Efficiency goal > 80%
- **Low field dipole magnet (booster)**
  - ⇨ $L_{mag} = 5$ m, $B_{min} = 30$ Gs, Errors $<5\times10^{-4}$
- **Vacuum system**
  - ⇨ 6m long cooper chamber
  - ⇨ RF shielding bellows
- **Electro-static separator**
  - ⇨ Maximum operating field strength: 20kV/cm
  - ⇨ Maximum deflection: 145 urad
- **Large scale cryogenics**
  - ⇨ 12 kW @4.5K refrigerator, Oversized,
  - ⇨ Custom-made, Site integration
- **HTS magnet**
  - ⇨ Advanced HTS Cable R&D: > 10kA
  - ⇨ Advanced High Field HTS Magnet R&D: main field 10~12T

Multiple prototypes have been constructed or are under design/construction

Why does China want to do it?

A Chinese contribution to the human civilization

Benefits for China

Technology:

Improve the existing technology to the world's leading level:
- Mechanics, vacuum, electronics, computer, …

Establish new technologies in China and lead the world, hopefully on a number of new enterprises:
- Cryogenics, RF power, SC cavities, ASIC chips, …

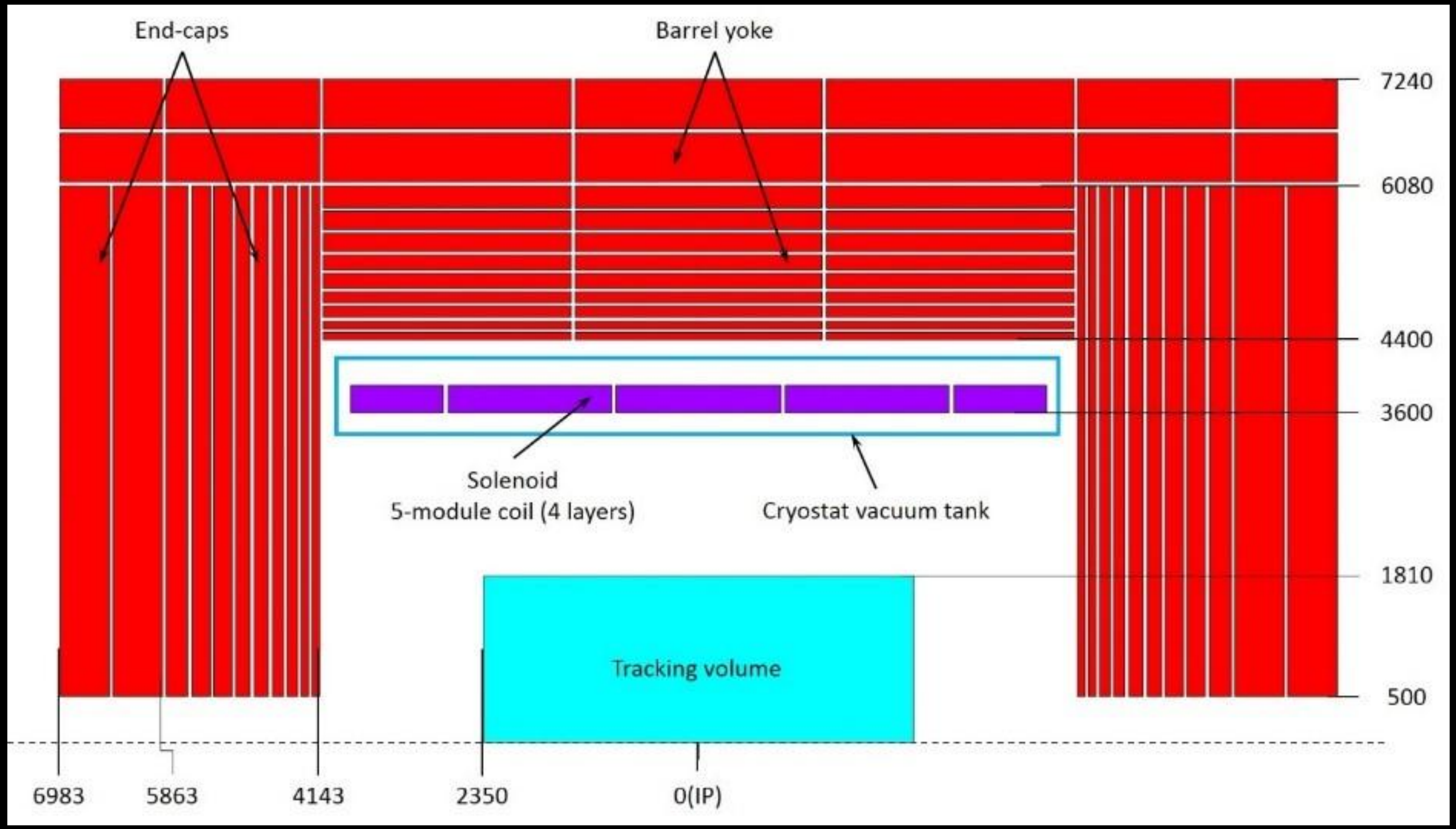
Push for revolutionary technologies:
- HTC superconducting cables

International science center:

Innovative personal training
Local economic development
New system of Science and Technology

Superconductor solenoid development

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



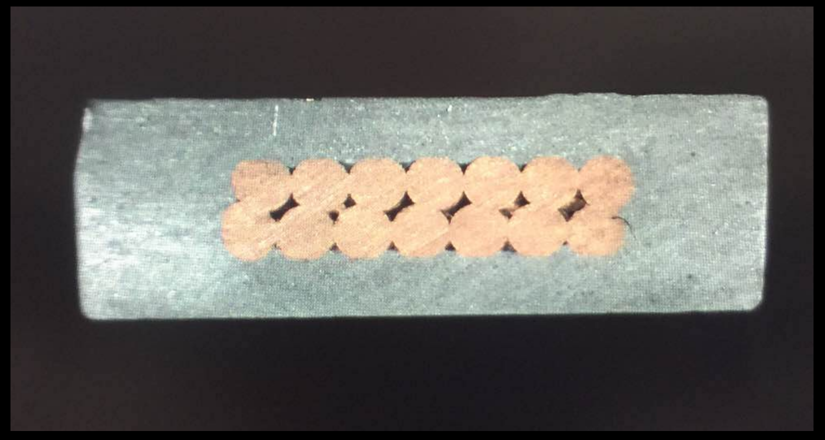
Main parameters of solenoid coil

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)



JUNO Collaboration

17 Countres & regions, 77 institution, 580 members

Europe (28)

Belgium(1)
ULB

Czech(1)
Charles U

Latvia(1)
IECS

Finland(1)
U.Oulu

France(5)
APC Paris
CPPM Marseille
IPHC Strasbourg
Subatech Nantes
CENBG-IN2P3

Italy(8)
INFN-Catania
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Mi-Bicocca
INFN-Padova
INFN-Perugia
INFN-Roma 3

Germany(7)
FZ Jülich
RWTH Aachen
TUM
U.Hamburg
IKP FZI Jülich
U.Mainz
U.Tuebingen

Russia(3)
INR Moscow
JINR
MSU

Slovakia (1)
FMPICU

America(6)

US(2)
UMD
UMD-Geo

Chile(2)
PCUC
UTFSM

Brazil（2）
PUC-Rio
UEL

Asia (38)

China（33）
BJ Nor. U.
CAGS
Chongqing U.
Shanghai JT U.
DGUT
ECUST
Guangxi U.
HIT
IHEP
U. Of South China
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Nankai U.
NCEPU
Pekin U.
SDU
Sichuan U.
CIAE
SYSU
Tsinghua U.
UCAS
USTC
Jilin U.
Wuhan U.
Wuyi U.
Xi'an JT U.
Xiamen U.

Armenia(1)
Yerevan Phys. Inst.

Thailand(3)
SUT
PPRLCU
NARIT

Parkistan(1)
PINSTECH

Organization of the Physics and Detector Working Group

Conveners

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

Machine Detector Interface	Vertex	Tracker	Calorimeter: ECal	Calorimeter: HCal	Calorimeter: Muons
Hongbo Zhu	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

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)	
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
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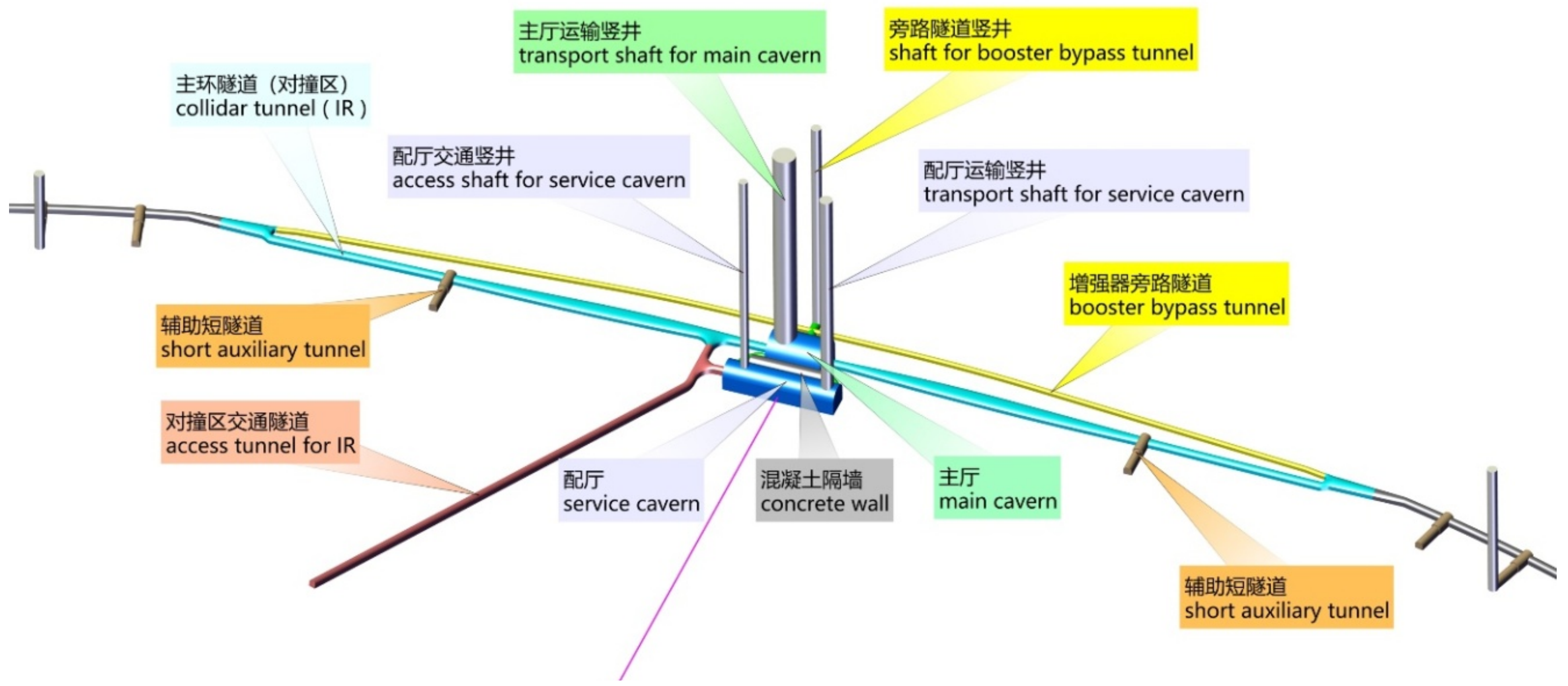
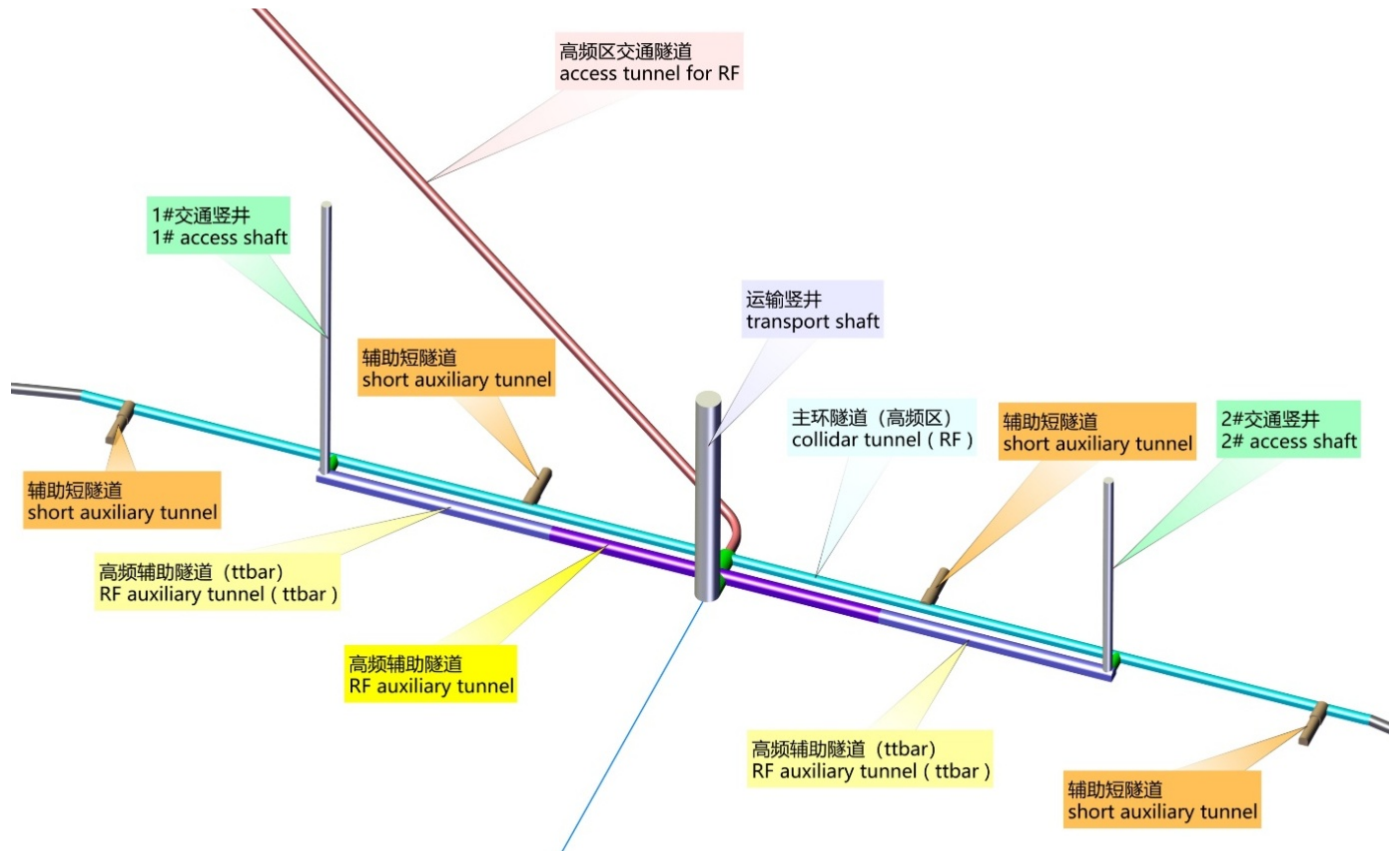
Luminosity/IP L (10^{34} $cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1

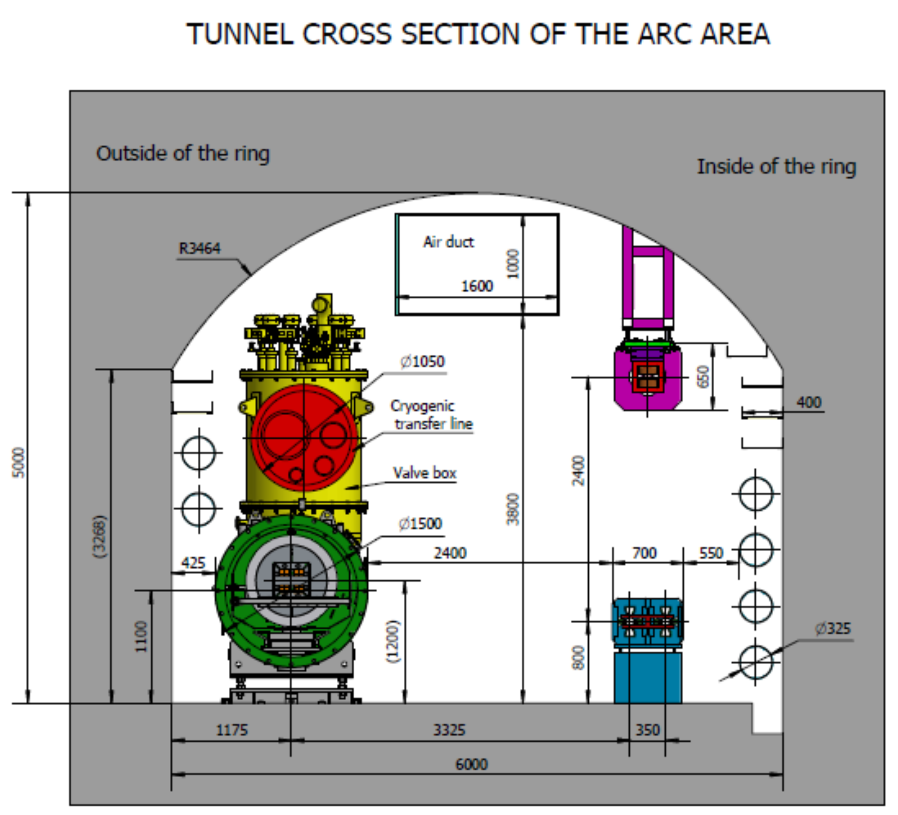
CEPC Civil Engineering Design and Implementation

CEPC Interaction Region

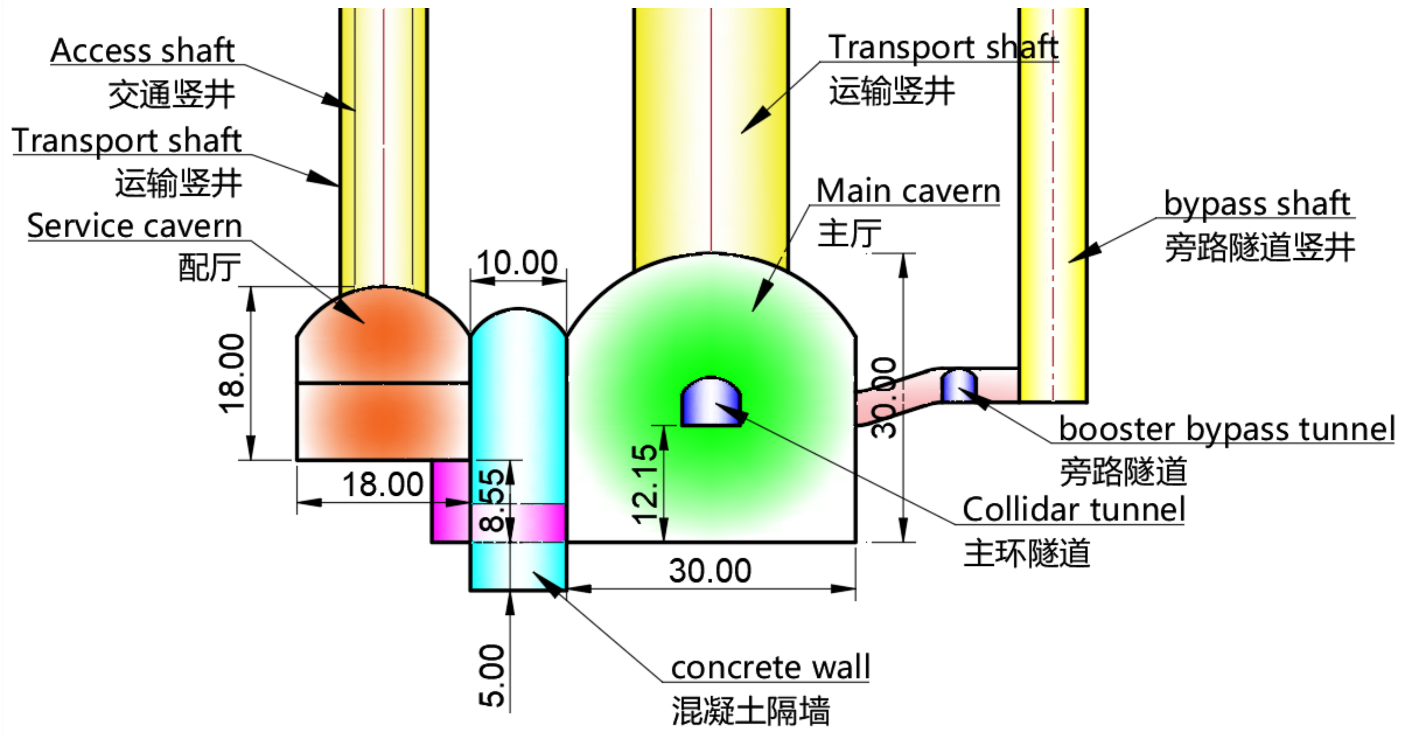


CEPC Injection Region

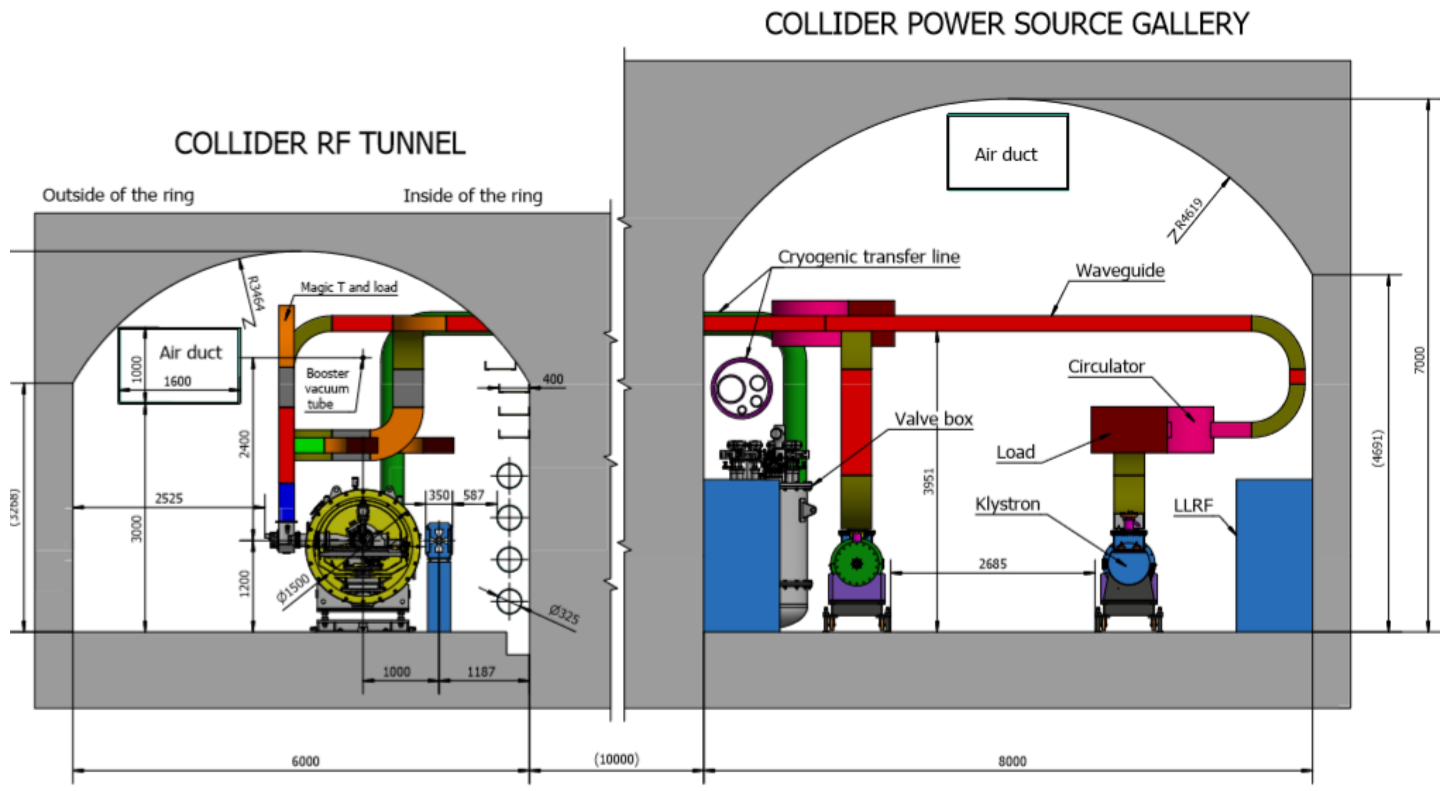




CEPC-SppC tunnel



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

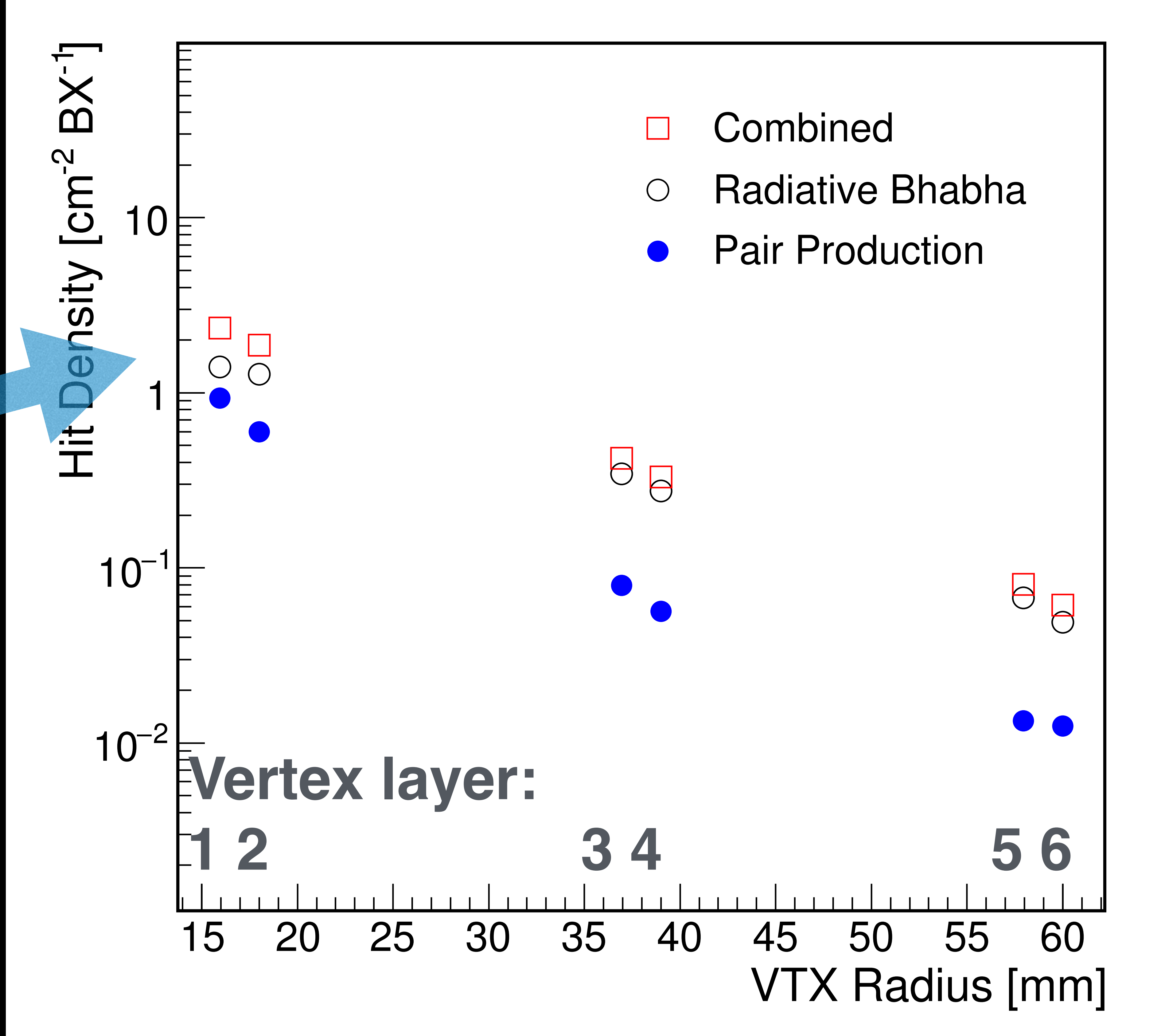
Studies for new configuration being finalized

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)



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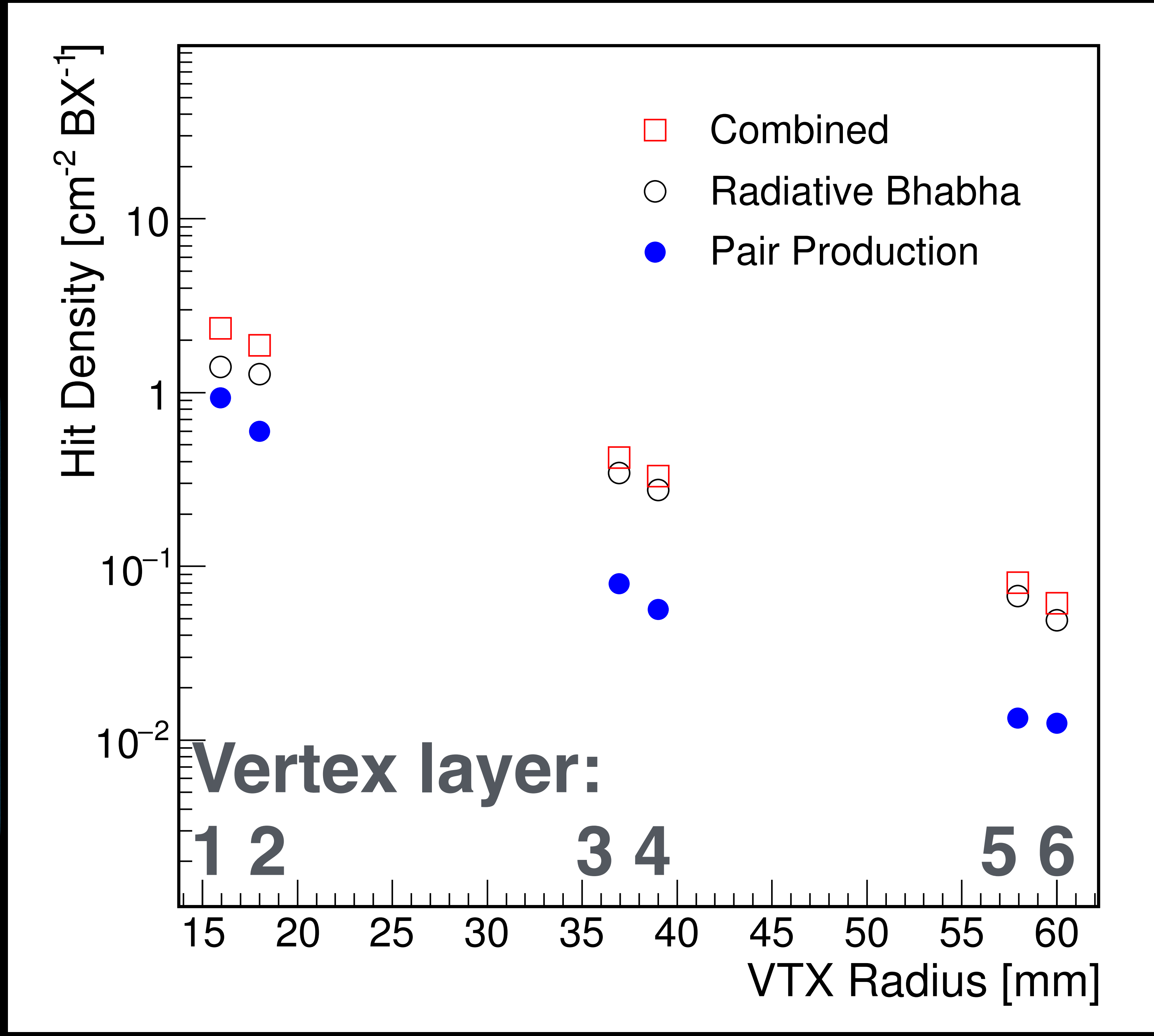
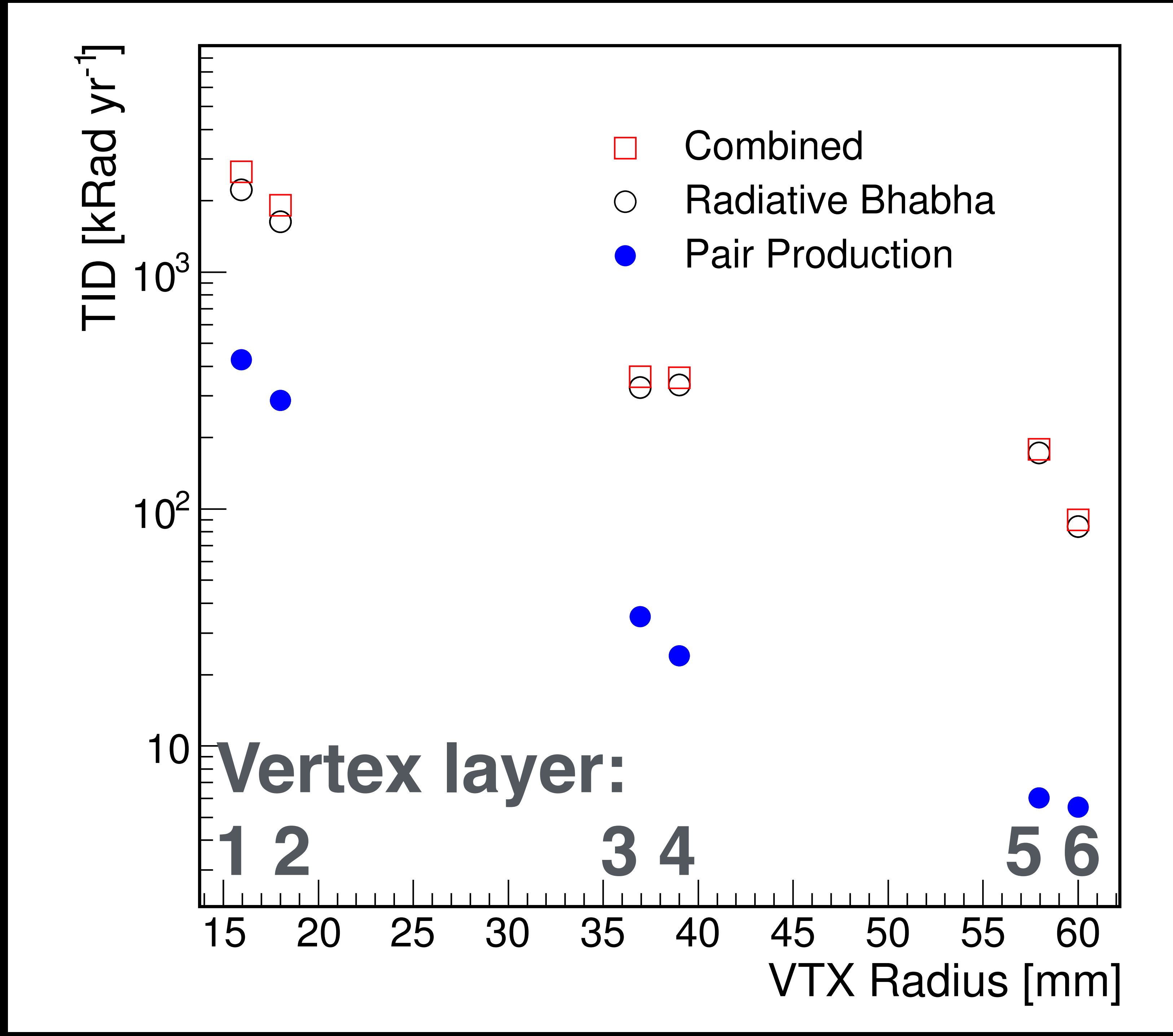




Vertex Detector Performance Requirements

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

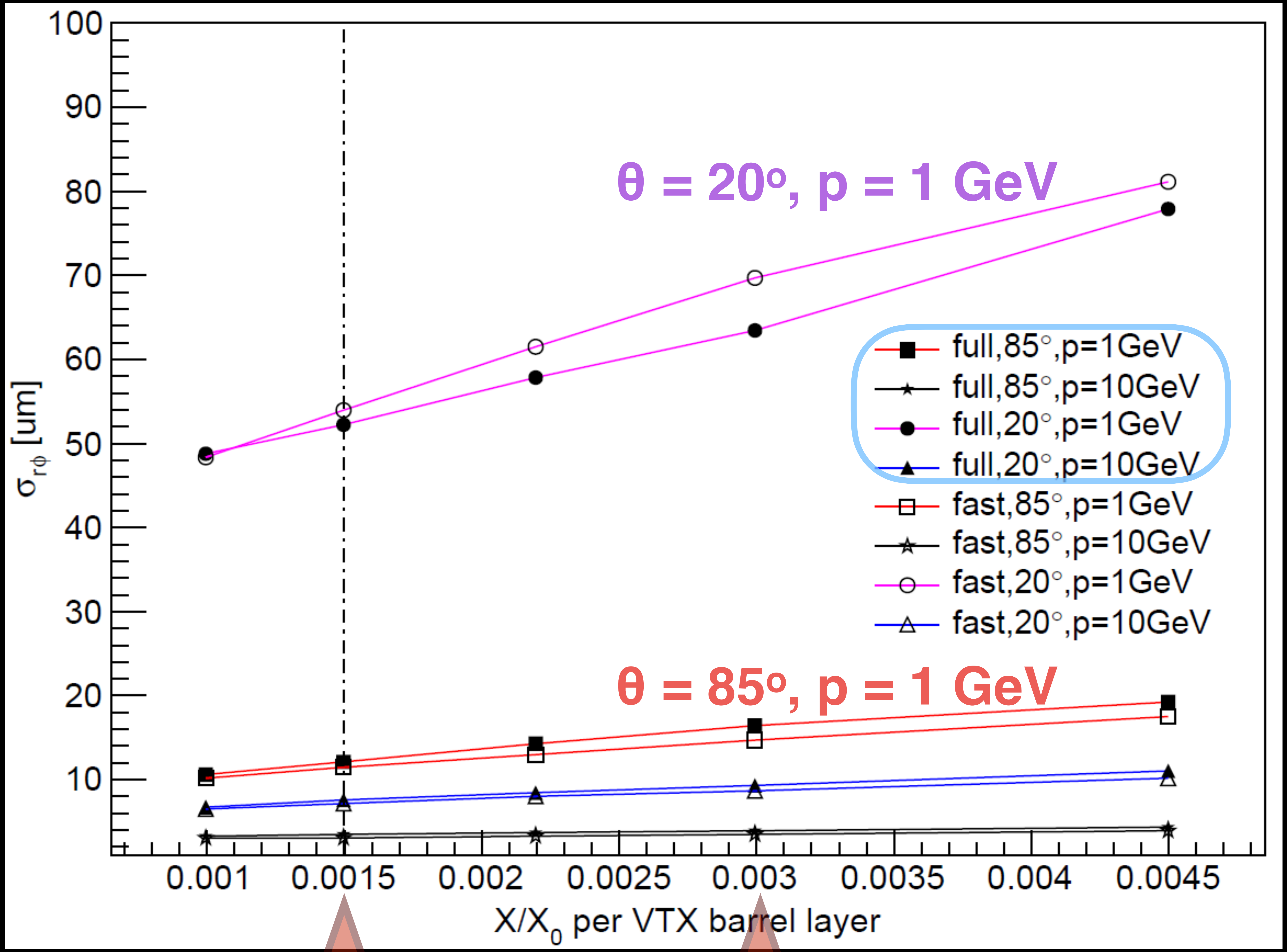
	Specs	Consequences
Single point resolution near IP:	< 3 μm	High granularity
First layer close to beam pipe:	r ~ 1.6 cm	
Material budget/layer:	≤ 0.15%X_0	Low power consumption, < 50 mW/cm² for air cooling
Detector occupancy:	≤ 1%	High granularity and short readout time (< 20 μs)

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

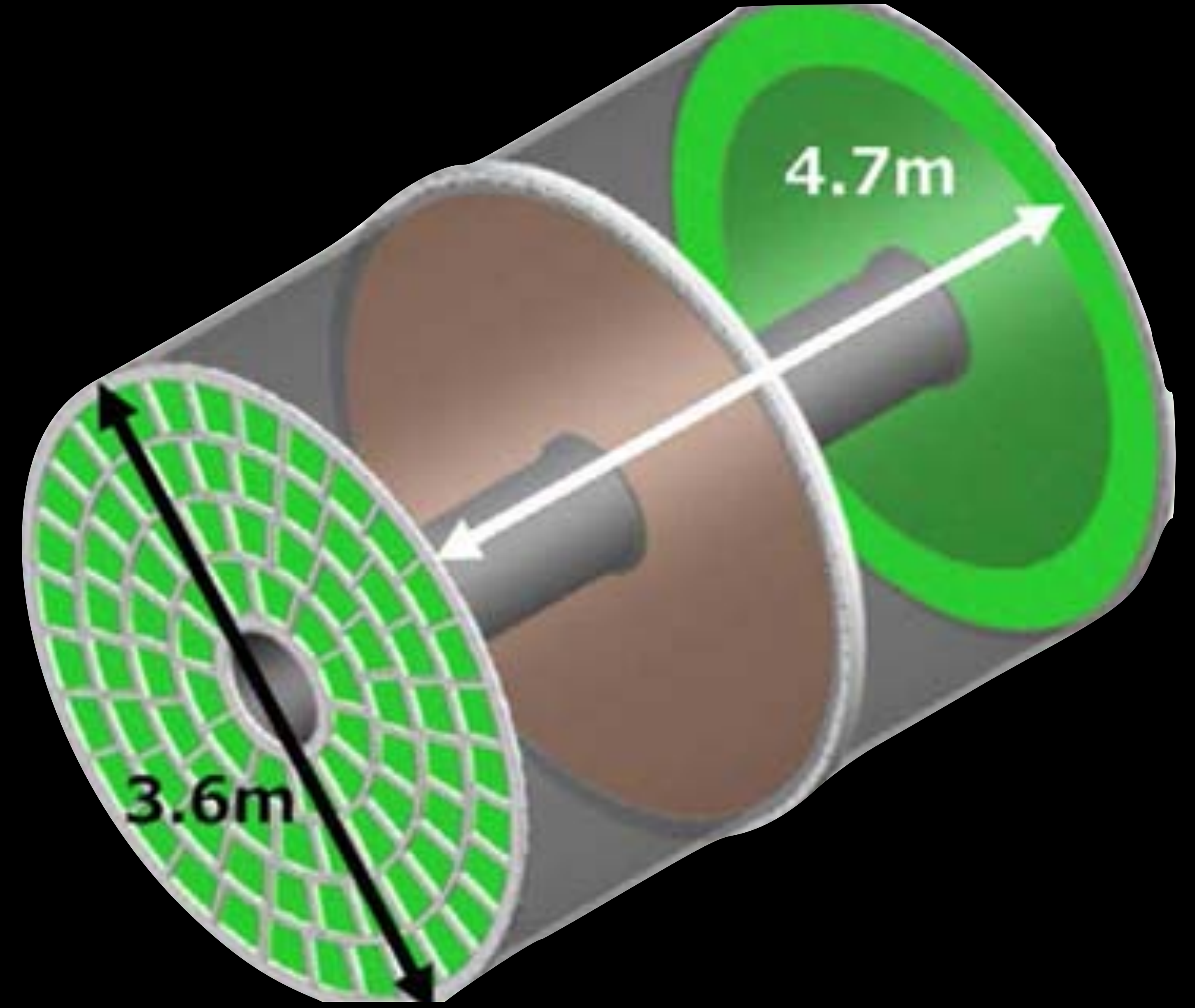
Impact parameter resolution goal achievable but only with low material budget

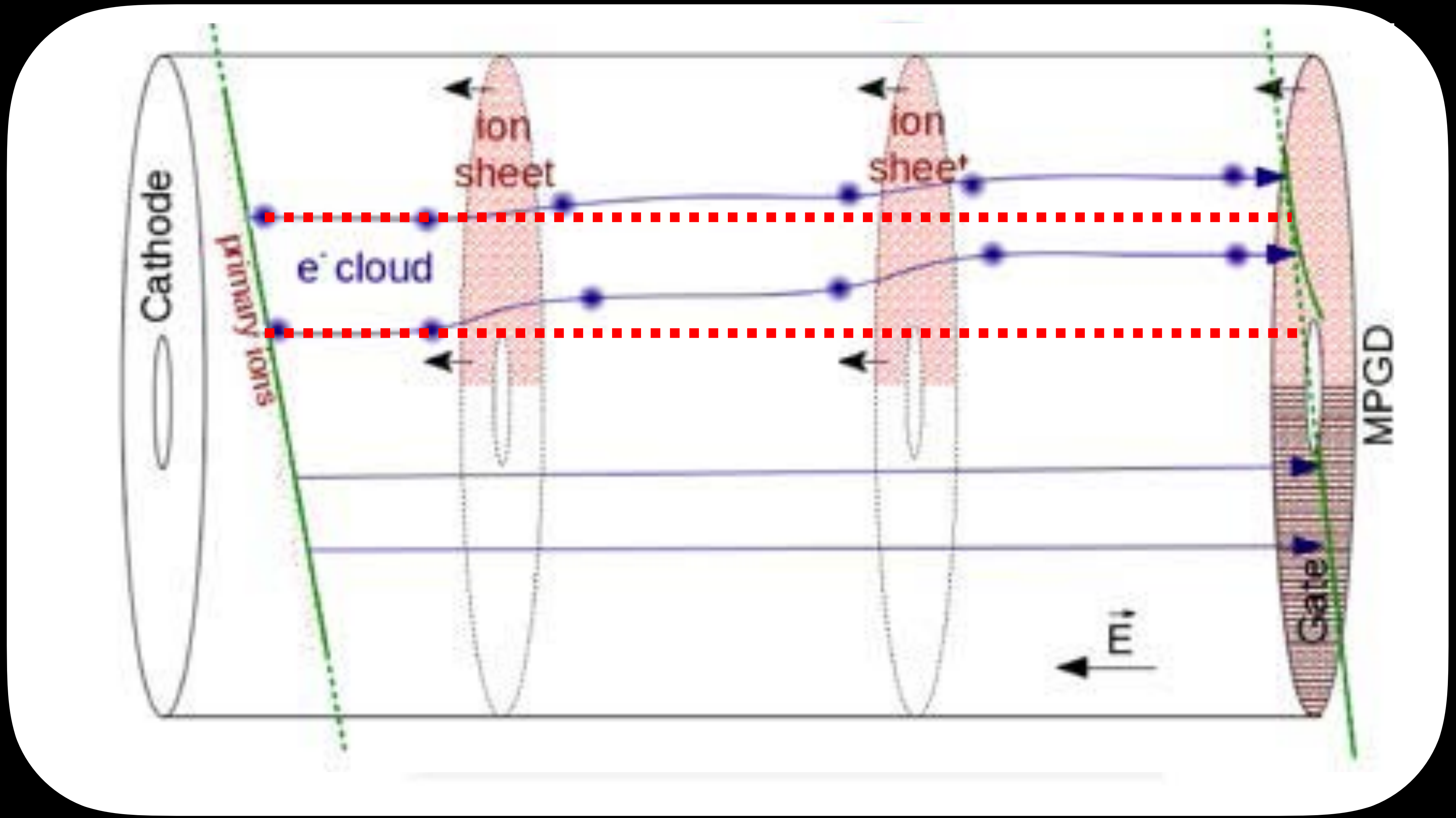
Time Projection Chamber (TPC)

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

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

TPC detector concept





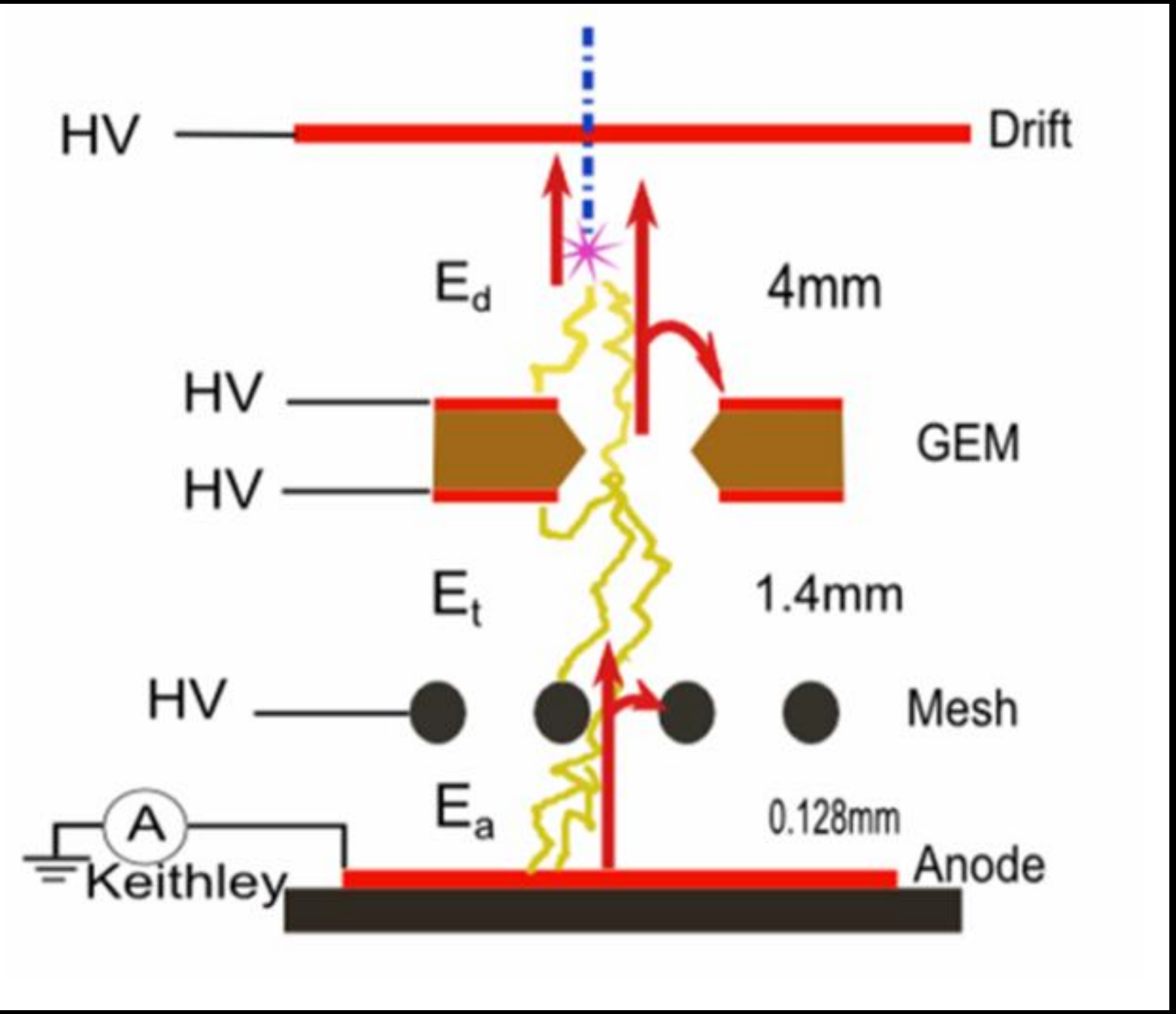
Prototype built

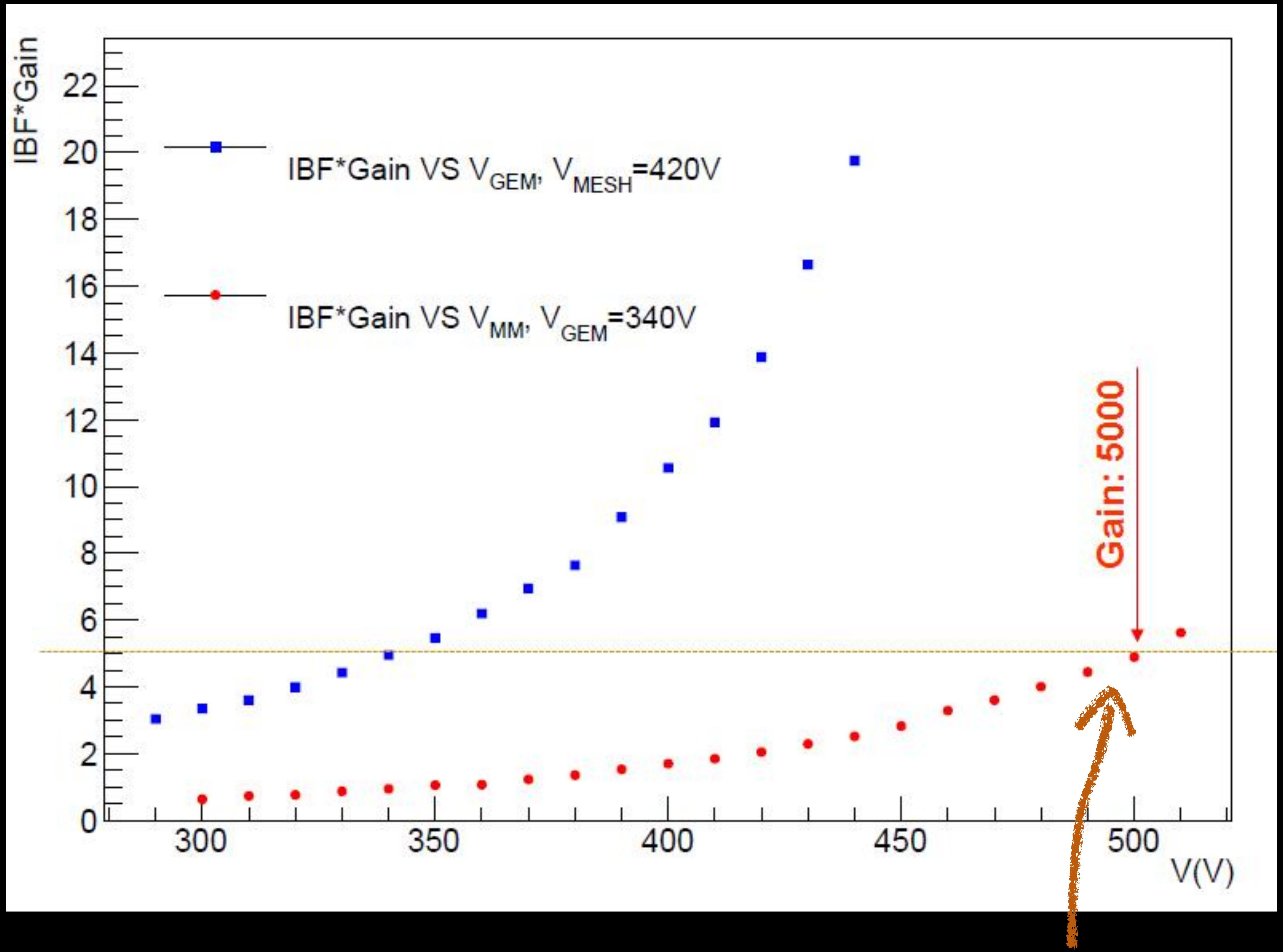
- R&D by IHEP, Tsinghua and Shandong
  - Funded by MOST and NSFC

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

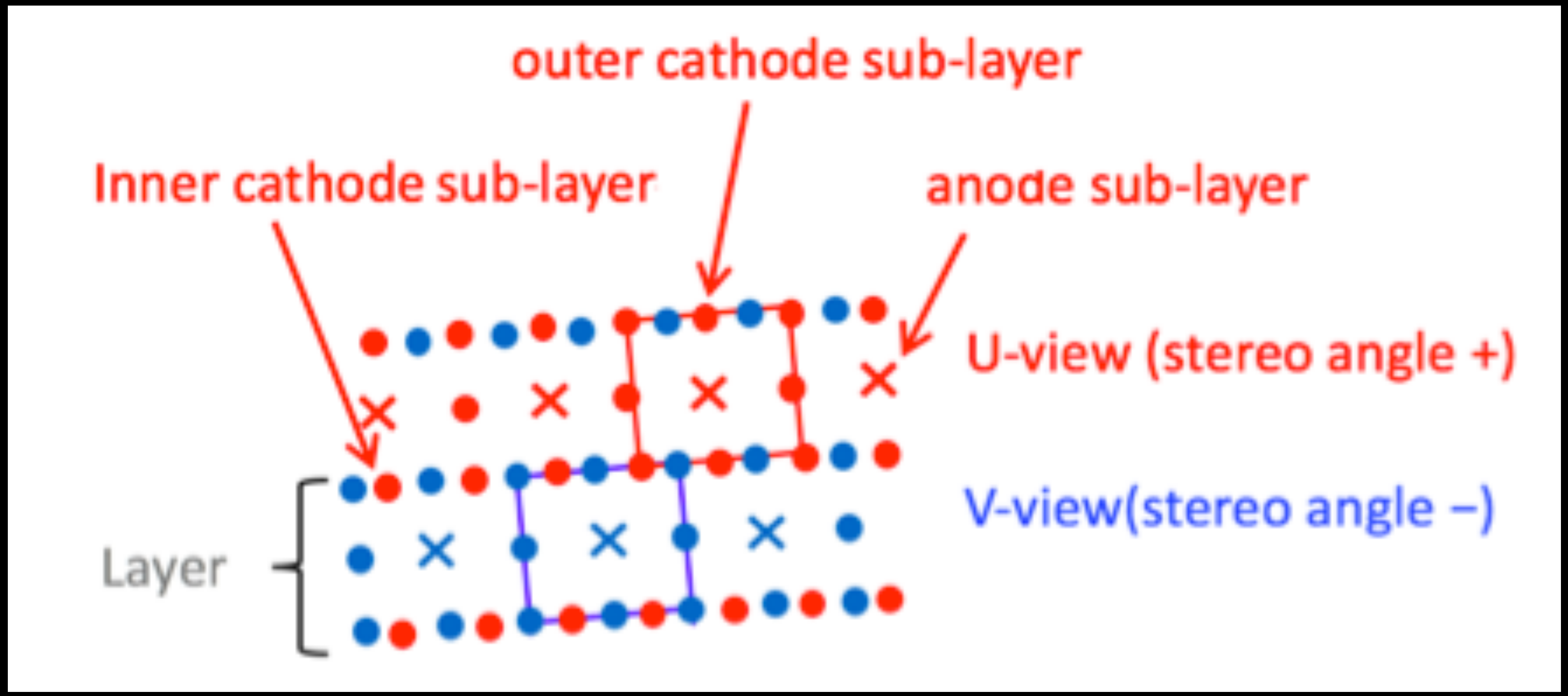
Follows design of the KLOE and MEG2 experiments

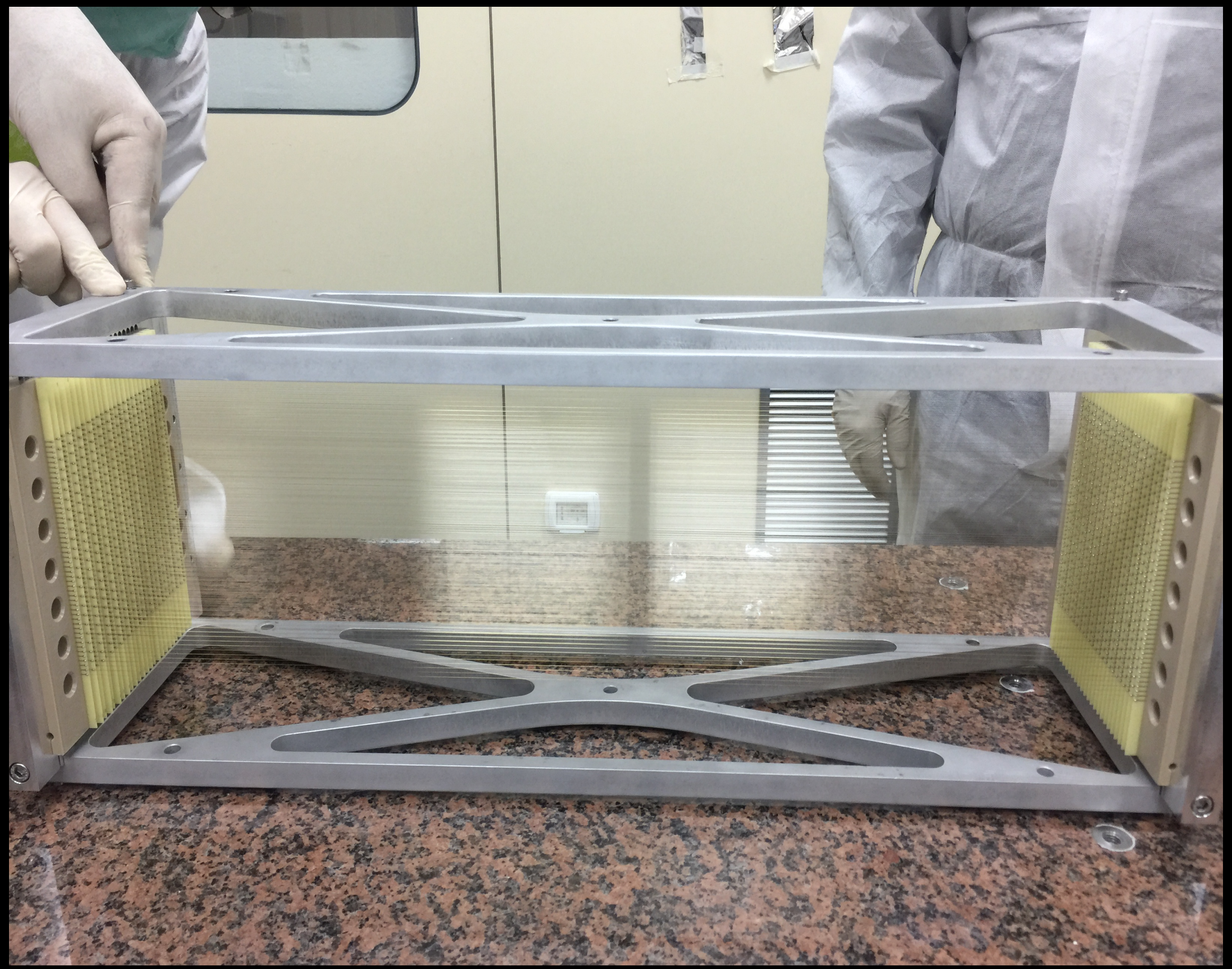
- Length: 4 m
- Radius: 0.3- 2m
- Gas: 90%He – 10%iC_4H_{10}
- Material: 1.6% X_0 (barrel)

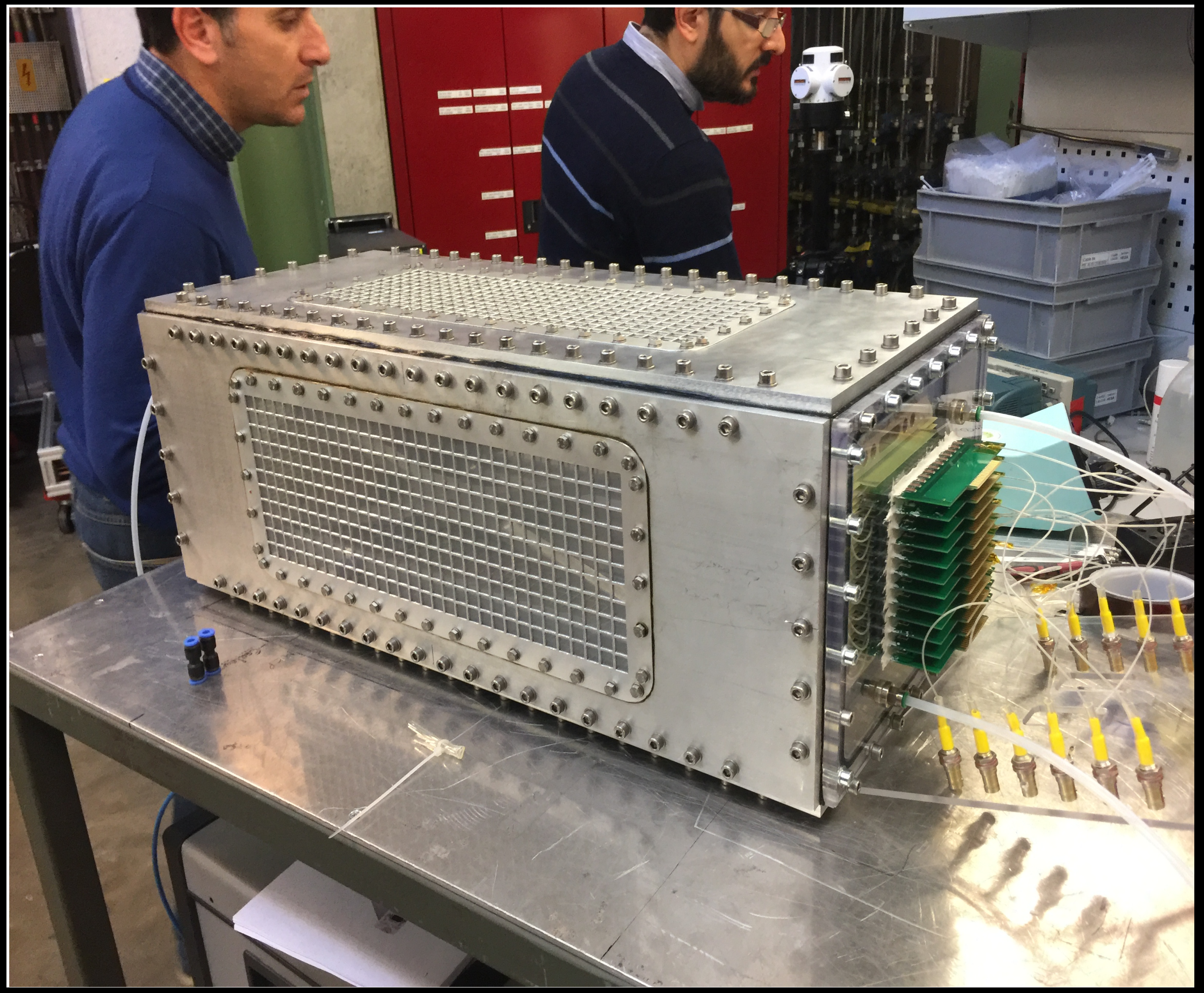
- Spatial resolution: < 100 μm
- dE/dx resolution: 2%
- Max drift time: <400 nsec
- Cells: 56,448

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

MEG2 prototype being tested



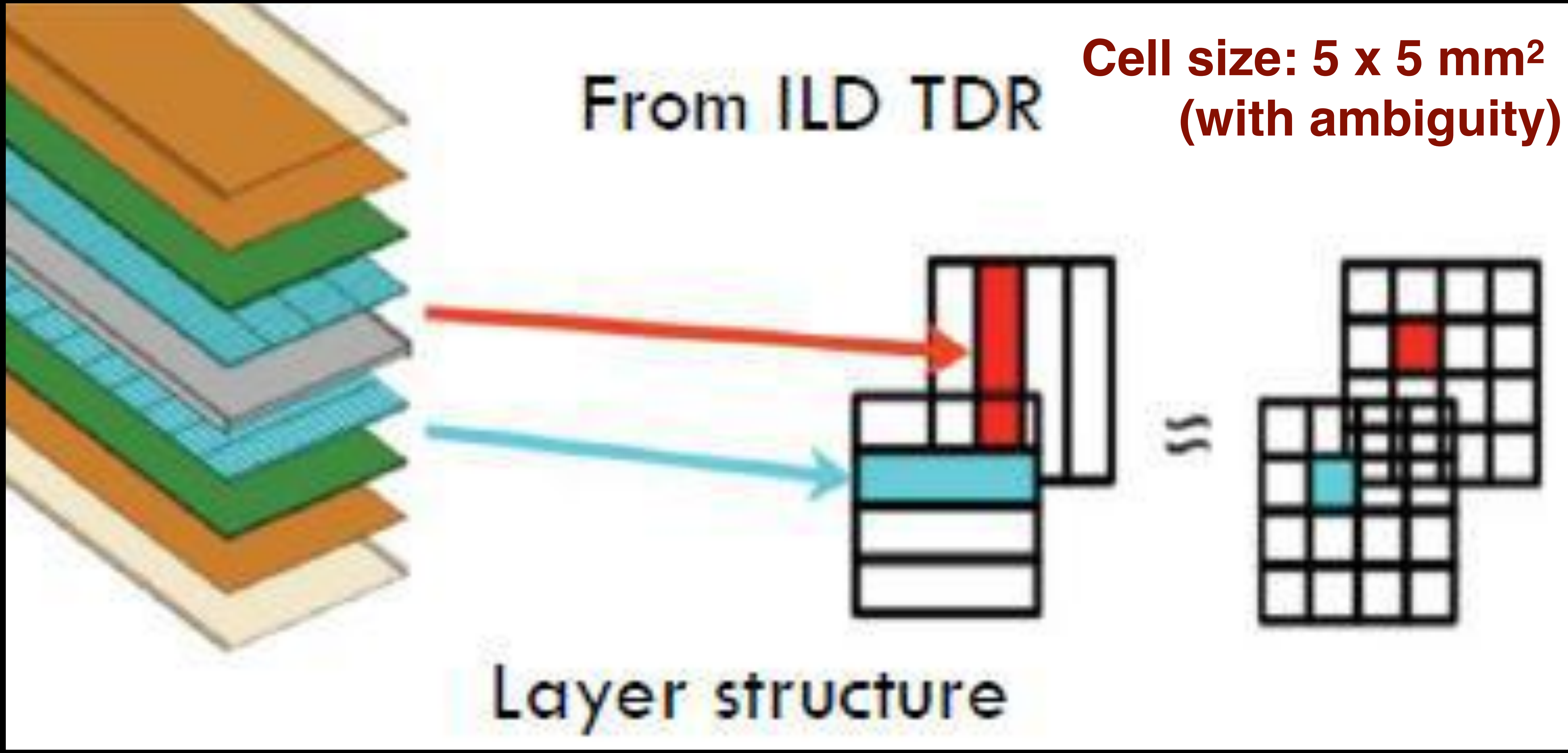




Stereo angle: 50-250 mrad

ECAL Calorimeter — Particle Flow Calorimeter

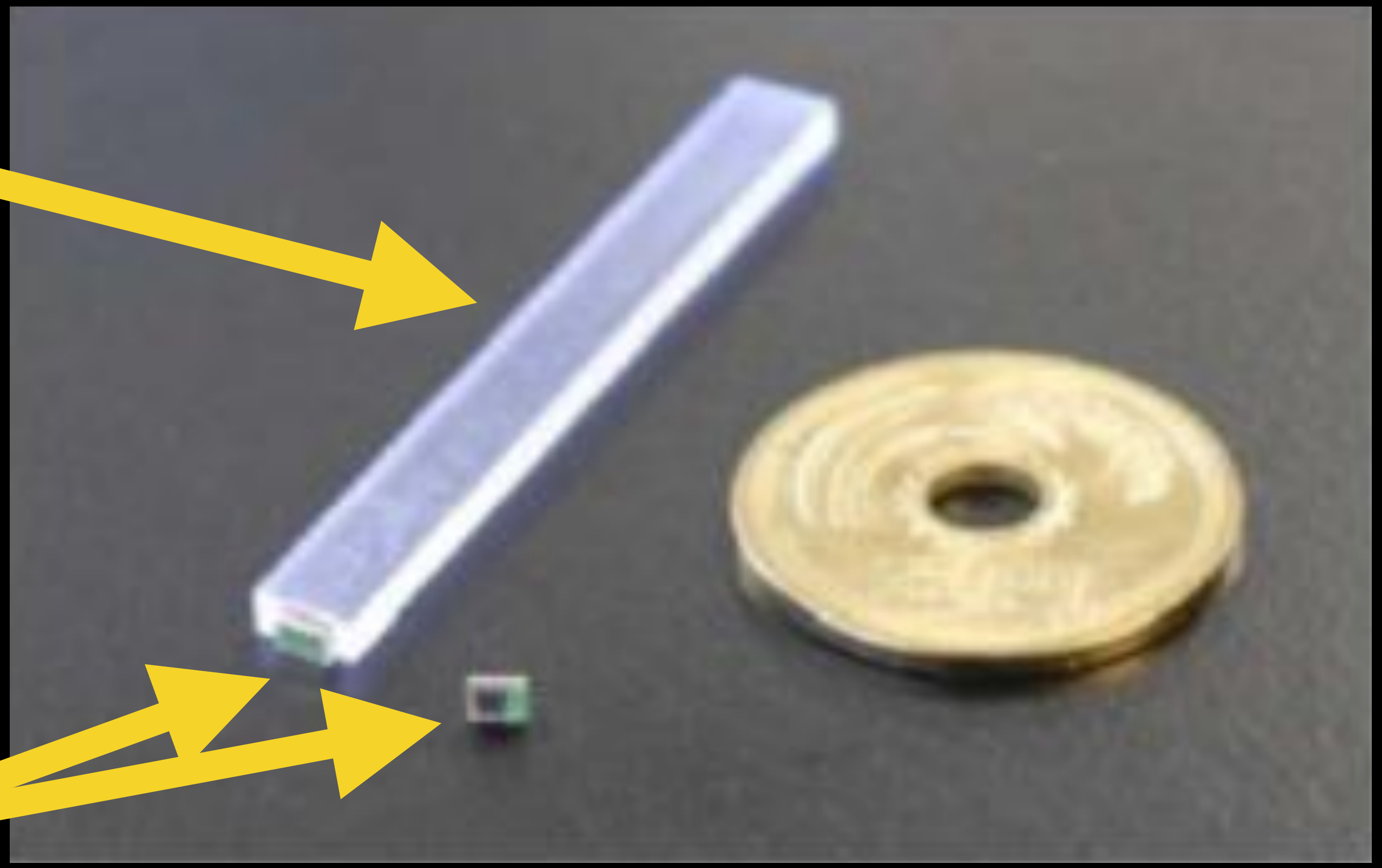
Scintillator-Tungsten Sandwich ECAL



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

Plastic scintillator
$5 \times 45\ mm^2$ (2 mm thick)

SiPM



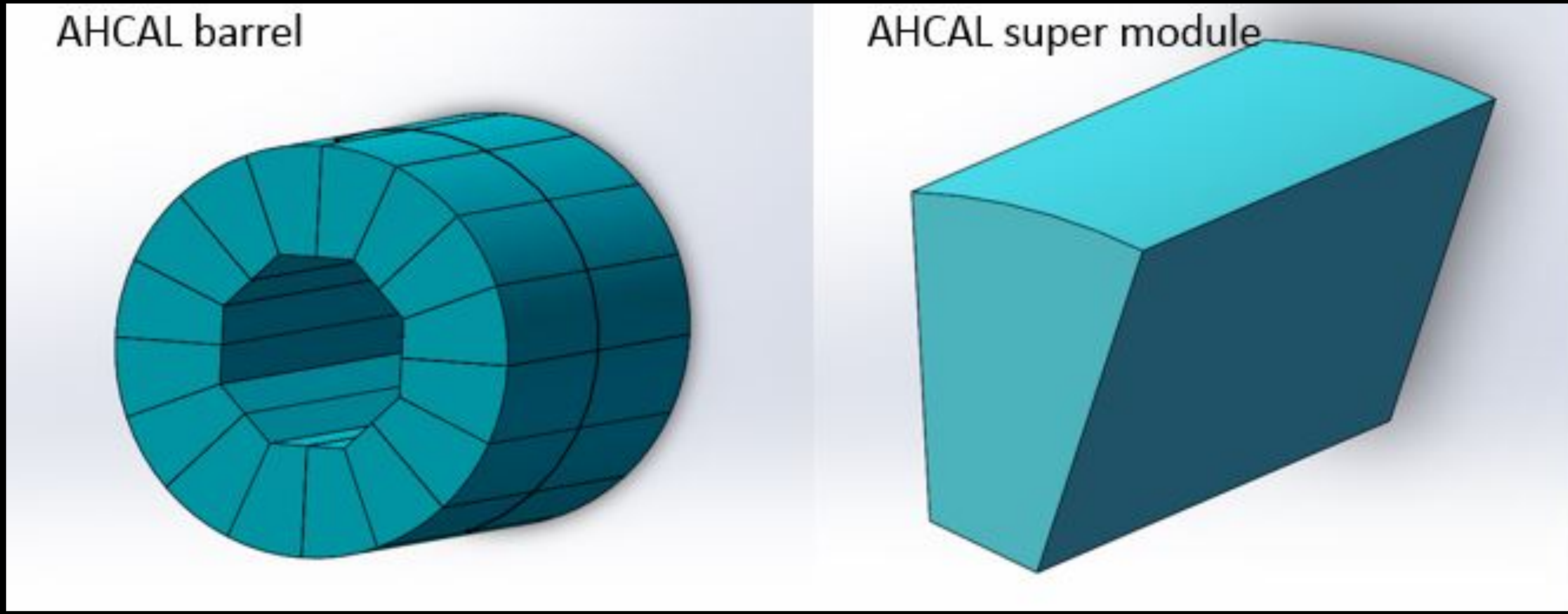
R&D on-going:
- SiPM dynamic range
- Scintillator strip non-uniformity
- Coupling of SiPM and scintillator

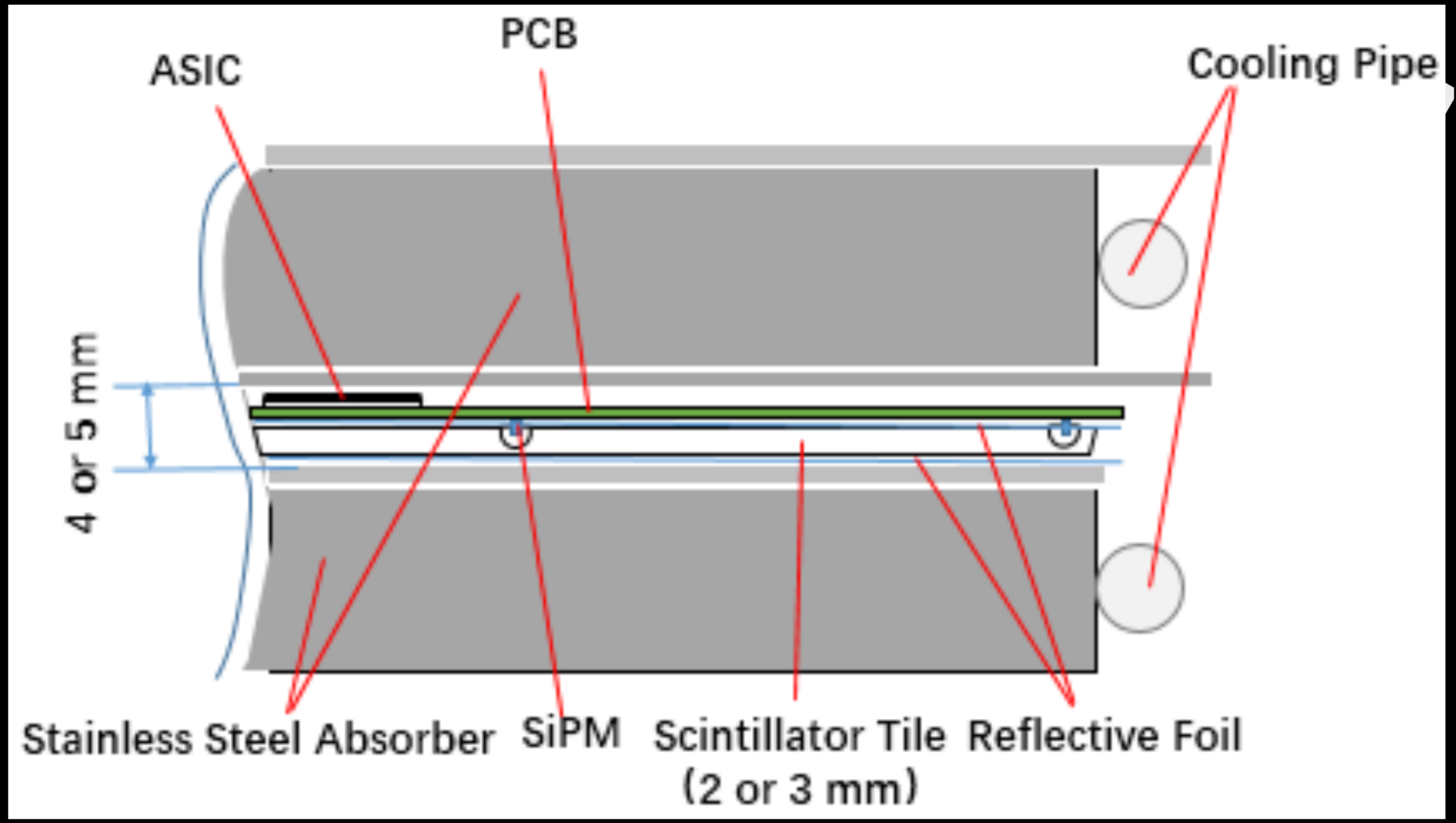
Mini-prototype tested on testbeam at the IHEP

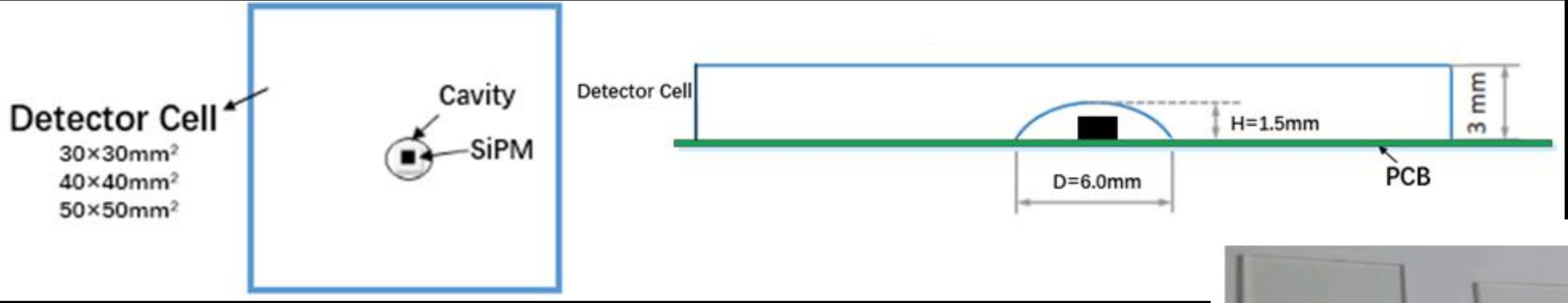
HCAL Calorimeter — Particle Flow Calorimeter

Scintillator and SiPM HCAL (AHCAL)

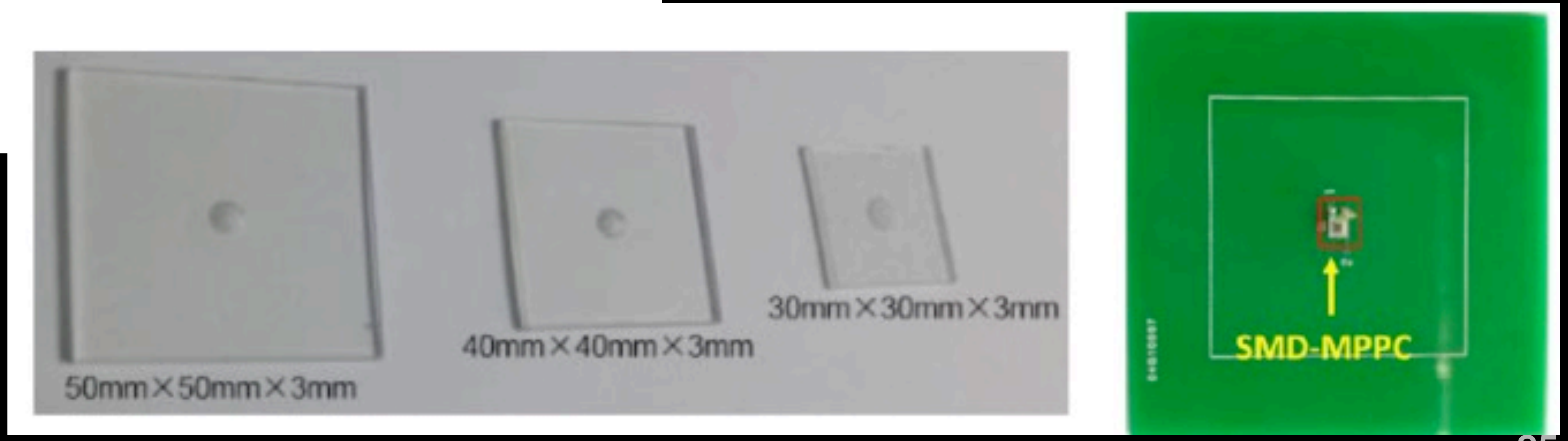
32 super modules **40 layers**







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

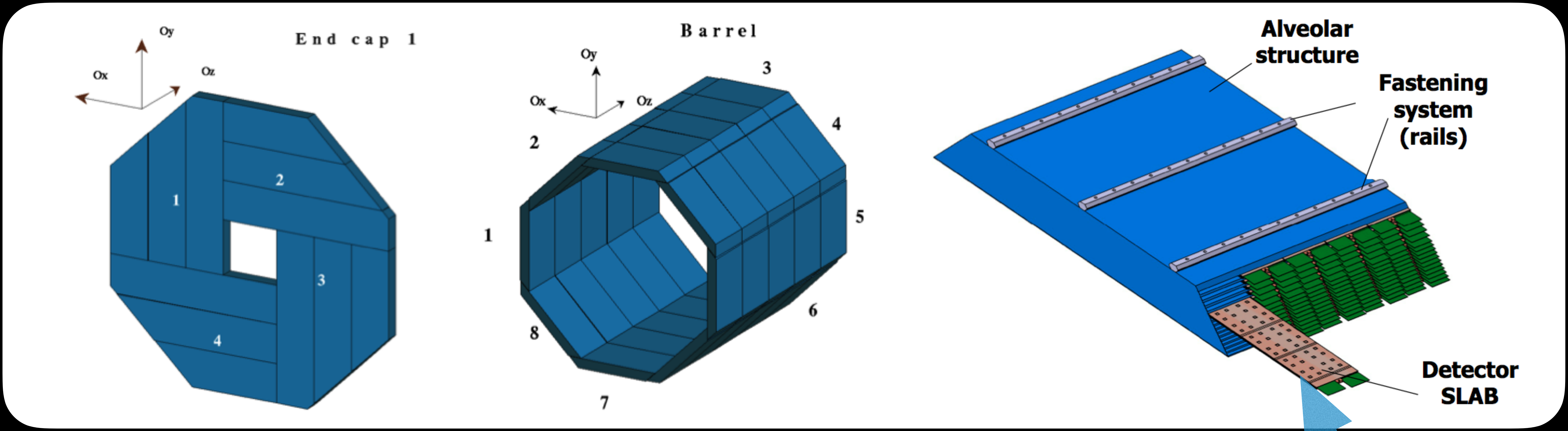


Prototype to be built: MOST (2018-2022)

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

Baseline ECAL Calorimeter — Particle Flow Calorimeter

Silicon-Tungsten Sandwich ECAL

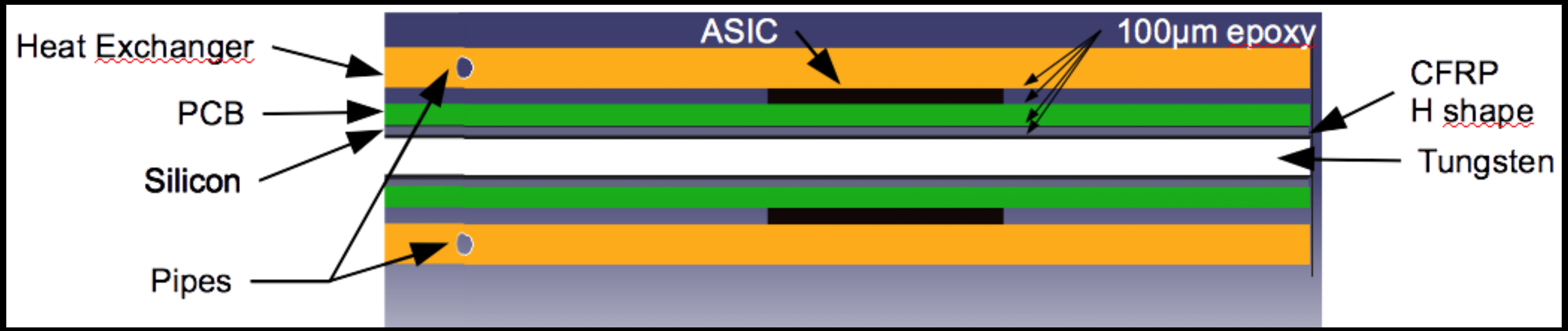


Cell size:

- 5 x 5 mm^2 - optimal for PFA
- 10 x 10 mm^2 - default
- 20 x 20 mm^2 - required for passive cooling

high granularity —> active cooling

CO_2 Active cooling



Sensor: high-resistivity silicon pin diodes

- Stability
- Uniformity
- Flexibility
- High S/N

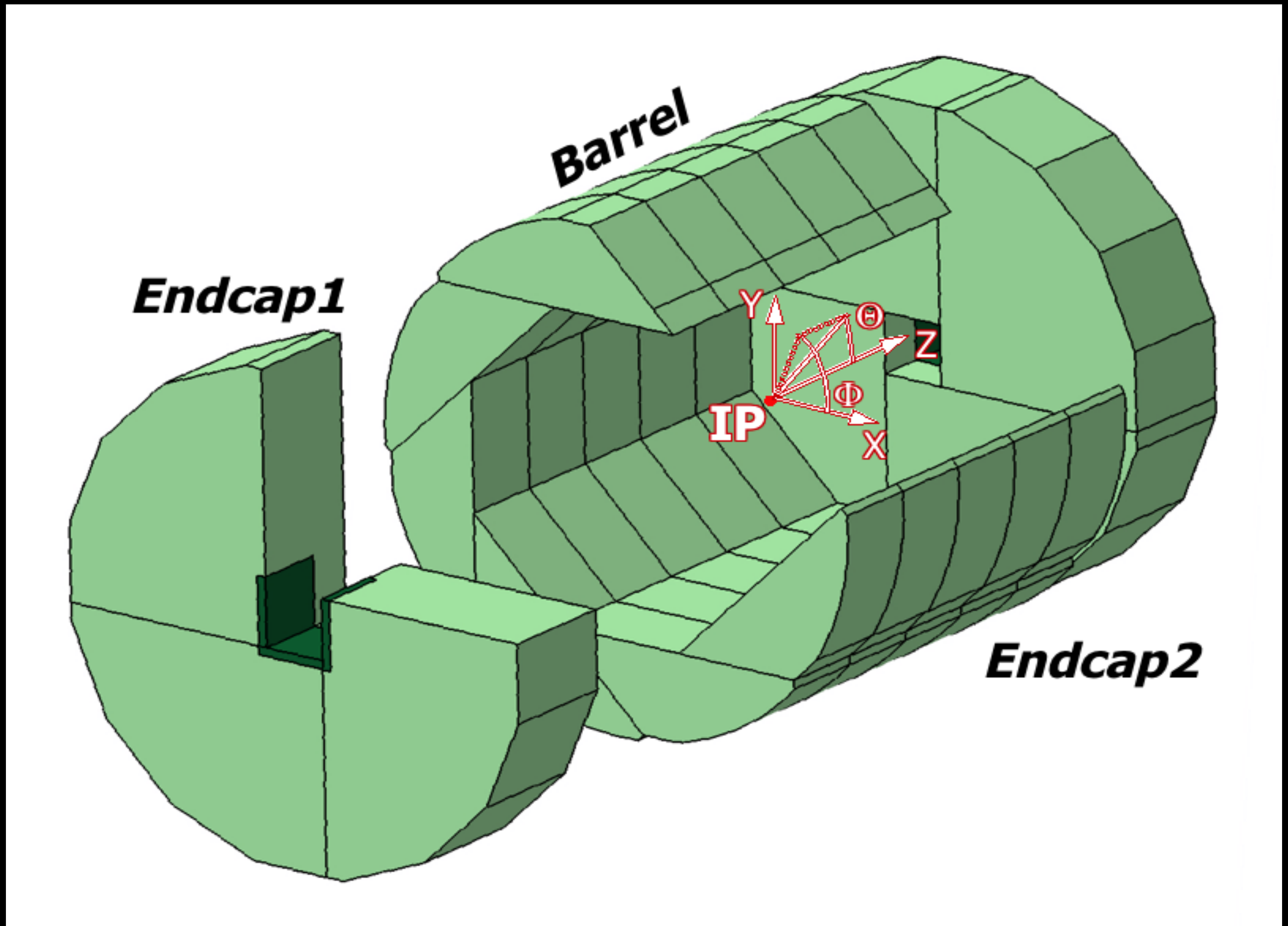
Preliminary simulation: ΔT ~ 2° C (HGCAL/ILD)

Baseline HCAL Calorimeter — Particle Flow Calorimeter

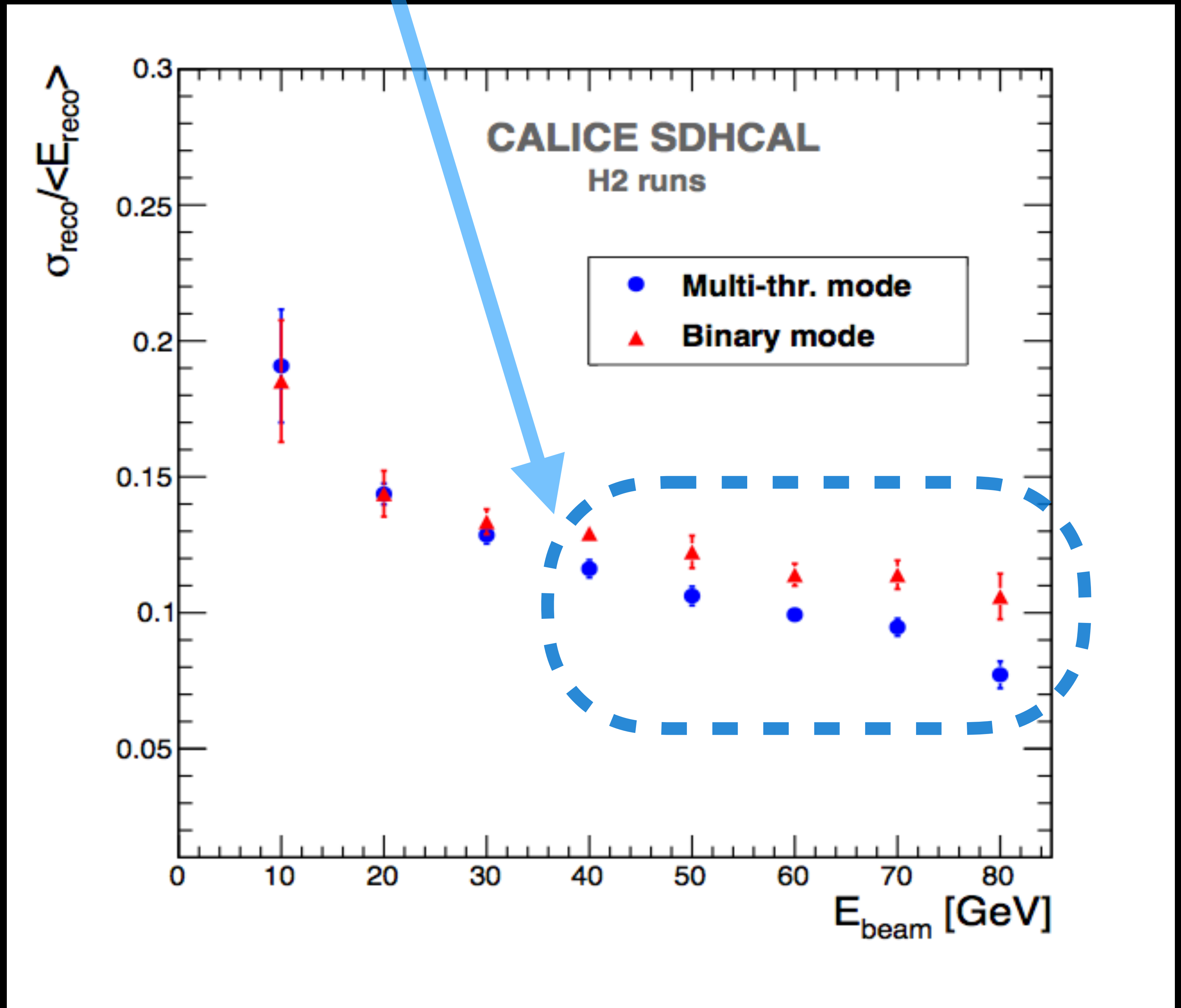
Calorimeter for ILC

Semi-Digital HCAL

Self-supporting absorber (steel)



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



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

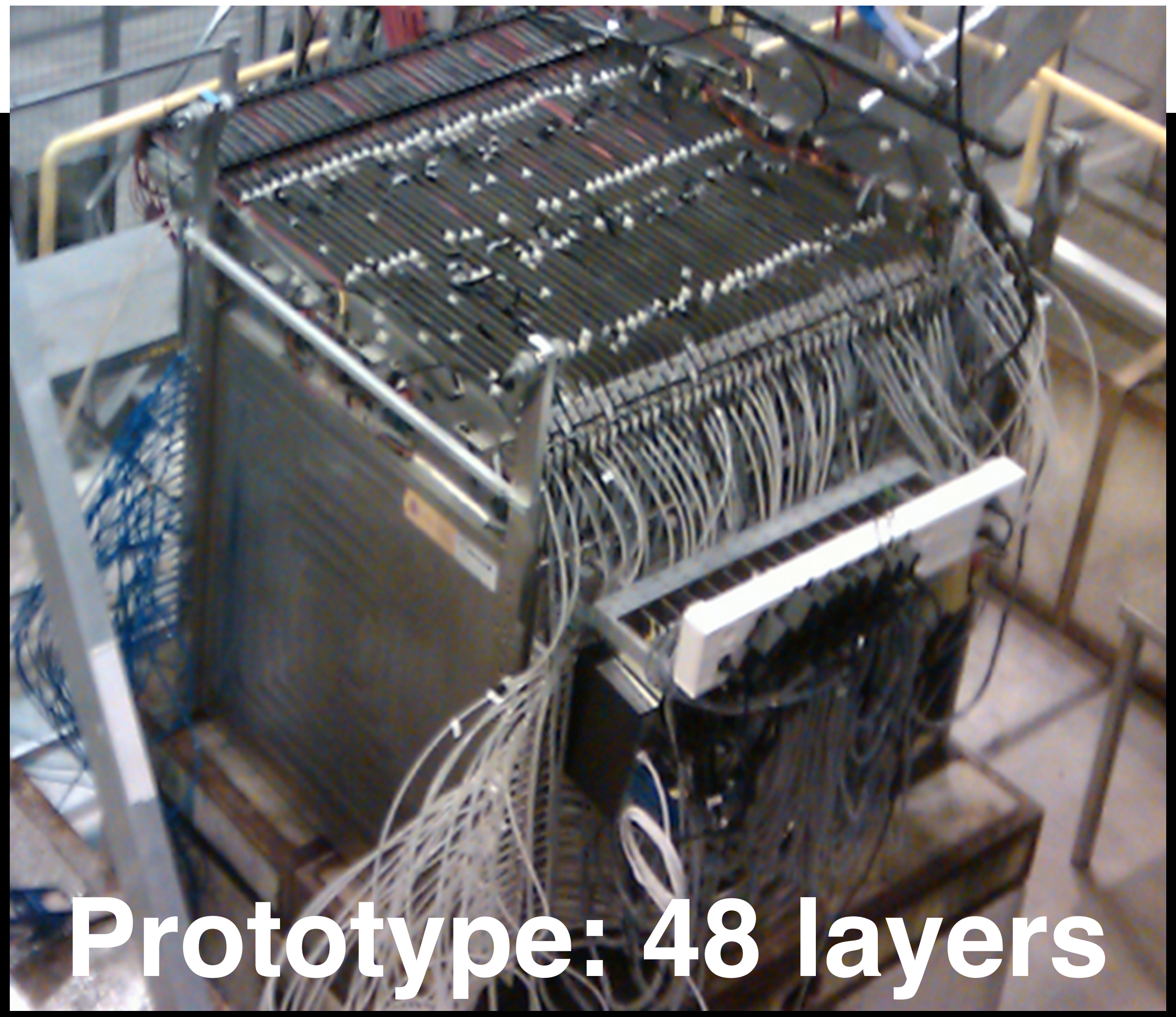
Challenges
- Power consumption —> temperature
- Large amount of services/cables

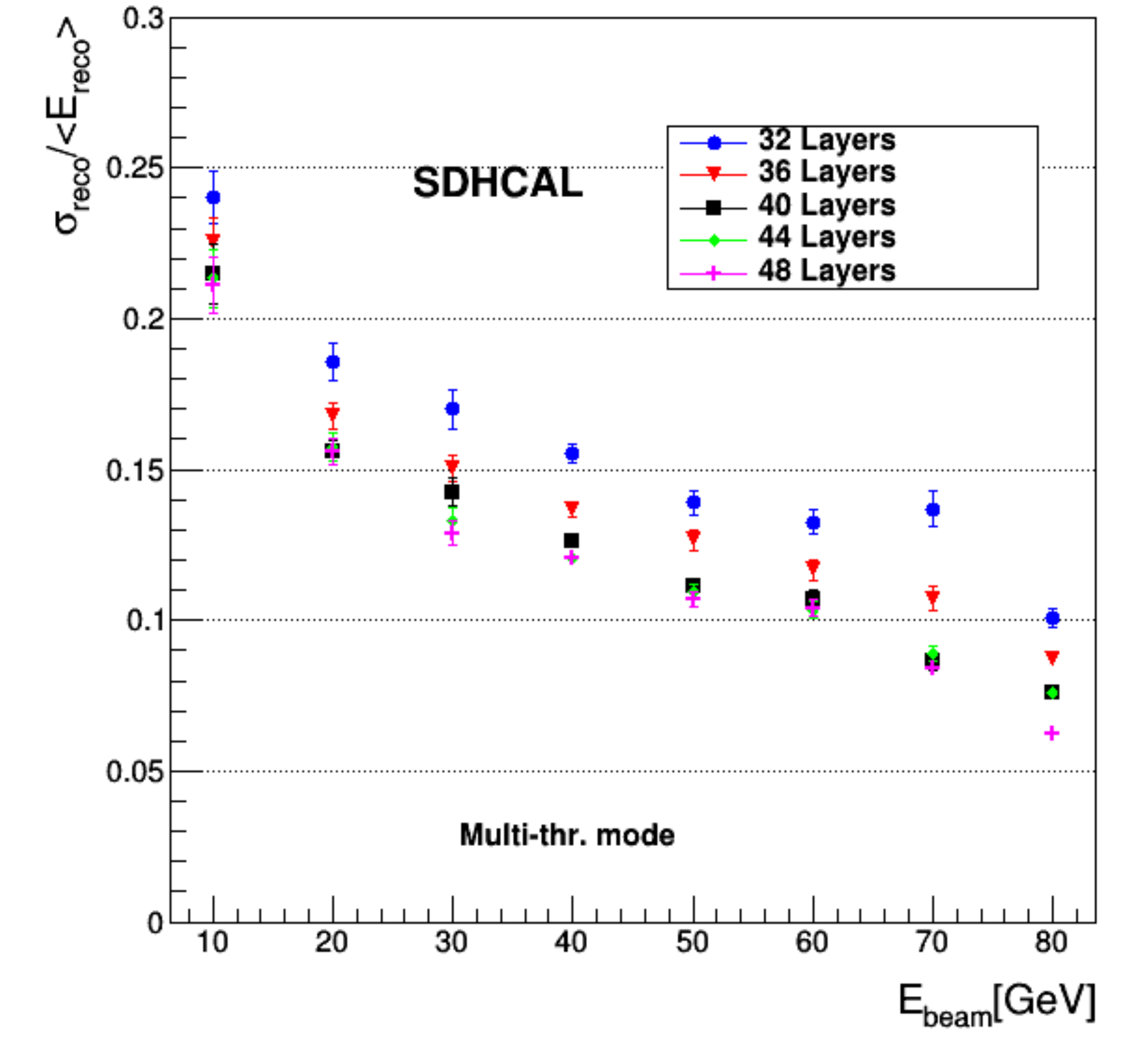
Baseline HCAL Calorimeter — Particle Flow Calorimeter

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

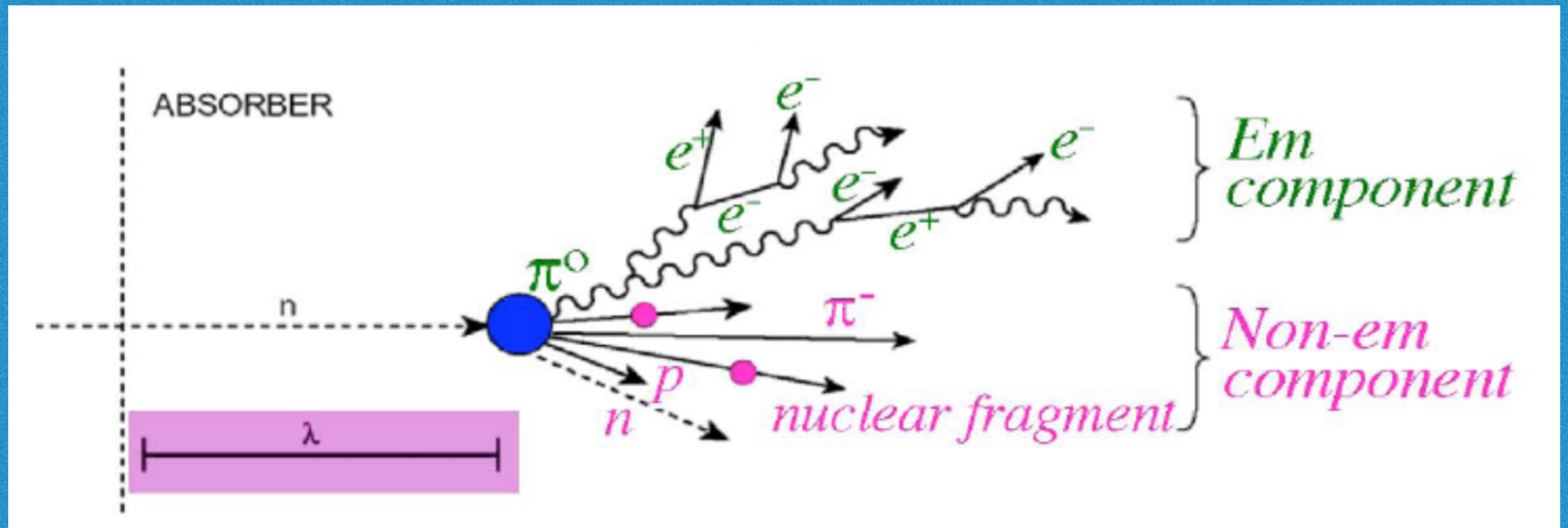
6mm gRPC + 20mm absorber

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:

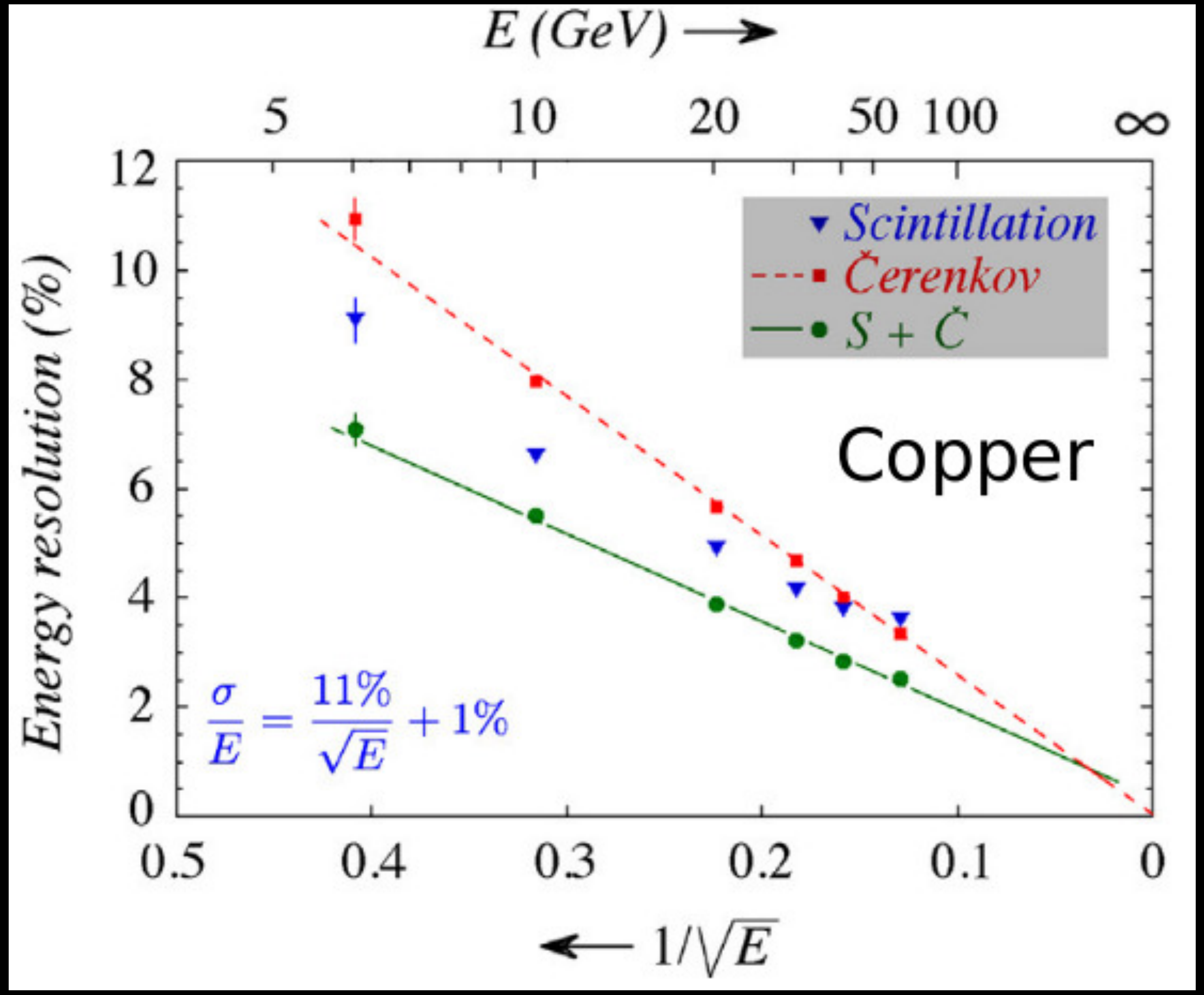
Cherenkov light (sensitive to relativistic particles)
Scintillator light (sensitive to total deposited energy)

Expected resolution:

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

Several prototypes from RD52 have been built

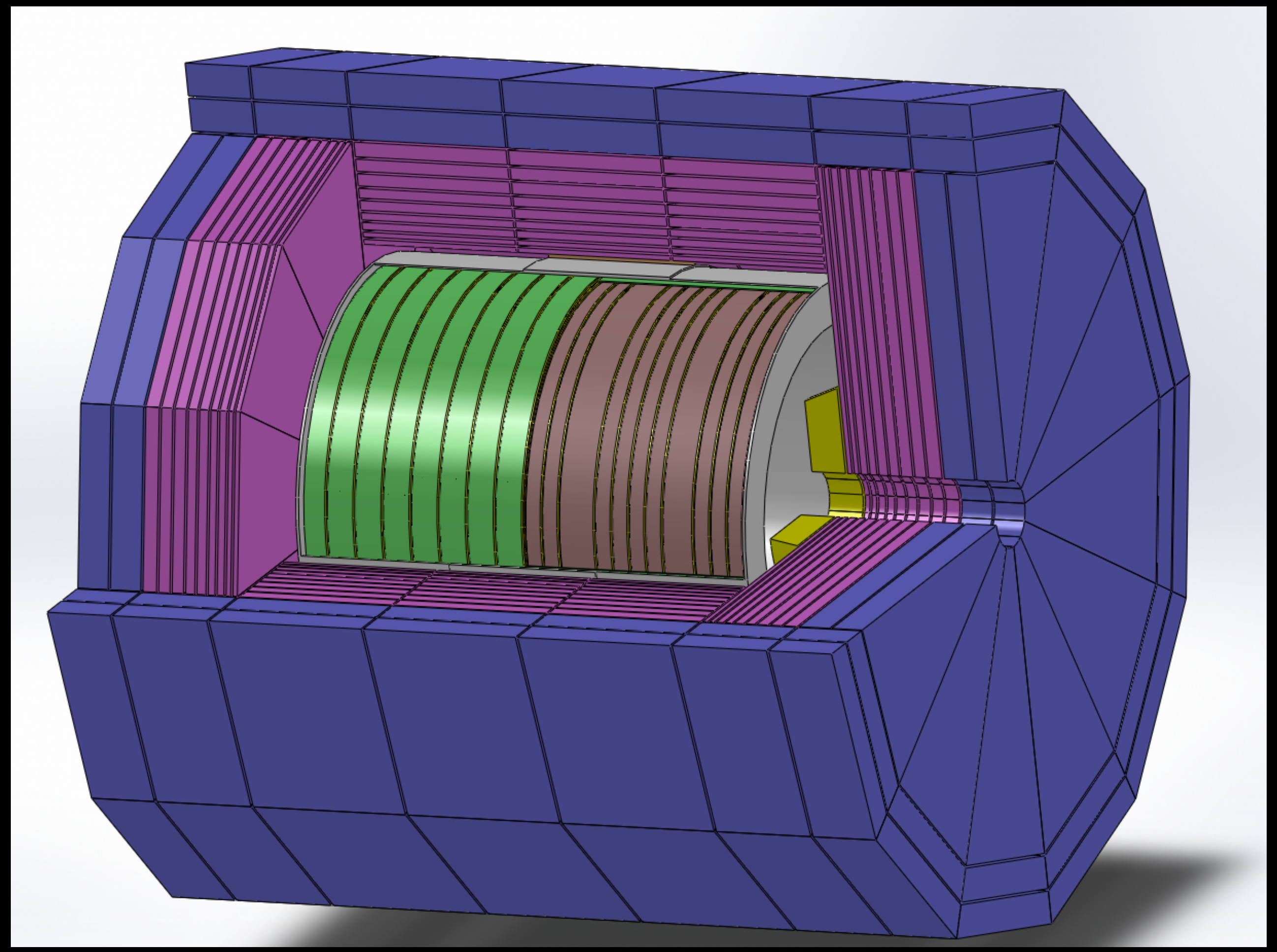
Energy resolution for electrons

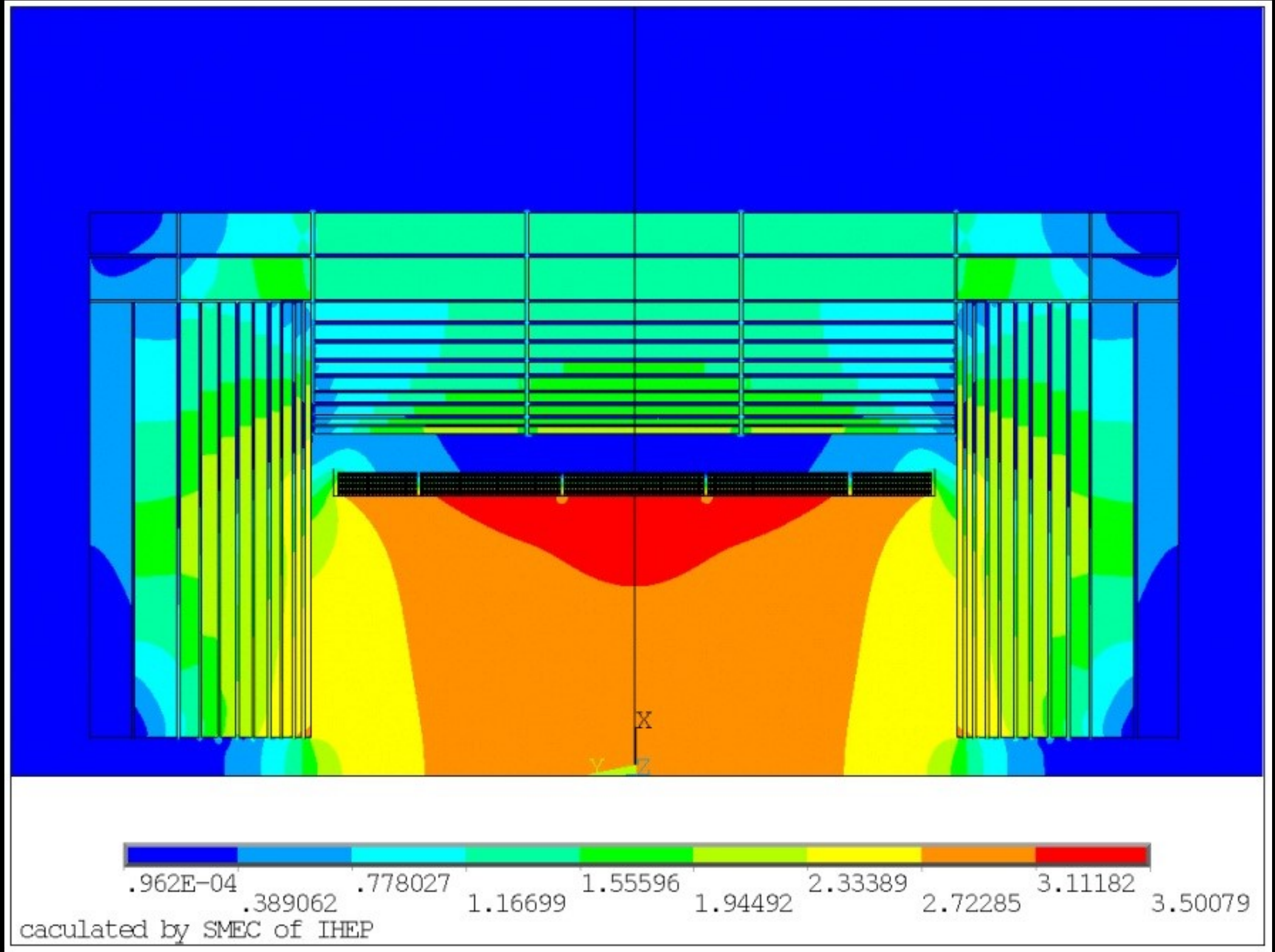


Superconductor solenoid development

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

Default: Iron Yoke



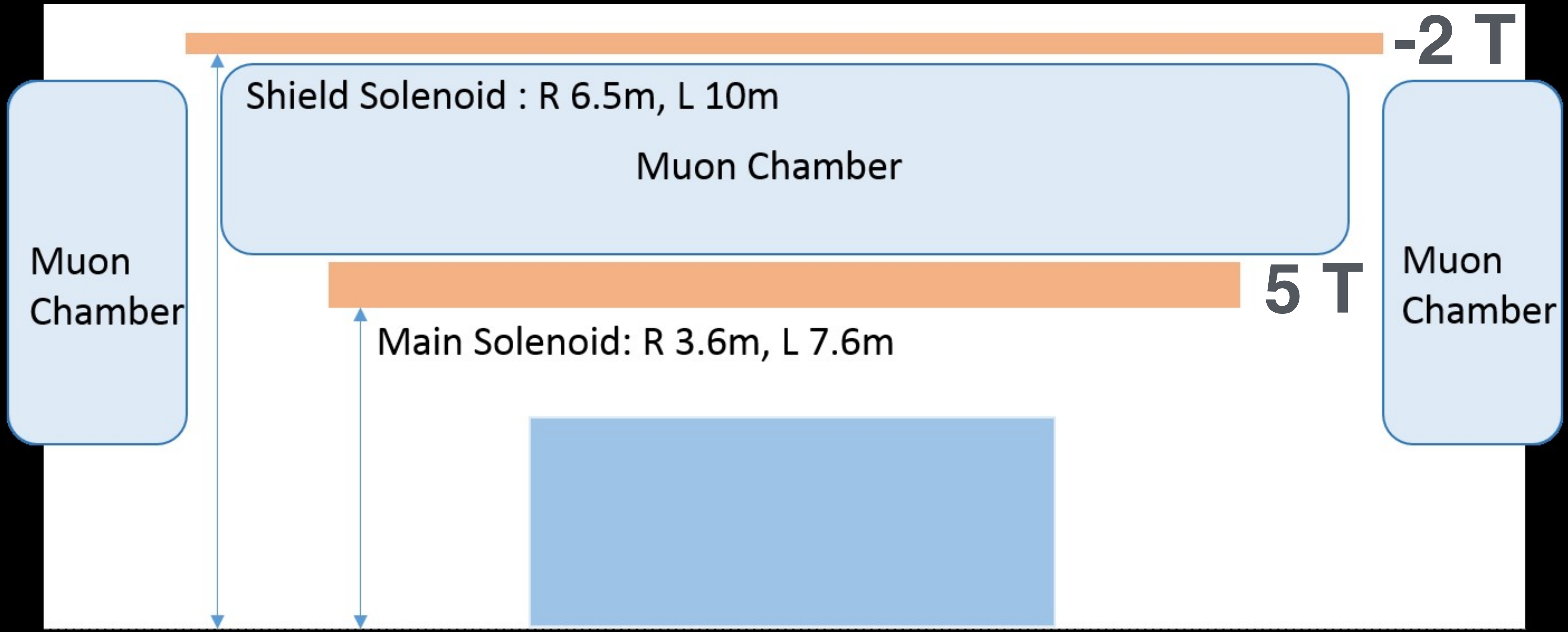


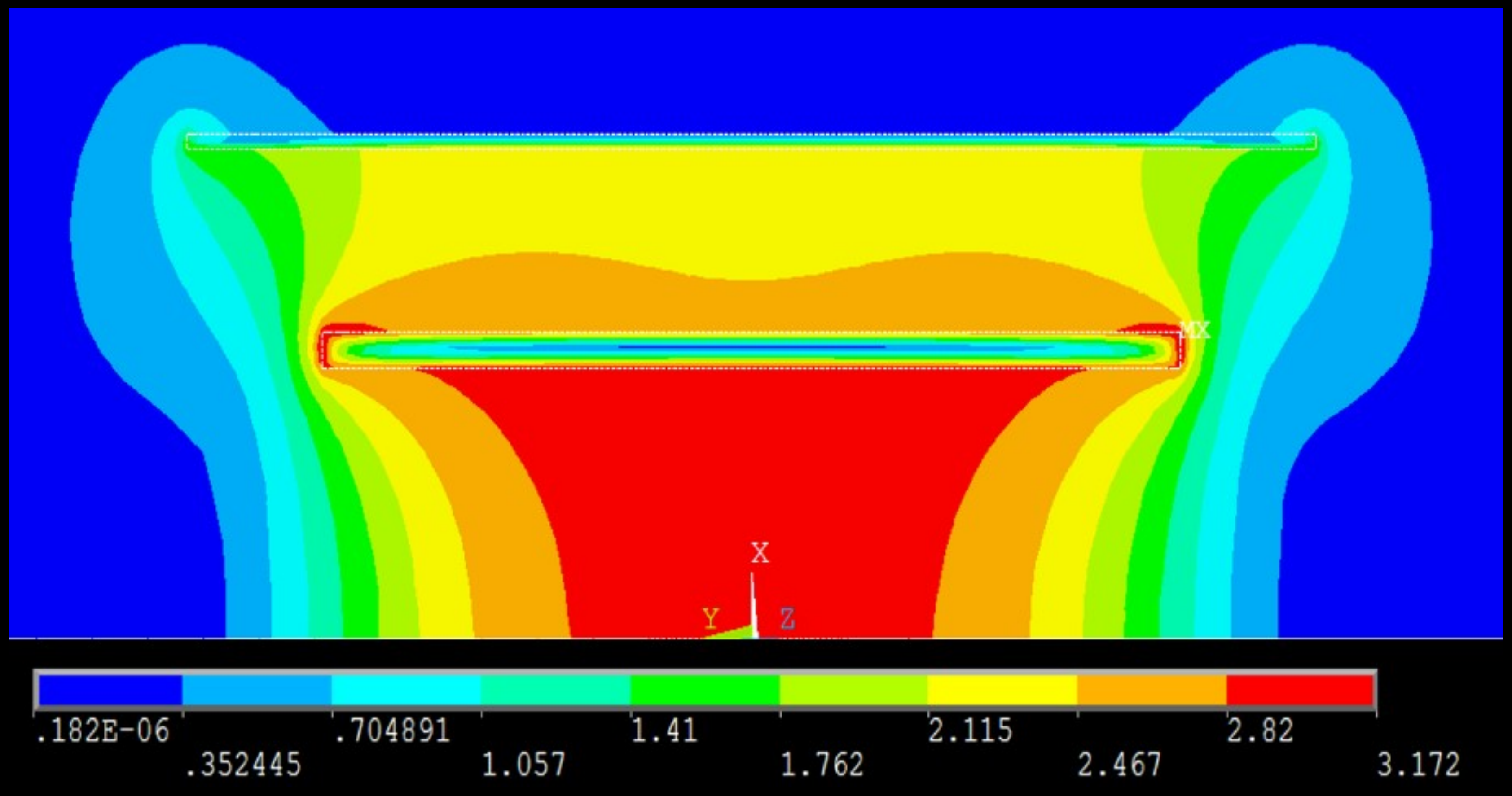
Non-uniformity	9.1%

Dual Solenoid Scenario

Lighter and more compact

Concept improved by FCC studies

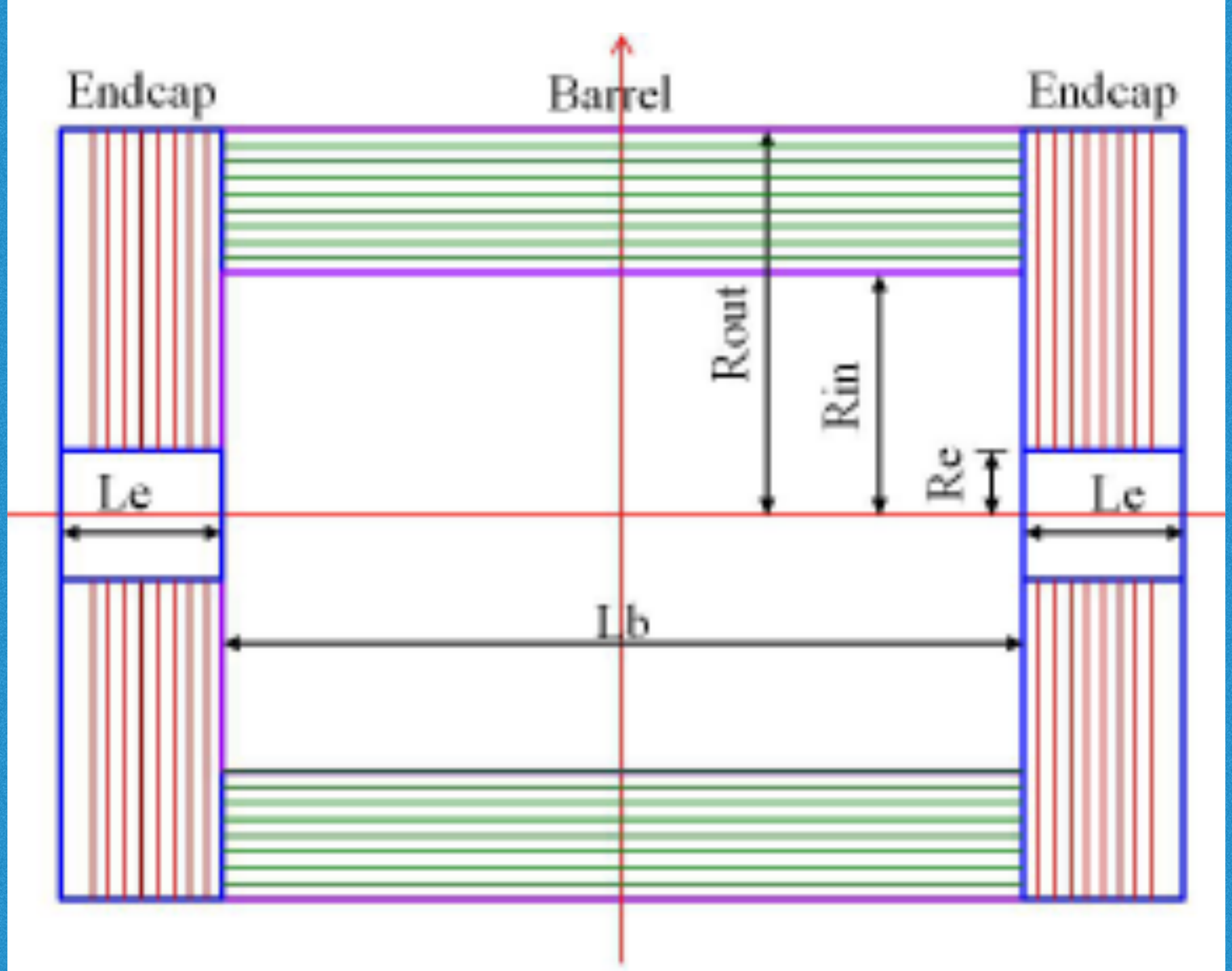




Muon detector

Baseline Muon detector

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

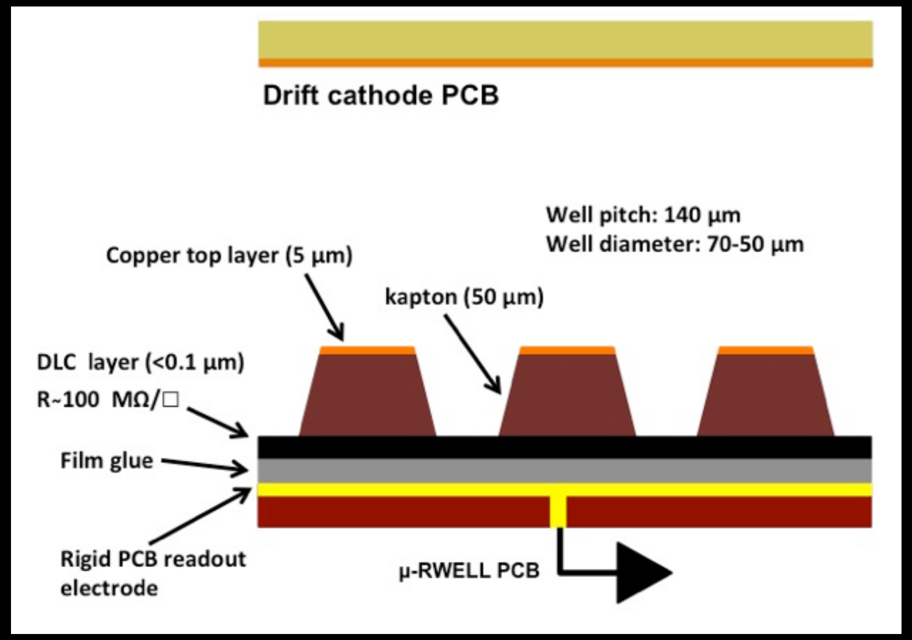


Technologies considered

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 $5 \times 5mm^2$
  - 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%.

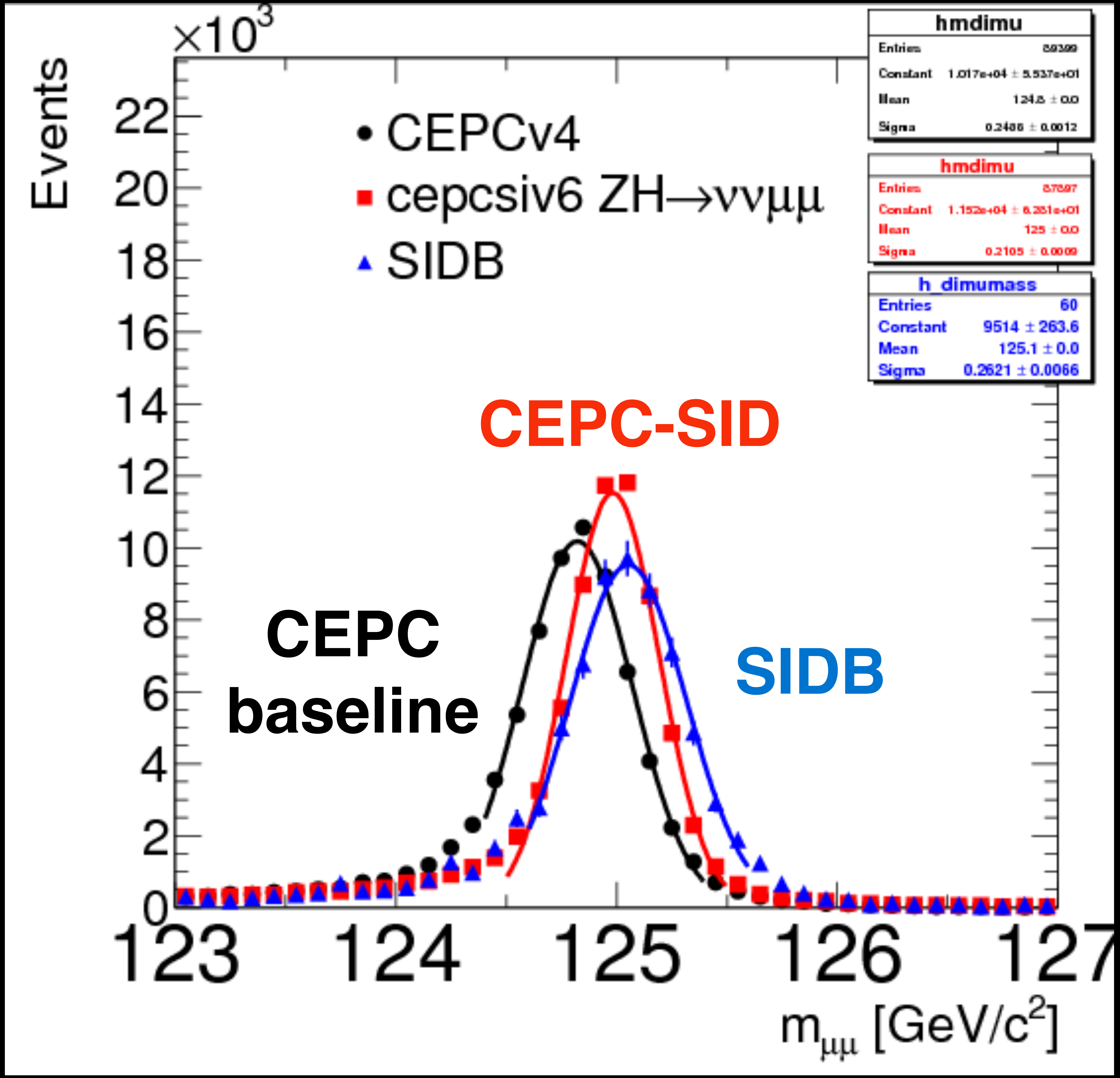
Ministry of Science and Technology – Funding 1

- 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



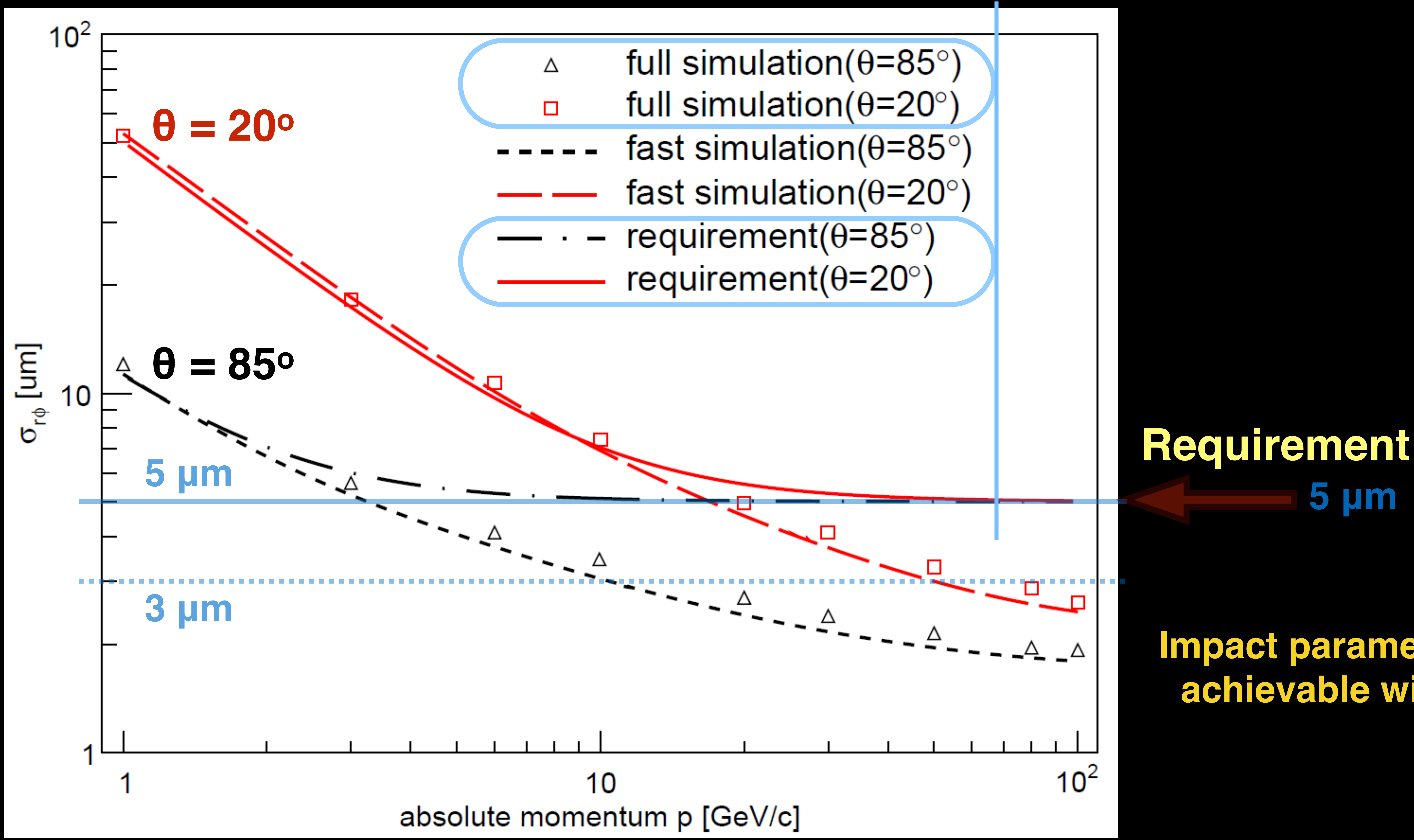
CEPC-SID: σ = 0.21 GeV

SIDB: σ = 0.26 GeV

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

Performance studies: Impact parameter resolution

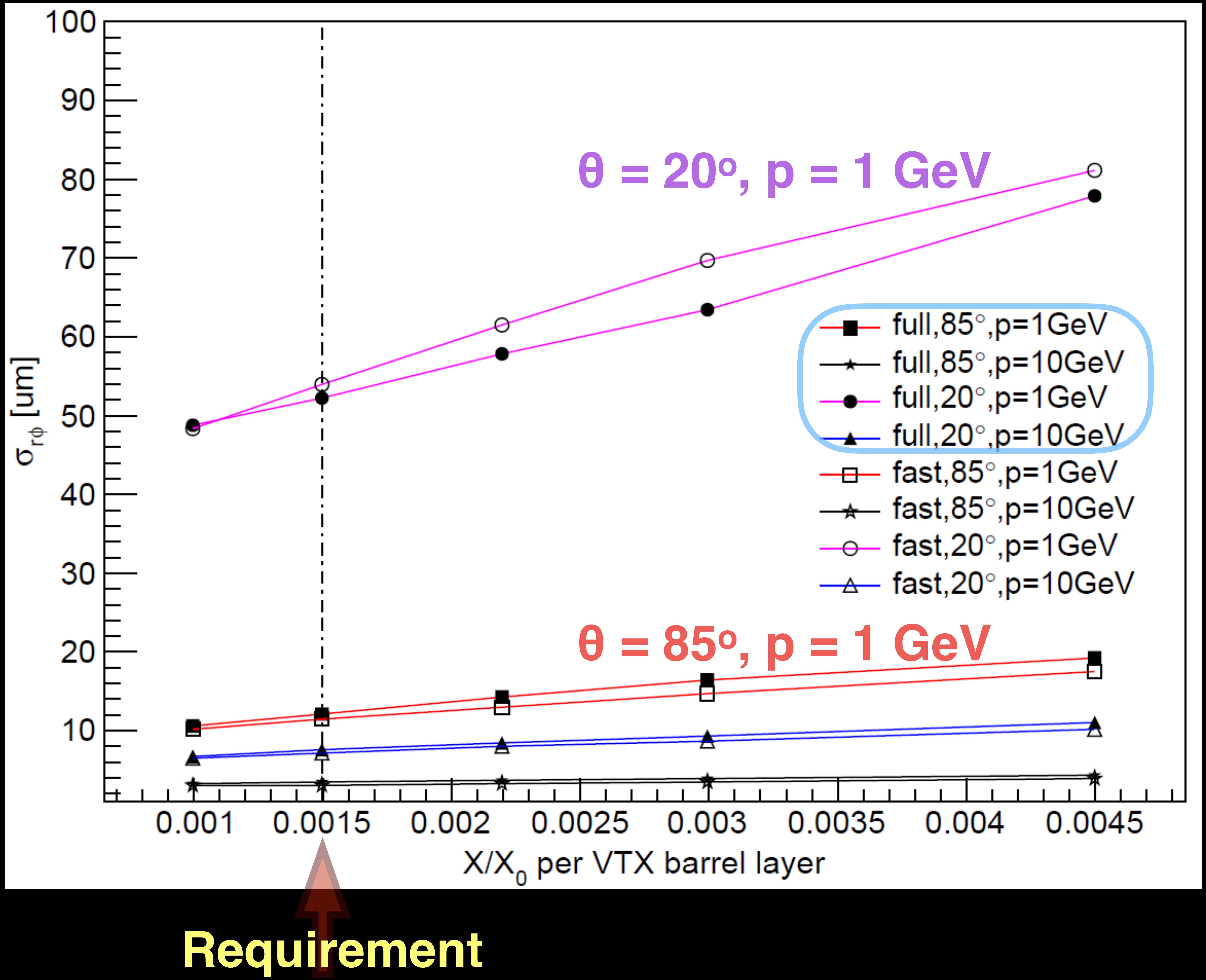
Transverse impact parameter resolution for single muons



Impact parameter resolution goal achievable with current design

Performance studies: Material budget

Transverse impact parameter resolution for single muons



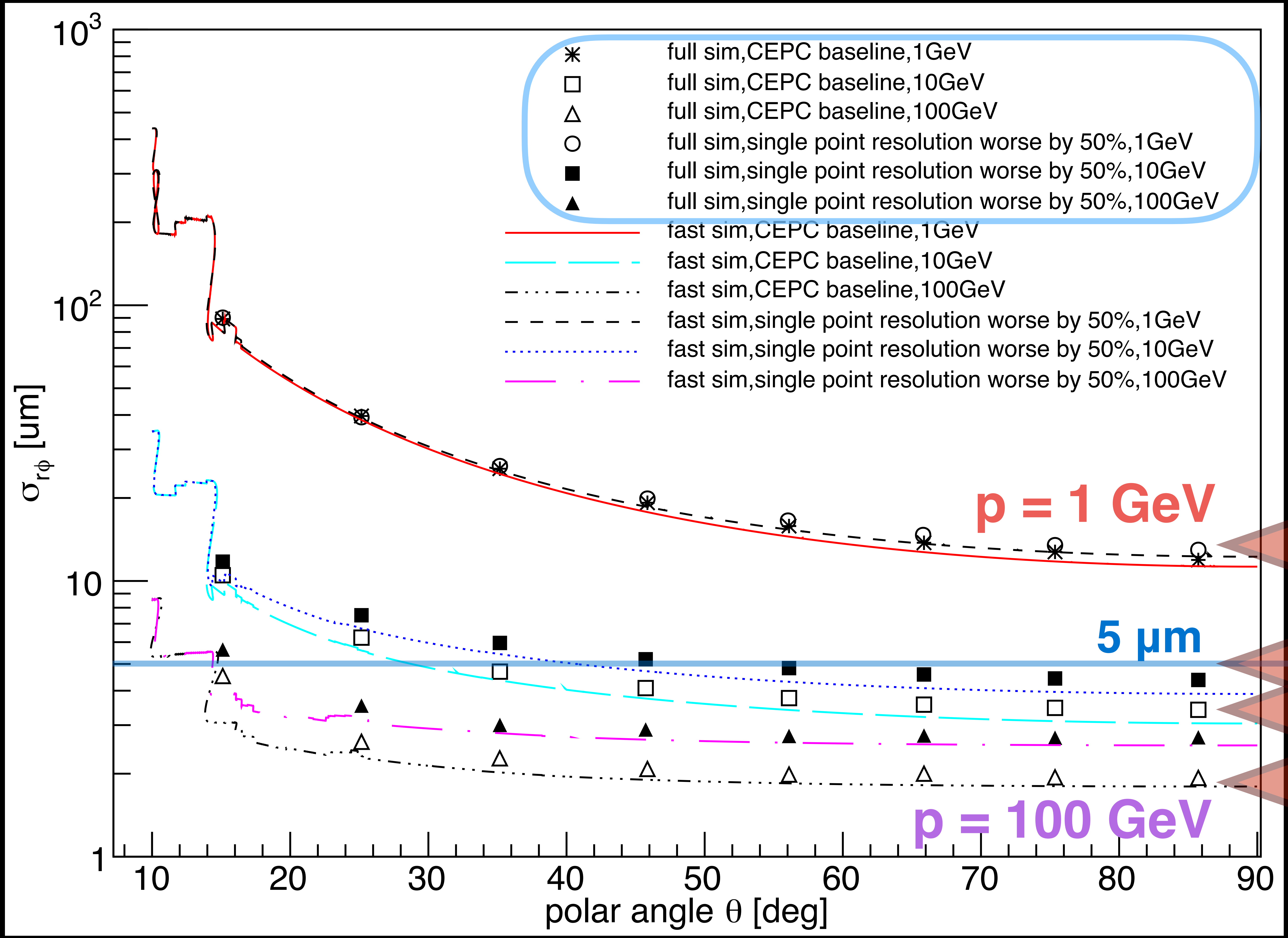
Baseline includes very small material budget for beam pipe, sensor layers and supports $\leq 0.15\% X_0$

× 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)

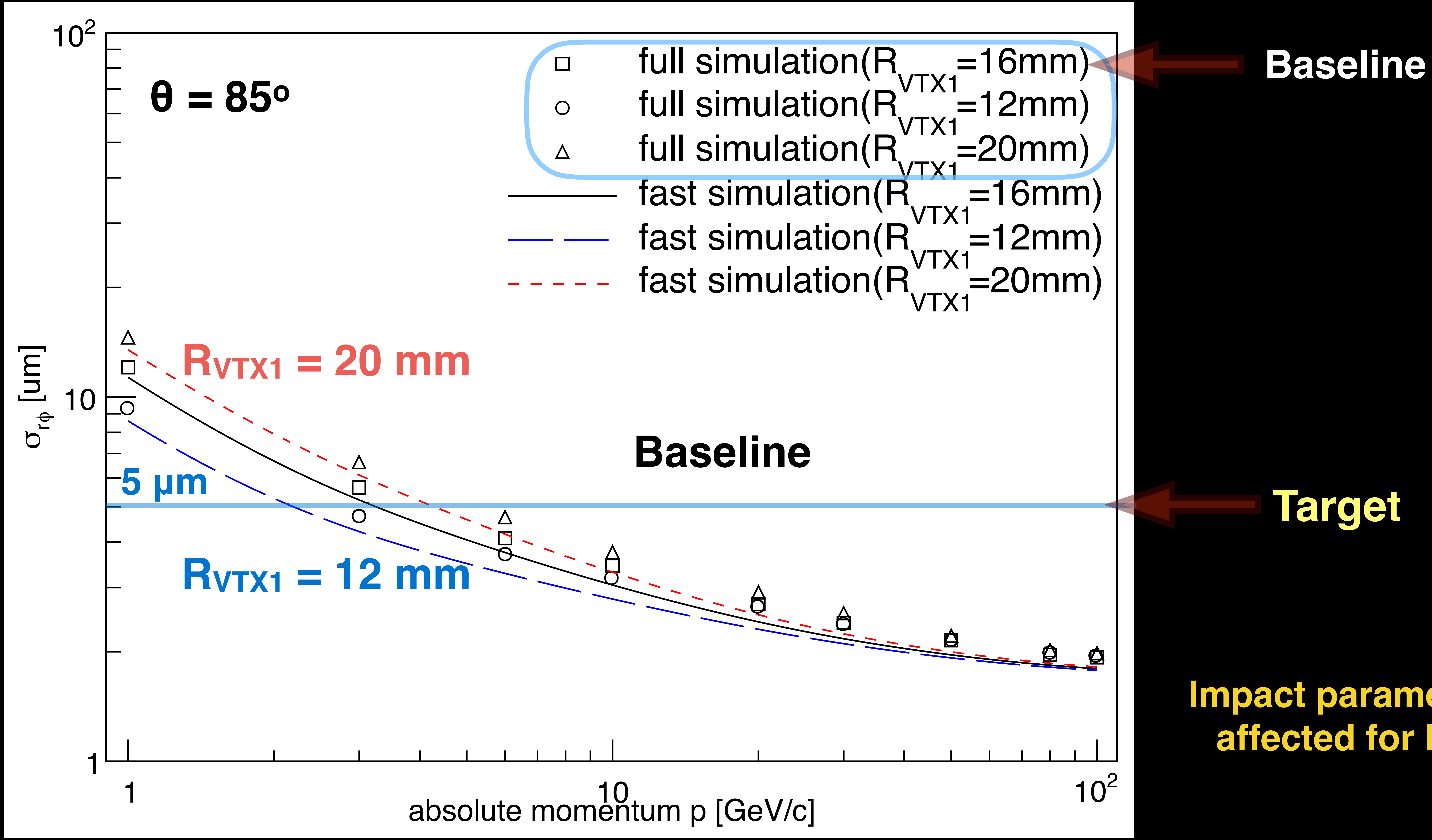
Target

Baseline p = 10 GeV

Baseline p = 100 GeV

Performance studies: Distance to IP

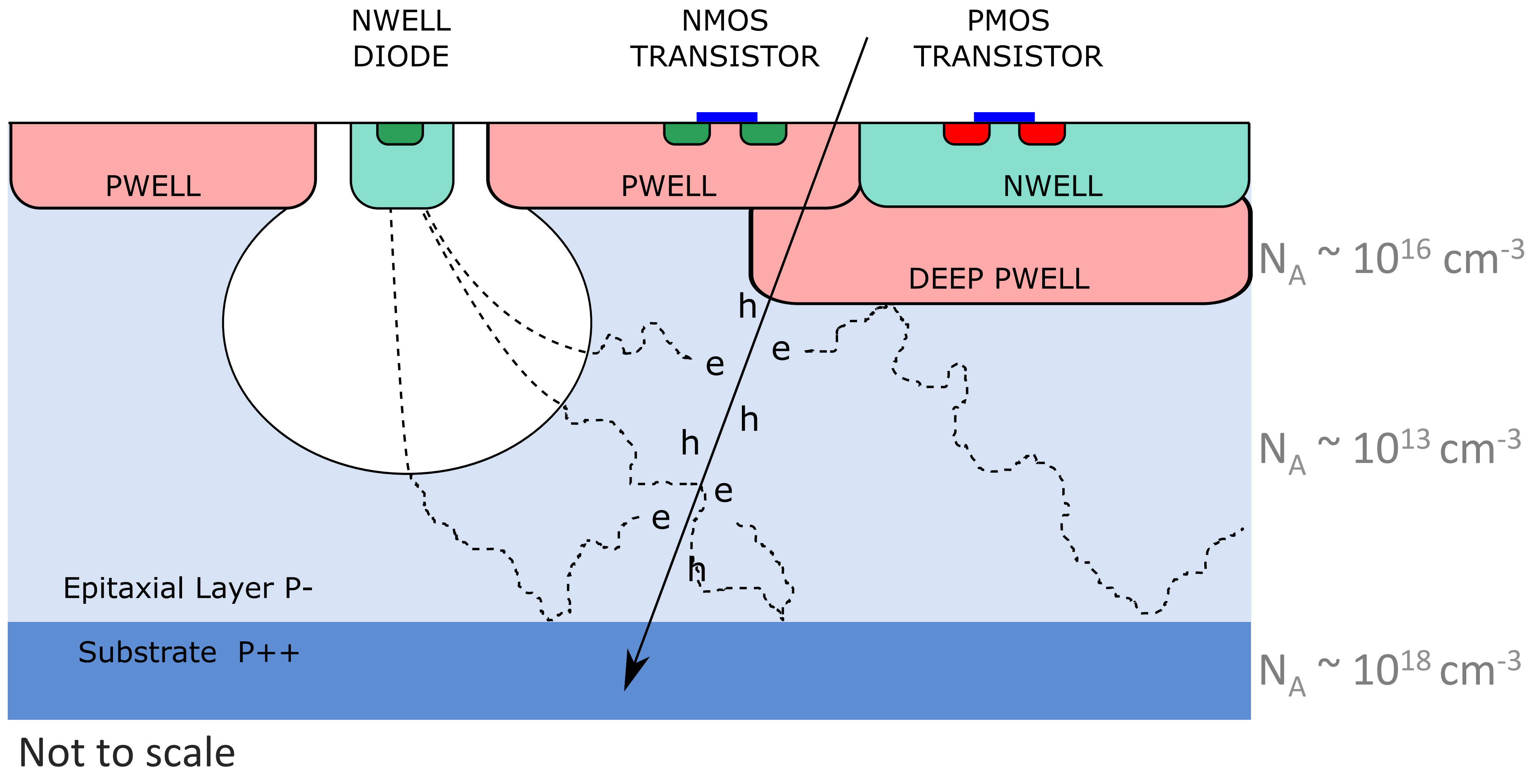
Transverse impact parameter resolution for single muons

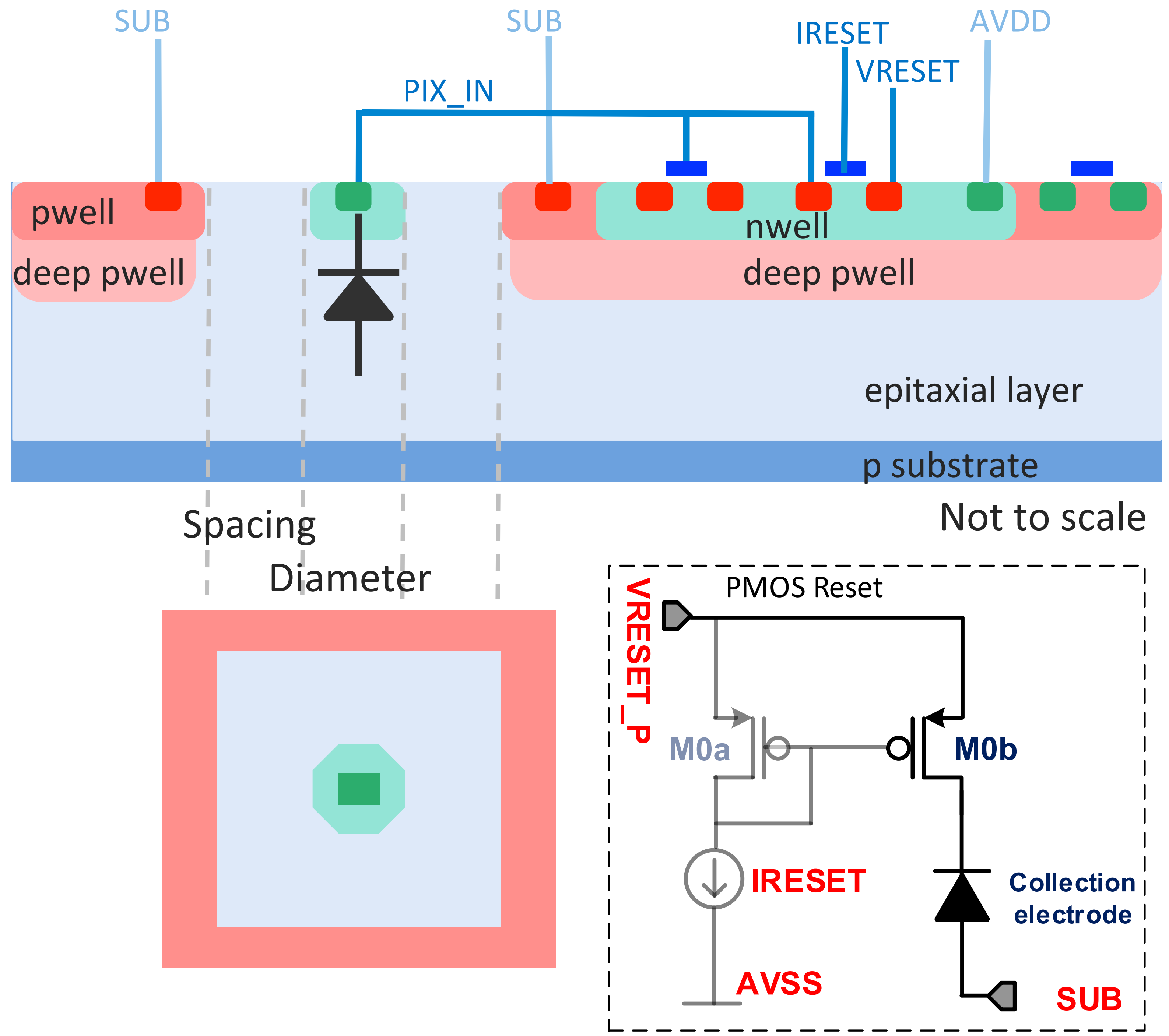


Impact parameter resolution affected for low-pt tracks

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

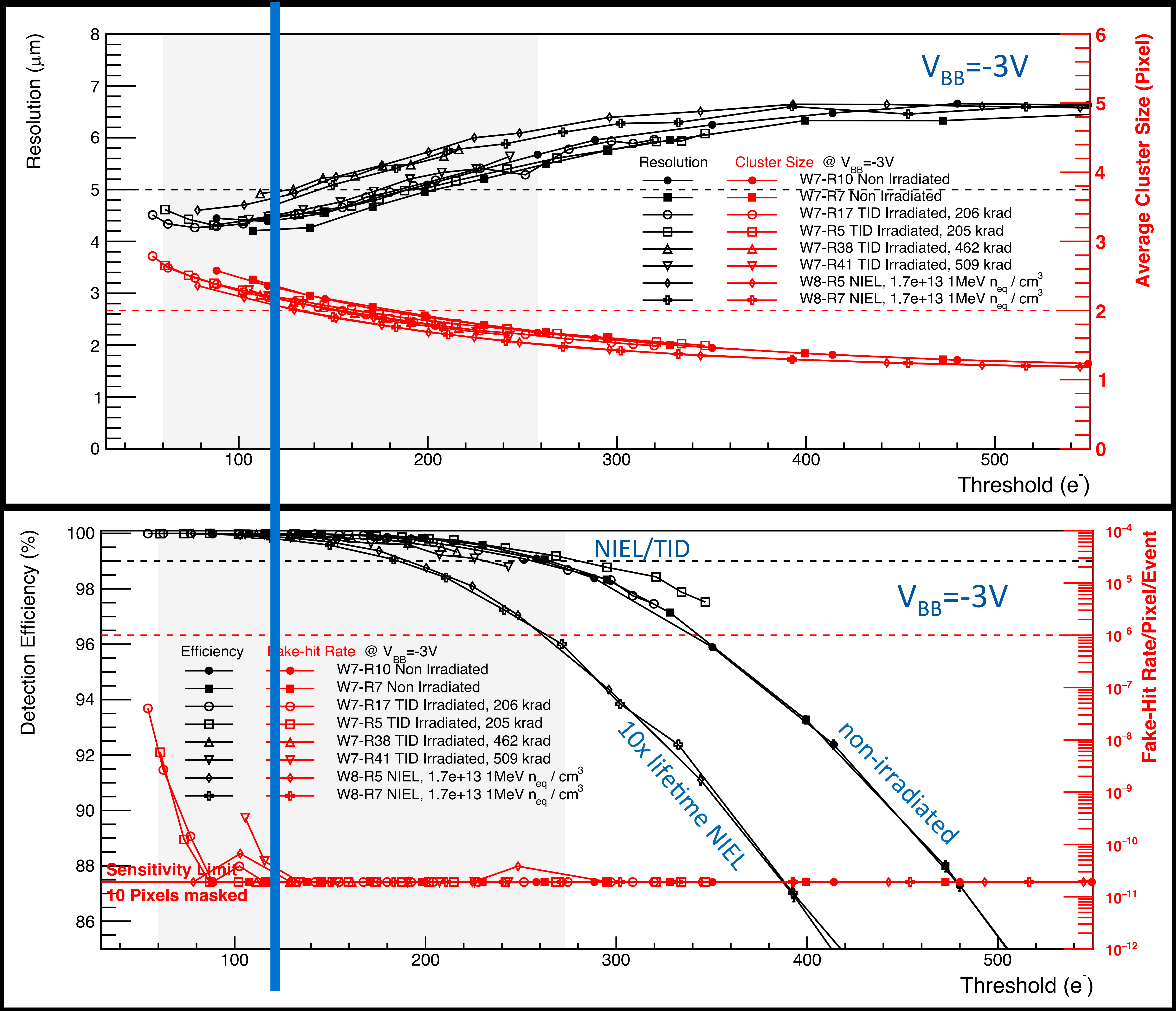
ALPIDE CMOS Pixel Sensor

	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

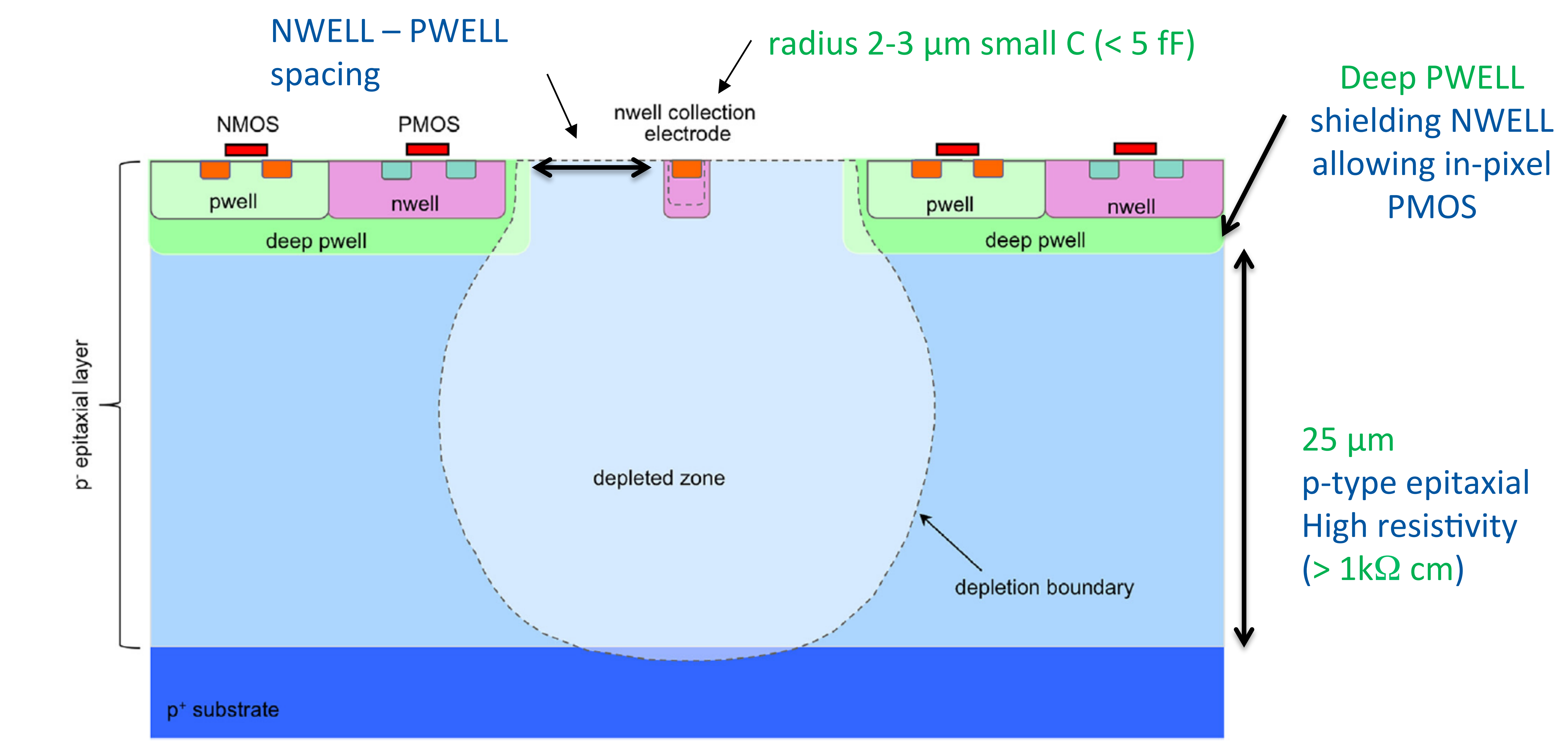
Need lower resolution

Higer radiation tolerance



ATLAS Modified TowerJazz process

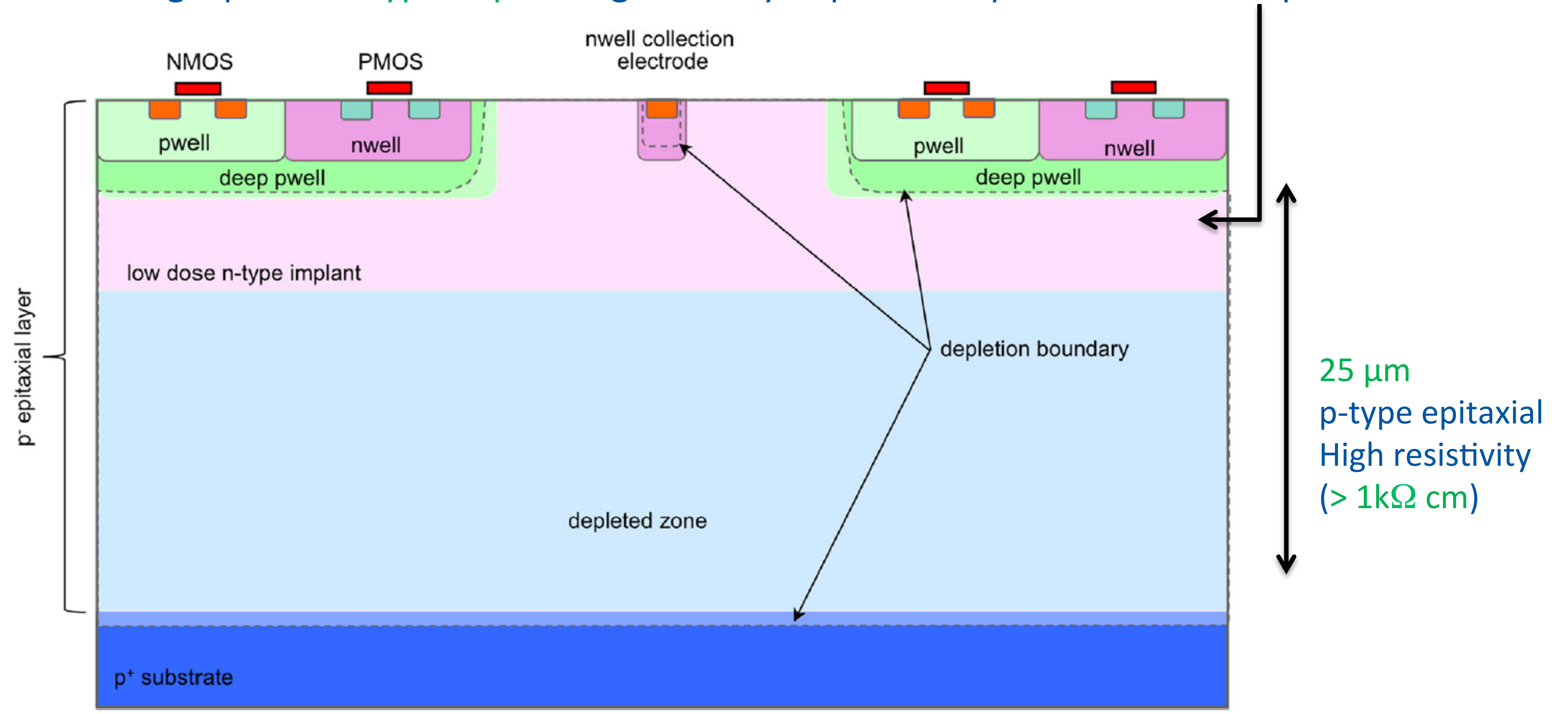
Standard process



- 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



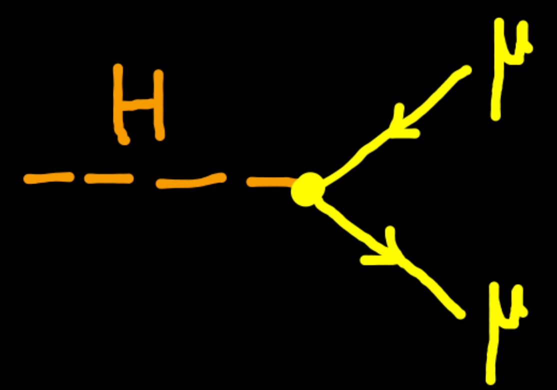
- Possibility to fully deplete sensing volume
- No significant circuit or layout changes required

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

Irradiation tests: $1\times10^{15}\ n_{eq}/cm^2$

Improvement of radiation tolerance by at least one order of magnitude

Optimization of TPC radius and B-field



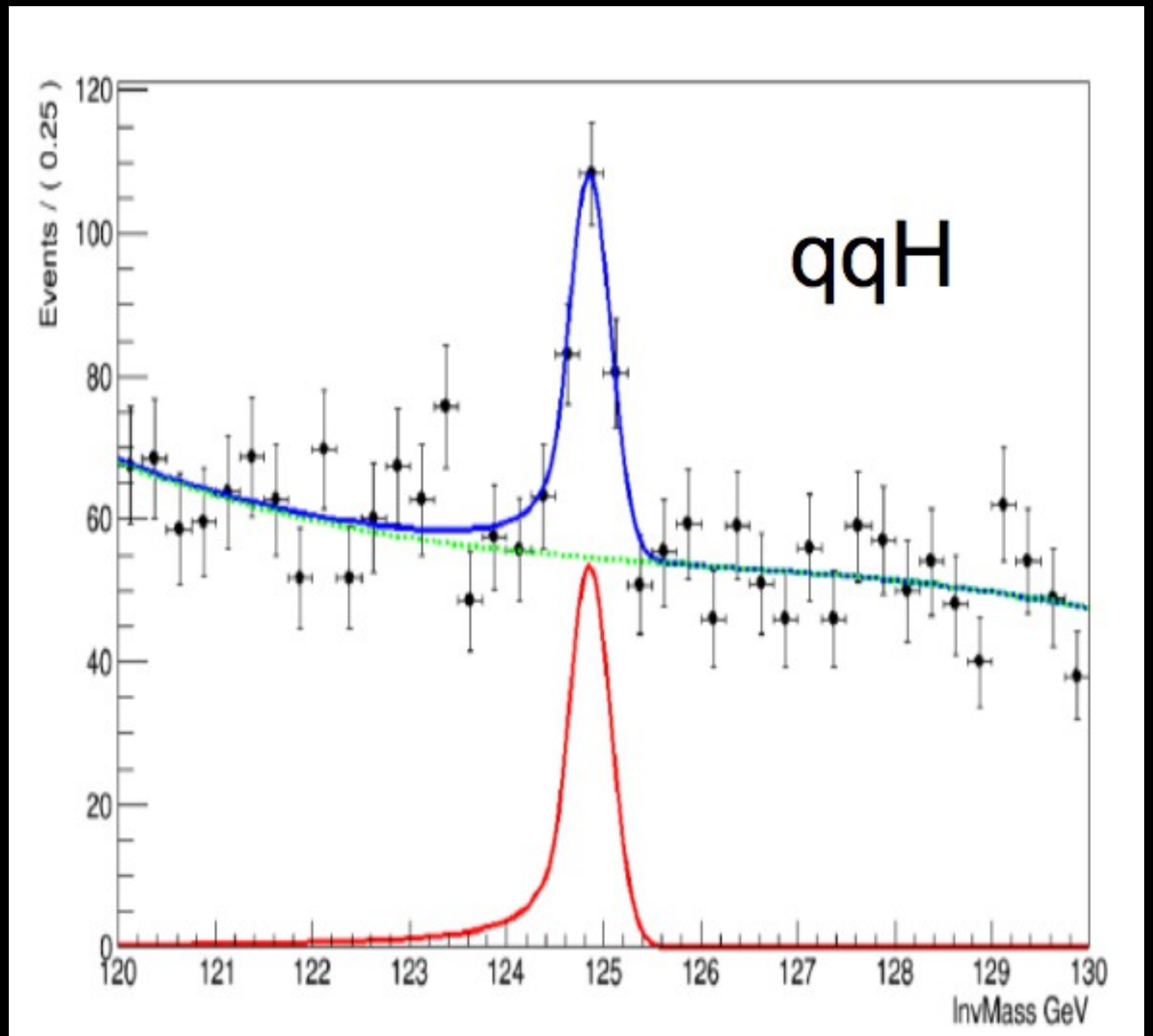
BR(H→μμ) measurement

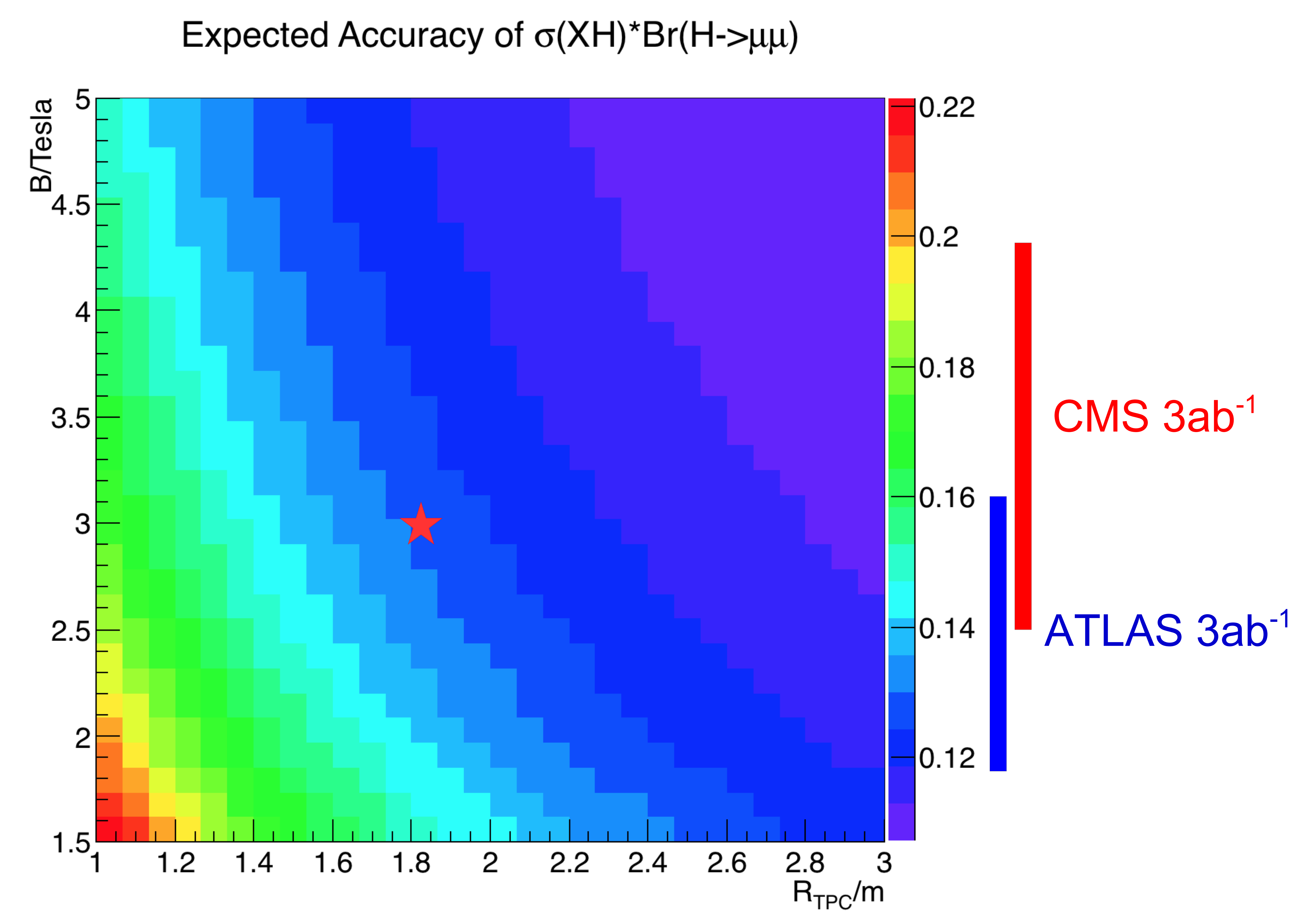
Detector cost sensitive to tracker radius, however:

- **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*

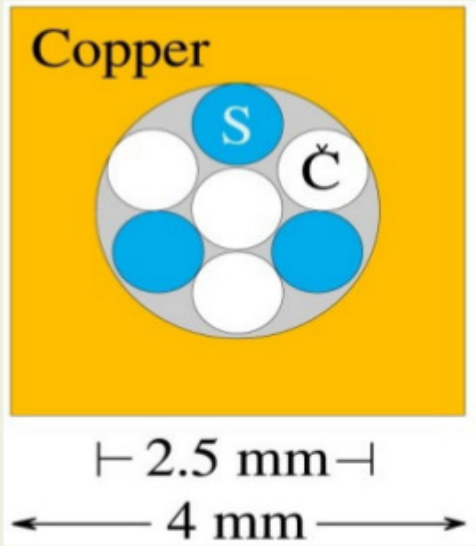
Dual Readout Calorimeter

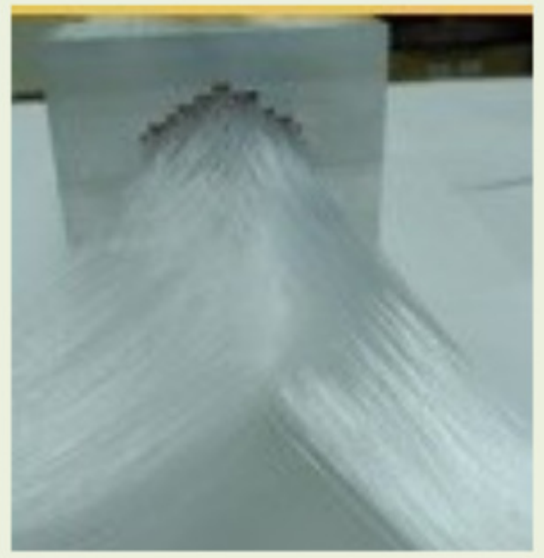
Hauptman, Santoro, Ferrari
Tomorrow, 11:30, 12:00, 12:30 am

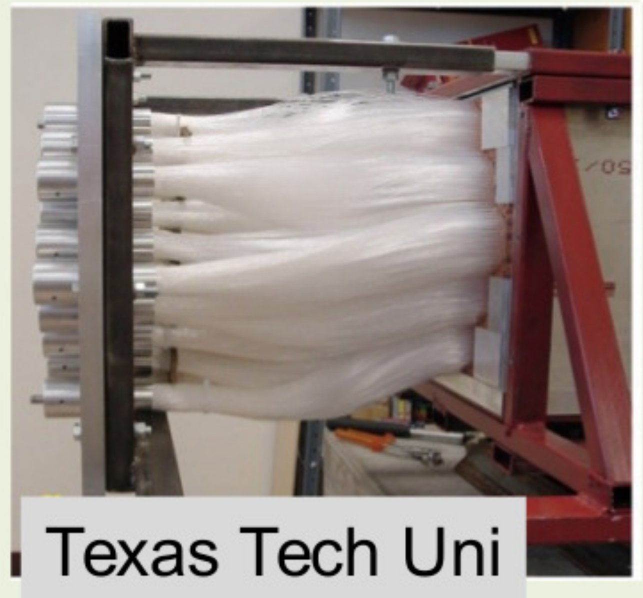
Lead by Italian colleagues: based on the DREAM/RD52 collaboration

2003 DREAM

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



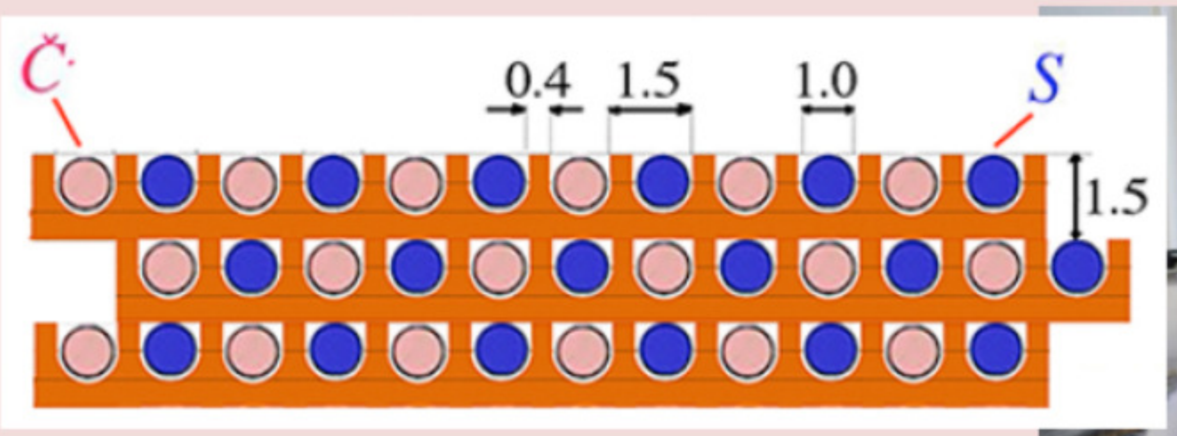




2012 RD52

Copper, 2 modules

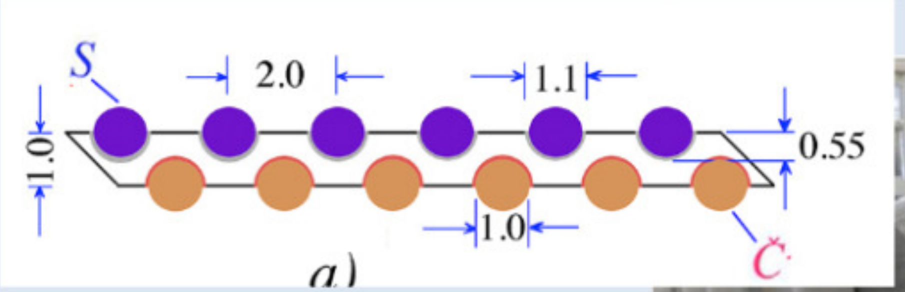
Each module: 9.3 * 9.3 * 250 cm^3
Fibers: 1024 S + 1024 C, 8 PMT
Sampling fraction: 4.5%, 10 λ_{int}

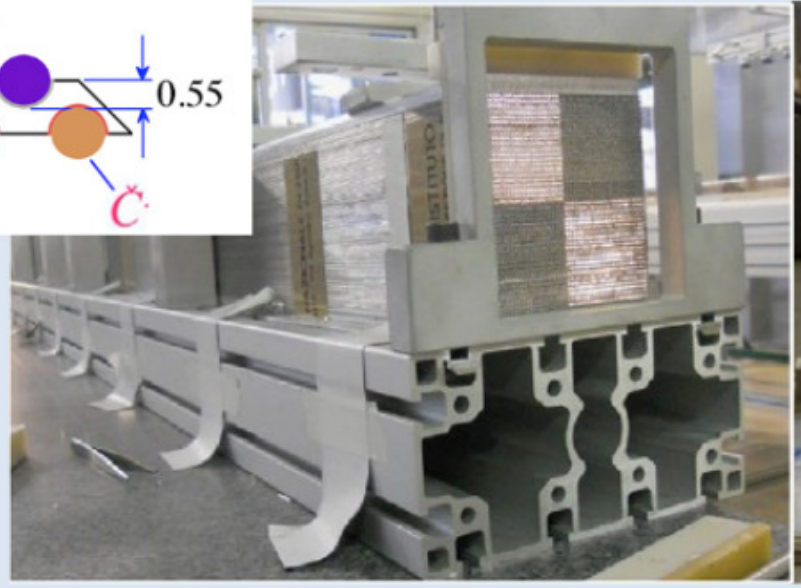


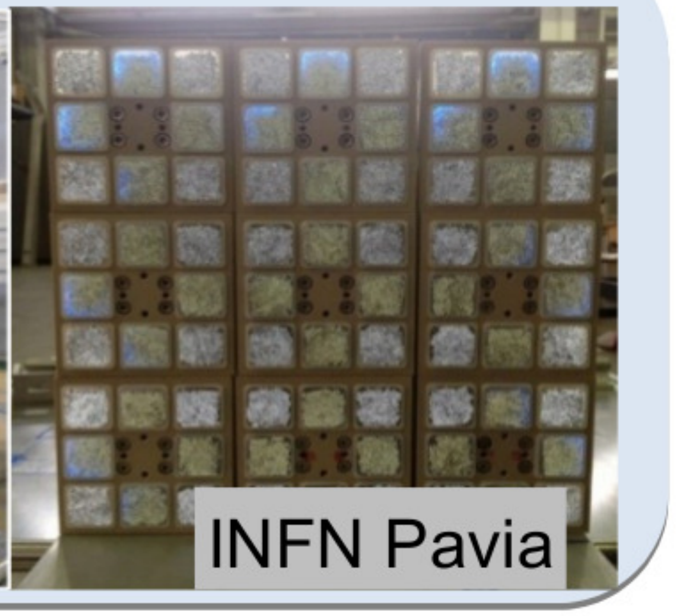
2012 RD52

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}

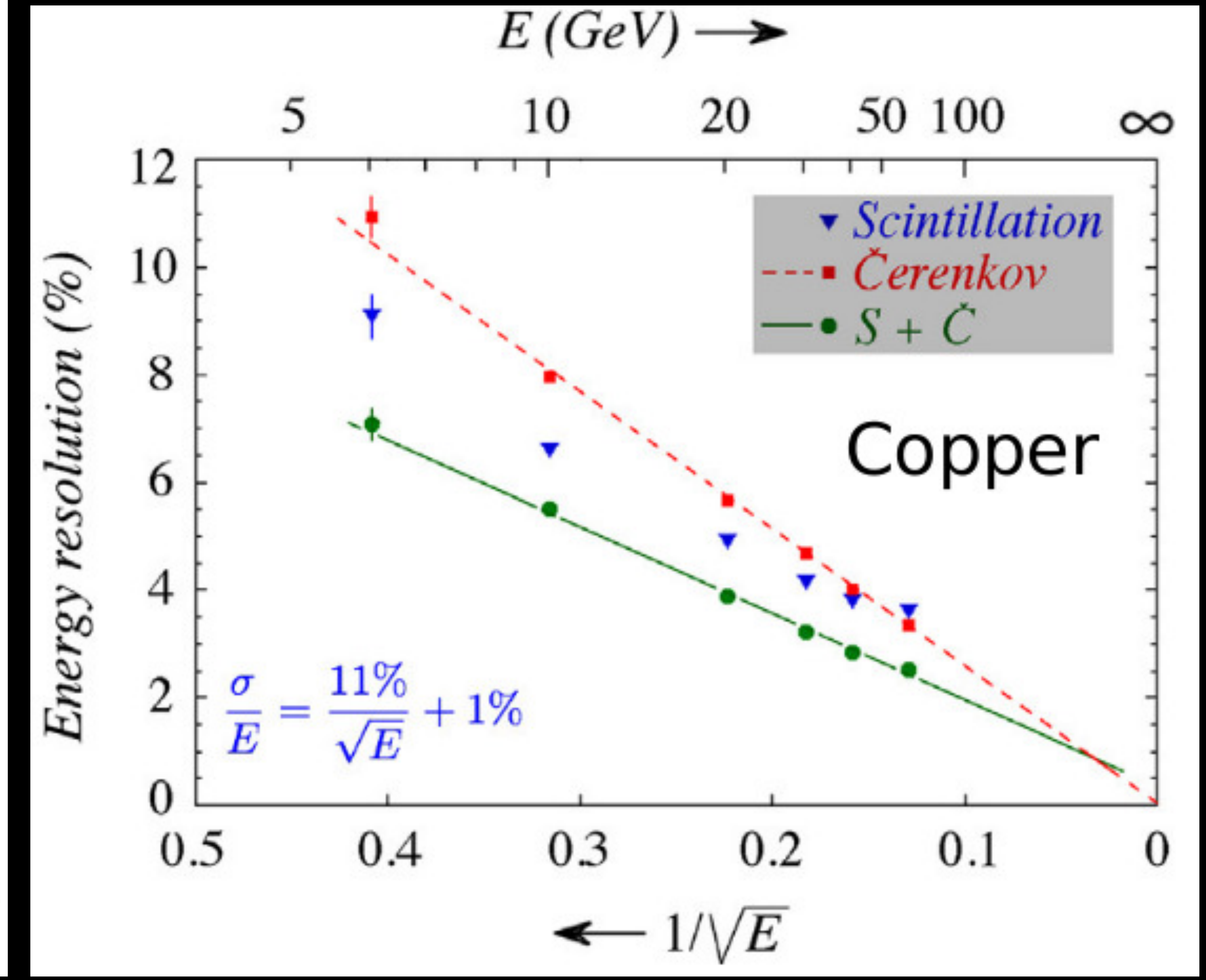






Expected resolution:
Electrons: 10.5%/sqrt(E)
Isolated pions: 35%/sqrt(E)

Energy resolution for electrons



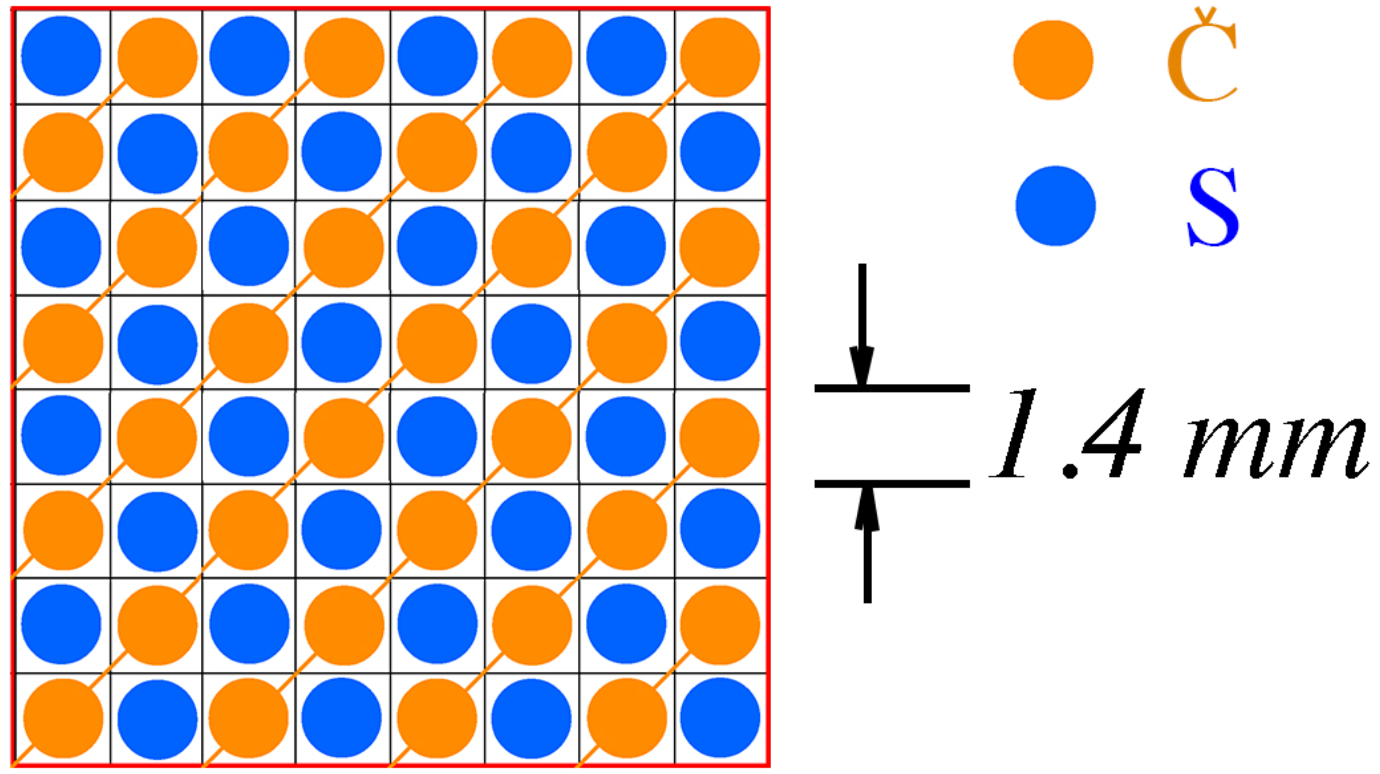
Dual Readout Calorimeter

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

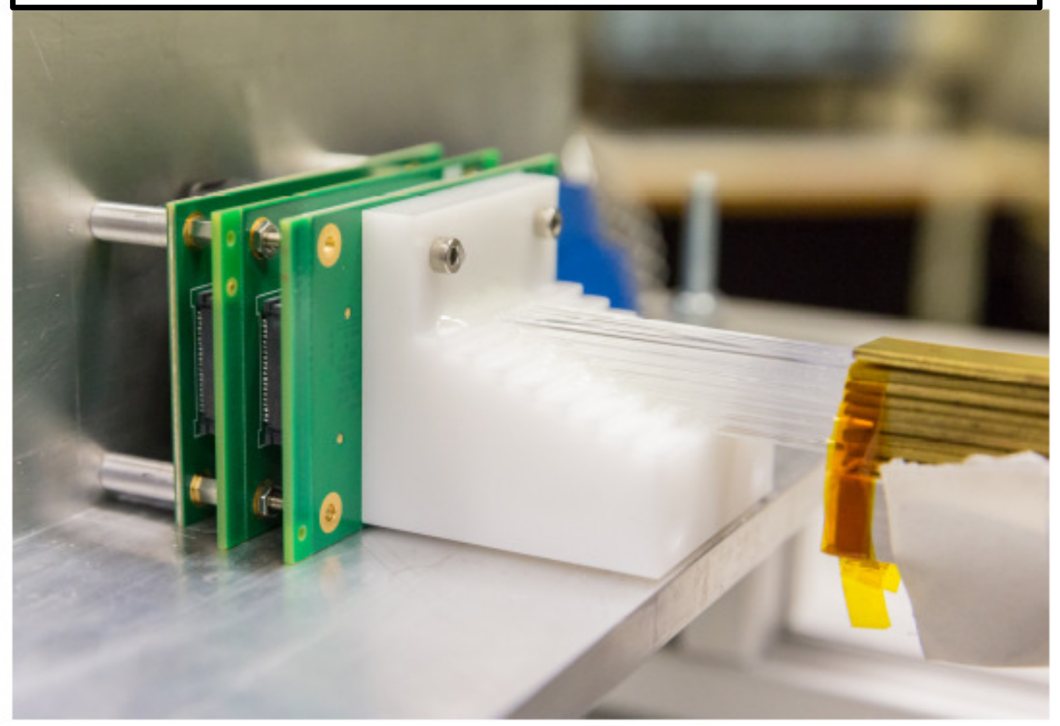
Lead by Italian colleagues

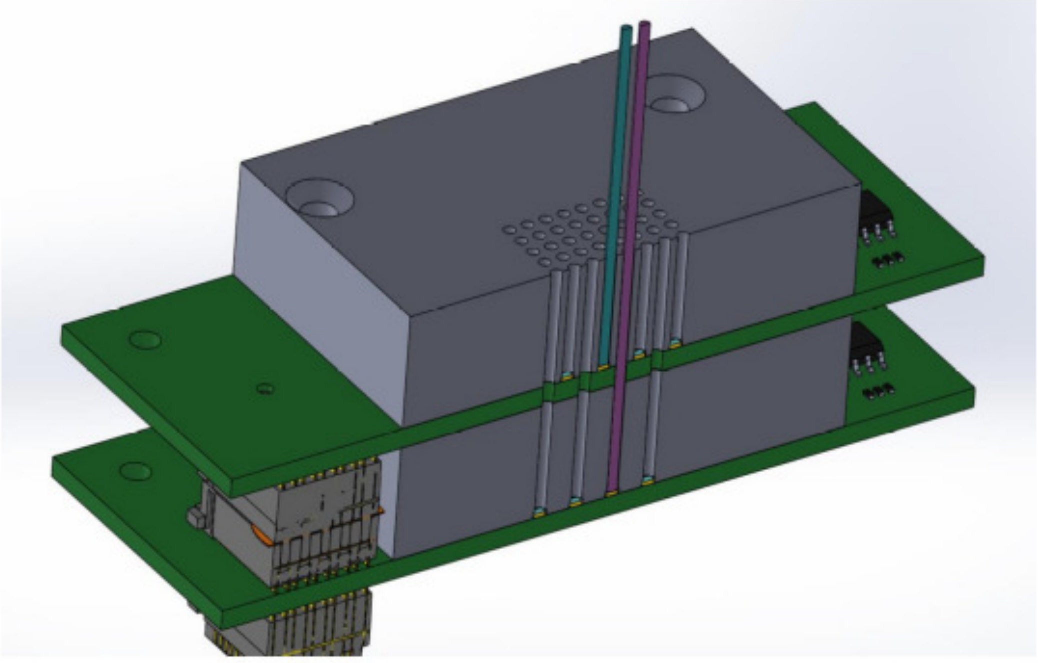
Brass module, dimensions: ~ 112 cm long, 12 x 12 mm²

section



Back





Experimental setup

Trigger : $(T_1 \cdot T_2 \cdot \overline{T_H})$