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高能环形正负电子对撞机(CEPC)近期进展

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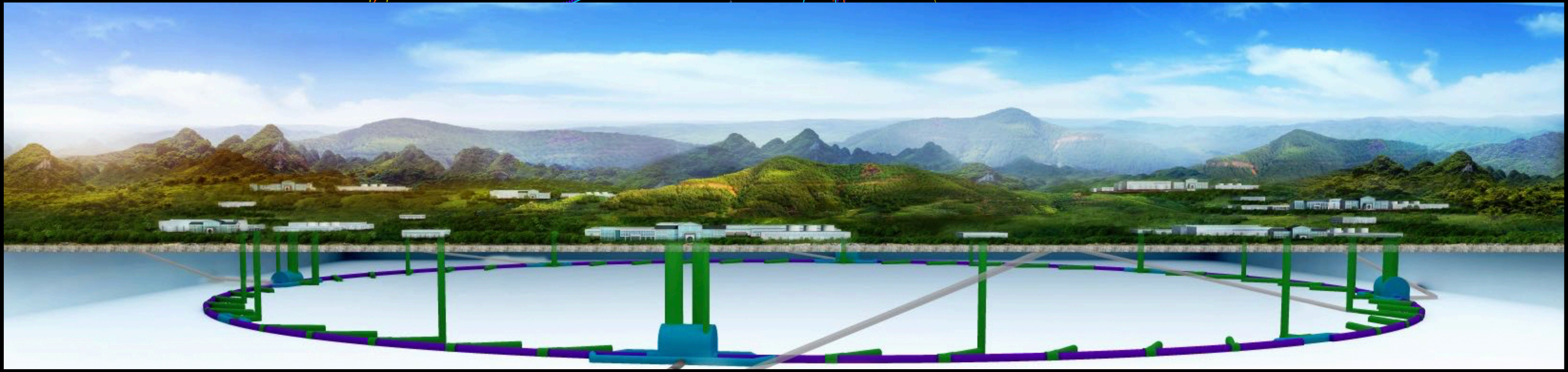
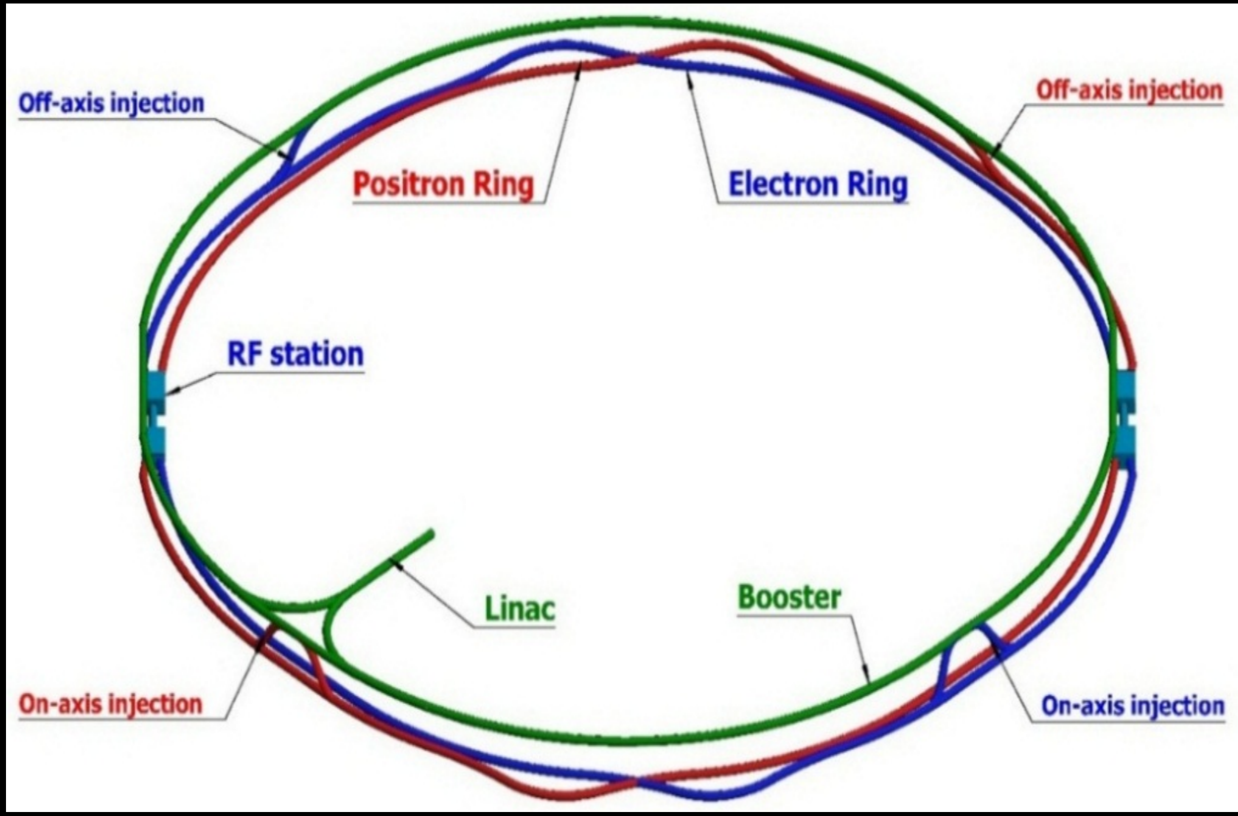
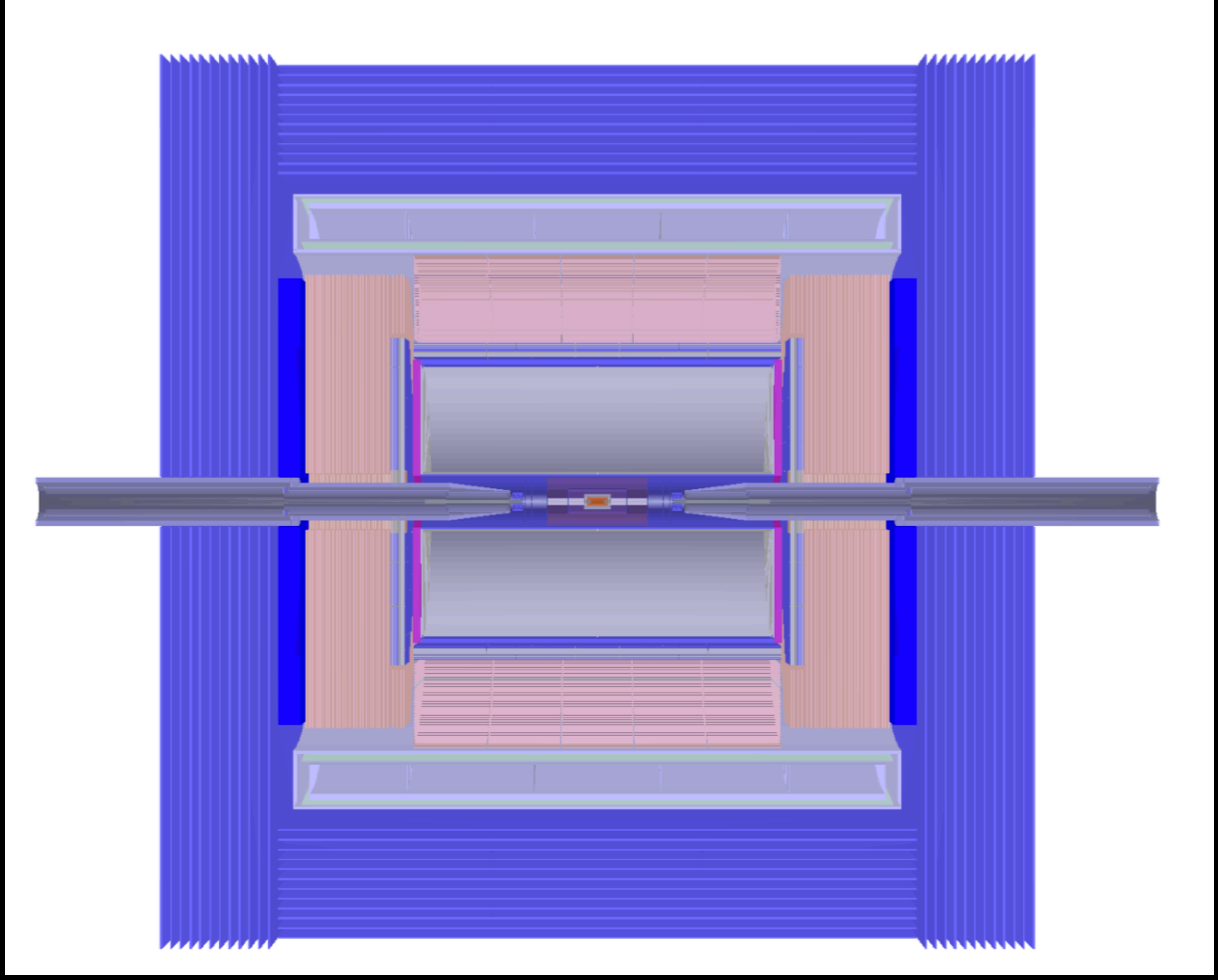


Outline

- Brief introduction
- Status and progresses
- Summary





What is CEPC?

希格斯粒子于2012年在 LHC 上被发现

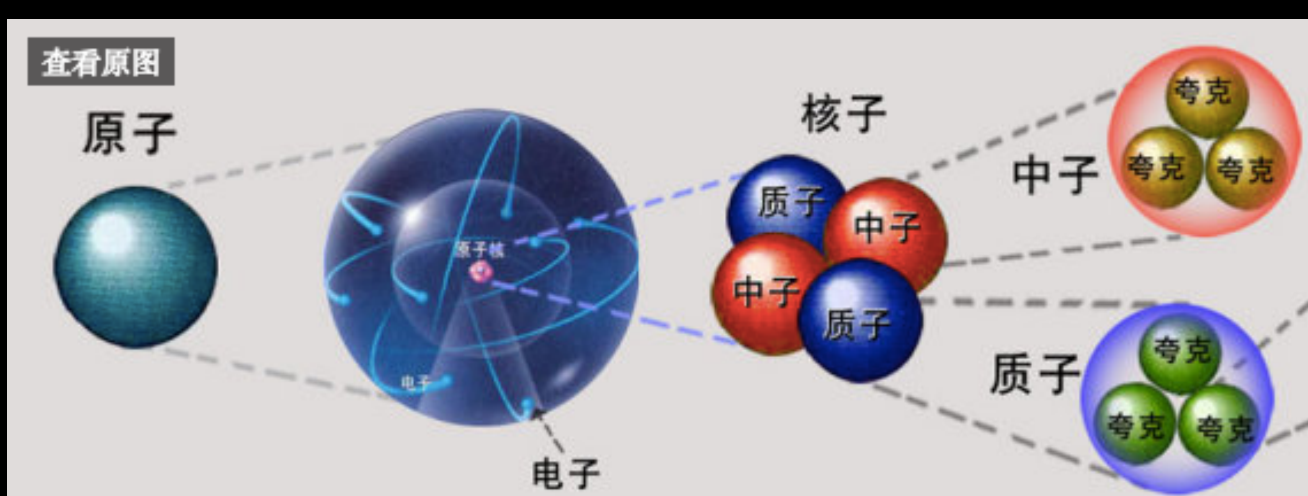
M_H ~ 125 GeV —— 环形对撞机的机遇

希格斯粒子的质量具有重要意义

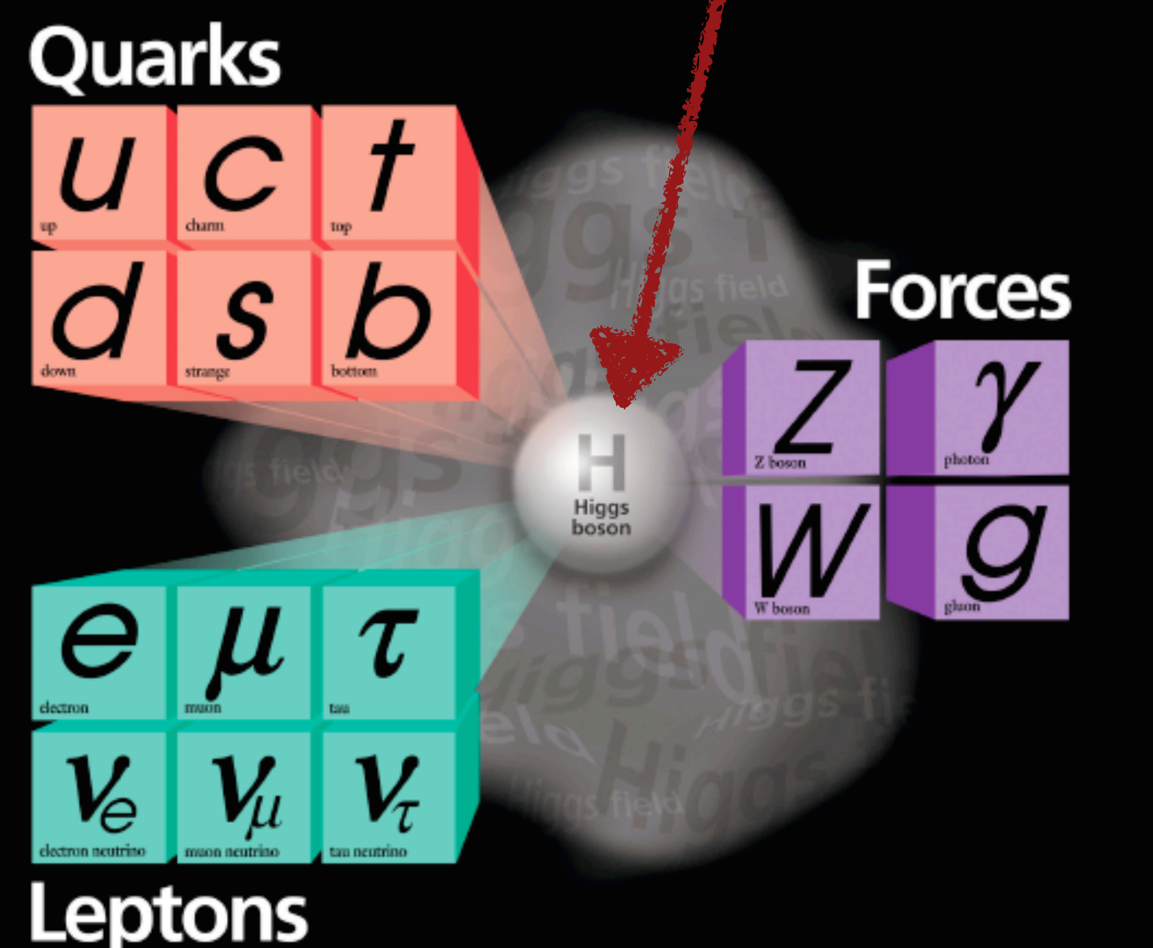
希格斯粒子是基本粒子的质量来源，couplings

希格斯粒子是寻找新物理的一个新窗口和新工具

如何寻找新物理?

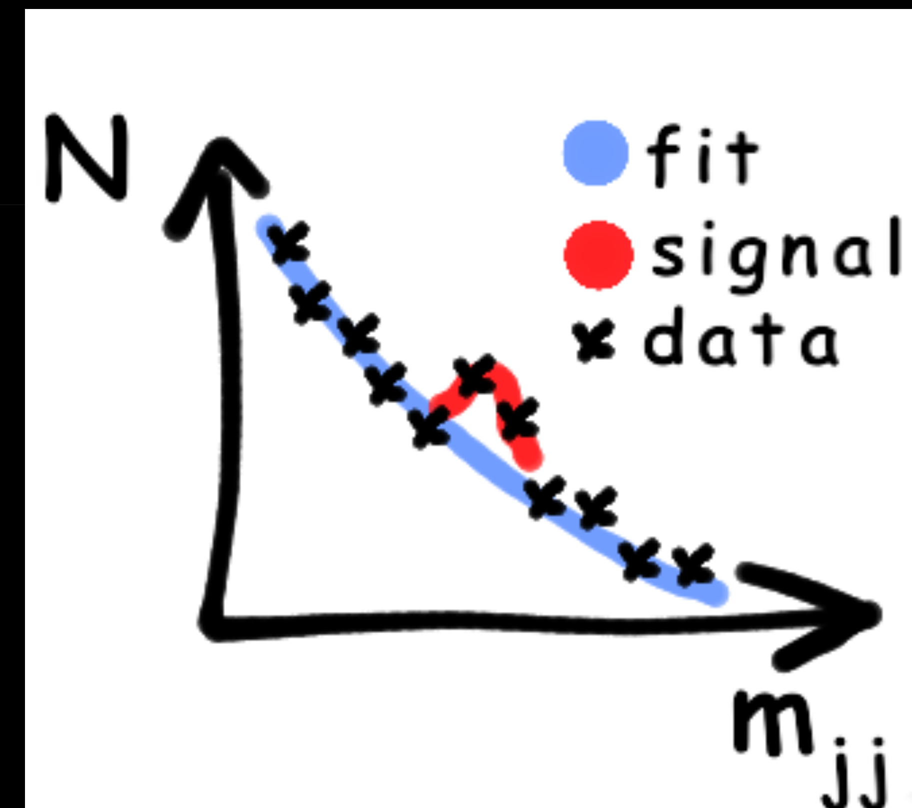


希格斯粒子

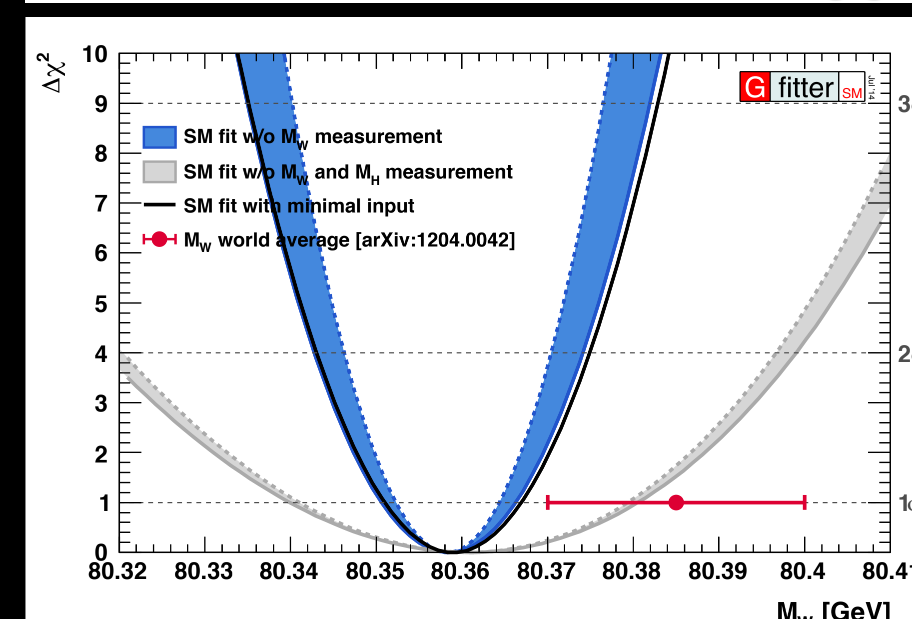


Two ways to go beyond SM
Precision measurements and direct searches

- Direct searches:
  - Based on a theory hypothesis, looking for excesses in the mass spectrum.
  - E.g. resonance searches



- Indirect searches, precision measurements:
  - Precisely measure SM parameters, compare with predictions, looking for differences.
  - The differences can come from something new
  - E.g. W boson mass measurements



高能环形正负电子对撞机
(Circular Electron Positron Collider, CEPC)

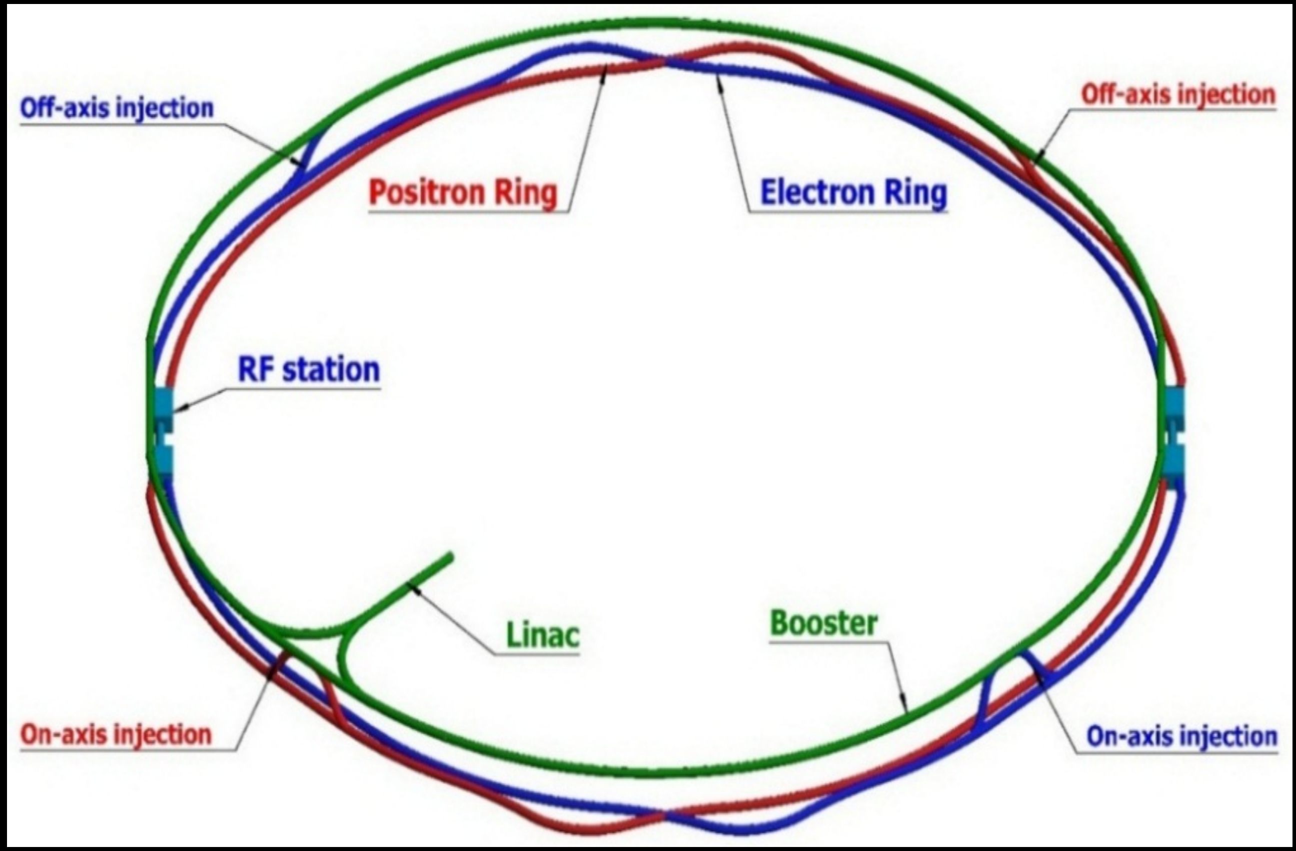
- 建造周长100 km 的对撞机
- 得益于Higgs 粒子的质量只有125 GeV，可以在质心能量240–250GeV 用正负电子对撞产生大量的 e^+e^- —> ZH 事例
- 两个对撞点，10年可以产生5.6/ab 积分亮度的数据用于 Higgs 性质的研究

初态精确可知、本底干净

Operation mode	Z factory	W threshold scan	Higgs factory
$\sqrt{s}$ (GeV)	91.2	158 - 172	240
L ($10^{34}\text{cm}^{-2}\text{s}^{-1}$)	16-32	10	3
Running time (years)	2	1	7
Integrated Luminosity (ab^{-1})	8 - 16	2.6	5.6
Higgs yield	-	-	10^6
W yield	-	10^7	10^8
Z yield	10^{11-12}	10^9	10^9

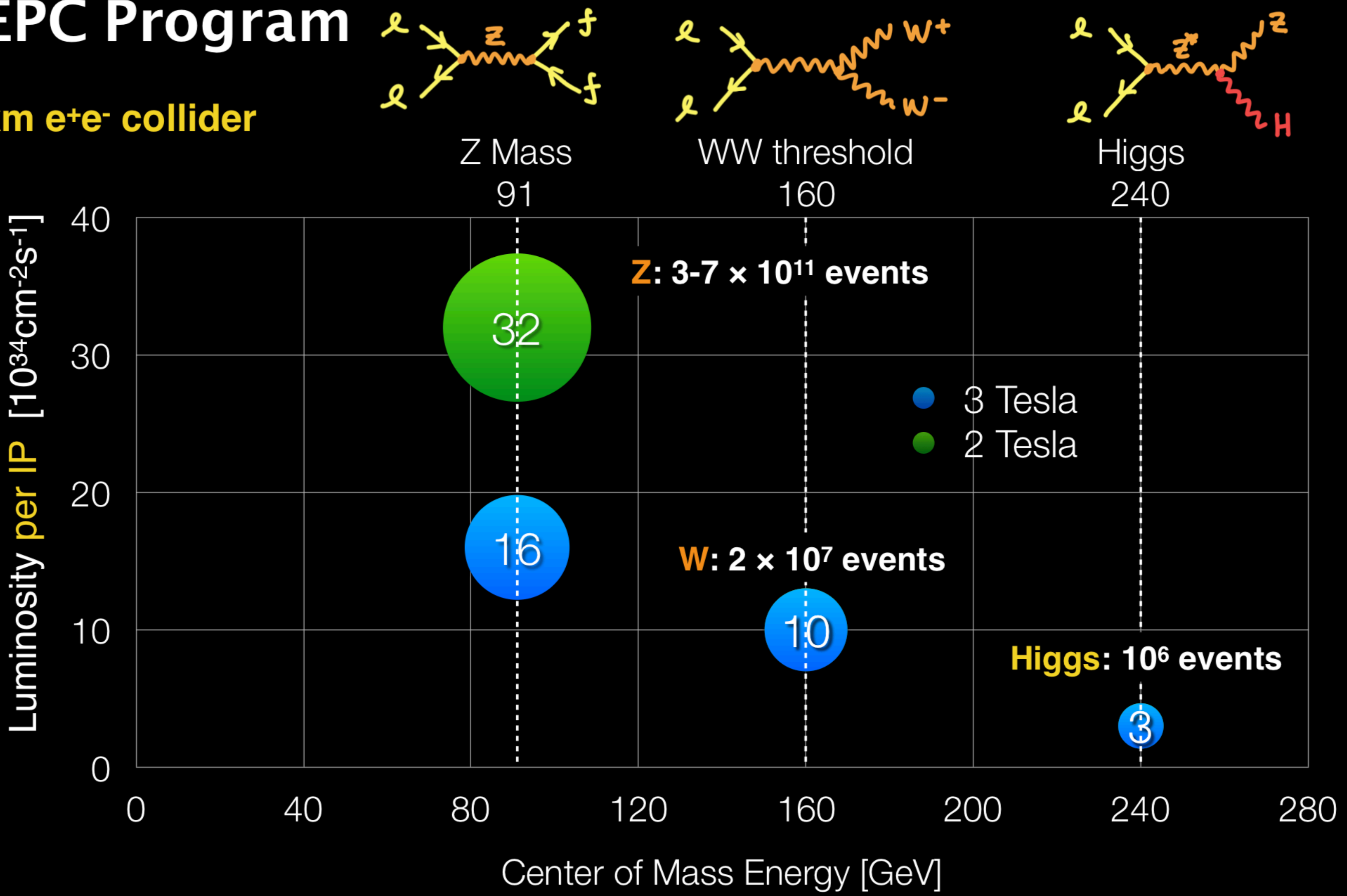
$$\sqrt{s} = (E_{e^+} + E_{e^-}, 0, 0, 0)$$

- 可以覆盖从 Z(90 GeV) 到 ZH (240GeV) （乃至350 GeV, top threshold）的能量范围
- 对 Higgs 进行高精度的绝对测量和高精度的 EW 关键参数测量；相比以前的最好结果，大部分测量的精度都会改善一个量级
- 可以升级为质心能量高达 100 TeV 的 质子、质子对撞机



The CEPC Program

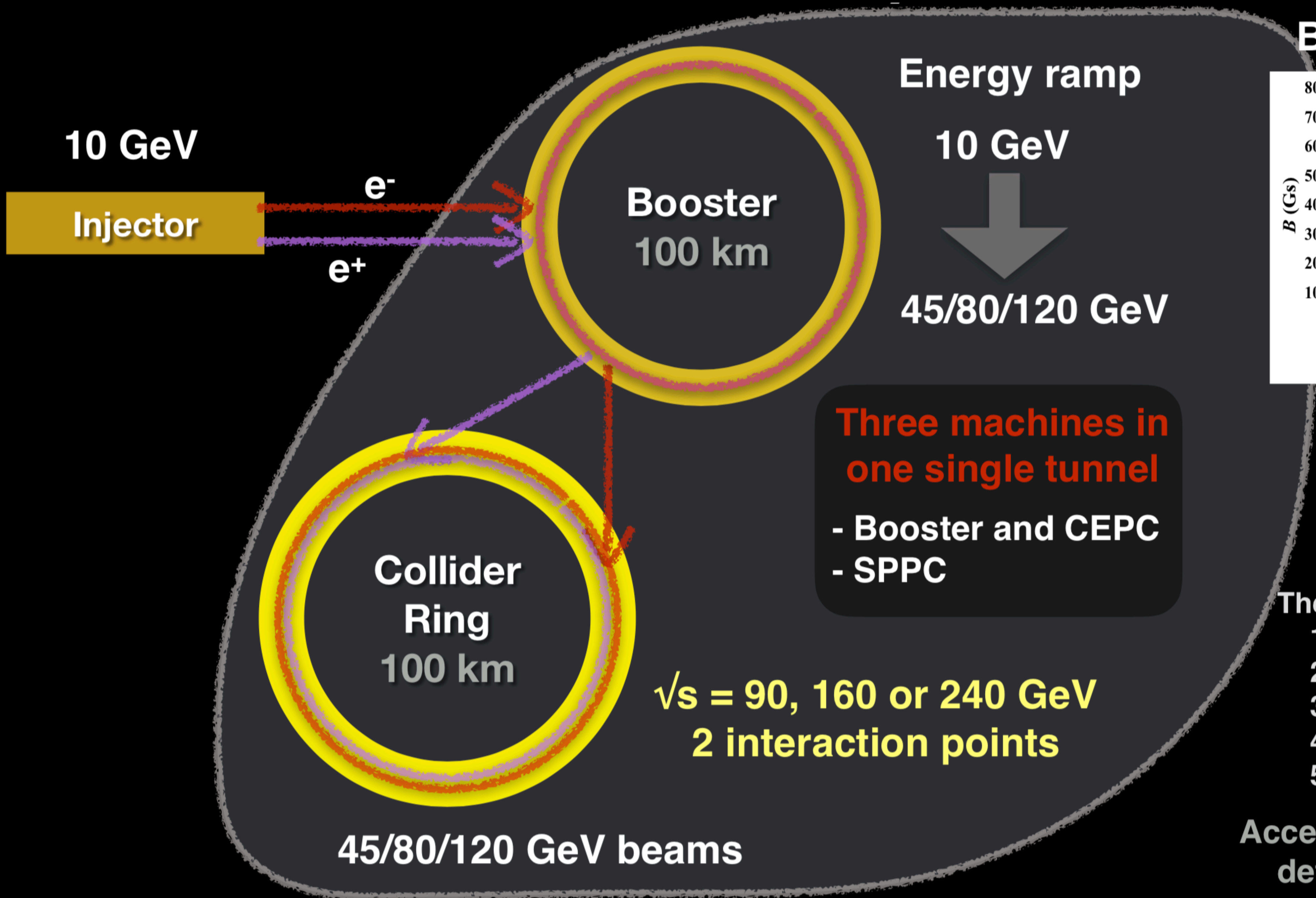
100 km e+e- collider



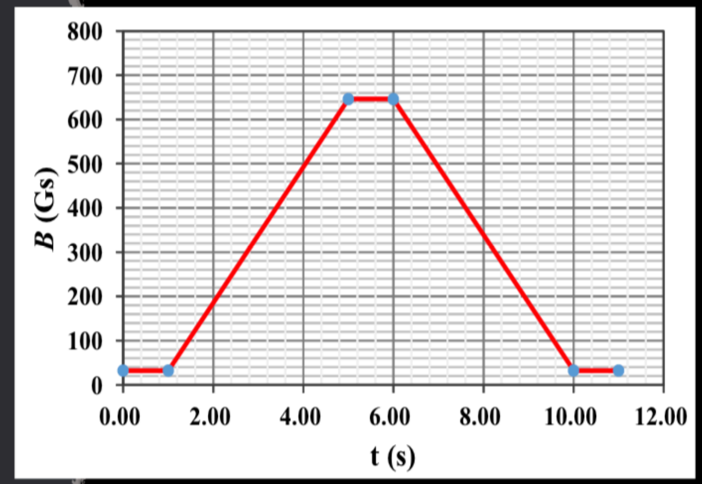
Main Parameters of Collider Ring

	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}

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

CEPC PFA detector concepts

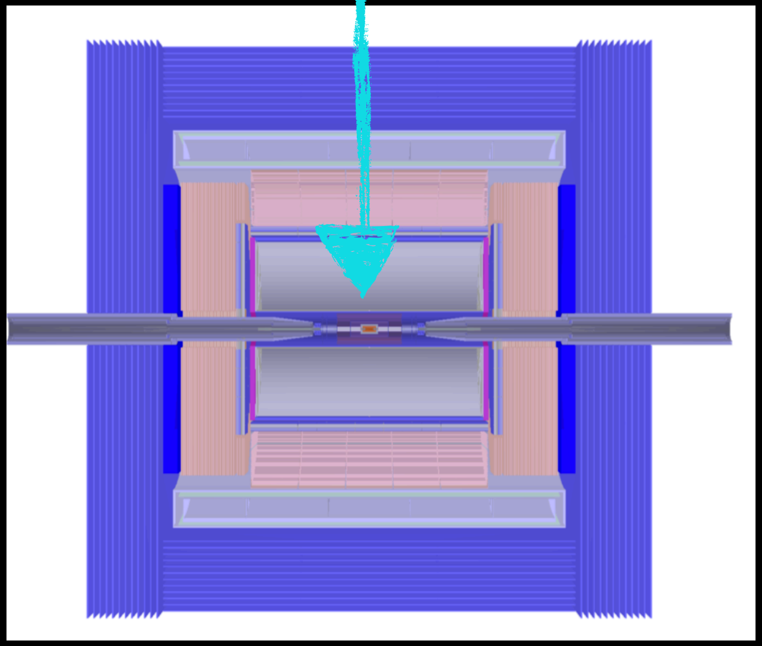
Particle flow: make use of the optimal sub-detector information in reconstruction and a high granularity calorimetry system required

Particles in jet	Fraction of E	Measured with	Resolutions (σ^2)
Charged tracks	~60%	Tracker	Negligible
Photons	~30%	Ecal	$0.11^2 E_{jet}$
Neutral hadron	~10%	Ecal+Hcal	$0.16^2 E_{jet}$
Conclusion	Required for 30%/sqrt(E)		$0.20^2 E_{jet}$

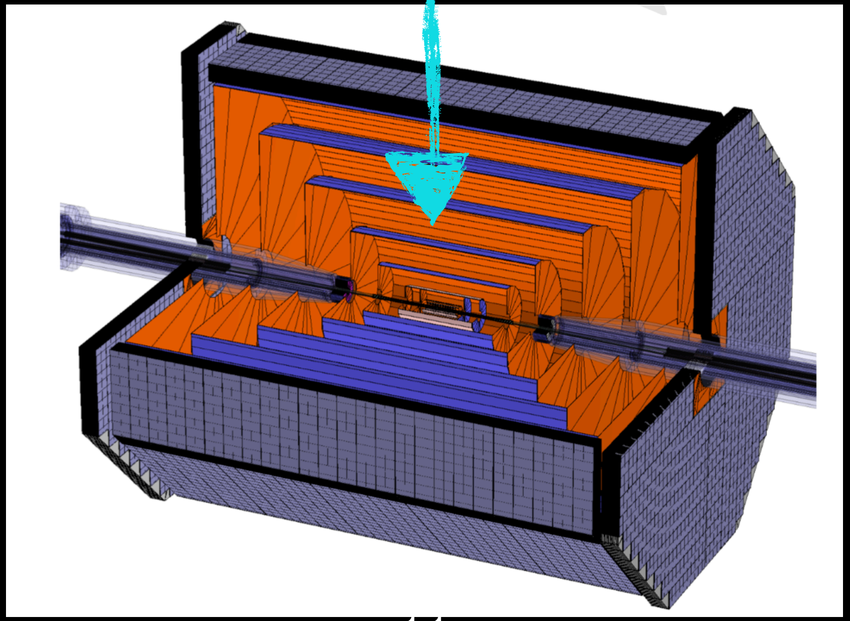
CEPC detector concepts

- Three detector concepts proposed
  - ★ Silicon + TPC + PFA calo - used for full simulation performance study
  - ★ Full silicon + PFA calo
  - ★ Silicon + DC + DR calo

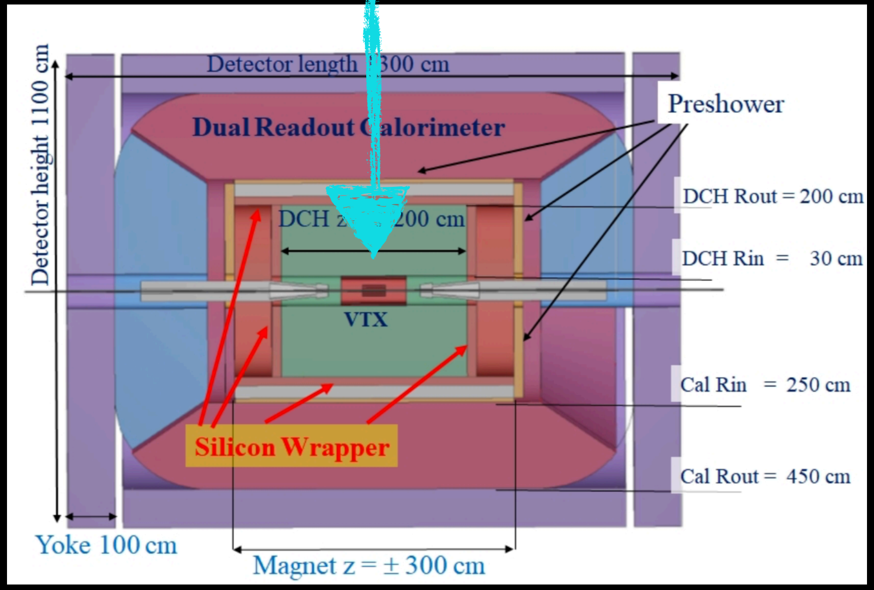
TPC: 3 Tesla



Silicon



Drift chamber: 2 Tesla



Detector R&D

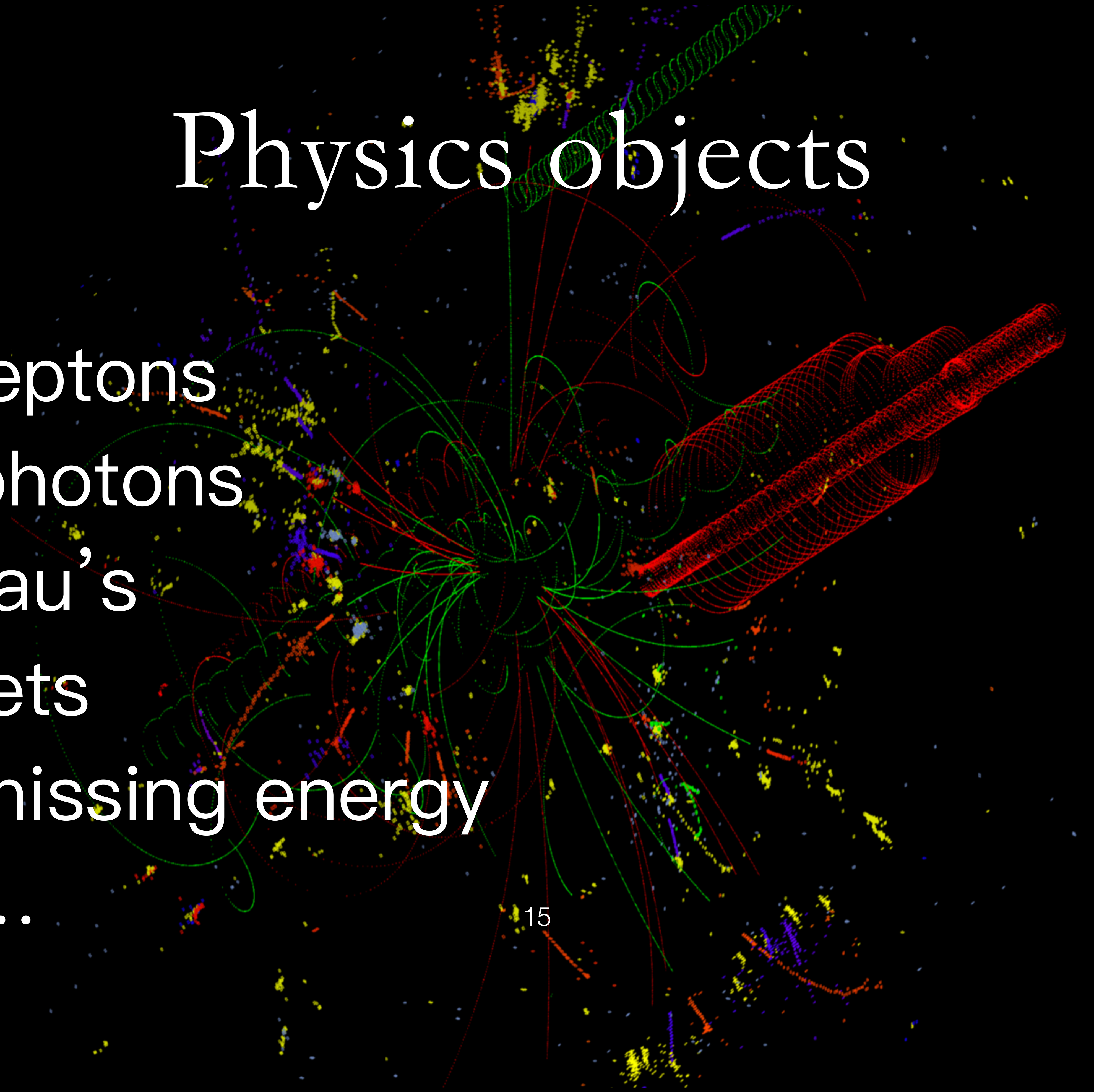
Physics requirements

- **Robustness and efficiency : record all physics events/objects in a noisy environment**
- **Ultimate goal: trace the whole cascade topology of a physics event, i.e. jet substructure!**
- **Excellent resolution and efficiency to reconstruct physics objects: better resolutions can compensate statistics**
- **Luminosity/beam energy calibration to meet physics goal**
  - **Luminosity: ~ 0.1% at 240 GeV and ~ 0.01% at 91 GeV**
  - **Ebeam: ~ 1 MeV at 240 GeV and ~ 0.1MeV at 91 GeV**
- **Highly hermetic coverage: advantage of e+e- collider — initial state precisely defined.**
- **PID: lepton/jet/hadron identification with high efficiency and rejection power**

Benchmarks for performance

Physics process	Measurands	Critical detector	Required performance
$ZH \rightarrow l^+l^-X$	m_H, σ_{ZH}	Tracker	$\Delta(1/P_T) = 2 \times 10^{-5} \oplus \frac{10^{-3}}{P(\mathrm{GeV})\sin^{\frac{3}{2}}\theta}$
$H \rightarrow \mu^+\mu^-$	$B(H \rightarrow \mu^+\mu^-)$		
$H \rightarrow b\bar{b}, c\bar{c}, gg$	$B(H \rightarrow b\bar{b}, c\bar{c}, gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV})\sin^{\frac{3}{2}}\theta}(\mu\mathrm{m})$
$H \rightarrow q\bar{q}, W^+W^-, ZZ$	$B(H \rightarrow q\bar{q}, W^+W^-, ZZ)$	ECAL, HCAL	$\sigma_E^{jet} = 3 \sim 4\,\%$ at 100GeV
$H \rightarrow \gamma\gamma$	$B(H \rightarrow \gamma\gamma)$	ECAL	$\frac{\Delta E}{E} = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

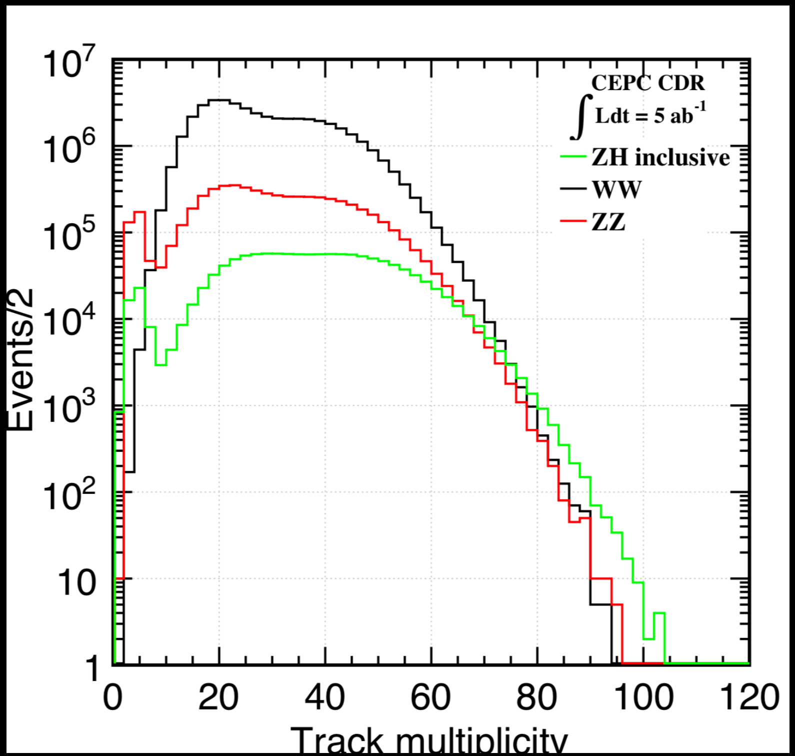
Physics objects

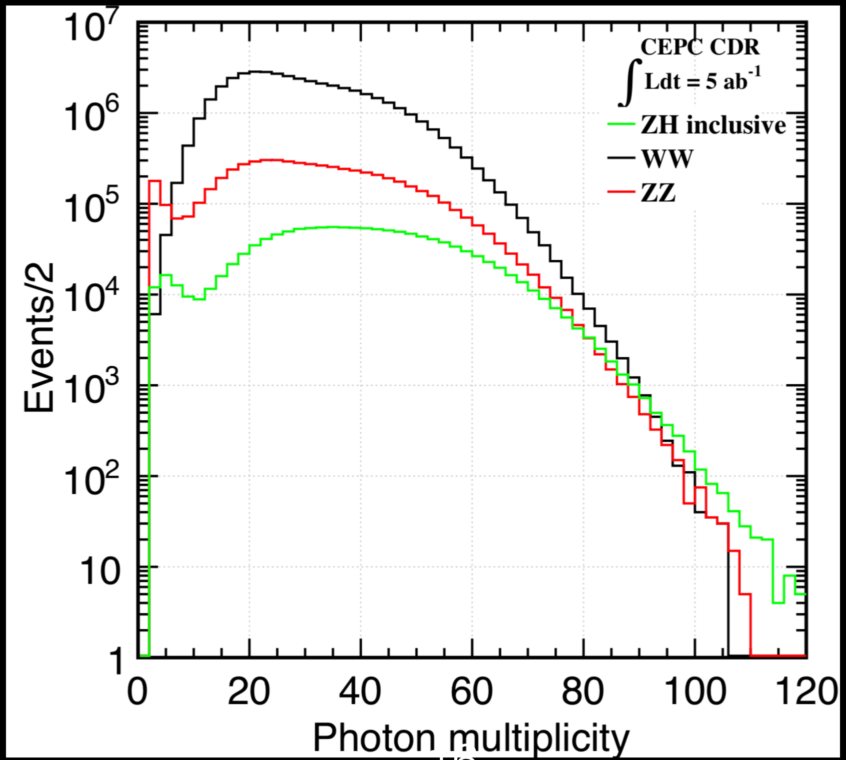


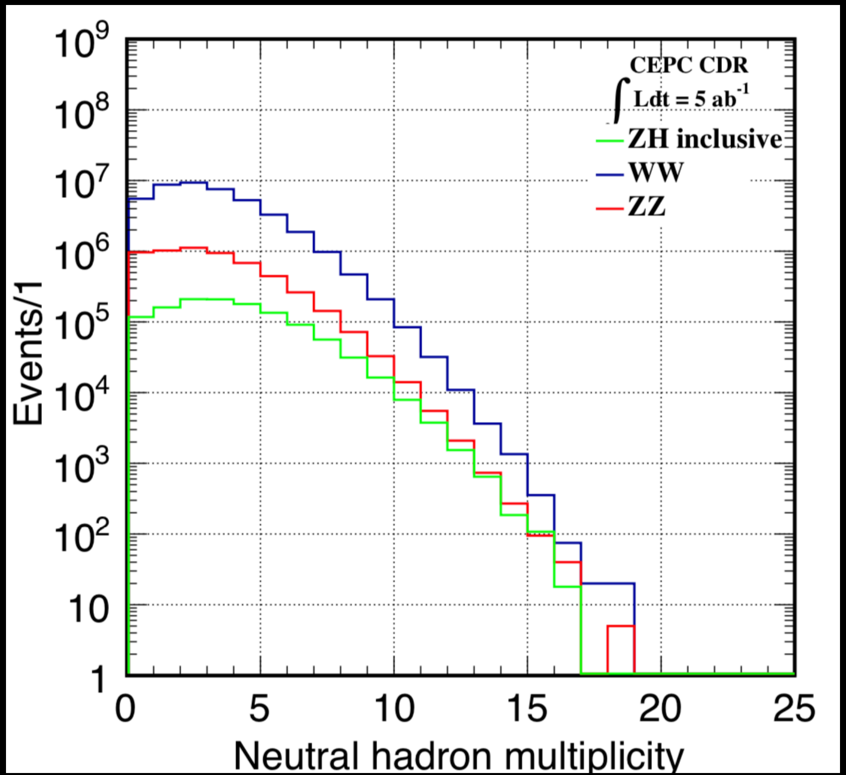
- leptons
- photons
- tau's
- jets
- missing energy
- …

Multiplicities of typical events

- Averaged multiplicities of the charged tracks and photons ~ 30, up to 100, which carry most of the energy of an event
- Neutral hadrons ~ 10% of the energy



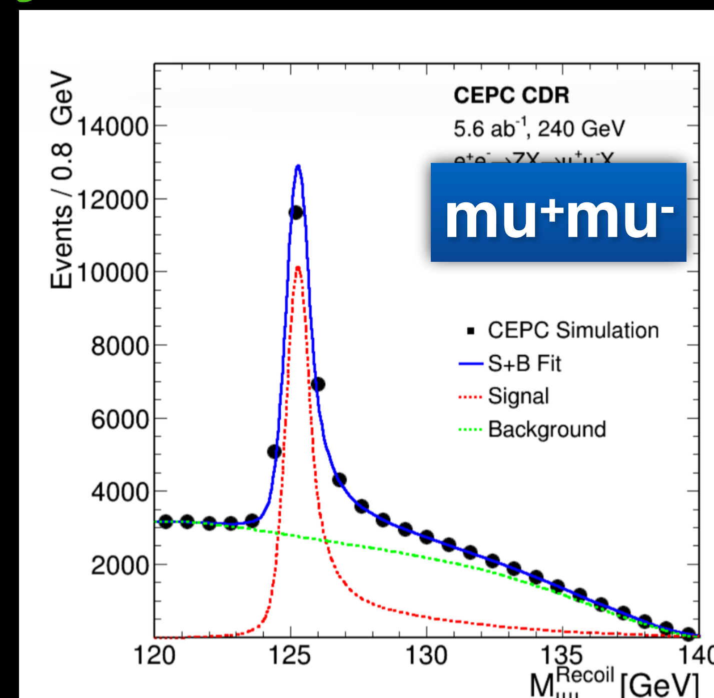


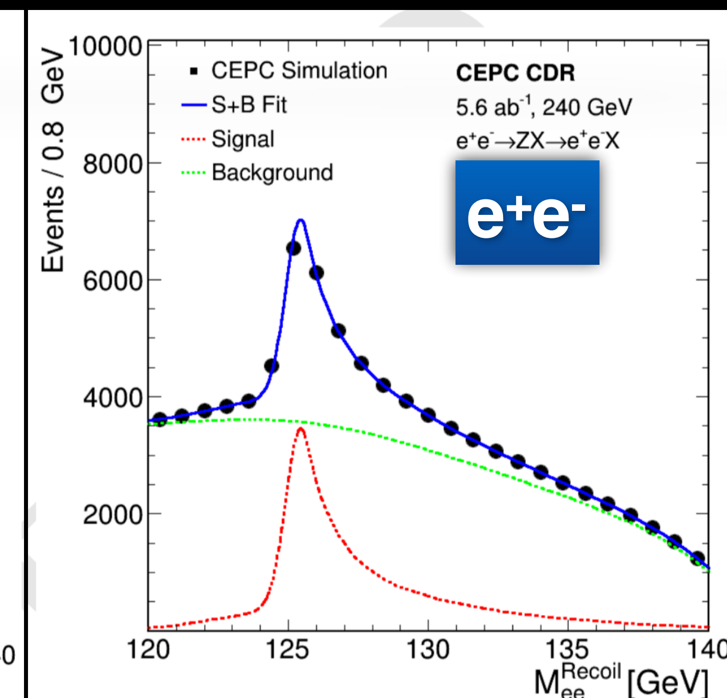


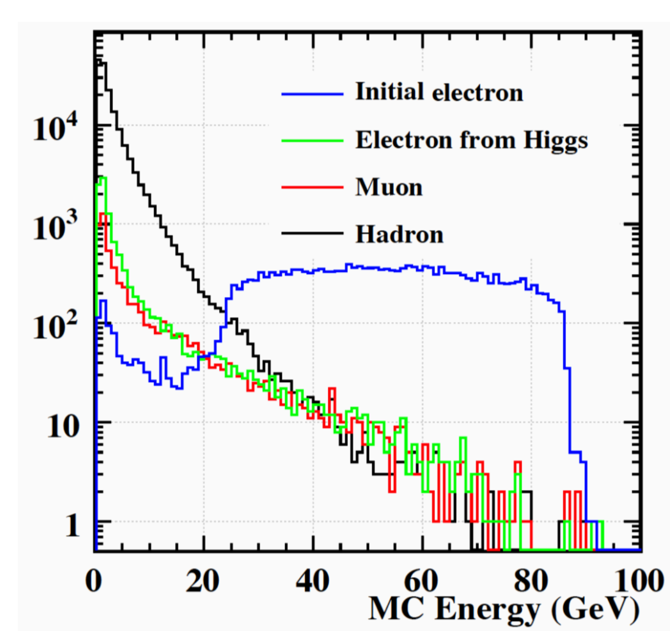
Leptons: tracking & ID

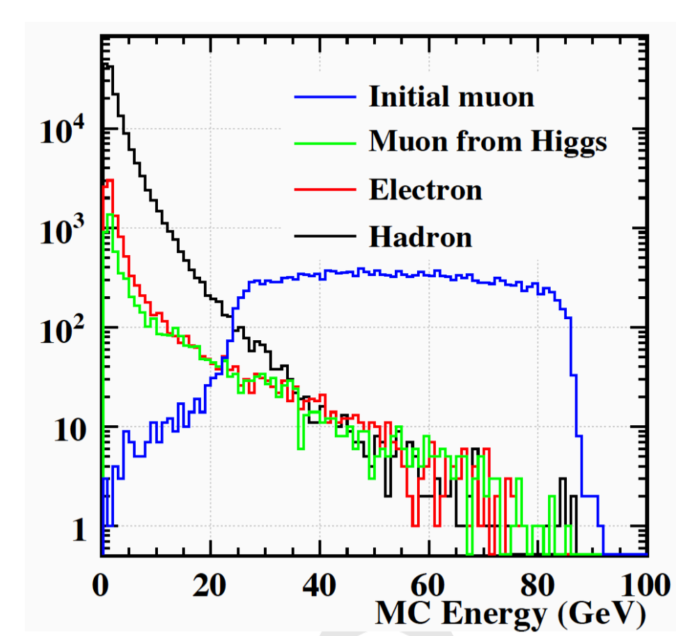
$e^+e^- \to ZH \to \mu^+\mu^-(e^+e^-)$+ inclusive

- Leptons extremely important for the model independent study of Higgs
- The momenta greater than 15 GeV
- High tracking efficiency, good lepton ID, and good resolution preferred



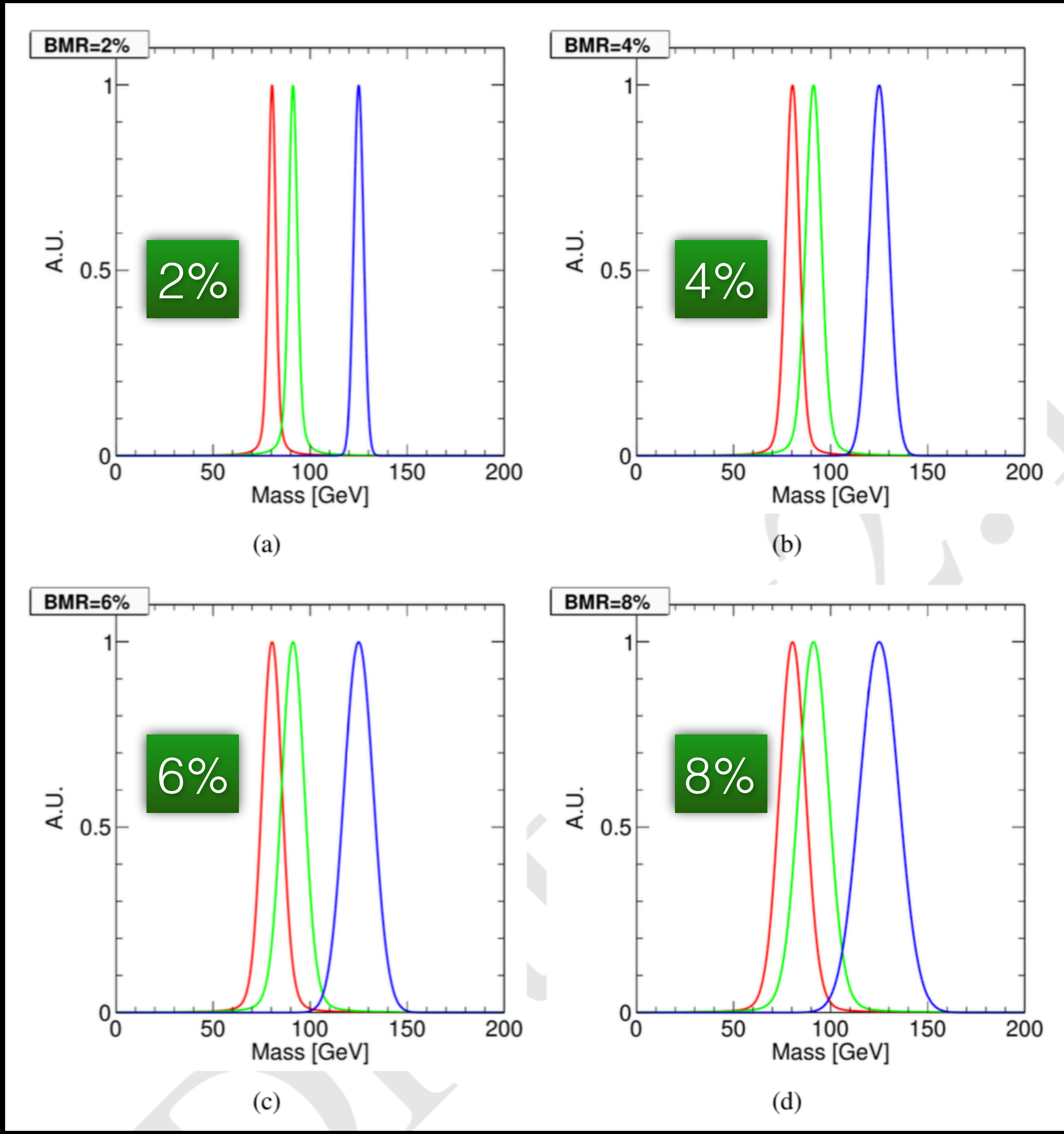






Jet energy resolution

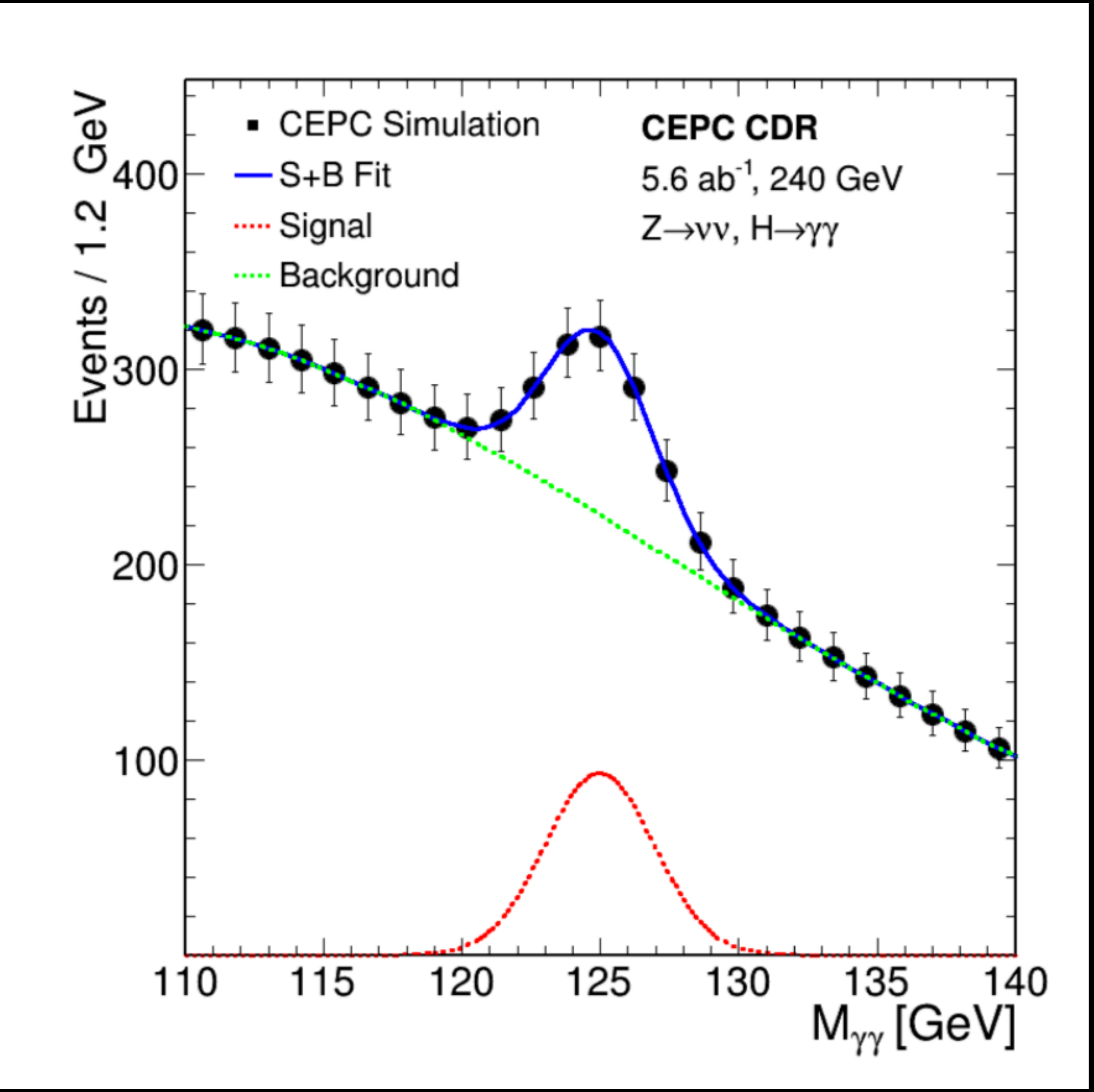
- Jet energy resolution (JER) is essential for boson reconstruction, left plots demonstrate the importance of boson mass resolution
- 4% is minimum requirement for W, Z&H boson separation



Photons

- Photon energy resolution is key issue for Higgs di-photon measurement, as well as π^0 and ISR photon tagging

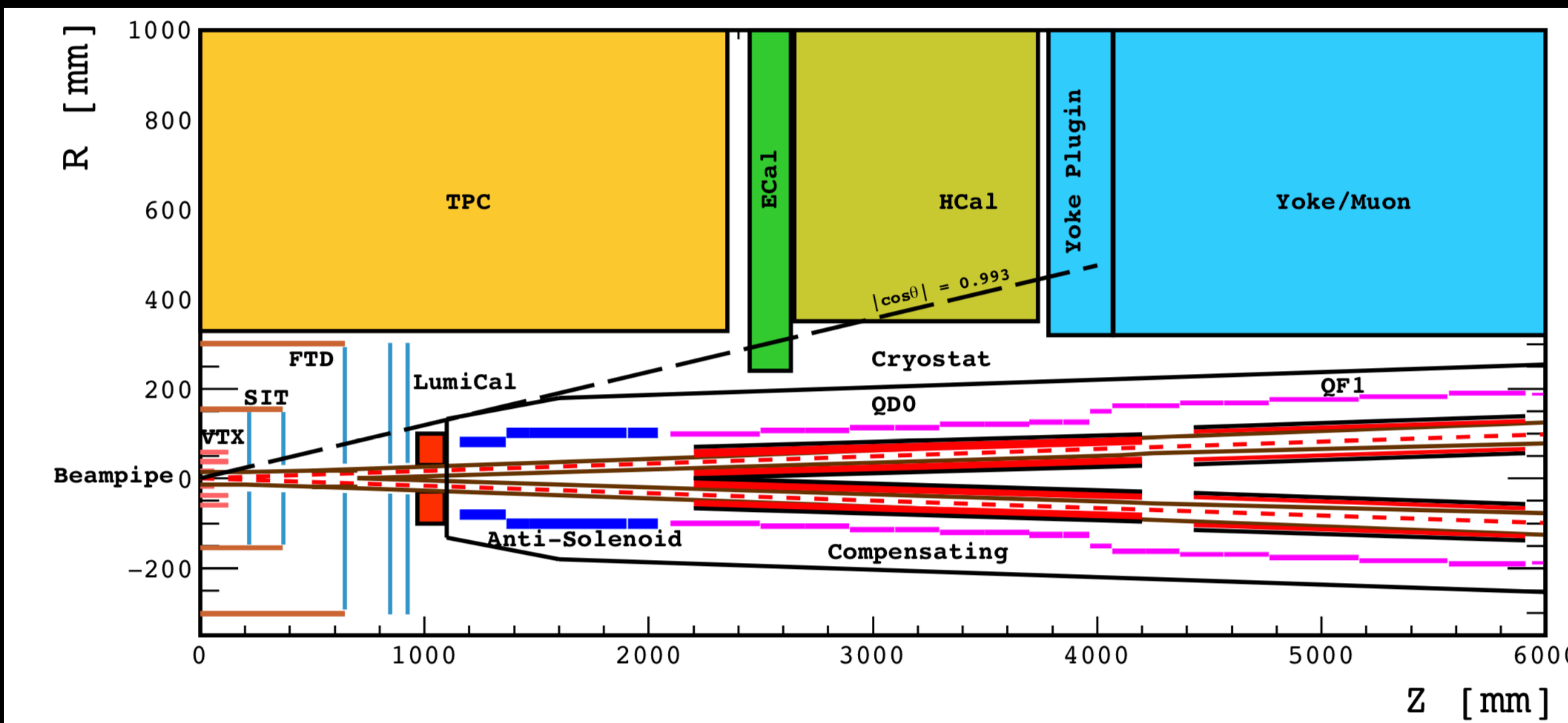
- Simulation shows 20%/$E^{1/2}$ is minimum requirement for Higgs to di-photon study.



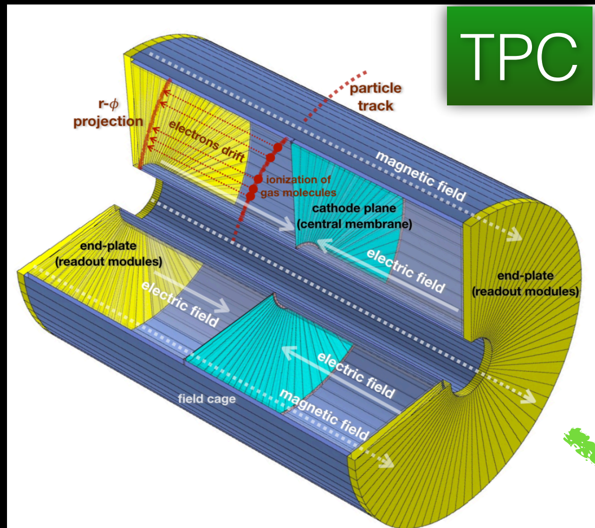
Experiment conditions

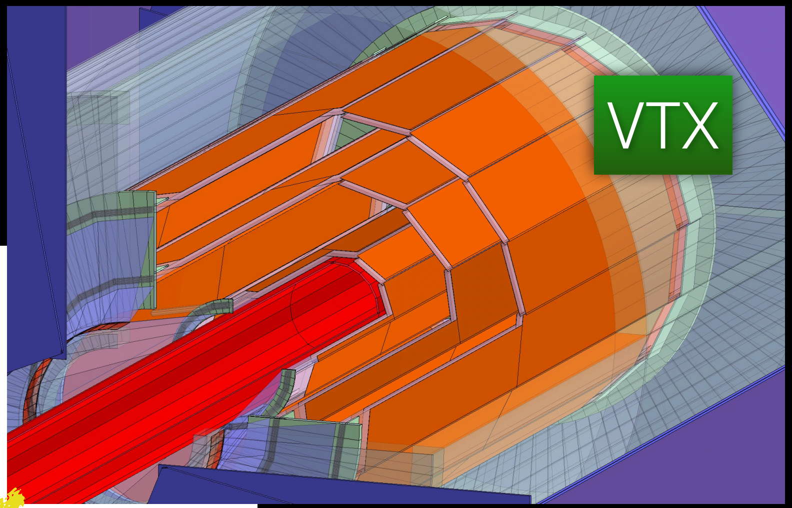
- CEPC design supposed to deliver more luminosities at all energies
- Constraint from machine
  - double ring
  - cross angle: 33 mrad
  - L* = 2.2 m, QD0, QF1 inside detector
  - Backgrounds : pair production & off-beam particles
  - Luminosity measurement very challenge
- Stringent requirements on detector design

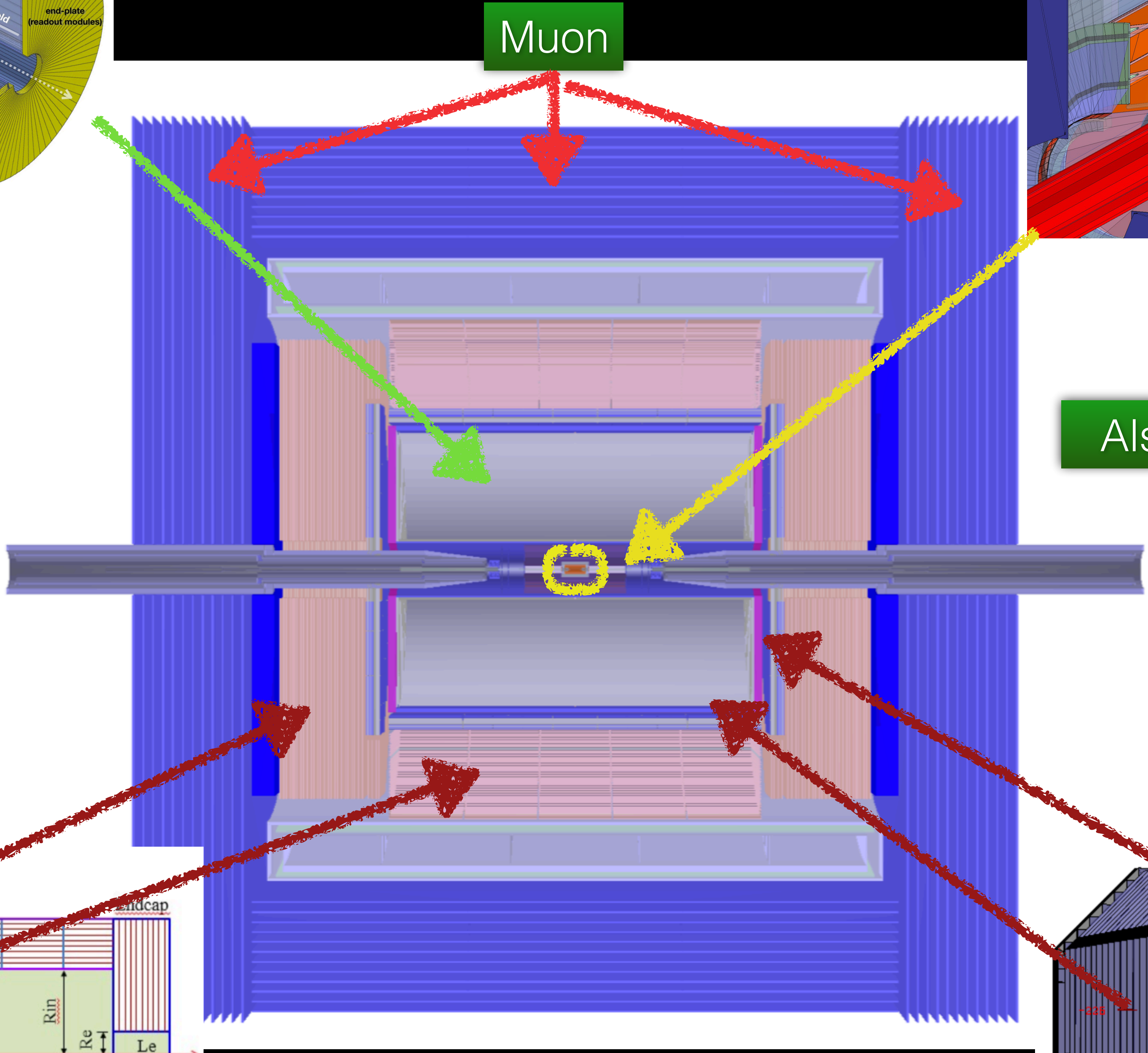
	H (240)	W (160)	Z (91)
Hit Density [hits/cm^2·BX]	2.4	2.3	0.25
TID [MRad/year]	0.93	2.9	3.4
NIEL [10^{12} 1 MeV n_{eq}/cm^2·year]	2.1	5.5	6.2

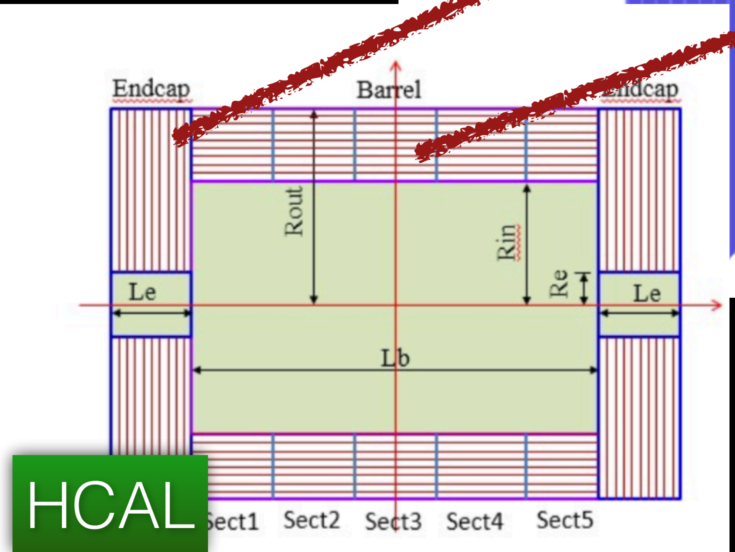


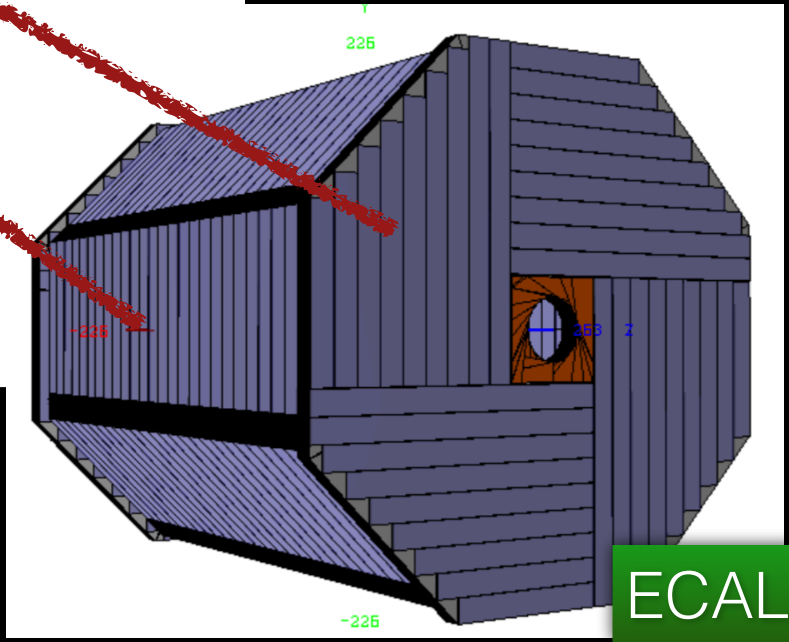
Baseline design









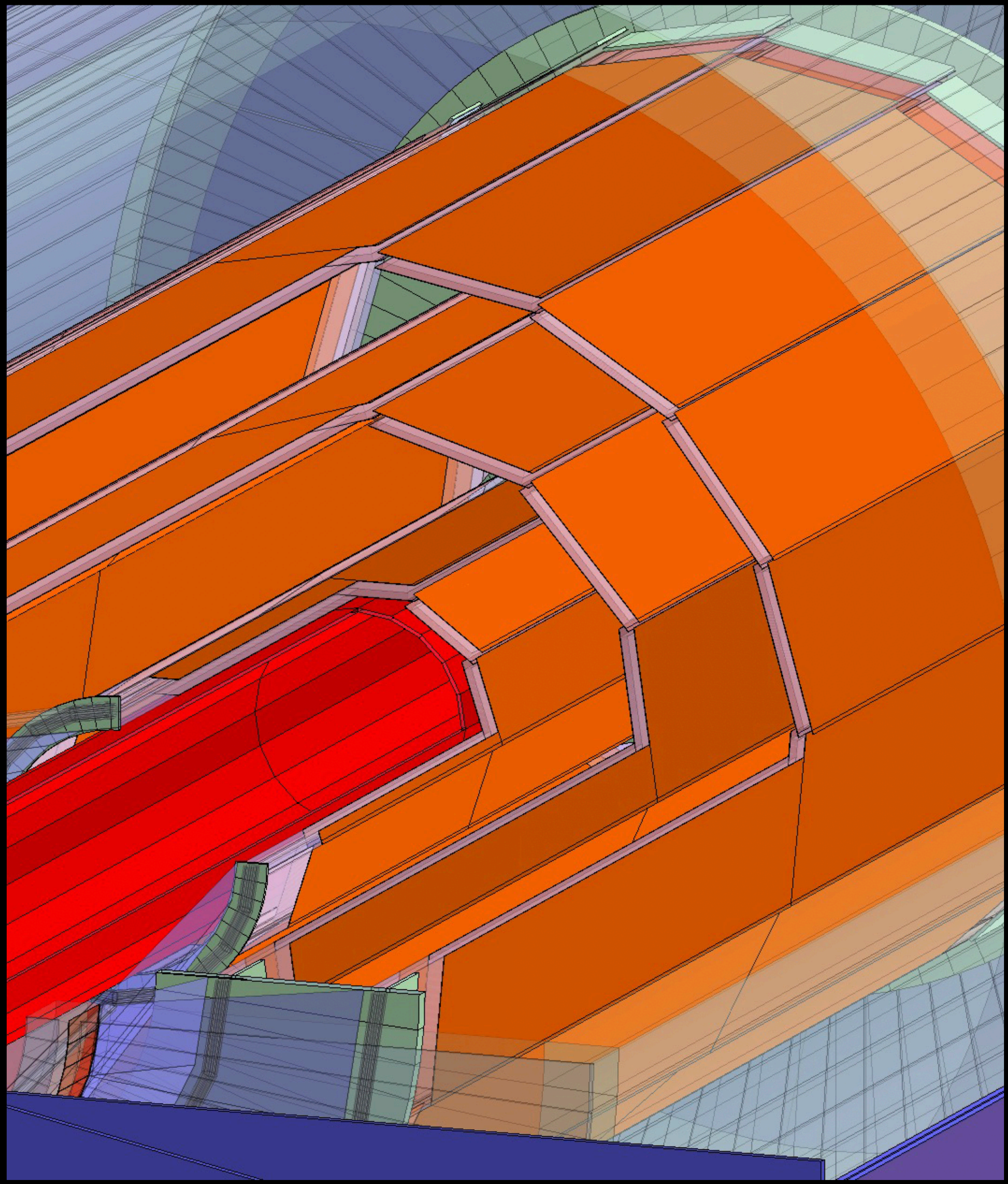


Silicon Vertex

- Three double layer pixel detector
- Rin = 16 mm
- Best single point resolution 3 microns
- Material 0.15%X_0 per layer
- Impact parameter resolution

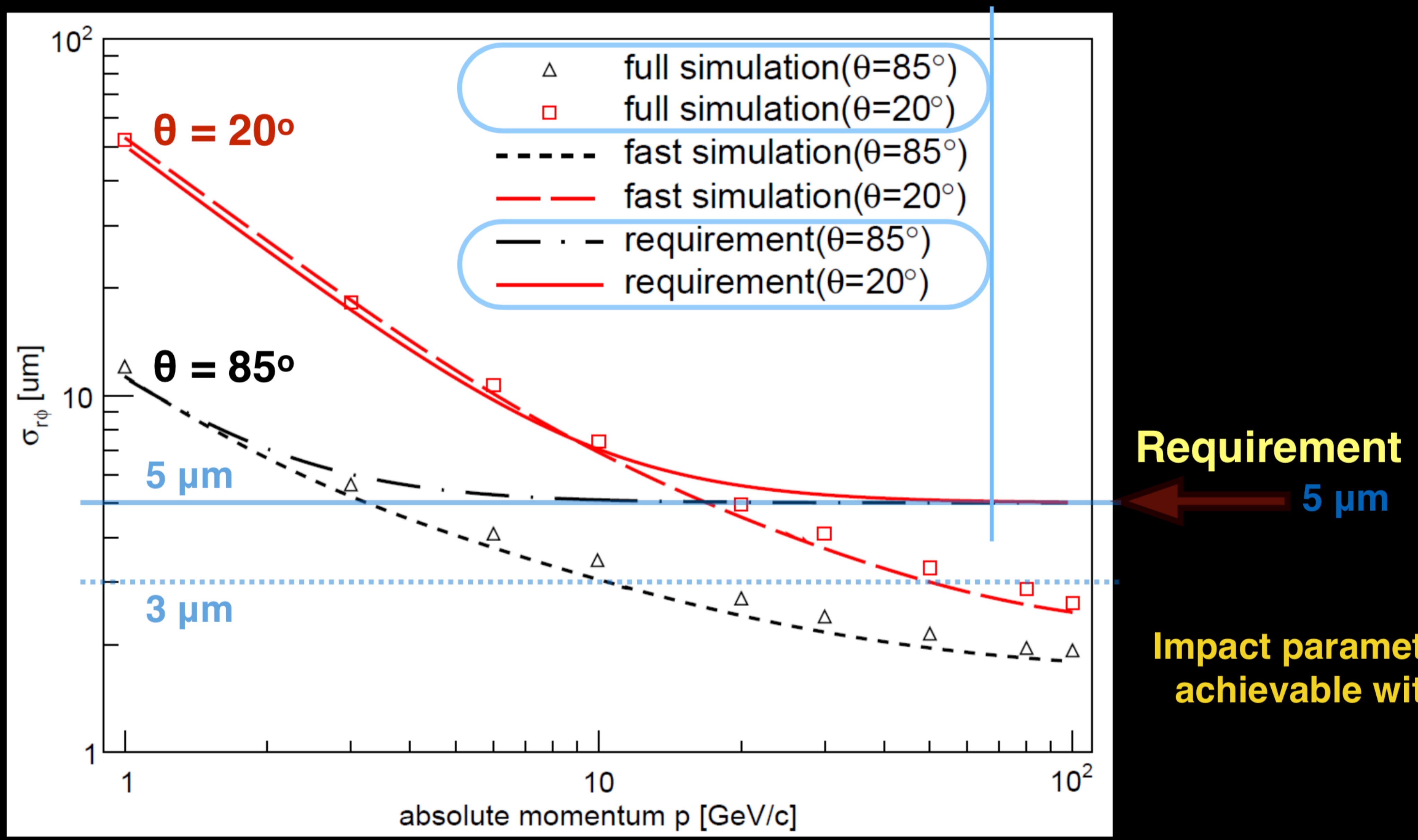
$$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV})\sin^{3/2}\theta}(\mu\mathrm{m})$$

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



Performance studies: Impact parameter resolution

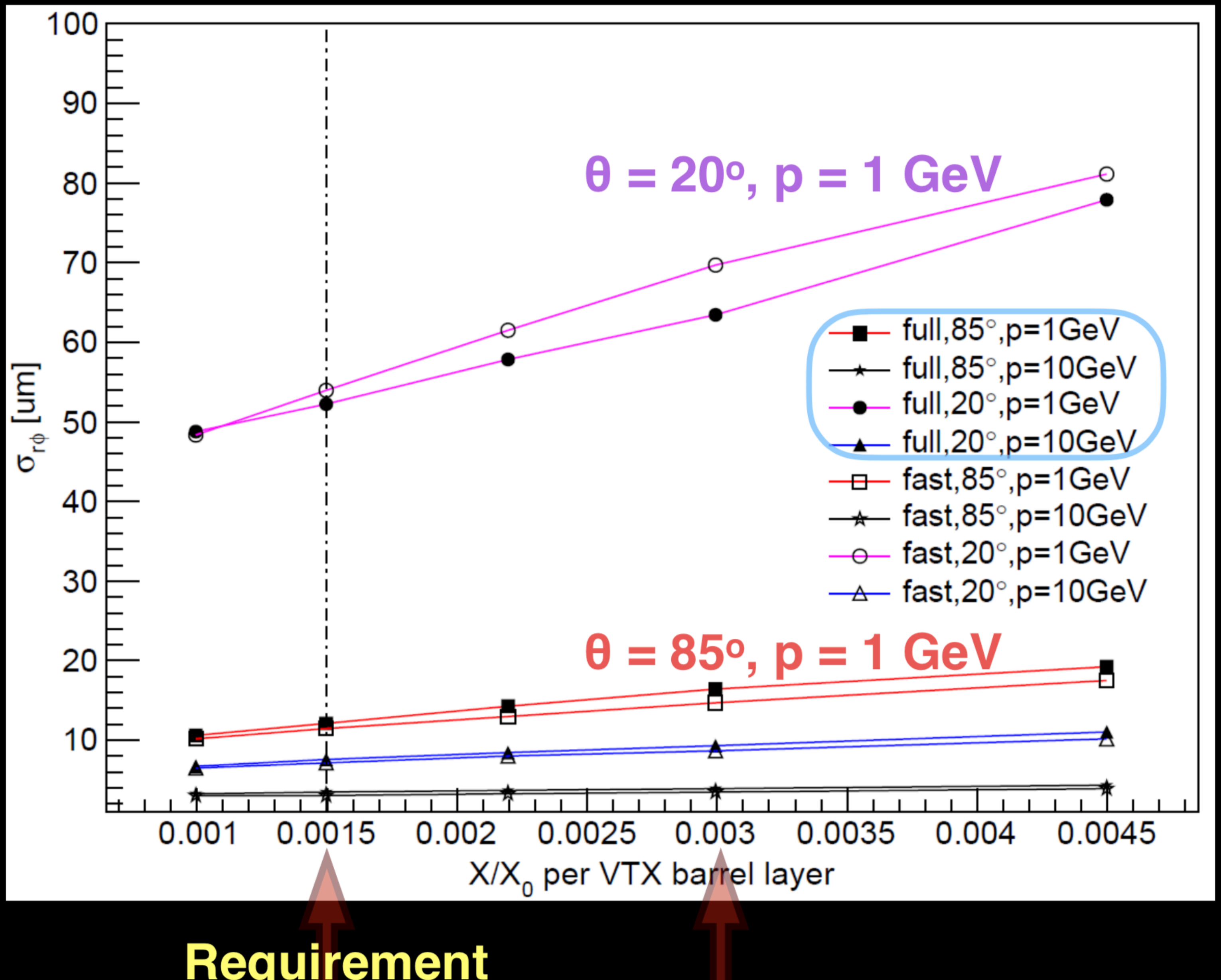
Transverse impact parameter resolution for single muons



Impact parameter resolution goal achievable with current design

Performance studies: Material budget

Transverse impact parameter resolution for single muons



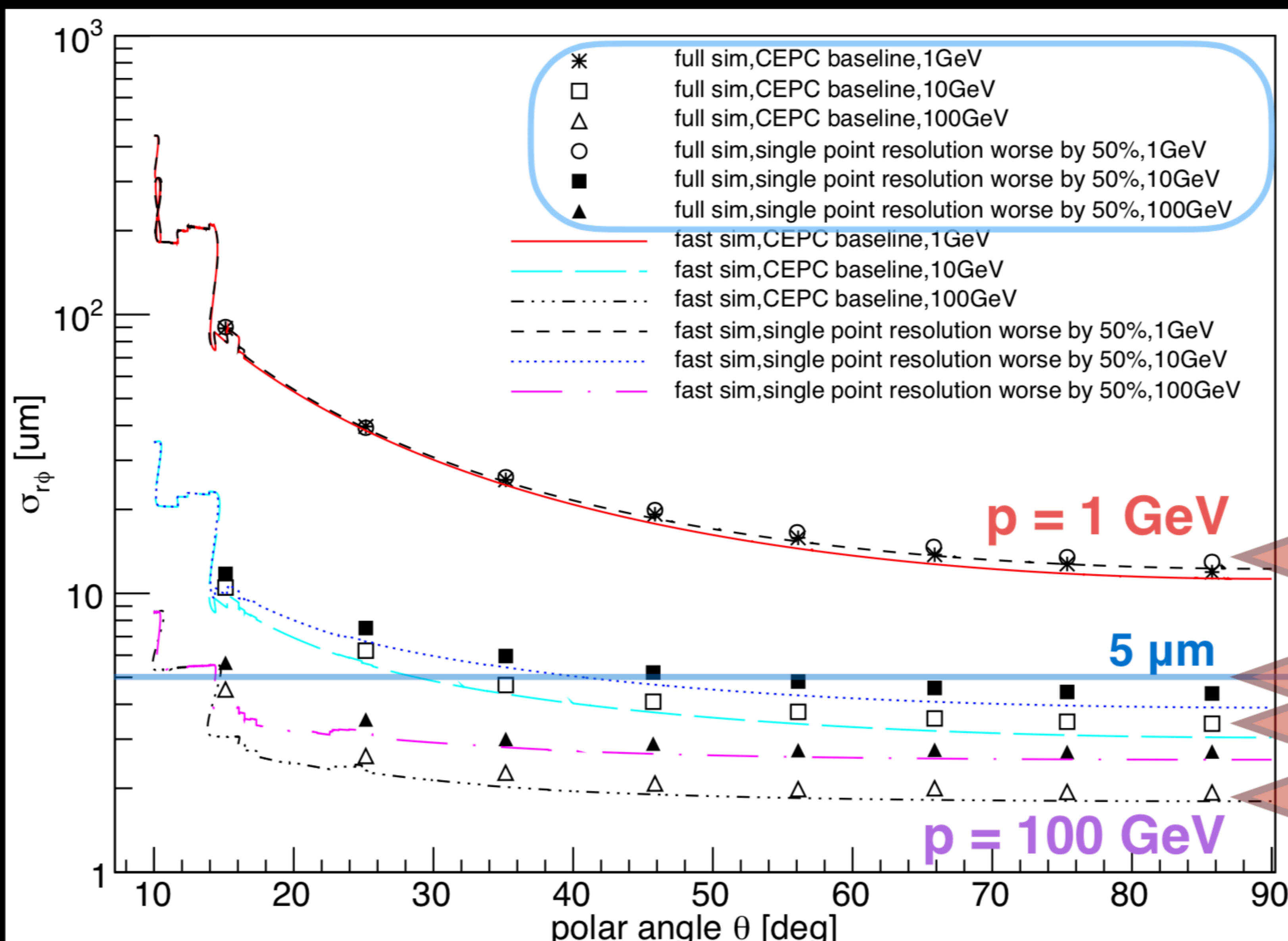
Baseline includes very small material budget for beam pipe, sensor layers and supports
≤ 0.15%X_0 / layer

× 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 muon



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

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

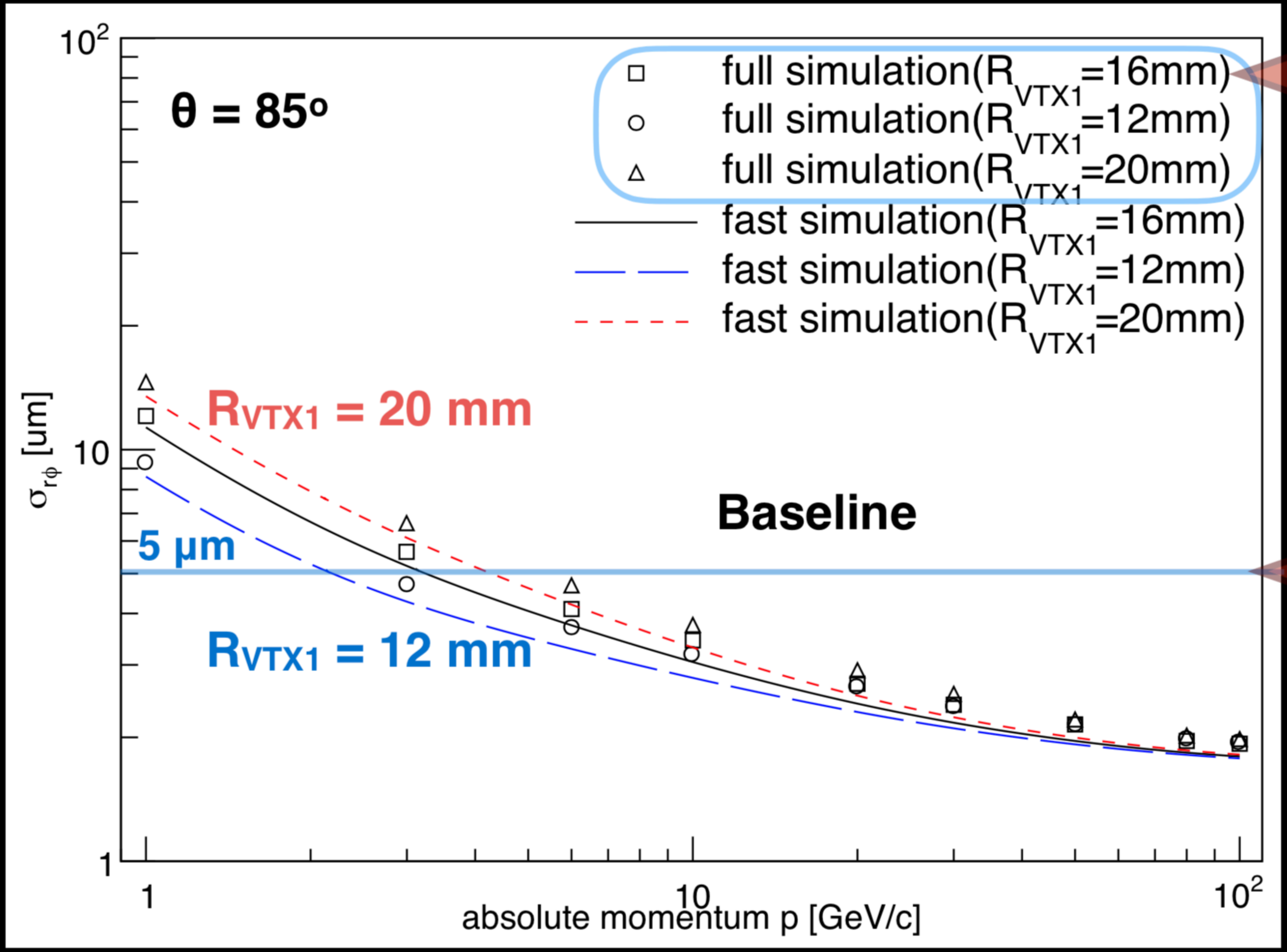
Target

Baseline p = 10 GeV

Baseline p = 100 GeV

Performance studies: inner radius of VXD

Transverse impact parameter resolution for single muons



Impact parameter resolution affected for low-pt tracks

Tracker

- **SIT: Silicon inner tracker**
- **SET: Silicon external tracker**
- **FTD: Forward tracking disk**
- **ETD: End-cap tracking disk**

高效率和高精度

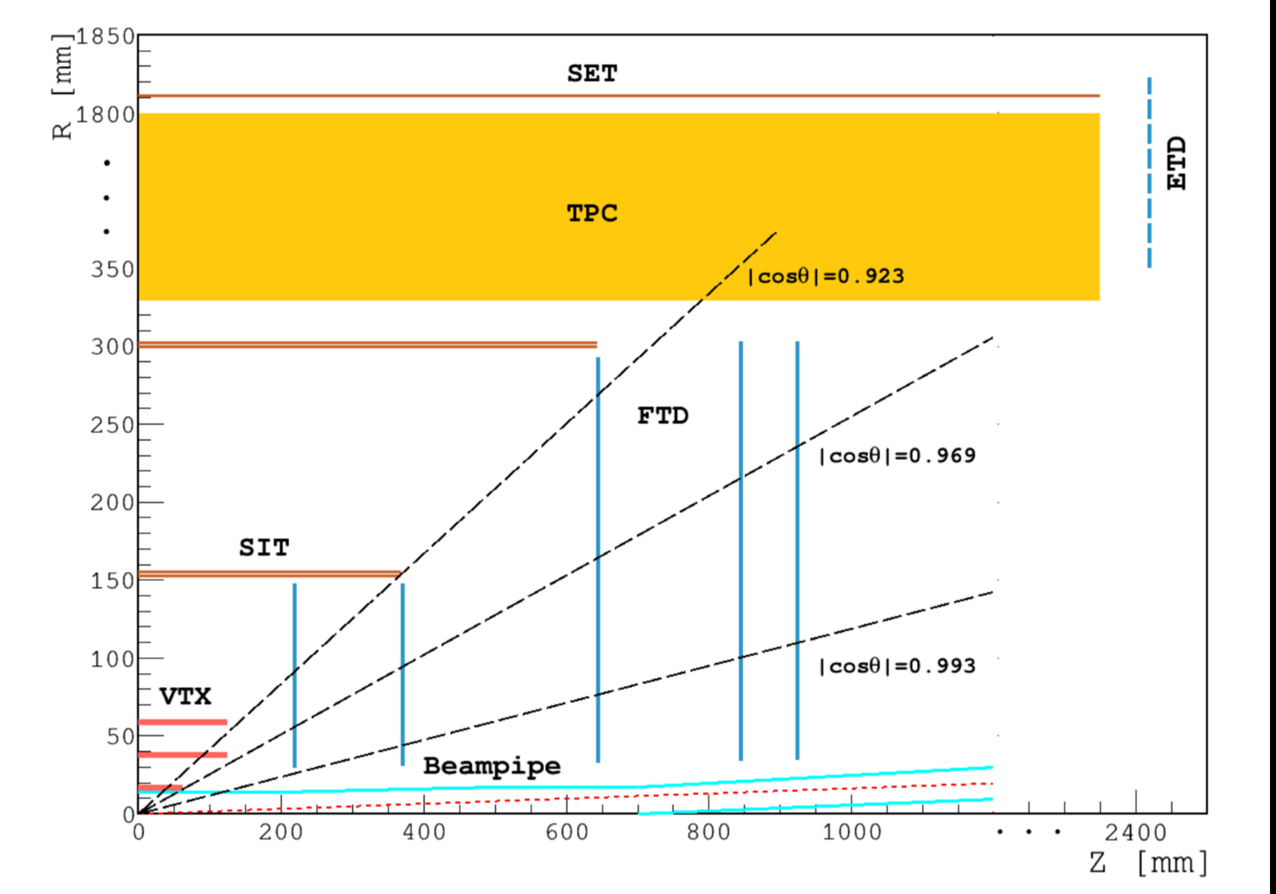
★ **Rin = 0.3 mm**

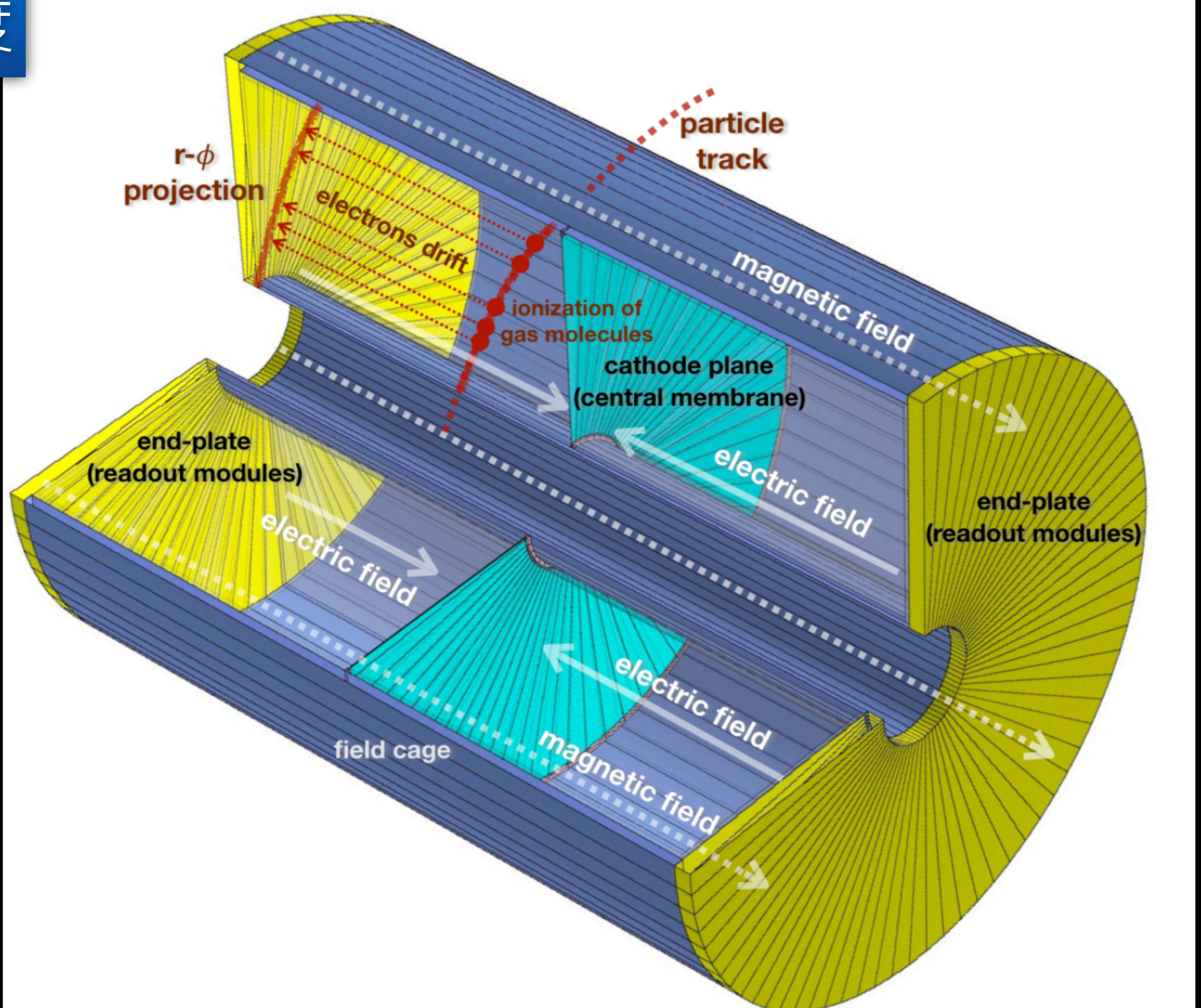
★ **Rout =1.8 m**

★ **Half Z = 2.35 m**

★ **Low material budget only 1%X0 in the central part**

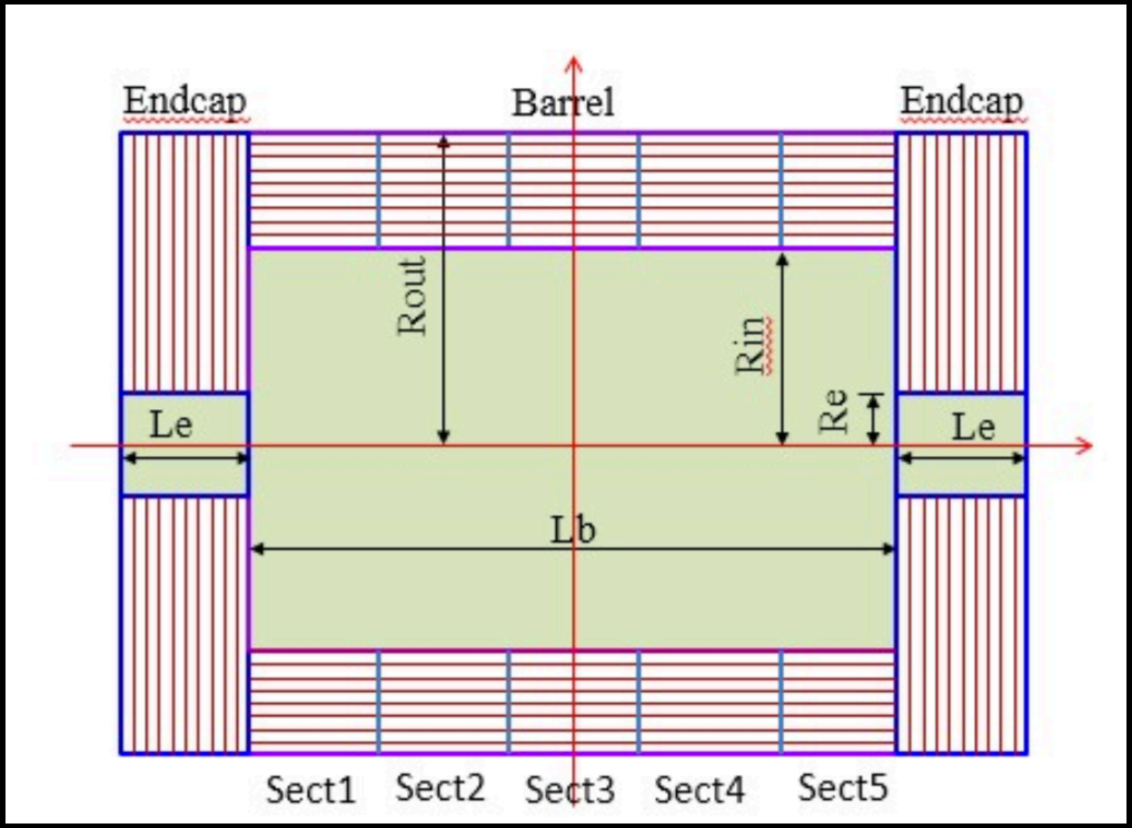
★ **Provide up to 220 points of 100 micron precision for tracking reconstruction and dE/dx for PID**

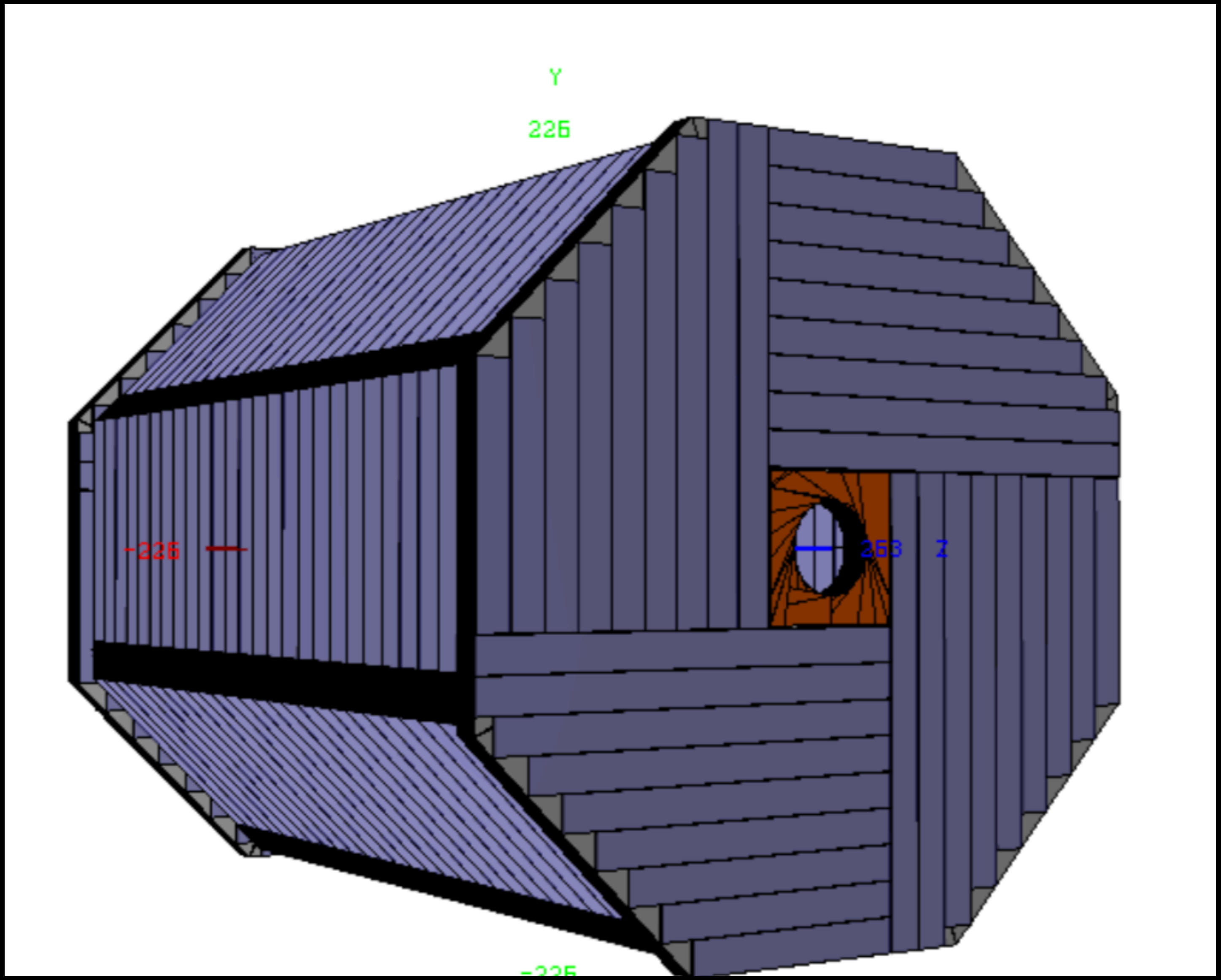


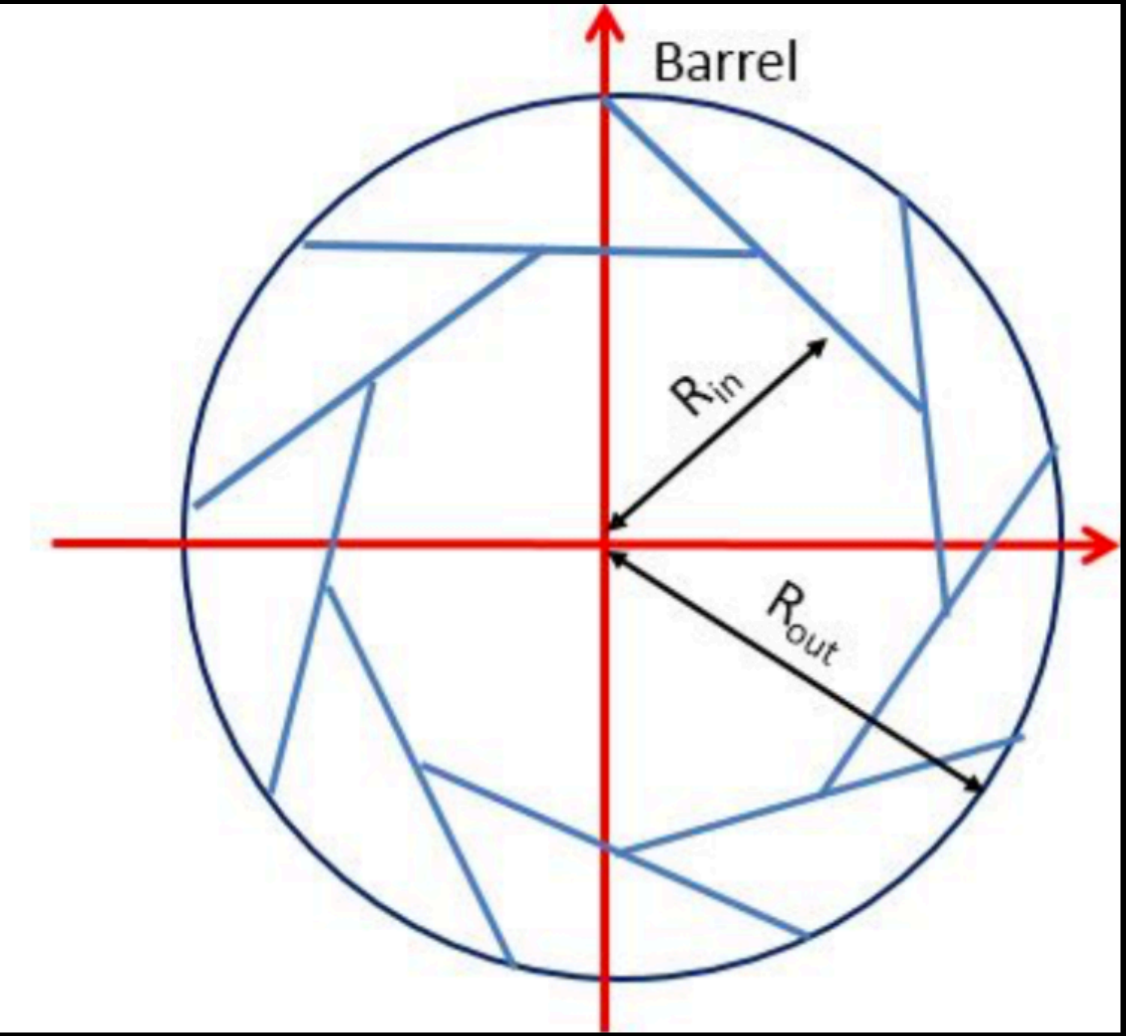


Calorimeter: key of PFA concept

- Ecal baseline
  - 30 layers
  - Cell size: $1 \times 1\text{cm}^2$
  - 24 X_0
- Hcal baseline
  - 40 layers
  - $\lambda_I = 4.9$

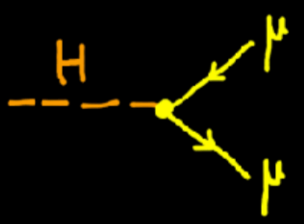


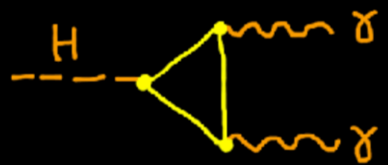




Detector optimization

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



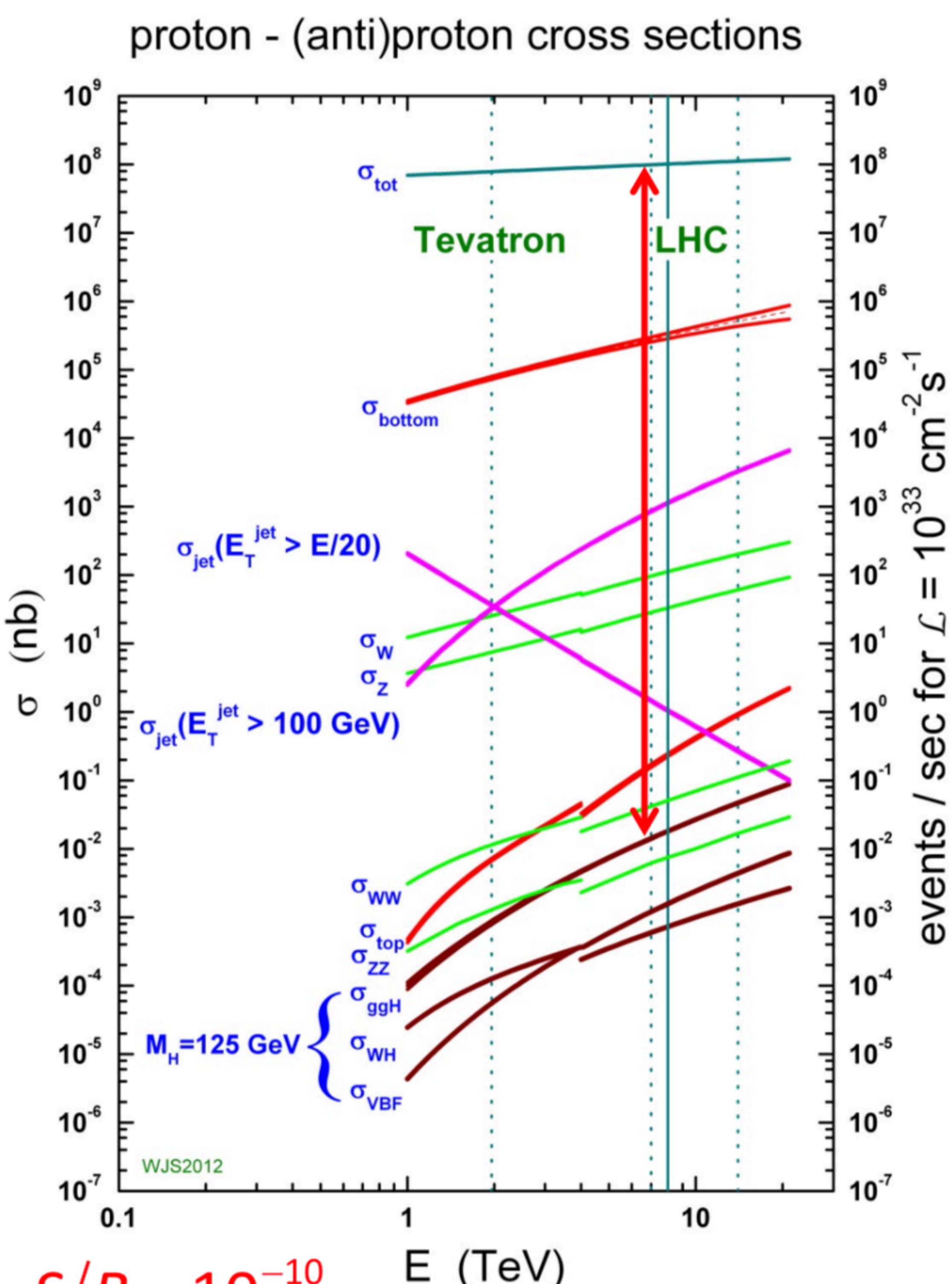


物理模拟

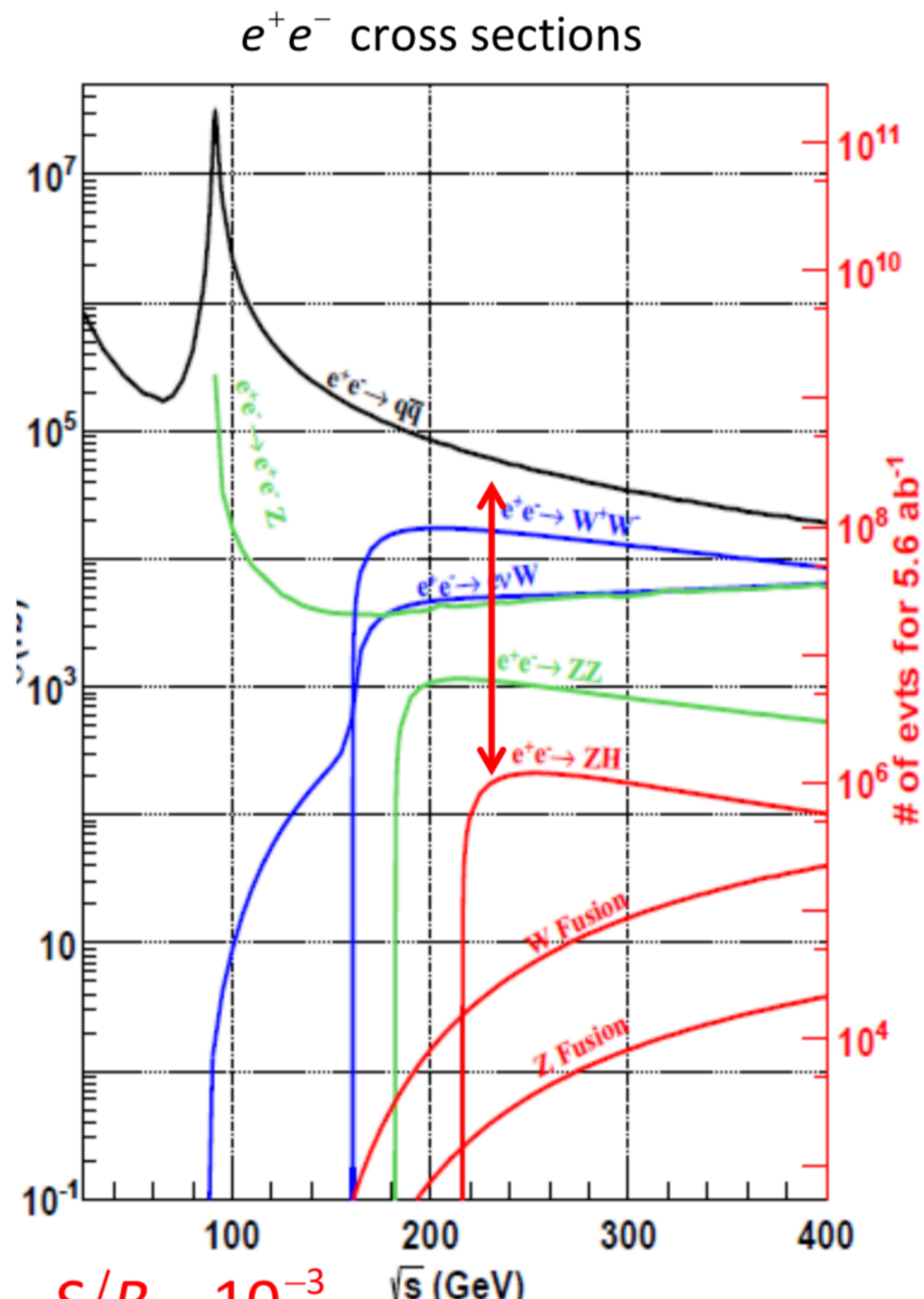
Event rate in 5.6/ab

Process	Cross section	Events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	196.2	1.10×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^- \to e^+e^- H$	0.28	1.57×10^3
Total	203.7	1.14×10^6
Background processes, cross section in pb		
$e^+e^- \to e^+e^- (\gamma)$ (Bhabha)	930	5.2×10^9
$e^+e^- \to q\bar{q}(\gamma)$	54.1	3.0×10^8
$e^+e^- \to \mu^+\mu^- (\gamma)$ [or $\tau^+\tau^- (\gamma)$]	5.3	3.0×10^7
$e^+e^- \to WW$	16.7	9.4×10^7
$e^+e^- \to ZZ$	1.1	6.2×10^6
$e^+e^- \to e^+e^- Z$	4.54	2.5×10^7
$e^+e^- \to e^+\nu W^- / e^-\bar{\nu} W^+$	5.09	2.6×10^7

Cross sections and S/B's



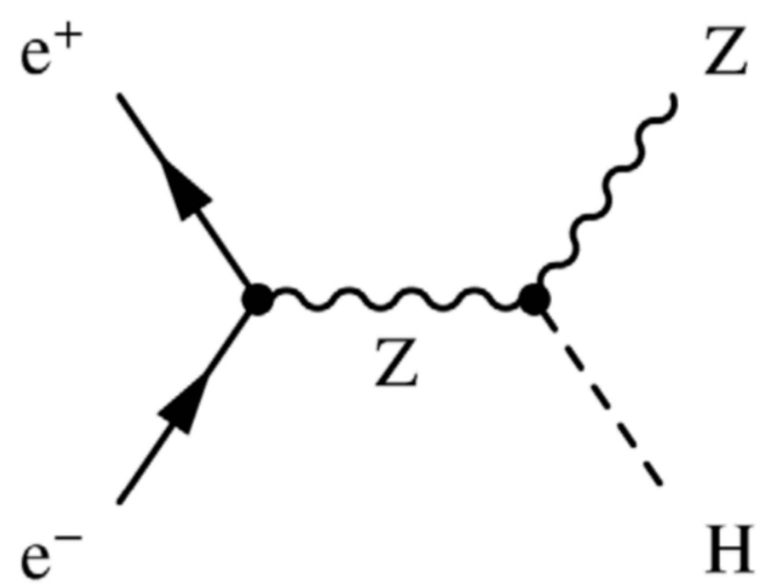
$S/B \sim 10^{-10}$

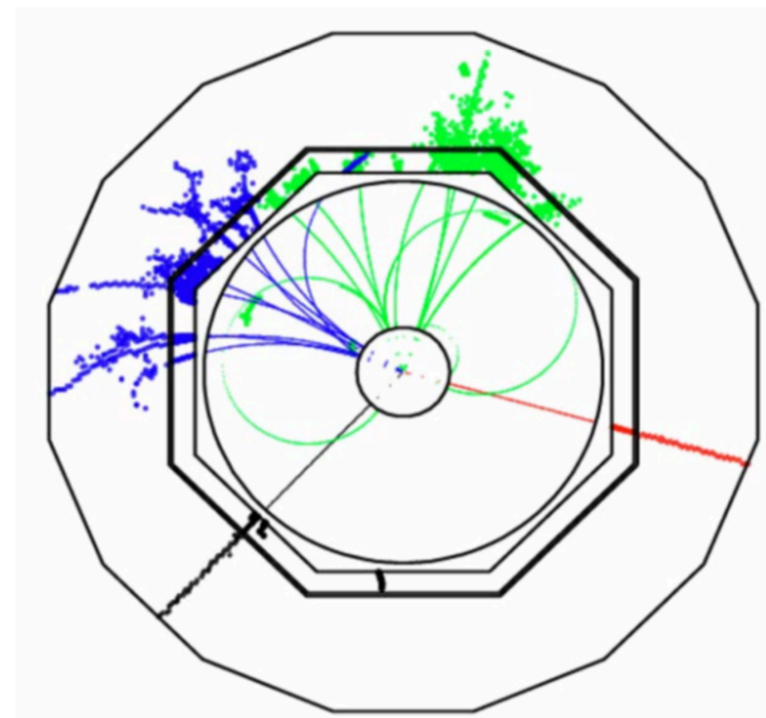


$S/B \sim 10^{-3}$

Model-independent Higgs study

Unique to lepton colliders, the energy and momentum of the Higgs boson in $ee \to ZH$ can be measured by looking at the Z kinematics only: $E_H = \sqrt{s} - E_Z$, $\vec{p}_H = -\vec{p}_Z$





Recoil mass reconstruction:

$$m^2_{\text{recoil}} = \left(\sqrt{s} - E_Z\right)^2 - \left|\vec{p}_Z\right|^2$$

$\Rightarrow$ identify the Higgs boson without looking at the Higgs boson.

Measure $\sigma\left(ee \to ZH\right)$ independent of its decay !

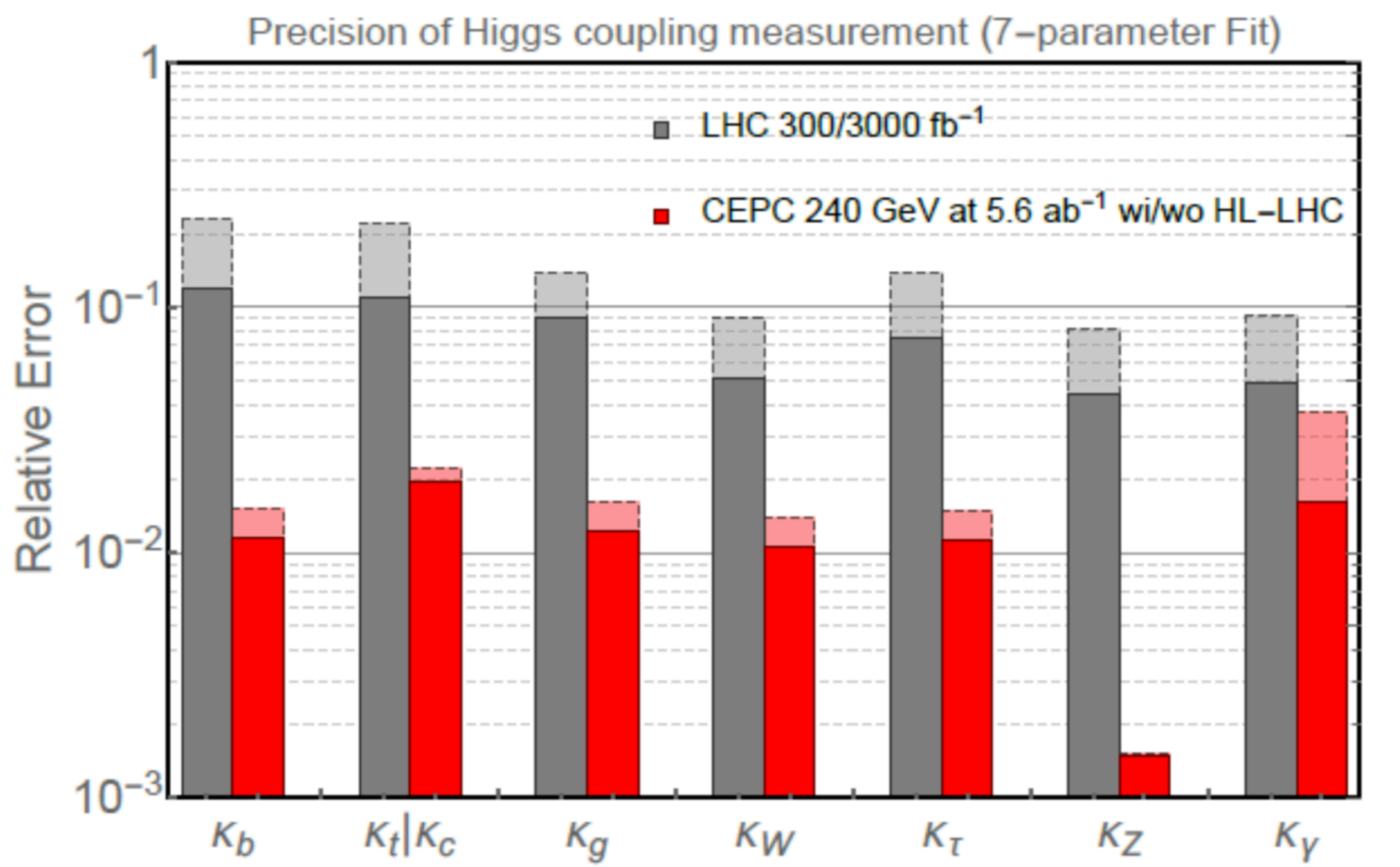
(LHC always measures $\sigma \times \text{BR}$)

Expected precision from combination

Property	Estimated Precision
m_H	5.9 MeV
Γ_H	3.1%
$\sigma(ZH)$	0.5%
$\sigma(\nu\bar{\nu}H)$	3.0%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to b\bar{b}$	0.27%	0.56%
$H \to c\bar{c}$	3.3%	3.3%
$H \to gg$	1.3%	1.4%
$H \to WW^*$	1.0%	1.1%
$H \to ZZ^*$	5.1%	5.1%
$H \to \gamma\gamma$	6.8%	6.9%
$H \to Z\gamma$	15%	15%
$H \to \tau^+\tau^-$	0.8%	1.0%
$H \to \mu^+\mu^-$	17%	17%
$H \to \mathrm{inv}$	–	$< 0.30\%$

$\Leftarrow$ 95% CL upper limit on BSM contribution



Statistical uncertainty only

《概念设计报告》国际评审

IHEP-CEPC-DR-2018-02

IHEP-EP-2018-XX

IHEP-TH-2018-XX

CEPC

Conceptual Design Report

Volume II - Physics & Detector

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Report of the Review of the Circular Electron Positron Collider Conceptual Design Report

This report was prepared by the international review committee:

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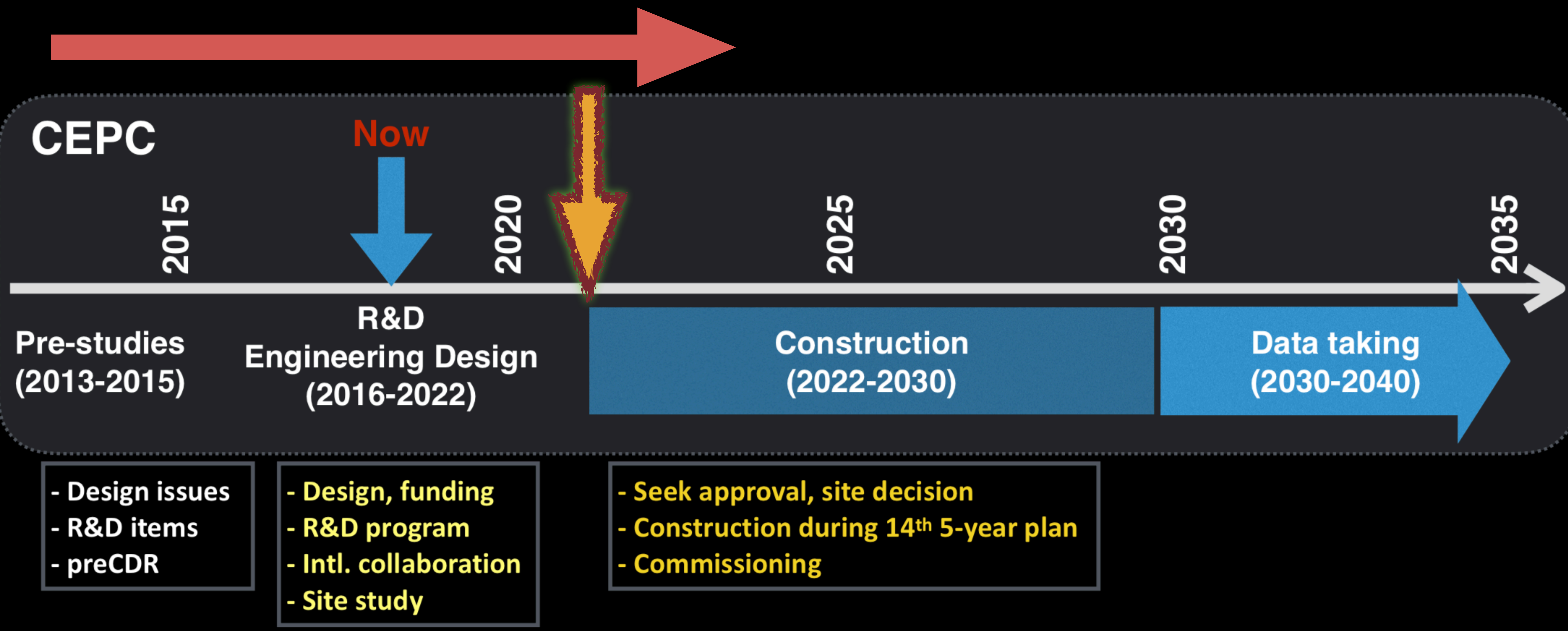
Tao Han, University of Pittsburgh, USA
Bill Murray, Warwick University and RAL, UK
Maxim Perelstein, Cornell University, USA
Marcel Stanitzki, DESY, Hamburg, Germany
Marcel Vos (chair), IFIC UV/CSIC, Valencia, Spain
Hitoshi Yamamoto, Tohoku University, Sendai, Japan

The report is based on v2.0 of the Conceptual Design Report and presentations by and discussions with the CEPC team during the three-day review from 13-15 September in Beijing, People's Republic of China.

… … The scientific goals presented in the report are well motivated and aligned with the priorities of the international high-energy physics community. The report also presents a conceptual design for the CEPC experiments, with plausible solutions to address the main challenges. We believe that the studies reported in the CDR fully achieved the goals appropriate at this stage of the project, and we strongly encourage the CEPC team to proceed with preparation of the technical design report … …

Next milestone - 2022 TDR



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

The 2018 international workshop
on the high energy Circular
Electron–Positron Collider

欢迎注册

2018年11月12–14日,高能所

小结

- CEPC 物理研究主要集中于 Higgs的精确测量，同时可以也包含电弱标准模型检验和味物理研究
- 在过去几年当中，得到各方支持，取得了多项进展。
- 加速器和探测器的《概念设计报告》已经顺利完成，已经通过了国际评审；在完成最后的改进和润色后，计划于下个月发布
- 计划于2022年完成技术设计报告，使建造准备工作就绪
  - ☑ 完成关键技术的攻关，给出完善的建设方案
  - ☑ 建立广泛的国际合作
- 还有很多研究工作未在报告中介绍，特此歉意
- CEPC 研究工作组是一个高效、强有力的团队，但能走到这一步，离不开整个 community 的支持，希望有更多人的参与和帮助，实现我们的共同梦想。

Thanks a lot

Extras

Comparison with FCC–ee

Relative precision of Higgs couplings

	CEPC		FCC-ee*
	5.6 ab^{-1}, 240 GeV		5 ab^{-1}, 240 GeV
Correlations	included	ignored	ignored
Γ_H	3.1%	2.9%	2.8%
κ_b	1.6%	1.4%	1.4%
κ_c	2.2%	2.1%	1.8%
κ_g	1.6%	1.5%	1.7%
κ_W	1.4%	1.3%	1.3%
κ_Z	0.25%	0.25%	0.25%
κ_γ	3.7%	3.7%	4.7%
κ_τ	1.5%	1.4%	1.4%
κ_μ	8.7%	8.7%	9.6%
BR_{inv}^{BSM}	$< 0.3\%$	$< 0.3\%$	–

* presented at ICHEP 2018