Mini-Workshop Summary: Physics Requirements for e^+e^- Colliders

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

João Guimarães da Costa
(for the Mini-workshop Speakers and Participants)

Why a physics requirements workshop?

- Current physics requirements on detectors for e^+e^- Circular Colliders mostly inherited from Linear Collider studies
  - There have been some discussions/thoughts about them, but no systematic re-analysis of their validity
  - Conditions are similar but not exactly the same (energy, backgrounds, …)

❖ Requirements:

CEPC/FCC-ee

➢ Constraints from physics (similar to LC …. but not exactly!)

Physics process	Measurands	Detector subsystem	Performance requirement	From CDR
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$	Too tight?
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$	Not enough?
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV	Too tight?
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$	Not enough?

- Excellent acceptance and luminosity control
- PID & π^0 ID for HF/τ physics
- Low B field to avoid emittance blow up
- Power pulsing not allowed

$\Big\}$ Not present at LC

Why a physics requirements workshop?

- Current physics requirements on detectors for e^+e^- Circular Colliders mostly inherited from Linear Collider studies
  - There have been some discussions/thoughts about them, but no systematic re-analysis of their validity

- Idea:
  - Bring together principals from the Linear Collider community, theorists and experimentalists from CEPC/FCC-ee to discuss how we got here, and what needs to be re-evaluated and re-considered.
  - Explore new ideas and consequent detector requirements that were not considered before

Workshop intended to be a kick-off of this work

Agenda

Session 1
Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA

09:00 - 10:00	**Physics at a Circular Collider (sqrt(s) = 91-365 GeV) [Slides]** **Jiayin GU** *Johannes Gutenberg University Mainz*
10:00 - 10:30	**Discussion**
10:30 - 11:00	Group Photo and Coffee Break (Venue: Open Area, 1/F)
11:00 - 11:45	**Theoretical Tools [Slides]** **Alessandro VICINI** *University of Milan*
11:45 - 12:30	**ILC Detector Requirements [Slides]** **Jim BRAU** *University of Oregon*
12:30 - 14:00	Lunch (Self-arranged)

Session 2
Chairs: Paolo GIACOMELLI and Joao GUIMARAES DA COSTA

14:00 - 14:45	**CLIC Detector Requirements [Slides]** **Andre SAILER** *CERN*
14:45 - 15:25	**Tracking Requirements [Slides]** **Zhijun LIANG** *Institute of High Energy Physics, Chinese Academy of Sciences*
15:25 - 16:05	**Calorimeter Requirements [Slides]** **Yong LIU** *Institute of High Energy Physics, Chinese Academy of Sciences*
16:05 - 16:25	Coffee Break (Venue: Open Area, 1/F)
16:25 - 16:55	**Future Activities at FCC [Slides]** **Paolo GIACOMELLI** *National Institute for Nuclear Physics (INFN, Bologna)*
16:55 - 17:40	**Future Activities and Discussion [Slides]** **Moderators: Paolo GIACOMELLI, Joao GUIMARAES DA COSTA and Manqi RUAN**

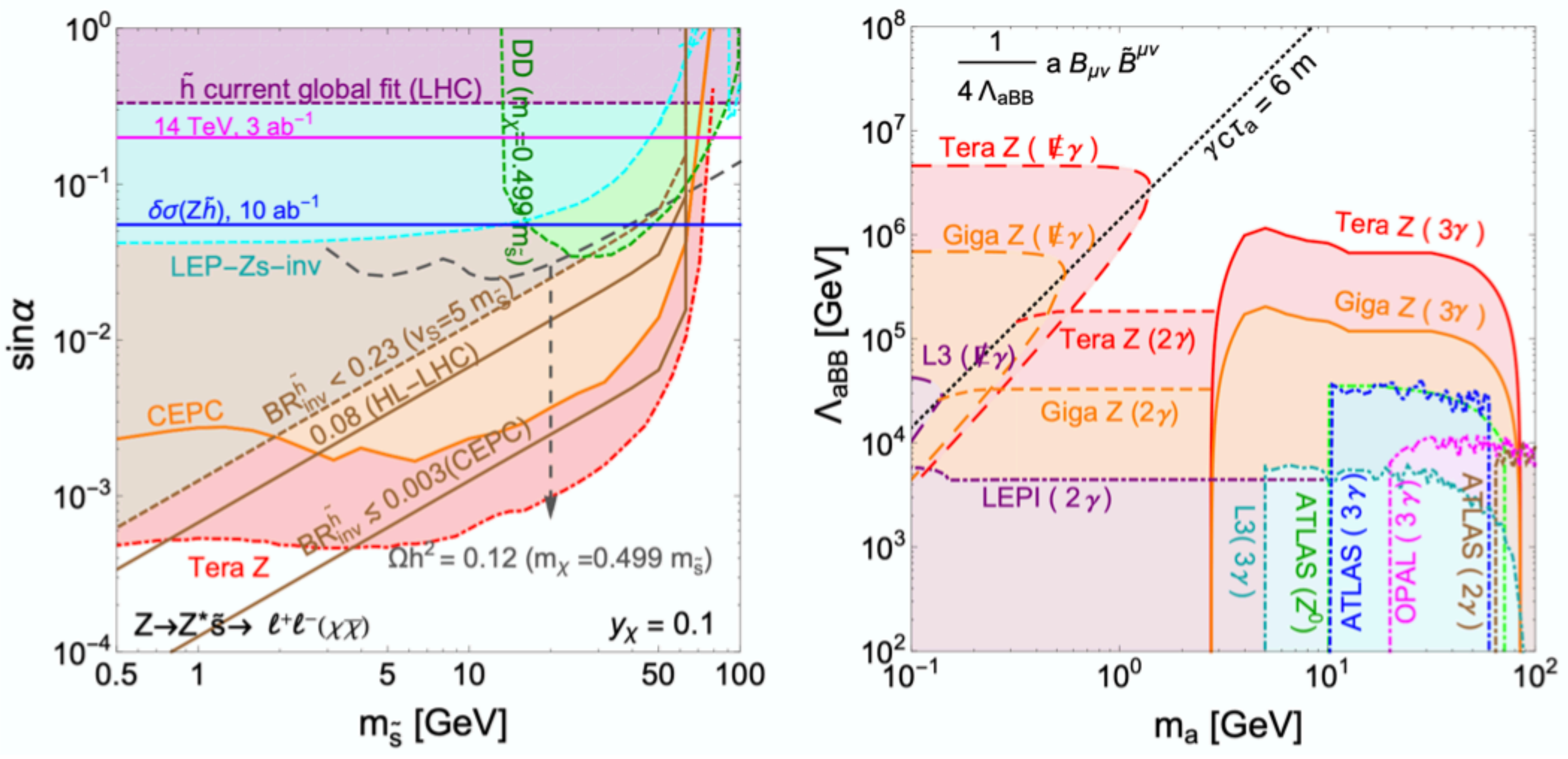
http://iasprogram.ust.hk/hep/2020/workshop_experiment.php

What can circular e^+e^- colliders do for us

- ***Z*** **factory** (~ 91 GeV)
  - *Z* mass, width, *Zff* couplings
  - *Z* Exotic decays, flavor...
- ***W*** **factory** (~ 157–172 GeV)
  - *W* mass, width, *Wff* couplings
- **Higgs factory!** (240 GeV)
  - Higgs mass, width, couplings
  - *WW* measurements (largest *WW* sample, also Triple Gauge Couplings)
  - Triple Higgs coupling (indirect)
  - Higgs Exotic decays
- **Top factory** (~ 340–365 GeV)
  - Top mass, width, couplings
  - Higgs couplings, triple Higgs coupling (indirect & global)
  - *WW* measurements (TGCs)
  - top exotic decays, (direct searches?)
- **Implications:** Hierarchy problem, dark matter, baryogenesis, ...

Photon benchmark: good angle separation

Dark matter / ALPs [arXiv:1712.07237] Liu, Wang, Wang, Xue



- **Left:** Higgs portal dark matter (sin α is the dark Higgs mixing angle).
- **Right:** Axion-like particle, $Z \to \gamma a$, $a \to \gamma\gamma$.

Flavor, radiative return and detector forward region

Flavor

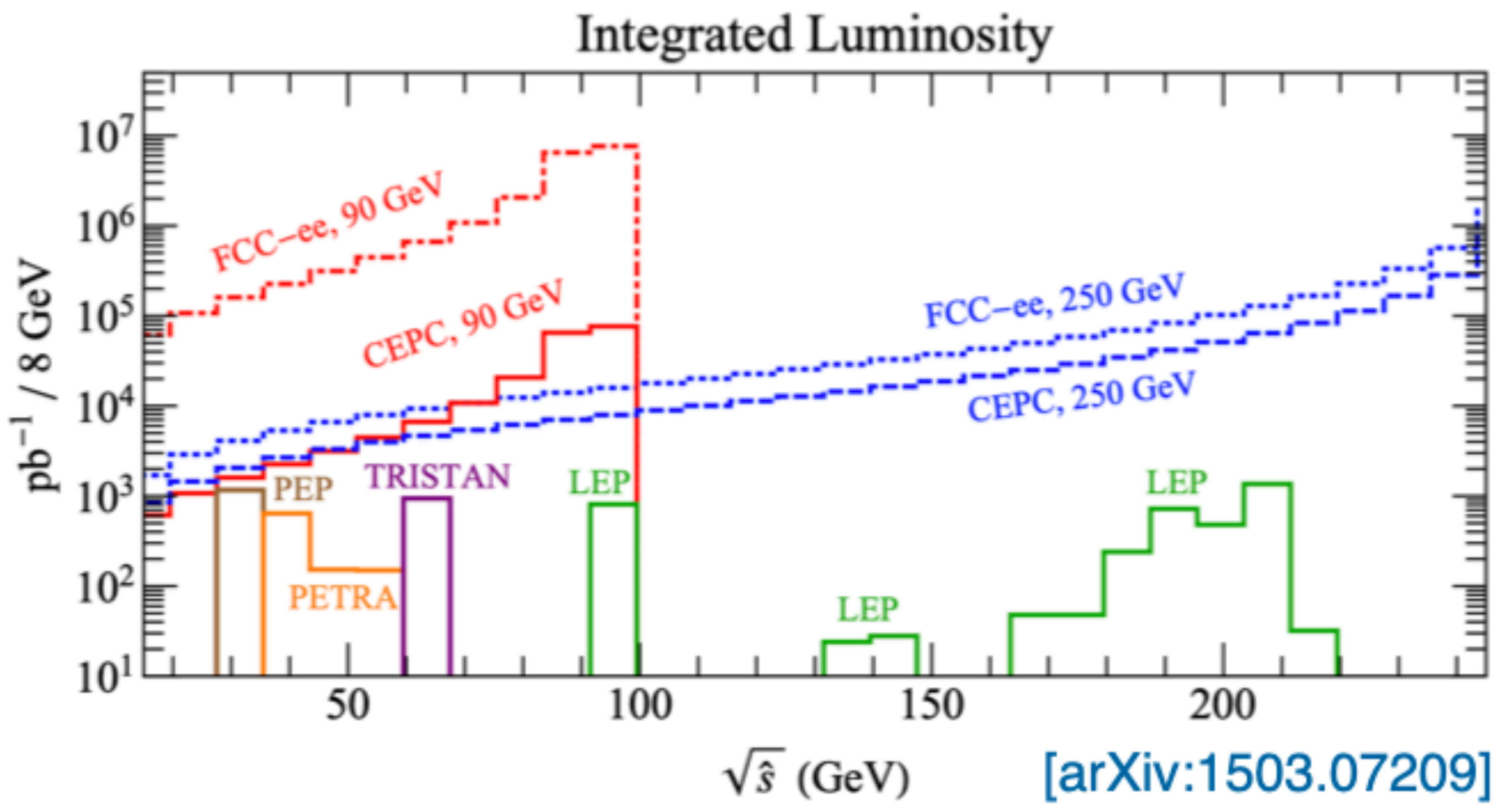
CEPC CDR

Particle	Tera-Z	Belle II	LHCb
b hadrons			
B^+	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} ($5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b	1×10^{10}		1×10^{13}
c hadrons			
D^0	2×10^{11}		
D^+	6×10^{10}		
D_s^+	3×10^{10}		
Λ_c^+	2×10^{10}		
τ^+	3×10^{10}	5×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	

CEPC CDR

$$\mathrm{BR}(Z\to\mu e)_{\mathrm{CEPC}} \lesssim 3\times10^{-9}\ [1/\sqrt{N}\ \mathrm{scaling}],\ 7\times10^{-12}\ [1/N\ \mathrm{scaling}],$$
$$\mathrm{BR}(Z\to\tau e)_{\mathrm{CEPC}} \lesssim 2\times10^{-8}\ [1/\sqrt{N}\ \mathrm{scaling}],\ 4\times10^{-11}\ [1/N\ \mathrm{scaling}],$$
$$\mathrm{BR}(Z\to\tau\mu)_{\mathrm{CEPC}} \lesssim 2\times10^{-8}\ [1/\sqrt{N}\ \mathrm{scaling}],\ 5\times10^{-11}\ [1/N\ \mathrm{scaling}],.$$

- Tera Z factory is also a flavor factory!
  - A lot of b, c hadrons and τ leptons from Z decays.
  - Cleaner environment, larger boost.
- Flavor violating Z decay.
- Covering lower $\sqrt{s}$ via radiative returns.
  - Most events are in the forward region.



[arXiv:1503.07209] Karliner, Low, Rosner, Wang

Theoretical tools and open issues for EW precision studies at a future e+e- collider

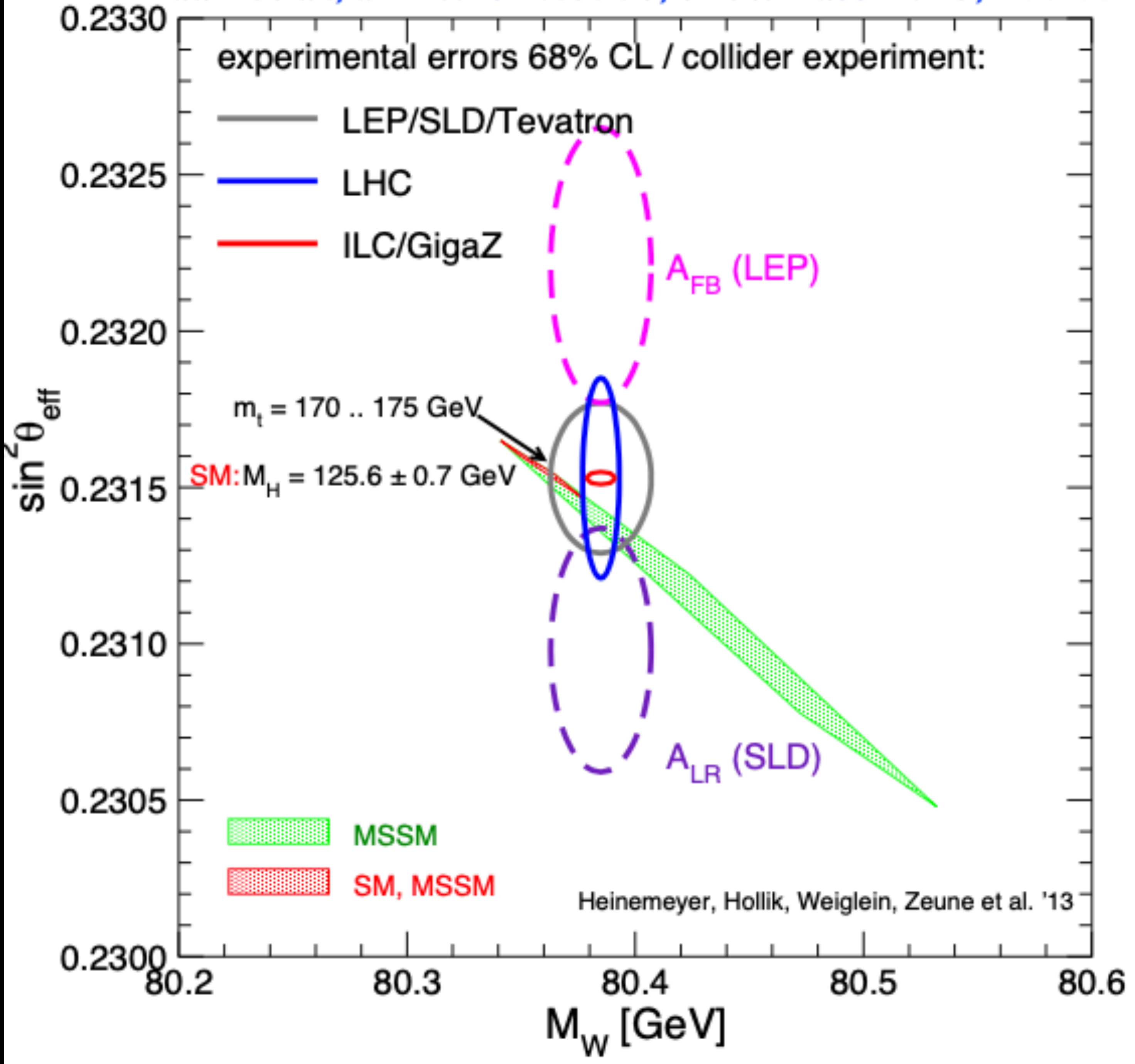
Alessandro Vicini

University of Milano, INFN Milano

Hong Kong, January 16th 2020

Relevance of new high-precision measurement of EW parameters

Baak et al., arXiv:1310.6708, Snowmass 2013, EW WG

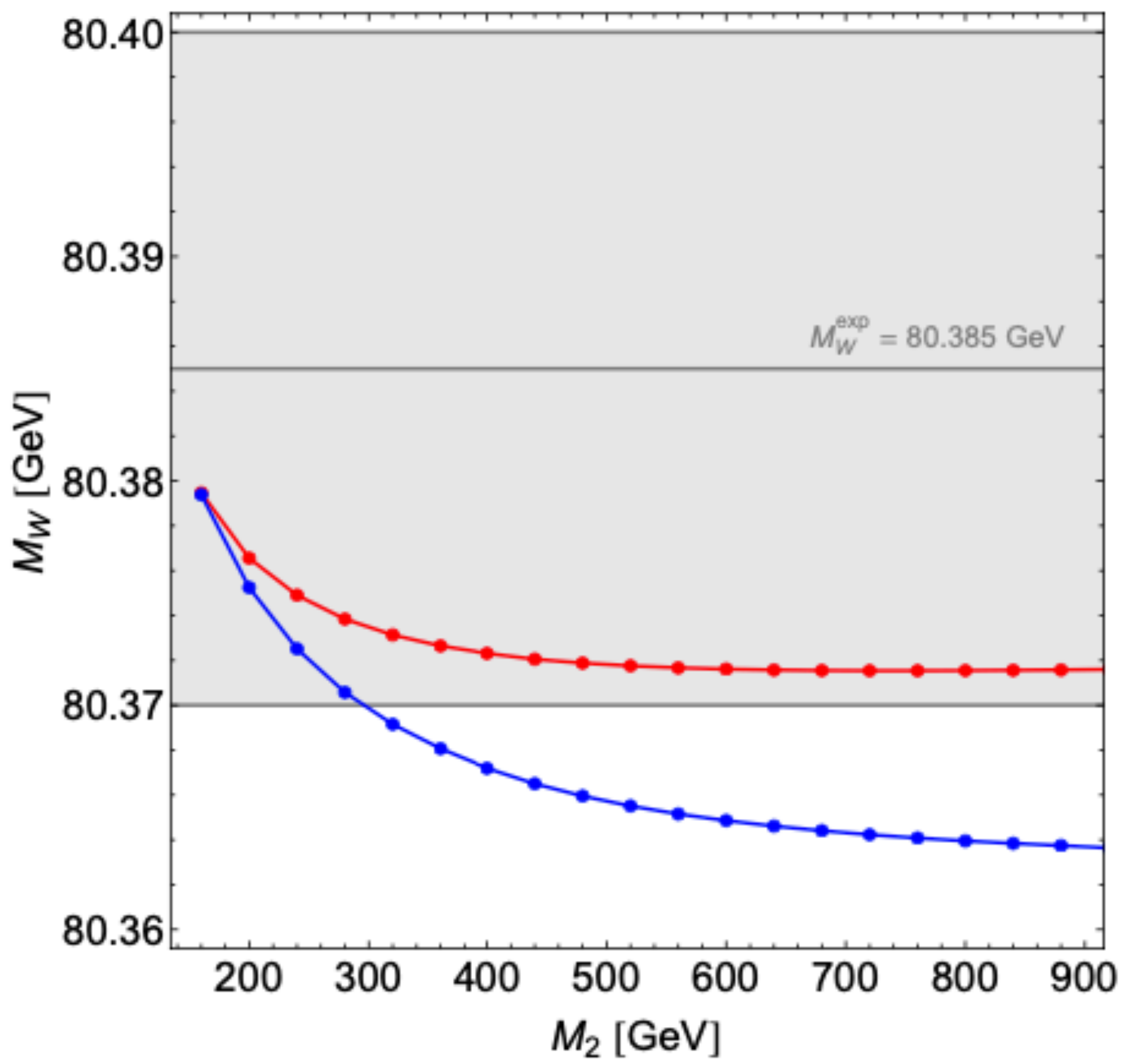


The precision measurement of MW and $\sin^2\theta_{eff}$
with an error of 0.7 MeV and 0.000004
(5 MeV and 0.000100 at a hadron collider)
(formidable challenges!)
would offer a very stringent test of the SM likelihood

In the case a BSM particle had been discovered
a very precise MW value would offer
a strongly discriminating tool about the mass spectra
in BSM models

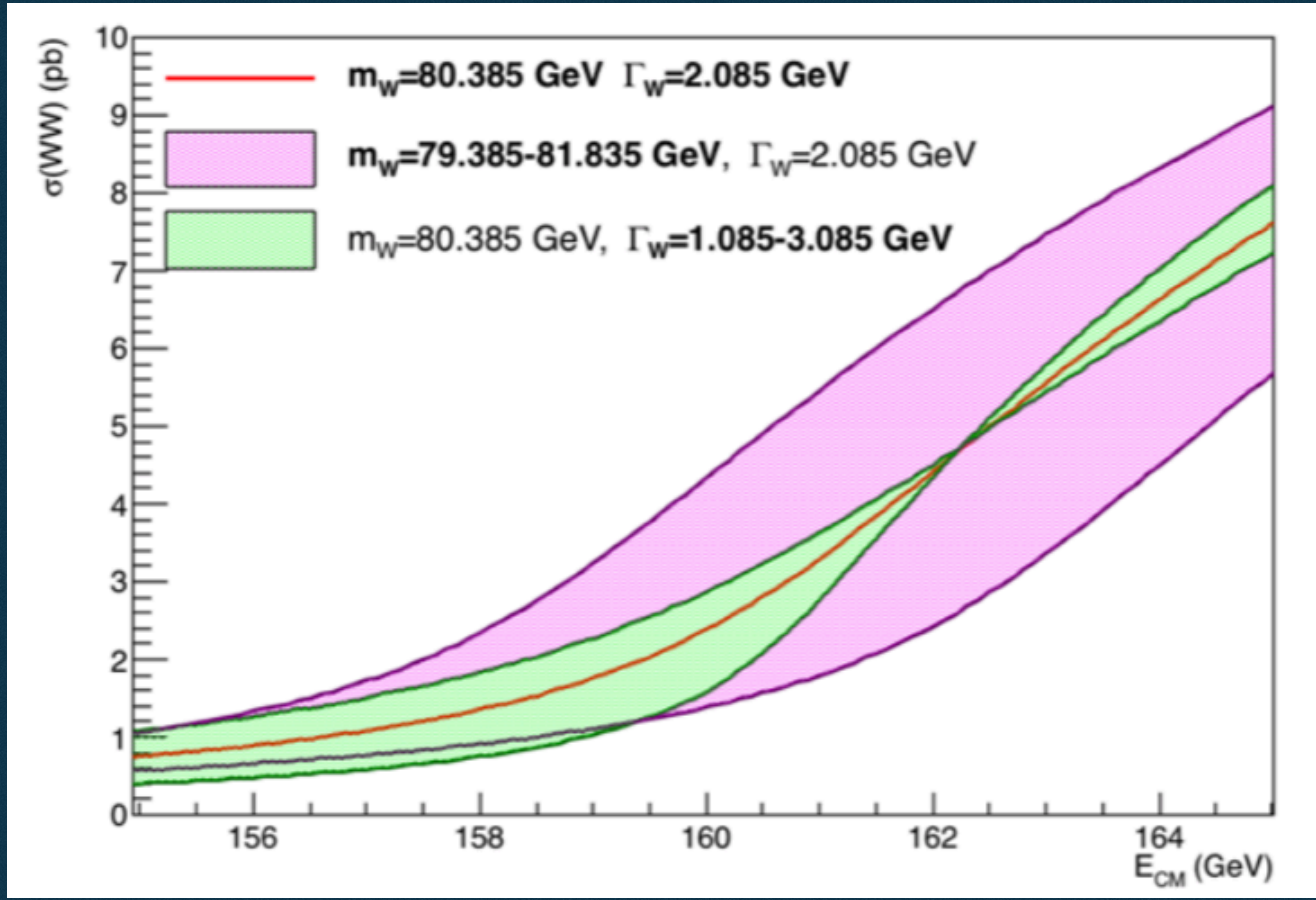
different dependence on the neutralino mass M_2
of the MW prediction in the MSSM and NMSSM

O. Stål, G. Weiglein, L. Zeune, arXiv:1506.07465



W Mass determination from WW Scan

W Mass from Threshold Scan



Similar to LEP technique
Use 3 √s points: 157.5, 161.5 and 162.5 GeV

Beam energy spread: <0.1%
E_{CM} uncertainty: <0.5 MeV

L = 2.6 ab^{-1} → $\Delta M_W \sim 1$ MeV

with E_1=157.1 GeV E_2=162.3
Δm_W=0.62 $\Delta\Gamma_W$=1.5 (MeV)

$$\sigma_0(s) \approx \frac{\pi\alpha^2}{s}\frac{1}{4s_W^4}4\beta + O(\beta^3)$$

$\Delta\sigma$=0.1% ⟶ ΔMW =1.5 MeV

Experimentally: $\Delta\sigma$ = 0.02 %

Theoretical goal: prediction $\Delta\sigma$ = 0.01 %

Will require the full NNLO-EW calculation (2→4 process!) with 3-loop contributions

Considerable theory work required to match experimental uncertainties

ILC Detector Energy Range

- Center-of-mass energies:
  - 200 GeV up to 1 TeV.
  - Special running at the Z-pole and WW threshold.
  - Higgs Factory, Giga-Z, Top Yukawa couplings, di-boson production, SUSY, other new physics motivated by alternative models.
  - Each physics topic creates a particular set of requirements.
- Detector designs developed for the full energy range.

TDR

ILC at 500 GeV

↓

ILC at 250 GeV milder conditions

Physics Drives Detector Requirements

Clean events with low backgrounds motivate unprecedented detector performance

Physics Process	Measured Quantity	Critical System	Critical Detector Characteristic	Required Performance
$H \to b\bar{b}, c\bar{c}, gg, \tau\tau$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impact parameter ⇒ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu} \to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR ($H \to \mu\mu$)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ ⇒ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$

Physics Drives Dete

Clean events with low backgrounds motiv

Physics Process	Measured Quantity	Critical System	
$H \to b\bar{b}, c\bar{c}, gg, \tau\tau$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impa
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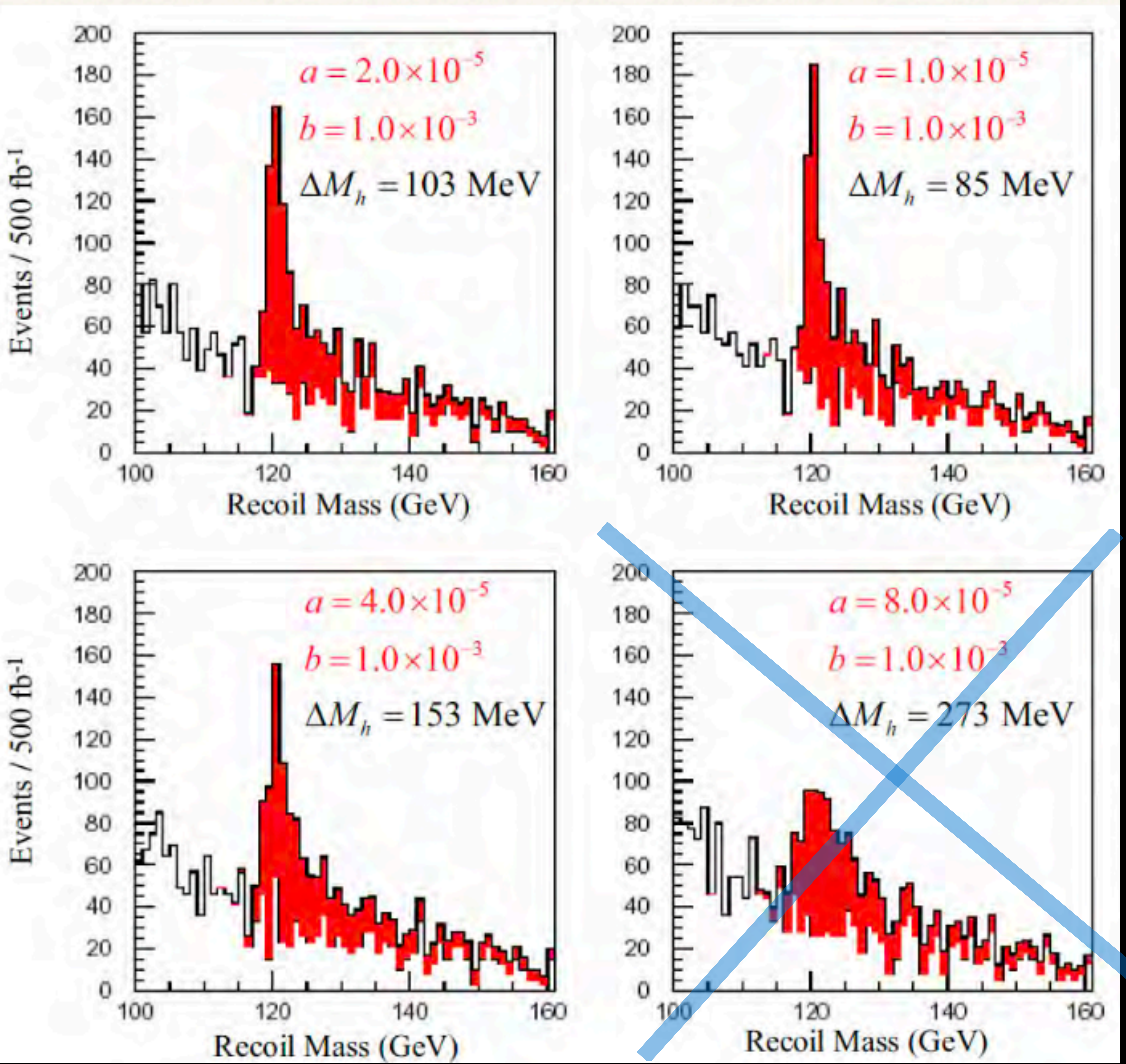
$$\delta p_T/(p_T)^2 = a \oplus b/(pT \sin\theta)$$



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ZH→$\ell^+\ell^-$X $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu}$ $\to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR (H →μμ)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ ⇒ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$
ZHH $ZH \to q\bar{q}b\bar{b}$ ZH→ZWW* $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass BR (H → WW*) σ(e+e- → νν W+W-)	Tracker & Calorimeter	Jet Energy Resolution, σ_E/E ⇒ Di-jet Mass Res.	~3% for E_{jet} > 100 GeV $30\%/\sqrt{E_{jet}}$ for E_{jet} < 100 GeV
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum resolution, Hermiticity ⇒ Event Reconstruction	Maximal solid angle coverage

High granularity, dense integration, super light materials, low power, air cooling, power pulsing

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CEPC

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

$$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$$

$$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\% \text{ at } 100 \text{ GeV}$$

Unprecedented Detector Challenges

- **Requirements for ILC**
  - Impact parameter resolution

    $$\sigma_{r\varphi} \approx \sigma_{rz} \approx 5 \oplus 10/(p \sin^{3/2}\vartheta)\ \mu m$$

  - Momentum resolution

    $$\sigma\left(\frac{1}{p_T}\right) \sim \text{few} \times 10^{-5}\ (GeV^{-1})$$

  - Jet energy resolution goal

    $$\frac{\sigma_E}{E_{jet}} = \ \sim 3\% \text{ for } E_{jet} > 100 \text{ GeV}$$

  - Maximal solid angle coverage

Compared to best performance to date

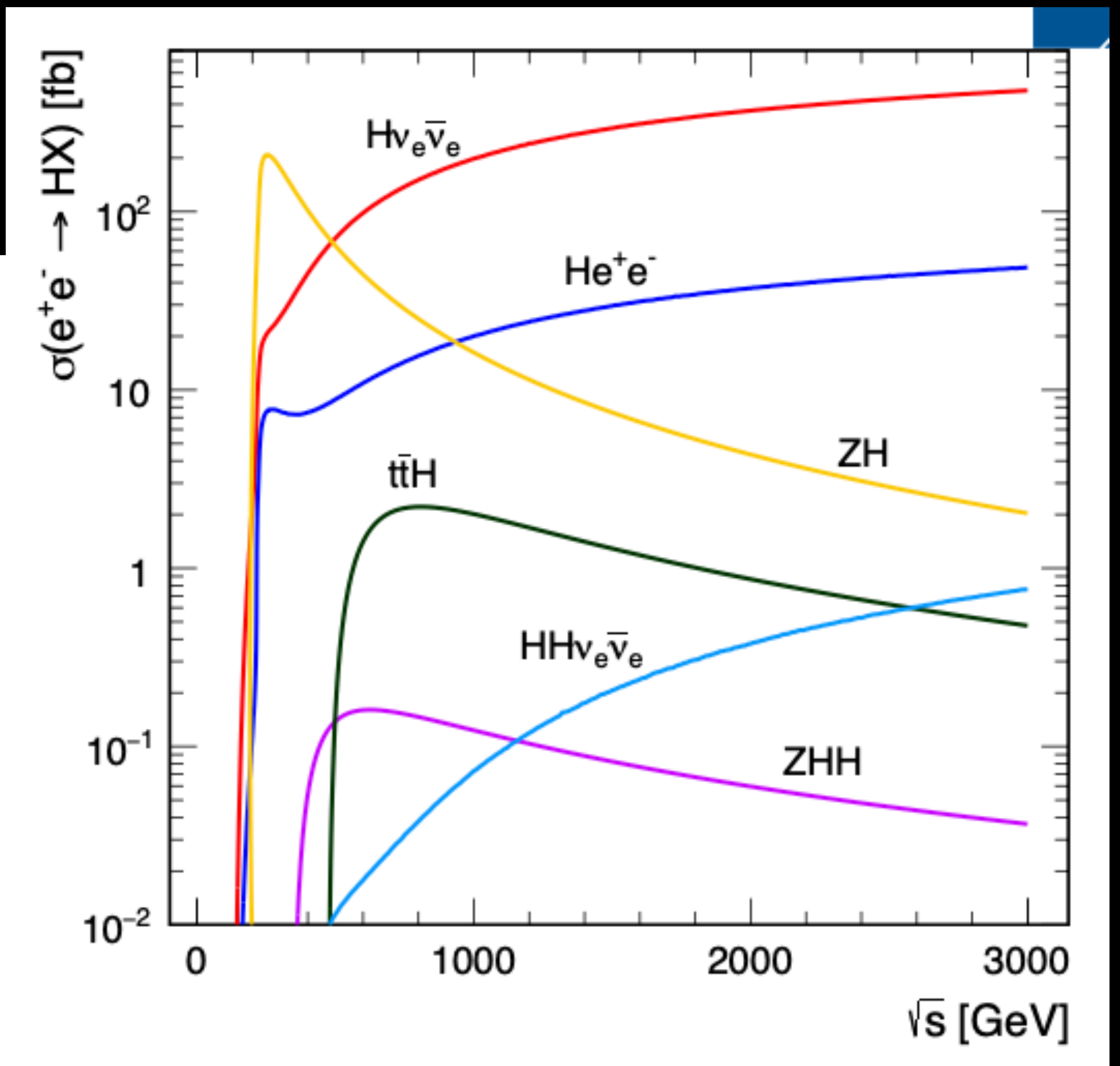
Requires 3 times better than SLD

Requires >10 (3) times better than LEP (CMS)

Requires 2 times better than ZEUS

Beyond prior experiments, LHC, LEP or SLD.

CLIC Detector: Design for physics up to 3 TeV



Detector for CLIC

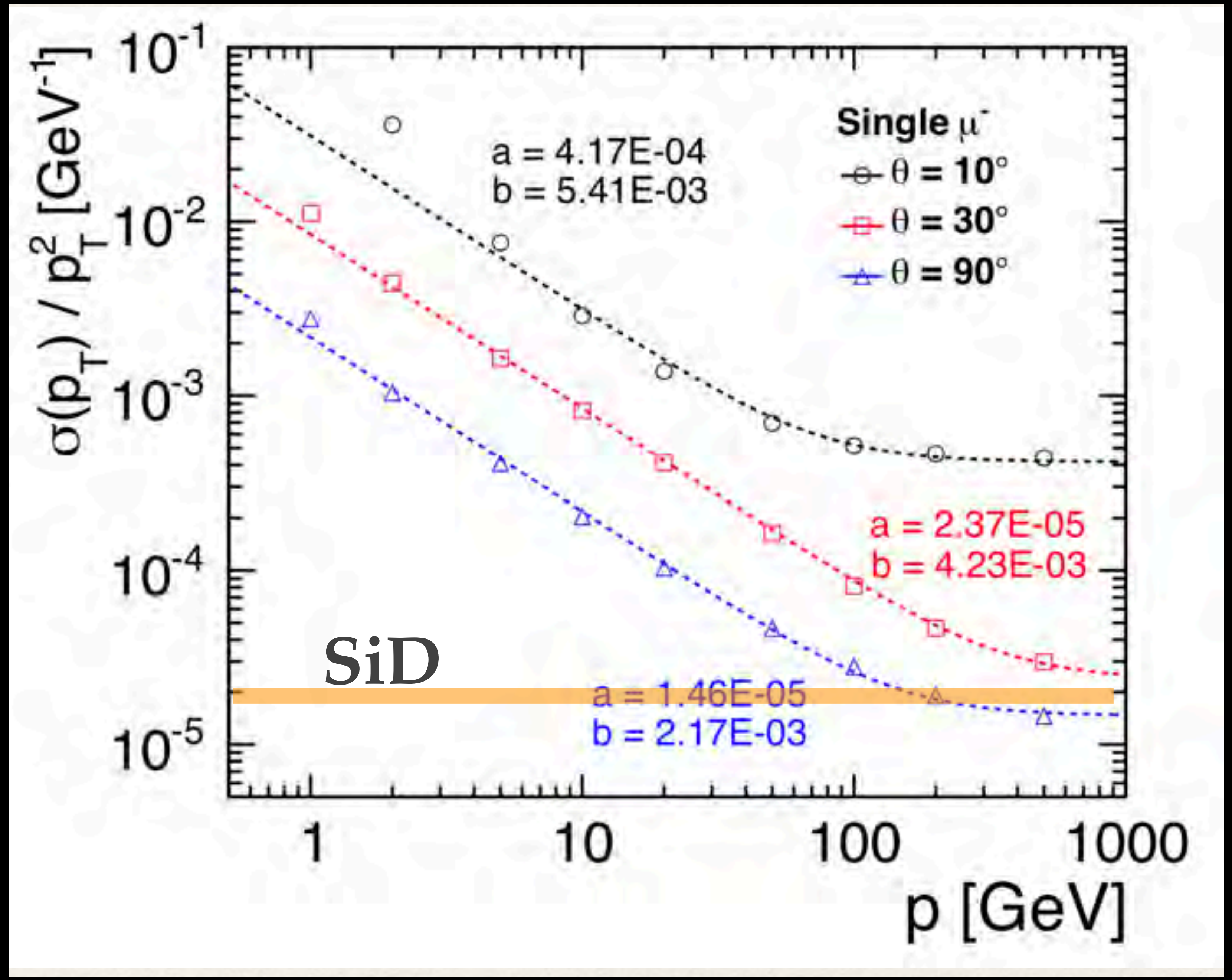
General purpose detector for Particle Flow reconstruction [3]

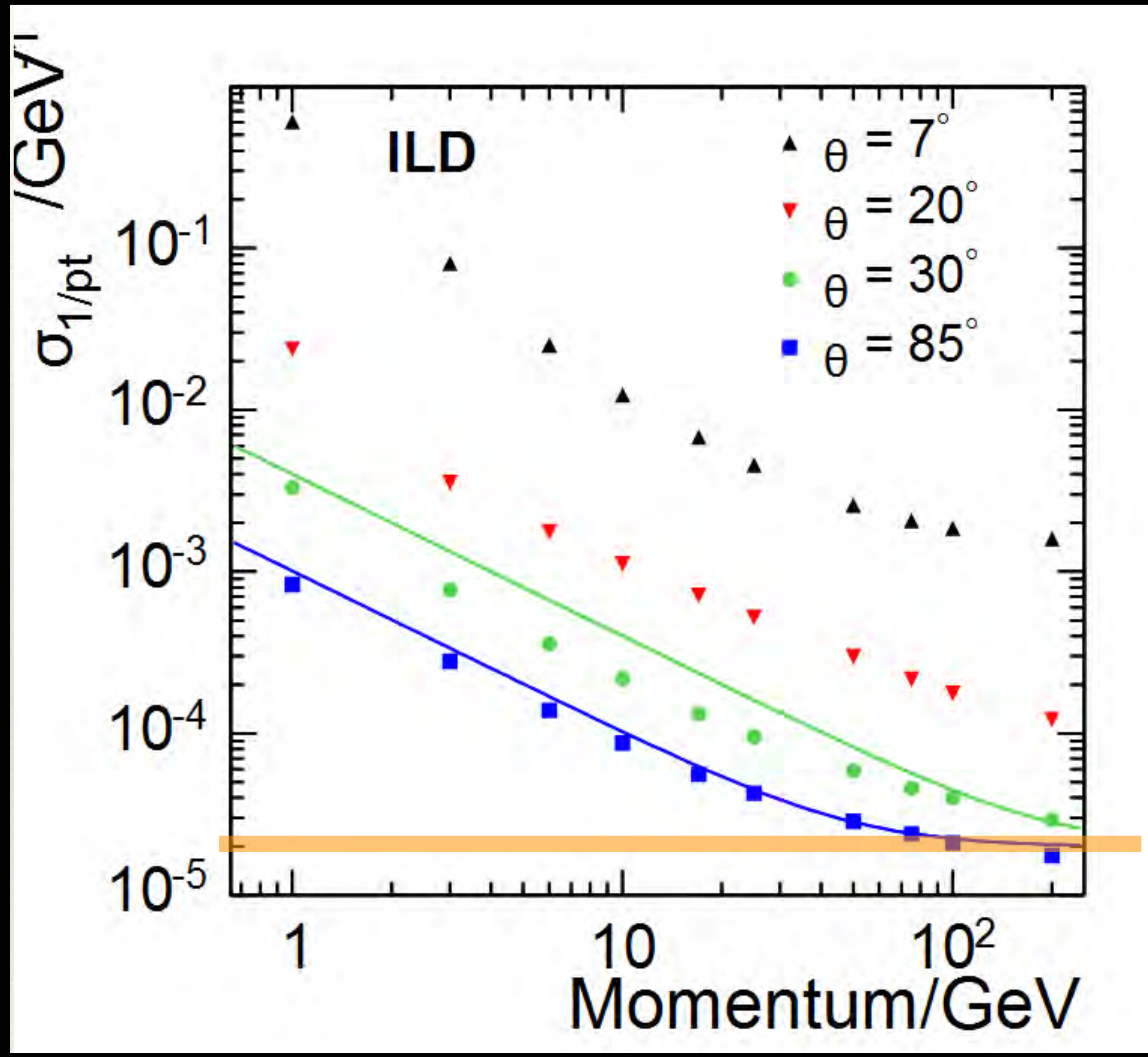
- Steel–Scintillator HCal with 3 cm cell-size
- Silicon–Tungsten ECal with 5 mm cell-size
- Silicon Tracker, mostly 50 μm pitch strips
- Vertex Detector with 25 μm pixels

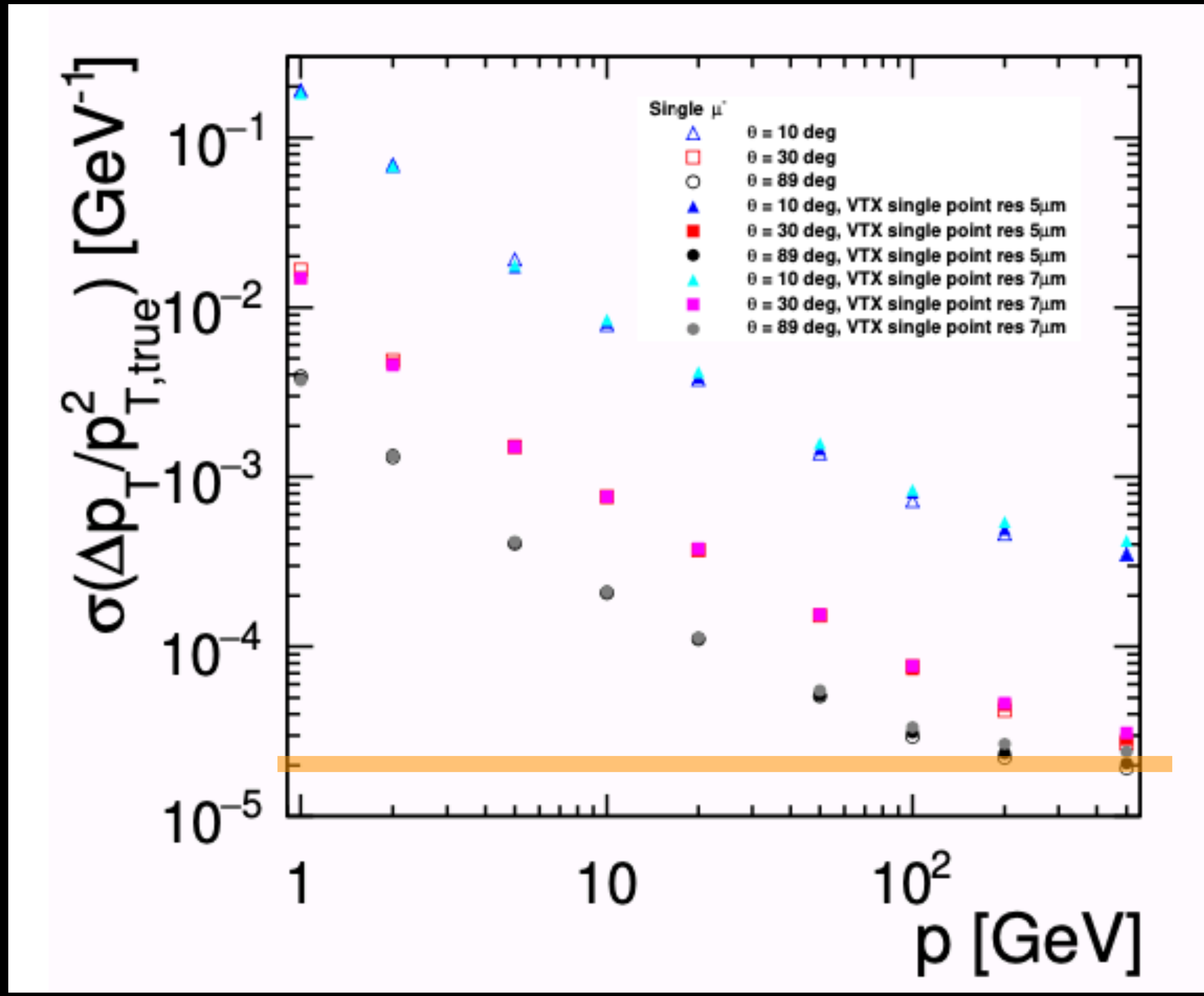
- Superconducting Solenoid of 4 T
- Iron Yoke with RPCs for Muon ID
- End-coils
- Forward calorimeters for EM coverage down to 10 mrad

Momentum resolution

SiD	ILD	CLICdet
5 Tesla	3.5 Tesla	4 Tesla







CEPC
+
FCC-ee

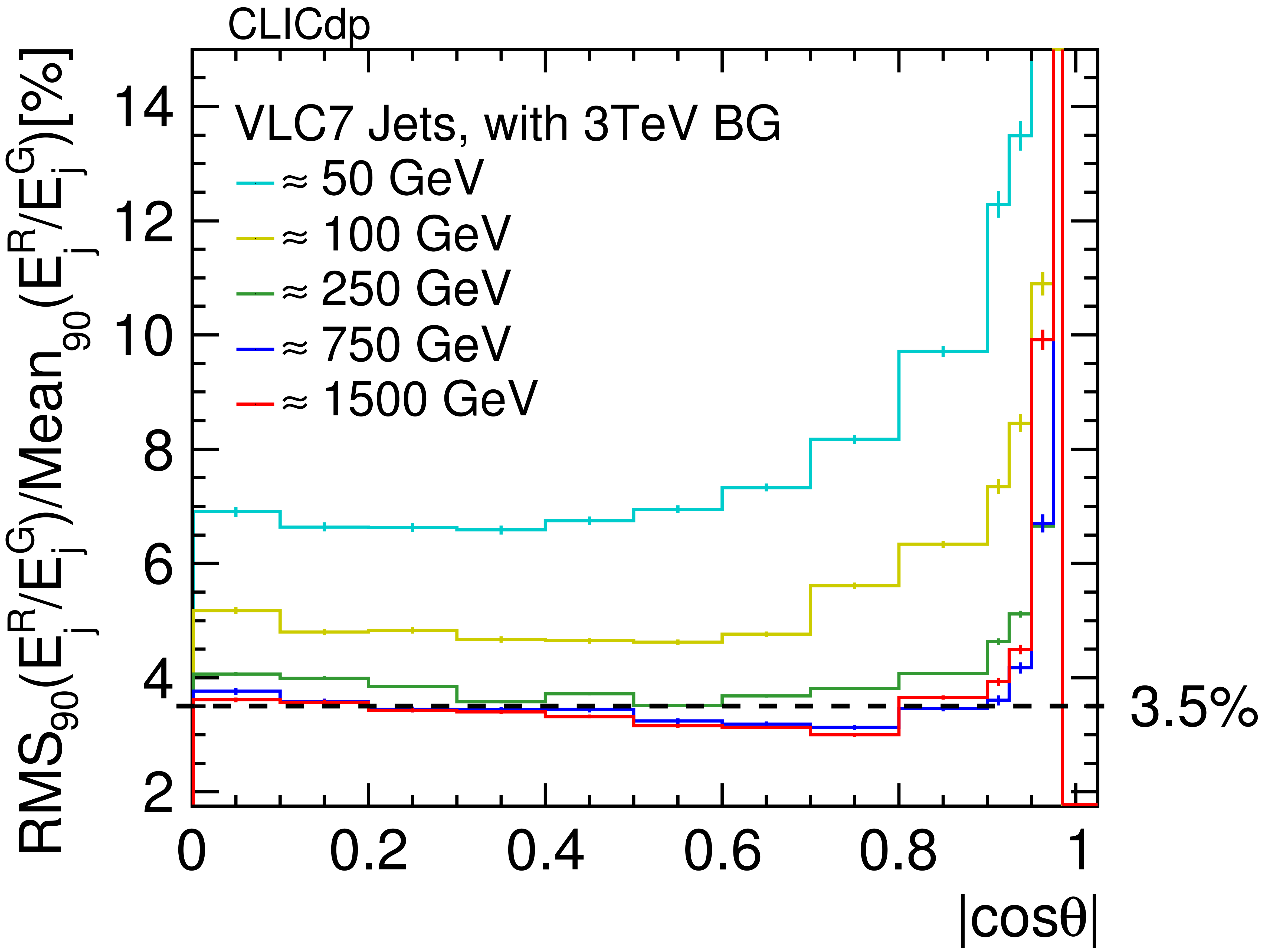
2 - 3 Tesla

Challenging to achieve same momentum resolution

Jet Energy Resolution

- Reaching 3.5% jet energy resolution for high energy jets in the barrel [6]
- **Endcap region more affected by** $\gamma\gamma \rightarrow$ hadron **backgrounds, which are forward peaked**

central jet energy resolution:
7% (50 GeV jets)
3.5% (1 TeV jets)

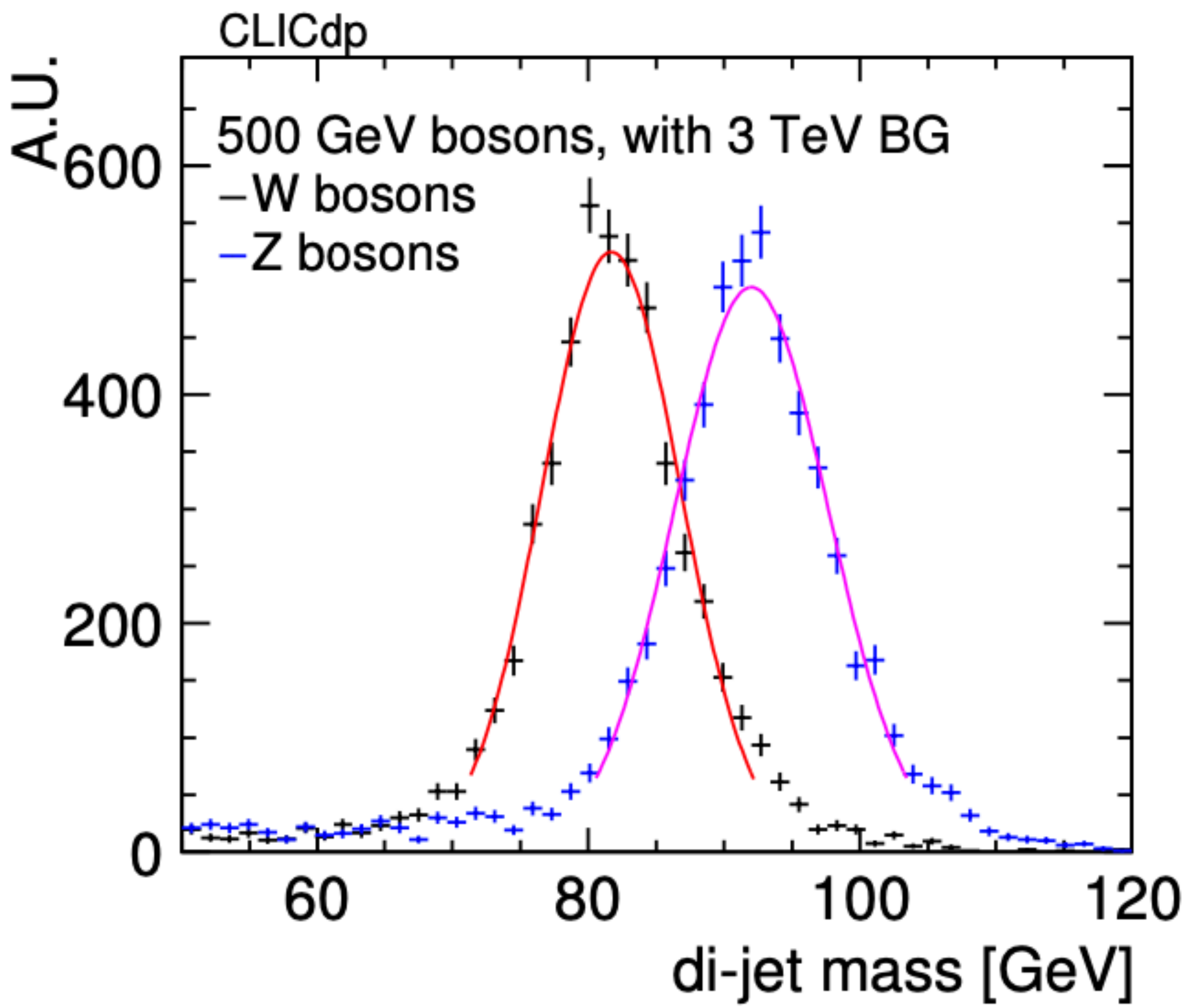


W/Z-Separation

https://clic.cern

- Jet energy resolution good enough for $\approx 2\sigma$ separation between jets from W and Z bosons [6]
- For different boson energies and including backgrounds

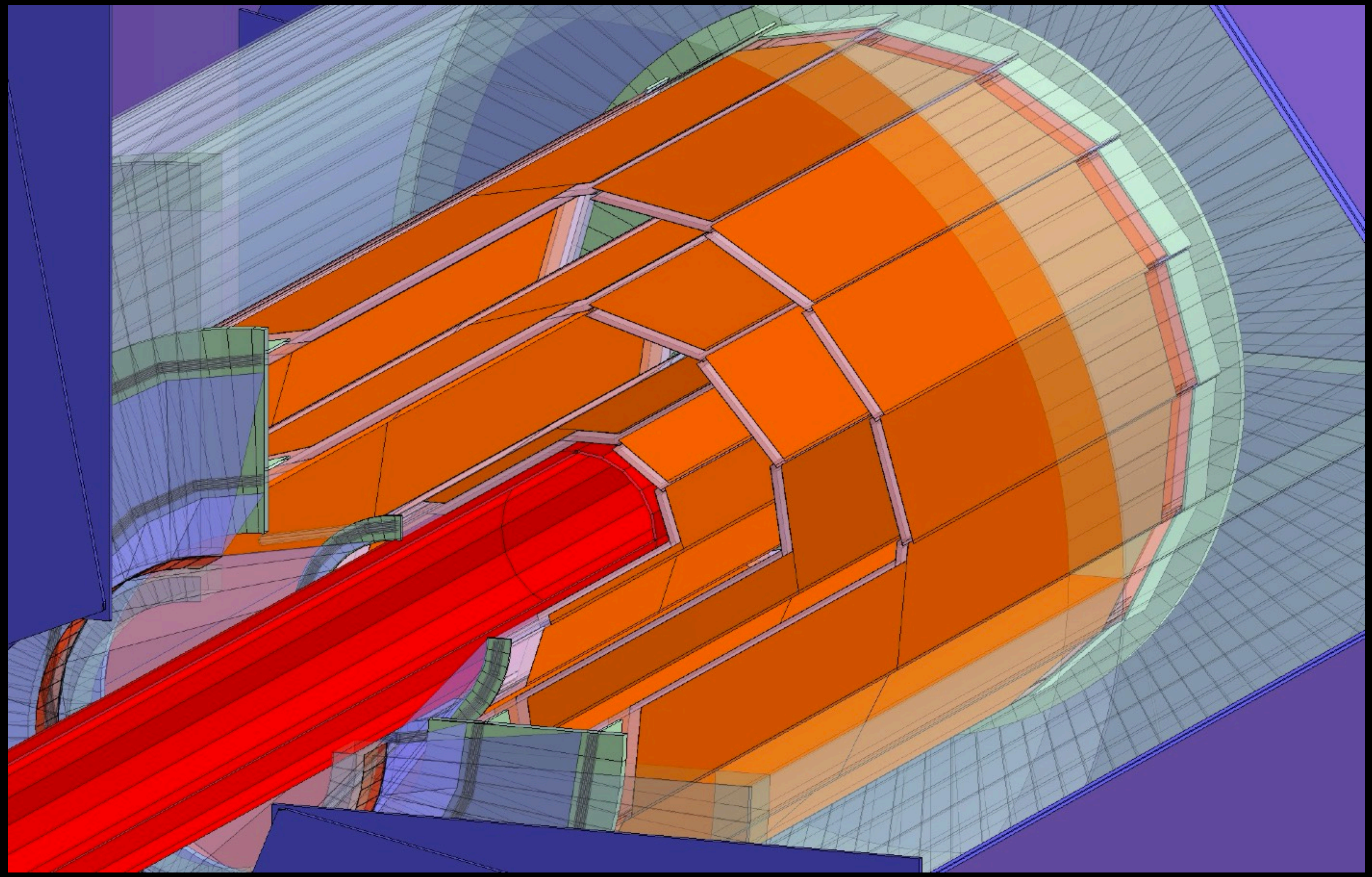
Background	$E_{\mathrm{W,Z}}$ [GeV]	$\sigma_{m(\mathrm{W})}/m(\mathrm{W})$ [%]	$\sigma_{m(\mathrm{Z})}/m(\mathrm{Z})$ [%]	ε [%]	Separation [σ]
no BG	125	5.5	5.3	88	2.3
	250	5.3	5.4	88	2.3
	500	5.1	4.9	90	2.5
	1000	6.6	6.2	84	2.0
3 TeV BG	125	7.8	7.1	80	1.7
	250	6.9	6.8	82	1.8
	500	6.2	6.1	85	2.0
	1000	7.9	7.2	80	1.7
380 GeV BG	125	6.0	5.5	87	2.2



Challenges in vertex detectors

Vertex detector design
driven by needs of flavor tagging

- Extremely accurate/precise
- Extremely light



Large surfaces: ~ 1 m^2

Single point resolution
$\sigma < 3 - 5\ \mu m$

→ Pixel pitch
~ 16 – 25 μm

Low material budget
< 0.1 — 0.3% X_0 per layer

→ Thin sensors and ASICs
Light-weight support

→ Power pulsing (LC)
Air cooling

↓

Low power dissipation
≤ 50 mW/cm^2

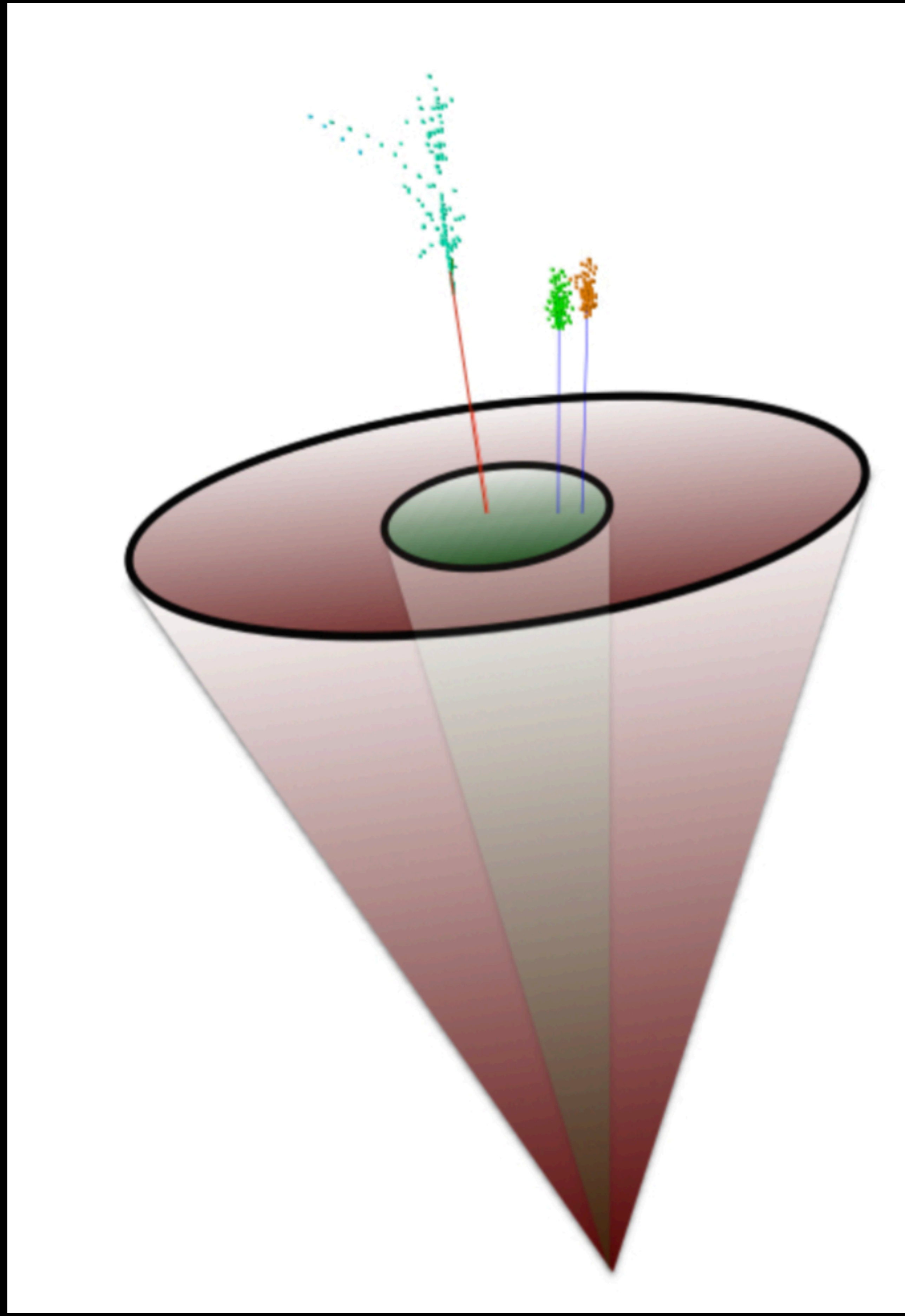
Time stamping
~10 ns (CLIC)
~300 ns — μs (ILC/CC)

Circular colliders: continuous operation → more cooling → more material

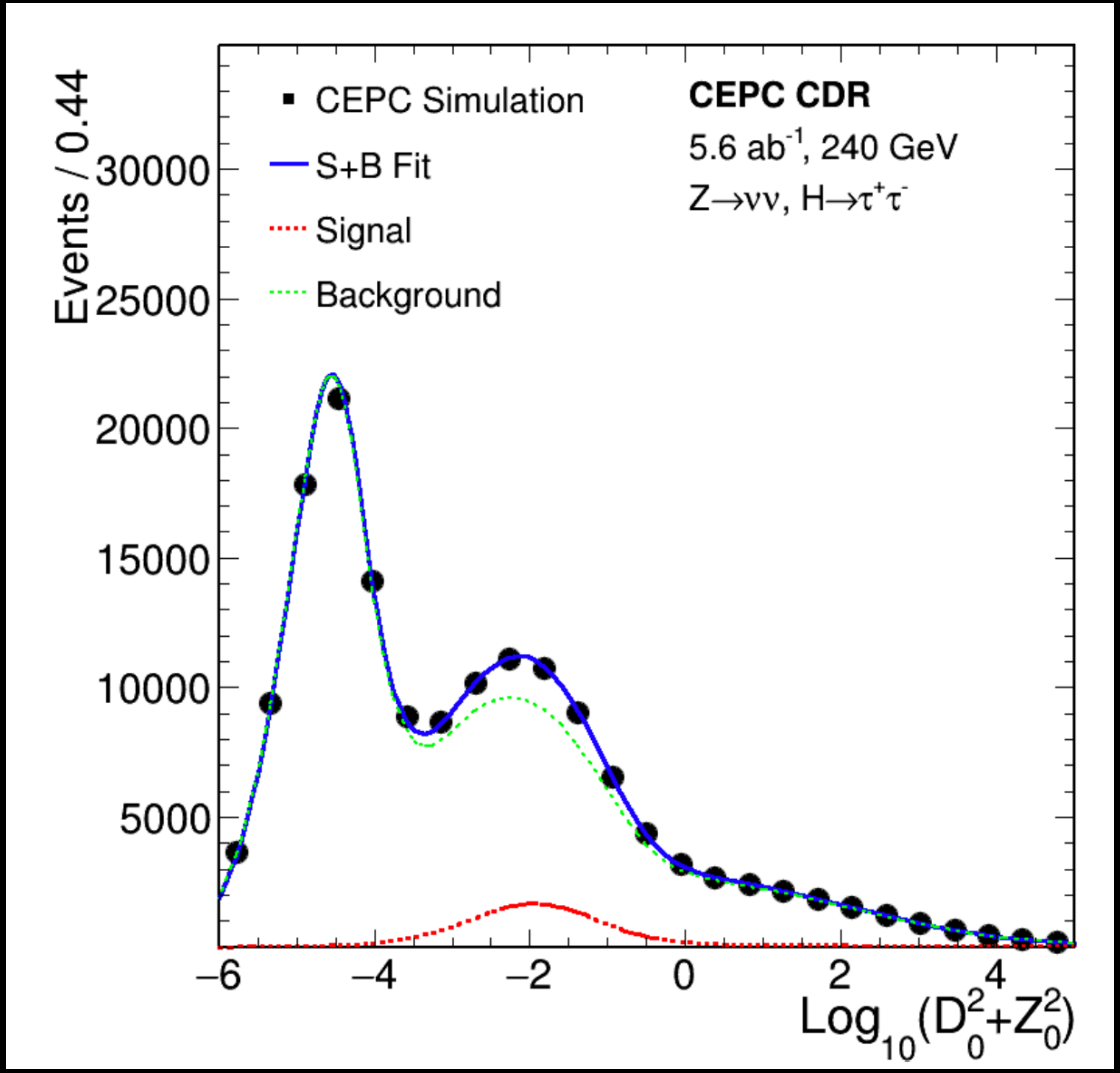
Measurements of Higgs branching ratio ($H \to \tau\tau$)

Zhijun Liang

- Use Impact parameters to separate signal $H \to \tau\tau$ from WW background
- 90% efficiency on τ reconstruction, and 70~90% purity



Precision	CEPC
$Z(\to e^+e^-)H$	~3%
$Z(\to \mu^+\mu^-)H$	~3%
$Z(\to \nu\nu)H$	~3%
$Z(\to qq)H$	~1%
Combined	**0.8%**



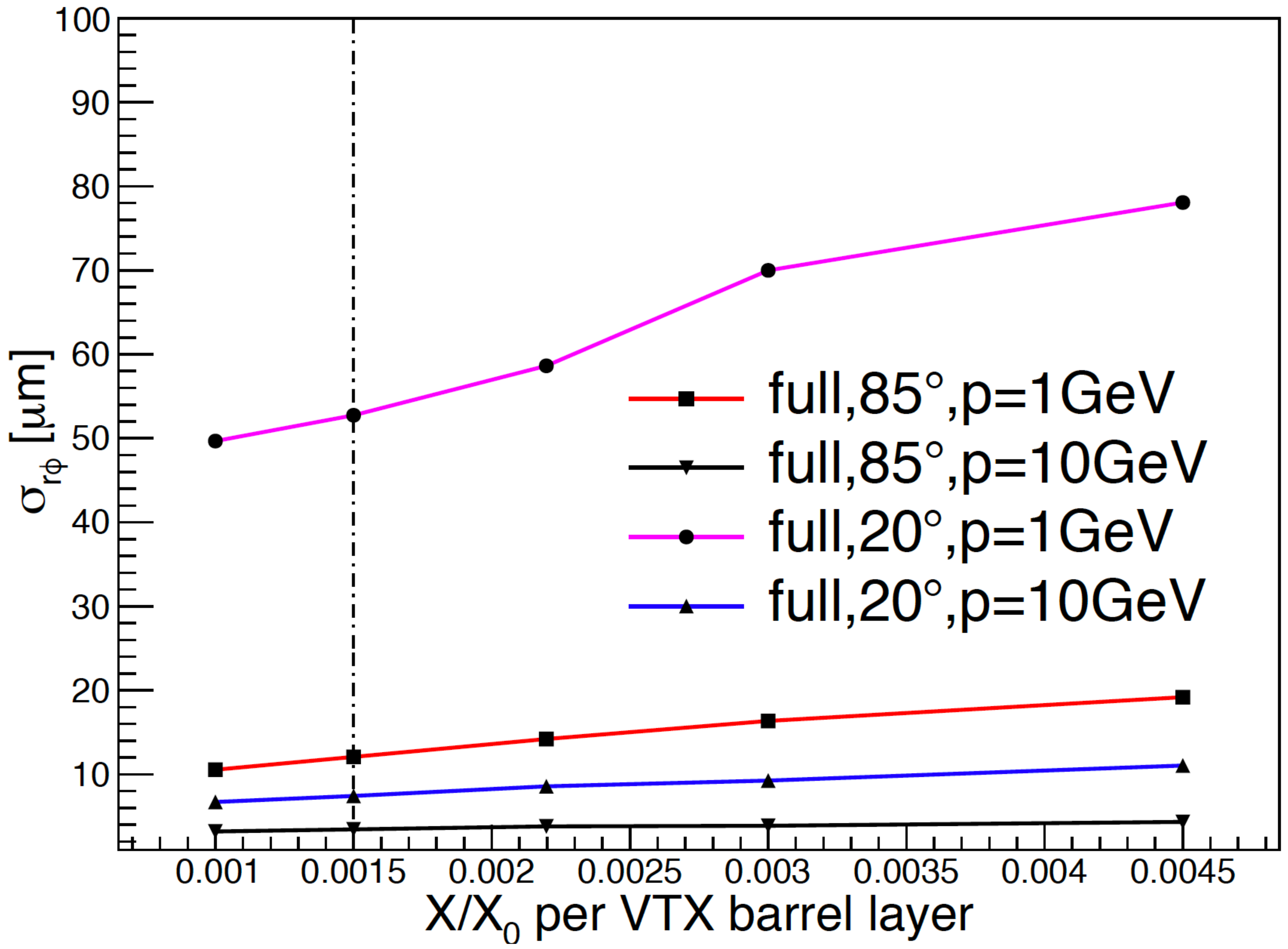
REQUIREMENT ON MATERIAL (2)

Zhijun Liang

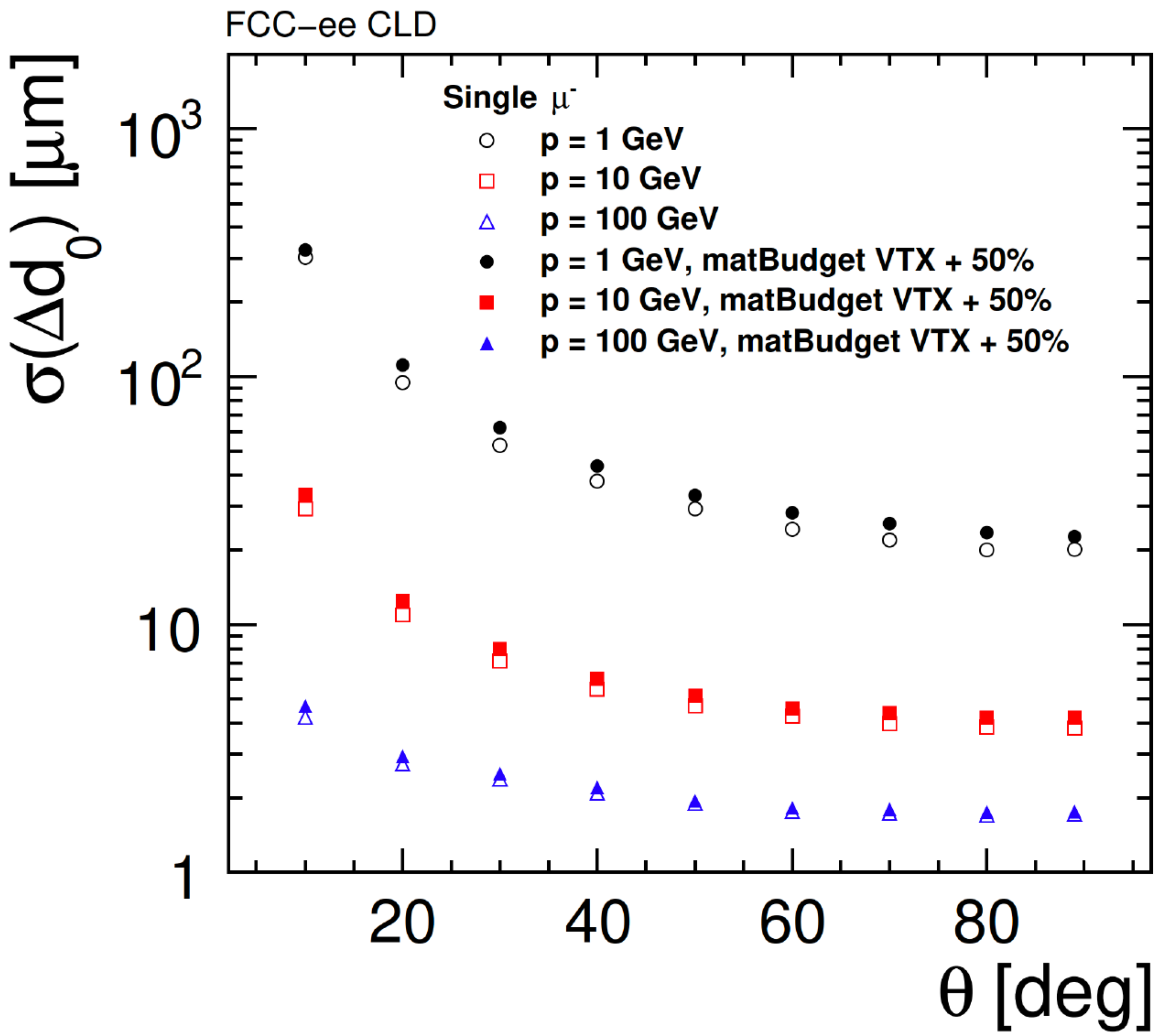
Material requirement can be relaxed!

- CEPC study on material of vertex detector：
  - Increase material budget by 300%
  - 20~30% impact worse on 1GeV track very small impact on 10GeV track (<10%)
- Fcc-ee study on material of vertex detector：
  - Increase material budget by 50% , small impact on impact parameter resolution

CEPC baseline detector



Fcc-ee CLD detector



Zhijun requirements wishes:

Increase material budget

Reduce single point resolution, $\sigma_{sp} < 3$ μm?

Reduce beam pipe radius:

- FCC-ee reduced beampipe radius from 17mm to 12mm —> Improve d0 resolution by 30~40%

Radiation harness: 1 MRad/year (although new studies indicate 6 MRad/year)

Long barrel detector without endcap design can have good air cooling performance

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

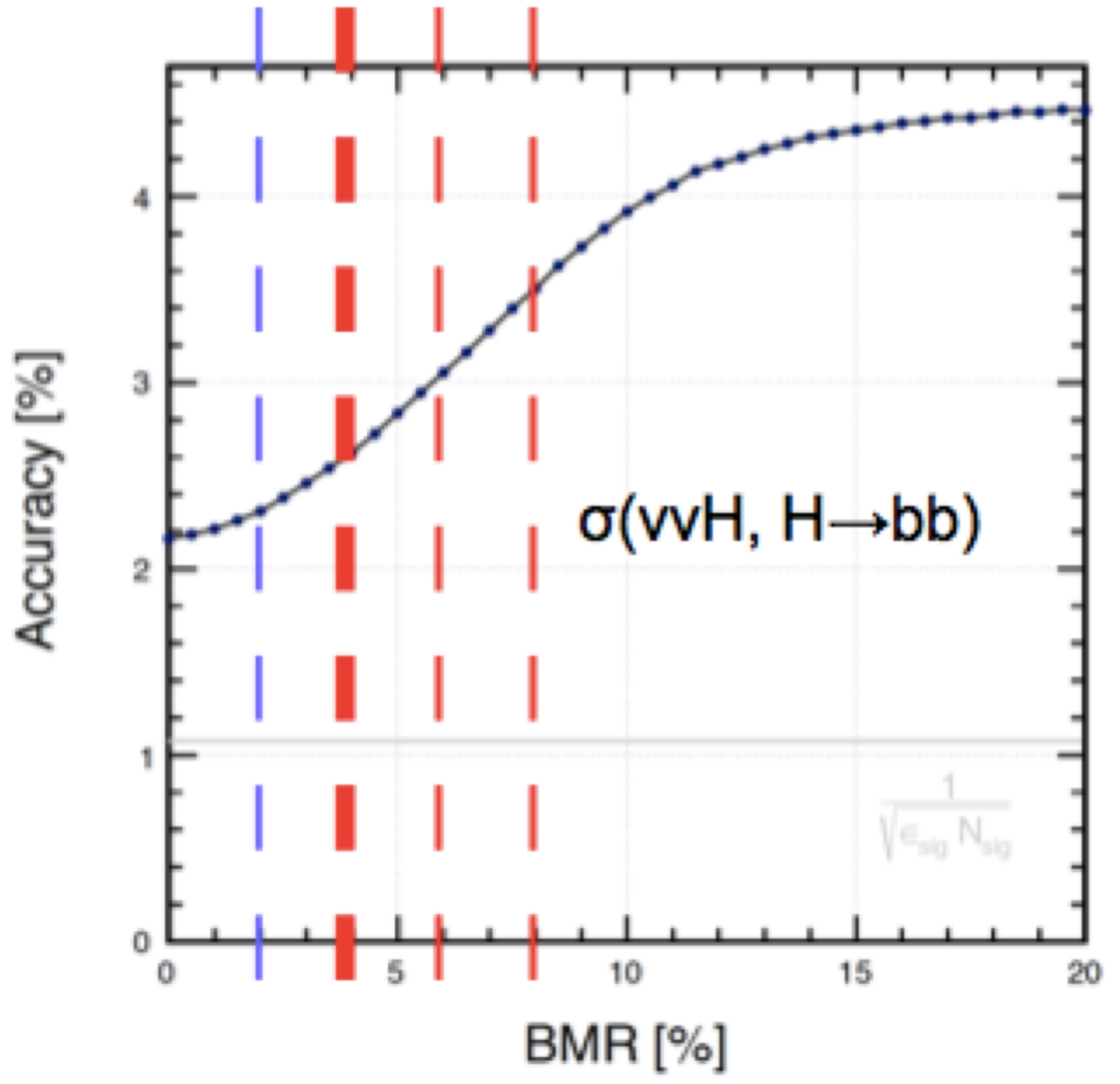
Calorimetry Requirements
with a focus on circular colliders

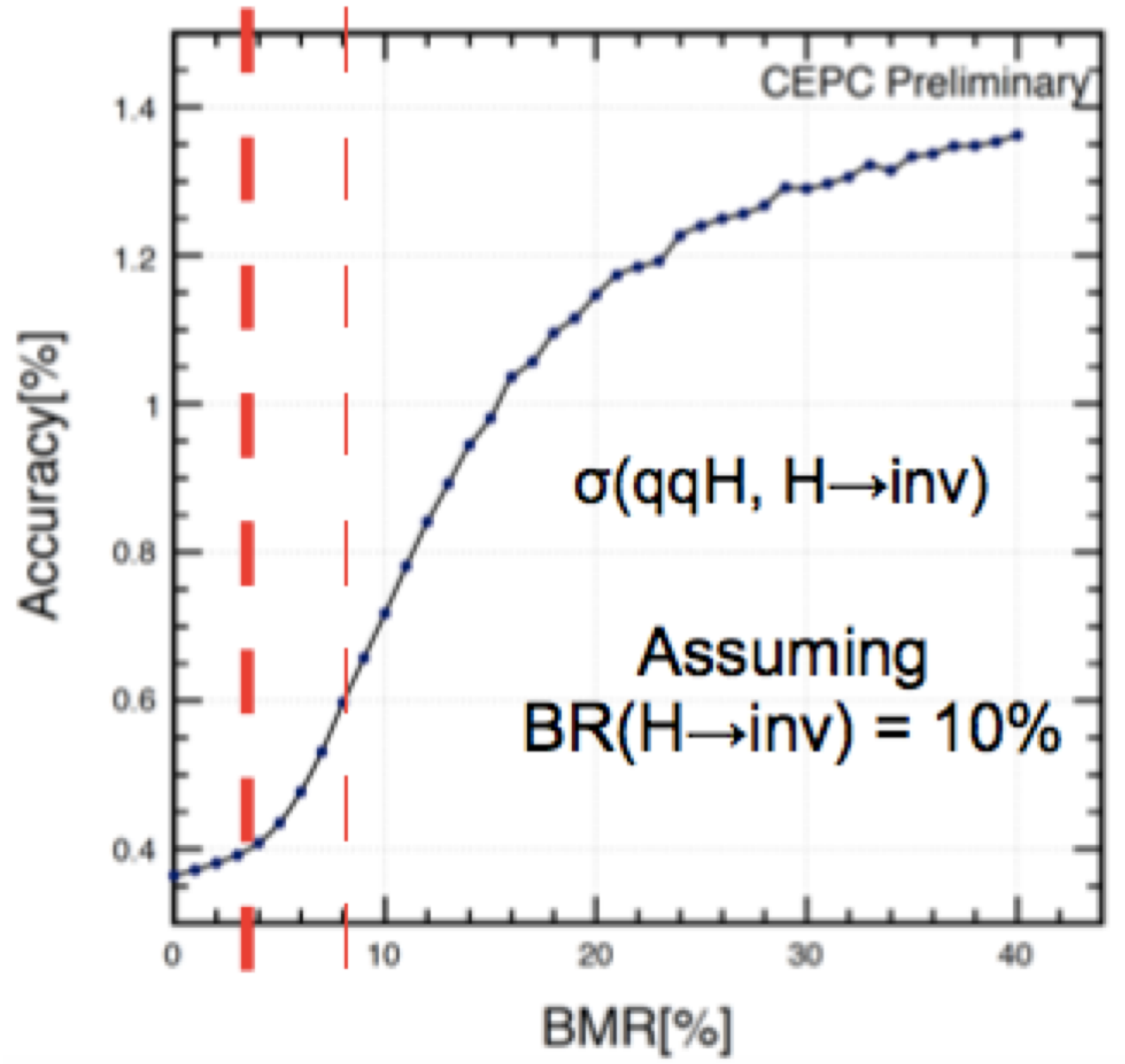
Yong Liu (Institute of High Energy Physics, Beijing)

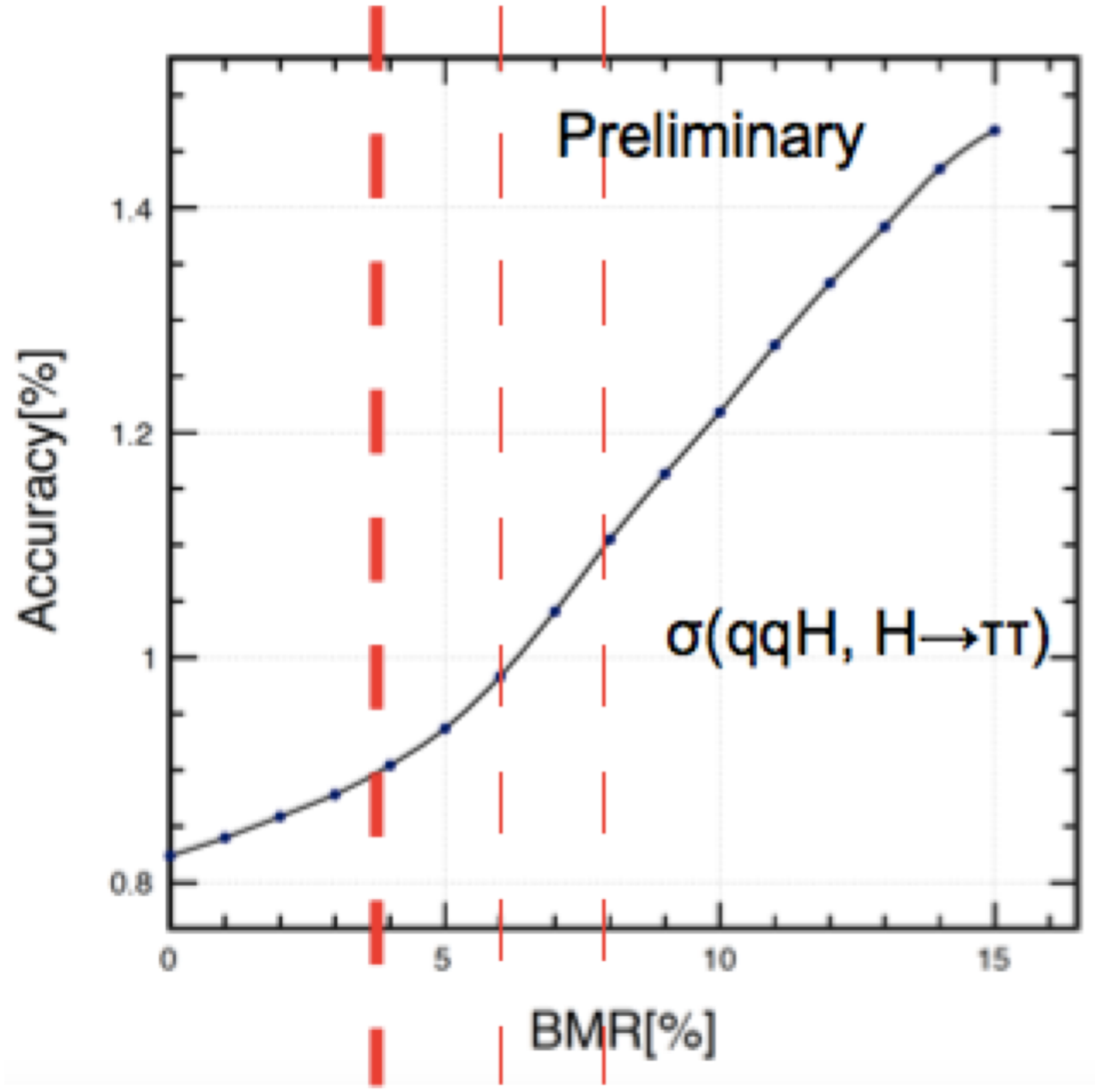
HKIAS Mini-Workshop: Experiment/Detector-Software and Physics Requirements for e+e- Colliders, Hong Kong, Jan. 16-17, 2020

Requirement from benchmark analysis: BMR < 4%

optimization underway







- Boson Mass Resolution: relative mass resolution of vvH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

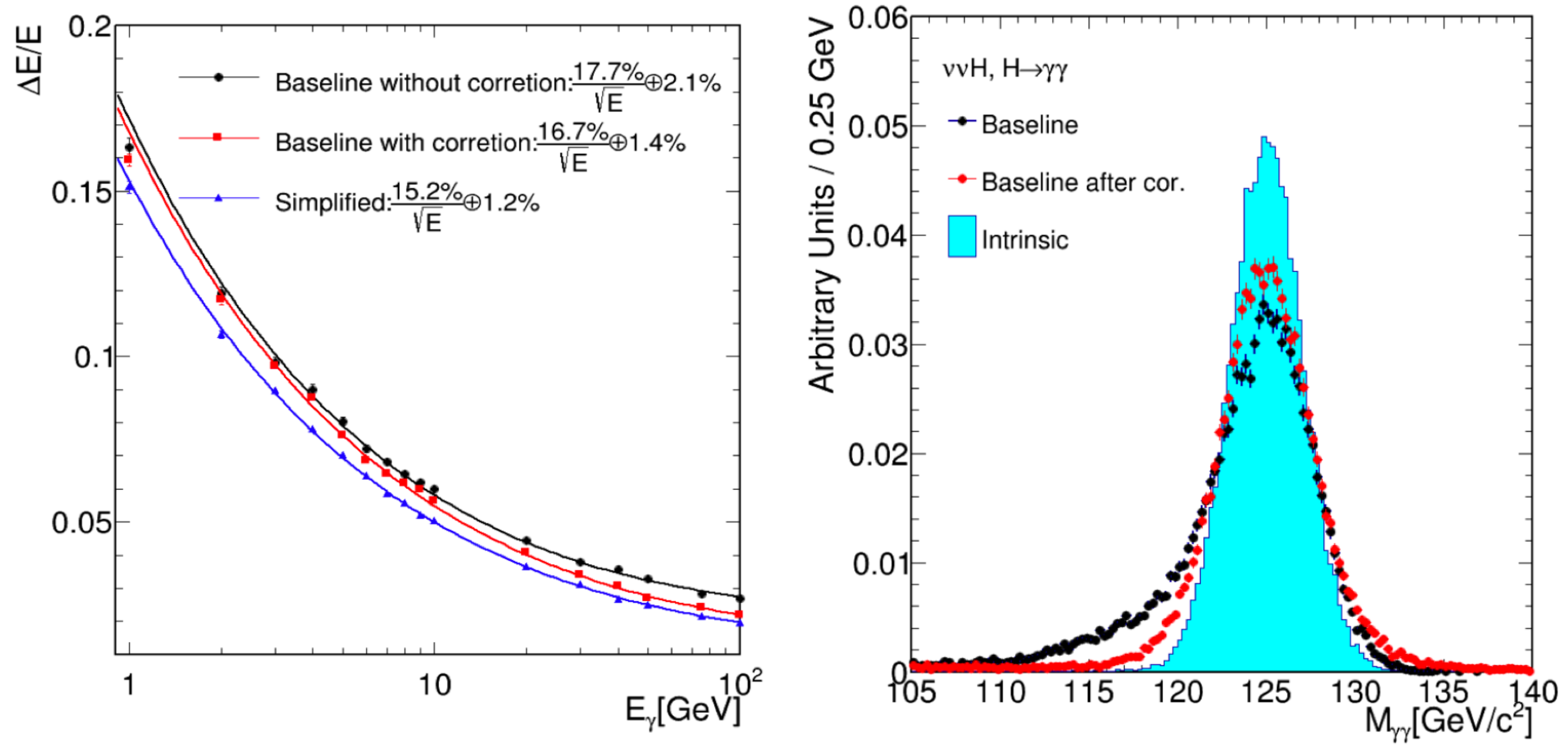
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

Manqi Ruan, CEPC Workshop 2019

Resolution of SiW ECAL

CEPC

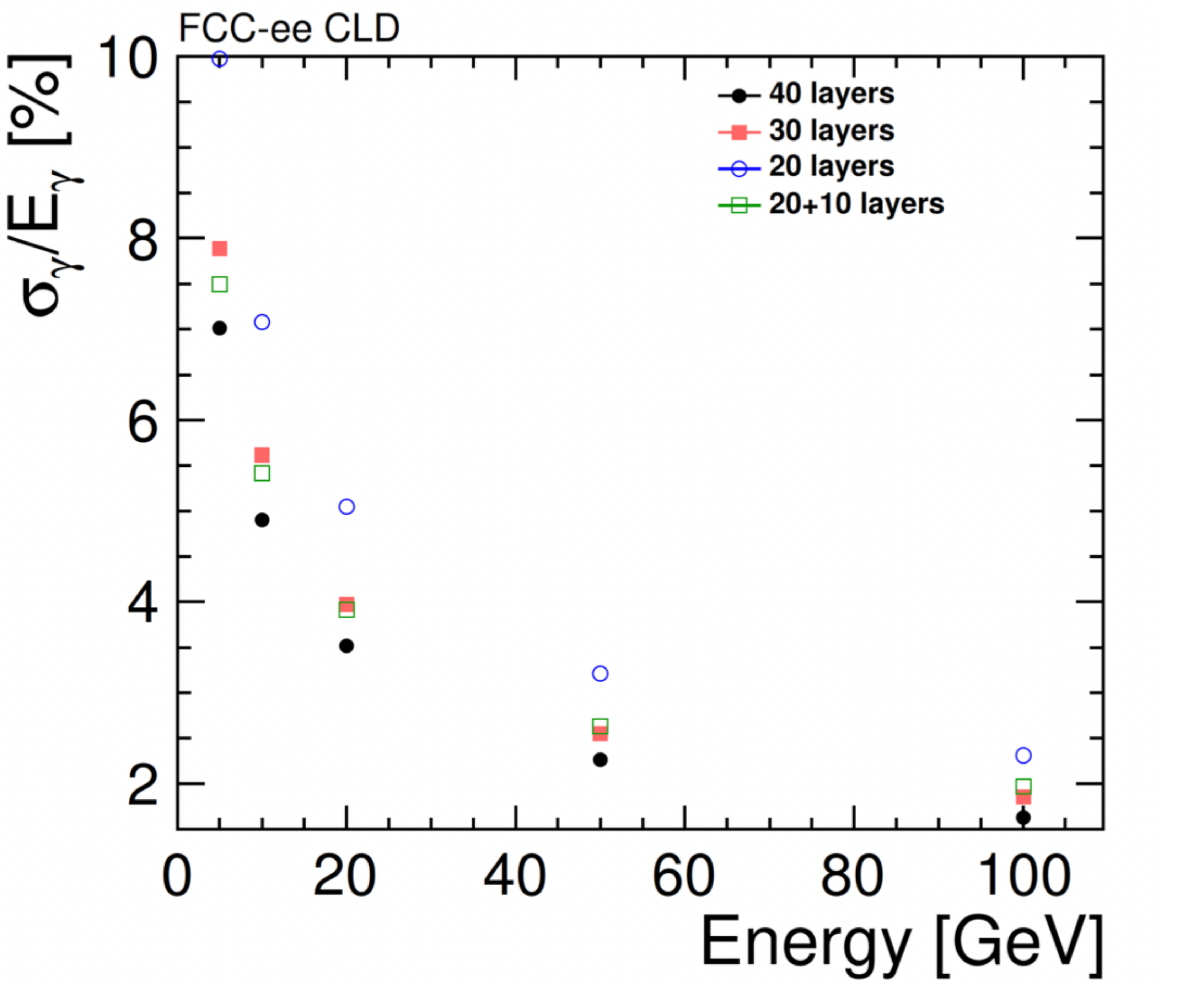
Higgs mass resolution ~2.2% in H → γγ



Photon energy resolution is improved with corrections for ECAL geometry defects

FCC-ee CLD

Photon resolution vs # layers



New

Crystal ECAL being consider:

- Homogeneous structure
  - Optimal intrinsic energy resolution:~3%/ √E ⊕~1%
- Fine-segmented crystal for PFA under study

FCC-ee detector requirements
future activities

Paolo Giacomelli
INFN Bologna

Experiment/detector Mini-workshop
Hong Kong, 16/01/2020

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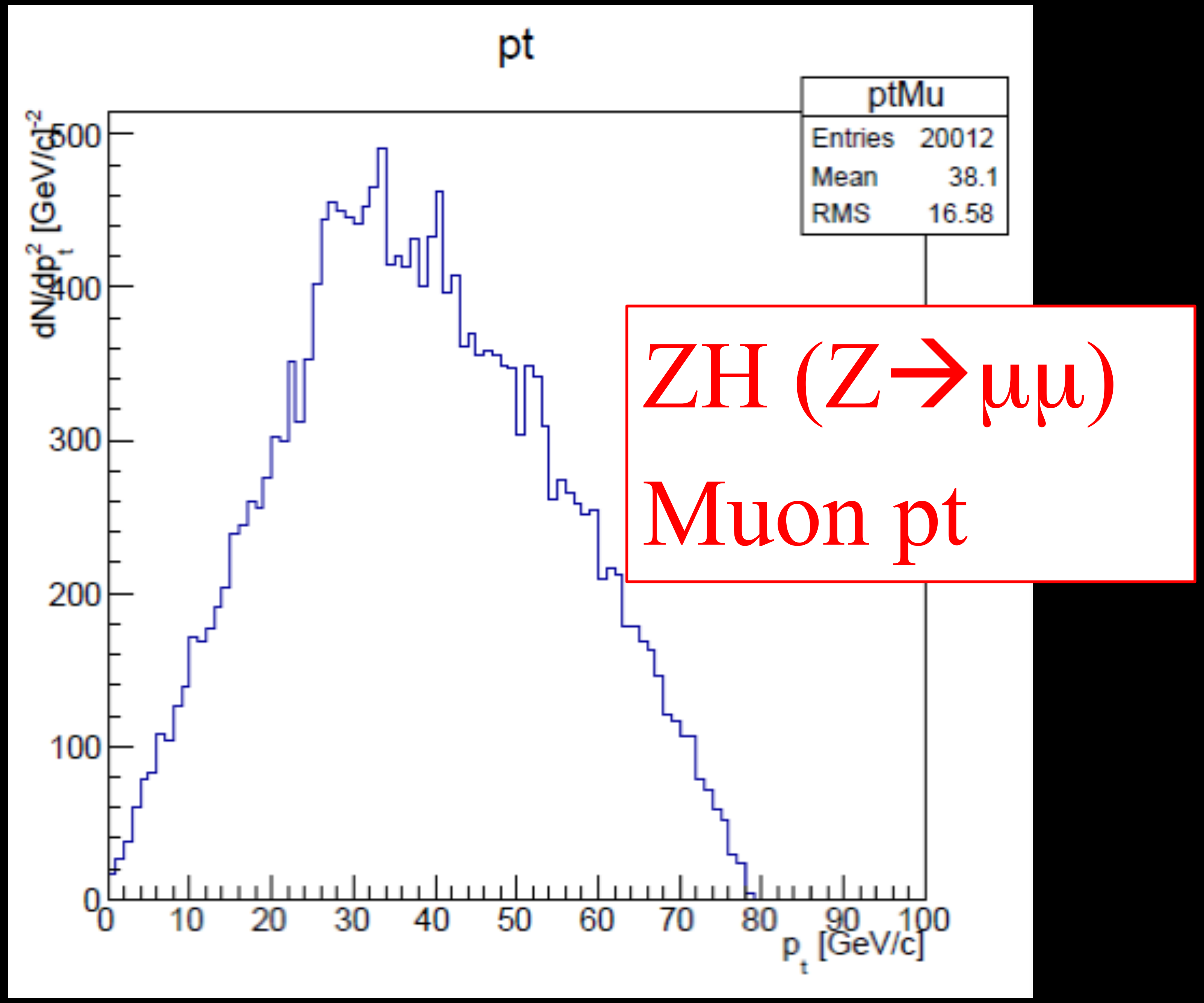
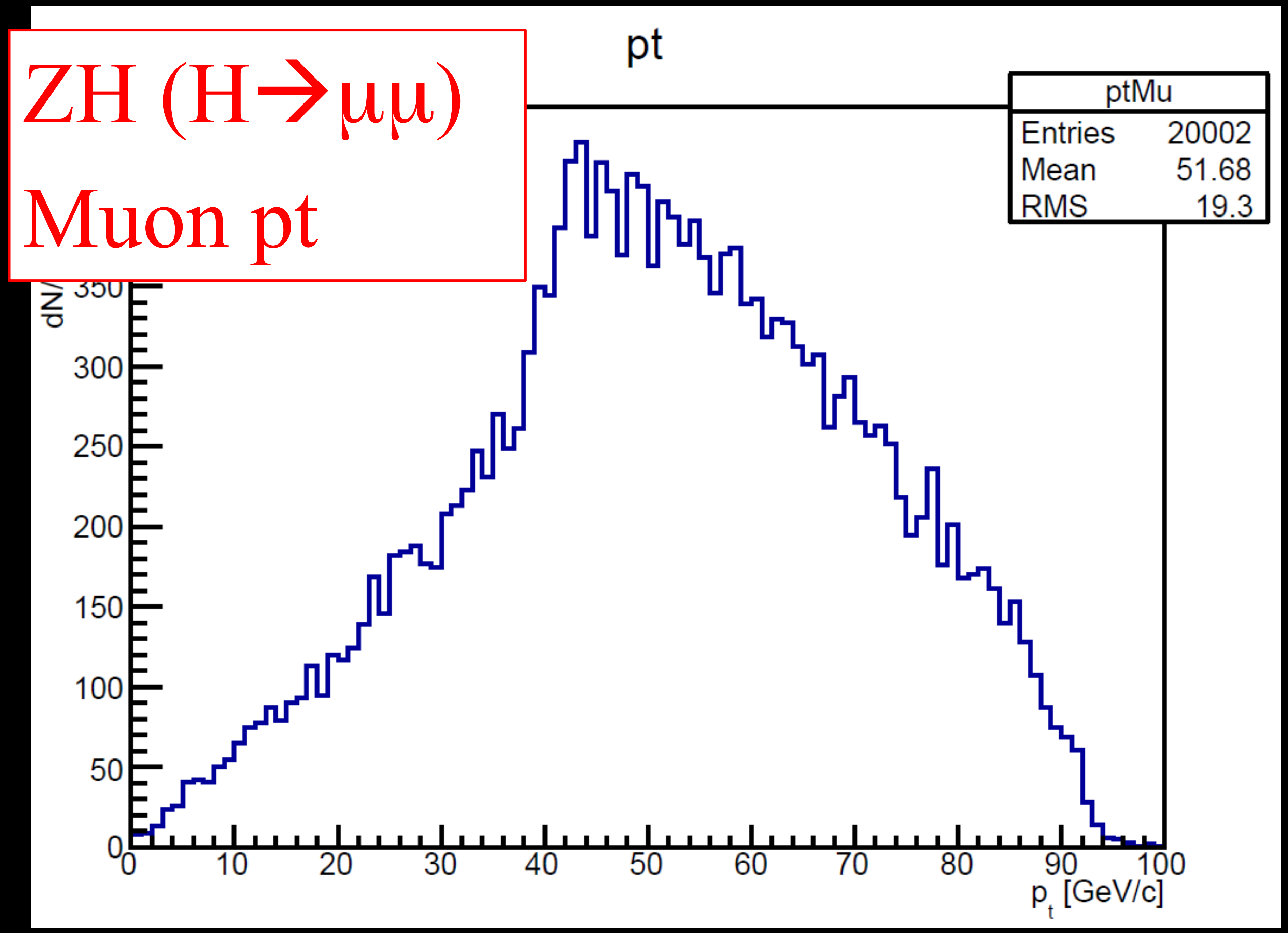
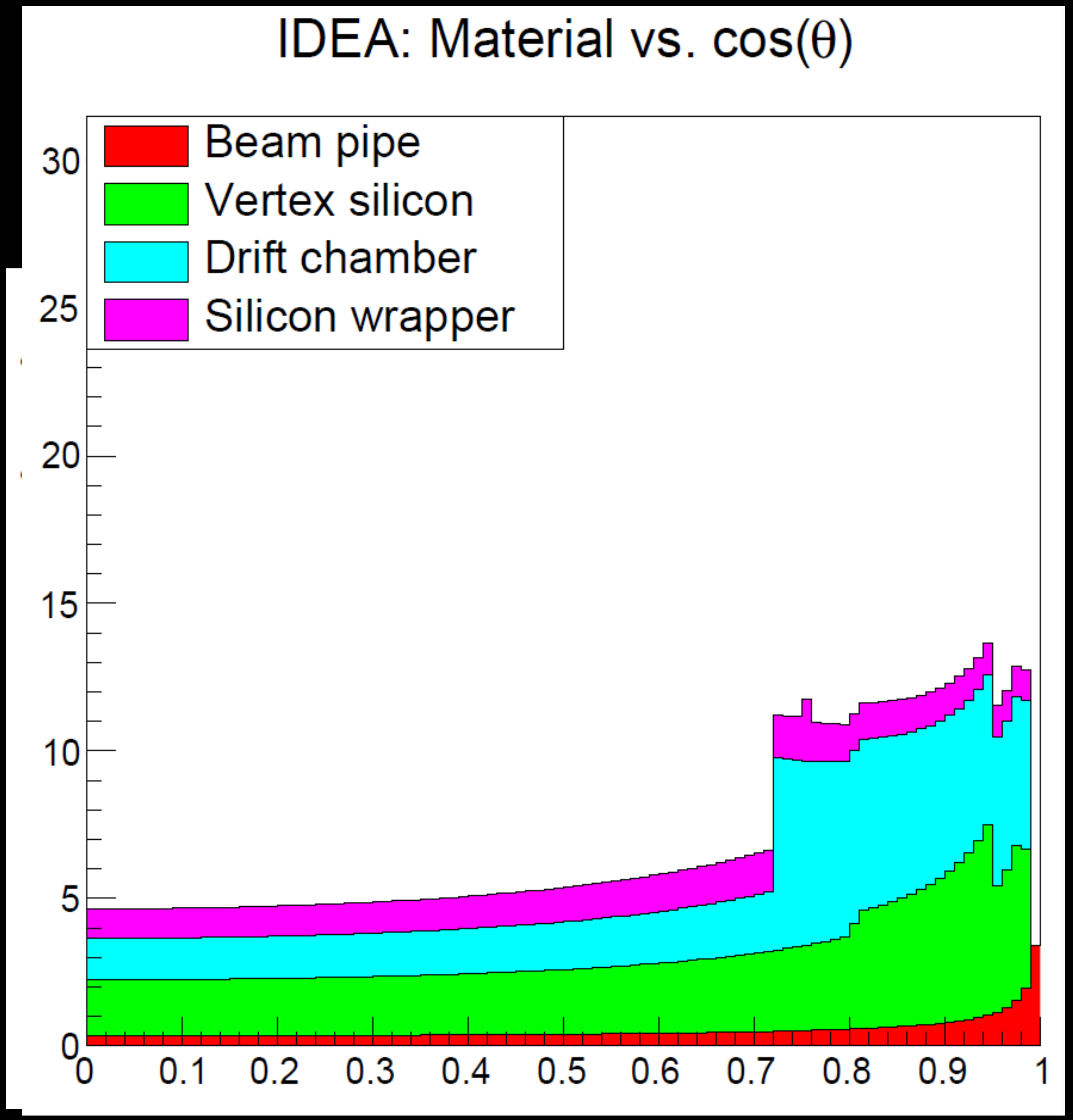
Photo J. Wenninger

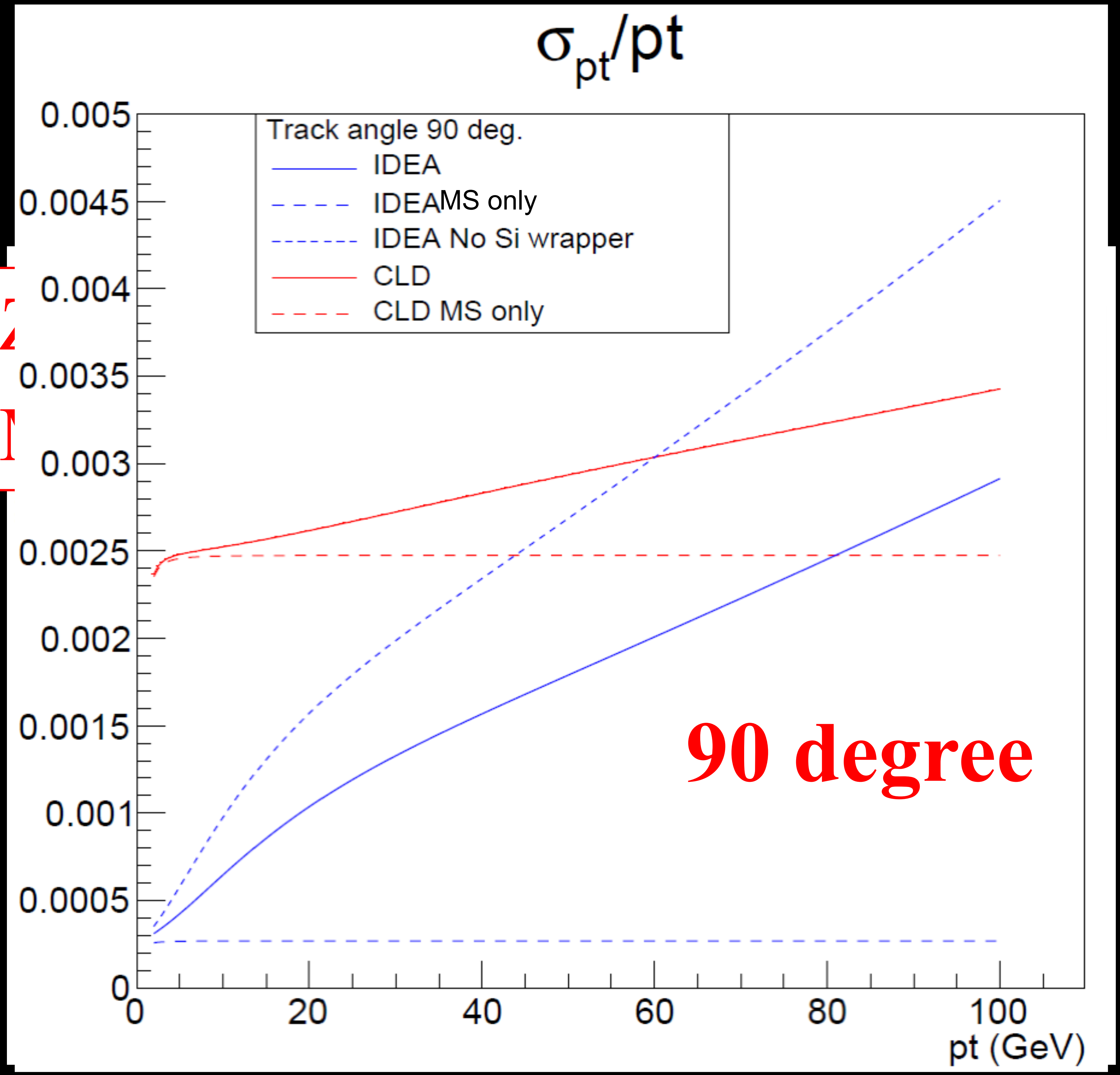
Design guidelines: Momentum resolution





- Z or H decay muons in ZH events have rather small p_t
  - Transparency more relevant than asymptotic resolution



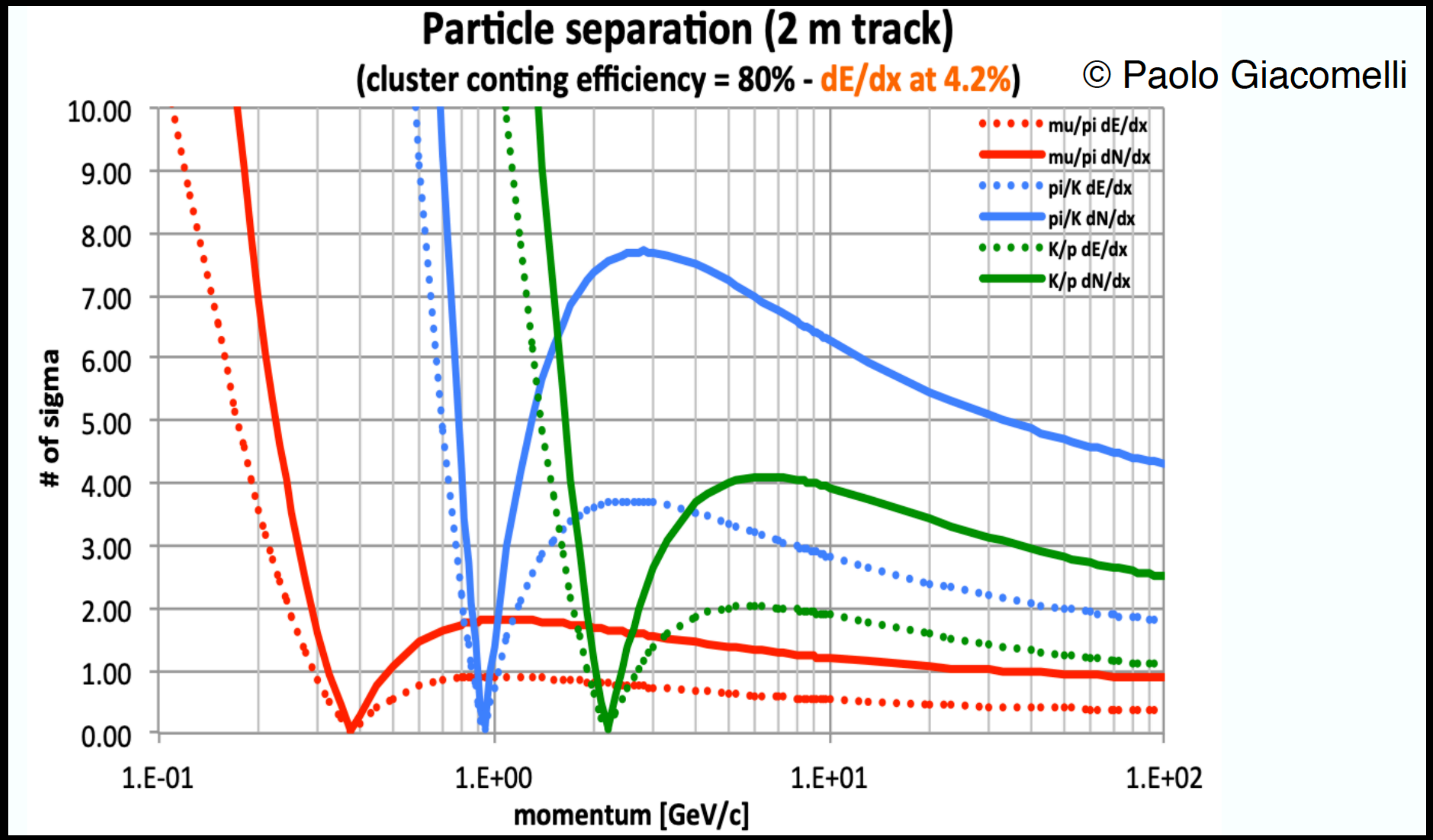


Hadron PID: p/K/π separation

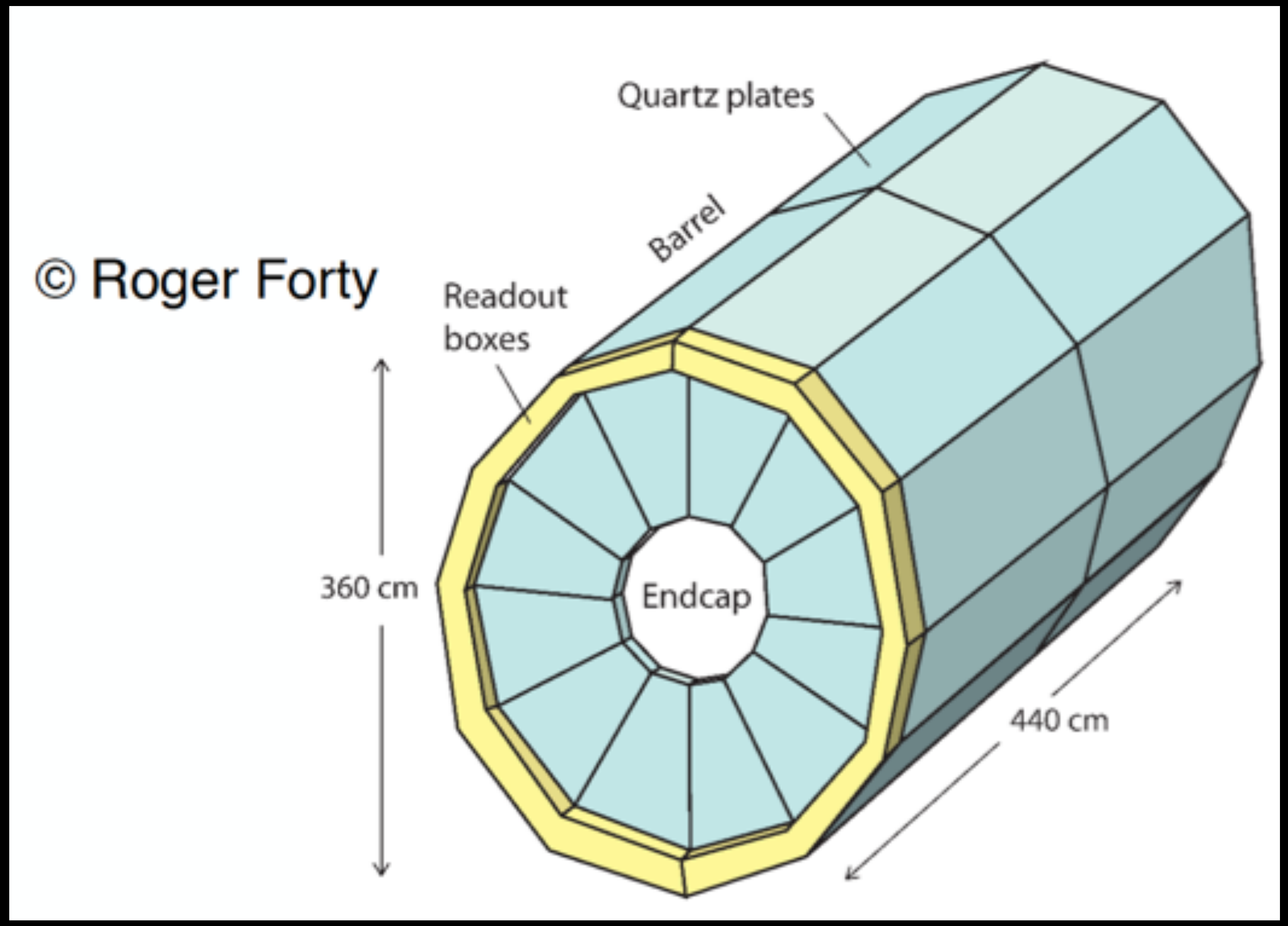
Clear benchmark still needed

CP violation in Bs → DsK
Tau physics
Lepton-flavor violation Z decays

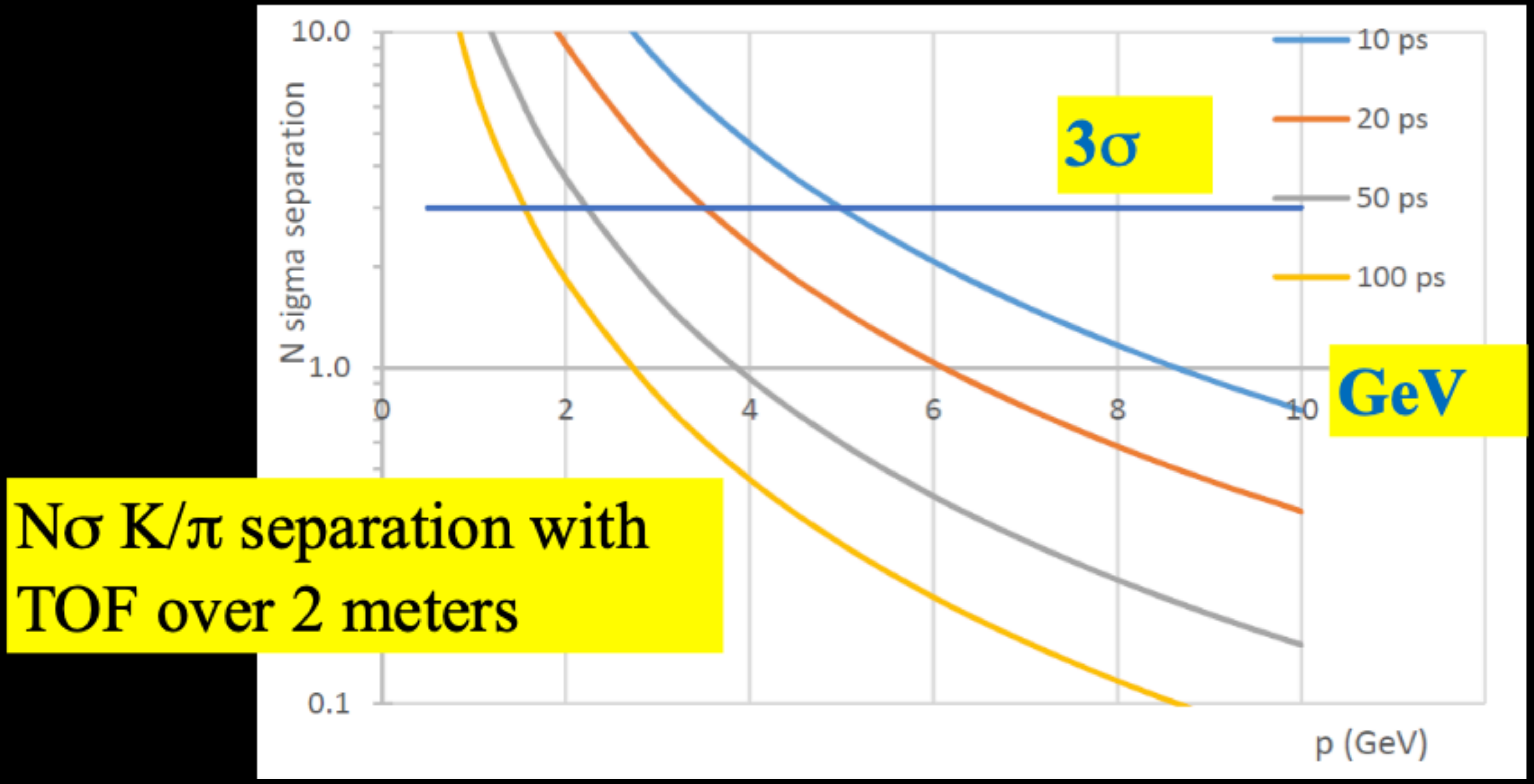
Drift Chamber: dE/dX



TORCH (RICH+TOF)



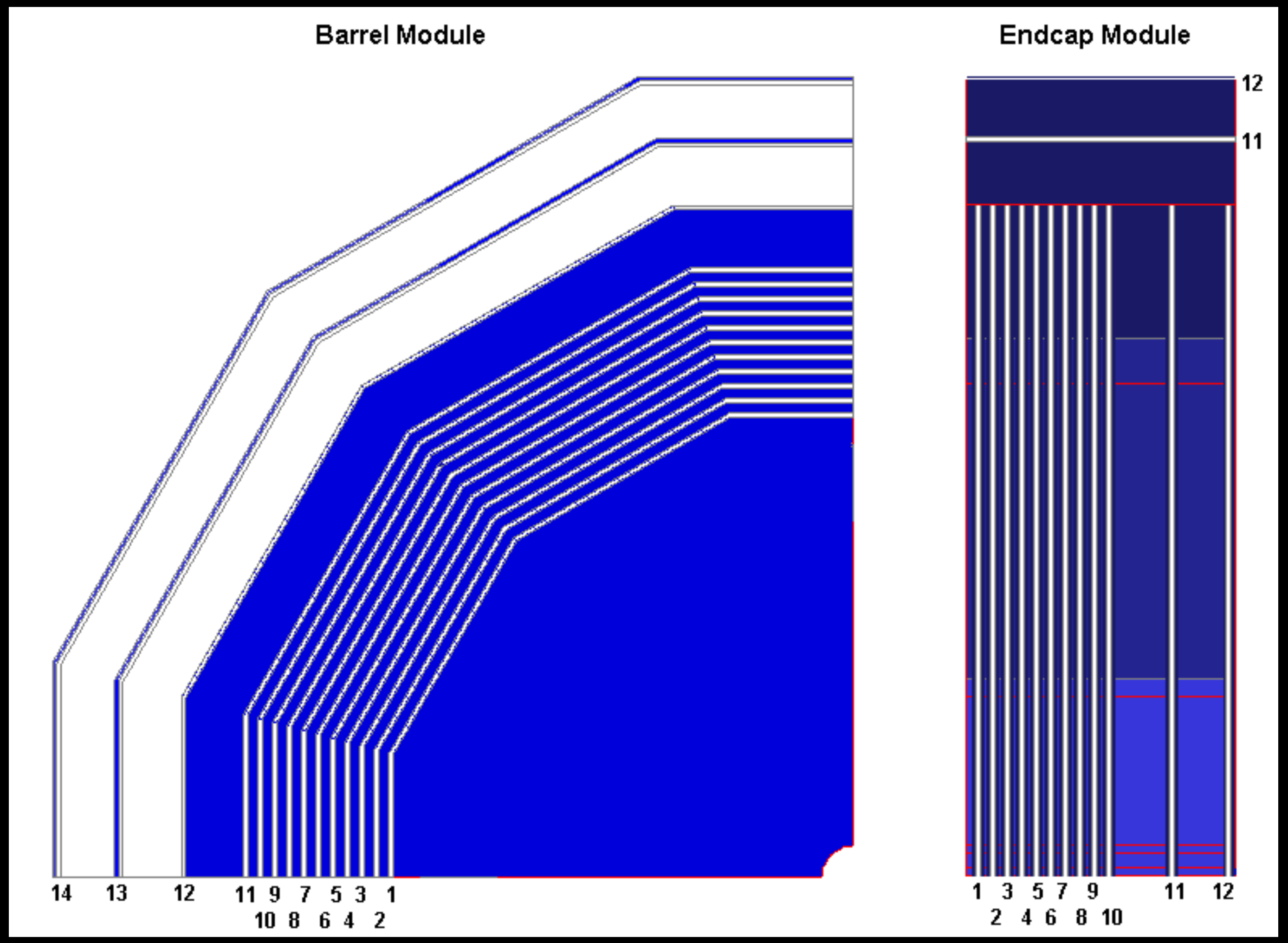
Time of flight



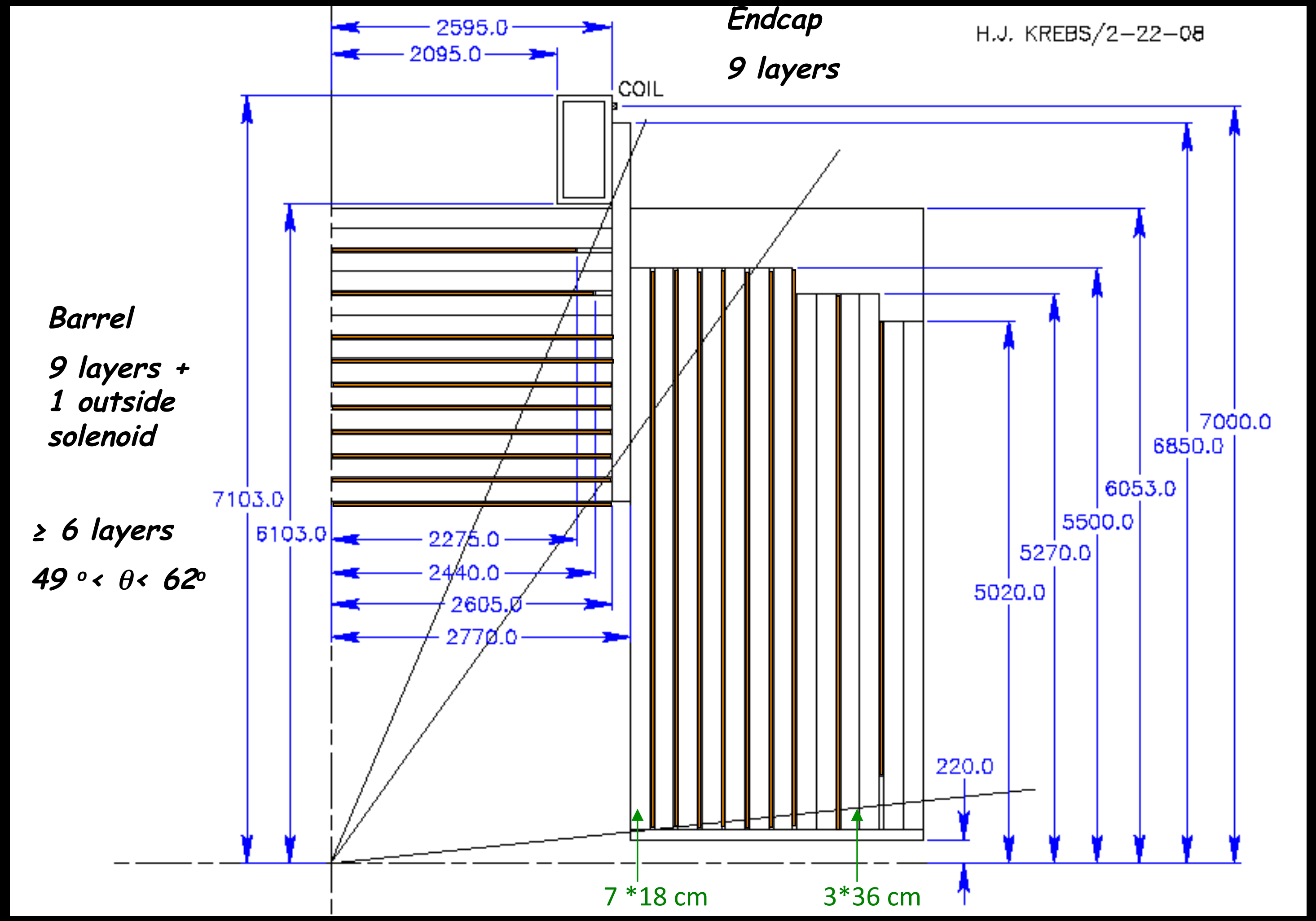
Muon Systems

(CLIC: Efficiency 99.8% for > 200 MeV muons)

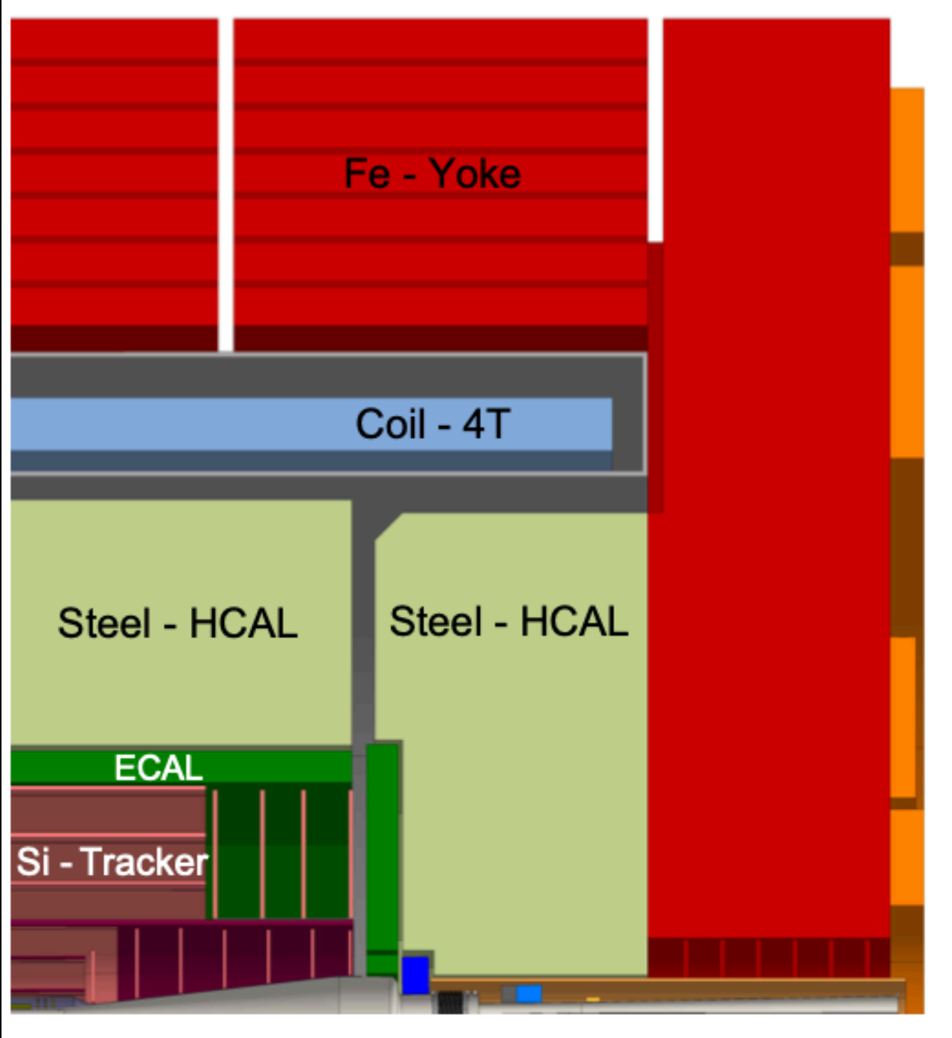
ILD: 12-14 sensitive layers



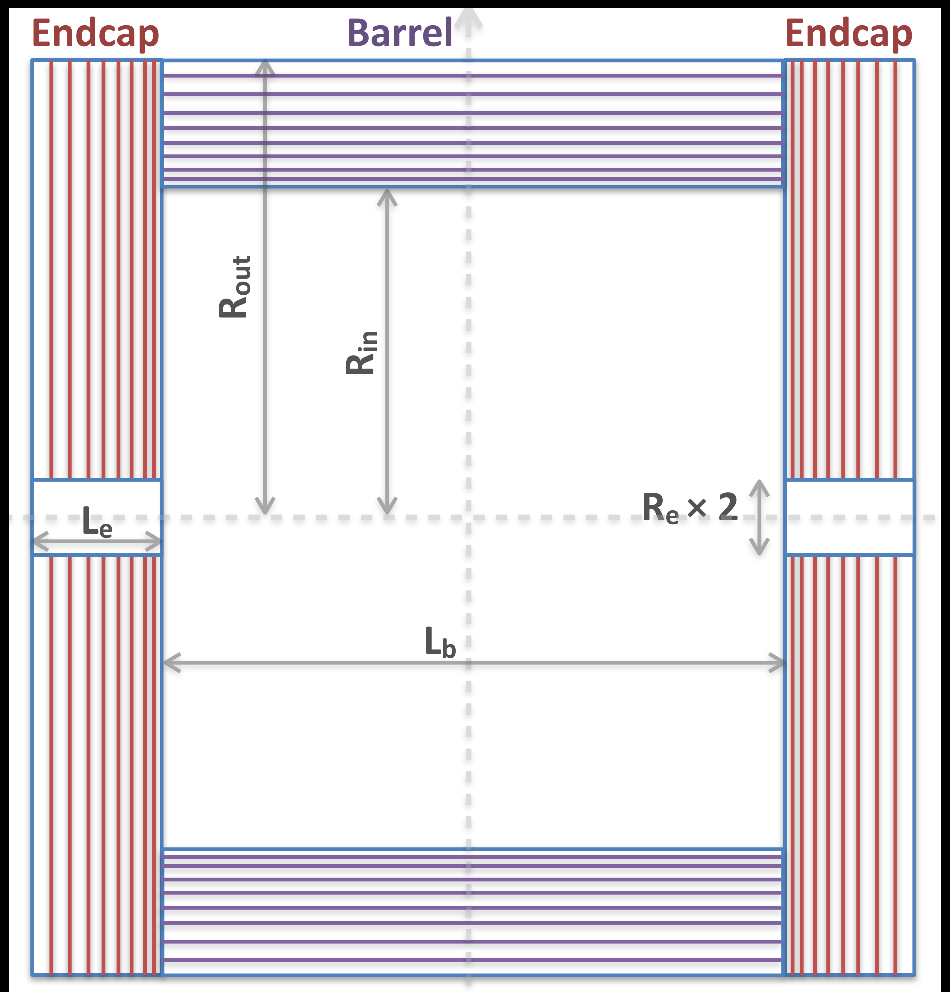
SiD: 9-10 sensitive layers



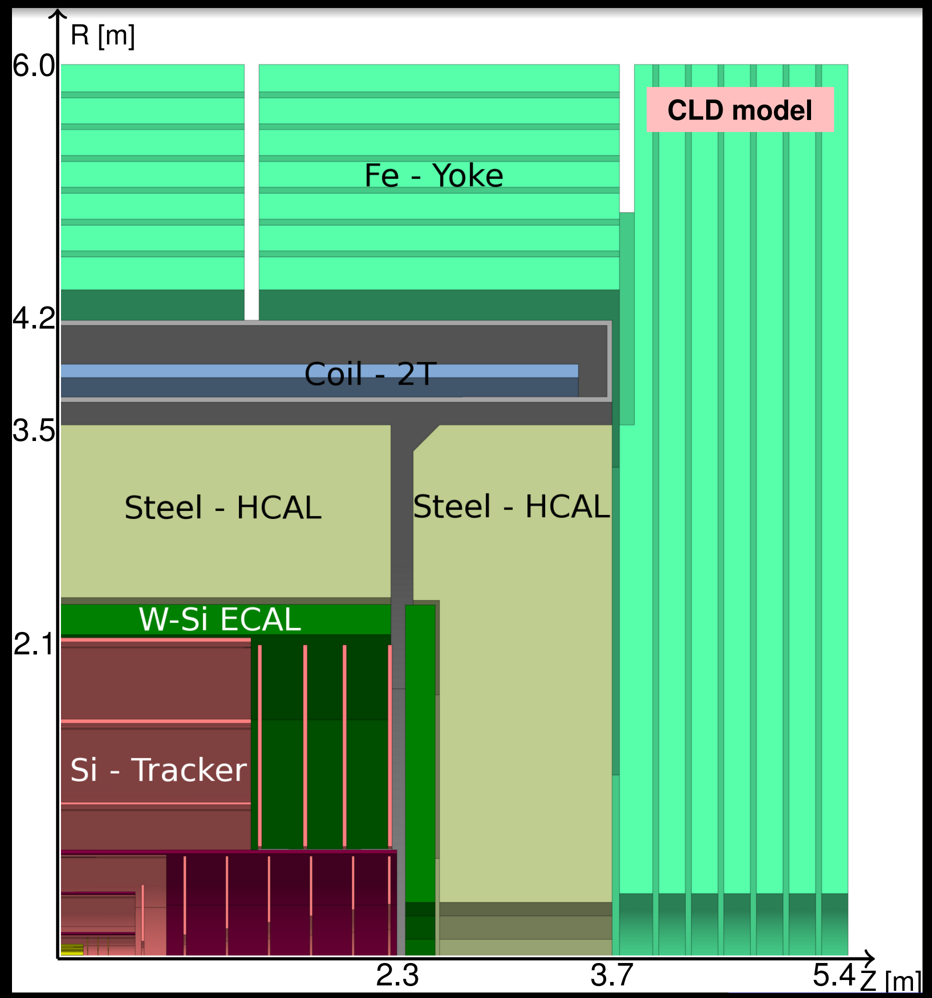
CLICdet: 6 sensitive layers



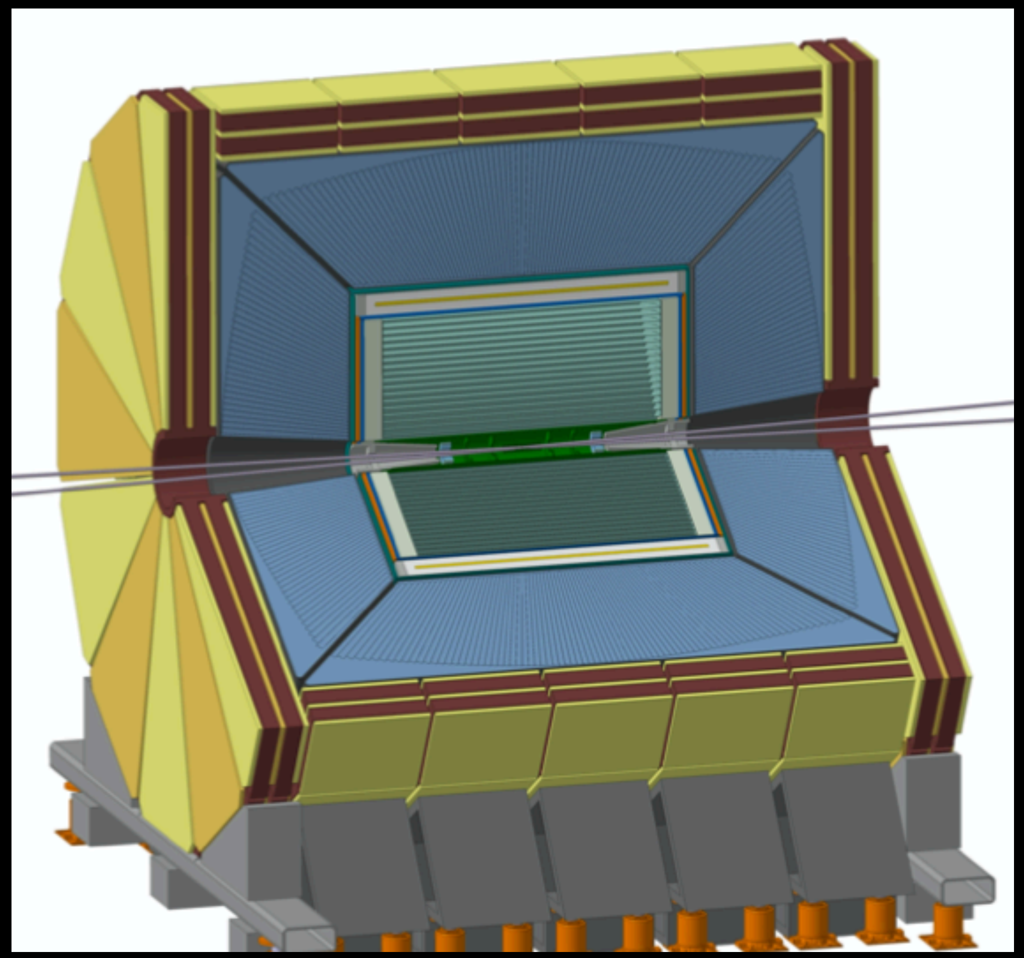
CEPC: 8 sensitive layers



FCC-ee - CLD: 6 sensitive layers



IDEA: 6 sensitive layers



Plans and Future Activities

Adapted from Paolo's slides

- Need to identify all relevant physics benchmark channels
  - Higgs decays and coupling measurements well identified
  - Special needs for high-statistics measurements, especially at the Z peak
  - Flavour physics processes Particularly interesting exotic channels
  - Unique channels, e.g. long-lived particles that could arise from beyond SM physics

- Many physics channels and consequences on detector requirements can be studied using fast simulations
  - Some channels will need to use full simulation of detectors and will therefore take more time to be studied

- A complete optimisation of proposed detectors should wait for the proper validation of the detector requirements

Plans and Future Activities

Adapted from Paolo's slides

- The FCC-ee and CEPC physics landscape is huge
- Detector requirements are partly similar to ILC and CLIC, but are different in several aspects (lower centre-of-mass-energy, lower momentum, higher luminosity and statistics, no power pulsing, etc.)
- Detector requirements for FCC-ee and CEPC are identical, apart from ttbar (not excluded from a possible CEPC physics program upgrade)
- It seems very natural, from a scientific point of view, to study and define the detector requirements with a joint FCC-CEPC effort!

Challenges in tracking detectors

Goal: very good momentum resolution

Different detector, each with large $B \times R^2$

- SiD, CLICdet, CEPC: all silicon tracker
- ILD, IDEA, CEPC: silicon + gaseous tracking

Silicon tracker challenges

Large surface area of O(100 m²)

Solution: Integrated sensors with large pixels/strips (~ 30 µm × 1-10 mm)

Maintain efficiency and good timing
(despite large detector area)

Mechanical stiffness with low-mass materials

Light-weight cooling methods

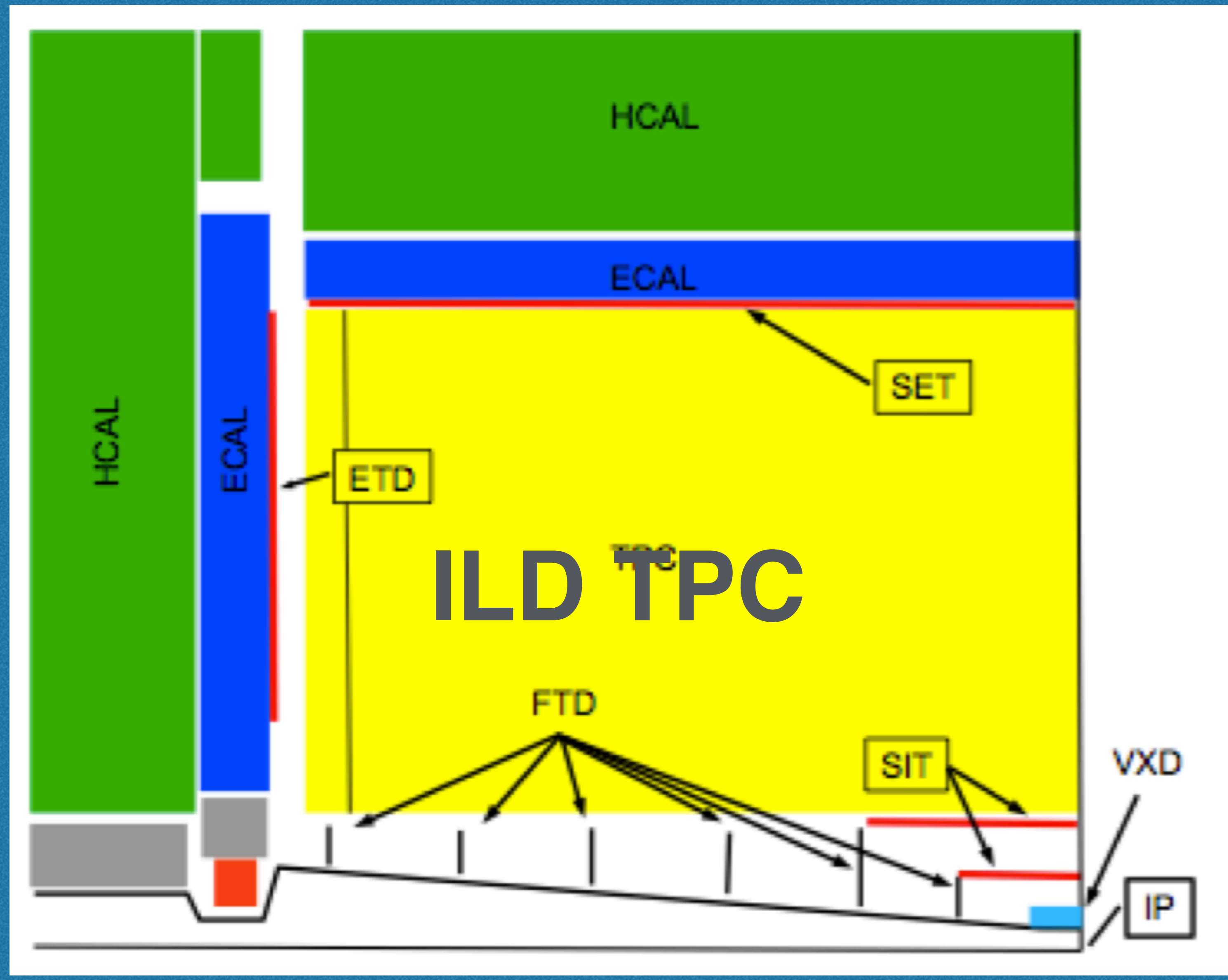
TPC challenges

Ion backflow → affects resolution

Solution: Gating concepts and new readout modules under study

Hit timing and momentum resolution

Solution: Silicon wrapper around TPC

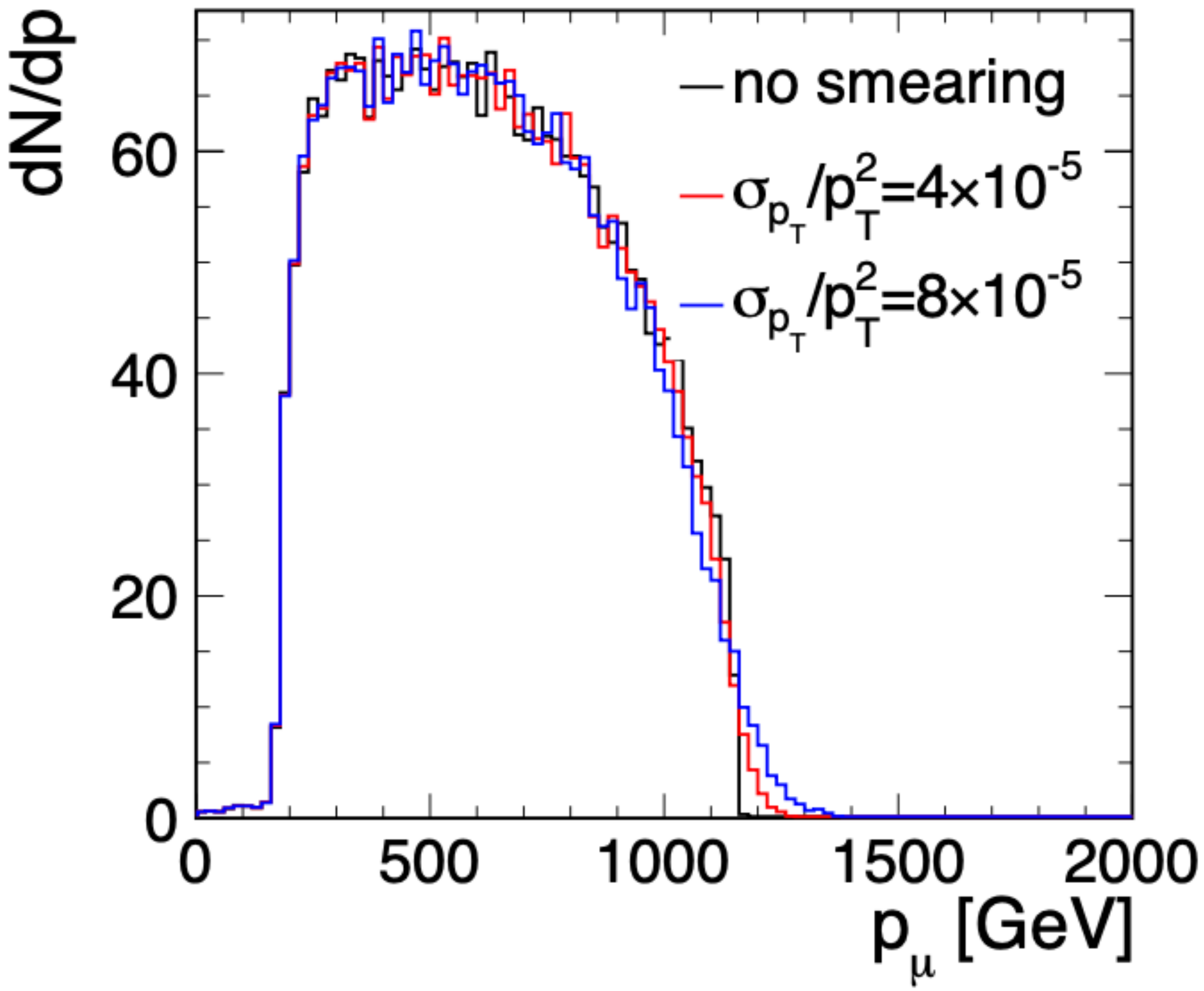


Occupancies at high event rates

Meets requirements for ILC
Under study for Z-pole running at CEPC

Track Reconstruction

- Full silicon tracking due to timing and occupancy
- Momentum resolution of $2 \times 10^{-5}/\mathrm{GeV}$ for central high momentum tracks
  - Needed for, e.g., **slepton measurements [4]**, Higgs to muons [1]



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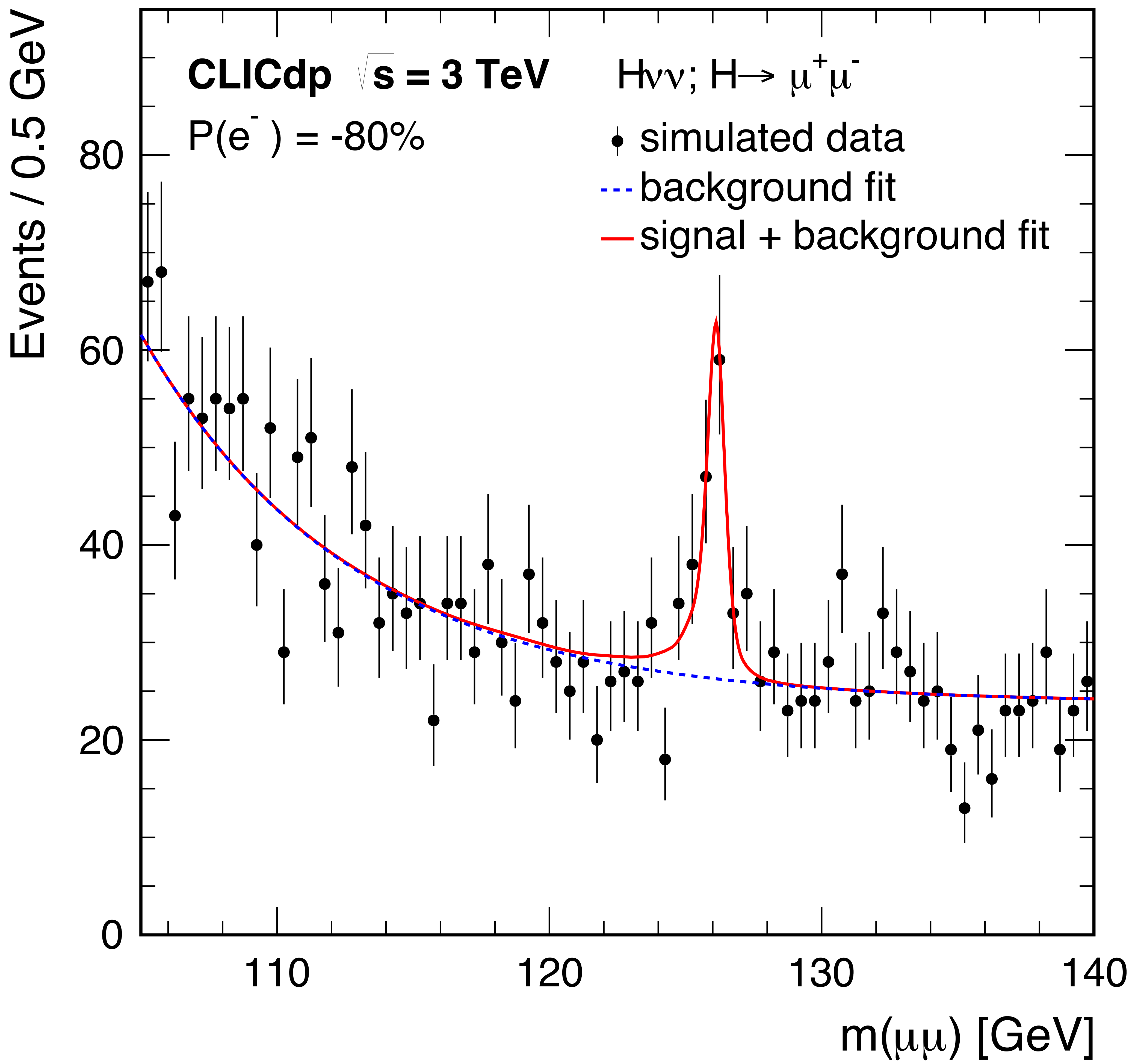


Updated Parameters of Collider Ring since CDR

	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	[illegible]	[illegible]	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	[illegible]	[illegible]	[illegible]	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	[illegible]	0.22	2.1	1.8
Luminosity/IP L (10^{34} cm^{-2}s^{-1})	2.93	5.2	32.1	101.6

These possible luminosity increases have not yet been absorbed into physics and detector studies

Luminosity increase factor: × 1.8 × 3.2

Physics requirements (from benchmark processes)

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

under discussion → started yesterday (QCD+performance session) **→ aim at workshop in Hong Kong**

CEPC CDR: Particle Flow Conceptual Detector

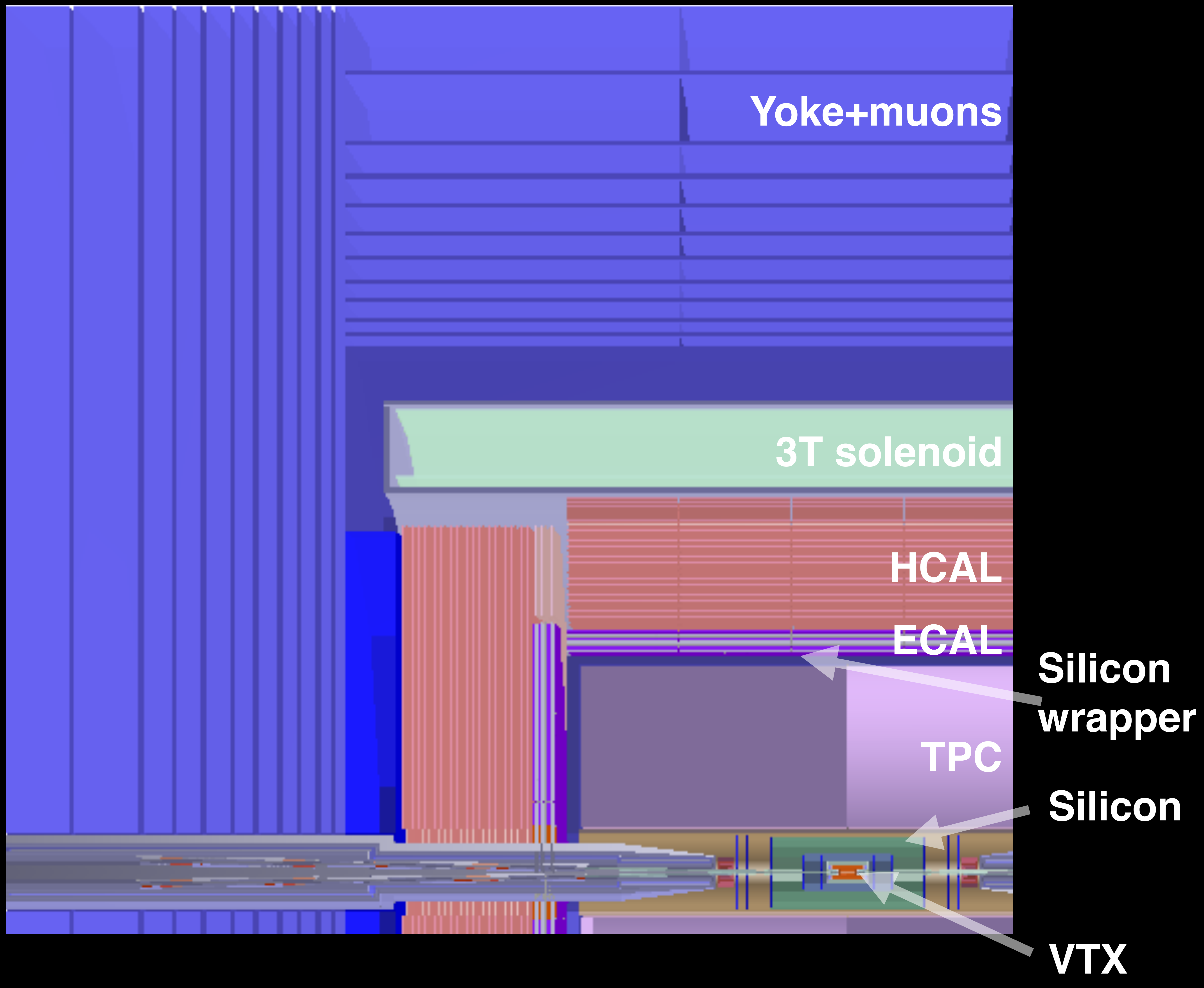
Major concerns being addressed

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

2. Low-material Inner Tracker design

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

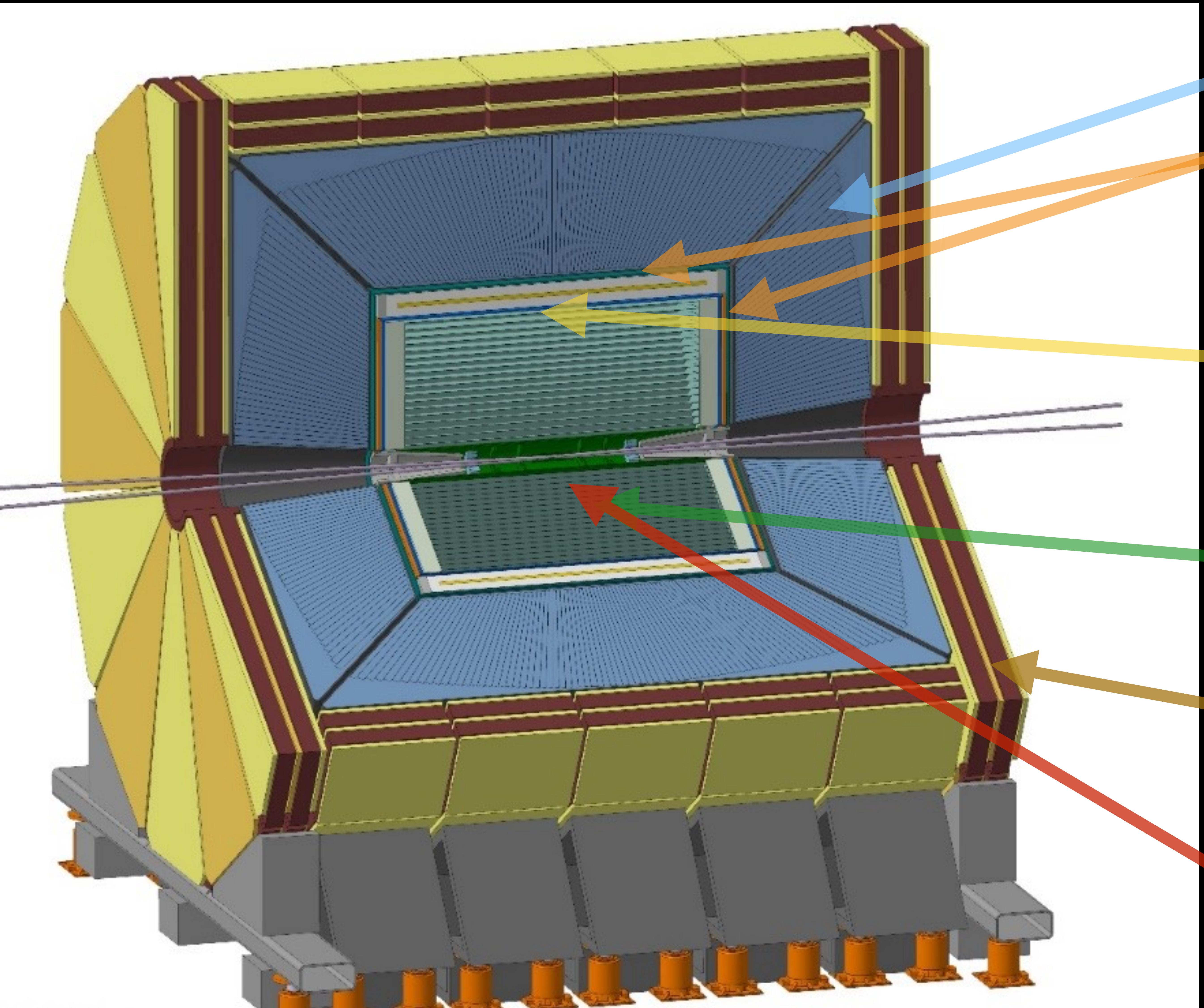
4. ECAL/HCAL granularity needs
Passive versus active cooling
Electromagnetic resolution



Magnetic Field: 3 Tesla

CEPC CDR: IDEA Conceptual Detector (CEPC + FCC-ee)

Inspired on work for 4th detector concept for ILC



Calorimeter outside the coil

* Dual-readout calorimeter: 2 m/8 λ_{int}
* Preshower: ~1 X_0

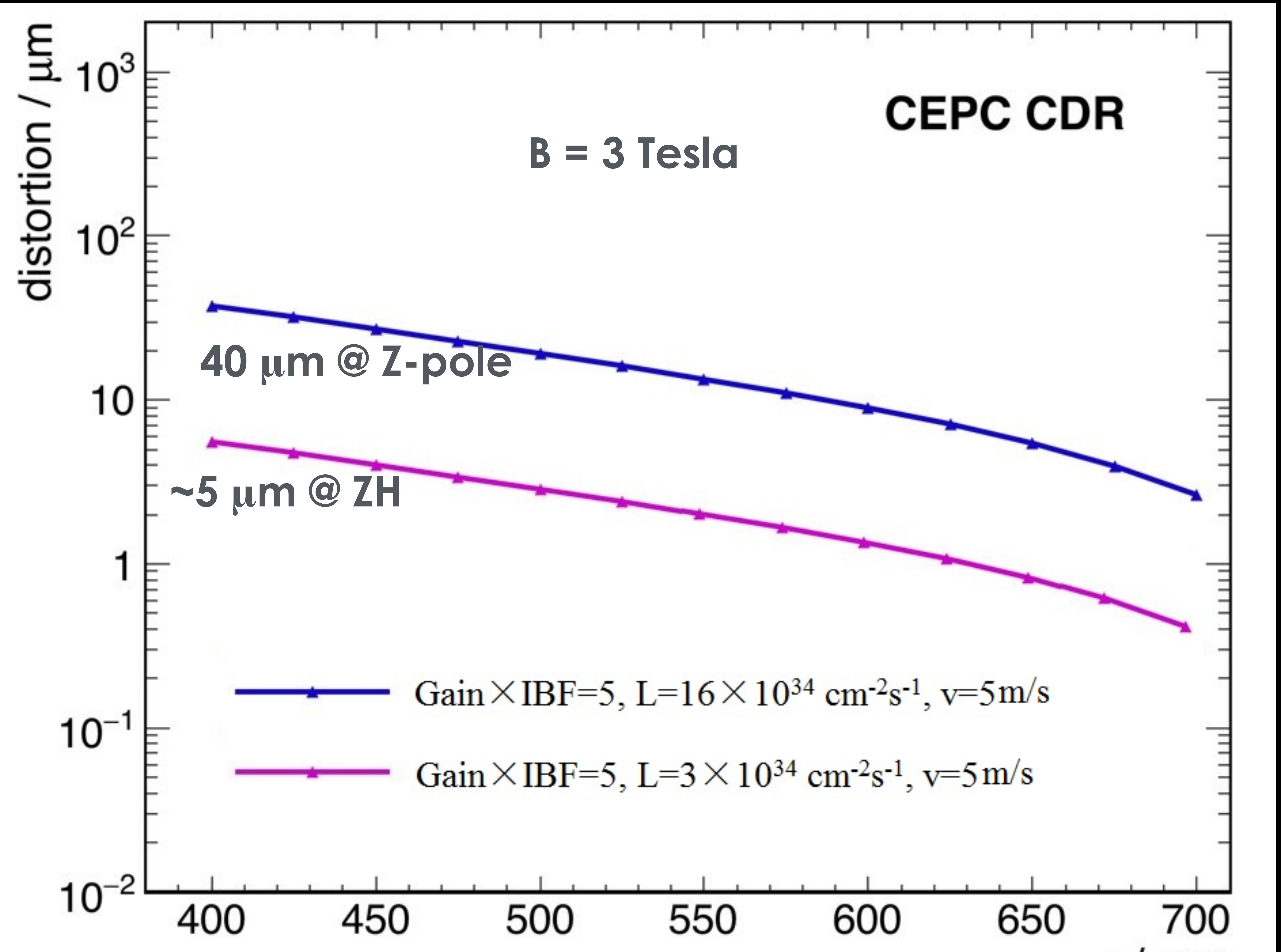
Magnet: 2 Tesla, 2.1 m radius

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

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

Vertex: Similar to CEPC default

Time Projection Chamber (TPC) – Challenges



Needs further studies

- Position resolution: ~100 μm in rϕ
- dE/dx resolution: 5%

- 3 Tesla magnetic field —> reduces diffusion of drifting electrons
- **Problem**: Ion Back Flow —> track distortion

Assumes, for each primary ionization, 5 ions backflow from readout into main gas system

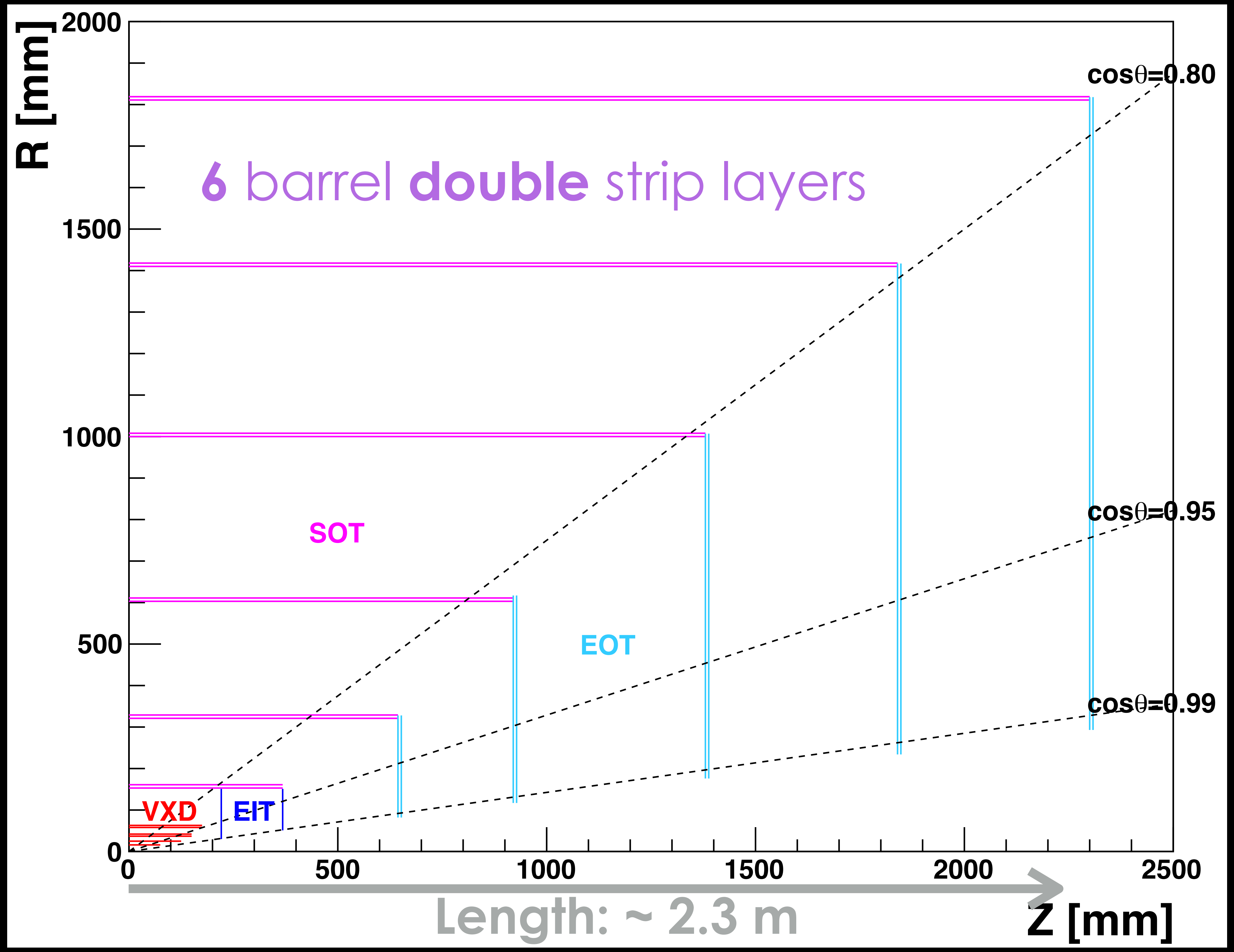
Hybrid: GEM and Micromegas readout

Mini-workshop, Hong Kong, IAS Jan 2019: http://iasprogram.ust.hk/hep/2019/workshop_cc.php

Full Silicon Tracker Concept

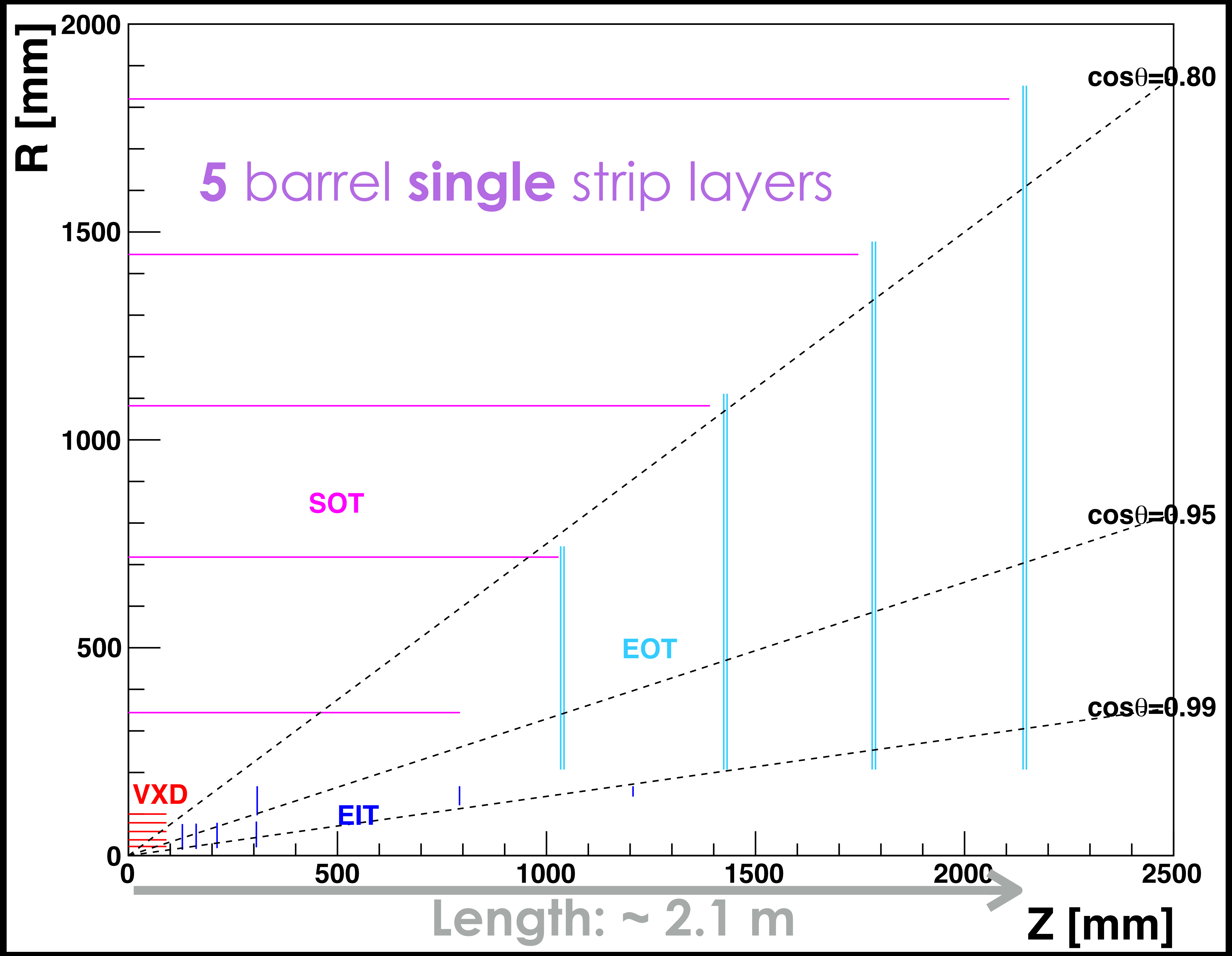
Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



Radius ~ 1.8 m

FST2 layout: Rad length up to 10%



Proposed by Berkeley and Argonne

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

New Ideas: Crystal Calorimeters

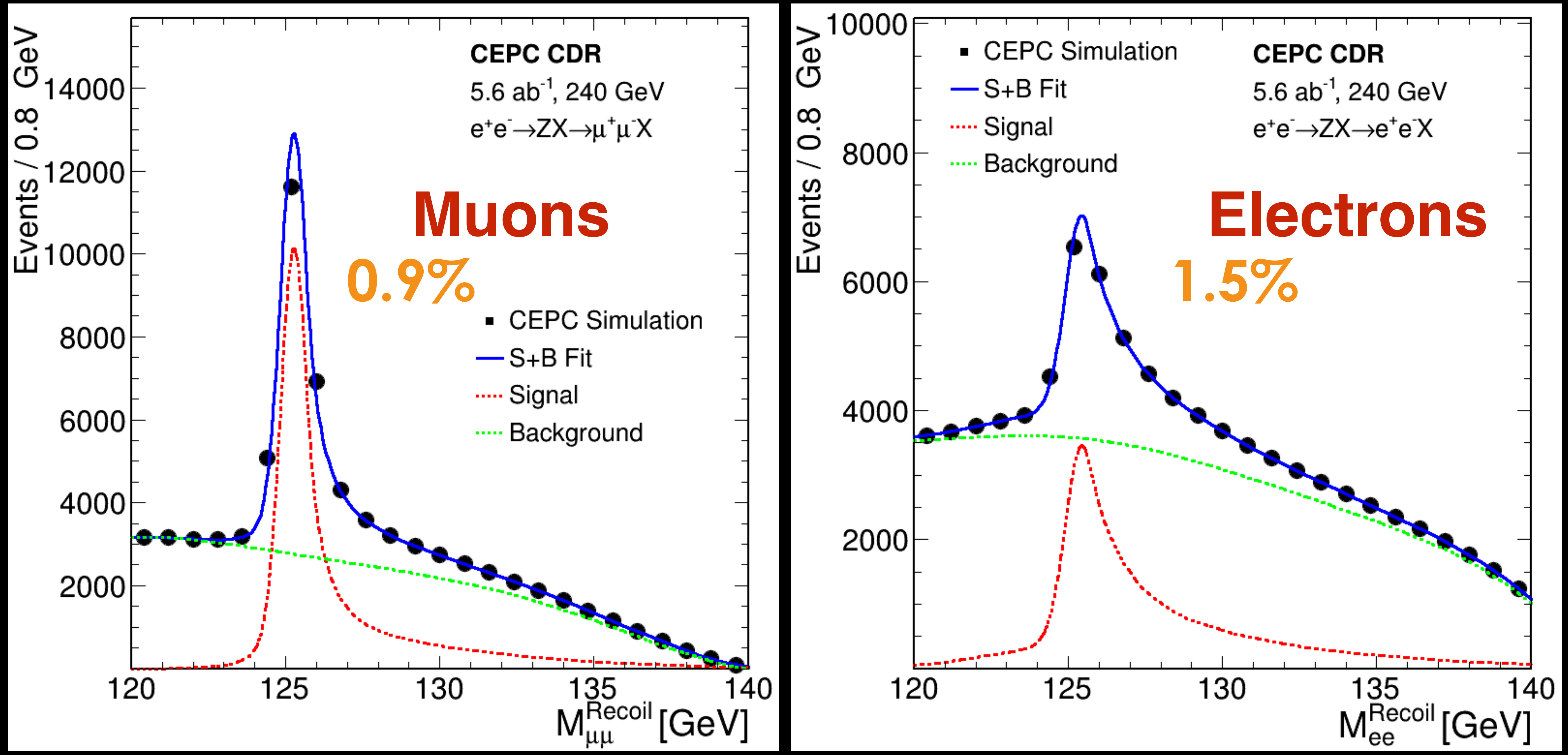
Topical Workshop on CEPC Calorimetry at IHEP • March 11-14, 2019
https://indico.ihep.ac.cn/event/9195/

Concern: **Electromagnetic resolution of PFA calorimeter not optimal**

Physics motivations:

- Electrons' Bremsstrahlung: energy recovery
- Improve angular resolution, and gamma counting
- Recoil photons: new physics and neutrino counting

Z boson recoil mass



Concepts parameter comparison

Concept	ILD	CEPC baseline	IDEA
Tracker	TPC/Silicon	TPC/Silicon or FST	Drift Chamber/Silicon
Solenoid B-Field (T)	3.5	3	2
Solenoid Inner Radius (m)	3.4	3.2	2.1
Solenoid Length (m)	8.0	7.8	6.0
L* (m)	3.5	2.2	2.2
VTX Inner Radius (mm)	16	16	16
Tracker Outer Radius (m)	1.81	1.81	2.05
Calorimeter	PFA	PFA	Dual readout
Calorimeter λ_I	6.6	5.6	7.5
ECAL Cell Size (mm)	5	10	-
ECAL Time resolution (ps)	-	200	-
ECAL X_0	24	24	-
HCAL Layer Number	48	40	-
HCAL Absorber	Fe	Fe	-
HCAL λ_I	5.9	4.9	-
DRCAL Cell Size (mm)	-	-	6.0
DRCAL Time resolution (ps)	-	-	100
DRCAL Absorber	-	-	Pb or Cu or Fe
Overall Height (m)	14.0	14.5	11.0
Overall Length (m)	13.2	14.0	13.0

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

Higher radiation tolerance