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CEPC

Optimization on silicon detectors at CEPC

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Outline

- Introduction
- Fast simulation and full simulation results
- Flavor tagging performance with different vertex geometry
- Influence of the material budget near beam pipe
- Performance of an ultra lightweight vertex layout
- Influence of SET on track and Higgs mass reconstruction
- Vertex detector prototype

Introduction

- H -> bb, cc and gg is the core part of the CEPC Higgs program
- Vertex system with high impact parameter resolution is crucial

Table 6.1 Required performance of the CEPC sub-detectors for critical benchmark Higgs processes.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_{\mathrm{T}}) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_{\mathrm{T}} \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

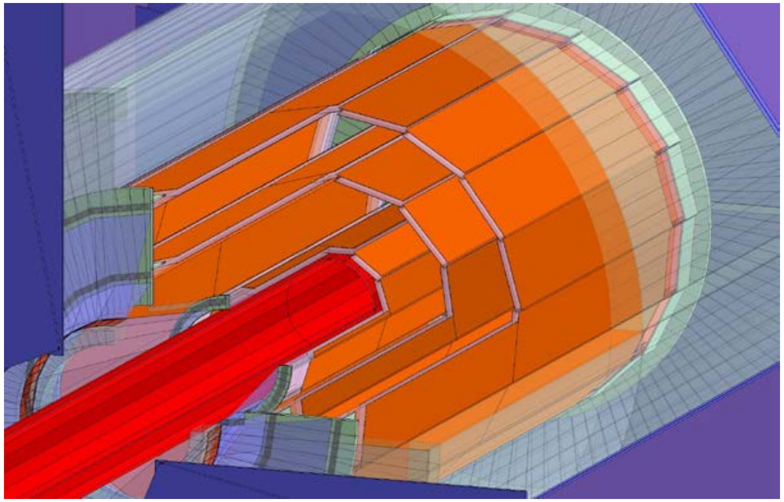


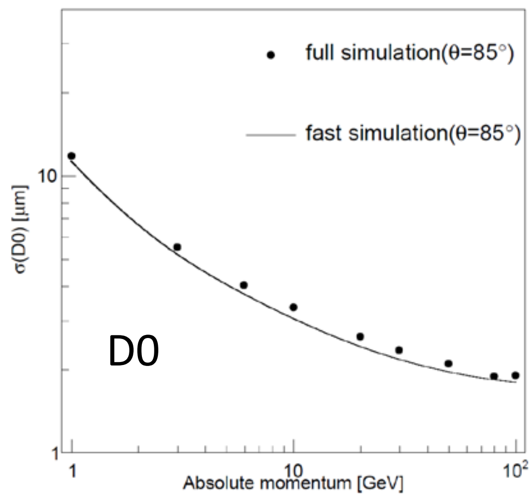
Table 1. Design parameters of the CEPC vertex system.

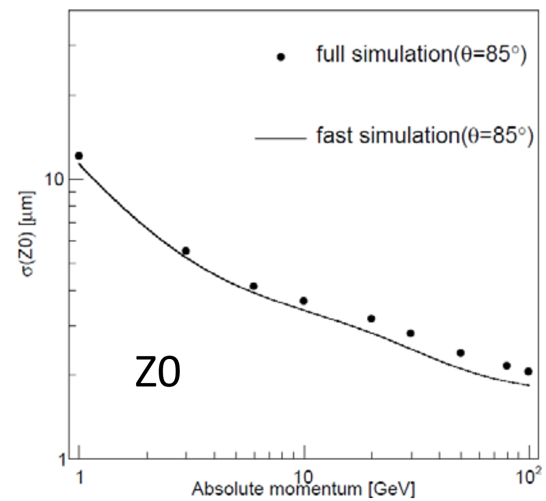
	R(mm)	| Z |(mm)	$\sigma(\mu m)$	material budget
Layer 1	16	62.5	2.8	$0.15\%/X_0$
Layer 2	18	62.5	6	$0.15\%/X_0$
Layer 3	37	125.0	4	$0.15\%/X_0$
Layer 4	39	125.0	4	$0.15\%/X_0$
Layer 5	58	125.0	4	$0.15\%/X_0$
Layer 6	60	125.0	4	$0.15\%/X_0$

Simulation tools

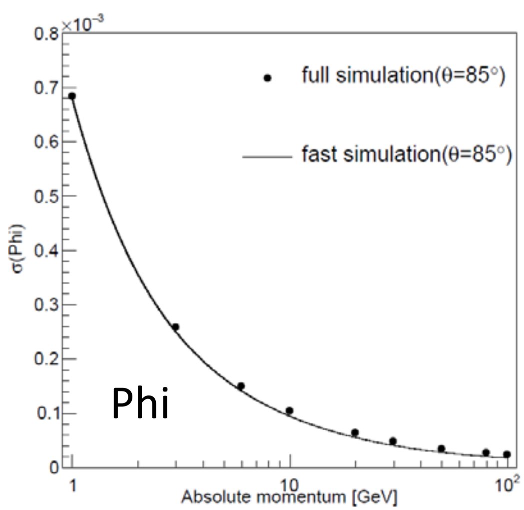
- Fast simulation："LiC Detector Toy" (LDT) software tool
- Full simulation： Mokka and Marlin

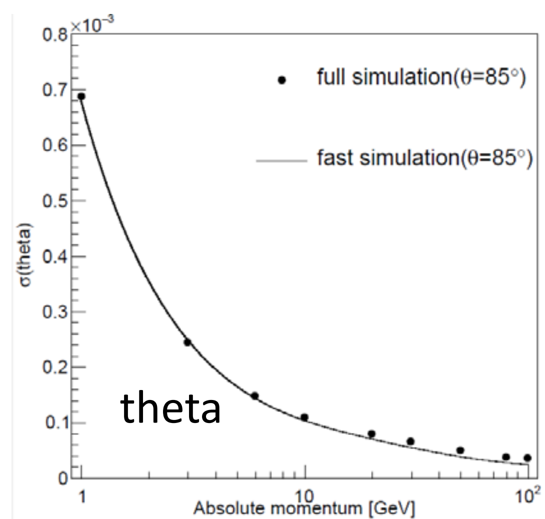
consistent





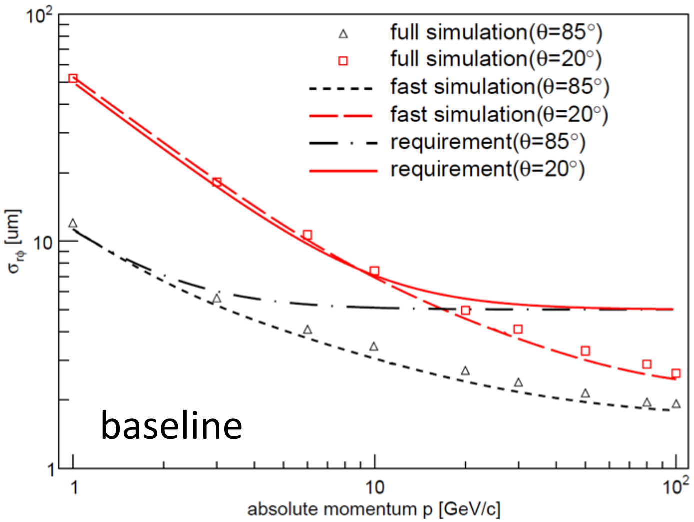
The key parameters' resolution of a helix track

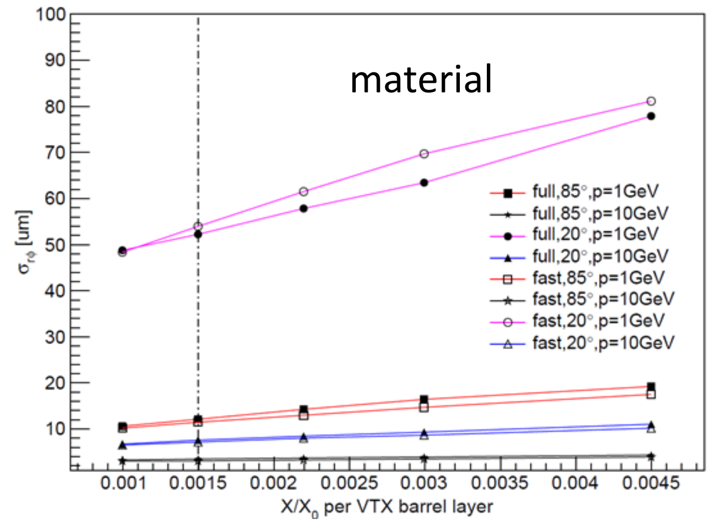


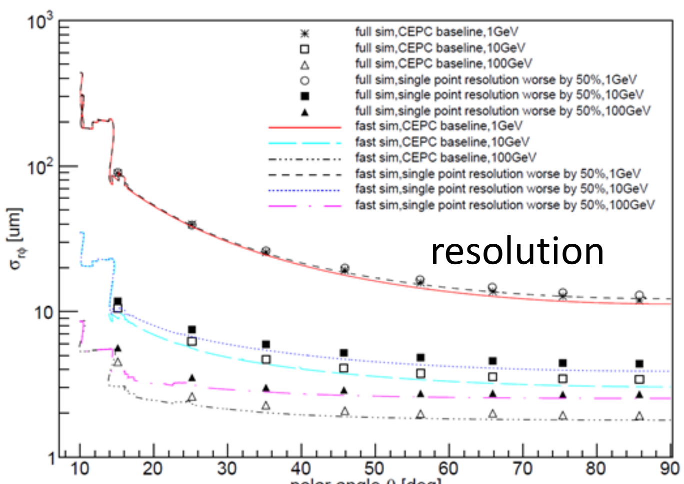


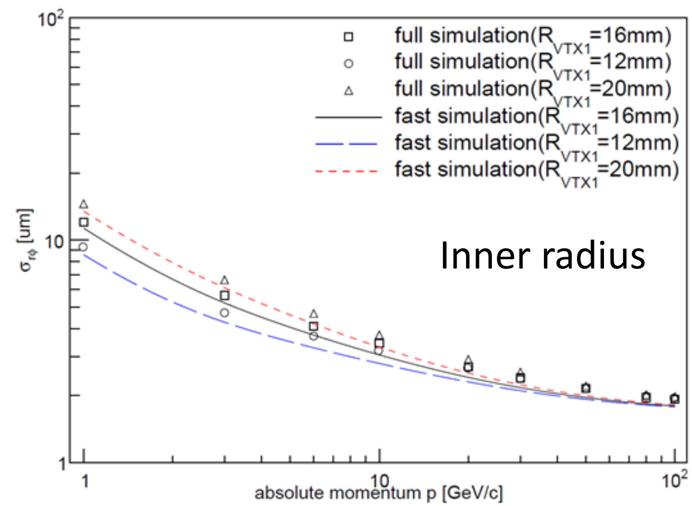
Key geometry parameters

- The influence of the geometry parameters on the impact parameter resolution
  - Inner radius, Material budget, Spatial resolution





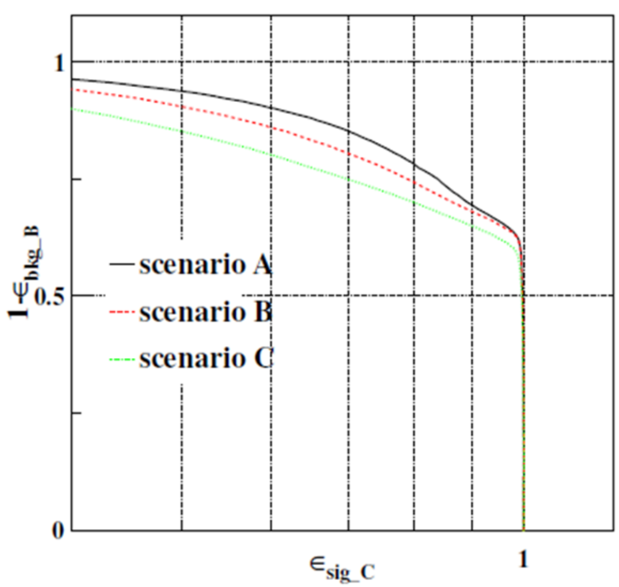




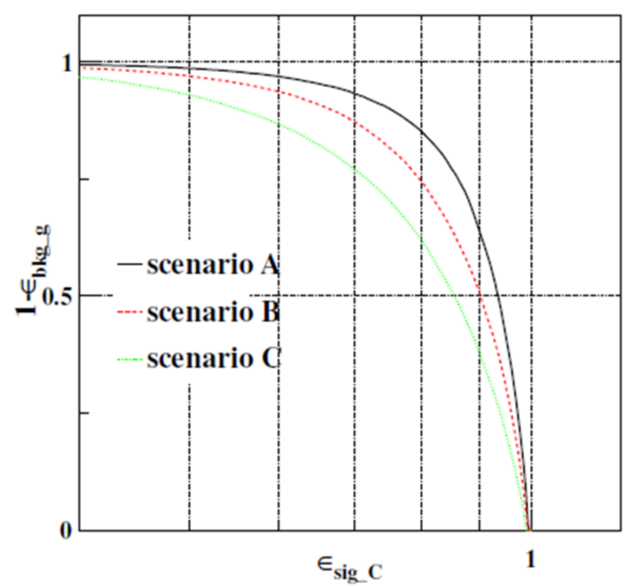
Flavor tagging performance

- Only di-jet final modes (bb, cc, gg) are considered, evaluated by ROC
- Case C: upgraded ALICE ITS; Case A: half values of the baseline design

Rejection ratio



C-tagging efficiency



C-tagging efficiency

	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/X_0	0.075	0.15	0.3
Spatial resolution/μm	1.4 - 3	2.8 - 6	5 - 10.7
R_{in}/mm	8	16	23

Br(H->bb, cc) measurement

- Br (H -> cc) is extremely sensitive to the vertex design
- Br (H -> bb) is less sensitive to the vertex design

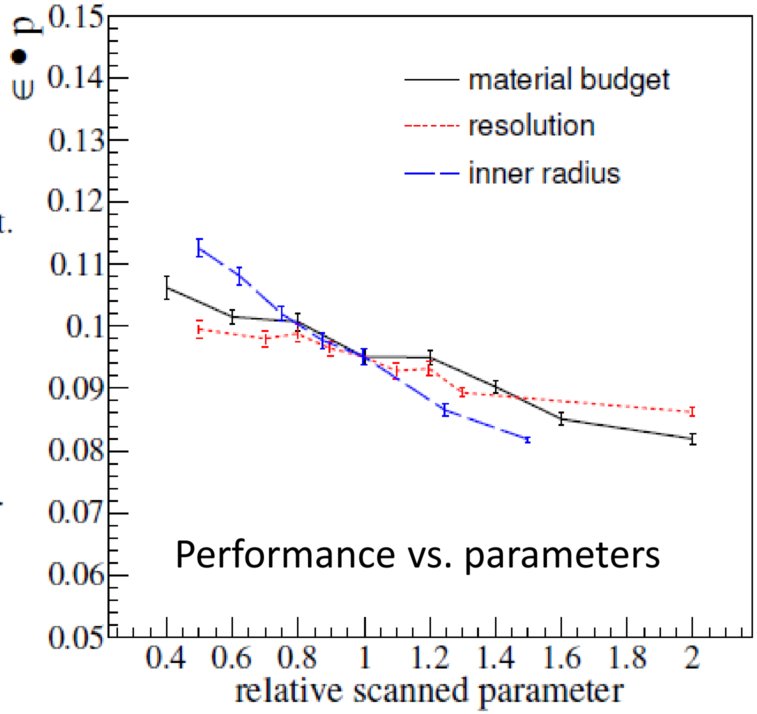
$$\frac{\delta_\mu}{\mu} \propto \frac{\sqrt{S+B}}{S} = \sqrt{\frac{1}{S}}\sqrt{\frac{S+B}{S}} \propto \frac{1}{\sqrt{\epsilon \cdot p}}.$$

Table 3. Maximum $\epsilon \cdot p$ value comparison for the $Br(H \to c\bar{c})$ measurement.

	Scenario A	Scenario B	Scenario C
$\epsilon \cdot p$	0.133 ± 0.002	0.095 ± 0.001	0.078 ± 0.001
	41%		-22%

Table 4. Maximum $\epsilon \cdot p$ value comparison for the $Br(H \to b\bar{b})$ measurement.

	Scenario A	Scenario B	Scenario C
$\epsilon \cdot p$	0.925 ± 0.001	0.914 ± 0.001	0.900 ± 0.001
	1%		-1.5%



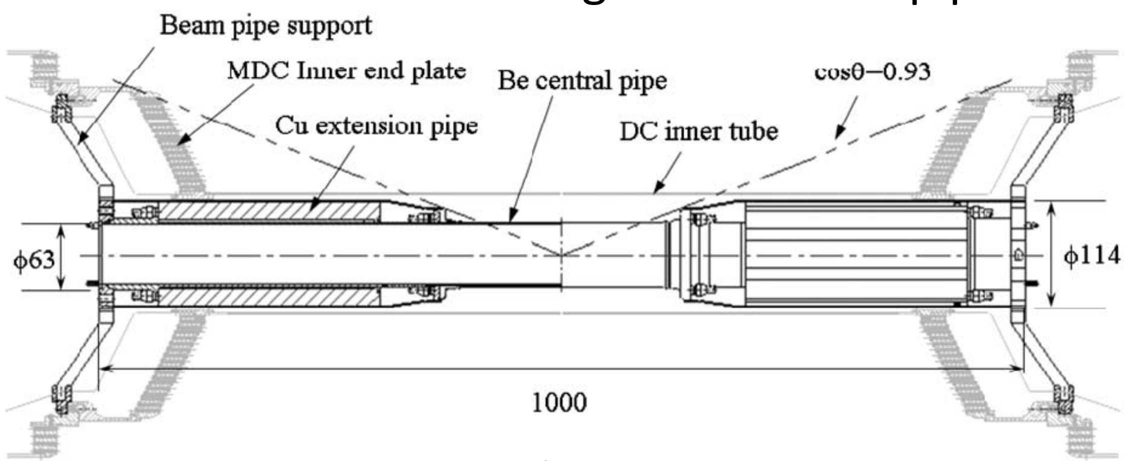
$$\epsilon \cdot \mathrm{p} = 0.095(1 - 0.14\frac{\Delta x_{material}}{x_{material}})(1 - 0.09\frac{\Delta x_{resolution}}{x_{resolution}})(1 - 0.23\frac{\Delta x_{radius}}{x_{radius}})$$

Inner radius is the most sensitive parameter

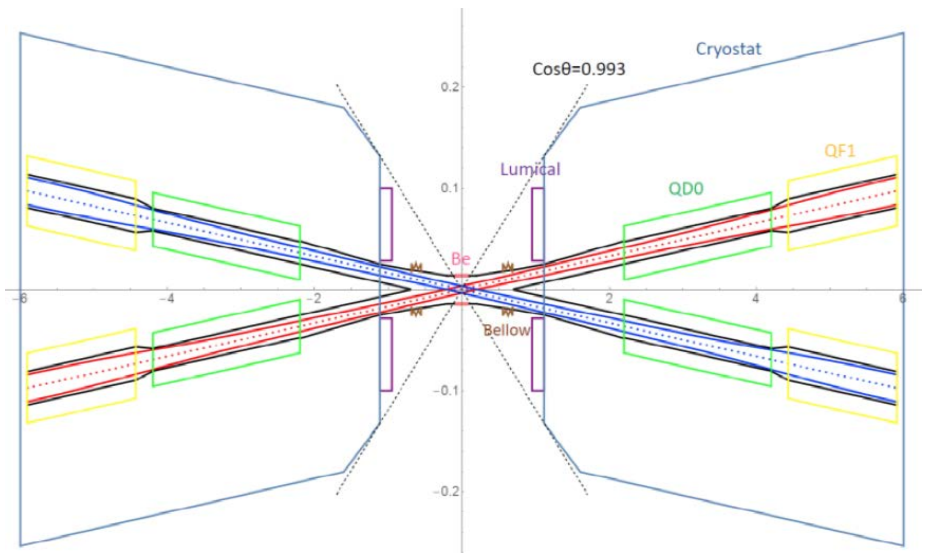
Material budget near beam pipe

- BESIII beam pipe material: 1.04%/X_0 (Be: 0.4%, gold: 0.44%, SMO: 0.2%)
- CEPC beam pipe material: 0.14%/X_0 Be, heat load more than 1000 W
- Have to increase the material budget near beam pipe due to cooling

BESIII

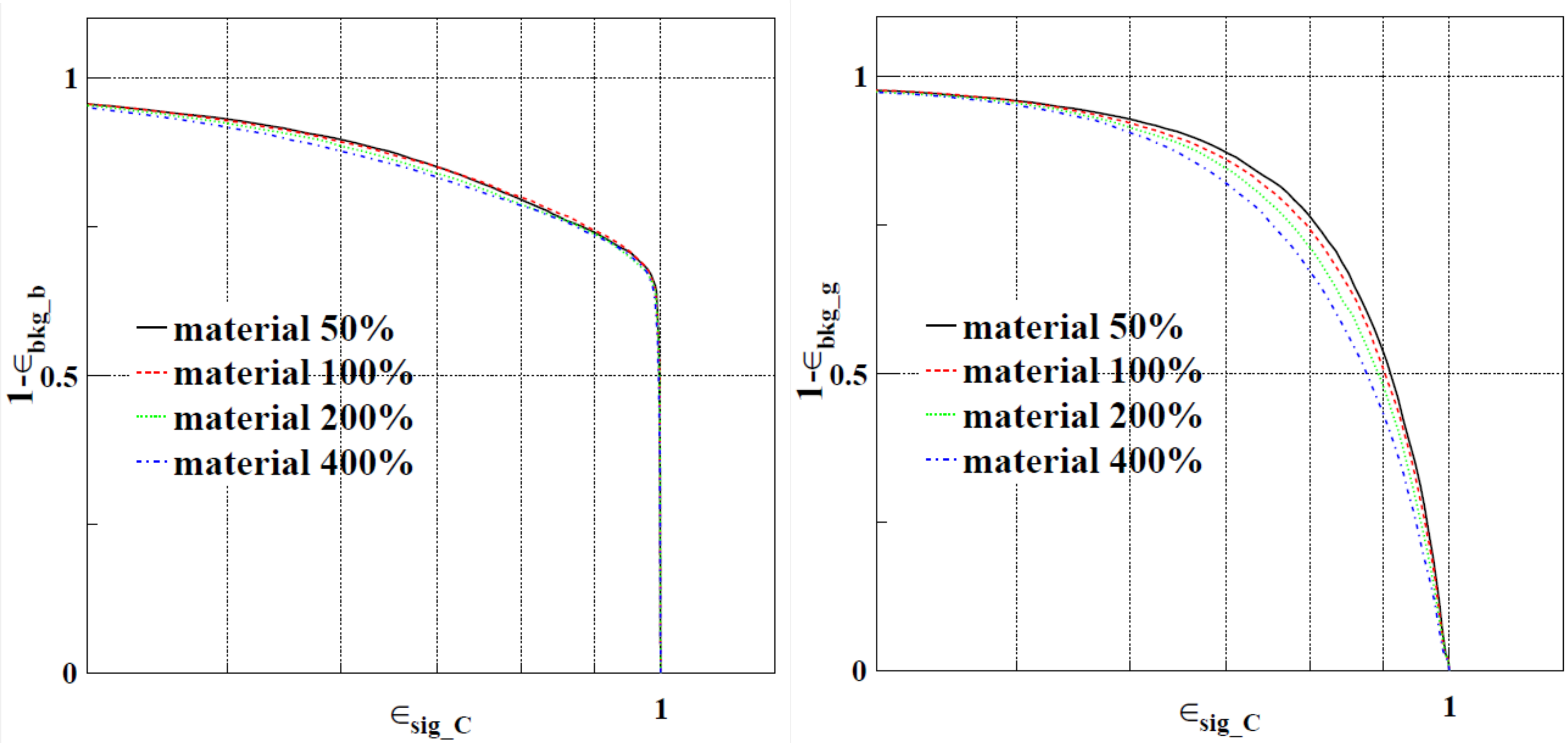


CEPC



Material budget near beam pipe

- Have to increase the material budget near beam pipe due to cooling system
- Influence is comparable with the material change of vertex detector



material	50%	100%	200%	400%
ε•p	0.1175	0.1145	0.1092	0.1057

-10%

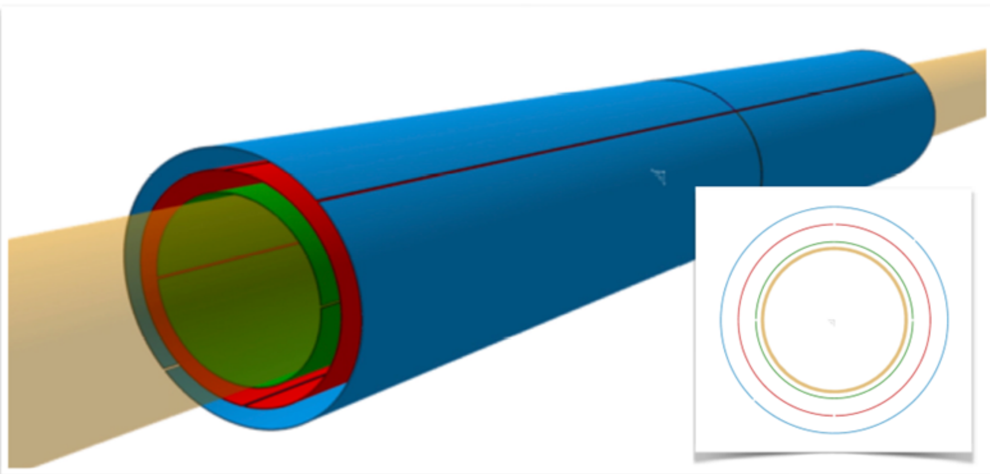
$$\varepsilon \bullet p \propto 1 - 0.025 \frac{\Delta x_{material}}{x_{material}}$$

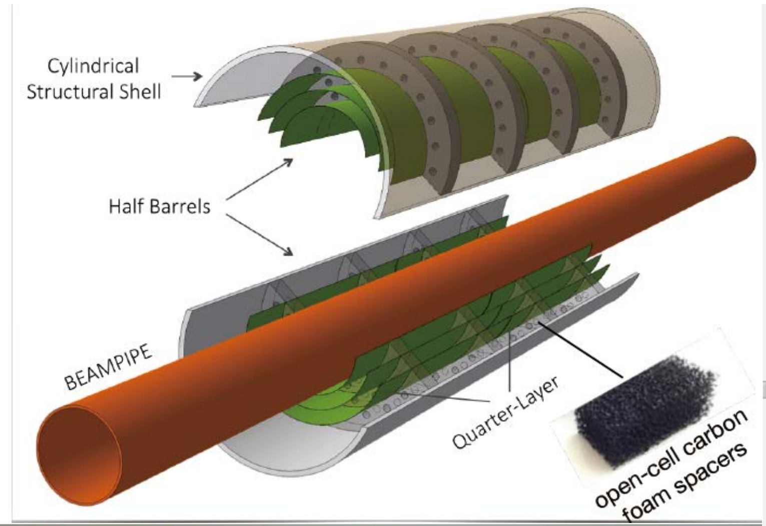
An ultra lightweight vertex layout

- ALICE ITS3: a cylindrical layer of silicon-only sensors, stitching and thinning
- The geometry is similar with CEPC baseline design

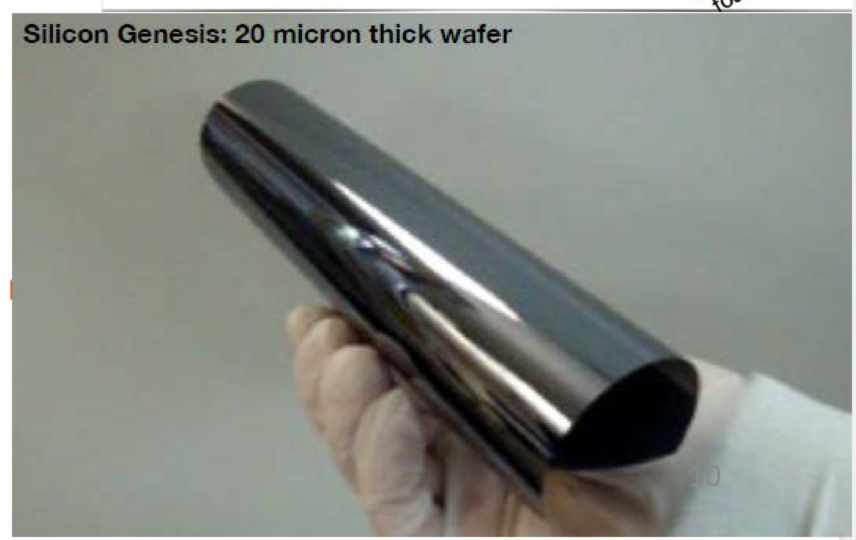
ALICE

Layout



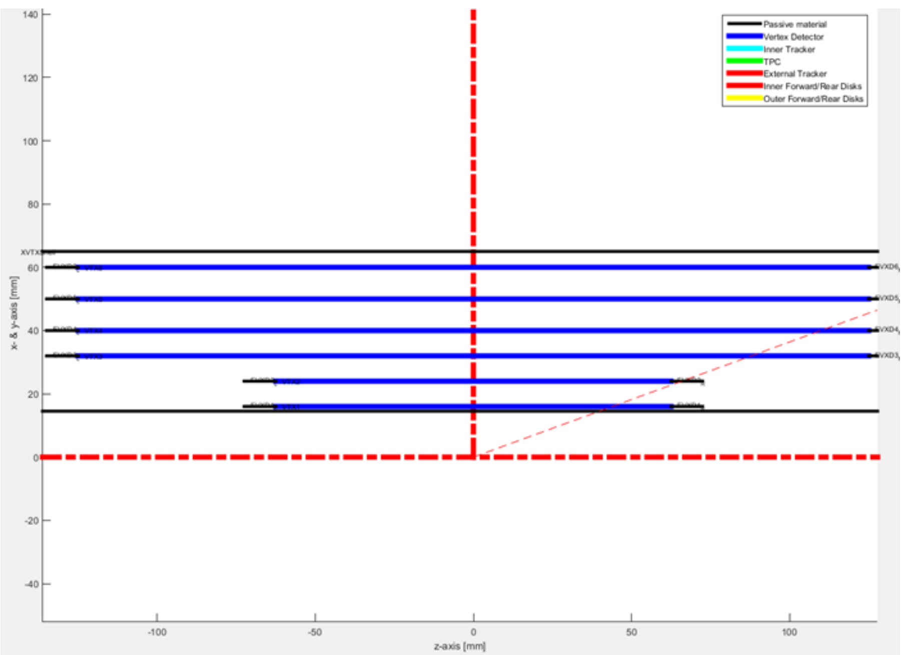


Beam pipe Inner/Outer Radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0 16mm	24.0	30.0
Length (sensitive area) (mm)	300 250mm		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area (cm²)	610	816	1016
Pixel sensor dimensions (mm²)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm²)	O (10 x 10)		

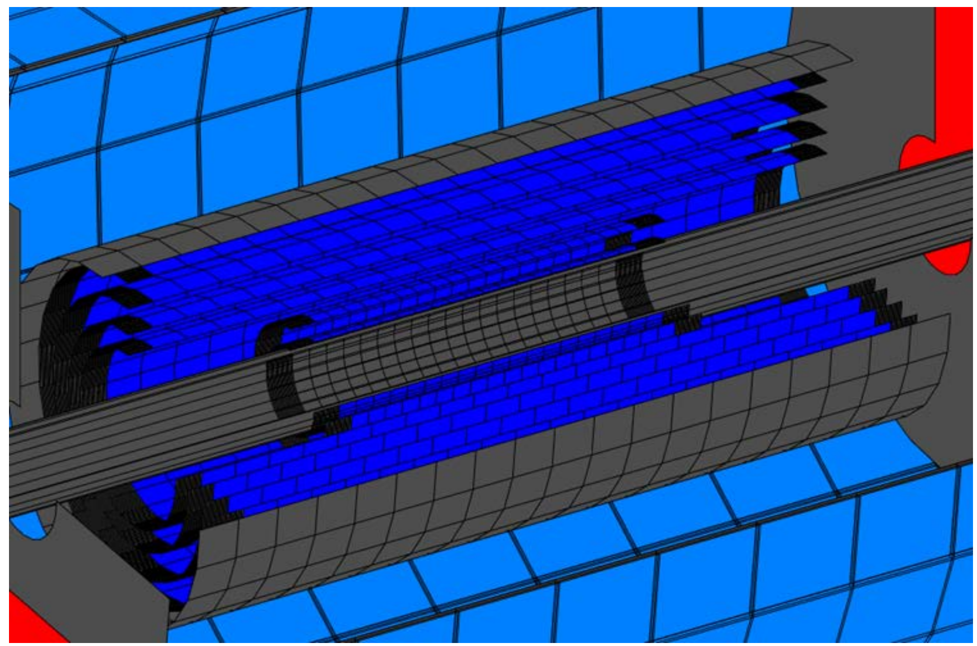


An ultra lightweight vertex layout

- new layout 1： 6 layers r(mm)=16,24,32,40,50,60; single point resolution 4μm/layer; 0.05%X_0/layer; B=3T
- new layout 2： 6 layers r(mm)=16,24,32,40,50,60; single point resolution 2.8μm/innermost layer, 4μm/outside layers; 0.05%X_0/layer; B=3T



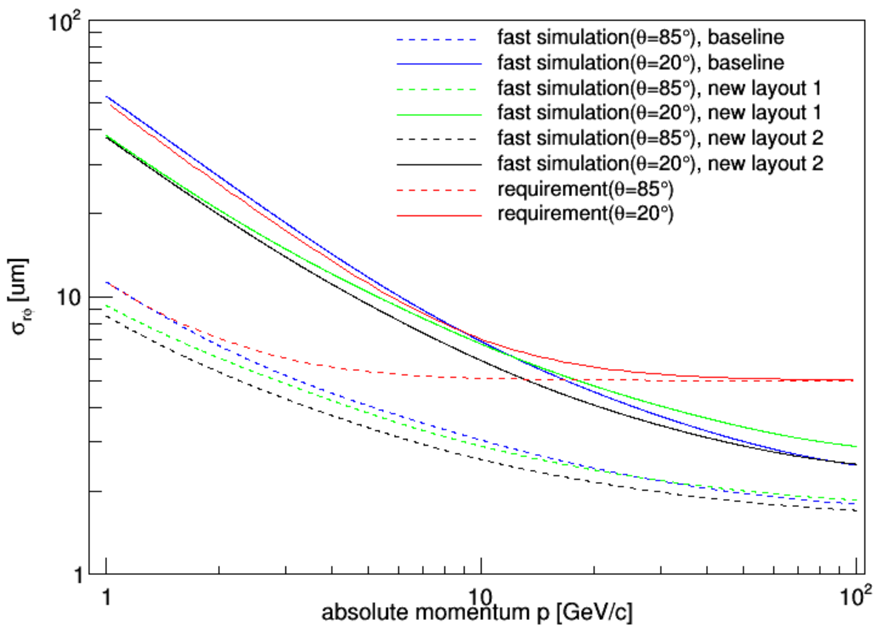
2D-schematic



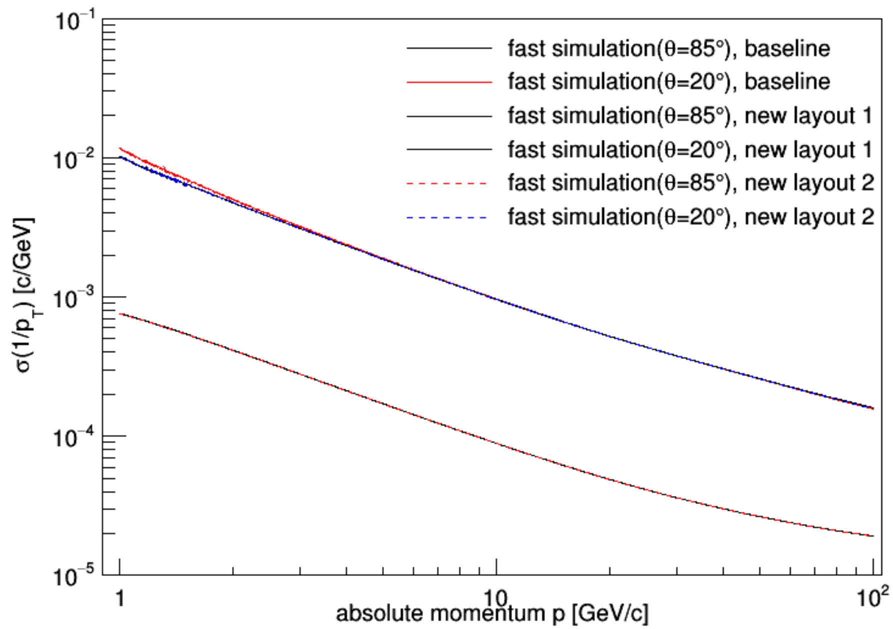
3D-schematic

Performance of an ultra lightweight vertex layout

- For impact parameter resolution, better performance (~20% improvement) for layout1 at low momentum, but poor performance at high momentum
- The performance of layout2 is better than baseline design
- Full simulation study is undergoing



Impact parameter resolution

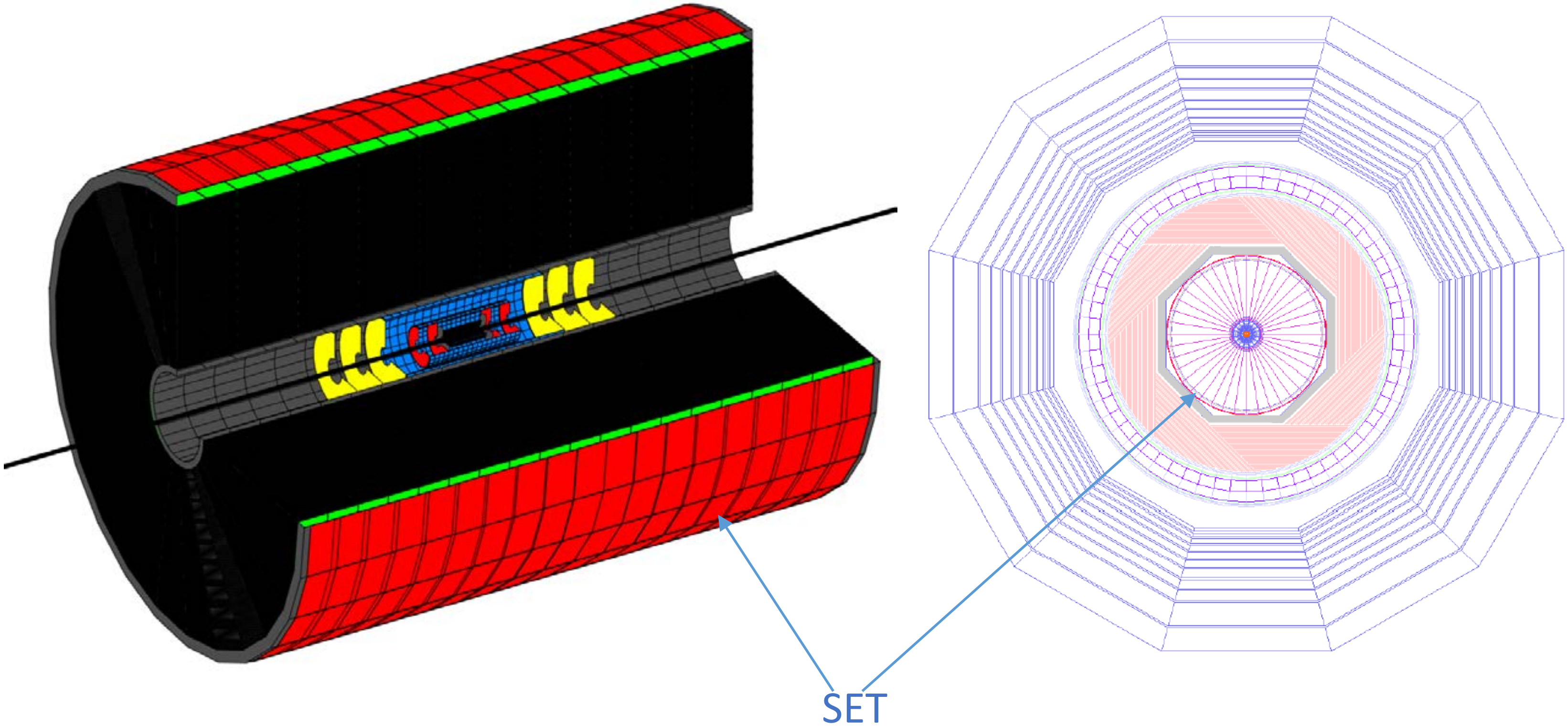


Transverse momentum resolution

Material budget plays a major role at low momentum, while resolution plays a major role at high momentum.

SET introduction

- Silicon External Tracker, providing precise hit points after the TPC
- Improving the overall tracking performance in the central region
- Extrapolating from the TPC to the calorimeter

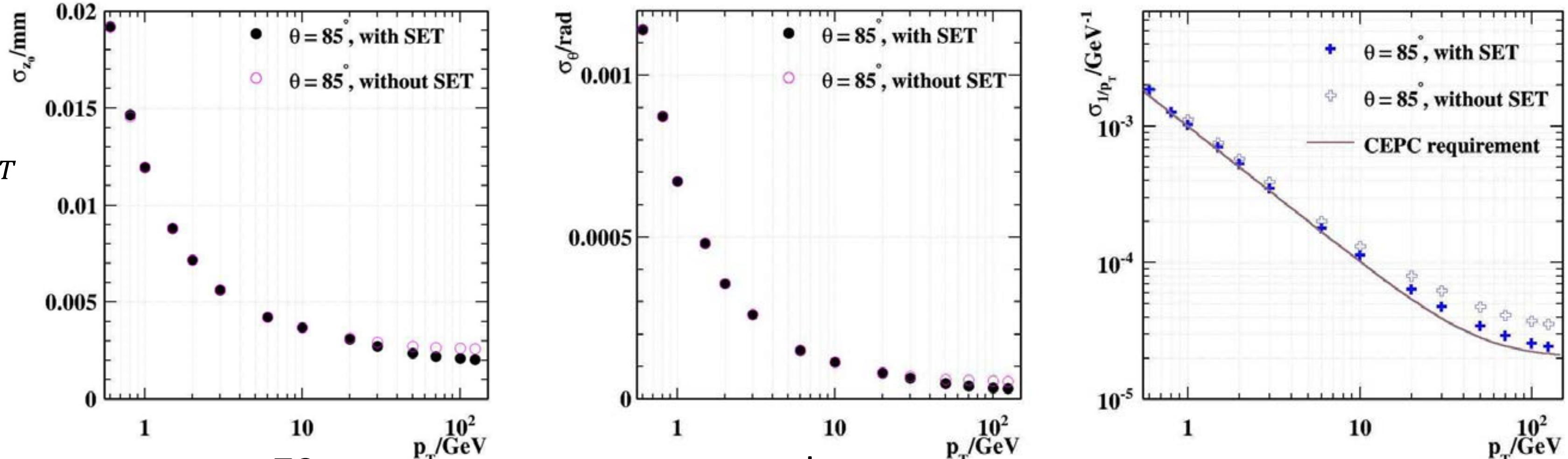


Effect of SET on track reconstruction

- SET has a high influence on the resolution of Z0, theta and omega
  - When Pt is high

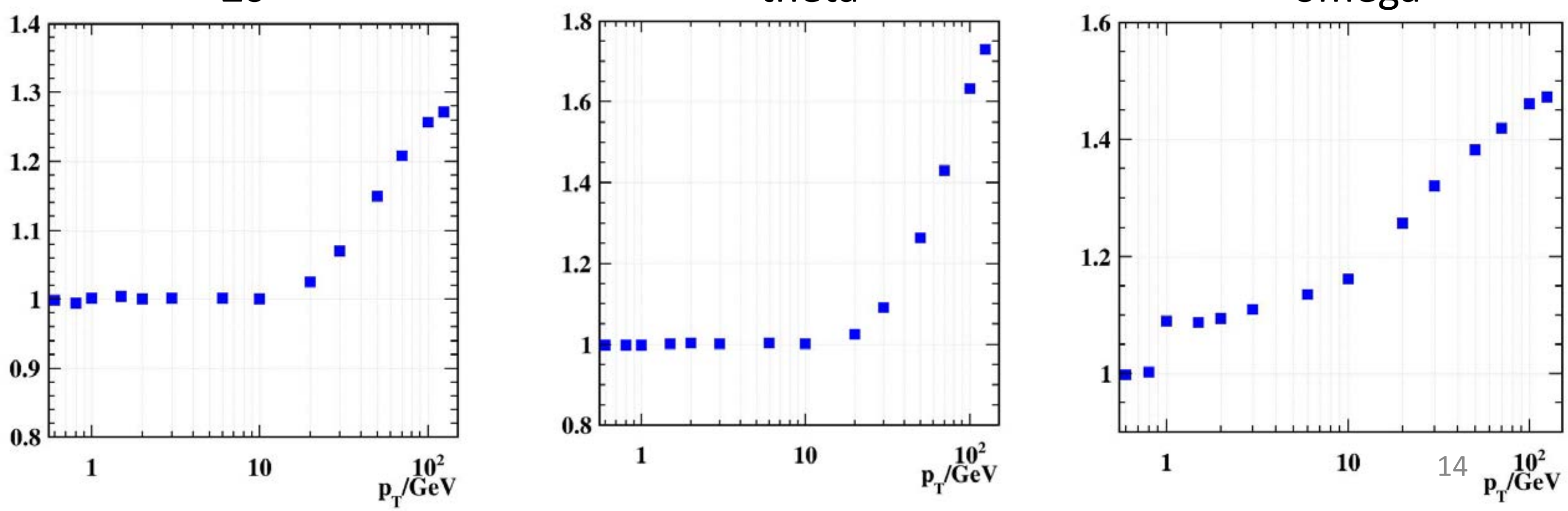
Made by Taifan.

$\sigma_{withoutSET}$ and $\sigma_{withSET}$



Z0 theta omega

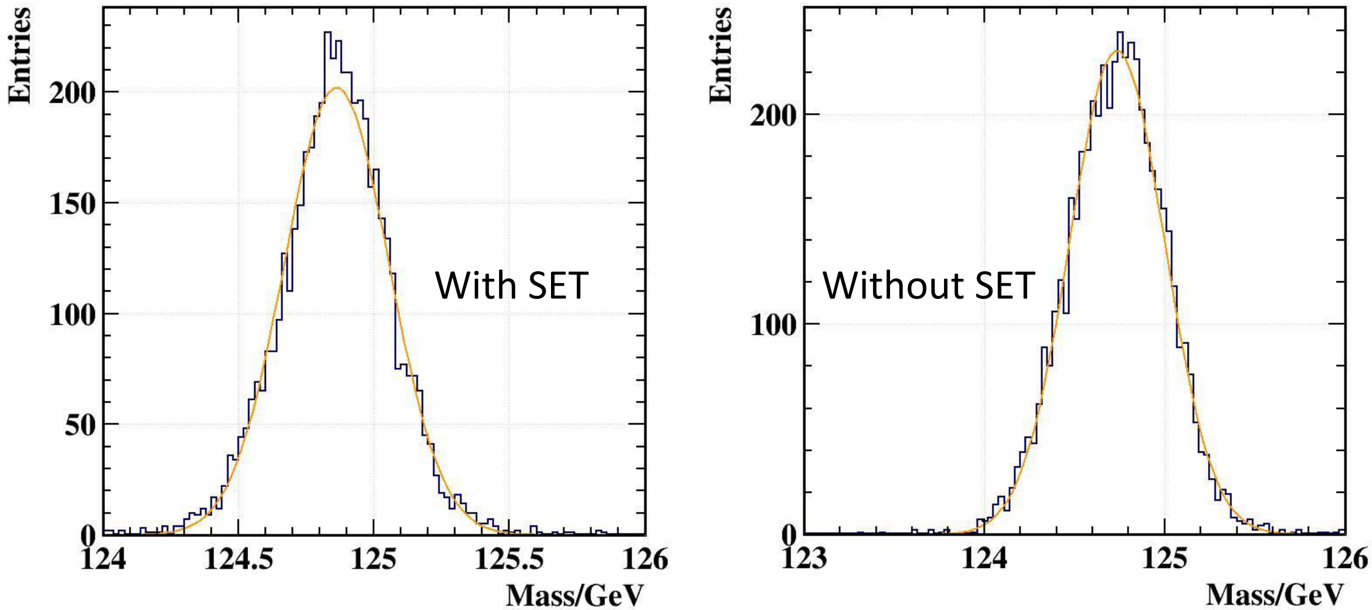
$$\frac{\sigma_{withoutSET}}{\sigma_{withSET}}$$



Effect of SET on Higgs Mass reconstruction

- Higgs mass resolution in $H \to \mu^+\mu^-$. Use MC information to find out true μ tracks
- High influence on Higgs Mass resolution

Made by Taifan.



Higgs mass resolution/MeV

	ZH recoil	nnH
withSET	213.4+-4.7	193.7+-2.2
w/o SET	297.5+-6.3	263.5+-2.7
	+39%	+36%

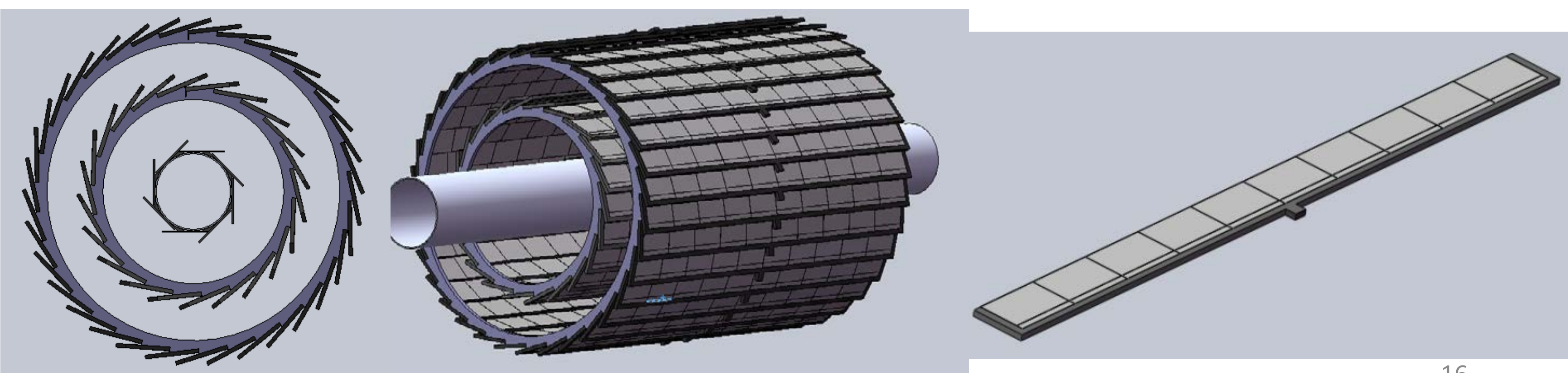
Vertex detector prototype

by Jinyu

- Plan to build a vertex detector prototype in 2~3 years
  - Supported by Ministry of Science and Technology (MOST)
  - With full-size support structure
  - Part of modules will be installed to test spatial resolution of vertex detector

Collaboration with Livepool and Oxford on detector structure design

Engineering design of vertex detector



Thanks for your attention!