国家重点研发计划“高能环形正负电子对撞机关键技术研发和验证”

Silicon tracker layout design

Z. ZHANG, B. LIU, J. FU, C. FU, Z. LIANG, K. WU, G. LI

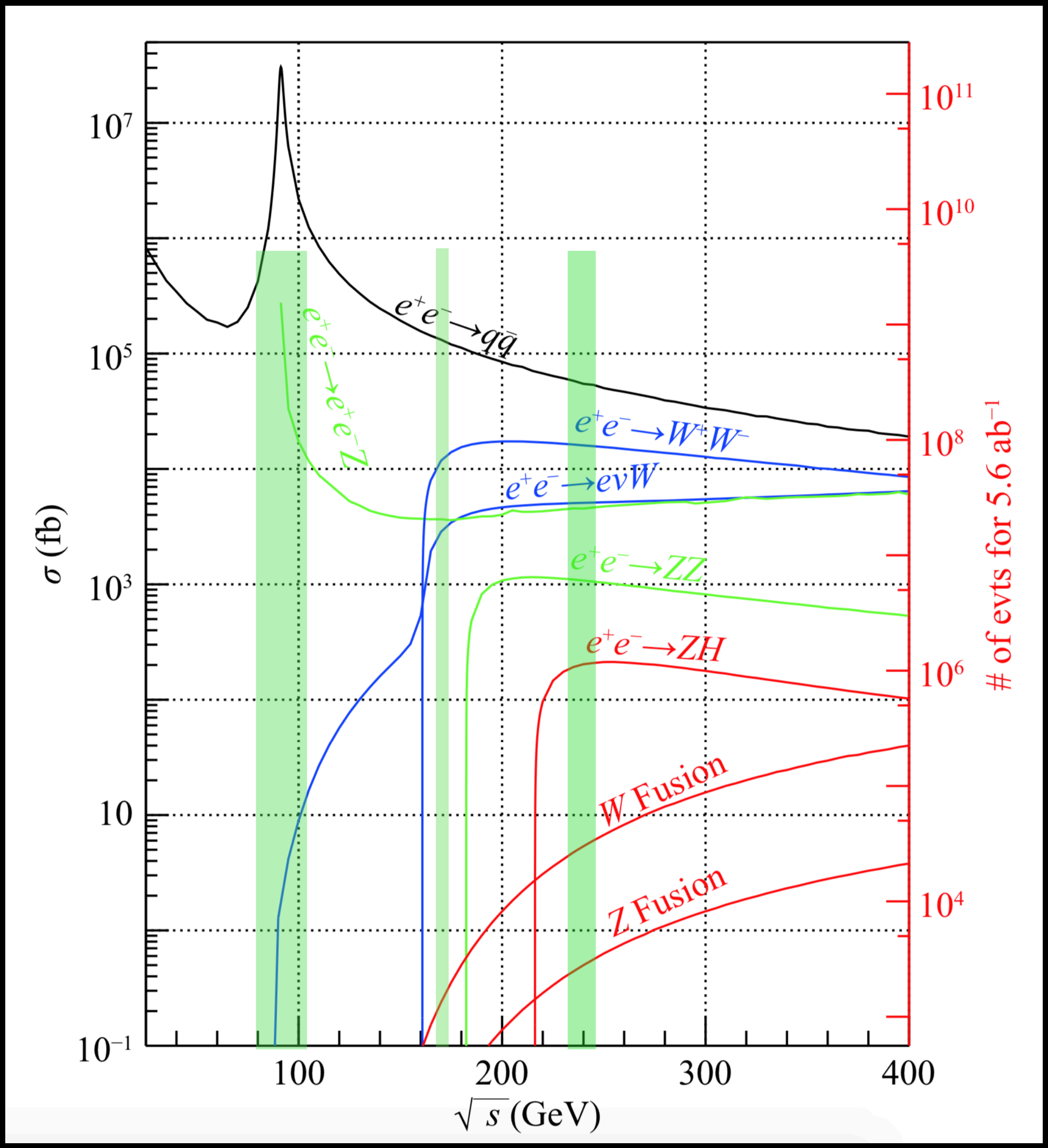
IHEP

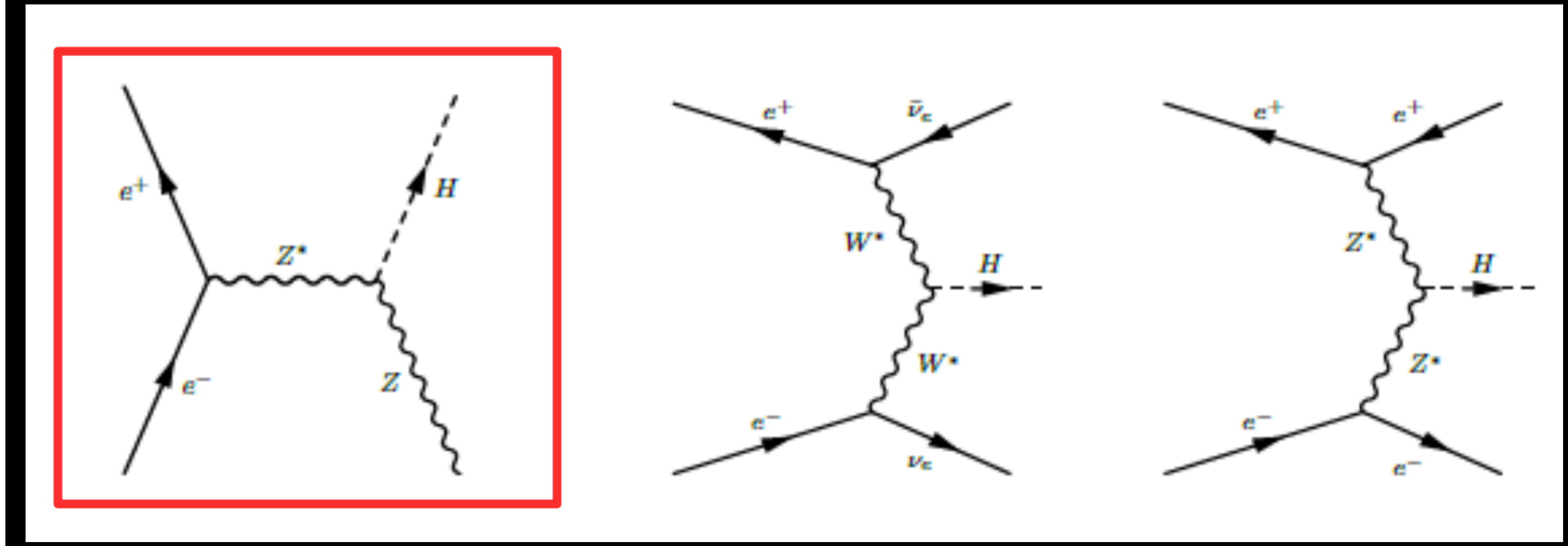
2019年4 月 29-30 日项目年会

OUTLINE

- **Introduction**
- **Optimization**
- **Summary & Plan**

CEPC: 1 M Higgs, 10^{11}~10^{12} Z bosons and ~10^{8} W Pairs

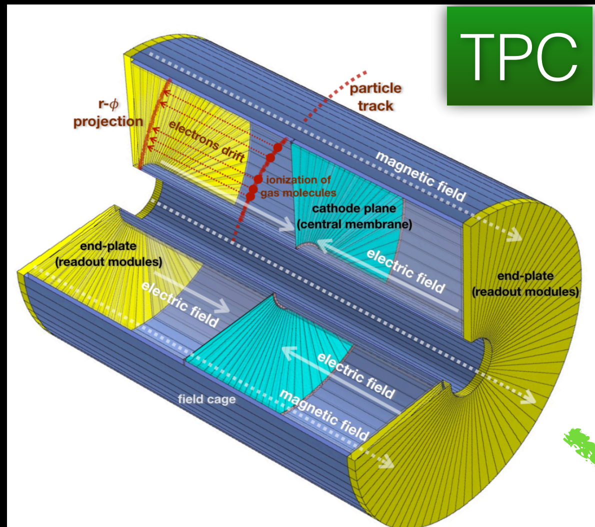




Process	Cross section	Events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	196.2	1.10×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^- \to e^+e^- H$	0.28	1.57×10^3
Total	203.7	1.14×10^6

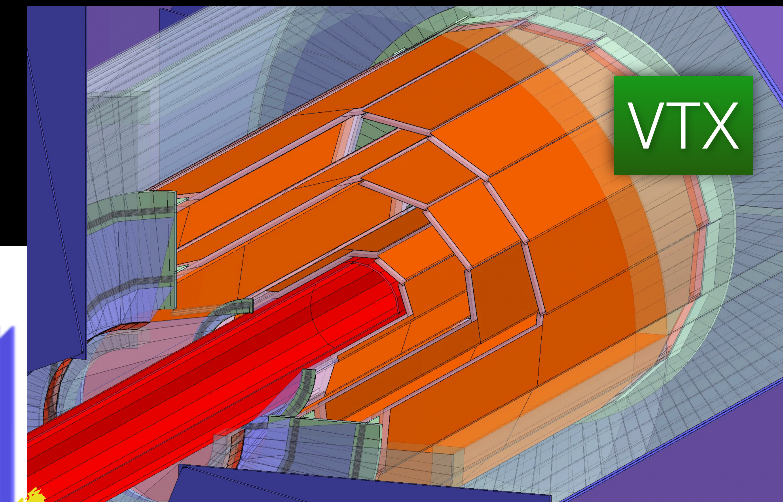
- Direct: Higgs mass, σ(ZH), Branching ratios, Diff. distributions
- Derived: Higgs width, couplings, quantum numbers, …
- EW Precision, tau physics, Flavor Physics, …

Baseline design

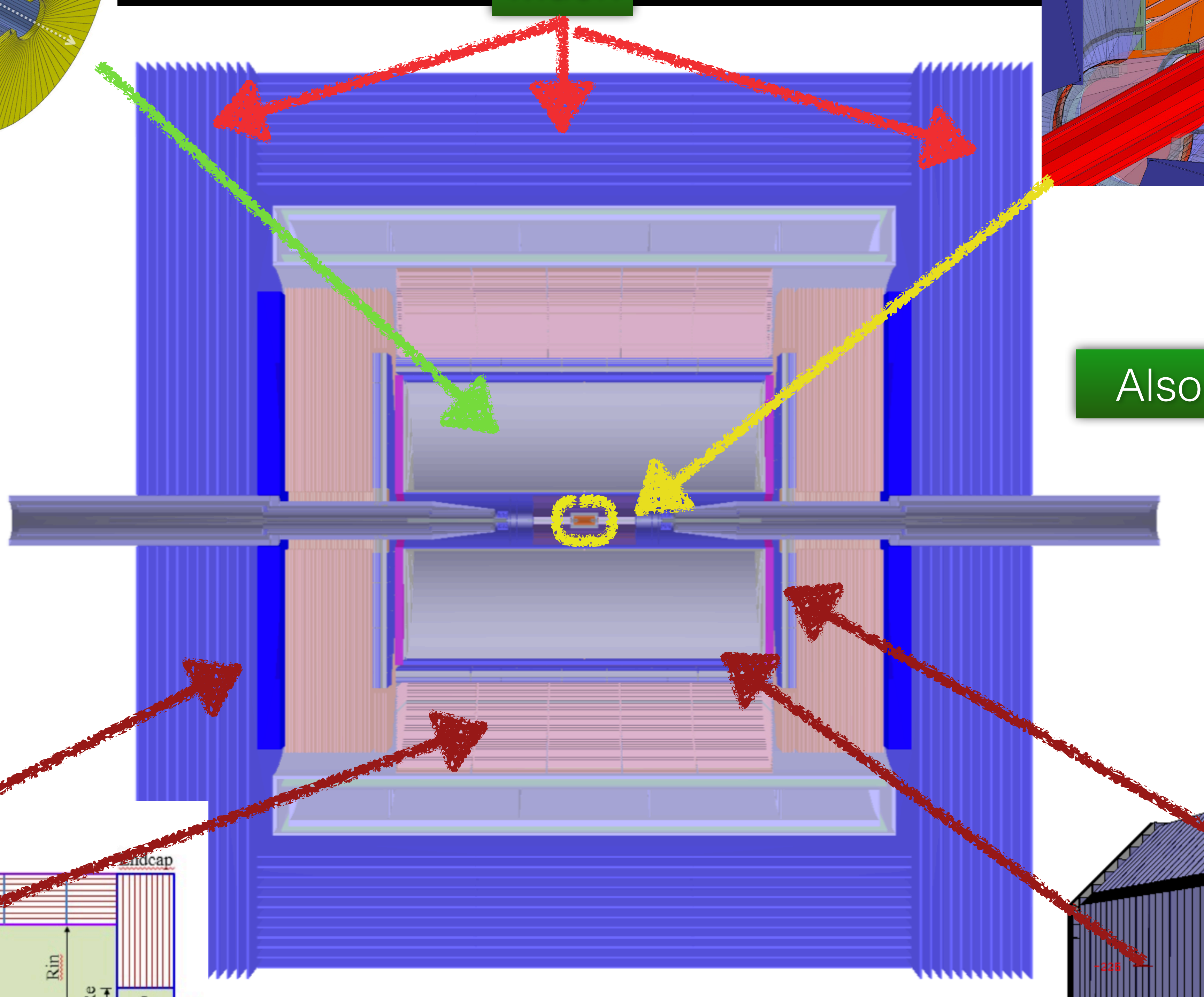


TPC

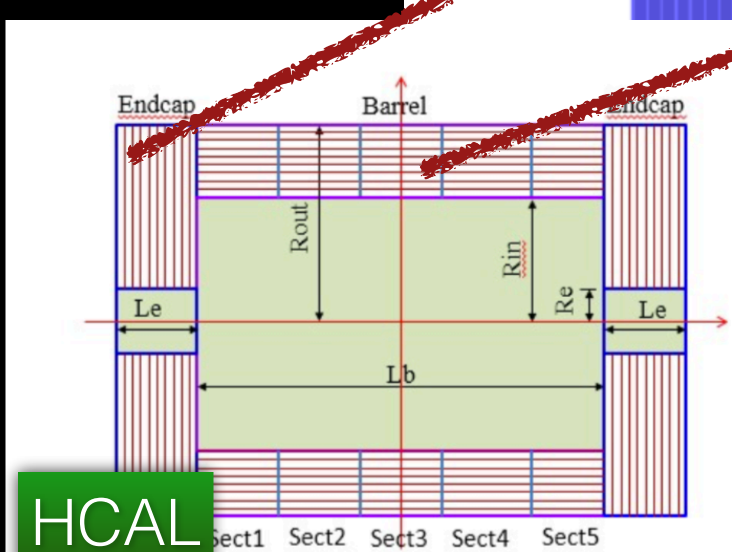
Muon



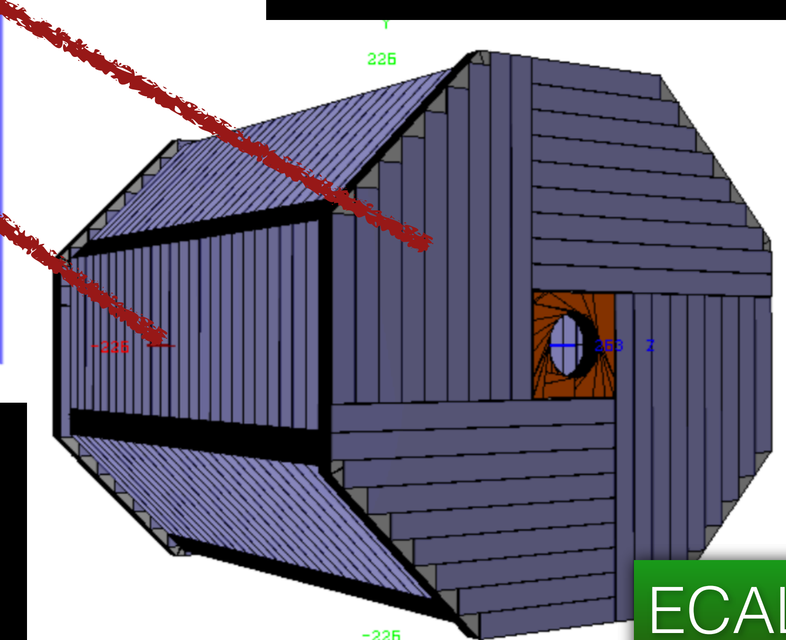
VTX



Also silicon tracker



HCAL



ECAL

Silicon Vertex

- ★ **Just outside the beampipe**
- ★ **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)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ (μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
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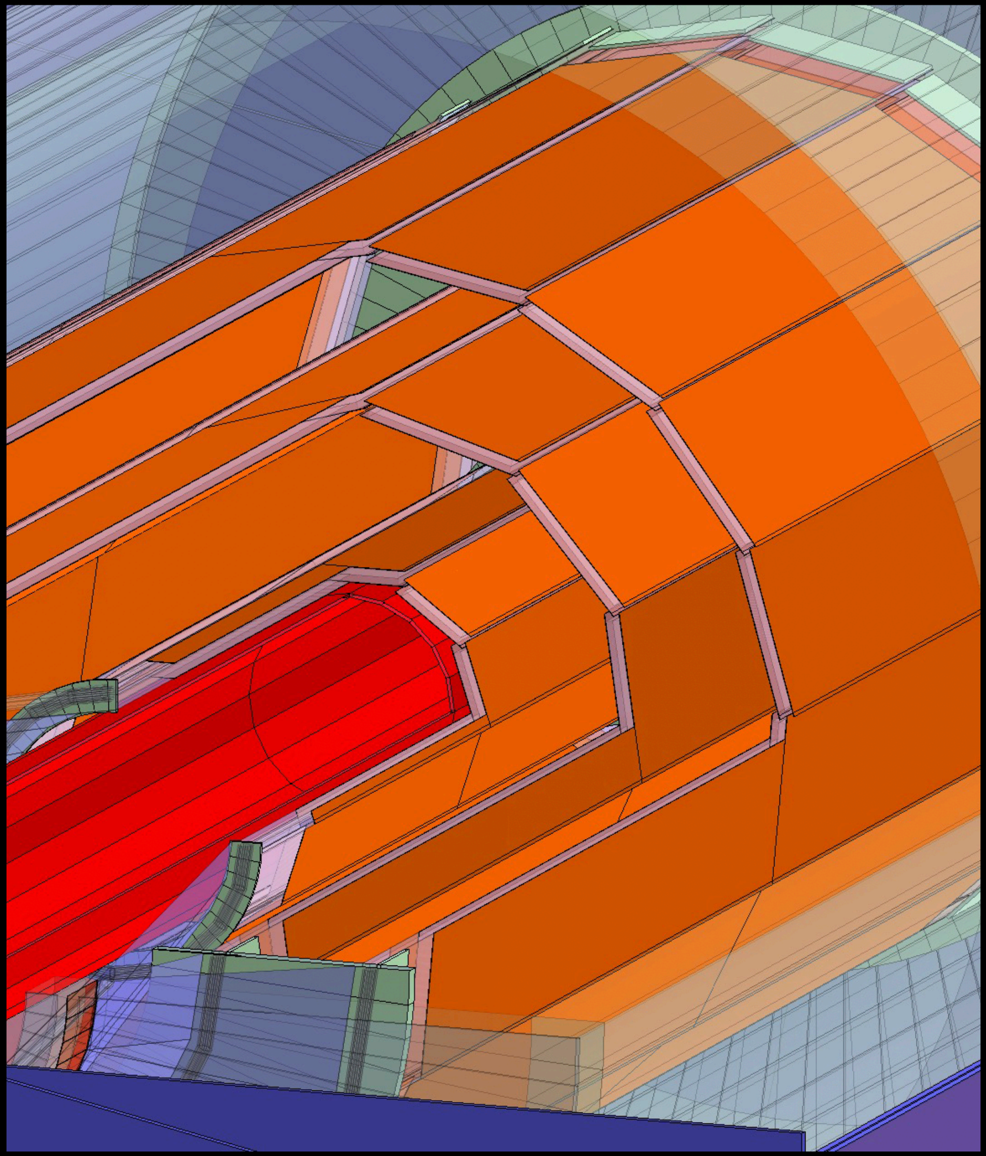
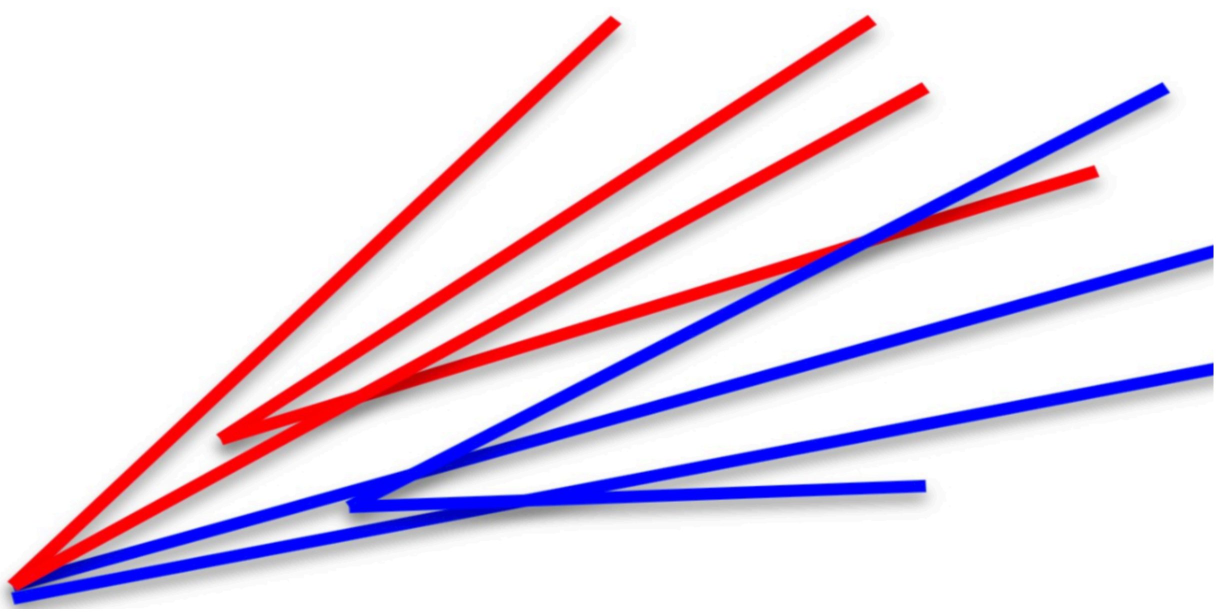
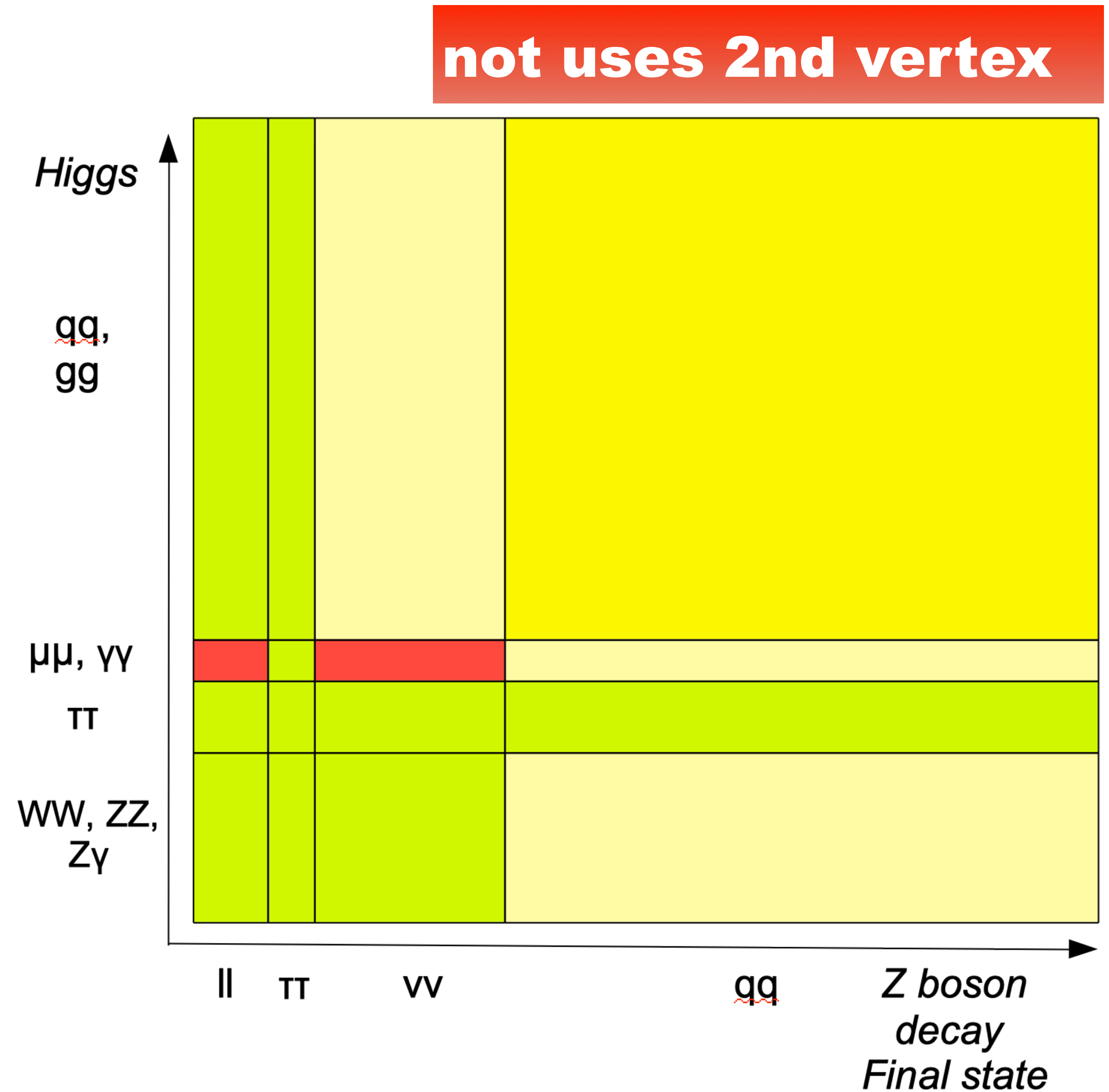


- **Jet flavor tagging is important for CEPC Higgs study, ~70% of Z, W, and H decay products are jets**
- **Jet flavor is determined with its vertex displacement and kinematics — jet sub-structure**
- **Silicon vertex detector is essential to measure the vertex displacement**

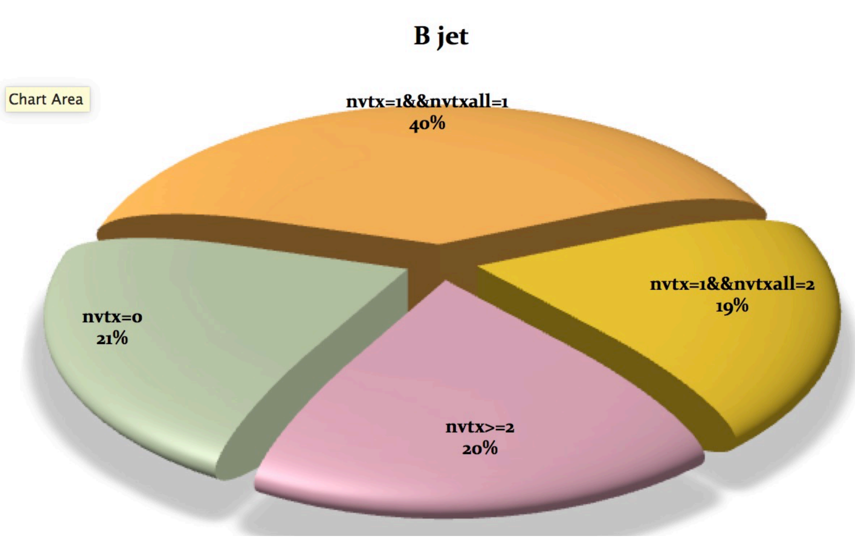


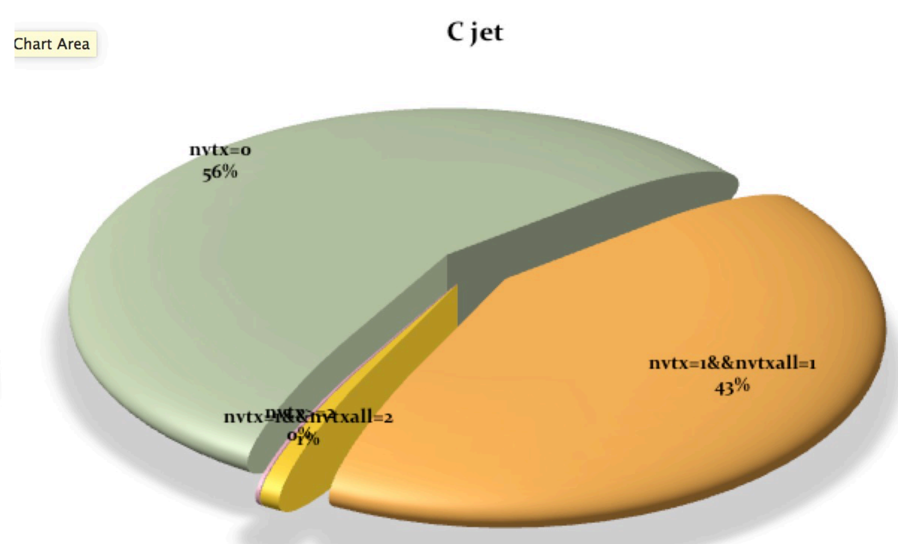
Vertex displacements

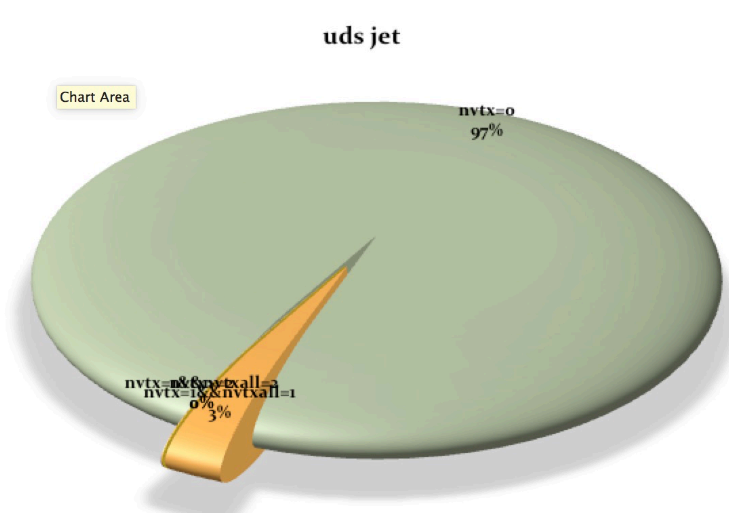


of 2nd vertex in Jets

Jet flavor	Total	nvtx==0	nvtx=1&& Nvtxall==1	nvtx==1&&nvtxal l==2	Nvtx>=2
B	395567	83099	156094	76239	80135
C	396692	223238	169400	3392	662
uds	393310	382522	10511	171	106

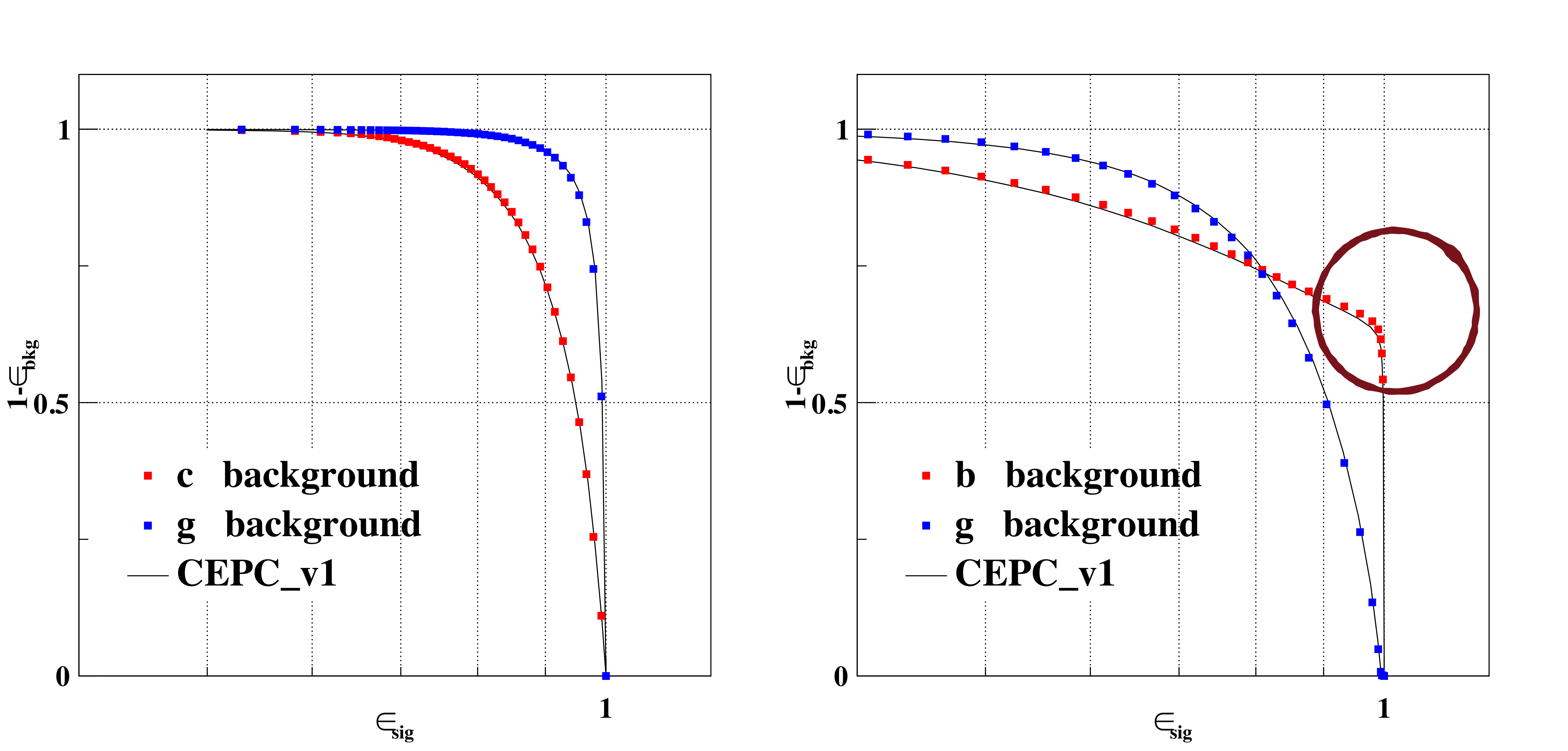






ROC used to evaluate the performance of flavor-tagging

Receiver Operating Characteristic curve



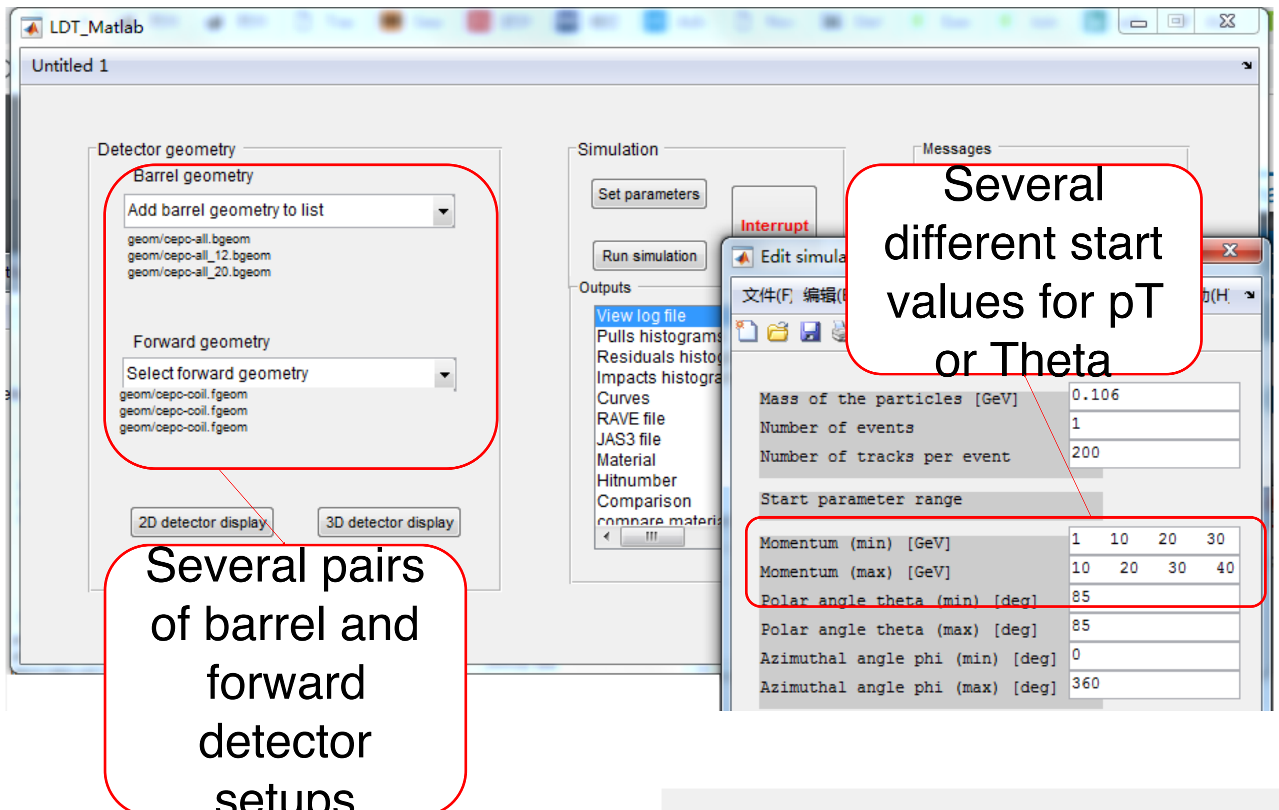
How to optimize: LDT

LiC Detector Toy

- A MATLAB based tool – easy to understand, handle and modify
- Compare track parameter resolutions of various detector setups
- Optimize size and position of the track sensitive devices, and of the detector material budgets
- Start parameters for simulated tracks are user-defined
  - VTX Geometry: Radius, Thickness..
  - Transverse momentum range, range of polar angle θ, number of tracks from the vertex.
- Weakness: Difficult to define new geometry parameters according to personal requests, e.g. rotation angle between two ladders

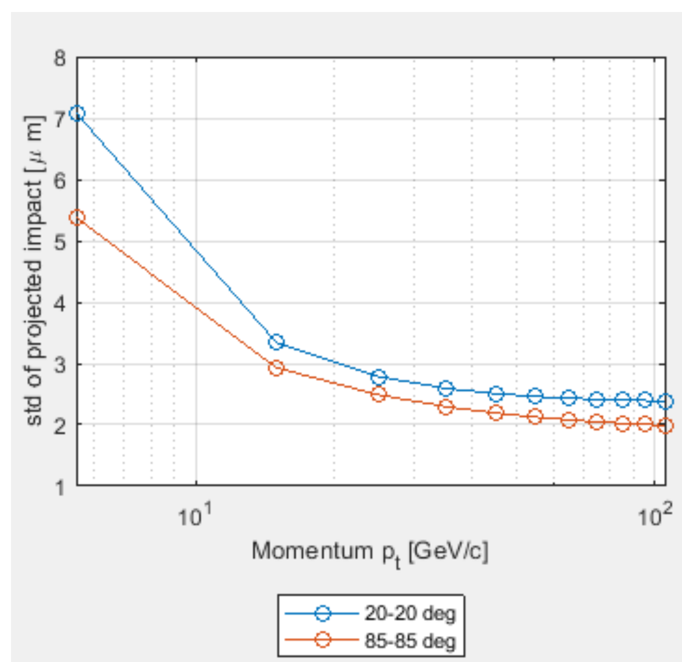
```
01 LiC Detector-Toy (barrel)
02 LDC-basic-Japan
03 Version:                     120208
04 Vertex Detector (VTX)
05
06 Number of layers            :   14
07 Description (optional)      : |-Beamt.-|---------------------------------------Vertex detector-------------------------------------------------------------------------------|
08 Names of the layers (opt.)  :   XBT,      VTX1,      XVTX1,     XVTX2,     VTX2,      VTX3,      XVTX3,     XVTX4,     VTX4,      VTX5,      XVTX5,     VTX6,      XVTX6,     XVTXSHELL
09 Radii [mm]                  :   14.5,     15.95,     16,        17,        18,        36.95,     37,        38,        39,        57.95,     58,        59,        60,        65
10 Upper limit in z [mm]       :   4225,      62.5,      62.5,      62.5,      62.5,      125,       125,       125,       125,       125,       125,       125,       125,       145
11 Lower limit in z [mm]       :  -4225,     -62.5,     -62.5,     -62.5,     -62.5,     -125,      -125,      -125,      -125,      -125,      -125,      -125,      -125,      -145
12 Efficiency RPhi             :   0,        0.99,      0,         0,         0.99,      0.99,      0,         0,         0.99,      0.99,      0,         0,         0.99,      0
13 Efficiency 2nd coord. (eg. z):  -1
14 Stereo angle alpha [Rad]    :   -pi/2
15 Thickness [rad. lengths]    :   0.0014,   0.00053,   0.00098,   0.00098,   0.00053,   0.00053,   0.00098,   0.00098,   0.00053,   0.00053,   0.00098,   0.00053,   0.00098,   0.0014
16 error distribution          :   0
17 0 normal-sigma(RPhi) [1e-6m] :            2.8,                  6,                    4,                    4,                    4,                    4,
18           sigma(z)    [1e-6m] :            2.8,                  6,                    4,                    4,                    4,                    4,
19 1 uniform-d(RPhi) [1e-6m]   :
20           d(z)     [1e-6m]  :
21
```

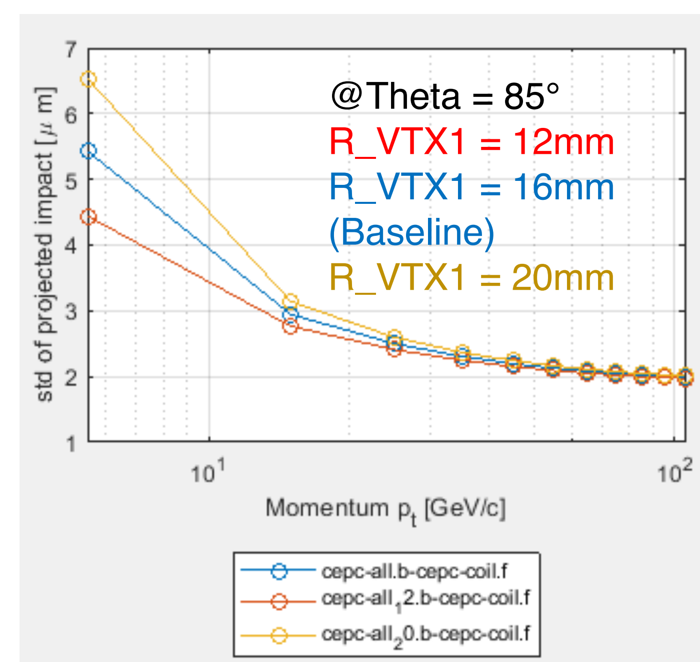
What are going to be Optimized?



Compare detector setups as function of – momentum – polar angle

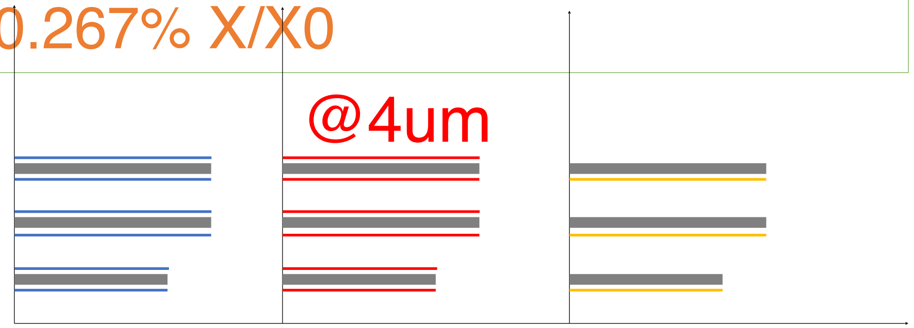
Output:
Impact parameter resolution as a function of pT with different Theta/different R of innermost layer





Basic Comparison

- Default
- Default@4um
- 3 single layers + sigma 4um per layer + supporting material 0.267% X/X0



	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(μm)
Layer 1	16	62.5	0.97	2.8
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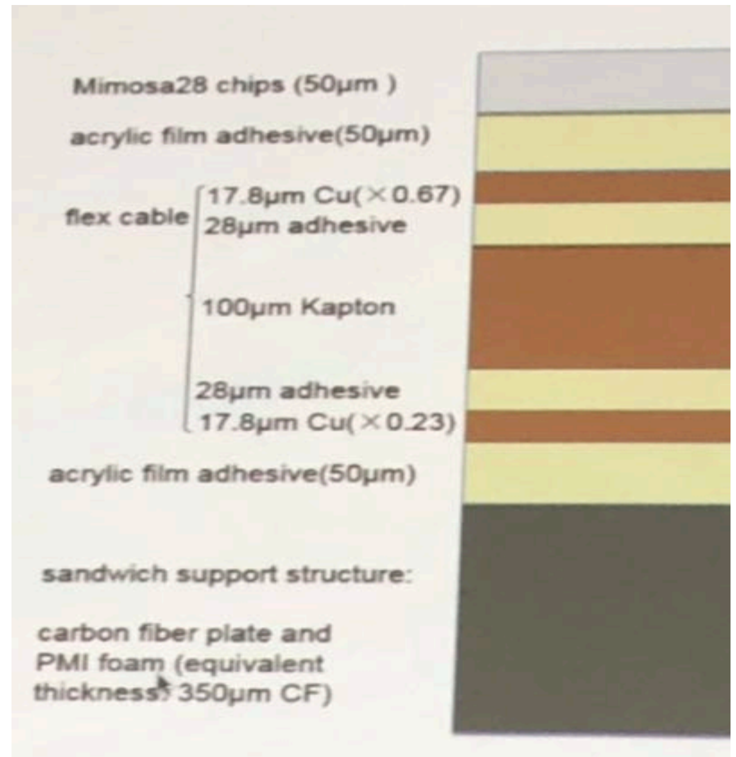
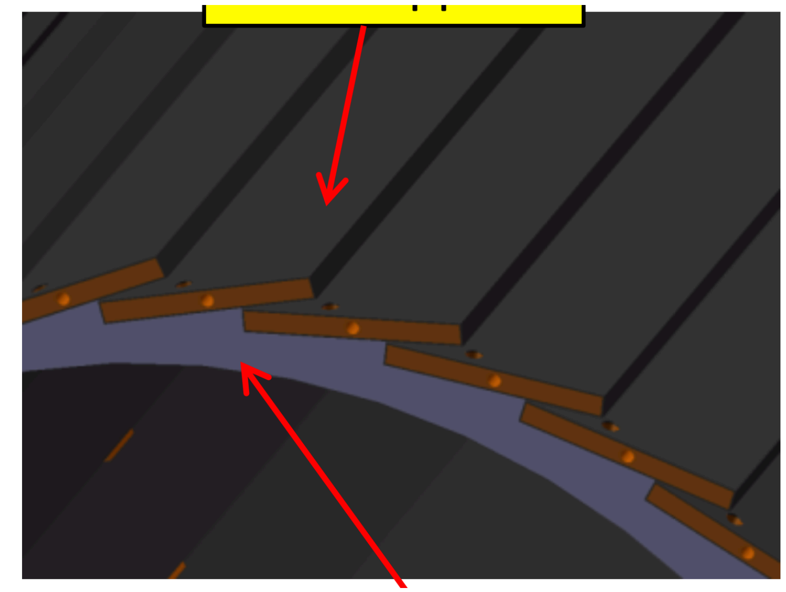


More details in Mingyi and Jinyu's talk

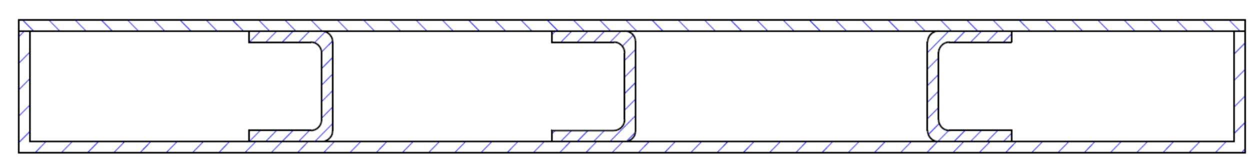


Si: 50 um/9.37cm = 0.053%
Al: 21 um/8.897 cm = 0.021%
Kapton: 100 um/57.6 cm = 0.017%
Adhesive: 156 um/33.5 cm = 0.0466%
Carbon fiber: 350 um/29 cm = 0.121%

0.205% —X1.3→ 0.267%

Not consider:

1. Carbon fiber C structure, which should increase the material budget
2. Structure to be optimized



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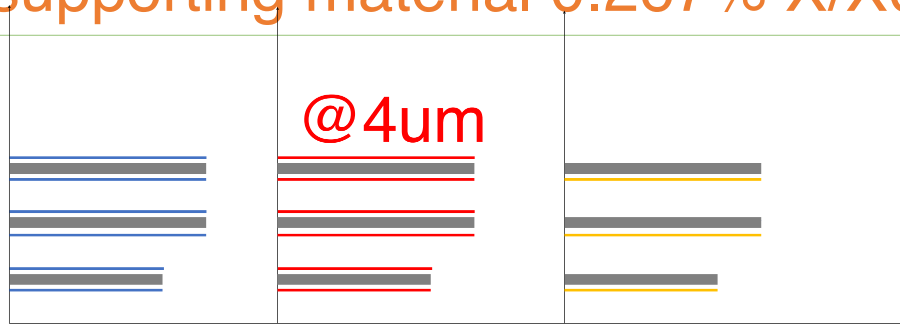

	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(µm)
Layer 1	16	62.5	0.97	2.8
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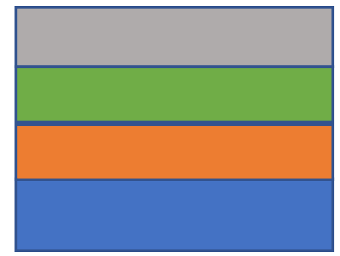
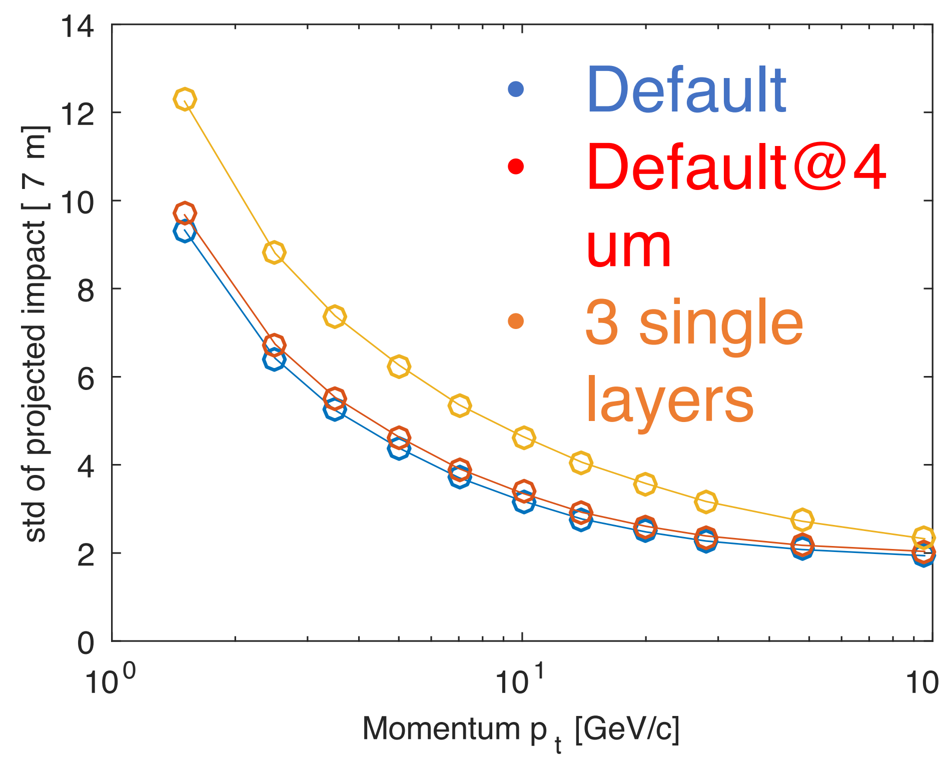
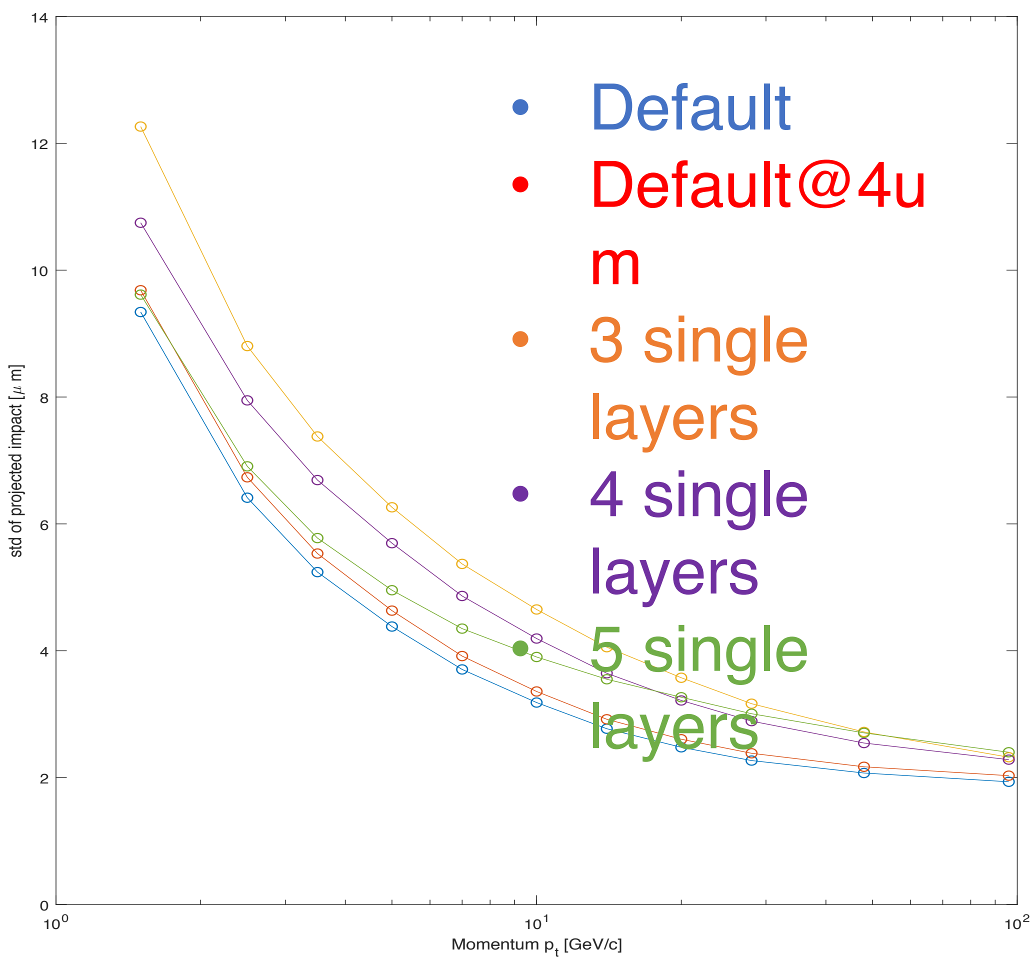


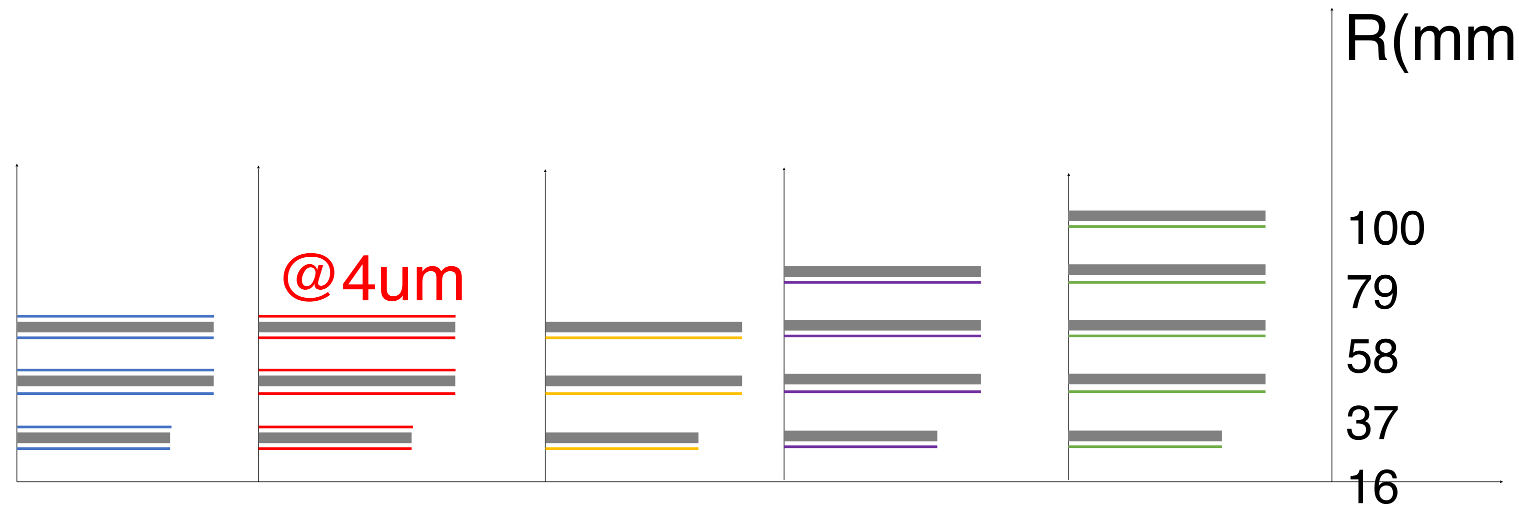
Si: 0.005cm/9.37cm = 0.053%
Al: 0.0013cm/8.897 cm = 0.015%
Kapton: 0.025 cm/57.6 cm = 0.043%
Carbon fiber: 0.03 cm/29 cm = 0.103%
0.267%

1. Overlap of
2. Carbon fiber C structure



Number of layers

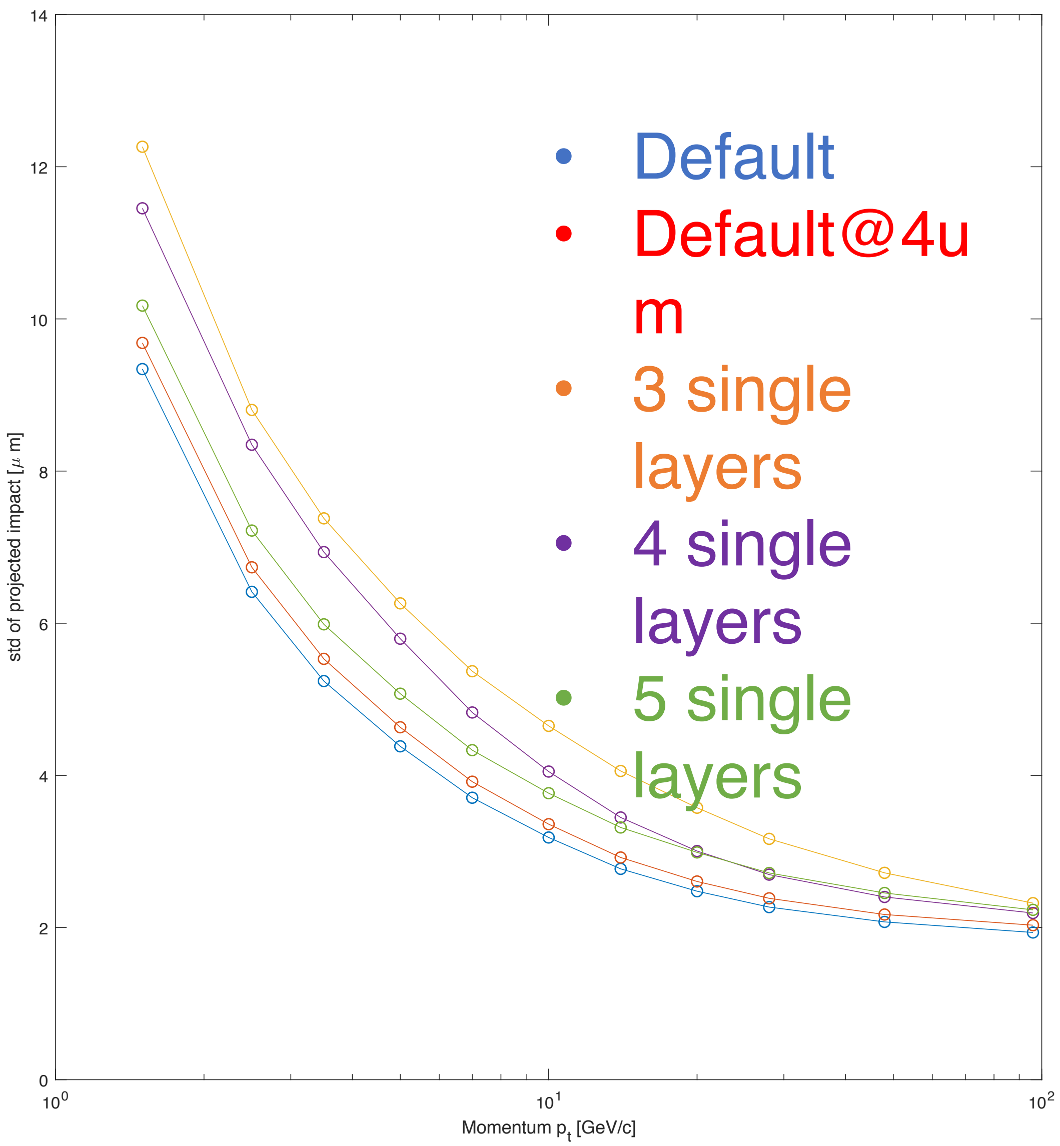


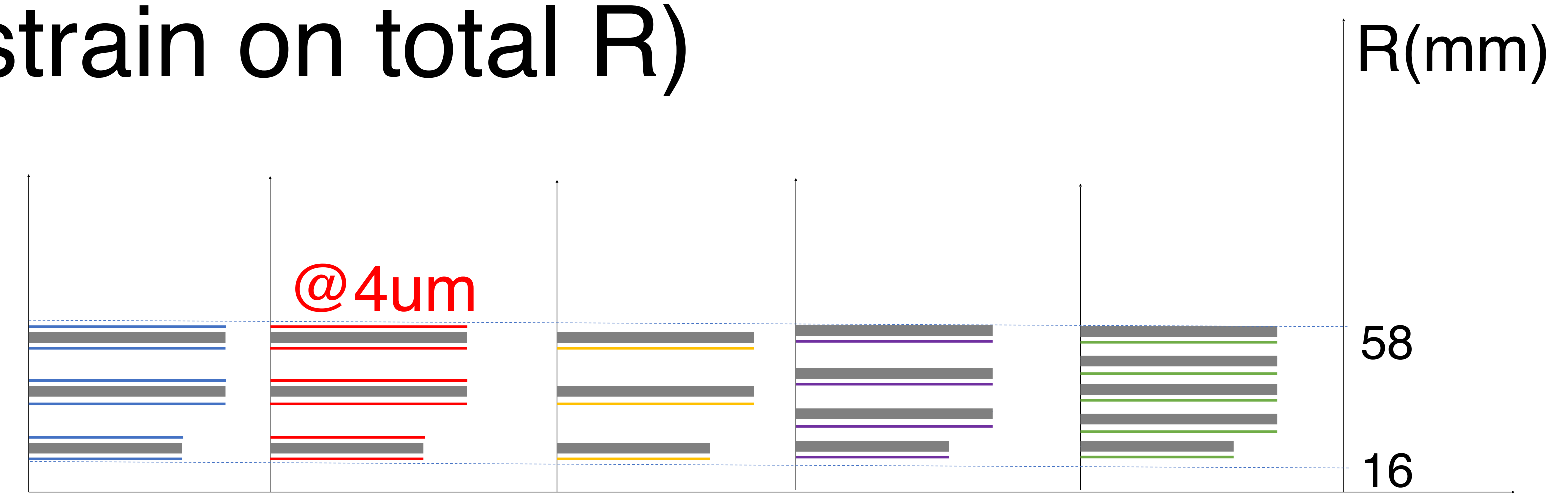


More layers give better resolution in lower pT, worse in high pT

	3 single layers	4 single layers	5 single layers
R1	16	16	16
R2	37	37	37
R3	58	58	58
R4		79	79
R5			100

Number of layers (Constrain on total R)

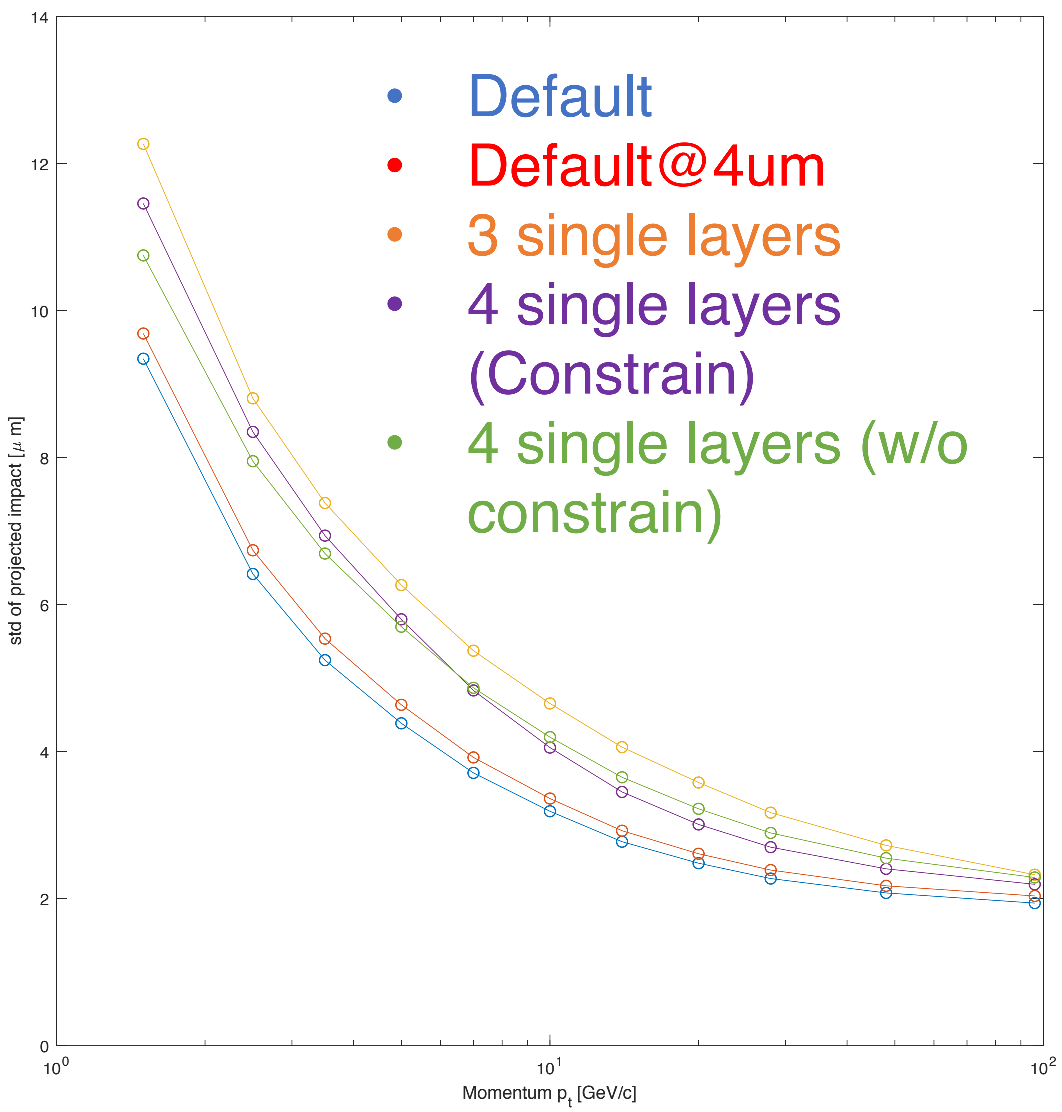


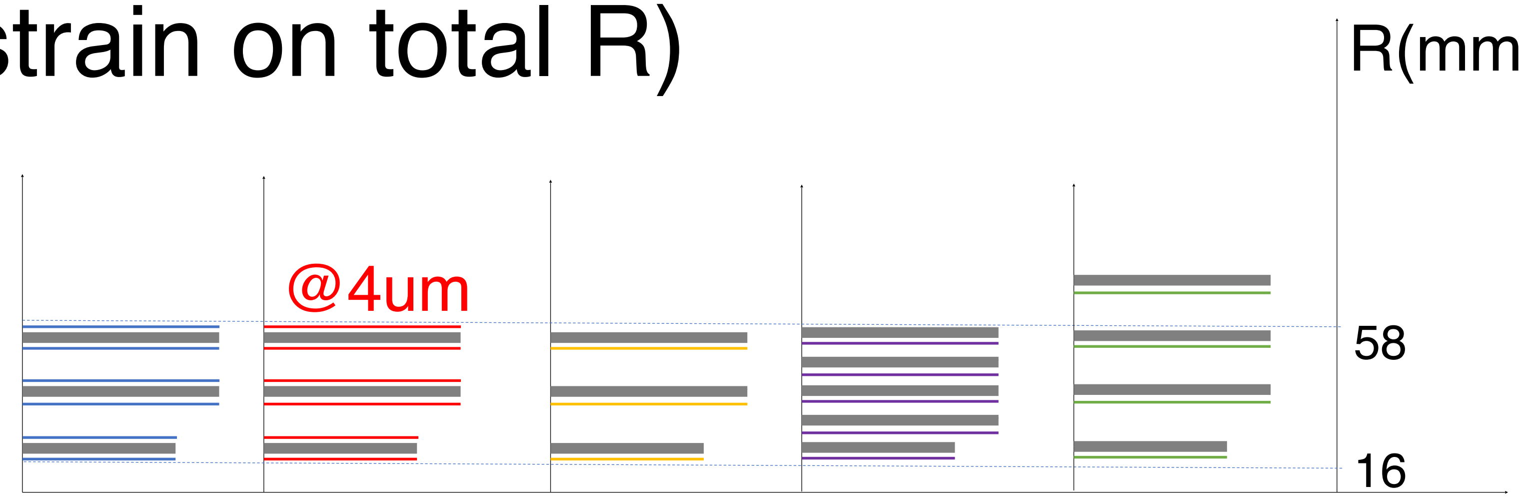


More layers give better resolution in lower pT, worse in high pT

	3 single layers	4 single layers	5 single layers
R1	16	16	16
R2	37	30	27
R3	58	44	38
R4		58	49
R5			58

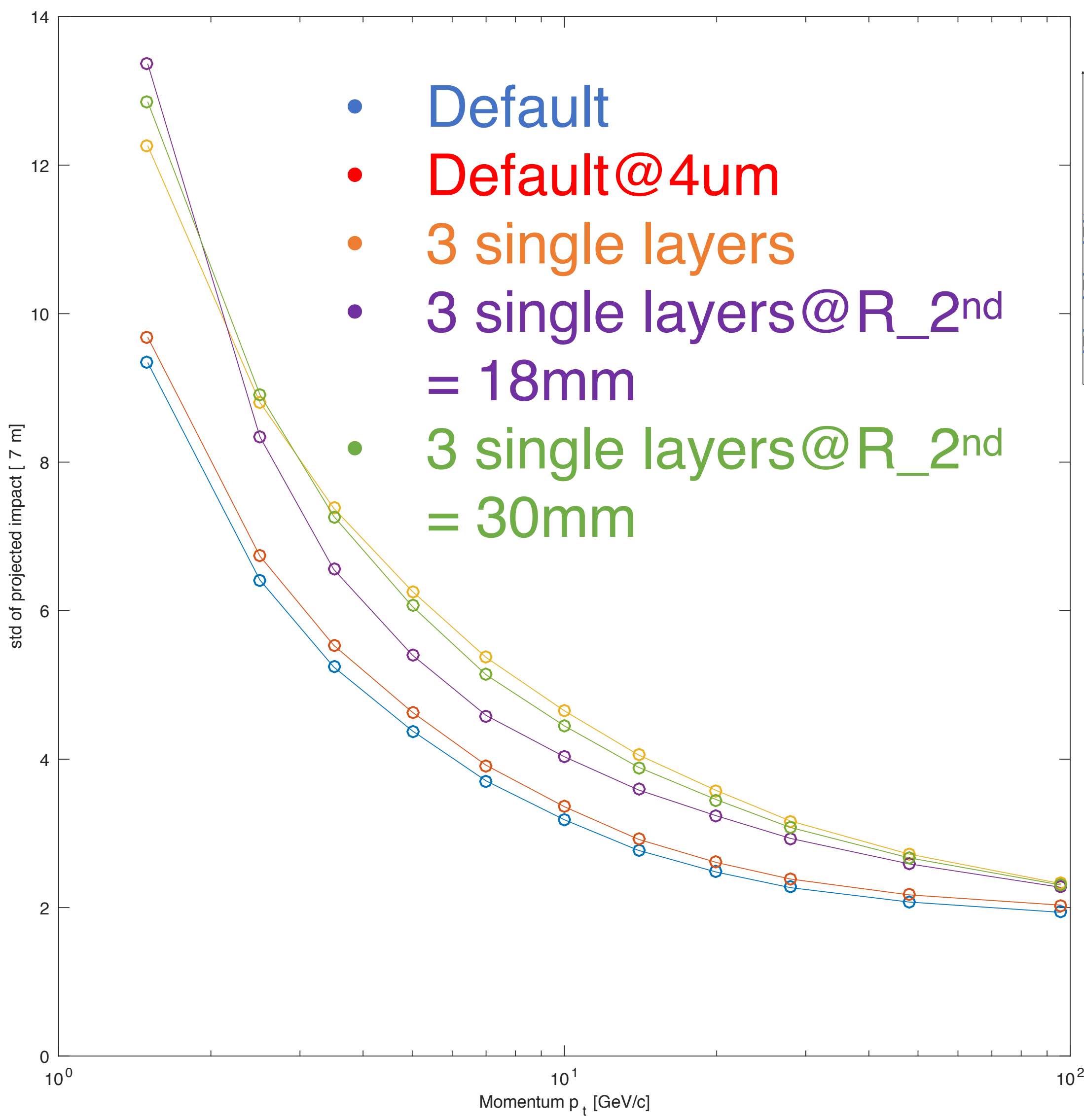
Number of layers (Constrain on total R)

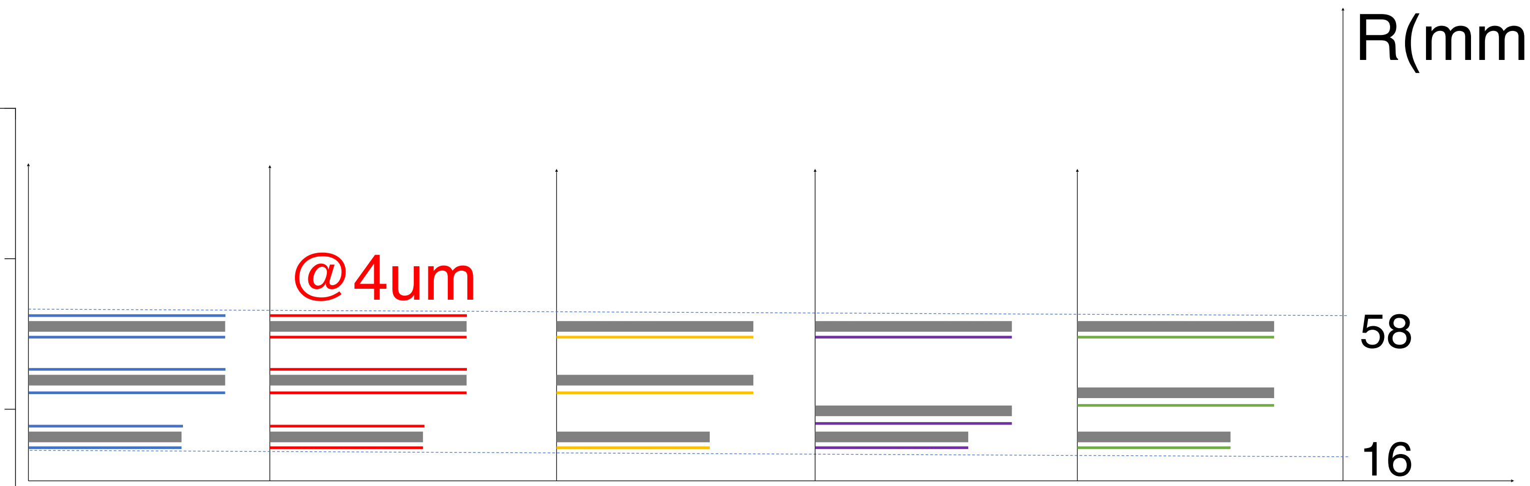




Silicon tracker is outside our VXD, constraint

Position of 2nd layer

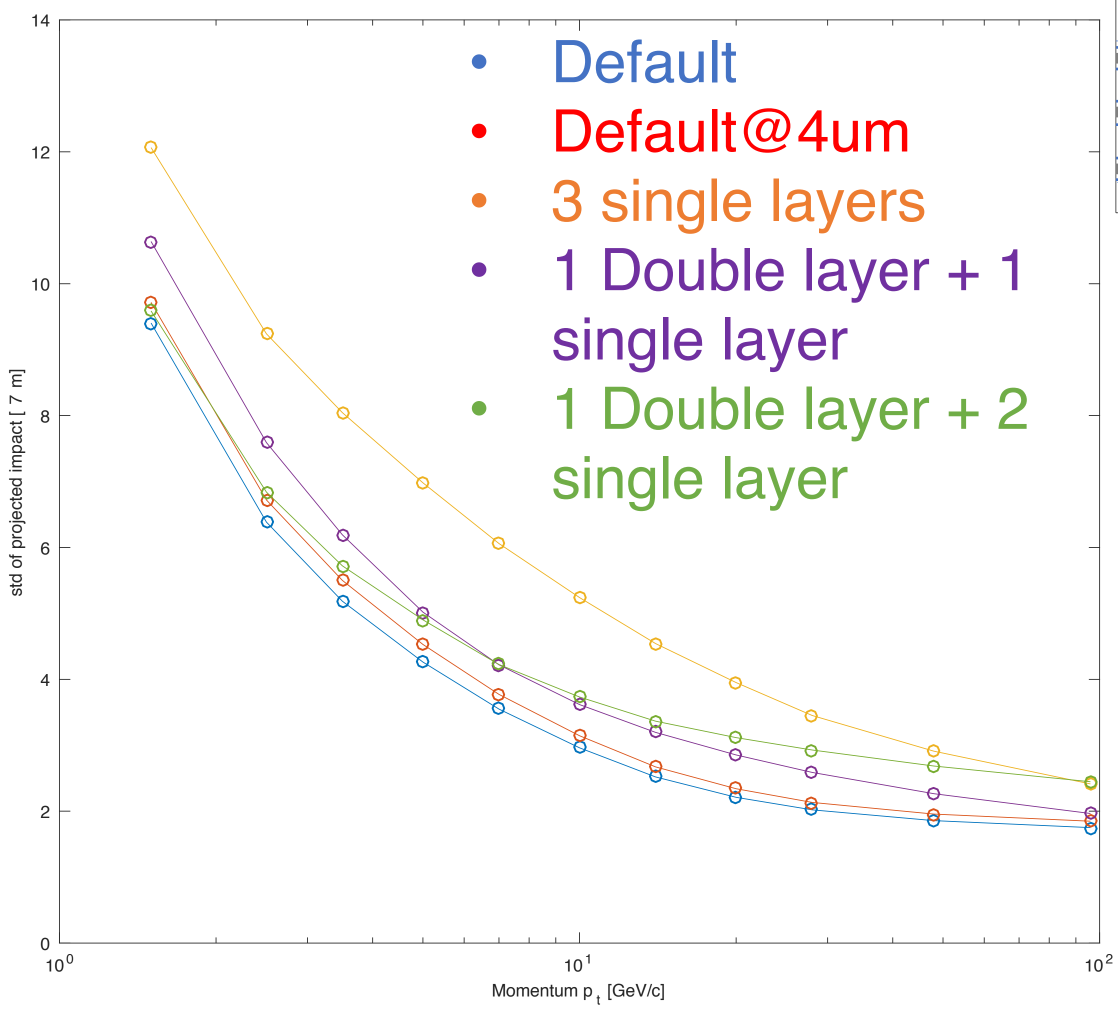


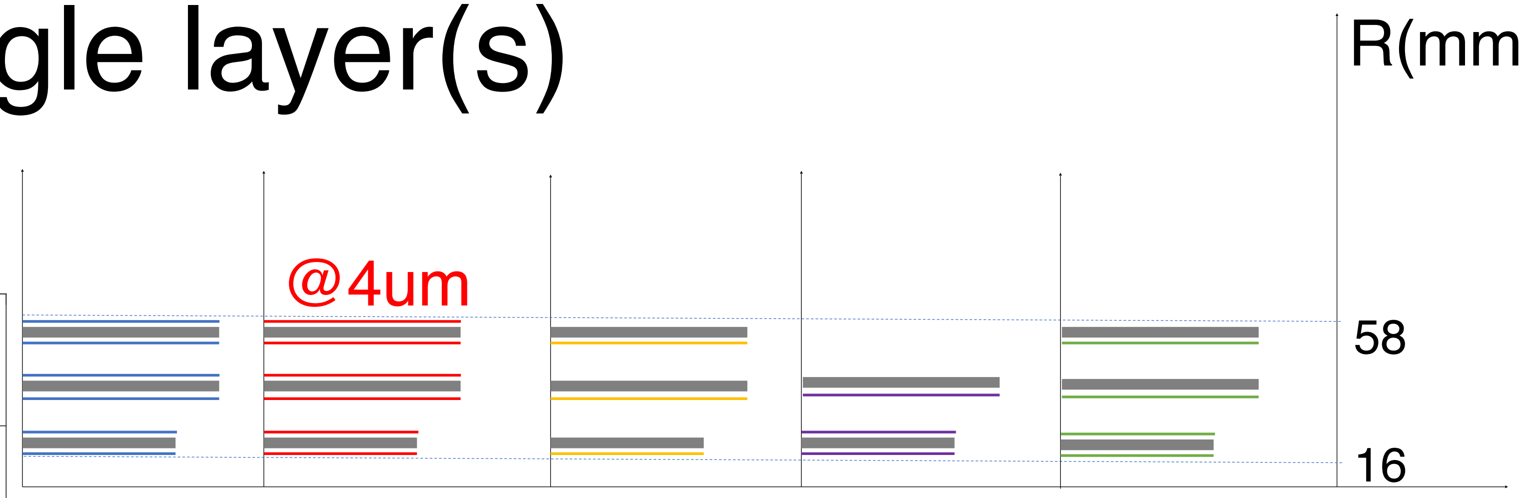


Closer to the 1st layer, better resolution at pT>2 GeV

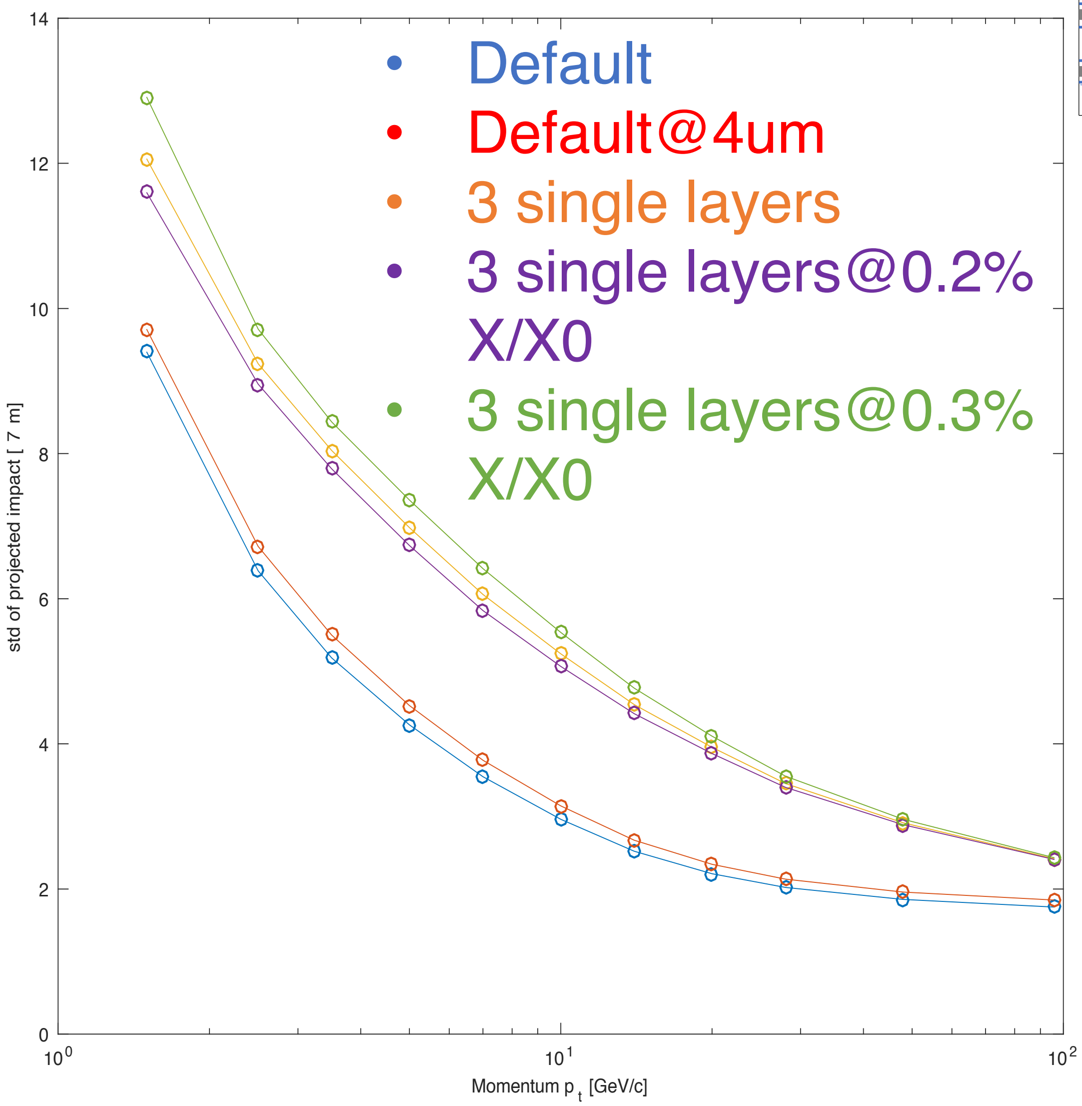
	3 single layers		5 single layers
R1	16	16	16
R2	37	18	30
R3	58	58	58

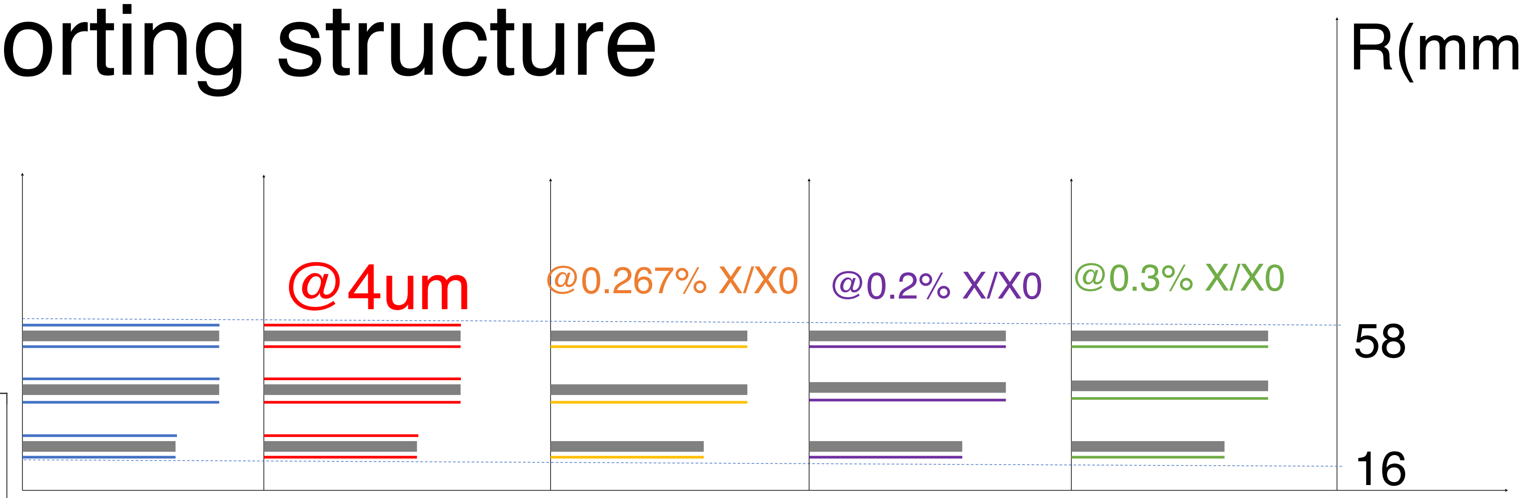
1 double layer + single layer(s)





Material budget of supporting structure





Summary

- Using LDT fast simulation for vertex detector layout optimization
  - Try three or four single layers configuration instead the baseline design
  - Test the position of middle layers
  - Test Material budget
- Generally, the performance of single layer layout worse than double layer, especially for lower pT region

Plan

- Tools for design and optimization
    - LDT
        - Test more detector configurations
        - Combined optimization with Silicon tracker
        - More realistic: geometry, materials, resolution, …
    - TkLayout as an alternative way for cross check
    - Full simulation(DD4HEP) to validate the fast results
- Demonstrates the performance of flavor tagging with LCFI+ and physics analysis
- Optimal results by the end 2019