CEPC VXD optimization and software

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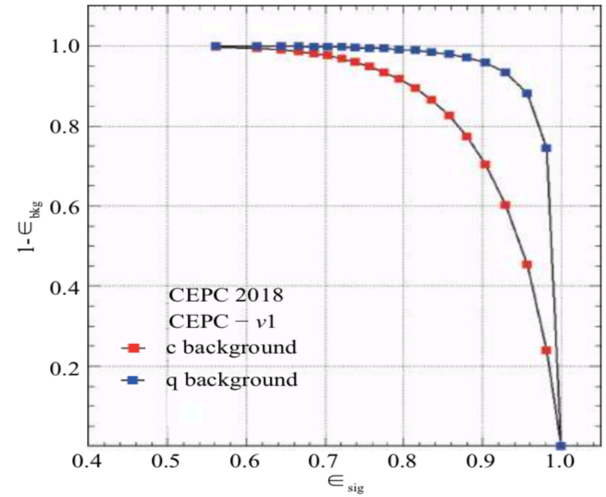
Outline

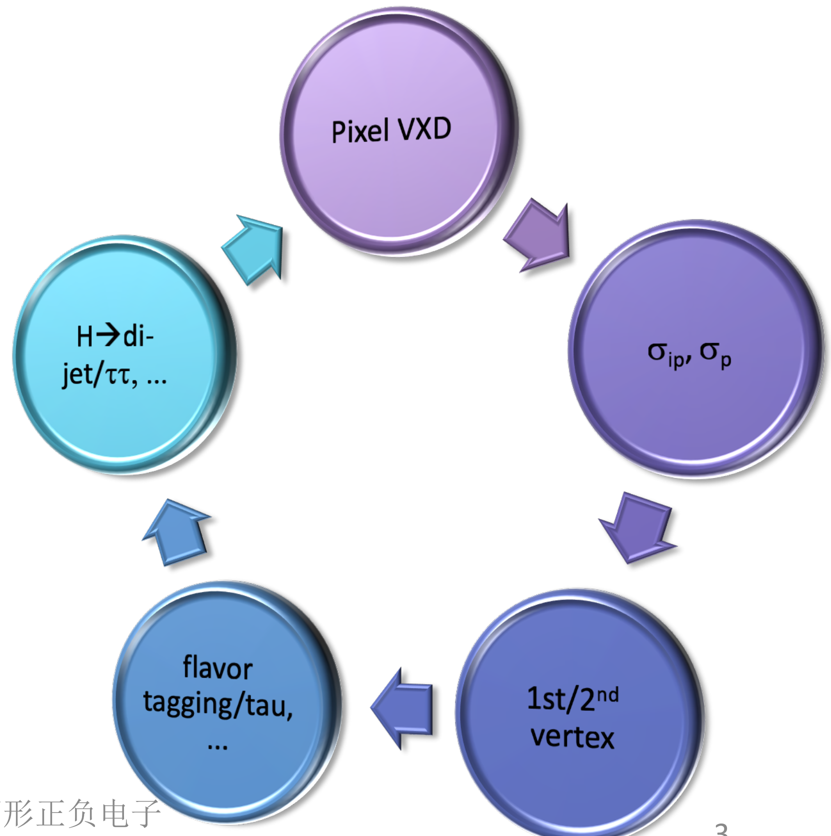
- Introduction
- Layout optimization
- Consideration on reconstruction software
- Future plan

Motivation

- Detector design motivated by physics motivation
  - Jet identification strongly depends on impact parameter precision

- CEPC dedicated to Higgs study, as well as SM and flavor physics
  - B, D, τ and other long-lived particles
- Physics always wants detector as good as possible
- Hardware gives the boundary
  - Resolution
  - Material budget
  - Power consumption
  - …
- Optimize Layout …

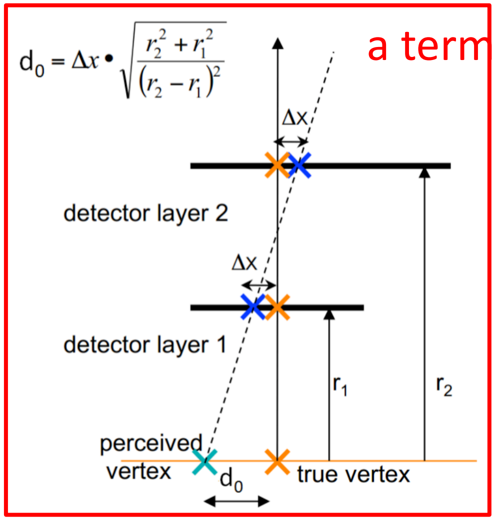


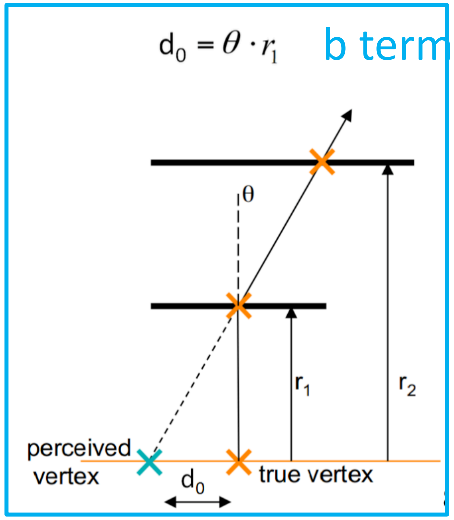


Impact Parameter Resolution:

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

- p: the track momentum
- θ: the polar track angle
- ‘a’ term: the intrinsic resolution of the vertex detector in the absence of multiple scattering, independent of the track parameters.
- ‘b’ term reflects the effects of multiple scattering.
- a = 5 μm and b = 10 μm · GeV from CDR.
- 3 double- layer pixelated vertex detector.

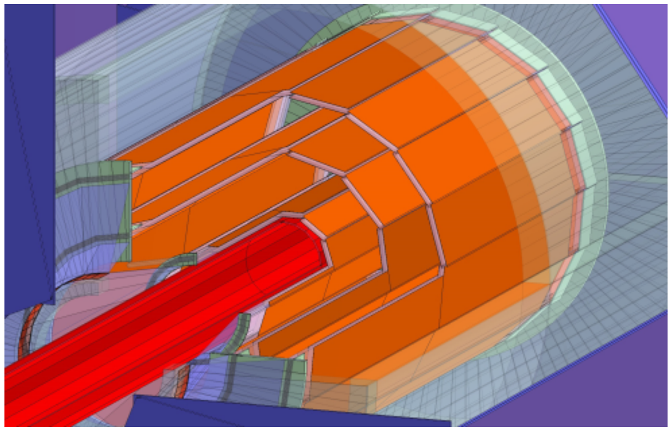




	R (mm)	$\lvert z\rvert$ (mm)	$\lvert\cos\theta\rvert$	σ (μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

Design goal

CDR vertex detector concept



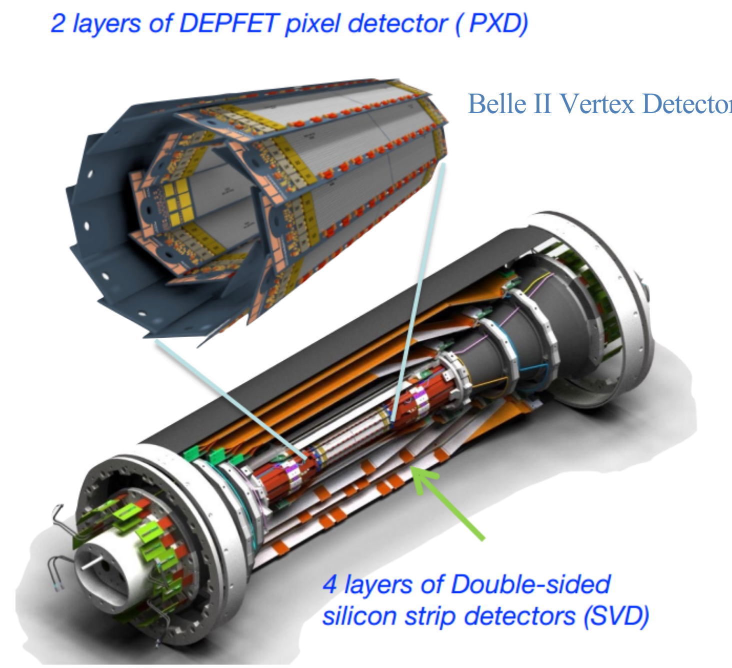
Vertex detector prototype

+ mechanics

+ electronics

+ cooling system

+ cable



	R (mm)	|z| (mm)	Current z in total
Layer 1	16	62.5	130.6 mm
Layer 2	18	62.5	
Layer 3	37	125.0	263.1 mm
Layer 4	39	125.0	
Layer 5	58	125.0	263.1 mm
Layer 6	60	125.0	

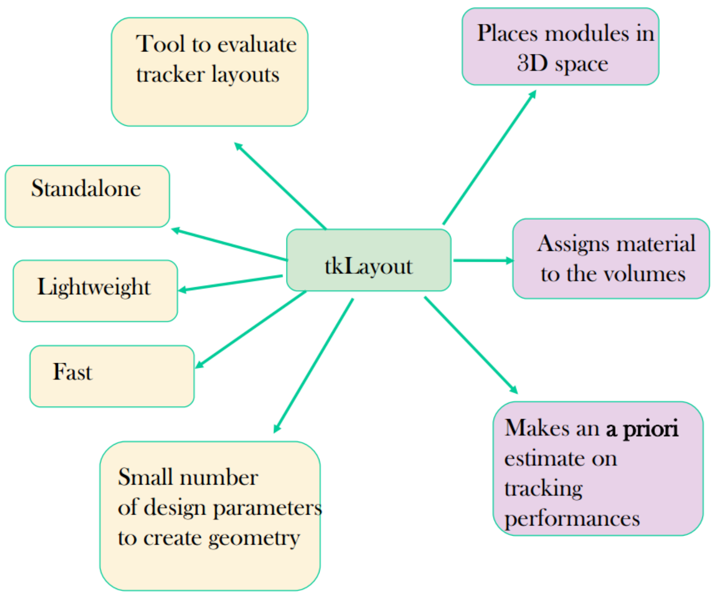
- Power dissipation: Final goal: ≤ 50 mW/cm2
- Current goal: ≤ 200 mW/cm2. (air cooling)
- Working temperature range: 20-50 ℃
- Single point resolution better than 5 µm.

Layout optimization

R_{2nd}, R_{in}, Materials, …

Fast simulation tool - tkLayout

What is tkLayout?



- Compare different detector layouts
- Fair comparison of layouts with a priori estimate of performance(occupancy, tracking and trigger approximate efficiencies, approximate financial cost, power consumption)
- Narrow down the parameter space
- Pre-optimized designs
- Does not depend on optimised reco algorithms

- IS NOT a replacement for the MC simulation
  - estimate impact on trigger
  - physics channels
  - occupancy
  - efficiency
  - ……

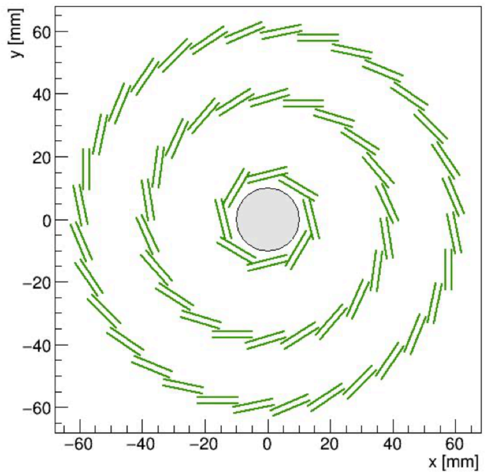
- From/validated by CMS
- Fast
- Flexibility to change detector design
- Automatic optimization
- Optimizing given layouts
- Realistic material description, power consumption, backgrounds, an so on

- Useful tool for CEPC vertex prototype layout optimization

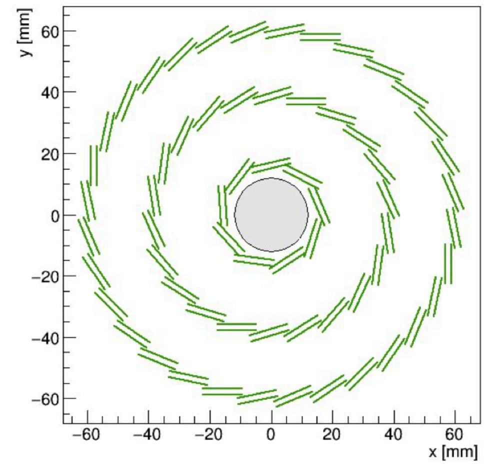
Resolution, material, power, …

The impact of R_{in}

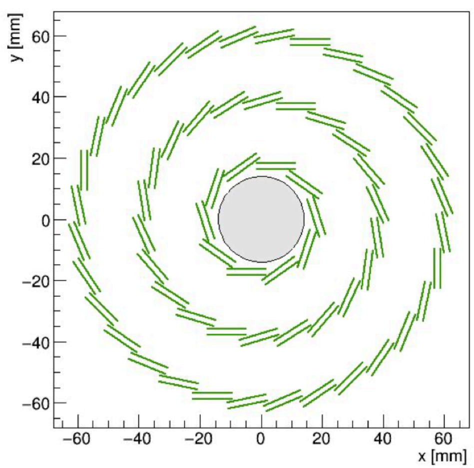
radius:10mm



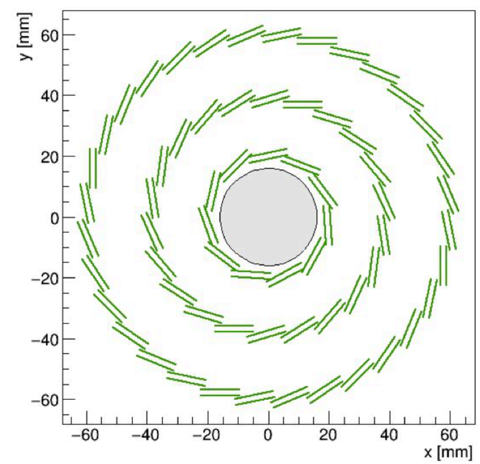
radius:12mm



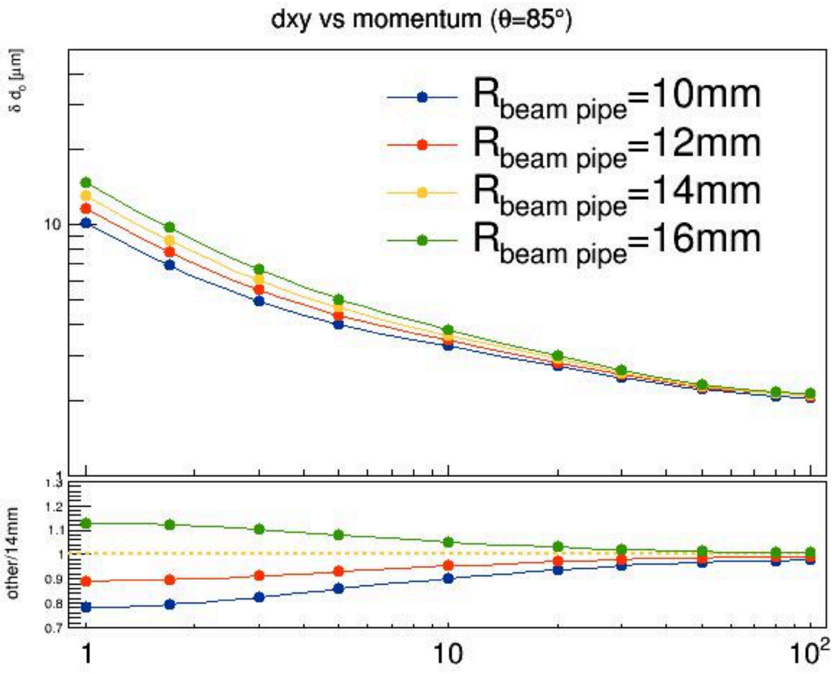
radius:14mm

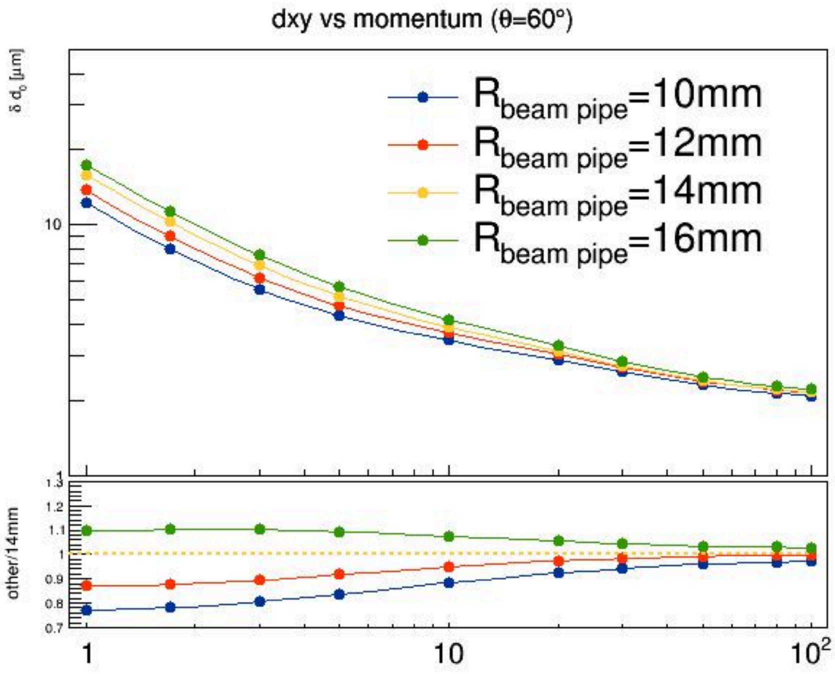


radius:16mm



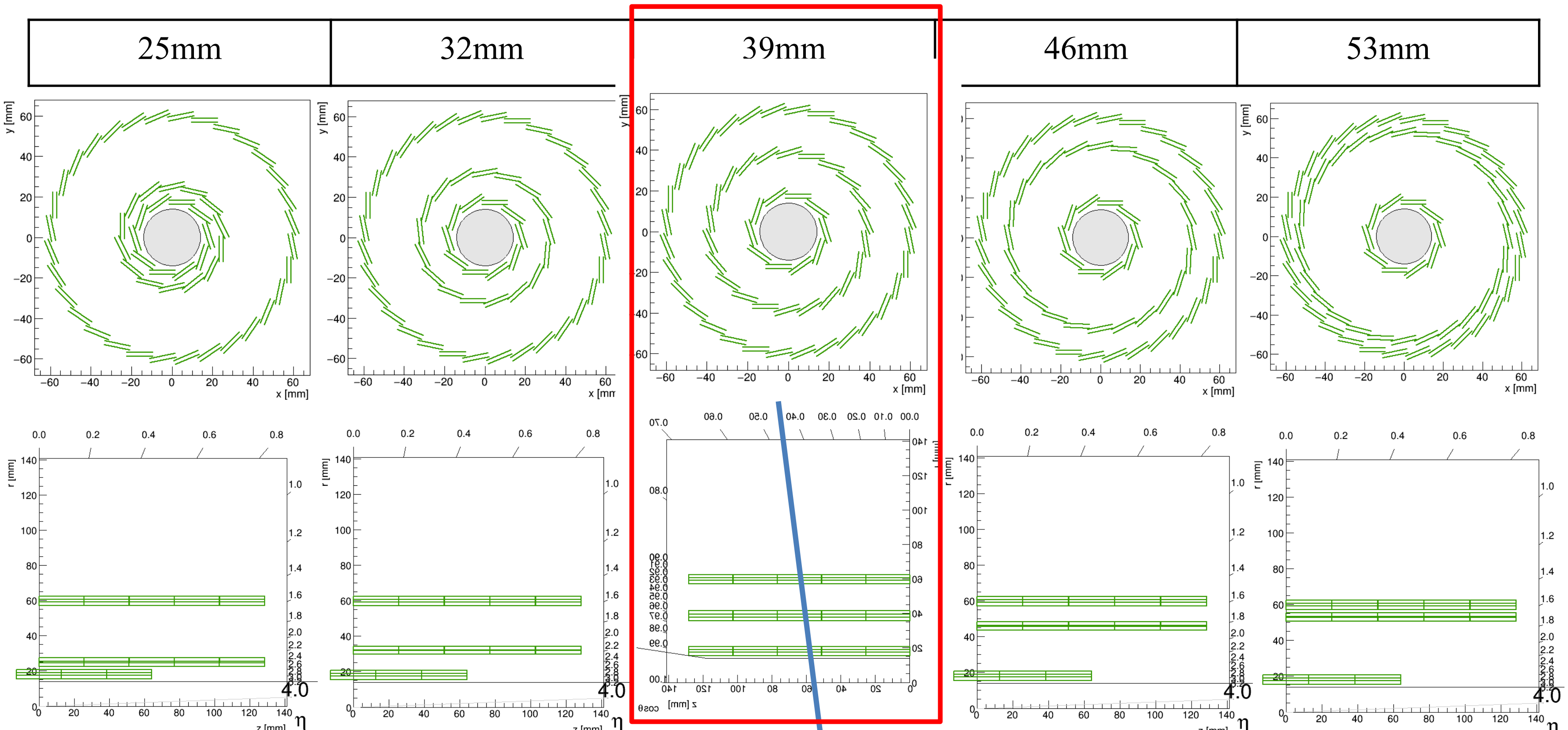
The impact of R_{in}





Significant impact on low momentum tracks,
Smaller radius is favored, resolution could be improve by ~20%
if reduce beam pipe radius to 10mm, but this a boundary from accelerator

The impact of R_{2nd}



prototype V1:

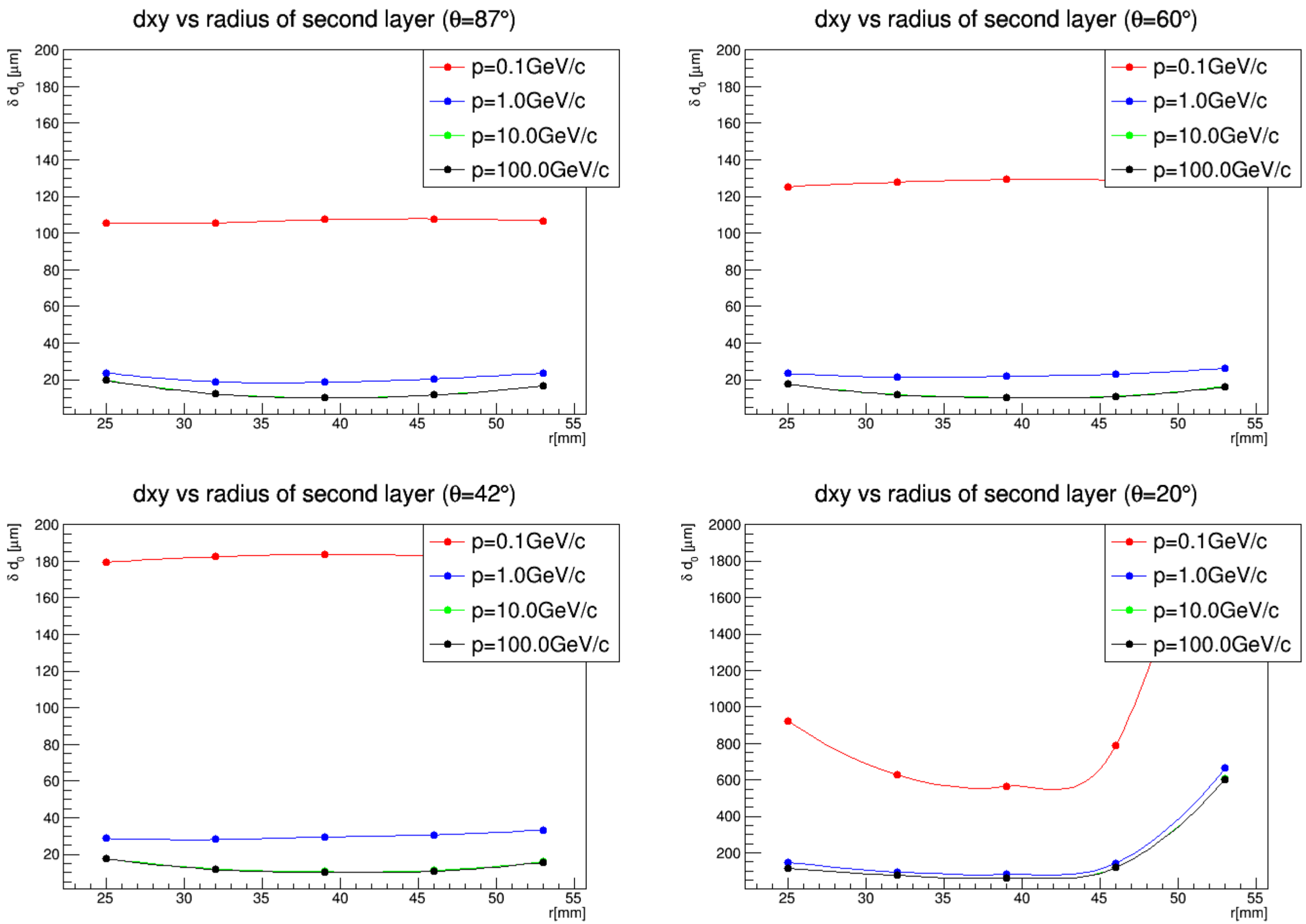
Barrel : PXB1

Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Barrel : PXB1

Layer	1	2	3	4	5	6
r	17.116	19.041	38.019	39.982	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

The impact of R_{2nd}



The middle (~40 mm) has the best resolution

- Smaller R_{2nd} favored by high momenta (10 GeV and 100 GeV) tracks
- For low momentum tracks, Smaller R_{2nd} worsen the d_0 a bit
- Second layer in middle is a better choice for mechanics design.

The impact of material budget

A realistic design

JI Quan

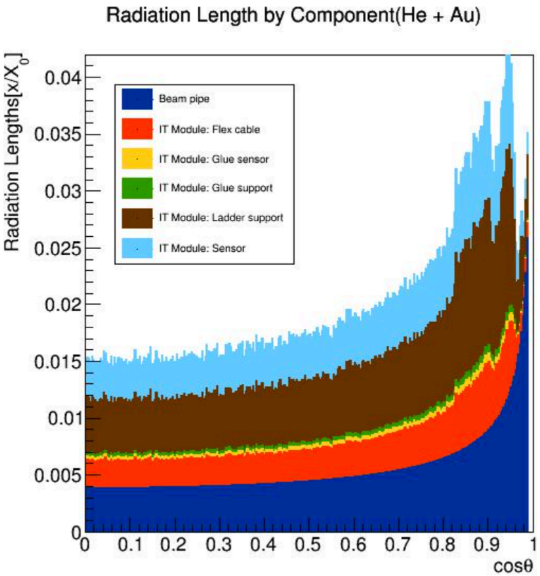
CDR: beam pipe 500 μm Be

500 μm Be + 500 μm (gam) + 350 μm Be

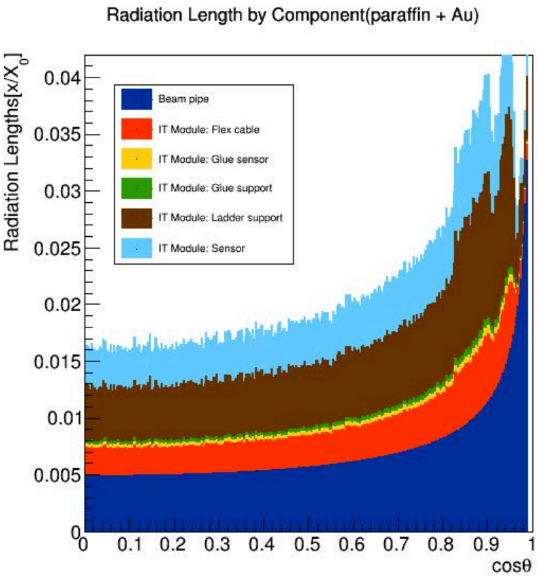
Radiation length	CDR	Helium gas coolant	Paraffin coolant
Au	0	0.001495	0.001495
Beryllium	0.001417	0.002409	0.002409
coolant	0	≈0	0.001037
total	0.001417	0.003905	0.004941

- ✓ Paraffin coolant: x/X_0 = 0.85mm/35.28cm + 0.50mm/48.22cm + 5um/0.3344cm = 0.004941
- ✓ Helium gas coolant: x/X_0 = 0.85mm/35.28cm + 0.50mm/5.671e+05cm + 5um/0.3344cm = 0.003905
- ✓ CDR beam pipe: x/X_0 = 500um/35.28cm = 0.001417 ≈ 0.15%

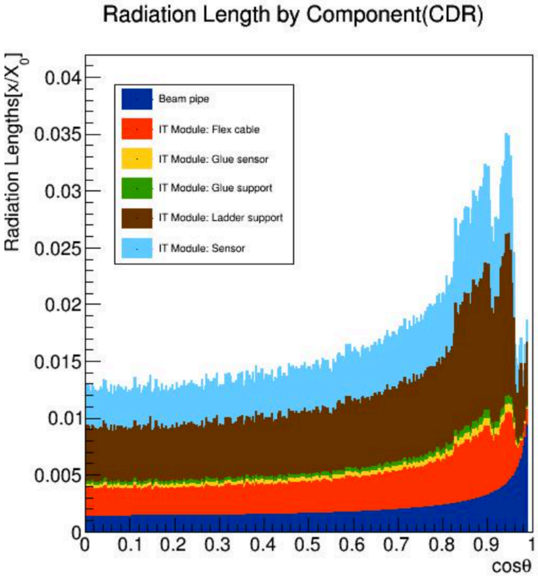
The impact of material budget



Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00558
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
total	0.02031

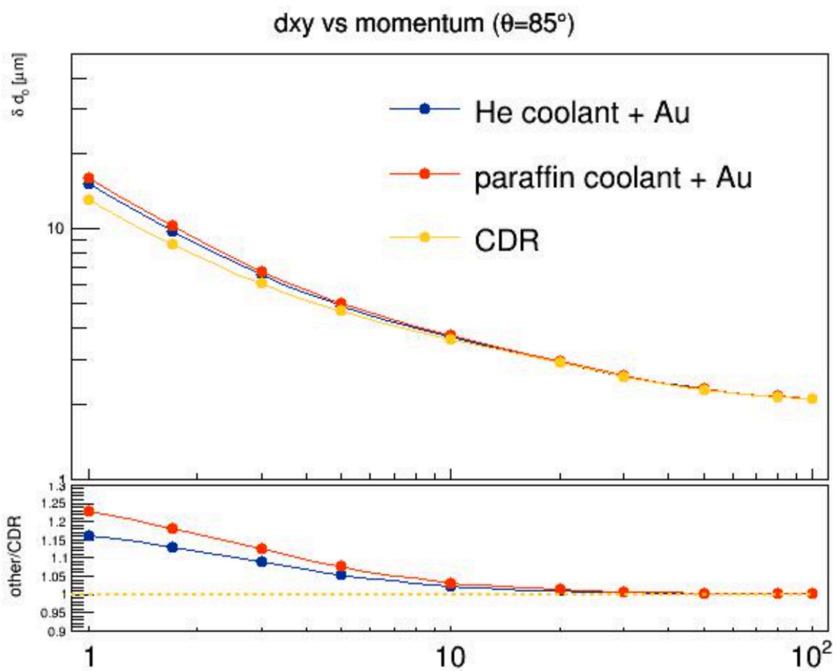


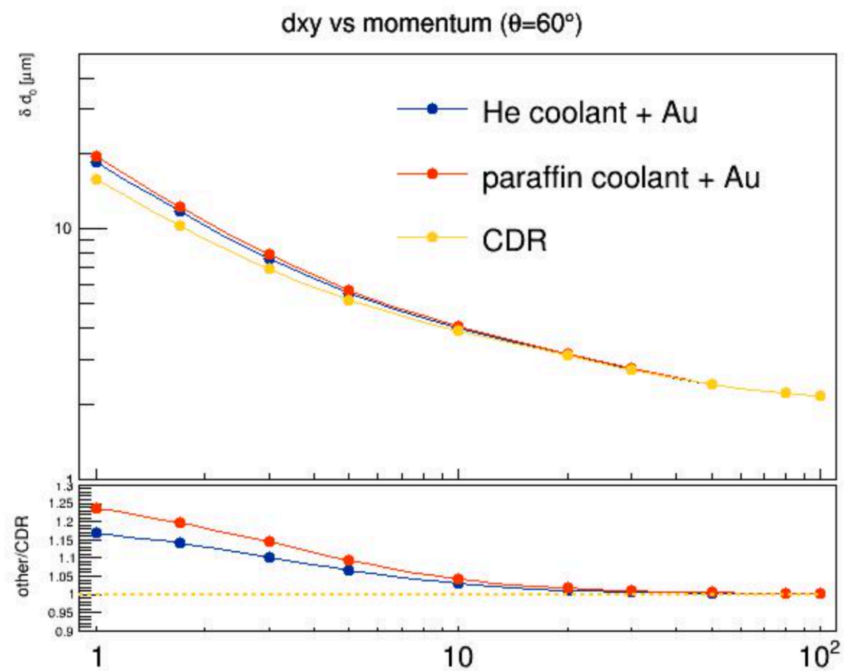
Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00707
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
total	0.02180



Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00203
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
Total	0.01676

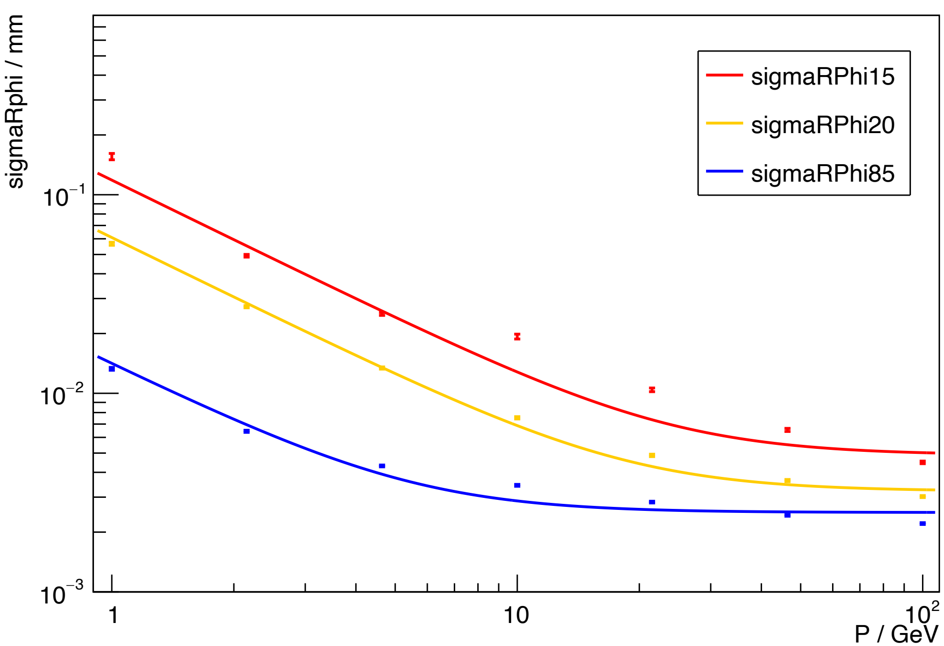
The impact of material budget





Also 20+% worse if we use paraffin coolant + Au
could be compensated by using smaller –radius beam pipe (10mm)

Full simulation--baseline tracker

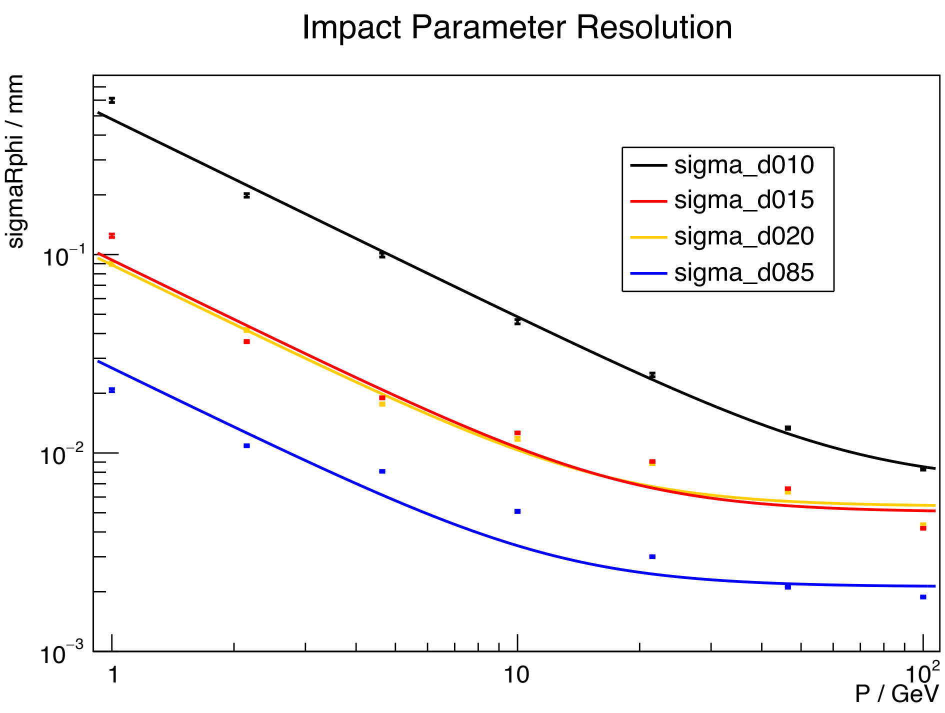


$$\sigma_{r\phi} = a \oplus \frac{b}{p(\mathrm{GeV})\sin^{3/2}\theta}$$

angle	a / μm	b / μm · GeV
15°	4.88	15.59
20°	3.21	12.16
85°	2.51	13.85
requirement	＜5	＜10

Layer	R (mm)	|z| (mm)
1	16	62.5
2	18	62.5
3	37	125.0
4	39	125.0
5	58	125.0
6	60	125.0

Full simulation -- FST



$$\sigma_{r\phi} = a \oplus \frac{b}{p(\mathrm{GeV})\sin^{3/2}\theta}$$

angle	a / µm	b / µm · GeV
10°	7.04	34.78
15°	5.03	12.35
20°	5.38	17.71
85°	2.12	26.59
requirement	<5	<10

Layer	R (mm)	|z| (mm)
1	15.9	78
2	25	125
3	36.9	150
4	38	150
5	57.9	175
6	59	175

Reconstruction and analysis software

ACTS: A Common Tracking Software

Web & GitHub

- ACTS
  - Encapsulate the existed code from ATLAS(currently), or other experiment
  - Thread safe/long vectorization
  - Modern C++ 17
  - Independent from experiment and framework
- Not only a tracking tool, but also integrated with an analysis framework, EDM, Geometry interfaces, simulation (interface to G4), and tracking fitting, etc

Plugins: DD4HEP, TGEO, Geant4...

Core

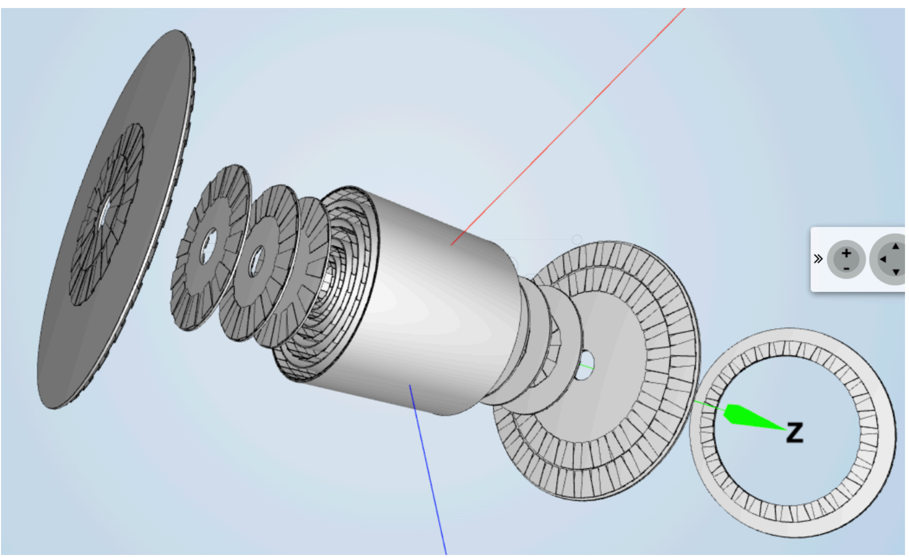
- Geometry
- Surface
- EDM
- Material
- MagneticField
- Utilities
- Fitter
- Seeding
- Vertexing
- TrackFinding
- Visualization
- Propagation

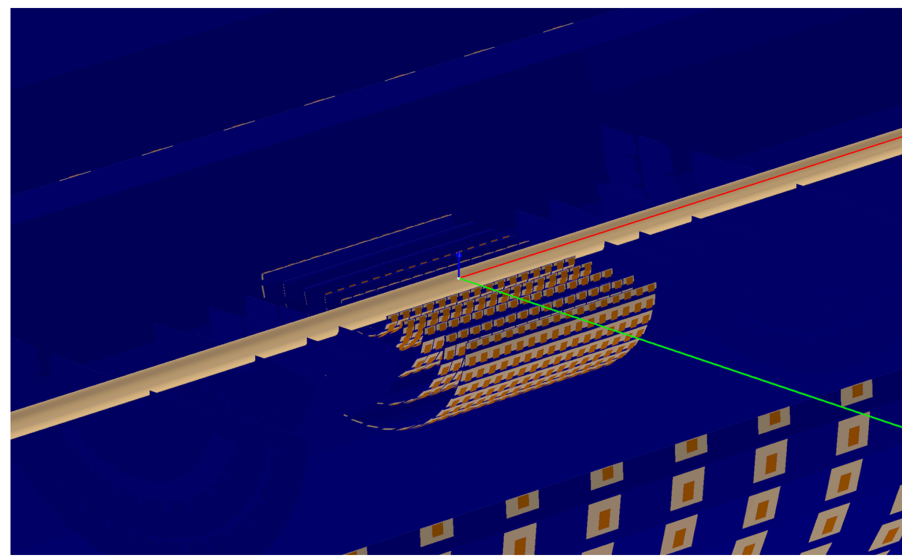
A light-weight Gaudi framework for integration and concurrency test

FATRAS: ATLAS fast simulation

First implement in ACTS a silicon tracker for test

- Geometry implemented with DD4HEP and under validation
- Need take more details into account
  - ✓ Support, cables, verification, material mapping

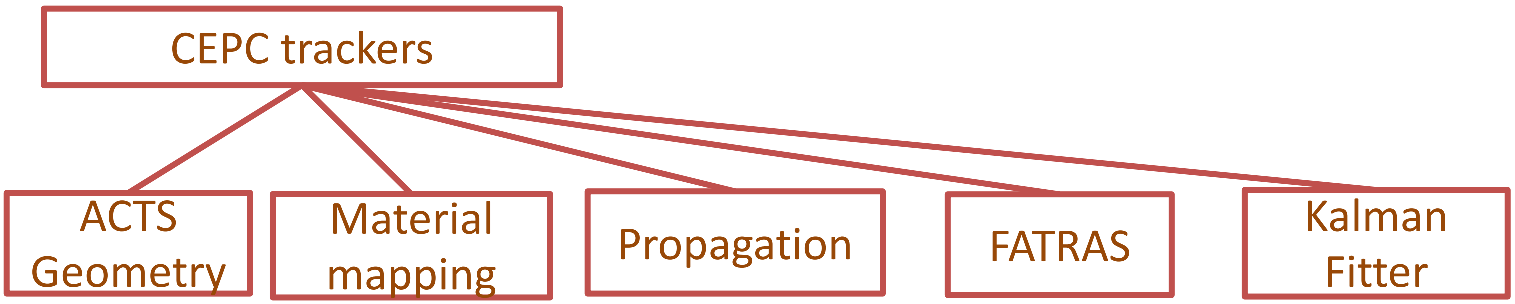




Status of CEPC-ACTS

Detector R&D

https://gitlab.cern.ch/jinz/acts-framework-cepc



- Two designs of CEPC tracking system implemented in ACTS with DD4HEP
  - ✓ Full silicon detector
    - ➢ Geometry and materials under validating
  - ✓ Baseline (silicon + TPC) for comparison

It can be done standalone or in new CEPCSW framework

Summary and plan

- The CEPC vertex detector optimized with TkLayout tool
  - The performance optimized with respective to the position of inner most layer and the position of 2nd layer
  - The material budget was examined carefully
  - The impact parameter performance in CDR can be reached
  - Can be updated quickly according to new mechanics designs

- Next step
  - Track reconstruction for test beam
  - Use ACTS (A Common Tracking Software) for tracking reconstruction
    - Material effect could be taken into account in the reconstruction
    - Alignment
    - Kalman fit

Backup slides