

# Vertex Geometry Optimization

---

Caterina & Zhi

07/02/2026

# Introduction

---

**Goal:** understand which VTX geometry choices drive tracking performance

- **Physics need:** precise vertexing and tracking over a broad angular range
- **Geometry question:** how much performance is gained from longer barrels vs additional end-cap disks?
- **Study strategy:** use Delphes-based fast simulation with Kalman Filter calculations

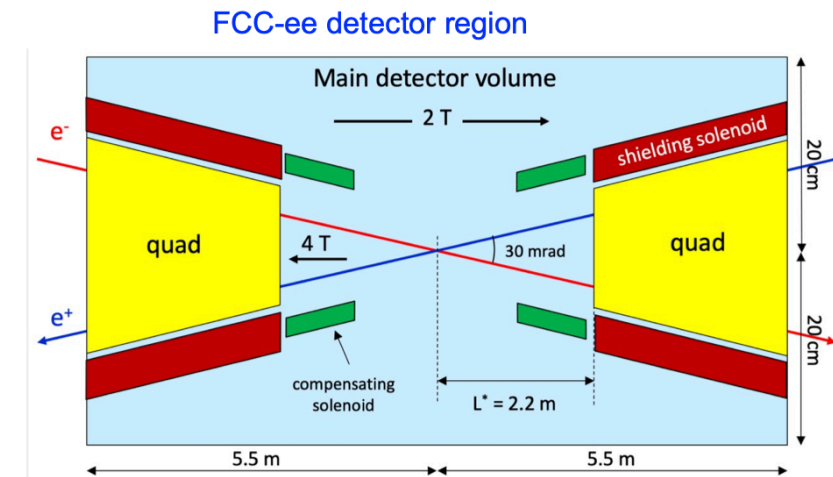
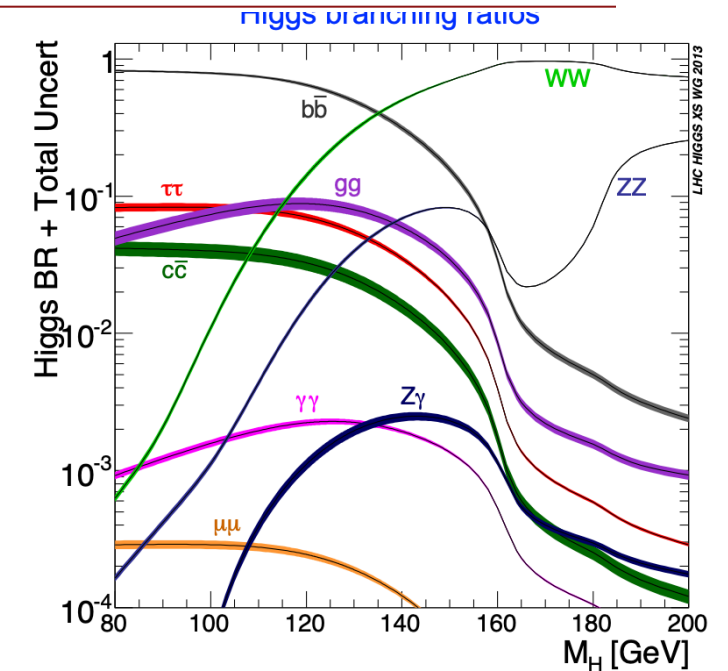
# Physics requirements and experimental constraints

## Physics goals:

- Precision **Higgs** / **EW** / **top** measurements
- Direct/indirect **BSM** searches
- Requires excellent Flavour tagging (c, b), life-time measurements
  - Vertex resolution:  $\sigma(d0) \sim 5 \oplus 15 / (p[\text{GeV}] \sin^{3/2} \theta) \mu\text{m}$ 
    - single-plane resolution  $\sim 3 \mu\text{m}$
    - low material budget  $< 0.2\% X_0$  per layer → low power+ air-flow cooling
- Pile-up / background rejection
  - **low-angle coverage**, **timing**

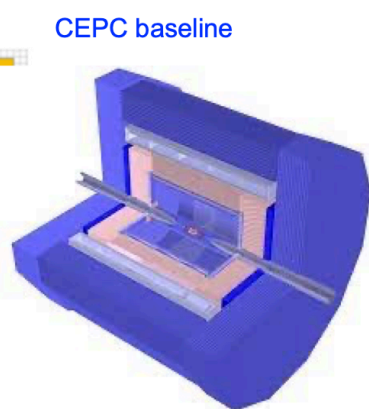
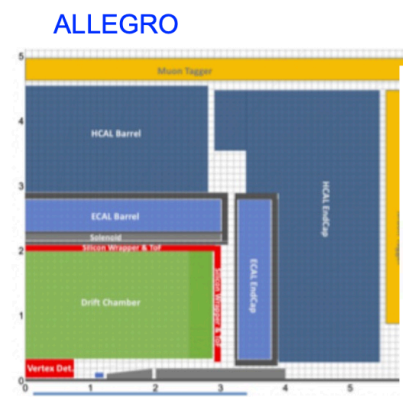
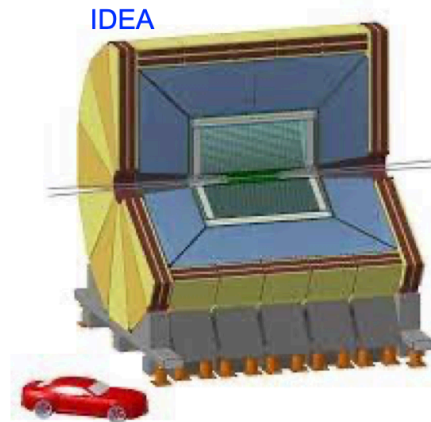
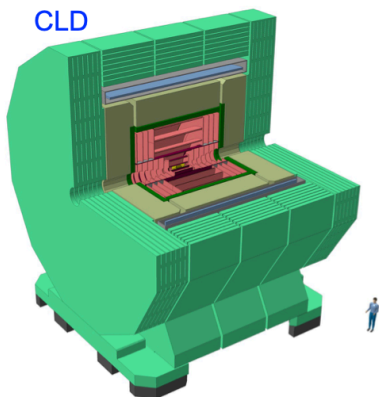
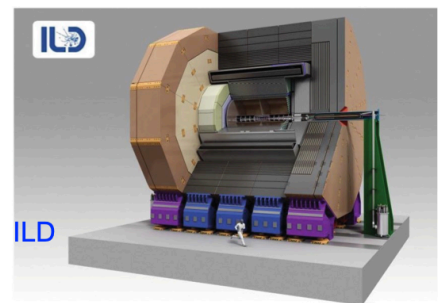
## Experimental constraints:

- 30 mrad crossing angle, focusing quadrupoles inside detector
- B-field limited to  $\sim 2$  Tesla
- High rate of physics events (up to 100 kHz, bx spacing down to 30 ns)
- **Integration time  $< 1 \mu\text{s}$**  for occupancy and pile-up (30 ns @ Z-pole)
- Fast detector frontend and DAQ
- Main backgrounds:
  - synchr. rad. (requires **shielding**) + incoherent pairs (up to  $\sim 200 \text{ MHz/cm}^2$ )
- Continuous collisions (100% duty cycle)
- **Pulsed powering not possible**
- Moderate radiation exposure:
  - NIEL:  $< 10^{14} \text{ neq/cm}^2/\text{y}$ ; TID:  $< 100 \text{ kGy / year}$**



# Detectors Concepts

Collider	FCC-ee					CEPC	
Detector Concept	FCC-ee ILD	CLD	FCC-ee IDEA	ALLEGRO	ALFA (new)	CEPC baseline	CEPC IDEA
B-field [T]	2	2	2	2	3*	3	2
Vertex inner radius [mm]	13	13	14	14	13	11	11
Tracker out. radius [m]	1.8	2.2	2.0	2.0	1.78	1.81	2.05
Vertex	Si-pixel	Si-pixel	Si-pixel	Si-pixel	Si-pixel	Si-pixel	Si-pixel
Tracker	TPC/ Si strips	Si-pixel	DC/ Si-strips	DC/Si-strips or Si-pixel	all-MAPS	TPC/Si-strips or Si-strips	DC/ Si-strips

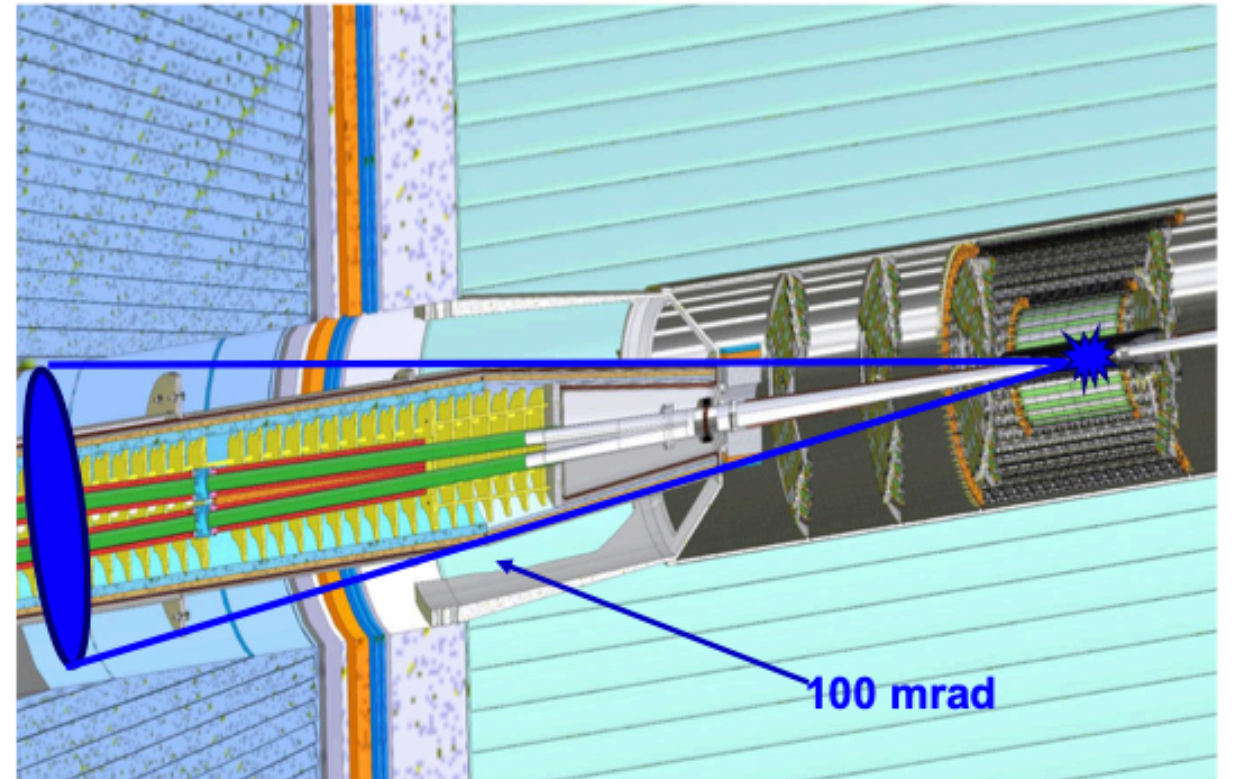
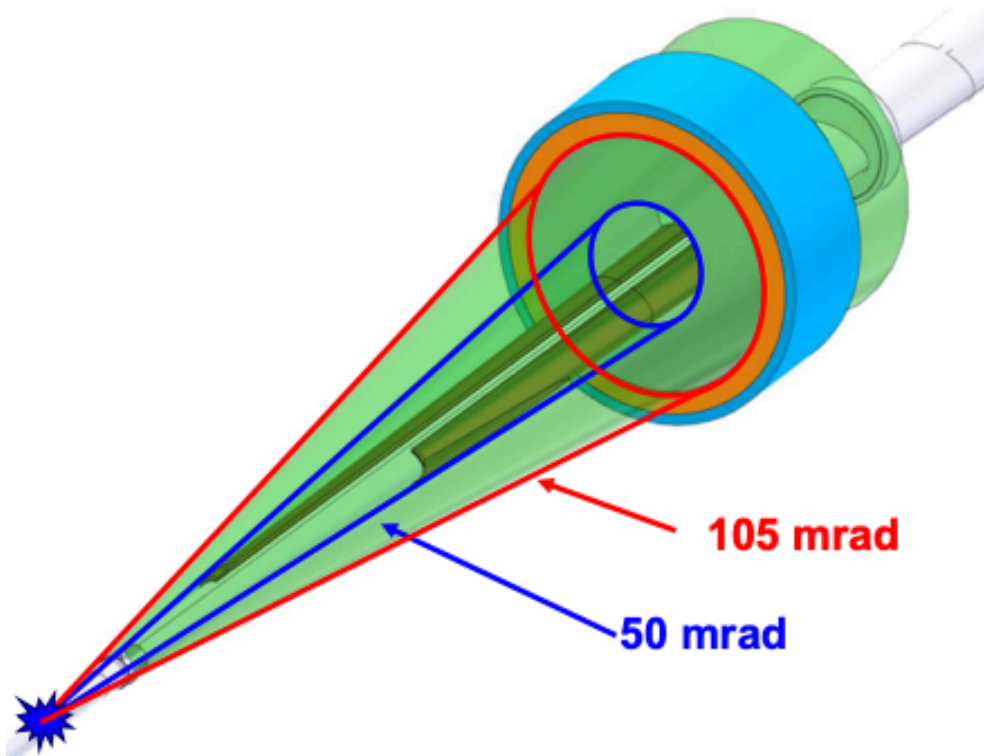


# FCC acceptance constraints

[Francesco Franesini FCC WS\(01/2025\)](#)

To achieve the required performance, it is necessary to have **low material budget** within the LumiCal acceptance (between **50 mrad** and **105 mrad** centered on the outgoing beam pipe).

Every component of the MDI must stay inside the **100 mrad detector acceptance cone**.



The forward region is geometrically constrained, so end-cap disk placement must be optimized together with acceptance and service constraints.

# IDEA Vertex Detector

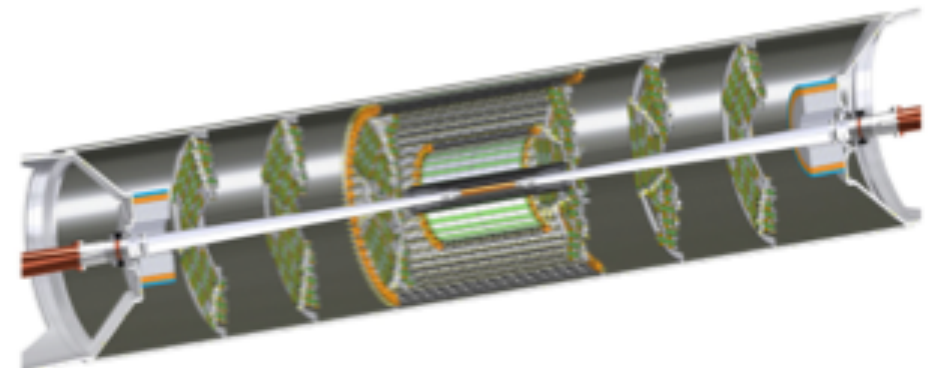
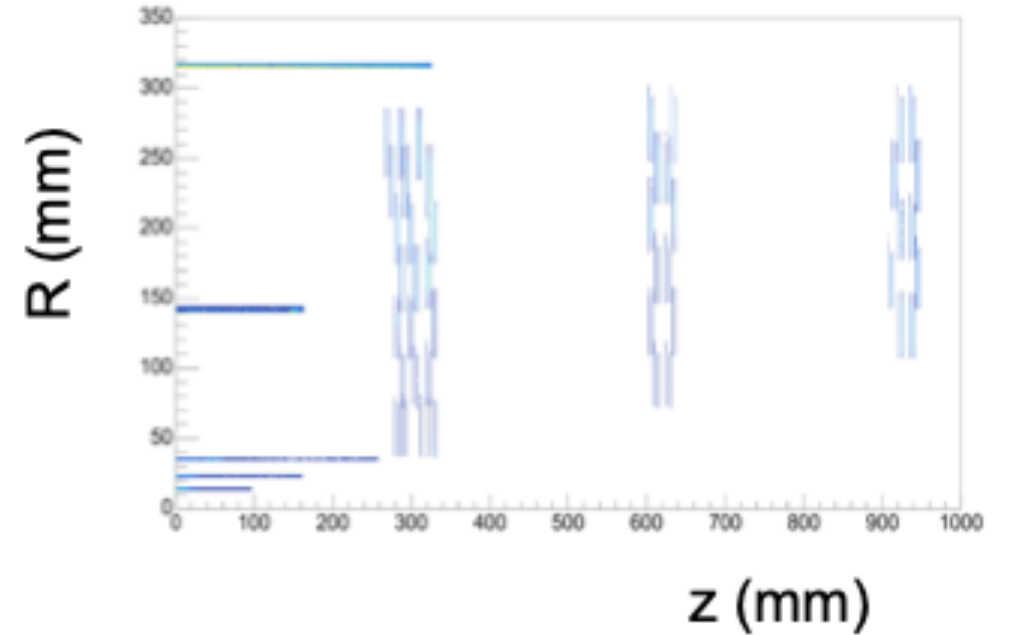
Default configuration:

- 5 layers (barrel) with innermost radius  $\sim 13.7\text{mm}$  and 3 disks
- Magnetic field: 2T (baseline)

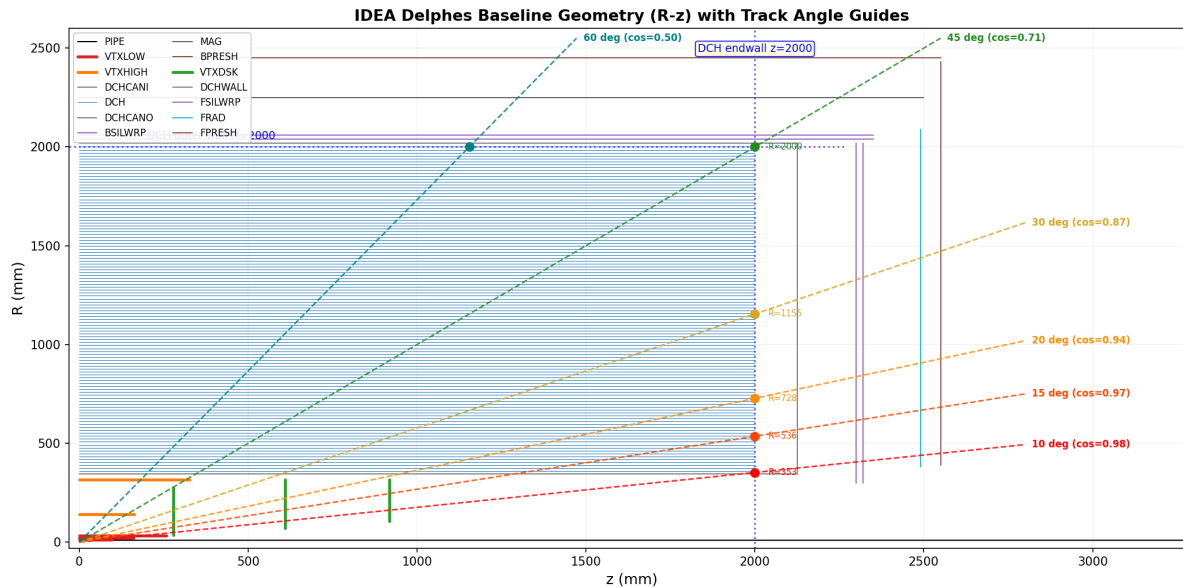
MAPS: material budget:  $\sim 280\ \mu\text{m Si} \sim 0.3\% X_0$  per layer

Inner barrel:  $25 \times 25\ \mu\text{m}^2$  pixels

Outer barrel:  $50 \times 150\ \mu\text{m}^2$  pixels

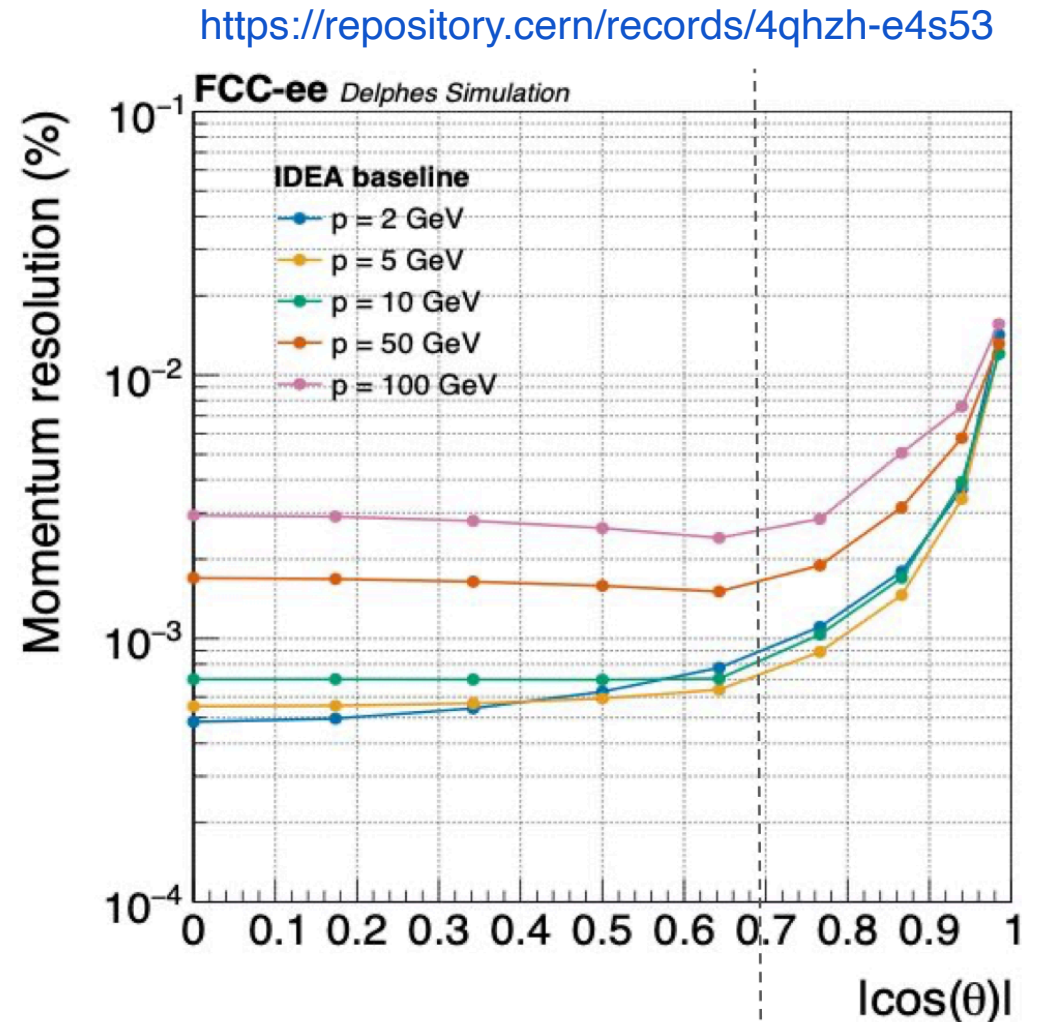


# Default IDEA performance



$$d\sigma(p)/p \sim p \sigma^{r\phi} / B + MS/B$$

- p resolution dominated by the DCH
- beyond  $\cos(\theta) > 0.7$ , pT resolution degrades rapidly because tracks exit the DCH with fewer measurement points



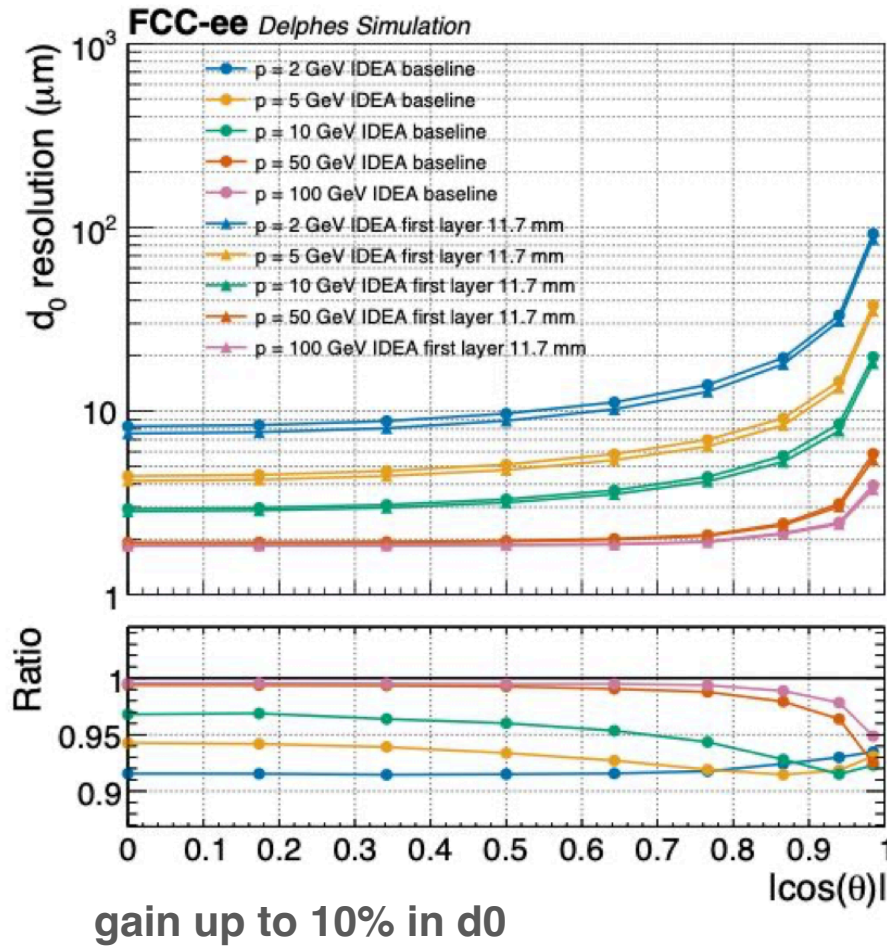
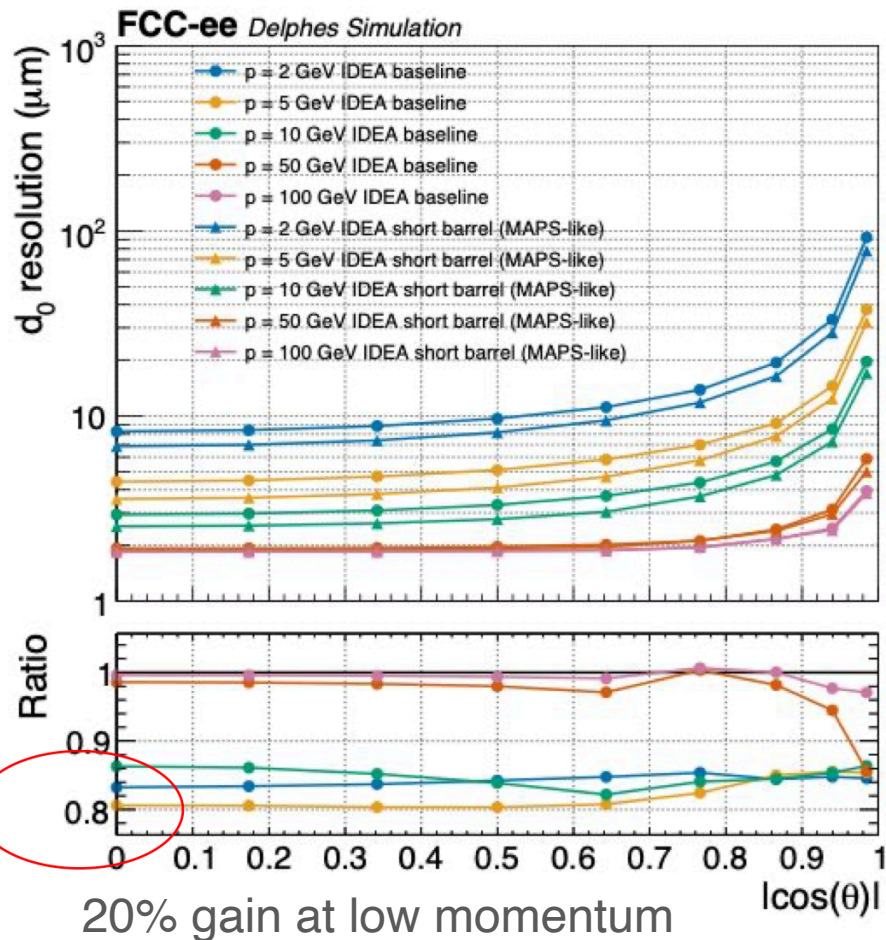
# Can we improve the current IDEA detector

## Short + Light barrel

With material changed to 0.24% X0

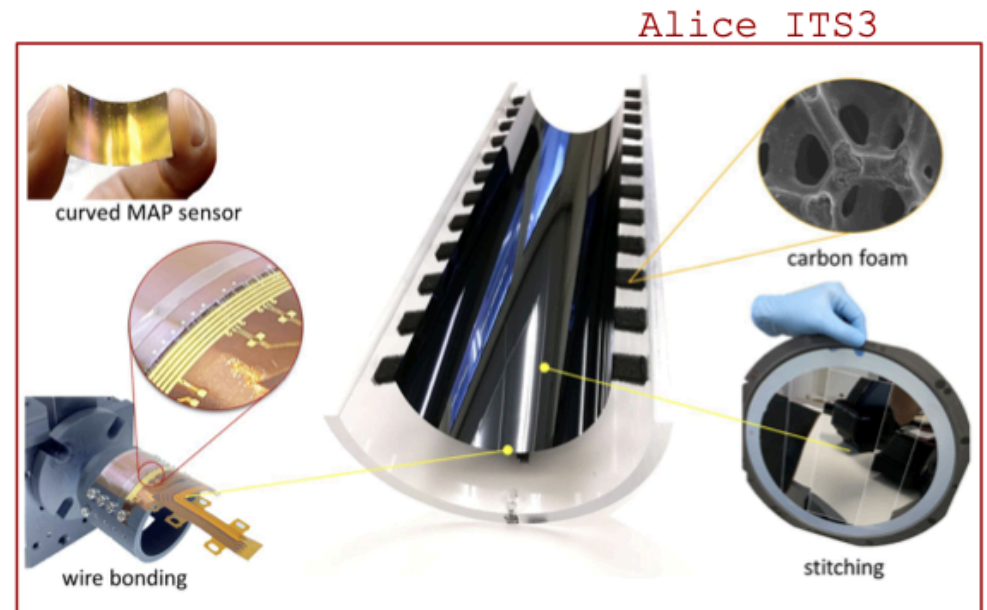
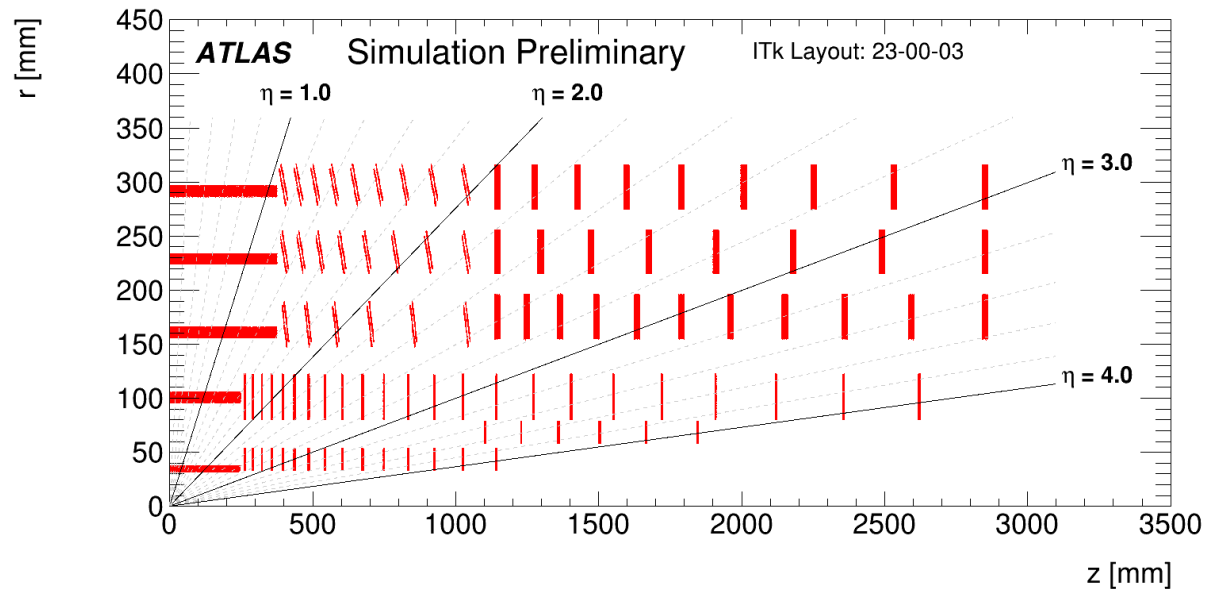
## First Layer position

13.7 mm  $\rightarrow$  11.7 mm on top of beam pipe



# Can we improve the current IDEEA detector

Inspired by ATLAS Inner Tracker design and Alice ITS3— can we gain from short barrel+low-Z end-caps



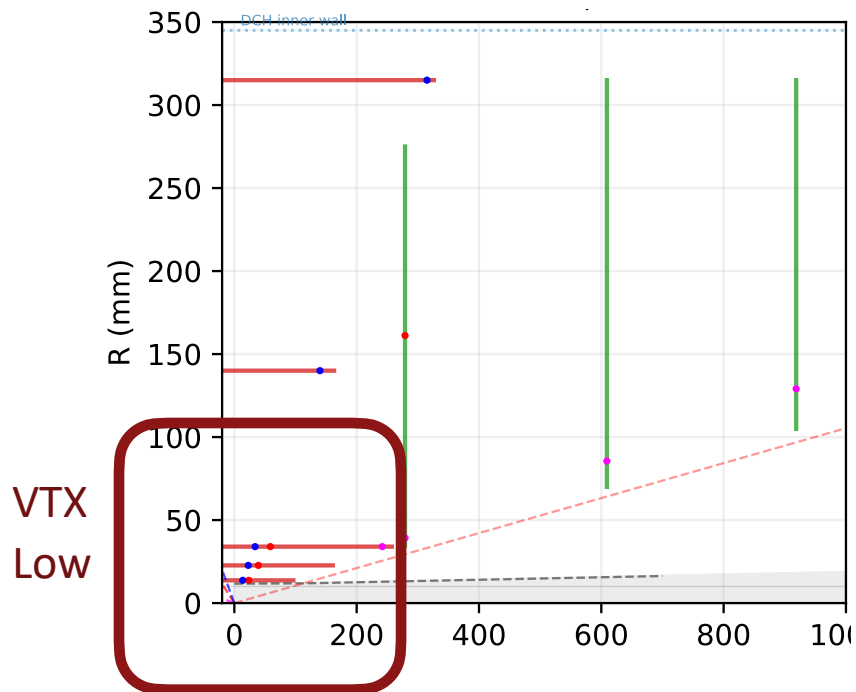
# Geometry scan: barrel length, disk multiplicity, and disk placement

We perform a systematic scan of vertex detector layouts to isolate the impact of barrel length and end-cap coverage.

Change the VTX low with short barrel and low-Z end-caps

- The barrel length is scanned up to the approximate 12-inch stitched-sensor scale motivated by ITS3-style wafer stitching

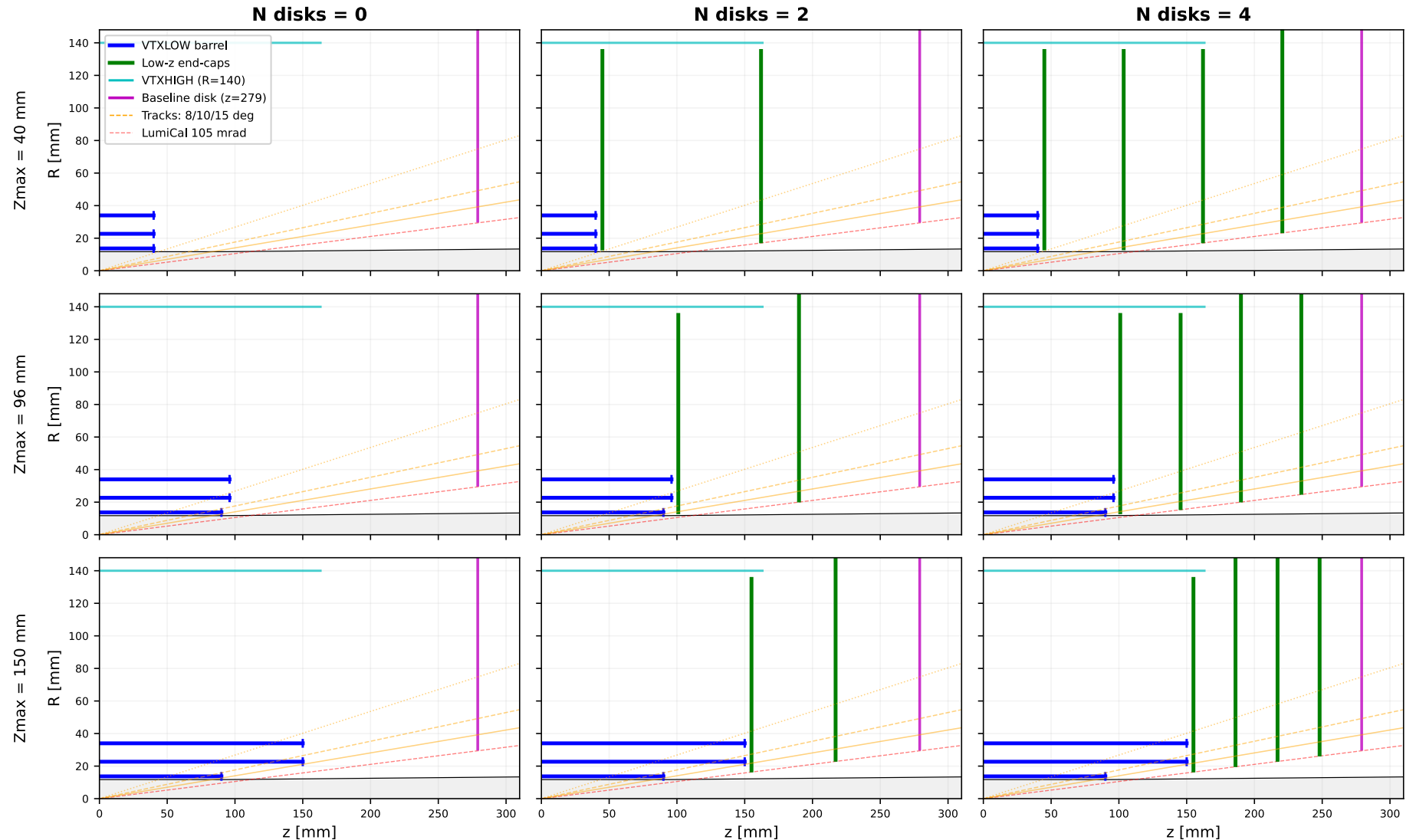
**Material budget can be reduced to 0.25% X** – Keep the material budget to be 0.25%X during the scan



Parameter	Values scanned	Motivation
Barrel half-length / z extent for VTX Low	Up to 12 inches 10mm step	motivated by stitched MAPS sensor length
Number of disks	0-4	test end-cap coverage impact
Track angle	8°, 10°, 30°, 45°	central-to-forward performance
Momentum	broad p range	separate MS-dominated and intrinsic regimes

# Scans of layouts: cover different barrel lengths and disk multiplicities

Simplify the disk placement strategy by positioning the first disk close to the barrel, then adding subsequent disks with approximately uniform spacing.



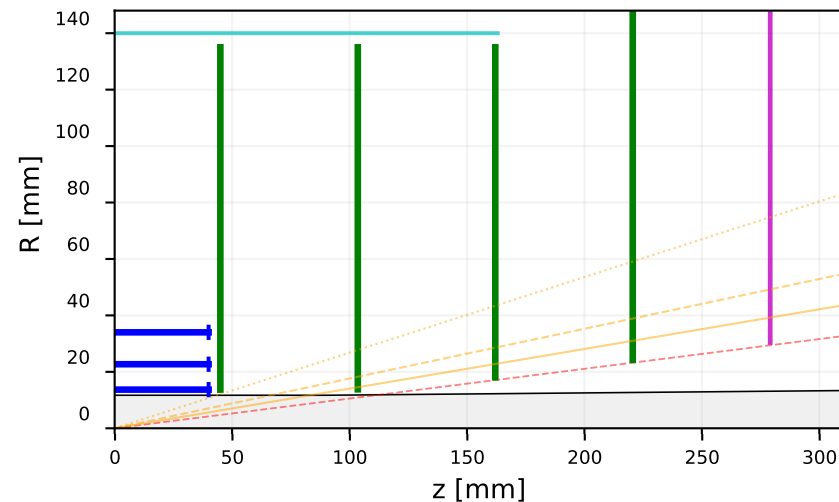
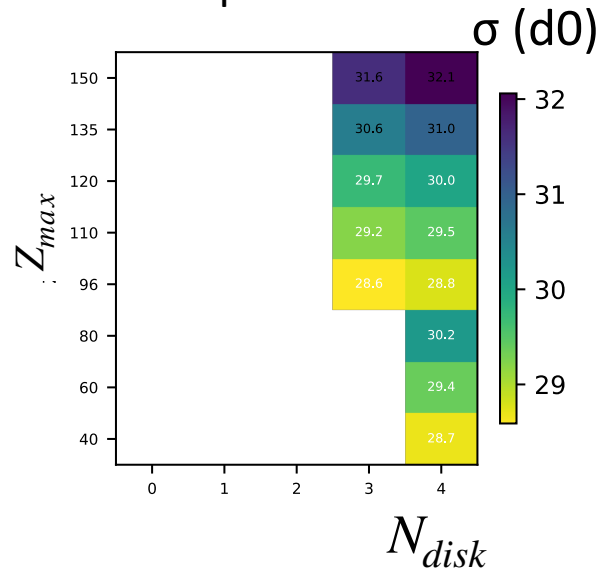
# Forward Region:

Forward tracks strongly benefit from added end-cap coverage

- For the very forward regions ( $8^\circ$ ), 3-4 disks are needed to fulfill the requirements of minimal hits (at least 6 hits)

$$\theta = 8^\circ$$

$p_T = 1 \text{ GeV}$



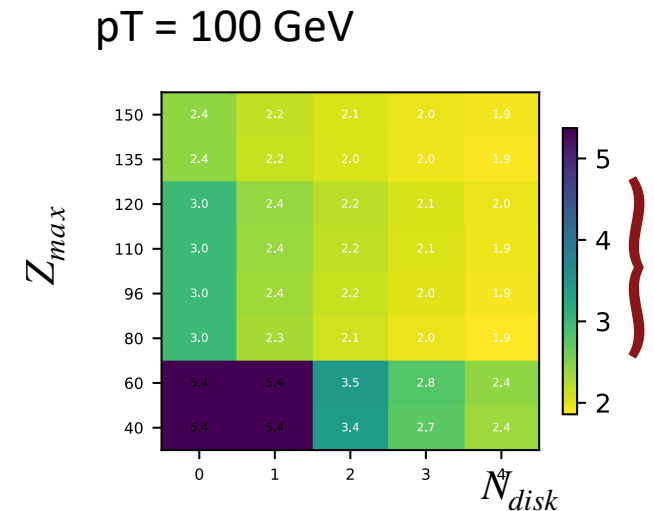
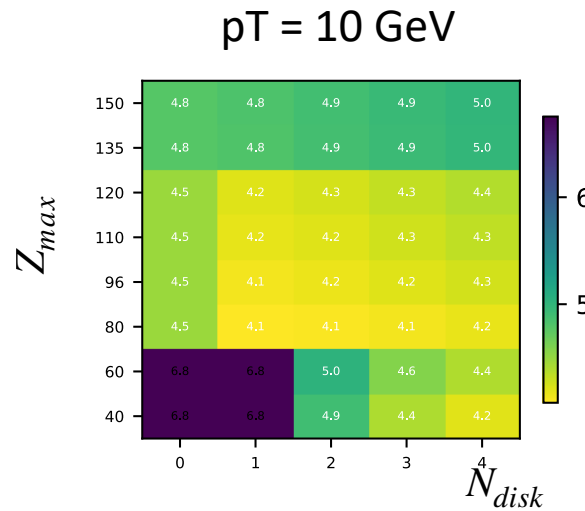
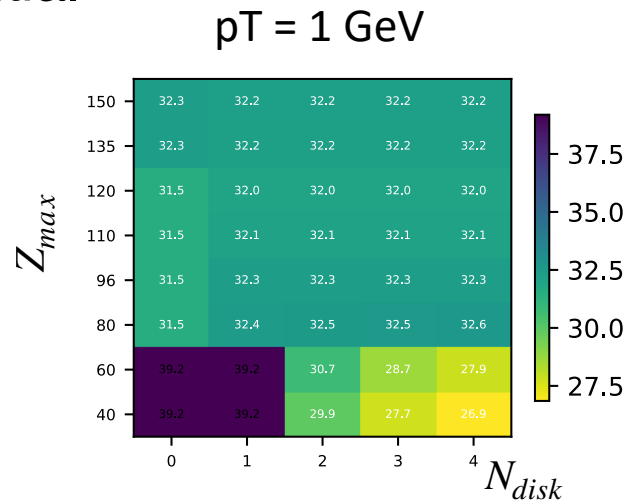
Need  $\geq 3$  disks at  $Z > 80$ mm to recover hits for very forward region

# Forward Region:

Forward tracks strongly benefit from added end-cap coverage

- For  $\theta \geq 10^\circ$ : longer barrel gives 1–2 additional hits that help, but disks are still essential

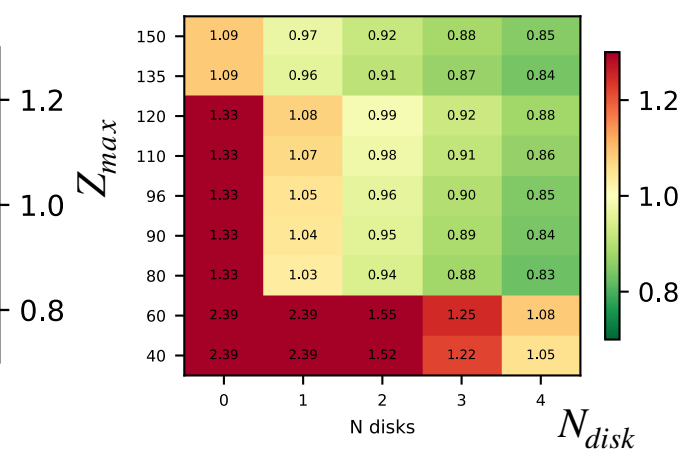
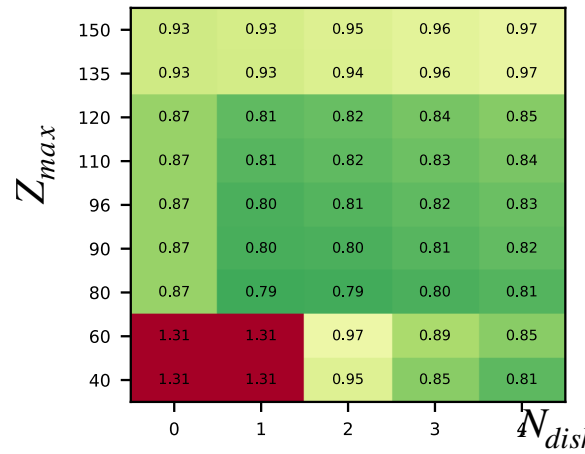
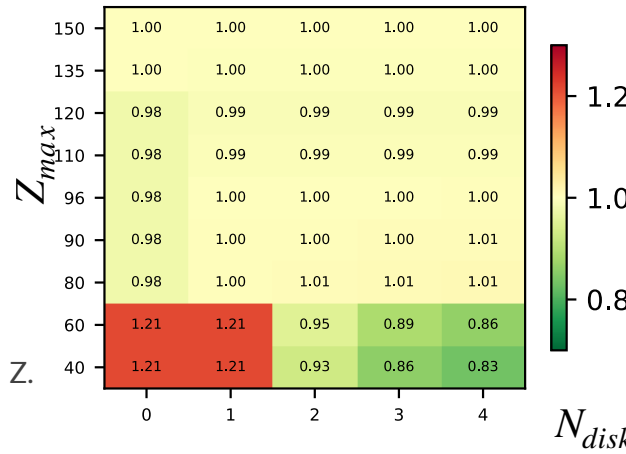
$\theta = 10^\circ$   
 $\sigma(d_0)$



for the Layer 1 hits in barrel

Ratio to baseline

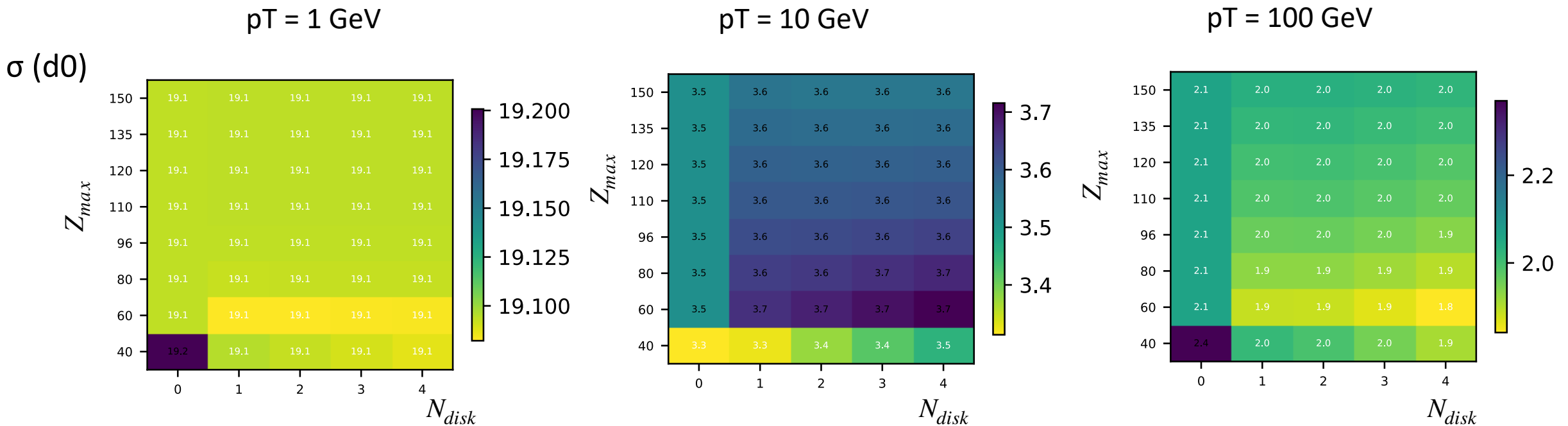
\*baseline geometry but with the same material budget assumptions



# Above 20°, performance is less sensitive to barrel z length

Barrel z-extension has weaker impact than in the 10° case

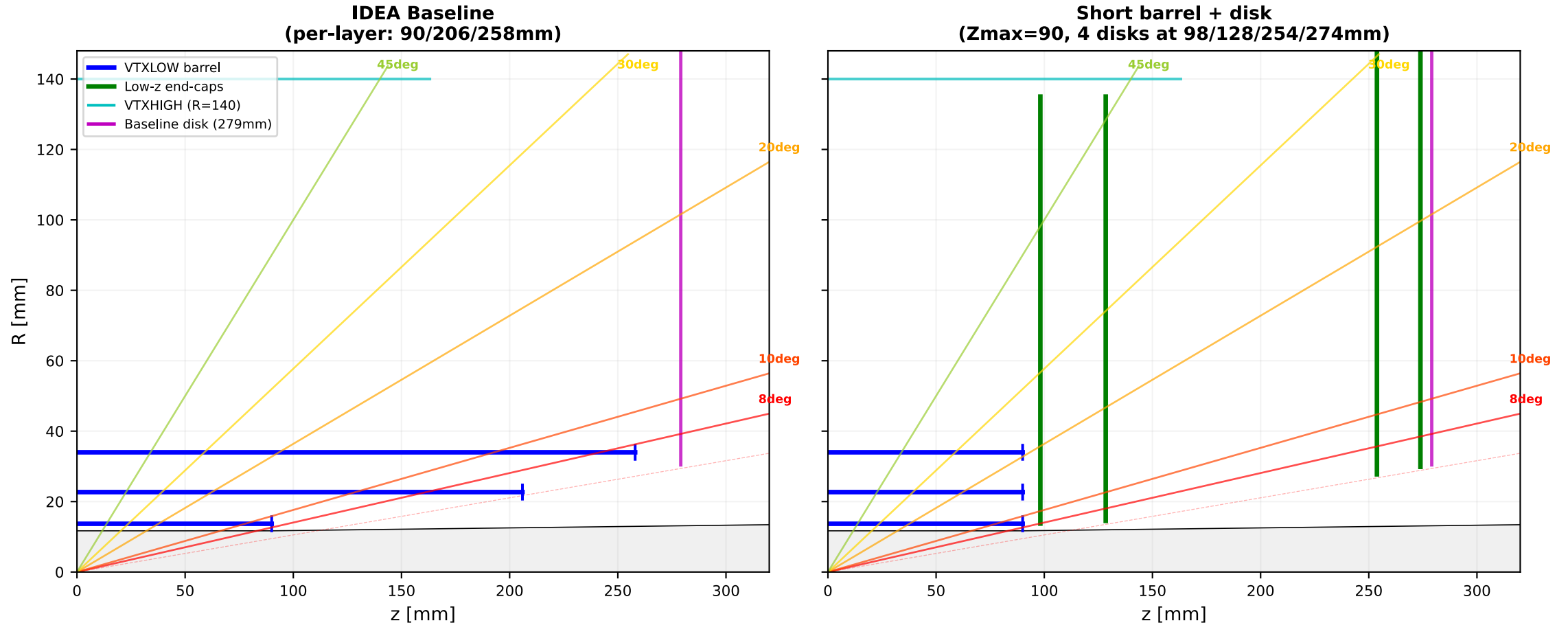
$\theta = 30^\circ$



Low momentum: dominated by material budget — fewer disks help reduce multiple scattering.

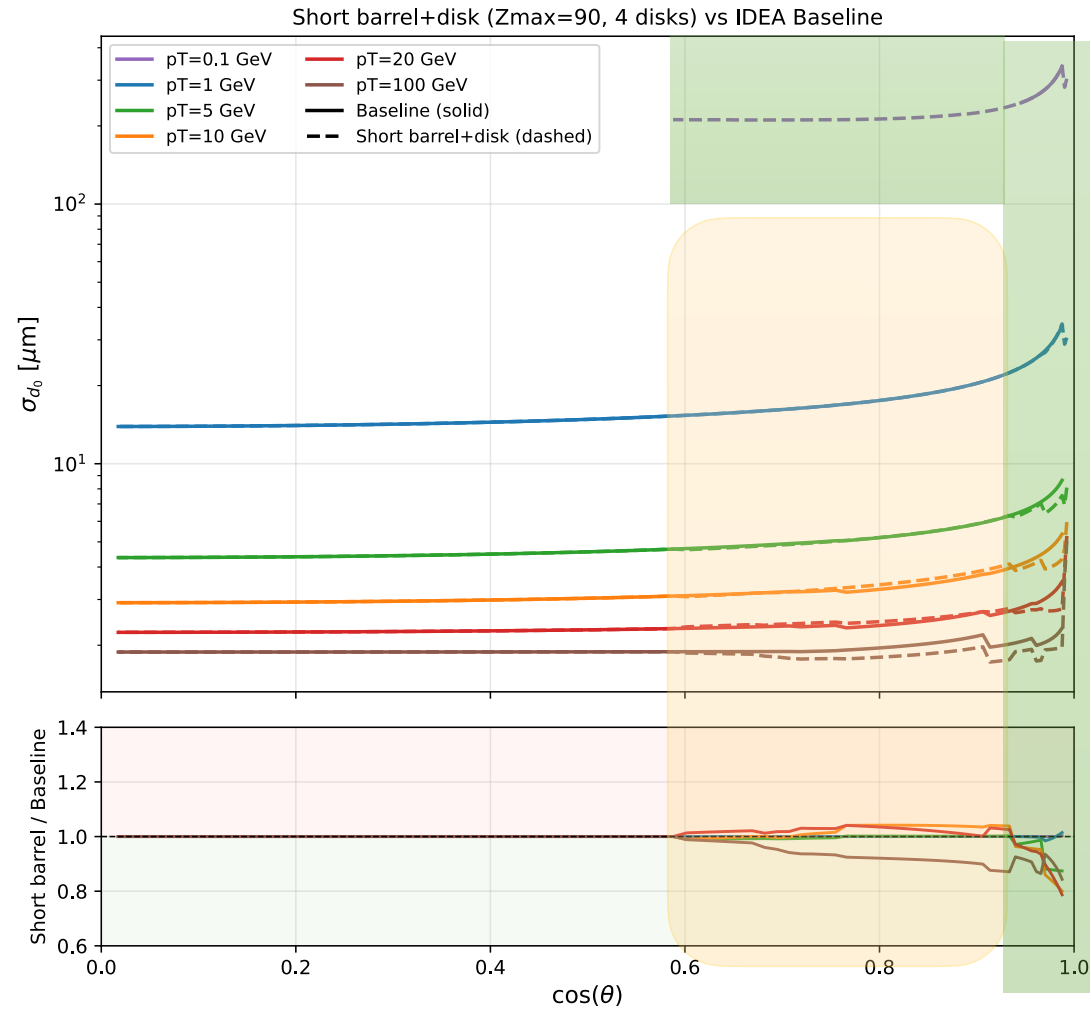
High momentum: dominated by hit statistics — more disks improve track measurement precision.

# Geometry candidates performance comparison



To isolate the effect of the geometry change, the material budget is set to 0.25%  $X_0$  in the IDEA baseline.

# Geometry candidates performance comparison



## Short barrel + disk discussion:

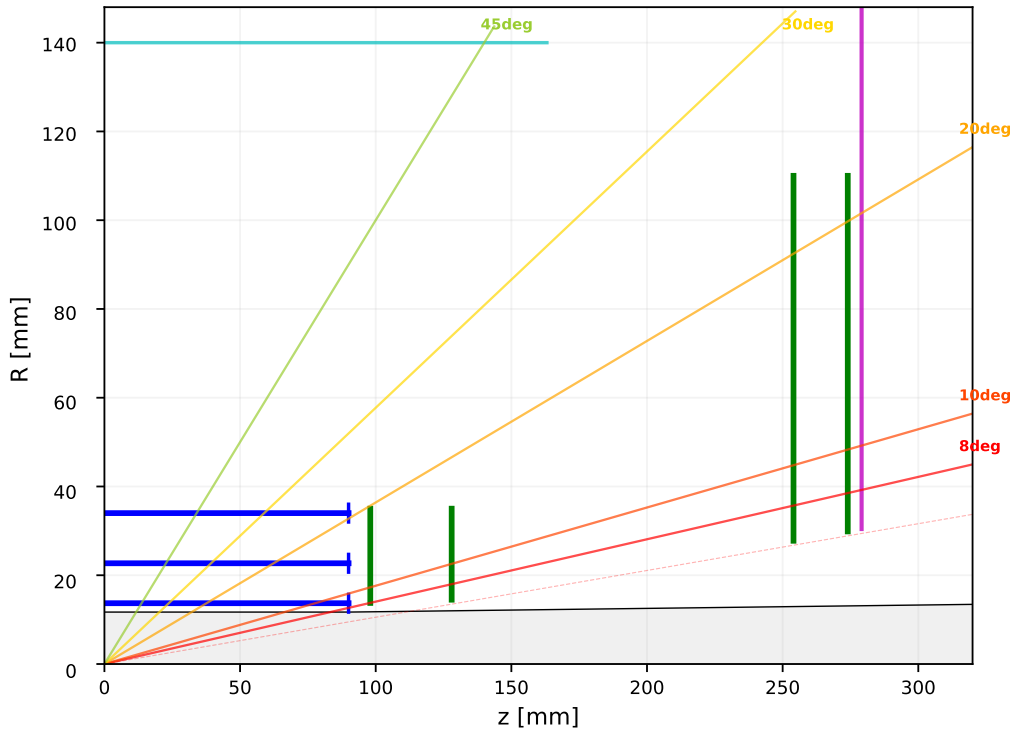
- Improves forward-region performance, especially for  $\theta < 20^\circ$
- Partially recovers acceptance for very low-momentum tracks (0.1 GeV)
- Slightly degrades pT regime 5-20 GeV performance in the transition region due to extra material from the large disks.
  - Further disk optimization (R, X0) could help recover the low performance (to-do).

# Summary

The optimized short barrel + disk geometry maintains baseline-level performance for  $\theta > 20^\circ$

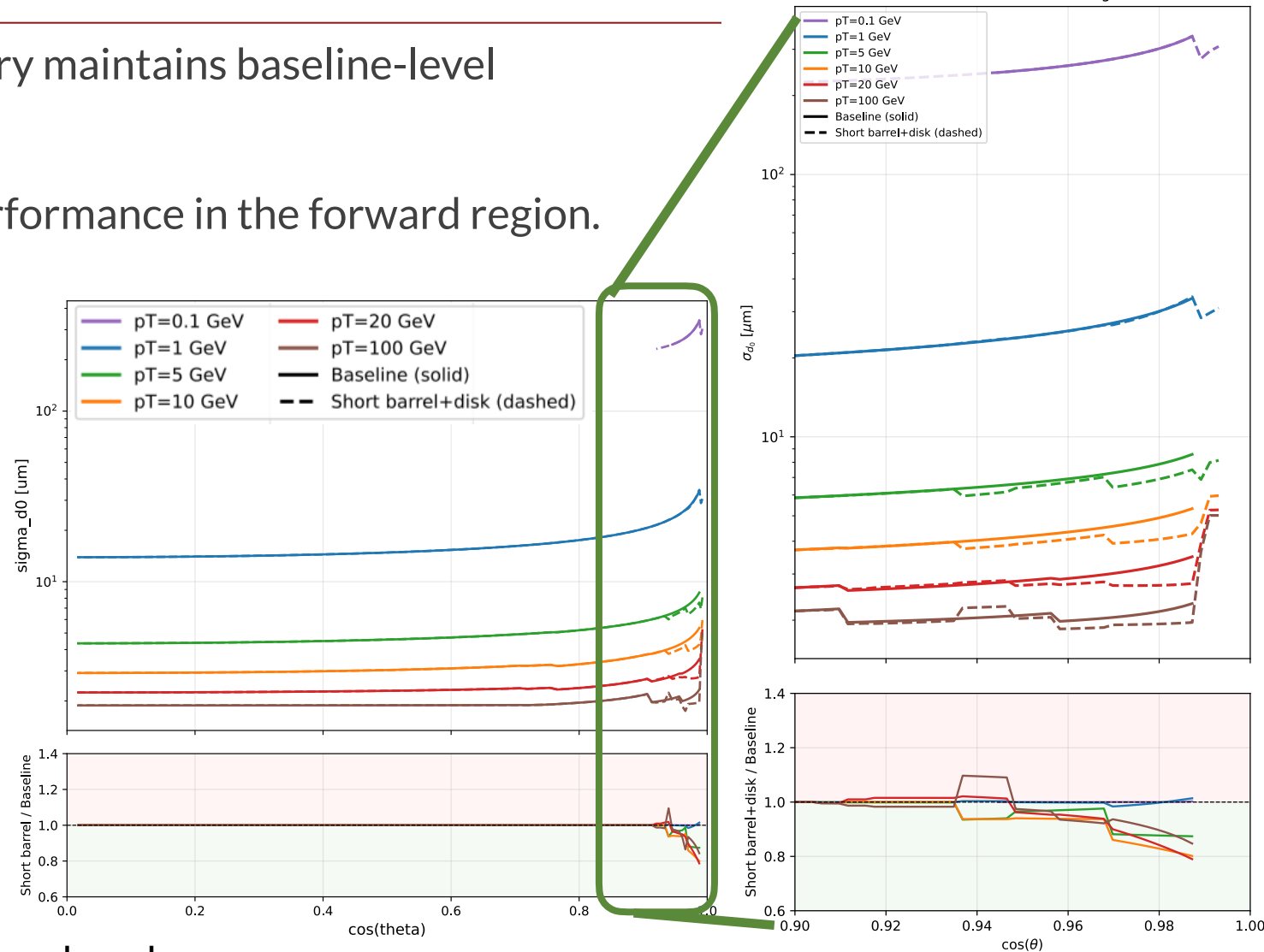
At the same time, it improves tracking performance in the forward region.

Short barrel+disk  
(Zmax=90, disks: 98/128@35mm, 254/274@110mm)



\* Mechanical constraints on also need to be explored

## Forward Region Zoom In



# VTX Performance:

## IDEA Baseline vs short barrel + disks model

