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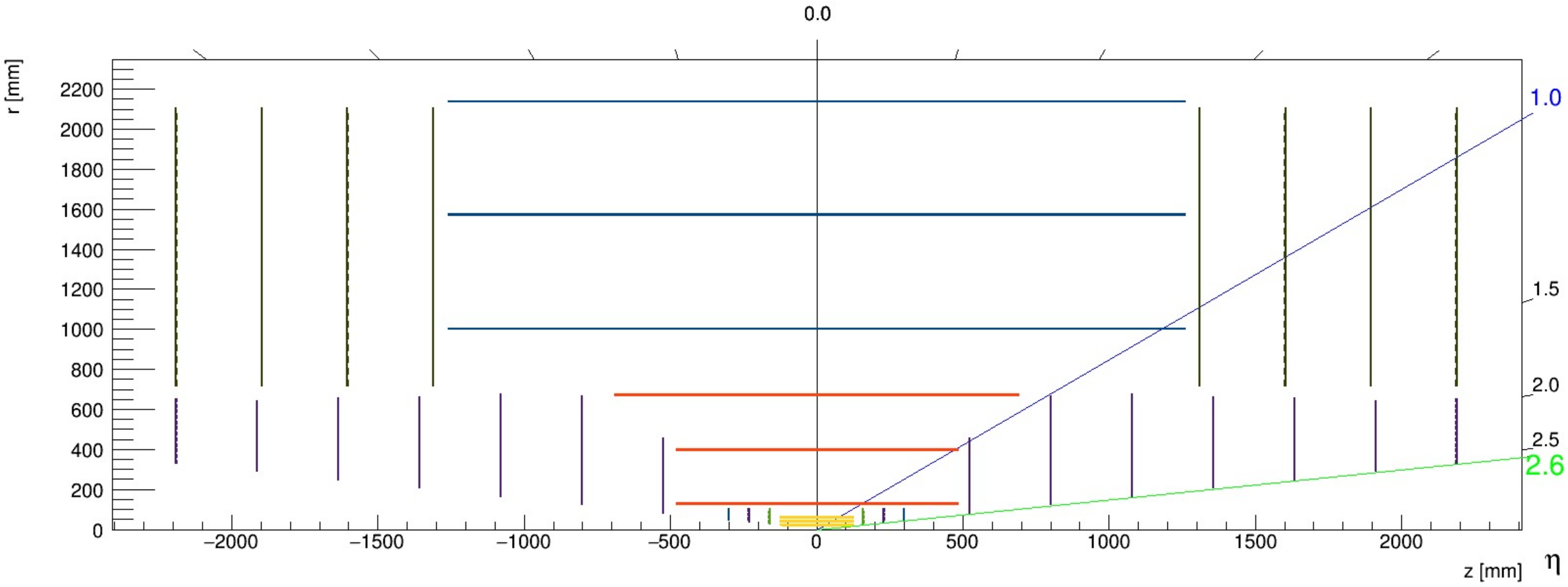
Université de Strasbourg

TRACKER GEOMETRY OPTIMIZATION AND TRACKING PERFORMANCE AT THE FUTURE CIRCULAR COLLIDER AT CERN



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under the supervision of

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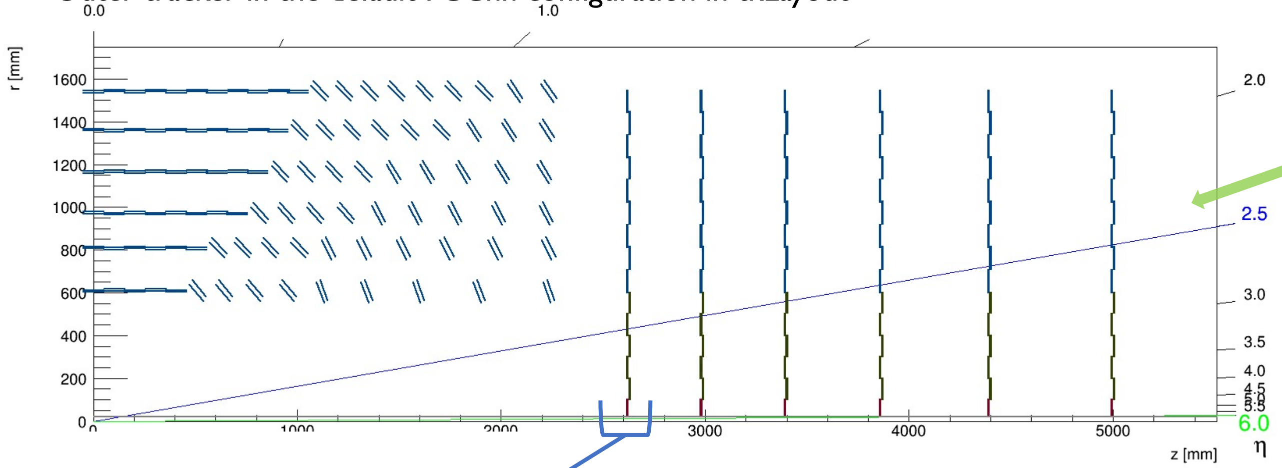
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

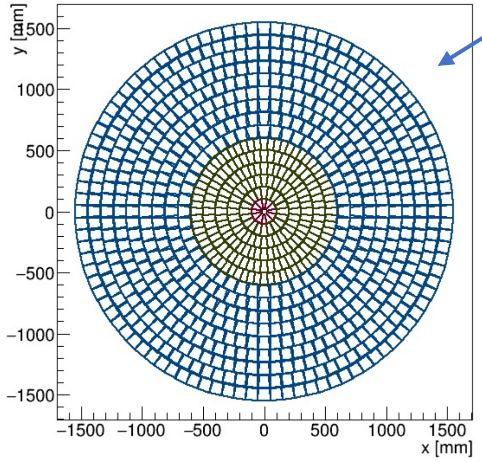
Plan

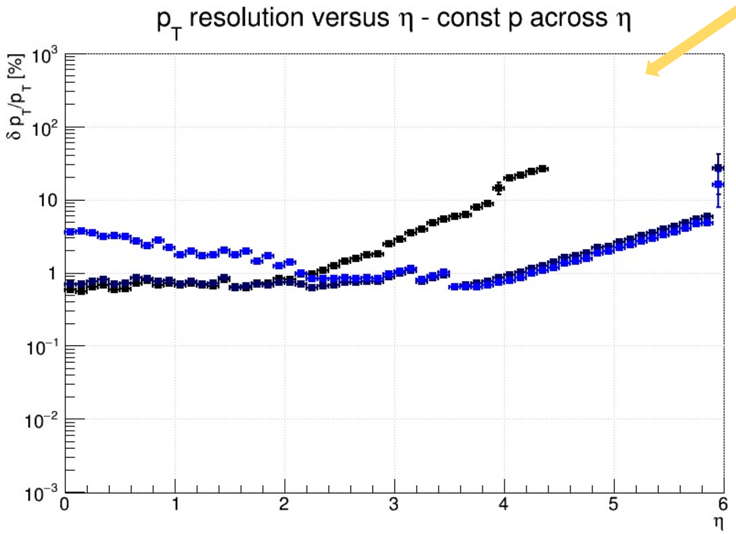
- ❖Short tkLayout recap (introduced in the IDEA presentation)
- ❖Description of our CLD implementation, a full-silicon, pixel-only tracker
- ❖Material budget and resolution comparison between tkLayout model and literature predictions
- ❖Study of the impact of material budget, sensor resolution, layers number and radius on the performances of the tracker

tkLayout

Outer tracker in the default FCChh configuration in tkLayout





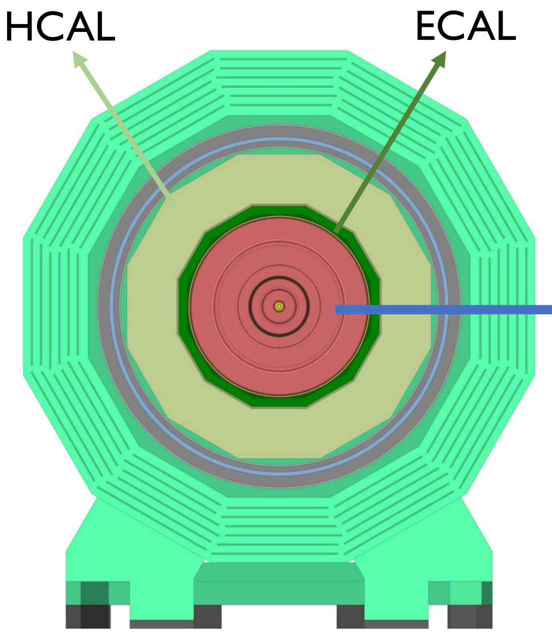


- Modeling and performance analysis tool for silicon trackers developed at CMS
- Conceived around hadronic collider architecture, we adapted it for FCC-ee
- Modular and fast, based on a single configuration file

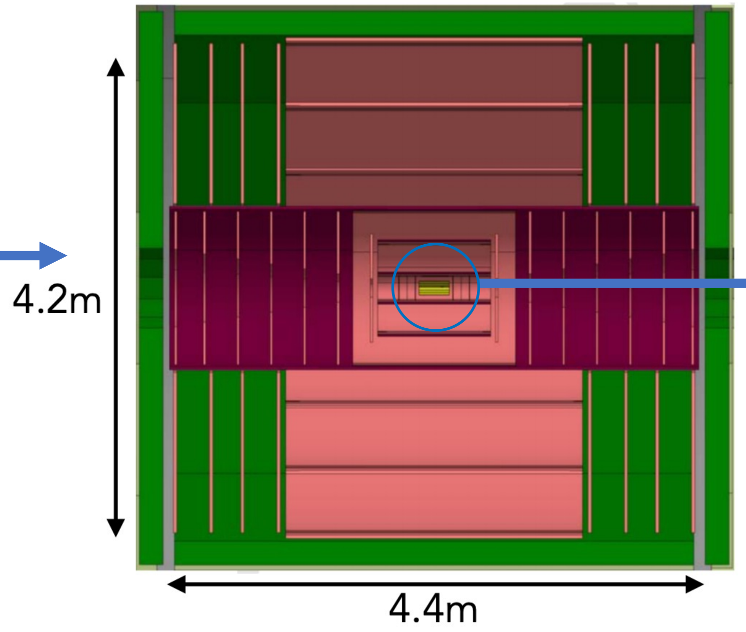
- Simulation parameters
- Beam pipe parameters
- Tracker 1
  - Barrel (one or more layers)
  - Endcap (one or morel disks)
- Tracker 2
  - …

(example in backup)

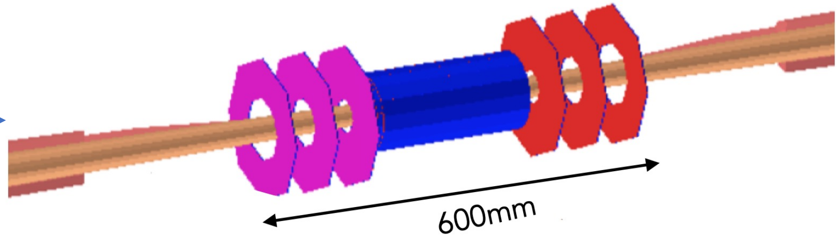
A reference tracker: CLD



CLIC-Like Detector (CLD)
(x, y) plane

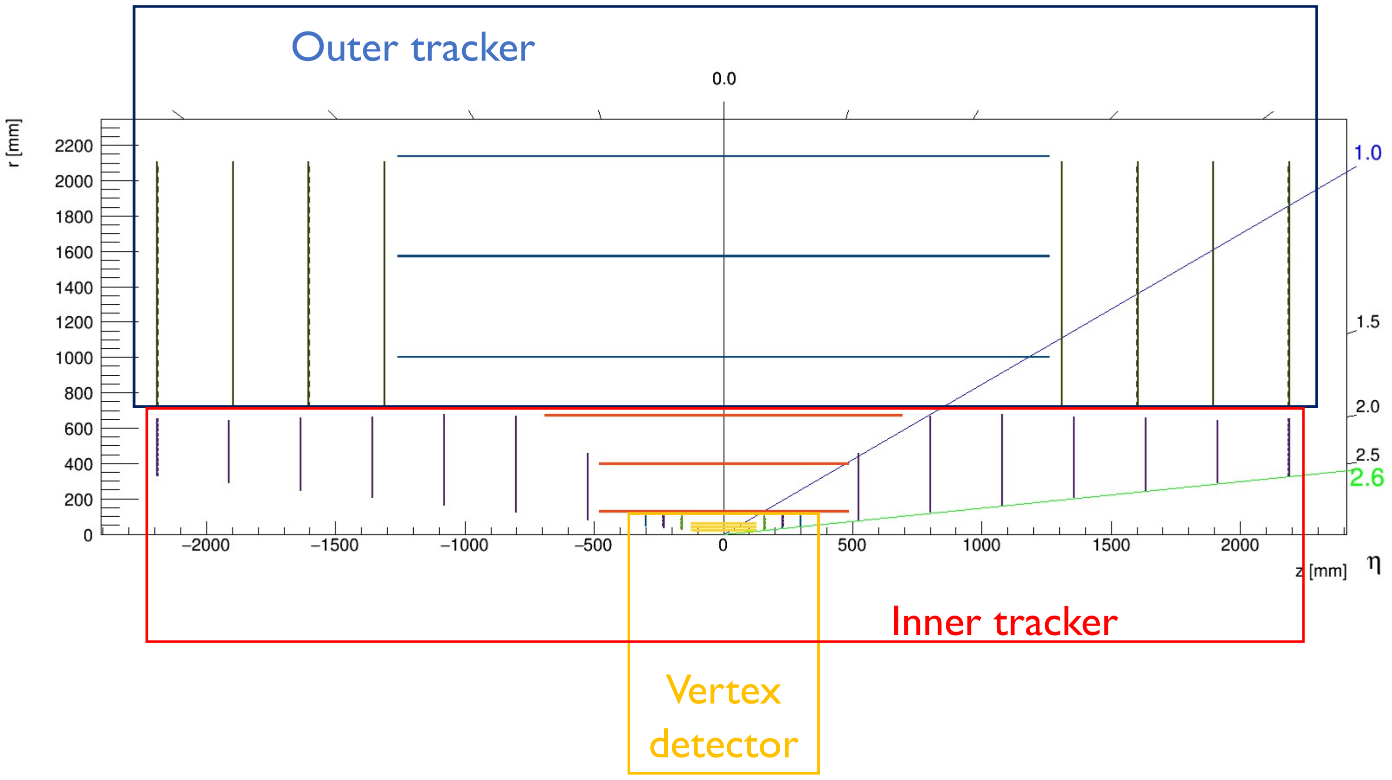


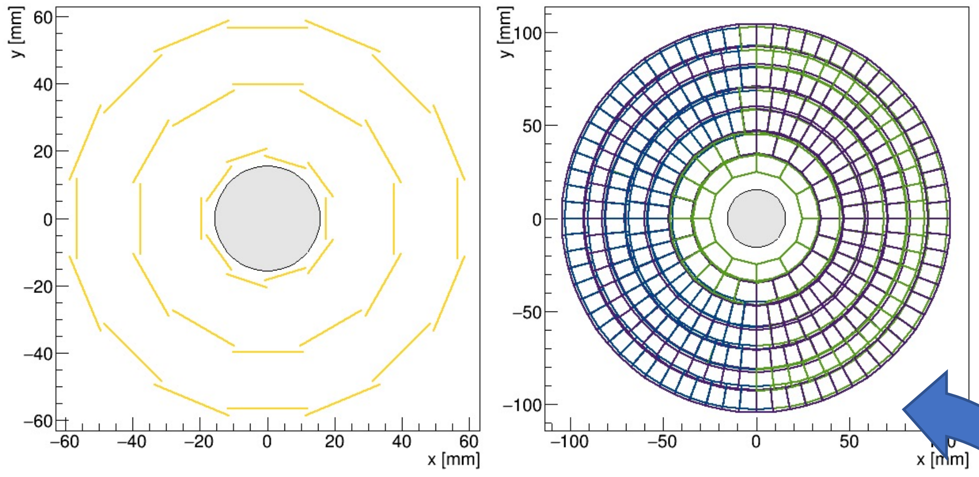
Tracking system
(z, r) plane



Vertex detector (VXD)
and beam pipe
Isometric view

A reference tracker: CLD



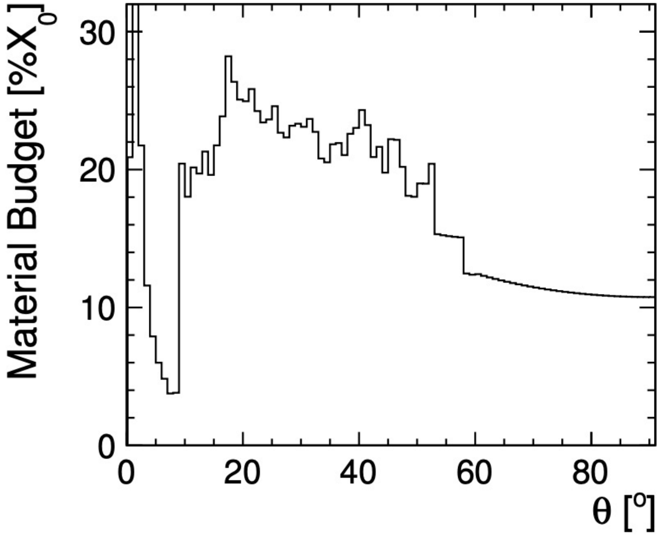


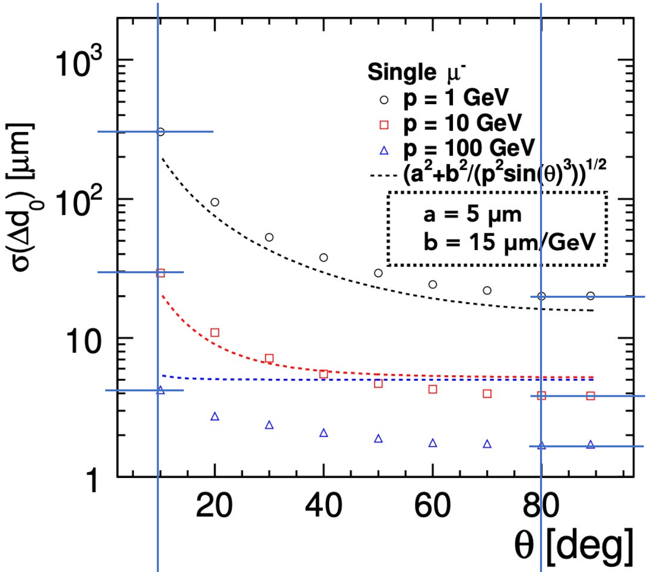
Tweaks:

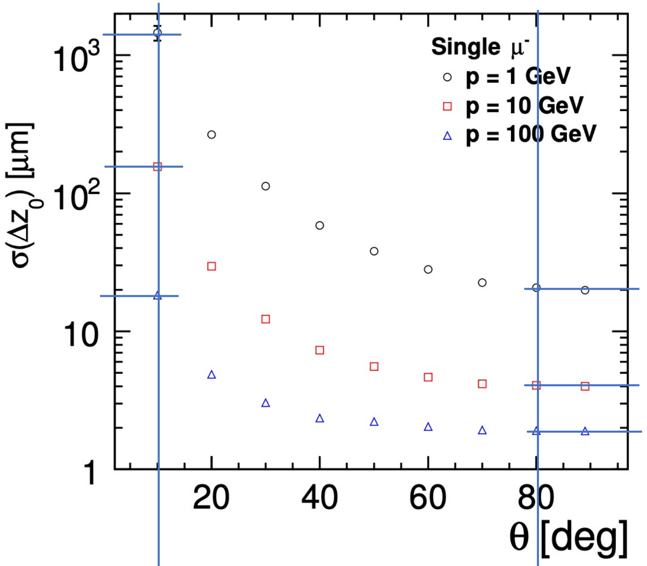
- First layer of vertex detector barrel: fewer, wider ladders
- Disc modules shape: symmetrically distributed square and trapezoidal modules
- Material budget implementation: averaged by layer and implemented as Si-equivalent on modules

A reference tracker: CLD

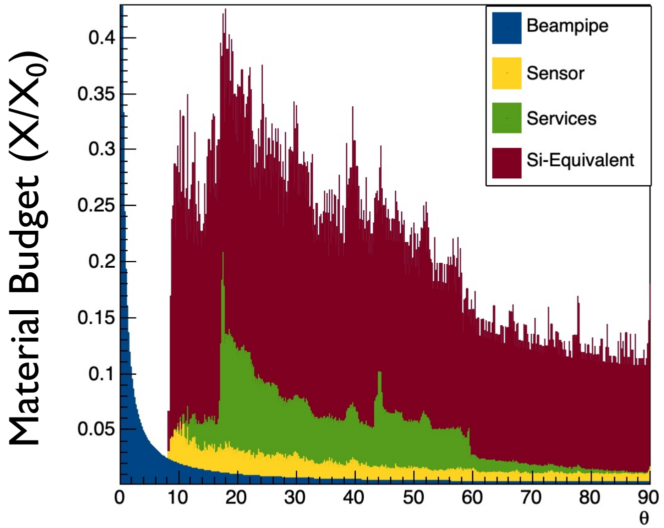
Projections in the literature

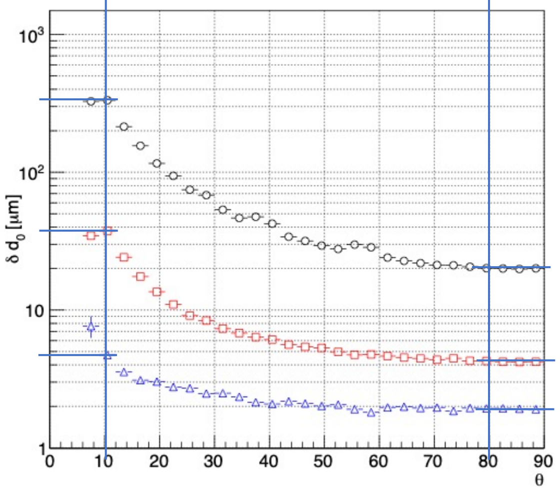


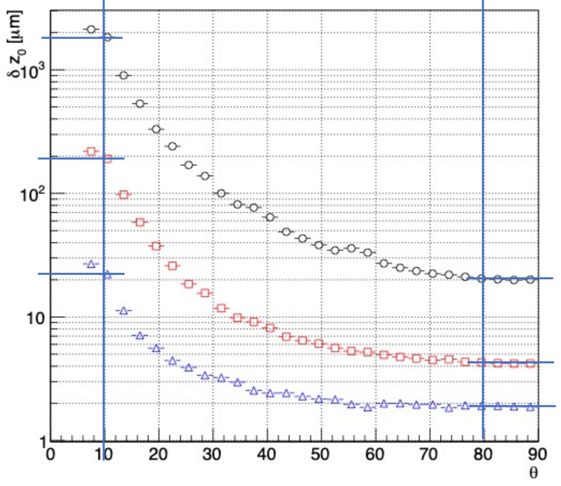




tkLayout results

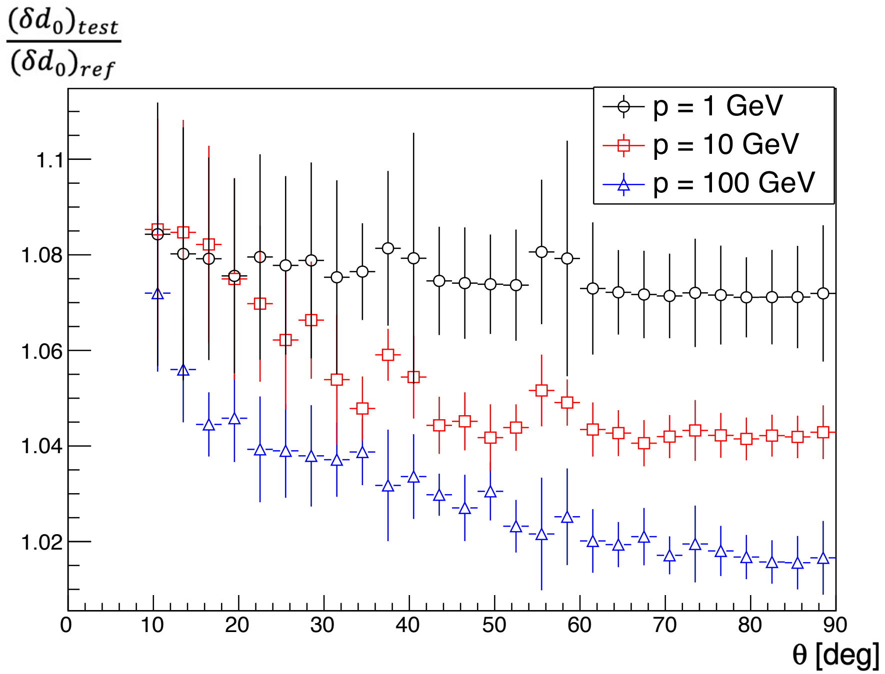


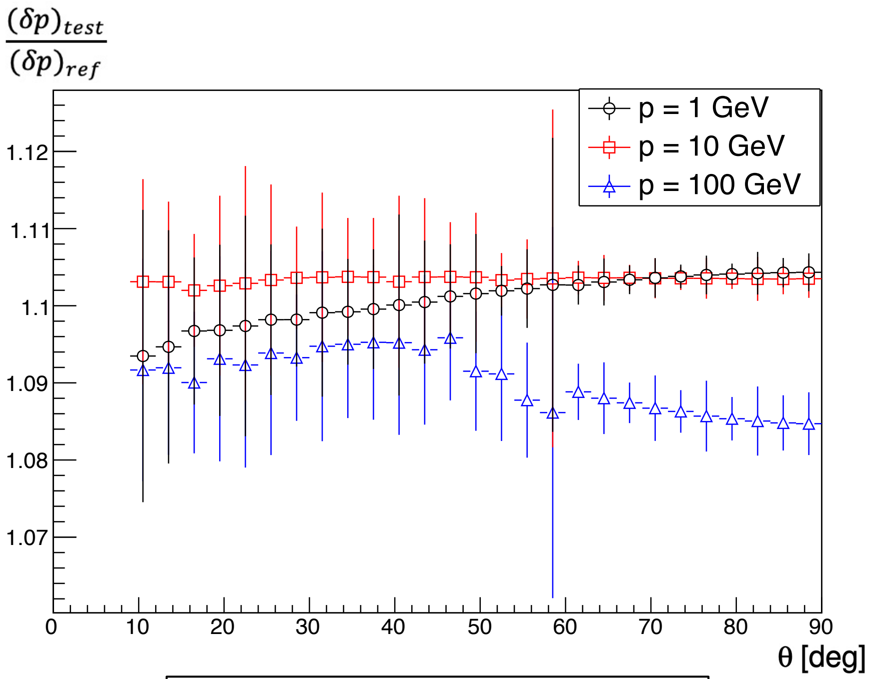




+20% material budget (sensors, cooling, support…)

Affects low p more than high p





Ratio of resolutions:

$$y(\theta) = \frac{(\delta d_0)_{test}}{(\delta d_0)_{ref}}$$

$$y(\theta) = \left(\frac{\delta p}{p}\right)_{test} \div \left(\frac{\delta p}{p}\right)_{ref}$$

Error margins:
- Calculated without correlation (formula in backup)
- Driven down statically with numerous tracks
- Persistent → correlation between runs, worth further exploring

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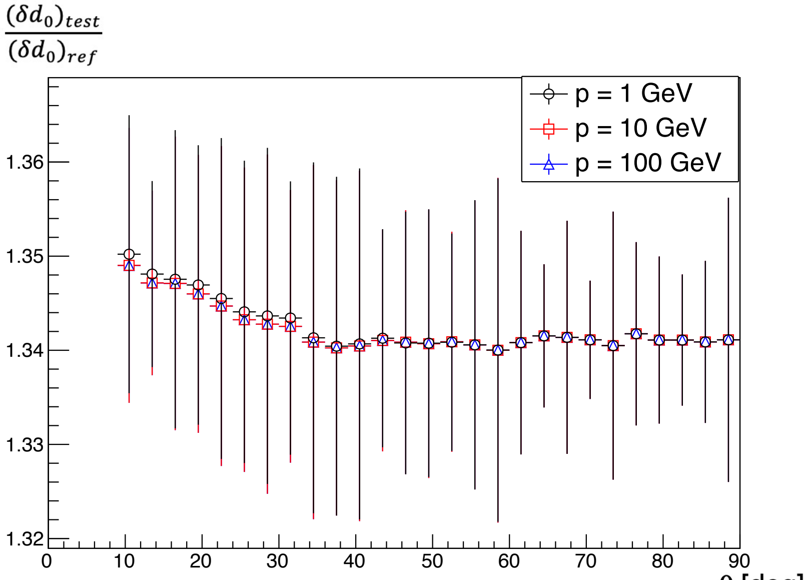
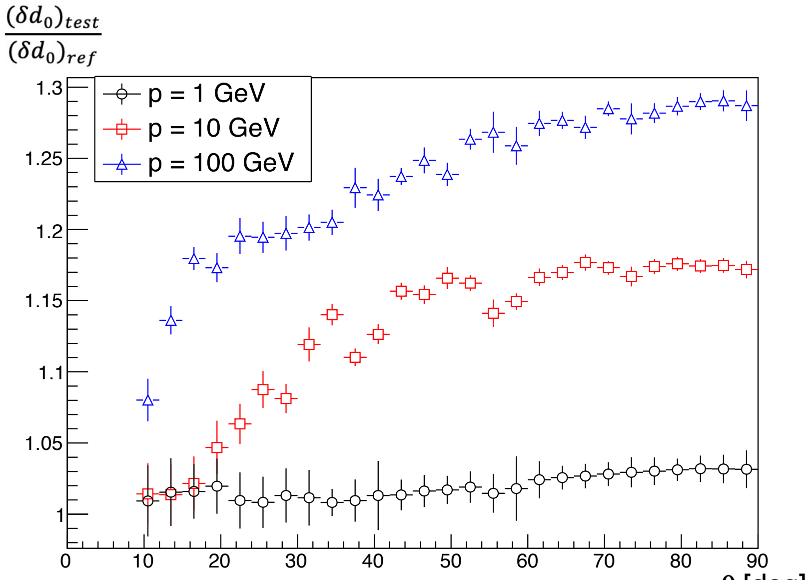
Lowering the local resolution

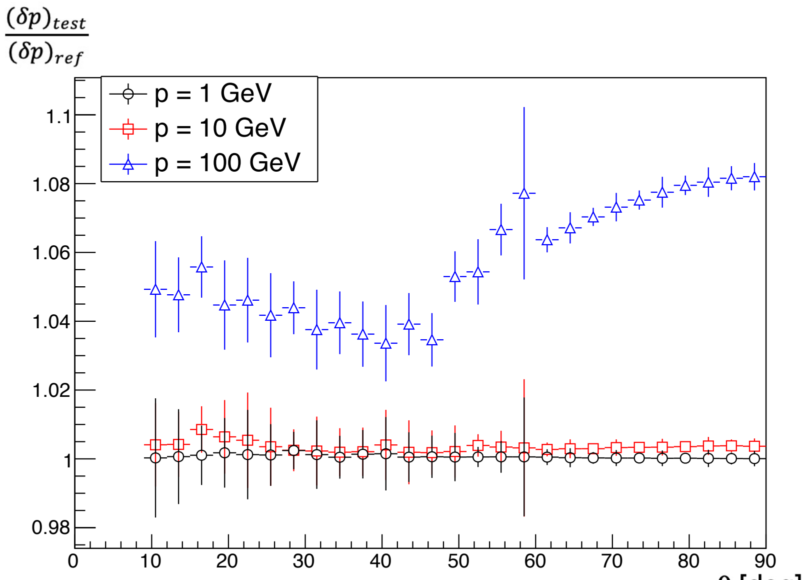
	Reference local resolution (μm^2)	Local resolution tested (μm^2)
Vertex Detector	3×3	4×4
Inner Tracker	4×4	7×7
Outer Tracker	4×4	7×7



Transverse impact parameter
Without material budget



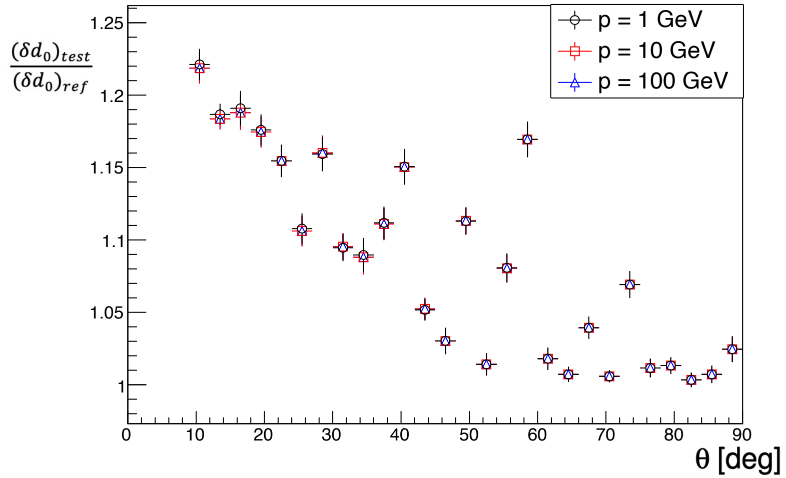
Transverse impact parameter
With material budget

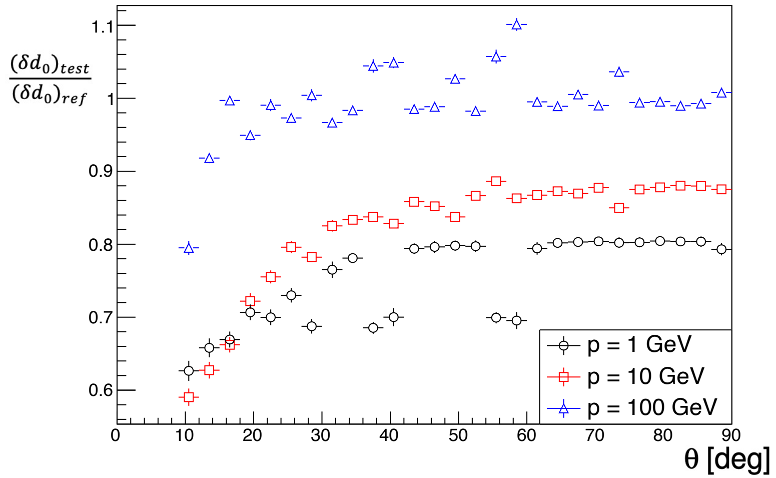


Momentum

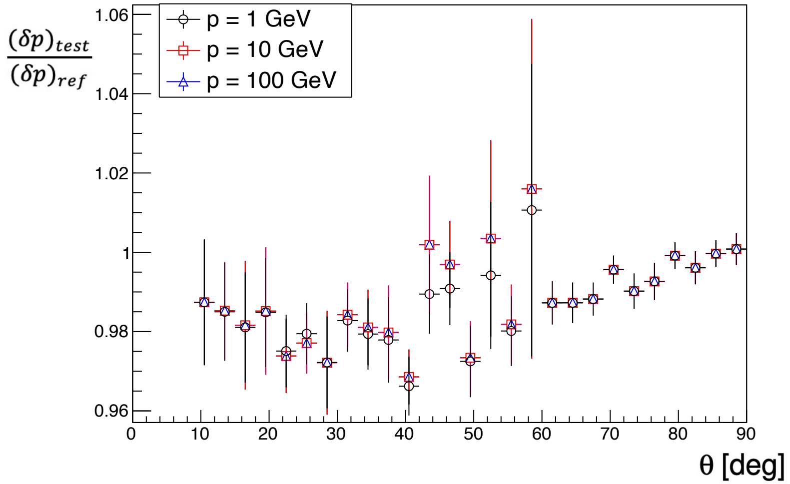
Single-layer vertex detector or double-layer trackers

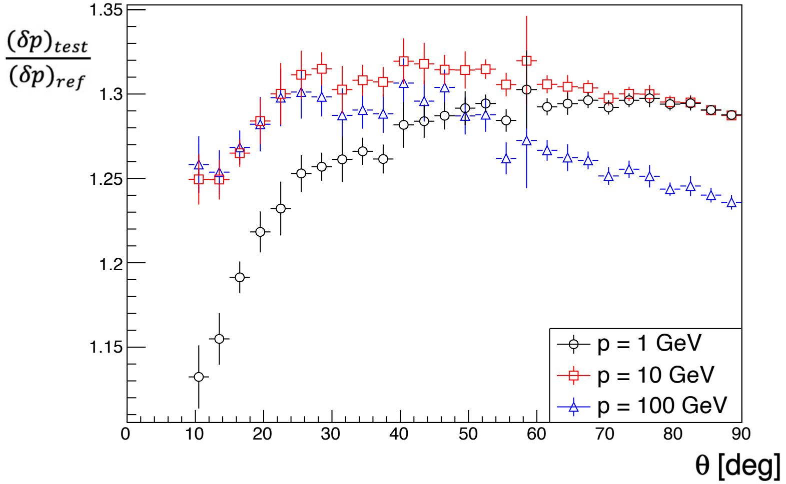
Single-layer vertex detector
&
−48% material budget
in the VXD





Double-layer inner
and outer trackers
&
+60% material budget
in the IT+OT



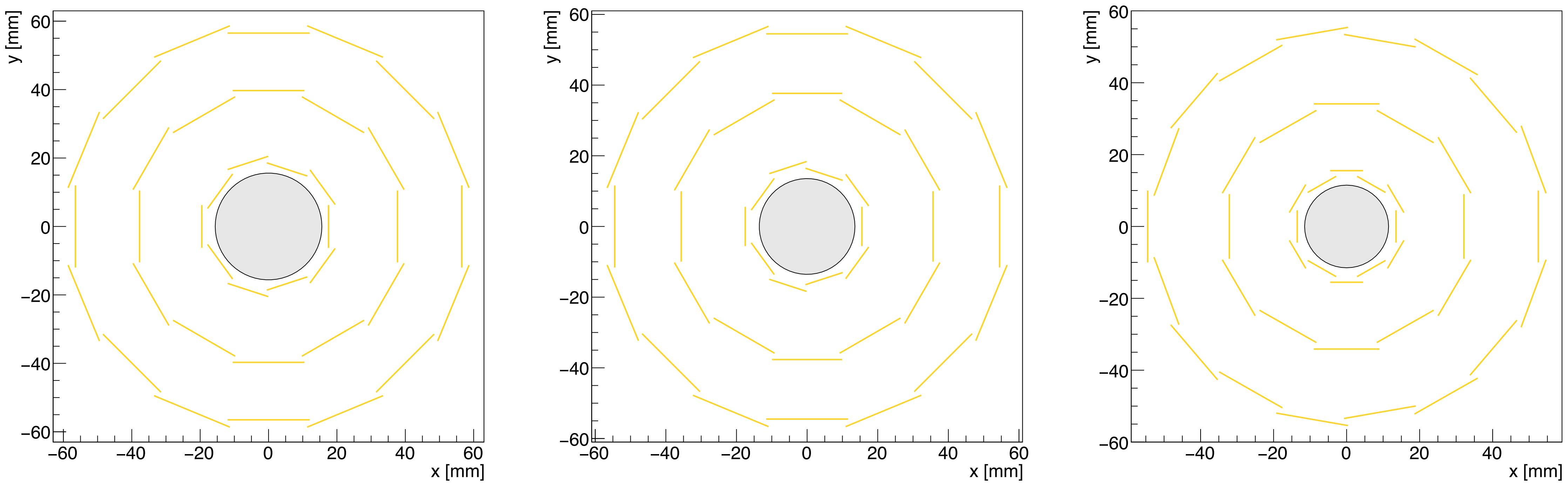


Without material budget

With material budget

Smaller beam pipe radius

Smaller beam pipe radius → Vertex detector closer to the beam



Reference configuration
15-mm beam pipe radius

−2 mm to the beam pipe
and barrel layers radii

−4 mm to the beam pipe
and barrel layers radii

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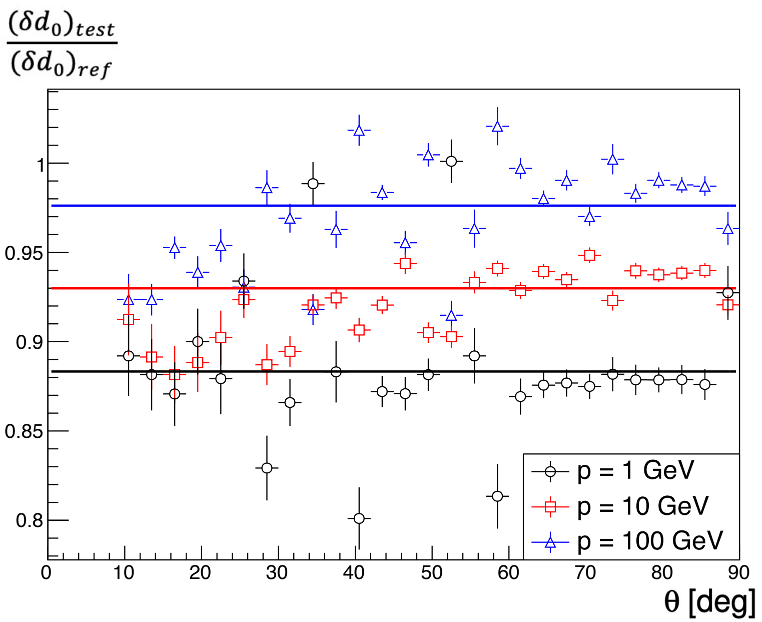
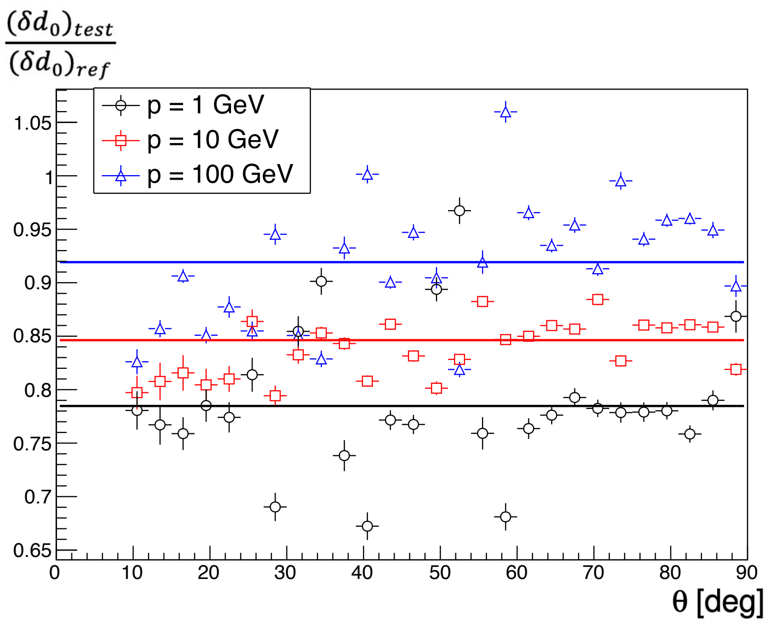
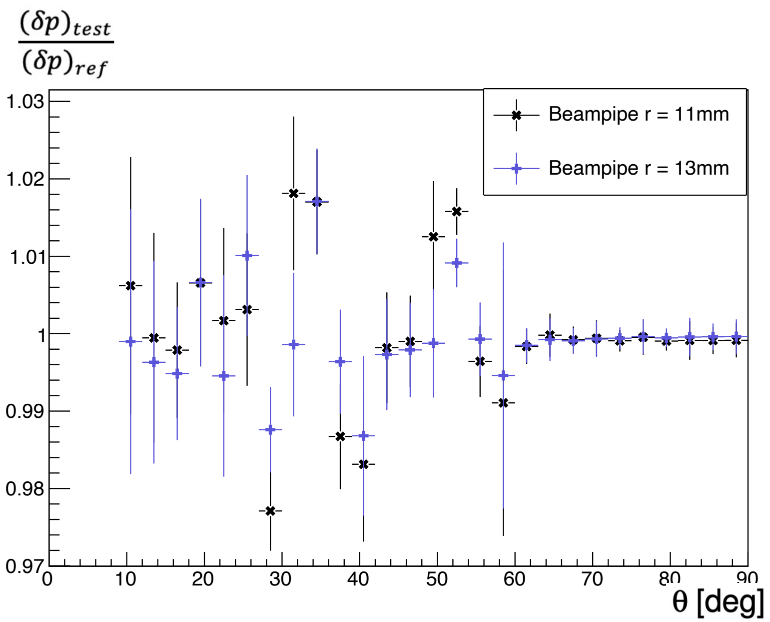
Smaller beam pipe radius



Beam pipe $r = 13$ mm



Beam pipe $r = 11$ mm



$p = 1$ GeV

Reference configuration: $r = 15$ mm

Significant improvements on impact parameter resolution, especially at low momentum

Conclusions

- Design choices are highly dependent on the momentum of the particles whose detection we favor
- For low-momentum particles, reducing the material budget can be very interesting. Ways to achieve this may include lower local resolution or single-layer detectors
- Reducing the beam pipe and vertex detector radii is a promising direction, with some technological prerequisites (ladder width, sensor time resolution…)

Side notes: tkLayout

- Promising tool, fast and modular
- Could benefit from being even more flexible: change of coordinates, plots in ϕ…
- Even some potential as an educational tool, but needs to be better documented and more user-friendly

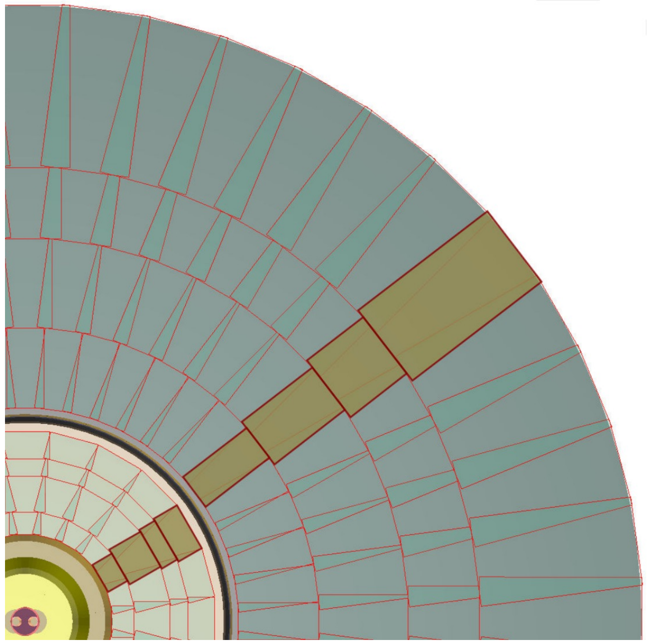
Backup

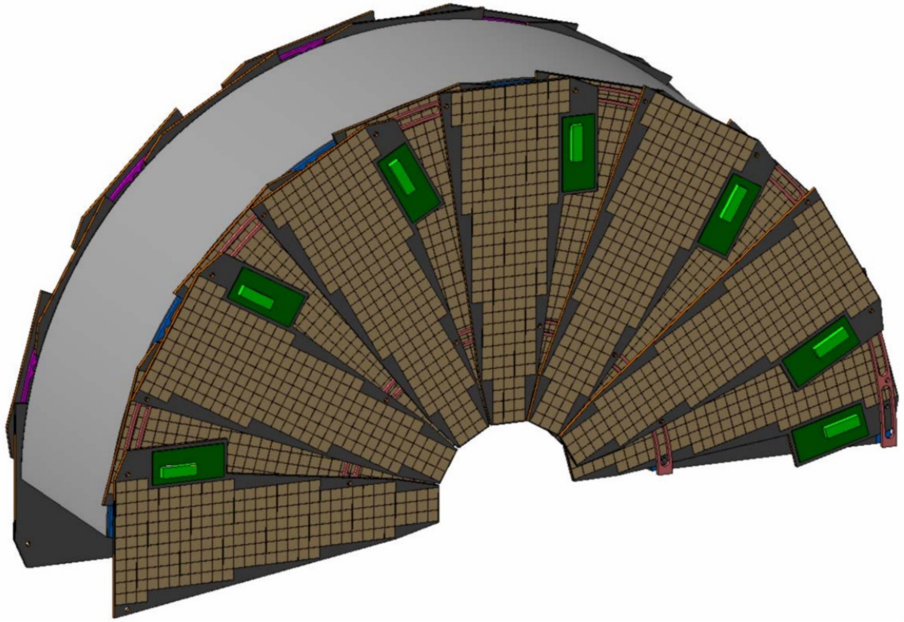
tkLayout CLD configuration file excerpt

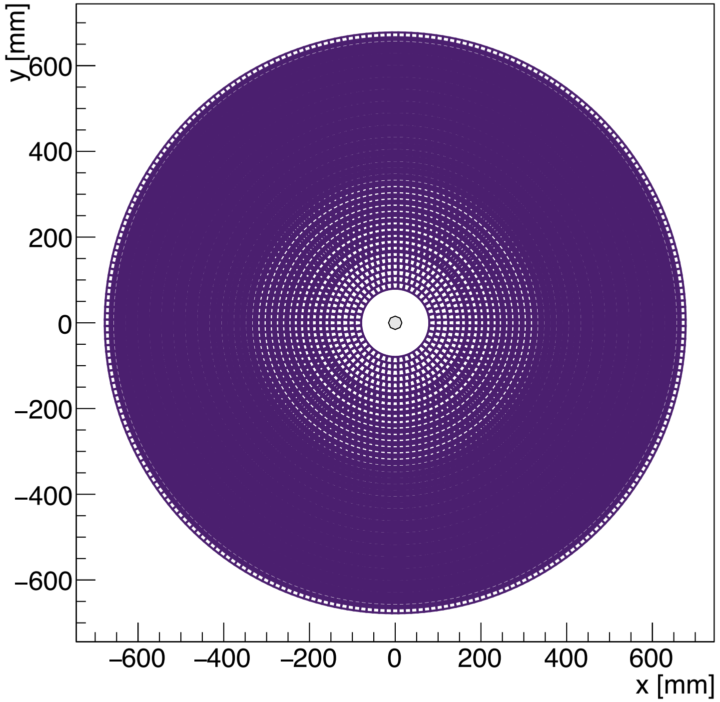
```
@include SimParms

BeamPipe Pipe {
    radius      15.0
    thickness   1.2
    radLength   0.0034014
    intLength   0.0028504
}

Tracker VXD {
    bigDelta 0.0
    smallDelta 0.0
    zOverlap 0.0
    phiOverlap 0.0
    rOverlap 0.0
    etaCut 2.6
    trackingTags VXD,Tracker
    Barrel VXD_B {
        numLayers 3
        @include Pixel_VXD_B.cfg
        @include Material_VXD_B.cfg
        bigDelta 1.0
        innerRadius 17.0
        outerRadius 112.0
        plotColor 3
        outerZ 125.0
        length 12.5
        phiSegments 2
        startZMode moduleedge
        isTilted false
        moduleType VXDPXL
        resolutionLocalX 0.003
        resolutionLocalY 0.003
```

```
         resolutionLocalX 0.003
         resolutionLocalY 0.003
        Layer 1 { radius 18 }
        Layer 2 { radius 37.5 }
        Layer 3 { radius 57.5 }
        Layer 1 {
            width 12.5
            numberRods 10
        }
        Layer 2 {
            width 21
            numberRods 12
        }
        Layer 3 {
            width 24
            numberRods 16
        }
    }
    Endcap VXD_D {
        @include Pixel_VXD_D.cfg
        @include Material_VXD_D.cfg
        bigDelta 0.5
        smallDelta 0.5
        numDisks 3
        plotColor 4
        phiSegments 12
        innerZ 160
        outerZ 300
        outerRadius 101
        moduleShape wedge
        moduleType VXDPXL
        resolutionLocalX 0.003
        resolutionLocalY 0.003
        Disk 1 {
            innerRadius 24
                Ring 1 {
                        waferDiameter 19
                }
                Ring 2 {
```

Disc designs

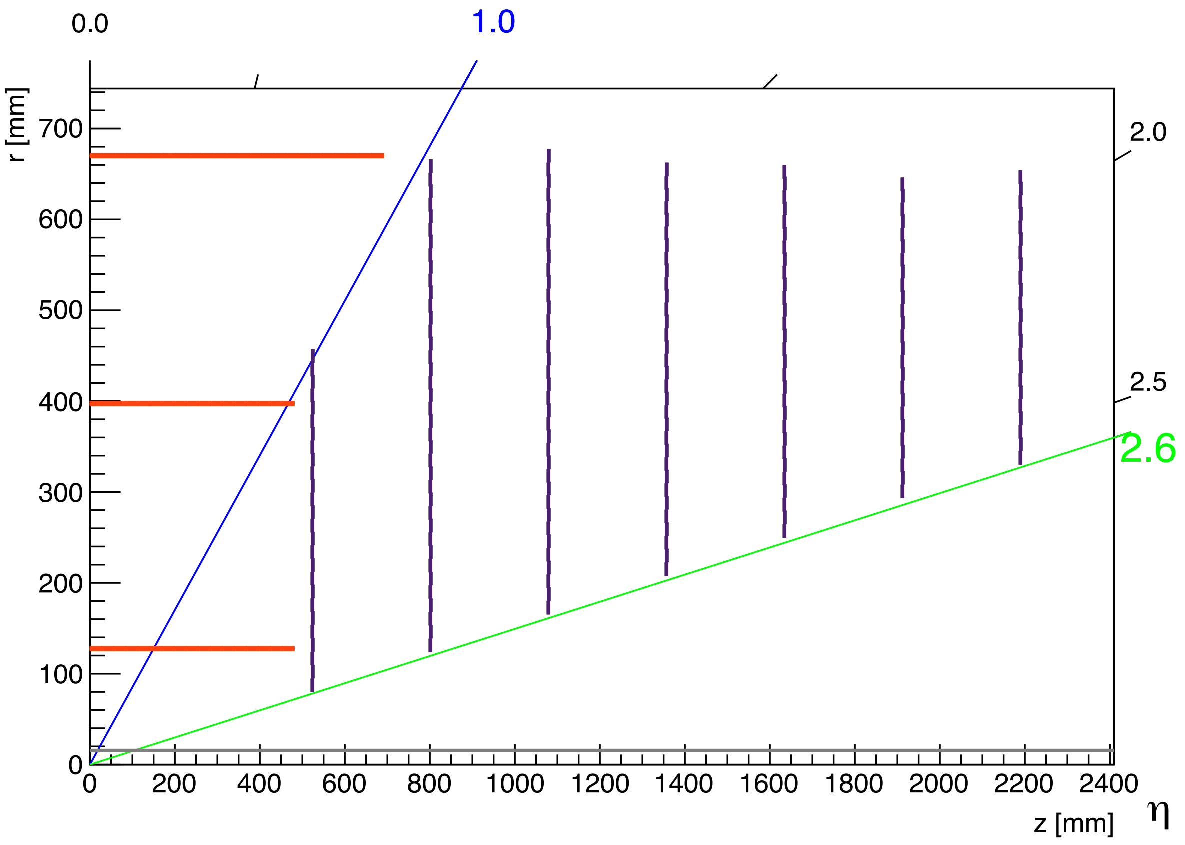






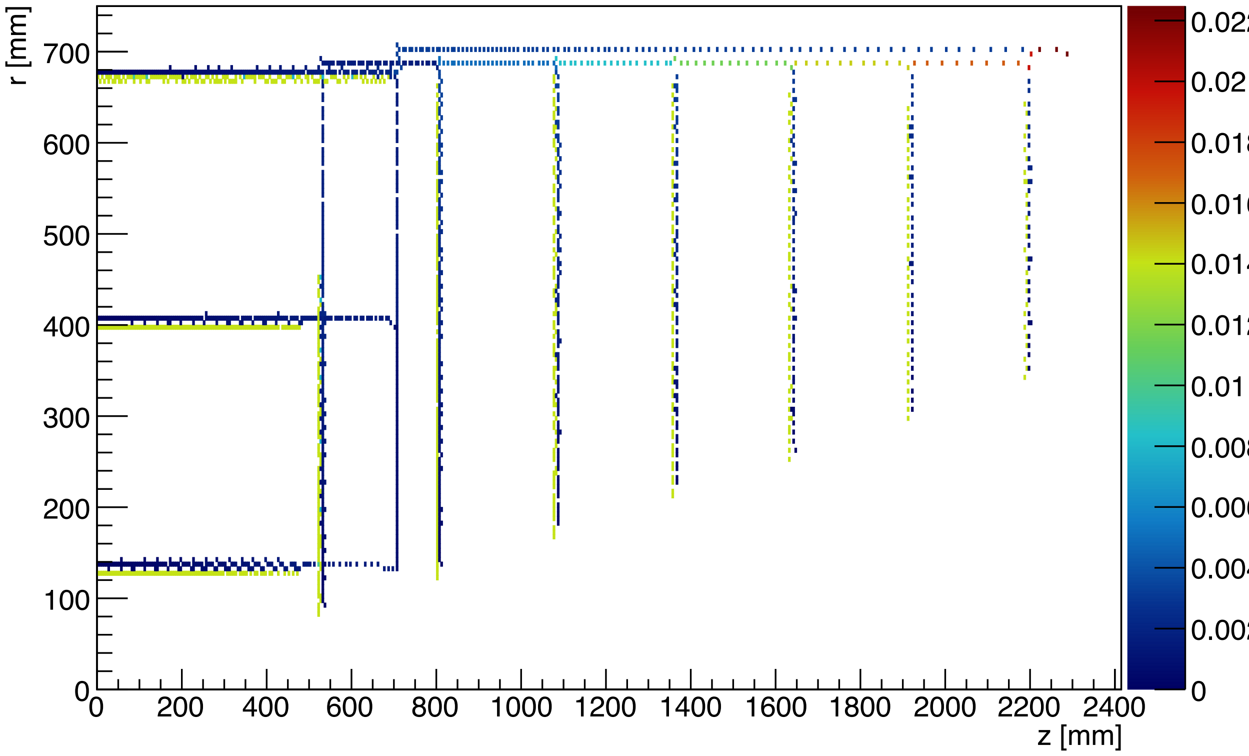
Disc designs found in the literature *VS* Design implemented in tkLayout

Cable mapping



Inner Tracker layout

IT Radiation length map



Inner Tracker radiation map with cable mapping appearing

Error Propagation

General formula: $f = \frac{A}{B}$ $\qquad \sigma_f = \sqrt{\left(\frac{\Delta A}{B}\right)^2 + \left(\frac{A \Delta B}{B^2}\right)^2}$

$$\sigma_{d_0} = \sqrt{\left(\frac{\Delta \delta d_{0_{test}}}{\delta d_{0_{ref}}}\right)^2 + \left(\frac{(\delta d_{0_{test}})(\Delta \delta d_{0_{ref}})}{(\delta d_{0_{ref}})^2}\right)^2}$$

$$\sigma_p = \sqrt{\left(\frac{\Delta \delta p_{test}}{\delta p_{ref}}\right)^2 + \left(\frac{(\delta p_{test})(\Delta \delta p_{ref})}{(\delta p_{ref})^2}\right)^2}$$