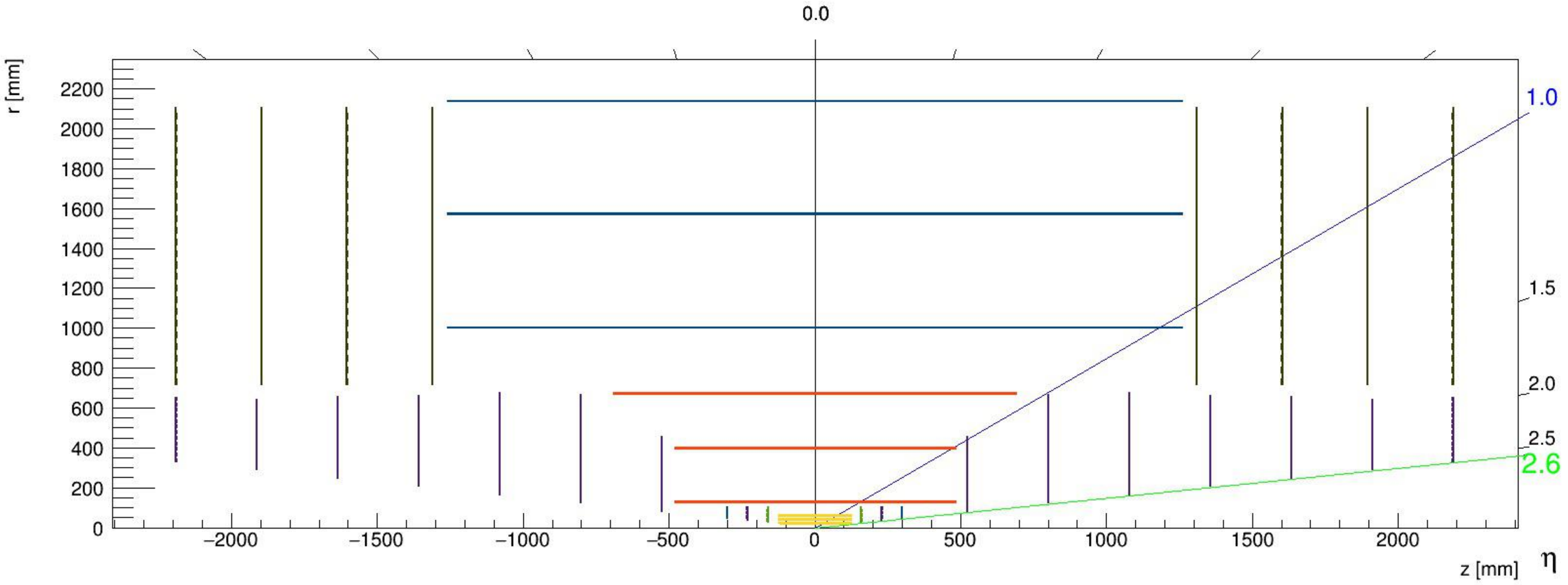
Faculté de physique et ingénierie
Université de Strasbourg

master Physique Subatomique Astroparticules

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



Nathan LORBER

under the supervision of

Jeremy ANDREA

Auguste BESSON

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

CNRS

An heir to the LHC/LEP

Large Electron-Positron Collider (1989-2000)

- 27 km diameter
- Up to 209 GeV

Large Hadron Collider (2009-present)

- 27 km diameter
- 13 TeV

Motivations for future colliders

- Study the Higgs Boson
- Search for dark matter
- Test supersymmetry models
- Study Z/W bosons, top quarks…

Some candidates

International Linear Collider

- 30-50 km long
- 250 GeV (baseline) 1 TeV (upgrades)

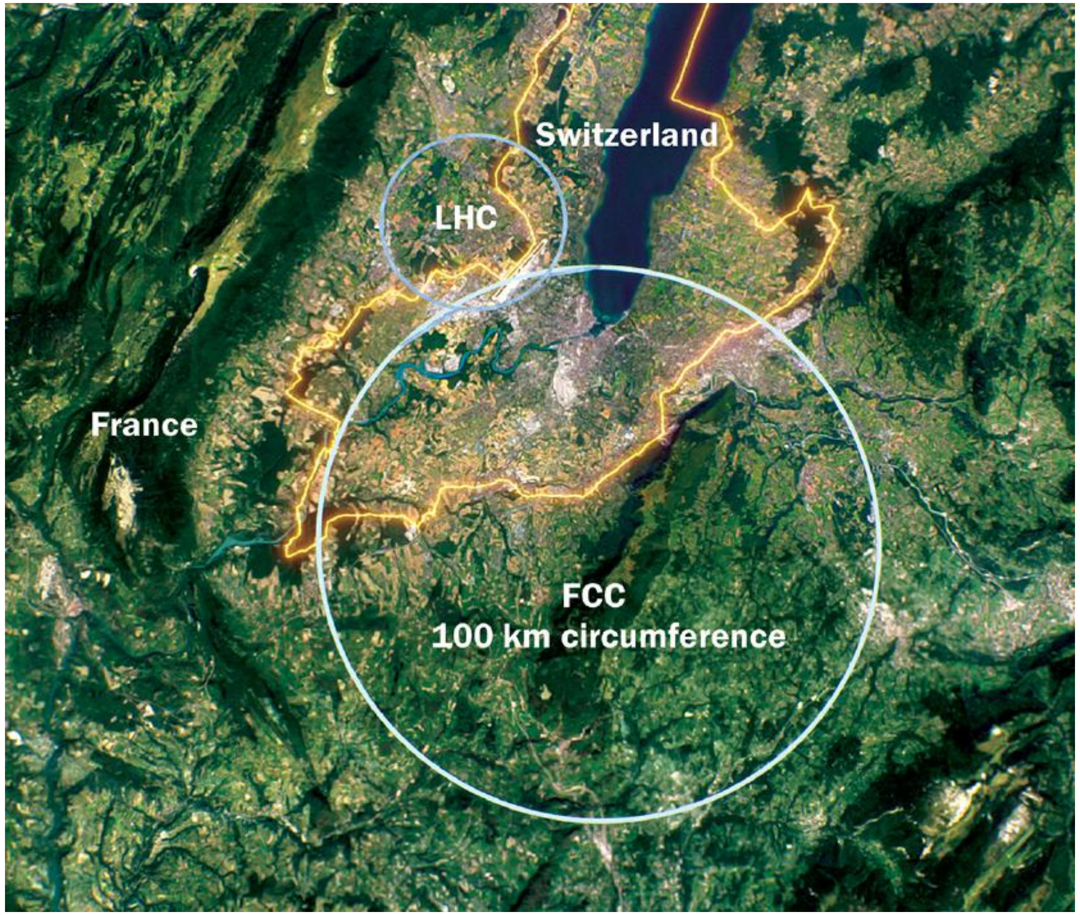
Compact Linear Collider

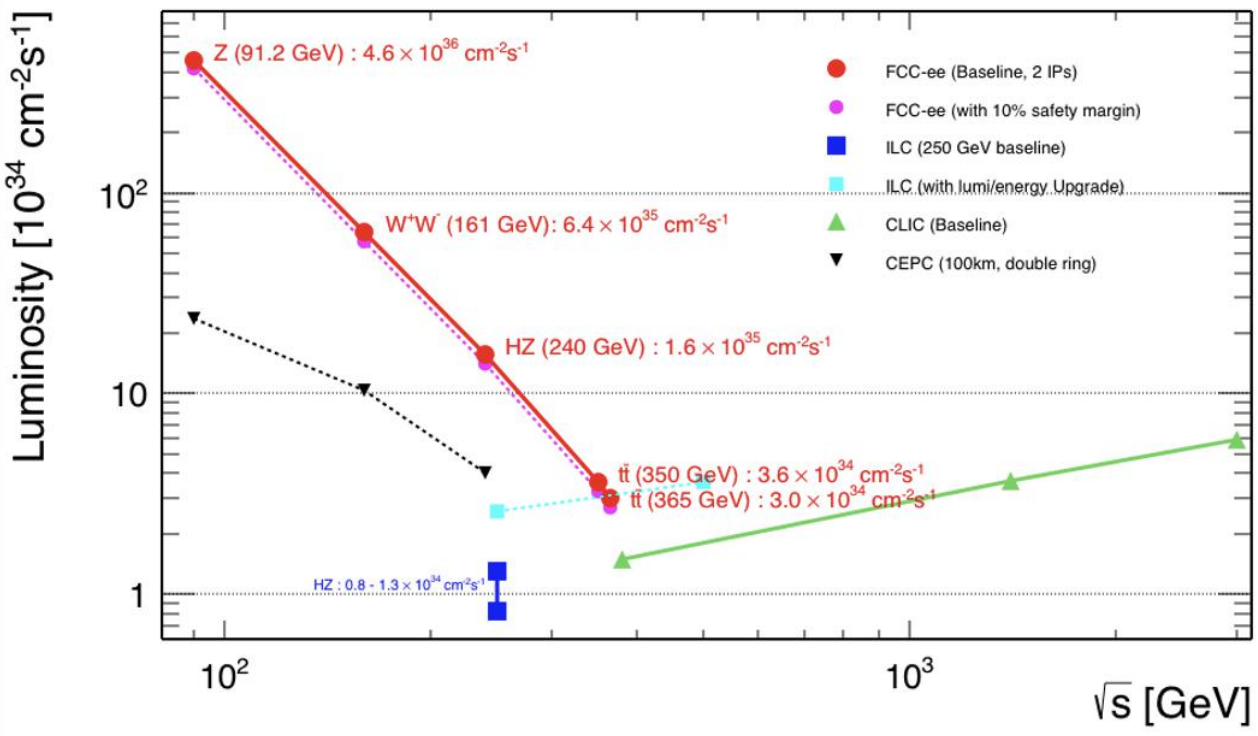
- 11-30 km long
- 380 GeV - 3 TeV

Future Circular Collider

- 80-100 km diameter
- Up to 365 GeV (ee) 100 TeV (hh)

FCC-ee


Switzerland
LHC
France
FCC
100 km circumference


Luminosity [10^{34} cm^{-2}s^{-1}]
$\sqrt{s}$ [GeV]
Z (91.2 GeV) : 4.6×10^{36} cm^{-2}s^{-1}
W$^+$W$^-$ (161 GeV): 6.4×10^{35} cm^{-2}s^{-1}
HZ (240 GeV) : 1.6×10^{35} cm^{-2}s^{-1}
$t\bar{t}$ (350 GeV) : 3.6×10^{34} cm^{-2}s^{-1}
$t\bar{t}$ (365 GeV) : 3.0×10^{34} cm^{-2}s^{-1}
HZ : 0.8 - 1.3×10^{34} cm^{-2}s^{-1}
FCC-ee (Baseline, 2 IPs)
FCC-ee (with 10% safety margin)
ILC (250 GeV baseline)
ILC (with lumi/energy Upgrade)
CLIC (Baseline)
CEPC (100km, double ring)

FCC-ee

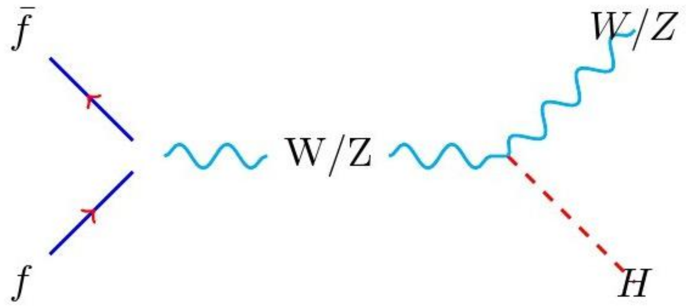
Synchrotron radiation

$$\Delta E \propto \frac{E^4}{m^4 R}$$ → Lower energy cap, BUT:

Circular collider → High luminosity

e+e- collision → Good knowledge of initial states

→ Clean production channels (no hadronic background noise) Ex: Higgs Strahlung



Good event reconstruction, provided that we have an efficient tracker →

- First subdetector on the particle's path
- Reconstructs trajectories of charged particles (tracks) and determine their momentum (thanks to $\vec{B}$)
- Essential to do track fitting and associate with hits in the following subdetectors

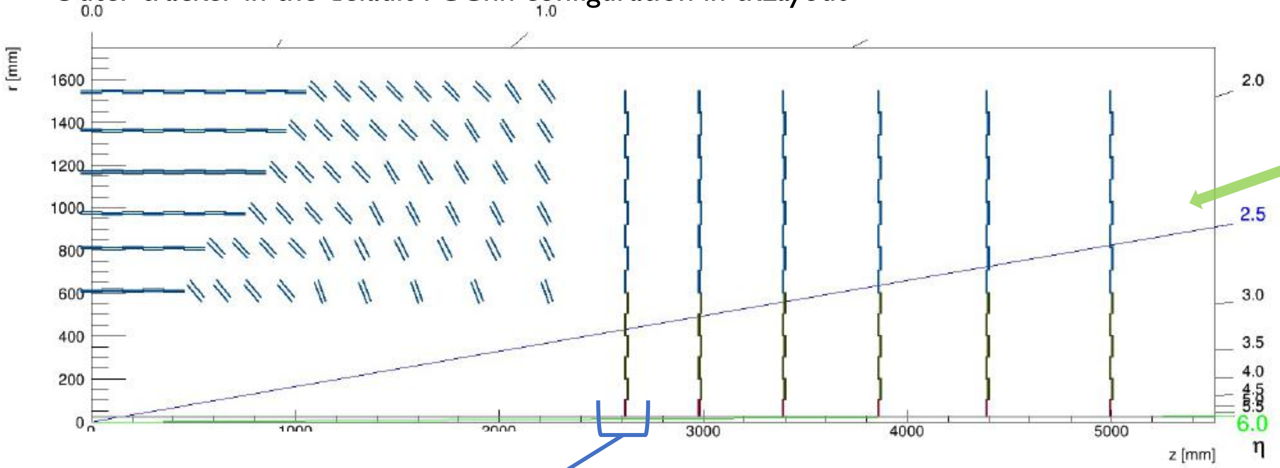
Goal of this internship: to explore elements of tracker configuration optimization for the FCCee

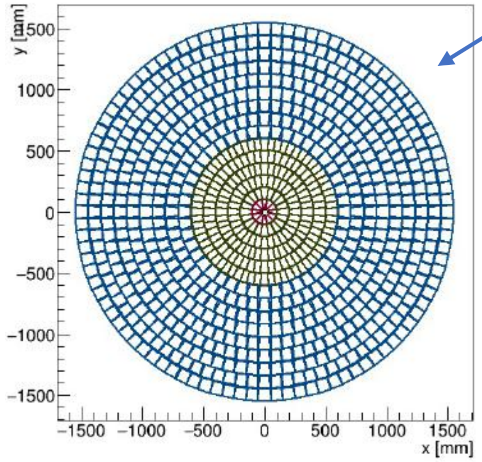
Faculté de physique et ingénierie
Université de Strasbourg

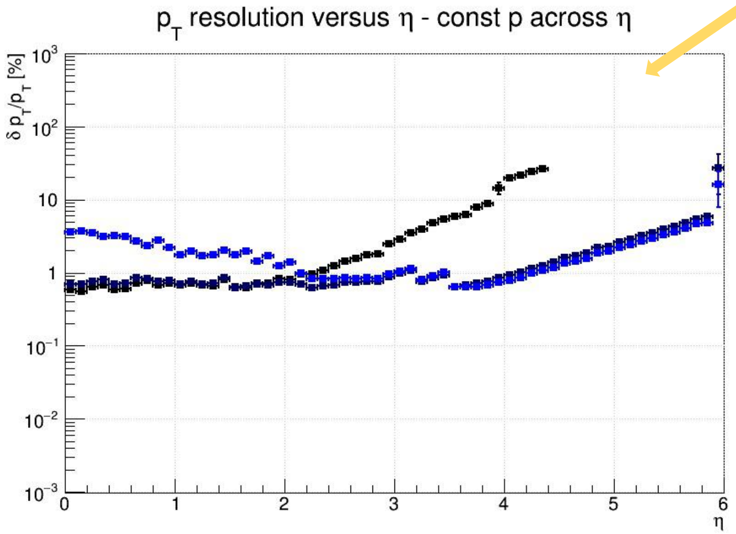
master PSA
Physique Subatomique Astroparticules

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

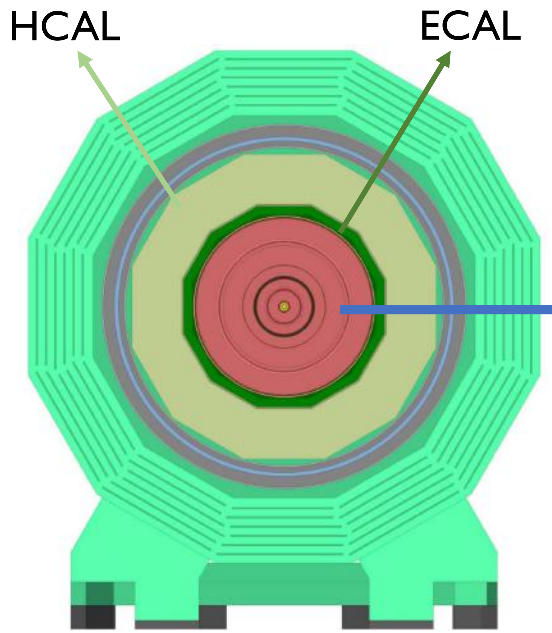
- ▪ Simulation parameters
- ▪ Beam pipe parameters
- ▪ Tracker 1
  - Barrel (one or more layers)
  - Endcap (one or morel disks)
- ▪ Tracker 2
  - …

(example in backup)

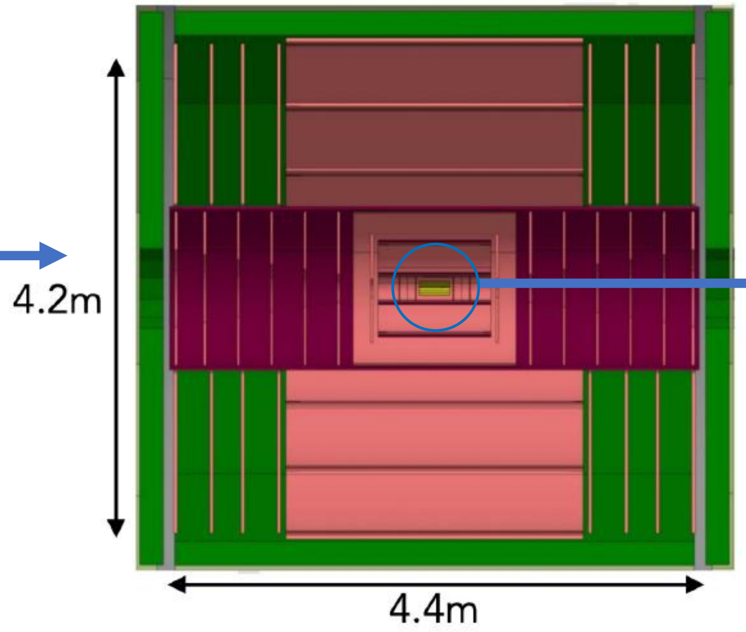
IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

CNRS

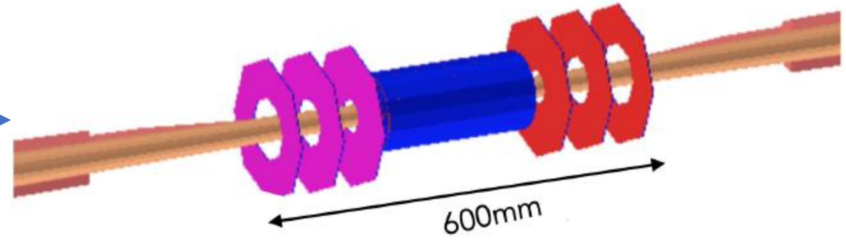
A reference tracker: CLD



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

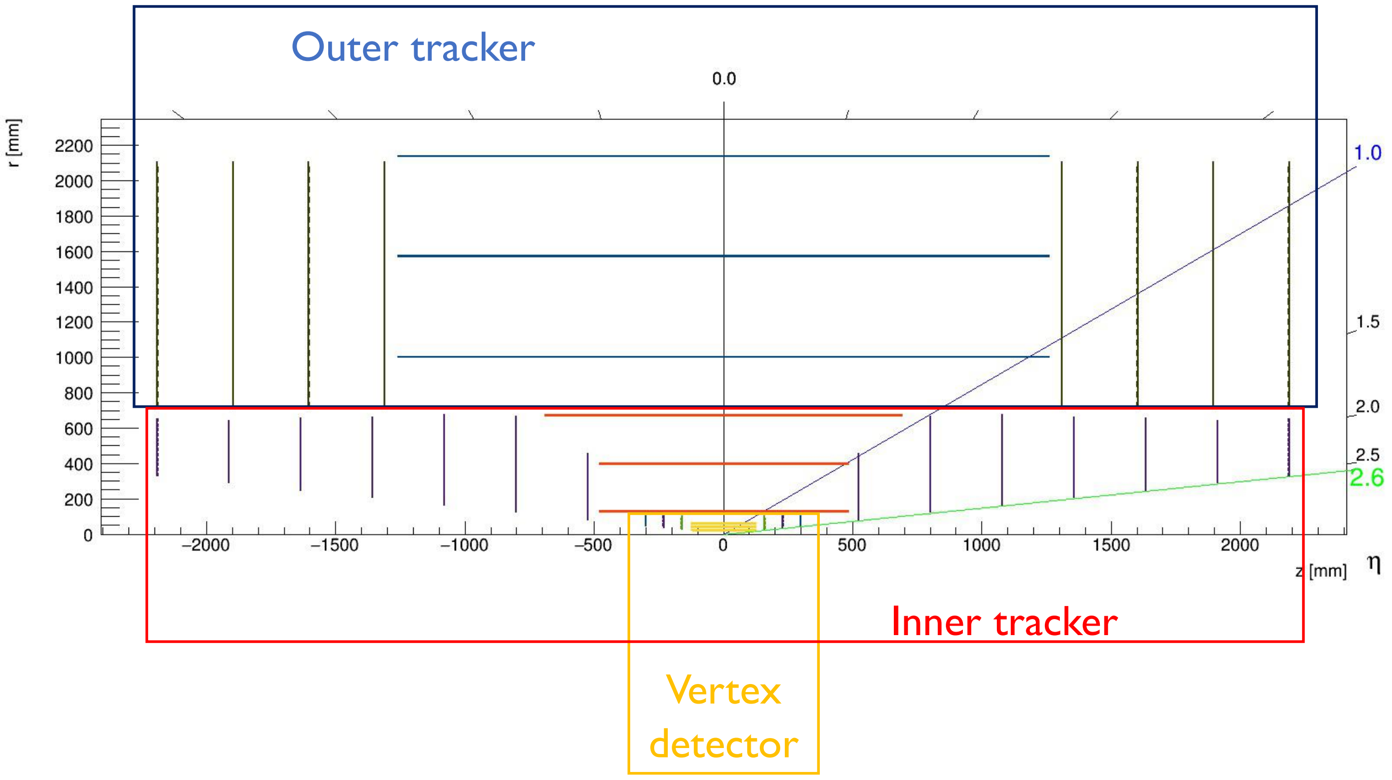


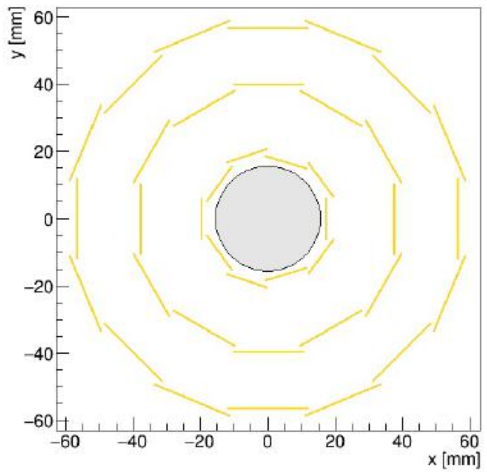
Tracking system
(z, r) plane

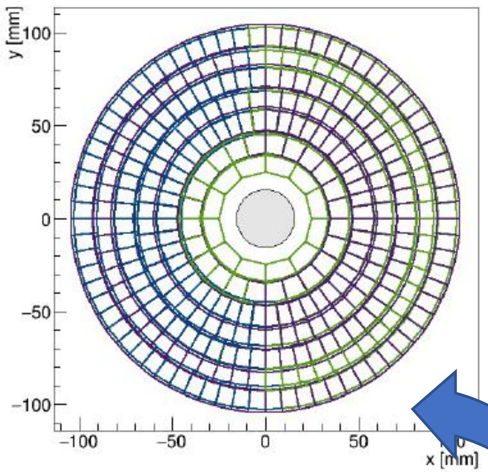


Vertex detector (VXD)
and beam pipe
Isometric view

A reference tracker: CLD





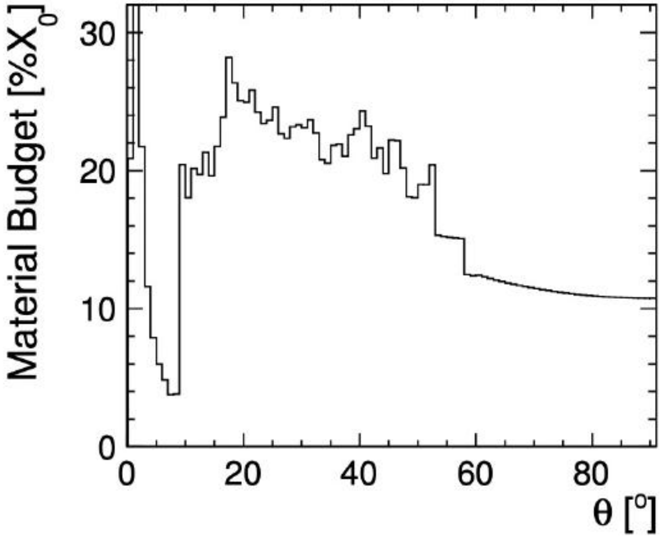


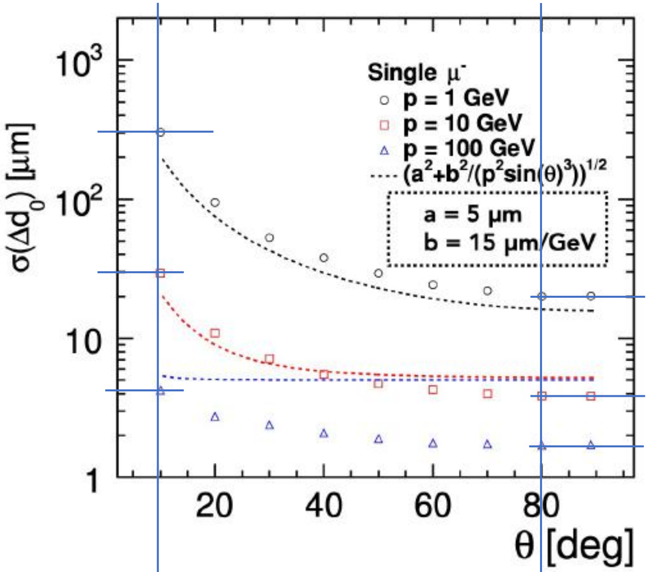
Tweaks:

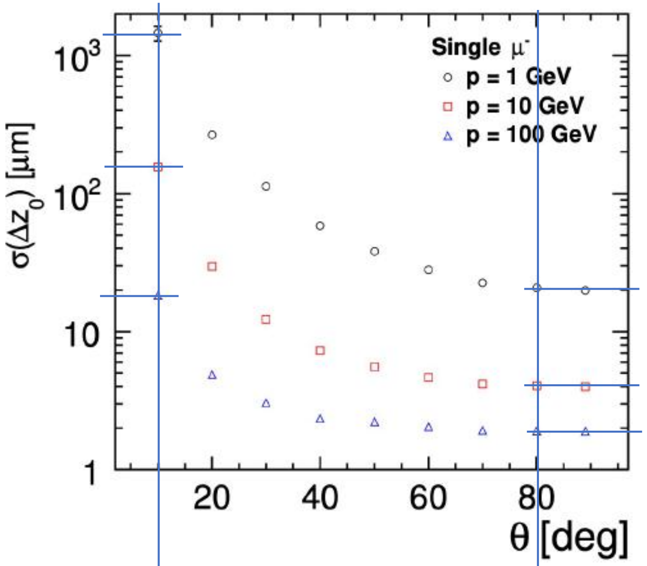
- First layer of vertex detector barrel: fewer, wider ladders
- Disc modules shape: symmetrically distributed square and trapezoidal modules
- Material budget implementation: averaged by layer and implemented as Si-equivalent on modules

A reference tracker: CLD

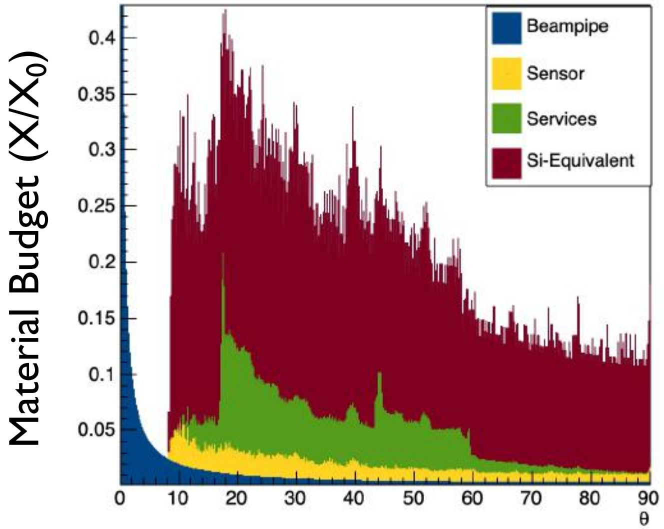
Projections in the literature

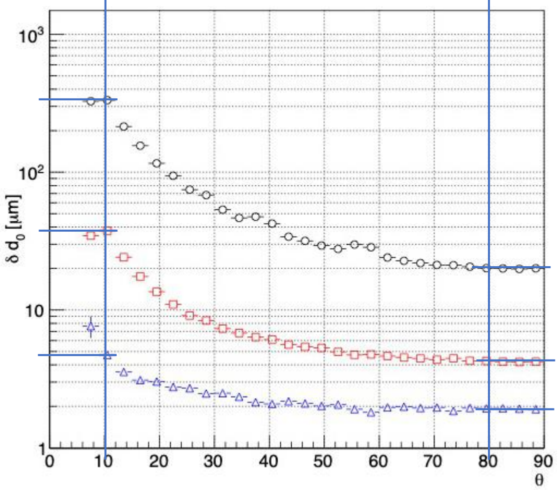


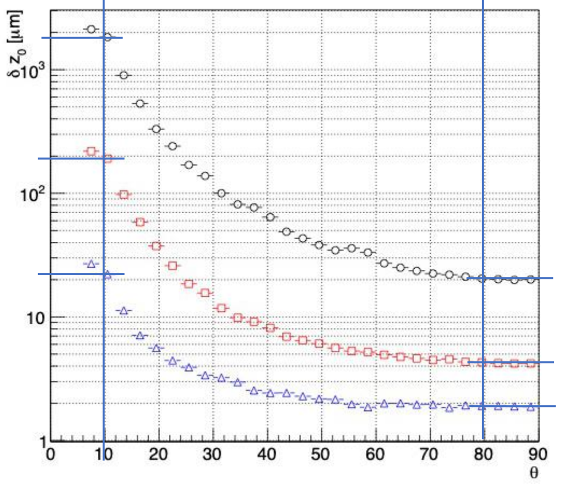




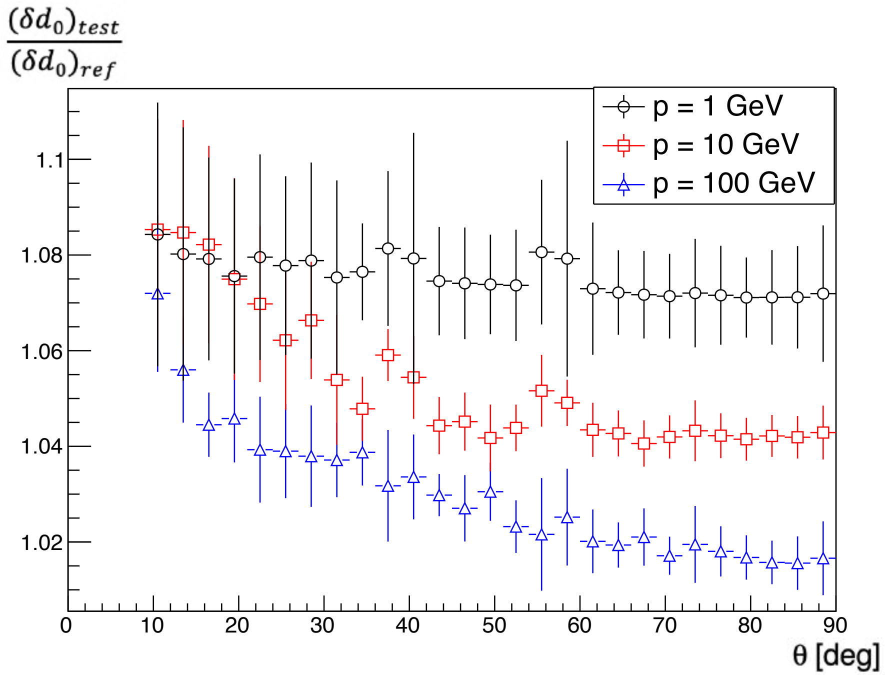
tkLayout results

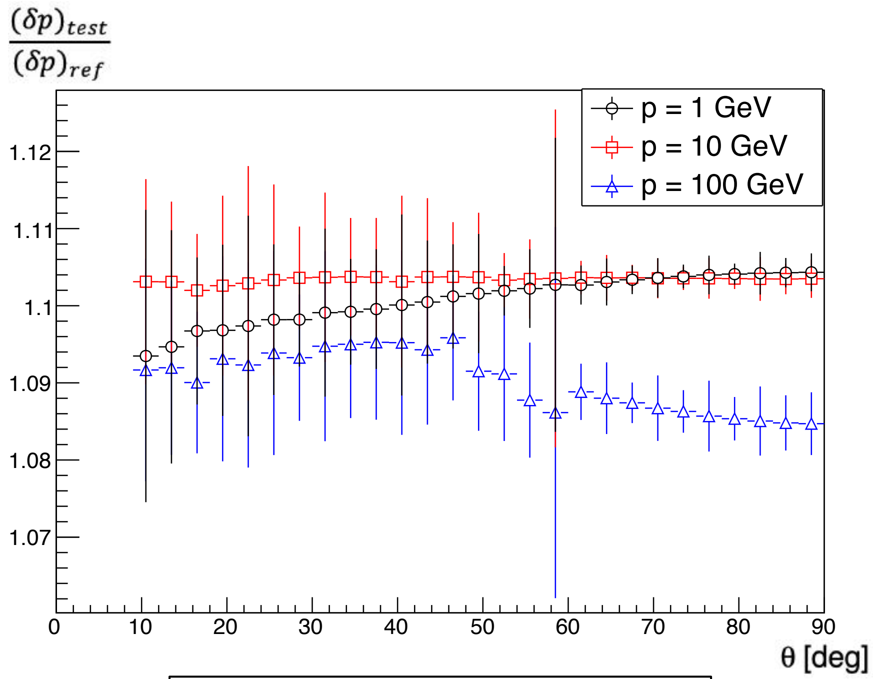






+20% material budget (sensors, cooling, support…)





Affects low p more than high p

Ratio of resolutions:

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

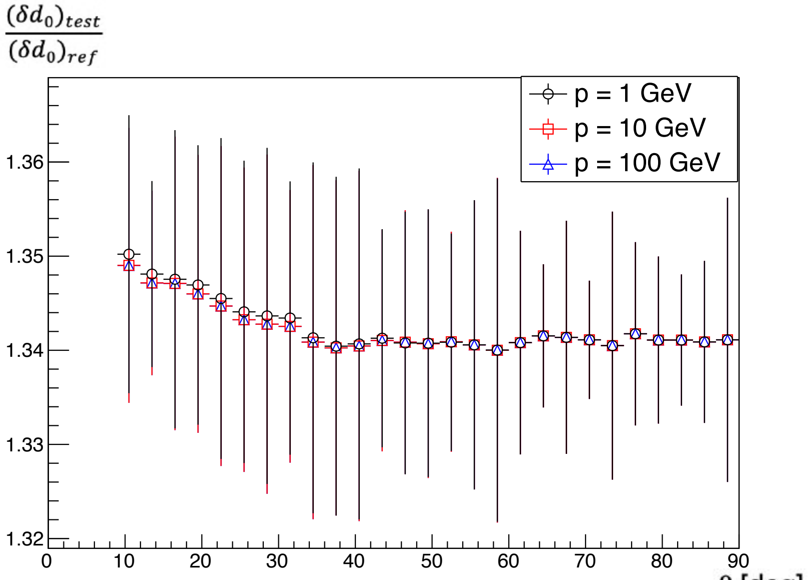
$$y(\theta) = \left(\frac{\delta p}{p}\right)_{test} \div \left(\frac{\delta p}{p}\right)_{ref}$$

Error margins:

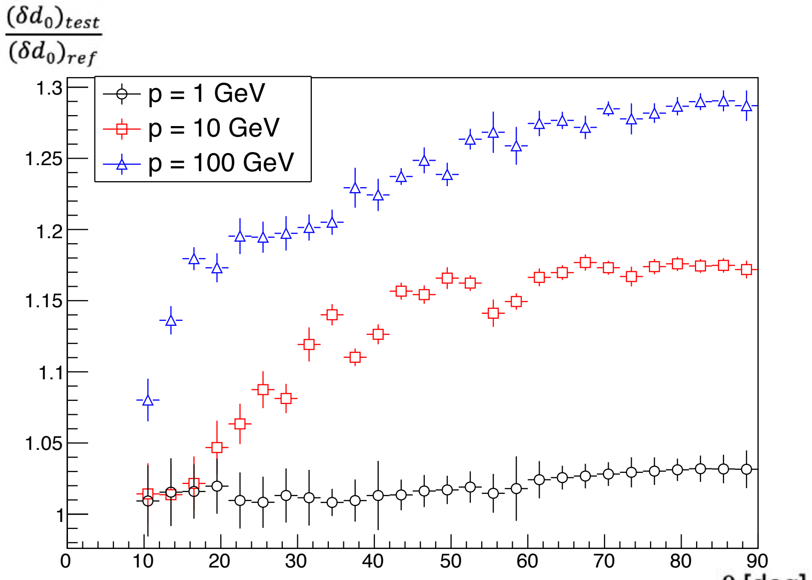
- Calculated without correlation (formula in backup)
- Driven down statically with numerous tracks
- Persistent → correlation between runs, worth further exploring

Lowering the local resolution

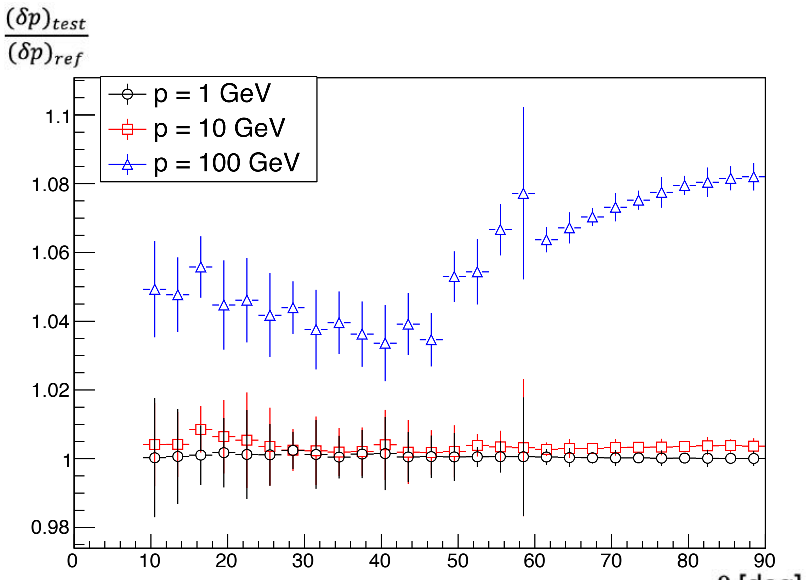
	Reference local resolution (μm^2)	Local resolution tested (μm^2)
Vertex Detector	3×3	4×4
Inner Tracker	4×4	7×7
Outer Tracker	4×4	7×7



Transverse impact parameter
Without material budget



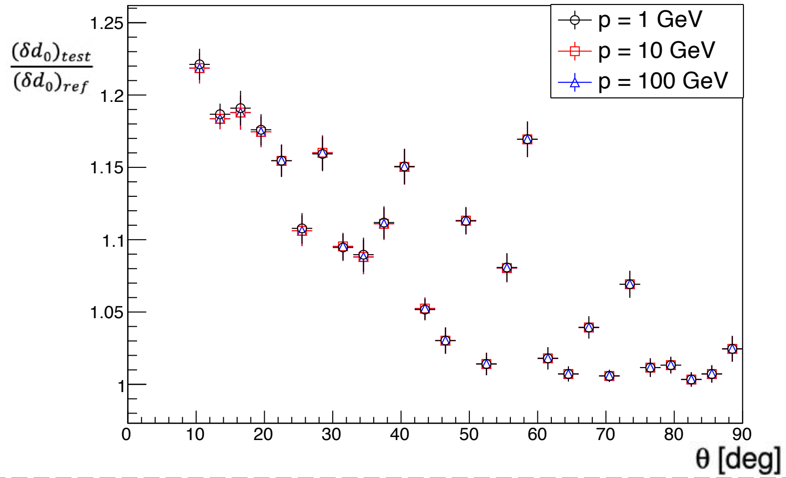
Transverse impact parameter
With material budget

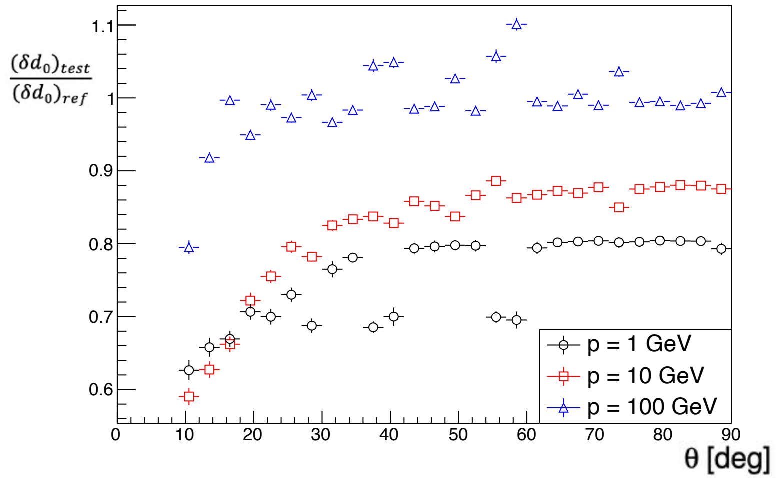


Momentum

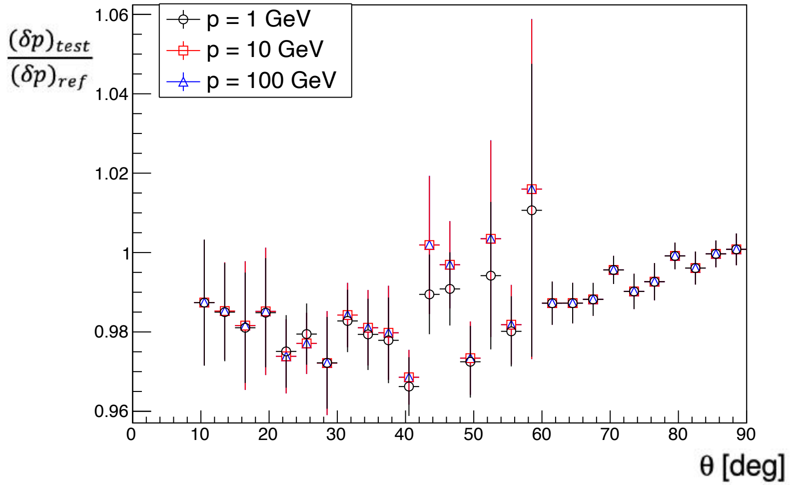
Single-layer vertex detector or double-layer trackers

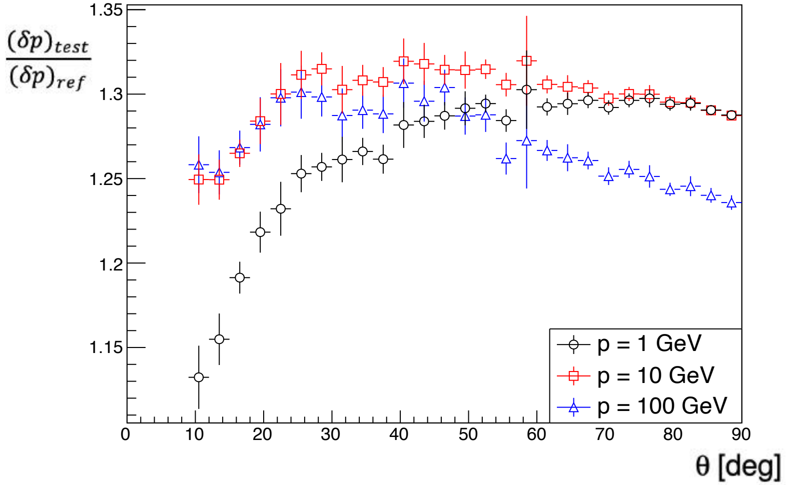
Single-layer vertex detector
&
−48% material budget
in the VXD





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



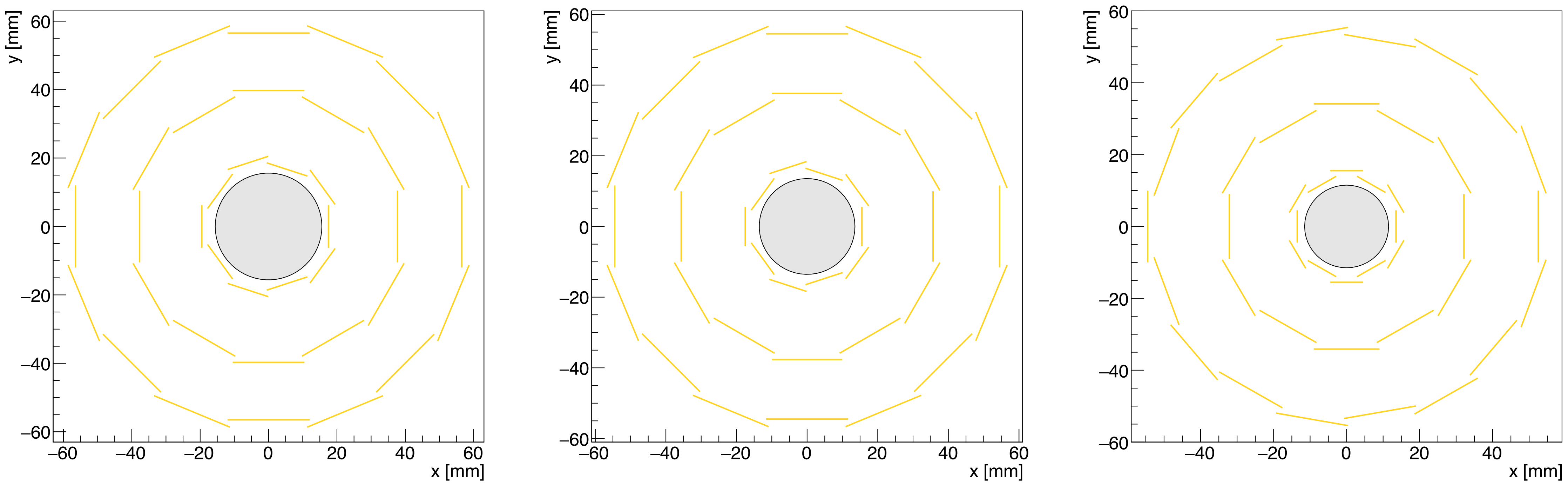


Without material budget

With material budget

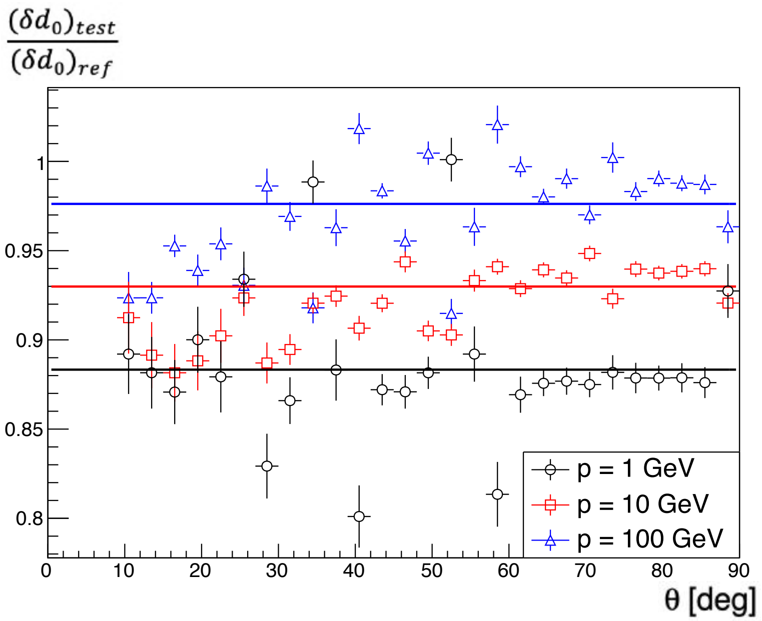
Smaller beam pipe radius

Smaller beam pipe radius → Vertex detector closer to the beam

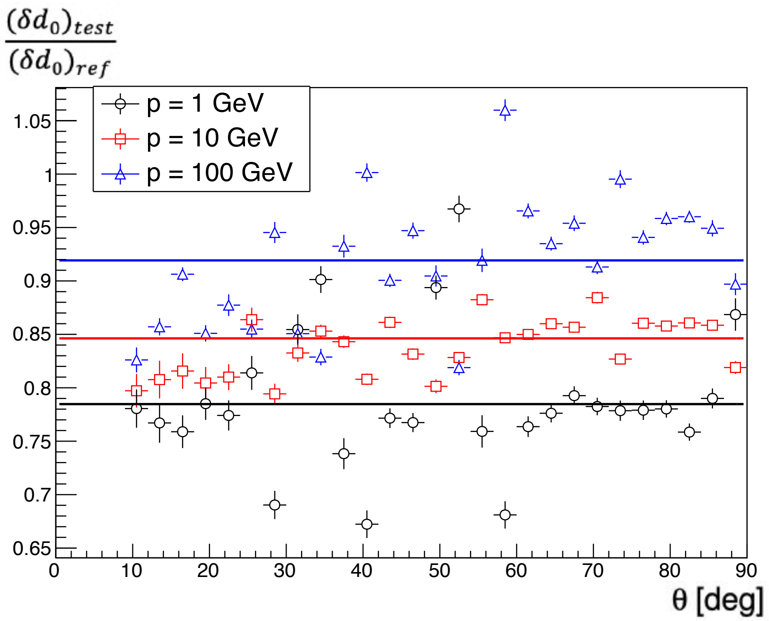


Reference configuration 15-mm beam pipe radius	−2 mm to the beam pipe and barrel layers radii	−4 mm to the beam pipe and barrel layers radii

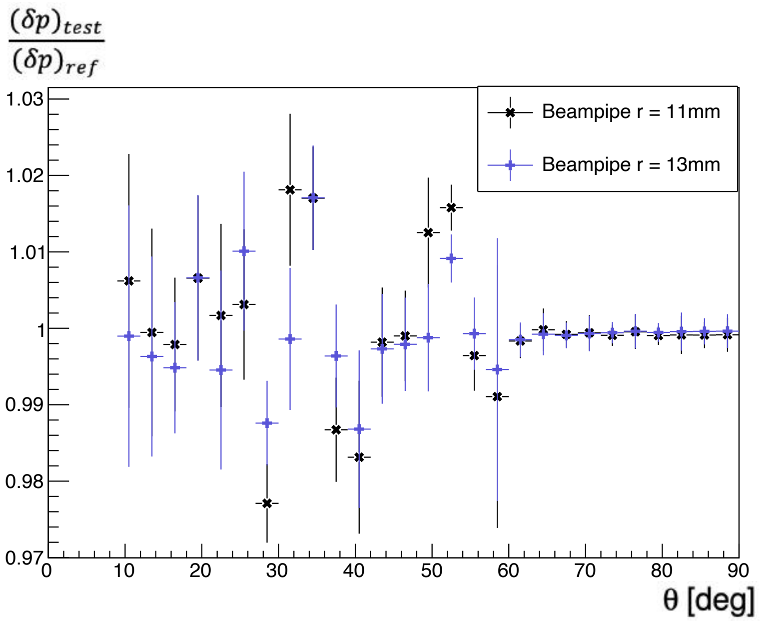
Smaller beam pipe radius



Beam pipe $r = 13$ mm



Beam pipe $r = 11$ mm



$p = 1$ GeV

Reference configuration: $r = 15$ mm

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

Faculté
de physique et ingénierie
Université de Strasbourg

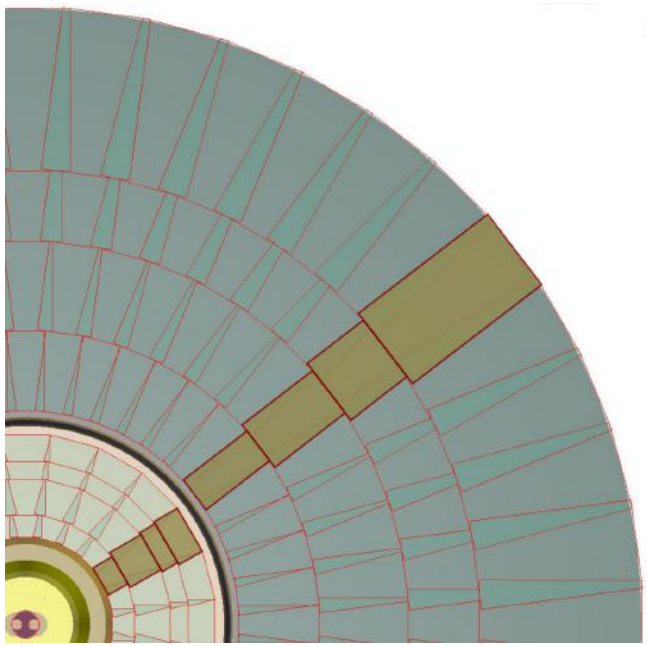
tkLayout CLD configuration file excerpt

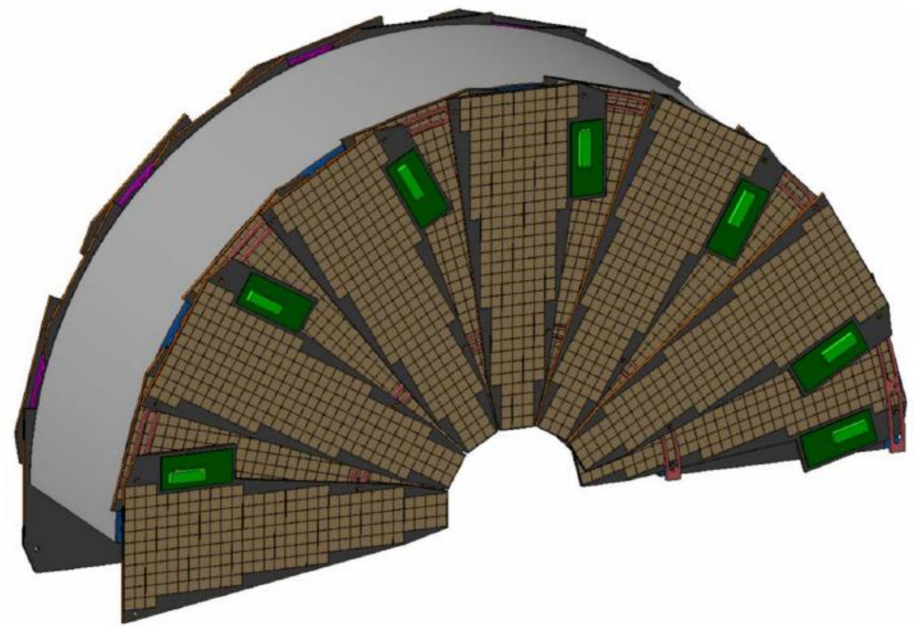
```
@include SimParms

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
```

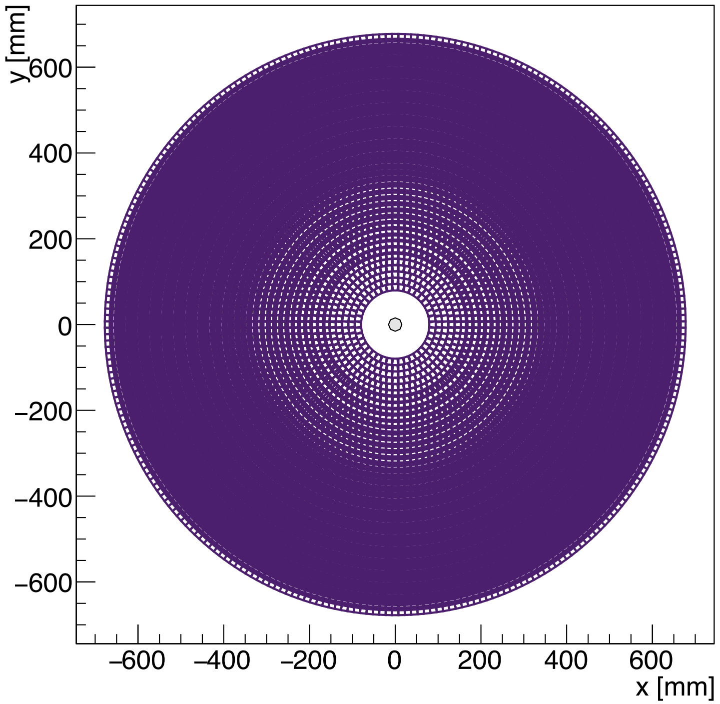
```
        resolutionLocalX 0.003
        resolutionLocalY 0.003
        Layer 1 { radius 18 }
        Layer 2 { radius 37.5 }
        Layer 3 { radius 57.5 }
        Layer 1 {
            width 12.5
            numberRods 10
        }
        Layer 2 {
            width 21
            numberRods 12
        }
        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 {
```

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

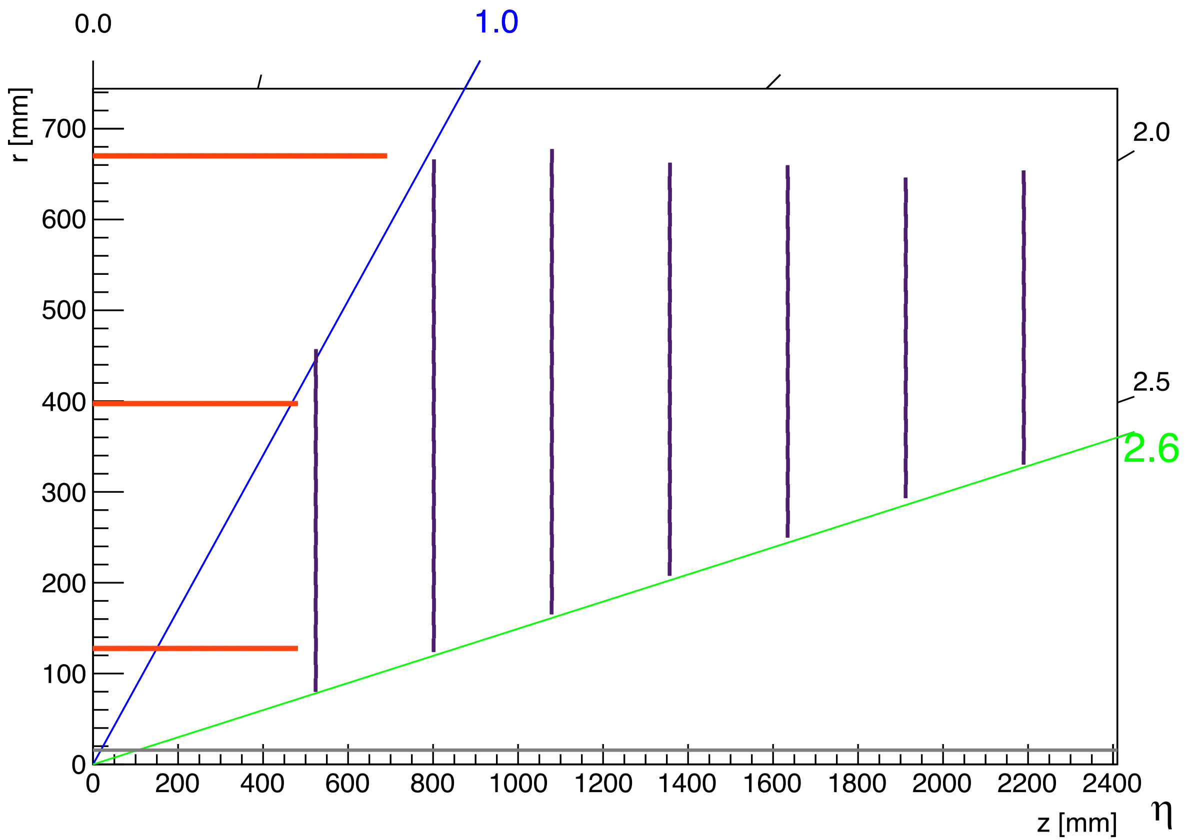
Disc designs

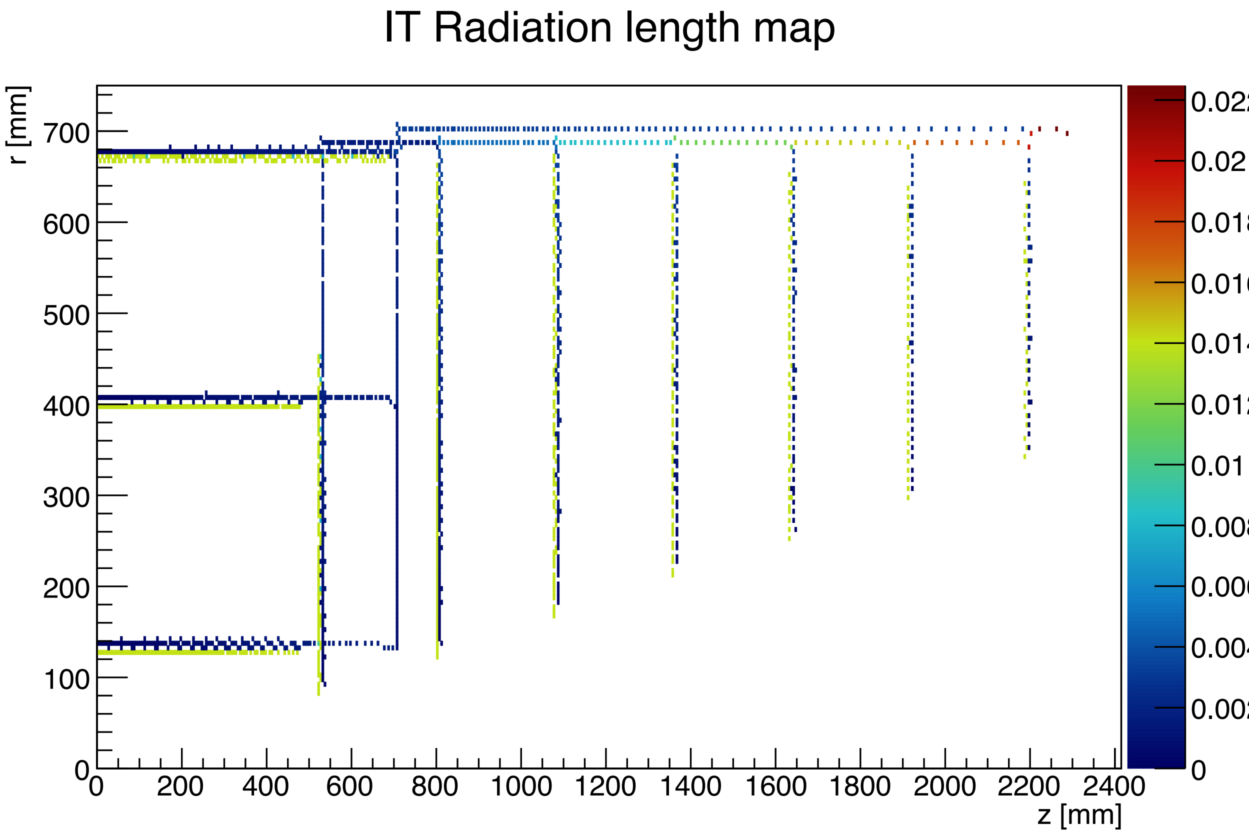






Cable mapping





Error Propagation

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

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

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