UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

University of Birmingham EICROOT simulation effort

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Introduction

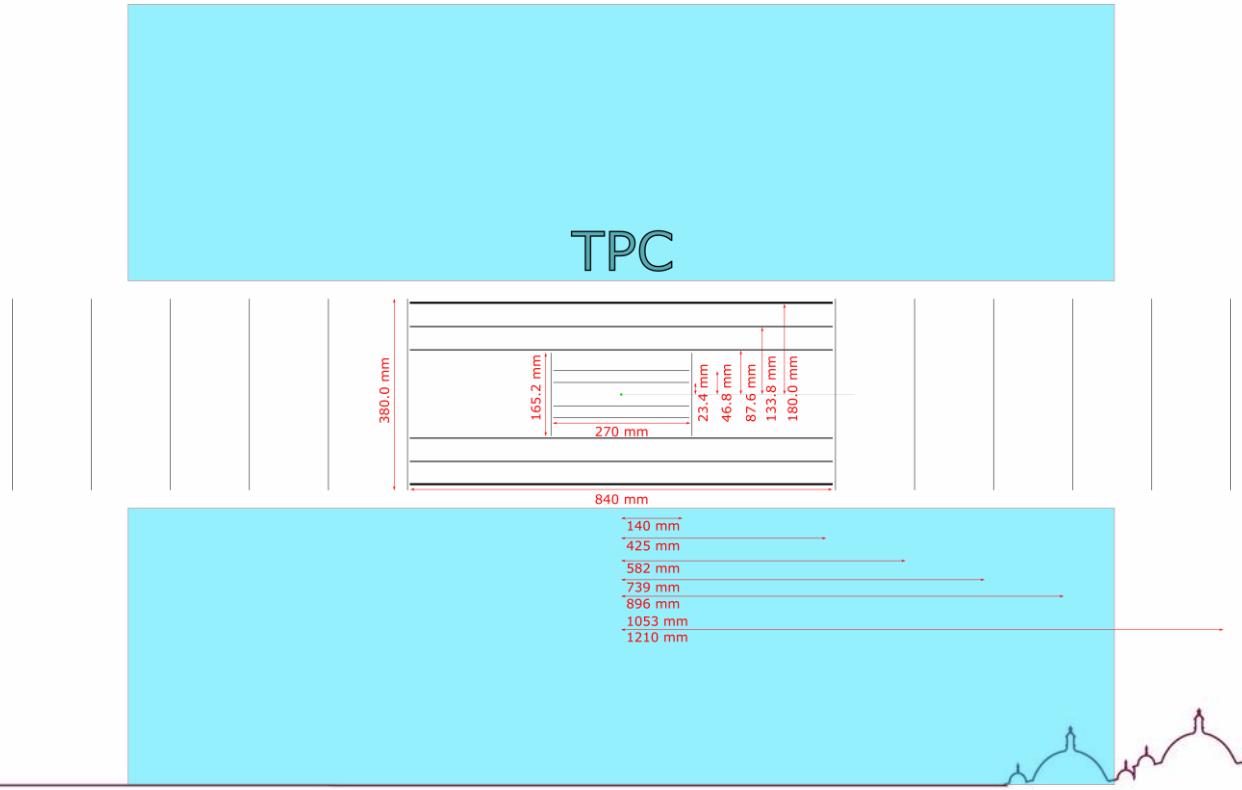
- Baseline performance studies for both the central and forward regions of a Si+TPC and an all-Si tracker design
- Studies have covered:
  - Central region (i.e. barrel)
  - Forward/backward regions (i.e. disks)
  - Interface region between barrel and disks
  - Si+TPC compared to all-silicon
- Figures of merit for studies:
  - Relative momentum resolution
  - Transverse and longitudinal pointing resolutions
- Highlights covered in this talk. Details available in full report

Full report: Simulations of a silicon vertex tracker for a future EIC http://cern.ch/go/xKk6

Contents

Silicon vertex tracker + TPC: baseline layout

- Sketch of the simulated silicon vertex tracker, with surrounding TPC
  - The beampipe runs through the centre of the detector, but is not shown in the figure
  - 5 barrel layers, 7 disks per side
  - TPC inner/outer radius: 225/775 mm
  - TPC length = 1960 mm



Simulation parameters used

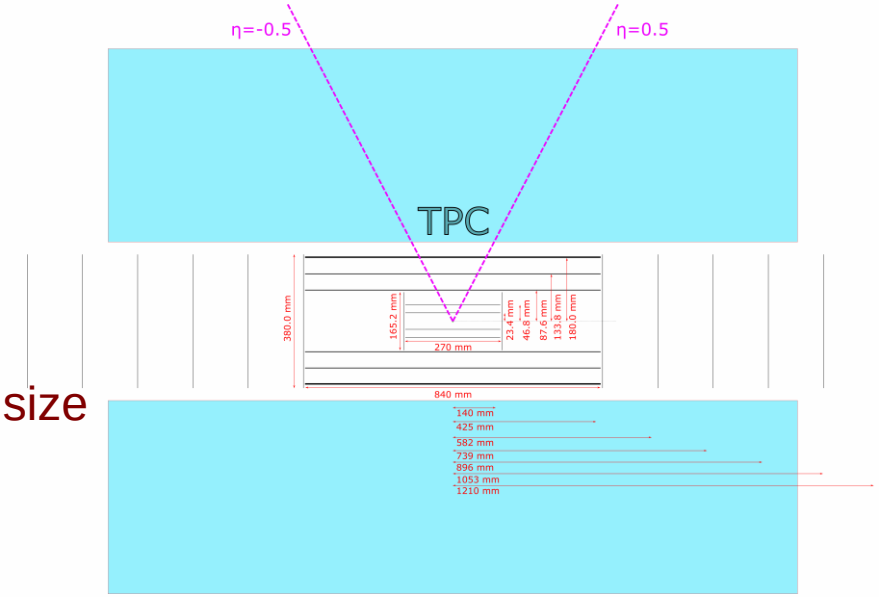
- Starting point: BeAST tracker
  - Radii of barrel layers adjusted to be consistent with ALICE ITS distances between layers (minimum distance between outer layers is 46.2 mm)

- Beampipe
  - 18 mm radius in central region (±400 mm), 0.8 mm thick beryllium
  - 20 mm radius aluminium further out

- TPC parametrisation default EICROOT one (conservative):
  - Transverse dispersion : 15.00 μm/√D[cm]
  - Transverse intrinsic resolution : 200.00 μm
  - Longitudinal dispersion : 1.00 μm/√D[cm]
  - Longitudinal intrinsic resolution: 500.00 μm
  - Vertical pad size : 0.50 cm

Barrel simulations

- Five layers
  - Two inner, two outer + time-stamping layer (see details on slide 7)



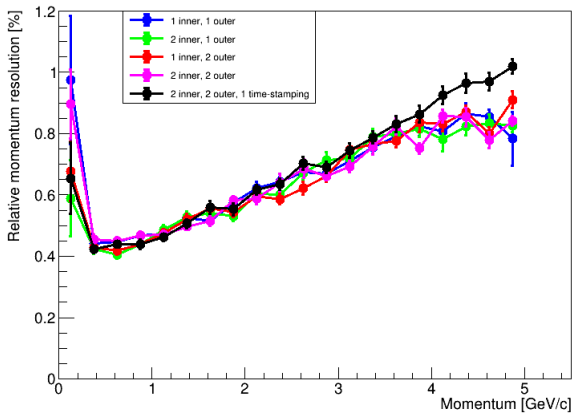
- Simulations studies performed
  - Pixel size
  - Number of layers
  - Radiation length scan
  - Time-stamping layer X/X_0 and pixel size

- Parameters used:
  - Particle: π+
  - Transverse momentum range: 0 to 5 and 0 to 50 GeV/c
  - Pseudorapidity range: $-0.5 \leq \eta \leq 0.5$
  - Default pixel size: 20x20 μm^2
  - Material budget: 0.3/0.8 % X_0 inner/outer layers, 1.6 % time-stamping layer
  - Magnetic field: uniform 1.5 T

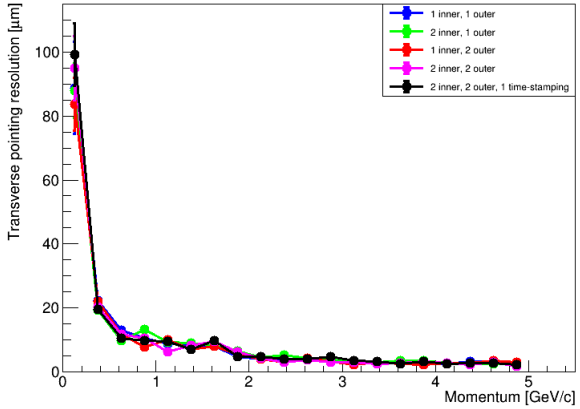
Barrel simulations: number of layers

- Different number of layers tested, keeping the innermost and outermost layers the same at a radius of 23.4 mm and 133.8 mm respectively

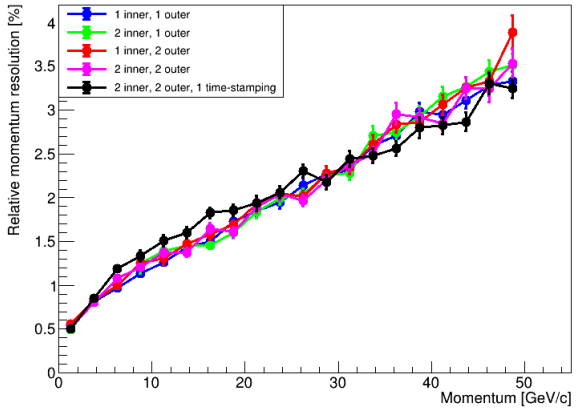
Relative momentum resolution



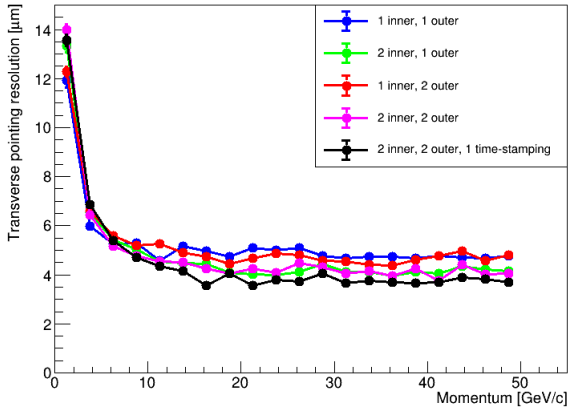
Transverse pointing resolution



Relative momentum resolution



Transverse pointing resolution



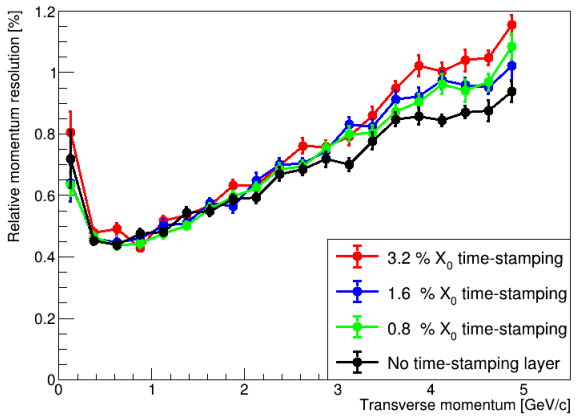
Time-stamping layer - details

- Adding time-stamping capability to the vertex and tracking detector would allow to **time-stamp bunch crossings** and thus **keep track of beam polarisation**
- With a bunch-crossing frequency of 112.6 MHz, a **time resolution <9 ns is needed**
- This **might** require a sensor with a **larger pixel size and power consumption** than those required for vertex and tracking measurements
- A dedicated time-stamping layer is therefore studied
- This layer is placed at a radius of 180.0 mm
- Investigations are done altering **thickness** (proportional to power consumption) and **pixel size** of the layer
- For thickness studies, a pixel size of 20x20 μm^2 is used. For pixel size studies, the thickness is kept at 1.6 % X_0

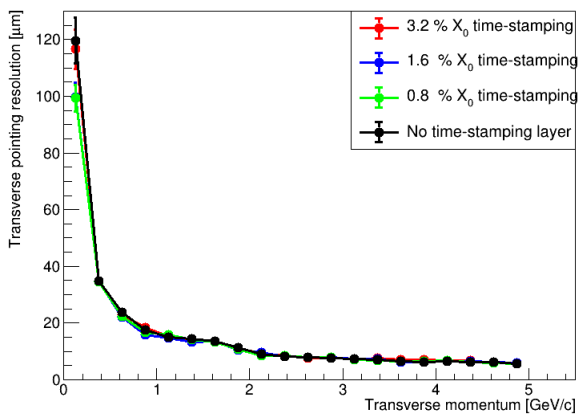
Addition of time-stamping layer - results

- Different thicknesses:

Relative momentum resolution

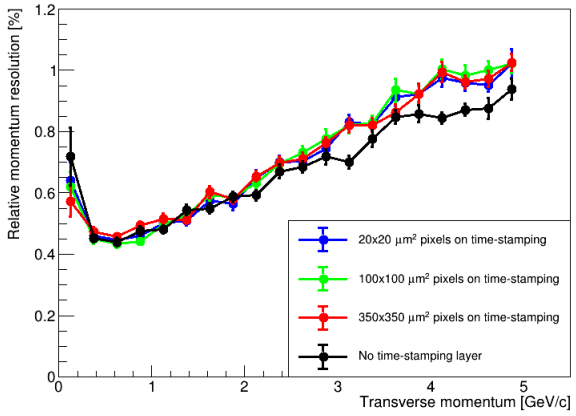


Transverse pointing resolution

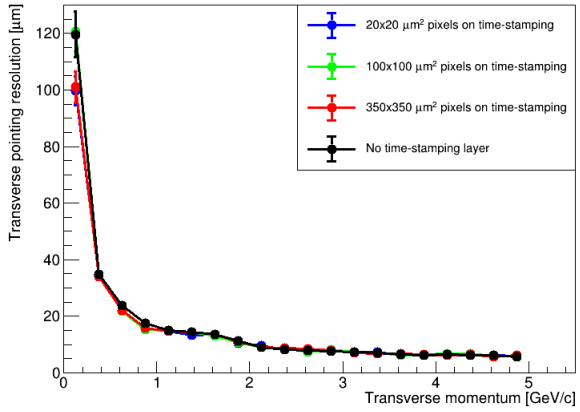


- Different pixel sizes:

Relative momentum resolution

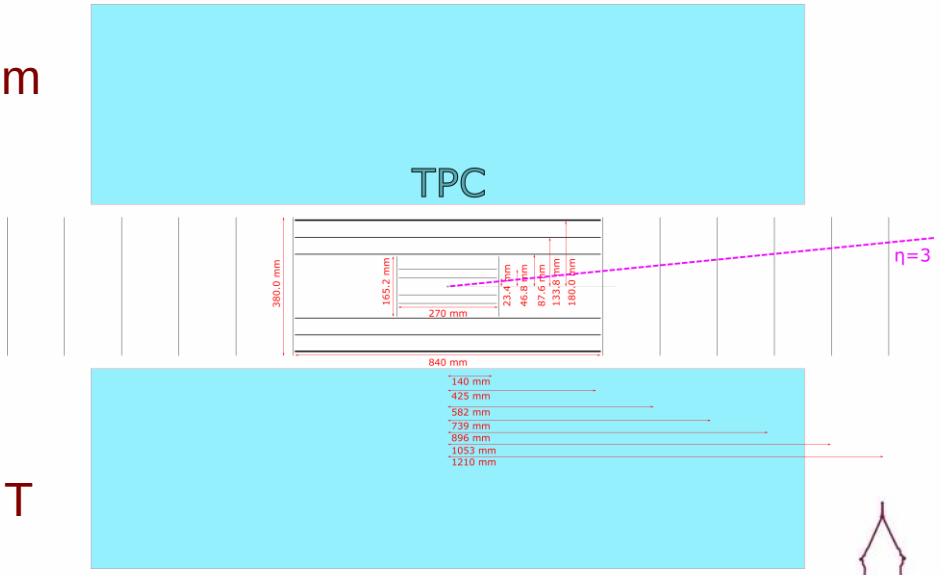


Transverse pointing resolution

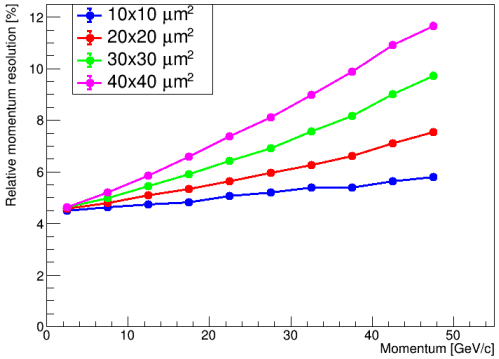


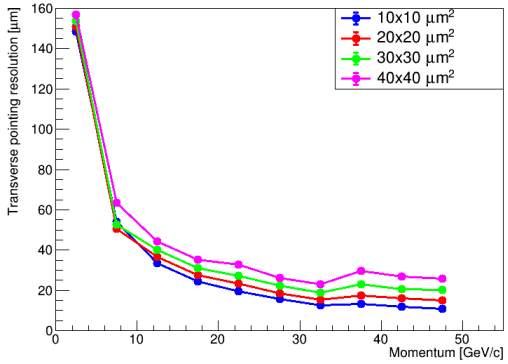
Simulations of disks – pixel sizes

- Simulations have studied two configurations, with either 7 or 5 disks per side
  - First disk 5 mm from inner layer edge (i.e. 140.0 mm from centre)
  - Remaining disks equidistant between 425.0 mm and 1210.0 mm
  - Radius of first disk: 82.6 mm
  - Radius of remaining disks: 190.0 mm
- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity: η = 3
  - Material budget: 0.3 % X_0 per disk
  - Magnetic field: uniform 1.5 T and 3 T
- Impact of pixel size investigated

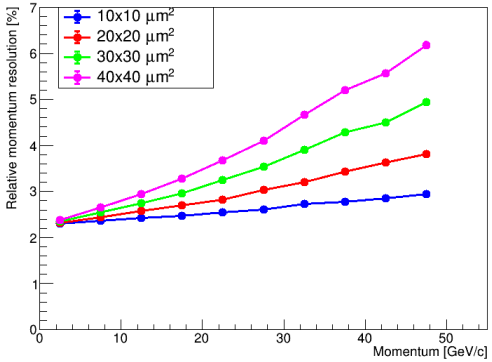


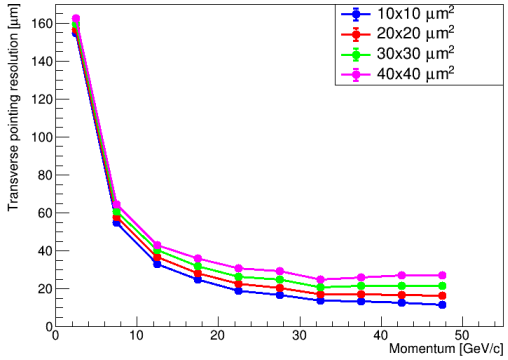
Disk pixel sizes - results



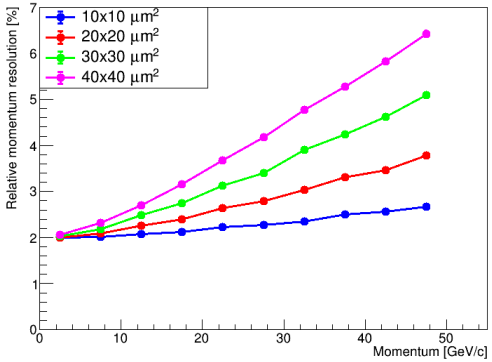


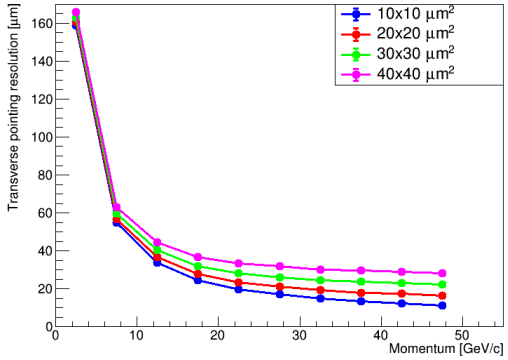
7 disks, 1.5 T





7 disks, 3 T



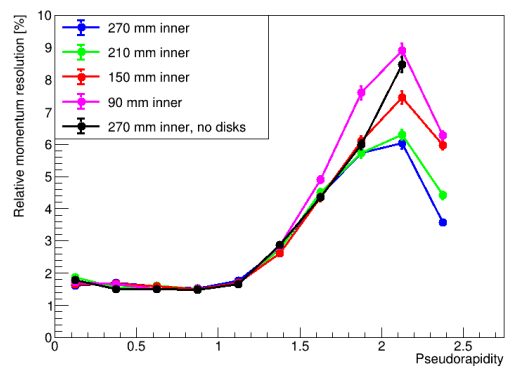


5 disks, 3 T

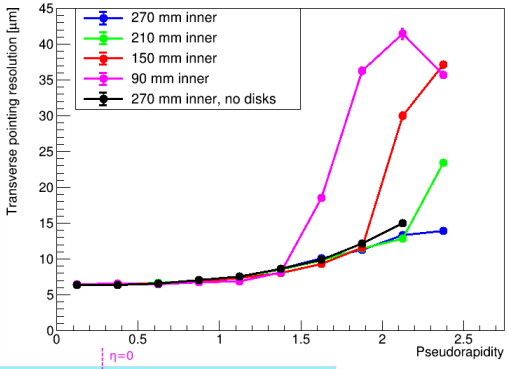
Barrel/disk interface region simulations

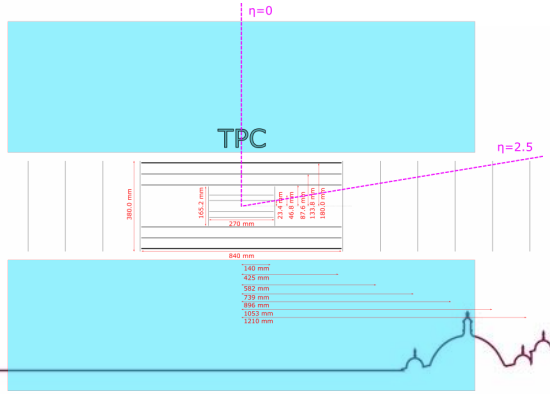
- Studies have looked at
  - Innermost disk position (at η = 3)
  - Length of inner barrel layers (at range of pseudorapidities)
- Length of inner barrel layer study presented here
- Innermost disk always 5 mm from inner barrel edge
- Parameters
  - Particle: e−
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity range: 0 ≤ η ≤ 2.5
  - Pixel size: 20 × 20 μm^2
  - Magnetic field: 1.5 T
- Results show that 270 mm long inner barrel is best

Relative momentum resolution vs η



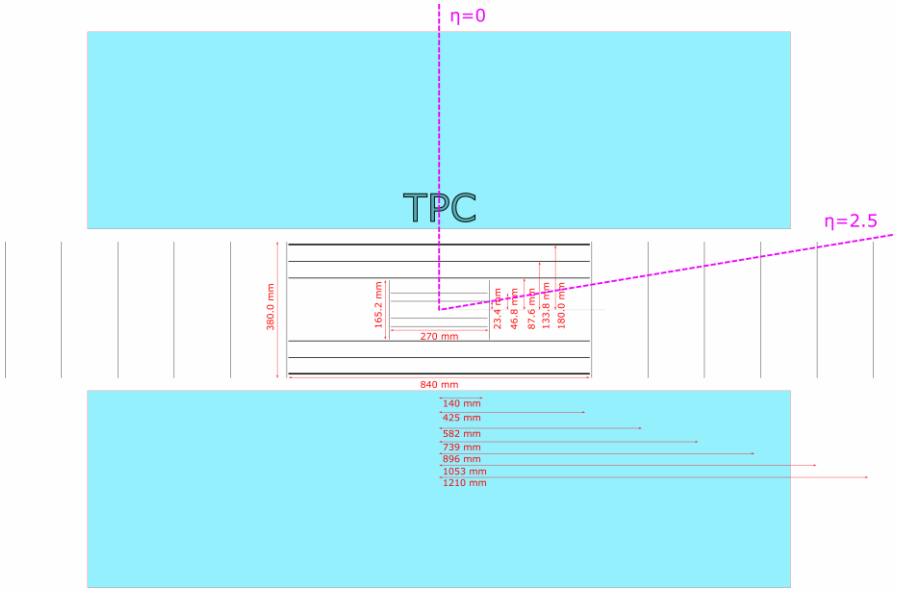
Transverse pointing resolution vs η





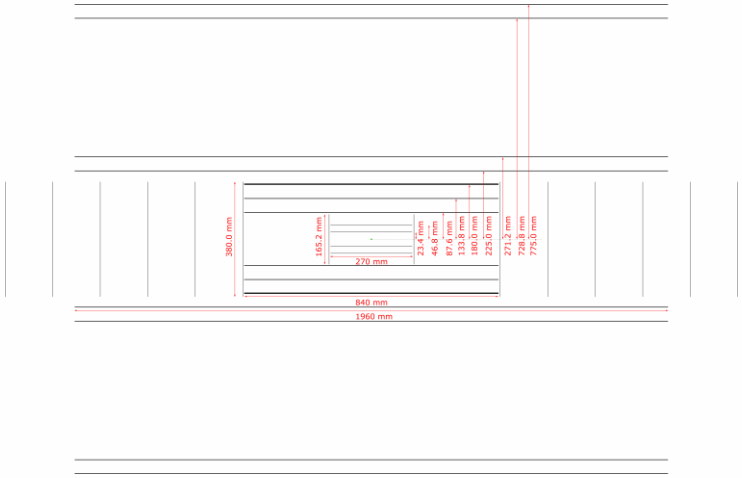
Silicon and gas TPC compared to all-silicon layouts

- Various all-silicon layouts tested. Details can be found in Section 3.9 here: http://cern.ch/go/xKk6
  - Key layouts are shown schematically on the next slide
- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity range: $0 \leq \eta \leq 2.5$
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Layer thickness in “TPC replacement”: 0.8 % X_0

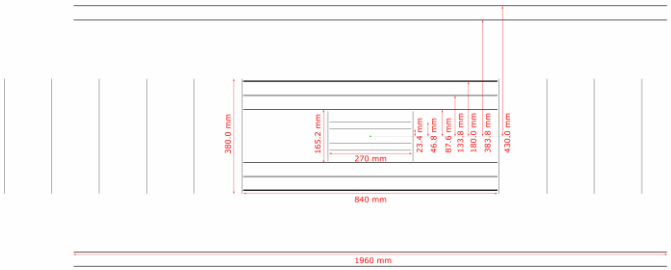


Key layouts and their aliases

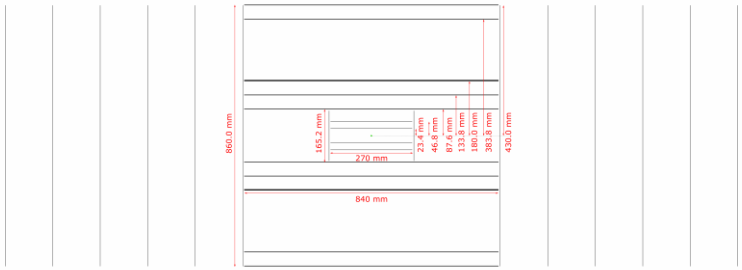
2+2 layers, long



2 layers, long, small radius



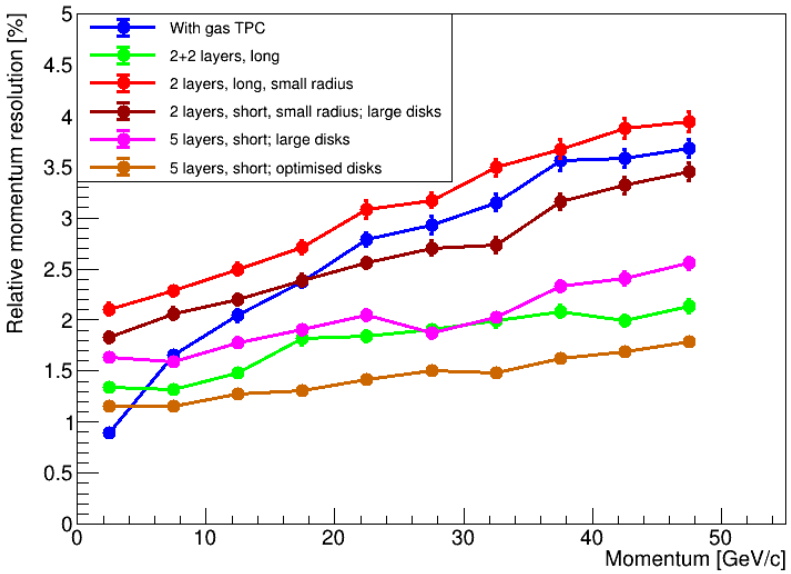
2 layers, short, small radius, large disks



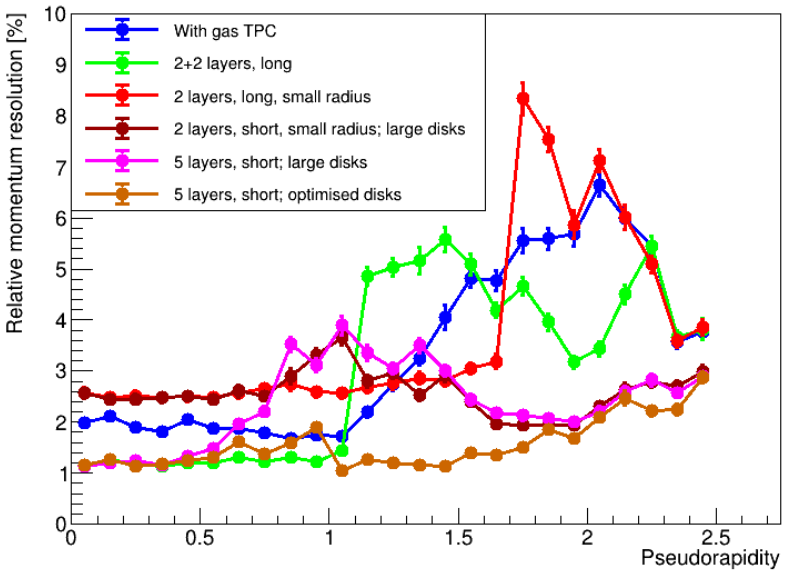
5 layers, short, optimised disks

All-silicon layouts - results

Relative momentum resolution vs p



Relative momentum resolution vs η



- Large disk coverage is important to keep resolution at higher η
- All-silicon layout can outperform Si+gas at p≥5 GeV/c

- Pointing resolutions do not change much between layouts, apart form where layers are missed

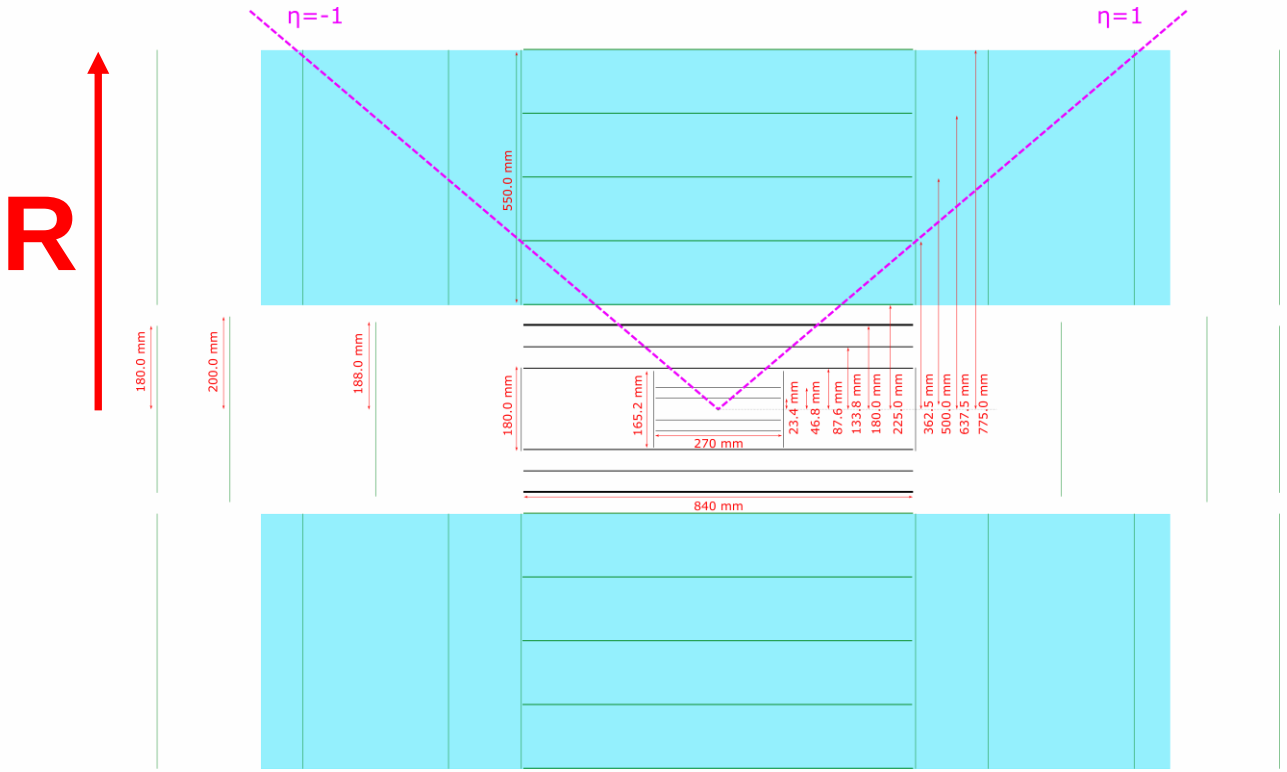
Decreasing radius study

- Goal: investigate performance of Si+gas and all-Si when outer radius is decreased
- Best-performing all-silicon layout used (“5 layers, short, optimised disks”, see slide 13). Outer radius decreased, layers kept equidistant
- Studies are made in central and forward regions for the all-silicon layouts, and in the central region for silicon+gas layouts
- The central region study comparing silicon+gas with all-silicon is presented here

- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 30 GeV/c
  - Pseudorapidity range: $0 \leq \eta \leq 1$
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Baseline barrel used (5 layers)

Decreasing radius study

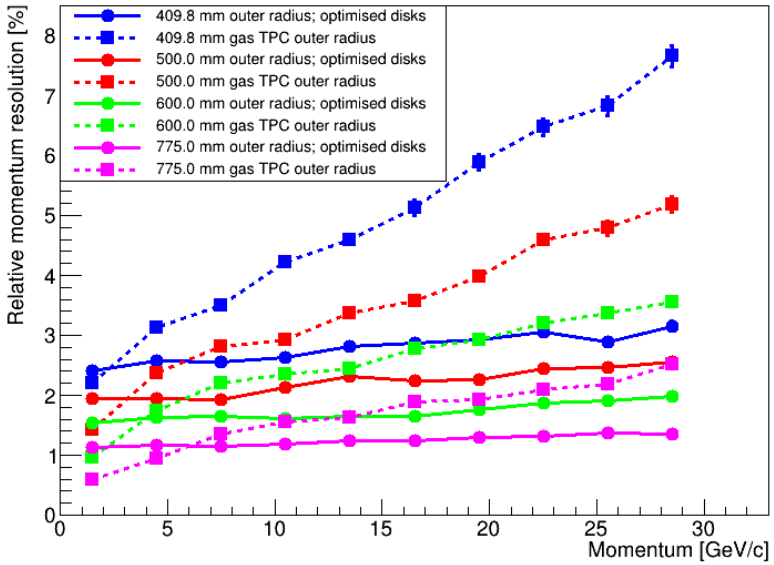
- Outer radii tested:
  - 409.8 mm,
  - 500.0 mm
  - 600.0 mm
  - 775.0 mm



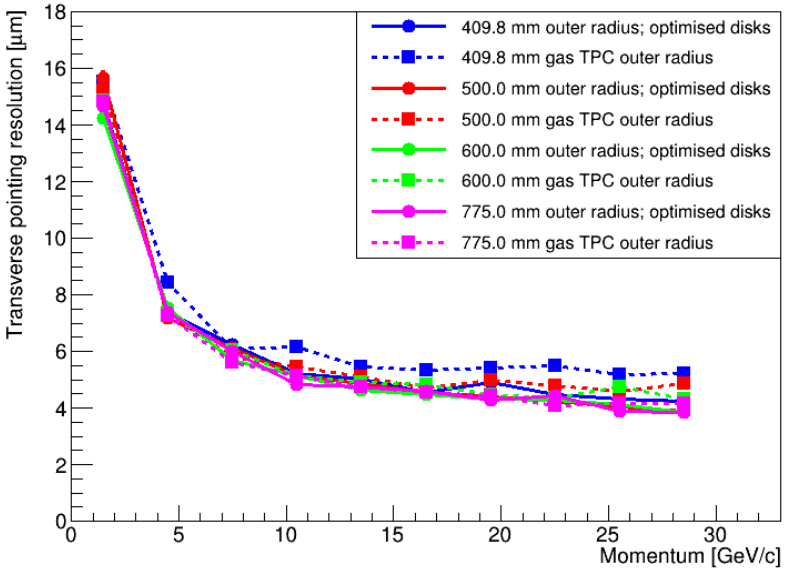
All-silicon layout superimposed with gas TPC

Decreasing radius study - results

Relative momentum resolution



Transverse pointing resolution



- Colours correspond to radii. Solid line with circular markers indicates all-silicon, and dashed line with square markers indicates silicon+gas TPC
- All-silicon layout relative momentum resolution deteriorates slower with increasing momentum
- The smaller the radius, the better the all-silicon compared to Si+gas

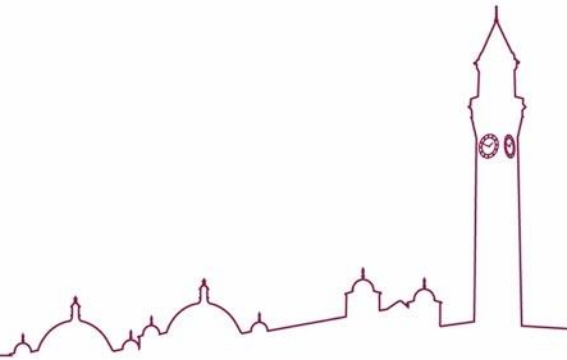
Conclusions

- Best layout, indicated from these simulations:
  - Two inner layers (two to keep redundancy)
  - Two outer layers (two to help in track reconstruction)
  - Optional time-stamping layer **is not severely detrimental** to resolutions
    - **Not necessary for tracking**, but potentially helps detection in other ways by keeping track of bunch crossings
  - Seven silicon disks in forward and backward regions
    - First disk as close as possible to interaction point, inside barrel
    - Remaining disks equidistant
    - 5 disks show similar performance, but 7 provide more coverage
- Pixel size needs to be kept **small**; current baseline 20x20 μm^2
  - Smaller is better, as long as power density can be kept low
- All-silicon layouts can match silicon+gas TPC layouts above a few GeV/c, and outperform them at higher momenta
- If **smaller radius** is desired, it appears better to replace gas TPC with silicon layers

More EICROOT studies for Pavia meeting

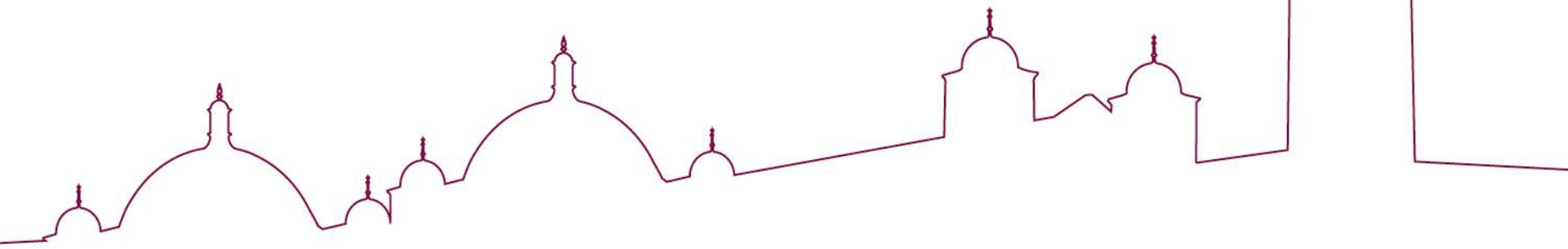
- Simulate best layouts with
  - New beampipe configuration (i.e. 31 mm radius)
  - 1.5 T and 3 T magnetic field comparison in barrel region
  - More realistic TPC, as simulated by eRD6

- Impact of adding a third inner layer (after discussion with Jin Huang), to be able to reconstruct even if a layer is missed



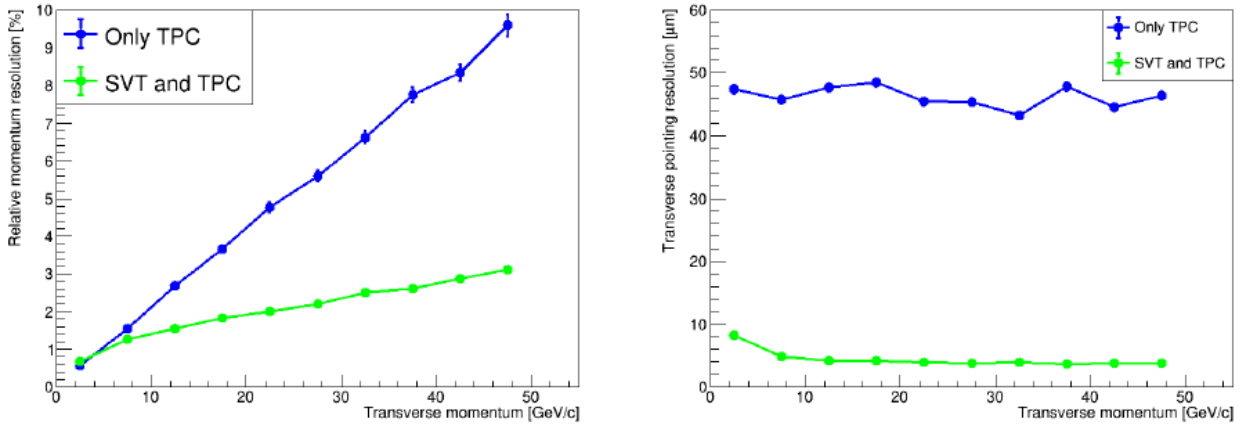
Backup/more studies

Note: still not all the results. See report for complete summary; http://cern.ch/go/xKk6



Comparison no SVT/SVT+TPC

- Parameters used:
  - Particle: π+
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity range: -0.5≤η≤0.5
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Baseline barrel used (5 layers)
- Goal:
  - See that SVT is necessary
- See Section 3.1 in report for details



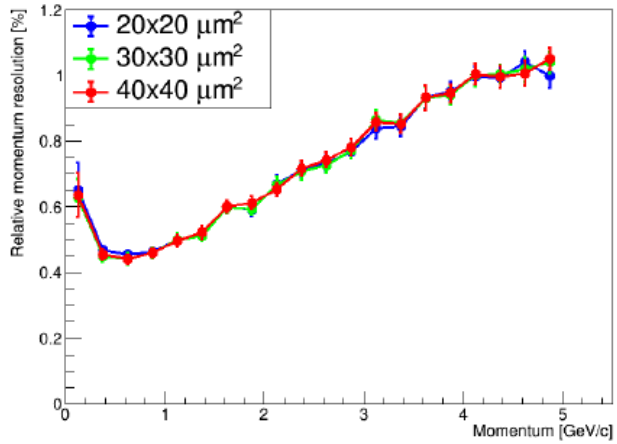
(a) Relative momentum resolution.

(b) Transverse pointing resolution.

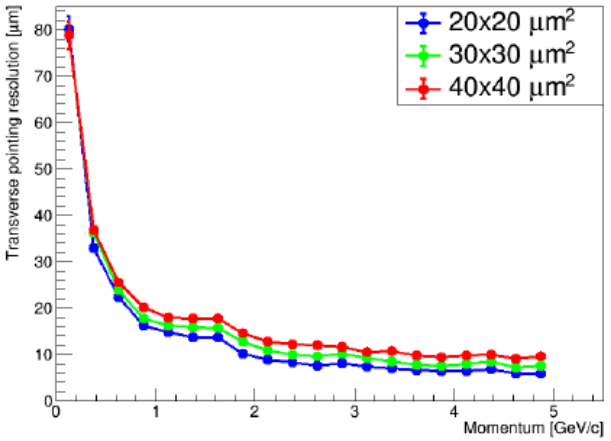
Figure 3: Relative momentum resolution and transverse pointing resolution, comparing having a standard barrel with a 20×20 μm^2 pixel size with a TPC outside, and just having a TPC extending all the way to the same innermost radius as the barrel.

Barrel pixel size

- Parameters used:
  - Particle: π+
  - Momentum range: 0 to 5 GeV/c
  - Pseudorapidity range: -0.5≤η≤0.5
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Baseline barrel used (5 layers)
- Goal:
  - Investigating effect of barrel pixel size on resolutions
- See Section 3.2 in report for details



(a) Relative momentum resolution.

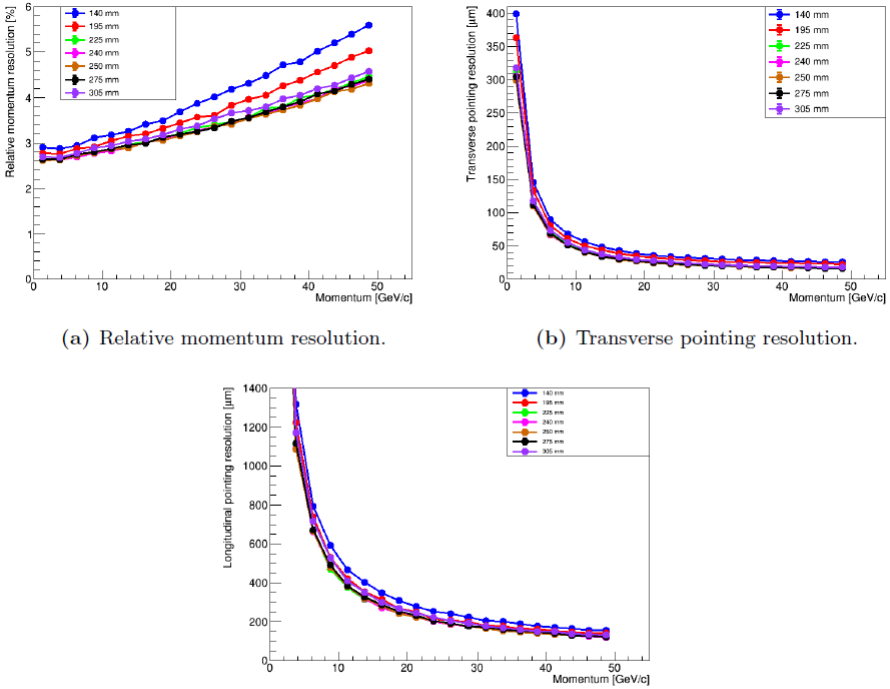


(b) Transverse pointing resolution.

Figure 4: Relative momentum resolution and transverse pointing resolution for different pixel sizes in the silicon vertex tracker barrel.

Innermost disk position

- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity: η = 3
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 3 T
- Goal:
  - Investigating effect of changing the innermost disk position
- See Section 3.7 in report for details
- Main conclusion is that as long as a disk is hit, it should be as close to the interaction point as possible.



(a) Relative momentum resolution.

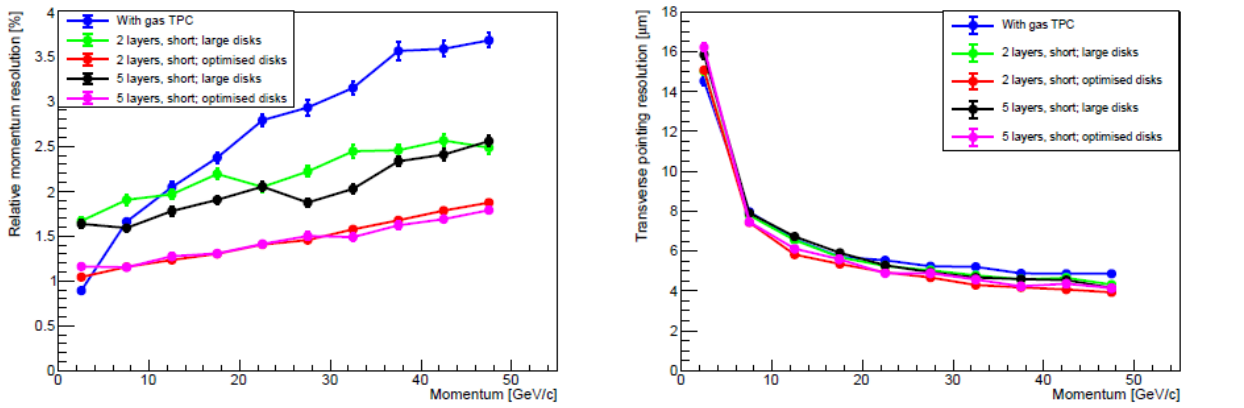
(b) Transverse pointing resolution.

(c) Longitudinal pointing resolution.

Figure 13: Relative momentum resolution and pointing resolutions for a 7 disk layout, with varying innermost disk positions.

All-silicon, comparing 2 layers and 5 layers

- Goal:
  - Investigate difference between 2 layer TPC replacement, and 5 layer TPC replacement
  - 5 layers would help with tracking
- See Section C.1.1 in report for details



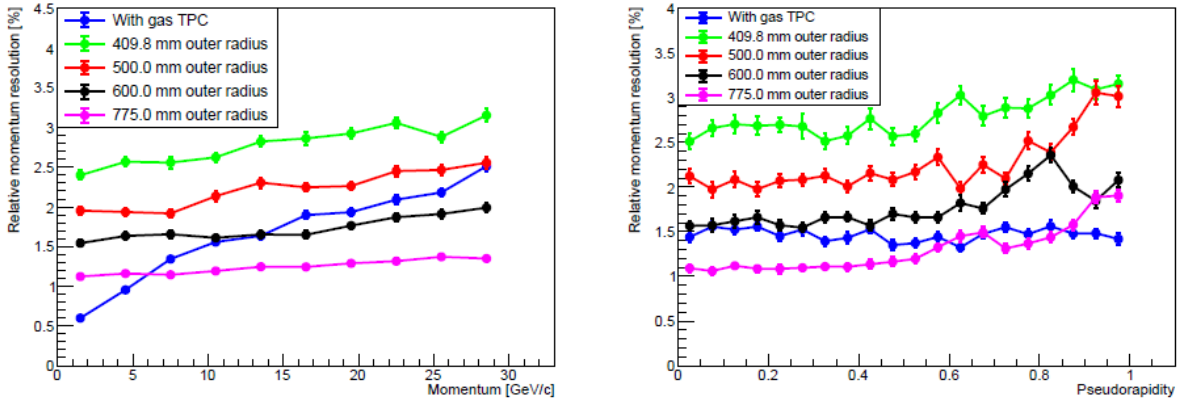
(a) Relative momentum resolution. (b) Transverse pointing resolution.

Figure 33: Relative momentum resolution and transverse pointing resolution versus momentum for 2 and 5 layers in the TPC replacement silicon barrel.

- Result: not severely detrimental to have 5 layers instead of 2

All-silicon outer radius studies

- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 30 GeV/c
  - Pseudorapidity range: $0 \leq \eta \leq 1$
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Baseline barrel used (5 layers)
- Goal:
  - Investigating effect of decreasing radius of all-silicon, compared to the baseline silicon+gas TPC layout
- See Section 3.9.2 in report for details



(a) Relative momentum resolution versus momentum.

(b) Relative momentum resolution versus pseudorapidity.

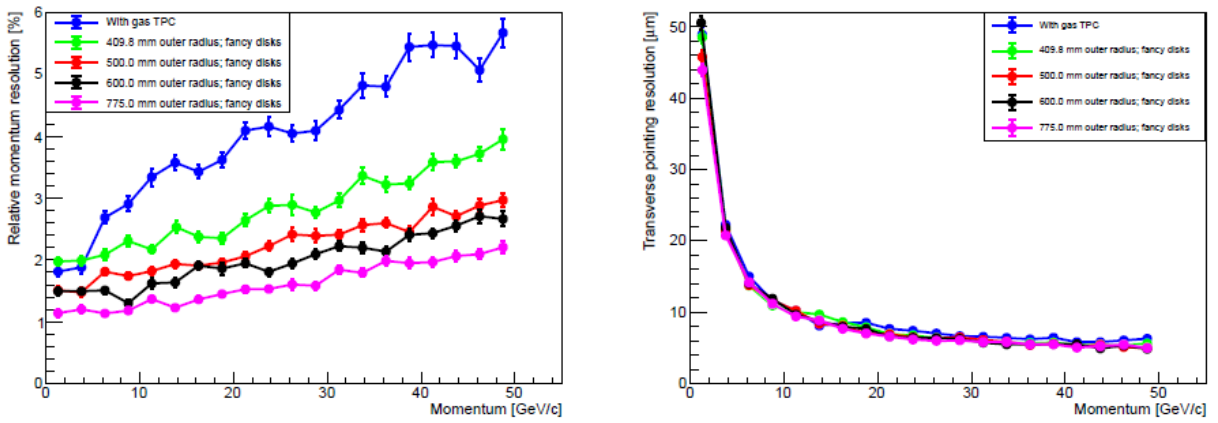
Figure 23: Relative momentum resolution versus momentum and pseudorapidity for different silicon TPC replacement outer radii, in the momentum range 0 to 30 GeV/c and pseudorapidity range $0 \leq \eta \leq 1$.

All-silicon outer radius studies

- Results:
  - At low momenta, Si+gas is always better
  - At increasing momentum, Si+gas loses performance faster than all-silicon.
  - At momenta above 6 GeV/c, all-silicon outperforms Si+gas
- See Section 3.9.2 in report for details

All-silicon outer radius studies – forward regions

- Parameters used:
  - Particle: e-
  - Momentum range: 0 to 50 GeV/c
  - Pseudorapidity range: $1 \leq \eta \leq 2.5$
  - Pixel size: 20x20 μm^2
  - Magnetic field: uniform 1.5 T
  - Baseline barrel used (5 layers)
- Goal:
  - Investigating effect of decreasing radius of all-silicon, compared to the baseline silicon+gas TPC layout, in forward regions
- See Section 3.9.2 in report for details



(a) Relative momentum resolution.

(b) Transverse pointing resolution.

Figure 24: Relative momentum resolution and transverse pointing resolution versus momentum for different silicon TPC replacement outer radii, with optimised disk layout. Forward regions ($1 \leq \eta \leq 2.5$).