Forward Silicon Detector:
Layout & performance of LANL 2020022DR

Astrid Morreale, LANL

SVT EIC Workshop.

September 2-4, 2020.

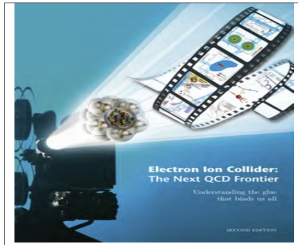
LA-UR-20-26997

Outline

- Introduction
- Detector layout and performance
- Related studies with other detectors

FST's TECHNICAL NOTE contains more details and the plots used in this presentation

LANL 2020022: Heavy flavor and jet program, detector R&D



A. Accardi et al, **Eur. Phy. J. A**, 52 9 (2016).

LDRD project (X. Li/ I. Vitev) funded by LANL 2020022DR
Primary goal is to develop a new heavy flavor and jet program for the future EIC and carry out relevant detector R&D.

LDRD
LABORATORY DIRECTED
RESEARCH & DEVELOPMENT

At the EIC HQ are produced from gluons carrying a large fraction x_B of the nucleons momentum (>0.1)

See Xuan's slides from this morning

Heavy quarks (HQ: c, d) play a special role & address essential physics at the EIC

Addressing the physics is accomplished by measuring the elementary particles that contain heavy quarks: D-mesons and B-mesons

Measuring Heavy Quarks

Open heavy flavor measurements:

Unambiguous signature via **displaced vertices**

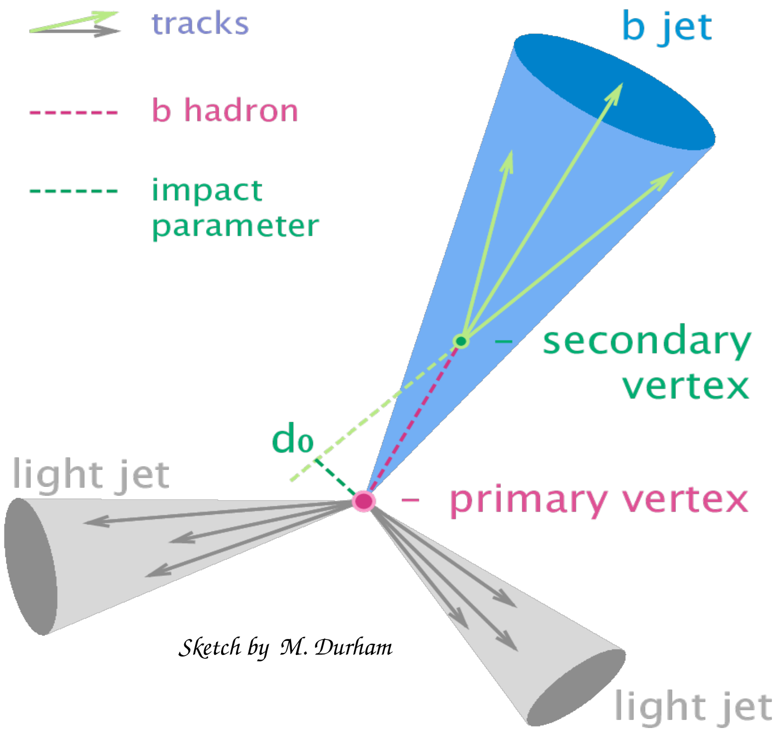
$$D^{\pm} \quad c\tau = 311.8\ \mu m$$

$$B^{\pm} \quad c\tau = 491.1\ \mu m$$

Need precise vertex determination
Need excellent spacial, timing resolution and low material budget.

$\longrightarrow$

precision measurements needed for a robust heavy flavor physics program



Goal: Measure heavy flavor products and their correlations in the forward direction

Detector Layout and Performance

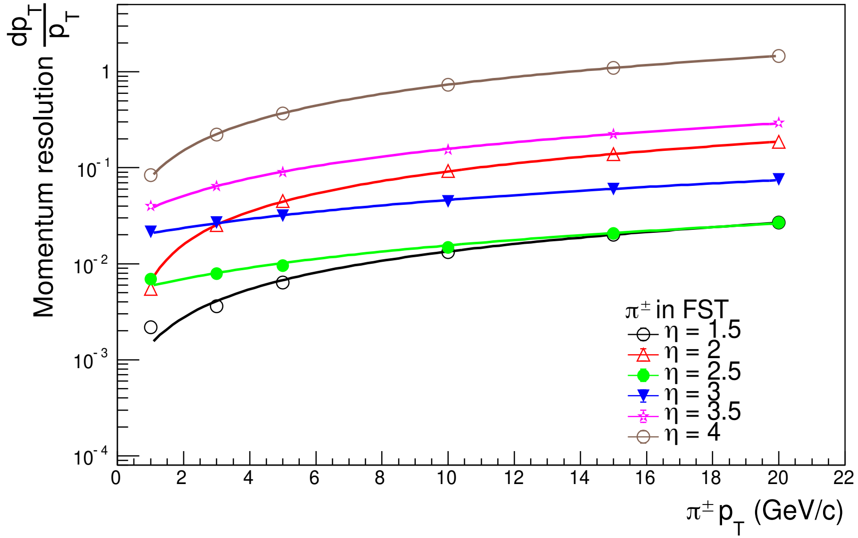
Fast simulations and full Geant4 simulations have been set up to explore:

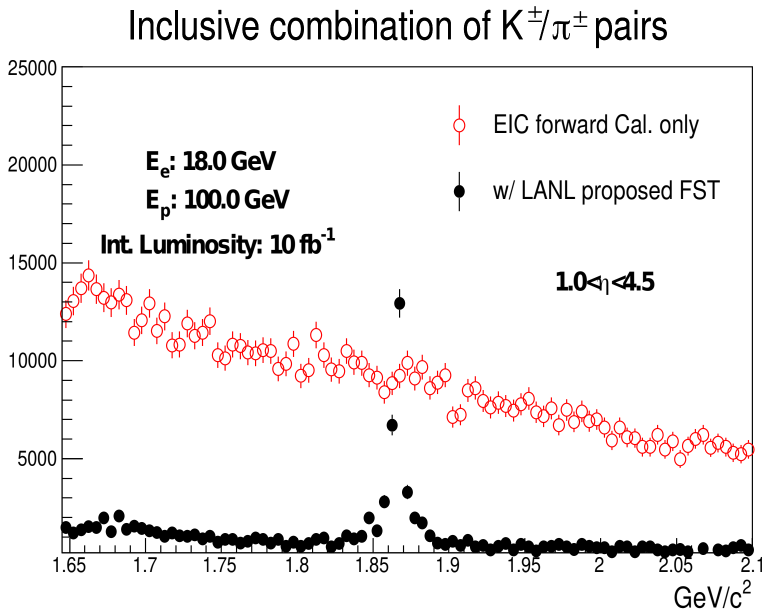
1. Relative momenta and pointing resolution performance,
2. Pixel size, χ_0, trigger integration time
3. Layout/geometries and integration with other baseline/new detectors.
4. IR design consequences to the detector performance.

1: Fast Simulations: Track performance

LiC Detector Toy (LDT) Xuan Li

Projected p_T dependent momentum resolution dp_T/p_T





PYTHIA8 MC
E_e = 18 GeV
E_p = 20 GeV
1.0 < η < 4.5
$\mathcal{L}_{int}$.: 10 fb^{-1}

Early geometry configuration at large z position

- 2 barrel layers MAPS or other silicon detector.
- *Forward silicon tracking detector (FST):* 5 forward planes of silicon detection.
- Left: Momentum resolution, dp_T/p_T in line with forward tracking requirements from EIC handbook.
- Right: Reconstruction of D^0 mesons with Pythia8 $\mathcal{L}_{int}$.: 10 fb^{-1}

EPJ Web of Conferences 235, 04002 (2020)

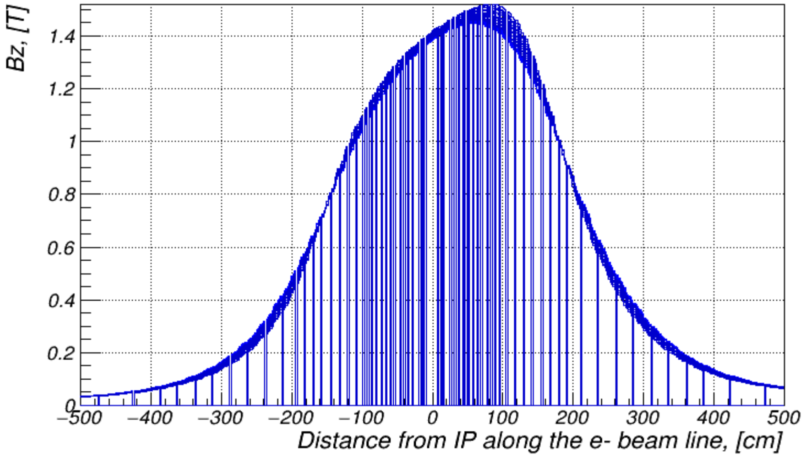
2: Full Simulations: B-field considerations

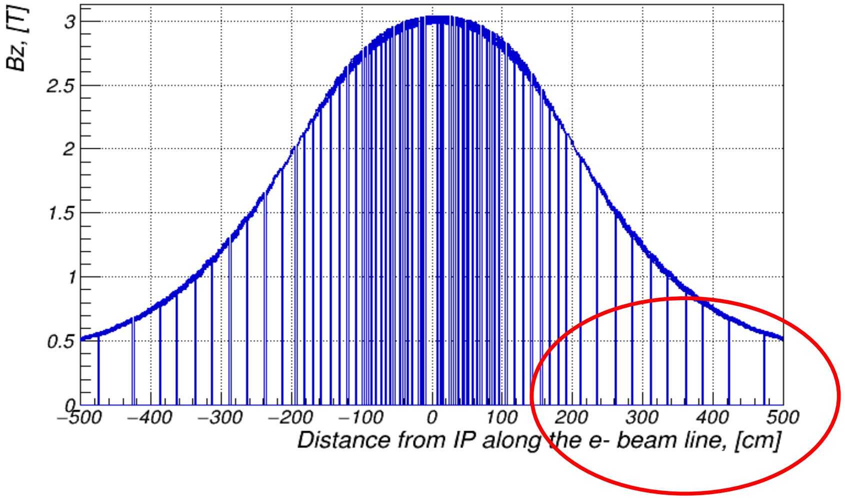
Elmer and Netgen. Astrid M

A concern that was coupled to early designs was the magnetic field strength and configuration.

- 1.5T field while it dealt with the fringe field it left very little B_z beyond 2m
- 3T field had more strength but it is an open field (no return yoke)

We reproduced and studied both fields using **NETGEN** and **Elmer** (open software A. Kisenev).





Left: By default the 1.5T field seems like the worse option for forward physics (high z, η>2)

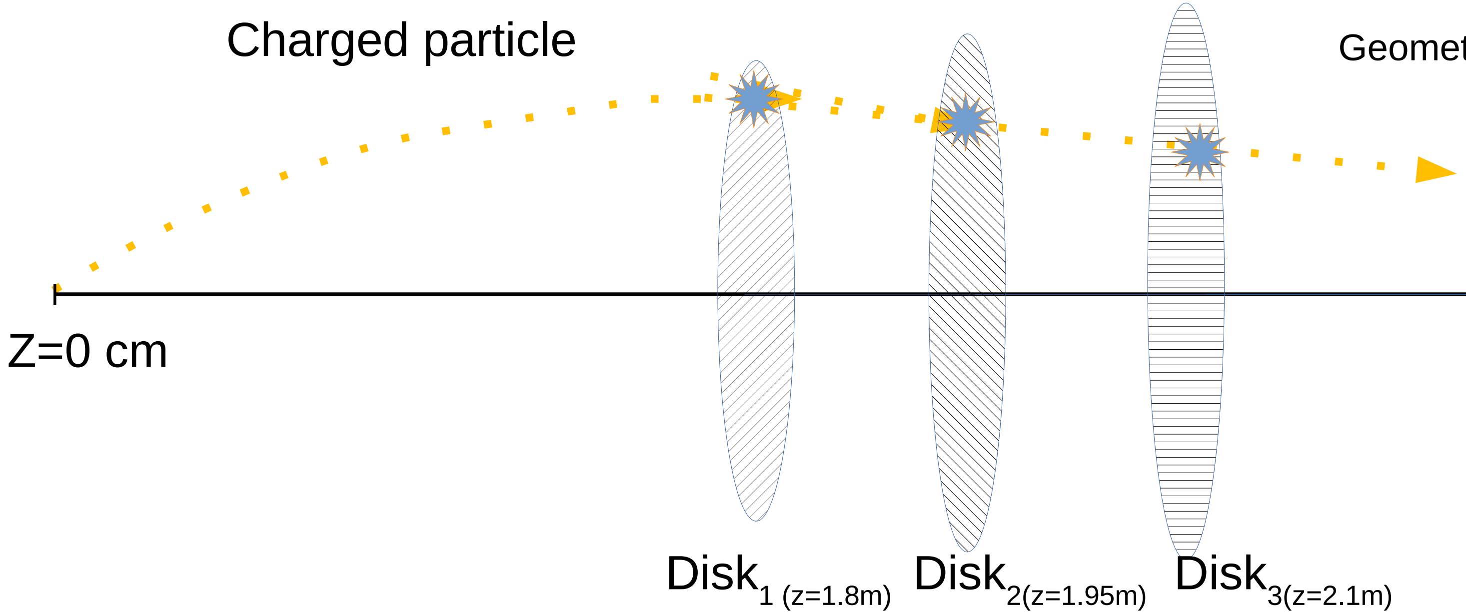
Right: 3T Open field and modified field (by us) with the addition of a return Yoke

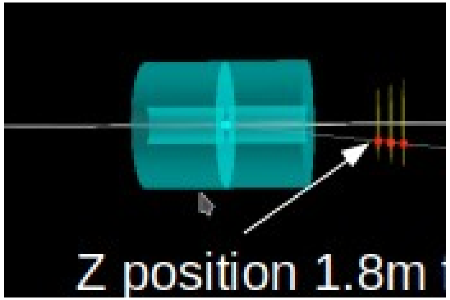
*EICRoot was used to test evaluate the field effect on charged particles.

B-Field: Curvature of charged tracks at forward rapidity

Geant4 EICRoot. Astrid M

Geometry studies from May 11 2020

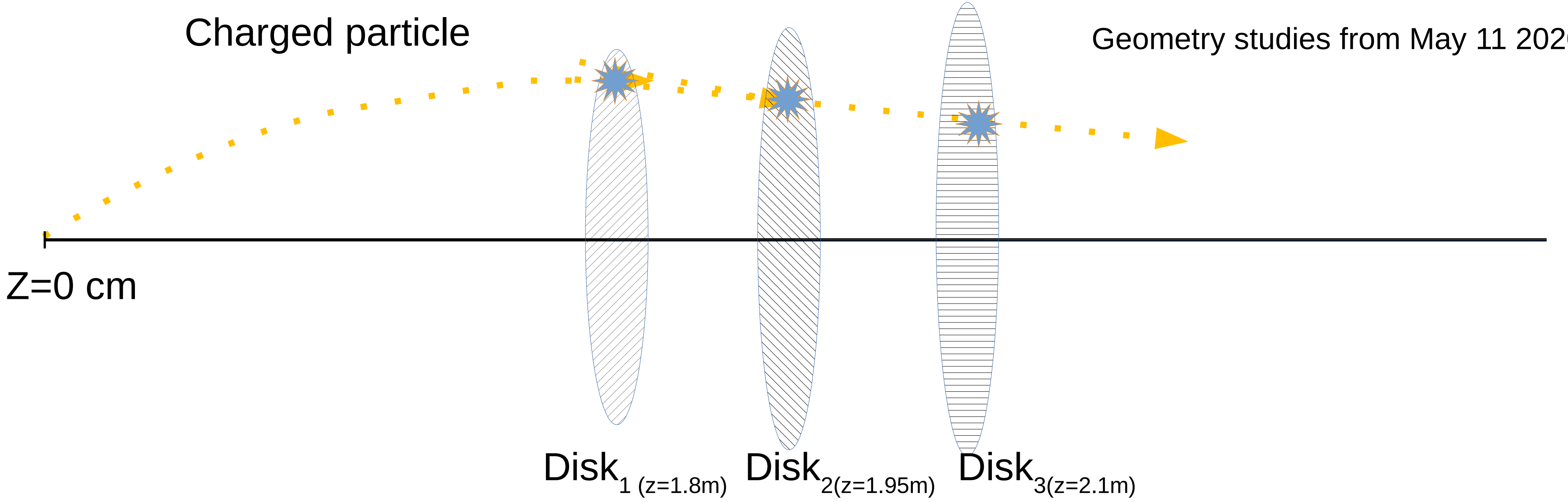




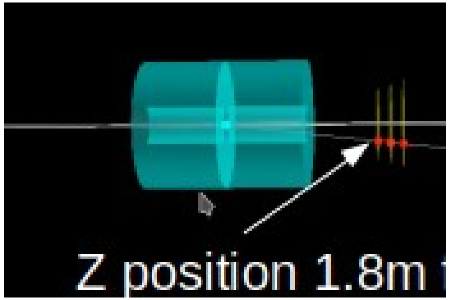
B-Field: Curvature of charged tracks at forward rapidity

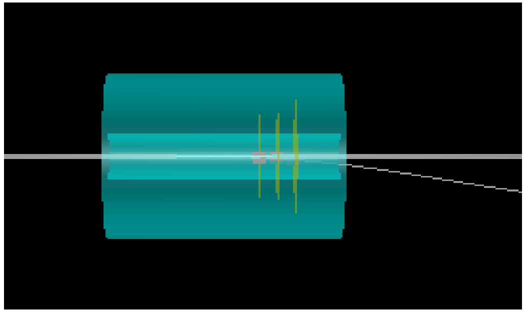
Geant4 EICRoot. Astrid M

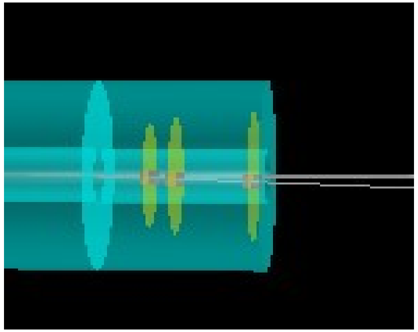
Geometry studies from May 11 2020



Evaluate azimuth hit position at at given z in each of these disks



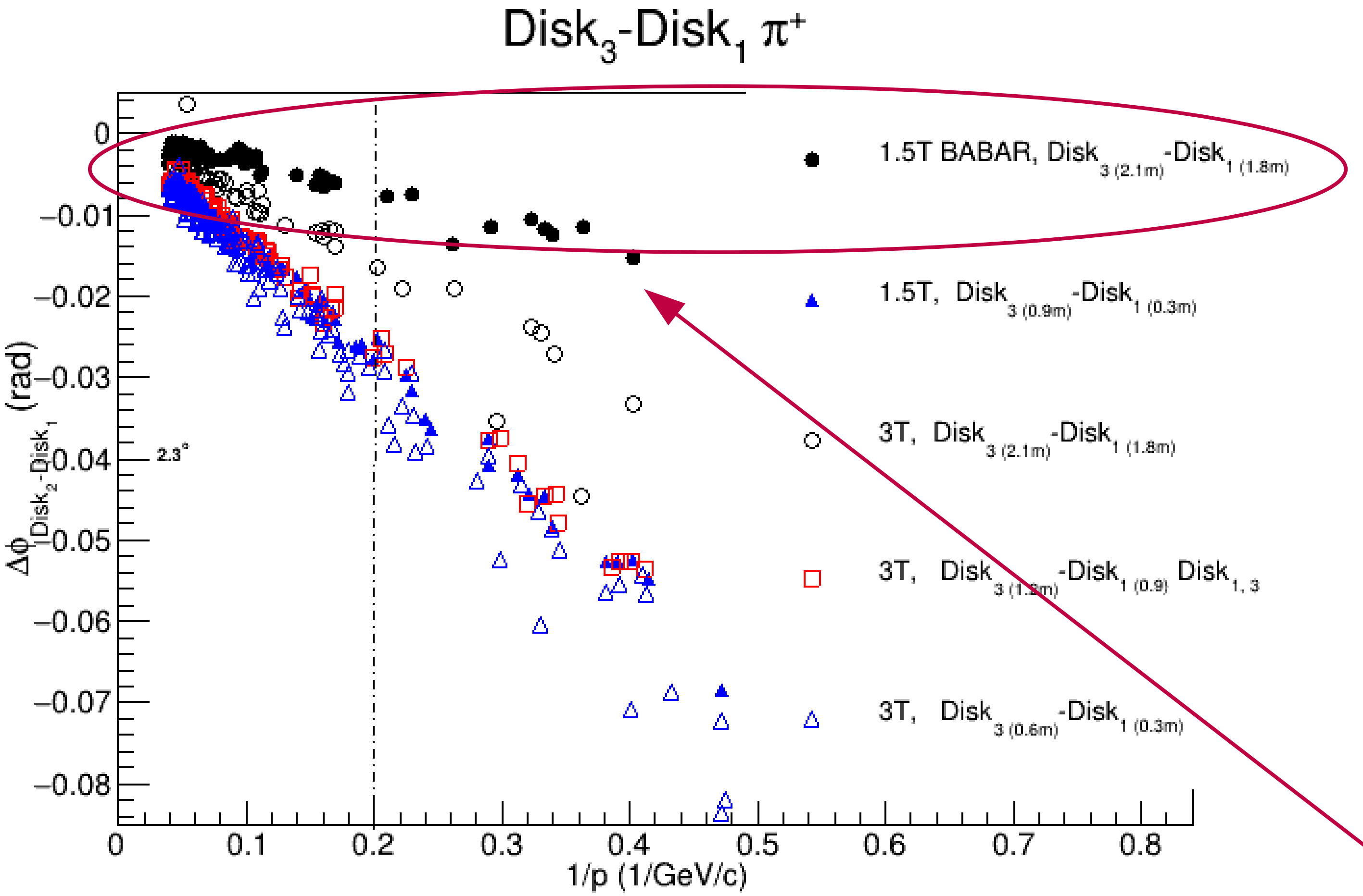


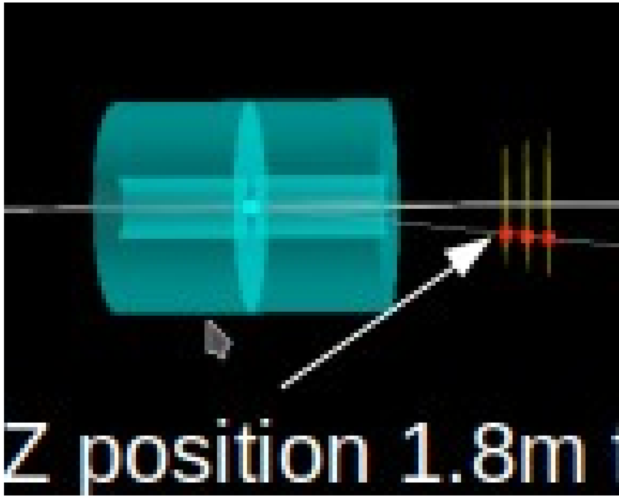


We evaluated
the field effect for Si planes
as well as GEMS

Curvature of charged tracks at forward rapidity 1.5T vs 3T

Geant4 EICRoot. Astrid M



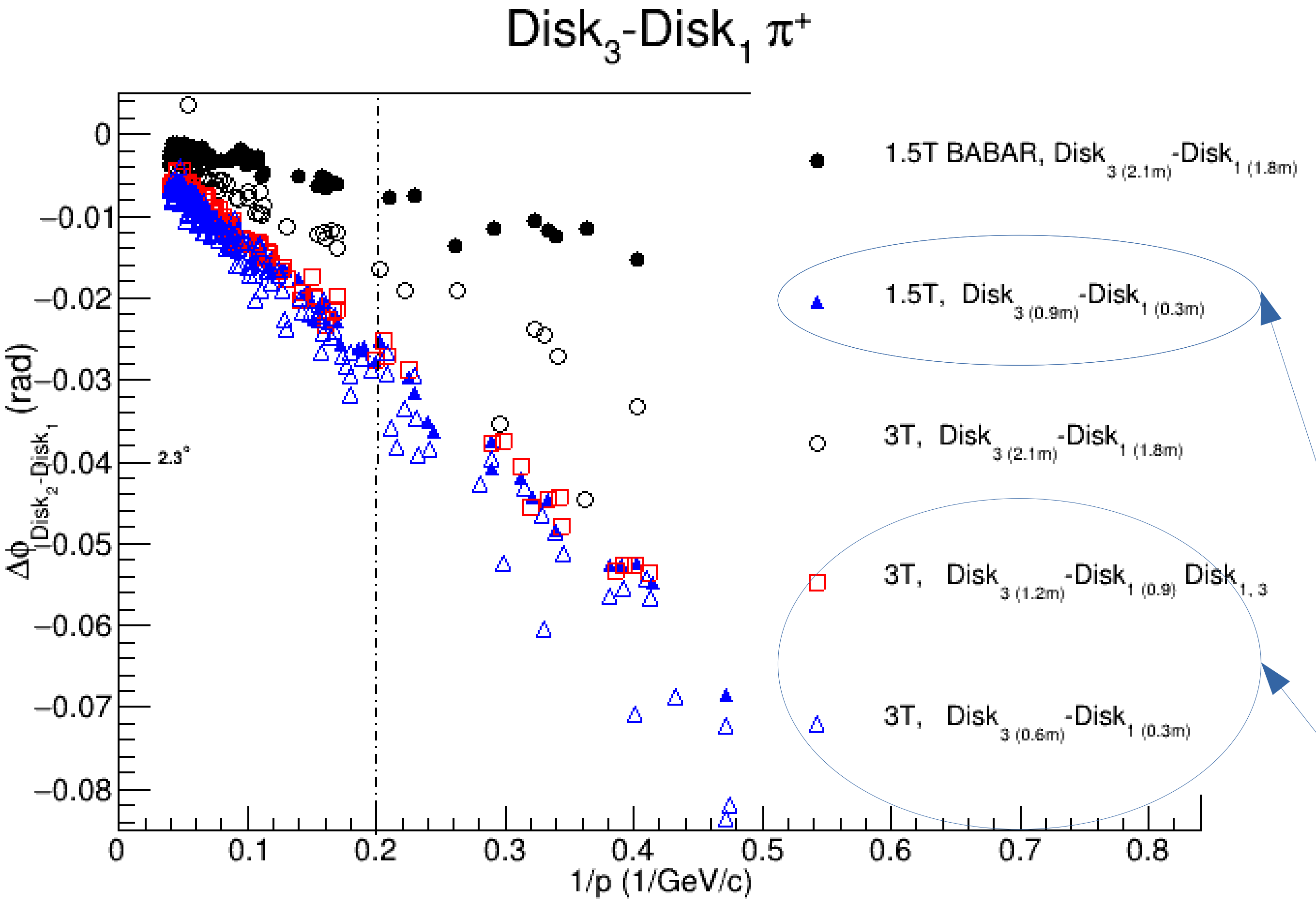


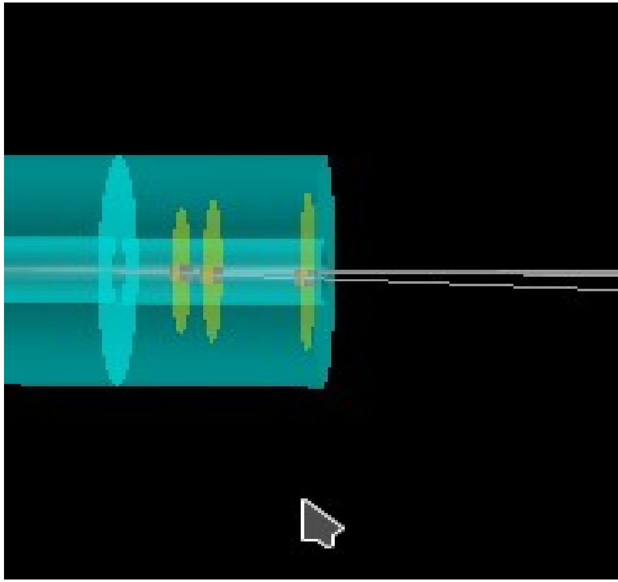
$Disk_1$ 1.8m → 0.3m
$Disk_3$ 1.95m → 0.9m

Little curvature at high z → difficult to reconstruct momentum

Curvature of charged tracks at forward rapidity 1.5T vs 3T

Geant4 EICRoot. Astrid M





$Disk_1$ 1.8m → 0.3m

$Disk_3$ 1.95m → 0.9m

Conclusions: these configurations are comparable

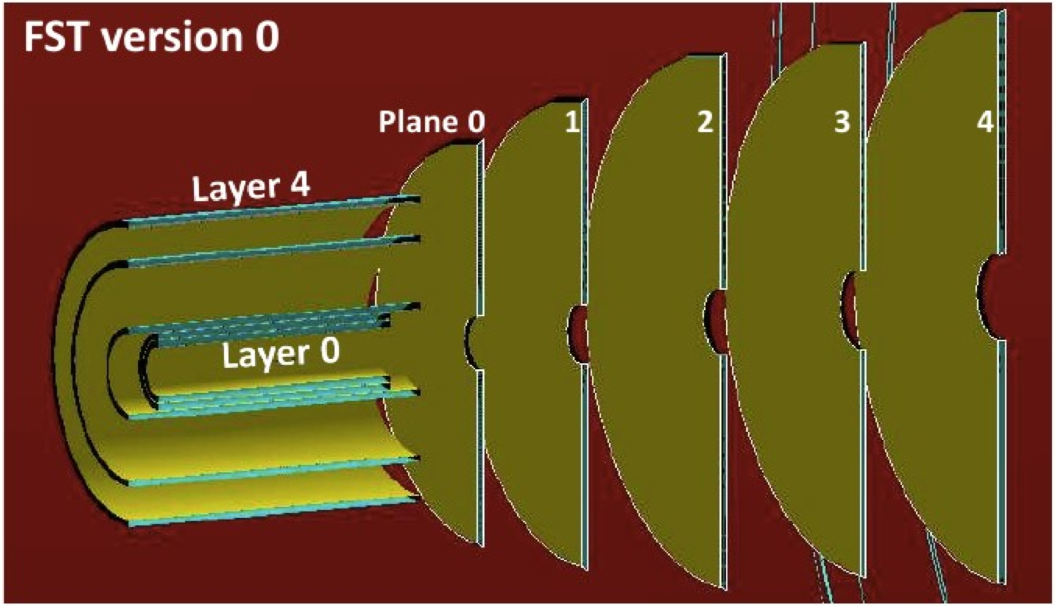
3.Forward Tracker in Fun4ALL (pions)

Fun4All
Cheuk-Ping Wong

New version 0 design puts the disks between 35cm~130cm from the IP.

sPHENIX based-simulation with 95% hit efficiency in both track and vertex reconstructions.

Kalman Filter algorithm and 20 μm vertex Gaussian smearing (x, y).



Barrel layer

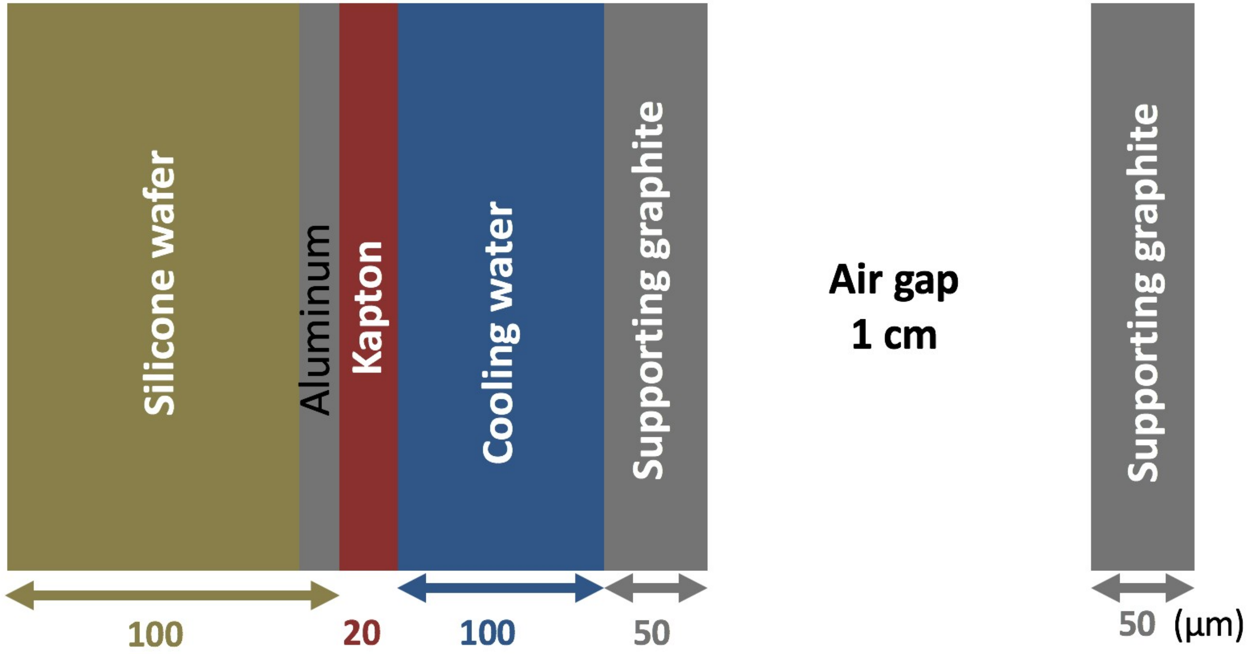
Layer	Half length (cm)	r (cm)
0	20	3.64
1	20	4.81
2	25	5.98
3	25	16
4	25	22

Plane detector

Plane	z (cm)	r_{in} (cm)	r_{out} (cm)
0	35	4	30
1	53	4.5	35
2	77	5	36
3	101	6	38.5
4	125	6.5	45

FST Structure, Material Budget

Fun4All
Cheuk-Ping Wong

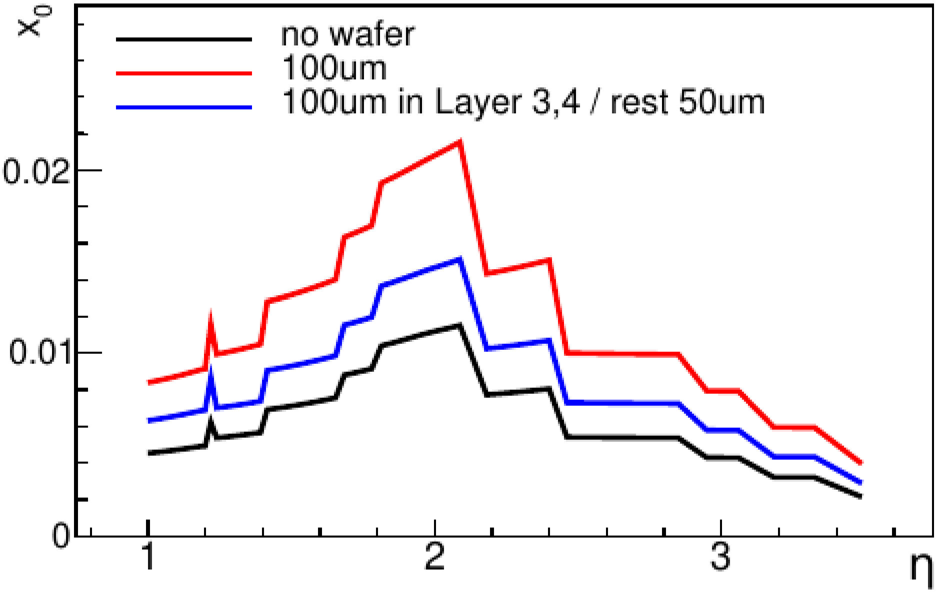


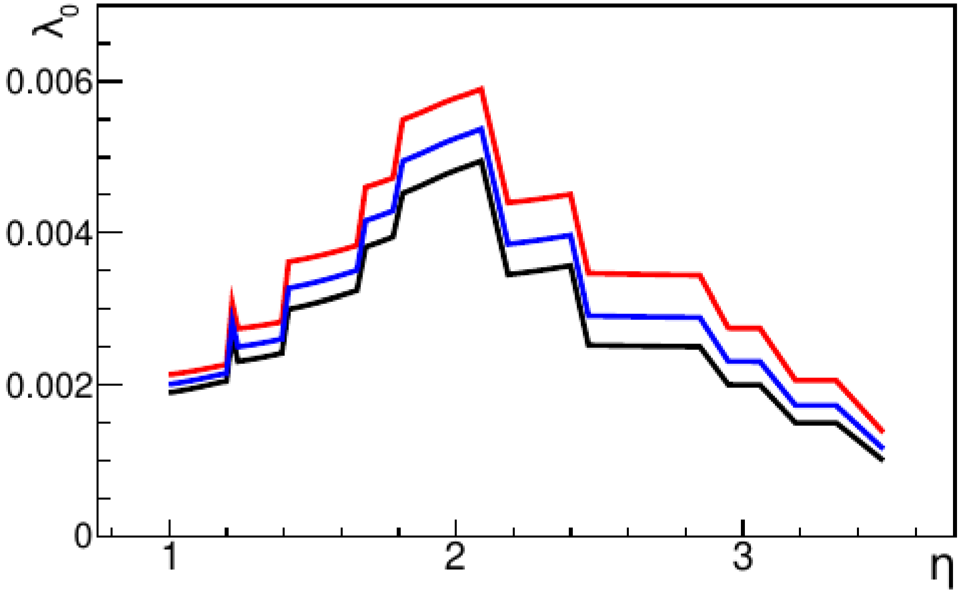
-Silicon wafer with a sheet of aluminum support
-Thin layer of Kapton followed by the cooling wafer and the supporting structure of graphite.

100 µm thickness: silicon wafer (including the aluminum base) both barrel detector and the FST

Material Budget

Fun4All
Cheuk-Ping Wong



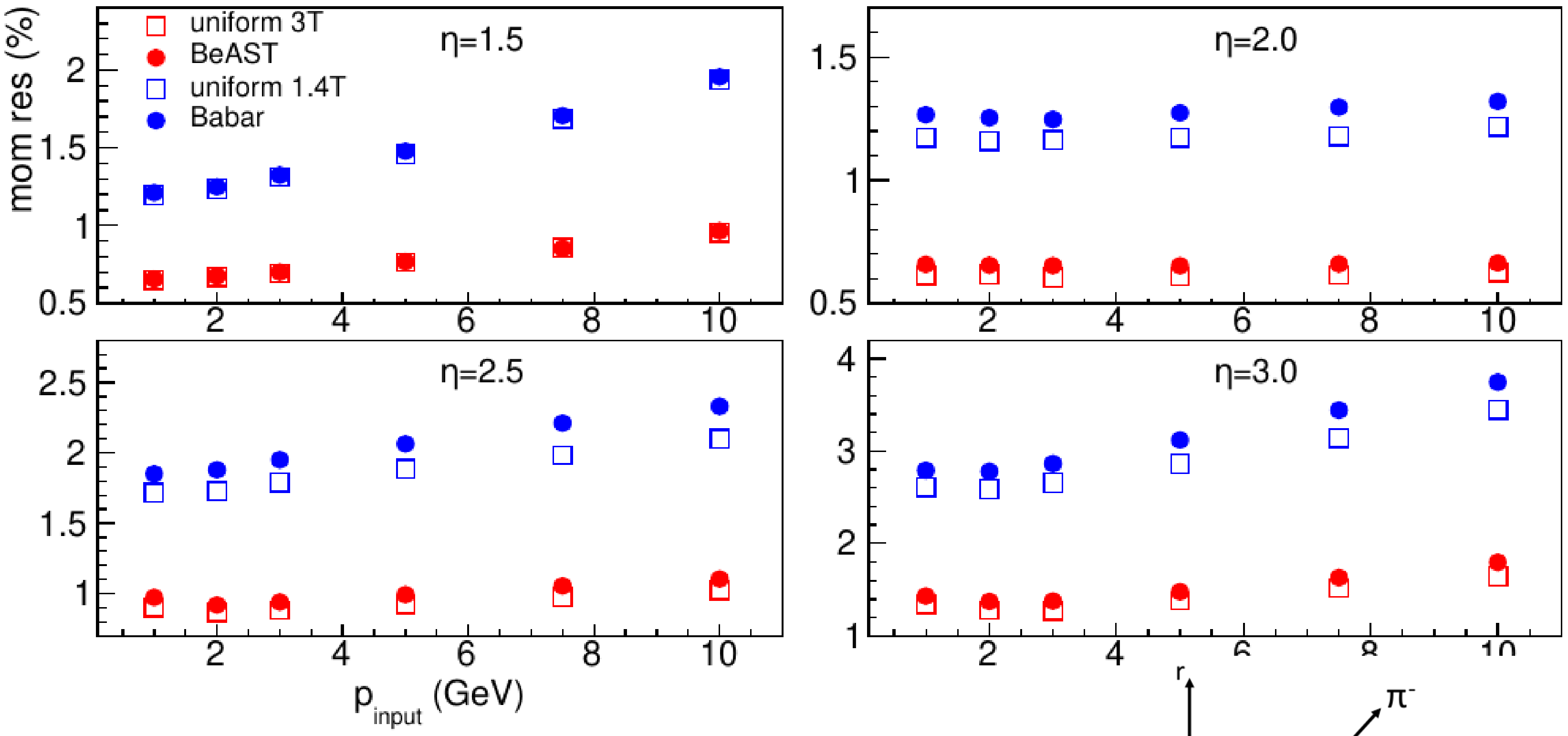


With 100 μm Si Thickness assumed on the full detector (barrel and FST) the highest material budget occurs at **θ ≈ 14◦ (η ≈ 2.1)**

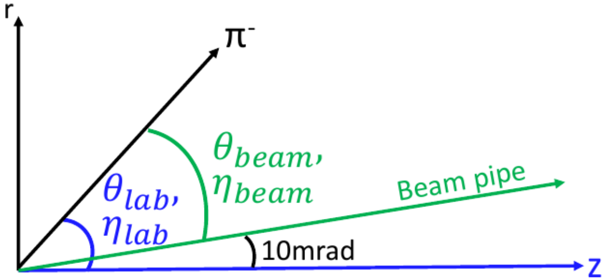
~ 2.2%x_0 , 1.4%x_0 and 1.1%x_0

Tracking performance: 3T vs 1.5T uniform/non-uniform B-Field

Fun4All, Cheuk-Ping Wong



A non-uniform B-field has an impact ~ η>2 with a larger effect on the 1.5T field.

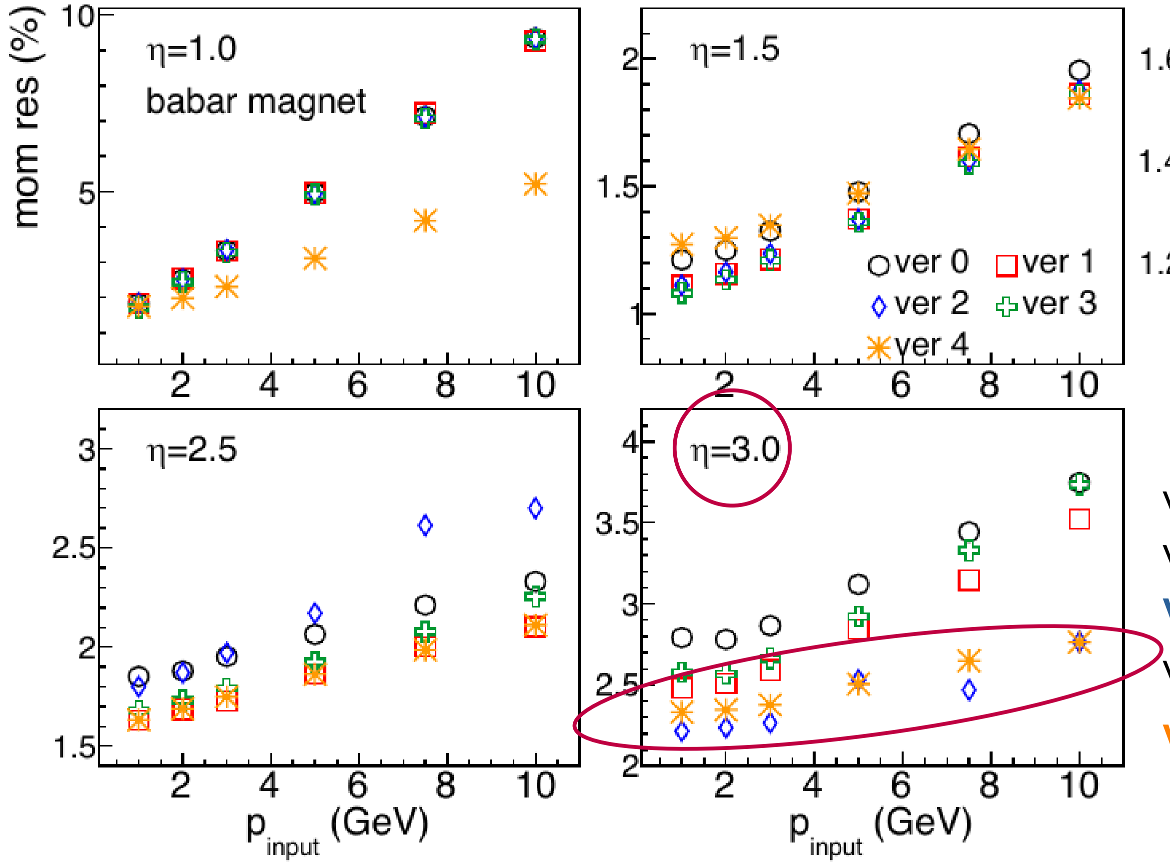


NB:Studies take into account correct pseudorapidity

LA-UR-20-26997

Disk z position and pixel size : 1.5T B-field

Fun4All



Fun4All
Cheuk-Ping Wong

V0: Slide 15 (five planes 35cm-130cm)

V1: Si Thickness 100µm → 50µm

V2: $Disk_4$ 1.25m → 2.7m; (Si @50µm)

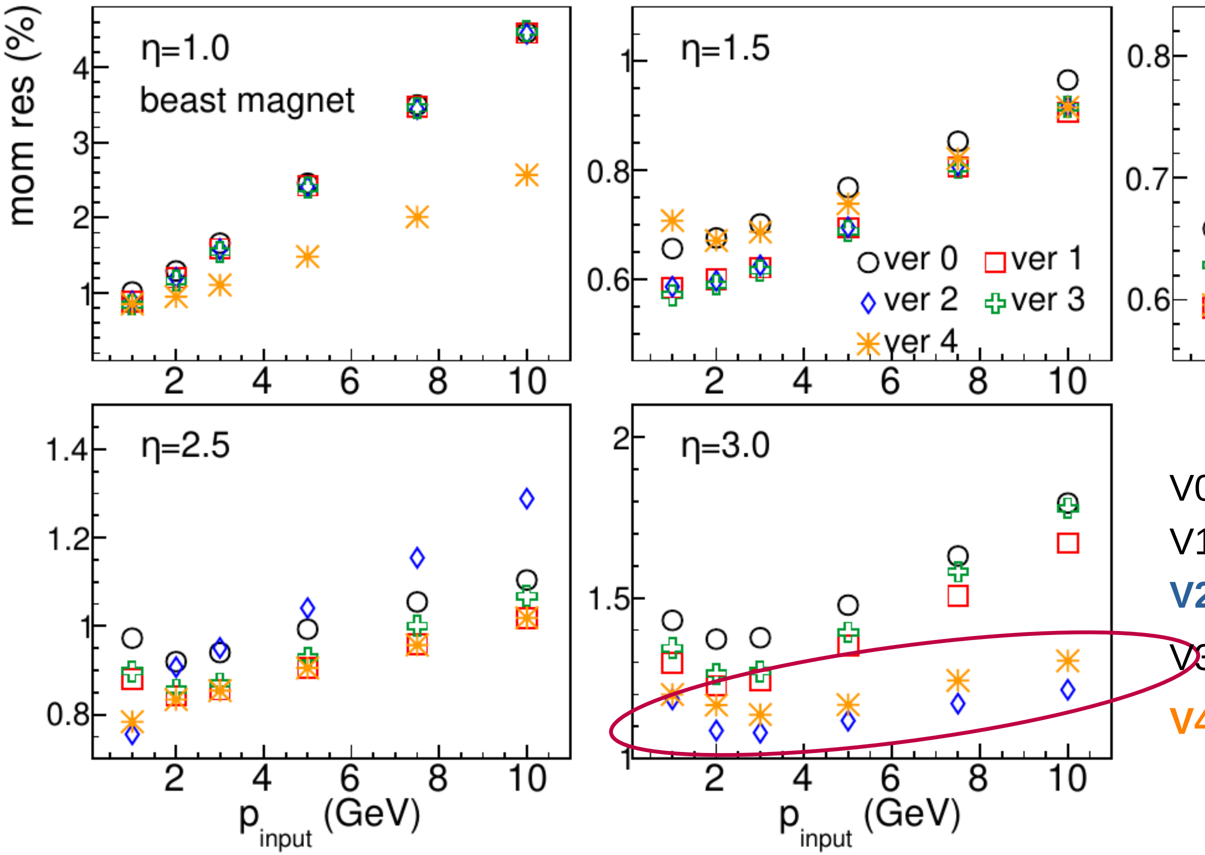
V3: $Disk_3$, $DIsk_4$ pitch 20µm → 36.4µm (Si@100µm)

V4: 6th disk and larger pipe hole r_1 (6.5cm → 15cm)

LA-UR-20-26997

Disk z position and pixel size: 3T B-field

Fun4All



Fun4All
Cheuk-Ping Wong

V0: Slide 15 (five planes 35cm-130cm)

V1: Si Thickness 100μm → 50μm

V2: Disk$_4$ 1.25m → 2.7m; (Si @50μm)

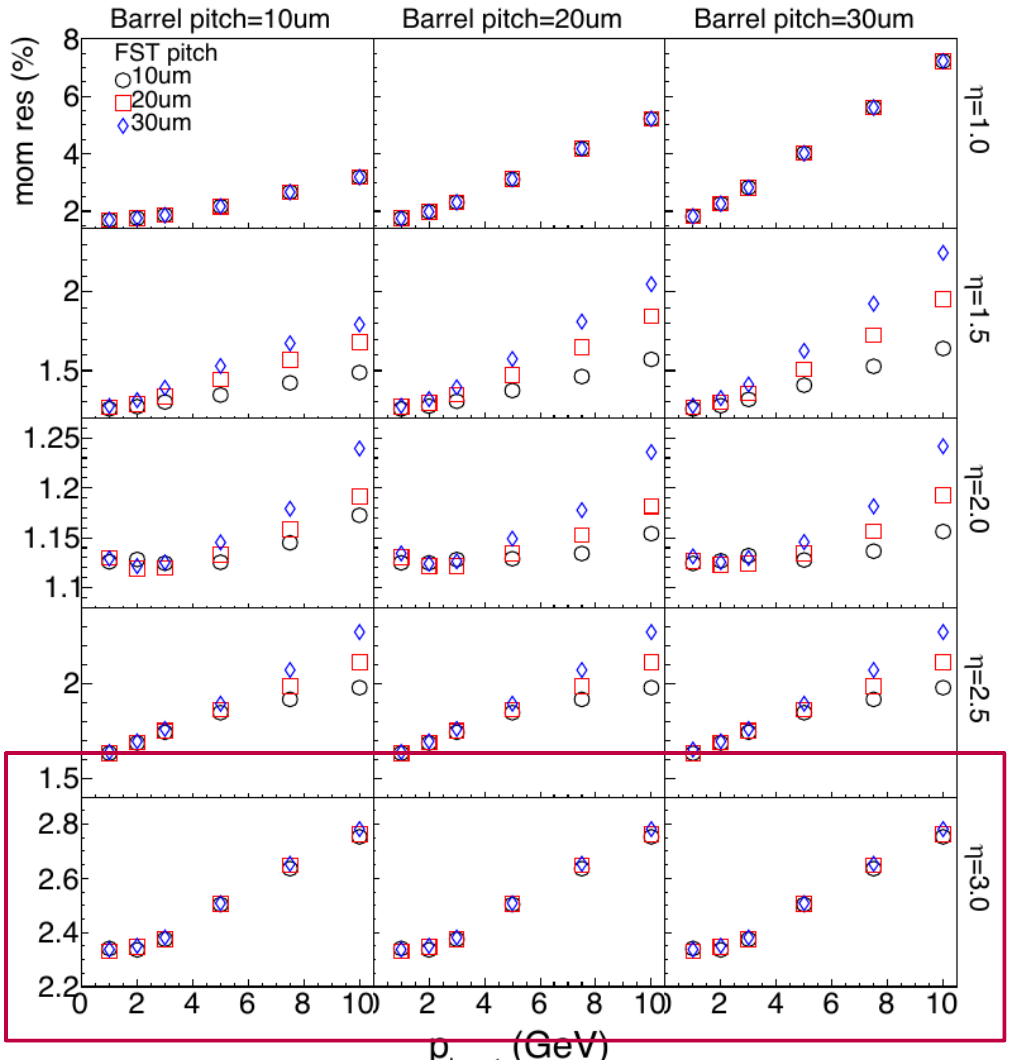
V3: Disk$_{3,}$ DIsk$_4$ pitch 20μm → 36.4μm (Si@100μm)

V4: 6th disk and larger pipe hole r$_1$ (6.5cm → 15cm)

Pixel Pitch effect on momentum resolution

Fun4All

Cheuk-Ping Wong



- η = 1 :

The momentum resolution heavily depends on the pixel pitch of the barrel detector

- η = 1.5 :

Dependence on the pixel pitch of both barrel and FST

- 2 ≤ η ≤ 2.5 :

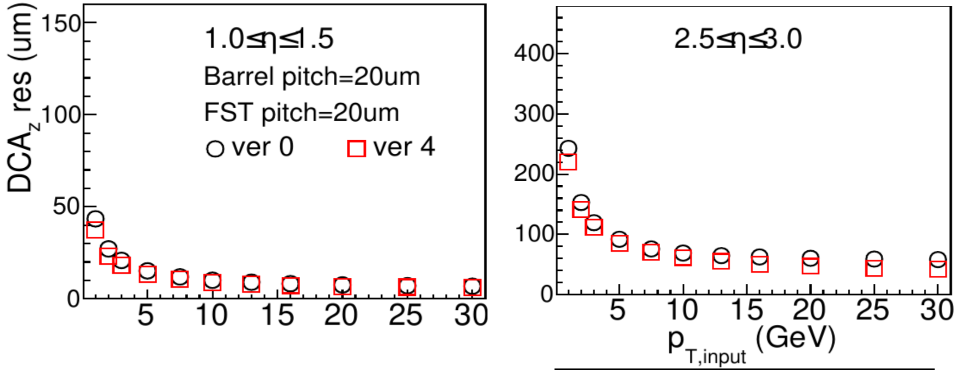
Dependance on the pixel pitch of the FST

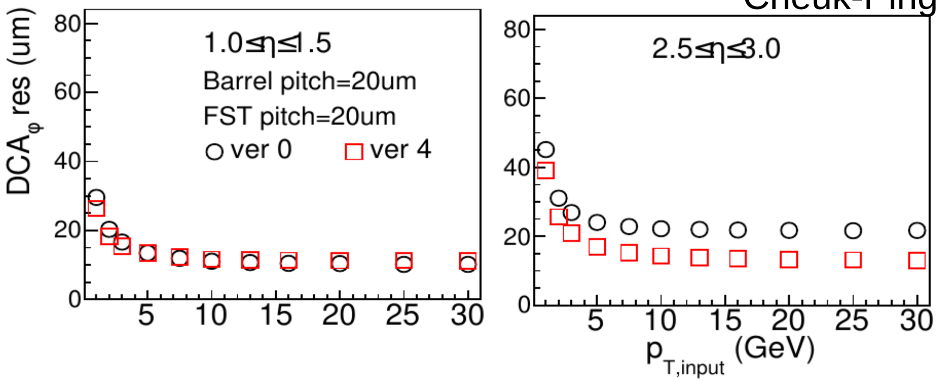
- η = 3 :

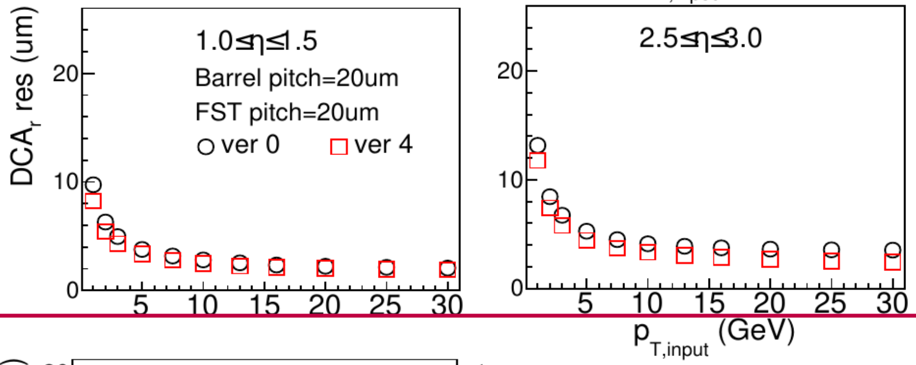
no significant pixel pitch dependence

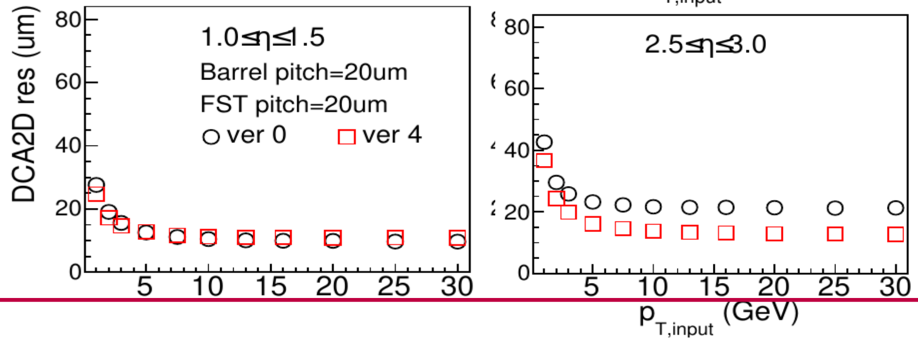
DCA resolution

Cheuk-Ping Wong









$$DCA_r = (pca - vtx) \cdot p_T \ ,$$

$$DCA_\phi = (pca - vtx) \times p_T \ ,$$

$$DCA_z = (pca_z - vtx_z) \cdot p_z \ ,$$

$$DCA2D = (pca - vtx) \cdot (p_T \times \hat{z}) \ ,$$

V0: Disks between 35cm-125cm

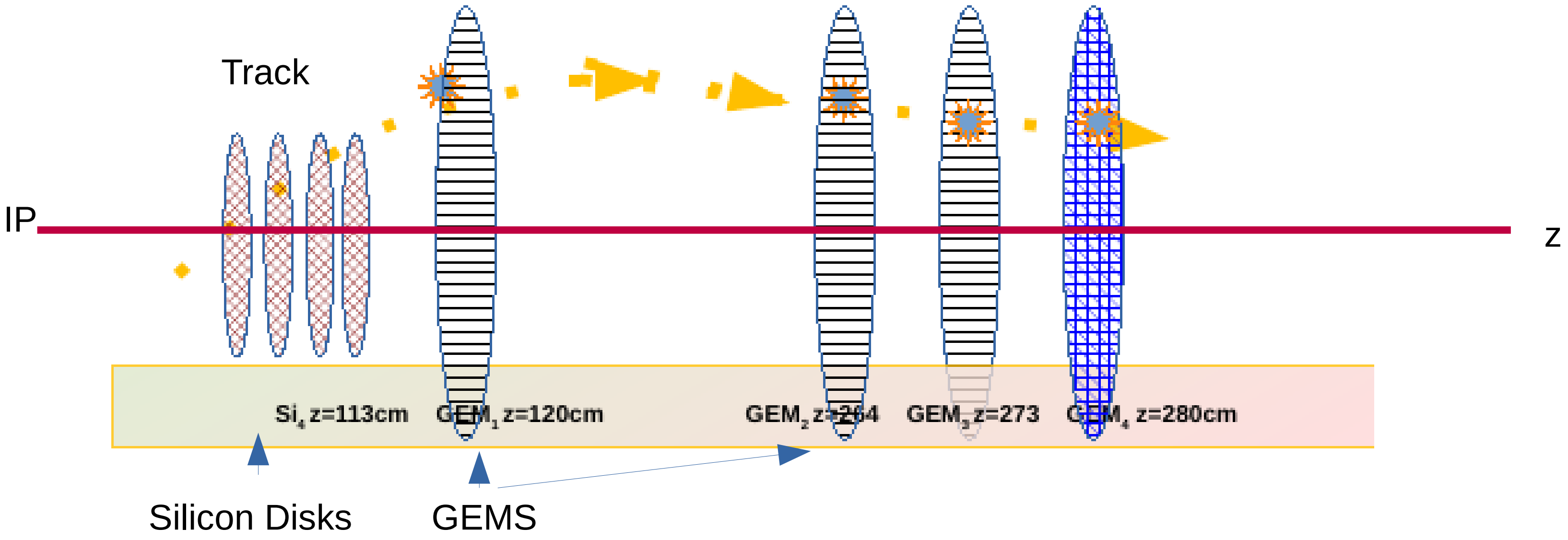
V4: Disk_4 1.25m → 2.7m; (Si @50μm)

How about GEMS at high z?

Silicon is unpractical and rather expensive to implement at high z (>2m)

Astrid M.

We have also studied the feasibility of measuring tracks with a Silicon design close to the IP (<1.3m) combined with large GEMS at the ends of the RICH (BeAST design)



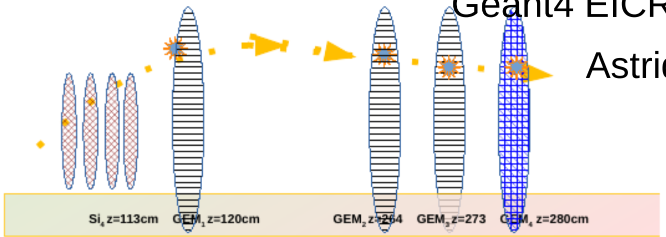
Measure the disk-difference in hit position for a given track

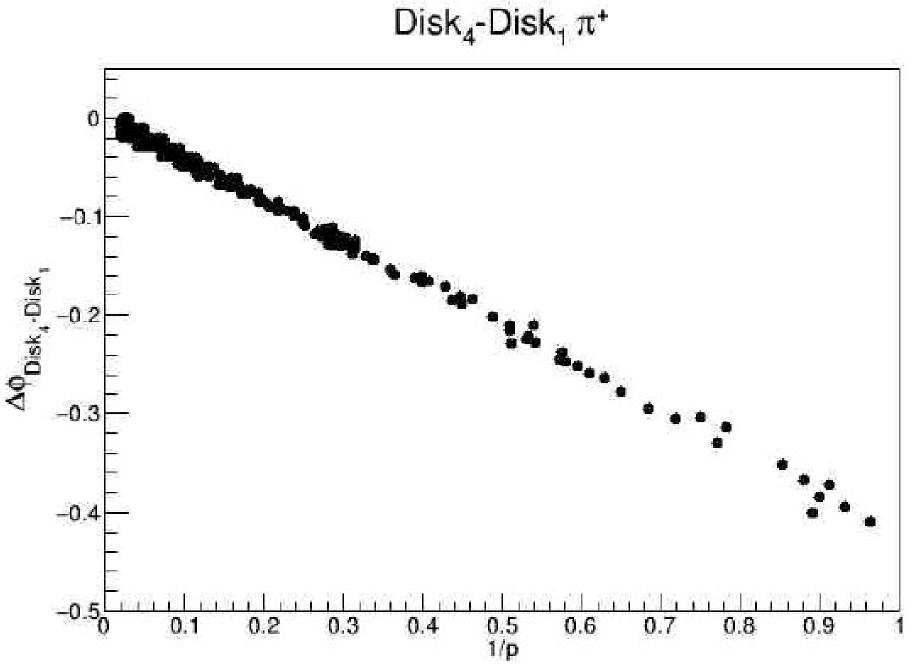
GEMS: track curvature under 3T

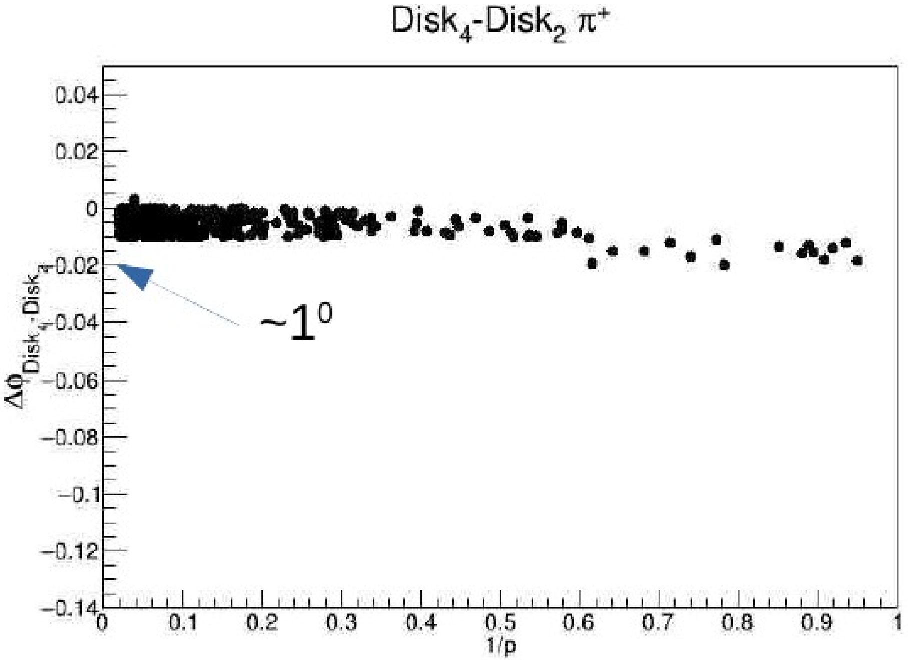
Geant4 EICRoot

Astrid M.

Last GEM Disk compared to first and adjacent disks







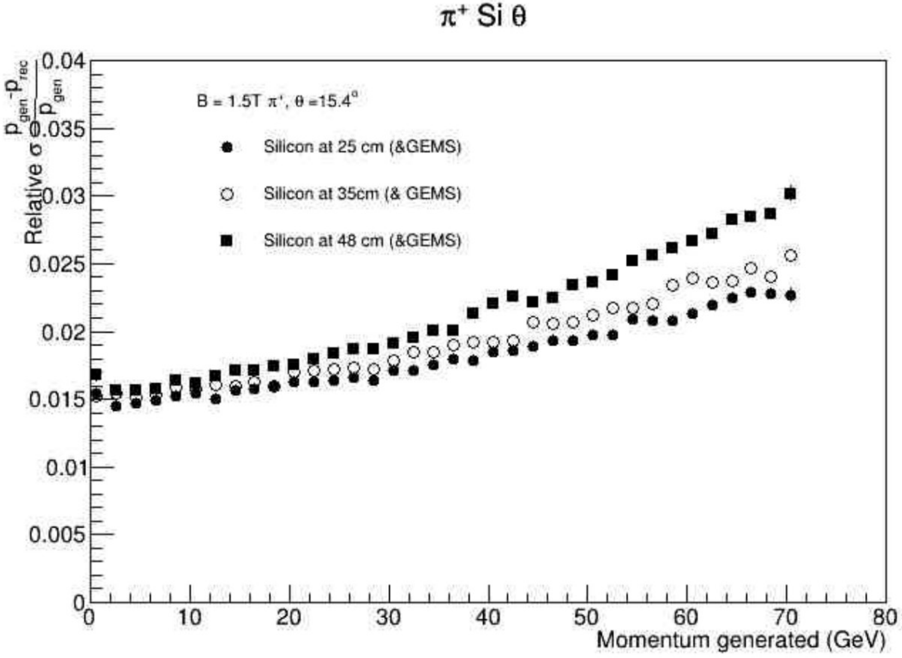
Adjacent disks at high z do not give us much (right figure), however combined with disks at around 1.2~1.4m you get enough tracking points to get enough curvature (left figure).

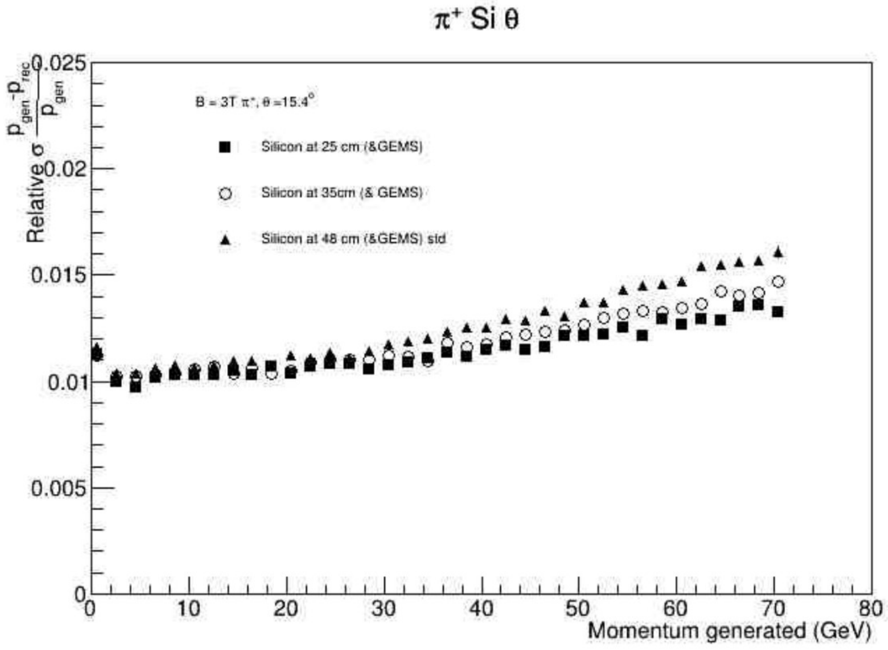
First disk position: Momentum resolution 1.5 vs 3T

Si+GEMS

Geant4 EICRoot
Astrid M.

Changing the z location of the first disk (Si) closest to IP:25cm → 48cm

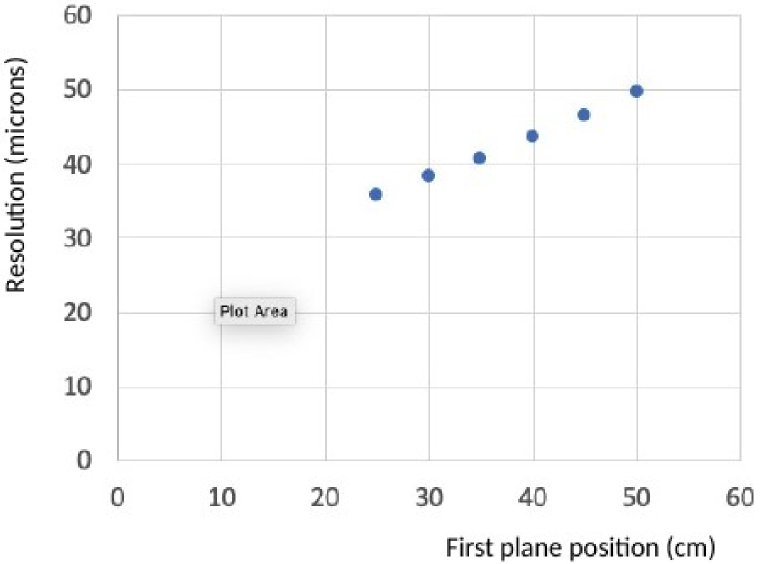


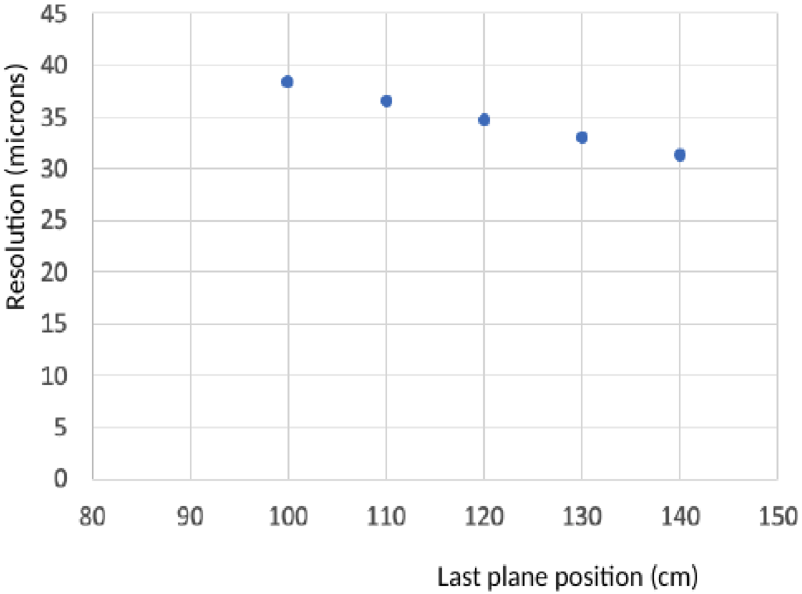


First plane position seems less relevant with the GEMS, the overall resolution is improved across all momenta.

Pointing resolution dependence of first/last plane

The distance from the interaction point to the vertex tracker has a significant effect on the pointing resolution from tracks back to the collision vertex.





Fast MC

Matt Durham

Left: Vertex pointing resolution varies ~35 microns to 50 microns when the first plane is 25 cm to 50 cm from the vertex.

Right: Vertex resolution varies from ~ 38 microns to 32 microns when the plane is moved out from

z=100 cm to 140 cm, a relatively small effect.

Summary

The current design (s) give a good pointing and momentum resolution.

The forward region (η >3) needs more research but we do not think it is an impossible quest.
-Different detectors at higher z,
-More disks/planes before and after the RICH's baseline position.
-Solenoid studies, finding an acceptable compromise with current magnet designs.

Lots of work ahead of us still

FST's TECHNICAL NOTE contains more details and the plots used in this presentation


Thank you!

DCA Study (Ping)

Simulation Setup for DCA Resolution Study

- Event configuration:
  - 10 π- per event.
  - Vertex (0,0,0)
  - 50k events in each p⊗η bin.
- Track configuration:
  - Momentum: 1-30 GeV with varying increments
  - Pseudorapdity: 1.5< η<2.5, 2.5< η<3.5
  - Hit efficiency at 95%.
- Magnetic Field
  - Beast Magnet peaks at 3T

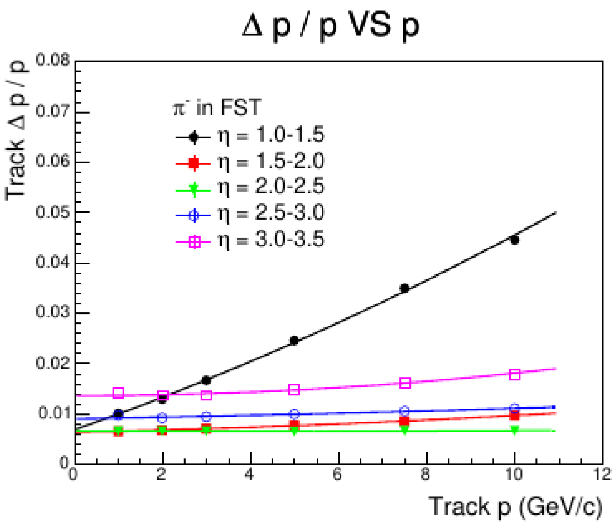
Tracking performance. B-field 3T

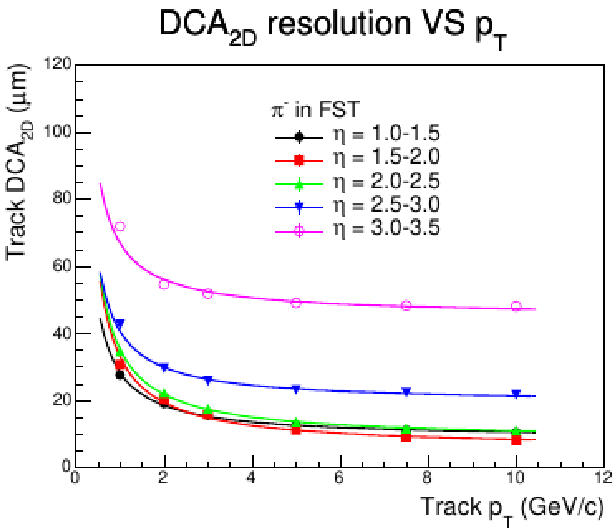
Fun4All

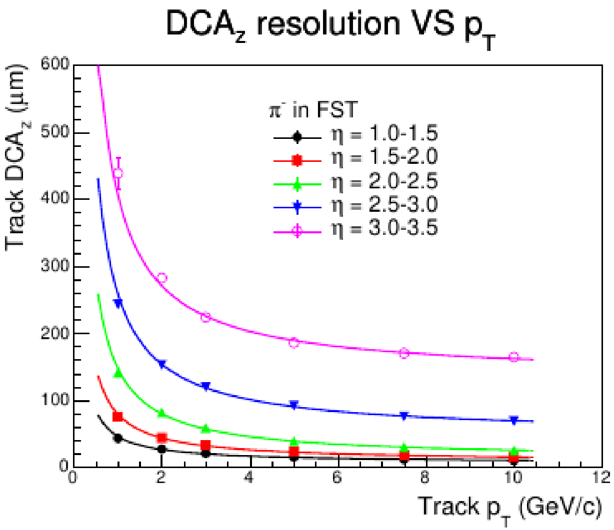
Pixel pitch for both barrel layers and forward planes are selected at 20 μm.

Fun4All

Xuan Li , Cheuk-Ping Wong





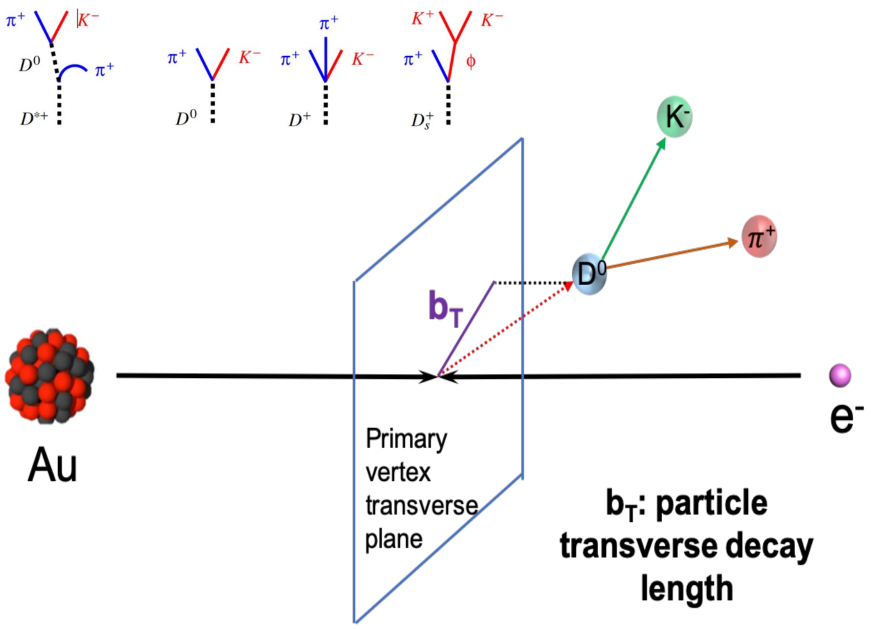


Left: relative momentum resolution in different η regions.

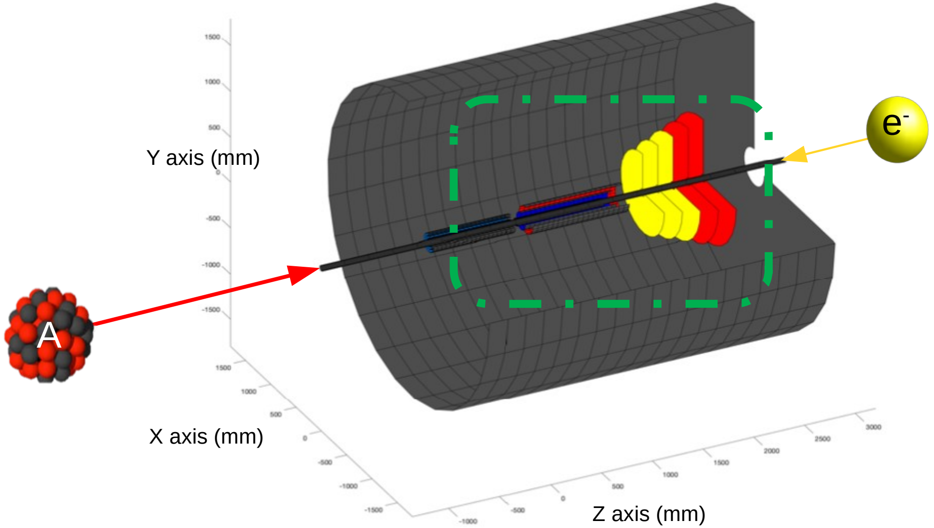
Middle: DCA_{2D} resolution

Right: DCA z resolution in the associated η regions.

1: Fast Simulations FST



Early geometry configuration at large z position



Mid-rapidity silicon vertex detector: 2 barrel layers MAPS or other silicon detector.

Forward-rapidity silicon tracking detector (FST): 5 forward planes of silicon detection.