2nd EIC Yellow Report Workshop

Pavia University (held online), 20-22 May 2020

Parallel session
Calorimeter & Particle ID & Tracking

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for the Tracking WG

Ongoing activities and available results

Ongoing activities:

- working on the following main deliverables:
  - ✓ evaluate all-silicon vs hybrid (silicon & gaseous) trackers
  - ✓ compare realistic alternatives (TPC, MPGD options) for gaseous detectors, barrel and forward
- preliminary performance studies (mainly EicRoot-based simulations):
  - ✓ central region Si-vertex + TPC + Fast MPGD Layers **advanced**
  - ✓ Cylindrical Micromegas (MPGDs) **just started**
  - ✓ endcap region GEM (MPGDs) trackers **just started**
  - ✓ all-silicon (barrel) tracker + forward/backward silicon disks **advanced**
  - ✓ comparisons all-silicon vs BeAST (Si-vertex + TPC + MPGDs) concepts **ongoing**
- effort on Fun4All and ESCalate frameworks:
  - ✓ first implementations of all-silicon tracker in Fun4All and G4E **ongoing**
  - ✓ plan to implement realistic material and services for all the tracking detectors **just started**

Available results:

- relative momentum and pointing resolutions (in different configurations and options)
- angular resolutions at DIRC (Si-vertex + TPC + Fast MPGDs different options)

Outline for today's discussion

Hybrid/gaseous detector options:

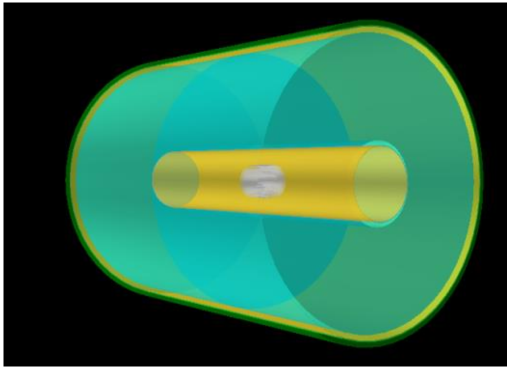
- central region Si-vertex + TPC + Fast MPGD Layers:
  - ✓ 3 options studied: no MPGDs + 2 different configurations with MPGDs before/behind DIRC
  - ✓ angular resolution before and behind DIRC position, relative momentum resolution
- cylindrical micromegas:
  - ✓ alternative to TPC, 2 different layer arrangements studied
  - ✓ Angular resolutions at DIRC position, relative momentum resolution
- material budget considerations
- pros/cons summary table

Silicon detector trackers:

- all-silicon tracker option:
  - ✓ tapered all-silicon in Fun4All, first estimates of the angular resolutions
- all-silicon and Si+TPC tracker studies
- pros/cons all-Si vs hybrid trackers

Si-vertex + TPC + MPDGs

Matt Posik, for eRD6

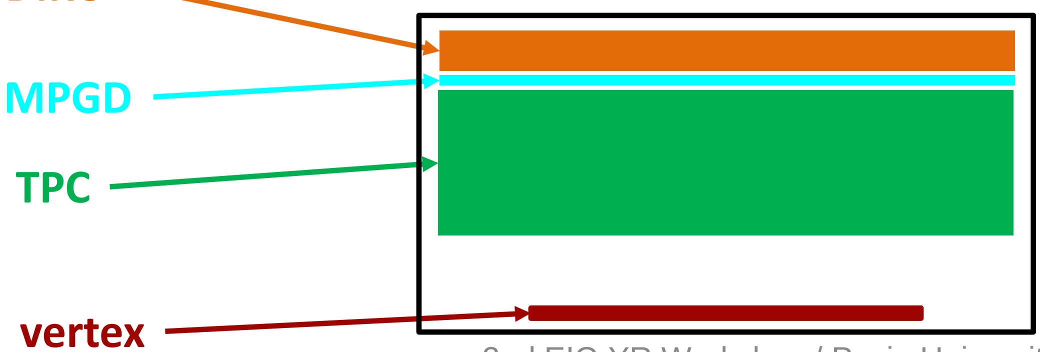


Detector setup:

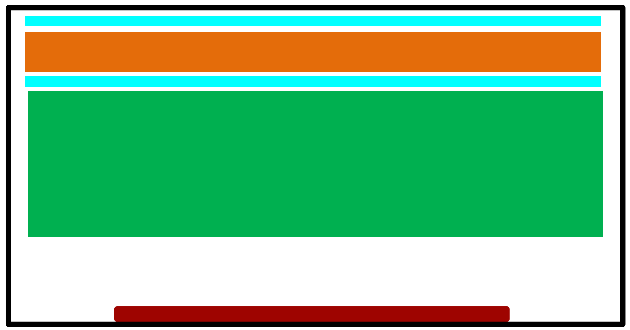
- Si-vertex tracker: 4 layers of 20 $\mu m \times 20\ \mu m$
- TPC: No distortion corrections, field cage and end cap materials included
  - Transvers Dispersion: 40 $\mu m/\sqrt{D}$
  - Transverse Resolution: 90 μm
  - Longitudinal Dispersion: 1 $\mu m/\sqrt{D}$
  - Longitudinal Resolution: 500 μm
- MPGDs in µTPC mode: $100\ \mu m \times 100\ \mu m\ (\phi \times Z)$
- 3 configurations investigated
  - No MPGDs
  - One MPGD layer in front of DIRC
  - 2 MPGD layers sandwiching DIRC

No MPGD

1 MPGD in front of DIRC



2 MPGDs "sandwiched" DIRC

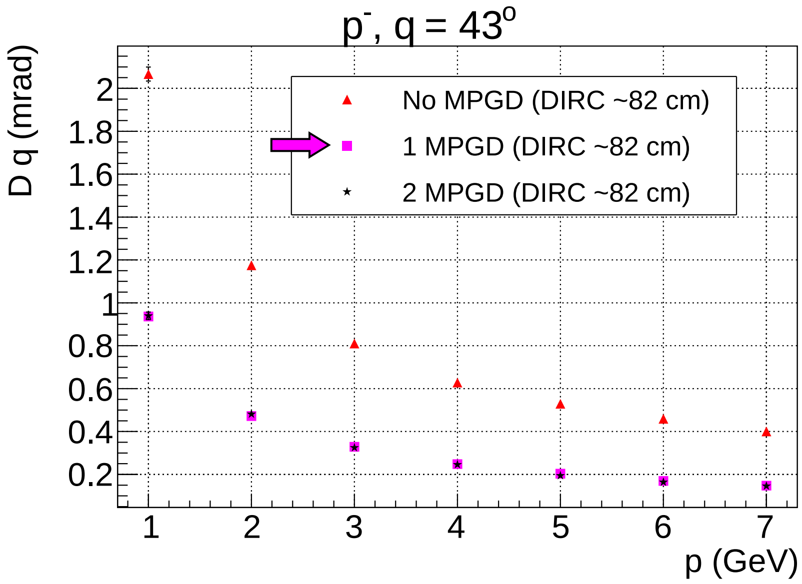


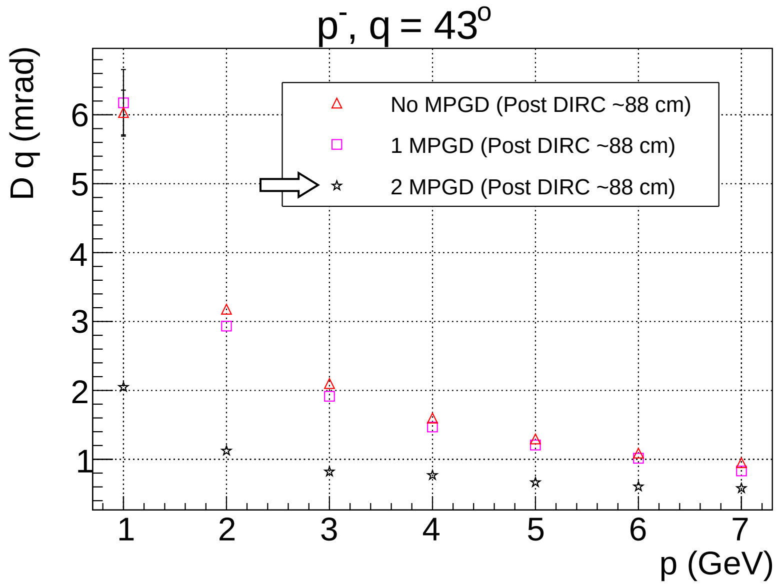
Si-vertex + TPC + MPDGs

Matt Posik, for eRD6

Angular resolution Δθ before and after the DIRC:

- B = 1.5 T,
- Solid Markers: At DIRC (~82 cm)
- Open Markers: Behind DIRC (~88 cm)
- Significant improvement seen in angular resolution behind the DIRC with MPGD layers sandwiching it
  - Angular resolution Δθ ~ 0.25 mrad before DIRC



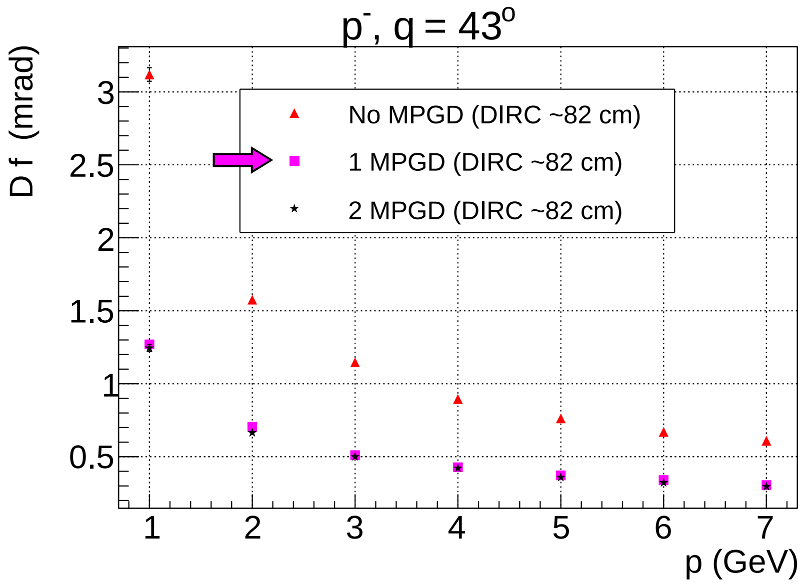


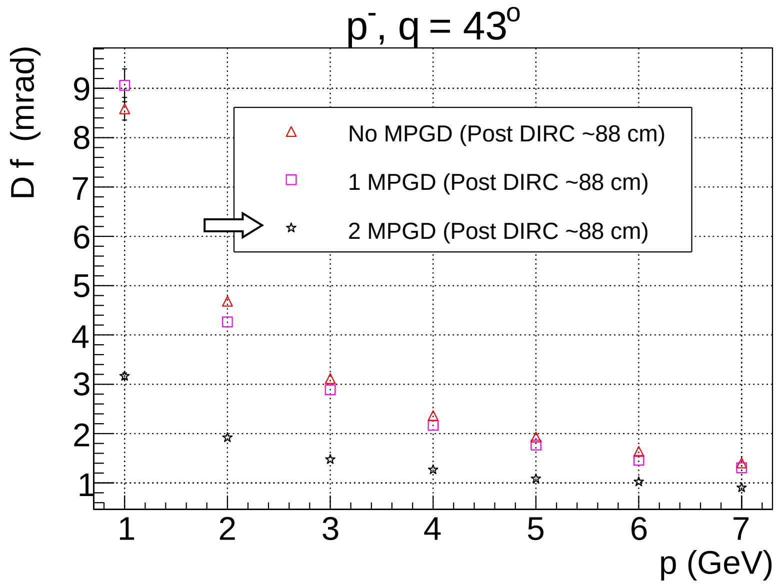
Si-vertex + TPC + MPDGs

Matt Posik, for eRD6

Angular resolution ΔΦ before and after the DIRC:

- π^{-}, B = 1.5 T, $\theta = 43^{0}$
- Significant improvement seen in angular resolution behind the DIRC with MPGD layers surrounding the detector
  - Around 1 mrad $\Delta\phi$ resolution moderate p (> ~5 GeV).





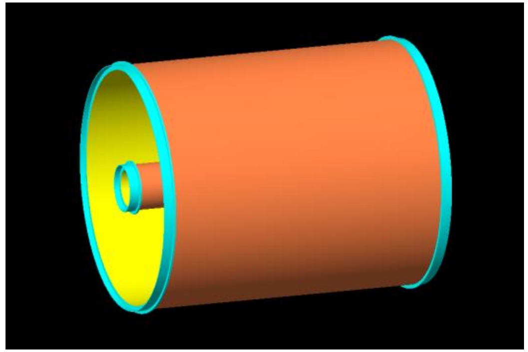
Si-vertex + TPC + MPDGs

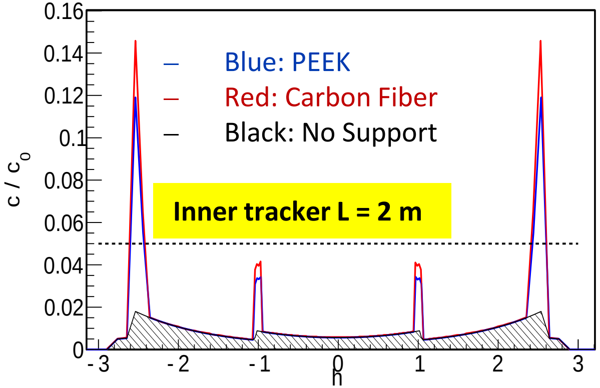
Matt Posik, for eRD6

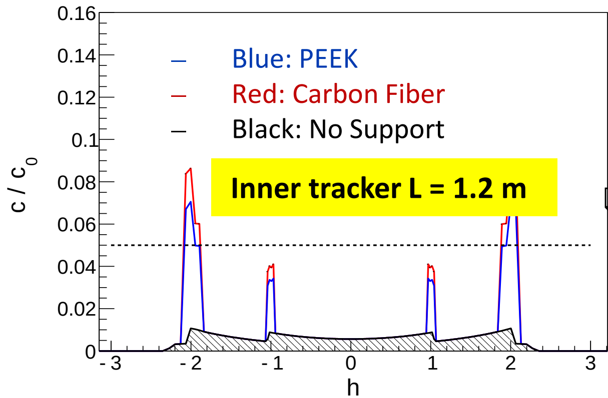
Material budget

- Detector configuration; Fast layers in barrel region
  - Outer µRWell layer: L =2 m; radius = 80.0 cm
  - Inner µRWell layer: L = 1.2 m; radius = 12.5 cm
- Support Ring Structure Geometry
  - Tube: thickness = 0.5 cm, length = 7.2 cm
  - Ring (inner): thickness = 1.6 cm, length = 1.2 cm
  - Ring (outer): thickness = 0.5 cm, length = 1.2 cm

Mock prototype (support ring)





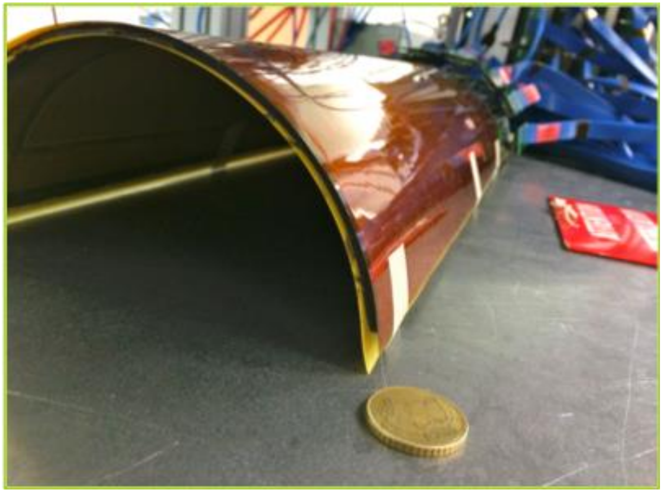


- Next Steps Implement
  - **supports every ~ 50 cm**
  - **Readout card material & endcap**

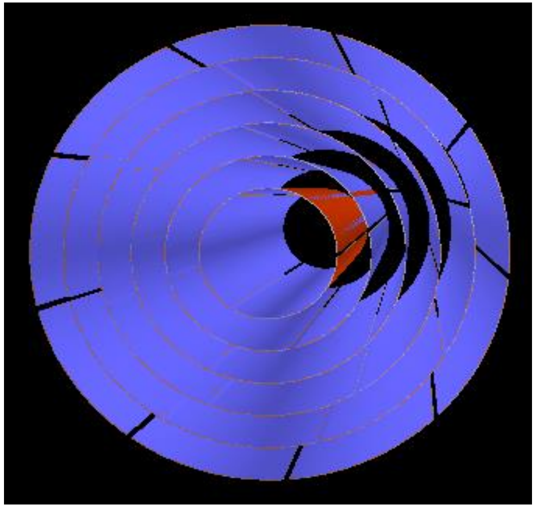
Cylindrical Micromegas

Qinhua Huang, CEA Saclay

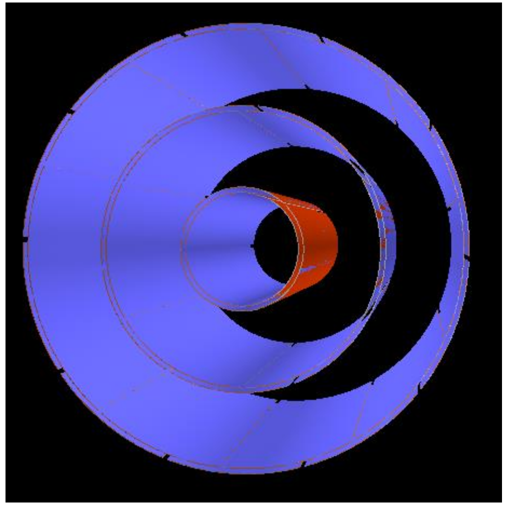
- Barrel MPGD tracker as TPC alternative:
  - Curved MPGD tiles with low material budget
  - Micromegas technology is being used in CLAS12
  - Possibly readout 2D coordinates on a single layer
- Simulation and performance study are under the ePhenix context
  - ePhenix TPC is replaced with the tracker
  - R is from 20 to 80cm, 2 tracker configs are studied



X/X0 ~ 0.3% per layer



6 equidistant layers



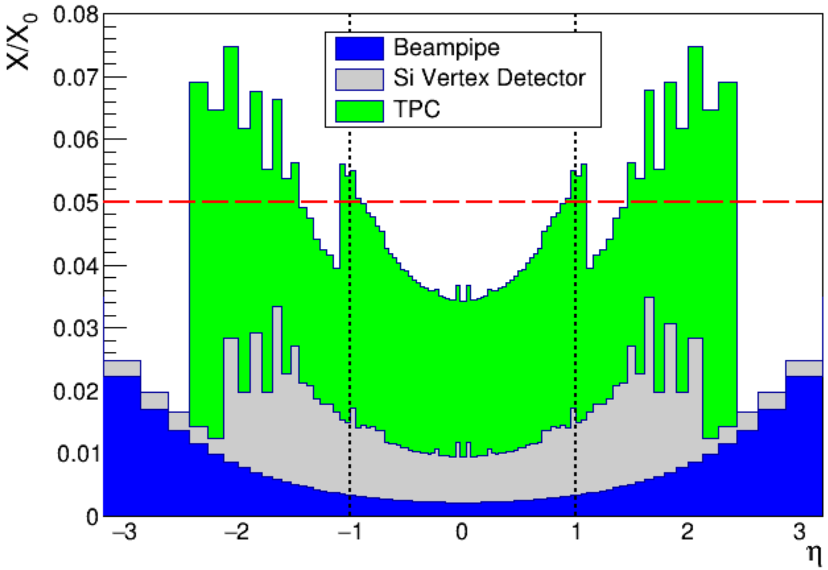
6 layers arranged as 3x2

Cylindrical Micromegas

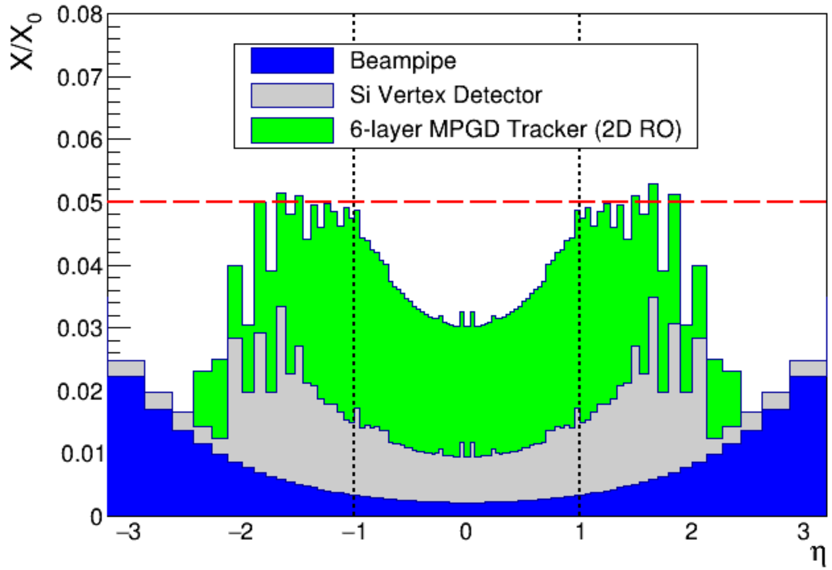
Qinhua Huang, CEA Saclay

- Compare material budget for TPC and 2D readout MPGD trackers
- Both TPC and 2D readout MPGD tracker are compatible with the requirement that X/X0<5% for central tracker

TPC



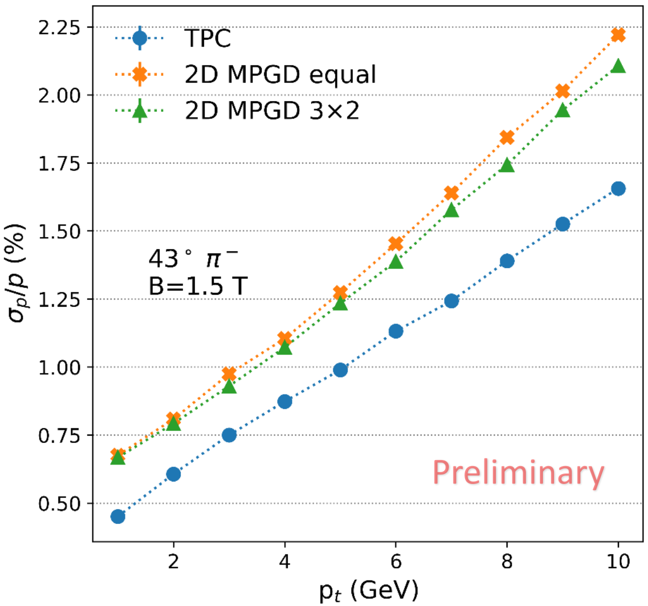
6-layer 2D RO MPGD tracker

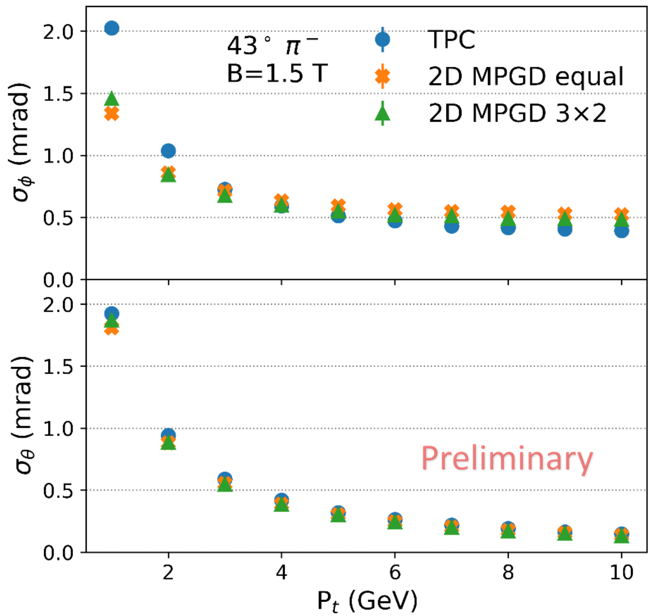


Cylindrical Micromegas

Qinhua Huang, CEA Saclay

- Compare momentum/angular resolutions at DIRC (r=81.5cm) of different configs
  - Each point contains 10k π^- shot from (0,0,0) and with a constant θ=43°
  - Track reconstruction includes SVTX measurements: σ(R/ϕ/Z)=5μm
  - For TPC: σ(ϕ)=200μm, σ(Z)=500μm
  - For MPGD: σ(ϕ)=150μm, σ(Z)=150μm
- Vigorous R&D ongoing at CEA Saclay to verify a potential improvement of the performance with micro-TPC mode



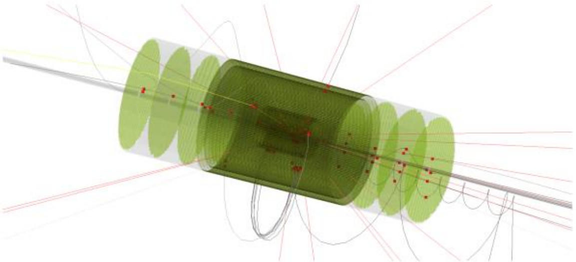


Gaseous Detectors: technology input for complementarity

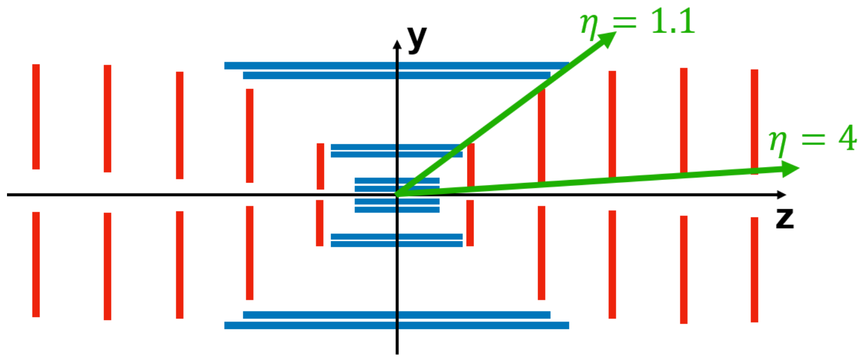
	TPC + Fast MPGD Layer	Cylindrical MPGD (Micromegas, µRWELL)	Drift Chambers / Straw Tubes	Planar MPGDs (GEM, Micromegas, µRWELL)	Small TGCs	MPGD-TRDs
Barrel region	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Space point & angular res. - Time resolution (< 10 ns) - **Low material in End cap** - **Cost & robustness**	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Alternative to cylindrical MPGDs arrangement in polygons - **Easier fabrication**	N/A	N/A Radiator size
	Cons: - **End cap material** - calibration space charge distortion	Cons: - Momentum res. - Fabrication challenges - **Material budget in barrel**	Cons: - **End cap material** - calibration - Stability issues	Cons: - Momentum res. - Detector space barrel - **Material budget in barrel**		
Hadron End Cap	N/A Only planar option		Pros: - momentum res.; - additional dE/dx; - **cost**	Pros: - Momentum & angular res. - Low material (< 0.4% X/X0 per layer) - **Cost & robustness**	Pros: - Momentum & angular res. - **Cost & robustness**	Pros: - Additional tracking - Angular res. for RICH - **Additional e/π PID**
			Cons: - **Material budget** - calibration - Stability issues	Cons: - **?**	Cons: - **Material budget**	Cons: - Radiator size
Electron End Cap	N/A Only planar option		N/A	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness**	N/A Mainly because of material budget	Pros: - Additional tracking - **Complement main e PID in electron end cap**
				Cons: - **?**		Cons: - Radiator size?

All-silicon angular resolutions

Rey Cruz-Torres, Winston DeGraw - UCB



Tapered All-Si Tracker in Fun4All



Functionality added by Chris Pinkenburg to project momenta onto cylinders or planes

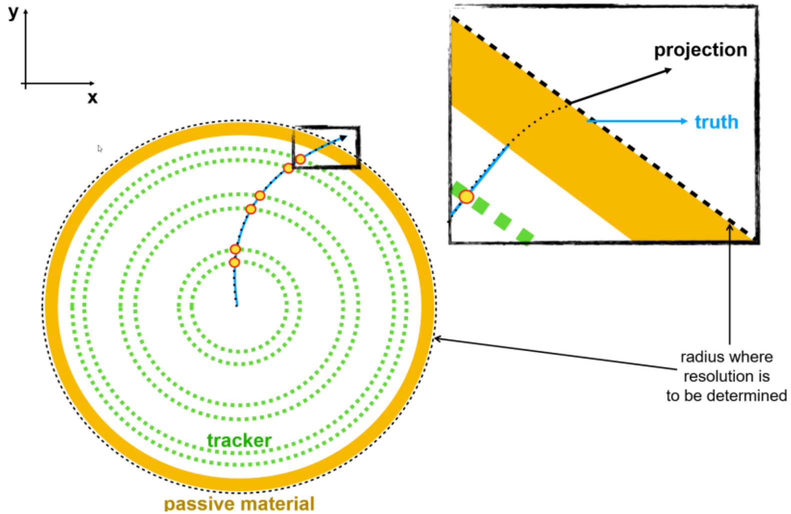
Kalman Filter: PHG4TrackFastSim

Generation (~5M events):
vertex: (0,0,0)
momentum: (0,50 GeV/c)
$|\eta|$: (0,4)
ϕ: (0,2π)

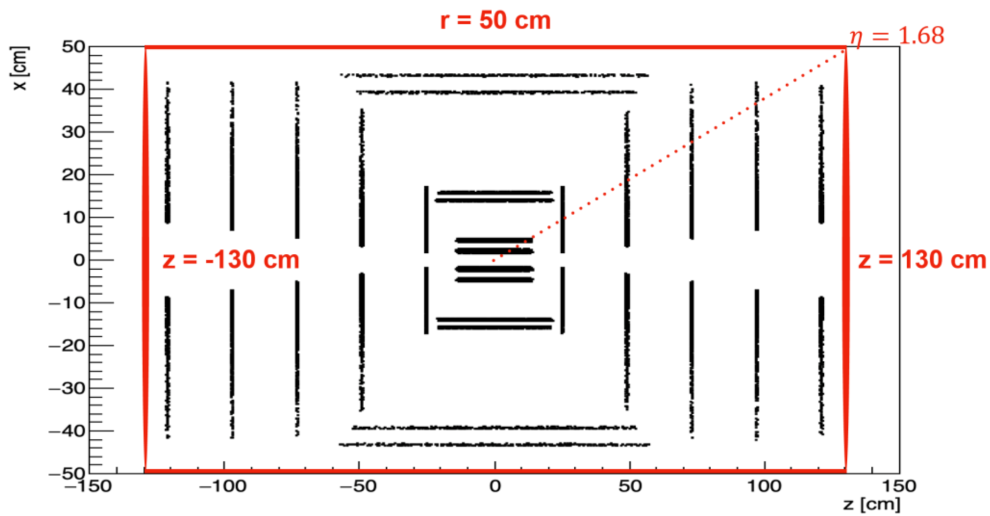
Additional parameters:
generated particle (π^+, π^-, μ^-, e^-)
B field: 1.5, 3.0 T (solenoidal)

Only the silicon is implemented in the simulation
No support structure/services implemented

All silicon angular resolution



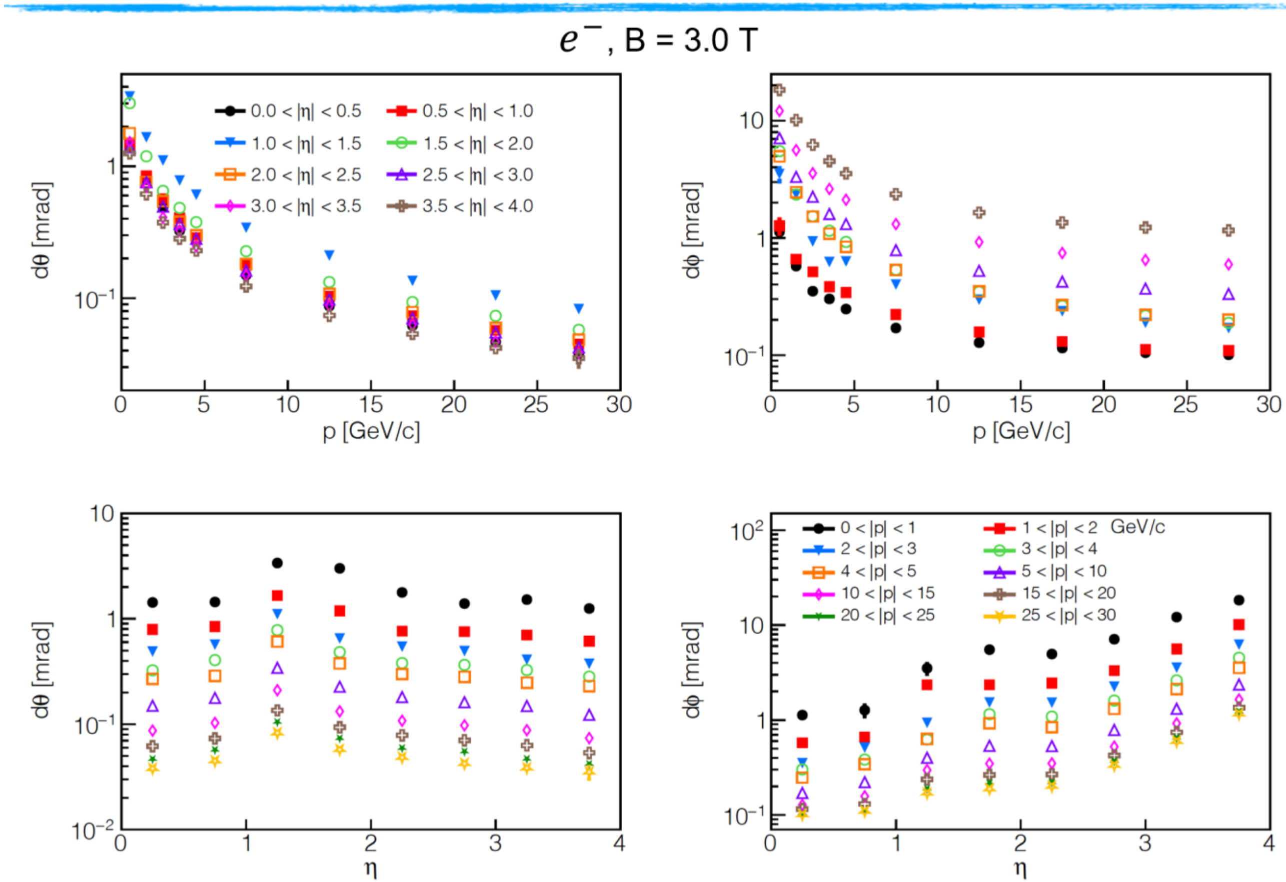
The tracking resolution is established by the projected track vs “truth” track



The angular resolution is shown on a cylindrical surface with the shown dimensions

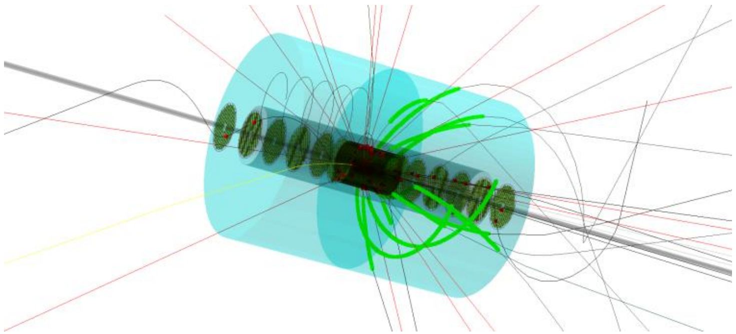
Rey Cruz-Torres, Winston DeGraw - UCB

Angular resolutions on detector outer surface

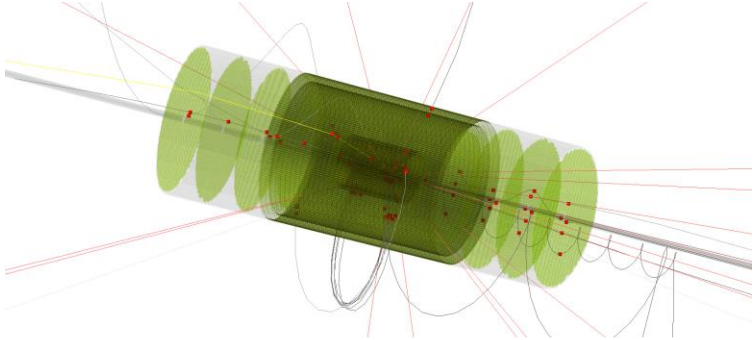


Rey Cruz-Torres, Winston DeGraw - UCB

All-silicon and Si+TPC studies



Beast TPC + Si barrels and disks (“hybrid”)



Si barrels and disks (“all silicon”)

All-silicon layout:

Two eRD18 vertex layers, seven eRD16 “tapered” equidistant disks in a BeAST configuration, and an ALICE-like outer barrel, in a 3T solenoidal field

<u>In addition:</u>

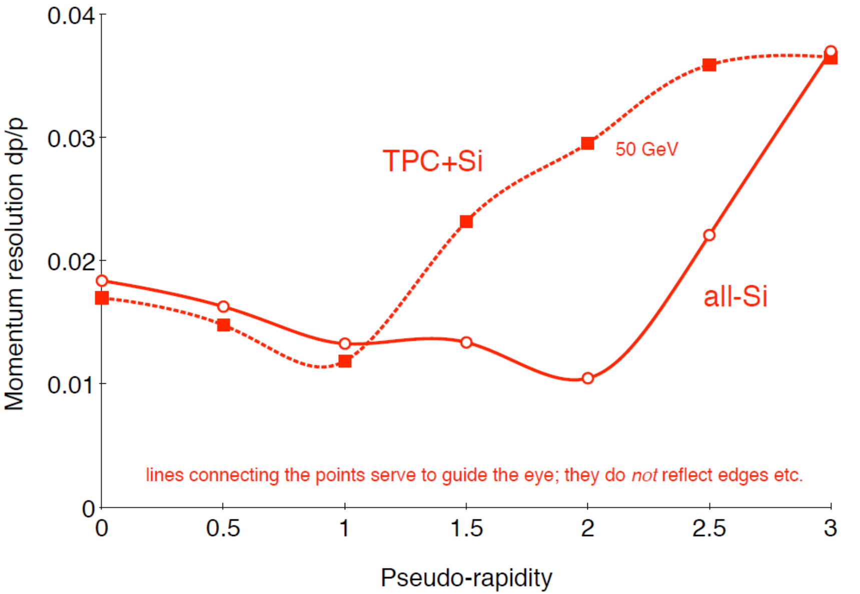
Material cones/cylinders surrounding the disks were implemented to make a start on the effects associated with support structures, read-out infrastructure, etc.

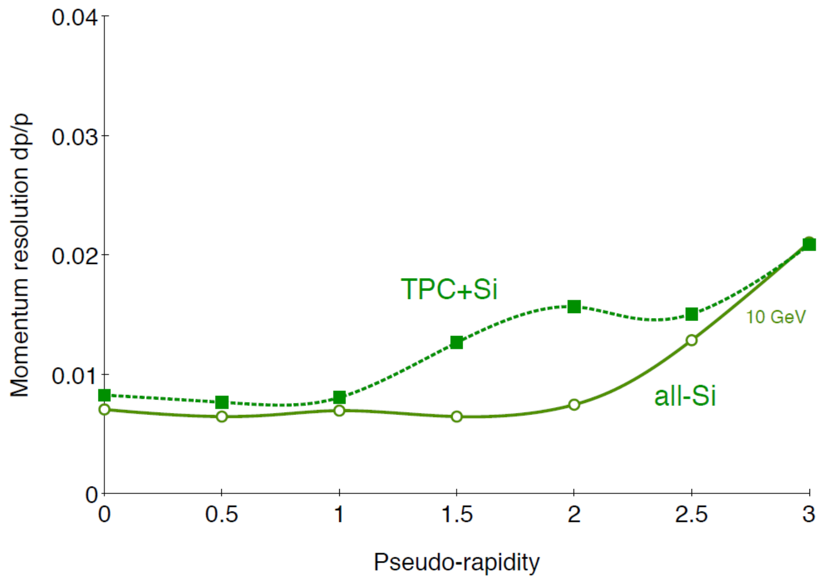
Ernst Sichtermann et al, eRD16

Ernst Sichtermann et al, eRD16

All-silicon and Si+TPC studies

Momentum resolution as a function of pseudo-rapidity

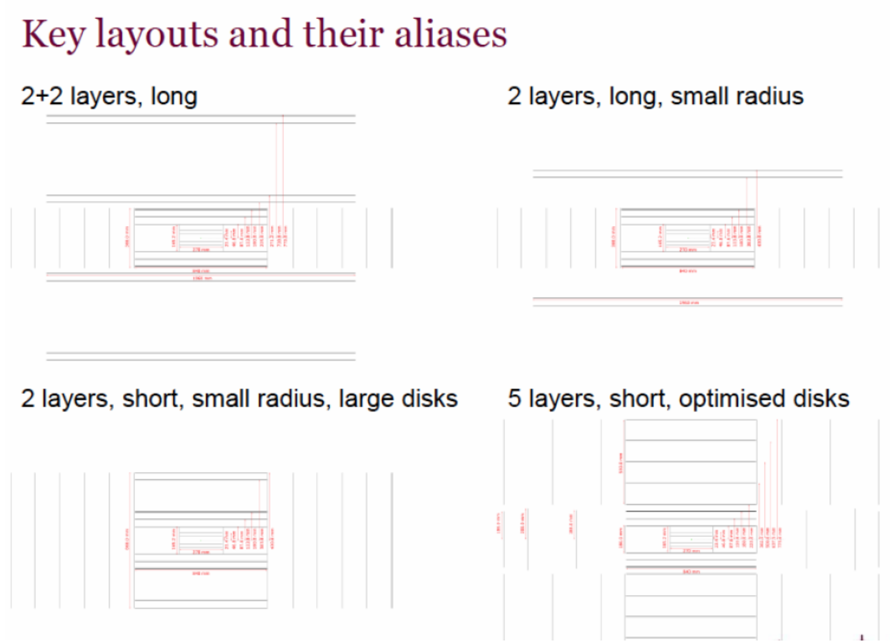


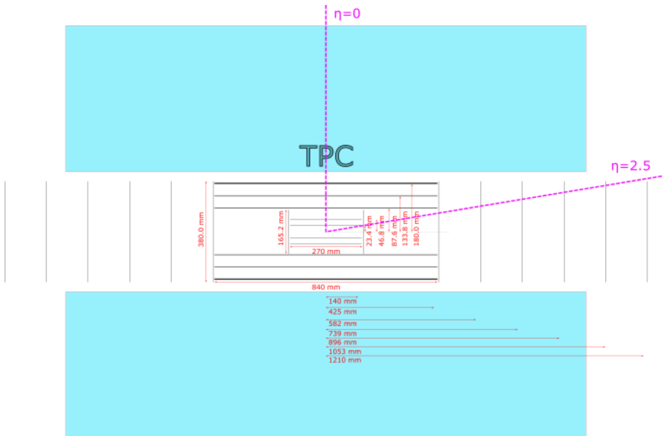


All-silicon and Si+TPC studies

Håkan Wennlöf et al, UoB

- Various all-silicon layouts tested
- 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 $\%X_0$

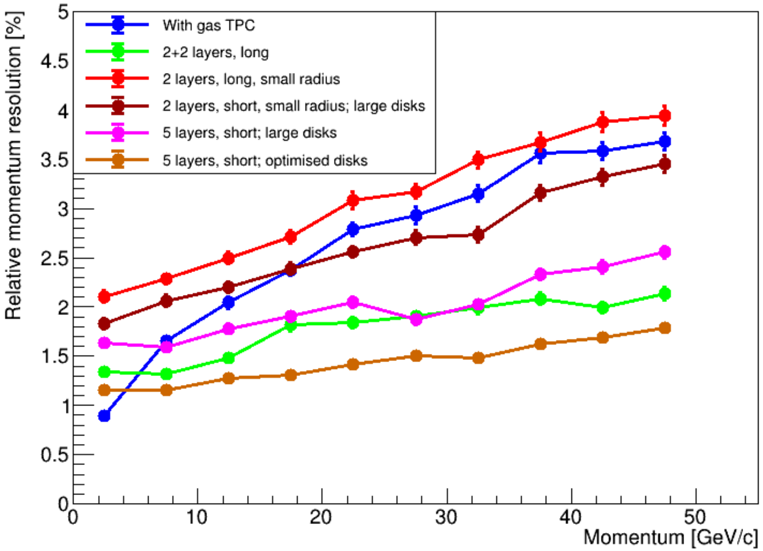




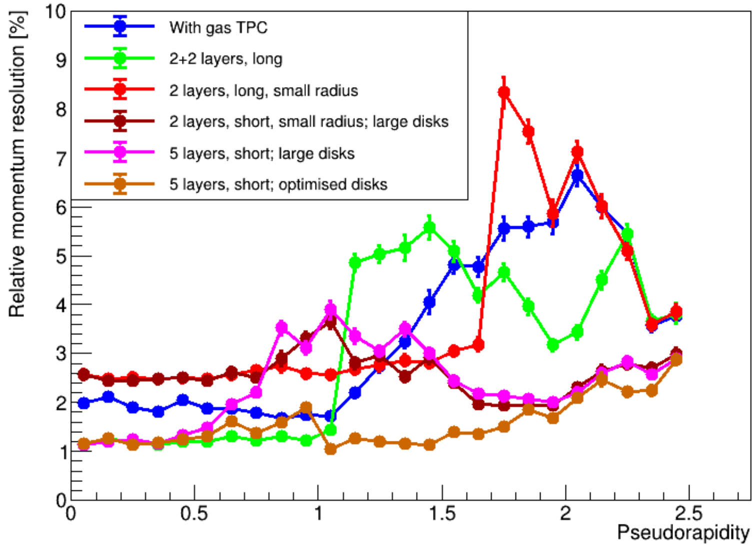
All-silicon and Si+TPC studies

Håkan Wennlöf et al, UoB

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+TPC at p≥5 GeV/c
- Pointing resolutions do not change much between layouts, apart when layers are missed

Tracking WG: technology input for complementarity

ITS3 silicon design parameters

Parameter	Wafer-scale sensor (this proposal)
Technology node	65 nm
Silicon thickness	20-40 µm
Pixel size	O(10 x 10 µm)
Chip dimensions	scalable up to 28 x 10 cm
Front-end pulse duration	~ 200 ns
Time resolution	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2
Max particle readout rate	100 MHz/cm^2
Power Consumption	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%
Fake hit rate	< 10^{-7} event/pixel
NIEL radiation tolerance	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	10 MRad

Tracking Si central detector (vertex + barrel + discs)

Technology: for the vertex, barrel and inner disc detectors, the only identified technology that meets the requirements are MAPS. No currently existing MAPS sensor appears to fully meet all of the EIC requirements (current simulations are based on ALPIDE sensors with a smaller pixel size 20 x 20 um^2). In order to produce a new sensor design that meets the EIC requirements a consortium of EIC groups are joining an ongoing sensor development effort at CERN. There are contingency plans for modification of existing sensor designs to meet EIC requirements should this CERN effort be unsuccessful.

There is general consensus that this is a promising path to pursue to deliver an EIC sensor in the given timeframe. Momentum and pointing resolution performance studies are in progress. EIC requirements seem satisfied.

	Stave X/X0
ITS3 like vertexing	~0.1%
ITS3 like barrel (up to 1.5m length)	0.55 %
ITS3 like disc (up to 60 cm diameter)	0.24%

Si + gaseous detector vs. all silicon

	Si + gaseous	All Si
Attributes for consideration	• dE/dx in gas for PID • Well understood technology - less R&D needed. • Costs less (likely) • Less material in tracking region • Worse single point resolution but more position samples	• Readout faster than TPC • Better momentum resolution than TPC at higher momentum (>~5GeV/c) • Can be made more compact • Less material in endcap regions • Fewer calibration/correction issues • Very high single point resolution

backup

Implications of 31 mm radius beam pipe

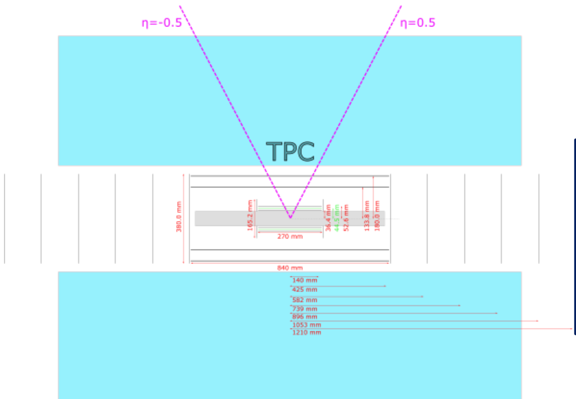
Old beam pipe r = 18 mm, new beam pipe r- = 31 mm

- Tests done with 2 and 3 inner layers
- 31 mm tests done with inner layers moved out, and new layout without time-stamping layer

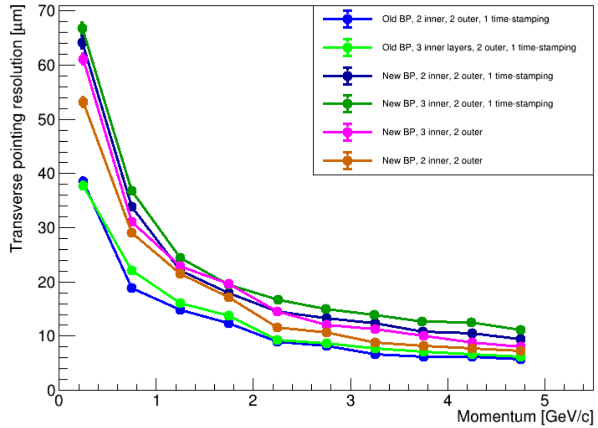
Same TPC (EICROOT standard) always present

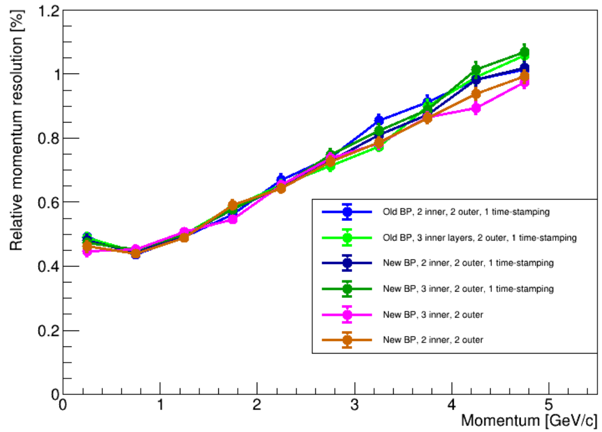
Parameters used:

- π+, Pt =0 to 5 GeV/c, -0.5 ≤ η ≤ 0.5, 20x20 μm^2, 0.3/0.8 % X_0 inner/outer layers, 1.6 % time-stamping layer
- uniform 1.5 T



Some loss of pointing resolution at low momentum for larger beam pipe





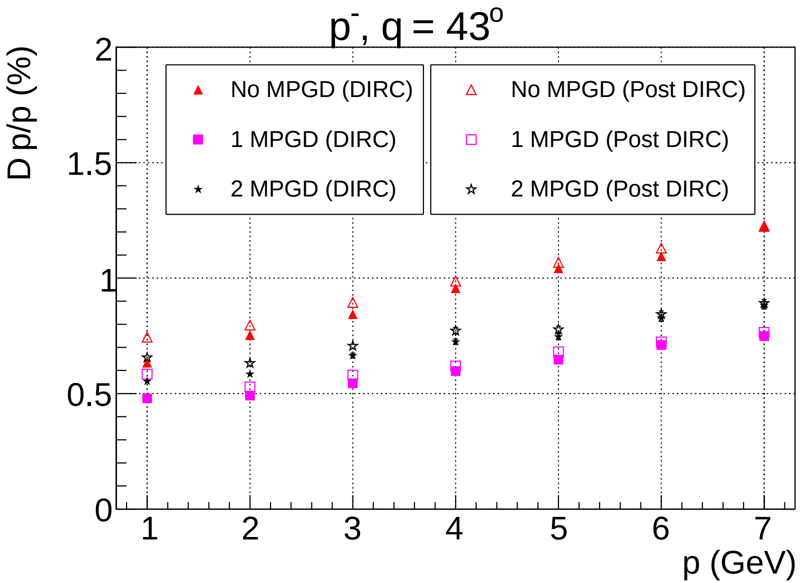
H. Wennlöf et al., UoB

Si-vertex + TPC + MPDGs

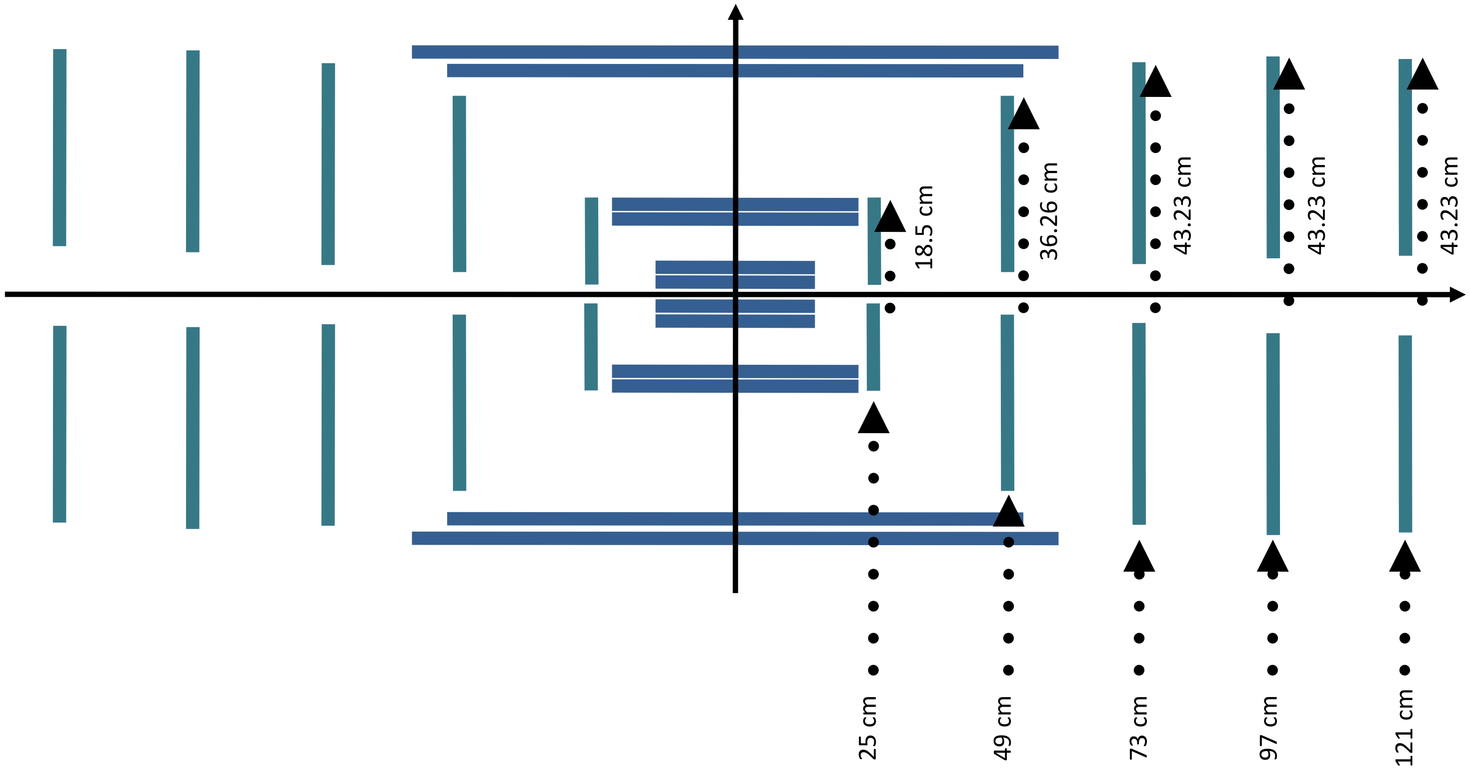
Matt Posik, for eRD6

Relative momentum resolution:

- One MPGD layer in front of DIRC significantly improves momentum resolution
- A second MPGD after DIRC slightly degrades performances because of multiple scattering in DIRC bar
  - However it is not really an issue as this data point is not needed for the momentum

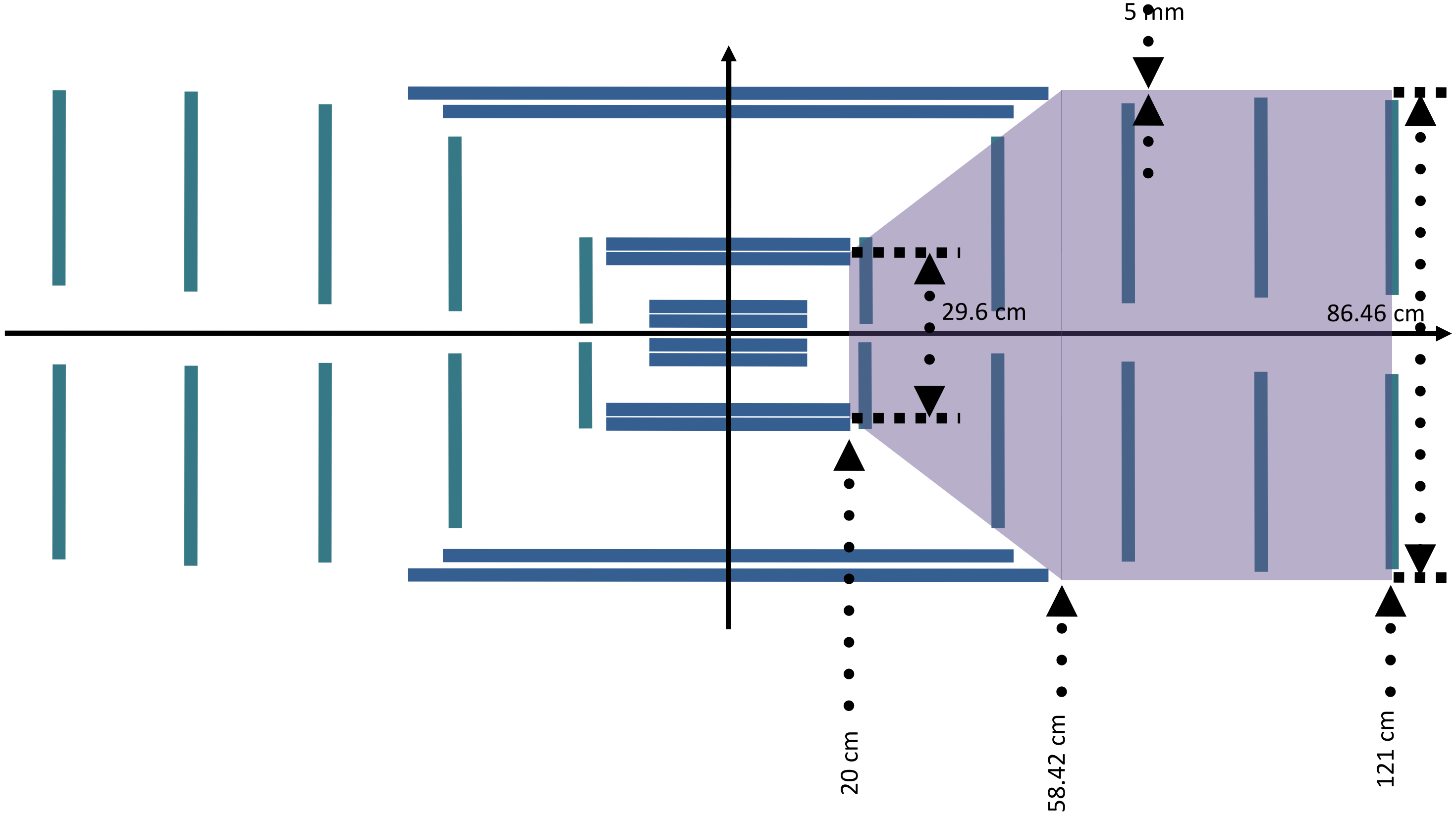


Disks

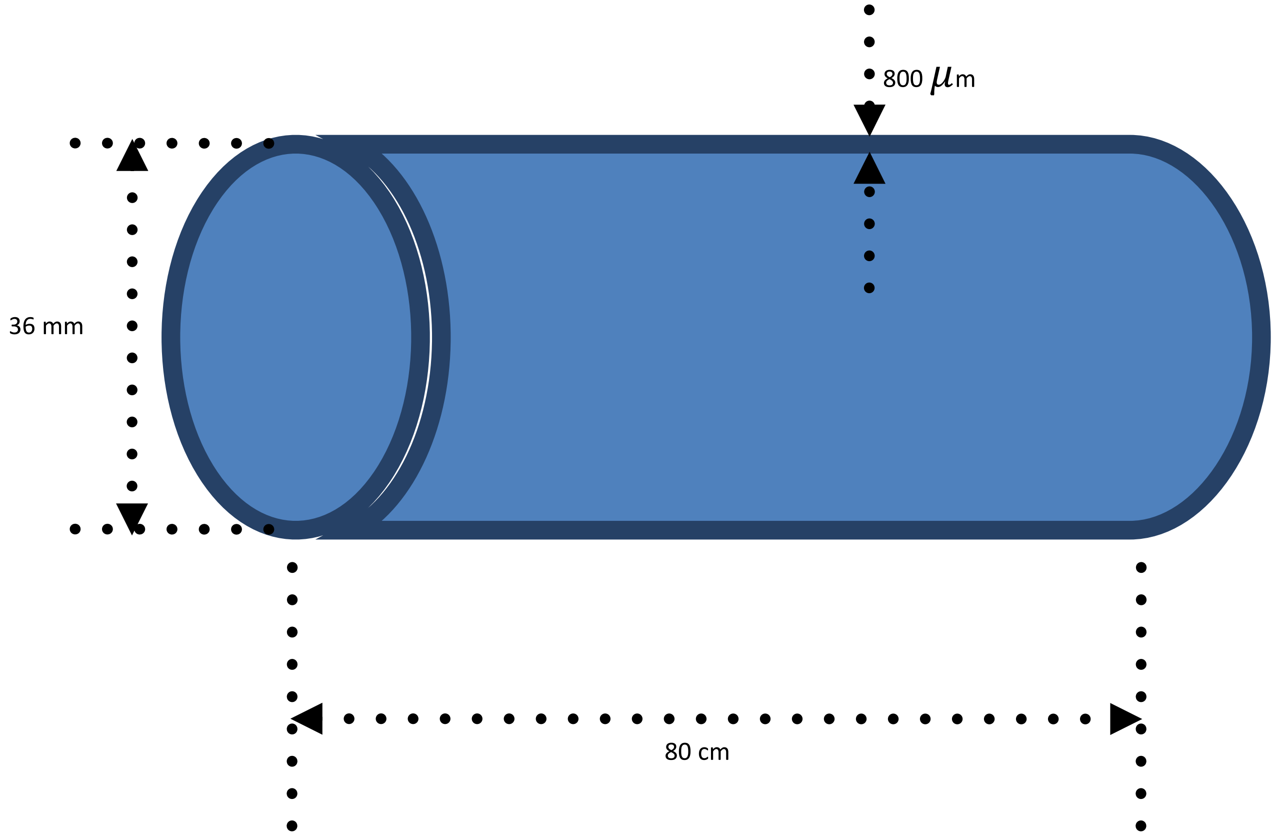


18.5 cm
36.26 cm
43.23 cm
43.23 cm
43.23 cm
25 cm
49 cm
73 cm
97 cm
121 cm

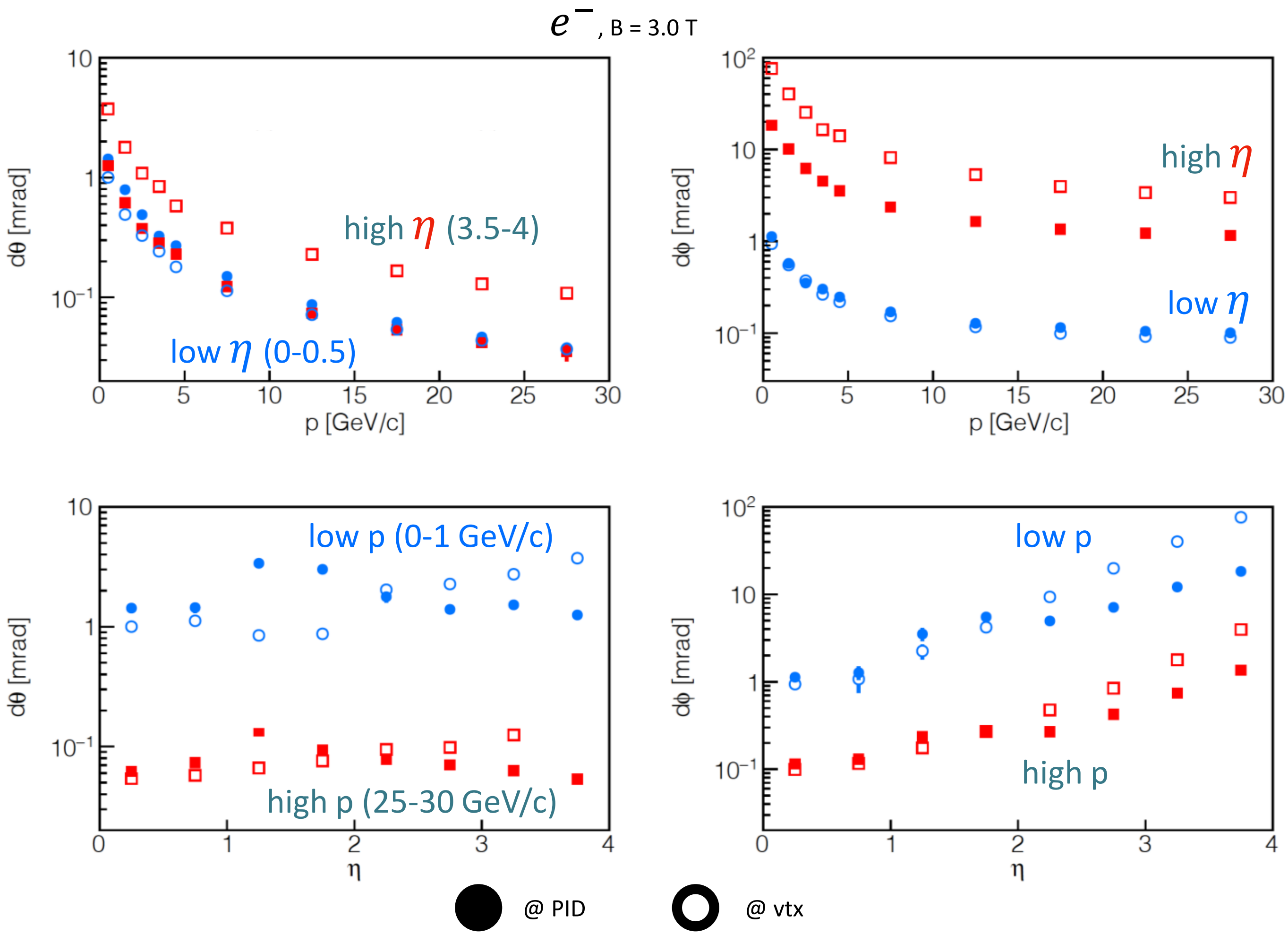
Aluminum Support Structure



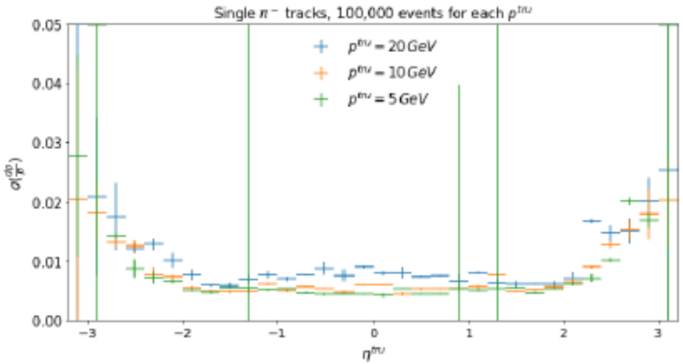
Beryllium beampipe

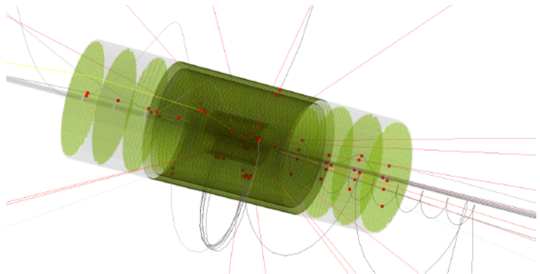


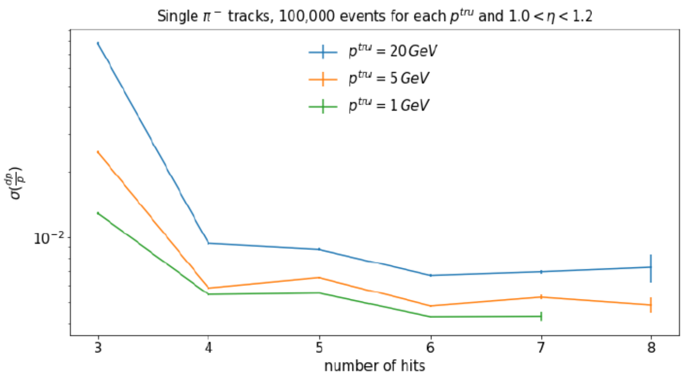
Comparison with vertex resolution



eRD16+ - recent simulations







Support and services (grey):

- simplified model,
- “along the cones”,
- uniform in azimuth

Studies of transition region,

- acceptance edges and gaps
- Single tracks to jets,
- Tracking robustness with dropped hits,

Transition(-ing) to Fun4All, Cori,

See Rey’s talk today (or next week)

Iteration to refine the concept.