ATHENA hybrid tracker

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EIC Project Detector, Tracking WG kick-off meeting

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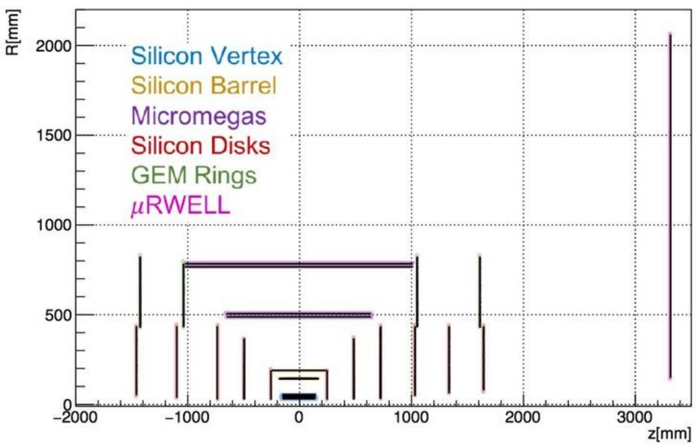
Introduction

- Aspects that have been considered to converge on the vertex and tracking detector concept for the ATHENA proposal are:
  - Physics.
  - Integration.
  - Cost.
  - Critical to reduce material in front of EMCal, especially in the backward direction.

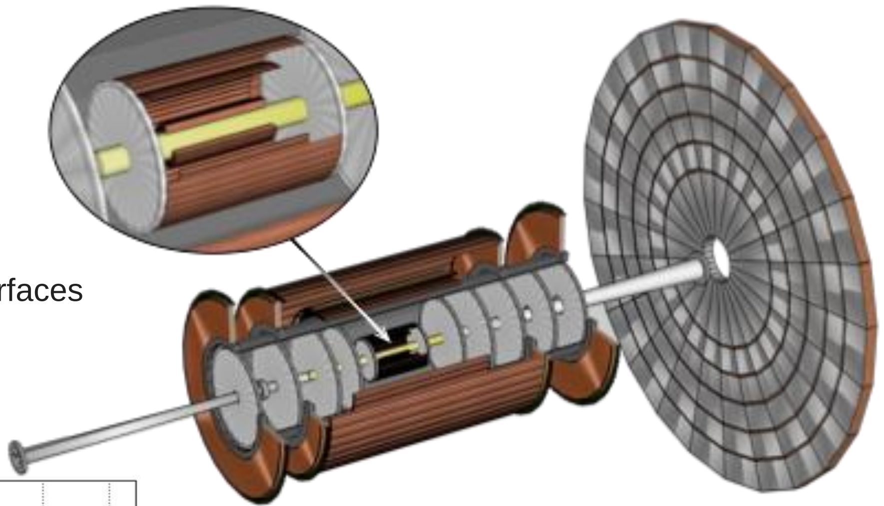
- Plus all the knowledge and technology developments from many years of eRD6 and eRD16/18/25.

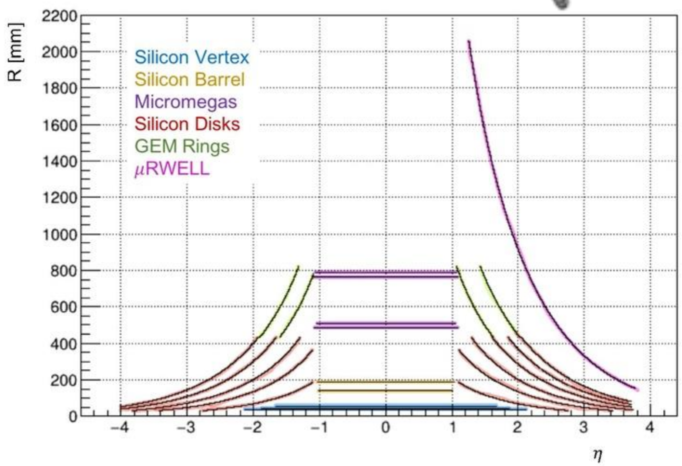
ATHENA tracking and vertex detector

- Silicon and gaseous hybrid tracker.
  - MAPS near the interaction point complemented by MPGDs at larger radii.
  - Full coverage of the available space → tracking acceptance $-3.8 < \eta < 3.75$.
  - Low material budget tracking with sufficient redundancy over a large lever arm.



Tracking material surfaces as a function of z





Tracking material surfaces as a function of pseudorapidity

Barrel

- 3 MAPS layers for vertexing (redundancy and low pT-threshold).
  - Radii from 1st eng CAD model based on possible stitched sensor size in phi.
  - Length = 28 cm: max length of a single sensor on wafer, allows for services on one side only; helps low material in negative direction.
  - ITS3 sensor and detector concept, i.e. wafer-scale sensors, thin and bent around the beam pipe, 0.05% X/X0 per layer (ITS3 design).

Silicon Tracker (3 Vertex + 2 Barrel Layers)

R (cm)	Length (cm)	Resolution	Active Area Material (X/X0 %)
3.3	28.0	10 um pixel pitch	0.05
4.35	28.0	10 um pixel pitch	0.05
5.4	28.0	10 um pixel pitch	0.05
13.34	34.34	10 um pixel pitch	0.55
17.96	46.68	10 um pixel pitch	0.55

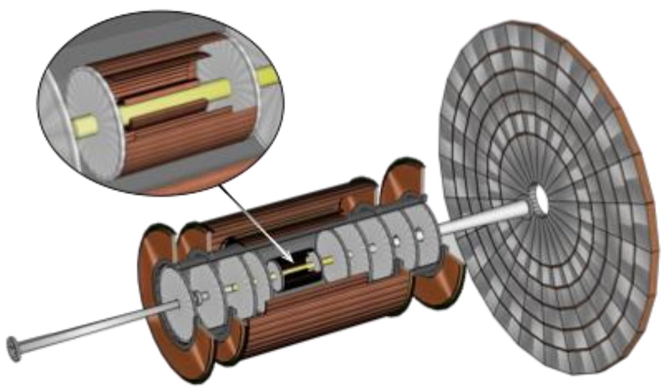
Micromegas Barrel (4 barrel layers)

R (cm)	Length (cm)	Resolution	Active Area Material (X/X0 %)
47.72	127.47	150 um (r-phi) x 150 um (z)	0.4
49.57	127.47	150 um (r-phi) x 150 um (z)	0.4
75.61	201.98	150 um (r-phi) x 150 um (z)	0.4
77.46	201.98	150 um (r-phi) x 150 um (z)	0.4

- 2 MAPS layers for sagitta measurements.
  - Conventional stave structure with smaller size ITS3 sensor for low cost large area coverage.
  - Conservative 0.55% X/X0 per layer, assumes water cooling, services running on the stave.
- 2+2 MicroMegas layers for tracking
  - Complement the Si for tracking and redundancy.
  - X/X0 ~ 0.4 % per layer.
  - Spatial resolutions ~150μm, conservative choice.
  - Modular design to simplify production and costs

Forward region

- 6 MAPS disks that extend until z = 165 cm for max lever arm.
  - Conventional disk structure with smaller size ITS3 sensor for low cost large area coverage.
  - 0.24% X/X0 per disk.
- Two GEM rings to extend acceptance and provide additional hit points for track reconstruction in 1.1 < eta < 2.0.
- uRWell layer behind the dRICH to aid PID and to improve the momentum resolution in the forward direction.



Silicon Disks

Inner R (cm)	Outer R (cm)	Z Position (cm)	Resolution	Active Area Material (X/X0 %)
3.18	18.62	25.0	10 um pixel pitch	0.24
3.18	36.50	49.0	10 um pixel pitch	0.24
3.47	43.23	73.0	10 um pixel pitch	0.24
5.08	43.23	103.65	10 um pixel pitch	0.24
6.58	43.23	134.33	10 um pixel pitch	0.24
8.16	43.23	165.0	10 um pixel pitch	0.24

Silicon Disk Support Material

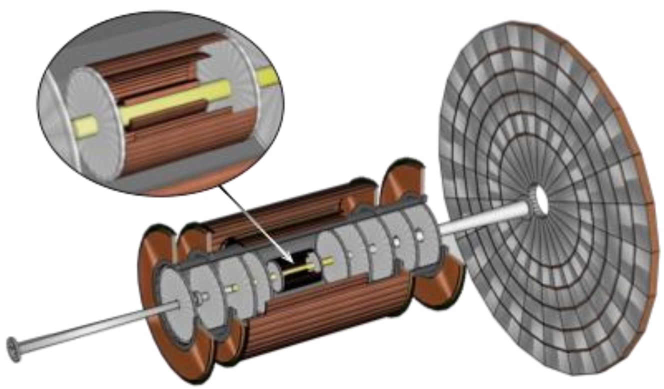
Material	Thickness (cm)	Geometry
Al	0.2	cone from (z [cm], rho [cm]) = (16.8, 12.58) to (58.42, 43.23) and cylinder from (58.42, 43.23) to (165, 43.23)

MPGD Trackers

Inner R (cm)	Outer R (cm)	Z Position (cm)	Resolution	Active Area Material (X/X0 %)
44.68	76.91	105.76	250 um (r) x 50 um (r-phi)	0.4
44.68	76.91	161.74	250 um (r) x 50 um (r-phi)	0.4
19.34	195.5	332.0	250 um (r) x 50 um (r-phi)	0.4

Backward region

- 5 MAPS disks that extend until z = -145 cm for max lever arm.
  - Conventional disk structure with smaller size ITS3 sensor for low cost large area coverage.
  - 0.24% X/X0 per disk.
  - 5 disks provide low material and enough of hits per track.
- Two GEM rings to extend the acceptance and provide additional hit points for track reconstruction in -1.1 < eta < -2.0.



Silicon Disks

Inner R (cm)	Outer R (cm)	Z Position (cm)	Resolution	Active Area Material (X/X0 %)
3.18	18.62	-25.0	10 um pixel pitch	0.24
3.18	36.50	-49.0	10 um pixel pitch	0.24
3.18	43.23	-73.0	10 um pixel pitch	0.24
3.95	43.23	-109.0	10 um pixel pitch	0.24
5.26	43.23	-145.0	10 um pixel pitch	0.24

Silicon Disk Support Material

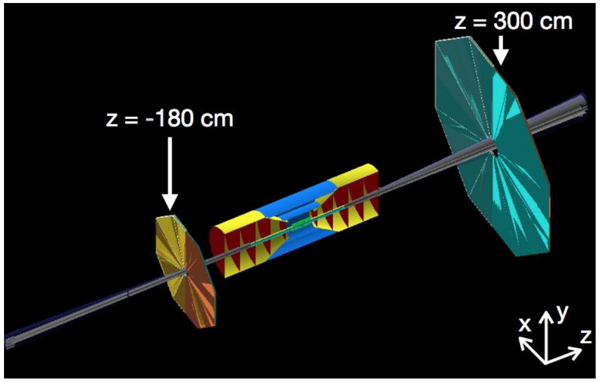
Material	Thickness (cm)	Geometry
Al	0.2	cone from (z [cm], rho [cm]) = (-16.8, 12.58) to (-58.42, 43.23) and cylinder from (-58.42, 43.23) to (-145, 43.23)

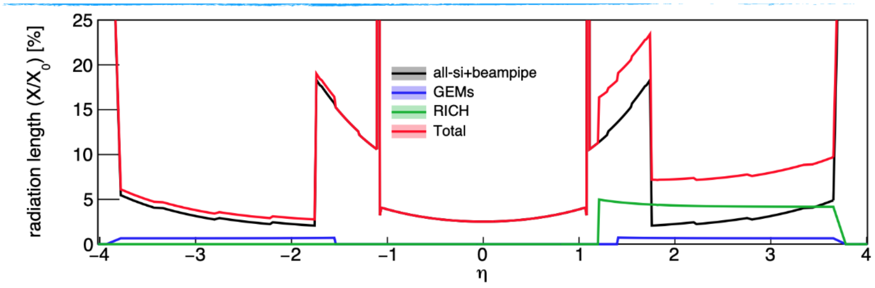
MPGD Trackers

Inner R (cm)	Outer R (cm)	Z Position (cm)	Resolution	Active Area Material (X/X0 %)
44.68	76.91	-103.0	250 um (r) x 50 um (r-phi)	0.4
44.68	76.91	-141.74	250 um (r) x 50 um (r-phi)	0.4

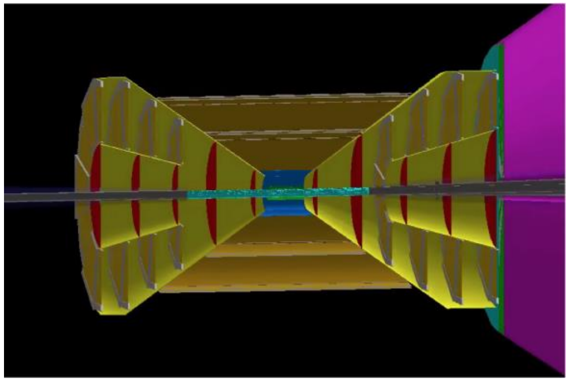
Fwd/bwd regions challenges

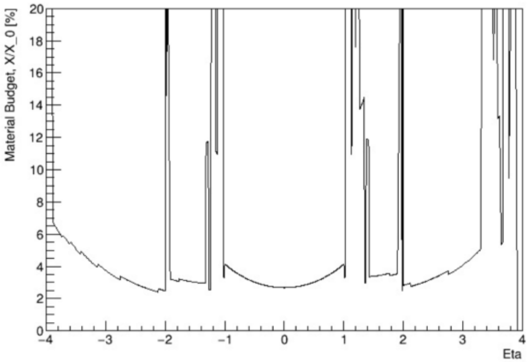
- The design of the forward and backward regions was the most challenging. We considered aspects of material optimisation and integration.
- The concern with all-silicon was the material in 1 < |eta| < 2, due to services running on the cone (otherwise, good for performance, cost and integration).





- A hybrid, projective configuration was proposed to overcome the problem and have services along well defined, smaller eta regions, but discussion with project engineers ruled it out because of complexity of integration.

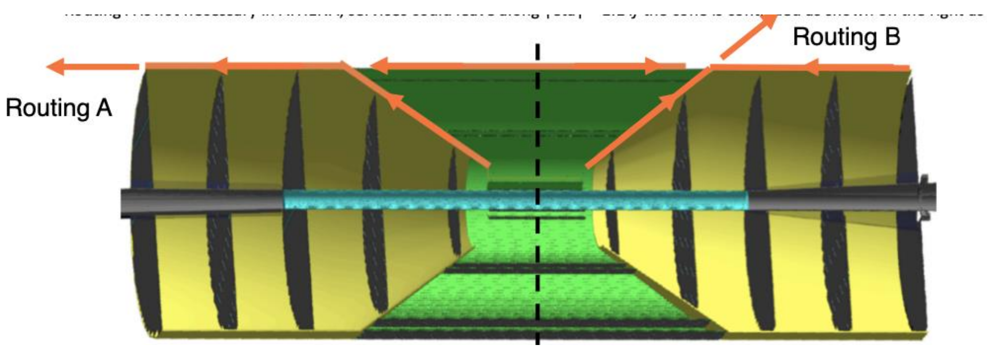


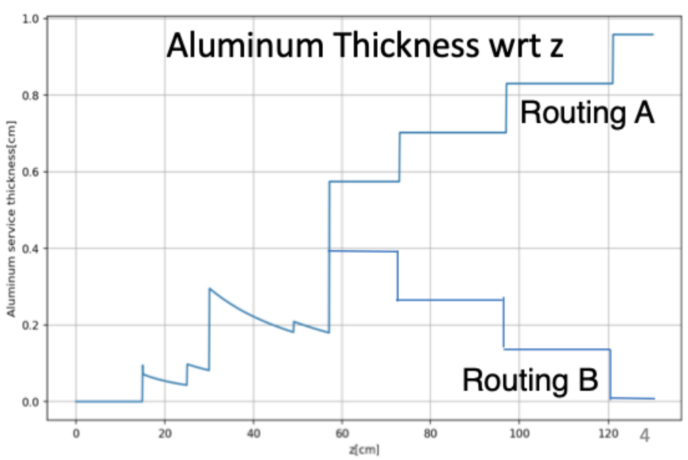


Fwd/bwd regions: Services routing optimisation

- Initially considered option A: services from vtx & trk layers converge at end of cone, then run on top of cylinder with services for disks → thick Al layer on cylinder, i.e. in 1 < |eta| < 2 → too much material in front of Ecal.
- This was solved with an optimised routing scheme (option B).
  - Services from vertex and tracking layers, and disks converge at the end of the cone and go out from there along |eta| = 1.1.
  - Significant reduction of aluminium in most eta ranges.
  - Can keep cone+cylinder structure, approved by integration team.

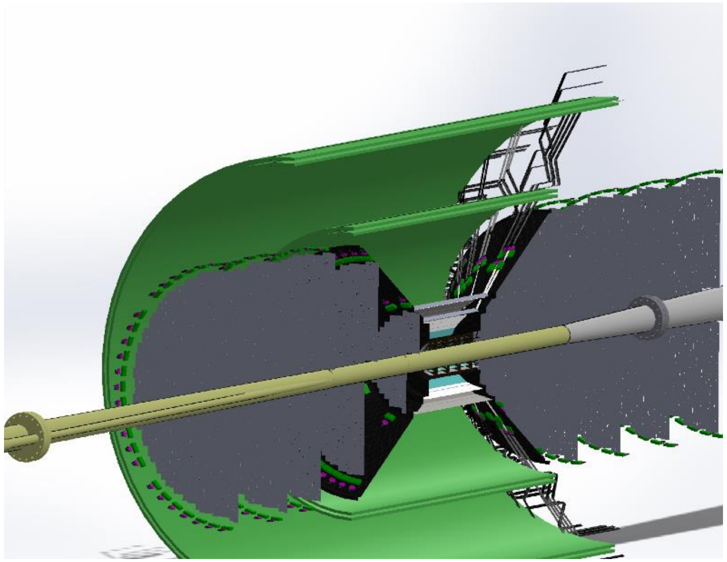
Services routing scheme (drawn on top of the original all-silicon configuration



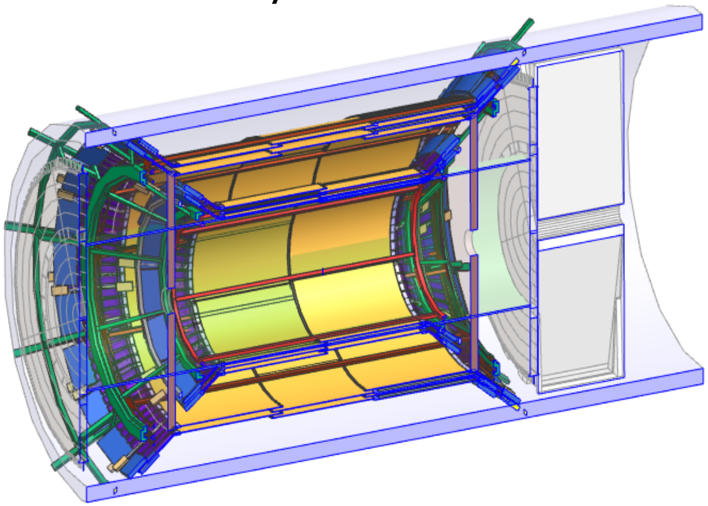


CAD model and integration

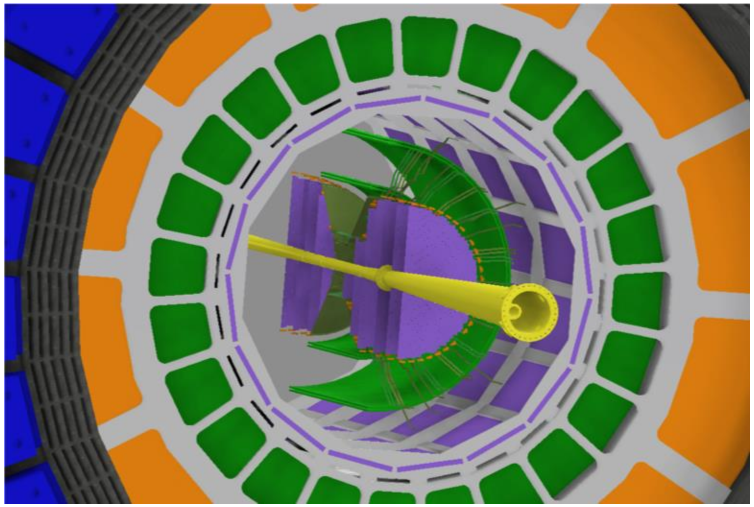
Silicon CAD model with MM



Preliminary MM CAD model



Integration in overall detector

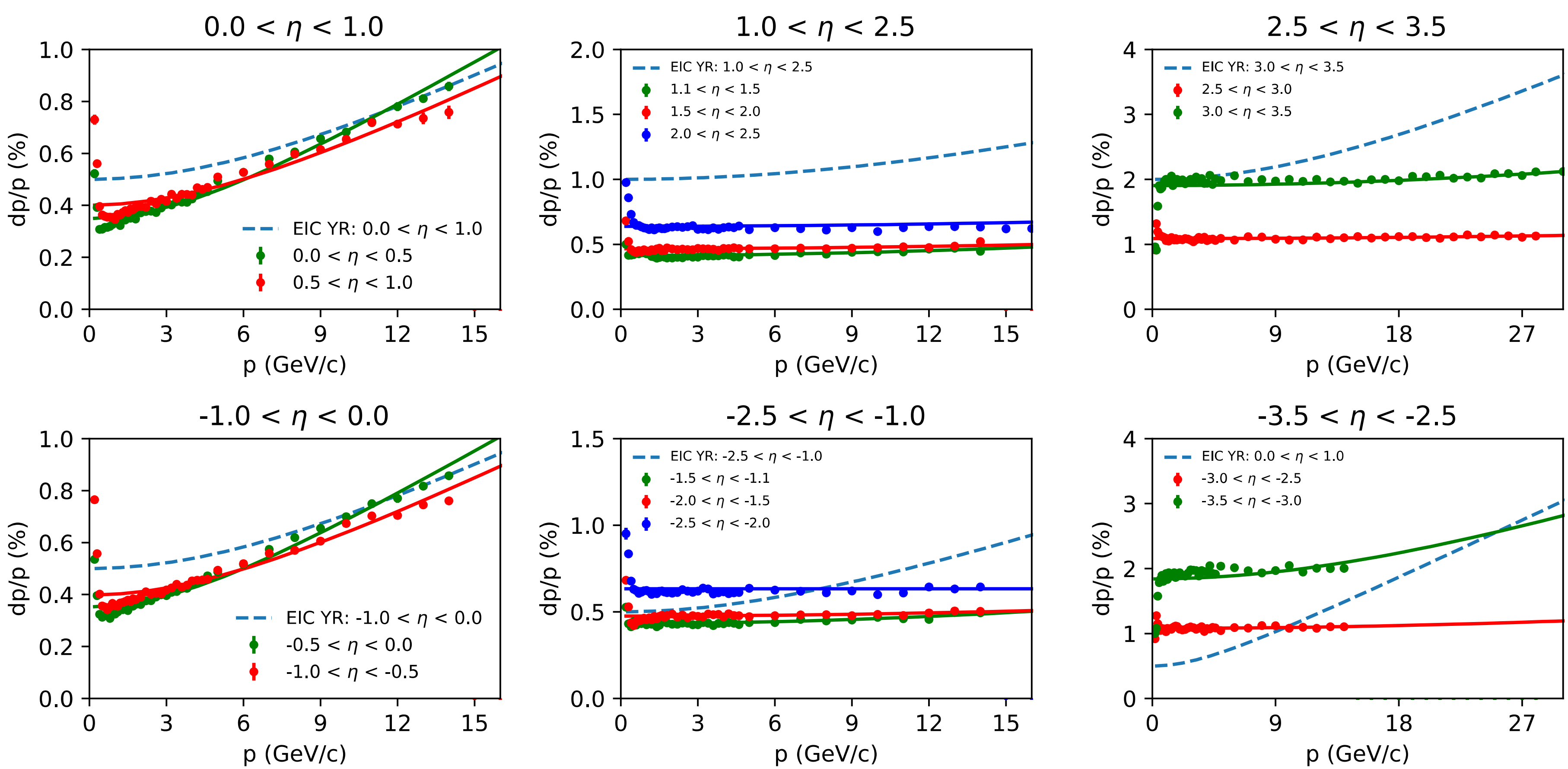


ATHENA simulation framework

- Detector implementation in DD4Hep.
  - Silicon detector includes staves/disks/support structures (carbon foam) and services (aluminium + Kapton) description.
  - Realistic description of MPGD active areas, preliminary versions of support structures and services

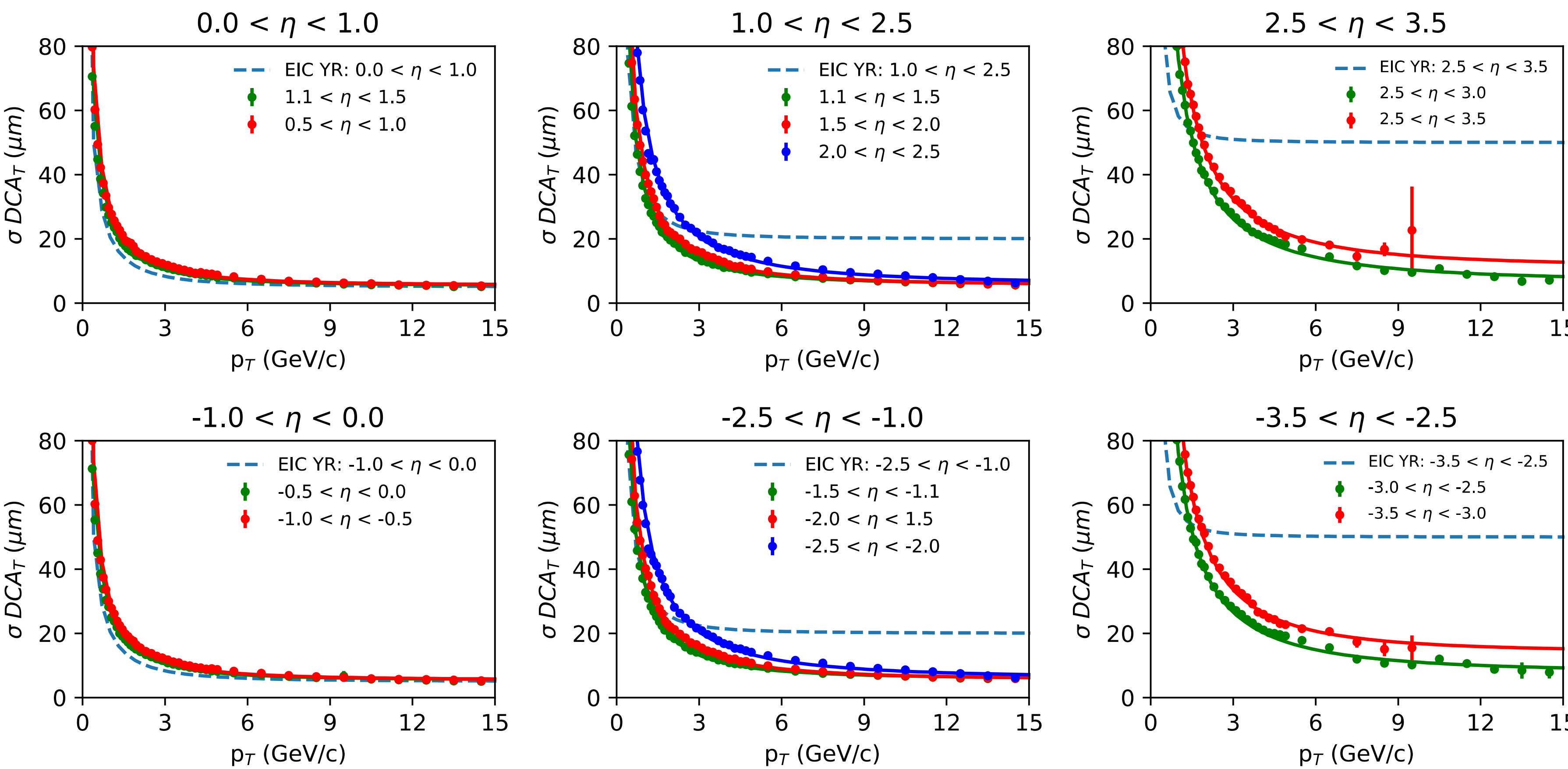
- Full event reconstruction
  - ACTS package for track reconstruction
  - MC Truth seeds to start the Kalman Filter
  - Due to limitations in the ACTS package, the cylindrical surfaces (both Si and MPGD) have been approximated with small flat surfaces
  - Digitisation: using pixels of sizes to match resolutions

Performance against physics requirements



- Tracking performance meets or exceed the momentum resolution requirements stated in the Yellow Report, except for the most backward eta ranges.

Performance against physics requirements



- Vertexing performance meet or exceed the DCA_T requirements stated in the Yellow Report, except for momenta below 2 GeV at very large eta ranges.

Further optimisations

- At the time of the proposal we were already aware of further optimisations that would have been needed.
- The radii of the vertex layers will need adjustment according to the final, ITS3 stitched sensor size.
  - NEW: We have learned on Monday at the EIC SC meeting that beam pipe bake out also requires and additional 5 mm clearance from the beam pipe.
- Progress on eRD104 and more conceptual design studies of staves could reduce the material of the sagitta layers significantly.
  - NEW: We have learned on Monday at the EIC SC meeting that for certain radii we might not need services in active area.
- Further optimisation of the number of MM layers to be done with pattern recognition in presence of background.
- Further performance studies and overall optimisation including an AC-LGAD layer at r ~ 50 cm.

Lesson learned

- Low material is critical for good performance of the tracker and neighbouring detectors, esp. in the electron-going direction.
  - Most challenging driver of detector design (also where needed the most time).
  - Achieving low material requires both further R&D into low material solutions as well as careful optimisation of services routing and support structures, and needs constant feedback with integration group.

- Even with state of the art Si and MPGD technologies, the EIC physics requirements are challenging to meet.
  - Further R&D into low material mandatory (but there is just so much we can do).
  - Combination of tracking and electromagnetic calorimetry information to improve electron measurement.
  - Different trade-off with the other detector subsystem in the associated acceptance region.
  - Alternative analysis approach.

Backup

Silicon technology for EIC

- ATHENA (as well as ECCE and CORE) has chosen 65 nm MAPS as the technology for its silicon vertex and tracking detector.
  - New generation MAPS developed by ITS3 (ALICE) for the LHC Run4 (HL-LHC).

- ITS3 sensor specifications meet or exceed EIC requirements → adopt for EIC.

ALICE

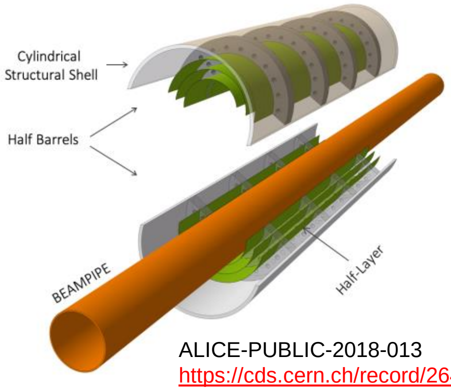
Specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 μm	20-40 μm
Pixel size	27 x 29 μm	O(10 x 10 μm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 μs	~ 200 ns
Time resolution	~ 1 μs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power Consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

M. Mager | ITS3 kickoff | 04.12.2019 |

ITS3 technology for EIC: vertex layers

- ITS3 detector layout: 0.05% X/X0 per layer → adopted for EIC vertex layers.
  - Wafer-scale sensor, thinned to 20-40um, bent around beam pipe.
  - Air cooling (sensor power consumption reduced by 50% wrt ALPIDE).
  - No services in active area (implies only one or two sensors along z per layers).
  - Carbon foam rings and cylindrical structural cell.



ALICE-PUBLIC-2018-013
https://cds.cern.ch/record/2644611

- Further considerations for EIC.
  - Use ITS3 sensor as is, no change.
  - The width of sensor is designed to match ITS3 radii; EIC has different (larger) radii
  - Sensor size sets a constraint in the radii we can achieve at the EIC (important to keep in mind during the optimisation phase).

ITS3 technology for EIC: barrel layers

- ITS3 wafer-scale sensor not suitable for staves & discs due to cost and expected yield.

- The EIC will developed an optimised ITS3 sensor size for low cost, large area coverage = EIC Large Area Sensor (LAS).
  - Same functionality and interfaces as ITS3 sensor, stitched but not wafer-scale.
  - Stitched sensor layout/size will need to be optimized to provide the coverage needed for each stave and disk.
  - Optimization will consider yield estimates from first engineering run.

- Staves derived from ITS2 structures; discs composed of overlapping staves or low mass CFC support discs

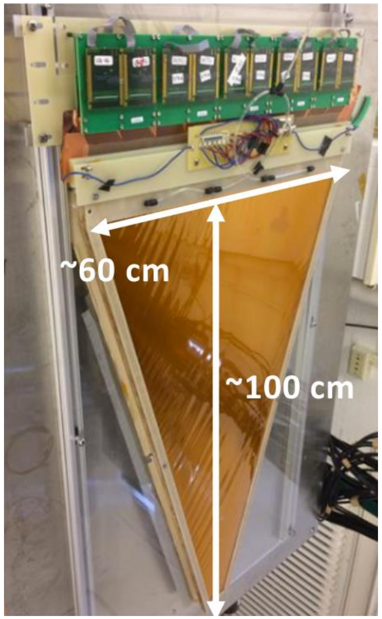
- Material budget estimate
  - Tracking layer X/X0 ~0.55%
  - Disks X/X0 ~0.24 %

EIC Silicon Consortium

- The EIC Silicon Consortium mission is to develop a well-integrated and large-acceptance EIC vertex and tracking detector, based on 65 nm MAPS.
- The EIC SC is made of collaborators from the EIC UG with interest to develop this tracking solution and welcomes members of any collaboration.
- Ongoing R&D
  - Sensor design in collaboration with ITS3.
  - eRD111: forming modules from stitched sensors; staves & Discs; mechanics, integration, & cooling.
  - eRD104: services reduction (Powering & readout)

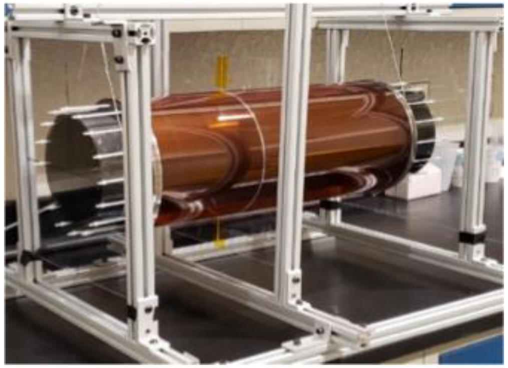
Triple-GEM

- Triple-GEM developed within eRD6 (UVa, Temple U, FIT).
- R&D completed.
- Low material budget: ~0.4% X/X0 per layer.
- Large area detectors.
- Good spatial resolutions: 50μm (rϕ) x 250 μm (r).
- Lightweight support structure.
- FEE and services outside acceptance.



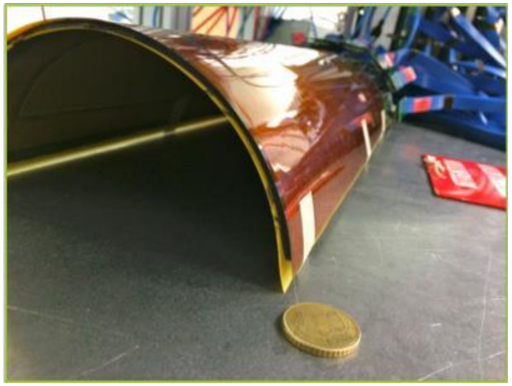
uRwell

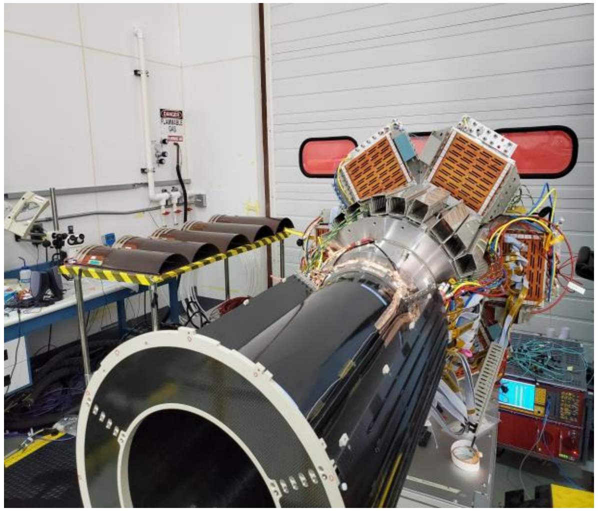
- μRWell active R&D ongoing within eRD6/108.
- Technology less mature, but promising.
- Spatial resolutions: comparable with GEM ones.
- Fallback solution: GEMs.
- R&D ongoing on large areas, 2D readout, cylindrical layers.



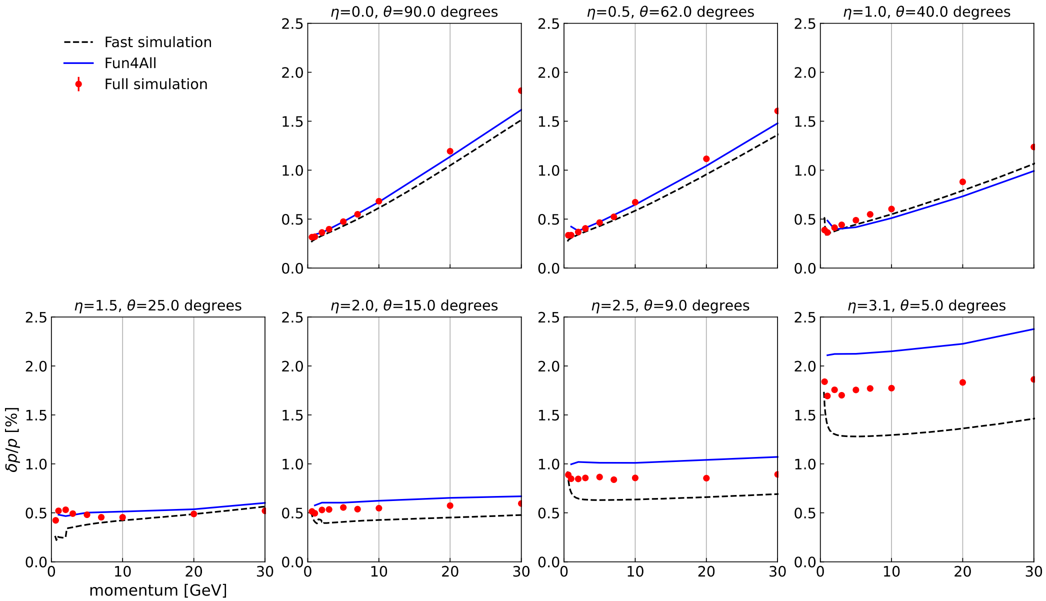
Cylindrical MicroMegas

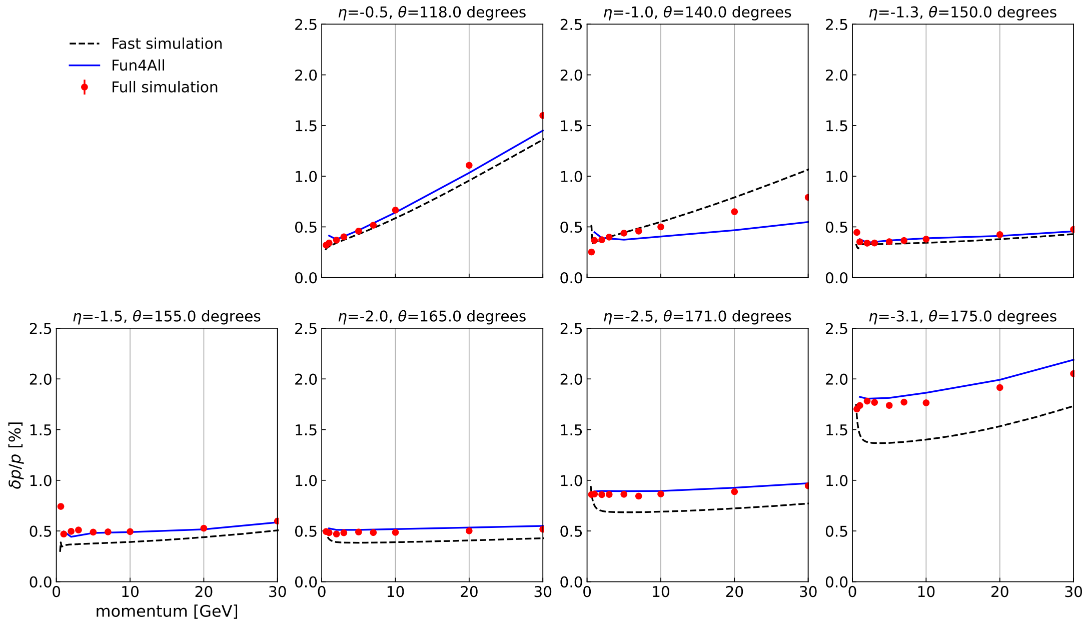
- Cylindrical MicroMegas developed at CEA Saclay.
- 1D technology in use already in CLAS12, 2D in ASACUSA.
- Low material budget: ~0.4% X/X0 per layer.
- Good spatial resolutions: ~100 µm with 1mm pitch.
- Targeted R&D to chose the best 2D readout.



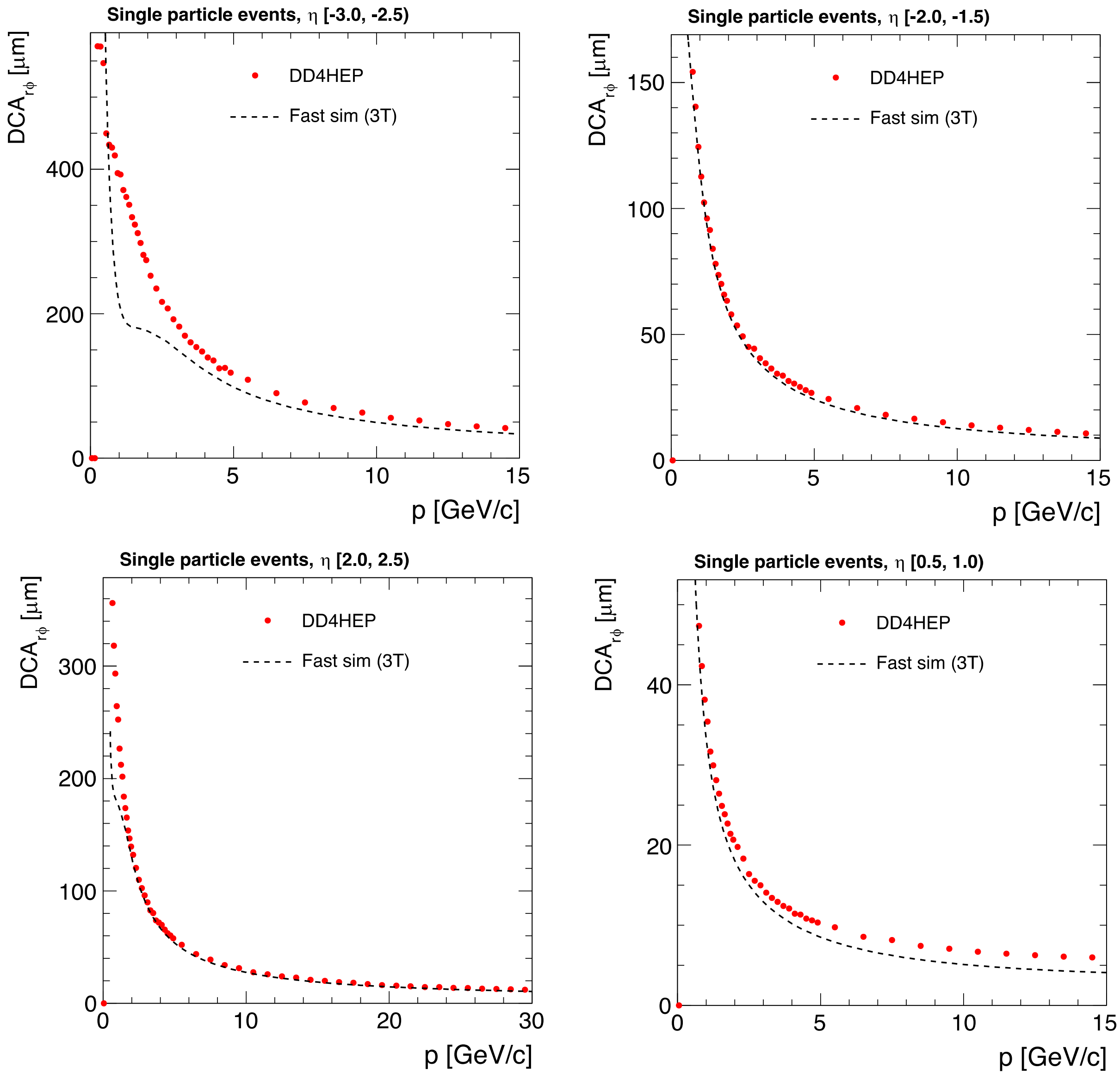


Simulation validation – dp/p

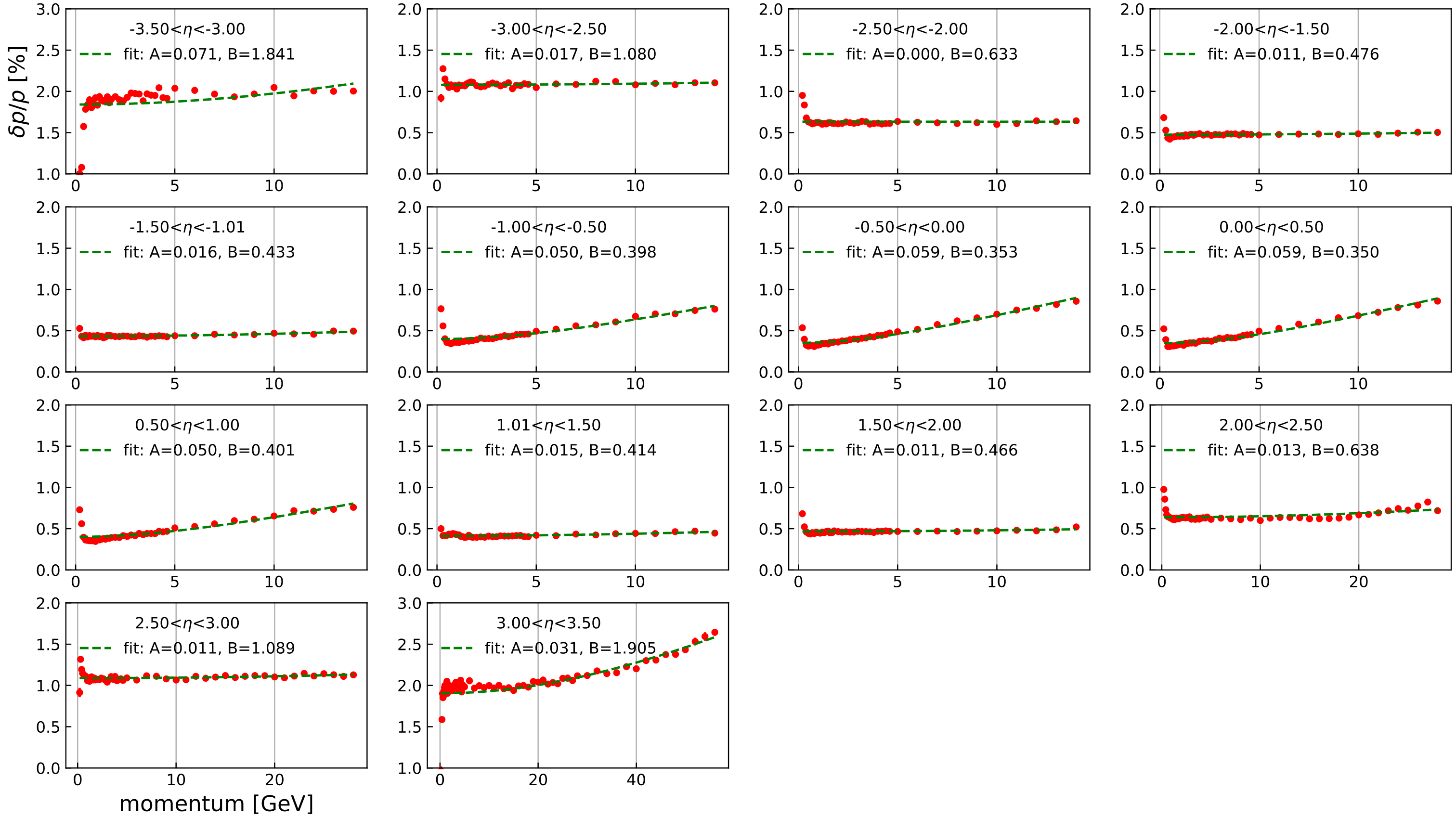




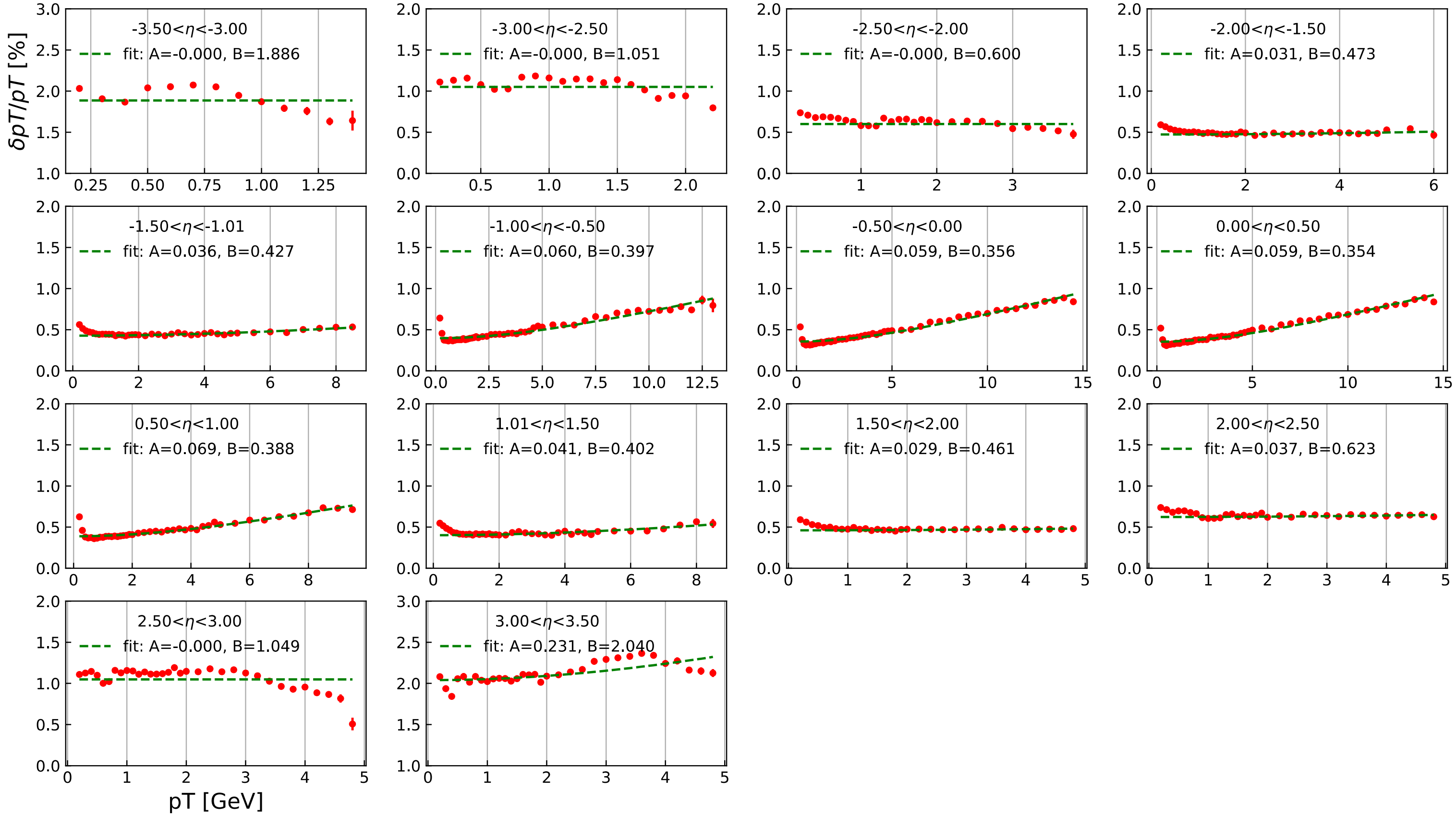
Simulation validation - DCA



Tracking performance – dp/p



Tracking performance – dp_T/p_T



Tracking performance – DCA