Hybrid Tracker Update

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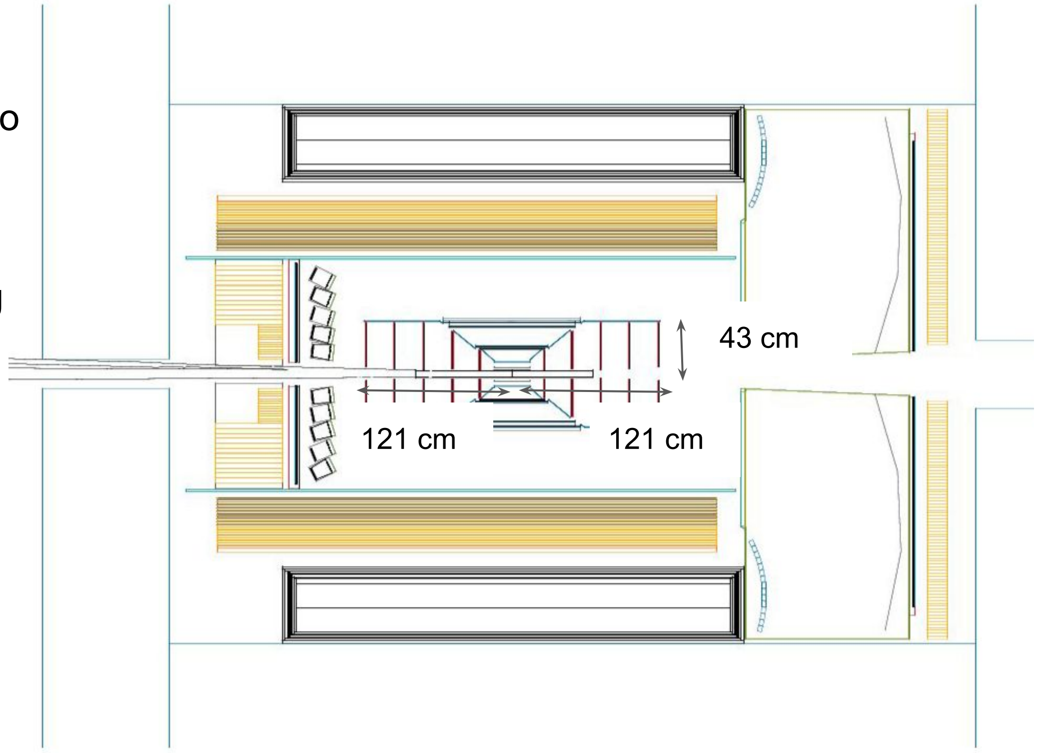
ATHENA WG Convener meeting
29 October 2021

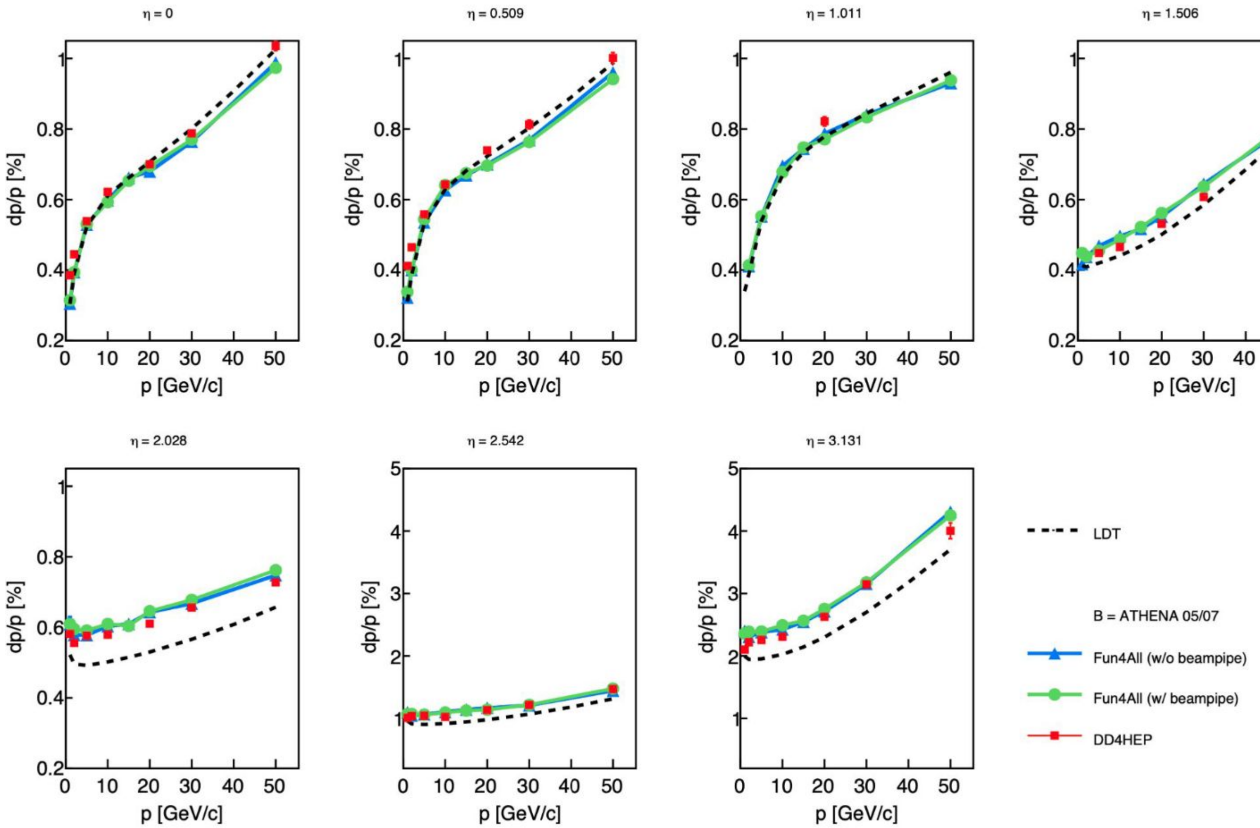
Baseline 0 (Acadia)

- First detector configuration implemented into ATHENA simulation framework
  - Thank you software group!
- Primary tracking system based on Si
  - Symmetric forward-backward tracking configuration
  - Radial tracking out to 43 cm
- GEM disk behind mRICH and dRICH



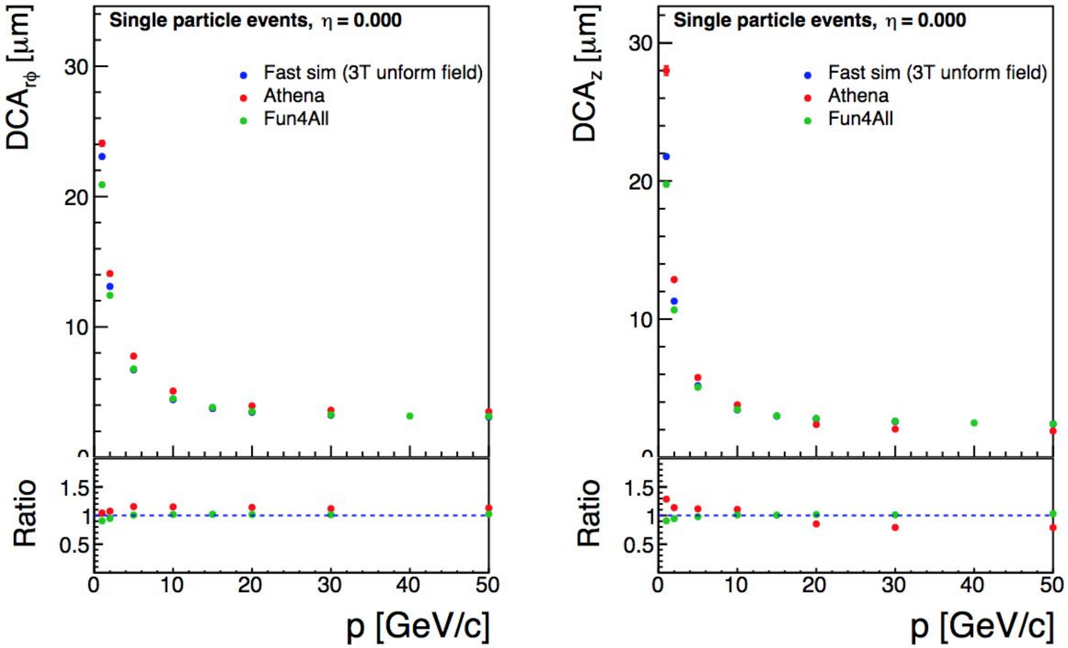
Baseline 0 (Acadia): Simulation Comparison

Rey, Shujie, and Ernst



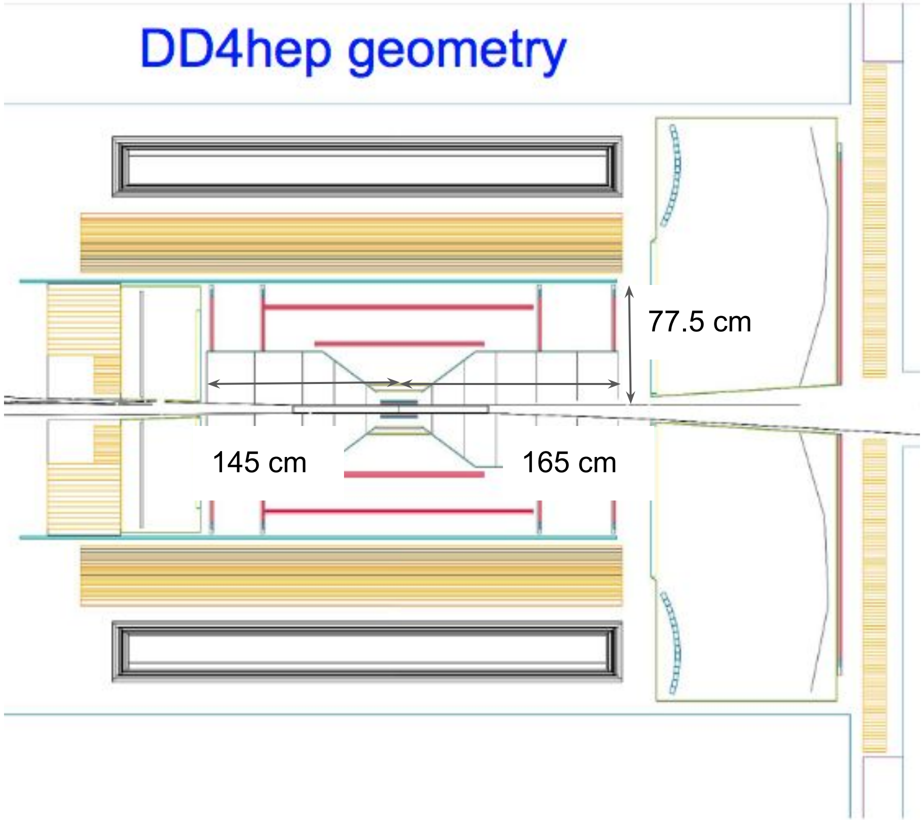
Baseline 0 (Acadia): Simulation Comparison

Wenqing Fan



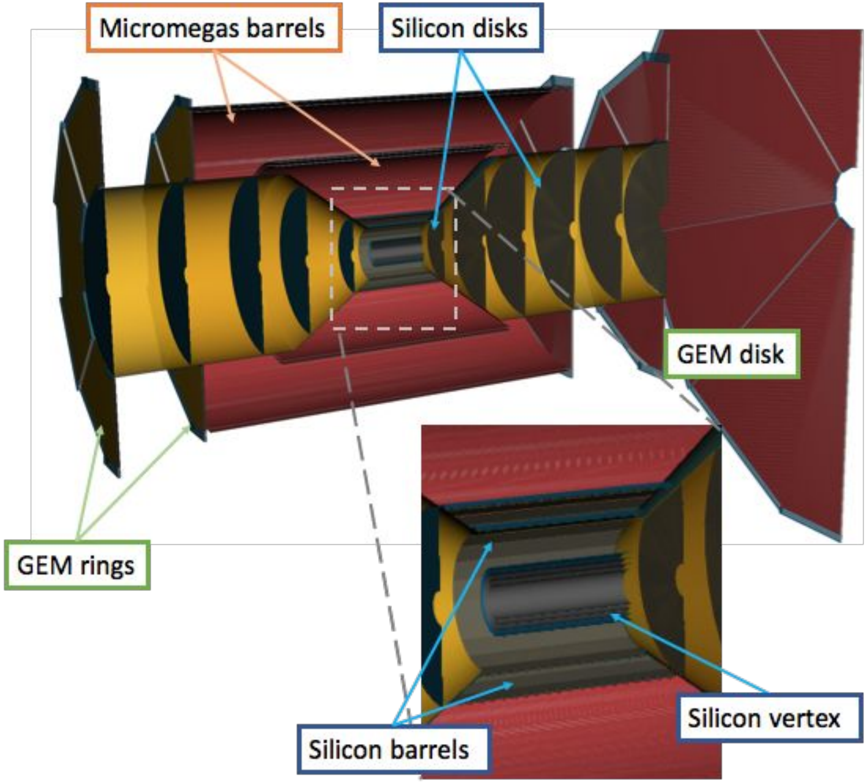
Baseline 2 (Canyonlands)

- Latest detector configuration implemented into ATHENA simulation framework
    - Thank you software group!
- Hybrid primary tracking system based on Si + MPGD
    - asymmetric forward-backward tracking configuration
    - Radial tracking out to 77.5 cm
- GEM disk behind dRICH for PID seeding



Baseline 2 (Canyonlands)

- Complementary silicon and MPGD technologies to provide a cost efficient tracking solution capable of achieving excellent momentum, angular, and vertex reconstruction resolutions and large eta coverage
- Central Tracker
  - 3 Si vertex layers
  - 2 Si barrel layers
  - 4 micromegas barrel layers
- Backward Tracker
  - 5 Si disks
  - 2 GEM rings
- Forward Tracker
  - 6 Si disks
  - 2 GEM rings
  - Large GEM disk behind dRICH (aid in PID seeding)
- GEMs are currently implemented in simulation, but will serve as fall back option if μRWell is not developed in time

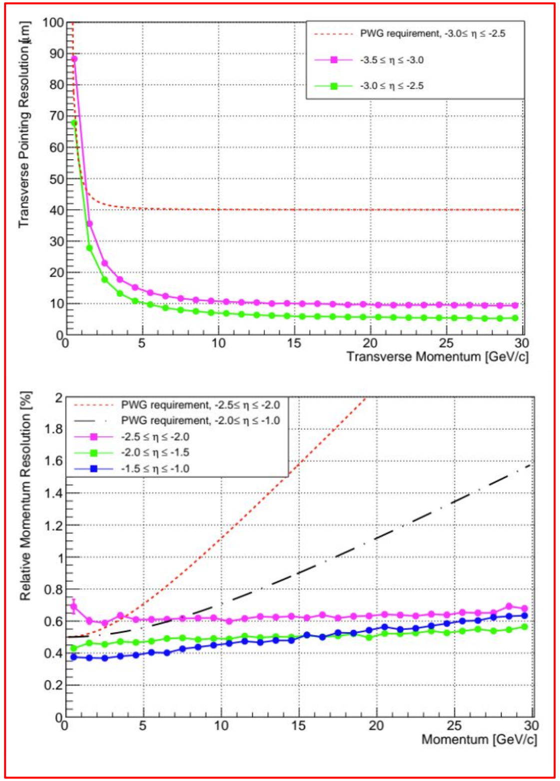


Baseline 2 (Canyonlands): Fun4All Studies

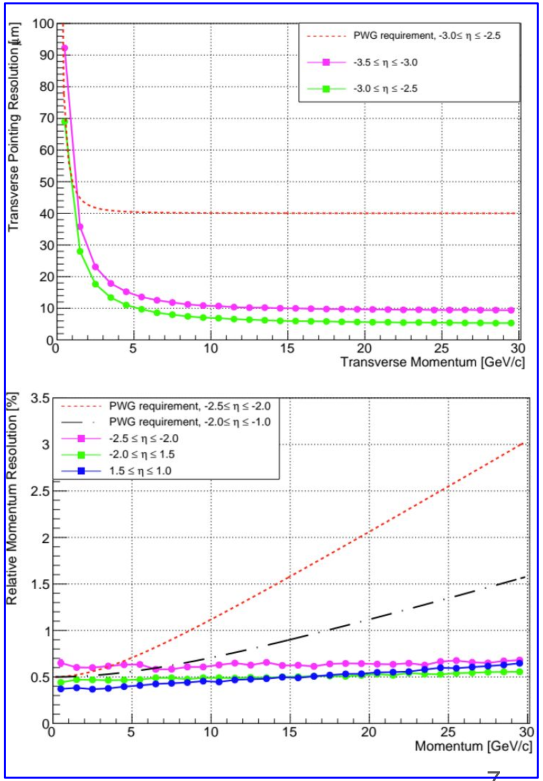
- Initial baseline 2 performance studies before ATHENA implementation (Nick)
- Additional studies done looking at effect of shortening vertex layer lengths (Stephen)
  - Shorter length allows services to be routed through only the hadron side
  - Not a significant effect

Stephen

30 cm Vtx



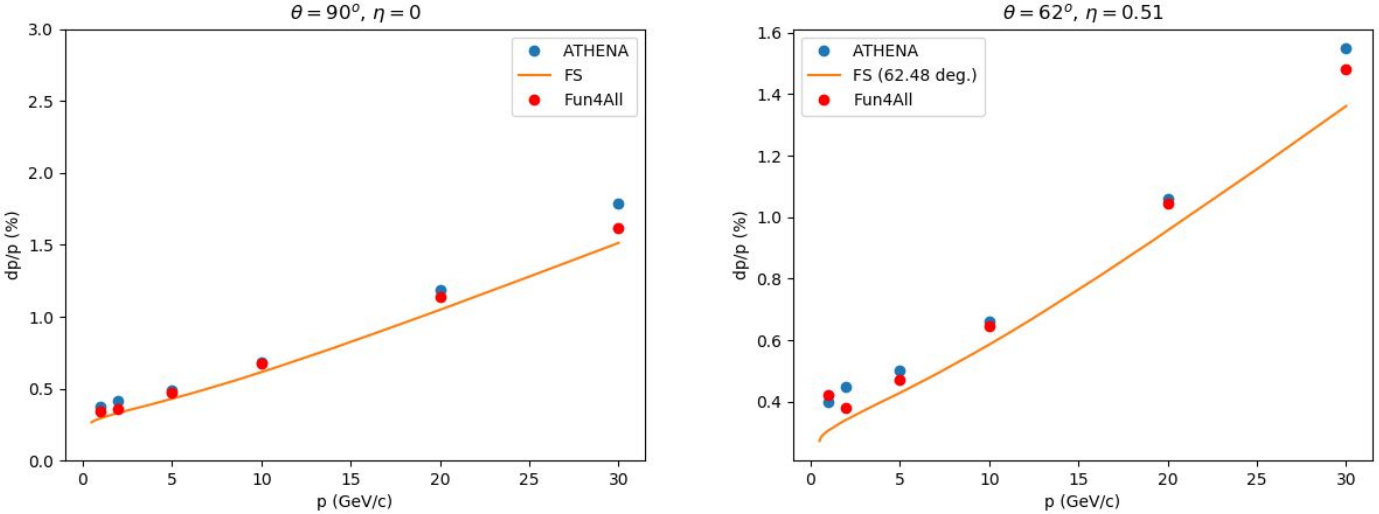
28 cm Vtx



Baseline 2 (Canyonlands): Simulation Comparison

- Tracking evaluation from ATHENA framework underway
- Low eta region shows good agreement with fast simulation and Fun4All
- Tracks at low momentum and large eta needs additional investigation to understand their behavior

Shujie and Ernst , and Nick



Proposal Material

1. The ATHENA Detector

1.1 Vertex and Tracking System (4 pages)

ATHENA will utilise a vertex and tracking system that comprises silicon Monolithic Active Pixel Sensors (MAPS) closest to the interaction point and Micro-Pattern Gaseous Detectors (MPGDs) further out. The layout of the vertex and tracking system is illustrated in Fig. 1.1. A compact inner silicon barrel is shown in blue and consists of three vertex layers and two barrel layers occupying a region that has a maximum radius of 18 cm and a total length of 48 cm. The vertex layers are made of large-area, wafer-scale, stitched sensors that are bent around the beam pipe. The barrel layers comprise a more traditional stave design that uses smaller stitched sensors. The two outermost barrel layers will each comprise two closely-spaced layers of micro mesh gas detectors (Micromegas) with mean radii of approximately 49 cm and 76 cm and maximum total length of approximately 200 cm.

In the forward and backward directions, the vertex and tracking system consists of silicon disks (shown in red) augmented by large-area gas electron multipliers (GEMs). The silicon disks will use the same sensor technology as the vertex and barrel layers. There are five disks in the backward (electron going) direction and six disks in the forward (proton/nucleus going) direction. They start 25 cm either side of the interaction point and extend to 145 cm in the backward direction and 165 cm in the forward direction. The maximum outer radius of the disks is approximately 43 cm. The minimum radii are determined by the divergence of the beam pipe. In the forward and backward directions there are two large-area triple-GEMs rings that extend the acceptance for tracks in the pseudorapidity interval $1.1 < |\eta| < 1.7$. A further large-area triple-GEM tracker is located behind the dRICH detector in the forward direction, whose primary purpose will be to seed the dRICH ring finder.

1.1.1 Choice of technology

The silicon detectors will use the latest 65 nm MAPS technology that was identified in the Yellow Report [1] as being the best candidate to meet the stringent requirements on vertex and momentum resolution for physics at the EIC. [Comment: Might want to rephrase this in light of the tracking performance. Were the requirements too stringent?] This technology is currently being developed for an upgrade of the inner tracking system of the ALICE experiment at the CERN LHC and the upgraded detector (ITS3) is expected to be ready for installation during the next long shutdown beginning at the start of 2025 and ending in mid-2027. To maximise the success of this development, groups external to ALICE have been invited to join the R&D effort with a view to develop the technology, also for other applications. One such group is the EIC Silicon Consortium, which has grown out of the EIC Generic R&D program (eRD16/eRD18/eRD25) and whose leadership is made up of members of the ATHENA collaboration. The specifications of proposed ITS3 sensor already meet most, if not all, of the requirements of the EIC. The overarching goal of ITS3 is to achieve a pixel pitch down to 10 μm while keeping power dissipation below 20 mW cm^{-2} to construct a vertex detector with a space point resolution of better than 5 μm for a material thickness of just 0.05% X/X_0 per layer. By comparison, the vertex layers in the current ALICE ITS (ITS2) have a pixel pitch of approximately 30 μm, dissipate 40 mW cm^{-2} and have a material thickness of 0.35% X/X_0.

For the three innermost vertex layers of the tracking system, ATHENA will adopt the ALICE ITS3 concept of large-area, wafer-scale stitched sensors, thinned to below 50 μm, bent around the beam pipe and held in place using low mass support structures [2]. The low power dissipation of the sensor will enable air cooling of the vertex layers, which is a key factor in reducing the material thickness of the inner

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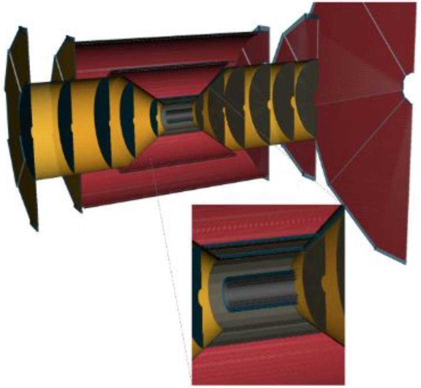

Figure 1.1: ATHENA baseline hybrid tracking system comprising silicon vertex and barrel layers and forward/backward silicon disks (MAPS) complemented by large-area Micro-Pattern Gaseous Detectors in the outer barrel layers (Micromegas) and forward/backward disks (GEMs).

most tracking layers, crucial to achieve the required vertex reconstruction resolution. The geometry of the beam pipe at the EIC differs from that in ALICE and the outer radius is somewhat larger but we expect to achieve a material thickness below 0.1% X/X_0 in the vertex layers. The barrel layers and forward/backward disks will use more conventional flat sensors, also stitched but not to wafer scale, mounted on flat support structures: staves and half-disks. The material thickness of the staves and disks has been estimated by scaling the material thickness of the existing ALICE ITS2 barrel layers [3] according to the power dissipation of the new 65 nm sensor. This leads to an estimate of 0.55% X/X_0 in each of the two barrel layers and 0.24% X/X_0 for the disks. The EIC Silicon Consortium will play a key part in the ITS3 sensor development, ensuring that it meets the requirements of the EIC, while also developing EIC-specific support structures and services, in particular for the barrel layers and disks (see Section 1.1.3).

[Comment: In the current hybrid design, the barrel layers are up to 48 cm in length. This is a factor of two smaller than the middle layers of ITS2, which have a material thickness of approximately 1% X/X_0. (About 50% of this comes from the flex cables). The estimate of 0.55% X/X_0 seems reasonable for the barrel layers but why are the thickness of the disks a factor of 2 smaller? Can this be justified?]

MPGD technologies such as GEMs, Micromegas and micro-resistive well (μRWell) detectors are a cost effective solution for large-area tracking systems requiring a low material budget. GEMs and

2

Proposal Material

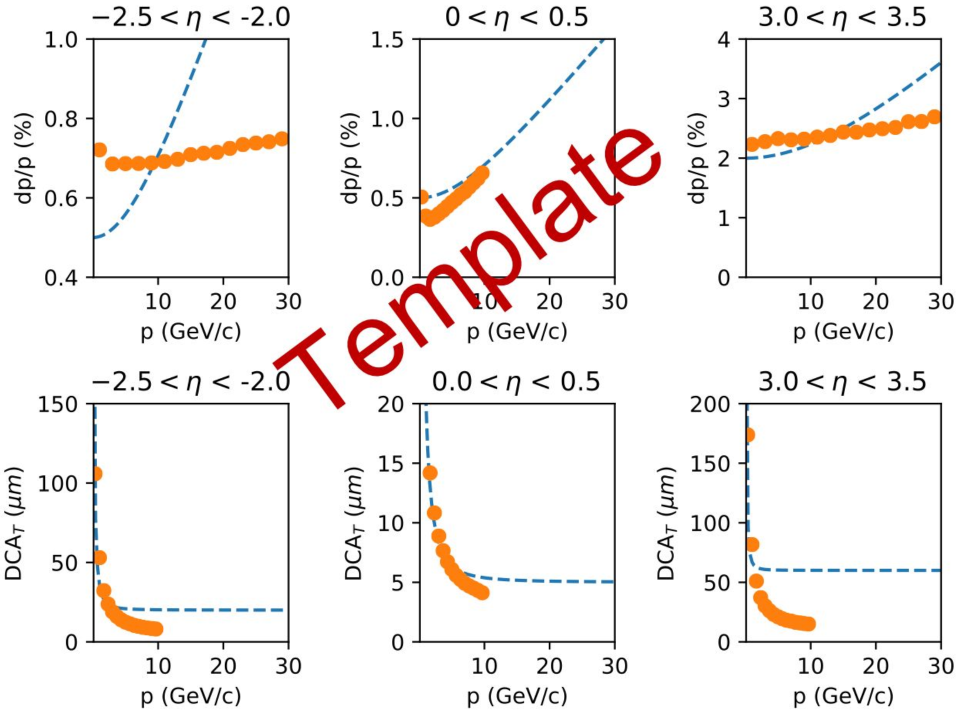

Figure 2: ATHENA tracking performance of generated pions compared to PWG requirements (curves) for selected η bins. Top row: momentum resolutions vs. momentum. Bottom row: Transverse DCA performance vs. momentum.

Proposal Material

Tracking performance (ATHENA baseline, B = 3 T)						
			Momentum res.		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 0.5%	dca(xy) ~ 60/pT µm ⊕ 20 µm	
-3.0 to -2.5						dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.02%×p ⊕ 1%	σp/p ~ 0.05%×p ⊕ 0.5%	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						
-1.5 to -1.0						
-1.0 to -0.5		Barrel	σp/p ~ 0.02%×p ⊕ 0.5%	σp/p ~ 0.05%×p ⊕ 0.5%	dca(xy) ~ 3[illegible]/pT µm ⊕ 5 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.02%×p ⊕ 1%	σp/p ~ 0.05%×p ⊕ 1%	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 2%	dca(xy) ~ 60/pT µm ⊕ 20 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						dca(xy) ~ 30/pT µm ⊕ 60 µm

TEMPLATE

Figure 3: Comparison of performance and PWG requirement parametrizations for relative momentum and transverse pointing resolutions as a function of momentum for the ATHENA baseline tracking system.

PWG Requirements

YR Table 3.1
Symmetric e/h large eta p requirements

η	θ	Nomenclature			Tracking: Resolution	Tracking: Relative Momentum	Tracking: Allowed X/X_0	Tracking: Minimum-pT	Tracking: Transverse Pointing Res.	Tracking: Longitudinal Pointing Res.	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	Electrons and Photons: Min E Photon	π/K/p: p-Range (GeV/c)	π/K/p: Separation	HCAL: Resolution σ_E/E	HCAL: Energy	Muons
< -4.6		↓ p/A	Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0					Not Accessible													
-4.0 to -3.5						Reduced Performance												Muons useful for bkg, improve resolution
-3.5 to -3.0			Central Detector	Backward Detector		σ_p/p ~0.2%×p⊕5%	~5% or less X	70-150 MeV/c (B=1.5 T)			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV	≤10 GeV/c	≥3 σ	50%/√E⊕10%	~500MeV	
-3.0 to -2.5																		
-2.5 to -2.0						σ_p/p~ 0.04%×p⊕2%												
-2.0 to -1.5									dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(z) ~ 100/pT µm ⊕ 20 µm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1:(1E-3 - 1E-2)	50 MeV					
-1.5 to -1.0																		
-1.0 to -0.5				Barrel		σ_p/p ~0.04%×p⊕1%		200 MeV/c	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(z) ~ 30/pT µm ⊕ 5 µm	2%/E ⊕(12-14)%/√E ⊕ (2-3)%	π suppression up to 1:1E-2	100 MeV	≤ 6 GeV/c		100%/√E+10%		
-0.5 to 0.0																		
0.0 to 0.5																		
0.5 to 1.0																		
1.0 to 1.5				Forward Detectors		σ_p/p ~0.04%×p⊕2%		70 - 150 MeV/c (B = 1.5 T)	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(z) ~ 100/pT µm ⊕ 20 µm	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/√E+10%		
1.5 to 2.0																		
2.0 to 2.5																		
2.5 to 3.0						σ_p/p ~0.2%×p⊕5%												
3.0 to 3.5																		
3.5 to 4.0		↑ e		Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5					Not Accessible													
> 4.6			Far Forward Detectors	Proton Spectrometer Zero Degree Neutral Detection														

p

YR Table 10.6
Asymmetric e/h large eta pT requirements

η	Nomenclature			Tracking: Resolution	Tracking: Allowed	Tracking: minimum-pT	Tracking: Si-Vertex	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	Electrons and Photons: min E	π/K/p: p-Range	π/K/p: Separati	HCAL: Resolution σ_E/E	HCAL: Energy	Muons
-6.9 to -5.8			low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5						300 MeV pions									
-4.5 to -4.0			Instrumentation to separate charged particles from photons			300 MeV pions		2%/√E(+1-3%)		50 MeV					
-4.0 to -3.5	↓ p/A	Auxiliary De				<100MeV pions, 135MeV kaons				50 MeV			~50%/√E + 6%		muons useful for bkg, improve resolution
-3.5 to -3.0		Central Detector	Backward Detector		~5% or less X				π suppression up to 1:1E-4	50 MeV	≤ 7 GeV/c	≥ 3 σ	~45%/√E+6%	~500 MeV	
-3.0 to -2.5				σpT/pT ~ 0.1%⊕0.5%			σ_xy ~ 30/pT µm + 40 µm			50 MeV					
-2.5 to -2.0				σpT/pT			σ_xy ~ 30/pT µm + 20 µm	2%/√E(+1-3%)		50 MeV					
-2.0 to -1.5				σpT/pT 0.05%⊕0.5%				7%/√E(+1-3%)		50 MeV					
-1.5 to -1.0								7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5			Barrel	σpT/pT ~0.05%×pT+0.5%			σxyz ~ 20 µm, d0(z) ~d0(rΦ) ~ 20/pTGeV µm + 5 µm	(10-12)%/√E(+1-3%)		50 MeV	≤ 10 GeV/c		~85%/√E+7%		
-0.5 to 0.0										50 MeV			~85%/√E+7%		
0.0 to 0.5										50 MeV			~85%/√E+7%		
0.5 to 1.0										50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5			Forward Detectors	σpT/pT ~0.05%×pT+1.0%			σ_xy ~ 30/pT µm + 20 µm		3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E		
1.5 to 2.0										50 MeV	≤ 50 GeV/c				
2.0 to 2.5										50 MeV					
2.5 to 3.0				σpT/pT ~ 0.1%×pT+2.0%			σ_xy ~ 30/pT µm + 40 µm			50 MeV	≤ 30 GeV/c				
3.0 to 3.5							σ_xy ~ 30/pT µm + 60 µm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0		Auxiliary Detectors	Instrumentation to separate charged particles from photons	Tracking capabilities are desirable for forward tagging						50 MeV					
4.0 to 4.5	↑ e		Neutron Detection			300 MeV pions				50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)		
4.5 to 5.0								4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV					
>6.2			Proton Spectrometer	σintrinsic(|t|)/|t| < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

pT

PWG Requirements

- Requirements listed here are labeled p, but correspond to pT values on Table 10.6
- We should clear up this discrepancy

Table 11.23: Comparison of performance and requirements for the all-silicon concept at 3 T magnetic field.

Tracking performance (All-silicon concept, B = 3 T)						
			Momentum res.		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 0.5%	dca(xy) ~ 60/pT µm ⊕ 20 µm	
-3.0 to -2.5						dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.02%×p ⊕ 1%	σp/p ~ 0.05%×p ⊕ 0.5%	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						
-1.5 to -1.0						
-1.0 to -0.5		Barrel	σp/p ~ 0.02%×p ⊕ 0.5%	σp/p ~ 0.05%×p ⊕ 0.5%	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.02%×p ⊕ 1%	σp/p ~ 0.05%×p ⊕ 1%	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 2%	dca(xy) ~ 60/pT µm ⊕ 20 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						dca(xy) ~ 30/pT µm ⊕ 60 µm

Table 11.25: Comparison of performance and requirements for the hybrid concept at 3 T magnetic field.

Tracking performance (Hybrid concept, B = 3 T)								
			Momentum res.		Minimum pT		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 50/pT µm ⊕ 10 µm	
-3.0 to -2.5					160-220 MeV/c	100-150 MeV/c		dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 25/pT µm ⊕ 3 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						100-150 MeV/c		
-1.5 to -1.0					300 MeV/c	100-150 MeV/c		
-1.0 to -0.5		Barrel	σp/p ~ 0.11%×p ⊕ 0.2% (0-5 GeV/c) σp/p ~ 0.03%×p ⊕ 0.5% (5-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%	400 MeV/c (90% acceptance)	100-150 MeV/c	dca(xy) ~ 15/pT µm ⊕ 2 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0								
0 to 0.5								
0.5 to 1.0								
1.0 to 1.5		Forward Detector	σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 1%	300 MeV/c	100-150 MeV/c	dca(xy) ~ 25/pT µm ⊕ 3 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					160-220 MeV/c	100-150 MeV/c		
2.0 to 2.5						100-150 MeV/c		
2.5 to 3.0			σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 50/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						100-150 MeV/c		dca(xy) ~ 30/pT µm ⊕ 60 µm