MC Activity tracking optimization

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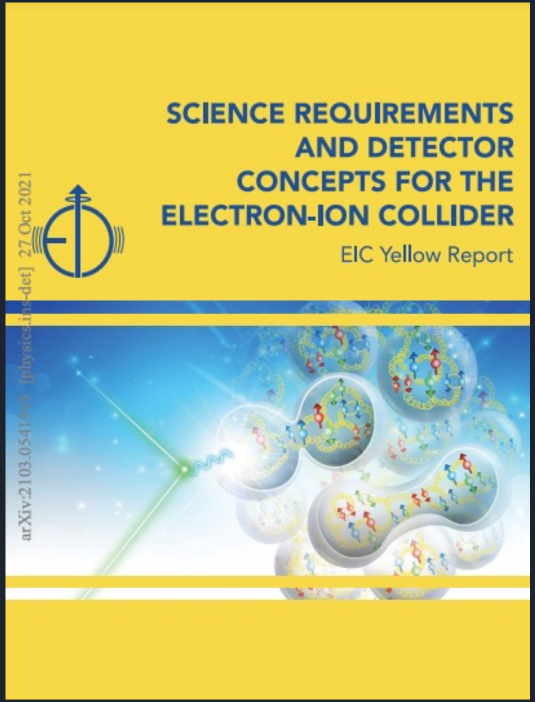
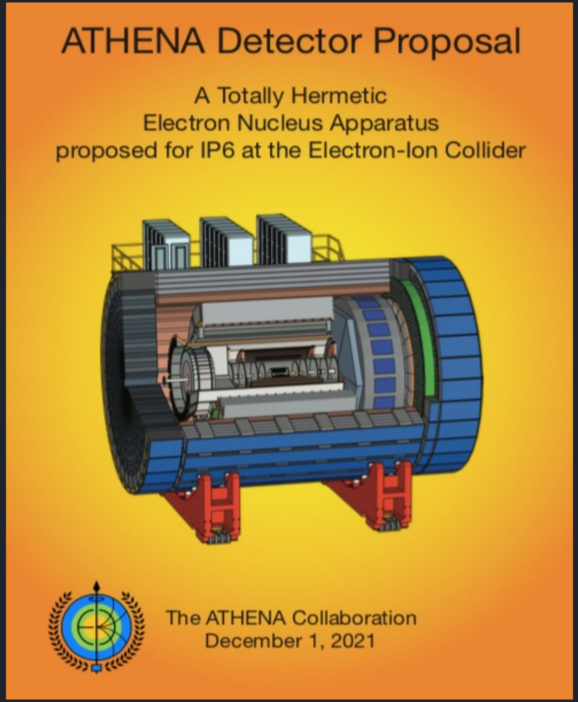
Brief Intro on the Tracking in EIC - ATHENA

- Tracker performance studies started for the Yellow Report https://arxiv.org/abs/2103.05419 where the EIC scientific goals were explained in detail. The specific detector requirements were defined to address those goals and the paper presented the evolving detector concepts to realize the EIC's experimental program.

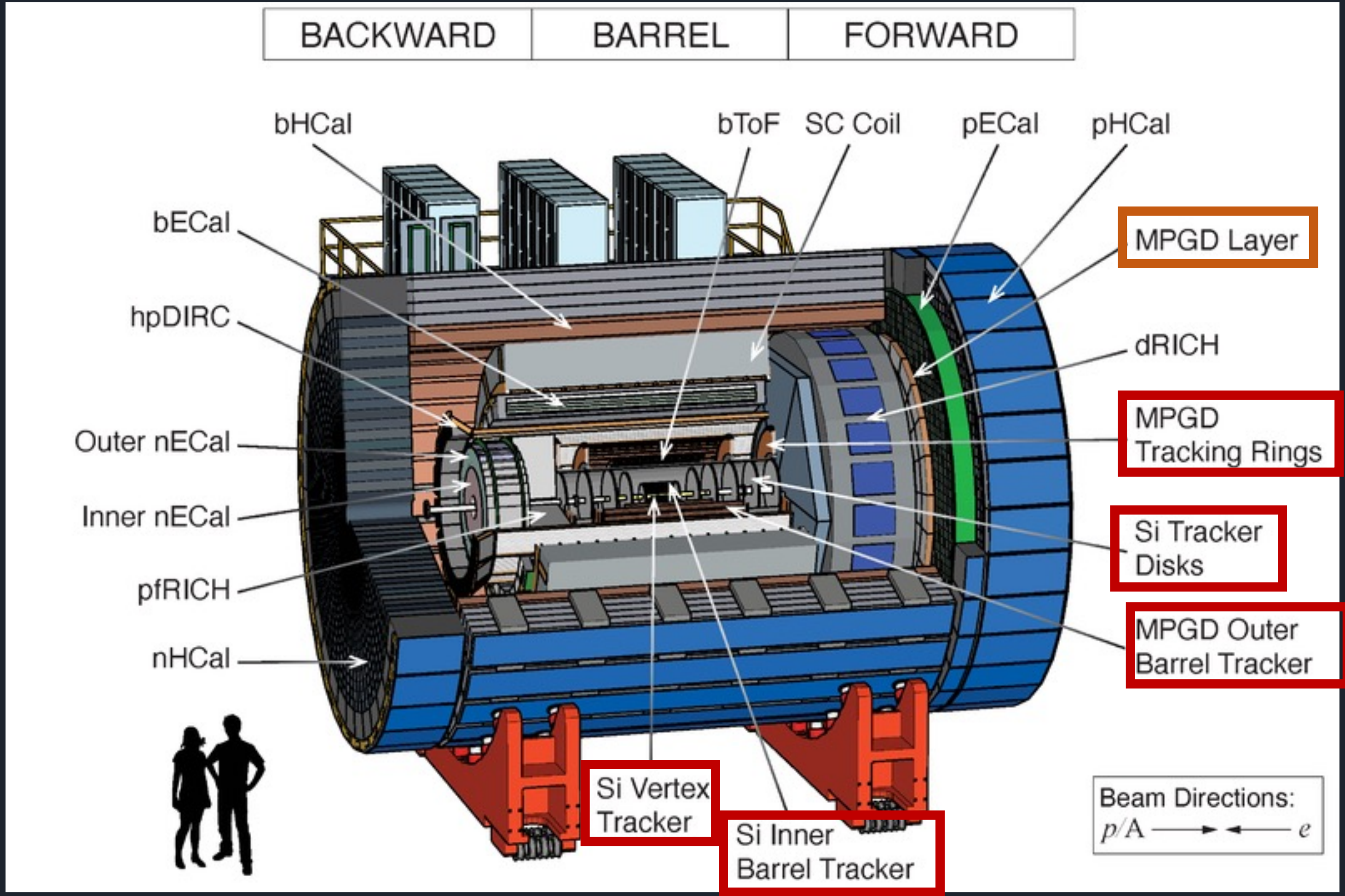
- Tracking system optimization started within the Tracking WG for the EIC YR (2020)
- Further studies and final design/performance optimization carried out within the Tracking WG for the ATHENA Proposal (2021)
- In the last two years several software tools were vailable and the tracking performances were exploited in lots of different conditions : detector tecnology, material budget, geometry and magnetic field maps





ATHENA Detector : overview

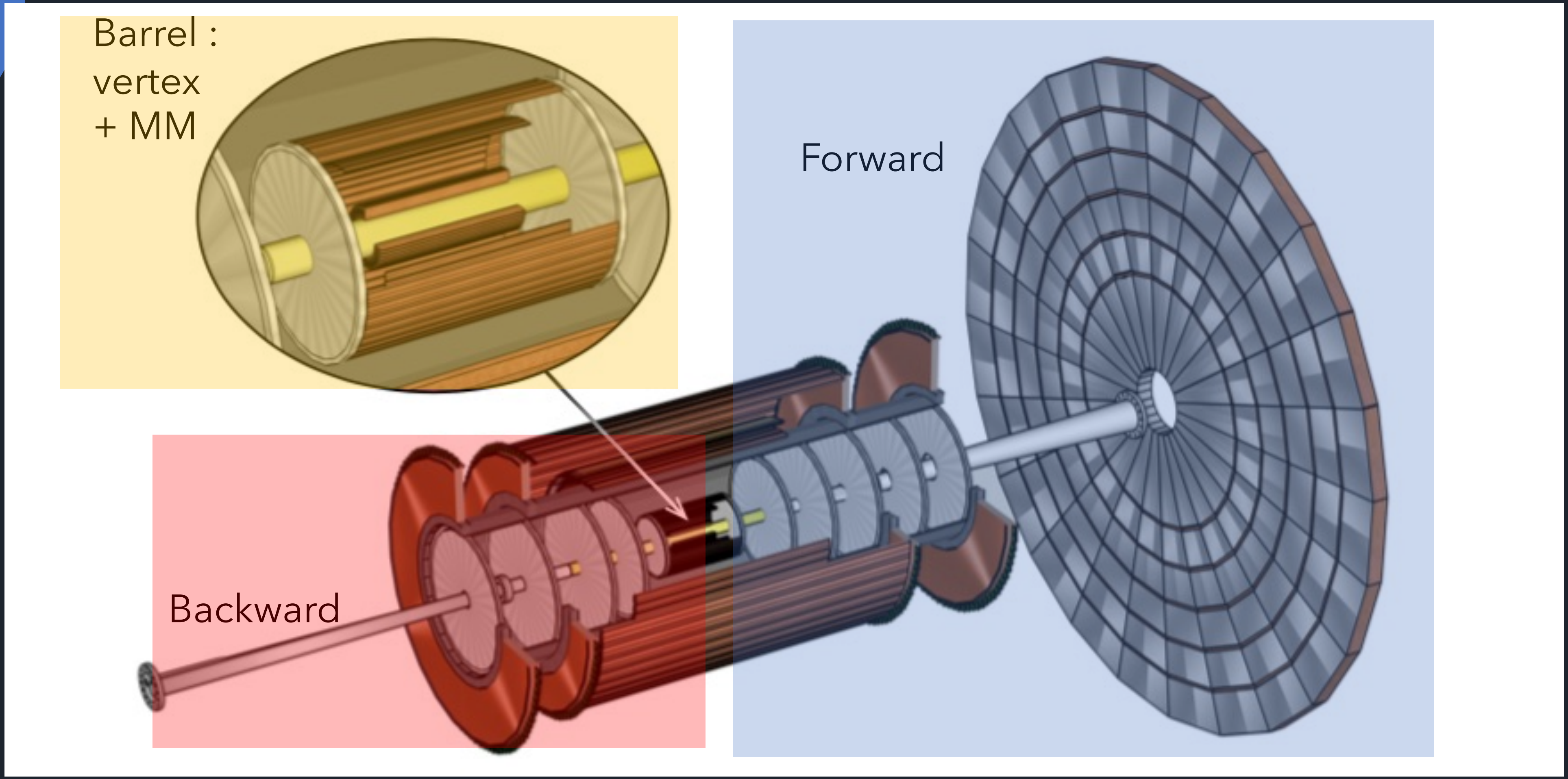
- https://wiki.bnl.gov/athena/index.php/Design_Concepts_and_Considerations



p/A → ← e

Right side = positive side
Left side = negative side

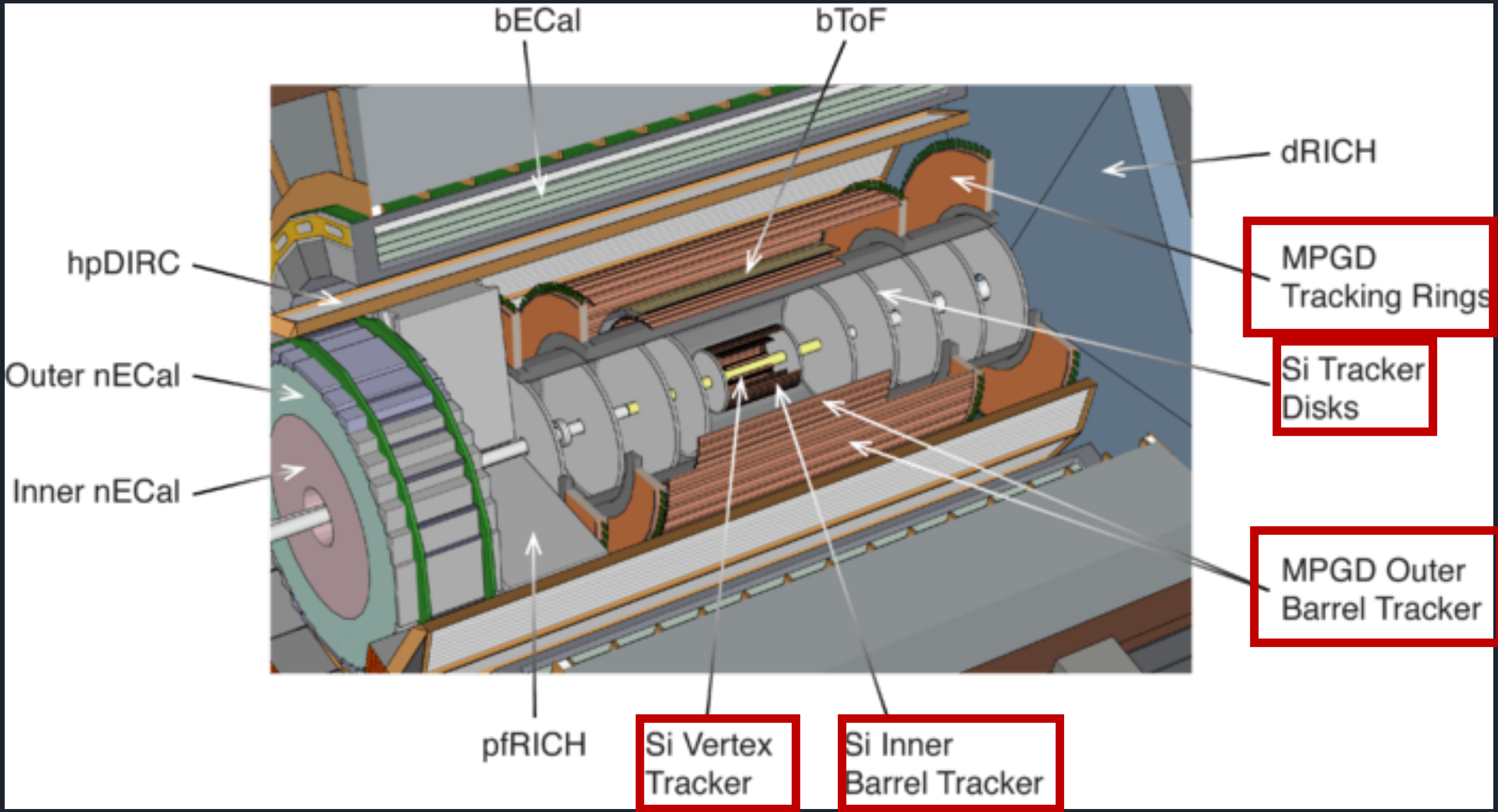
ATHENA Detector tracker



Choices done to optimize :

- tracking and vertex reconstruction performance
- cost
- ease of integration
- minimising material in front of the electromagnetic calorimeters.

ATHENA Detector : tracker

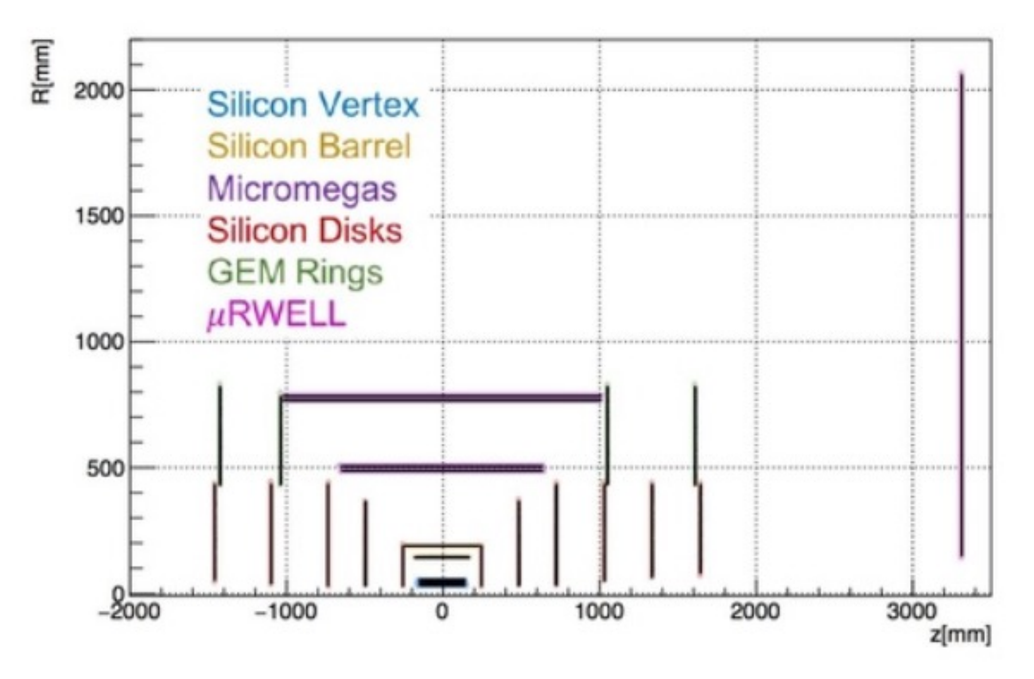


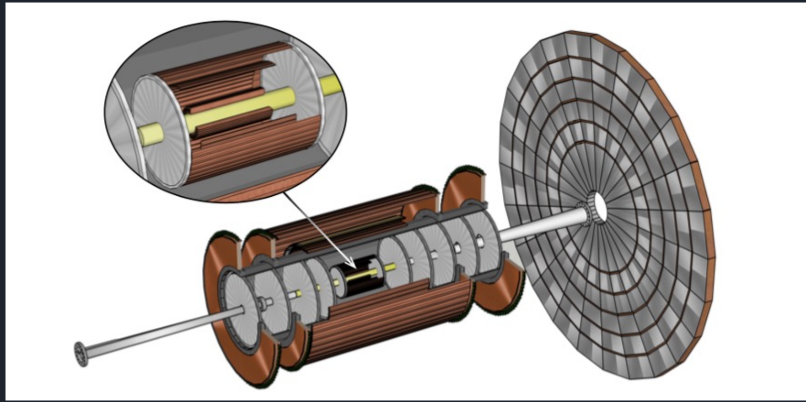
Barrel :
- 3+2 Cilinders of MAPS
- 4 Cilinders of MicroMegas

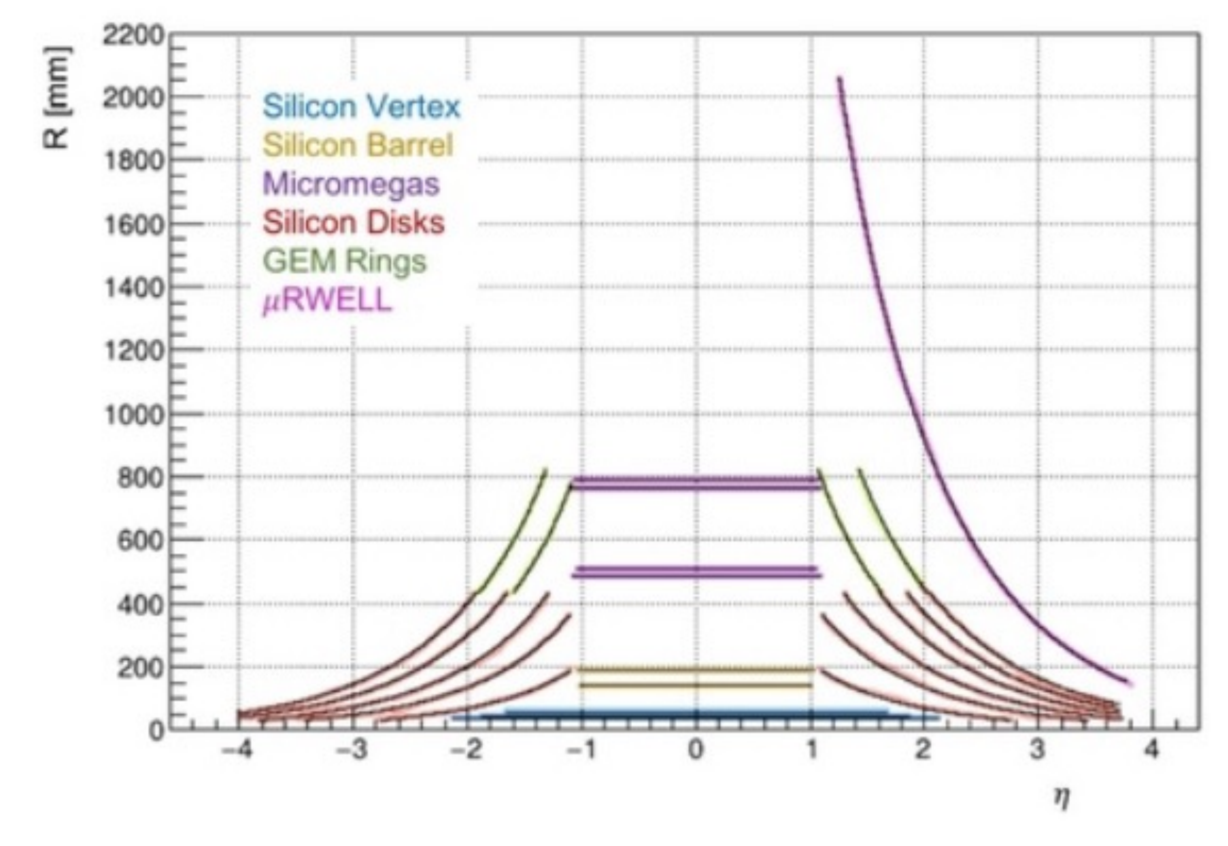
Forward:
- 6 Disks of MAPS + 2 GEM tracking rings
- 1 μRWELL to constraint the track in the dRICH

Backward :
- 5 Disks of MAPS + 2 GEM tracking rings

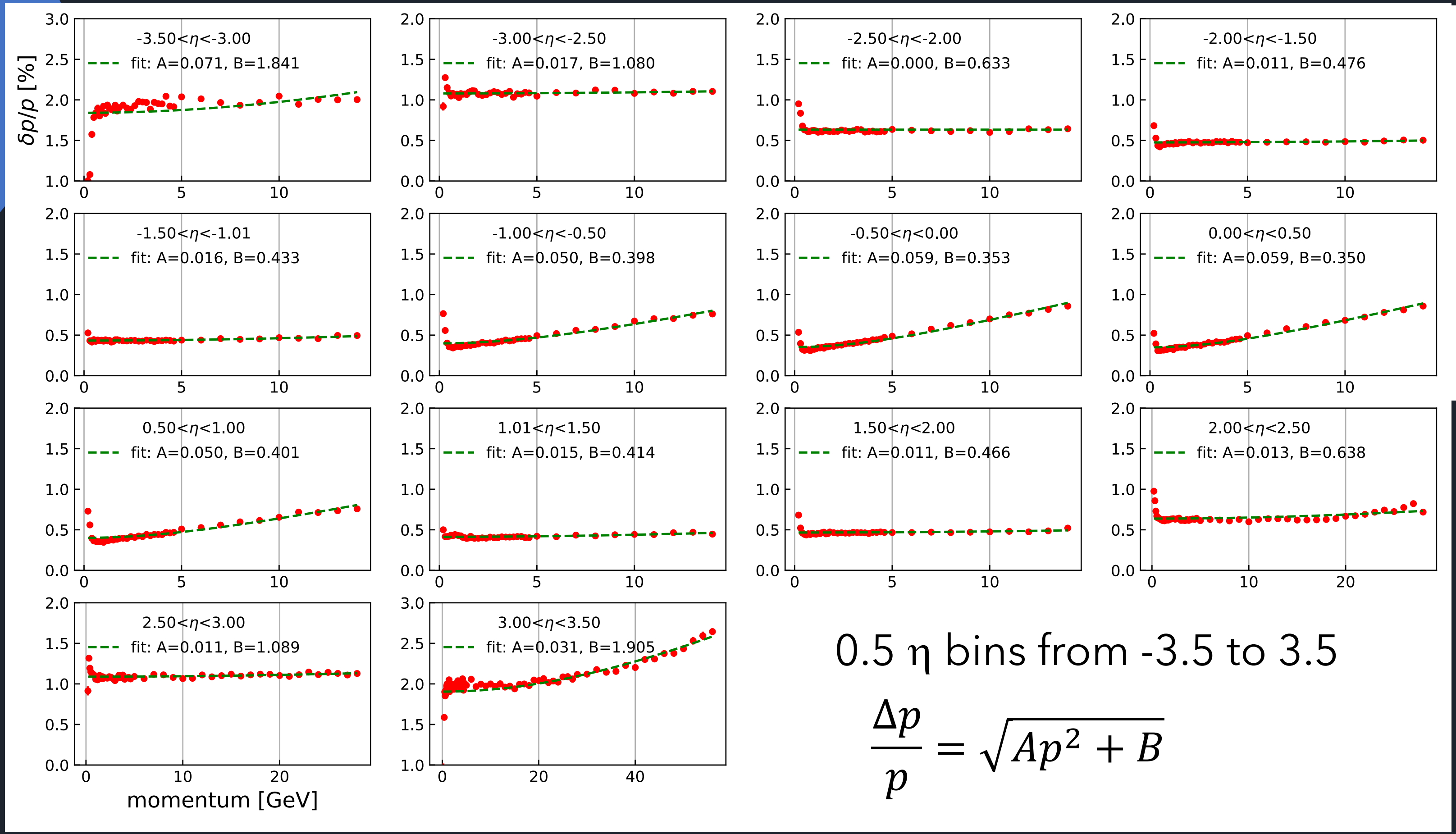
Tracker acceptance





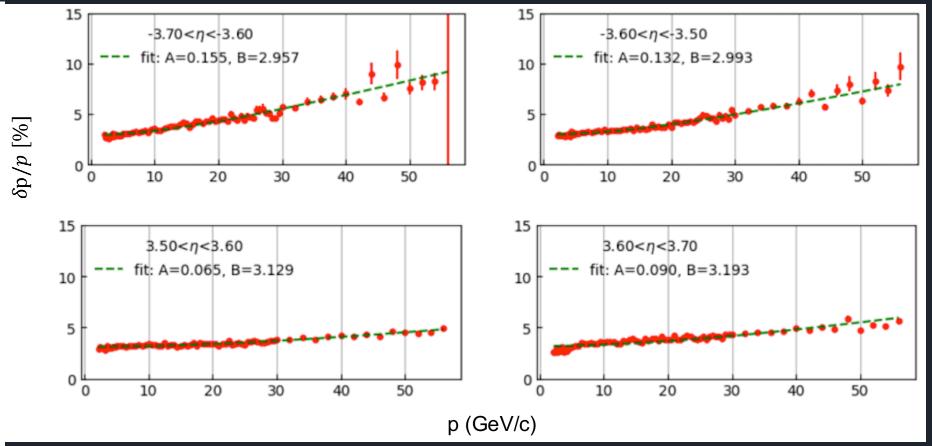


Tracker performances : $\Delta p/p$



0.5 η bins from -3.5 to 3.5

$$\frac{\Delta p}{p} = \sqrt{Ap^2 + B}$$

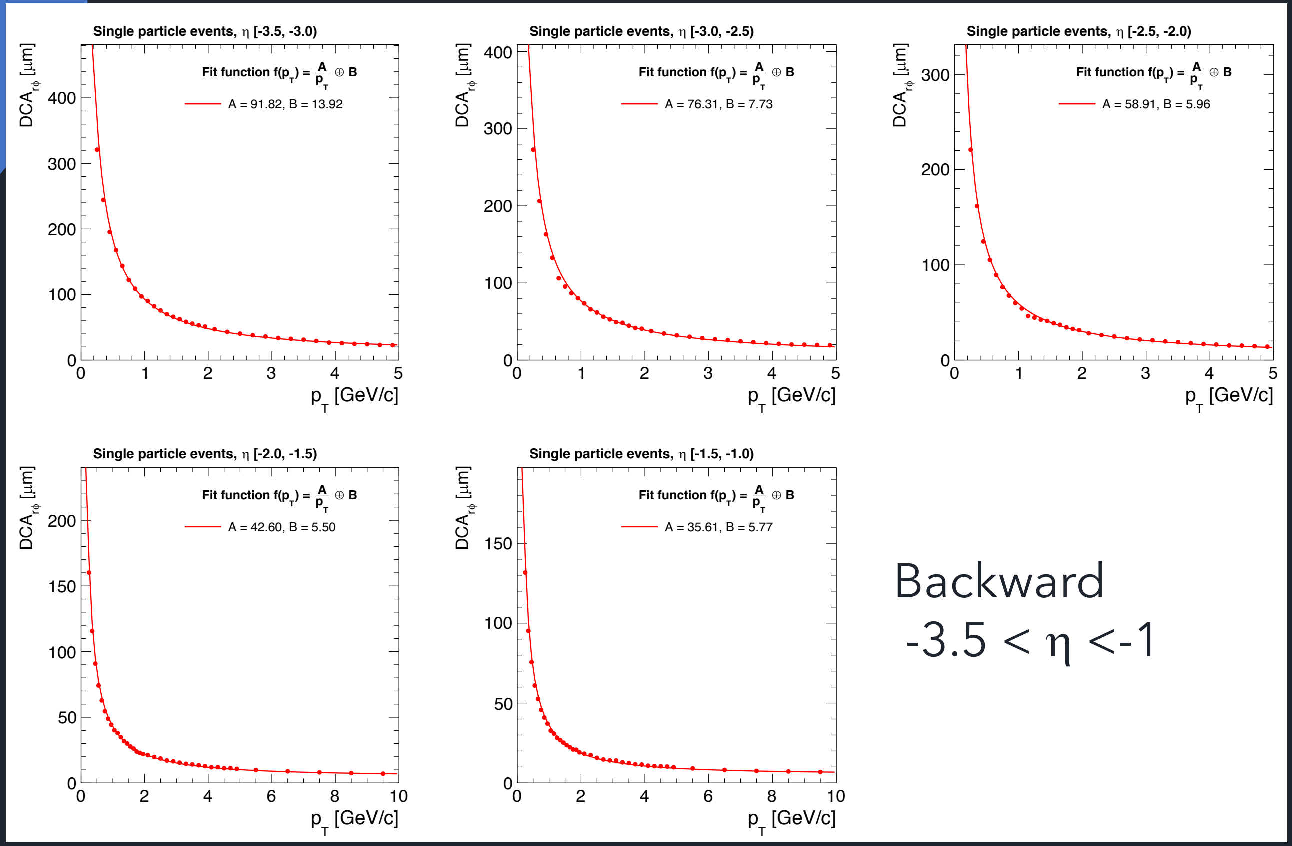


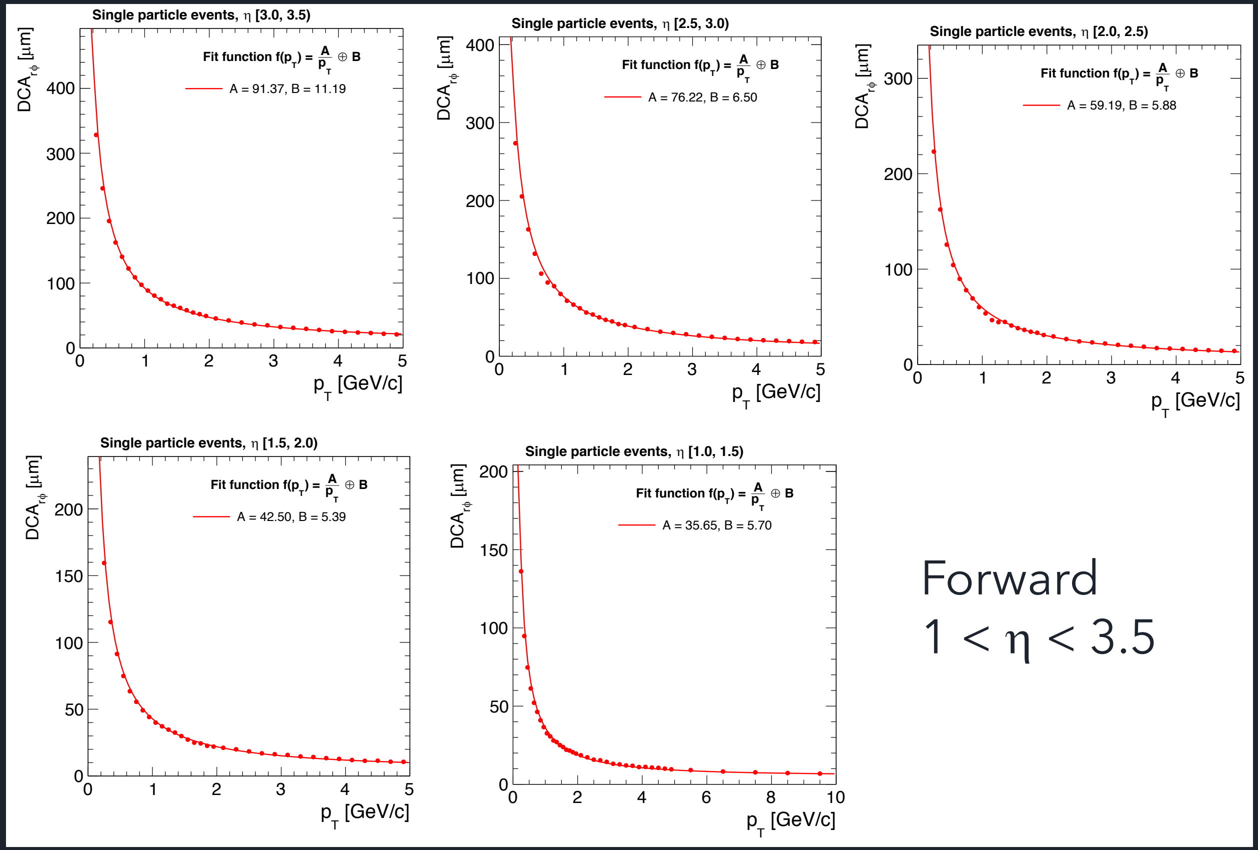
largest |η| bins 3.5-3.7

Trends compatible to the expected parametrization

https://wiki.bnl.gov/athena/index.php/Vertex_and_Tracking_System

Tracker performances : pointing resolution r-ϕ

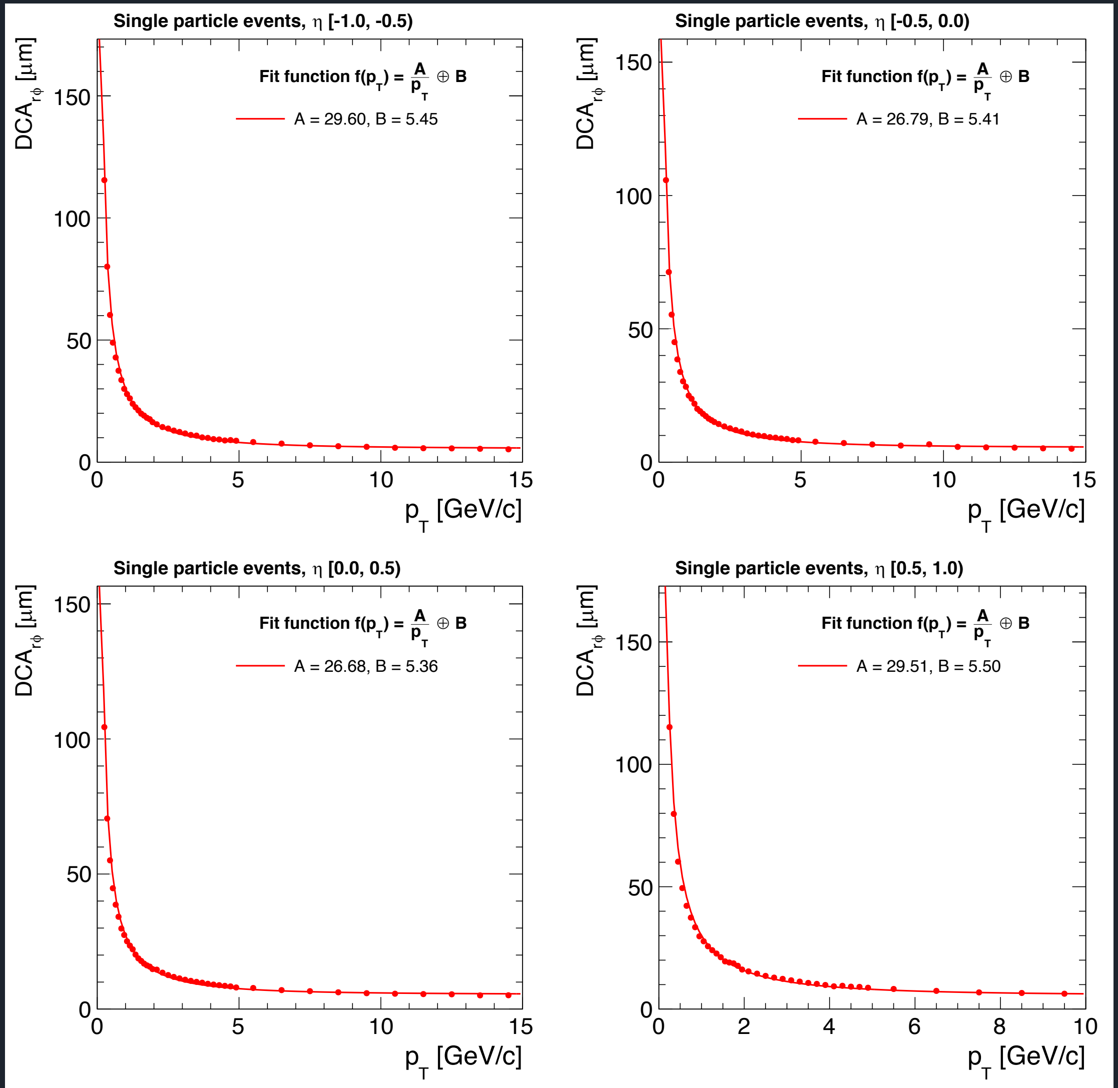




$$DCA_T = \sqrt{\frac{A^2}{{p_T}^2} + B^2}$$

Trends compatible to the expected parametrization
Same holds for DCA_Z

Tracker performances : pointing resolution r-ϕ

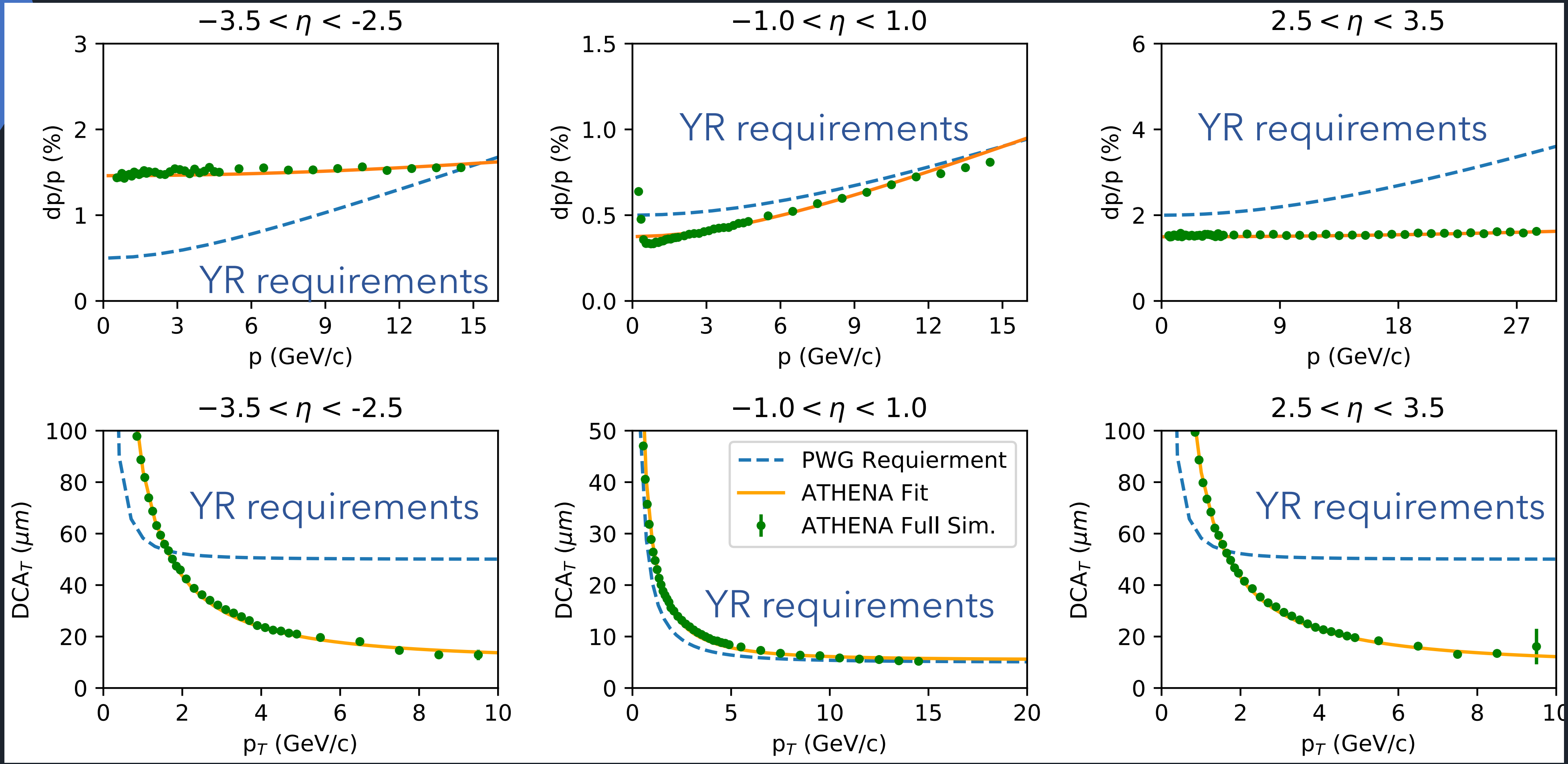


Central $-1 < \eta < 1$

$$DCA_T = \sqrt{\frac{A^2}{{p_T}^2} + B^2}$$

Trends compatible to the expected parametrization
Same holds for DCA_Z

Tracking performances

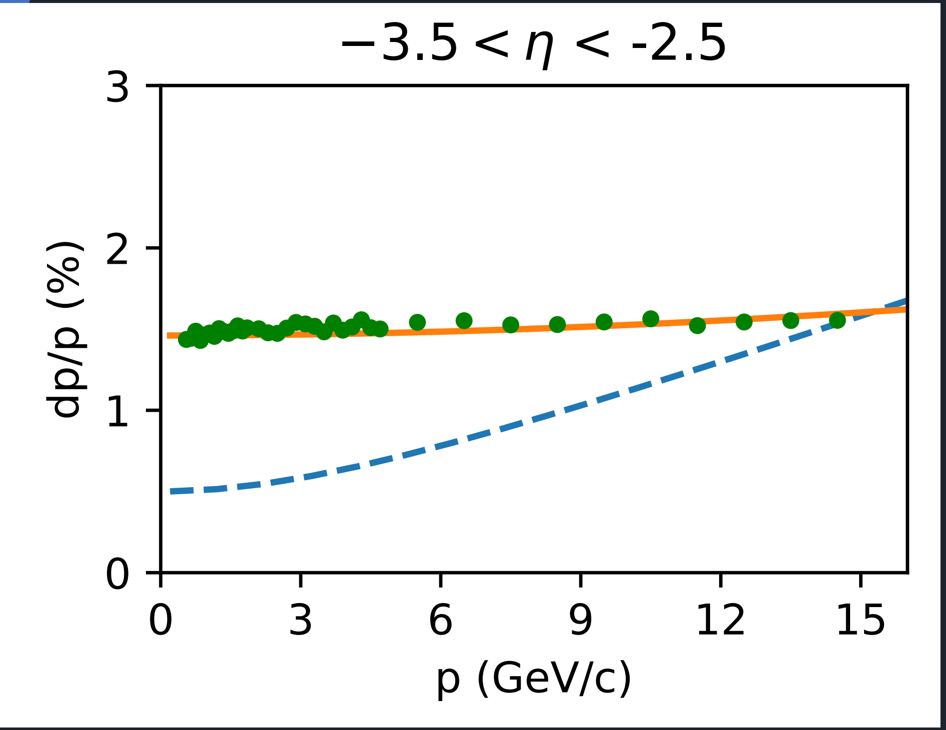


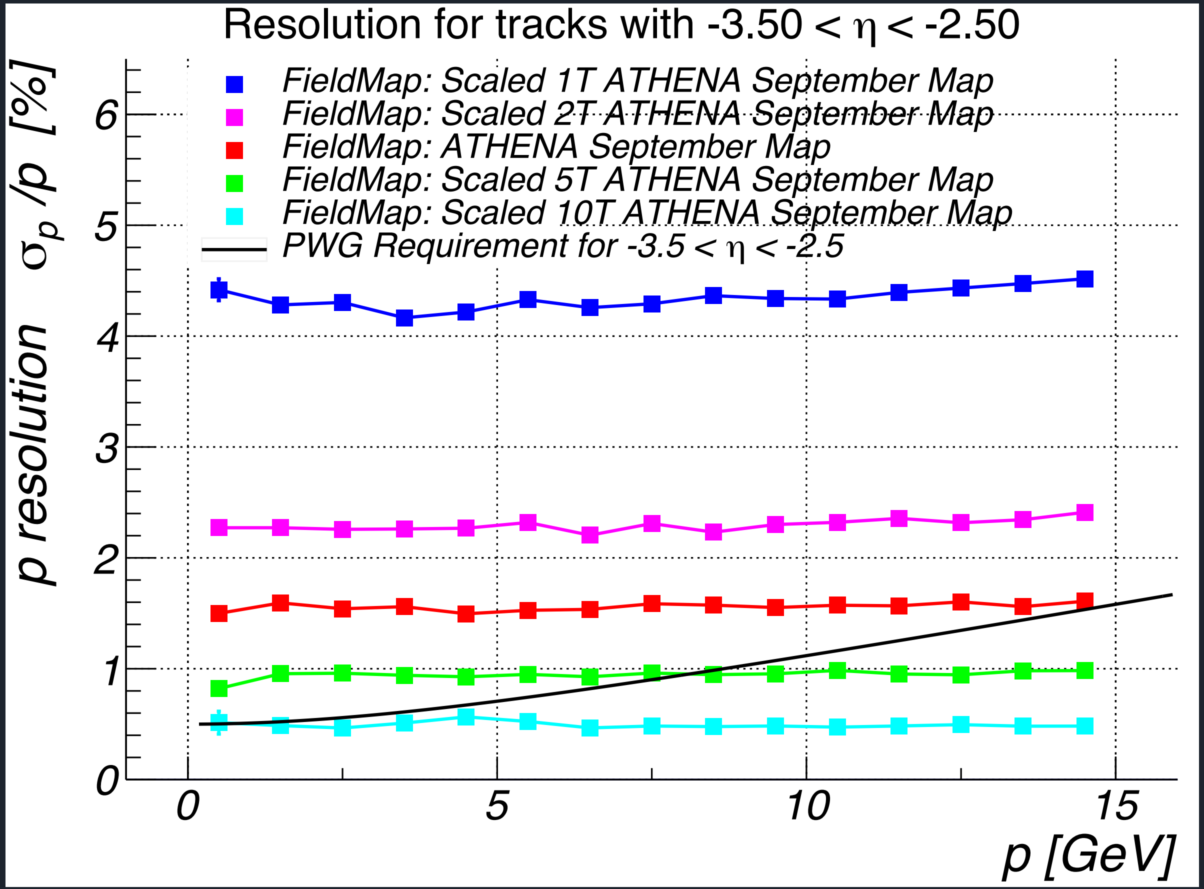
δp/p : requirements satisfied in all η bins except the most backward region

DCA_T:

- central : ok apart from 1-5 GeV/c
- F/B : not satisfactory performance below 2 GeV/c

Backward region performance study on B





- In order to satisfy the YR Requirements 10T B field is necessary!

MC simulations

Experience with the tracking studies

Starting point: Yellow Report

Tracking requirements from PWGs

η			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
-3.5 to -3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 0.5\%$		100-150 MeV/c	
-3.0 to -2.5		Backward Detector			100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 40 μm
-2.5 to -2.0			$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 20 μm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5						
-0.5 to 0	Central Detector					
0 to 0.5		Barrel	$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$	~5% X0 or less	100-150 MeV/c	dca(xy) ~ 20/pT μm ⊕ 5 μm
0.5 to 1.0						
1.0 to 1.5					100-150 MeV/c	
1.5 to 2.0		Forward Detector	$\sigma_p/p \sim 0.05\% \times p \oplus 1\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 20 μm
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 40 μm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 60 μm

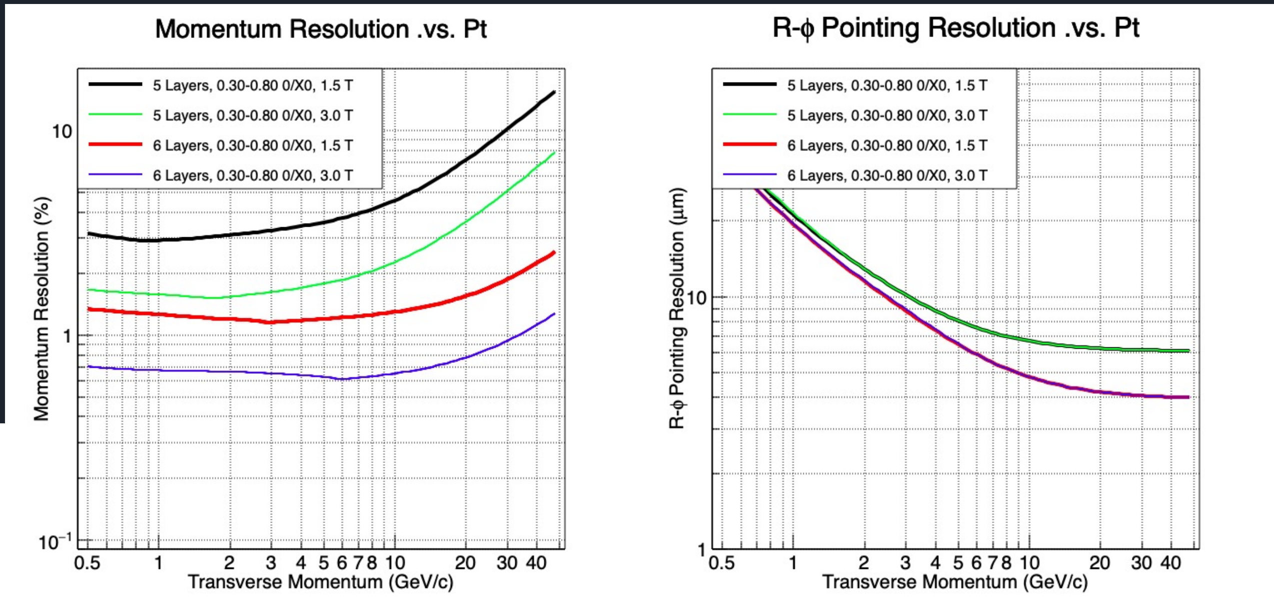
Several MC tools were available (JANA, eic-smear, eic-root, but also jupyter-notebooks interfaces, etc.)
Our choice :

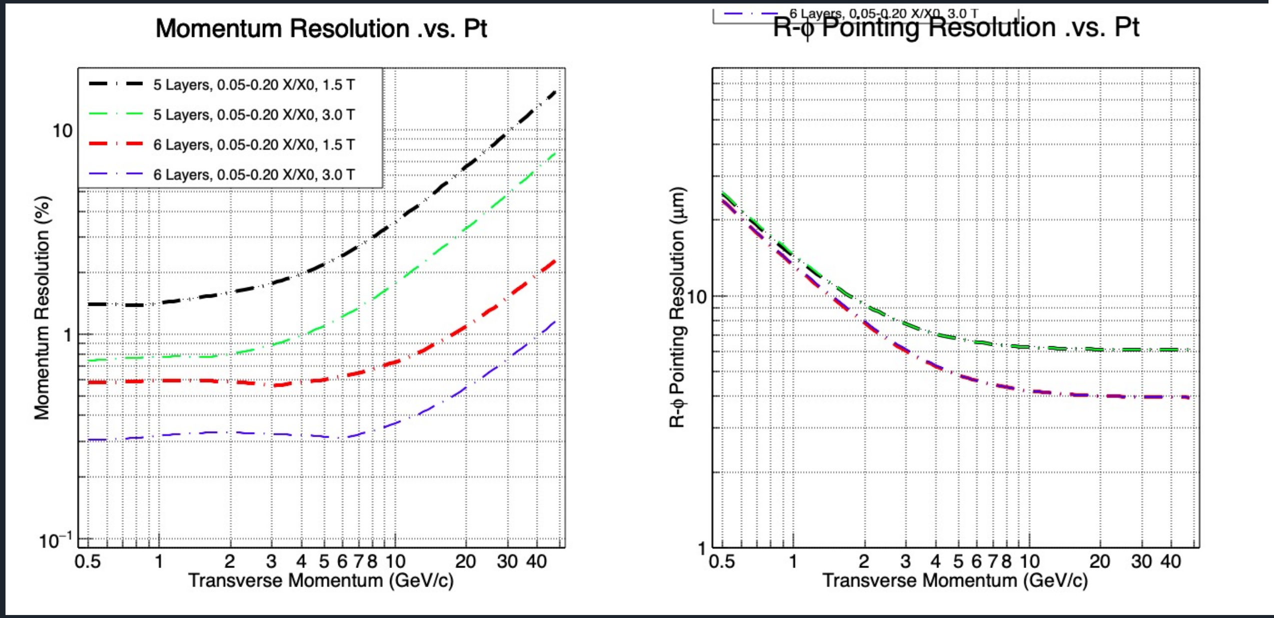
1) Perform studies with a well known Fast Simulation Tool for barrel tracking
2) Use root with EIC libraries : eicroot
3) Recently : fun4all

Studies always performed with dockers

Studies begin: Fast Simulation Tool

Tracking performances results from analytical calculations
Quality factors: $\Delta p/p$ e d_0
Tested in several configuration of layers, material budget and magnetic field



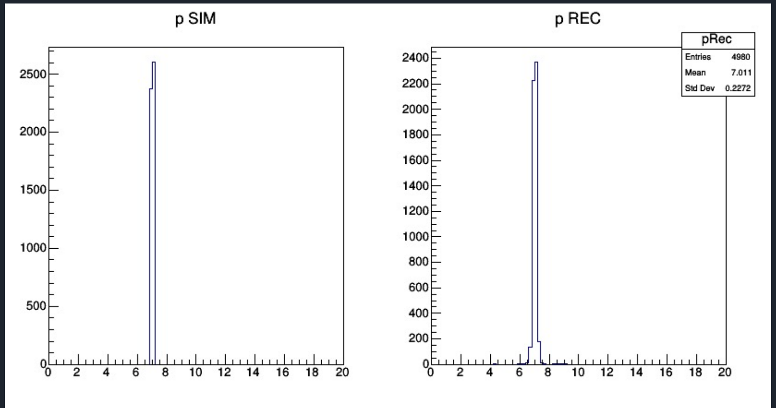


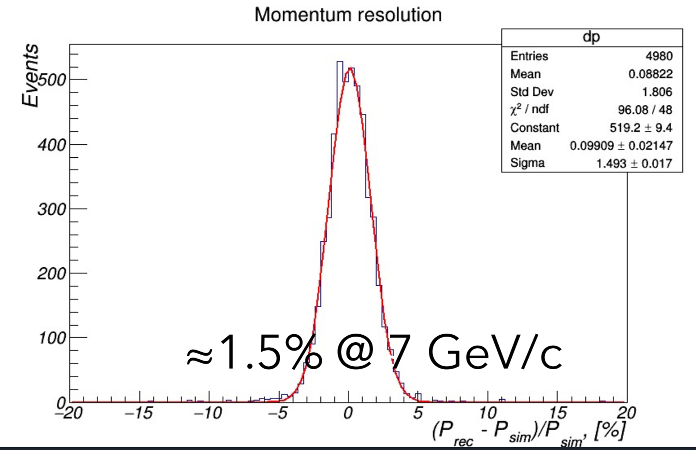
$\Delta P/P$ @ 5 Layers, 3T, 0.05-0.2 % X/X_0
- 0.75% at 0.7 GeV/c
- 1.5 % at 7 GeV/c

Results with eicroot

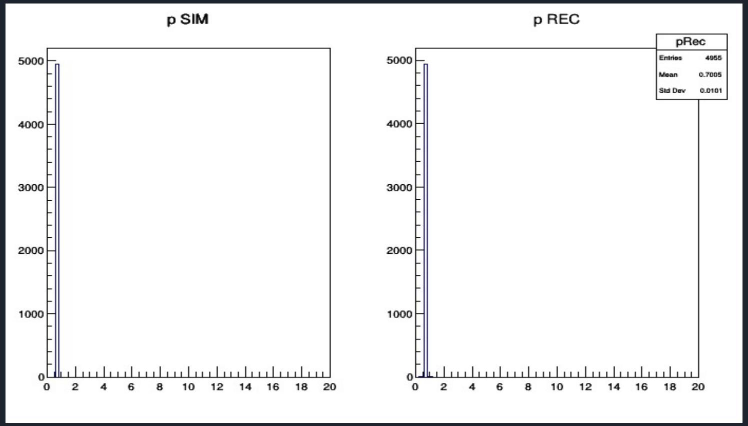
eicroot : first full simulation software used in the tracking WG

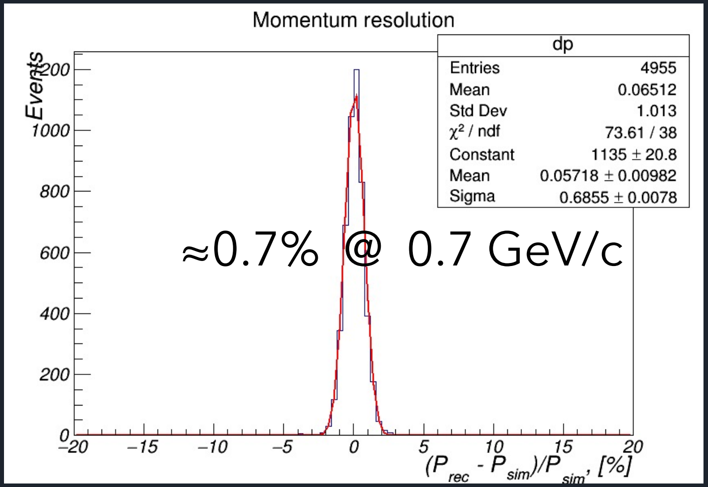
5 Layers,
standalone tracking
B= 3 T
5 layers
- 0.05% X/X_0 inner
- 0.2% X/X_0 outer





Results in agreement with the FS tool





Such initial studies were useful to define the initial configuration geometries for the YR

Tracker optimization history

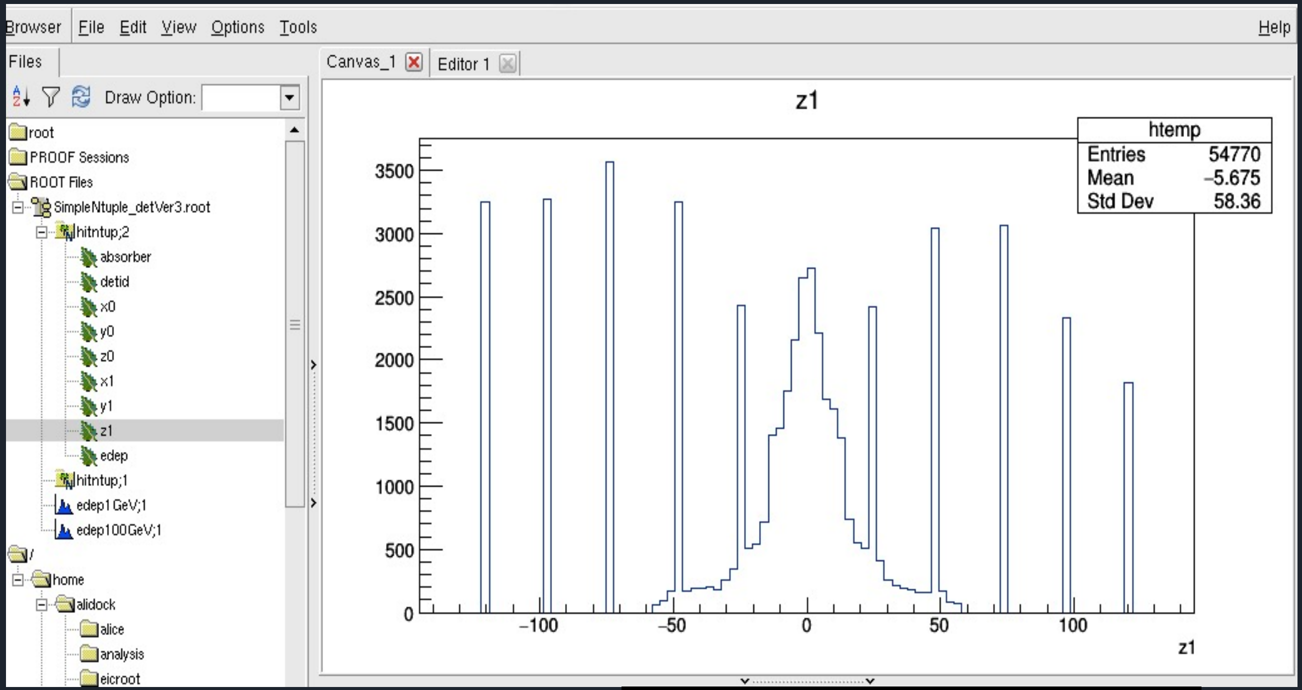
- Latest YR configurations:
  - ALL-SILICON tracking system 6-layer barrel, 5+5 disks for back/forward regions
  - HYBRID tracking system: silicon vertex + TPC (barrel), 7 silicon disks for back/forward region
- ATHENA main configuration parameters
  - Baseline 0 : 2 vertexing layers, 0.05% X/X0, 2+2 barrel layers, 0.55% X/X0, 5 disks per side, 2 GEM endcap
  - Baseline 1 : 3 vertex layers, 0.05% X/X0, 2 barrel layers, 0.55% X/Xo, 5 disks per side, 2+3 MicroMegas, 1 GEM on N side and 2 GEM on P side
  - "Baseline 2 represents the final optimization based on :
    - The outer MPGD barrel layers of baseline 2 have larger radii, corresponding to higher p_T tresholds, and coarser resolutions than the (smaller) MAPS outer barrel radii
    - Three versus two MicroMegas outer layers
    - 1 disk less on P side
    - The tracker extends further in z,

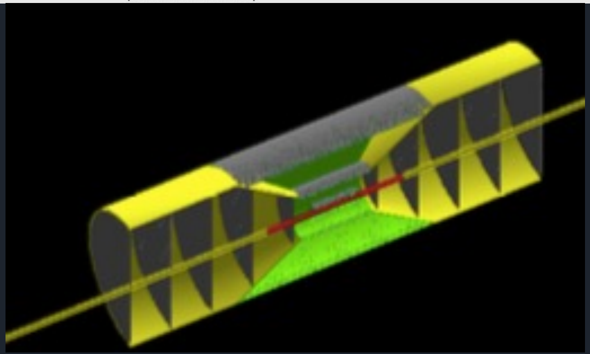
fun4all

- fun4all is a software which provides full simulations. Extensively used in the tracking working group.
- Most of the geometries have been defined in eicroot first, then exported to fun4all and tested
- The tracking performances of the 3 ATHENA baselines were tested with fun4all
- Lately the software working group prepared the dd4hep (+acts) for eic studies and a validation campain started
- Starting with the same geometry the tracking performances were studied in both softwares and they were found to be compatible

fun4all

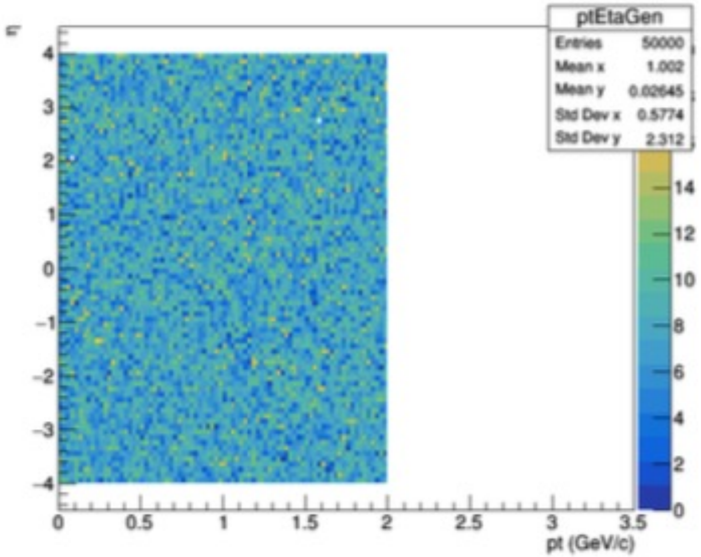
PROs
Developed since some time
Documentation available
Docker usage ☺
Easy to install
Input : .C configuration file
Output : root files

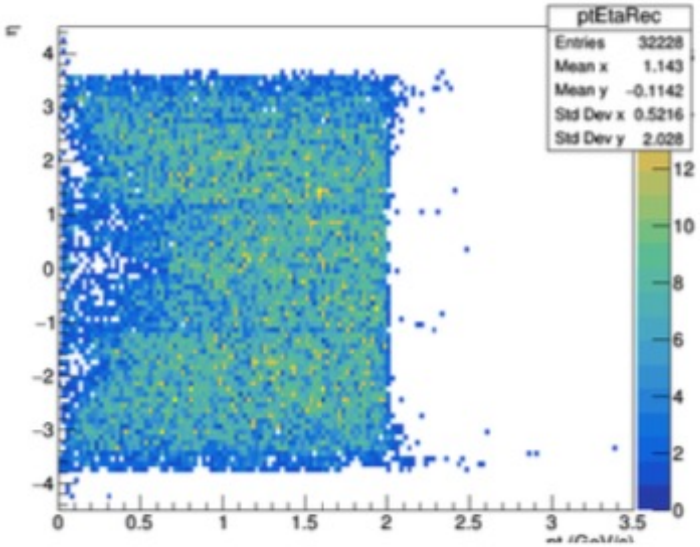




CONs
Docker usage ☹
Not possible to get necessary information of the track (e.g.: track parameters) by adding one more branch

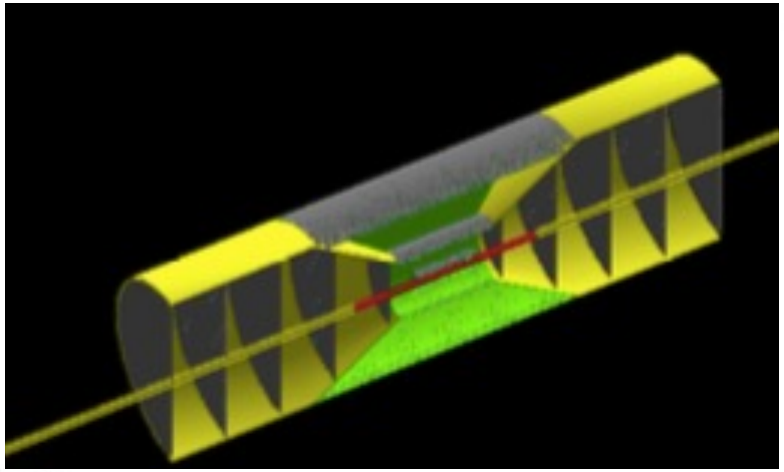
MC Simulations in fun4all

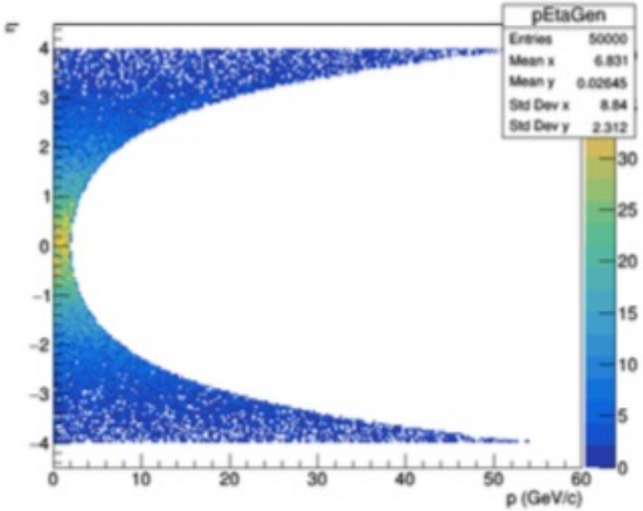


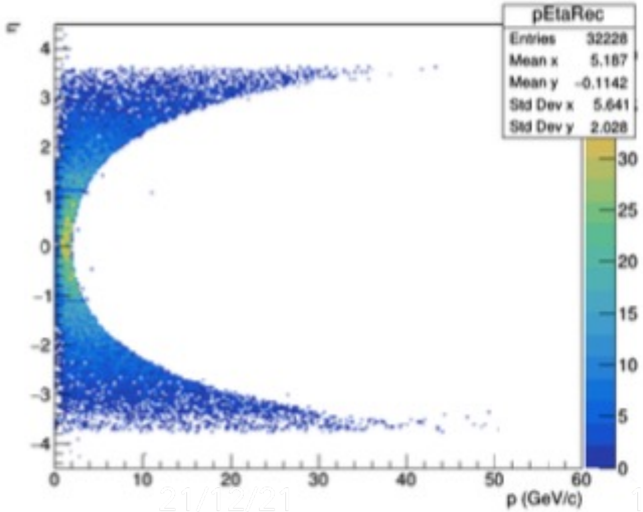


π- box : flat pt [0-2]
flat η ($|\eta|<4$)

Intermediate configurations

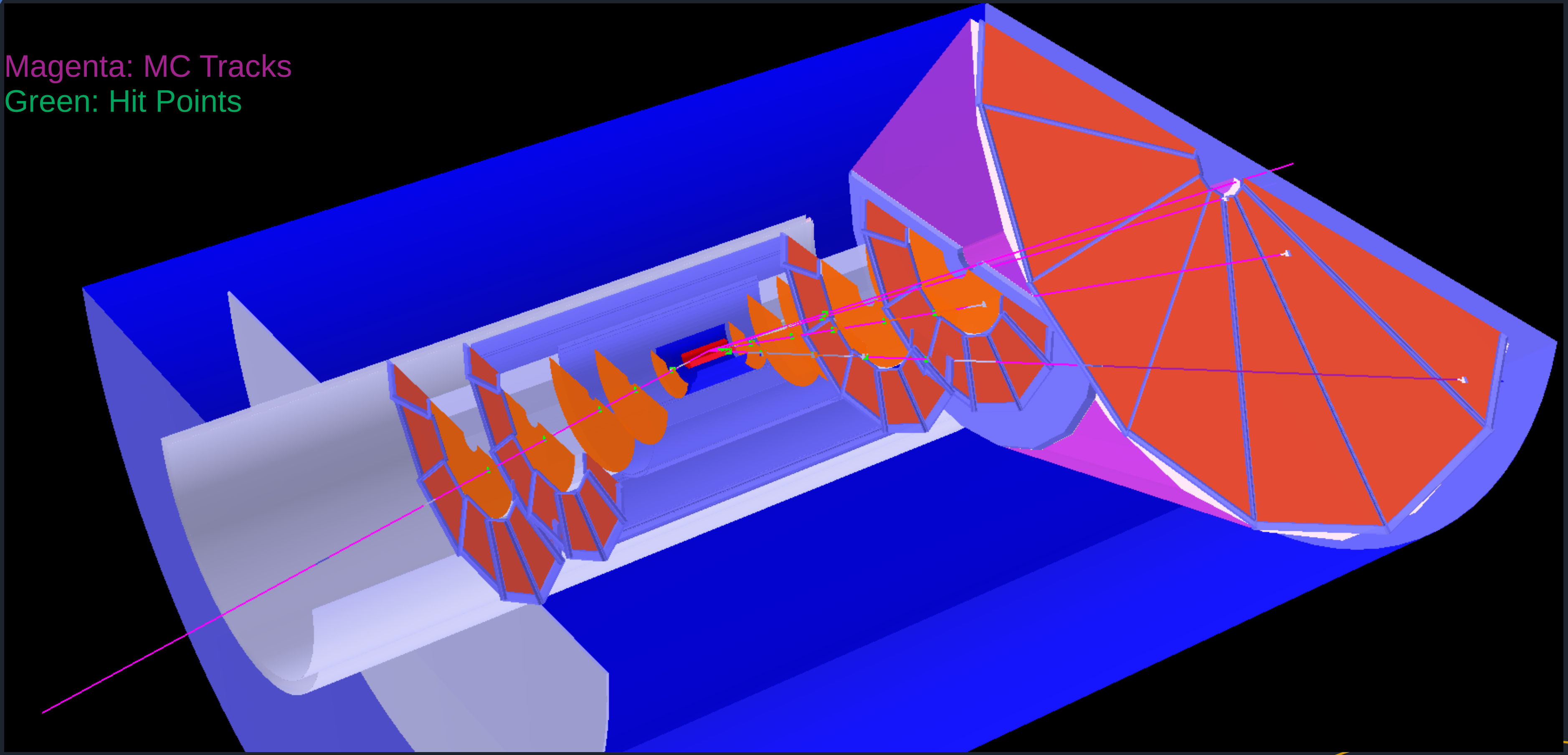






MC full simulation in fun4all

ATHENA tracker in fun4all.
N.B.: ATHENA software used for the Proposal is dd4hep

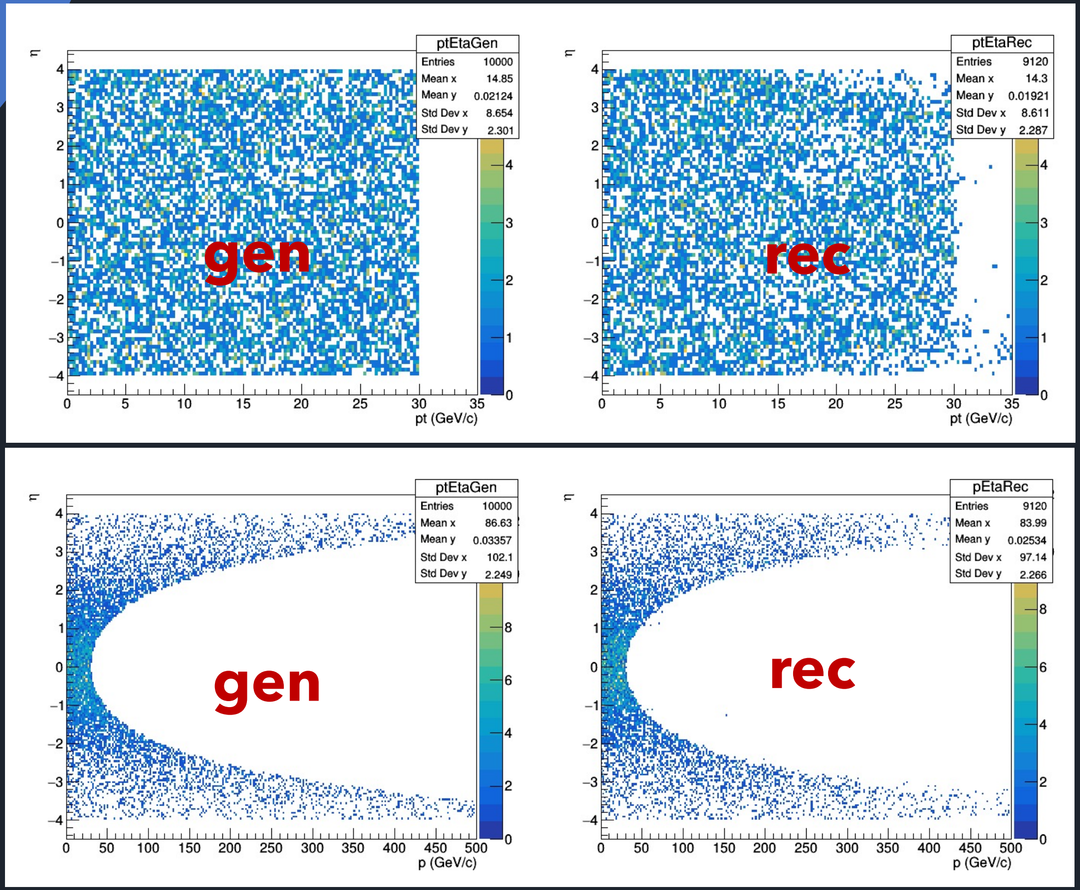


Shyam Kumar
Uniba-Postdoc

Checks:
- $\delta p/p$
- DCA
- Efficiency

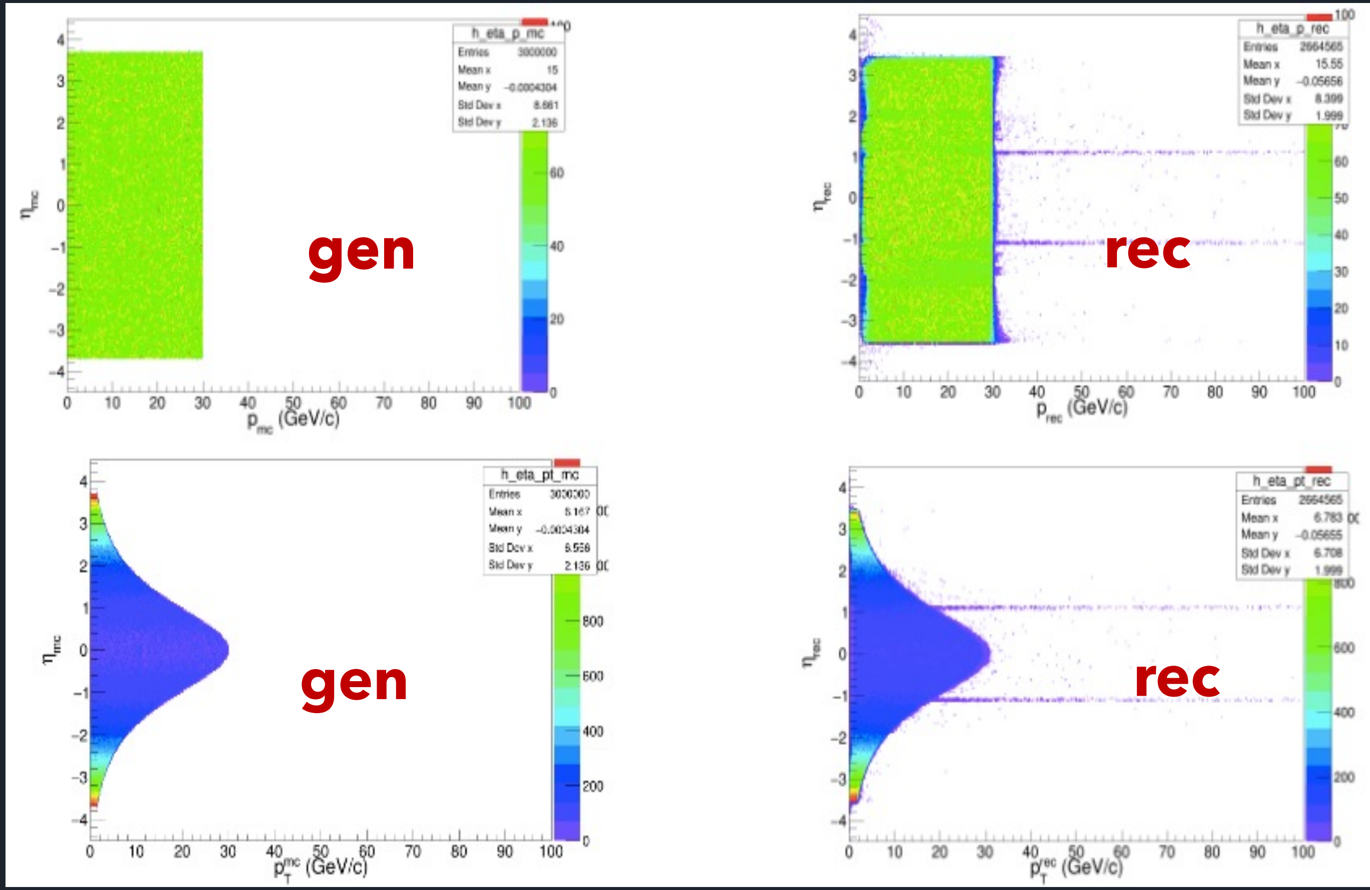
Tracker acceptance : box of π

flat η and p_T



flat η and p

Shyam Kumar



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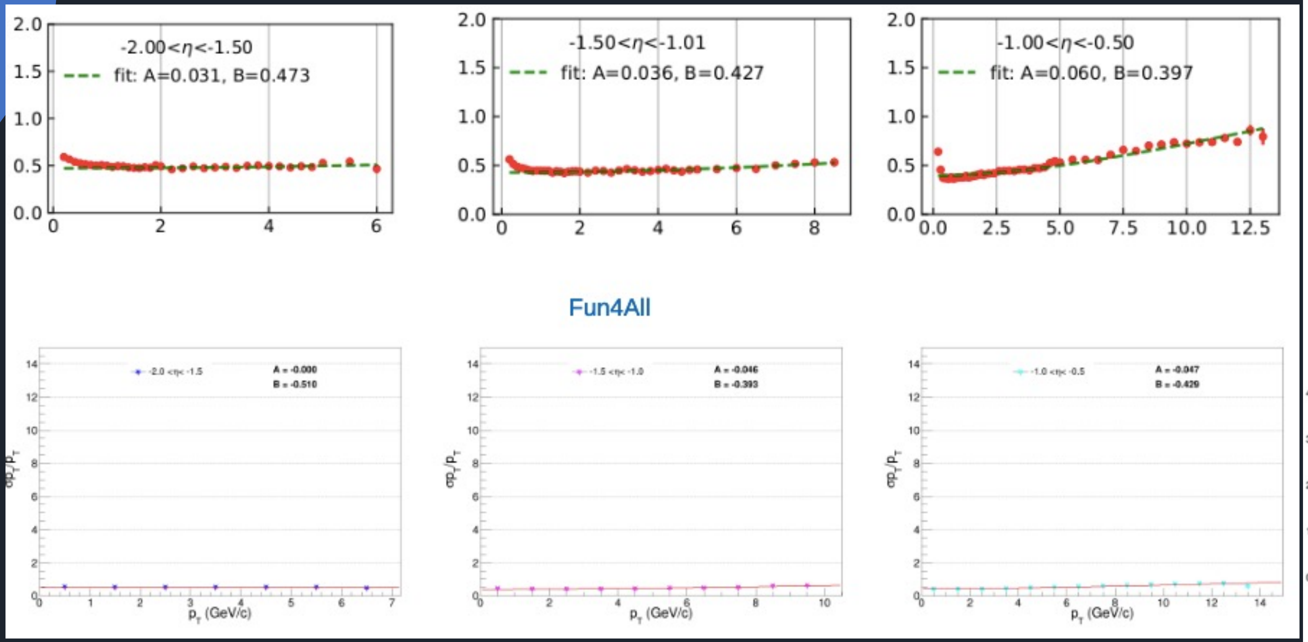
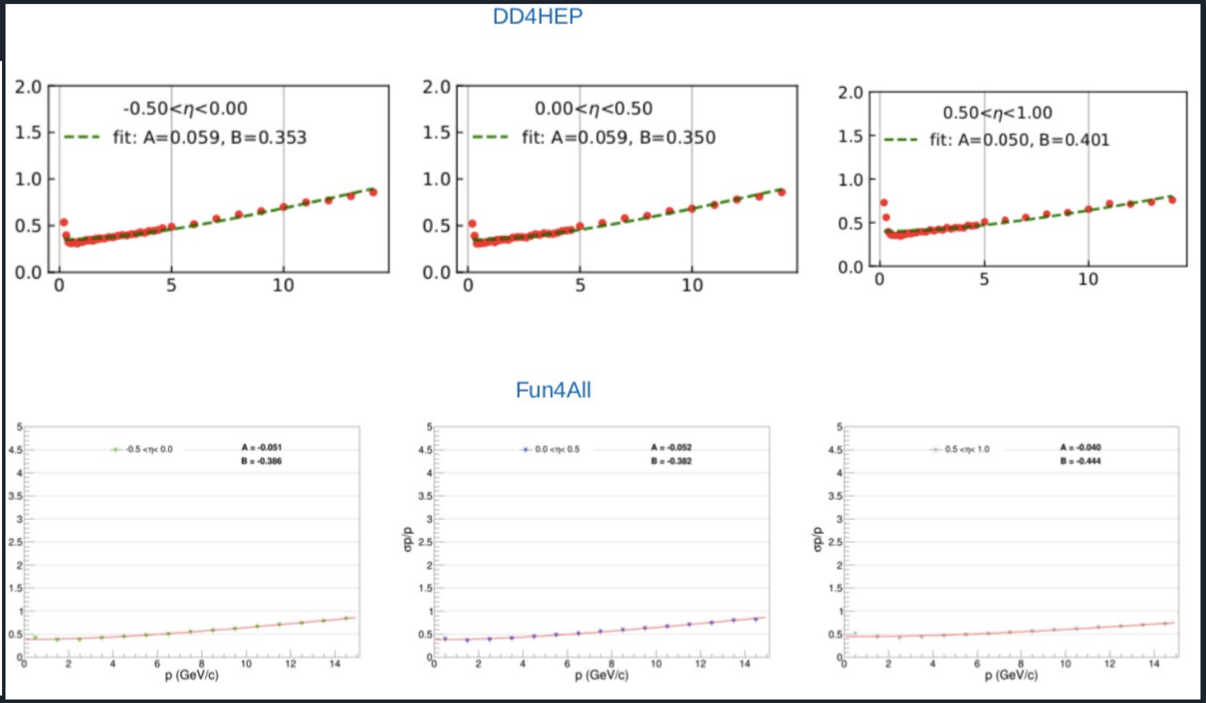
MC simulation in fun4all vs dd4hep

Trends quite compatible





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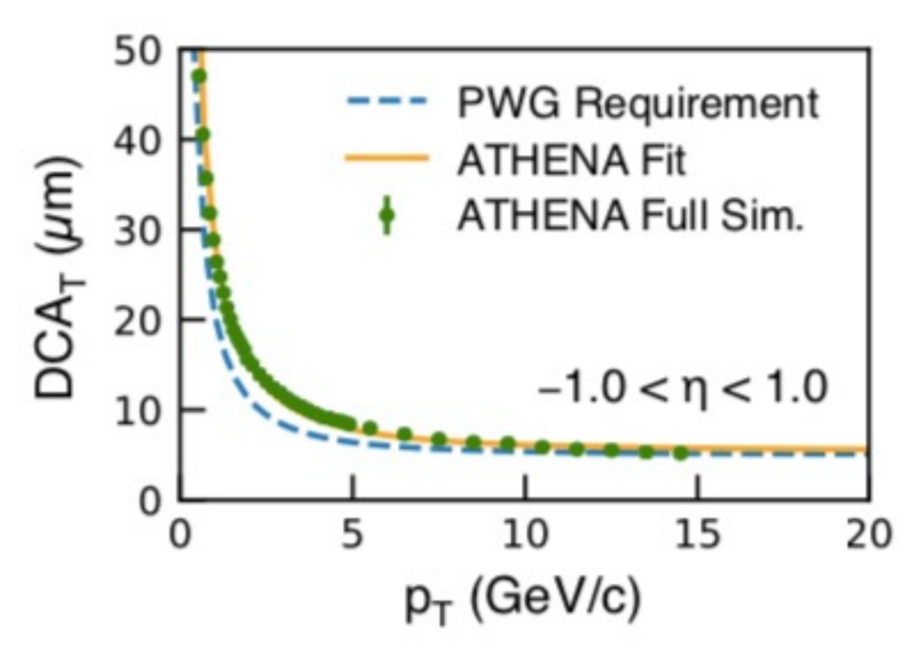
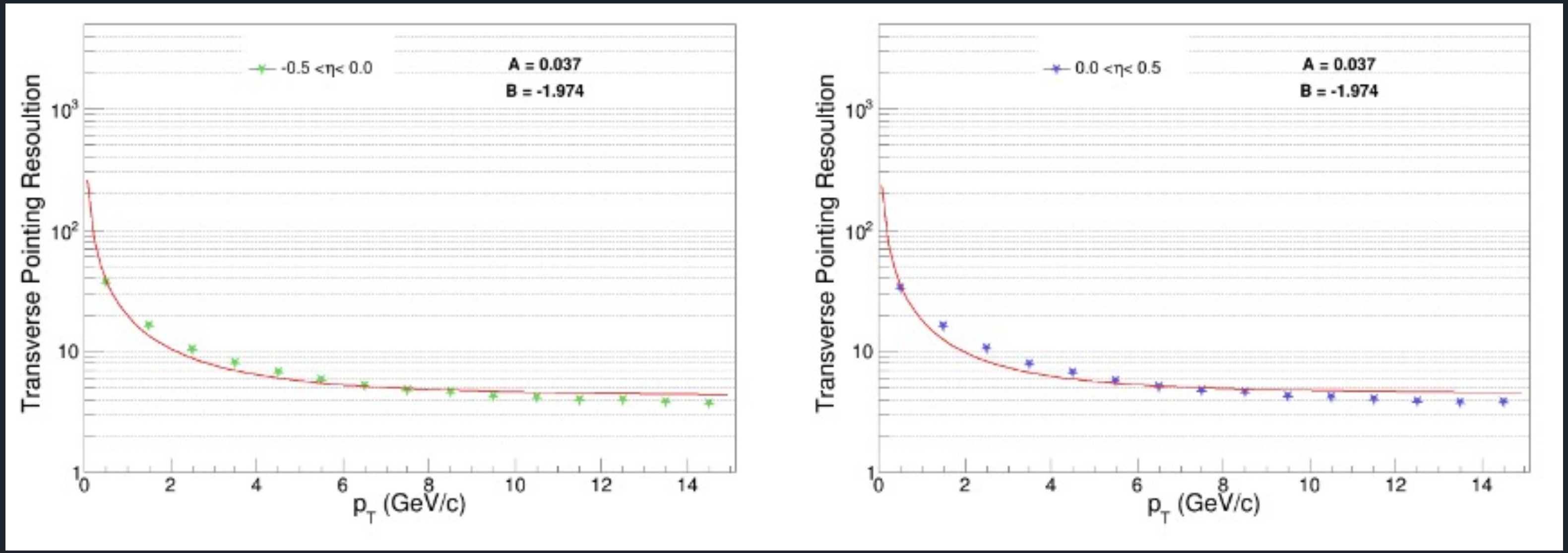
Trends quite similar at all η
Low momentum tracking efficiency poor in fun4all (known issue)

The official software for ATHENA is dd4hep (after its validation with fun4all)

MC simulation in fun4all vs dd4hep

fun4all trends similar to dd4hep as expected





Shyam Kumar

Despite fun4all is not the official ATHENA software, it remains an important software for crosschecks

Summary

- MC studies on tracker performances were done by means of several software tools (necessary crosscheks)

- Agreed ATHENA software isDD4hep and the tracker performances were published according to it, nevertheless they were always tested with fun4all

- MC experience with EIC -> ATHENA software is quite good (tutorials, documentations, email exchange, support)

- Further studies in physics performances foresee central MC production and fun4all will be a valid cross check for the physics results

- Next step: usage of dd4hep

https://eic.github.io/organization/swg.html

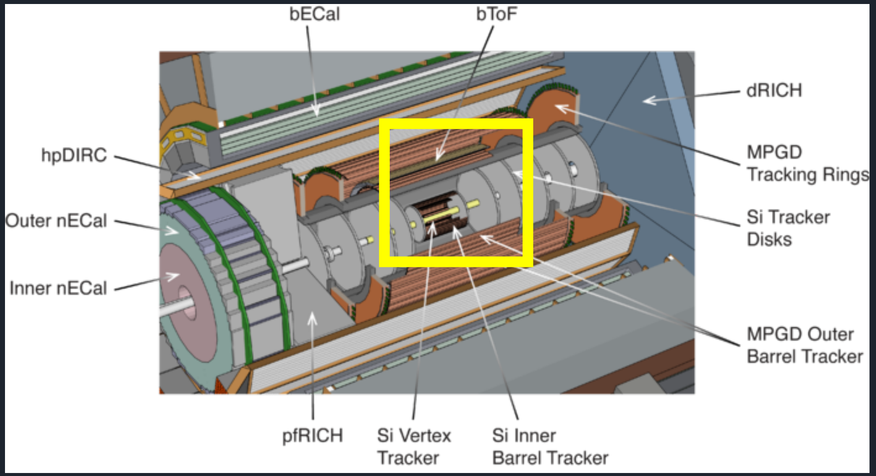
Baseline 2 : Central tracker

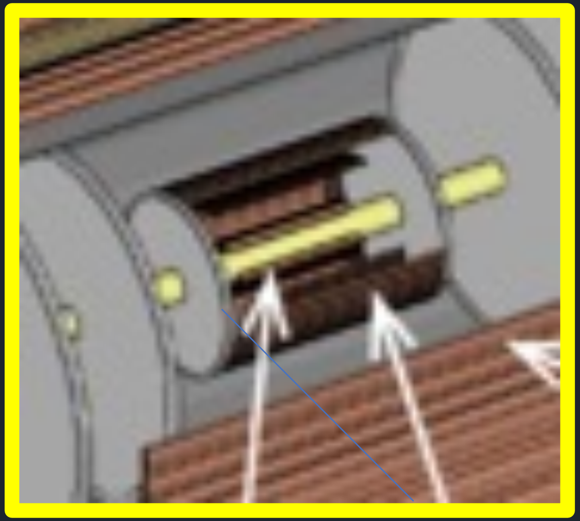
Silicon Tracker (3 Vertex + 2 Barrel Layers)

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

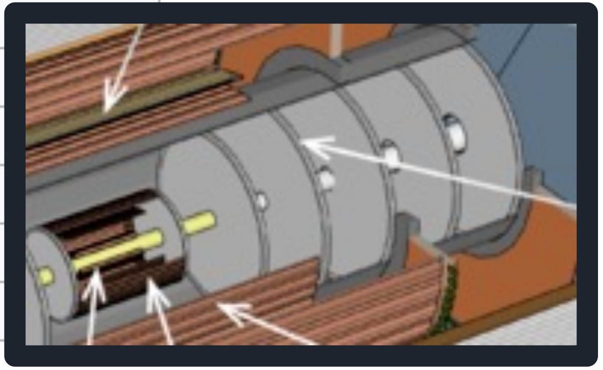




Forward Tracker : P-2.0

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
3.47	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

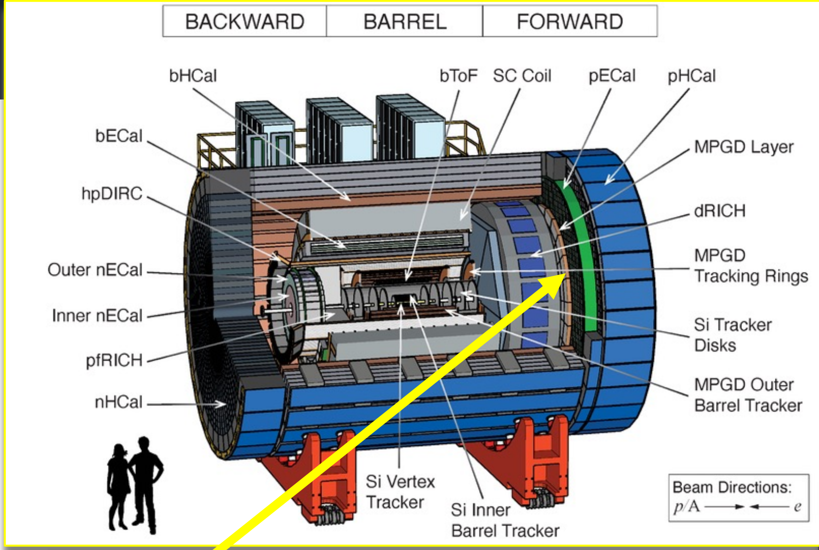


Silicon Disk Support Material

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

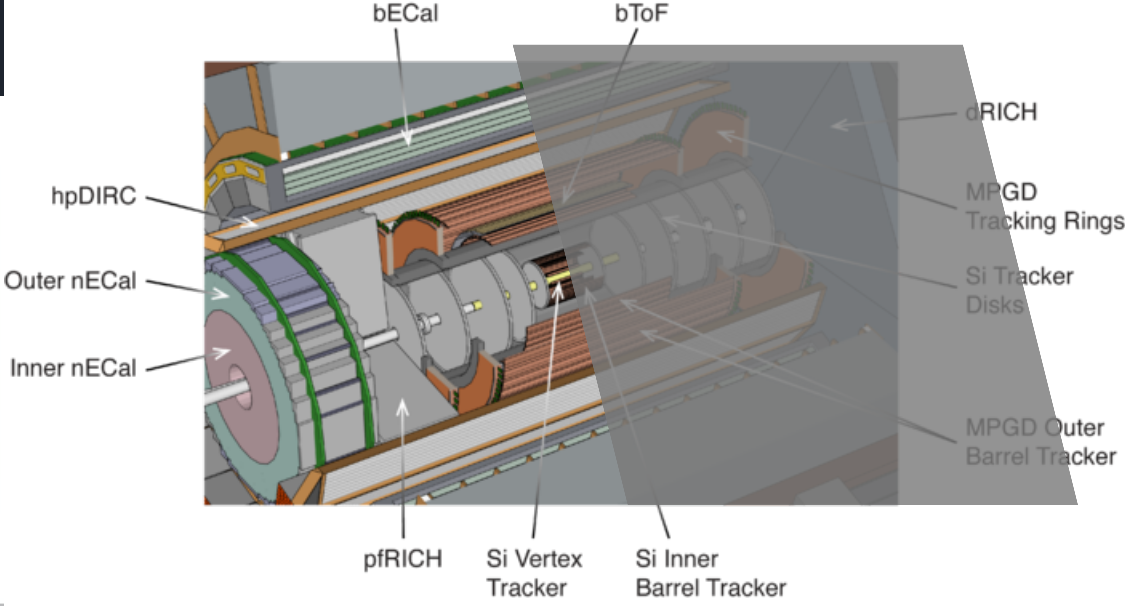
Inner R (cm)	Outer R (cm)	Z Position (cm)	Resolution	Active Area Material (X/X0 %)
44.68	76.91	105.76	250 um (r) x 50 um (r-phi)	0.4
44.68	76.91	161.74	250 um (r) x 50 um (r-phi)	0.4
19.34	195.5	332.0	250 um (r) x 50 um (r-phi)	0.4



6 vertical disks
[Silicon and MPGDs]

1 MPGD
[to constraint the track to the dRICH]

Backward tracker N-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