Fast Simulation Tool for tracker geometry optimization

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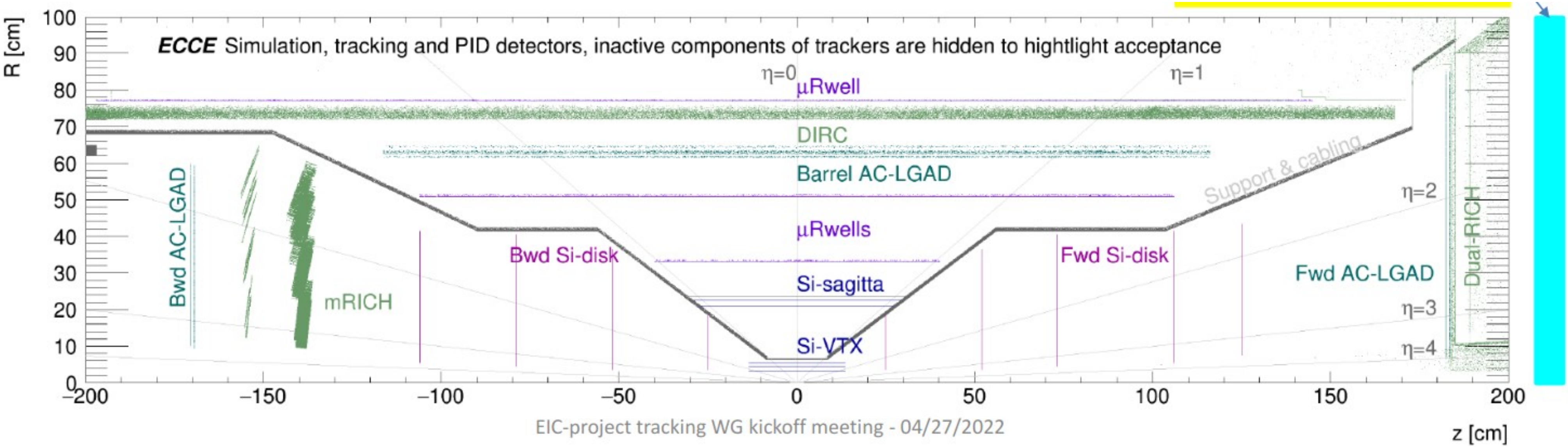
Conceptual Design Report for the Upgrade of the ALICE ITS (Pages 53-58)

https://cds.cern.ch/record/1431539/files/LHCC-G-159.pdf

ECCE Setup (Fun4All)



Magnetic field: 1.4 Tesla

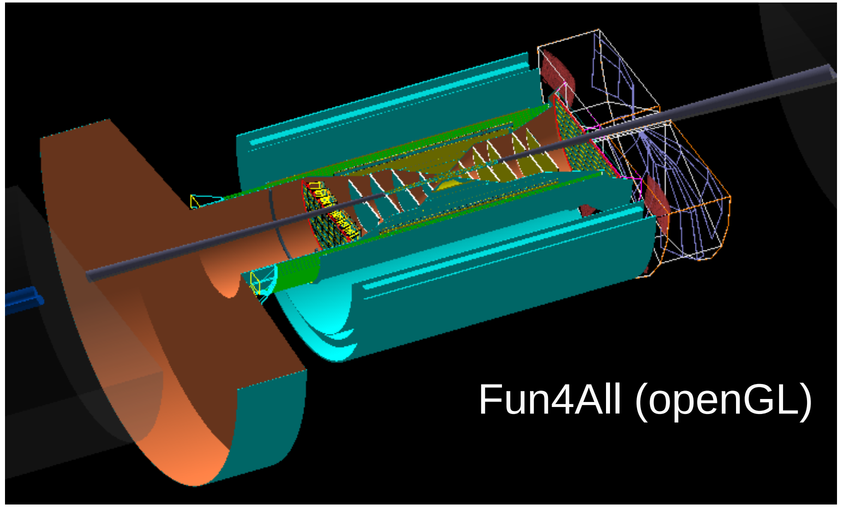
Barrel Tracker

Name	Radius (cm)	X/X0	R-Phi resol (cm)	R-Z resol (cm)
BeamPipe	3.1	0.0022	----------------------------------	
Vtx1	3.3	0.0005	10.0e-4/sqrt(12)	10.0e-4/sqrt(12)
Vtx2	4.35	0.0005	10.0e-4/sqrt(12)	10.0e-4/sqrt(12)
Vtx3	5.40	0.0005	10.0e-4/sqrt(12)	10.0e-4/sqrt(12)
VtxSupport	6.3	0.3/30	--	
Barr1	21.0	0.0005	10.0e-4/sqrt(12)	10.0e-4/sqrt(12)
Barr2	22.68	0.0005	10.0e-4/sqrt(12)	10.0e-4/sqrt(12)
BarrSupport	23.50	0.03/30	---	
MM1	33.14	0.0026	55.0e-4	55.0e-4
MM2	51.0	0.0026	55.0e-4	55.0e-4
ACLGAD	64.0	0.0558	30.0e-4	30.0e-4
DIRC	72.96	0.1274	--	
MM3	77.0	0.0026	55.0e-4	55.0e-4

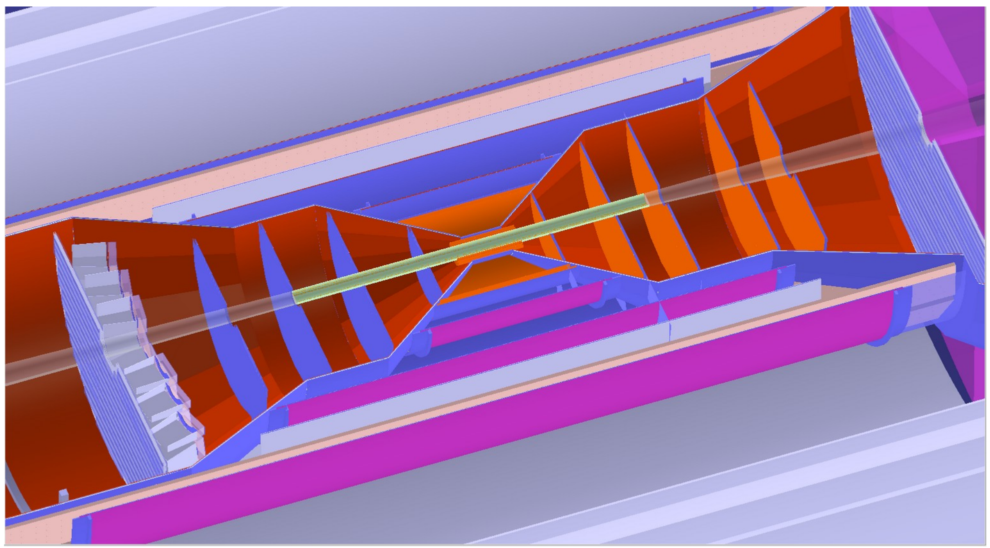
Material budget for Vtx support should be similar to Barrel support

ECCE Geometry and Event Display

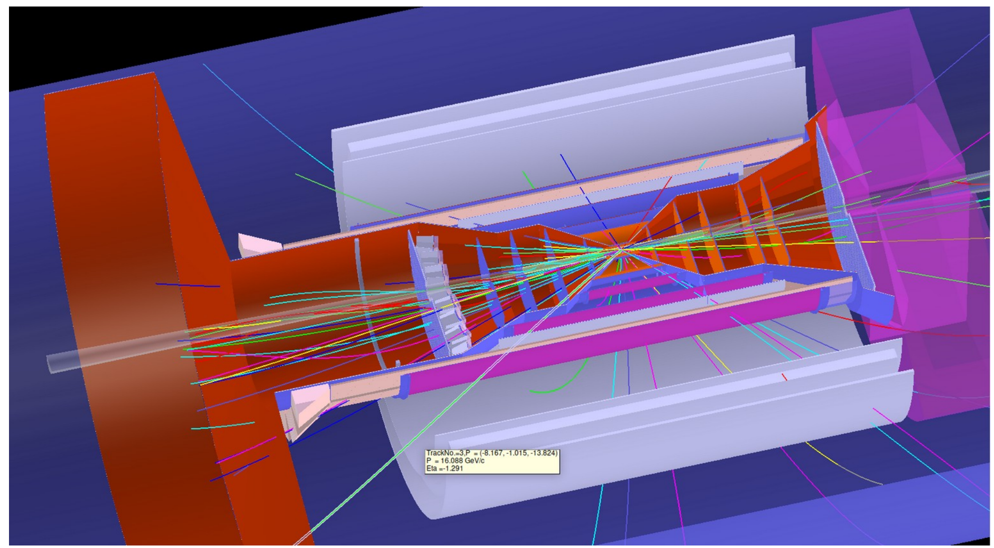
Geometry used for the simulation in Fun4All



EveManager

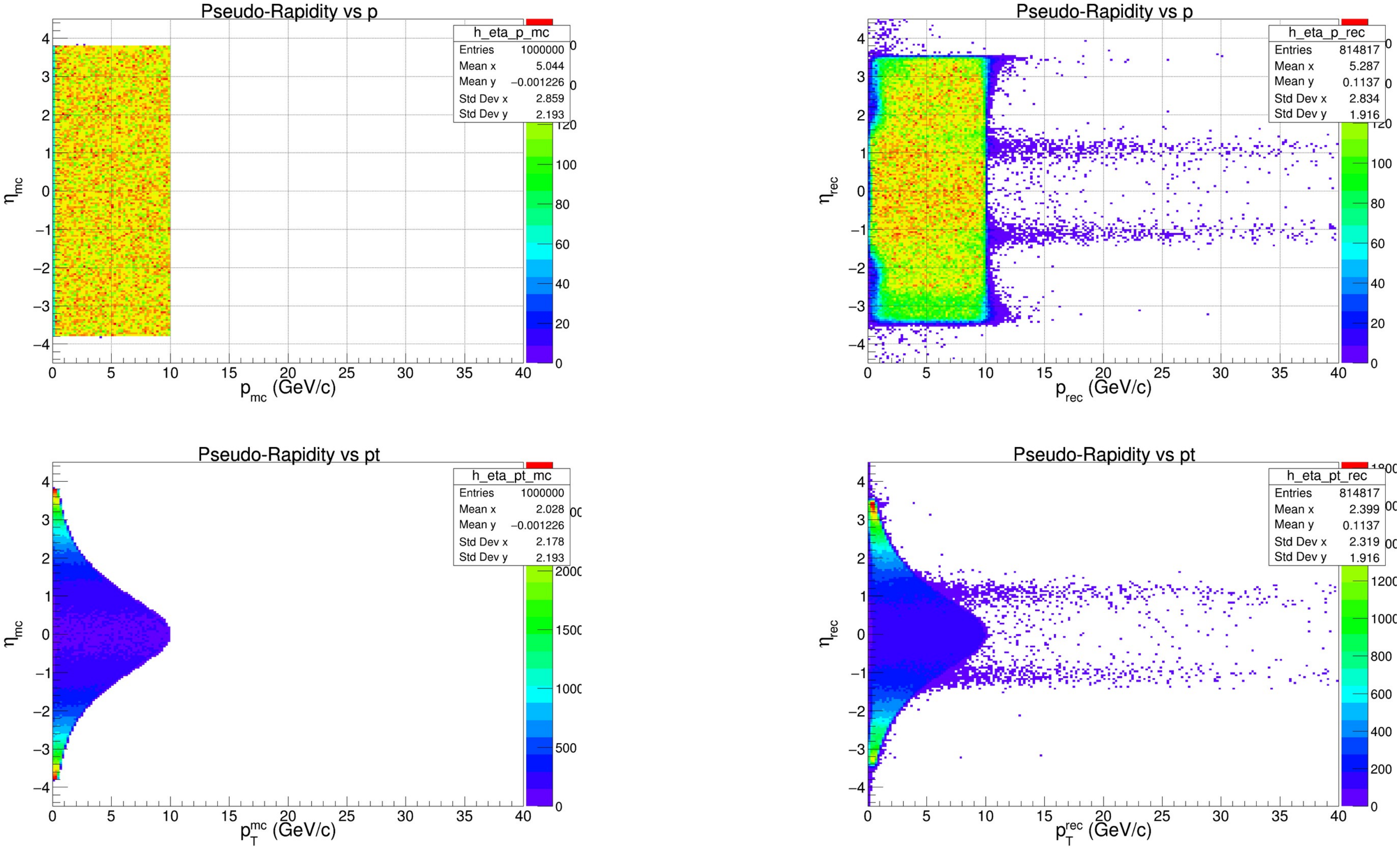


EveManager with tracks



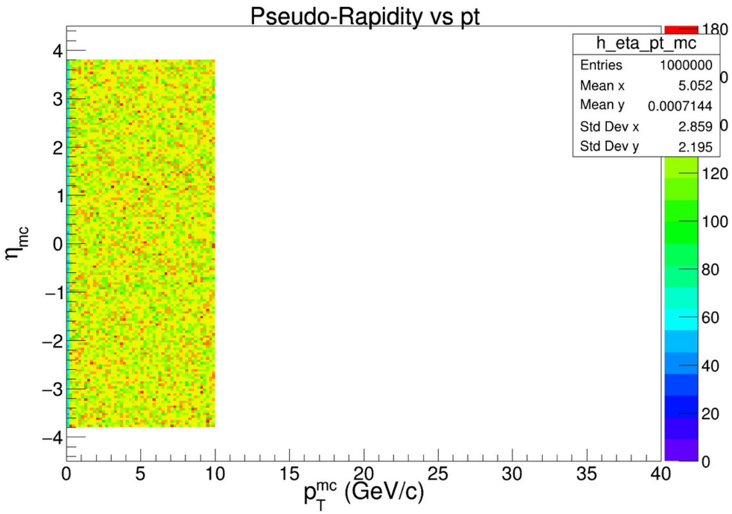
Particle Simulation

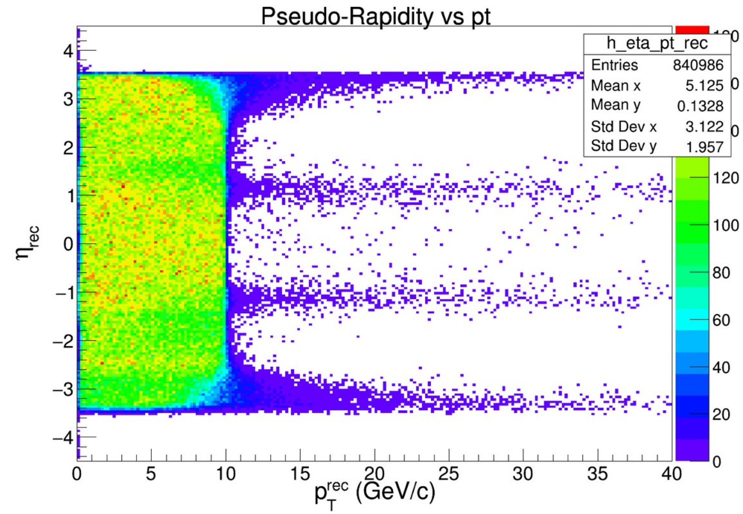
1M Negative Pions uniform in η [-3.5,3.5] and momentum [0.1,10.]

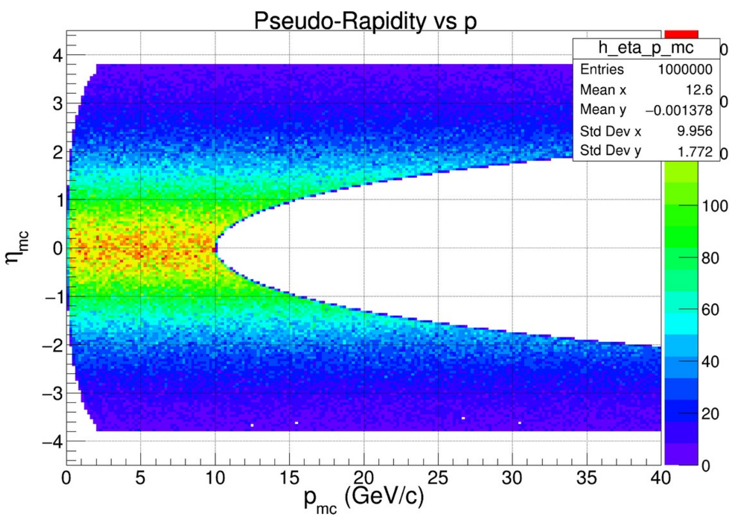


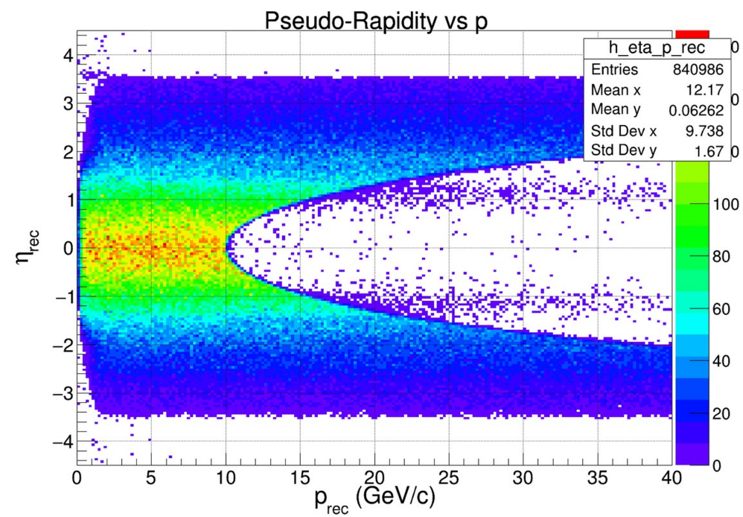
Particle Simulation

1M Negative Pions uniform in η [-3.5,3.5] and transverse momentum [0.1,10.]





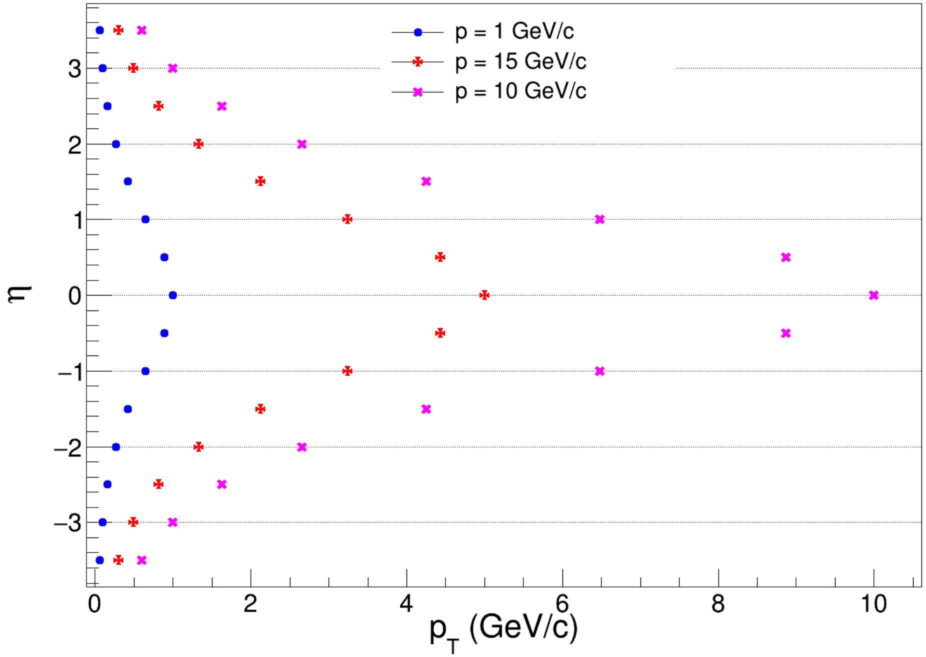




Basic Kinematics

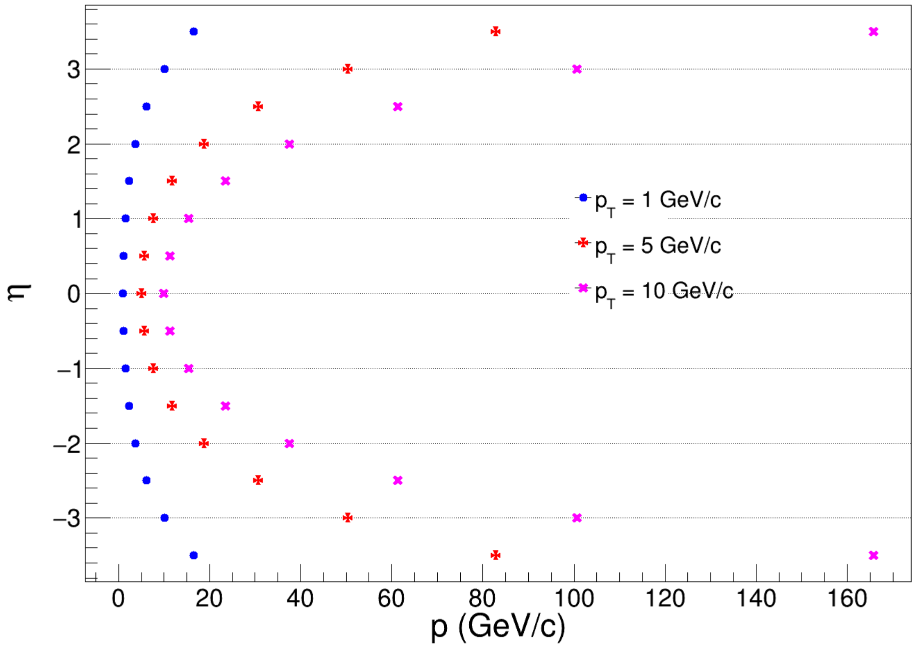
Particle uniform in p

$$p_T = \frac{p}{\cosh(\eta)}$$

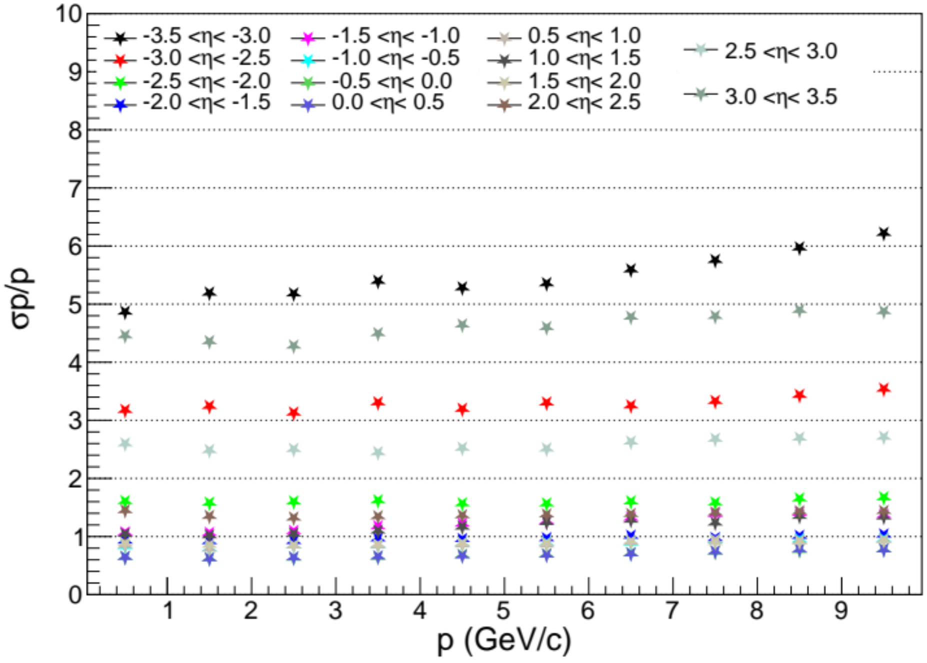


Particle uniform in p_T

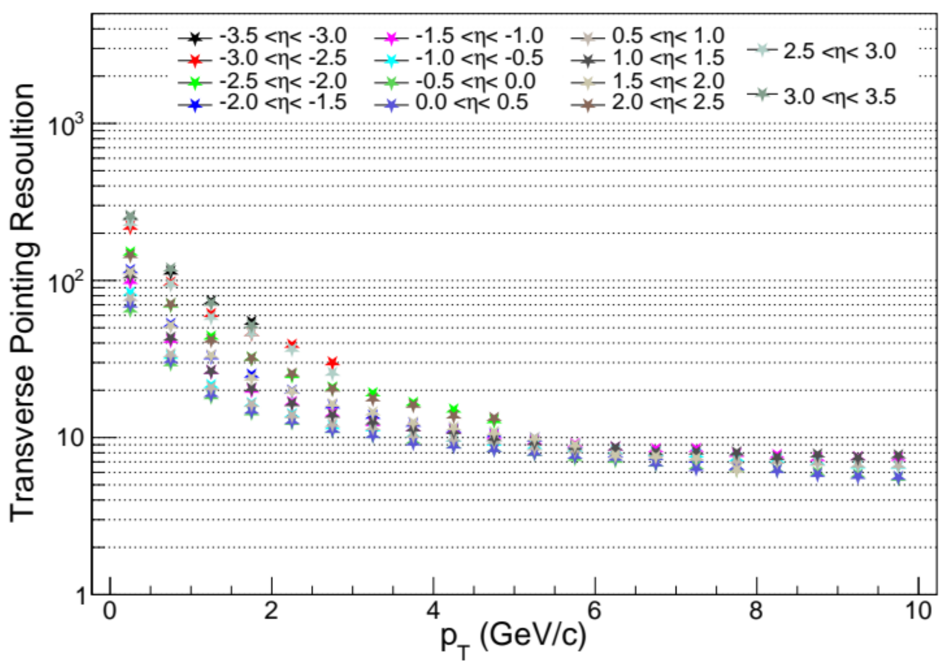
$$p = p_T \cosh(\eta)$$



Results



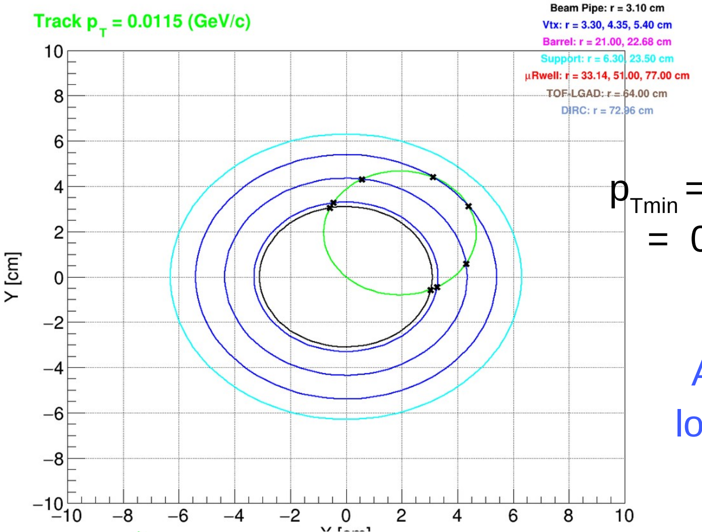
σp/p
p (GeV/c)
-3.5 <η< -3.0
-3.0 <η< -2.5
-2.5 <η< -2.0
-2.0 <η< -1.5
-1.5 <η< -1.0
-1.0 <η< -0.5
-0.5 <η< 0.0
0.0 <η< 0.5
0.5 <η< 1.0
1.0 <η< 1.5
1.5 <η< 2.0
2.0 <η< 2.5
2.5 <η< 3.0
3.0 <η< 3.5



Transverse Pointing Resoultion
p_T (GeV/c)
-3.5 <η< -3.0
-3.0 <η< -2.5
-2.5 <η< -2.0
-2.0 <η< -1.5
-1.5 <η< -1.0
-1.0 <η< -0.5
-0.5 <η< 0.0
0.0 <η< 0.5
0.5 <η< 1.0
1.0 <η< 1.5
1.5 <η< 2.0
2.0 <η< 2.5
2.5 <η< 3.0
3.0 <η< 3.5

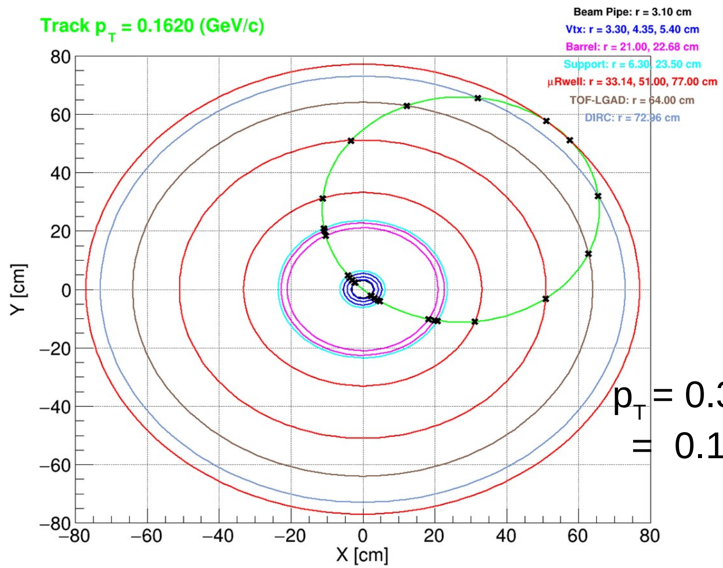
Barrel Tracker

p_T (GeV/c)= 0.3 B[T] R[m]

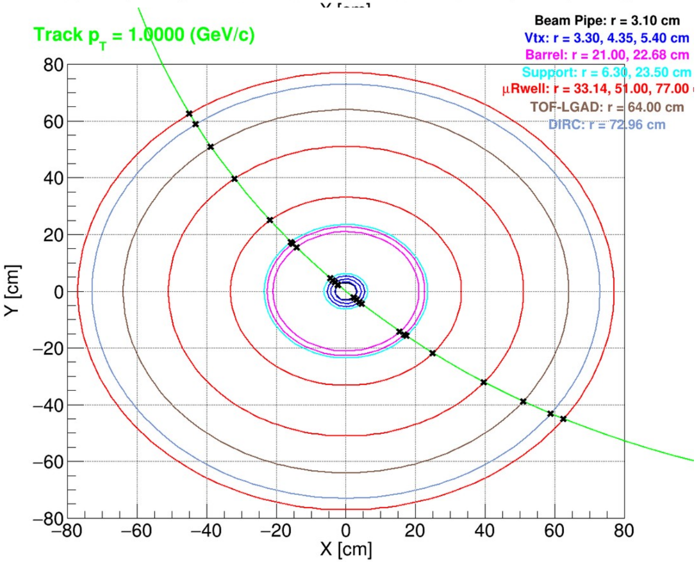


p_{Tmin} = 0.3*1.4*0.054/2
= 0.01134 GeV/c

At this p_T huge energy loss, multiple scattering



p_T = 0.3*1.4*0.77/2
= 0.1617 GeV/c



Detector ECCE: "ITS"

Name	r [cm]	X0	phi & z res [um]		layerEff
0. vertex	0.00	0.0000	-	-	-
1. bpipe	3.10	0.0022	-	-	-
2. VTX1	3.30	0.0005	3	3	1.00
3. VTX2	4.35	0.0005	3	3	1.00
4. VTX3	5.40	0.0005	3	3	1.00
5. VTXSUPPORT	6.30	0.0100	-	-	-
6. BARR1	21.00	0.0005	3	3	1.00
7. BARR2	22.68	0.0005	3	3	1.00
8. BARRSUPPORT	23.50	0.0010	-	-	-
9. MM1	33.14	0.0026	55	55	1.00
10. MM2	51.00	0.0026	55	55	1.00
11. TOF	64.00	0.0558	30	30	1.00
12. DIRC	72.96	0.1274	-	-	-
13. MM3	77.00	0.0026	55	55	1.00

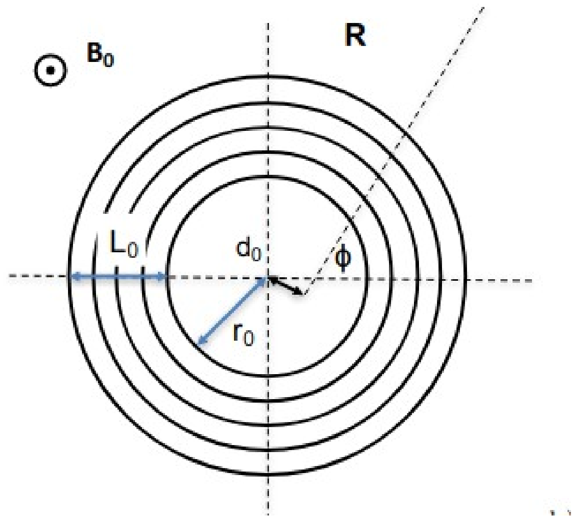
Momentum Resolution

Zbynek Drasal, Werner Riegler

arXiv:1805.12014

Tracking Performances: Momentum and DCA resolutions

Momentum Resolution:affects width of invariant mass peak



p_T resolution:

$$\frac{\Delta p_T}{p_T}\Big|_{res.} = \frac{\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{720 N^3}{(N-1)(N+1)(N+2)(N+3)}}$$

$$\approx \frac{12\,\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

Linear term

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}}\,\frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}\left(1+0.038\ln\frac{d}{X_0\,\sin\theta}\right)$$

Constant term (at β<1 increase)

Based on Gluckstern Approach (equal distance between planes and equal spatial resolutions)

SR (Spatial Resolution): Uncertainity associated with finite size of pixels

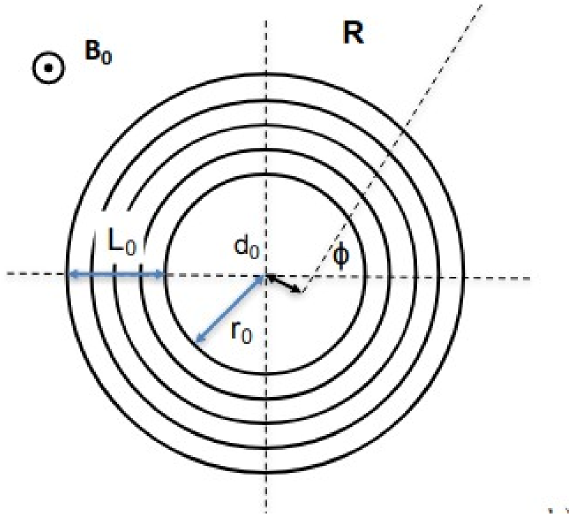
MS (Multiple Scattering): Uncertainity associated with thickness of Material

$$\frac{\sigma_{pT}}{p_T} = \sqrt{\left(\frac{\sigma_{pT_{SR}}}{p_T}\right)^2 + \left(\frac{\sigma_{pT_{MS}}}{p_T}\right)^2}$$

DCA$_{xy}$ Resolution

DCA Resolution: Reconstruction of secondaries

arXiv:1805.12014



DCA$_{xy}$ resolution:

$$\Delta d_0|_{res.} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}}\sqrt{1+\frac{8r_0}{L_0}+\frac{28r_0^2}{L_0^2}+\frac{40r_0^3}{L_0^3}+\frac{20r_0^4}{L_0^4}}$$

$$\Delta d_0|_{m.s.} \approx \frac{0.0136\,\mathrm{GeV}/c}{\beta p_T} r_0\sqrt{\frac{d}{X_0\sin\theta}}\sqrt{1+\frac{1}{2}\left(\frac{r_0}{L_0}\right)+\frac{N}{4}\left(\frac{r_0}{L_0}\right)^2}$$

$$\sigma_{d_0}=\sqrt{\sigma^2_{d\,0_{SR}}+\sigma^2_{d\,0_{MS}}}$$

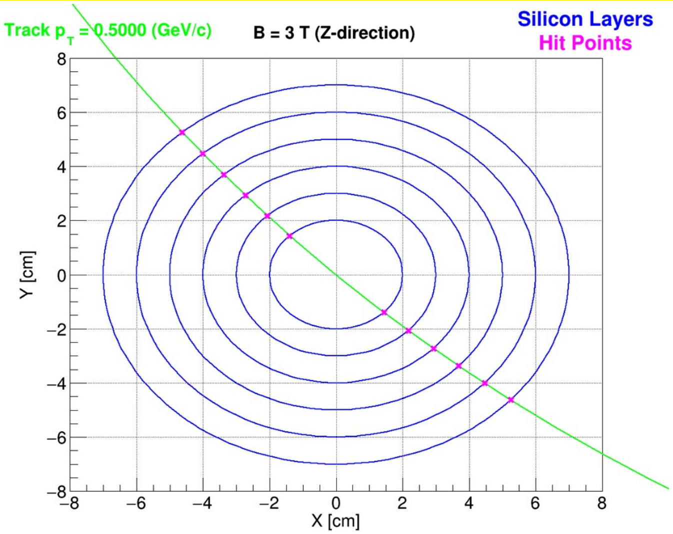
(r_0/L_0) is very important for DCA$_{xy}$ resolutions

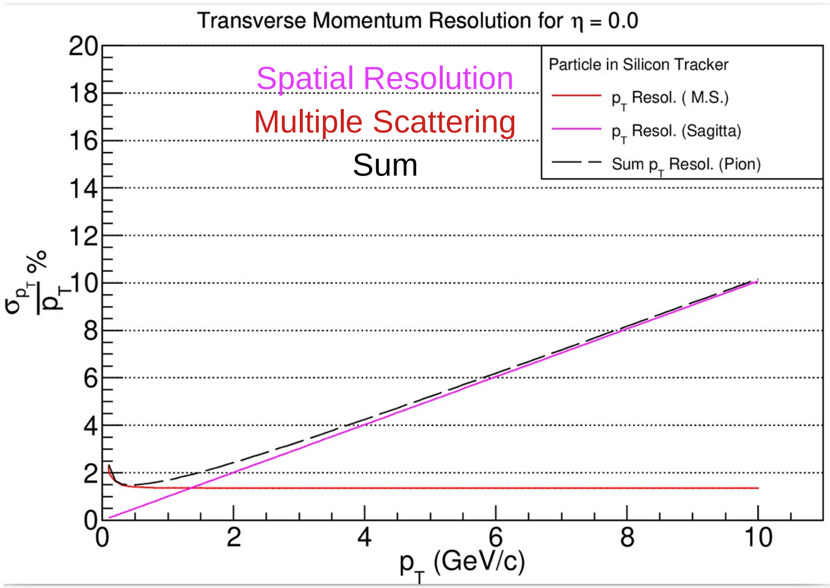
Simple Example

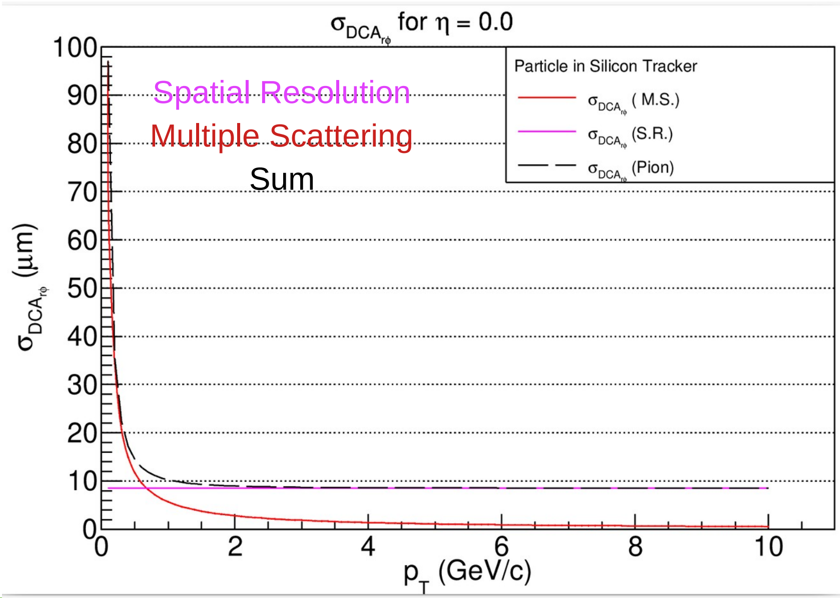
Consider an example of silicon layers of 50 μm thickness

r_0 = 2 cm L_0 = 7-2 = 5 cm;

$$\sigma_{r\phi} = 10\,\mu m$$

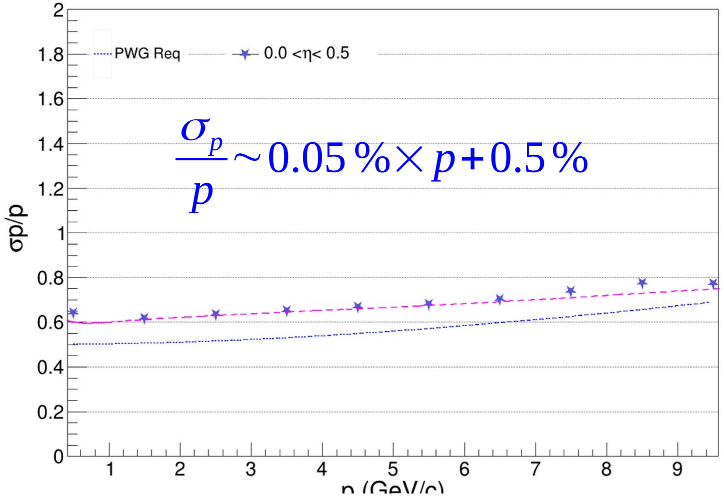


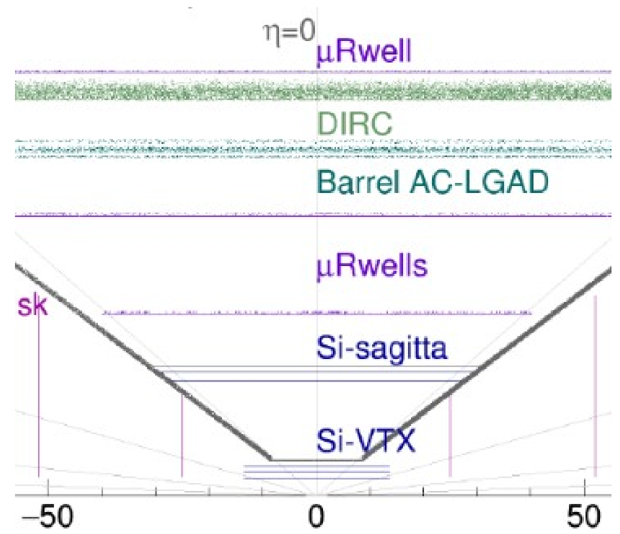




Tracking Performances

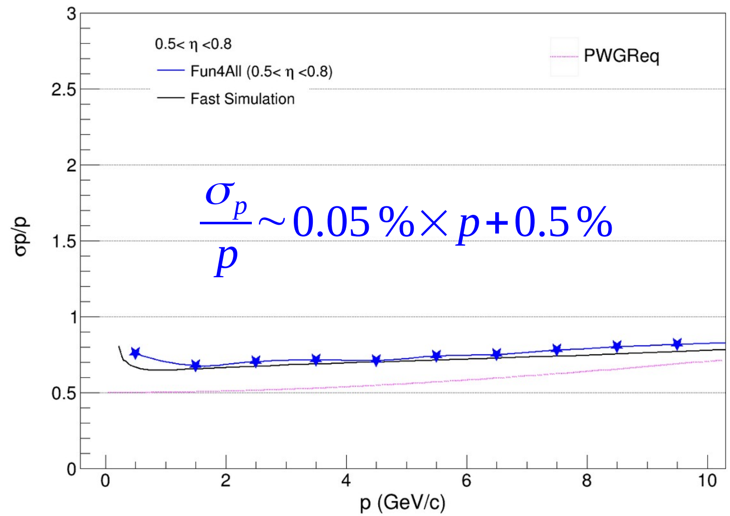
Markers (Fun4All), Magenta (FastSim), Blue lines (PWG requirement)



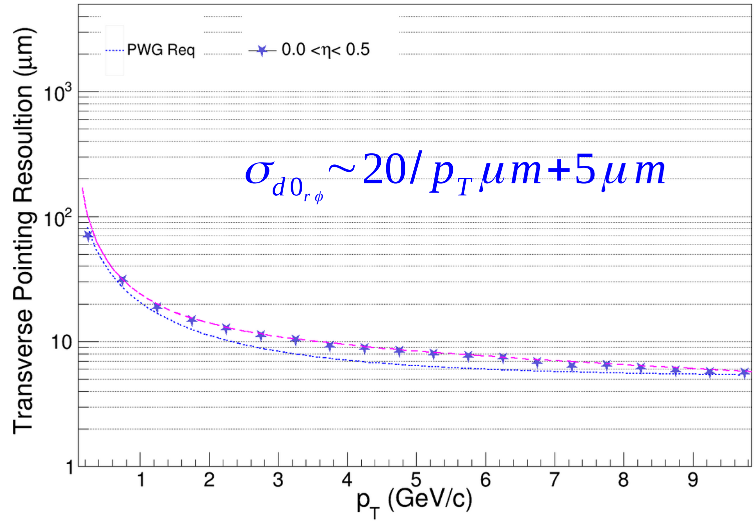


η=1

Fast simulation tool based on Kalman filter



Code always start from last layer

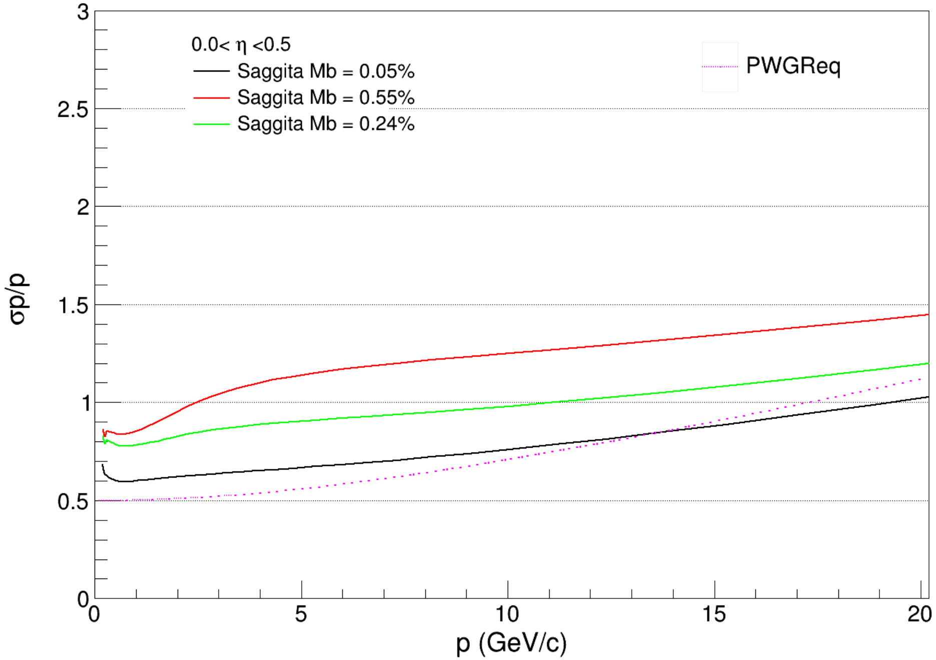


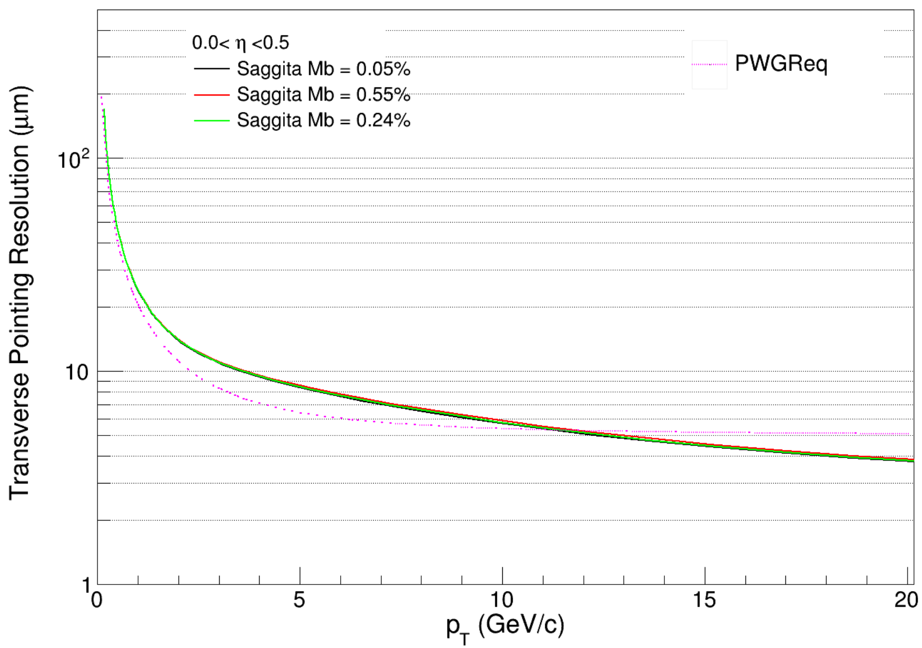
Studies with Detector1 Geometry (FastSim)

- Changing the Material Budget of Sagitta Layers
- Shifting Sagitta Layers from the Default Position (default radius -14.0 cm and default radius + 9.0 cm)
- Changing the Resolution of Micromegas Layers (55 µm, 100 µm, 150 µm)
- Moving Last Micromegas Layer Apart (default (77 cm), 100 cm, 300 cm)

Changing Material Budget of Sagitta Layers

p_{Tmin} = 0.35357 GeV/c algorithm can handle

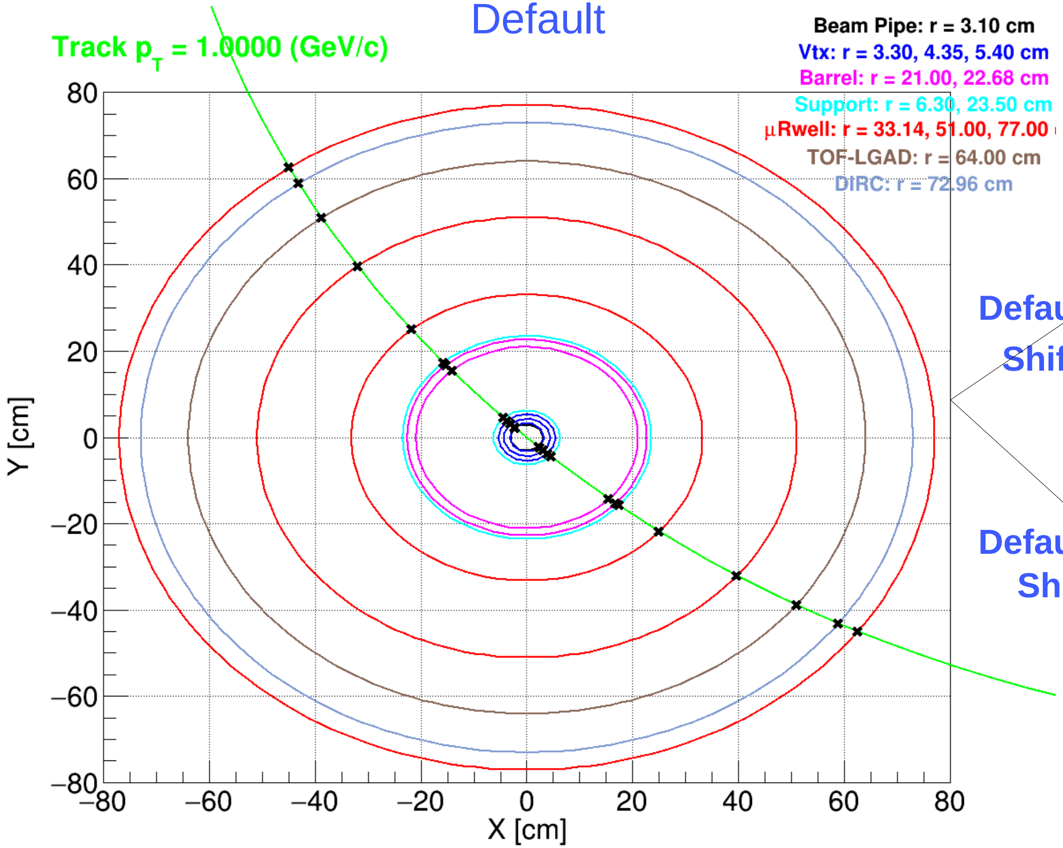




Shfiting Sagitta Layers

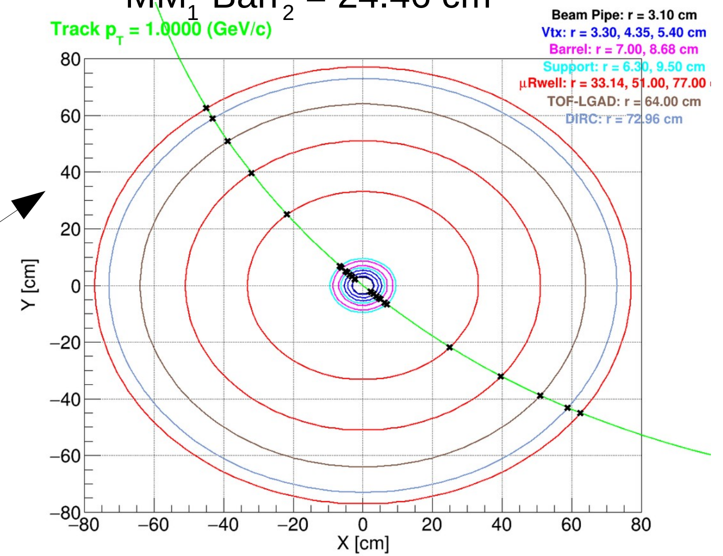
$Barr_1$-Vtx_3 =15.6 cm

Default

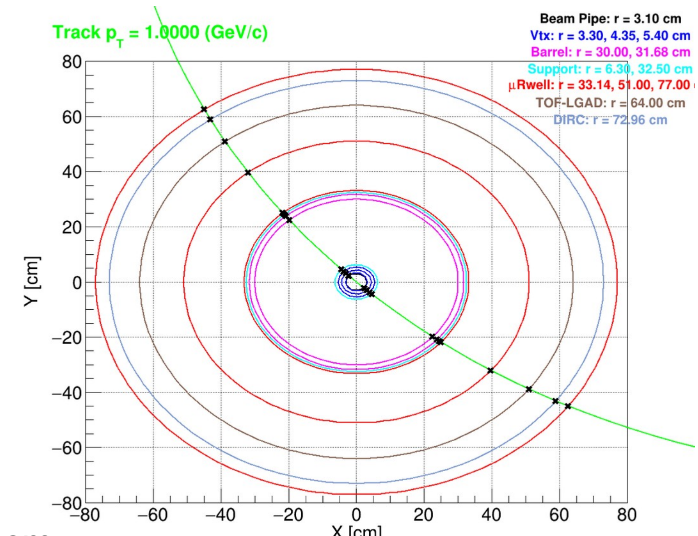


Default+Sagitta Shift -14.0cm

MM_1-$Barr_2$ = 24.46 cm



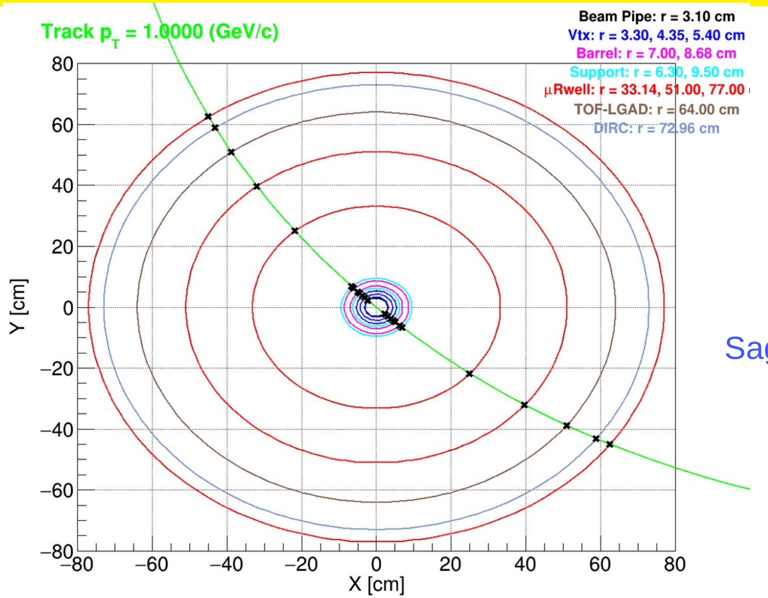
Default+Sagitta Shift 9.0cm



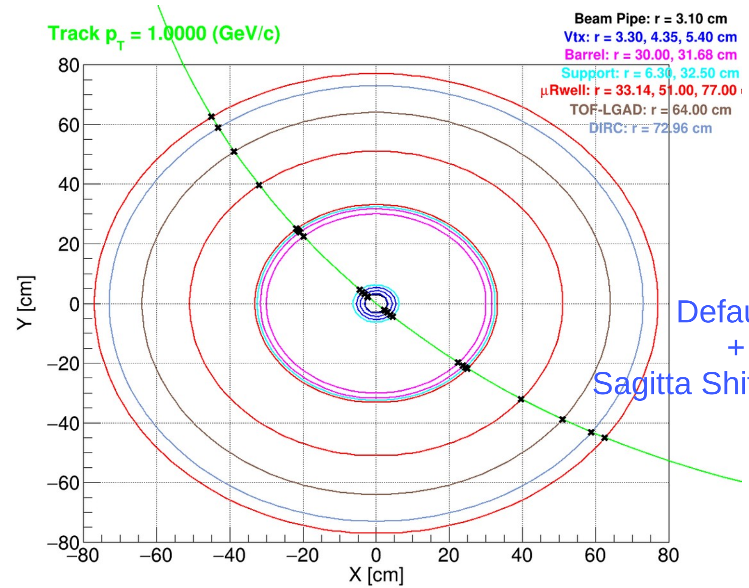
$Barr_1$-Vtx_3 =24.6 cm

Material budget of sagitta layers = 0.55 % and also VTX_Support = 0.1 %

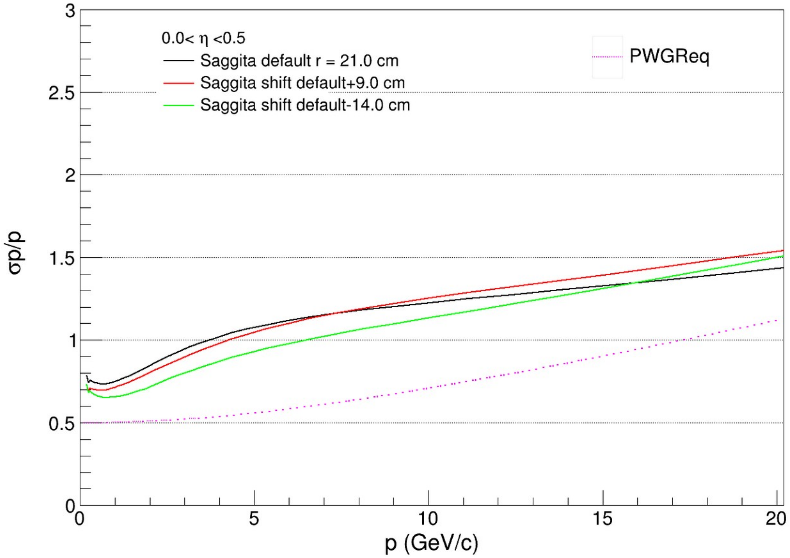
Tracking Performance with Sagitta layer Shifting

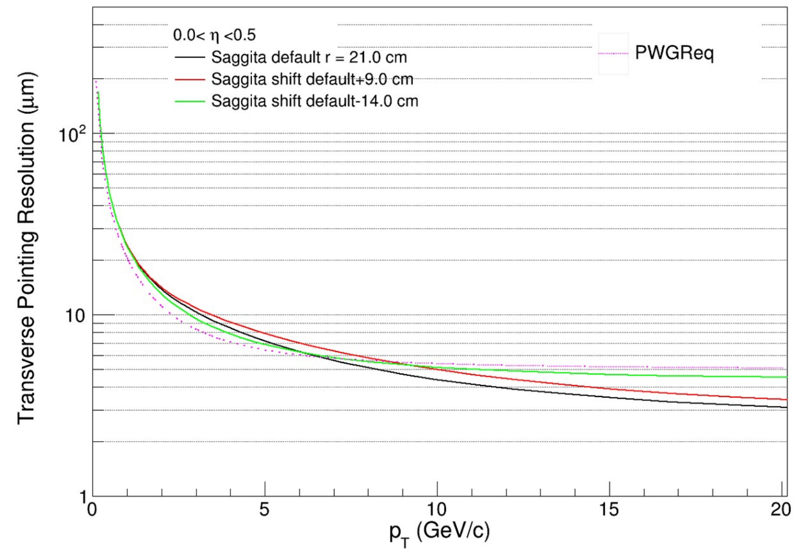


Default
+
Sagitta Shift -14.0cm

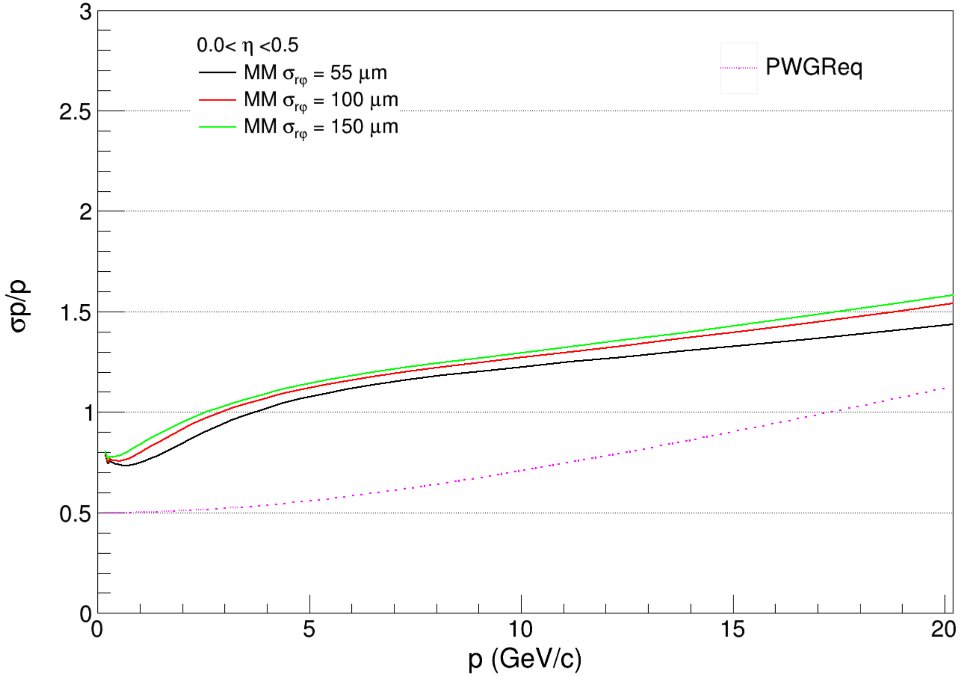


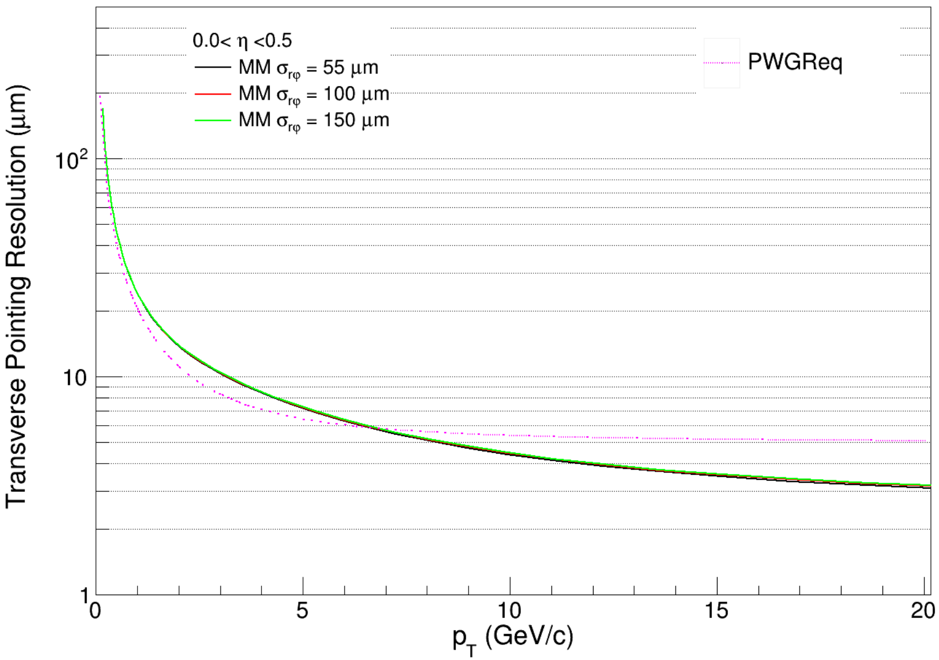
Default
+
Sagitta Shift 9.0cm





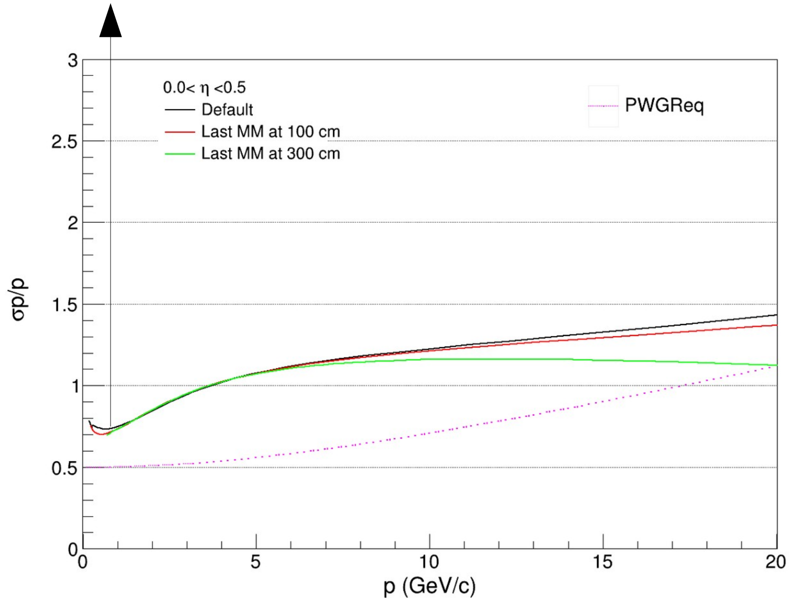
Different Micromegas Resolution

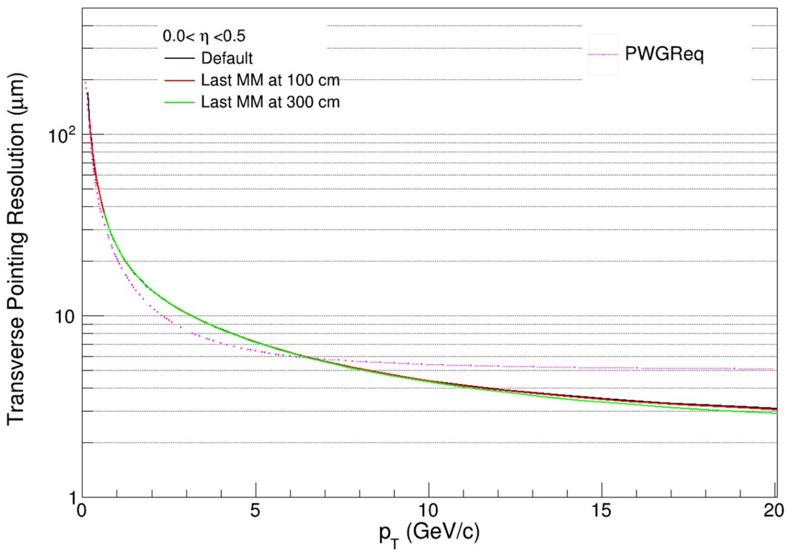




Moving Last MM Apart

$p_T = 0.3*1.4*3.0/2 = 0.63$ GeV/c (last layer)





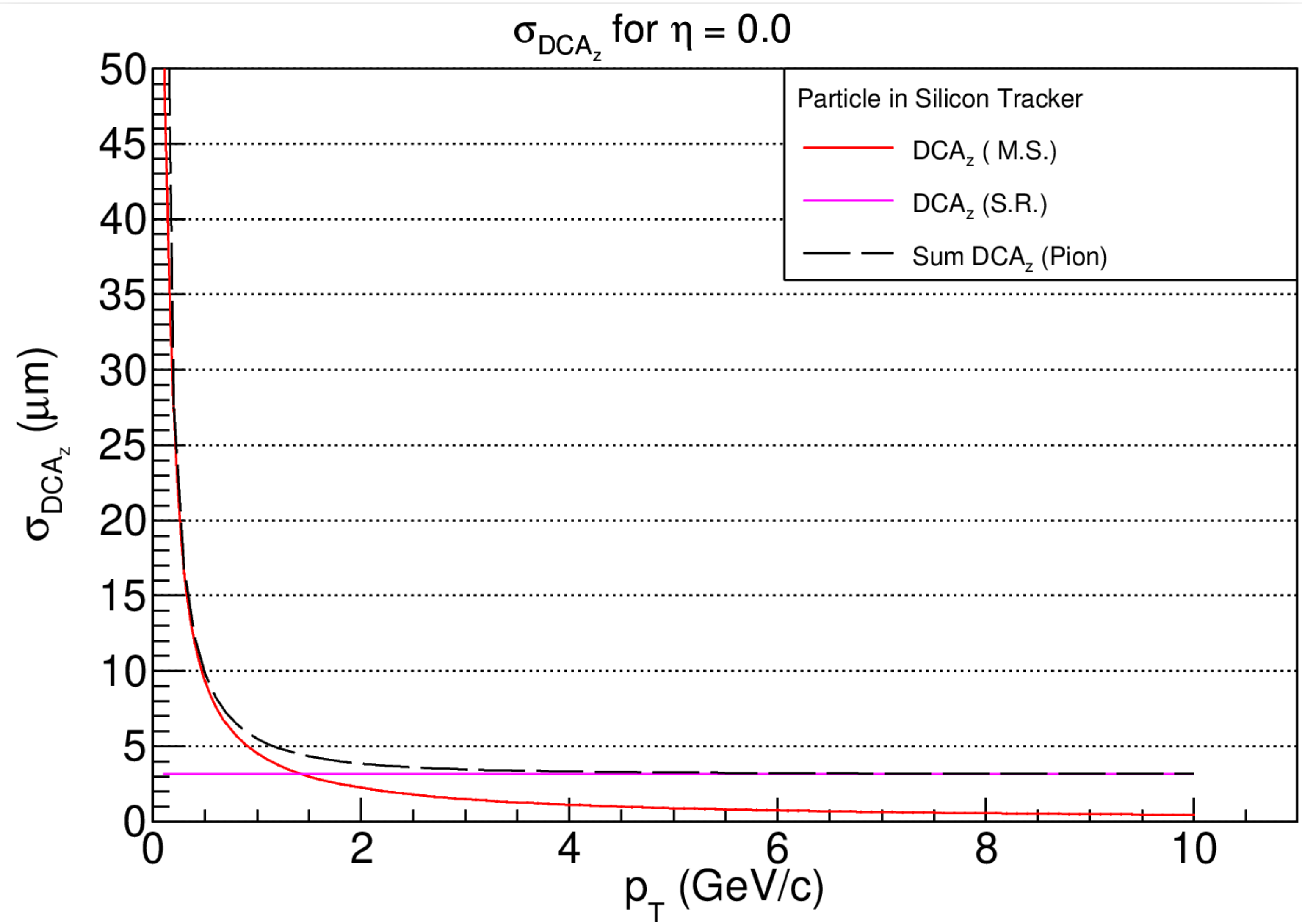
- Moving last layer apart increases lever arm so improves resolution (slope of linear term decreases) at high momentum.
- At the same time p_{Tmin} to reach at the last layer is increased.

Summary and Future Steps

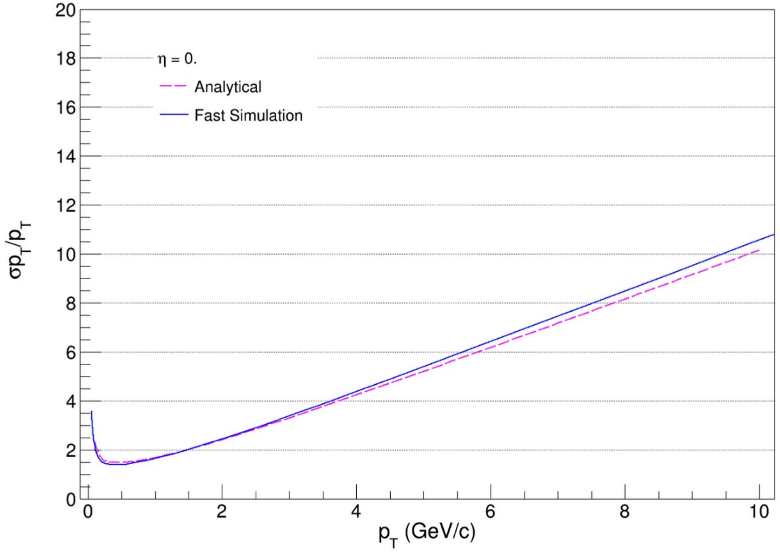
- Extracted basic performances as an excercise for the ECCE geometry in Fun4All.
- Fast Simulation compared with the full simulation in Barrel region for validation.
- Also presented, the effect after changes in the setup.
- This Fast simulation tool can help to optimize the detector layout in the barrel region.
- Still trying other configuration to understand the peformances (it’s easy and quick).

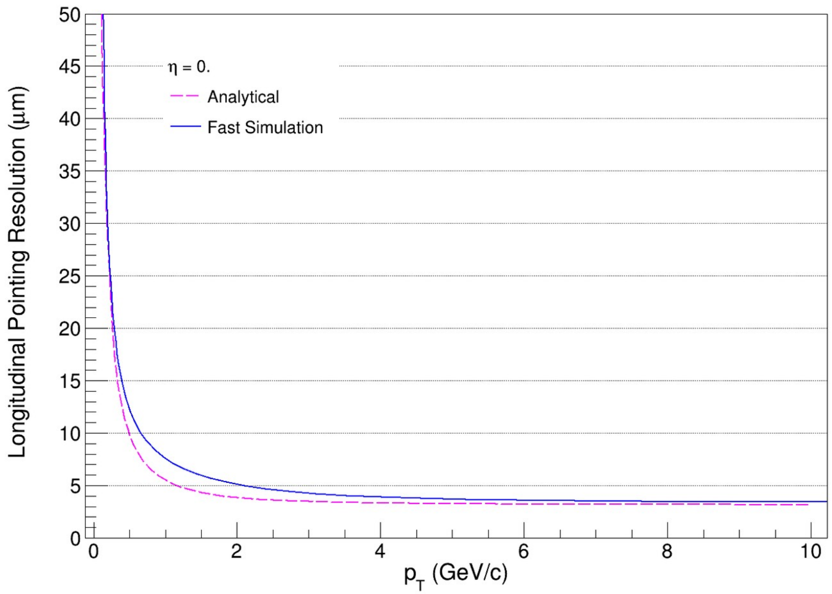
Thank you !!!!!

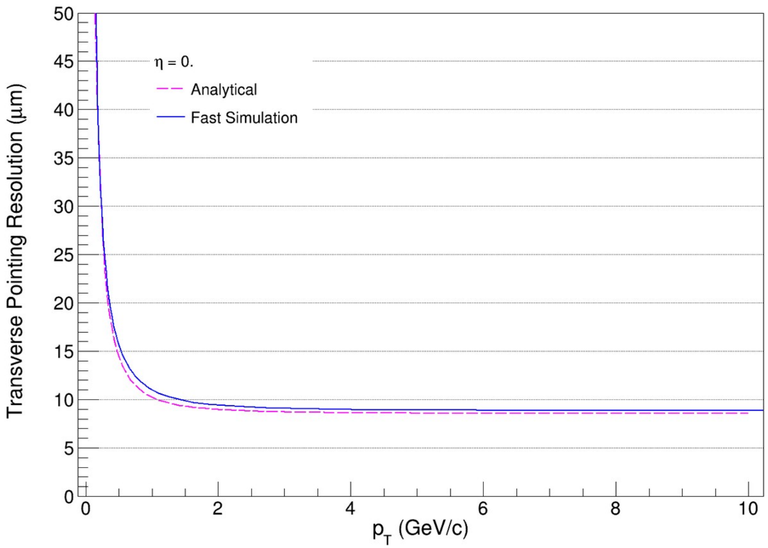
Longitudinal DCA_z



Comparison with Fast Simulation



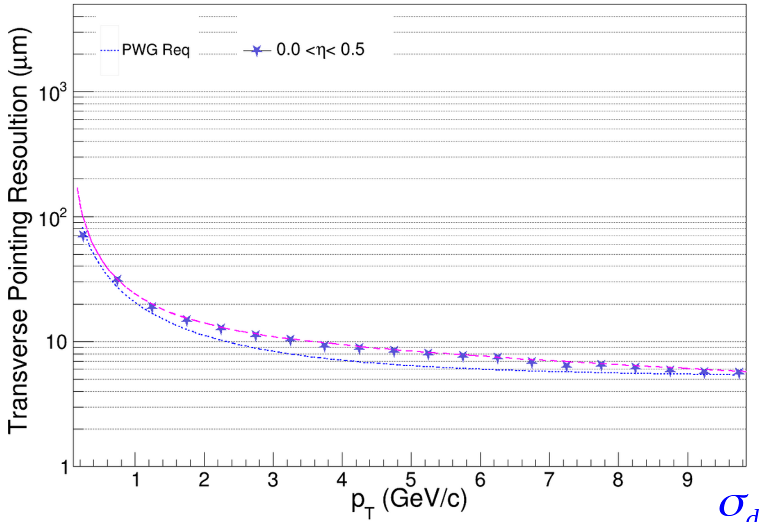


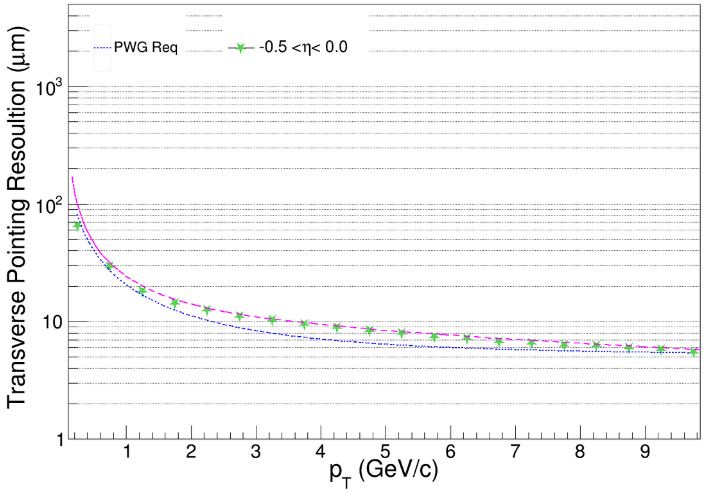


Corresponding to Simple example of geometry on slide 11

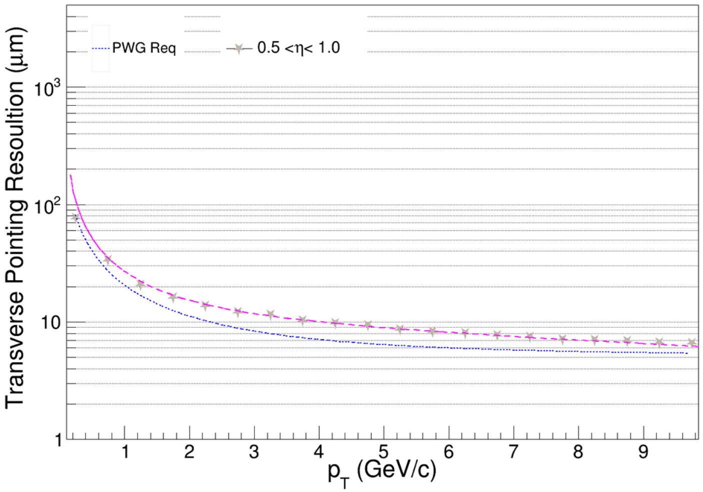
Transverse DCA Resolutions

Markers (Fun4All), Magenta (FastSim), Blue lines (PWG requirement)



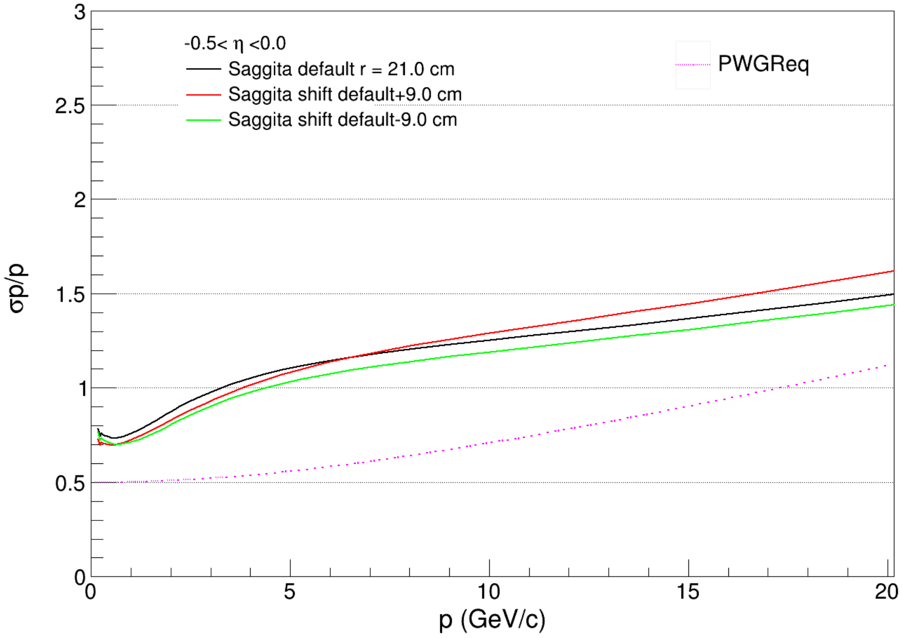


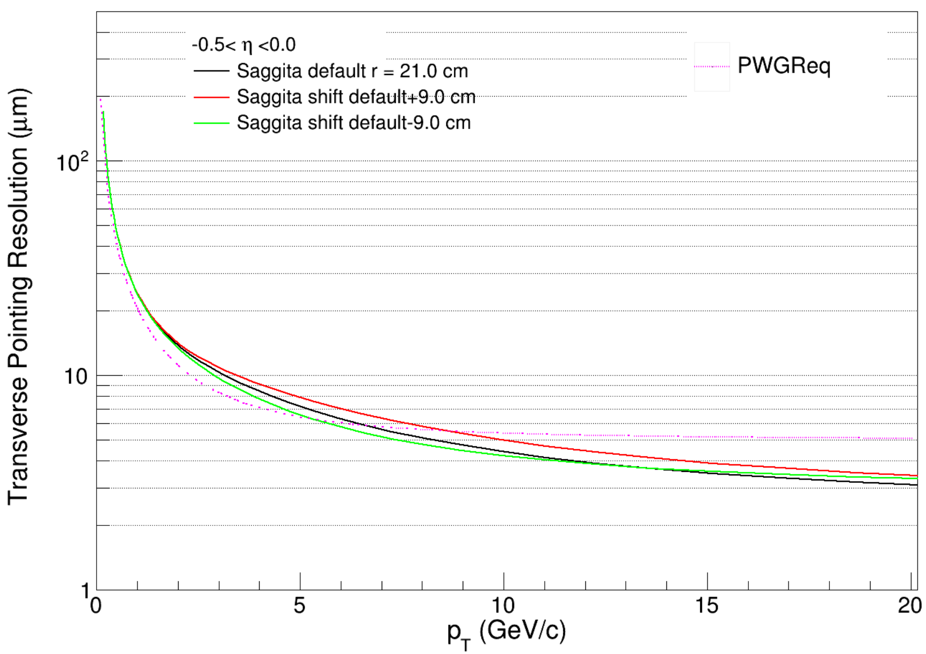
$$\sigma_{d0_{r\phi}} \sim 20/p_T\,\mu m + 5\,\mu m$$



Tracking Performance with Sagitta layer Shifting

Shifting sagitta layers with the equal radius





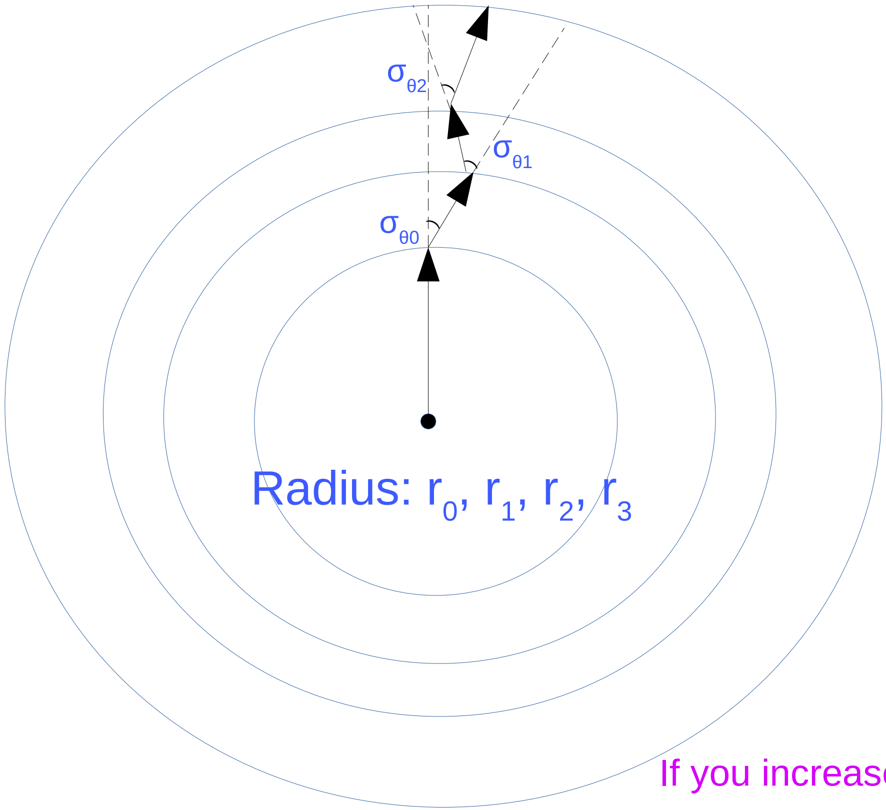
Theta MS σ_θ (Rad): 0.000226371 Theta MS σ_θ (deg): 0.0129701 (50 µm thick Silicon)

ϵ_p will be very small (ignore)

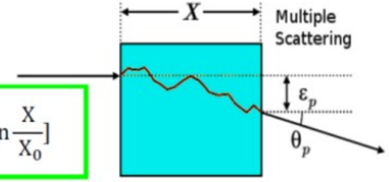
Layer1 smearing: $\sigma_1 = [(r_1 - r_0)*\sigma_{\theta 0}]$

Layer2 smearing: $[(r_2 - r_1)*\sigma_{\theta 1}] + [(r_2 - r_0)*\sigma_{\theta 0}]$

Layer3 smearing: $[(r_3 - r_2)*\sigma_{\theta 2}] + [(r_3 - r_1)*\sigma_{\theta 1}] + [(r_3 - r_0)*\sigma_{\theta 0}]$



Multiple Scattering (M.S.)



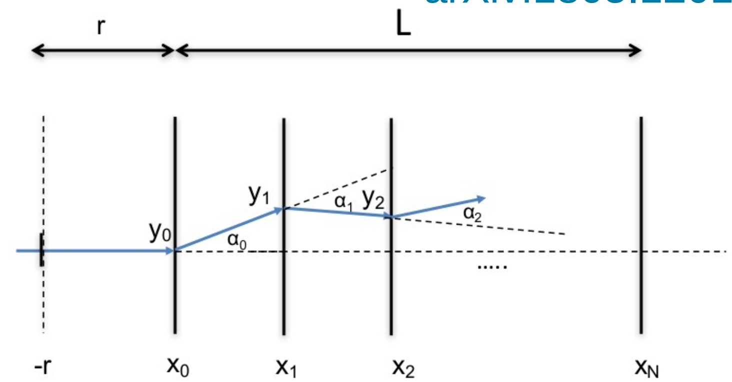
$$\sigma_\theta = 13.6 \frac{\text{MeVz}}{\beta cp} \sqrt{\frac{X}{X_0}} [1 + 0.038 \ln \frac{X}{X_0}]$$

$$\epsilon_p \approx \frac{1}{\sqrt{3}} \theta_p X$$

Ref: "Particle Detectors", C. Grupen and B. A. Shwartz

At low p: m.s. dominated by $\propto \frac{1}{p}$

arXiv:1805.12014



$$\begin{aligned} y_0 &= f(x_0) + u_0 \\ y_1 &= f(x_1) + u_1 + \alpha_0(x_1 - x_0) \\ y_2 &= f(x_2) + u_2 + \alpha_0(x_2 - x_0) + \alpha_1(x_2 - x_1) \\ &\vdots \\ y_n &= f(x_n) + u_n + \sum_{m=0}^{n-1} \alpha_m (x_n - x_m) \qquad n = 0, 1, ..., N \end{aligned}$$

If you increase spacing smearing effect increases so multiple scattering !!!