Study of Baseline2 Tracker using Fast Simulation and first attempts with DD4HEP

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Inputs for Fast Simulation

// Vertexing 3 layers Material Budget = 0.05%

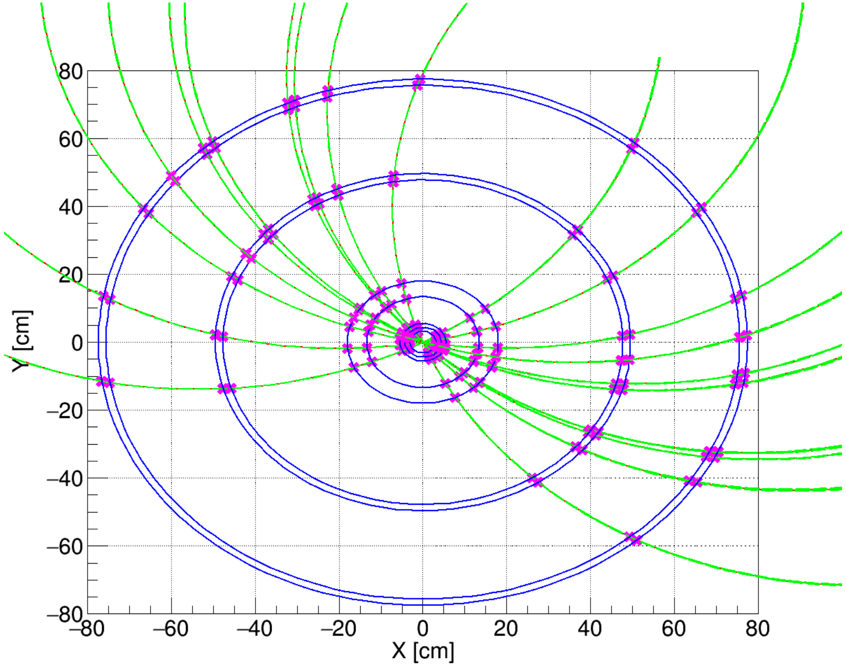
```
double si_vtx_r_pos[] = {3.3,4.35,5.4};
double si_z_vtxlength[] = {28, 28, 28};
double si_thick_vtx = 0.05/100.*9.37;
```

$$\sigma_{r\phi} = \sigma_z = 10./\sqrt{(12)}\,\mu m$$

// Barrel Material Budget 0.55 %

```
double si_r_pos[] = {13.34, 17.96};
double si_z_length[] = {34.34, 46.68};
double si_thick_bar = 0.55/100.*9.37;
```

$$\sigma_{r\phi} = \sigma_z = 10./\sqrt{(12)}\,\mu m$$



// Micromegas: Material Budget 0.4 %

```
double BMT_r[4] = {47.72, 49.57, 75.61, 77.46};
```

$$\sigma_{r\phi} = \sigma_z = 150\,\mu m$$

Baseline-2.0

B: Barrel,
P: Positive,
N: Negative

Original code

https://github.com/alisw/AliRoot/tree/master/ITSMFT/ITS/FT1

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

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

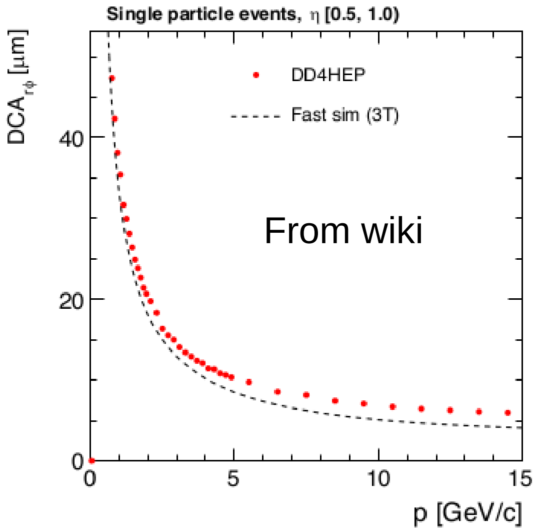
Inputs for Fast Simulation

```
// and finally considered as dead layer
its.AddLayer((char*)"bpipe",3.1,0.0022/sin_theta); // thickness 760 mum; x/x0 = 0.076/35 = 0.0022;
its.AddLayer((char*)"vertex",     0,      0); // dummy vertex for matrix calculation
// new ideal Pixel properties?
Double_t x_x0VTX     = 0.0005; // Per layer VTX
Double_t x_x0BARR    = 0.0055; // Per layer BARR
Double_t x_x0MM      = 0.004; // Per layer Micromegas
Double_t resRPhiVTX     = 10.0e-4/sqrt(12);
Double_t resRPhiBARR    = 10.0e-4/sqrt(12);
Double_t resRPhiMM      = 150.0e-4;
Double_t resZVTX        = 10.0e-4/sqrt(12);
Double_t resZBARR       = 10.0e-4/sqrt(12);
Double_t resZMM         = 150.0e-4;
Double_t eff            = 1.0;
//
//
its.AddLayer((char*)"VTX1",  3.3 ,  x_x0VTX/sin_theta, resRPhiVTX, resZVTX,eff);
its.AddLayer((char*)"VTX2",  4.35 ,  x_x0VTX/sin_theta, resRPhiVTX, resZVTX,eff);
its.AddLayer((char*)"VTX3",  5.40 ,  x_x0VTX/sin_theta, resRPhiVTX, resZVTX,eff);
its.AddLayer((char*)"BARR1", 13.34, x_x0BARR/sin_theta, resRPhiBARR, resZBARR,eff);
its.AddLayer((char*)"BARR2", 17.96, x_x0BARR/sin_theta, resRPhiBARR, resZBARR,eff);
its.AddLayer((char*)"MM1",  47.72 ,  x_x0MM/sin_theta, resRPhiMM, resZMM,eff);
its.AddLayer((char*)"MM2",  49.57 ,  x_x0MM/sin_theta, resRPhiMM, resZMM,eff);
its.AddLayer((char*)"MM3",  75.61 ,  x_x0MM/sin_theta, resRPhiMM, resZMM,eff);
its.AddLayer((char*)"MM4",  77.46 ,  x_x0MM/sin_theta, resRPhiMM, resZMM,eff);
```

Fast-Simulation Code Details

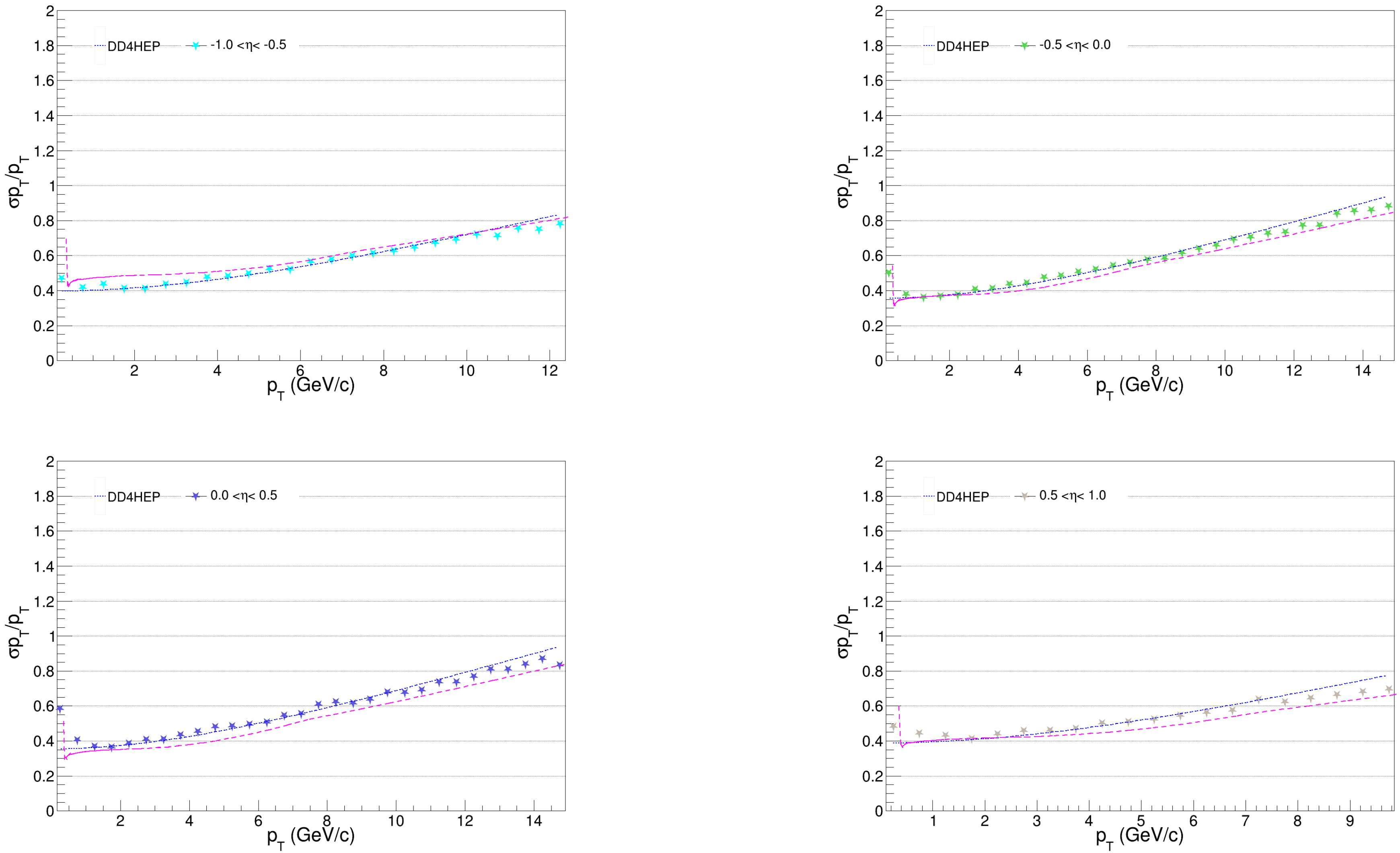
- The code works for Barrel layers where track model is implemented
- Main Idea is to start the track with collision vertex and angle theta (eta), propagate to the Radius correspond to the transverse momentum
- Start back propagation with an extrapolation to each layer and updating the measurement in covariance matrix due to detector spatial resolution and multiple scattering effect (Kalman filter) see more detail in back up
- Finally propagate the track to the vertex and evaluate the DCA, Momentum, p_T resolution
- I tried this code for Baseline2 tracker performance and with adding an extra TOF layer also some other studies in back up
- We can also add TPC but need to configure

  several parameters, so it can be very useful for a quick check



p_T Resolution

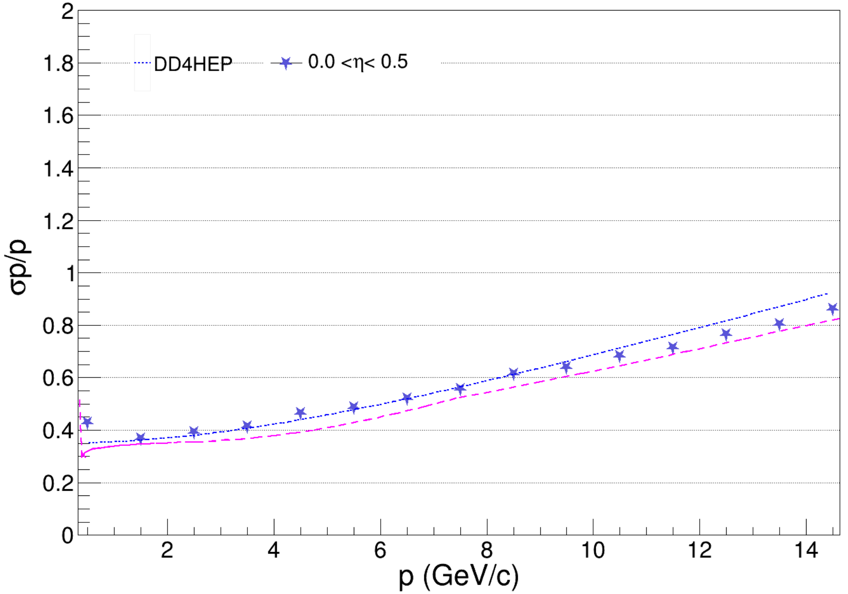
Fun4All Points (All Markers), Blue dotted line (DD4HEP), Magenta (Fast Simulation-dotted lines)

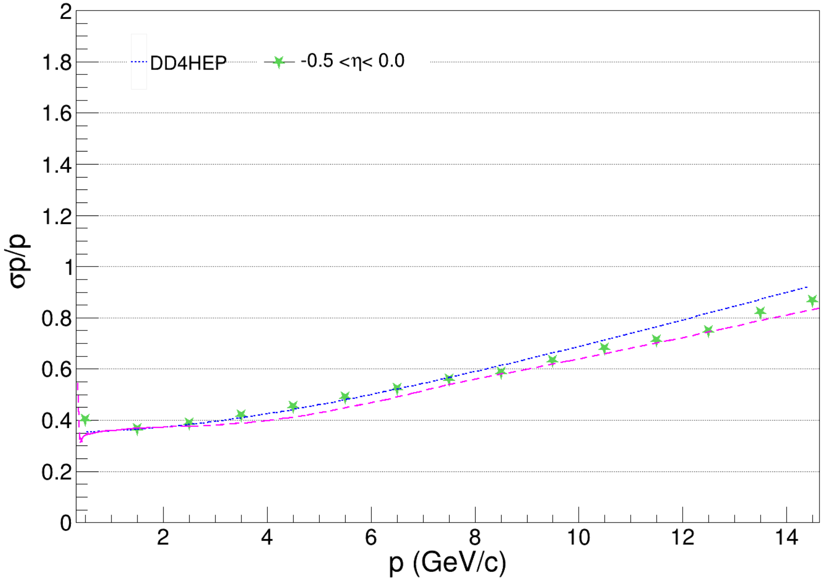


Momentum Resolution

Fun4All Points (All Markers), Blue dotted line (DD4HEP), Magenta (Fast Simulation-dotted lines)

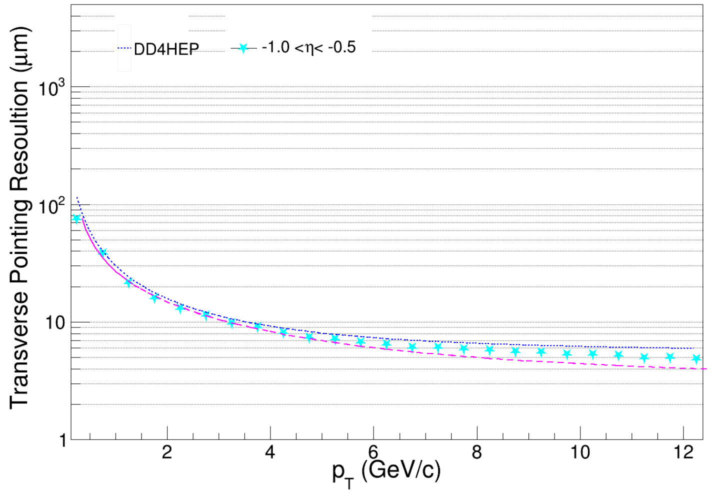
Assuming $1/p_t$ and Tanλ uncorrelated (slide 13)

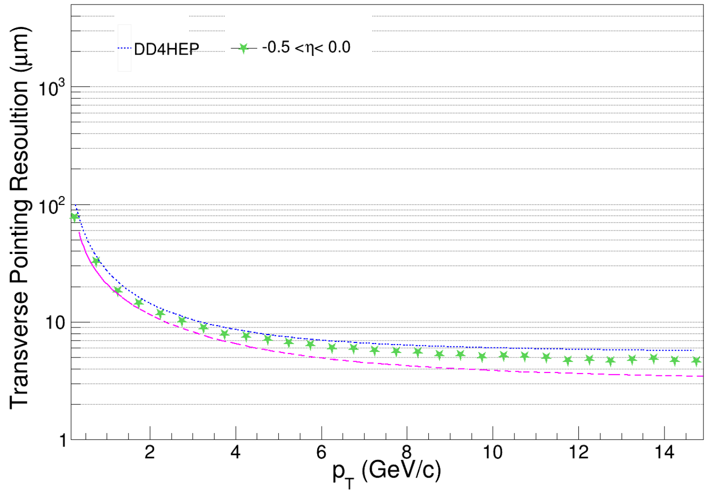


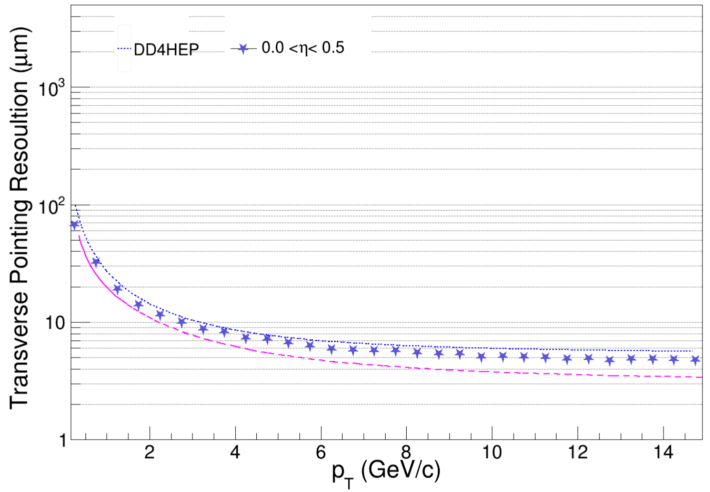


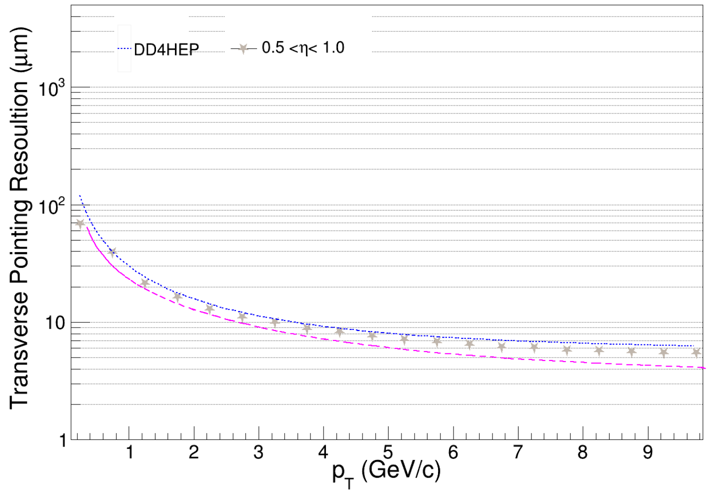
Transverse Pointing Resolution vs p_T

Fun4All Points (All Markers), Blue dotted line (DD4HEP), Magenta (Fast Simulation-dotted lines)



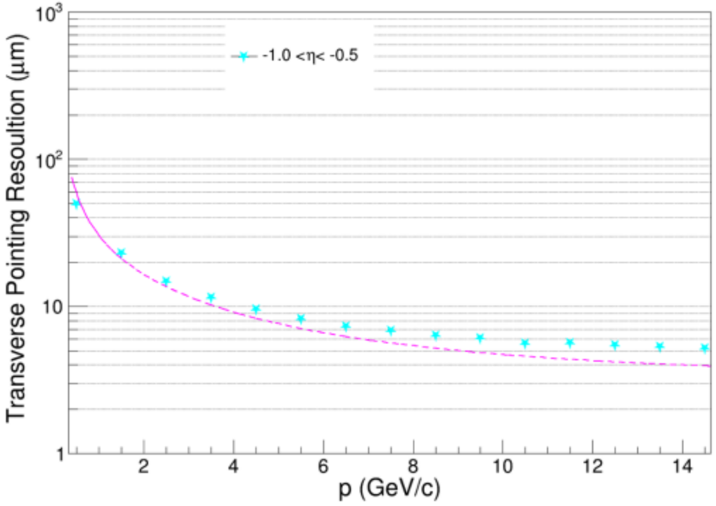


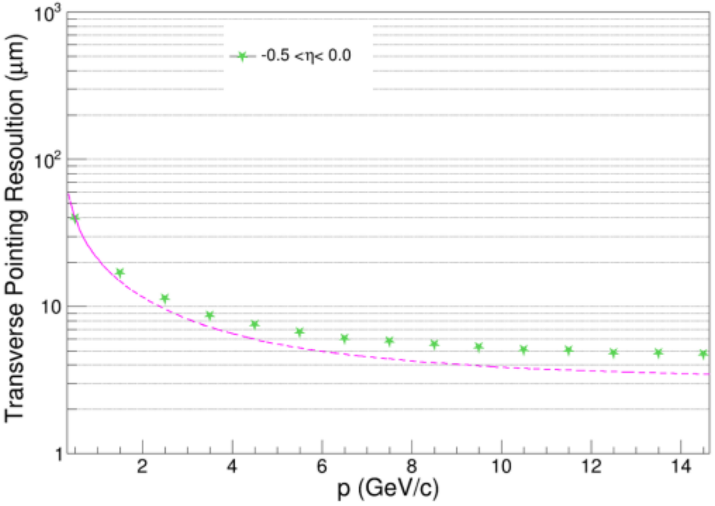


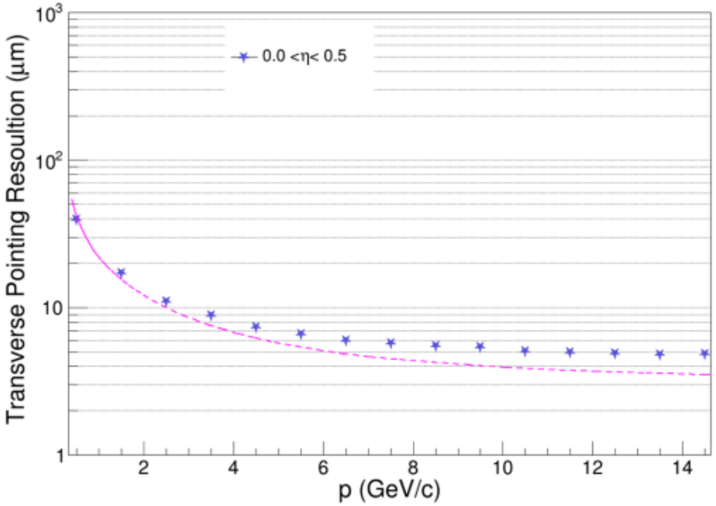


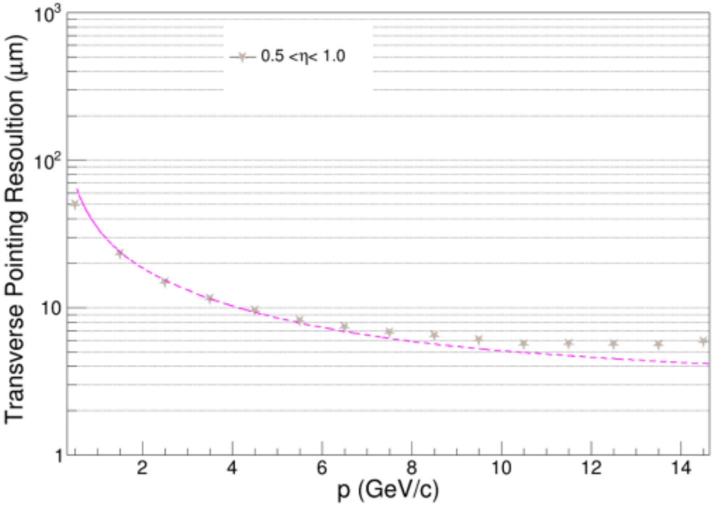
Transverse Pointing Resolution vs Momentum

Fun4All Points (All Markers), Magenta (Fast Simulation-dotted lines)



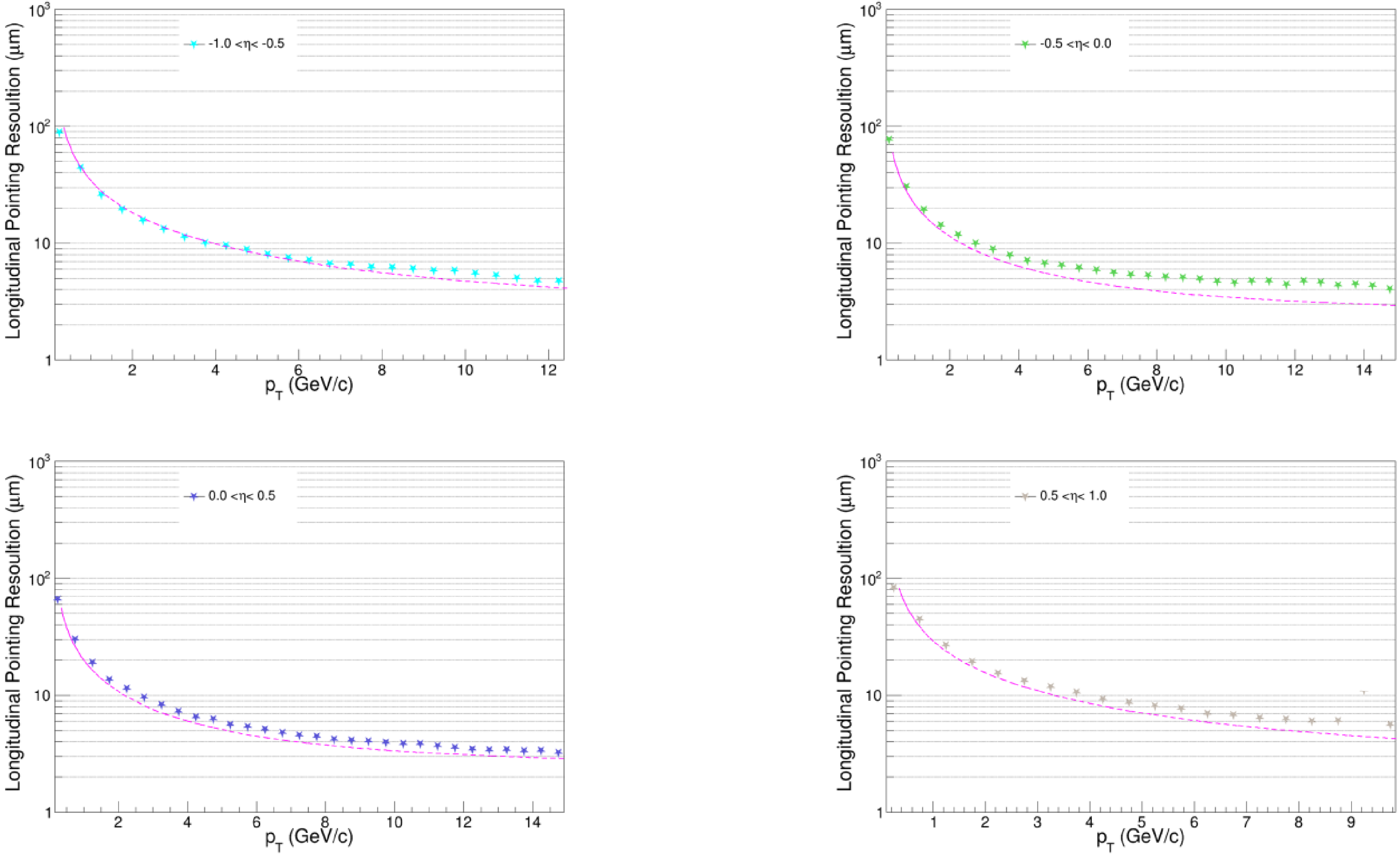






Longitudinal Pointing Resolution vs p_T

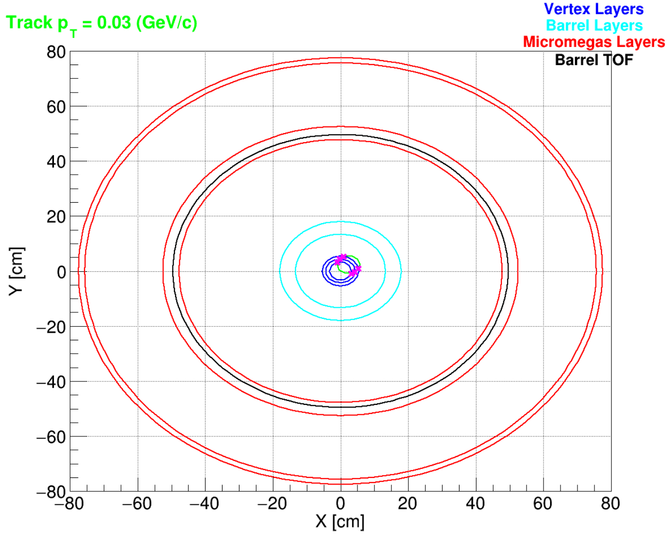
Fun4All Points (All Markers), Magenta (Fast Simulation-dotted lines)

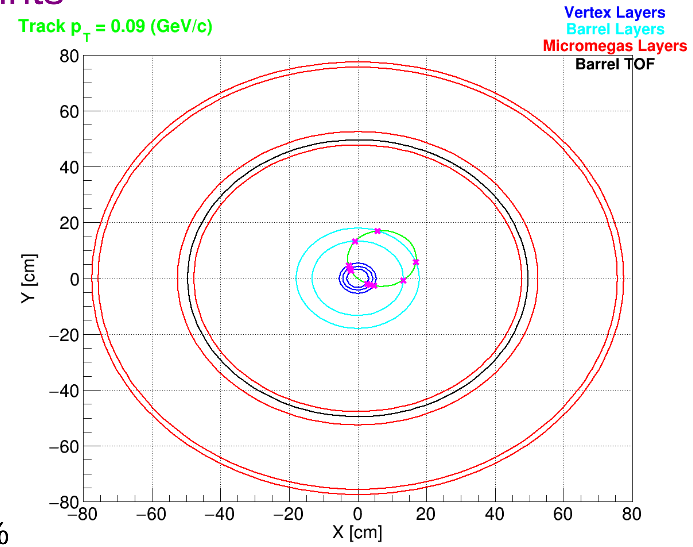


Baseline2+BTOF

$p_T min = 0.3 * 3 * 0.027 = 0.0243\, GeV/c$

Track with Hit Points

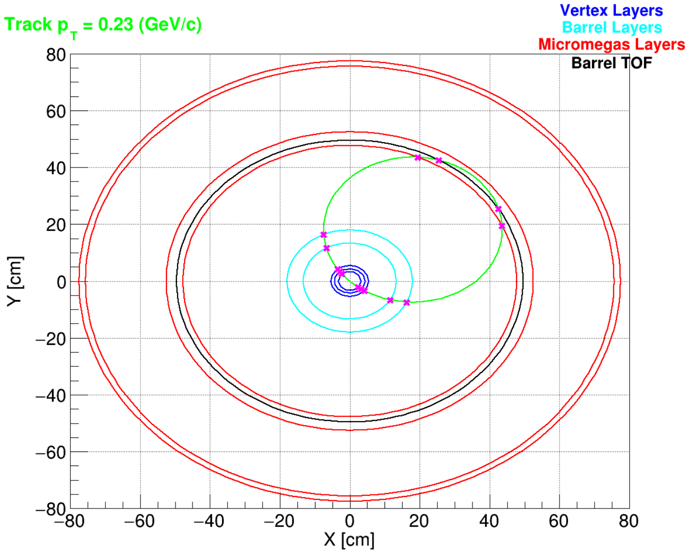




TOF Layer detail:

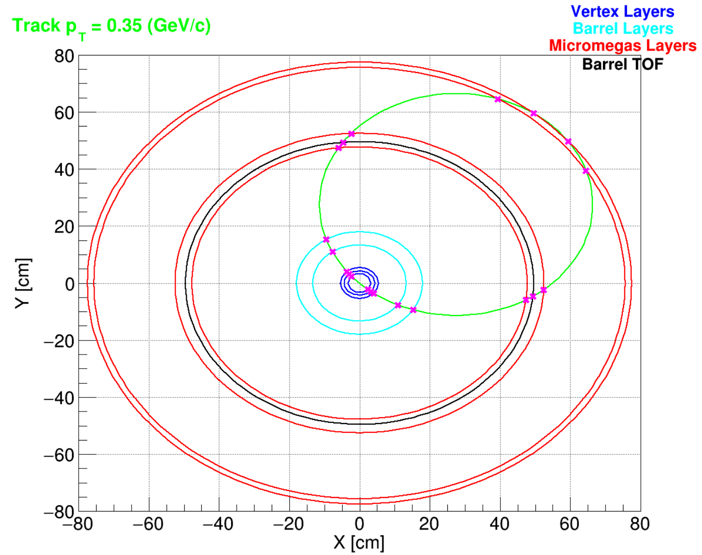
Radius = 52.5 cm,

Material Budget= 1%

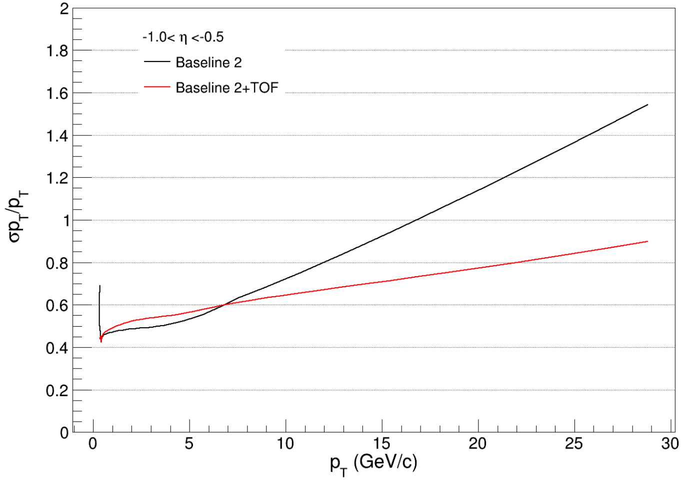


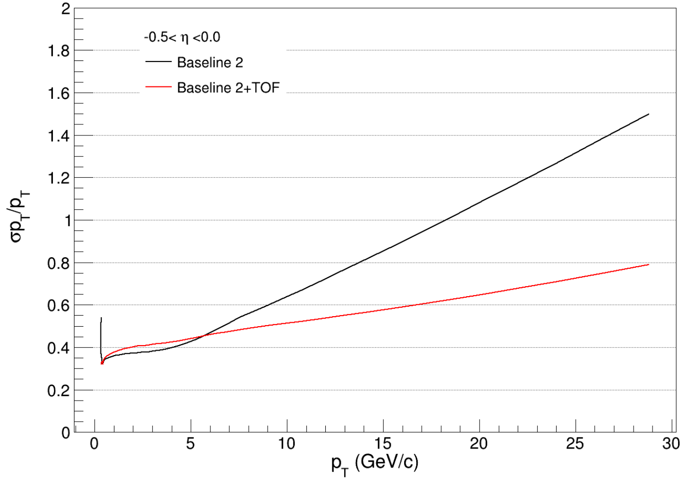
$\sigma_{r\phi} = 15\,\mu m$

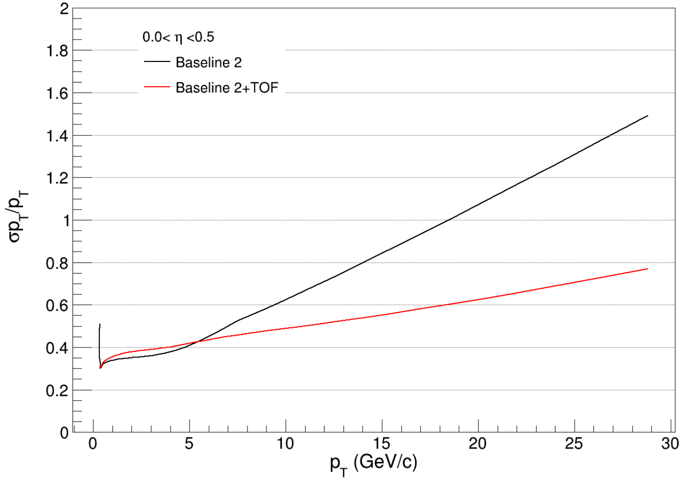
$\sigma_z = 2.8/\sqrt{(12)}\, cm$

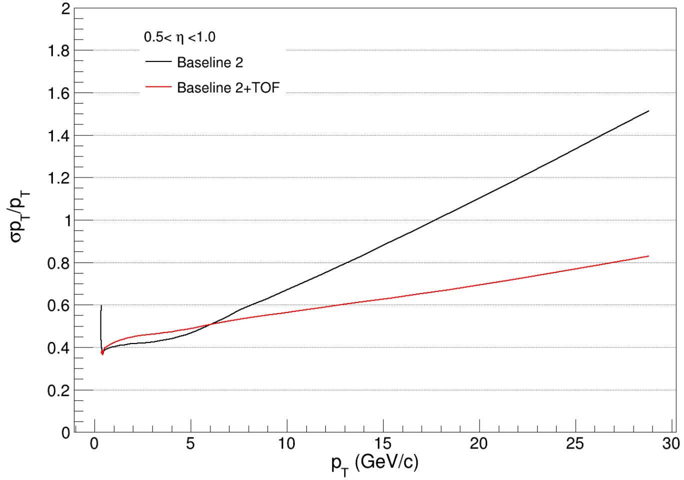


Baseline2+Barrel ToF Layer

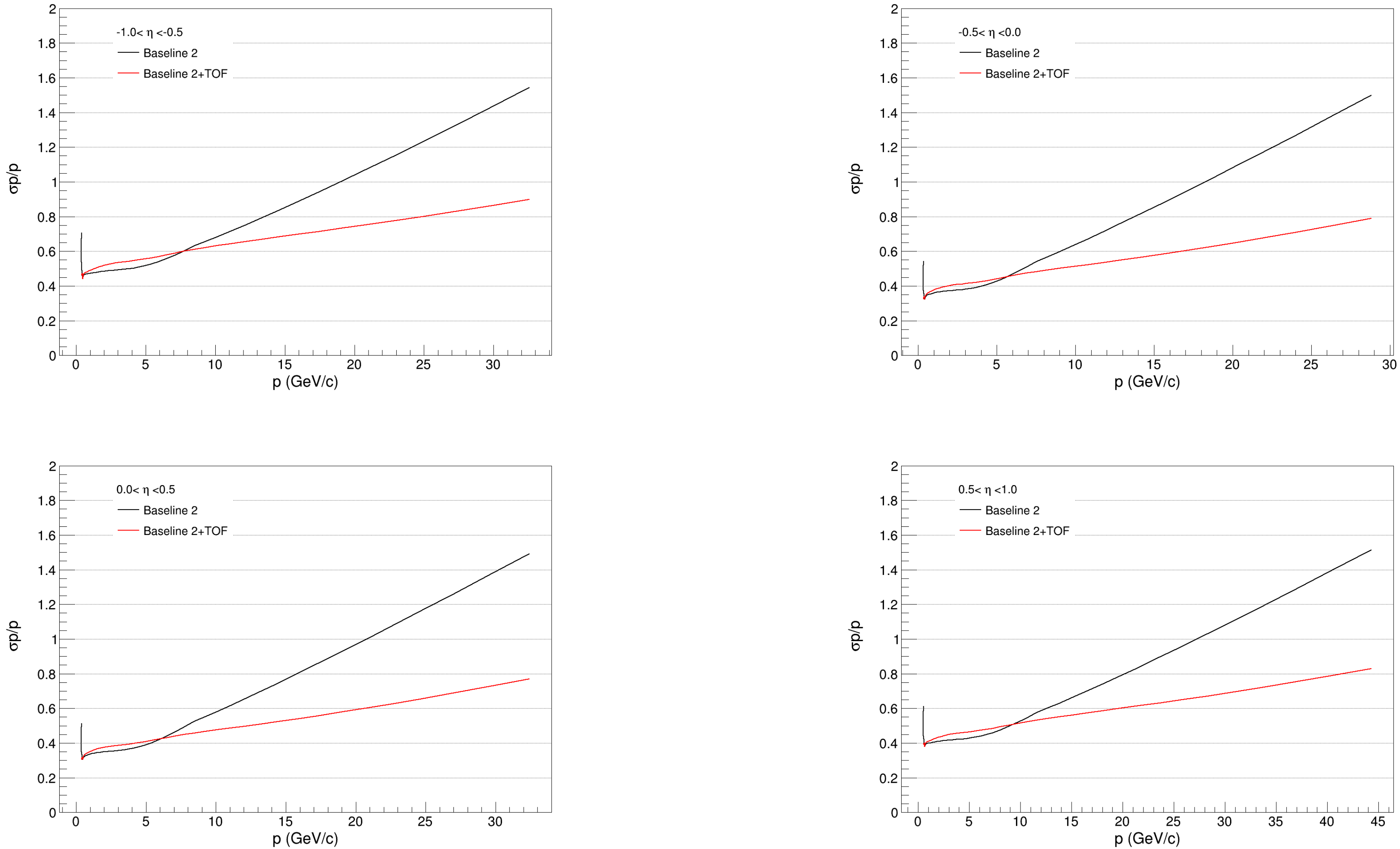




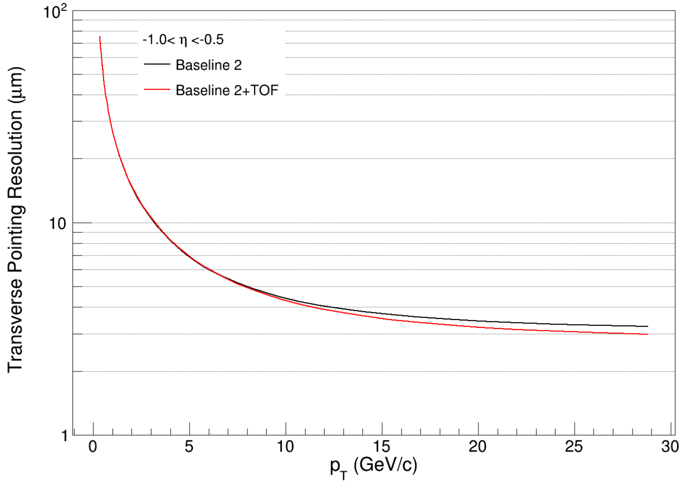


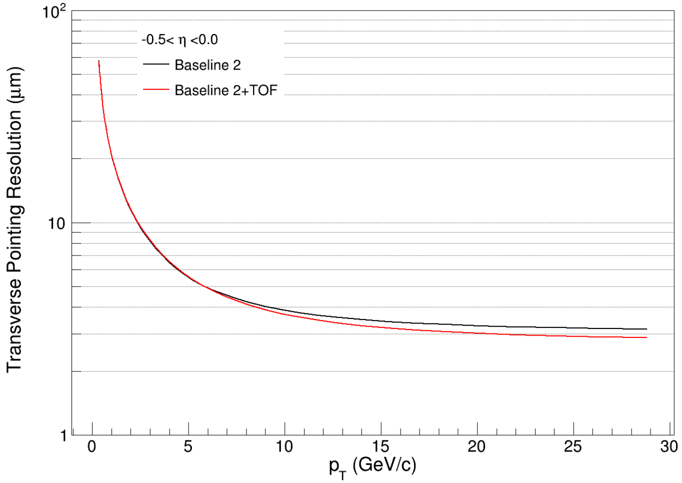


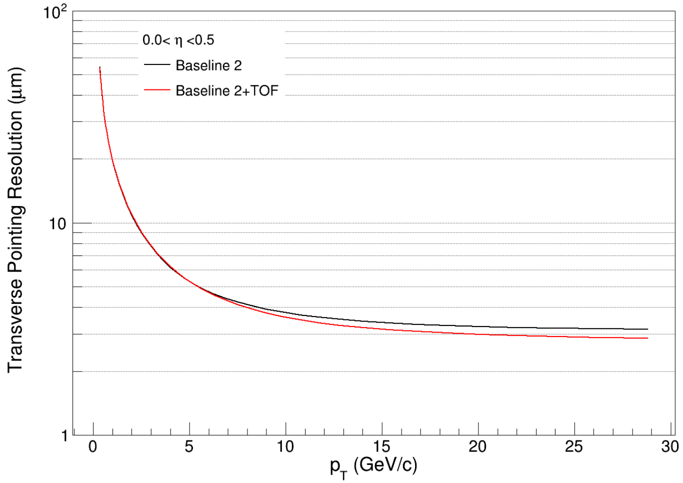
Baseline2+Barrel ToF Layer

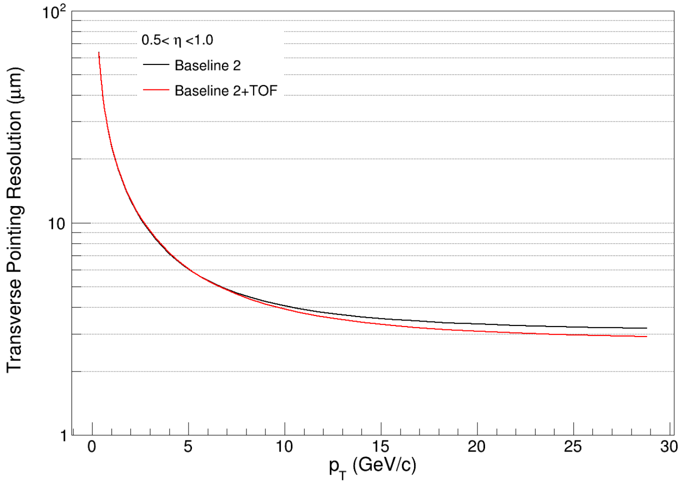


Transverse Pointing Resolution vs p_T

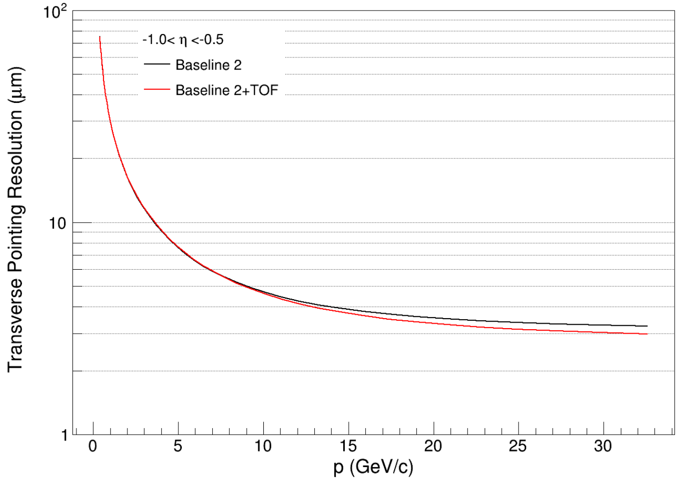


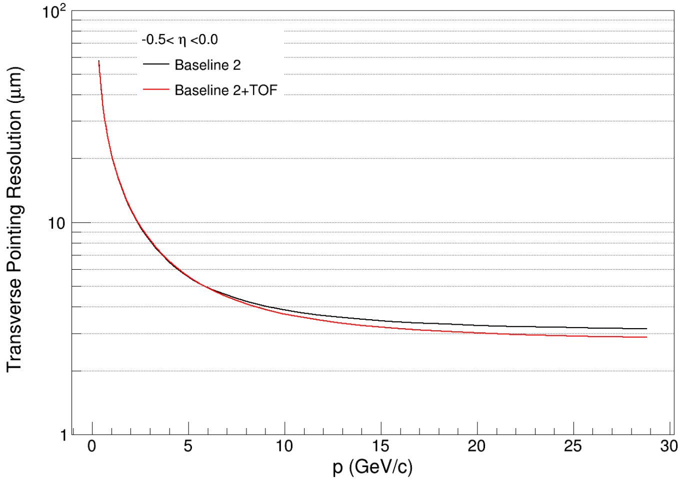


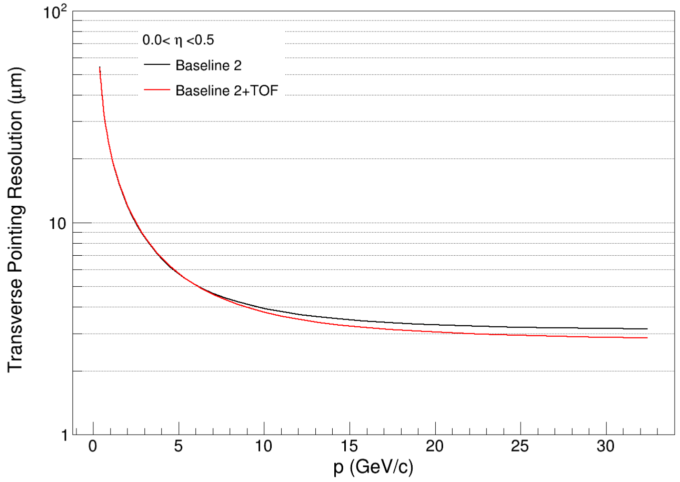


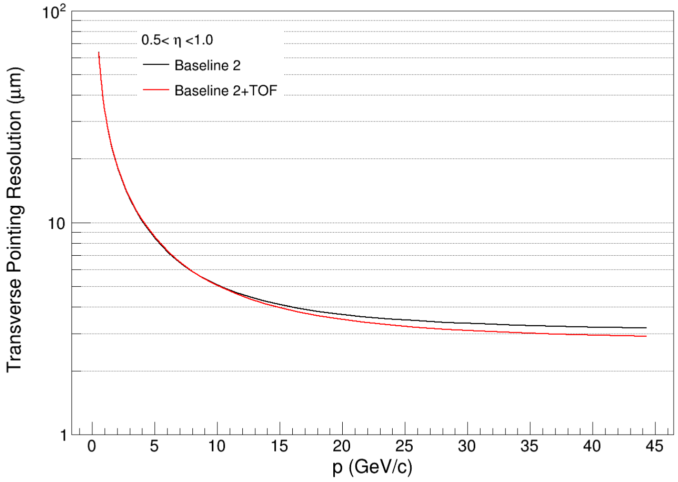


Transverse Pointing Resolution vs Momentum







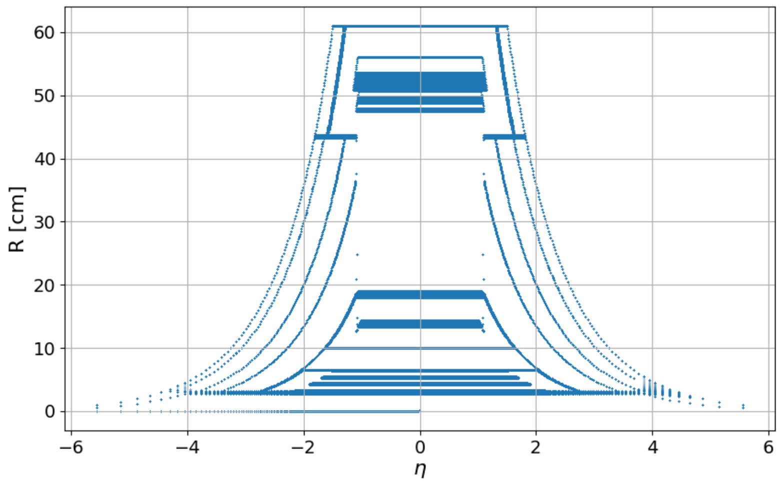


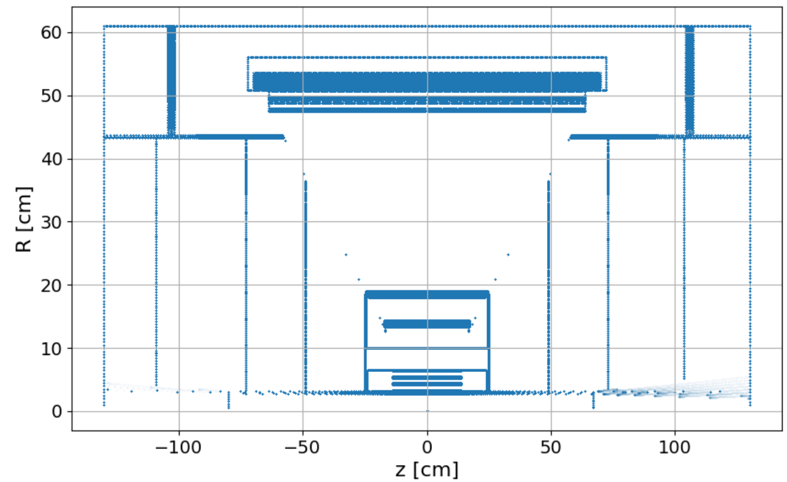
DD4HEP

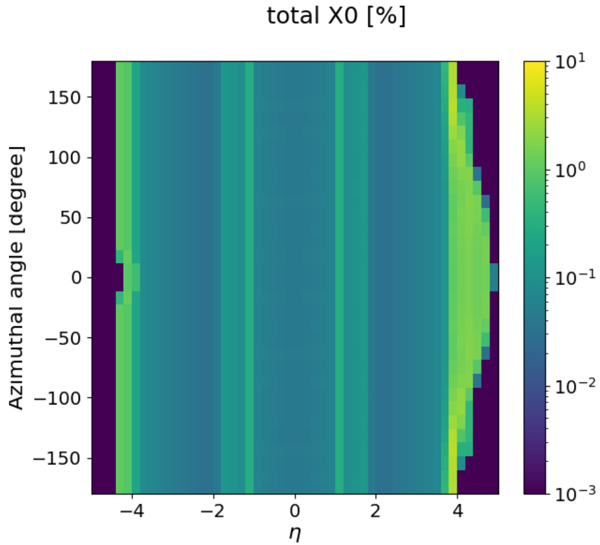
- Previously, I presented simulation study using Fun4All
- Since we are using DD4HEP therefore, I started learning about the framework
- Installed the software and started looking at the examples
- Finally produced a material budget plot using material scan on the next slide
- Still learning and getting more familiar with it

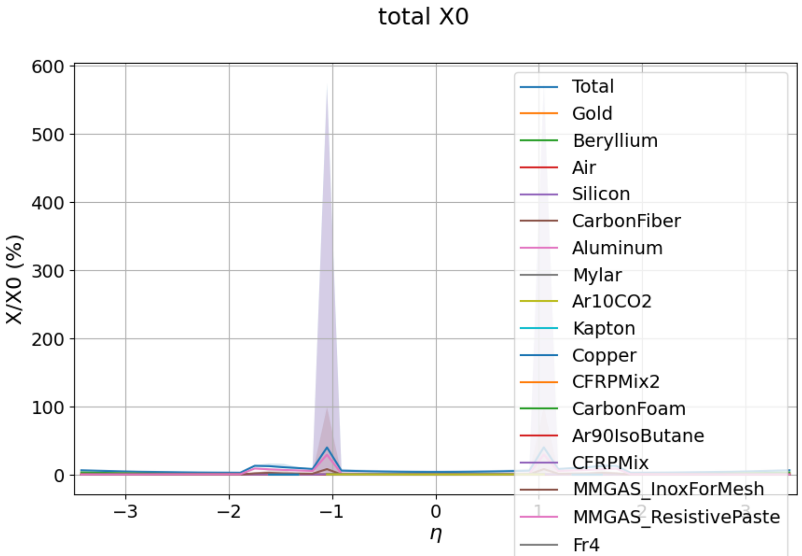
Material Map using DD4HEP

Thanks Shuji







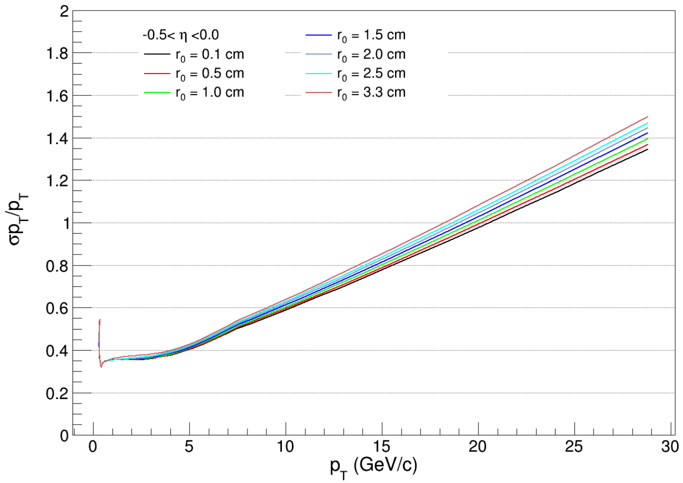


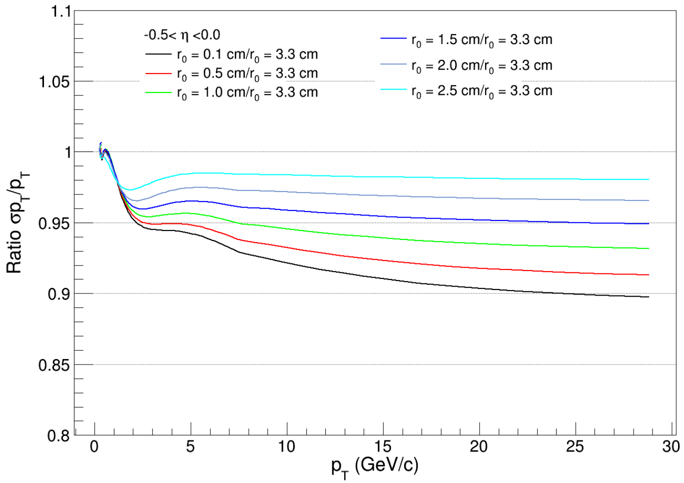
Summary

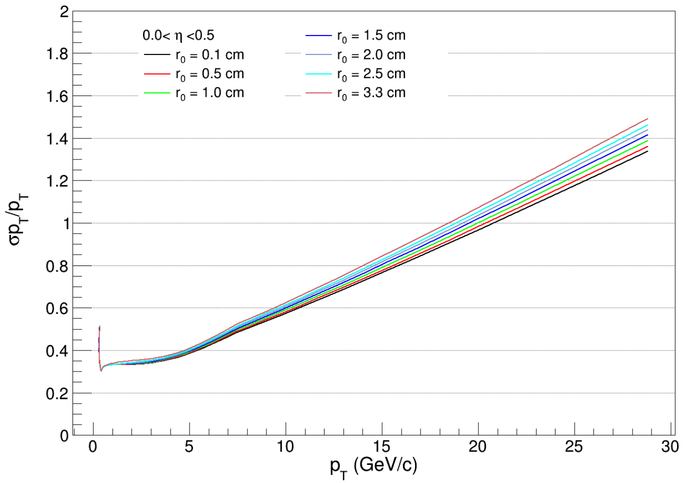
- Compared Fun4All, Fast-Simulation, DD4HEP results in the Barrel region.
- Study of Baseline2 Tracker+ Barrel Time of flight using fast simulation code.
- Started working and getting experience with DD4HEP with running example of material scan.
- Additional training sessions and guidance from the software working group will be very helpful to contribute in the future developments for tracking in the central framework.

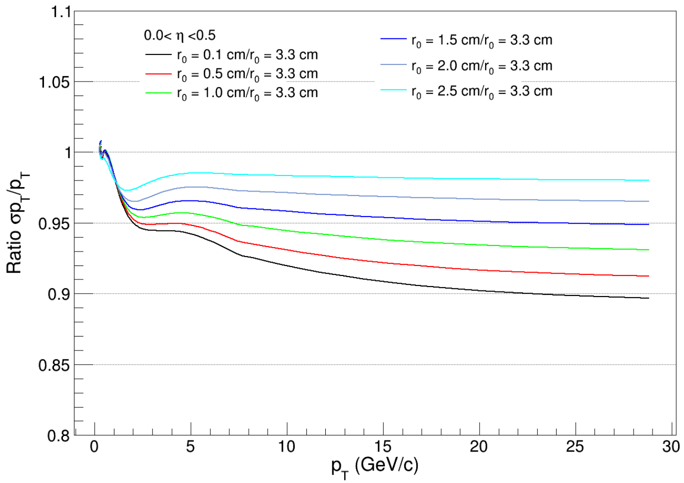
Thank You !!!

First Layer at different Positions from Vertex

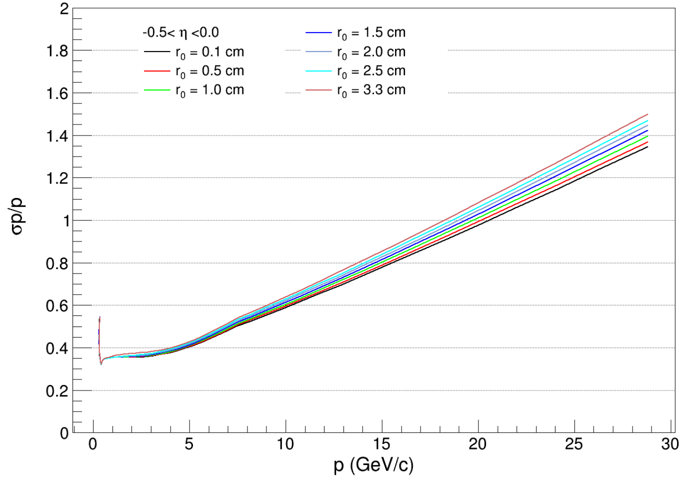


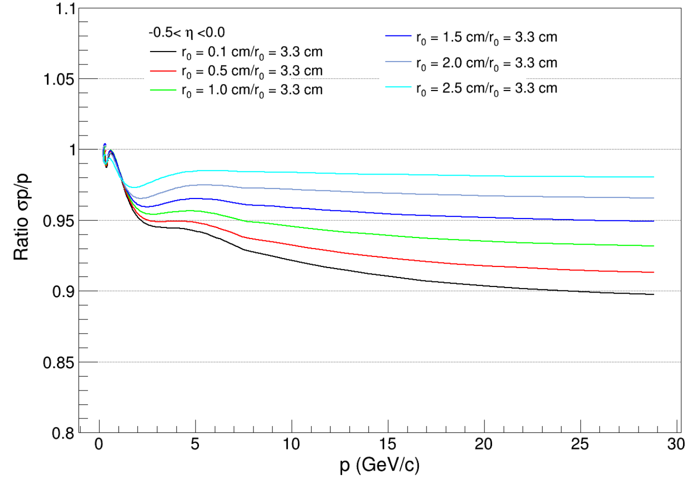


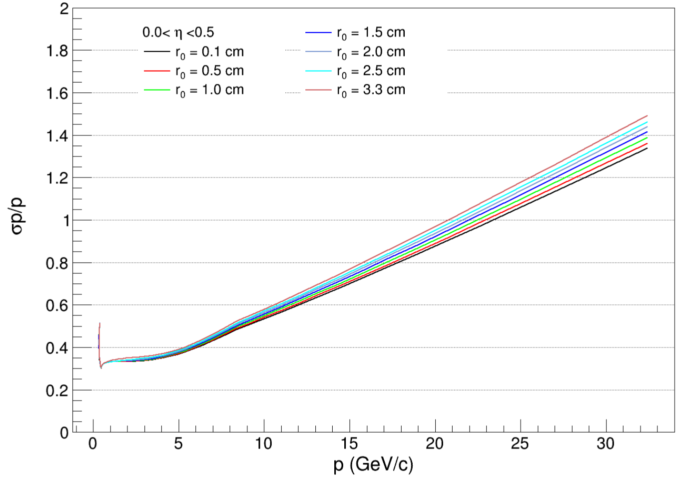


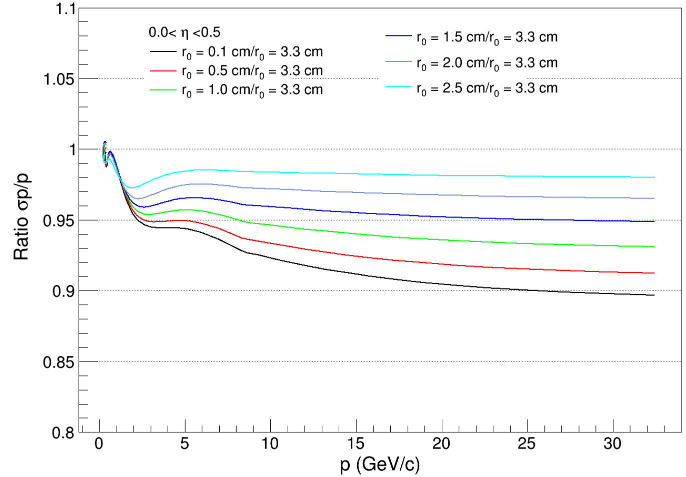


First Layer at different Positions from Vertex









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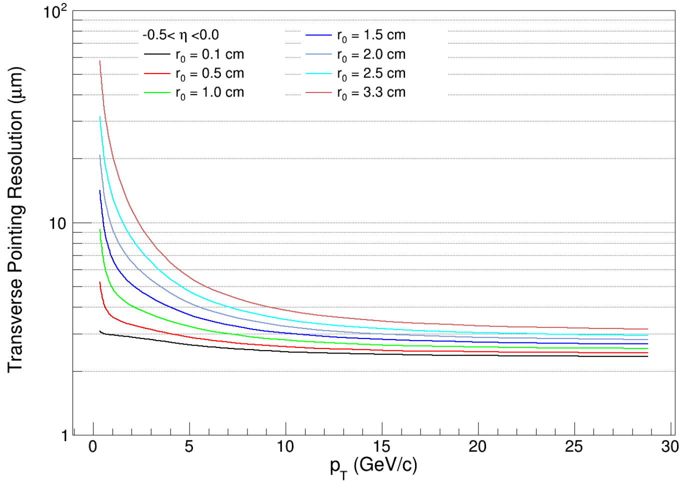
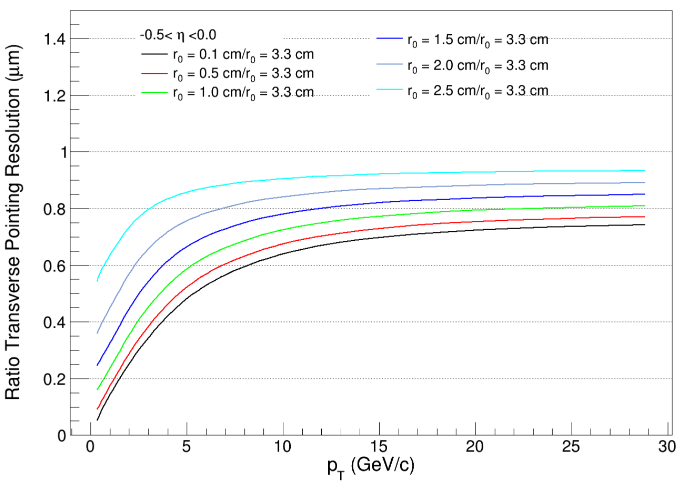
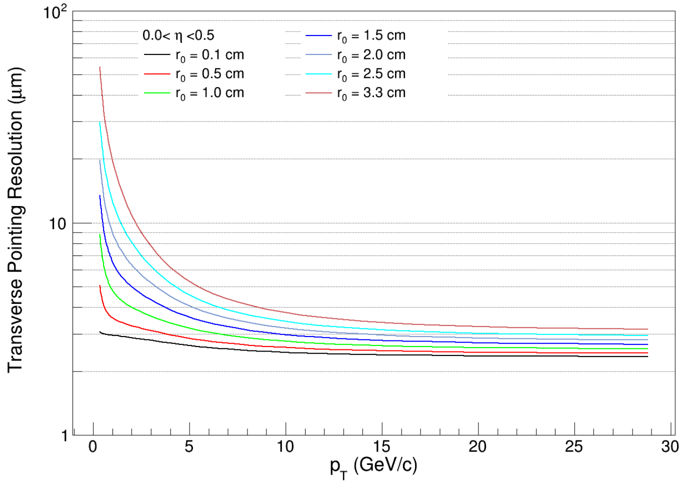
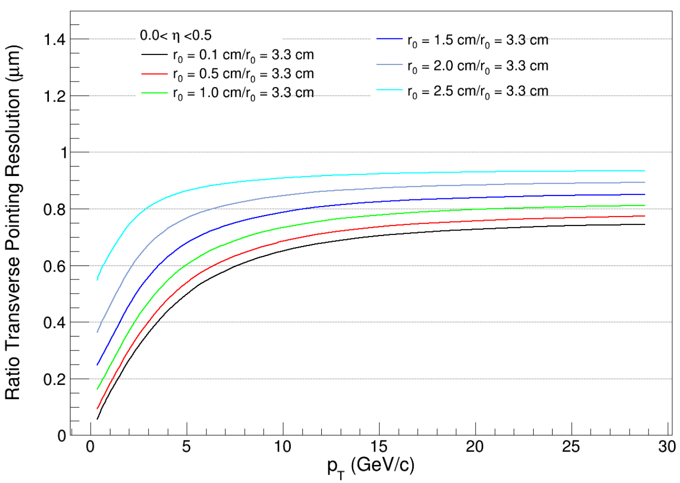
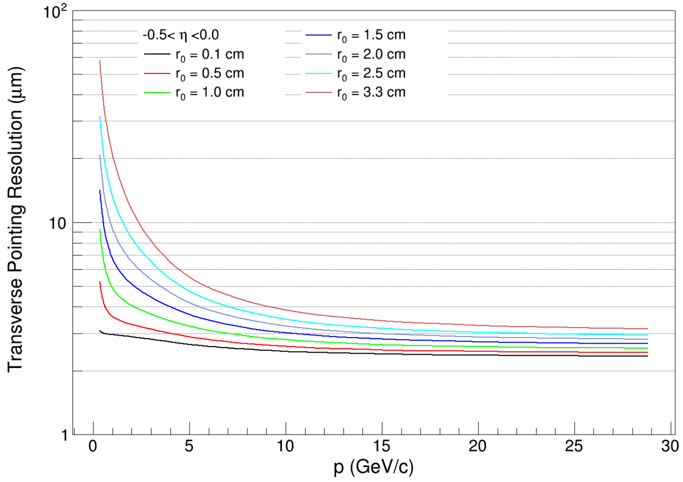


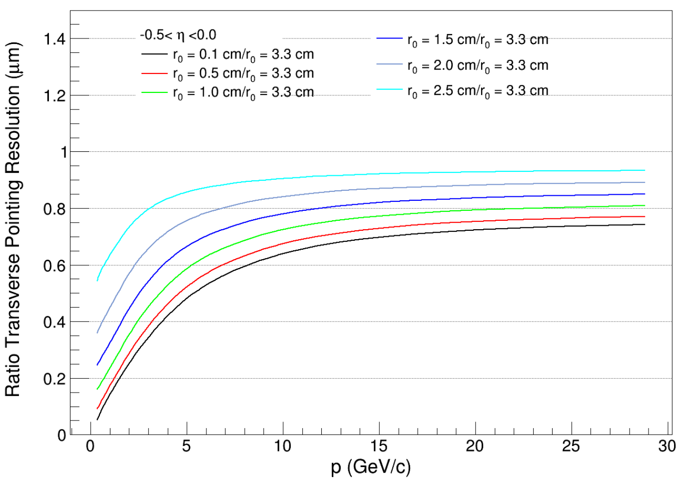


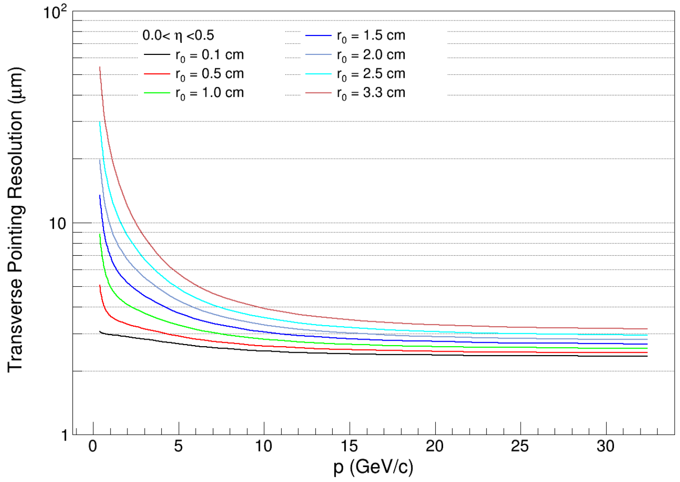


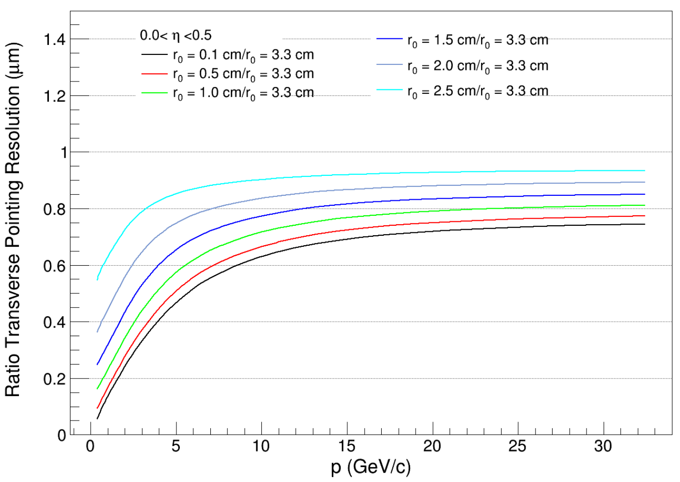


First Layer at different Positions from Vertex

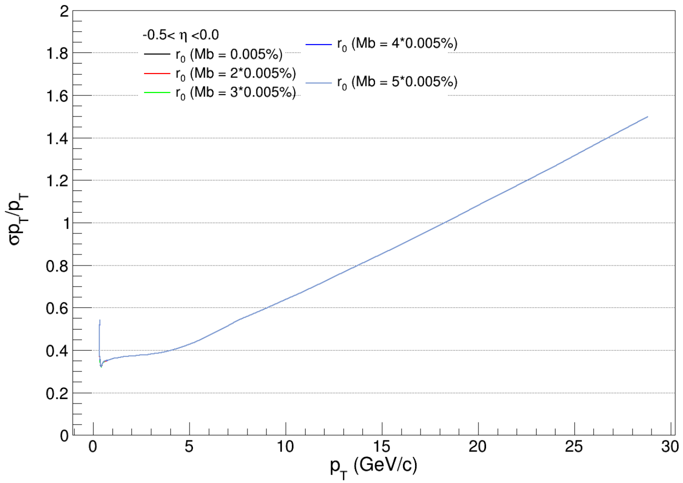


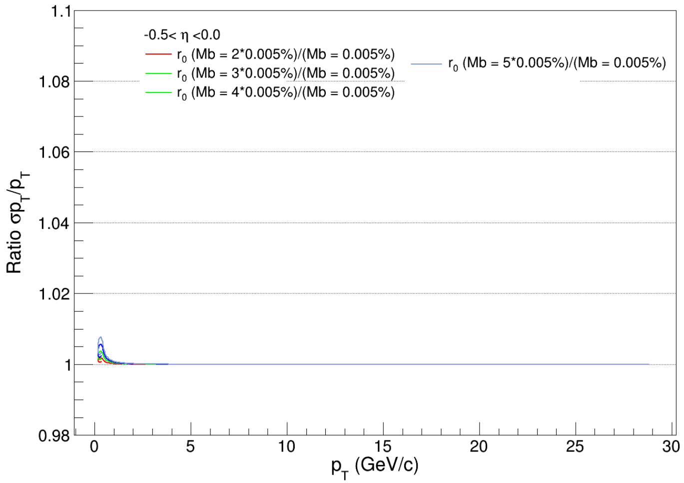


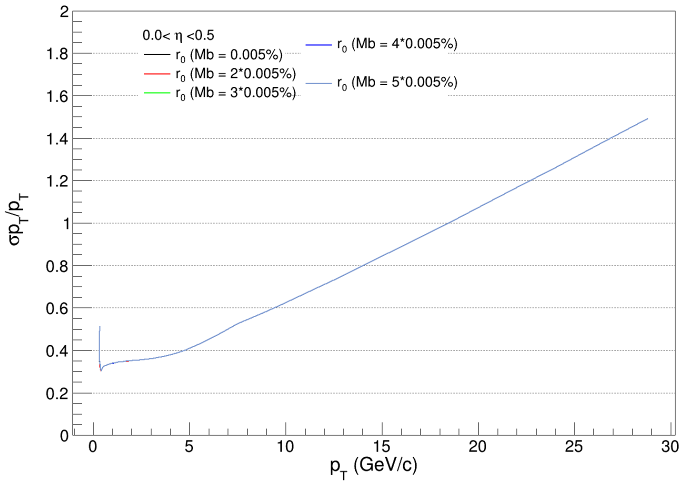


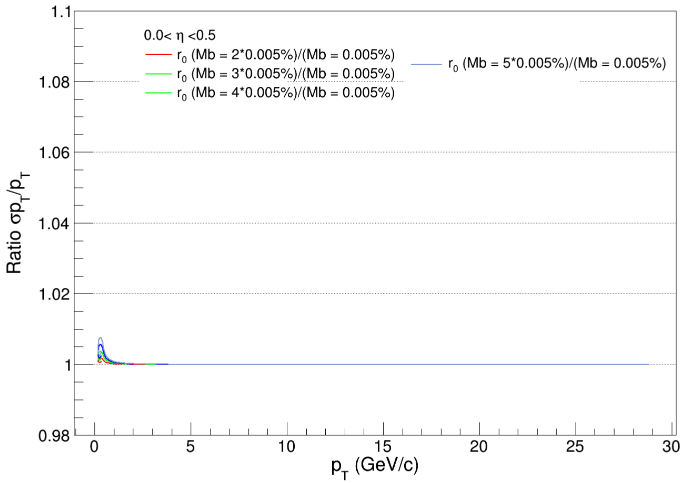


First Layer with Different Material Budget ($r_0 = 3.3$ cm fixed)

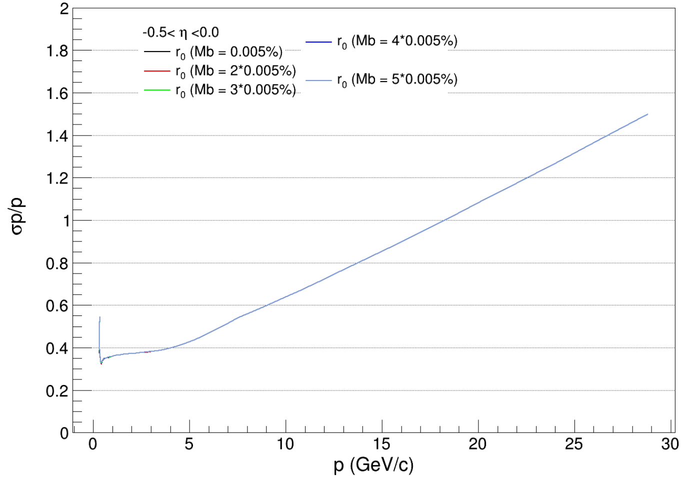


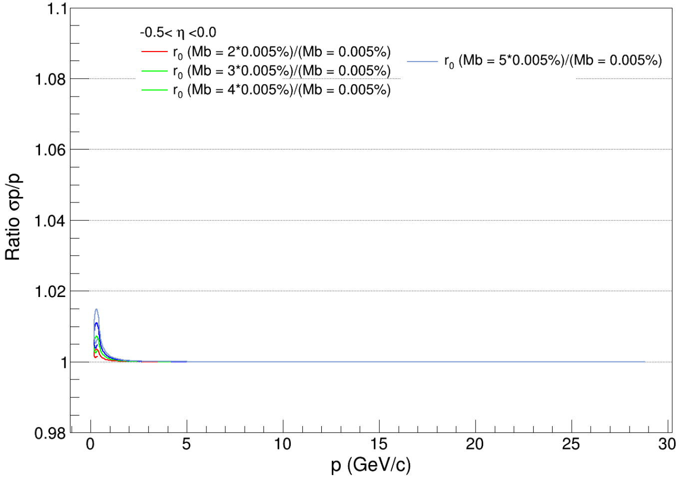


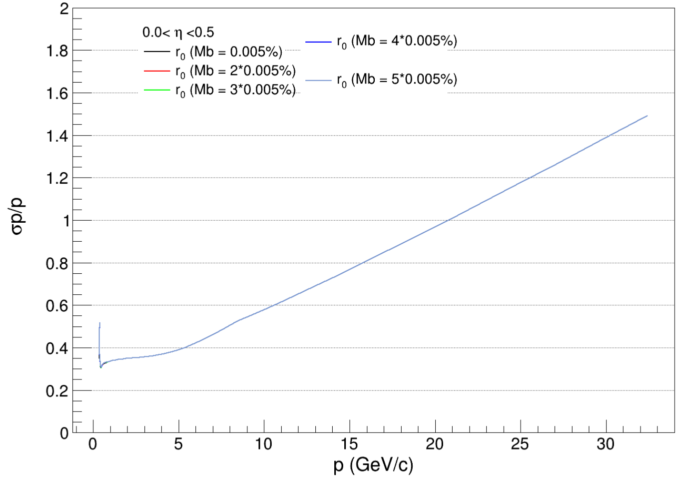


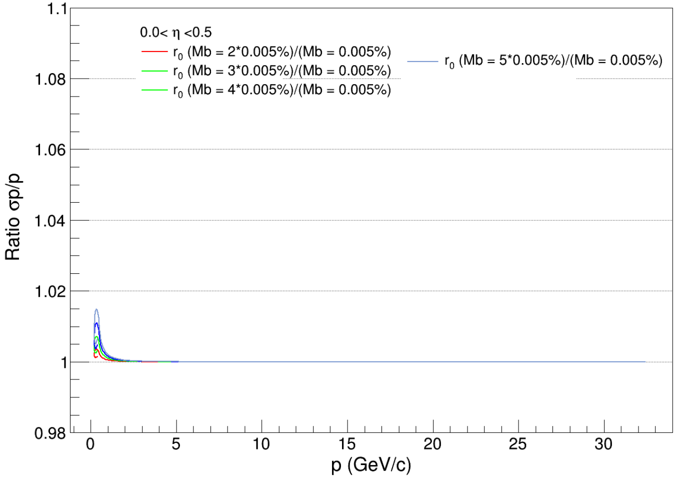


First Layer with Different Material Budget (r_0 = 3.3 cm fixed)

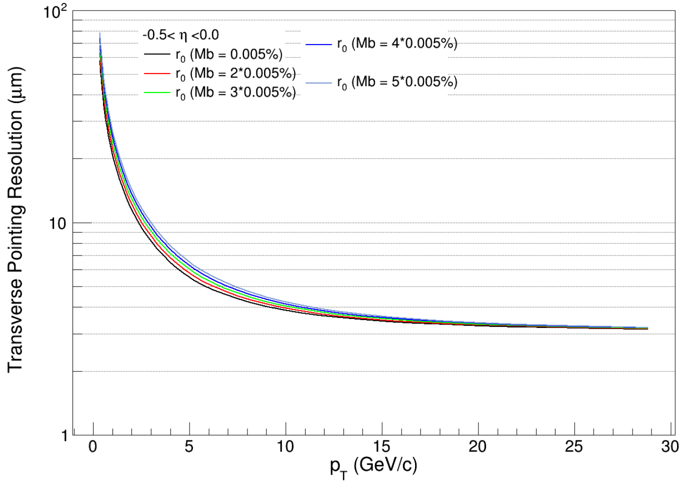


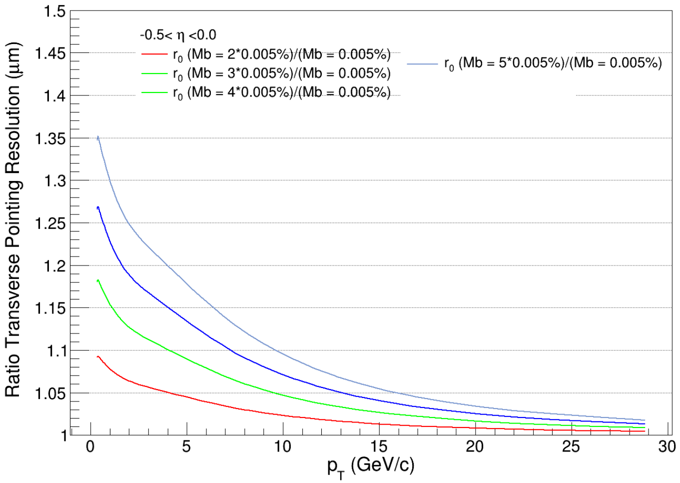


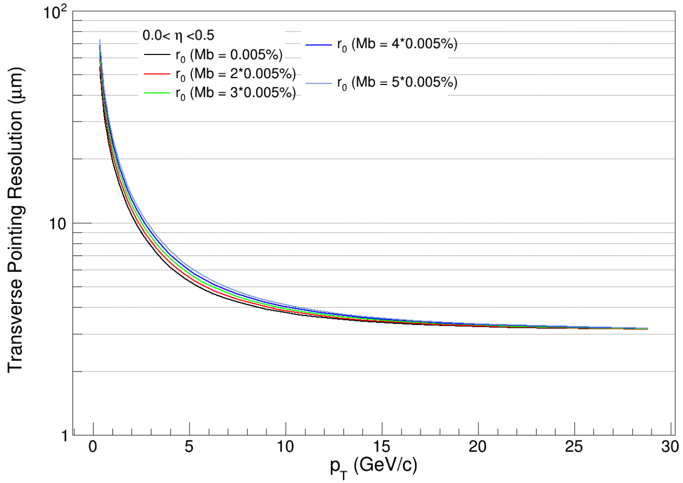


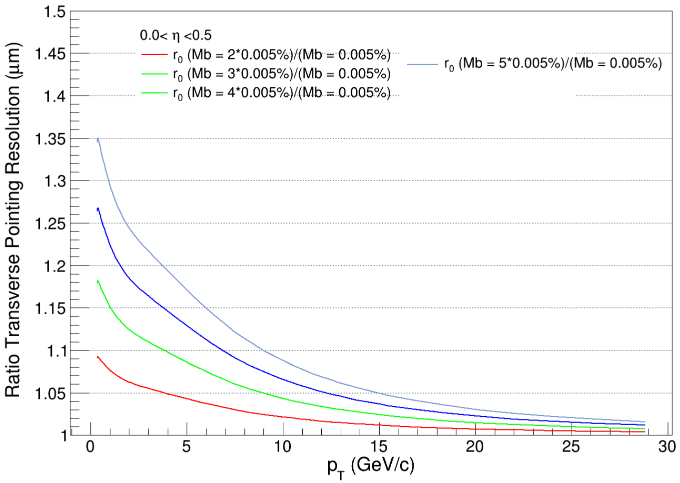


First Layer with Different Material Budget (r_0 = 3.3 cm fixed)

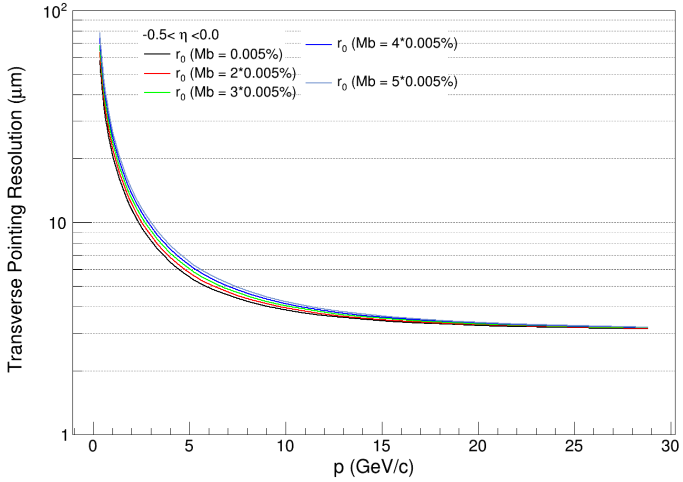


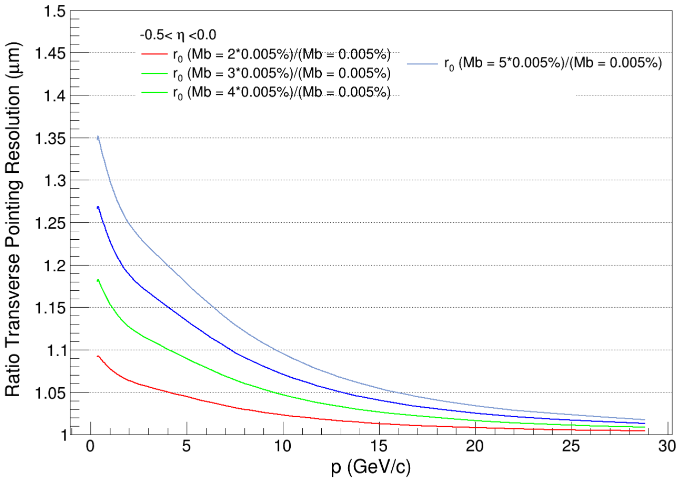


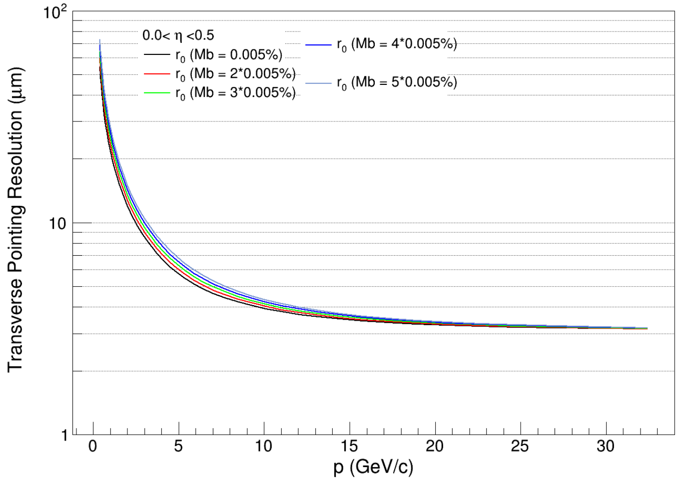


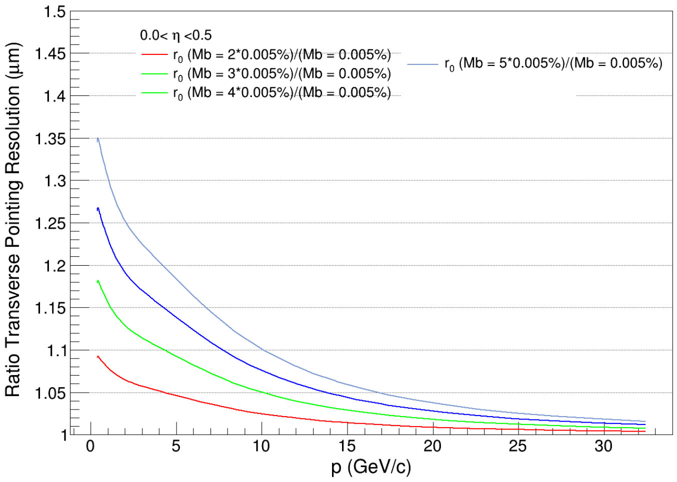


First Layer with Different Material Budget (r_0 = 3.3 cm fixed)







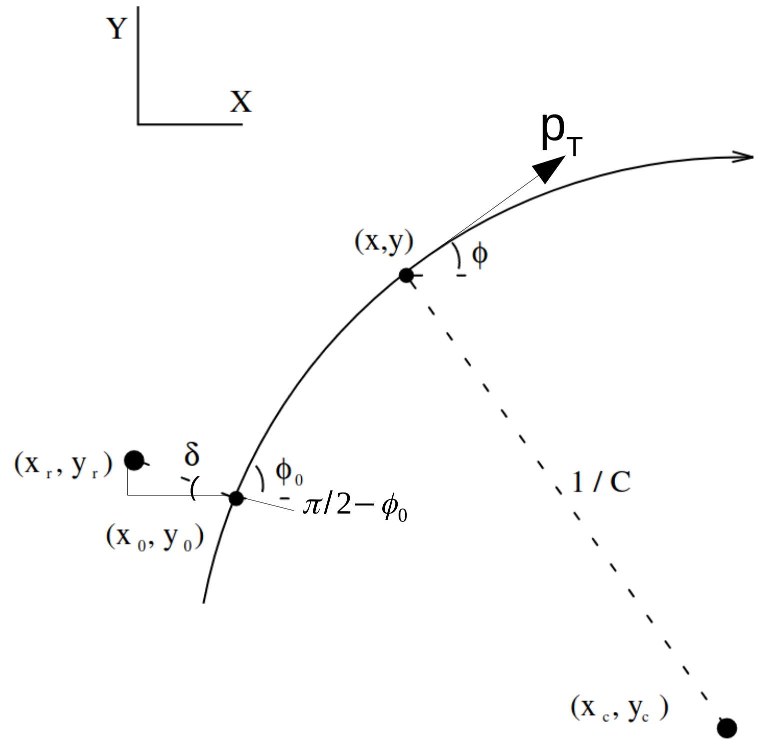


DCA Evaluation

Reference point (primary vertex in our case), DCA point (x_0,y_0) and (x_c,y_c) are not in straight line

Signed DCA = δ

$$\phi_0 = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$



$$\sin\phi_0 = \frac{-(x_0 - x_r)}{\delta}$$

$$\cos\phi_0 = \frac{(y_0 - y_r)}{\delta}$$

$$(x_0 - x_r)\times(-\sin\phi_0) = -\delta\sin\phi_0\times(-\sin\phi_0)$$

$$(y_0 - y_r)\times(\cos\phi_0) = \delta\cos\phi_0\times(\cos\phi_0)$$

$$\delta = -(x_0 - x_r)(\sin\phi_0) + (y_0 - y_r)(\cos\phi_0)$$

(x_r,y_r) = (0,0) Primary Vertex

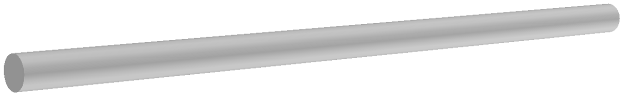
$$\delta = -x_0(\sin\phi_0) + y_0(\cos\phi_0)$$

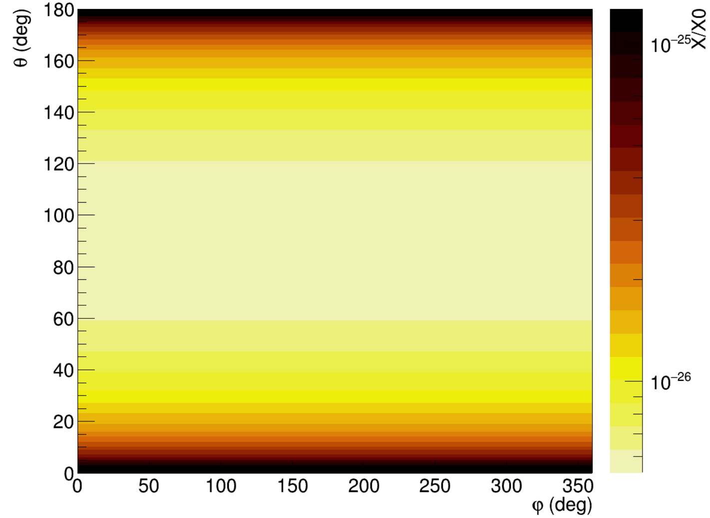
In ALICE local y is rotated by α (=φ_0) w.r.t Global hence local y is simply the DCA_{xy}

$$y_l = -x_g\sin\alpha + y_g\cos\alpha = -x_g\sin\phi_0 + y_g\cos\phi_0$$

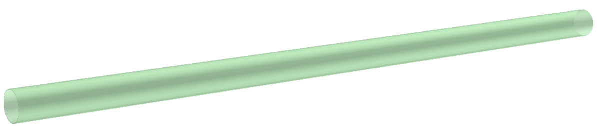
https://desy.de/~fedorch/L3_helix.pdf

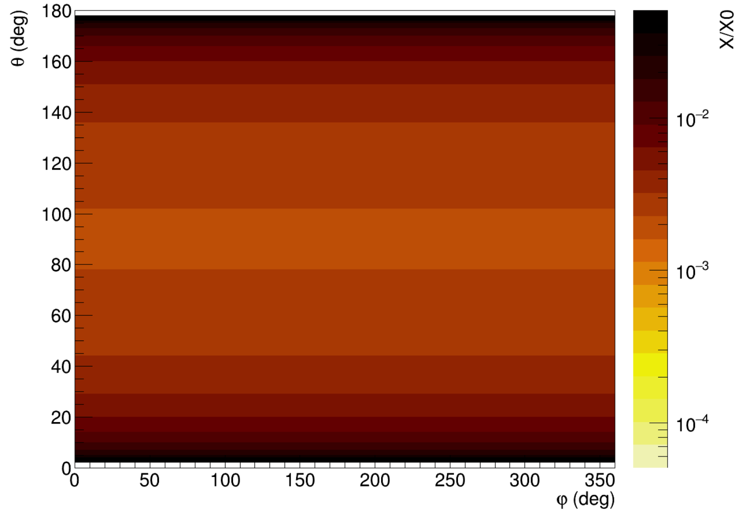
VAC_BE_PIPE0





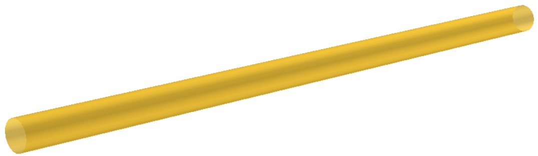
BE_PIPE1

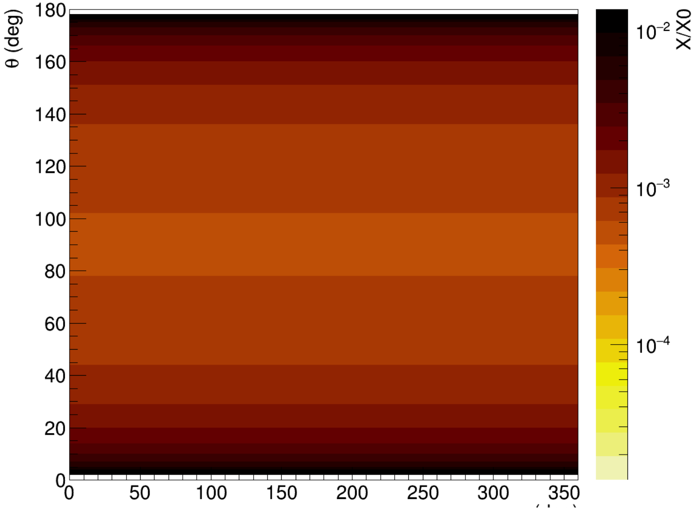




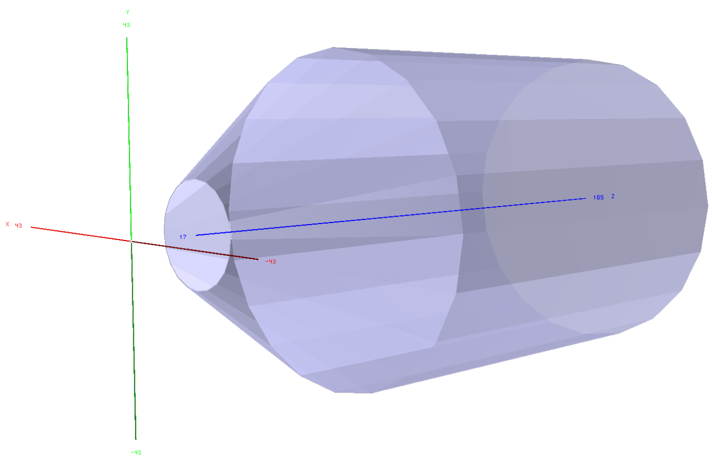
If we see blank plot: check z-position in GeoManager

AU_BE_PIPE2

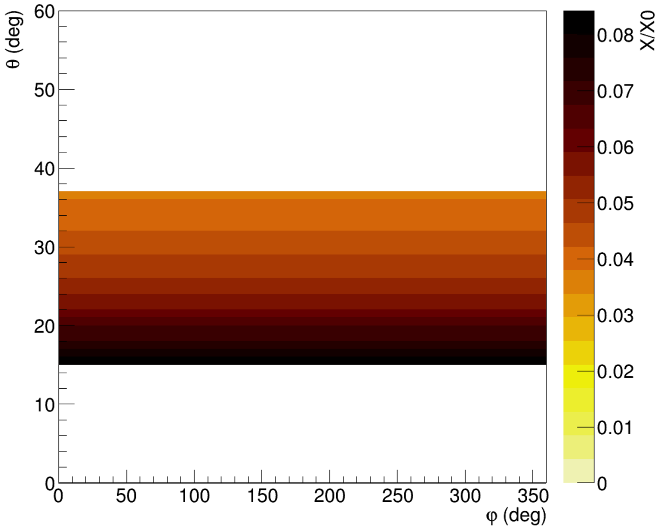




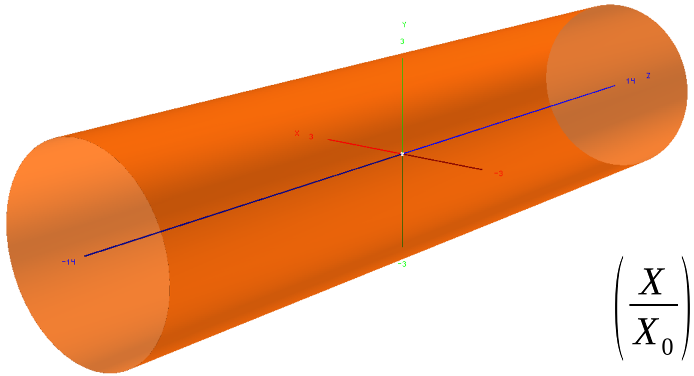
support_pos



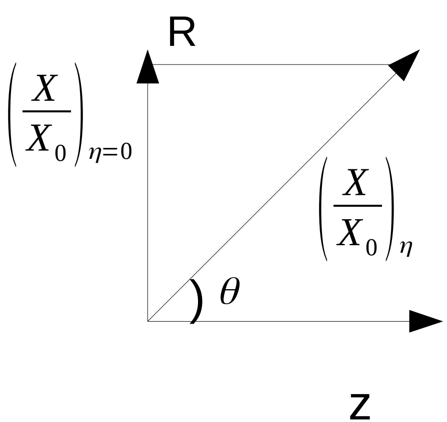
$$\frac{X}{X_0} = \frac{0.2\,cm}{8.87889\,cm} = 0.0225$$

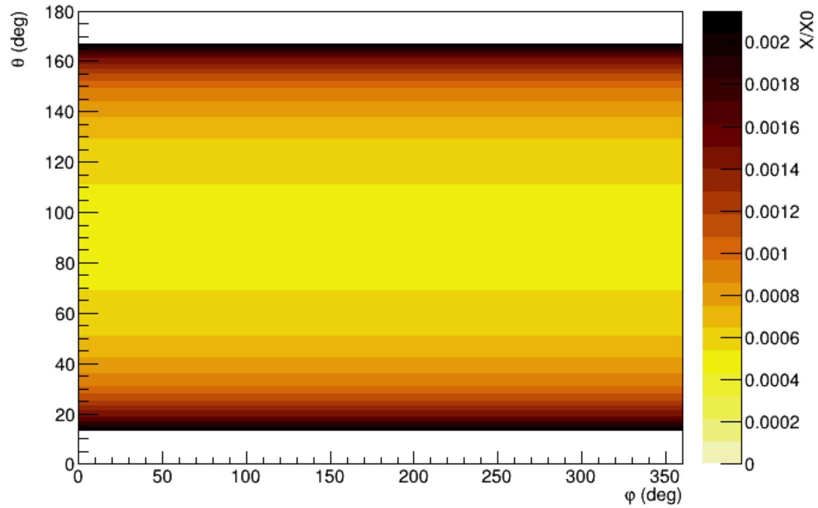


Vertex

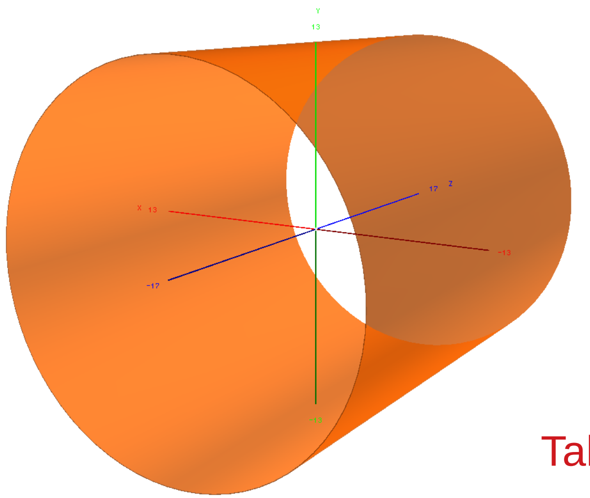


$\eta = 0$



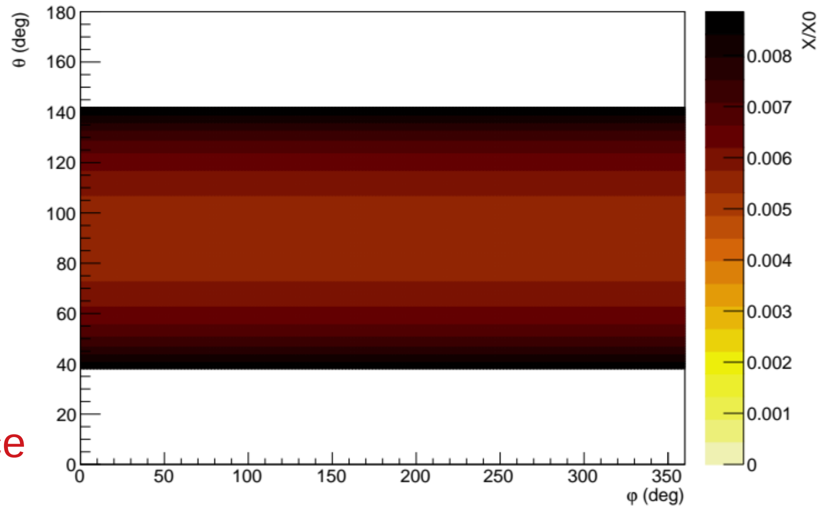


Barrel

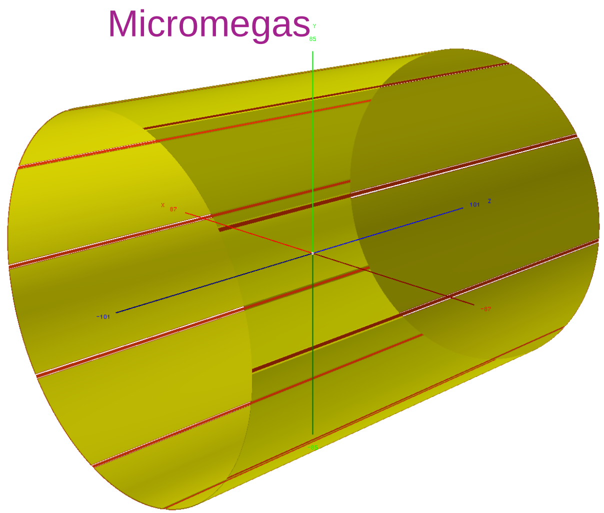


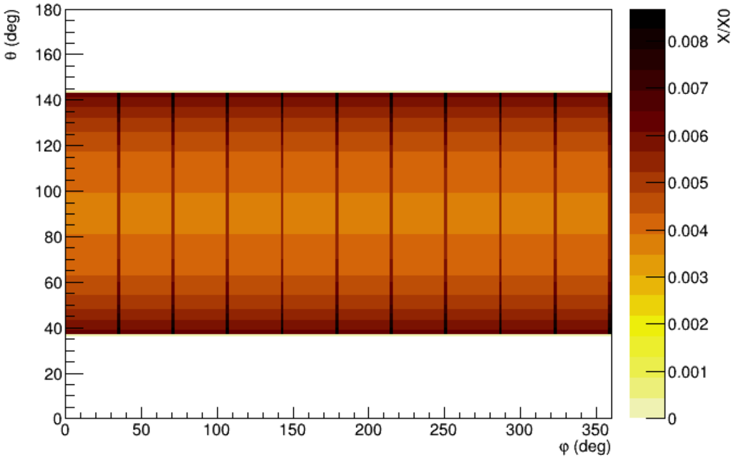
$$\left(\frac{X}{X_0}\right)_{\eta} = \frac{\left(\frac{X}{X_0}\right)_{\eta=0}}{\sin\theta}$$

Taking care of η dependence



Micromegas Material Budget





void DetectorK::SolveViaBilloir(Int_t flagD0,Int_t print, Bool_t allPt, Double_t meanPt, char* detLayer)

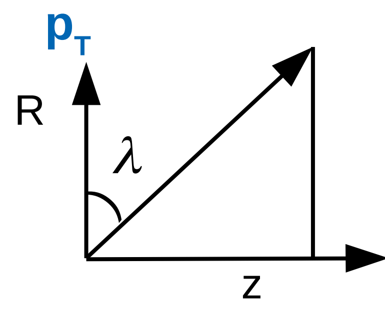
static AliExternalTrackParam probTr; // track to propagate

probTr.Print(); // Print at each propoagation

enum {kY,kZ,kSnp,kTgl,kPtl}; // track parameter aliases (5 because one fixed by position)

enum {kY2,kYZ,kZ2,kYSnp,kZSnp,kSnp2,kYTgl,kZTgl,kSnpTgl,kTgl2,kYPtl,kZPtl,kSnpPtl,kTglPtl,kPtl2}; // cov.matrix

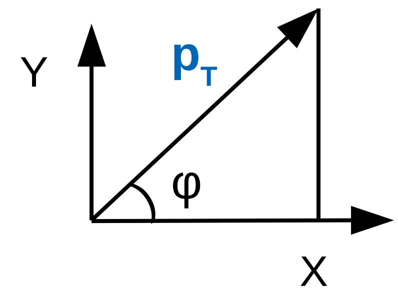
Track Parameters (Local): $\left(y\,, z\,, \sin\phi, \tan\lambda\,, q/p_T\right)$



Local coordinates rotated by alpha with respect to Global coordinates

Covariance matrix = 5X5 matrix; 5(5+1)/2 = 15 independent entries

double *trPars = (double*)probTr.GetParameter(); // Reset to 0
double *trCov = (double*)probTr.GetCovariance(); // Reset to 0



trPars[kY] = 0; // start from Y = 0

trPars[kZ] = 0; // Z = 0

trPars[kSnp] = 0; // track along X axis at the vertex

trPars[kTgl] = tgl; // dip (**for eta dependence**)

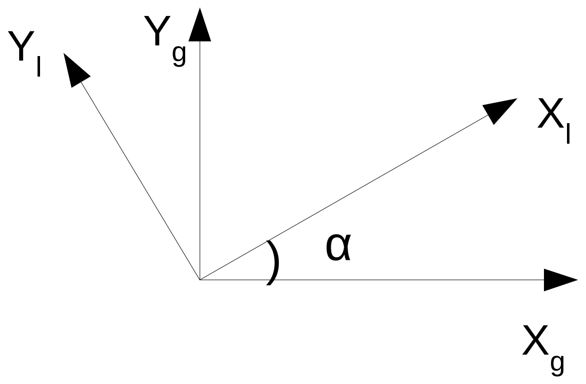
trPars[kPtl] = charge/pt; // q/pt

// put tiny errors to propagate to the some larger than outer radius

trCov[kY2] = trCov[kZ2] = trCov[kSnp2] = trCov[kTgl2] = trCov[kPtl2] = 1e-9;

Global to Local Coordinates (ALICE)

In ALICE: Local coordinate system rotated by α w.r.t Global coordinate system (see figure)



f_x: local x

* external param0: local Y-coordinate of a track (cm) *

* external param1: local Z-coordinate of a track (cm) *

* external param2: local sine of the track momentum azimuthal angle *

* external param3: tangent of the track momentum dip angle *

* external param4: 1/pt (1/(GeV/c))

$$\begin{pmatrix} X_g \\ Y_g \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} X_l \\ Y_l \end{pmatrix}$$

On cylinderical surface:

$$f_x^2 + y^2 = R^2$$

https://twiki.cern.ch/twiki/bin/viewauth/ALICE/AliDPGtoolsTrackProperties

AliExternalTrackParam.cxx lines: 1944-1950

```
Bool_t AliExternalTrackParam::GetXYZ(Double_t *r) const {
// This function returns the global track position
r[0]=fX; r[1]=fP[0]; r[2]=fP[1]; // local coordinates
return Local2GlobalPosition(r,fAlpha);
}
```

AliVParticle.cxx 65-85

```
Bool_t AliVParticle::Local2GlobalPosition(Double_t r[3], Double_t alpha) const {
//This function performs local->global transformation of the track position.
// When called, the arguments are:  r[0] = local x,  r[1] = local y,  r[2] = local z, alpha - rotation angle.
// The result is returned as:  r[0] = global x,  r[1] = global y,  r[2] = global z
Double_t cs=TMath::Cos(alpha), sn=TMath::Sin(alpha), x=r[0];
r[0]=x*cs - r[1]*sn; r[1]=x*sn + r[1]*cs; // From the above matrix
return kTRUE;
}
```

TestDetectorup.C

if (!PropagateToR(&probTr,last->radius + kTrackingMargin,bGauss,1)) continue;

```
 Initial Track Parameters from Verex to  some larger than LastLayer
AliExternalTrackParam: x = 0              alpha = 0
  parameters:           0            0            0            0     -2.82829
  covariance:       1e-09
                        0        1e-09
                        0            0        1e-09
                        0            0            0        1e-09
                        0            0            0            0        1e-09
 Final Track Parameters from Verex to some larger than LastLayer
AliExternalTrackParam: x = 75.2963        alpha = 1.64817
  parameters:     -18.6015           0     0.918308            0     -2.82829
  covariance:  1.45209e-05
                        0  9.40765e-06
              2.42158e-07            0  4.15864e-09
                        0  9.69879e-08            0        1e-09
             -4.93245e-08            0 -1.13892e-09            0        1e-09
 Resetting Large Errors in Covariance Matrix
AliExternalTrackParam: x = 75.2963        alpha = 1.64817
  parameters:     -18.6015           0     0.918308            0     -2.82829
  covariance:          25
                        0           25
                        0            0         0.49
                        0            0            0         0.49
                        0            0            0            0       7441.3
```

Initial Parameter

Parameter at larger than last layer

Reset Large errors on diagonal

TestDetectorup.C

```
======================================================================
 Propagating Parameters to Layer:  MM4
AliExternalTrackParam: x = 12.1296       alpha = 2.81196
  parameters:     -76.5044            0   -0.0151575           0      -2.82829
  covariance:      4.29182
                         0       25.174
                 -0.598681            0            1
                         0    -0.291983            0        0.49
                  -11.8819            0      36.1987           0       7441.3
Update the track by measurement {0.000,0.000000} err {2.250e-04 0.000e+00 2.250e-
04}
 AfterUpdate Measurment
AliExternalTrackParam: x = 77.46         alpha = 1.3984
  parameters:  5.32907e-15            0     0.985177           0      -2.82829
  covariance:   0.00022452
                         0  0.000224998
              -3.43136e-05            0    0.0269812
                         0 -2.60967e-06            0    0.486613
               -0.00396946            0      5.92662           0       7408.48
```

Propagate the track to last layer MM4

Upate measurement with Rphi Resol and Z-resolution

```
 After MS correction
AliExternalTrackParam: x = 77.46         alpha = 1.3984
  parameters:  5.32907e-15            0     0.985177           0      -2.82829
  covariance:   0.00022452
                         0  0.000224998
              -3.43136e-05            0     0.026982
                         0 -2.60967e-06            0    0.486643
               -0.00396946            0      5.92662           0       7408.48
```

MS Correction on Covariance

TestDetectorup.C

Propagate the track to last layer MM3 (Extrapolation)

```
======================================================================
 Propagating Parameters to Layer:  MM3
AliExternalTrackParam: x = 5.05774       alpha = 2.7968
  parameters:     -75.4406            0    -0.209348            0     -2.82829
  covariance:      922.642
                         0       32.9623
                  -30.1911            0            1
                         0     -4.00509            0     0.486643
                  -2540.89            0       85.372            0      7408.48
Update the track by measurement {-0.000,0.000000} err {2.250e-04 0.000e+00 2.250e-
04}
```

Upate measurement with Rphi Resol and Z-resolution

```
 AfterUpdate Measurment
AliExternalTrackParam: x = 75.61         alpha = 1.29295
  parameters: -3.55271e-15            0     0.961647            0     -2.82829
  covariance:  0.000224988
                         0  0.000224998
              -3.08722e-05            0  0.000954481
                         0 -2.73385e-05            0  6.64355e-06
               -0.00926262            0     0.626257            0      411.442
```

MS Correction on Covariance

```
 After MS correction
AliExternalTrackParam: x = 75.61         alpha = 1.29295
  parameters: -3.55271e-15            0     0.961647            0     -2.82829
  covariance:  0.000224988
                         0  0.000224998
              -3.08722e-05            0  0.000955804
                         0 -2.73385e-05            0  2.42271e-05
               -0.00926262            0     0.626257            0      411.442
```

Propagate the track to last layer MM2 (Extrapolation)

```
====================================================================
 Propagating Parameters to Layer:  MM2
AliExternalTrackParam: x = -16.2013      alpha = 2.58589
  parameters:     -46.8477            0    -0.939651            0     -2.82829
  covariance:        10000
                         0    0.0353047
                      -100            0            1
                         0 -0.000922295            0  2.42271e-05
                   -2028.4            0       20.284            0      411.442
Update the track by measurement {0.000,0.000000} err {2.250e-04 0.000e+00 2.250e-
04}
```

Upate measurement with Rphi Resol and Z-resolution

```
 AfterUpdate Measurment
AliExternalTrackParam: x = 49.57         alpha = 0.682142
  parameters:  1.77636e-15            0     0.630457            0     -2.82829
  covariance:     0.000225
                         0  0.000223575
               6.88419e-06            0  9.31123e-07
                        -0 -5.84064e-06            0  2.85811e-07
               0.000139639            0  3.35822e-05            0    0.0012792
```

MS Correction on Covariance

```
 After MS correction
AliExternalTrackParam: x = 49.57         alpha = 0.682142
  parameters:  1.77636e-15            0     0.630457            0     -2.82829
  covariance:     0.000225
                         0  0.000223575

               6.88419e-06            0  4.33051e-06
                        -0 -5.84064e-06            0  5.92773e-06
               0.000139639            0  3.35822e-05            0    0.0012792
```

TestDetectorup.C

```
=====================================================================
 Propagating Parameters to Layer:  MM1
AliExternalTrackParam: x = 36.1238       alpha = 1.36428
  parameters:      -31.1812            0   -0.0598694            0      -2.82829
  covariance:  0.000143443
                         0  0.000283906
           -1.16453e-05            0  9.59208e-06
                        -0 -1.97923e-05            0  5.92773e-06
           -2.53012e-05            0  7.03417e-05            0     0.0012792
Update the track by measurement {0.000,0.000000} err {2.250e-04 0.000e+00 2.250e-
04}
 AfterUpdate Measurment
AliExternalTrackParam: x = 47.72         alpha = 0.652189
  parameters:  7.10543e-15            0     0.606928            0      -2.82829
  covariance:  6.02046e-05
                         0  0.000125522
           -5.14069e-06            0  5.92016e-06
                         0 -8.75068e-06            0  5.15797e-06
            -1.4028e-05            0  5.55674e-05            0    0.00127801
 After MS correction
AliExternalTrackParam: x = 47.72         alpha = 0.652189
  parameters:  7.10543e-15            0     0.606928            0      -2.82829
  covariance:  6.02046e-05
                         0  0.000125522
           -5.14069e-06            0  9.39292e-06
                         0 -8.75068e-06            0   1.0656e-05
            -1.4028e-05            0  5.55674e-05            0    0.00127801
=====================================================================
 Propagating Parameters to Layer:  BARR2
AliExternalTrackParam: x = 8.56122       alpha = 1.30438
  parameters:      -15.7882            0    -0.746948            0      -2.82829
  covariance:    0.0483868
                         0   0.00982786
            -0.00256685            0   0.00014094
                         0 -0.000321659            0   1.0656e-05
            -0.00701983            0  0.000407438            0    0.00127801
Update the track by measurement {0.000,0.000000} err {8.333e-08 0.000e+00 8.333e-
08}
 AfterUpdate Measurment
AliExternalTrackParam: x = 17.96         alpha = 0.230459
  parameters:  8.88178e-16            0     0.228425            0      -2.82829
  covariance:  8.33327e-08
                         0  8.33326e-08
           -1.35793e-08            0  1.02338e-05
                         0 -2.72742e-09            0  1.28396e-07
           -2.53621e-08            0  5.13216e-05            0   0.000259601
 After MS correction
AliExternalTrackParam: x = 17.96         alpha = 0.230459
  parameters:  8.88178e-16            0     0.228425            0      -2.82829
  covariance:  8.33327e-08
                         0  8.33326e-08
           -1.35793e-08            0  1.61476e-05
                         0 -2.72742e-09            0  6.36774e-06
           -2.53621e-08            0  5.13216e-05            0   0.000259601
```

TestDetectorup.C

```
======================================================================
 Propagating Parameters to Layer:   BARR1

AliExternalTrackParam: x = 12.7813       alpha = 0.460918
  parameters:      -3.82008            0     -0.119651           0     -2.82829
  covariance:   0.000429075
                            0  0.000141002
             -9.69794e-05            0  2.19614e-05
                            0 -2.99555e-05            0  6.36774e-06
             -0.000273818            0  6.36978e-05            0  0.000259601
Update the track by measurement {-0.000,0.000000} err {8.333e-08 0.000e+00 8.333e
08}
 AfterUpdate Measurment
AliExternalTrackParam: x = 13.34         alpha = 0.17049
  parameters: -8.88178e-16             0      0.169665           0     -2.82829
  covariance:   8.33157e-08
                            0  8.32841e-08
             -1.95093e-08            0  4.60987e-08
                            0 -1.76935e-08            0  7.52226e-09
             -5.54927e-08            0  1.80916e-06            0  8.48982e-05
 After MS correction
AliExternalTrackParam: x = 13.34         alpha = 0.17049
  parameters: -8.88178e-16             0      0.169665           0     -2.82829
  covariance:   8.33157e-08
                            0  8.32841e-08
             -1.95093e-08            0  6.02551e-06
                            0 -1.76935e-08            0  6.16416e-06
             -5.54927e-08            0  1.80916e-06            0  8.48982e-05
======================================================================
 Propagating Parameters to Layer:  VTX3
AliExternalTrackParam: x = 5.20112       alpha = 0.34098
  parameters:      -1.45203            0     -0.202109           0     -2.82829
  covariance:   0.000407215
                            0  0.000389512
             -5.26038e-05            0  6.90001e-06
                            0 -4.89949e-05            0  6.16416e-06
             -3.87427e-05            0  7.90259e-06            0  8.48982e-05
Update the track by measurement {0.000,0.000000} err {8.333e-08 0.000e+00 8.333e-
08}
 AfterUpdate Measurment
AliExternalTrackParam: x = 5.4           alpha = 0.0687341
  parameters:   2.22045e-16            0       0.06868           0     -2.82829
  covariance:    8.3315e-08
                            0  8.33155e-08
             -1.13826e-08            0  1.10179e-07
                            0 -1.04799e-08            0  2.63541e-09
             -8.22974e-09            0  2.95303e-06            0   8.1213e-05
 After MS correction
AliExternalTrackParam: x = 5.4           alpha = 0.0687341
  parameters:   2.22045e-16            0       0.06868           0     -2.82829
  covariance:    8.3315e-08
                            0  8.33155e-08
             -1.13826e-08            0   5.4207e-07
                            0 -1.04799e-08            0  4.36574e-07
             -8.22974e-09            0  2.95303e-06            0   8.1213e-05
```

TestDetectorup.C

```
====================================================================
 Propagating Parameters to Layer:  VTX2
AliExternalTrackParam: x = 4.33534       alpha = 0.137468
  parameters:    -0.356796           0   -0.0267574           0     -2.82829
  covariance:  7.42595e-07
                         0  5.88435e-07
             -6.32379e-07           0  6.07915e-07

                          0 -4.69714e-07           0  4.36574e-07
             -3.52598e-06           0  3.72835e-06           0   8.1213e-05
Update the track by measurement {0.000,0.000000} err {8.333e-08 0.000e+00 8.333e-
08}
 AfterUpdate Measurment
AliExternalTrackParam: x = 4.35          alpha = 0.0553538
  parameters:  5.55112e-17           0    0.0553256           0     -2.82829
  covariance:  7.48741e-08
                          0  7.29958e-08
             -6.39017e-08           0  1.23769e-07
                          0 -5.82684e-08           0  1.08139e-07
             -3.56718e-07           0  1.02929e-06           0  6.61704e-05
 After MS correction
AliExternalTrackParam: x = 4.35          alpha = 0.0553538
  parameters:  5.55112e-17           0    0.0553256           0     -2.82829
  covariance:  7.48741e-08
                          0  7.29958e-08
             -6.39017e-08           0  5.55981e-07
                          0 -5.82684e-08           0  5.41678e-07
             -3.56718e-07           0  1.02929e-06           0  6.61704e-05
====================================================================
 Propagating Parameters to Layer:  VTX1
AliExternalTrackParam: x = 3.29221       alpha = 0.110708
  parameters:    -0.226611           0   -0.0267376           0     -2.82829
  covariance:  8.41094e-07
                          0  7.93974e-07
             -6.71943e-07           0  5.83092e-07
                          0 -6.27641e-07           0  5.41678e-07
             -1.76851e-06           0  1.65641e-06           0  6.61704e-05
Update the track by measurement {0.000,0.000000} err {8.333e-08 0.000e+00 8.333e-
08}
 AfterUpdate Measurment
AliExternalTrackParam: x = 3.3           alpha = 0.0419834
  parameters:  2.77556e-17           0    0.0419711           0     -2.82829
  covariance:  7.57888e-08
                          0  7.54177e-08
             -6.06585e-08           0  9.47829e-08
                          0 -5.96181e-08           0  9.26527e-08
             -1.59733e-07           0  3.71284e-07           0  6.27886e-05
 After MS correction
AliExternalTrackParam: x = 3.3           alpha = 0.0419834
  parameters:  2.77556e-17           0    0.0419711           0     -2.82829
  covariance:  7.57888e-08
                          0  7.54177e-08
             -6.06585e-08           0  5.27246e-07
                          0 -5.96181e-08           0  5.25879e-07
             -1.59733e-07           0  3.71284e-07           0  6.27886e-05
```

```
=====================================================================
 Propagating Parameters to Layer:  bpipe
AliExternalTrackParam: x = 3.09693          alpha = 0.0839669
  parameters:     -0.137995            0  -0.00509161            0      -2.82829
  covariance:  1.21187e-07
                          0  1.20355e-07
             -1.6689e-07           0  5.29718e-07
                          0 -1.64881e-07           0  5.25879e-07
            -2.45288e-07           0  4.84646e-07            0  6.27886e-05
Update the track by measurement {0.000,0.000000} err {1.000e+12 0.000e+00
1.000e+12}
 AfterUpdate Measurment

 AliExternalTrackParam: x = 3.1          alpha = 0.0394376
   parameters:            0            0    0.0394274            0      -2.82829
   covariance:  1.20947e-07
                          0  1.20355e-07
             -1.66597e-07           0  5.28909e-07
                          0 -1.64881e-07           0  5.25879e-07
             -2.45045e-07           0  4.84276e-07            0  6.27886e-05
  After MS correction
 AliExternalTrackParam: x = 3.1          alpha = 0.0394376
   parameters:            0            0    0.0394274            0      -2.82829
   covariance:  1.20947e-07
                          0  1.20355e-07
             -1.66597e-07           0  2.74515e-06
                          0 -1.64881e-07           0  2.74557e-06
             -2.45045e-07           0  4.84276e-07            0  6.27886e-05
 =====================================================================
  Propagating Parameters to Layer:  vertex
 AliExternalTrackParam: x = 0            alpha = 0.0788753
   parameters:   2.8616e-14            0   -0.0787935            0      -2.82829
   covariance:  2.78013e-05
                          0  2.74857e-05
             -8.82822e-06           0  2.82516e-06
                          0 -8.66953e-06           0  2.74557e-06
              -4.4553e-06           0  2.23388e-06            0  6.27886e-05
  Final Extrapolation to Vertex
 AliExternalTrackParam: x = 0            alpha = 0.0788753
   parameters:   2.8616e-14            0   -0.0787935            0      -2.82829
   covariance:  2.78013e-05
                          0  2.74857e-05
             -8.82822e-06           0  2.82516e-06
                          0 -8.66953e-06           0  2.74557e-06
              -4.4553e-06           0  2.23388e-06            0  6.27886e-05
```

2.78013e-05 → $\sigma^2_{dcaR\phi}$

2.74857e-05 → σ^2_{dcaZ}

$$\frac{\sigma_{1/p_t}}{(1/p_t)} = \frac{1/p_t^2 * \sigma_{pt}}{(1/p_t)} = \frac{\sigma_{pt}}{p_t}$$

$$P = \frac{\sqrt{(1+\tan\lambda^2)}}{(1/p_t)}$$

Momentum Resolution is evaluated by standard error propagation

```
//      deltaPoverP         =  TMath::Sqrt(probTr.GetSigma1Pt2())/probTr.Get1P();  // Absolute magnitude so ignore charge
deltaPoverP          =  TMath::Sqrt(probTr.GetSigma1Pt2())/TMath::Abs(probTr.GetSigned1Pt());
fMomentumRes[i]      =  100.* TMath::Abs( deltaPoverP );               // results in percent
fResolutionRPhi[i]   =  TMath::Sqrt( probTr.GetSigmaY2() ) * 1.e4;     // result in microns
fResolutionZ[i]      =  TMath::Sqrt( probTr.GetSigmaZ2() ) * 1.e4;     // result in microns
//      equivalent[i]  =  TMath::Sqrt(fResolutionRPhi[i]*fResolutionZ[i])          ;  // Equivalent circular radius
```

σ_{pT}/p_T — deltaPoverP / fMomentumRes

$\sigma_{dcaR\phi}$ — fResolutionRPhi

σ_{dcaZ} — fResolutionZ

Geometry Details (B-2.0)

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

Barrel Tracker (B-2.0, numbers from ATHENA Canyonlands_v1.2 Tag)

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)

Forward Trackers (P-2.0, Numbers from ATHENA Canyonlands_v1.2 Tag)

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 Tracker (N-2.0)

Backward Trackers (N-2.0, Numbers from ATHENA Canyonlands_v1.2 Tag)

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