Lancaster University

Momentum resolution investigation using LDT tool

Lizi Hutchinson
Yubin Zhong
Harald Fox

Introduction

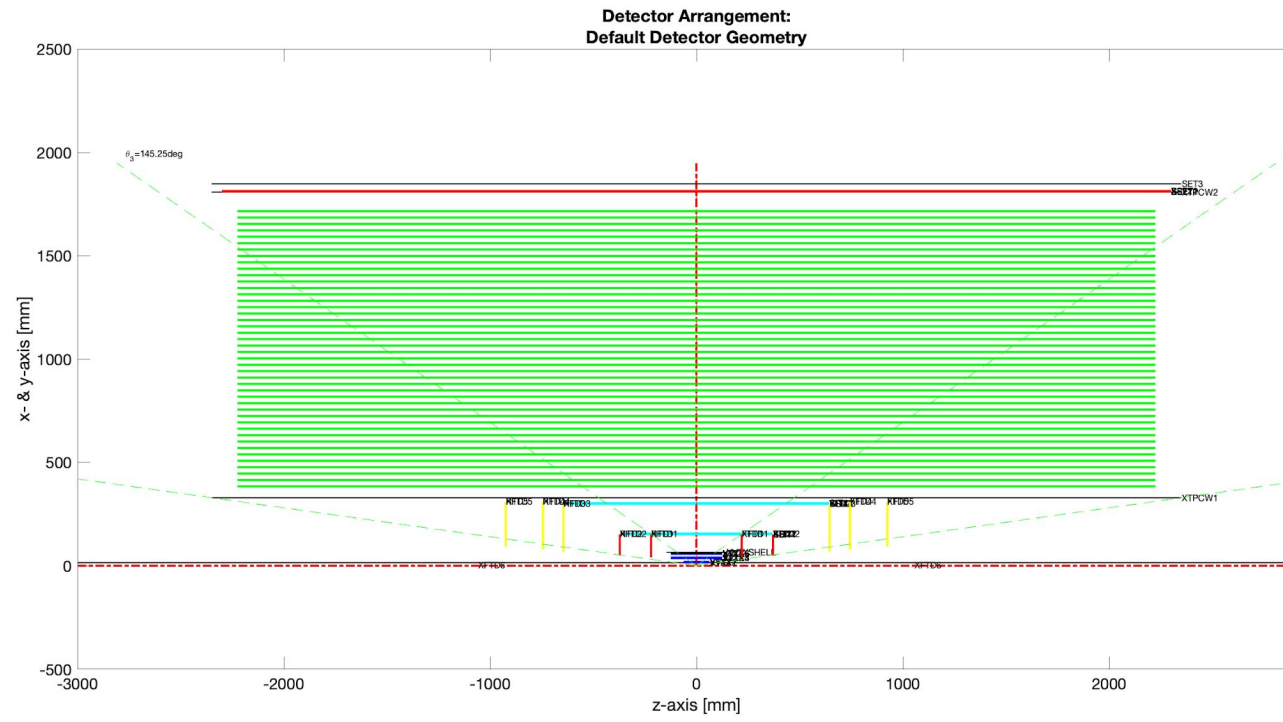
Default Geometry:

VTX: thickness of layers = 0.151% X0, pixel size varies from 2.8, 4, 6 (corresponds to 9.7, 13.9, 20.9), 6 active layers, efficiency 0.99

SIT: thickness of layers = 0.681% X0, pixel size of 7x86 (25x300), 4 active layers

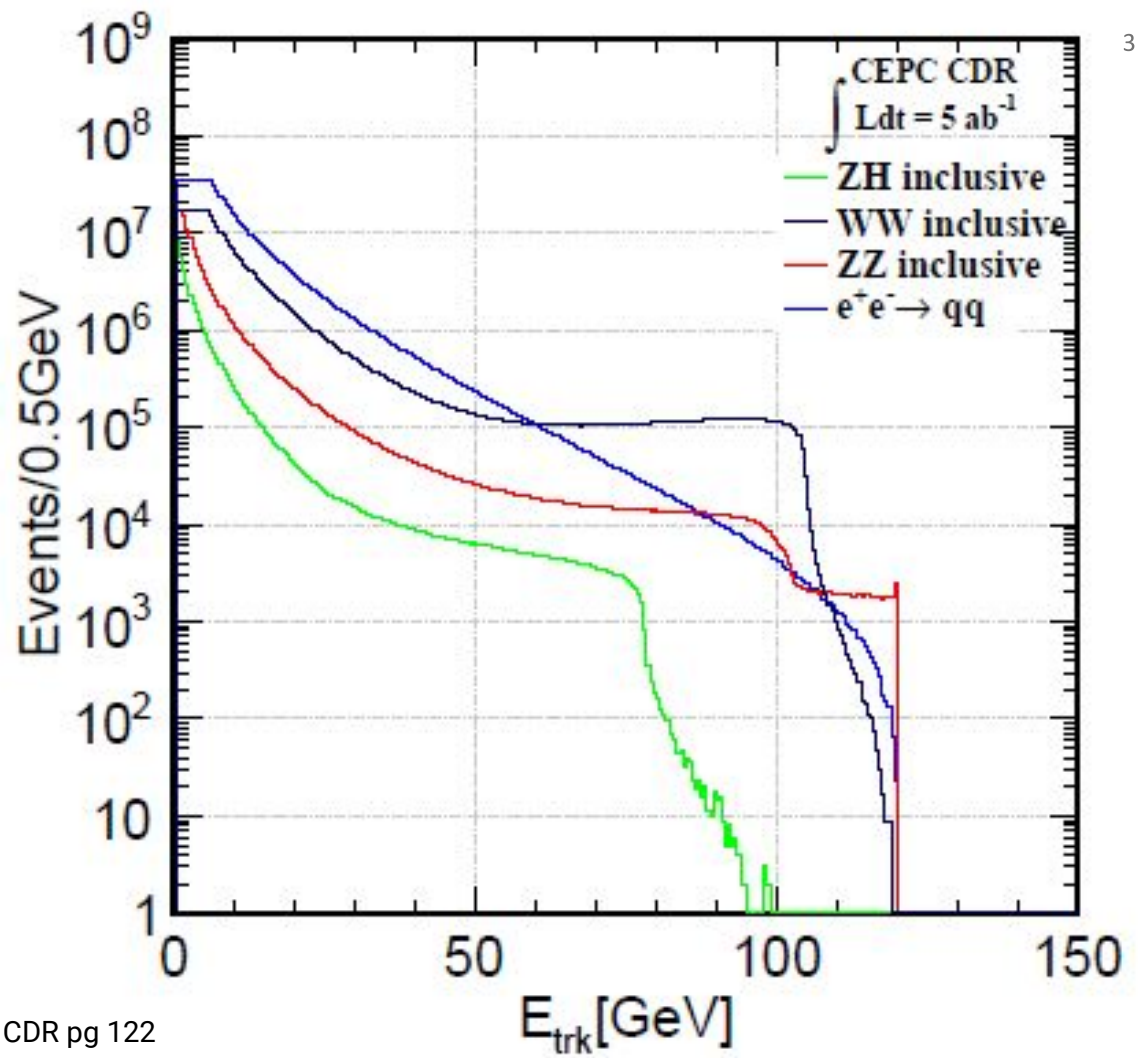
SET: thickness of layers = 0.681% X0, pixel size of 25x25, 2 active layers

Full file in backup



What is the muon momentum range we should be looking at?

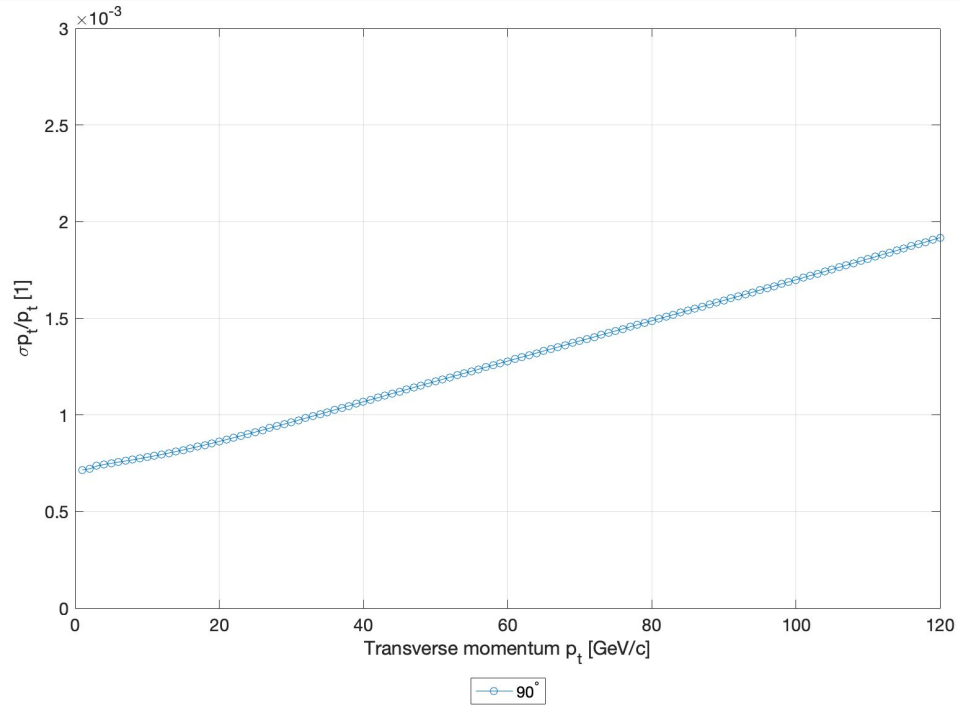
Graph seems to cut off at 120 GeV for all but ZH, which seems to cut off at ~100 GeV.



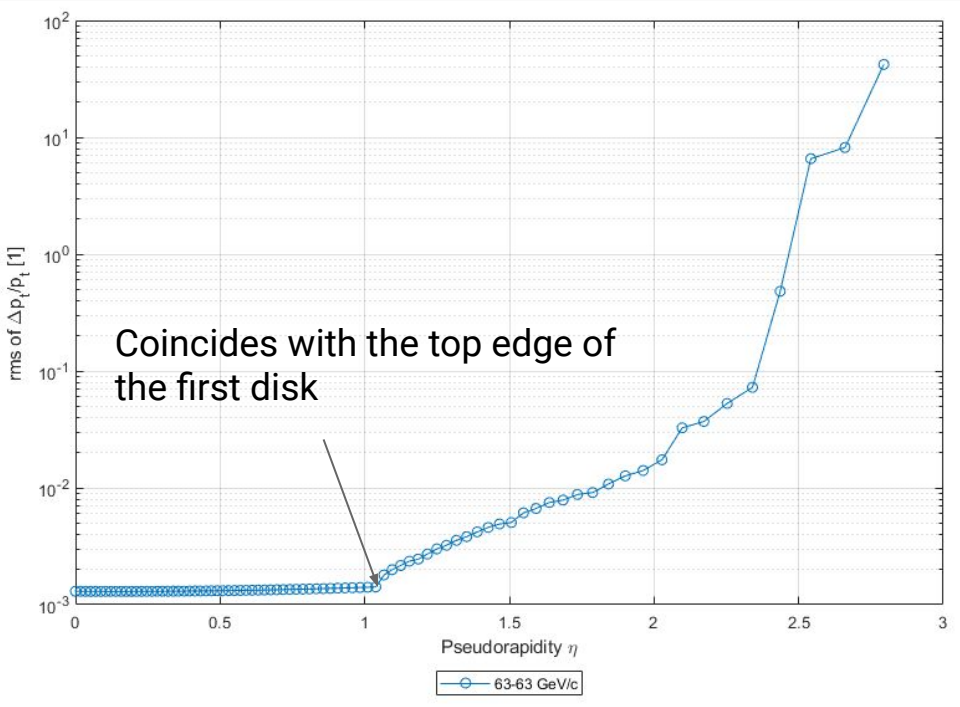
CDR pg 122

Lancaster University

Momentum dependence of the resolution for 90 degrees:



Incident angle dependence on the resolution:

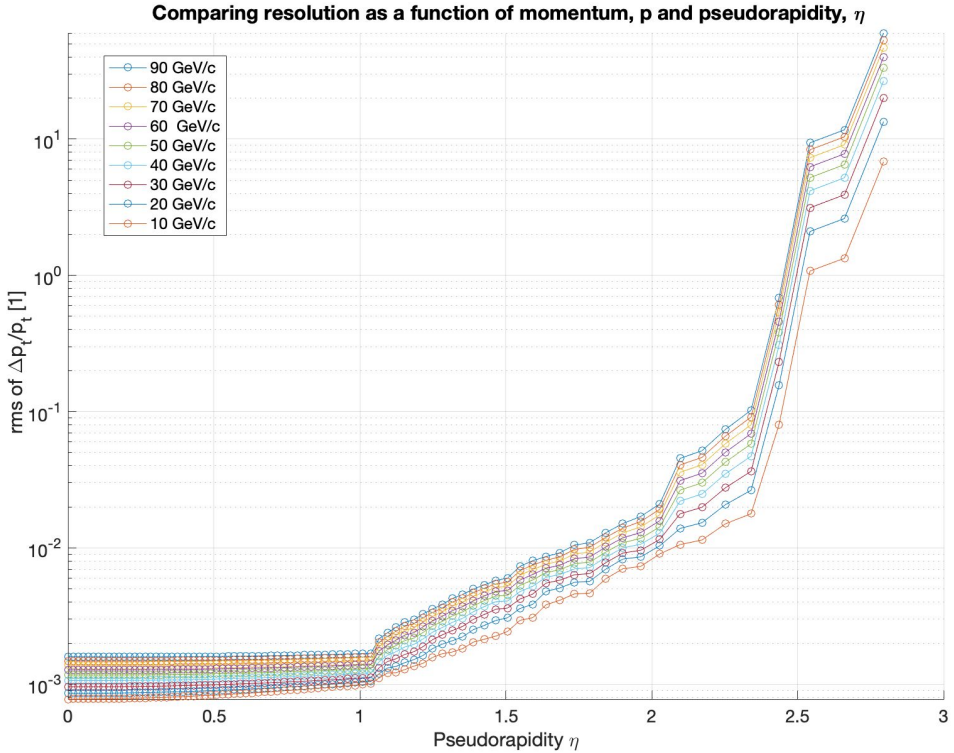


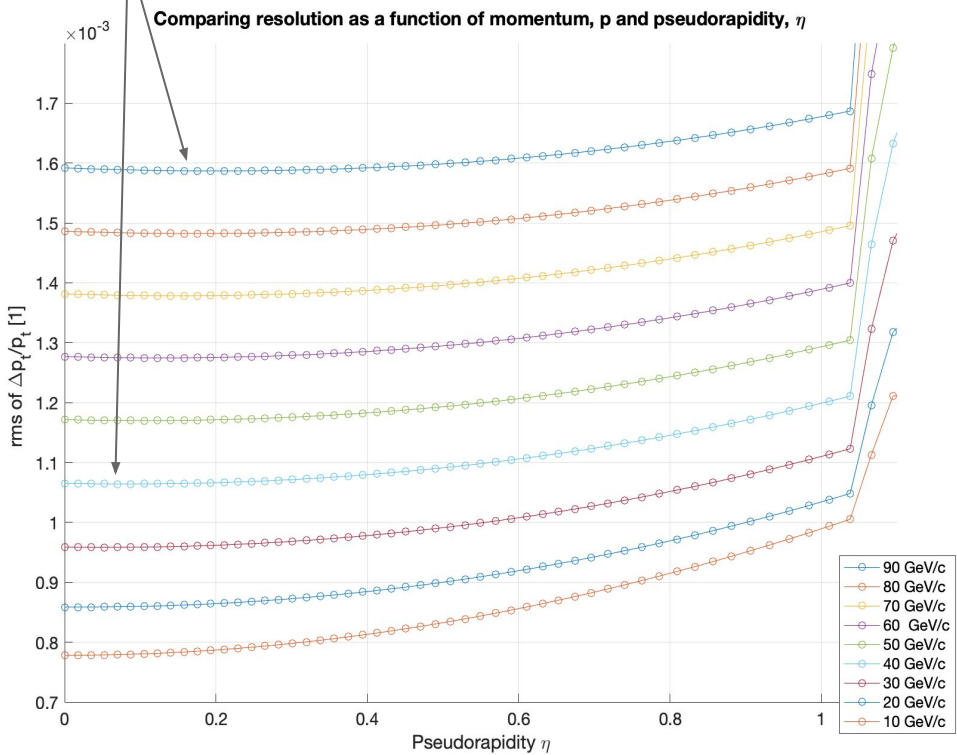
Combination of both angle and pT (no changes to detector)

Lancaster University

Can see that the higher the momentum, the higher (and worse) the resolution becomes in the high eta (low theta) range.

Minimum point of curve shifts depending on momentum.

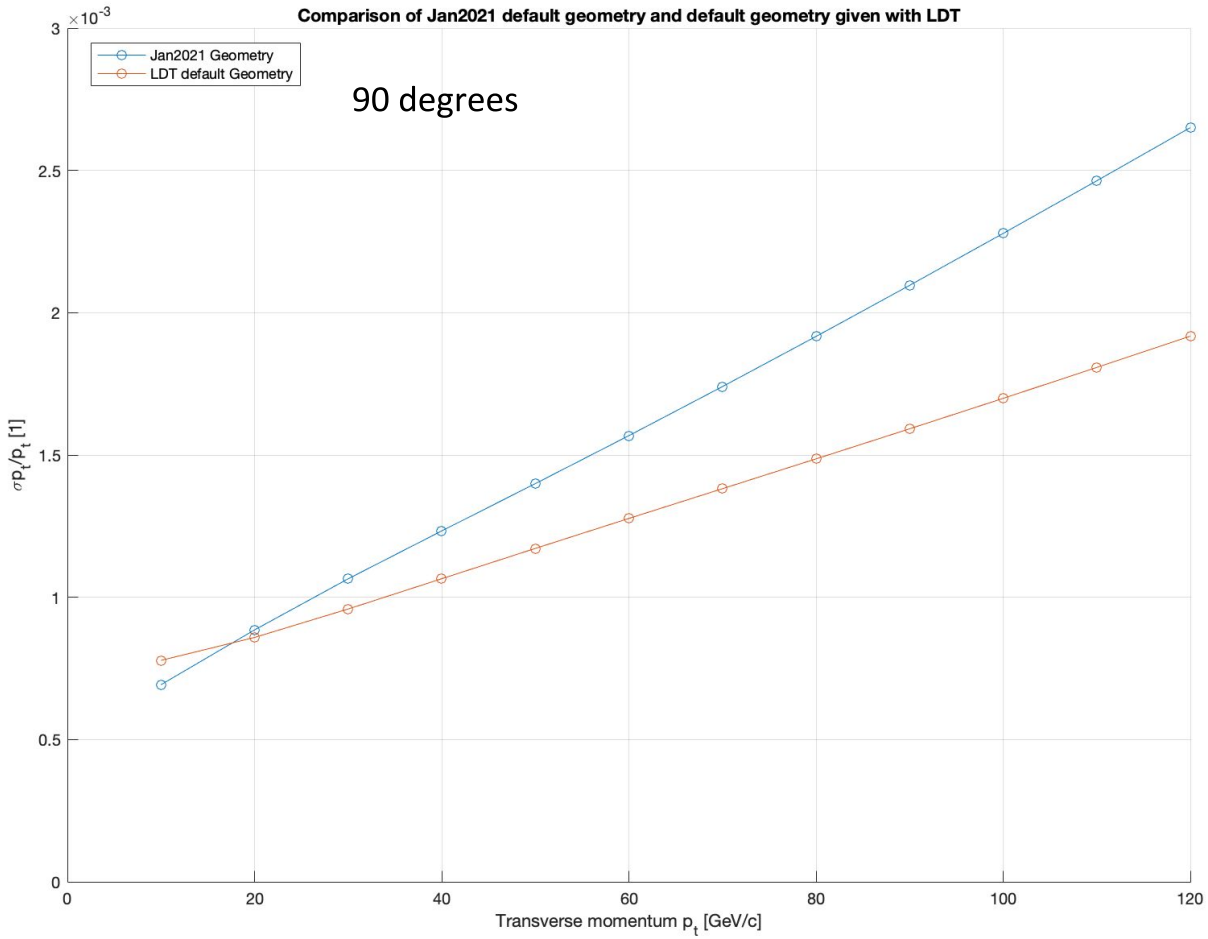




Geometry file comparison

VTX detector, σ_{xy} and σ_{z}, TPC identical.

My file has more active layers (4 in mine, 3 in standard for SIT; 2 in mine, 1 in standard for SET).



- What is the effect of the pixel size in the inner tracker layers on the resolution?
- What is the effect of the radiation length in the inner tracker layers (i.e., how does the resolution change with X0)?

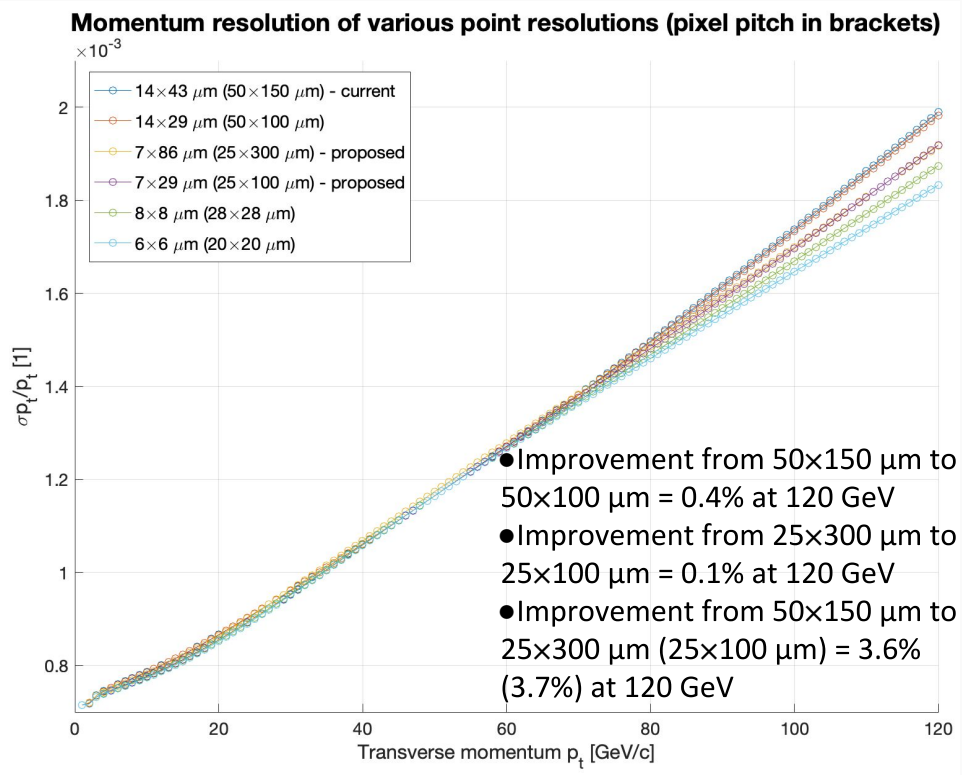
24 Number of layers	:	9							
25 Description (optional)	:	|----------Inner tracker----------							|TPC inner wall|
26 Names of the layers (opt.)	:	SIT1,	XSIT1,	XSIT2,	SIT2,	SIT3,	XSIT3,	XSIT4,	SIT4,	XTPCW1
27 Radii [mm]	:	152.9,	153.1,	154.4,	155.4,	299.9,	300.1,	301.4,	302.4,	329
28 Upper limit in z [mm]	:	368,	368,	368,	368,	644,	644,	644,	644,	2350
29 Lower limit in z [mm]	:	-368,	-368,	-368,	-368,	-644,	-644,	-644,	-644,	-2350
30 Efficiency RPhi	:	0.99,	0,	0,	0.99,	0.99,	0,	0,	0.99,	0
31 Efficiency 2nd coord. (eg. z)	:	0.99,	0,	0,	0.99,	0.99,	0,	0,	0.99,	0
32 Stereo angle alpha [Rad]	:	0,	0,	0,	0,	0,	0,	0,	0,	0
33 Thickness [rad. lengths]	:	0.00213,	0.00468,	0.00468,	0.00213,	0.00213,	0.00468,	0.00468,	0.00213,	0.0051
34 error distribution	:	0								
35 0 normal-sigma(RPhi) [1e-6m]	:	7								
36 sigma(z) [1e-6m]	:	86								
37 1 uniform-d(RPhi) [1e-6m]	:									
38 d(z) [1e-6m]	:									
39										

Point resolution = pixel pitch / √12

Investigating pixel size/material budget in SIT

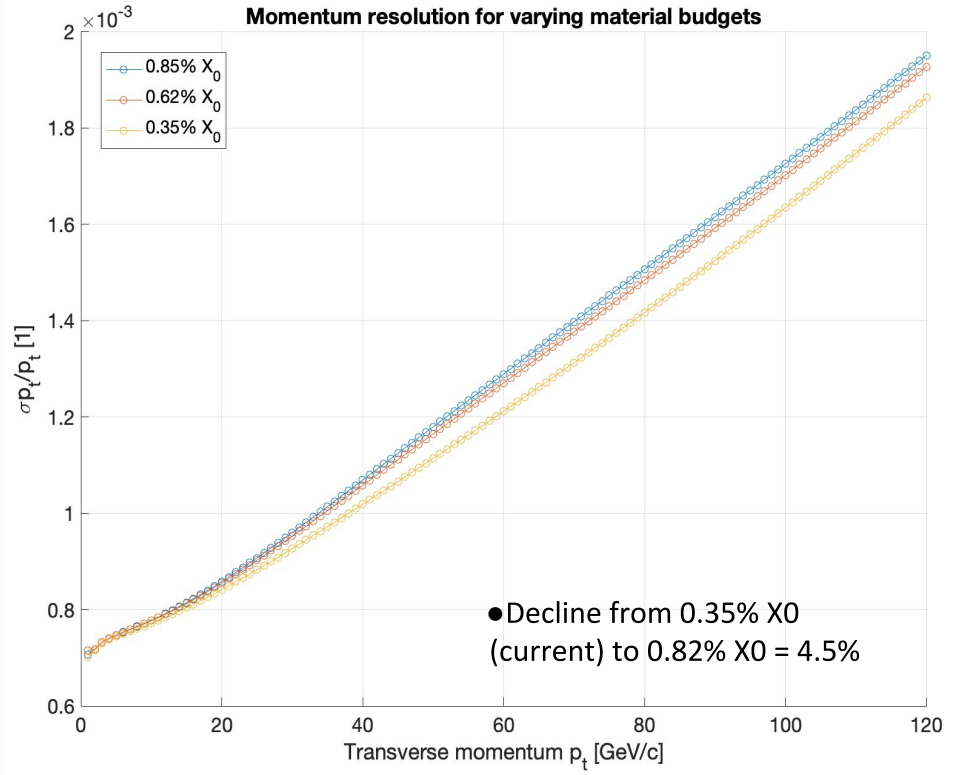
Lancaster University

What is the effect of the pixel size in the inner tracker layers (SIT) on the resolution?



- Improvement from 50×150 µm to 50×100 µm = 0.4% at 120 GeV
- Improvement from 25×300 µm to 25×100 µm = 0.1% at 120 GeV
- Improvement from 50×150 µm to 25×300 µm (25×100 µm) = 3.6% (3.7%) at 120 GeV

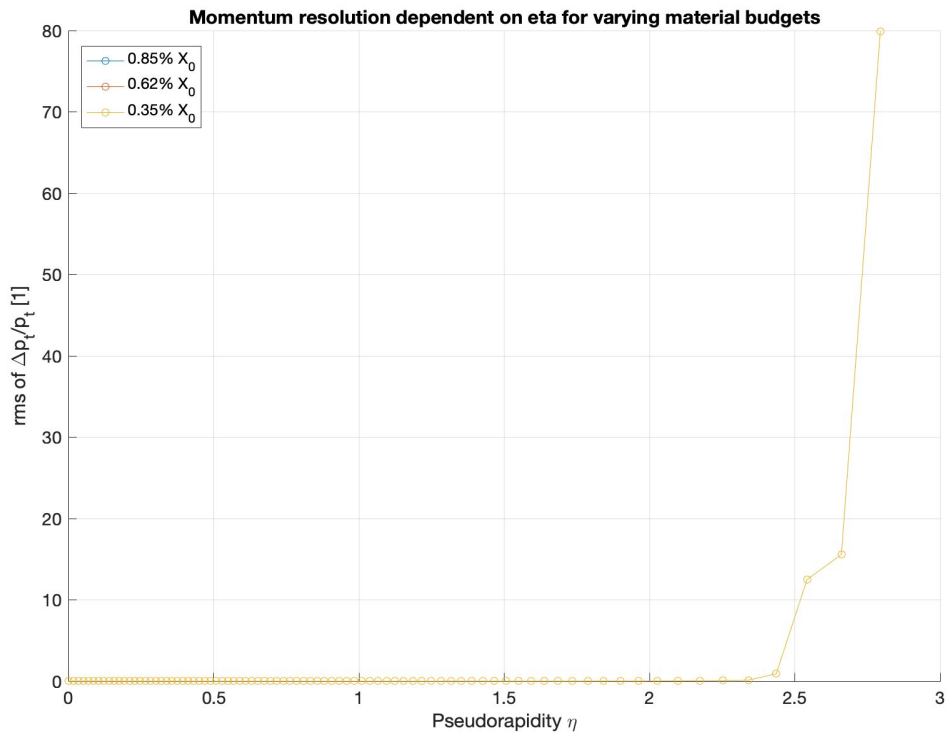
What is the effect of the material budget in the inner tracker layers (SIT) on the resolution?

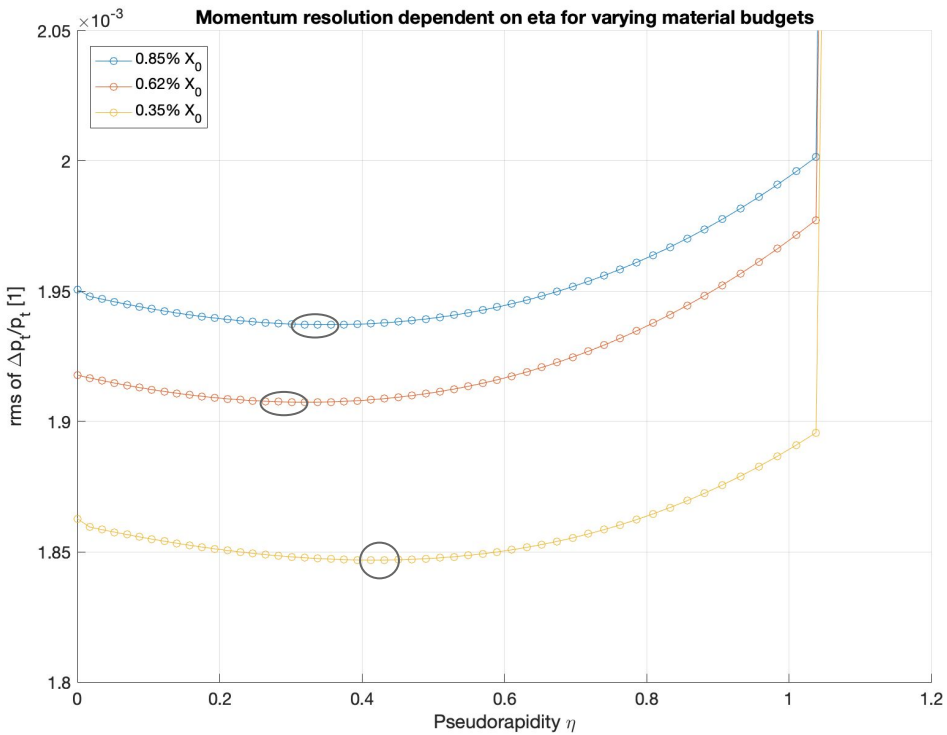


- Decline from 0.35% X0 (current) to 0.82% X0 = 4.5%

Angle and X0 (SIT)

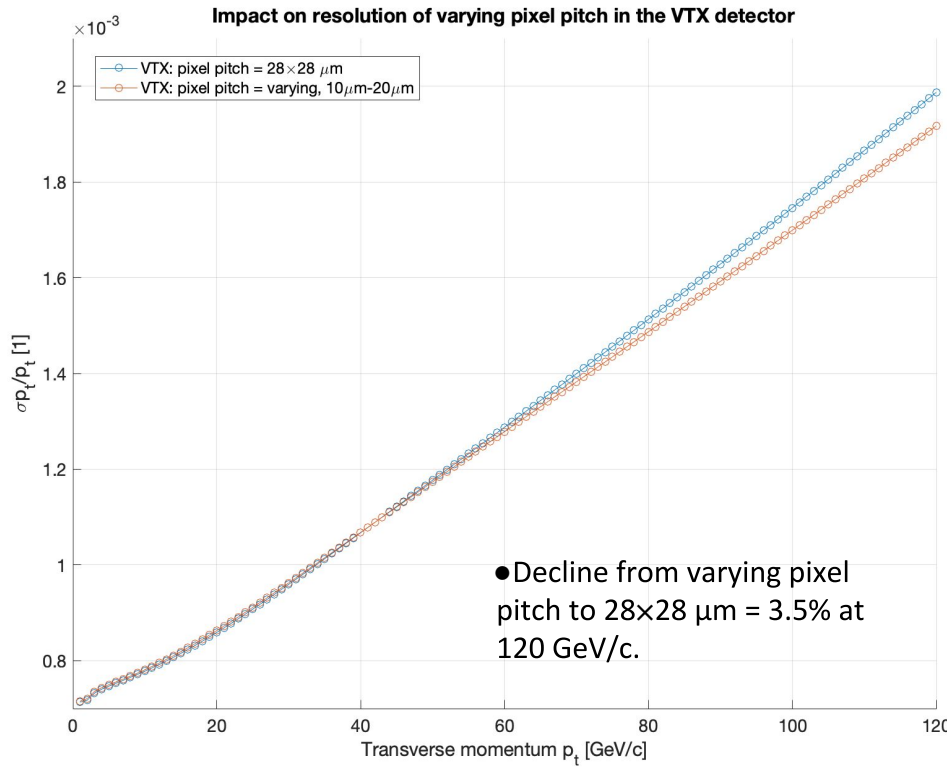
X0 (%)	eta	sigma
0.85%	0.36	0.001937
0.62%	0.32	0.001907
0.35%	0.41	0.001847





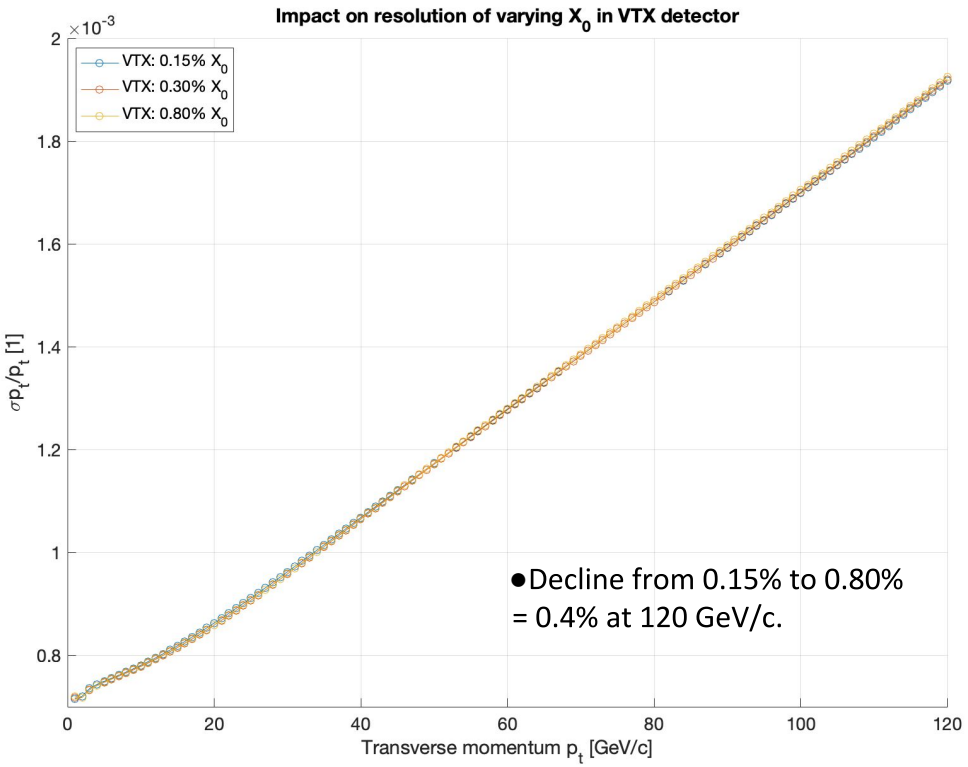
VTX detector parameters and resolution

Varying pixel pitch



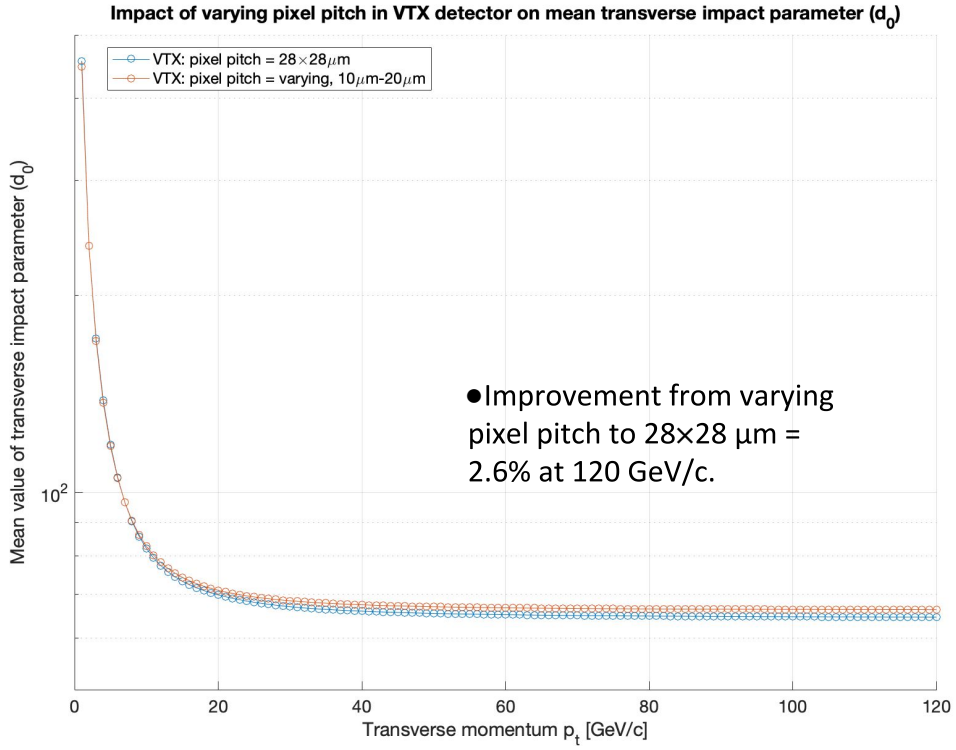
- Decline from varying pixel pitch to 28×28 µm = 3.5% at 120 GeV/c.

Varying layer thickness

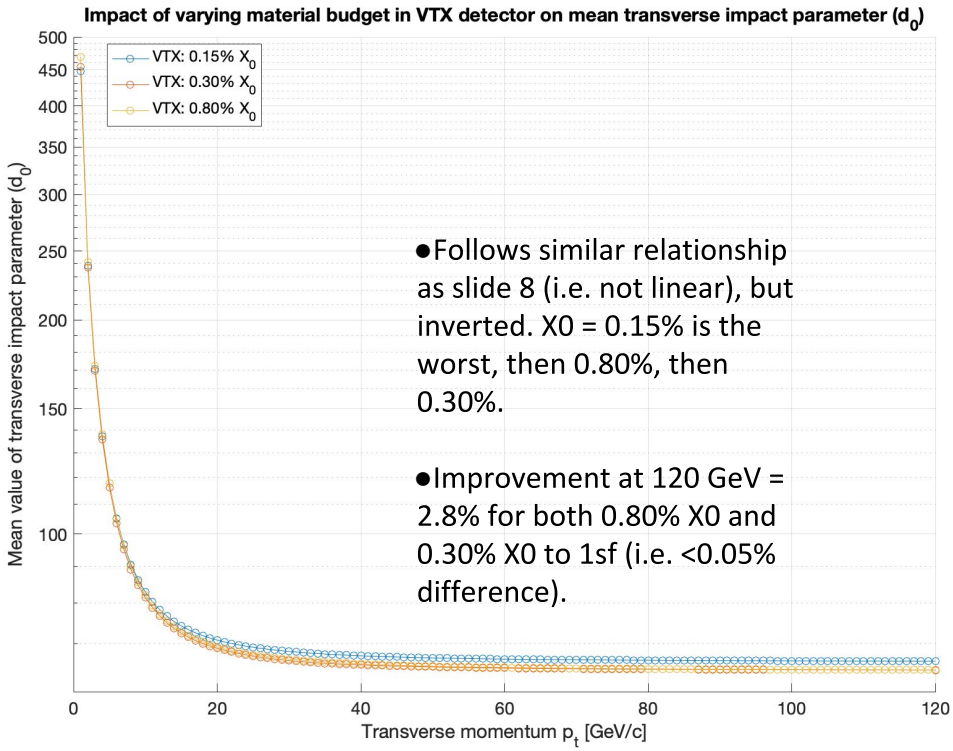


- Decline from 0.15% to 0.80% = 0.4% at 120 GeV/c.

VTX detector parameters and d_0

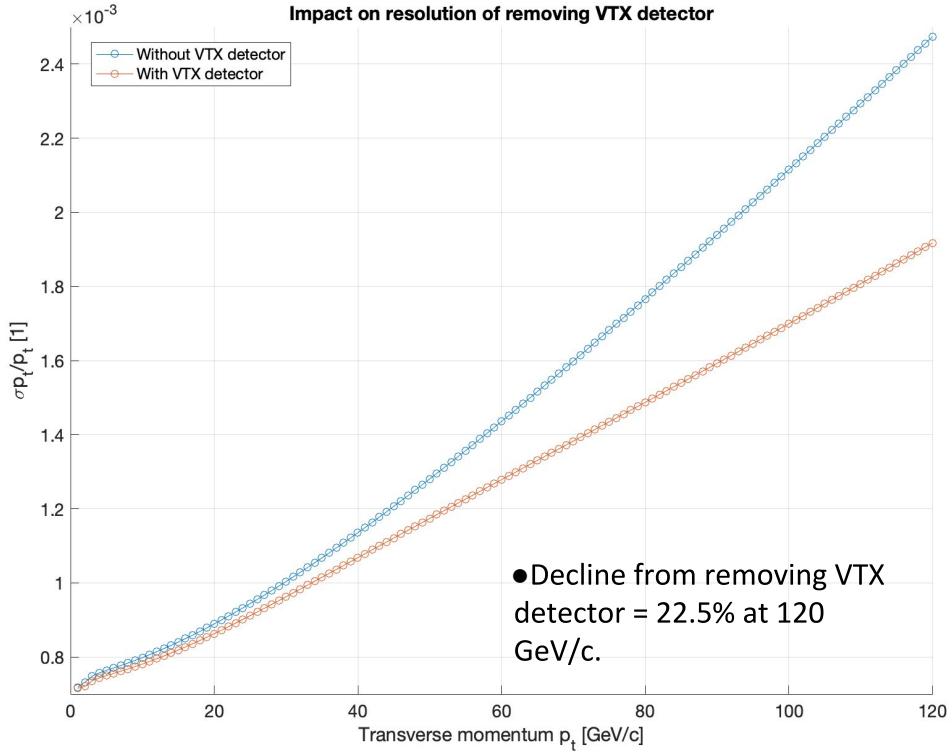


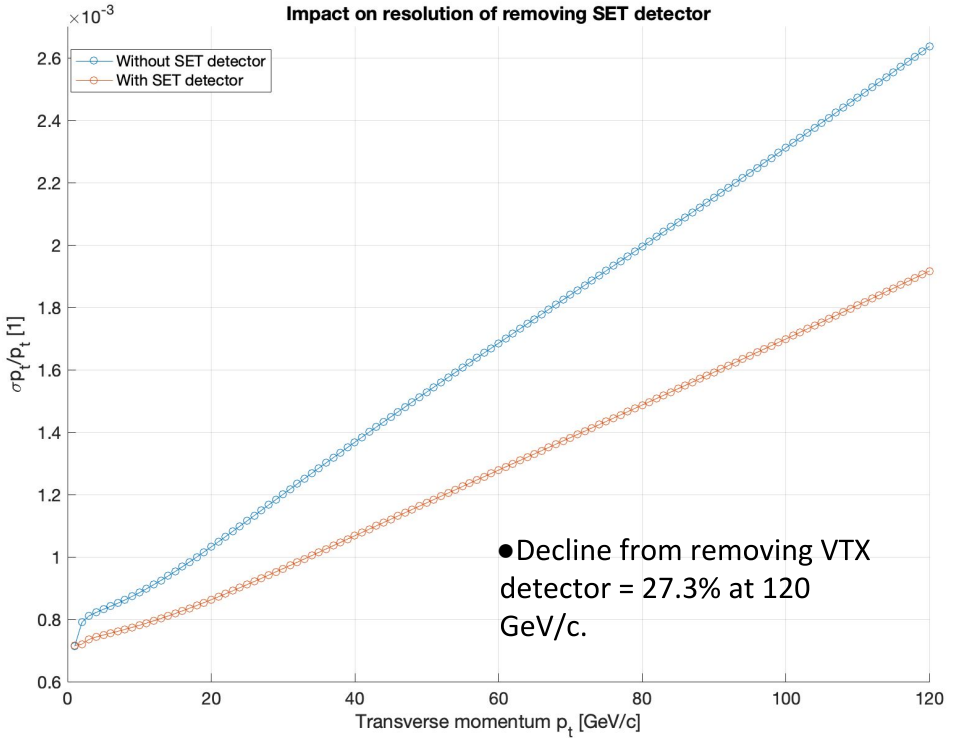
- Improvement from varying pixel pitch to 28×28 μm = 2.6% at 120 GeV/c.



- Follows similar relationship as slide 8 (i.e. not linear), but inverted. X0 = 0.15% is the worst, then 0.80%, then 0.30%.
- Improvement at 120 GeV = 2.8% for both 0.80% X0 and 0.30% X0 to 1sf (i.e. <0.05% difference).

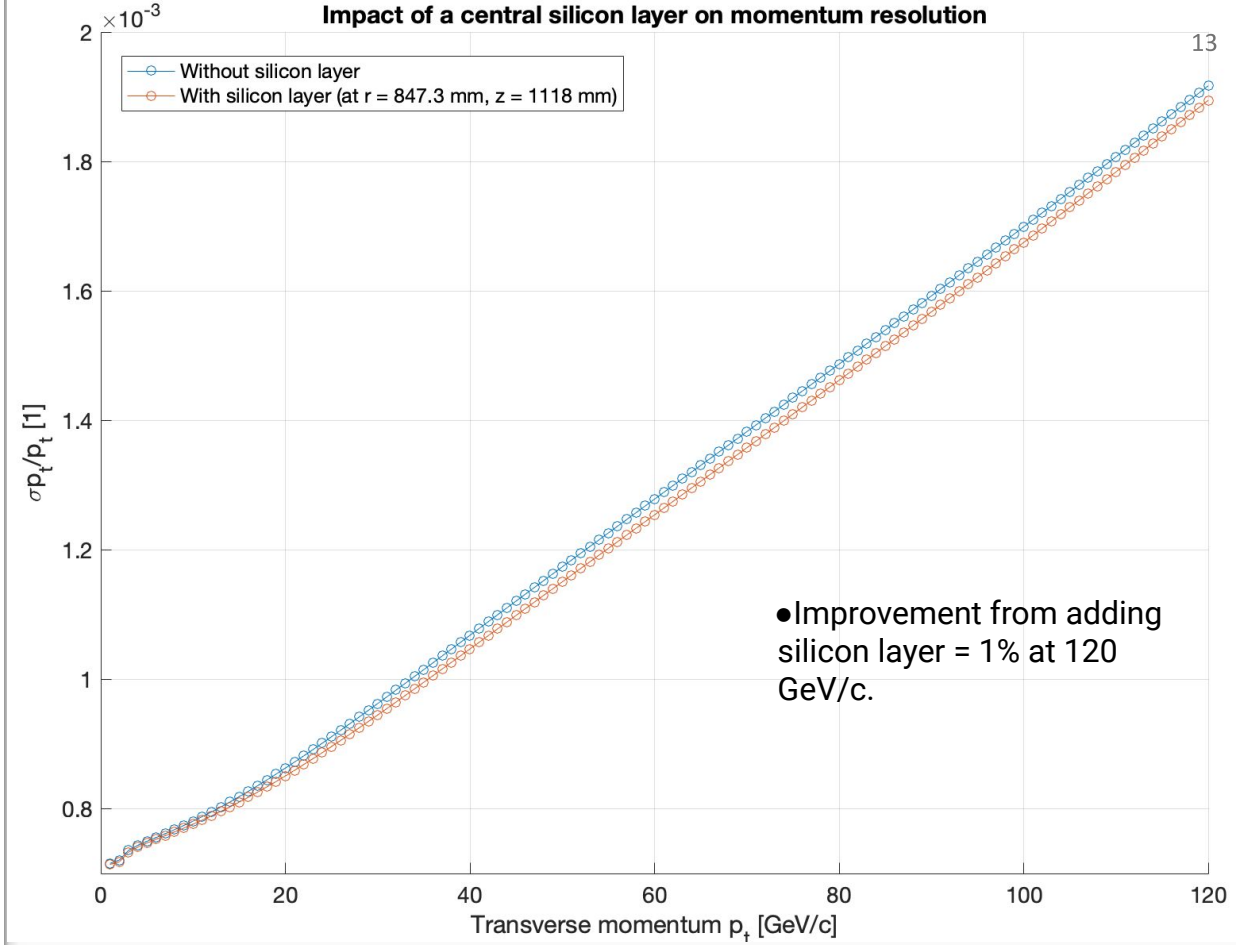
What is the impact of totally removing the VTX detector, or the SET detector?

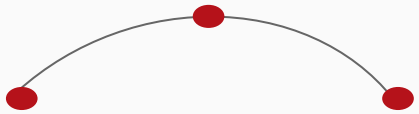




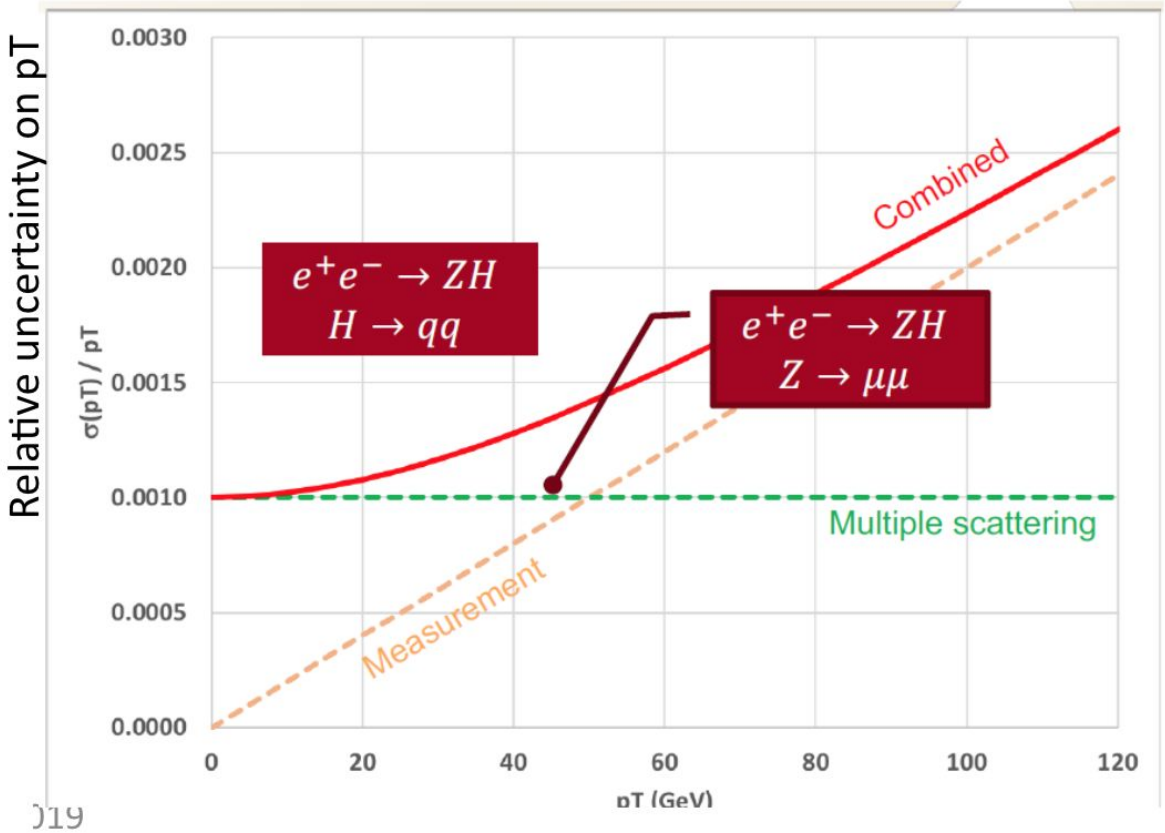
Would we gain anything by having a silicon layer in the middle of the first and last active layers?

Involves a silicon layer in TPC, not ideal, unless FST (Full Silicon Tracker) implemented.





Does our data fit the equation in the CDR?



Multiple scattering

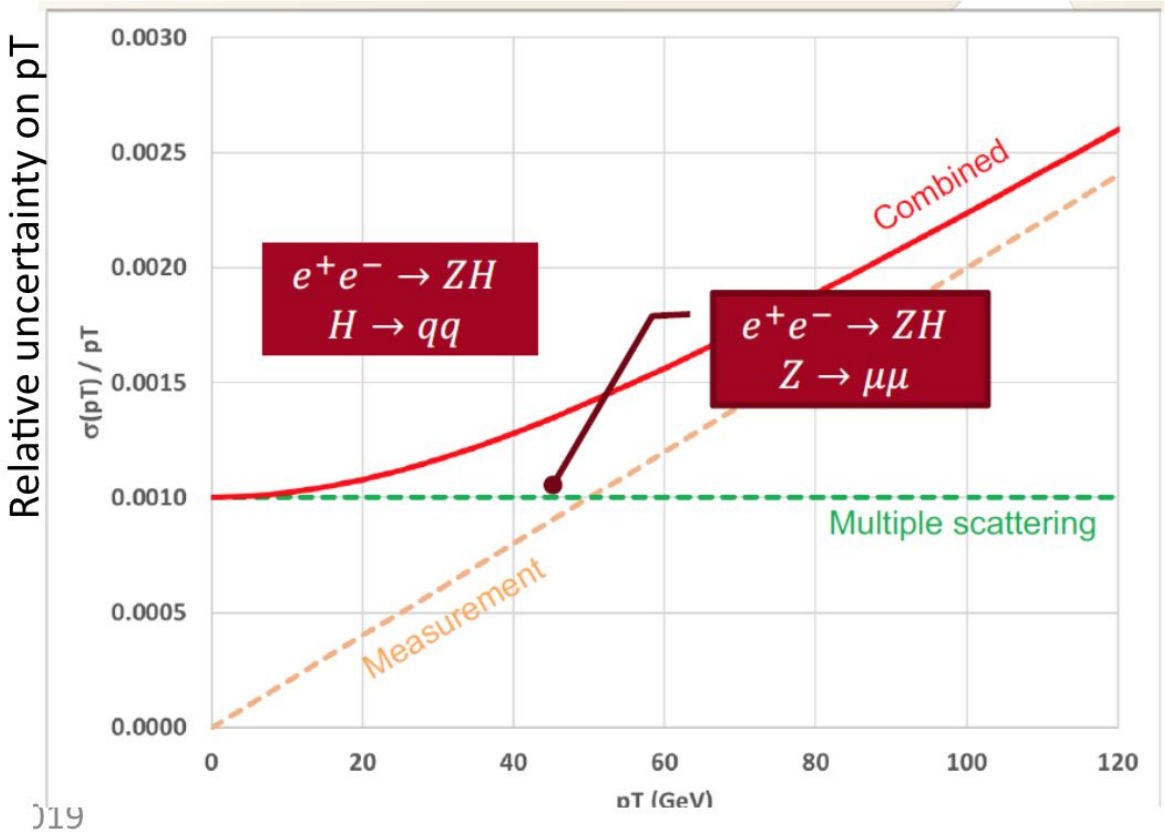
$$\sigma_{1/p_T} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

Intrinsic detector resolution

Impact parameter resolution driven by separating b, c, τ

FCCDay_TrackVertexDet_20200911.pdf

Does our data fit the equation in the CDR?



Multiple scattering

$$\sigma(p_T)/p_T = a\ p_T \oplus \frac{b}{\sin^{3/2}\theta}$$

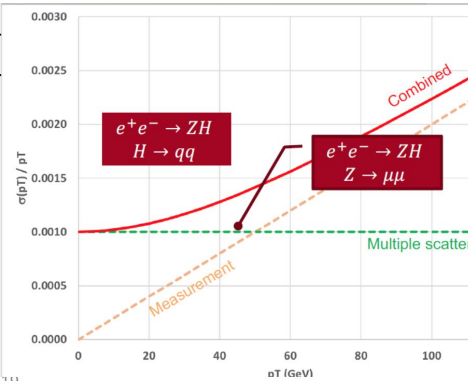
Intrinsic detector resolution

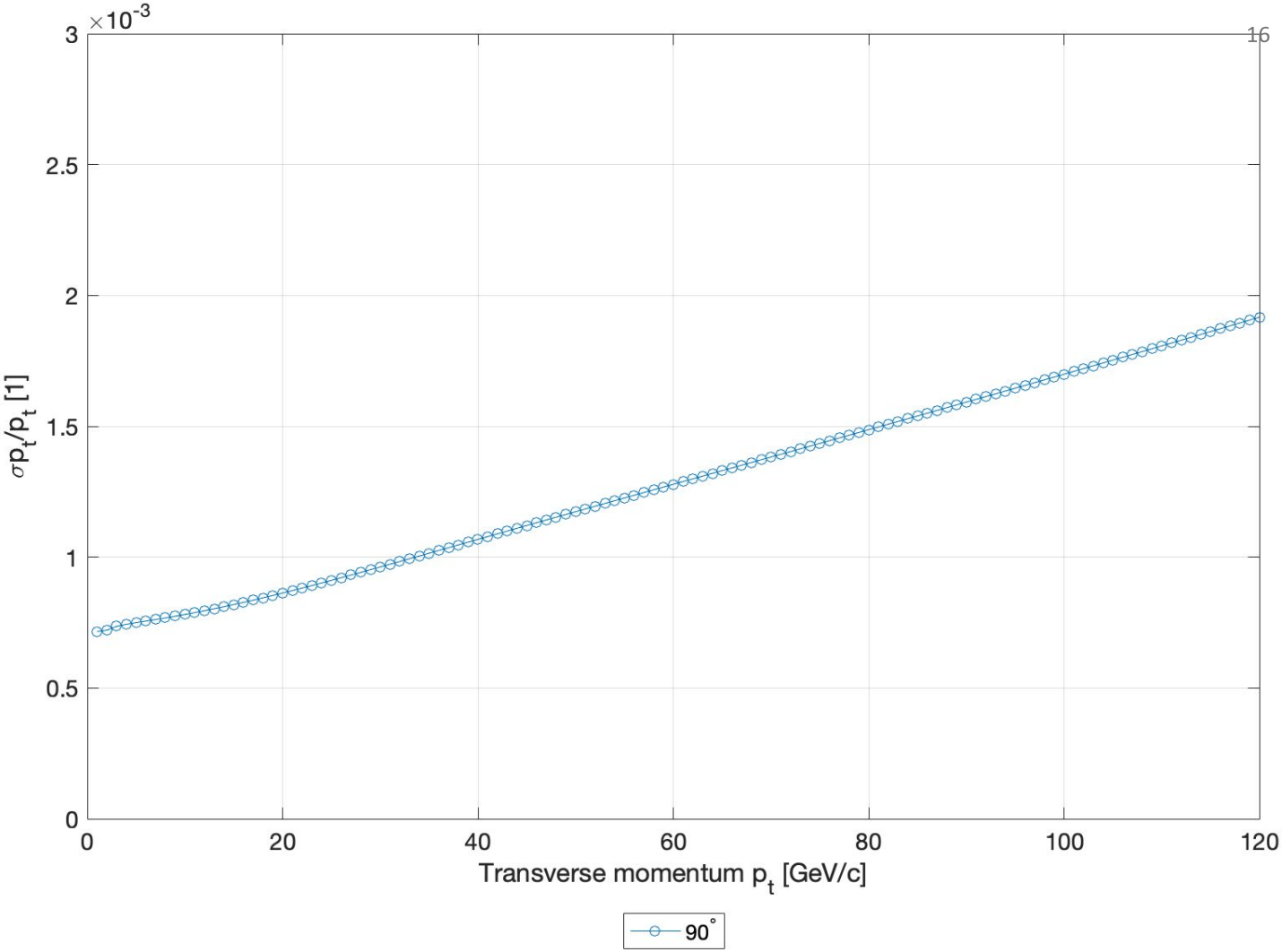
(corrected formula)

Impact parameter resolution driven by separating b, c, τ

FCCDay_TrackVertexDet_20200911.pdf

Good thing: our data for σpT/pT looks like this (see right and below).
Bad thing: The equation given in Young slide does not follow this pattern.

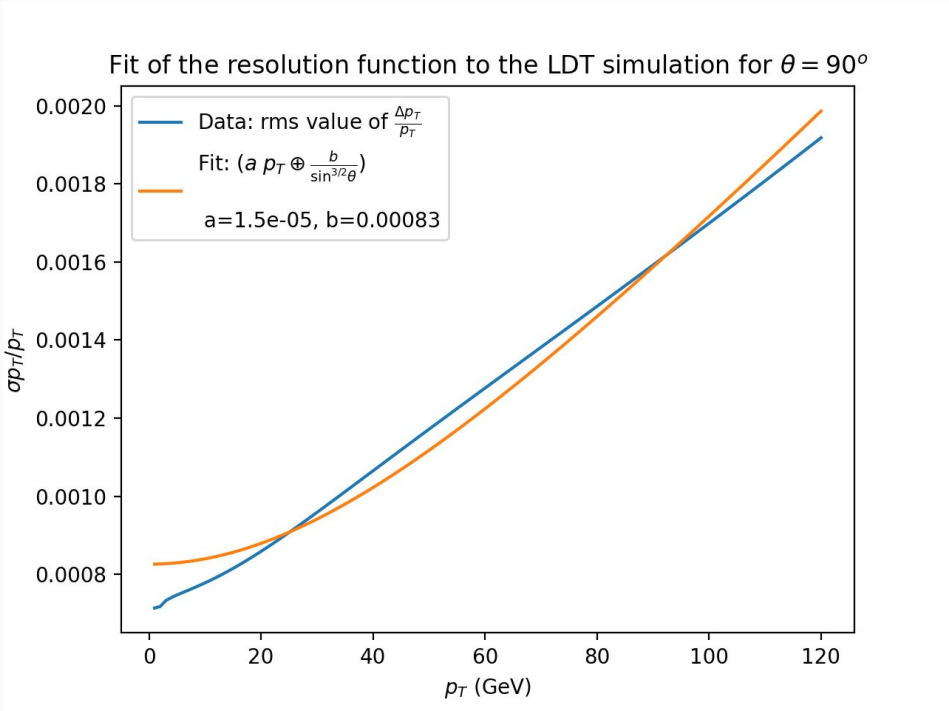




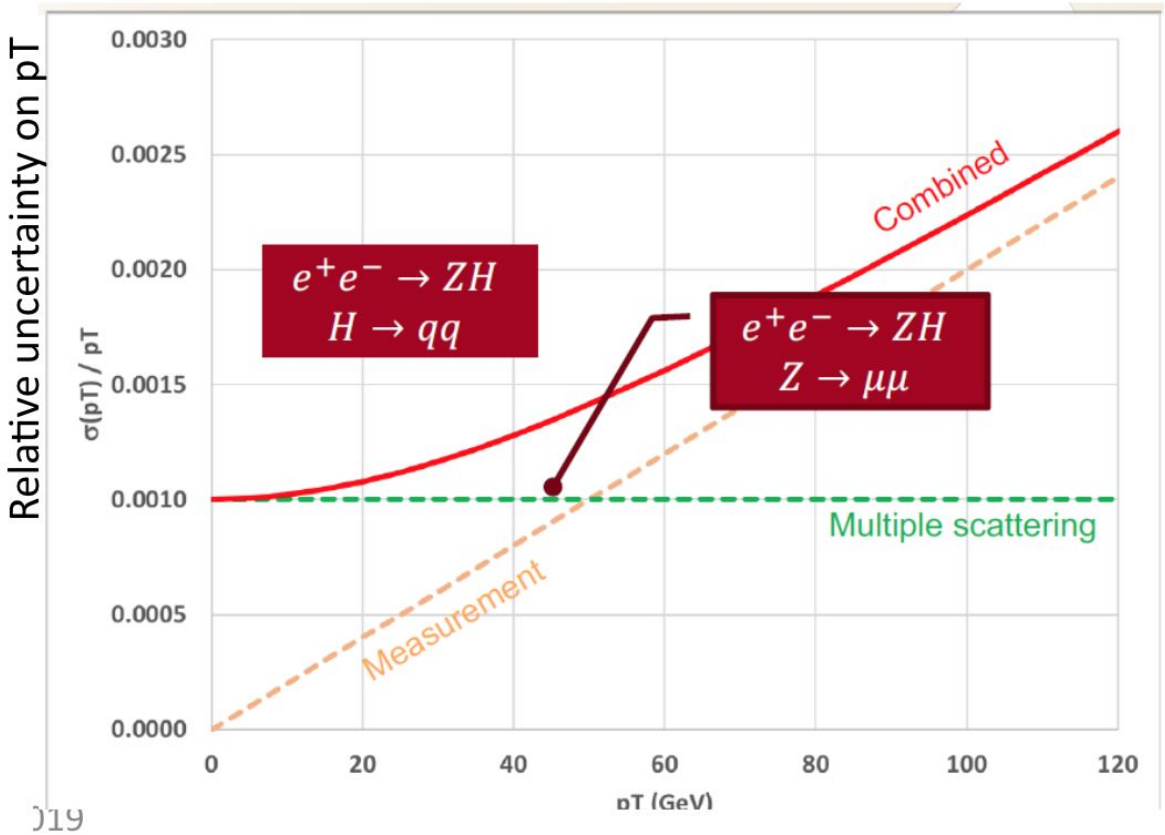
Lancaster University

Note: CDR values are a=2e-5, b=1e-3

Fit values: a=1.5e-5, b=0.83e-3 for $\sigma(p_T)/p_T$



Charlie Young



Multiple scattering

$$\sigma_{1/p_T} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

Intrinsic detector resolution

Impact parameter resolution driven by separating b, c, τ

FCCDay_TrackVertexDet_20200911.pdf

Summary - should be no surprises

- What is the effect of the pixel size in the tracker layers on the resolution?
  - A larger pixel size means a worse resolution, however, changing from the current resolution (50×150 µm) to the proposed resolution (25×300 µm) results in the resolution improving by 3.6%. Changing to 25×100 µm results in an improvement of 3.7%.
- What is the effect of the radiation length in the tracker layers (i.e., how does the resolution change with X0)?
  - Higher X0 means a worse resolution, with a 4.5% difference between 0.82% X0 and 0.35% X0.
- What is the effect of incident angle on the resolution?
  - Resolution is maximised at 90 degs, declines rapidly when theta approaches 0 or 180 deg.
- What is the effect of momentum on the resolution?
  - Higher momentum means worse resolution, with a mostly linear relationship above ~18 GeV/c.
- What is the minimum angle limit?
  - Minimum that LDT allows is around 7 degrees, CDR specifies a target minimum of 5.1 degrees.
- What is the effect of the external layer?
  - Resolution is improved with the SET detector compared to without, by a factor of 27.3%

Summary - should be no surprises

- What is the impact of the vertex detector?
  - Similarly, better resolution with than without (22.5%).
- Would we gain anything by having a silicon layer between the first and last active layers?
  - A small amount (1%) that probably wouldn't be worth the extra cost and manpower of placing it in the TPC.
- What is the muon momentum range should we be looking at?
  - Up to 120 GeV maximum from CDR plots/MC truth level.
- Does our data fit the equation in the CDR?
  - Our data matches the CDR well.

Lancaster University

Thank you for listening.

Lancaster University

Backup slides

The Questions:

- What is the effect of momentum on the resolution?
- What is the effect of incident angle on the resolution?
- What is the effect of the pixel size in the tracker layers on the resolution?
- What is the effect of the radiation length in the tracker layers (i.e., how does the resolution change with X0)?
- What is the minimum angle limit?
- What is the effect of the external layer (outside of the TPC and in front of the calorimeter)?
- What is the impact of the vertex detector?
- Would we gain anything by having a silicon layer between the first and last active layers?
- What is the muon momentum range should we be looking at?
- Does our data fit the equation in the CDR?

What is the minimum angle limit?

The ZH process has a flat $\cos\theta$ distribution, whereas the background processes are more forward region dominated. A large solid angle coverage is essential for large acceptance and for the separation of different processes. Thus a coverage of up to $|\cos(\theta)| = 0.99$ is benchmarked.

CDR pg 122

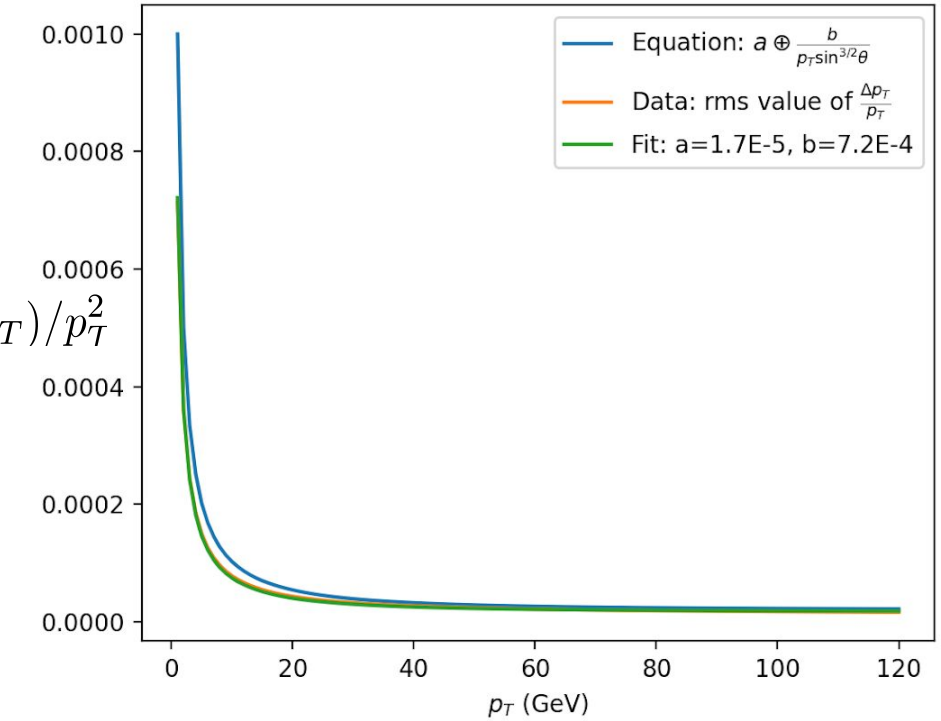
Figure 3.8: The (a) r–z and (b) r–ϕ view of the baseline detector concept. In the barrel from inner to outer, the detector is composed of a silicon pixel vertex detector, a silicon inner tracker, a TPC, a silicon external tracker, an ECAL, an HCAL, a solenoid of 3 Tesla and a return yoke with embedded a muon detector. In the forward regions, five pairs of silicon tracking disks are installed to enlarge the tracking acceptance (from $|\cos(\theta)| < 0.99$ to $|\cos(\theta)| < 0.996$).

CDR pg 131

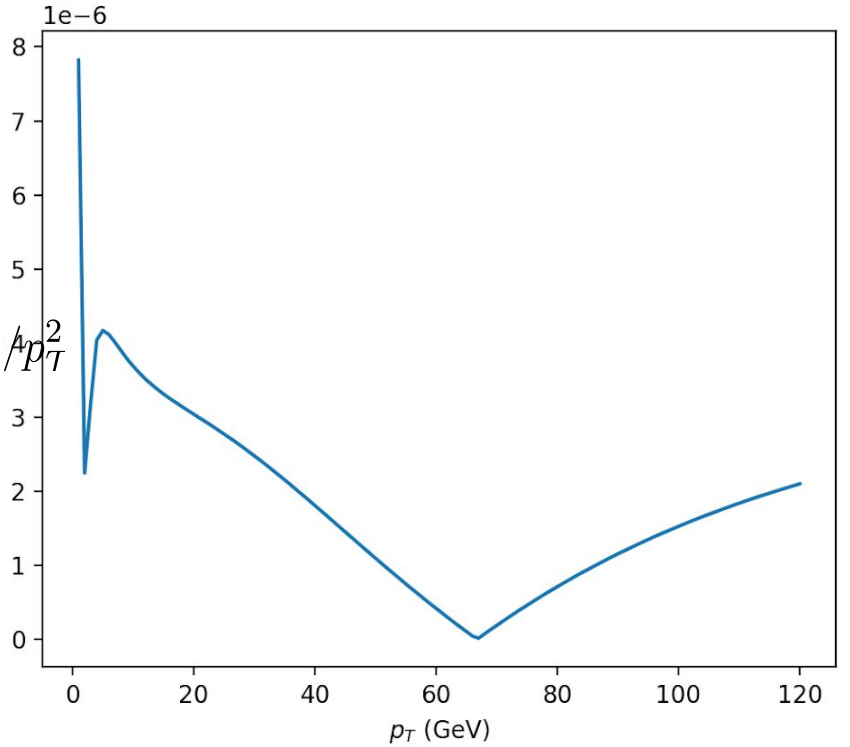
LDT goes down to 7 degs minimum before it doesn't work

Cos(θ) = 0.99, θ = 8.1 degs
Cos(θ) = 0.996, θ = 5.1 degs

Plot comparing the CEPC CDR equation for resolution, data obtained using the LDT, and a python fit of the CDR equation.



Plot showing absolute value of difference in fit and data.



Momentum (GeV/c)	Corresponding value of eta (x co-ord)	Minimum point of resolution (y co-ord)
10	0	0.00078
20	0.0175	0.00086
30	0.0524	0.00096
40	0.0874	0.0011
50	0.1049	0.0012
60	0.1225	0.0013
70	0.1401	0.0014
80	0.1754	0.0015
90	0.1932	0.0016

We can see that as the momentum increases, the value of eta (the minimum point of the curve) shifts along

```
06 Number of layers                : 14
07 Description (optional)          : |-Beamt.-|--------------------------------------Vertex detector---------------------------------------------------------------------------------------|
08 Names of the layers (opt.)      : XBT,    VTX1,    XVTX1,   XVTX2,   VTX2,    VTX3,    XVTX3,   XVTX4,  VTX4,    VTX5,    XVTX5,   VTX6,    XVTX6,   XVTXSHELL
09 Radii [mm]                      : 14.5,   15.95,   16,      17,      18,      36.95,   37,      38,     39,      57.95,   58,      59,      60,      65
10 Upper limit in z [mm]           : 4225,   62.5,    62.5,    62.5,    62.5,    125,     125,     125,    125,     125,     125,     125,     125,     145
11 Lower limit in z [mm]           : -4225,  -62.5,   -62.5,   -62.5,   -62.5,   -125,    -125,    -125,   -125,    -125,    -125,    -125,    -125,    -145
12 Efficiency RPhi                 : 0,      0.99,    0,       0,       0.99,    0.99,    0,       0,      0.99,    0.99,    0,       0.99,    0,       0
13 Efficiency 2nd coord. (eg. z)   : -1
14 Stereo angle alpha [Rad]        : 0
15 Thickness [rad. lengths]        : 0.0014, 0.00053, 0.00098, 0.00098, 0.00053, 0.00053, 0.00098, 0.00098, 0.00053, 0.00053, 0.00098, 0.00053, 0.00098, 0.0014
16 error distribution              : 0
17 0 normal-sigma(RPhi) [1e-6m] :          2.8,             6,               4,               4,               4,               4,
18         sigma(z)    [1e-6m]      :          2.8,             6,               4,               4,               4,               4,
19 1 uniform-d(RPhi) [1e-6m]       :
20         d(z)    [1e-6m]         :
21
22 Silicon Inner Tracker (SIT)
23
24 Number of layers                : 9
25 Description (optional)          : |-----------------------------------------------Inner tracker-----------------------------------------------|TPC inner wall|
26 Names of the layers (opt.)      : SIT1,     XSIT1,     XSIT2,     SIT2,     SIT3,     XSIT3,     XSIT4,     SIT4,          XTPCW1
27 Radii [mm]                      : 152.9,    153.1,     154.4,     155.4,    299.9,    300.1,     301.4,     302.4,         329
28 Upper limit in z [mm]           : 368,      368,       368,       368,      644,      644,       644,       644,           2350
29 Lower limit in z [mm]           : -368,     -368,      -368,      -368,     -644,     -644,      -644,      -644,          -2350
30 Efficiency RPhi                 : 0.99,     0,         0,         0.99,     0.99,     0,         0,         0.99,          0
31 Efficiency 2nd coord. (eg. z)   : 0.99,     0,         0,         0.99,     0.99,     0,         0,         0.99,          0
32 Stereo angle alpha [Rad]        : 0,        0,         0,         0,        0,        0,         0,         0,             0
33 Thickness [rad. lengths]        : 0.00213,  0.00468,   0.00468,   0.00213,  0.00213,  0.00468,   0.00468,   0.00213,       0.0051
34 error distribution              : 0
35 0 normal-sigma(RPhi) [1e-6m] : 7
36         sigma(z)    [1e-6m]      : 86
37 1 uniform-d(RPhi) [1e-6m]       :
38         d(z)    [1e-6m]         :
39
```

```
40 Time Projection Chamber (TPC)
41 sigma^2=sigma0^2+sigma1^2*sin(beta)^2+Cdiff^2*6mm/h*sin(theta)*Ldrift[m]
42 Number of layers            :  222
43 Radii [mm]                  :  384,1716
44 Upper limit in z [mm]       :  2225
45 Lower limit in z [mm]       : -2225
46 Efficiency RPhi             :  1
47 Efficiency z                :  1
48 Thickness [rad. lengths]    :  0.00005194
49 sigma0(RPhi) [1e-6m]        :  50
50 sigma1(RPhi) [1e-6m]        :  900
51 Cdiff(RPhi)  [1e-6m/sqrt(m)] :  25
52 sigma0(z)    [1e-6m]        :  400
53 sigma1(z)    [1e-6m]        :  0
54 Cdiff(z)     [1e-6m/sqrt(m)] :  80
55
```

```
56 Silicon External Tracker (SET)
57
58 Number of layers                 :  6
59 Description (optional)           : |TPC outer wall|----------External Tracker----------------------------------------|
60 Names of the layers (opt.)       :    XTPCW2,      SET1,       XSET1,      XSET2,     SET2,          SET3
61 Radii [mm]                      :    1808,        1810.9,     1811.1,     1812.4,    1813.4,        1847.4
62 Upper limit in z [mm]           :   2350,        2300,       2300,       2300,      2300,          2350
63 Lower limit in z [mm]           :   -2350,       -2300,      -2300,      -2300,     -2300,         -2350
64 Efficiency RPhi                 :    0,          0.99,       0,          0,         0,             0
65 Efficiency 2nd coord. (eg. z)   :    0,          0,          0,          0,         0.99,          0
66 Stereo angle alpha [Rad]        :    7*(pi/180),  7*(pi/180),  7*(pi/180),  7*(pi/180), 7*(pi/180),  90*(pi/180)
67 Thickness [rad. lengths]        :    0.00518,     0.00213,    0.00468,    0.00468,   0.00213,       0
68 error distribution              :    0
69 0 normal-sigma(RPhi) [1e-6m] :    7,          7,          7,          7,         7,             7
70         sigma(z)    [1e-6m]     :    7,          7,          7,          7,         7,             7
71 1 uniform-d(RPhi) [1e-6m]       :
72          d(z)    [1e-6m]        :
73
74 Magnetic field and beam spot
75
76 Solenoid magnetic field [T]  :  3.5
77 Range in x [mm]             : -0    0
78 Range in y [mm]             : -0    0
79 Range in z [mm]             : -0    0
```