Seeding in the Tracker Subsystem: Results from g+laser Scenario

LUXE Simulation and Analysis Meeting

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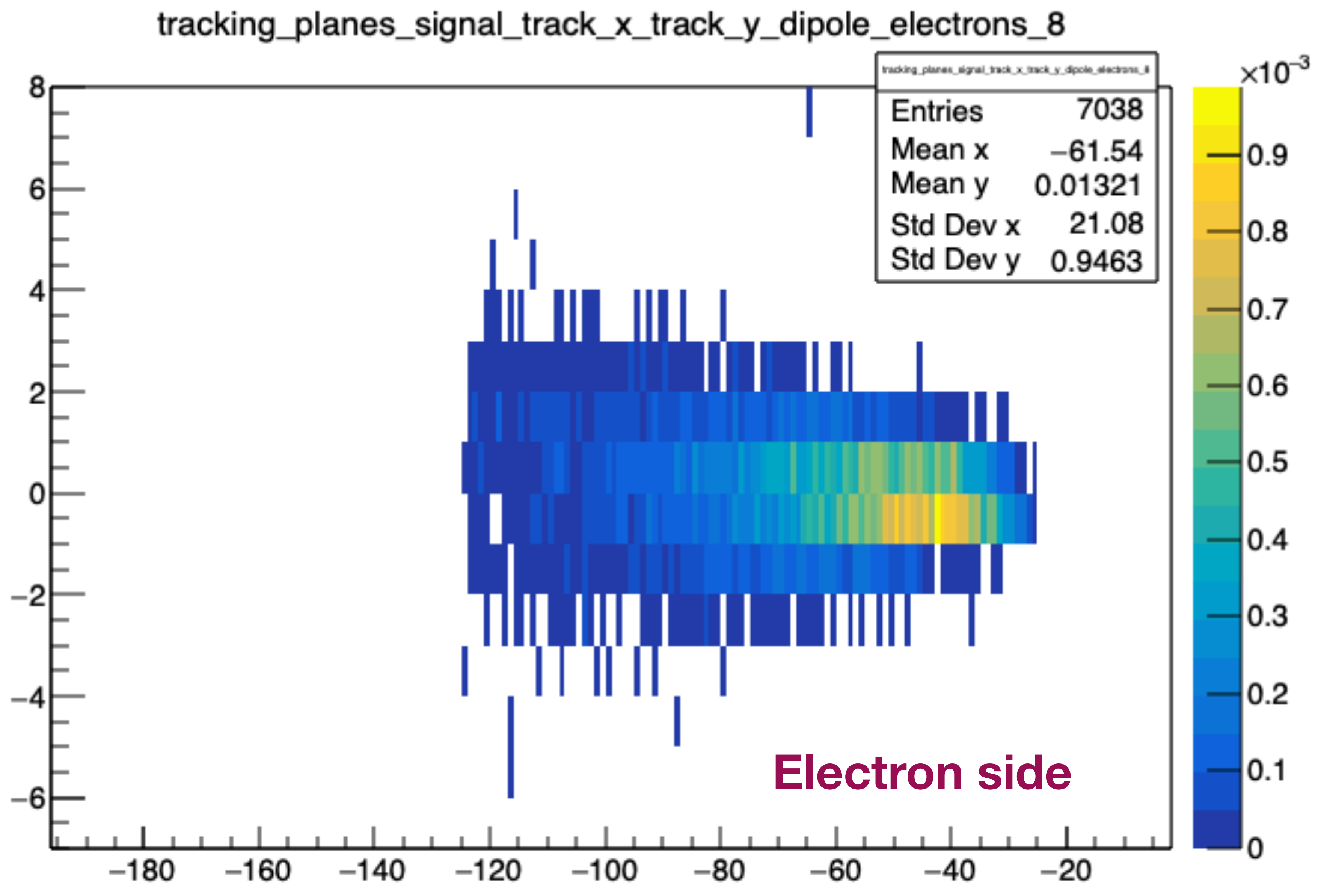
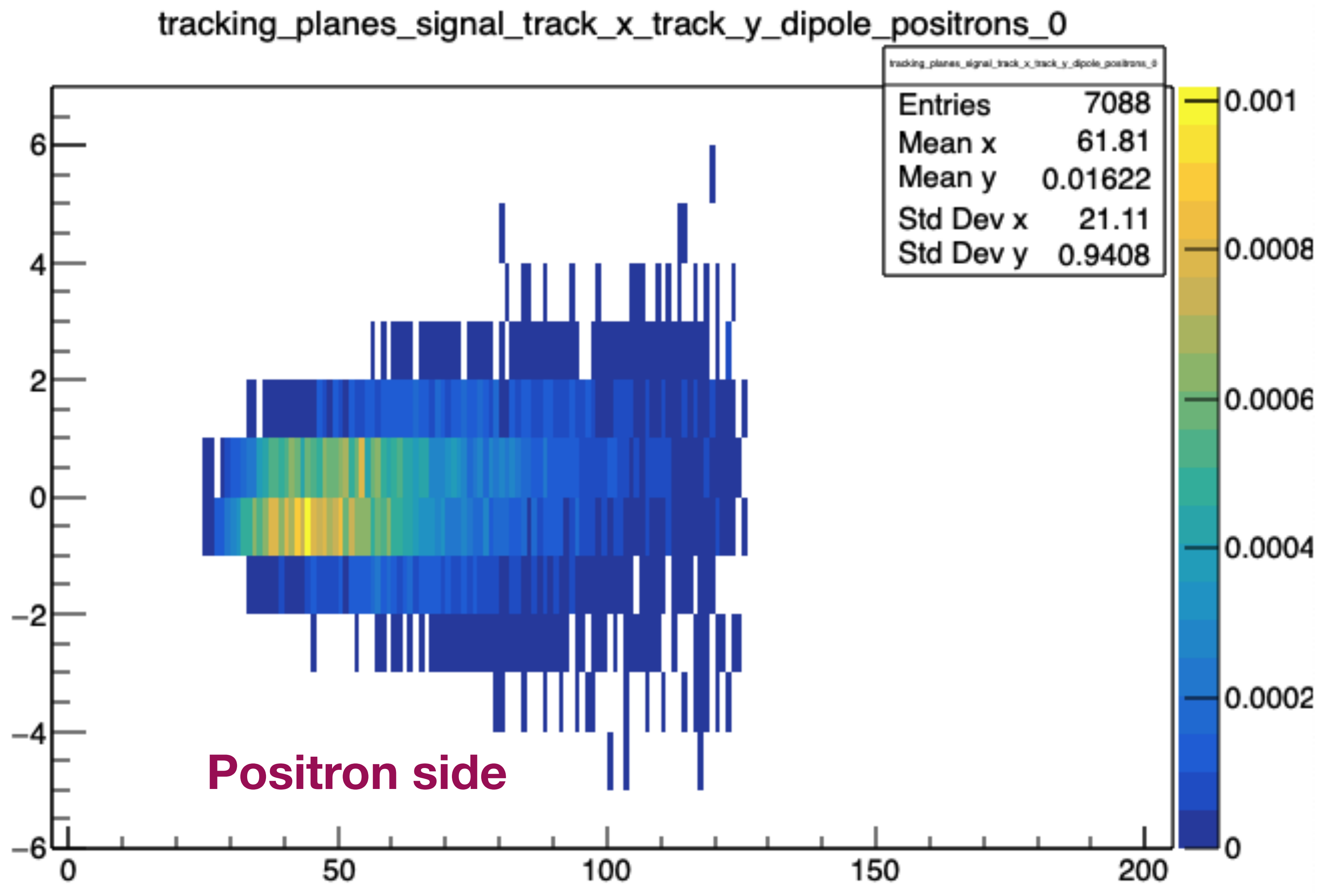
Seeding Algorithm on g+laser system

- Last week, Sasha produced the g+laser signal and background.
- Processed them and tried to see the how seeding is performing for this setup.
- Took background from the g+laser background only case.
- Injected signal per BX on top of the background.
- Few minor tweaks were done to the algorithm which was optimised for hics scenario.

Looking at the signal at the dipole exit plane





- Looked at the bppp signal (Spot size 3000 nm) at the dipole exit window.
- This signal is narrower than the hics.
    - Dipole exit window cut for good seeds changed to 20 mm < track_x_at_Dipole < 140 mm
        - For hics, this was 20 mm < track_x_at_Dipole < 165 mm
    - Dipole exit window cut in y < 6.5 mm
    - Different magnetic field for bppp (1.6 T)

Some basic optimisation of seed cuts: Positron side

- Played with the seeding algorithm cuts
  - Tweaked the SVD fit parameter cuts.
  - Optimized cuts on y momentum of fit tracks.
  - Optimized the outlier distance (d) cut on the tracks.
  - Slightly different cut for electron side and positron side.
  - Still need to loosen the cuts a bit to increase the efficiency.
- Room to improve
  - Much can be done with the SVD fit parameter and other cuts

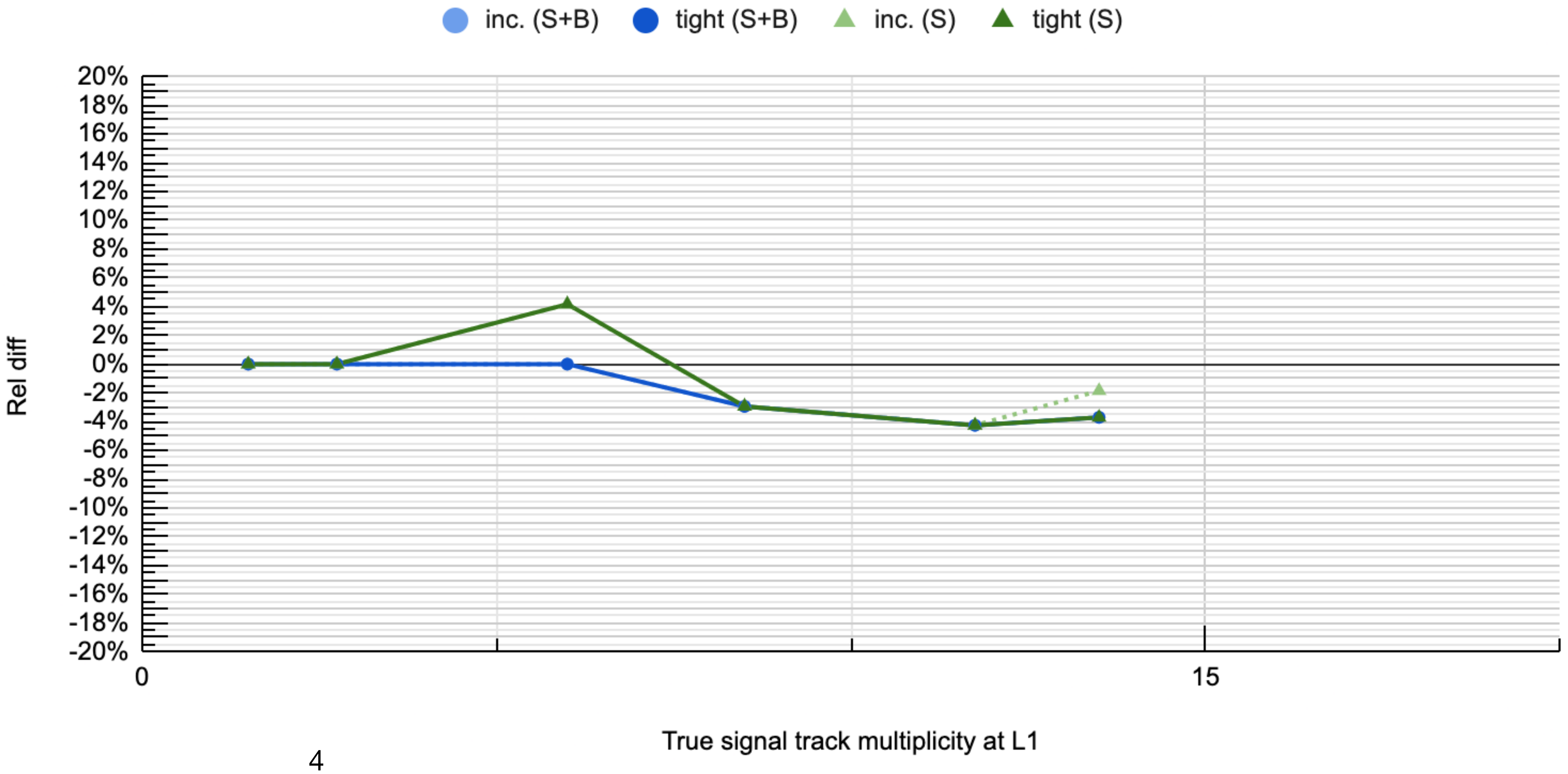
★d cut < 0.015
★Py cut < 0.004 (for preliminary seed less than 10)
★Py cut < 0.04 (for preliminary seed more than 10)

--- Summary ---

Sig, # of Tru	B-only			S+B					S-only				
	# of seeds w/o fit	# of seeds w/ fit loose	# of seeds w/ fit tight	# of seeds w/o fit	# of seeds w/ fit	Rel diff inc. (S+B)	# of seeds w/ fit	Rel diff tight (S+B)	# of seeds w/o fit	# of seeds w/ fit	Rel diff inc. (S)	# of seeds w/ fit	Rel diff tight (S)
--	0.0	0.0	0.0	--	--	--	--	--	--	--	--	--	--
1.5				2.8	1.5	0%	1.5	0.0%	1.5	1.5	0%	1.5	0.0%
2.8				4.0	2.8	0%	2.8	0.0%	3.0	2.8	0%	2.8	0.0%
6.0				7.8	6.0	0%	6.0	0.0%	6.0	6.3	4%	6.3	4.2%
8.5				10.0	8.3	-3%	8.3	-2.9%	7.5	8.3	-3%	8.3	-2.9%
11.8				13.0	11.3	-4%	11.3	-4.3%	11.0	11.3	-4%	11.3	-4.3%
13.5				14.5	13.0	-4%	13.0	-3.7%	11.5	13.3	-2%	13.0	-3.7%

Within 4%

Relative difference wrt true signal



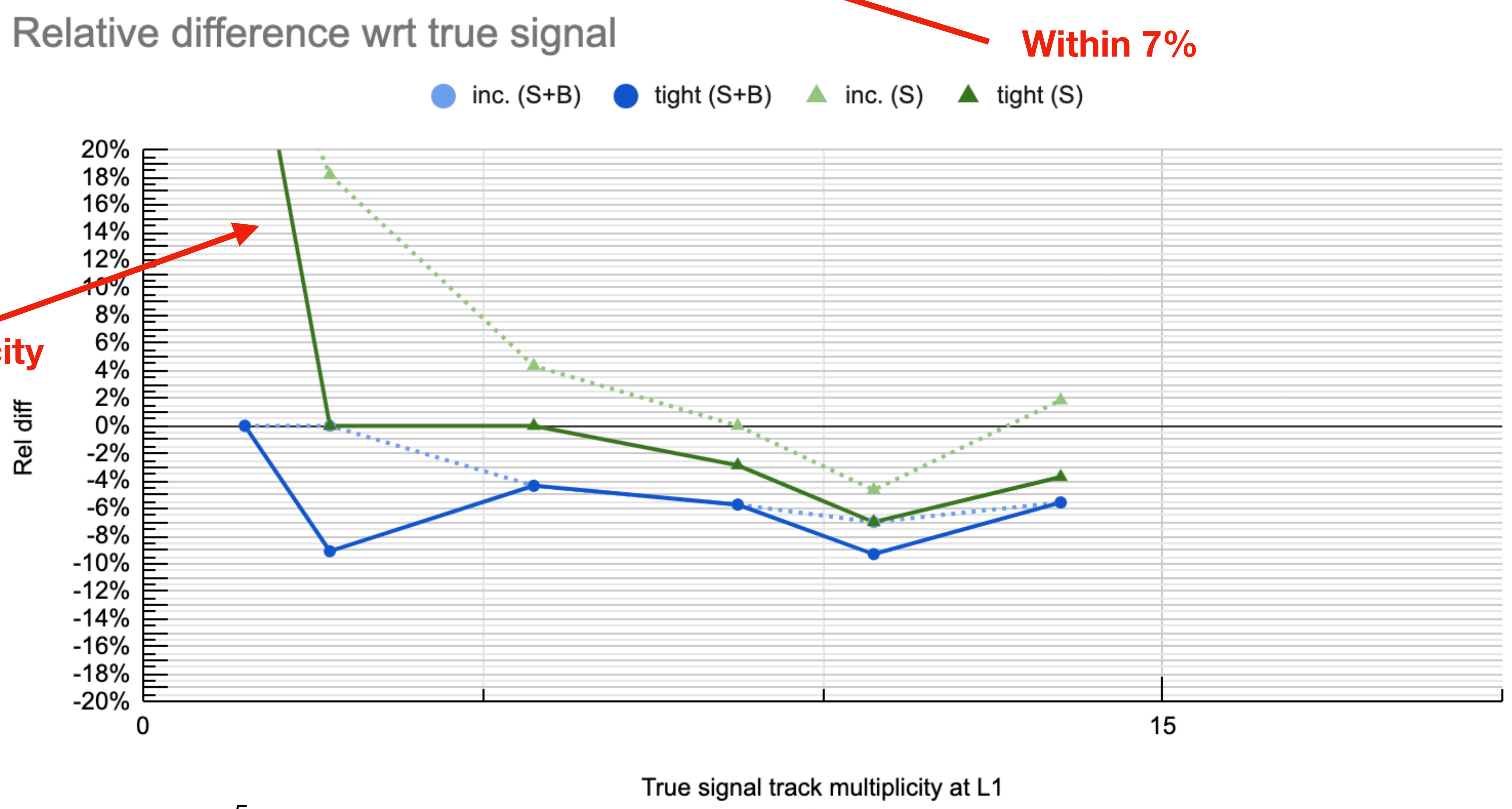
Some basic optimisation of seed cuts: Electron side

- Played with the seeding algorithm cuts
  - Tweaked the SVD fit parameter cuts.
  - Optimized cuts on y momentum of fit tracks.
  - Optimized the outlier distance (d) cut on the tracks.
  - Slightly different cut for electron side and positron side
- Much room to improve
  - Electron side is not very clean like positron side
  - Need to see if any other cut apart from the above mentioned cut can improve the situation.

--- Summary ---

Sig, # of Tru	B-only: # of seeds w/o fit	B-only: # of seeds w/ fit loose	B-only: # of seeds w/ fit tight	S+B: # of seeds w/o fit	S+B: # of seeds w/ fit	S+B: Rel diff inc. (S+B)	S+B: # of seeds w/ fit	S+B: Rel diff tight (S+B)	S-only: # of seeds w/o fit	S-only: # of seeds w/ fit	S-only: Rel diff inc. (S)	S-only: # of seeds w/ fit	S-only: Rel diff tight (S)
--	0.0	0.0	0.0	--	--	--	--	--	--	--	--	--	--
1.5				5.0	1.5	0%	.5	0.0%	1.3	2.0	33%	2.0	33.3%
2.8				5.8	2.8	0%	.5	-9.1%	2.5	3.3	18%	2.8	0.0%
5.8				9.0	5.5	-4%	.5	-4.3%	5.3	6.0	4%	5.8	0.0%
8.8				11.0	8.3	-6%	.3	-5.7%	7.5	8.8	0%	8.5	-2.9%
10.8				12.8	10.0	-7%	.8	-9.3%	9.3	10.3	-5%	10.0	-7.0%
13.5				16.3	12.8	-6%	2.8	-5.6%	11.5	13.8	2%	13.0	-3.7%

Within 7%



Issue with the low track multiplicity

★d cut < 0.01 (for preliminary seed less than 10)
★d cut < 0.04 (for preliminary seed more than 10)
★Py cut < 0.04 (for preliminary seed less than 10)
★Py cut < 0.4 (for preliminary seed more than 10)

Cut flow from the background only case

- Applied seeding algorithm to 130 BX of background only scenario.

Cutflow positron side

('noCut', 1896994),
('x1Gtx4', 636903),
('x1*x4Negative', 636903),
('z1Eqz4', 636903),
('yDipoleExitGt6p5', 116755),
('xDipoleExitLt20', 103498),
('xDipoleExitGt140', 51751),
('xDipoleExitLt0', 25924),
('seedEnergy', 12001),
('checkClusterTracksMiddleLayers', 260),
('checkClusterFit', 76),
('trackEnergy', 64),
('checkClusterXDistance', 31),
('checkClusterTrackPy', 4),
('checkClusterTrackPyLoose', 0),
('checkClusterTrackPyTight', 4)

Cutflow electron side

('noCut', 2106178),
('x1Gtx4', 659022),
('x1*x4Negative', 659022),
('z1Eqz4', 659022),
('yDipoleExitGt6p5', 119275),
('xDipoleExitLt20', 106183),
('xDipoleExitGt140', 51671),
('xDipoleExitGt0', 26054),
('seedEnergy', 12120),
('checkClusterTracksMiddleLayers', 276),
('checkClusterFit', 75),
('trackEnergy', 65),
('checkClusterXDistance', 30),
('checkClusterTrackPy', 13),
('checkClusterTrackPyLoose', 9),
('checkClusterTrackPyTight', 4)

- ✦Electron side has more tracks surviving
  - ✦Checked some of the tight tracks (details in the backup).
  - ✦Three of them are coming from -3000 mm < vtx_z < -1500 mm, from the shielding wall enclosing the upstream beam dump
    - ✦Have energy > 3 GeV
    - ✦If we can shield it in a better way, then these tracks will not survive.

Summary:

- ✦Looked at the seeding of g+laser setup for the first time
  - ✦Only a minor optimisation had good result.
  - ✦Upstream better shielding can kill more tracks.
  - ✦Lots of room for optimisation.
    - ✦Will look at the fit parameter and other seed cuts
  - ✦Adding new bkg samples produced by Sasha - will play with
    them as well.
- ✦Looked at the 281 BX of electron beam only background.
  - ✦The cutflow looks okay.

Cutflow positron side: 281 BX of electron beam only case

('noCut', 1516590),
('x1Gtx4', 574153),
('x1*x4Negative', 574153),
('z1Eqz4', 574153),
('yDipoleExitGt5p4', 86342),
('xDipoleExitLt25', 79796),
('xDipoleExitGt165', 33366),
('xDipoleExitLt0', 15541),
('seedEnergy', 11955),
('checkClusterTracksMiddleLayers', 150),
('checkClusterFit', 21),
('trackEnergy', 19),
('checkClusterXDistance', 6),
('checkClusterTrackPy', 4),
('checkClusterTrackPyLoose', 4),
('checkClusterTrackPyTight', 0)

Backup

Surviving electron tight tracks

track 1:
vertex positions first layer: xpos -264.677 ypos 0.35721 energy 3.42792 vtx_x 22.1301 vtx_y -4.47649 vtx_z -2569.47
vertex positions second inner layer: xpos -279.614 ypos 0.384673 energy 3.42505 vtx_x 22.1301 vtx_y -4.47649 vtx_z -2569.47
vertex positions third inner layer: xpos -294.551 ypos 0.411611 energy 3.42482 vtx_x 22.1301 vtx_y -4.47649 vtx_z -2569.47
vertex positions third outer layer: xpos -296.344 ypos 0.414833 energy 3.42468 vtx_x 22.1301 vtx_y -4.47649 vtx_z -2569.47
vertex positions last layer: xpos -311.264 ypos 0.454023 energy 3.42442 vtx_x 22.1301 vtx_y -4.47649 vtx_z -2569.47

track2:

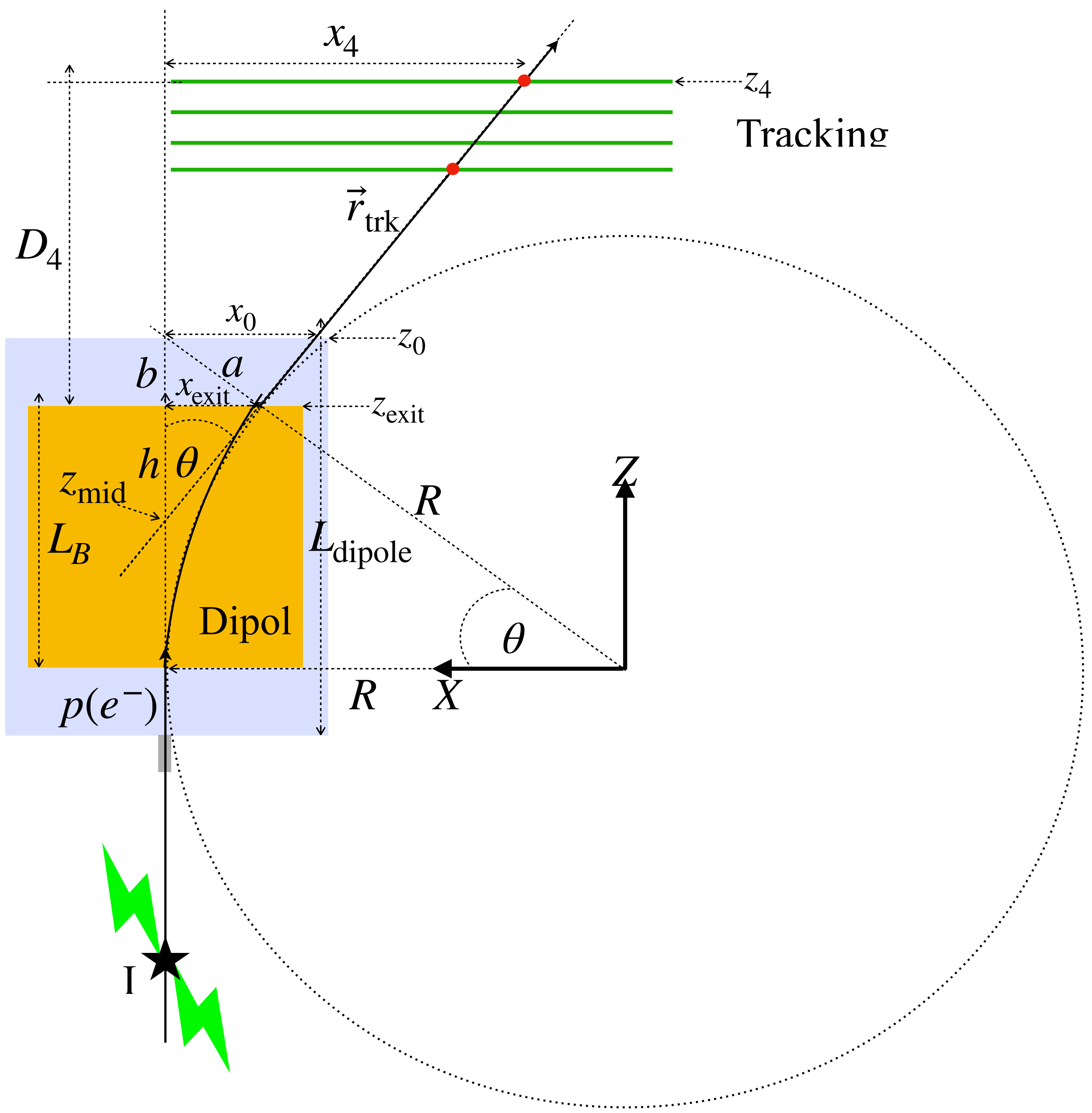
vertex positions first layer: xpos -269.639 ypos -4.86386 energy 3.34035 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17
vertex positions second inner layer: xpos -284.942 ypos -4.83392 energy 3.33981 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17
vertex positions second outer layer: xpos -286.779 ypos -4.82878 energy 3.33963 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17
vertex positions third inner layer: xpos -300.245 ypos -4.79405 energy 3.33952 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17
vertex positions third outer layer: xpos -302.079 ypos -4.78925 energy 3.33941 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17
vertex positions last layer: xpos -317.372 ypos -4.7541 energy 3.33917 vtx_x 21.1441 vtx_y -7.69225 vtx_z -1585.17

track3:
vertex positions first layer: xpos -174.446 ypos 4.10115 energy 4.70883 vtx_x -20.0565 vtx_y 10.2039 vtx_z -3084.9
vertex positions second inner layer: xpos -184.466 ypos 4.02038 energy 4.70869 vtx_x -20.0565 vtx_y 10.2039 vtx_z -3084.9
vertex positions third inner layer: xpos -194.493 ypos 3.93495 energy 4.70844 vtx_x -20.0565 vtx_y 10.2039 vtx_z -3084.9
vertex positions last layer: xpos -204.493 ypos 3.81886 energy 4.70796 vtx_x -20.0565 vtx_y 10.2039 vtx_z -3084.9

Positions prediction, Using More Realistic Dipole Setup from GEANT4

$p[\mathrm{GeV}] = 0.3 \cdot B[\mathrm{T}] \cdot R[\mathrm{m}]$

$$R = \frac{p}{0.3B}$$



From Noam

Circle equation wrt the origin at the centre of the circle defined by the track: $X^2 + Z^2 = R^2$

$$Z_{\mathrm{exit}} = L_B \longrightarrow X_{\mathrm{exit}} = \sqrt{R^2 - L_B^2}$$

$$x_{\mathrm{exit}} = R - X_{\mathrm{exit}} = R - \sqrt{R^2 - L_B^2}$$

Tangent equation: $Z = m \cdot X + c$. The tangent gradient, m, is -1 over the gradient of the radius at the point where the tangent is defined, i.e.: $m = -1/(\Delta Z/\Delta X)$ at the point $\left(Z_{\mathrm{exit}}, X_{\mathrm{exit}}\right)$

$$m = -1/(\Delta Z/\Delta X) = -\left(X_{\mathrm{exit}} - 0\right)/\left(Z_{\mathrm{exit}} - 0\right) = -\left(\sqrt{R^2 - L_B^2}\right)/L_B = -\sqrt{\frac{R^2}{L_B^2} - 1}$$

Using the point $\left(Z_{\mathrm{exit}}, X_{\mathrm{exit}}\right)$ we get the intersection: $c = Z - m \cdot X$

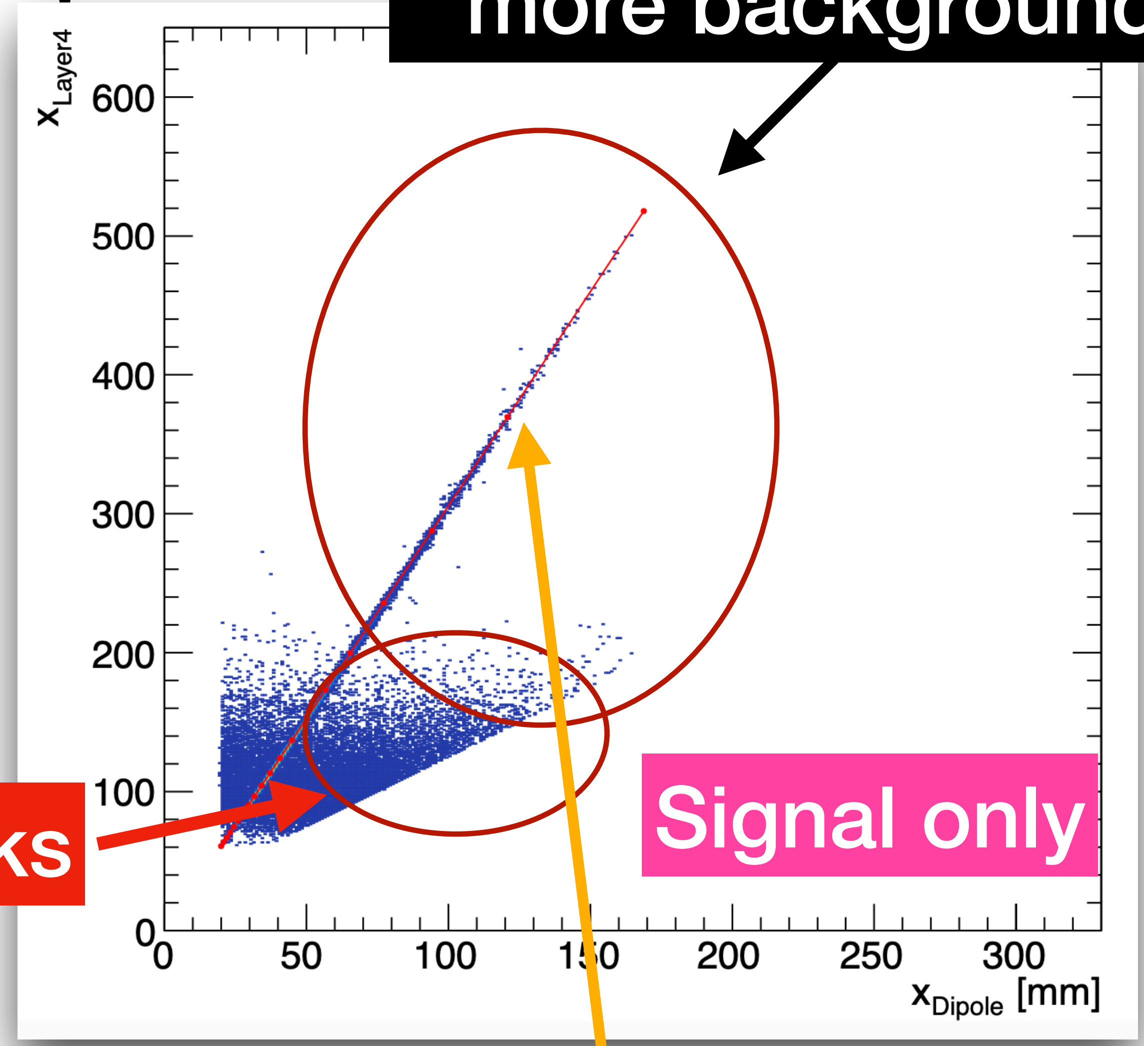
$$c = L_B - \left(-\sqrt{\frac{R^2}{L_B^2} - 1}\right) \cdot \sqrt{R^2 - L_B^2} = L_B + \frac{R^2 - L_B^2}{L_B} = \frac{R^2}{L_B}$$

$$Z_{\mathrm{tangent}} = -\sqrt{\frac{R^2}{L_B^2} - 1} \cdot X_{\mathrm{tangent}} + \frac{R^2}{L_B}$$

$$X_{\mathrm{tangent}} = \left(\frac{R^2}{L_B} - Z_{\mathrm{tangent}}\right)\frac{L_B}{\sqrt{R^2 - L_B^2}}$$

Putting $Z_4 = L_B + D_4$ or $Z_0 = L_B + \frac{L_{\mathrm{dipole}} - L_B}{2} = \frac{L_B + L_{\mathrm{dipole}}}{2}$ or $Z_{\mathrm{exit}} = L_B$ in the X_{tangent} expression, it is possible to get the prediction for the distance x from the beam axis ($z = 0$), recalling that: $x = R - X_{\mathrm{tangent}}$

Want to exploit this correlation to reduce more background

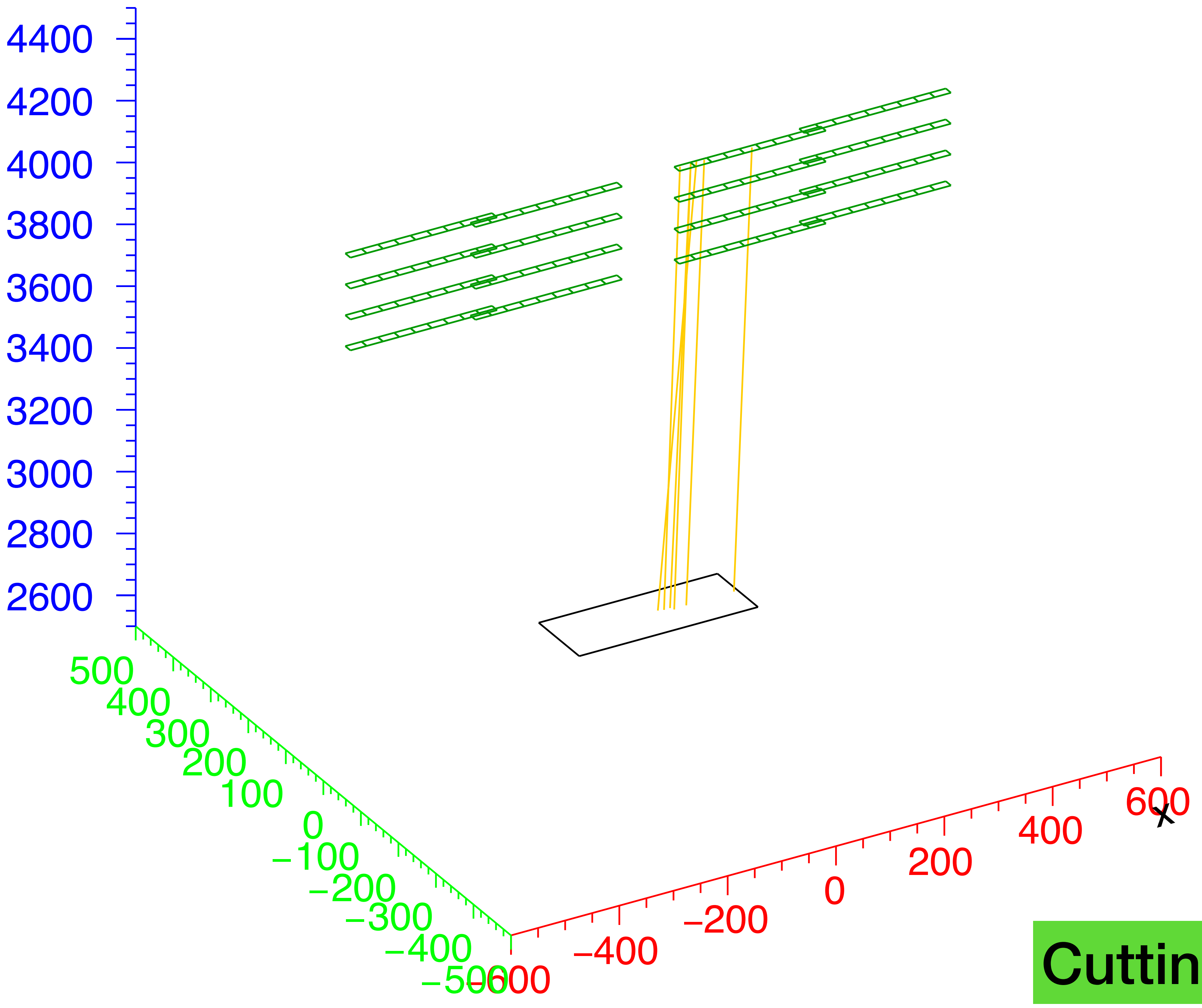


Signal only

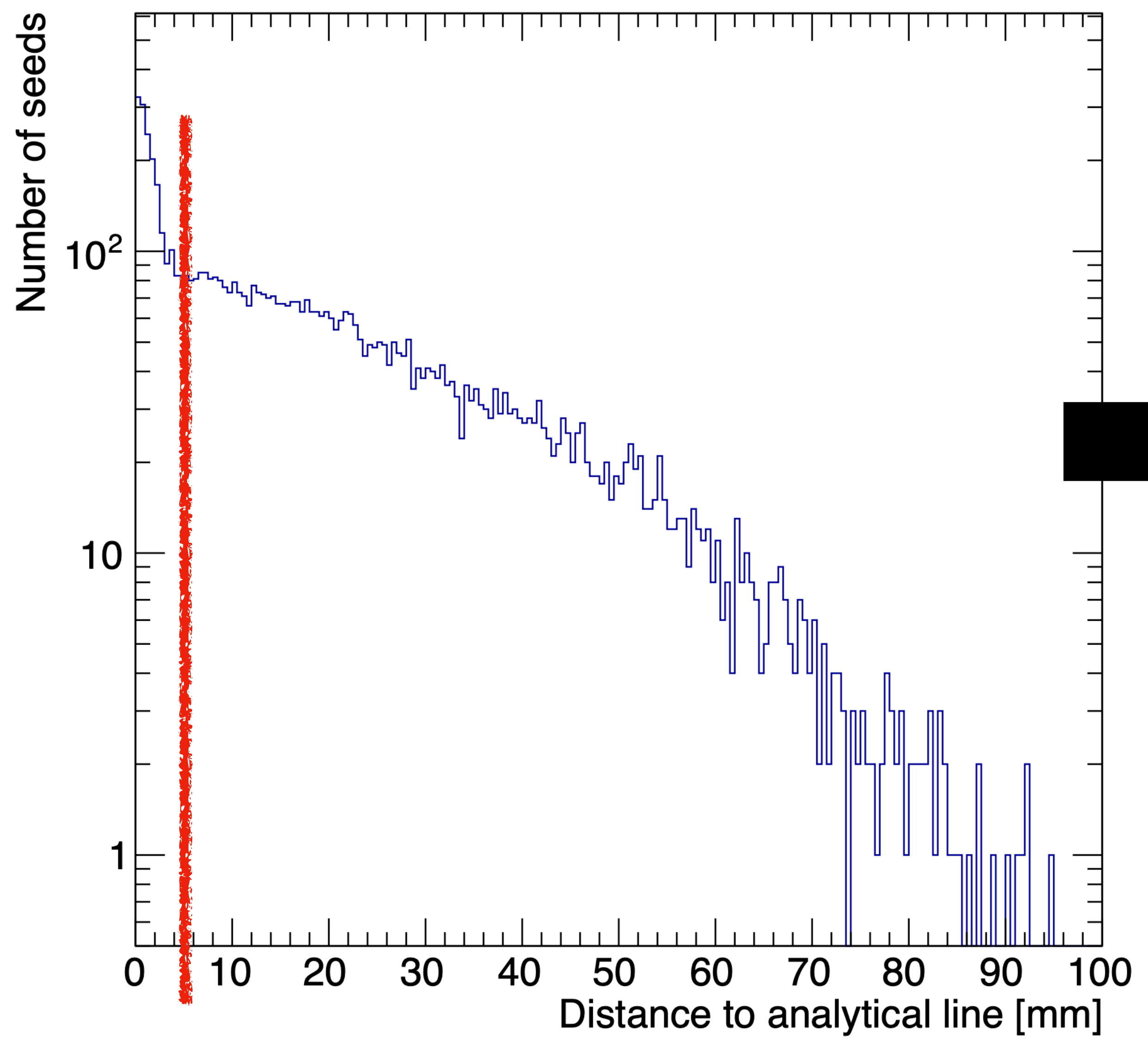
Wrong combination of tracks

Any point far away from this line is not interesting

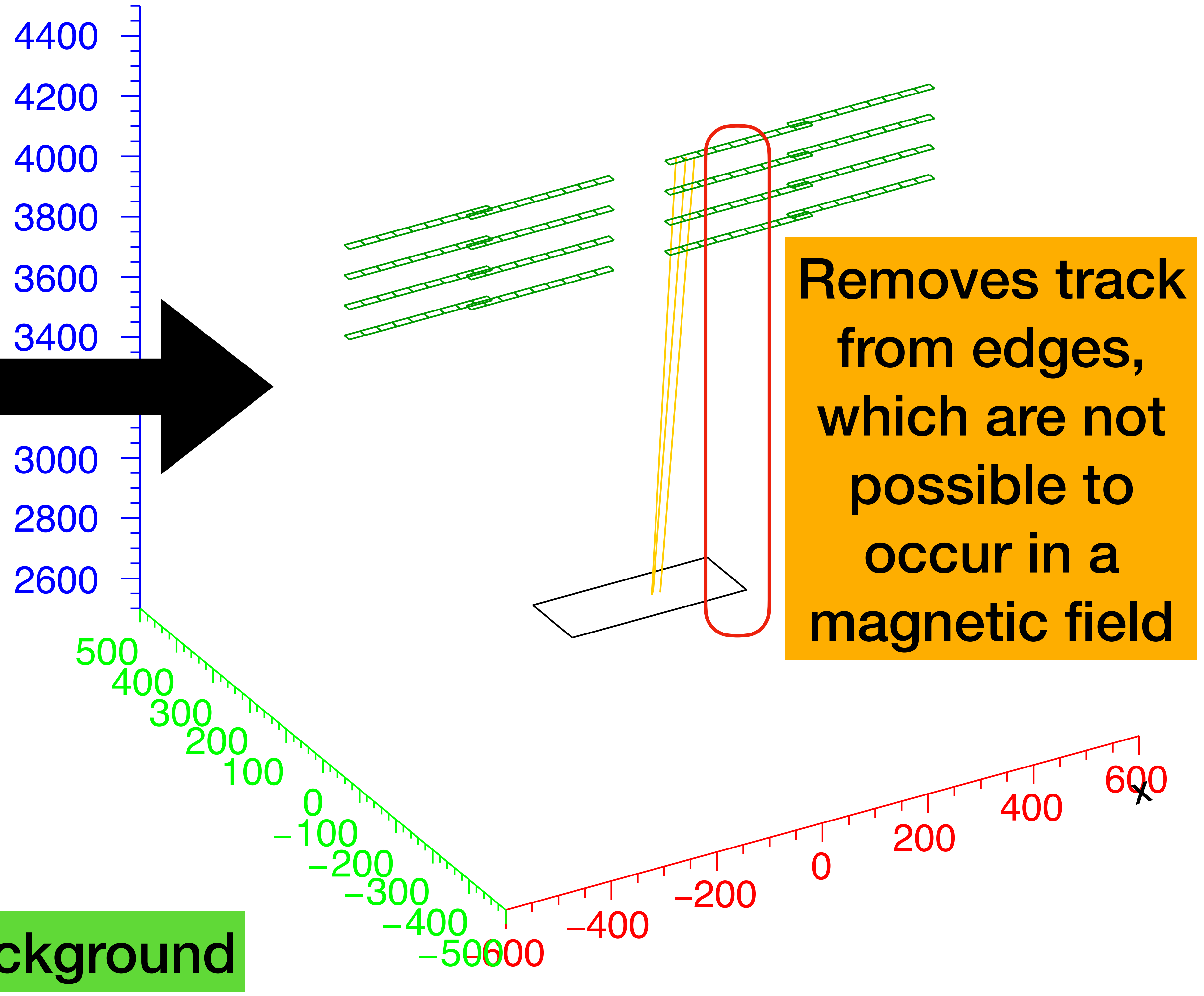
Plot from Electron Beam only Setup: Effect of Distance Cut on the Background



Electron beam only case without any cut on the distance from x_Layer4:x_Dipole straight line



Cutting around d < ~5 mm reduces the background



Removes track from edges, which are not possible to occur in a magnetic field

Electron beam only case with a cut on the distance from x_Layer4:x_Dipole straight line: d < 5 mm

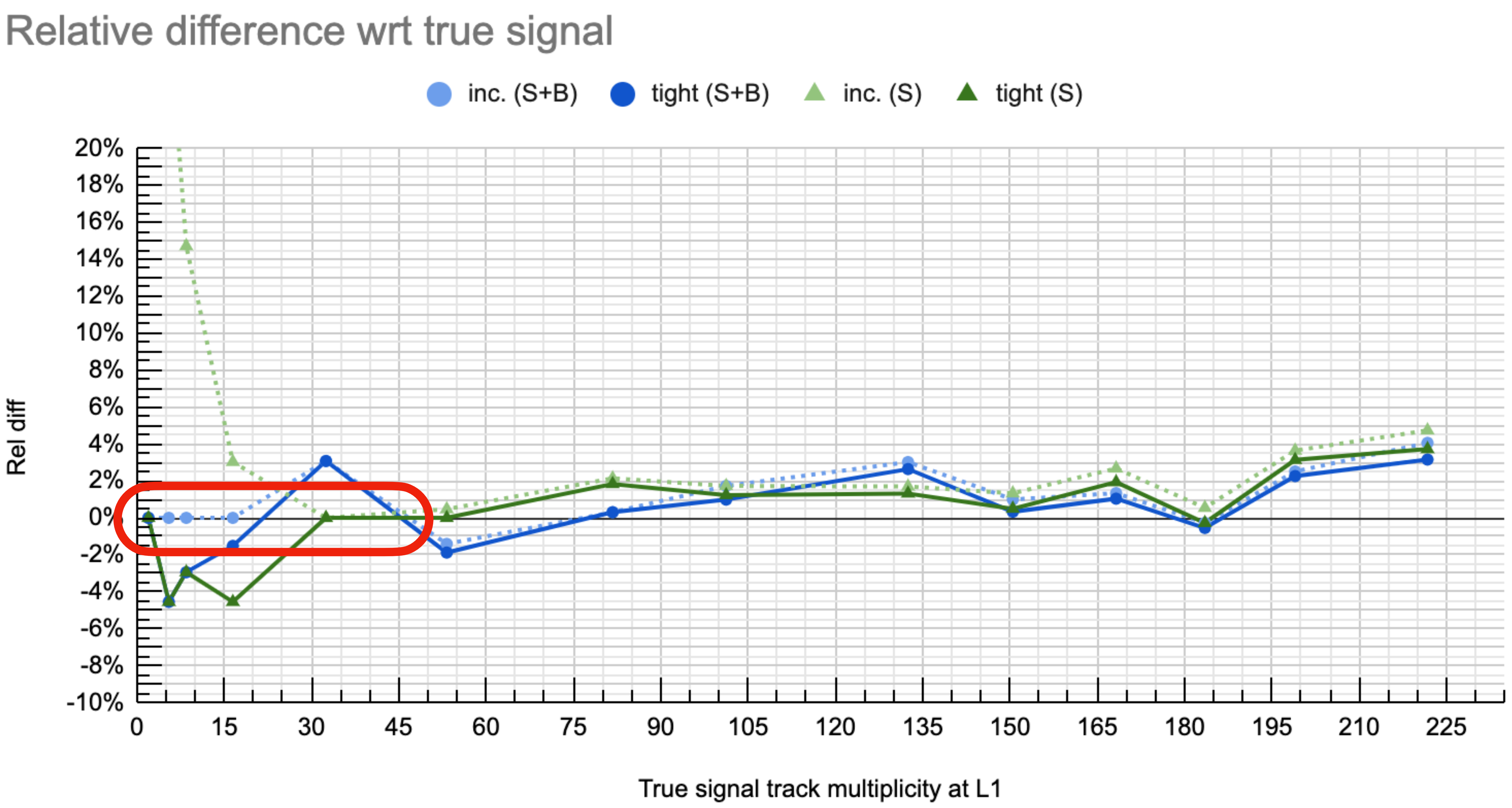
Update on the Seeding Cuts (hics)

- Discussed the basic cuts in the previous talk.
    - Not good at very low energy end (< 2 GeV)
    - Relative difference not good for low multiplicity case
- New today:
    - Put an energy cut of > 2 GeV.
    - Loosened the cut in the low track multiplicity region.
        - For low energy (< 4 GeV), road width is now 220 um instead of 130 um
        - The track fit cut and track y-momentum cuts were also changed depending on the track energy and the tight or loose tracks.
        - Full list of cuts in the backup

<table>
<tr><td rowspan="2">Seed exit window</td><td colspan="10">25<|xExit|<330/2</td></tr>
<tr><td colspan="10">|yExit|<5</td></tr>
<tr><td>Seed Energy [GeV]</td><td colspan="10">0.2<E<18</td></tr>
<tr><td>Seed energy region [GeV]</td><td colspan="5">E > 4 GeV</td><td colspan="5">E < 4 GeV</td></tr>
<tr><td>Road width [μm]</td><td colspan="5">130</td><td colspan="5">220</td></tr>
<tr><td>Pre-fit seed mult.</td><td>Large</td><td colspan="2">Moderate</td><td colspan="2">Small</td><td>Large</td><td colspan="2">Moderate</td><td colspan="2">Small</td></tr>
<tr><td># of seeds thresh.</td><td>N>320</td><td colspan="2">50<N<320</td><td colspan="2">N<50</td><td>N>320</td><td colspan="2">50<N<320</td><td colspan="2">N<50</td></tr>
<tr><td># of true signal trks</td><td>N>100</td><td colspan="2">15<N<100</td><td colspan="2">N<15</td><td>N>100</td><td colspan="2">15<N<100</td><td colspan="2">N<15</td></tr>
<tr><td>Track Energy [GeV]</td><td colspan="10">2<E<15</td></tr>
<tr><td>Track energy region [GeV]</td><td colspan="5">E > 4 GeV</td><td colspan="5">E < 4 GeV</td></tr>
<tr><td>Category</td><td>All</td><td>Tight</td><td>Loose</td><td>Tight</td><td>Loose</td><td>All</td><td>Tight</td><td>Loose</td><td>Tight</td><td>Loose</td></tr>
<tr><td>2nd SVD par.</td><td>0.05</td><td>0.06</td><td>0.06</td><td>0.1</td><td>0.065</td><td>0.08</td><td>0.06</td><td>0.06</td><td>0.1</td><td>0.2</td></tr>
<tr><td>3rd SVD par.</td><td>0.01</td><td>0.06</td><td>0.06</td><td>0.1</td><td>0.065</td><td>0.02</td><td>0.05</td><td>0.05</td><td>0.1</td><td>0.05</td></tr>
<tr><td>Track y-momentum [GeV]</td><td>0.005</td><td>0.005</td><td>0.005</td><td>0.035</td><td>0.031</td><td>0.005</td><td>0.005</td><td>0.005</td><td>0.01</td><td>0.0095</td></tr>
<tr><td>x4:xExit outliers dist. [m]</td><td>0.003</td><td>0.004</td><td>0.003</td><td>0.004</td><td>0.005</td><td>0.005</td><td>0.006</td><td>0.005</td><td>0.006</td><td>0.005</td></tr>
</table>

Improvement in the relative difference

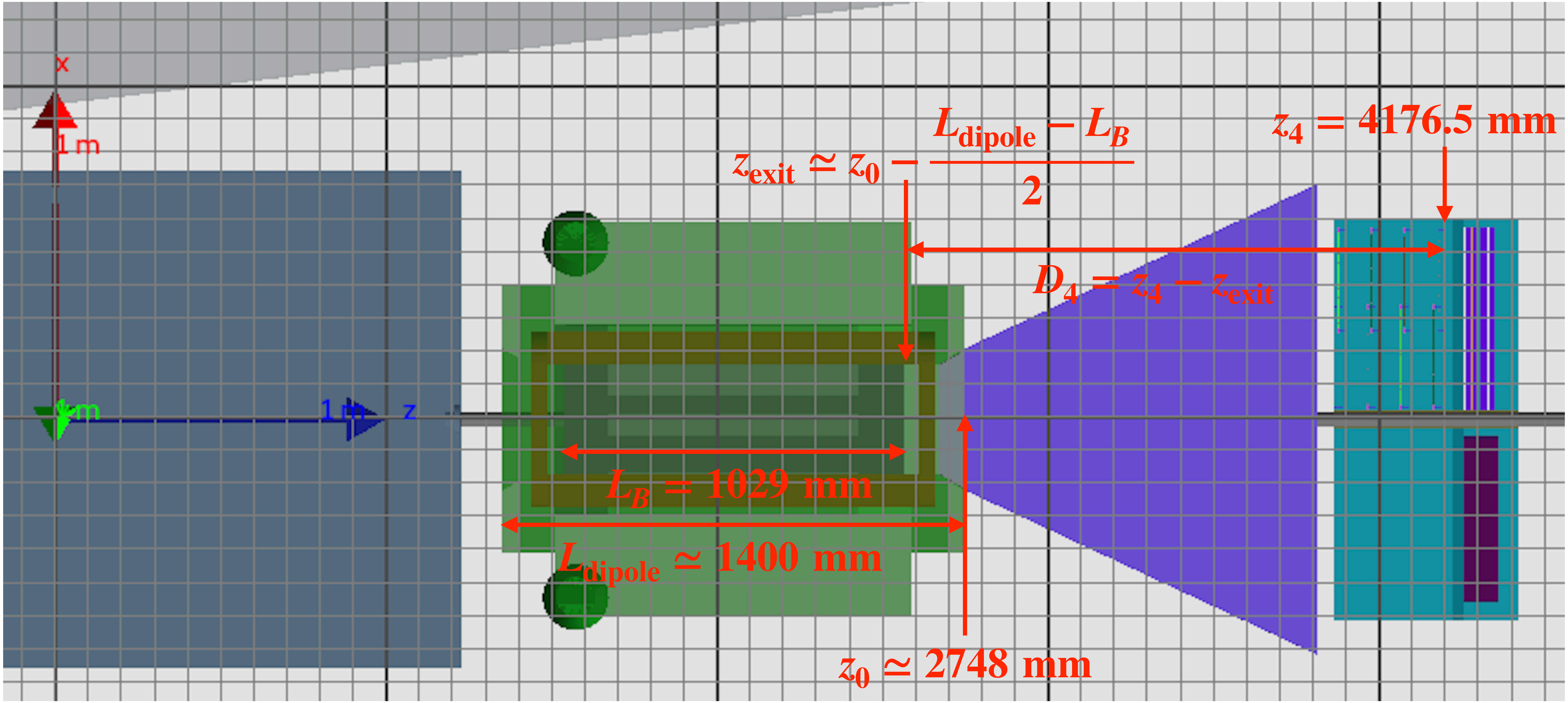
Approximate multiplicity of true signal tracks	S+B					S-only				
	# of seeds w/o fit	# of seeds w/ fit	Rel diff inc. (S+B)	# of seeds w/ fit	Rel diff tight (S+B)	# of seeds w/o fit	# of seeds w/ fit	Rel diff inc. (S)	# of seeds w/ fit	Rel diff tight (S)
0 (bkg only)	--	--	--	--	--	--	--	--	--	--
1	32.5	2.0	0%	2.0	0.0%	2.0	3.8	88%	2.0	0.0%
5	36.8	5.5	0%	5.3	-4.5%	5.5	7.0	27%	5.3	-4.5%
10	39.3	8.5	0%	8.3	-2.9%	8.3	9.8	15%	8.3	-2.9%
20	56.0	16.5	0%	16.3	-1.5%	17.5	17.0	3%	15.8	-4.5%
30	92.3	33.5	3%	33.5	3.1%	41.0	32.5	0%	32.5	0.0%
50	132.0	52.5	-1%	52.3	-1.9%	67.3	53.5	0%	53.3	0.0%
80	232.8	82.0	0%	82.0	0.3%	134.8	83.5	2%	83.3	1.8%
100	333.0	103.0	2%	102.3	1.0%	209.3	103.0	2%	102.5	1.2%
130	491.0	136.5	3%	136.0	2.6%	318.8	134.8	2%	134.3	1.3%
150	570.8	152.0	1%	151.0	0.3%	377.8	152.5	1%	151.3	0.5%
170	774.3	170.5	1%	170.0	1.0%	544.0	172.8	3%	171.5	1.9%
185	854.0	183.0	0%	182.5	-0.5%	578.8	184.5	1%	183.0	-0.3%
200	1091.0	204.0	3%	203.5	2.3%	782.5	206.3	4%	205.3	3.1%
220	1413.0	230.8	4%	228.8	3.2%	1040.0	232.3	5%	230.0	3.7%



✦Low track multiplicity region now improved for S+B case
✦The relative difference is within 5% for high multiplicity case for S+B inclusive case, and close to 0% for low multiplicity case.

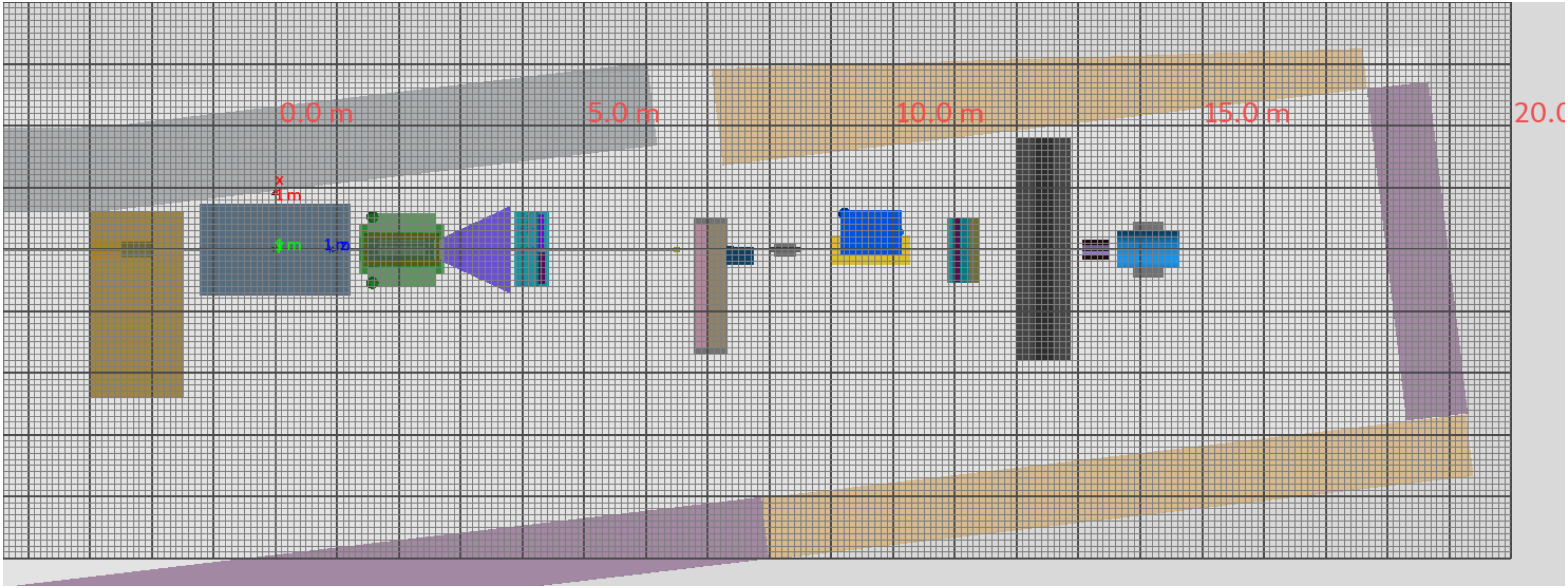
Numbers

z4: 4176.5 [mm], z0: 2748 [mm], zExit: 2562.5 [mm], D4: 1614 [mm]



From Noam

The entire subsystem

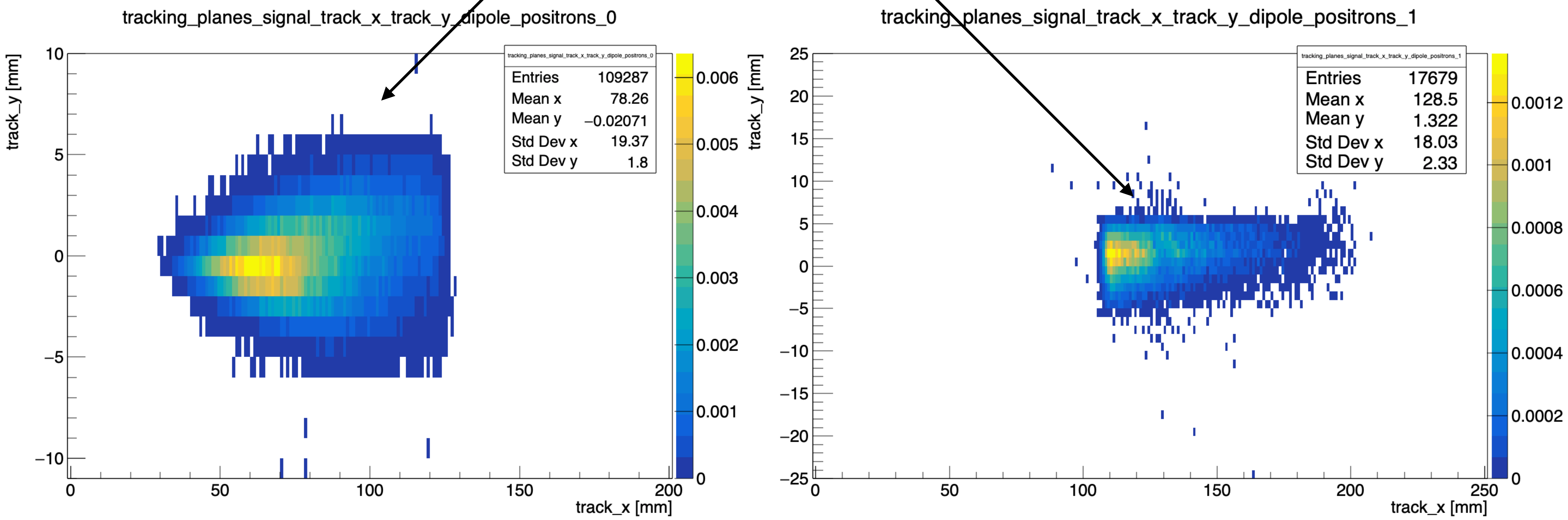


Plots from Sasha

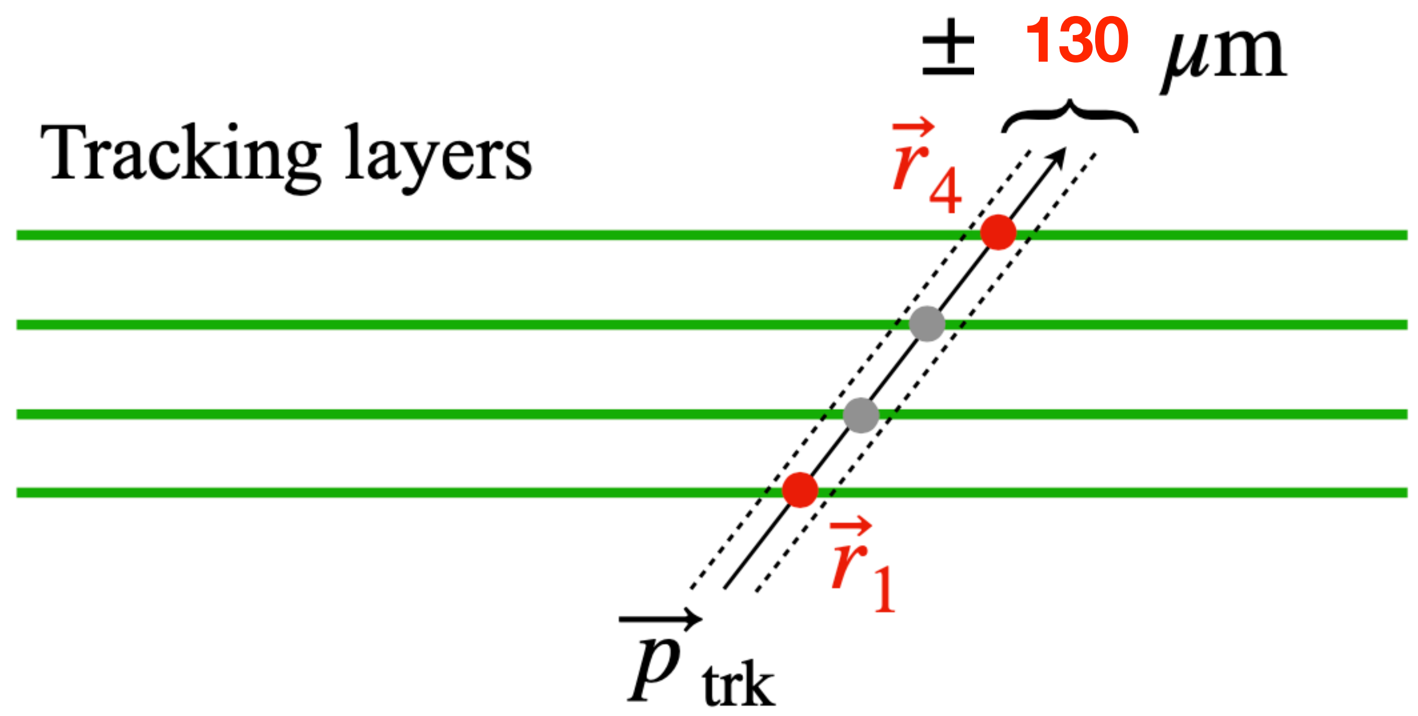
The seeding algorithm

- Keep unique set of tracks from first layer and last layer of tracker.
  - Overlap region is removed (by cutting on x value of the tracks from
    the outer stave of first layer (innermost) and from the inner stave of
    the last layer (outermost).
- Loop over all pairs in layers 4 and 1, now only positron side (x>0).
- Reject pair of clusters if
  - |x1| > |x4| or they have different sign
  - |z1| == |z4|
  - |y_exit| > 5.4 mm
  - |x_exit| < 20 mm and |x_exit| > 165 mm
  - If not one cluster in the road of 130 (220 um for < 4 GeV) um connecting vector r1 and r4 in both layer 2 and layer 3.
  - The seed energy is greater than 17.5 GeV or less than 0.5 GeV.
    - The seed energy is calculated from the track.
  - Apply the SVD fit parameter cut, distance cut and p_Y cut
    - After a good fit, the energy requirement of the track is [2,13] GeV

P side Signal at the Dipole exit (New signal)



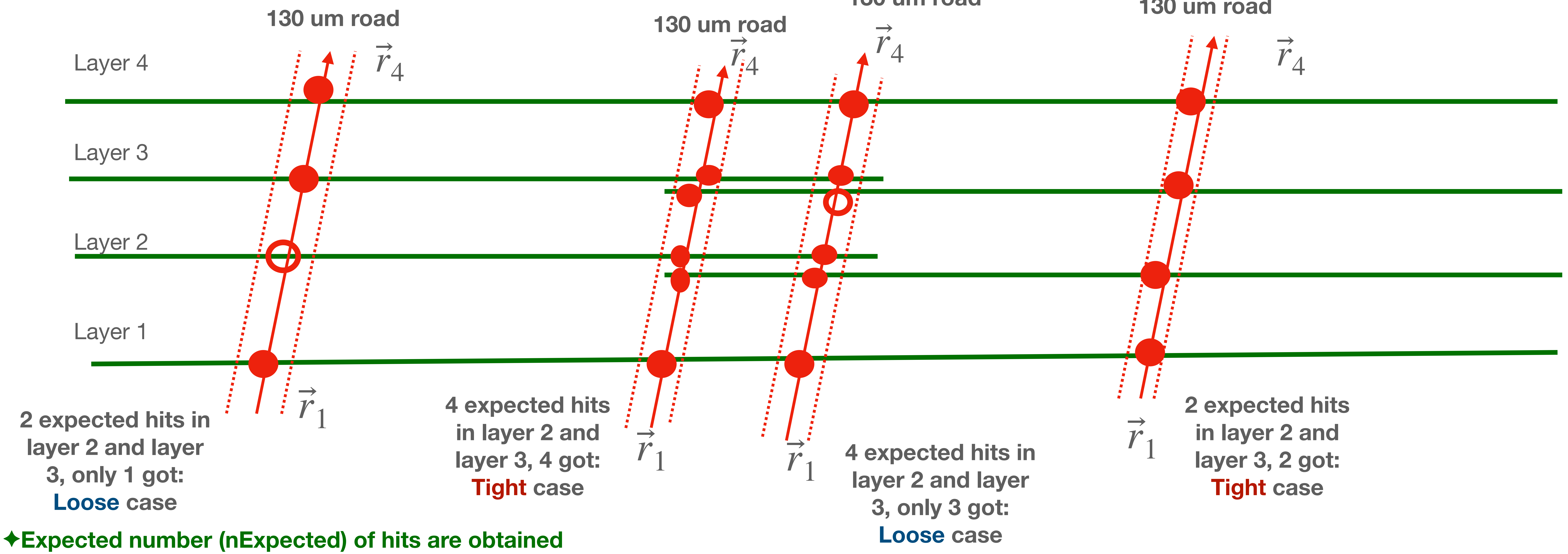
Stave 0 Stave 1



Tight Tracks and Loose Tracks Scenario Depending on the Hits in the Tracker Layers

- The seeding algorithm always starts from one hit in layer 4 (outer layer) and one hit in layer 1 (inner layer).

Representative diagram of the LUXE tracker



✦Expected number (nExpected) of hits are obtained
by the projection of line joining $\vec{r}_1$ and $\vec{r}_4$ and see how many hits expected in layer 2 and layer 3 given the direction.
if the projection road goes through the inactive material between two chips, then expected hit in that layer is 0.

✦Tight case if expected hit equals to obtained hit (nObtained == nExpected)

✦Loose case if obtained hit is one less than expected hit (nObtained == nExpected - 1)

✦Any other scenarios are rejected from further processing.

SVD track fitting

- A common application of the singular value decomposition (SVD) is in fitting solutions to linear equations.
- Suppose we collect (x_i, y_i) data, which can be fit to some linear homogeneous equation $ax_i + by_i - c = 0$. If we have our data in a matrix A, and the coefficients in some vector v, we can write this problem as $Av = 0$, where we'd like to figure out what v is given A
- We usually have more data than coefficients, in which case we can't solve this
- However, we can fit v to A in order to minimise the value of Av via SVD
- Suppose we take the singular value decomposition of $A \rightarrow A = U\Sigma V^{\mathrm{T}}$
- If one of the singular values is 0 then we have an exact solution
- If none of the singular values are zero, we have no exact solution
- However, it can be shown that the smallest singular value corresponds to the solution of the linear least squares fitting problem
- Namely, if we want to find the least squares fit to the data, we need to look at the smallest (usually the last) singular value and read the respective column of V to get the best fit coefficients (a, b, c)

From Noam