GBP-MC Simulation Update

Kyle Fleck, Niall Cavanagh and Dr. Gianluca Sarri

10/05/21

Updates

- After discussion with Tom, found that there is a fault with the angular distribution with the IPstrong MC data for the IP
- The GEANT4 simulation analysed to far has been using this
- New Ptarmigan data for xi = 1.0, w0 = 5 μm is being used now in FLUKA simulations

Ptarmigan Parameters

- Ptarmigan parameters used to generate xi = 1.0, w0 = 5.0 µm MC data
- Initial electron energy 16.5 GeV, 1e6 macro-particles
- Coordinate system defined along beam axis
- RMS divergence is divergence of source electron beam 8.672 µrad
- Assumes beam emittance of 1.4 mm mrad with transverse size 5.0 µm
- Laser energy 1.55 eV

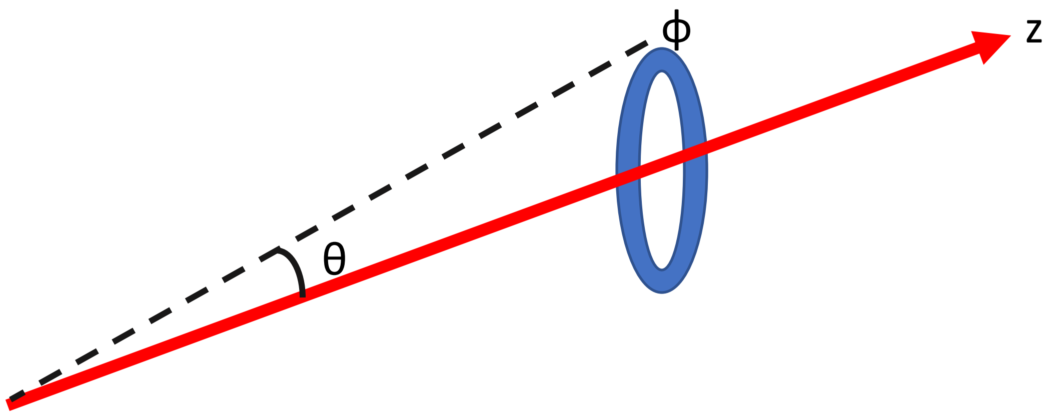
```yaml
---
control:
  dt_multiplier: 0.1

laser:
  a0: xi
  wavelength: wavelength
  fwhm_duration: 25.0 * femto
  # w0 [micron] = 147.839 sqrt(E [J]) lambda [micron] / (a0 sqrt(t [fs]))
  waist: 147.839 * sqrt(laser_energy) * wavelength / (xi * sqrt(25.0))

beam:
  ne: 1000000
  charge: 1.5e9 * e
  gamma: initial_gamma
  sigma: 0.001 * initial_gamma
  radius: [5.0 * micro, normally_distributed]
  length: 24.0 * micro
  collision_angle: -17.2 * degree
  rms_divergence: 8.672 * micro

output:
  ident: 1.00x5
  dump_all_particles: plain_text
  electron: [energy]
  photon: [energy:birth_a]

stats:
  electron:
    - total number
    - mean energy
  photon:
    - total number
    - mean energy

constants:
  laser_energy: 0.8 # joules
  wavelength: 0.8 * micro
  xi: 1.0
  initial_gamma: 16.5 * GeV / (me * c^2)
```

Geometrical Discussion

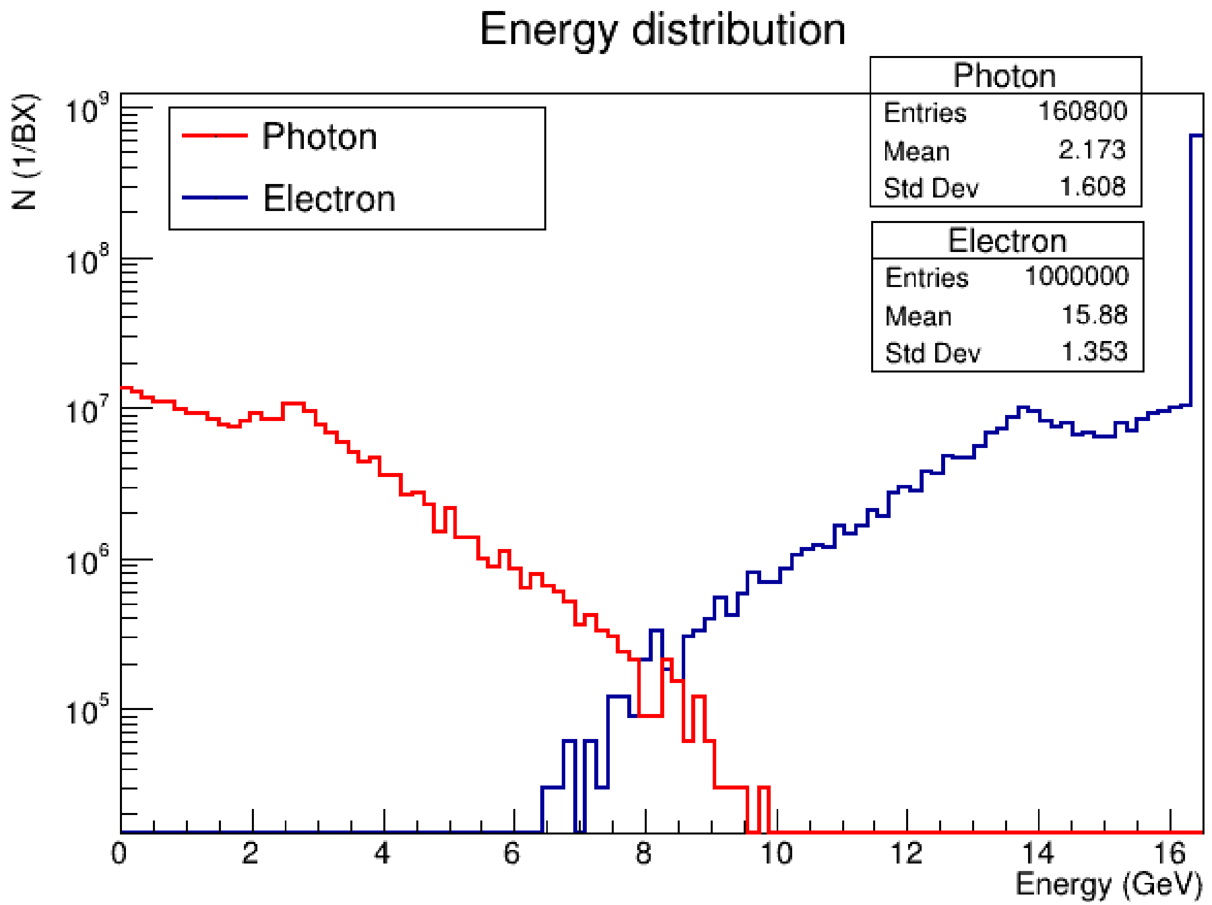
- Polar axis defined along electron beam direction (z)
- Polar angle then deflection from beam axis
- Azimuthal angle is angle around beam
- Angles calculated from direction cosines of momentum vector

```
#-----------------------------------------------------------------------------------------------------------------------------------
# Particle properties when tracking stops
#-----------------------------------------------------------------------------------------------------------------------------------
# First interacting species: electron          Second interacting species: laser
# First initial particle energy = 10.0000 +/- 0.1000 GeV, Sigma_xyz = 5.00 5.00 24.00 microns
# Laser peak intensity = 8.56 x 10^18 W/cm^2, wavelength = 800.00 nm, pulse length = 25.00 fs, beam waist = 10.58 microns
# Pulse peak xi = 2.0000, chi = 0.2321
#-----------------------------------------------------------------------------------------------------------------------------------
```

# E (GeV)	x (micron)	y (micron)	z (micron)	p_x (GeV/c)	p_y (GeV/c)	p_z (GeV/c)	PDG_NUM	MP_Wgt	MP_ID	t (um/c)	xi
1.003729e1	-5.598046e0	-3.273277e0	9.411929e0	7.358768e-5	-1.264559e-5	1.003729e1	11	1.500000e3	0	1.516238e1	0.000000e0
1.010601e1	7.151462e0	-5.089289e0	-1.069144e1	4.185433e-5	9.300425e-7	1.010601e1	11	1.500000e3	1	3.060678e1	0.000000e0
1.006825e1	4.444457e0	7.241354e-1	2.428494e0	-5.390687e-5	2.446395e-6	1.006825e1	11	1.500000e3	2	1.885478e1	0.000000e0
9.938964e0	-6.493028e0	-1.277404e0	7.456709e0	6.354960e-5	-9.029412e-5	9.938964e0	11	1.500000e3	3	1.730143e1	0.000000e0
1.016594e1	5.475384e0	3.724210e0	1.804165e1	1.363695e-4	-1.646280e-4	1.016594e1	11	1.500000e3	4	3.639566e0	0.000000e0
9.798048e0	5.570407e0	-1.038583e0	1.619203e1	4.898384e-5	1.155994e-4	9.798048e0	11	1.500000e3	5	5.371172e0	0.000000e0
8.490772e0	-1.070701e1	-6.911075e0	-2.935829e0	5.206560e-5	-5.642856e-5	8.490772e0	11	1.500000e3	6	2.846774e1	0.000000e0
8.801542e0	-4.406956e0	1.689439e0	5.716518e0	-1.854832e-4	-1.471069e-4	8.801542e0	11	1.500000e3	7	1.833275e1	0.000000e0
1.004843e1	6.413293e-1	4.190397e0	2.003385e1	9.283460e-6	1.237667e-4	1.004843e1	11	1.500000e3	8	3.181200e0	0.000000e0
9.964726e0	-5.601759e0	1.940726e0	-1.309887e0	-5.267399e-6	1.528170e-4	9.964726e0	11	1.500000e3	9	2.539923e1	0.000000e0
1.004526e1	-1.758977e0	-2.039647e0	3.003312e1	3.260226e-5	-3.123452e-5	1.004526e1	11	1.500000e3	10	-5.667815e0	0.000000e0
1.001196e1	-3.146929e-1	1.837328e0	-9.104778e-1	2.119801e-5	2.205038e-7	1.001196e1	11	1.500000e3	11	2.346391e1	0.000000e0
9.963854e0	-1.253322e1	1.210741e0	3.232870e1	-5.754779e-5	-2.787090e-5	9.963854e0	11	1.500000e3	12	-4.687421e0	0.000000e0



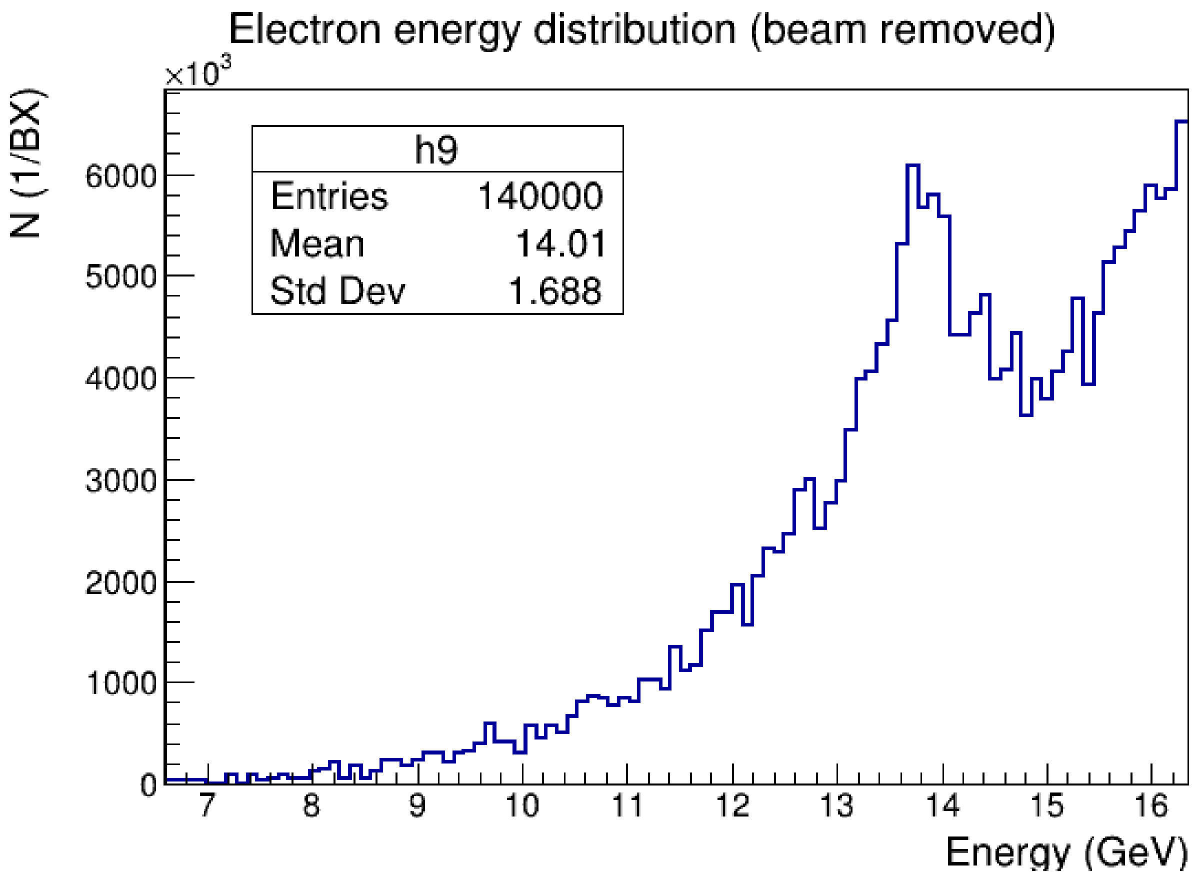
Ptarmigan – energy distribution



- For electron-laser (HICS) setup, maximum photon energy is ~10 GeV
- Peak in electron spectrum at 16.5 GeV corresponds to source XFEL beam
- First order Compton edge at ~3 GeV as expected from

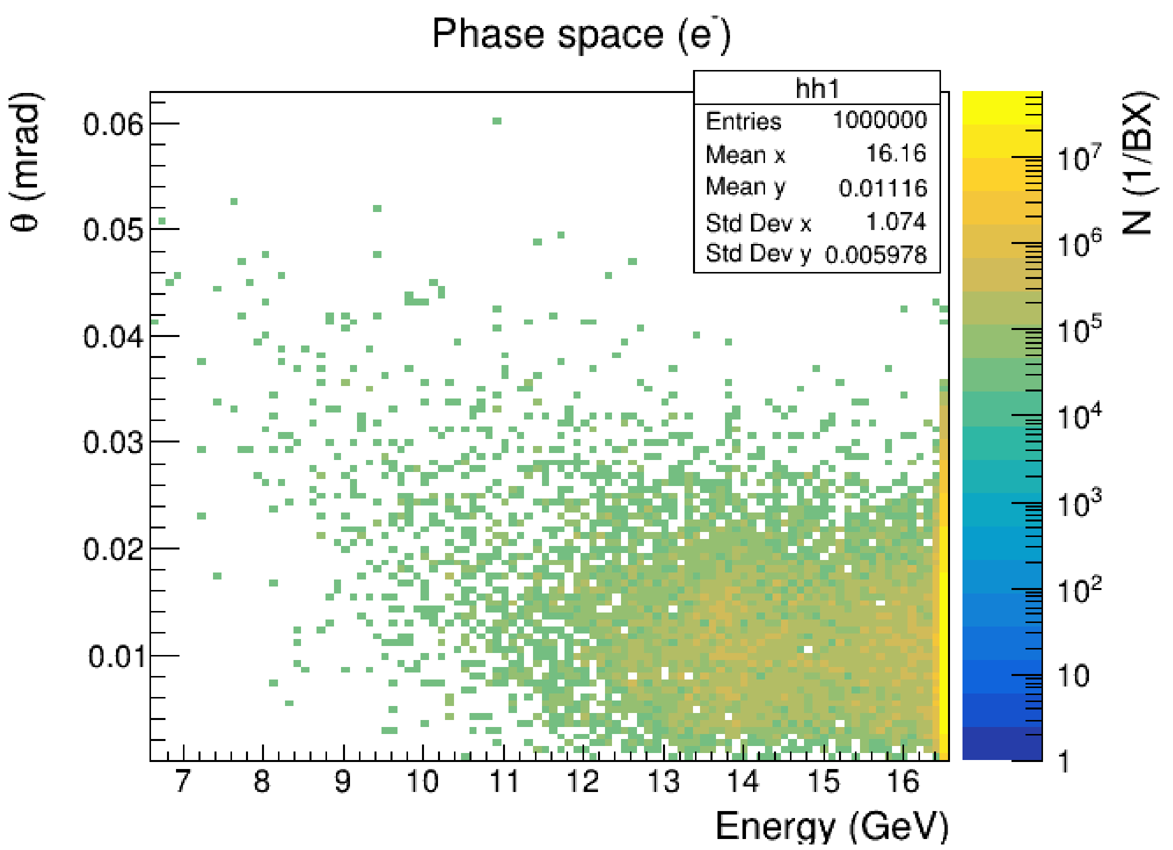
$$\omega' \approx \frac{4\gamma^2\omega_0}{1+\xi^2}$$

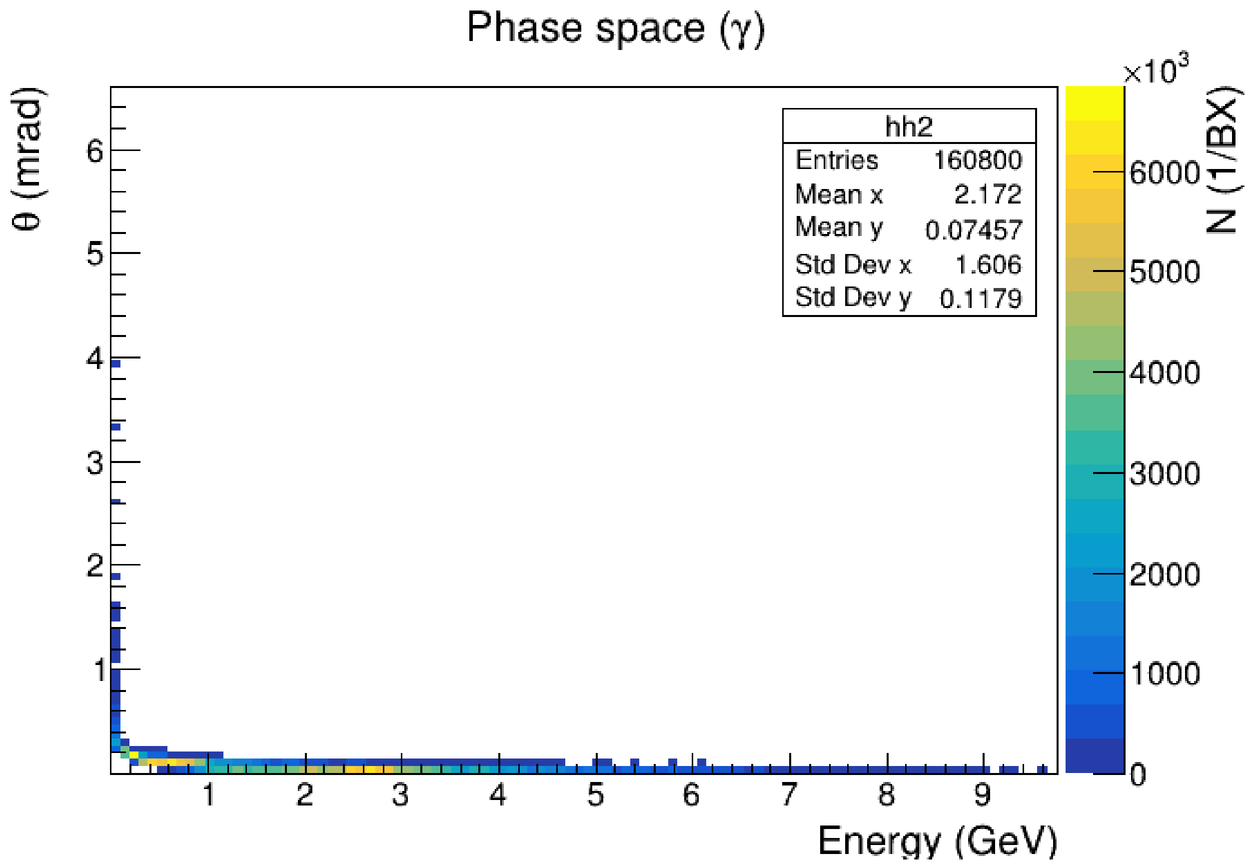
Ptarmigan – electron energy distribution



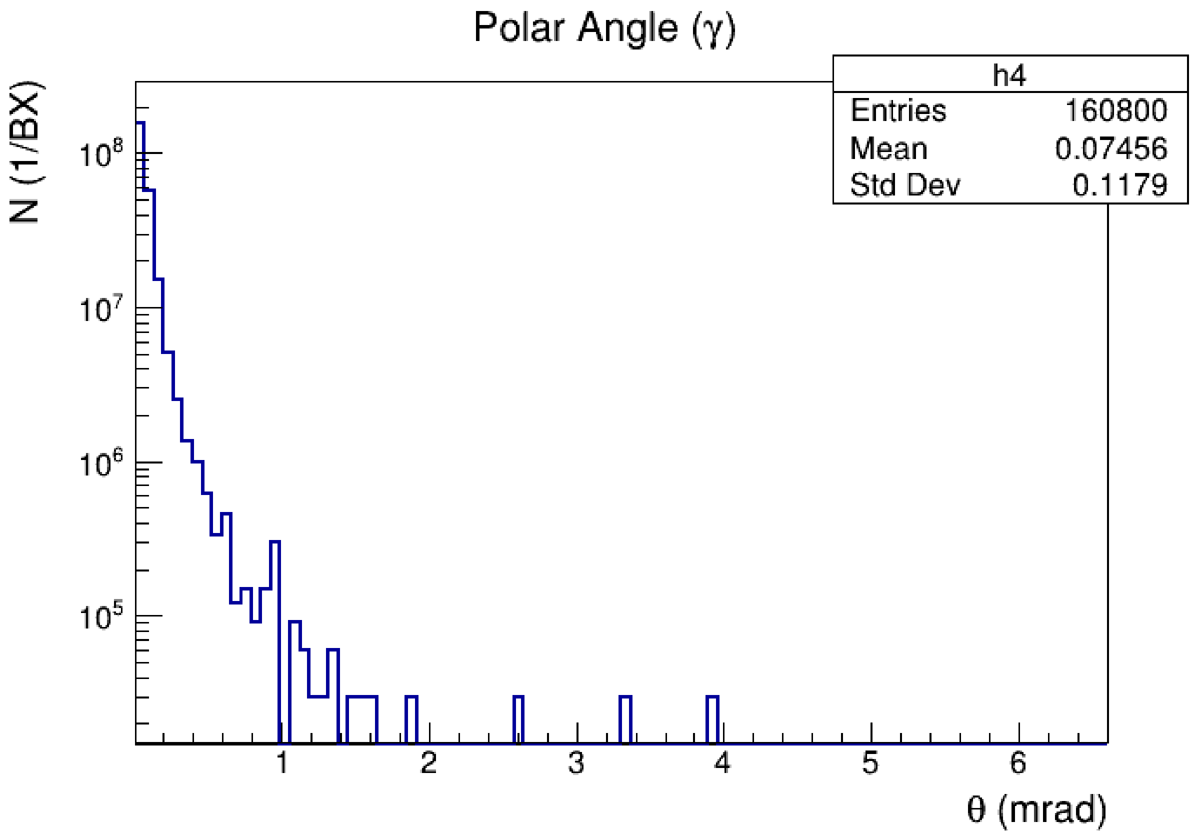
- Contribution due to source beam on energy distribution removed
- Mean electron energy 14.0 GeV
- Corresponds to a Lorentz factor of 27397
- Xi/gamma = 36.5 μrad

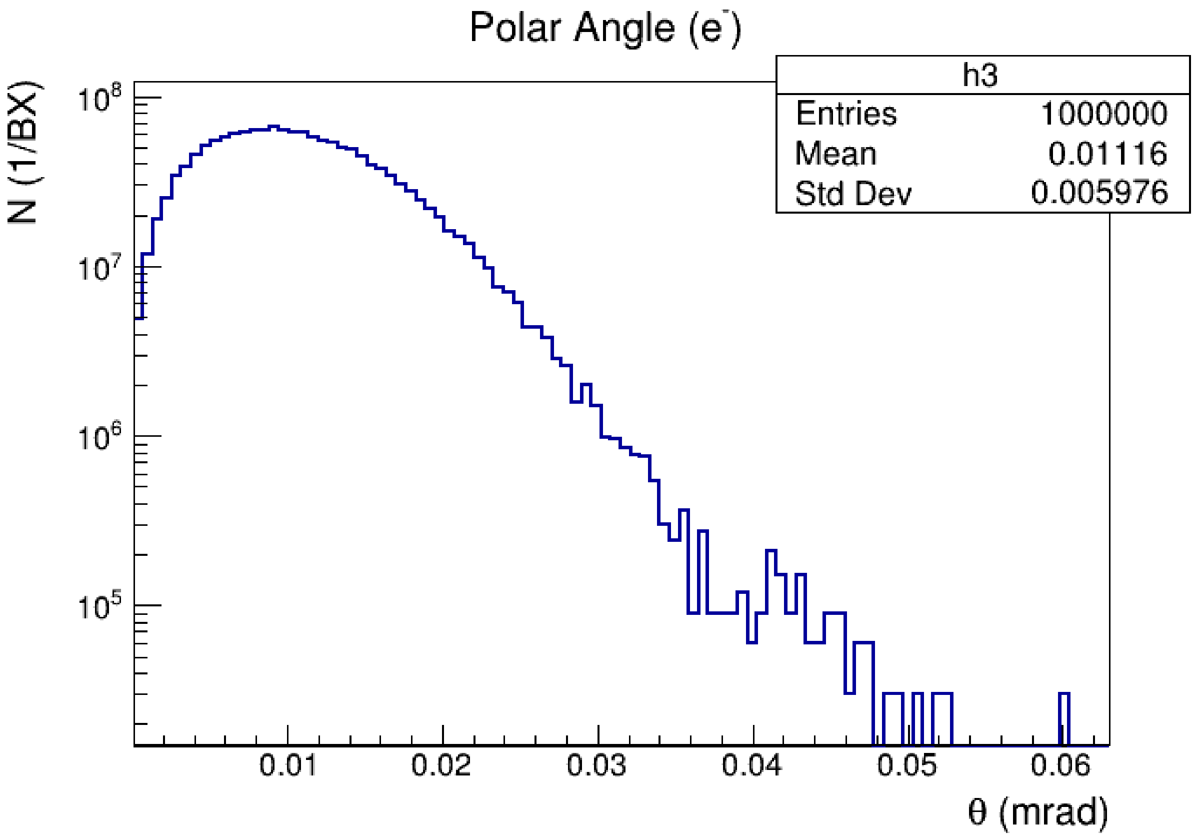
Ptarmigan – phase space





Ptarmigan – polar angle



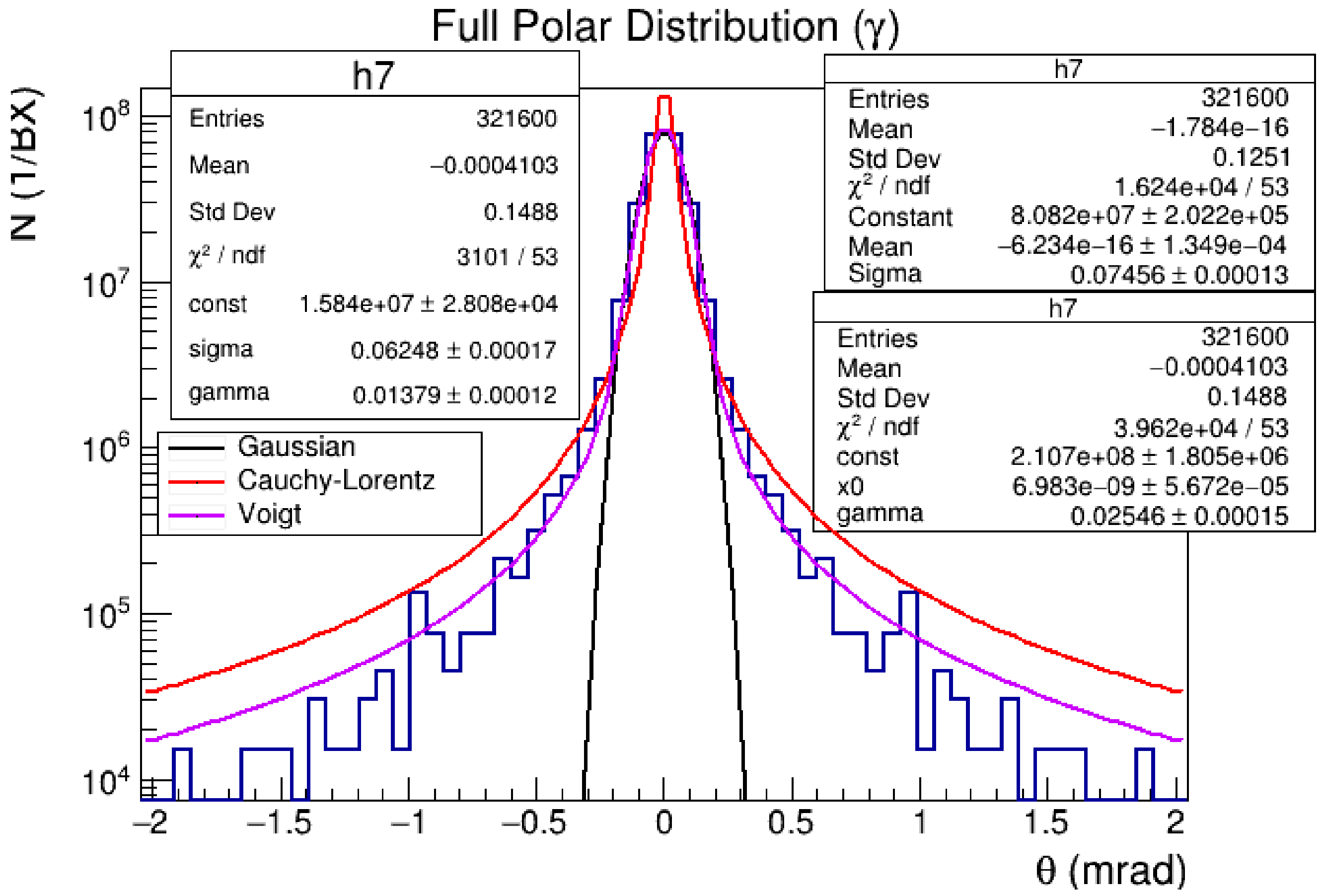


Ptarmigan – measurement of beam width

- Photon polar angle assumed to be symmetric about 0.0 with weights satisisfying

$$W(|\theta|) = W(\theta) + W(-\theta)$$

- Fitted with Gaussian, Cauchy-Lorentz and Voigt profiles
- Within central range of –2.0 mrad to 2.0 mrad, Voigt profile gives best fit
  - Captures peak like Gaussian fit
  - Tails extend farther into data

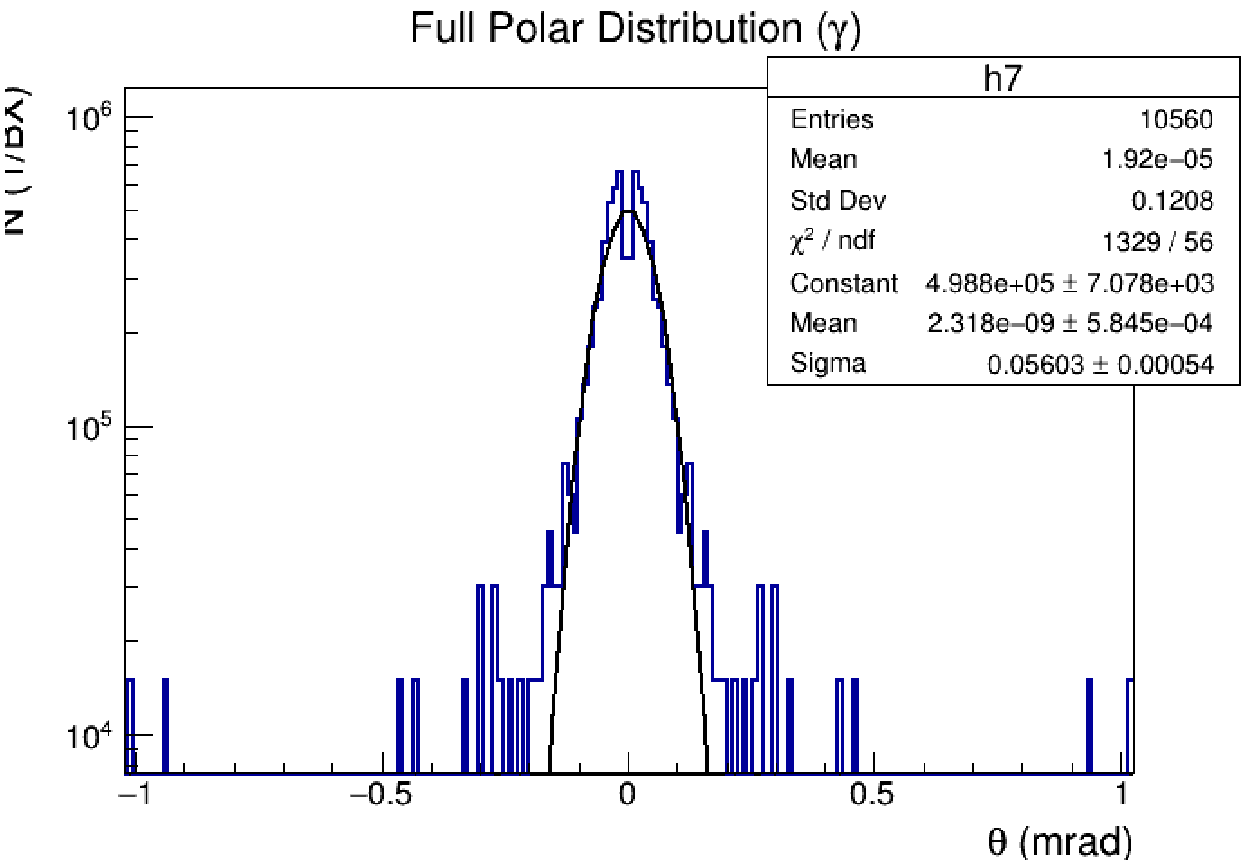


Measurement of beam width

- Around central peak, Gaussian (and Voigt) give good fit
- From Gaussian fit, sigma = 74.56 μrad
- Using average xi/gamma from slide 6, photon divergence 37.5 μrad

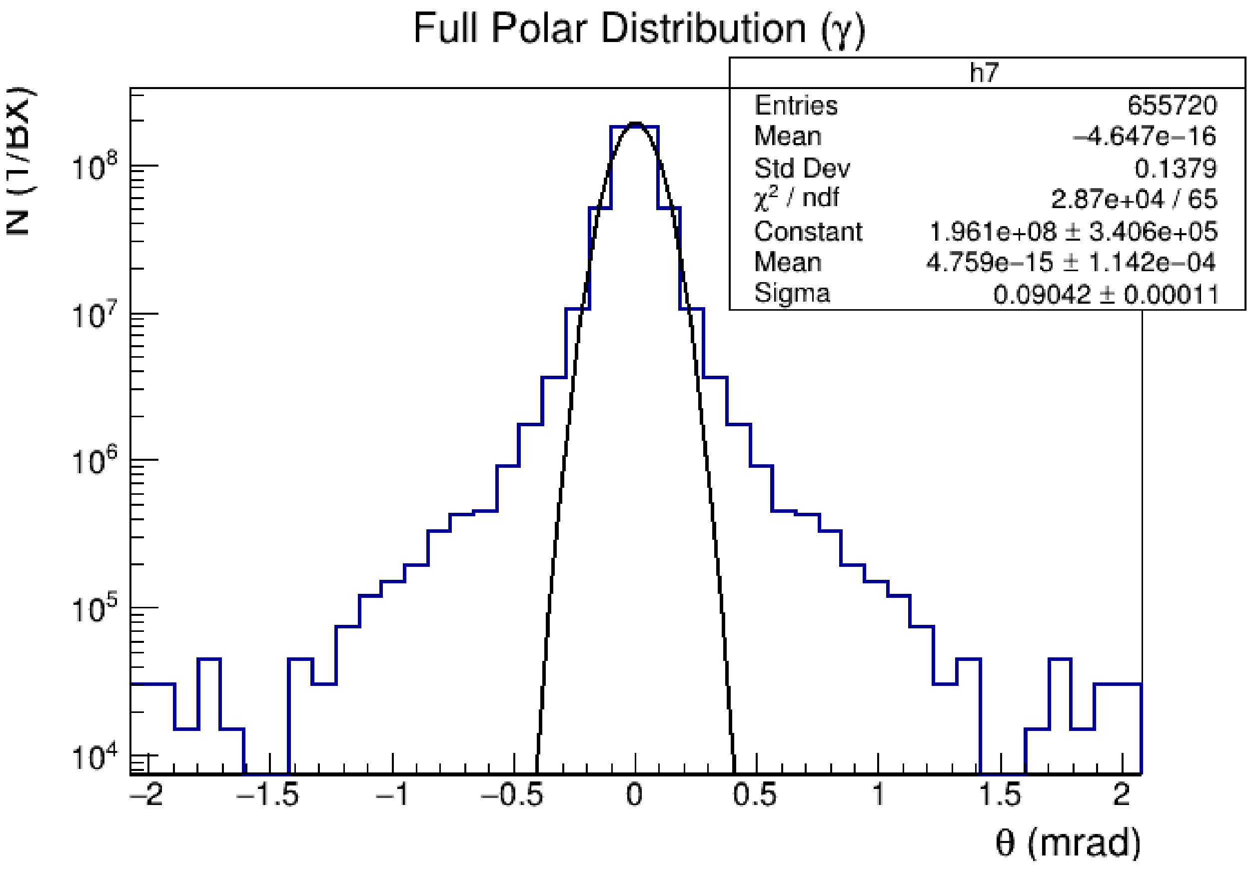
Ptarmigan – xi = 0.15, w0 = 5μm

- Following similar procedure
  - Average electron energy after interaction = 14.06 GeV -> gamma = 27516
  - Xi/gamma = 5.45 μrad; 1/gamma = 36.34 μrad
  - Std dev from Gaussian fit to polar angle distribution = 56.03 μrad
  - Anticipated photon divergence = 8.76 μrad



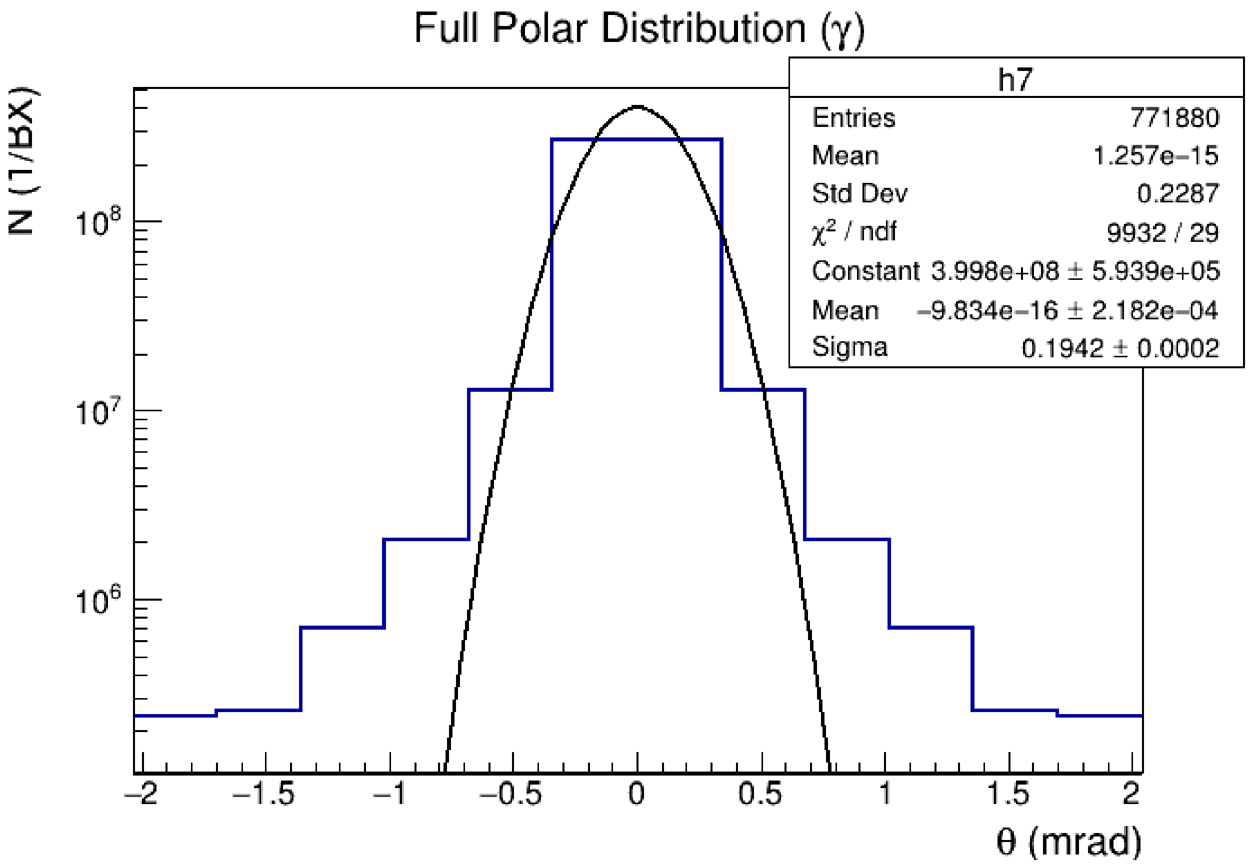
Ptarmigan – xi = 2.0, w0 = 5µm

- Following similar procedure
  - Average electron energy after interaction = 13.75 GeV -> gamma = 26908
  - Xi/gamma = 74.32 µrad
  - Std dev from Gaussian fit to polar angle distribution = 90.42 µrad
  - Anticipated photon divergence = 74.8 µrad



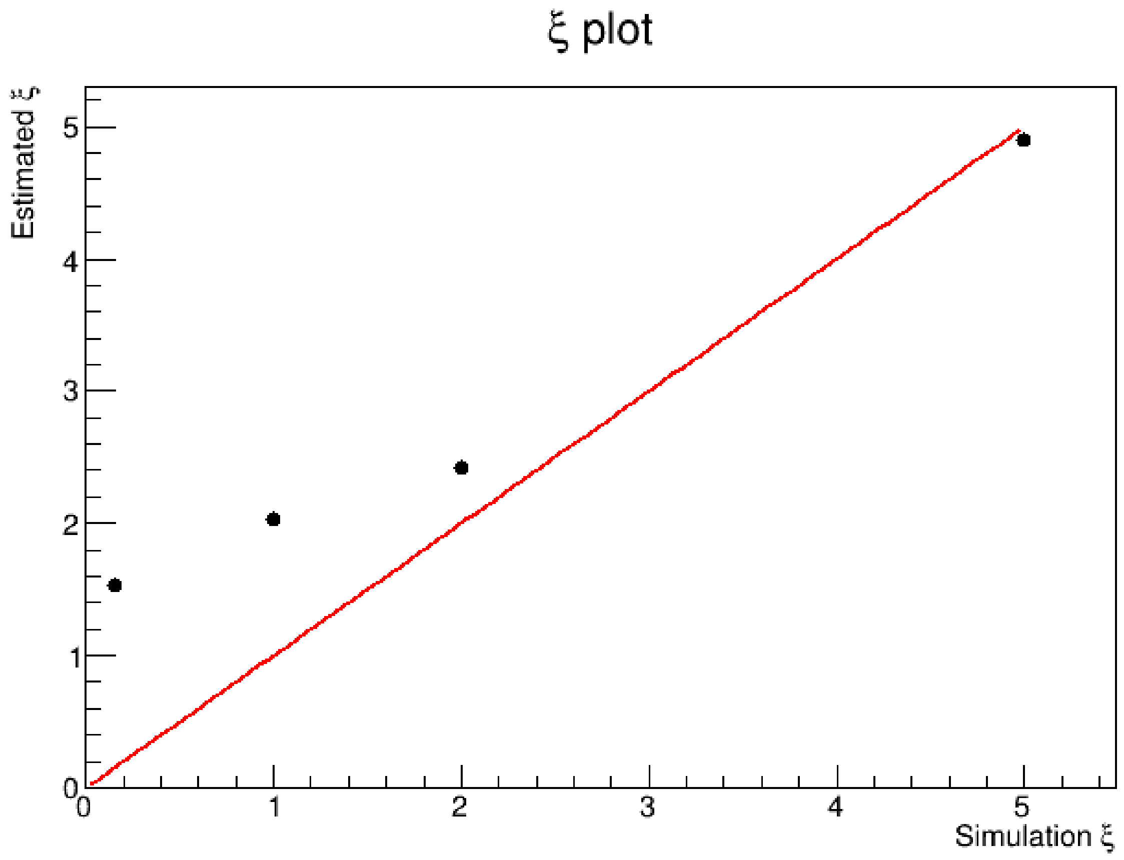
Ptarmigan – xi = 5.0, w0 = 5μm

- Following similar procedure
  - Average electron energy after interaction = 12.9 GeV -> gamma = 25240
  - Xi/gamma = 198.10 μrad
  - Std dev from Gaussian fit to polar angle distribution = 194.2 μrad
  - Anticipated photon divergence = 198.23 μrad



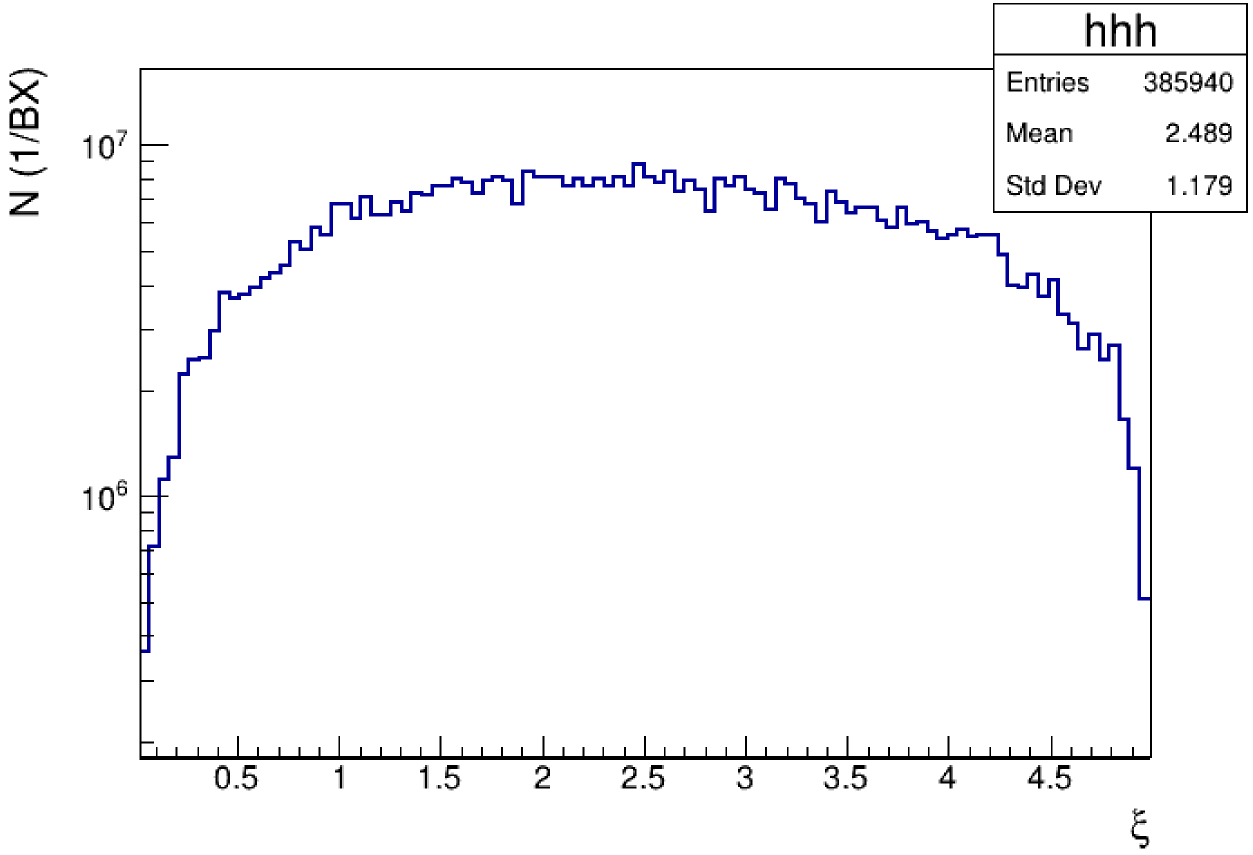
Ptarmigan – simulation xi vs estimated xi

- Reverse engineering of previous method
- Taking sigma as the photon divergence, calculate xi/gamma as $\frac{\xi}{\langle\gamma\rangle} \approx \sqrt{\theta_\gamma^2 - \theta_e^2}$
- Using average Lorentz gamma factor of electrons, calculate estimated value of xi
- Ideally, the estimated value should equal the exact simulation value

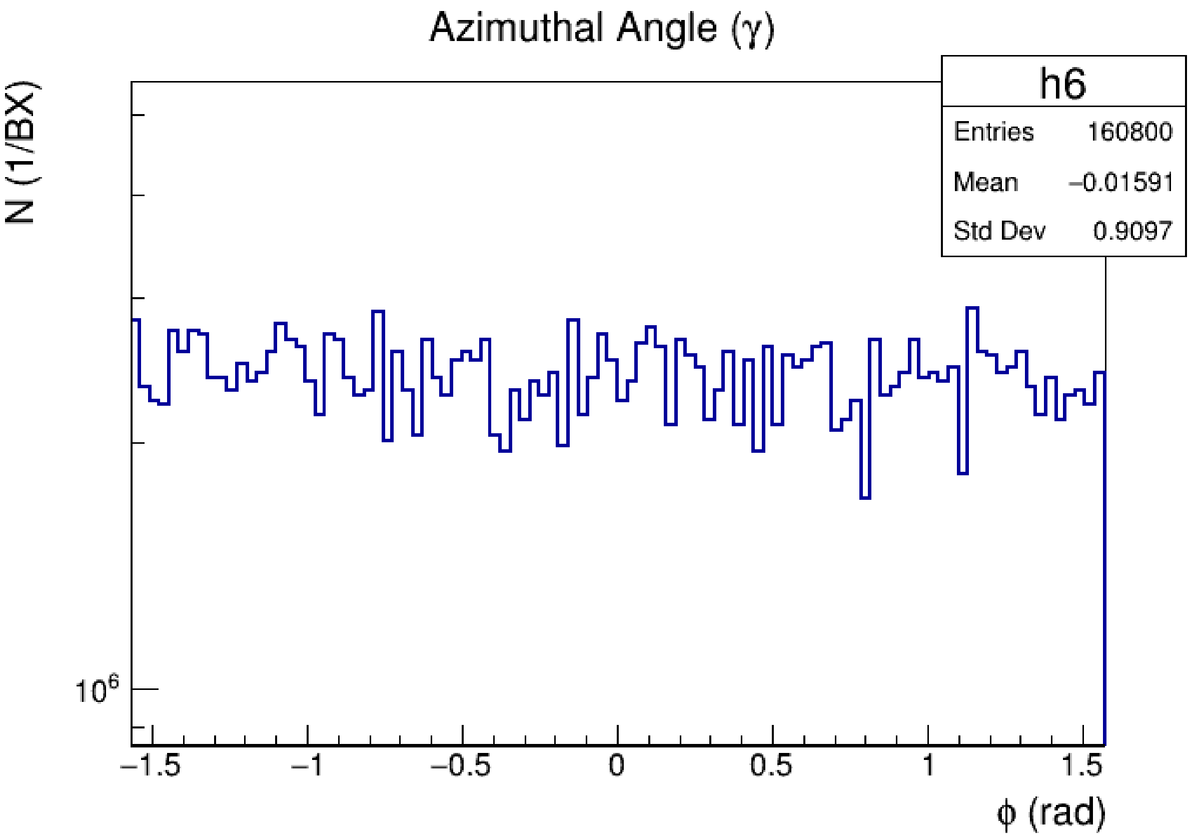


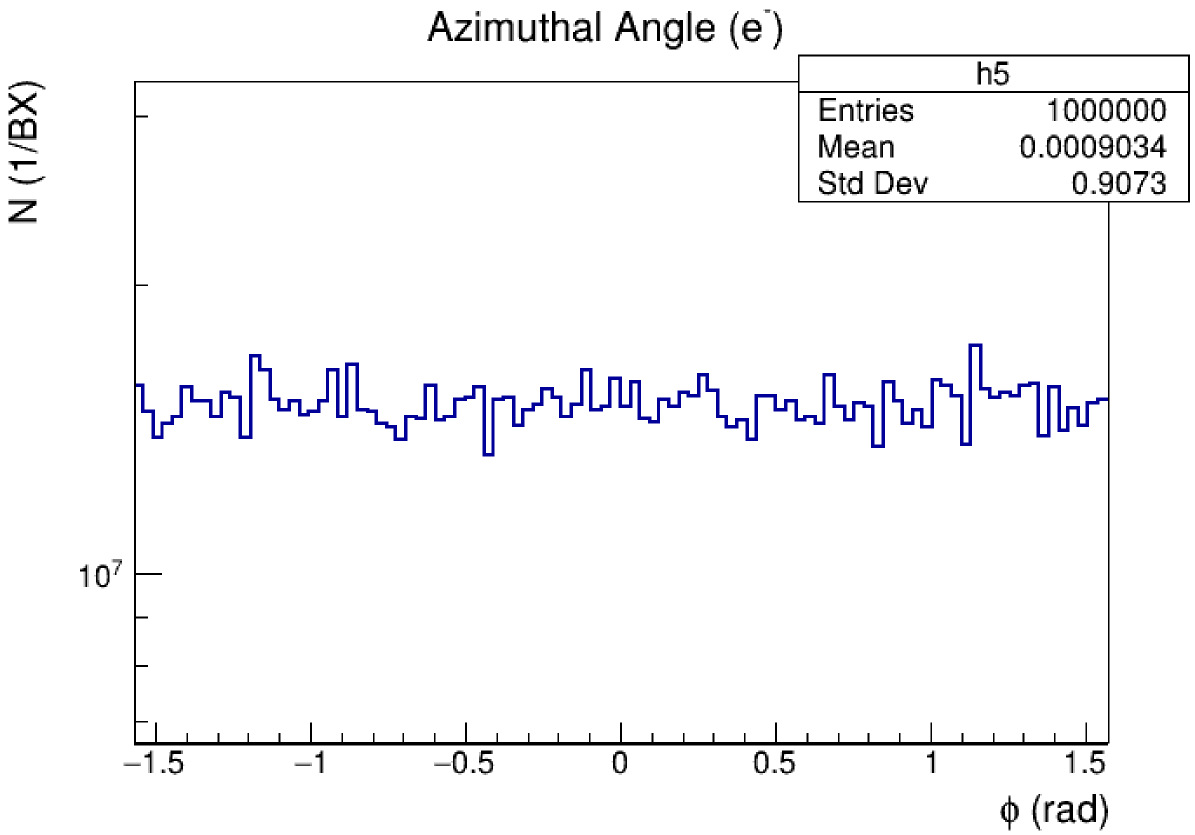
Ptarmigan – particle xi

- Ptarmigan data also includes the xi (a0) value that each macro-particle experiences
- For peak xi = 5.0, distribution shown on right
- Maximum xi value is 5.0, but most particles see a lower value of xi
- How to deal with this?



Ptarmigan – azimuthal angle





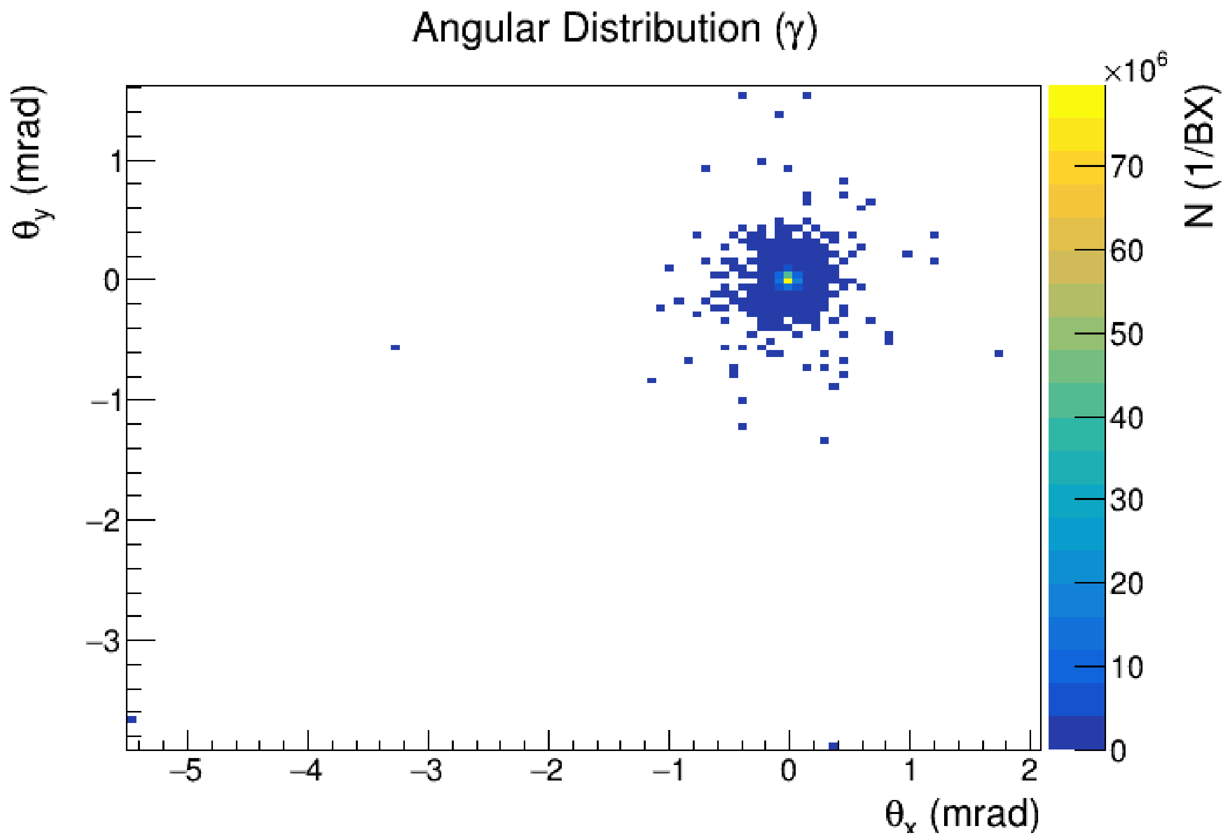
- Expect azimuthal angle to be uniformly distributed as laser is circularly polarised

Ptarmigan – Alternative angle measurement

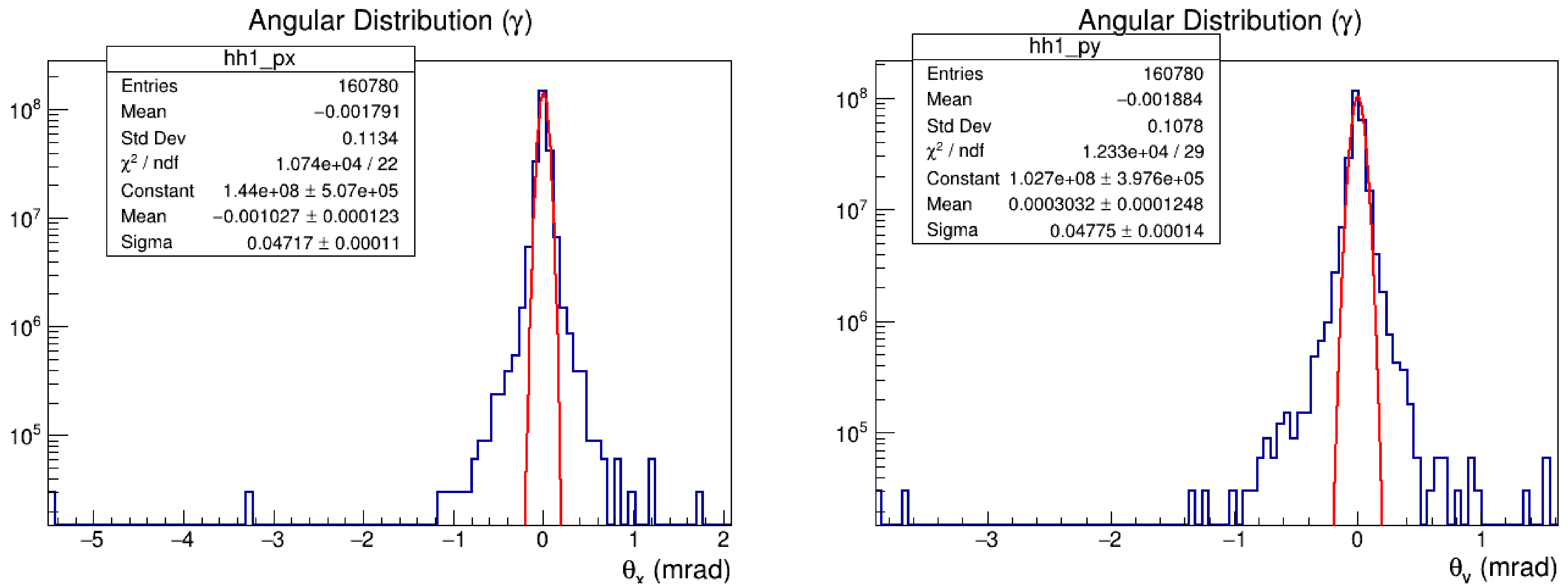
- Rather than generate the polar and azimuthal angles, make a 2D distribution of the x and y direction cosines
- Allows for independent measurement of xi in two orthogonal directions – more similar to method used for profiler
- Estimated xi can be calculated using a weighted average of the two measuremtents for circular polarisation
- For linear polarisation (not yet simulated), ratio of measurements van be taken to extract value of xi

Ptarmigan – xi = 1.00

- Arccosine of each momentum direction cosine expressed in mrad
- Subtracted from pi/2 to centre distribution at zero
- Orthogonal projections of this distribution can be used to estimated photon divergence



Projections of direction cosine distributions

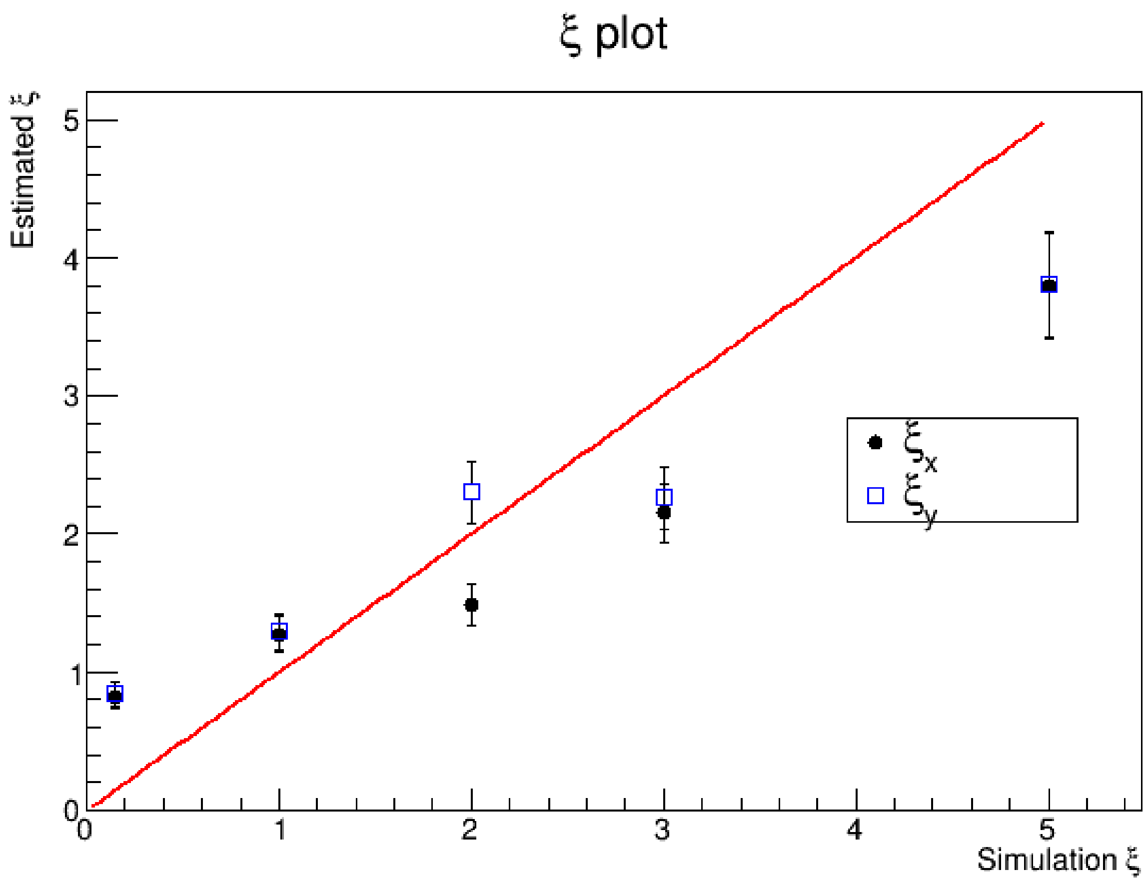


Extraction of xi

- Standard deviation taken from Gaussian fitting used as photon divergence
- Xi value found from

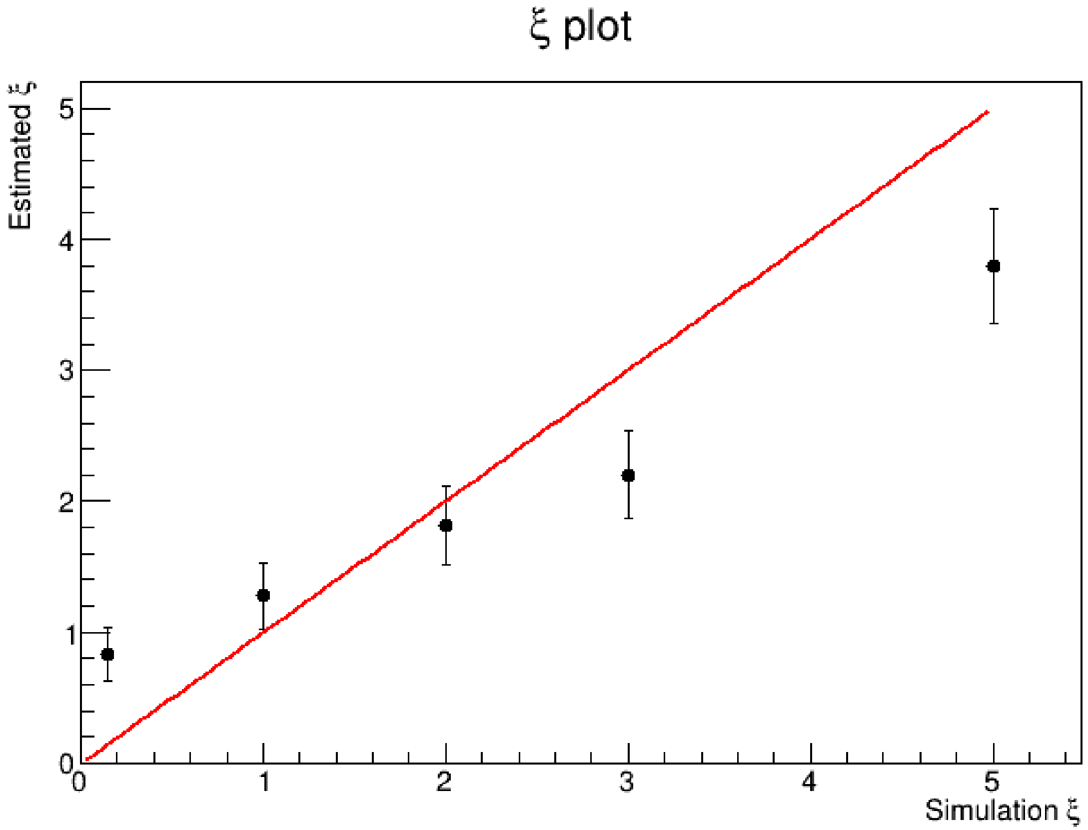
$$\xi \approx \langle\gamma\rangle\sqrt{\theta_\gamma^2 - \theta_e^2}$$

- Mean gamma found using mean electron energy like in slide 6
- Error bars come from error in fitting and a nominal 10% error in estimating mean gamma – corresponds to ± 1 GeV



Extraction of xi

- Weighted mean of x and y values of xi calculated to give estimated xi
- For xi less than 1, 1/gamma cone is more dominant so don't expect a good measurement of xi here
- At larger xi, various effects occur
  - Nonlinear photon interaction means mean gamma becomes harder to estimate and increases divergence
  - Photon divergence lower than xi/gamma due to various impact parameters of electrons*



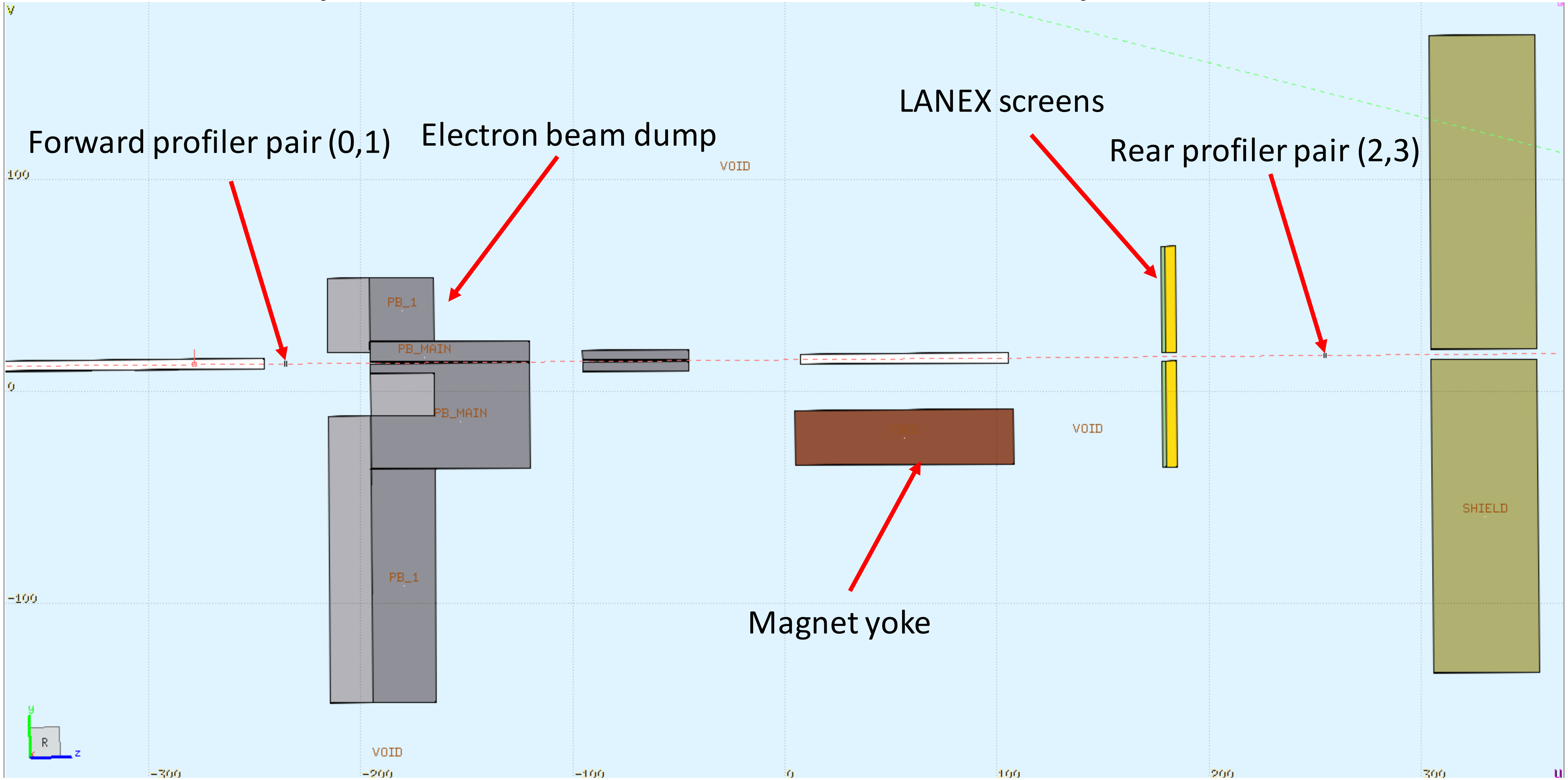
*see Blackburn, T. - Higher fidelity simulations of photon emission in intense laser pulses, pages 18 - 19

GBP-MC Simulation Update

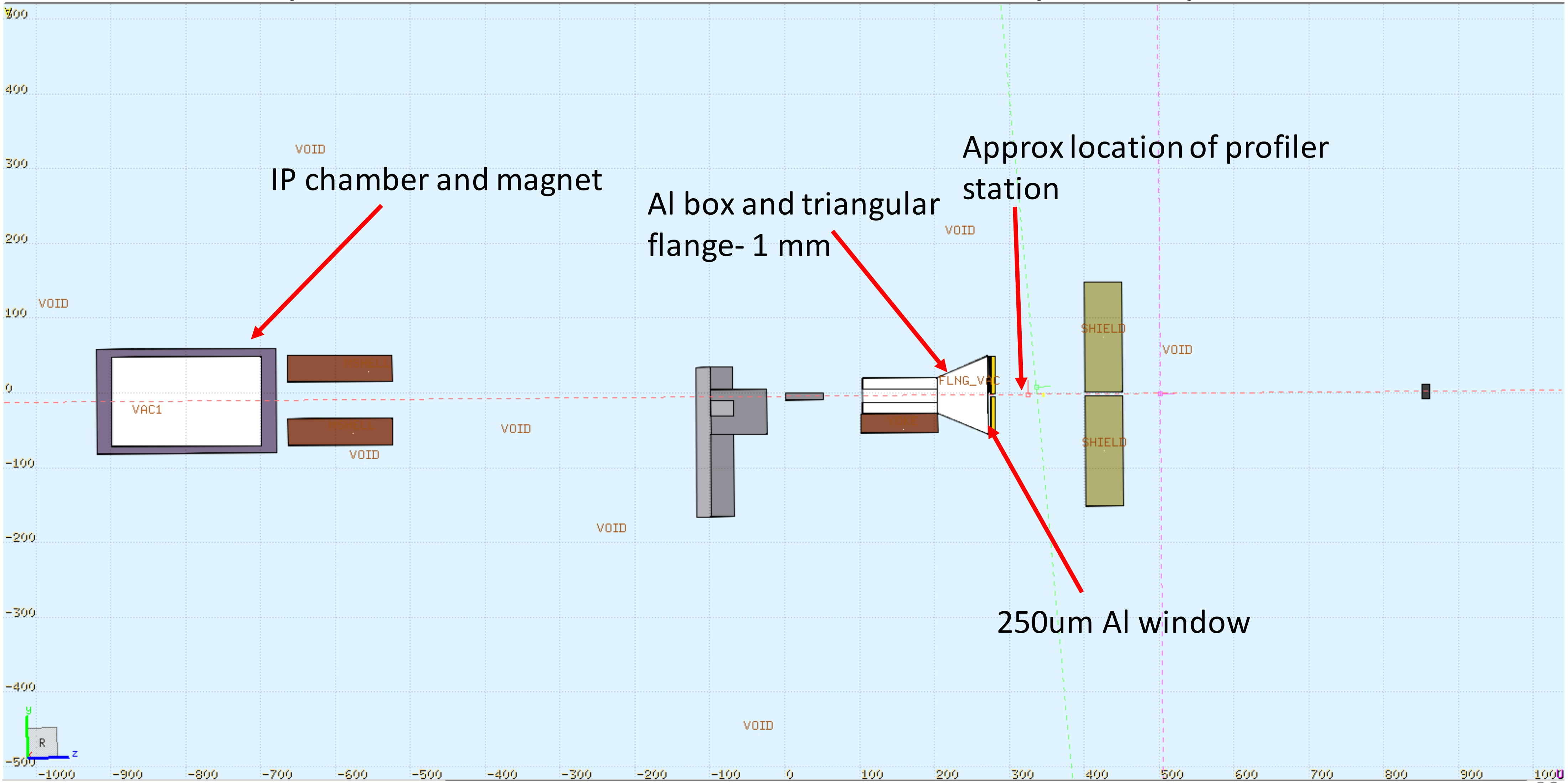
Kyle Fleck, Niall Cavanagh and Dr. Gianluca Sarri

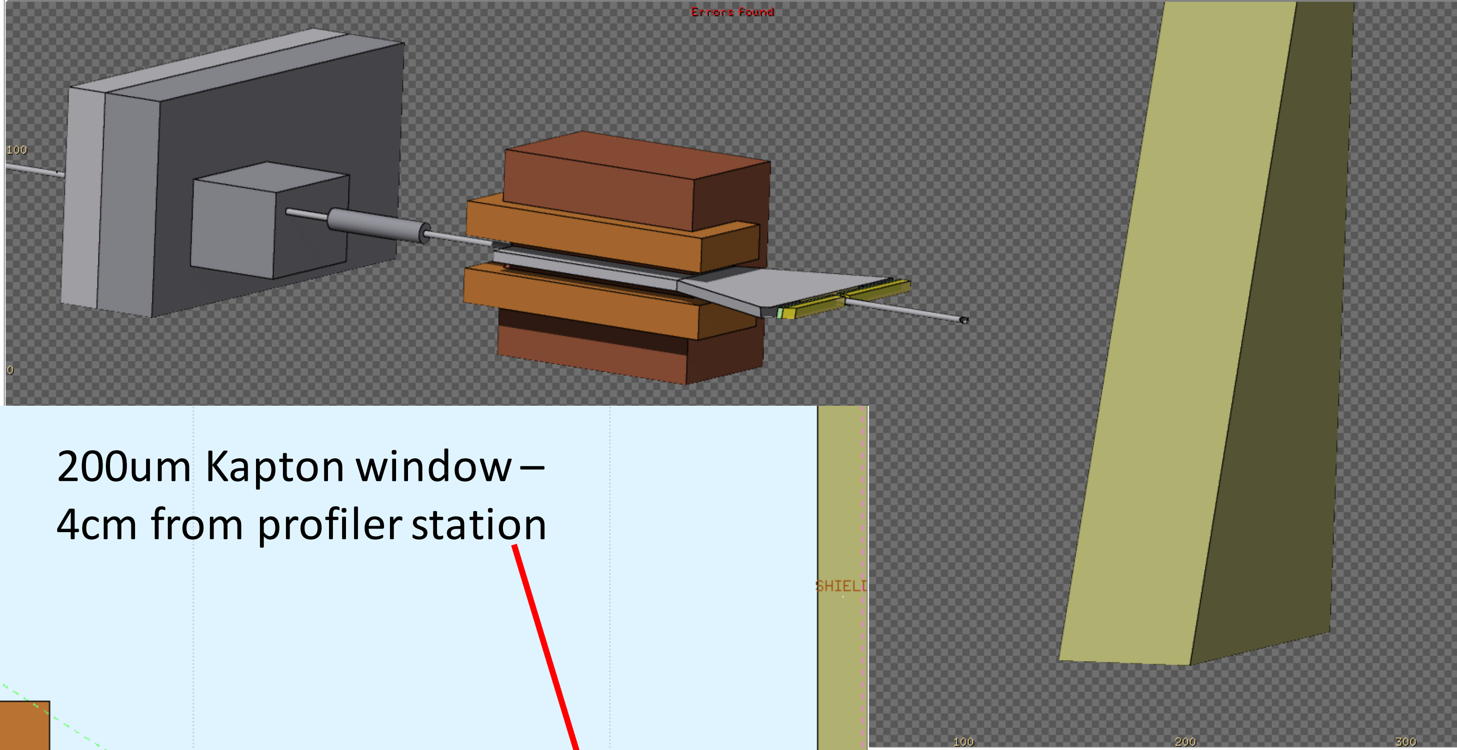
26/04/21

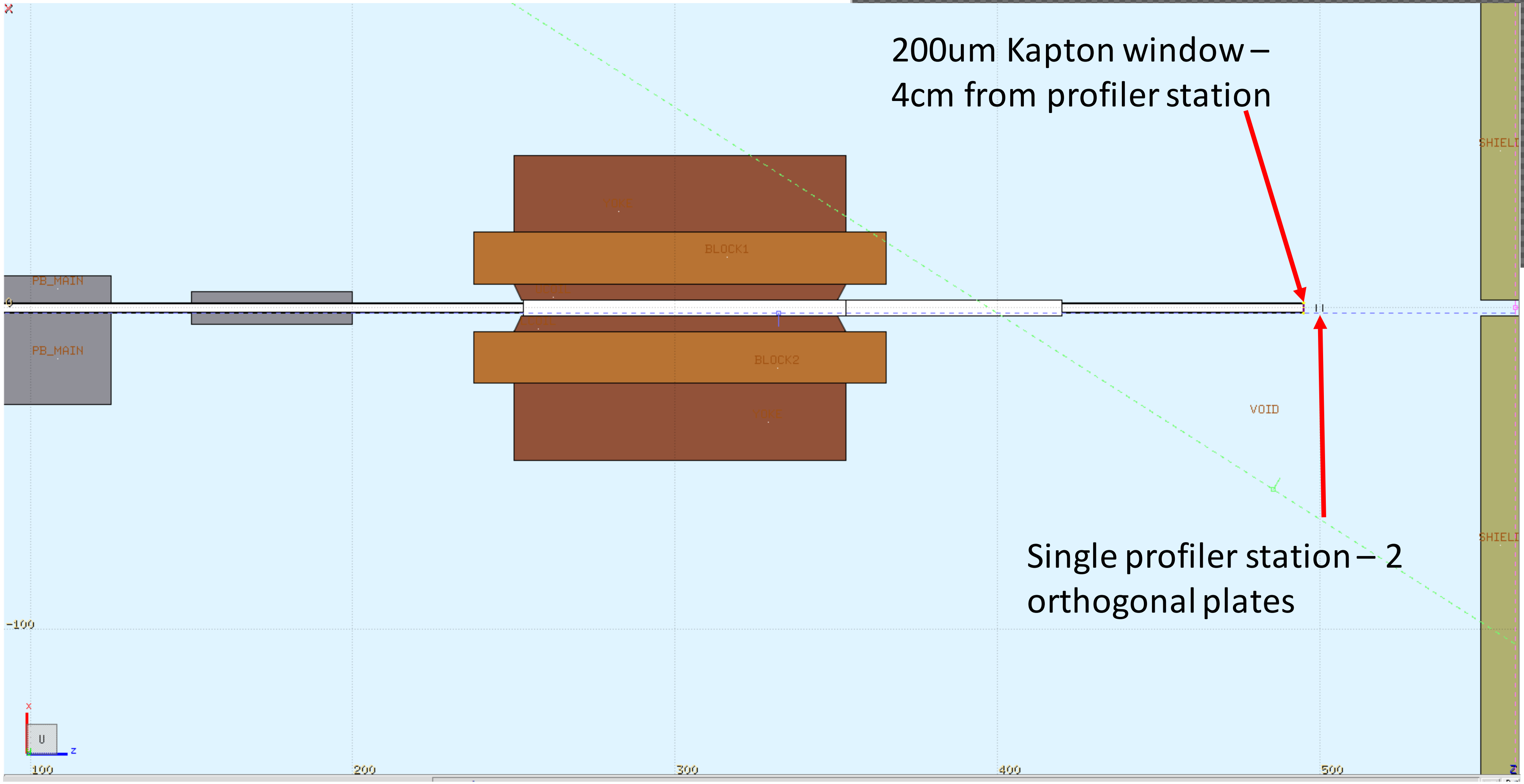
FLUKA Spectrometer Geometry - Old



FLUKA Spectrometer Geometry - Updated




Errors Found
100
0
100
200
300


200um Kapton window –
4cm from profiler station
PB_MAIN
PB_MAIN
BLOCK1
BLOCK2
VOID
Single profiler station – 2
orthogonal plates
-100
100
200
300
400
500

Things in progress

- Spectrometer geometry has been updated and simulations are running to test signal at profiler
- Aim to test 3 different profiler thicknesses – 50um, 100um and 150um
- Begin investigating charge sharing effects and a more realistic output from profiler after discussion of digitisation

GBP-MC Simulation Update

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12/04/21

Fitting Data

- Standard function for fitting is a Gaussian

$$f(x) = A\exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$$

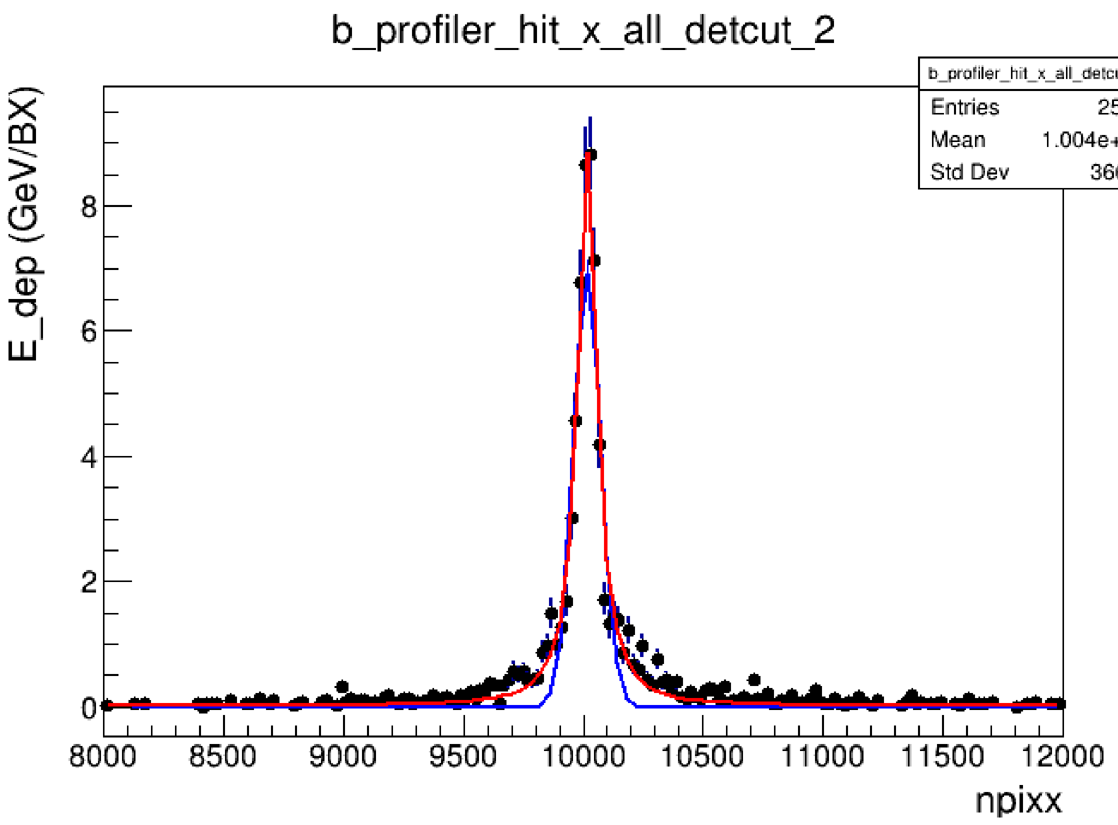
- Another possibility is a Cauchy-Lorentz distribution – similar to Gaussian but sharper peak

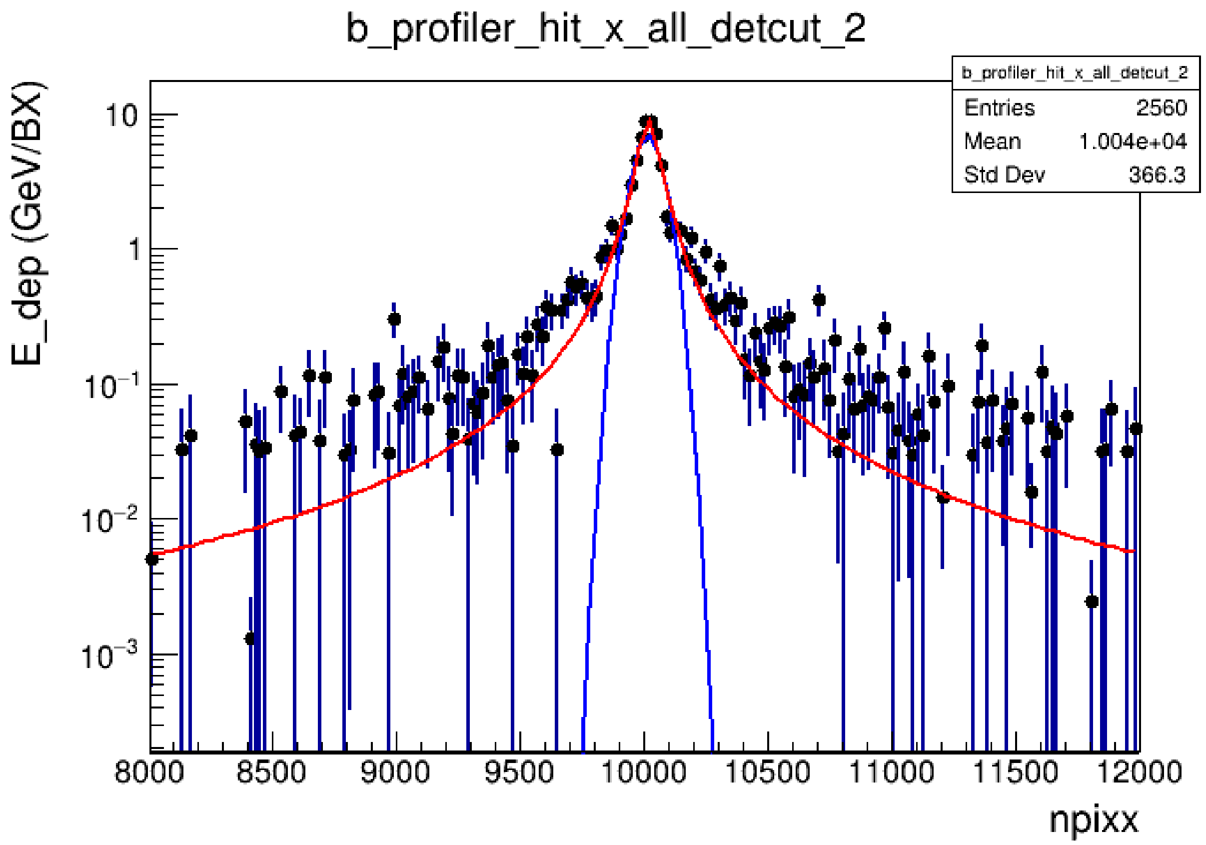
$$f(x) = \frac{A}{1+\left(\frac{x-x_0}{\gamma}\right)^2}$$

- Positional parameters: mu for Gaussian (mean) and x0 for CL
- Dispersion parameter: sigma for Gaussian (standard deviation) and gamma for CL -> related to FWHM

$$FWHM = 2\sigma\sqrt{2\ln 2} \qquad FWHM = 2\gamma$$

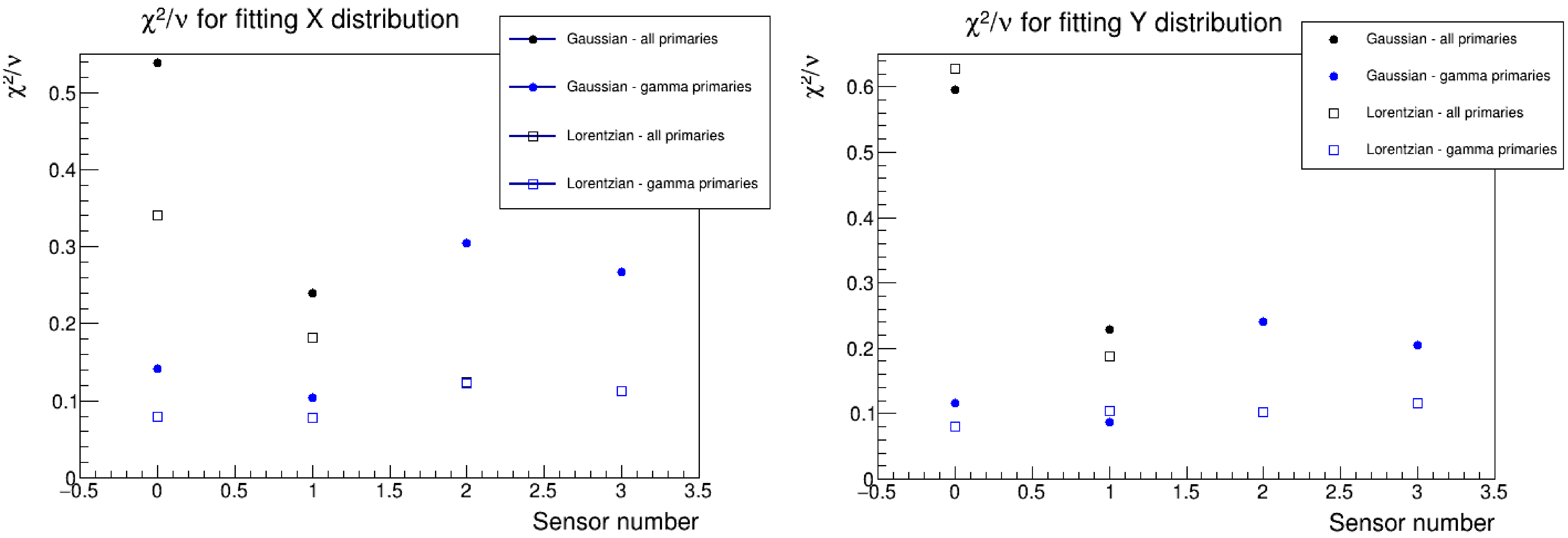
Example of fitting



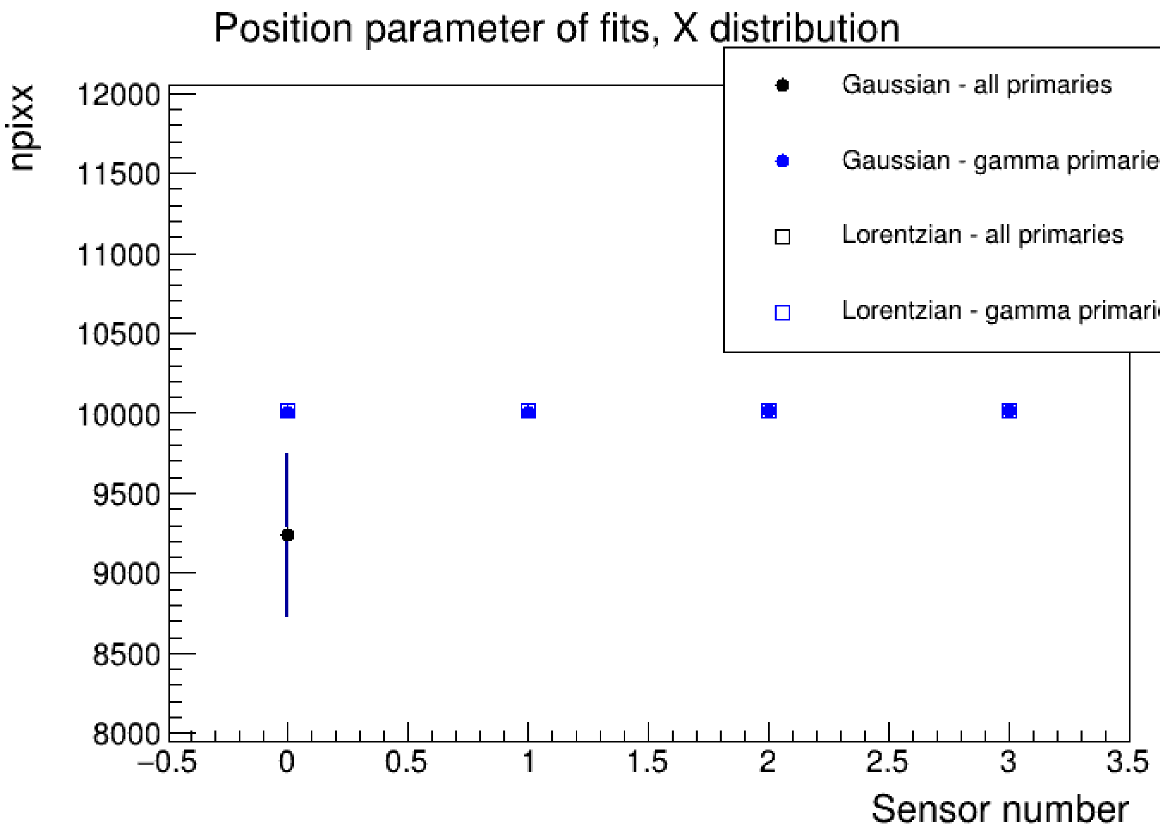


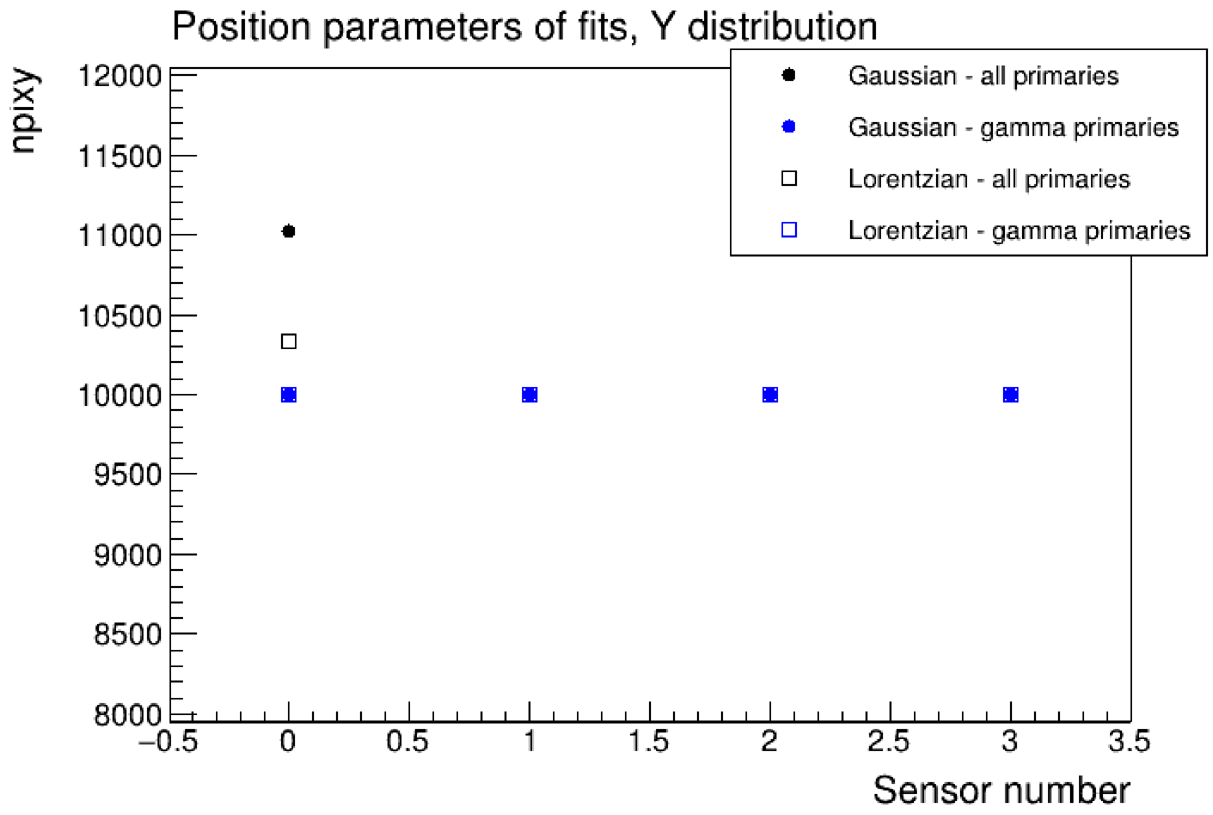
Cauchy-Lorentz
Gaussian

Comparison of goodness of fit



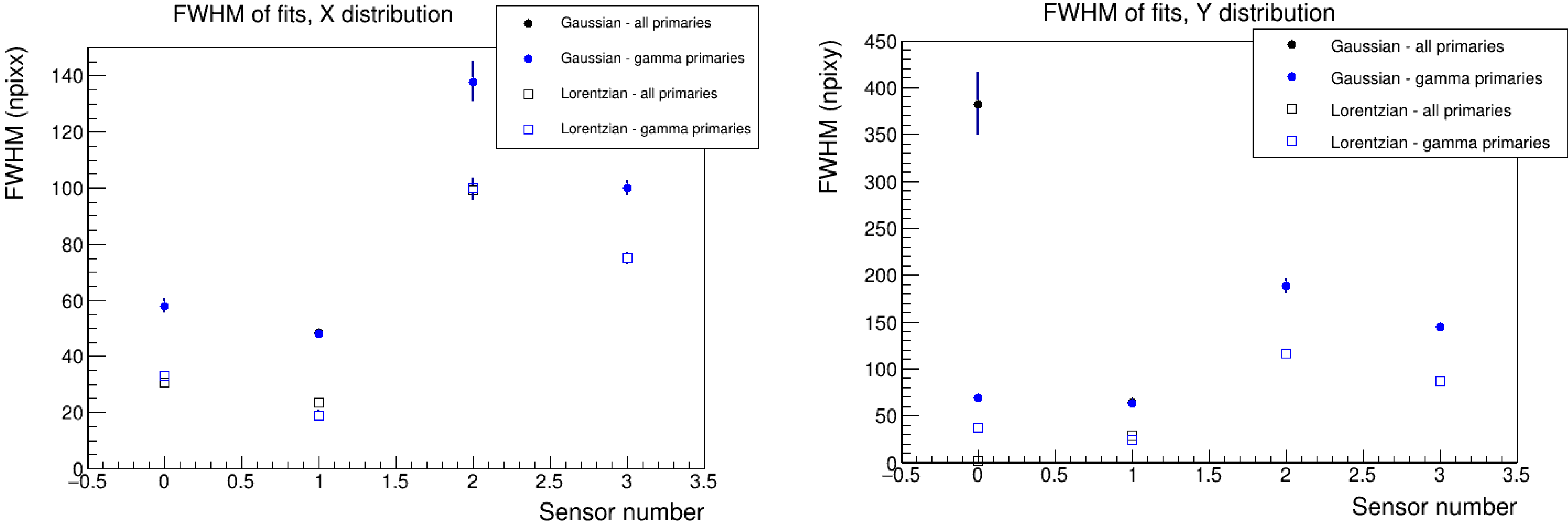
Location of centre of distributions





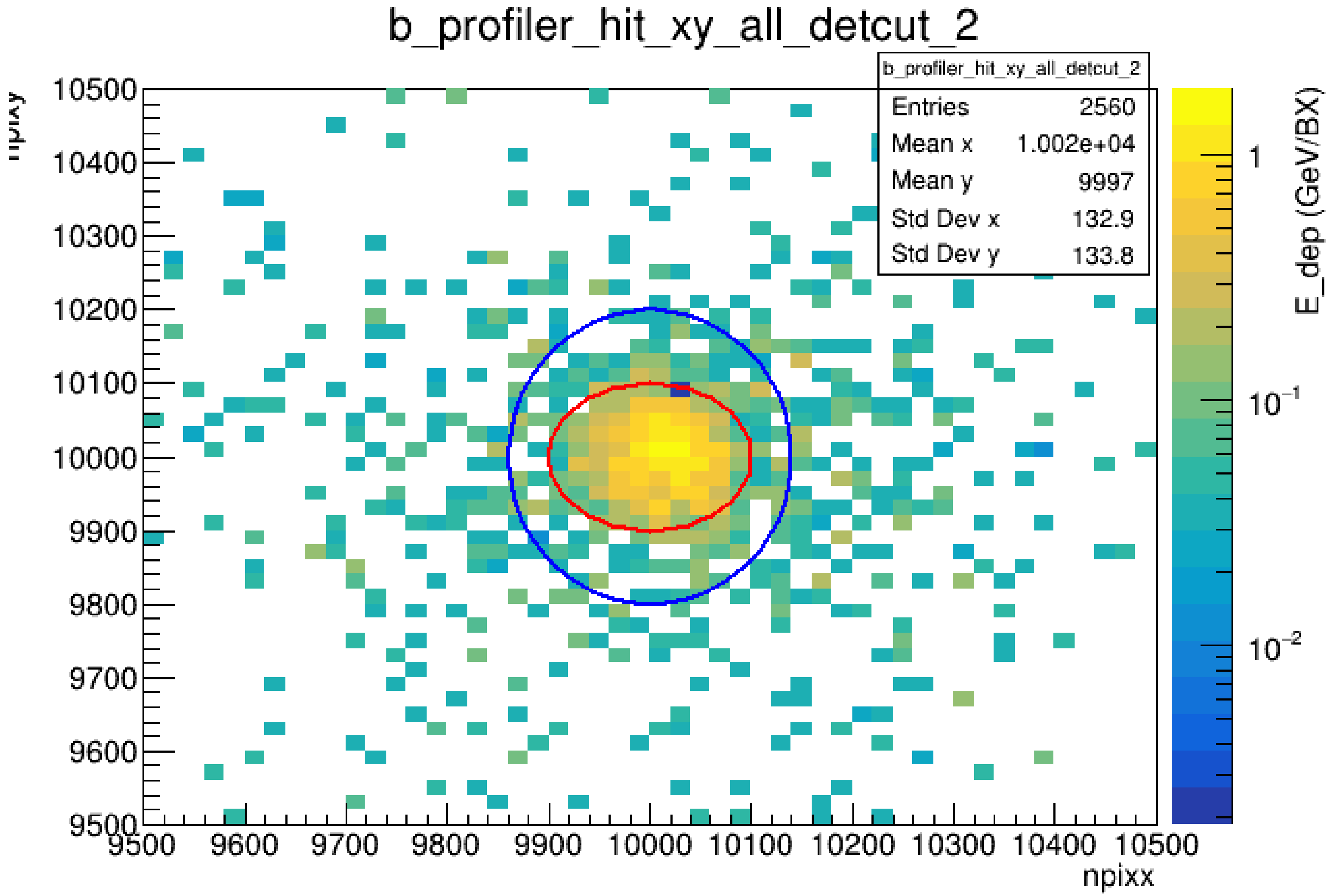
$$\text{npixx} = 200x[\text{mm}] + 10000$$

Spread of distributions



$$\Delta \mathrm{npixx} = 200 \Delta x [\mathrm{mm}]$$

2D Distribution



- 2D distribution of energy deposition on sensor 2 profiler – GEANT4 data
- Lines show the ellipses with radii given by appropriate FWHM from previous slide
- Red – Cauchy-Lorentz fit
- Blue – Gaussian fit

Summary

- Gaussian and Cauchy-Lorentz distributions can be used to estimate the FWHM and hence shape of the energy distribution from energy deposition measurement
- Cauchy-Lorentz gives a slightly better agreement to the shape
- Needs to be compared to the true photon distribution to determine overestimation
- FLUKA simulations for profilers of different thicknesses still running
- Effect of strip width in profiler can be done by rebinning histograms and re-running the fitting algorithm

GBP-MC Simulation Update

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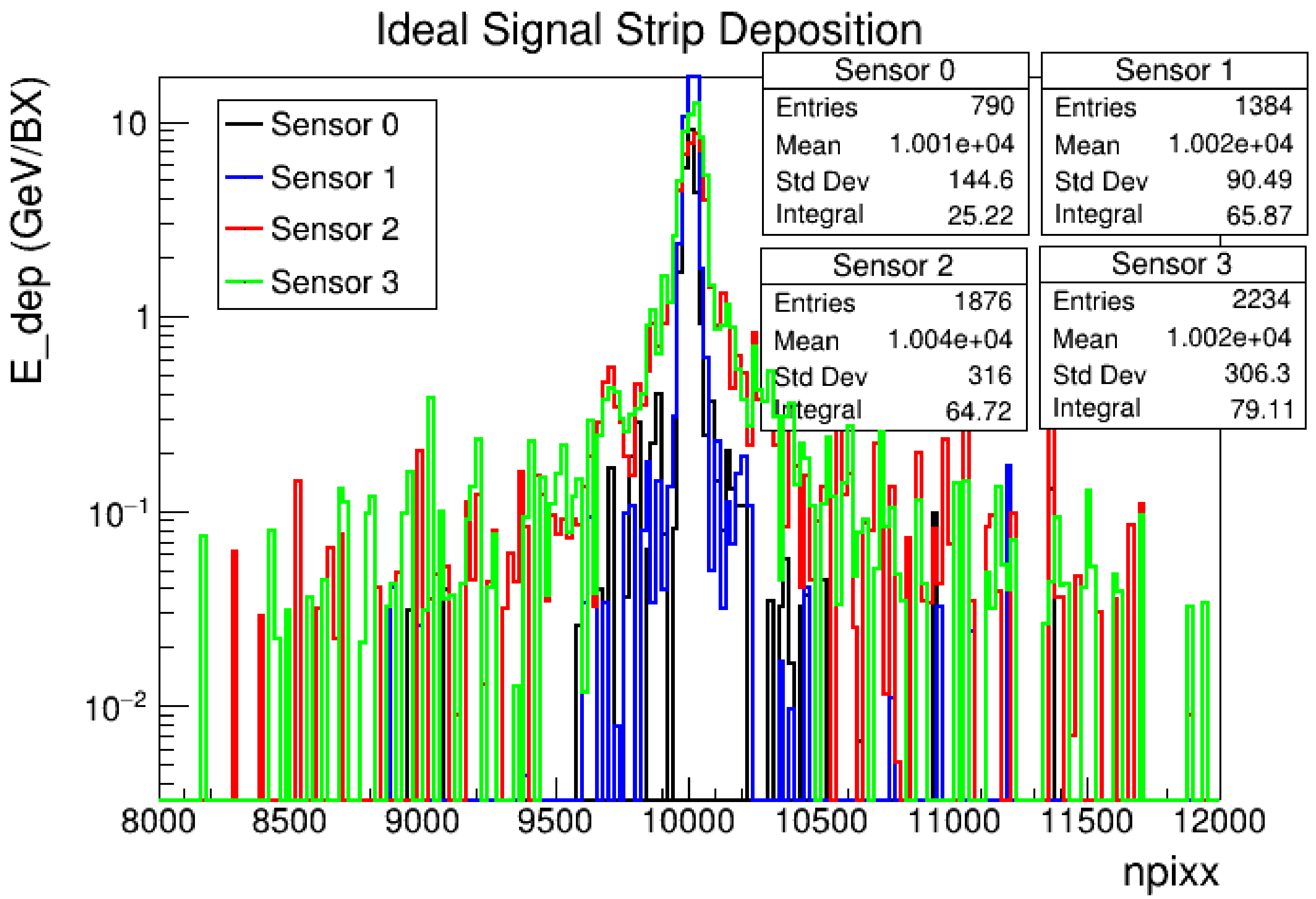
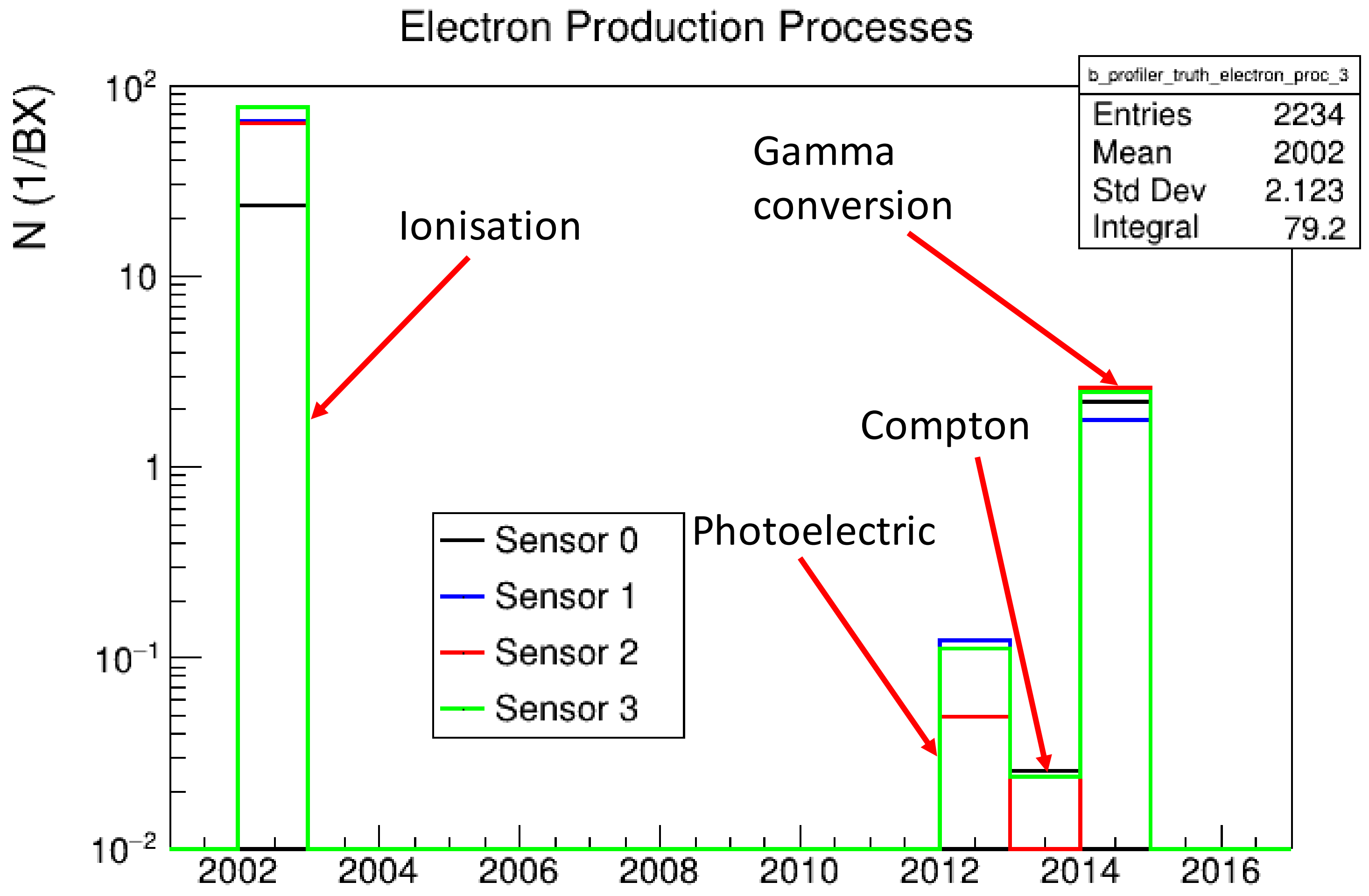
19/03/21

Truth signal



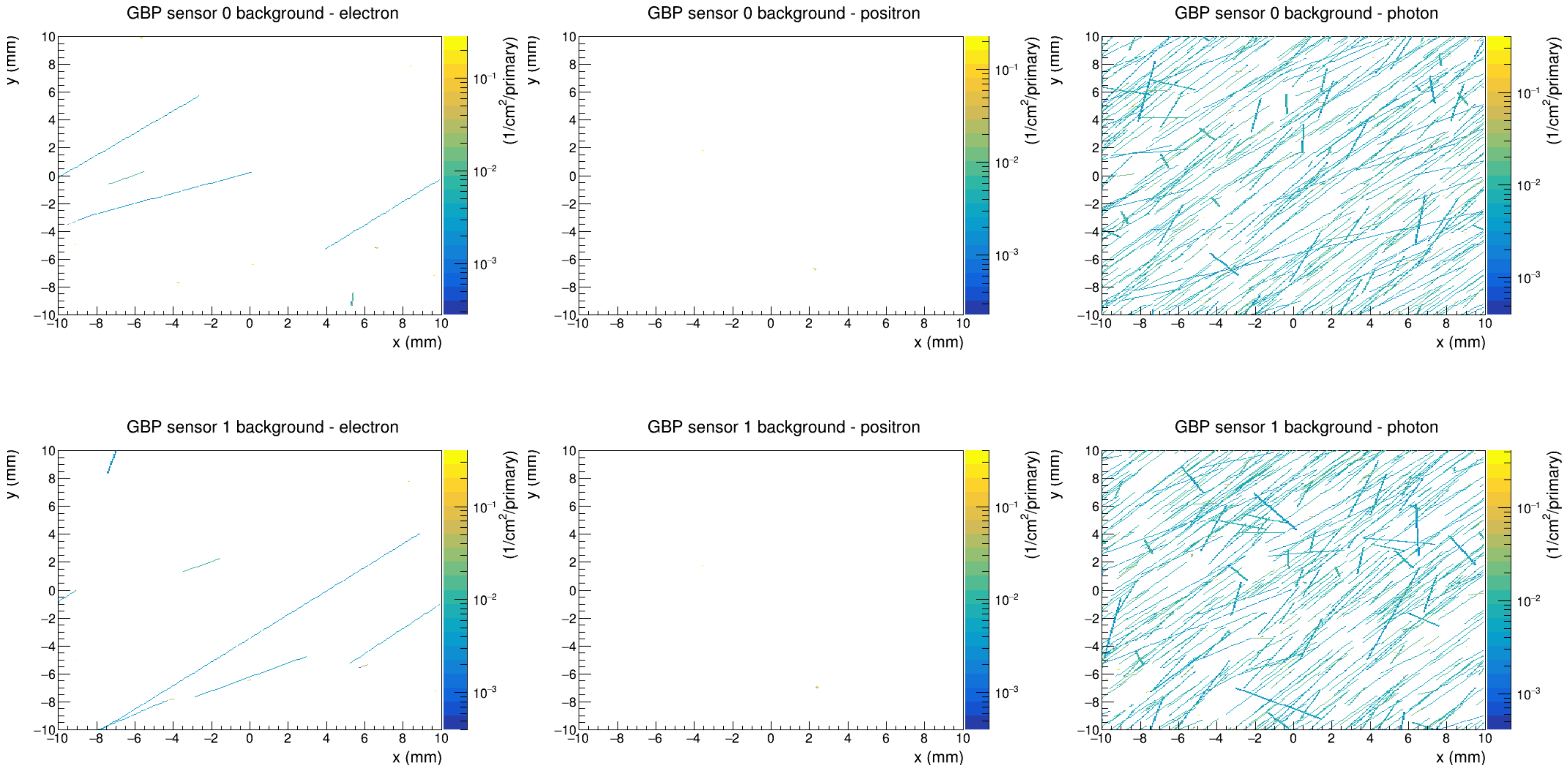
- 8000 – 12000 npixx corresponds to central –10.0 to 10.0 mm of profiler
- Range ~100 GeV across central ±2.5 mm
- Conversion from npixx to mm – 1 npixx width = 0.005mm

Electron production processes

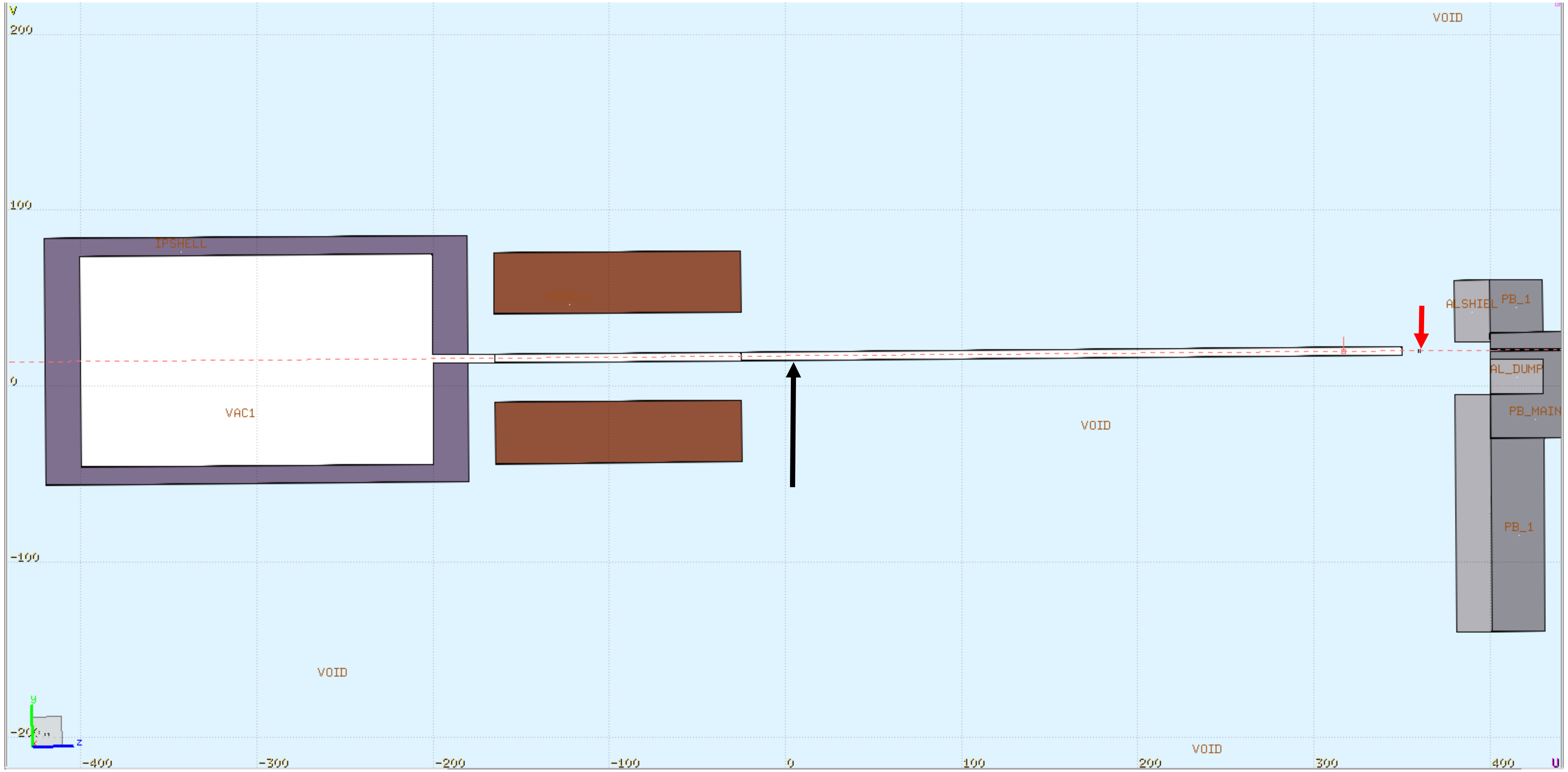


FLUKA background plots

- Previous results for background contained long (projected) particle tracks in plane of profiler – problematic for energy deposition
- Two causes of this phenomenon
  - Slight misalignment of magnetic field in FLUKA caused both vertical and horizontal deflection of electron beam
  - Difference in how beam dumping is handled in current FLUKA simulation compared to GEANT4
- First problem fixed – results shown on next slide
- Second problem requires more detailed adaptions to FLUKA geometry which affect background only, not the main signal simulations

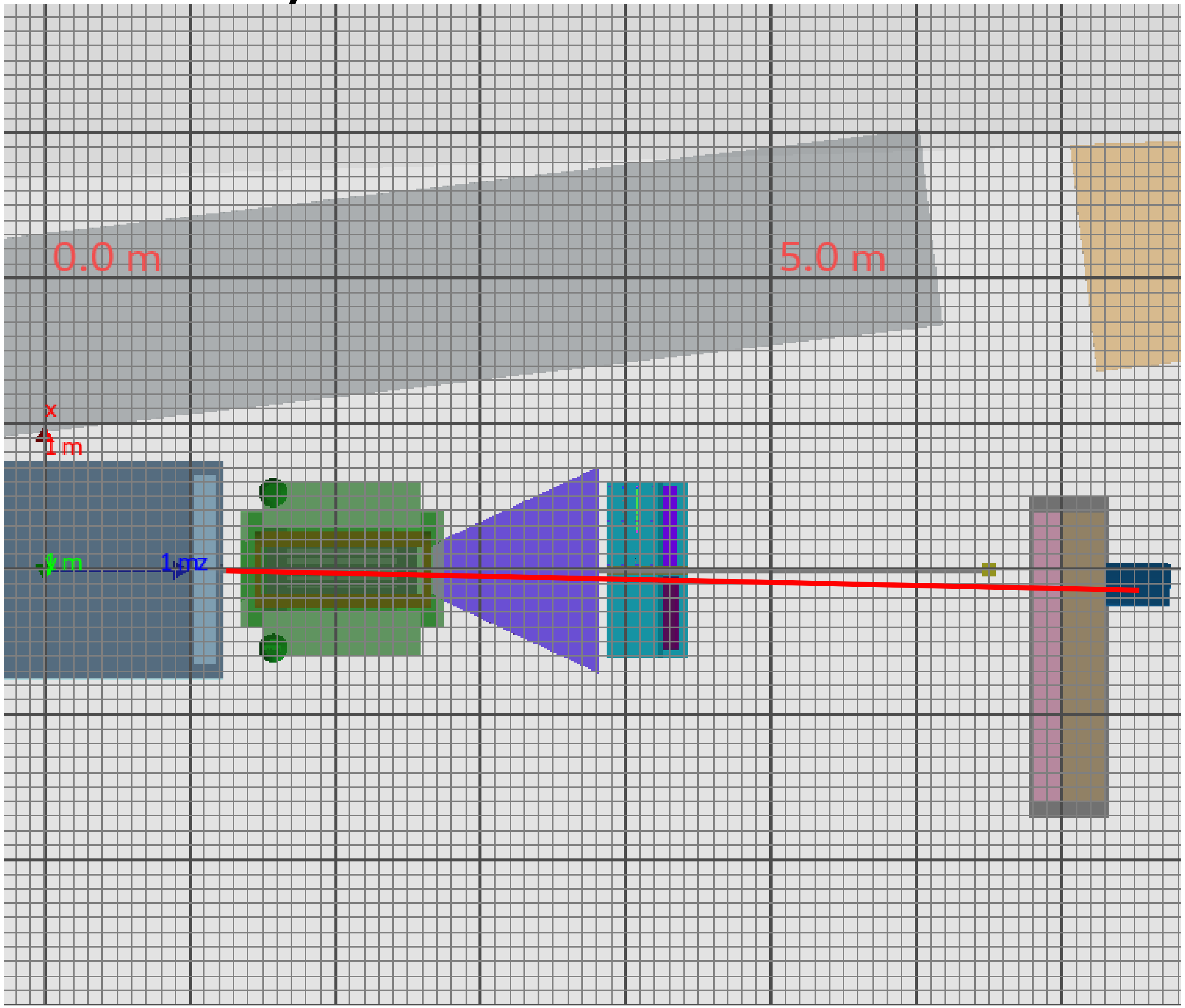

GBP sensor 0 background - electron
GBP sensor 0 background - positron
GBP sensor 0 background - photon
GBP sensor 1 background - electron
GBP sensor 1 background - positron
GBP sensor 1 background - photon
y (mm)
x (mm)
(1/cm^2/primary)
10^{-1}
10^{-2}
10^{-3}

FLUKA Beam Dump Geometry



- FLUKA simulation – electron beam passed through vacuum pipe wall into dump
  - Magnetic field 1.2T
  - 16.5 GeV electrons
  - Magnet length 140cm
  - Deflection ~30 mrad
- GEANT4 simulation – electron beam directed through triangular fan component rather than beam pipe itself
- Reduces amount of off-axis noise reaching profilers

GEANT4 Geometry



Summary

- "Truth" signal generated in detector deposits predominantly within central 2.5 mm for all detector planes
- Track anomalies from FLUKA simulation accounted for – simulation needs more detail to compare with GEANT4 simulation; currently results only comparable for rear profilers (sensors 2 & 3 at z = 11.8m)

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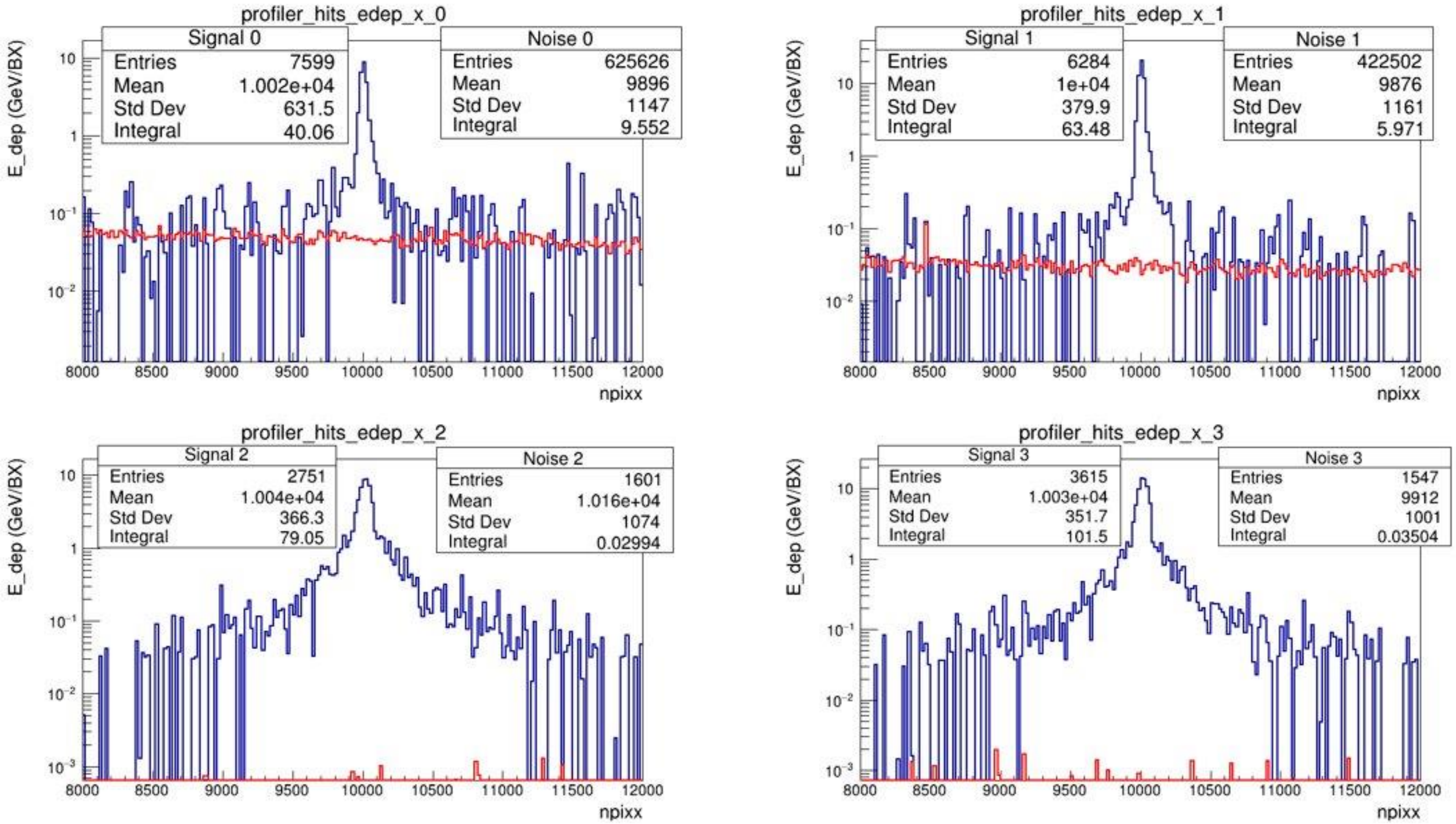
08/03/21

Overview

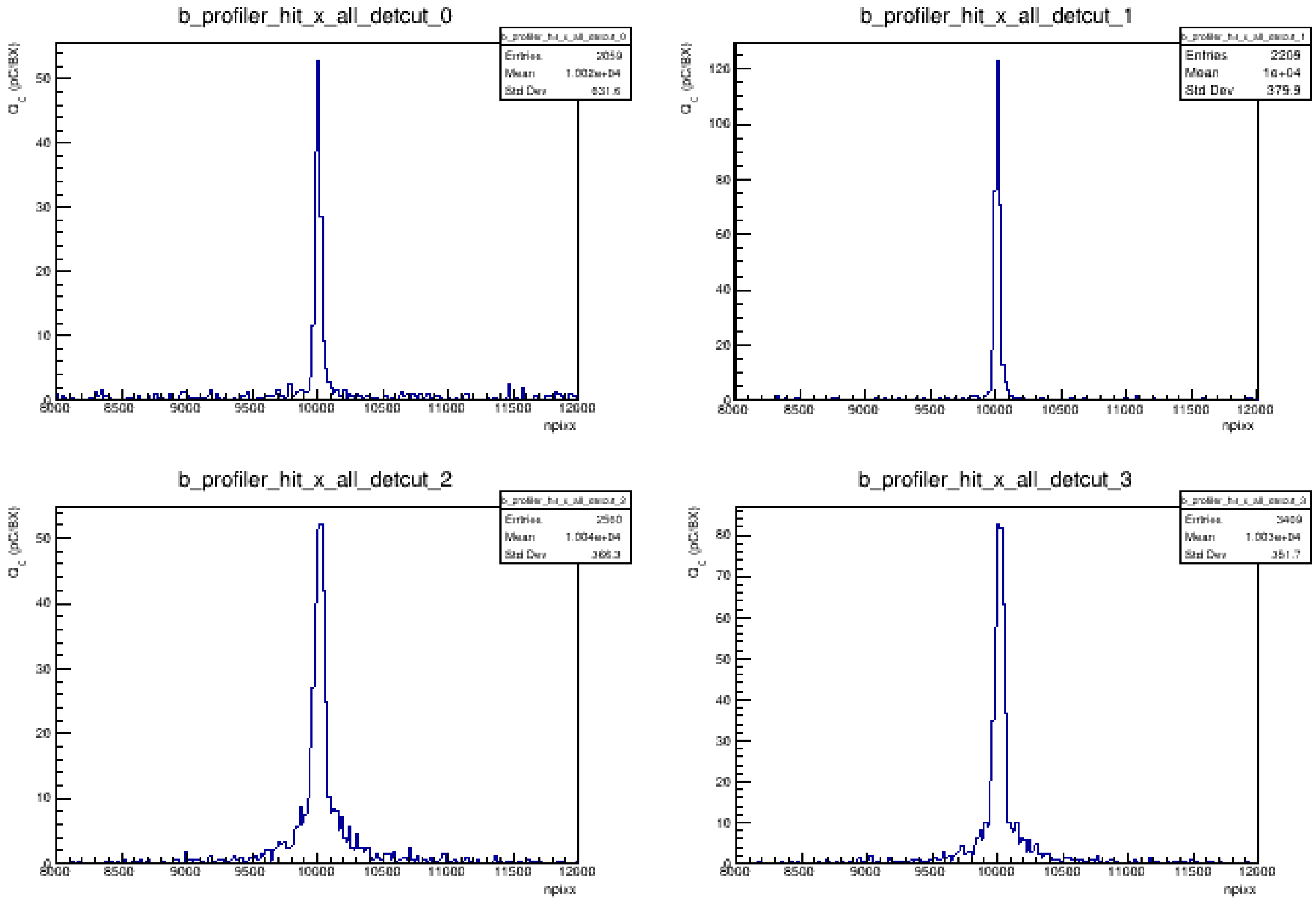
- Analysed background on profiler due to electron beam colliding with beam dump
- Managable S/B ratio on both pairs of detectors (total energy deposition)
  - S/B > 2 across central 2.5mm of plane for forward detectors
  - S/B > 500 across entire plane for rear detectors

S/B Comparison



- S/B ratio > 10 between npixx = 9800 and 10200 for front profilers
- Corresponds to a spatial range of ±1 mm
- S/B ratio > 2 between 9500 and 10500 -> spatial range ±2.5 mm
- S/B ratio > 500 across entire detector for rear profiler pair
- Higher S/B ratio at front profilers due to proximity to electron dump

Charge Collection Estimate

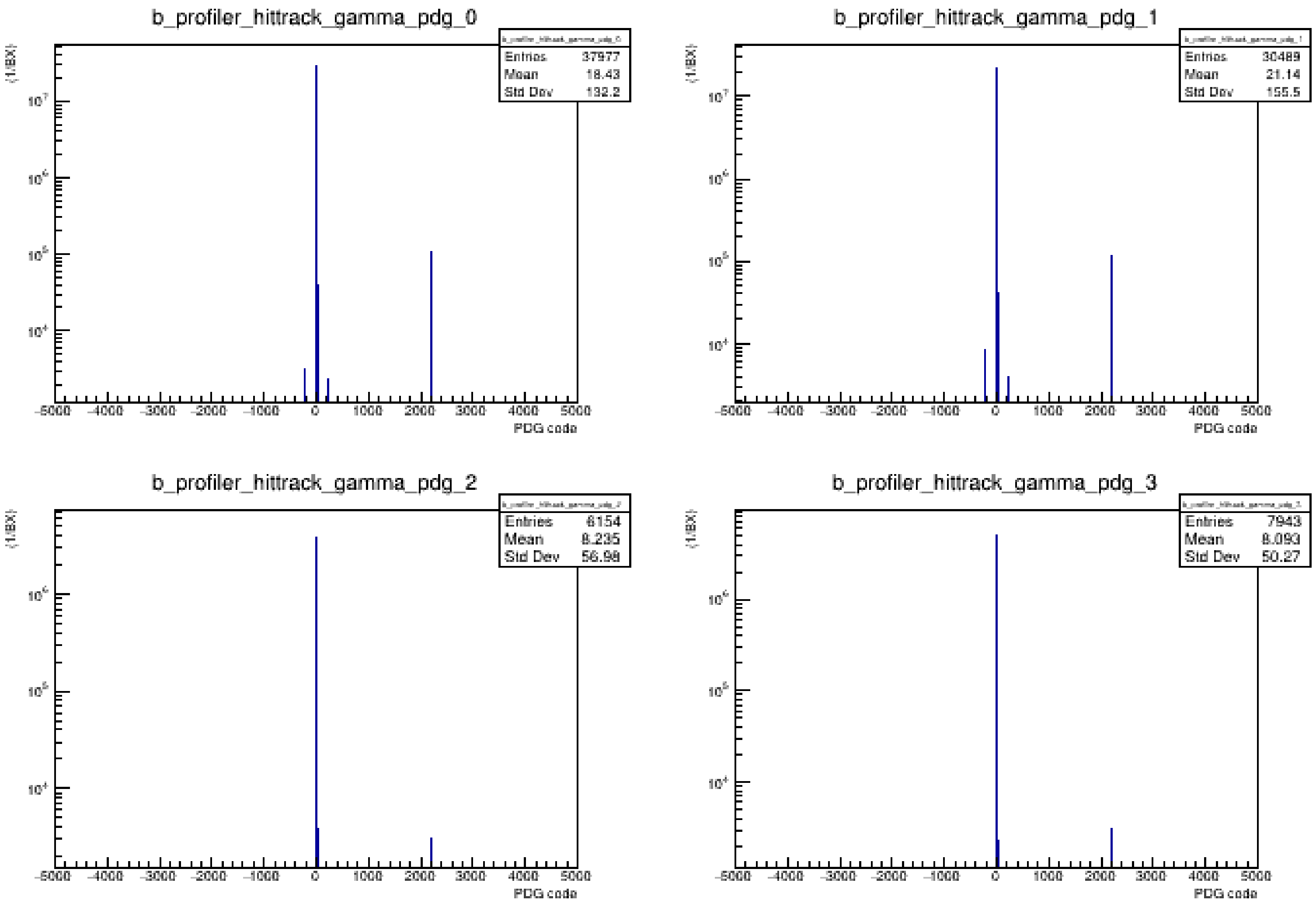


- Rough estimate of charge collected in each strip (pC/BX)

$$Q_c = \eta e N_{eh}$$

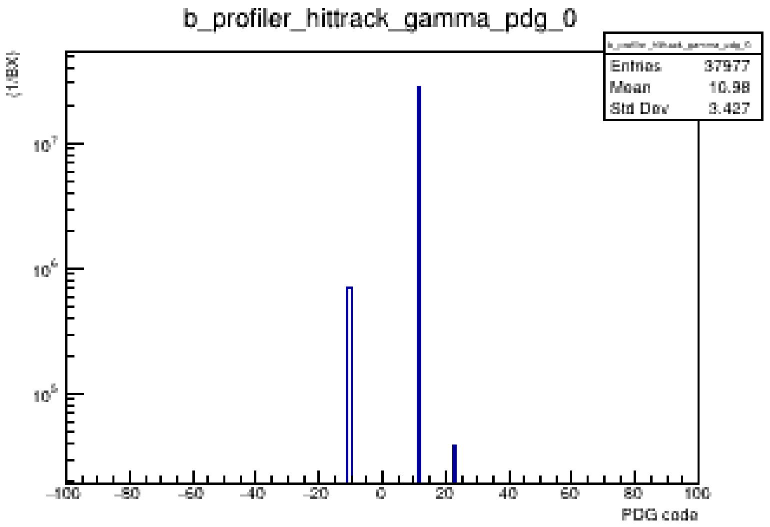
- Collection efficiency assumed to be 1.0
- From Marco's slides, energy to create e-h pair for sapphire = 27.0 eV

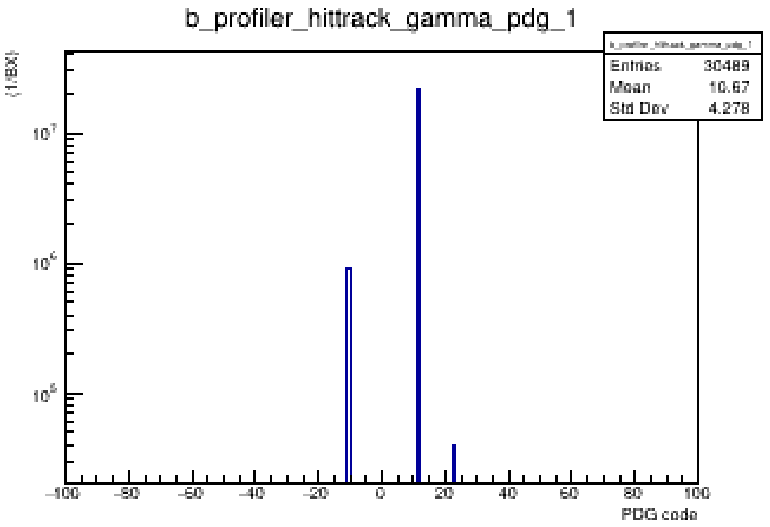
Particle Types

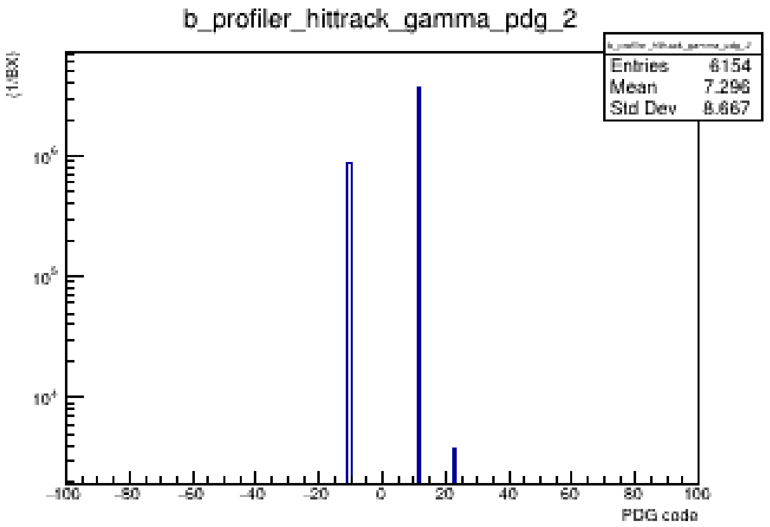


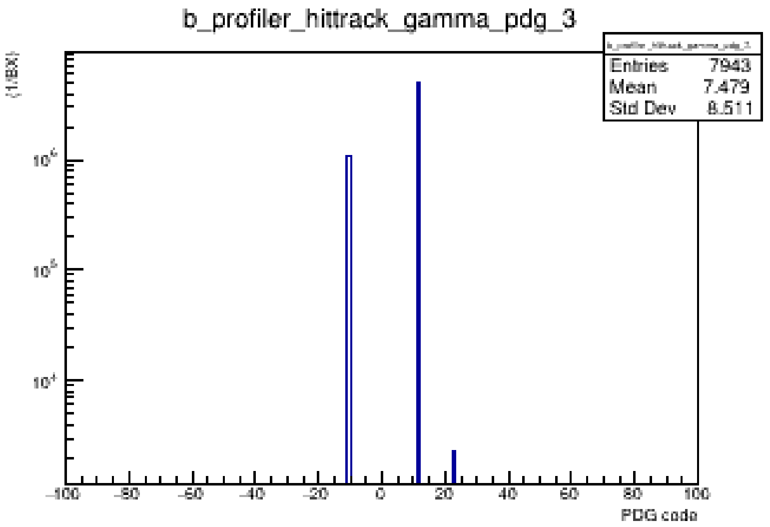
- Seems that main particles hitting profilers are
  - Electrons
  - Positrons
  - Photons
  - Pions (+/-)
  - Protons

Particle Types









Summary

- Still in process of analysing signal on profiler
- Want to look at electrons generated within each profiler by gamma beam – this is "ideal" signal
  - Main processes to consider photoelectric effect, Compton scattering, pair production etc.
- Determine particle fluences on profiler

GBP- MC Simulation Update

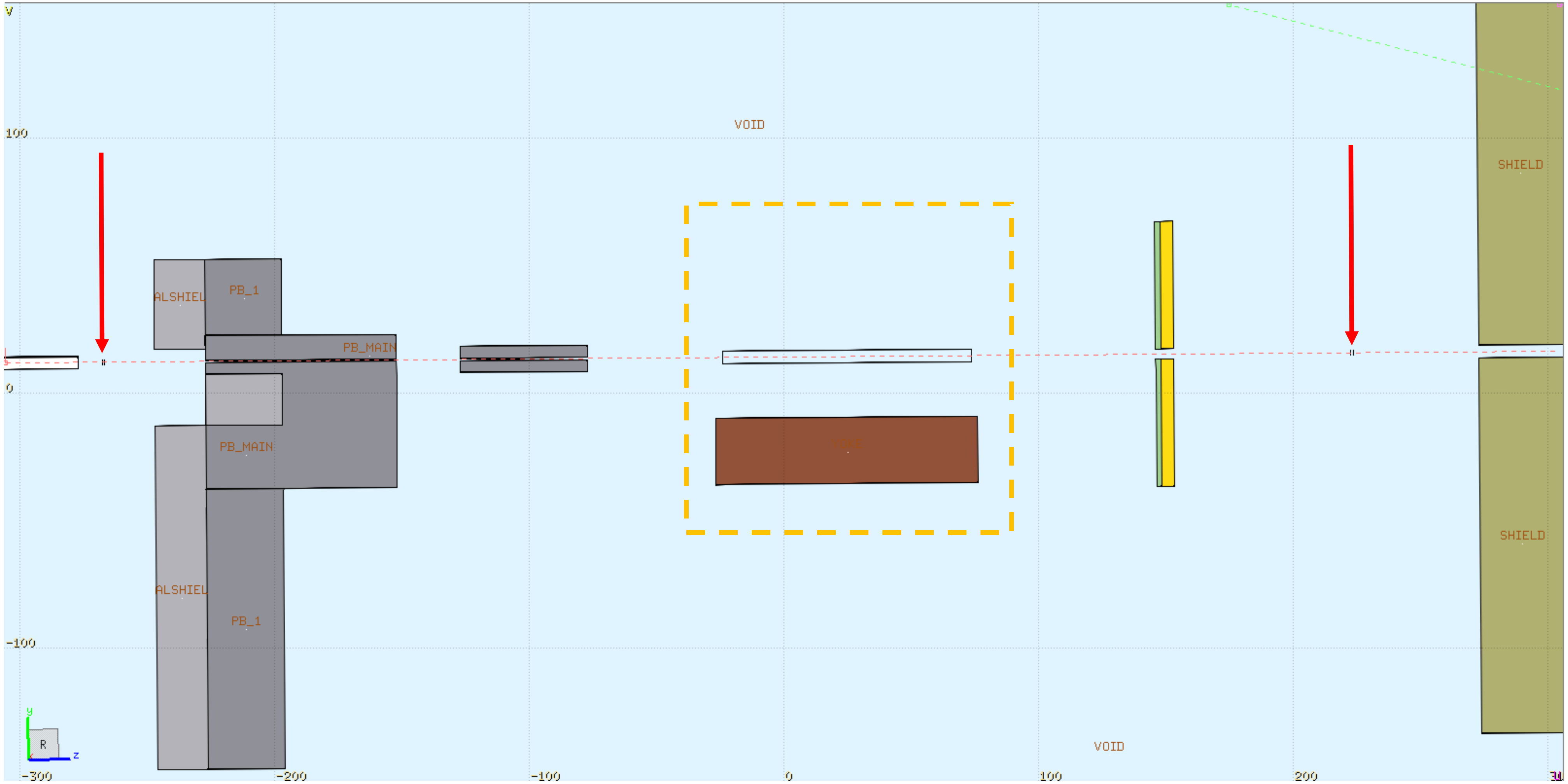
Kyle Fleck, Niall Cavanagh and Dr. Gianluca Sarri

22/02/21

Overview

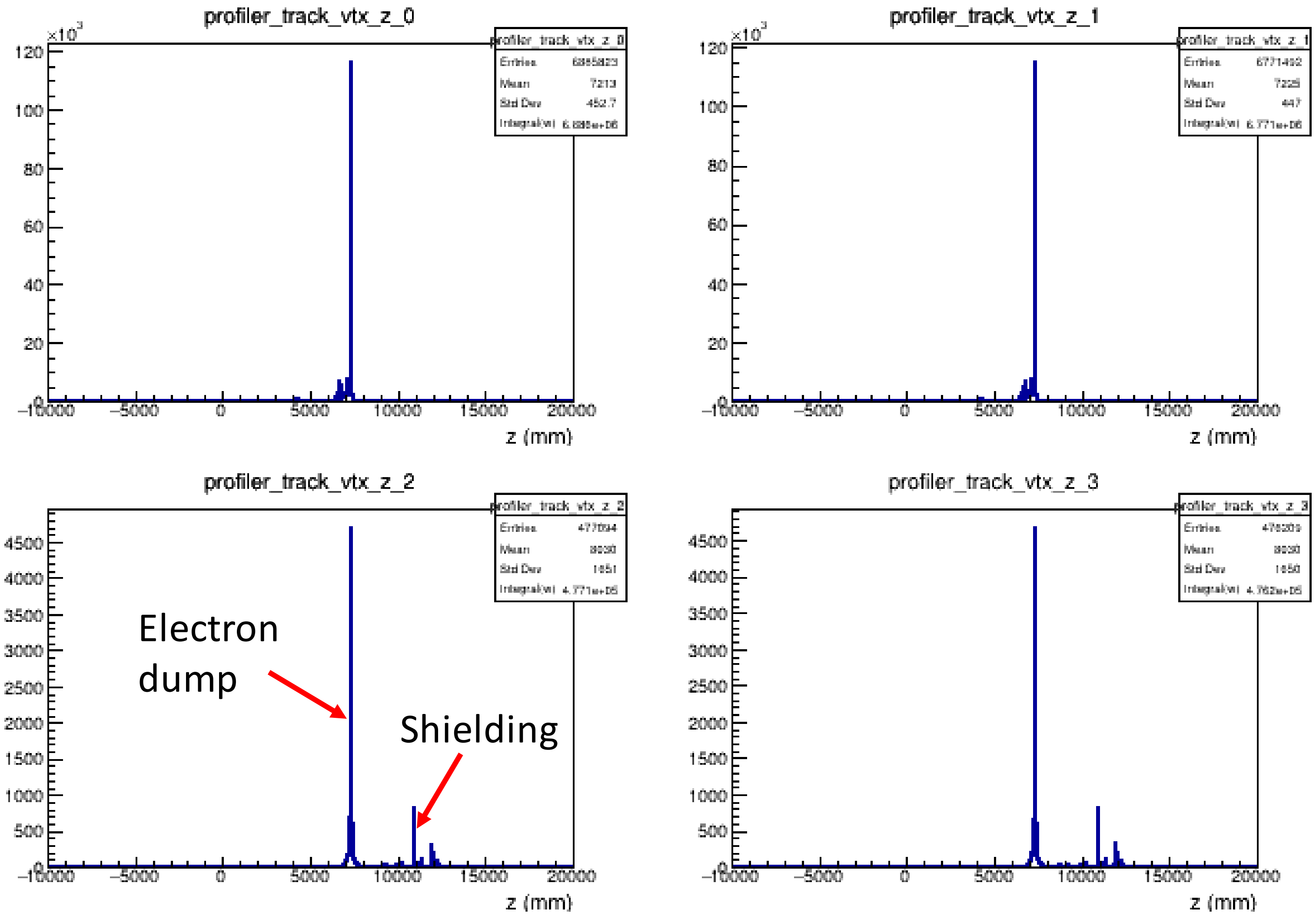
- Previous FLUKA simulations for entire forward spectrometer (PDS – photon detection system) done for 1e5 primary electrons
- Higher statistics simulation in FLUKA still running, data should be available soon
- GEANT4 MC data exists for both signal and background for entire LUXE setup – now includes beam profilers
- Profilers extend from –50.0 mm to 50.0 mm in x and y; actual profiler size can be determined by restriction –10.0 mm to 10.0 mm
- Background for 0.1855 BX
- For profilers, sapphire (Al2O3) composition
  - Density = 3.98 g/cm**3
  - Pixel volume = 20.0cm/nx * 20.0cm/ny * 0.01 cm (nx, ny = no. bins in x, y resp.)
  - Dose conversion factor: GeV/g -> Gy = 1.60e-7

PDS geometry (FLUKA)



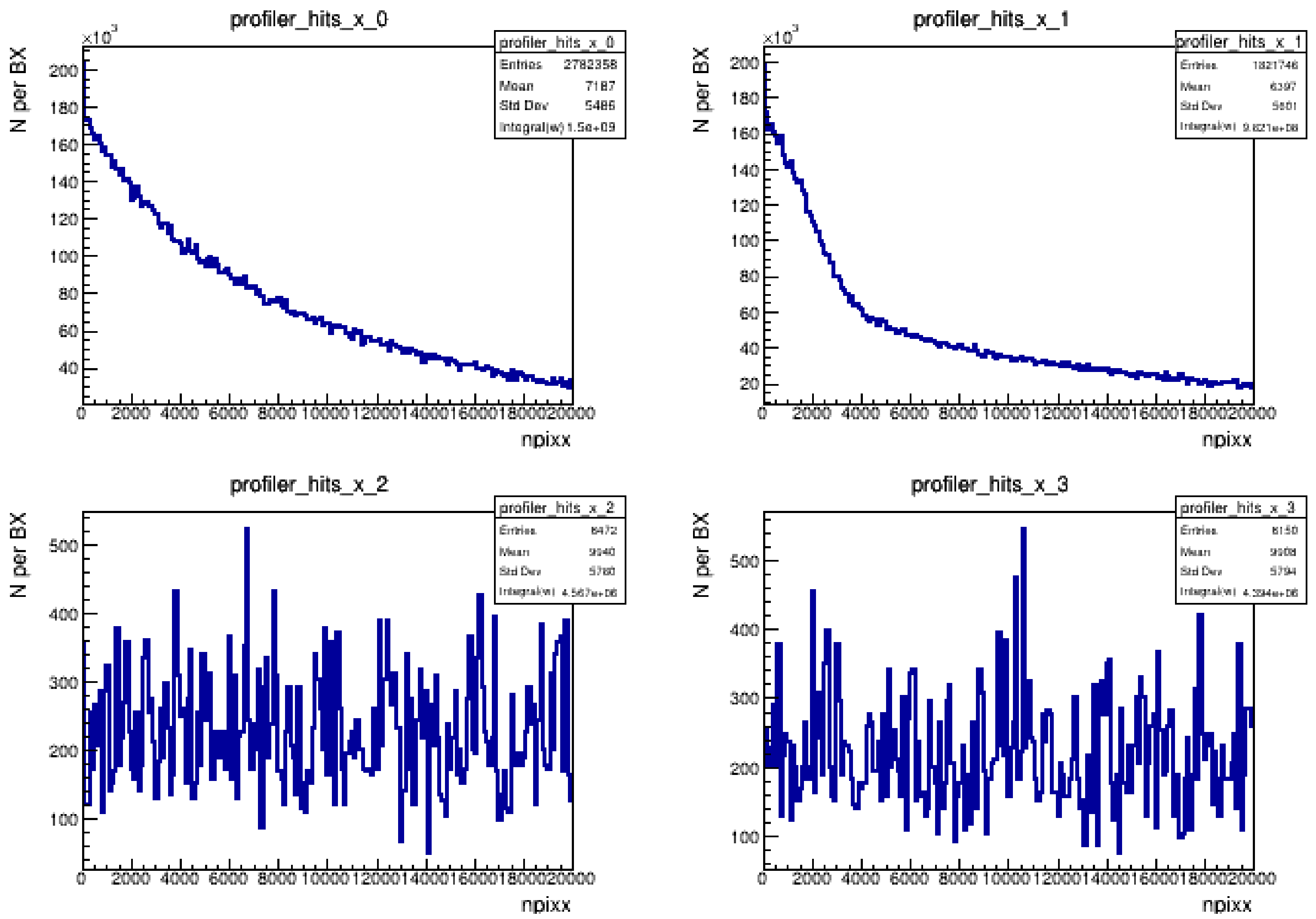
- Profiler locations indicated by red arrows
- Magnet region marked by orange dashed box
- "VOID" is air environment
- Geometry simplified in comparison to full GEANT4 geometry e.g. no supports, simplified electron dump, simplified LANEX screens (green) and Cerenkov detector (yellow)

Production Vertices



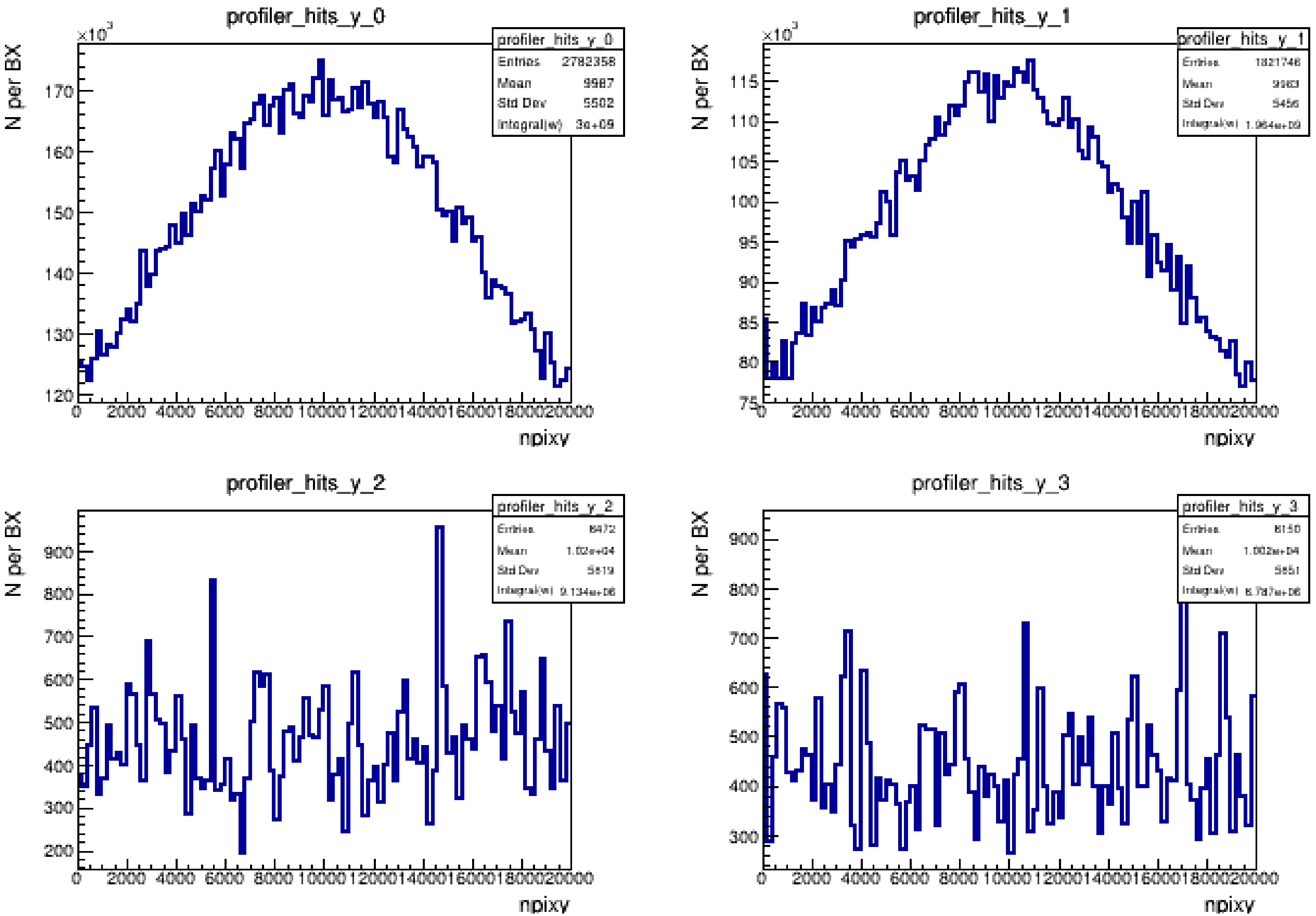
- Plots showing z production vertex of particles incident on profilers
- Main component of background comes from z = 7000mm -> electron beam dump
- Rear profiler pair also see some backscattering from shielding at z = 12000mm

Transverse hits profile (horizontal)



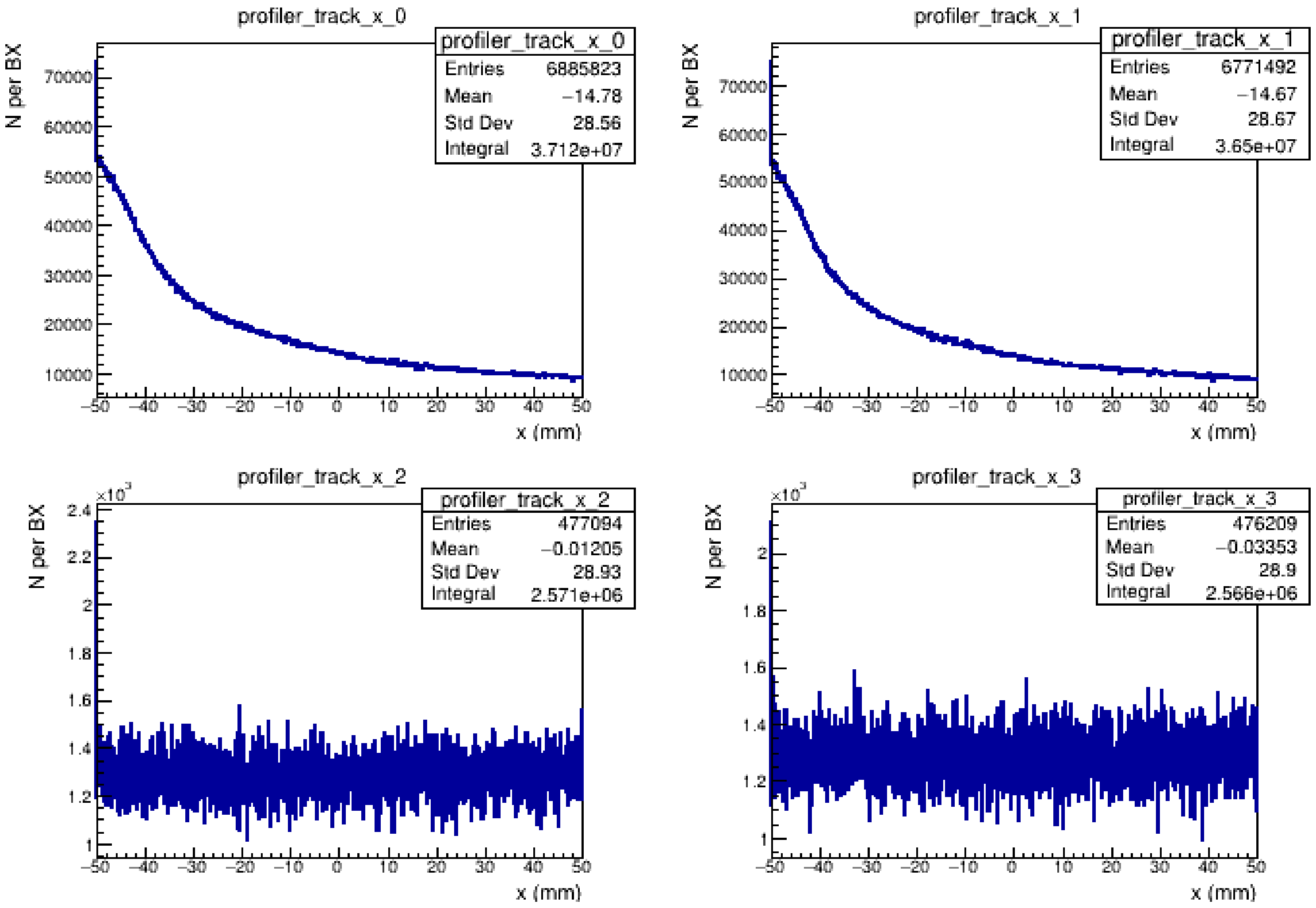
- For rear profiler pair, hits distributed uniformly across profiler in x direction
- Due to air environment and components of experiment, forward x distribution of hits not distinguishable at rear profilers
- For front pair, number of hits decreases across the detector
- Left edge (npixx = 0) corresponds to edge closest to electron dump

Orthogonal hits profile (vertical)



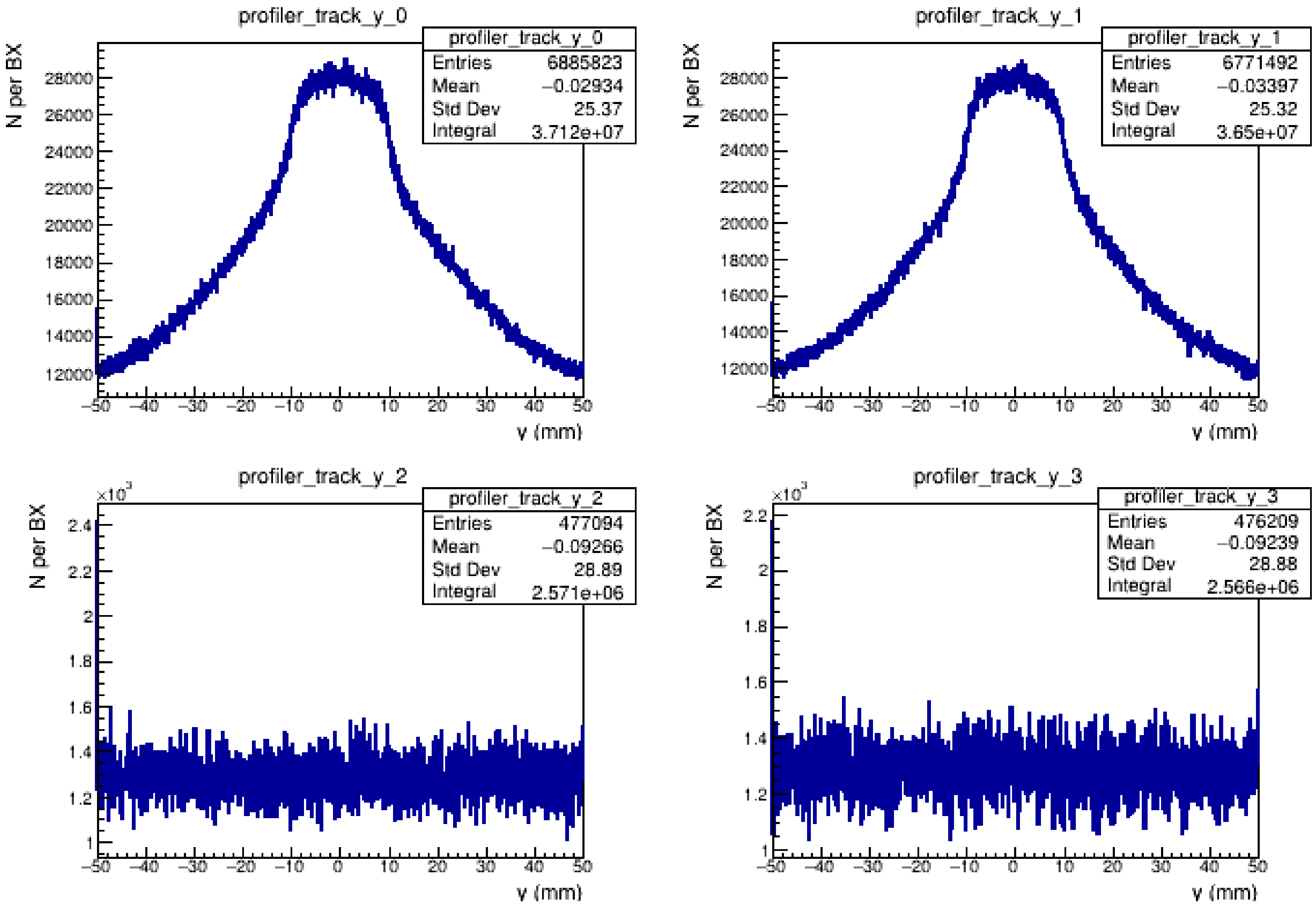
- Uniform distribution of hits for rear profilers
- Front profilers have peak at npixy = 10000 -> y = 0.0 mm
- This corresponds to the plane in which electron dump is vertically centred

Transverse tracks profile

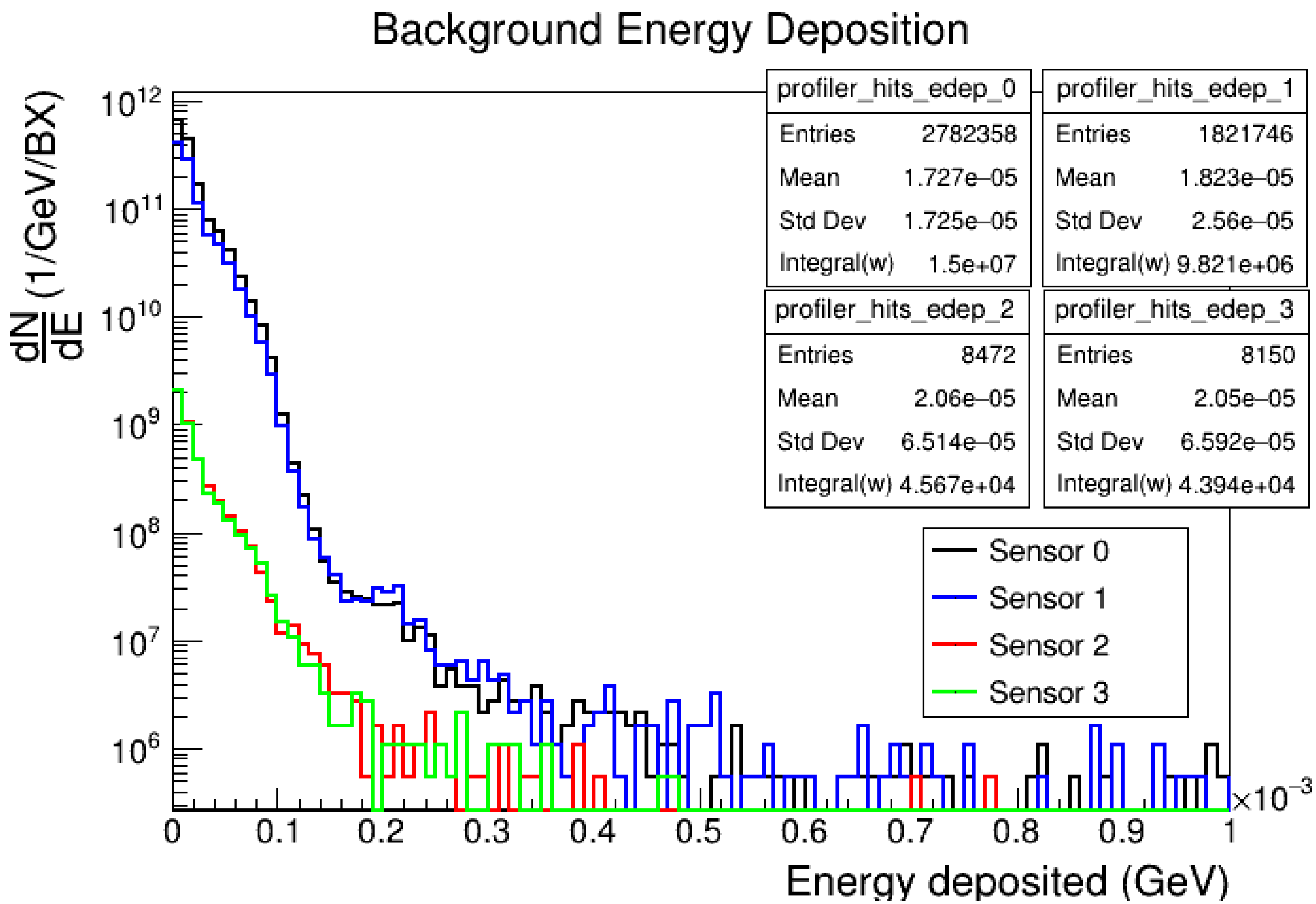


- Similar trend to hits profiles
- Rear profiles have a uniform distribution in transverse direction of background
- Front pair is highly skewed due to location of electron dump

Orthogonal tracks profile

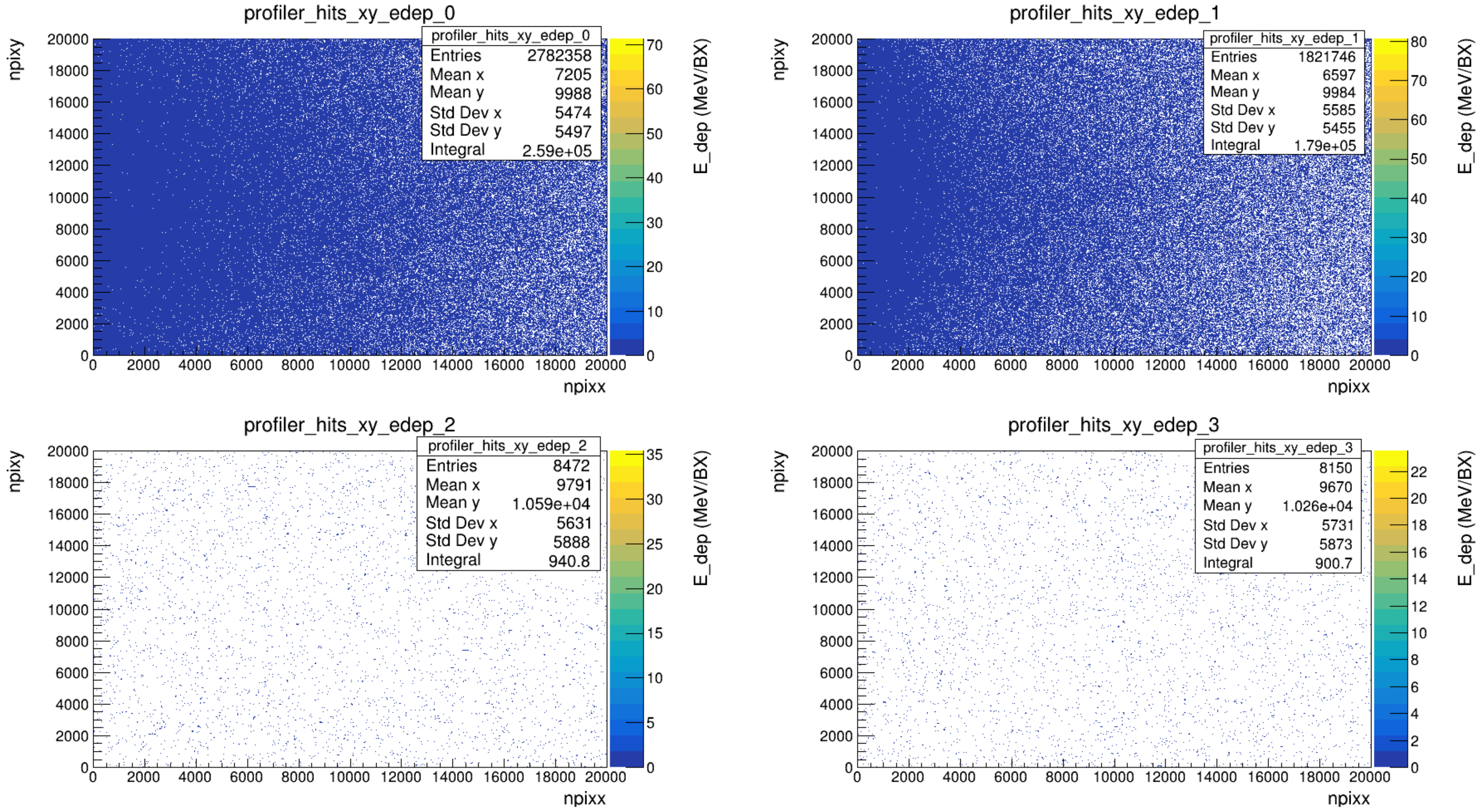


Spectrum of deposited energy



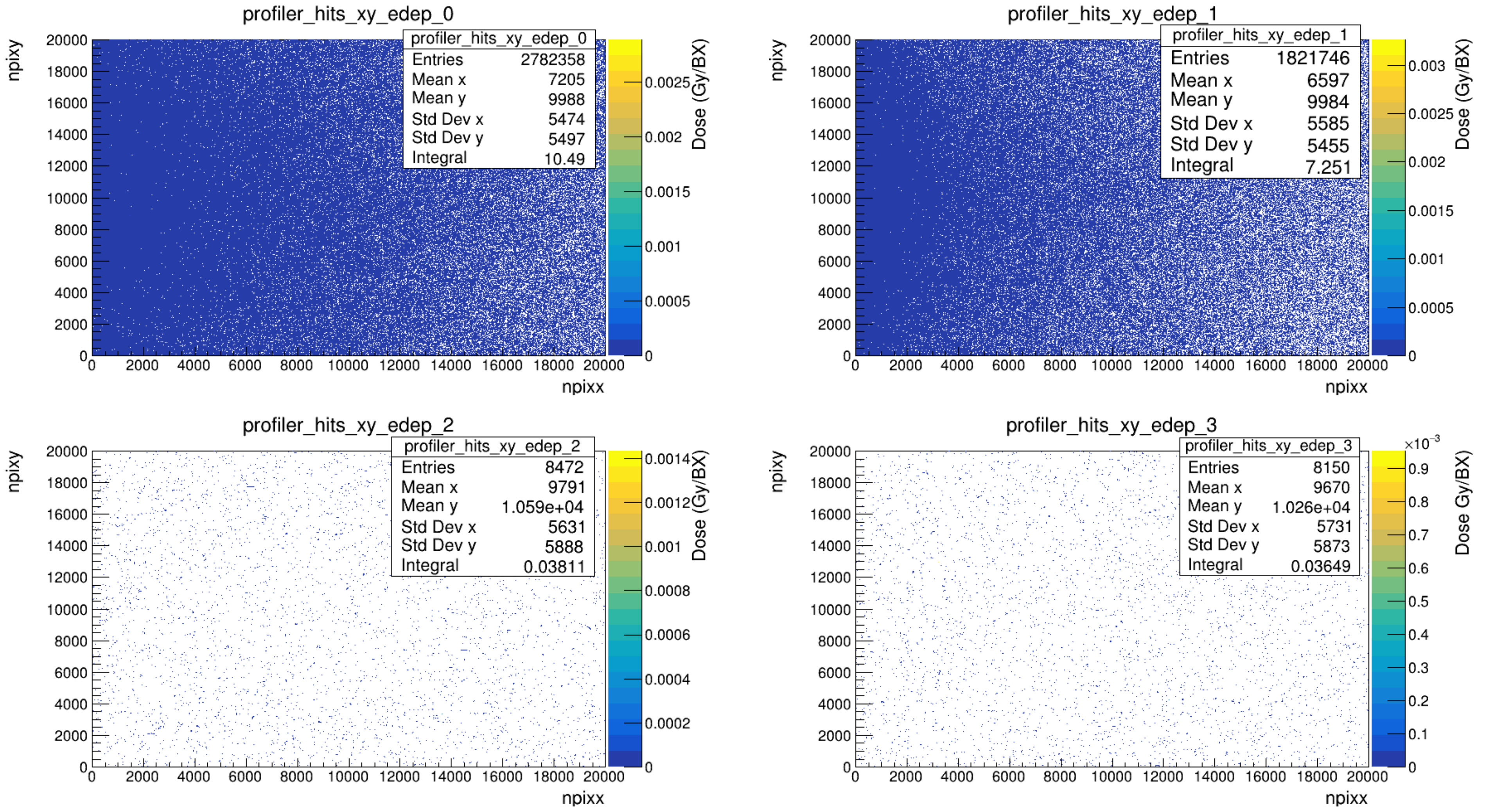
- For all detectors, large number of particles which deposit low amount of energy (E<0.2 MeV)
- Total number of hits given by value "Integral(w)"

Energy Deposition



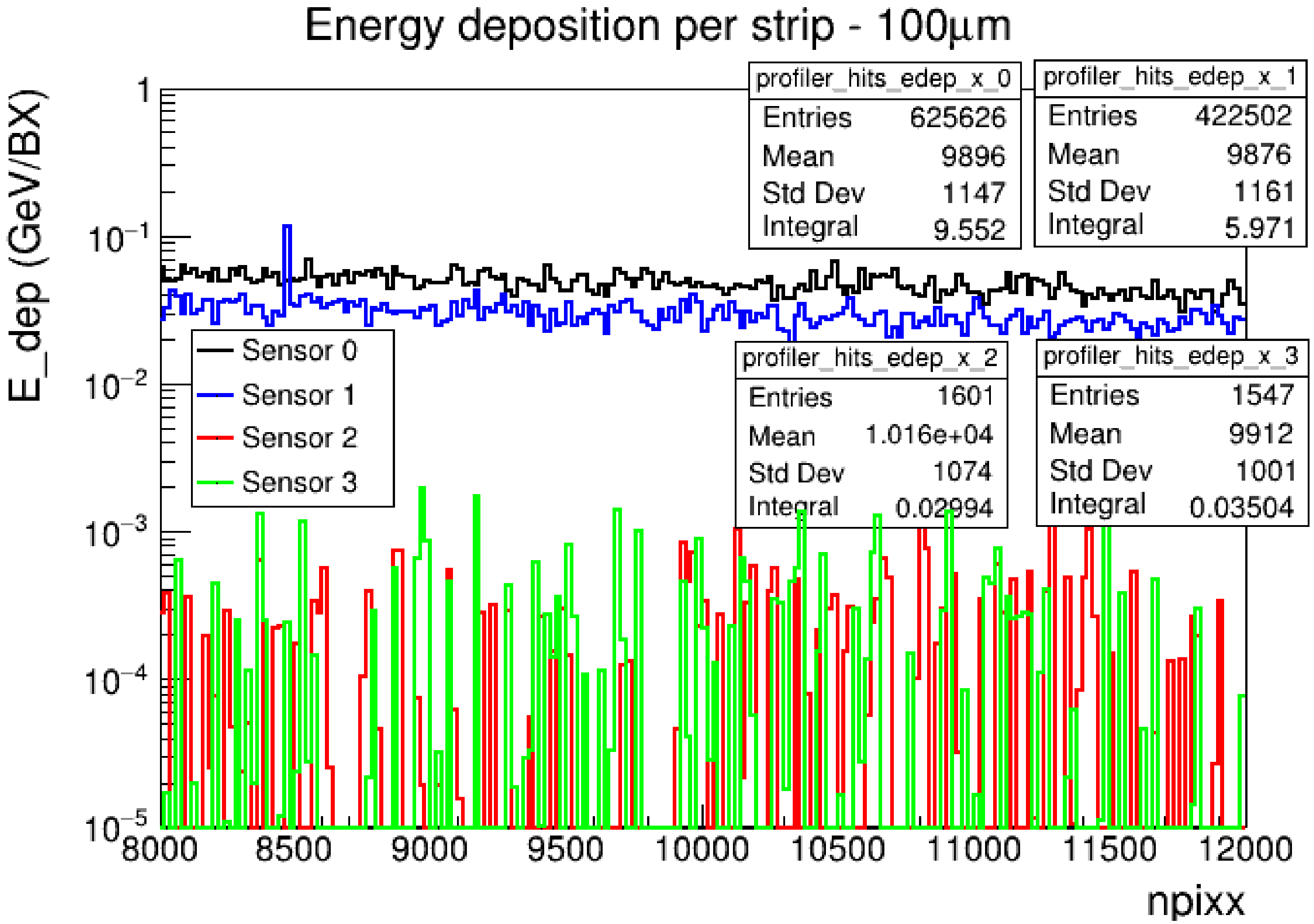
- Front profilers have a much higher energy deposition from background due to proximity to electron dump
- Random/uniform distribution of noise apparent on rear profilers

Absorbed dose



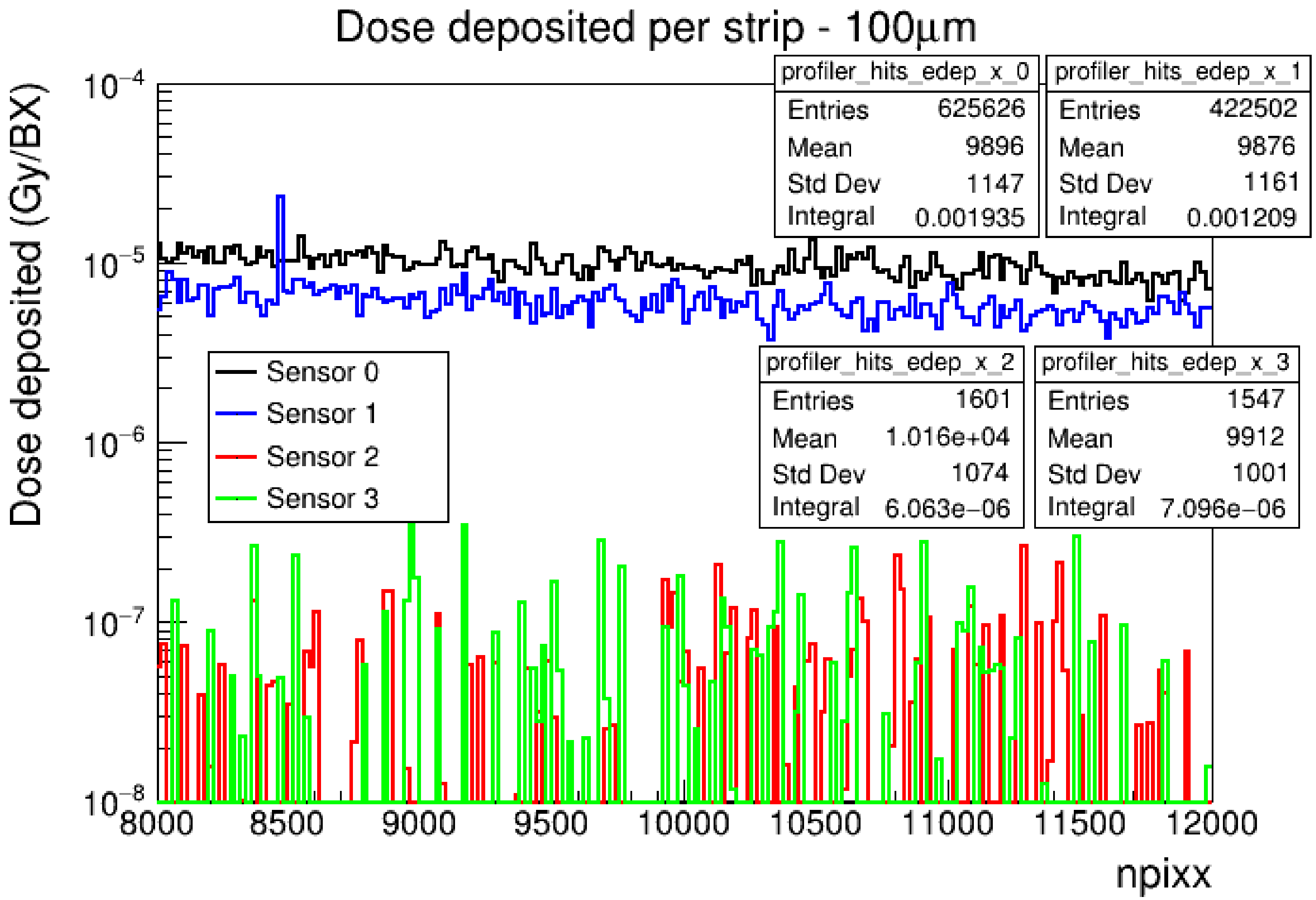
- Calculated from energy deposition map by dividing by bin volume and using scaling factor from slide 2
- For front profilers, total dose ~1e-5 Gy/BX from total energy deposited in previous slide
- Rear profilers experience ~0.5e-2 times this = 5e-8 Gy/BX

Energy deposition in segmented strips



- Npixx range from 8000 to 12000 corresponds to spatial range –10.0mm to 10.0mm with 200 bins
- For forward pair, energy deposition is uniform across strips with Edep ~ 0.05 GeV/BX
- Rear profiler pair has energy deposition ~0.0001 GeV/BX
- Total energy deposited over all strips is given by integral value in GeV/BX

Absorbed dose in segmented strips



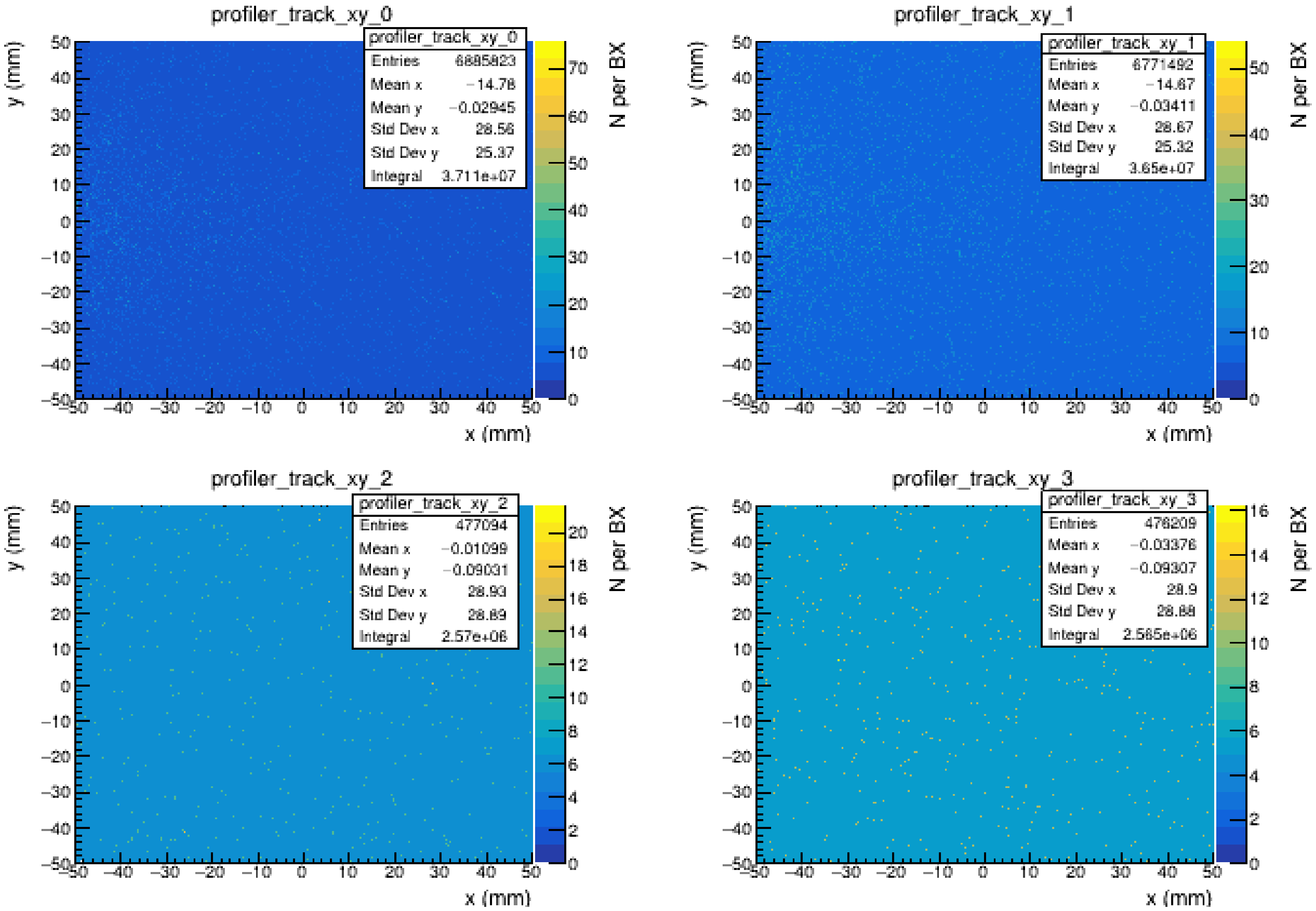
- Dose calculated from energy deposition in previous slide using volume of each strip
  - Vol = 2.0/200 * 2.0* 0.01 cm**3
- Total dose can be calculated from total energy deposition over entire 0.04 cm**3 volume of each detector

Summary

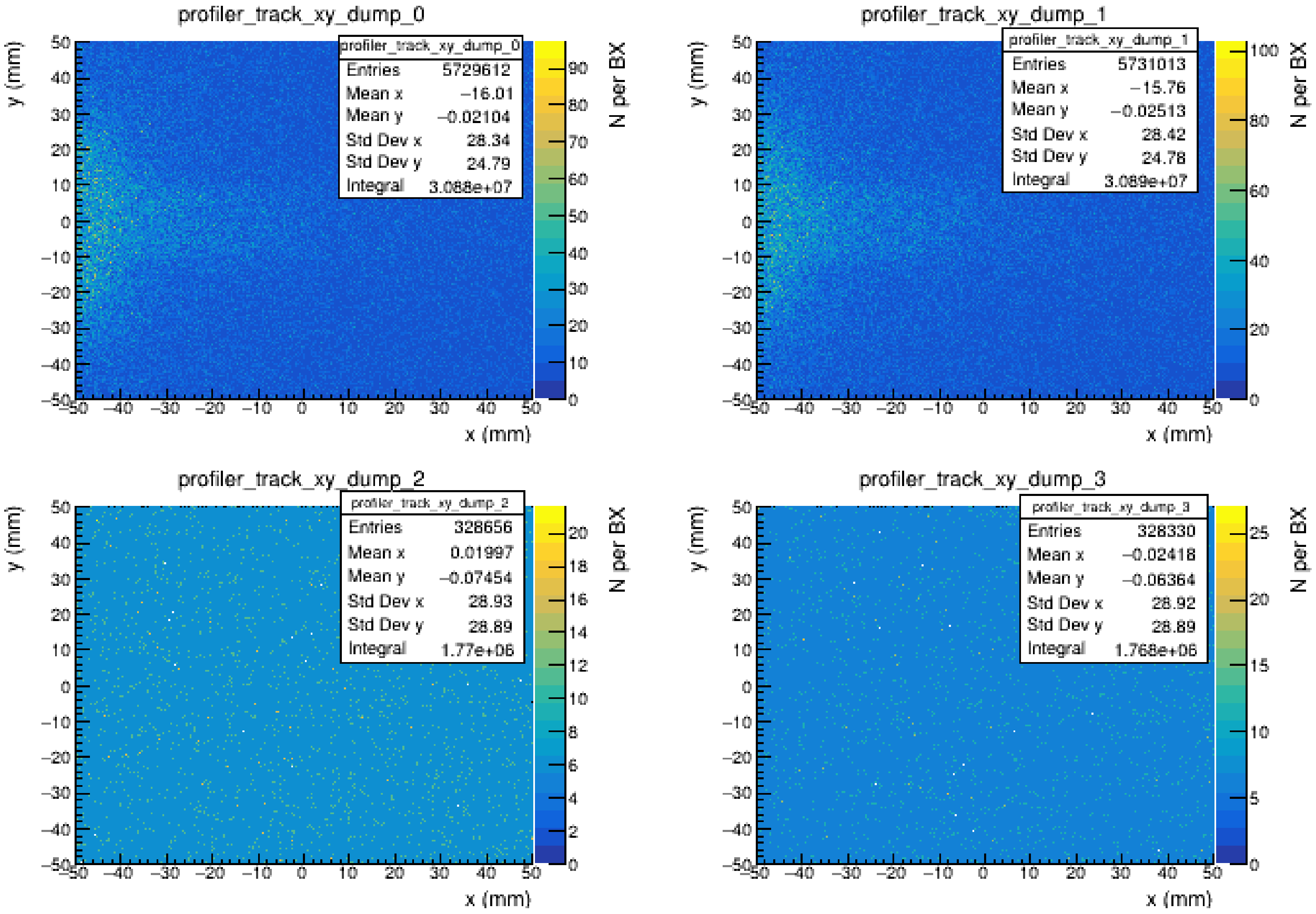
- Background has been analysed using GEANT4 data for 0.1855 BX
- For front profiler pair, background which deposits energy is expected to be ~1e7 particles/BX
- For rear pair, background ~5e4 particles/BX
- Background deposition mostly low energy < 0.2 MeV
- Maximum dose per strip depends on profiler location (front or rear) but in either location does not exceed ~3e-5 Gy/BX
- Flux and current response still to be calculated

Backup

Background tracks



Background tracks – vtx_z in electron dump



Background tracks – vtx_z in shielding