FastSim Parametrization of Beam Dump

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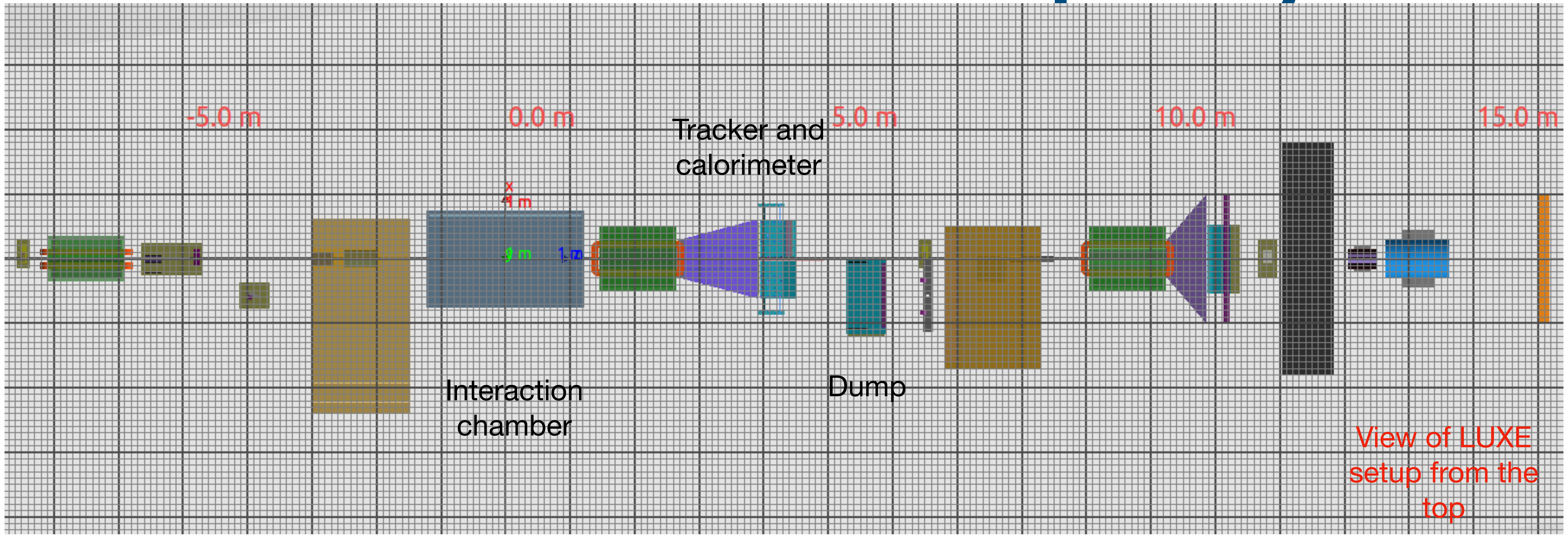
Introduction

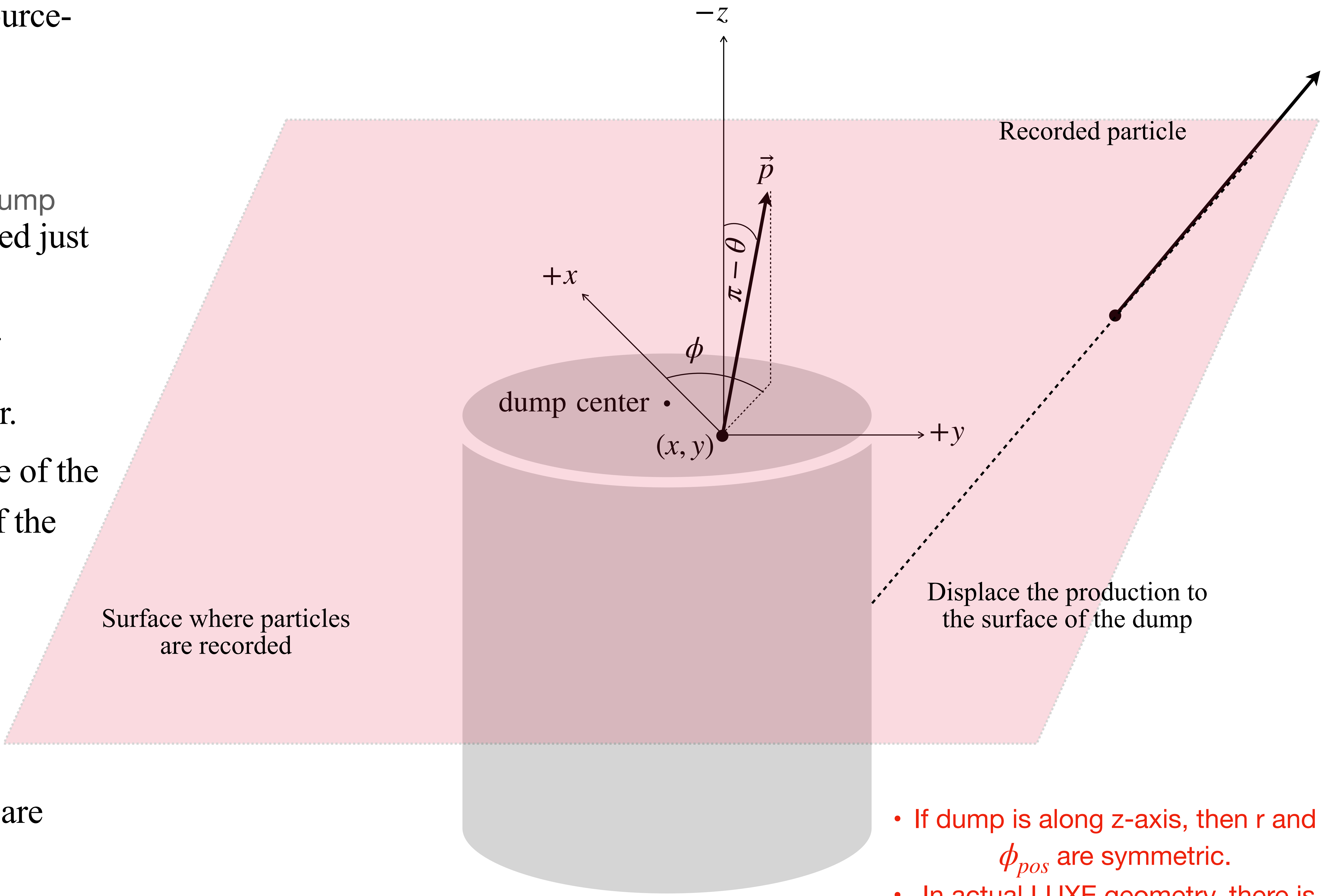
Parametrization of beam dump: Why do we need this?



- Need many BXs/events of simulated background samples to characterize the detector performances, otherwise the results are **statistically limited.**
- We have used Geant4 simulation using LUXE geometry
    - Simulation inside the beam-dump is **computationally expensive.**
        - Limits the number of BXs we can generate.
        - We only have 2 BX of e+laser background sample for TDR.
- **Way out:**
    - Not properly simulate the dump in Geant4, but try to **parametrize the response of the dump.**
    - This is faster by at least **one order of magnitude**.
        - Can overcome the computation challenge.

Fast simulation strategy

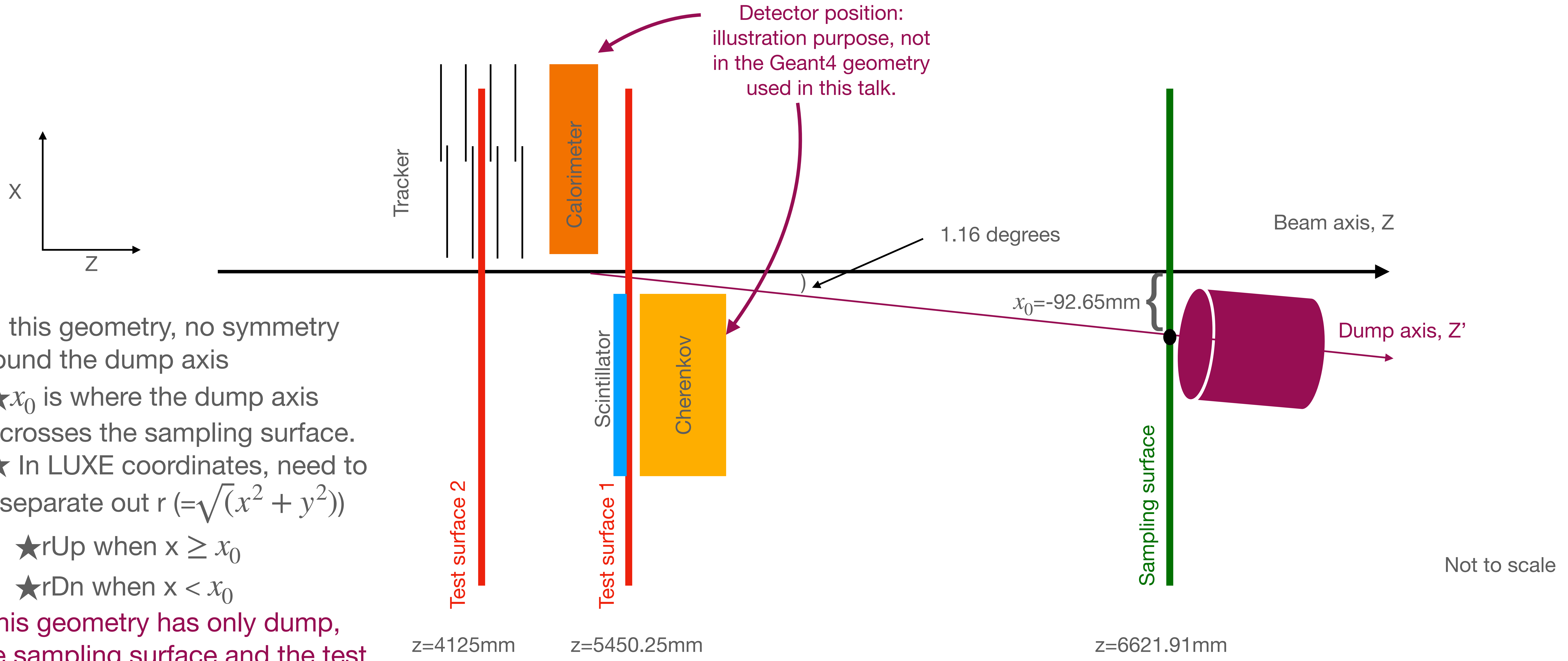
- Disable the dump and replace all its "output" by source-like particles
  - ★ At the tracker last layer
    - ★ 100% of the neutron come from dump
    - ★ >10% of the photons come from dump
    - ★ ~1% of the electrons and positrons from the dump
- Look at the dummy volume (sampling plane) located just outside of the surface of the dump
  - will plot $(\frac{dN}{dE}$ and $\frac{dN}{dt})$ or $\frac{d^2N}{dEdt}, \frac{d^2N}{drd\theta_p}, \frac{d^2N}{d\phi_p d\phi_{pos}}, \ldots$
    - Here r is just $\sqrt{x^2+y^2}$, position parameter.
    - θ_p, ϕ_p is the polar angle and azimuthal angle of the momentum → representative of direction of the particle.
    - ϕ_{pos} is position azimuthal angle, and t is time.
  - Later: generate from the sampling plane according to these plots
    - ★ Use TH1D::GetRandom() and TH2D::GetRandom2() (for variables that are correlated) methods.



- If dump is along z-axis, then r and ϕ_{pos} are symmetric.
- In actual LUXE geometry, there is a shift - r and ϕ_{pos} are asymmetric there.

Dump in the LUXE Geometry

Schematic diagram of the dump in the LUXE geometry



★In this geometry, no symmetry around the dump axis

- ★x_0 is where the dump axis crosses the sampling surface.
- ★ In LUXE coordinates, need to separate out r (=$\sqrt{(x^2+y^2})$)
  - ★rUp when x $\geq x_0$
  - ★rDn when x $< x_0$

★This geometry has only dump, the sampling surface and the test surfaces

- ★No detector planes.

Strategy for FastSim in LUXE Geometry

- The symmetry in r and ϕ_{pos} is unavailable for the dump particles in LUXE geometry, we need to come up with this strategy:

1.Plot $\frac{d^2N}{dxdy}$ → randomly draw x and y from this distribution.

2.This gives r and ϕ_{pos};

(i)depending on x > x_0 or x < x_0, we select r_{Up} or r_{Dn}.

3.Plot $\frac{d^2N}{dr_{Up}d\theta_p}$ and $\frac{d^2N}{dr_{Dn}d\theta_p}$ → given the r, we project this distribution on θ_p to get $\frac{dN}{d\theta_p}$ (1D distribution)

4.Plot $\frac{d^2N}{d\phi_p d\phi_{pos}}$ → given the ϕ_{pos}, we project this distribution on ϕ_p to get $\frac{dN}{d\phi_p}$ (1D distribution)

5.Randomly draw $\theta_p$from $\frac{dN}{d\theta_p}$ and ϕ_p from $\frac{dN}{d\phi_p}$

6. We have x, y, ϕ_{pos}, θ_p and ϕ_p

7.Energy and time can be randomly drawn from $\frac{d^2N}{dEdt}$ (for neutron) or $\left(\frac{dN}{dE} \text{ and } \frac{dN}{dt}\right)$(for photons).

Plot labels:

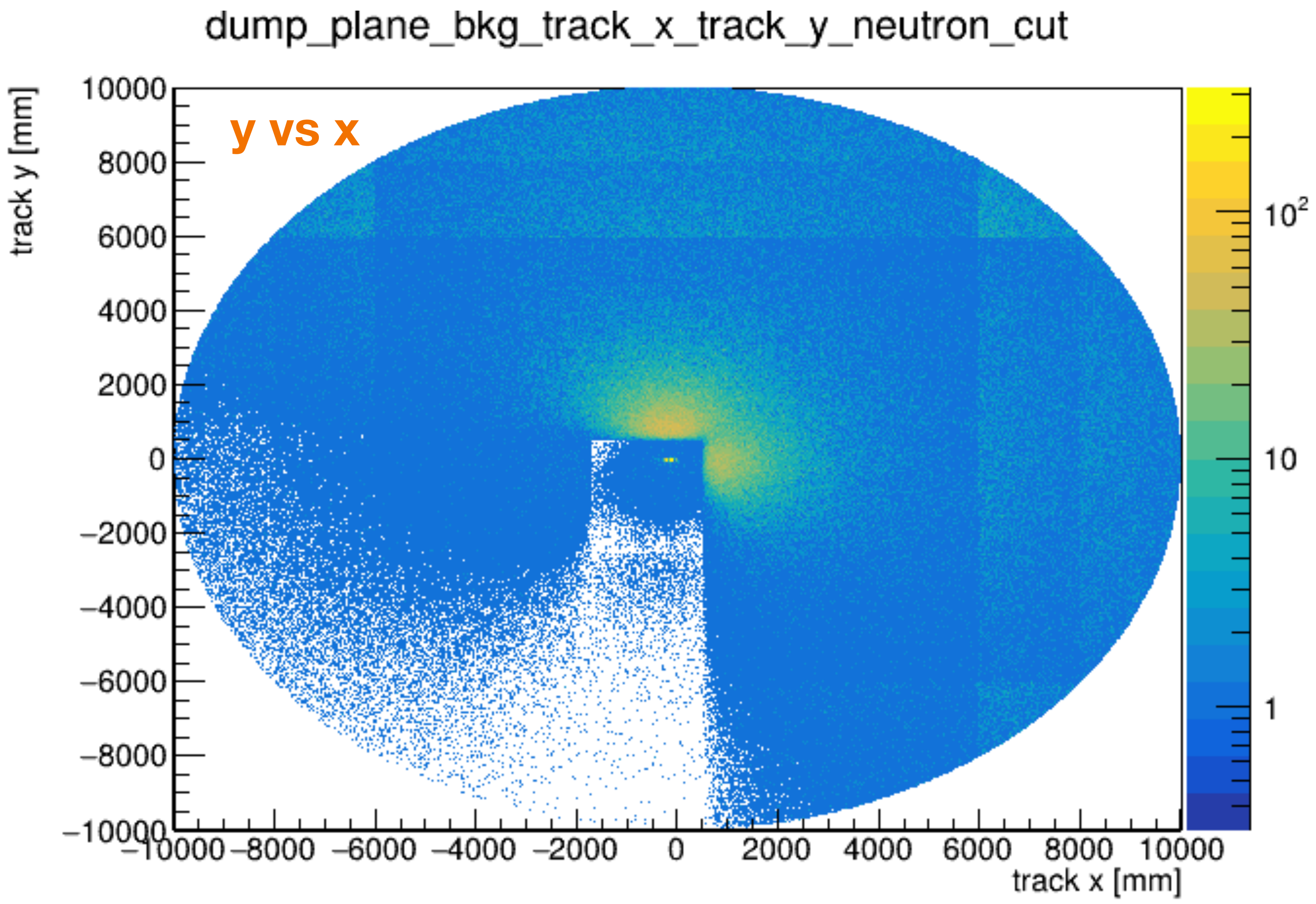
- In this talk there will be **three types of plots** compared:

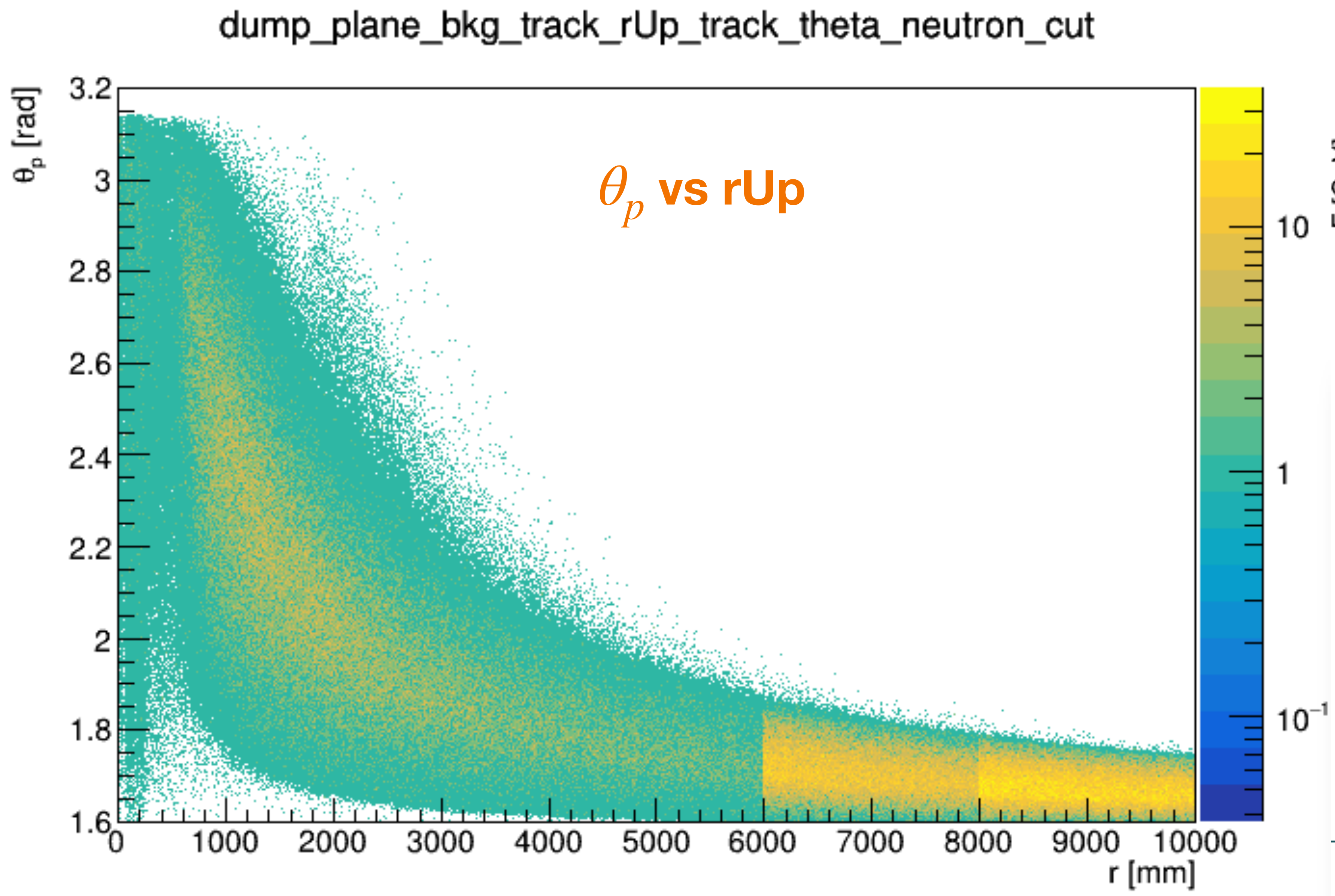
    1. **FullSim** - Distributions from full Geant4 processing of the dump
    2. **Fast Sampling**: sampled randomly from the FullSim distribution at the sampling plane.
    3. **FastSim** - Geant4 processing where dump is replaced by particles following distributions in Fast Sampling above.

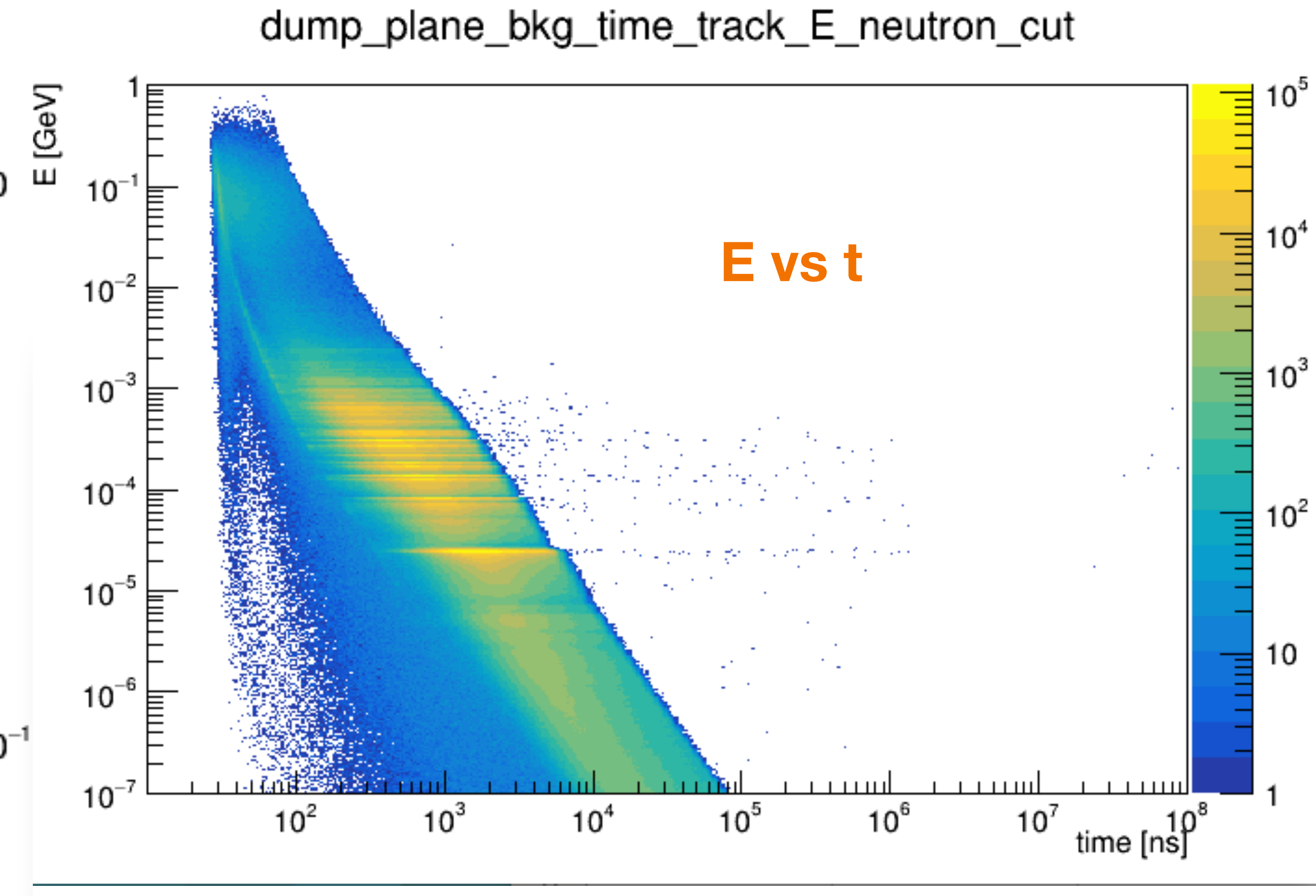
Baseline distribution plots for LUXE geometry at the sampling surface (z=6621.91mm)

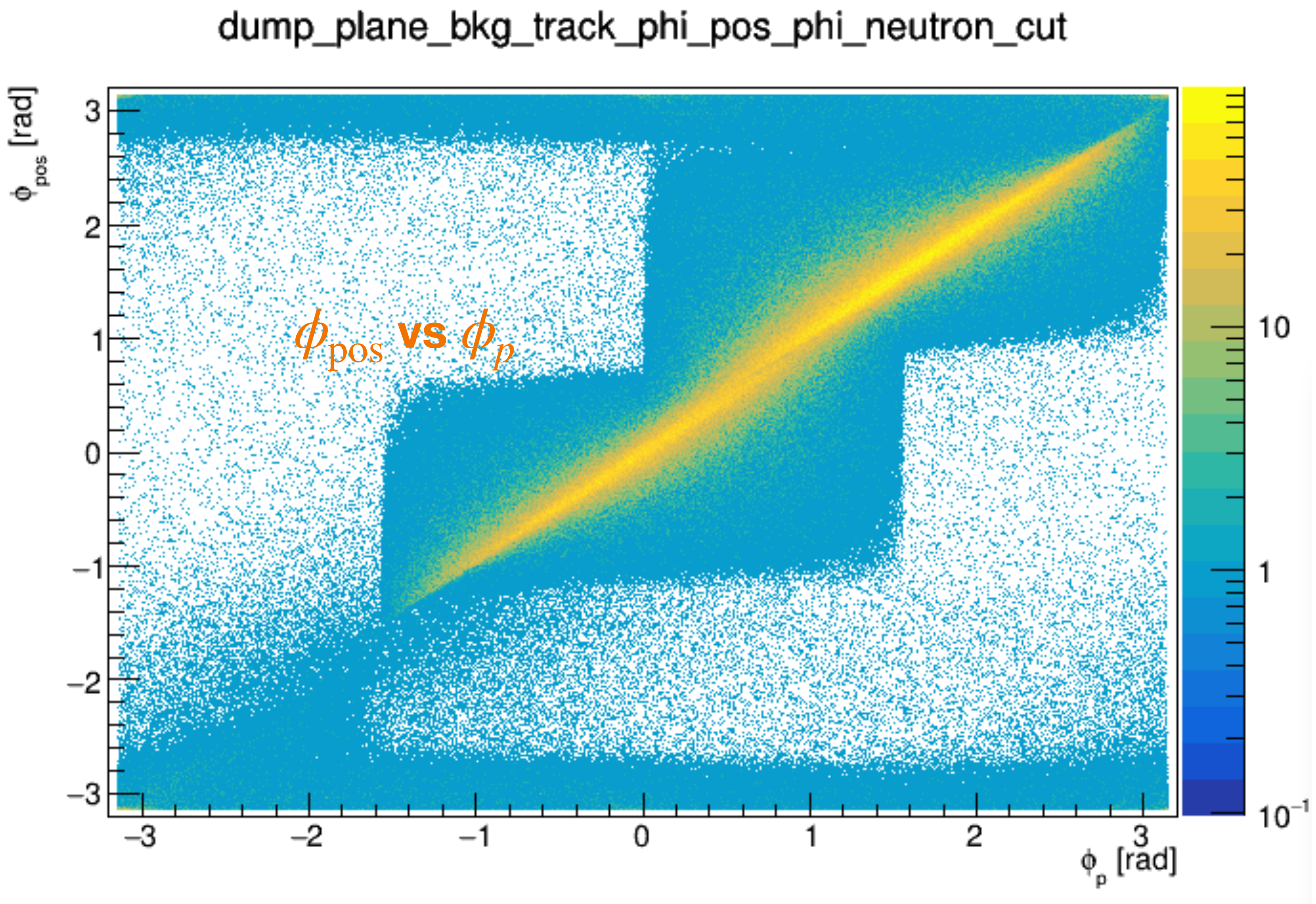
★ Plots used for sampling.

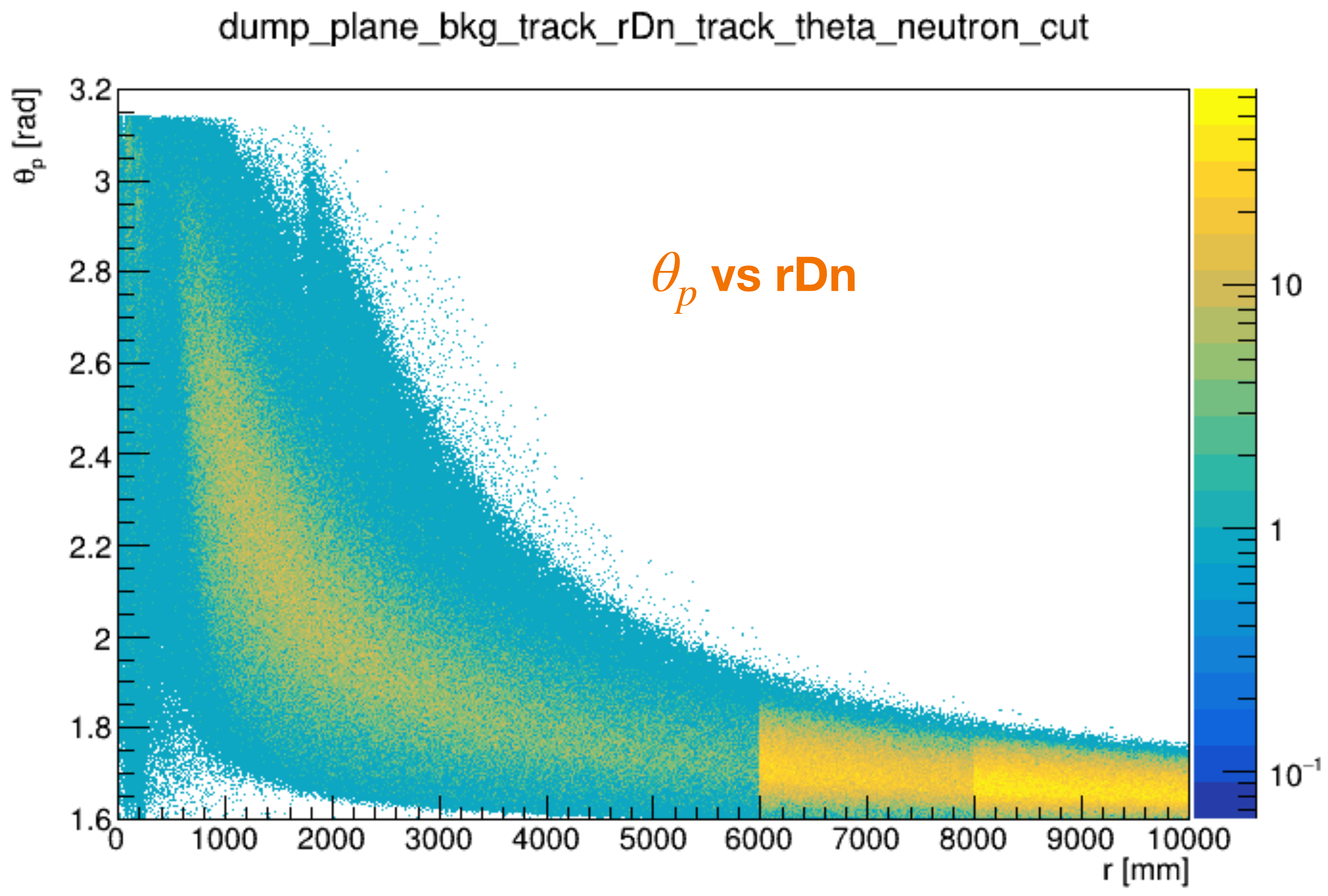
Baseline distributions from FullSim in LUXE: neutron at sampling surface







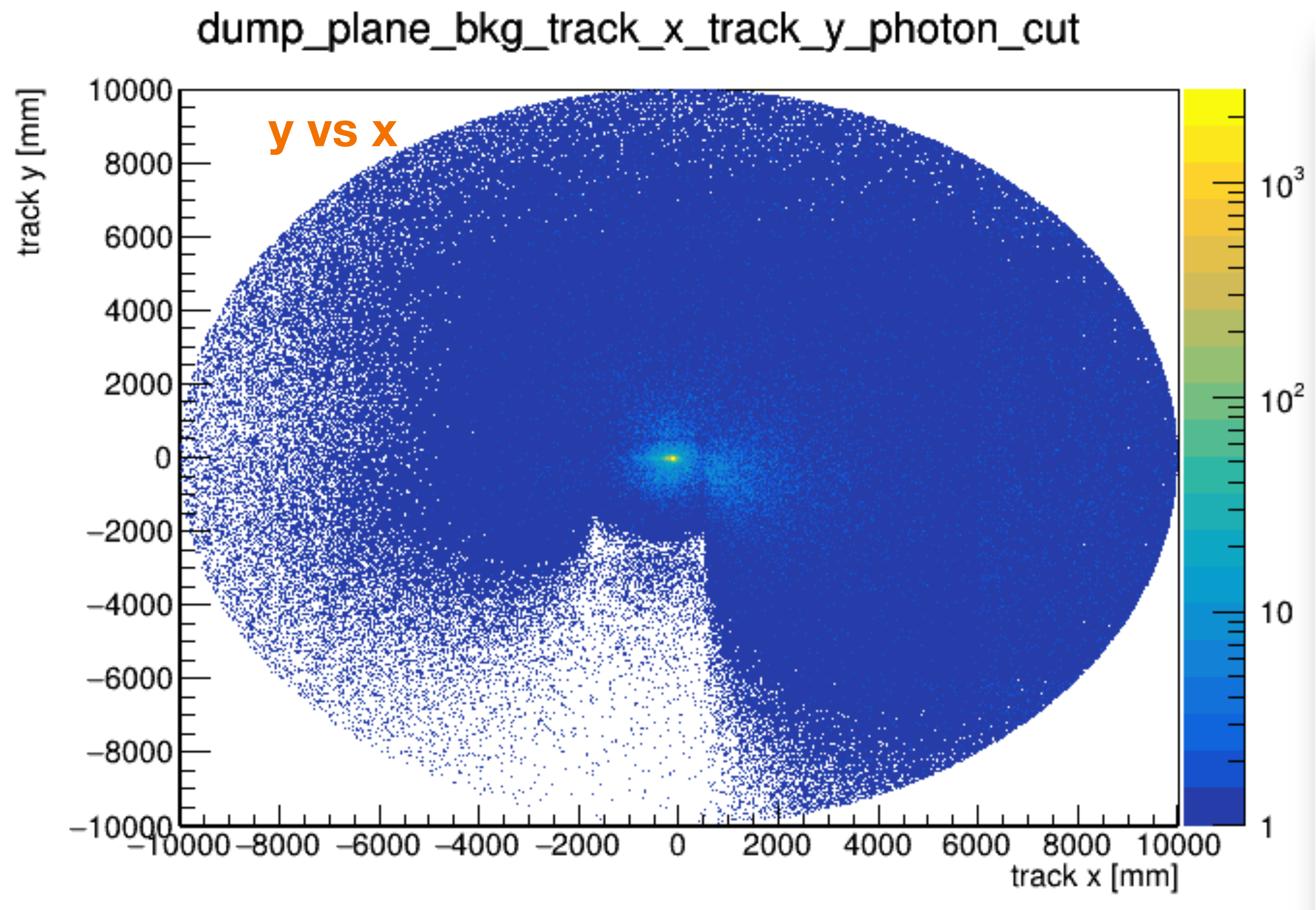


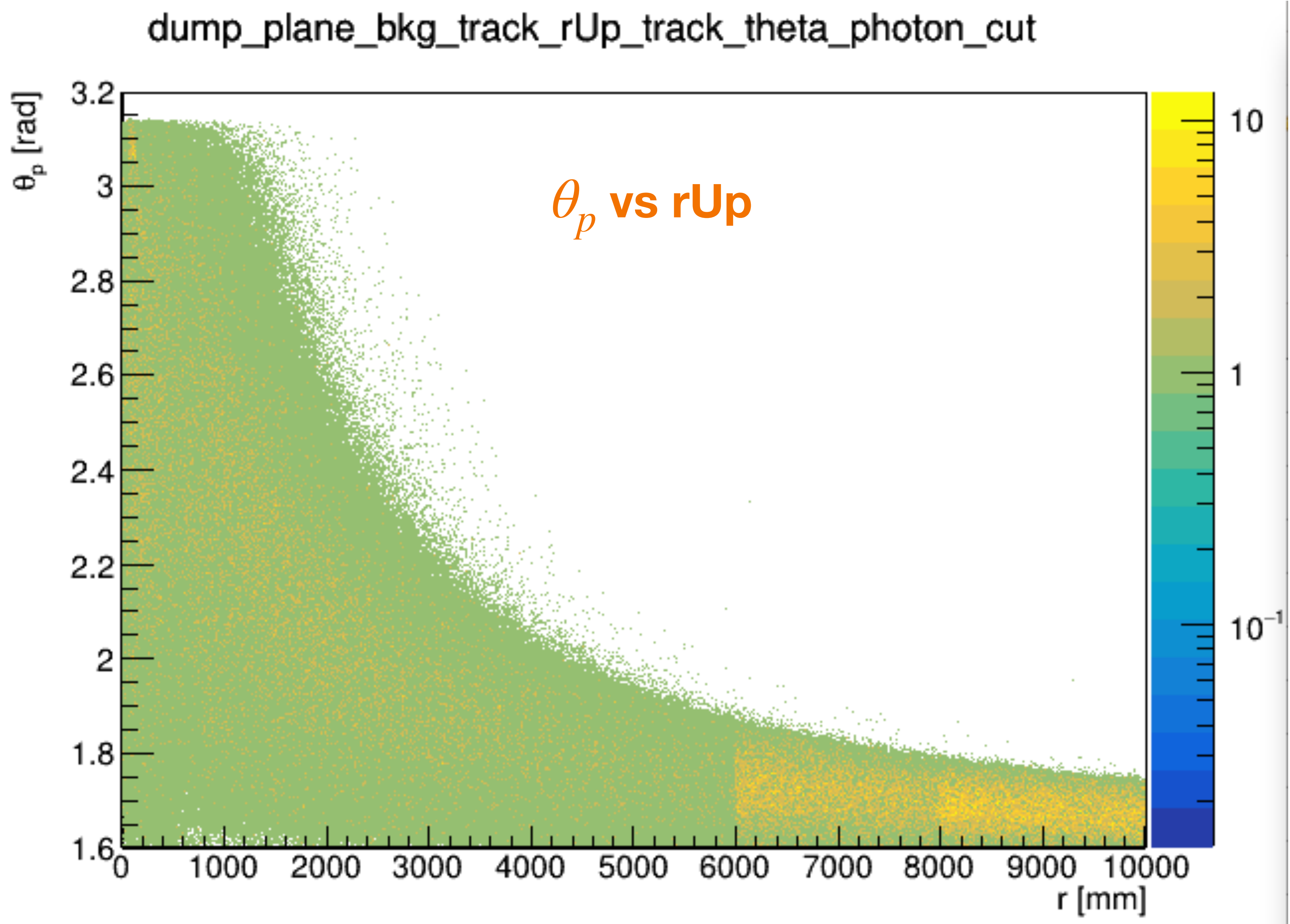


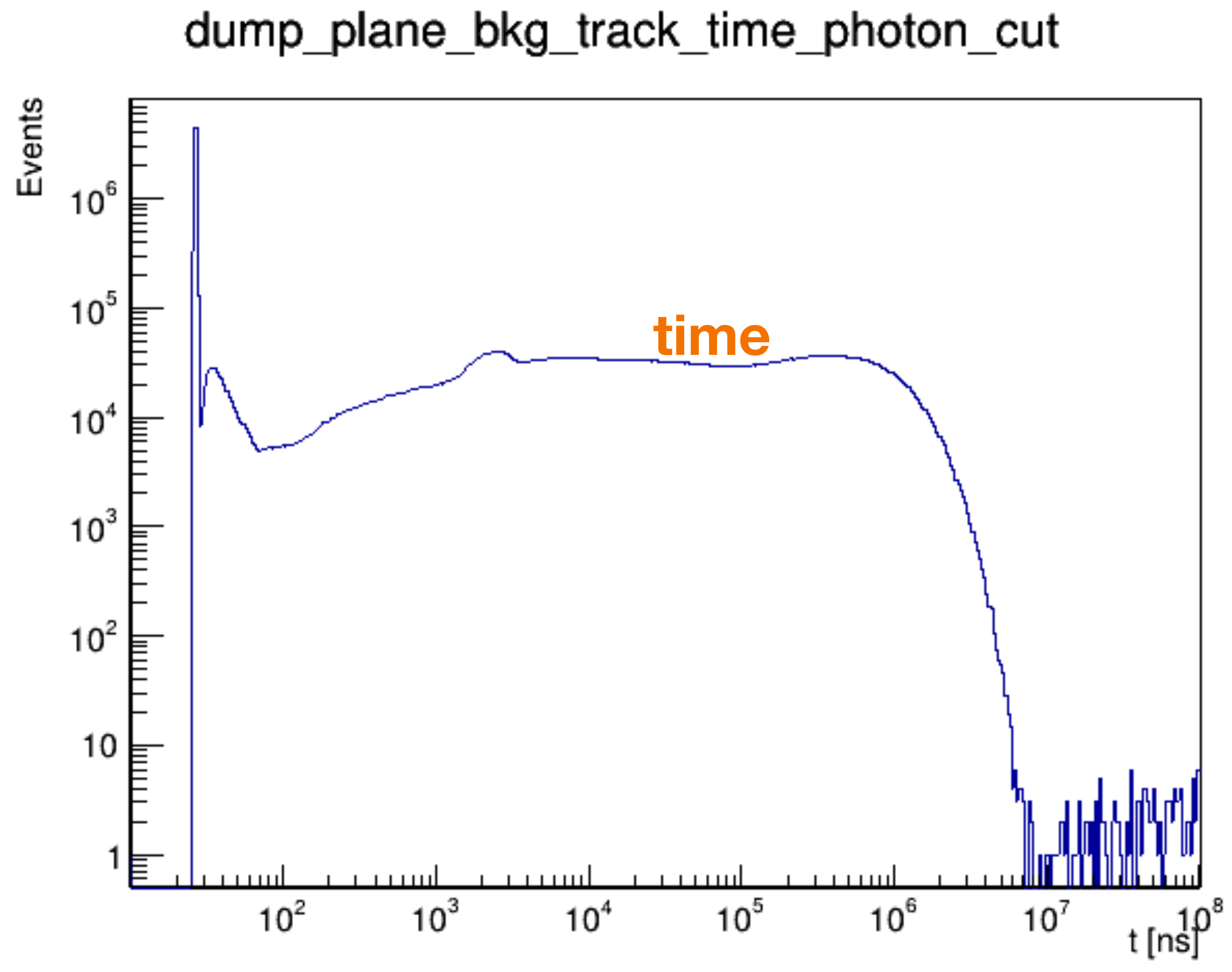
★For E vs t plot of neutron, we only go up to 100 eV of neutron.

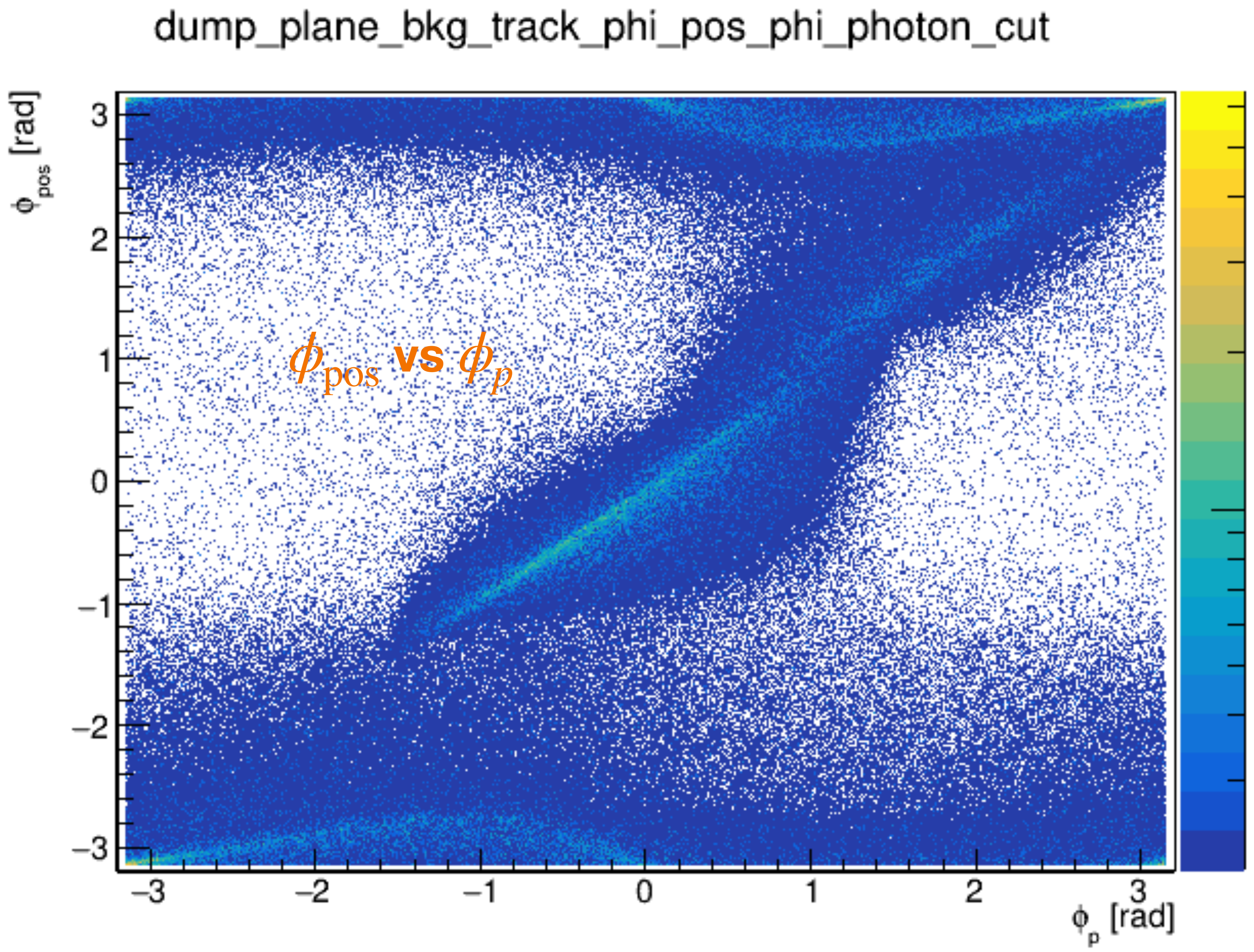
★Neutron less energetic than that are not interesting.

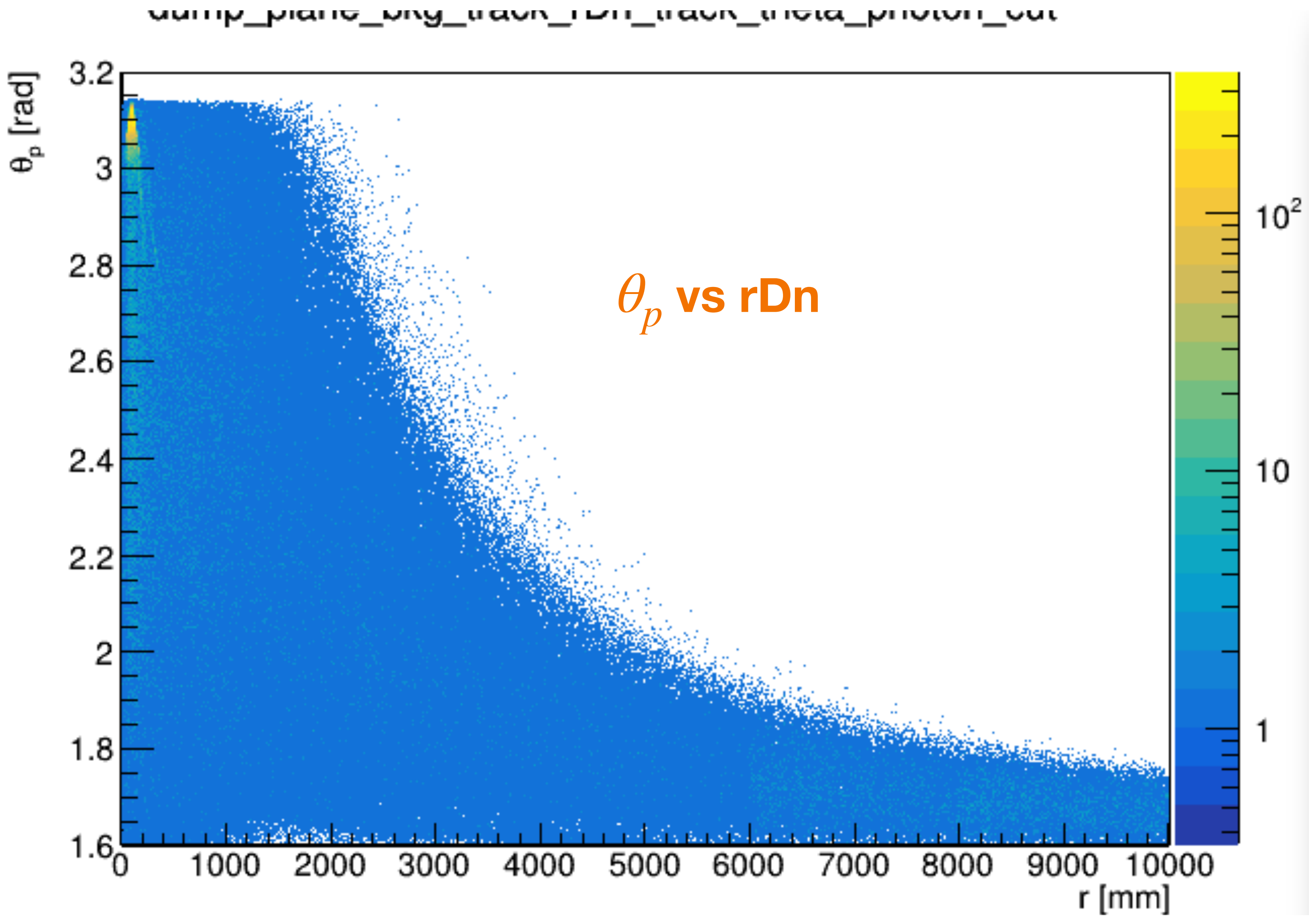
Baseline distributions from FullSim in LUXE: photon at sampling surface

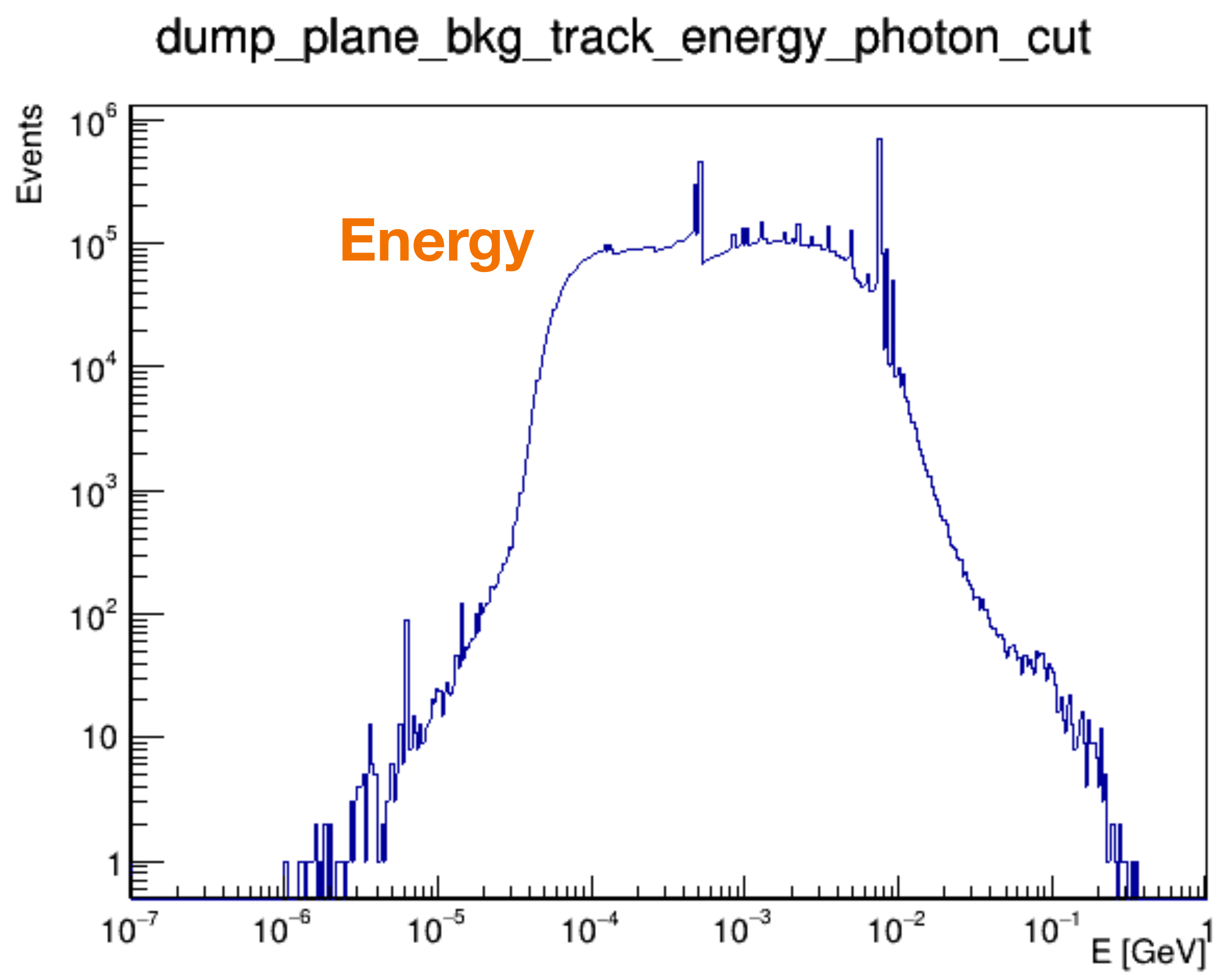








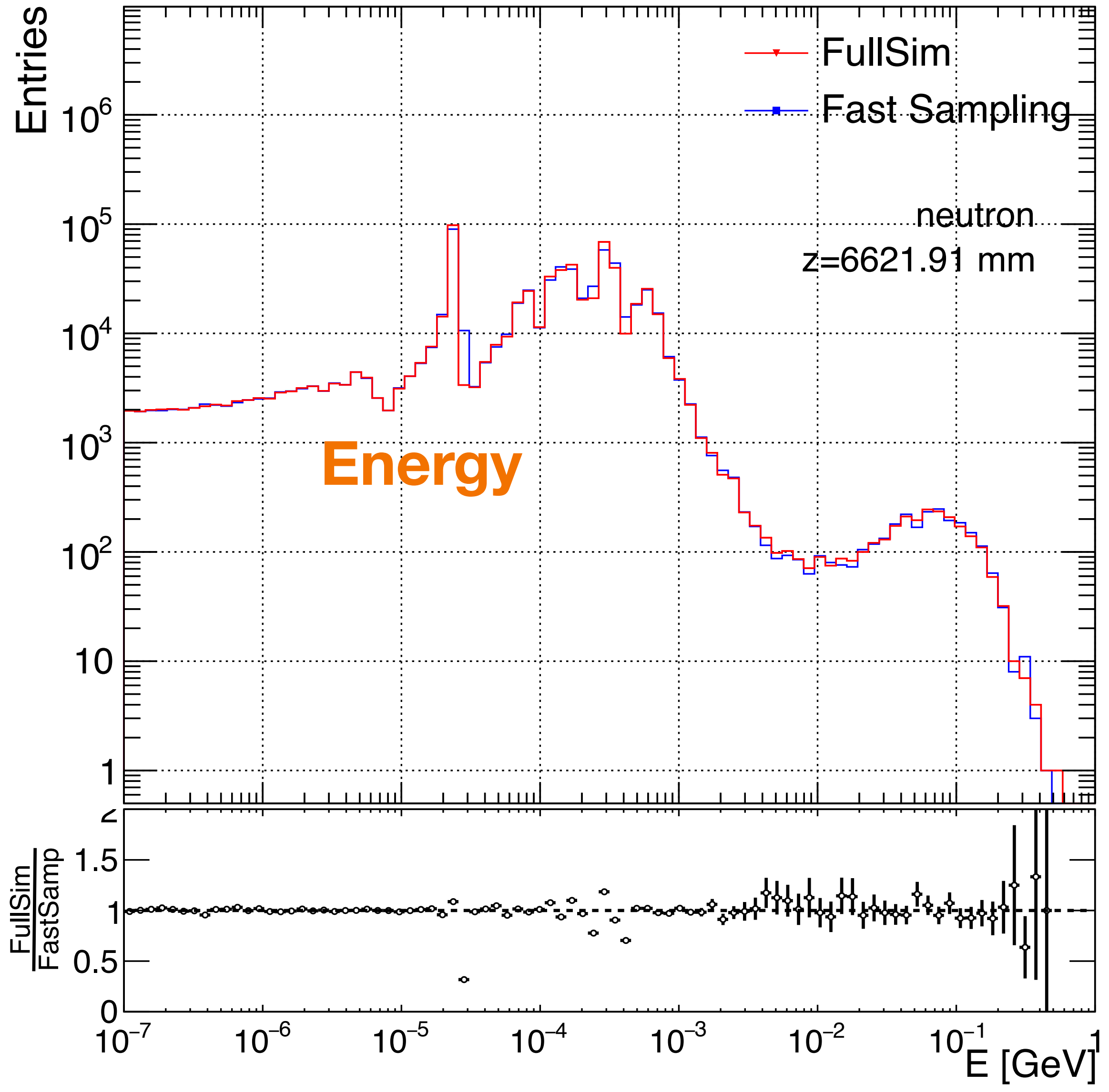


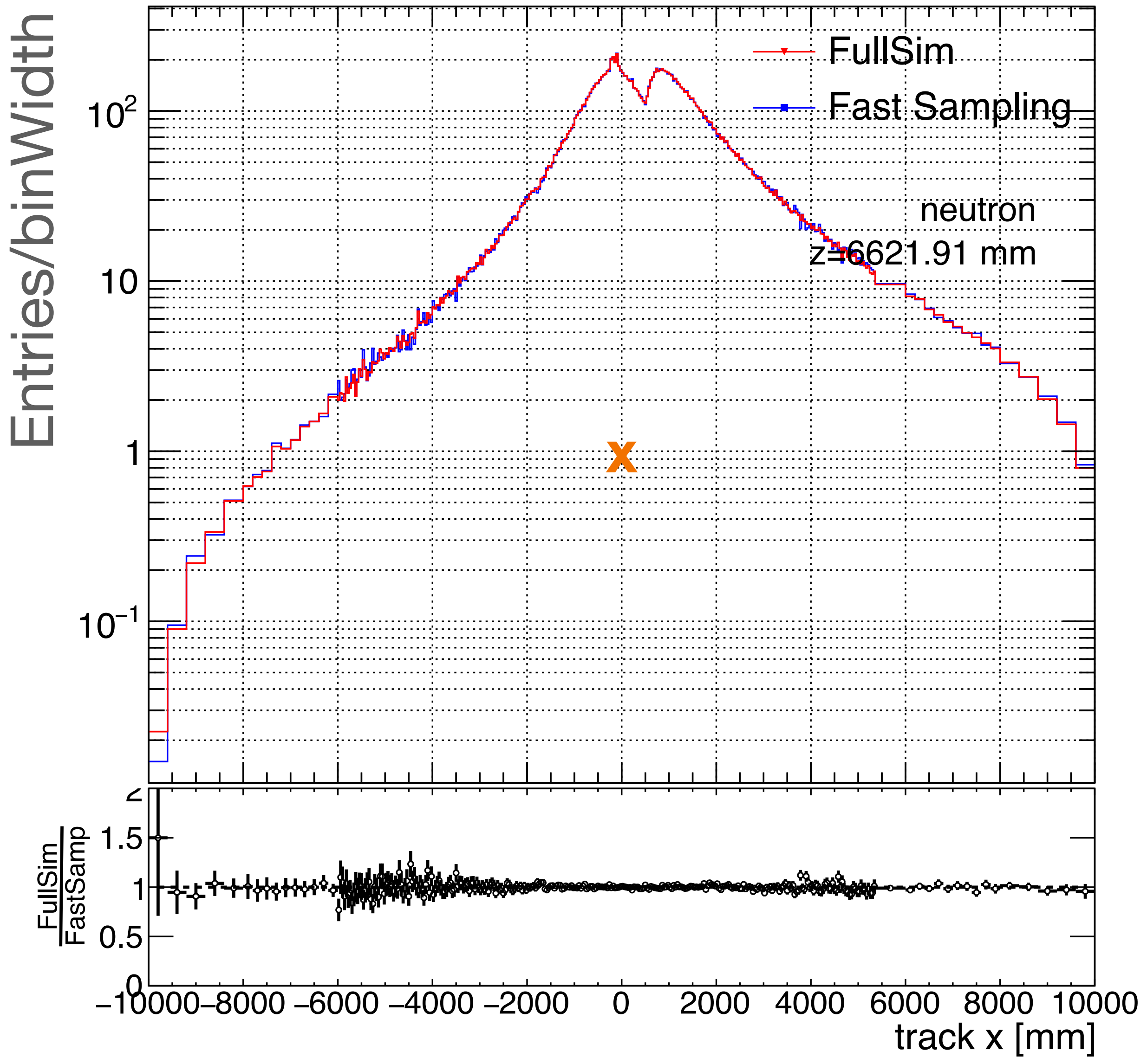


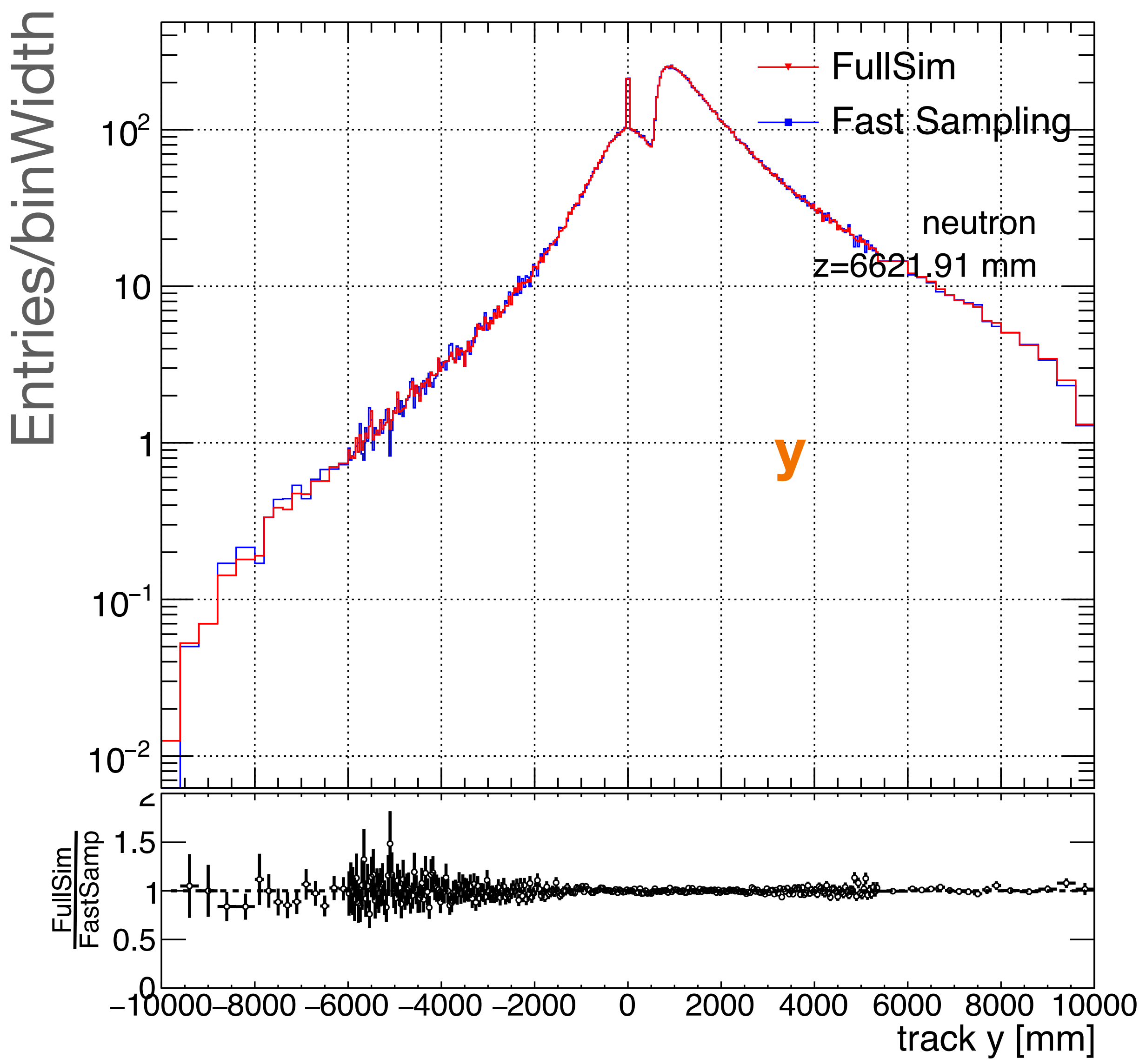
Comparison of FullSim and Fast Sampling distributions from histograms at the sampling surface (z=6621.91 mm) in LUXE geometry

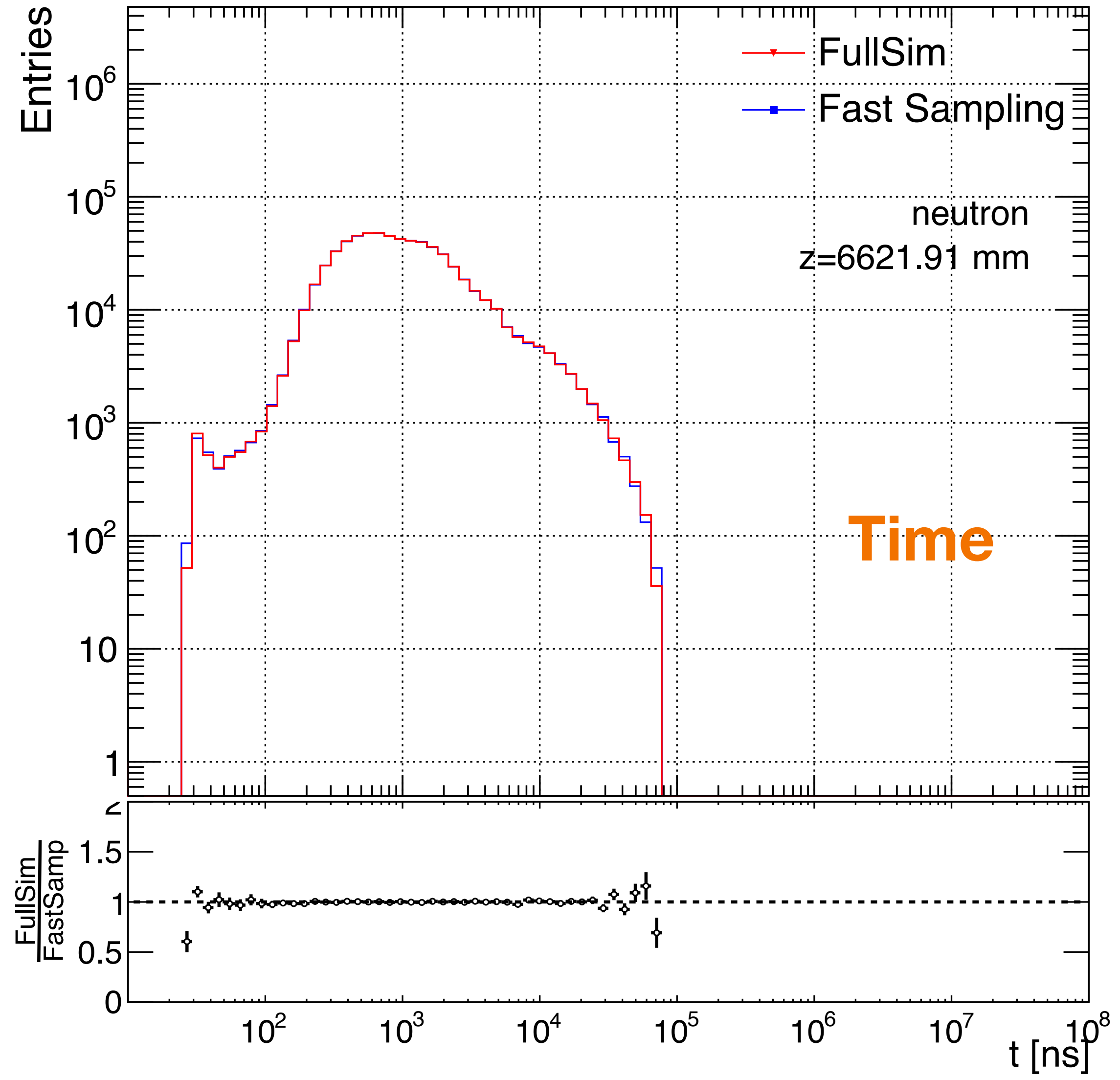
★ No z propagation in particles.

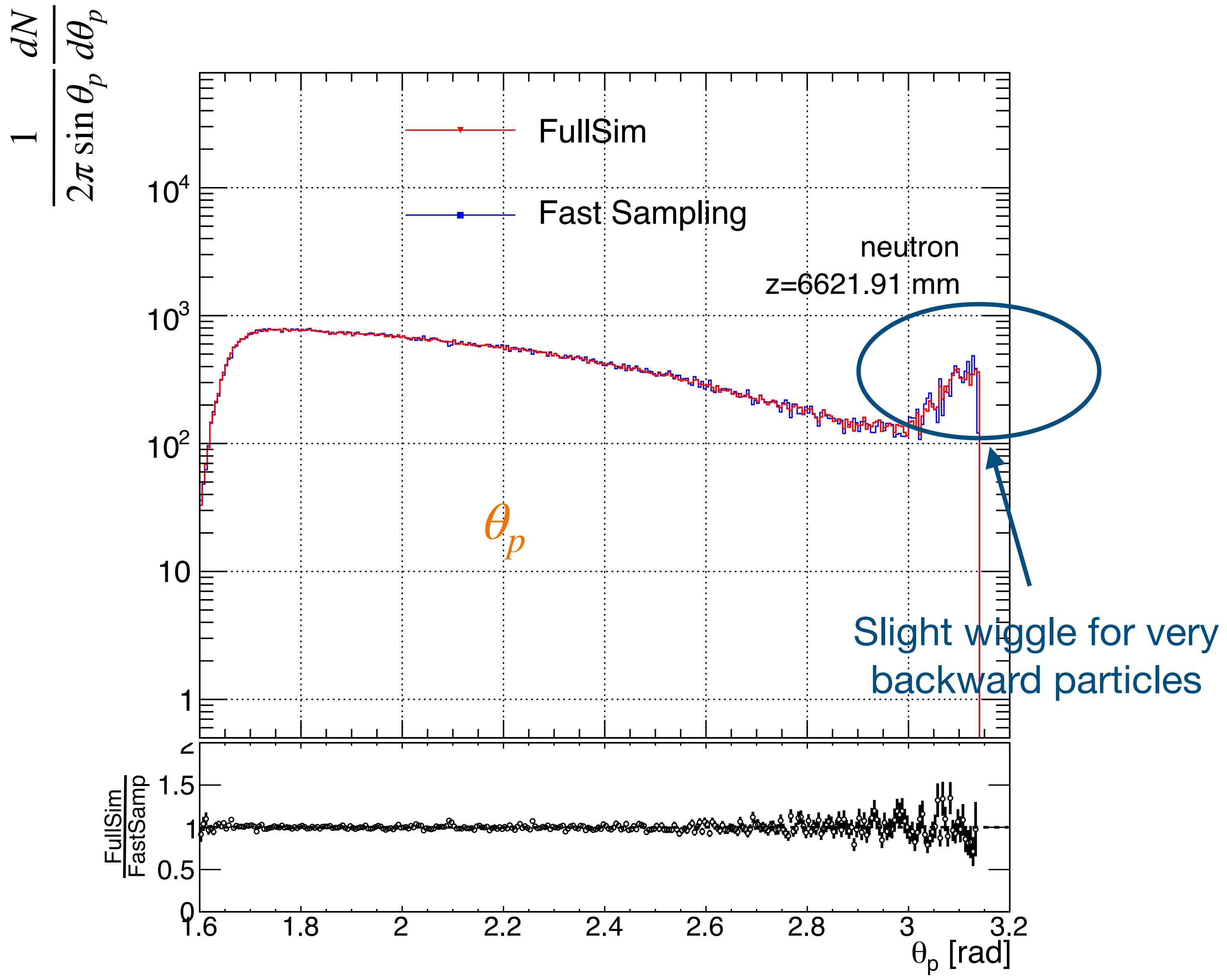
Comparison of FullSim and Fast Sampling distributions at the sampling surface for the LUXE geometry: neutron

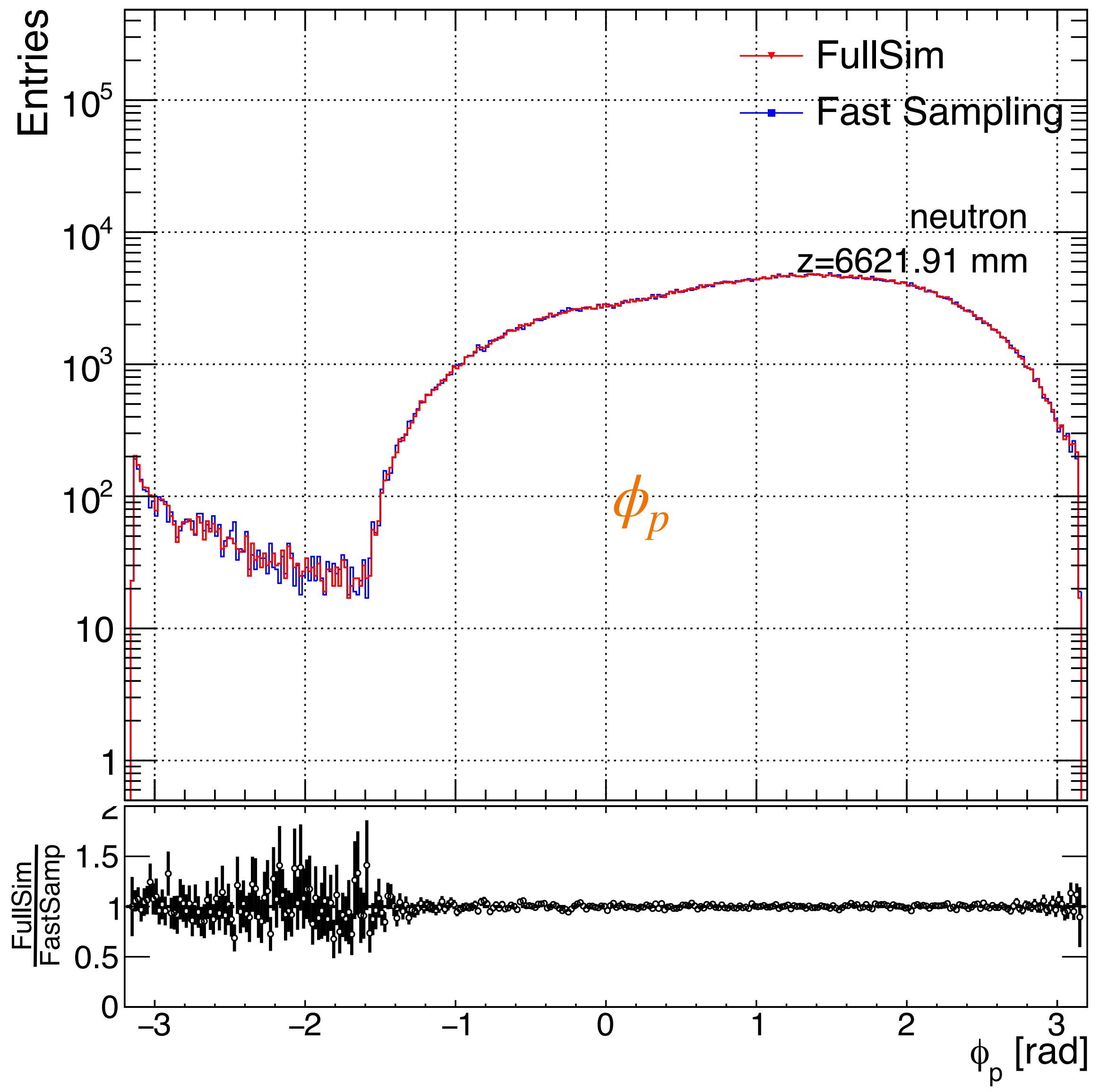






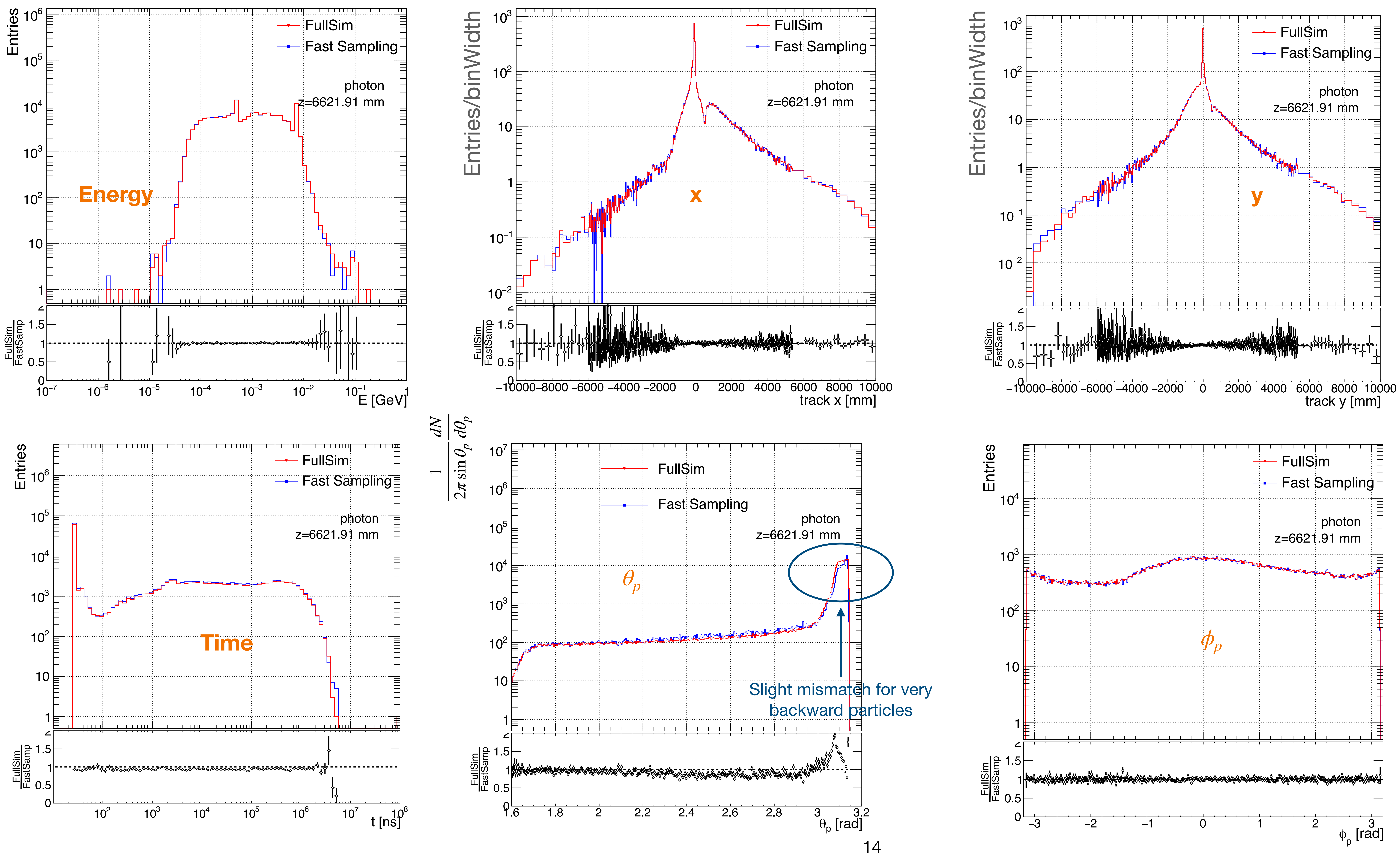






- ★Comparison of distribution at sampling surface for neutrons
  - ★Agreement is very good within the statistics except momentum direction at very backward direction.
    - ★Need to see its effect in the test surfaces.
  - ★The good modeling between FullSim and Fast Sampling is **a sanity check.**

Comparison of FullSim and Fast Sampling distributions at the sampling surface for the LUXE geometry: photon



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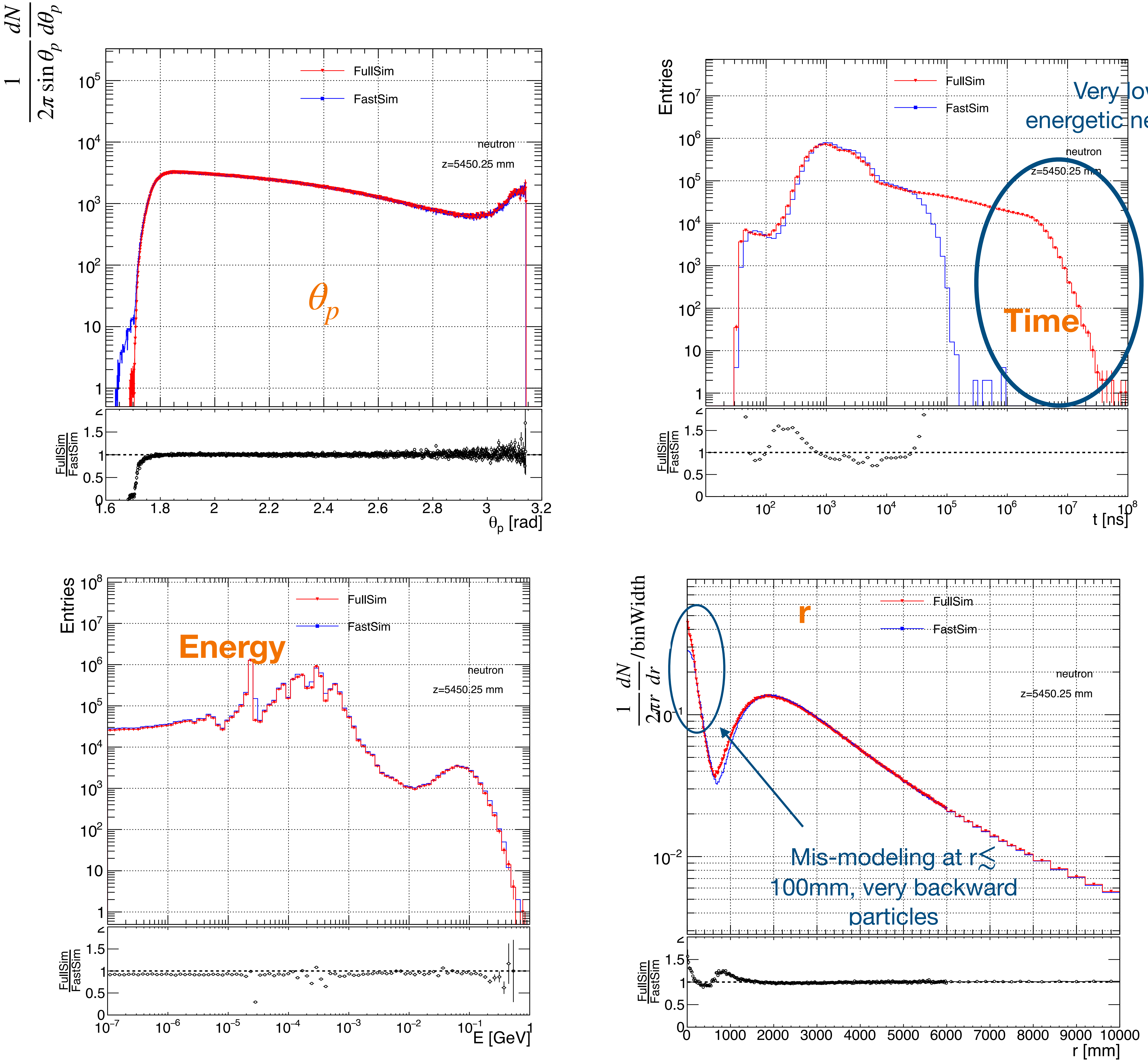
Comparison of FullSim and FastSim distributions at the test surface 1, z=5450.25mm

★ Particles generated at sampling plane are propagated to test surfaces by Geant4.

A few 1D distributions between FastSim and FullSim: neutron at the test surface 1



★Distributions are looked at **z=5450.25mm**.

★FullSim and FastSim has comparable statistics.

★FullSim and FastSim distributions are matching quite well.

★Mis-modeling in very backward particles ($r \lesssim 100$ mm at z=5450.25mm).

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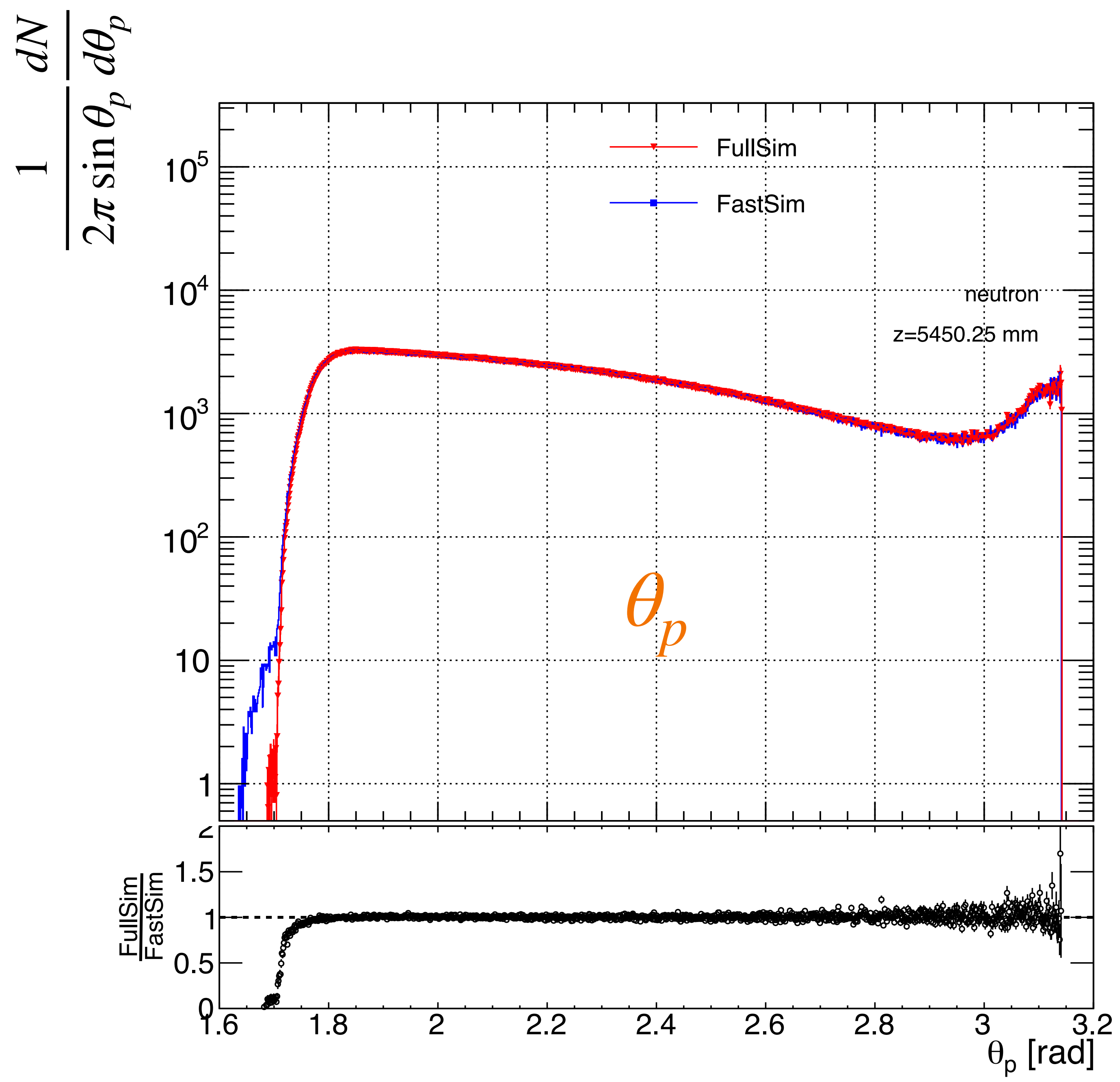

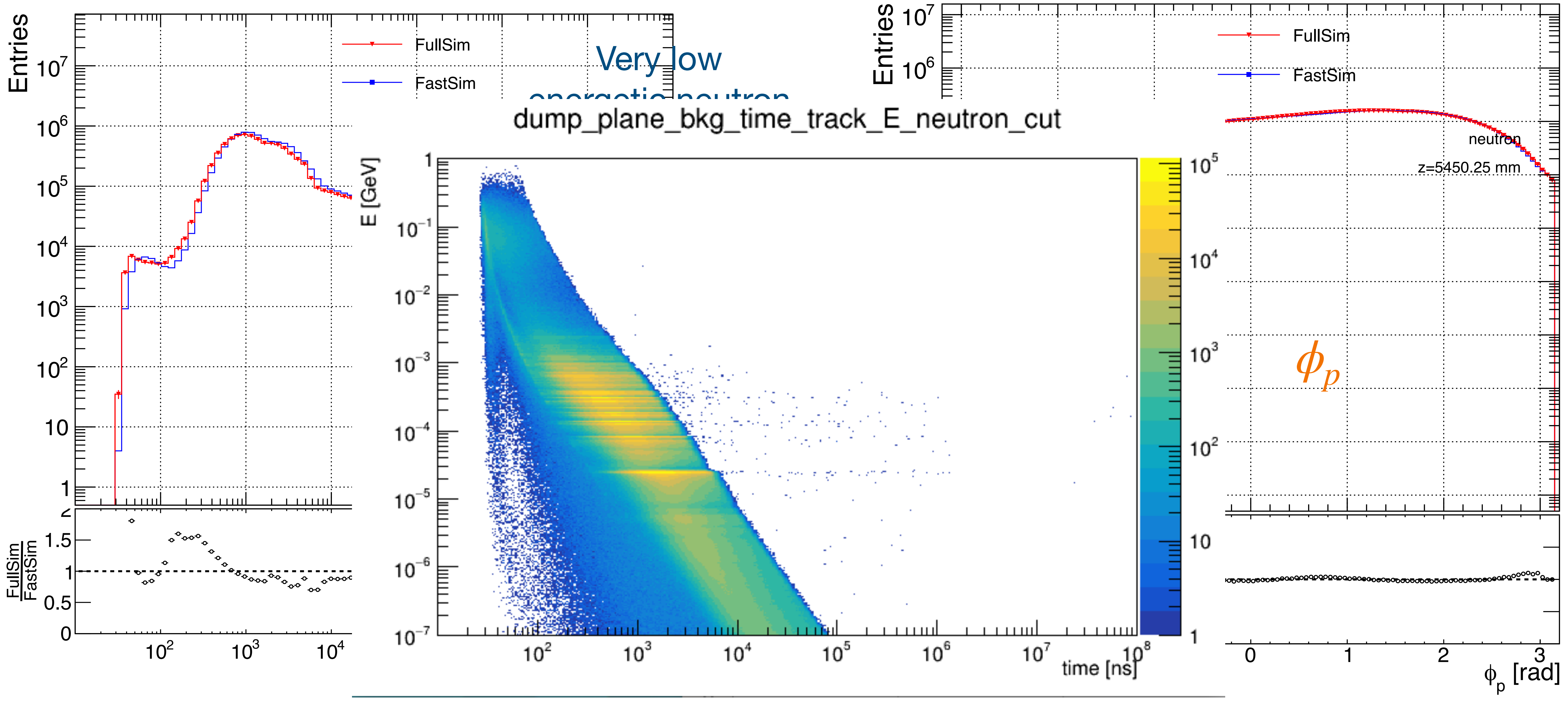

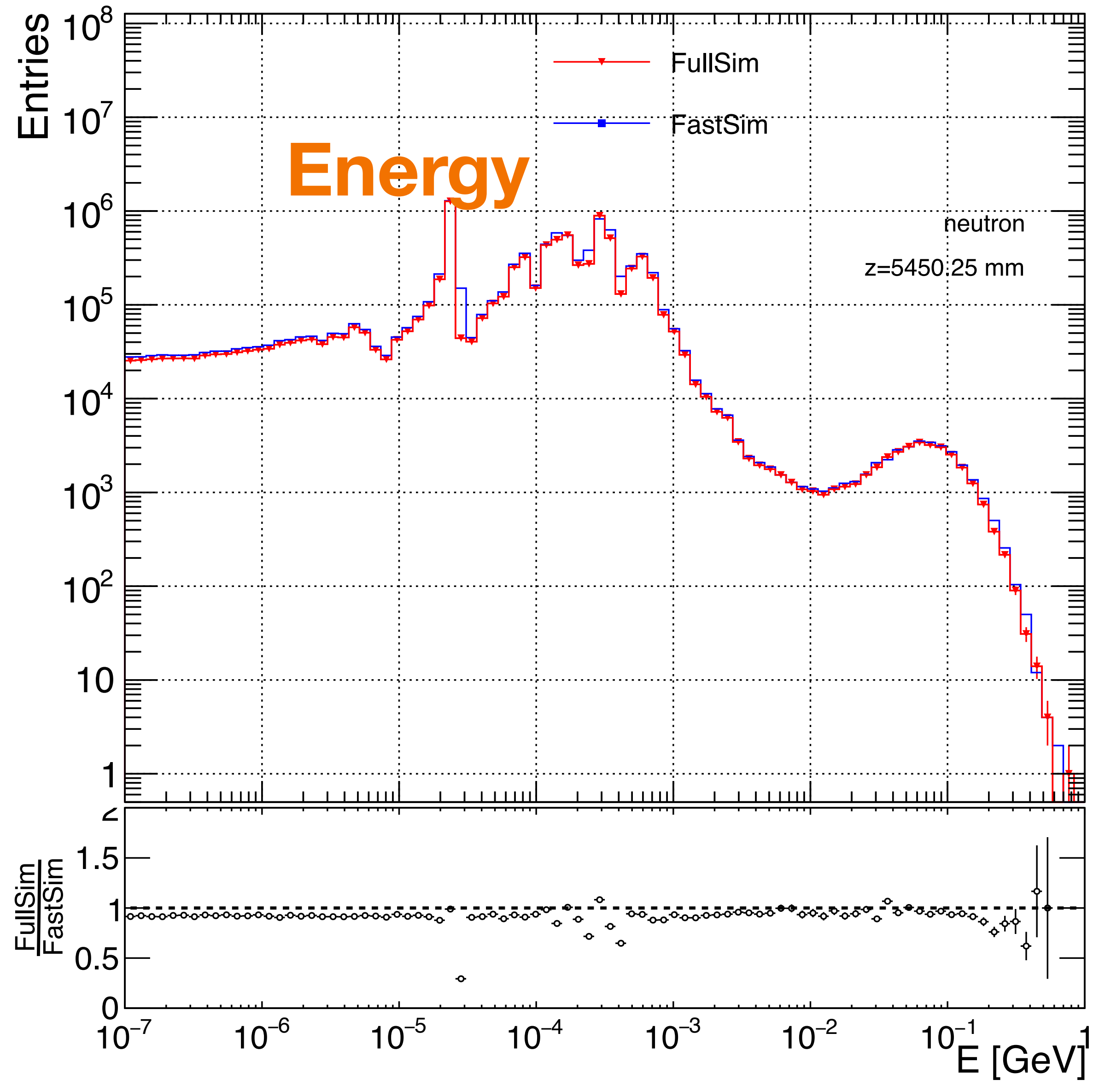

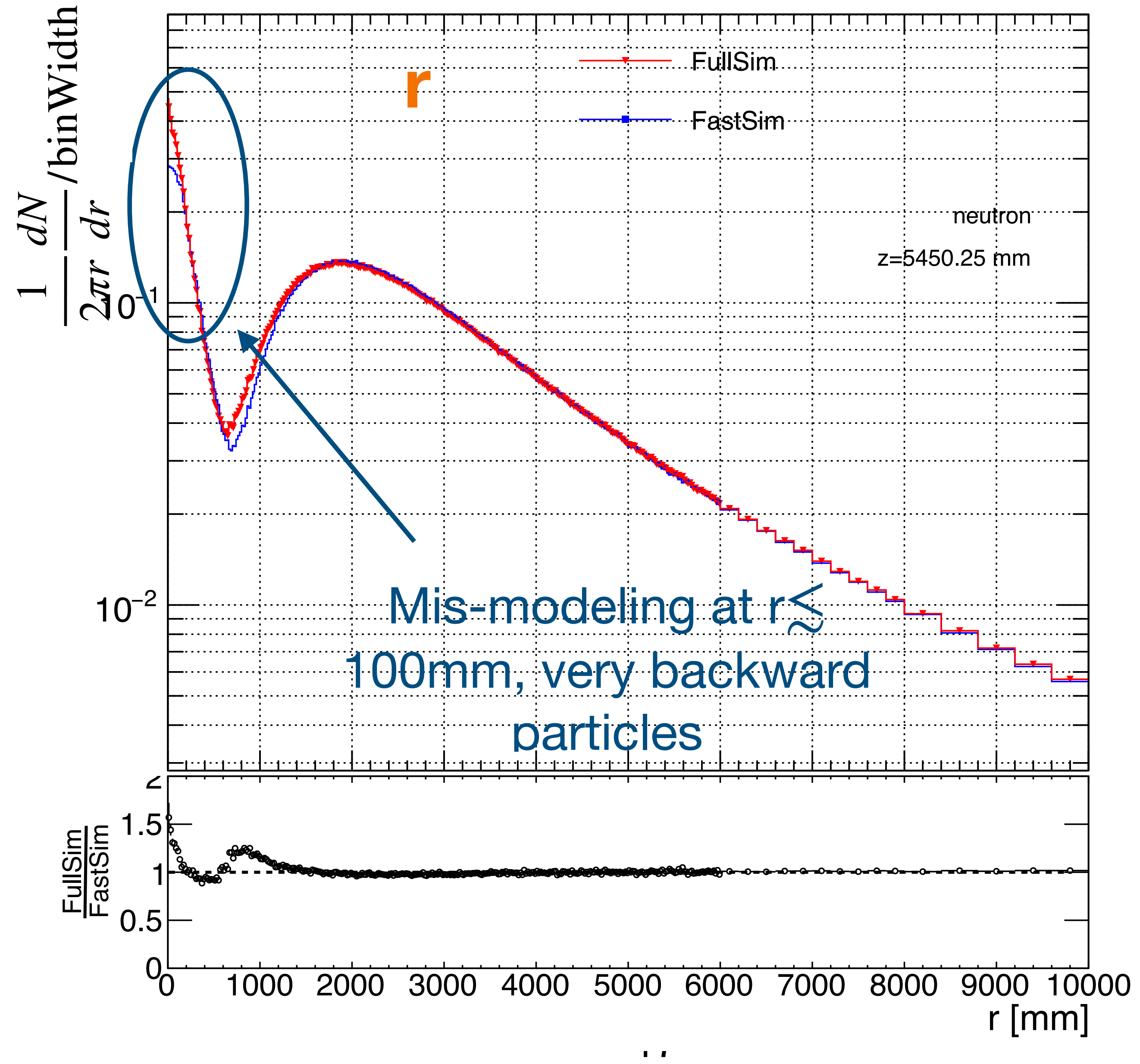

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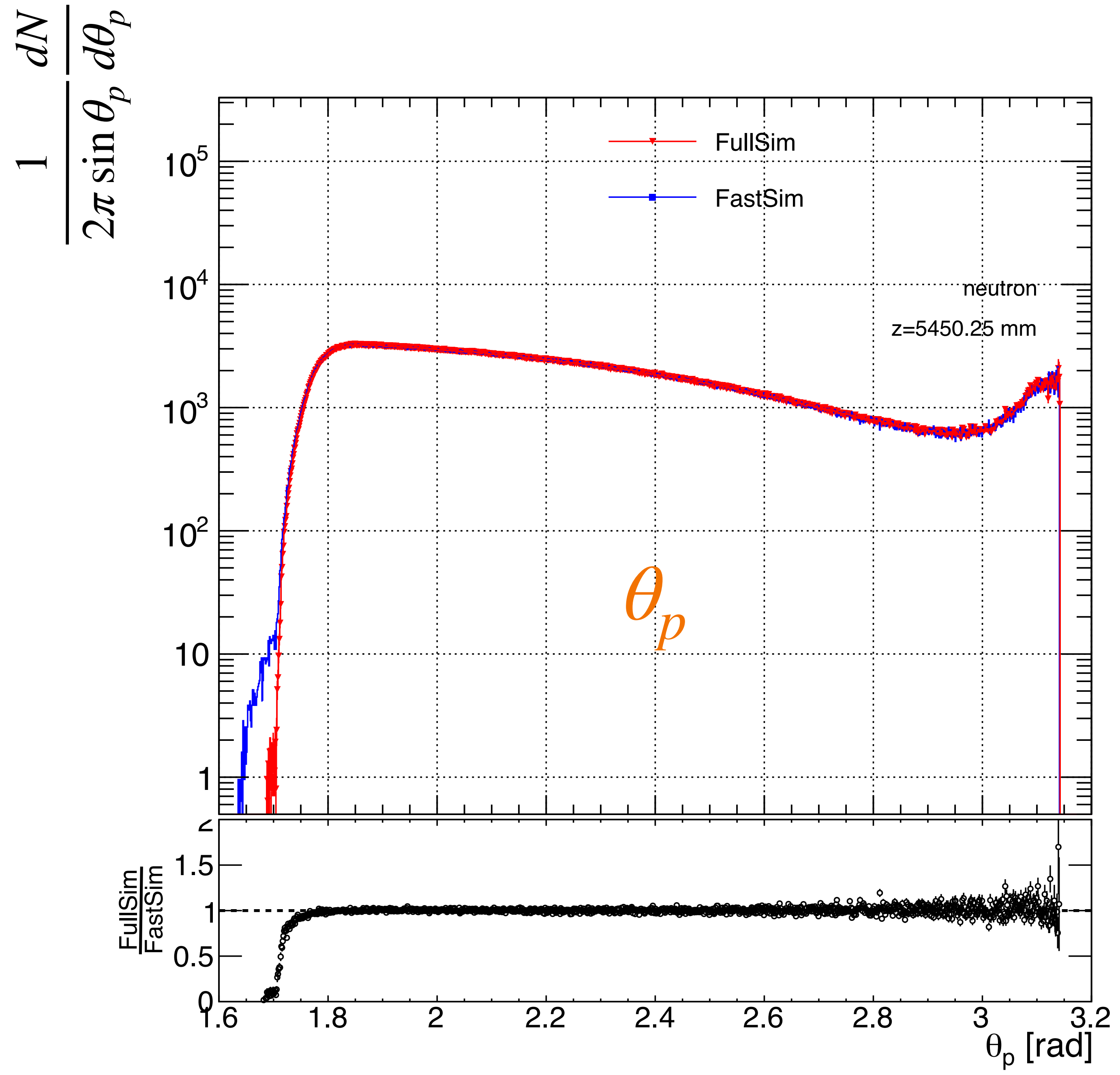

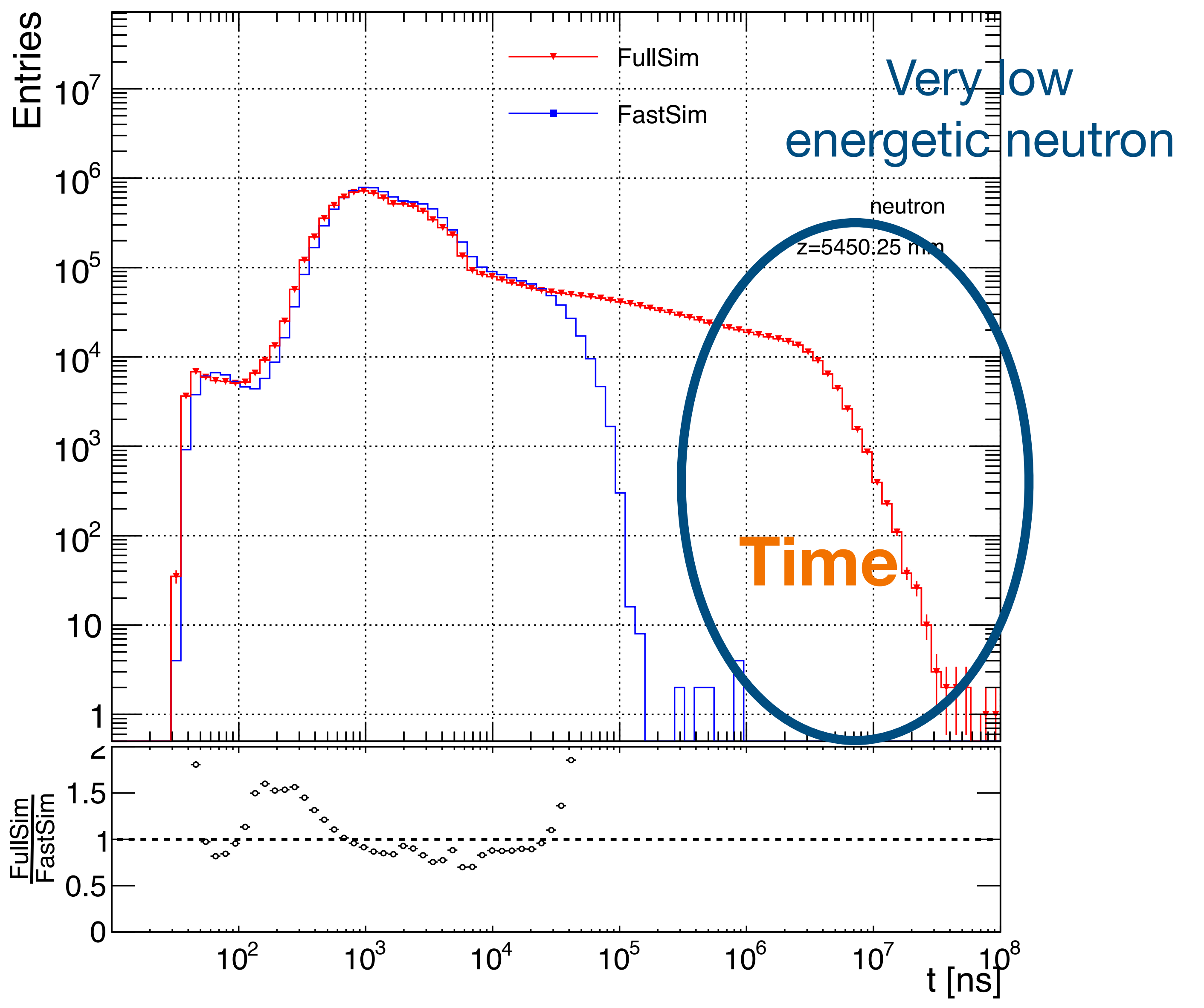

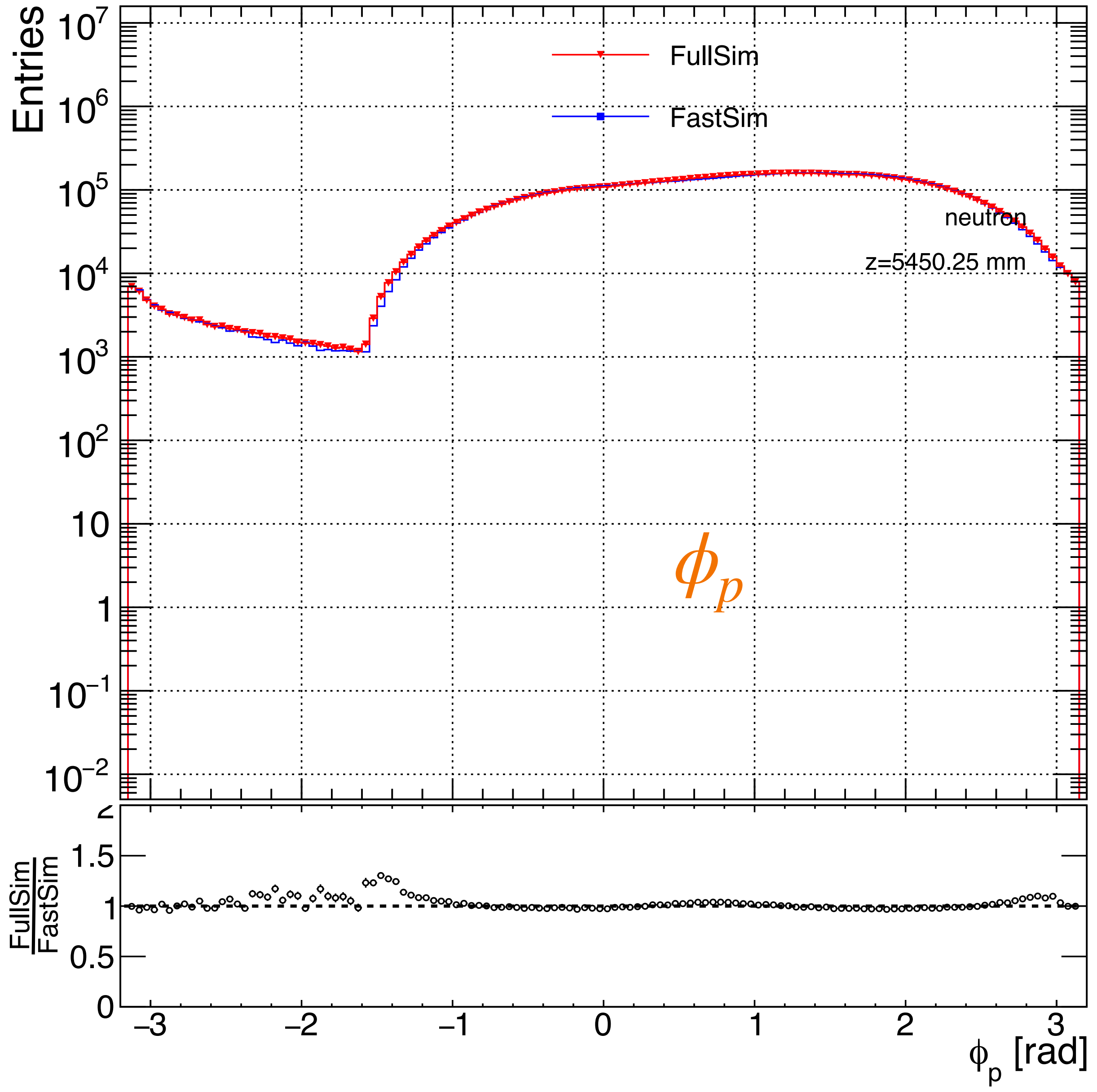

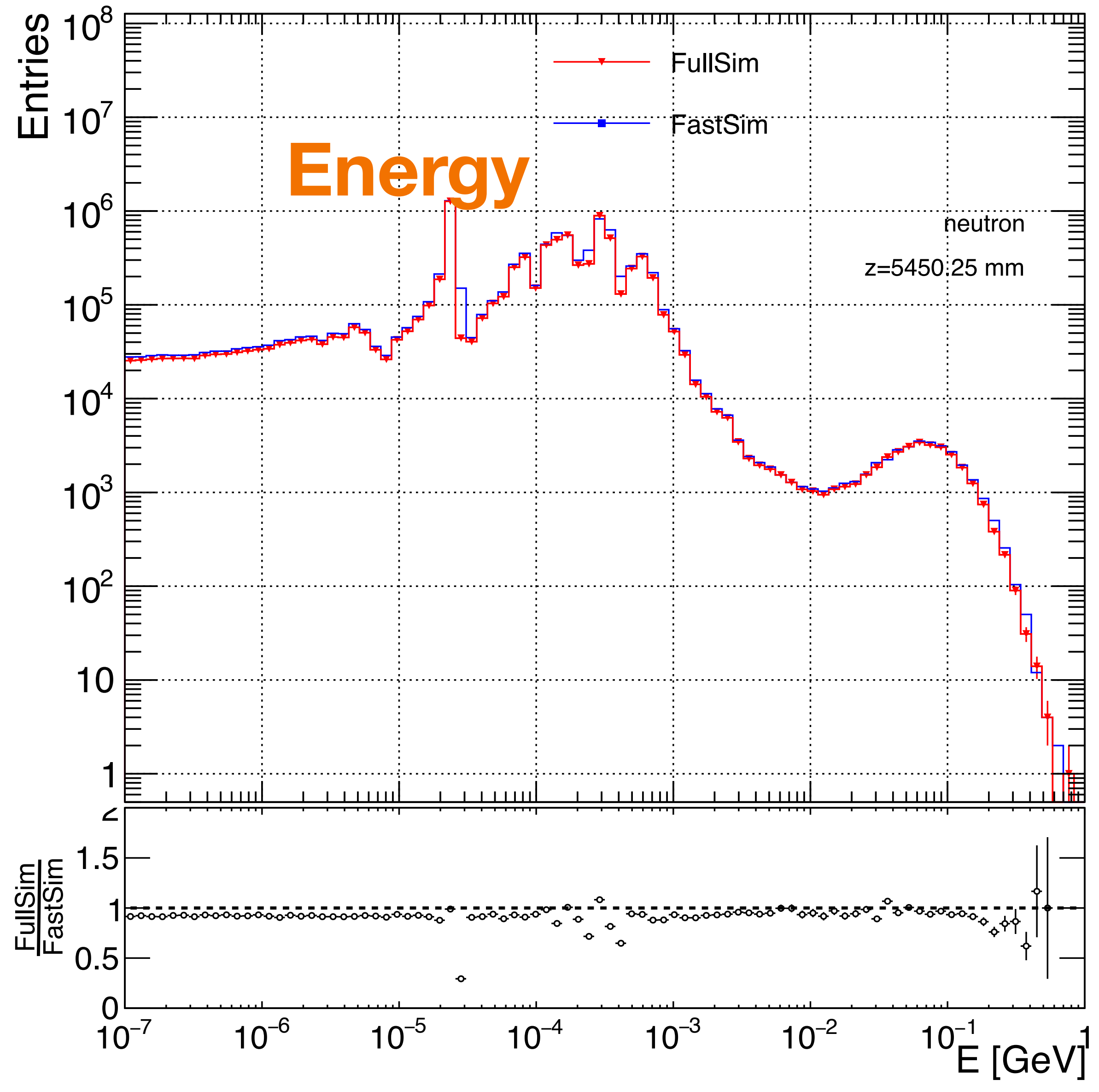

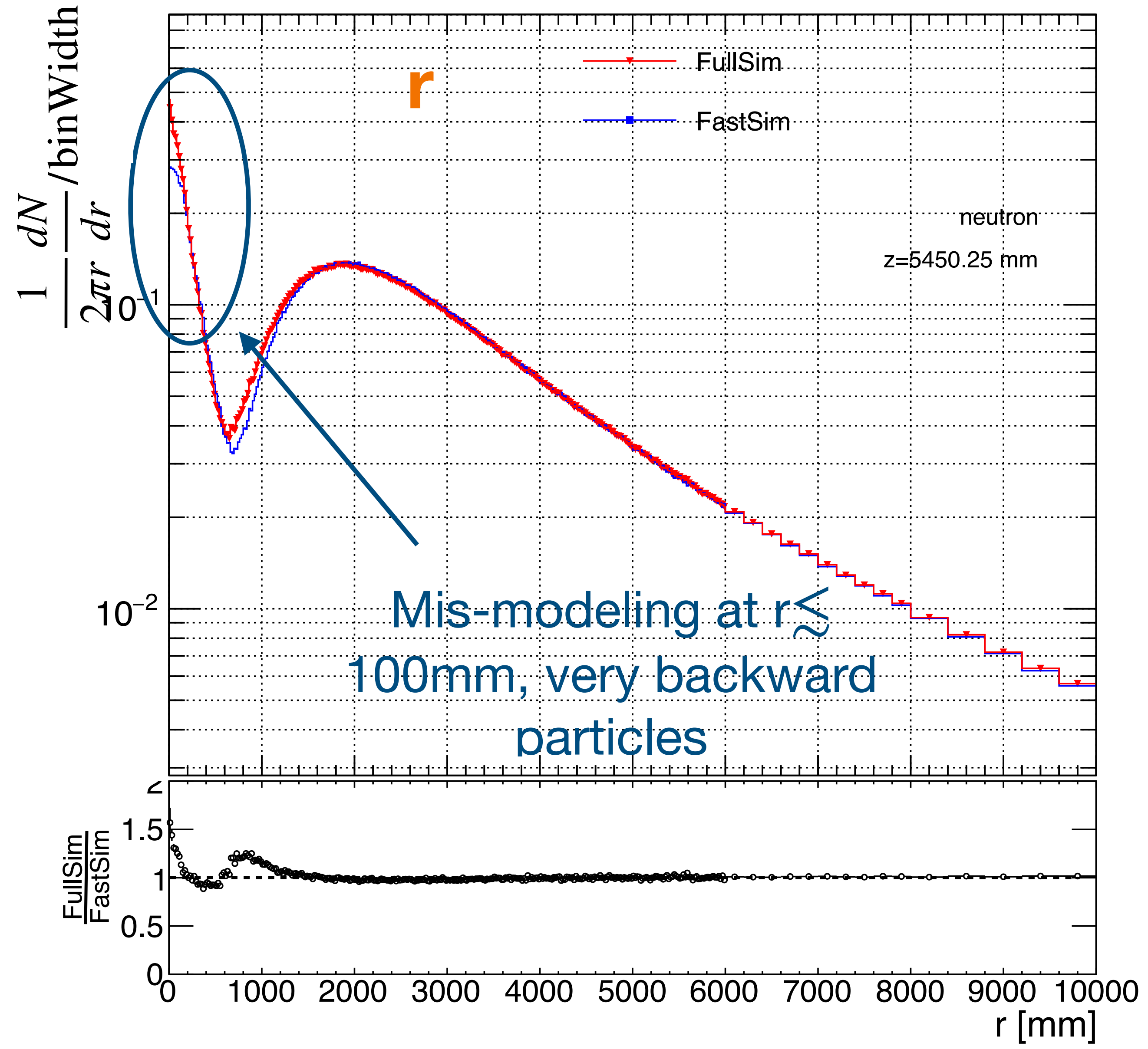

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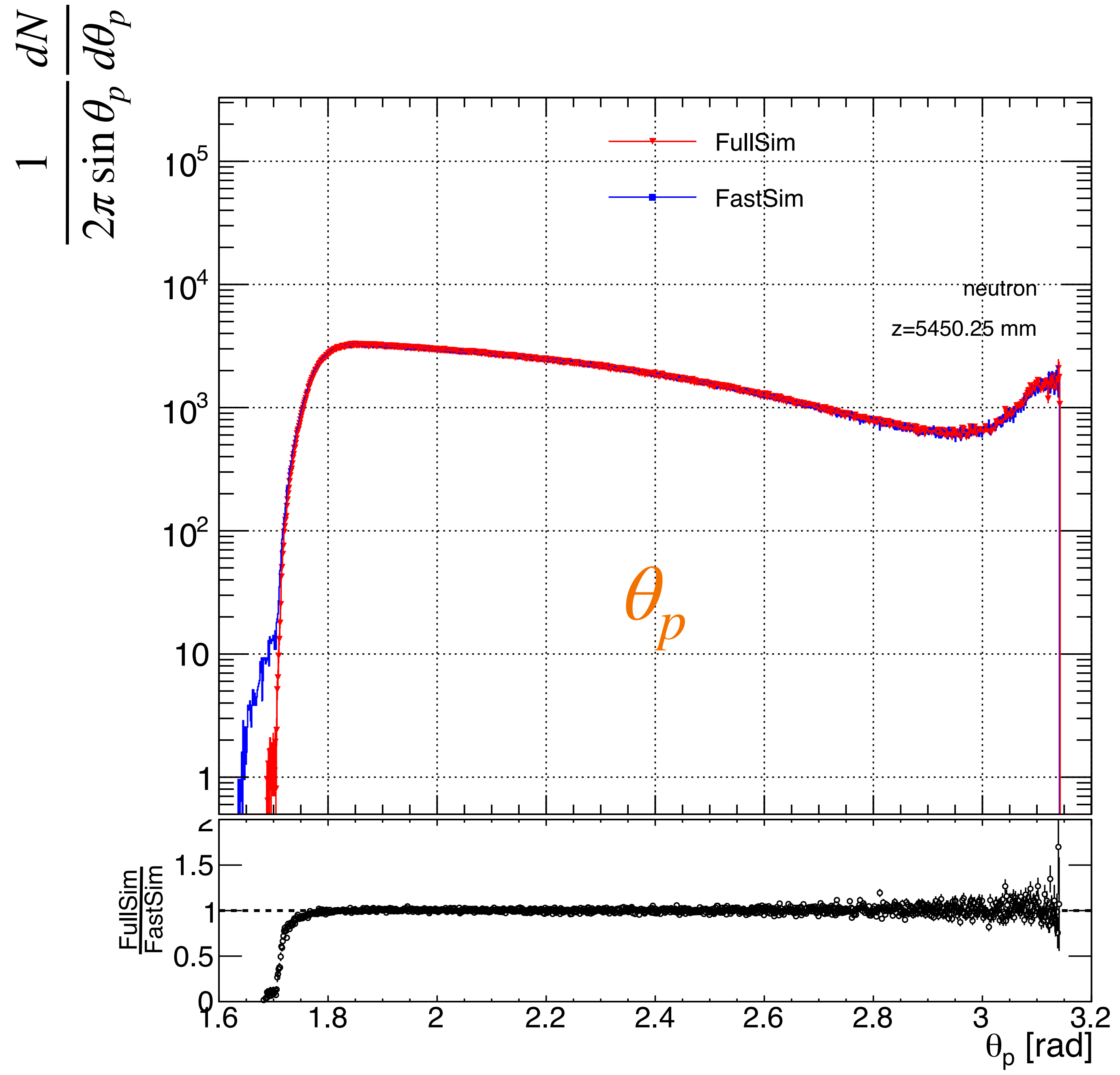

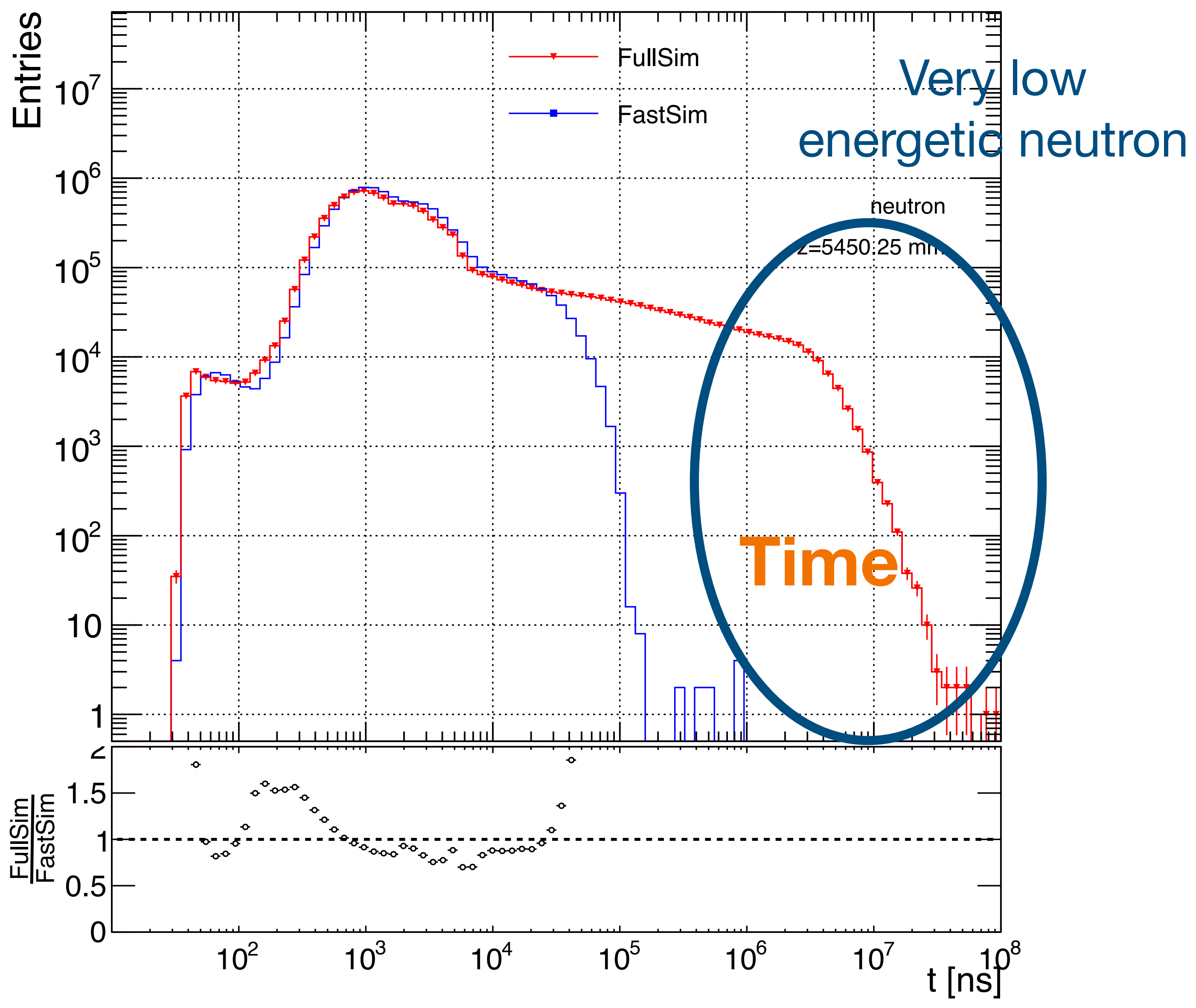

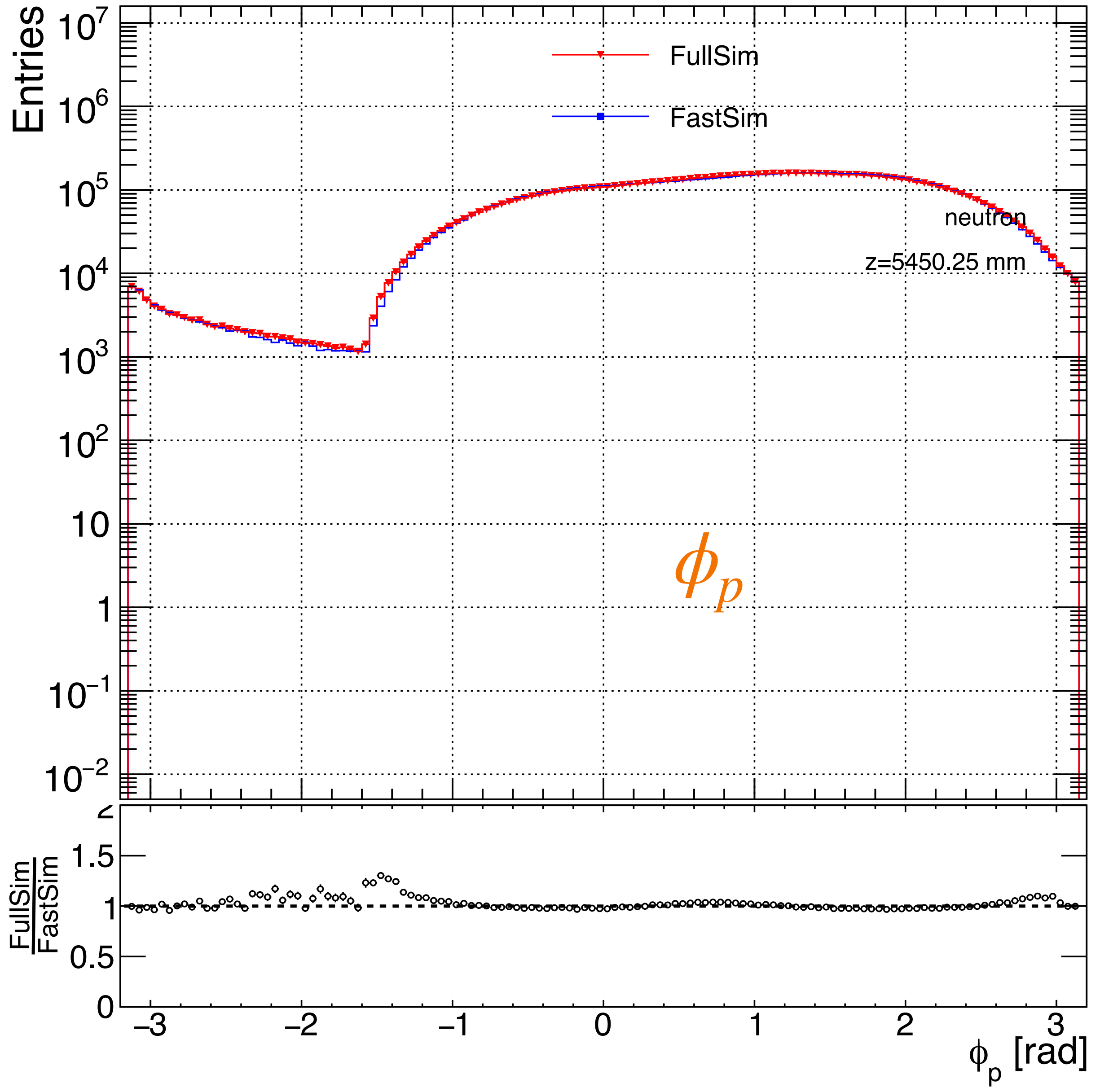

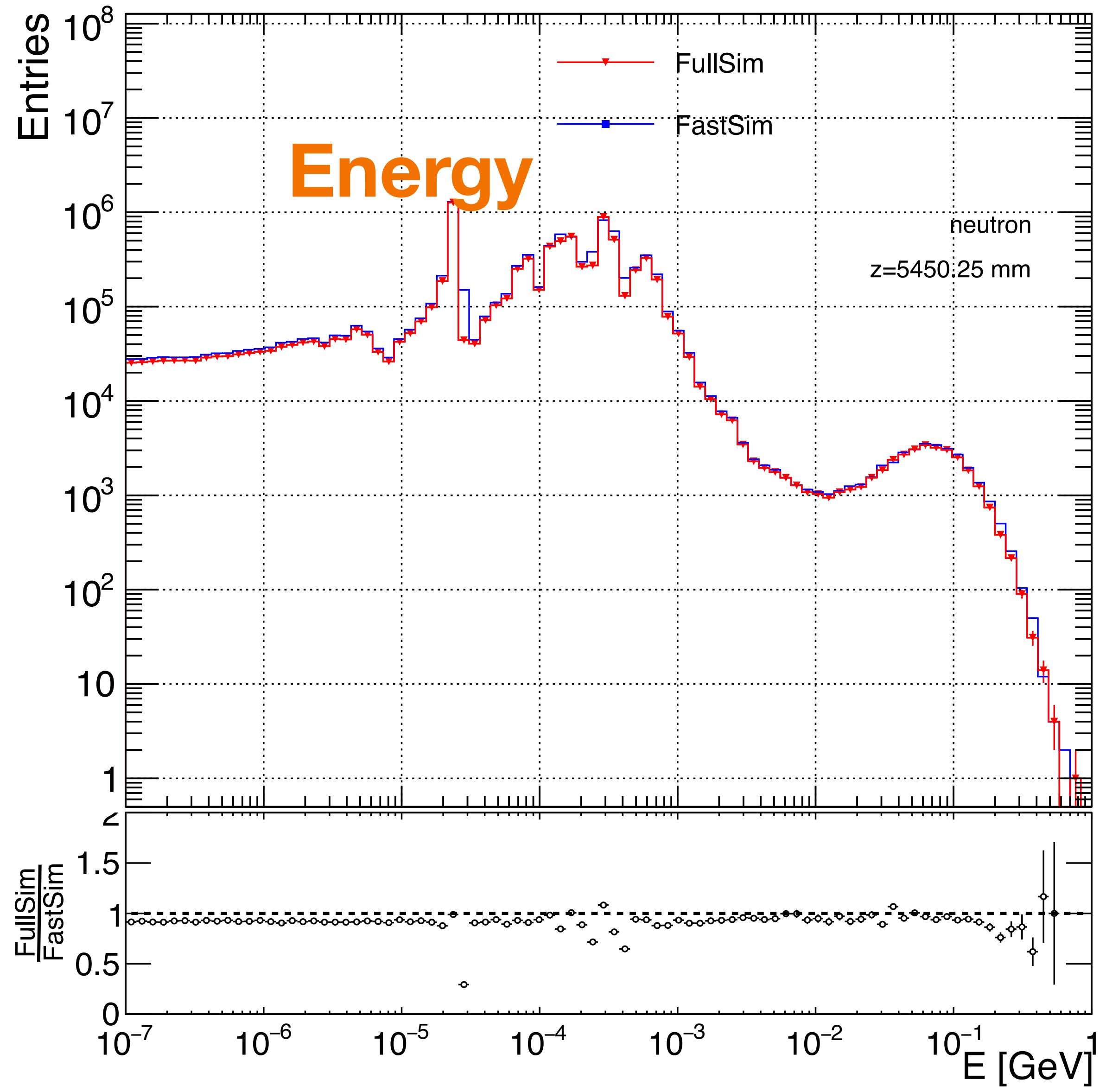

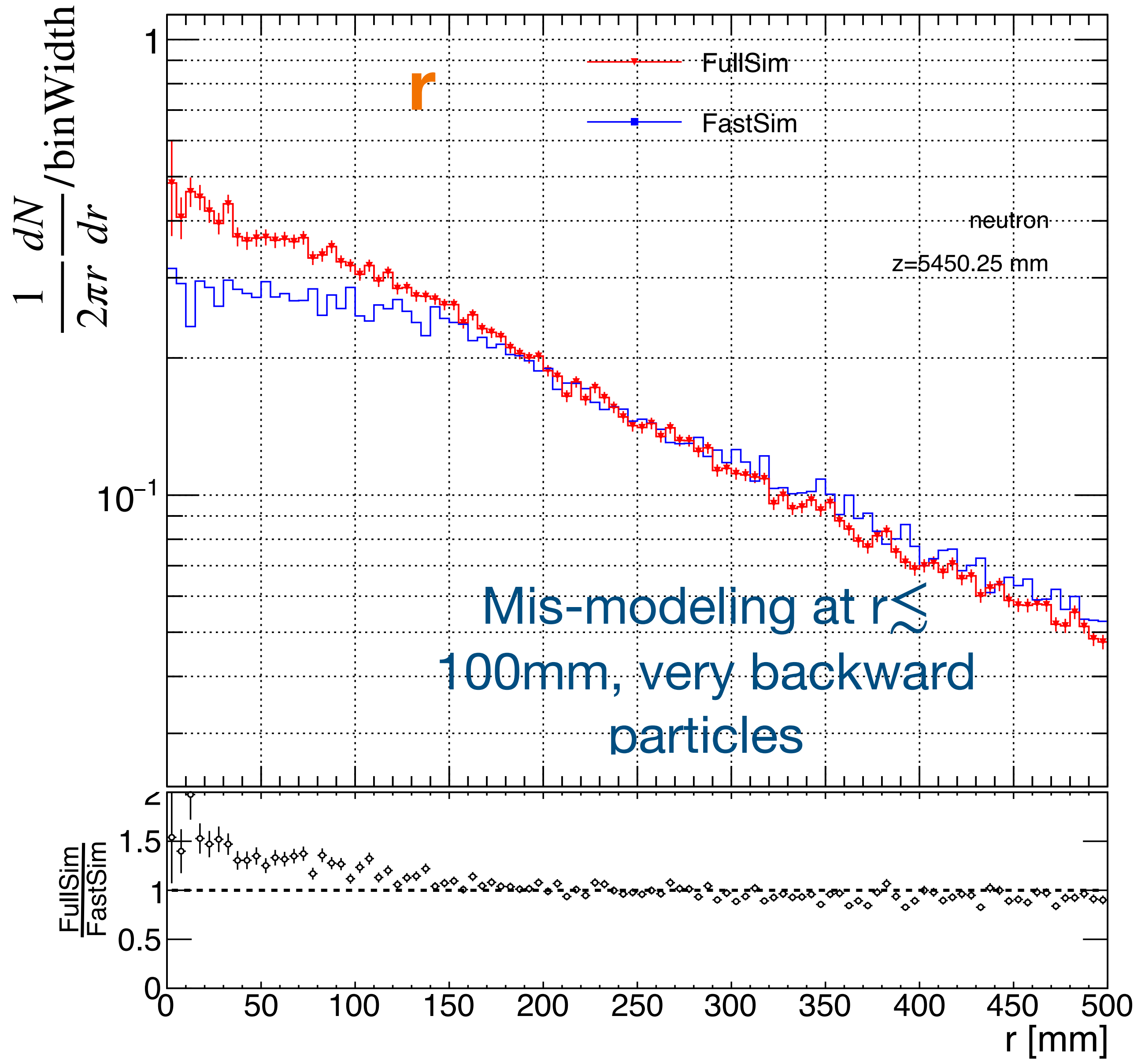

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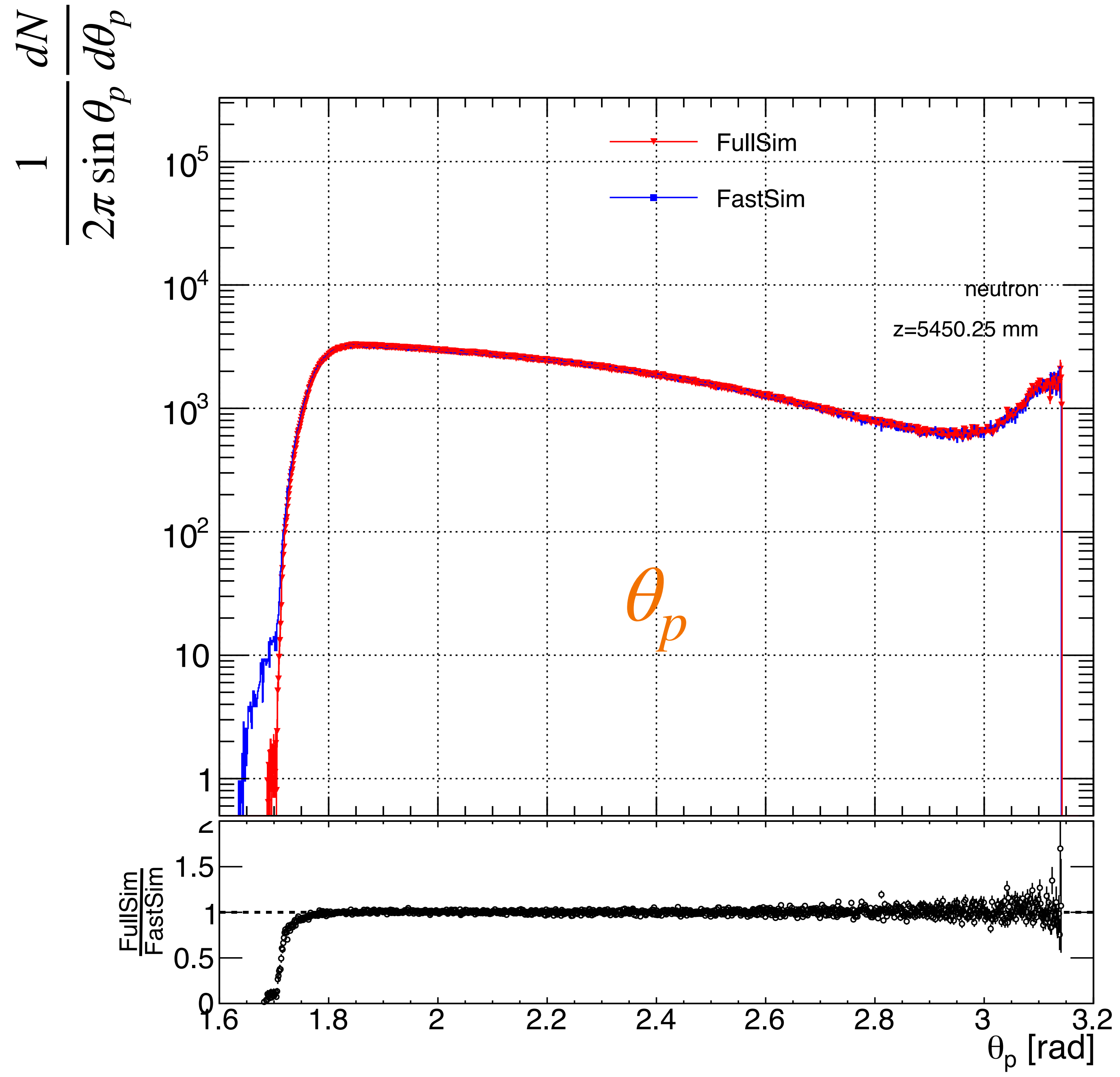

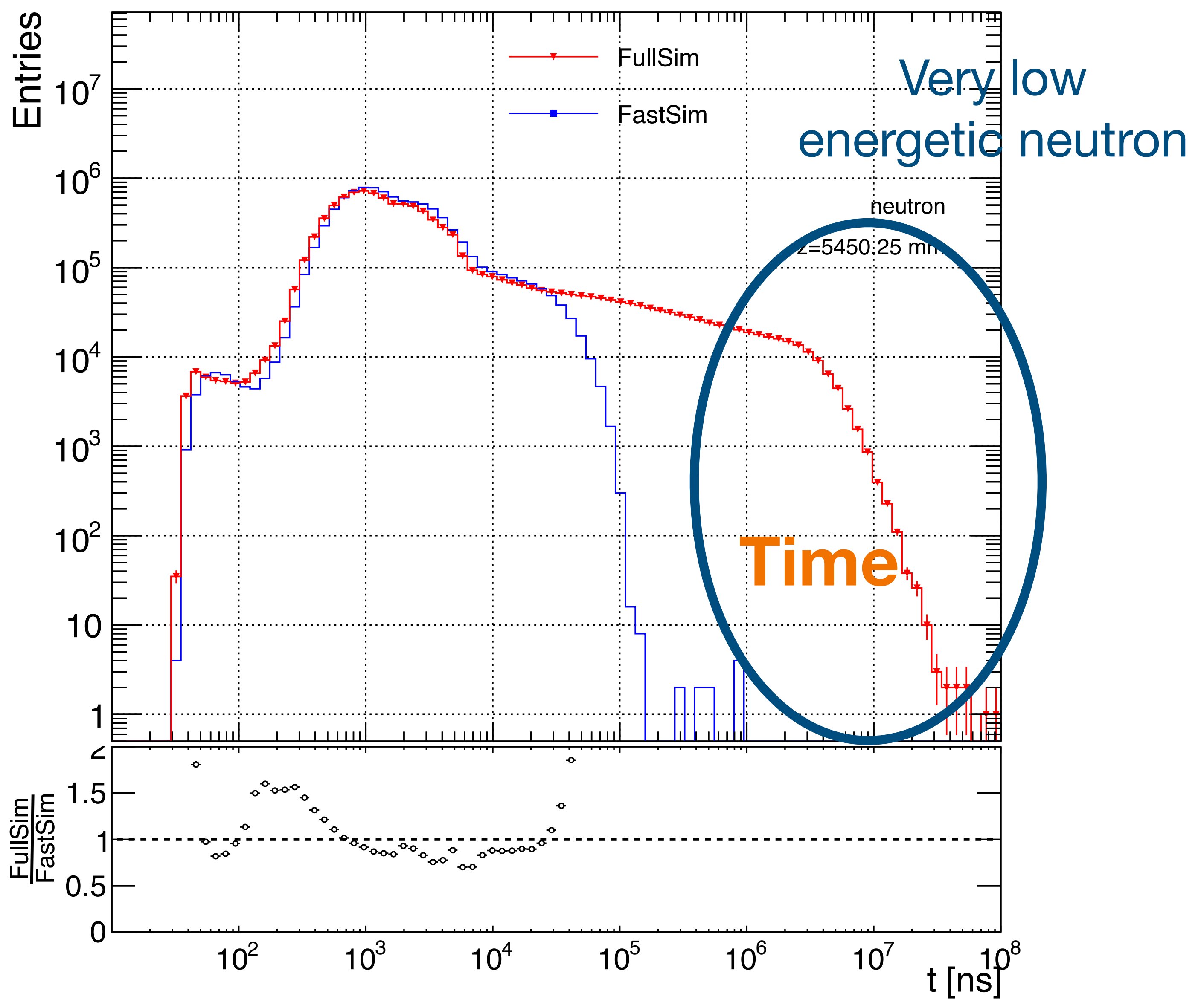

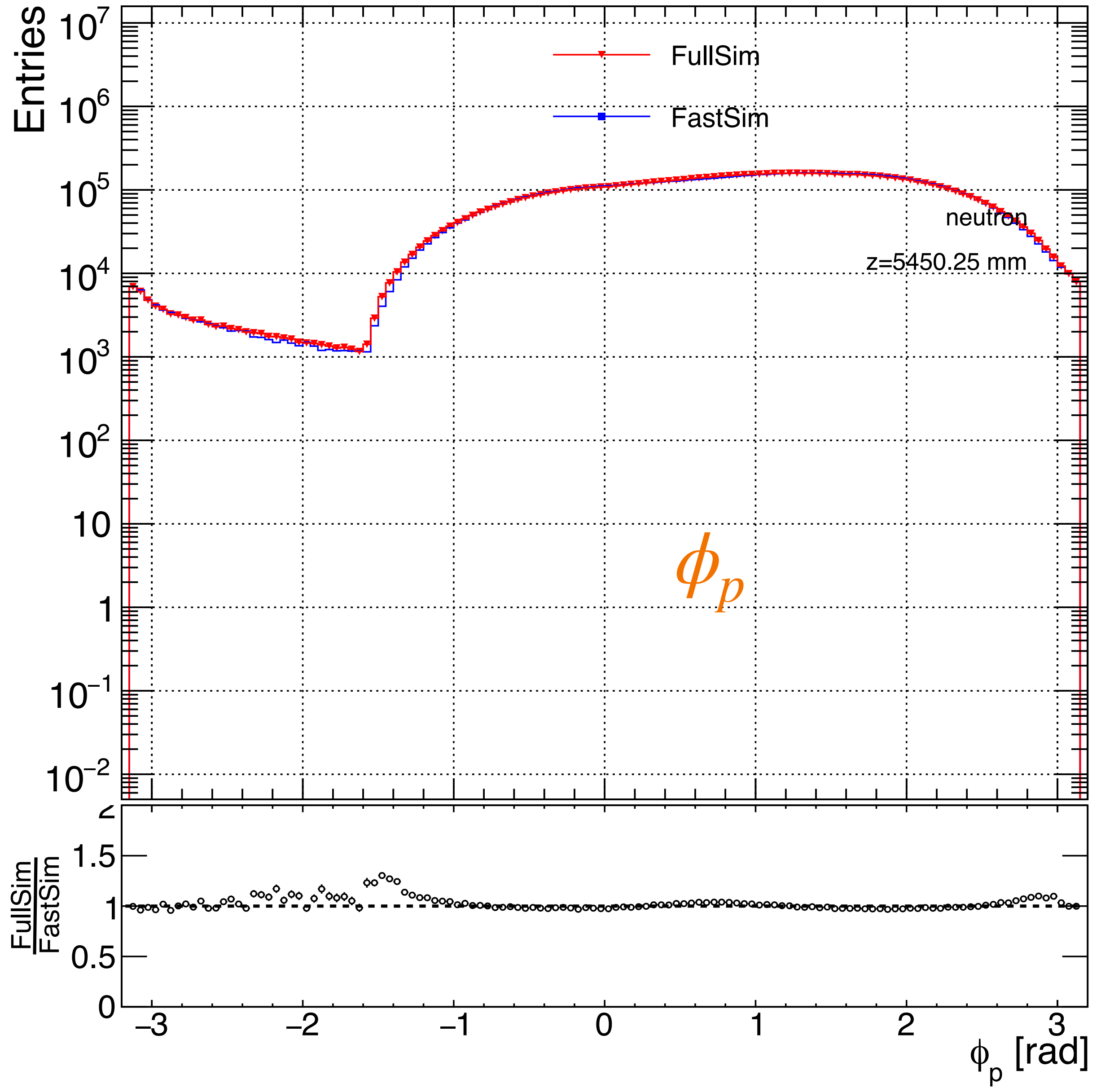

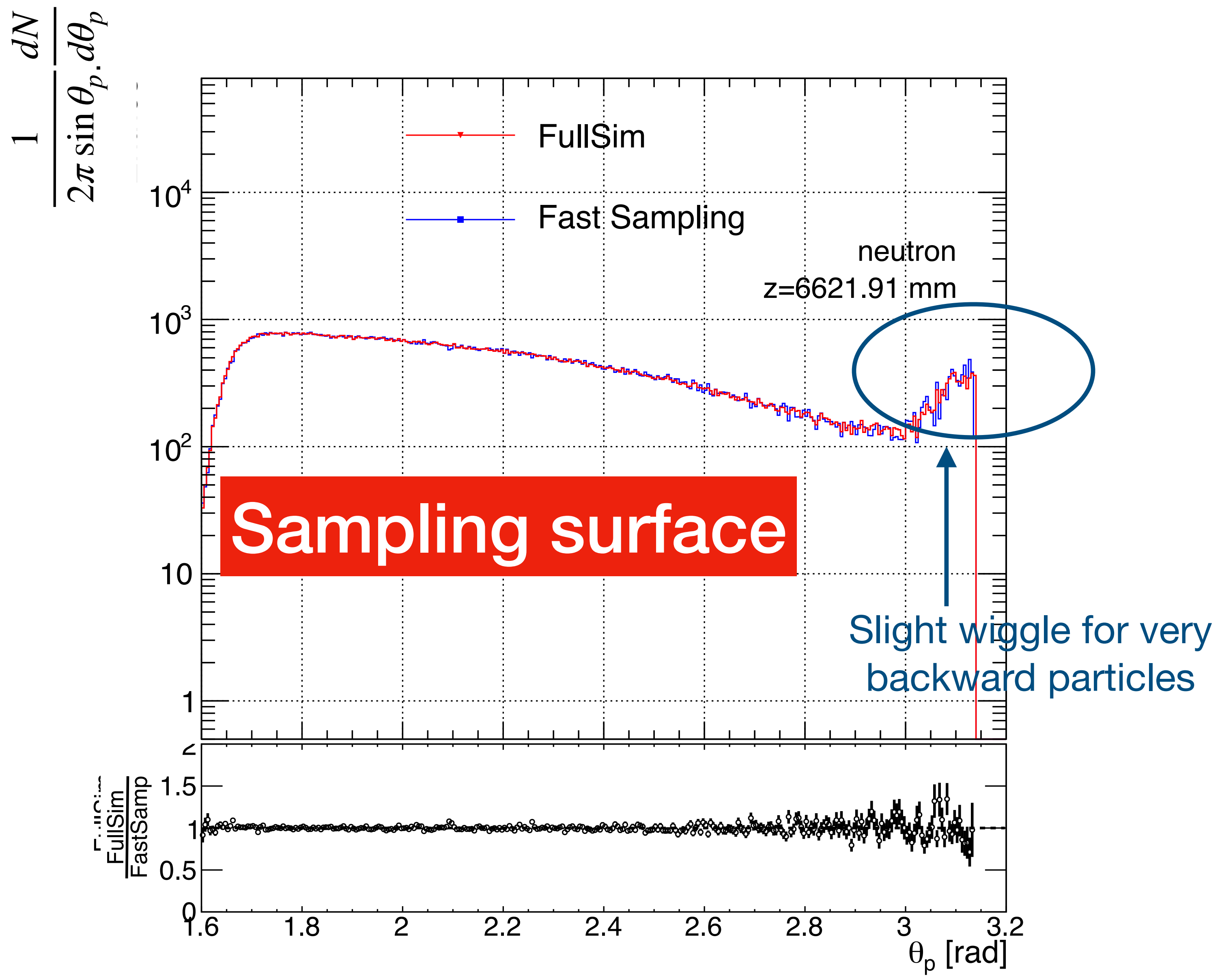

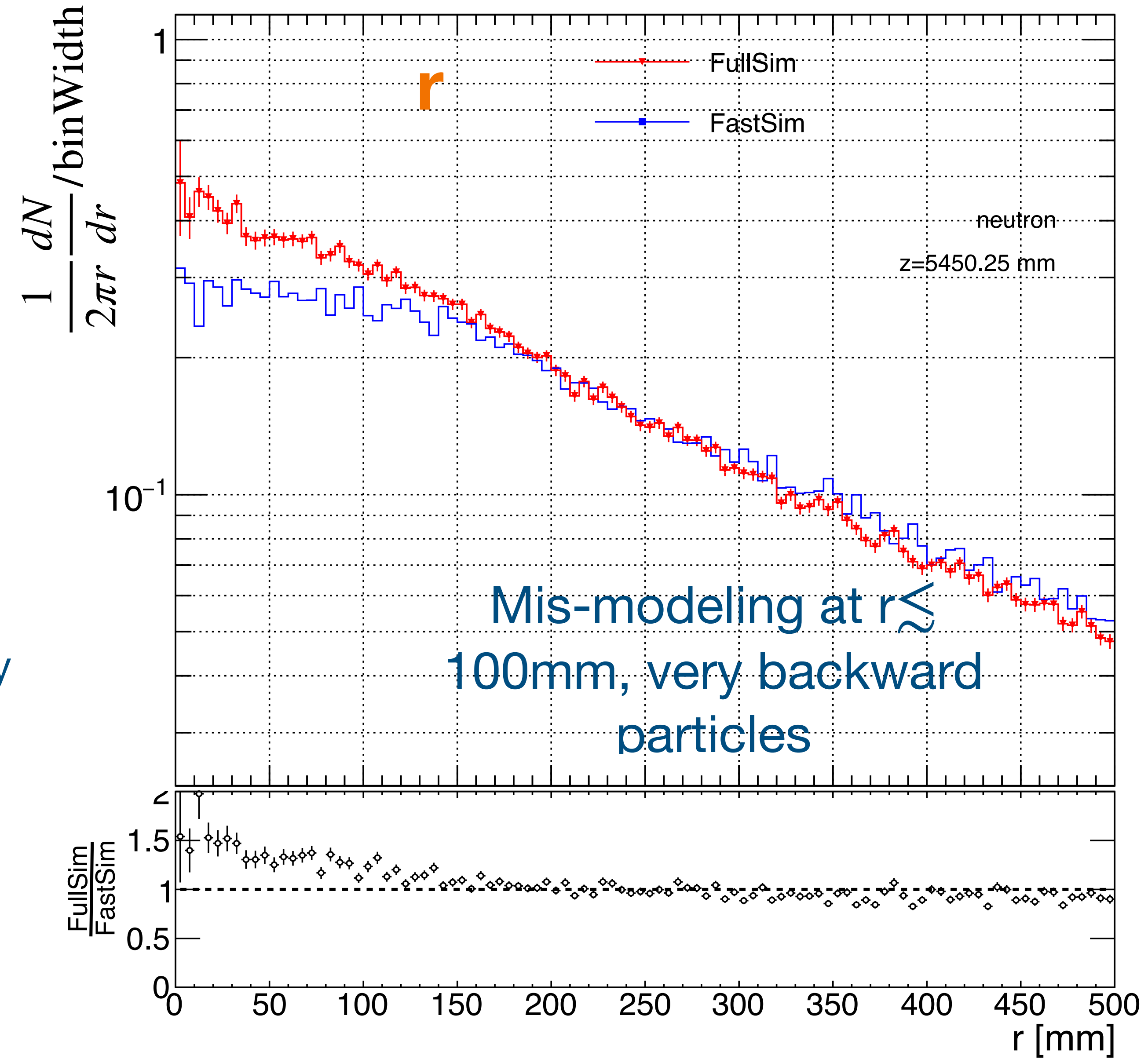

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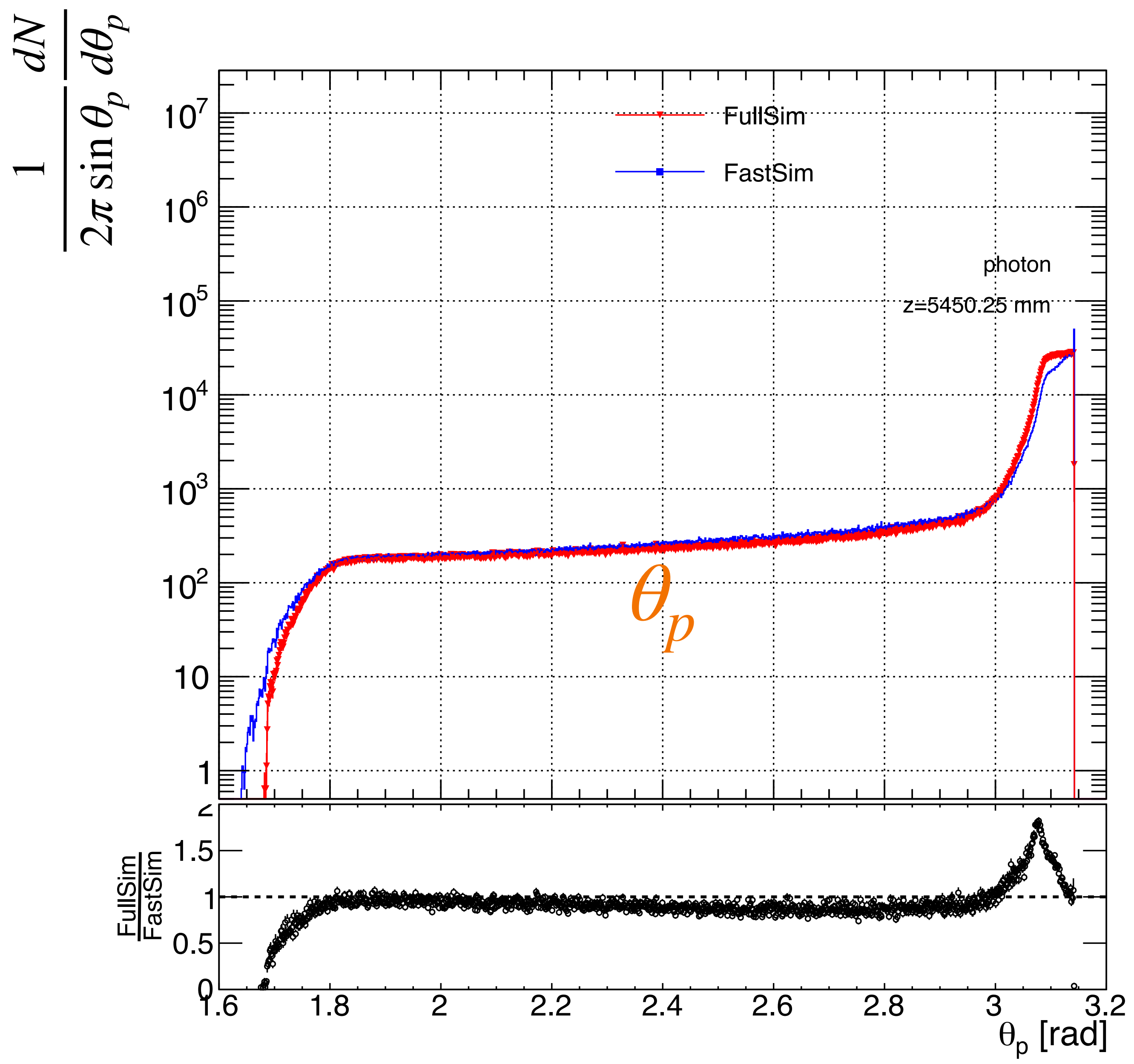

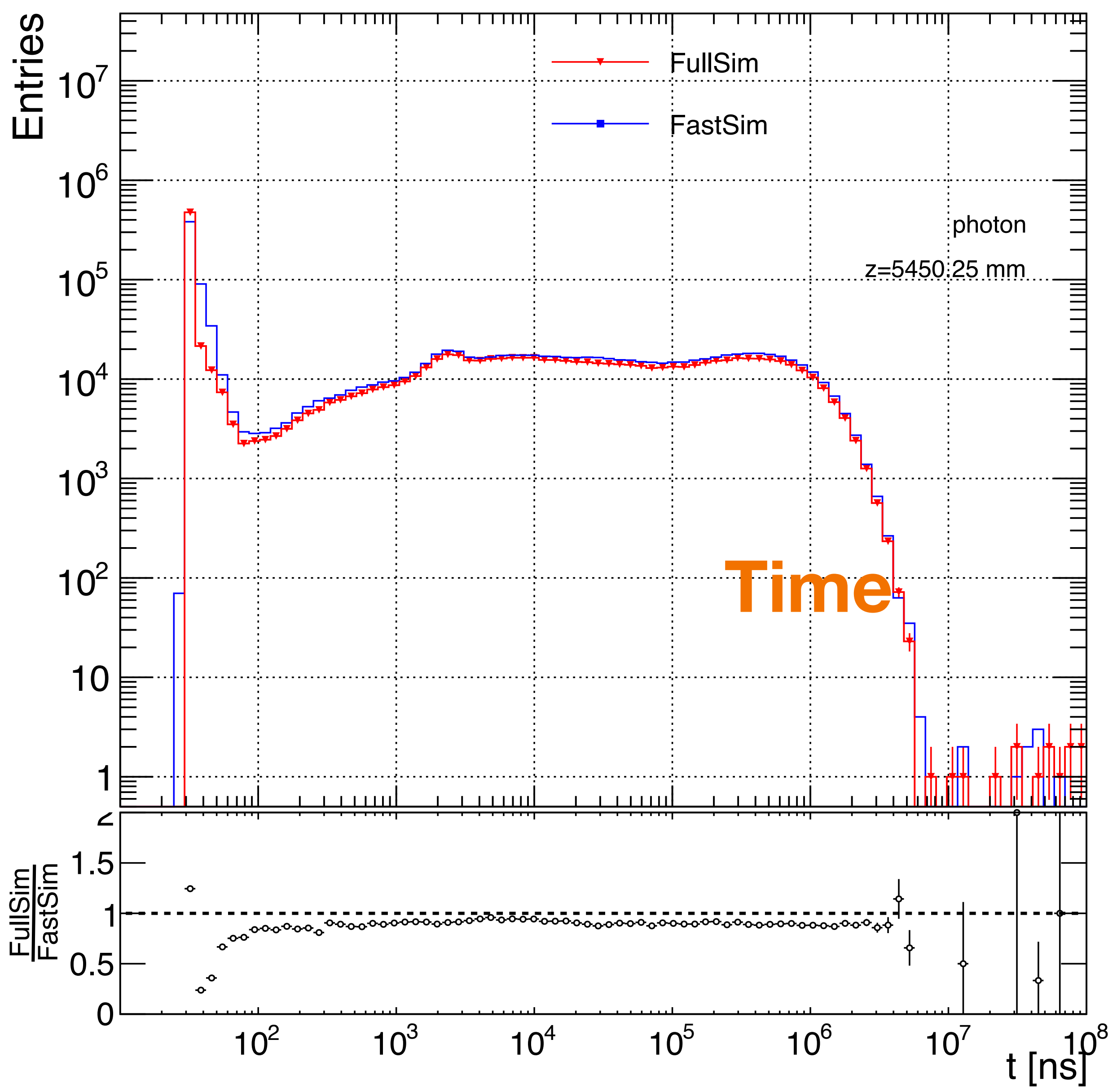

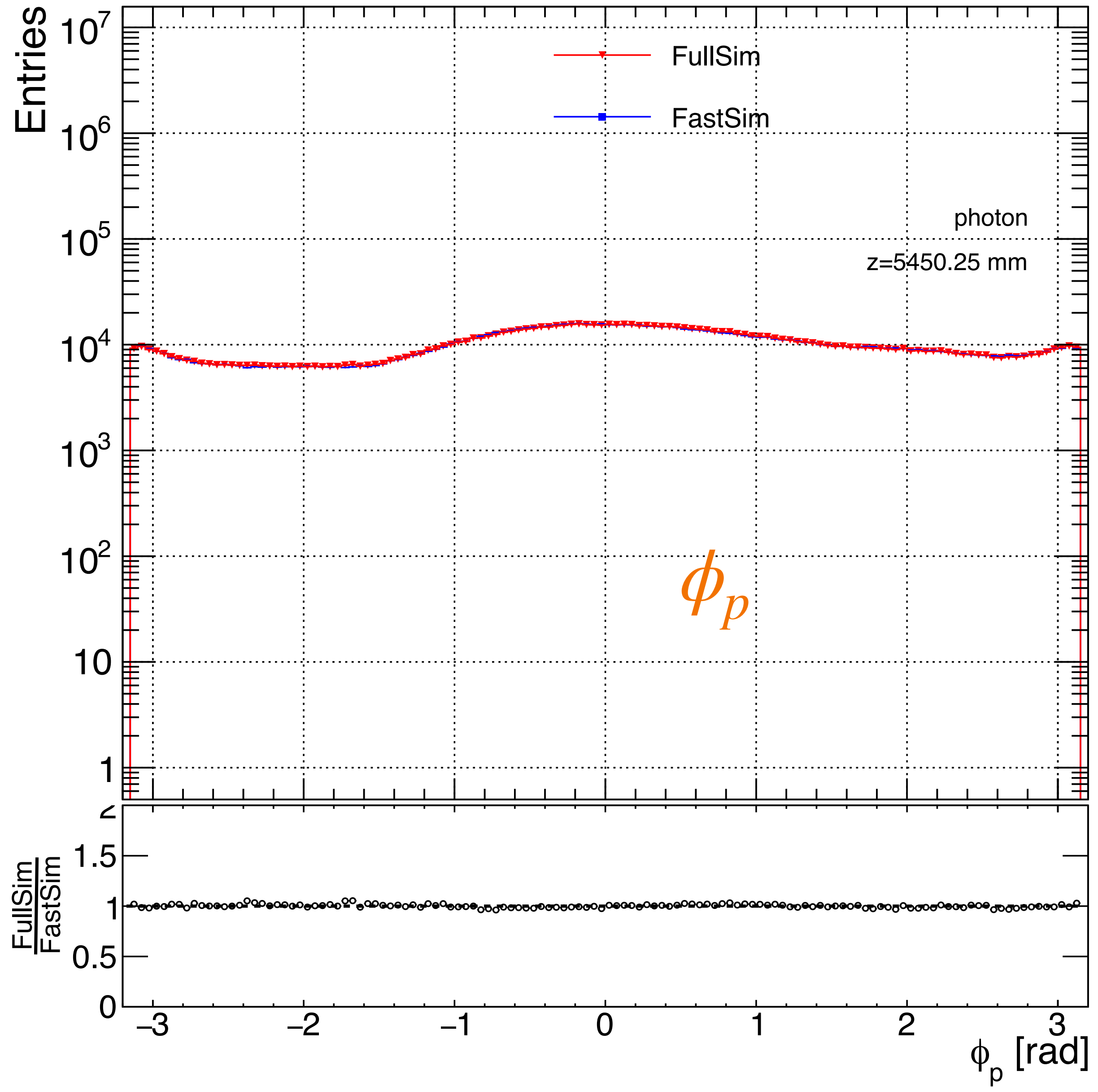

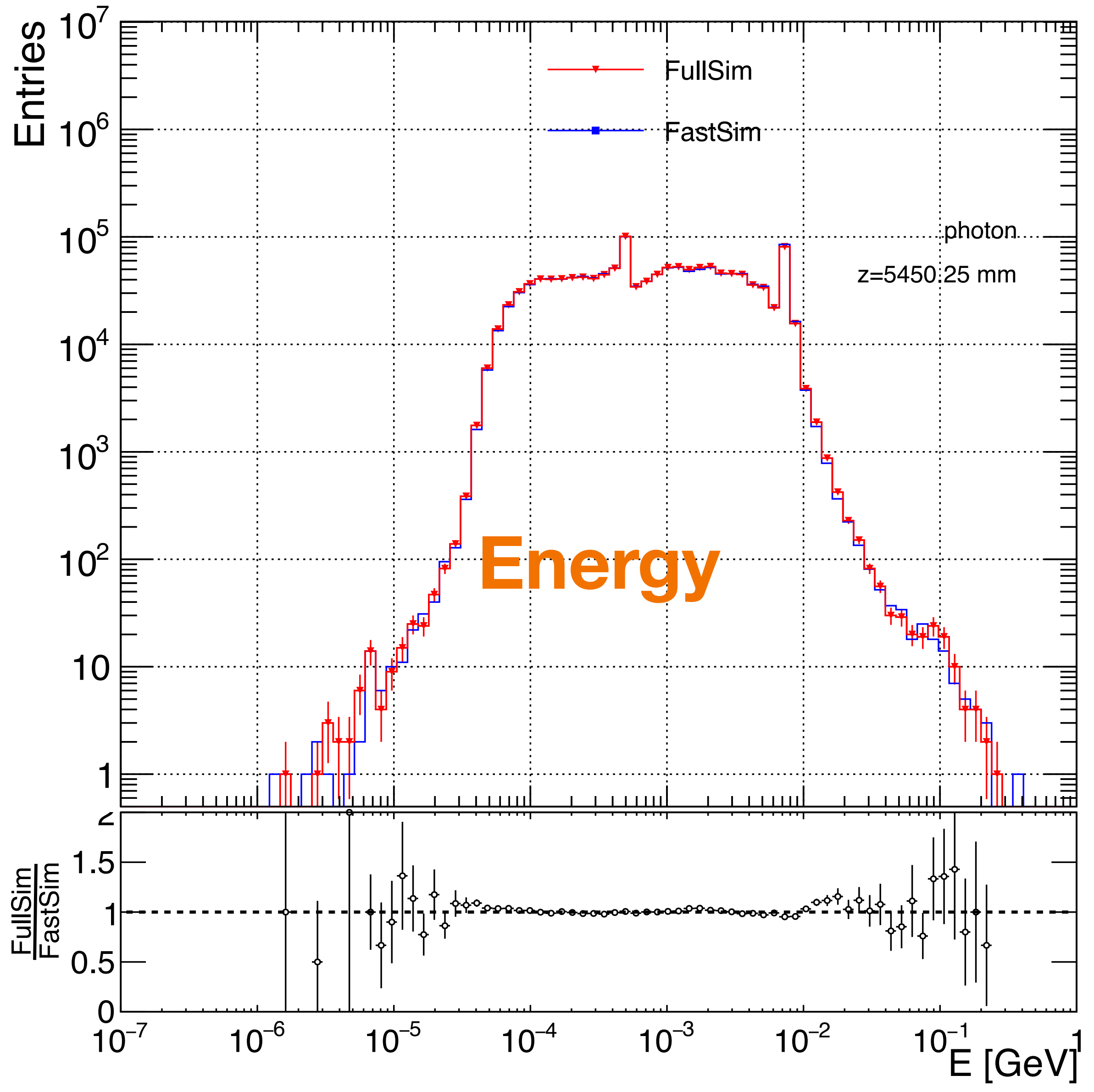

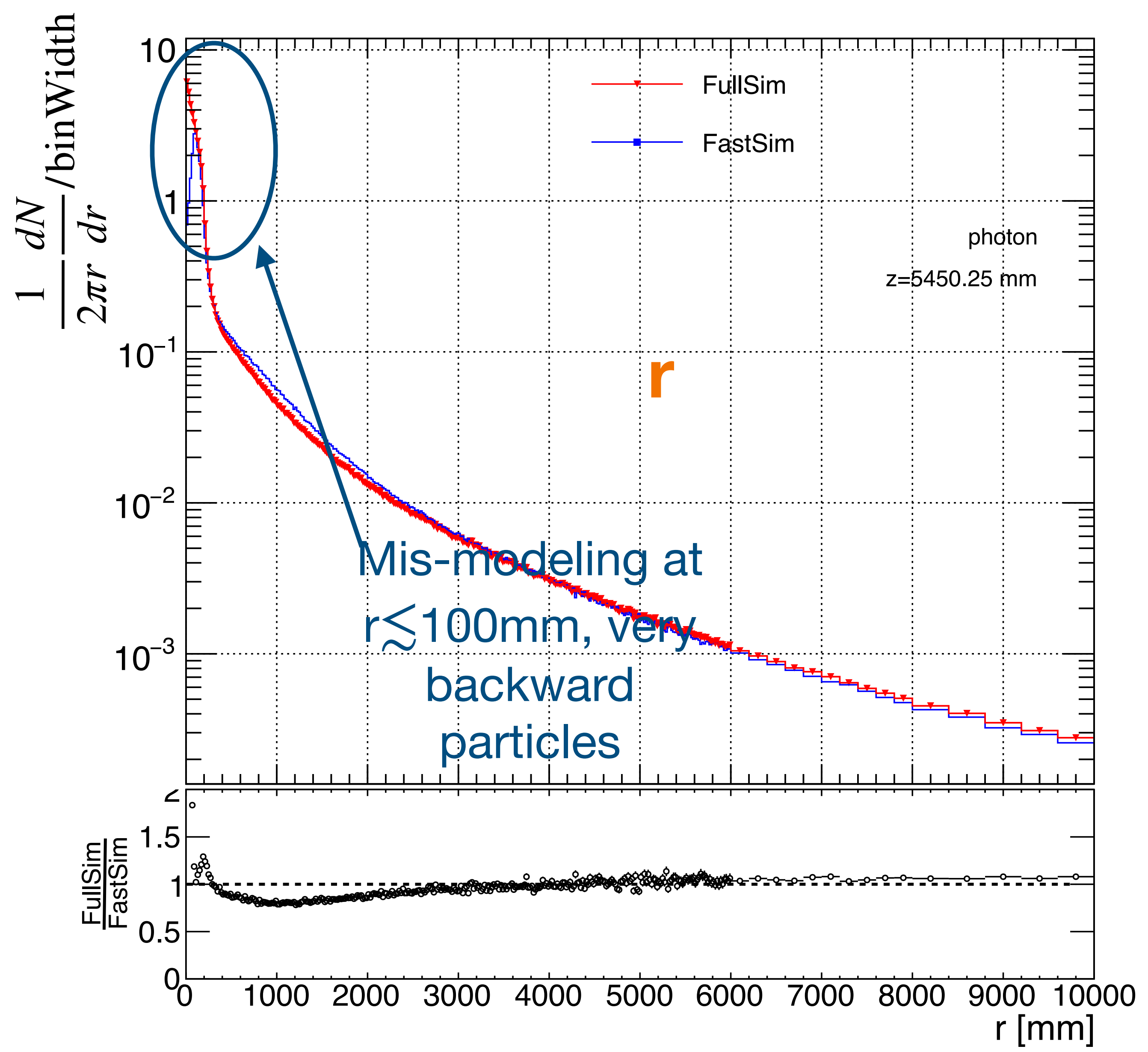

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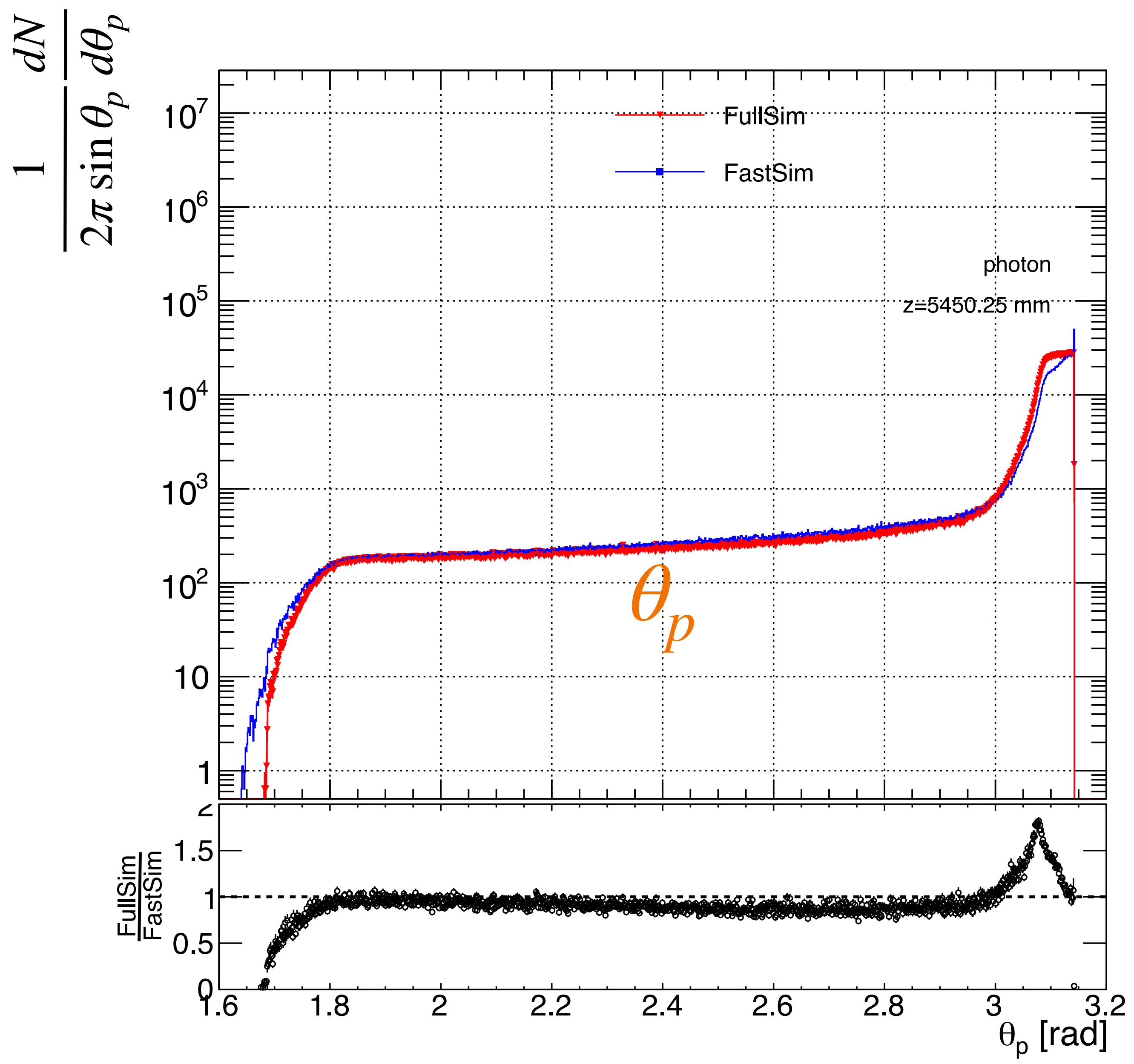

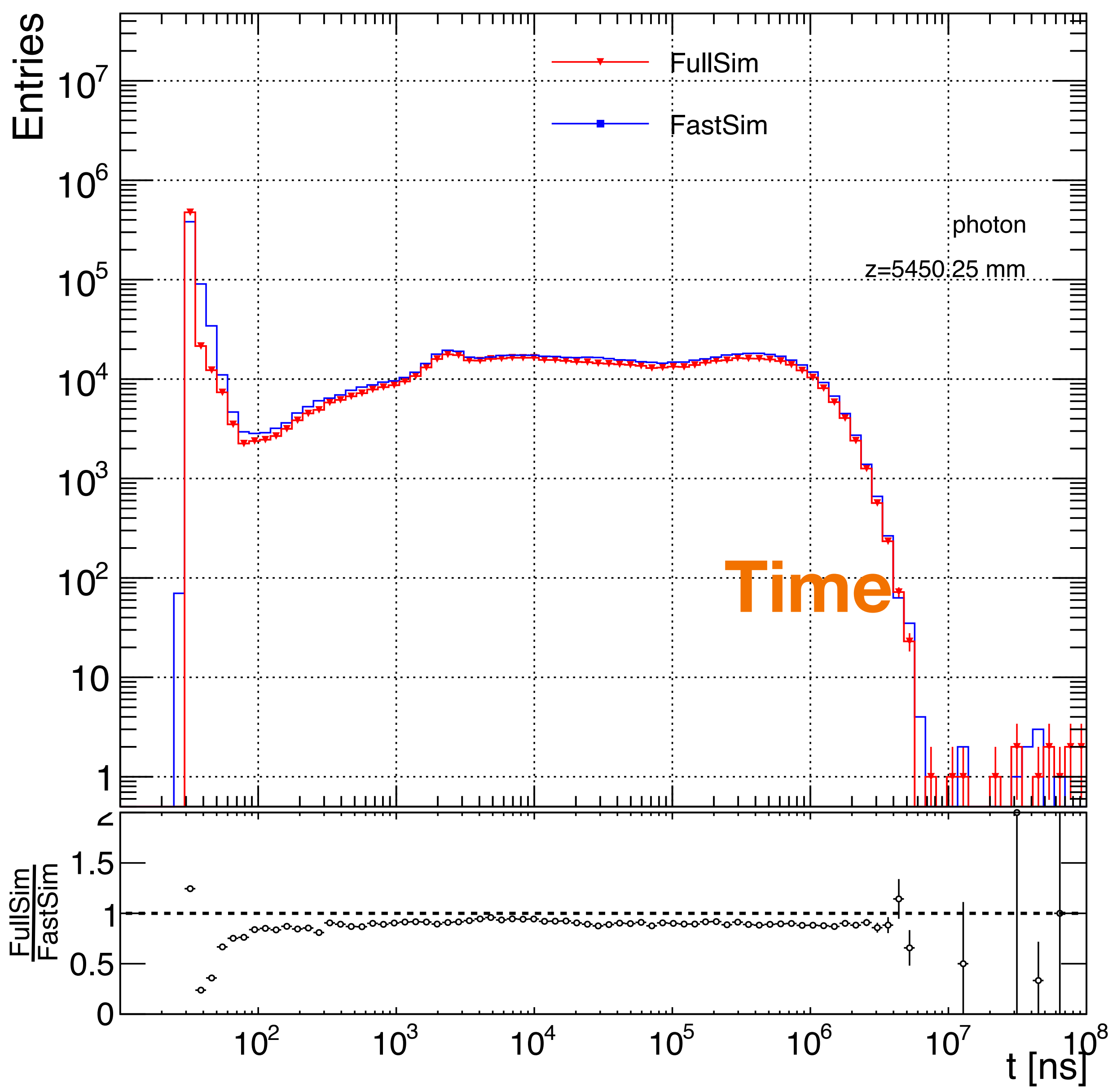

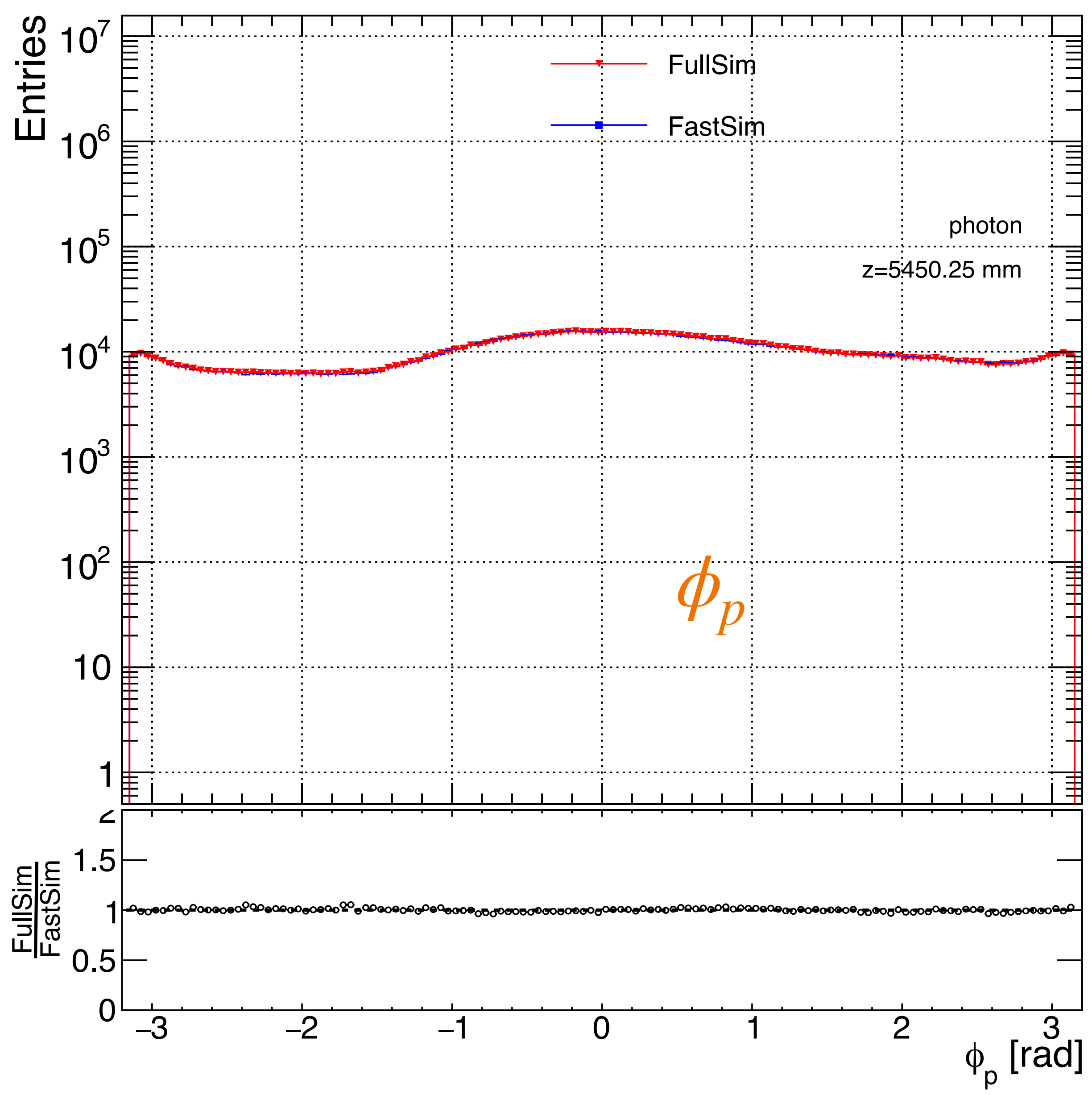

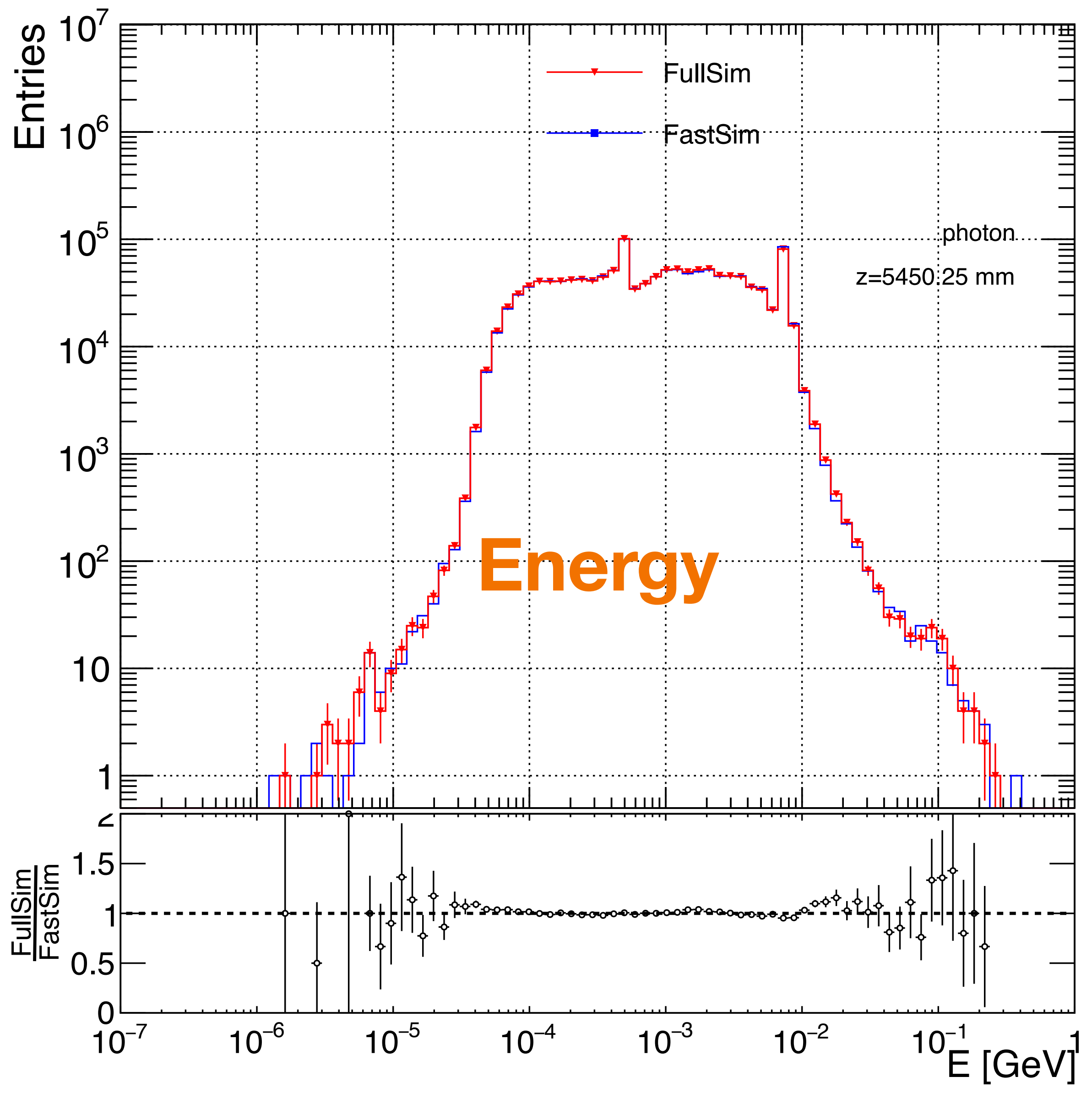

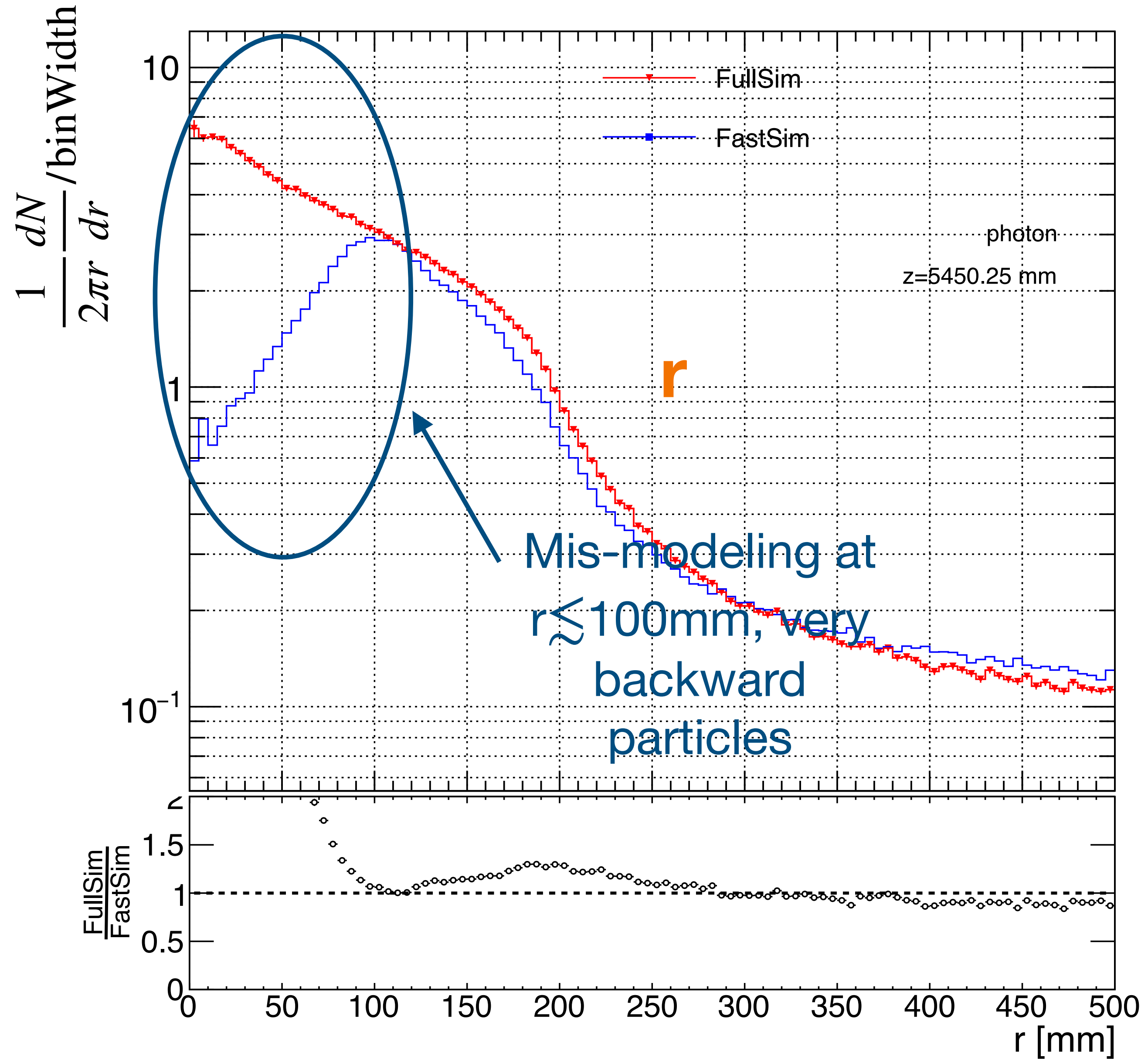

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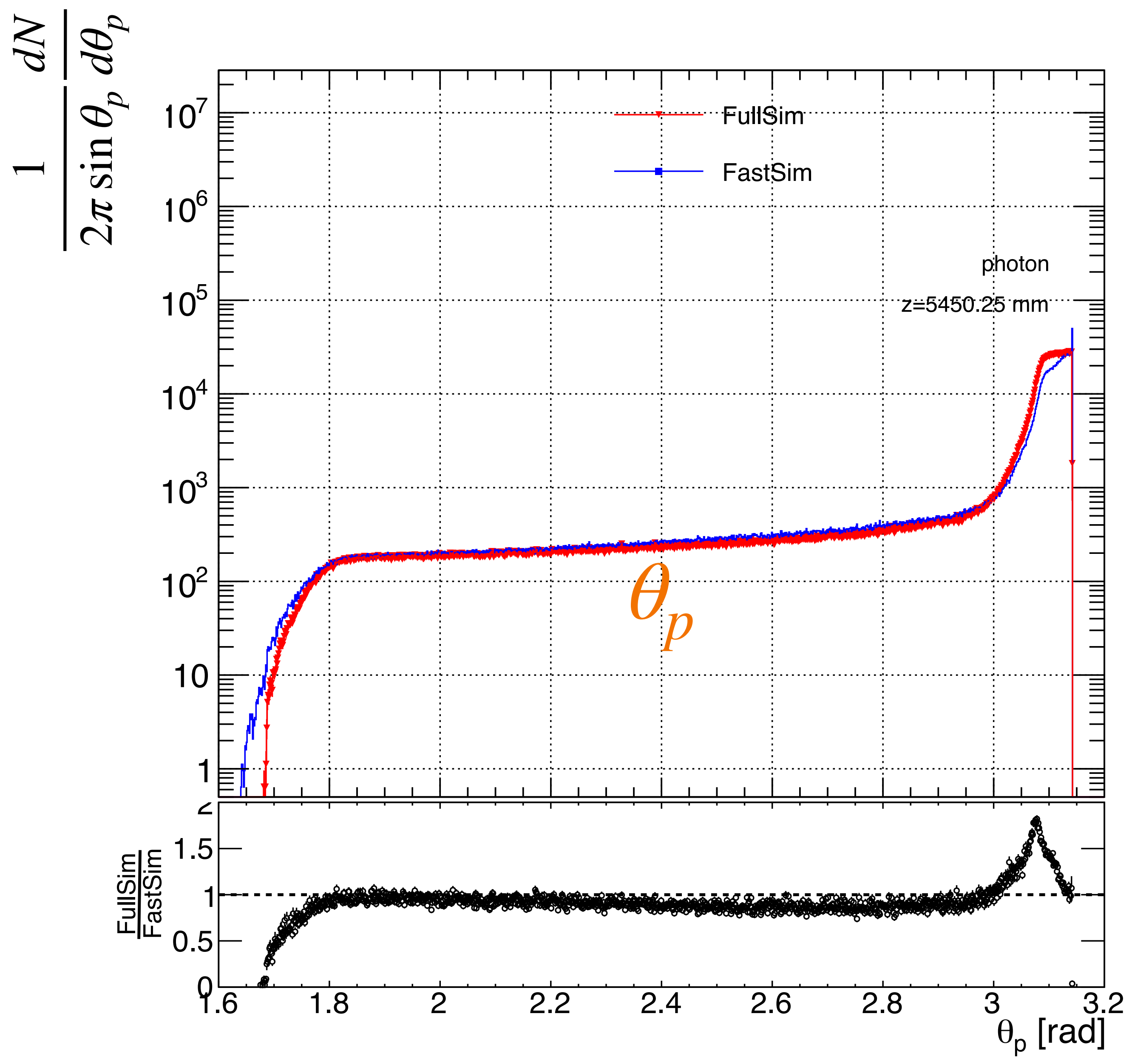
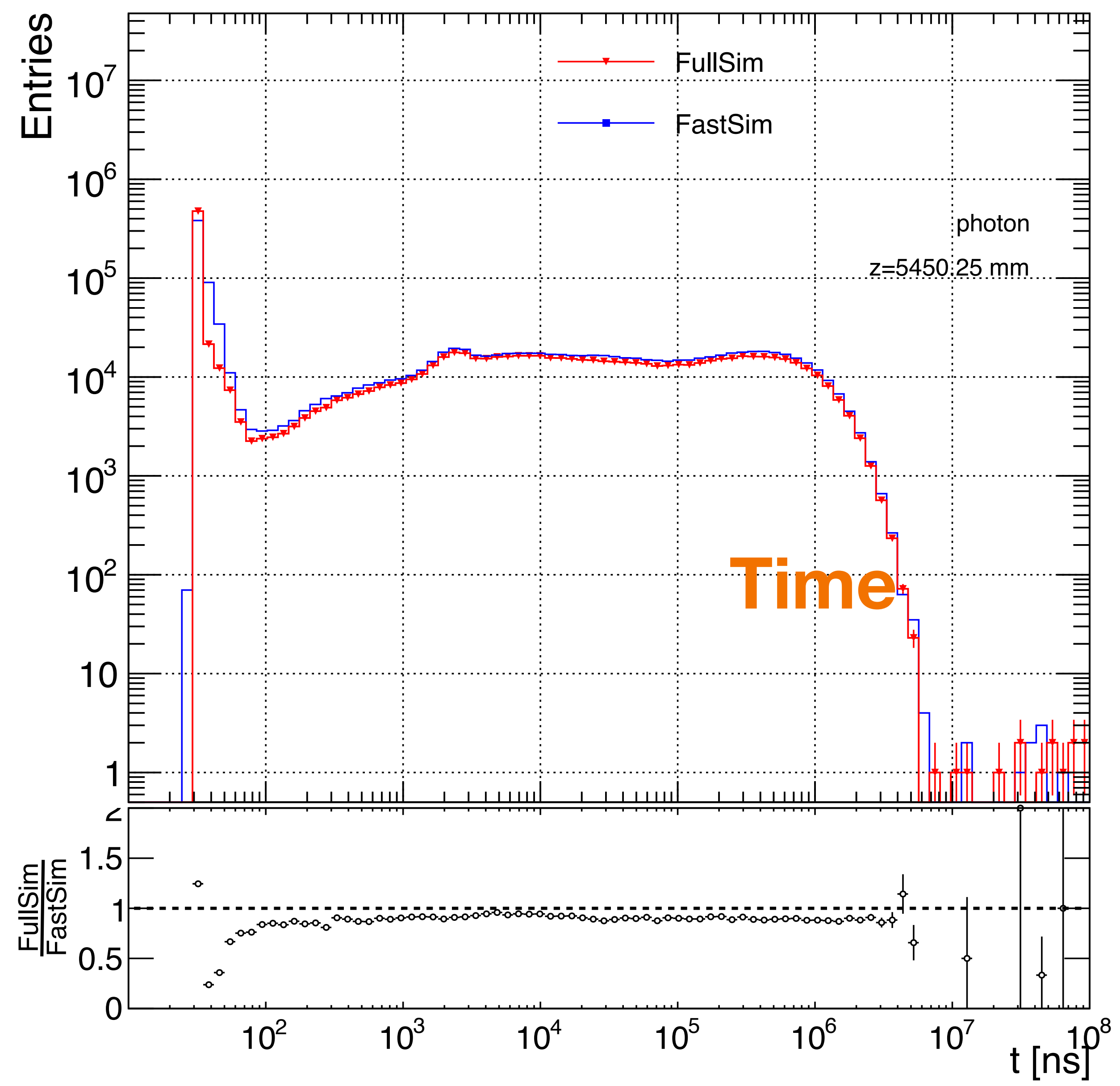
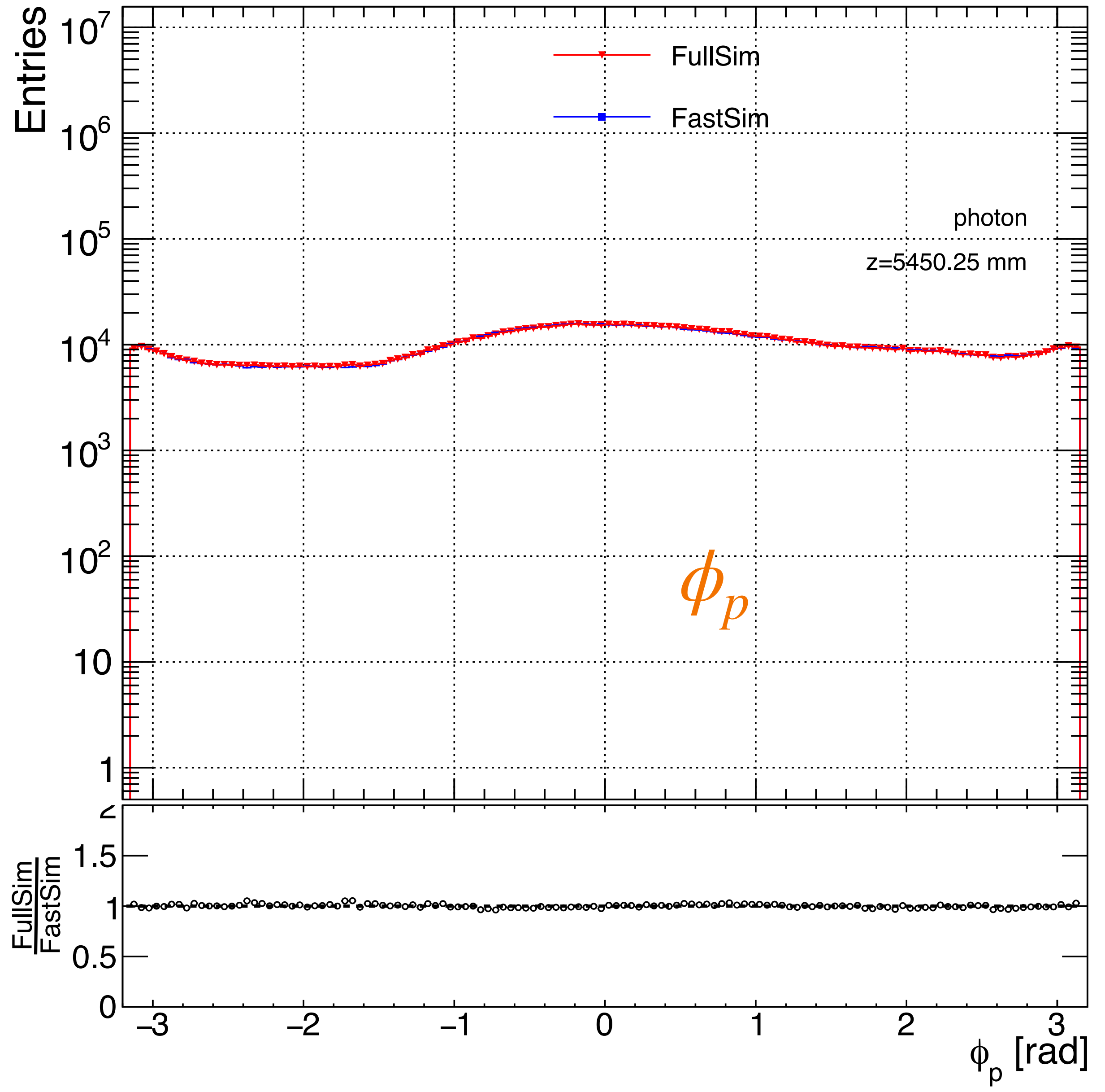
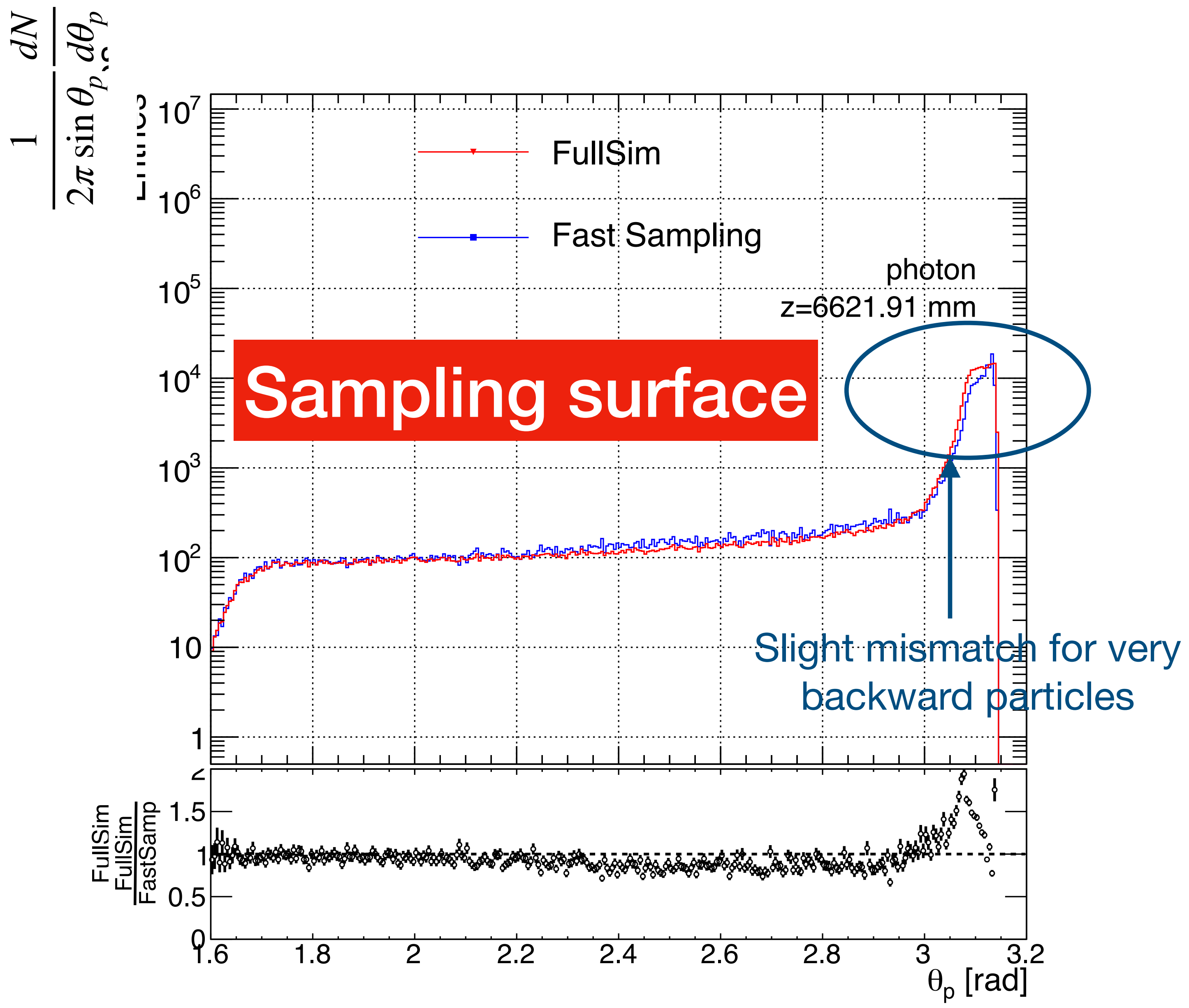
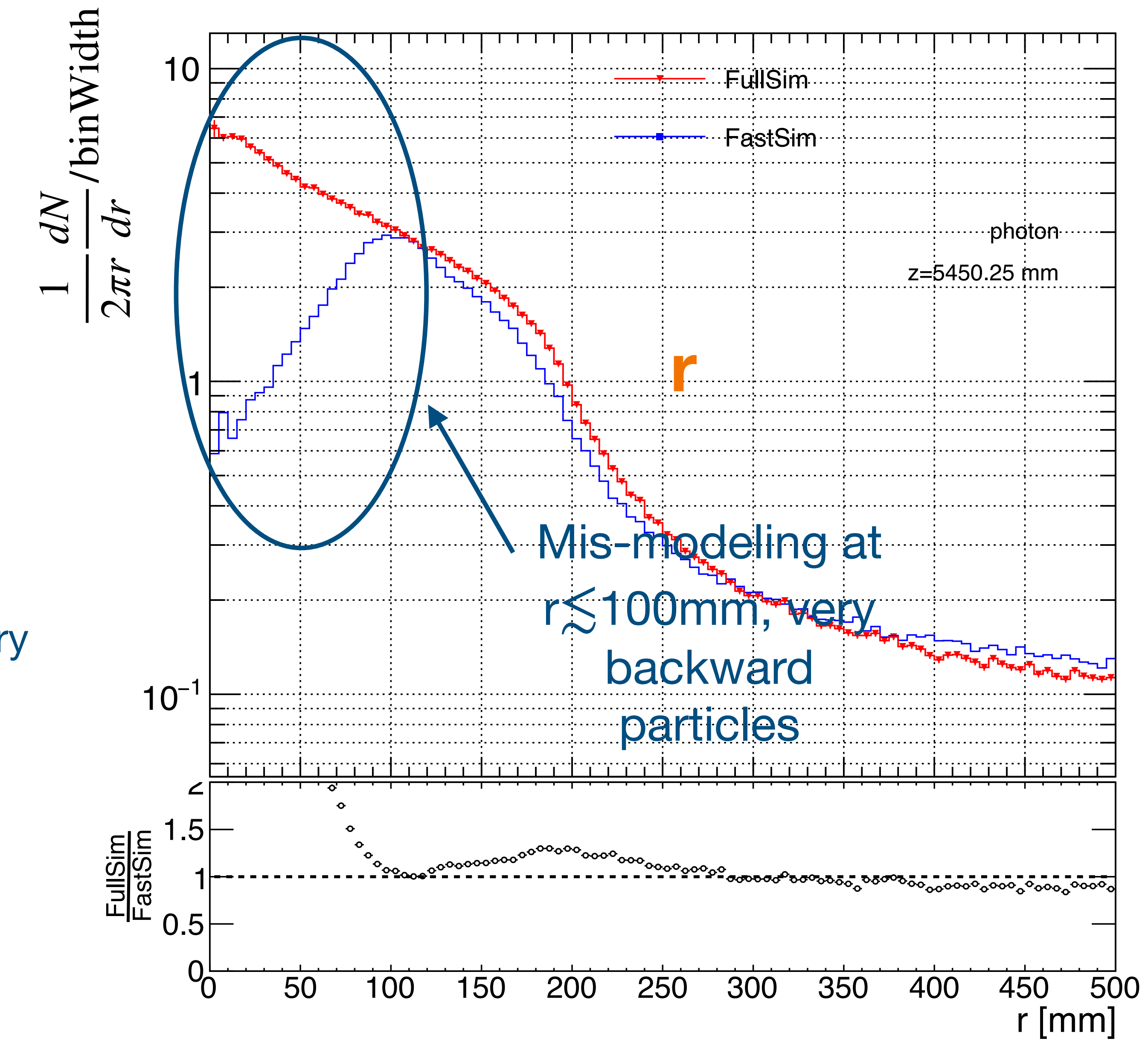








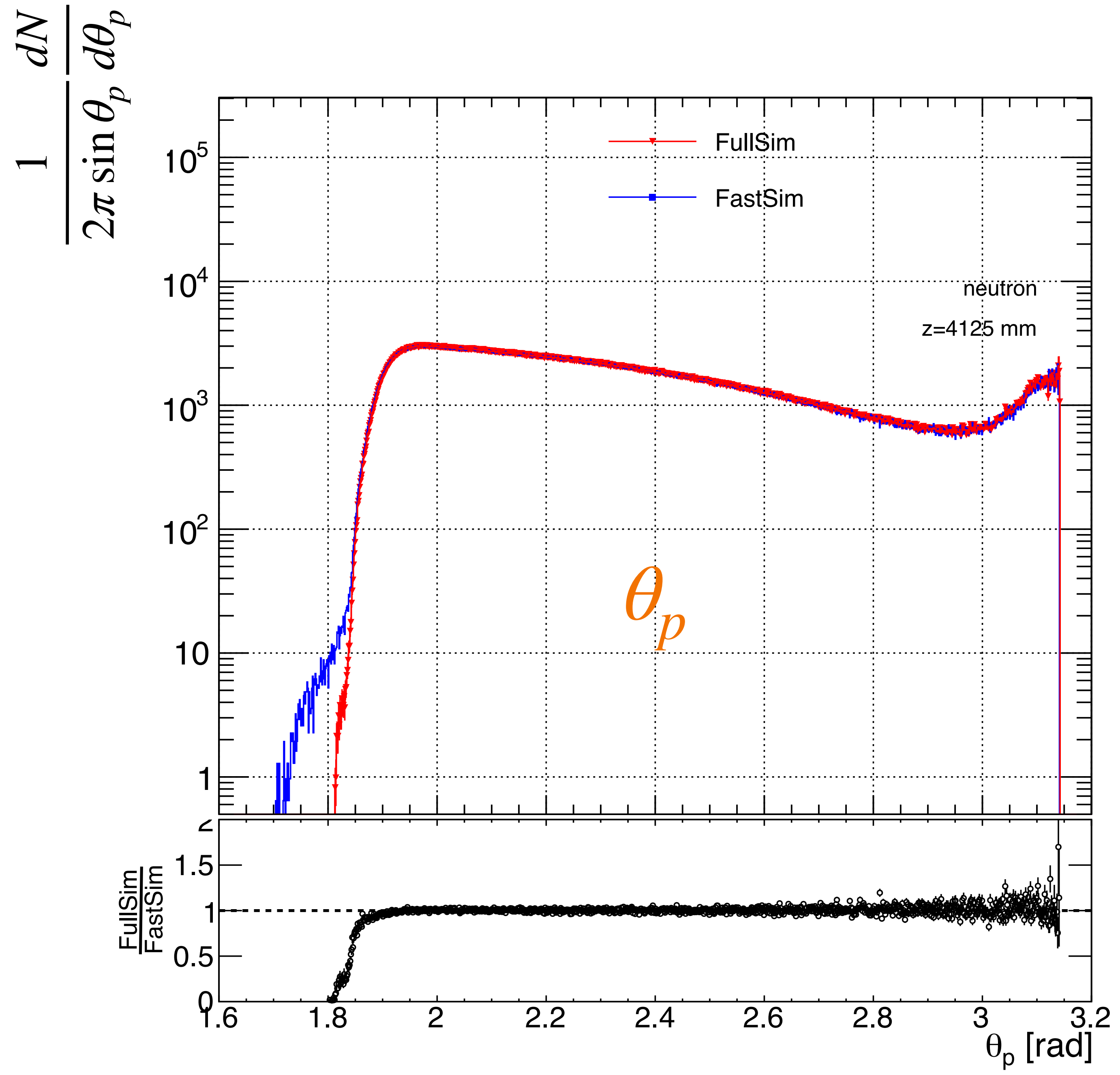


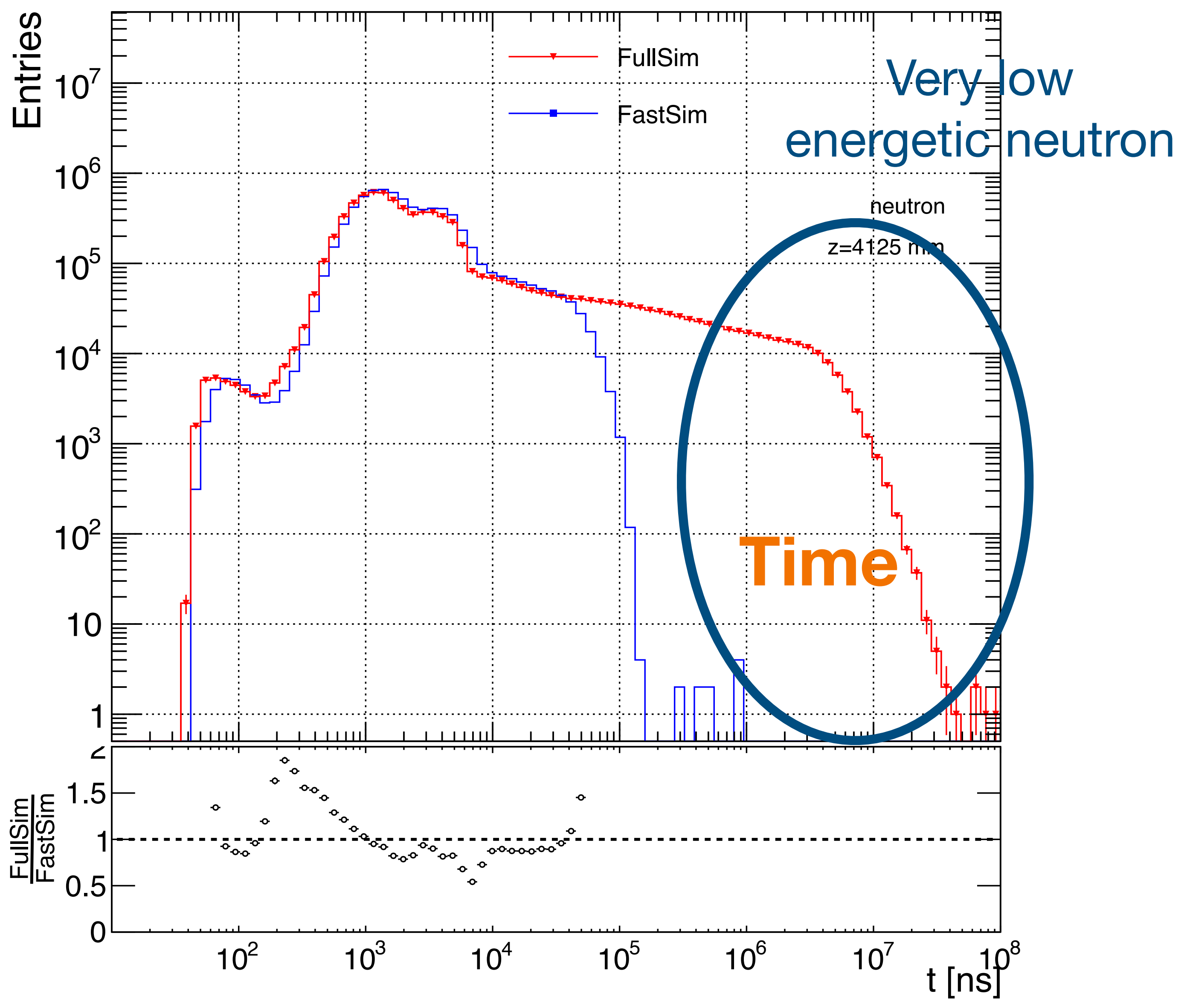
- ★Distributions are looked at **z=5450.25mm**.
- ★FullSim and FastSim has comparable statistics.
- ★FullSim and FastSim distributions are comparable.
  - ★Mis-modeling in very backward particles ($r \lesssim 100$ mm at z=5450.25mm).
  - ★Problem may be because we have very few forward particles in FullSim to sample the distribution from.
  - ★We can modify the θ_p (direction of the particles) such that this problem is resolved.

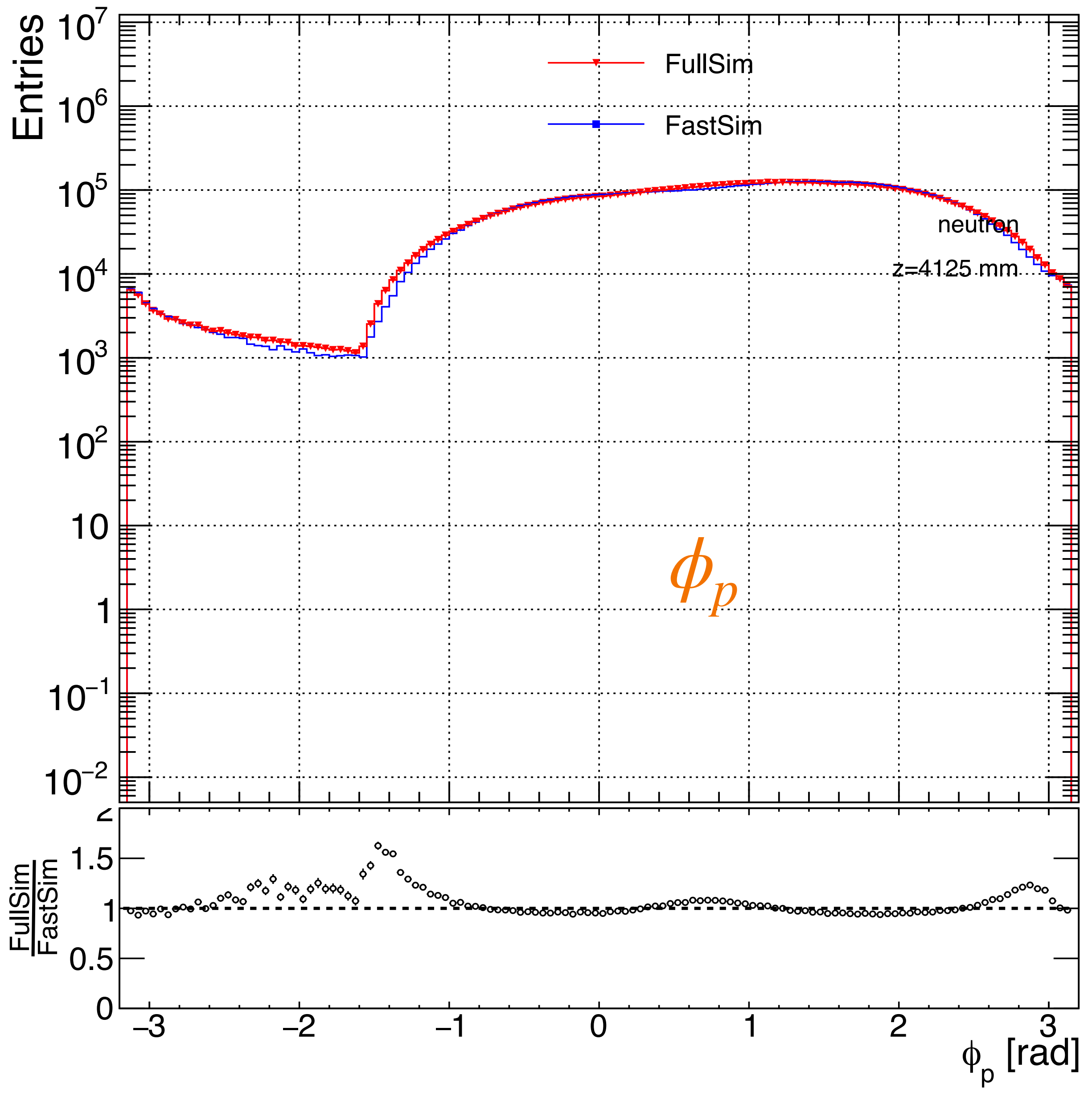
Comparison of FullSim and FastSim distributions at the test surface 2, z=4125mm

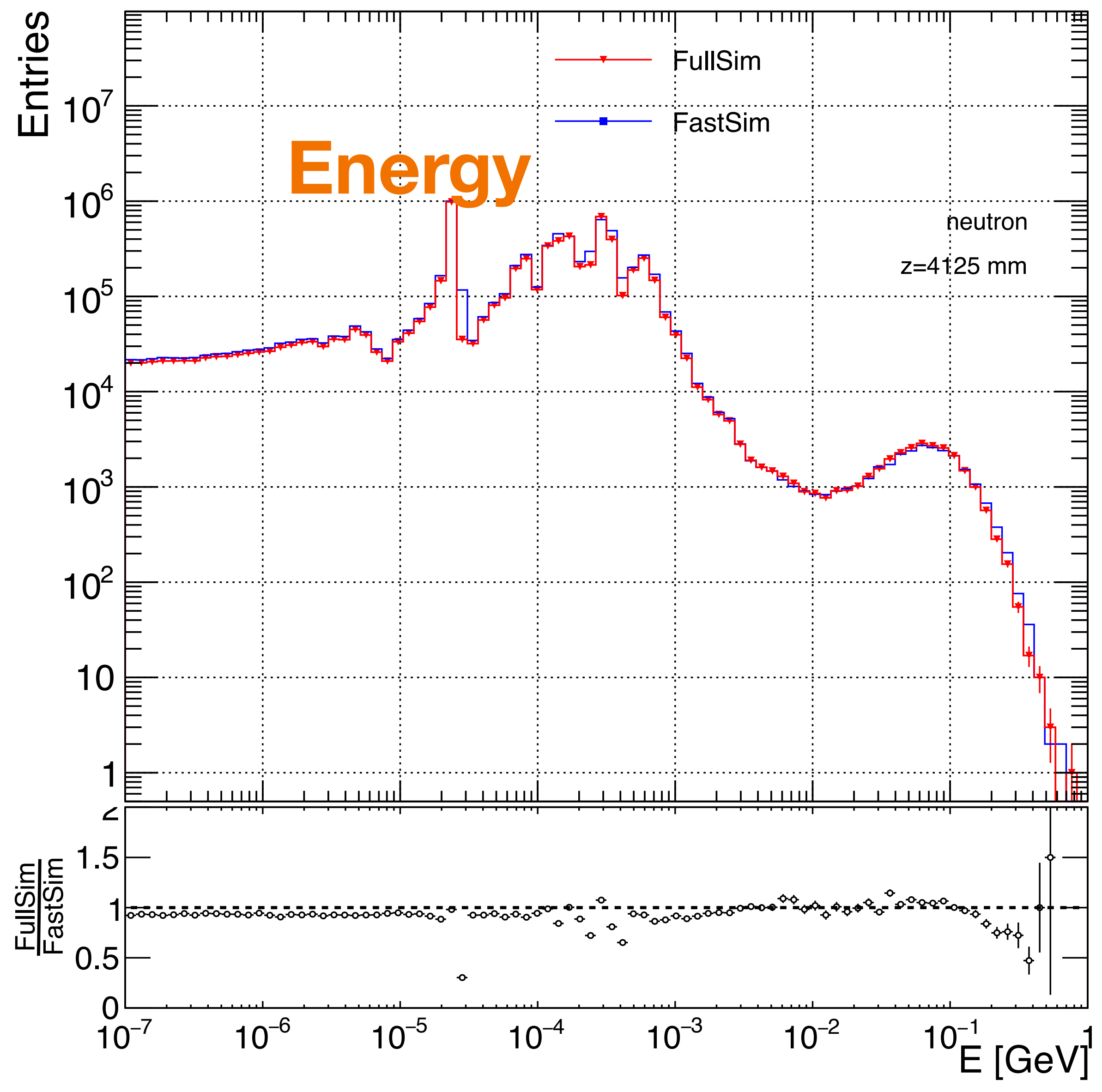
★Particles generated at sampling plane are propagated to test surfaces by Geant4.

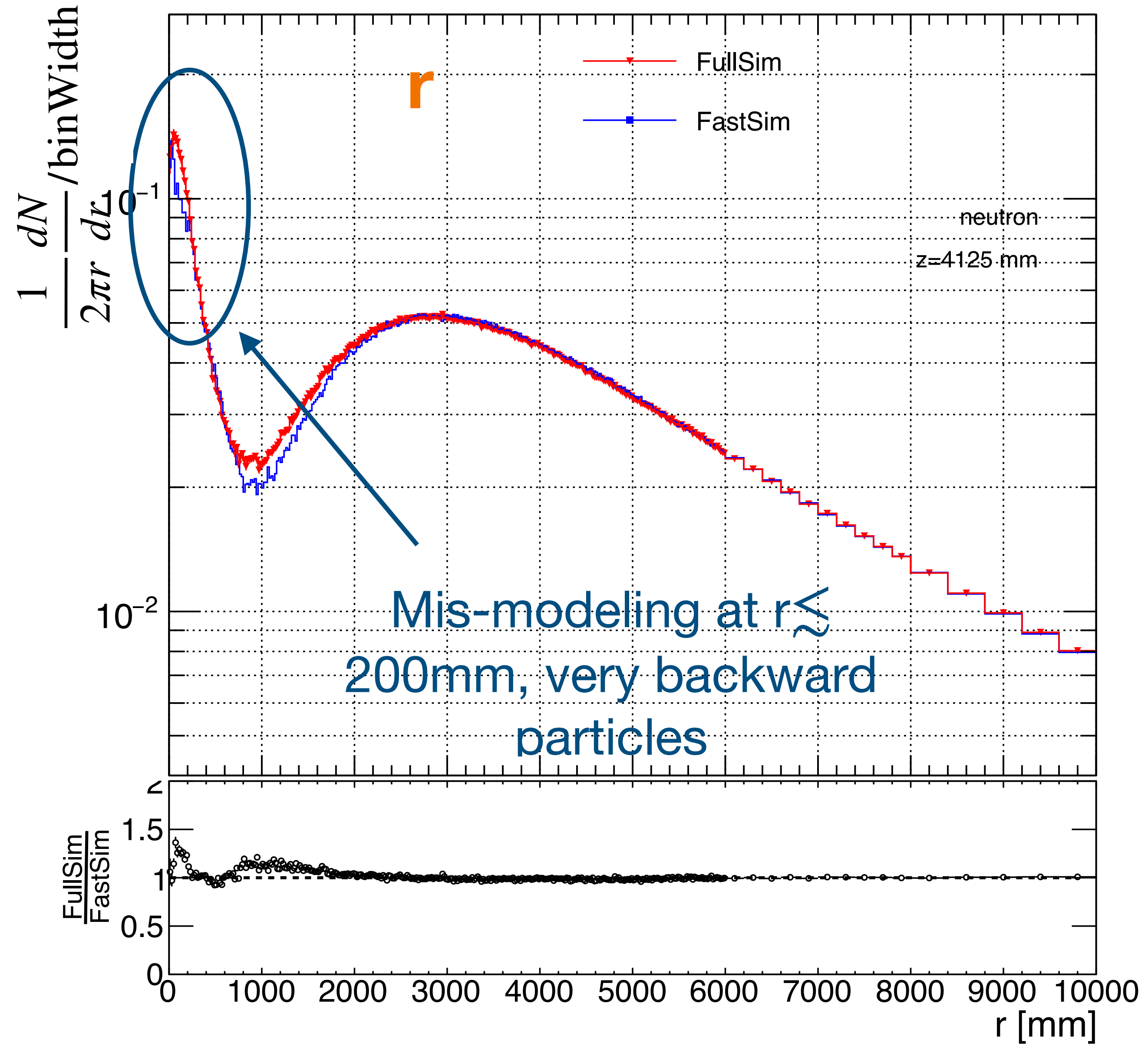
A few 1D distributions between FastSim and FullSim: neutron at the test surface 2





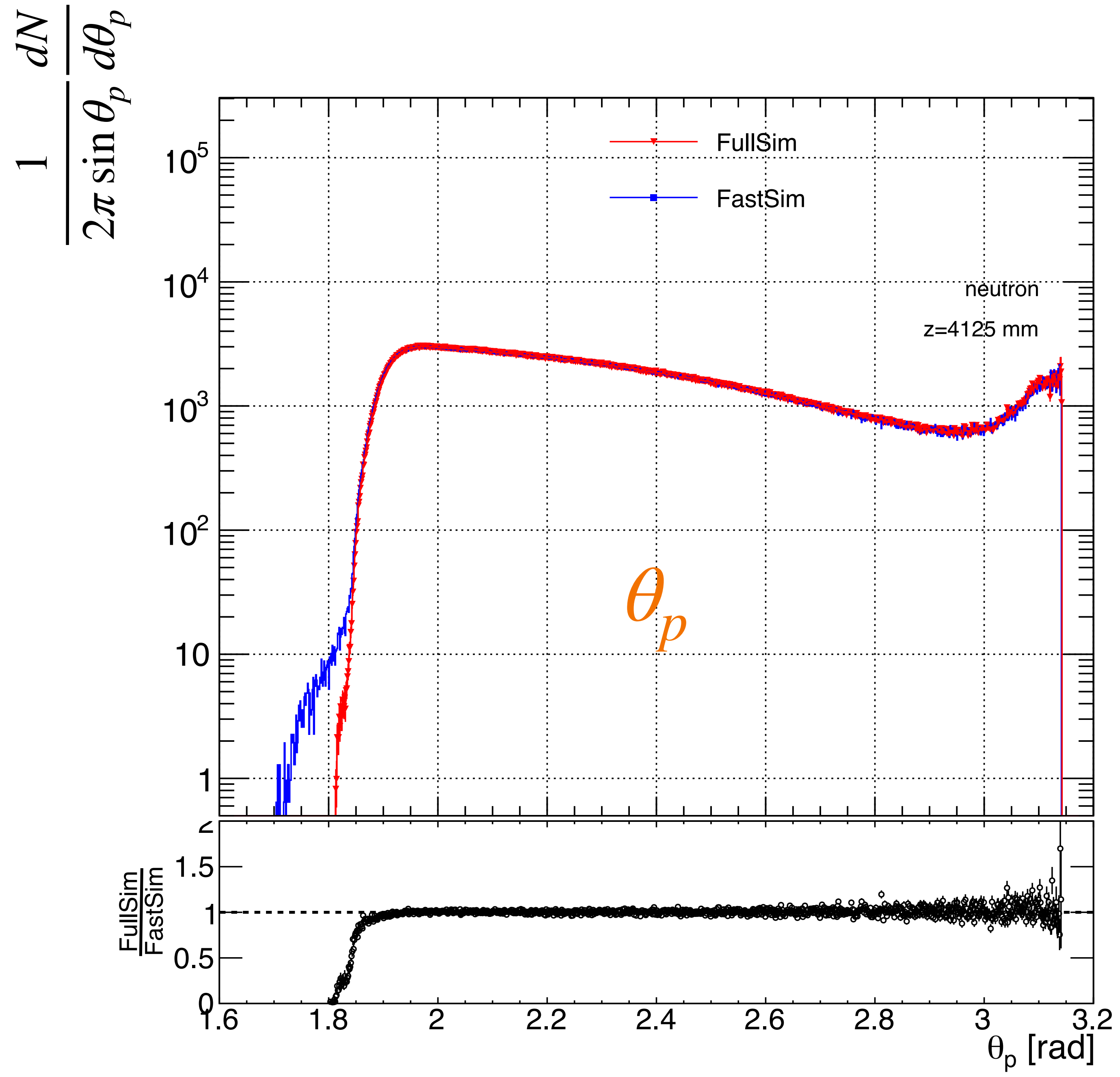


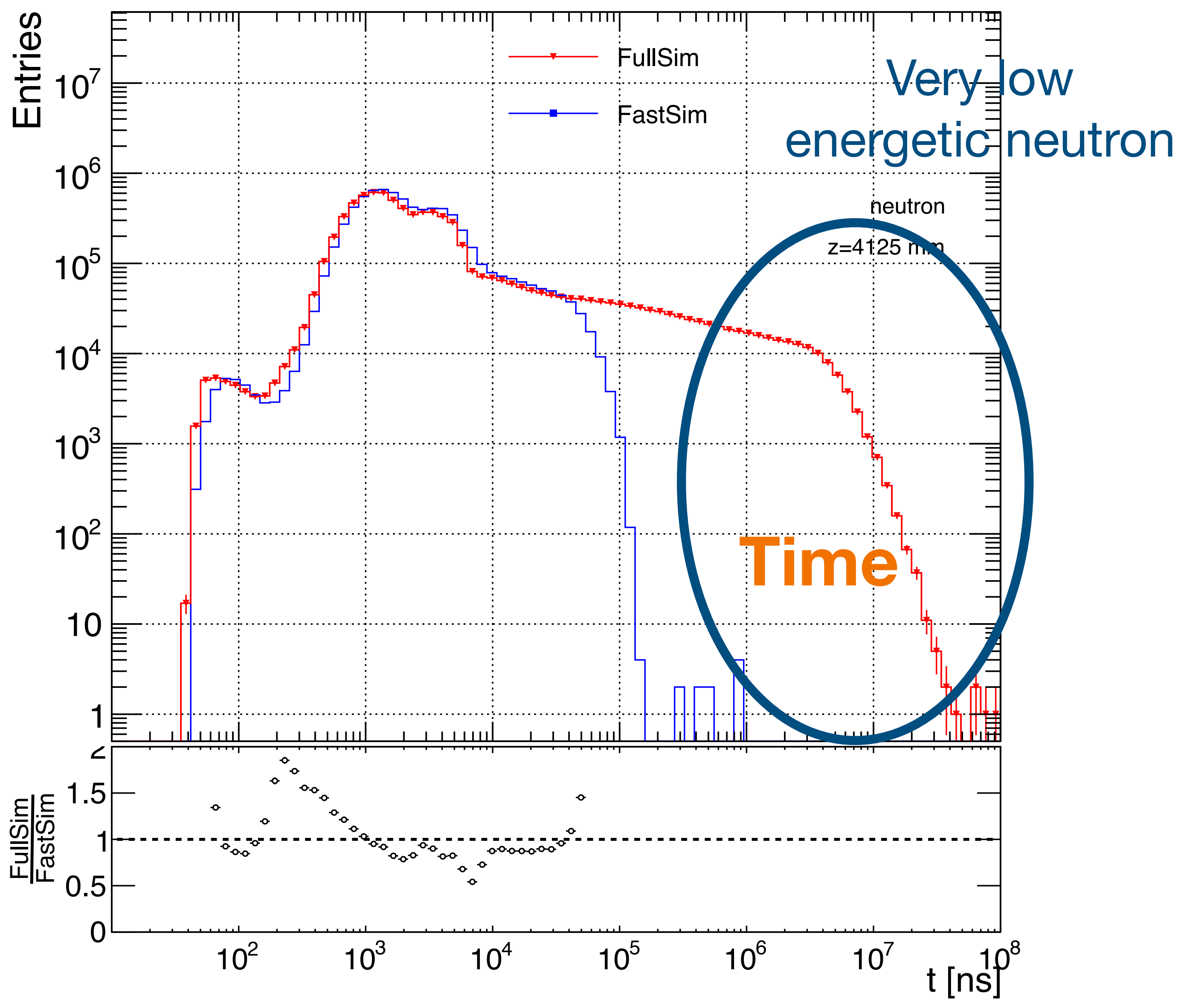


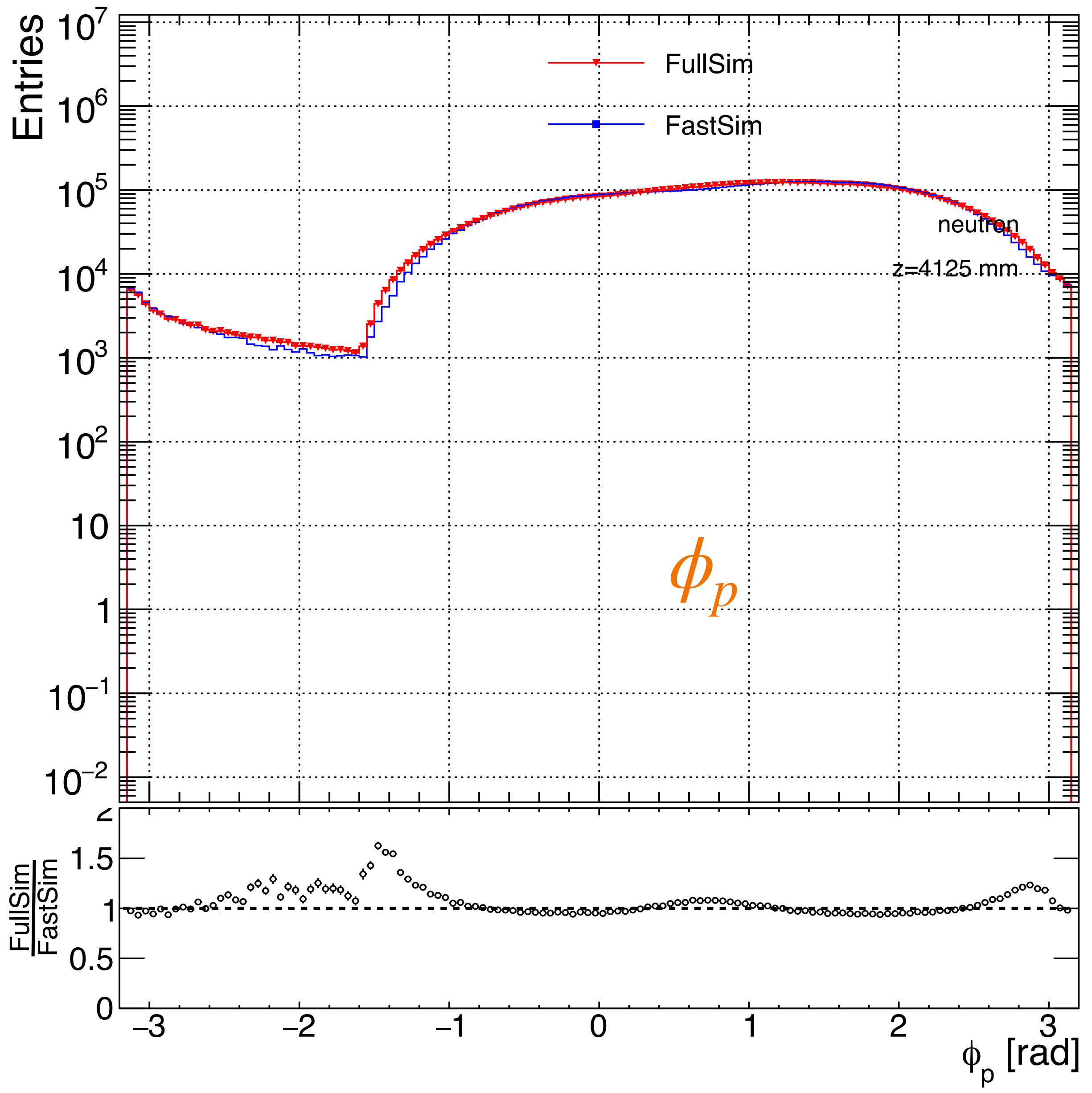


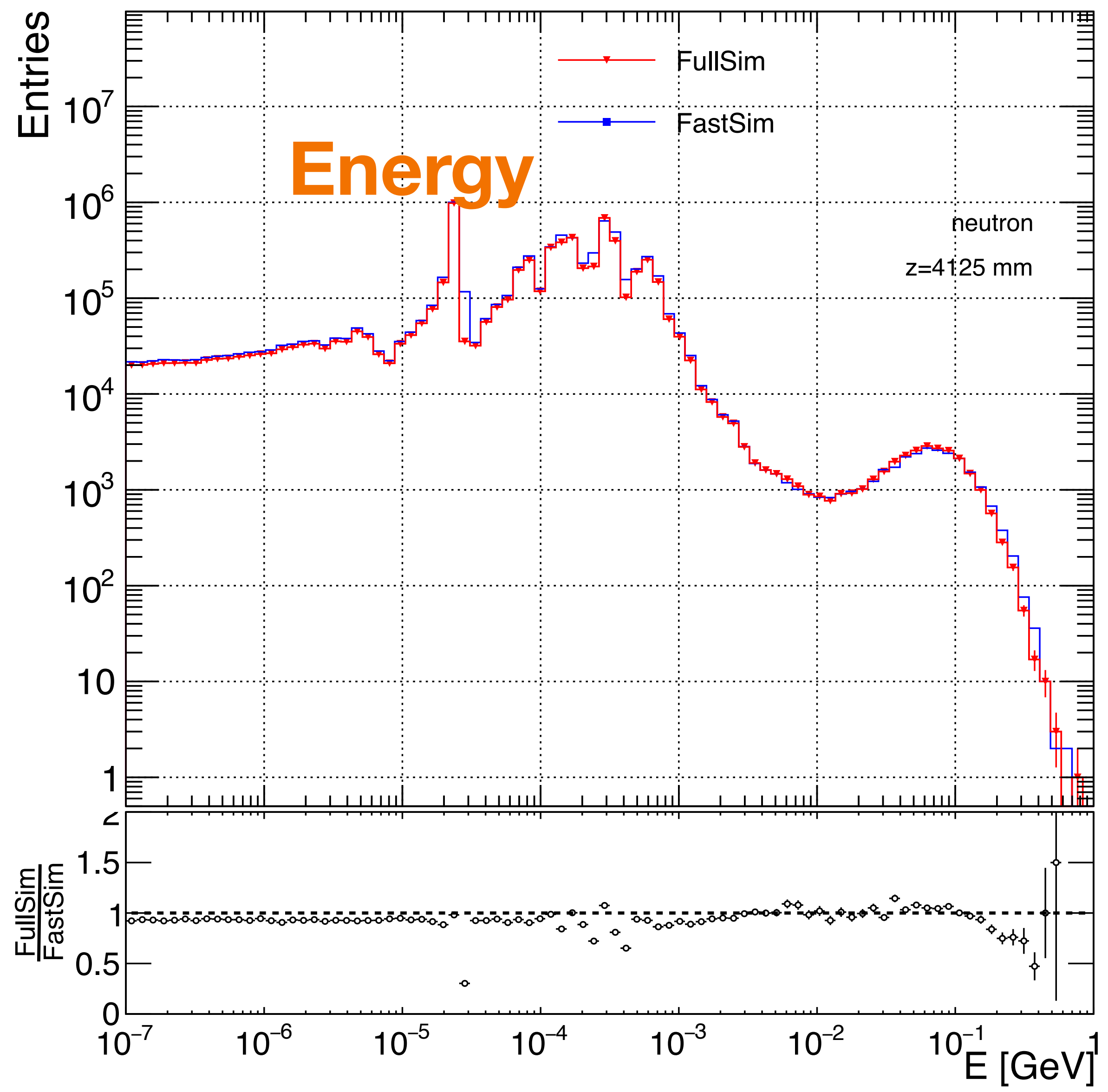
- ★Distributions are looked at **z=4125mm**.
- ★FullSim and FastSim has comparable statistics.
- ★FullSim and FastSim distributions are matching quite well.
  - ★Mis-modeling in very backward particles ($r \lesssim 200$ mm at z=4125mm).

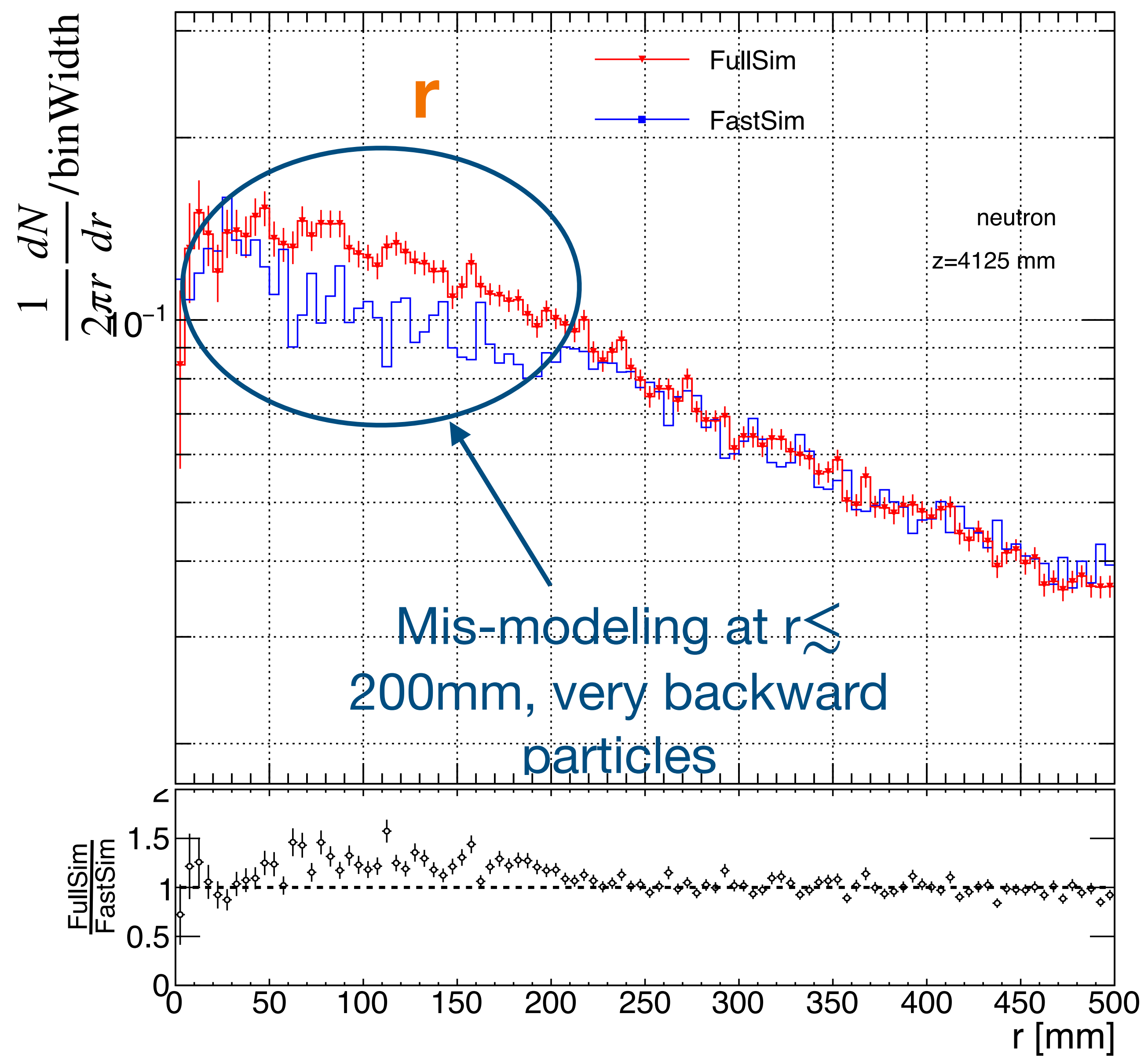
A few 1D distributions between FastSim and FullSim: neutron at the test surface 2











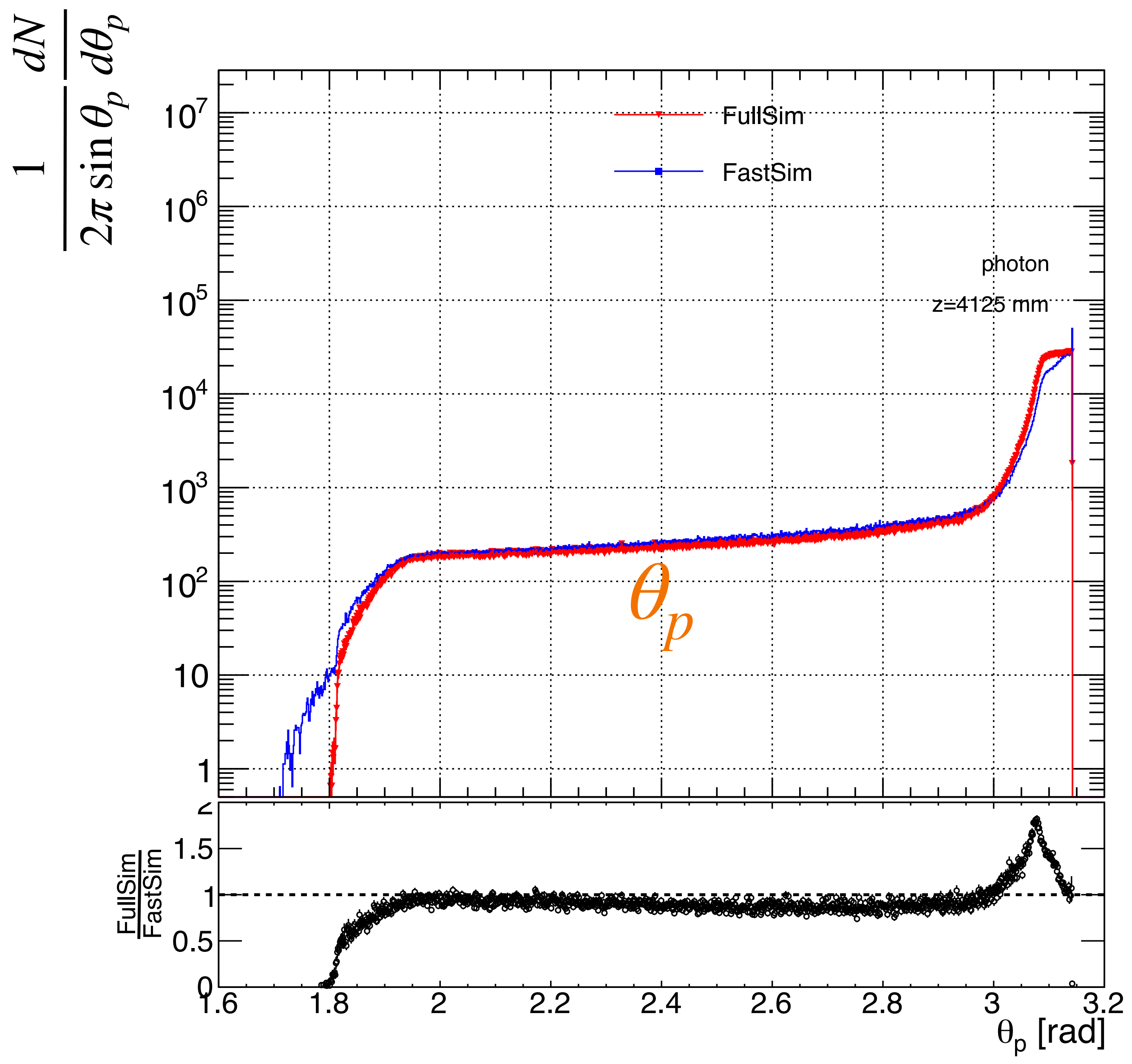
★Distributions are looked at **z=4125mm**.

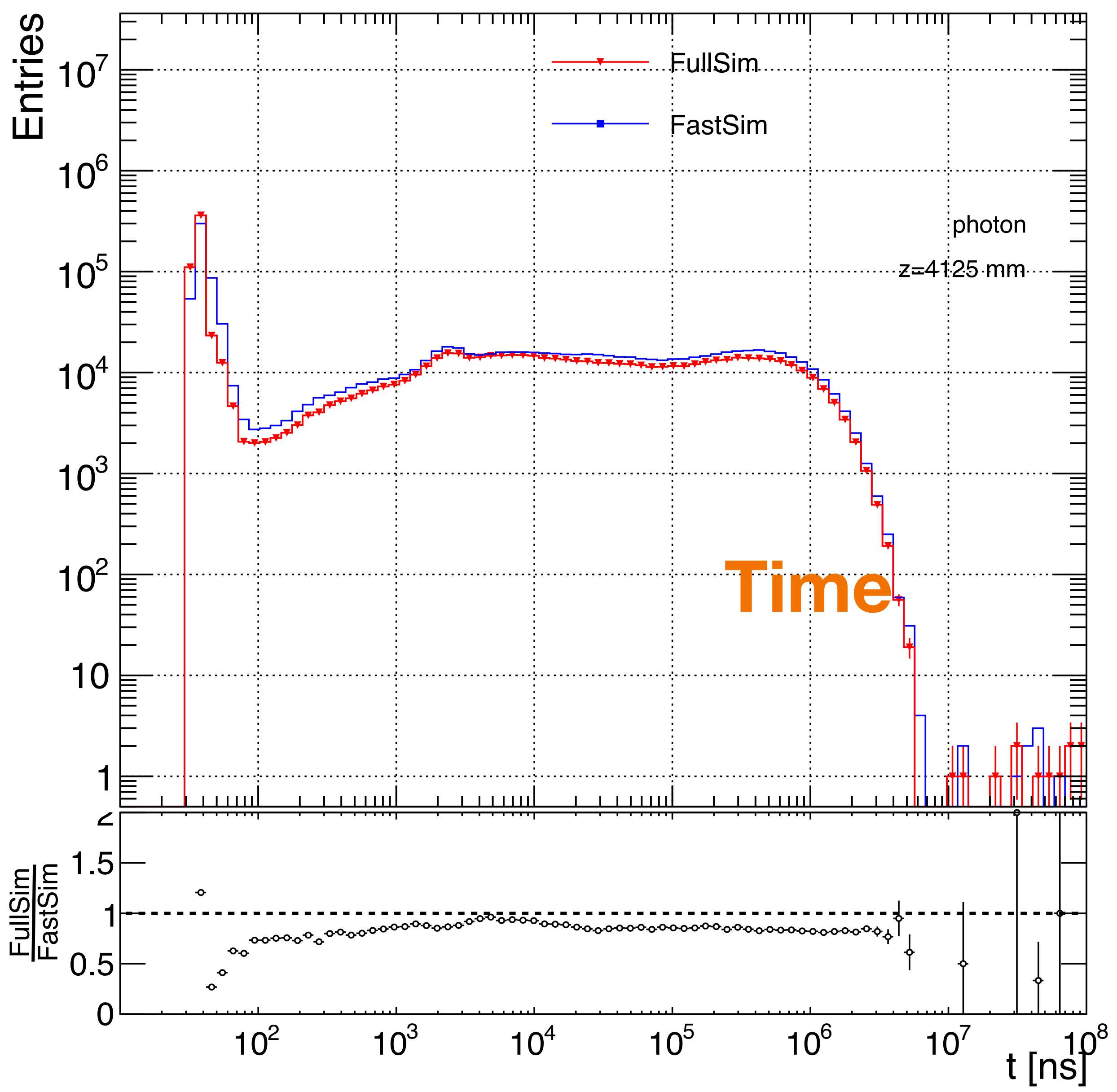
★FullSim and FastSim has comparable statistics.

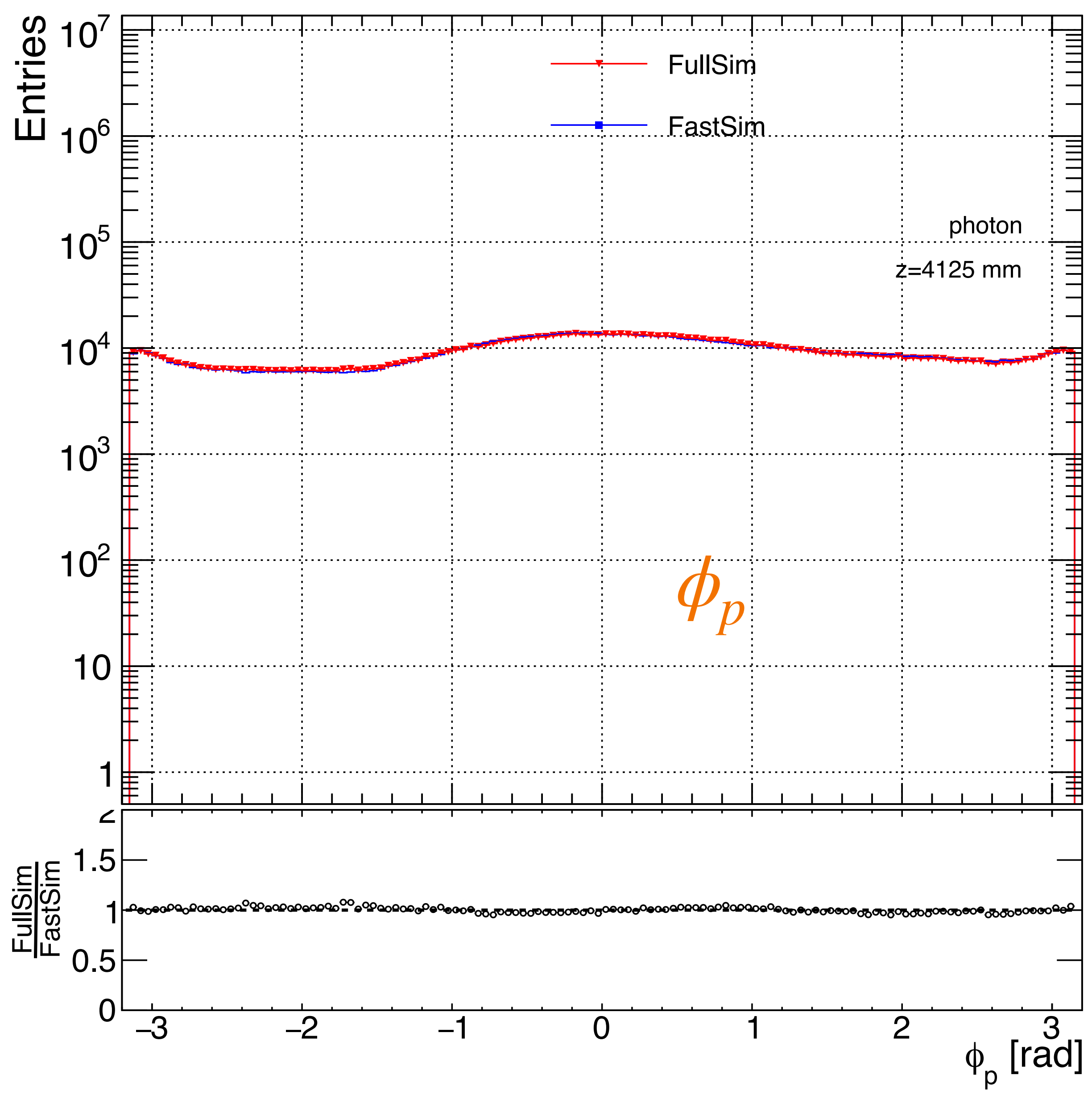
★FullSim and FastSim distributions are matching quite well.

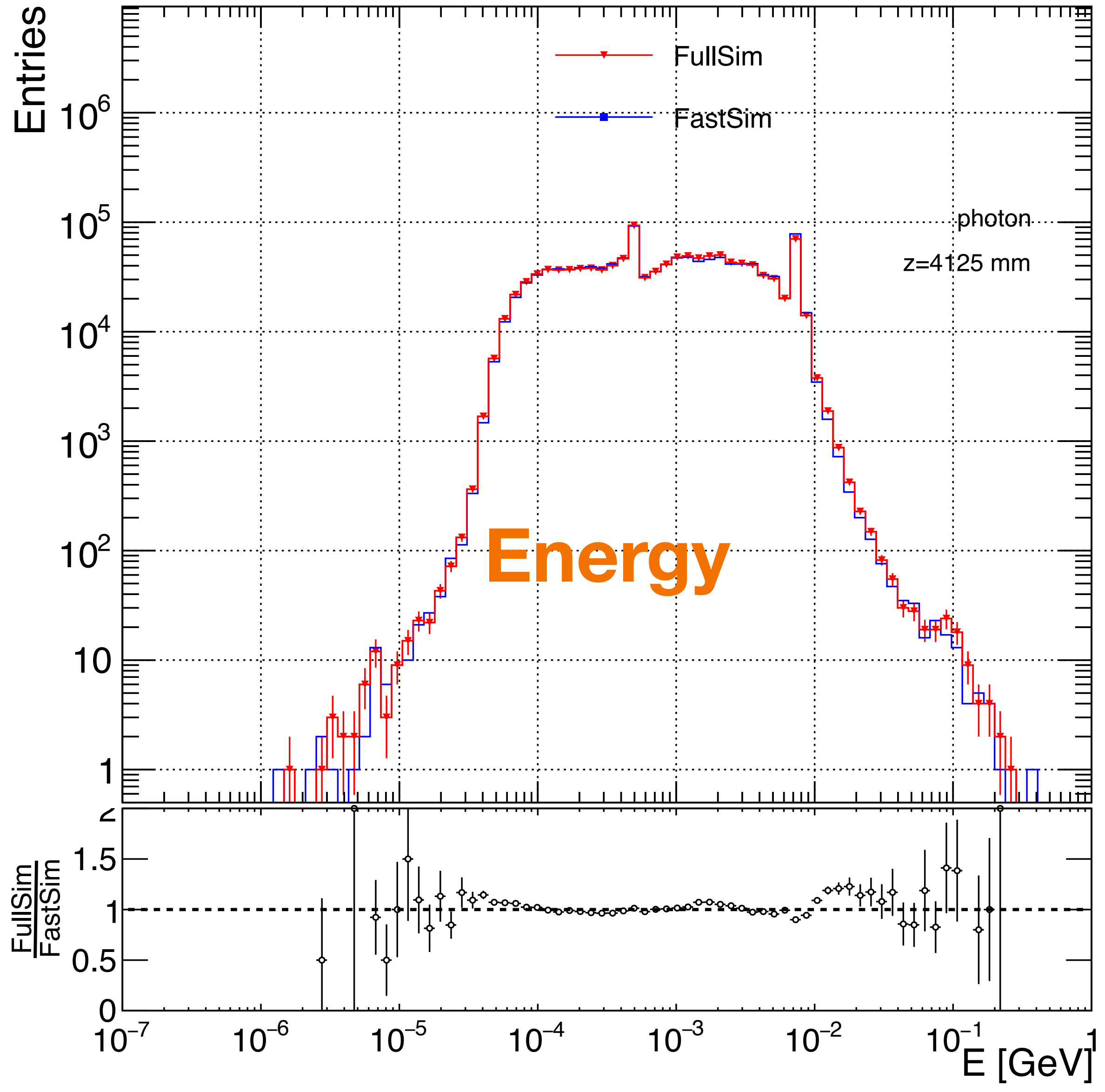
- ★Mis-modeling in very backward particles ($r \lesssim 200$ mm at z=4125mm).

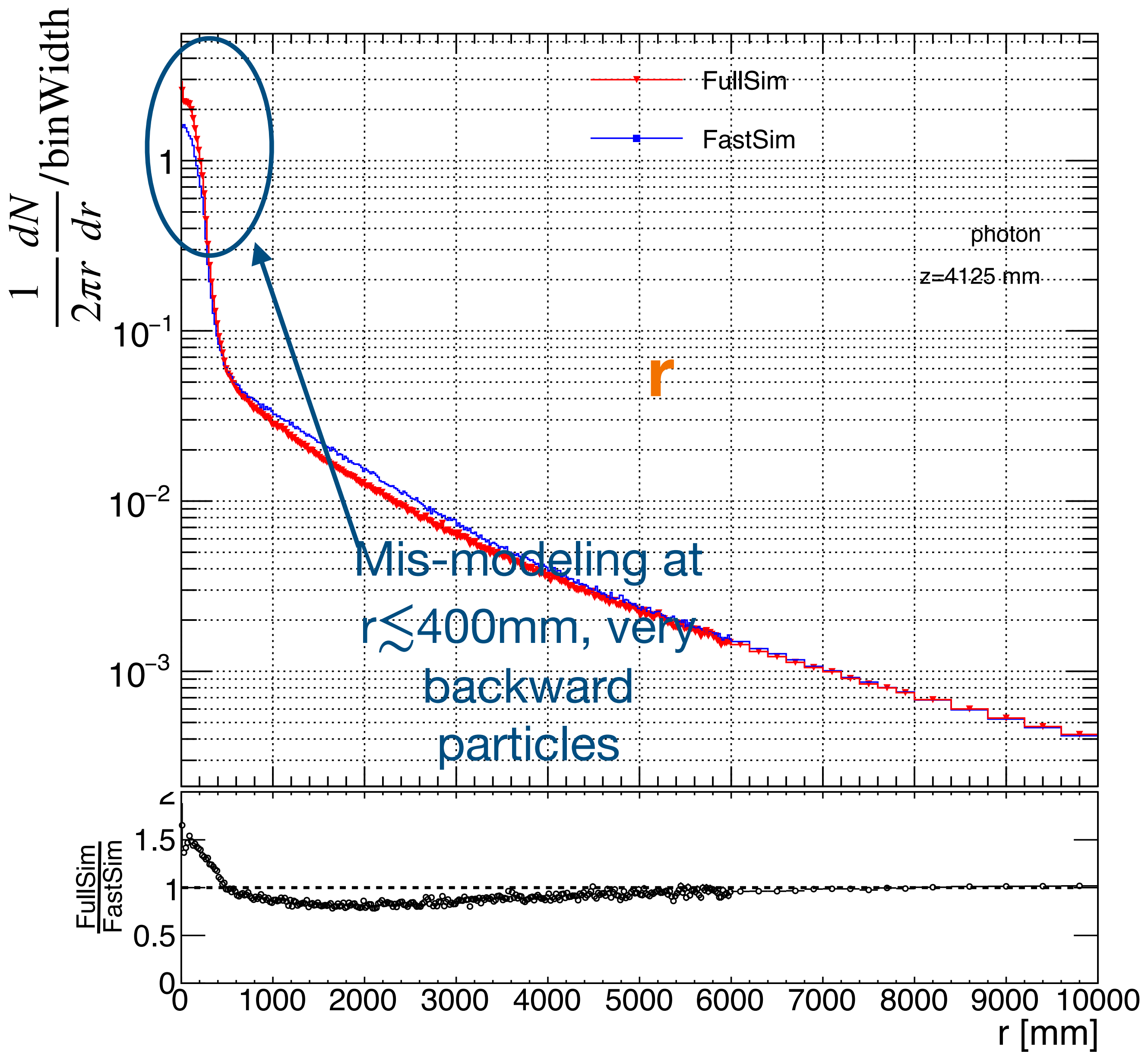
A few 1D distributions between FastSim and FullSim: photon at the test surface 2





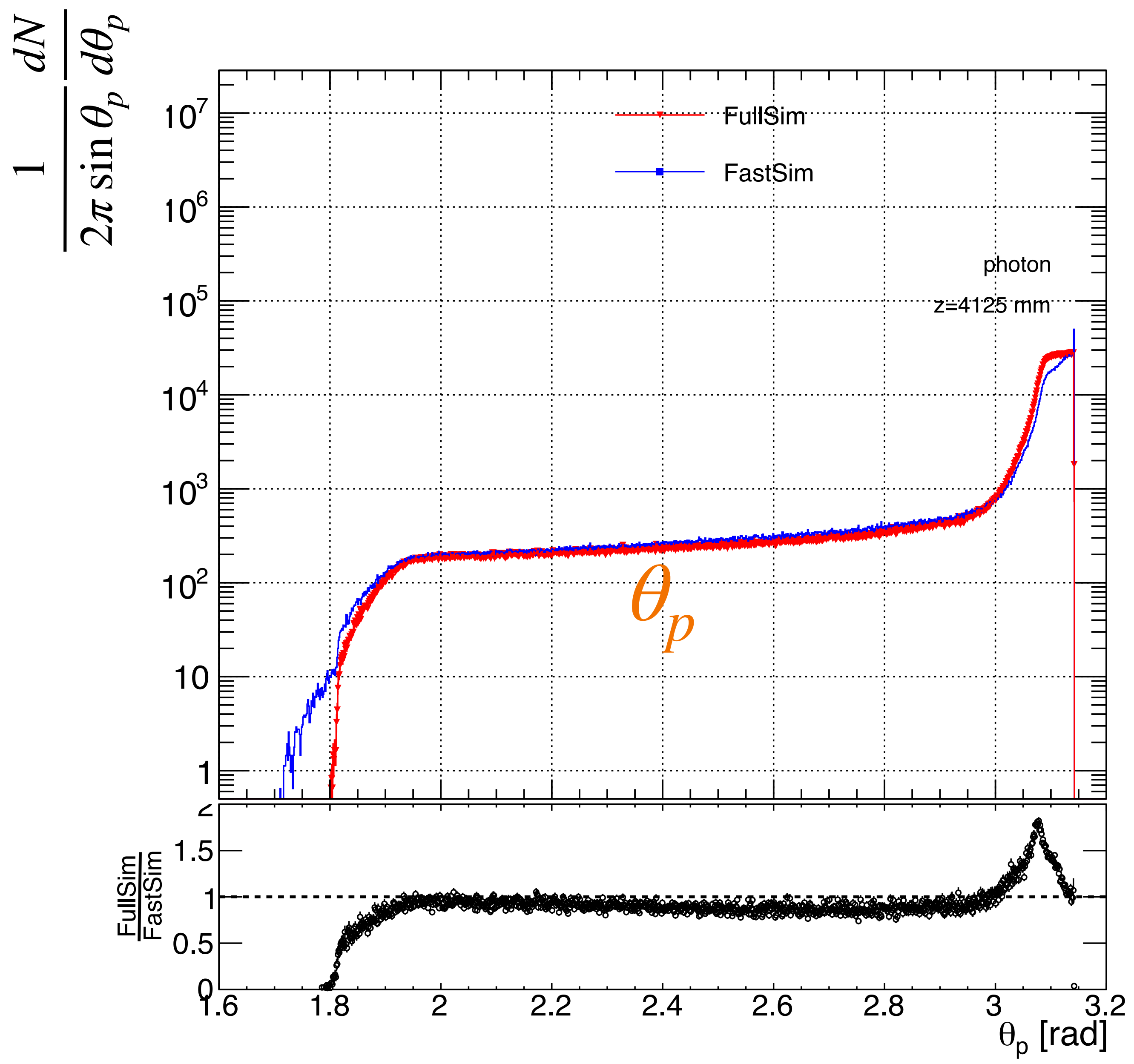


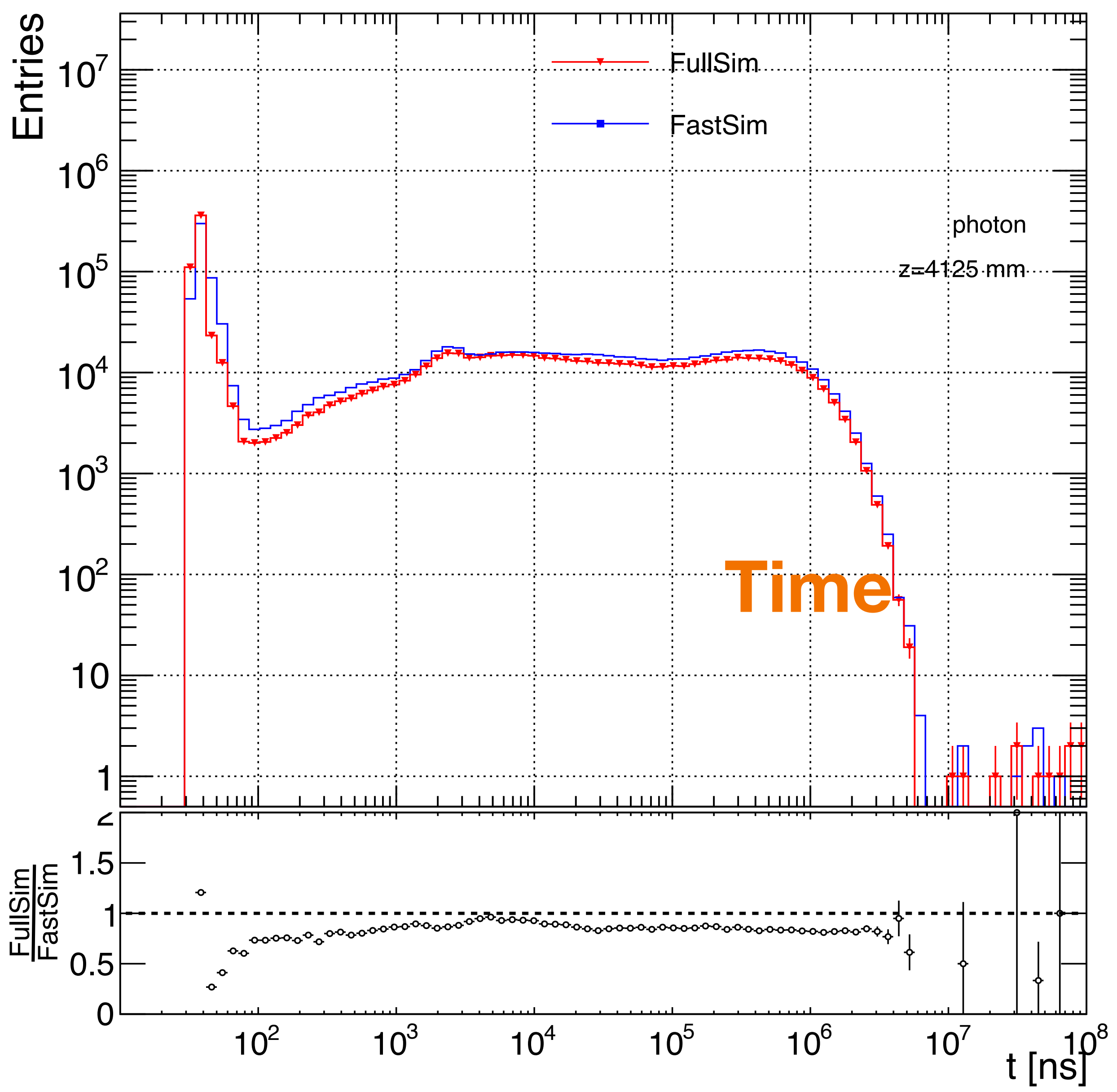


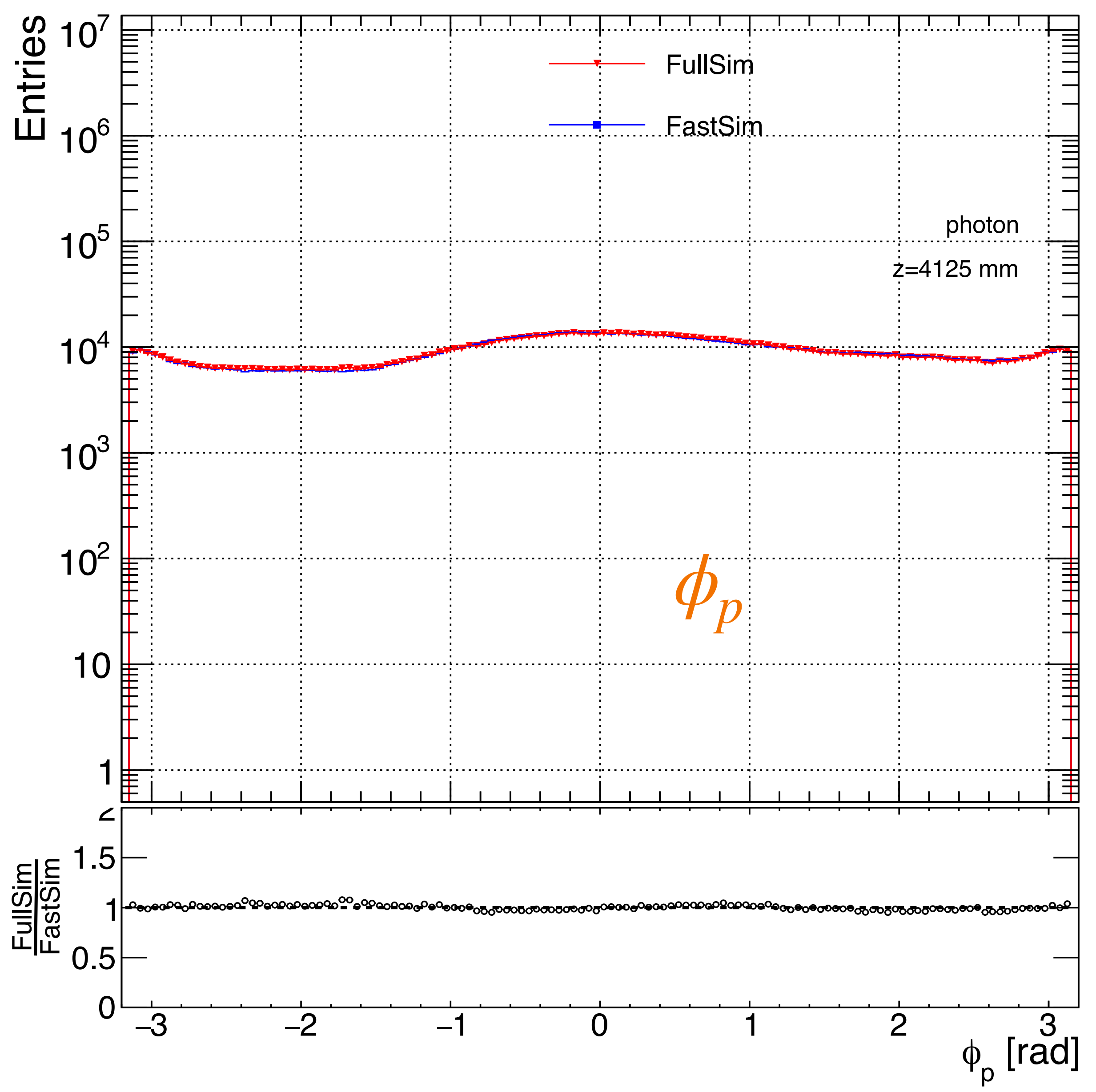


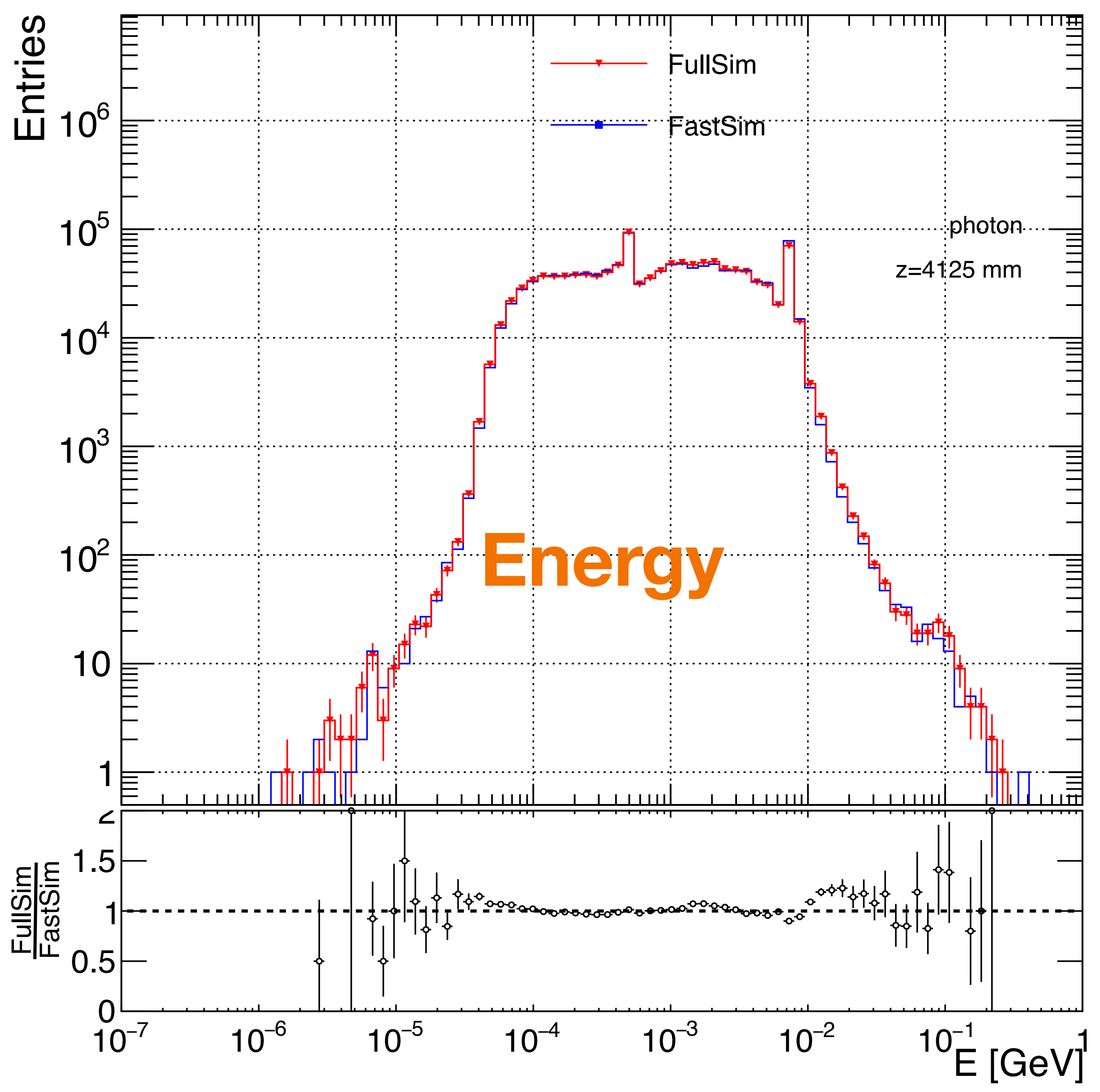
- ★Distributions are looked at **z=4125mm**.
- ★FullSim and FastSim has comparable statistics.
- ★FullSim and FastSim distributions are comparable.
  - ★Mis-modeling in very backward particles ($r \lesssim 400$ mm at z=4125mm).

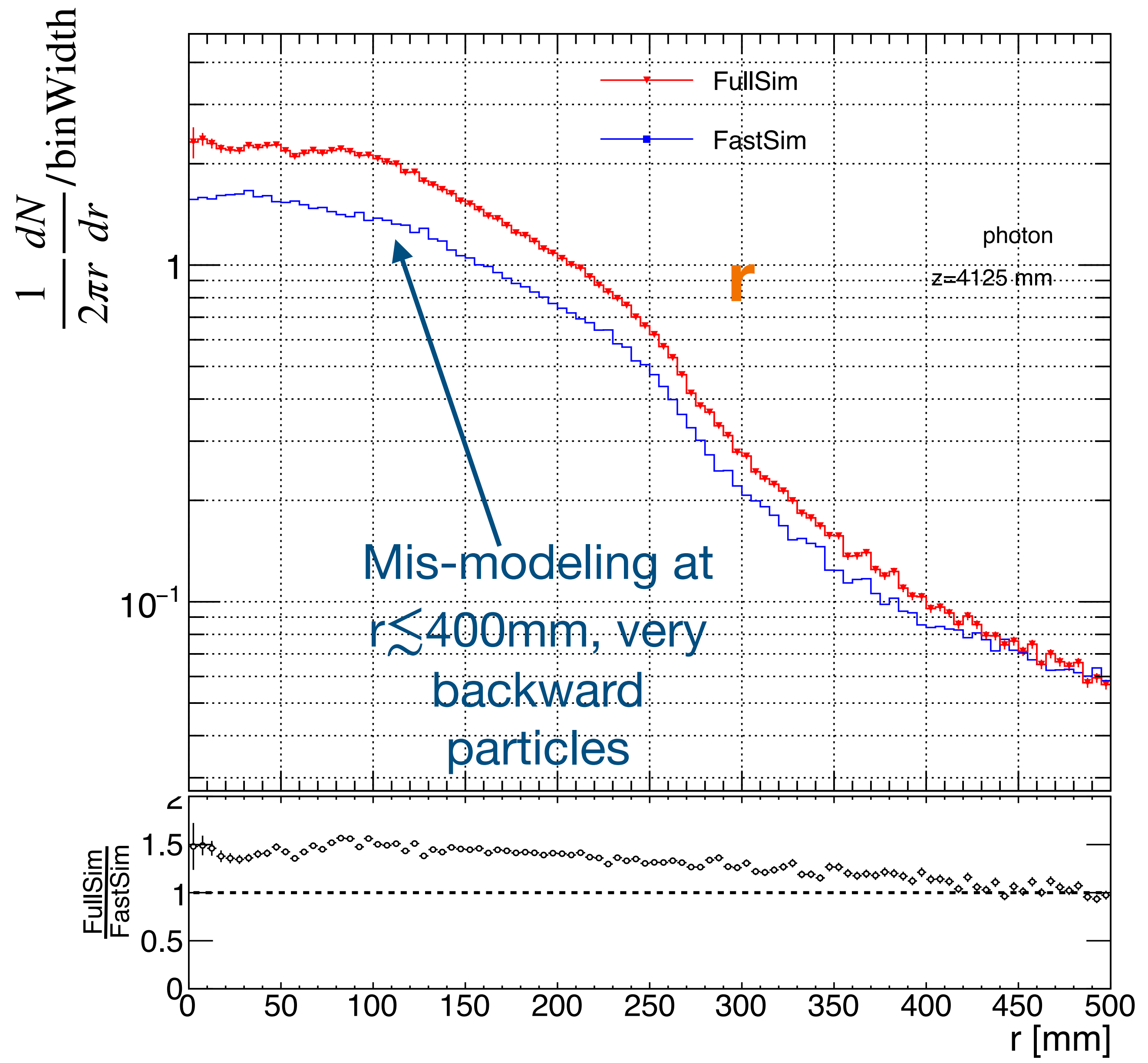
A few 1D distributions between FastSim and FullSim: photon at the test surface 2











★Distributions are looked at **z=4125mm**.
★FullSim and FastSim has comparable statistics.
★FullSim and FastSim distributions are comparable.
★Mis-modeling in very backward particles ($r \lesssim 400$ mm at z=4125mm).

Summary and Outlook

Summary and next steps:

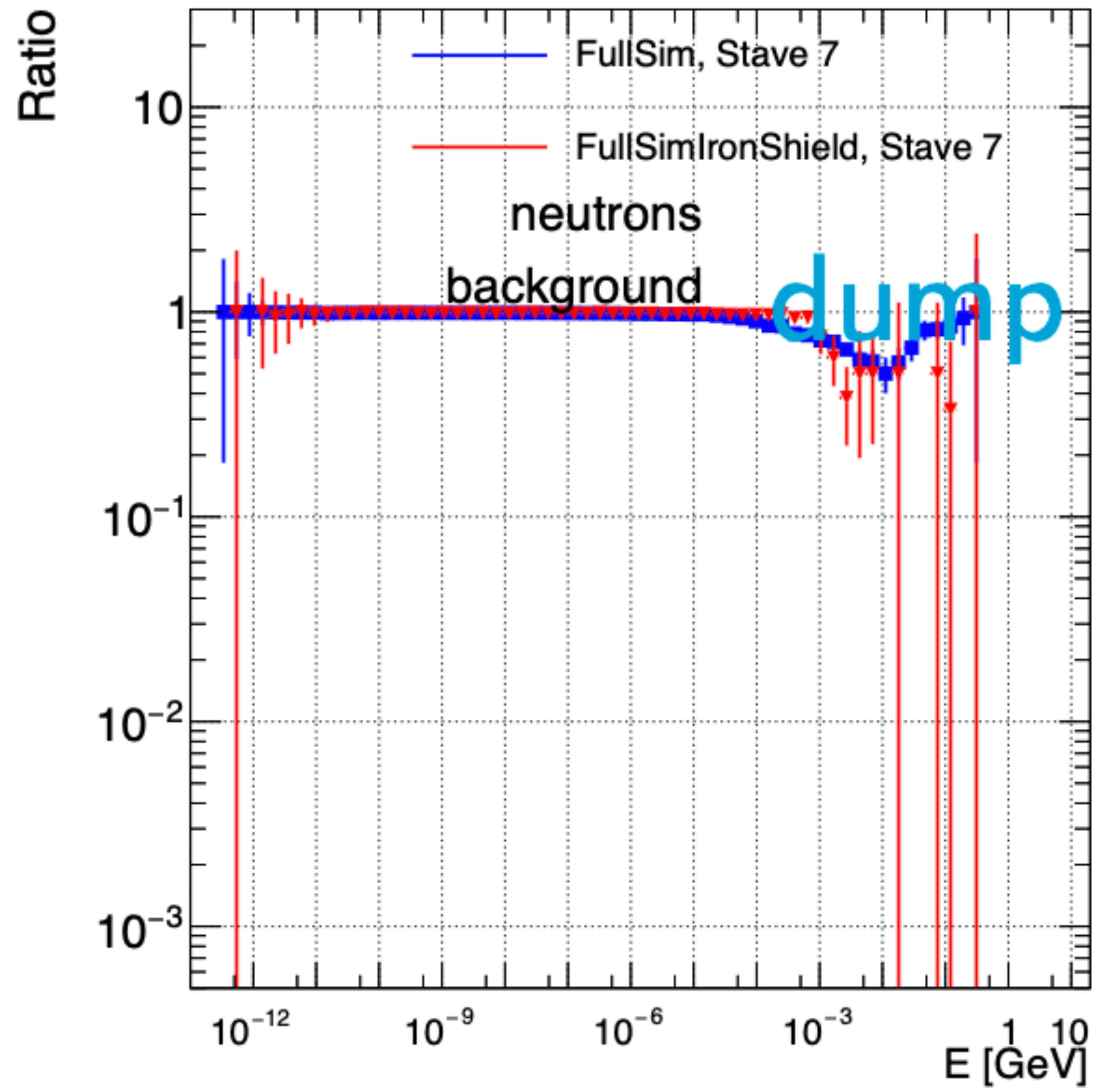
- Distributions between FastSim and FullSim are compatible at different distances for LUXE dump only geometry.
    - Shown comparison plots from test surfaces at z=5450.25 mm and at z=4125mm.
  - Residual mis-modeling - **source of systematic uncertainty.**
- **Mis-modeling in very forward particles**
  - **This is because the FullSim sample is statistically limited in this region.**
    - **Plan is to modify the direction θ_p to match with FullSim before sampling.**
    - Work on-going.
  - May shift to Generative Adversarial Network for better result.
    - The Network should be able to handle the mis-modeling of θ_p.

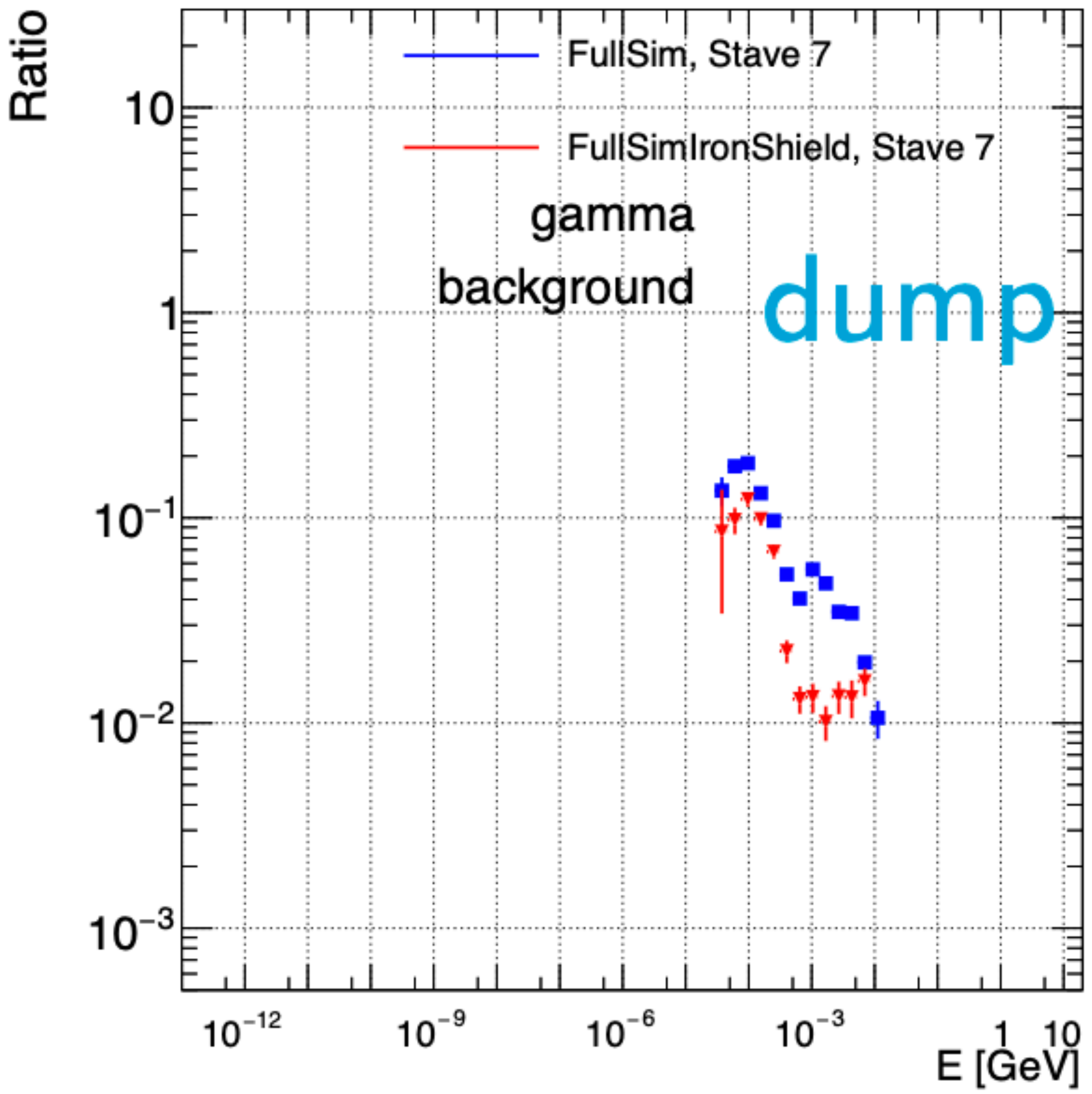
Thank you!

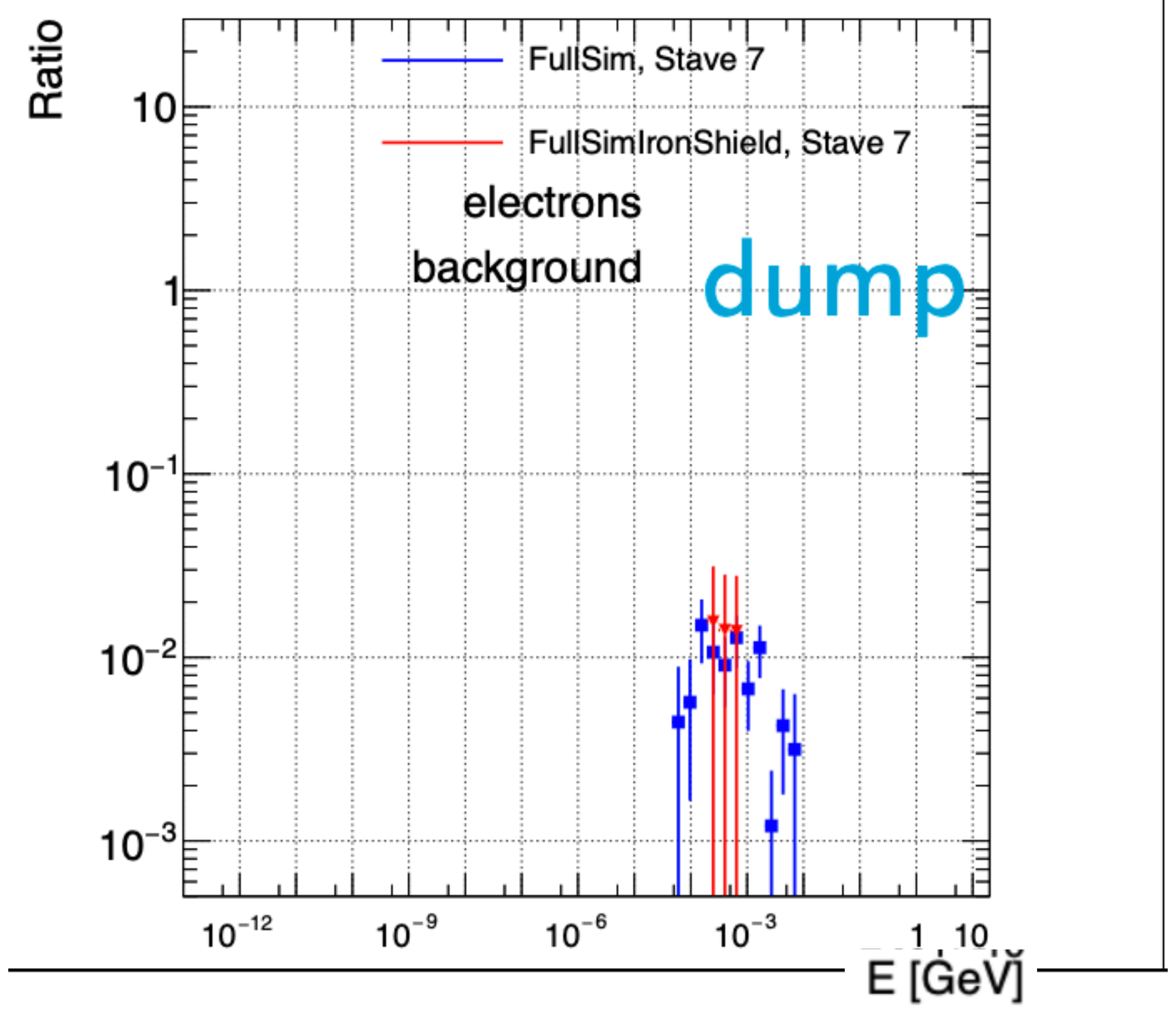
Backup

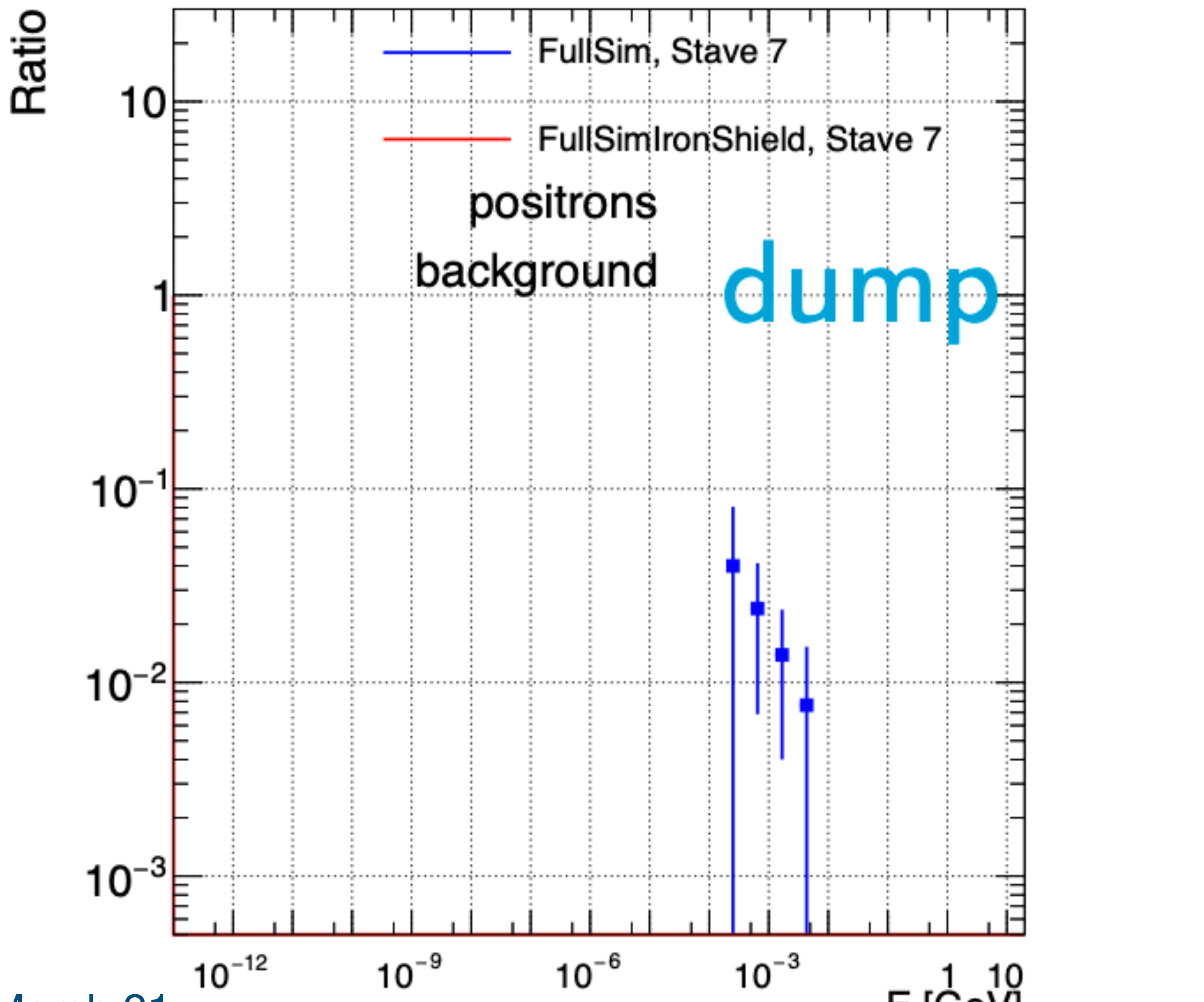

Laser
electrons
IP
FWD
BSM
LUXE
e + laser mode
BSM detector
$a \to \gamma\gamma$
γ_{ALPs} detector (TBD)
ALPs
γ dump
Backscattering calorimeter
Shielding
γ-profiler
Scint. screen
e^+
e^-
Dipole magnet 2
Shielding
Electron beam dump
γ-converter
Compton γ's
Calorimeter
Cherenkov counter
behind a Scint. screen
e_C^-
Pixel tracker
e^+
e^-
Laser pulse
Dipole magnet 1
Electron beam
from the XFEL
IP
$\theta = 17^0$
Forward detectors
Γ_{γ_C}, ξ
IP detectors
$\Gamma_{e^+}, \Gamma_{e_C}$
y
z
x
e+laser mode
(not to scale)

Different particles generated from dump: FullSim result









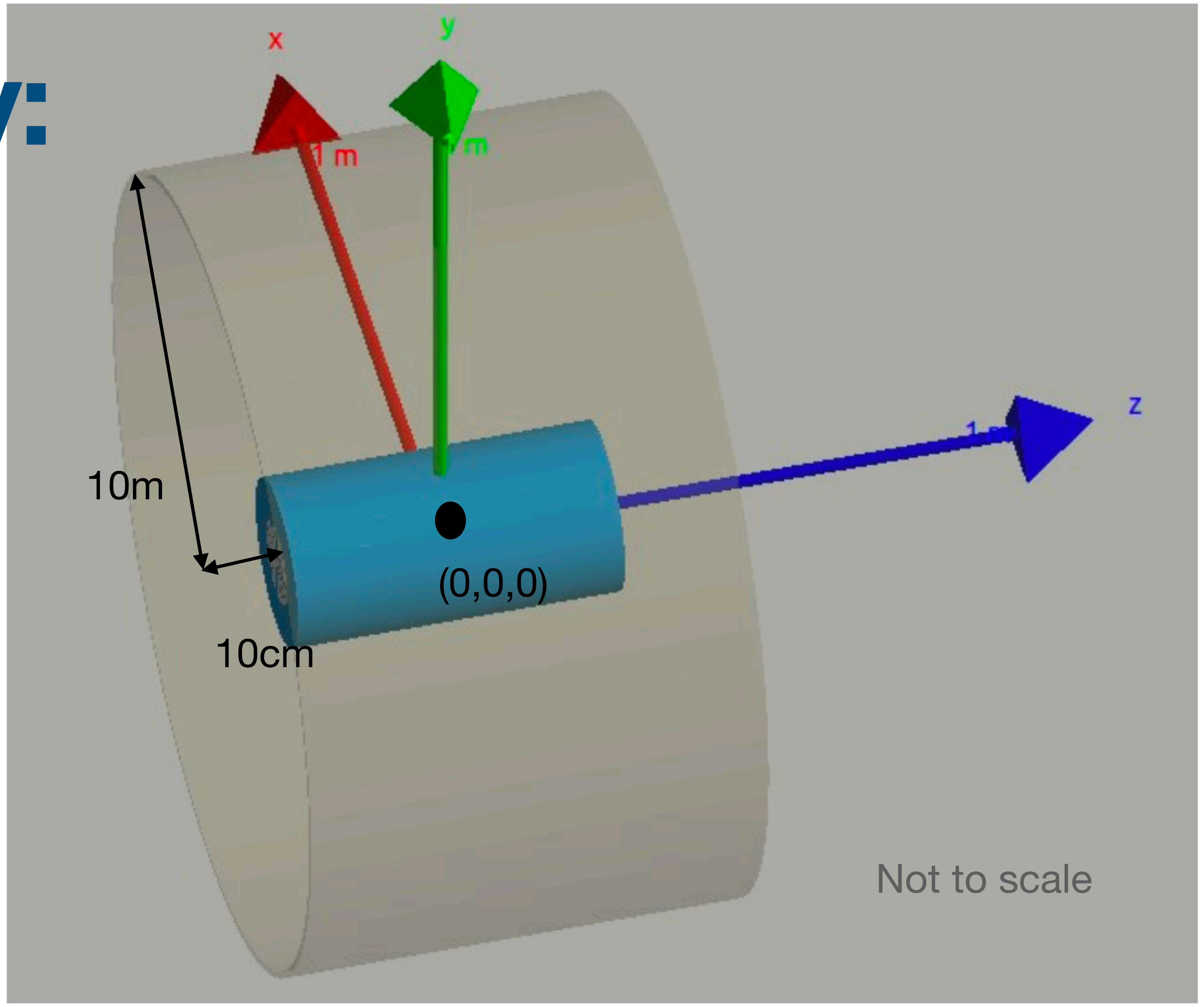
Y-axis is ratio of particle coming from dump over all the sources to the tracker last layer.

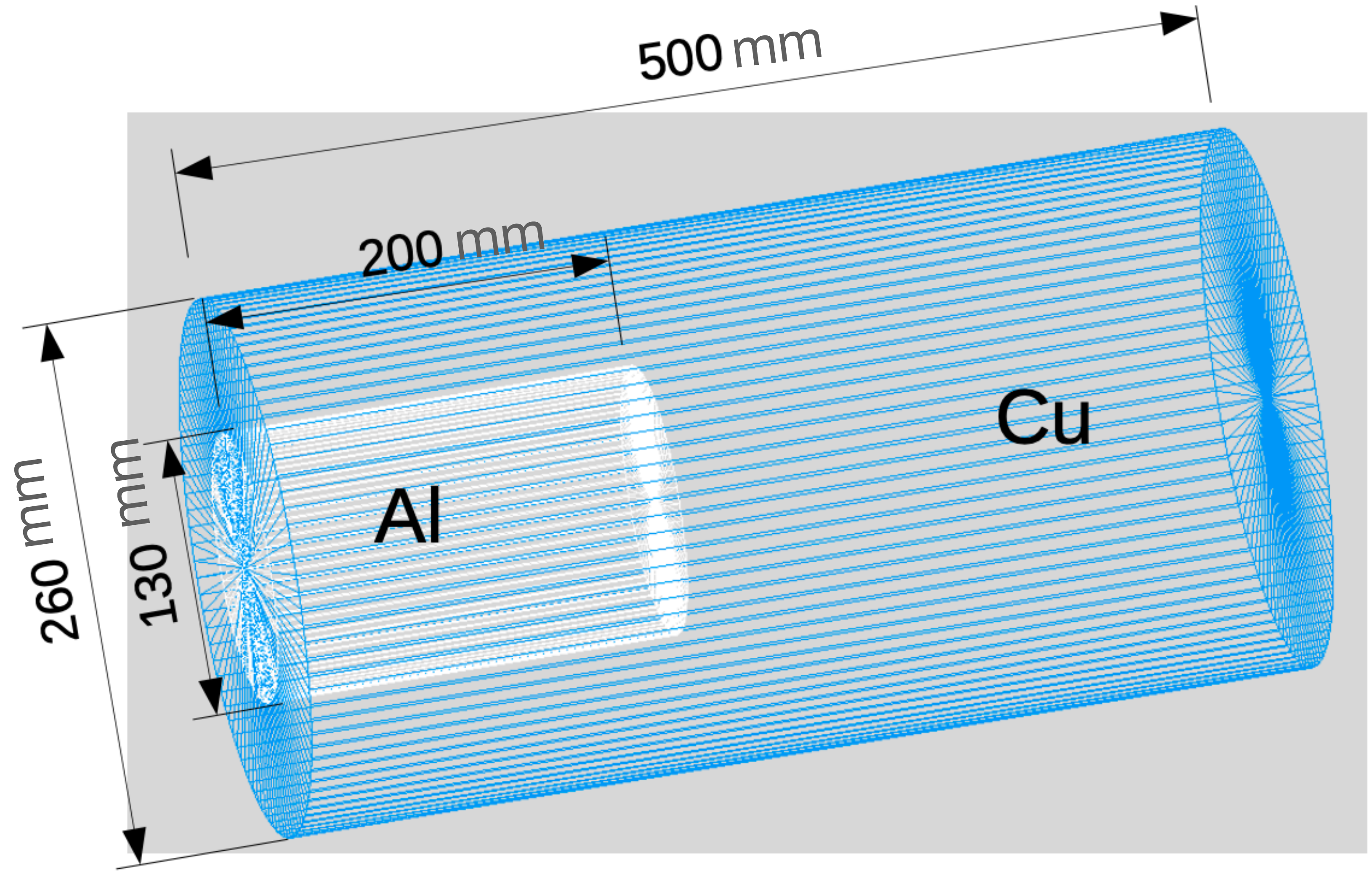
- ★At the tracker last layer
  - ★100% of the neutron come from dump
  - ★>10% of the photons come from dump
  - ★~1% of the electrons and positrons from the dump

Plots shown on SAS Meeting, March 21

Simulation for dump only geometry:

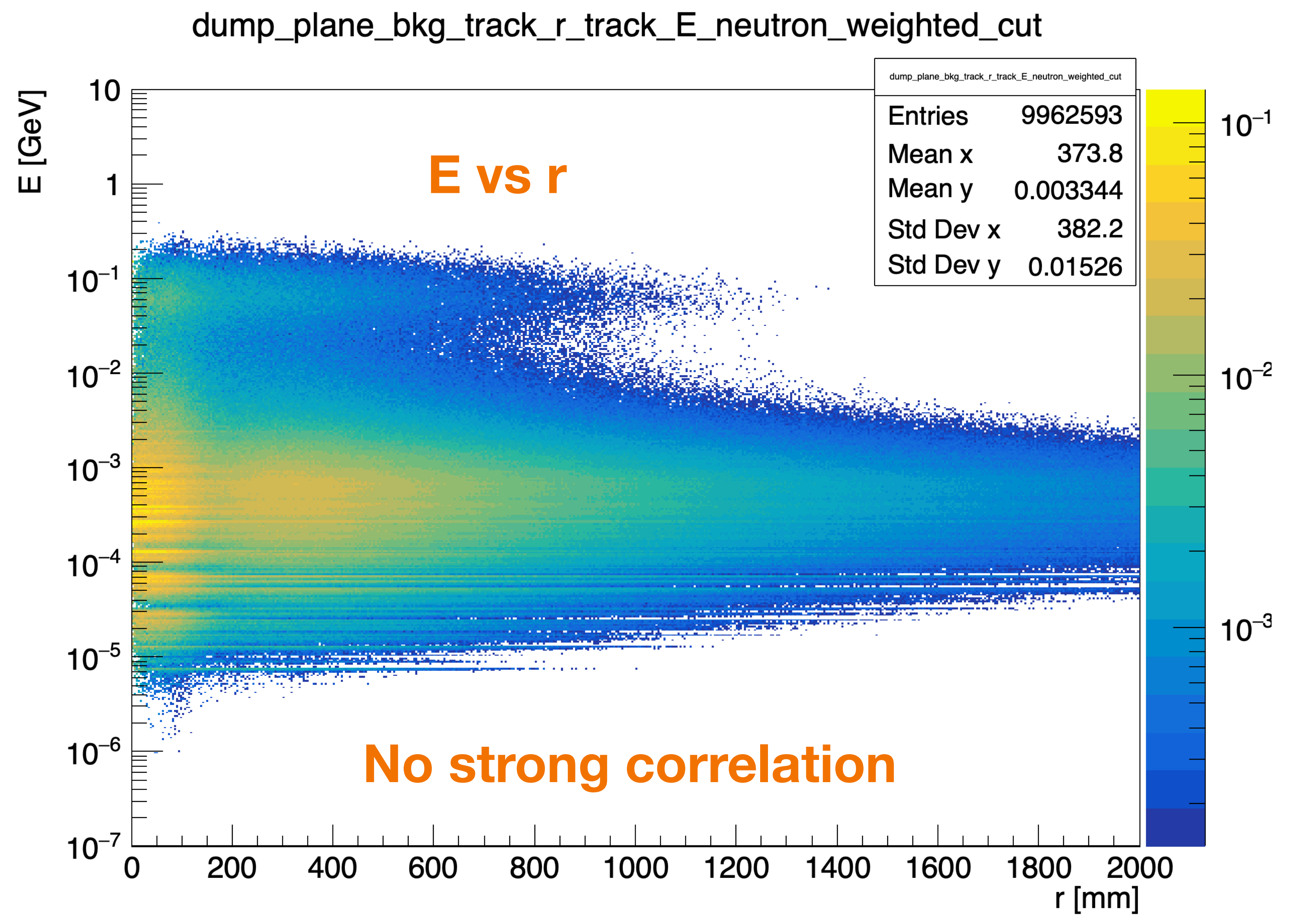
- We had **0.0056 BX** of dump only simulation - FullSim previously produced by Sasha
    - That geometry had only the dump, and then four particle recording planes.
- Electron beam of 16.5 GeV directly hitting the dump
- This dump is made of Aluminum and Copper
    - The origin is at the center of the dump.
    - We look at FullSim distributions from z=-350mm (**sampling surface**), as this is closest to the dump face.
        - There are **test surfaces** which record particles at z=-5000mm, z=-10000mm and z=-15000mm.
- In this talk there will be **three types of plots** compared:
    1. **FullSim** - Full Geant4 processing of the dump
    2. **Fast Sampling**: sampled randomly from FullSim distribution.
    3. **FastSim** - Geant4 processing where dump is replaced by particles following distributions in 2 above.

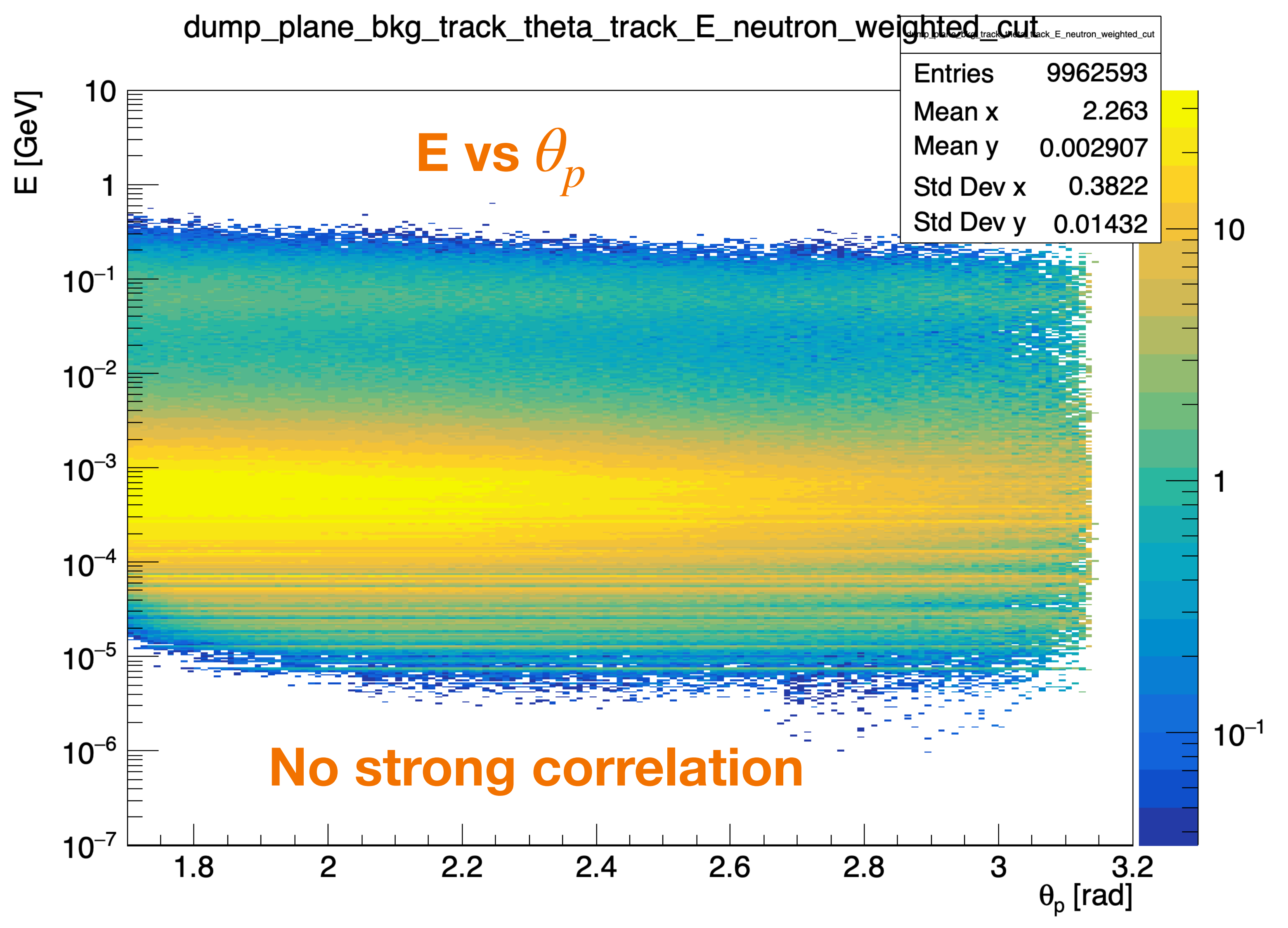


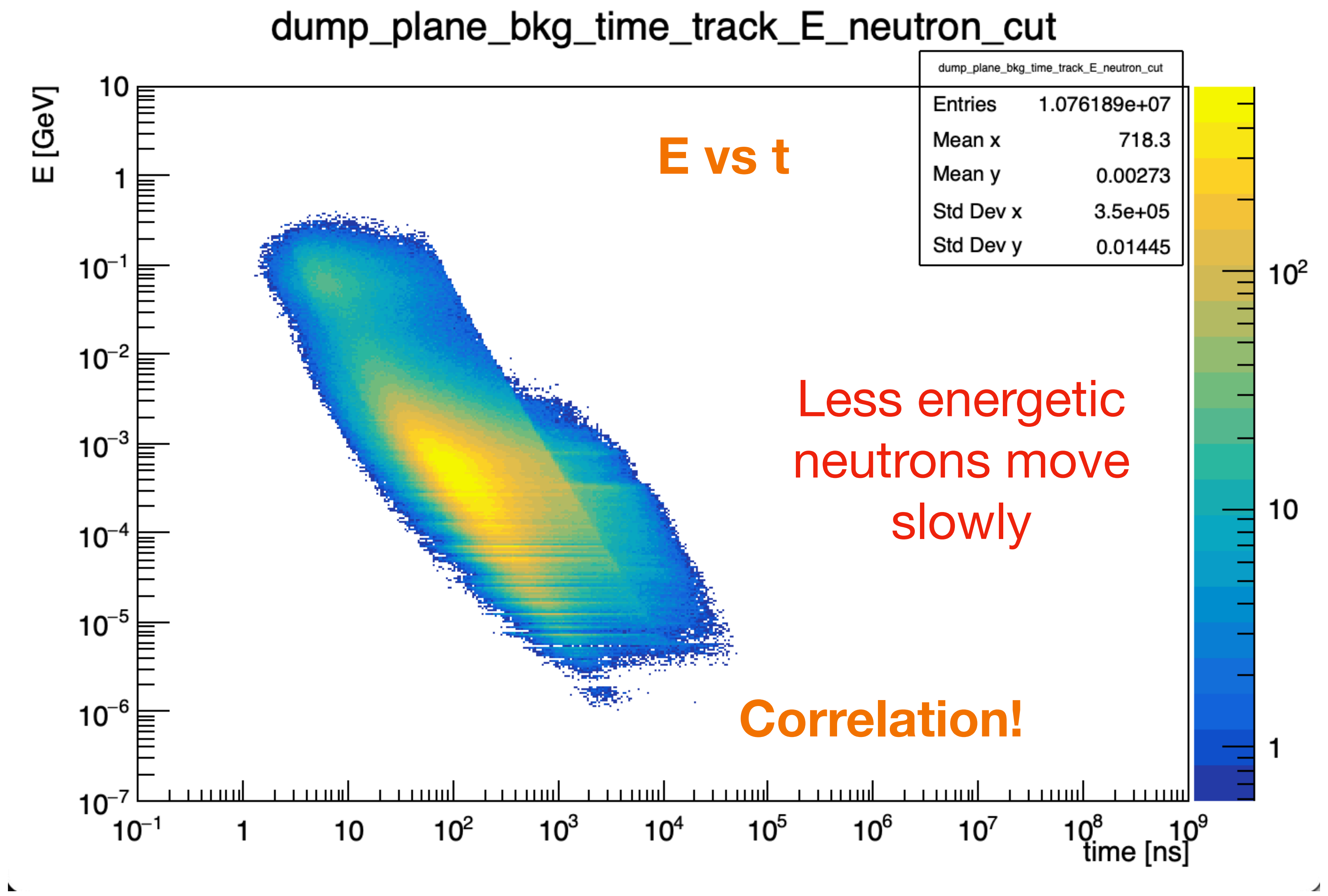


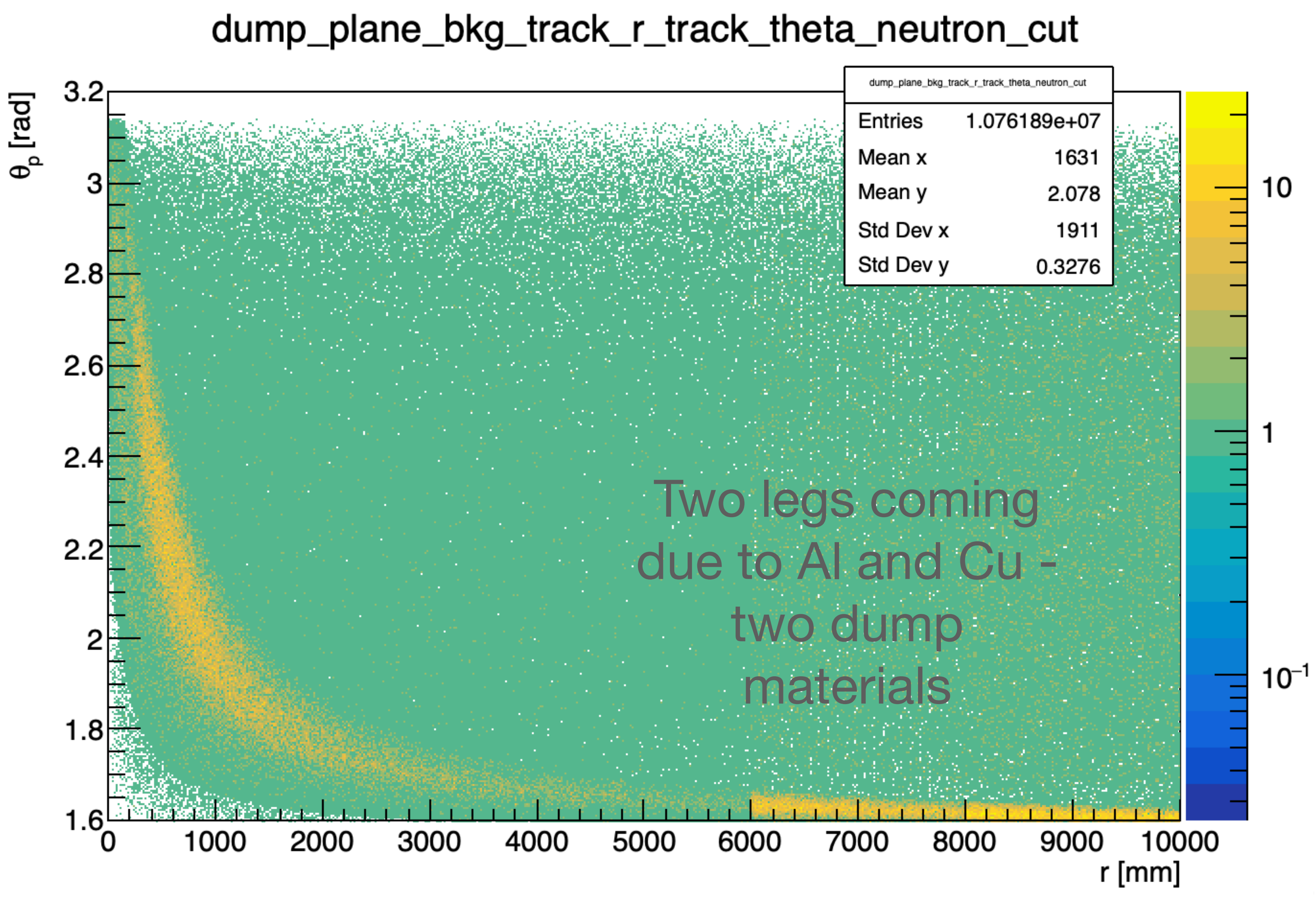
Baseline distribution plots for dump only geometry

Baseline distributions from FullSim: neutron at sampling surface

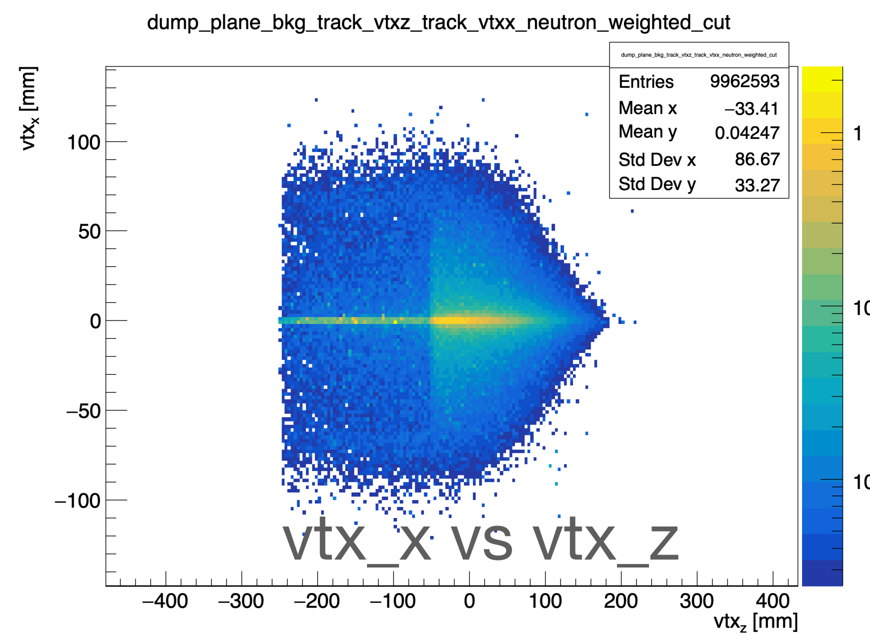






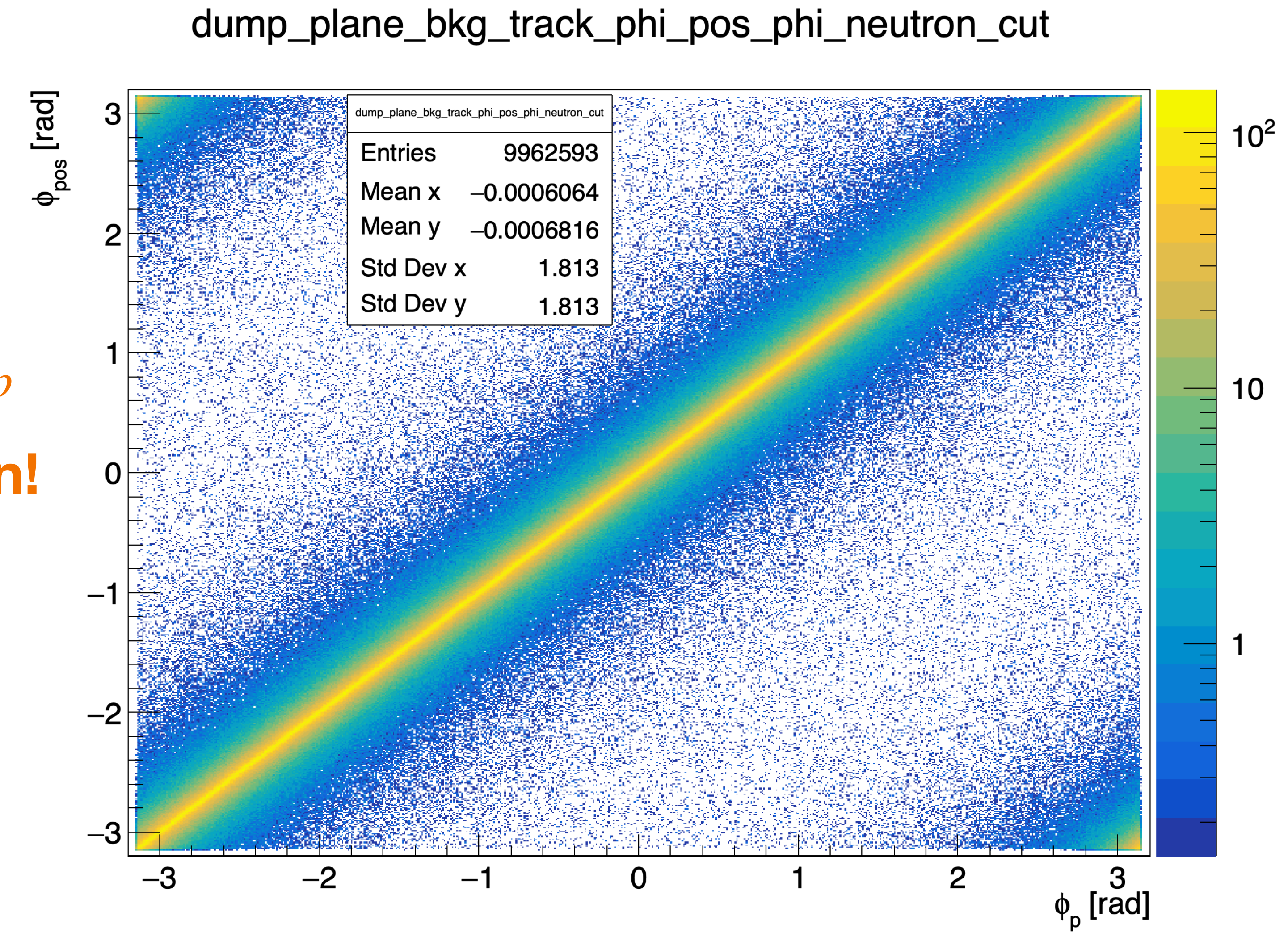


θ_p vs r Correlation!



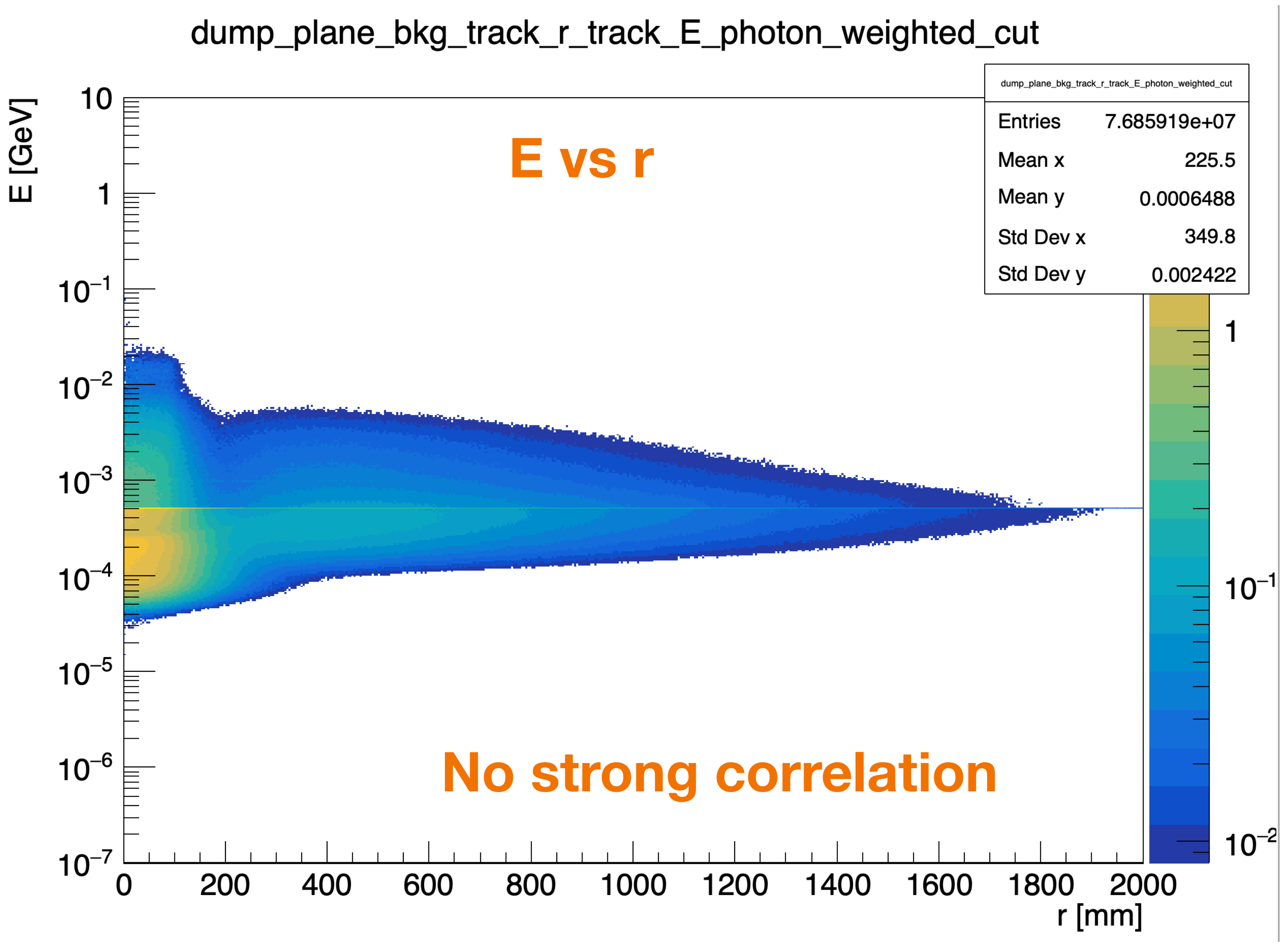
ϕ_{pos} vs ϕ_p

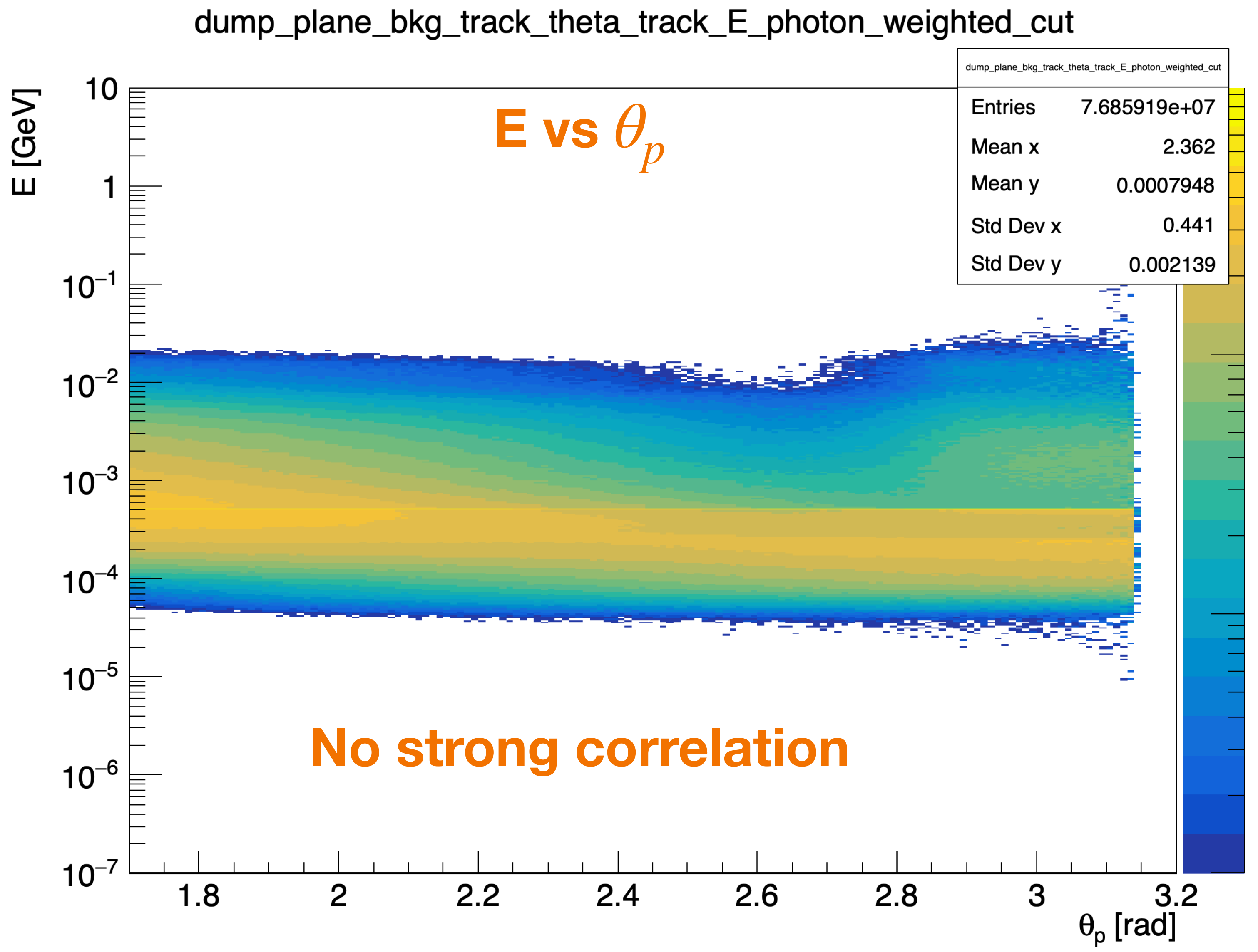
Correlation!

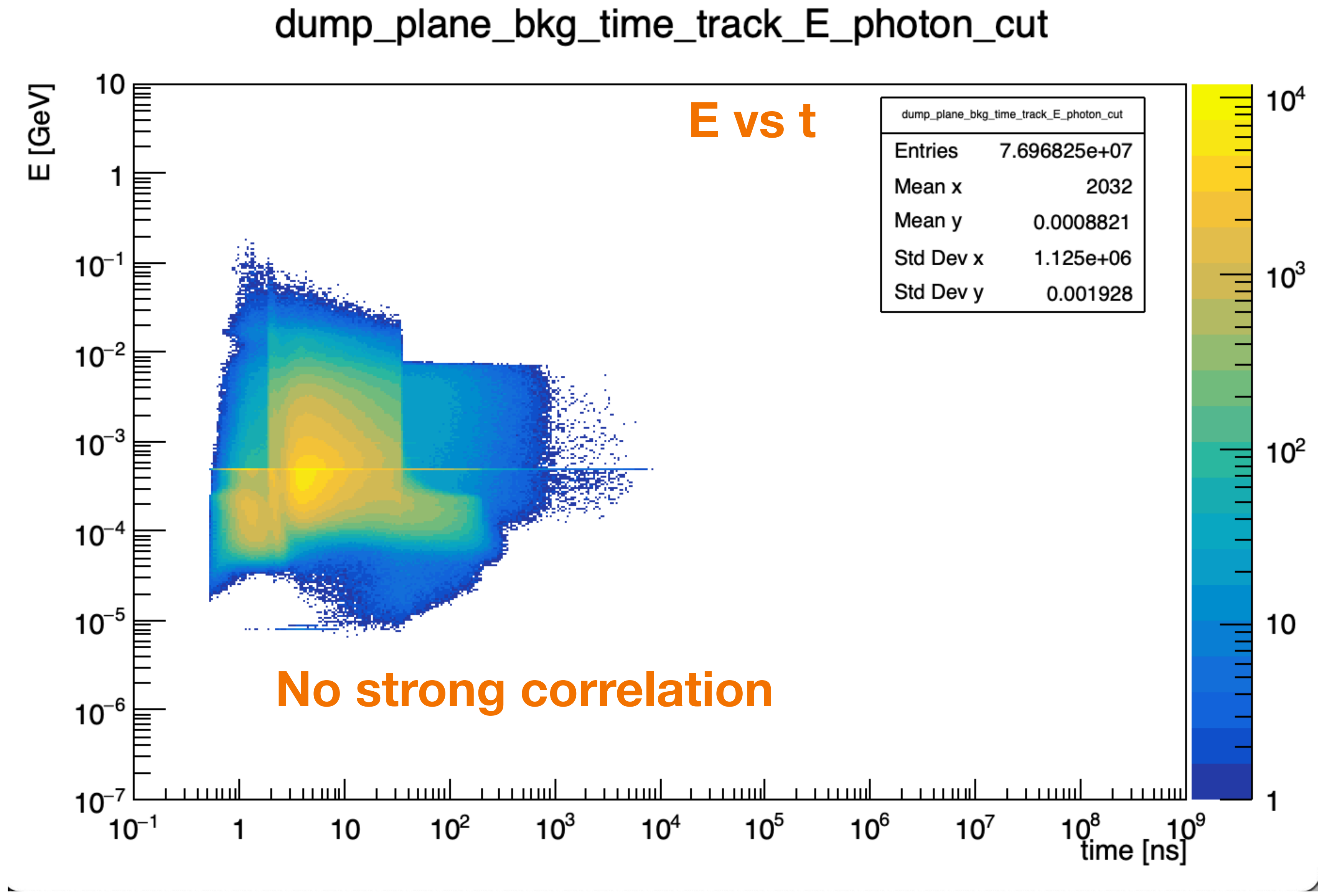


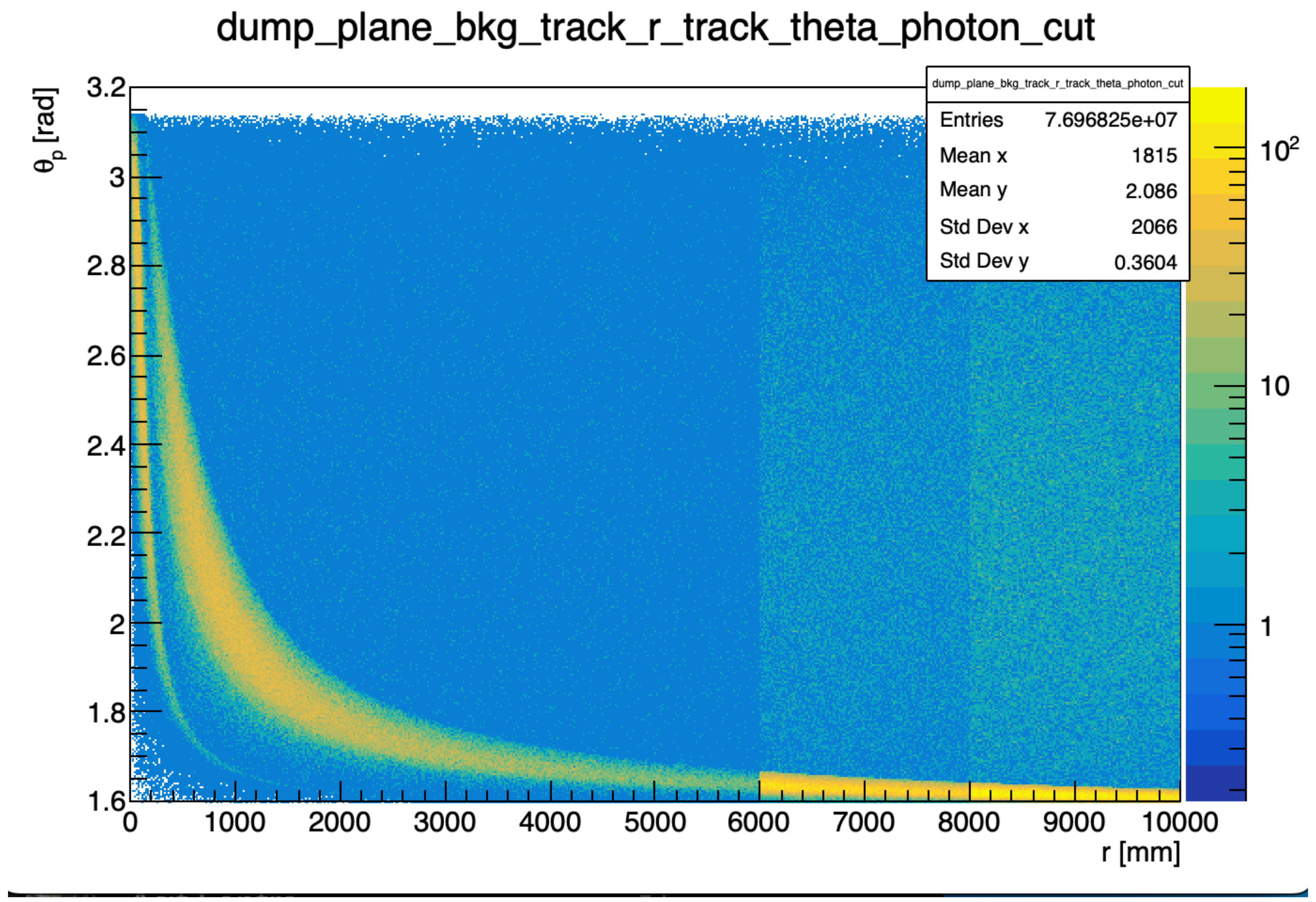
- ★θ_p and r, E and t, ϕ_p and ϕ_{pos} are correlated.
- ★E and r, E and θ_p are not correlated.
- ★To parametrize the neutrons from dump, we can utilize
  - ★Correlation of θ_p and r
  - ★Correlation of E and t
  - ★Correlation of ϕ_p and ϕ_{pos}

Baseline distributions from FullSim: photon at sampling surface

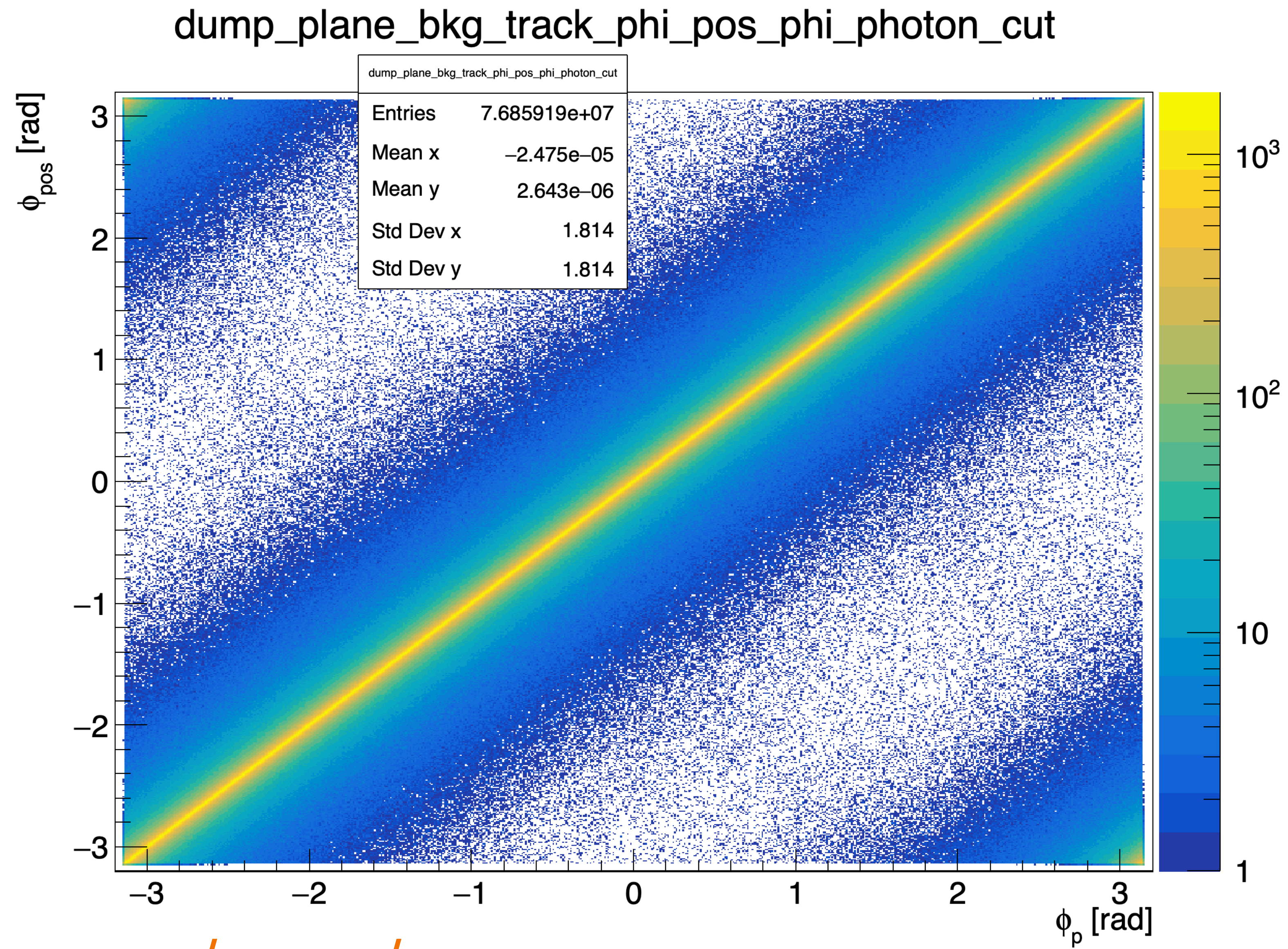








θ_p vs r Correlation!

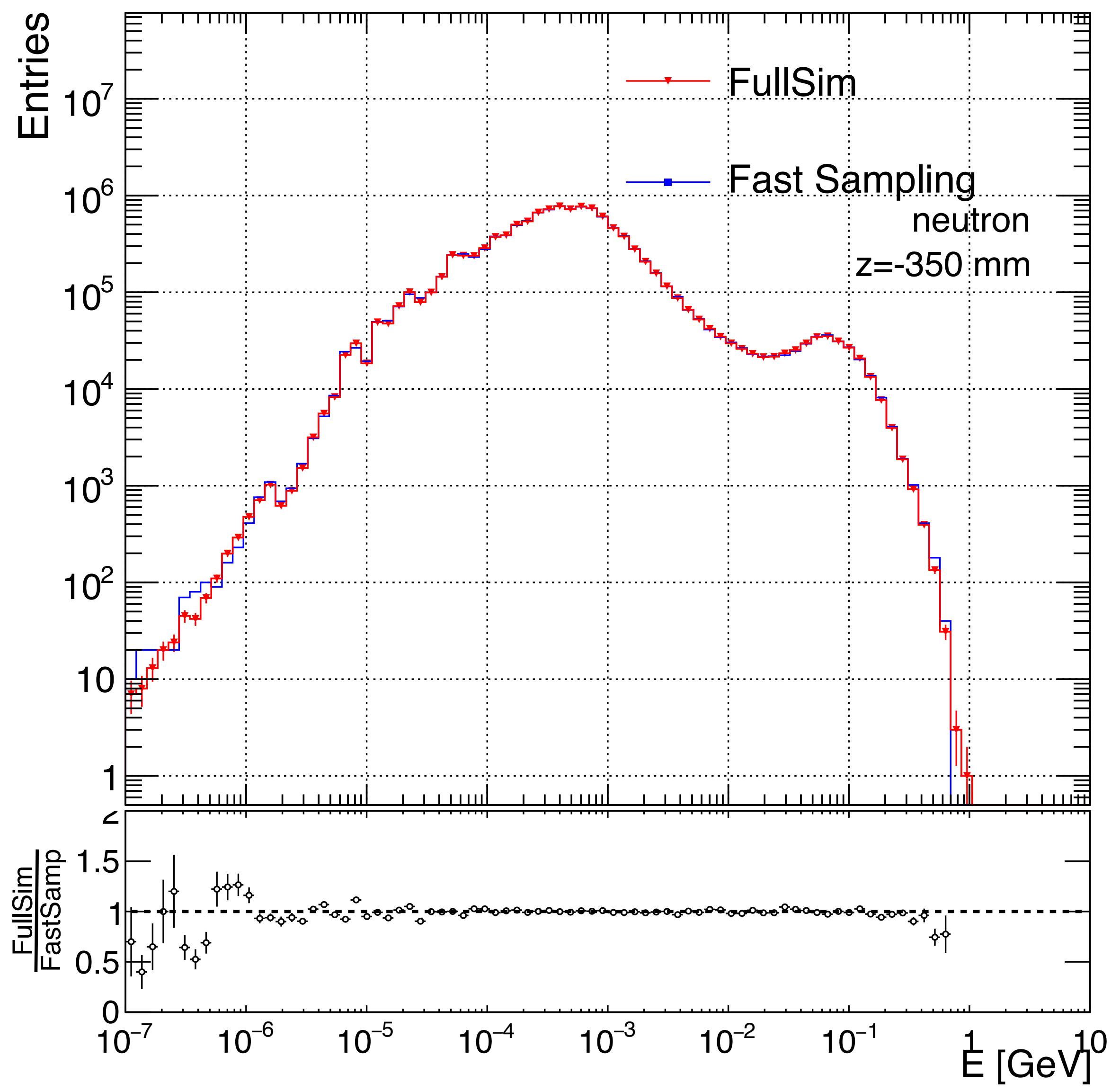


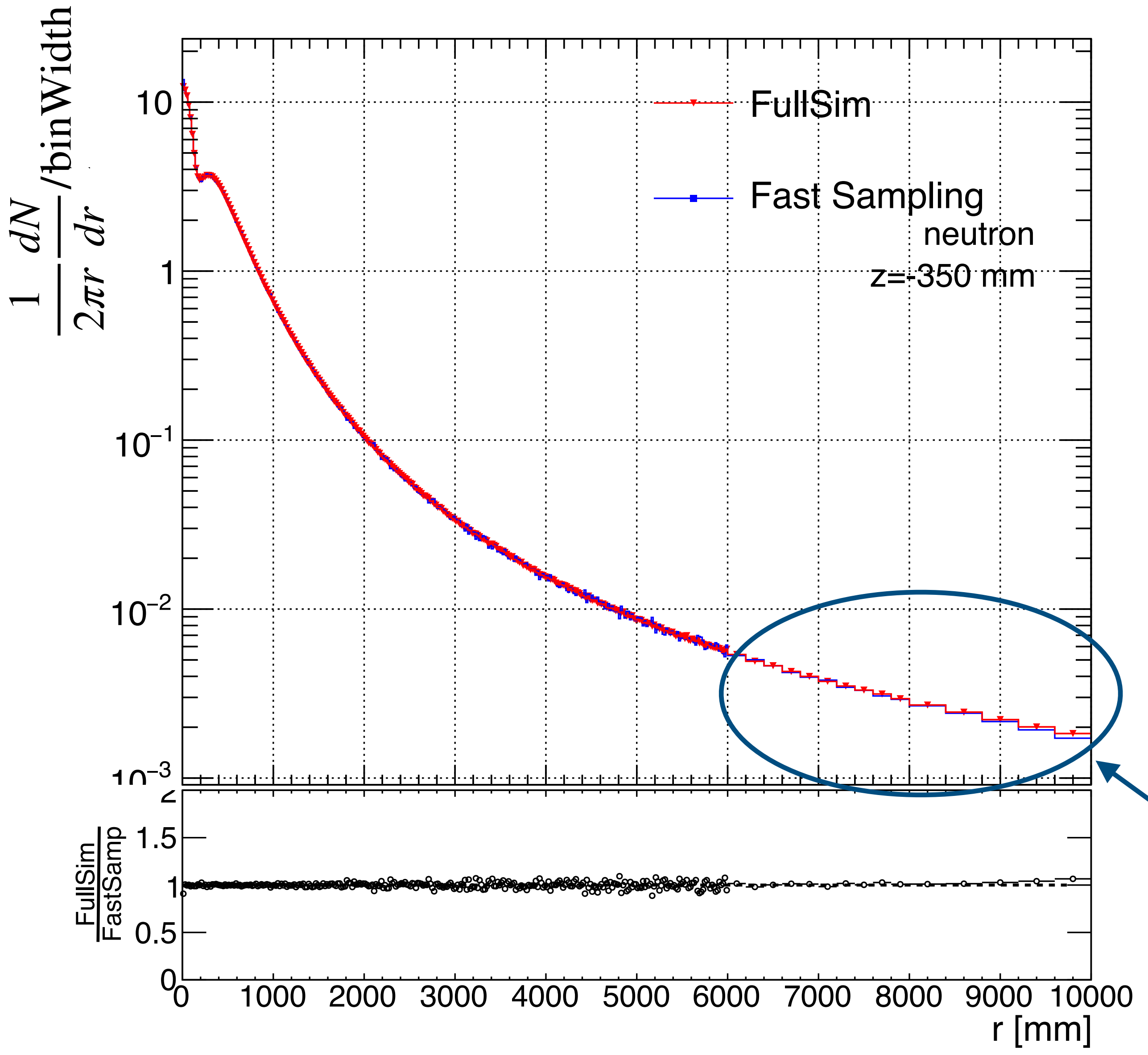
ϕ_{pos} vs ϕ_p
Correlation!

- ★θ_p and r, ϕ_p and ϕ_{pos} are correlated.
- ★E and r, E and θ_p are not correlated.
- ★To parametrize the neutrons from dump, we can utilize
  - ★Correlation of θ_p and r
  - ★Correlation of ϕ_p and $\phi_{\rm pos}$
- ★Time and energy are generated from 1D timing distribution of photon (in backup).

Comparison of FullSim and Fast Sampling distributions from histograms at the sampling surface

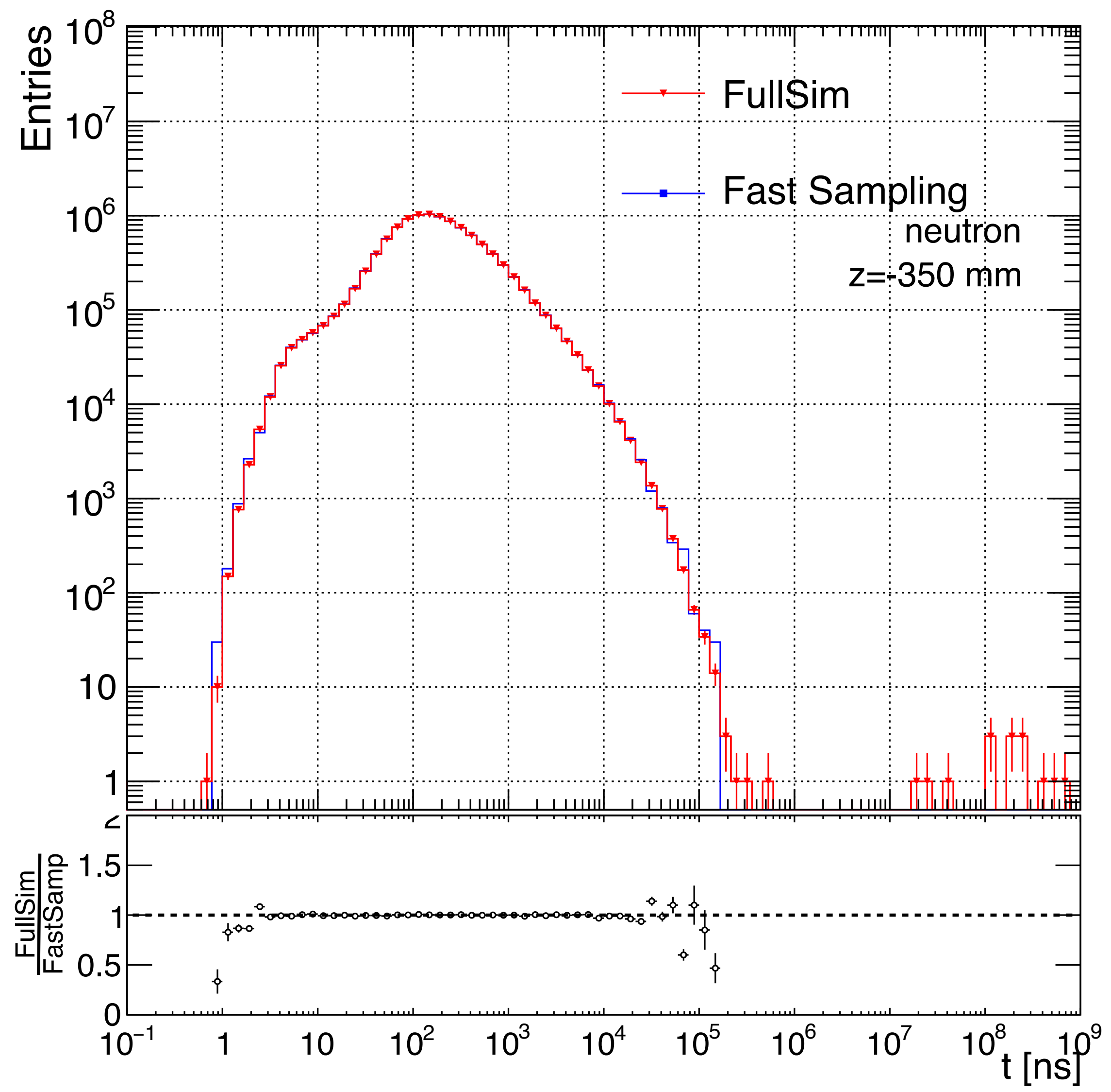
Comparison of FullSim and Fast Sampling distributions at the sampling surface: neutron

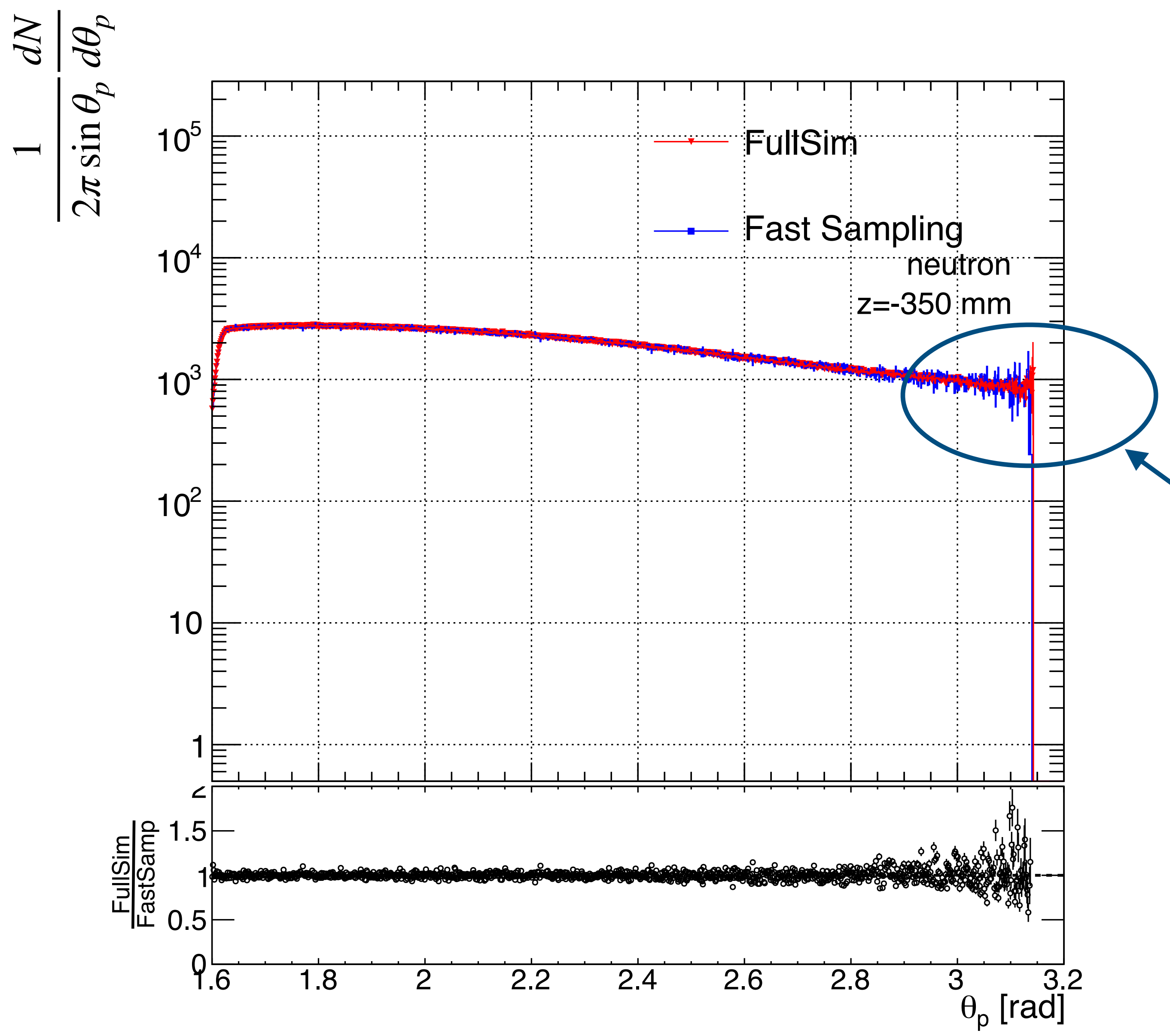




Variable binning

- ★Fast Sampling distributions are those solely prepared from FullSim histograms.
- ★They are not processed by Geant4.
  - ★These are what fed to Geant4 for FastSim preparation.

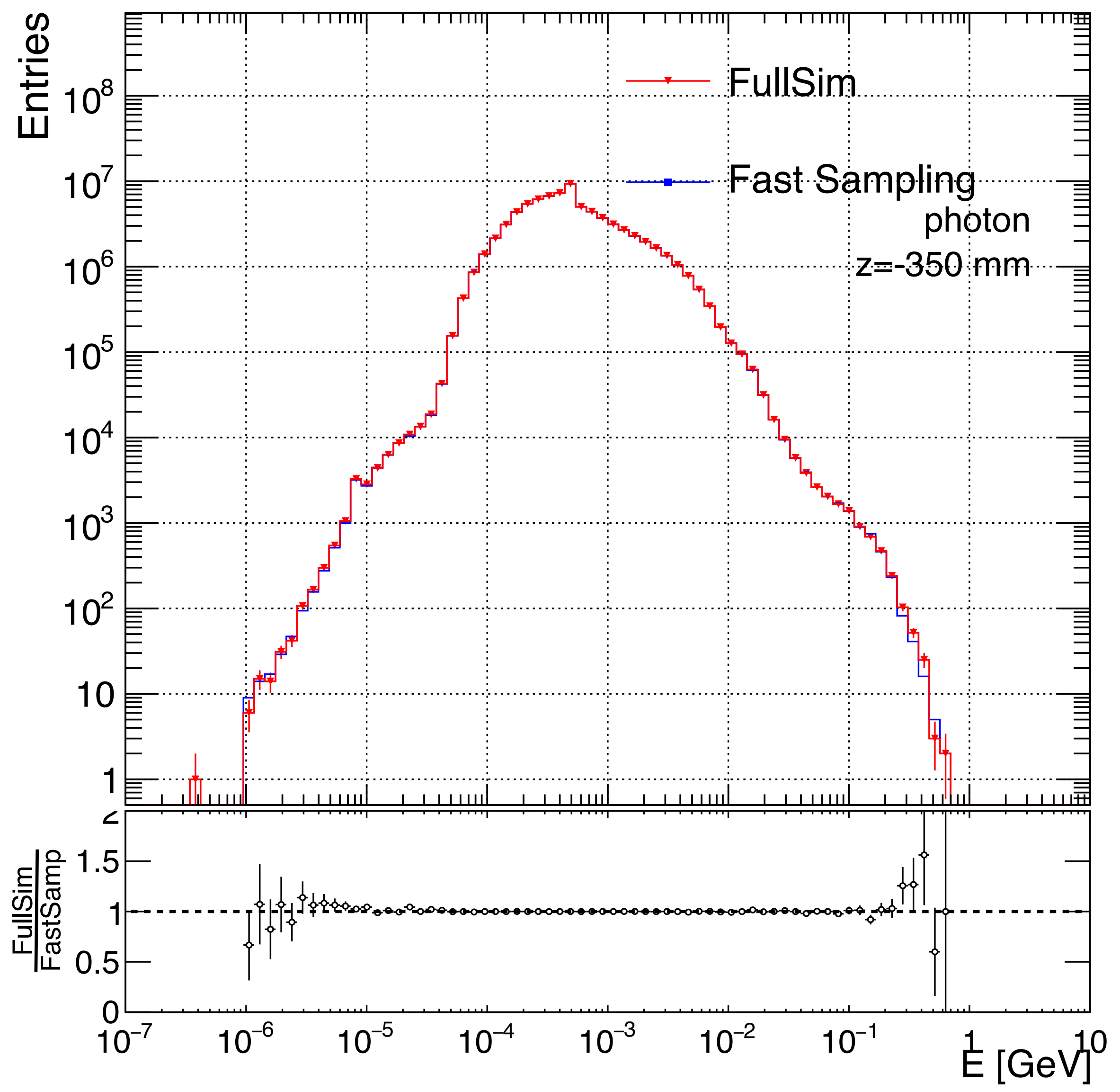


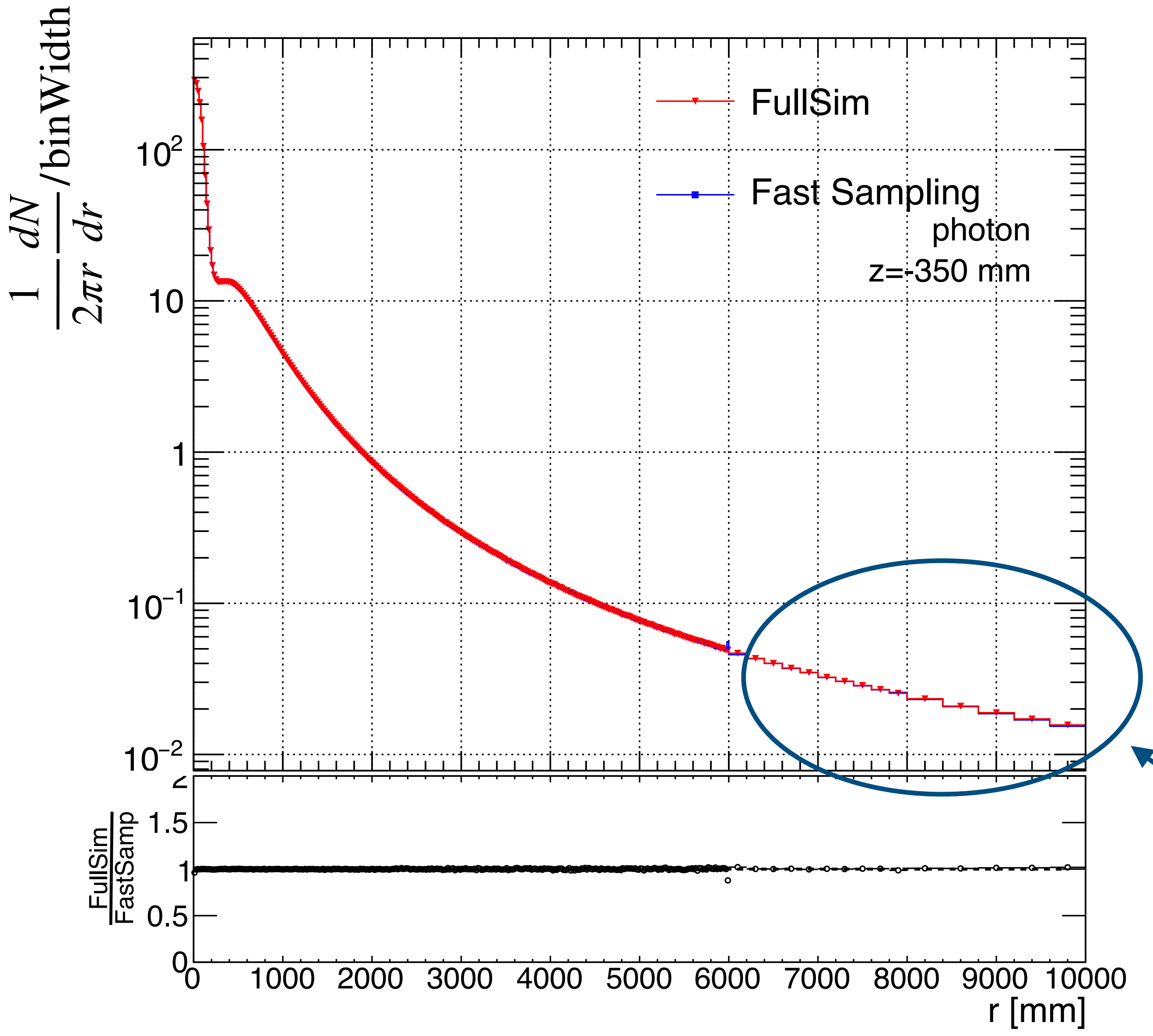


Slight wiggle for very backward particles

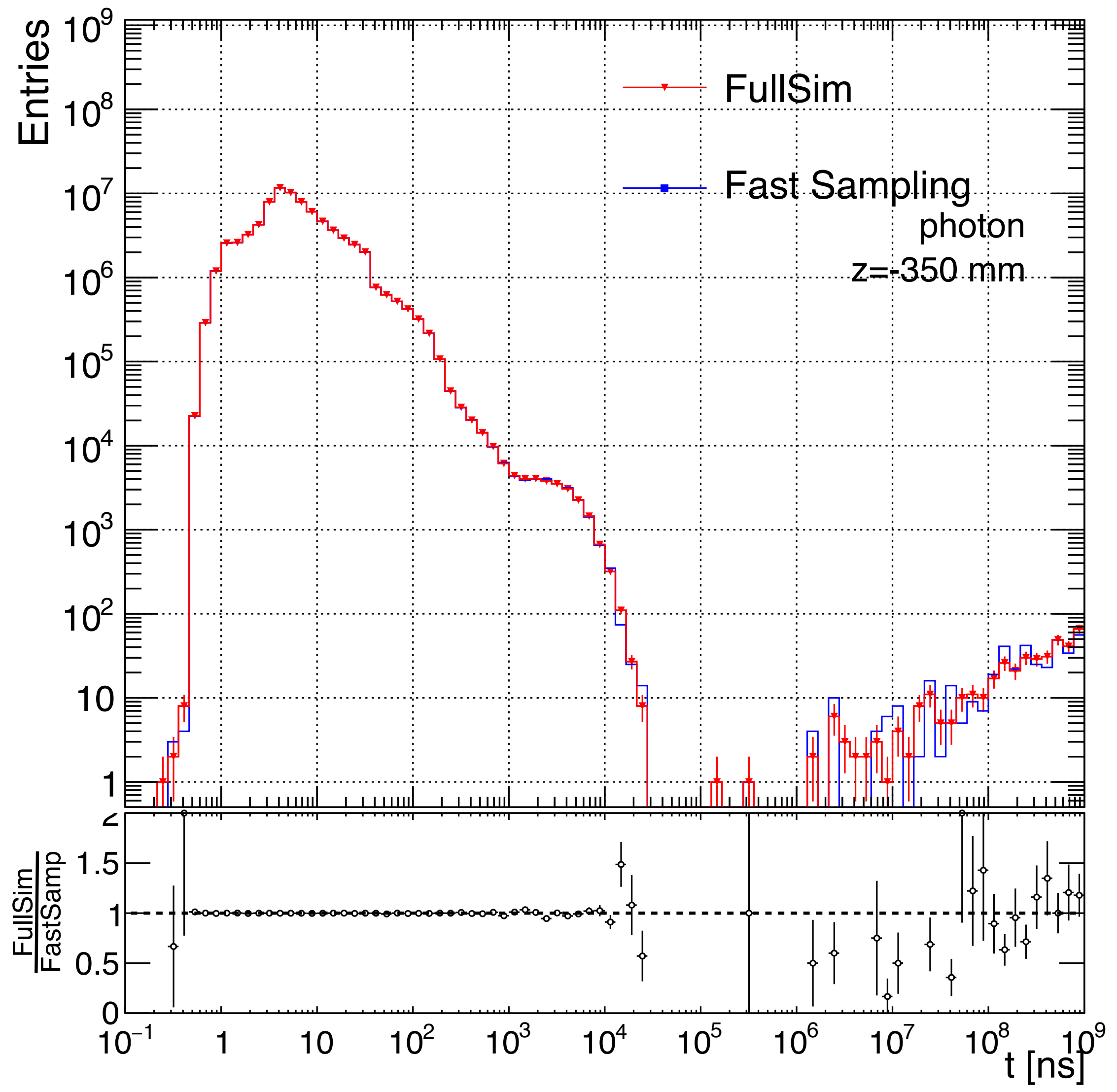
- ★Comparison of distribution at sampling surface for neutrons
  - ★This is the point from where the FastSim distributions were created.
  - ★Agreement is very good within the statistics.
  - ★The good modeling between FullSim and random generation is **a sanity check.**

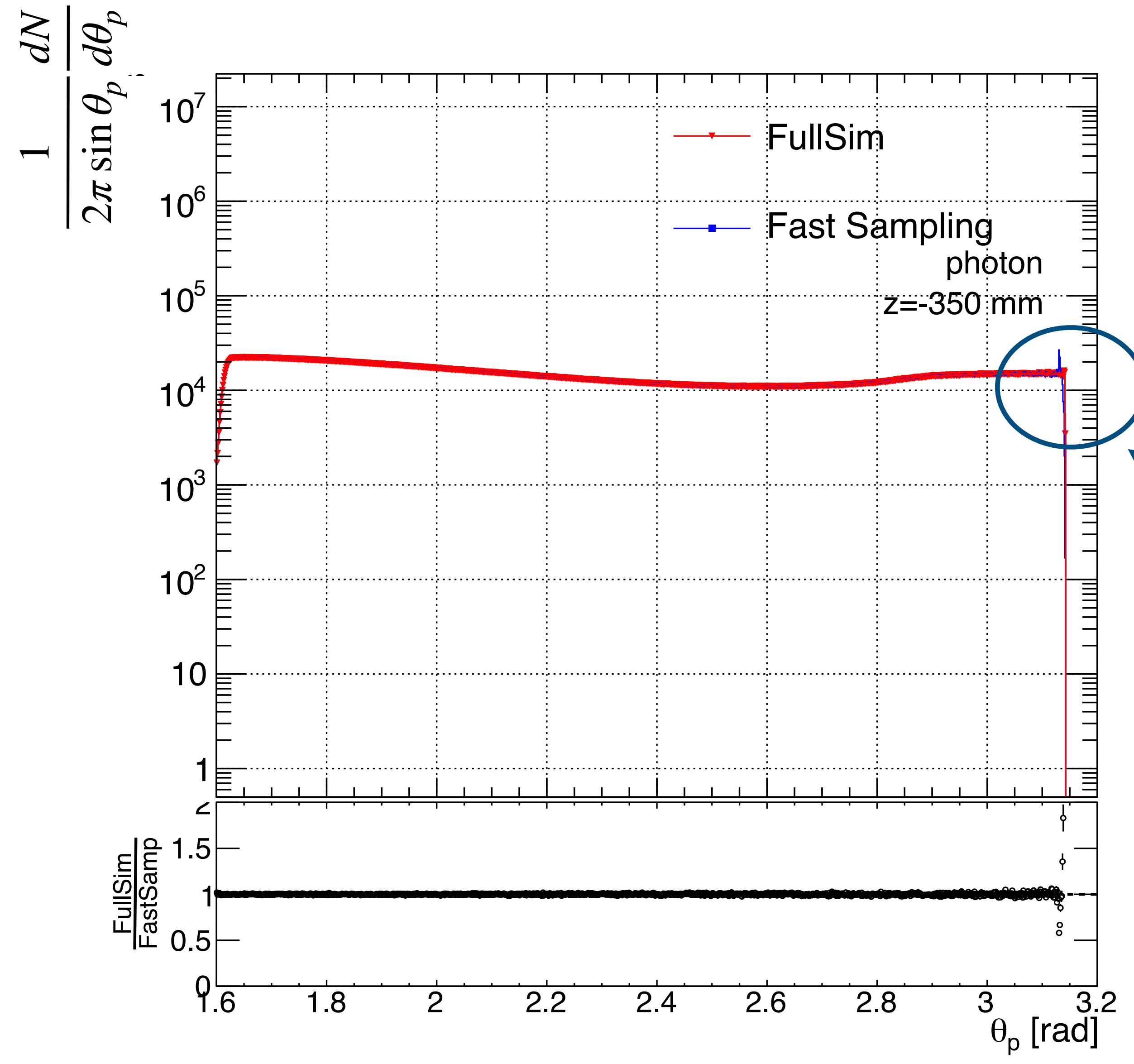
Comparison of FullSim and Fast Sampling distributions at the sampling surface: photon





Variable binning





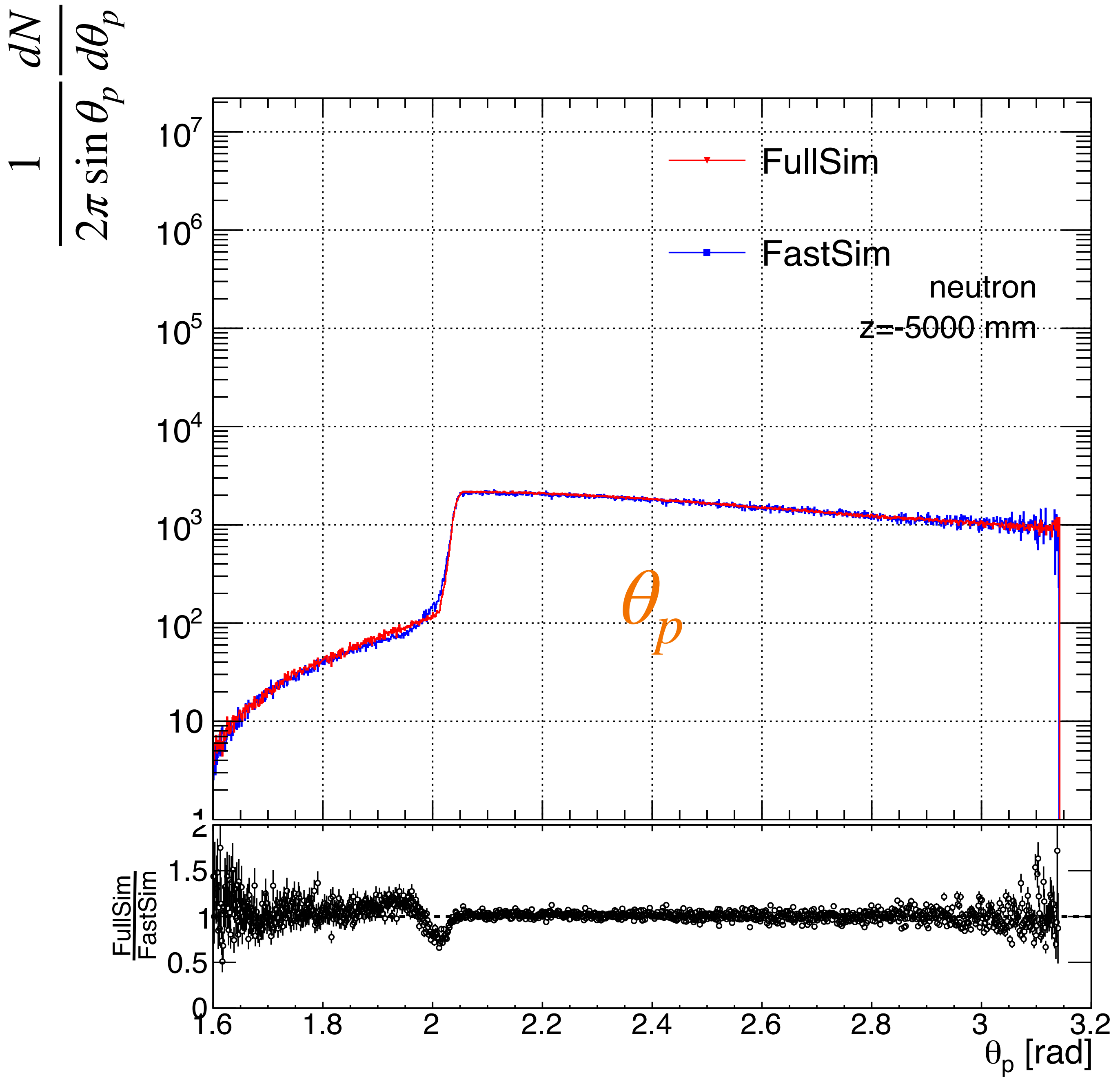
Slight wiggle for very backward particles

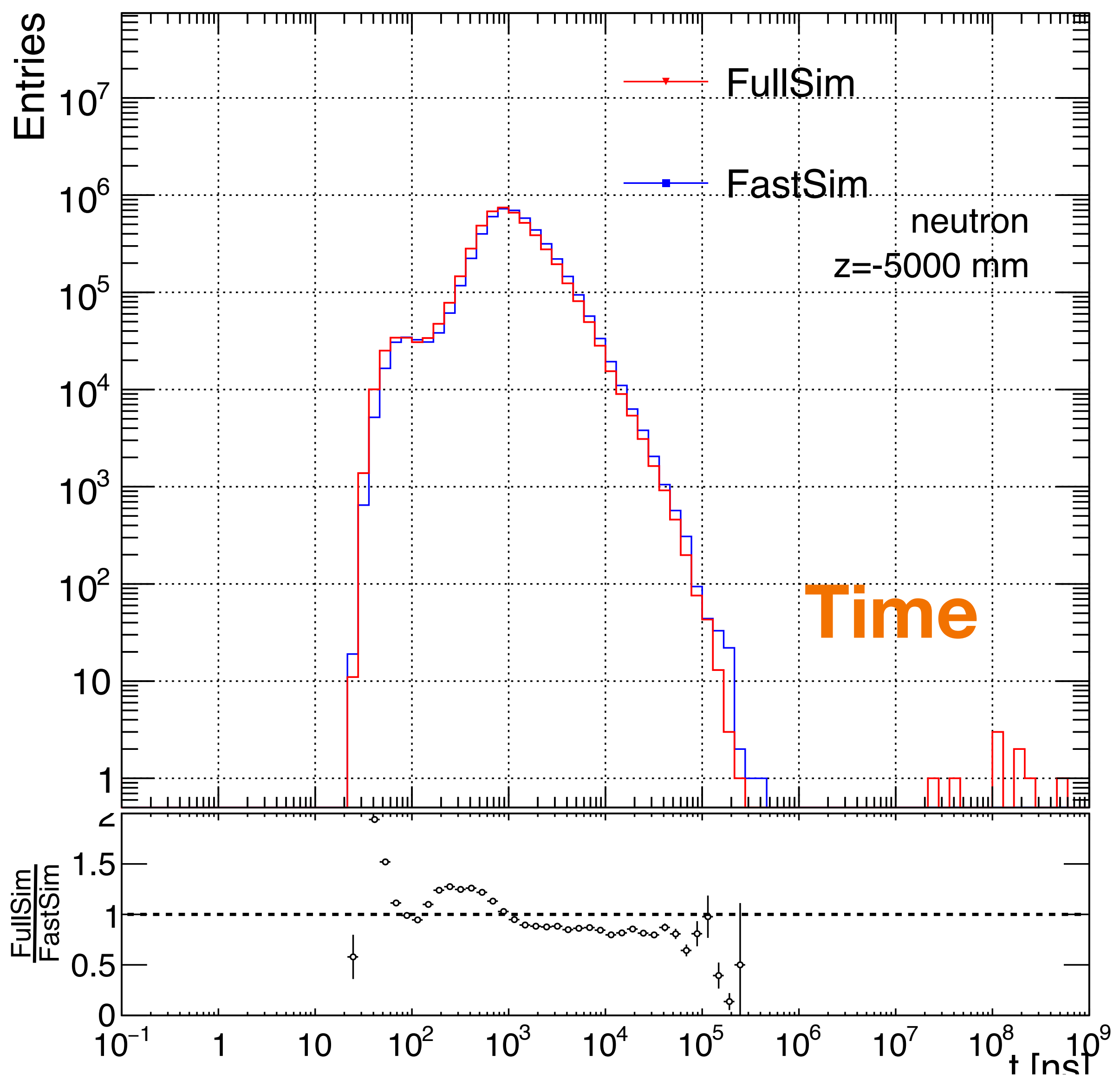
- ★Fast Sampling distributions are those solely prepared from FullSim histograms.
- ★They are not processed by Geant4.
  - ★These are what fed to Geant4 for FastSim preparation.

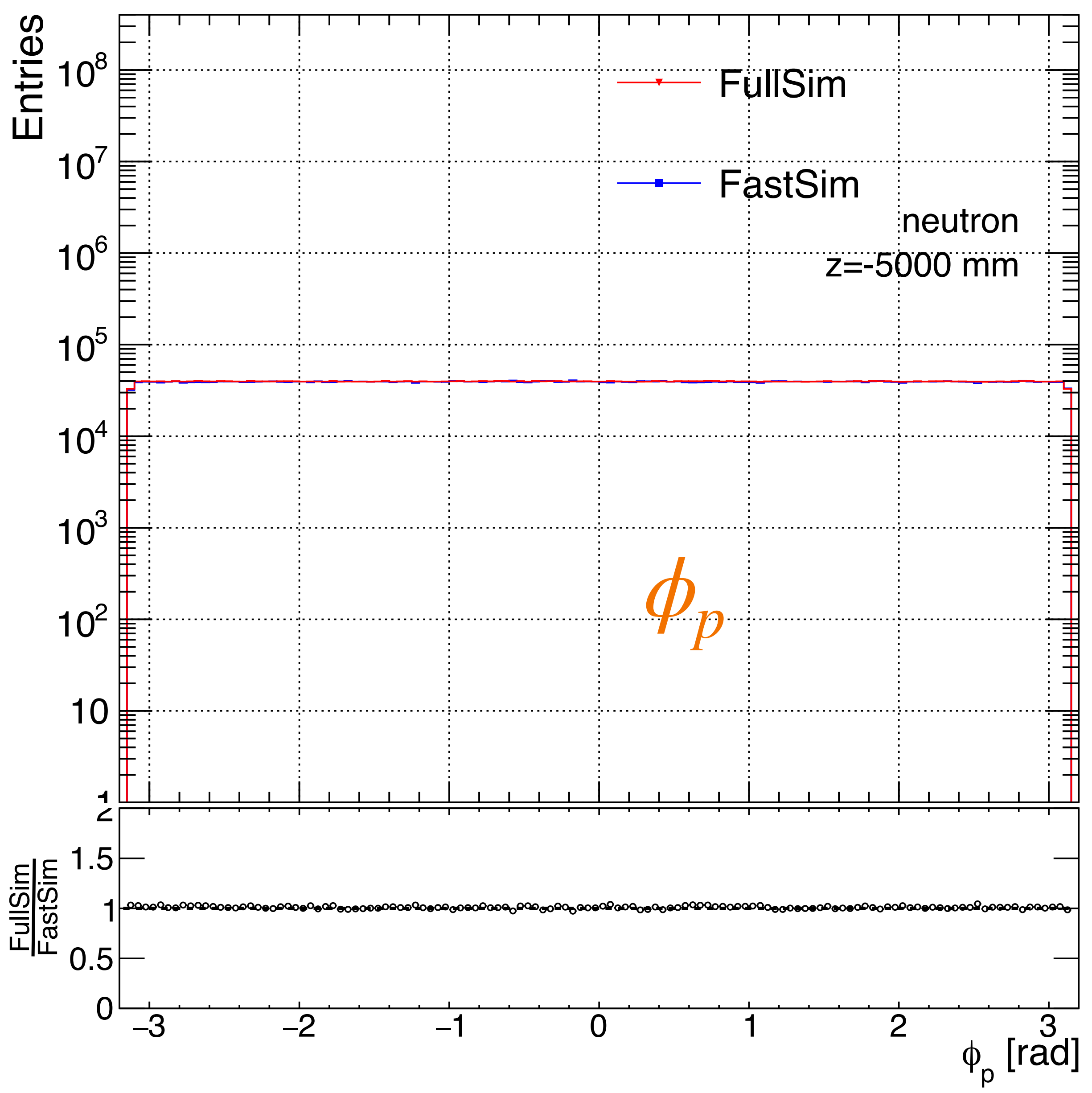
- ★Comparison of distribution at sampling surface for neutrons
  - ★This is the point from where the FastSim distributions were created.
  - ★Agreement is very good within the statistics.
  - ★The good modeling between FullSim and random generation is **a sanity check.**

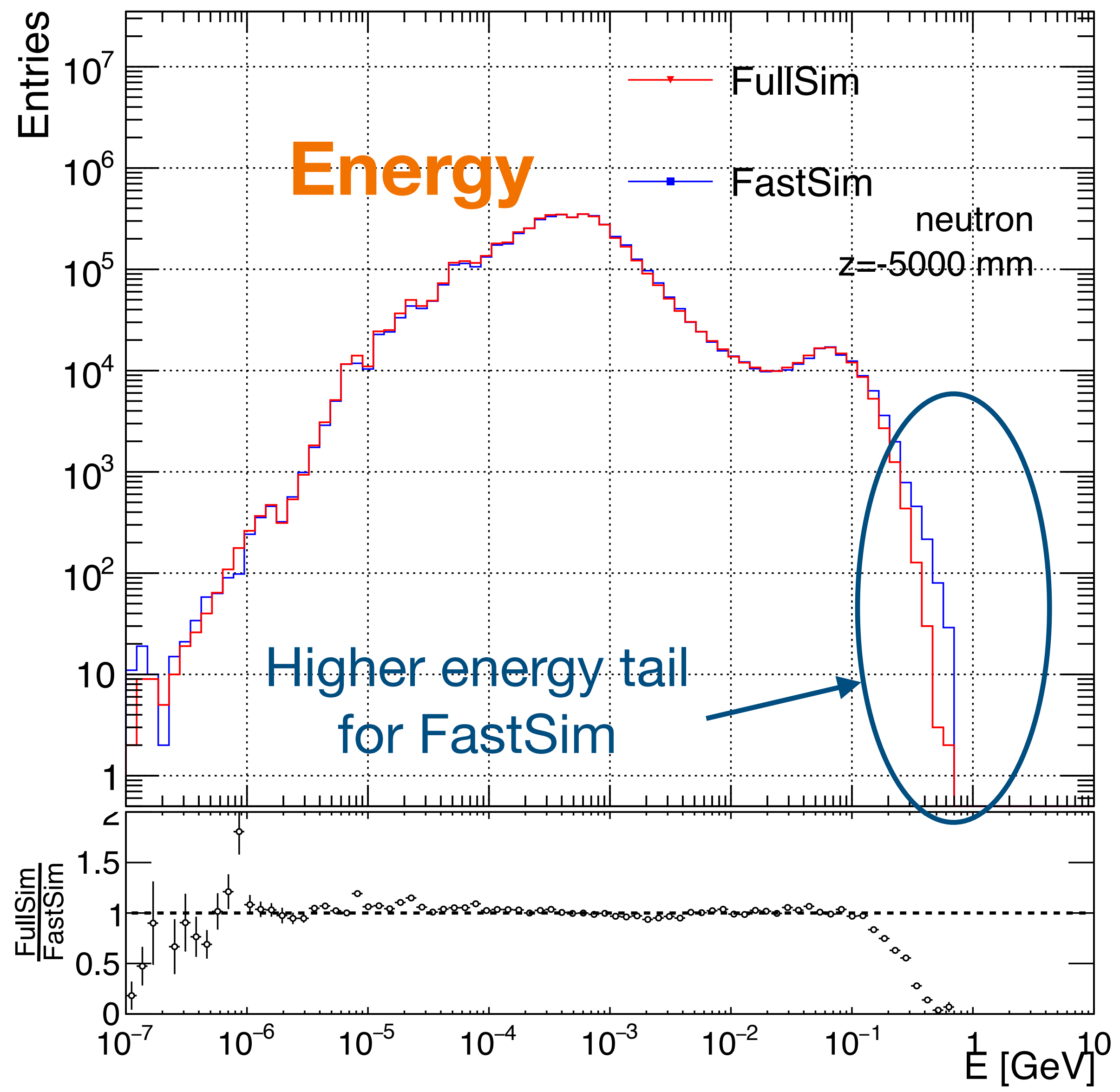
Comparison of FullSim and FastSim distributions at the test surface, z=-5000mm

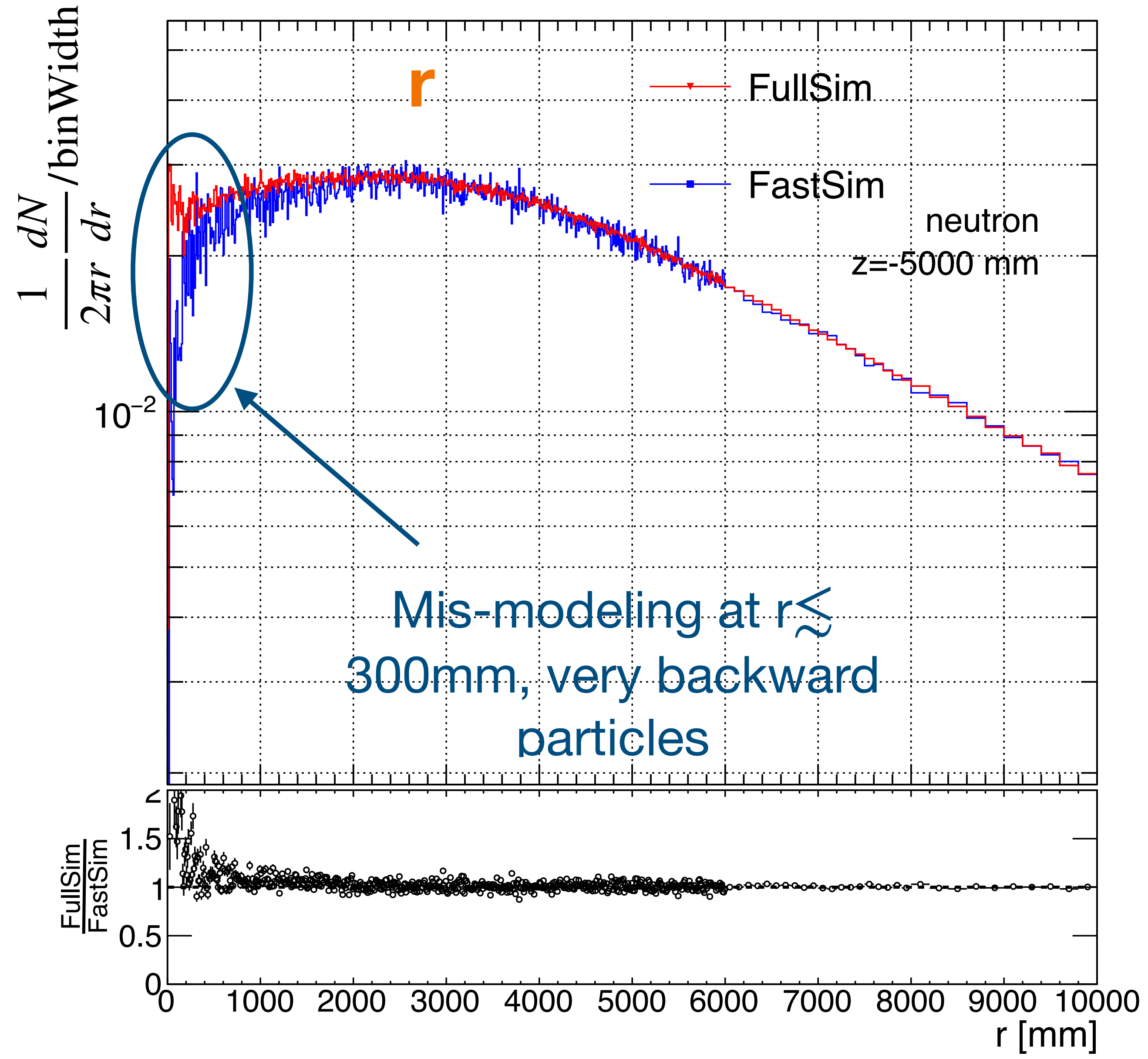
A few 1D distributions between FastSim and FullSim: neutron





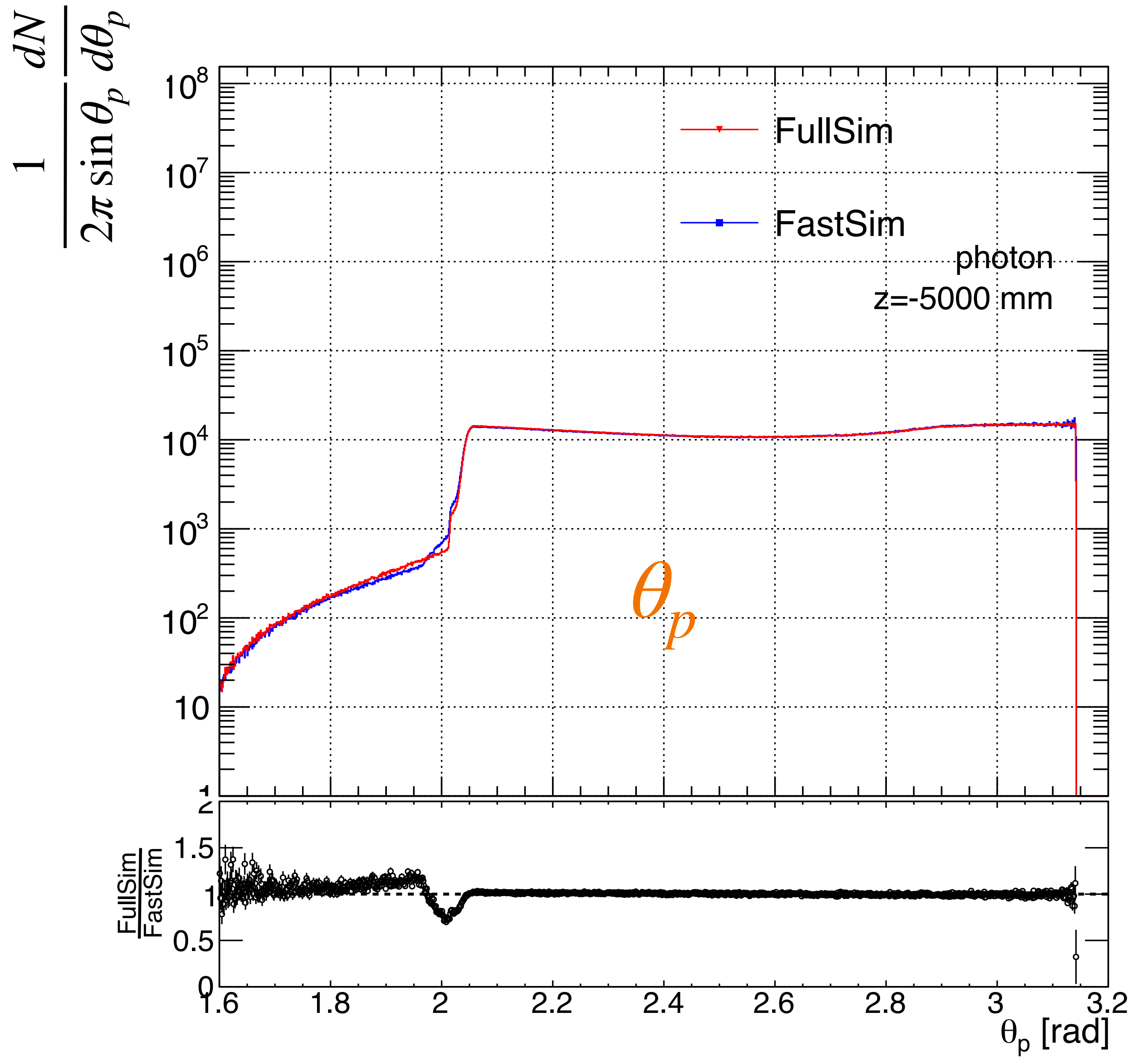


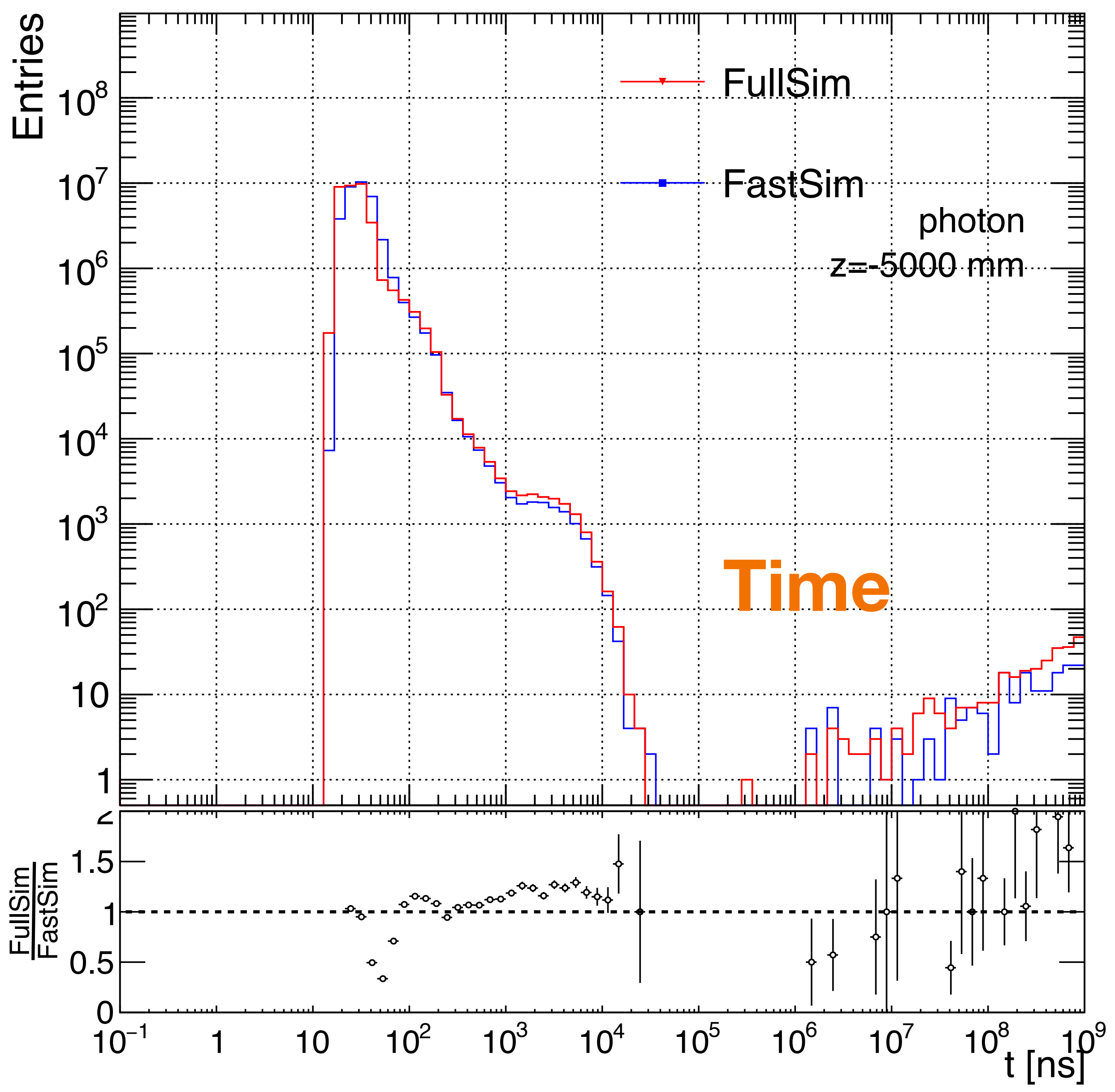


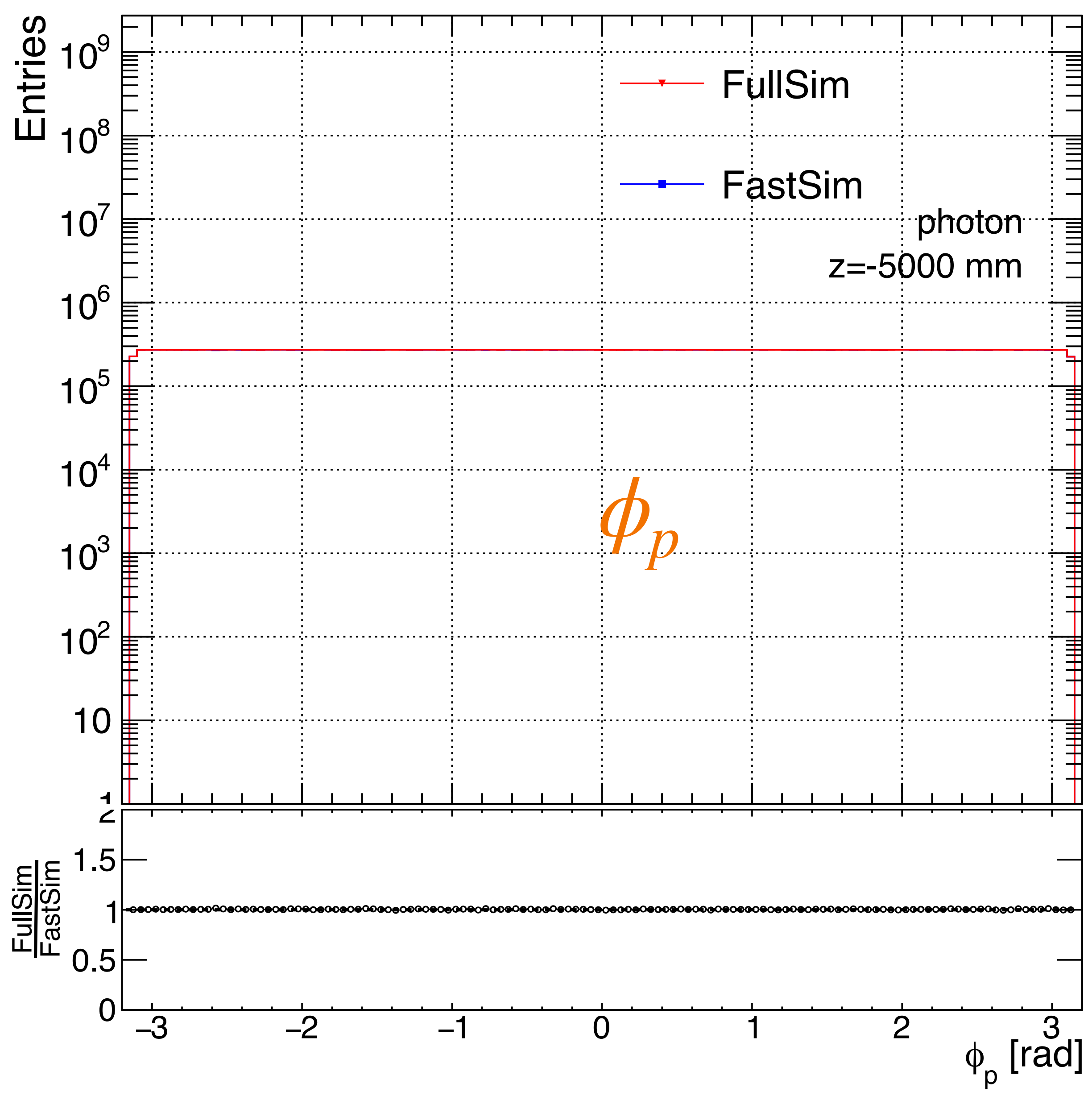


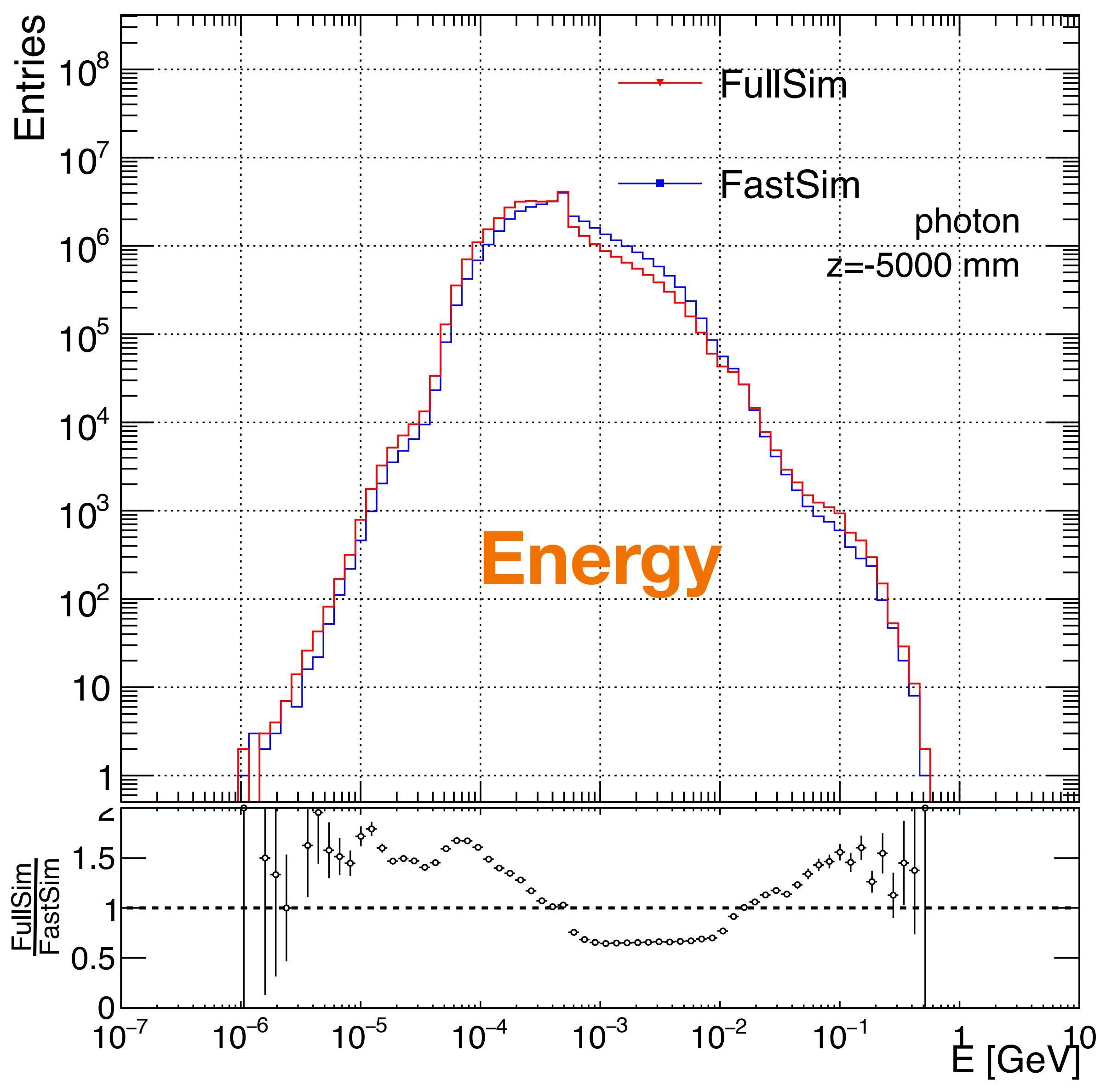
- ★Distributions are looked at **z=-5000mm**.
- ★FullSim and FastSim has comparable statistics.
- ★FullSim and FastSim distributions are matching quite well.
  - ★Higher energy tail for FastSim - not very concerning.
    - ★These neutrons are not very likely to generate shower in the calorimeter.
    - ★Neutrons are invisible in the tracker.
  - ★Mis-modeling in very backward particles ($r \lesssim 300$ mm at z=-5000mm).
    - ★This can be source of systematic uncertainty in FastSim.
    - ★Need to see what the situation is for LUXE geometry.

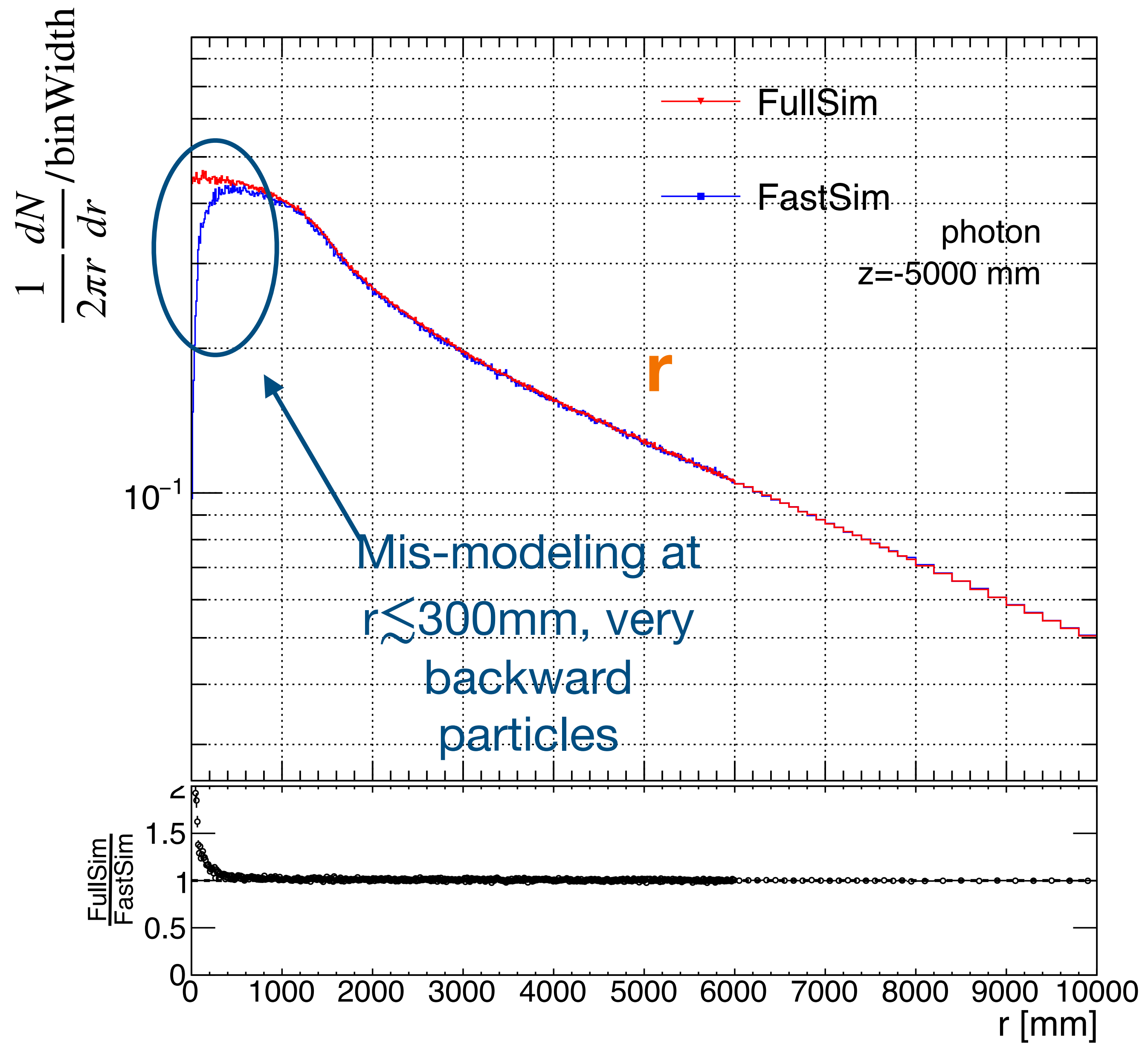
A few 1D distributions between FastSim and FullSim: photon









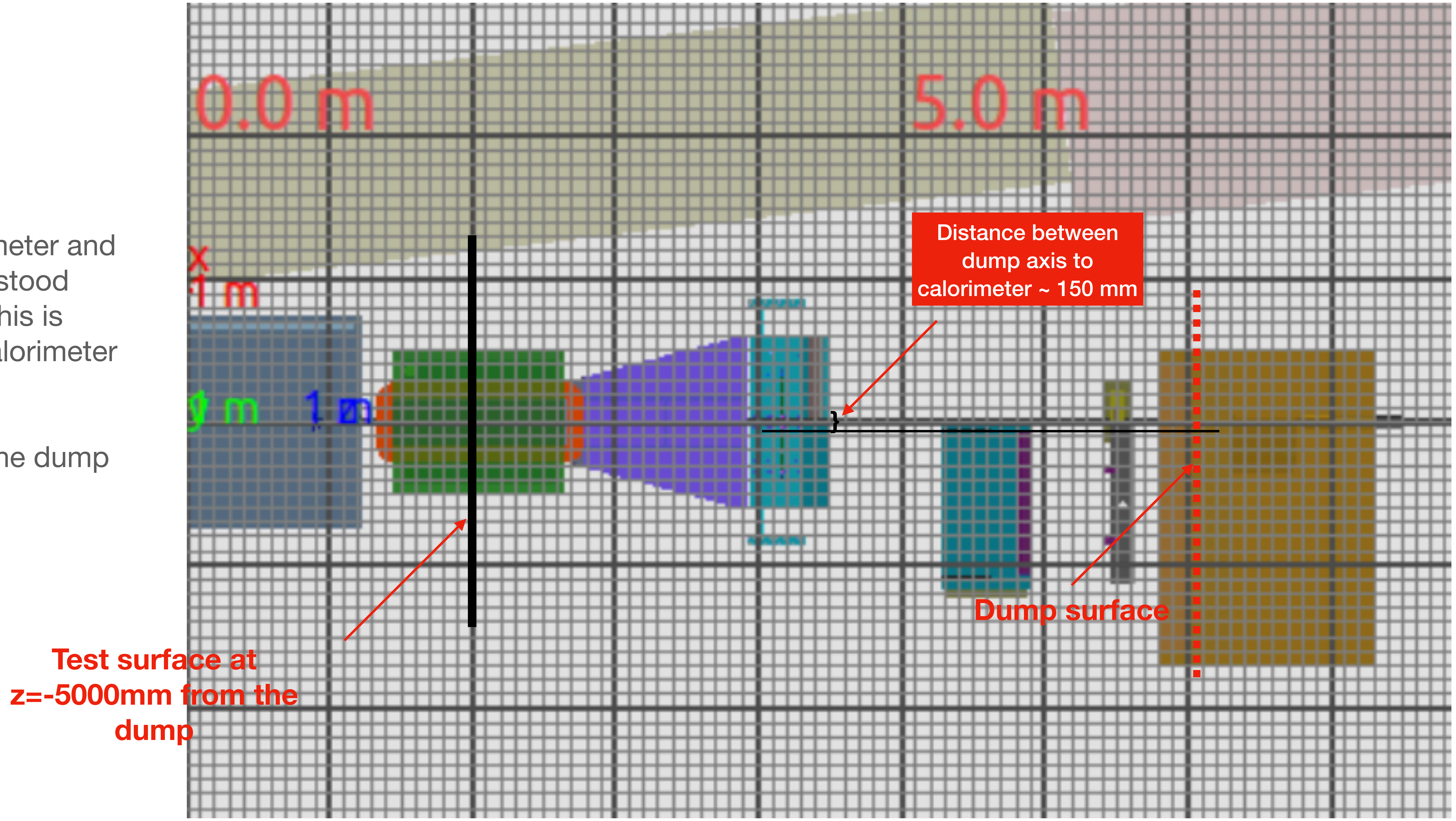


- ★Distributions are looked at **z=-5000mm**.
- ★FullSim and FastSim has comparable statistics.
- ★FullSim and FastSim distributions are comparable.
  - ★Mis-modeling in very backward particles ($r \lesssim 300$ mm at z=-5000mm).
  - ★This can be source of systematic uncertainty in FastSim.
    - ★Need to see what the situation is for LUXE geometry.

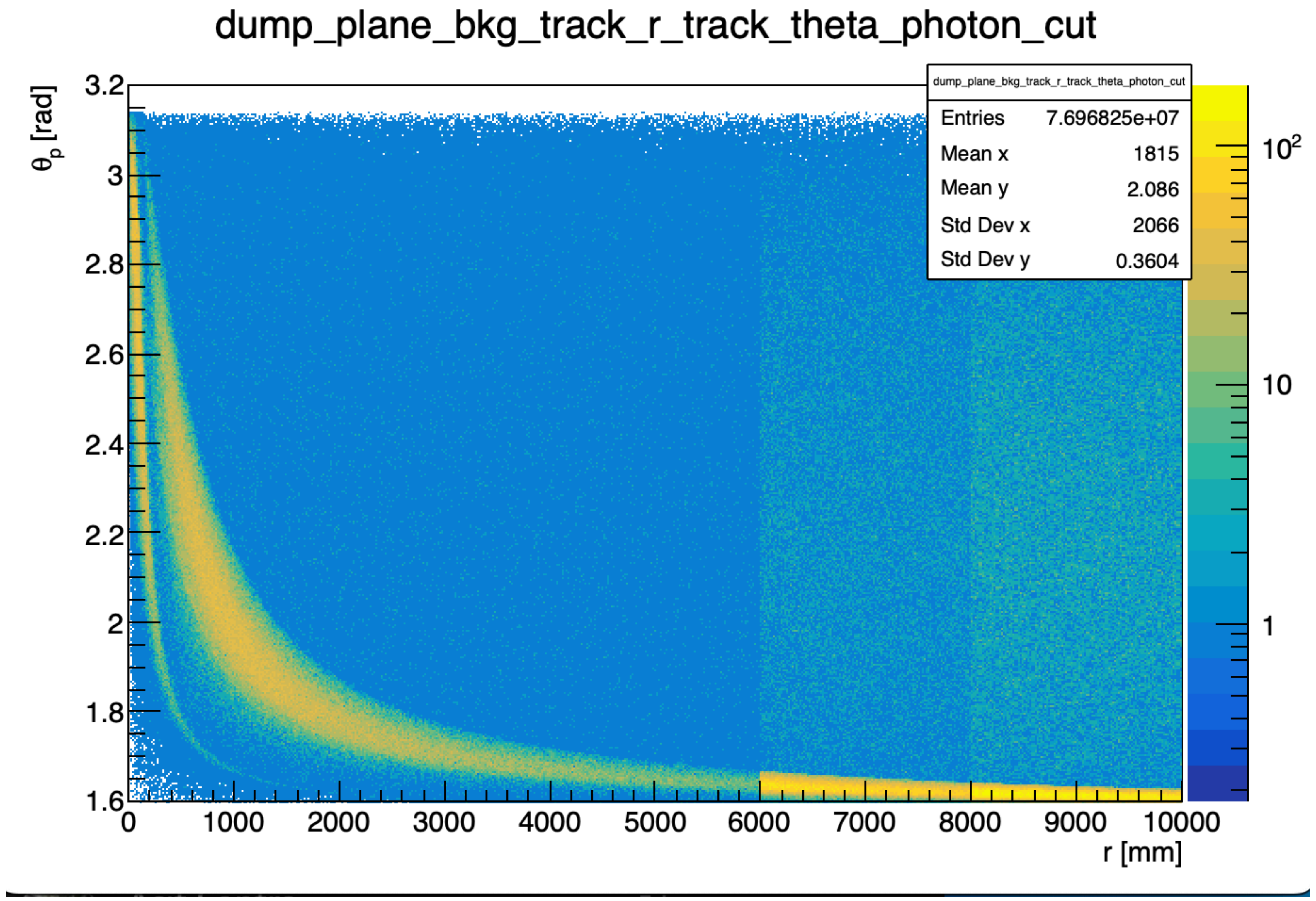
Dump geometry translated to LUXE

★The effect of mis-modeling on calorimeter and LUXE tracker cannot be readily understood from z=-5000 mm testing surface as this is quite far from the actual position of calorimeter or tracker.

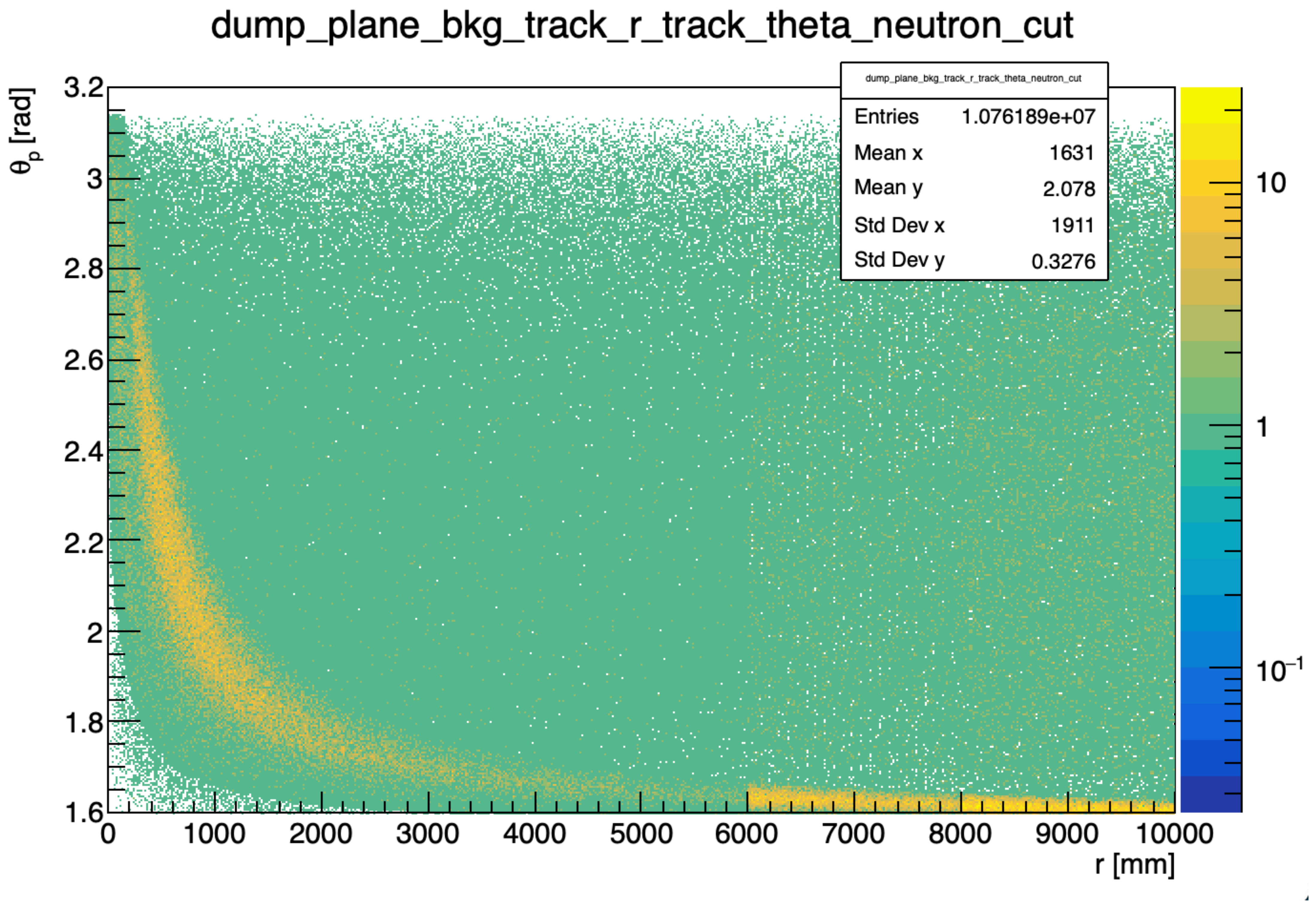
- ★We need to keep in mind that the calorimeter is 150mm away from the dump axis.



r vs θ_p distributions without phase space weight: FullSim at the sampling surface

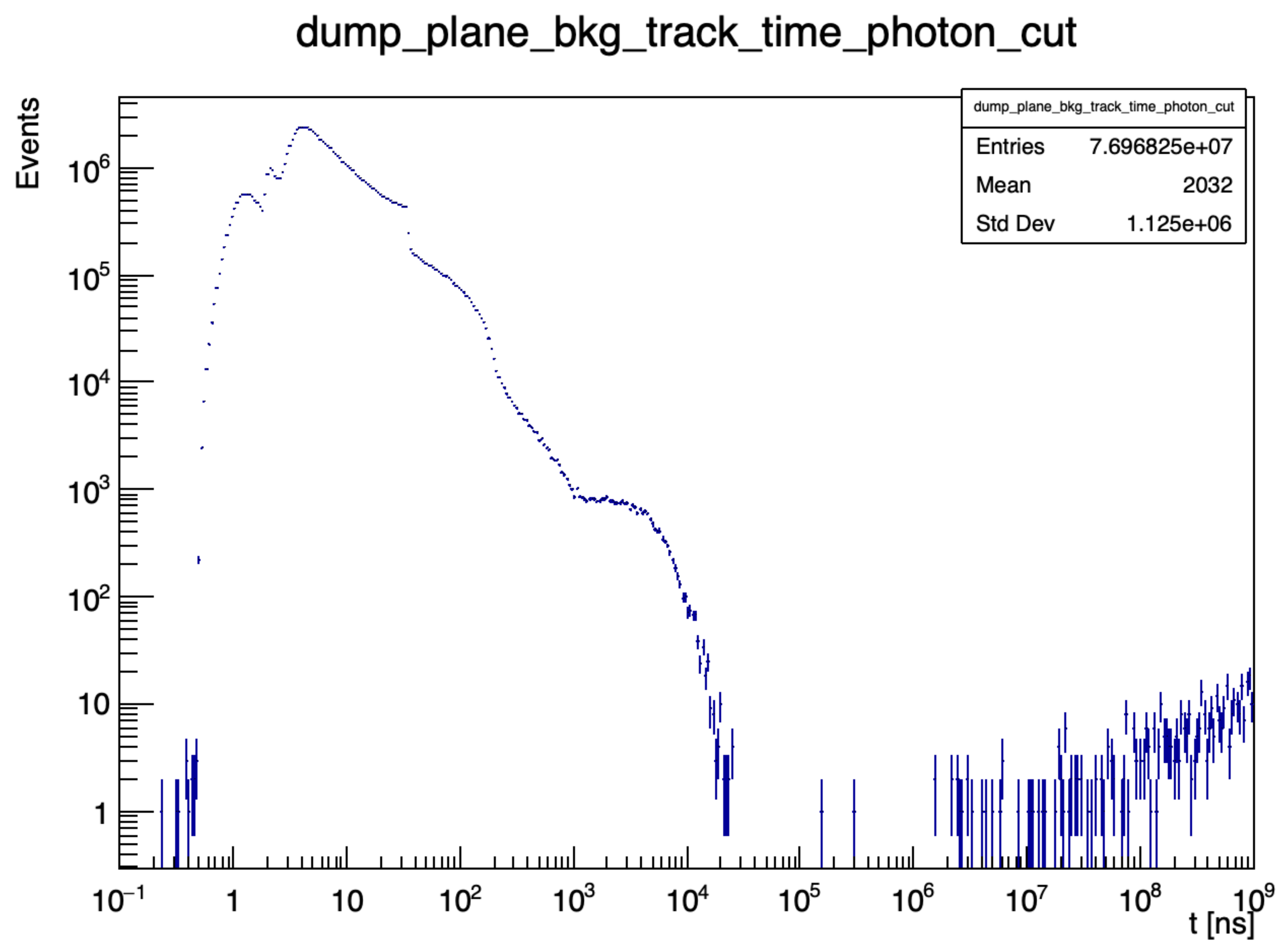


photon

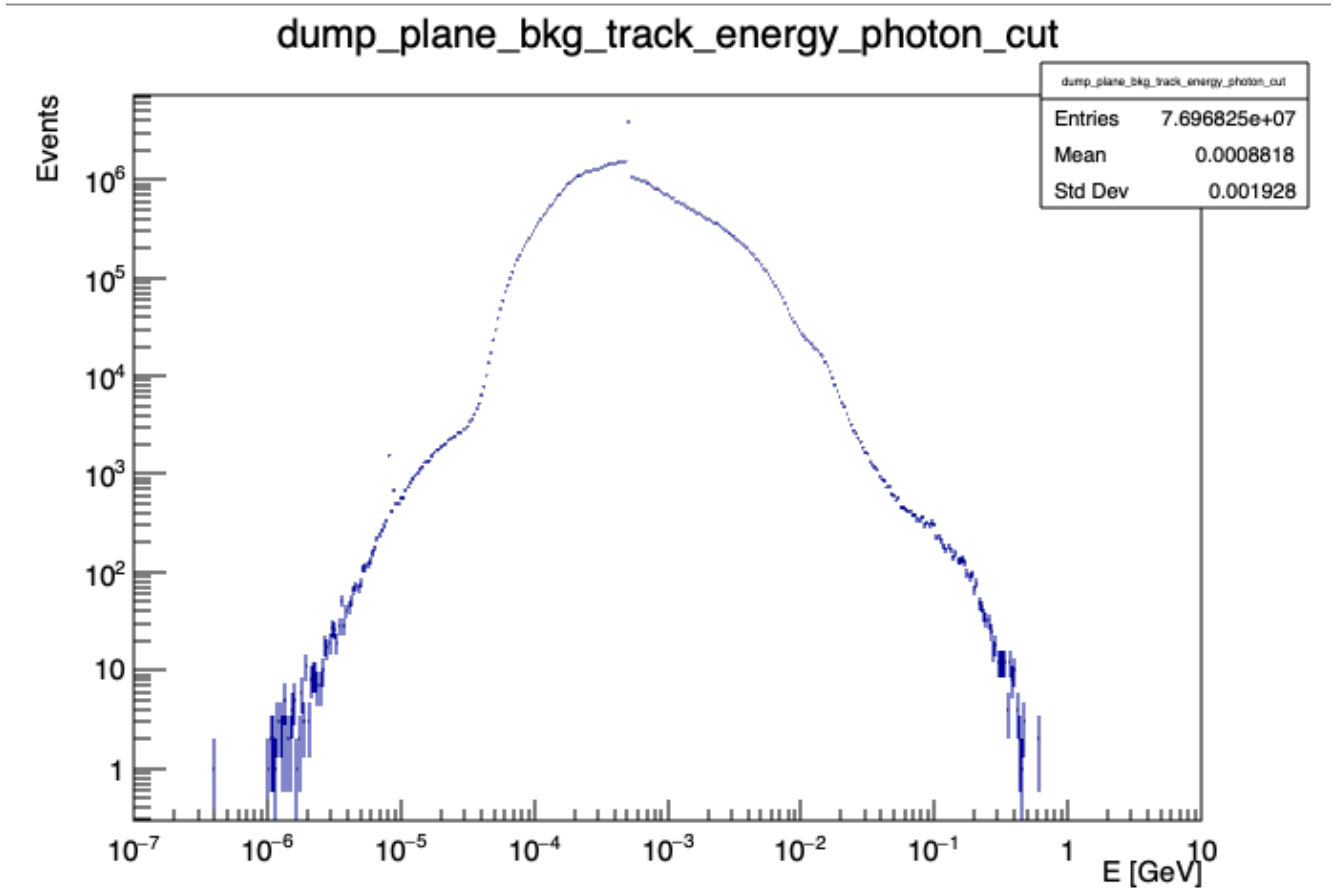


neutron

1D distribution of photons : FullSim at the sampling surface



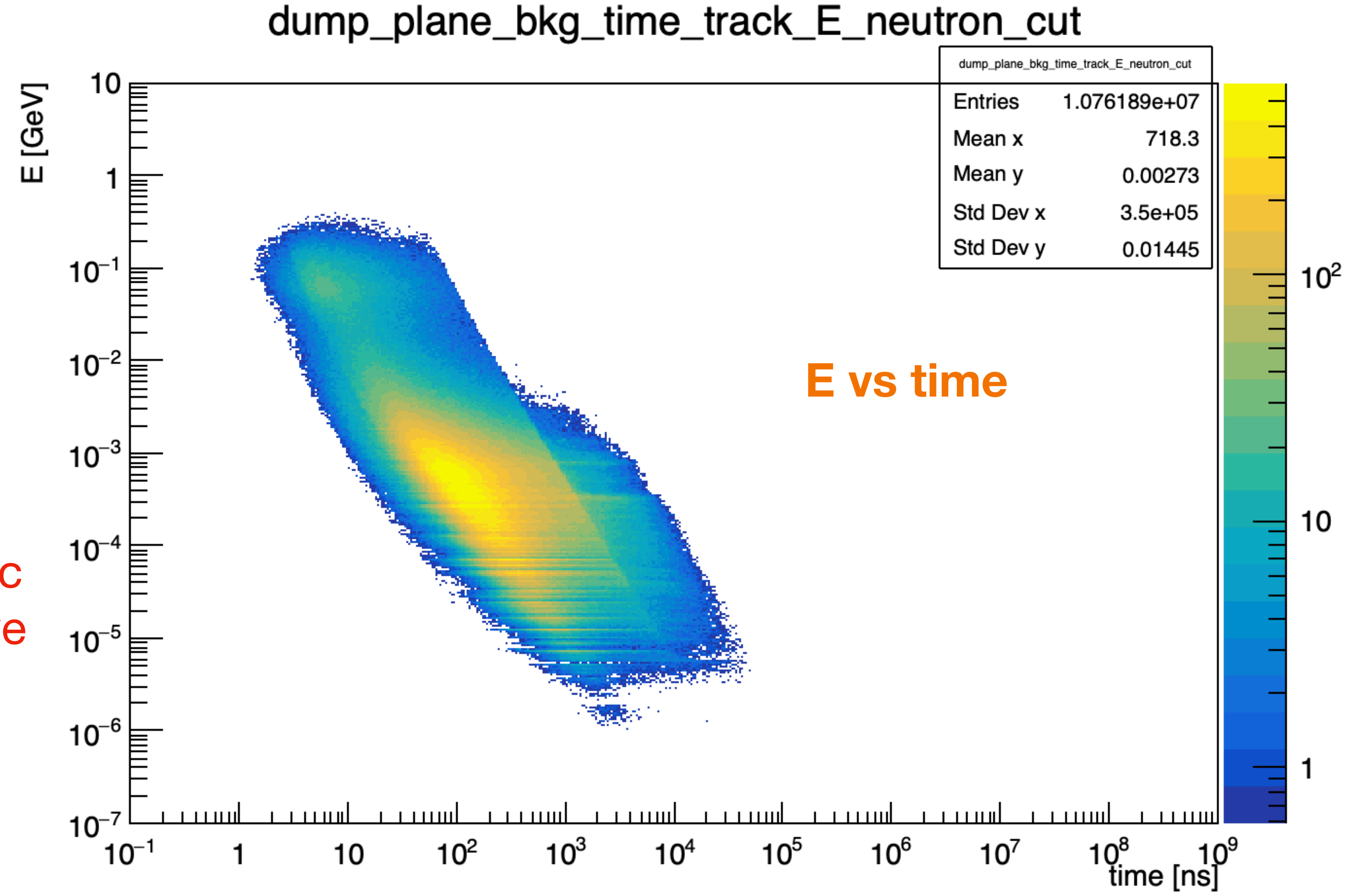
time

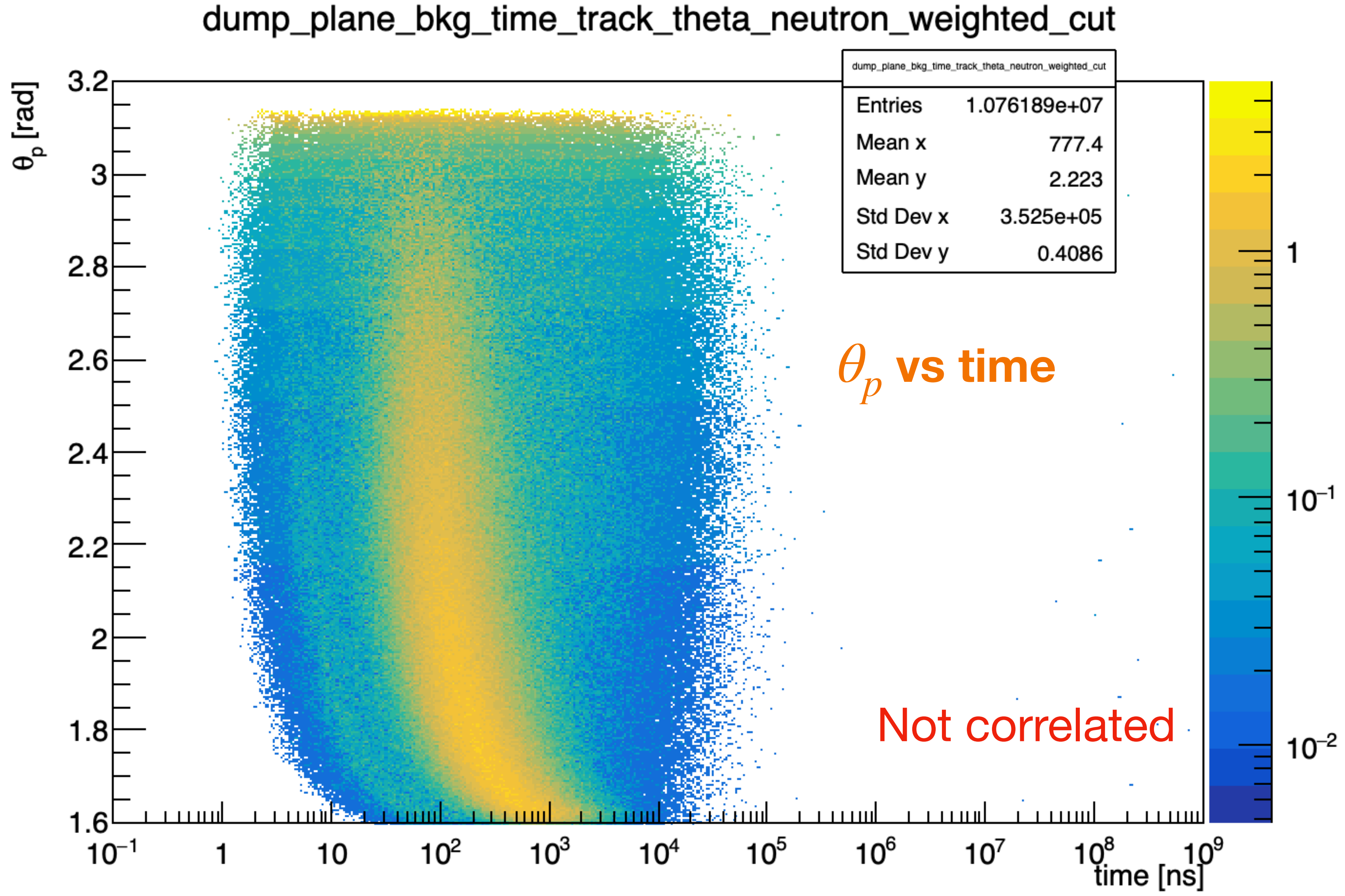


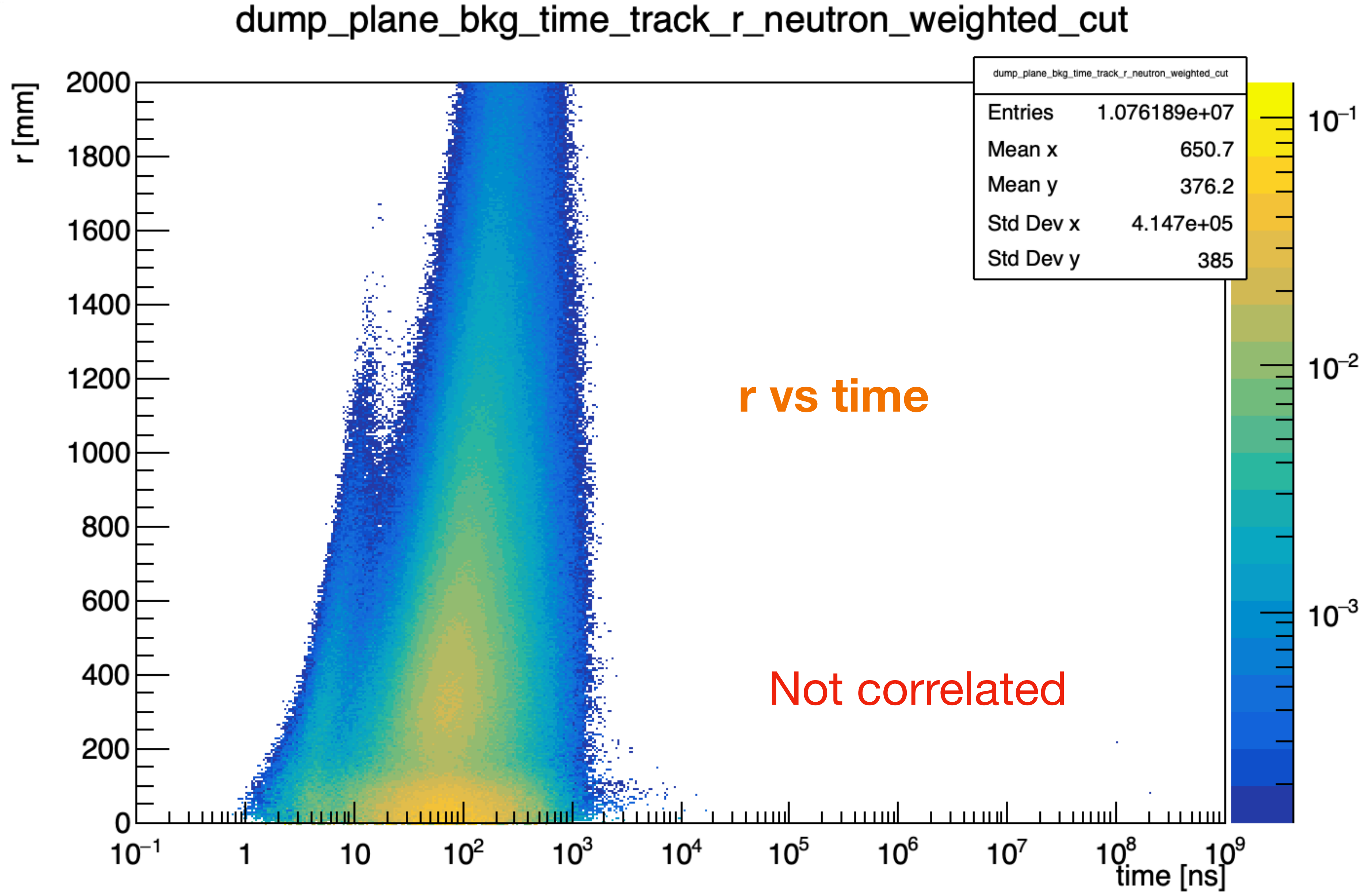
Energy

Correlation with time: neutron

Less energetic neutrons move slowly







★Time for neutron is generated from E vs t 2D plot

Input tree for Geant4 simulation

- Putting the distributions in tree branches for Geant4 input

- The name of the branches are same as the **Tracks** tree used by Sasha

  - Branch details:

```
Int_t            eventid;
vector<int>      trackid;
vector<int>      detid;
vector<int>      pdg;
vector<int>      physproc;
vector<double>   t;
vector<double>   vtxz;
vector<double>   vtxy;
vector<double>   vtxx;
vector<double>   E;
vector<double>   px;
vector<double>   py;
vector<double>   pz;
vector<double>   theta;
vector<double>   phi;
Double_t         weight;
vector<int>      ptrackid;
```

For photons and neutrons, track id from 0 to number of generated particles.

detid==-10 —> assignment to particles randomly generated from dump distributions

physproc==7000 for particles randomly generated from dump distributions.

Randomly generated from dump distributions

Constant at the dump surface

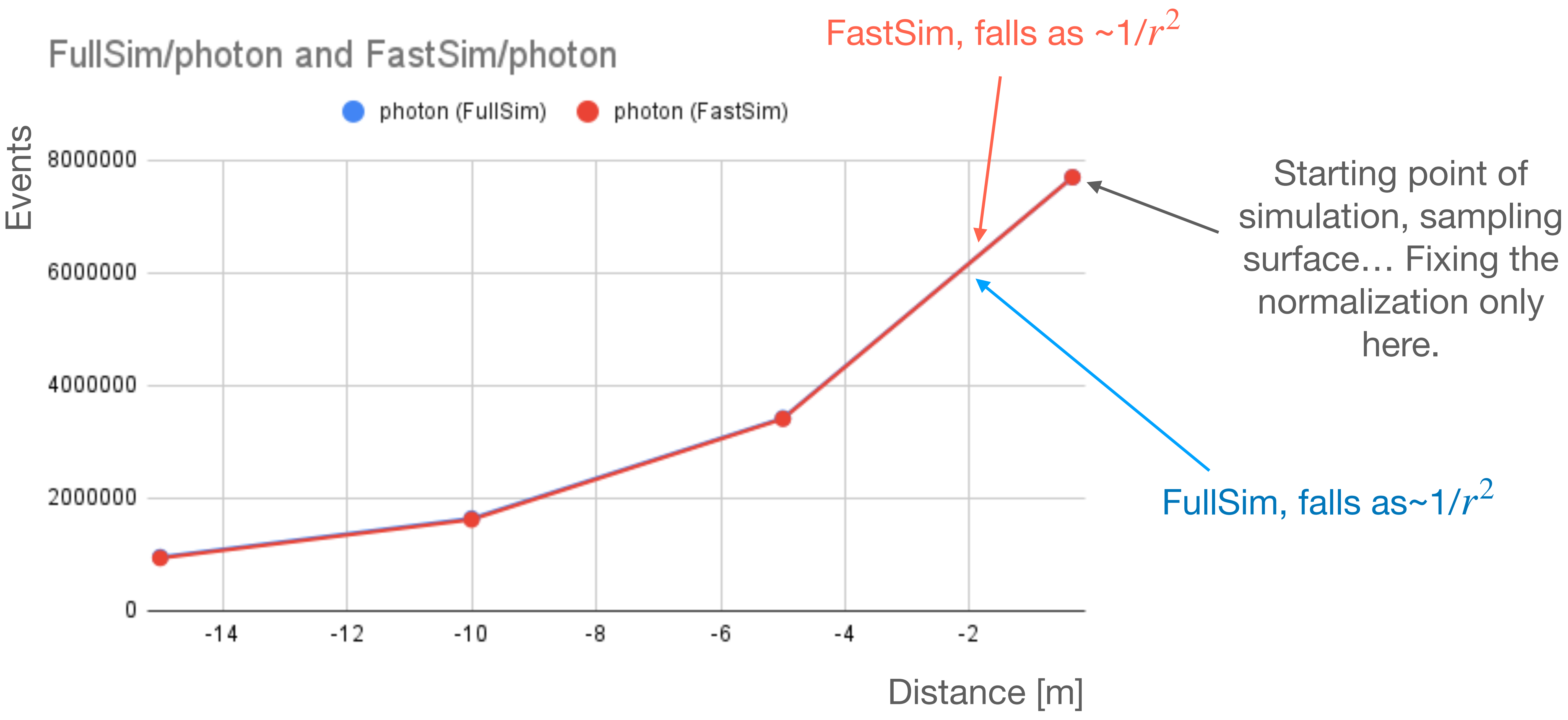
Randomly generated from dump distributions

weight==1, for background particles

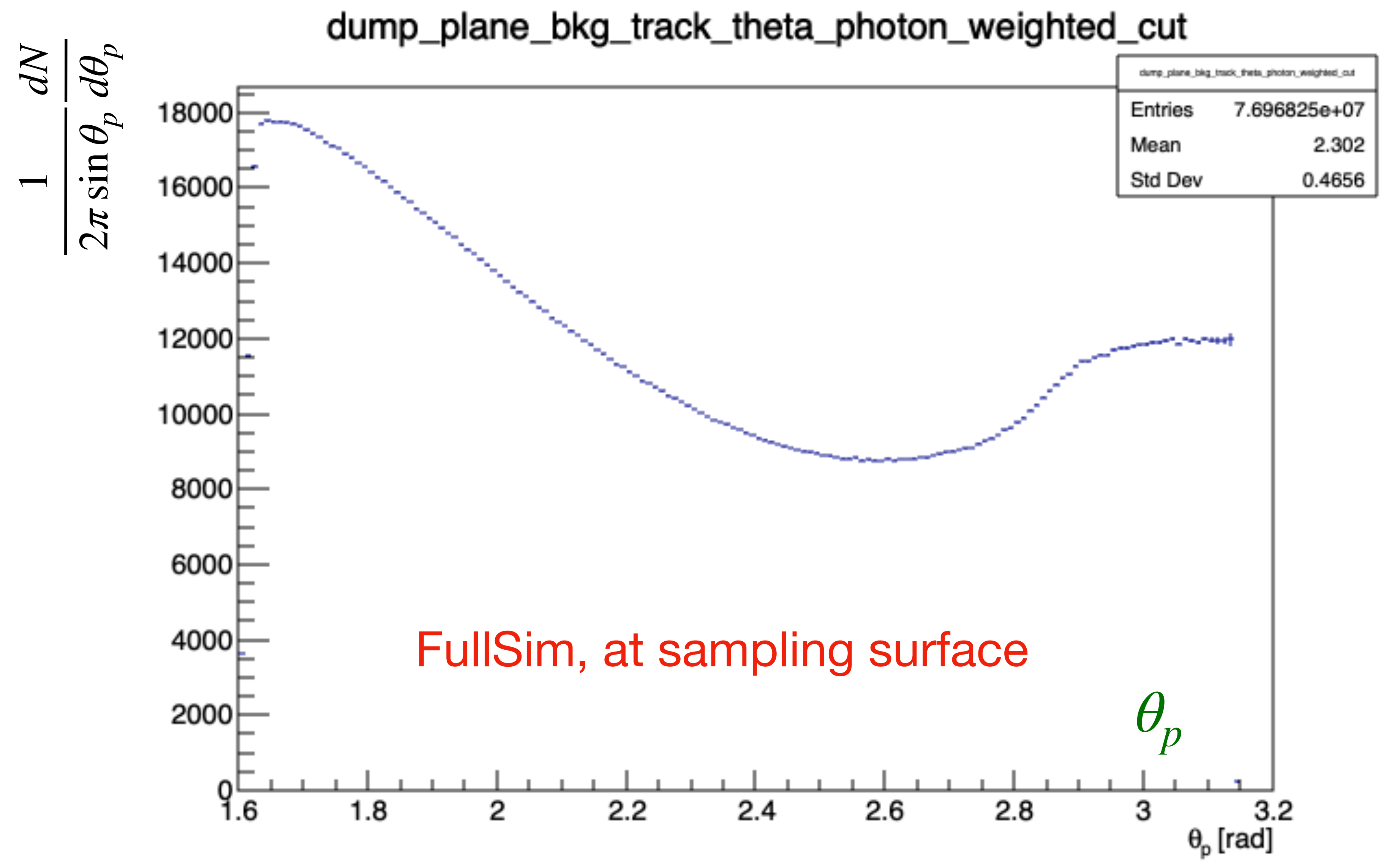
ptrackid==-10 —> assignment to particles randomly generated from dump distributions

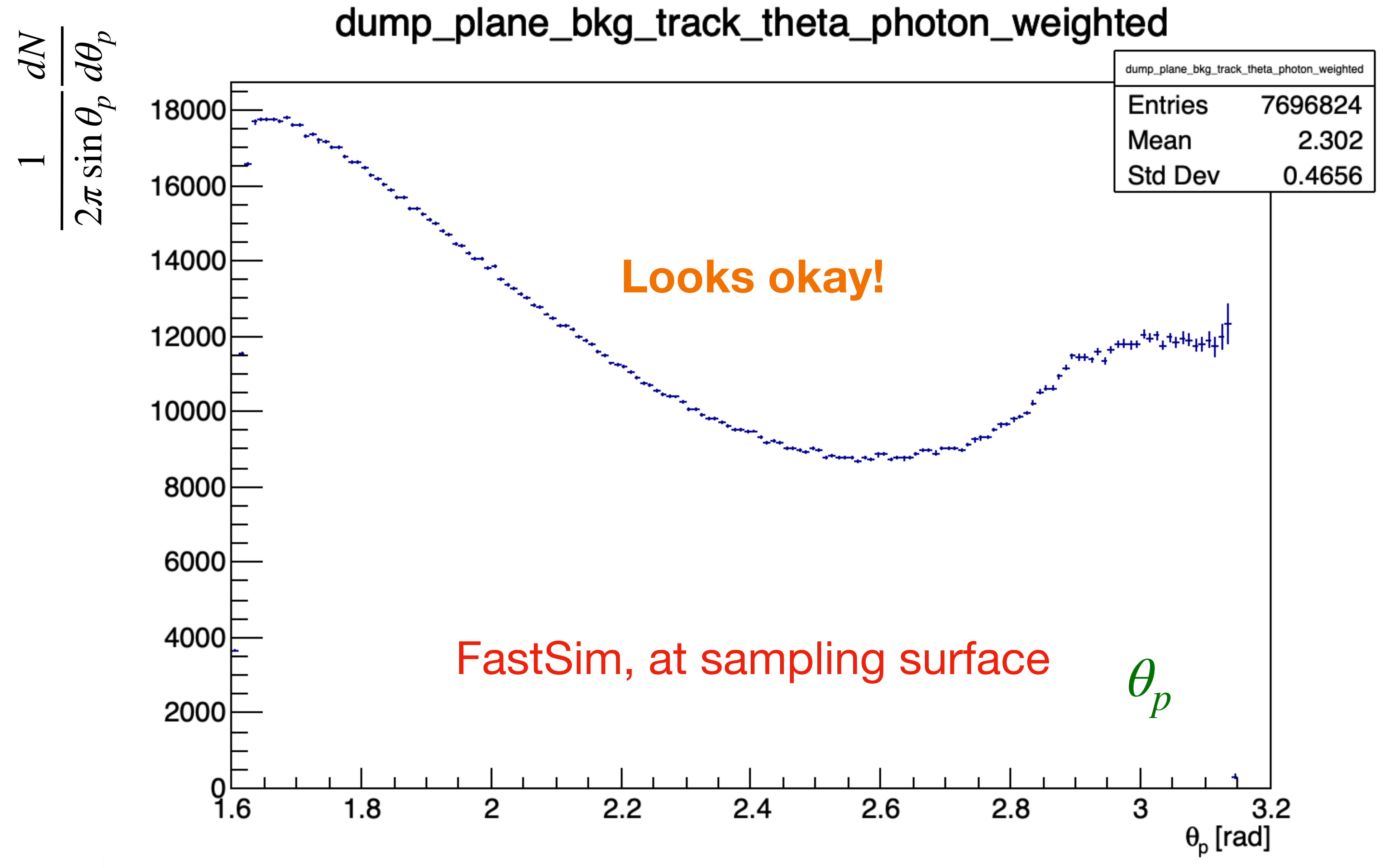
The normalization in FastSim: photon

★drawing r and θ_p from **unweighted** r vs θ_p plot



	FullSim	FastSim	
Distance [m]	photon	photon	(FullSim-FastSim)/Fullim (%)
-0.35	7696824.7	7696824	0.000009094659518
-5	3423511.6	3409093	0.4211640469
-10	1642582.5	1620353	1.353326241
-15	957161.6	937693	2.033993006

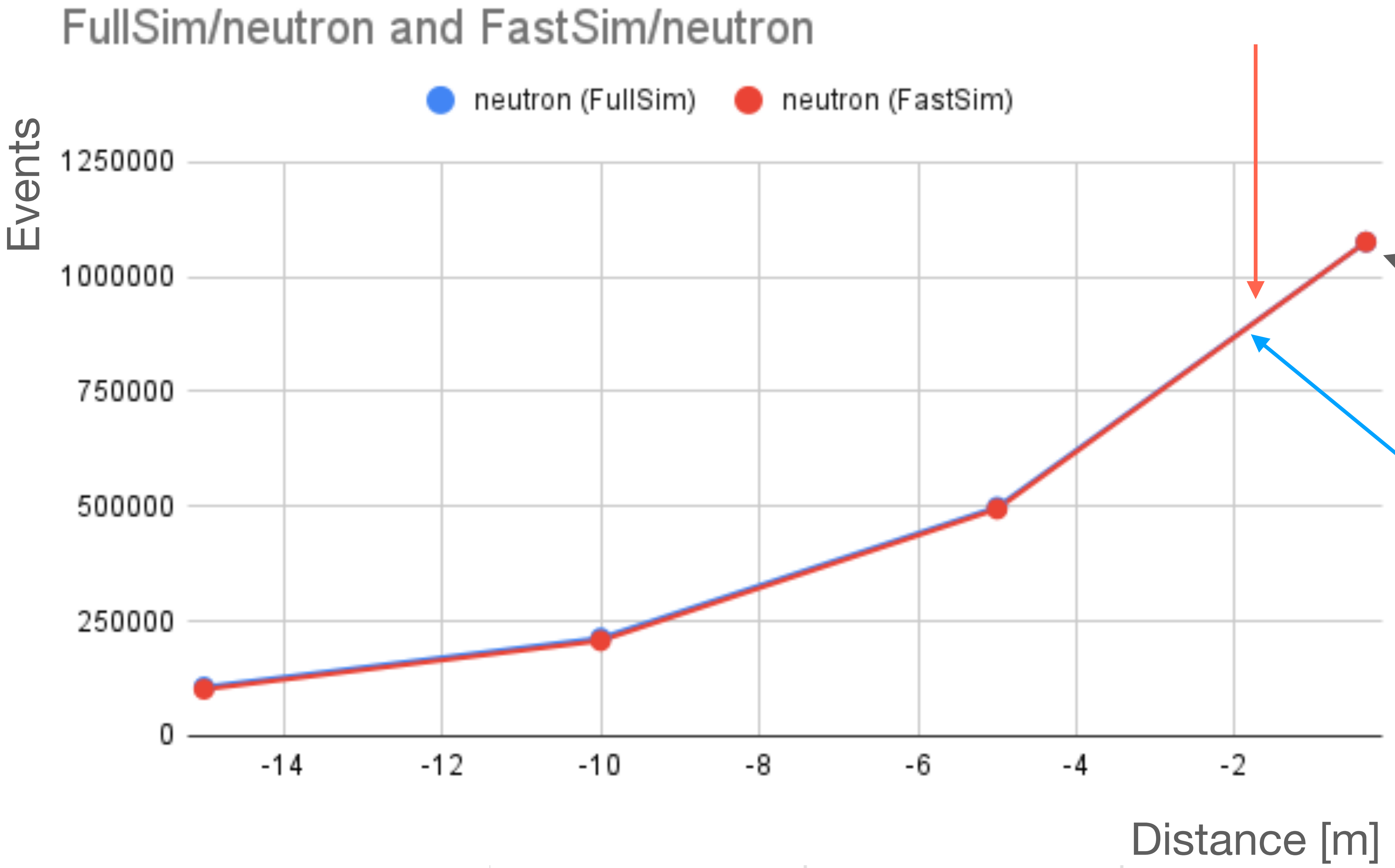




★The momentum azimuthal angle distribution looks similar between FastSim and FullSim.
★The photon normalization looks okay at different z

The normalization in FastSim: neutron

★drawing r and θ_p from **unweighted** r vs θ_p plot

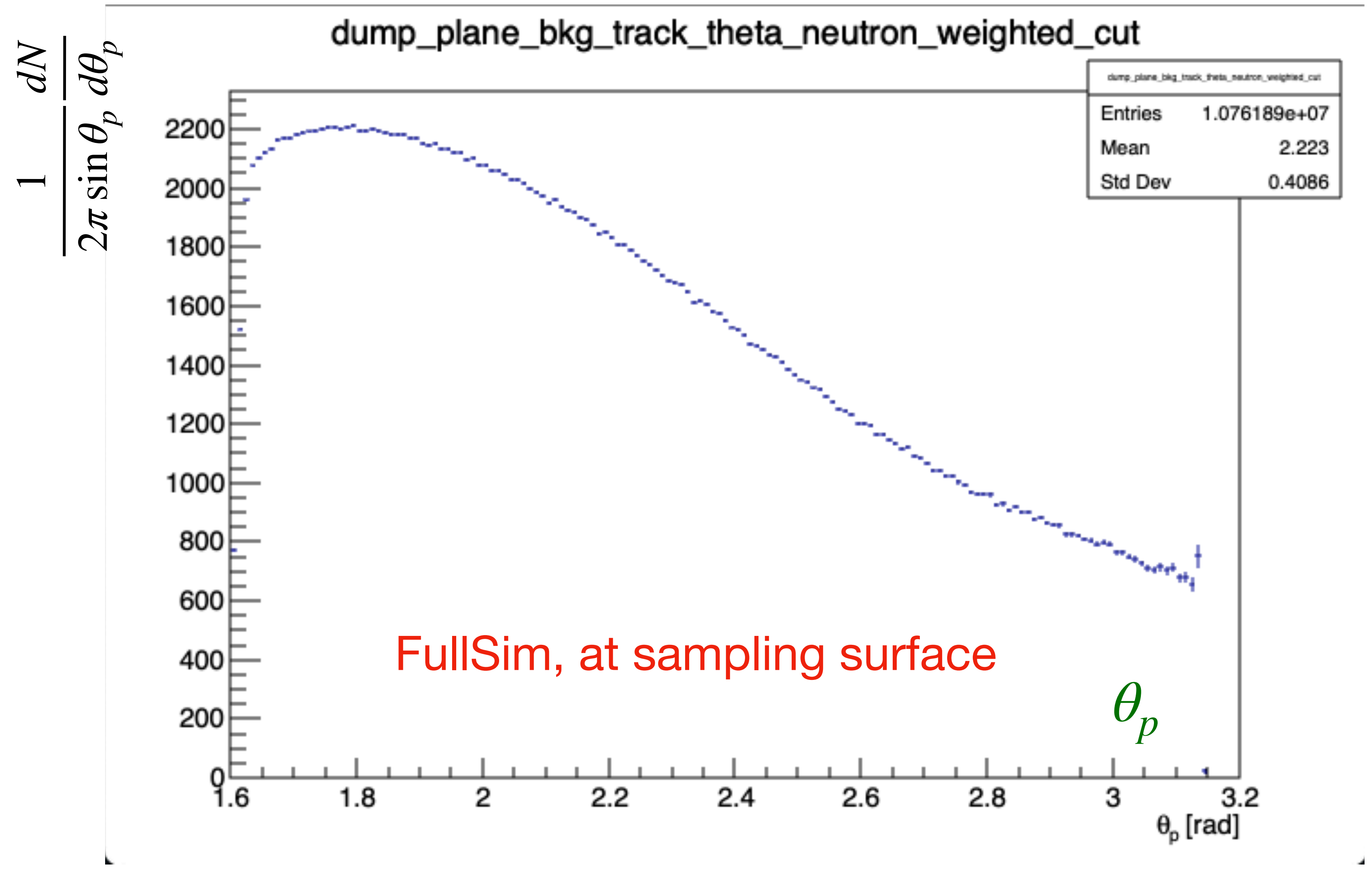


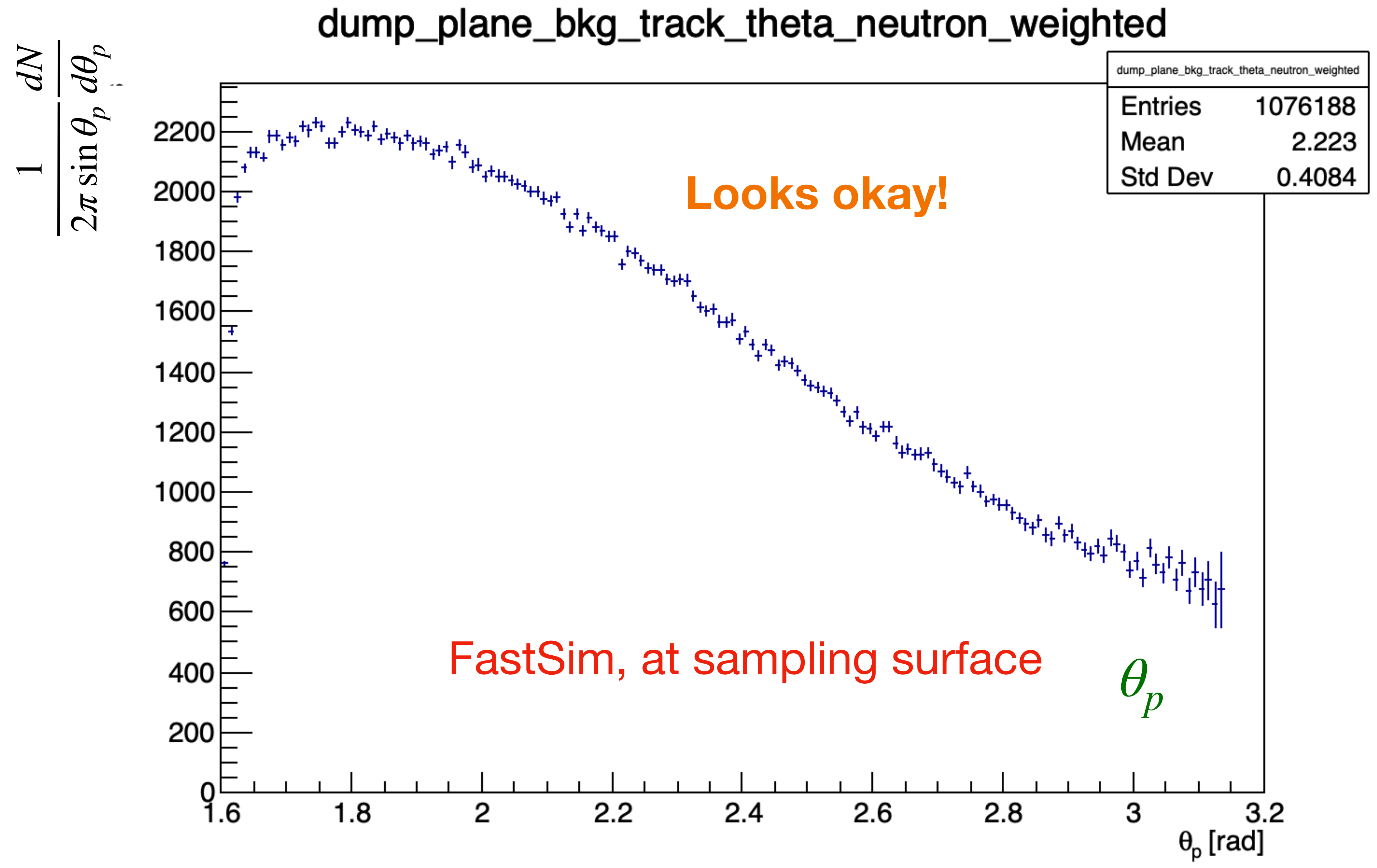
FastSim, falls as ~$1/r^2$

Starting point of simulation, sampling surface… Fixing the normalization only here.

FullSim, falls as~$1/r^2$

	FullSim	FastSim	
Distance [m]	neutron	neutron	(FullSim-FastSim)/Fullim (%)
-0.35	1076188.8	1076188	0.00007433639897
-5	499001.4	494407	0.9207188597
-10	213871.6	207697	2.887059338
-15	107177.5	101932	4.894217536





★The momentum azimuthal angle distribution looks similar between FastSim and FullSim.
★The neutron normalization looks okay at different z