Xenon Doping

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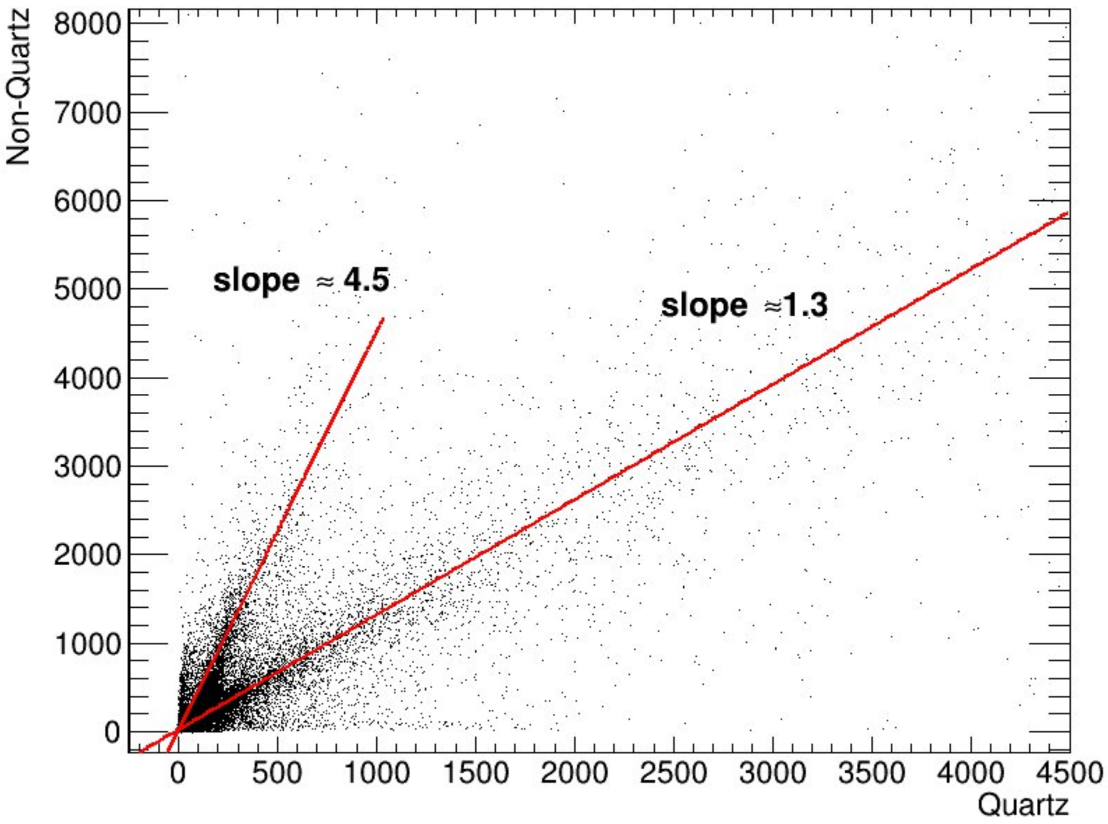
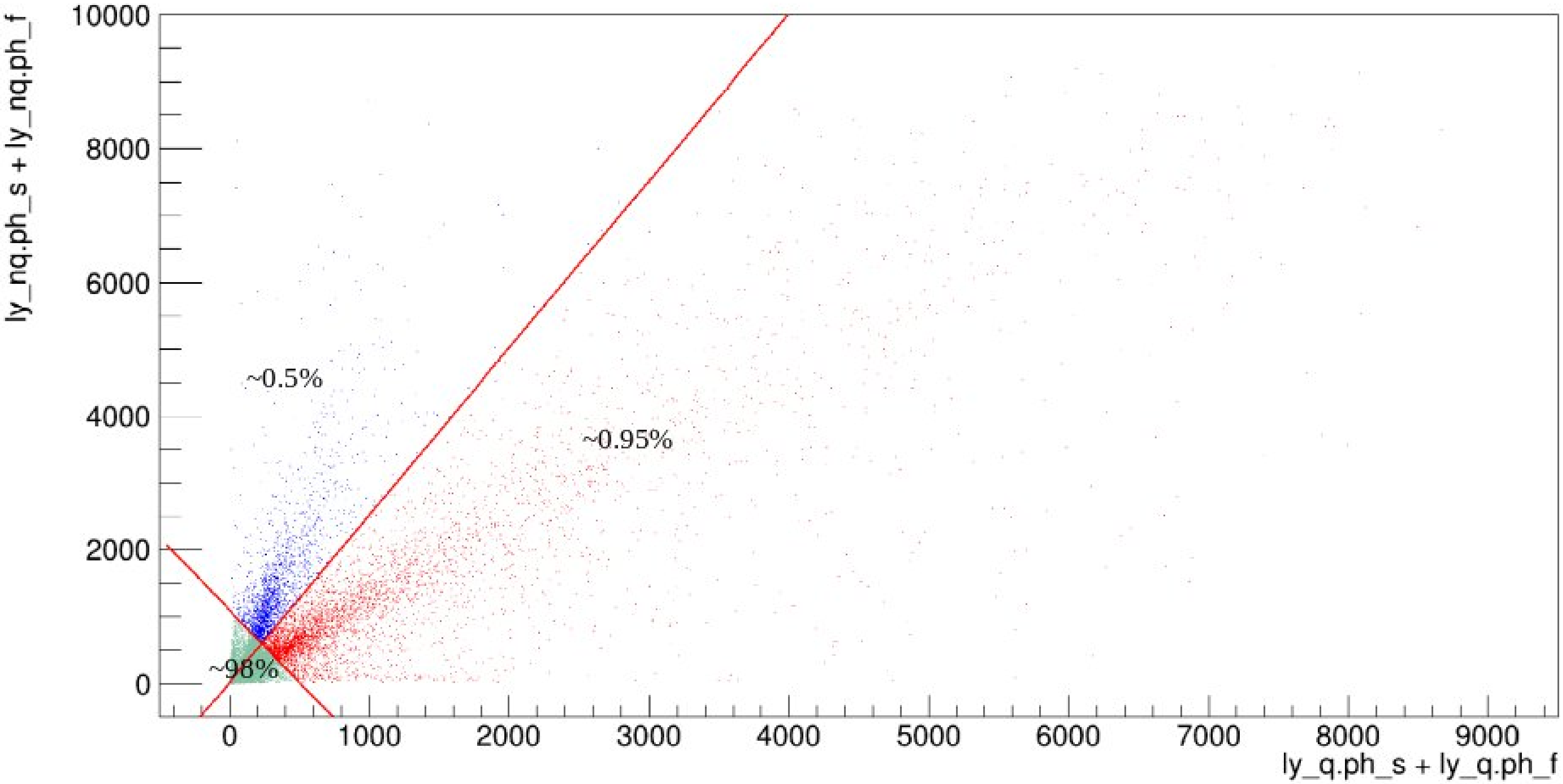
07/08/2020

Scatter-plot

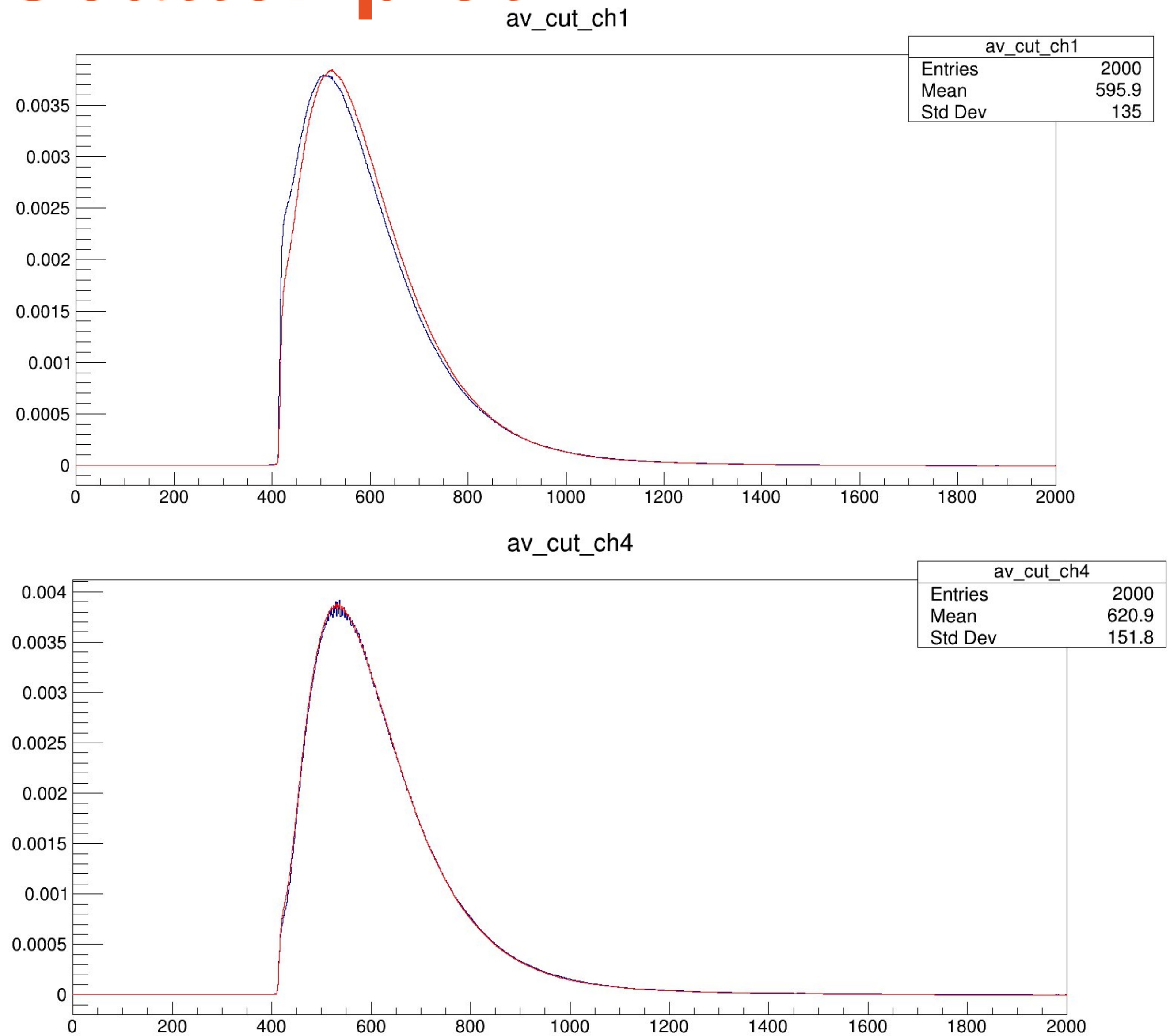


- Scatter-plot of NQ-Arapuca vs Q-Arapuca
- 2 different contributions (lobes)

Scatter-plot



Scatter-plot



Shape seems very similar despite the a subtle difference in the fast component for NQ

Average light detected (Light yield)

- Average number of photons per trigger was retrieved for each doping.

- A growth in the average is related to the overall efficiency (emission and/or collection)

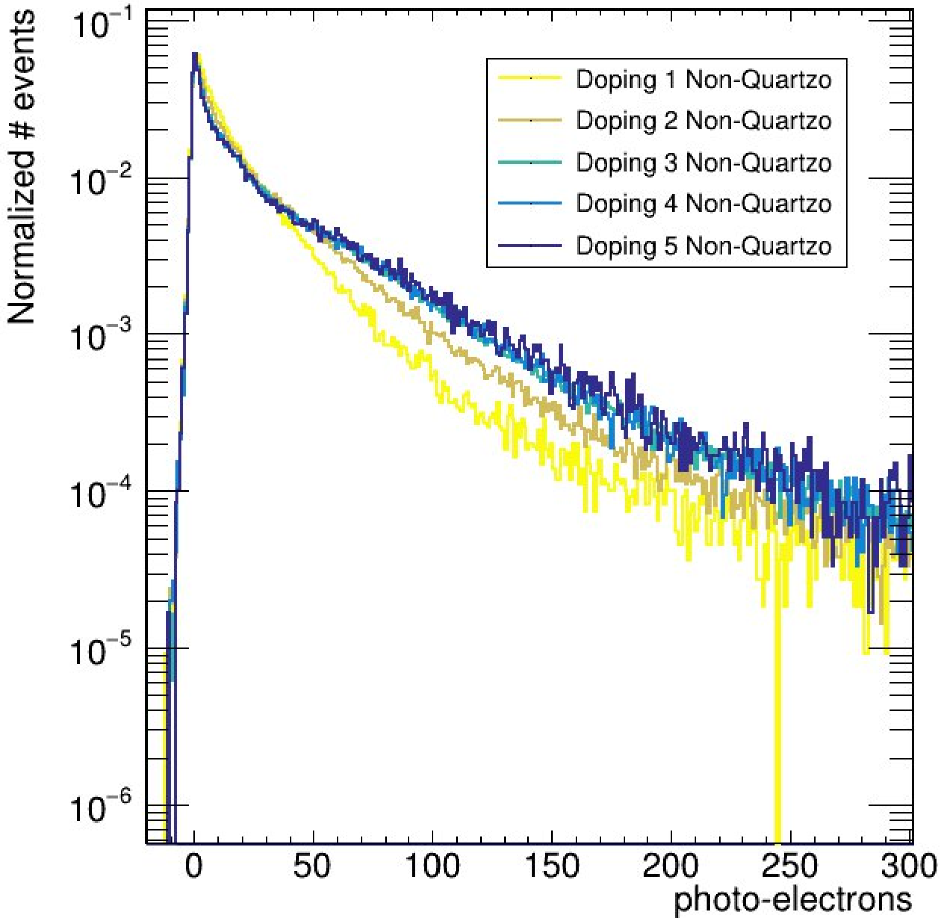
- Is the ratio affected by geometry ?

	Average photons per trigger	
Xe (ppm)	No Quartz	Quartz
0.8	33.5	7.8
3.3	45.5	19.5
11	56.6	34.5
15	56.9	37.4
20	58.3	38.1

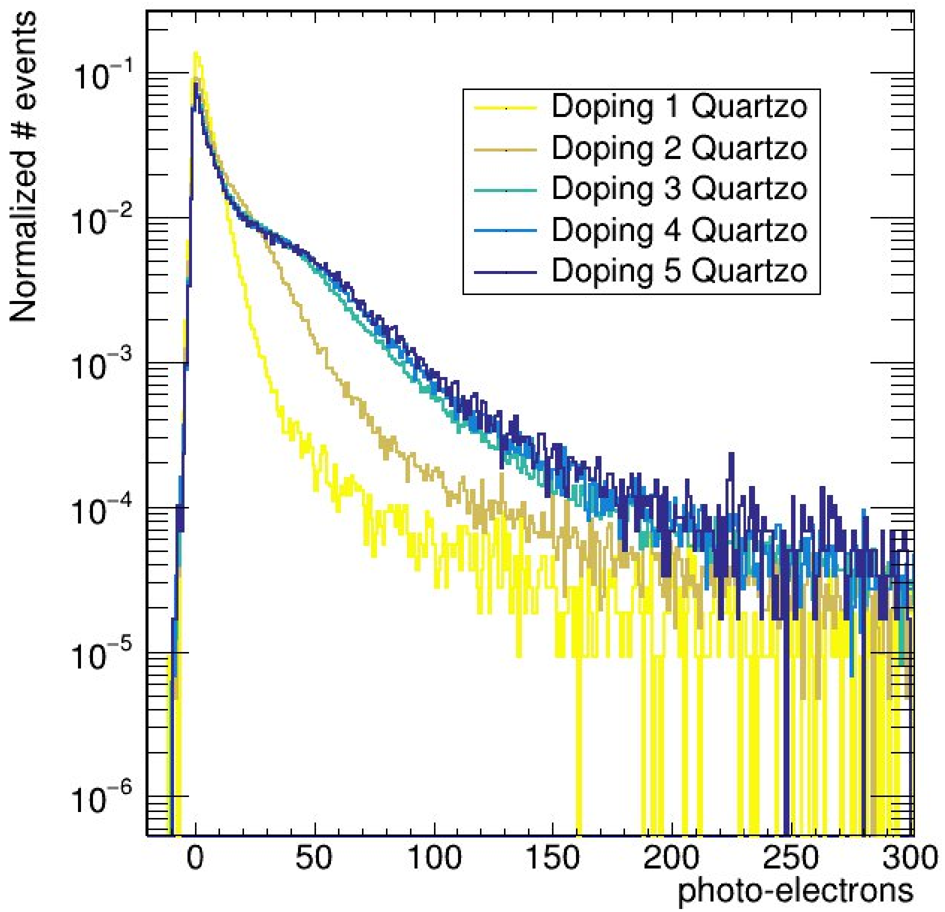
Xe (ppm)	Relative NQ	Q / NQ
0.8	1.000	0.234
3.3	1.360	0.428
11	1.691	0.610
15	1.702	0.657
20	1.741	0.655

Average light detected (Light yield)

NQ - Light distribution



Q - Light distribution



Simulation motivation

A simulation could be helpful to:

- Explain the two lobes observed in the scatter-plot
- Check if the relation between the average number of photons and the light yield is linear
- Verify the muon spectrum response obtained by the two x-arapucas.
- Check the ratio between $Xe/(Ar + Xe)$

Monte Carlo - Toy model

Why a toy model Monte-Carlo?

- Is not a complete ***Geant4*** simulation. It does not take into account many physical properties, trying only to bring relevant processes and appropriate approximations

- Everything was implemented from scratch, mistakes can be made :)

- Basically only geometrical effects will have an impact on the results

MC - implementation

Muon generation:

Phys. Rev. D58, 05401 (1998)

$$\mathcal{D}_\mu\left(p, h = 1030\ \mathrm{g/cm}^2, \vartheta = 0^\circ\right) = Cp^{-(\gamma_0+\gamma_1 \log p+\gamma_2 \log^2 p+\gamma_3 \log^3 p)}$$

TABLE II. Parameters of the fitting formula (3.4) for the vertical energy spectrum of conventional muons at sea level.

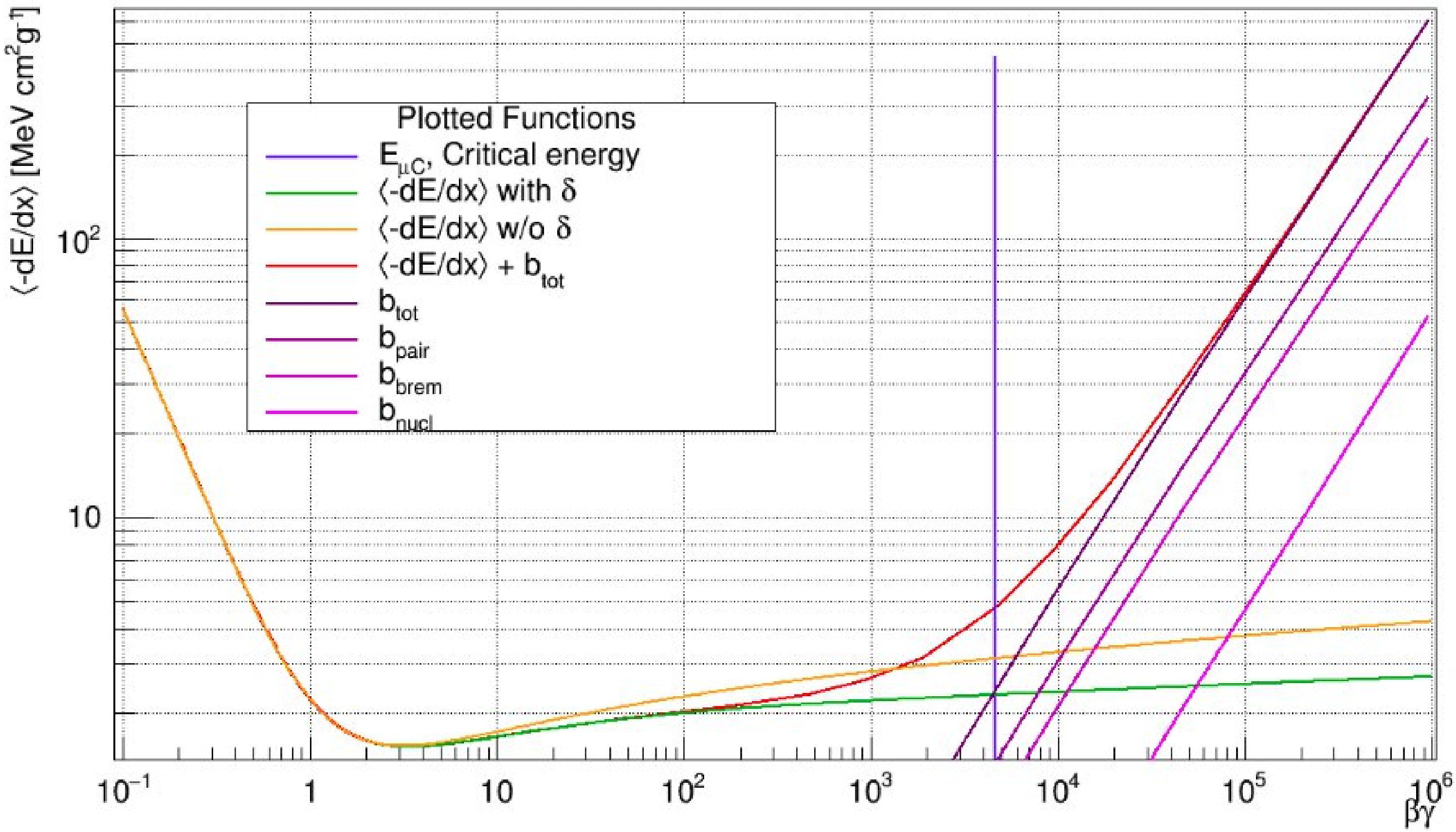
Momentum range (GeV/c)	C (cm^{-2}s^{-1}sr^{-1}GeV^{-1})	γ_0	γ_1	γ_2	γ_3
$1 \div 9.2765 \times 10^2$	2.950×10^{-3}	0.3061	1.2743	-0.2630	0.0252

From p = 1 to 10 GeV/c

Angular distribution:
- Zenith: $\cos^2\theta$
- Azimuth: uniform

MC - implementation

Muon energy loss:



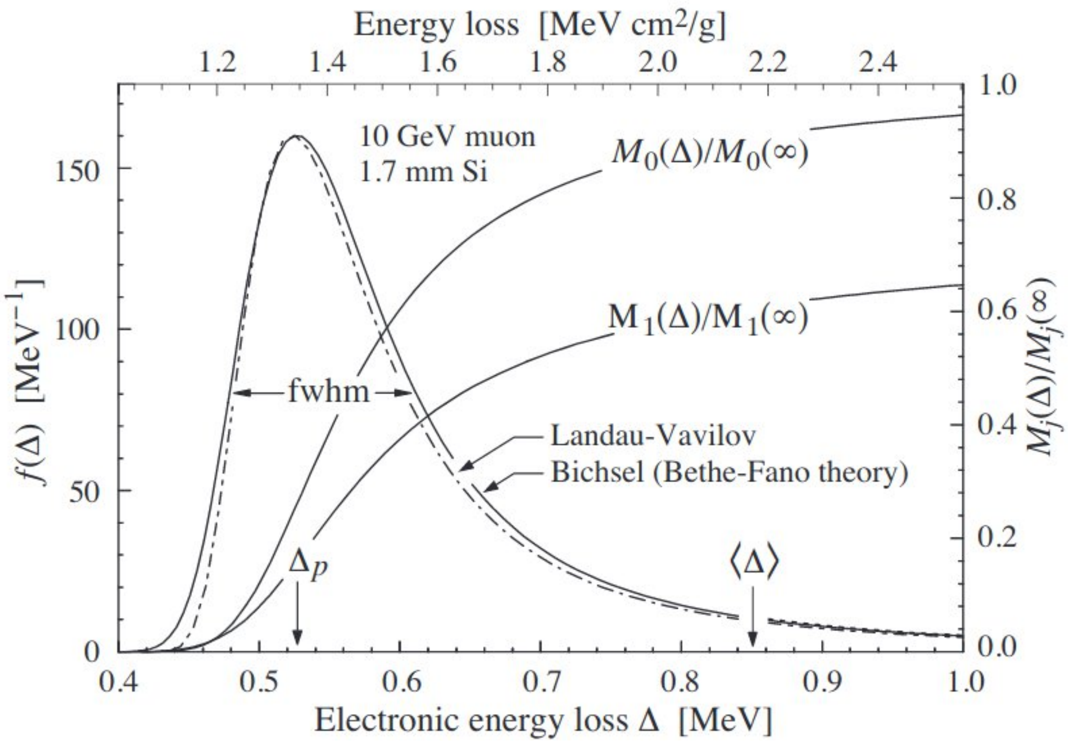
https://indico.fnal.gov/event/14933/contributions/28526/attachments/17961/22583/Final_SIST_Paper.pdf

MC - implementation

Muon energy loss:

fwhm set as 4ξ, where

$$\xi = (K/2)\,\langle Z/A\rangle\, z^2 (x/\beta^2)\ \mathrm{MeV}$$

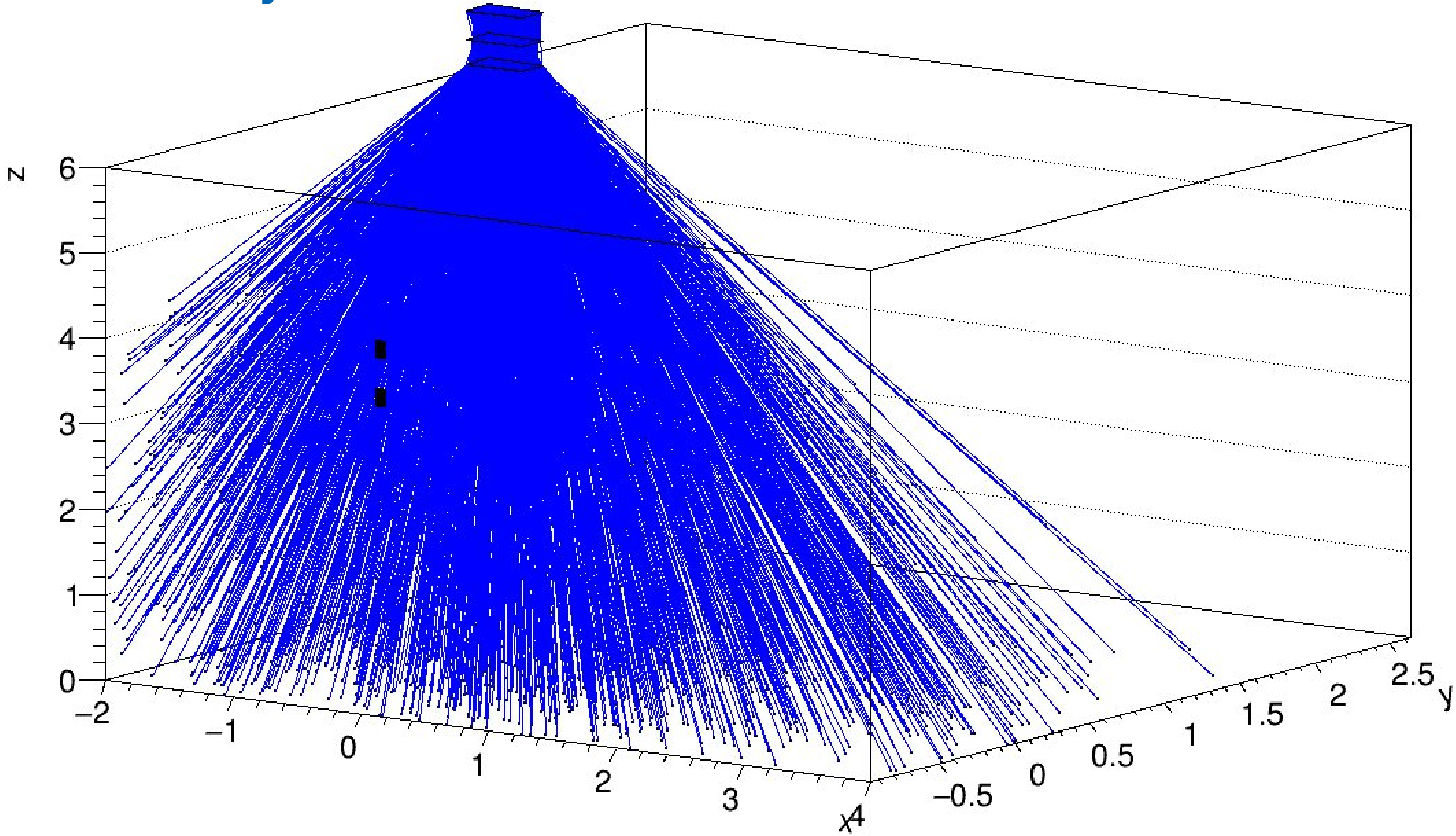


Just an approximation: we still have many muons stopping inside the detector (but this did not affect sensibly the results).

https://pdg.lbl.gov/2012/reviews/rpp2012-rev-passage-particles-matter.pdf

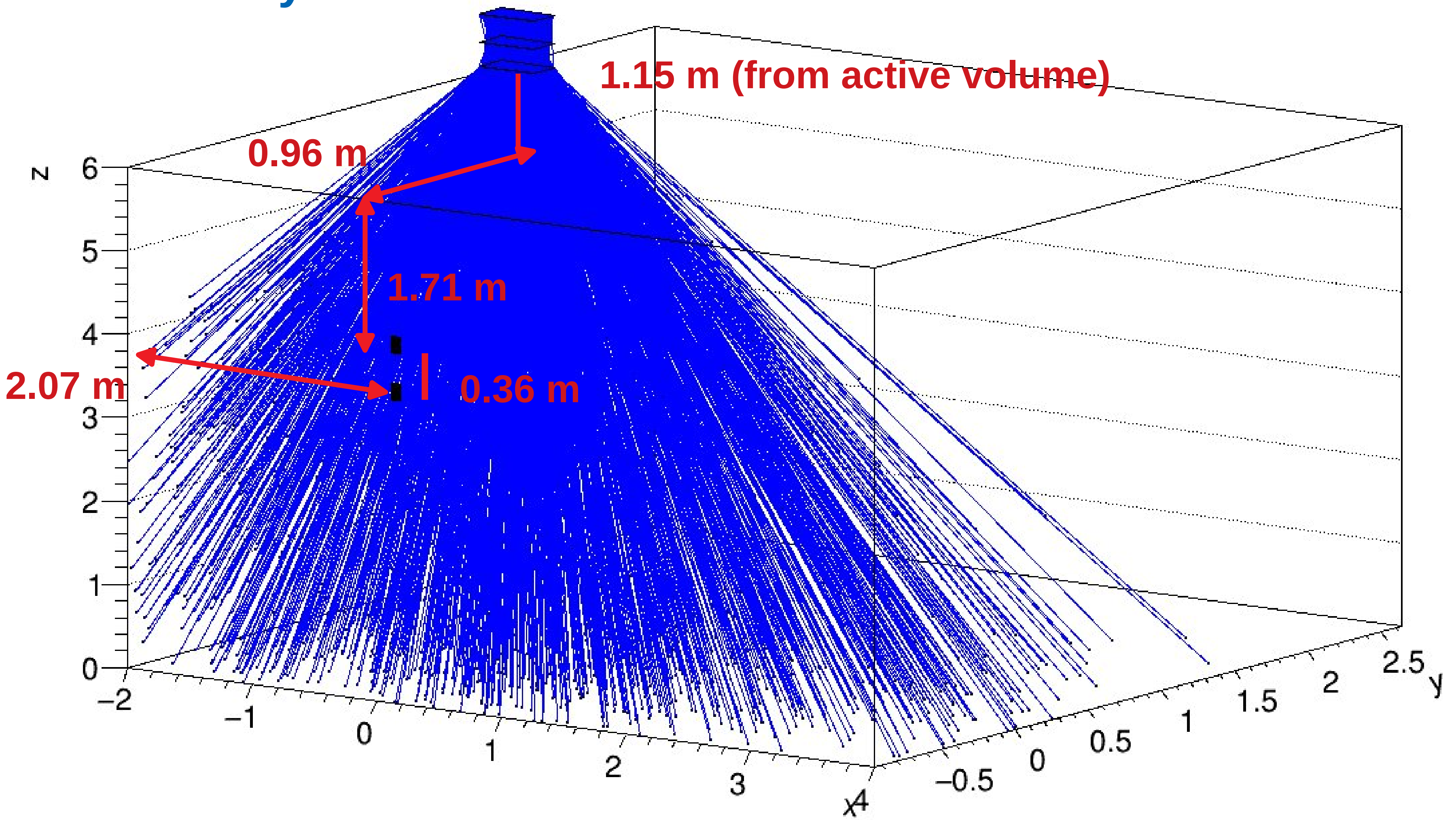
MC - implementation

Geometry:

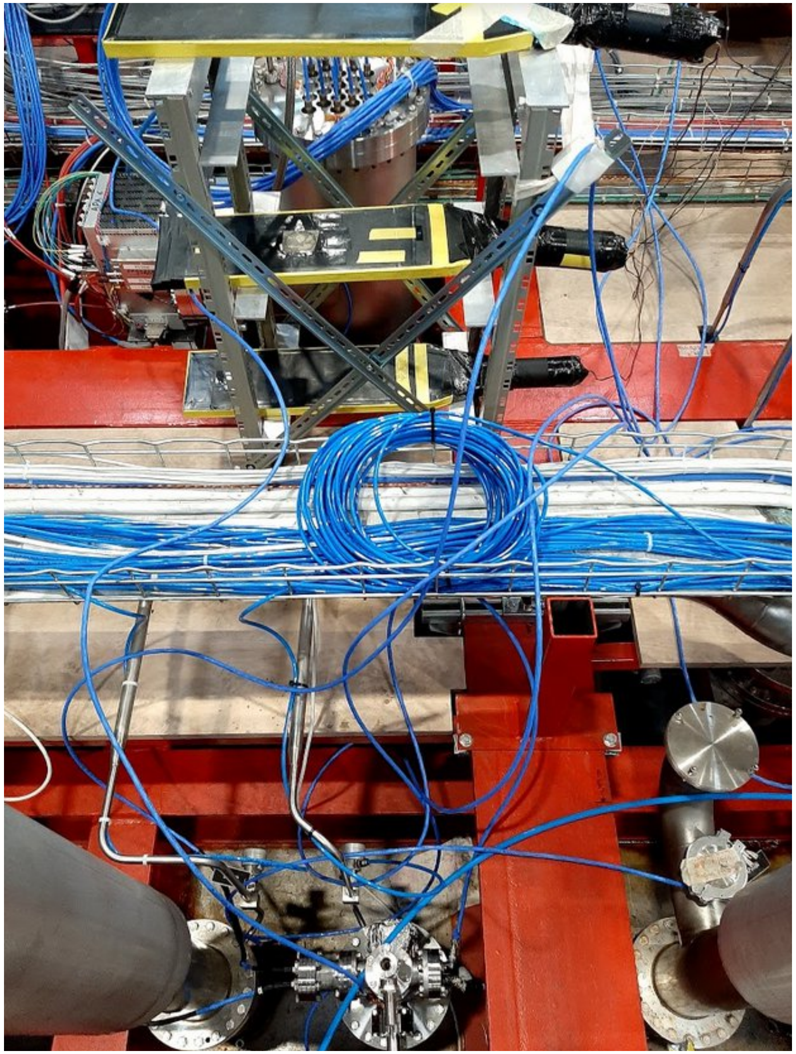


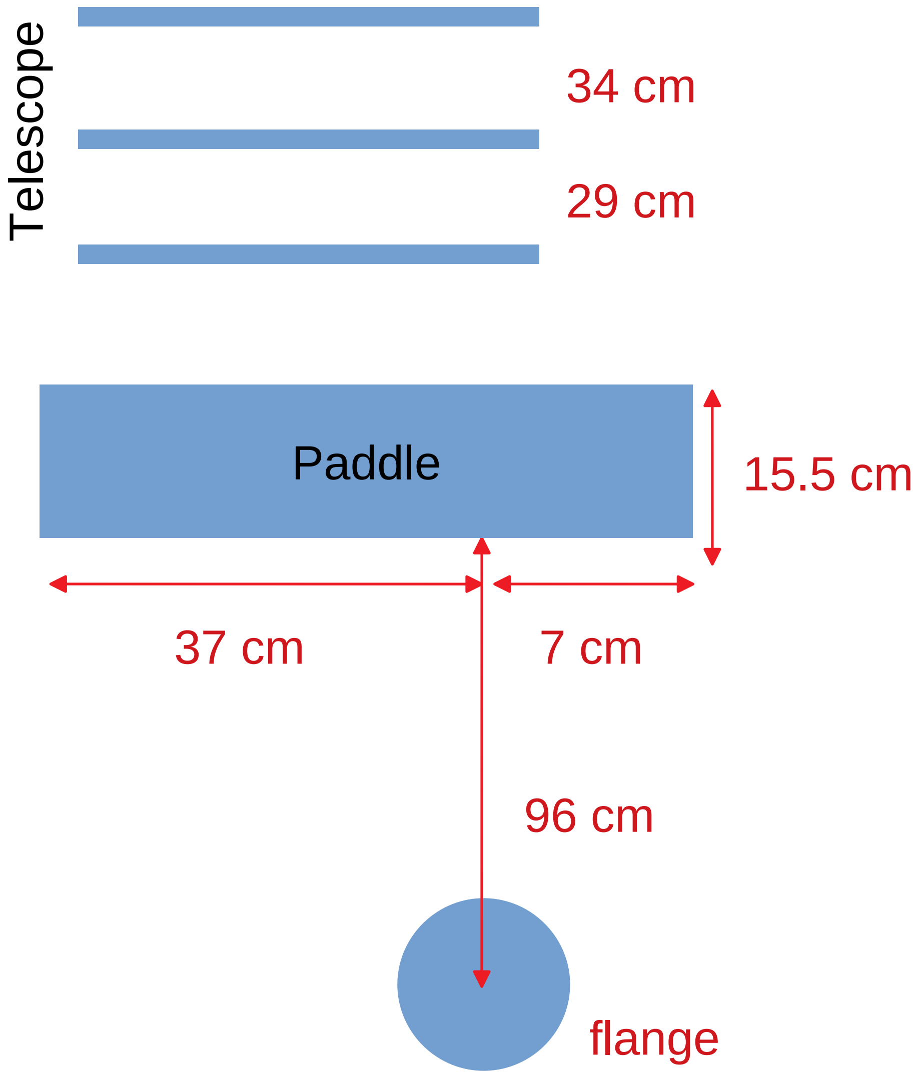
MC - implementation

Geometry:



MC - implementation





MC - implementation

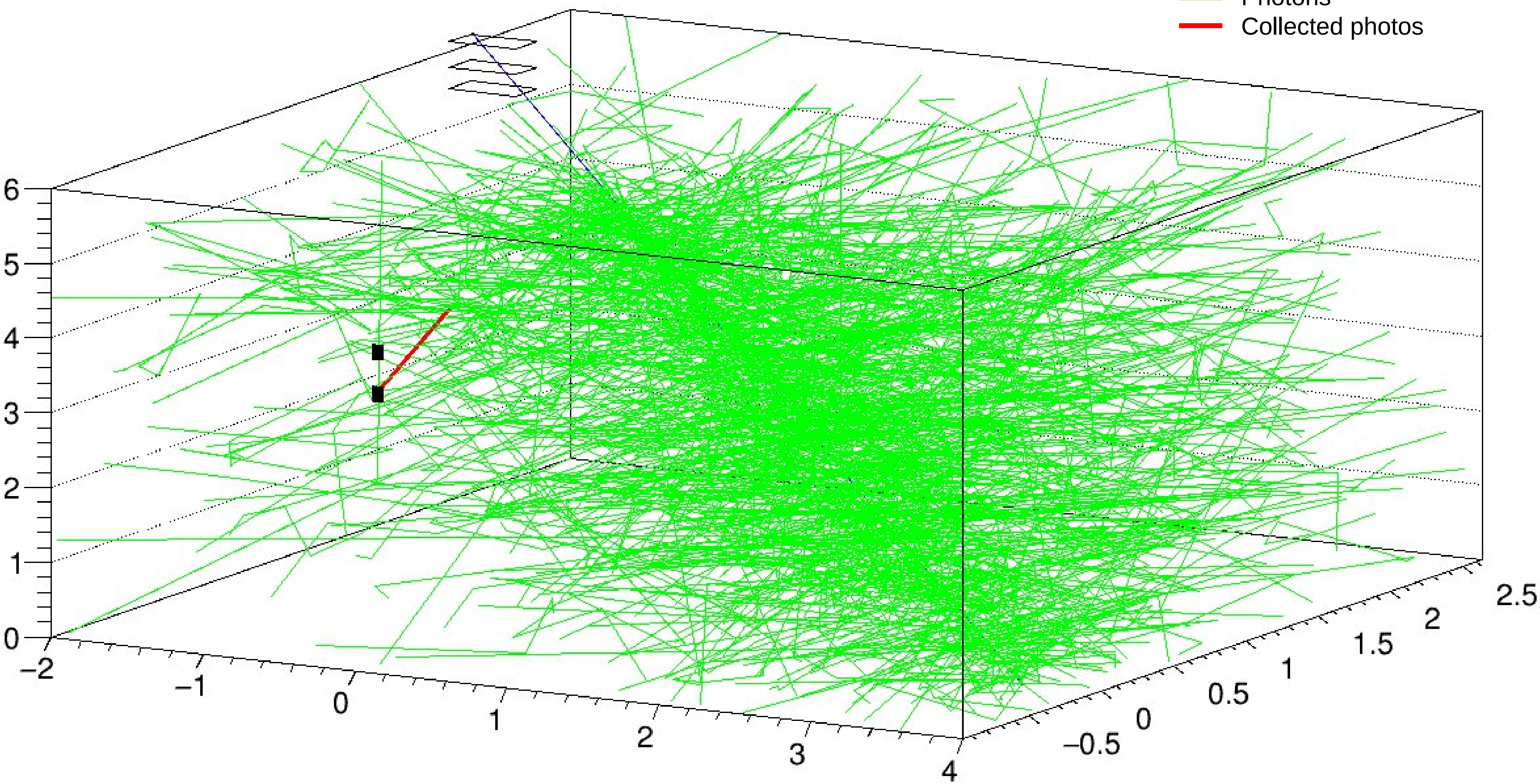
Photon emission:

- Isotropic emission
- Light yield was set as 400 photons/MeV. This (roughly) correspond to a 1% efficiency of the X-ARAPUCA.
- Rayleigh Scattering with λ = 1 m
- Absorption [1] with λ = 20 m
- The “type” (128 nm or 175 nm) of photon is decided in the emission, 70% for Xe and 30 % Argon.
- To speed up simulation, we tried to set the photon "type" only if it hit the X-ARAPUCA window. No change in the output was noticed.

[1] Jones, B J P et al. “A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level.” Journal of Instrumentation 8.07 (2013): P07011–P07011. https://arxiv.org/abs/1306.4605v2.

MC - implementation

Photon emission:



MC - implementation

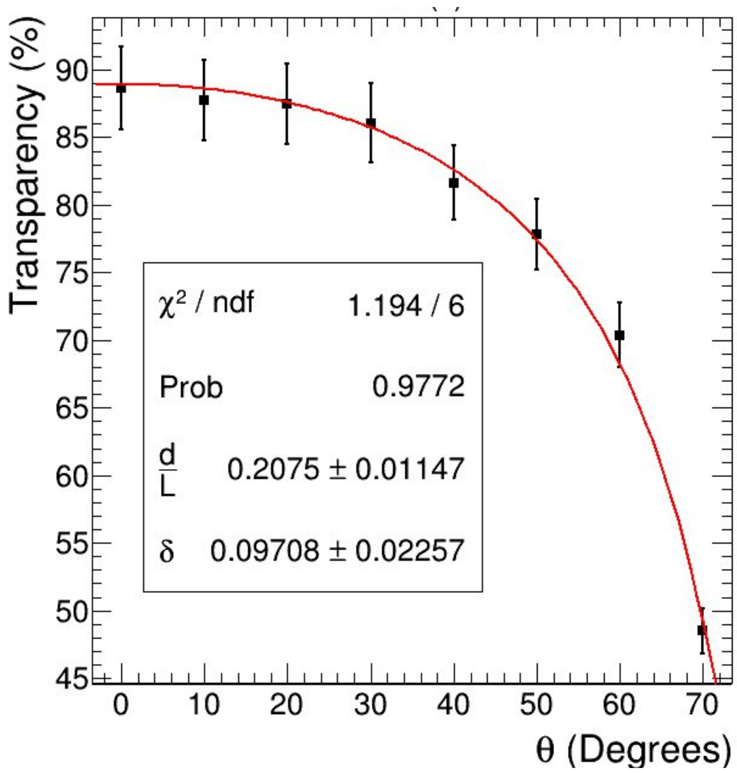
Shadow due to grids:

In front of the x-arapucas there are:

- 6 TPC wires ➜ d = 0.15 mm (diameter) and L = 4.75 mm (pitch)
- Two sets of ground grids (transparency measured at UNICAMP)

Fitting function

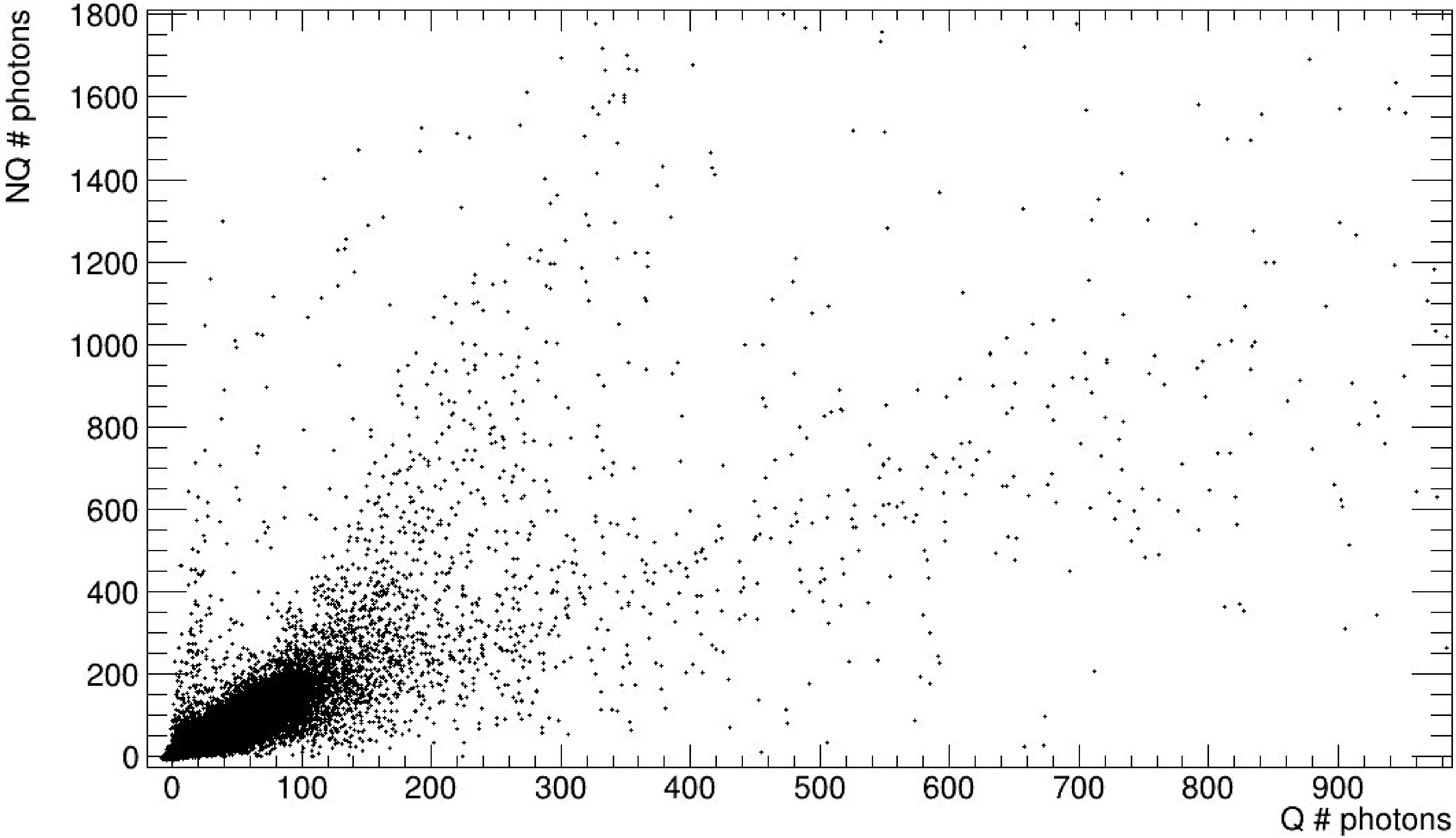
$$1 - \frac{d}{L}\frac{1}{\cos(\theta)} + \delta$$



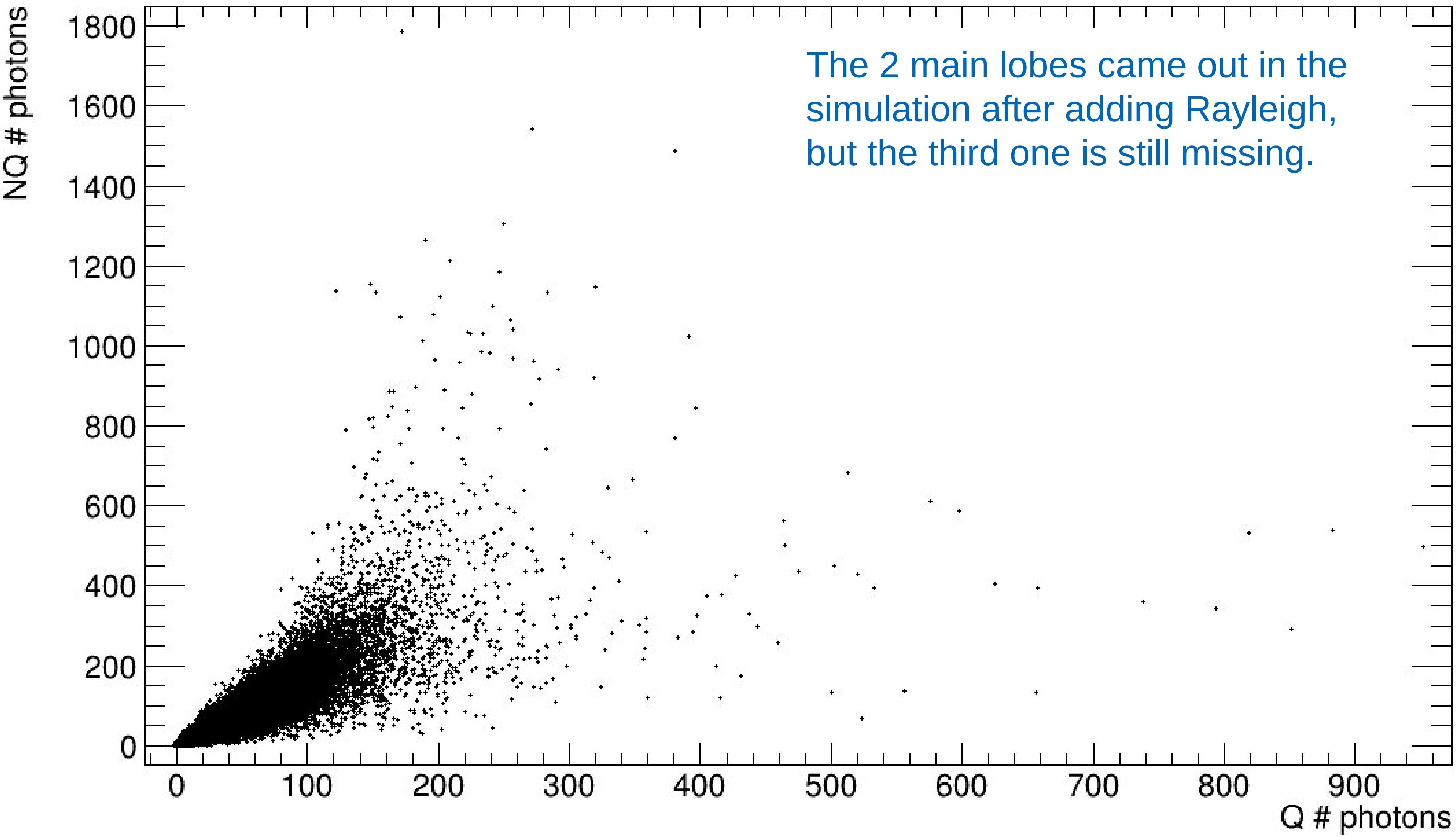
For each photon, we save the angle relative to the normal of the X-ARAPUCA.

The photon must go through all the 6 + 2 grids with a survival probability given by the formula above.

Doping 5 Scatter plot

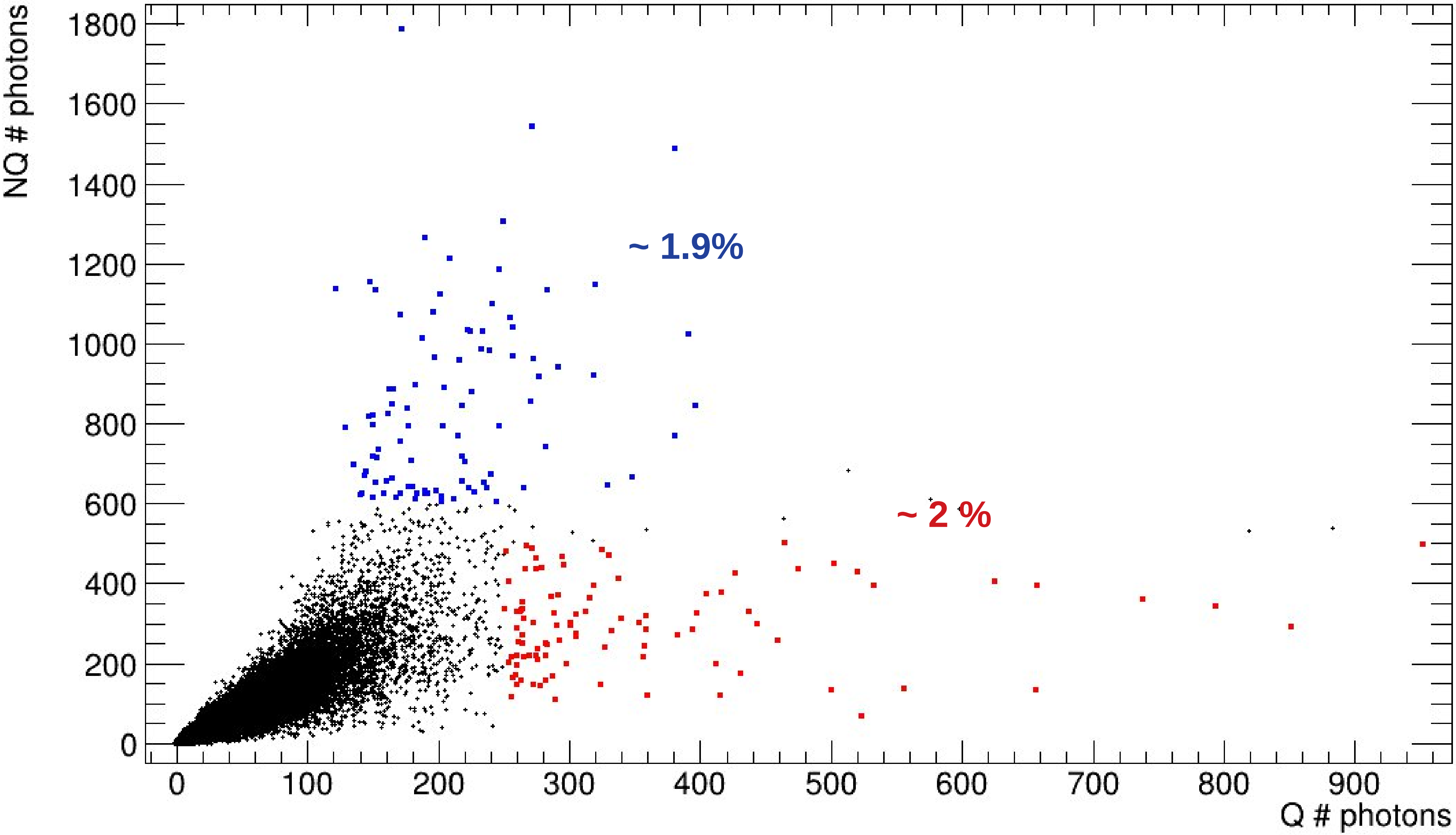


MC - Results



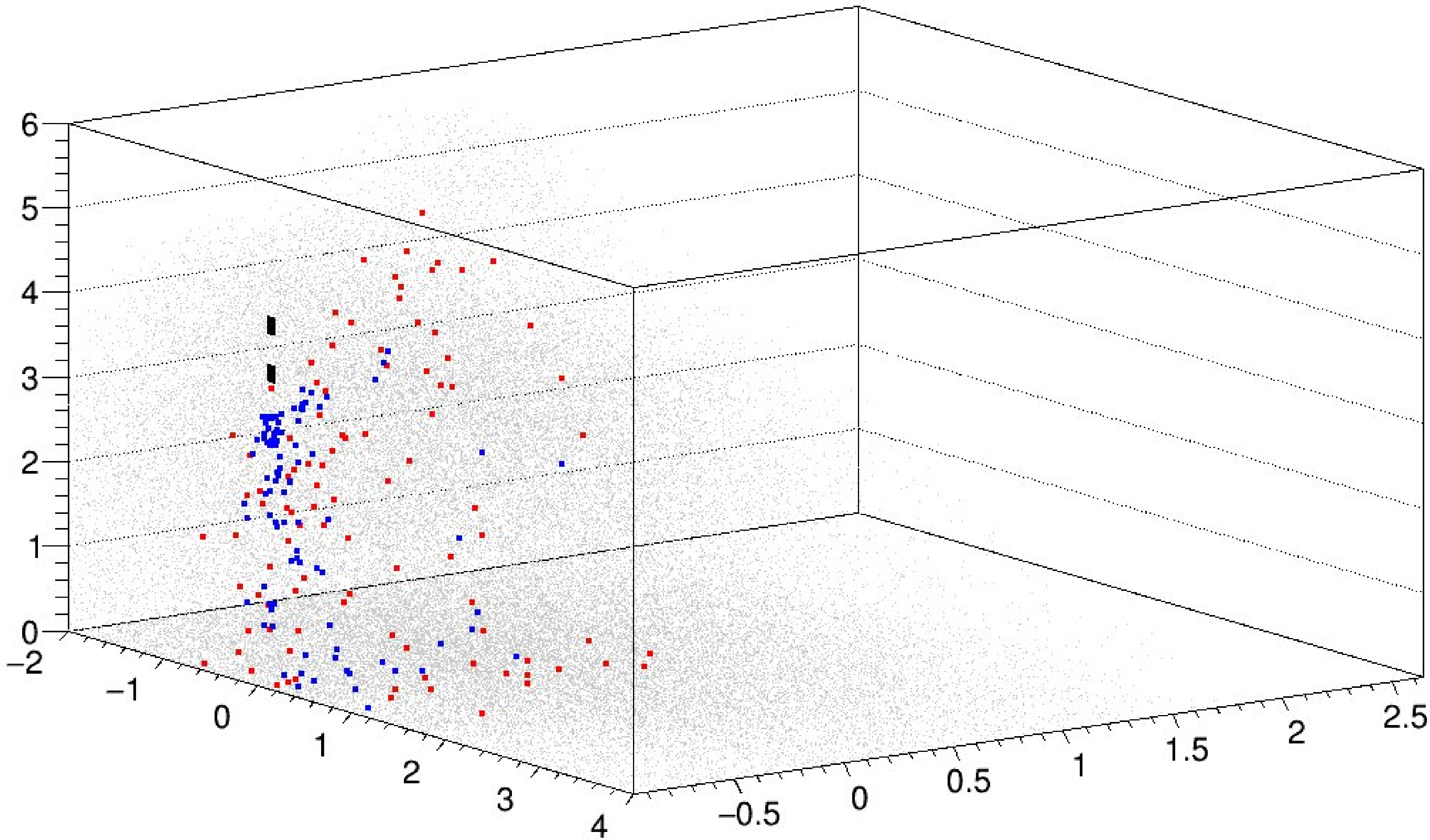
NQ # photons
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
Q # photons
The 2 main lobes came out in the simulation after adding Rayleigh, but the third one is still missing.

MC - Results



NQ # photons
1800
1600
1400
1200
1000
800
600
400
200
0
~ 1.9%
~ 2 %
0
100
200
300
400
500
600
700
800
900
Q # photons

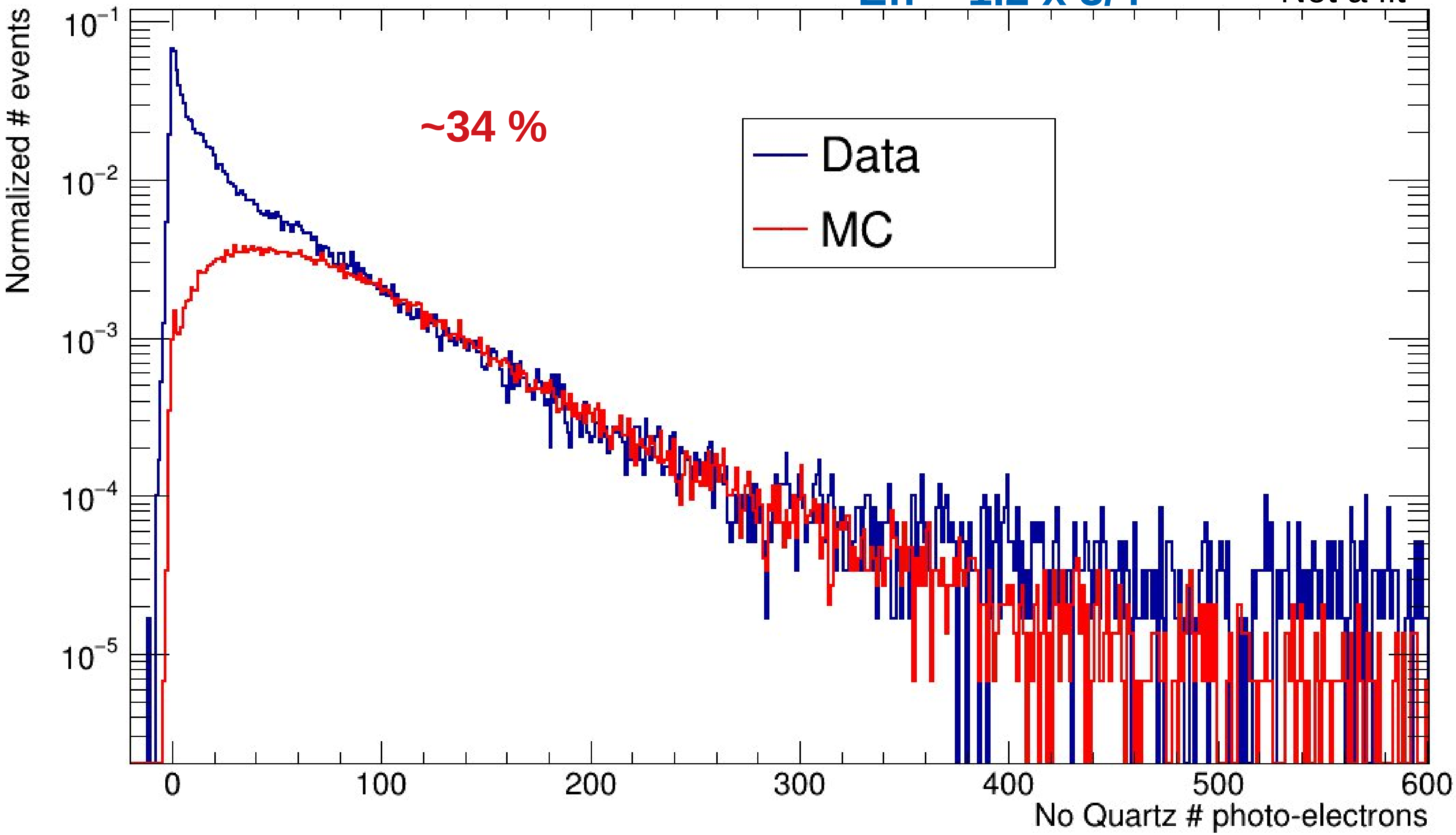
MC - Results



MC - Results

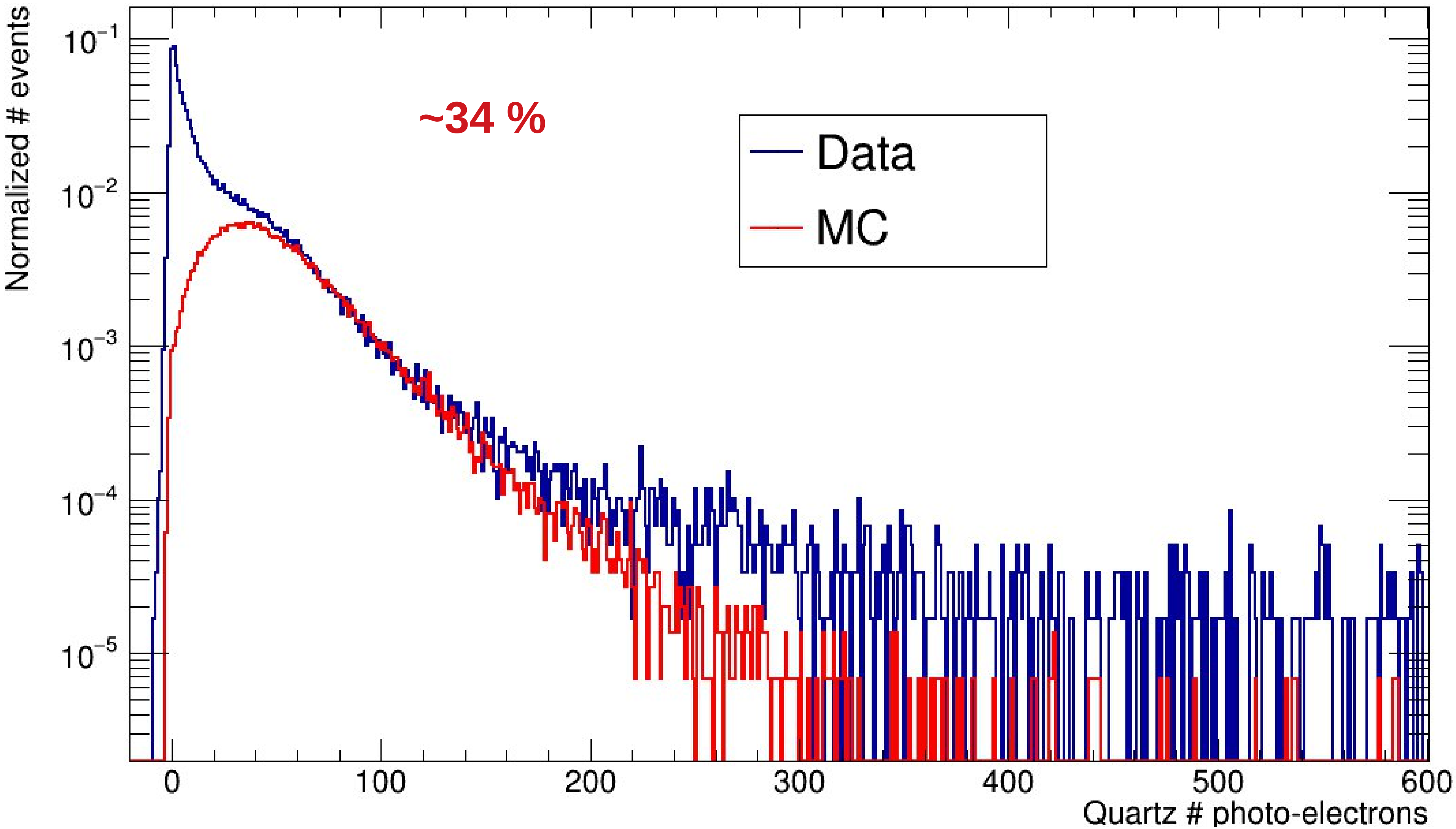
Eff = 1.2 x 3/4

Not a fit

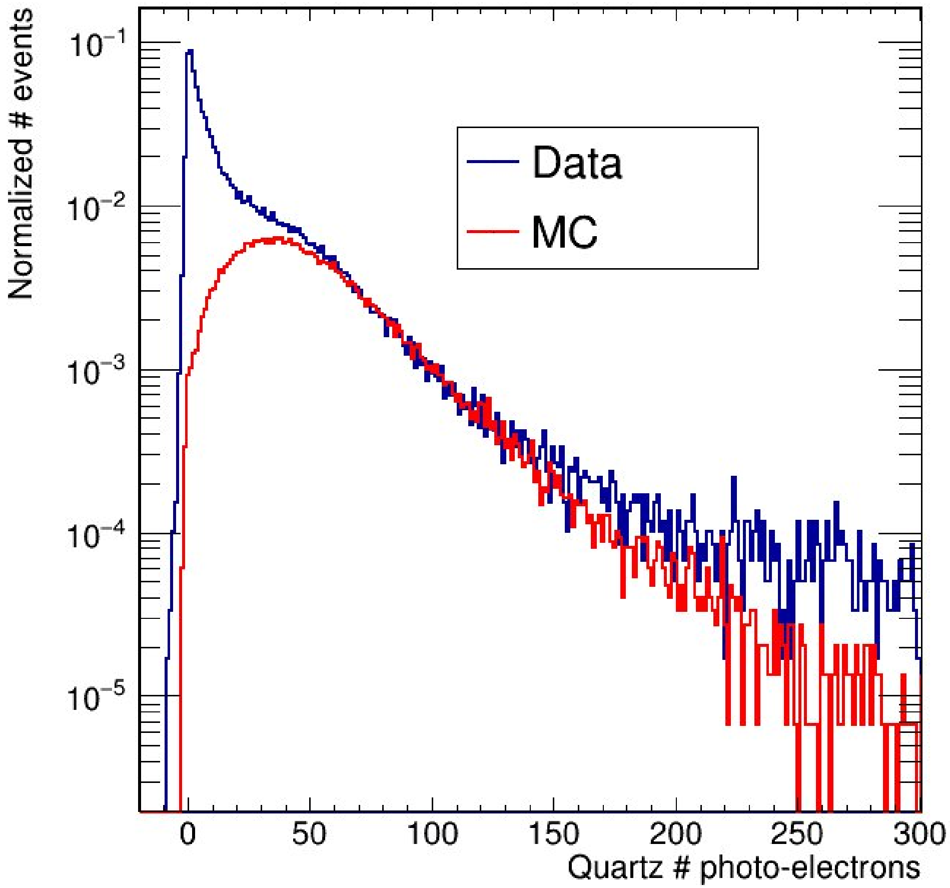


MC - Results

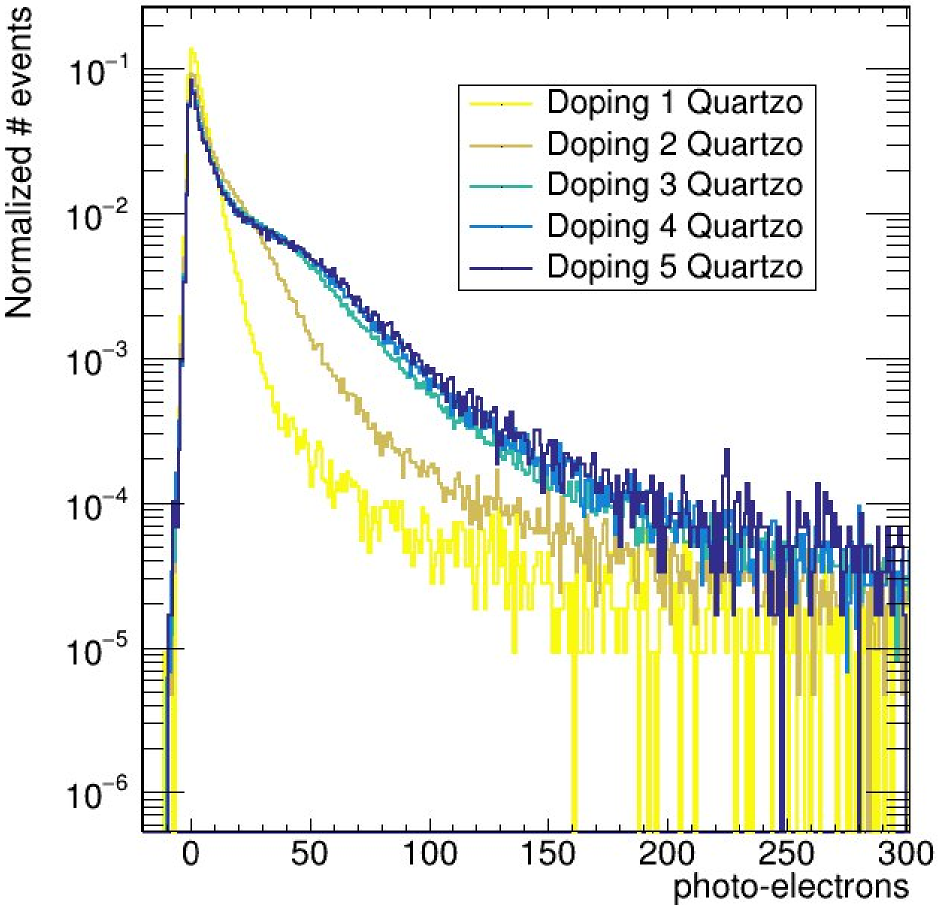
Eff = 1.2 x 3/4 x 0.8 Not a fit



MC vs Data



Normalized # events
Data
MC
Quartz # photo-electrons



Normalized # events
Doping 1 Quartzo
Doping 2 Quartzo
Doping 3 Quartzo
Doping 4 Quartzo
Doping 5 Quartzo
photo-electrons

Summary

- Start from the problem with the two lobes we decided to investigate with a Toy Monte-Carlo simulation

- Toy model Monte-Carlo indicates that the two lobes are mainly geometrical effects with Rayleigh scattering.

- 3rd (and 4th) lobes did not show up in the simulation. Possible causes are still to be investigated. (Cherenkov, muons passing the APA, APA modules shadowing ?)

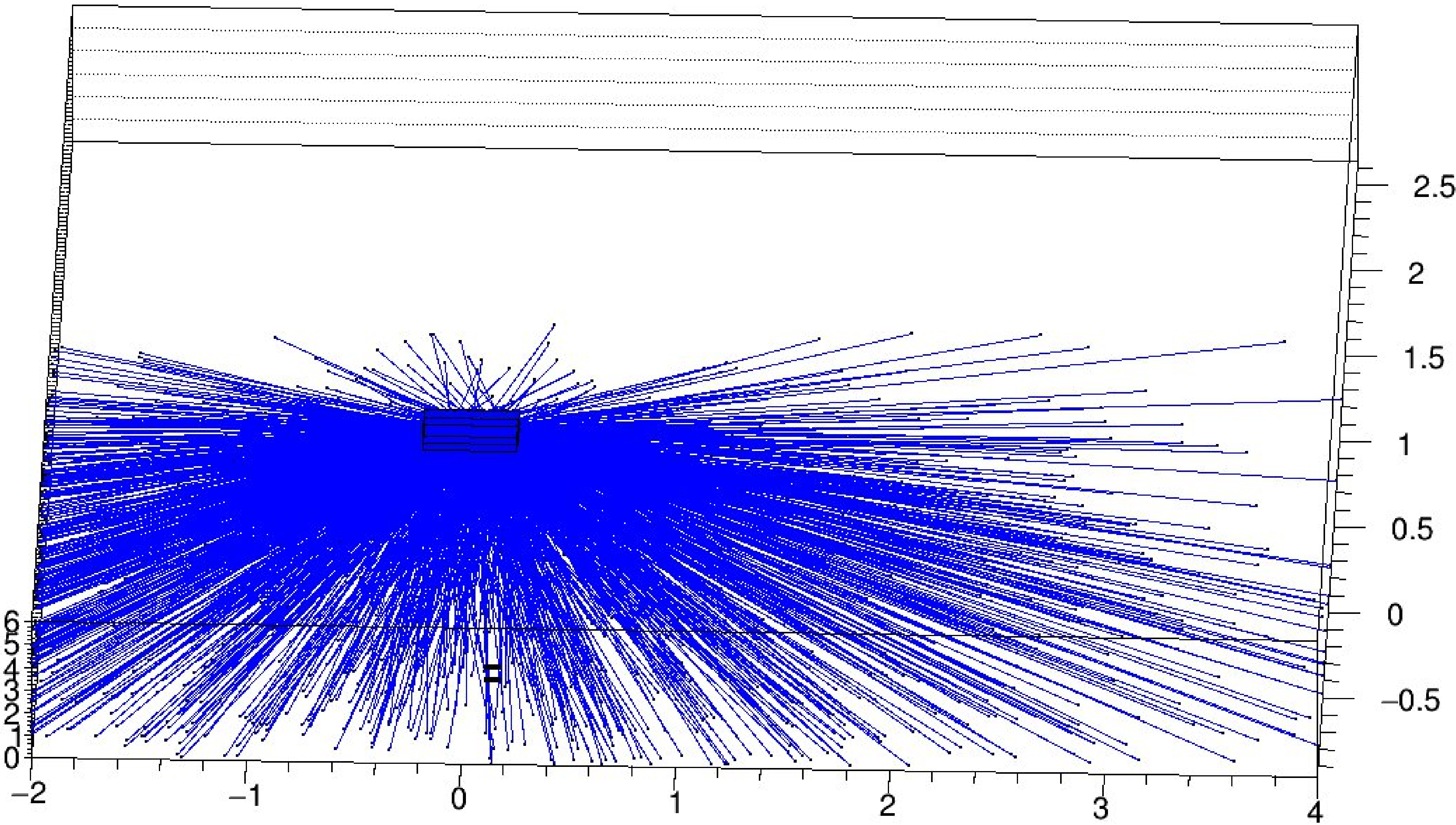
- The Biggest difference between data and simulation is the amount of events with zero or few photons (atmospheric showers giving "false triggers" ?)

- For MC simulation, average number of photons per trigger has a linear relation with Light Yield

- If we don't consider the Quartz window blocking light, MC simulation gives a ratio Xe/(Xe+Ar) ~7% higher than the one set. (we set 0.70 and the output was 0.75. With Quartz window the output is 0.6 → 0.75*0.8)

Backup slides

Backup slides



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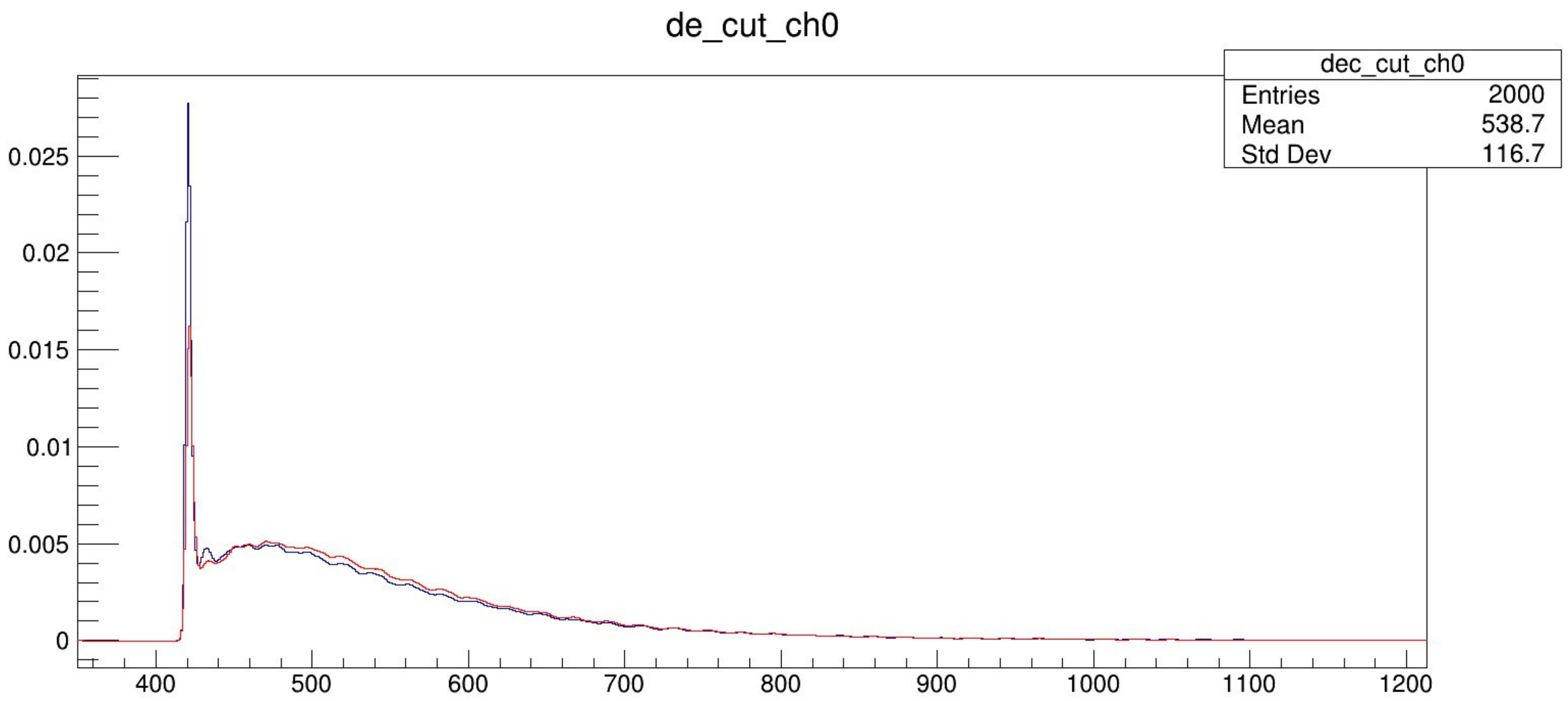

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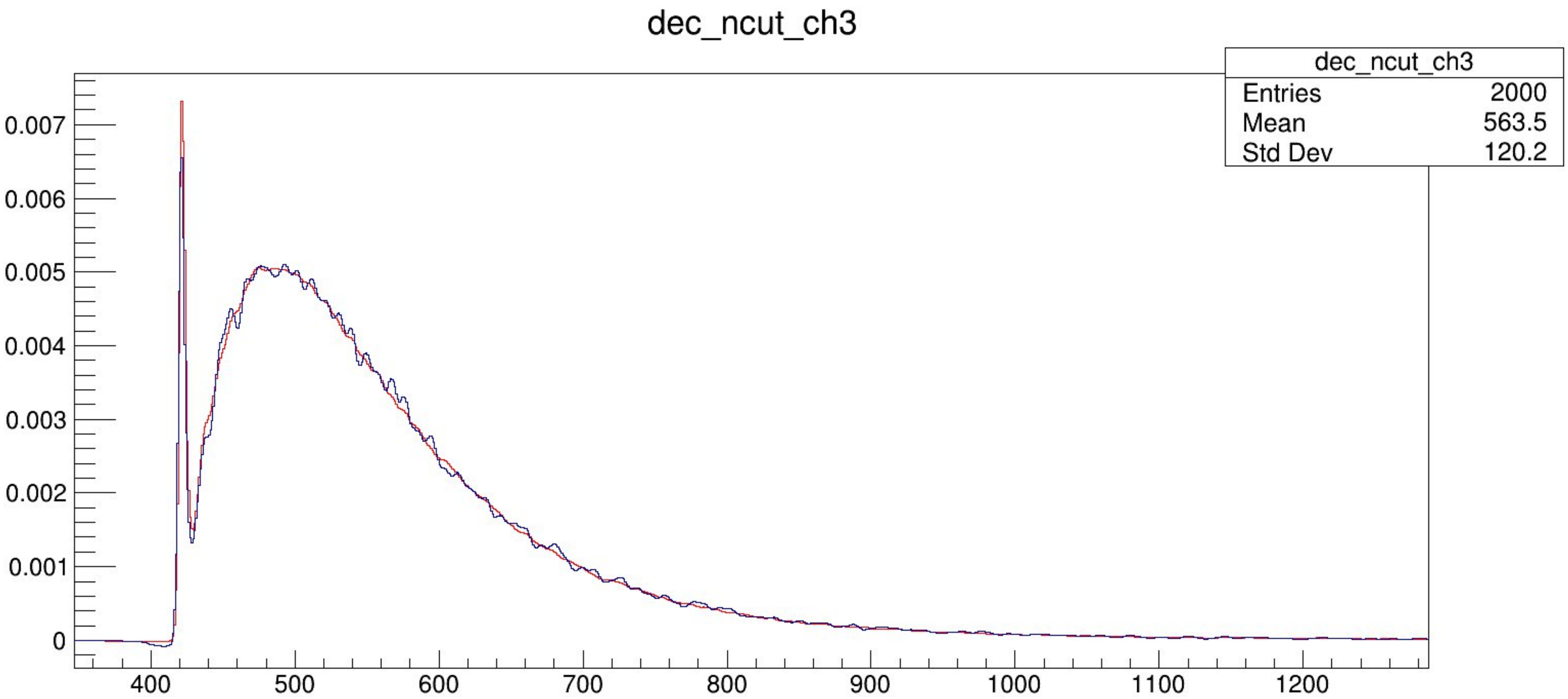

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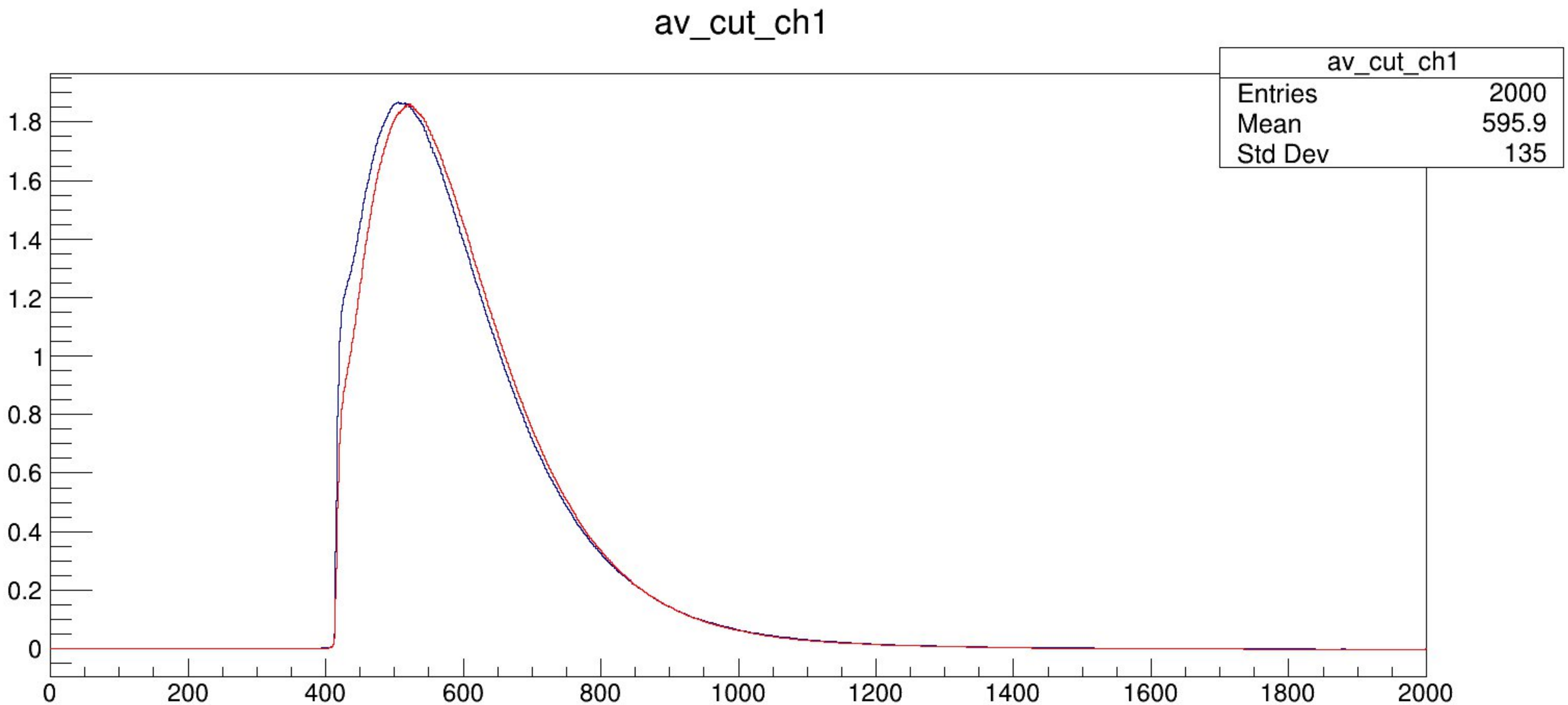

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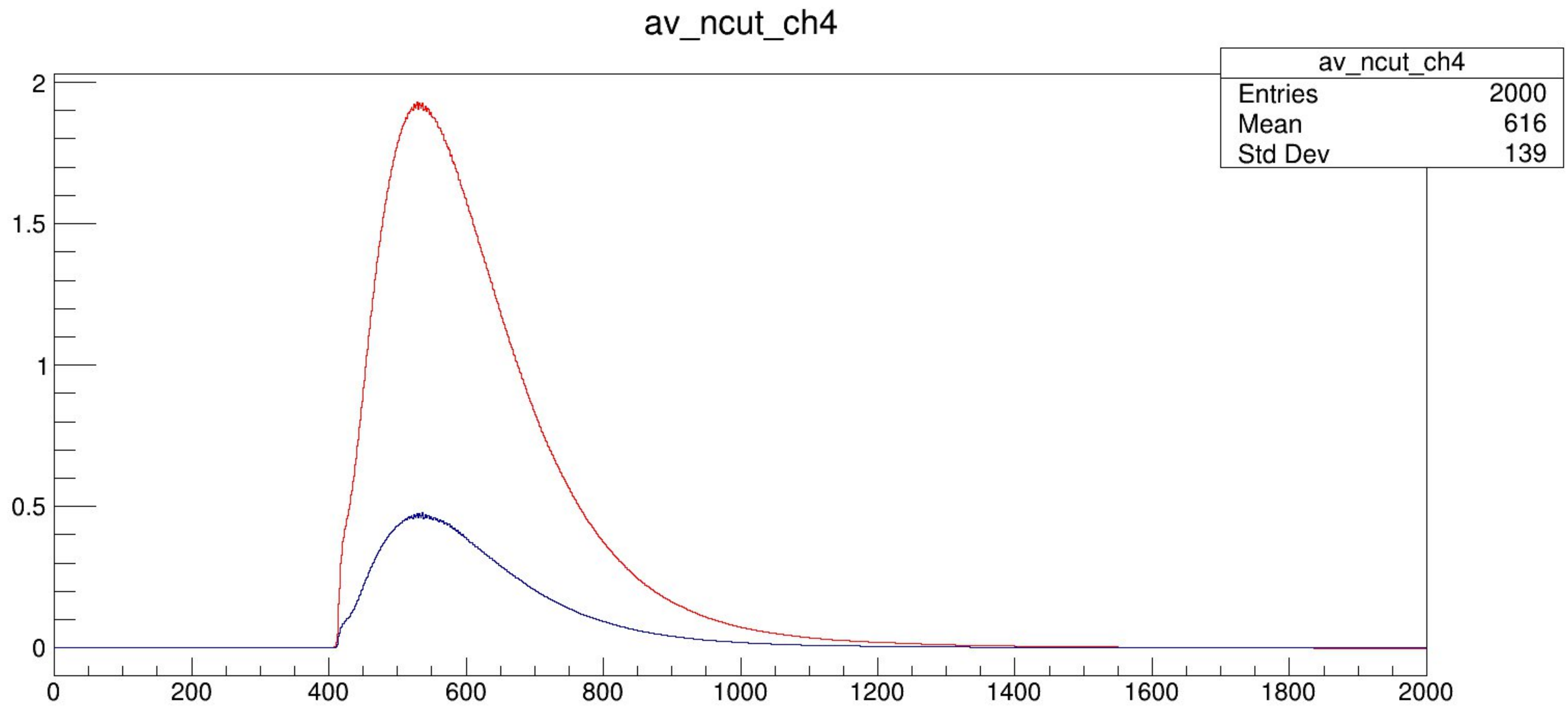

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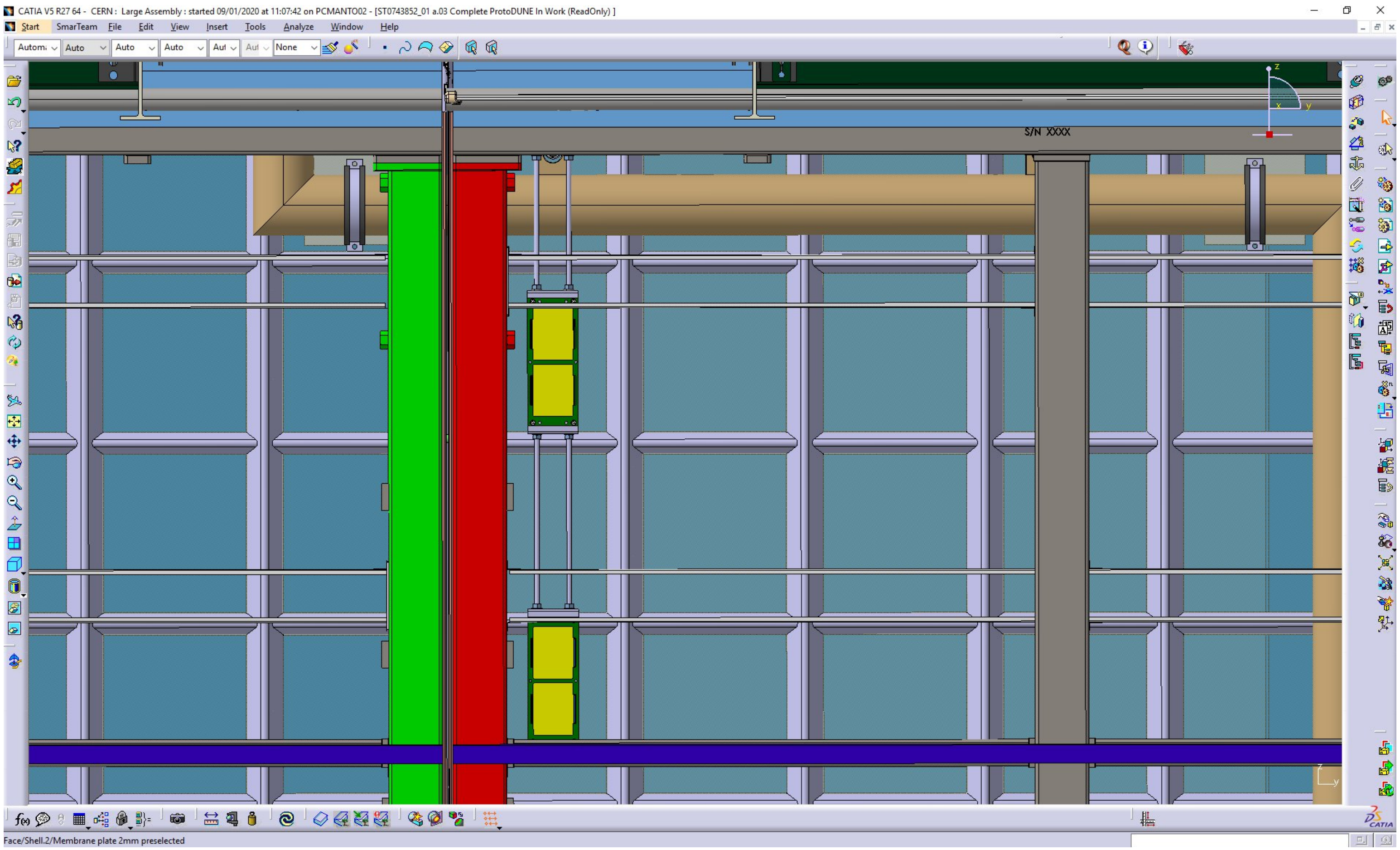

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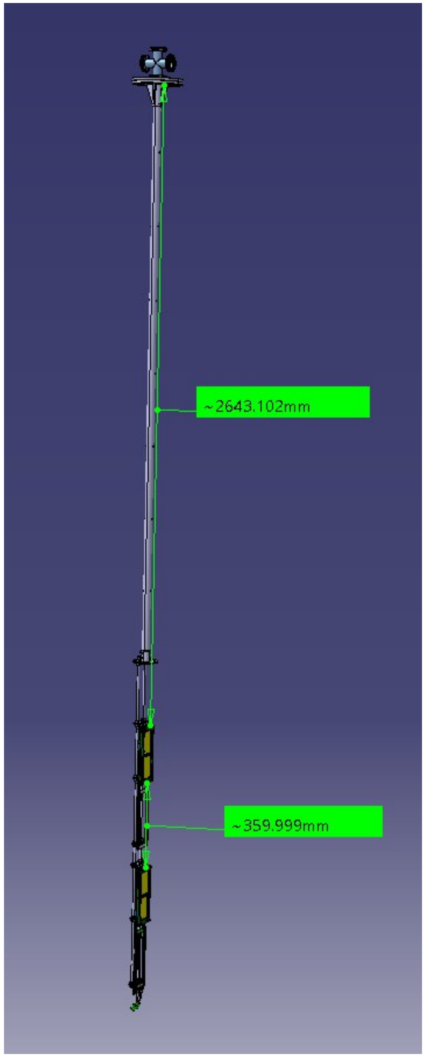

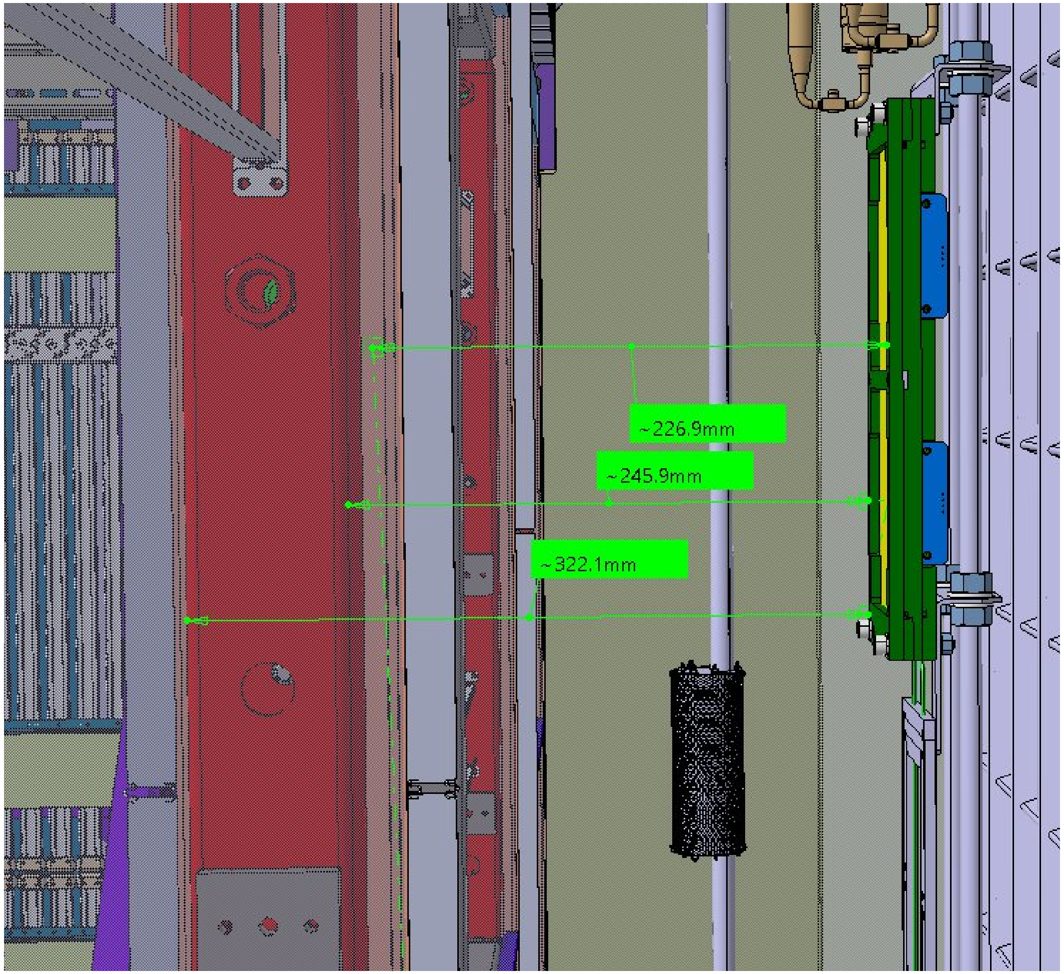

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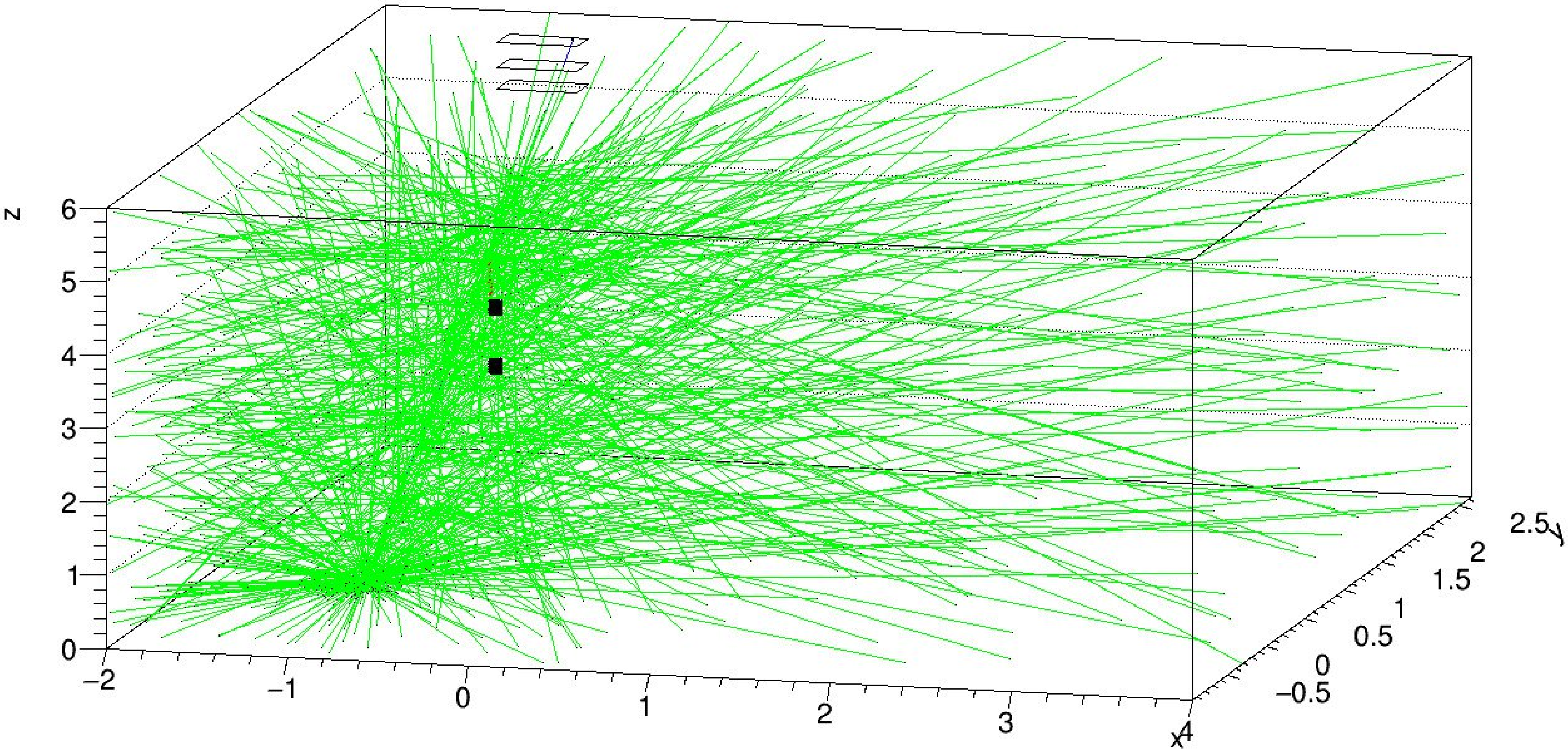
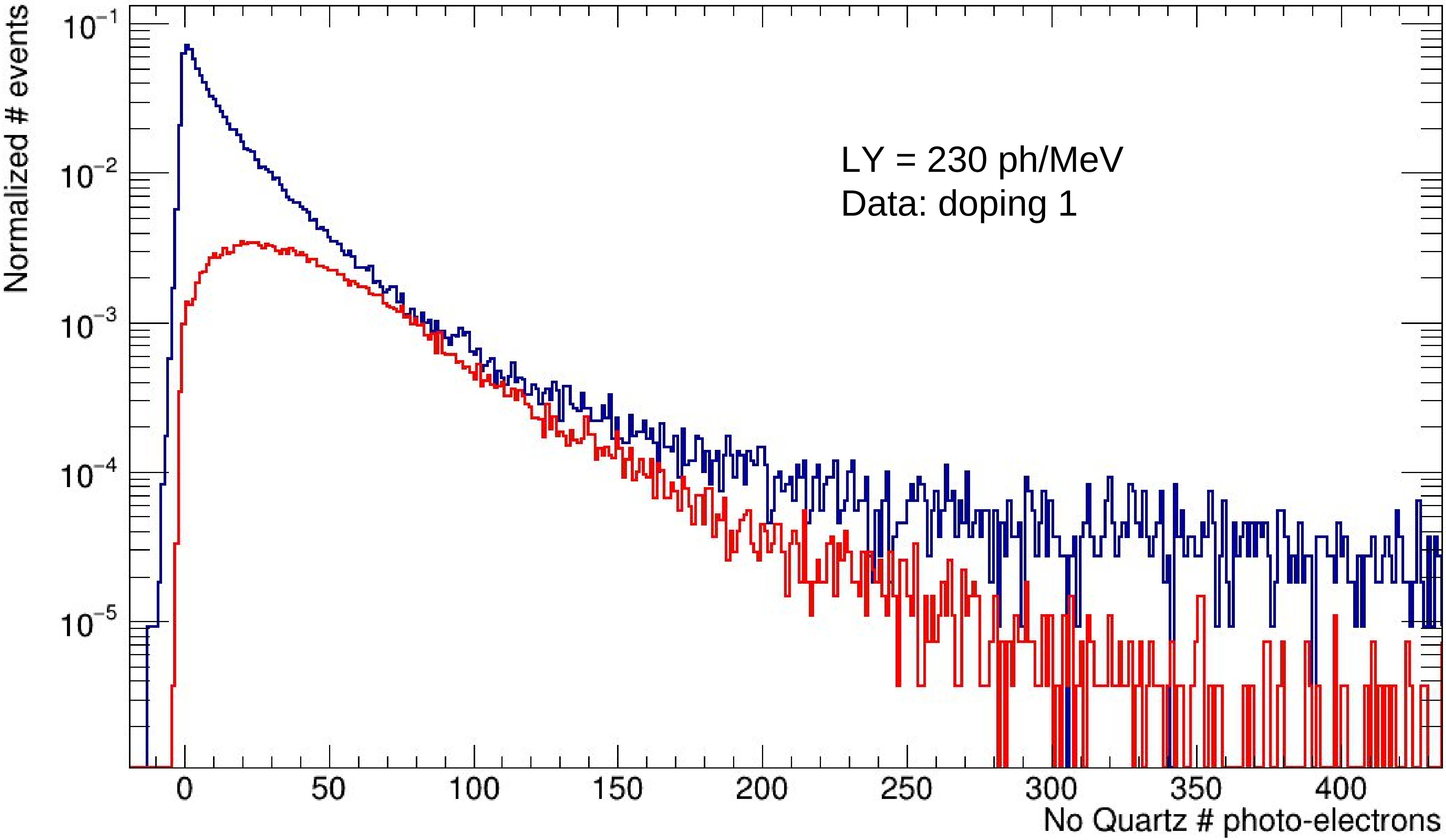
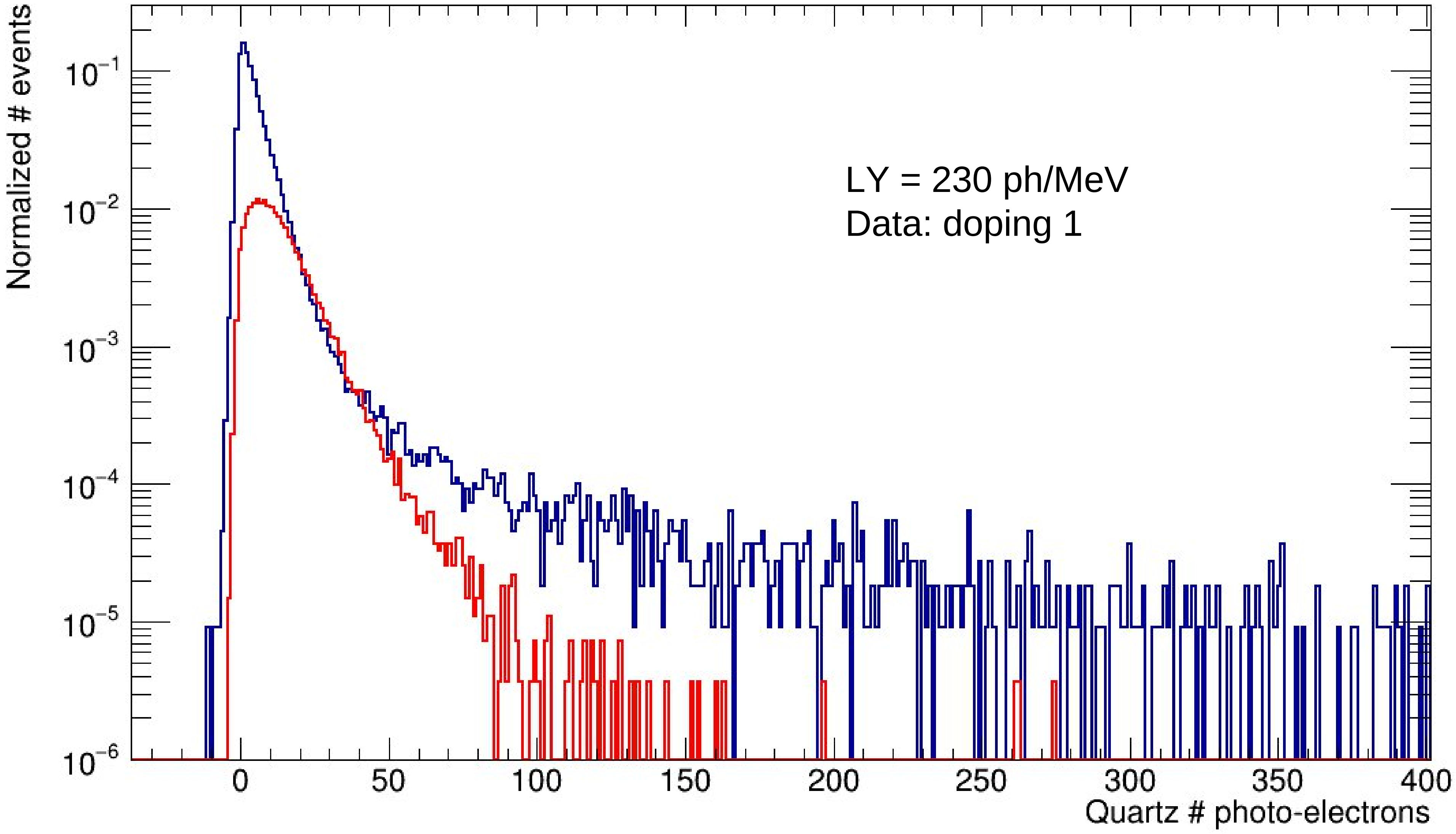


No Rayleigh scattering

Backup slides



Backup slides



Backup slides