GEM Simulation

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Background and Motivation

Relativistic Electron ionizes gas to create primary electrons

Primary electrons deposit their energies to secondary electrons until not enough energy to further ionize

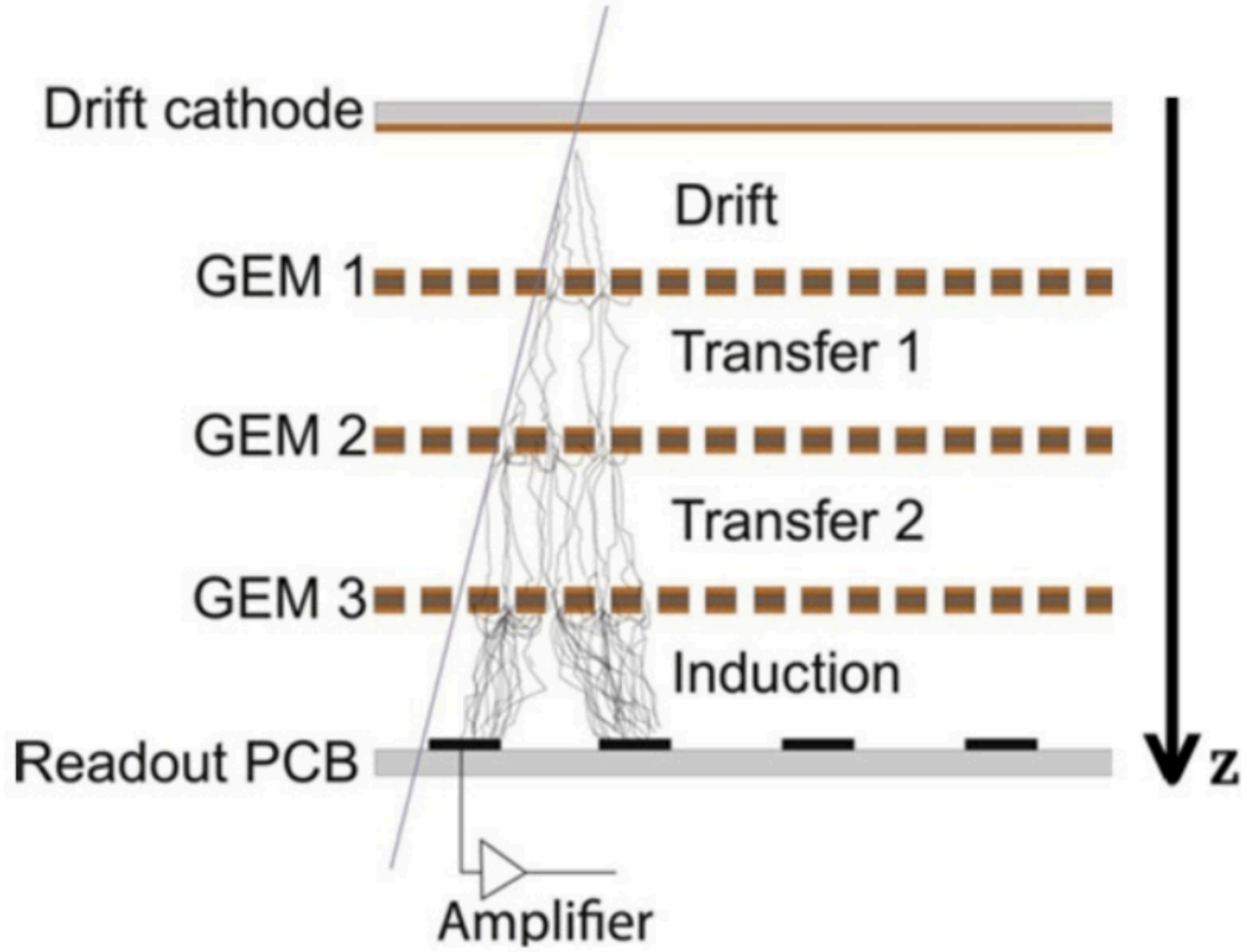
Secondary electrons are pulled by E-Field to gems which cause cascading showers

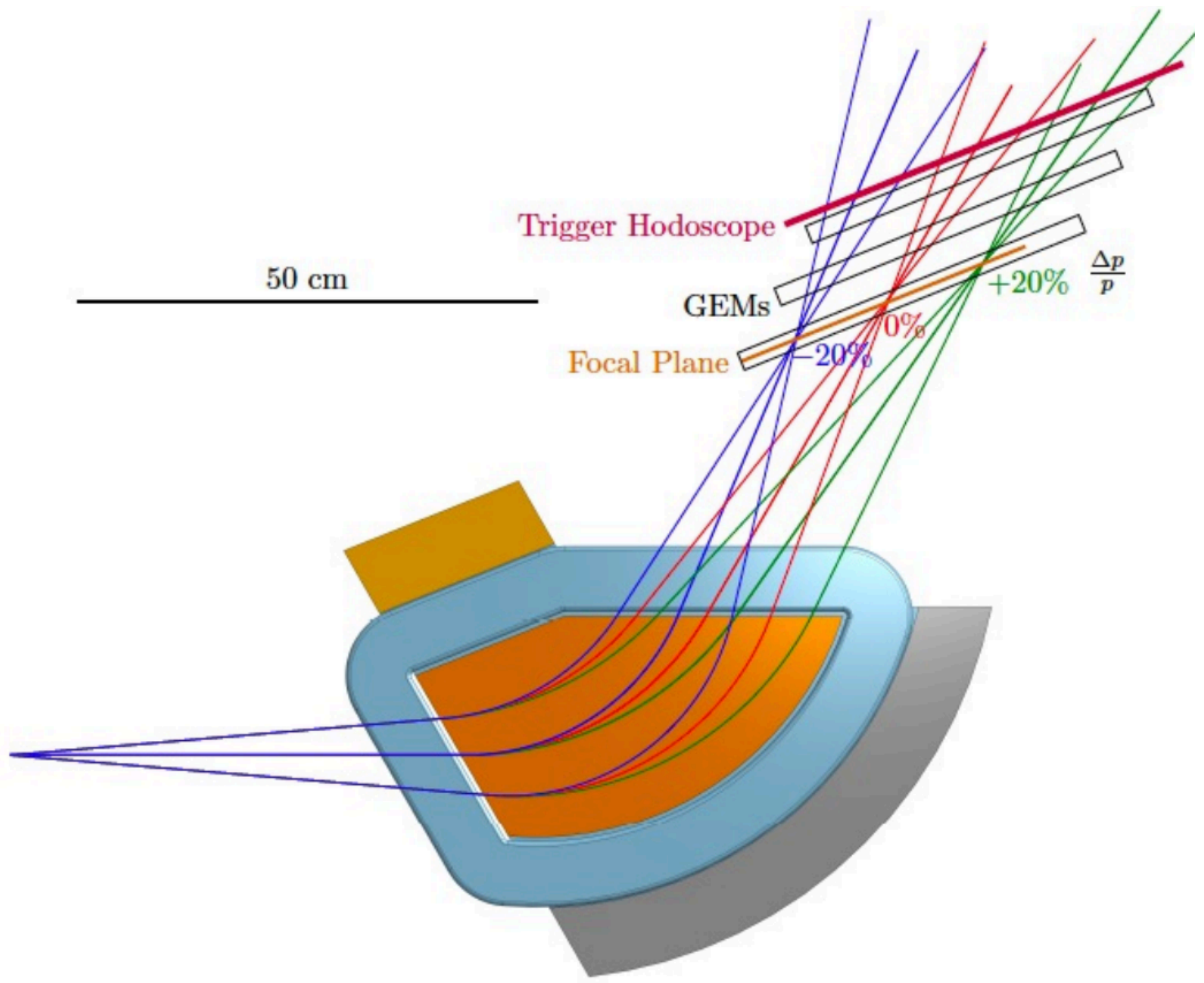
Relativistic electrons may generate several primary electrons

If electrons have significant incident angle, multiple showers will cause a “smear” over readout wire grid

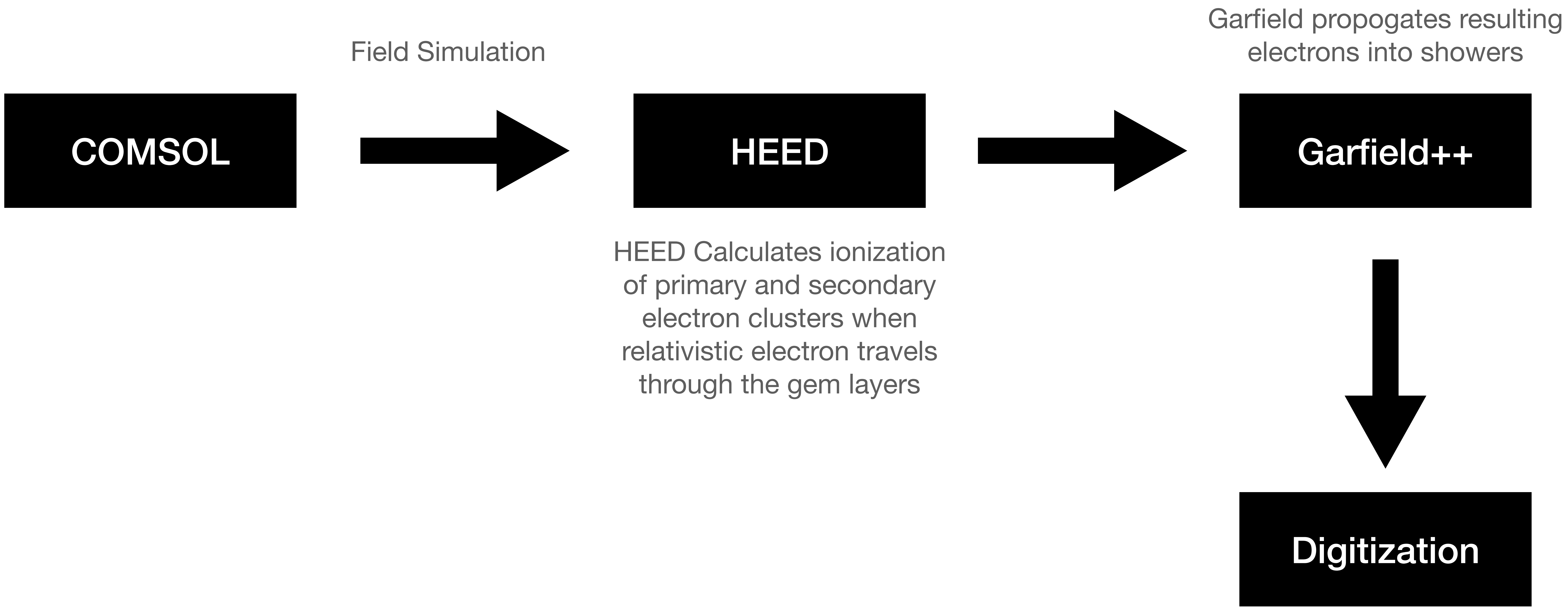
In Darklight, electrons will have large angle of incidence, thus would decrease spatial resolution

Goal is to understand distribution of electrons at readout wires with shallow incident angles





Simulation Overview



Simulating Showers

Over each layer of gems, 1-2 primary electrons are excited, each which also excits 1-2 secondary electrons

Each layer of Gems have gain~25 per electron -> ~40,000 electrons after 3 layers

In practice, simulating showers caused by each electron over 3 layers of gems is computationally impractical

Simulating Showers

Computational Workaround

To prevent having to simulate each shower in the cascade, monte carlo simulations are used to measure the spacial, temporal, and gain distribution of showers and then parameterized.

Showers can be simulated by sampling electrons through parameterized distributions

Garfield++ would not need to simulate each electron shower

Simulating Showers

Computational Workaround

After HEED determines position of secondary electrons, Garfield++ “drifts” electrons through E-field to find which holes they enter

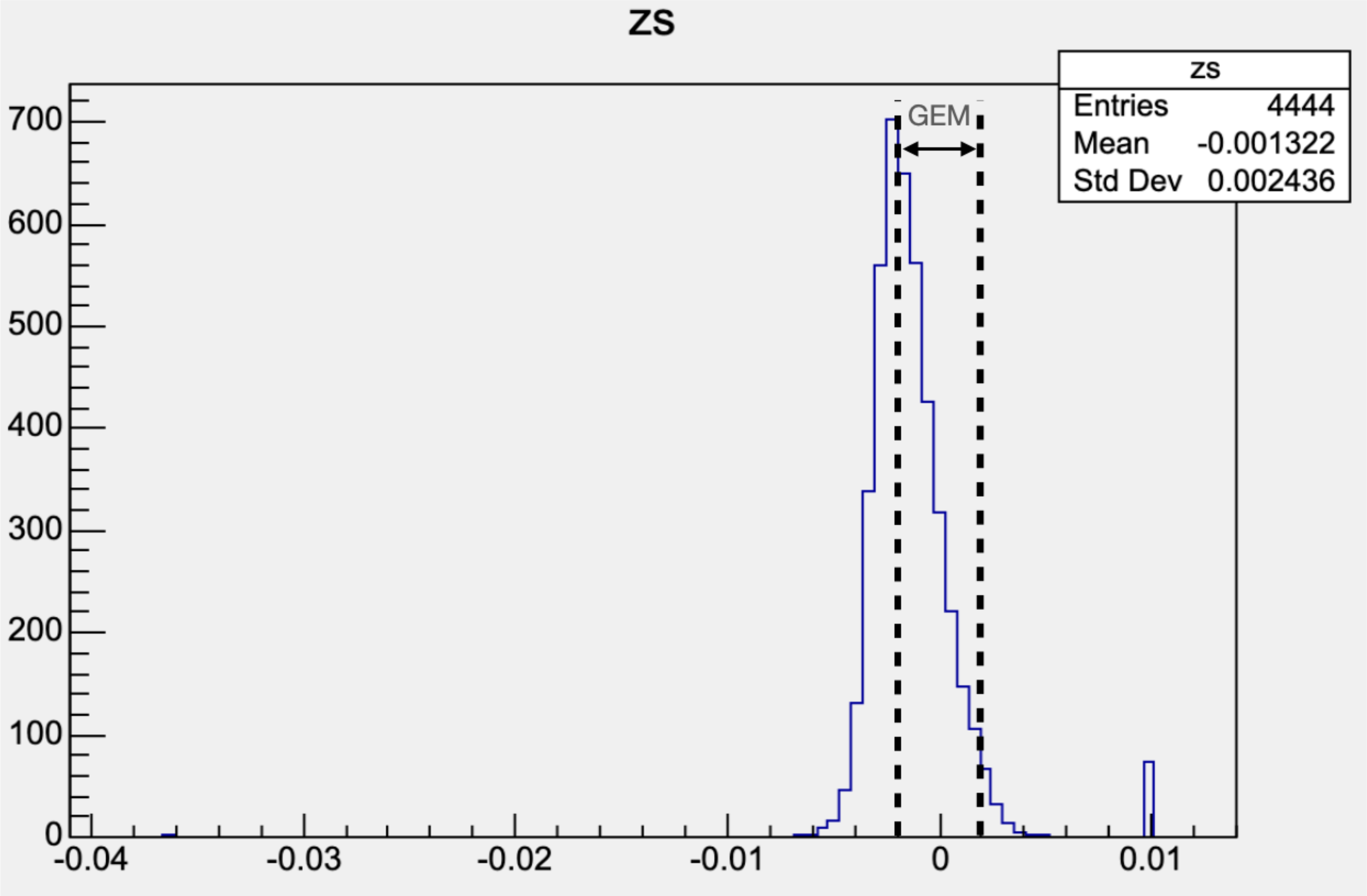
Showers are generated from parameterized distributions

Randomly generated shower electrons are then placed above next GEM layer and drifted again to determine which hole they enter

This works and can be accurate because ionization only happens in GEM holes

Ionization

Generation of shower electrons happen between holes



Simulating Showers

Determining shower gain and spread distributions

Electrons are randomly placed above GEM Holes and resulting distribution and gain is measured.

Sensors placed 2mm below

$\Delta V_{gem} = 400,$

bottom plate of previous gem and top plate of next gem has 700V diff

70% Ag, 30% CO2

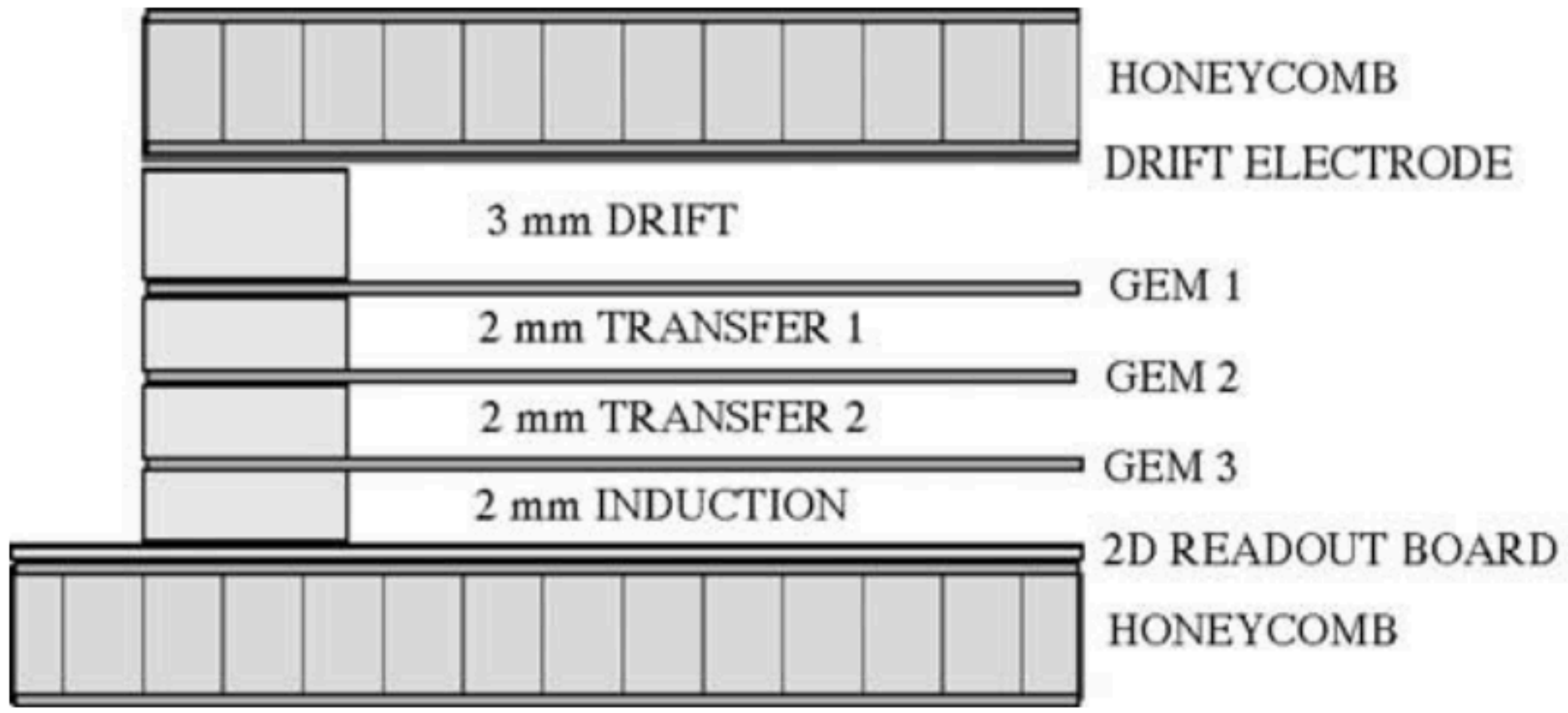


Fig. 4. Schematic cross-section of the triple-GEM detector.

Design of GEM from Altunbas, et al. 2002

Same GEMs as the COMPASS experiment

Sidenote: Voltage Data

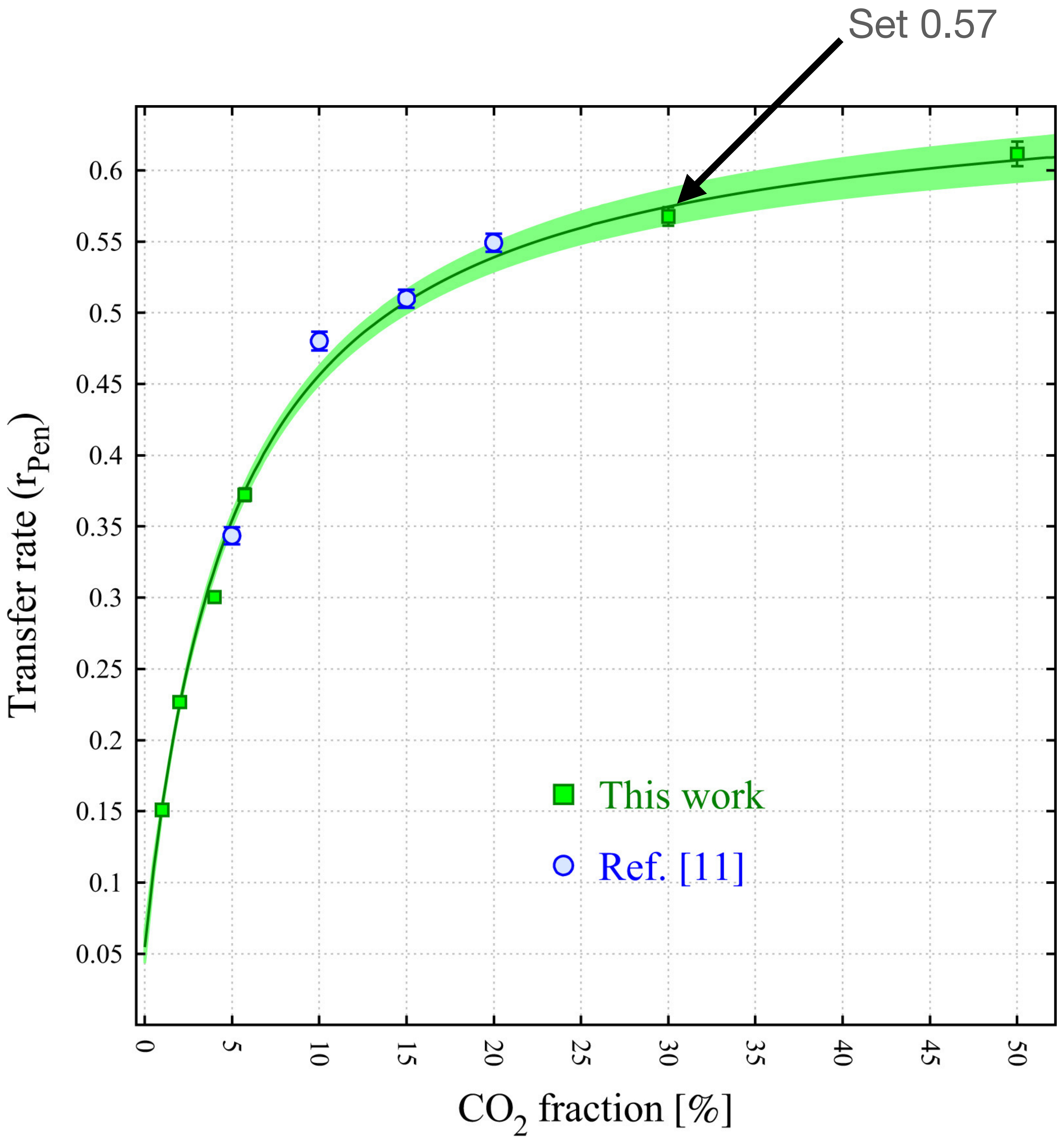
Altunbas, et al. 2002

https://doi.org/10.1016/S0168-9002(02)00910-5

Electrode	Voltage (V)	Field (kV/cm)	ΔV (V)	Gain	ΔV′(V)	Gain′
Drift	−4100	2.49				
GEM1 TOP	−3353		410	50	392	34
GEM1 BOT	−2943	3.73				
GEM2 TOP	−2196		374	23	376	24
GEM2 BOT	−1822	3.73				
GEM3 TOP	−1075		328	8.5	330	9
GEM3 BOT	−747	3.73				
PCB	0		TOT 1112	9775	1098	7344

The last two columns give values in the case of one shorted segment in the first GEM. The quoted values are numerical estimates; exact values vary from detector to detector, both due to geometry and to tolerances of the resistor dividers.

Sidenote: Penning Transfer Rate



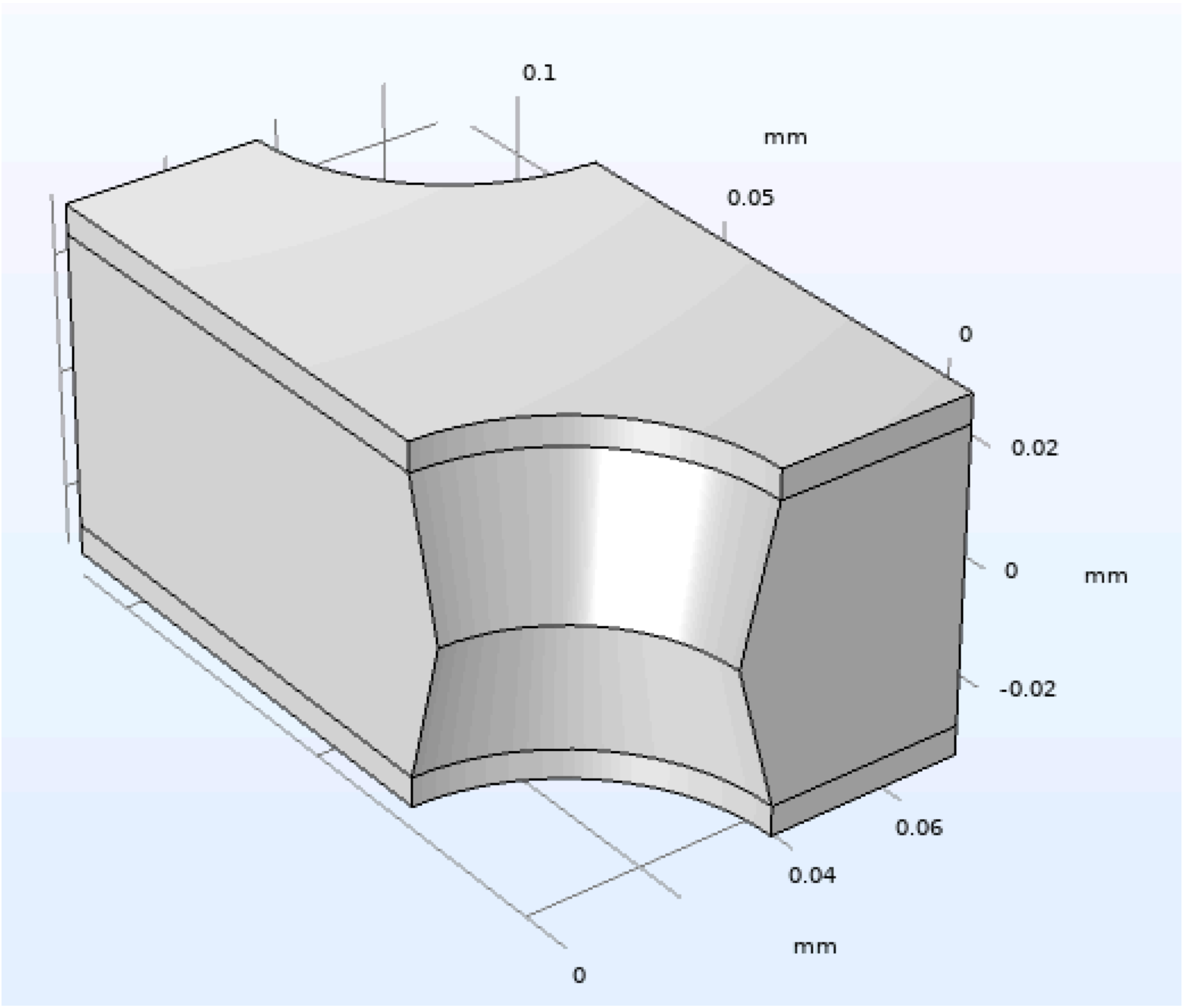
Sahin, et al. 2014

https://doi.org/10.1016/j.nima.2014.09.061

Probability that excited Ar ionized CO2, which increases gain

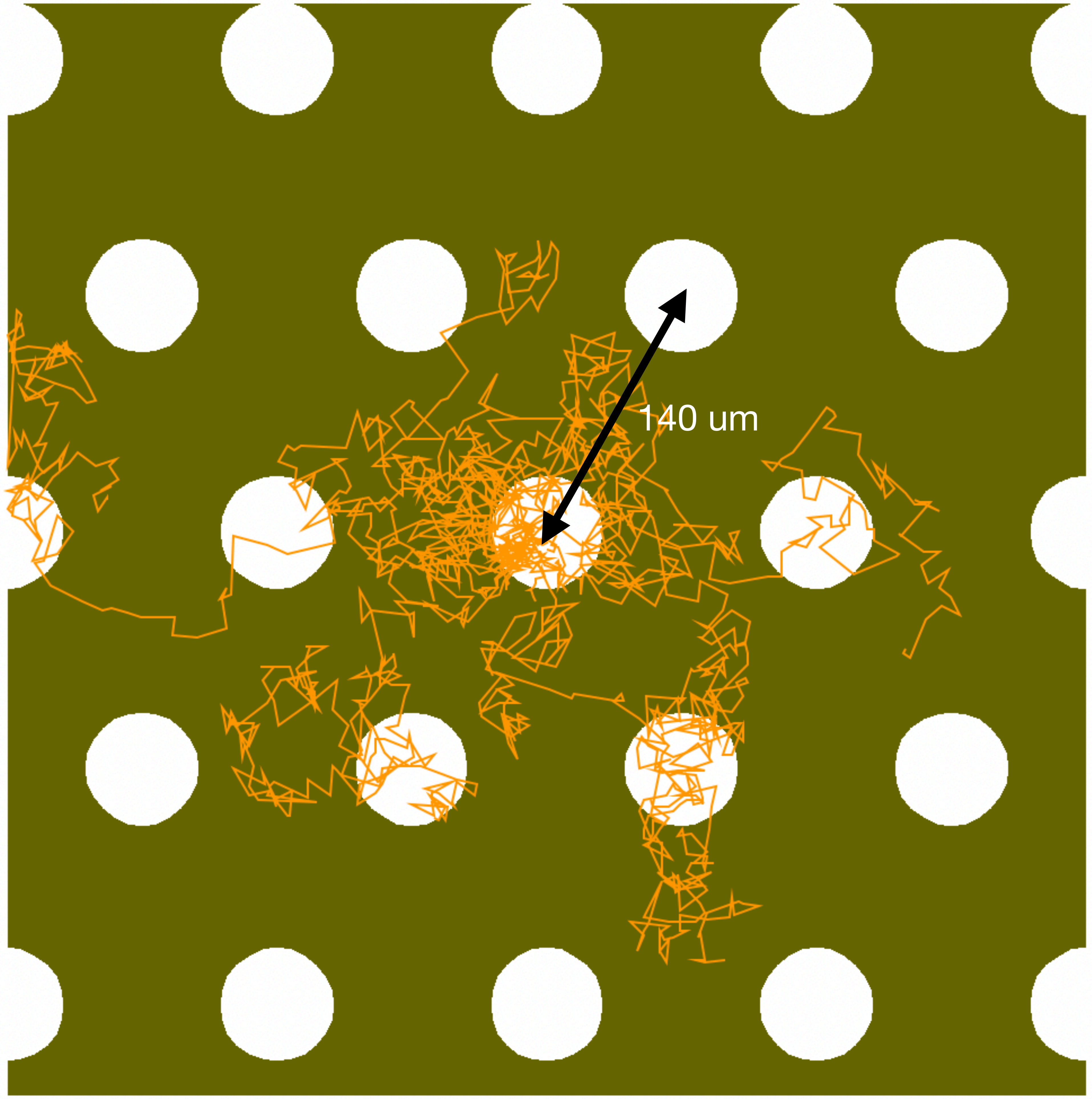
$$\mathrm{Ar}^* + \mathrm{CO_2} \rightarrow \mathrm{Ar} + \mathrm{CO_2^+} + e^-$$

Sidenote: COMSOL model



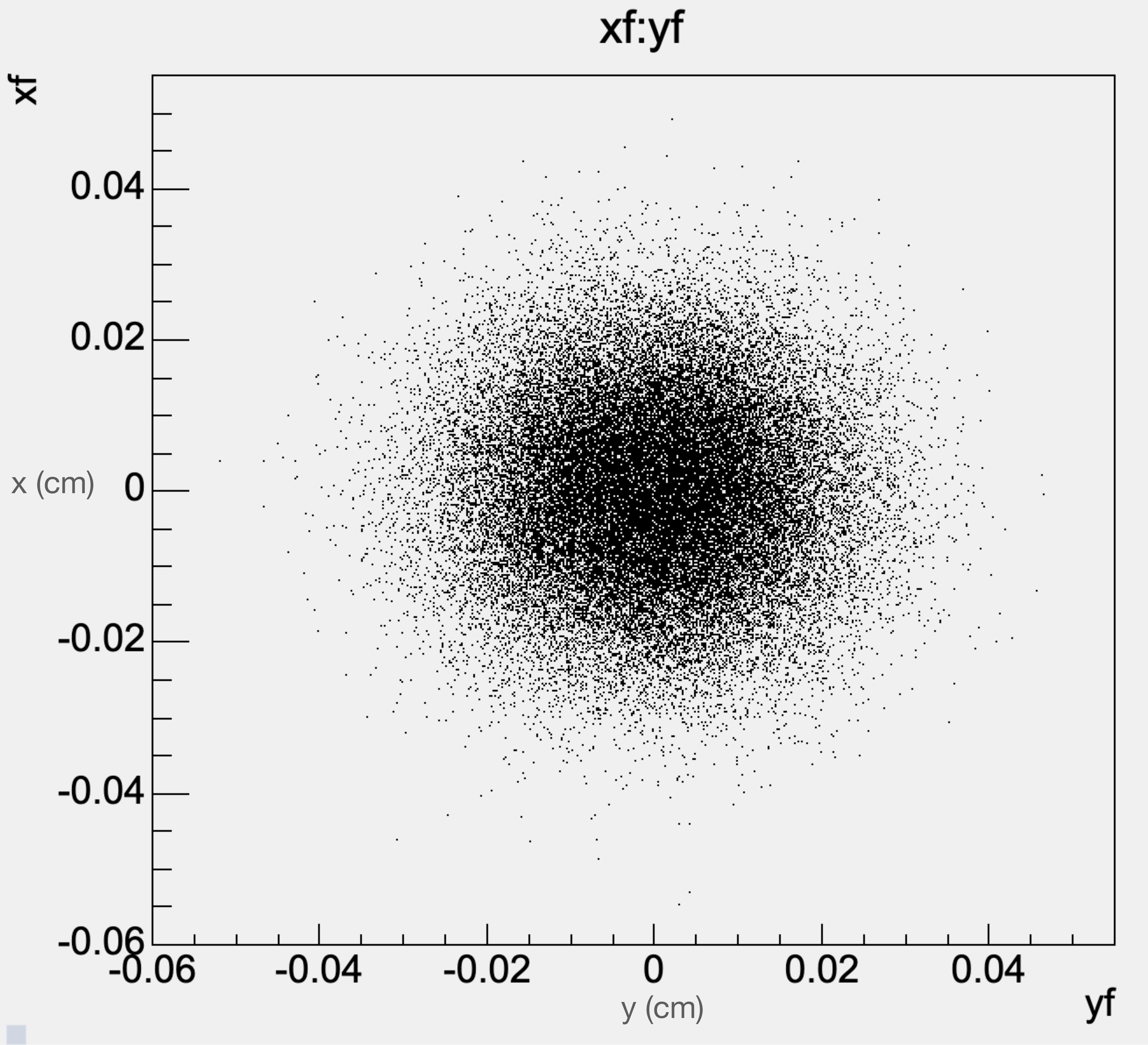
This works because of we can set periodic boundary conditions in comsol

Hole pattern repeated to create grid in garfield++



Simulating Showers

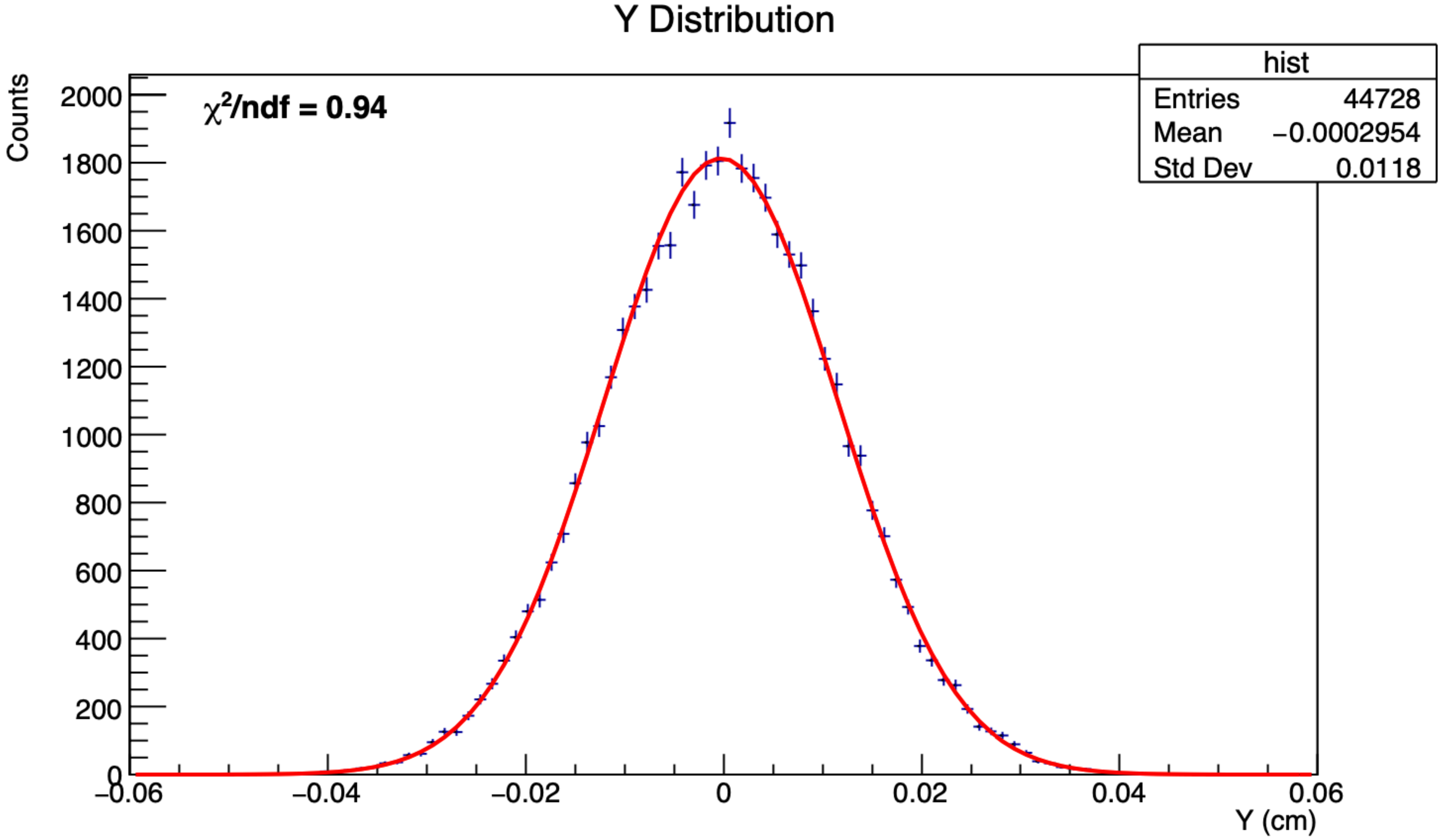
Determining Distribution

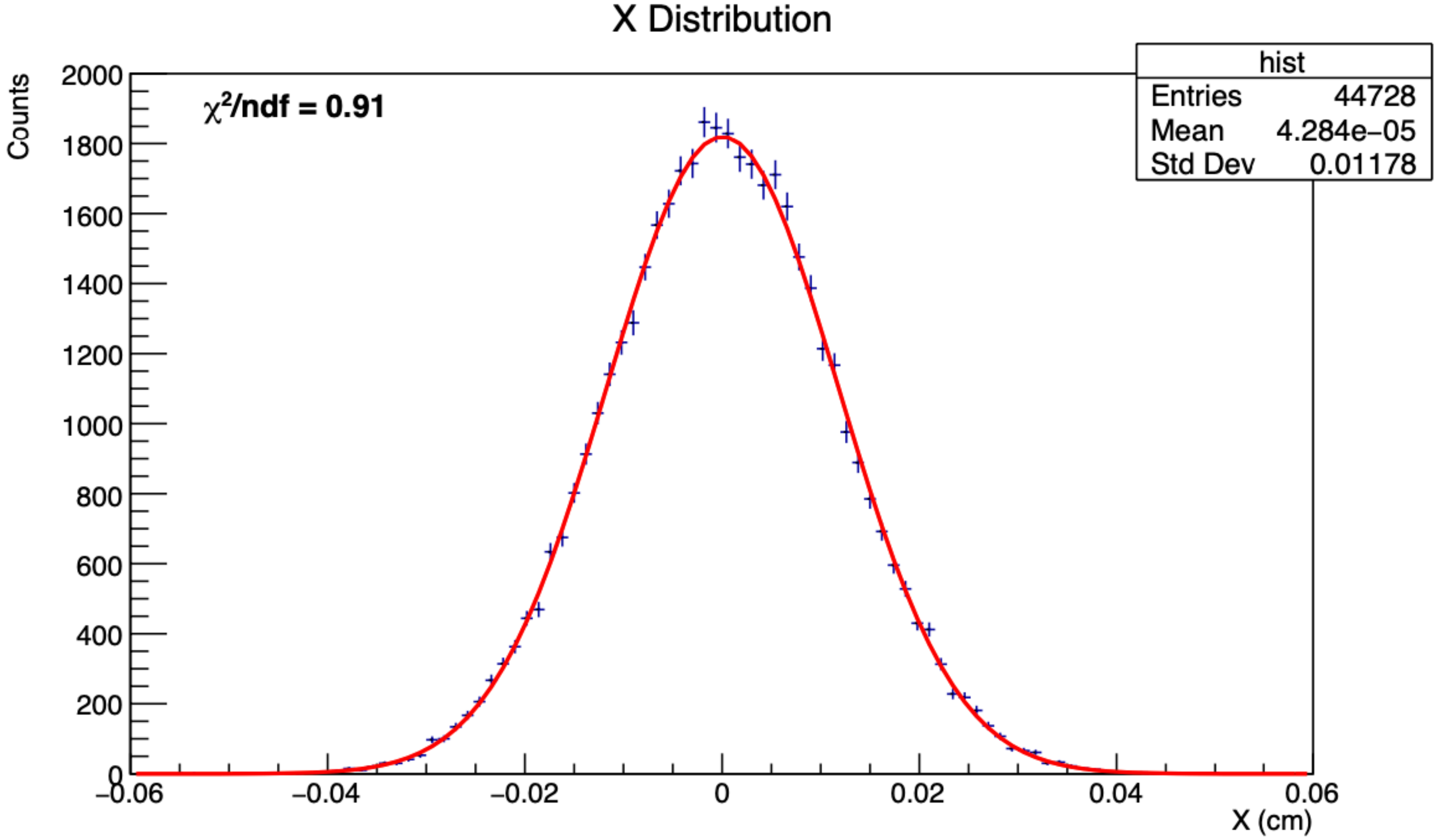


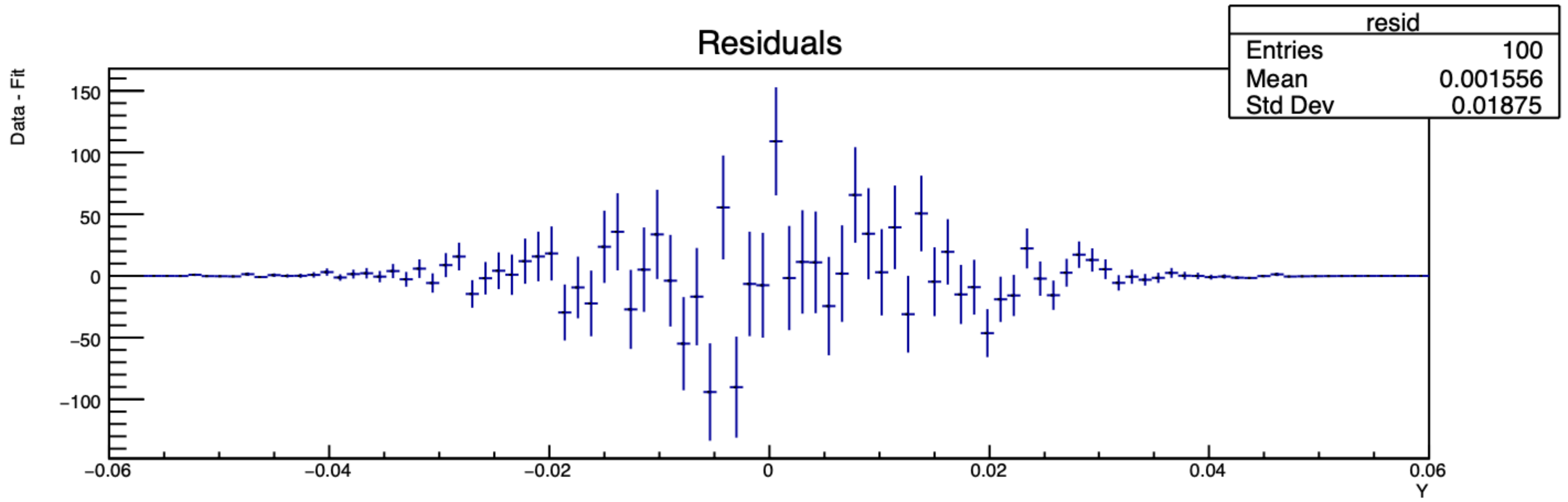
Simulating Showers

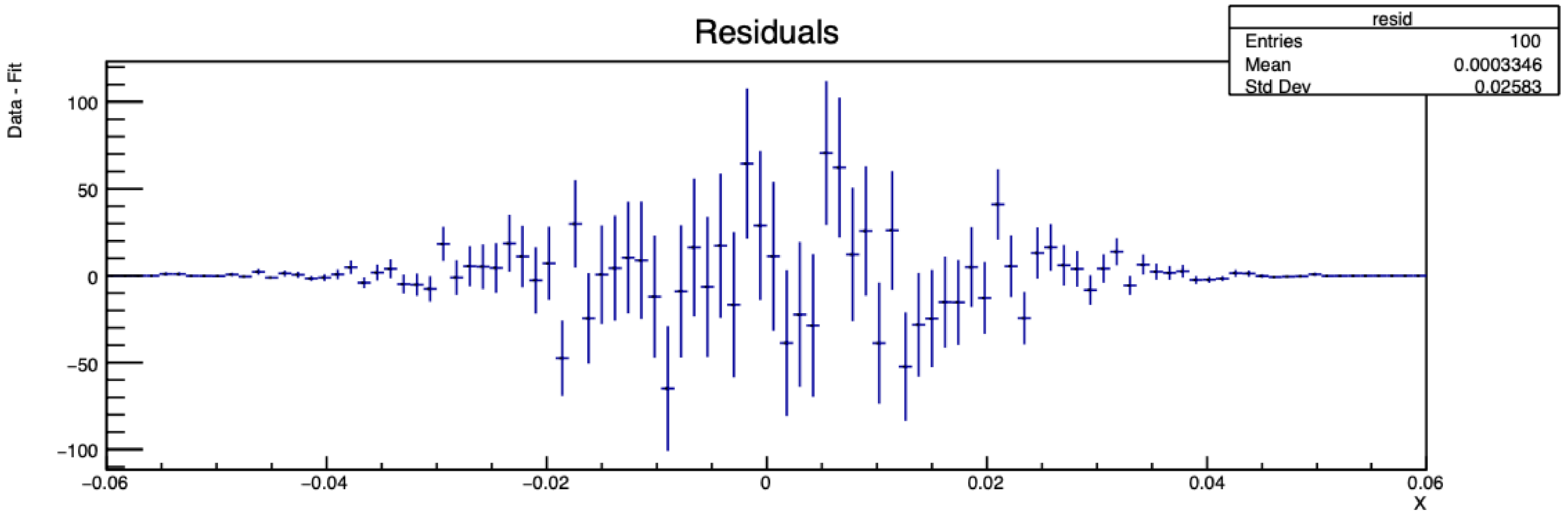
Parameterizing Distribution

Spacial Distribution matches that of gaussian





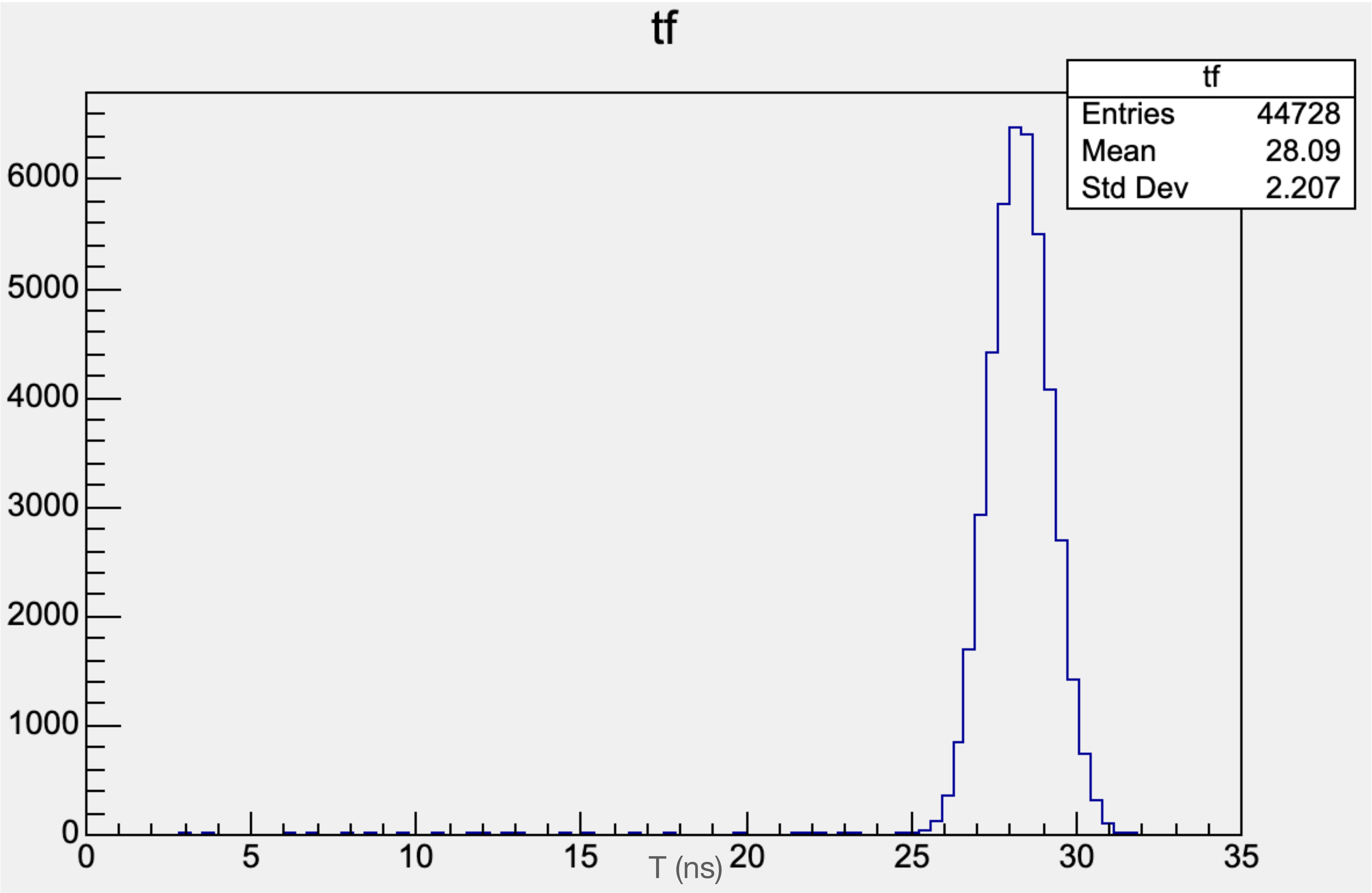




Simulating Showers

Temporal Distribution

Arrival time of electrons on next layer



Simulating Showers

Determining Gain

Altunbas, et al. 2002

https://doi.org/10.1016/S0168-9002(02)00910-5

Simulated GEM 1

Electrode	Voltage (V)	Field (kV/cm)	ΔV (V)	Gain	ΔV′(V)	Gain′
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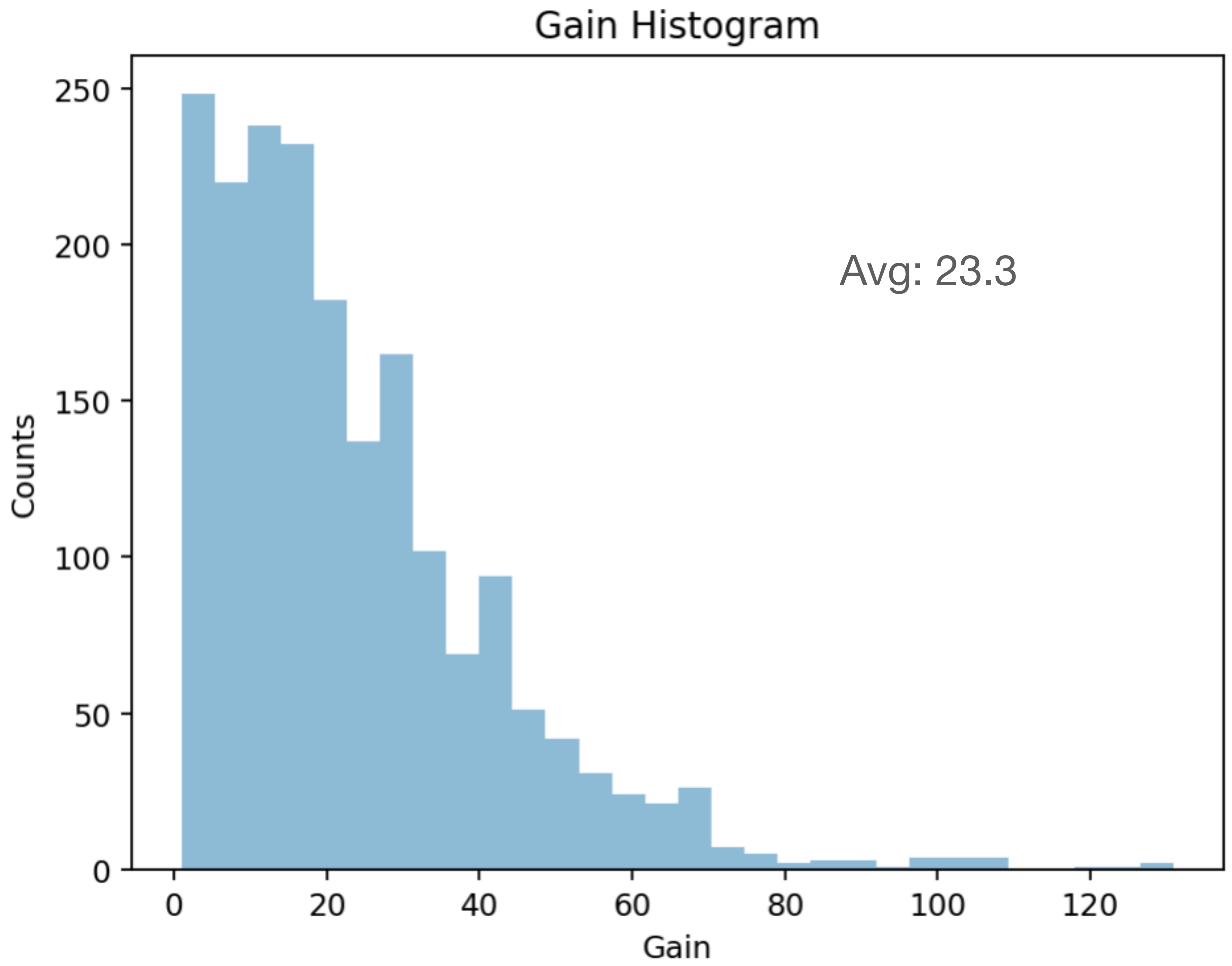


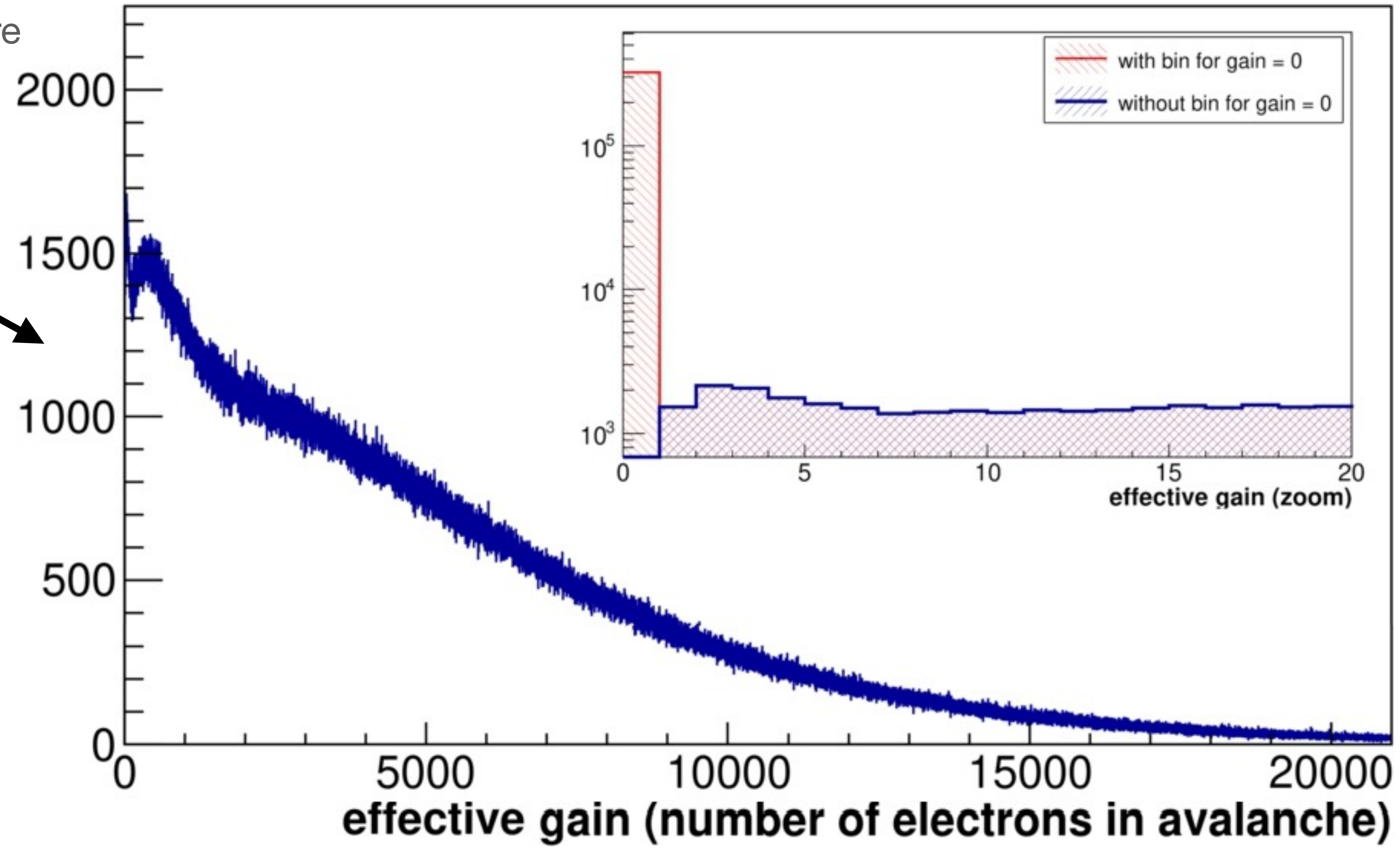
Gain is lower than true value. However, it is known through the community that simulated gain in Garfield++ is factor of 2~3 lower than experimentation. We will correct by simply doing a x2 during sampling

https://twiki.cern.ch/twiki/bin/view/MPGD/WG4-Simulation#

Results similar to literature

A. Amoroso, et al. 2024

https://doi.org/10.1016/S0168-9002(02)00910-5



Note this is for 3 Gems

Simulating Showers

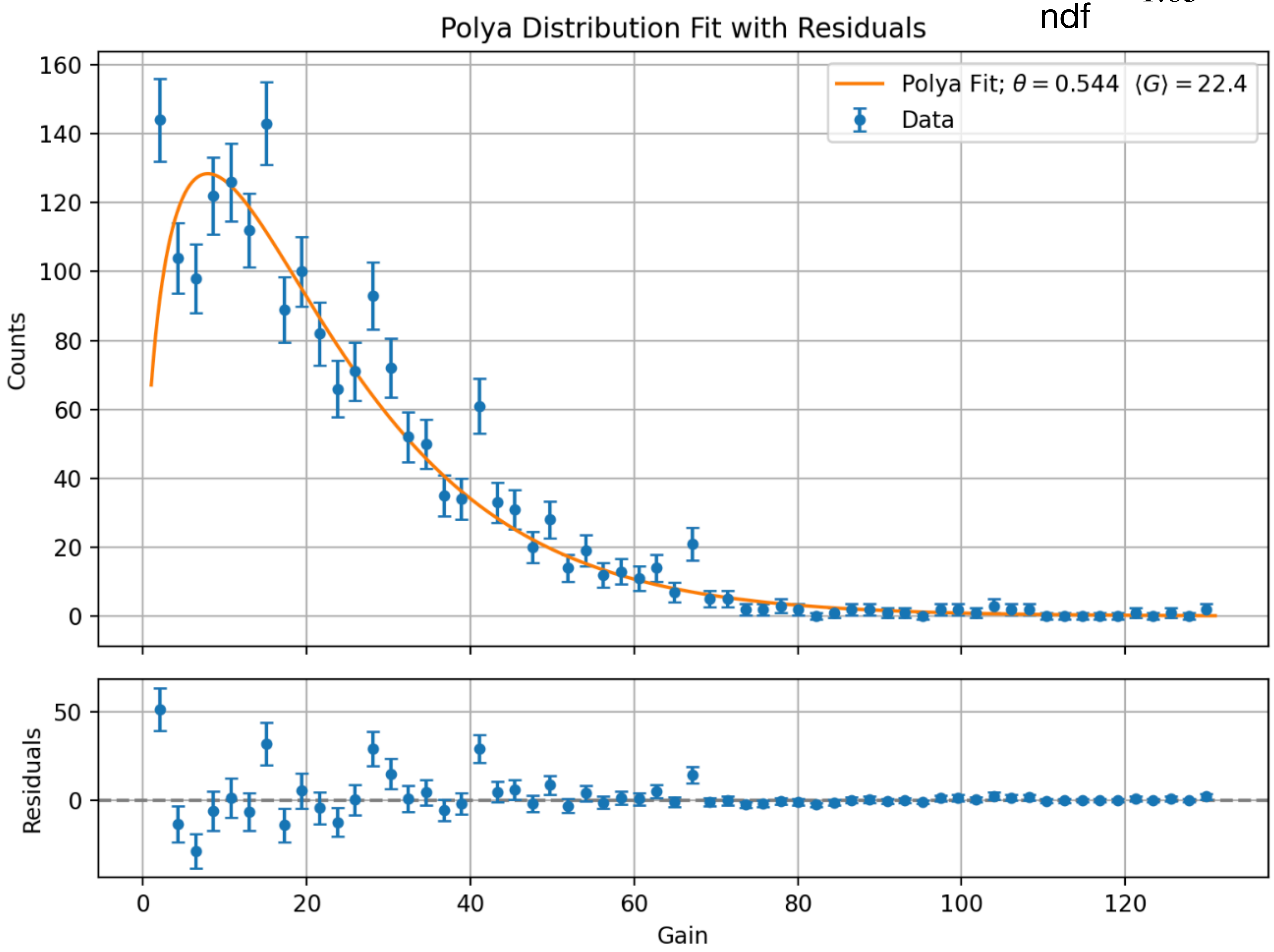
Parameterizing Gain

Gain distribution of GEMs follow Polya / Gamma Distribution

Alkhazov, 1970
https://doi.org/10.1016/0029-554X(70)90818-9

$$P(G) \propto \left(\frac{G}{\langle G\rangle}\right)^{\theta} \exp\left(-(1+\theta)\frac{G}{\langle G\rangle}\right)$$

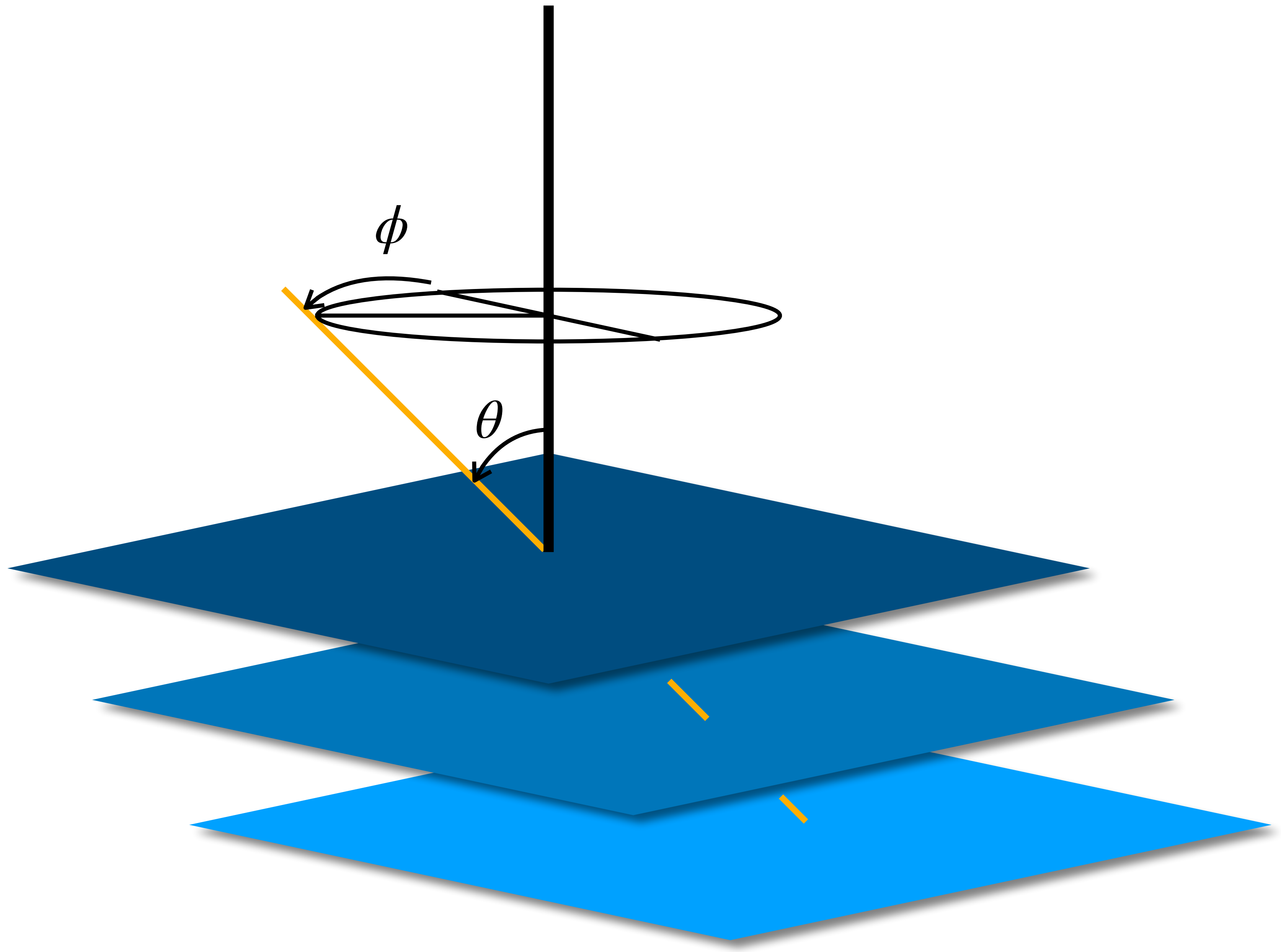
$$\frac{\chi^2}{\text{ndf}} = 1.85$$



Full Simulation Setup

Parameterizing Gain

Two input parameters to determine angle of incident



θ determines impact angle

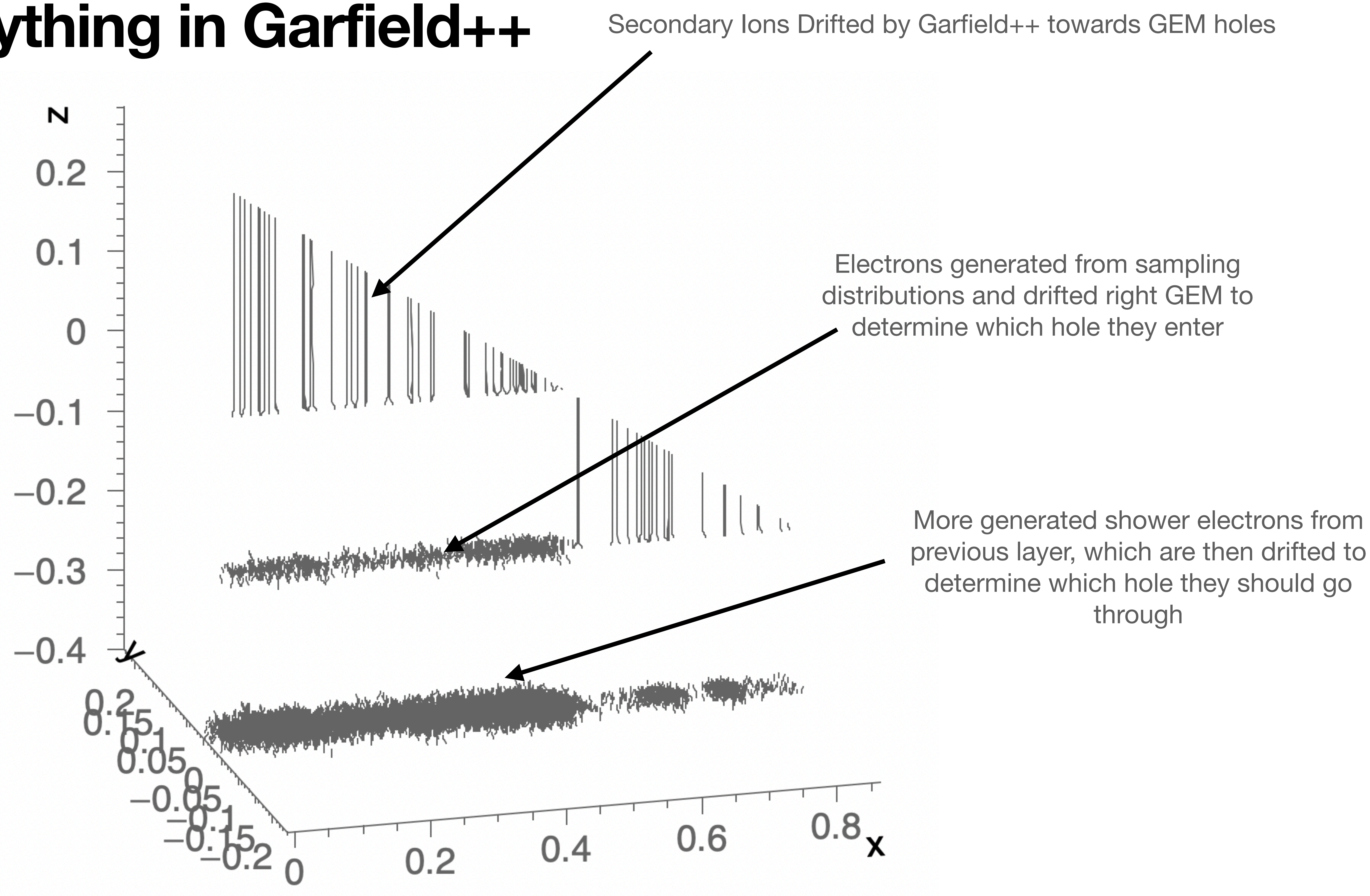
ϕ determines angle in XY plane

Note that $\phi = 0 \implies || \hat{x}$

Full Simulation

Putting Everything in Garfield++

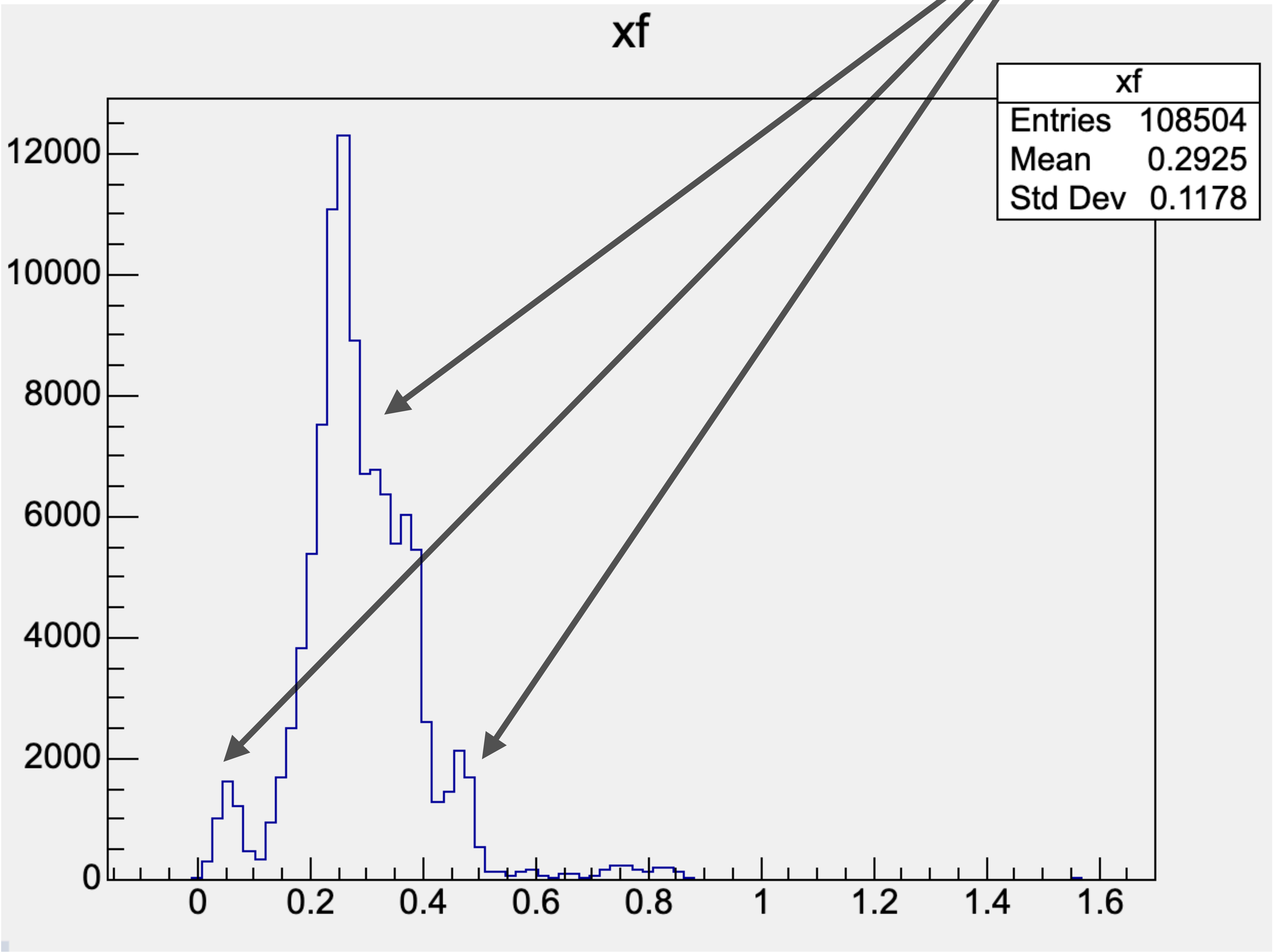
$\theta = 40^o \; \phi = 0$

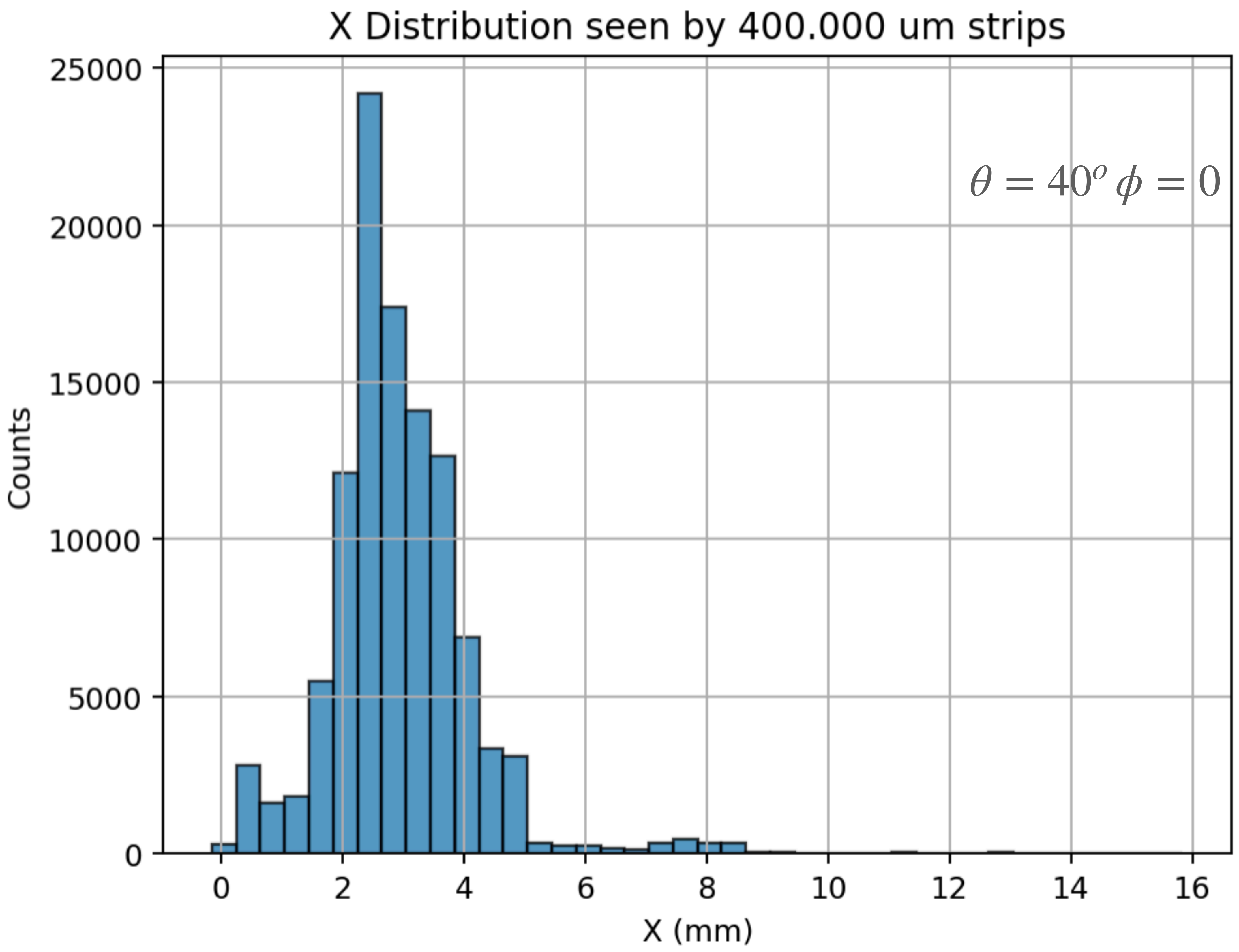


Full Simulation

Results

We see multimodal distributions caused by different showers generated by distinct primary ionization clusters



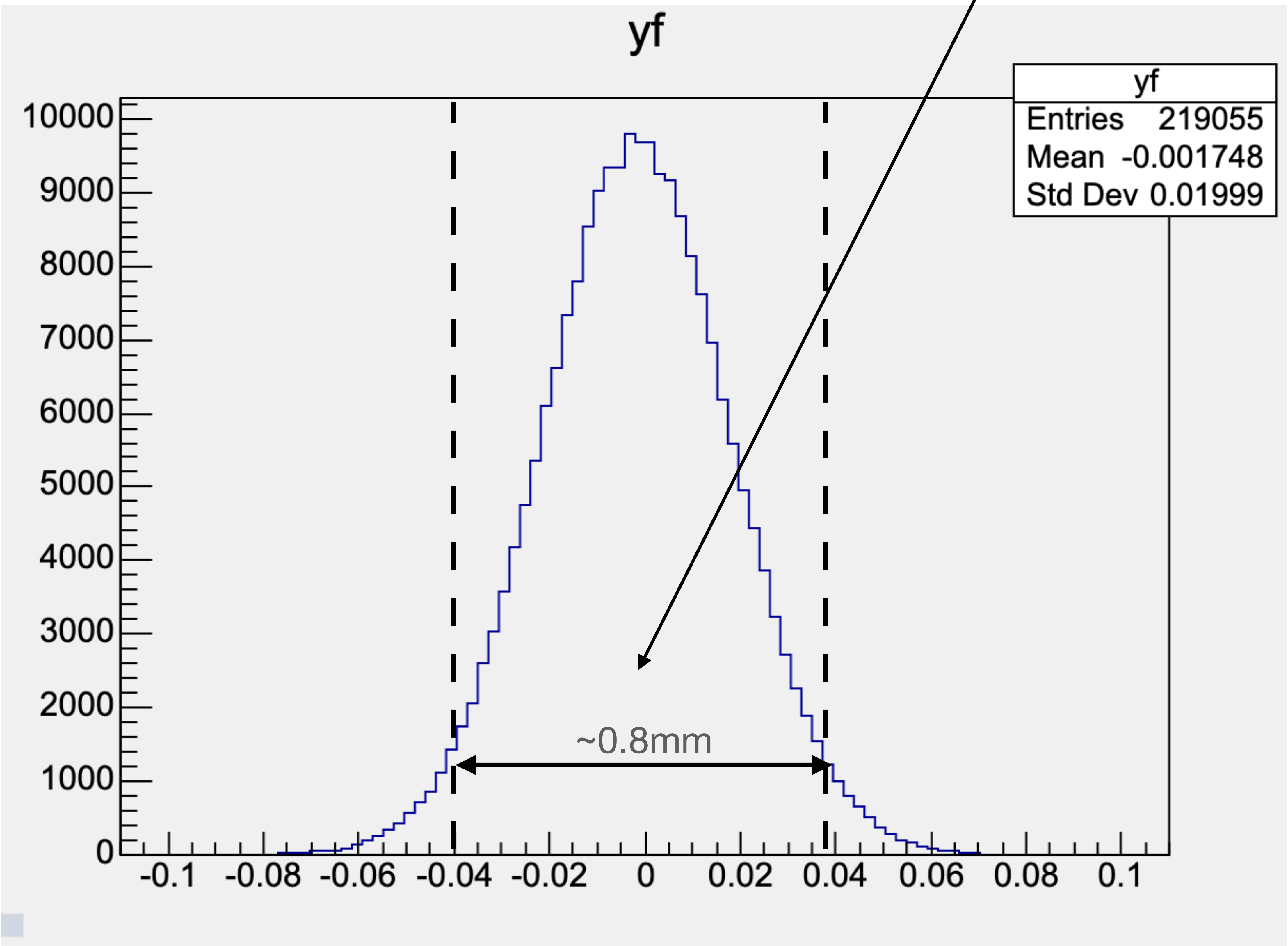


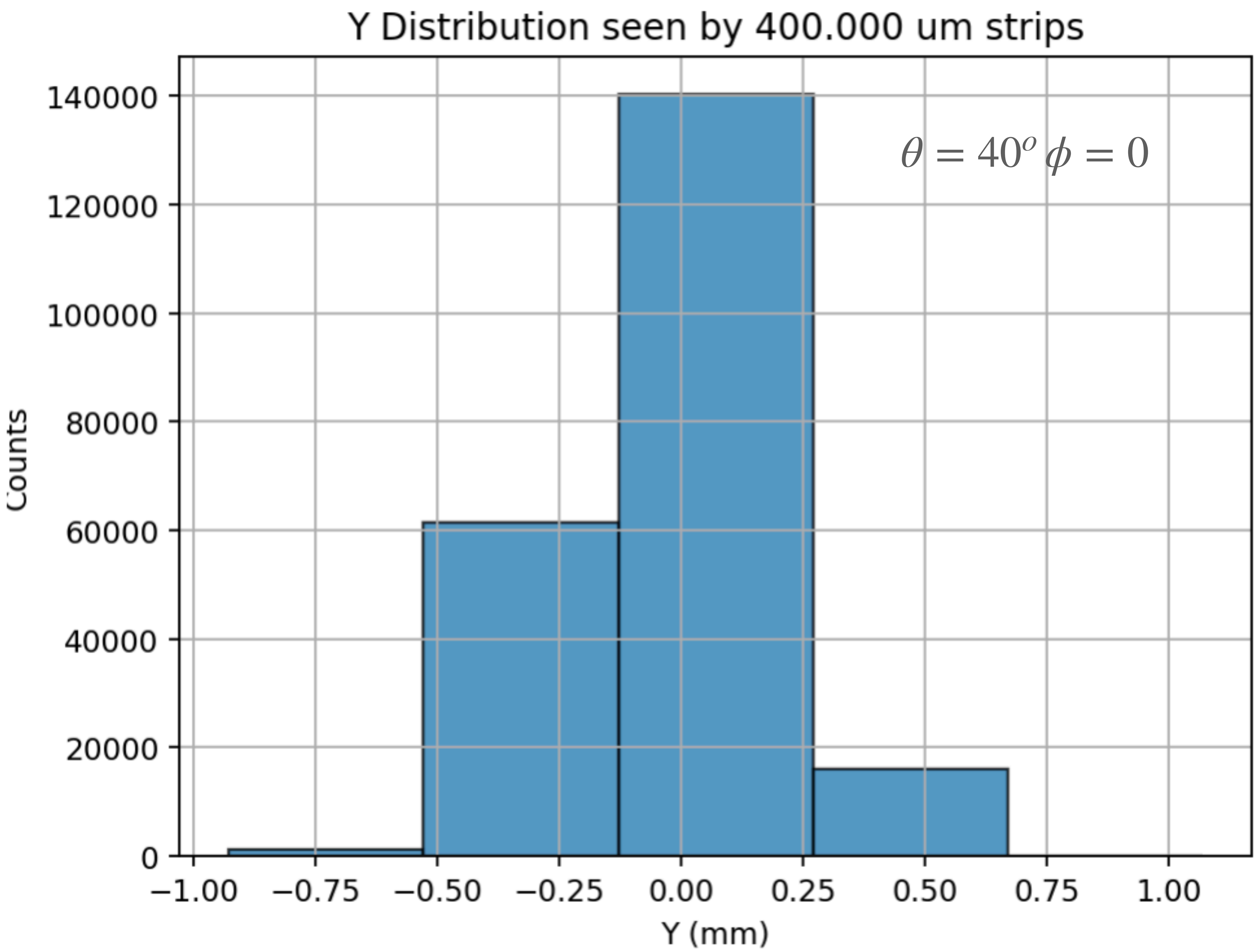
Full Simulation

Results

Charge clouds of ~1mm as expected from

https://einnconference.org/2017/presentations/02_Nov/W2/Kohl.pdf



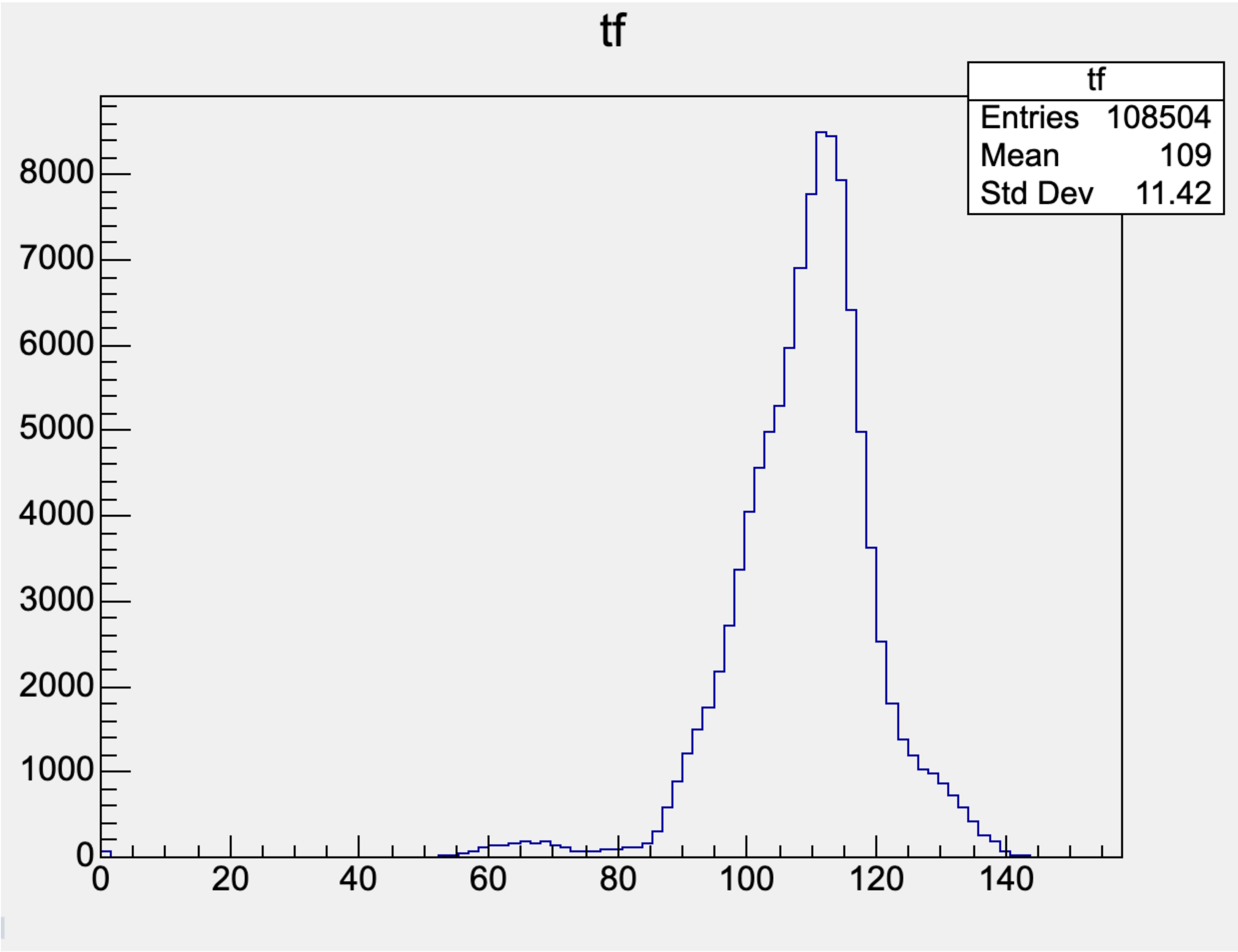


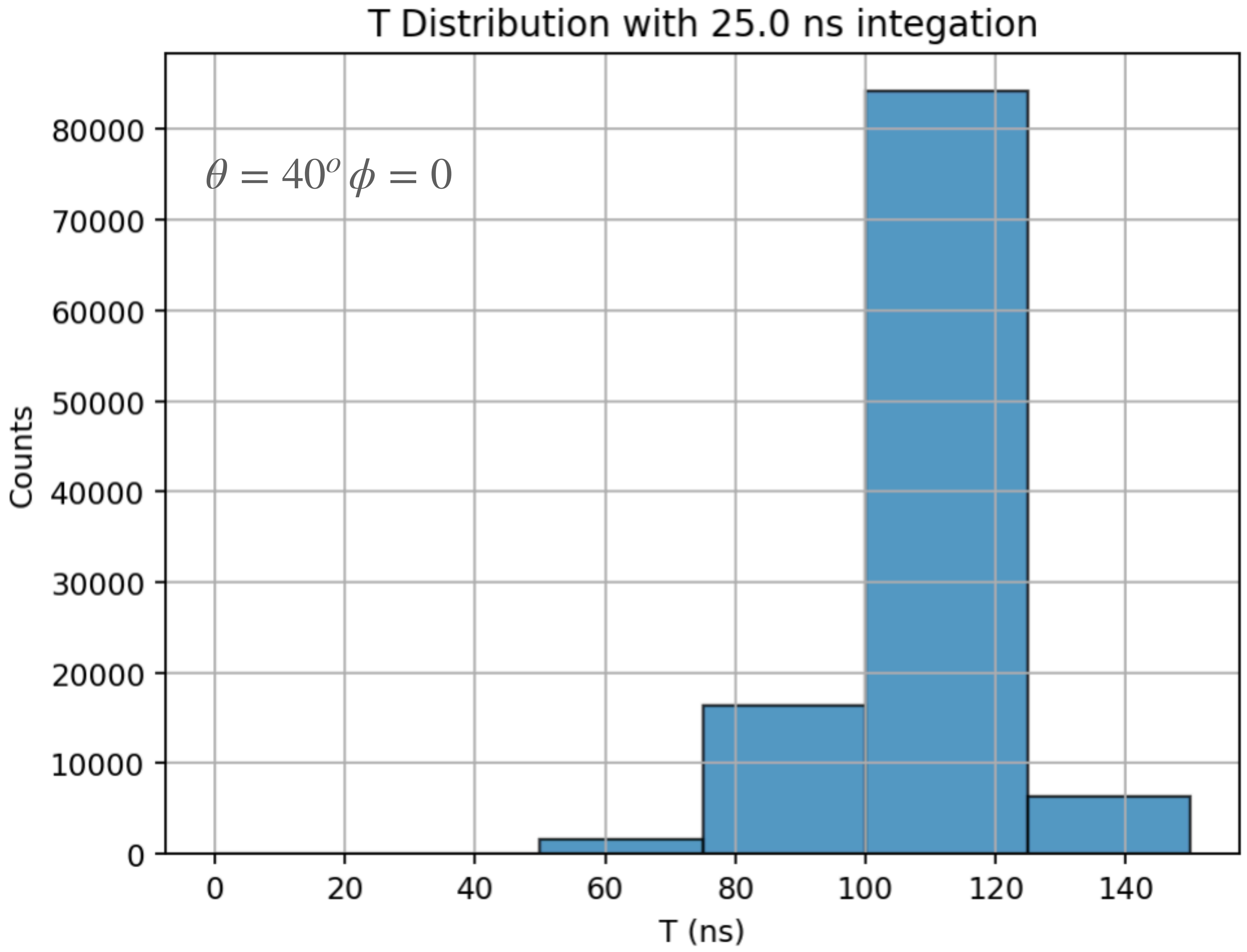
To a good approximation, resulting distribution is just gaussian convolved with itself 3 times

Full Simulation

Results

Multimodal distribution of arrival times caused by showers generated on different levels





Full Simulation

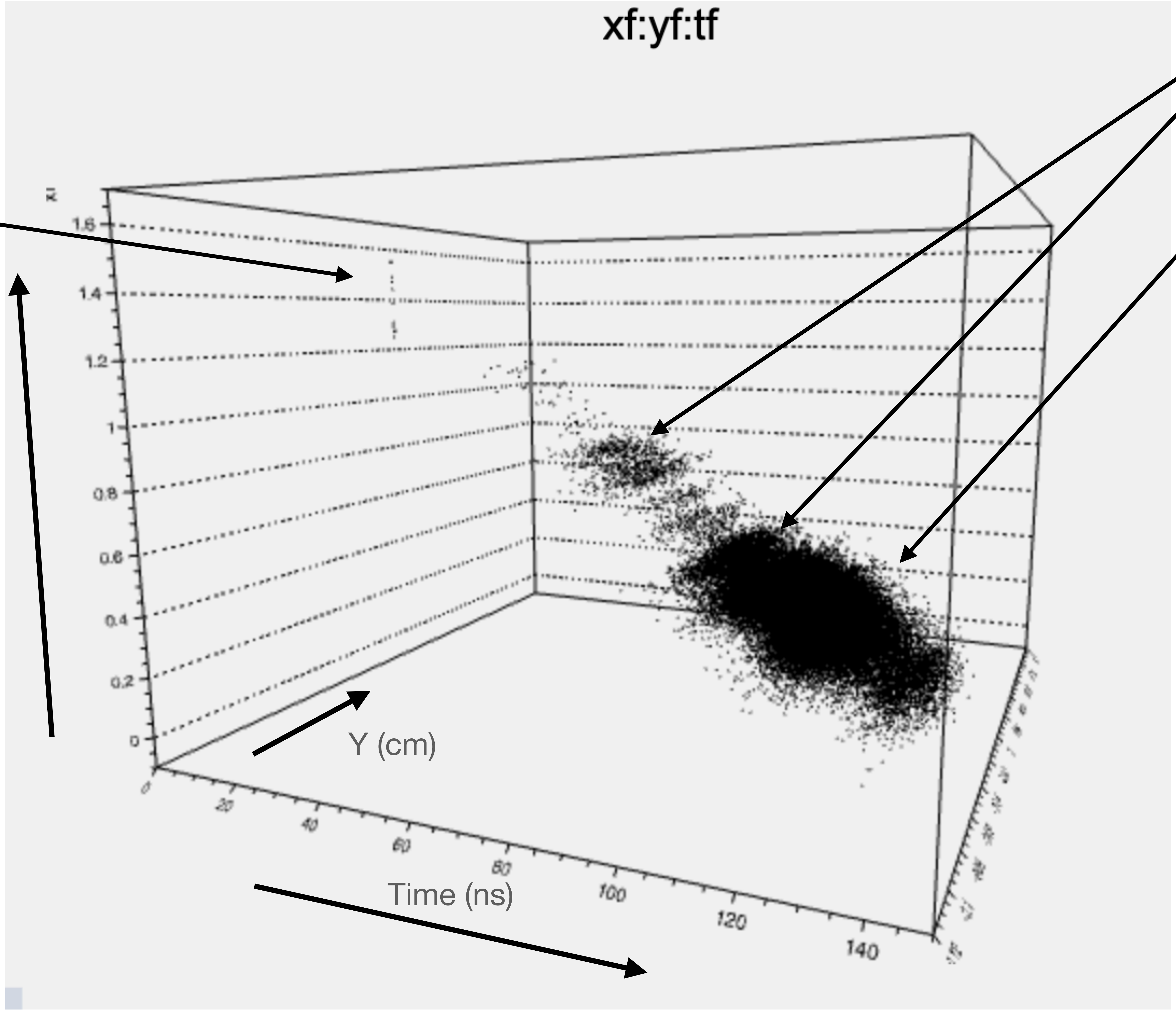
Results

Different Clusters of shower electrons arriving at different times

Showers originating from higher gem levels have higher gain and arrive later

Some secondary electrons that are ionized in area between 3rd Gem and readout arrive significantly earlier

X (cm)

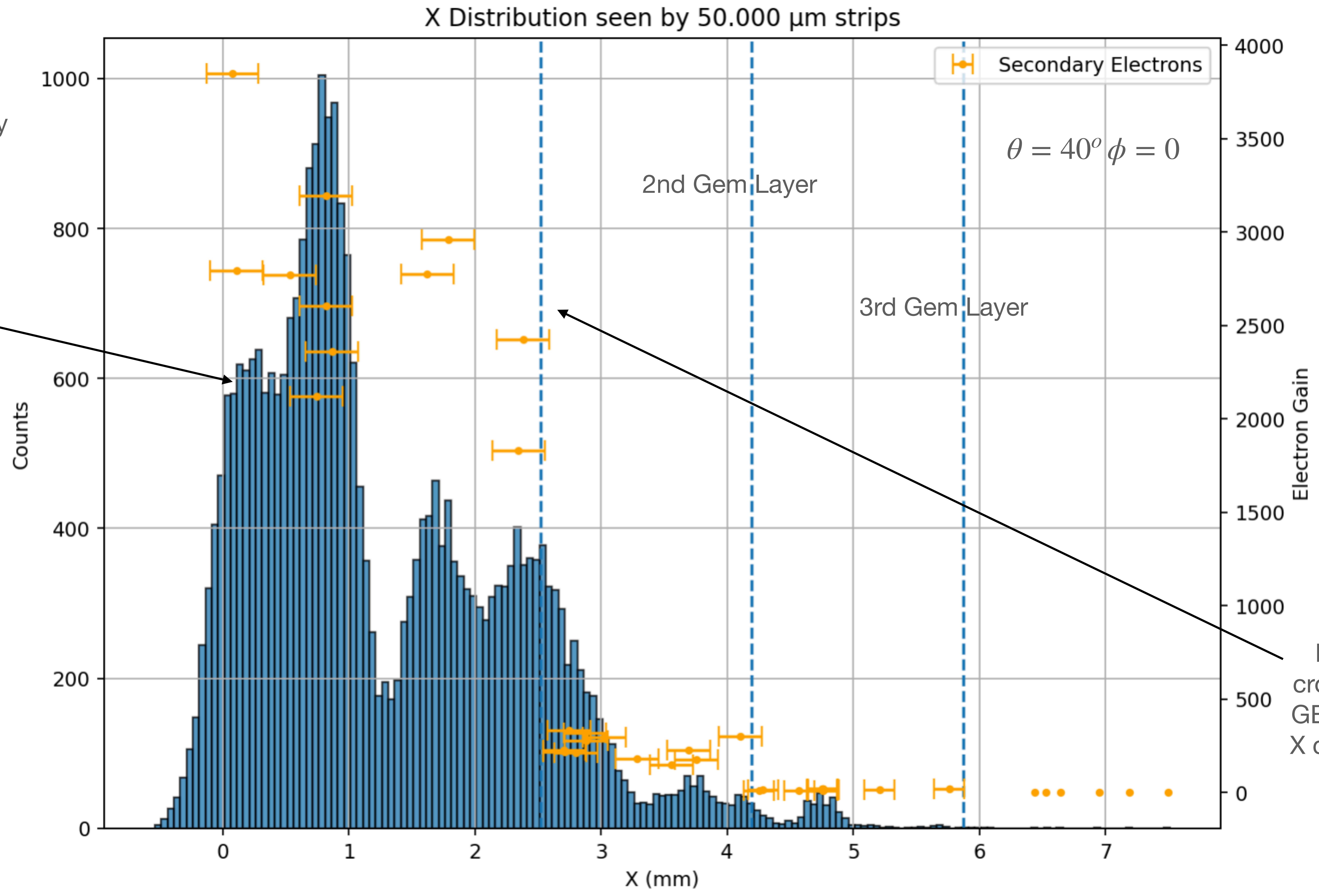


Correlating Gain and X Distribution

X error bars is the expected std of gaussian caused by shower of secondary electrons on their respective layers

With high enough resolution, we see the corresponding gaussian to each secondary electron

NOTE: different event from previous slides



Particle crosses 1st GEM at this X coodinate

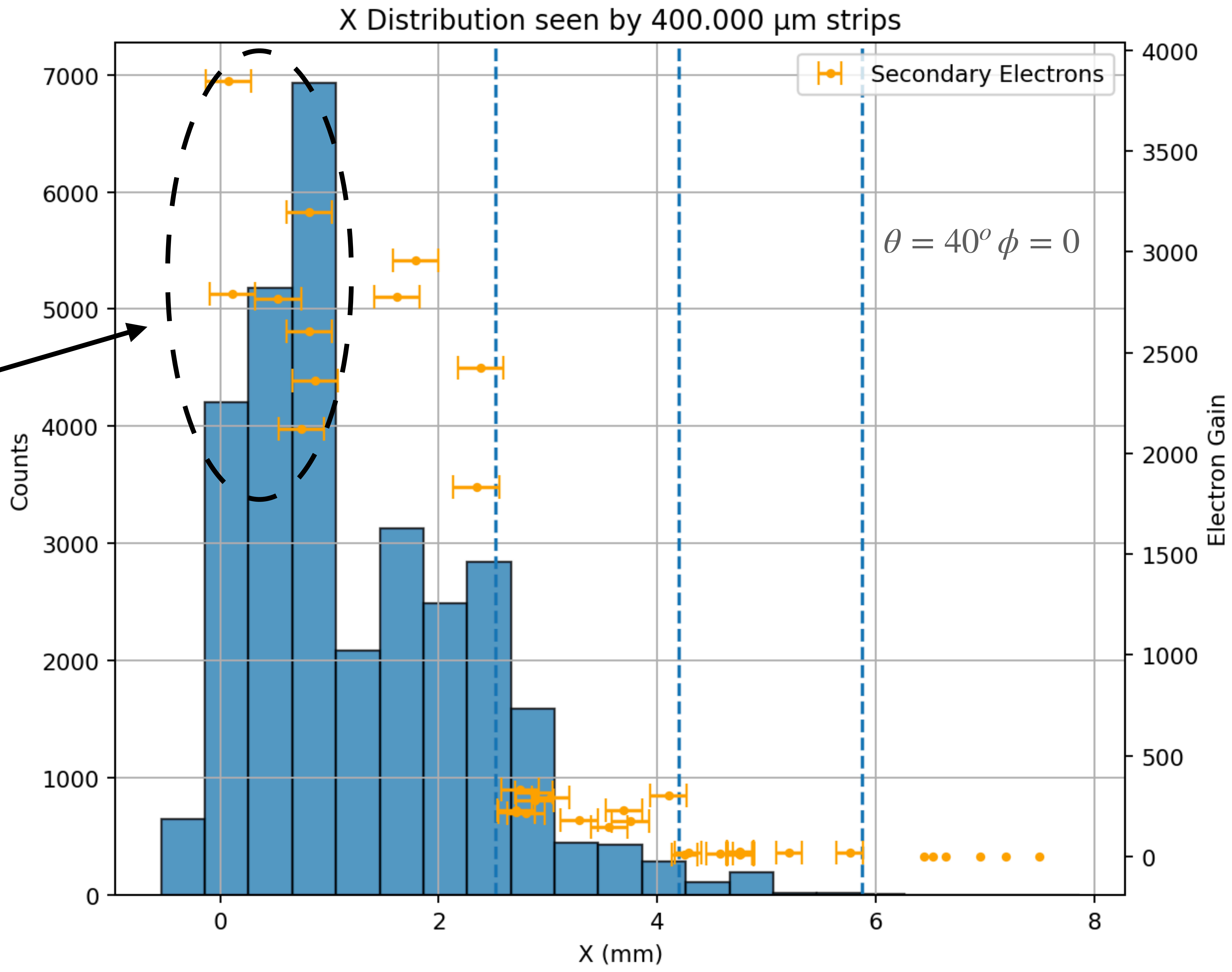
Correlating Gain and X Distribution

Continued

At a lower resolution of 400um, showers from multiple secondary electrons merge into a single gaussian

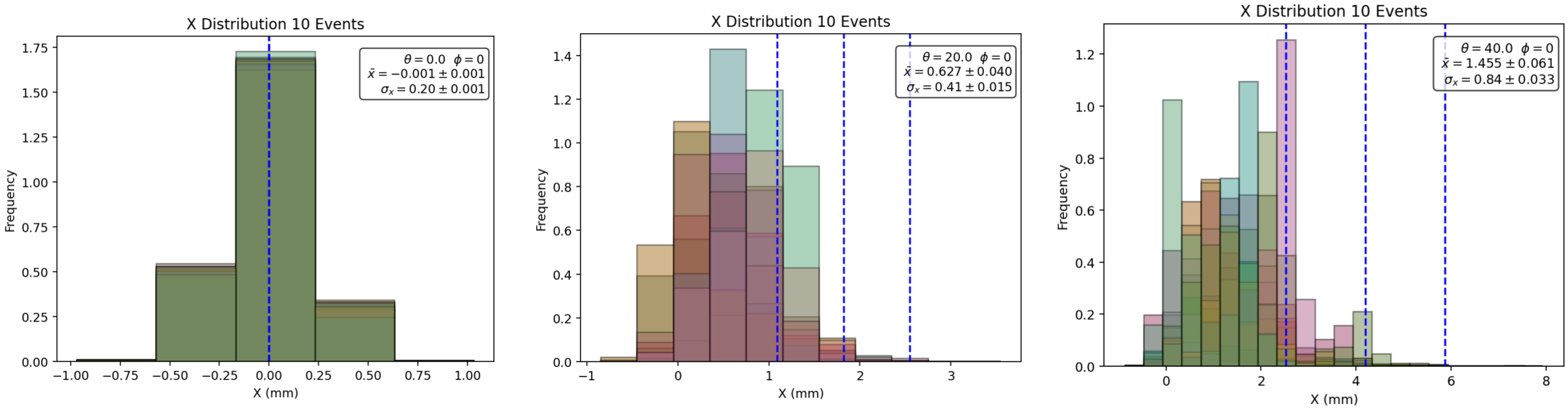
Showers caused by these electrons are indistinguishable from eachother

Most of the signal comes from electrons ionized between drift electrode and 1st Gem



Analysis

Correlating Angle and Distribution Parameters

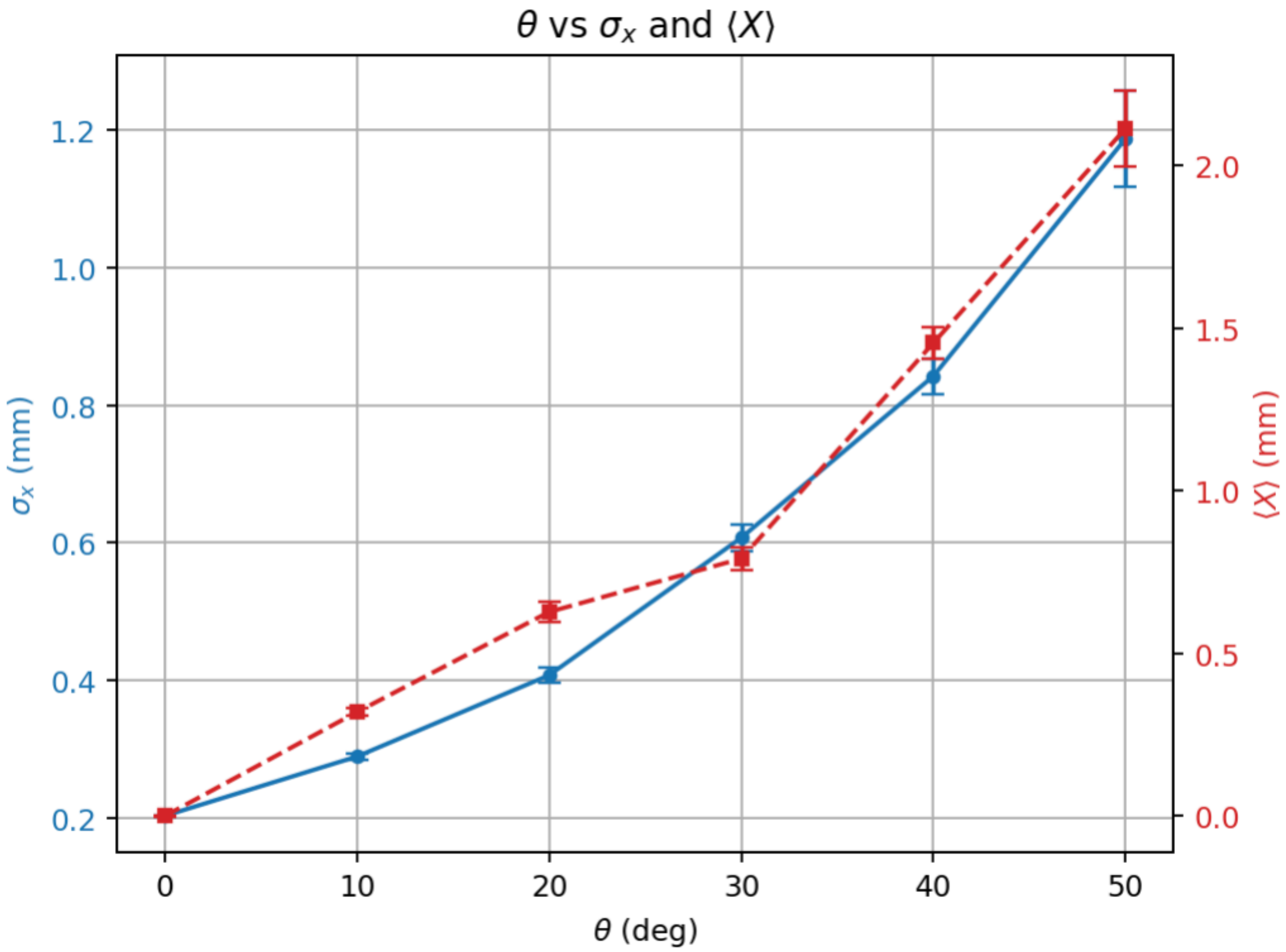


We see a departure from unimodal distributions ~ $\theta = 20^o$

General Trend of More Spread as Angle Increases

Analysis

Spacial distribution dependence on theta

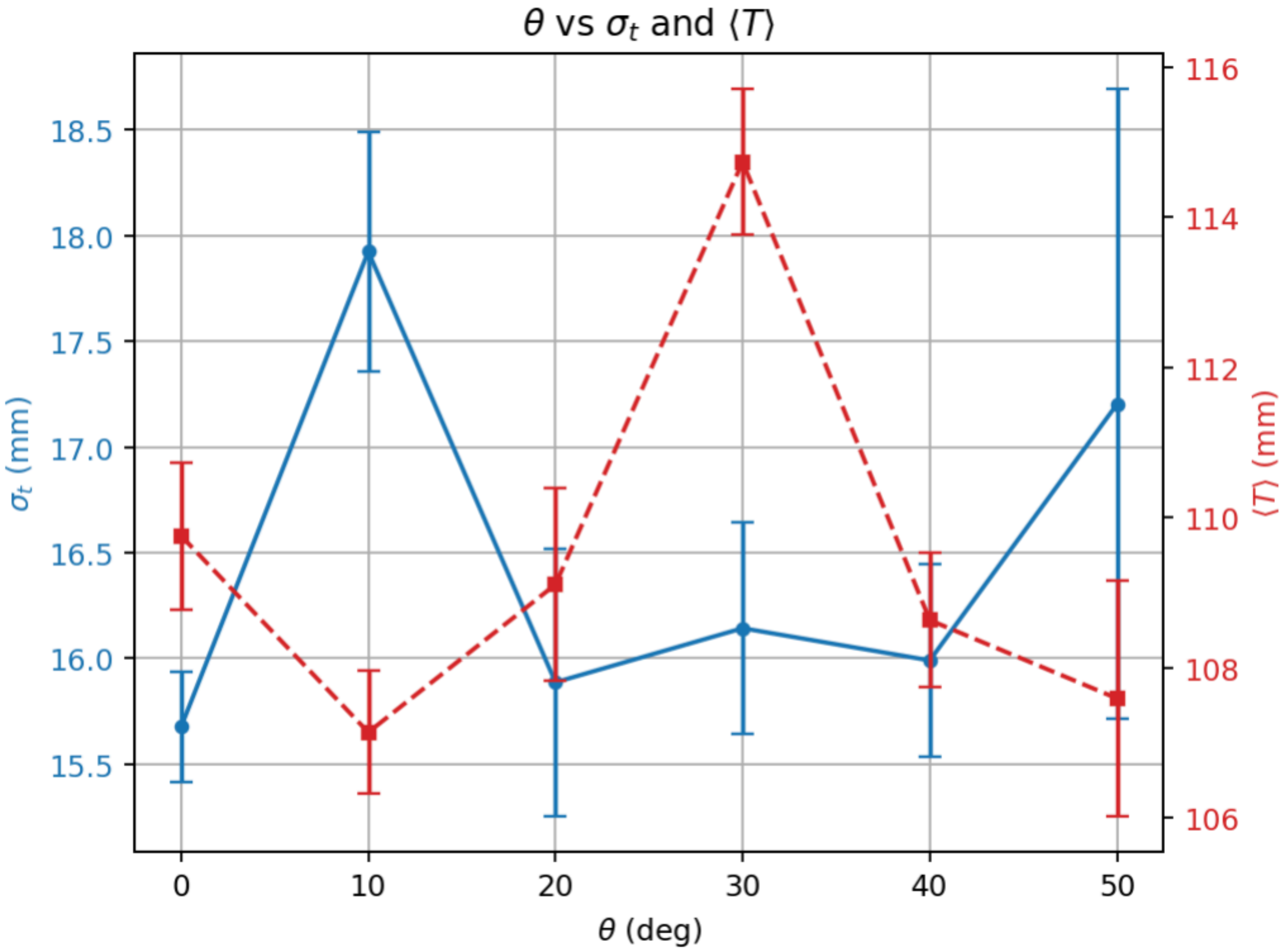


We see surprisingly well behaved trend in the standard deviation of X distribution

However, it is important to note that at high angles distributions are not unimodal, which contributes to the std

Analysis

Temporal distribution dependence on theta



Future Work

Using the simulated spatial and temporal distributions in this study to better simulate GEM readout during digitization

Use these more realistic simulations to find better method for GEM position reconstruction, ie try different fitting functions