Use of Allpix^2 in the LUXE experiment: Digitizing the Hits of the Tracker Sub-detector

Arka Santra, Noam Tal Hod
Department of Particle Physics and Astrophysics

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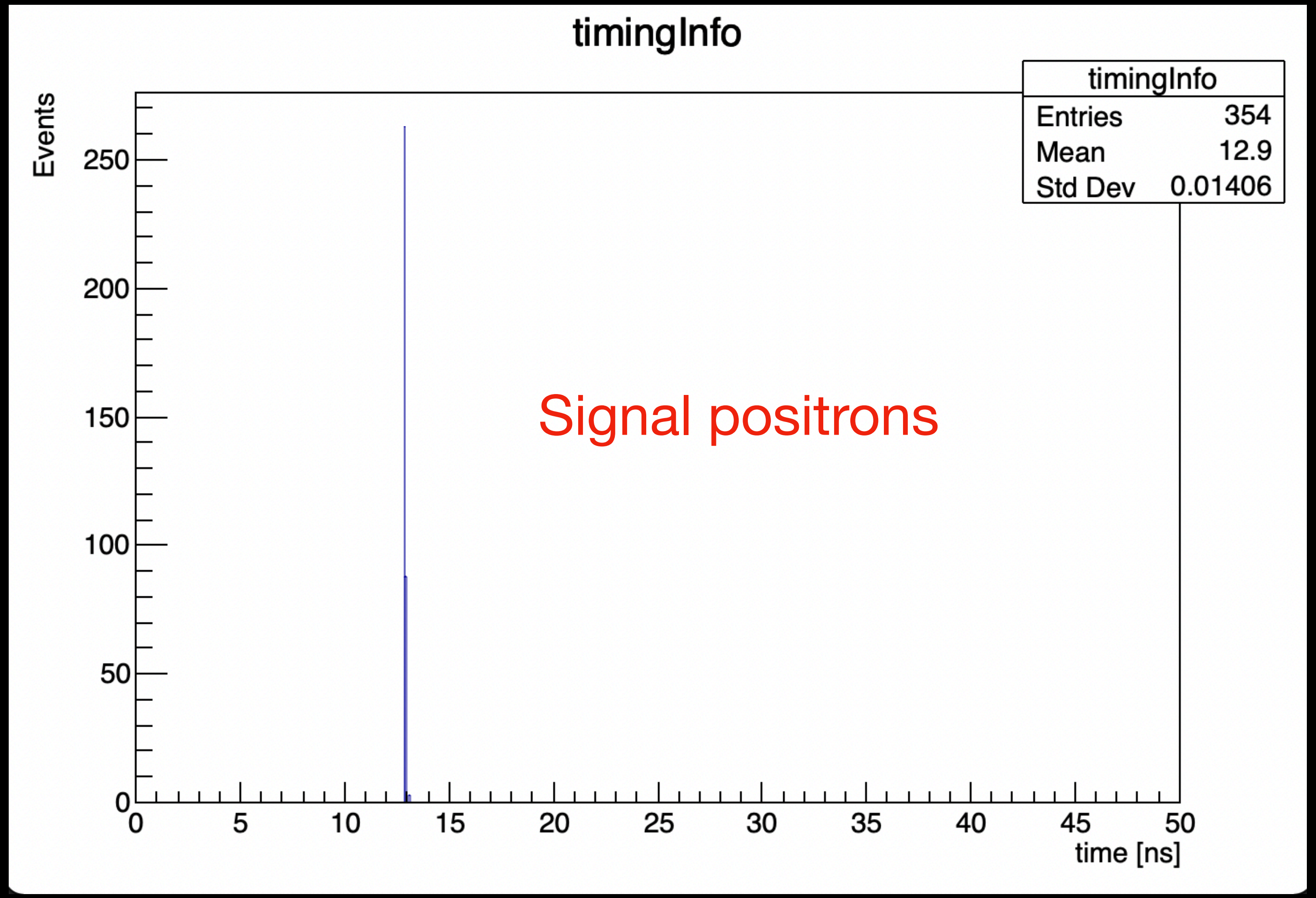
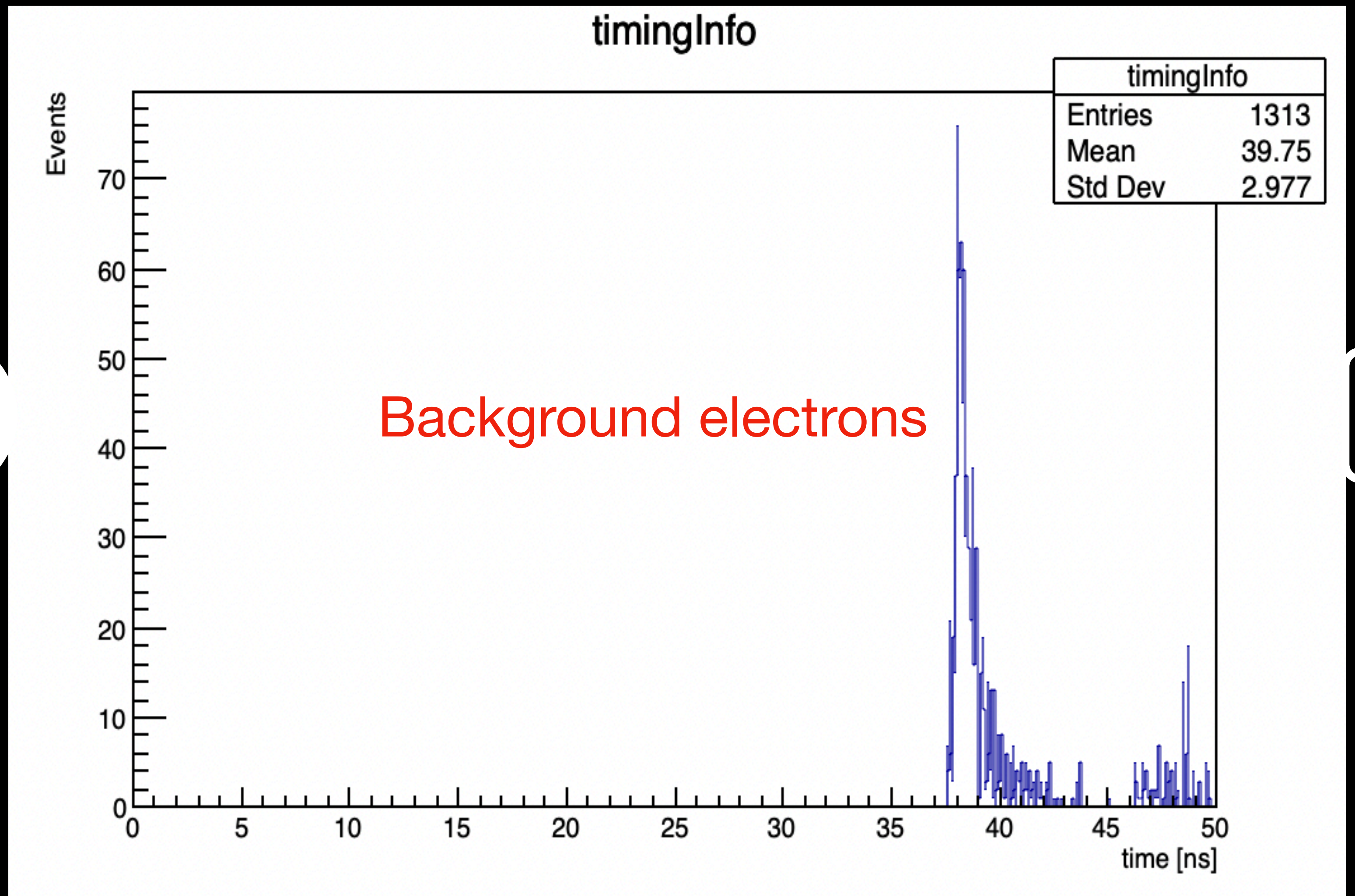
In the previous presentation:

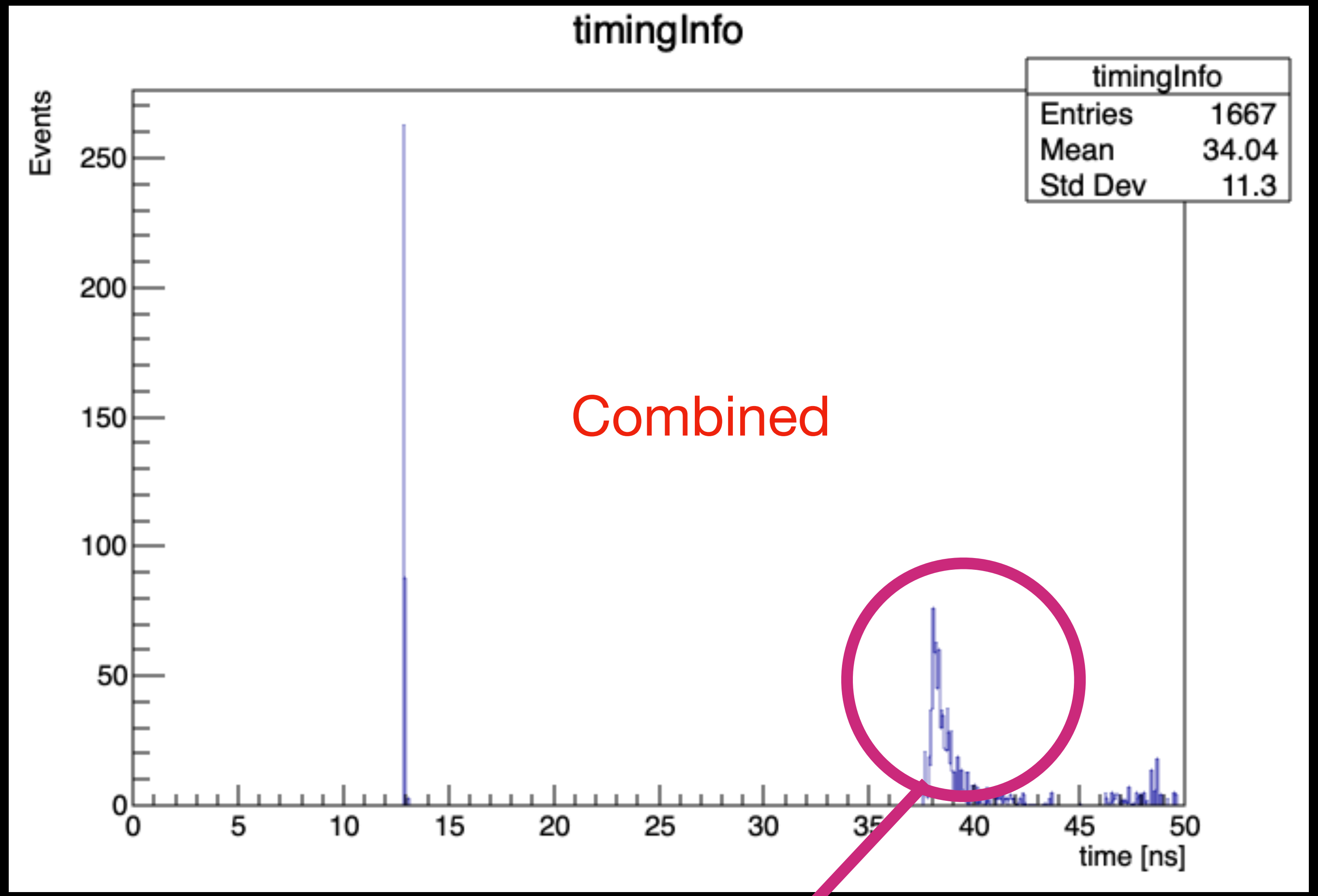
- Custom electric field functionality of Allpix^2 proves to be very useful.
  - After lots of efforts, the result from our simulation is now very close to the Allpix paper (2002:12602) result.
- Applied the custom electric field to particle gun relevant for LUXE tracker.
  - The cluster energy and size distribution for low energetic electron beam is markedly different from that of the high energetic signal positron.
- Progress over the last month: use the LUXE tracker energy deposition as input to Allpix^2
  - Digitize the LUXE tracker hits using Allpix^2.
    - Used the CDR simulation files for signal and background.
  - Look at the clusters made by high energetic positron signals with low energetic electron background.

Timing distribution

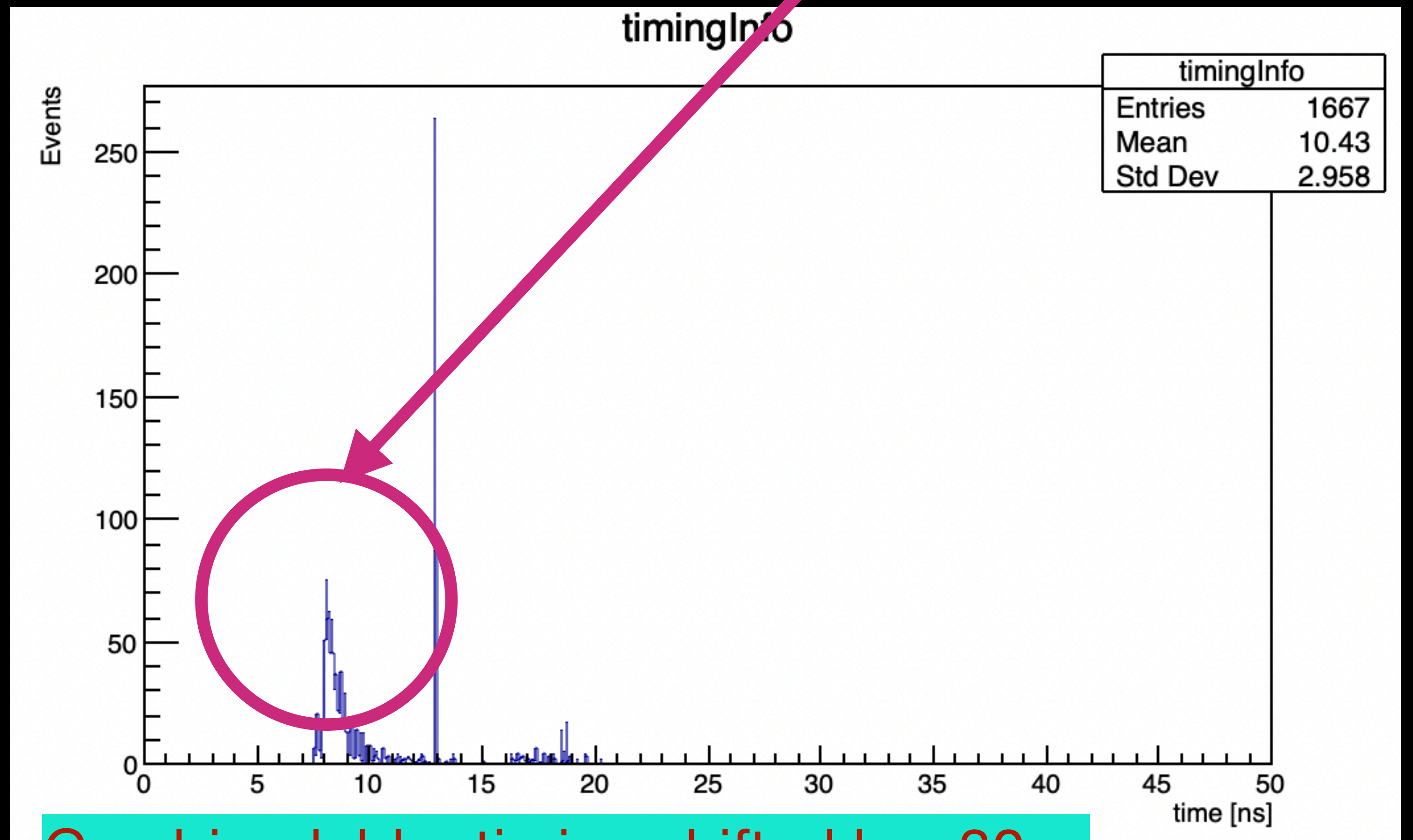
- From the simulation, found that the timing information of the signal and distribution are different.





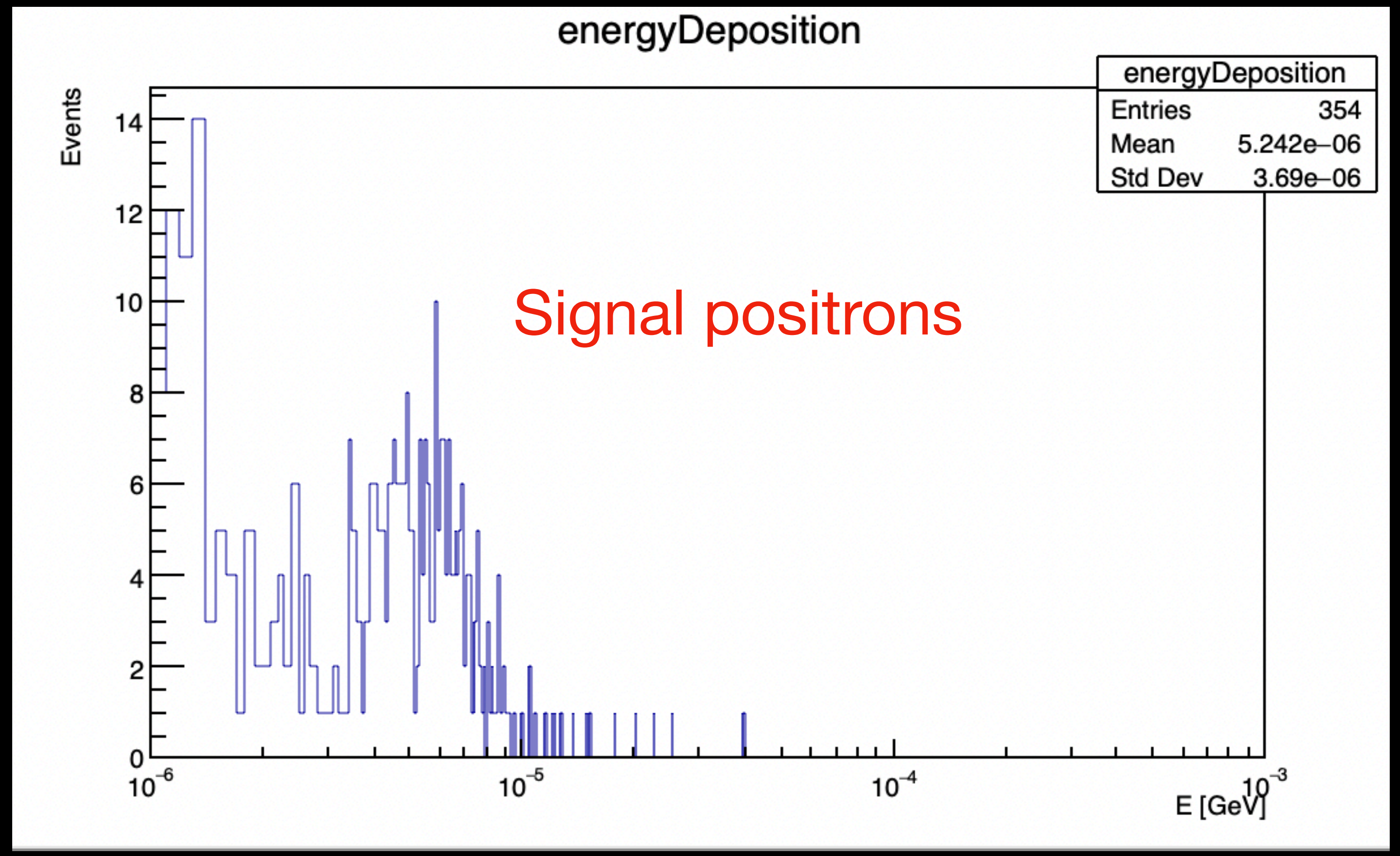


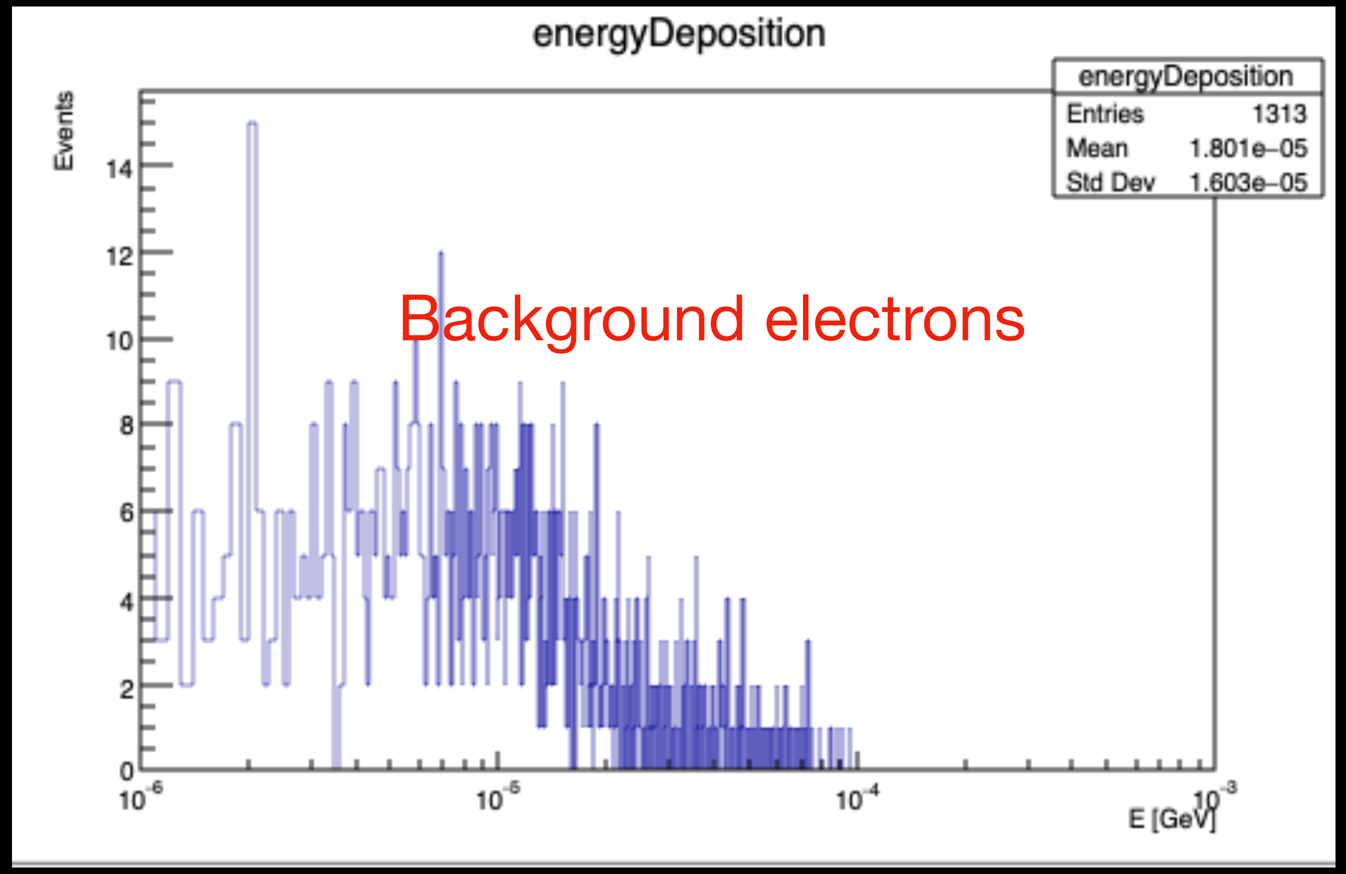
- Signals are arriving faster than the background.
  - Timing resolution of ALPIDE due to the **readout** is ~μs (though intrinsic resolution ~ns).
- Used charge integration time (time within which charge carriers are propagated) to be 20 ns in the digitization framework.
  - The 20ns window is selected from a testbeam, to match the charge MPV of data.
  - Shifted the timing of background particles by -30 ns to make it comparable with the signal timing.

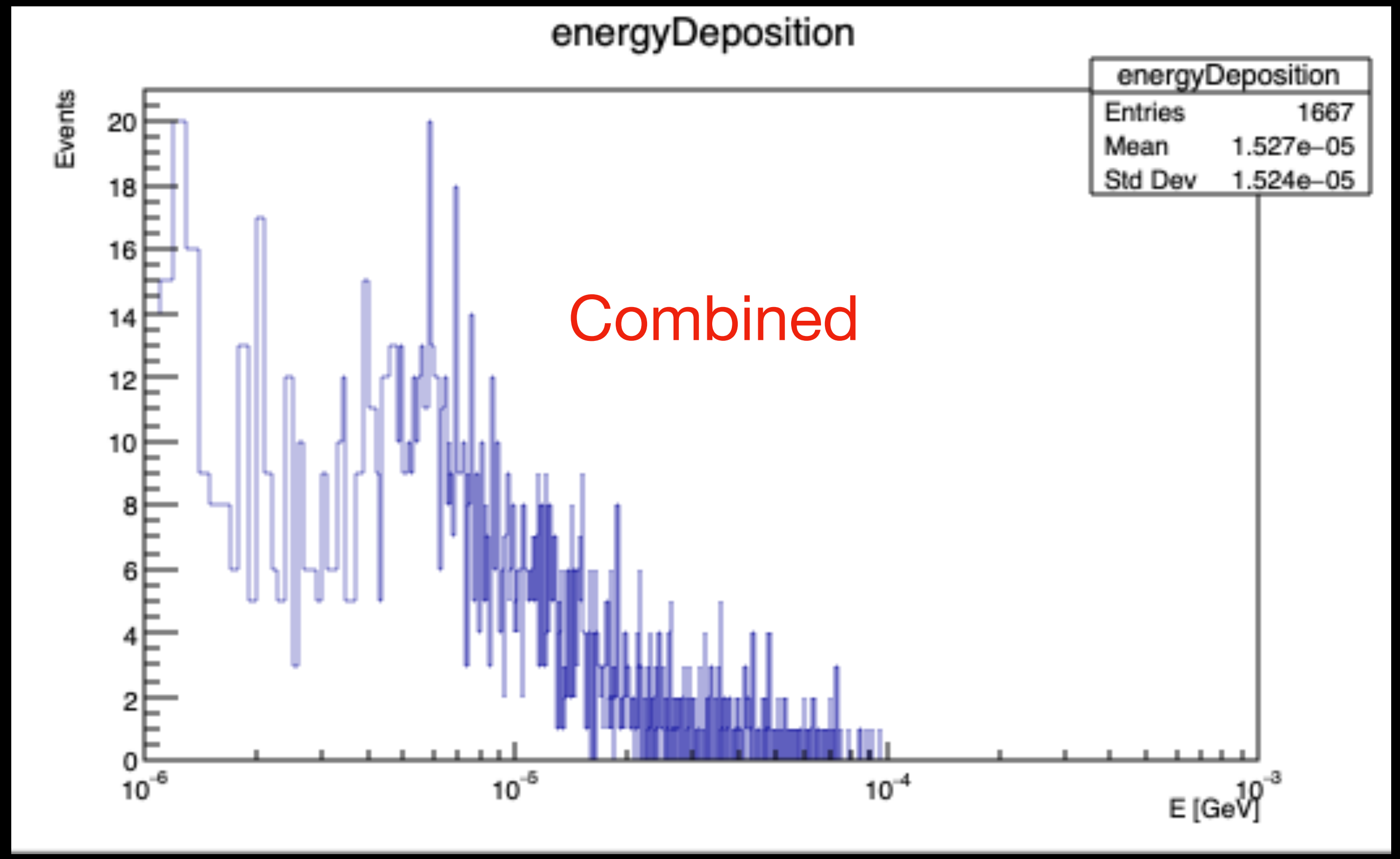


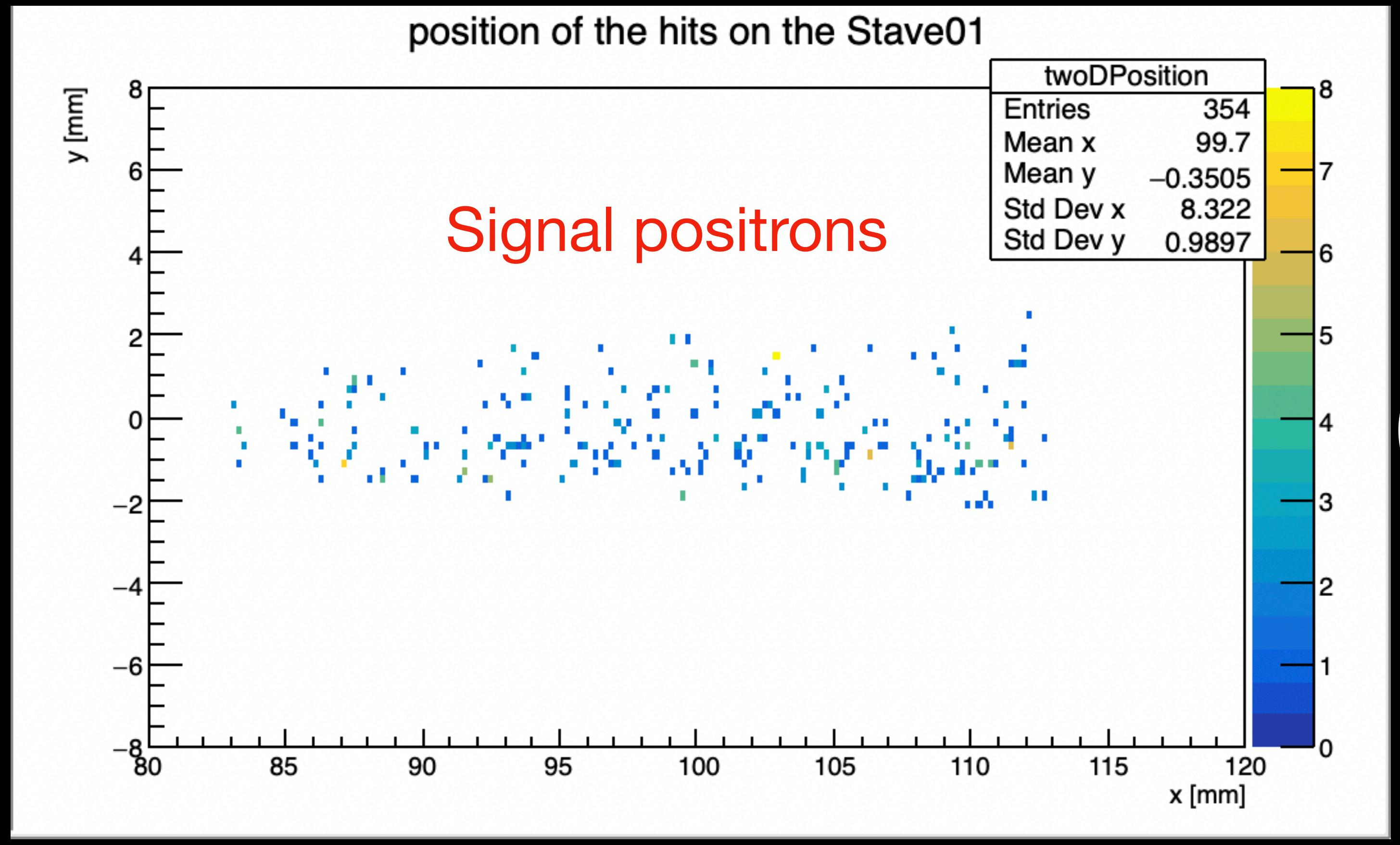
Combined, bkg timing shifted by -30ns

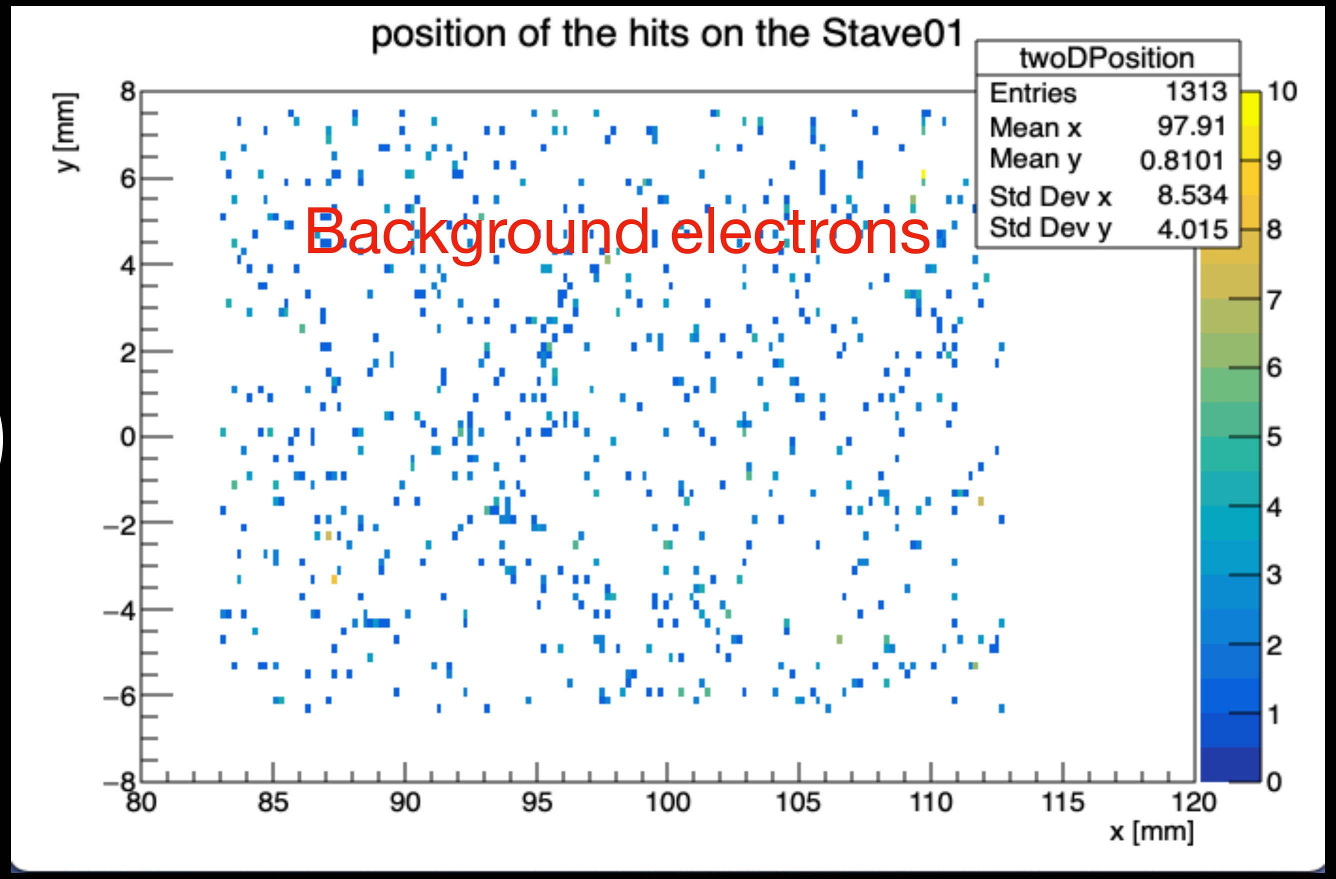
Input to Allpix^2 framework:

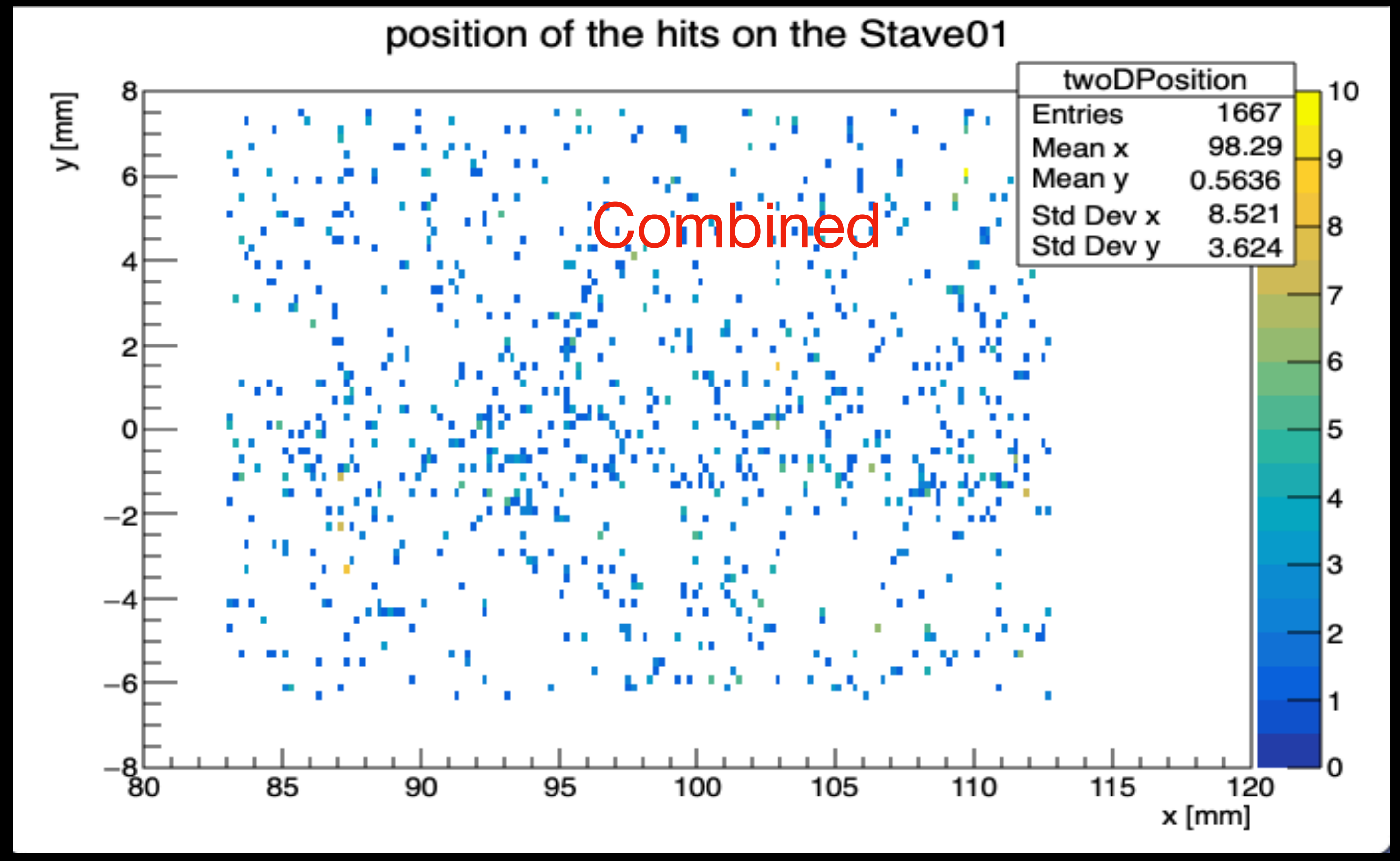








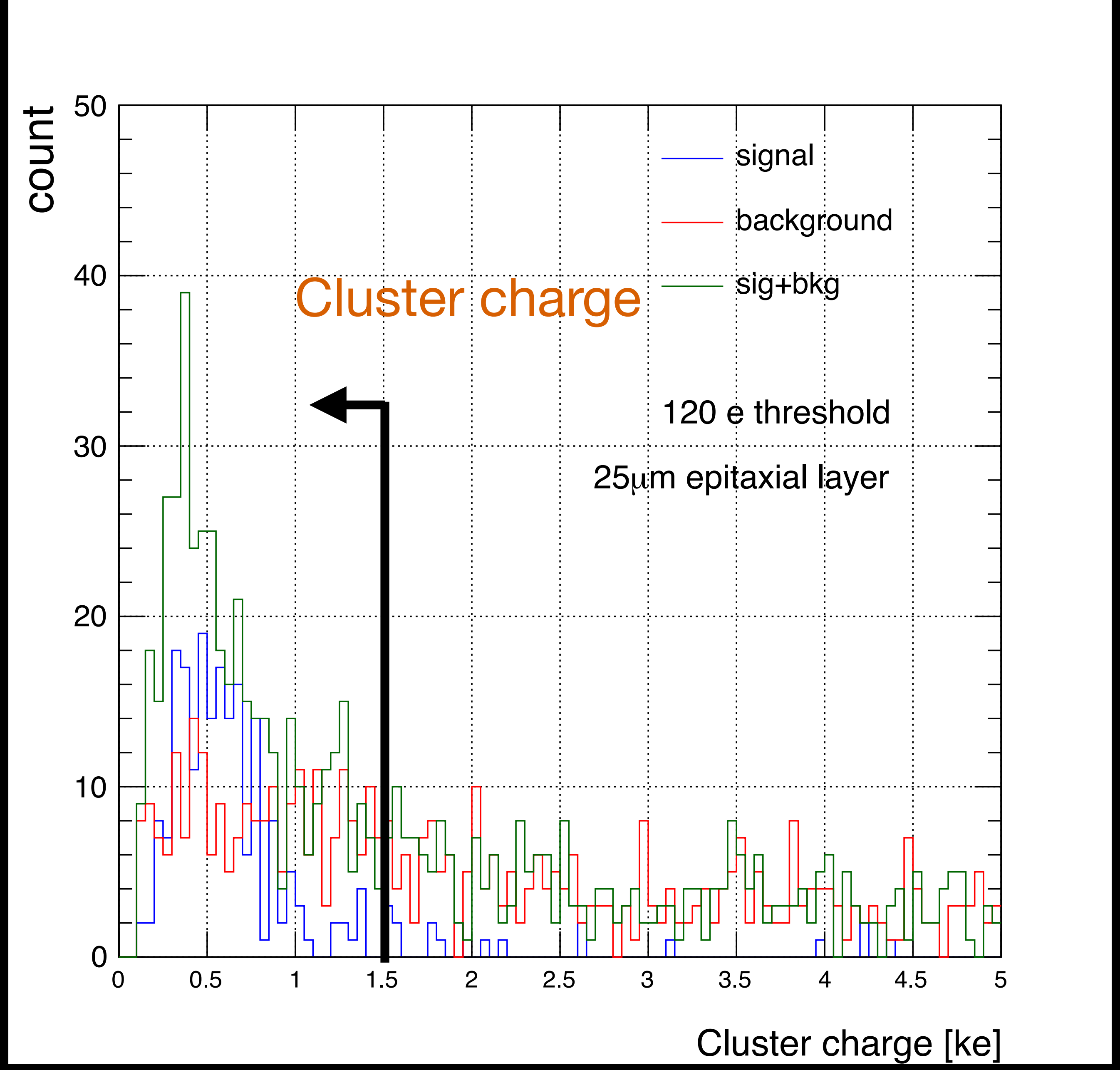


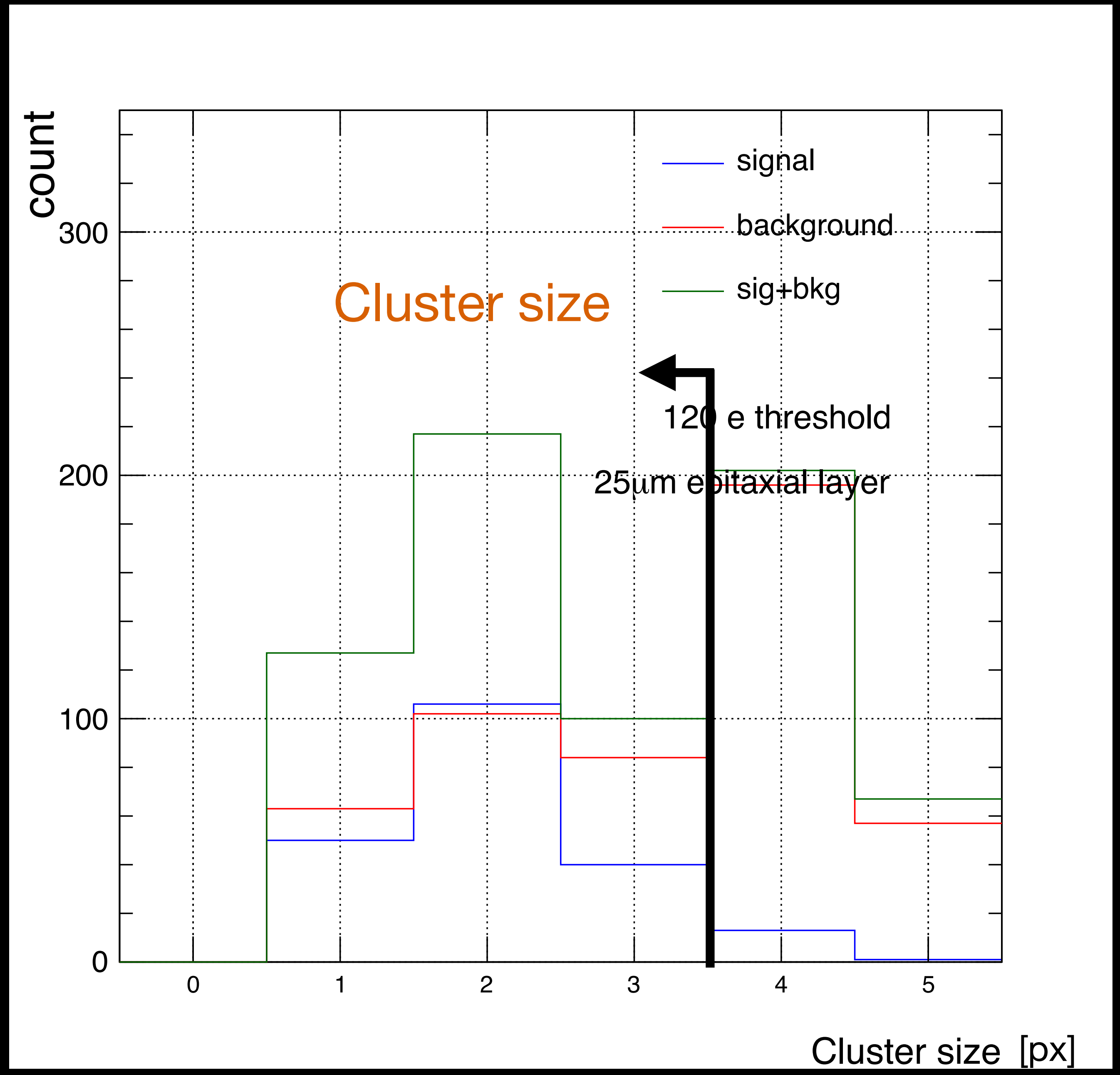


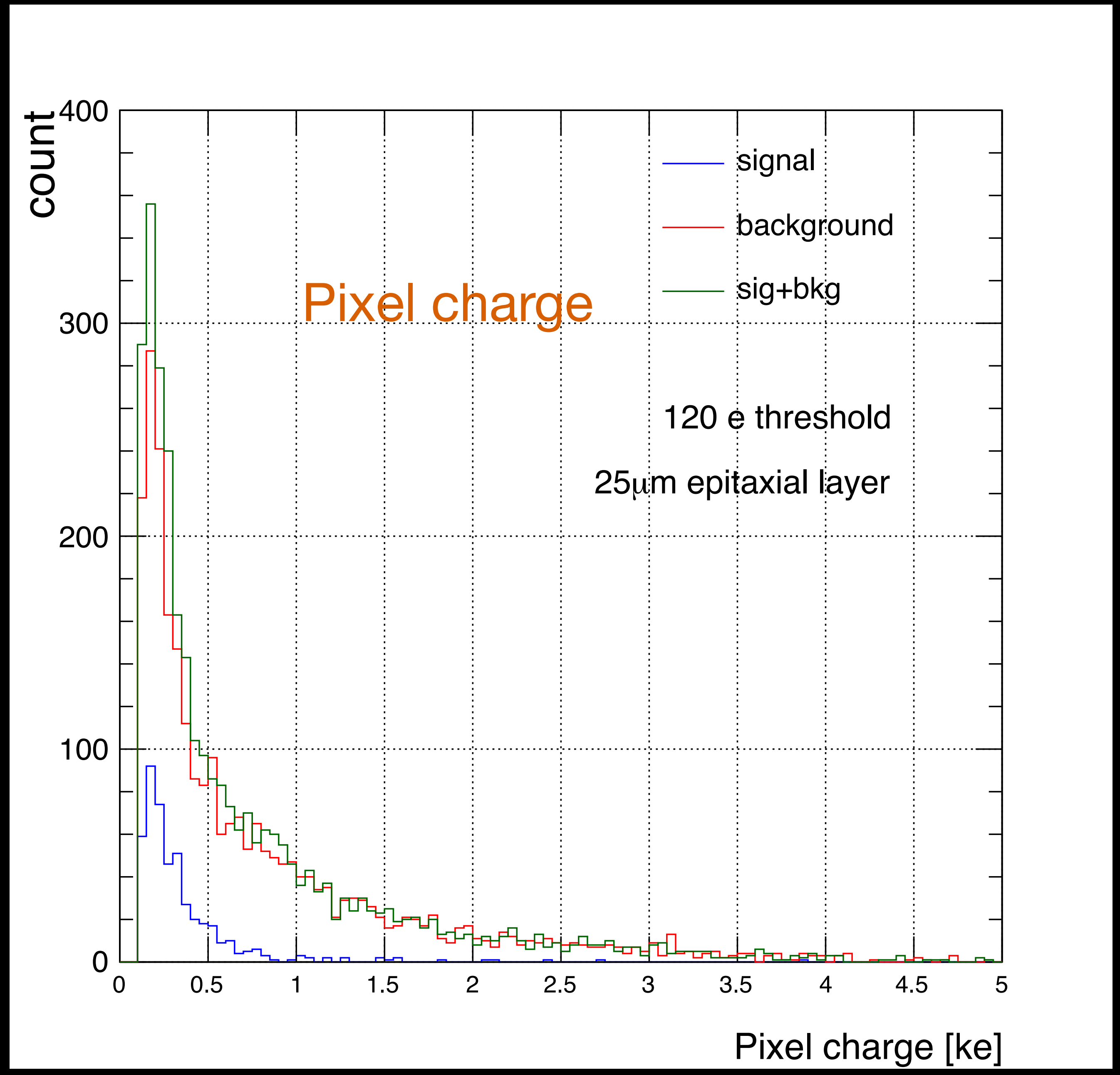
★Used only second chip on the first layer, first stave in the tracker (for now): Stave01

★Allpix^2 needs the energy deposition and the position of the hits for the simulation.

Result after digitization by Allpix^2







- ★If we cut on cluster charge $\lesssim 1.5$ ke
  - ★Signal efficiency 93%
  - ★Background rejection 62%
- ★If we cut on cluster size $\lesssim 3$ pixels
  - ★Signal efficiency 98%
  - ★Background rejection 32%
- ★Need to match the clusters with the tracks to understand which tracks are coming from the particle, which are coming from secondary interactions of the signal.

- ★After digitization, Allpix^2 gives us the clusters, cluster charge, cluster position, pixel charge etc.
- ★The clustering algorithm used in Allpix^2 is very basic:
  - ★Add all the adjacent pixels which got fired.
  - ★This may be a good starting point for us.
  - ★Complicated scenario like pixel sharing among two clusters may be worked on later.

Summary and To Do:

- Digitization of LUXE simulation on tracker are done by Allpix^2 framework.
    - We can exploit the cluster size and cluster charge distribution to cut on background before we even go for Kalman Filter algorithm.
    - The exact cuts need to be decided after seeing the simulation from the new samples.
- Clustering
    - Using basic clustering now, any adjacent pixels which are fired are added to the cluster.
- Challenges:
    - The digitization is slow.
    - Only one stave with couple of BXs took ~10 minutes.
    - Divide and conquer
        - Thinking of dividing the tracker into each chip and each BX.
        - submit jobs to the batch.

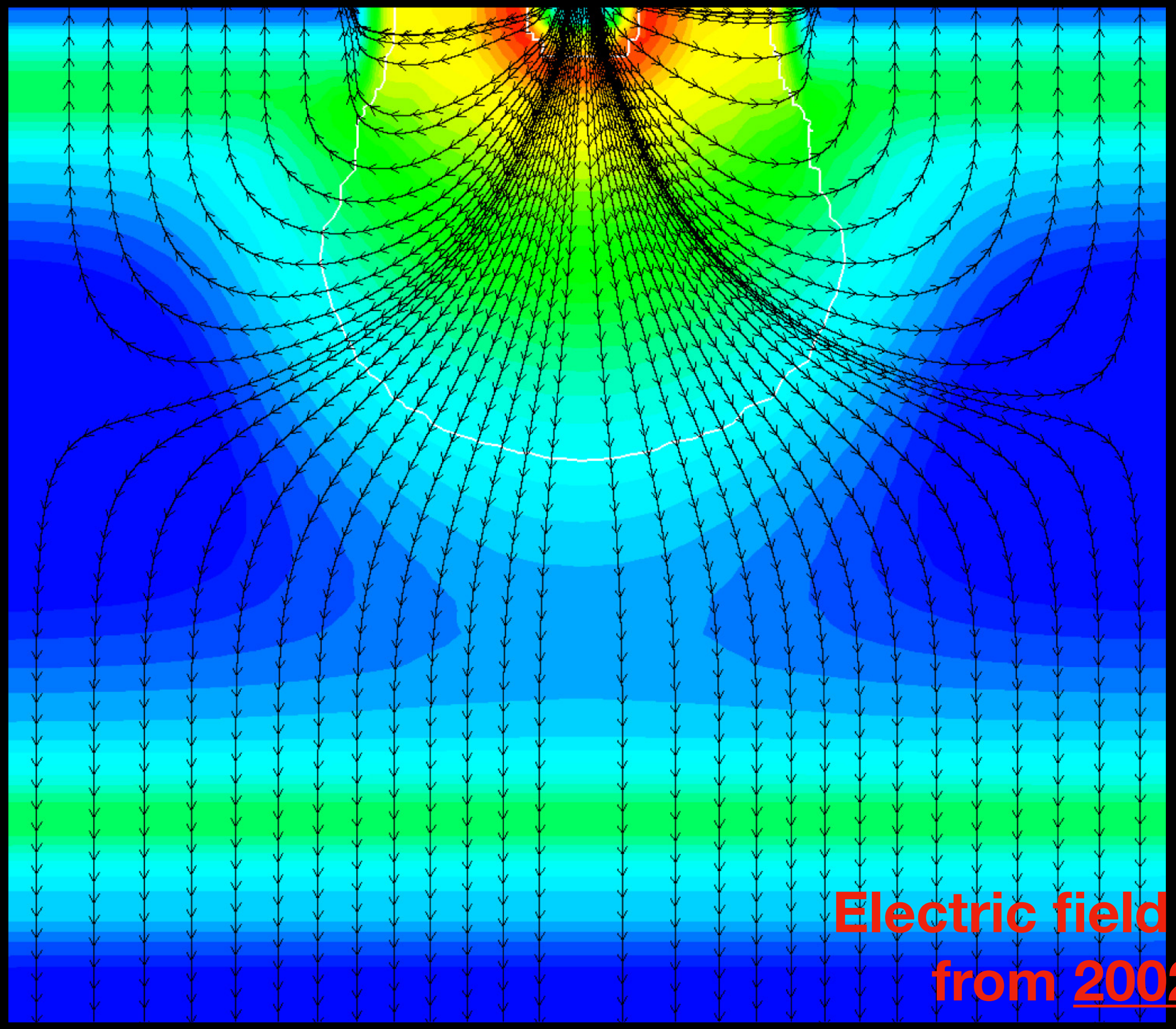
Back up

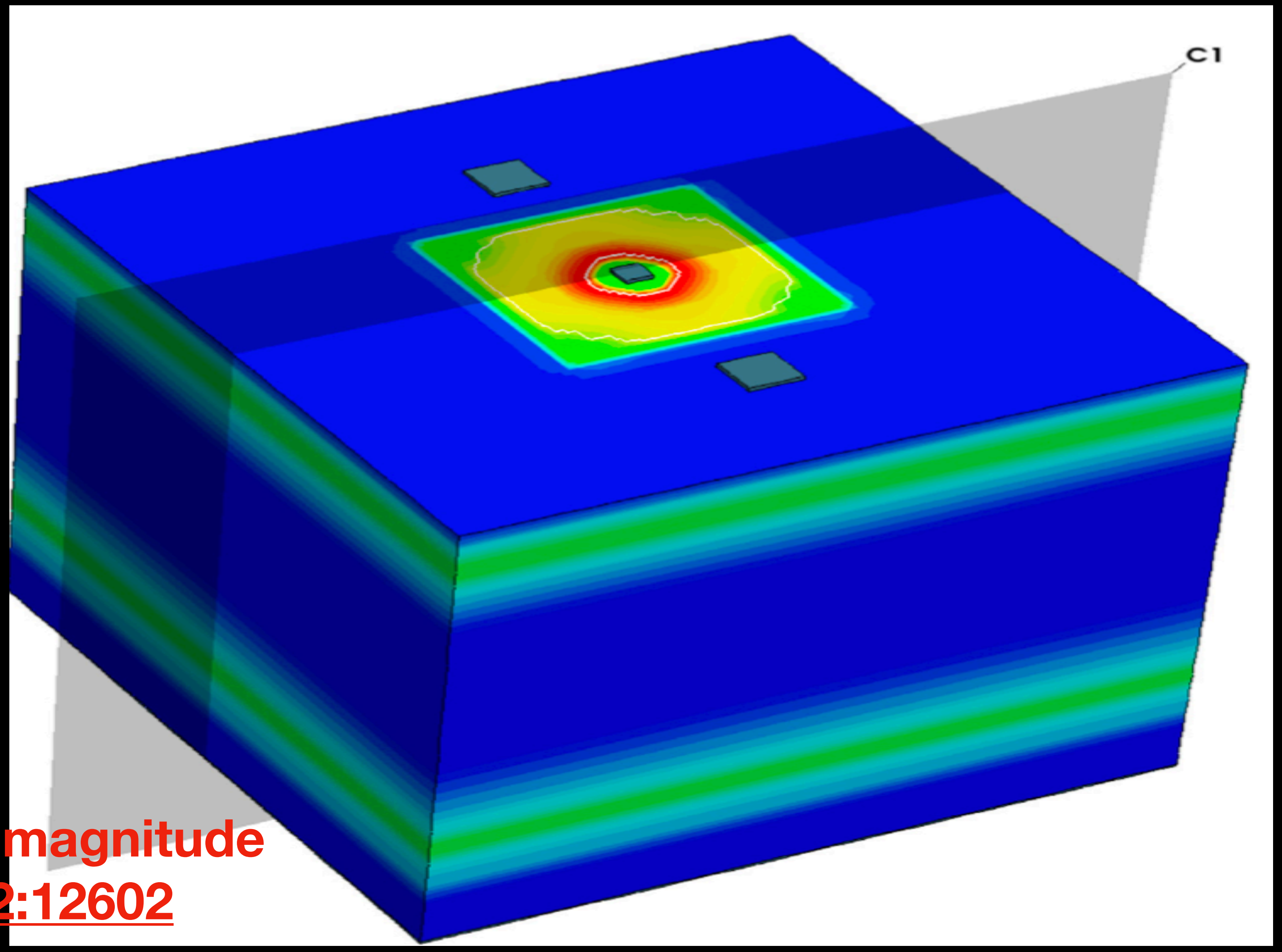
Check the response of ALPIDE in Allpix^2

- A paper (2002:12602) written by the Allpix^2 developers working on CMOS monolithic pixel chip - compared the simulation with data.
  - We want to reproduce some of the results from the paper in order to see the response of our ALPIDE chips.
  - After reproducing the result from arXiv 2002:12602, we will produce same kind of plots from the Geant4 simulated deposited energy on the tracker.
- Why are we interested in this?
  - The paper uses an electric field based on precise TCAD simulation.
  - This field depends on many properties of the ALPIDE (e.g. doping profiles etc) which are proprietary of TowerJazz.
  - We do not yet have the E-field mesh from the TCAD simulation: hoping to get it at some point
  - In principle, if we had the doping profiles from TowerJazz, we could produce the TCAD simulation ourselves but this is even more difficult than getting the E-field itself.
  - **Custom electric field in Allpix^2 bypasses the problem of not having precise TCAD field.**
  - Started with simple linear electric field up to a certain depletion depth.
    - Move to a tailored custom-field similar to what is in the paper.

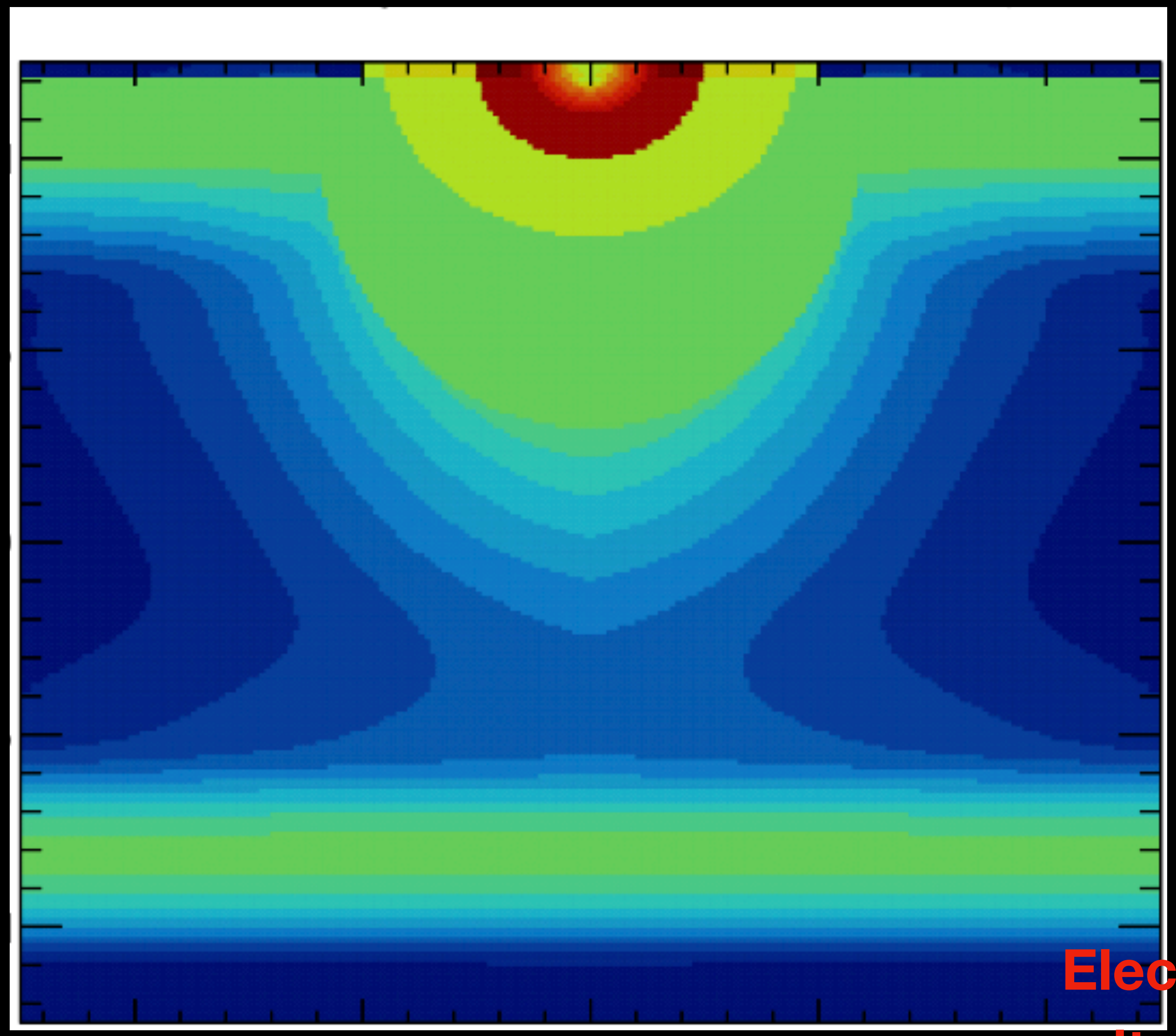
Custom electric field

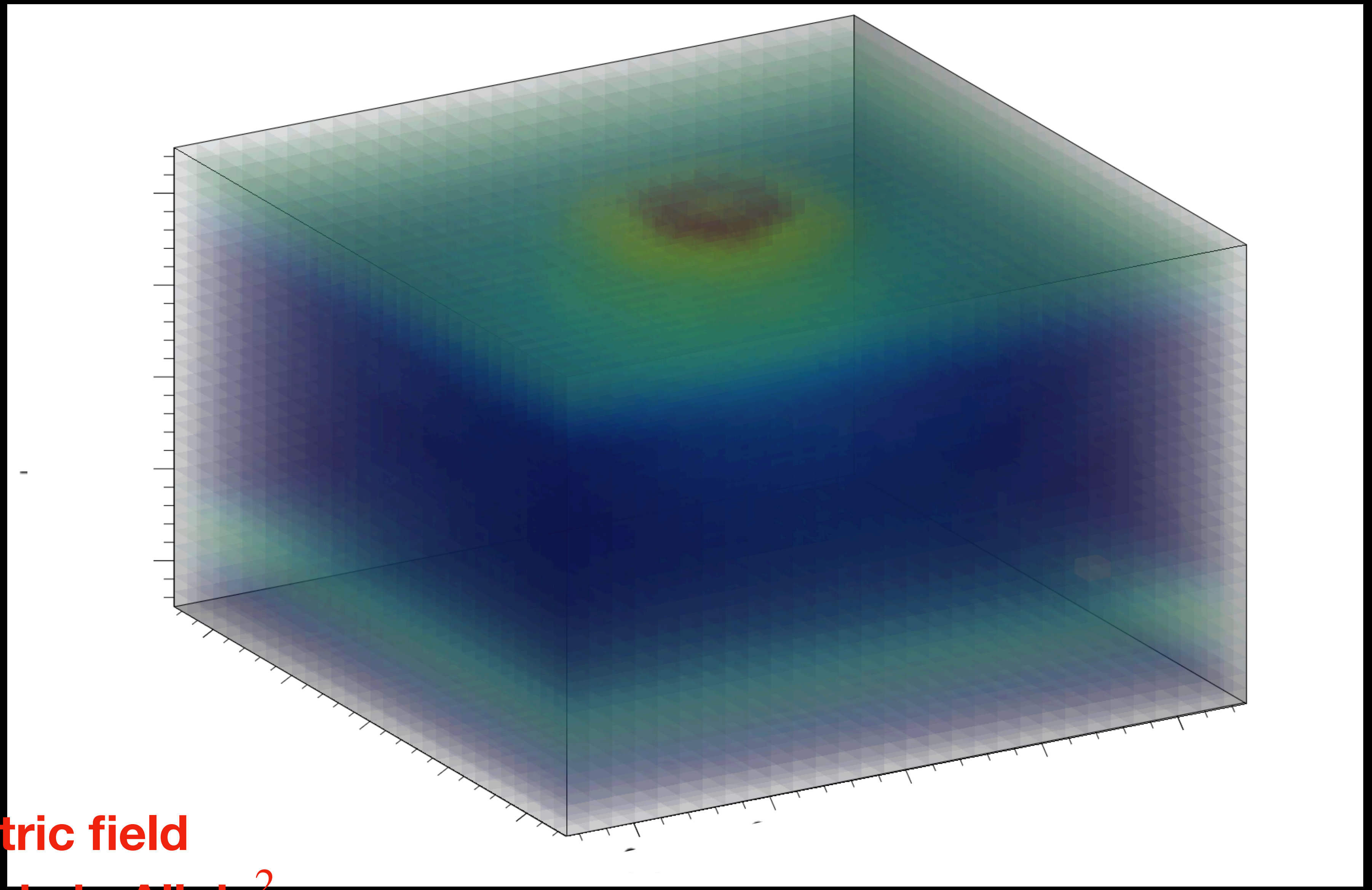
- Allpix^2 version 2 included the possibility of introducing a custom electric field.
- Here custom electric field can be defined using ROOT::TF3 objects: provide three functions for $E_x(x, y, z), E_y(x, y, z)$ and $E_z(x, y, z)$.
    - Built custom electric field to look as much as the field produced by the mesh.
    - Took a lot of effort because the plot from 2002:12602 shows the 3D magnitude of the electric field without the axes scales.
        - Needed to find three custom electric field functions such that their quadrature looks like that in the paper.
    - Had to do a lot of trial and error method in the dark to match the electric field both visually and in terms of replication of the cluster charge, cluster size, efficiency etc results.





Electric field magnitude from 2002:12602





Electric field magnitude in Allpix^2

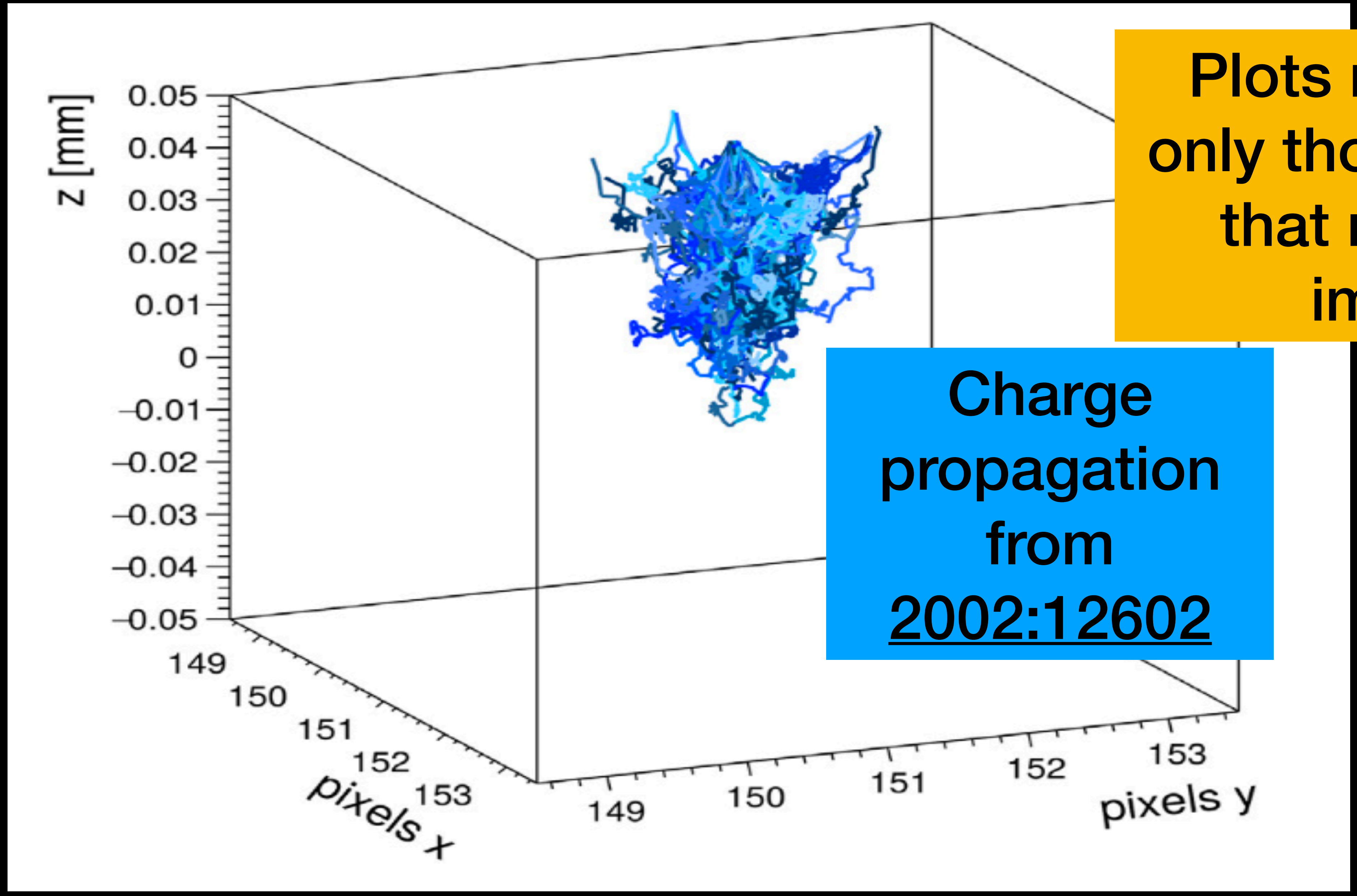
Settings comparison for custom electric field

- The 2002:12602 Allpix^2 paper used:
  - CMOS monolithic chip with thickness 100 um (25 um epitaxial layer thickness, 75 um silicon substrate)
  - Pion beam with 120 GeV energy
  - Used more rigorous Generic propagation for charge transfer
    - Used TCAD electric field model, they have more accurate charge transport
  - Digitizer charge collection threshold 120e unless otherwise stated.

- I used:
  - ALPIDE chip with thickness 100 um (epitaxial layer thickness)
  - Pion beam with 120 GeV energy
  - We did not have TCAD model, we only used a custom electric field going into 25 um.
    - No electric field from 25 um to 100 um depth.
  - Used generic propagation.
  - Digitizer charge collection threshold 120e unless otherwise stated.

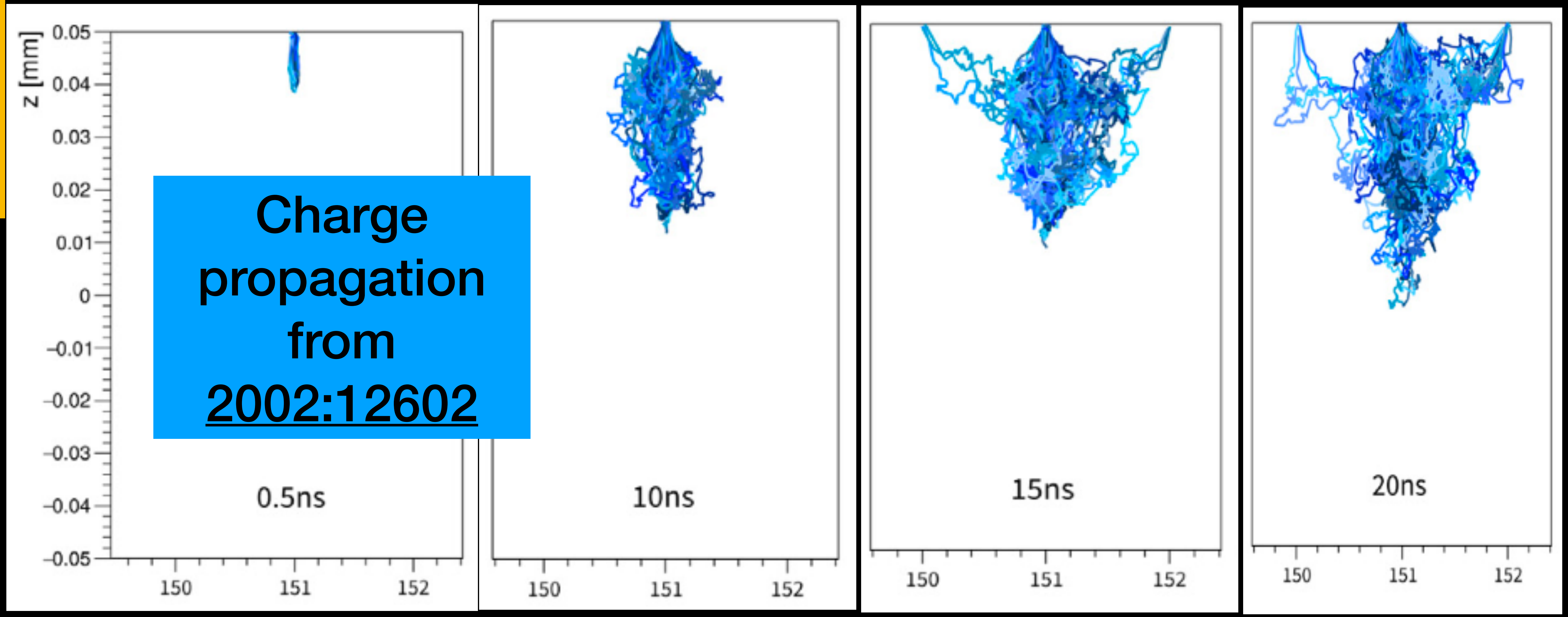
- Results shown are from a "demonstrator" ALPIDE sensor.
  - The differences to the nominal ALPIDE are not expected to be very different.

Charge propagation in custom electric field:

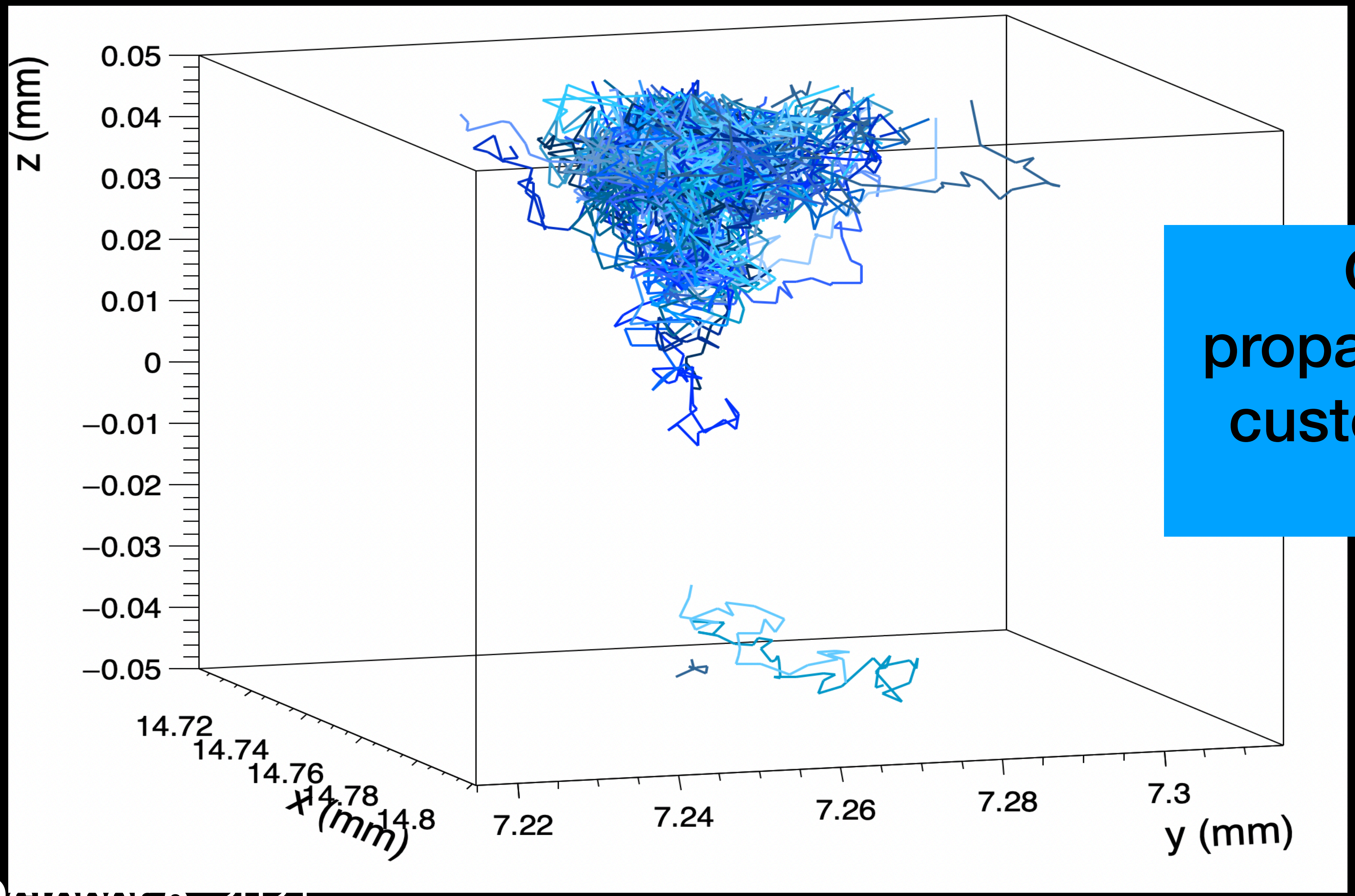


Plots made with only those charges that reach the implant

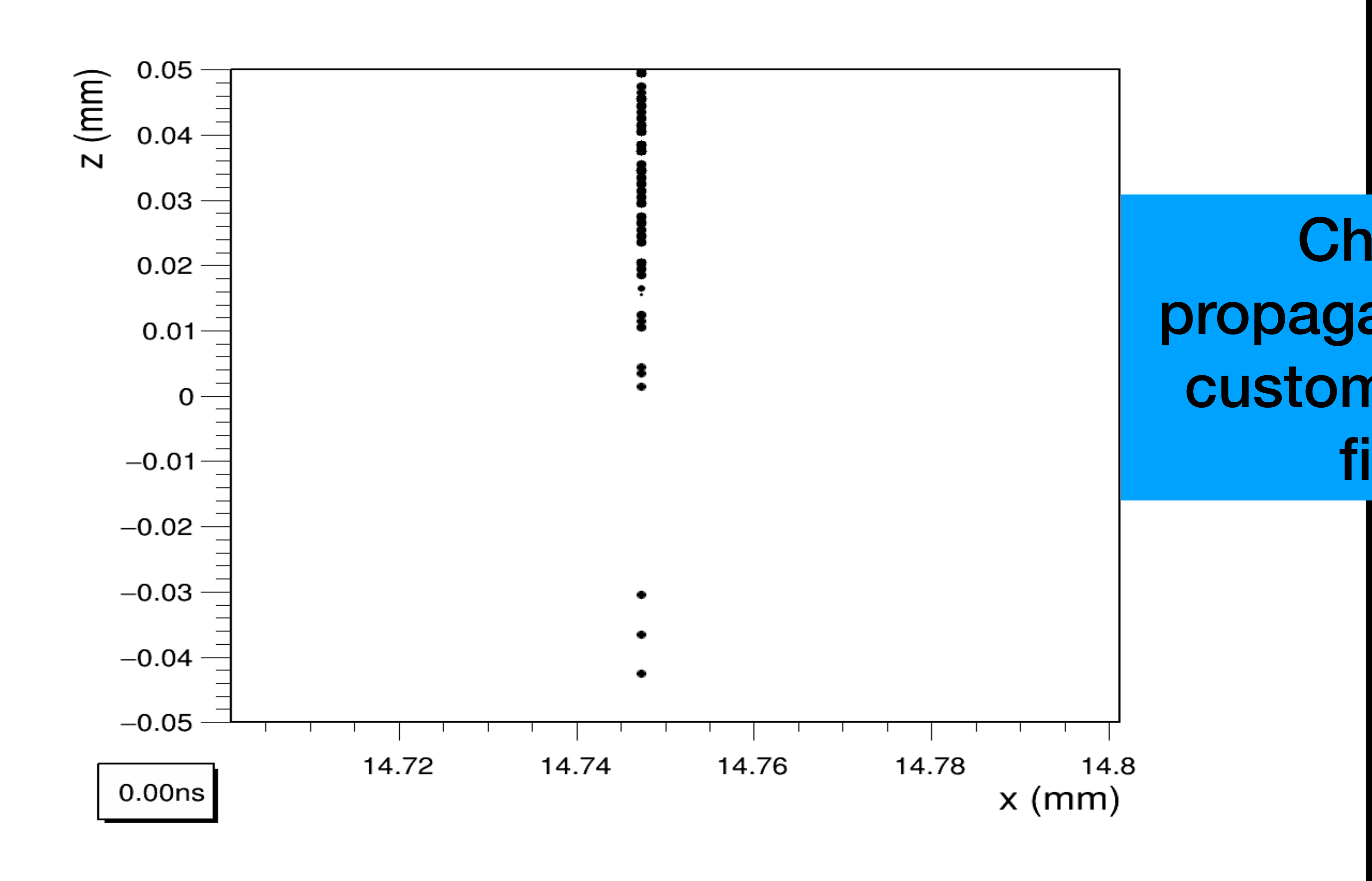
Charge propagation from 2002:12602



Charge propagation from 2002:12602

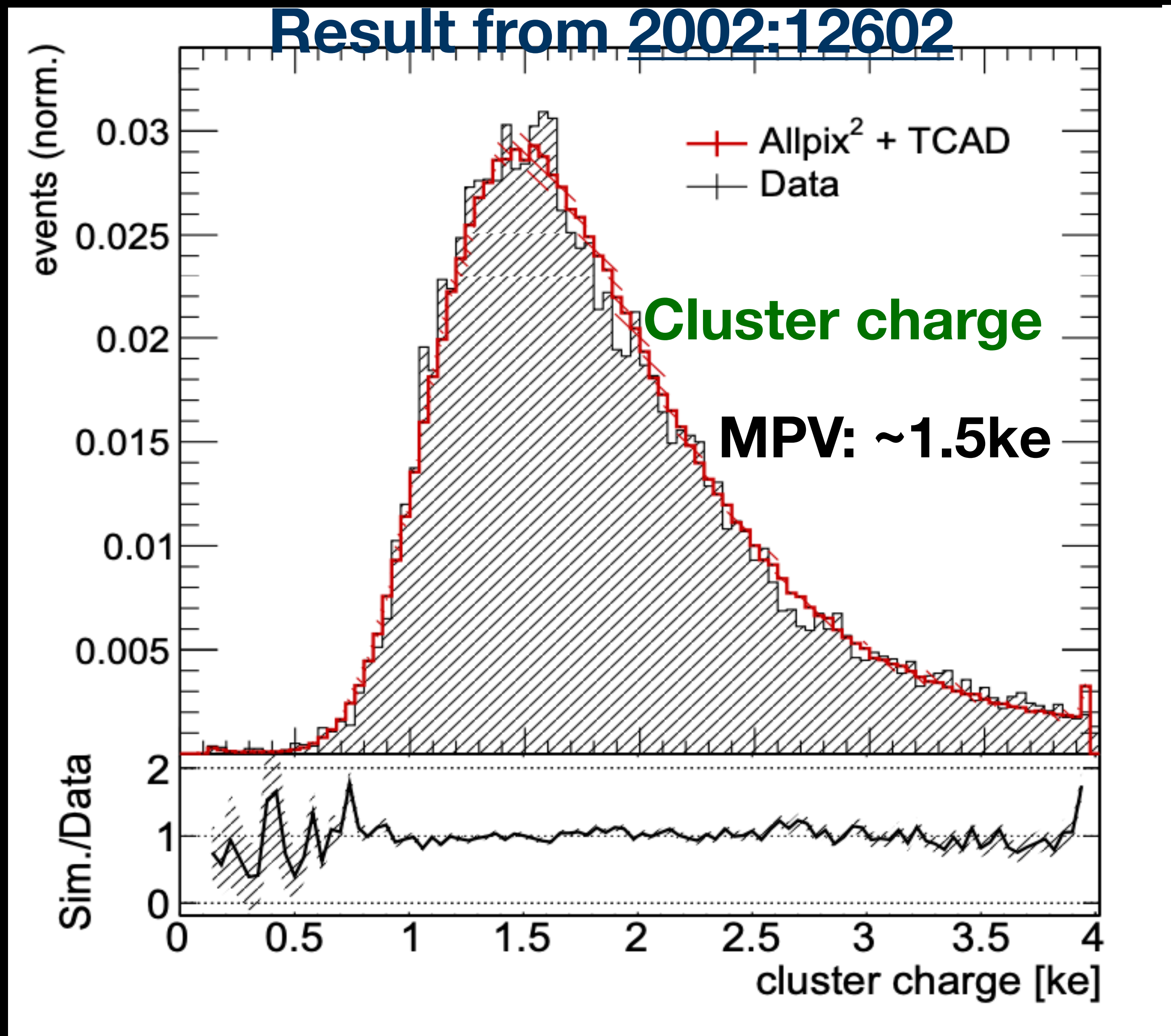


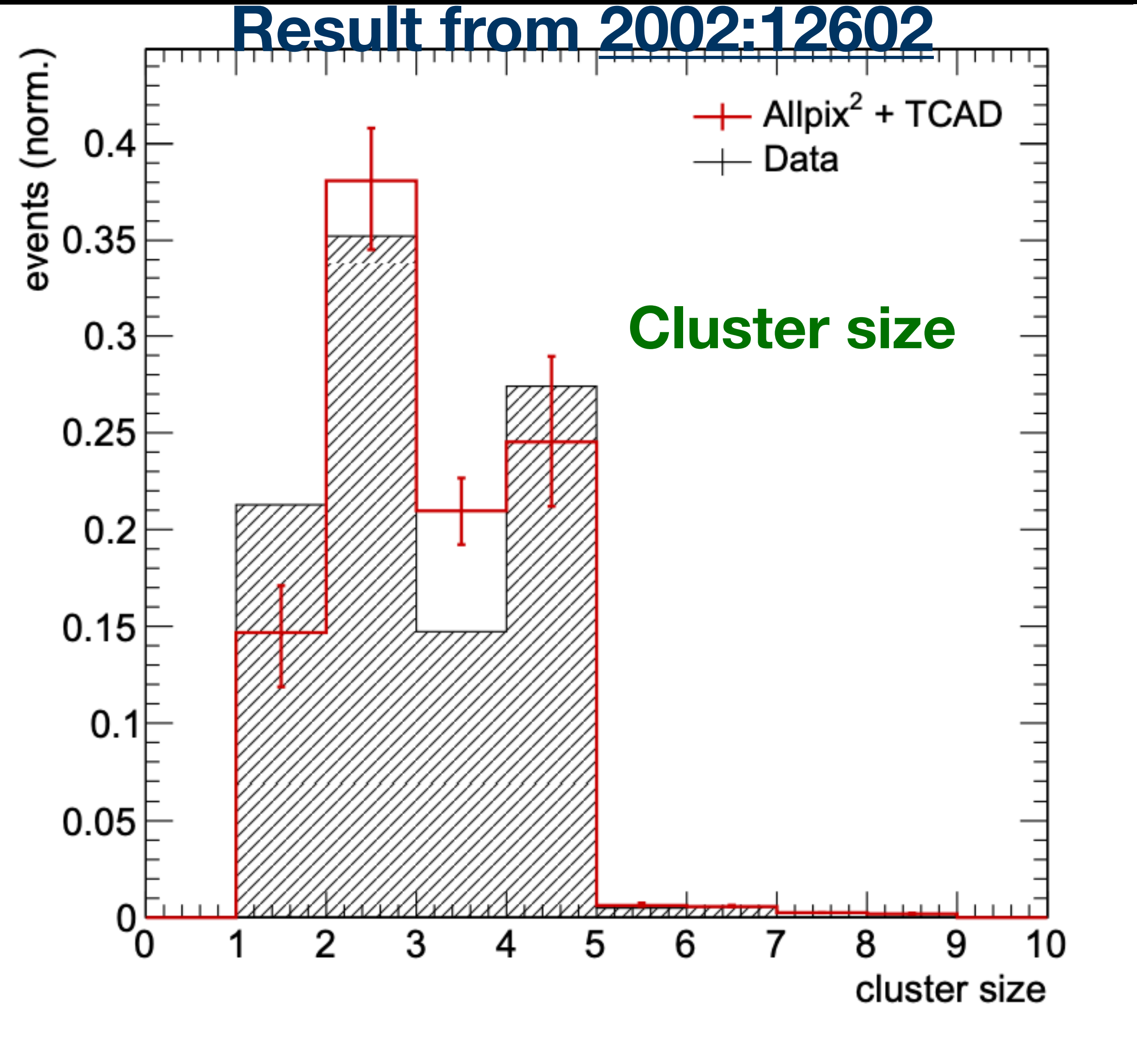
Charge propagation from custom electric field

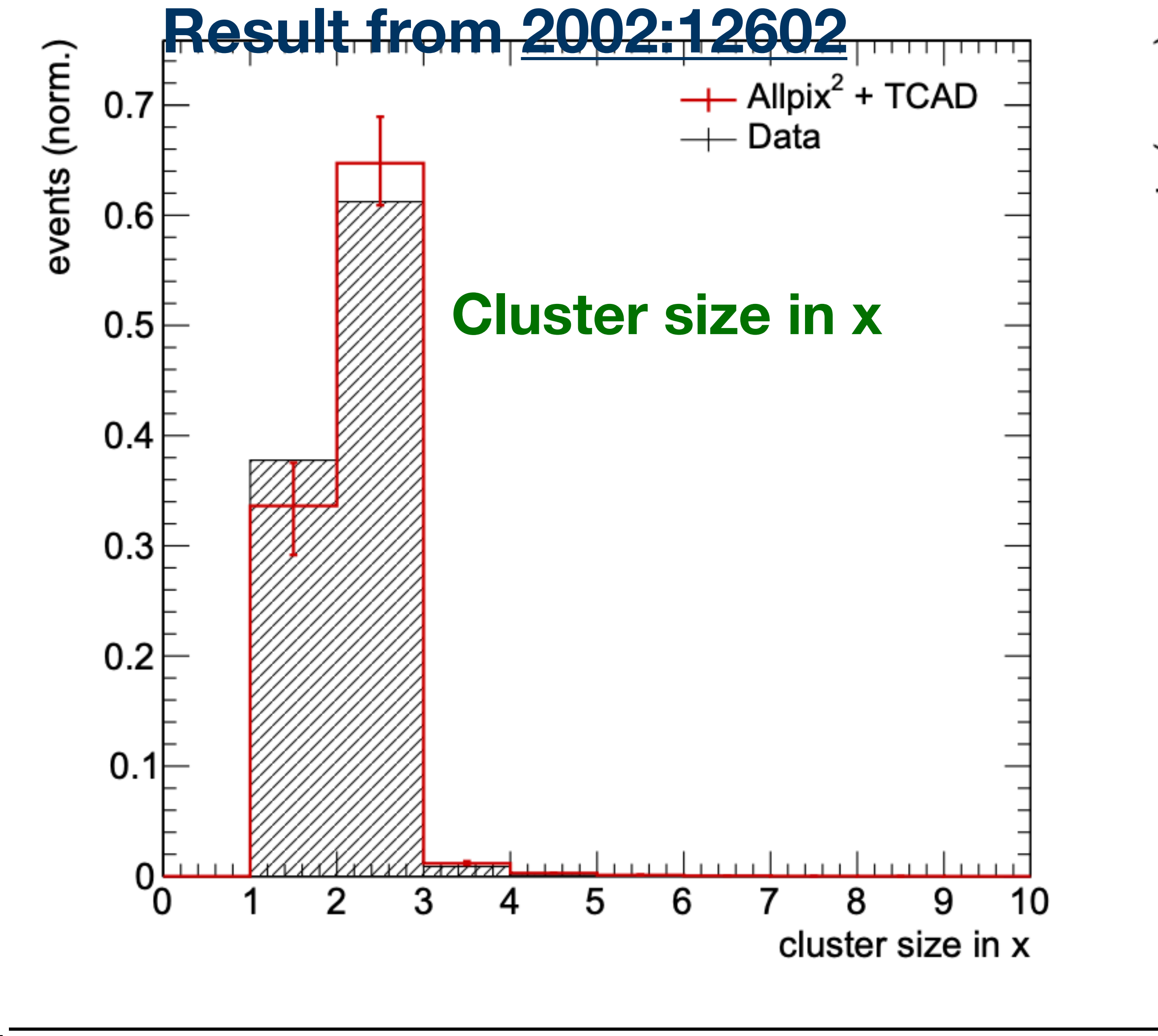


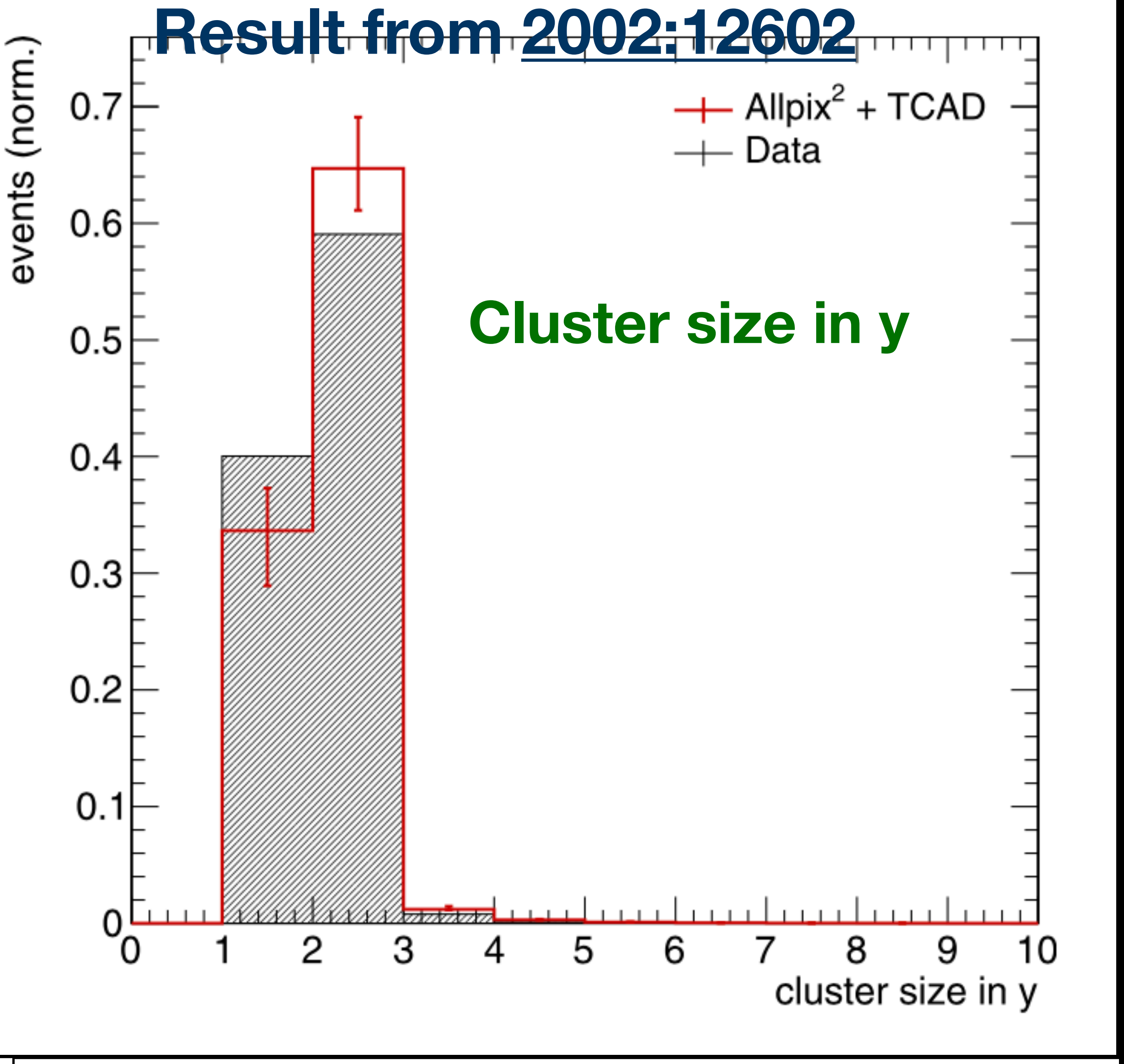
Charge propagation from custom electric field

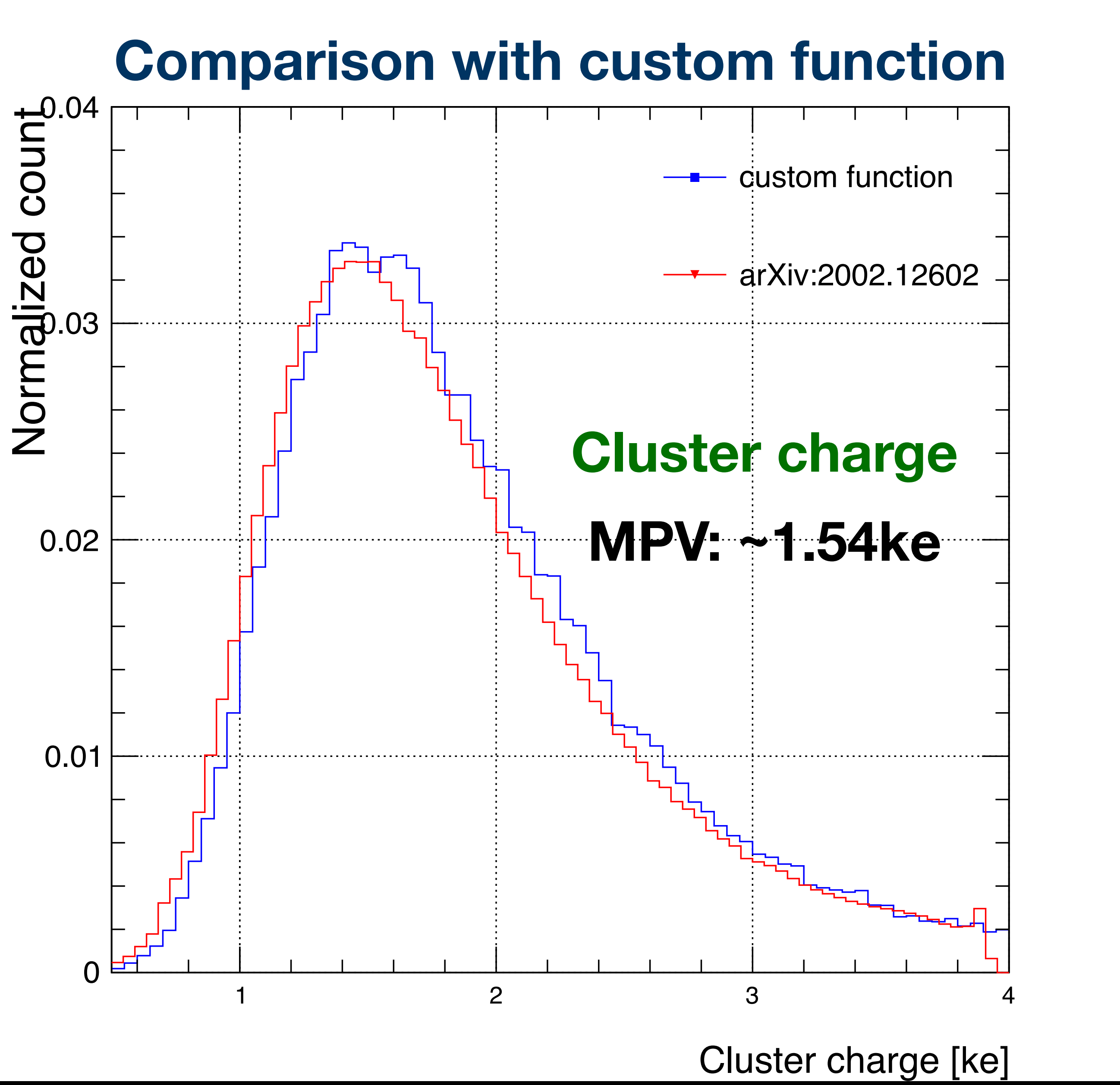
Comparison between 2002:12602 and custom electric field: I

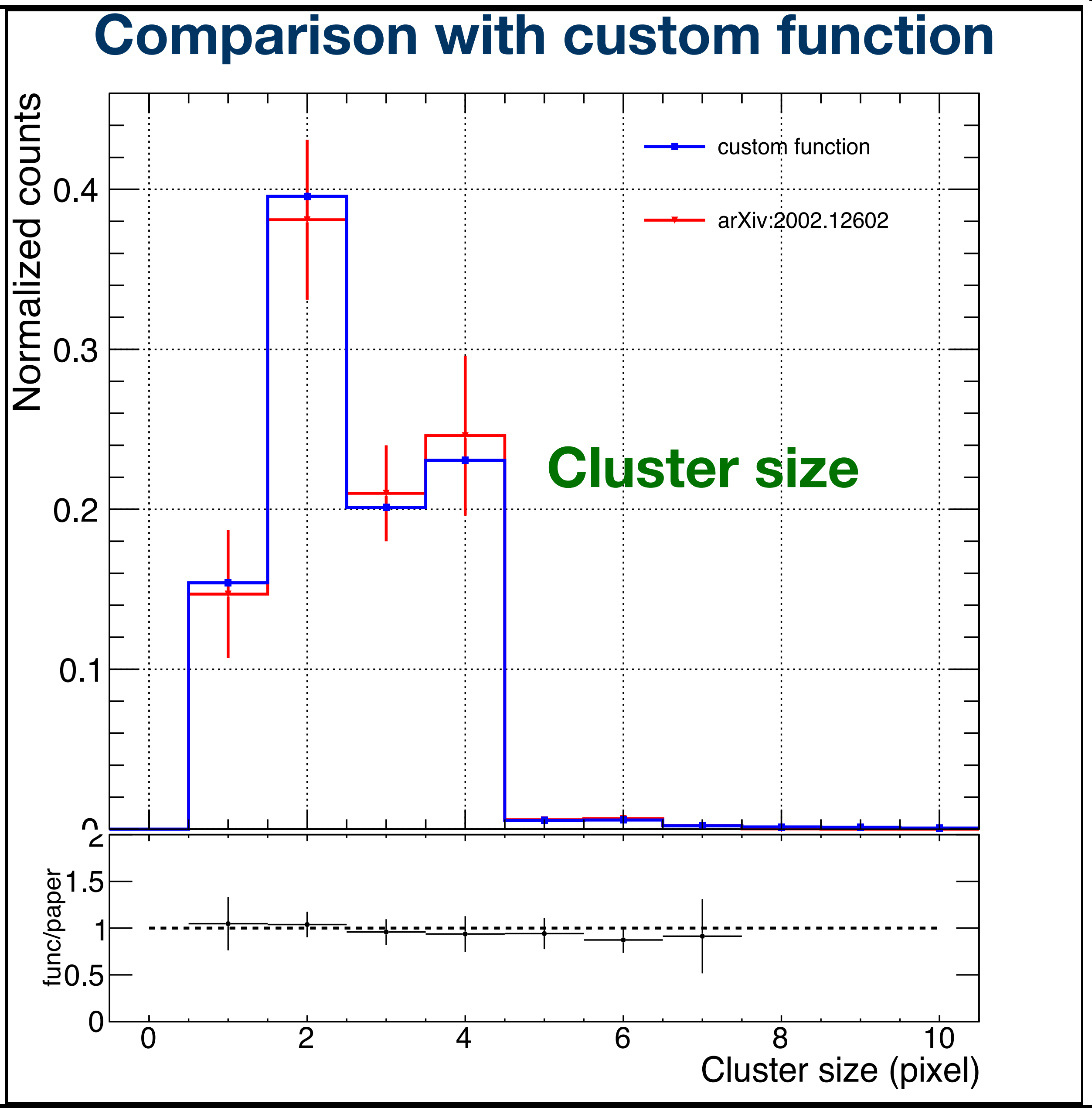


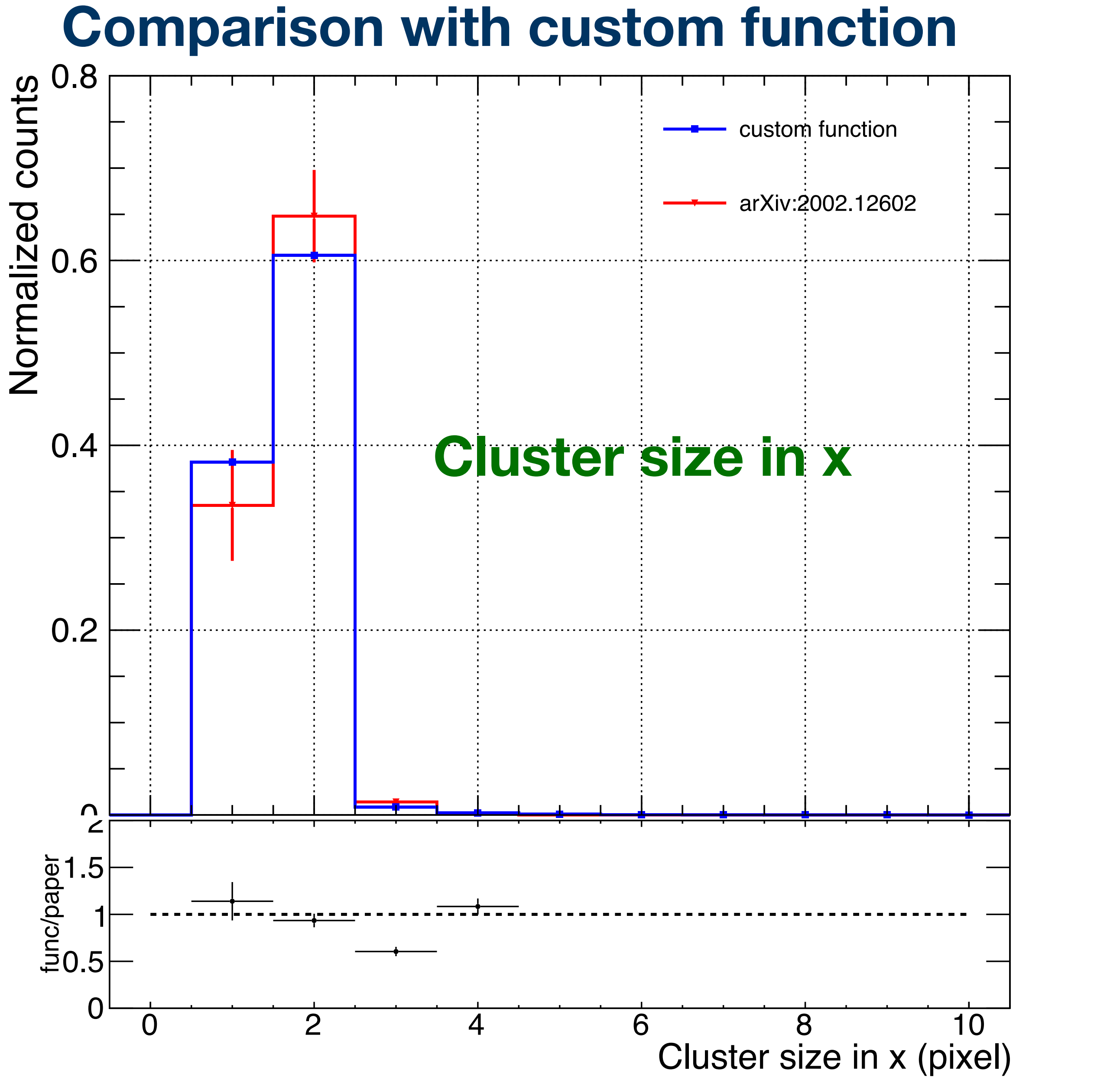


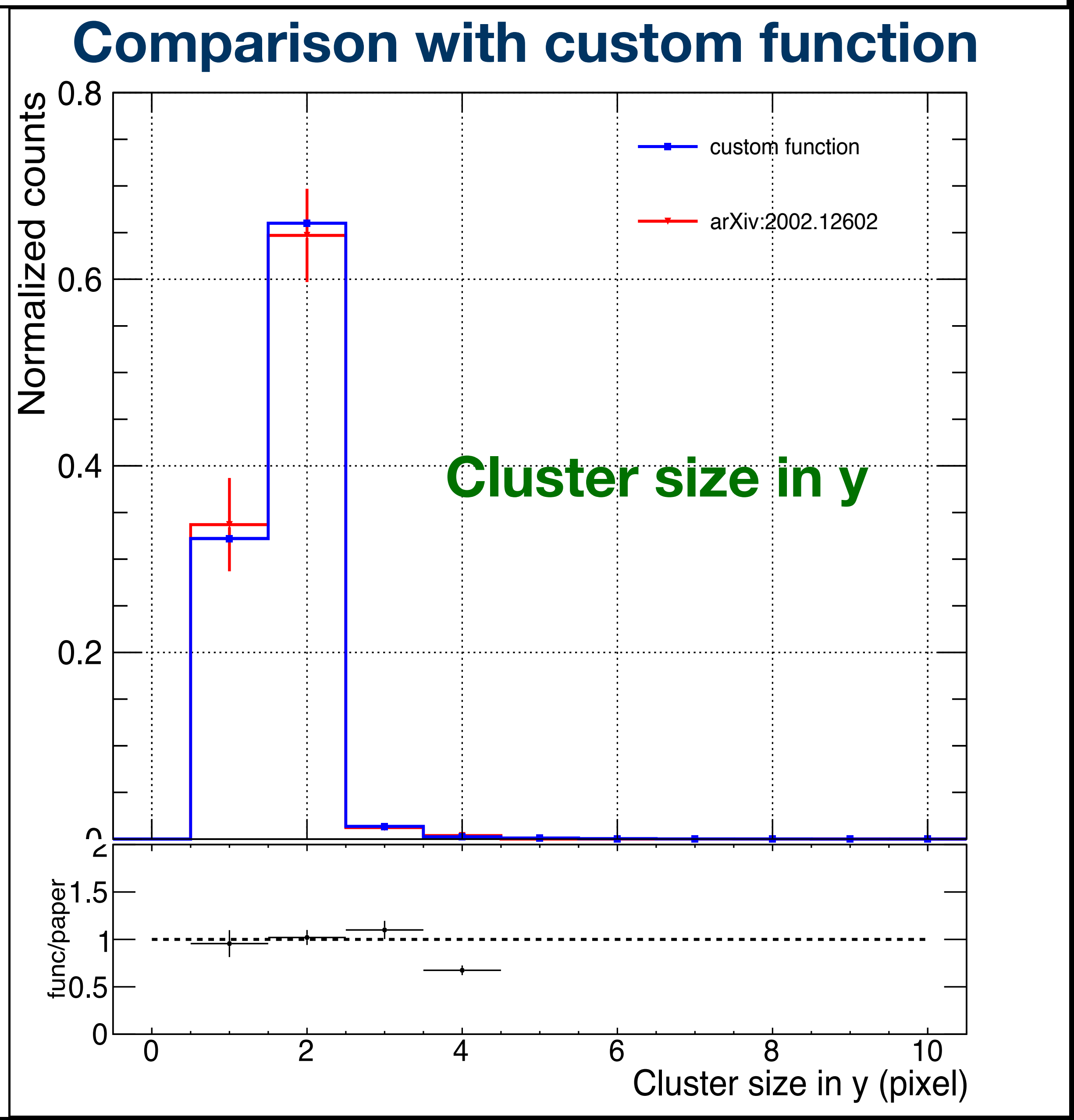




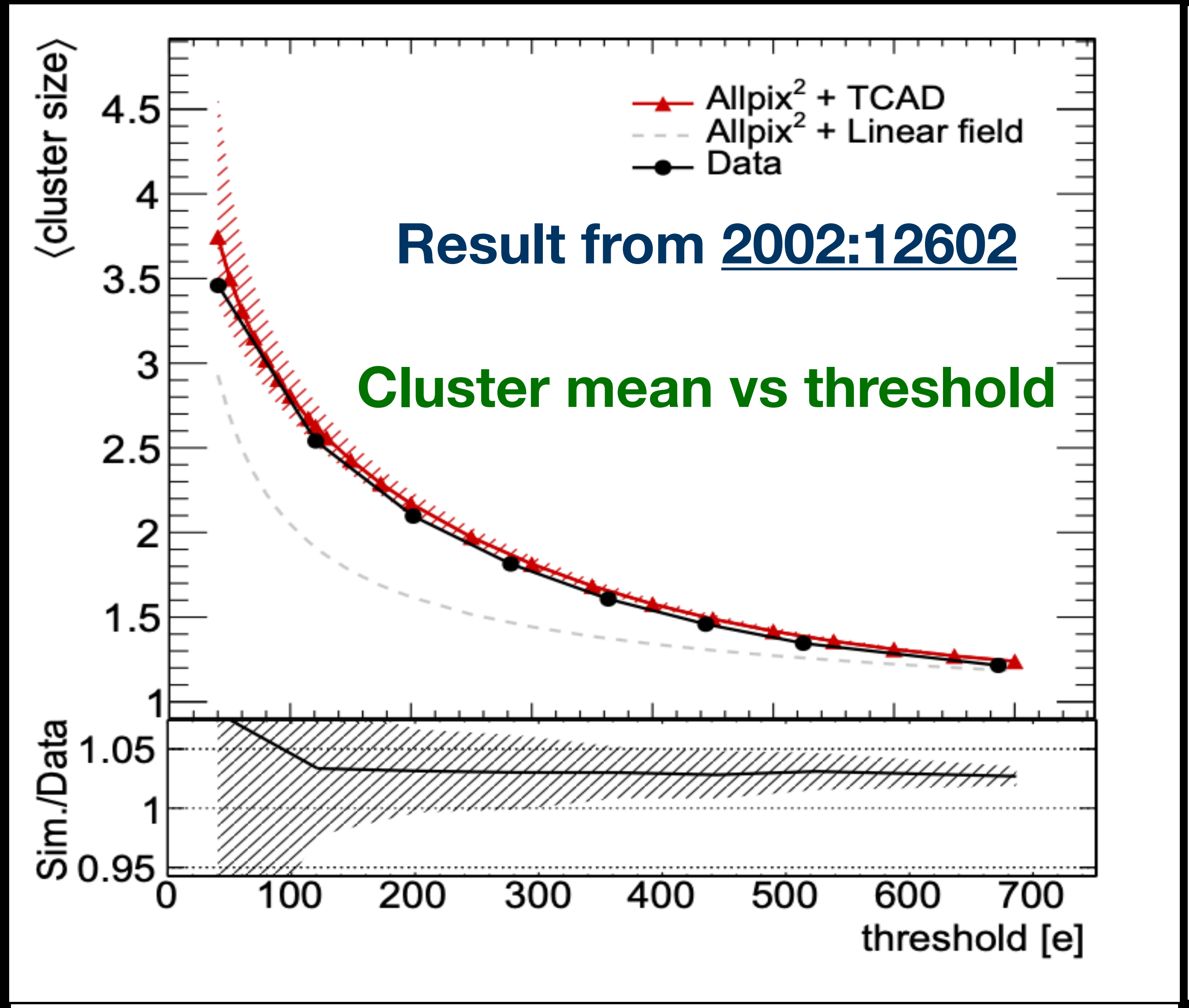


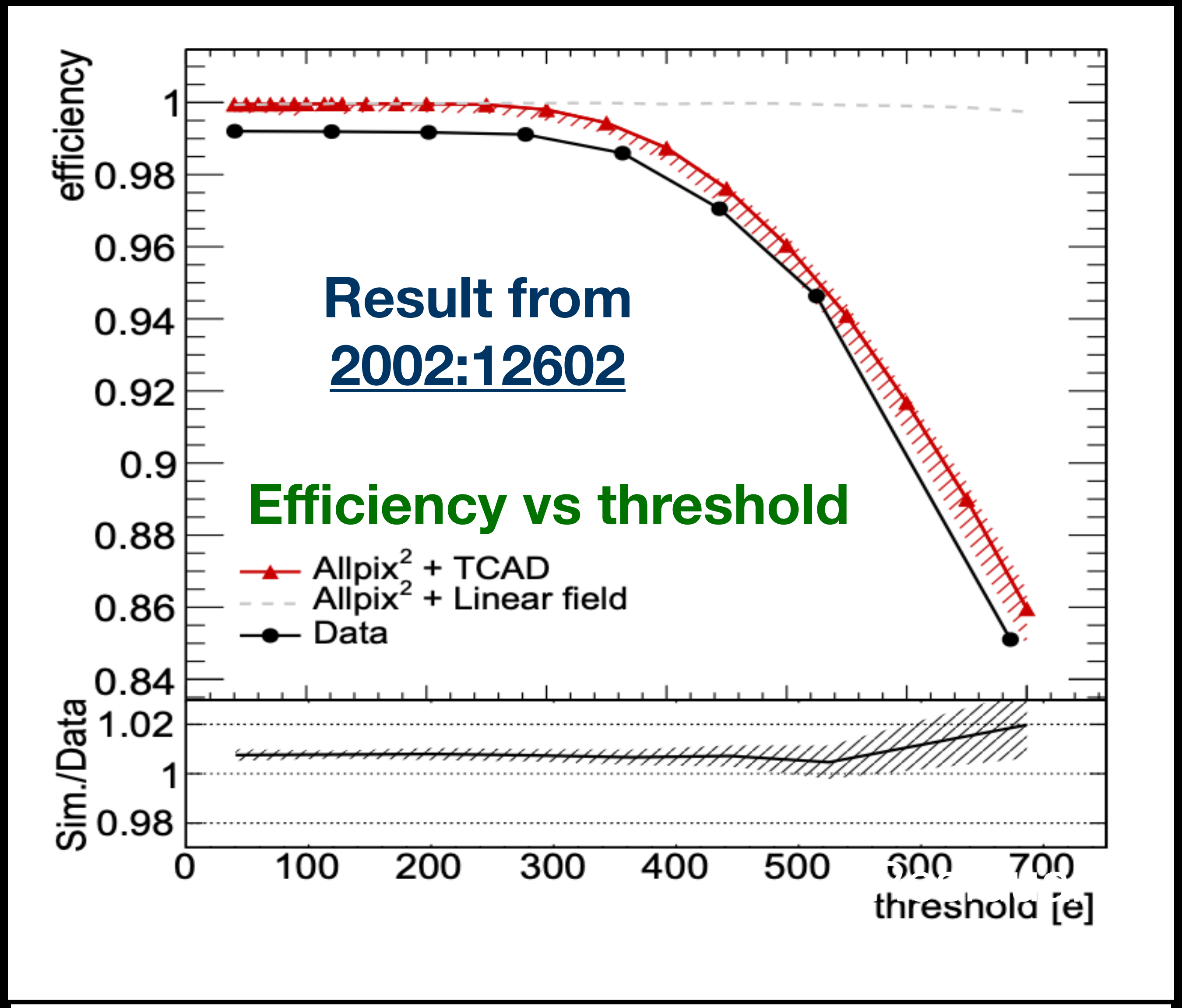


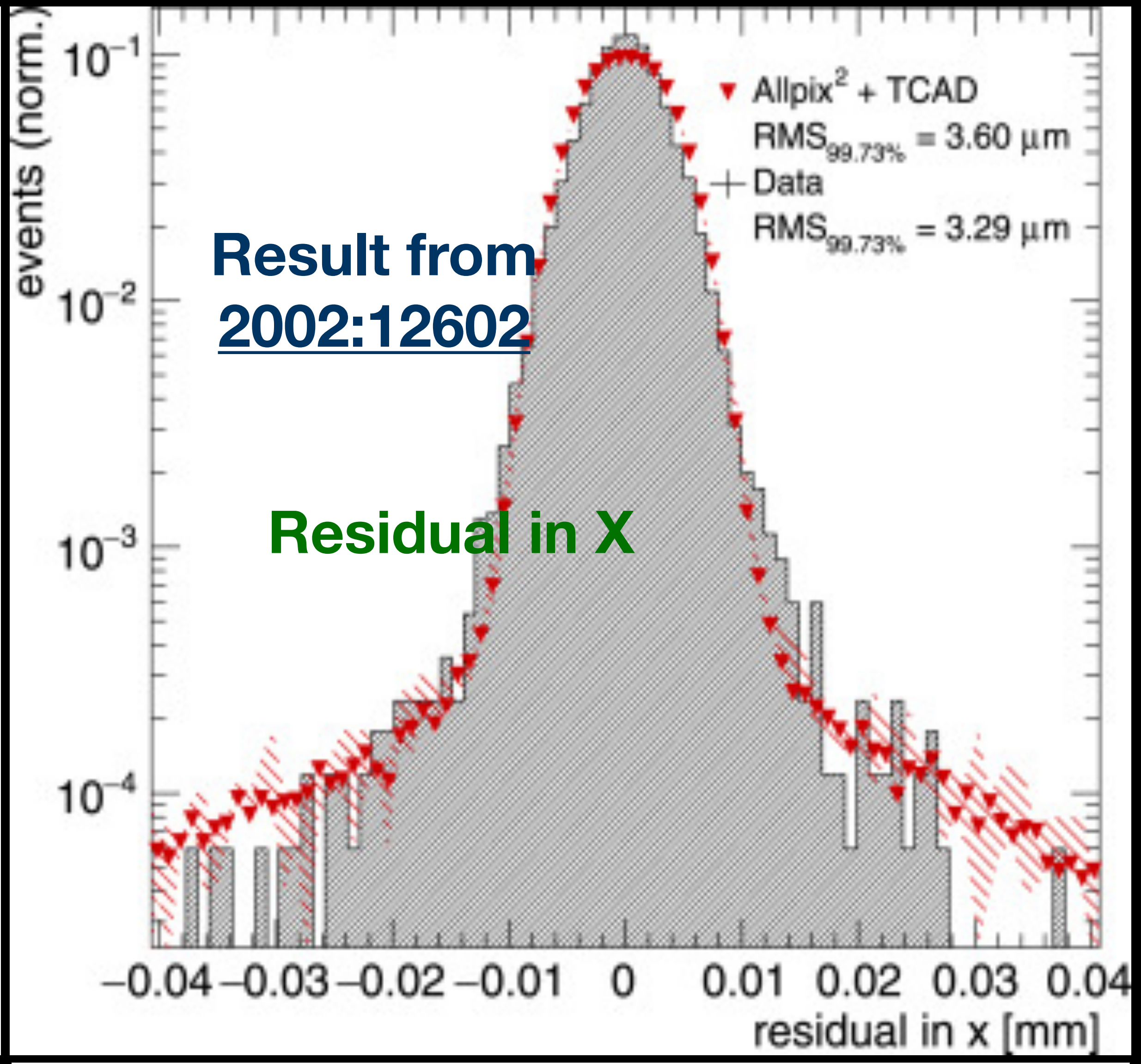


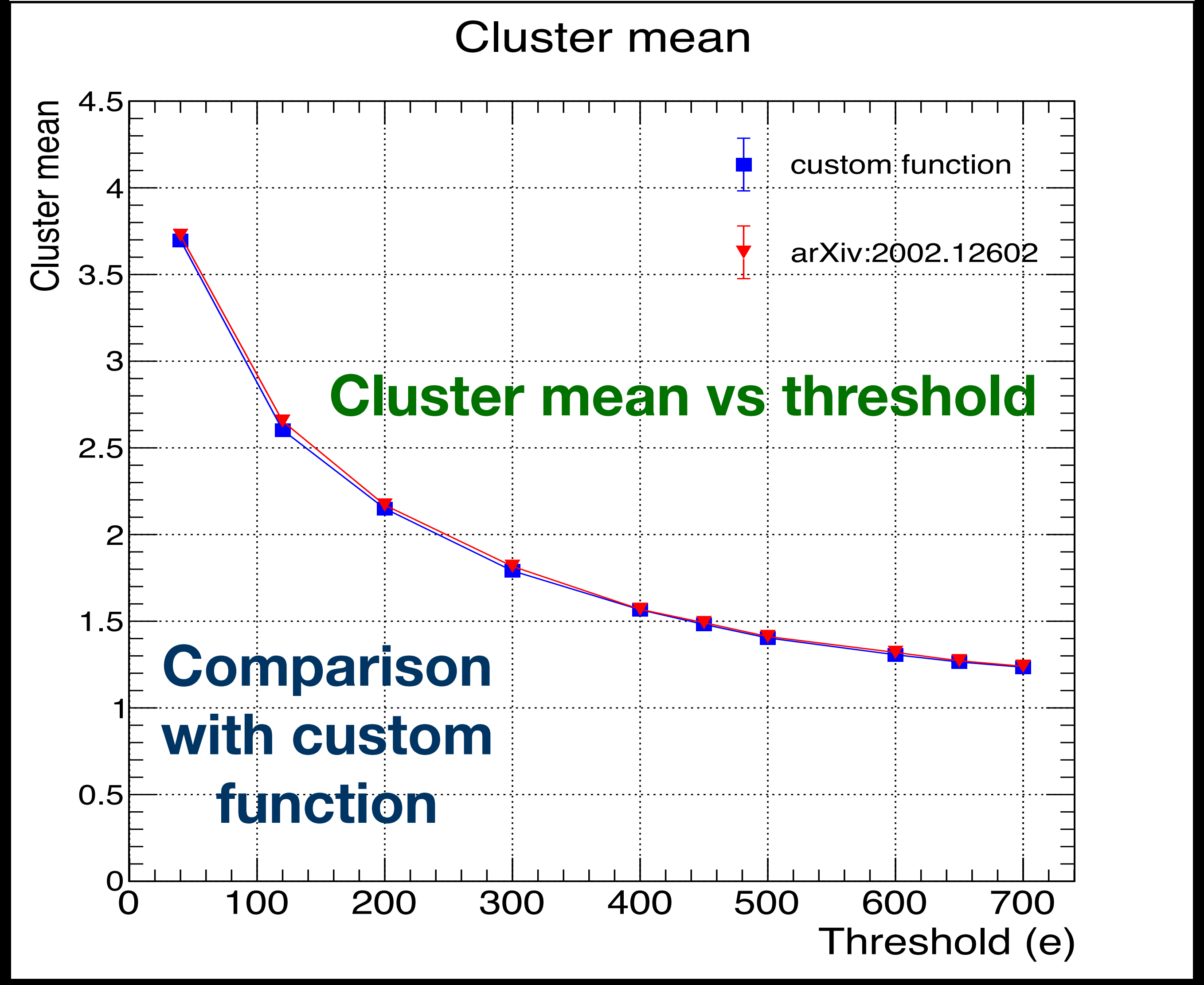


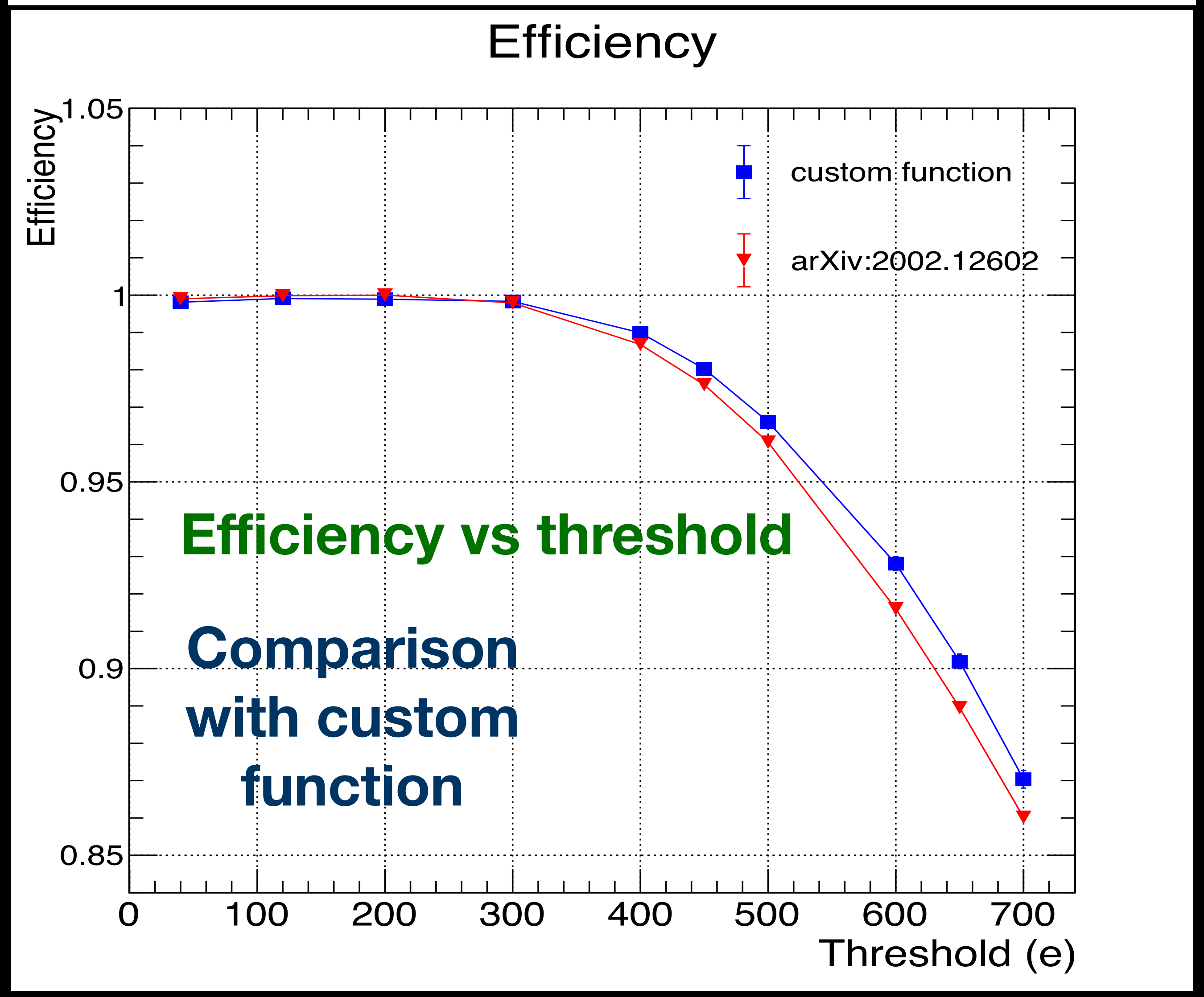
Comparison between 2002:12602 and custom electric field: II

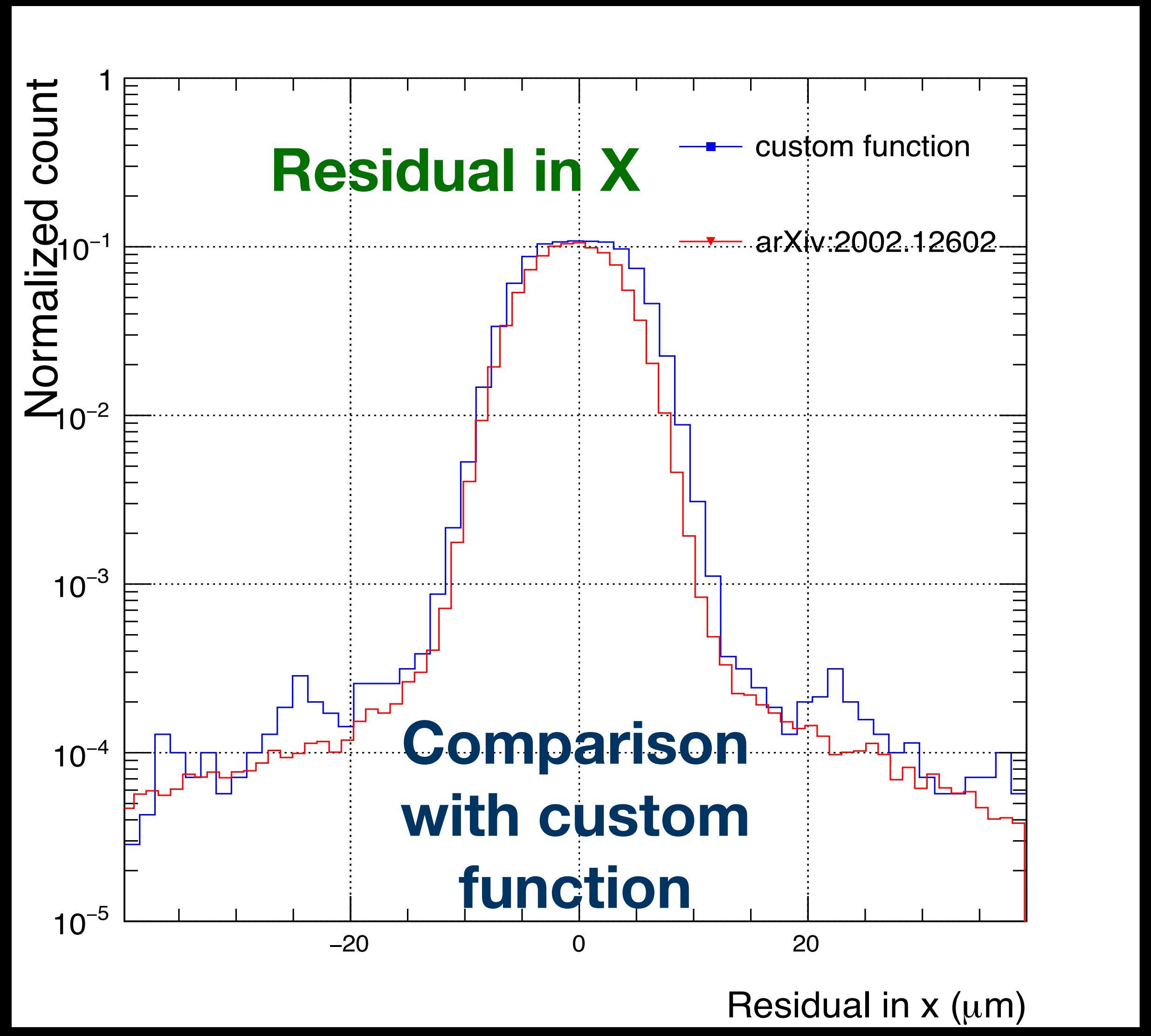








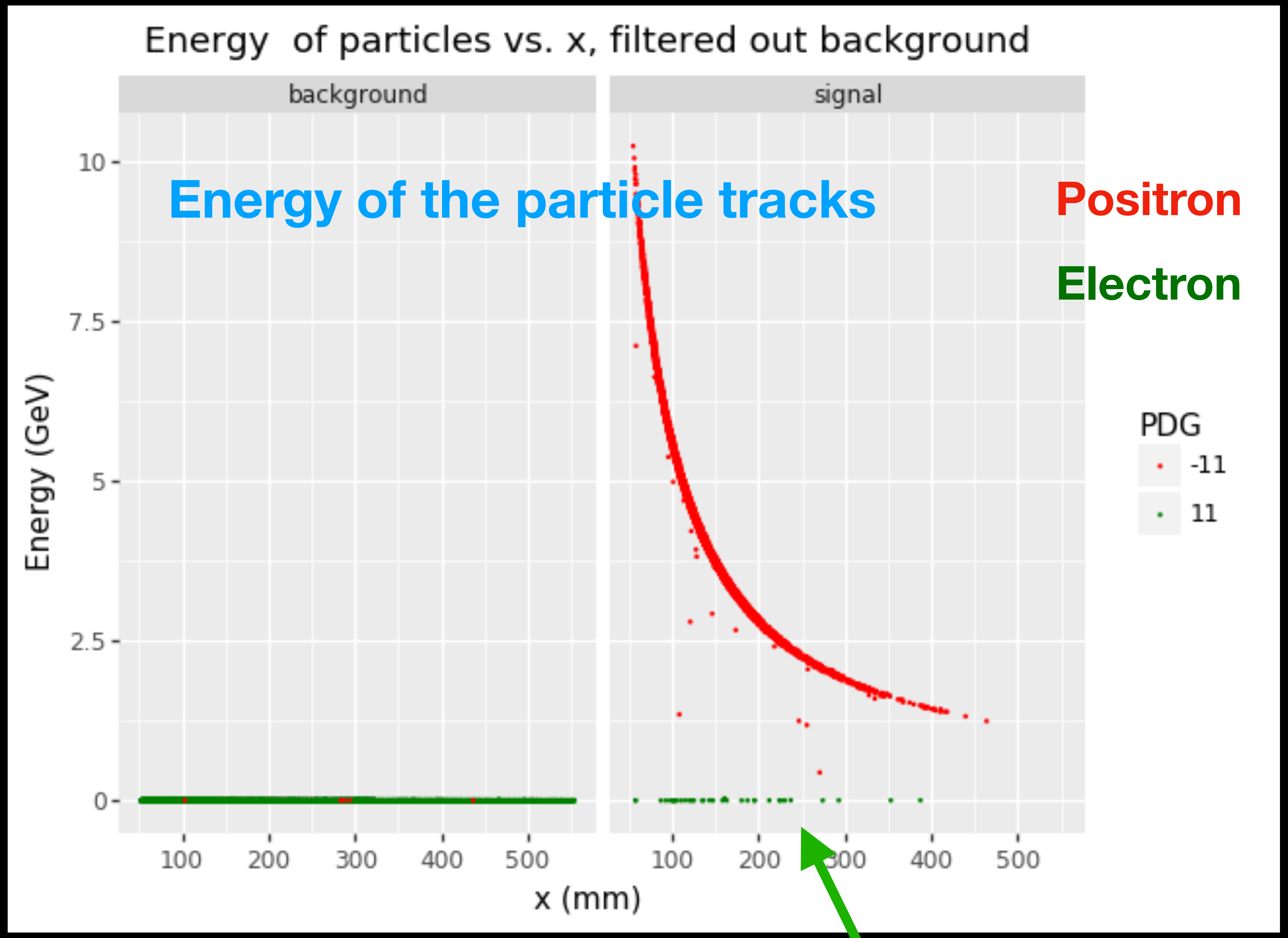




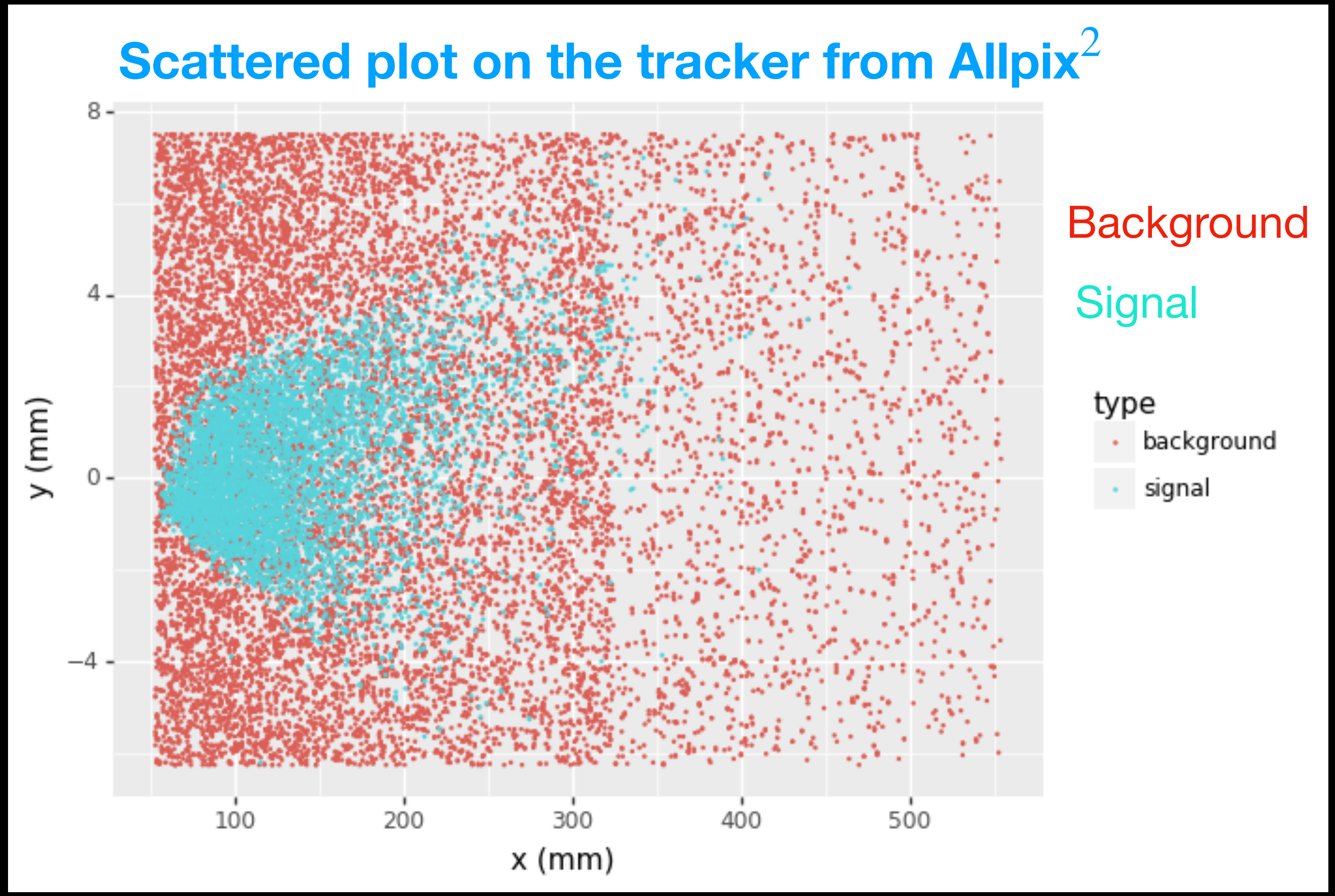
★Cluster size mean for different charge collection threshold match perfectly.
★Our efficiency is little higher than the paper for high charge collection threshold.
★Still optimizing the field.

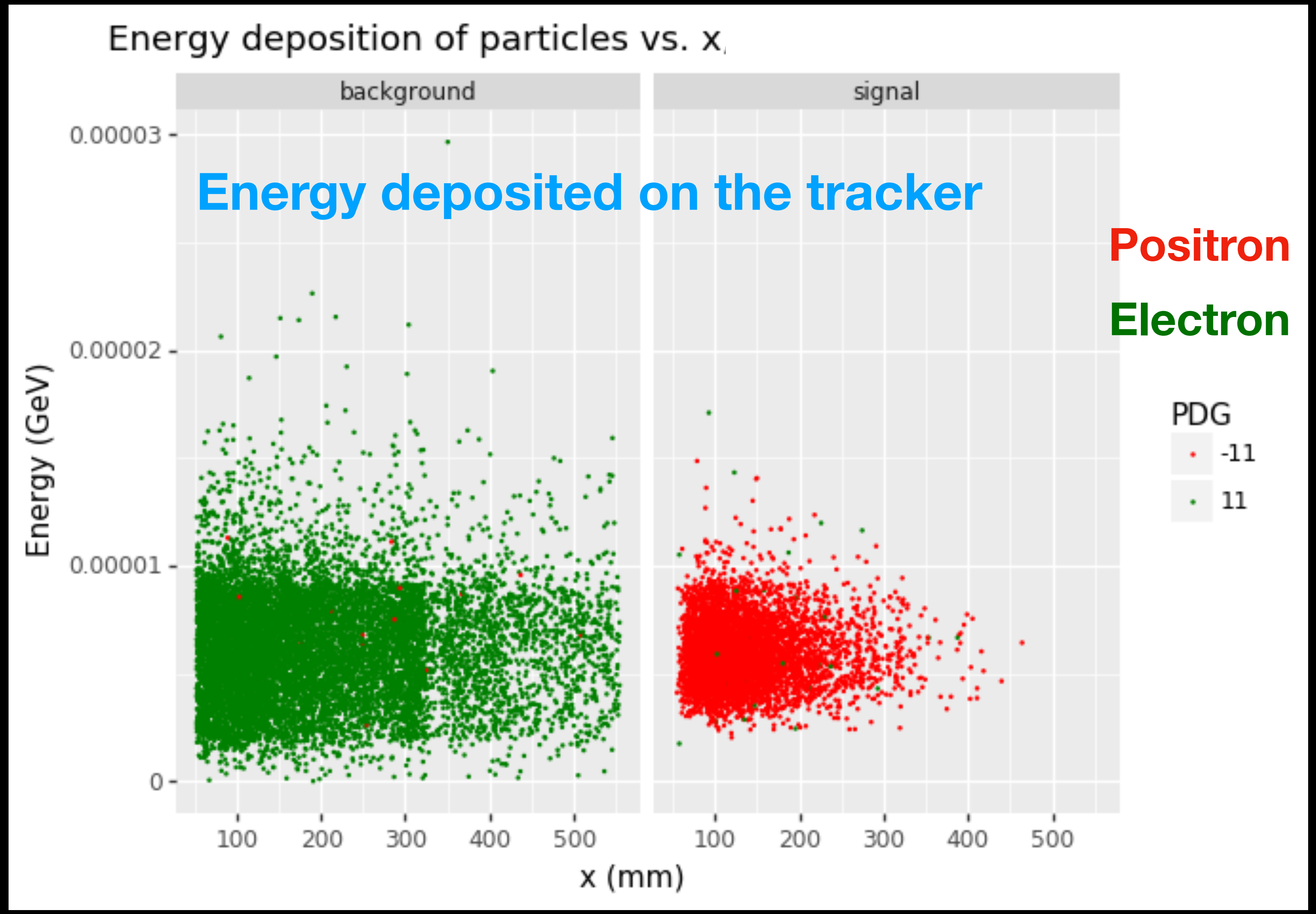
What we want to achieve

- Digitize the hits of signal and background
- Look at the hits, cluster sizes, cluster charge etc in signal and background samples
  - Want to check the sensor's response when signal and background hit the sensor together.
- Need to get the realistic electric field inside the ALPIDE chips for good simulation.



This background comes from signal hitting tracker material.





From Meir Weissman, Jonathan Kogman, and Shimon Nowik, linear electric field.

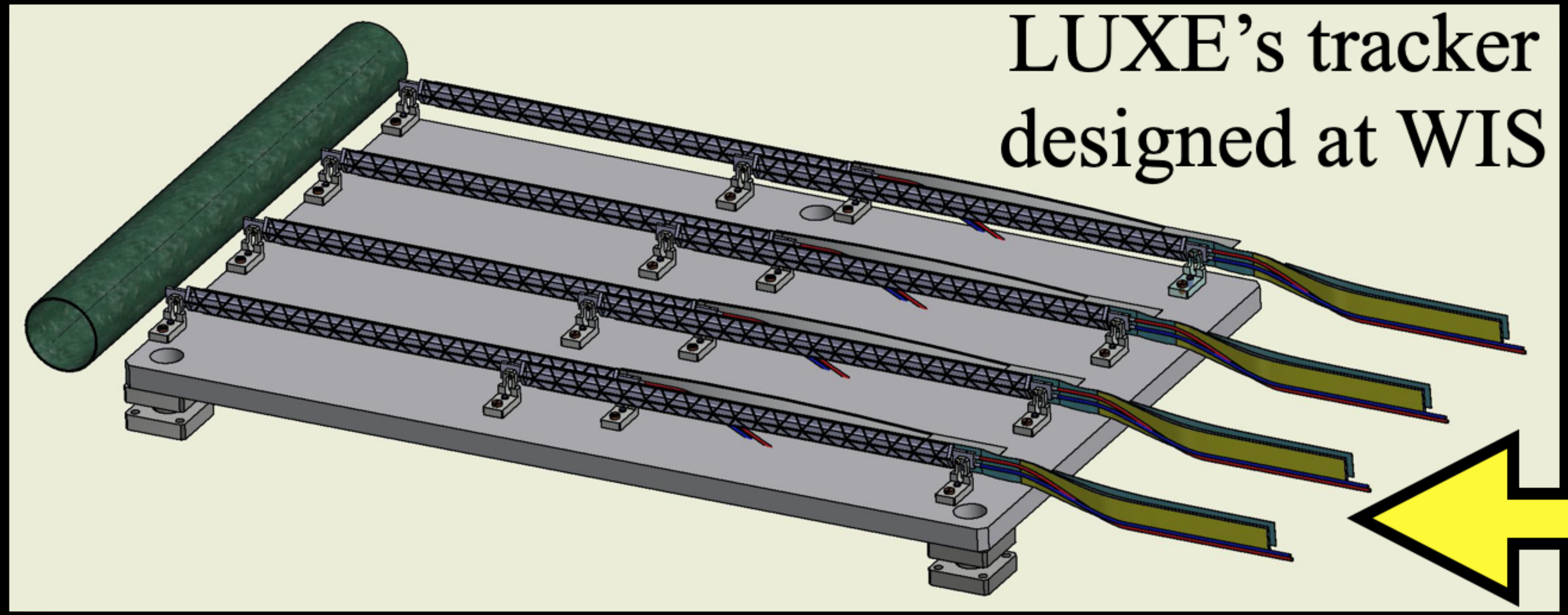
Sample config file

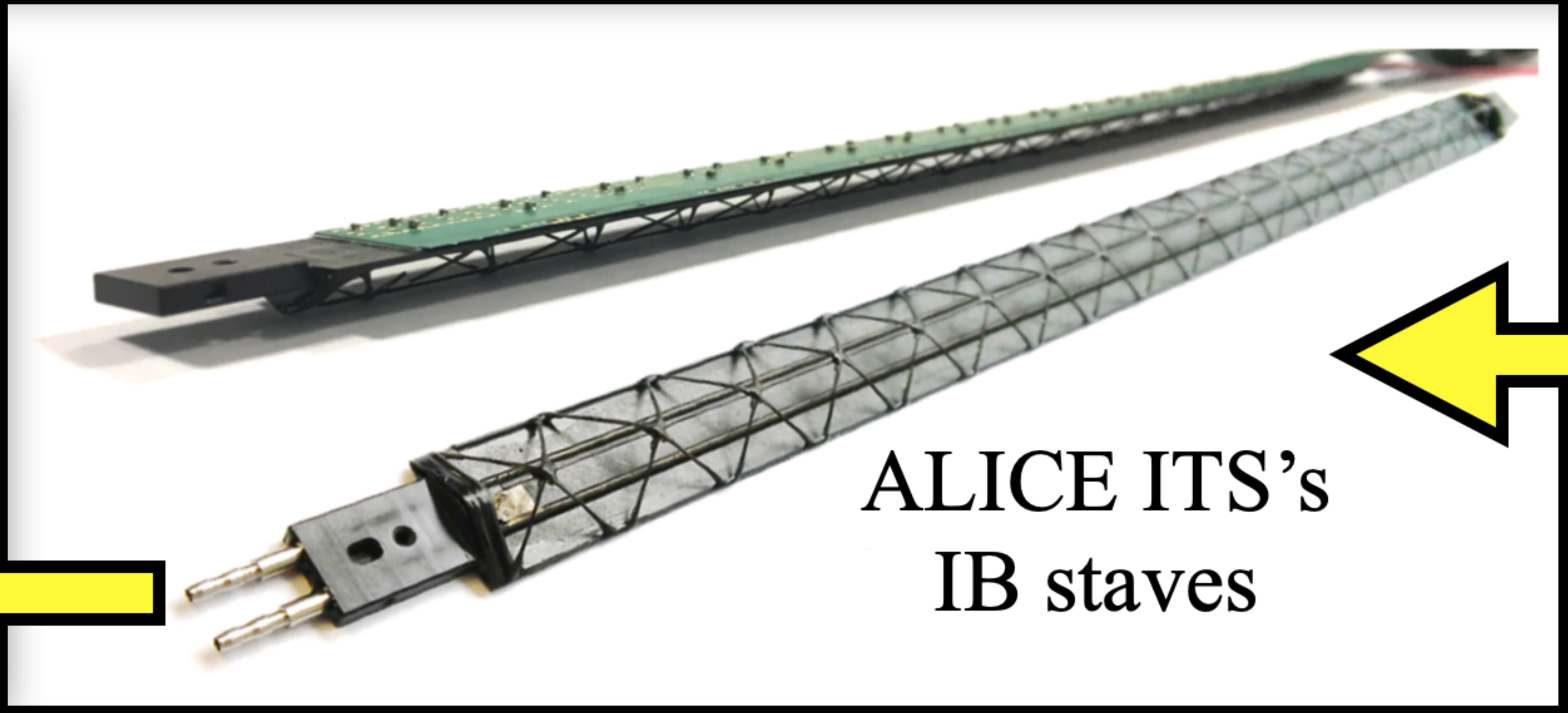
```
[Allpix]
number_of_events = 1000
model_paths = "/Users/arkasantra/AllPix2/allpix-squared/examples/arkaExamples"
log_level = "WARNING"
detectors_file = "tutorial-geometry.conf"
multithreading = true
workers = 15
root_file = "modules_customElectricField.root"

[GeometryBuilderGeant4]


[DepositionGeant4]
physics_list = "FTFP_BERT_EMY"
enable_pai = true
particle_type = "Pi+"
source_type = "beam"
source_energy = 120GeV
source_position = 0um 0um -200um
beam_size = 0.5mm
beam_direction = 0 0 1
number_of_particles = 1
max_step_length = 1.0um

################################################
#### custom electric field prepared by Noam ####
################################################

[ElectricFieldReader]
model = "custom"
log_level = "WARNING"
########################################
########## simpleField #########

field_function = "[0]*(x*x+z*z)"
field_parameters = 125000V/mm
depletion_depth = 25um
output_plots = 1
output_plots_project = y
output_plots_single_pixel = true

[GenericPropagation]
temperature = 293K
charge_per_step = 5
timestep_min = 0.5ps
timestep_max = 0.5ns
integration_time = 20ns

[SimpleTransfer]
output_plots = 1

[DefaultDigitizer]
log_level = "WARNING"
electronics_noise  = 10e
threshold          = 120e
threshold_smearing = 5e
output_plots = 1

[DetectorHistogrammer]
log_level = "WARNING"
output_plots = 1

[ROOTObjectWriter]
```

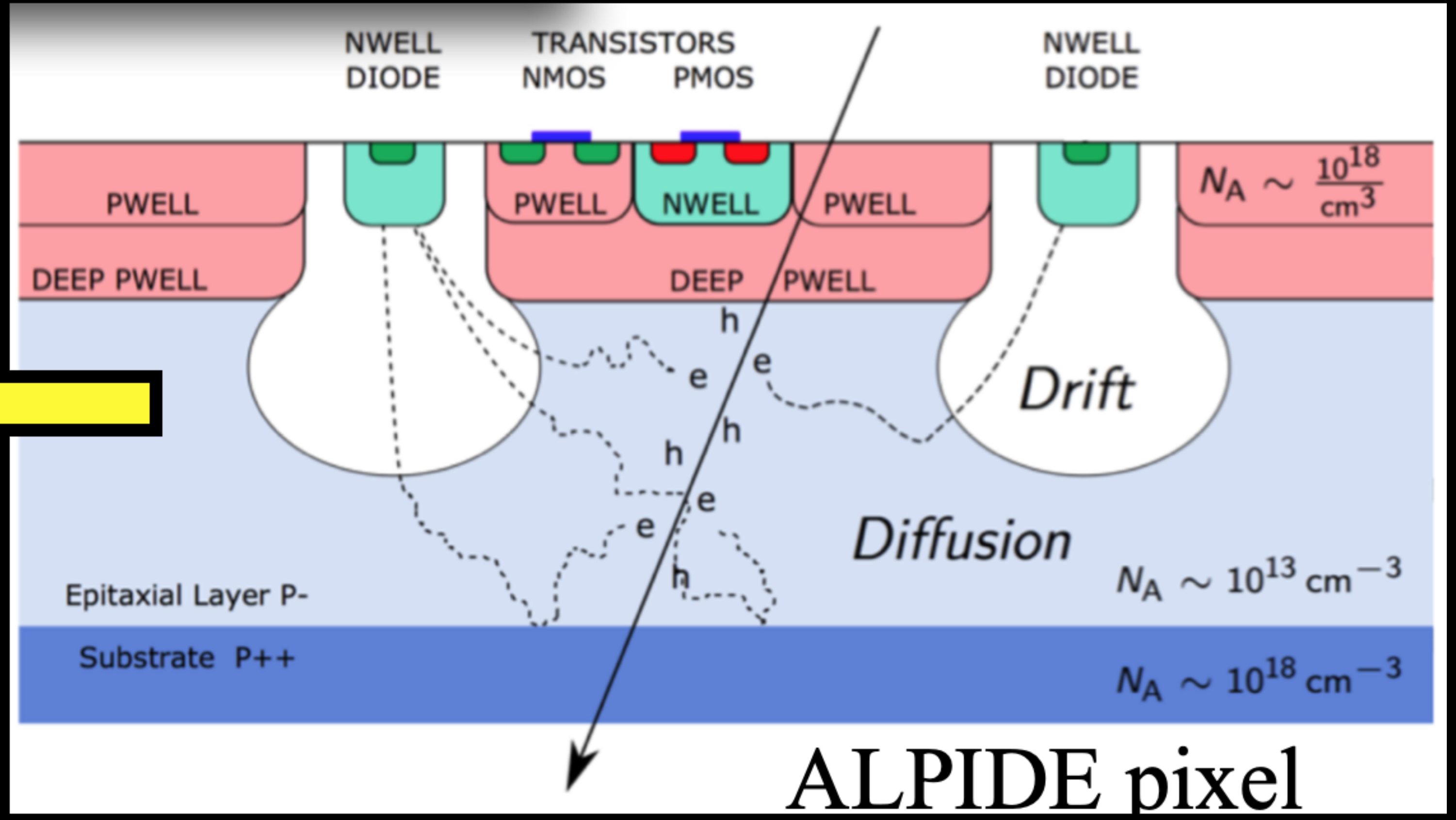
The Tracker Sub-detector

- ✦ Using the ALPIDE pixel sensors
  - ✦Built for the ALICE ITS phase-1 upgrade - already installed
- ✦Manufactured by TowerJazz in Israel
  - ✦Many proprietary restrictions.

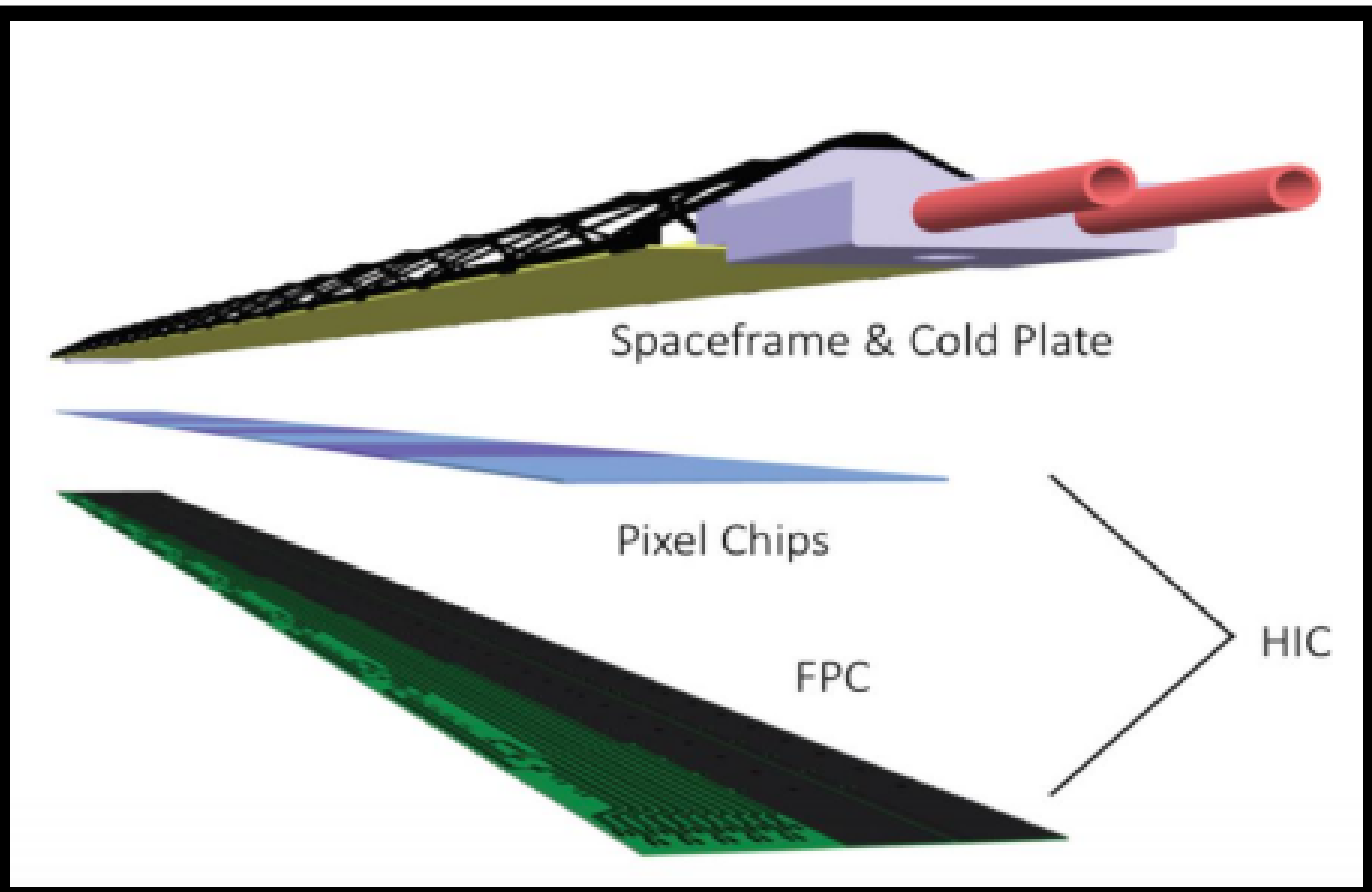
- ★The timing resolution of ALPIDE isn't great
  - ★Not a problem for LUXE as the repetition rate of the laser is <10Hz
  - ★Electron bunches will arrive at LUXE in 10 Hz at most.







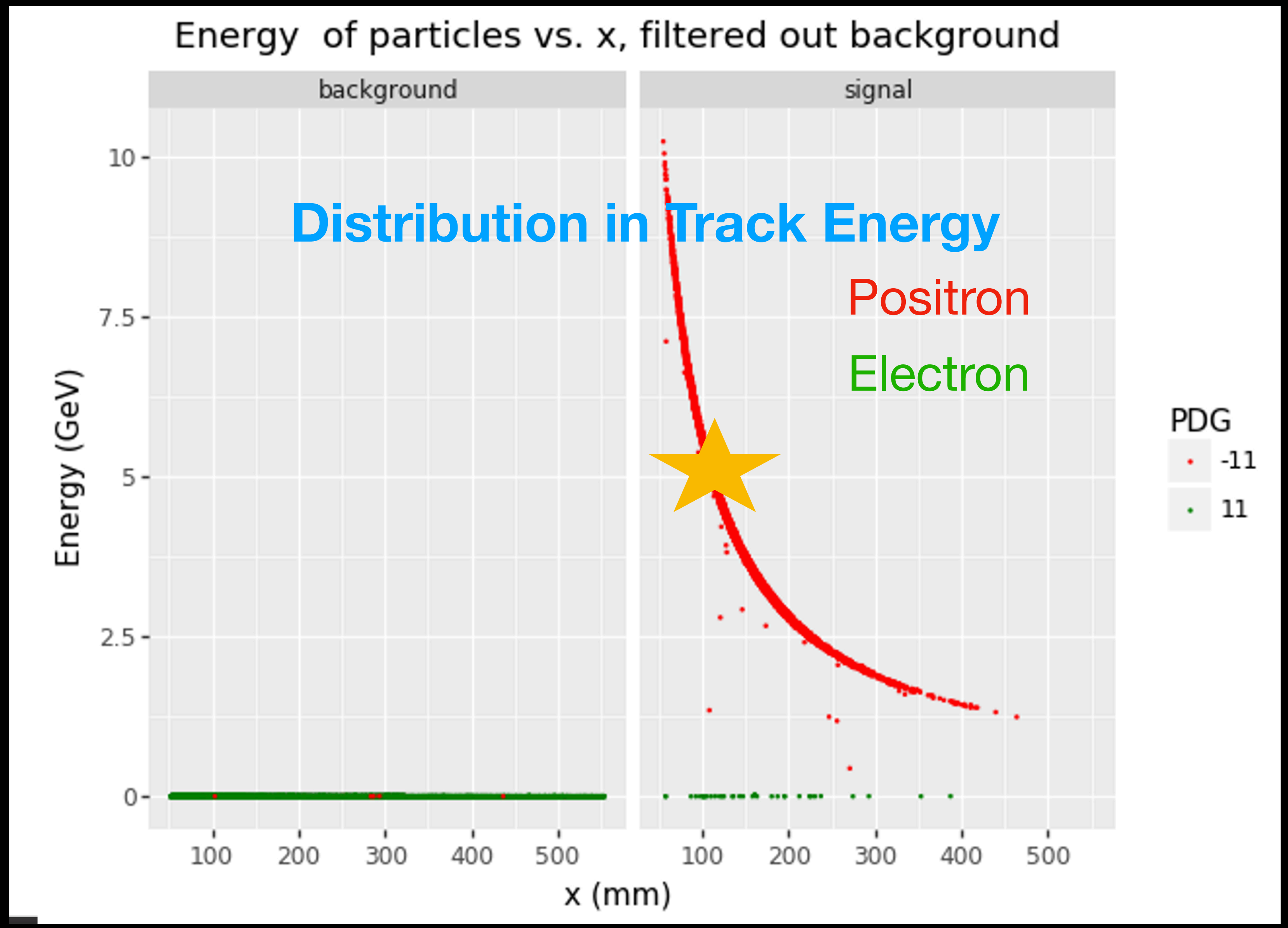
- ✦ALPIDE silicon pixel chip size: 15 x 30 mm^2.
- ✦Each chip has 1024×512 pixels.
- ✦Pixel size: 27 x 29 μm^2 , spatial resolution ~5 μm.
- ✦Good performance under irradiation
  - ✦Tolerate ionization dose of up to 2.7 Mrad.

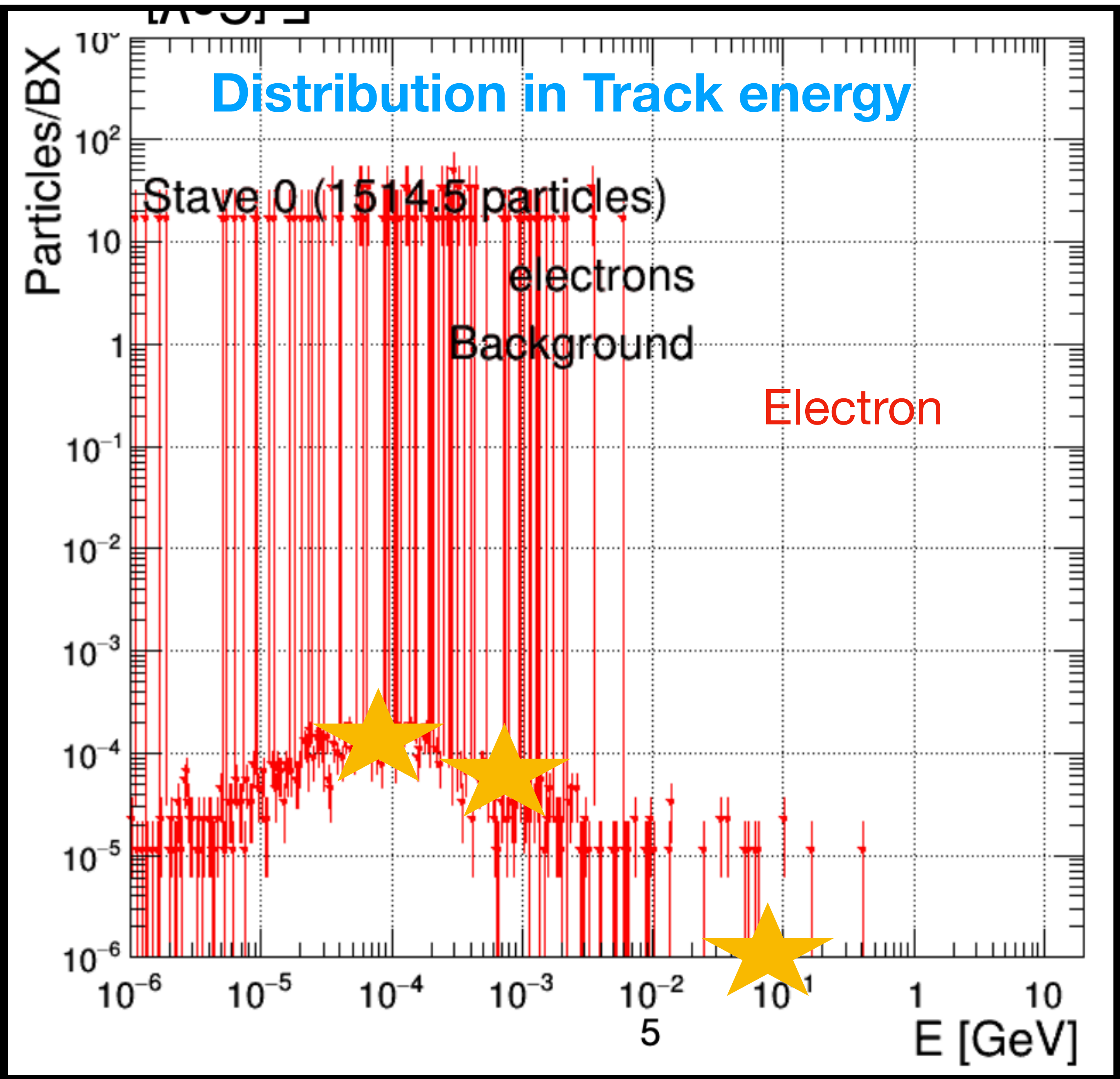


Use of Custom Electric Field to Particle Gun related to LUXE Tracker

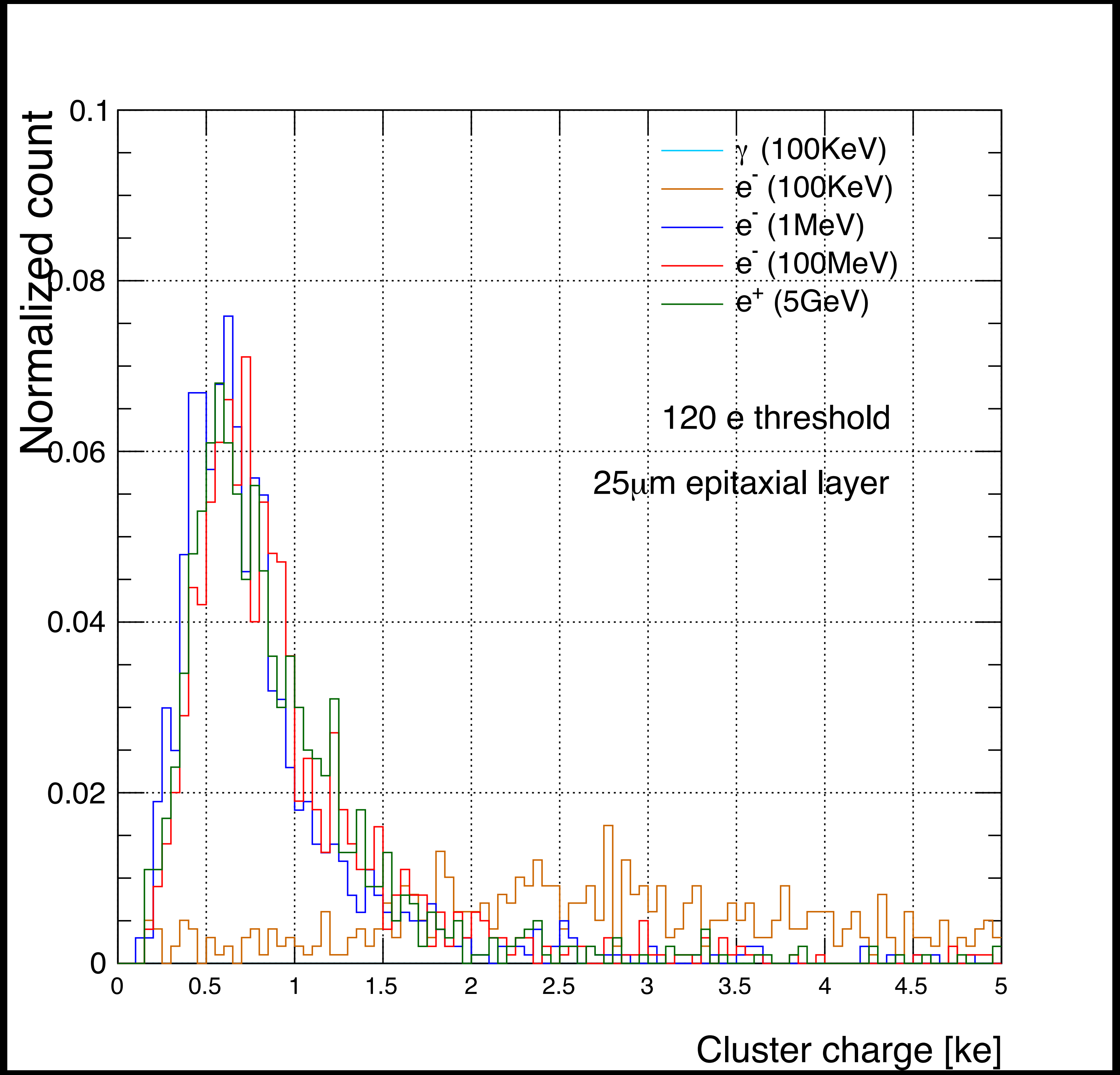
Particle Gun Settings

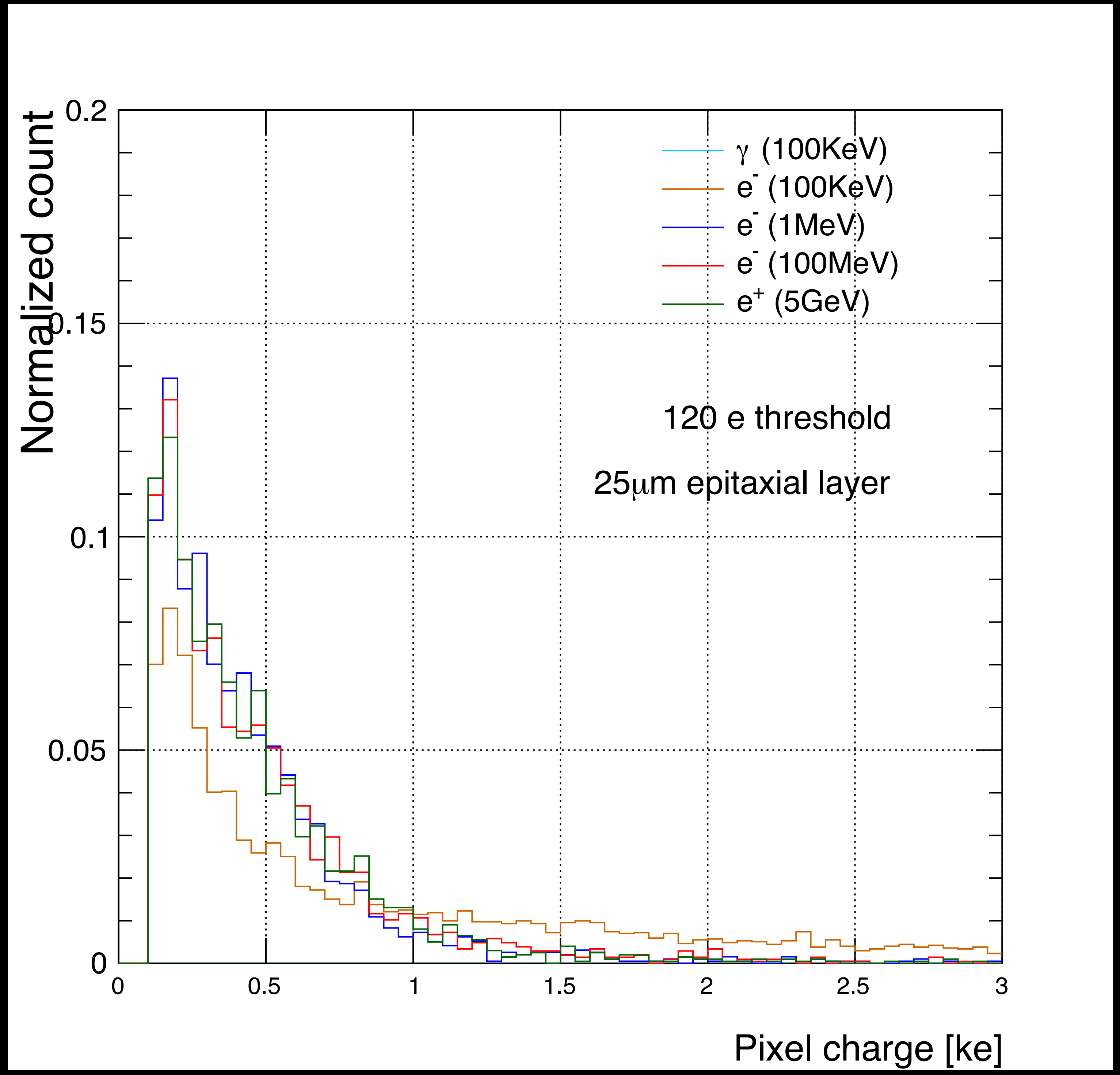
- ALPIDE epitaxial layer thickness 25 um
- Positron particle
  - Energy 5 GeV
  - source_position = 0um 0um -200um
  - beam_size = 0.5mm
- Electron particle
  - Energy 100 KeV, 1 MeV and 100 MeV
  - source_position = 0um 0um -200um
  - beam_size = 0.5mm
- Photon particle
  - Energy 100 KeV
  - source_position = 0um 0um -200um
  - beam_size = 0.5mm
  - But it was found that they do not make hits on the ALPIDE.
- Custom electric field

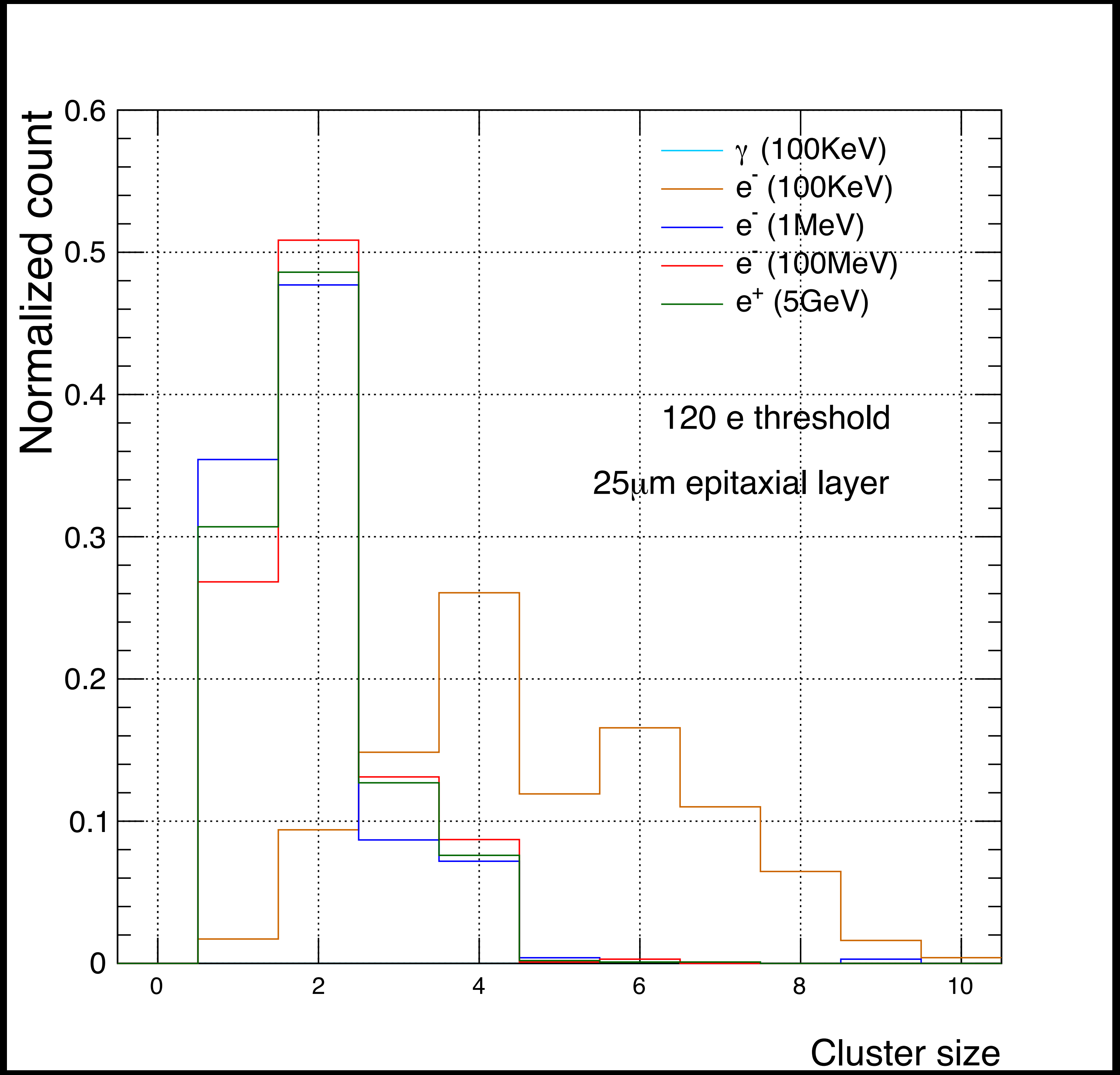




Results from Allpix^2 for particle guns







- ★Cluster charge MPV for 5 GeV positron: 0.89 ± 0.04 ke
- ★Cluster charge MPV for 1 MeV electron: 0.53±0.24 ke
- ★Cluster charge MPV for 100 MeV electron: 0.56±0.24 ke
  - ★Fit with Landau function

Low energy electrons can be removed if we cut on cluster size > 4

Electron $\dfrac{dE}{dx}$ distribution