ECAL Performance
Towards the experiment

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on behalf of the ECAL workforce

LUXE Workshop 2023

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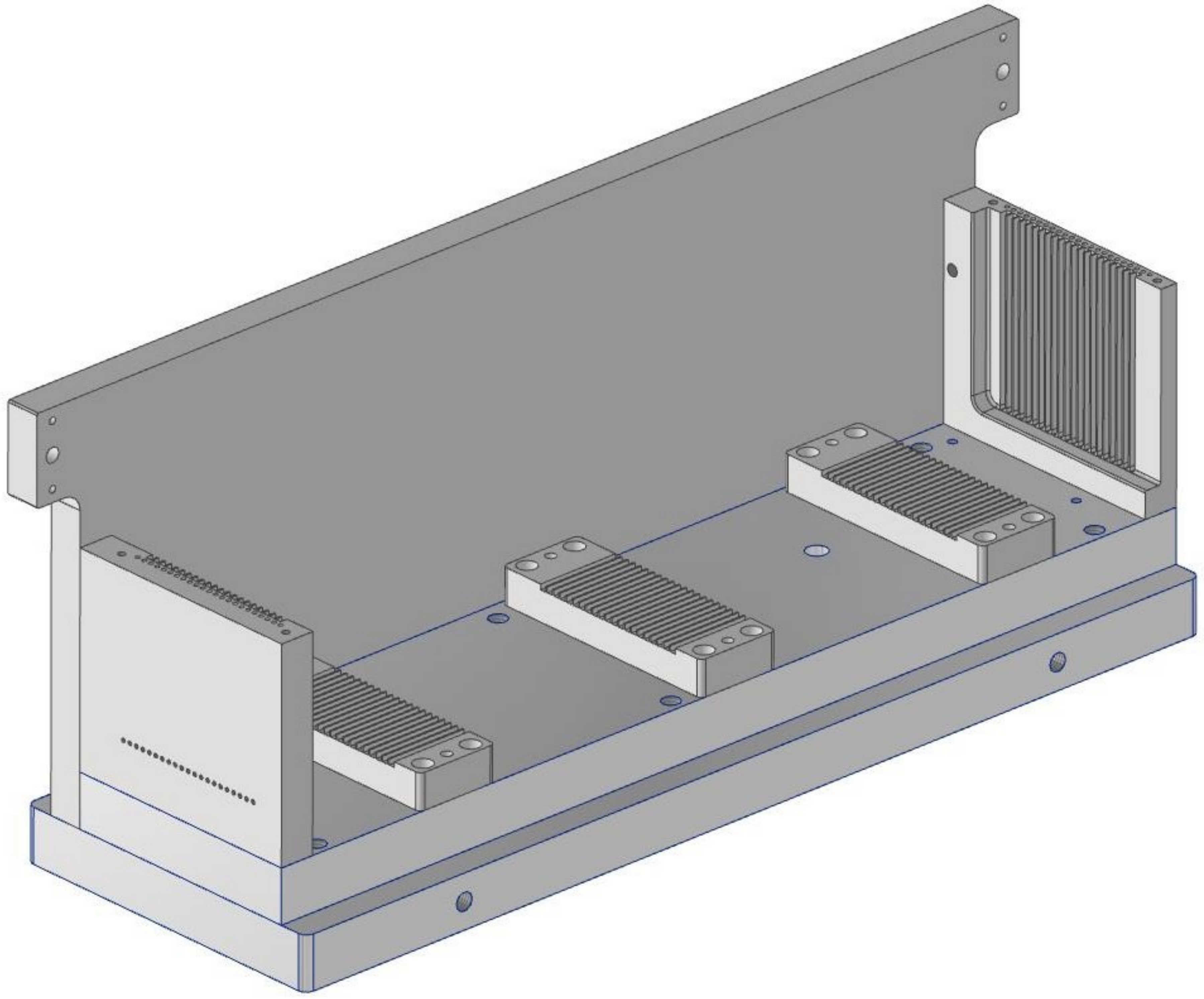
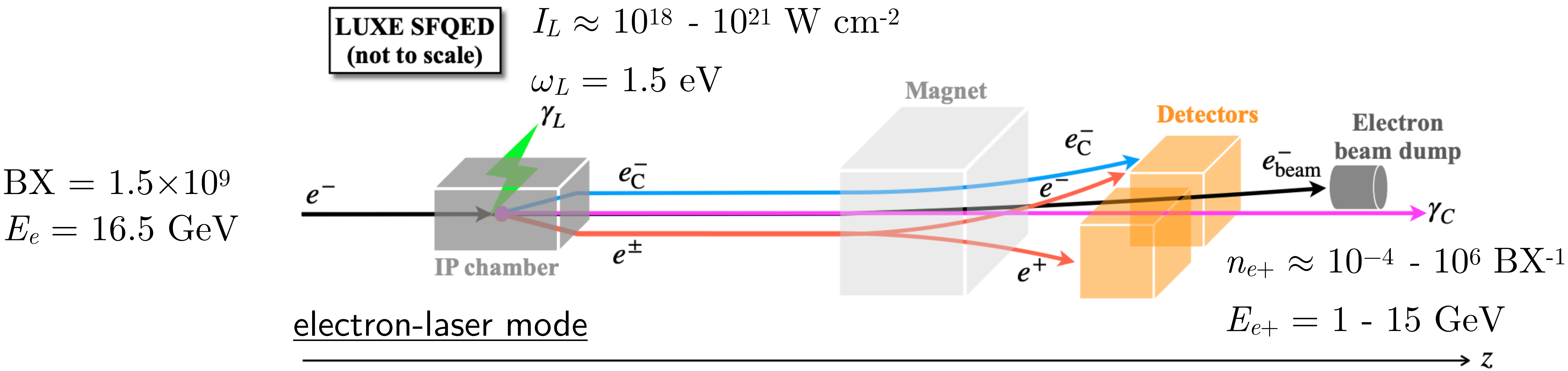
People on ECAL Performance

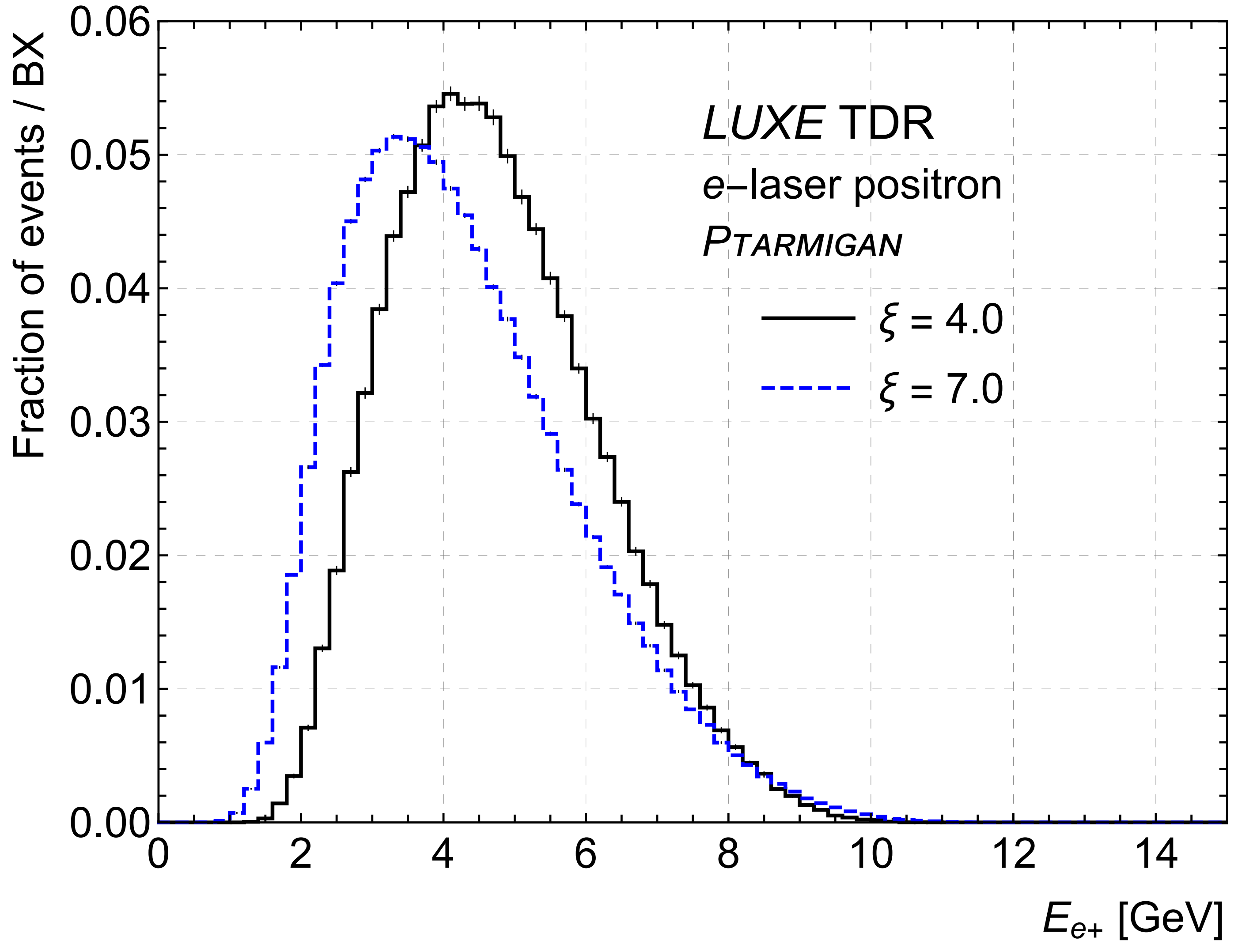
(Alphabetically)

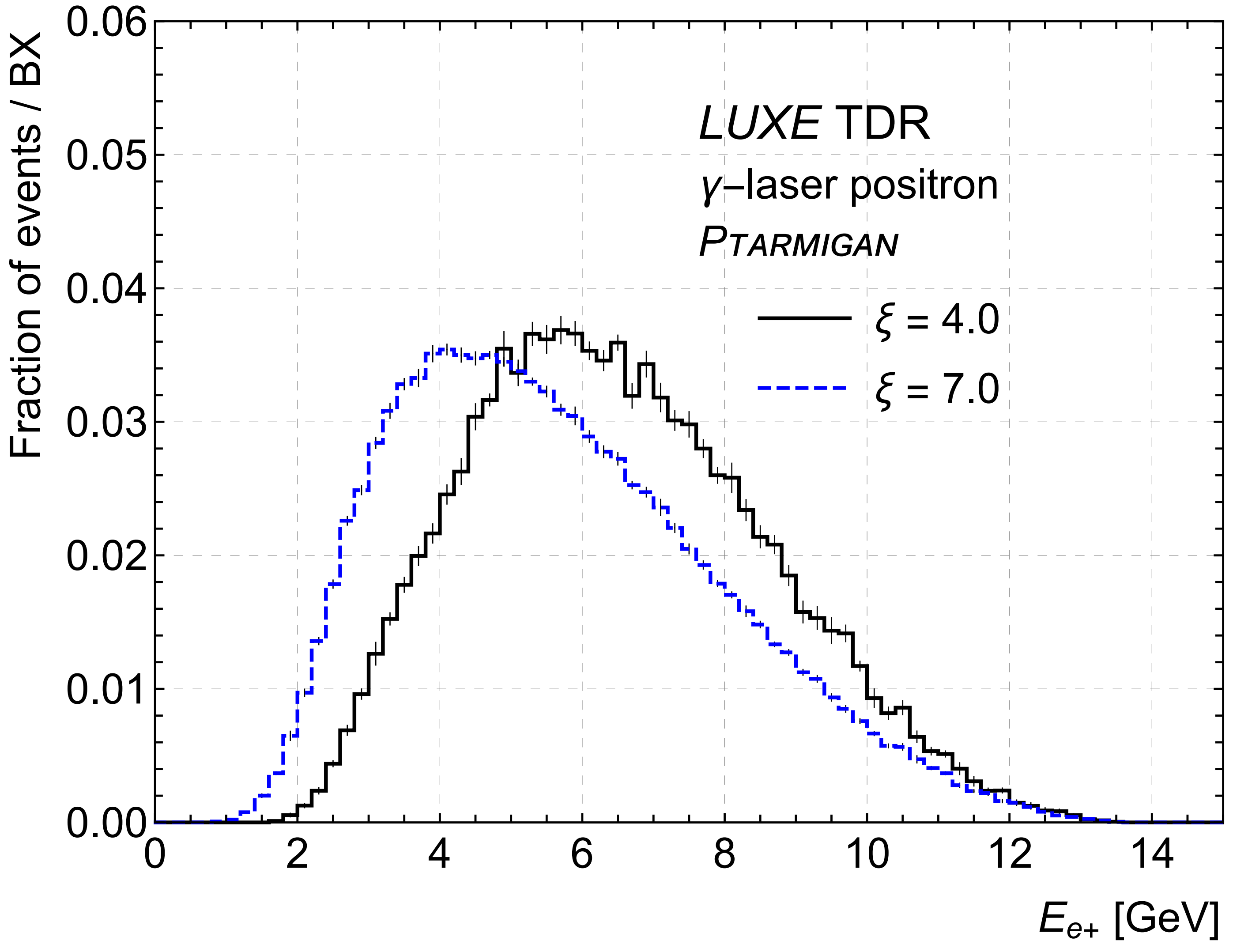
- AGH: Dawid, Jakub, Marek
- DESY: Wolfgang
- ISS: Alina, Mihai, Veta
- TAU: David, Dor, Halina, Michal, Nir, Shan
- UW: Filip, Grzegorz, Kamil, Piotr

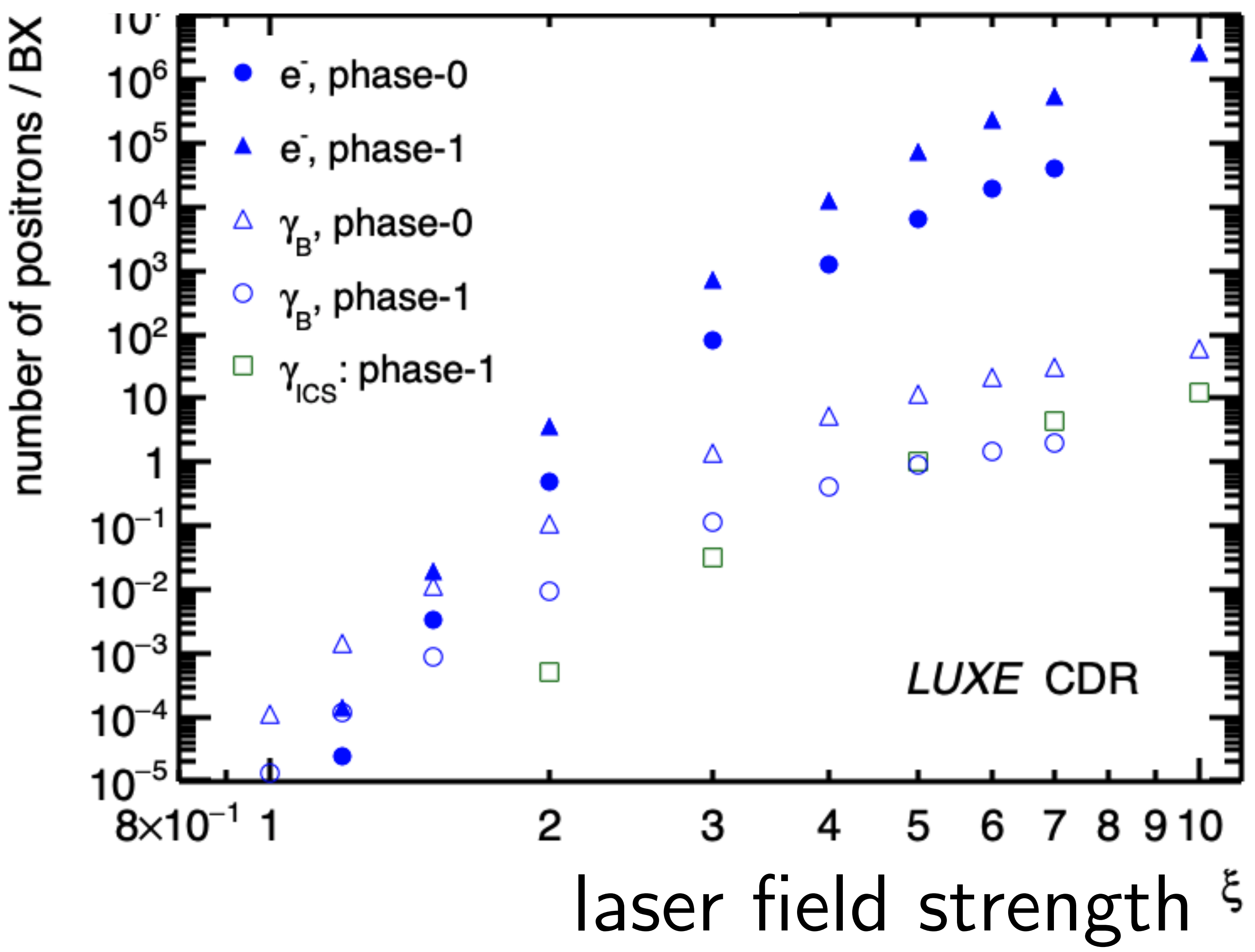


ECAL-P Overview









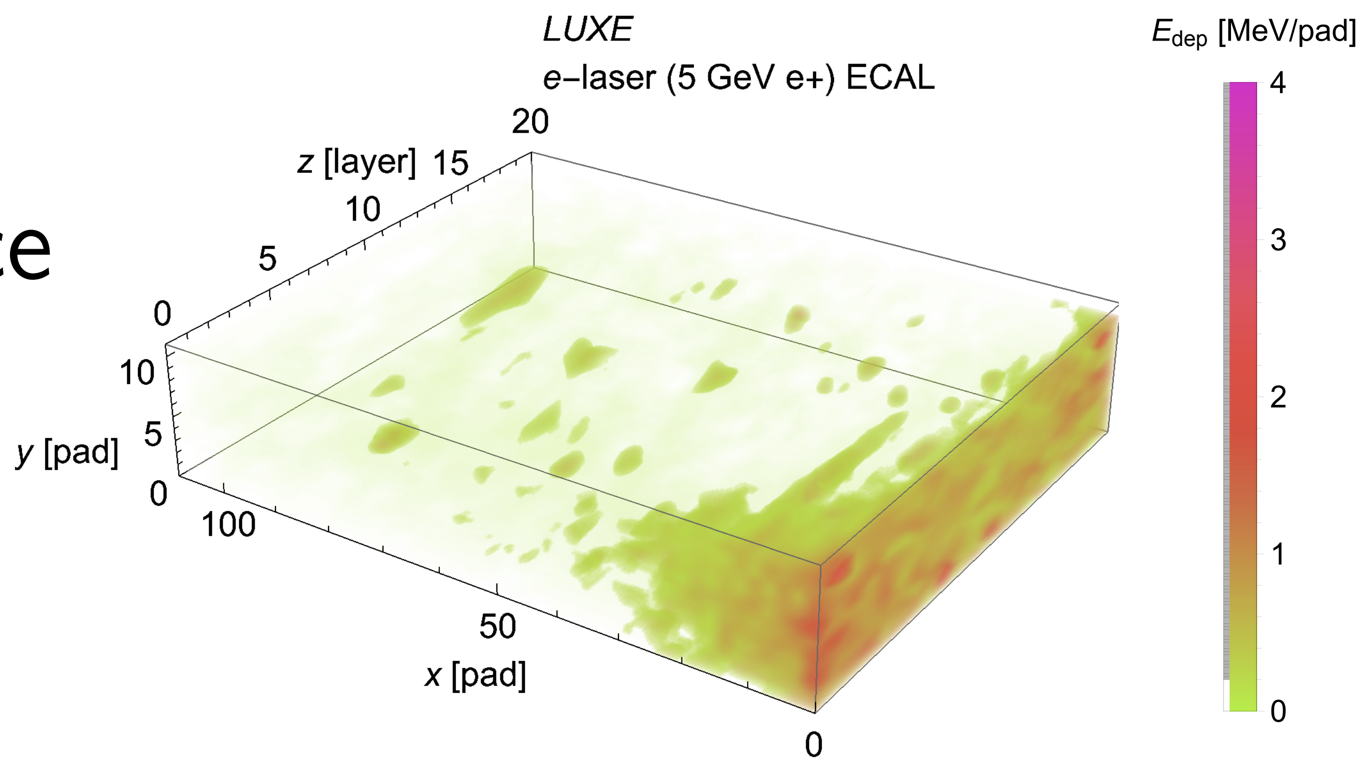
Outline

- Background
- Calibration and Optimization
- Position reconstruction
- Spectrum reconstruction

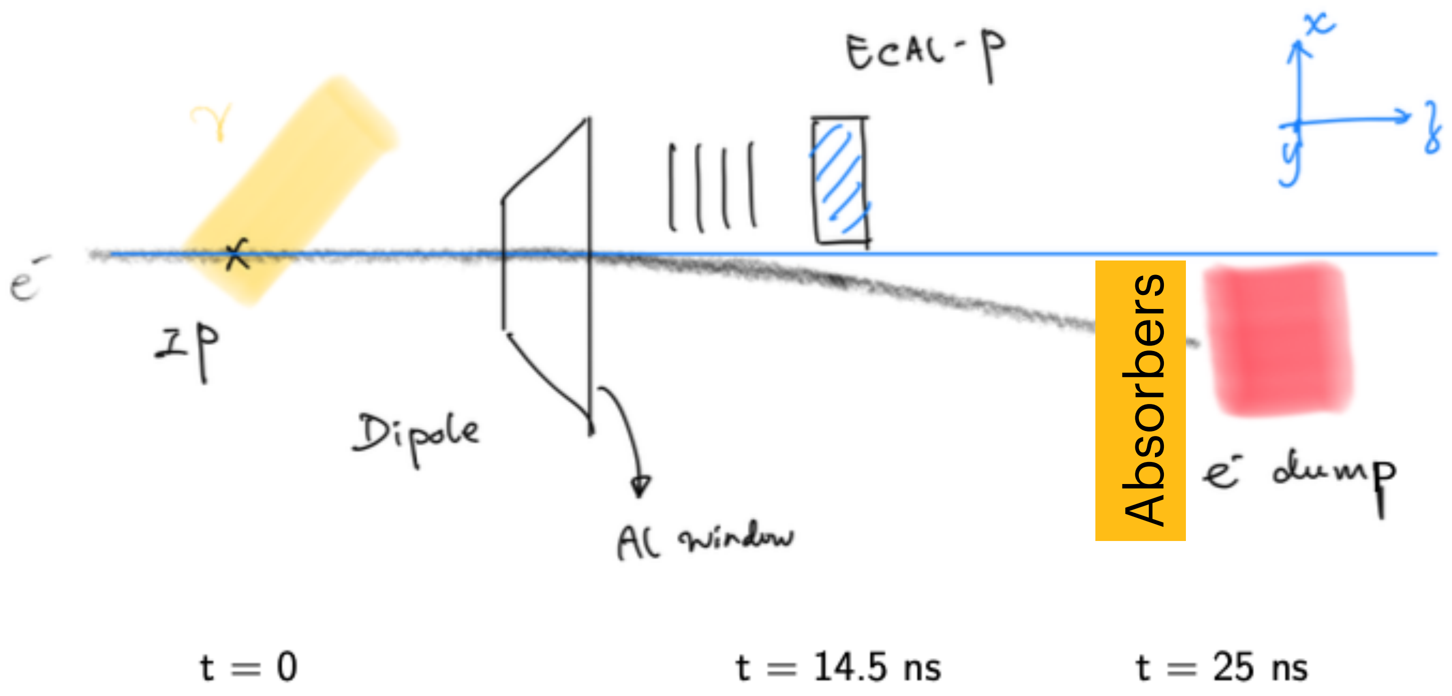
- One more thing ...

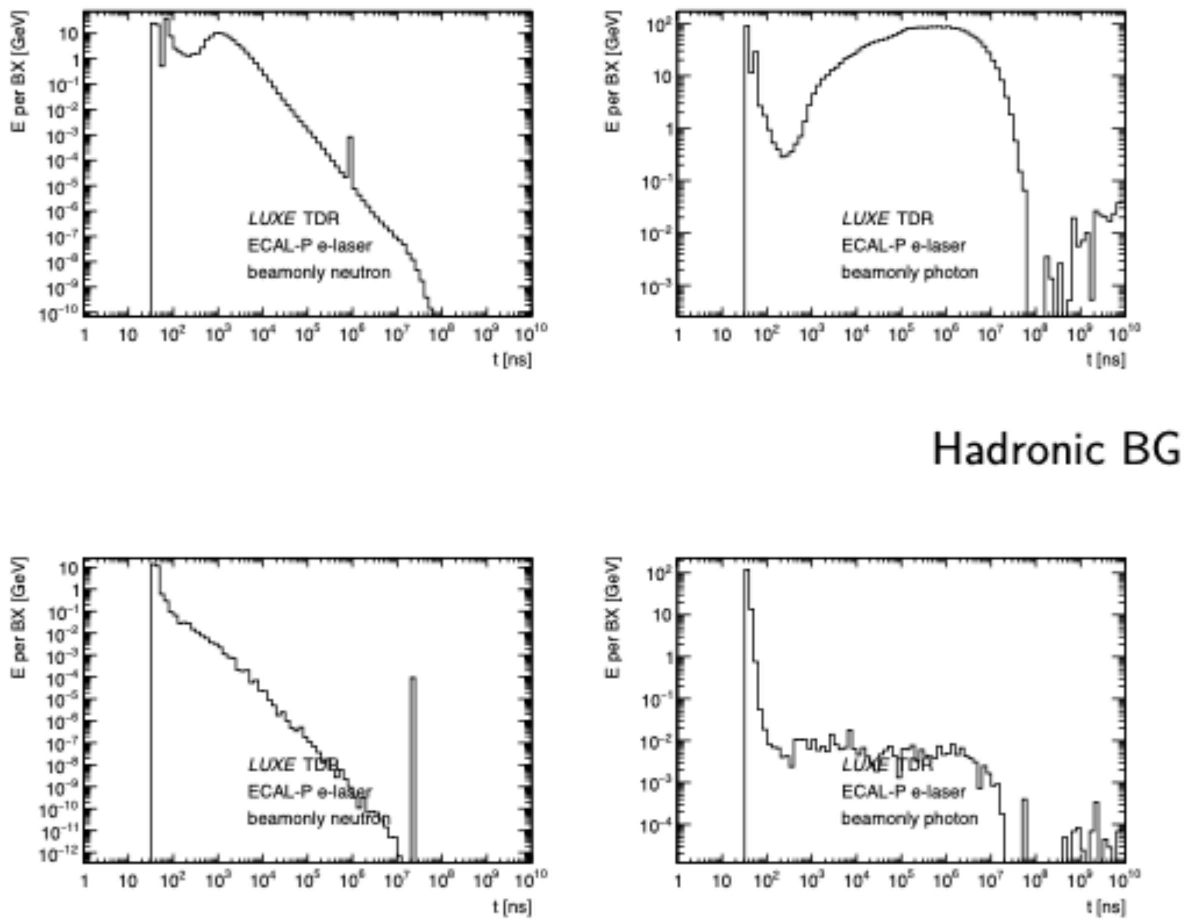
ECAL-P Background

- Electromagnetic background of ECAL-P had been well discussed in the CDR
  - electron-laser: beamline $\Longrightarrow$ extra shielding
  - gamma-laser: IP box $\Longrightarrow$ enlarged IP box entrance



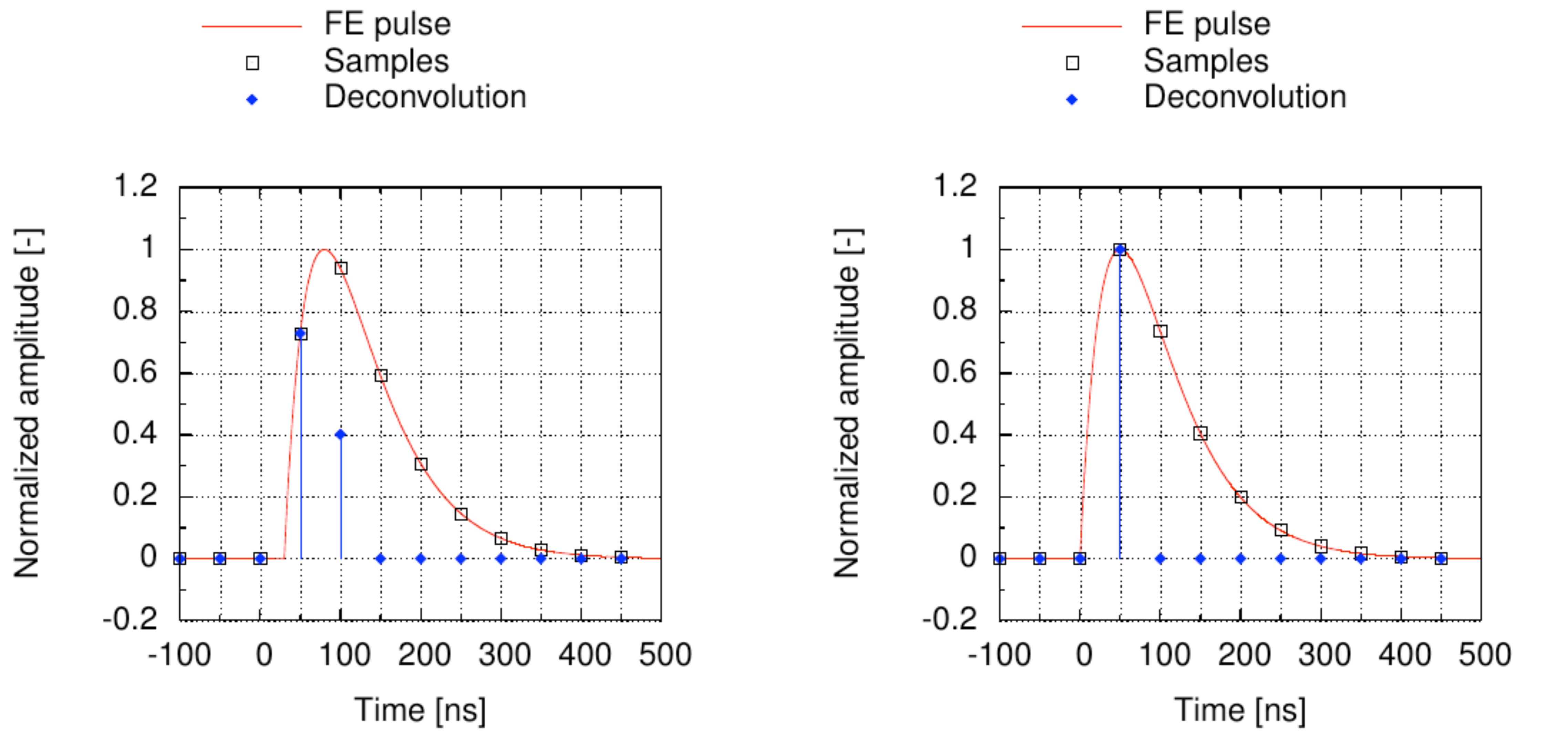
- Hadronic processes were off and particles were killed at dump in CDR simulations
- Severe hadronic background was found in the full simulation
  - Electron dump
  - Al window
  - EM background





ECAL-P Background

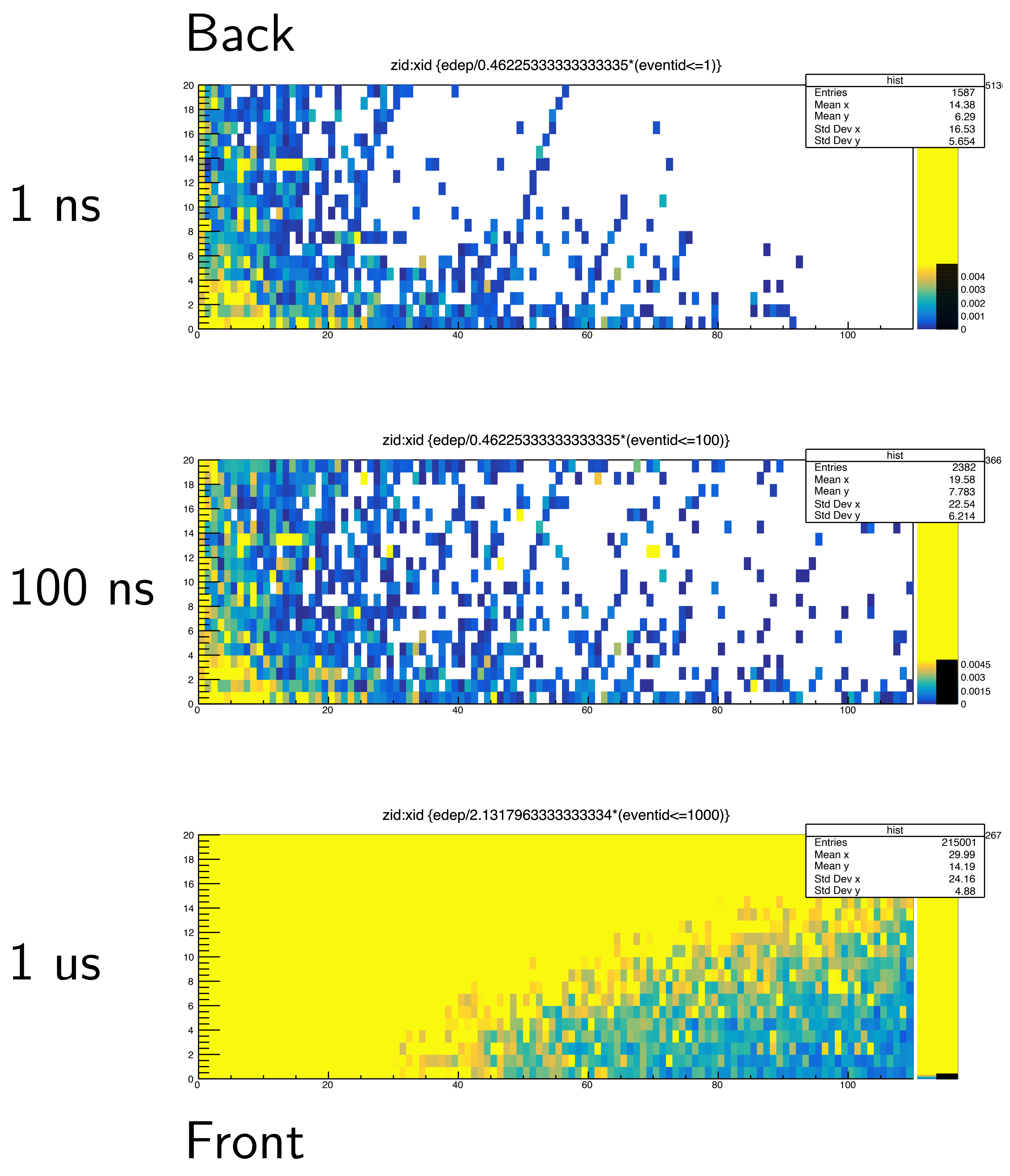
- The charge deposit is proportional to the peak amplitude of filter output
- The readout system needs at least two timeframes (100 ns) to obtain the peak value



a) Example of asynchronous sampling with two non-zero filter output samples at $t_0 = 30$ ns

b) Example of synchronous sampling with only one non-zero filter output sample at $t_0 = 0$ ns

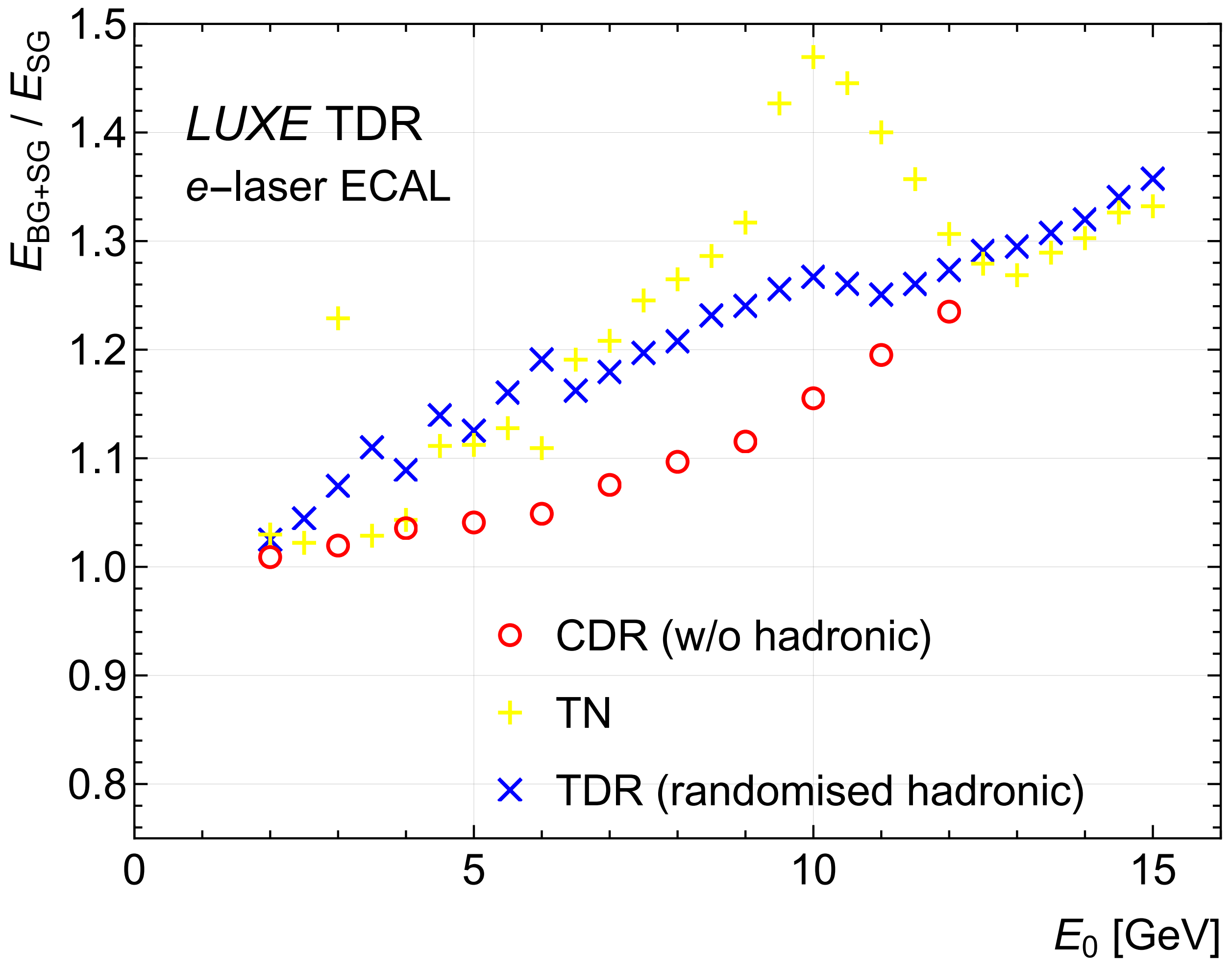
Figure 2.29: Examples of deconvolution filter output at $T_{smp} = \tau_{sh} = 50$ ns.

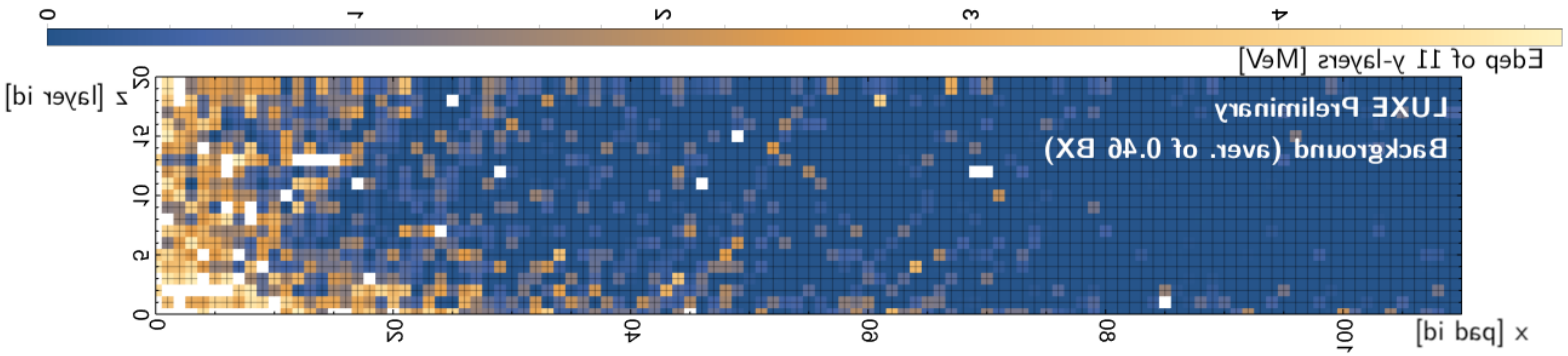


ECAL-P Background

- Irregularly high deposits (∼100 MIPs) were found
- It was contributed by nuclear reaction, e.g. $\mathrm{n} + \mathrm{Si} \rightarrow \mathrm{p} + \mathrm{D} + \mathrm{Mg}$
- It took place tens of times per BX in the central area
- The high deposits were "smeared" in the whole area by randomized redistribution

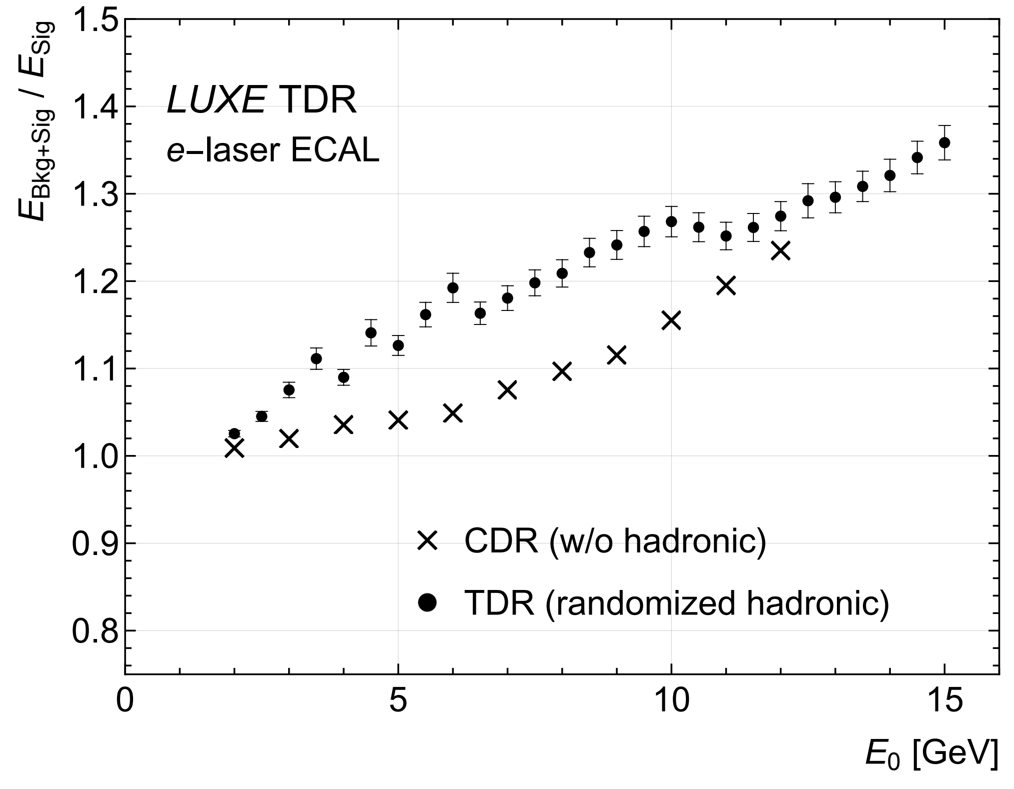
$$\text{Background sample} = \text{Constant background} + \text{redistributed high deposits}$$

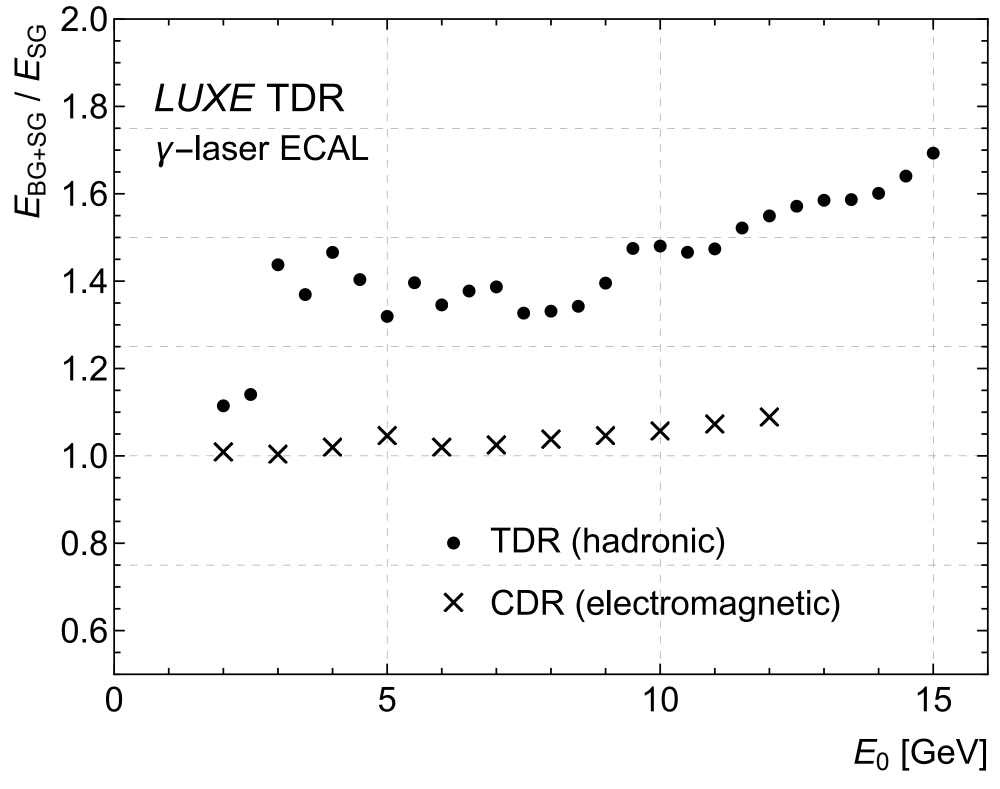




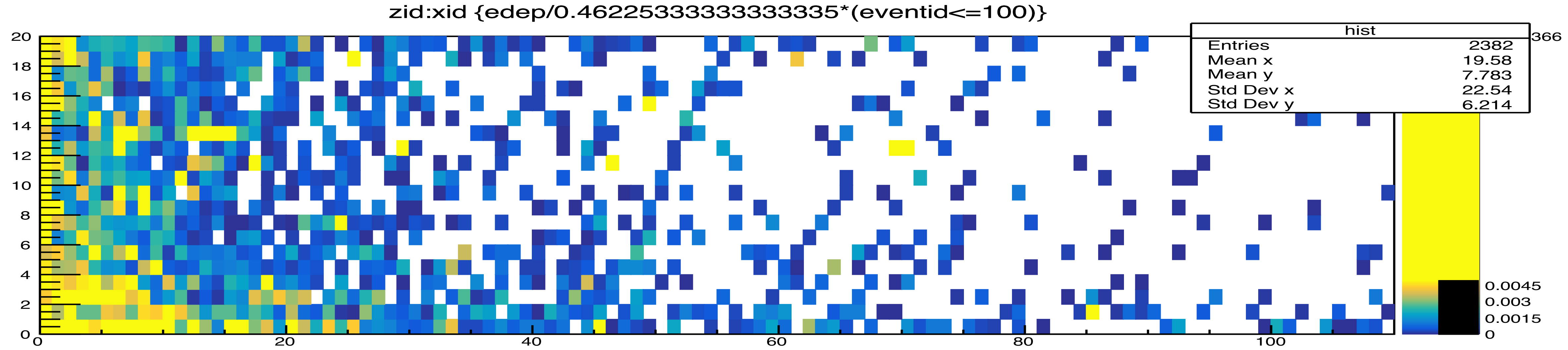
ECAL-P Background

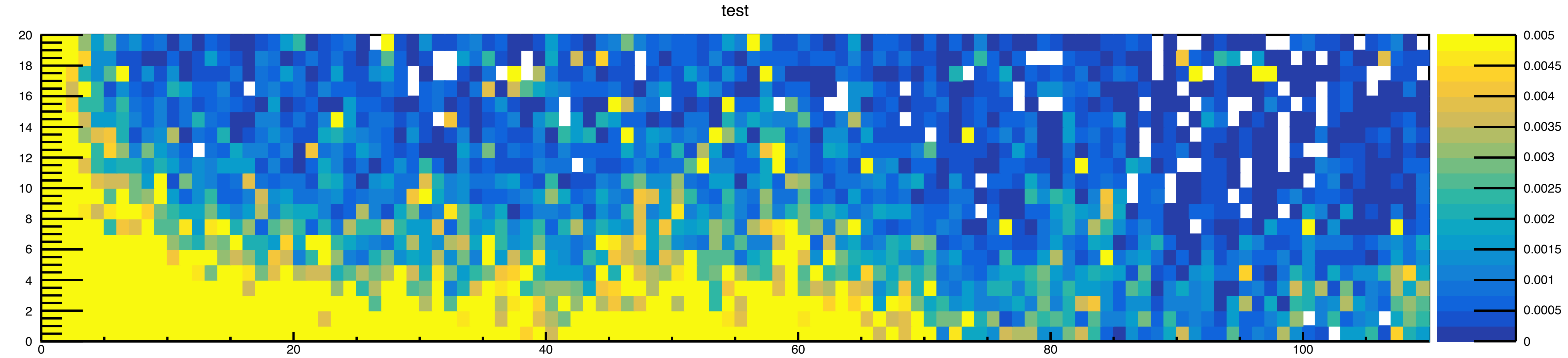
- The signal-to-noise ratio in gamma-laser setup is worse than in the electron-laser, but still acceptable (below 1.5 on the graph)
- More "consistent" in the central area
- Sourced back to the upstream dump

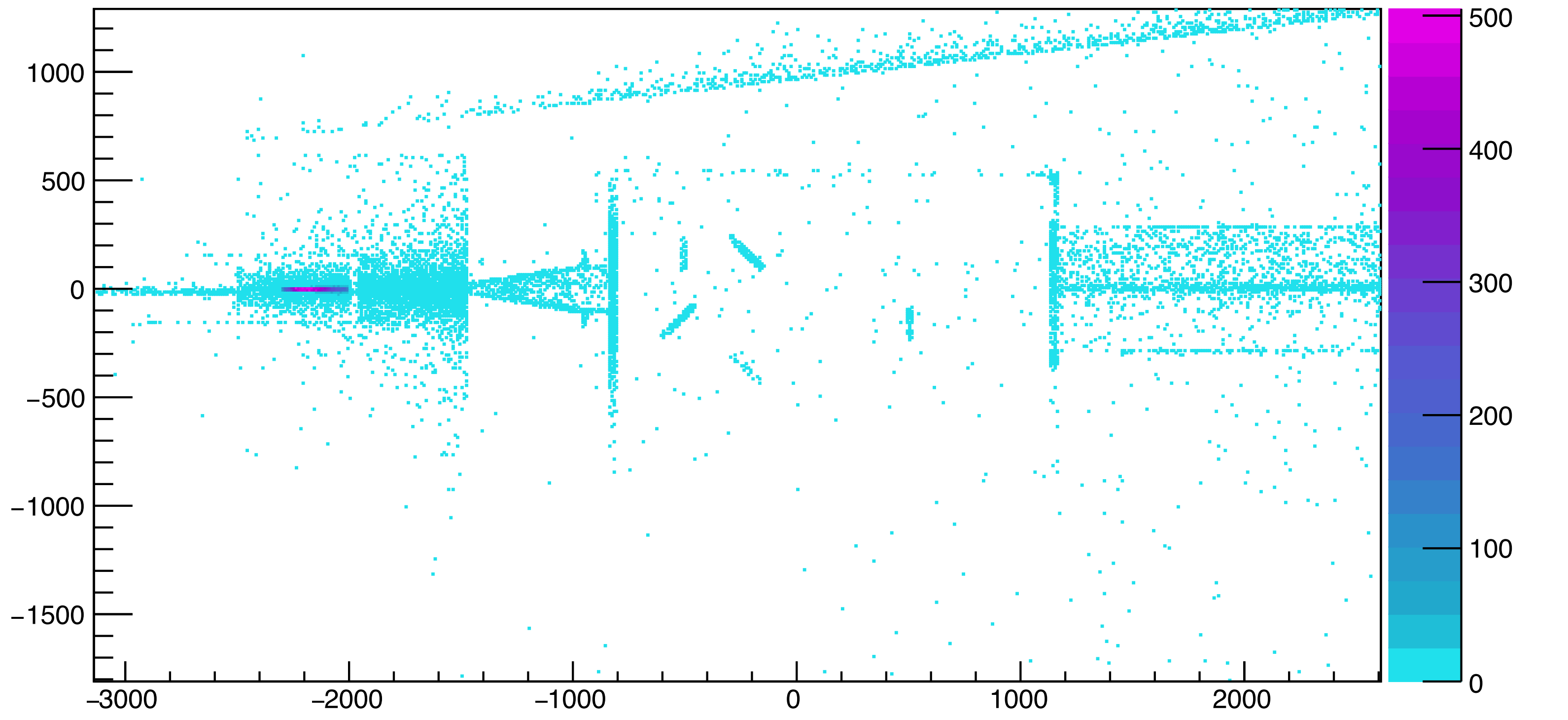




The accumulated background at 100 ns, topped at 5 MeV (50 MIPs) for e-laser and g-laser setups







Outline

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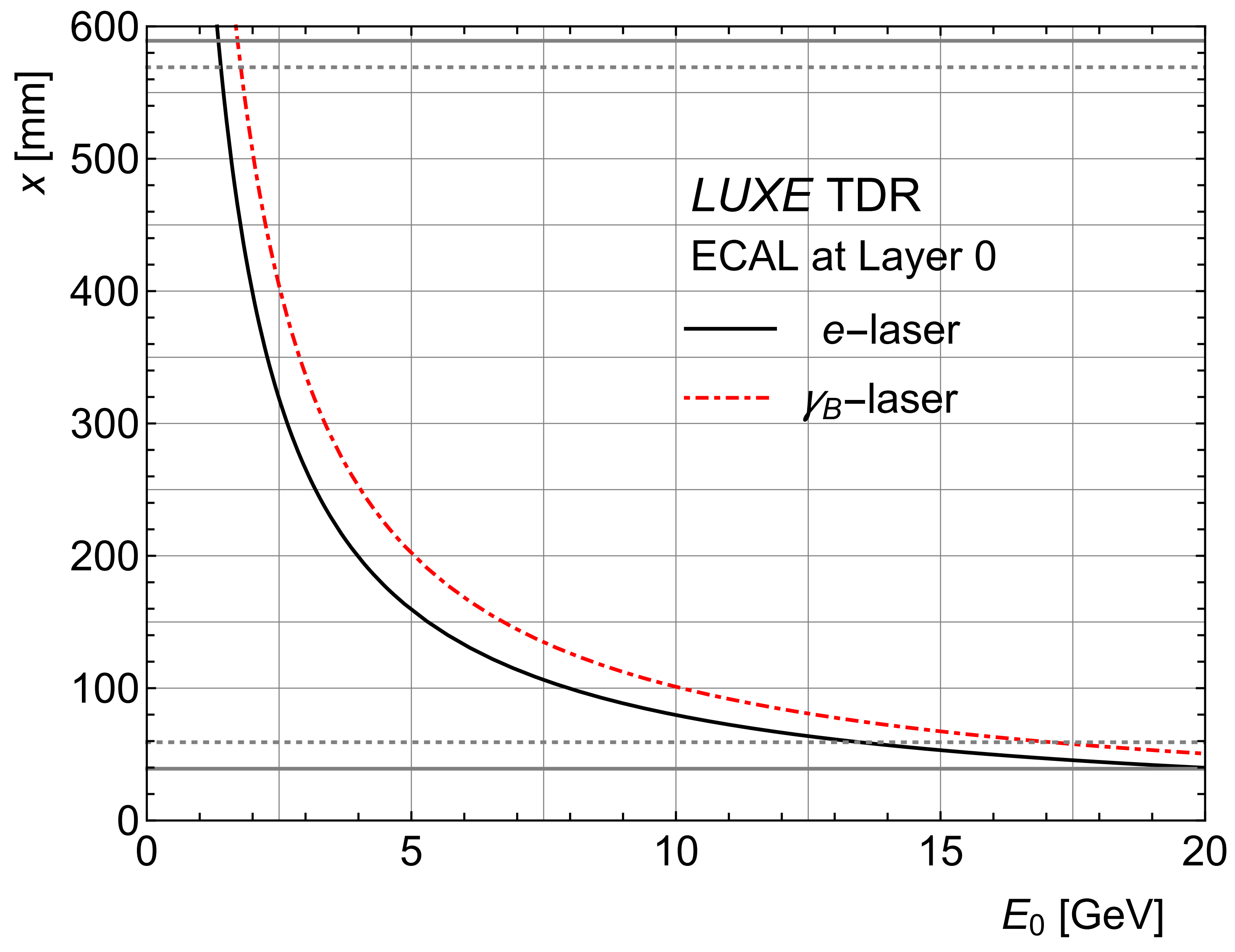
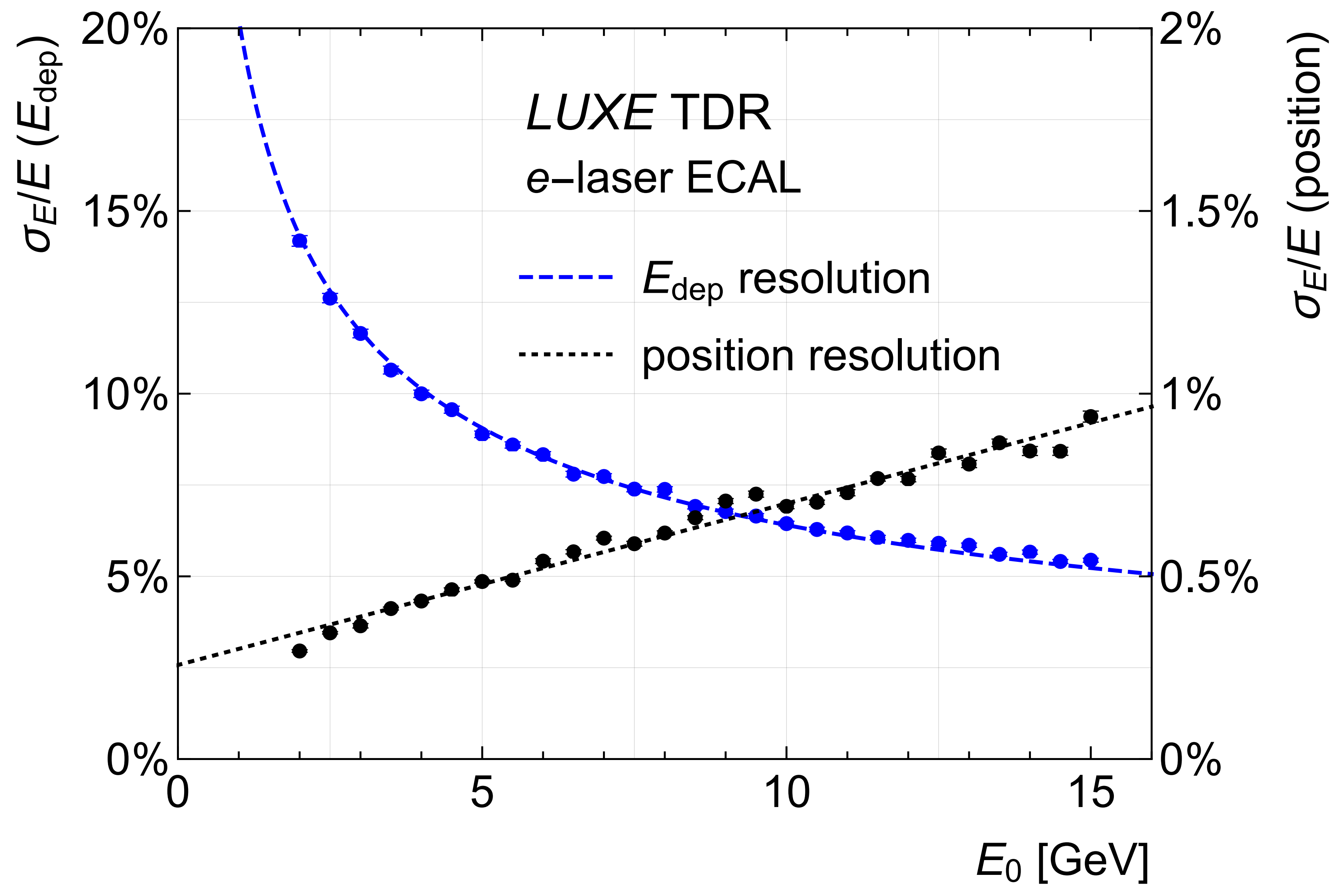
ECAL-P Resolution

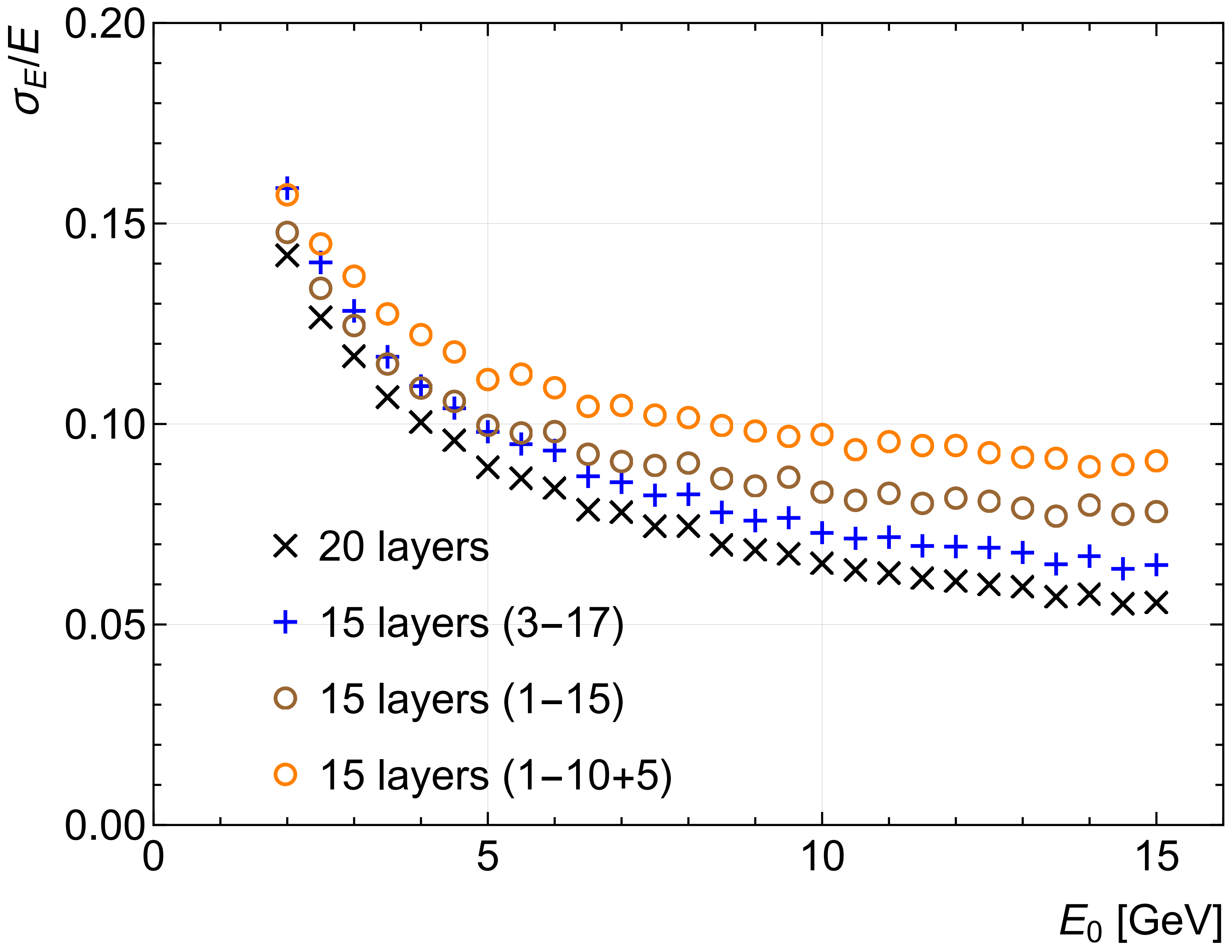
- The ECAL is going to calibrate the position-energy dependence created by the magnetic dipole
- A full 20-layer ECAL has the energy resolution of 20%/sqrt(E/GeV) (in the CDR)
- Due to funding limit, it is likely that the ECAL-P will only have 15 active layers
- Several combinations of sampling schemes are under investigation



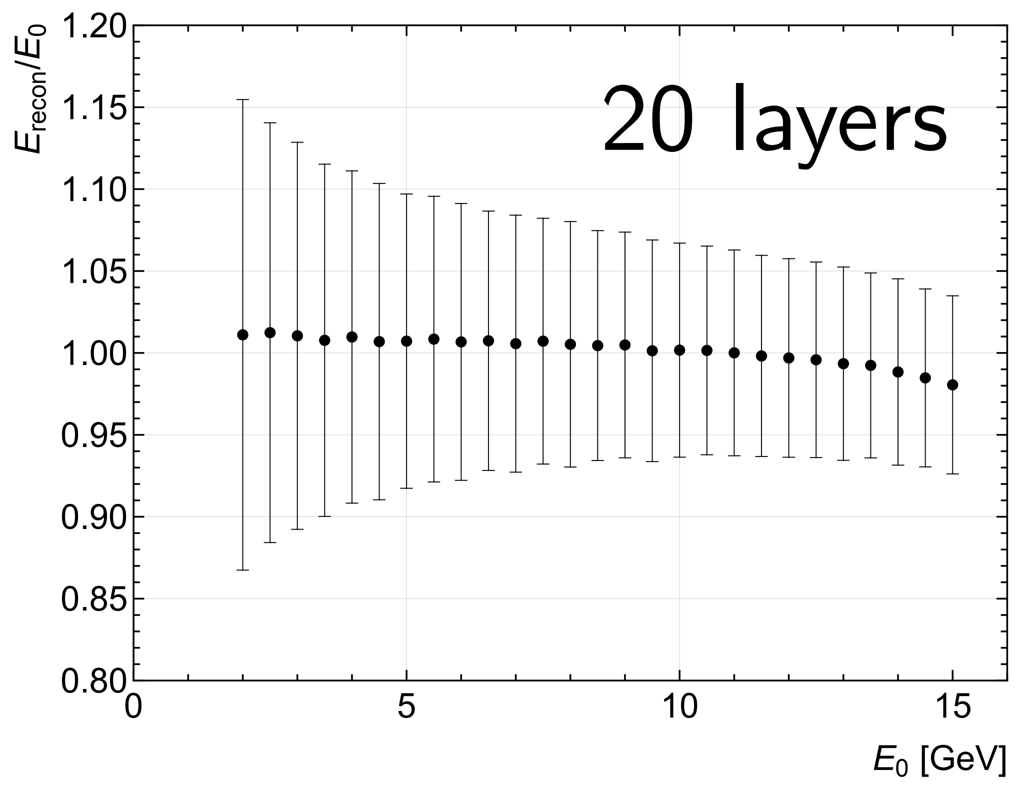


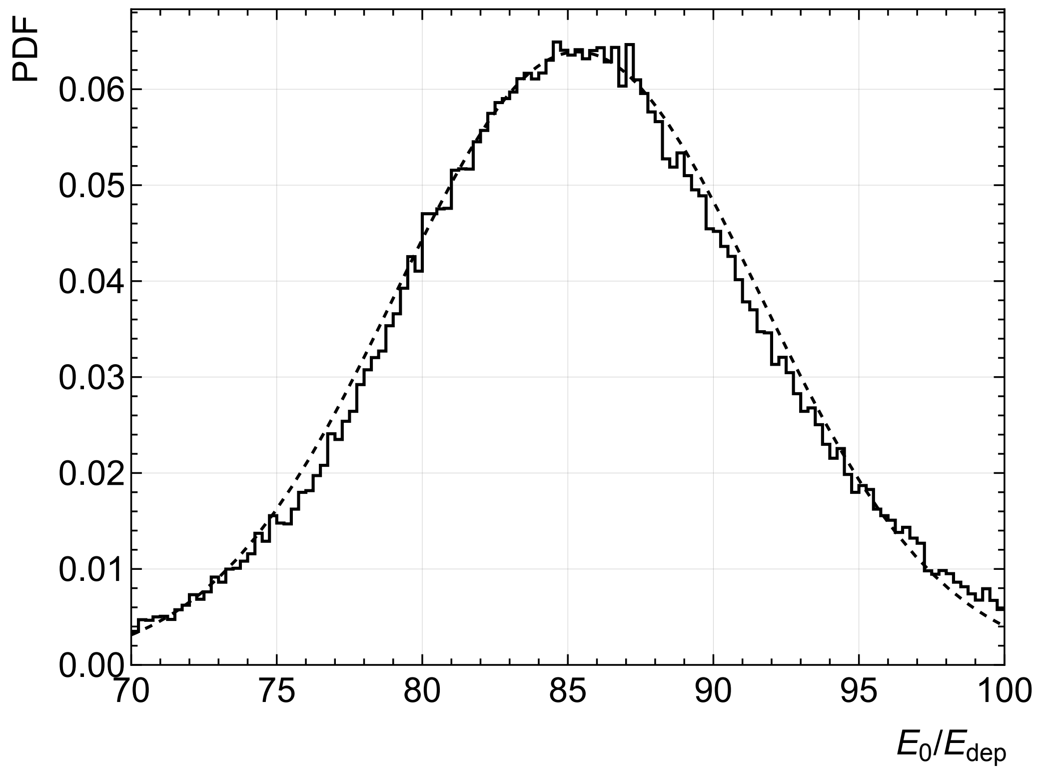
Optimization

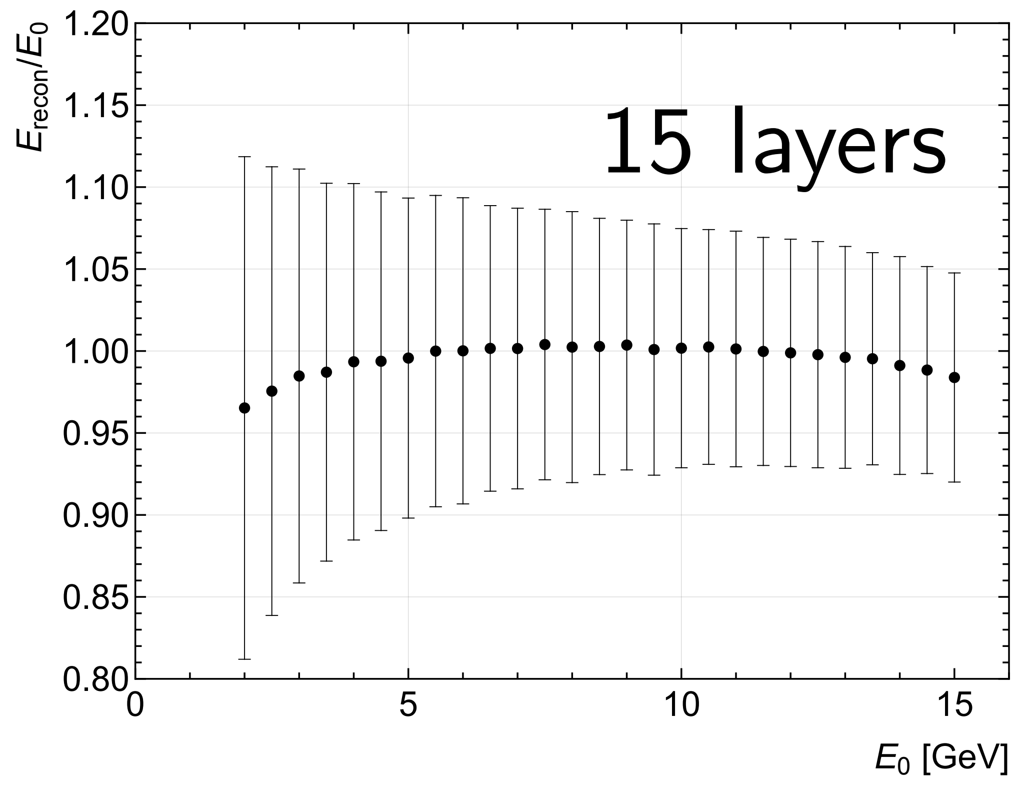
- An enumeration of all possible combinations were run to find the best 15 layers
- The simplest method, calibration by a constant ratio, was used

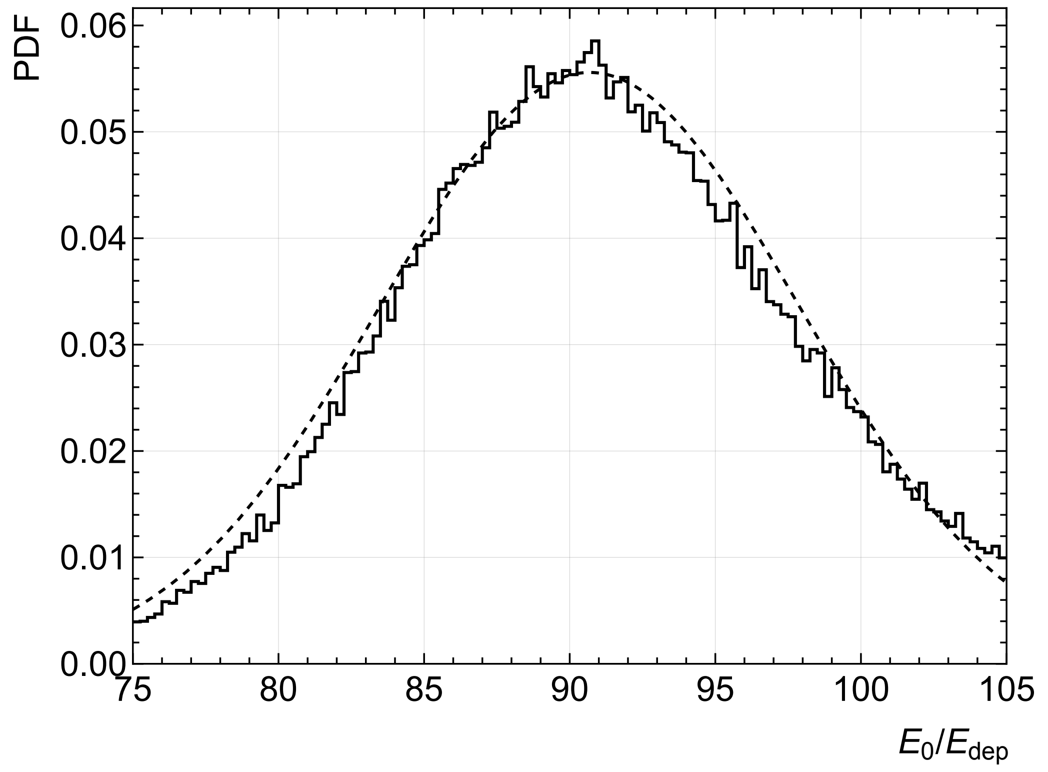


20 layers



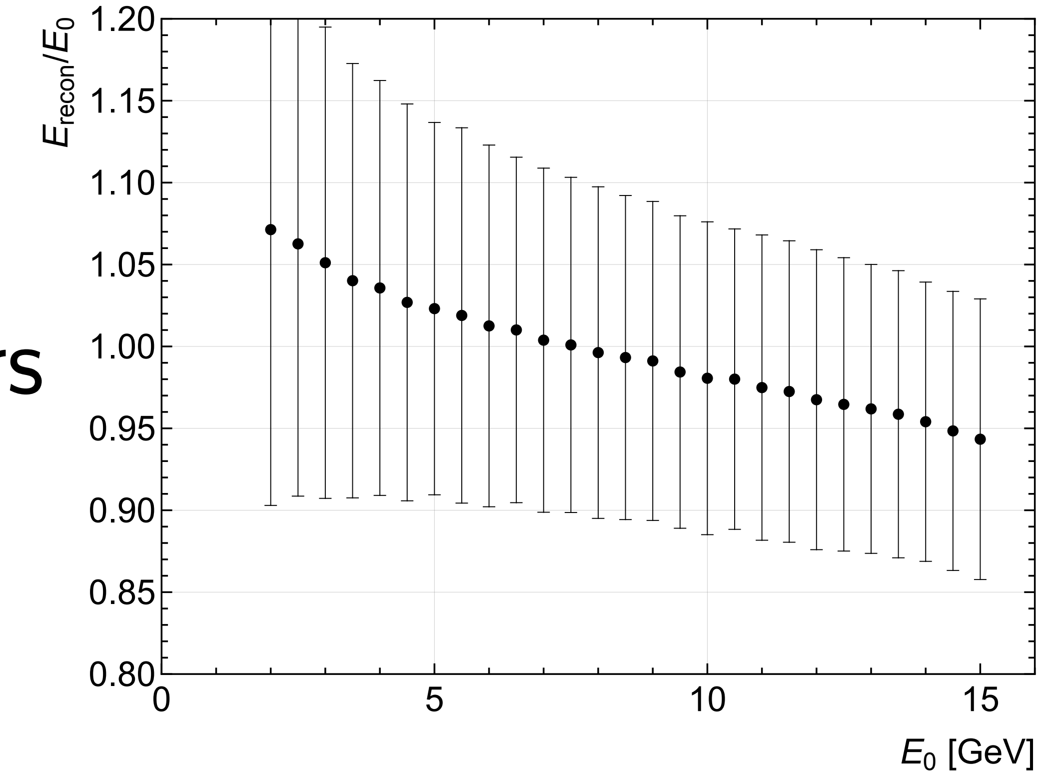






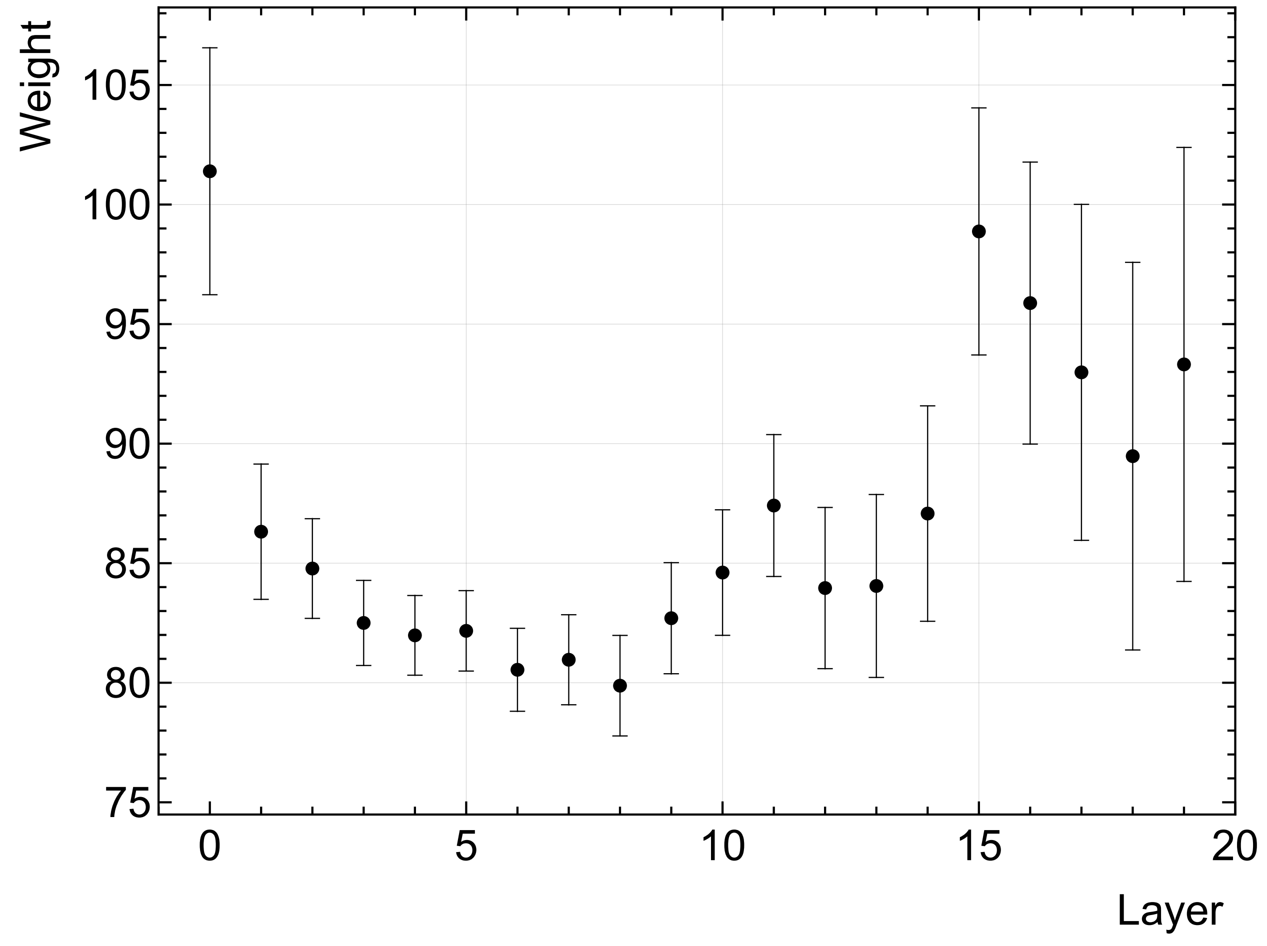
15 layers (15 X0)

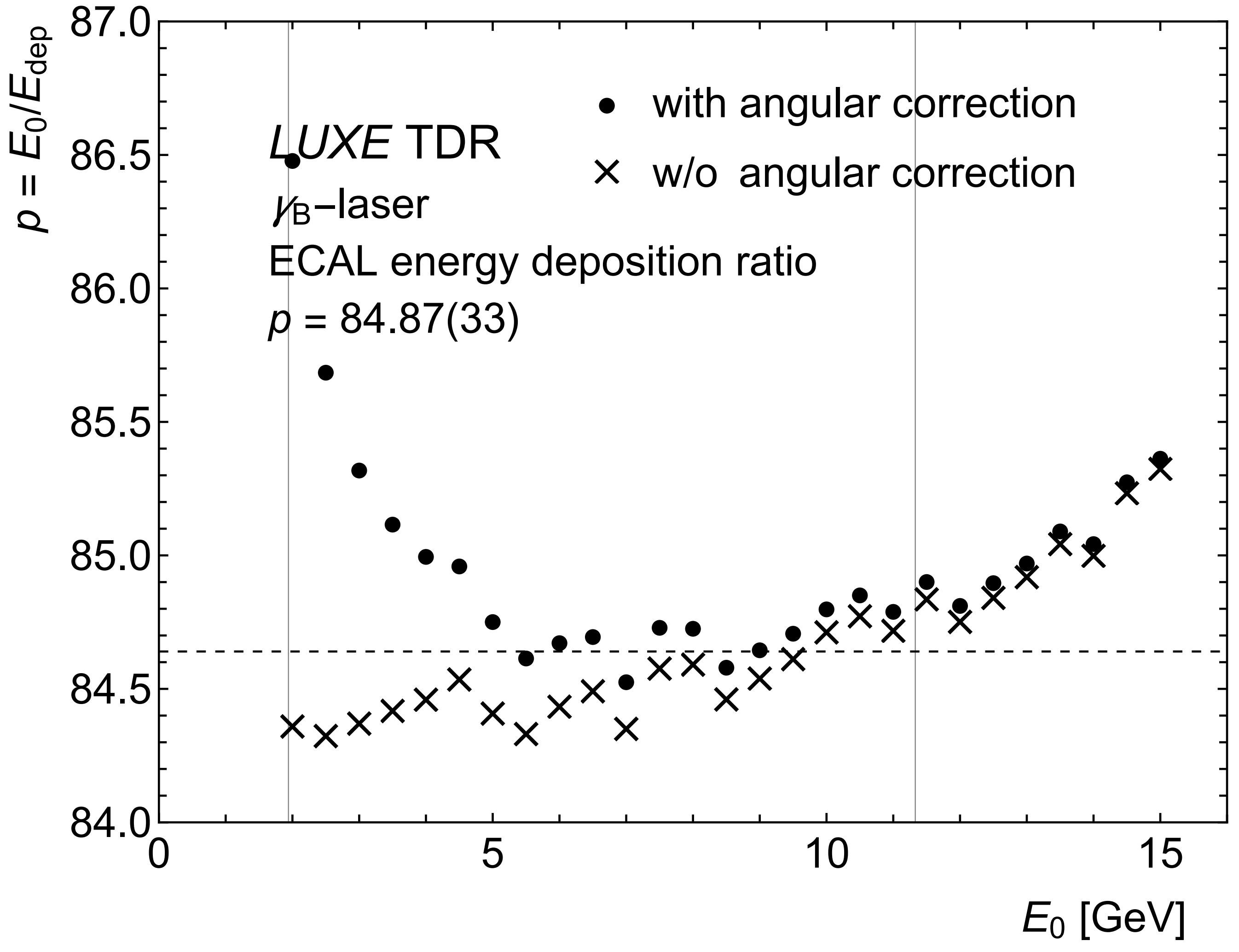
10+5 layers (20 X0)

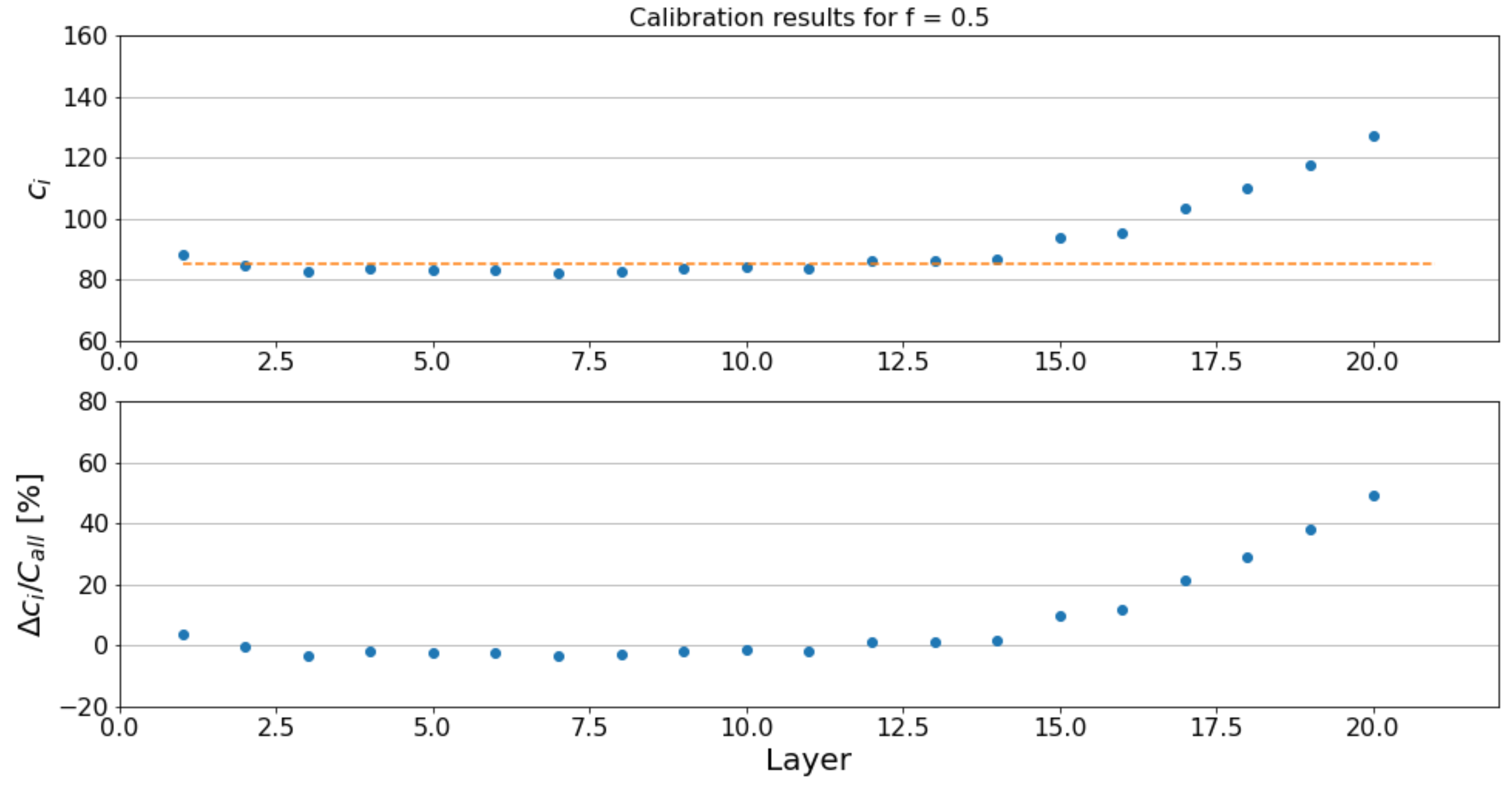


Calibration

- In the CDR, a constant calibration factor was used for all layers
- It has been found out that different energy has different optimized calibration ratio
- An algorithm of compensation has been developed by giving different layer different calibration ratio

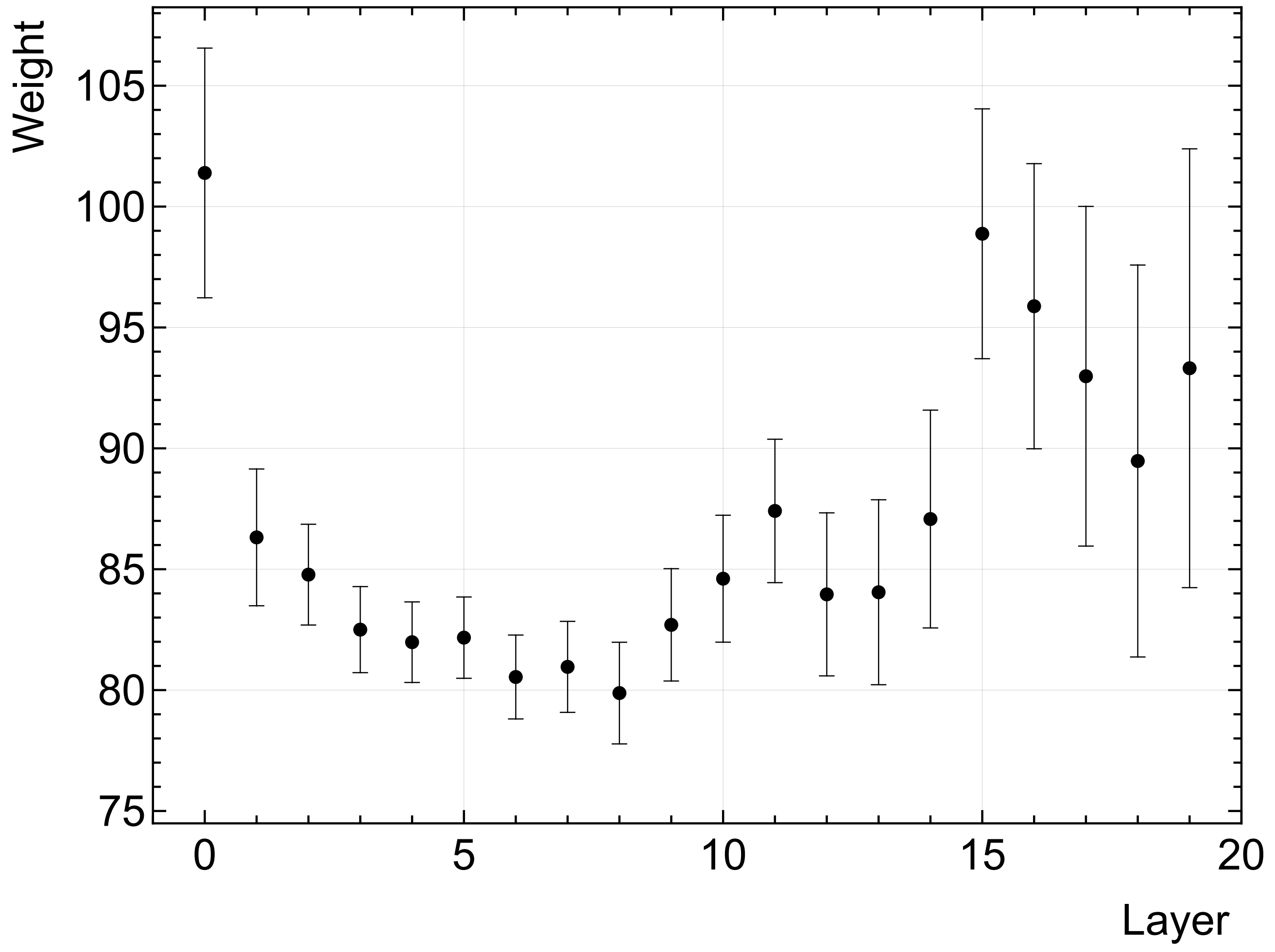


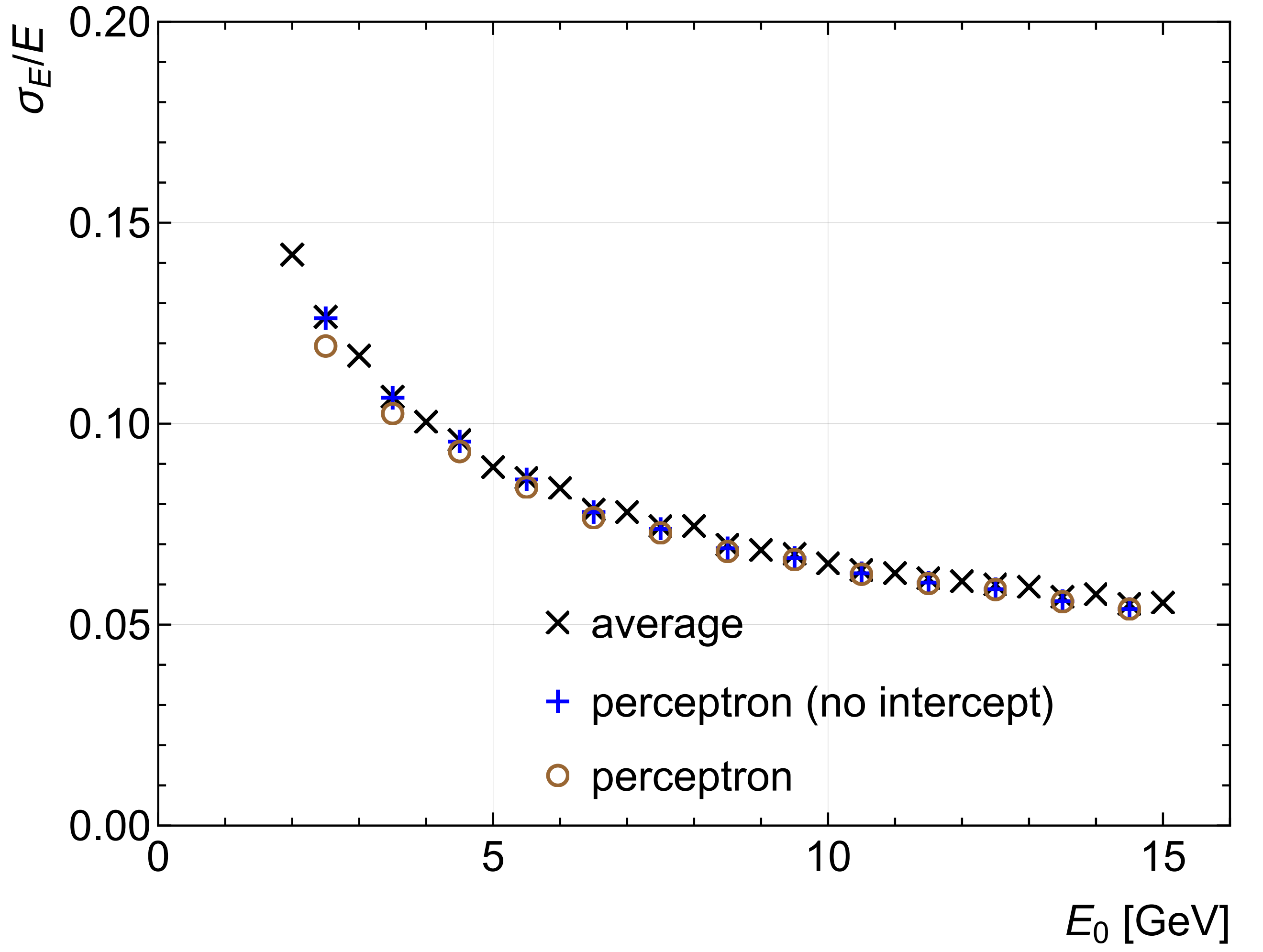




Calibration

- In the CDR, a constant calibration factor was used for all layers
- It has been found out that different energy has different optimized calibration ratio
- An algorithm of compensation has been developed by giving different layer different calibration ratio
- A perceptron was also trained and confirmed the trending of weight distribution

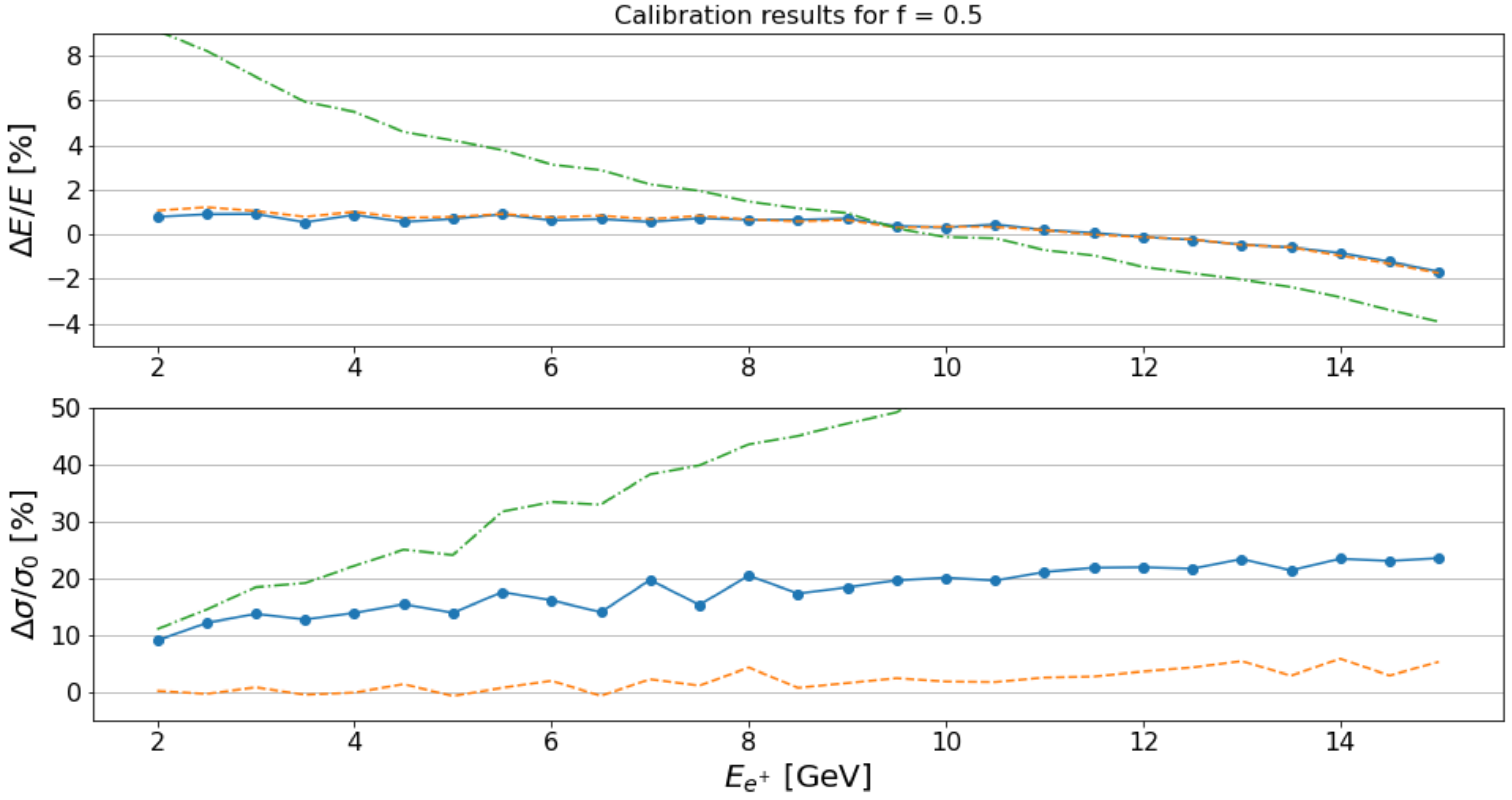


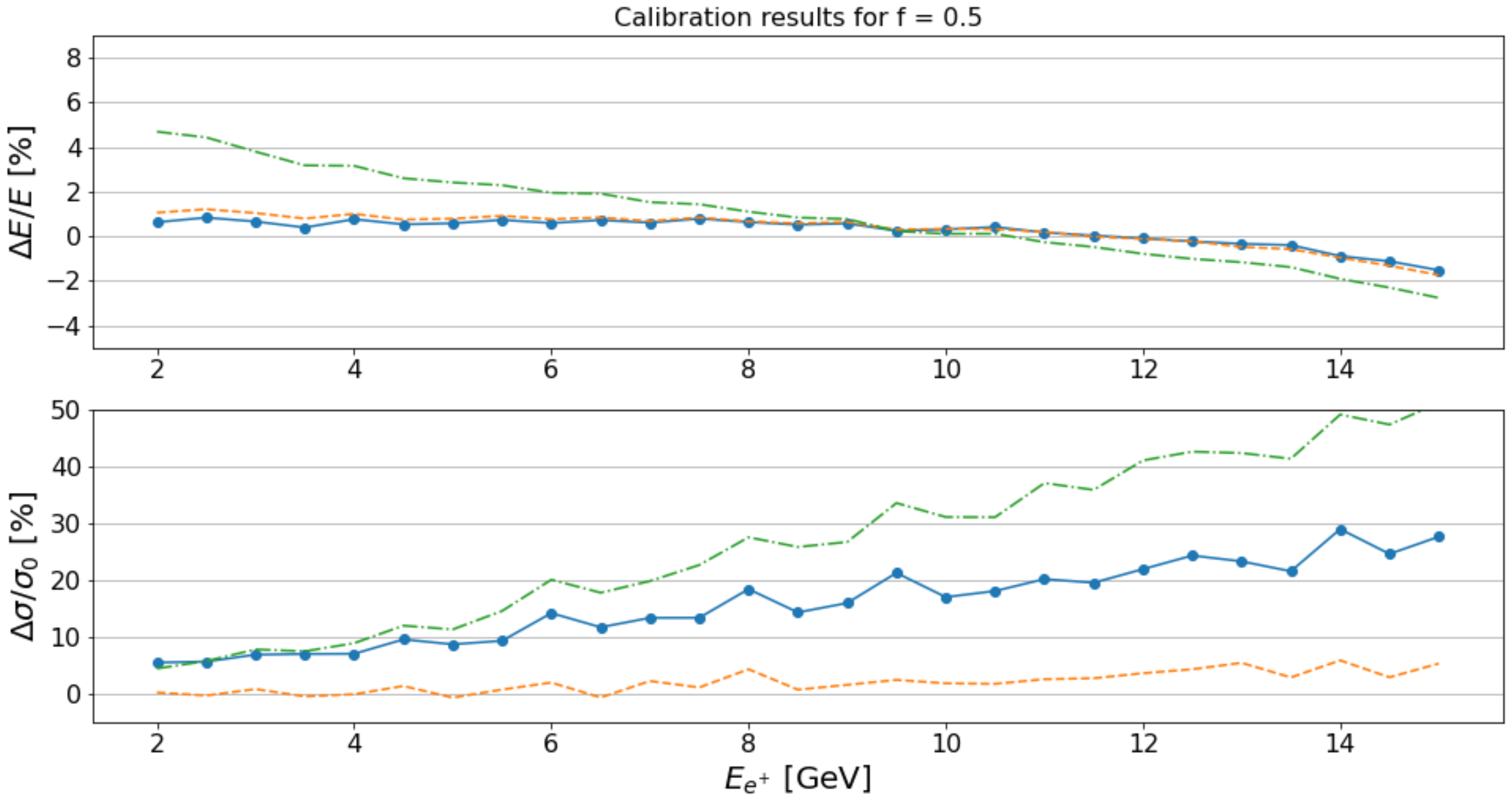


Calibration

- The framework developed by Filip gave a faster result with more flexibility

10+5 layers (20 X0)

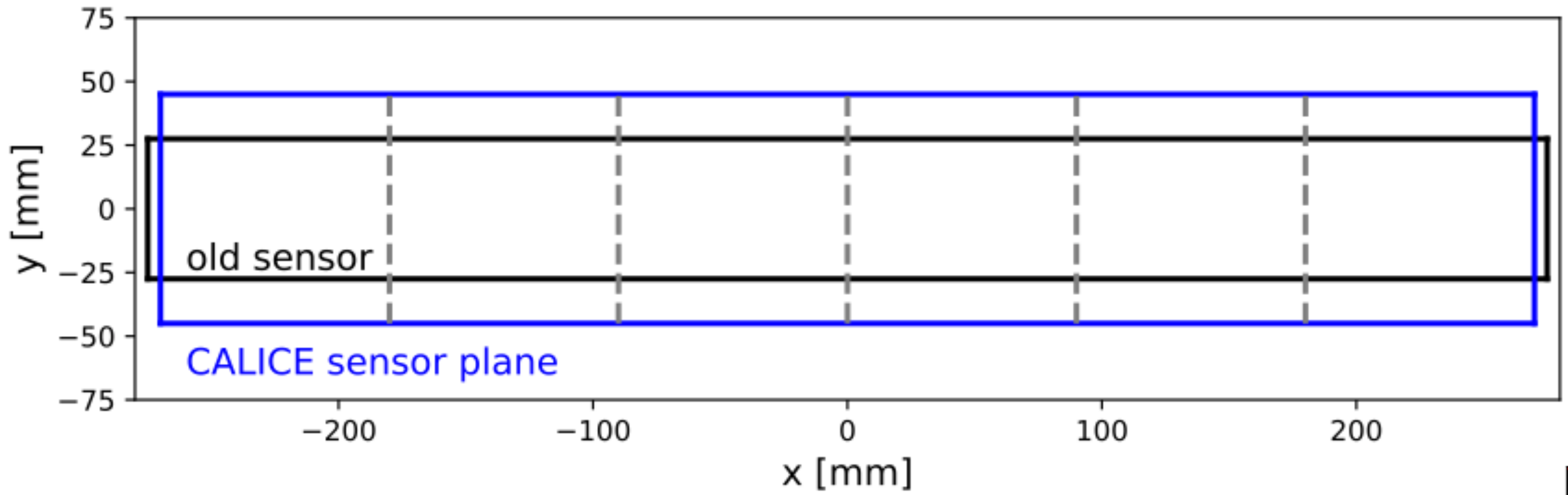


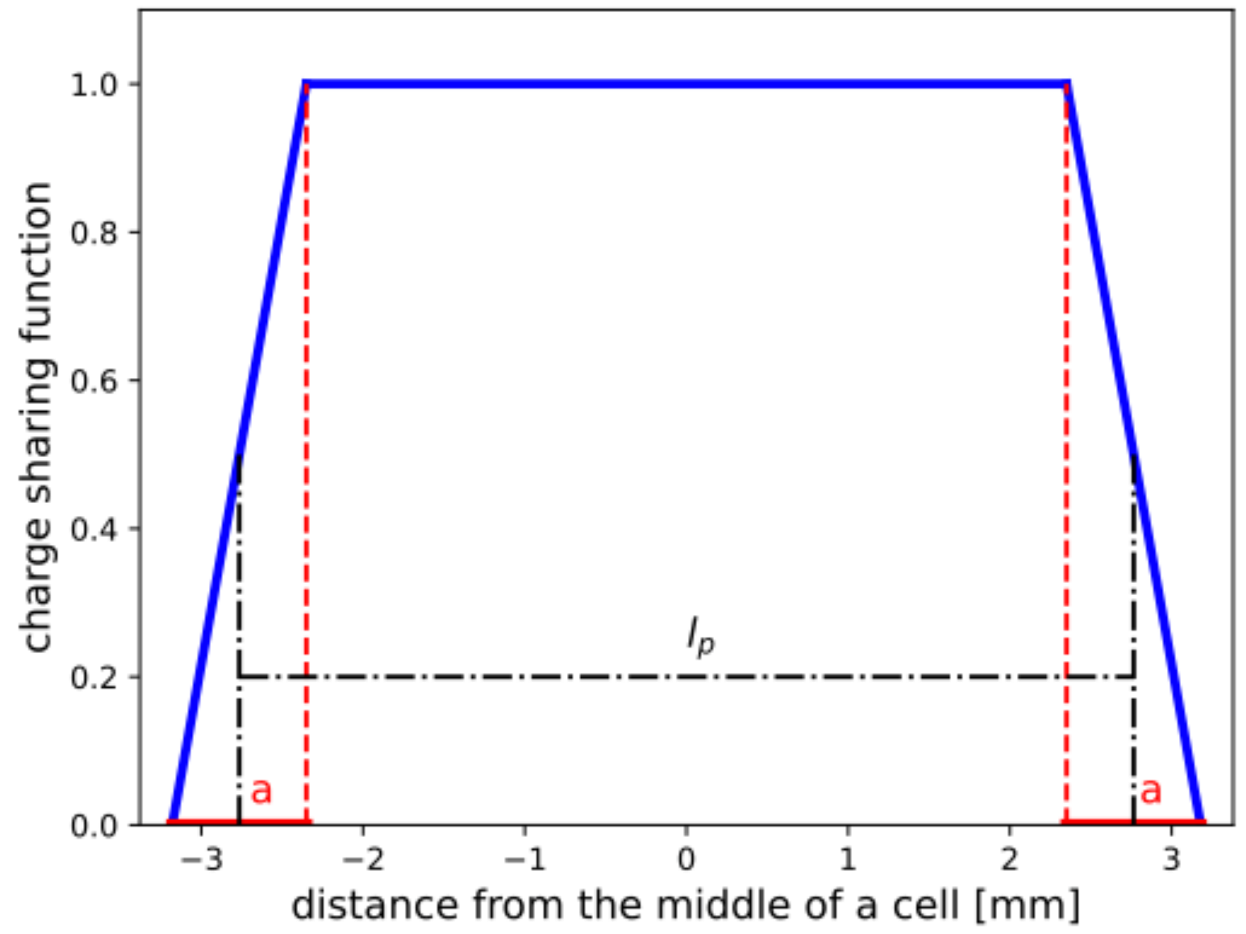


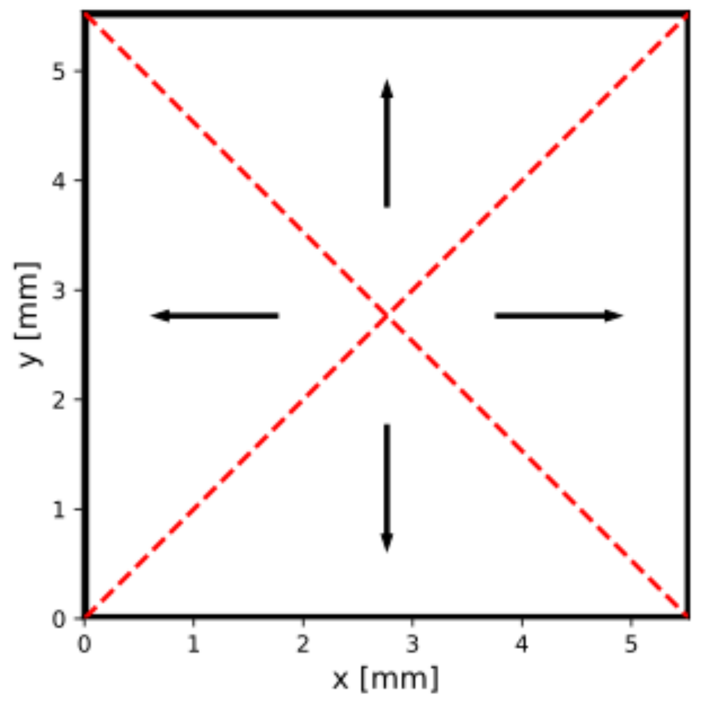
15 layers (15 X0)

Re-segmentation

- A new segmentation is going to be implemented in the analysis
  - Pad size: from 5 x 5 mm^2 to 5.5 x 5.5 mm^2; sensor size from 55 x 5.5 cm^2 to 54 x 9 cm^2
- The digitalization and charge sharing, and the effect of misalignment between layers will be considered







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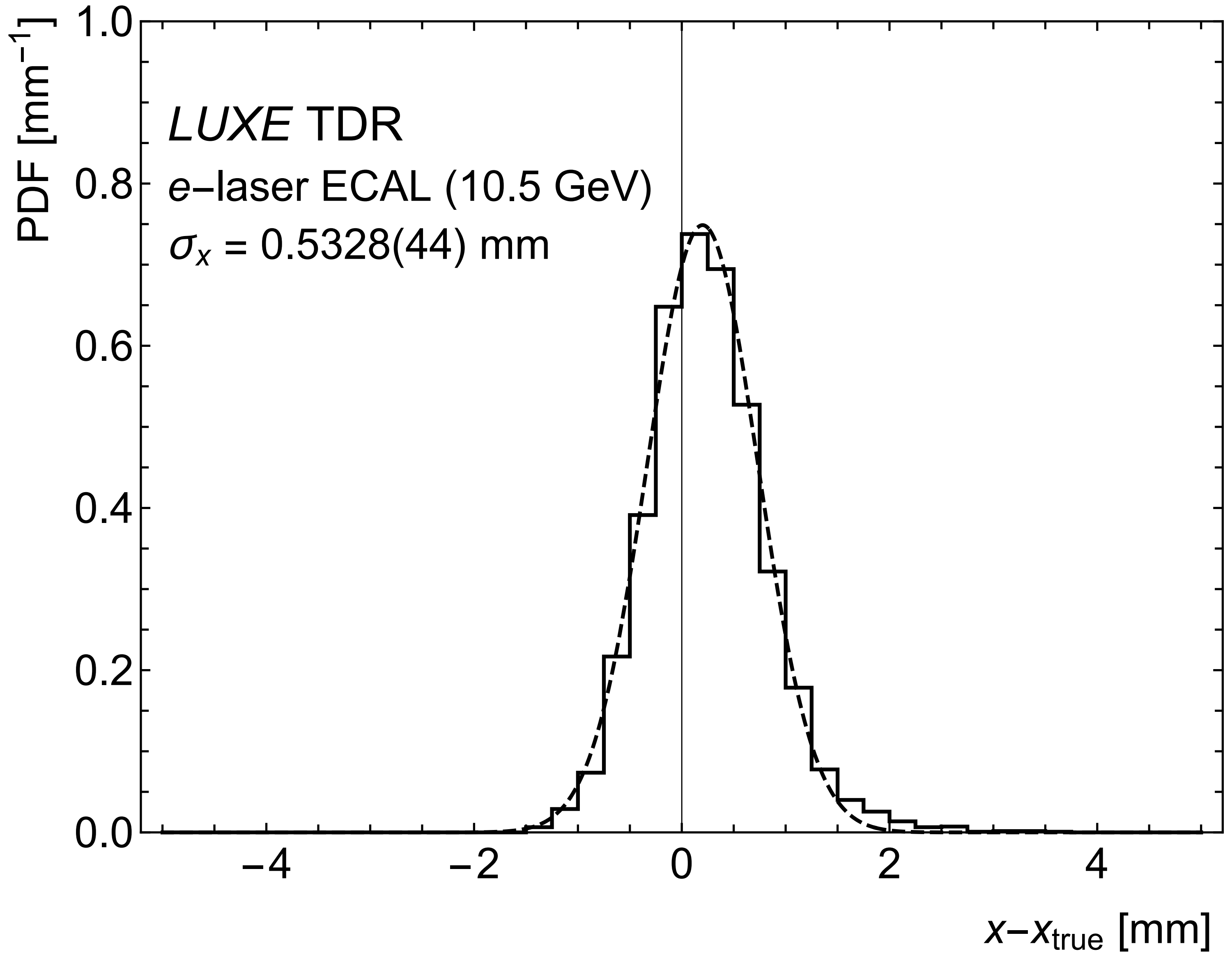
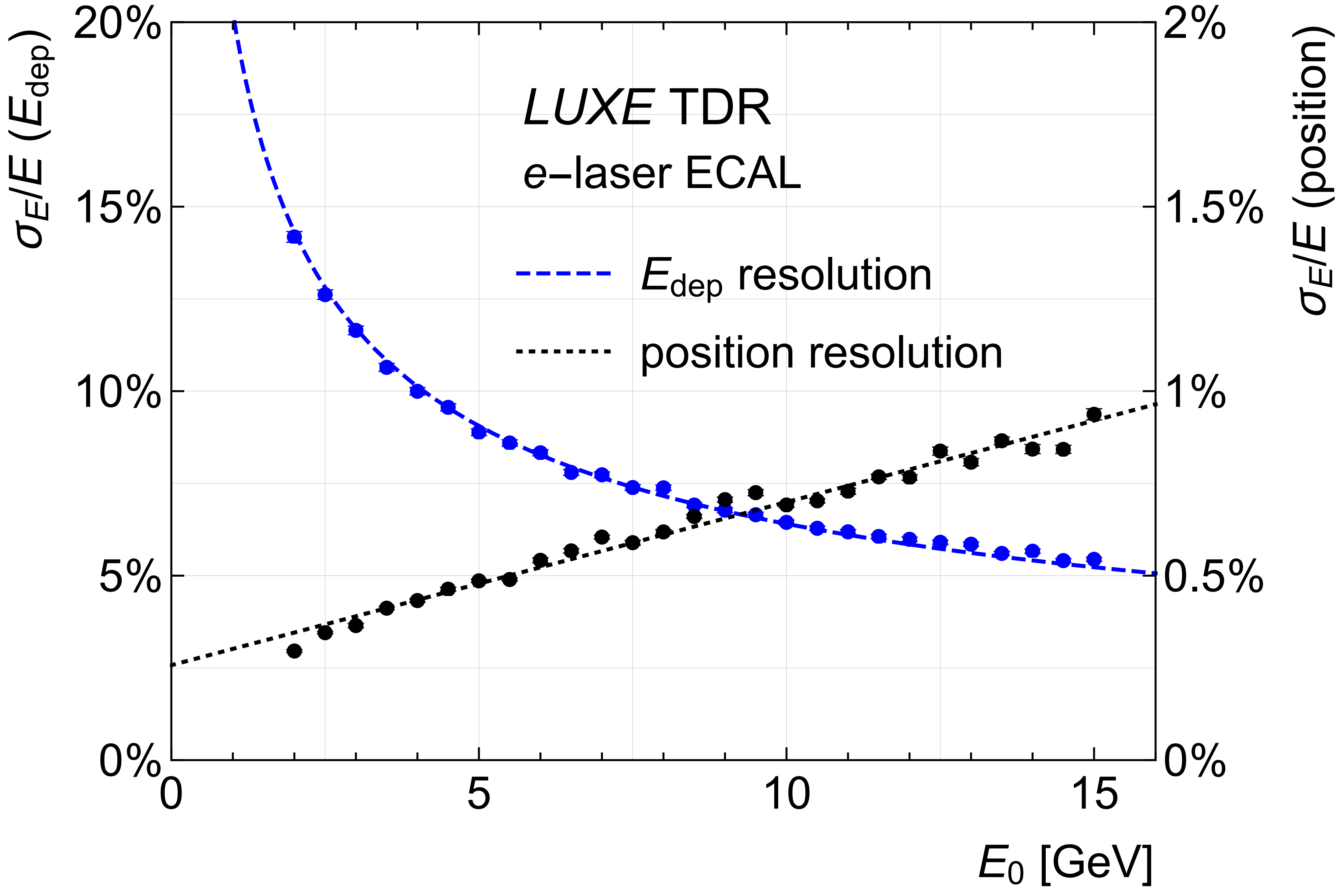
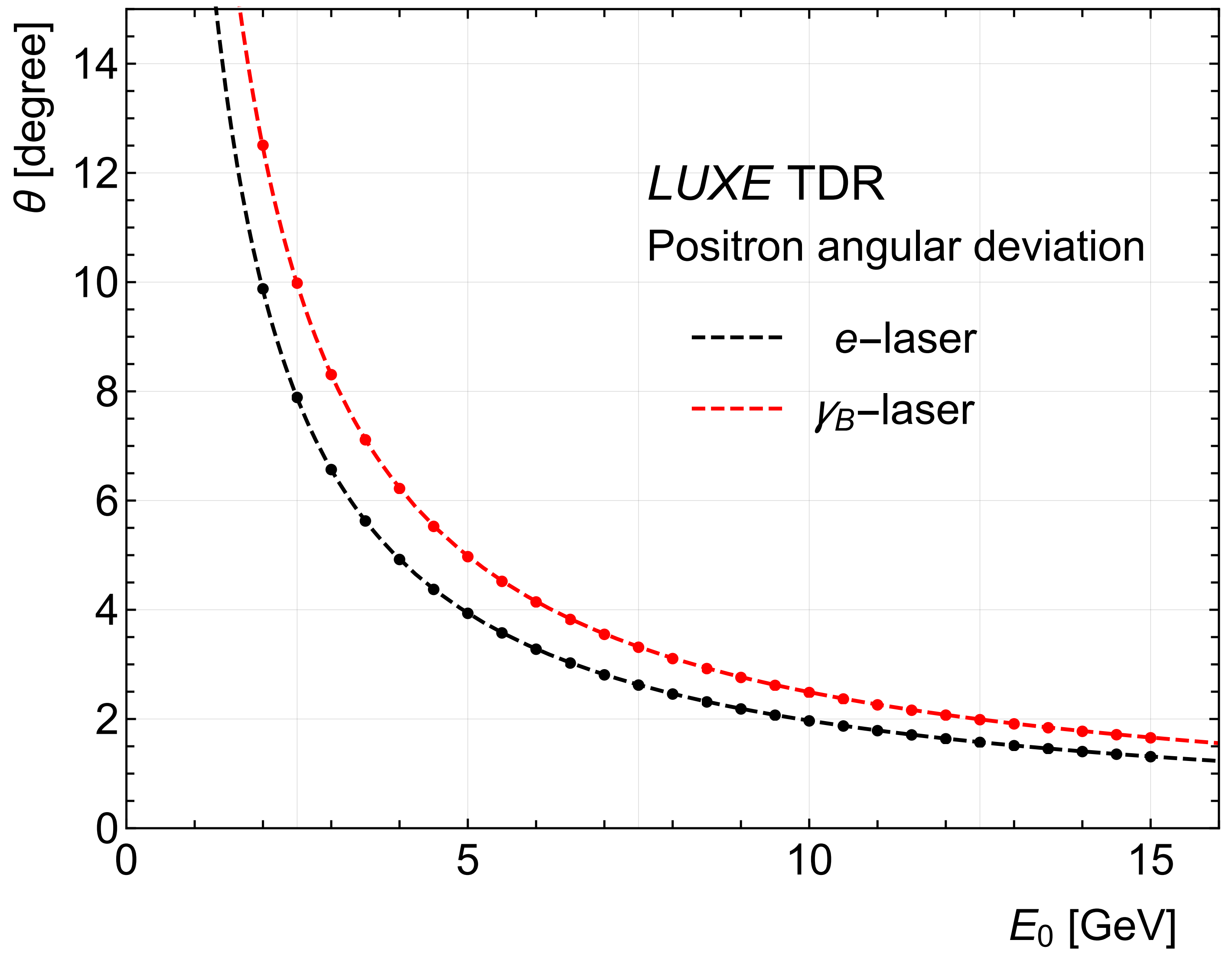
- One more thing ...

Logarithmic weighting

- The weighting method exploits the symmetry of cigar-shaped shower
- By introduced a logarithmic cut-off, the weighting method is more sensitive and more robust against random remote deposits (by photon)
- The magnetic dipole introduces an angle-energy distribution and creates bias in weighting method
- An algorithm based on machine learning is being developed







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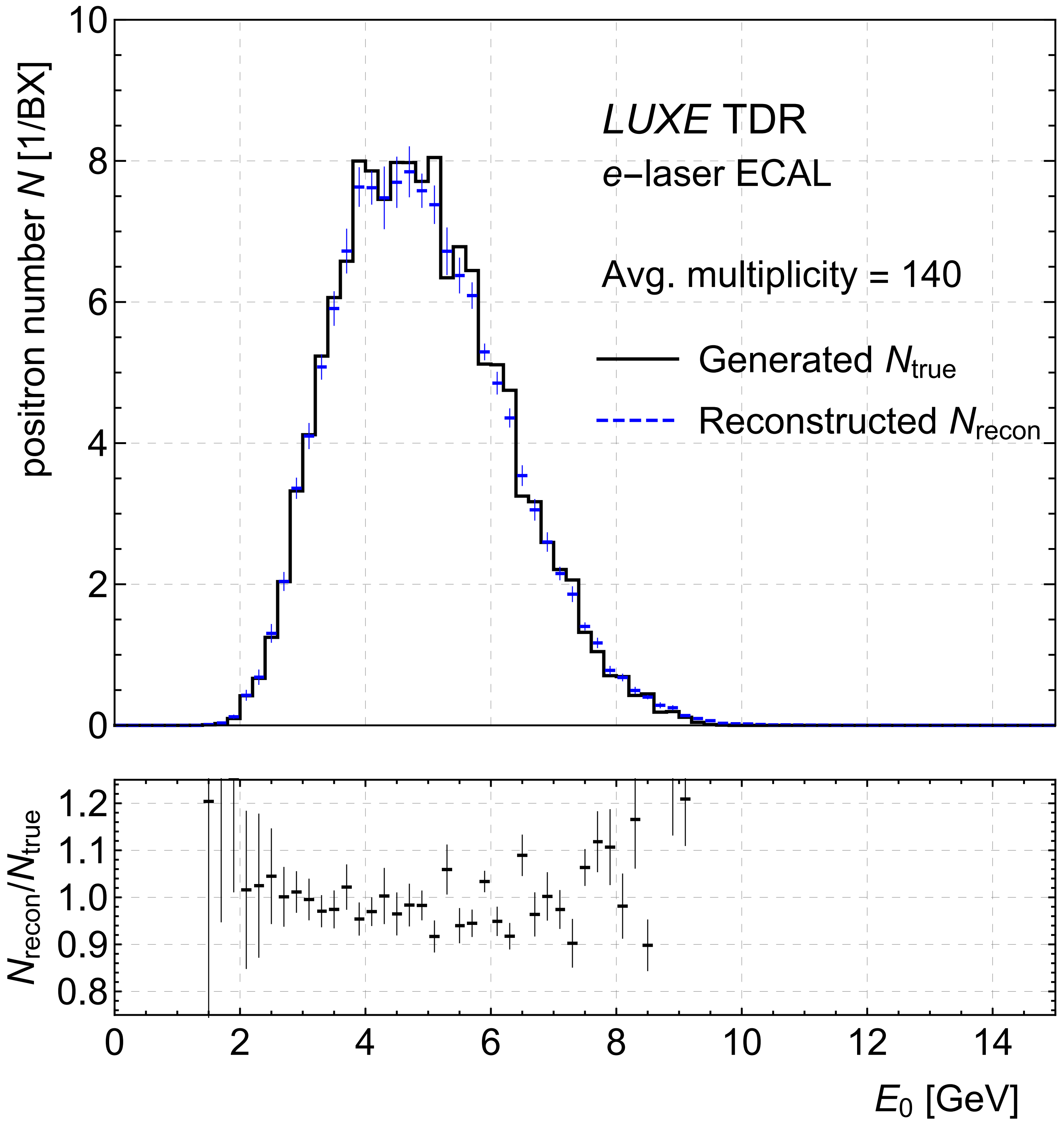
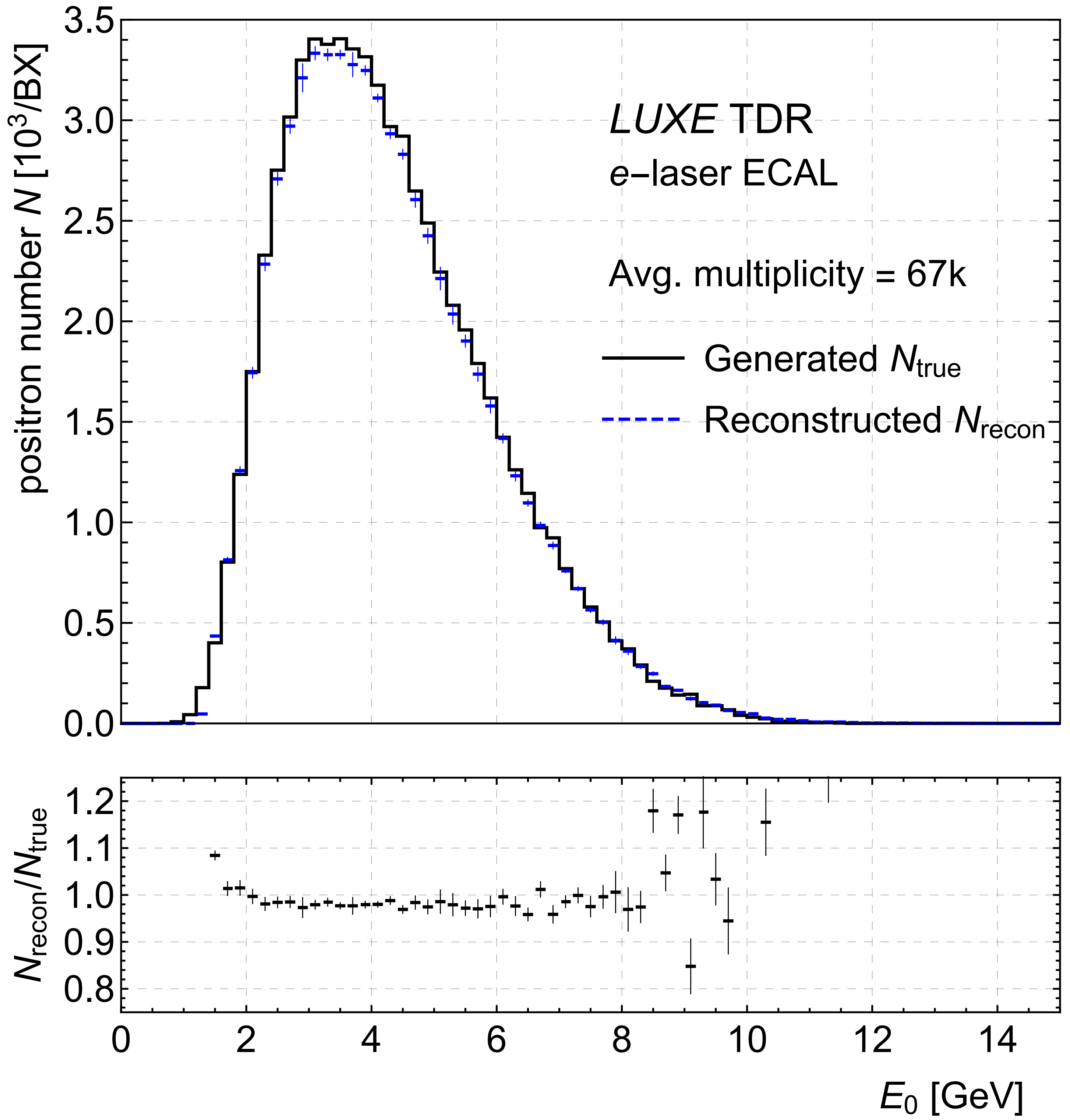
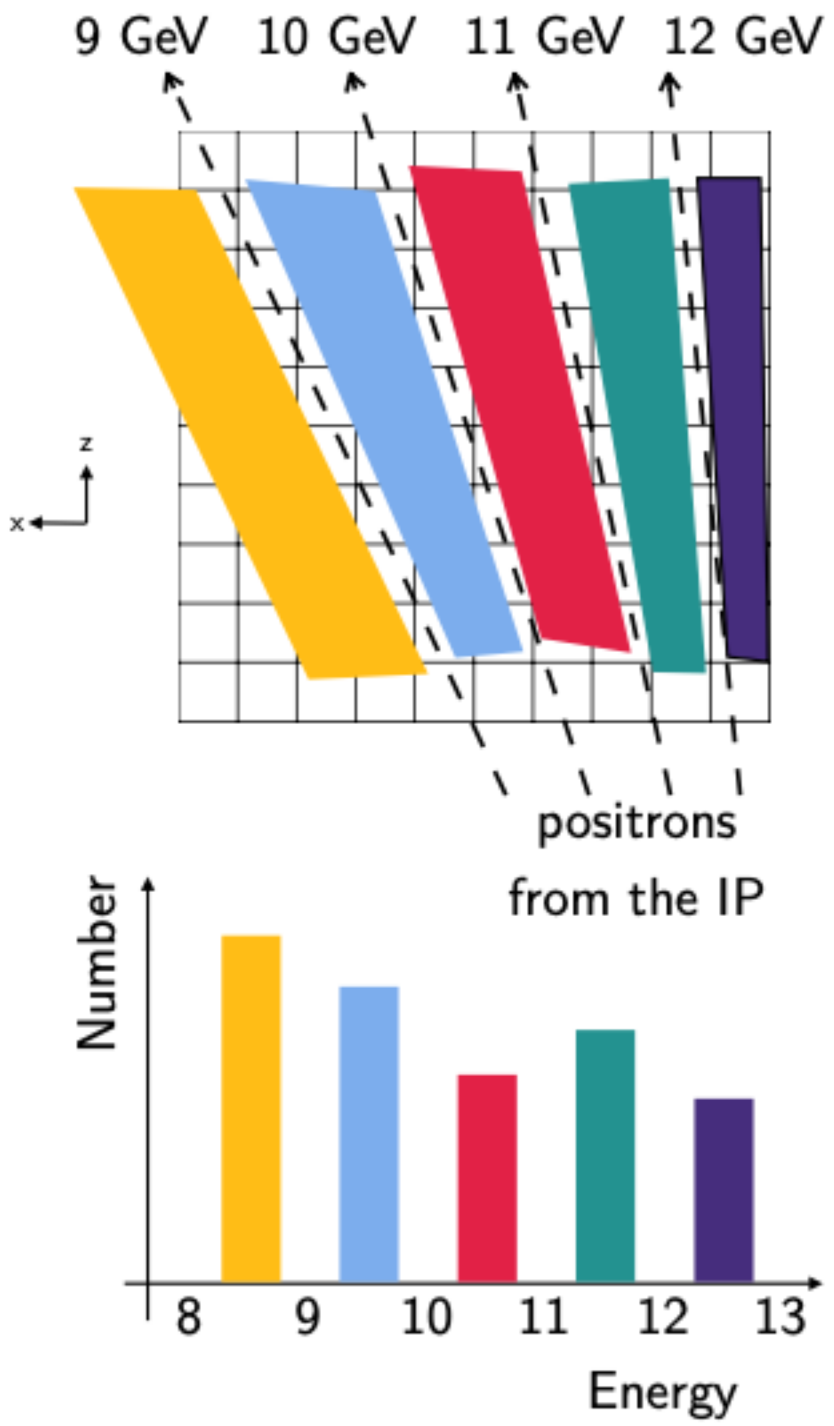
Energy flow



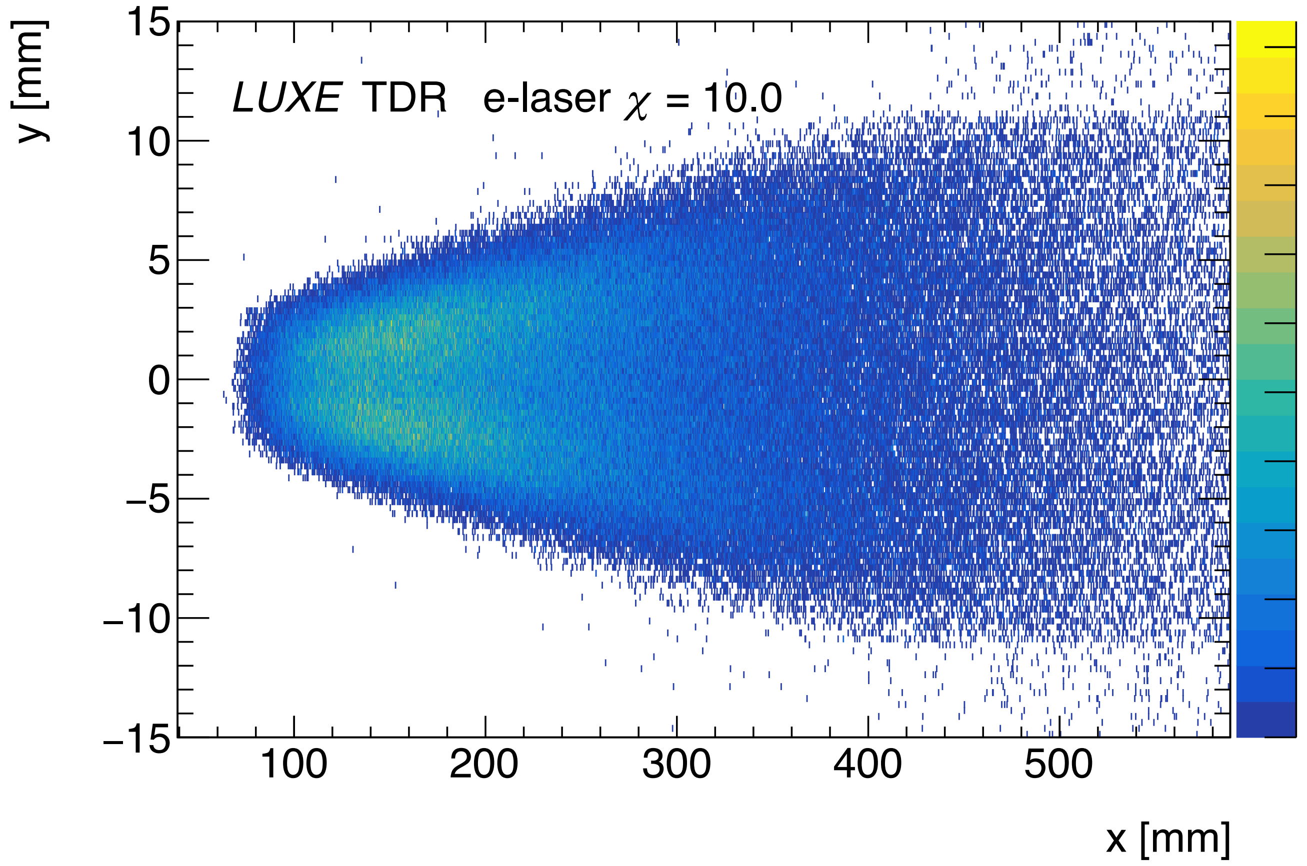
LUXE TDR
e–laser ECAL
Avg. multiplicity = 140
Generated N_{true}
Reconstructed N_{recon}
positron number N [1/BX]
N_{recon}/N_{true}
E_0 [GeV]



LUXE TDR
e–laser ECAL
Avg. multiplicity = 67k
Generated N_{true}
Reconstructed N_{recon}
positron number N [10^3/BX]
N_{recon}/N_{true}
E_0 [GeV]



9 GeV
10 GeV
11 GeV
12 GeV
positrons
from the IP
Number
Energy

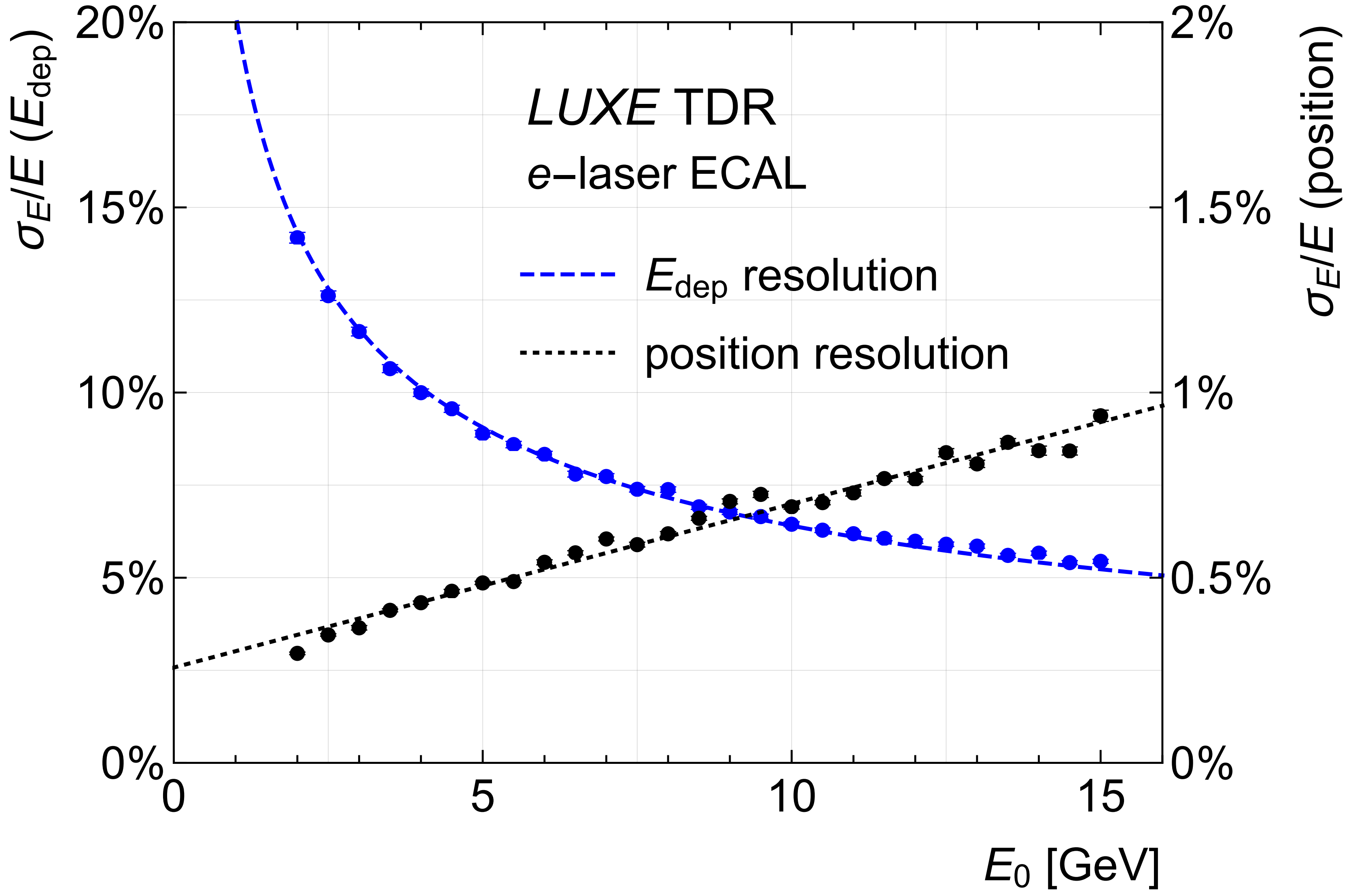


LUXE TDR e-laser χ = 10.0
y [mm]
x [mm]

Reconstruction Network

- The energy flow method is essentially a hand-written "network" that associates the energy deposit of all pads to the bins of energy spectrum
- The idea of using machine learning is to find the weights in an efficient way
- A convolutional neural network is used to "recognize the image"
- The neural network is learning the dependency between position and energy that benefits the resolution

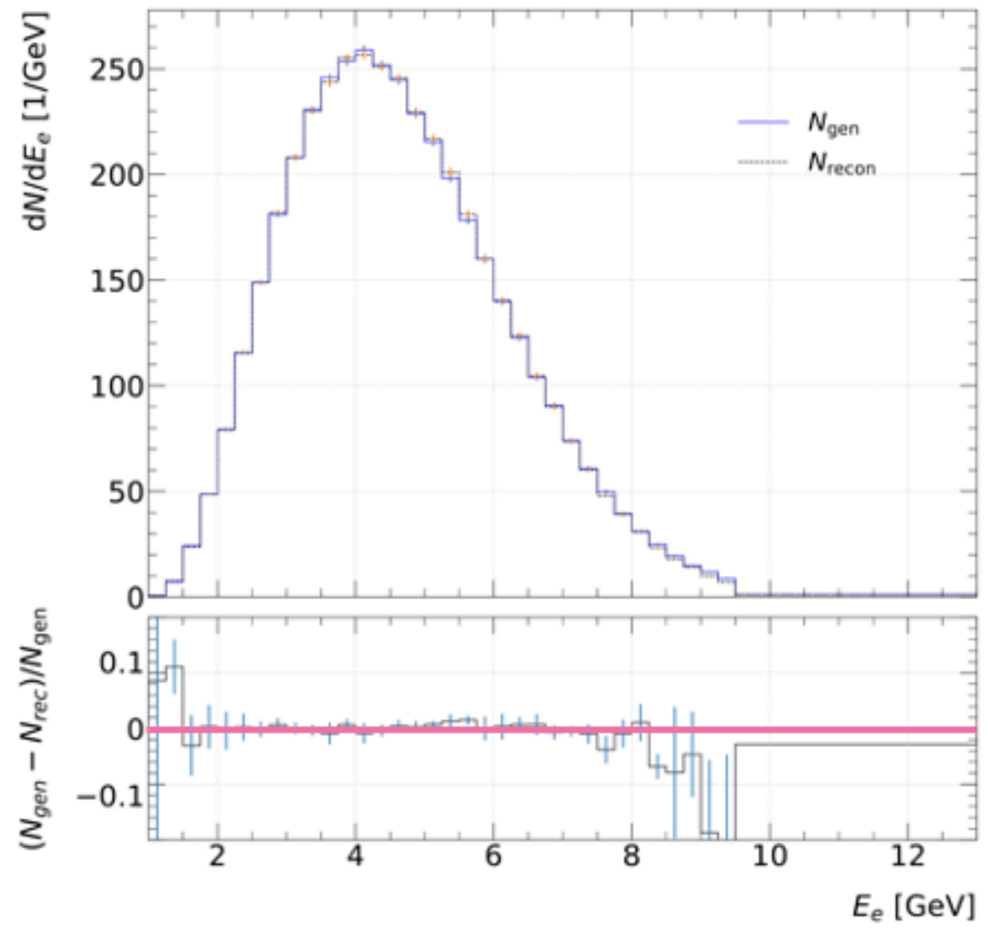
```
Model architecture
========================================
==========================================================================================
Layer (type:depth-idx)                   Input Shape               Output Shape
==========================================================================================
Model                                    [128, 1, 110, 21]         [128, 60]
├─Conv2d: 1-1                            [128, 1, 110, 21]         [128, 8, 56, 11]
├─Conv2d: 1-2                            [128, 8, 56, 11]          [128, 16, 28, 6]
├─Linear: 1-3                            [128, 2688]               [128, 256]
├─Linear: 1-4                            [128, 256]                [128, 60]
==========================================================================================
Total params: 705,012
Trainable params: 705,012
Non-trainable params: 0
Total mult-adds (M): 118.36
```



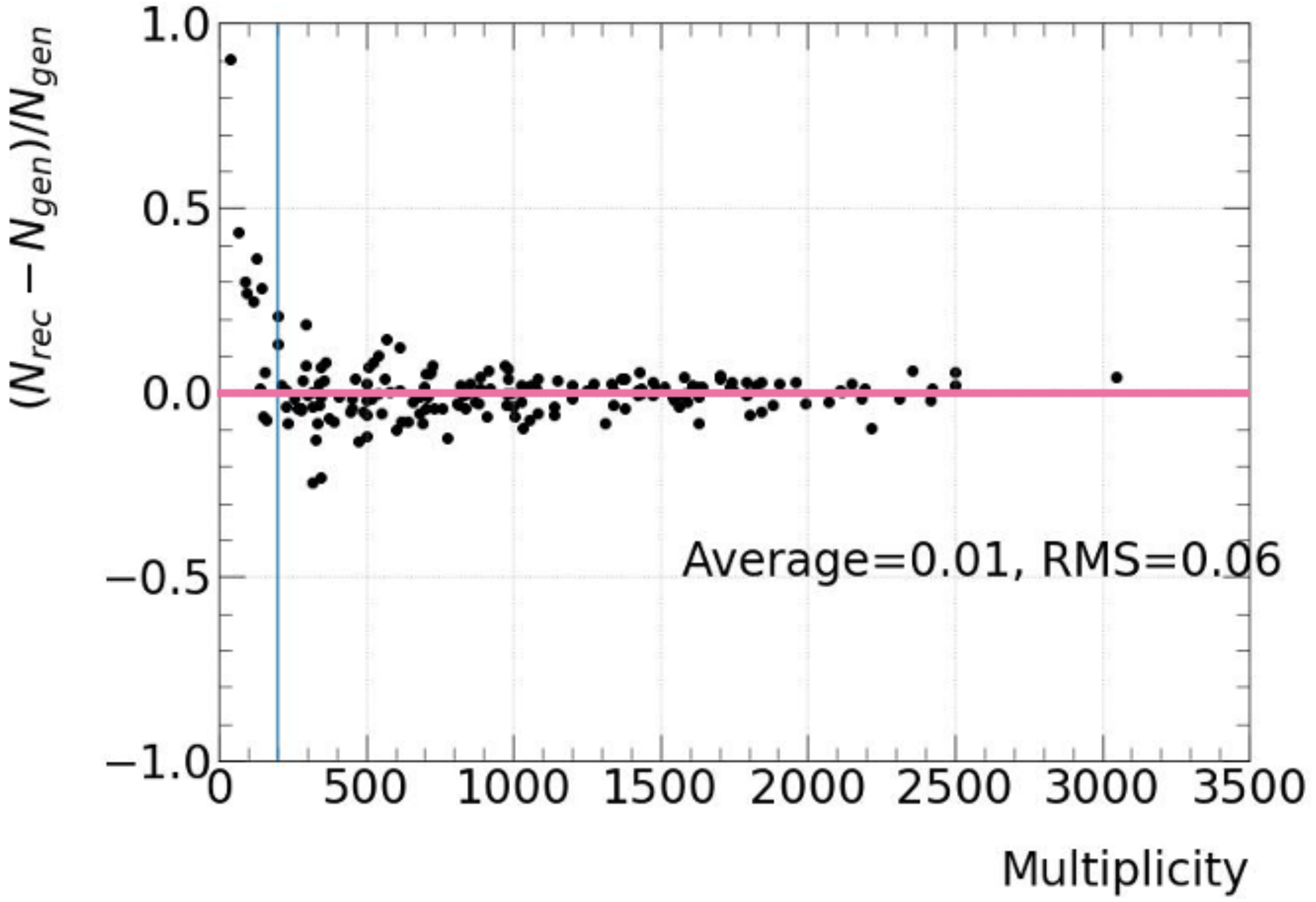
CNN based algorithm

- The CNN successfully reconstruct the energy spectrum not only with 20 or 15 layers, but also even with only 5 layers above a multiplicity threshold
- The method has a difficulty with generalization
- We are working on striping out the information of multiplicity

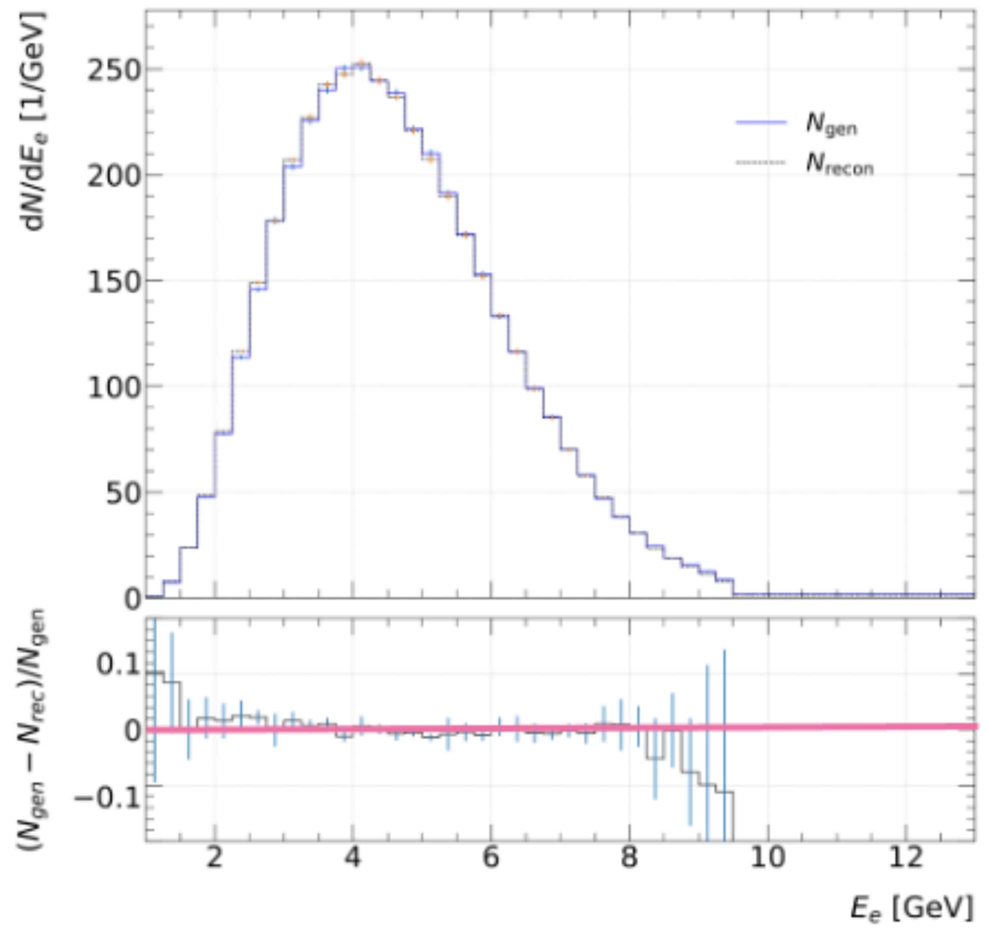
20-LAYER ECAL
WITH THE BACKGROUND



5-LAYER ECAL
WITH THE BACKGROUND



5-LAYER ECAL
WITH THE BACKGROUND



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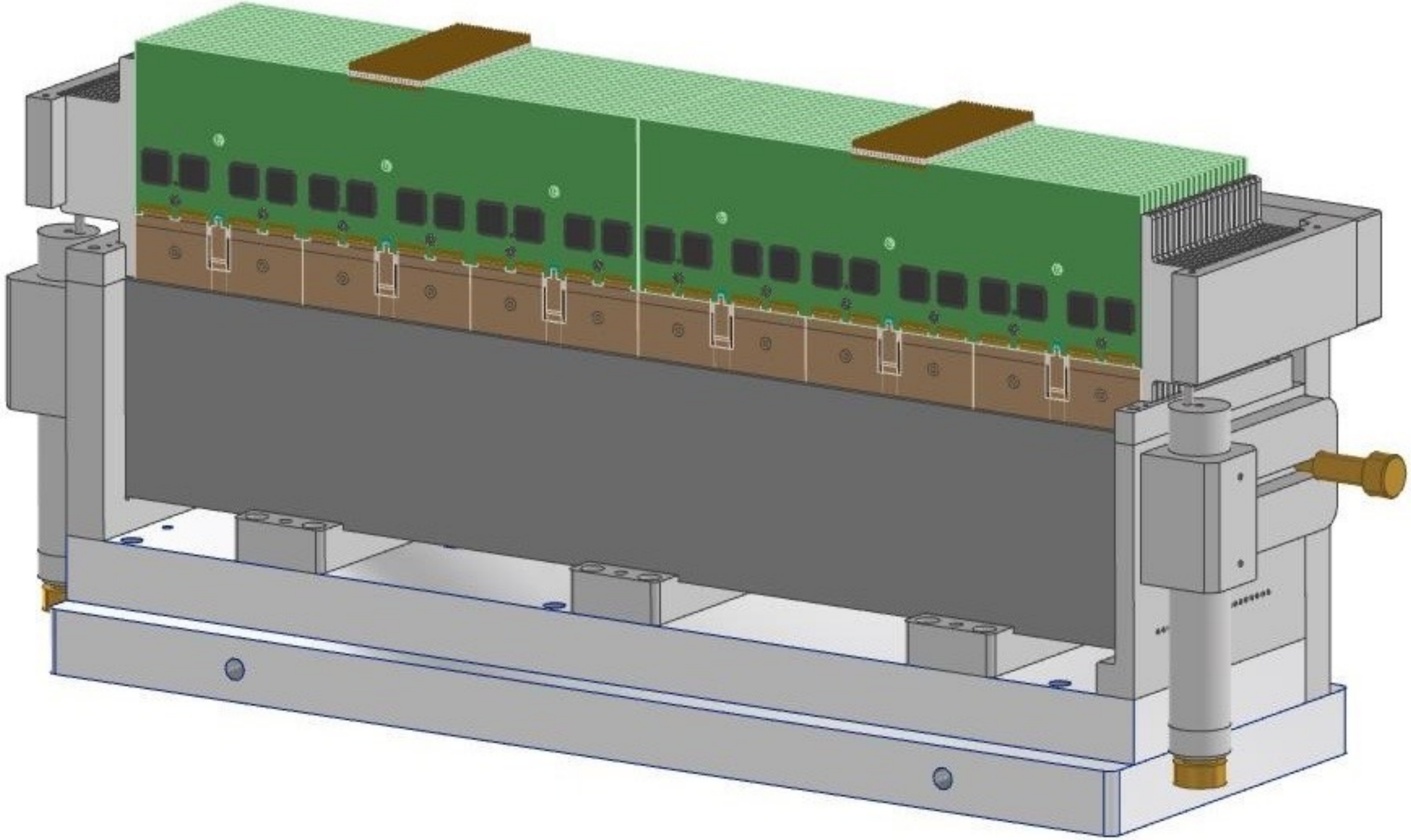
Summary

- The LUXE ECAL group is working towards the final design of the ECAL-P and a ready-use reconstruction toolkit
- The background study so far confirms that the signal-to-noise ratios are generally acceptable
- A framework has been developed to find out the optimized design of ECAL-P
- Logarithmic weighting is so far one of our best methods for position reconstruction
- A machine learning method based on CNN is successfully reconstruct the positron beam's spectrum with very few X_0, comparing to the benchmark of energy flow

- Things are still on our list:
  - Uncertainty of background subtraction (fast simulation)
  - Digitalization and other effects
  - Clustering (for the cases of multiplicity around 10)
  - Thorough studies on ECAL-E



Thank you for your attention!

Backup of TB