ECAL Performance
Towards the experiment

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on behalf of the ECAL group

LUXE Workshop 2023

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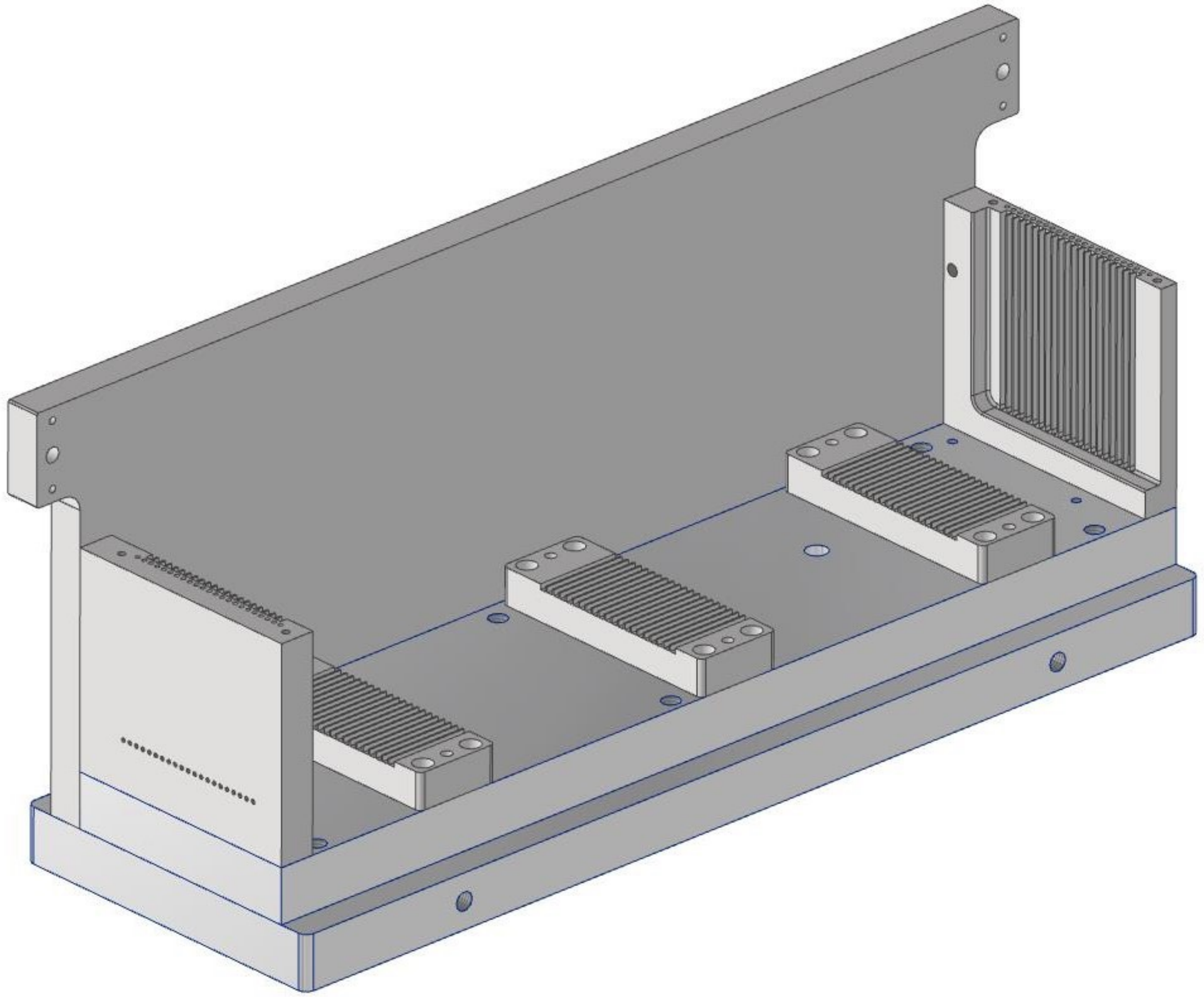
People on ECAL Performance

(Alphabetically)

- AGH: Marek Idzik, Jakub Moroń, Dawid Pietruch
- DESY: Wolfgang Lohmann
- ISS: Alina T. Neagu, P. Mihai Potlog, Veta Ghenescu
- TAU: Halina Abramowicz, Michal Elad, David Horn, Shan Huang, Dor Miron, Nir Zadok
- UW: Grzegorz Grzelak, A. Filip Żarnecki, Piotr Zbińkowski, Kamil Zembaczyński



ECAL-P Overview

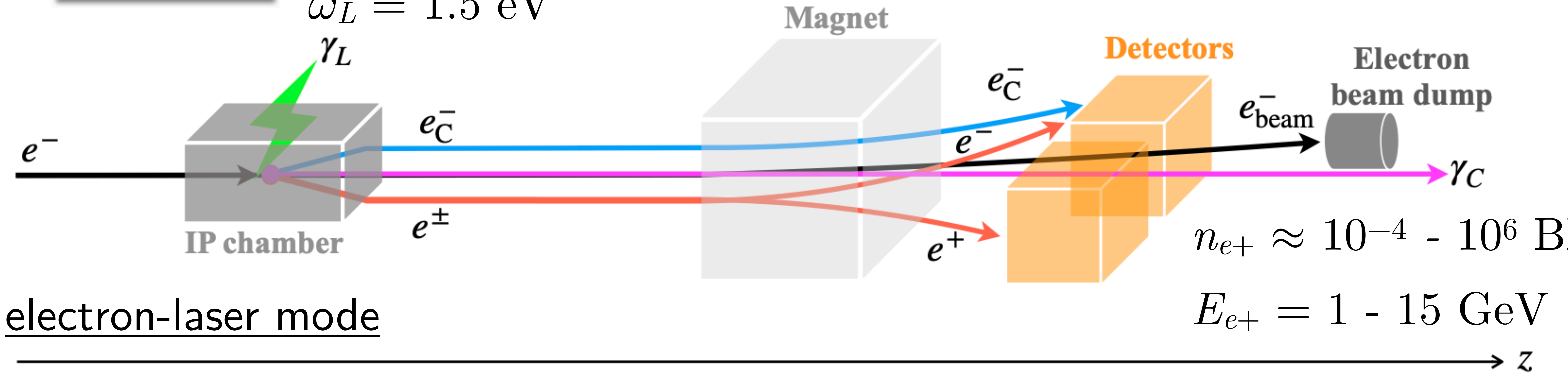
LUXE SFQED (not to scale)

$I_L \approx 10^{18}$ - 10^{21} W cm^{-2}

$\omega_L = 1.5$ eV

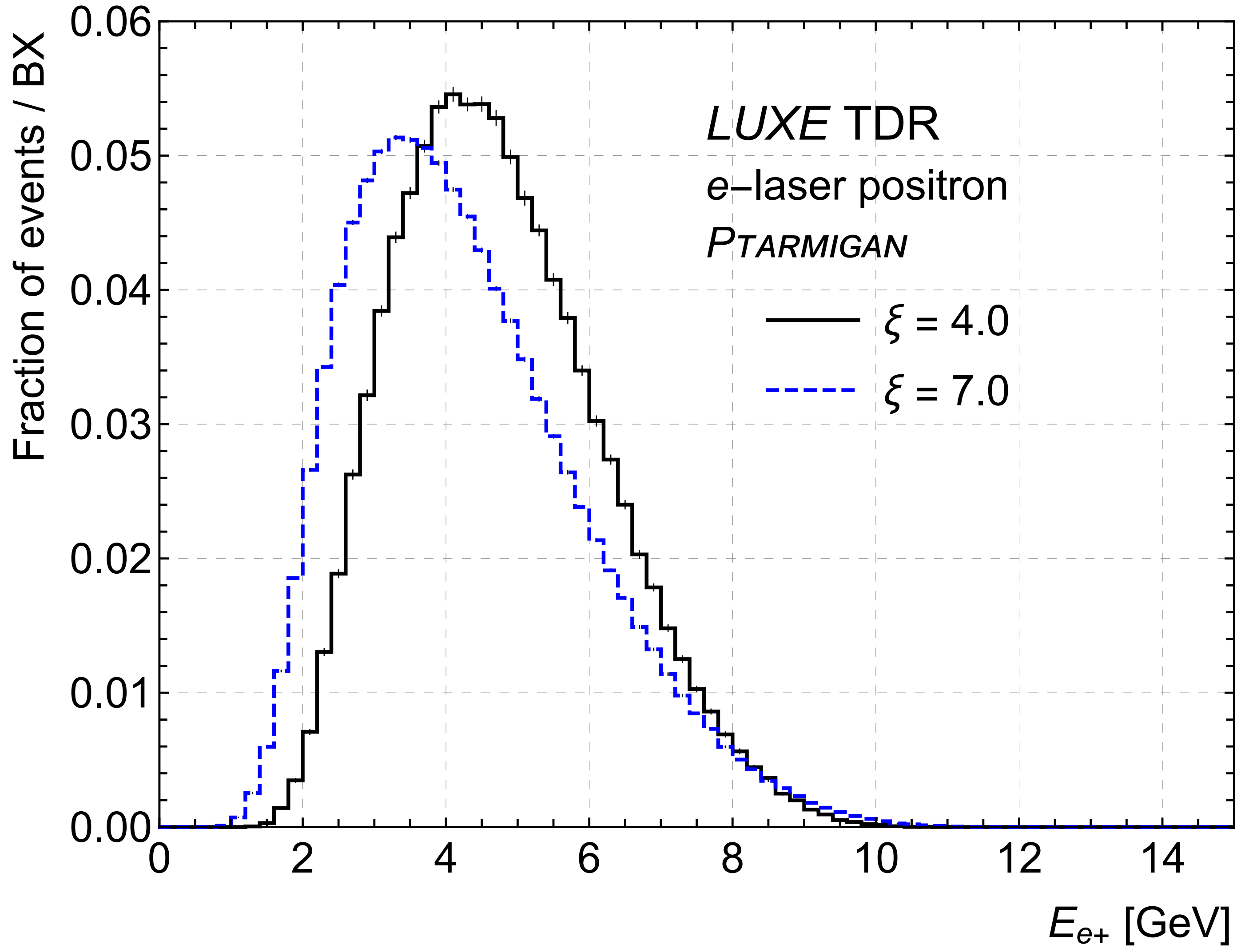
BX $= 1.5\times10^9$

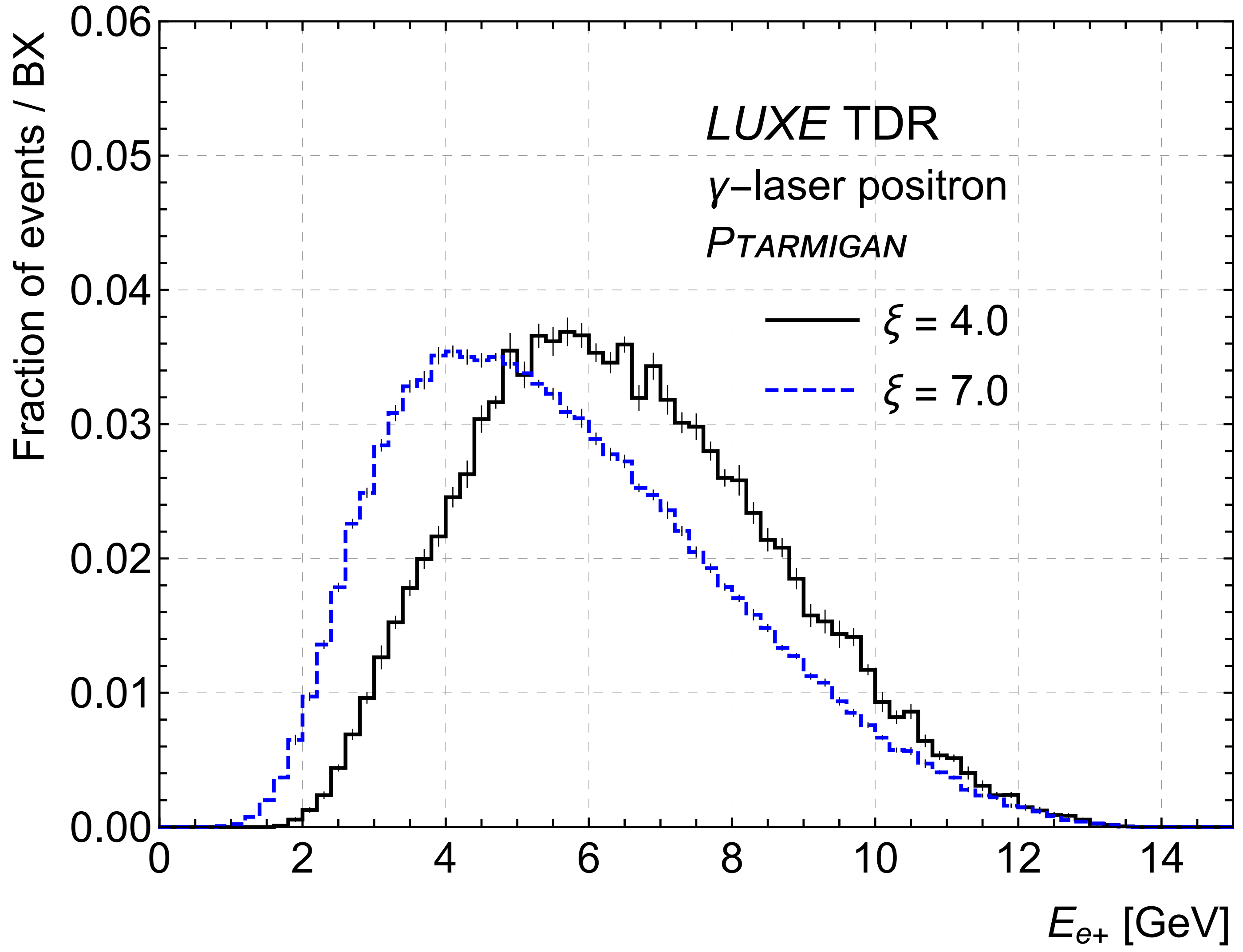
$E_e = 16.5$ GeV

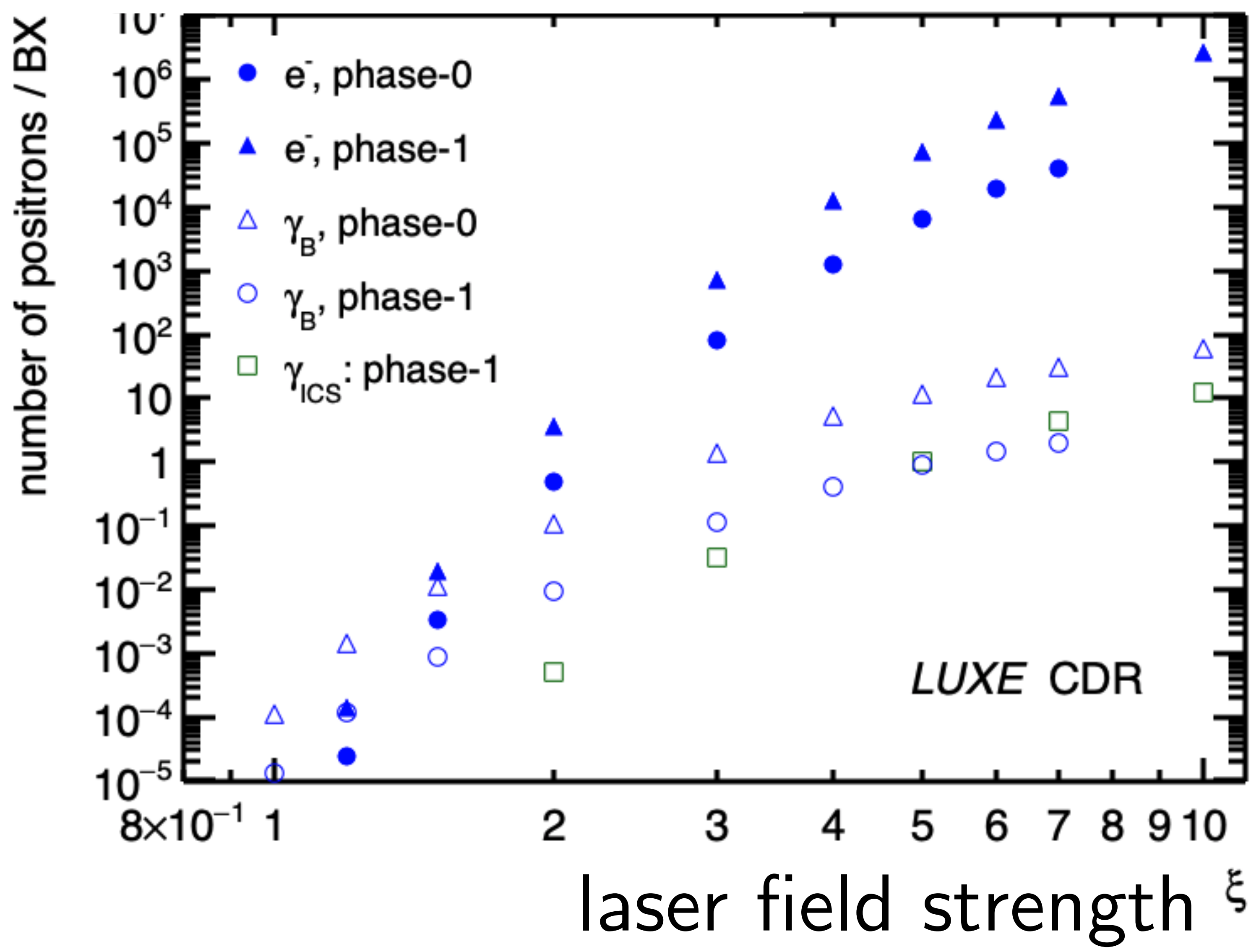


$n_{e+} \approx 10^{-4}$ - 10^6 BX^{-1}

$E_{e+} = 1$ - 15 GeV







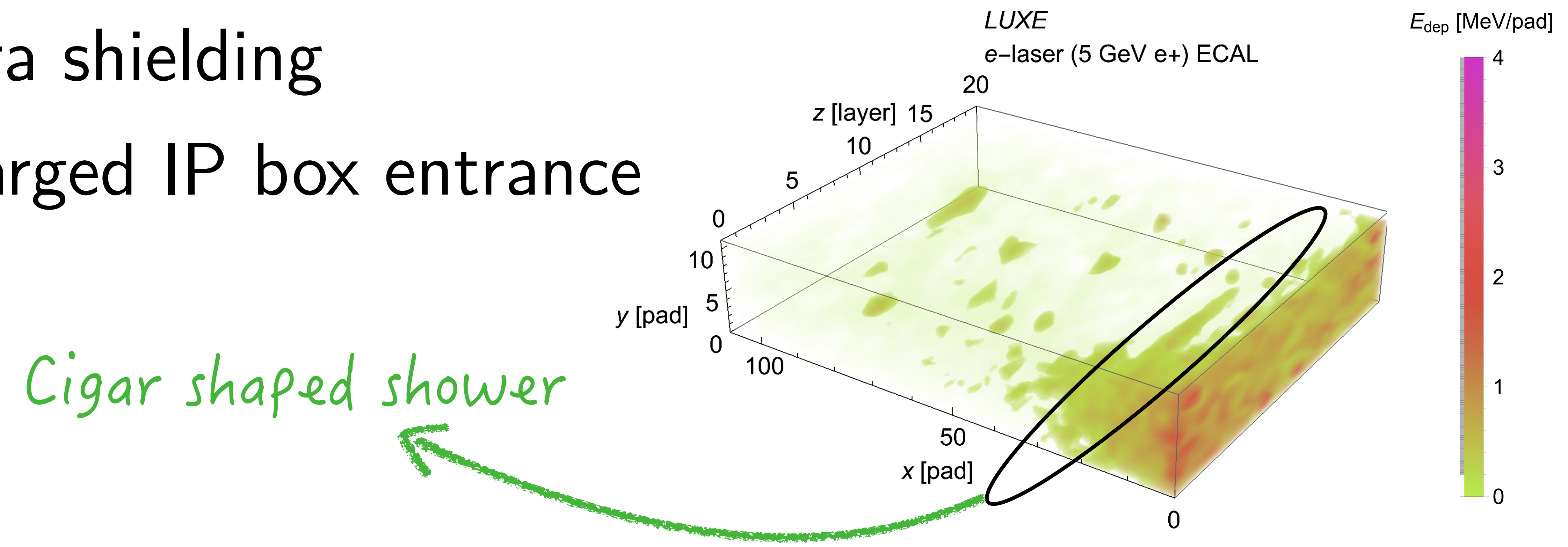
Outline

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

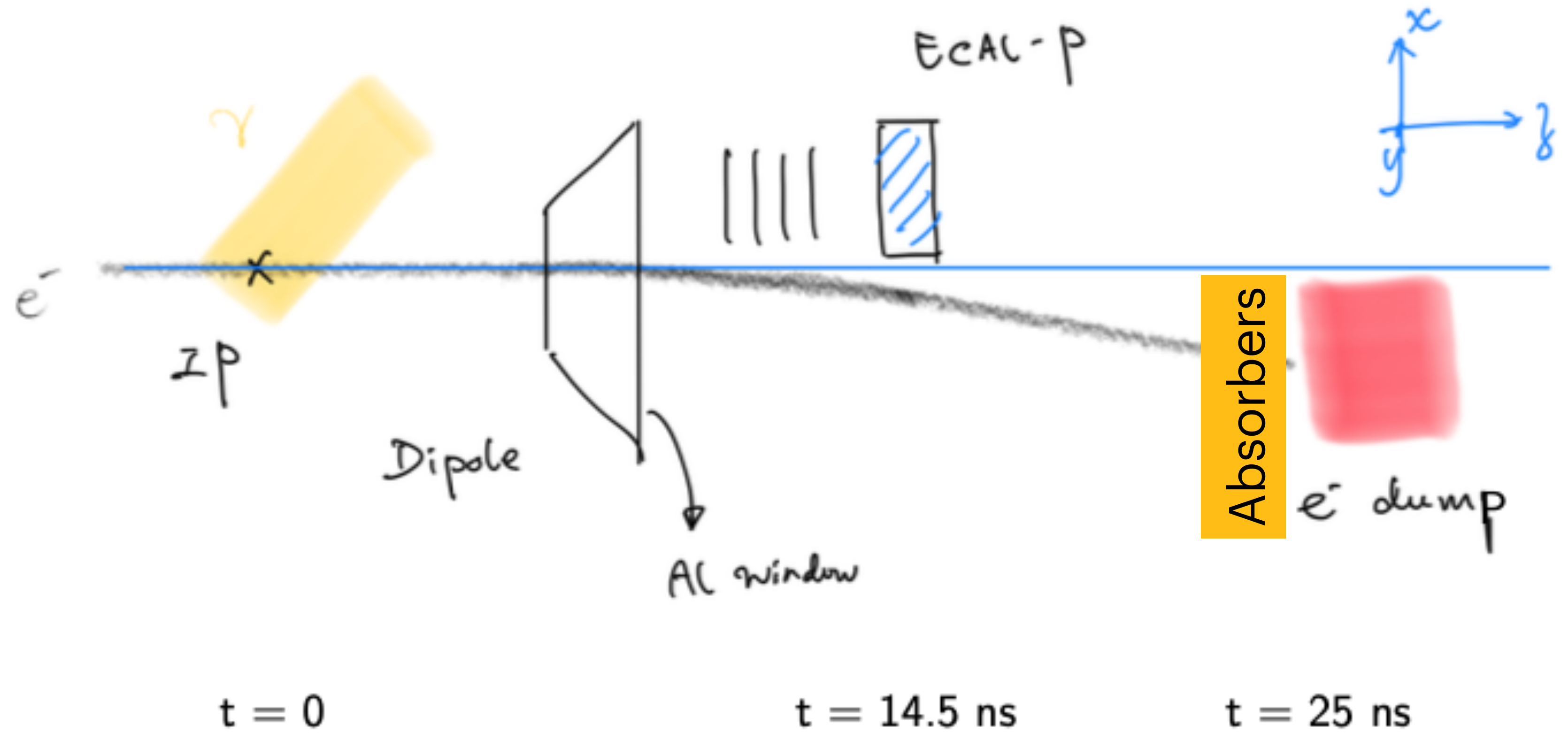
- One more thing ...

ECAL-P Background

- Electromagnetic background of ECAL-P had been well discussed in the CDR
  - electron-laser: beamline ⟹ extra shielding
  - gamma-laser: IP box ⟹ 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

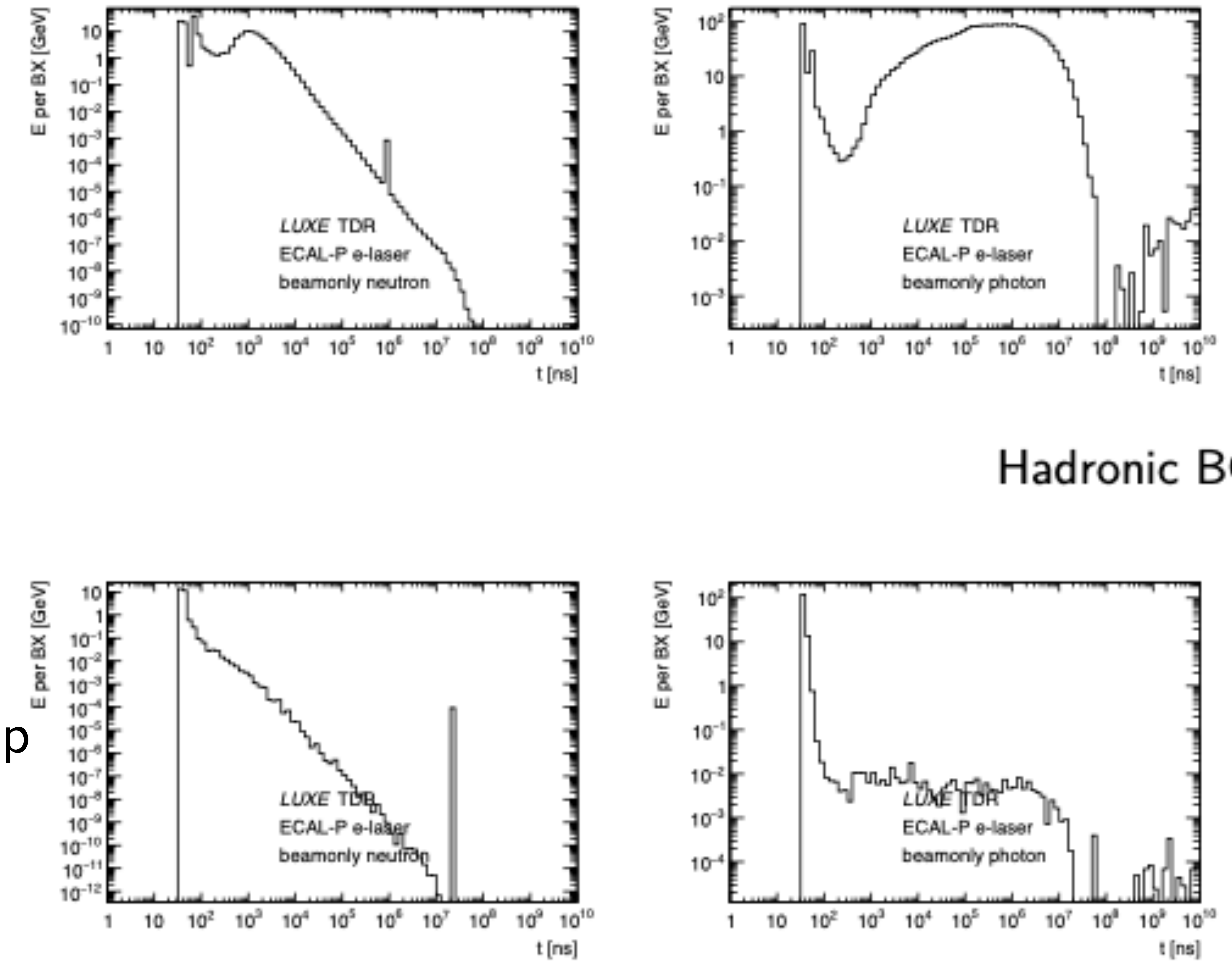


ECAL-P Background

- The readout system needs at least two timeframes (100 ns) to obtain the peak value

Full

No dump



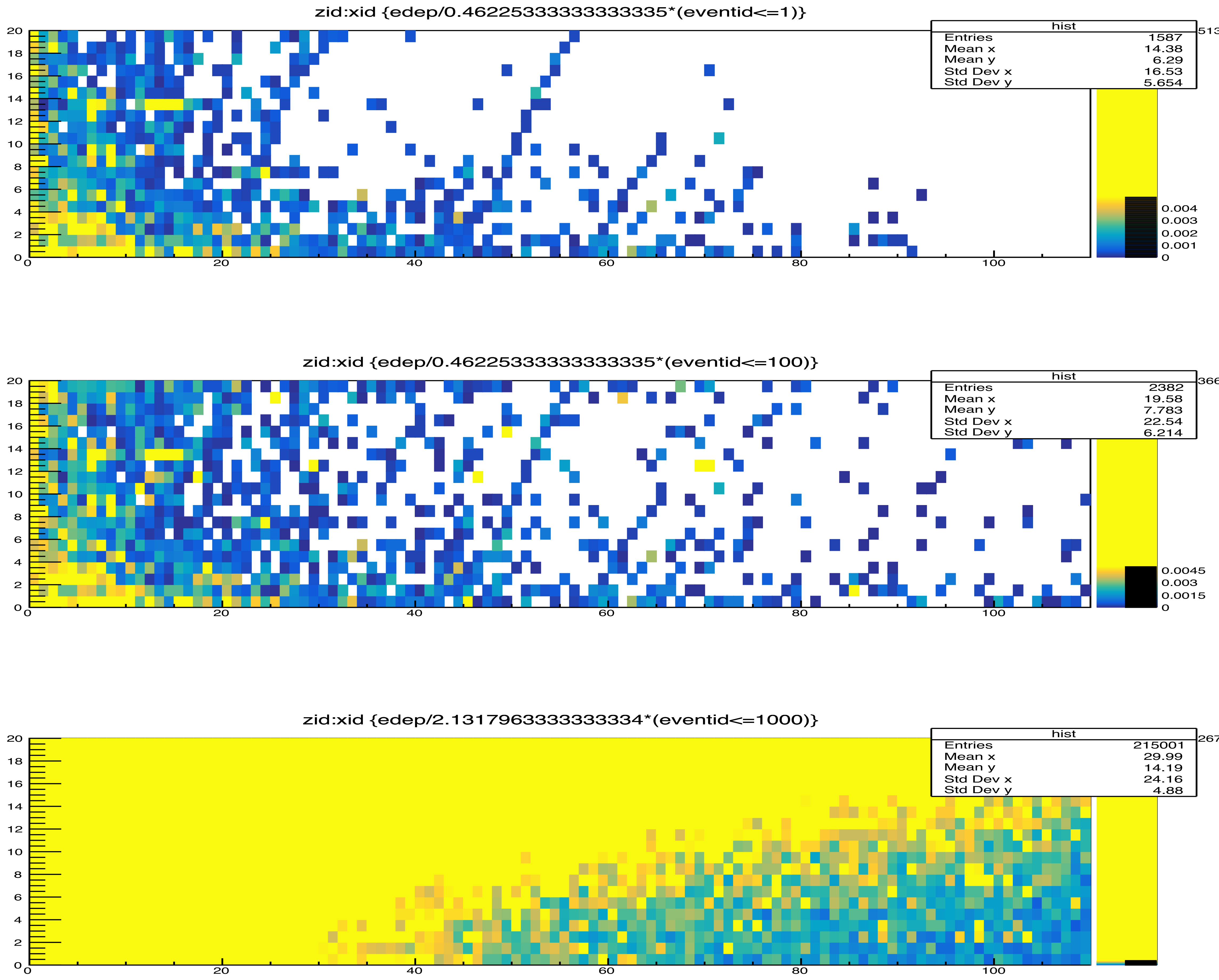
Hadronic BG

Back

1 ns

100 ns

1 us



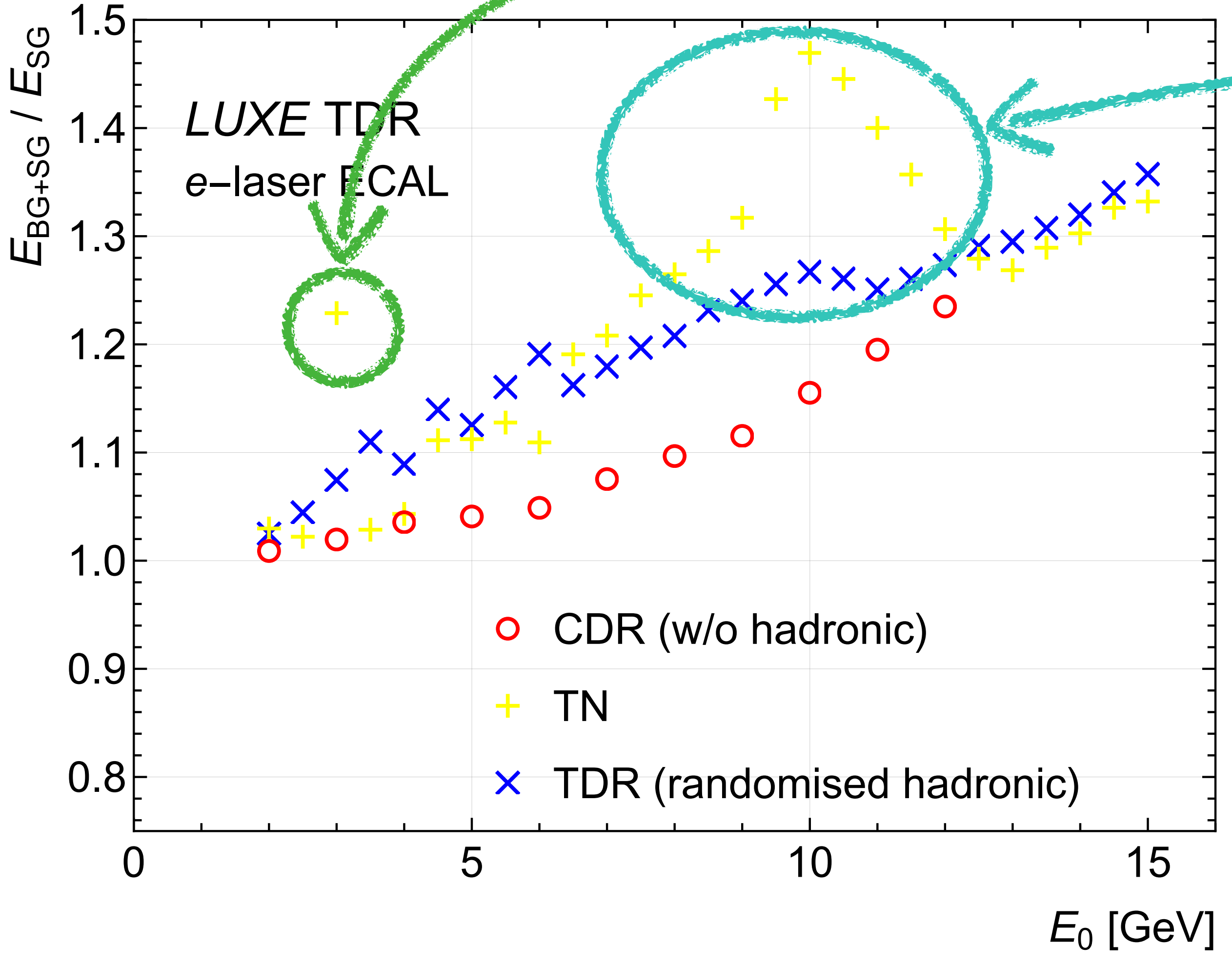
Front

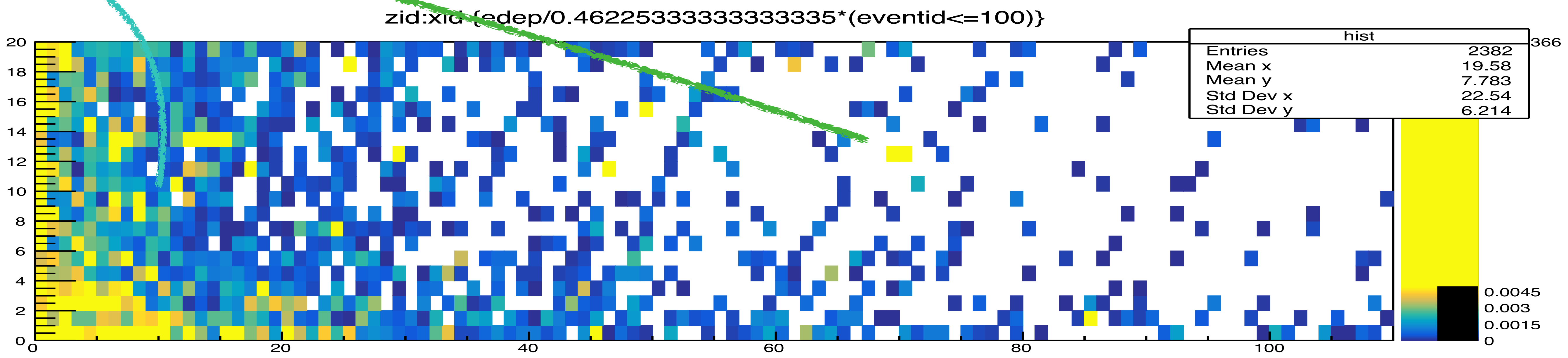
ECAL-P Background

- Irregularly high deposits (~100 MIPs) were found
- They were contributed by nuclear reaction, e.g. $n + Si \rightarrow p + D + Mg$ $(E_{dep} = 13\ \text{MeV})$
- It took place tens of times per BX in the central area
- The high deposits were "smeared" in the whole area by randomized redistribution

$$1/\text{“SNR”} = (\text{Sampled Background} + \text{Signal})/\text{Signal}$$

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

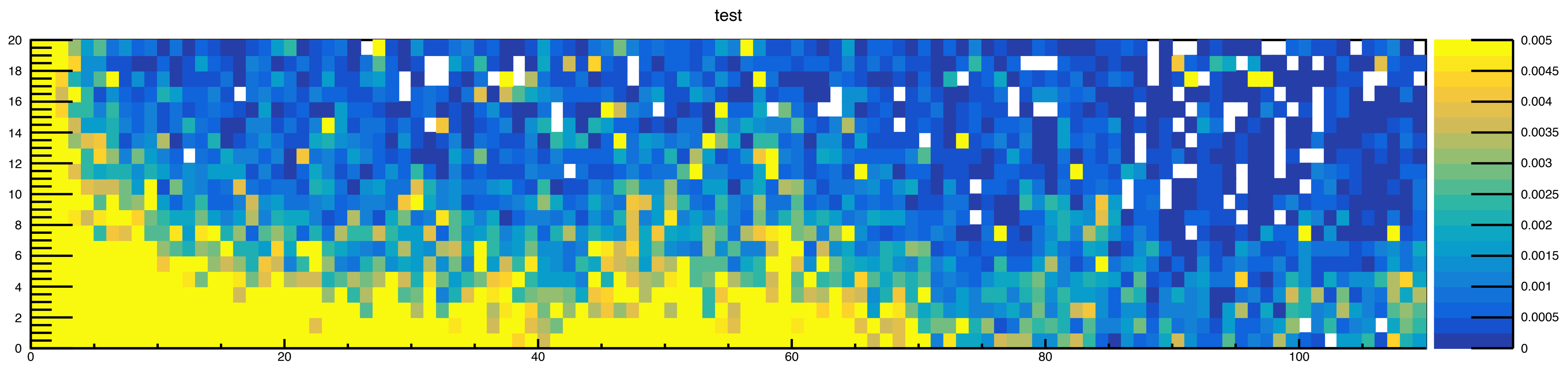


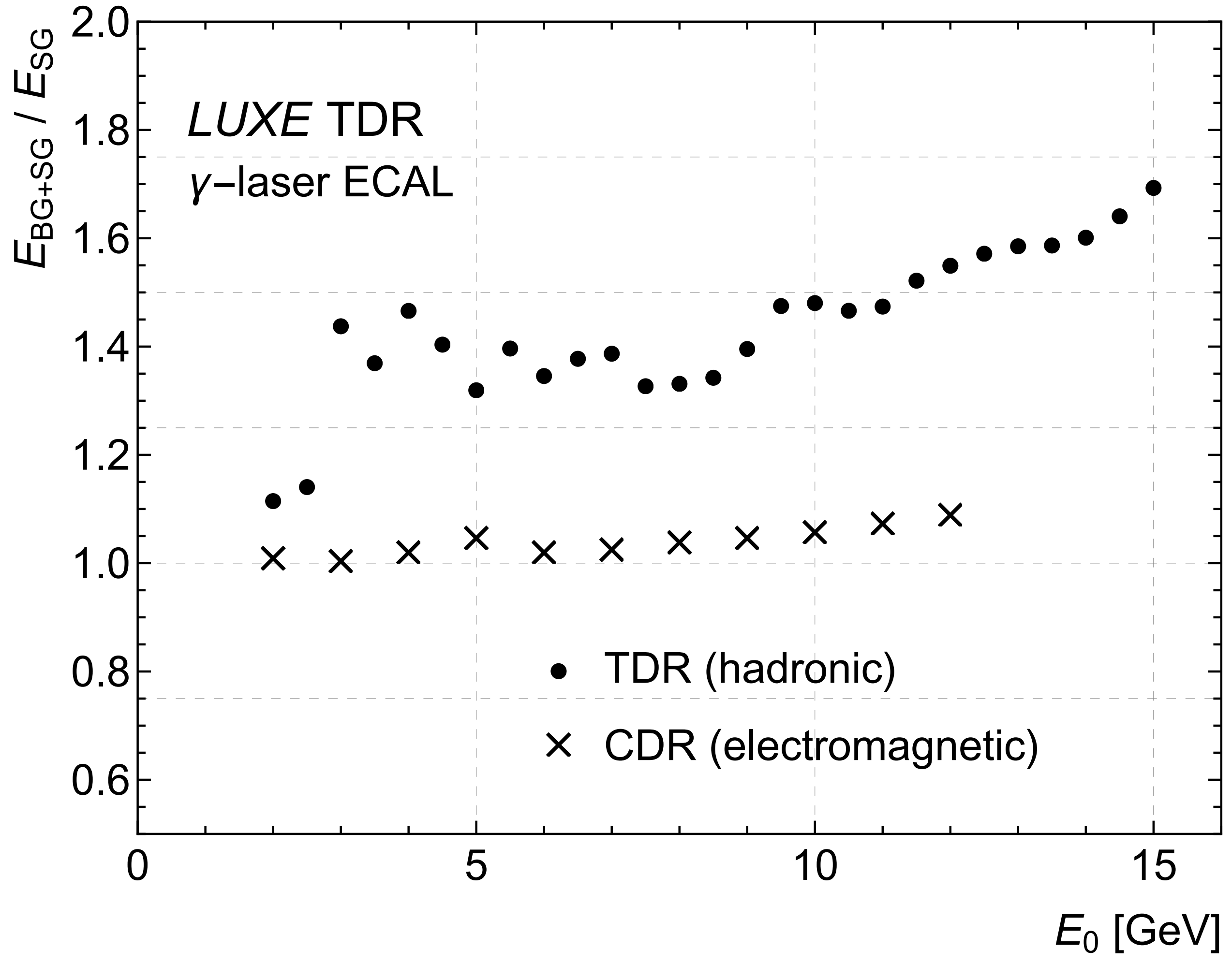


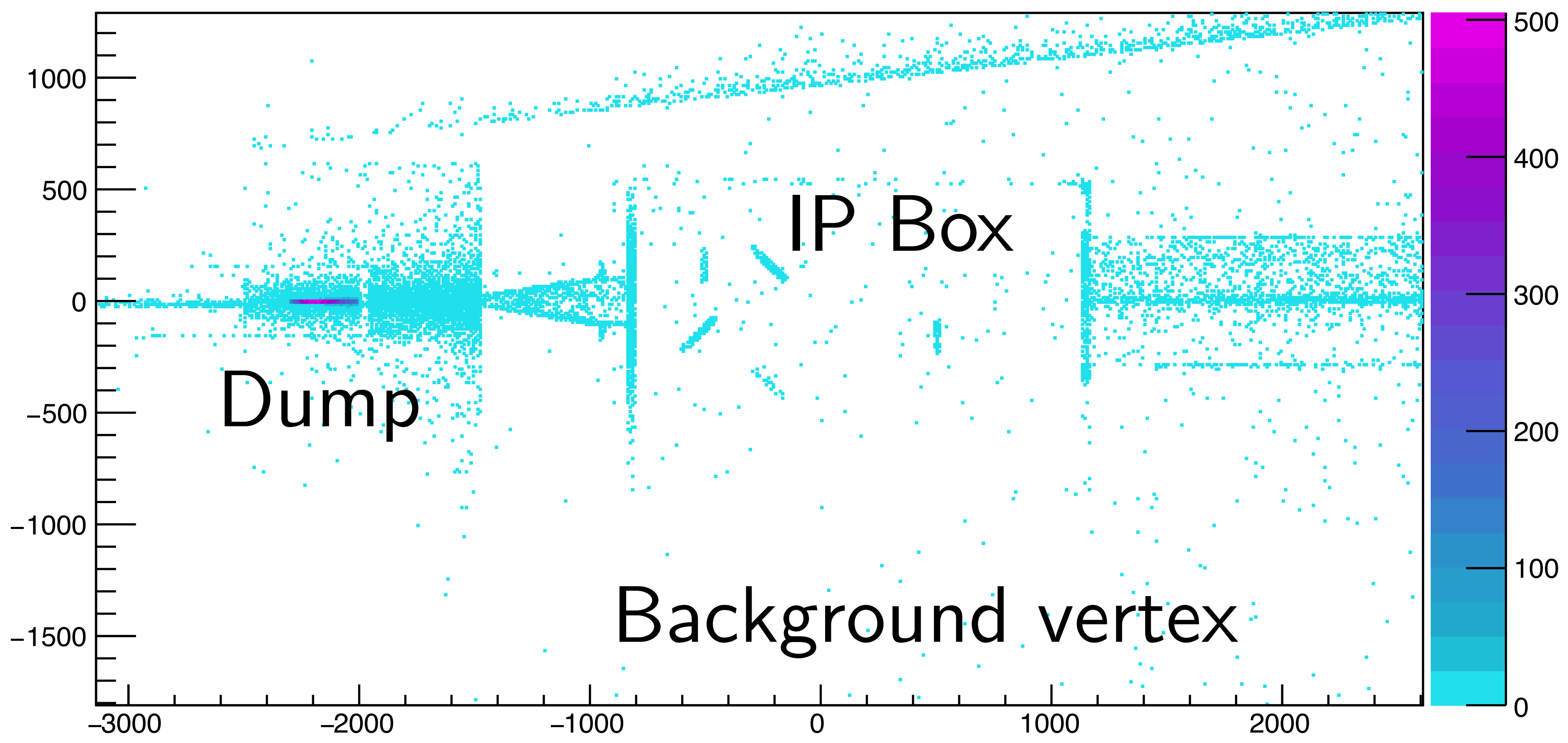
ECAL-P Background

- 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 g-laser setup







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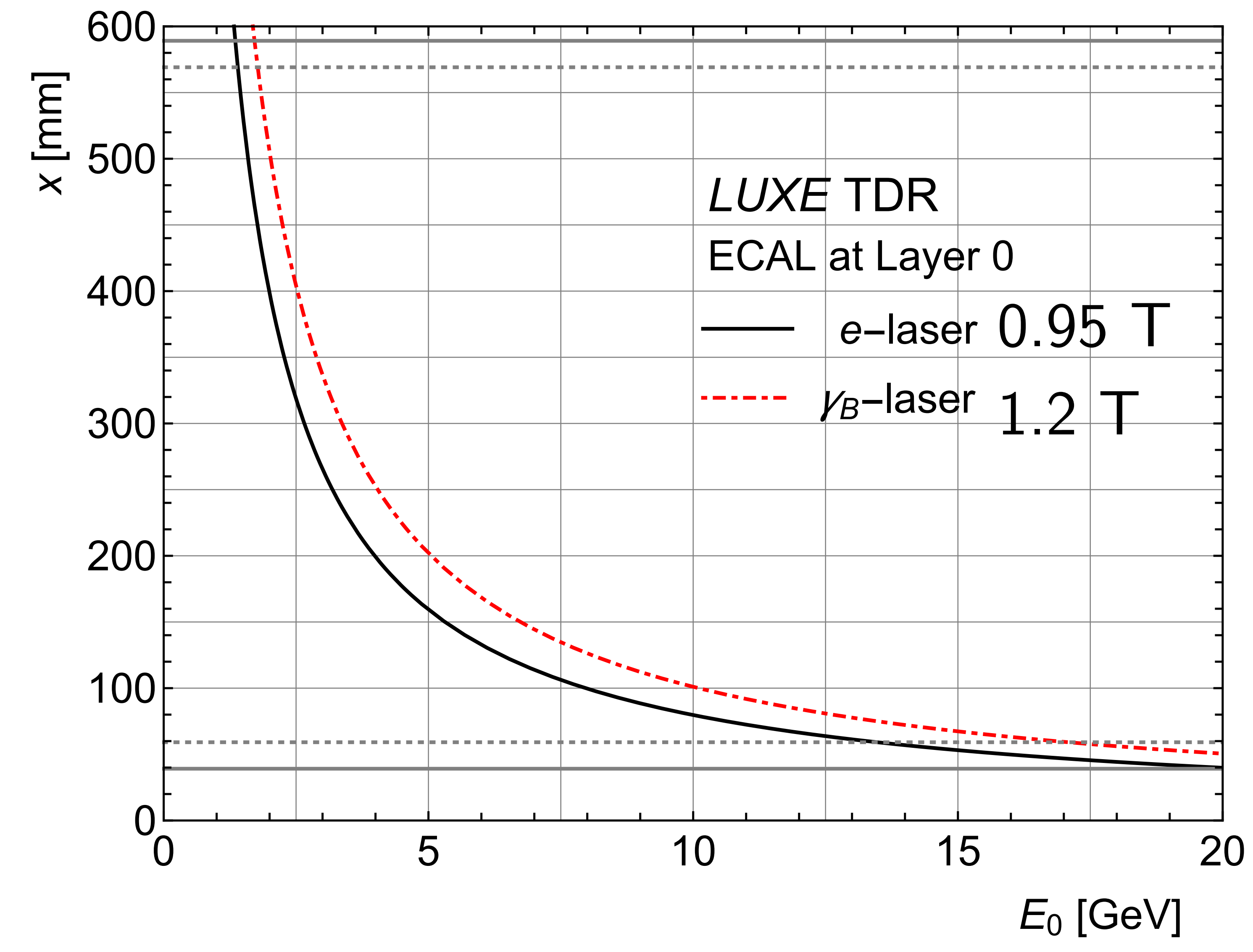
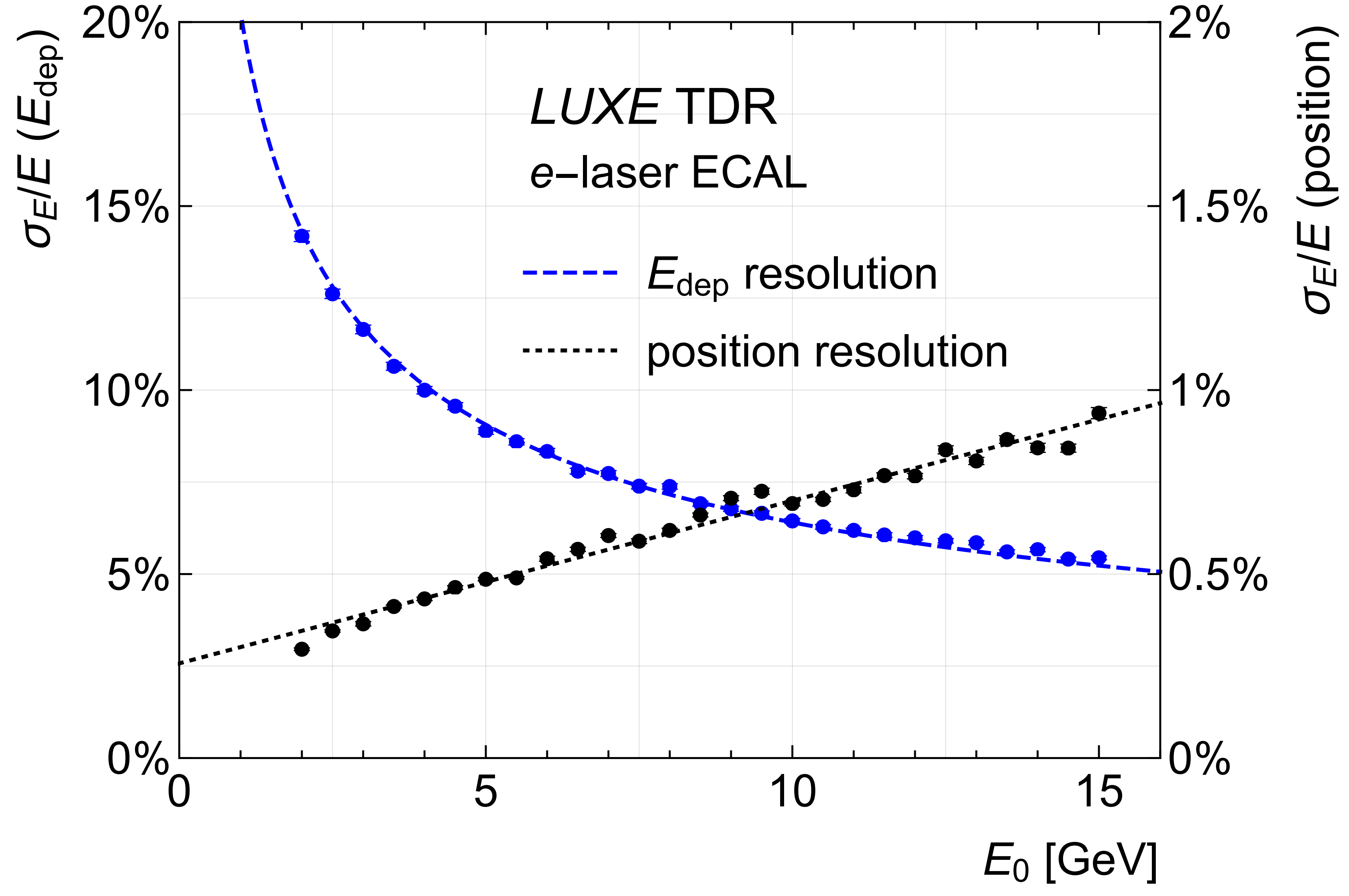
ECAL-P Resolution

- The ECAL is going to calibrate the position-energy dependence created by the magnetic dipole
- The energy deposit for one primary particle follows Gaussian distribution with an average (linearity) and standard deviation (resolution)
- A full 20-layer ECAL has
  - energy resolution of 20%/sqrt(E/GeV)
  - good linearity
  - position related resolution <1%

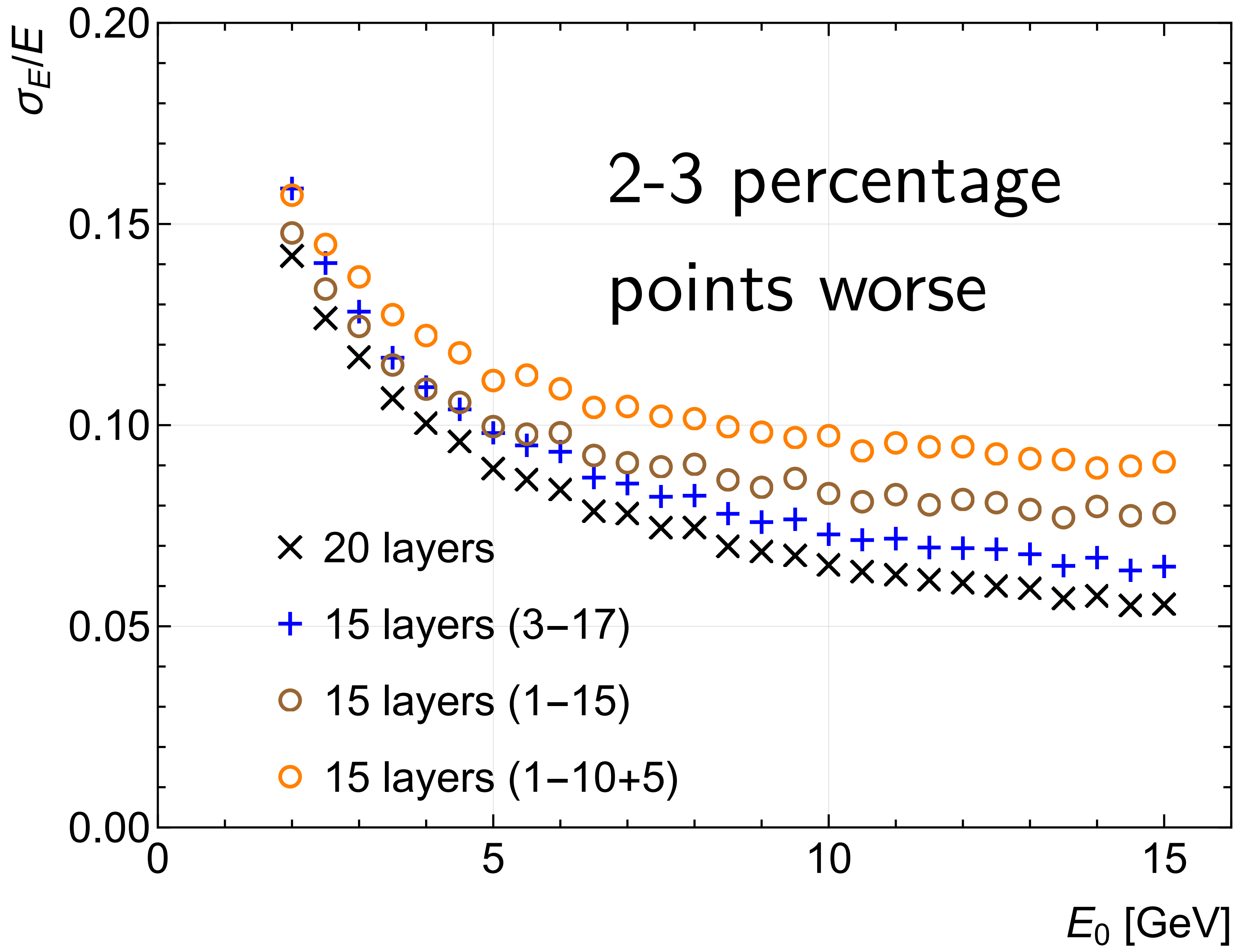
- Due to funding limit, it is likely that the ECAL-P will only have 15 active layers
- **Where to put the 15 layers in a $20X_0$ ECAL?**



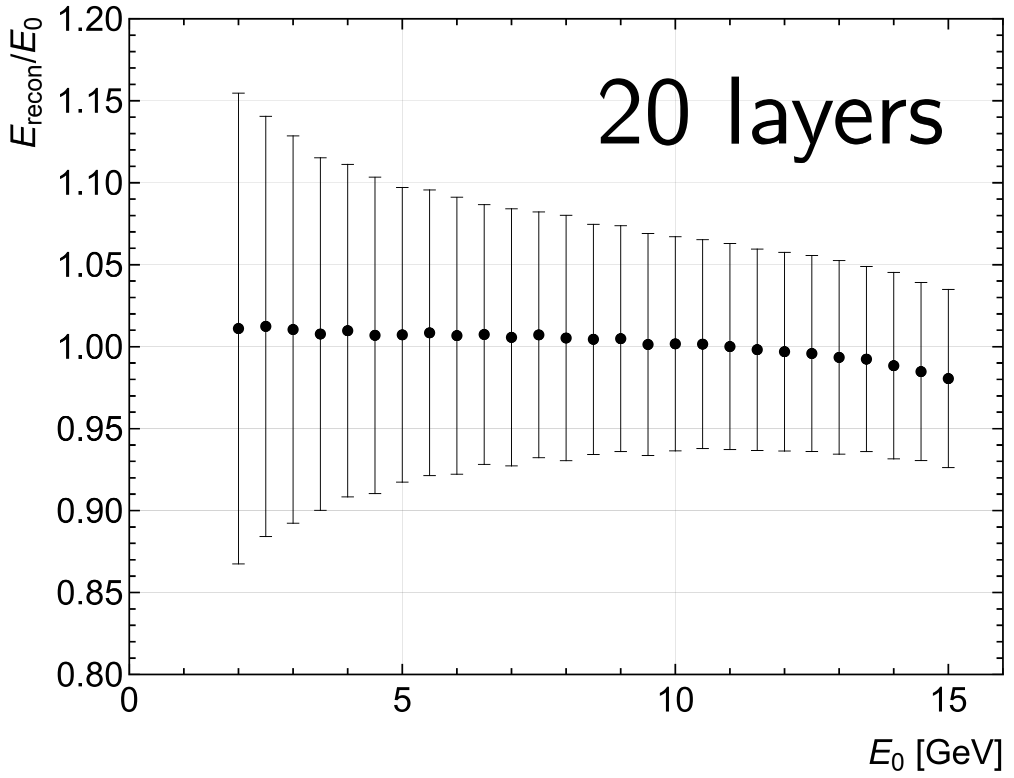


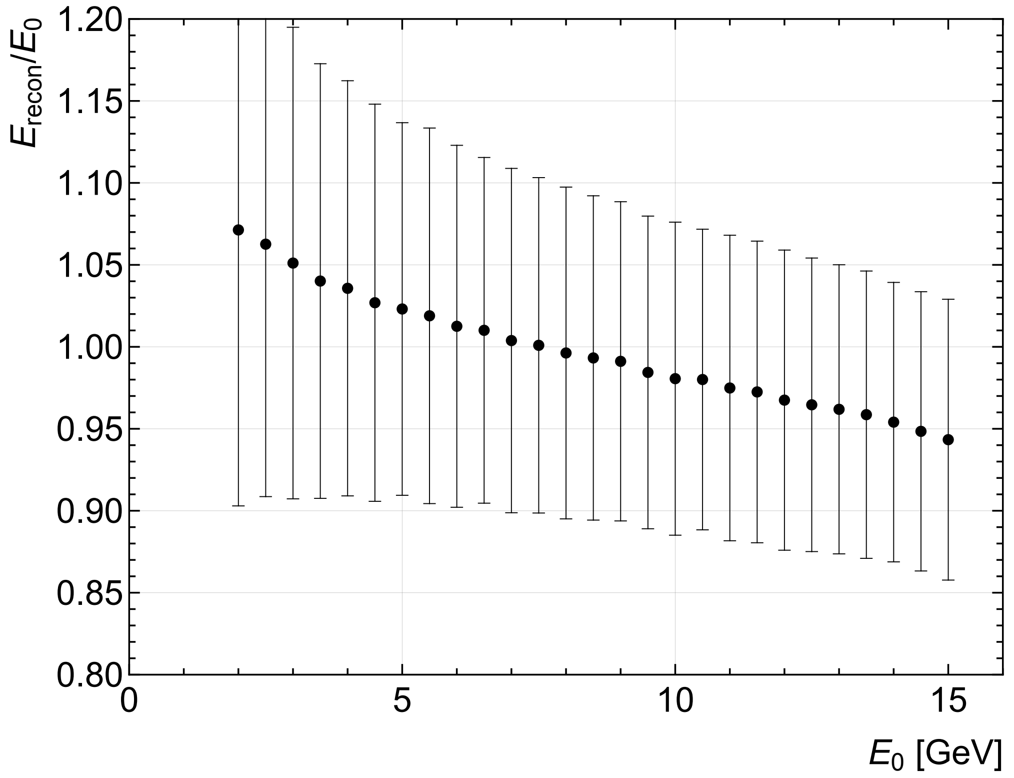
Optimization via enumeration

- An enumeration of all possible combinations were run to find the best 15 layers
- The simplest method with a constant calibration ratio was used
- Three selected layouts are presented

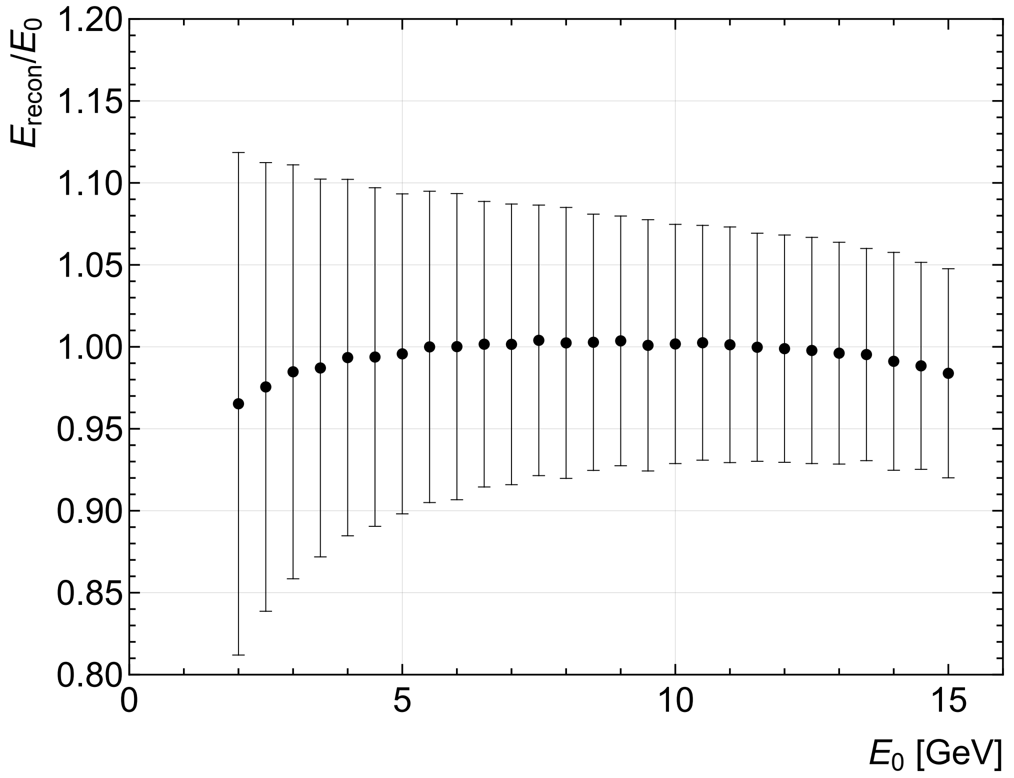


Linearity is not always preserved





10+5 layers
(First ten layers then every second layer)

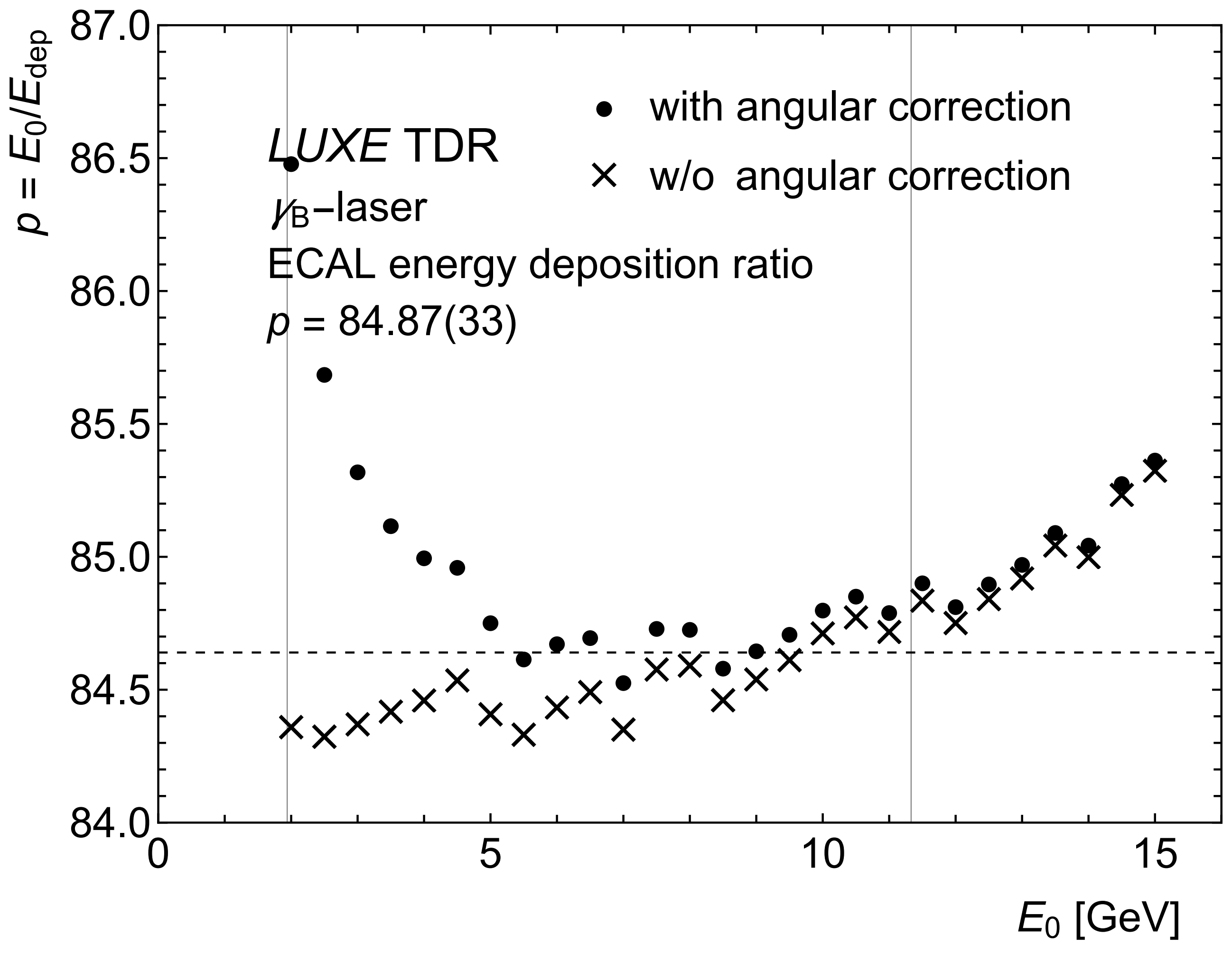


15 layers (1-15)

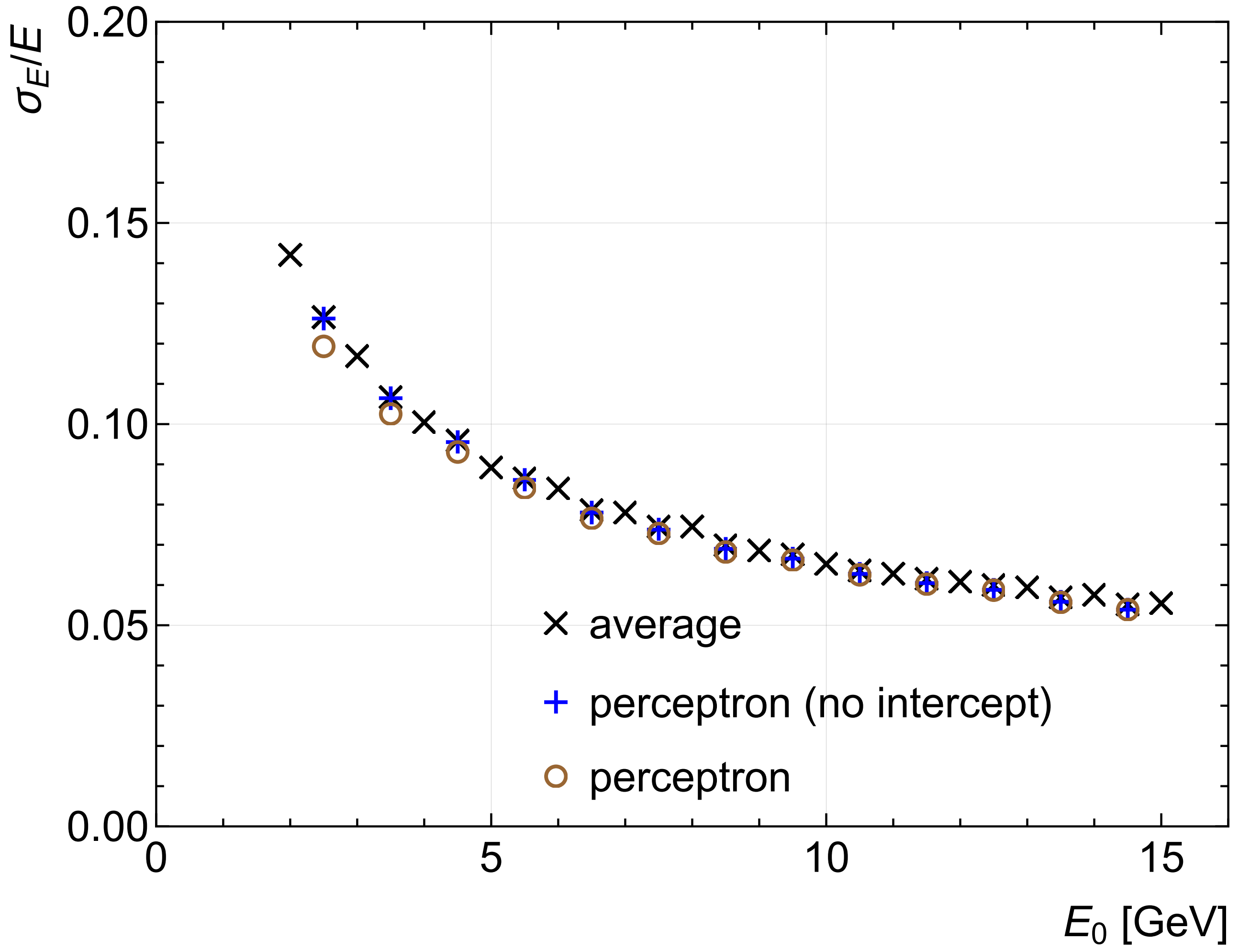
Why not variable?

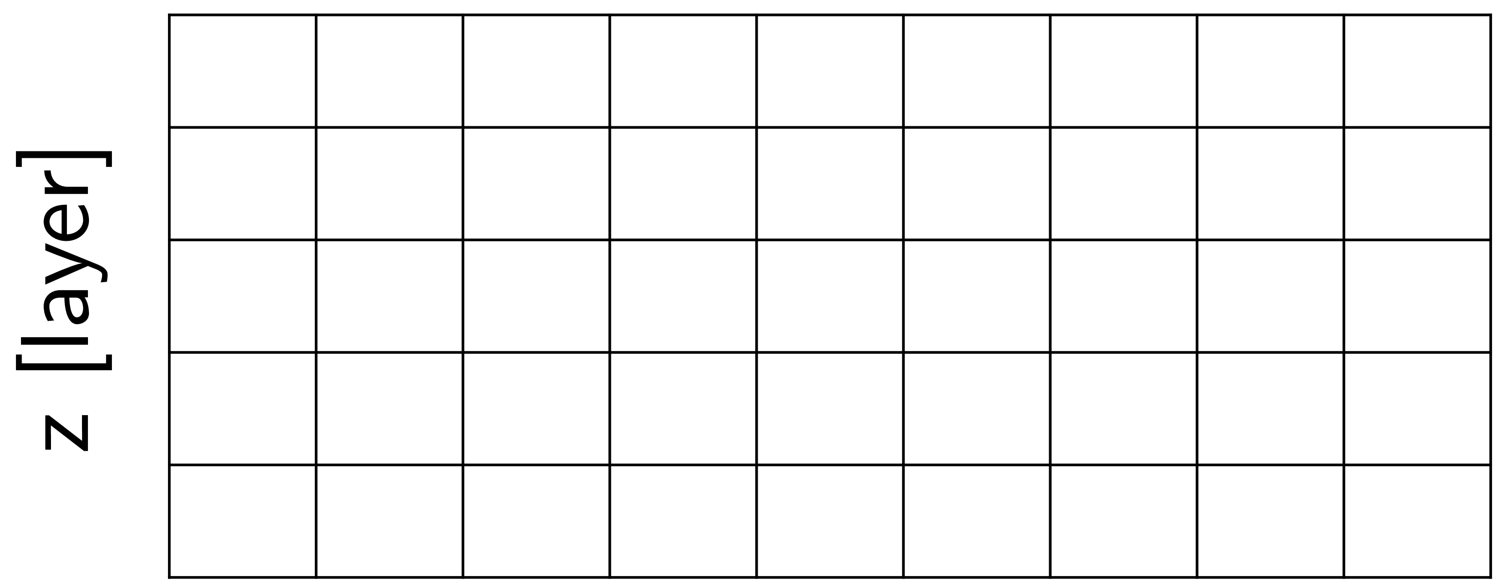
Variable calibration

- In the CDR, a constant calibration factor was used for all layers
- It has been observed that different energy has different optimized calibration ratio
  - angular compensation by giving tower-related calibration
  - leakage compensation by giving layer-related calibration
- Perceptron: fully connected one-layer neural network
- Weight = calibration ratio
- The energy resolution is slightly improved

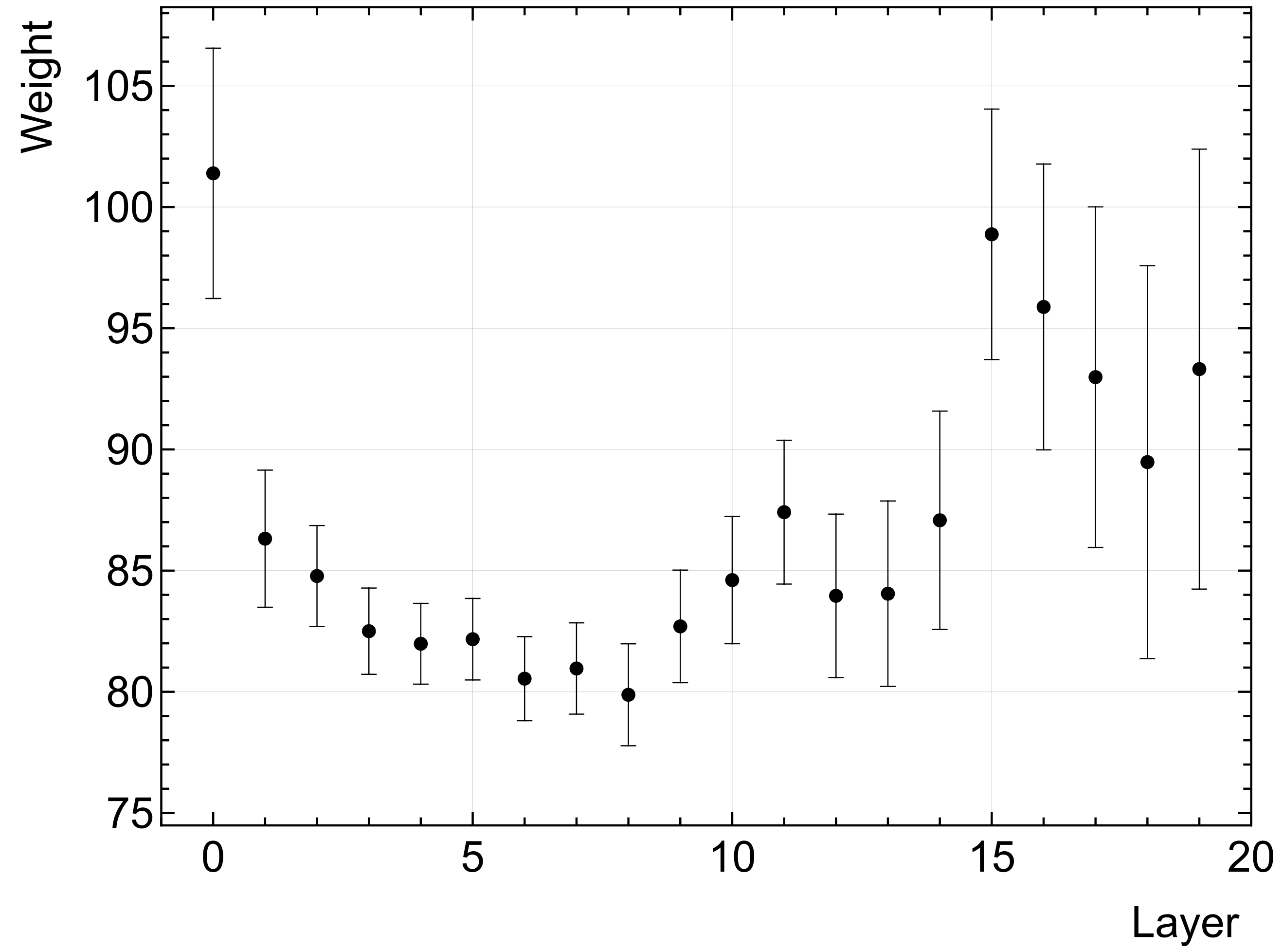


Tower by tower (transverse)





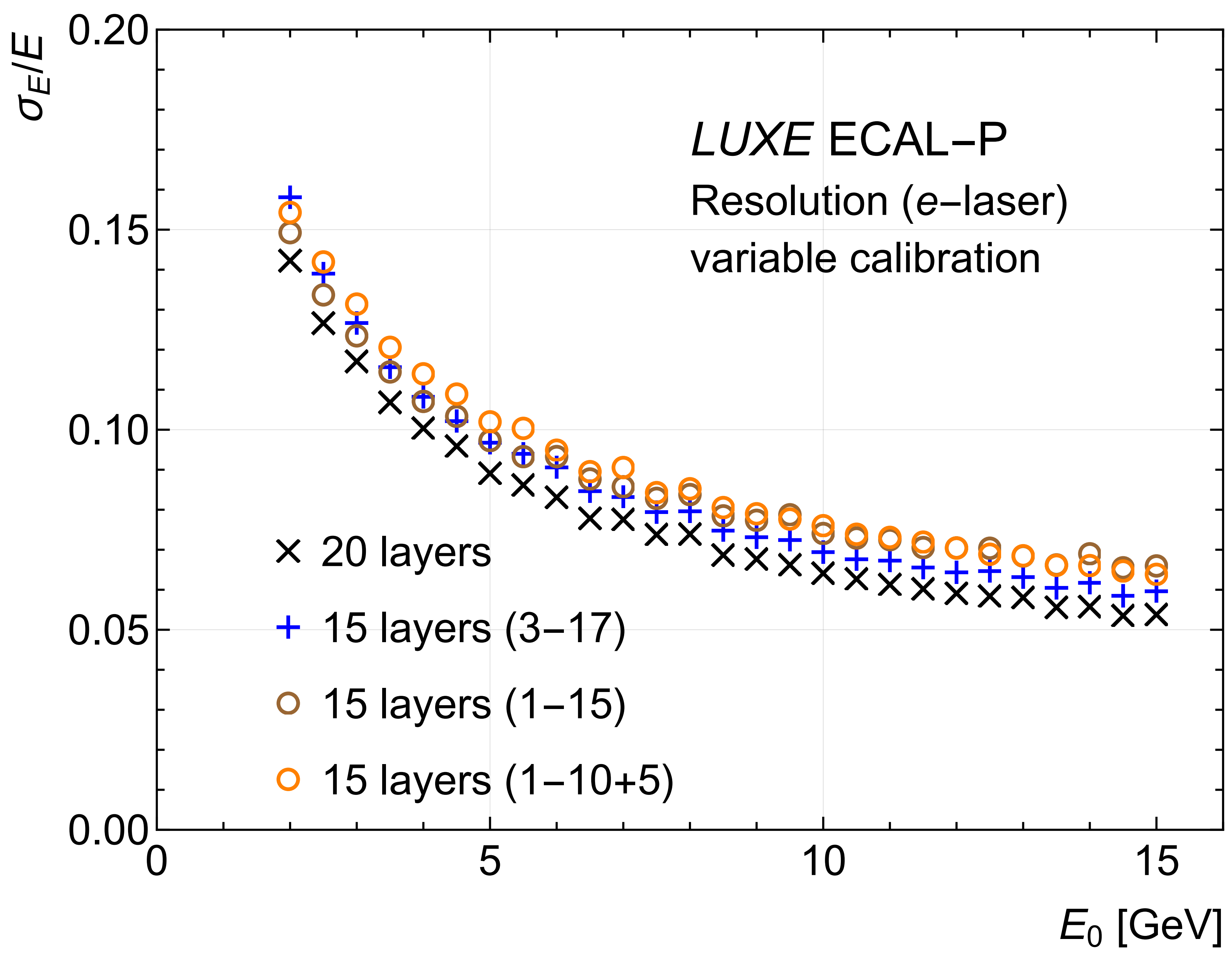
x [tower]

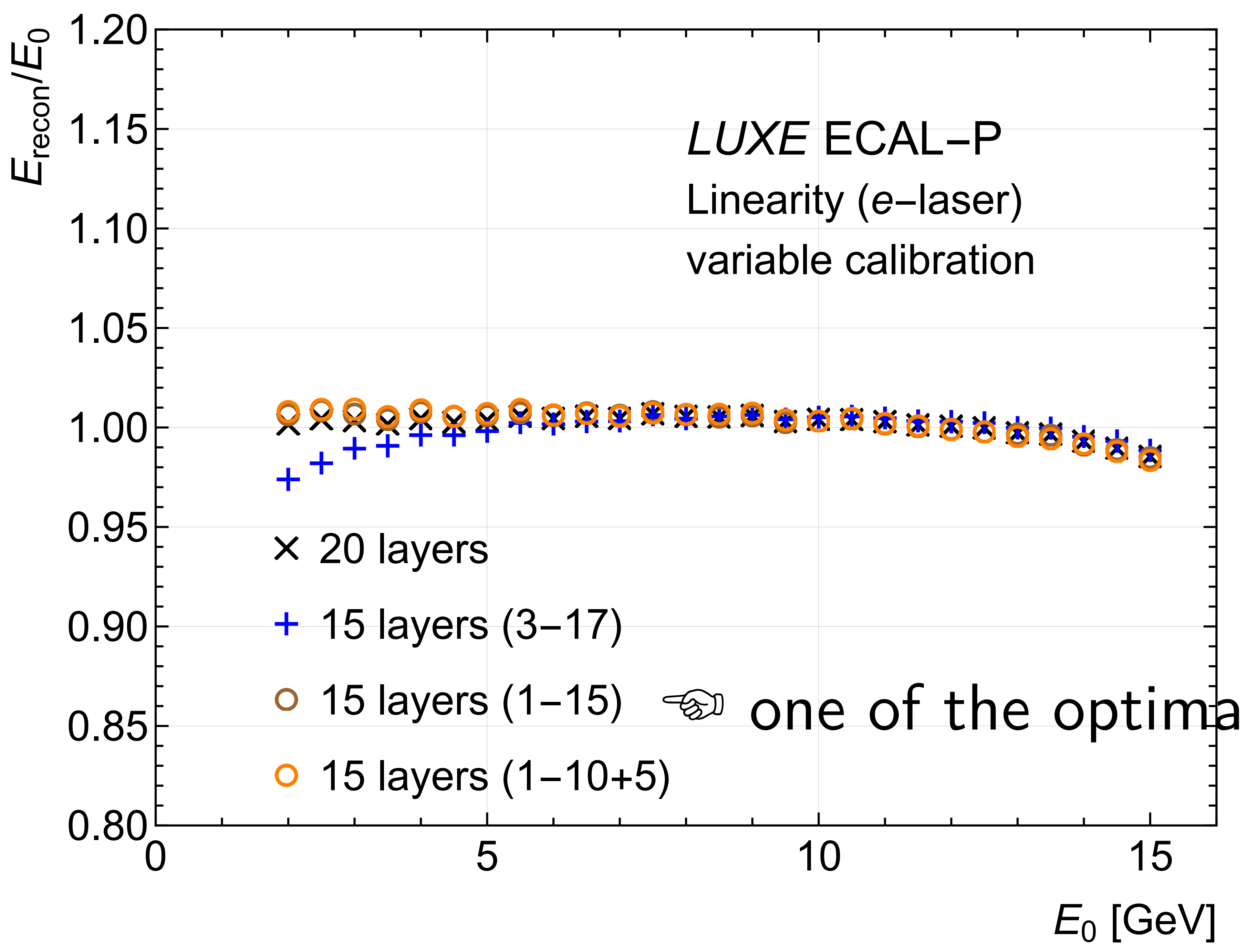


Layer by layer (longitudinal)

Variable calibration

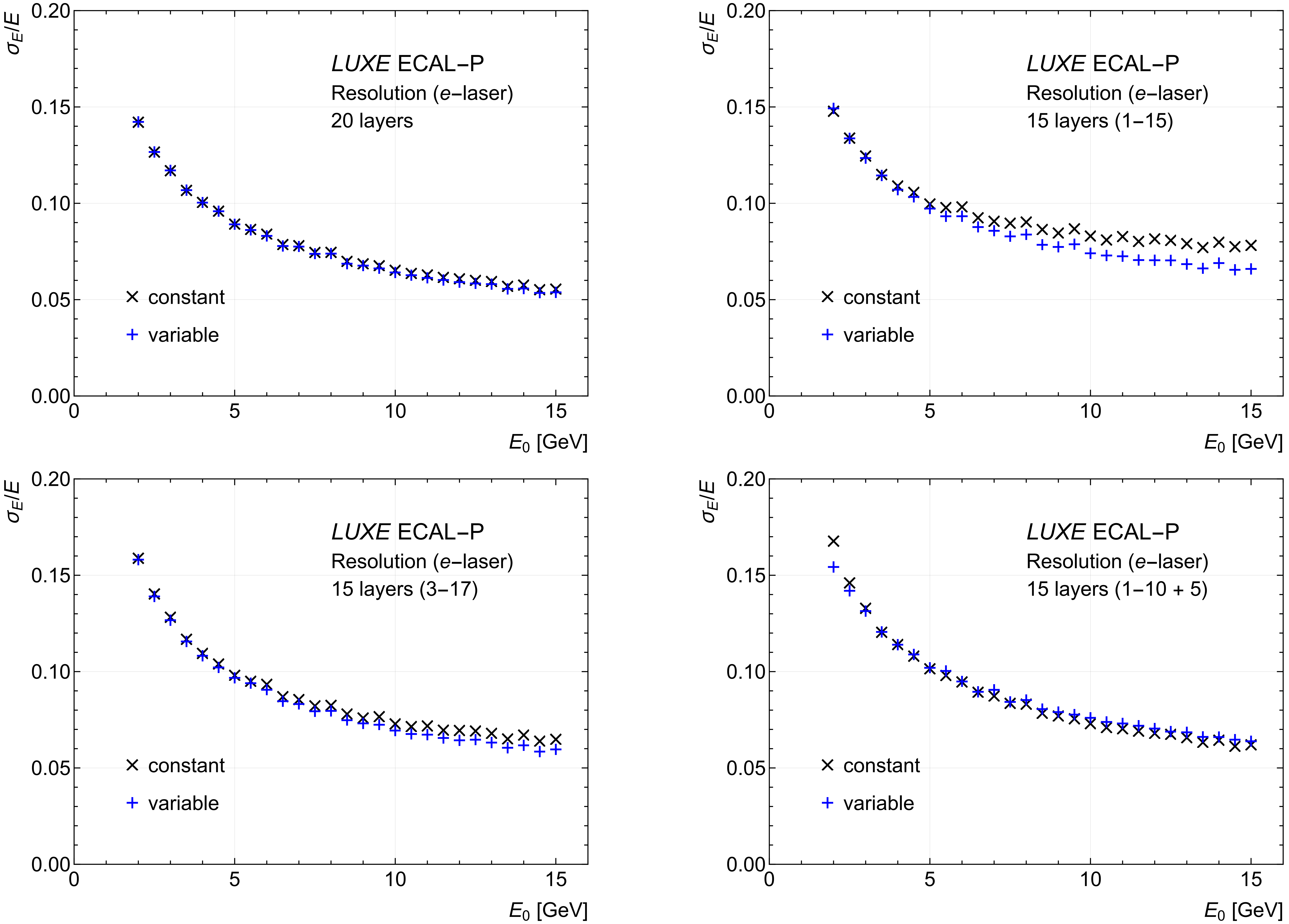
- The framework developed by Filip gave faster results (comparing to the enumerated perceptrons) with more flexibility to find the balance between linearity and resolution
- Improved both the resolution and linearity comparing to the constant calibrations





☜ one of the optimal

Variable vs Constant



☜ one of the optimal

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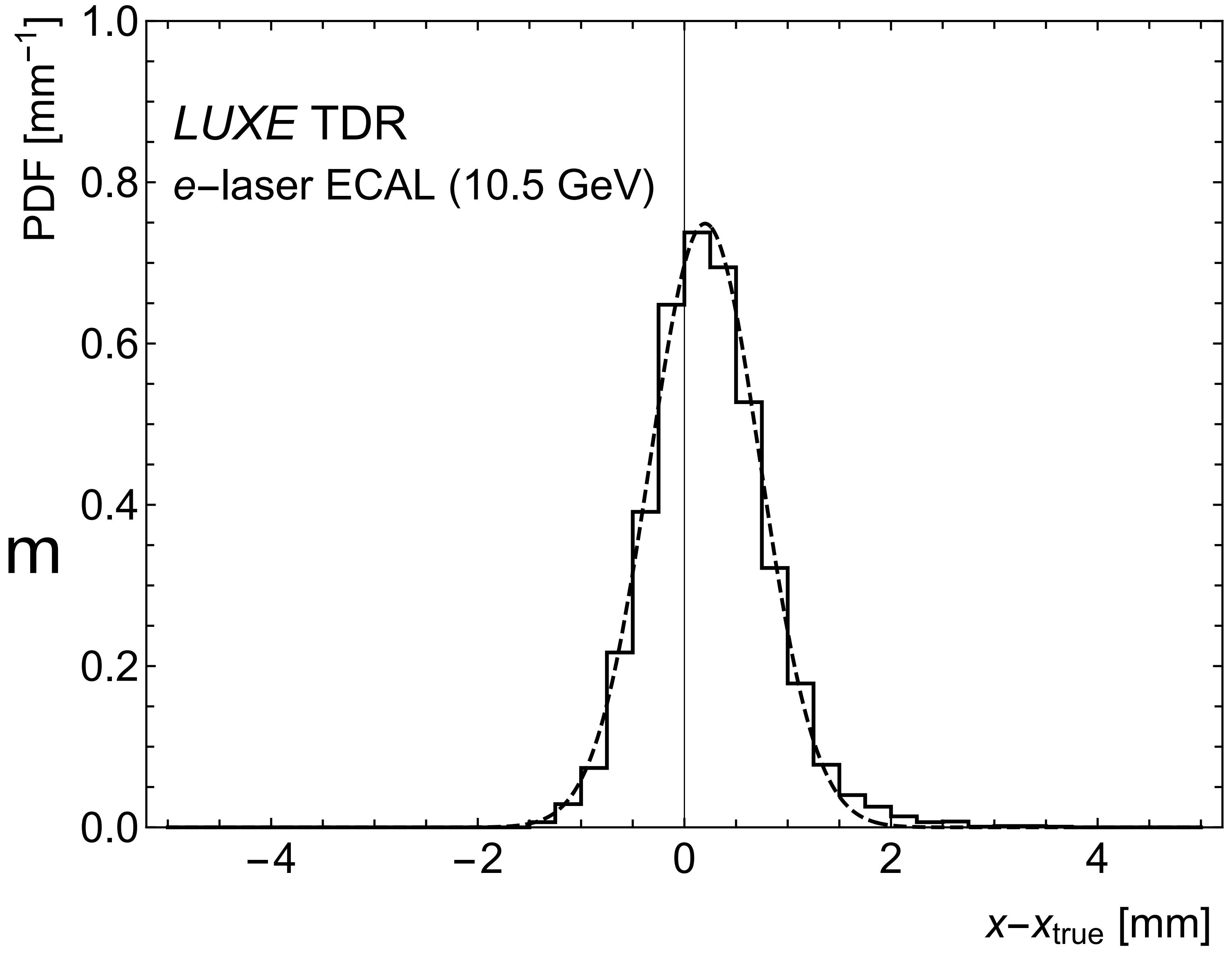
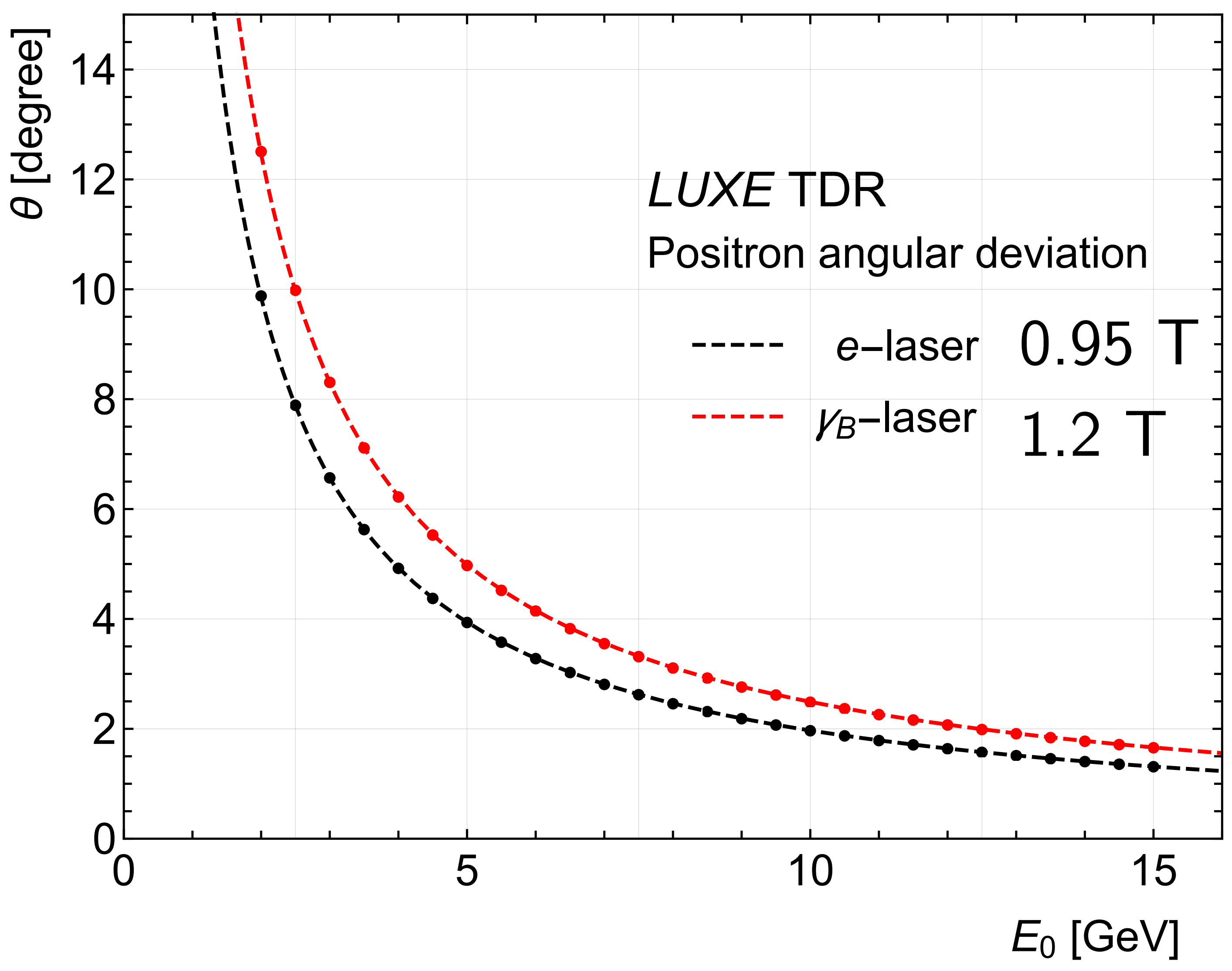
Position reconstruction

- 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, resolution improved by around 20% and no bias

Pad size 5 mm

Position resolution 0.5 mm





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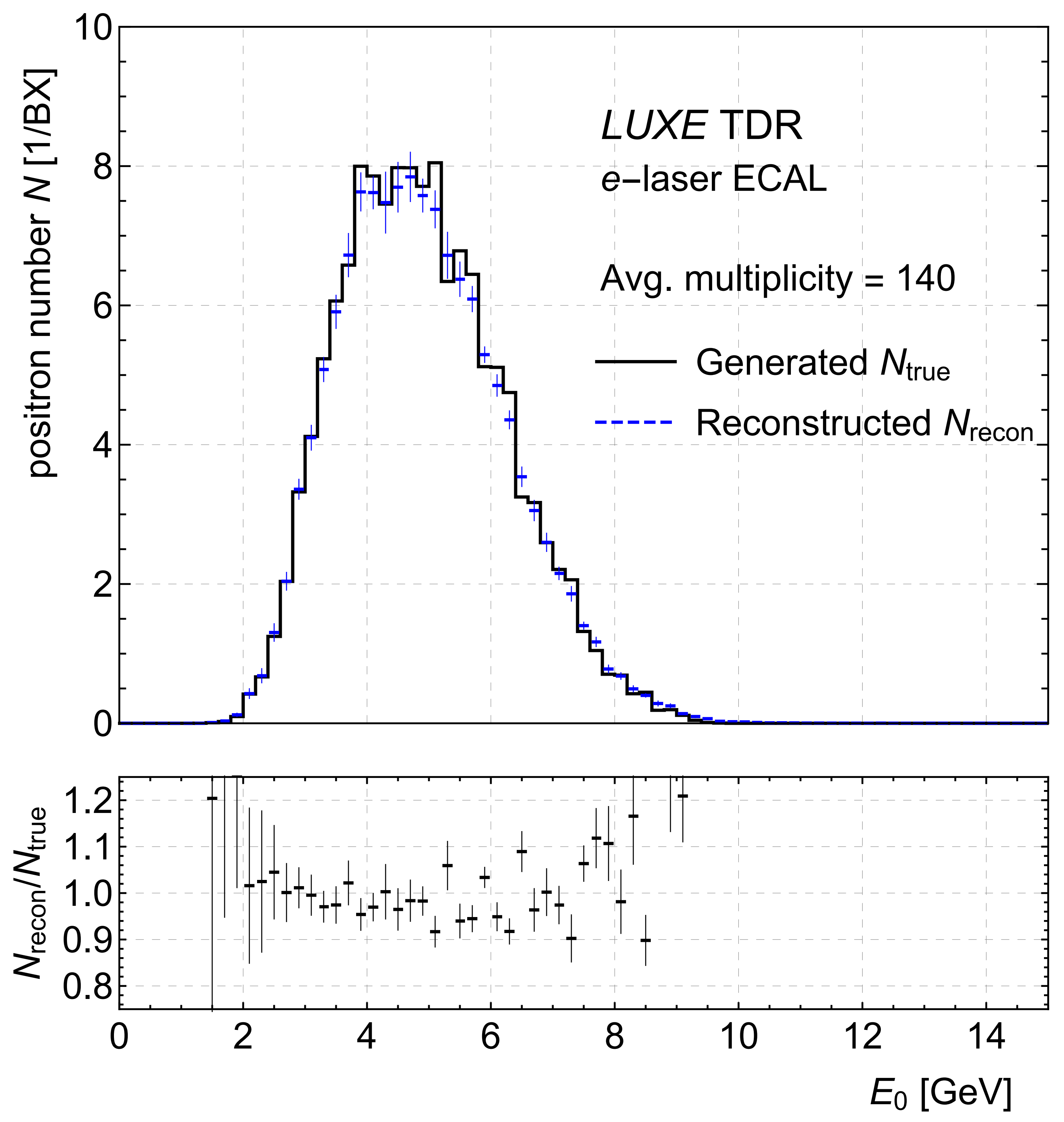
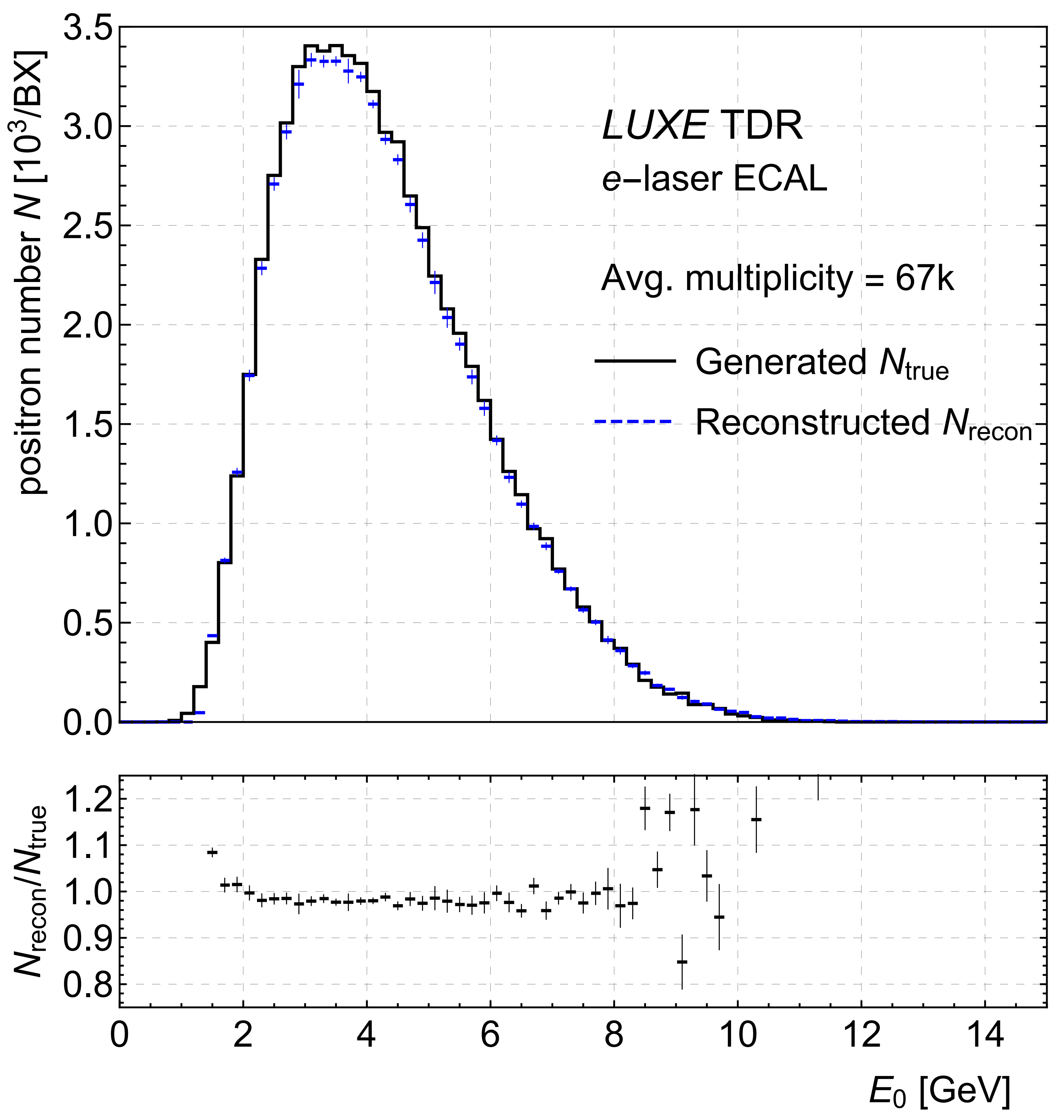
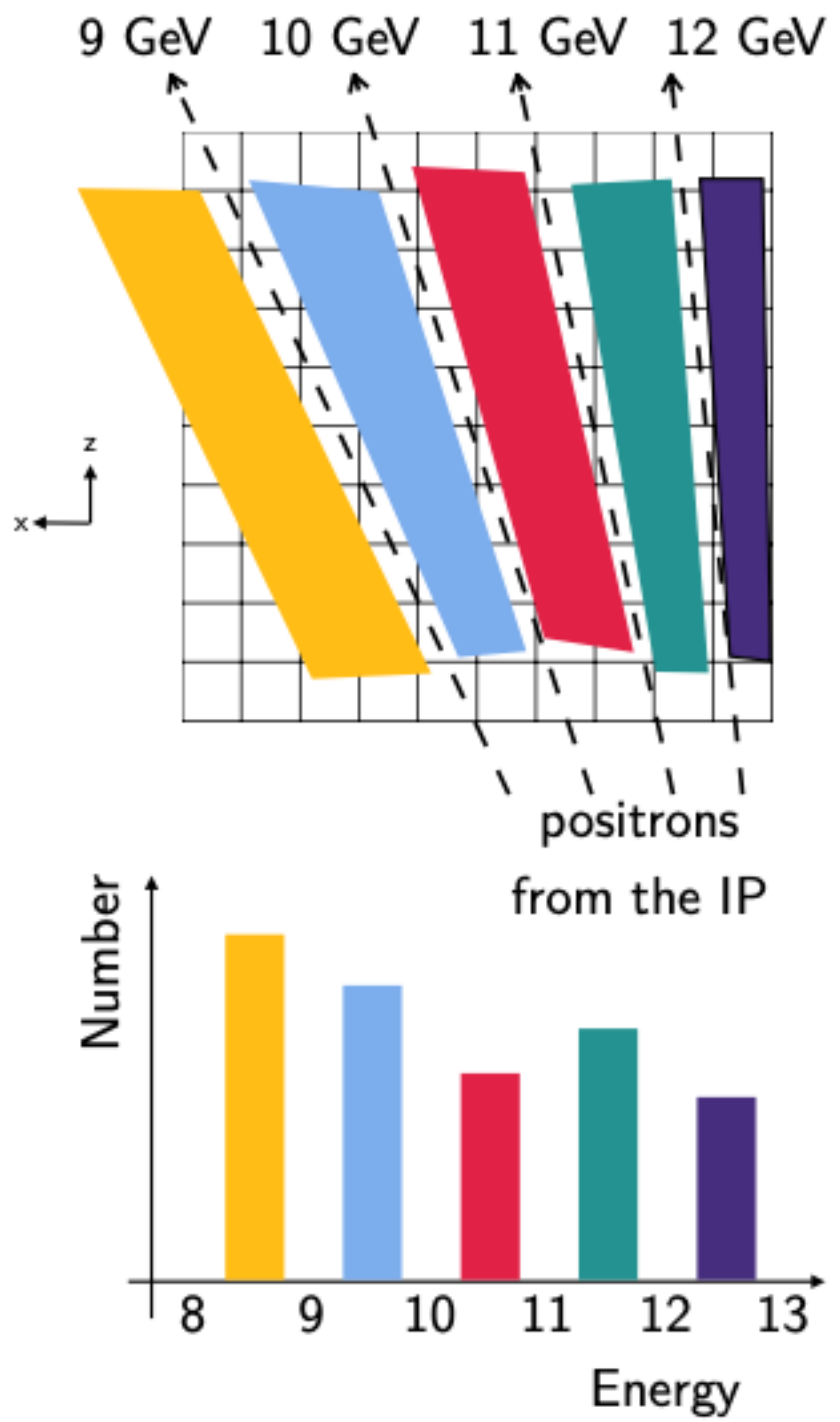
Energy flow for overlapping showers



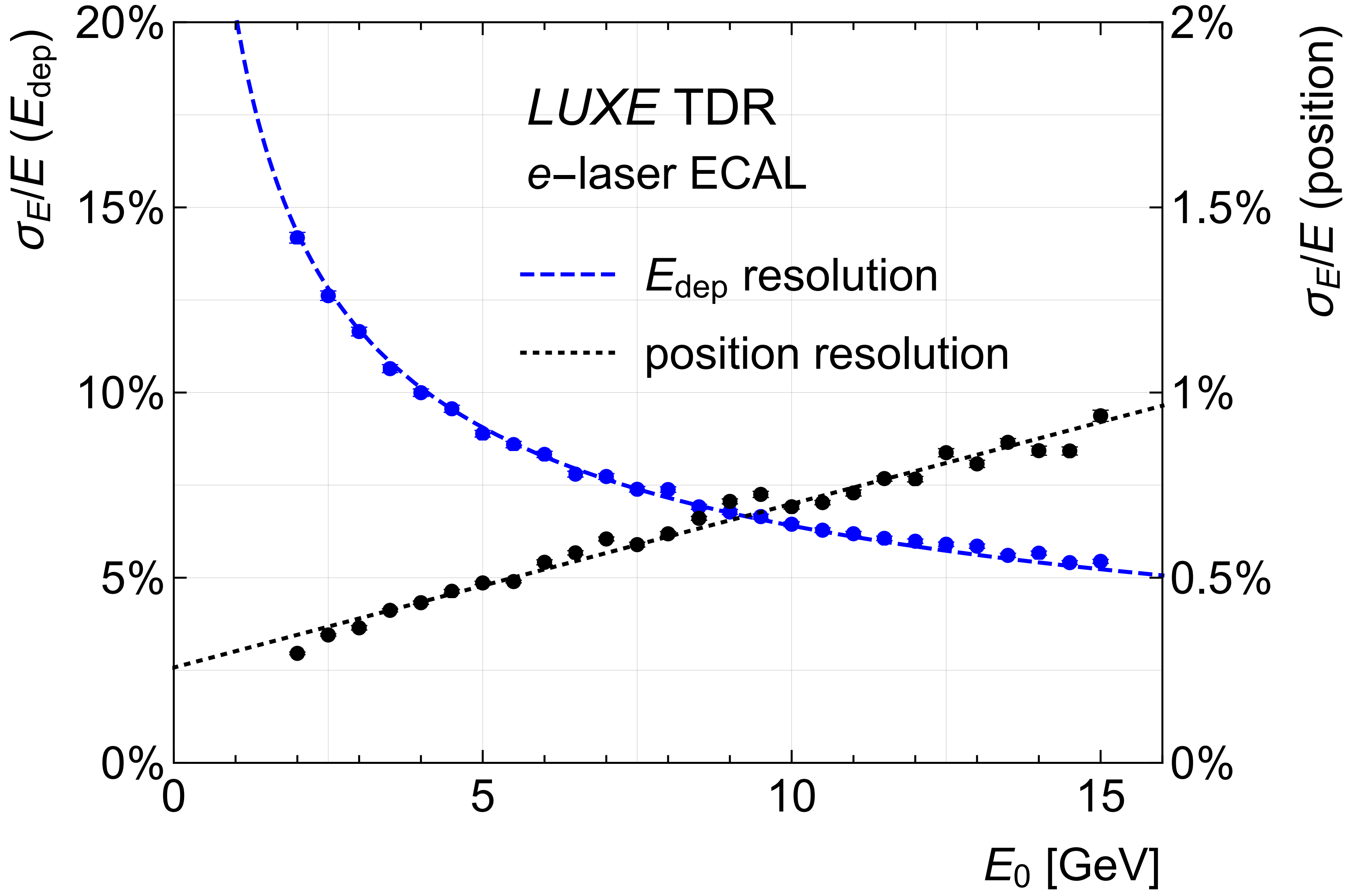




Machine learning reconstruction

- 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
- The neural network is learning the dependence between position and energy that benefits the resolution
- A convolutional neural network is used to "recognize the image"

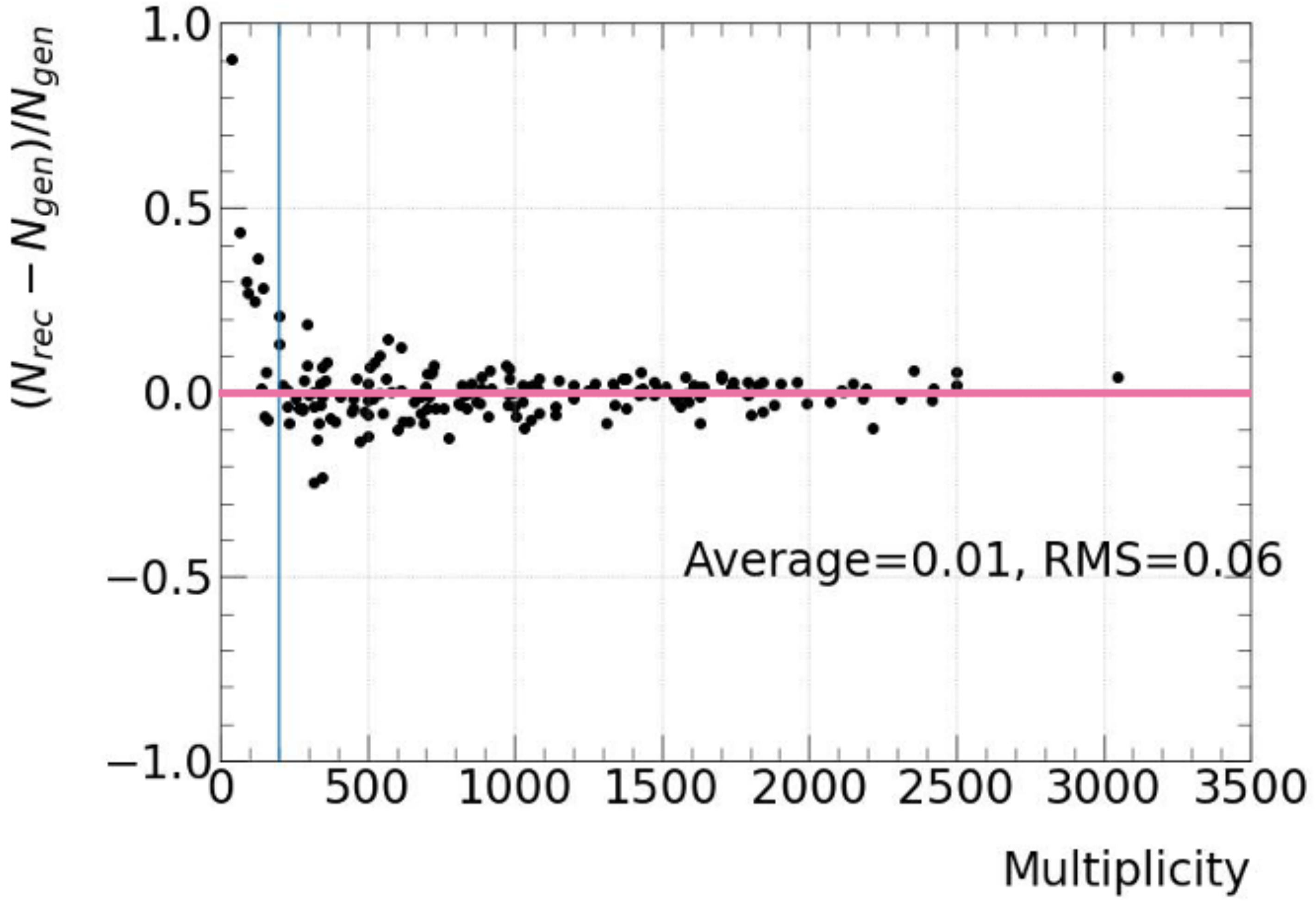
```
Model architecture
========================================
==========================================================================================
Layer (type:depth-idx)                  Input Shape               Output Shape
==========================================================================================
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 reconstruction

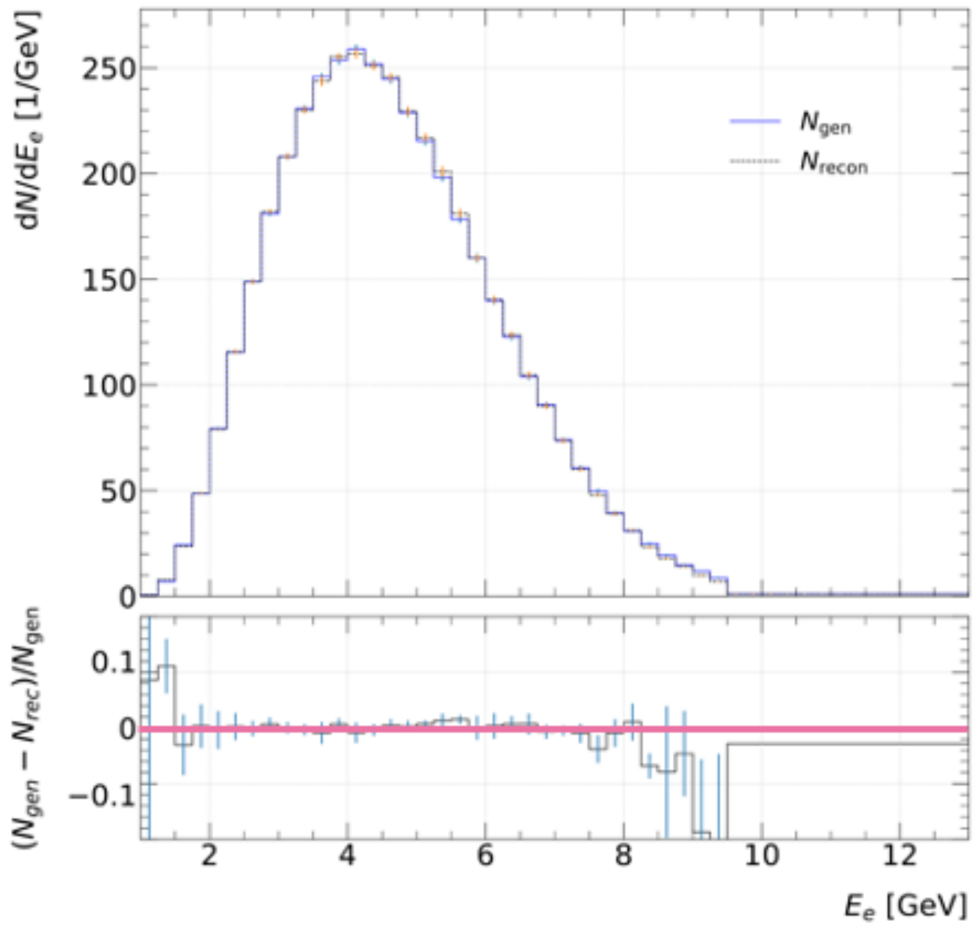
- The CNN successfully reconstruct the energy spectrum not only with 20 or 15 layers, but also even with only 5 layers above a multiplicity threshold
- The method has a difficulty with generalization
- We are working on striping out the information of multiplicity

5-LAYER ECAL
WITH THE BACKGROUND

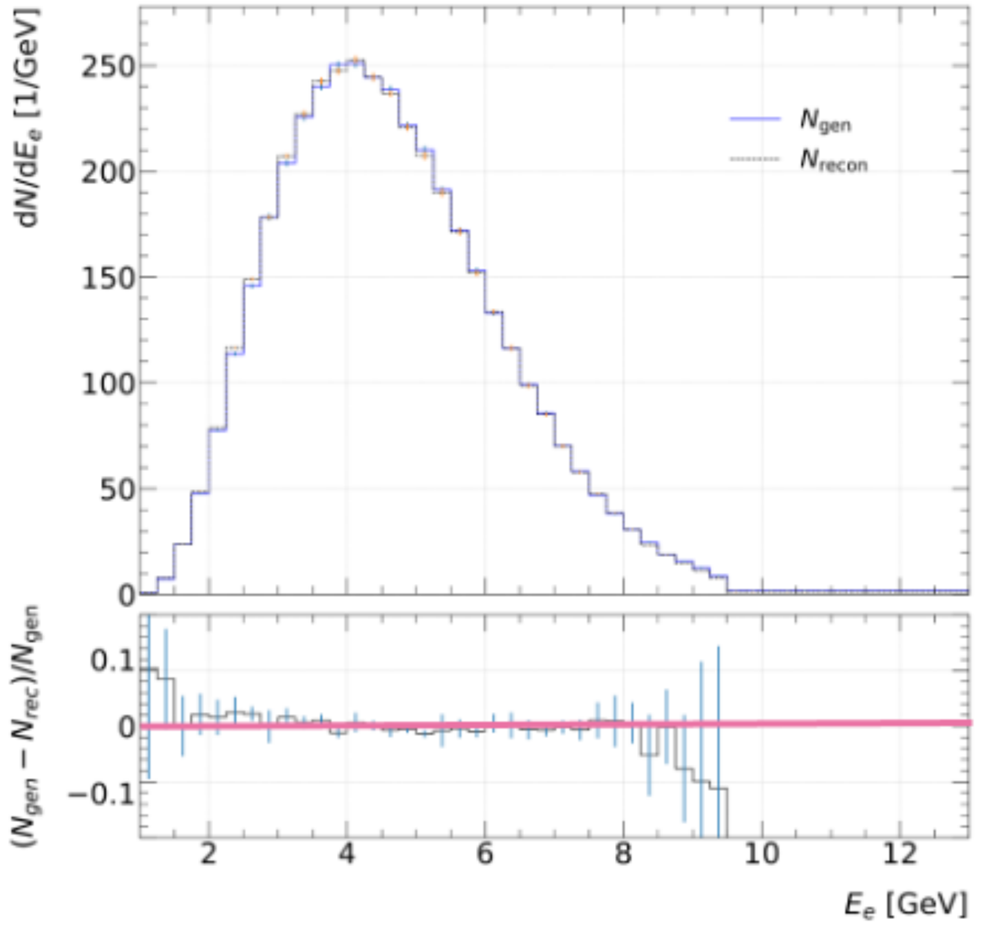


Performance getting worse for multiplicity below 200

20-LAYER ECAL
WITH THE BACKGROUND



5-LAYER ECAL
WITH THE BACKGROUND



Summary

- The LUXE ECAL group is working towards the final design of the ECAL-P and a reconstruction toolkit
- The background study so far confirms that the signal-to-noise ratios are 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 successfully reconstructs the positron spectrum with very few X_0, comparing to the benchmark of energy flow of 20 X_0

- 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

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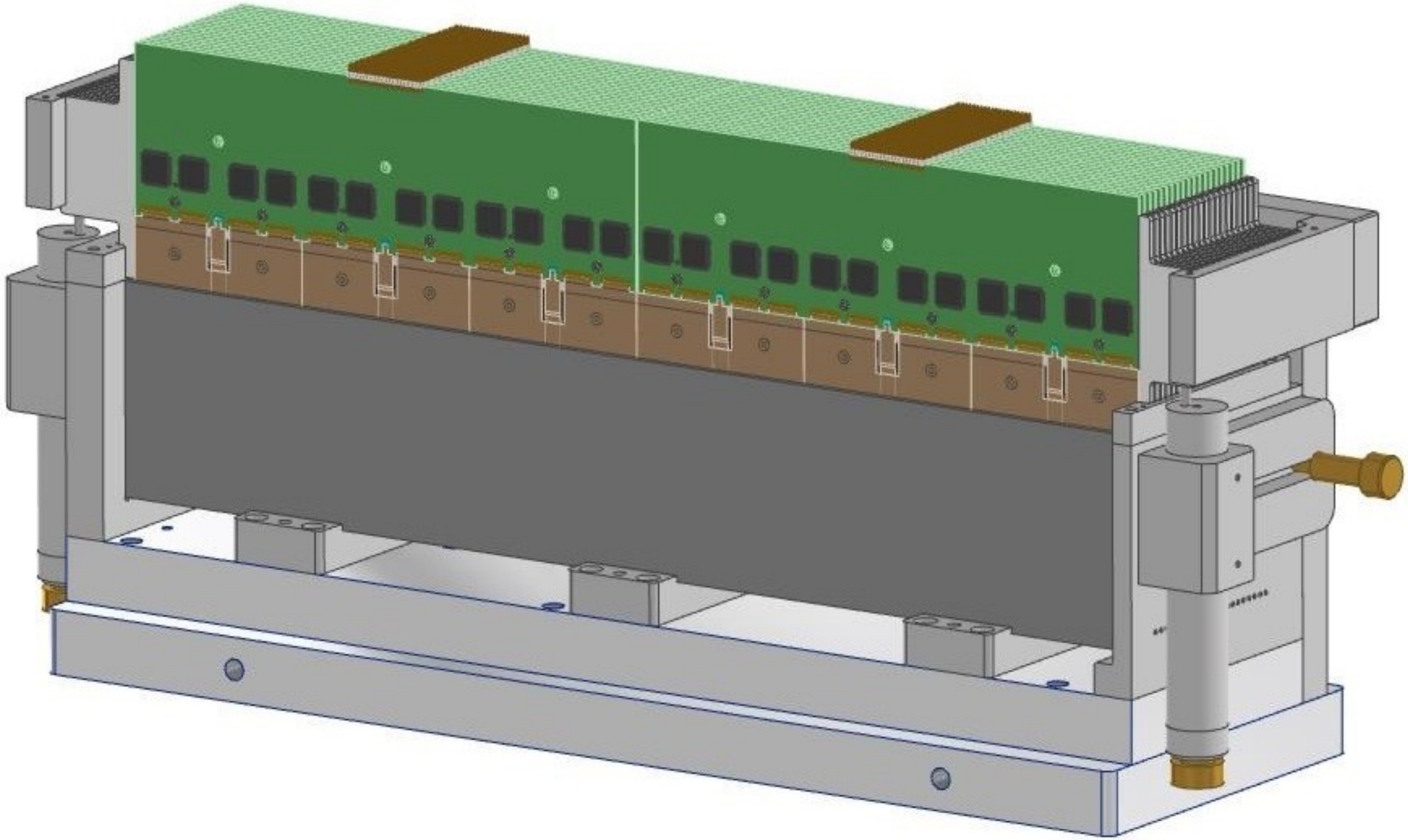
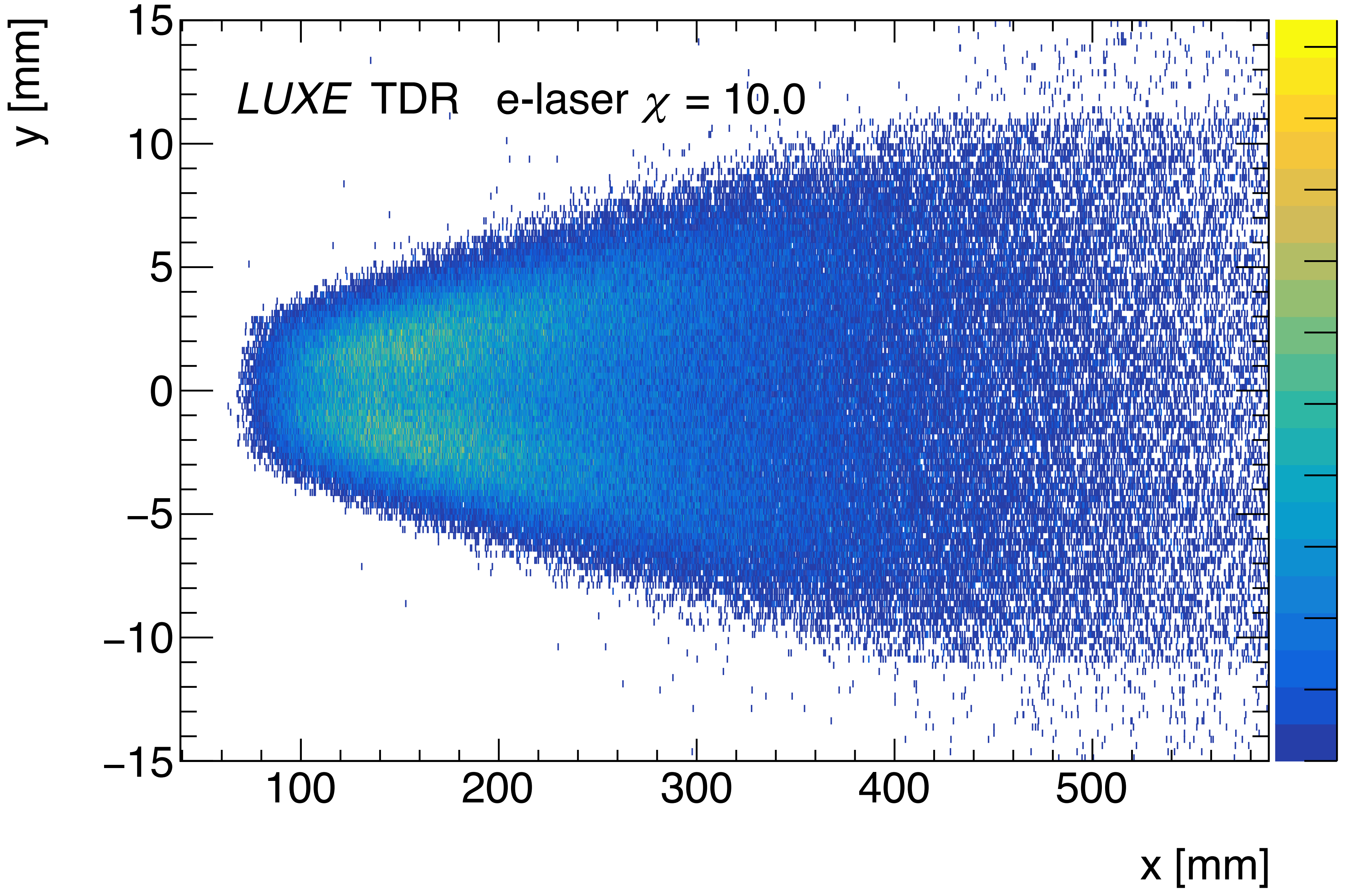


Thank you for your attention!

Backup of TB



LUXE TDR e-laser χ = 10.0
y [mm]
15
10
5
0
−5
−10
−15
100
200
300
400
500
x [mm]

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