Summer student project: Cerenkov detector geometry

Optimizing the number and layout of the Cerenkov straws with respect to detection efficiency, energy acceptance and energy resolution

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HELMHOLTZ

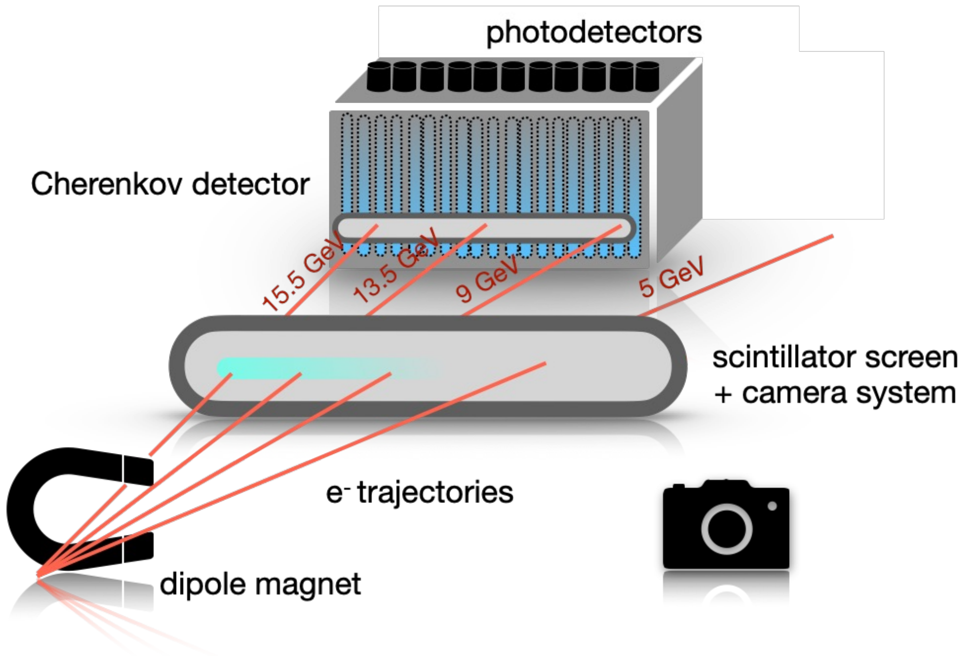
DESY.

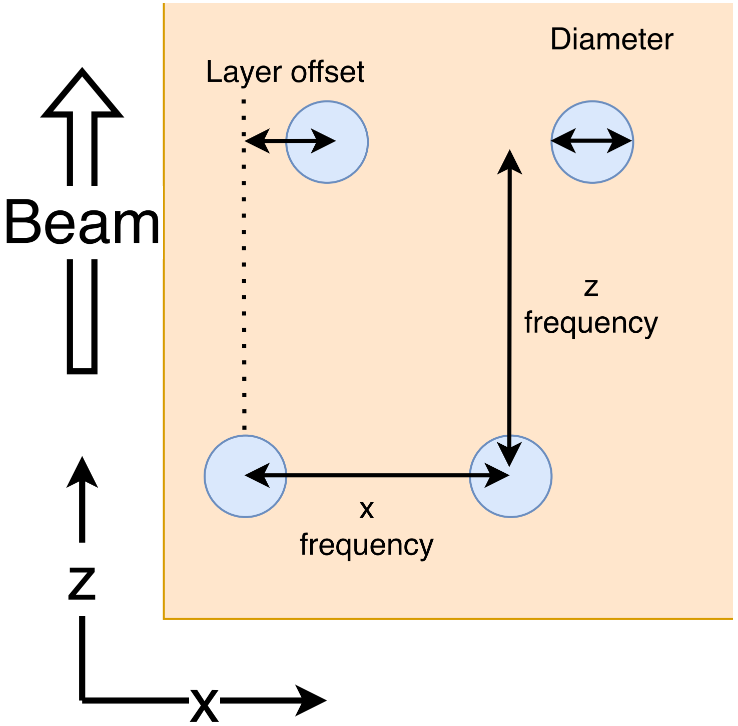
The project

Finding the optimal layout of the Cherenkov straws

The layout parameters

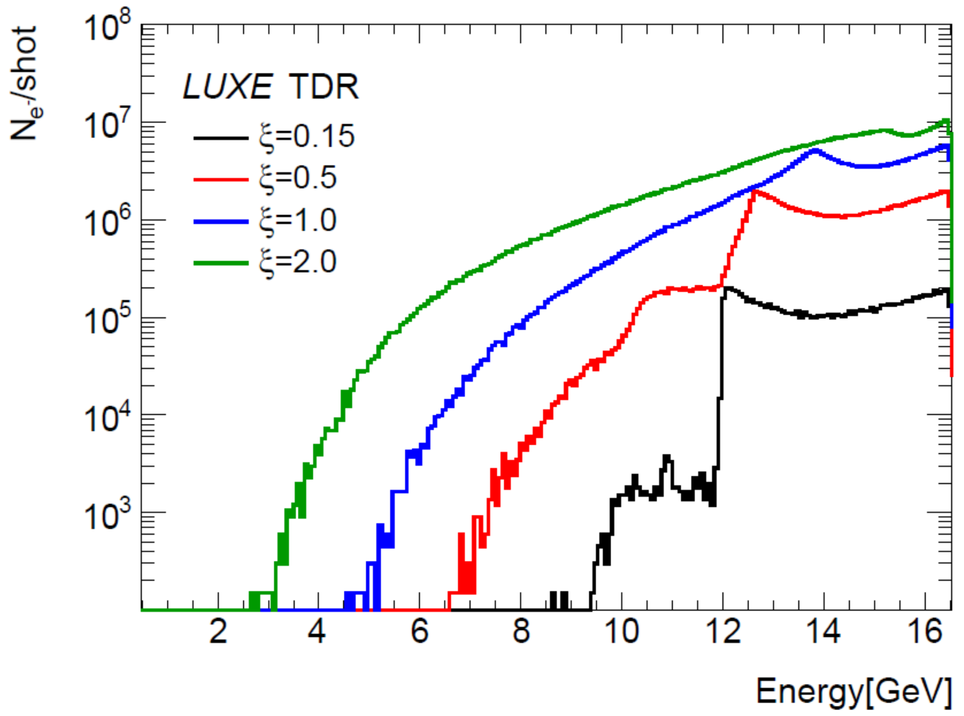
- Multiple layers, each slightly offset to the right
  - Number of layers
  - X frequency: distance between two straws (same layer)
  - Z frequency: distance between two straws (different layers)
  - Layer offset: offset between two layers
  - Straw radius
- The different configurations are simulated using a reduced version of the full Geant4 luxe simulation





The project

Finding the optimal layout of the Cherenkov straws

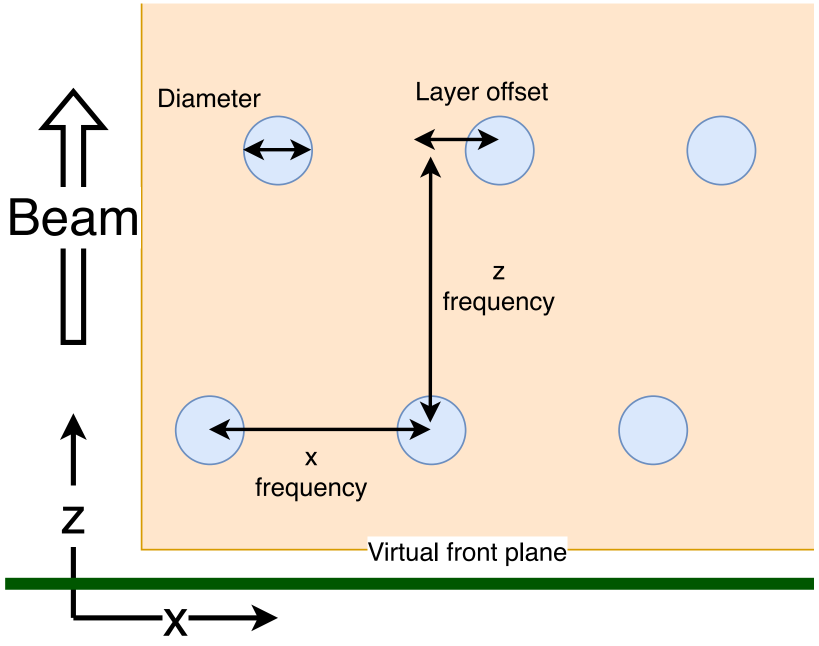


How is *optimal* defined ?

- Ultimately: the best energy distribution reconstruction
  - Especially in the edge zone: 8 GeV → 14 GeV
- High detector efficiency
  - Efficiency = # straw hits / # true electrons
  - Not weighted
- Flat acceptance
  - Acceptance = # electrons hitting straws / # true electrons hitting straws
  - The straw hits are weighted depending on the path length inside the straw
- Good energy resolution ($\sigma_E/E < 2\%$)

Reconstruction

From straw hit distribution and path lengths to energy distribution

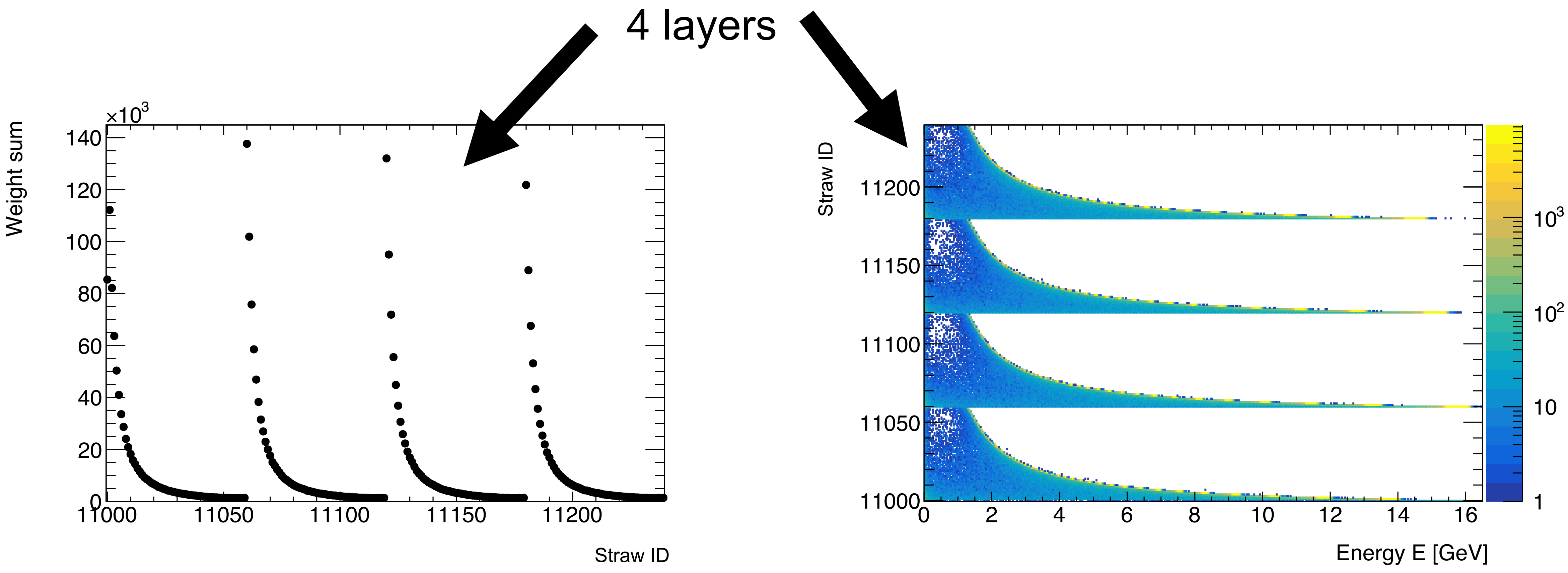


Methodology

- Only Geant4 tracks have been used for this study
- *True* energy spectrum = energy spectrum at the virtual plane
- Associating straw hits to front plane hits
- Transfer matrix used to reconstruct the energy distribution
- For each energy (at the front plane) and each straw, the relative path lengths inside of the straw of all the electrons are added together
  - The relative path length is a proxy to the number of Cerenkov photons expected in each straw
- This transfer matrix distributes the straw hits on different energies → Energy spectrum from the straw hit spectrum (using the Compton scattering signal spectrum)

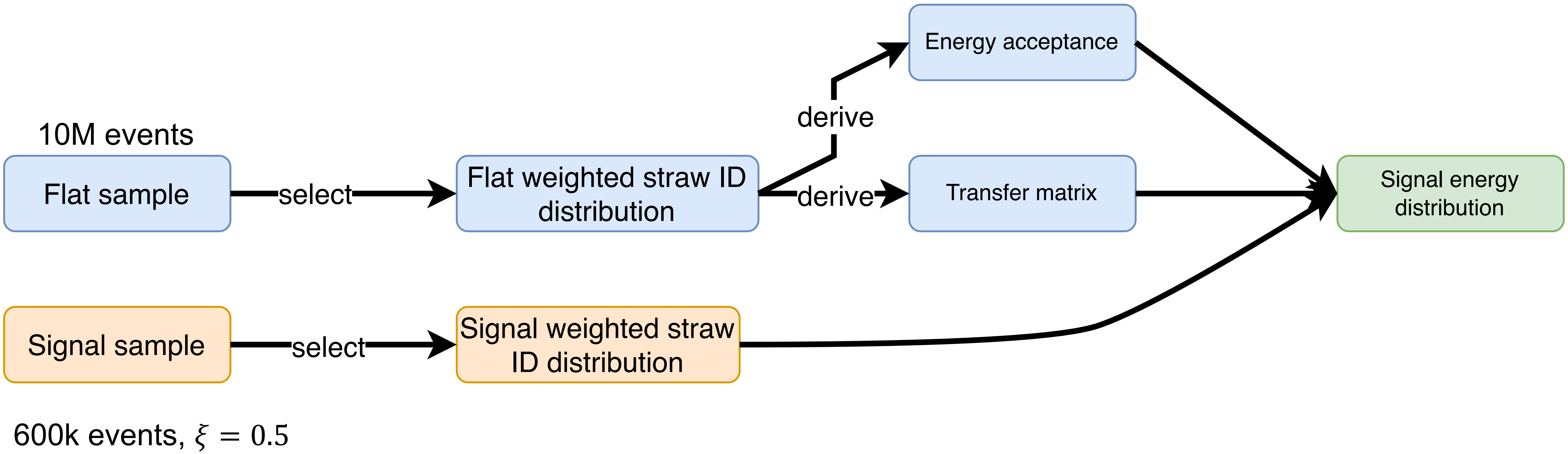
Reconstruction method

Weighted sum of for each straw and transfer matrix



Reconstruction

From straw hit distribution and path lengths to energy distribution

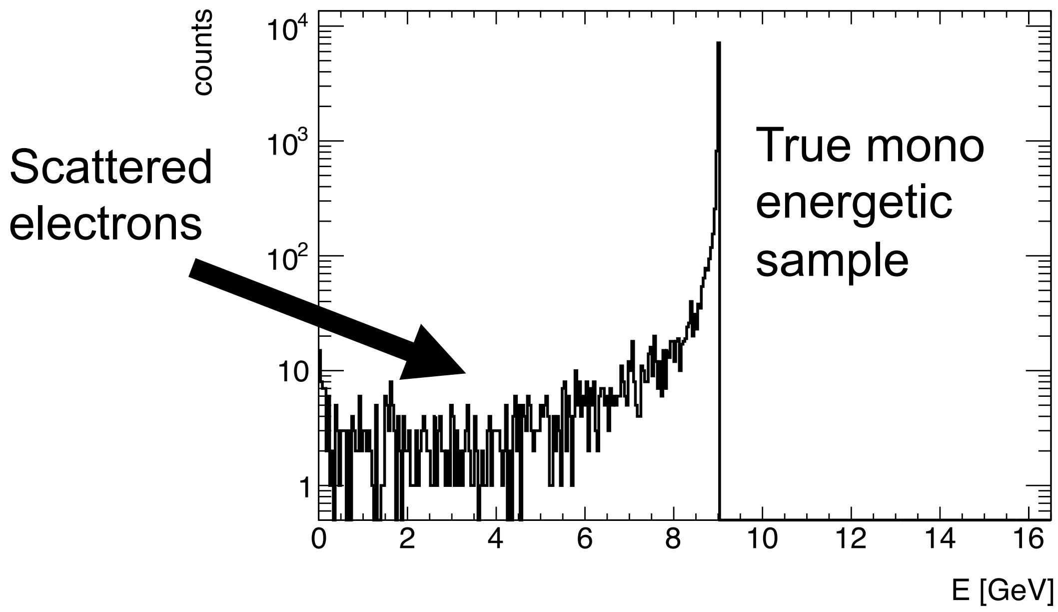


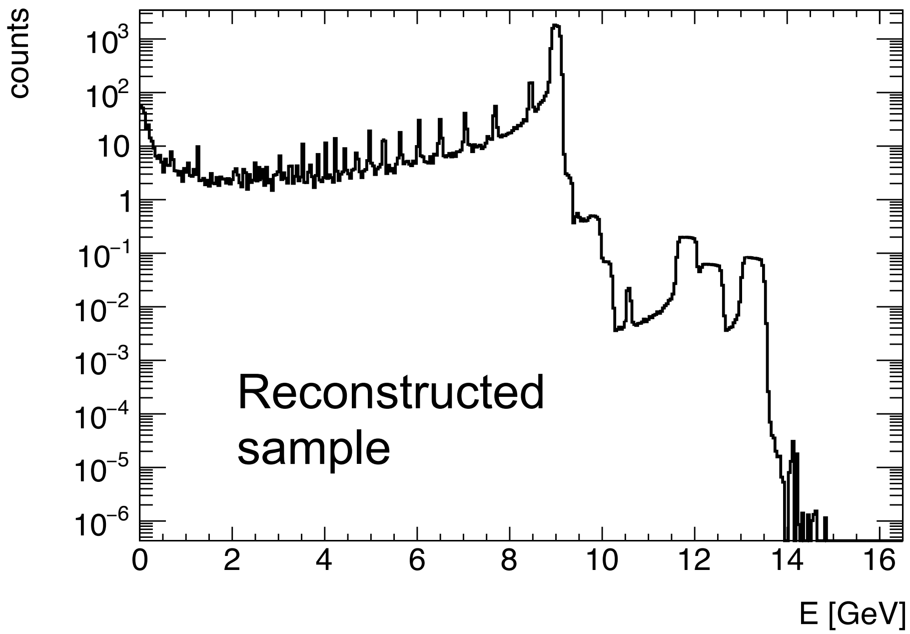
Resolution

Estimating energy resolution dependance on the detector geometry

Energy resolution

- Mono energetic electron samples are through the magnet and onto the Cerenkov detector
  - 10k events, every GeV from 3 GeV to 16 GeV
- The transfer matrix is applied to the straw hits → reconstructed energy spectrum
- A Crystal Ball function is fitted to extract σ_E/E

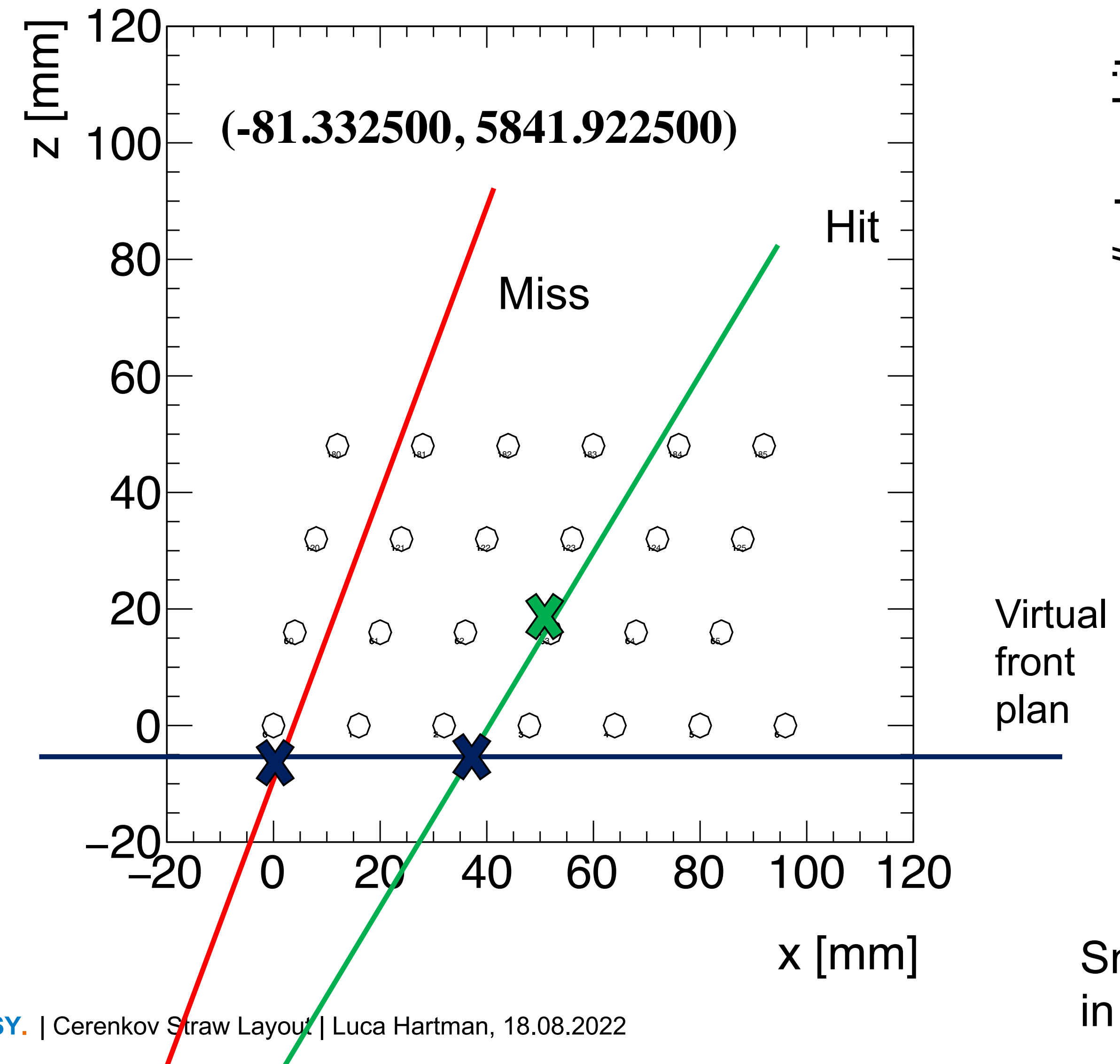


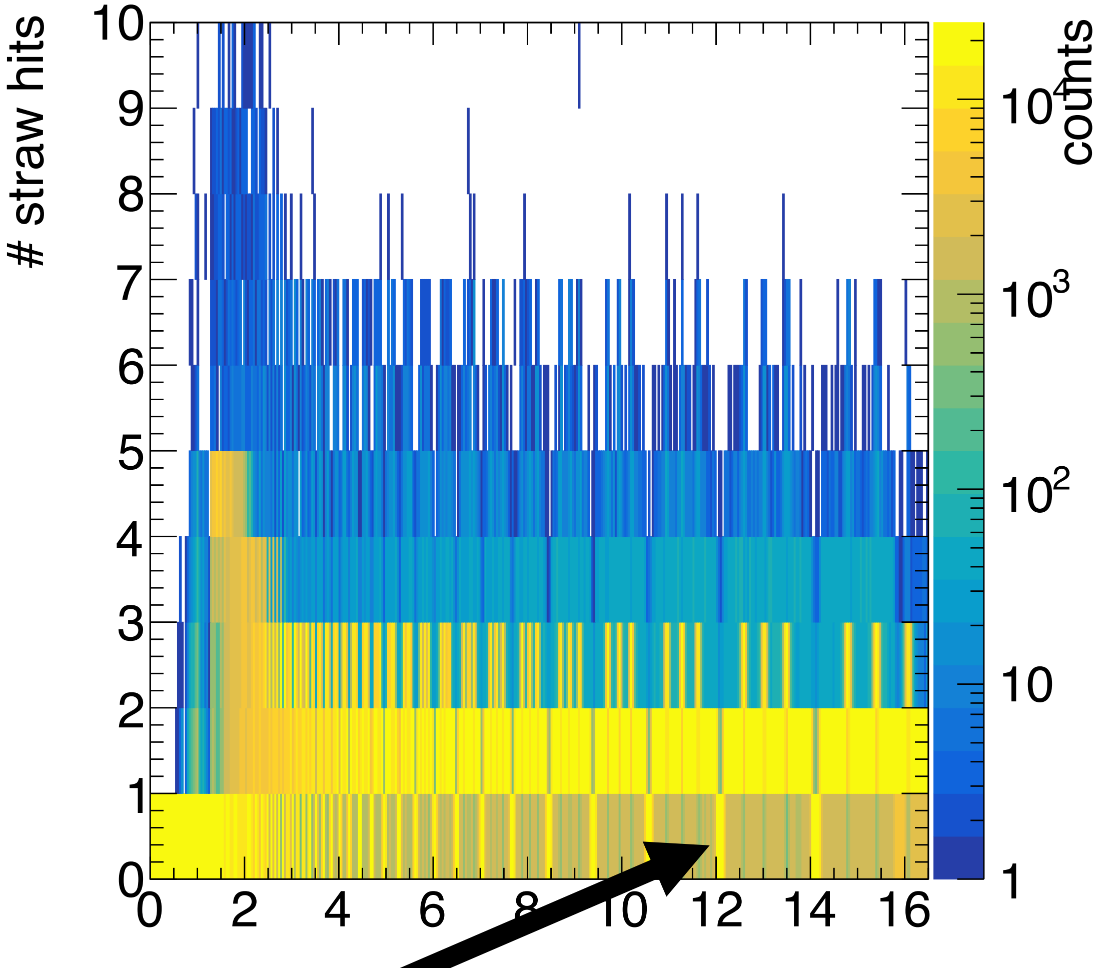


Default layout

Default configuration

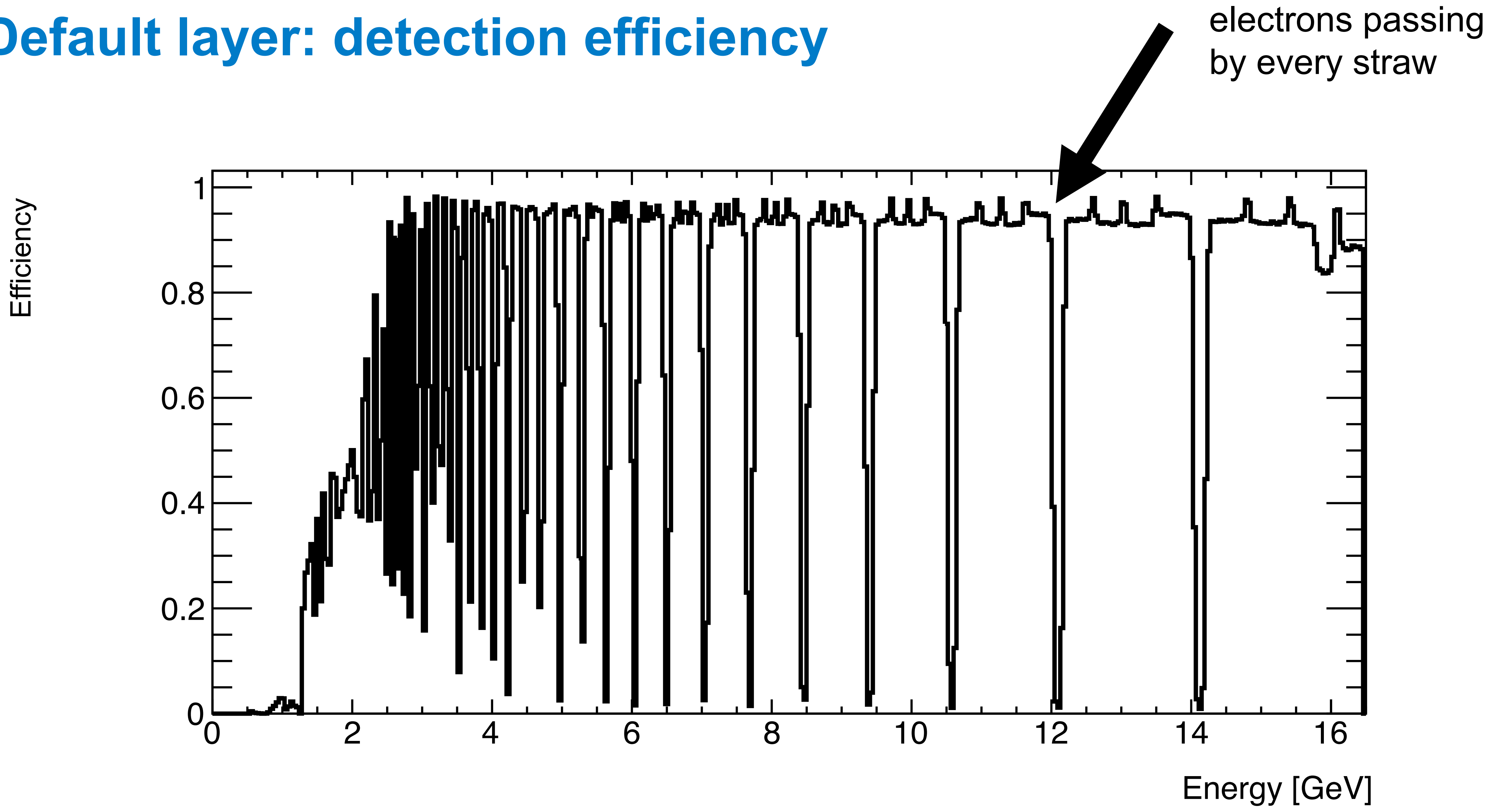
16 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 4 layers, 240 straws, 4.02 mm diameter





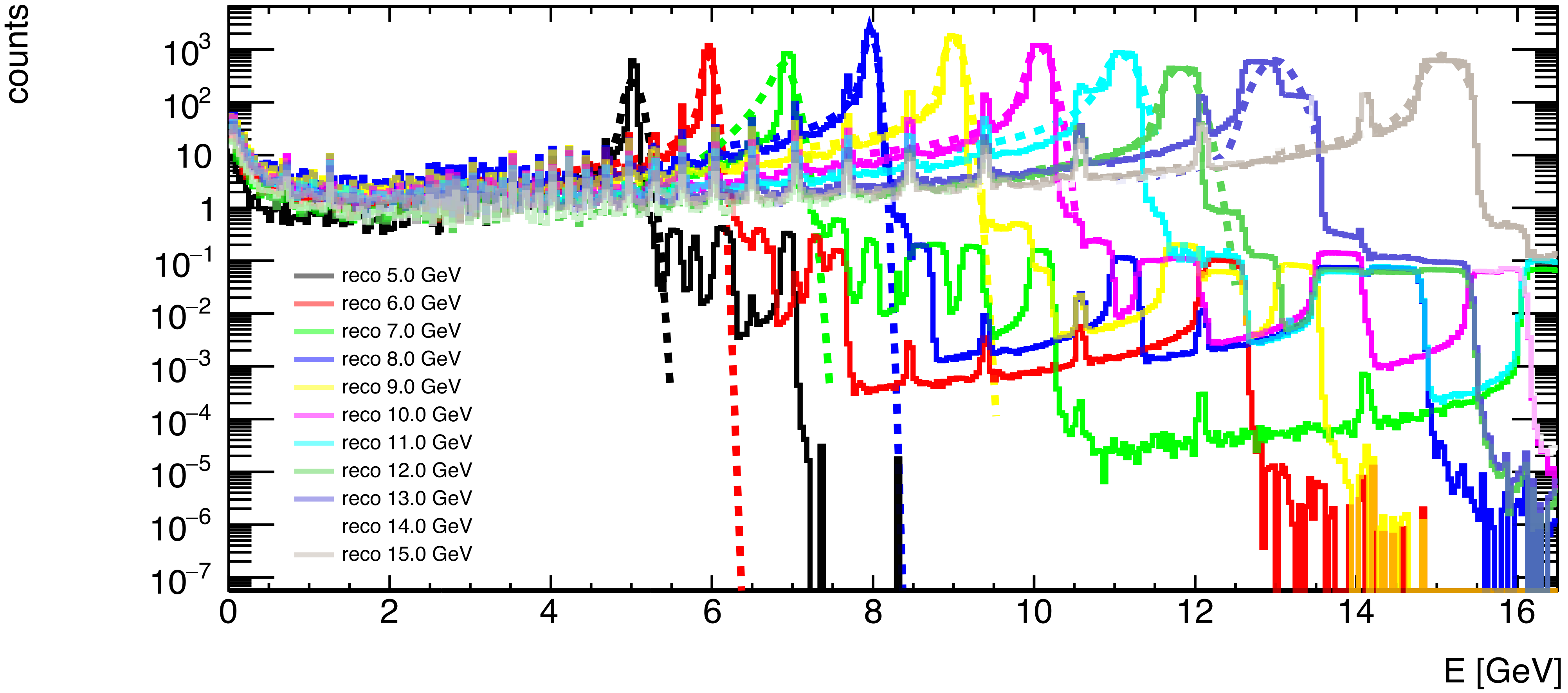
Small spikes
in 0 straw hits

Default layer: detection efficiency



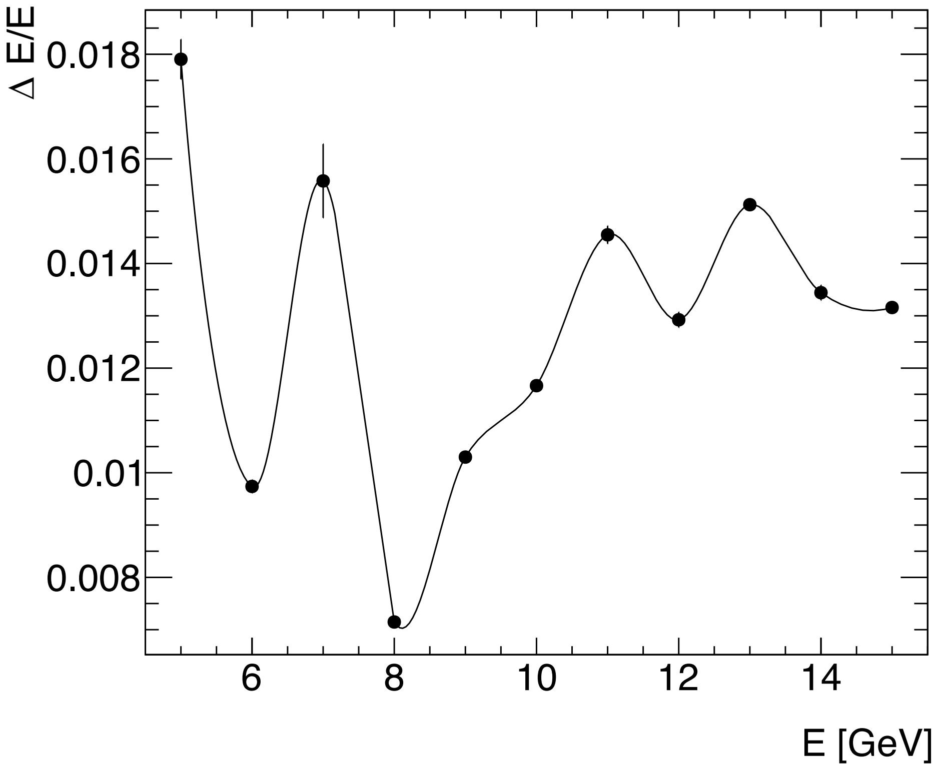
Default layer: energy resolution

High energy peaks broader than low energy peaks



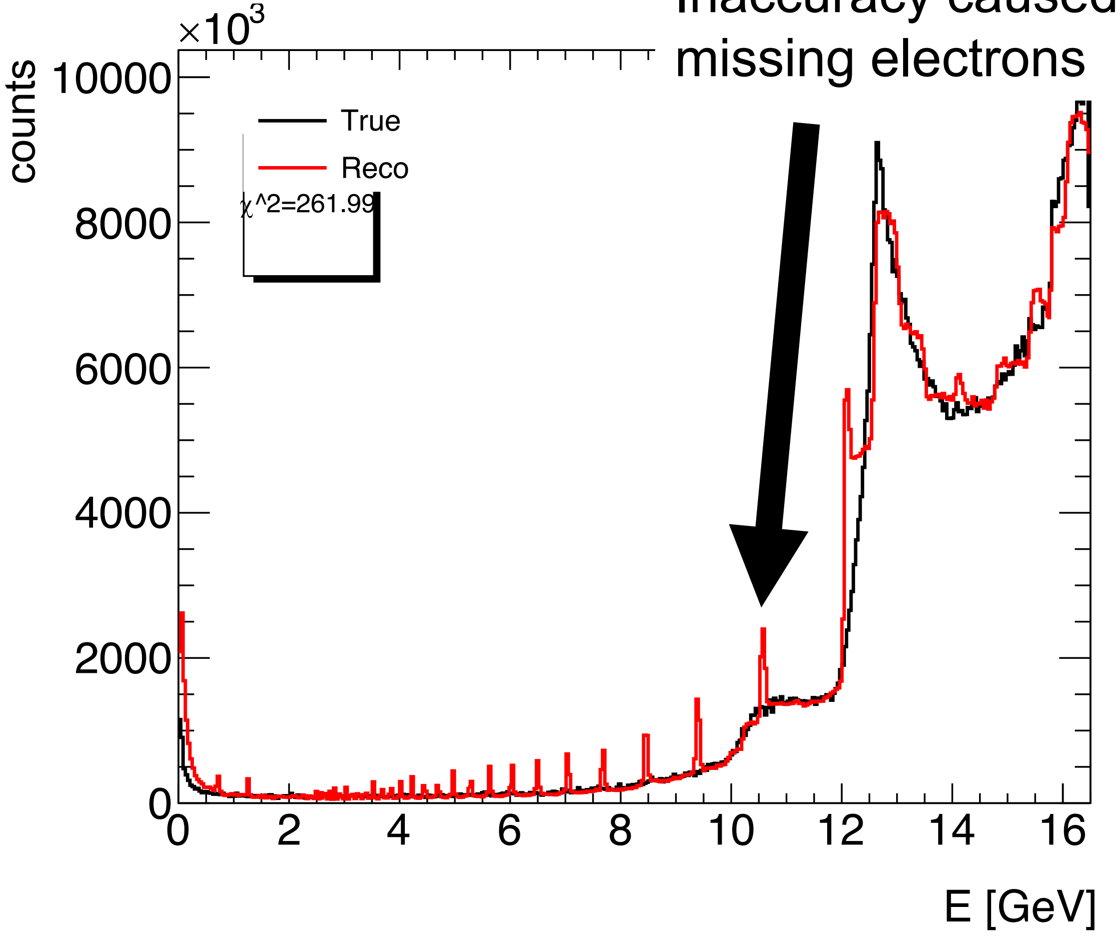
Default layer: finale measurements

16 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 4 layers, 240 straws, 4.02 mm diameter



Relatively flat energy resolution

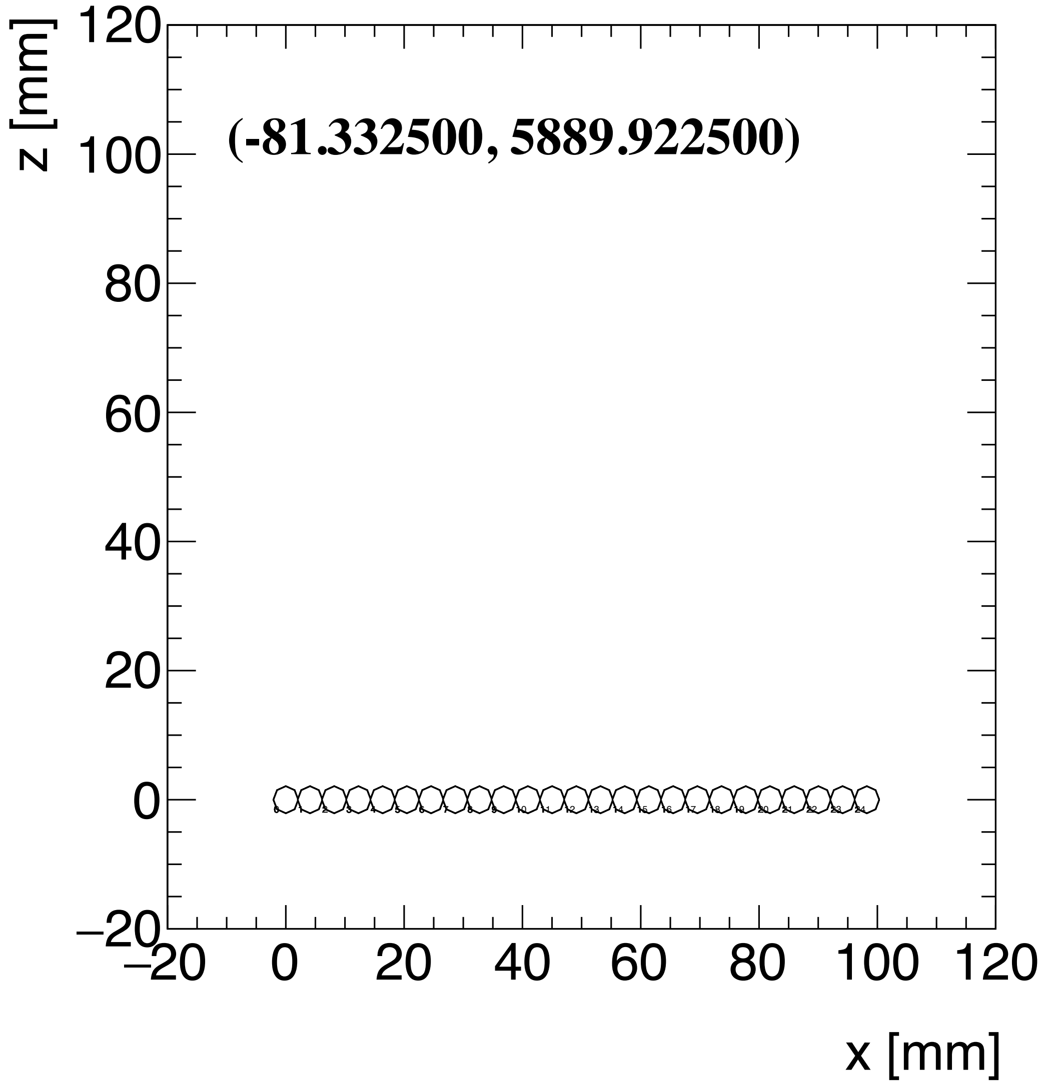
Inaccuracy caused by missing electrons

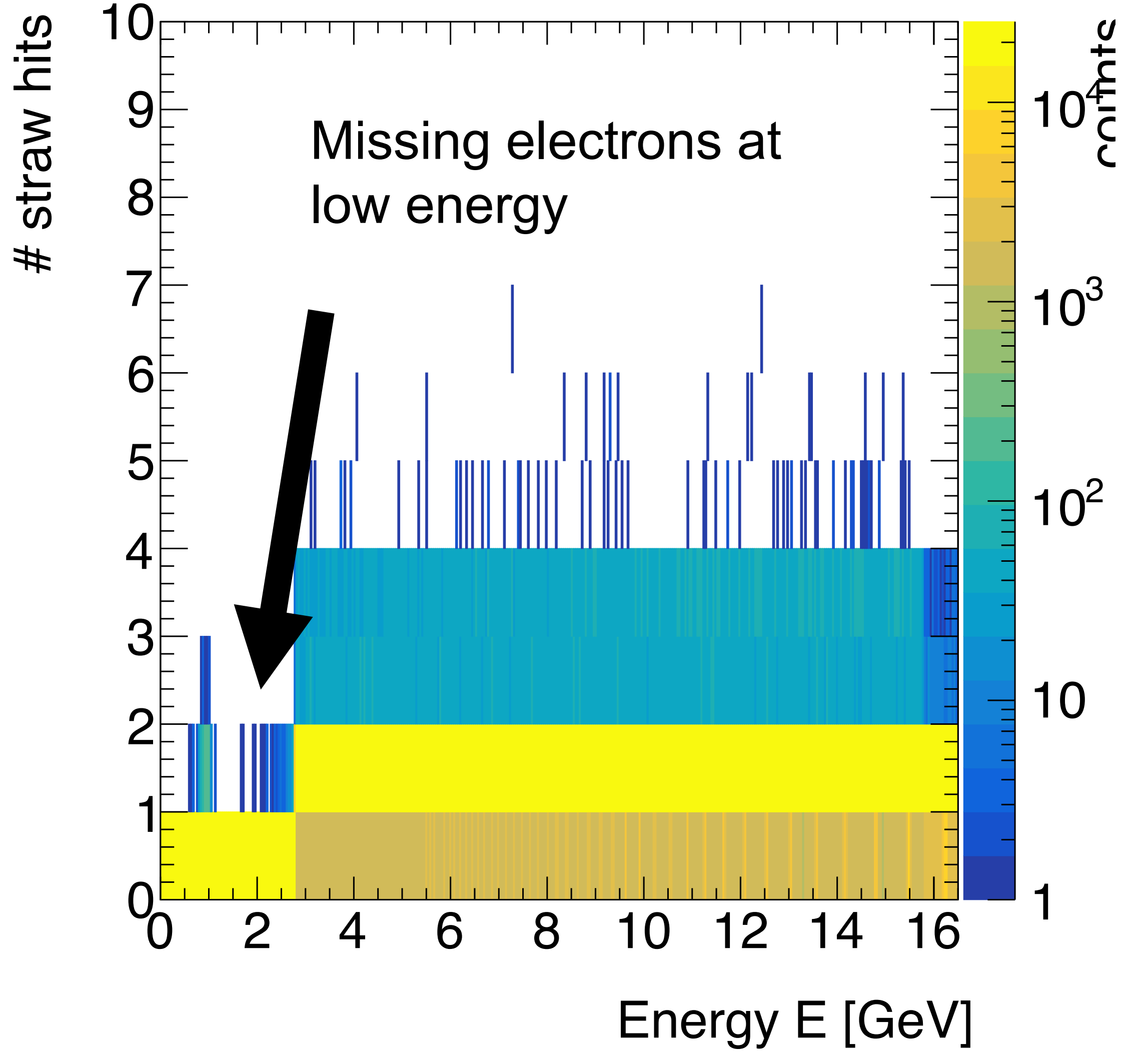


Dense single layer layout

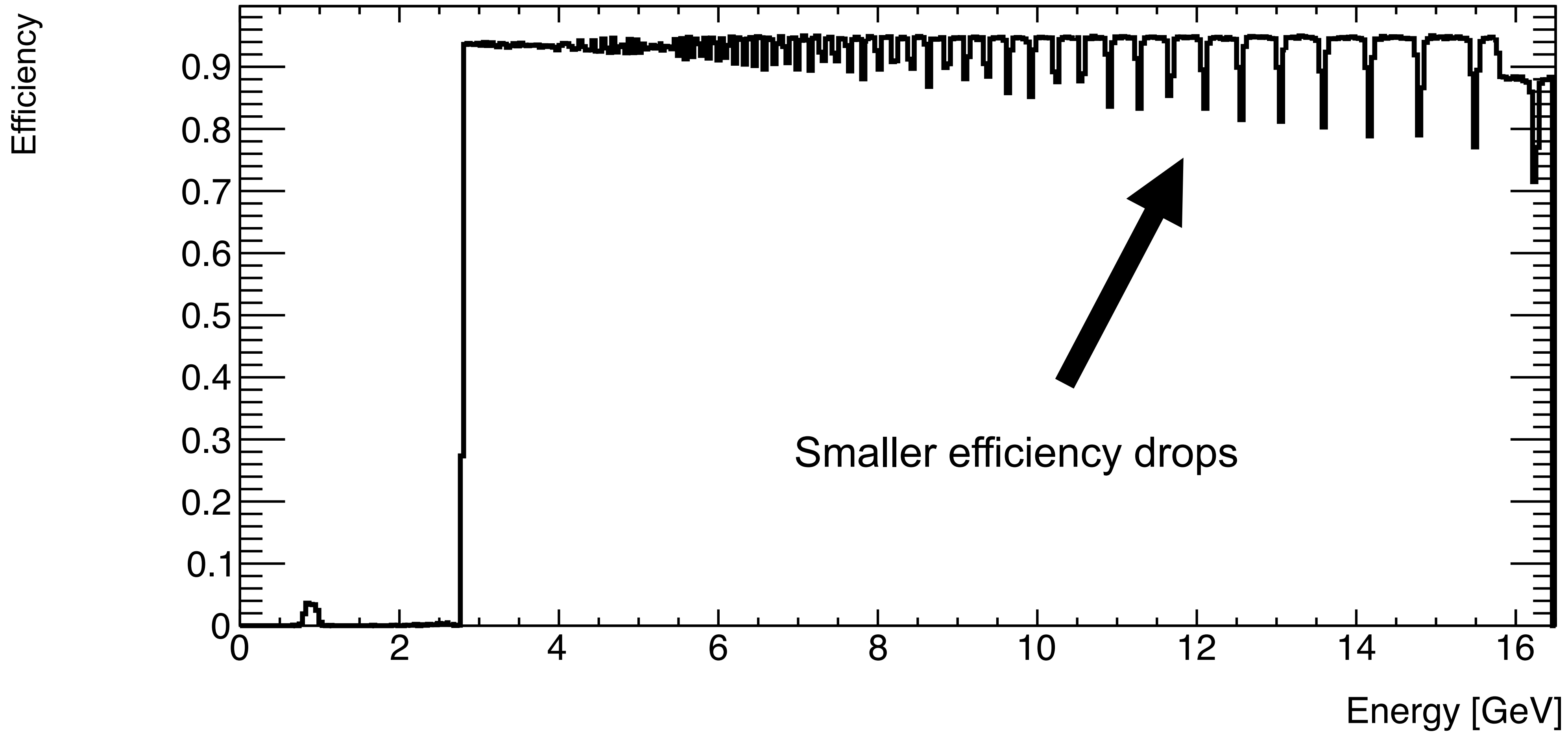
Dense single layer layout

4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 1 layer, 100 straw, 4.02 mm diameter

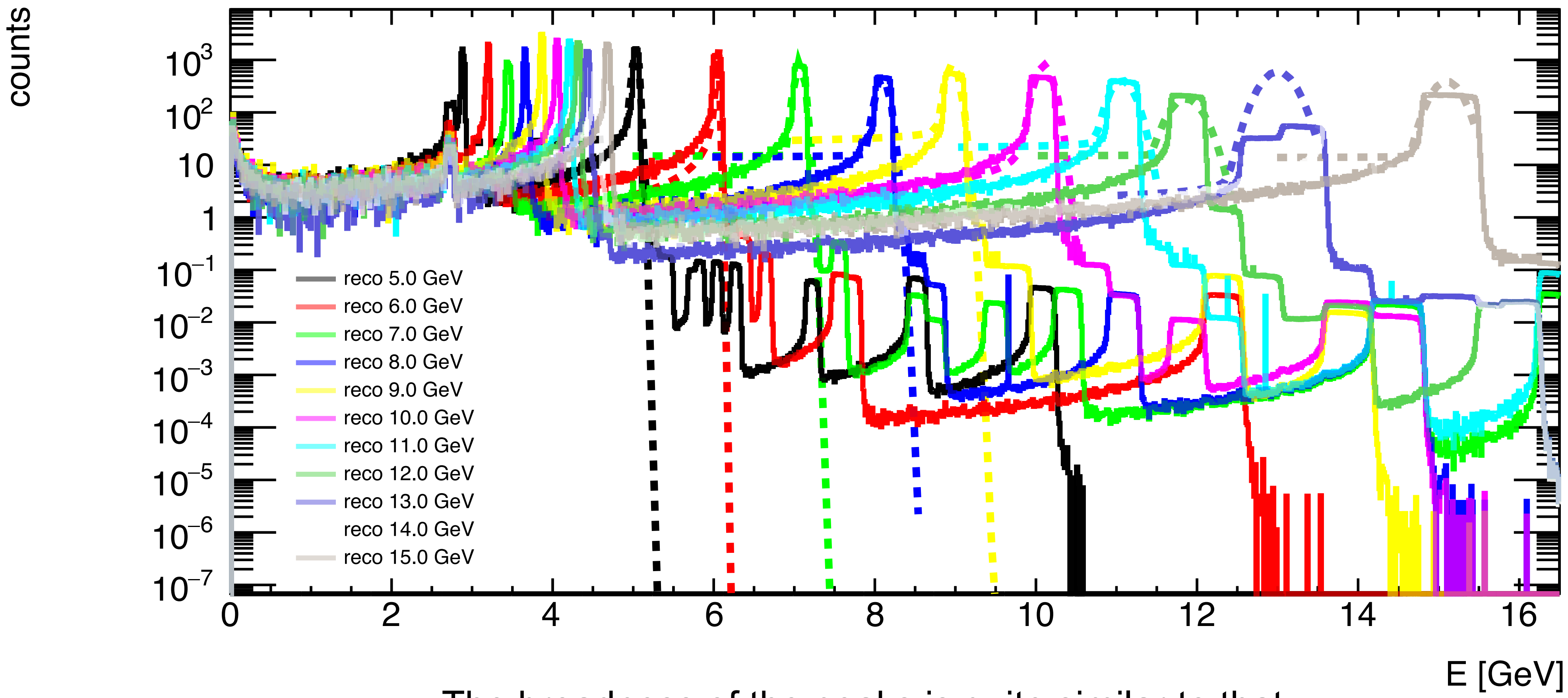




Dense single layer layout: efficiency



Dense single layer layout: energy resolution

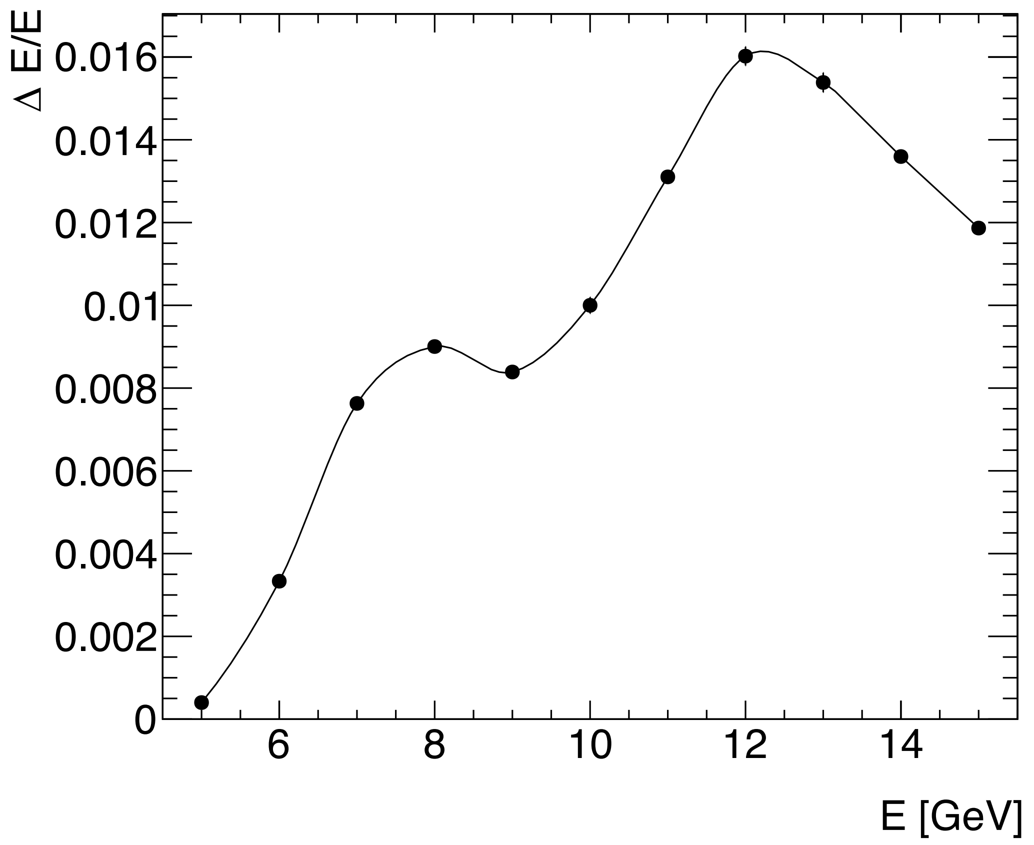


The broadness of the peaks is quite similar to that obtained using 4 layers, but the tails are much smoother, because there is less drops in detection

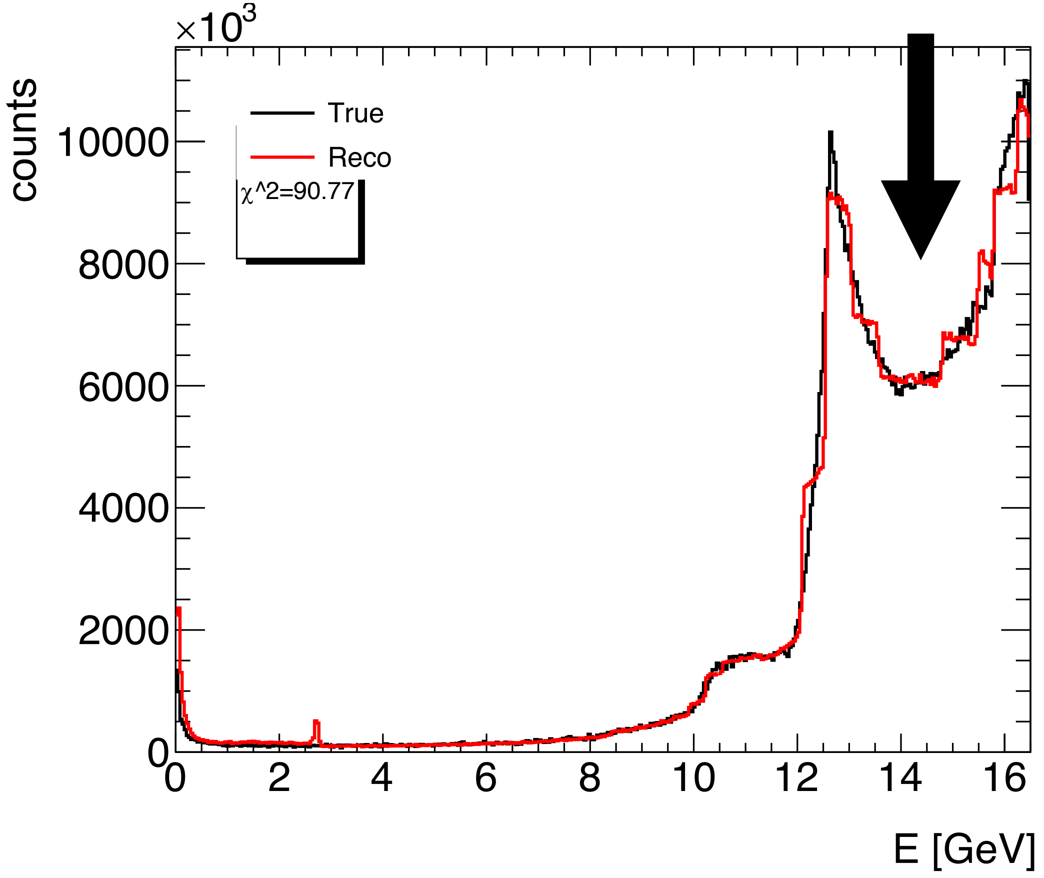
Dense single layer layout: final measurements

4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 1 layer, 100 straws, 4.02 mm diameter

An increasing relative resolution is expected



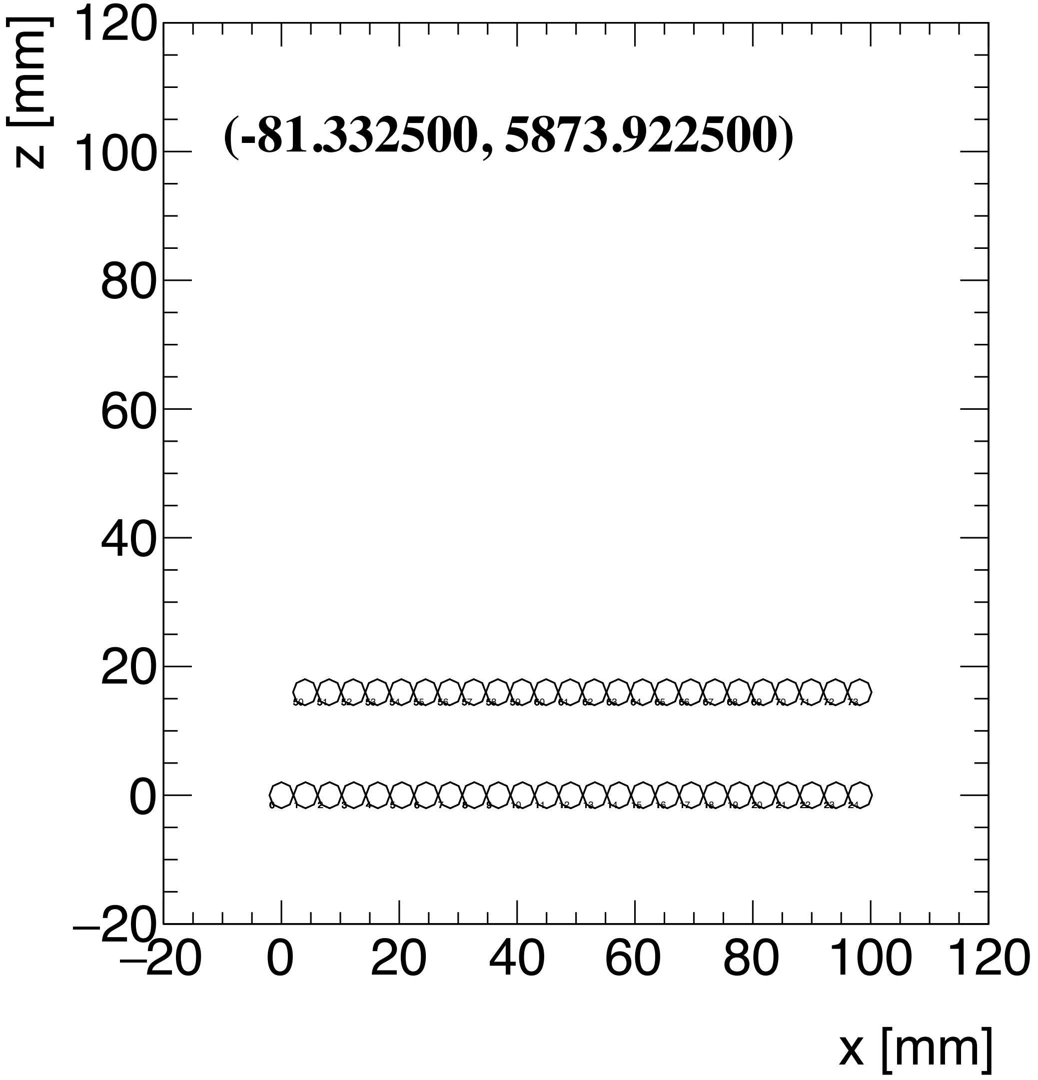
Wiggly reconstruction



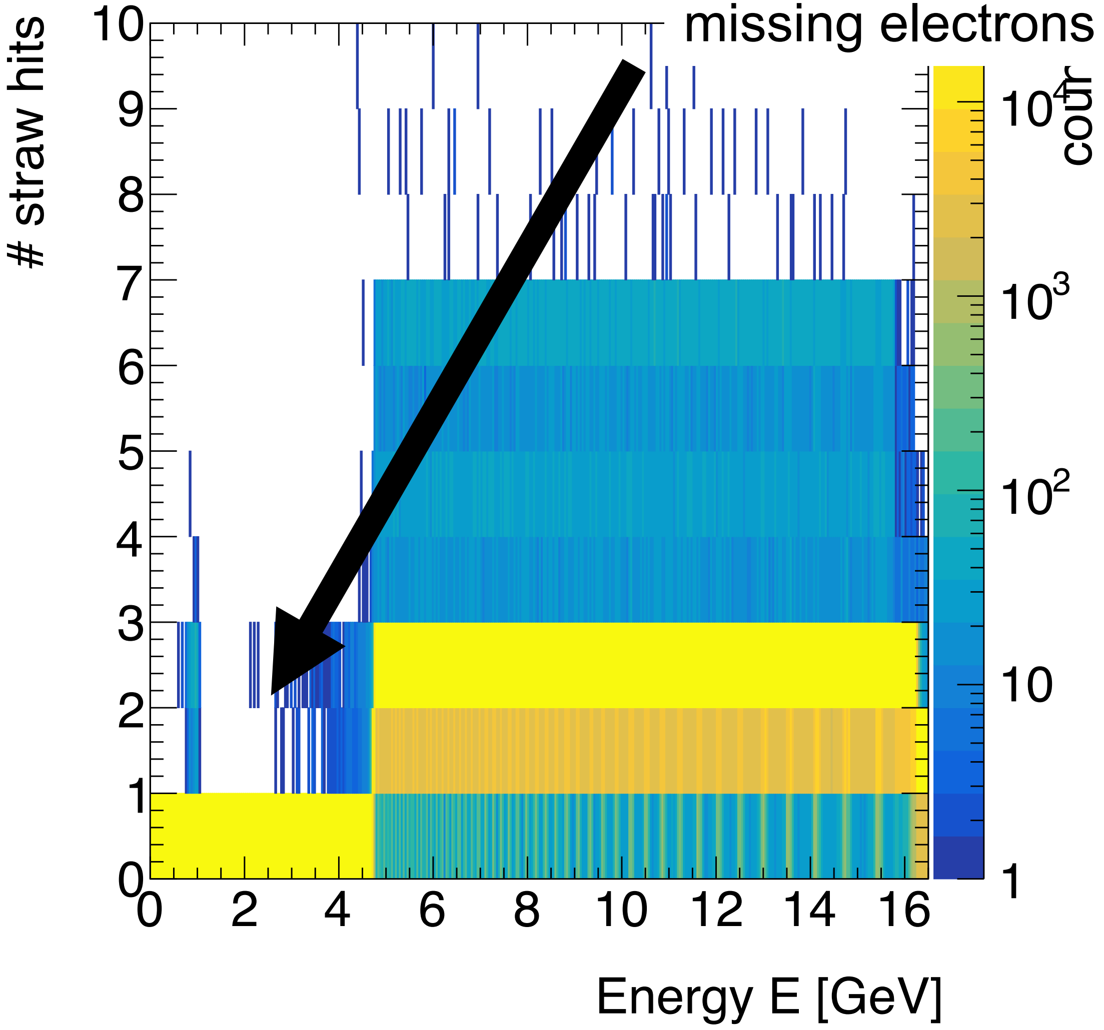
Dense double layer layout

Dense double layer layout

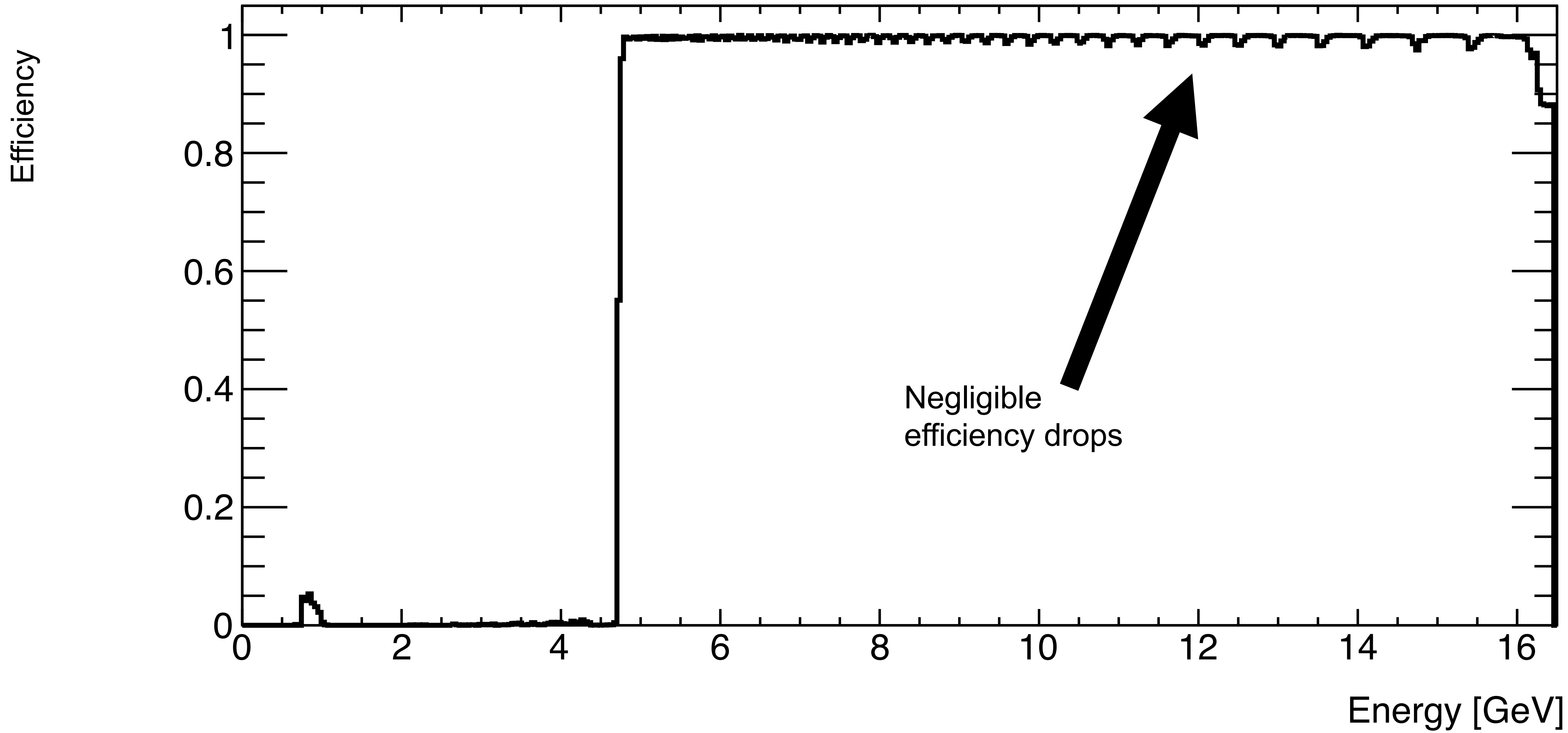
4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 2 layer, 100 straws, 4.02 mm diameter



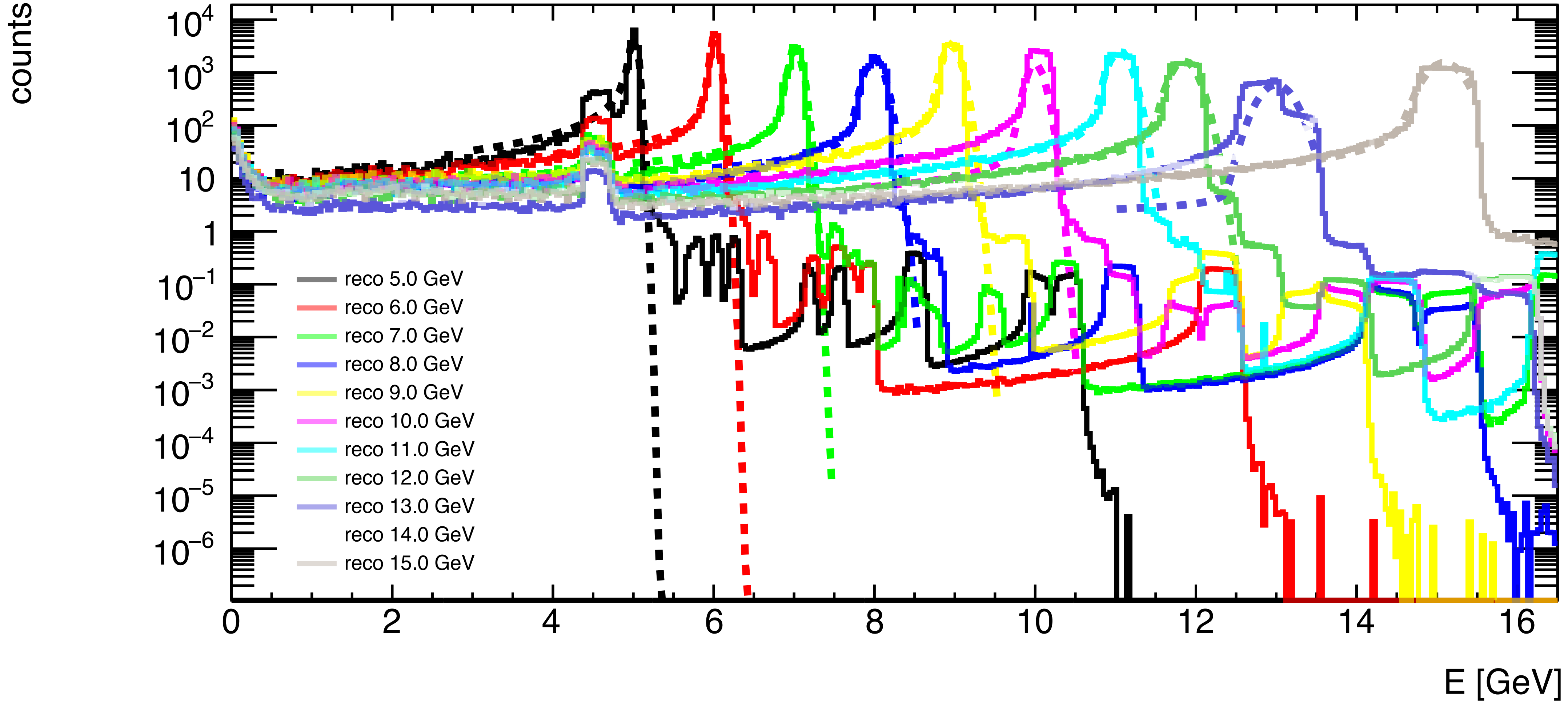
Larger zone of missing electrons



Dense double layer layout: efficiency

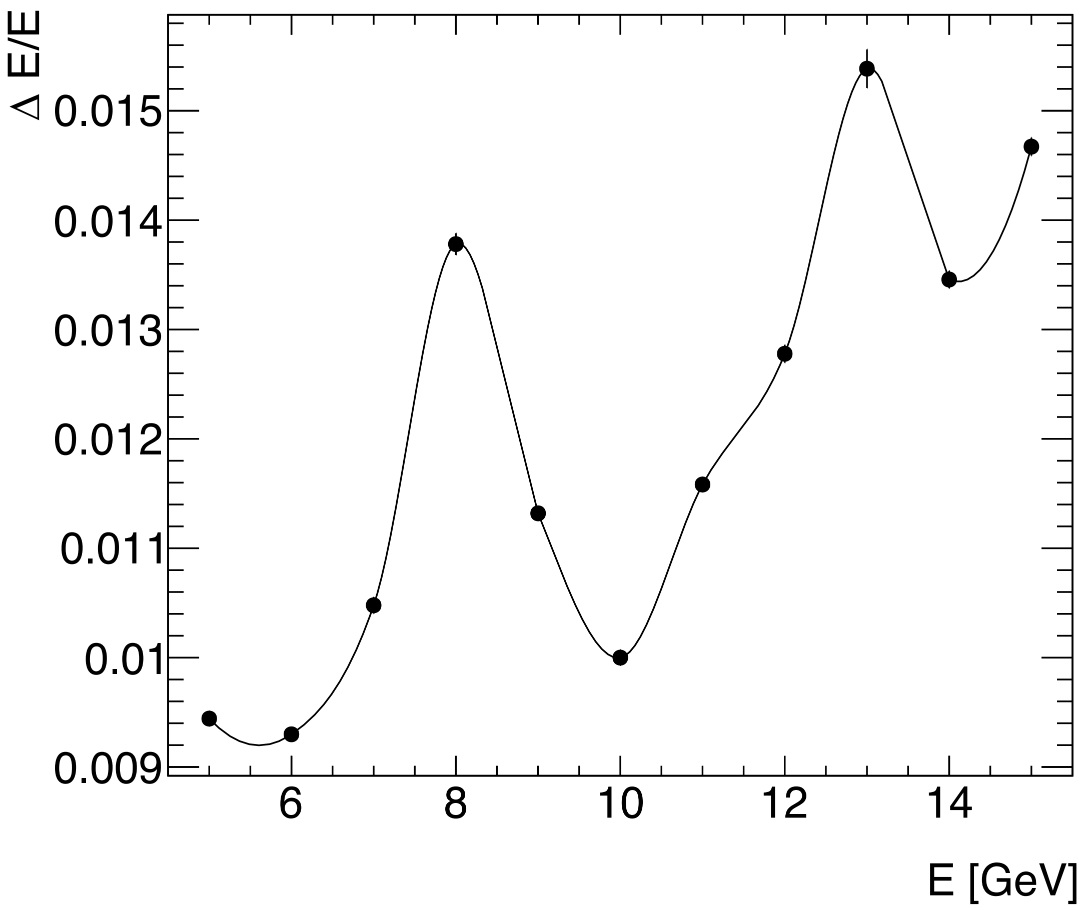


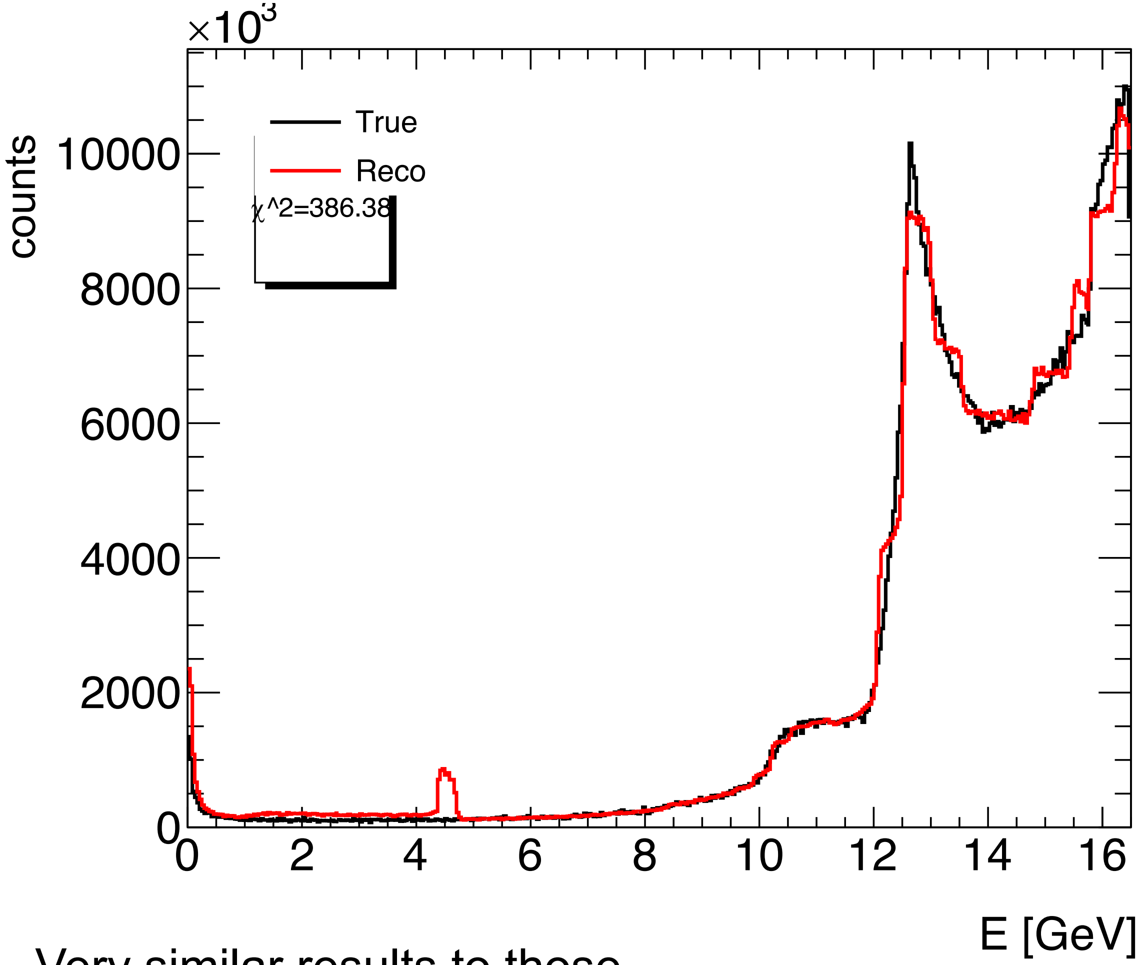
Dense double layer layout: energy resolution



Dense double layer layout: final measurements

4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 2 layer, 100 straws, 4.02 mm diameter



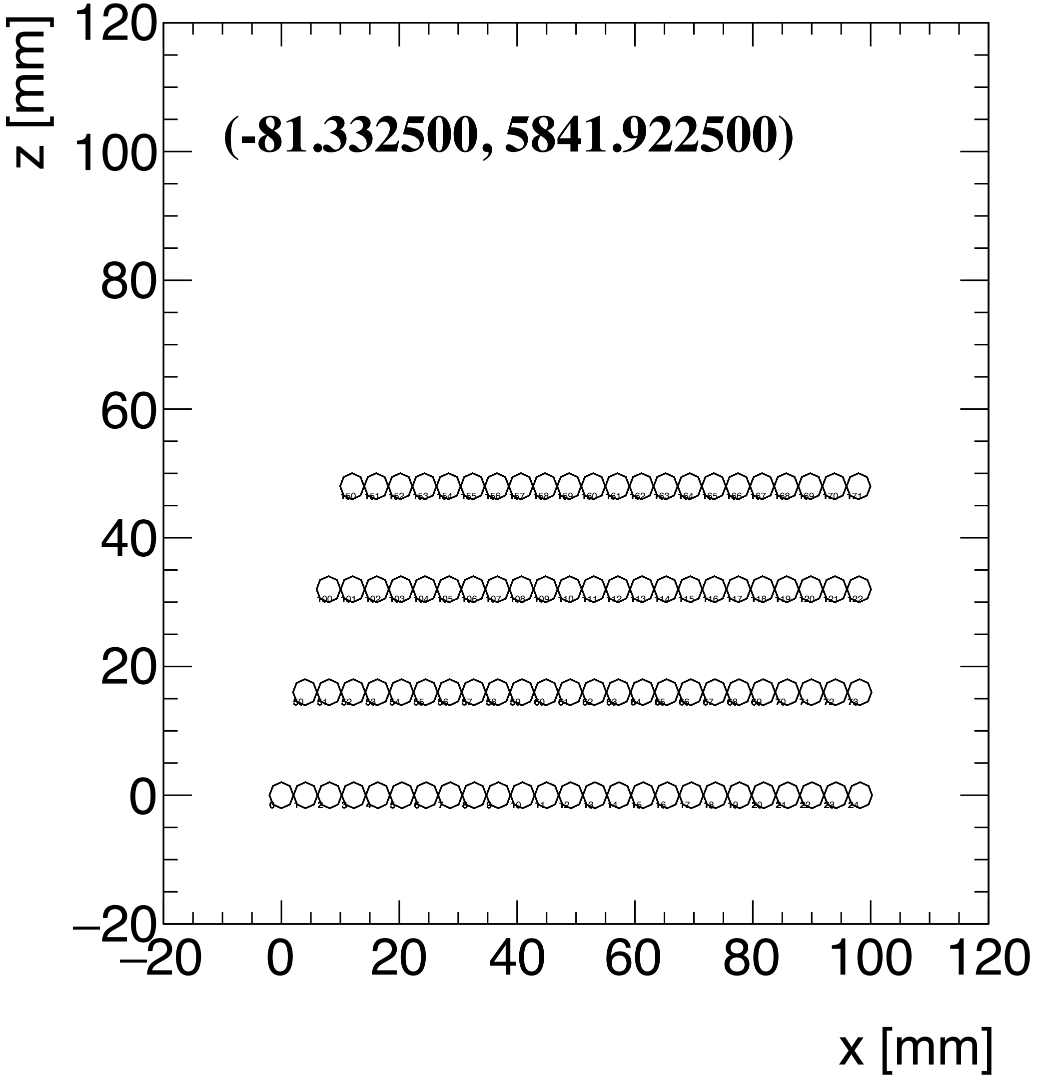


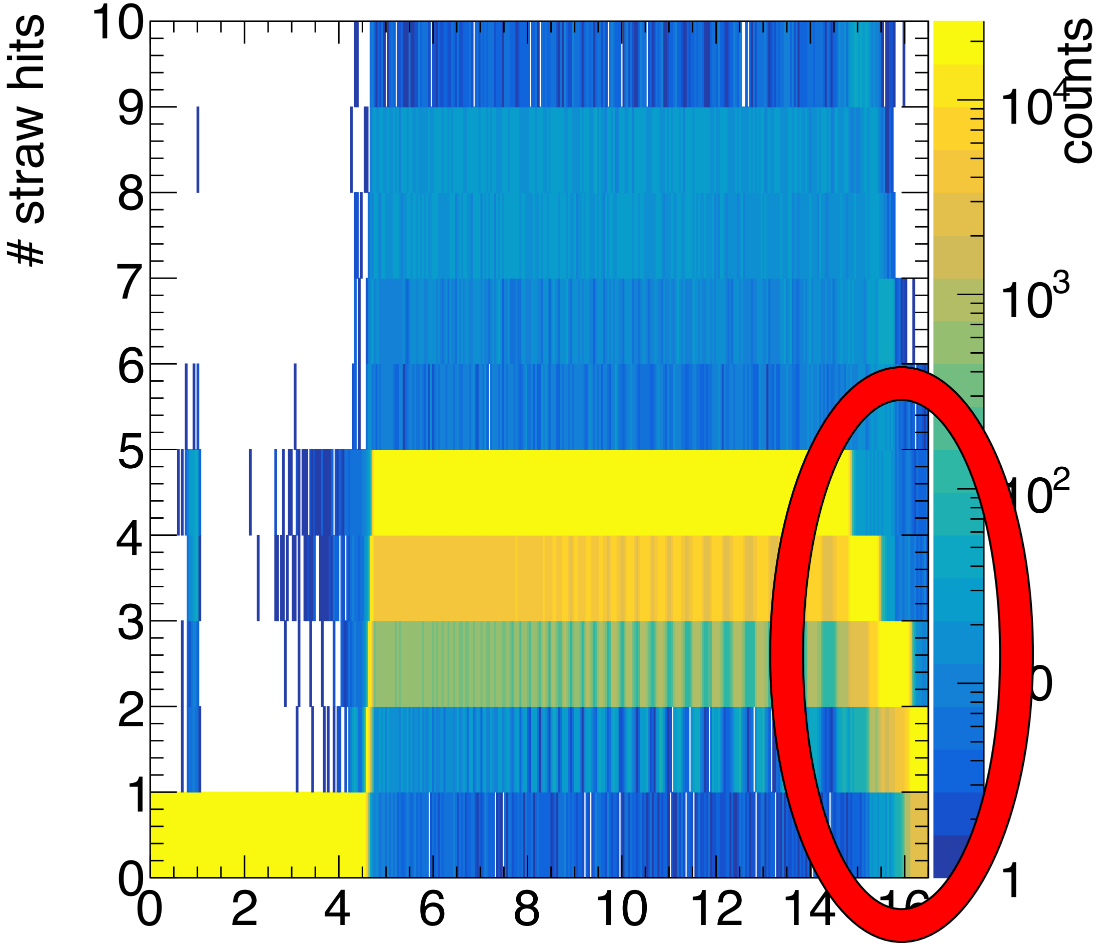
Very similar results to those obtained using a single layer

4 dense layers layout

4 dense layers layout

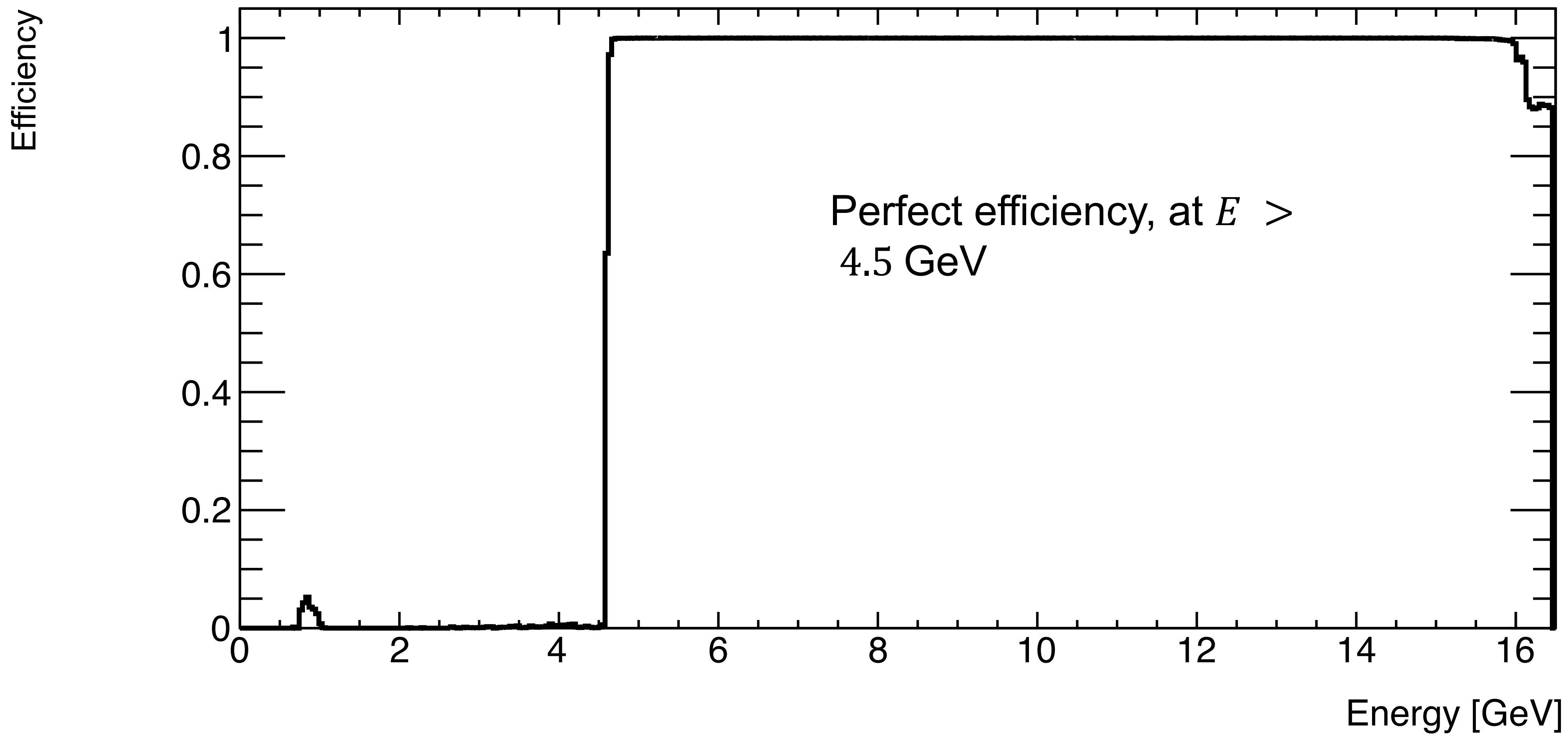
4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 4 layer, 200 straws, 4.02 mm diameter



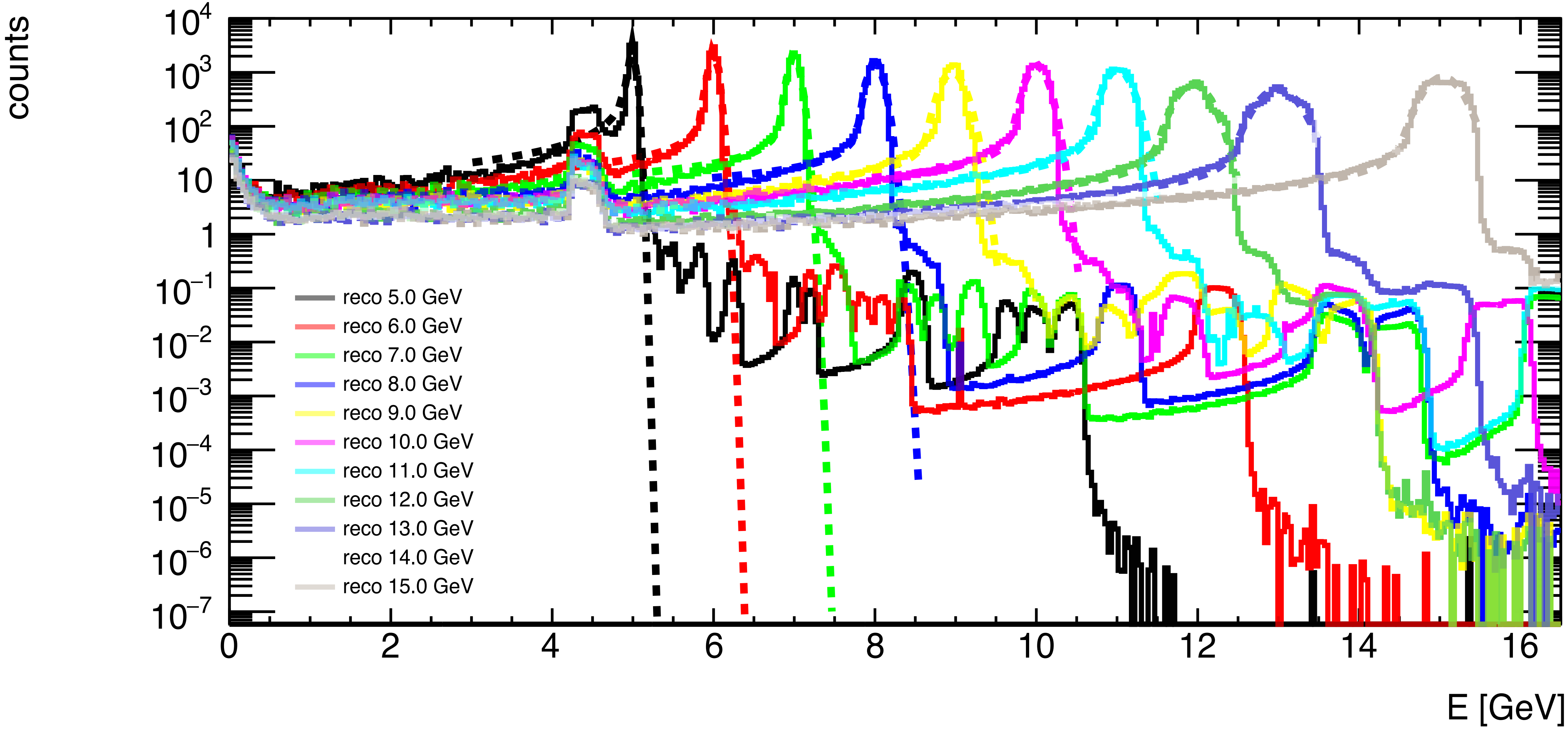


The staggered layout is clearly visible in this case

4 dense layers layout: efficiency



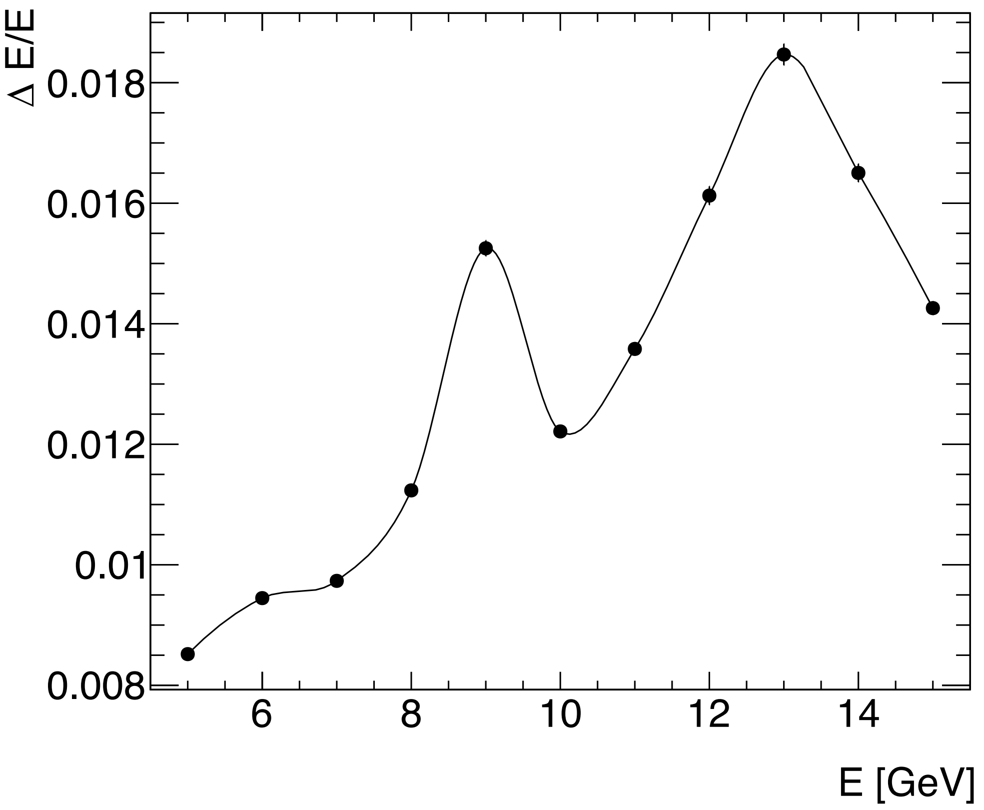
4 dense layers layout: energy resolution

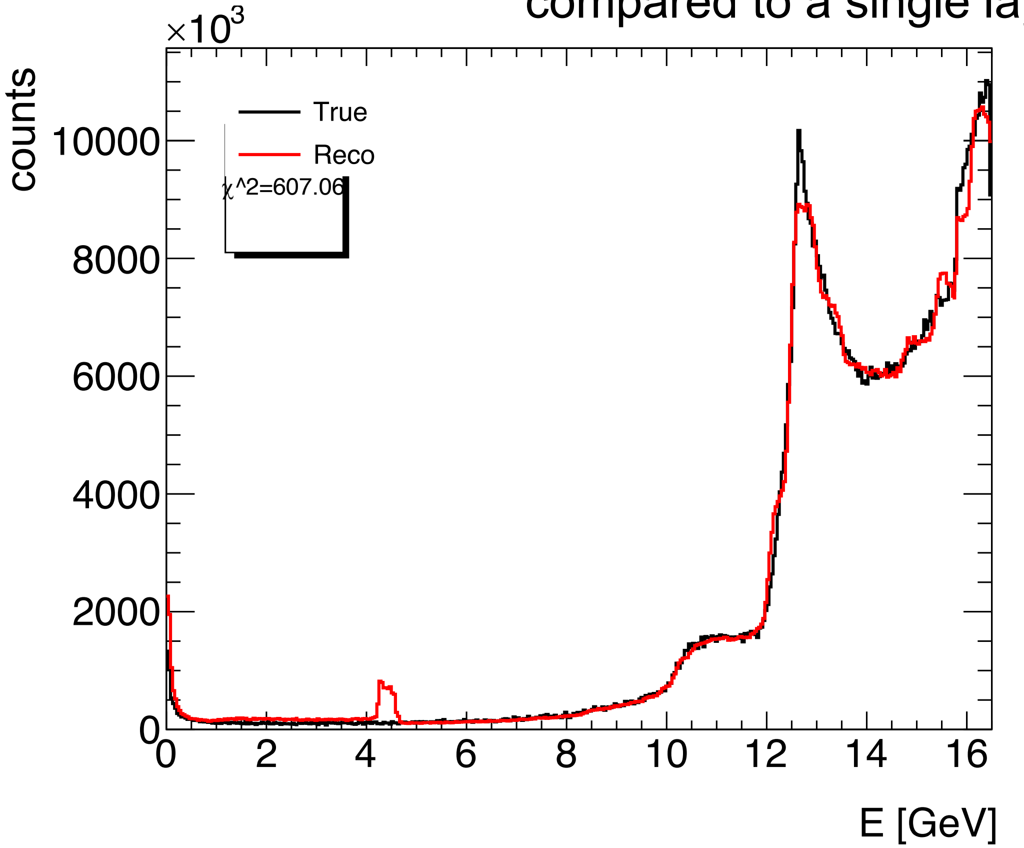


4 dense layers layout: final measurements

4.0924 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 4 layers, 4.02 mm diameter

The reconstructed energy distribution is much less wiggly compared to a single layer

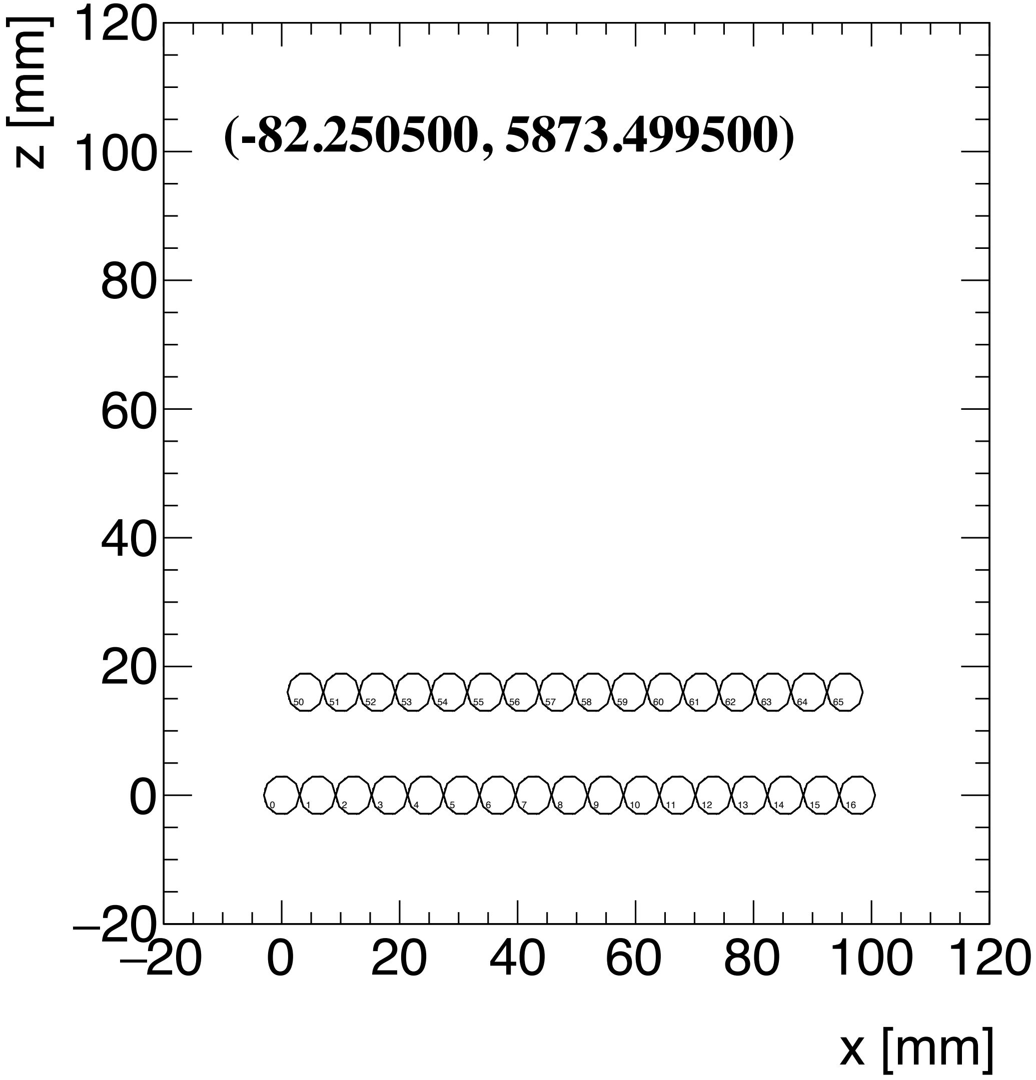


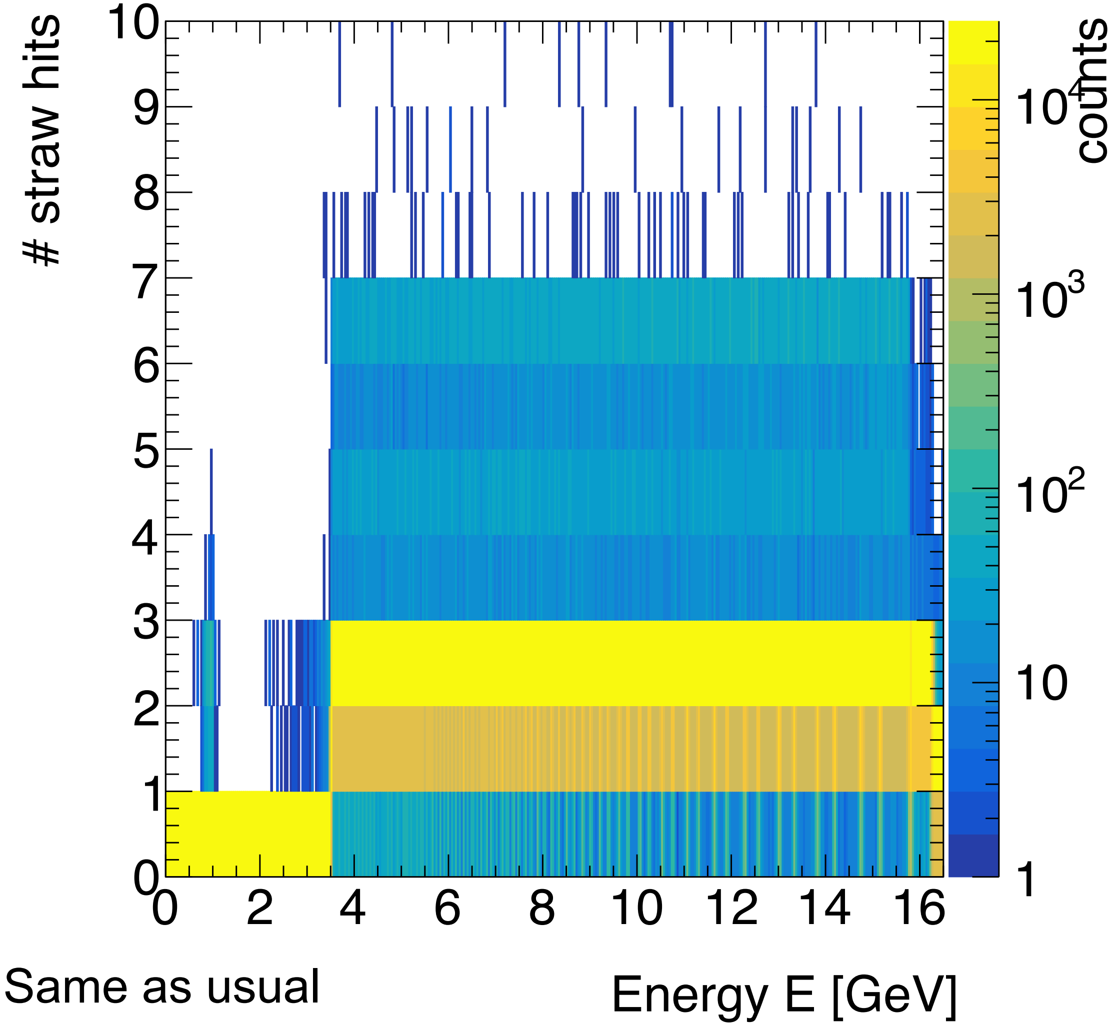


Double layer layout,
6 mm straws

Double layer layout, *6* mm straws

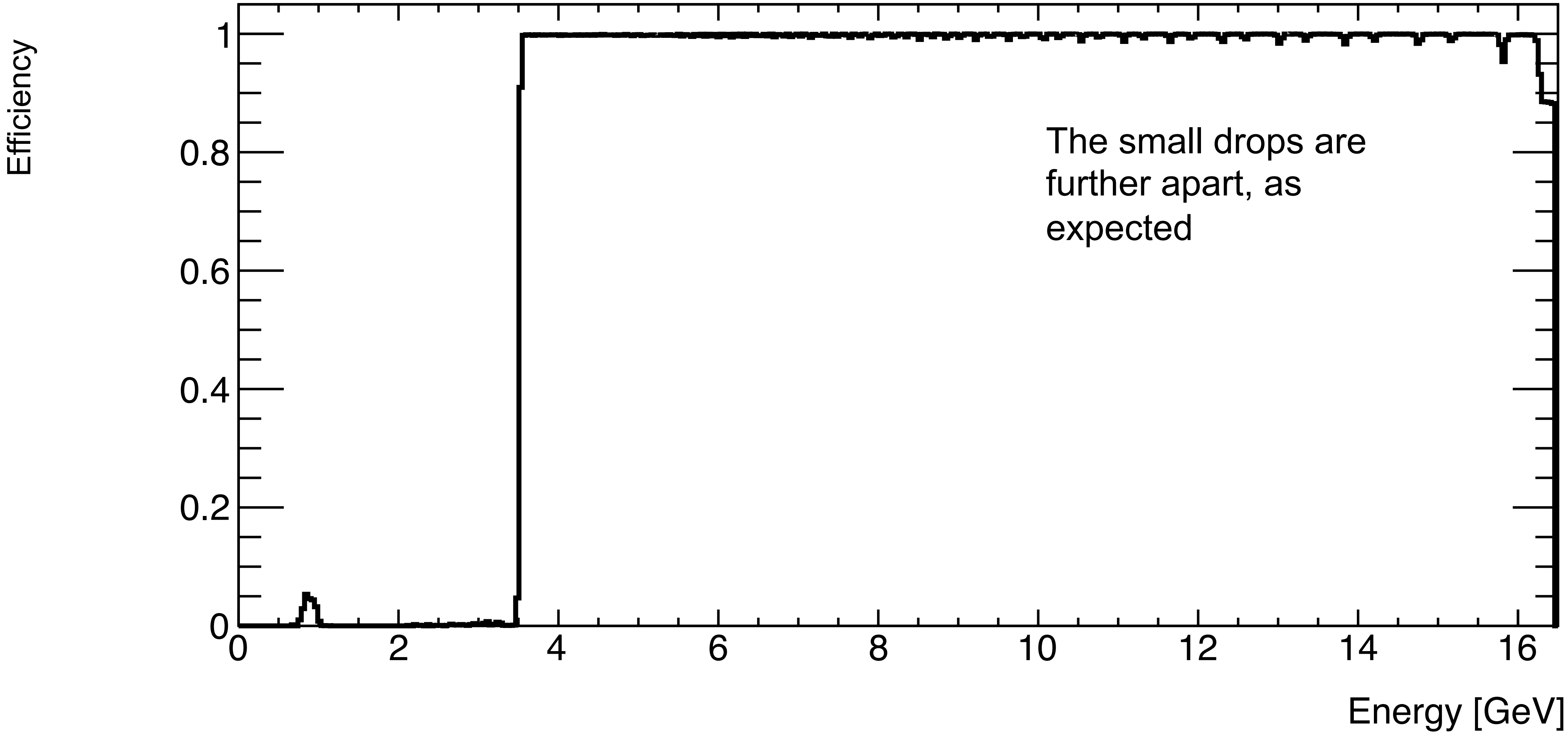
6.1 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 2 layer, 200 straws, 6 mm diameter





Same as usual

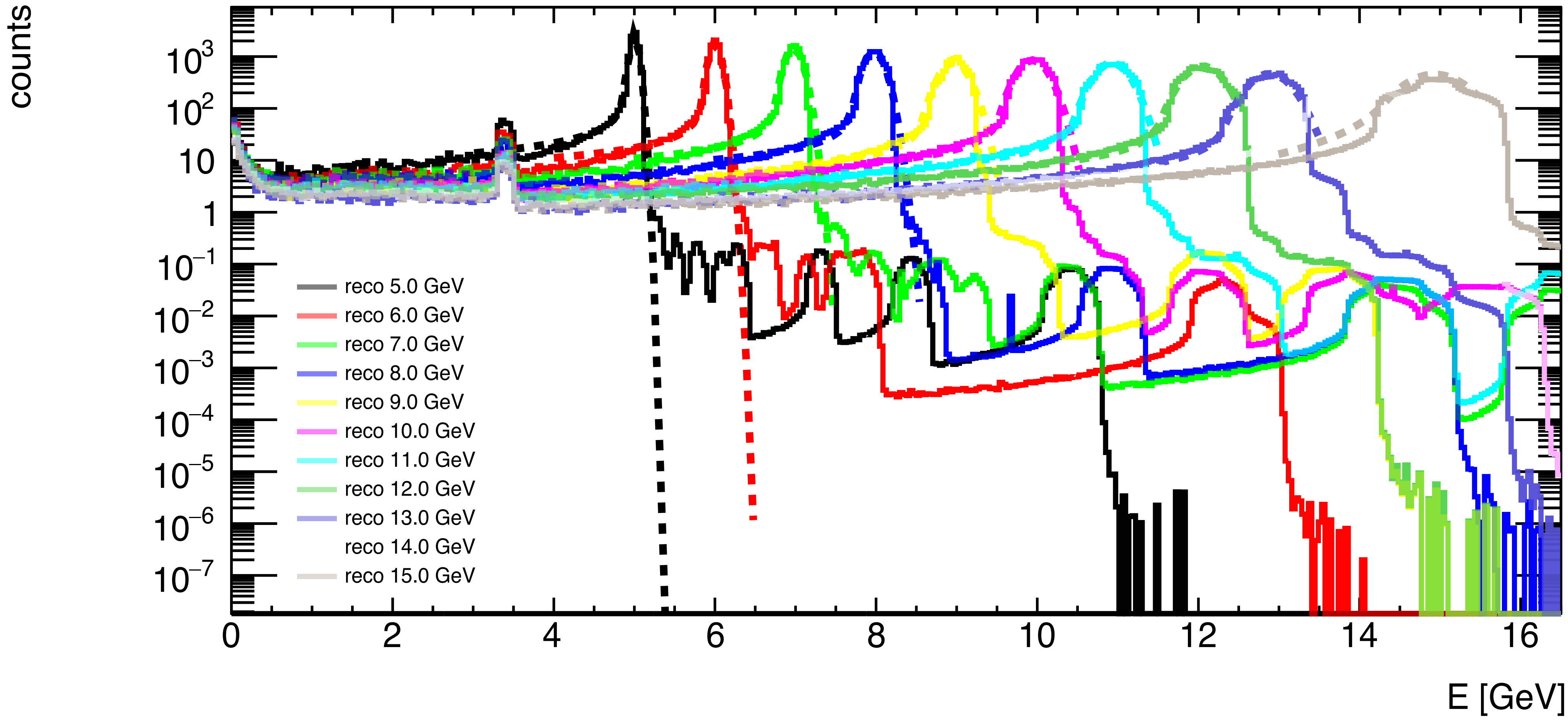
Double layer layout, *6* mm straws: efficiency



The small drops are further apart, as expected

Larger straws layout: energy resolution

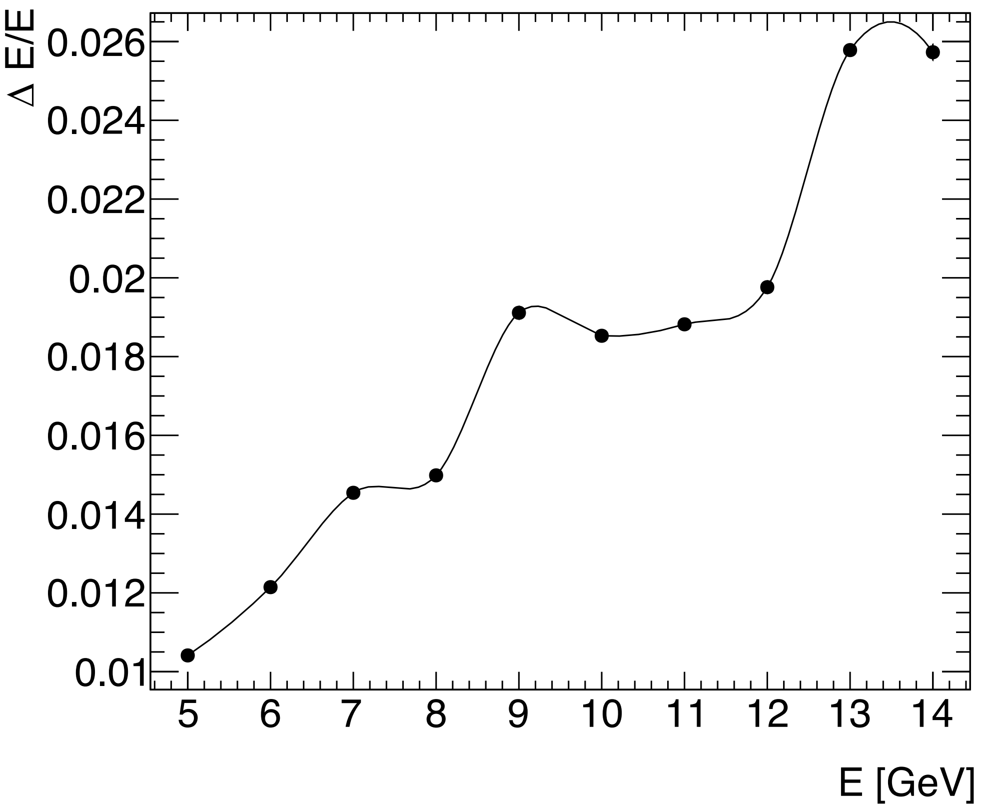
Broader peaks compared to 4 mm diameter straws



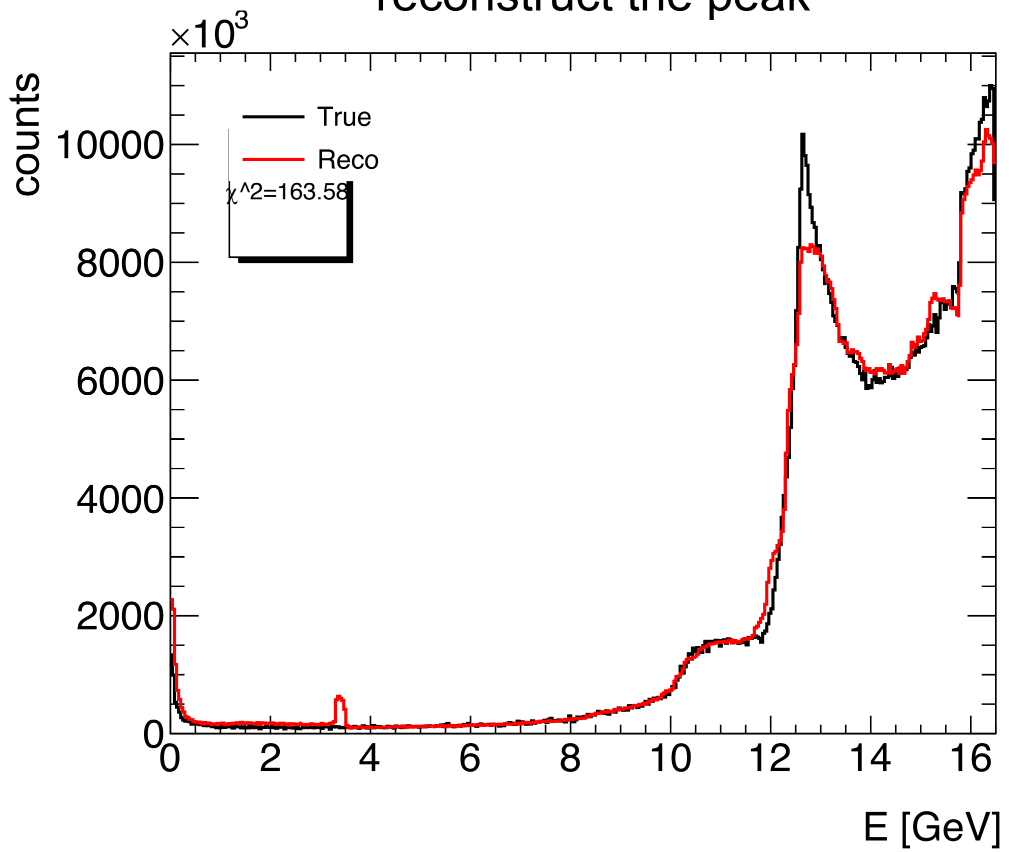
Double layer layout *6* mm straws : final measurements

6.1 mm X frequency, 16 mm Z frequency, 4 mm layer offset, 2 layers, 6 mm diameter

Larger energy resolution



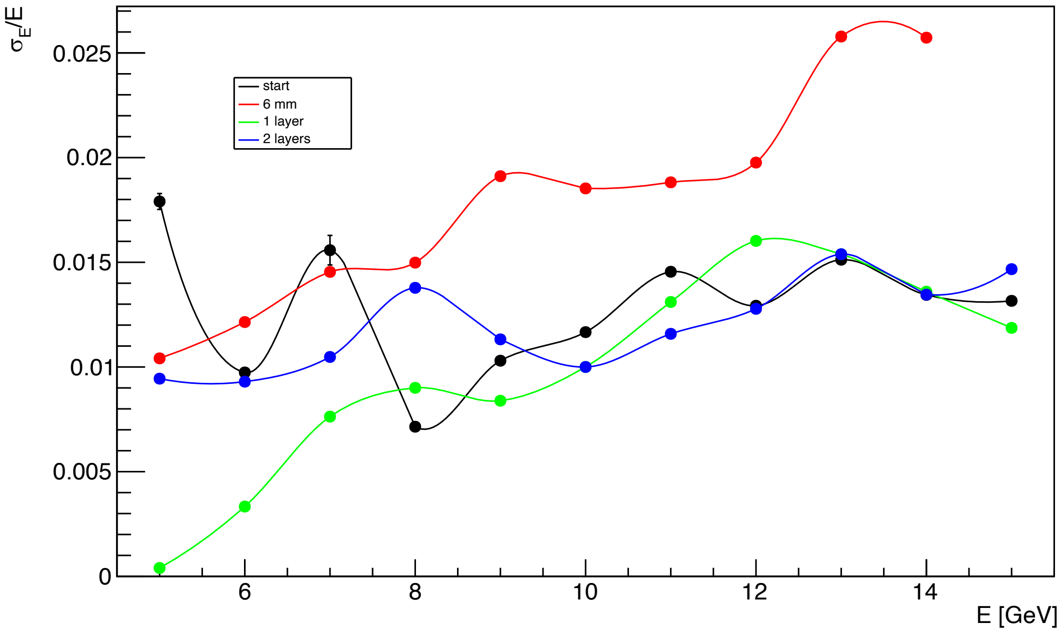
Unable to perfectly reconstruct the peak



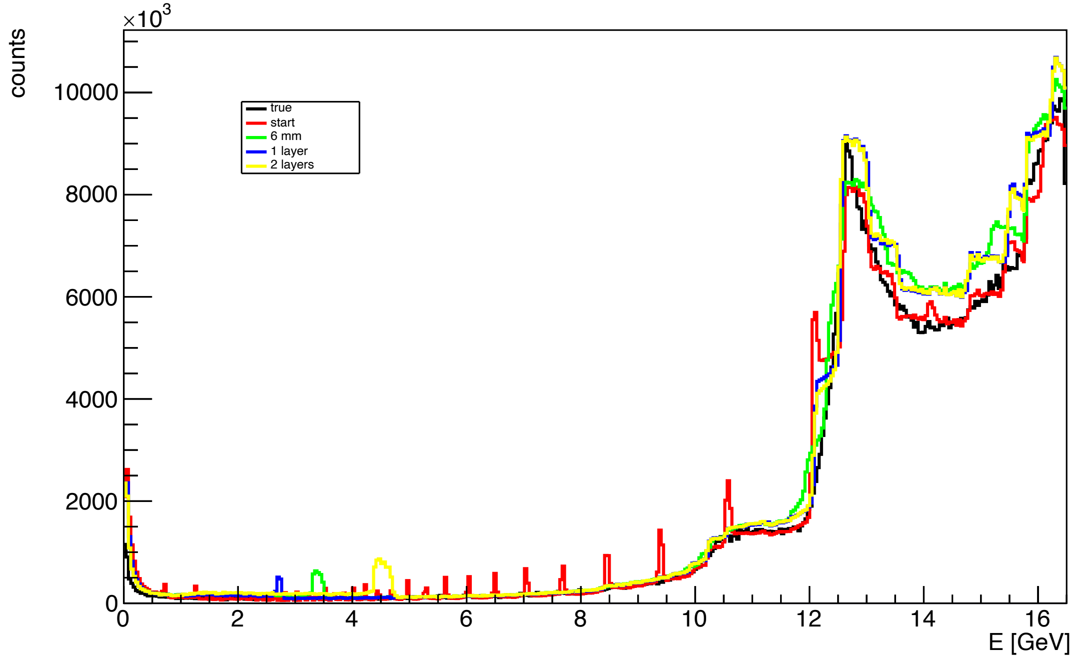
Summary

Comparing all the layouts

6 mm straws are worse than 4 mm straws
Energy resolution is not dependent on the number of layers



The energy reconstructed very good in all cases



Conclusion

- **The reconstruction method has been tried and tested**
- **The first layouts have been explored and some preliminary results obtained**
- **One layer is sufficient to detect a large majority of the electrons**
  - Two layers would provide security in case of a malfunctioning straw
- **Energy resolution is independent of the layout, but is strongly linked to the straw radius**
  - Possibility to use larger straws for lower energy electrons, while keeping resolution in the high energy region
  - More comprehensive study of the systematic errors is expected to highlight some layout dependance
- **Varied straw diameters and an added straw for high energy electrons should be studied**
- **Impact of systematic errors should be studied further**
  - e.g., small straw position displacement or one malfunctioning straw