HIGH-D

Bundesministerium
für Bildung
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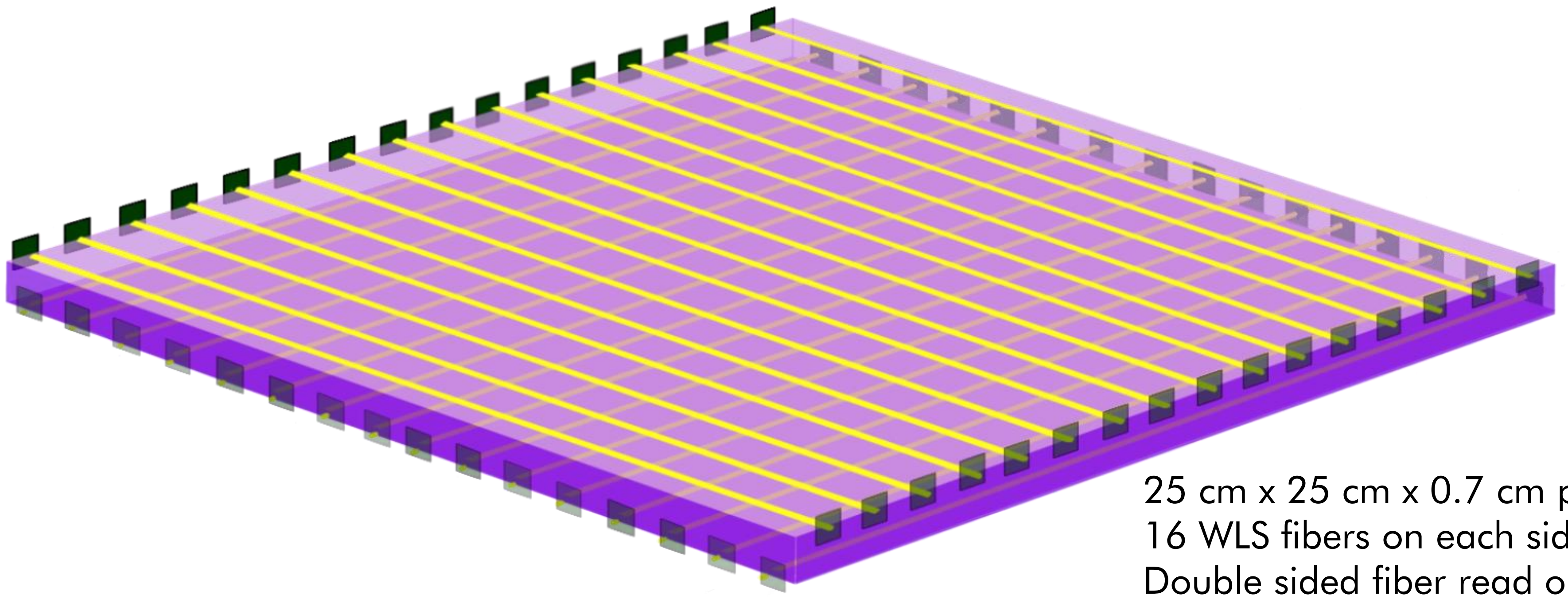
Reconstruction of the particle hit position using machine learning

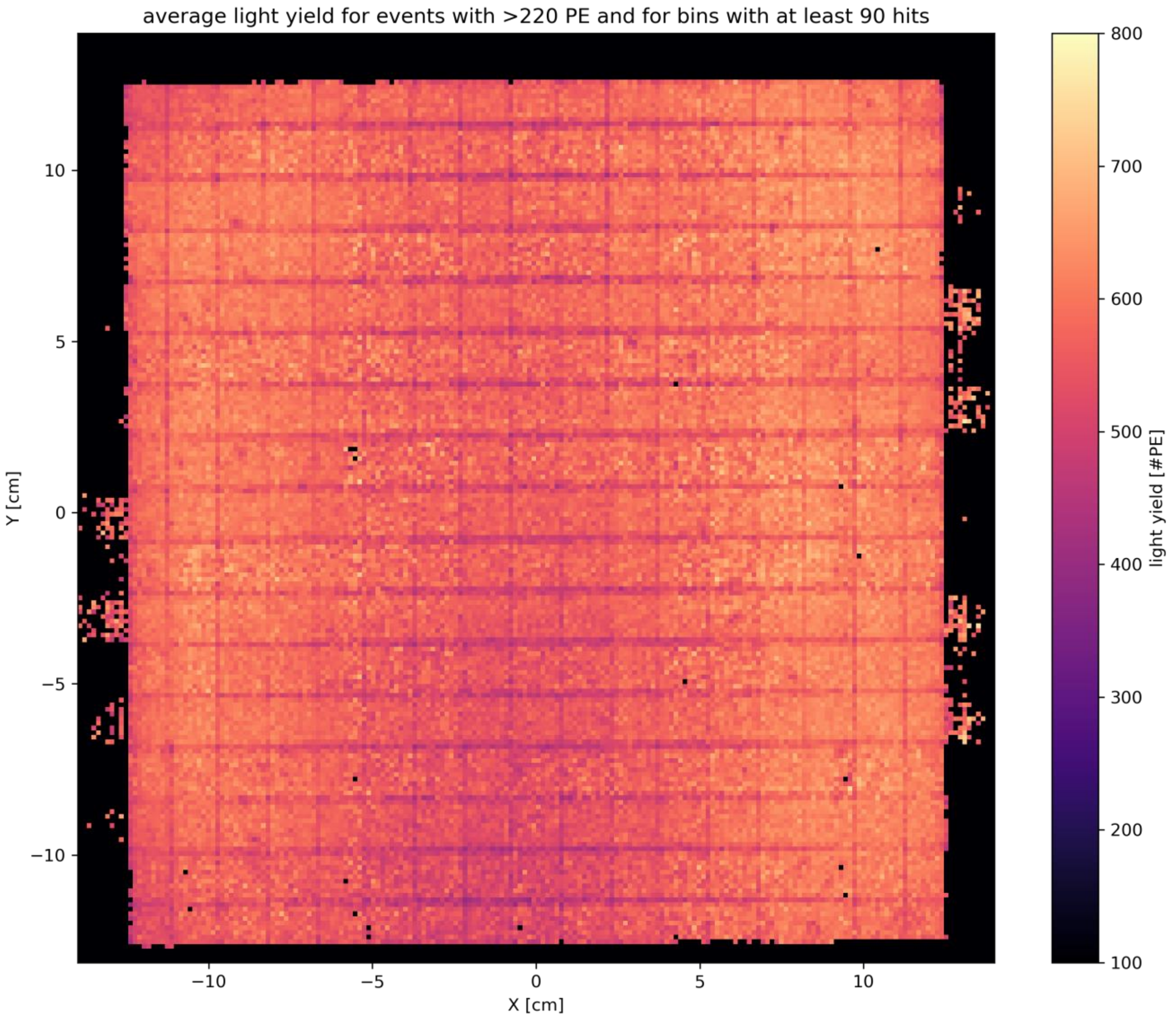
20.02.2024



25 cm x 25 cm x 0.7 cm plastic scintillator
16 WLS fibers on each side
Double sided fiber read out by SiPMs

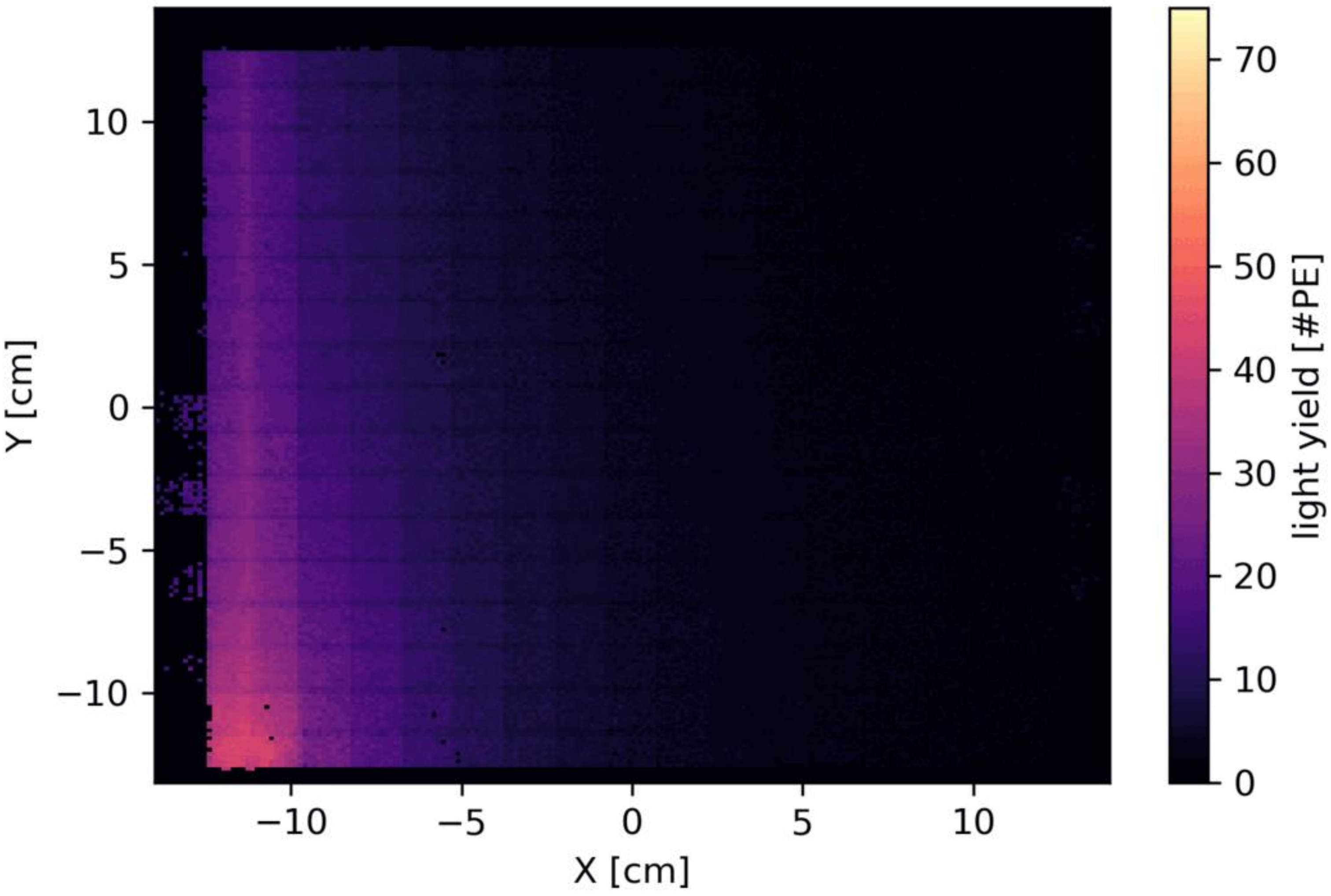
CheapCal: Fiber-structured, position sensitive plastic scintillator detector

- For the test beam we know the hit position from the reconstructed telescope tracks
  - Challenge: Reconstruct the hit position from the response of the 64 SiPMs



First results from the test beam

- Total light yield rather homogeneous over the prototype in the test beam but some regions collect more light than others



- Response of individual SiPMs inhomogeneous
    - Probably due to reflections, different optical coupling, groove quality etc
    - Calibration not trivial and needs a lot of data analysis

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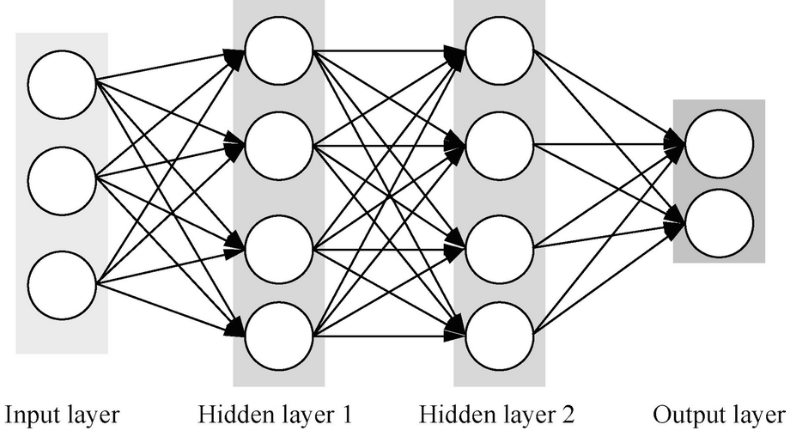
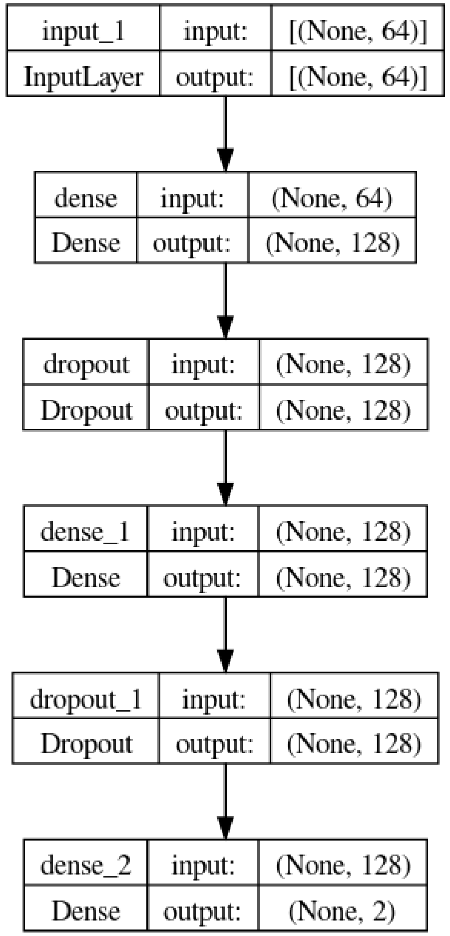


Alternative approach:
Train a neural network (NN) on the data to learn and exploit the non-linear response for fast hit position reconstruction

- Input features:
  - Light yields of the 64 SiPMs
- Deep layers:
  - Two dense layers with 128 neurons and dropout
- Output:
  - Linear output of two parameters (x, y)
- Training:
  - Minimization of the mean squared error of the output (x, y) and the expected hit position from the telescope tracks



Activation: ReLU

Activation: ReLU

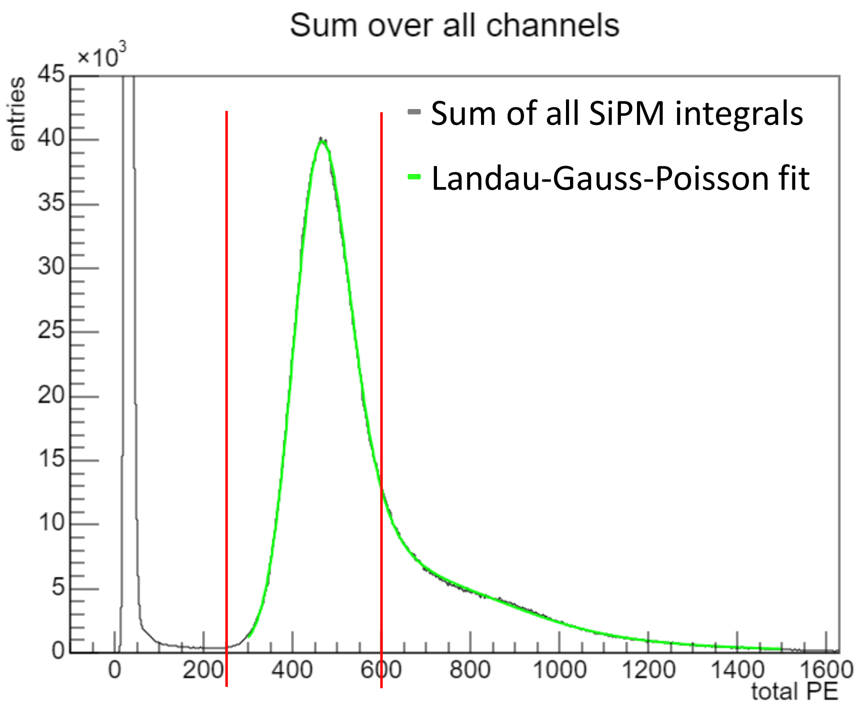
Activation: Linear

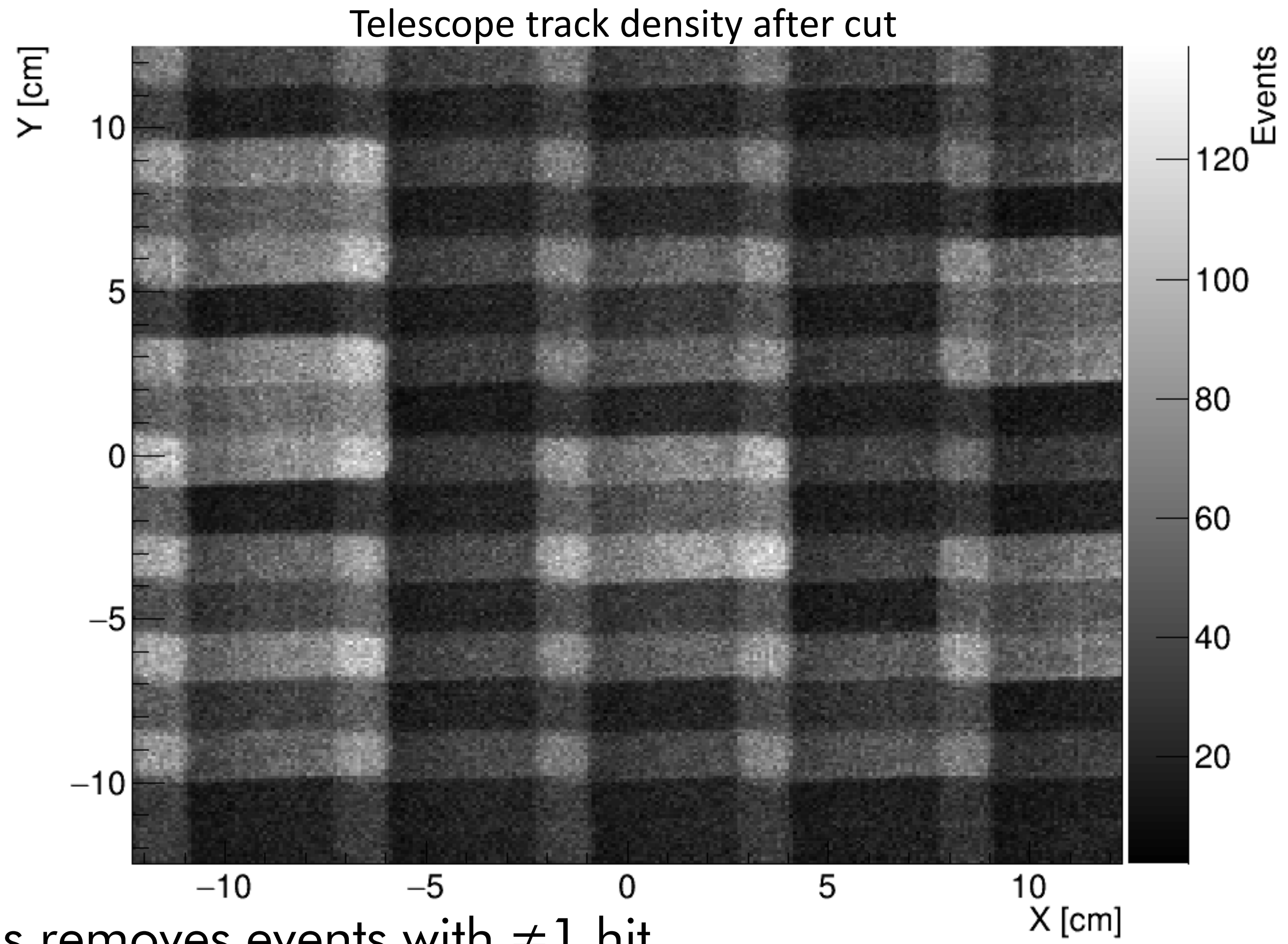
TensorFlow

Keras

scikit learn

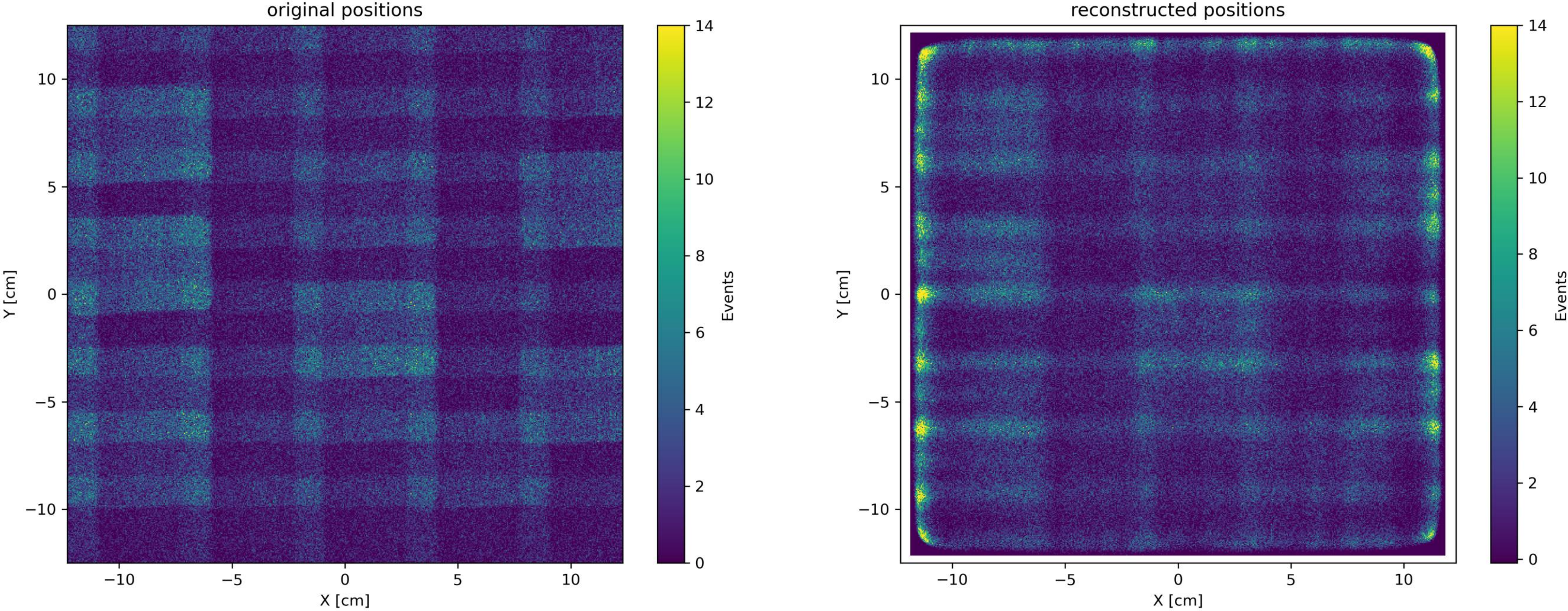
wavecatcher-analysis



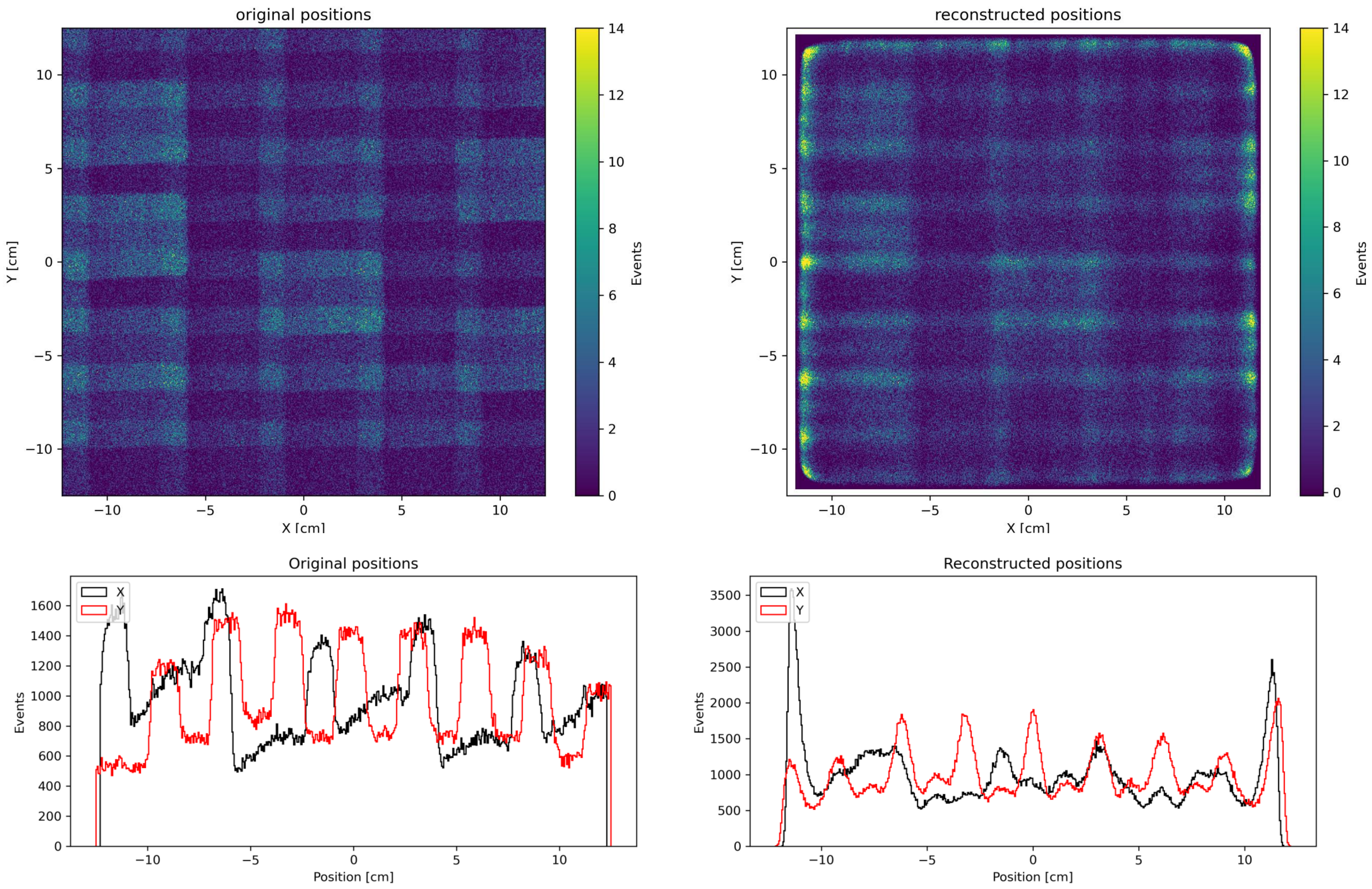


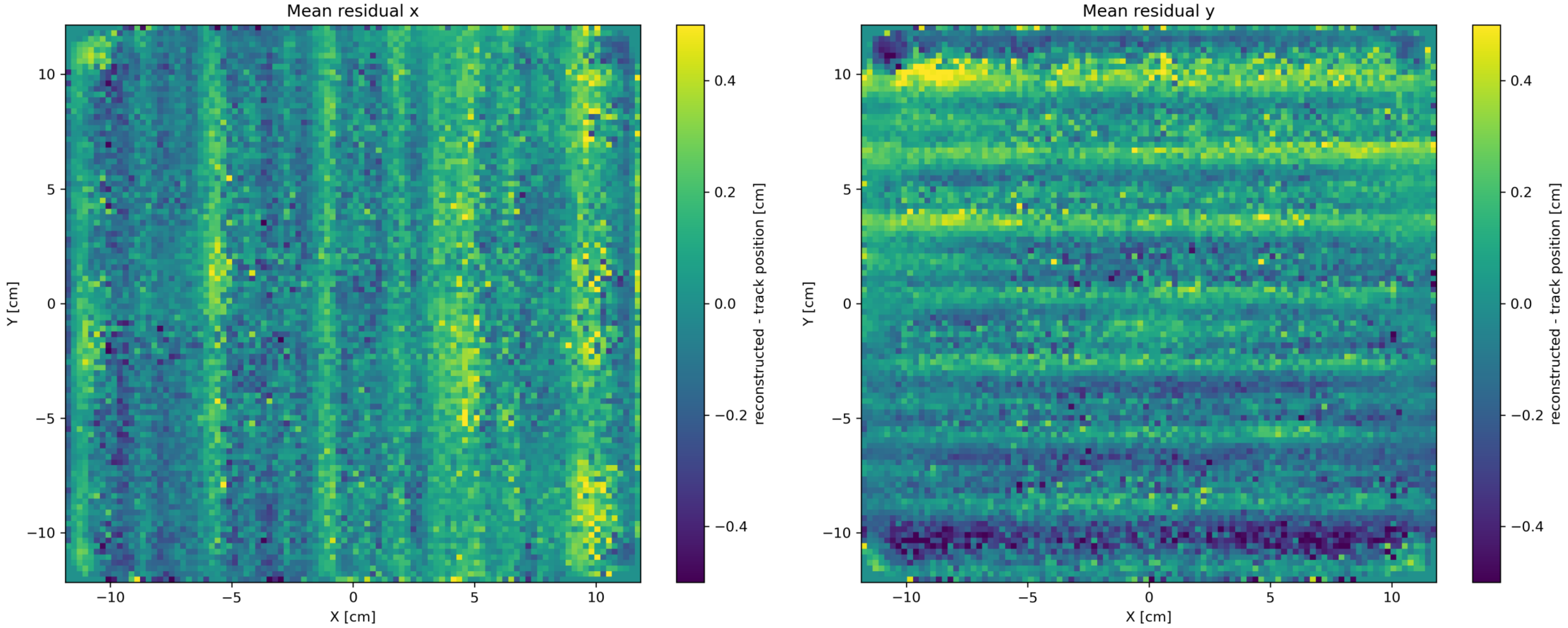
Data preparation:

- Cut on 250 - 600 photo-electrons removes events with $\neq 1$ hit
- Cut on -12.3< x <12.3, -12.5< y <12.5 cm removes events with track outside the scintillator
- Inhomogeneous track density could lead bias in the training
  - Events are weighted by the amount of tracks in a bin (250x250 bins)
- Data is randomized and split to 80% training and 20% validation data
  - 2 M events for training and 0.5 M validation



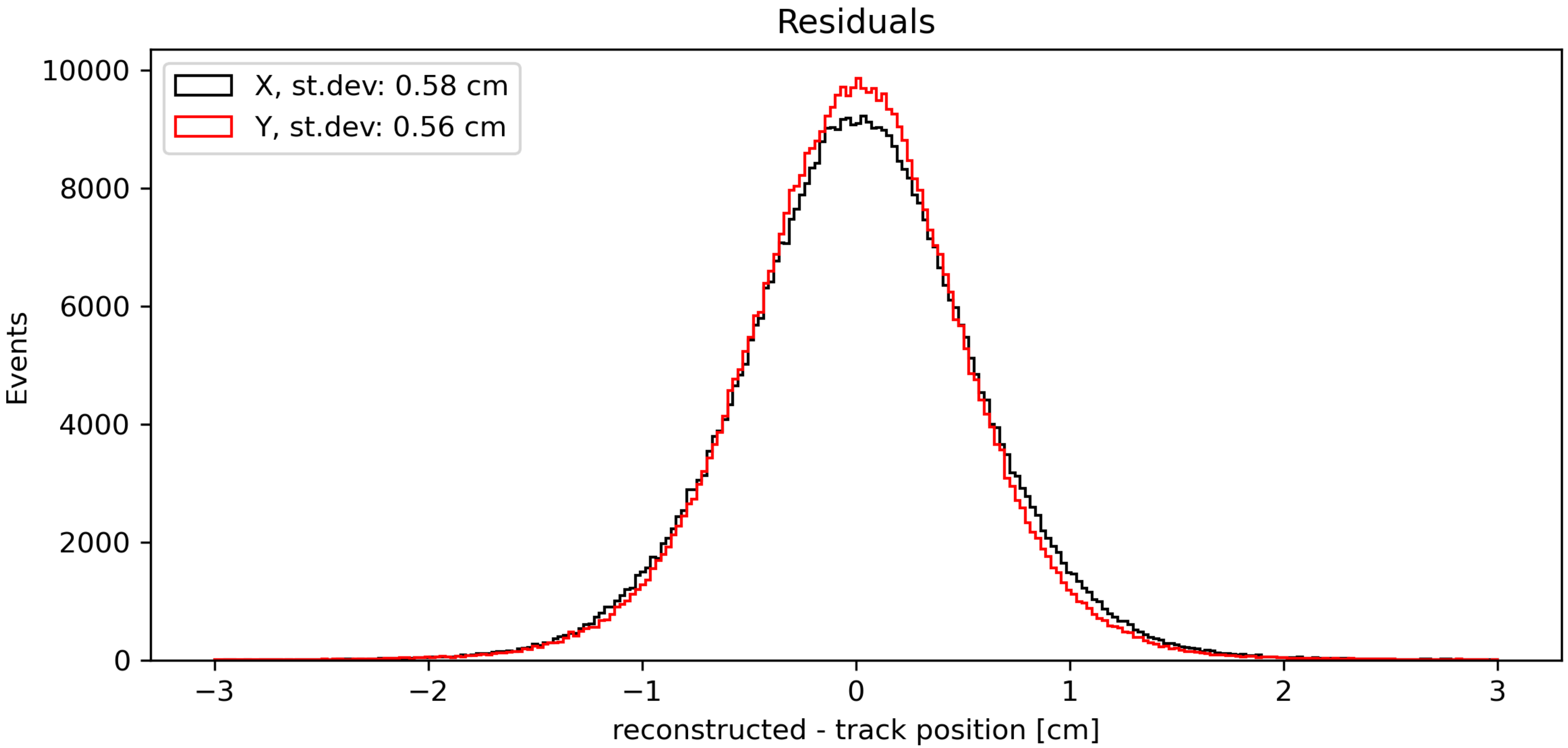
- Performance of the reconstruction is tested with 0.5 M validation events
  - Homogeneous reconstruction of the track position in the central region
  - Bias visible at the corners of the scintillator plate


original positions
reconstructed positions
X [cm]
Y [cm]
Events
Original positions
Reconstructed positions
X
Y
Position [cm]
Events

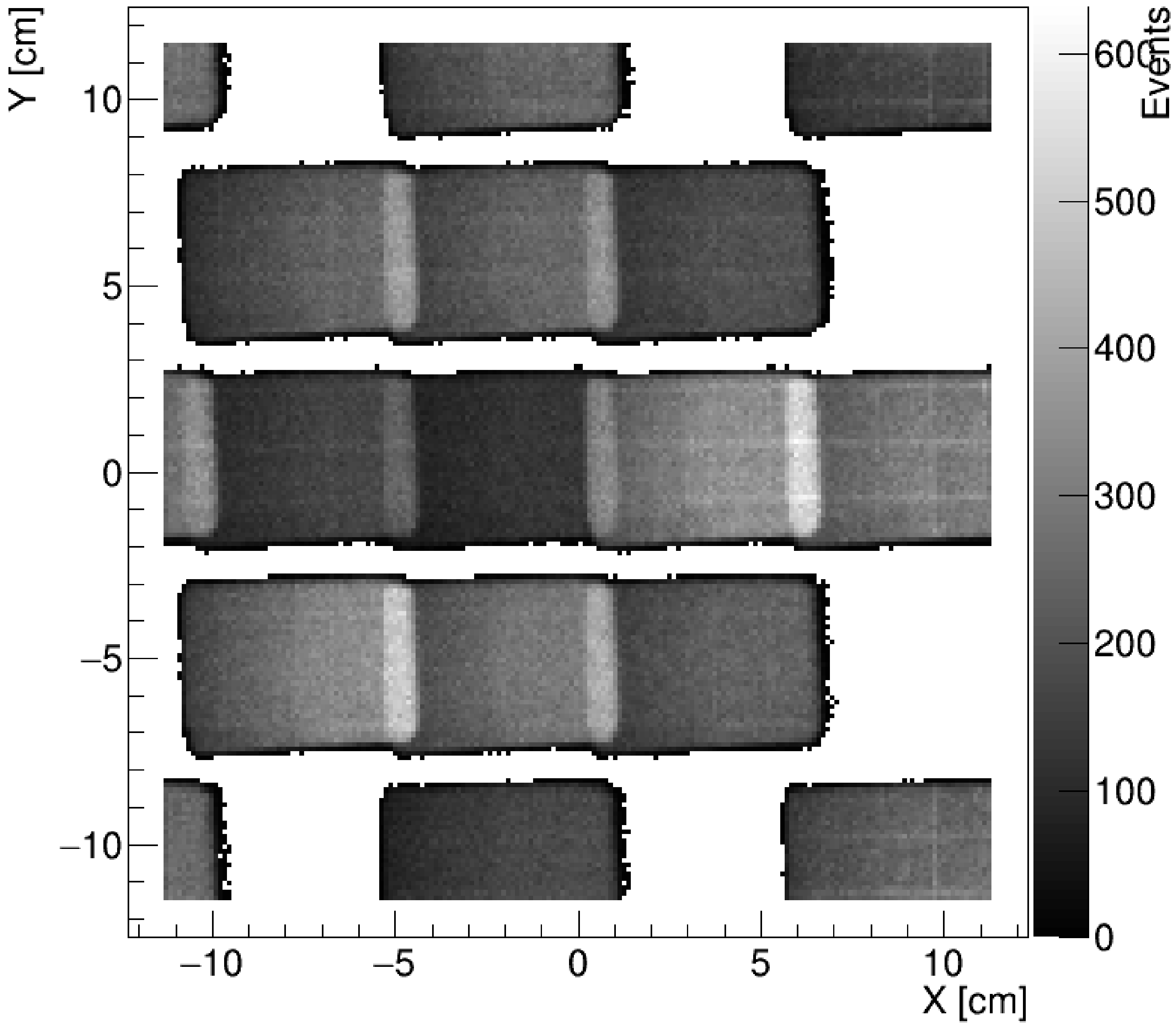


Averaged residuals show the bias of the reconstruction

- Larger bias at the edges and systematically along certain fibers

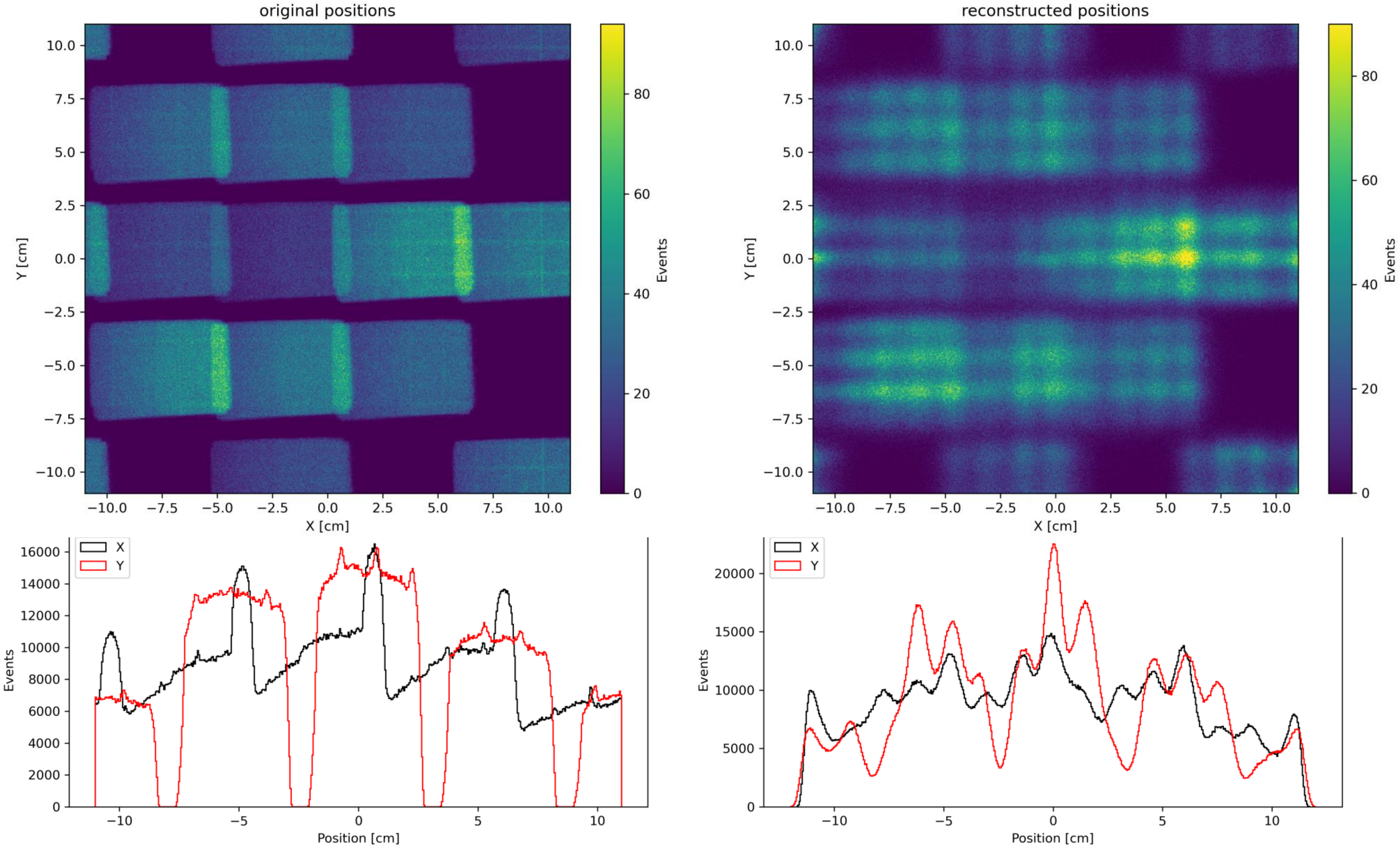


- A standard deviation of <0.6 cm can be reached with this simple model (fiber spacing 1.5 cm)

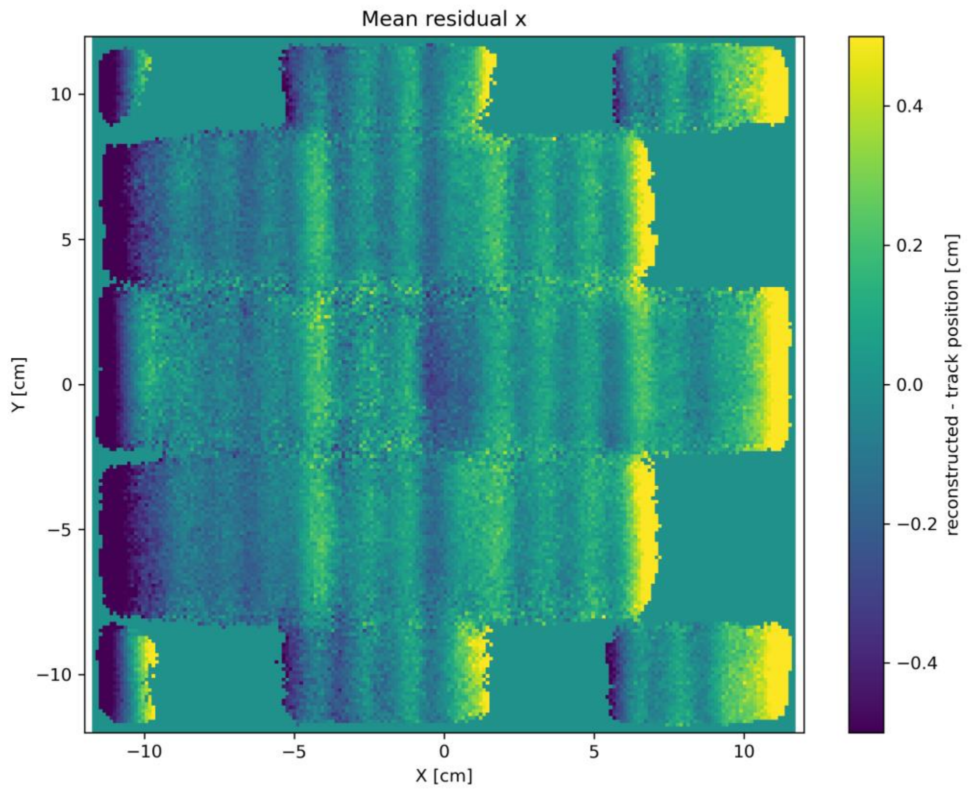


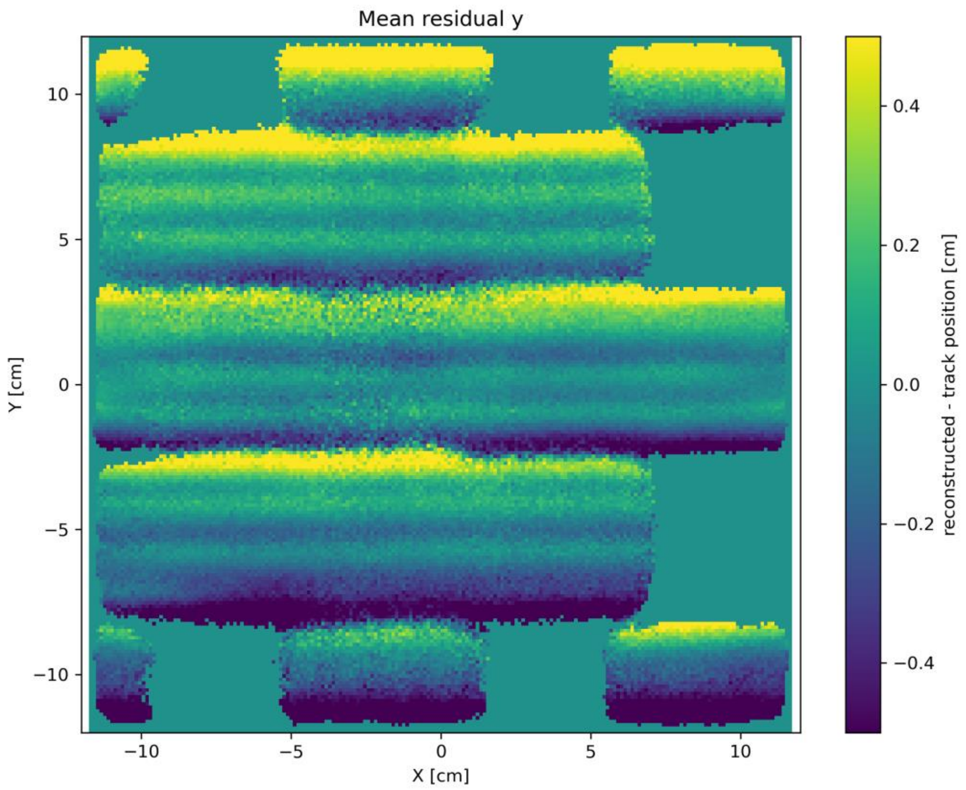
Testing NN performance with independent test beam runs

- Cut -11 cm< x, y <11 cm
- Same cut on light yield
- 4.5 M events for testing

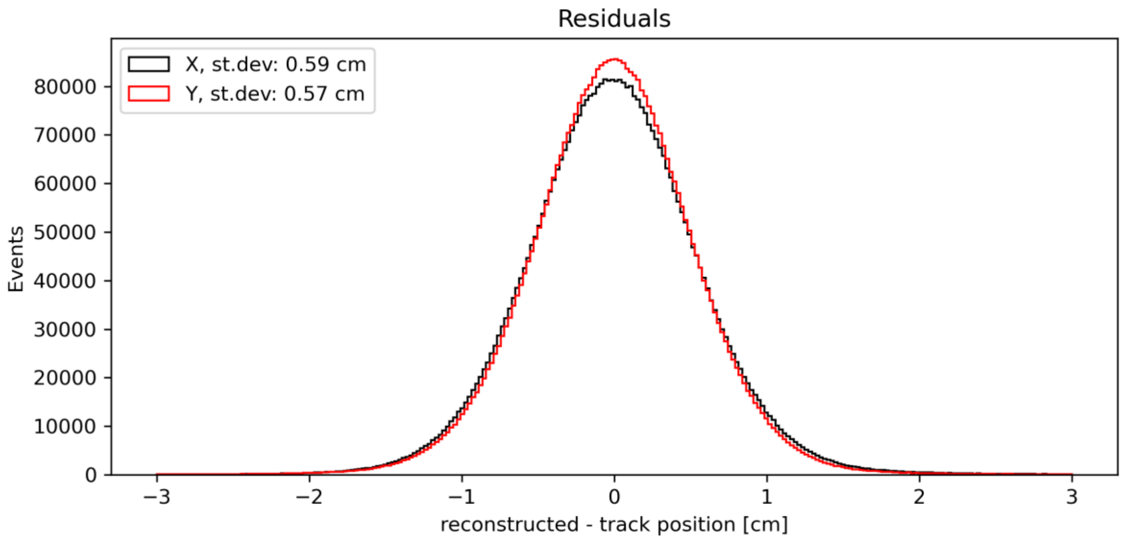


- Performance with 4.5 M events from independent runs
    - Clustering along fibers again visible



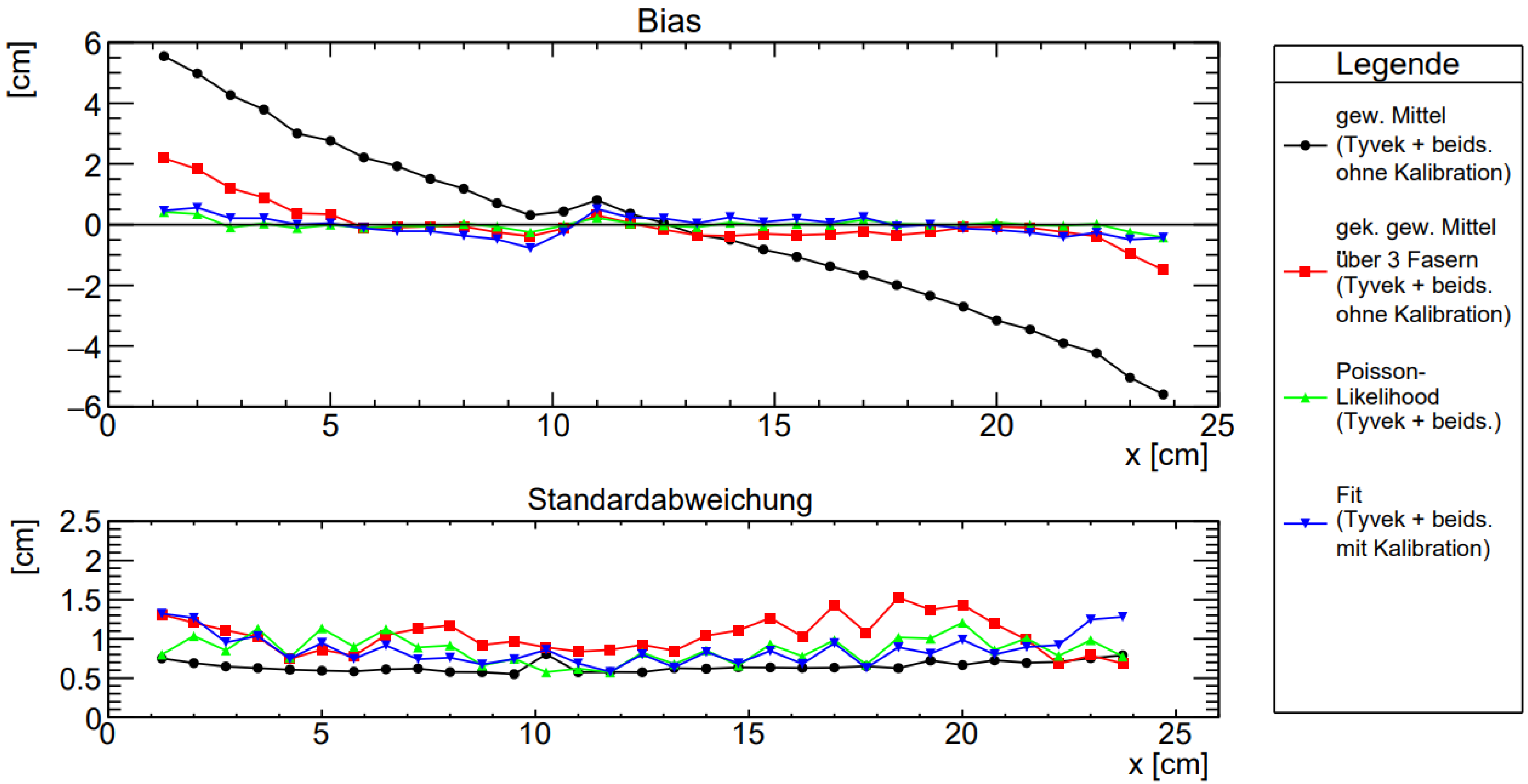


- Performance with 4.5 M events from independent runs
  - Similar resolution
  - Strong systematic bias visible
    - To be followed up

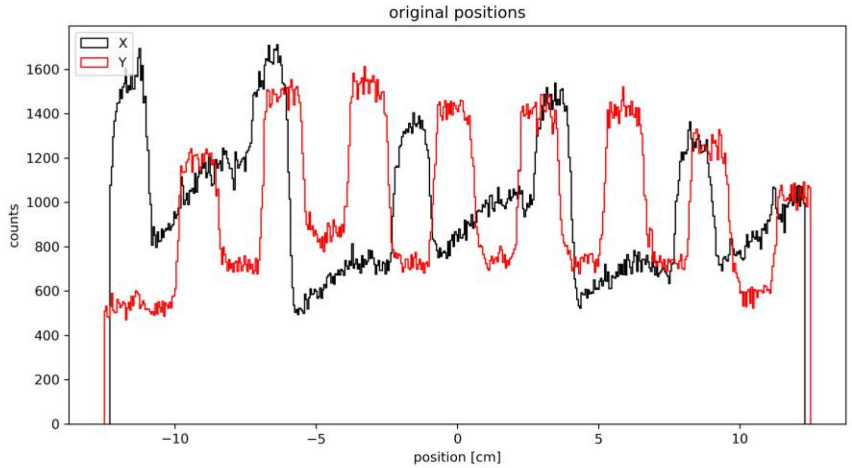


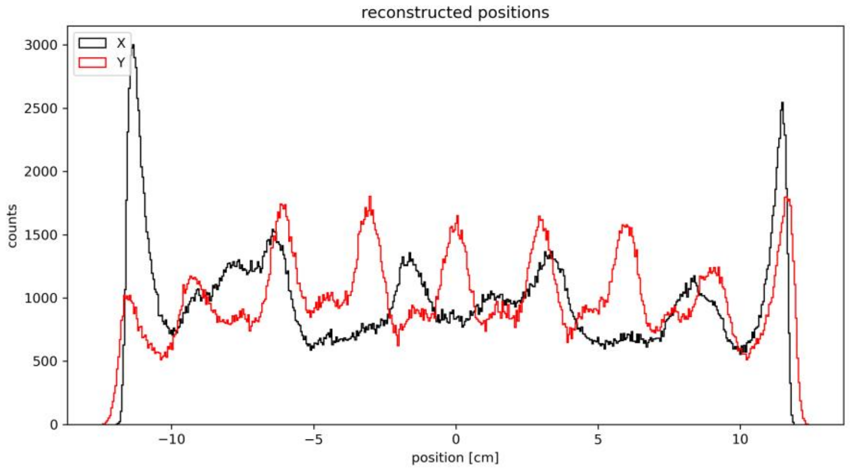
Summary

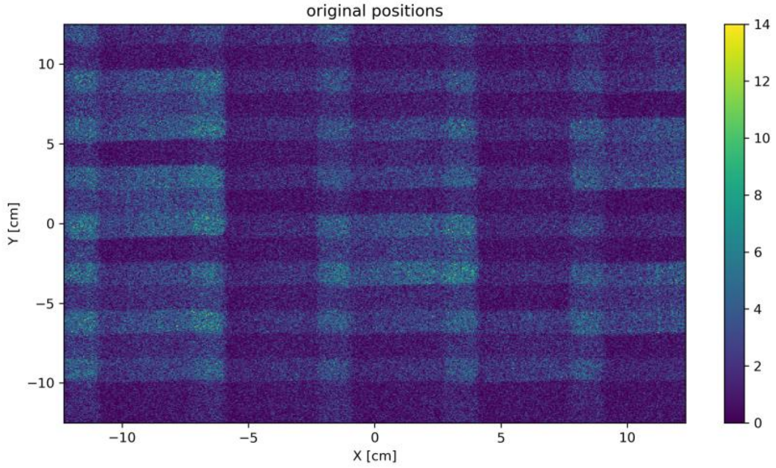
- The response of our prototype detector is inhomogeneous, complicating traditional methods for the reconstruction of hit positions
- Using a very simple neural network it is possible to reconstruct the hit position of a MIP with a standard deviation of better than 0.6 cm in x and y, without the need for manual calibration

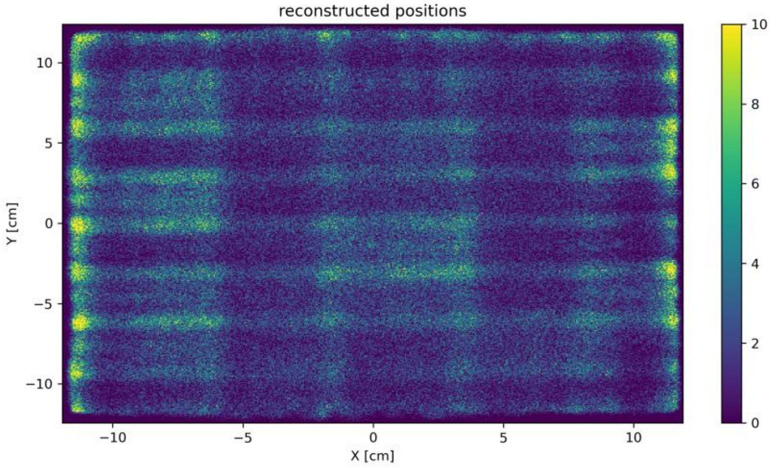


- Several reconstruction methods explored by Ben Skodda w/ first prototype in 1D



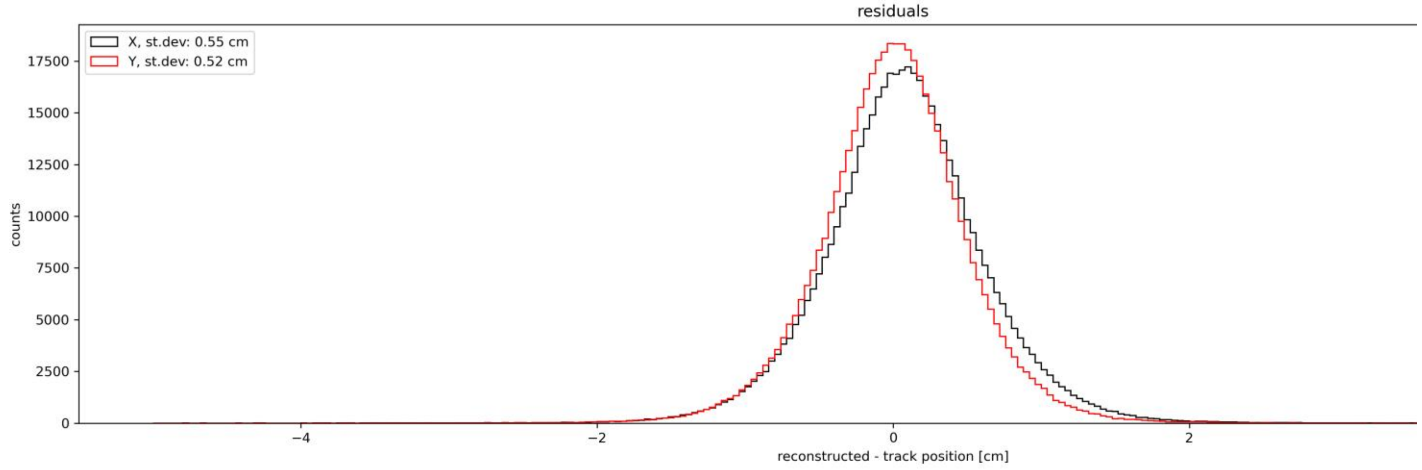


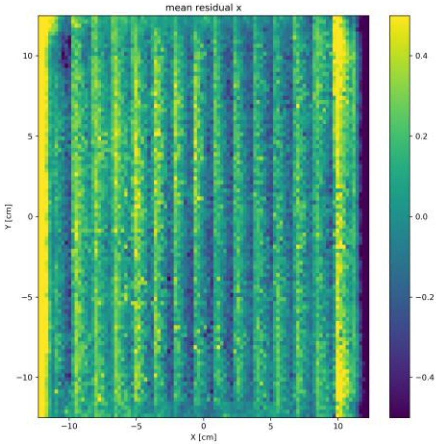


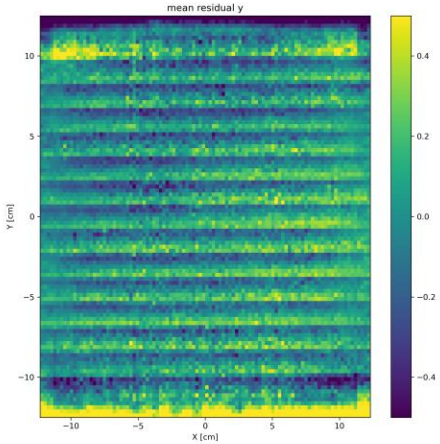


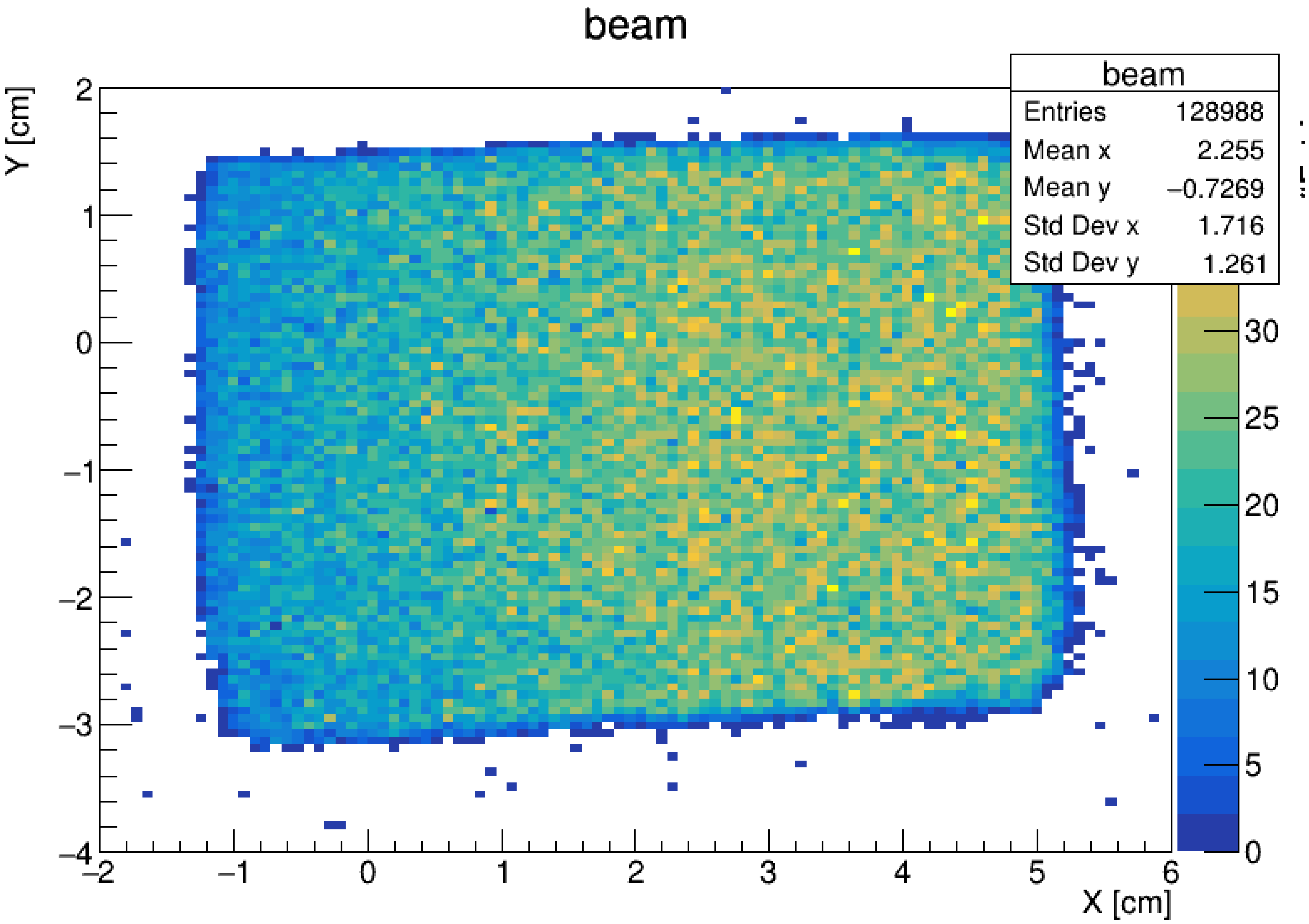
Convolutional NN with integrals:

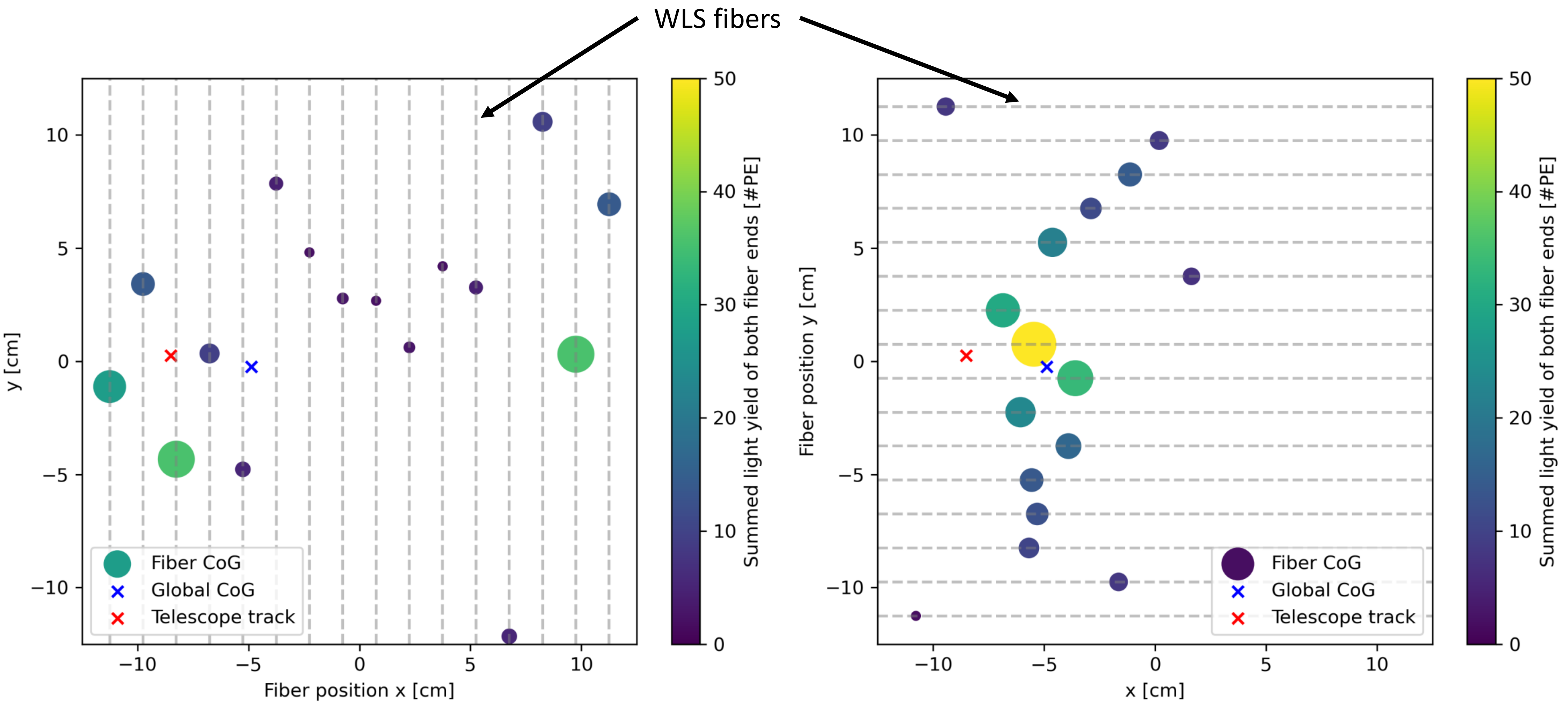
- Similar resolution
- Better in the corners
- Stronger bias visible at fibers








beam
beam
Entries 128988
Mean x 2.255
Mean y −0.7269
Std Dev x 1.716
Std Dev y 1.261
Y [cm]
X [cm]
2
1
0
−1
−2
−3
−4
−2
−1
0
1
2
3
4
5
6
30
25
20
15
10
5
0



Naive approach to reconstruct the hit position from the integral of the SiPM signal:

- Center of gravity $CoG = \frac{\sum LY_i * x_i}{\sum LY_i}$ for each fiber and from these the global CoG of each event
  - CoG approach needs calibration