Updates from machine learning of TOF

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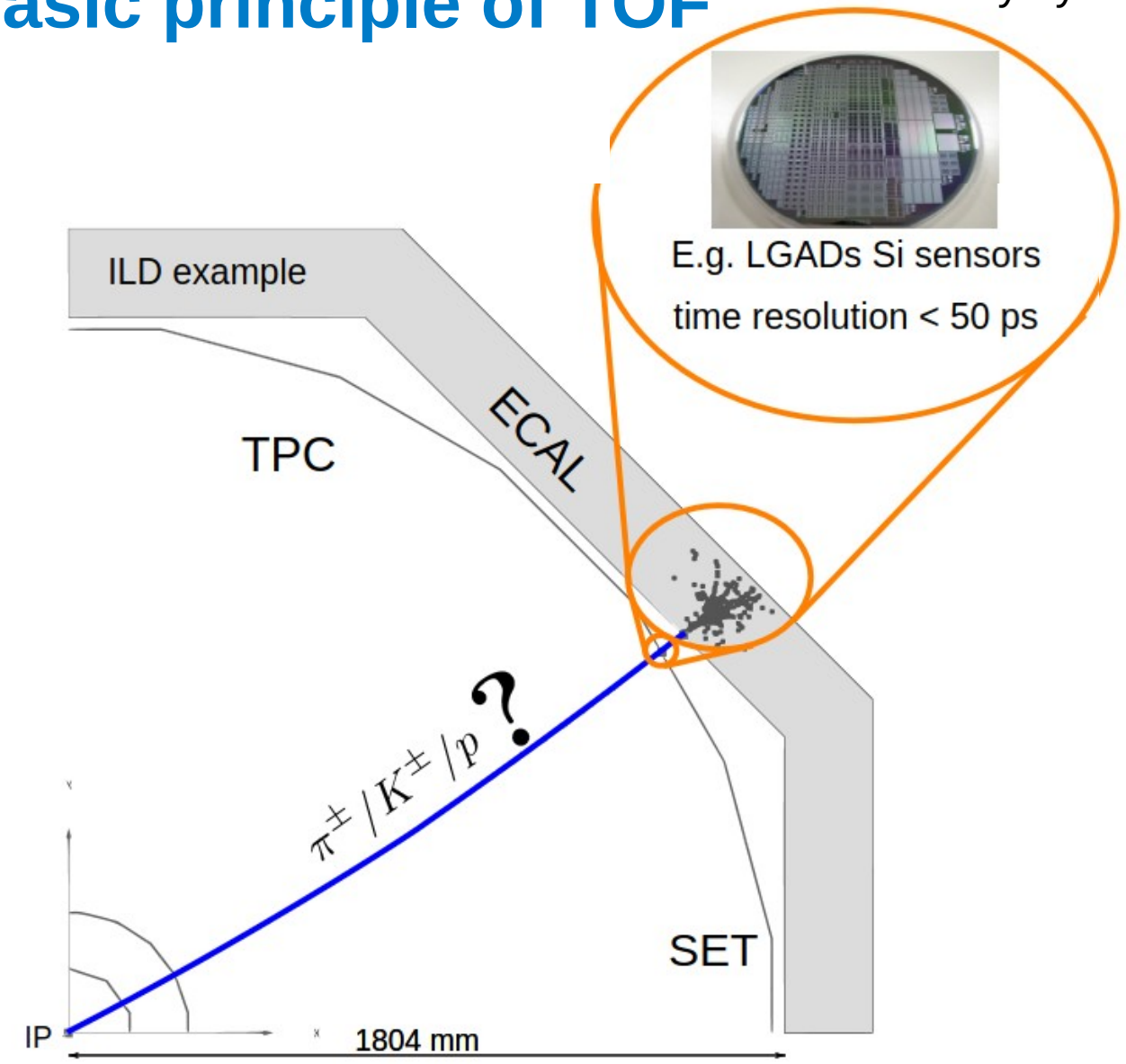
HELMHOLTZ

DESY.

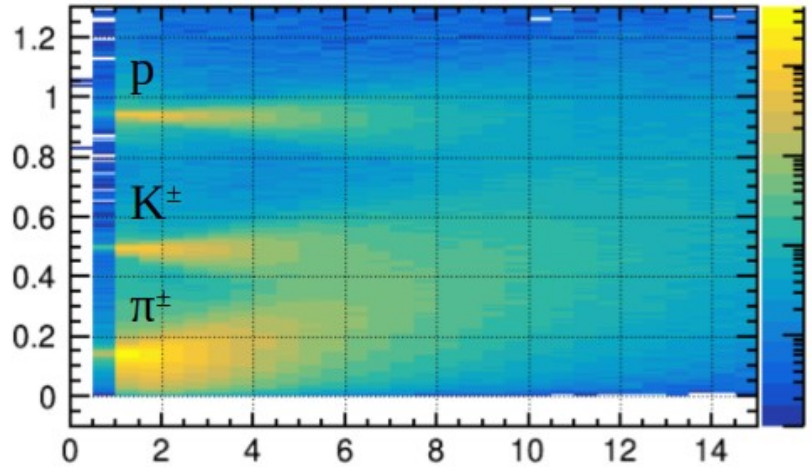
Basic principle of TOF

Study by Bohdan Dudar

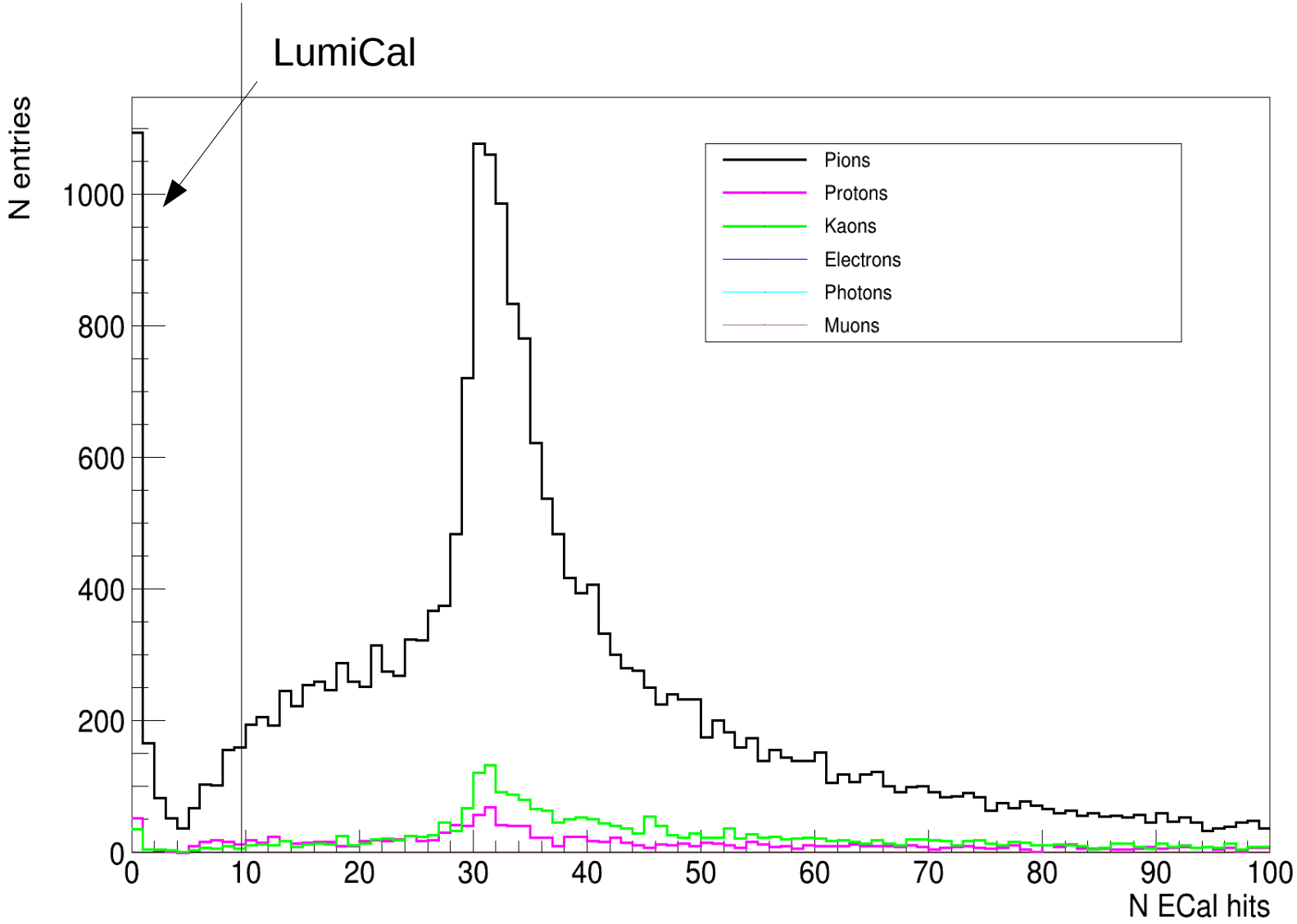


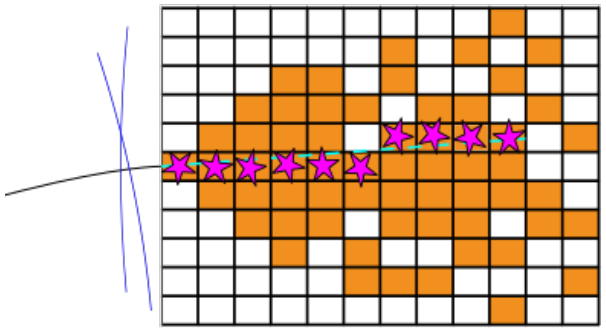
$$\beta = \frac{\ell_{\text{track}}}{c \cdot \text{TOF}}$$

$$m = \frac{p}{\beta}\sqrt{1-\beta^2}$$



N hits in the ECal for different particles





Average or fit of 10 hits closest to the extrapolated line

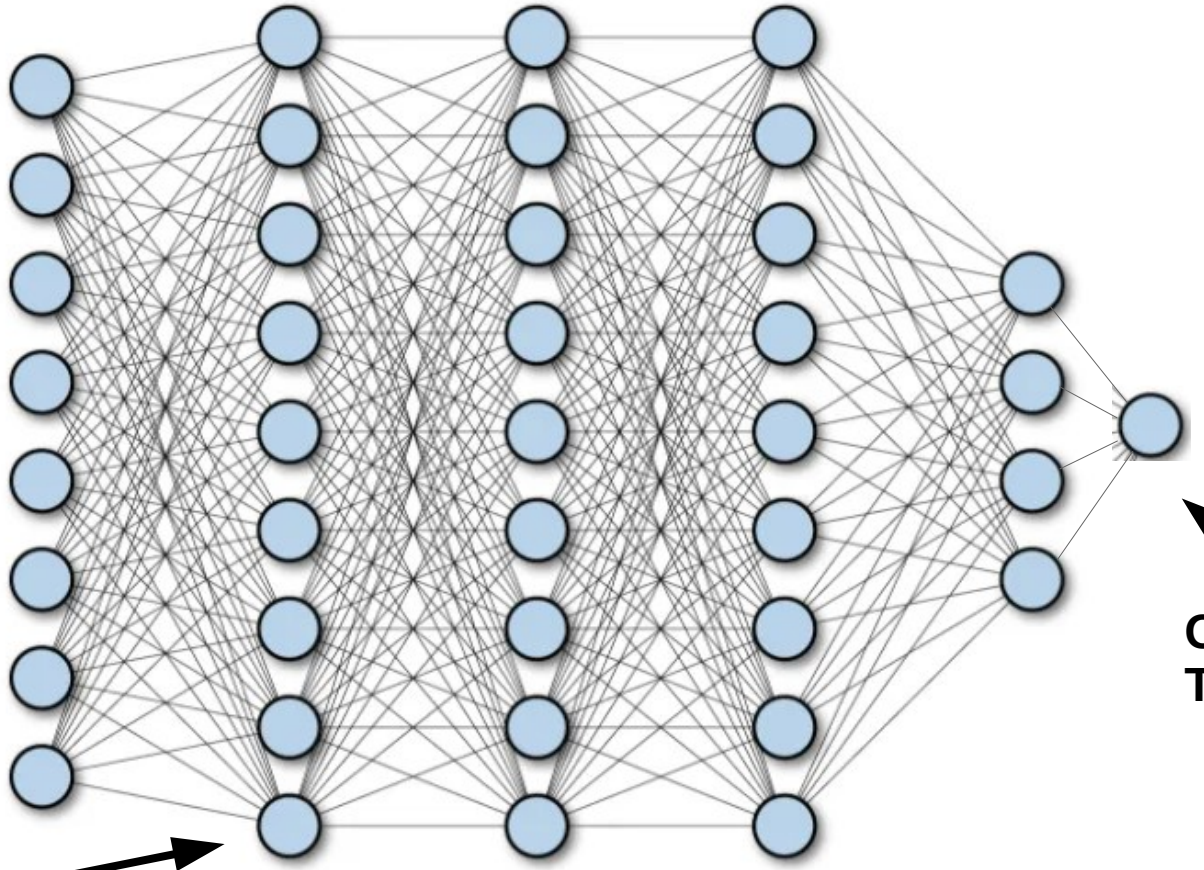
Improving understanding of number of hits in the shower (Ecal)

Fully connected neural network

First choice, main reason: the easiest one to start off

Input layer: 53 nodes:
- Track p, pT, theta

For each of 10 Ecal hits:
- time (smeared 50 ps)
- energy
- distance to track (coordinates)

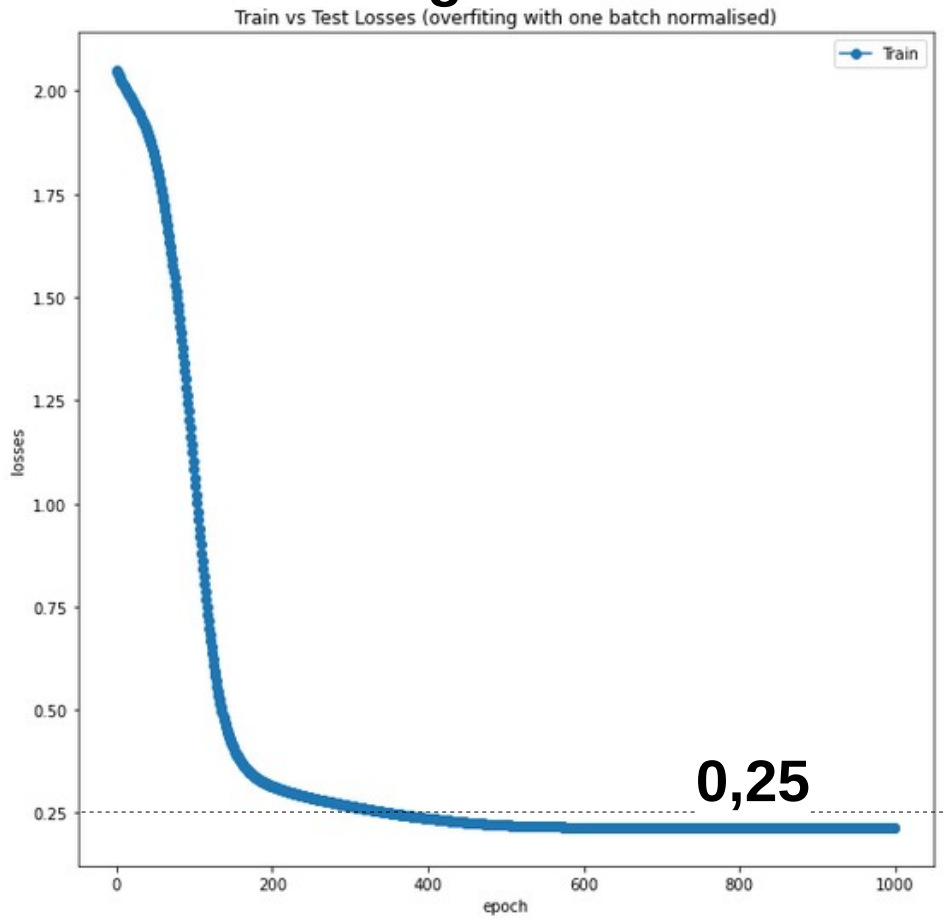


Output - TOF

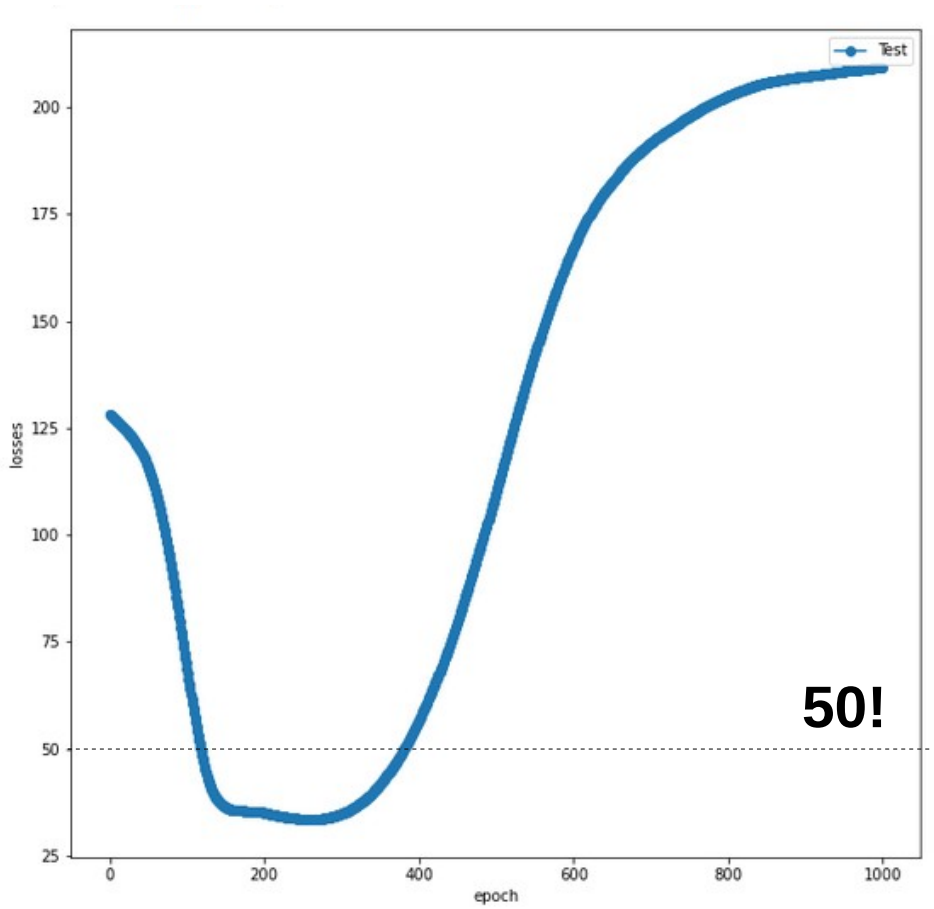
2 layers (60 nodes each)

Fully connected neural network: trying to overfit 1 batch

Training loss



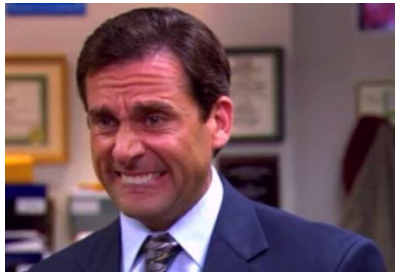
Test loss



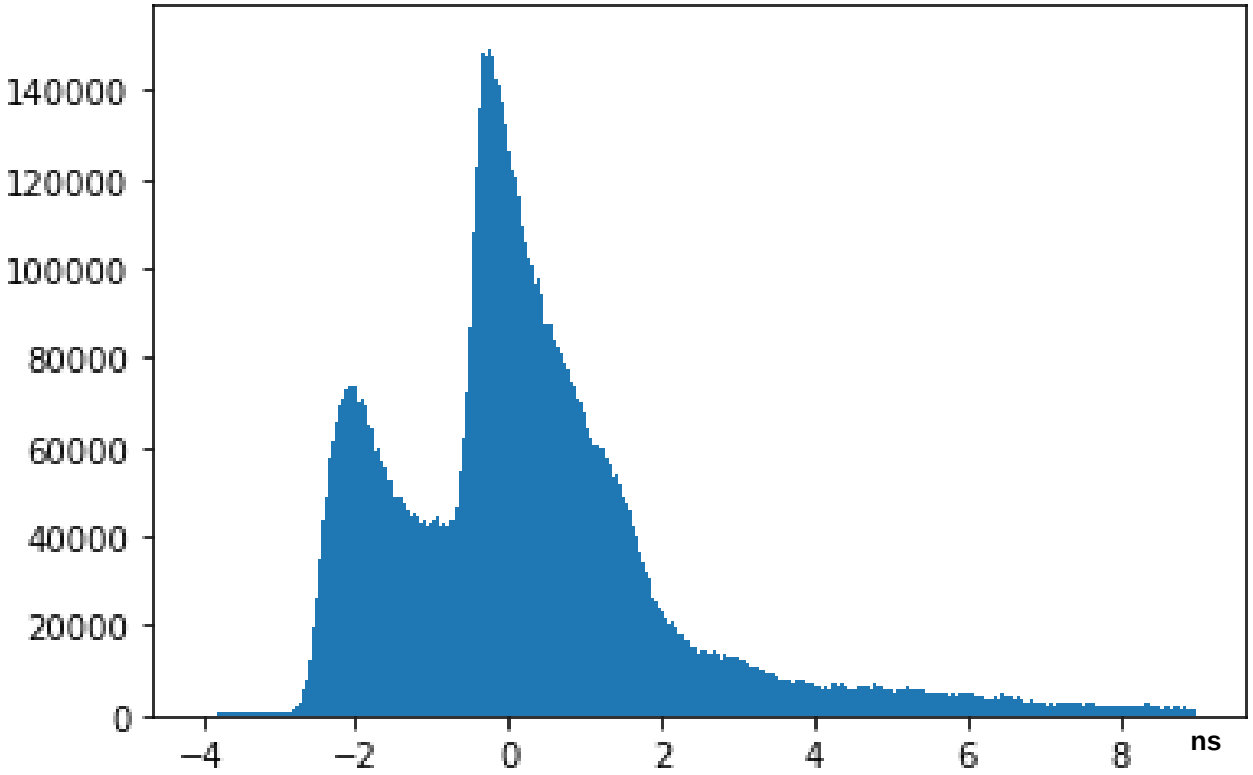
“Successful overfitting”

Fully connected neural network

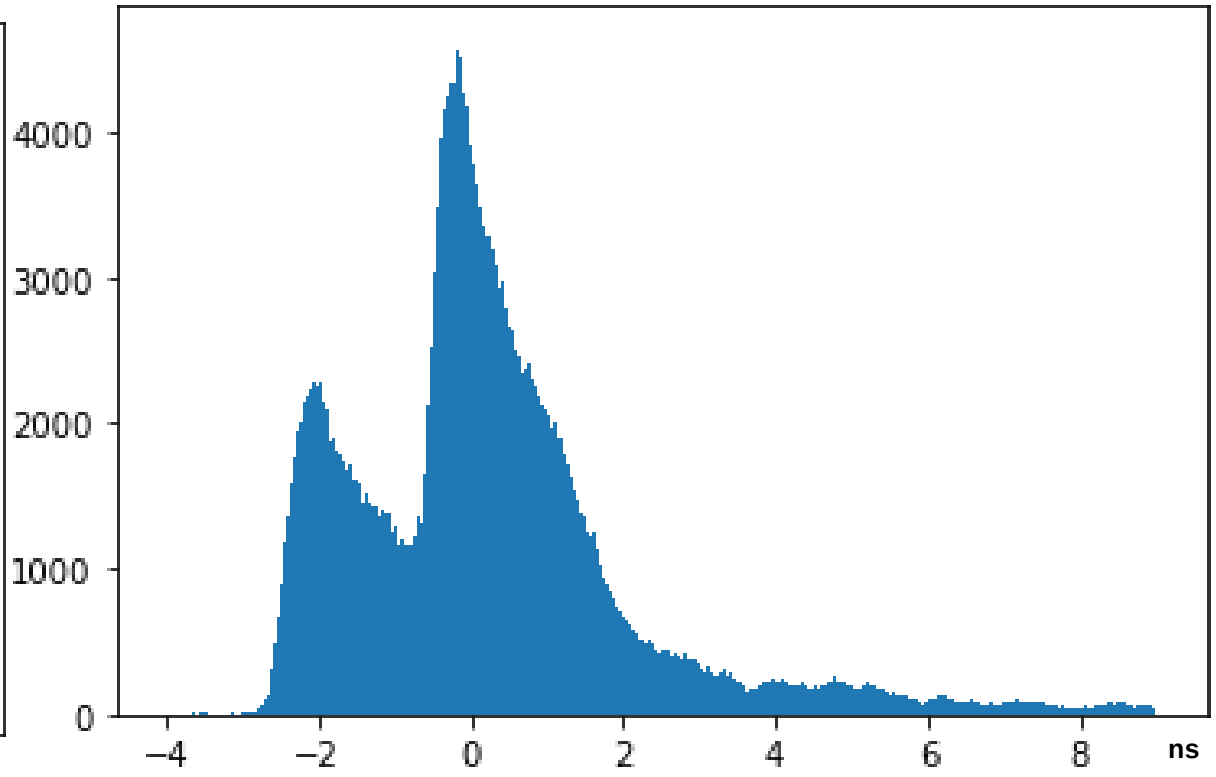
How we count accuracy:
histogram with difference between correct values and predicted ones



Differences for training (100 epochs)



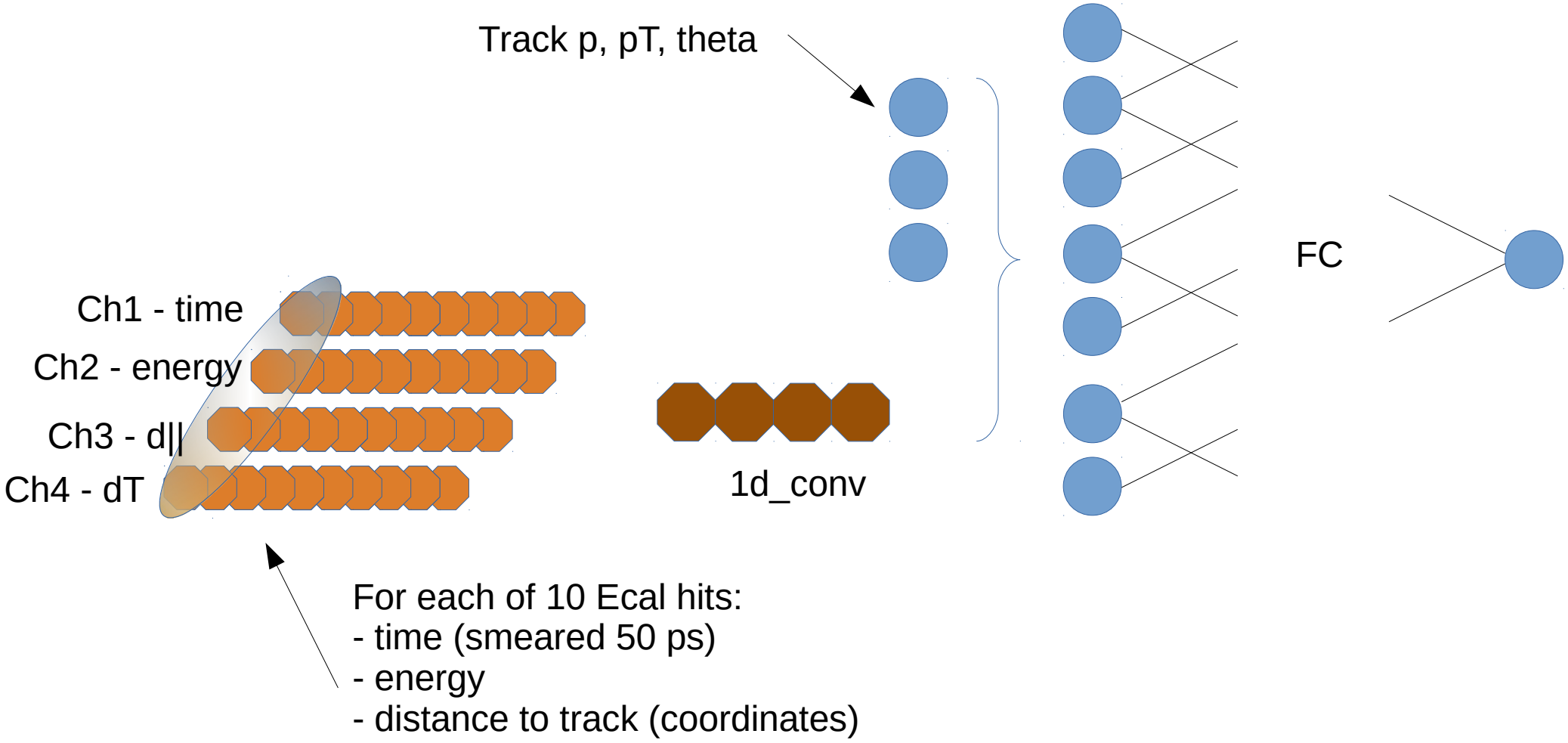
Differences for testing (100 epochs)



Anatolii came up with a better NN architecture idea!

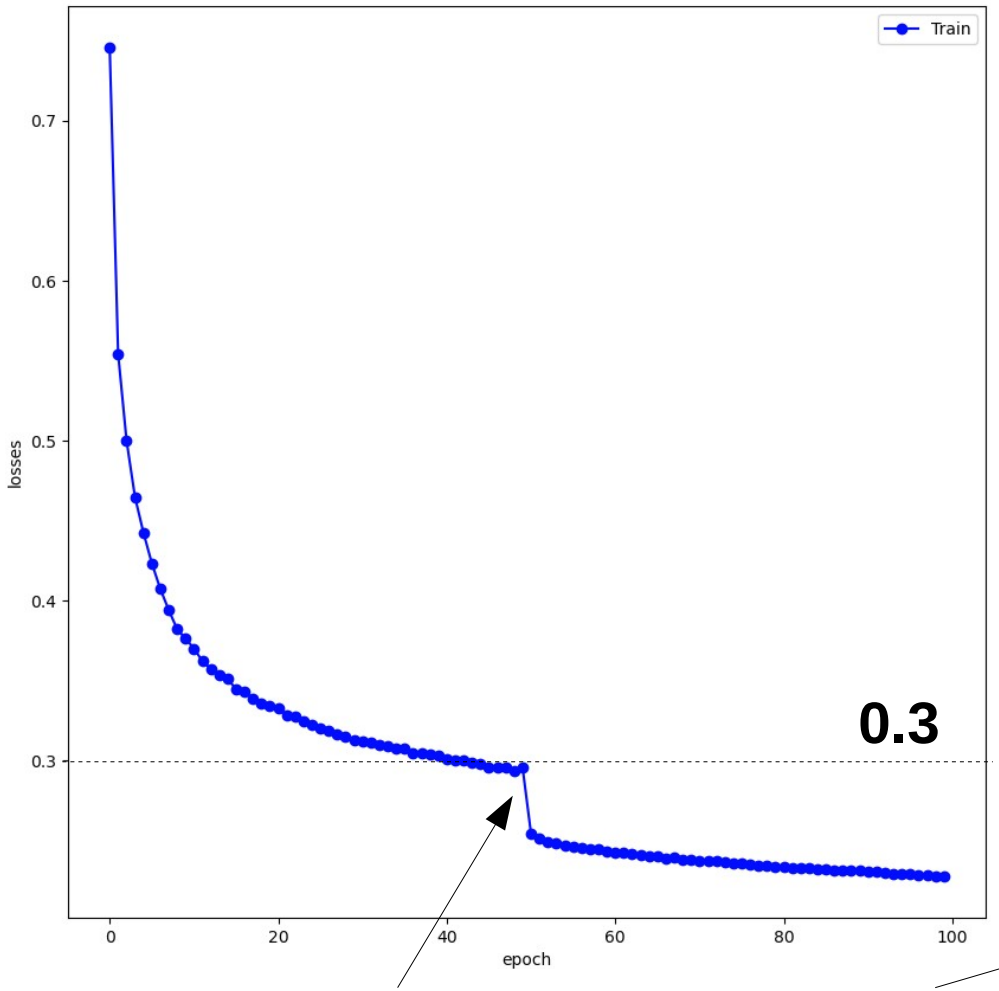
Convolutional Neural Network

Second choice

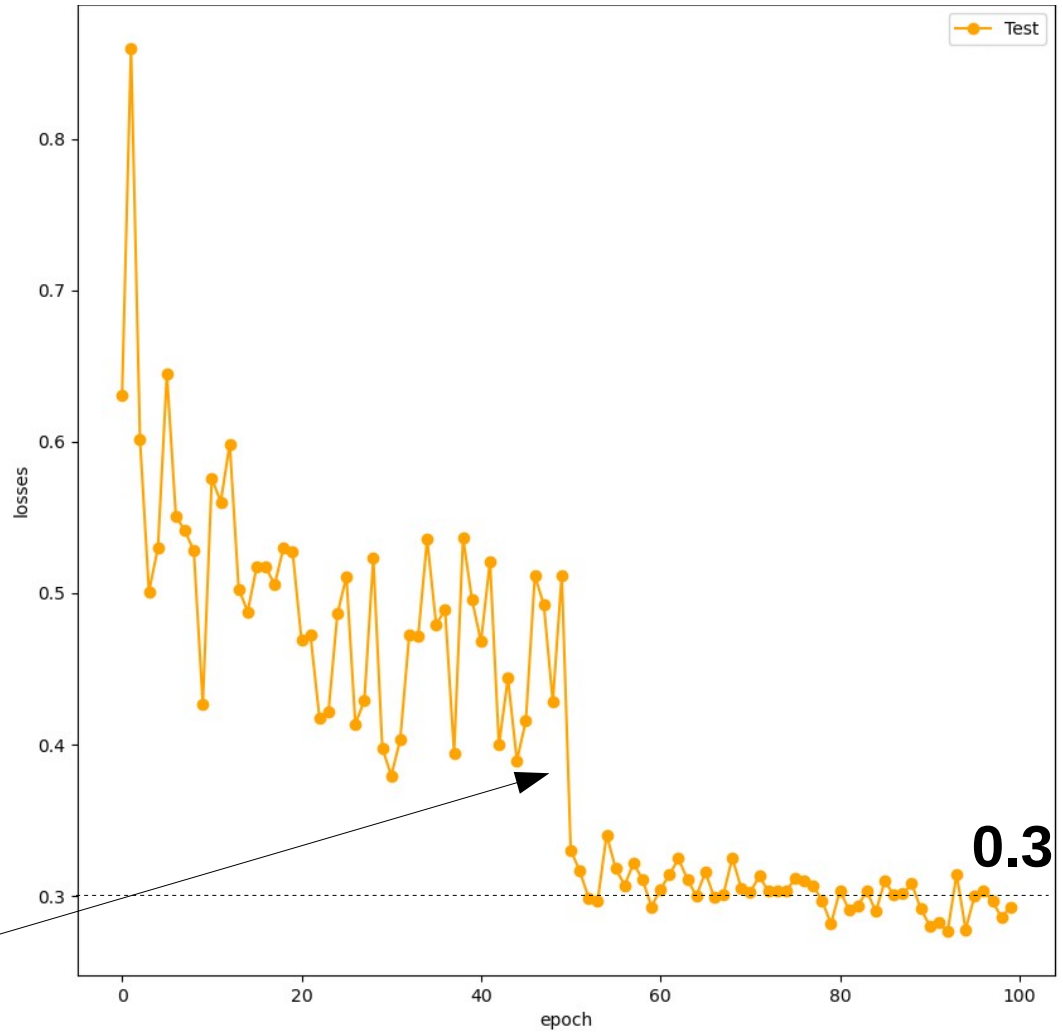


Convolutional Neural Network

Train losses for 100 epochs



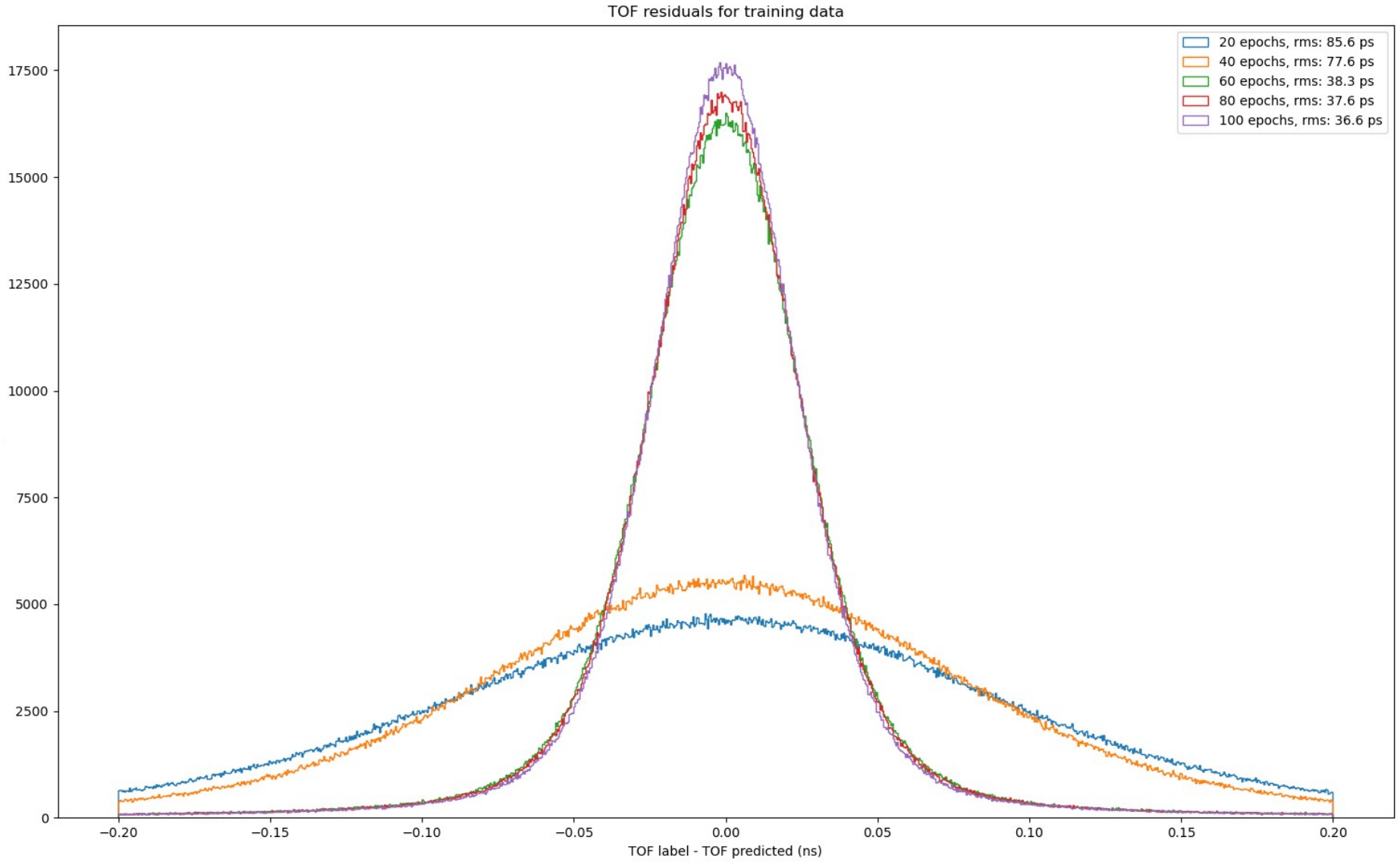
Test losses for 100 epochs



After 49 epochs training mode was changed on validation

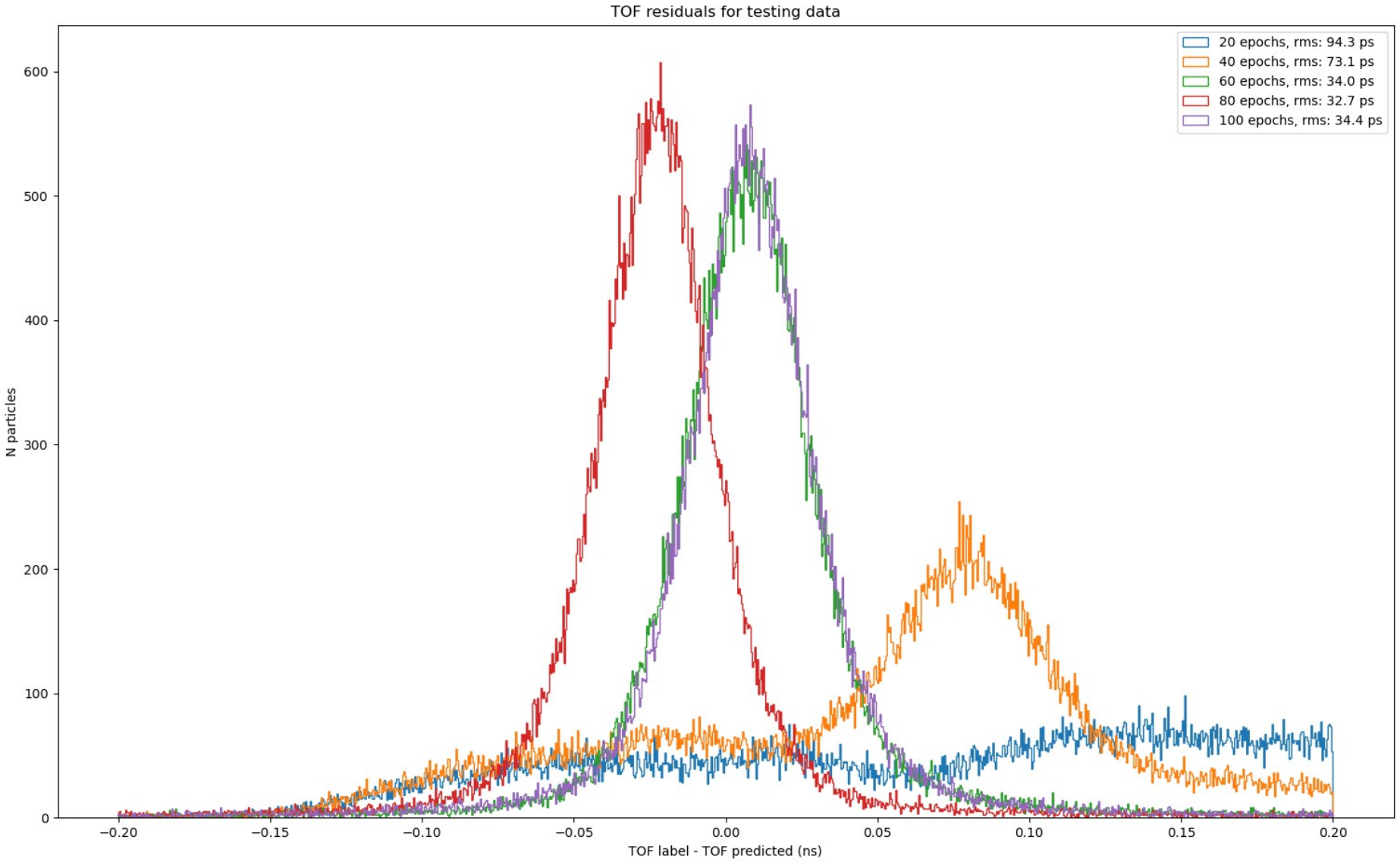
CNN: residual

histogram with difference between correct values and predicted ones (training)



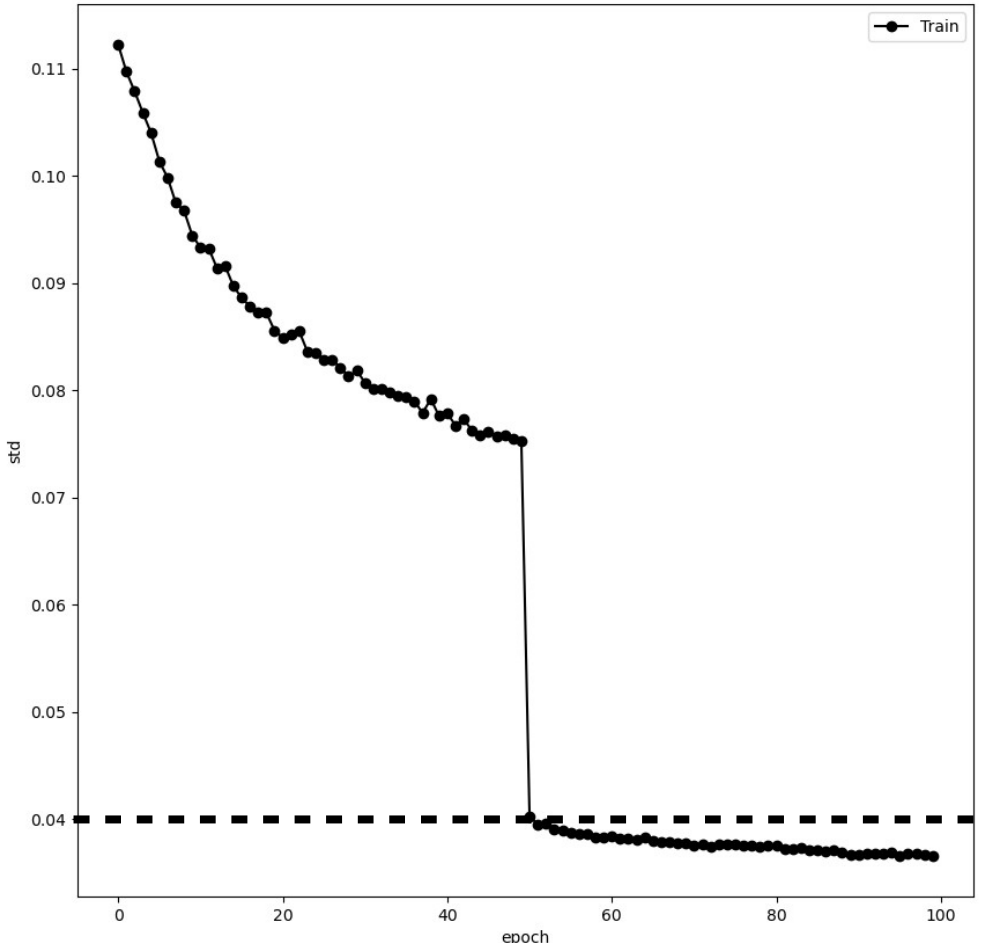
CNN: residual

histogram with difference between correct values and predicted ones (testing)

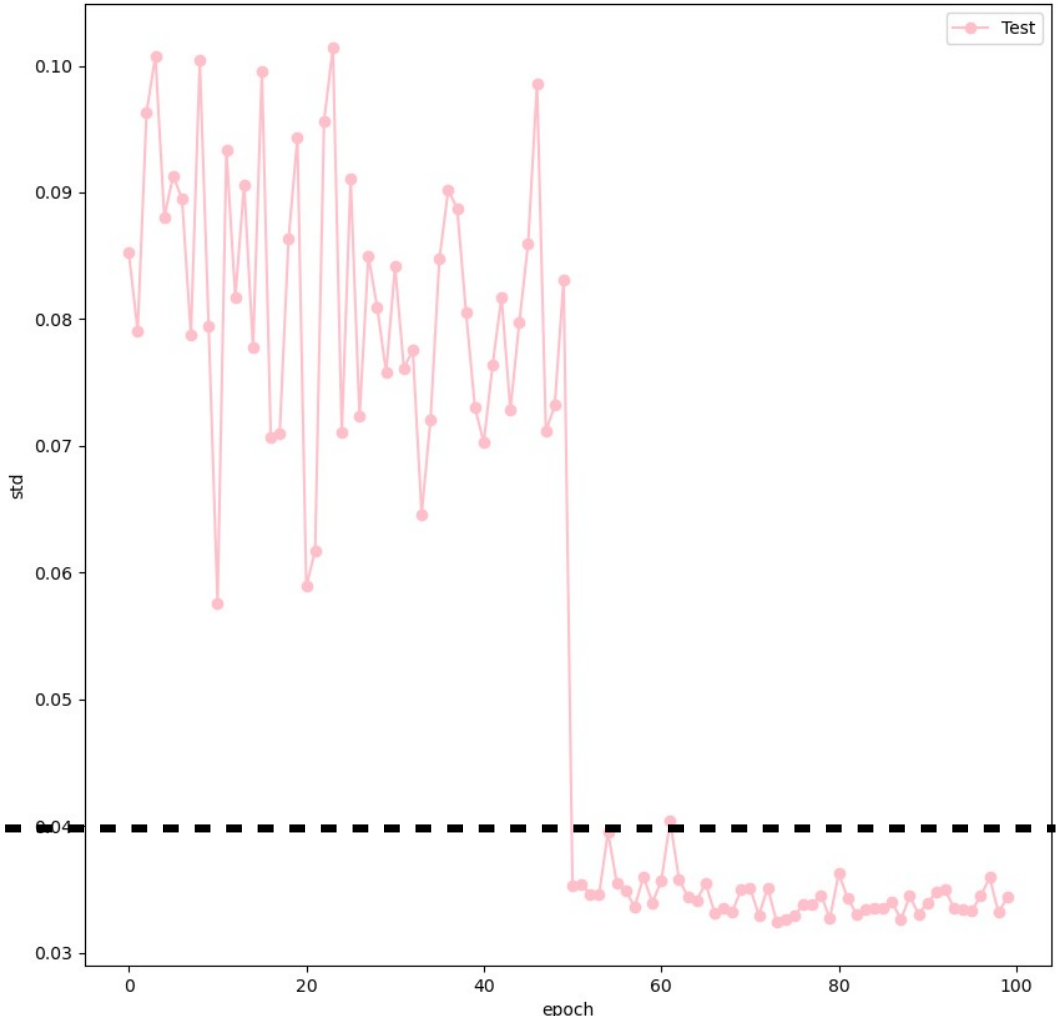


Convolutional Neural Network

Train standard deviation for 100 epochs



Test standard deviation for 100 epochs



40 ps

After 49 epochs training mode was changed on validation

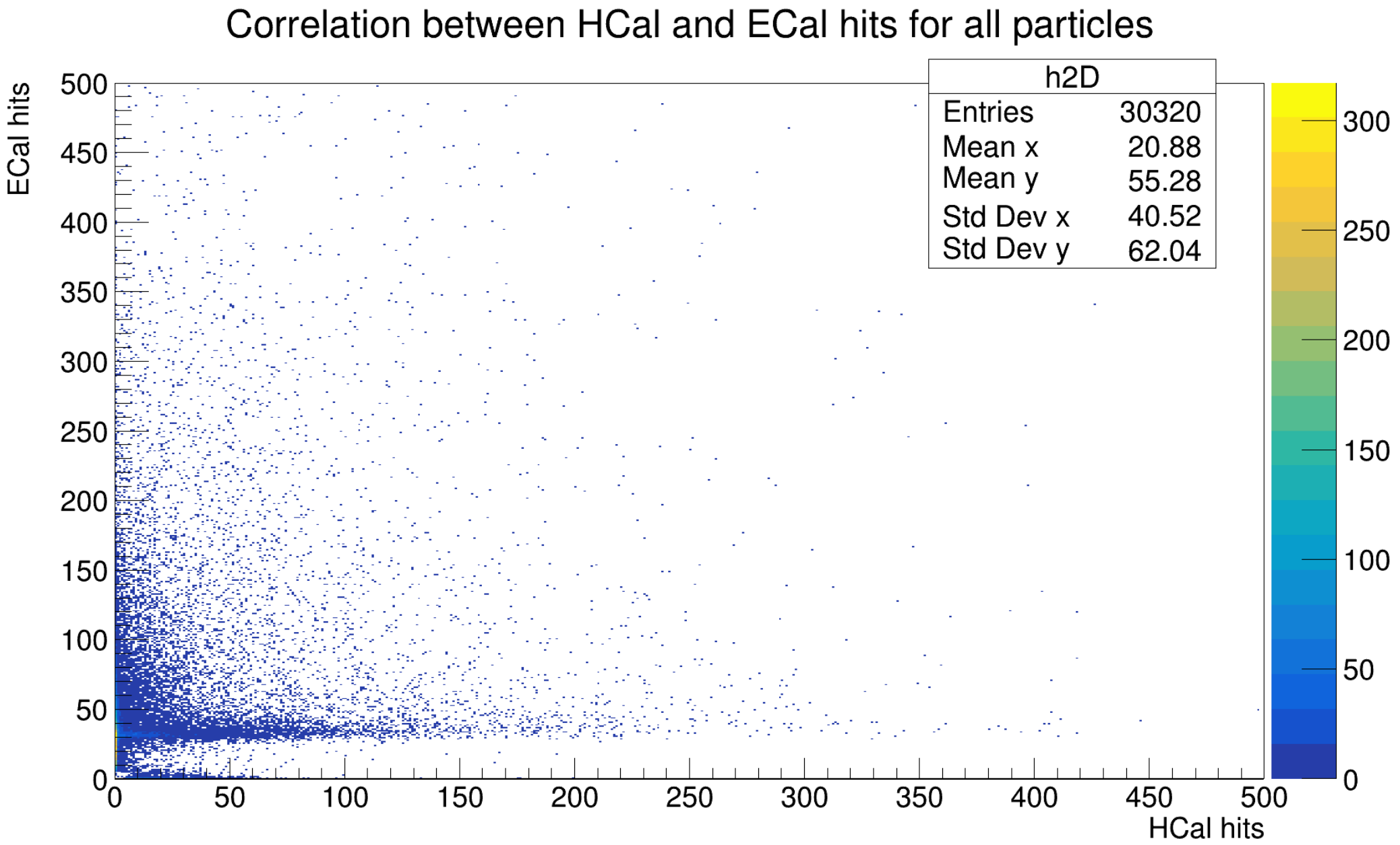
Conclusions

- It was my first time working on python and machine learning, so this experience is priceless

- It works!
- We have achieved **34.4 ps** TOF resolution using CNN after 100 epochs
  compared to **15.8 ps** of Baseline method “Frank’s average” (50/sqrt(10))
- Not the final result, it is still possible to improve
  - Train more epochs
  - Use more data (for now – we use 160 000 events with total ~2 800 000 particles)
  - Play with learning rate and NN architecture
- No systematic hyperparameter scans done yet

Thank you!

Backu


Correlation between HCal and ECal hits for all particles
h2D
Entries 30320
Mean x 20.88
Mean y 55.28
Std Dev x 40.52
Std Dev y 62.04
ECal hits
HCal hits
0
50
100
150
200
250
300
350
400
450
500

Backup: math for TOF

$$\ell_{\text{track}} = \sum_{i=0}^{n} \ell_i = \sum_{i=0}^{n} \sqrt{\left(\frac{\varphi_{i+1} - \varphi_i}{\Omega_i}\right)^2 + (z_{i+1} - z_i)^2}$$

$$p_i = e\frac{|B_z|}{|\Omega_i|}\sqrt{1 + \tan^2 \lambda_i}$$

$$\beta = \frac{\ell_{\text{track}}}{c \cdot \text{TOF}}$$

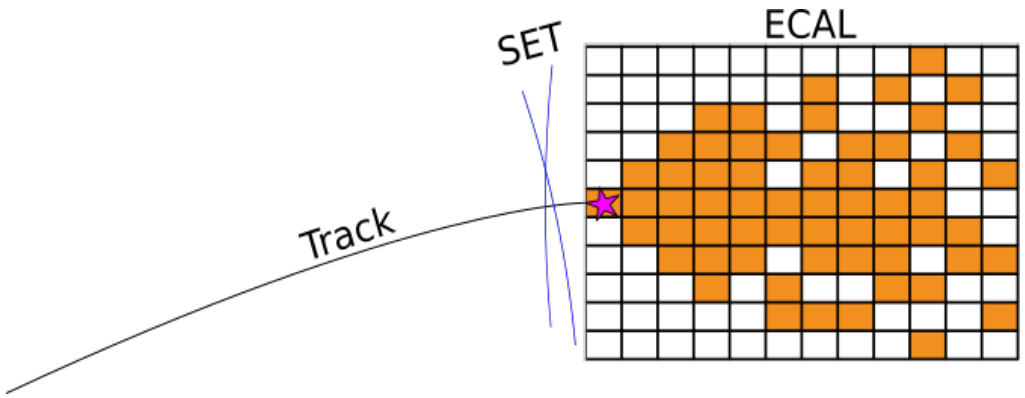
$$p = \sqrt{\langle p^2 \rangle_{HM}} = \sqrt{\sum_{i=0}^{n} \ell_i \Big/ \sum_{i=0}^{n} \frac{\ell_i}{p_i^2}}$$

$$m = \frac{p}{\beta}\sqrt{1 - \beta^2}$$

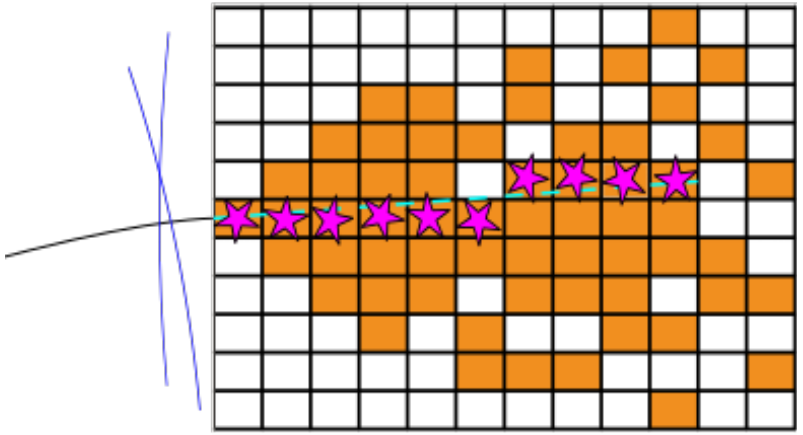
Winfried A. Mitaroff

arXiv:2107.02031

Backup: How do we implement TOF in the detector?



Single closest/fastest hit



Average or fit of 10 hits closest to the extrapolated line

Contact

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Synchrotron DESY

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