Digitization procedure of MC simulation of LUXE ECAL

Kamil Zembaczyński[1]

Advisors: Wolfgang Lohmann[2], Aleksander Filip Żarnecki[1], Grzegorz Grzelak[1]

[1]University of Warsaw
[2]Deutsches Elektronen-Synchrotron

Plan of the study

- Implement a procedure of converting energy deposits from Geant4 simulation into ADC units,
- Adjust calibration parameters to obtain agreement between TB results and MC simulation,
- Apply the procedure to MC with tungsten absorber in front of the sensor and check the agreement with TB results.

Analysis setup

Files used:

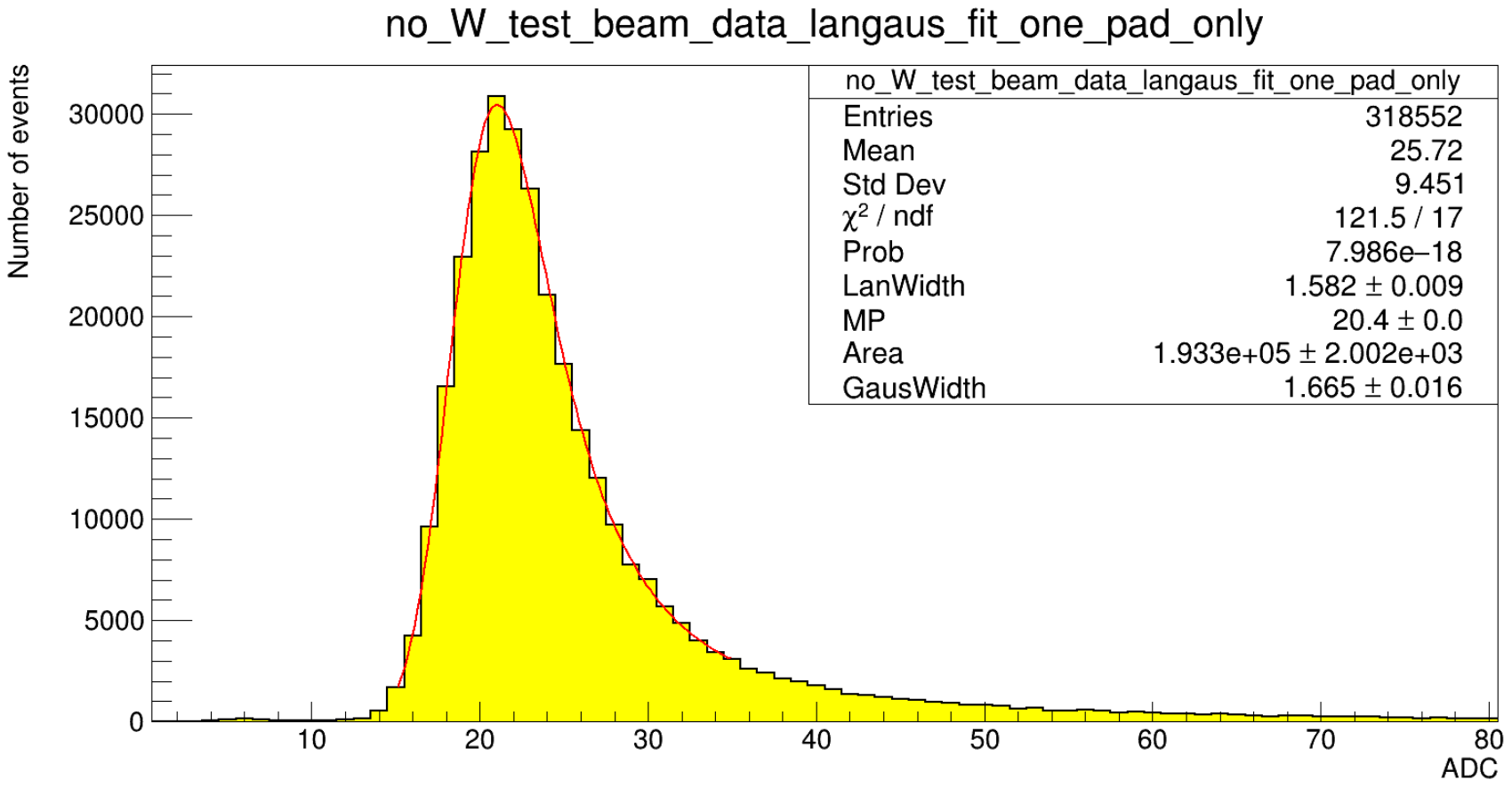
- TB_FIRE_4533.pickle: TB data with Si sensor (**500µm**) without tungsten layer, 1M events,
- TB_FIRE_4749.pickle: TB data with Si sensor (**500µm**) with tungsten layer, 500k events,
- Si-e-5GeV-500um-ev500k.root: Geant4 simulation, 500k events, **500µm** silicon sensor, generated by Mihai Potlog,
- mc21.singlePositron_50GeV_ECALP_run2.G4gun.SIM.se0003.root: Geant4 simulation, 20k events, **320µm** silicon sensor, generated by Shan Huang,

In all cases the energy of the electron (or positron) was 5GeV.

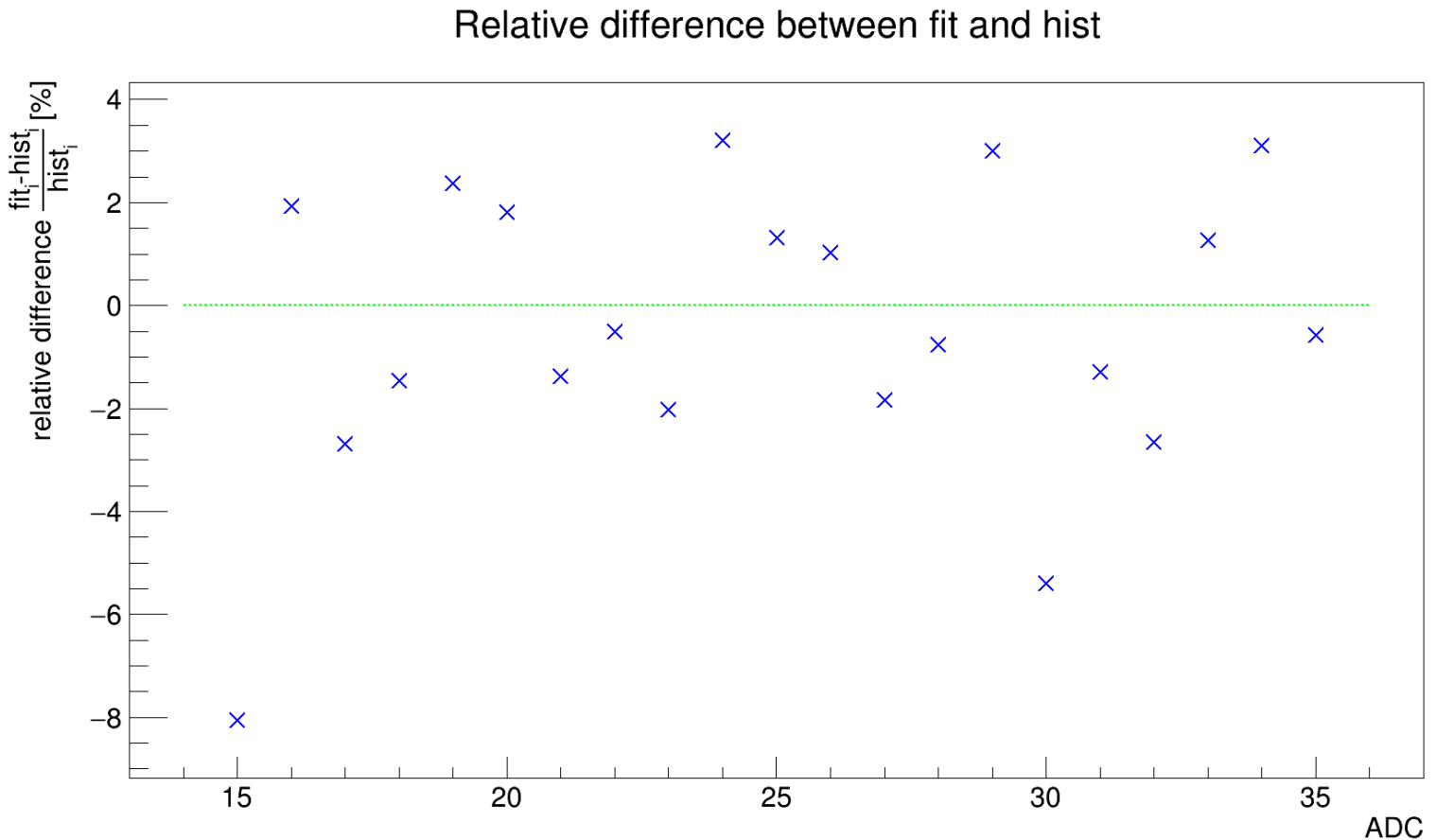
Setup of the Langaus function fit

- Histogram of single-particle signal distribution (both from MC and test-beam data) is fitted with **Langaus** function (Landau ⊕ Gauss)
- Langaus function has four parameters:
  - LanWidth: scale parameter of the Landau distribution
  - MP: MPV of the Landau distribution
  - Area: total area, normalization constant
  - GausWidth: width of the convoluted Gaussian function
- Files without tungsten: only events with one hit were selected, to minimize effects caused by secondary particles
- Files with tungsten: only cells with non-zero deposits were considered in conversion procedure

Langaus fit to TB data
without tungsten absorber



Langaus fit to TB data
without tungsten absorber



MC deposit conversion procedure

- Conversion procedure from MeV to ADC:
  - Conversion from MeV to fC using conversion factor: a*3.6 eV/electron-hole, where a is an calibration parameter,
  - Conversion from fC to ADC using gain factor for high-gain: 4.07 ADC/fC, assume saturation at 200 fC,
  - Additional Gaussian variation with sigma equal to noise parameter (taken from pedestal measurements),
  - Additional smearing from Landau distribution (with mean equal to zero and adjustable scale parameter, LanPar).

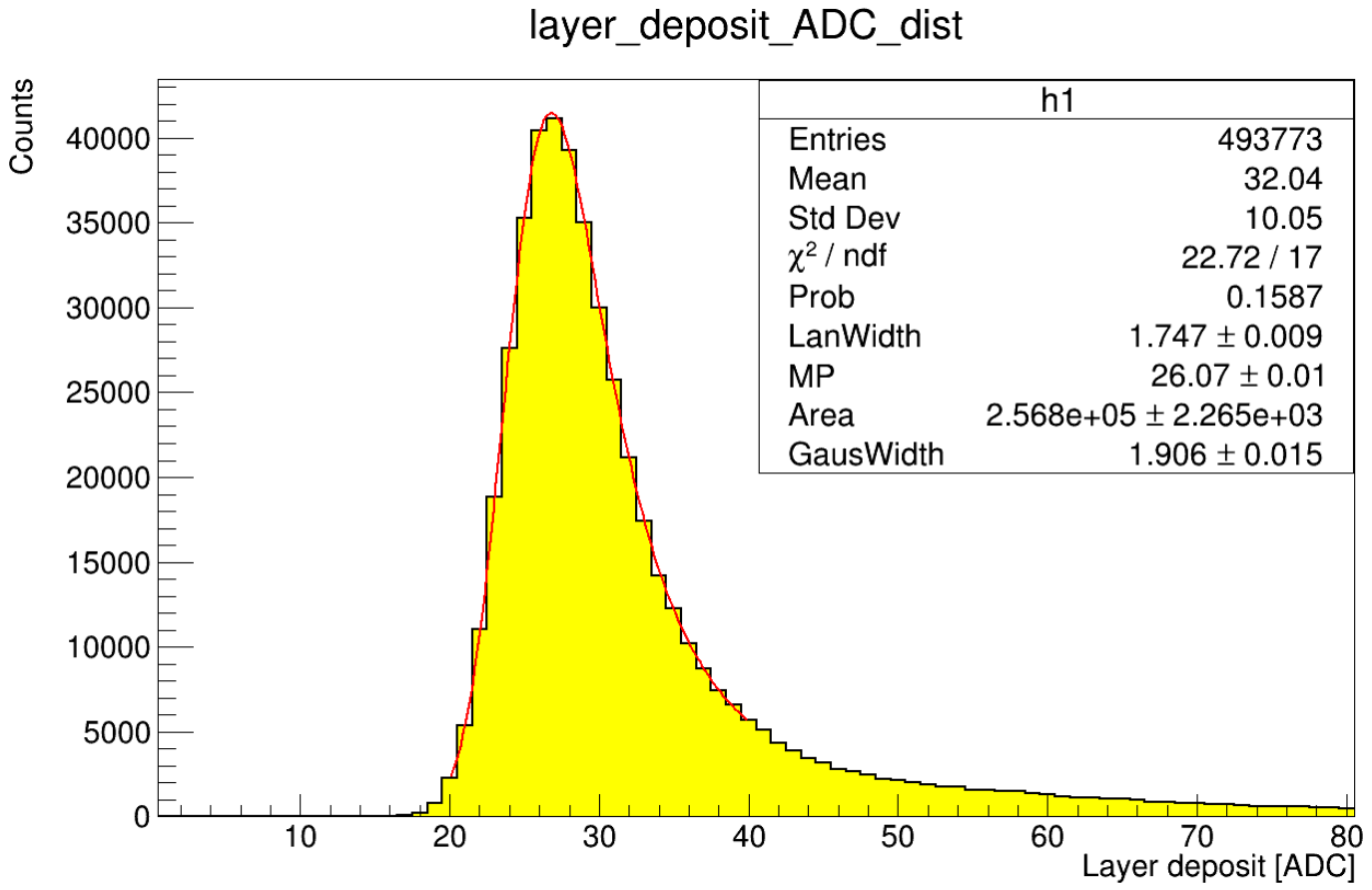
Langaus fit to MC sample

- noise = 1.478 ADC
- a = 1
- LanPar = 0

- ➔ LanWidth too big
- ➔ MP value bigger than in TB
- ➔ GausWidth too big

Parameters from fit to test-beam data:

- LanWidth = 1.582
- MP = 20.4
- GausWidth = 1.665



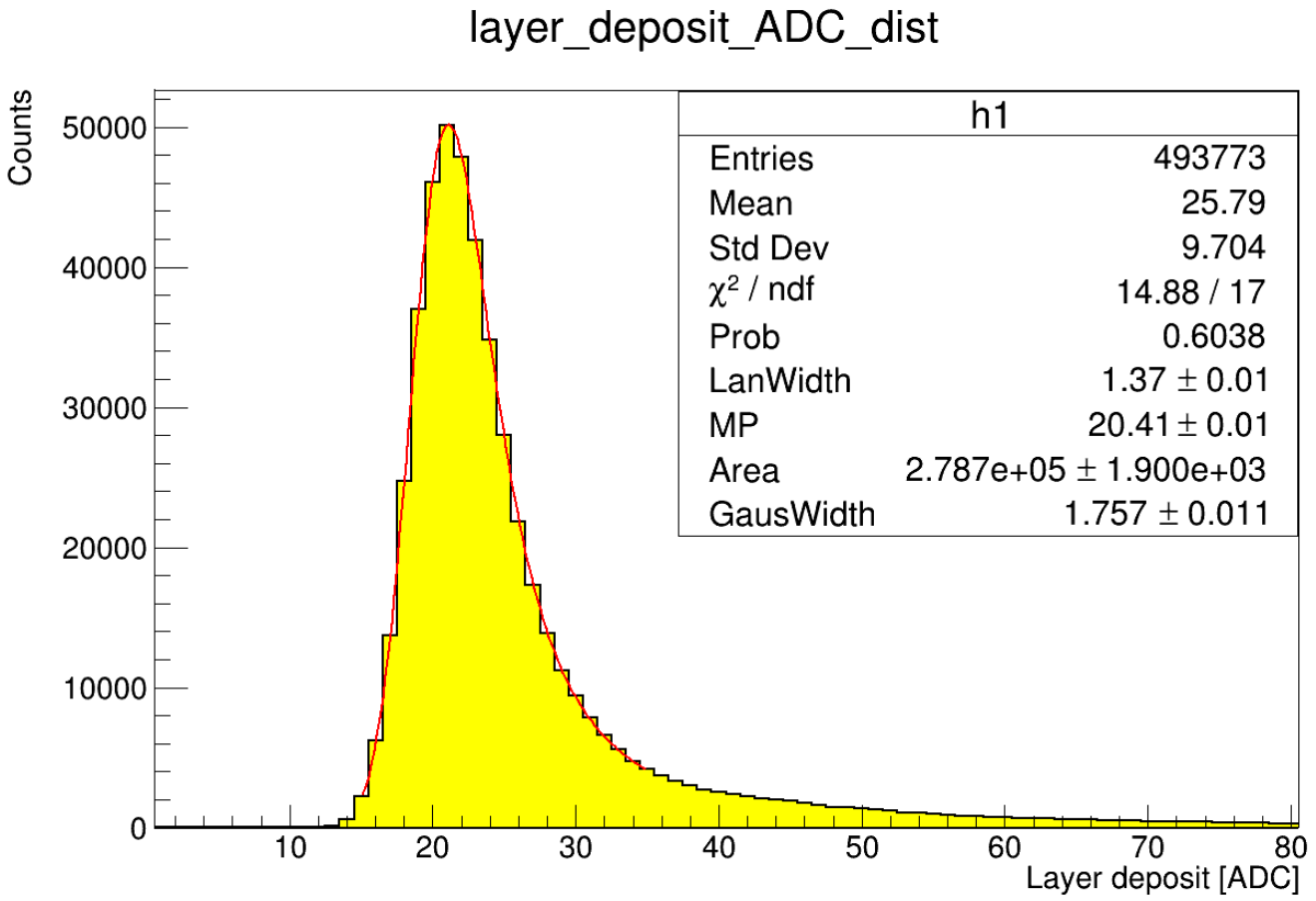
Applying calibration factor

- noise = 1.478 ADC
- a = 26.07/20.4 = 1.2779
- LanPar = 0

- ➔ LanWidth too small
- ➔ MP value in agreement with TB
- ➔ GausWidth slightly too big

Parameters from fit to test-beam data:

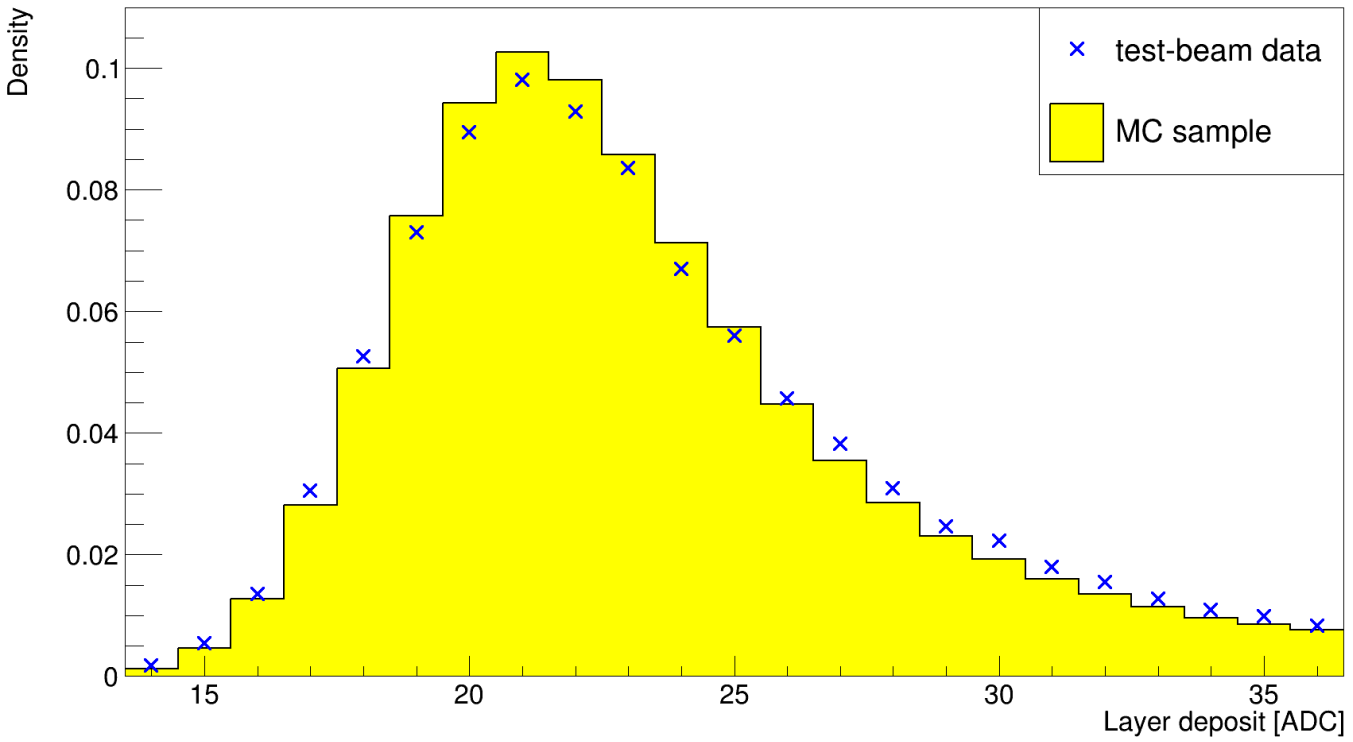
- LanWidth = 1.582
- MP = 20.4
- GausWidth = 1.665



Applying calibration factor

- noise = 1.478 ADC
- a = 1.2779
- LanPar = 0

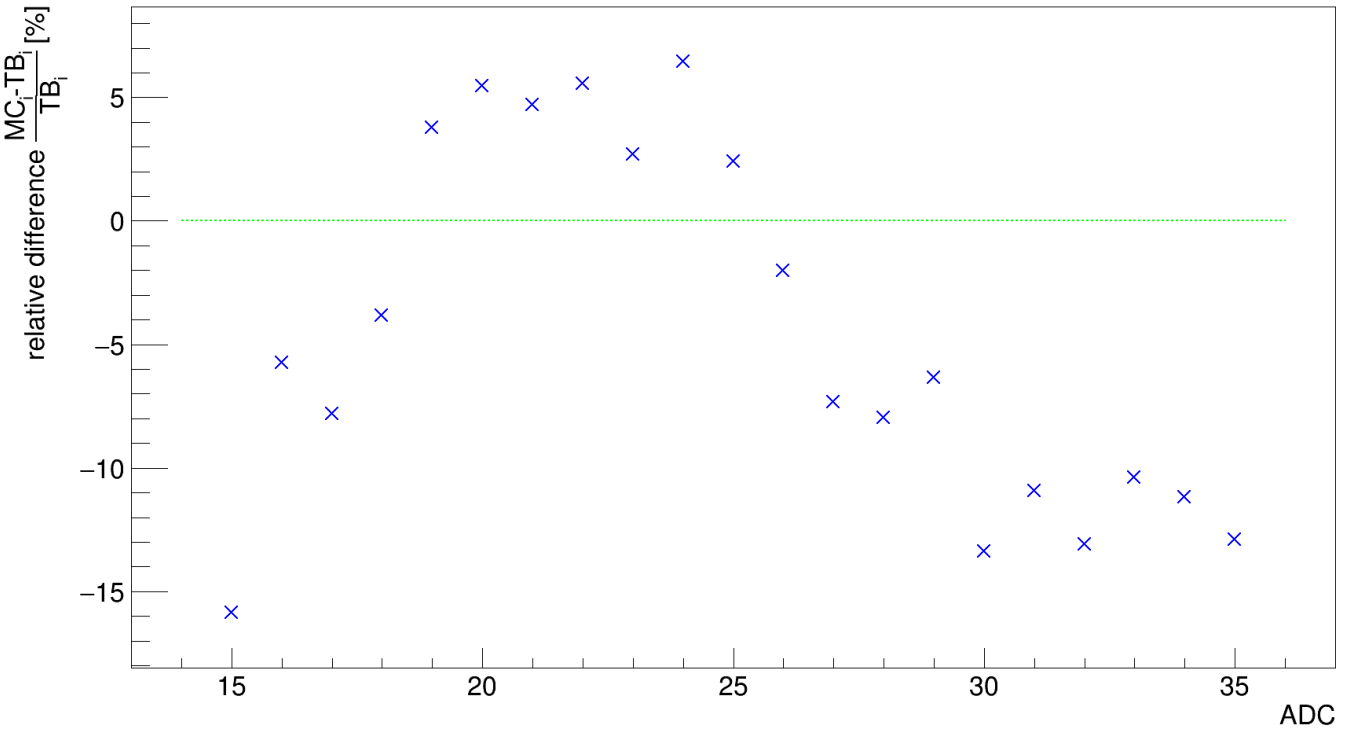
distributions of signal from test-beam are presented together with MC sample



Applying calibration factor

- noise = 1.478 ADC
- a = 1.2779
- LanPar = 0

relative difference between MC sample and test-beam data is presented



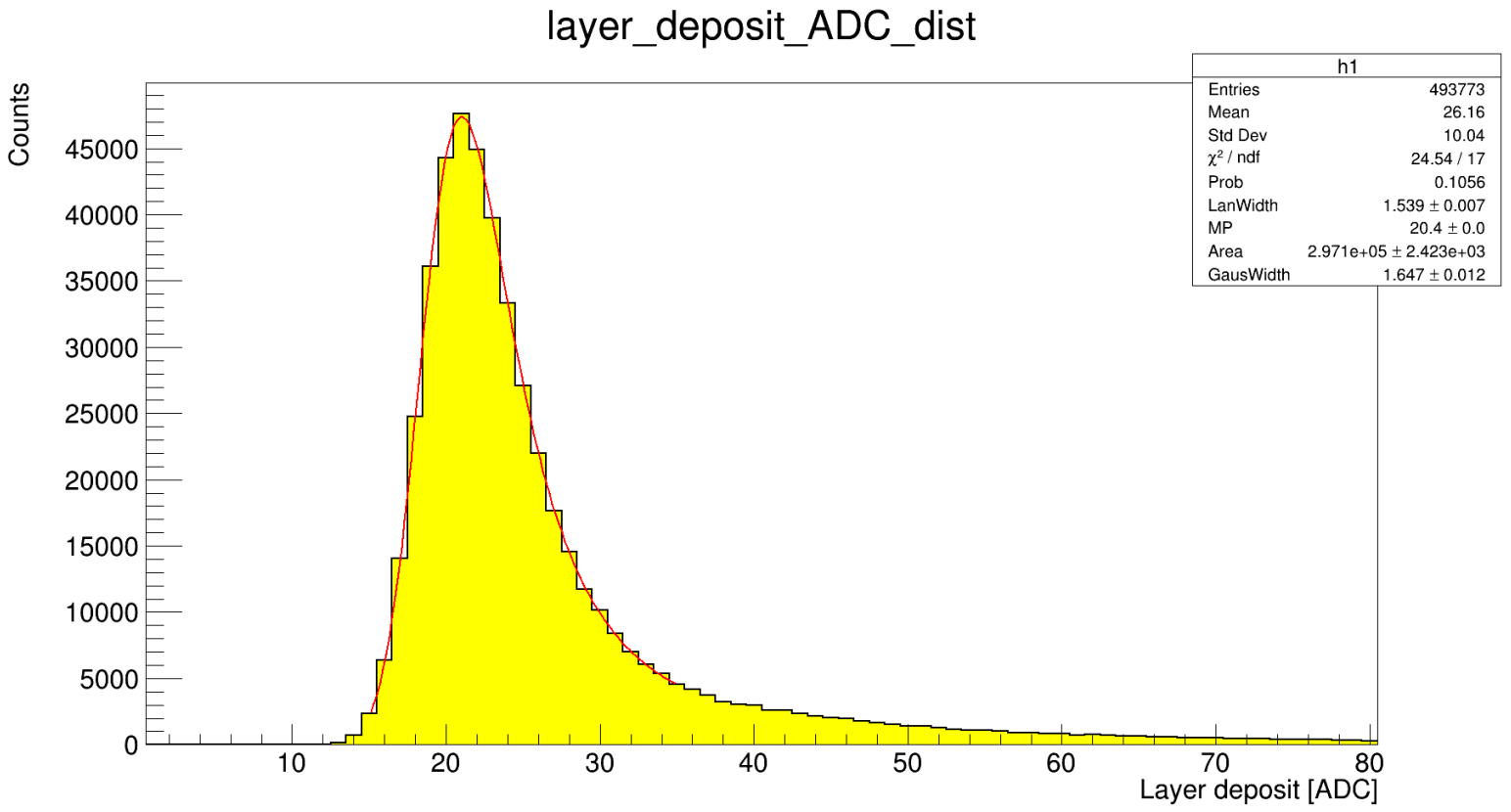
Tuning the parameters

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212

➔ all parameters are in good agreement with test-beam

Parameters from fit to test-beam data:

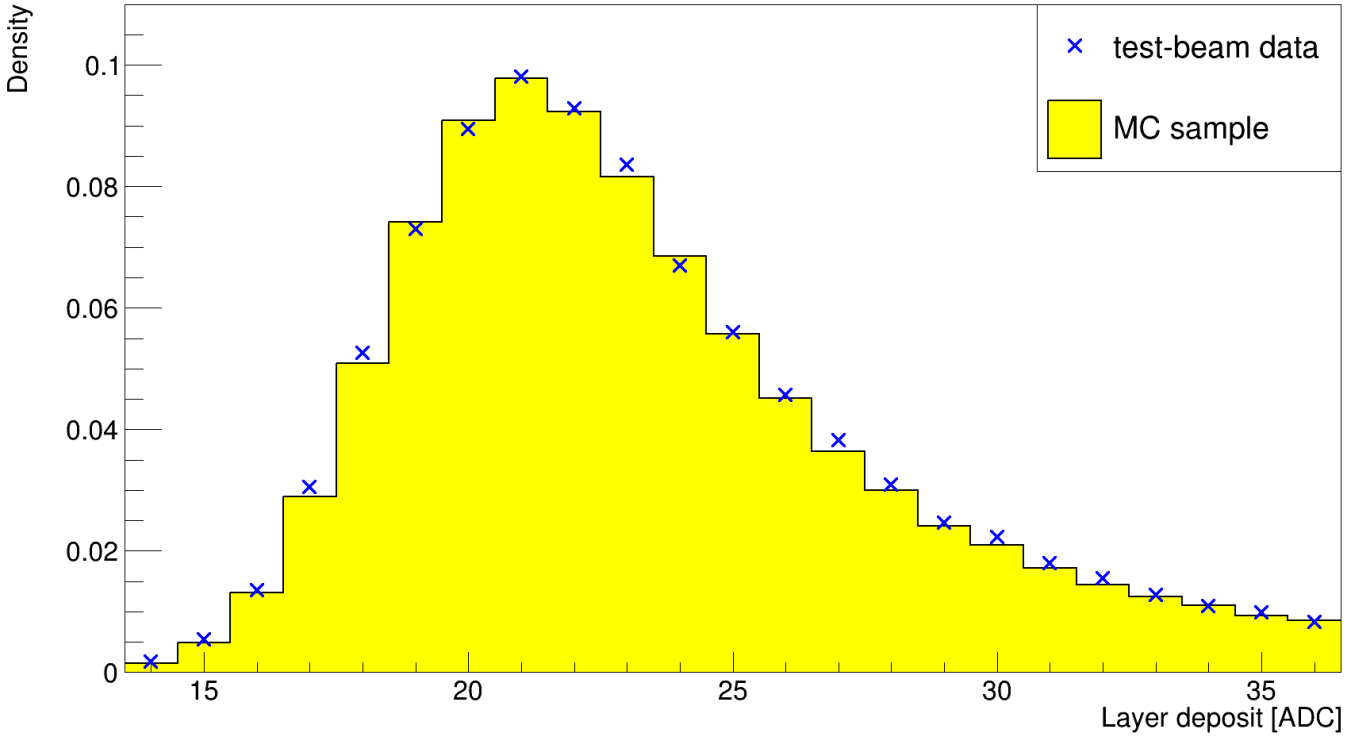
- LanWidth = 1.582
- MP = 20.4
- GausWidth = 1.665



Tuning the parameters

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212

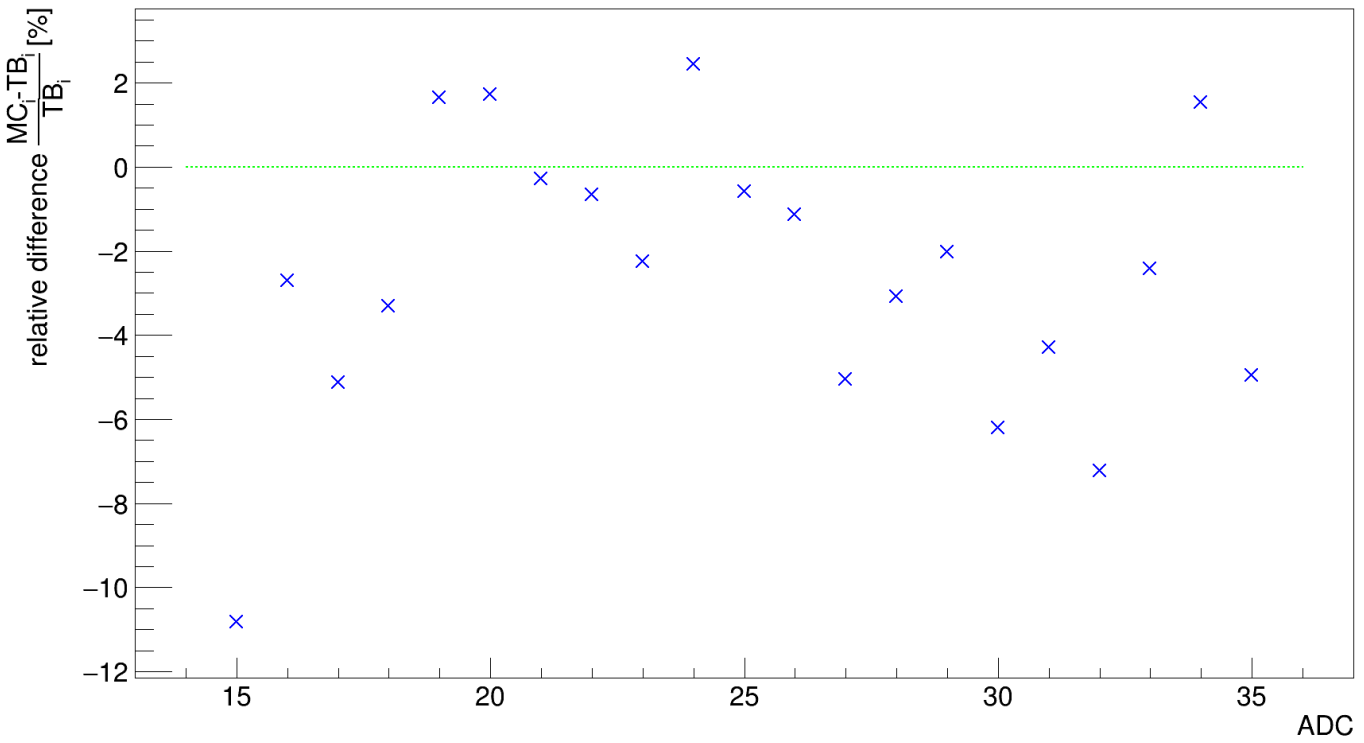
distributions of signal from test-beam are presented together with MC sample



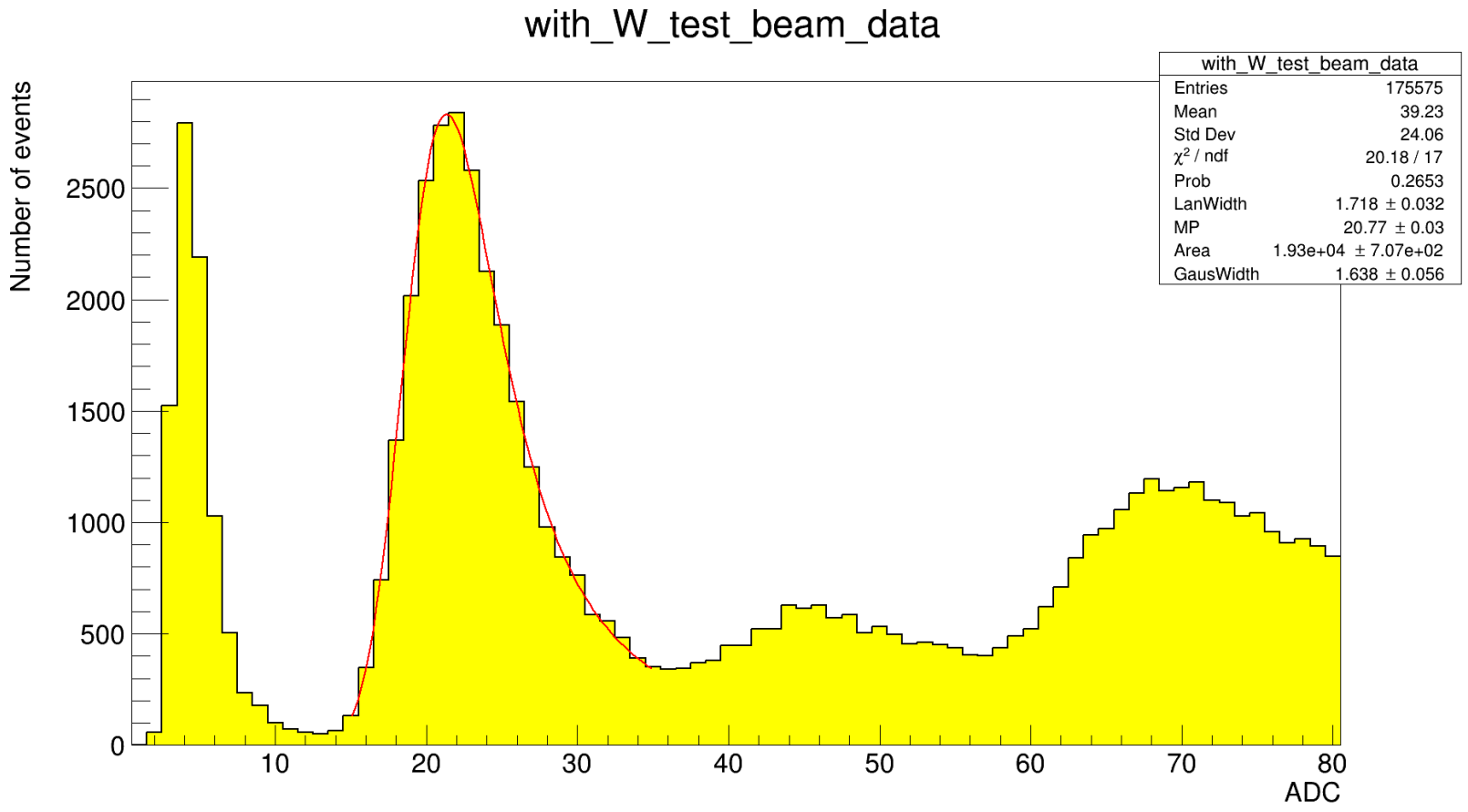
Tuning the parameters

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212

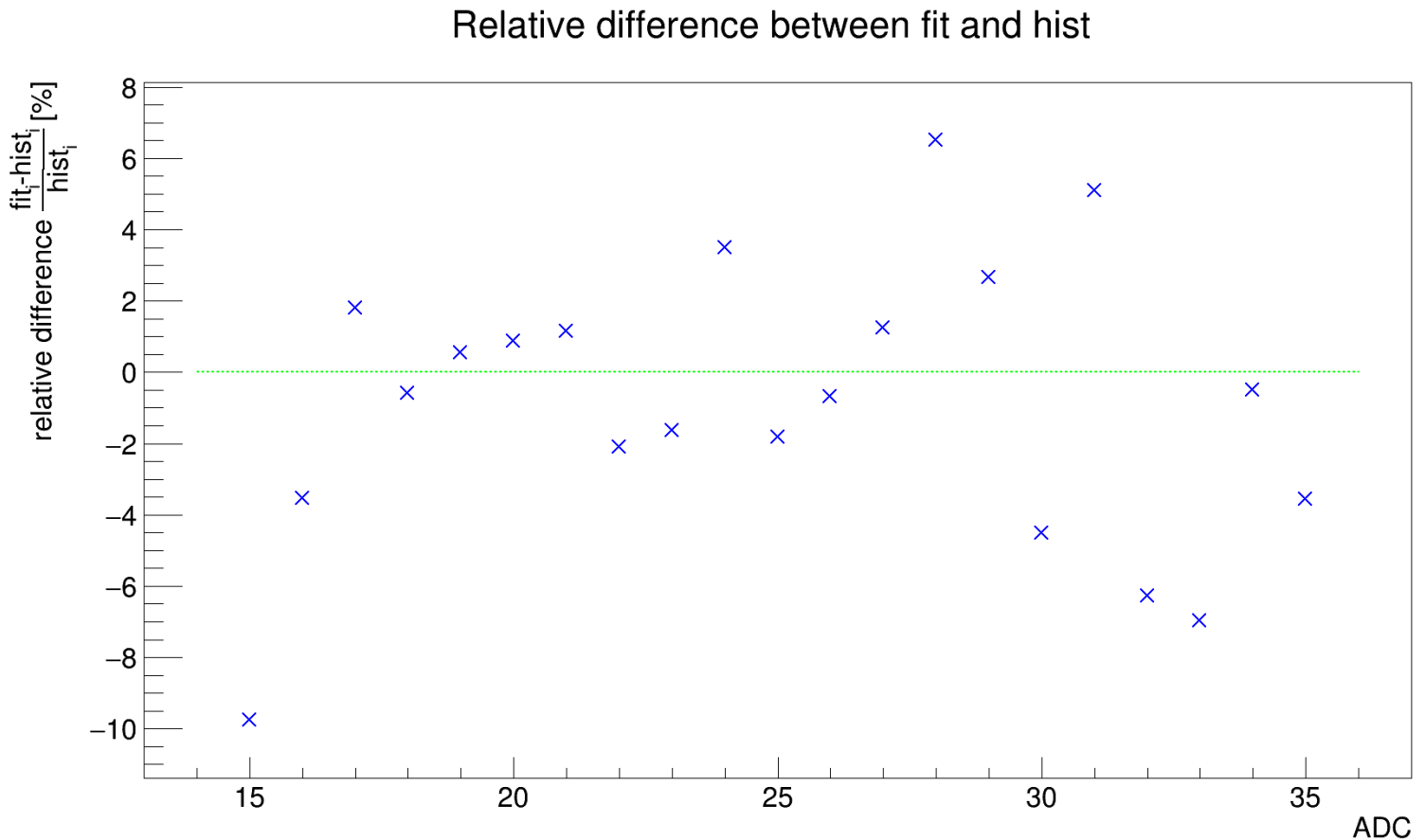
relative difference between MC sample and test-beam data is presented



Langaus fit to TB data
with $1X_0$ tungsten absorber



Langaus fit to TB data
with $1X_0$ tungsten absorber

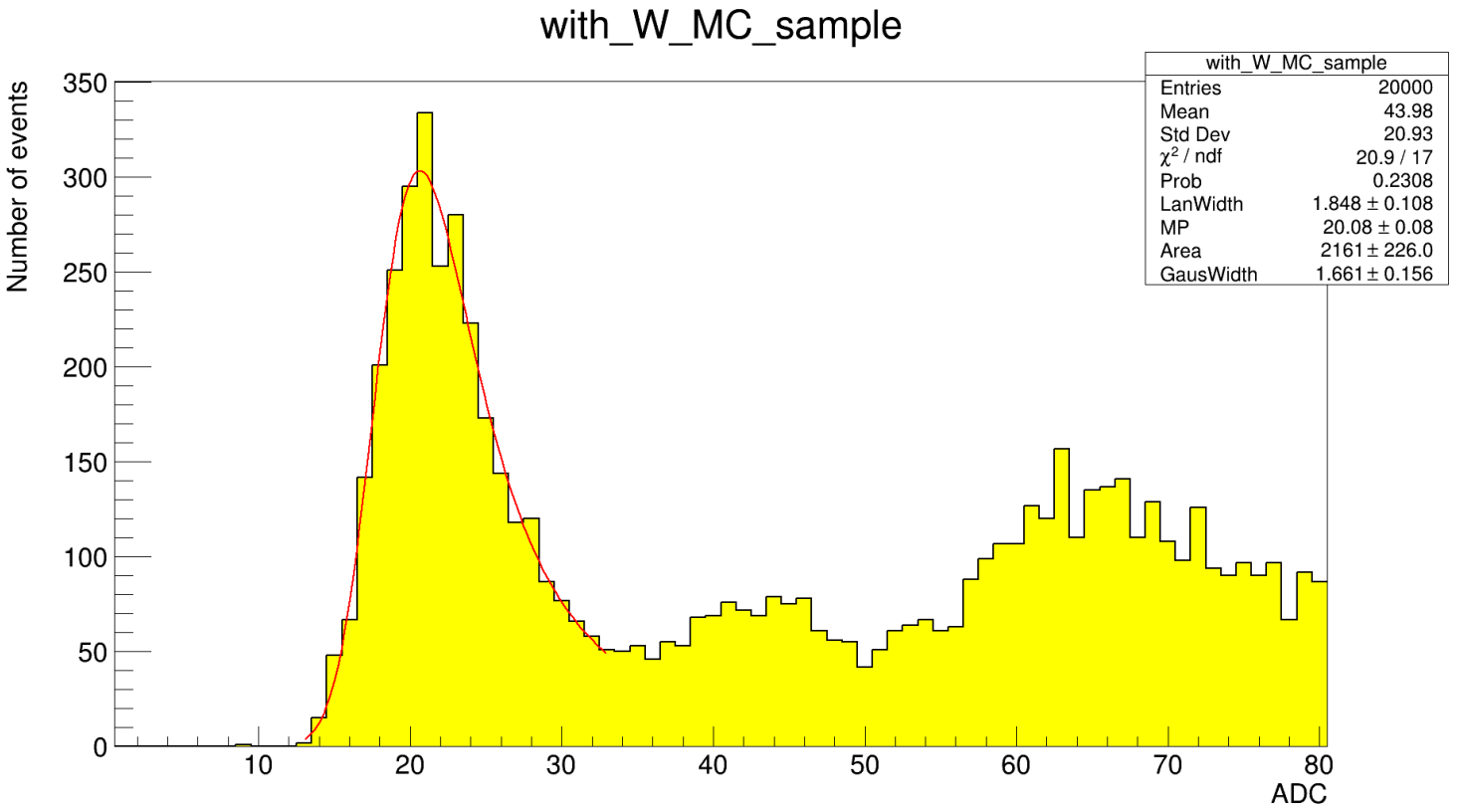


Impact of sensor thickness

- In MC with tungsten absorber the sensor is 320µm thick,
- Need for scaling every deposit by the factor 500/320 to get proper MPV,
- Larger Landau fluctuations expected for thinner sensor, no way to correct for that →larger Landau width expected.

Applying procedure to MC sample with tungsten absorber

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212
- sensor thickness correction



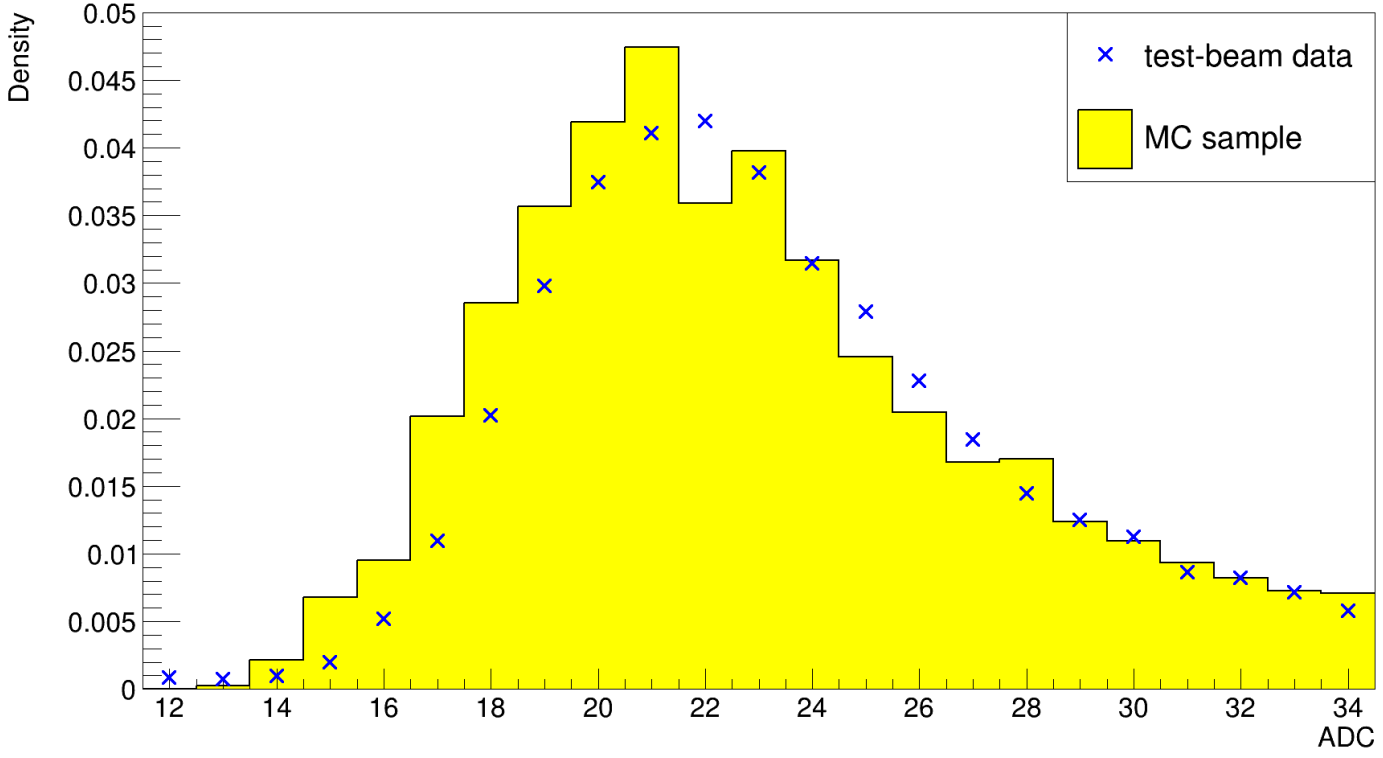
Parameters from fit to test-beam data:

- LanWidth = 1.718
- MP = 20.77
- GausWidth = 1.638

Applying procedure to MC sample with tungsten absorber

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212
- sensor thickness correction

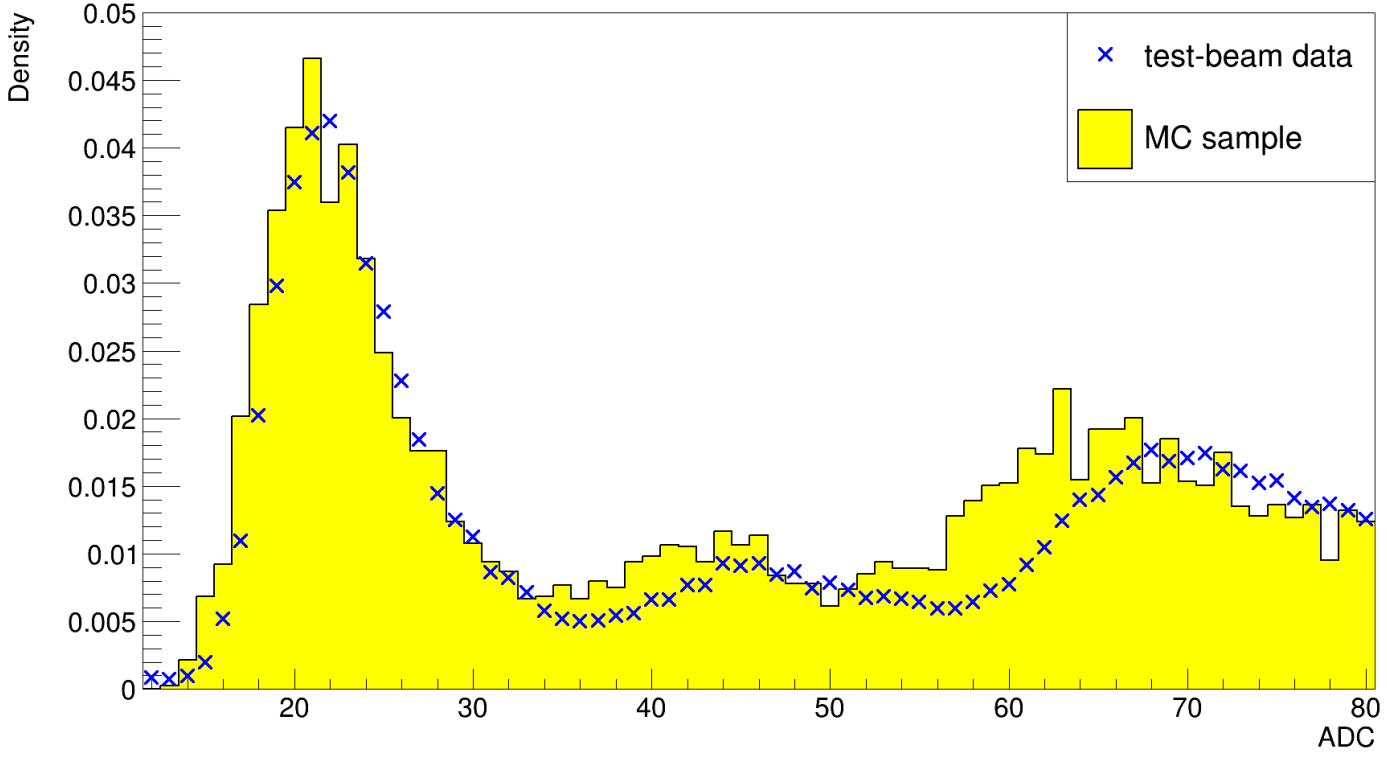
distributions of signal from test-beam are presented together with MC sample



Applying procedure to MC sample with tungsten absorber

- noise = 1.371 ADC
- a = 1.315
- LanPar = 0.212
- sensor thickness correction

distributions of signal from test-beam are presented together with MC sample



Conclusions

- Parameters of conversion procedure (noise, calibration factor, LanPar) can be adjusted to reproduce the shape of deposits distribution from TB.
- Why the width of Landau distribution doesn’t agree between TB and MC?
- MC samples with conversion procedure applied does reproduce data (after correcting for different thickness of sensor in TB and MC).

References

1) Jakub Moroń, *FLAME SoC readout ASIC for electromagnetic calorimeter,* TWEPP 2022,
2) Marek Idzik, *The FLAME and FLAXE ASICs,* XII Front-End Electronics Workshop 2023,
3) Wikipedia – properties of Landau distribution.

Backup slides

Convoluted Gaussian and Landau distribution

- Shan Huang implementation of convoluted Landau and Gaussian distribution was used,
- Based on Tmath::Landau function from ROOT,
- Parameters:
  - par0 – LanWidth,
  - par1 – MP,
  - par2 – Area,
  - par3 – GausWidth.

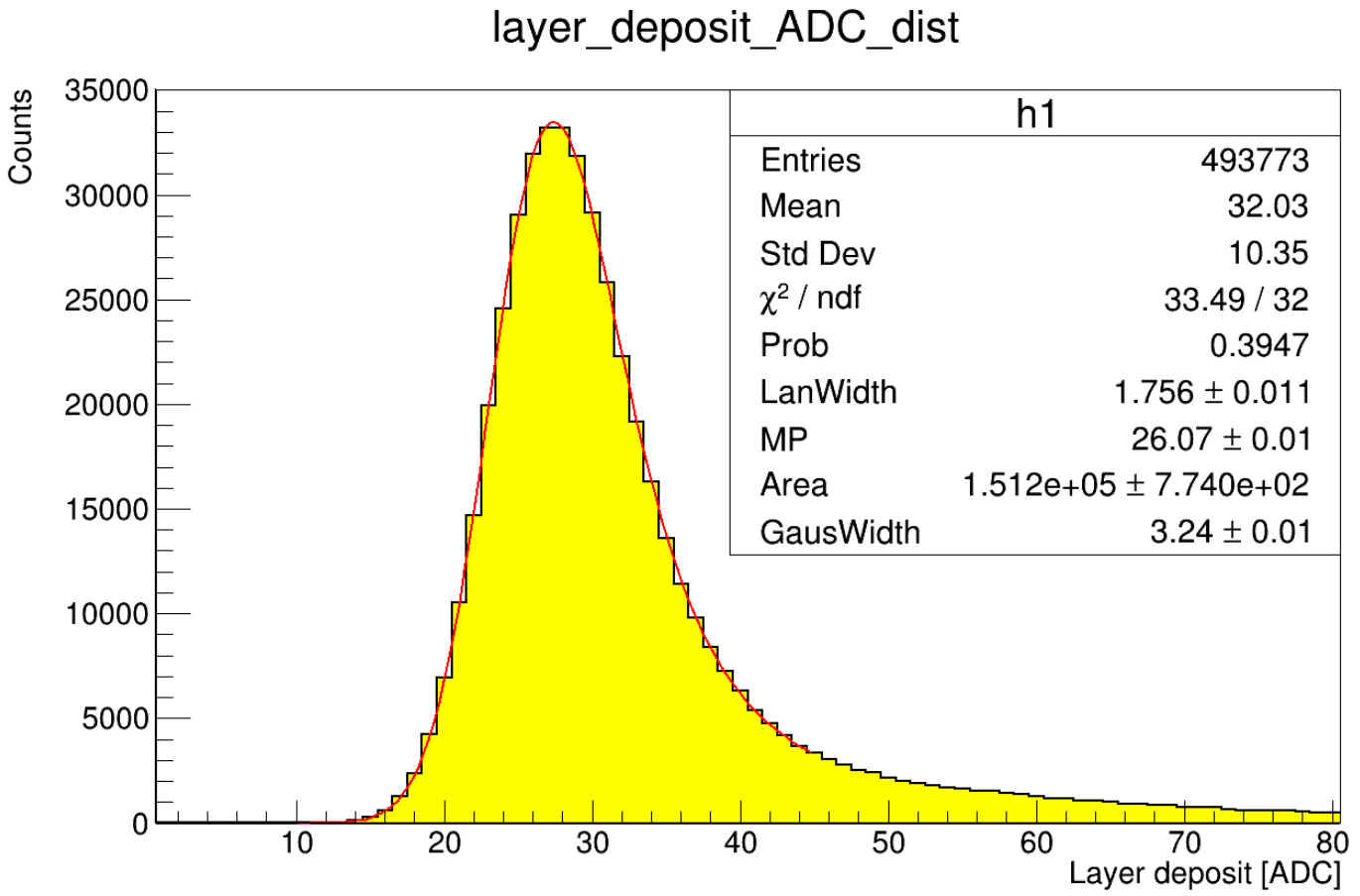
```
Double_t langaufun(Double_t x, Double_t par0, Double_t par1, Double_t par2, Double_t par3) {
      Double_t invsq2pi = 0.3989422804014;   // (2 pi)^(-1/2)
      Double_t mpshift  = -0.22278298;       // Landau maximum location
      // Control constants
      Double_t np = 100.0;      // number of convolution steps
      Double_t sc =   5.0;      // convolution extends to +-sc Gaussian sigmas
      // Variables
      Double_t xx;
      Double_t mpc;
      Double_t fland;
      Double_t sum = 0.0;
      Double_t xlow,xupp;
      Double_t step;
      Double_t i;
      // MP shift correction
      mpc = par1 - mpshift * par0;
      // Range of convolution integral
      xlow = x - sc * par3;
      xupp = x + sc * par3;
      step = (xupp-xlow) / np;

      // Convolution integral of Landau and Gaussian by sum
      for(i=1.0; i<=np/2; i++) {
         xx = xlow + (i-.5) * step;
         fland = TMath::Landau(xx,mpc,par0, 0) / par0;
         sum += fland * TMath::Gaus(x,xx,par3);

         xx = xupp - (i-.5) * step;
         fland = TMath::Landau(xx,mpc,par0, 0) / par0;
         sum += fland * TMath::Gaus(x,xx,par3);
      }
      return (par2 * step * sum * invsq2pi);
}
```

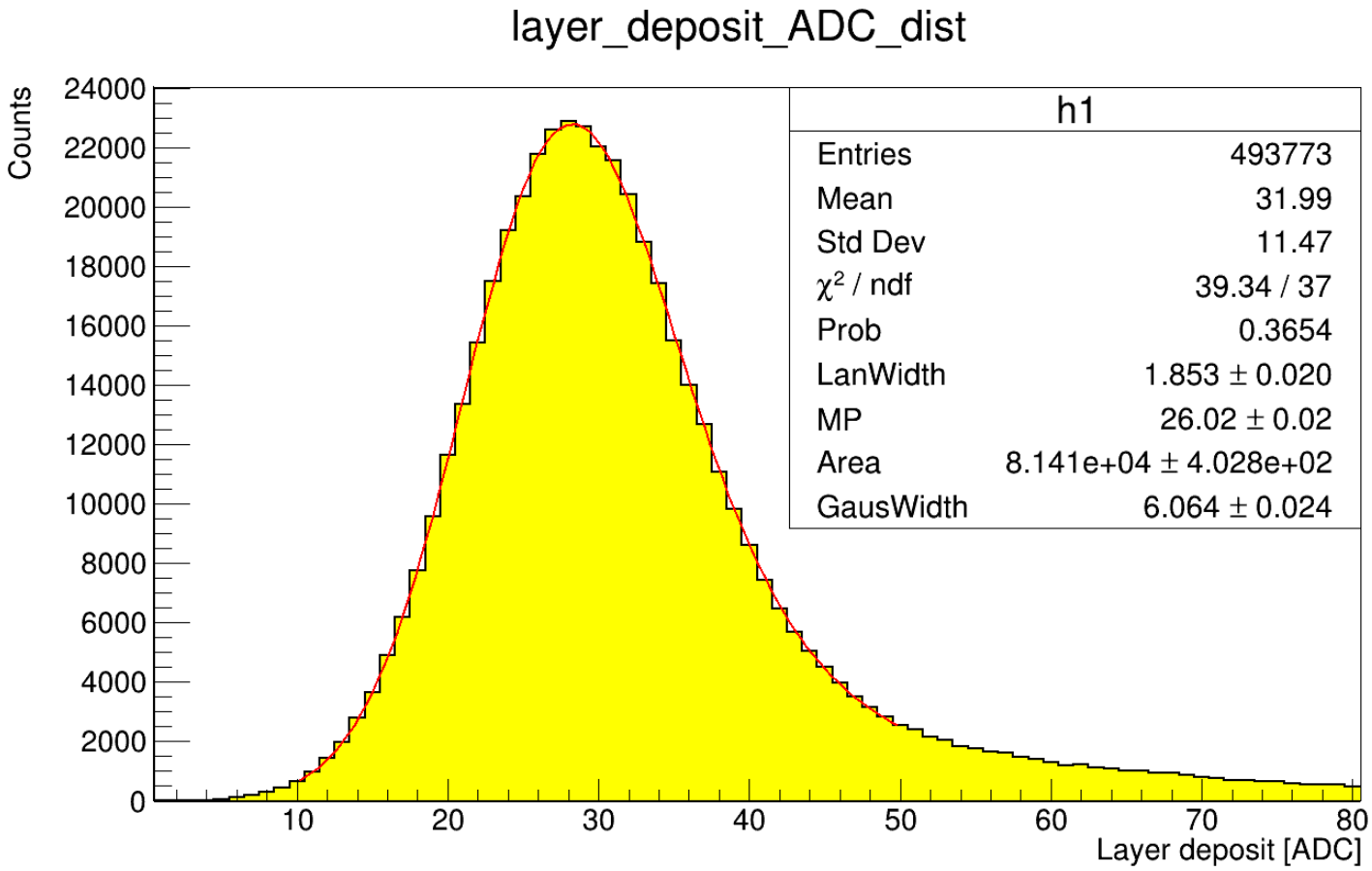
Fit with different noise

- noise = 3 ADC
- a = 1
- LanPar = 0
- GausWidth changes comparing to fit from slide 9



Fit with different noise

- noise = 6 ADC
- a = 1
- LanPar = 0
- GausWidth changes comparing to fit from slide 9
- LanWidth weakly depends on noise

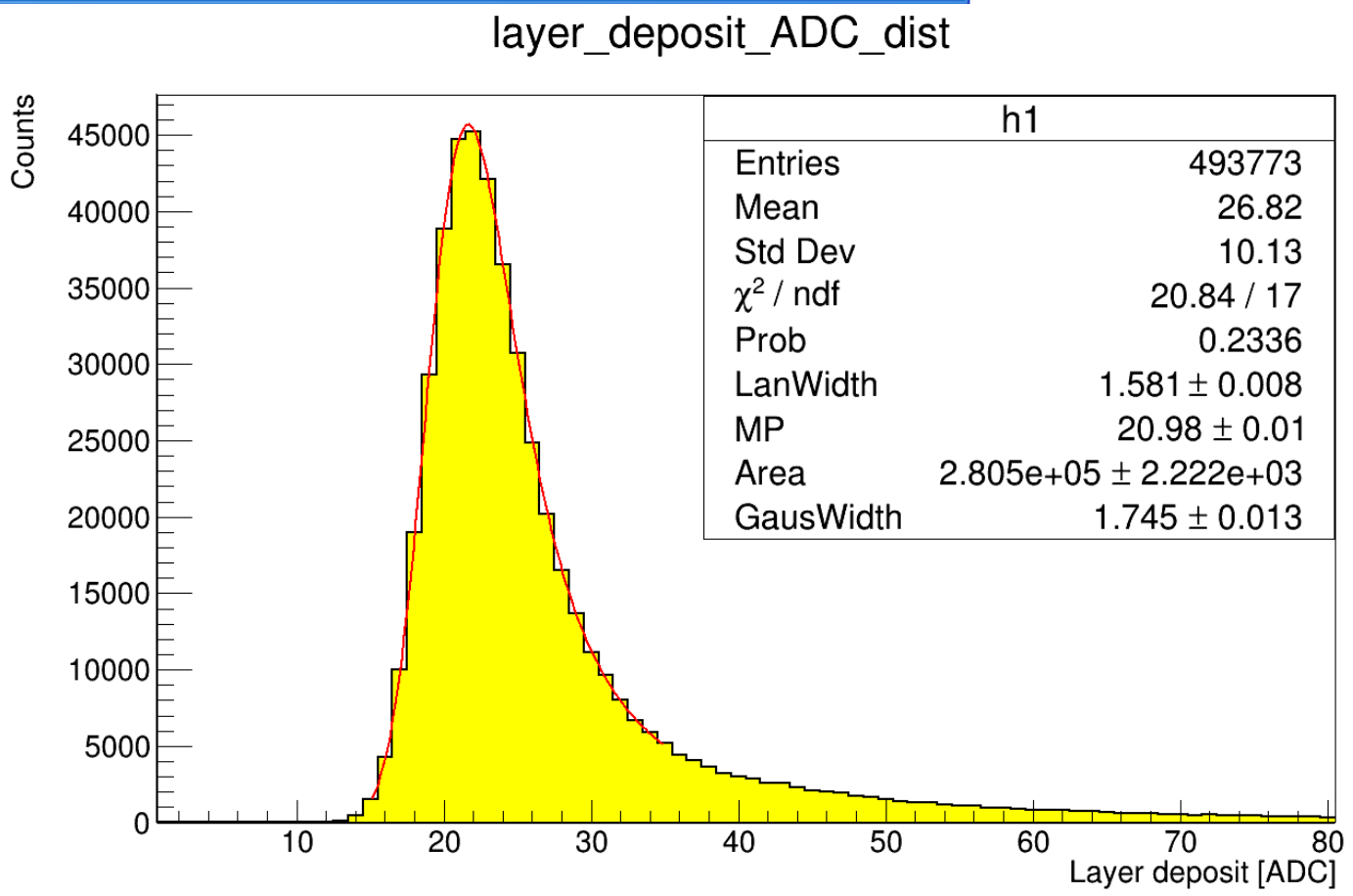


Adjusting LanPar

- noise = 1.478 ADC
- a = 1.2779
- LanPar = 0.212
- MP slightly too big
- GausWidth slightly to big
- LanWidth in agreement with TB

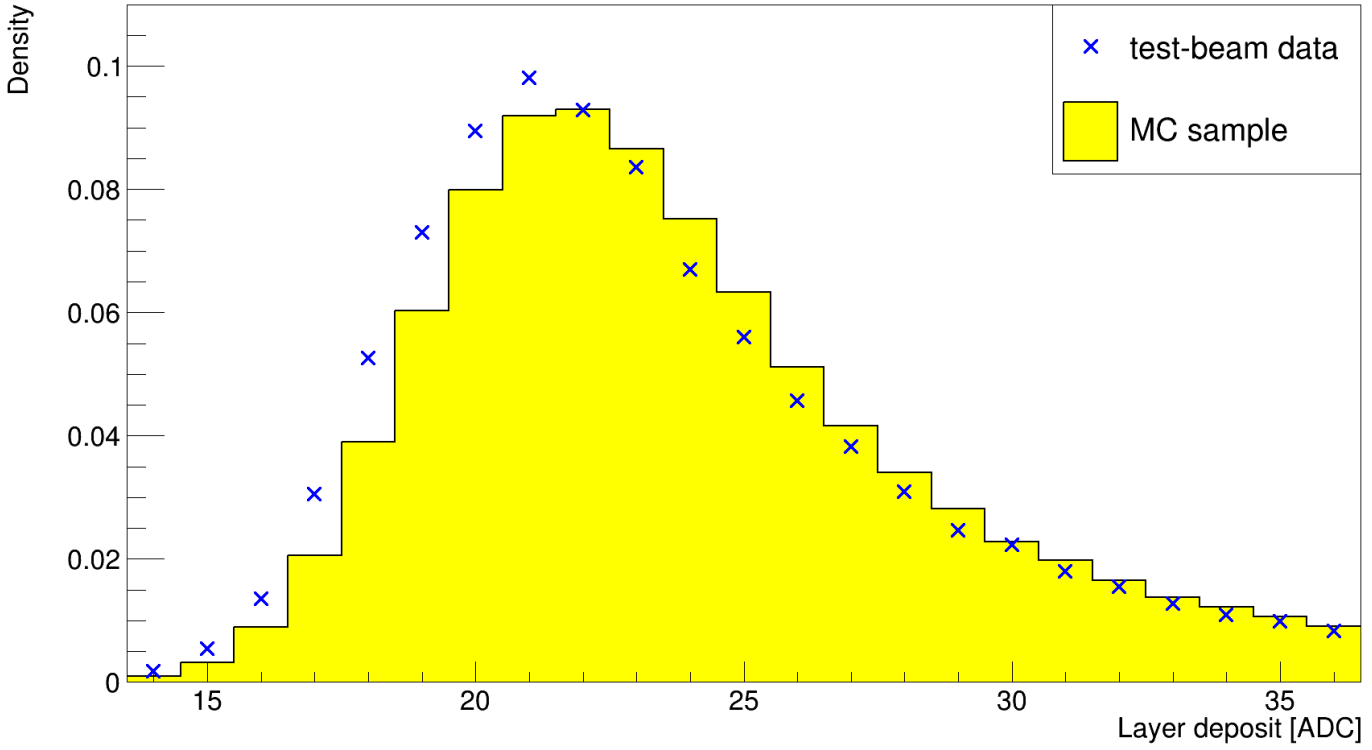
Parameters from fit to test-beam data:

- LanWidth = 1.582
- MP = 20.4
- GausWidth = 1.665



Adjusting LanPar

- noise = 1.478 ADC
- a = 1.2779
- LanPar = 0.212
- distributions of signal from test-beam are presented together with MC sample
- distributions are normalised



Noise level

- Level of electronics noise was calculated as a mean of standard deviations of pedestals measured before data taking during TB in 2022,
- Noise data was provided by prof. Marek Idzik,
- Pedestals collected at 10:18 on 15.09.2022 were used,
- Mean of the pedestals' standard deviations is 1.478 ADC, channels with zero pedestal's standard deviation were omitted.