Electron energy calibration with low pile-up runs For W mass measurement

LABORATOIRE
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Orsay

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Outline :

1. Introduction :
    - Motivation
    - Calibration procedure

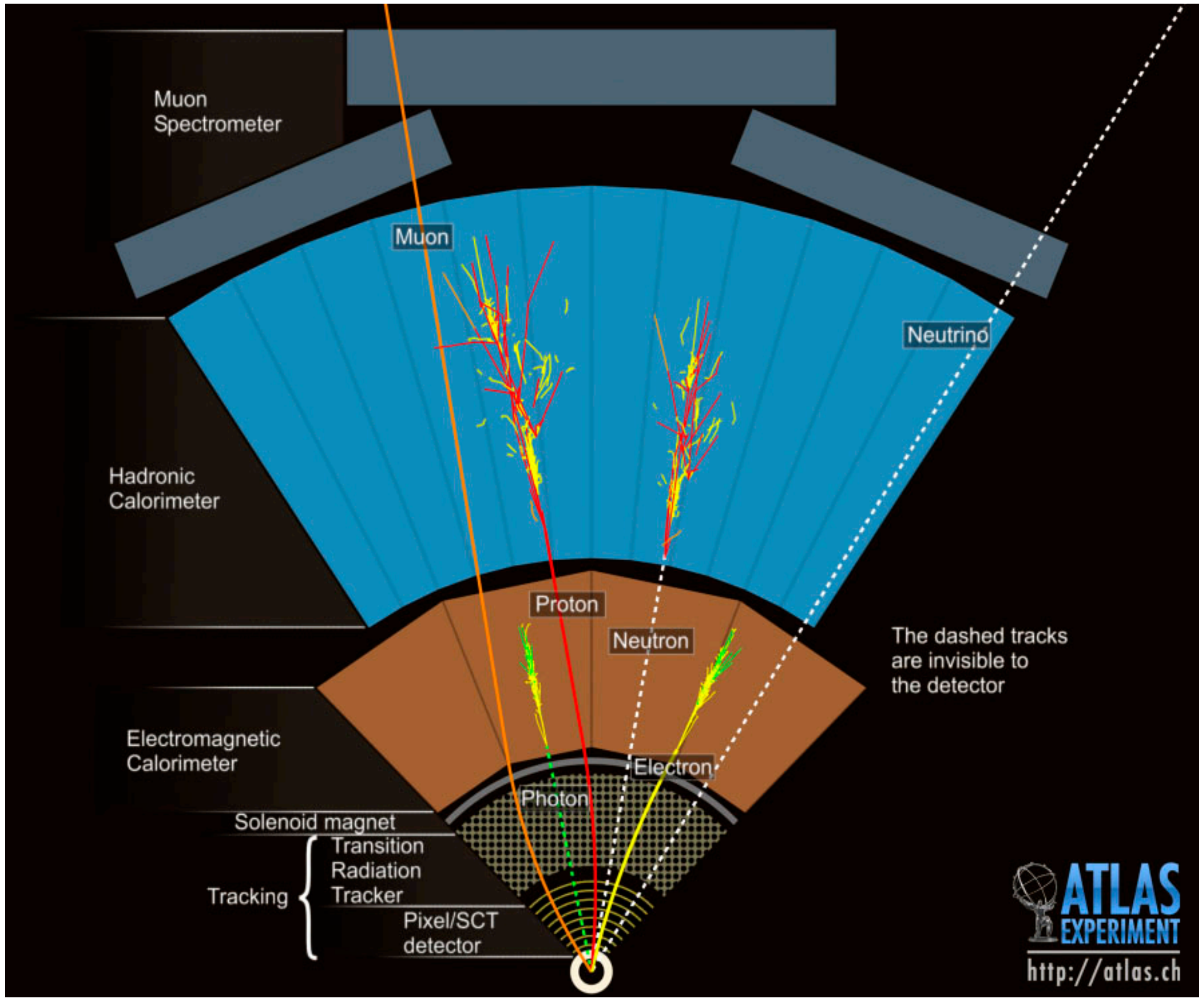
2. Template method :
    - Electron scale factors

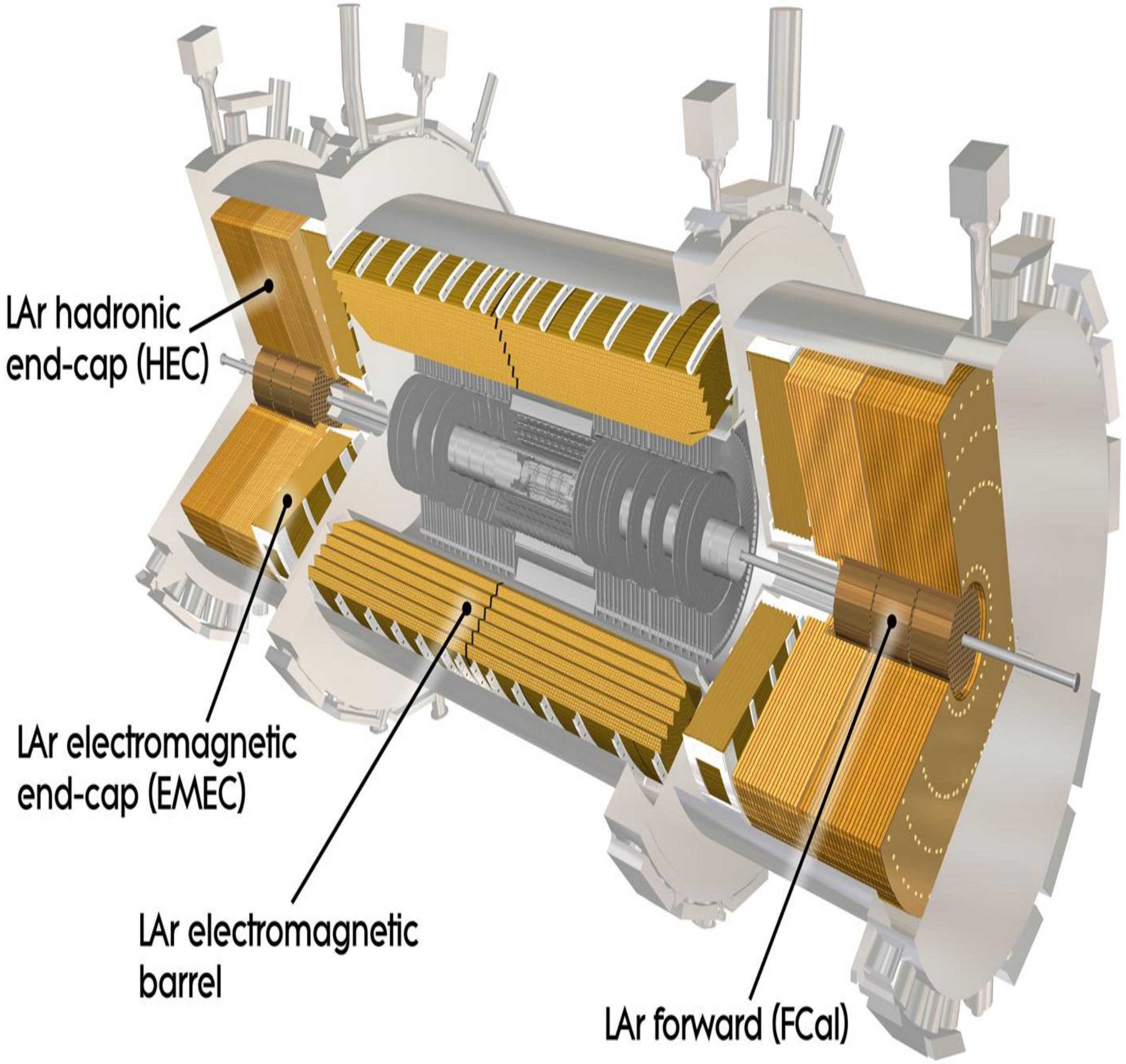
3. Electron energy calibration :
    - Energy scale factors
    - Additional constant term

4. Low pile-up calibration :
    - Extrapolation study
    - Extrapolation systematics

5. Conclusion.

Introduction : What we want to do ?





ATLAS reconstructs physics objects (electrons, photons, jets, MET) based on a combination of sub-detectors: tracker, electromagnetic and hadronic calorimeters, muon spectrometer.

Goal: We want to calibrate the EM calorimeter to rush a high precision for the W mass measurement (thesis topic)

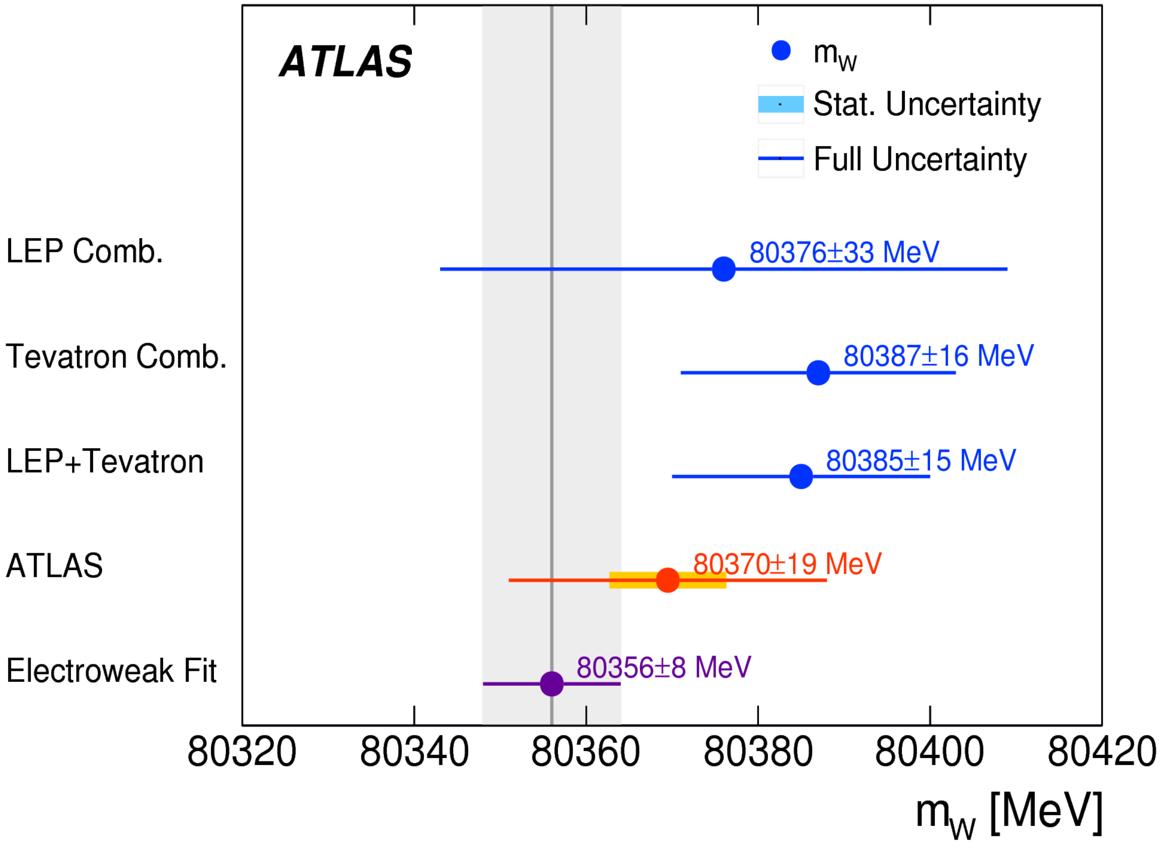
Introduction : Motivation

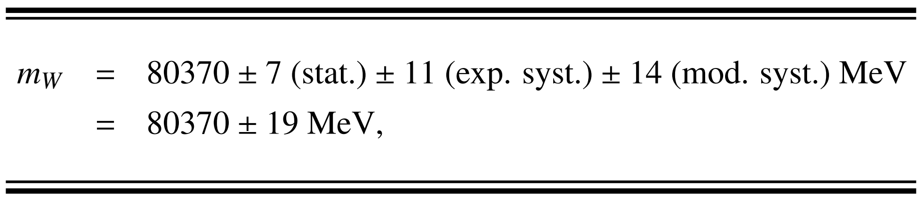
- **Electromagnetic particles are heavily used in precision measurements due to the high precision reachable by the electromagnetic (EM) calorimeter.**

Measuring the mass of the W boson with an uncertainty less than 19 MeV

The measurement of the properties of the Higgs boson ($H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$)

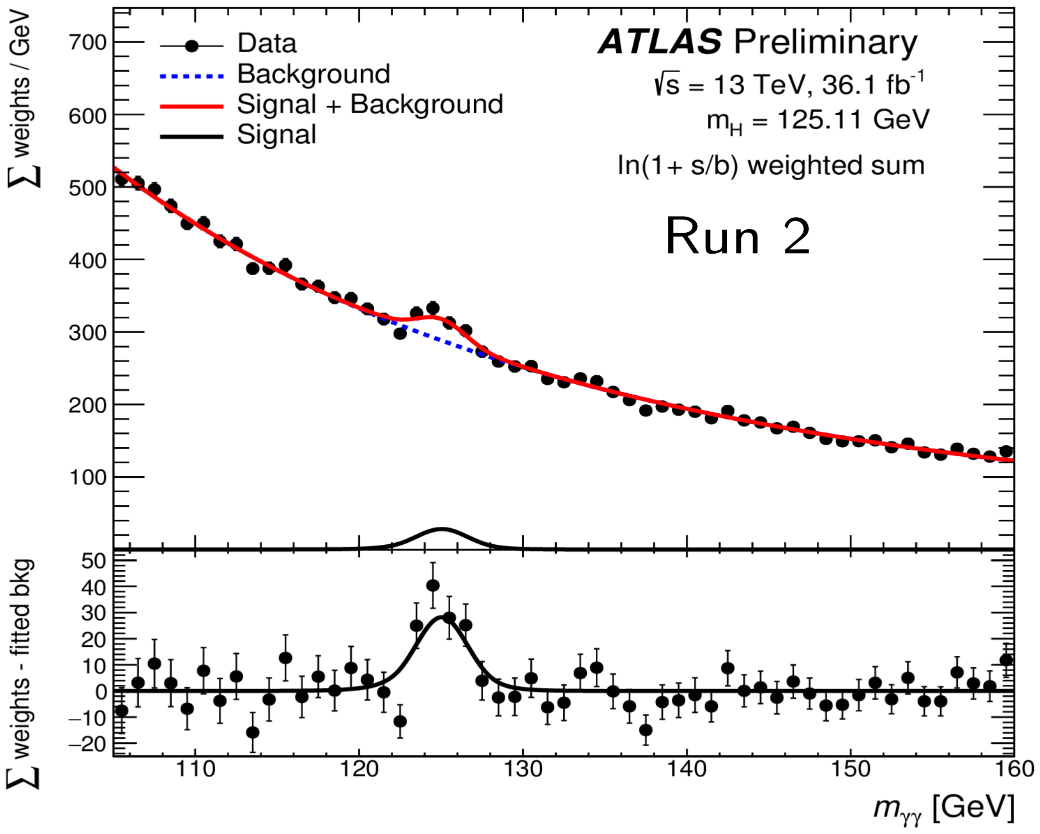
arXiv:1701.07240

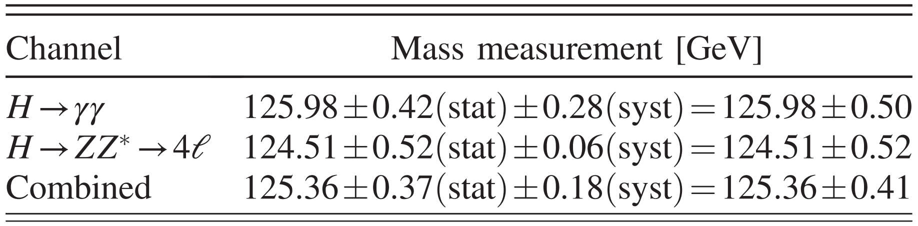




$$\begin{aligned} m_W &= 80370 \pm 7\ (\text{stat.}) \pm 11\ (\text{exp. syst.}) \pm 14\ (\text{mod. syst.})\ \text{MeV} \\ &= 80370 \pm 19\ \text{MeV}, \end{aligned}$$

arXiv:1806.00242





Channel	Mass measurement [GeV]
$H \rightarrow \gamma\gamma$	$125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{syst}) = 125.98 \pm 0.50$
$H \rightarrow ZZ^* \rightarrow 4\ell$	$124.51 \pm 0.52(\text{stat}) \pm 0.06(\text{syst}) = 124.51 \pm 0.52$
Combined	$125.36 \pm 0.37(\text{stat}) \pm 0.18(\text{syst}) = 125.36 \pm 0.41$

To reach a high precision in property measurements, a precise calibration of the energy of electrons and photons is required.

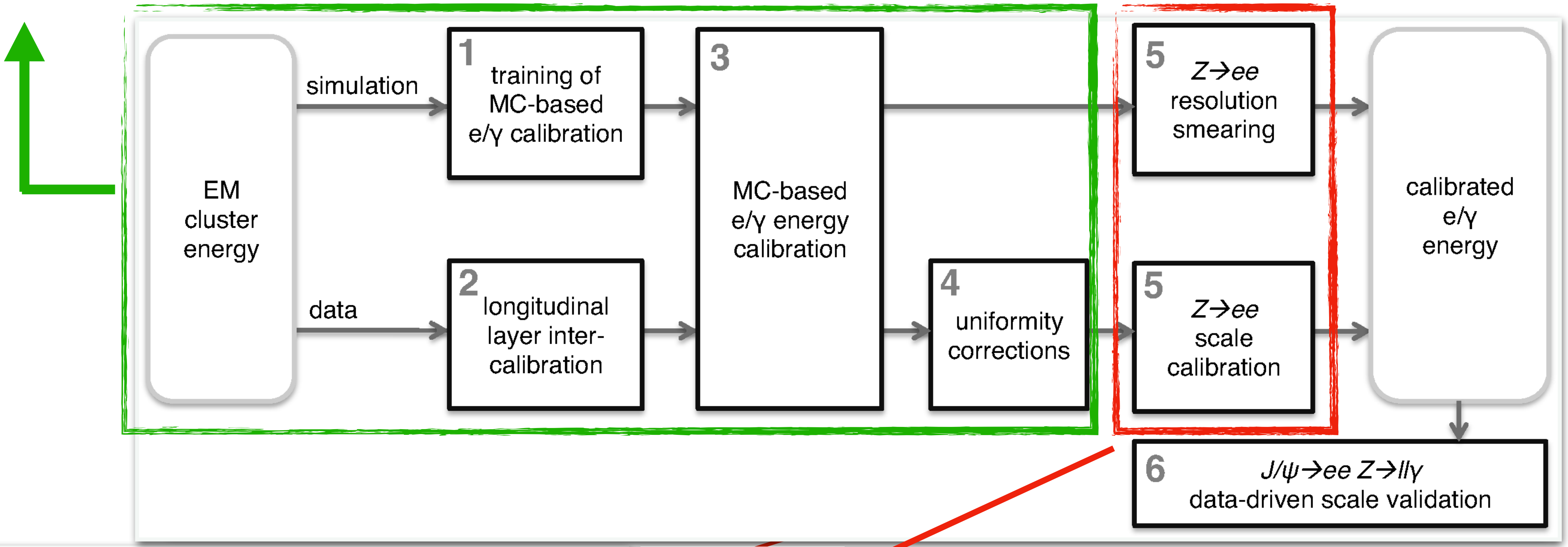
Introduction : Calibration procedure.

MC based calibration :

❶ The EM cluster properties are calibrated to the original electron and photon energy in simulated MC samples using multivariate techniques.

❷ Since the EM calorimeter is longitudinally segmented : Equalise scales of different longitudinal layers between data/MC.

❸ Apply MC response on data/mc clusters.



EM cluster energy

simulation

data

1 training of MC-based e/γ calibration

2 longitudinal layer inter-calibration

3 MC-based e/γ energy calibration

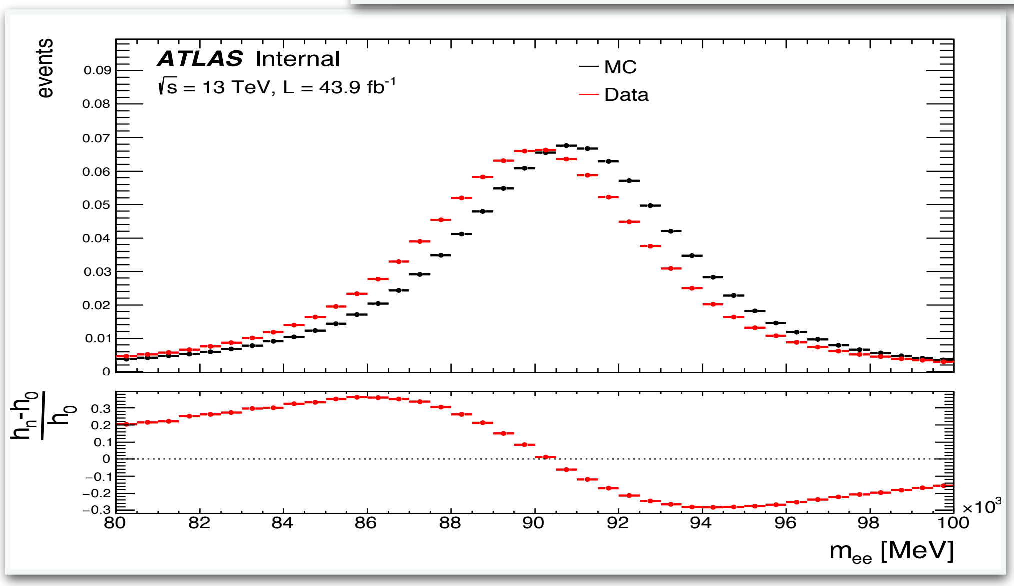
4 uniformity corrections

5 *Z→ee* resolution smearing

5 *Z→ee* scale calibration

calibrated e/γ energy

6 *J/ψ→ee Z→llγ* data-driven scale validation



- **Last step in calibration chain (step 5).**
- **Correct residual data-MC differences by energy scale/resolution factors applied to data and MC.**
- **Use good knowledge of Z mass to extract the scale factors : compare electrons from Z→ee.**

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    - Calibration procedure
2. **Template method :**
    - **Electron corrections factors**
3. Electron energy calibration :
    - Energy scale factors
    - Additional constant term
4. Low pile-up calibration :
    - Extrapolation study
    - Extrapolation systematics
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Template method : Correction scale factors

- To correct the residual difference between data and simulation, we apply two eta-dependent correction scale factors (i=index of the η bin).

1

➢ **Energy scale factor α_i :**

A first correction is applied on both electrons coming from the Z decay in order to shift the central value of the data distribution.

Scale correction of electron energy in data :

$$E_i^{\text{data}} = E_i^{\text{MC}} \cdot (1 + \alpha_i)$$

2

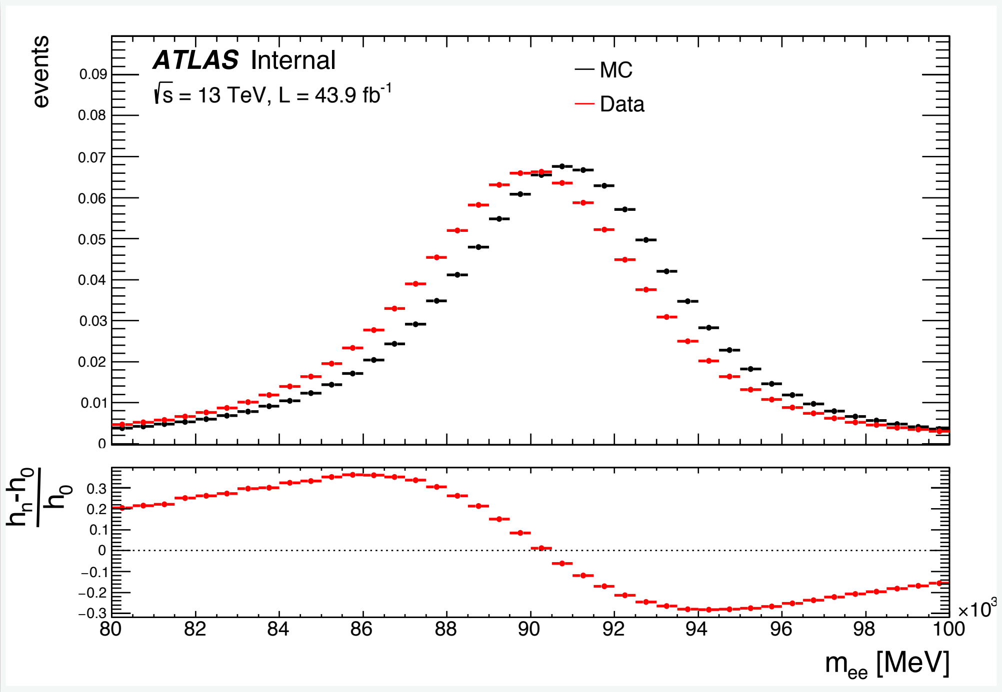
➢ **Additional constant term C_i :**

additional constant term "C_i" is used to enlarge the MC resolution up to the data one. Both MC electrons undergo the correction.

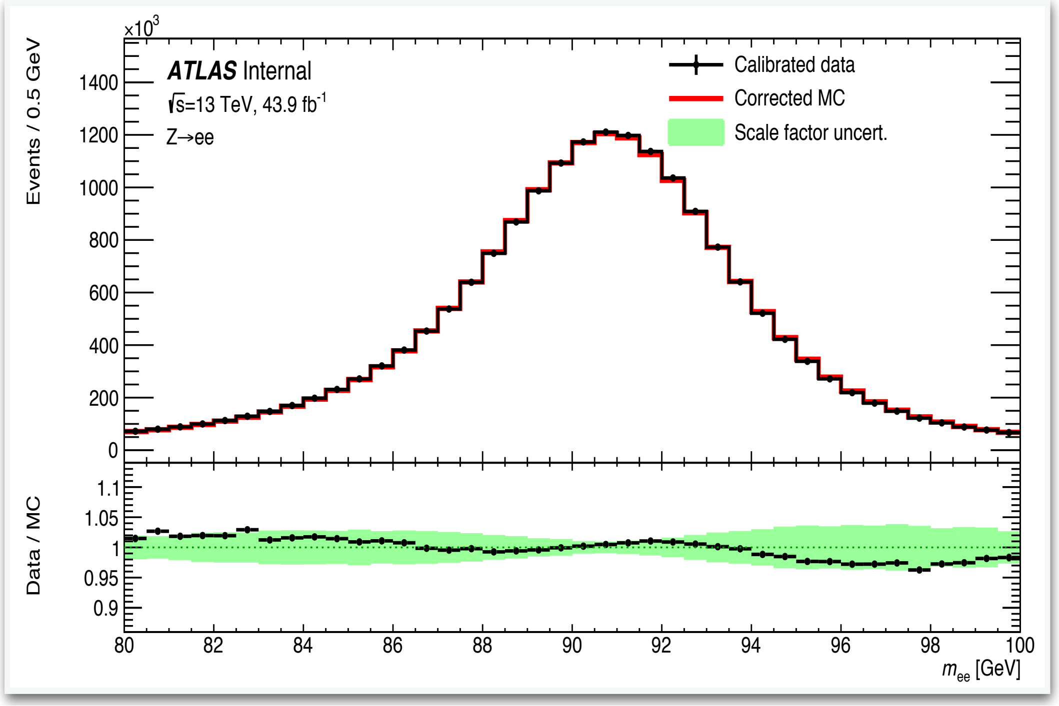
Smearing of electron energy in MC :

$$E^{corr} = E^{true}(1 + \mathcal{N}(0,1) * C)$$

with $\mathcal{N}$(0,1) a Gaussian distribution.



After correction



OutLine :

1. Introduction :
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2. Template method :
    - Electron scale factors
    - Template method description

3. **Electron energy calibration :**
    - **Energy scale factors**
    - **data/MC comparison**

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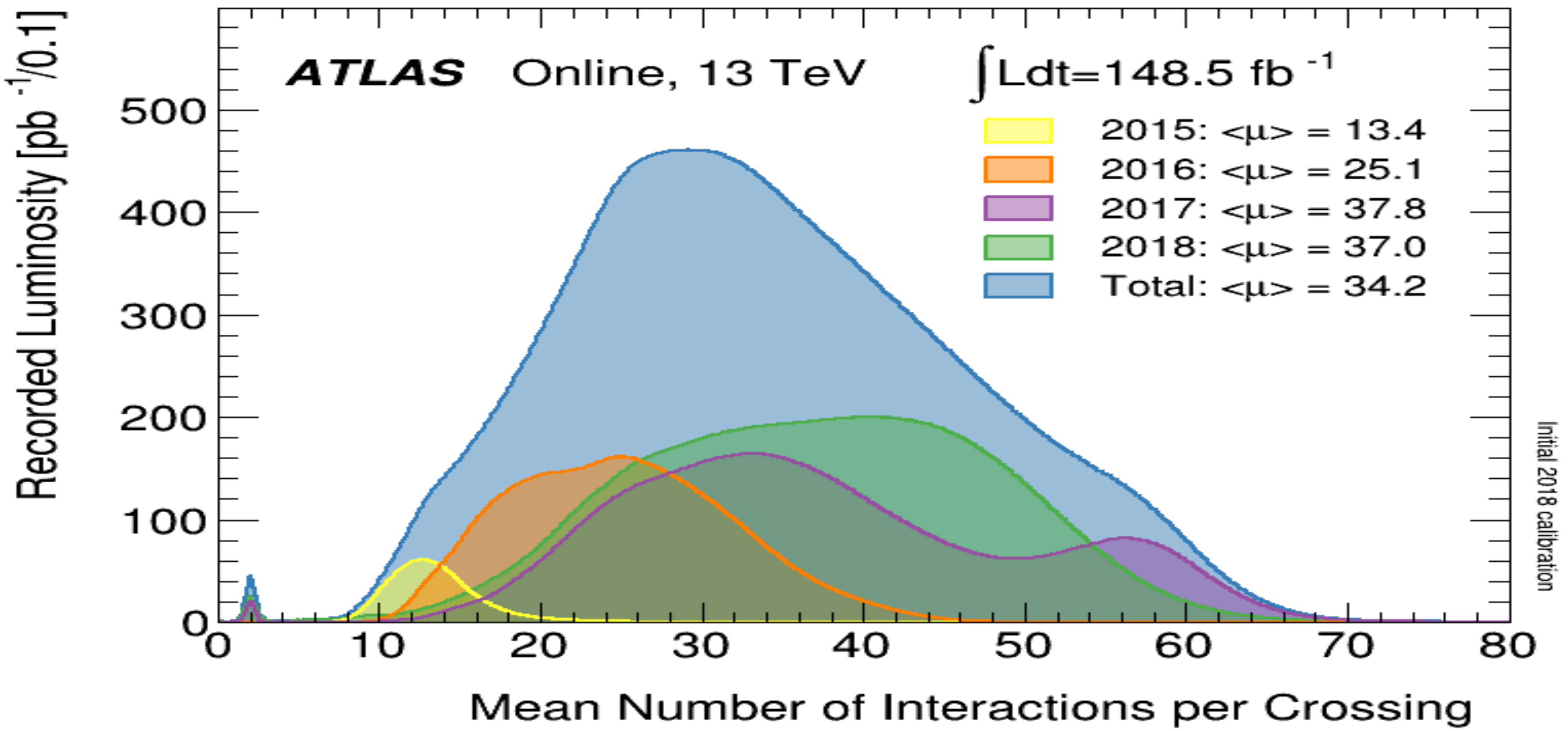
Electron scale factors for high pile-up runs : datasets.

- **Pile-up** : proton-proton collisions in addition to the collision of interest.

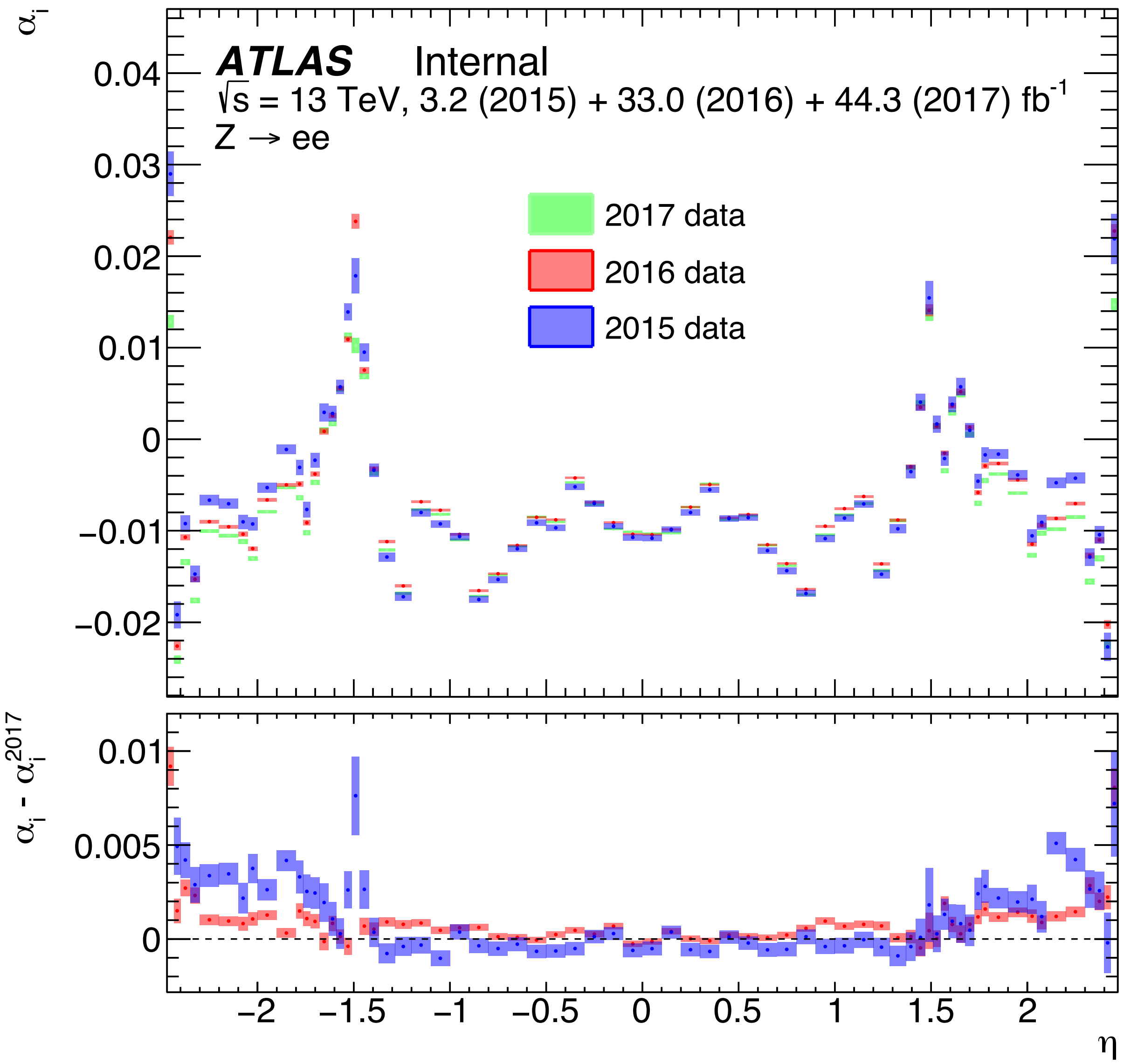


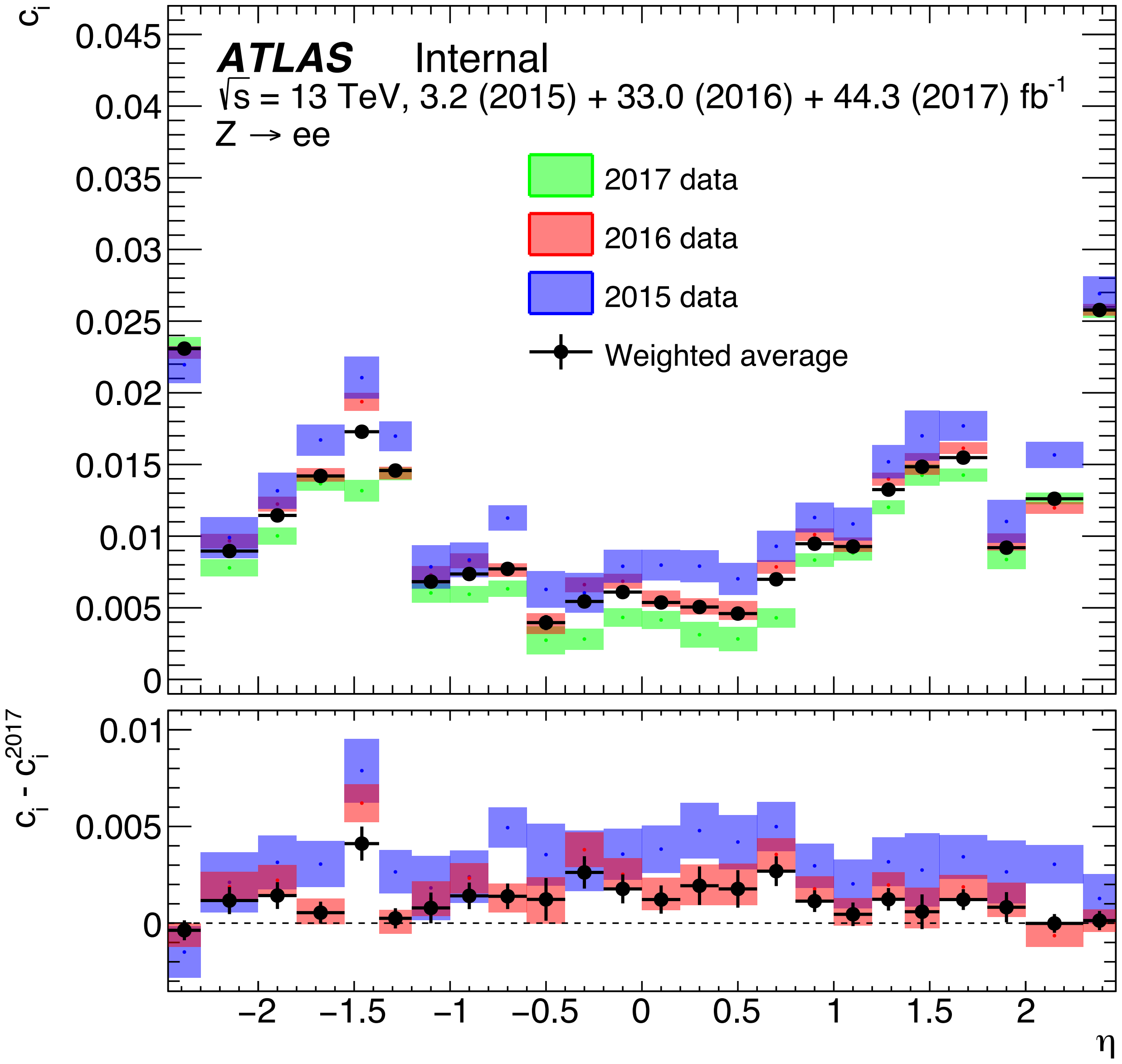
high pile-up dataset

mc16a	17.9M
mc16d	17.2M
mc16e	28.9M

data 15	1.5M
data 16	14.8M
data 17	19.1M
data 18	25.5M

Correction scale factors:



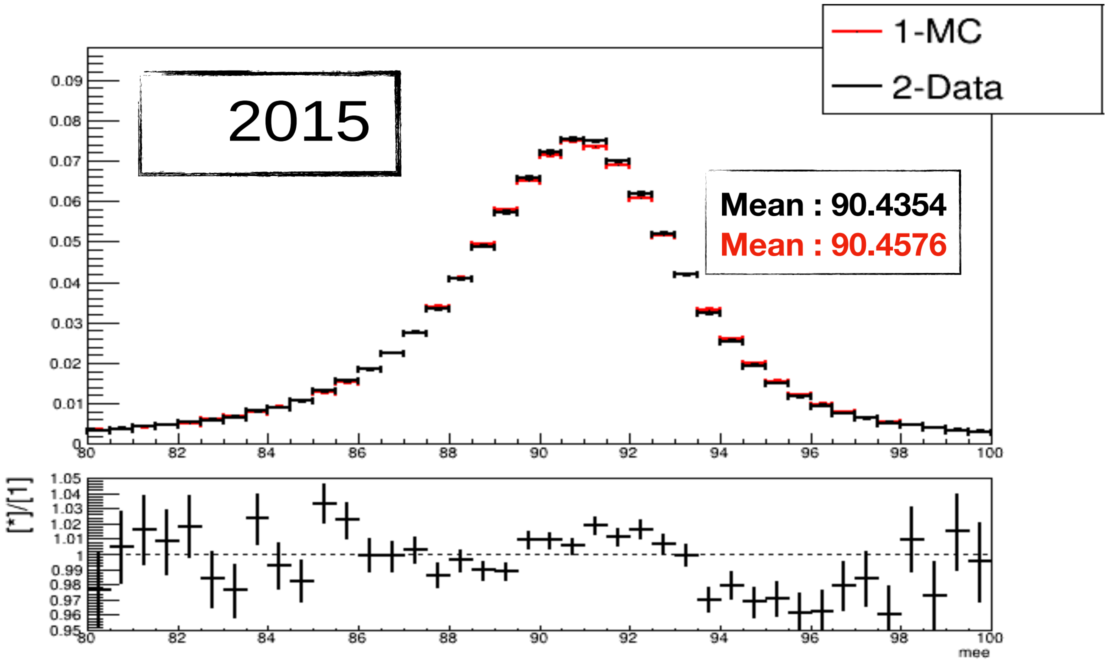


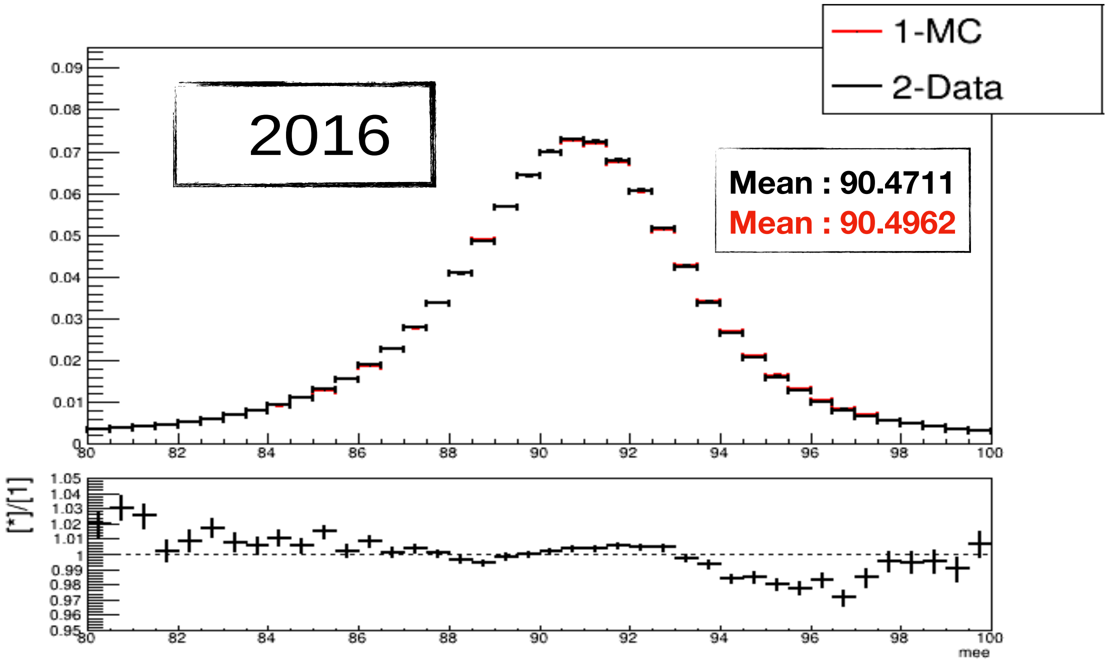
The energy scale factors α: results are compatible between different years in the barrel region, the observed effect in the end-cap is explained by the small luminosity dependence of the calorimeter response.

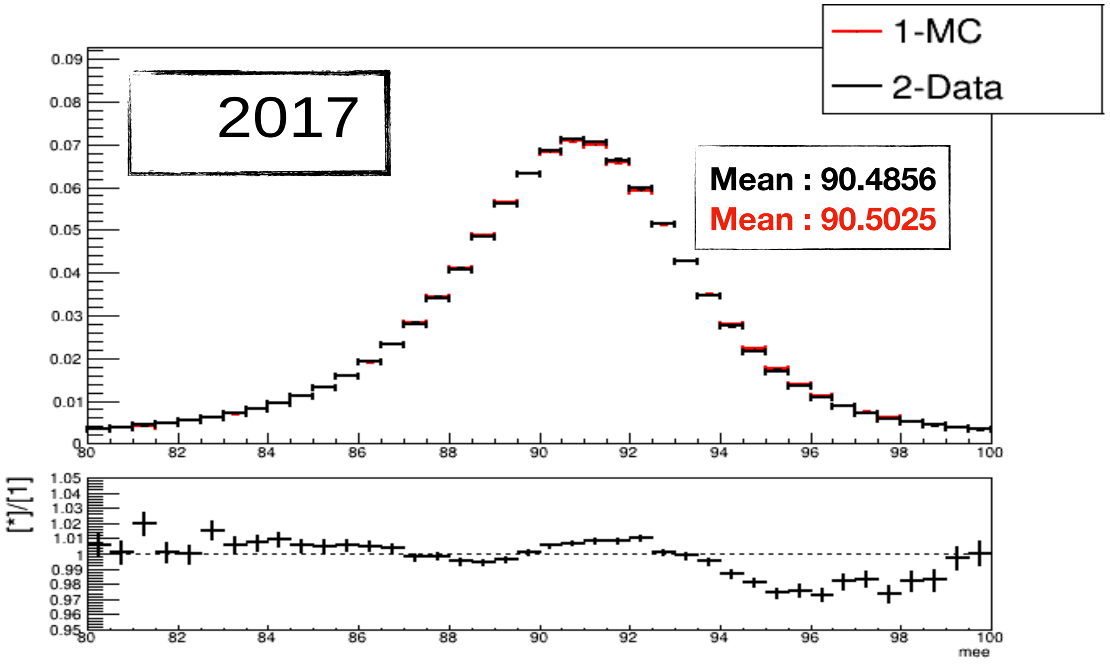
The additional constant term c': The constant c' depend on the pile-up: this effect is due to an overestimation of the pile-up noise is MC ⇒ the constant c' absorbs this mis-modeling.

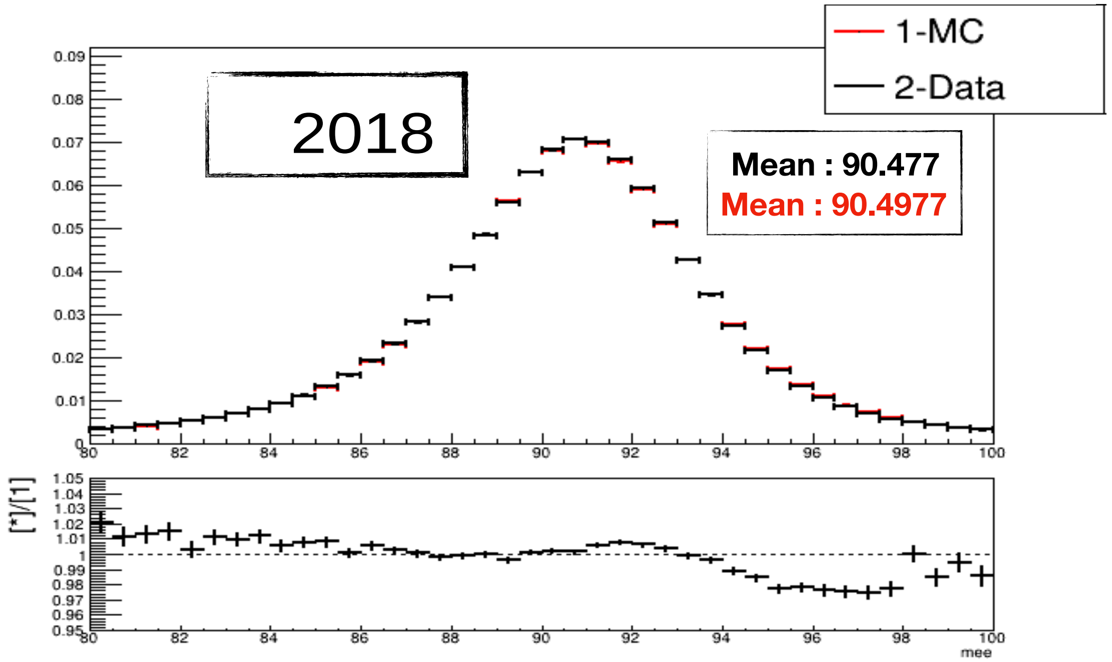
Electron scale factors for high pile-up : data/MC comparison

- Inclusive di-electron invariant mass distribution from Z→ee decays in data compared to MC for the high-mu runs after applying the full calibration.
- Small but non negligible difference (~2 e-4) between average of data and MC.









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   - **Extrapolation systematics**

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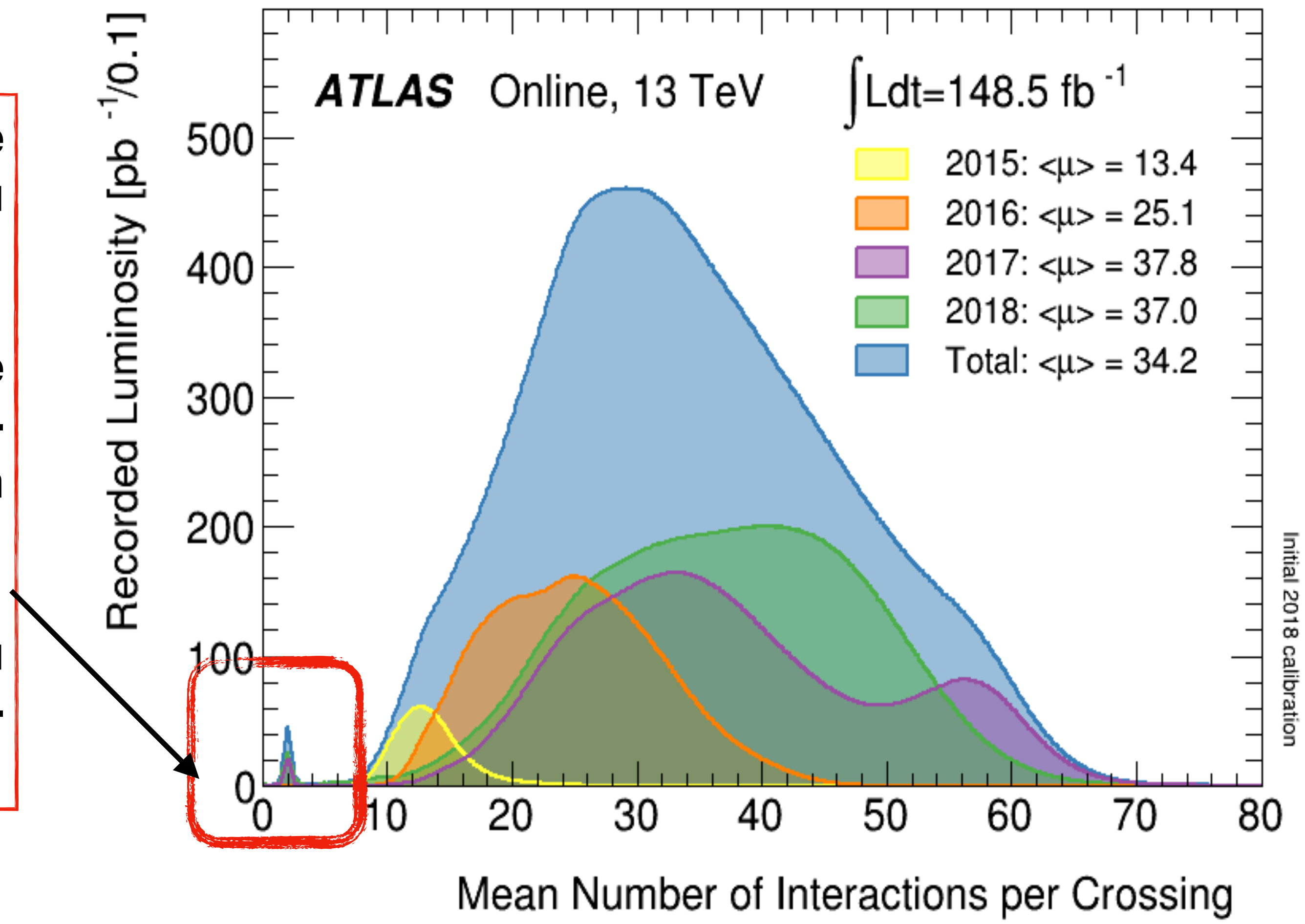
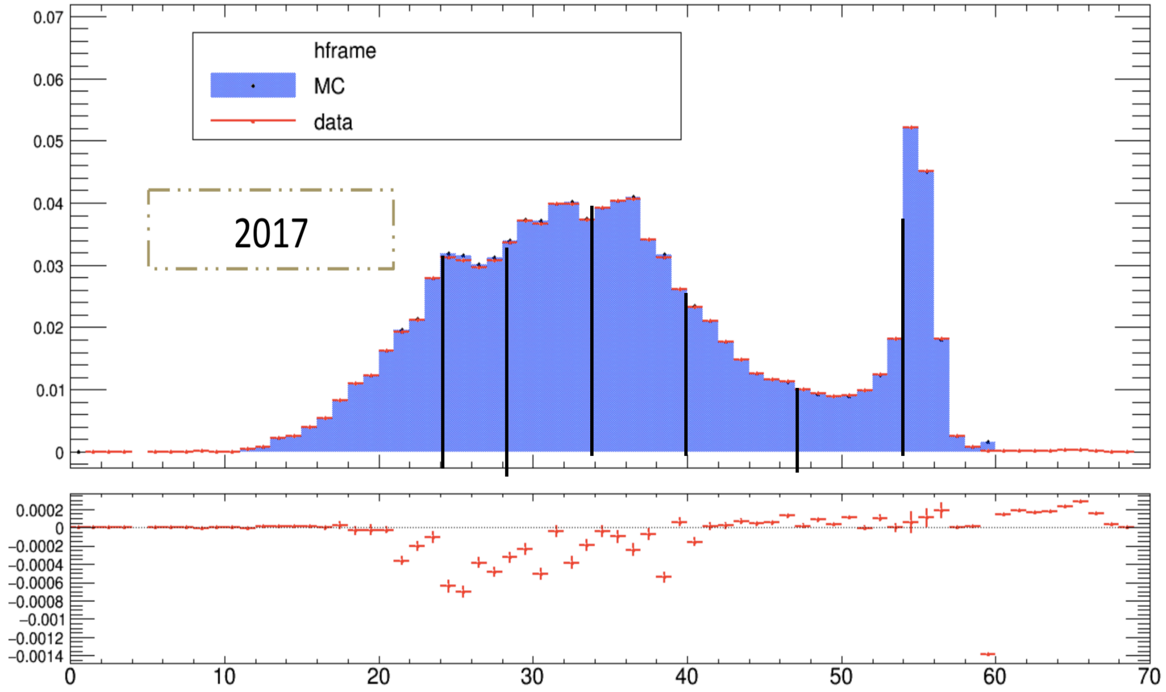
low pile-up run : dataset.

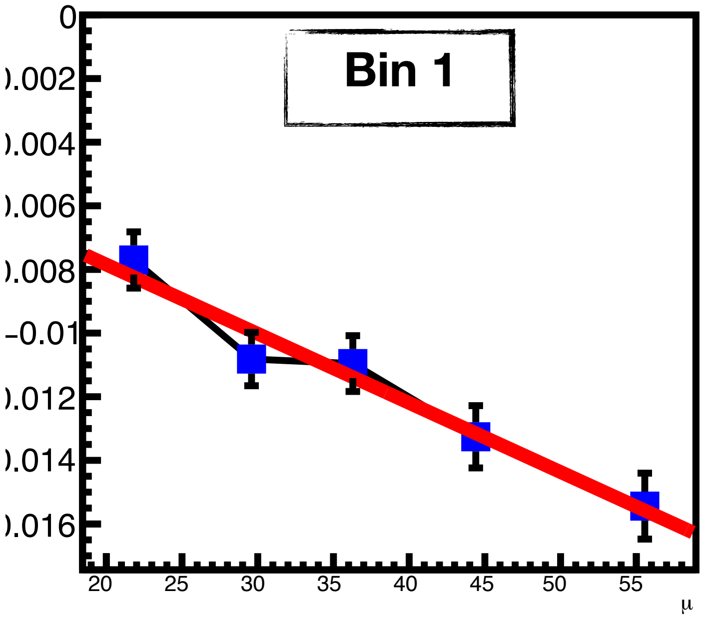
- **The same procedure applied to correct the difference observed between data and simulation for the high-mu dataset is applied also for low pile-up dataset.**
- **Because of some problems in the correction procedure used for the low-mu dataset, related mainly to the low-stat of low pile-up dataset, another alternative approach is also used to calibrate the low-mu dataset.**
- **This complementary approach used for the low-mu dataset, is based mainly on the extrapolation of high-mu results to the low-mu.**

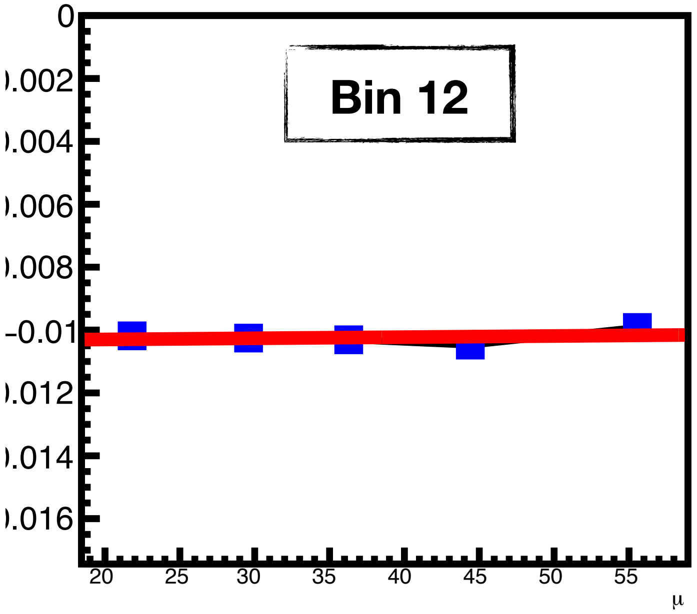


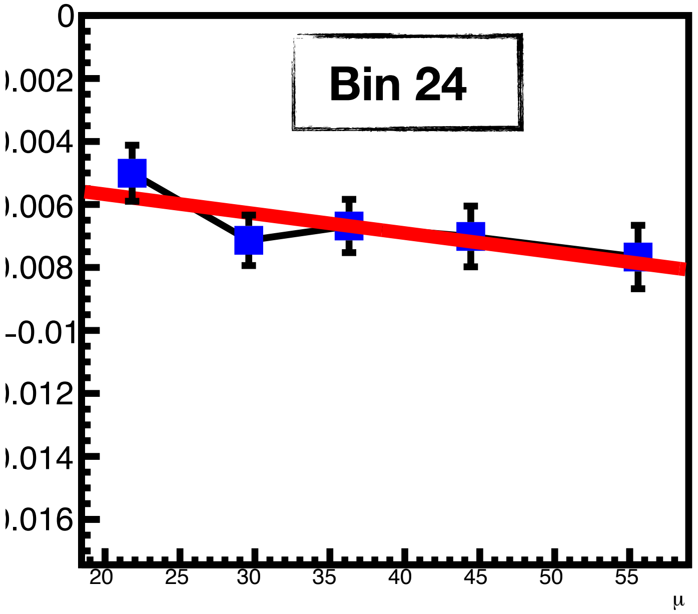
- **Because of some problems in the correction procedure used for low pile-up dataset, related principally to the low stat of low pile-up dataset, another approach is used to calibrate the low pile runs.**
- **The approach used for the low pile-up dataset, is based principally on the extrapolation of high pile-up results to low pile-up :**



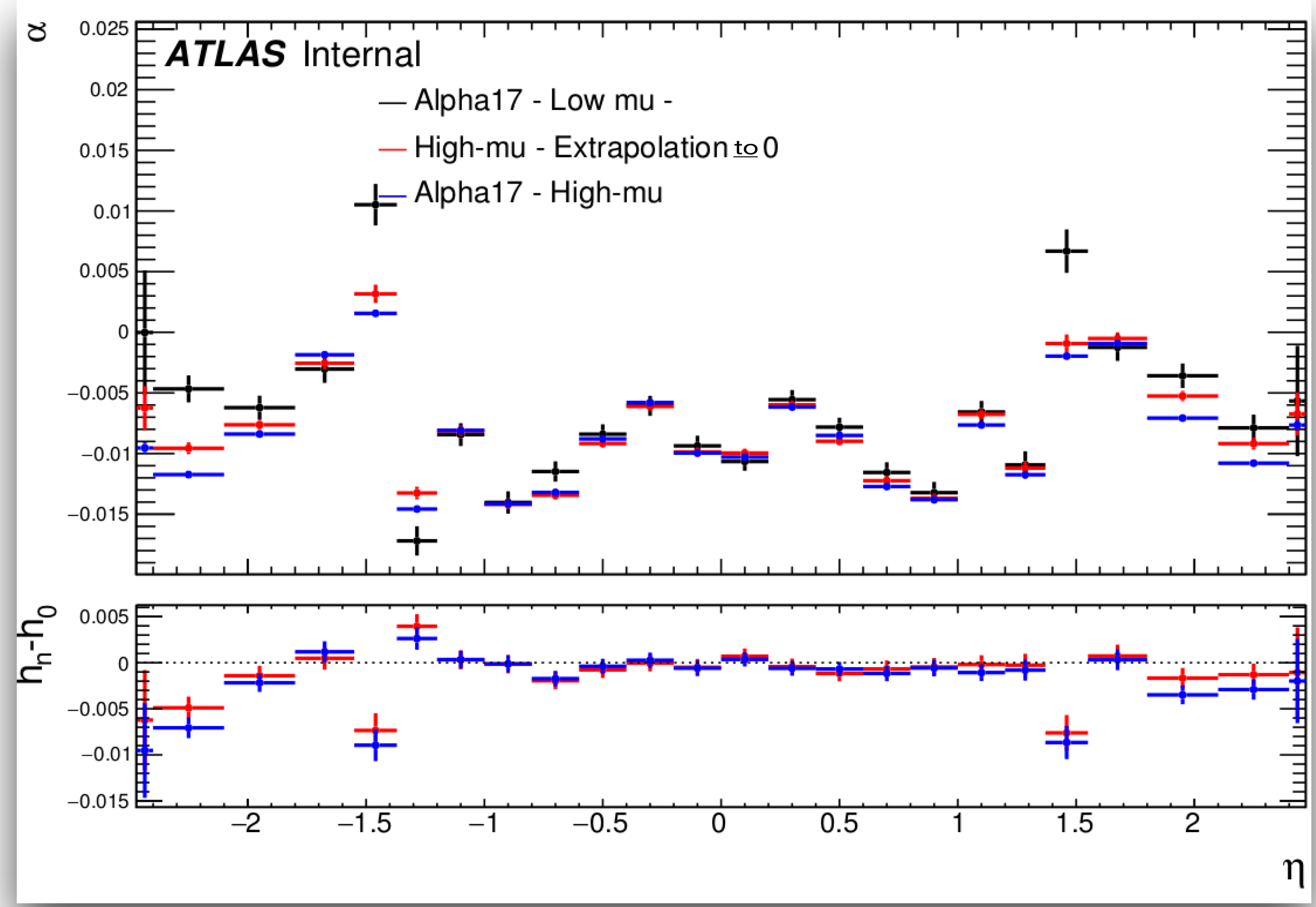
Extrapolation study : results



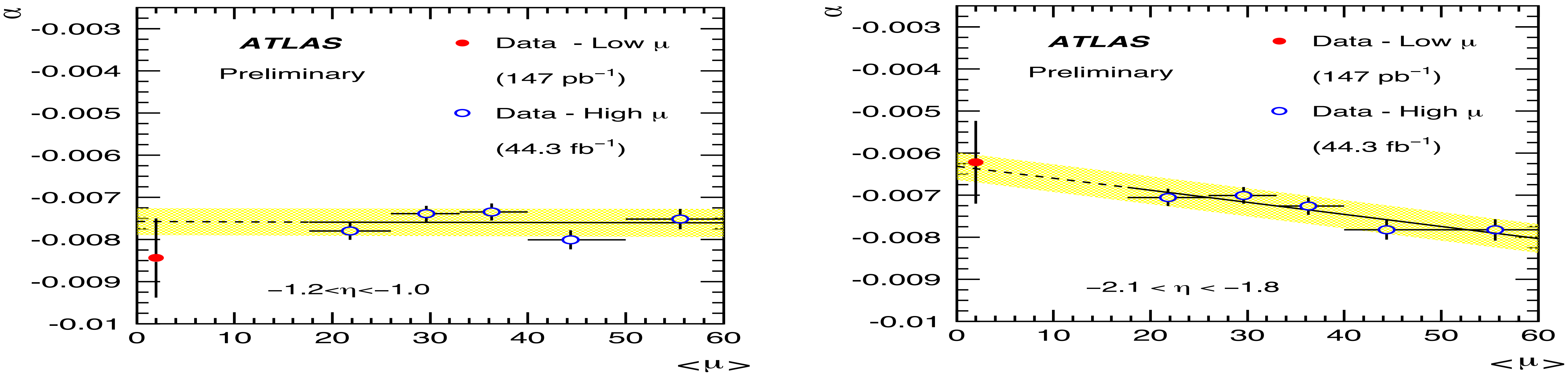




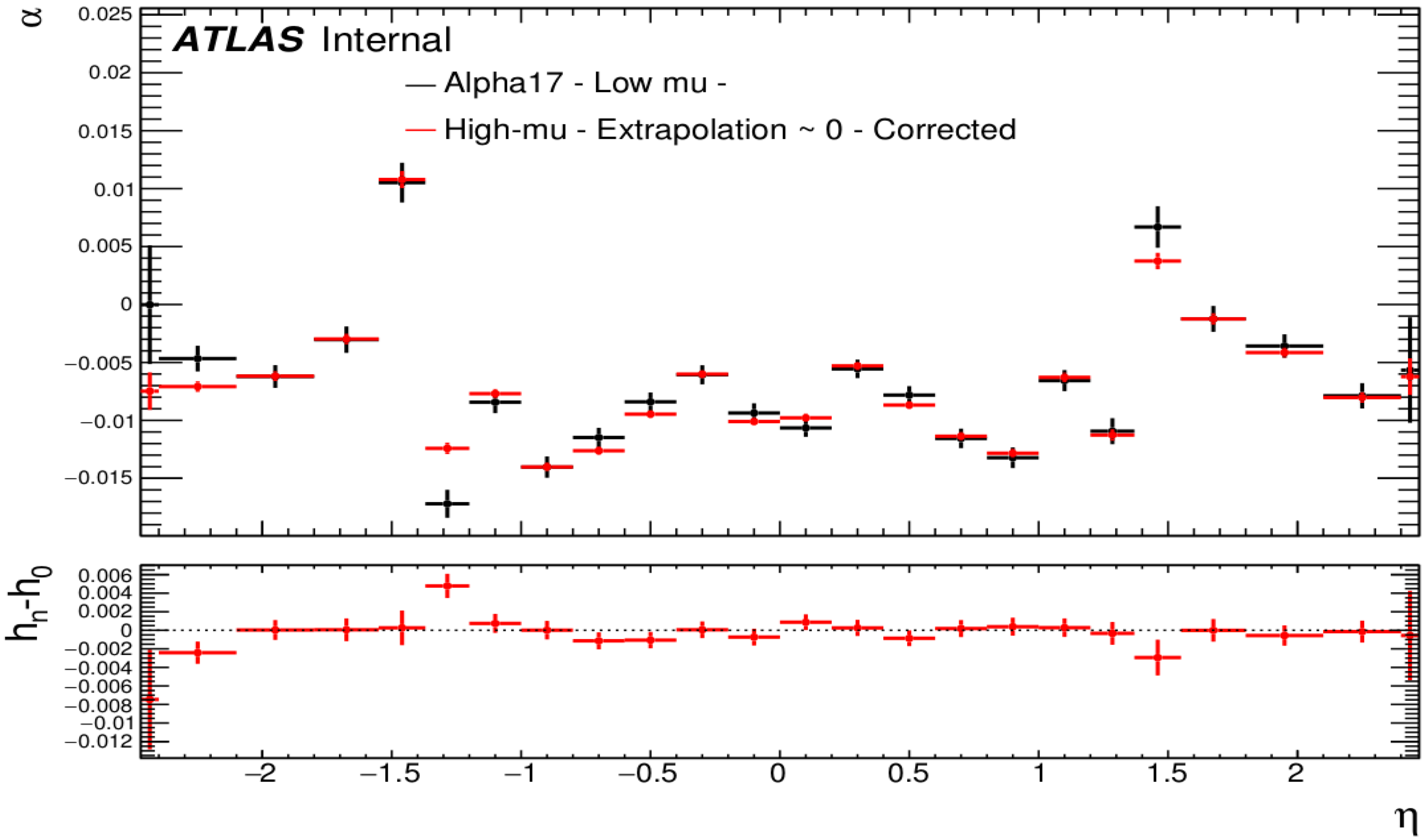
- **For the extrapolation, a linear function is used (higher order is used to define a systematic).**
- **The extrapolation results (red) must be closer to the low-mu results (black).**
- **Residual difference to be understood (low μ extraction problems due to number of bins, bias ...)**
- **The extrapolation results must be corrected with the difference in the topocluster noise threshold between high and low pile-up runs.**
- ***From now on : 24 bins in η for α (baseline).***



Extrapolation study : Results.

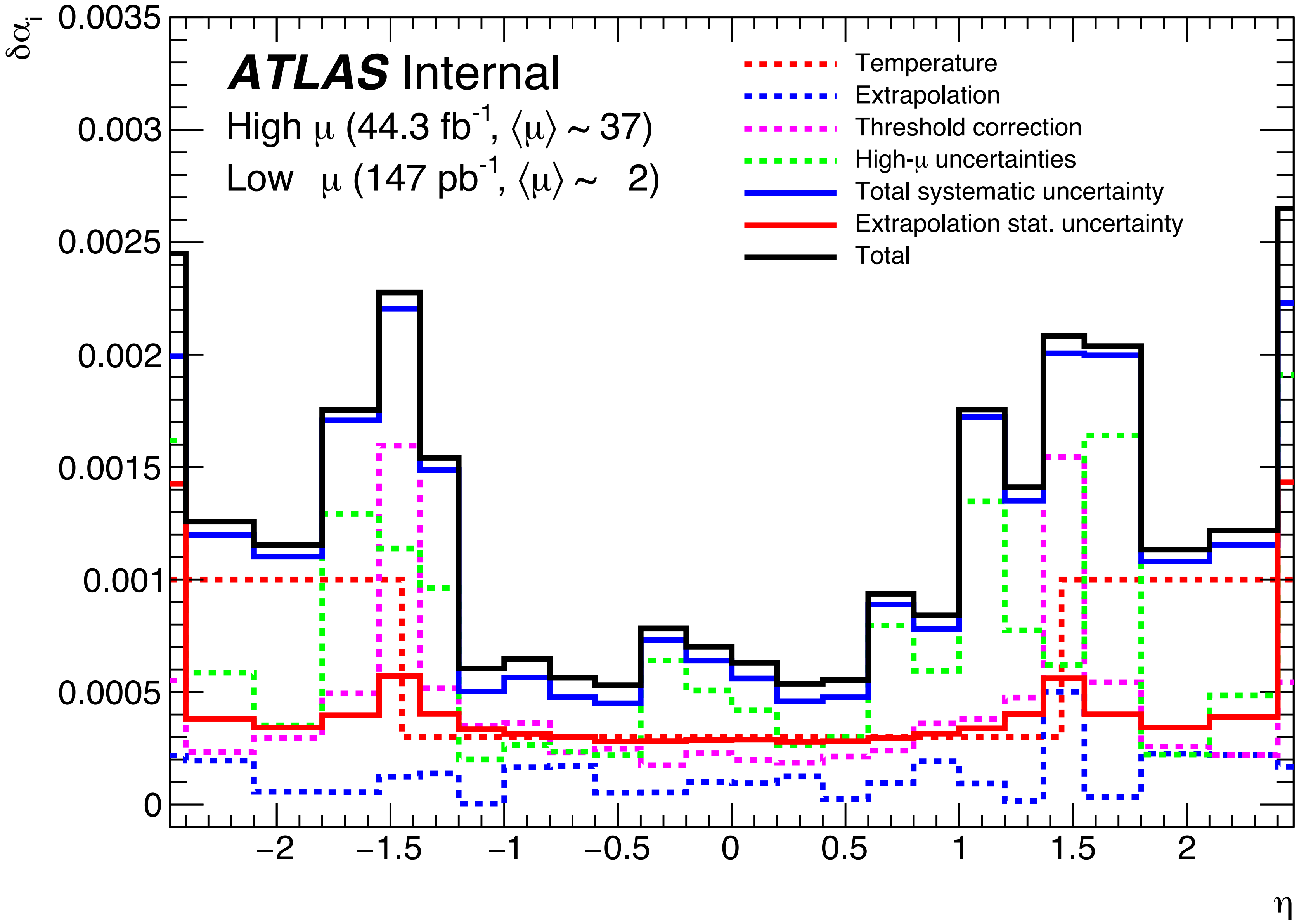


- If we exclude the transition region, it seems that the extrapolation results are similar to low pile-up results, with a difference of the order or smaller of 1e-3.



Low pile-up uncertainties : summary

➡**Uncertainties on the energy scale corrections as a function of η for the low-pileup data.**



- **Extrapolation uncertainty**: related to the choice of the extrapolation function and the number of μ intervals.
- **Temperature uncertainties**: related to the non-linear variation of the LAr temperature with μ.
- **Threshold correction**: related to the difference of threshold between low and high pile-up runs.
- **The total uncertainty on the extrapolated energy scale factors is about 0.05% in the barrel, and on average 0.15% in the end-cap.**

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5. **Conclusion.**

Conclusion :

Electron energy Calibration for standard runs:

- Some discrepancies are observed between data/simulation : energy response & resolution.
- The template method is used to correct these discrepancies.
- The template method use several 1D fits to extract the correction scale factors.
- The correction scale factors are luminosity dependent.

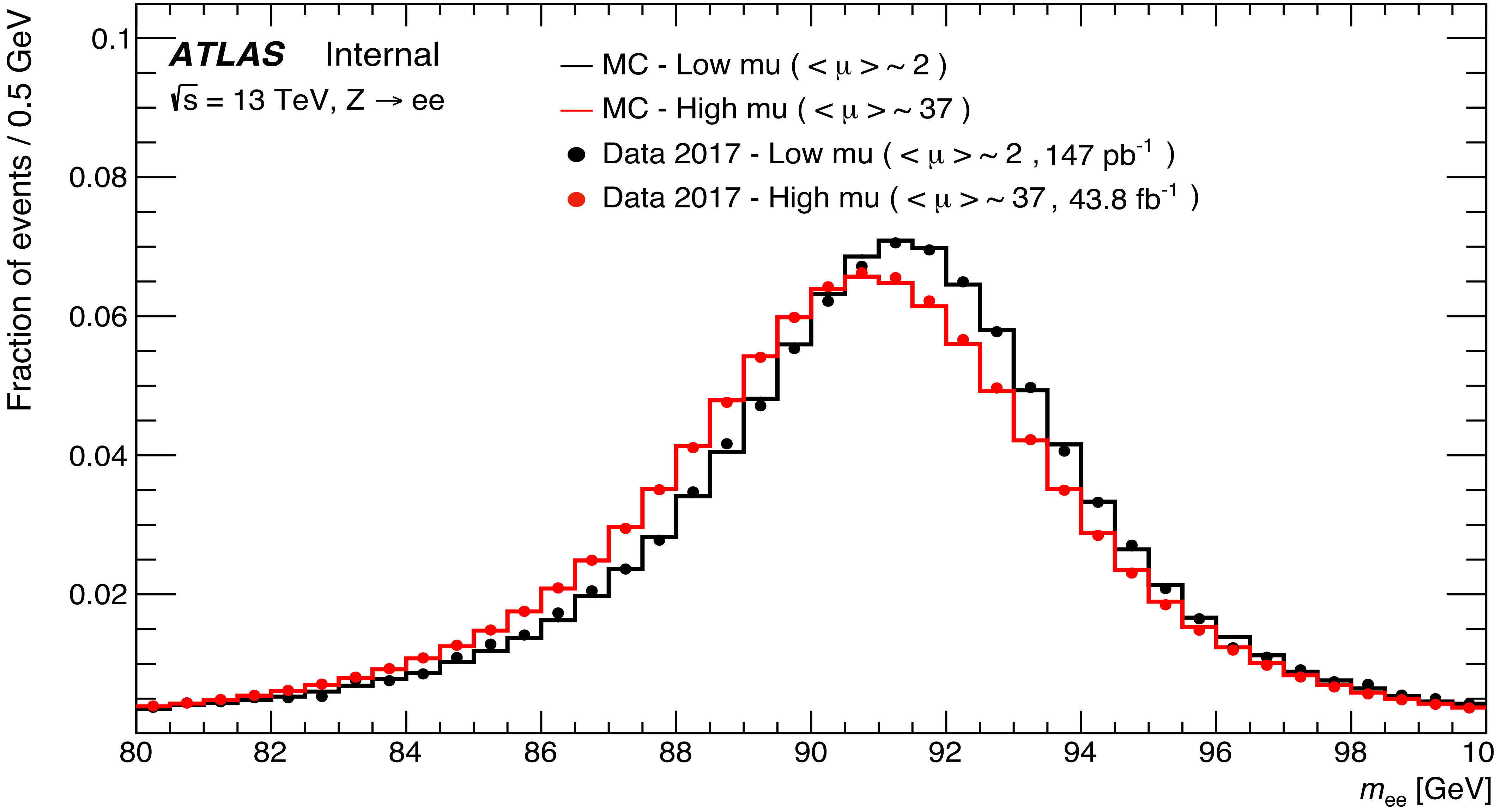
Electron energy calibration for low pile-up runs :

- low pileup energy calibration can also be done with high pileup calibration with additional extrapolation and correction.
- Energy scales factor difference $\delta\alpha$ between high/low noise threshold is directly measured with low pile-up simulation and data.
- α central value is extrapolated from high pile-up calibration with a linear fit.
- Extrapolation systematics are of the order of few 5**-4.

Backup

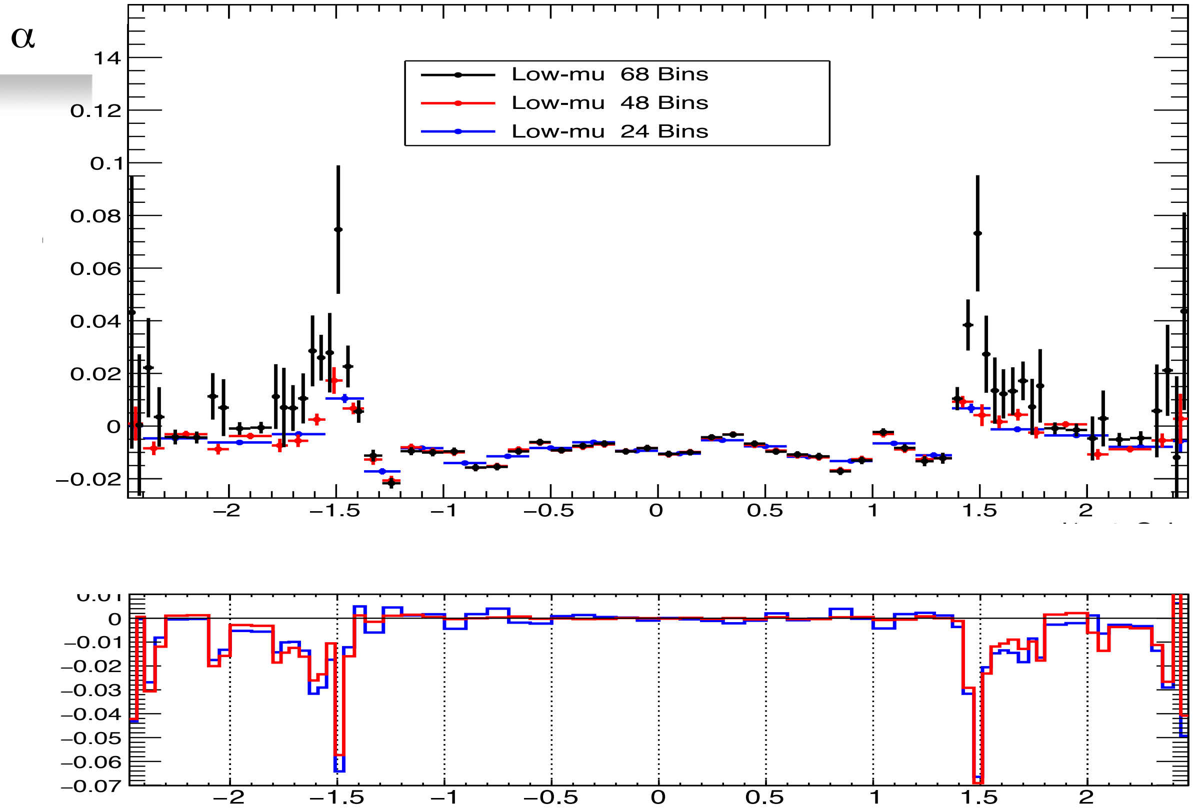
Extrapolation study : difference of threshold.

- **For high and low pile-up runs, we use different topo-cluster noise threshold for the energy reconstruction.**
- **The difference of threshold can be illustrated in the plot below : for the low pile-up data, the threshold for the energy reconstruction is lower ans thus more more energy is collected in the cluster and the reconstructed invariant mass in higher on average.**

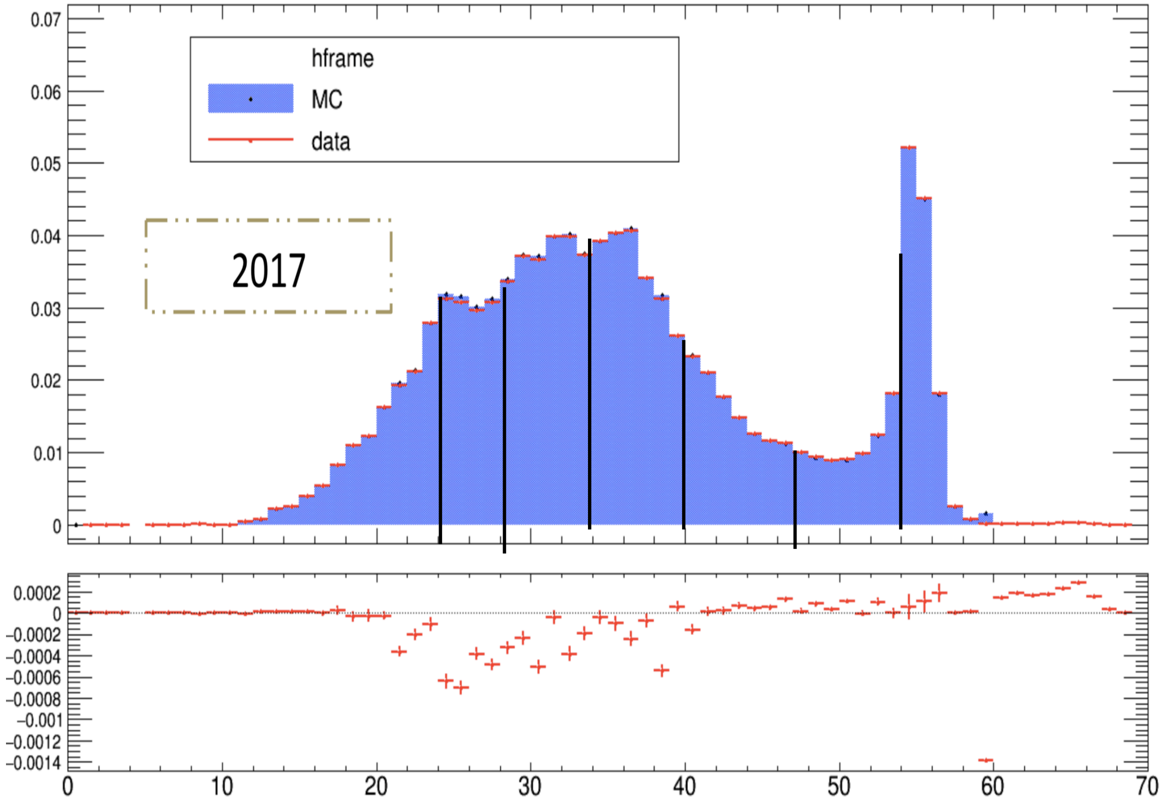


Electron energy scale for low pile-up runs :

- The number of bins chosen for the high-mu analysis : 68 bins, and because of low-stat of low pile-up runs, we change the number of bins to 48bins → wider bin size is used in the EC.
- With even wider bin size (24bins) the results are similar with 48bins in the barrel → there seems still to be a small bias in the end-cap.
- 24 bins are the baseline for low pile-up runs.



- Because of some problems in the correction procedure used for low pile-up dataset, related principally to the low stat of low pile-up dataset, another approach is used to calibrate the low pile runs.
- The approach used for the low pile-up dataset, is based principally on the extrapolation of high pile-up results to low pile-up :

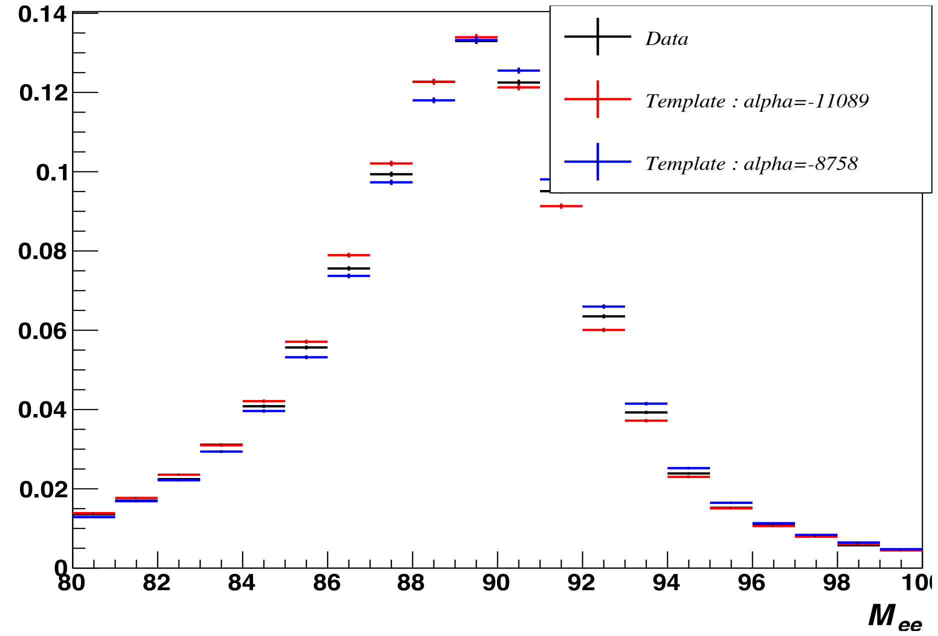


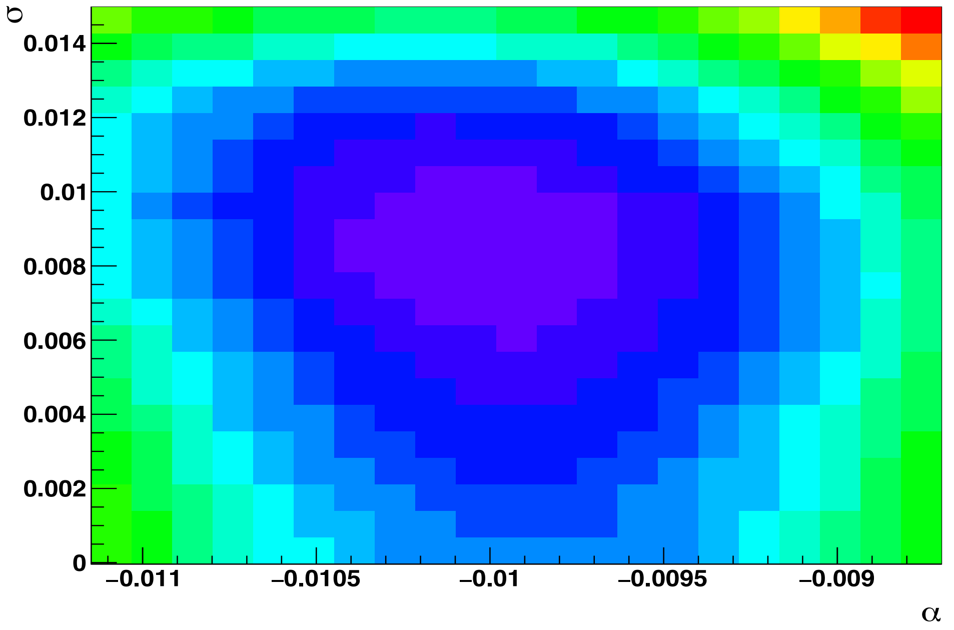
Backup :

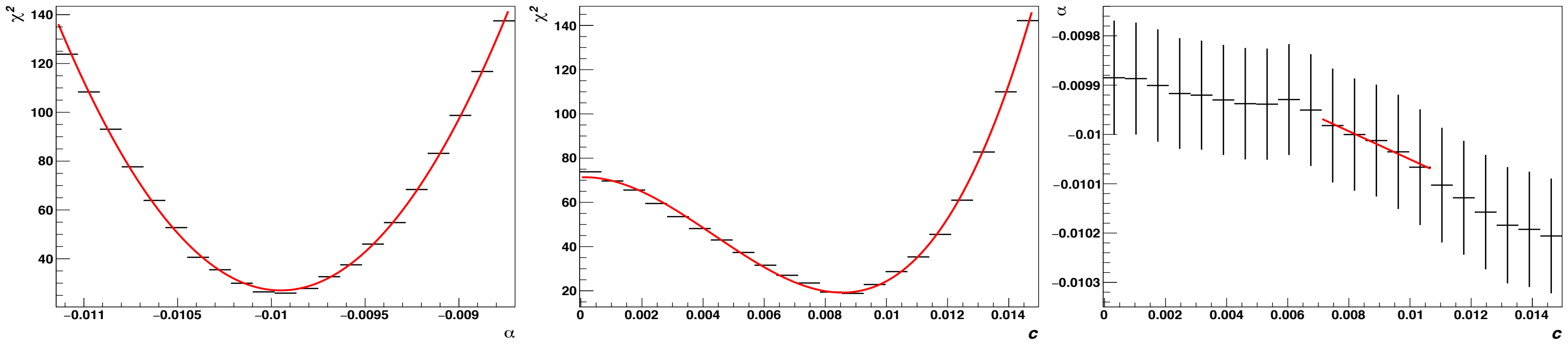
Template method

Used to measure α_{ij} and C_{ij} at the same time.

- Create distorded MC (= templates) with test values of α_{ij} and C_{ij}
- **Compute χ^2 between Z mass distribution of data and template**
- **Fit the minimum of the χ^2 distribution** in the (α_{ij}, C_{ij}) plane. Fit performed in 2 steps of 1D fits:
  - fit $\chi^2 = f(\alpha_{ij})$ at constant C_{ij} (lines) → $(\alpha_{ij,min}, \chi^2_{min})$
  - fit $\chi^2_{min} = f(C_{ij}) \rightarrow (C_{ij}, \Delta C_{ij})$
  - project C_{ij} in $\alpha_{ij,min} = f(C_{ij})$, corresponding bin giving (α_{ij},$\Delta\alpha_{ij}$)







Backup :

Inversion procedure

Obtaining scale factors of electrons from the Z ones requires the minimization of the following χ^2:

- $\alpha_i + \alpha_j = 2\alpha_{ij} \Rightarrow \chi^2 = \sum_{i,j\leq i} \frac{(\alpha_i+\alpha_j-2\alpha_{ij})^2}{(\Delta\alpha_{ij})^2}$
- $C_i^2 + C_j^2 = 2C_{ij}^2$: **not linear!** $\Rightarrow$ 3 different methods can be used for the inversion procedure:
    - **Analytical minimization** of $\chi^2 = \sum_{i,j\leq i} \frac{(\frac{C_i^2+C_j^2}{2}-C_{ij}^2)^2}{\Delta^2 C_{ij}^2}$, but the possibility to have $C_i^2 < 0$ exists (used in Run 1)
    - **Fit minimization** of $\chi^2 = \sum_{i,j\leq i} \frac{(\frac{C_i^2+C_j^2}{2}-C_{ij}^2)^2}{\Delta^2 C_{ij}}$, imposing $C_i^2 > 0$
    - **Fit minimization** of $\chi^2 = \sum_{i,j\leq i} \frac{(\sqrt{\frac{C_i^2+C_j^2}{2}}-C_{ij})^2}{\Delta^2 C_{ij}}$, with $C_i > 0$

NB: In blue, the current implemented parametrization.

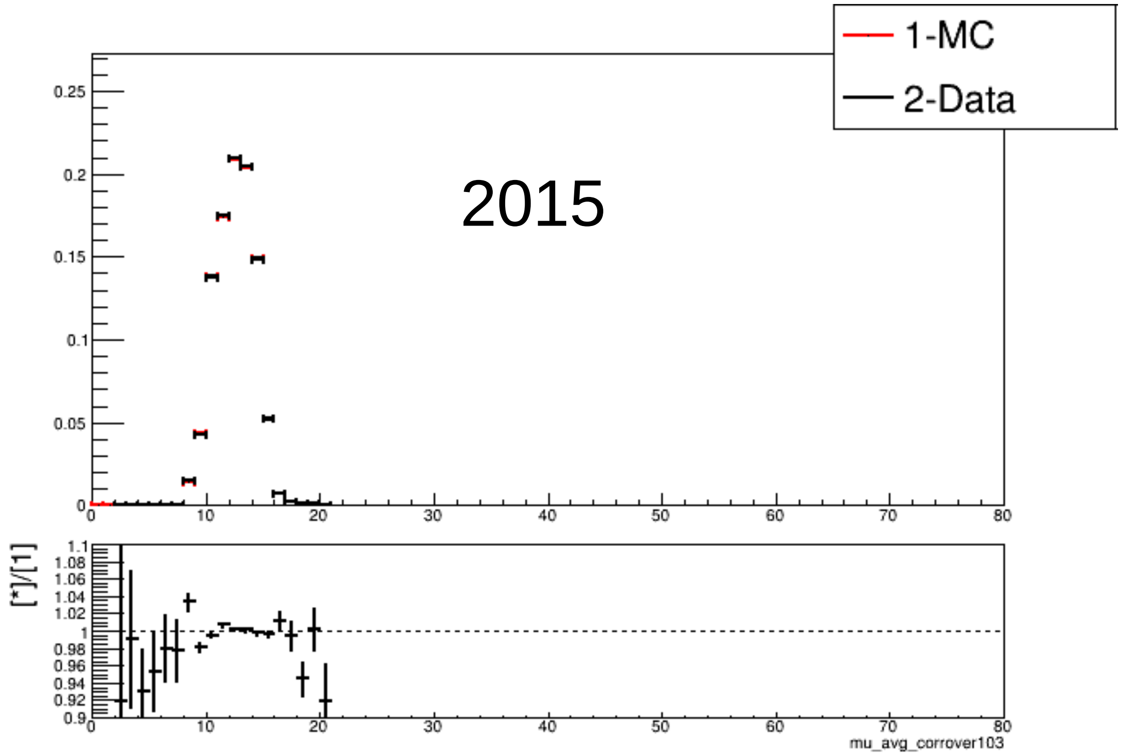
<u>**Correlation**</u> →

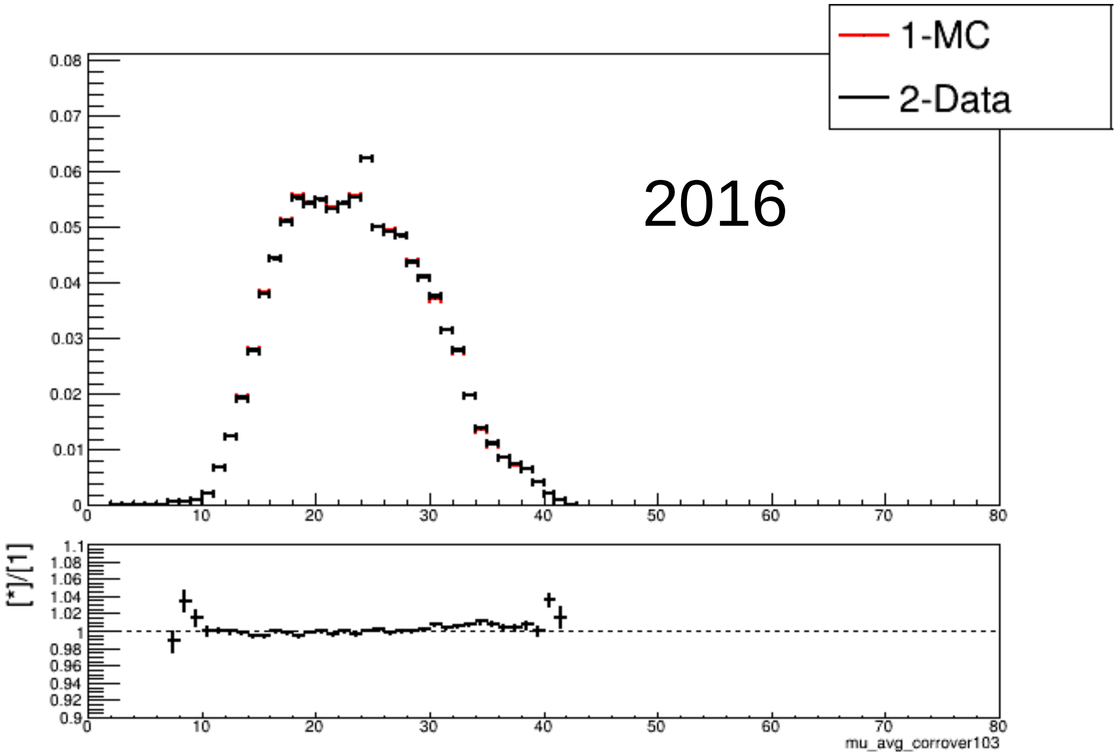
$$\chi^2_\alpha = \sum_{i,j\leq i} \frac{(\frac{\alpha_i+\alpha_j}{2}-\alpha_{ij})^2}{(\delta\alpha_{ij})^2}$$

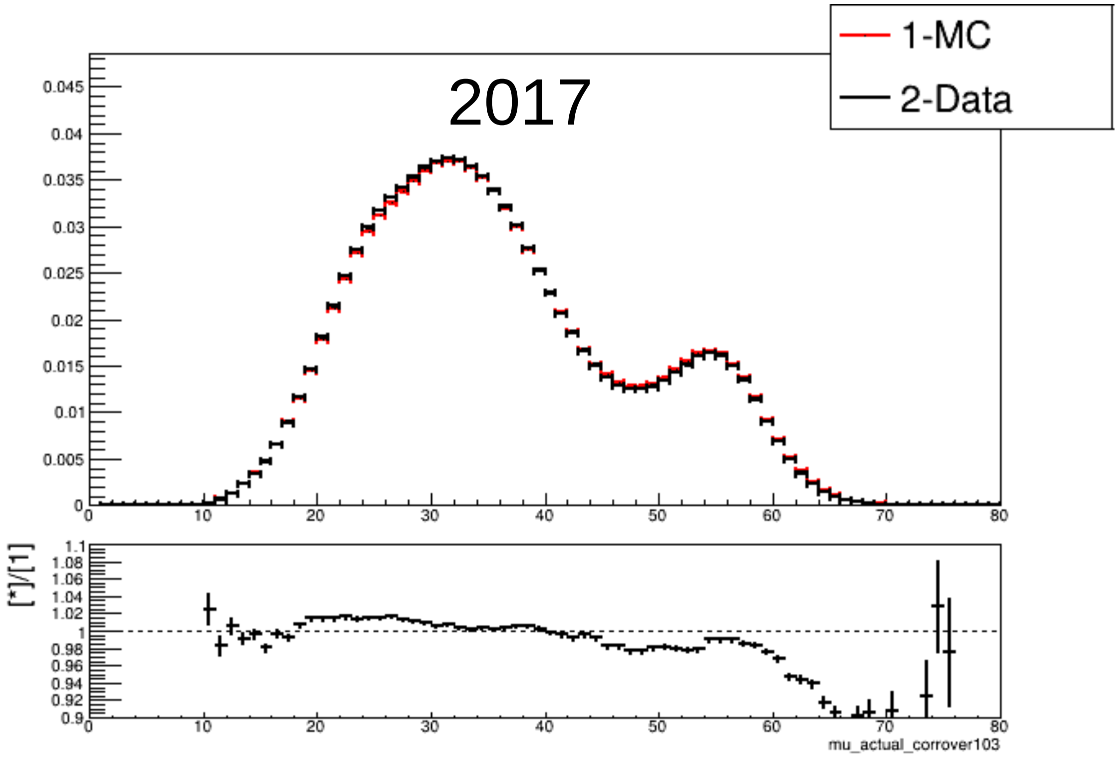
$$\chi^2_c = \sum_{i,j\leq i} \frac{(\sqrt{\frac{c_i^2+c_j^2}{2}}-c_{ij})^2}{(\delta c_{ij})^2}$$

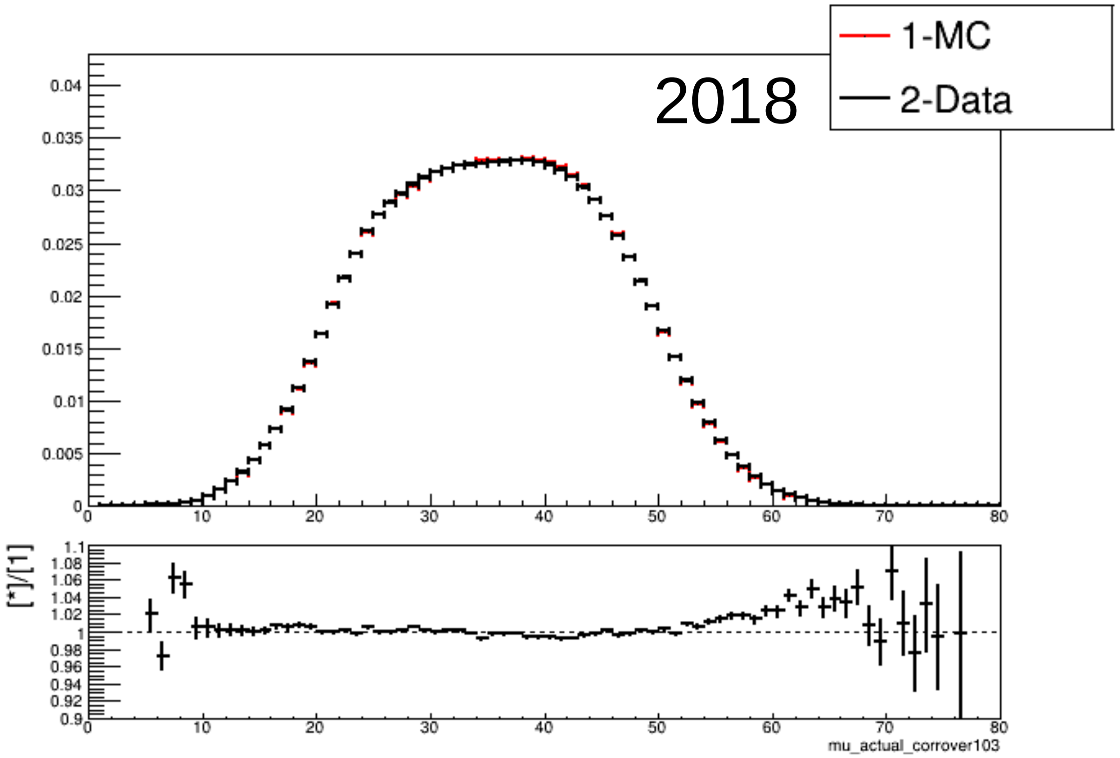
Backup :

- Pile-up distribution comparison between data and MC :









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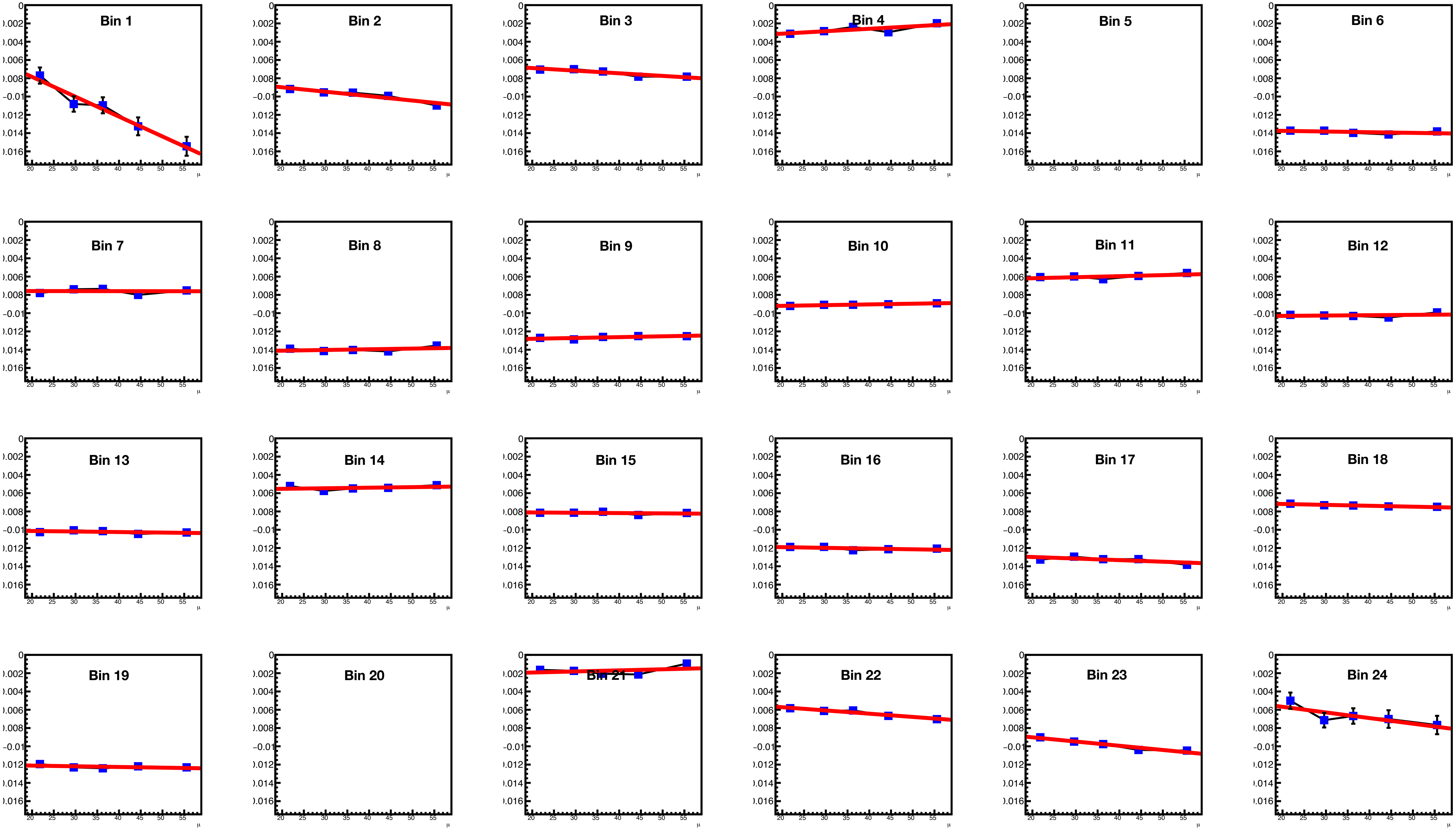
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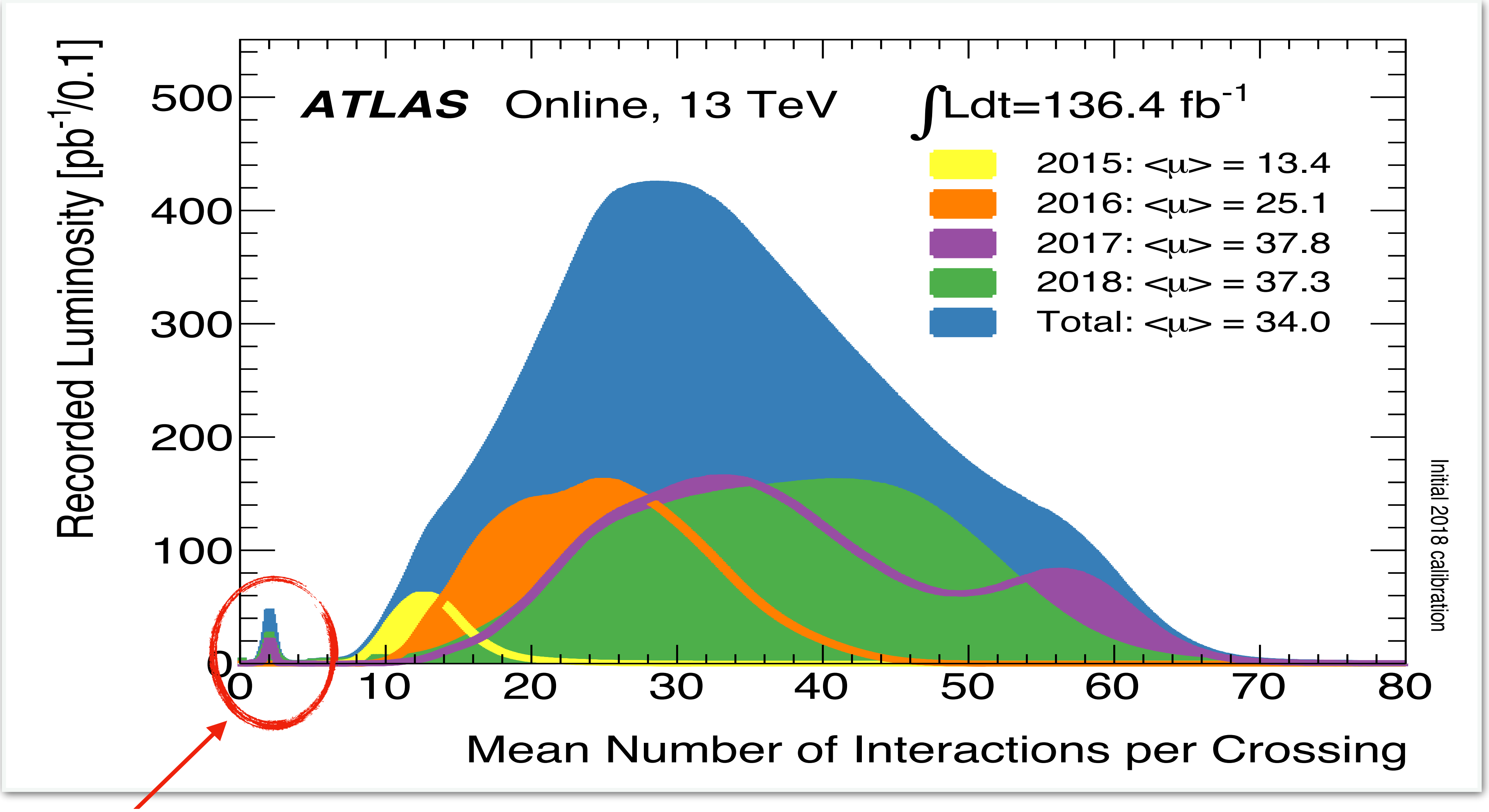
μ

Electron scale factors for high pile-up runs : datasets.

- **Pile-up** : proton-proton collisions in addition to the collision of interest.



low pileup dataset

data 2017 (146.6 pb^{-1})	150 k
simulation 2017	*350 k*

high pileup dataset

mc16a	17.9M
mc16d	17.2M
mc16e	28.9M

data 15	1.5M
data 16	14.8M
data 17	19.1M
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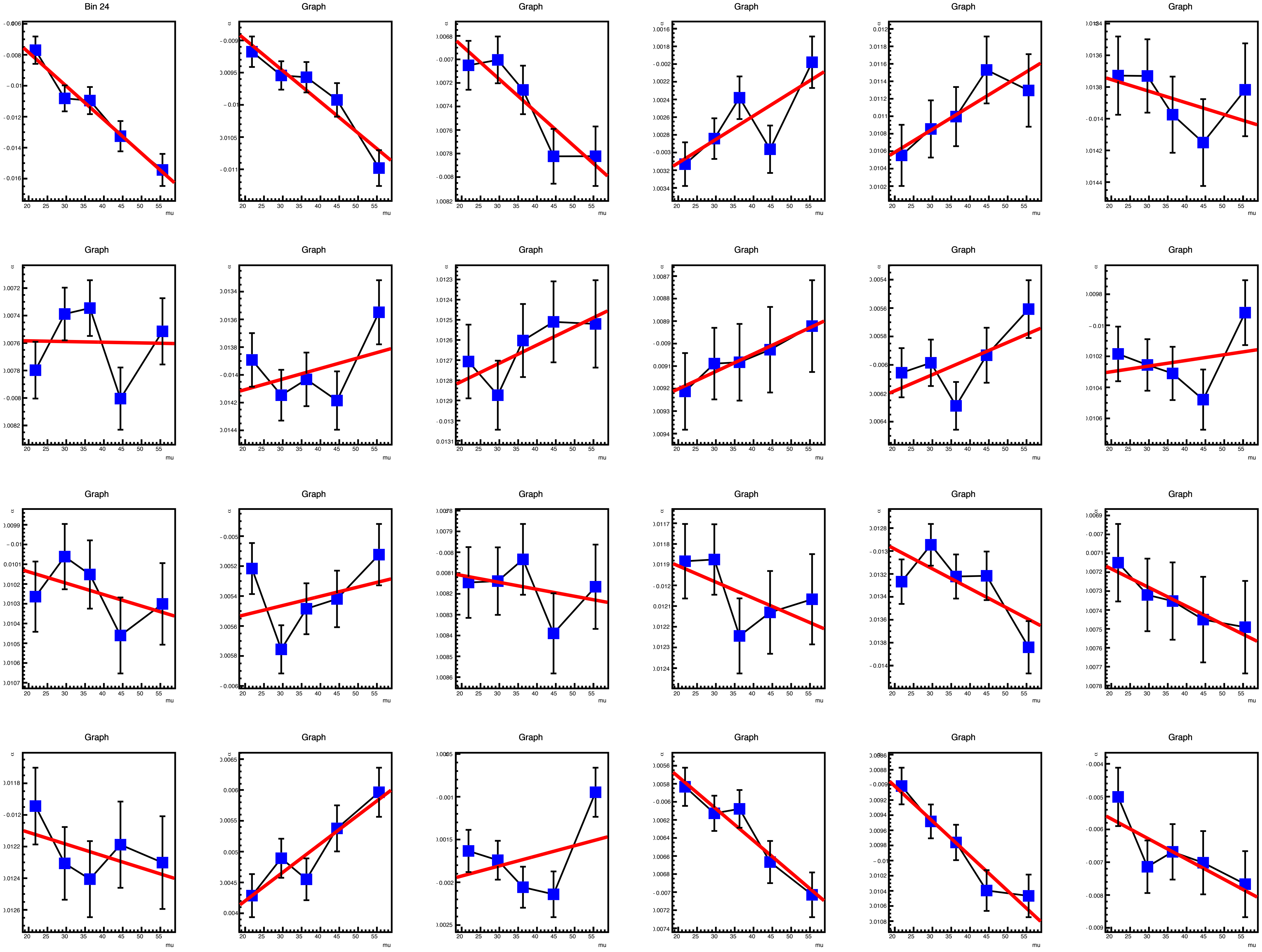
Bin 24
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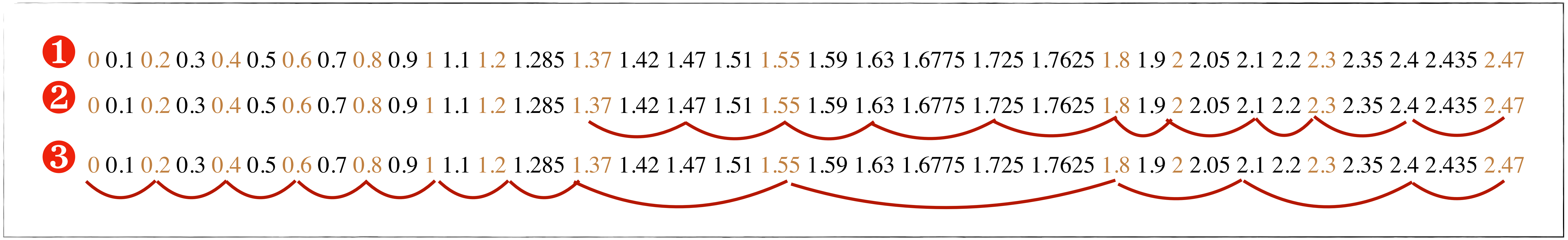
backup : bais study

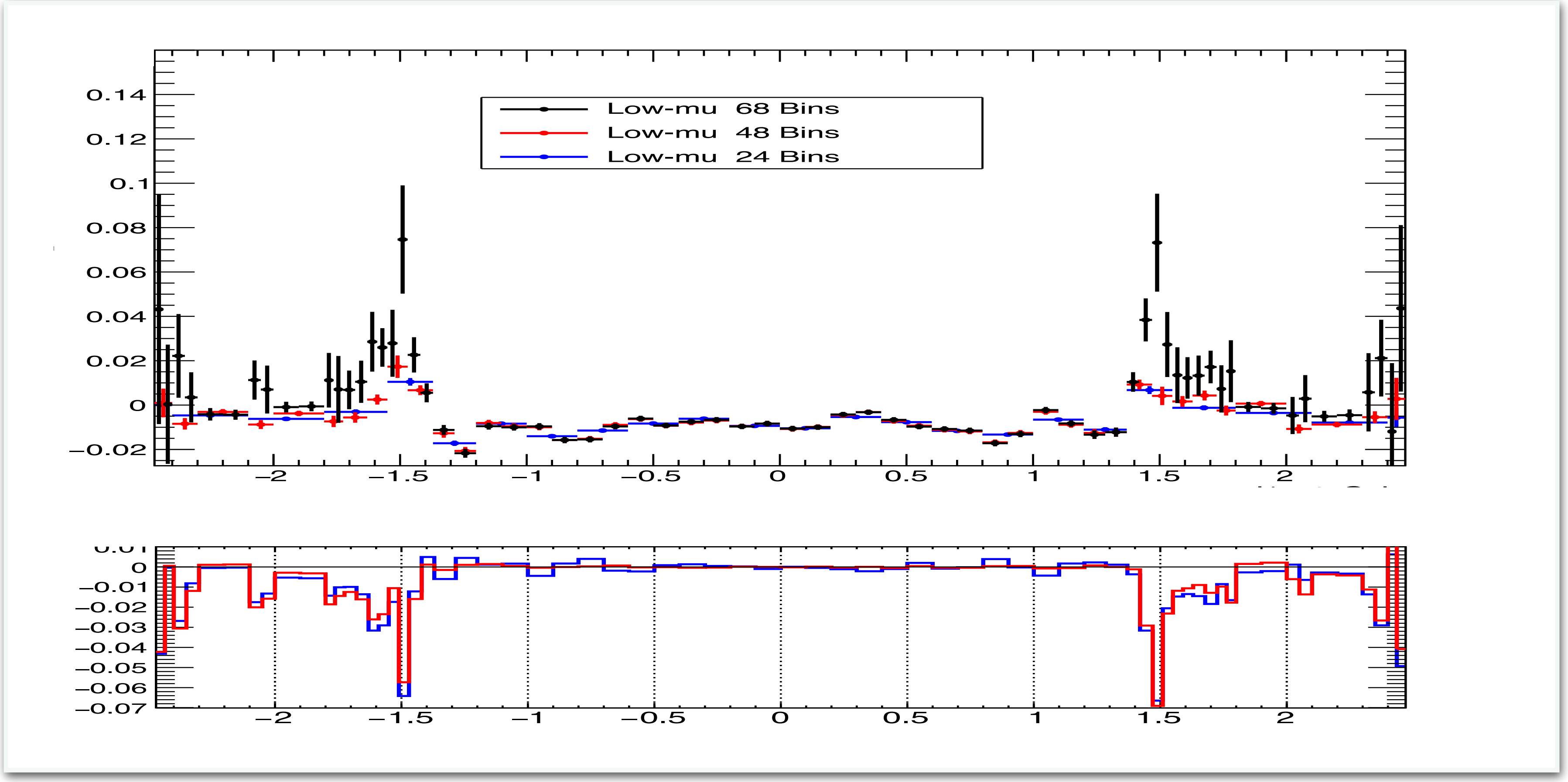
- The number of bins chosen for the high-mu analysis : 68❶, and because of the low-stat of low-mu runs, we change the number of bins to 48❷ ➔ Wider bins are used in the EC.
- There is one idea to use wider bin - 24❸ bins, and the results are similar with 48bins in the barrel ➔ there seems still to be a small bais in the end-cap.



❶ 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.285 1.37 1.42 1.47 1.51 1.55 1.59 1.63 1.6775 1.725 1.7625 1.8 1.9 2 2.05 2.1 2.2 2.3 2.35 2.4 2.435 2.47

❷ 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.285 1.37 1.42 1.47 1.51 1.55 1.59 1.63 1.6775 1.725 1.7625 1.8 1.9 2 2.05 2.1 2.2 2.3 2.35 2.4 2.435 2.47

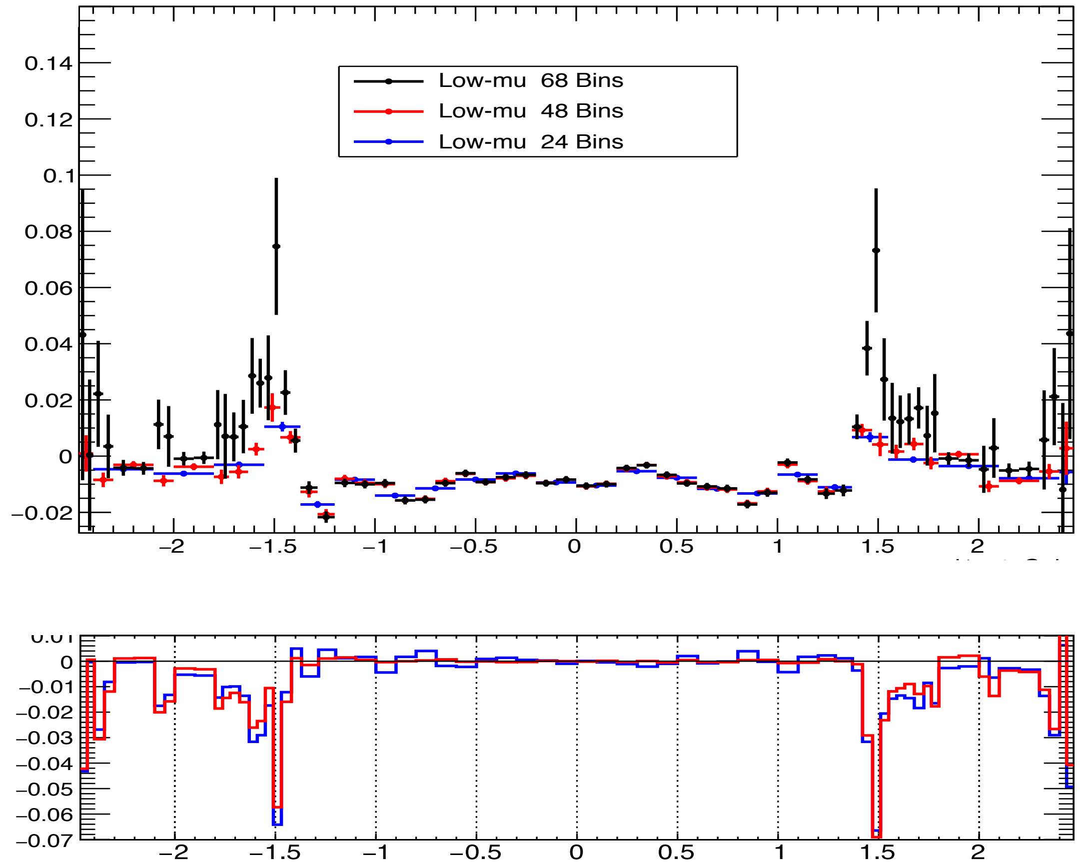
❸ 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.285 1.37 1.42 1.47 1.51 1.55 1.59 1.63 1.6775 1.725 1.7625 1.8 1.9 2 2.05 2.1 2.2 2.3 2.35 2.4 2.435 2.47

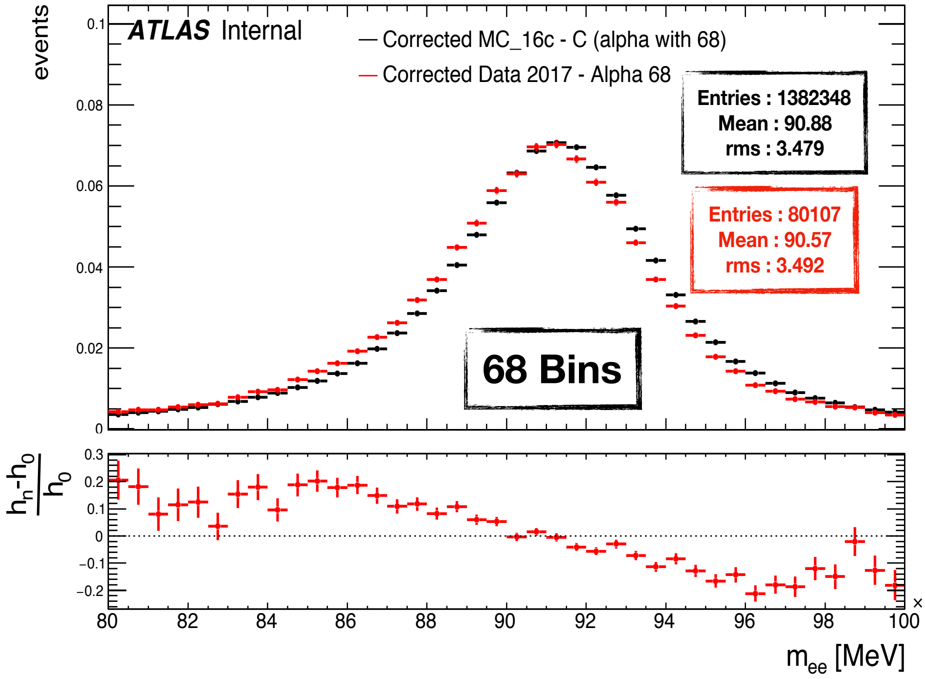


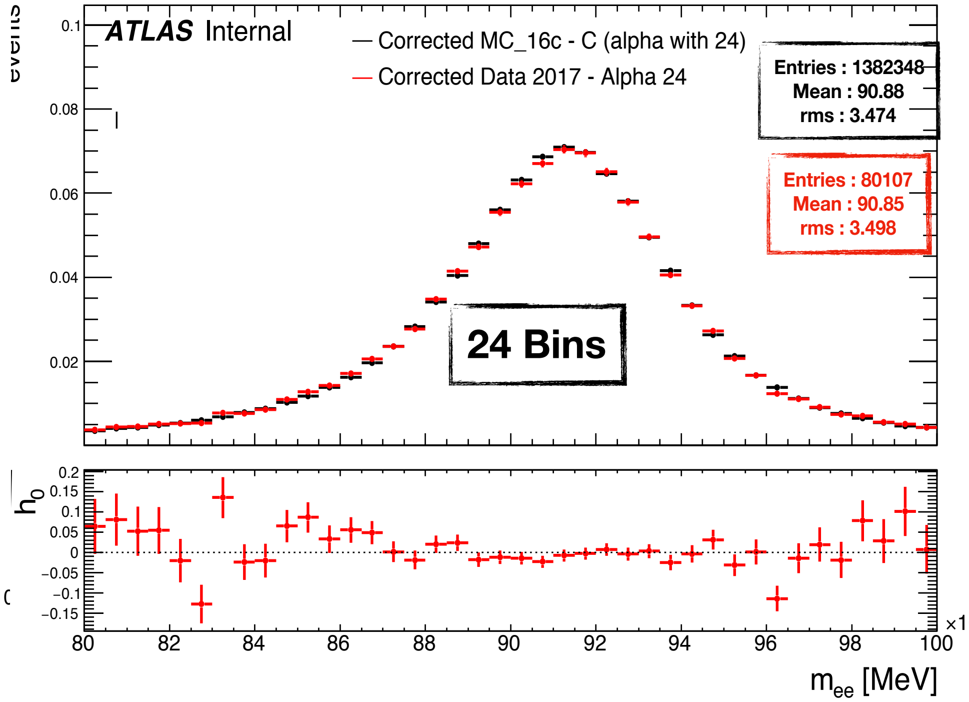
Low-mu run : bias between 24 and 48 bins.

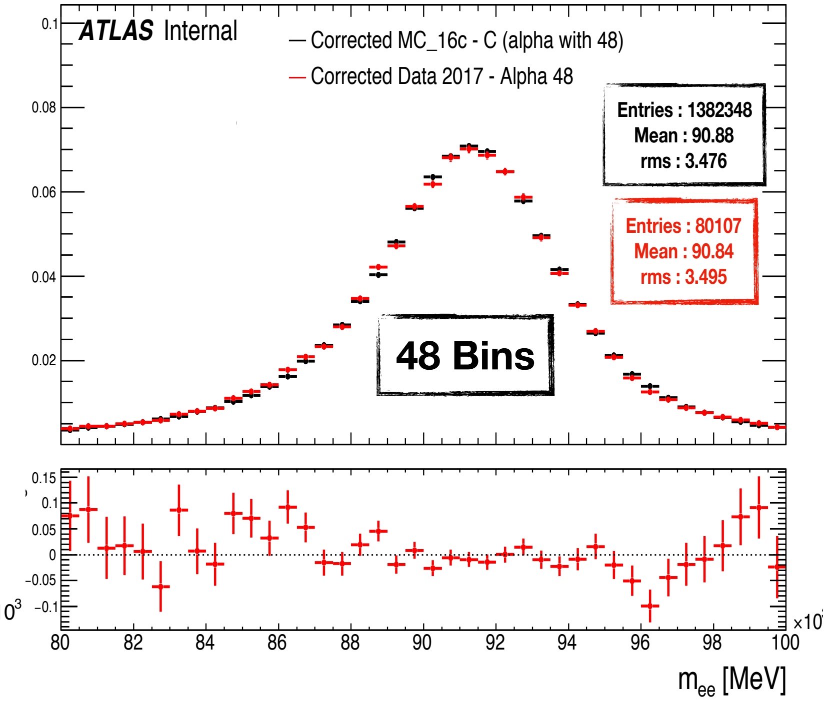
For 68 bins there is a bais

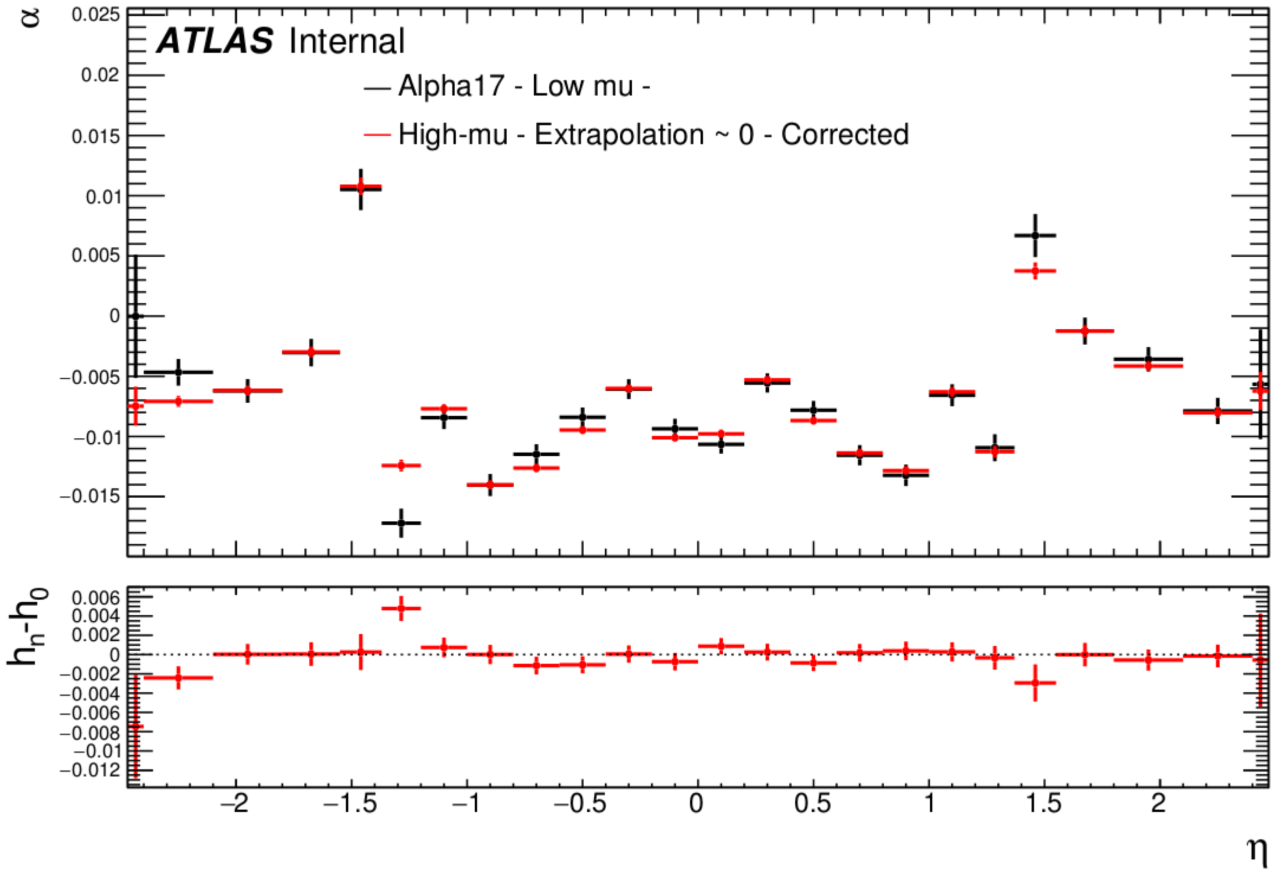
- the number of bins chosen for the high-mu analysis : 68, and because of the stat of low-mu runs, we change the number of bins to 48 -- Wider bins are used in the EC.
- there is one idea to use wider bins - 24 Bins, and the results are similar with 48 Bins in the barrel. there seems still to be a small biais in the End-Cap (to be understood).
- Average of Data is changing with number of bins and the difference Data/mc > 3e-4



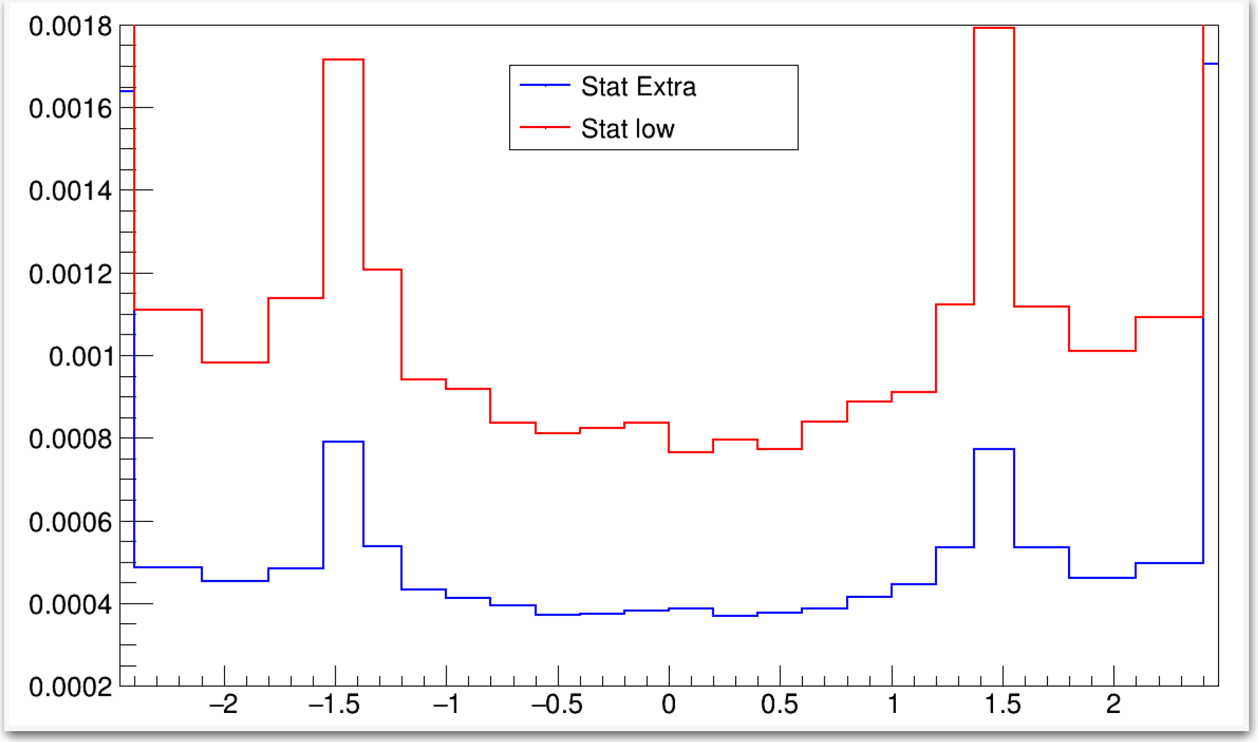




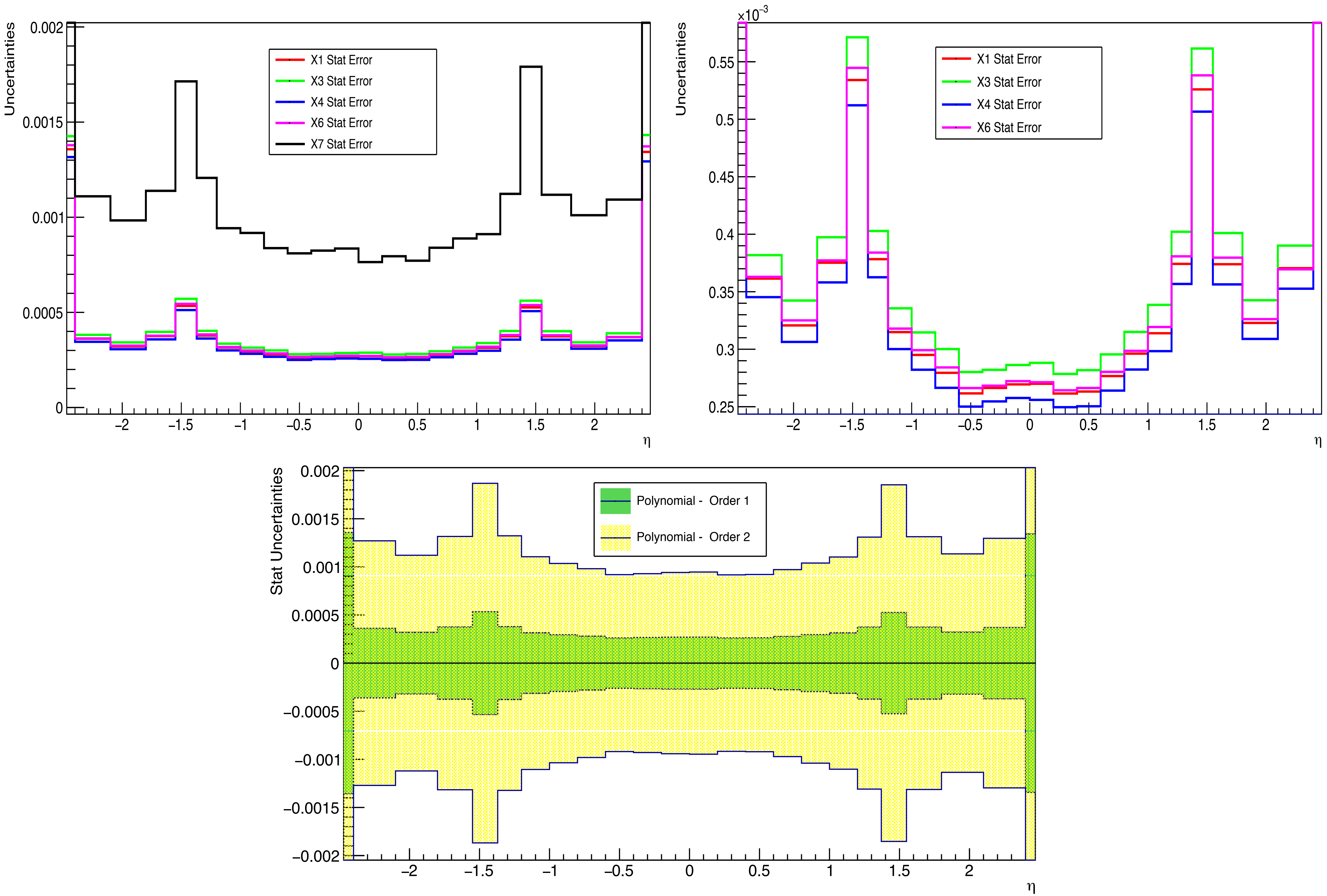




Stat error for low-mu and extrapolation



Extrapolation Systematics : Stat Error



Formules

X1 = Fit[$5^{tr}(1)$] : Extrapolation using 5 intervals of μ and polynomial function of order 1.
X2 = Fit[$5^{tr}(2)$] : Extrapolation using 5 intervals of μ and polynomial function of order 2.
X3 = Fit[$3^{tr}(1)$] : Extrapolation using 3 intervals of μ and polynomial function of order 1.

X4 = Fit[$5^{tr}(1)$ + low μ] : Extrapolation using 5 intervals of μ and polynomial function of order 1 + low μ results.
X5 = Fit[$5^{tr}(2)$ + low μ] : Extrapolation using 5 intervals of μ and polynomial function of order 2 + low μ results.
X6 = Fit[$3^{tr}(1)$ + low μ] : Extrapolation using 3 intervals of μ and polynomial function of order 1 + low μ results.

X7 = low μ : low pileup results.

X8 = [X7/ σ^2 (X7) + X1/ σ^2 (X1)] / [1/σ^2 (X7) +1/σ^2 (X1)] : Combinaison of low mu and extrapolation results.

➢ **Events after selections :**

2017 : data low mu = 79.9 k
MC low mu = 1.38 M

2018 : data low mu = 107.2 k
MC low mu = 1.41 M