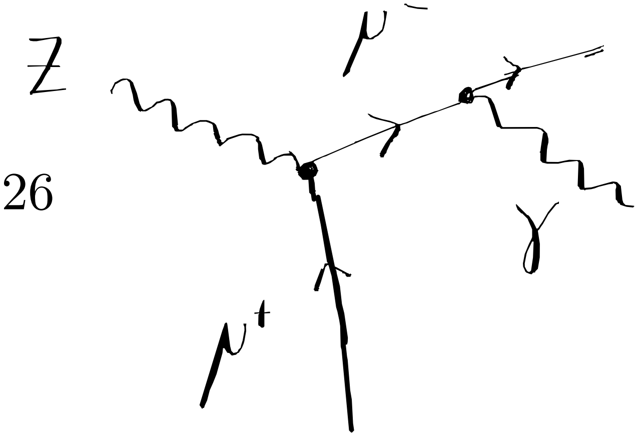
Extraction of the γ energy scale correction with Z$\rightarrow\mu\mu\gamma$ events



Group meeting 01/14/2026

Christian Verollet

Plan of the presentation

Introduction

1) Samples used and selection criterias

2) Data & MC kinematics

3) Method used

4) Results

Conclusion & perspectives

Introduction

- Photons are reconstructed using the ECAL response $\rightarrow$ not perfect
- As a result, the reconstructed photon energy must be corrected

- Important for instance for the Higgs mass measurement where the final states containing photons is directly sensitive to the photon energy scale:

$$\Delta m / m \simeq \Delta E / E$$

- Inaccurate energy calibration would lead to important systematic errors

Introduction

- The photon energy scale is currently derived using $Z \to e^+e^-$ events, using the Z boson mass and assuming an electron-photon showers equivalence in the ECAL. (data are rescaled and MC smeared)
- This method relies on extrapolating electron-based corrections to photons and thus provides an indirect calibration

$Z \to \mu\mu\gamma$ events provide a direct calibration of the photon energy scale, using the precision measurement of the muons and the Z mass.

→ Provides a complementary and independent calibration with direct sensitivity to photons.

1) Samples used and selection criterias

→ Reused the datas and MC used by a previous intern (Mathias) to check my results.

- Framework: Higg-dna
- Data: Muon/Run2022F(G)-PromptNanoAODv11 v1-v2 with int. lumi. of 18.0 fb -1 (F) and 3.1 fb -1 (G), still missing blocks C to E (from Jie, with Scale and Smearing already applied)
- MC:/Run3Summer22EENanoAODv11/DYto2L-2Jets MLL-50 TuneCP5 13p6TeV amcatnloFXFX-pythia8/NANOAODSIM

1) Samples used and selection criterias

- Dimuon selection:
  (already done)
  $I_{charged}/p_T < 0.2$
  $p_T > 10$ GeV
  $m_{\mu\mu} > 35$ GeV
  $\eta_{\mu\mu} < 2.4$

- Photon selection:
  (already done)
  $p_T > 20$ GeV
  $1.566 < |\eta| < 2.5$

- FSR selection:
  Min $(\Delta R(\mu^{\pm},\gamma)) < 0.8$
  $p_T > 30$ for the muon the furthest of γ
  $m_{\mu\mu\gamma} \in [60,120]\ GeV$
  $m_{\mu\mu\gamma} + m_{\mu\mu} < 180$

- Endcap, Barrel and R9 selection:
  Ecal Barrel (EB) $|\eta| < 1.442$
  Ecal Endcap (EE) $2.5 > |\eta| > 1.566$
  low/high R9 $R_9 </> 0.94$

1) Samples used and selection criterias

Number of events:

- Data EE low/high R9: 8381 / 24290
- Data EB low/high R9: 34623 / 68755
- MC EE low/high R9: 14144 / 52851
- MC EB low/high R9 60427 / 137977

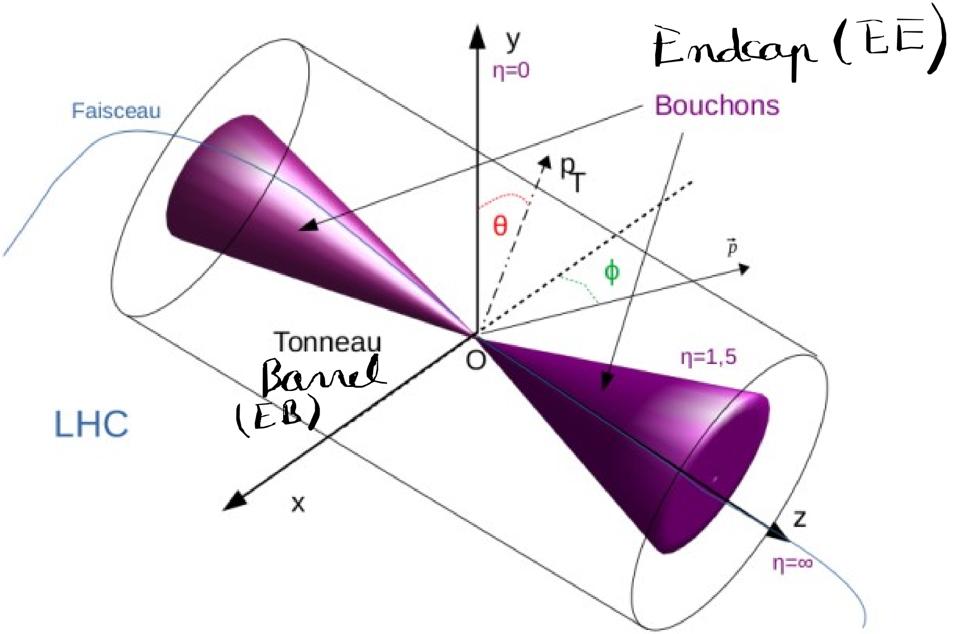
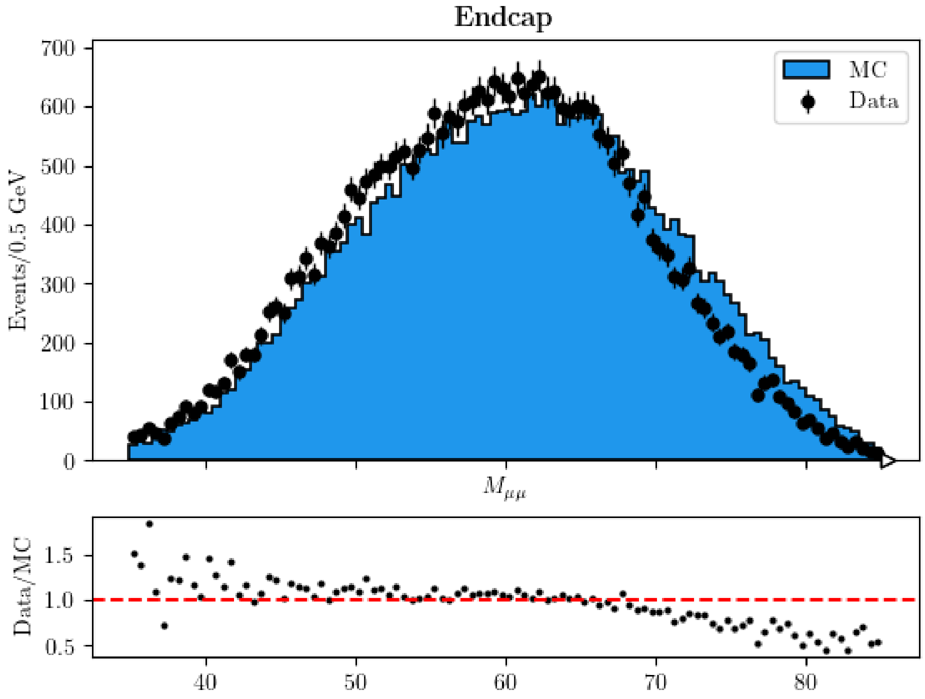
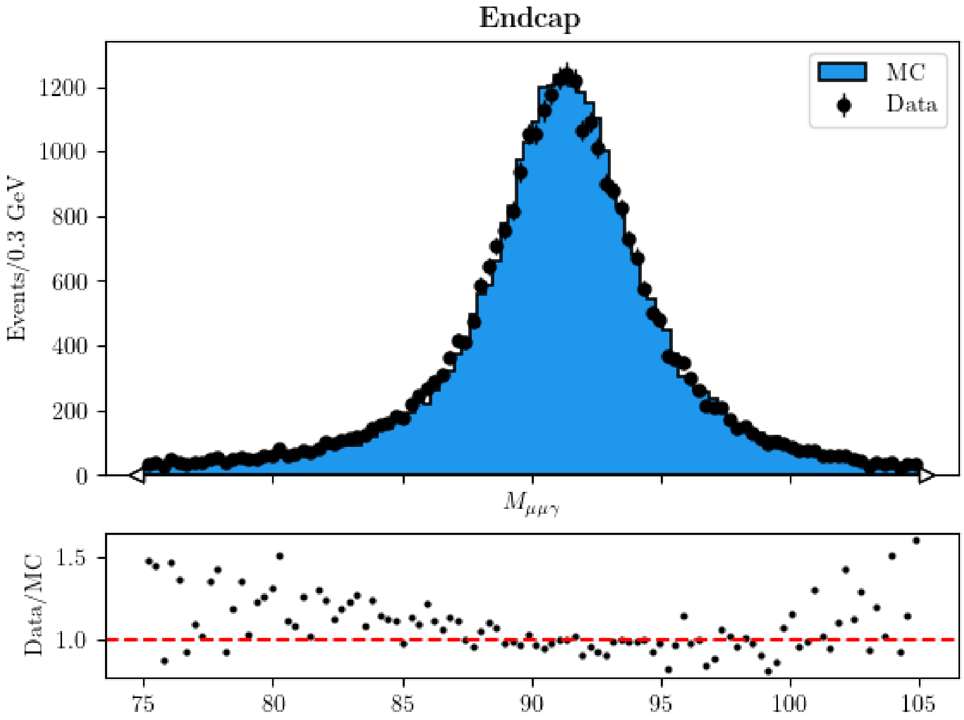


Image from Antoine Lesauvage

2) Data & MC kinematics

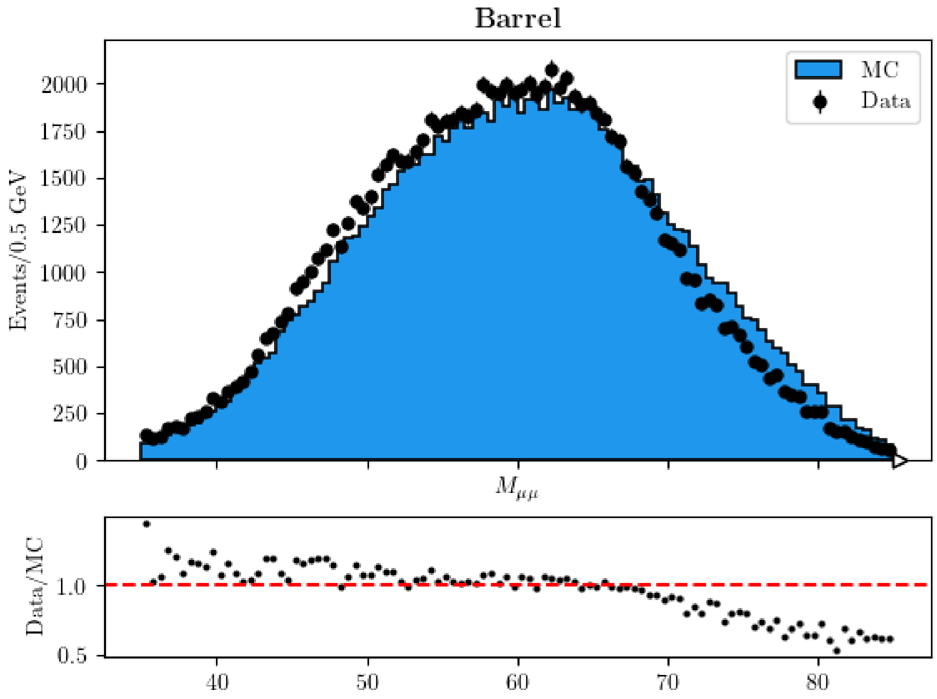
- Distribution of $M_{\mu\mu\gamma}$ and $M_{\mu\mu}$ for the Endcap

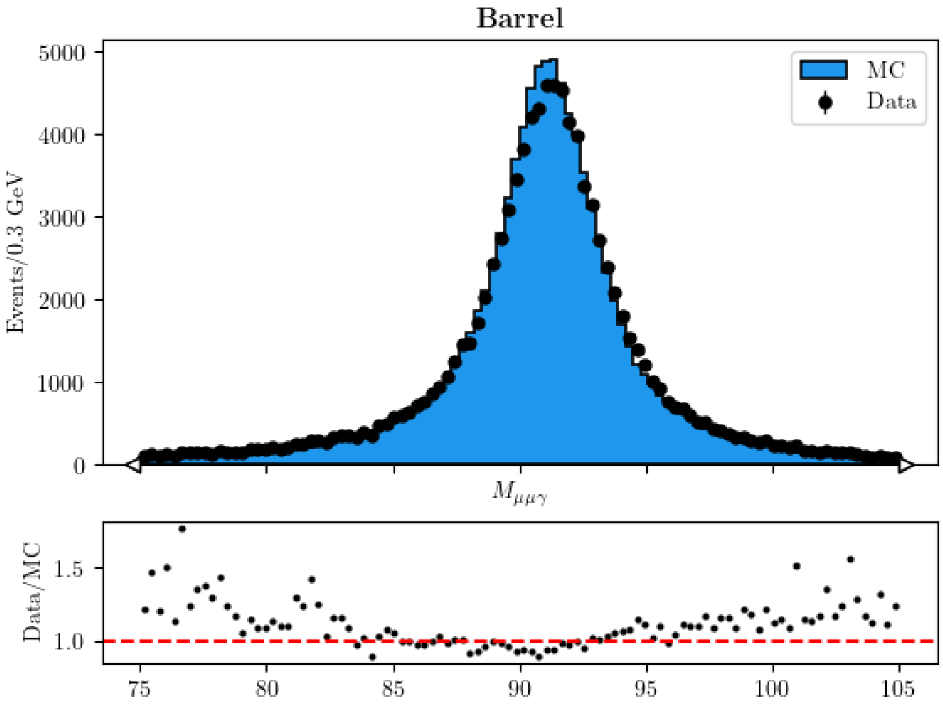




2) Data & MC kinematics

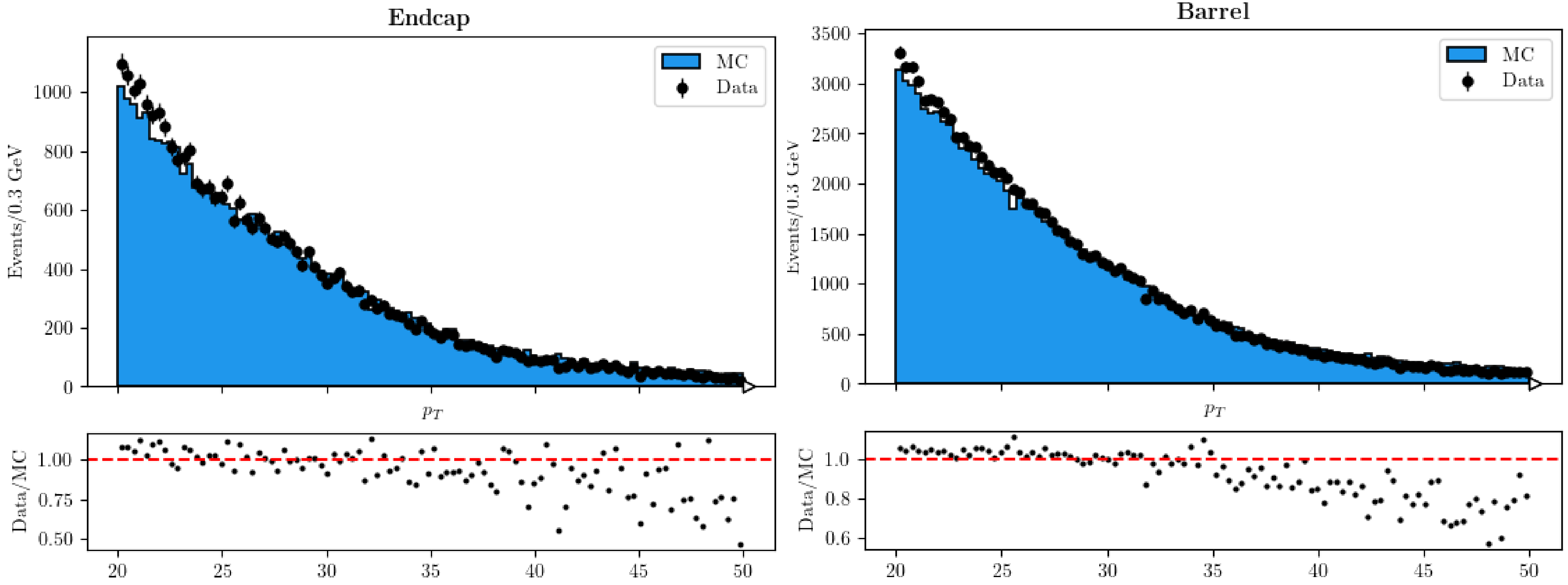
- Distribution of $M_{\mu\mu\gamma}$ and $M_{\mu\mu}$ for the Barrel





2) Data & MC kinematics

- Distributions of p_T of γ for Endcap and Barrel



3) Method used

The goal is to correct the photon 4-momentum with a coefficient $1/(1+S)$ with

$$1 + S = \frac{M^2_{\mu\mu\gamma} - M^2_{\mu\mu}}{m^2_Z - M^2_{\mu\mu}}, \quad \text{where}$$

- $M_{\mu\mu\gamma}$, $M_{\mu\mu}$ comes from the events
- m_Z is the PDG value

→ For simplification, we suppose that $S \in [-0.5, 0.5]$

3.1) Method used: fitting of S for each %

- We separate the data with increment of 1% from 100% to 60%, we fit the S distribution for all these samples.

- The function used for the fit is a Voigtian distribution, using an unbinned fit with negativ likelyhood (iminuit):

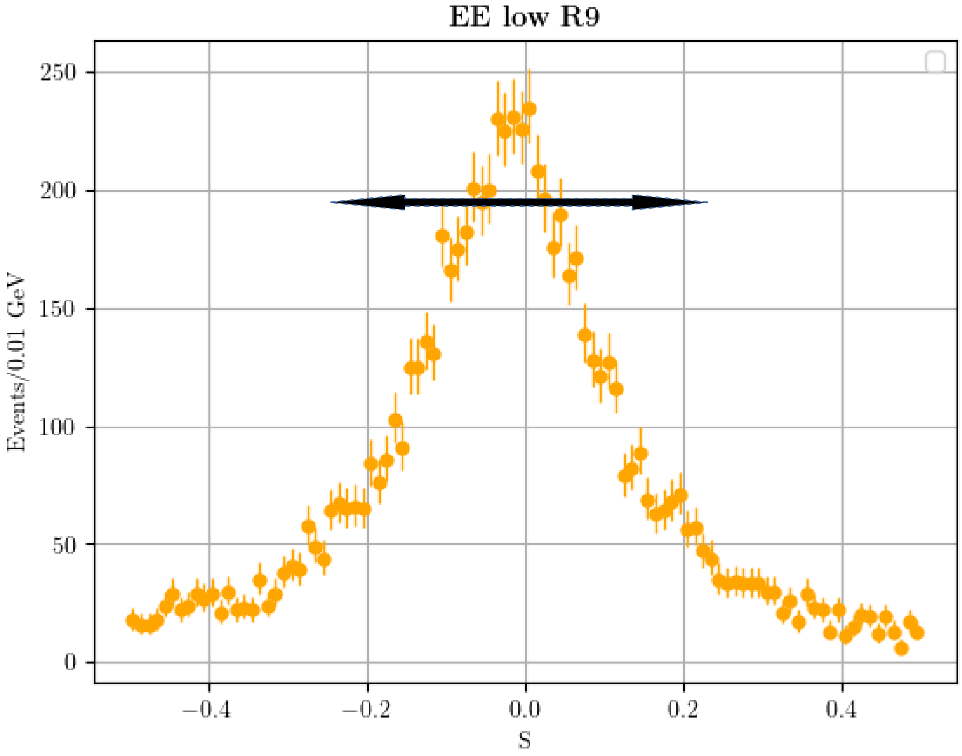
$$V(m, \mu, \sigma, \gamma) = \int_{-\infty}^{+\infty} G(x, \sigma) L(m - x, \mu, \gamma) \, \mathrm{d}x$$

$$\text{with} \quad G = \frac{1}{\sqrt{2\pi\sigma}} \exp^{\left(\frac{-x^2}{2\sigma^2}\right)} \quad \text{and} \quad L(x, \mu, \gamma) = \frac{\gamma}{\pi\left((x-\mu)^2 + \gamma^2\right)}$$

- In order to compute the χ^2 and p-value, we choose a number of bins corresponding to a smooth distribution of the EE low R9 data, and keep it for all other samples.

3.1) Method used: Selection of %

- We start from the bin with the most events, and take one bin on each side until until we reach the correct %.



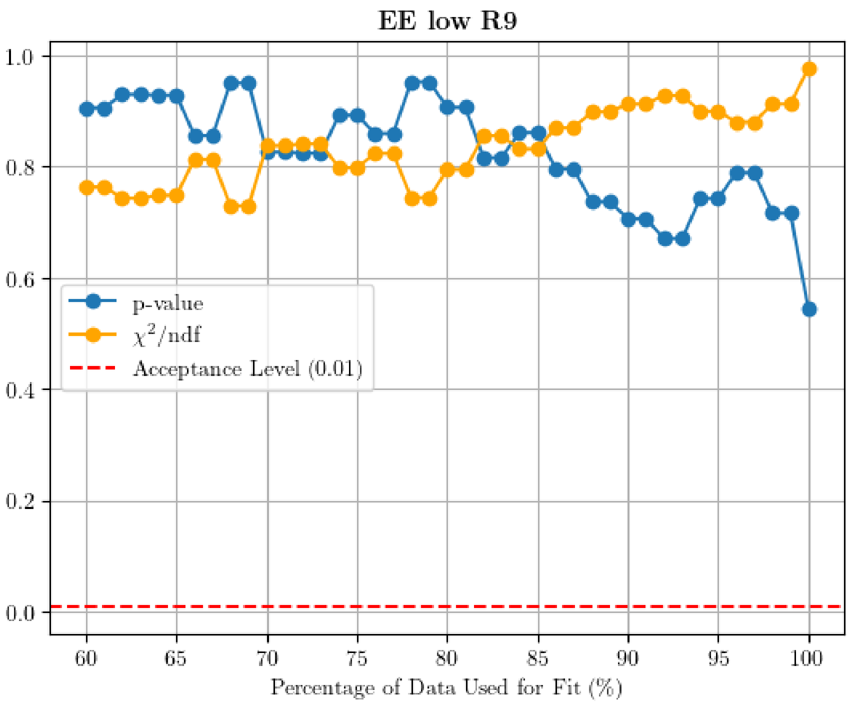
- If one of the side of the distribution is reach we stop.

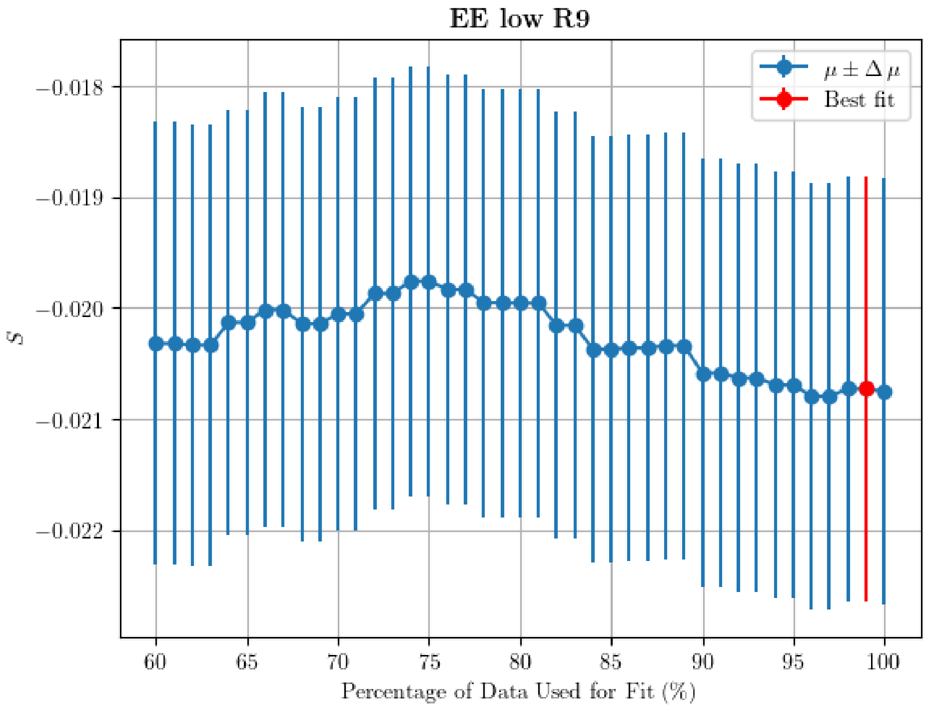
- Don't enable to take precise % (see next slides)

  → to be updated

3.1) Method used: Selection of %

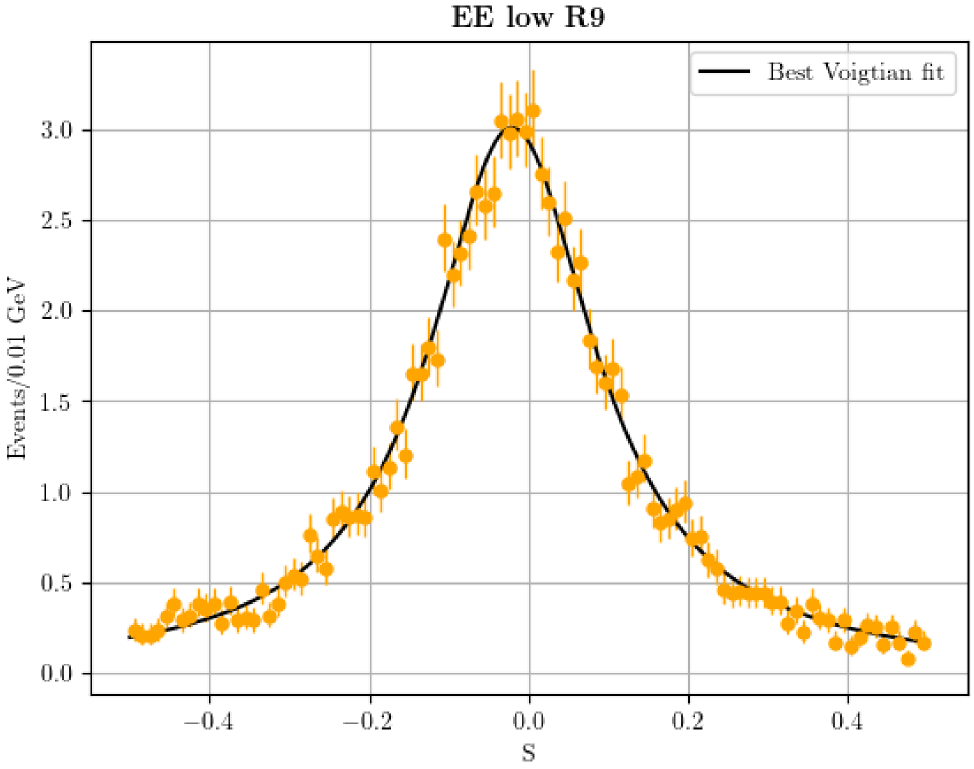
- The p-values, χ^2 / ndf and S with its statistical uncertainty are computed for each fit and are used to select the best fit. We see the effect of the % choice method on the left.





3.2) Method used: Best fit selection

- To select the best fit, we look at all the fits using 90-100% of data, and we keep the one having the smallest statistical uncertainty on S as well as a p-value above 10^{-2} .



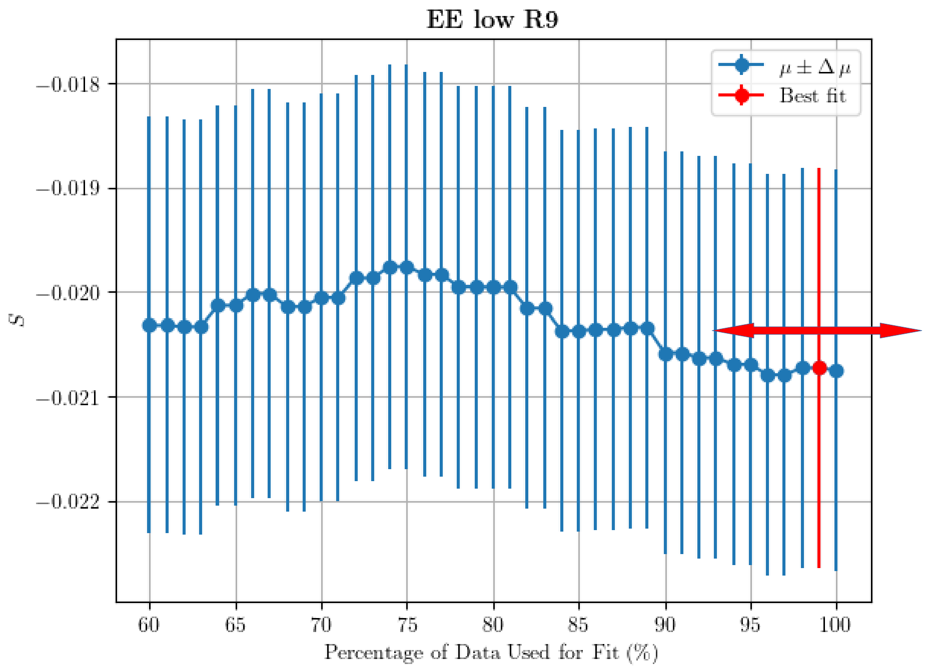
If none of the fits in the 90-100% interval satisfies this condition, we repeat the process in the 80-90% interval and so on. If none of the fits have a p-value above 10^{-2} , we restart, but change the selection to fits with a p-value above 10^{-3} and so on.

For EE low R9, best fit is at 99%

S = -0.02 ± 0.0019

3.3) Method used: Systematic error due to the choice of the interval

- We take the maximum difference between the chosen best fit S and the other μ in a 20% around the chosen percentage.



$$\mathrm{err}_1 = \max\left(S - \mu_{20\%}\right)$$

S = -0.02 ± 0.0019 ± 0.00077

3.4) Method used: Systematic error due to the choice of the fit

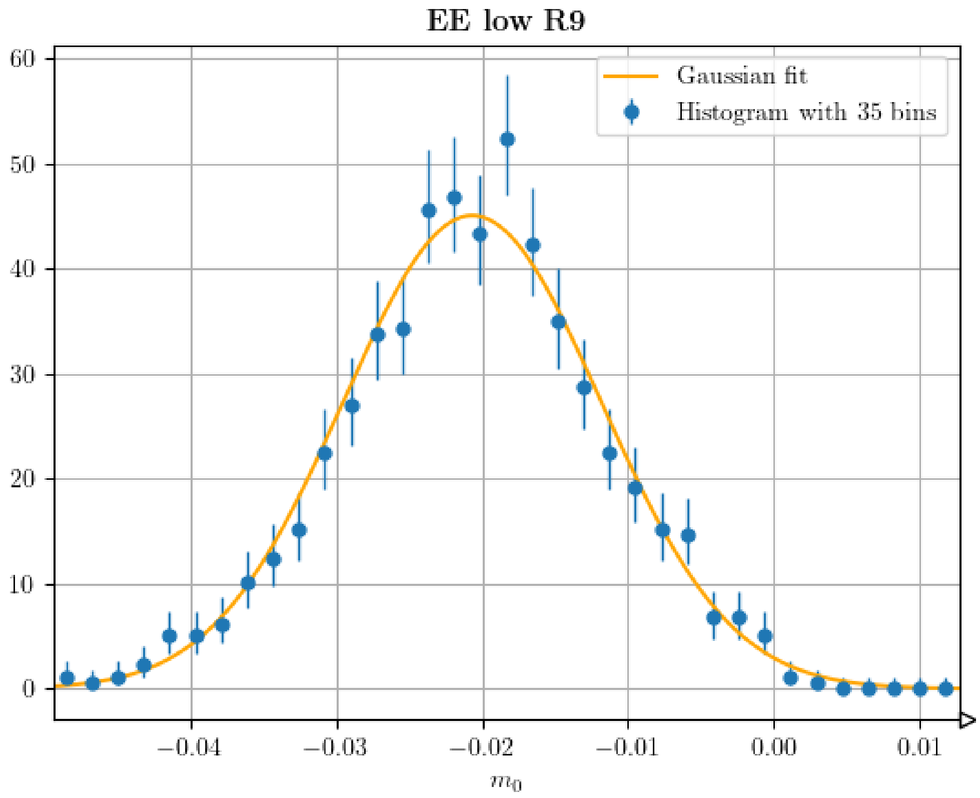
- With the parameters of the best fit, we generate 1000 toys models of 10 000 events each. Each of these toys model is fitted with a Cruijff function:

$$C(m; m_0, \sigma_L, \sigma_R, \alpha_L, \alpha_R) = \exp\left(\frac{-(m - m_0)^2}{2\sigma^2 + \alpha(m - m_0)^2}\right)$$

$$\sigma, \alpha = \begin{cases} \sigma_L, \alpha_L & \text{if} \quad m - m_0 < 0 \\ \sigma_R, \alpha_R & \text{if} \quad m - m_0 > 0 \end{cases}$$

- Then we fit a gaussian distribution on the 1000 m_0 of the previous toys model.

3.4) Method used: Systematic error due to the choice of the fit



- The difference between the μ of the latter gaussian and the one of our best fit is the systematic error.

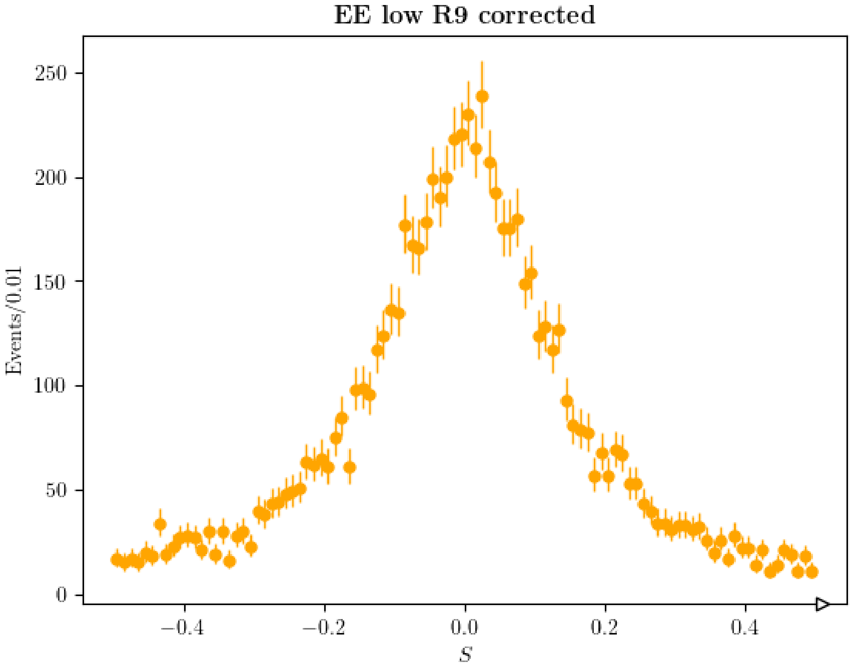
S = -0.02 $\pm$ 0.0019 $\pm$ 0.00077 $\pm$ 0.00003

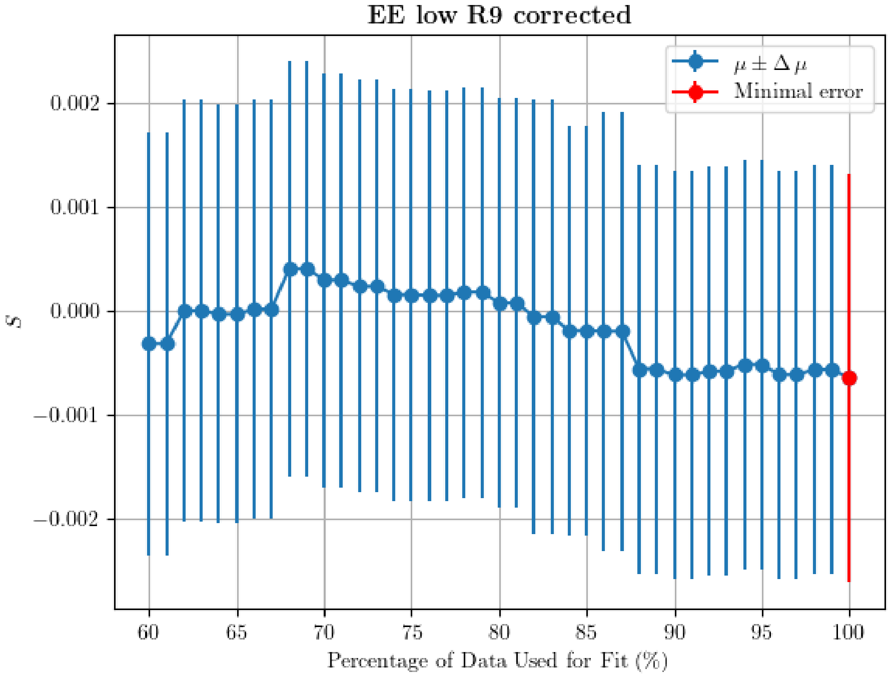
3.5) Autoclosure test:

- To test the validity of the code, we compute S. Correct p_γ and recompute

$$M^2_{\mu\mu\gamma} = (p_\gamma + p_{\mu^+} + p_{\mu^-})^2$$

- Then we expect S to be 0 with the uncertainties

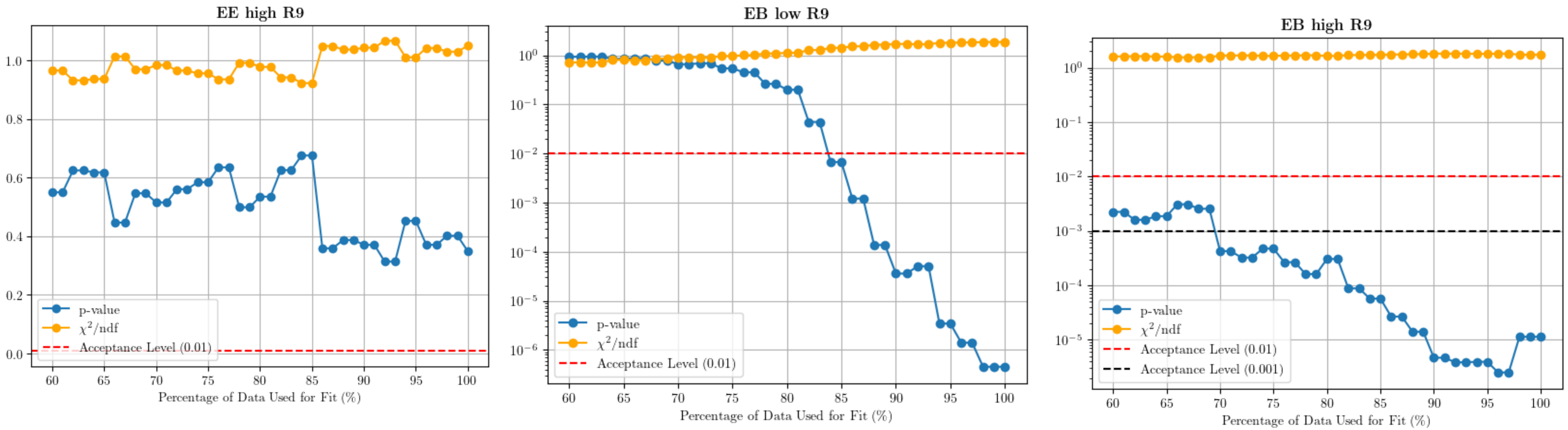




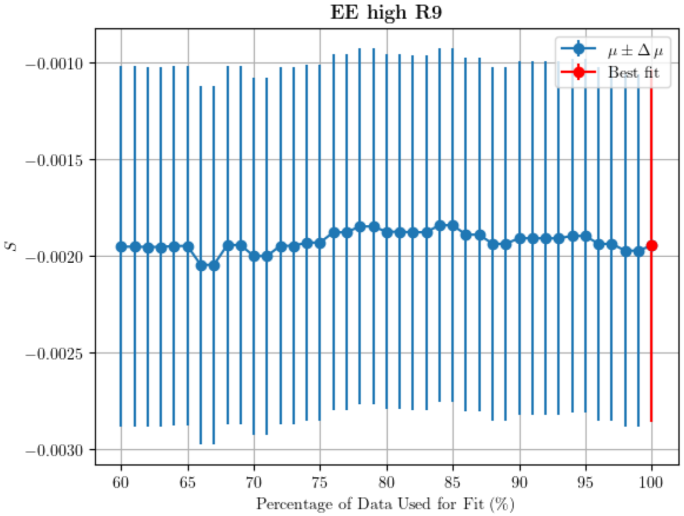
4) Results

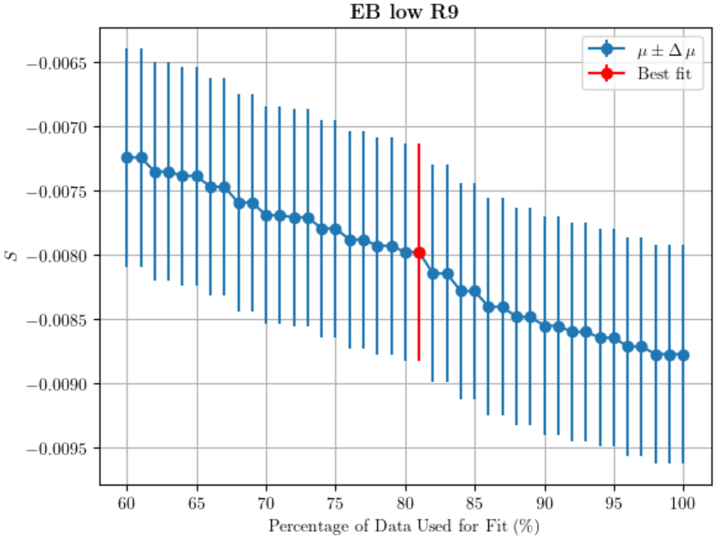
Sample	S	%	p-val	stat	err_1	err_2
EE low R9	-0.02	99	0.716	0.0019	8.10-4	3.10-5
EE high R9	-0.0019	100	0.349	0.00091	1.10-4	8.10-5
EB low R9	-0.0079	81	0.2	0.00084	0.0005	0.0007
EB high R9	-0.004	69	0.003	0.00042	0.00015	8.10-6

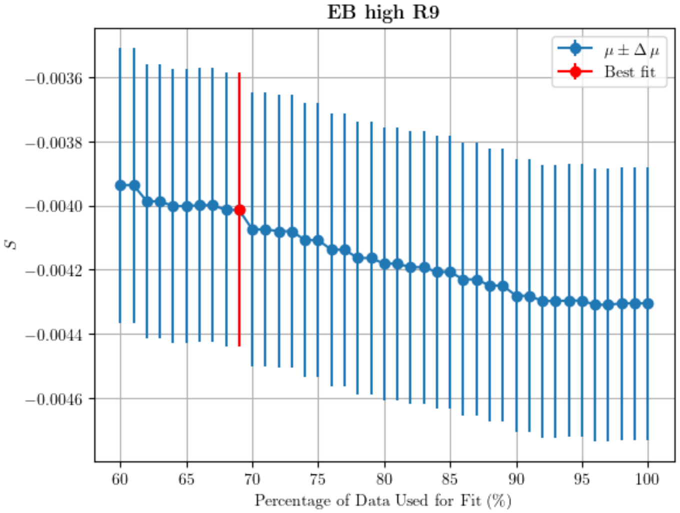
4) Results: p-value and χ^2



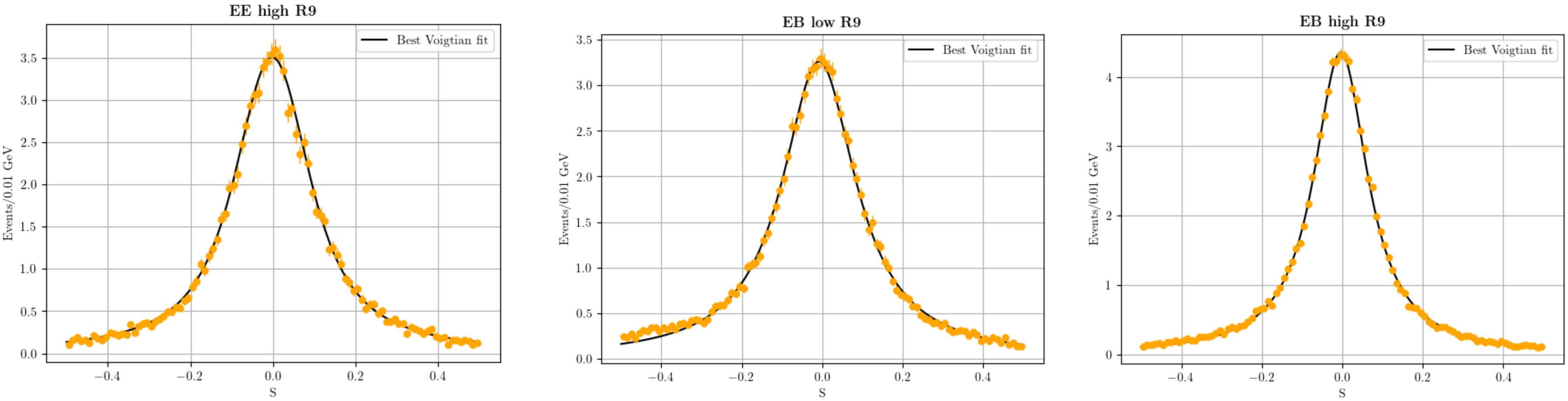
4) Results: S vs %



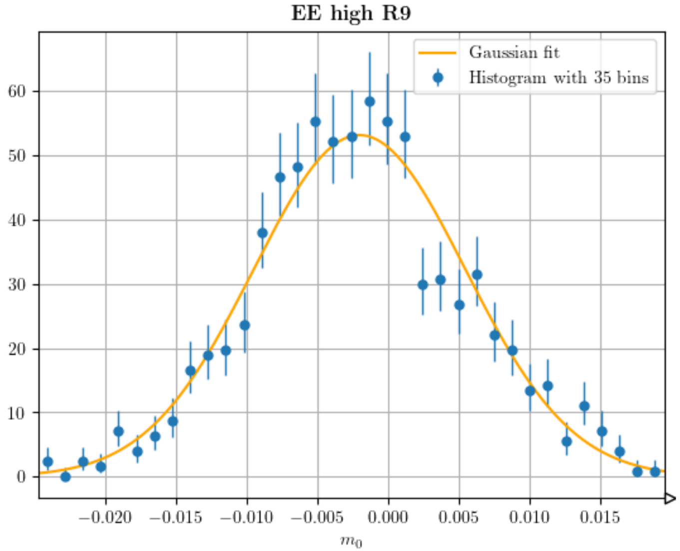


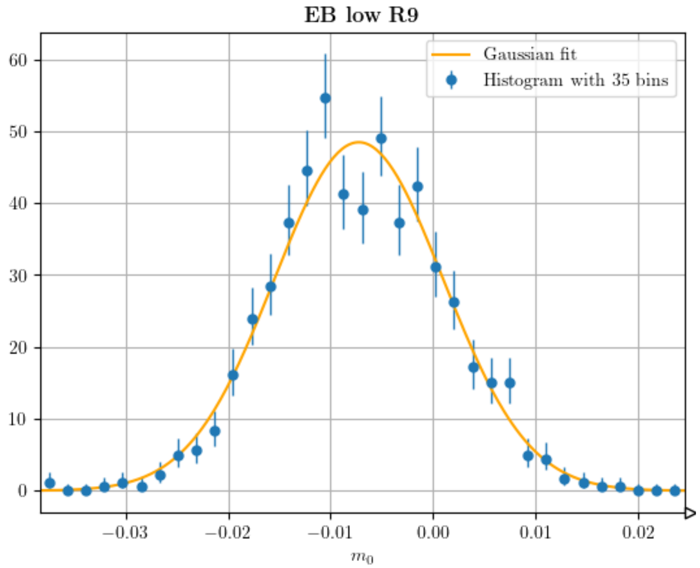


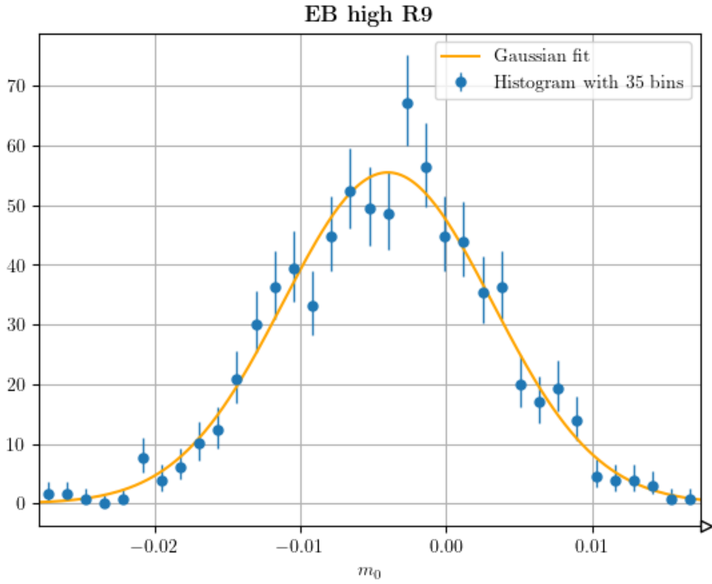
4) Results: best fit



4) Results: m_0 gaussian fits







4) Results: auto-closure test

Sample	S	%	p-val	stat	err_1	err_2
EE low R9	- 6.10-4	100	0.352	0.0019	7.10-4	1.10-5
EE high R9	- 3.10-6	100	0.489	0.0009	8.5 10-5	3.5 10-4
EB low R9	- 8.6 10-4	81	0.013	0.00084	0.0003	0.0007
EB high R9	- 3.10-3	73	0.011	0.00042	9.87 10-5	2.9 10-4

4) Conclusion and perspectives

- Results of the code are satisfying, but it still need to be perfectionned and optimized in order to be shared (number of bins, handling of the %, taking into account the weights for MC, move from ipyn to an efficient package)

- Plots of p_T need to be added

- Supplementary corrections on μ need to be applied

- Objectiv: apply the code to the run 2 Ultra legacy and compare with the result of Paul (from Saclay) and the code IJazz