Higgs boson mass and on-shell width measurements

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12/11/2019

on behalf of the HZZ mass & on-shell width group

AN-19-248

Available on the CMS information server **CMS AN-19-248**

The Compact Muon Solenoid Experiment

CMS Draft Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

2020/12/10
Archive Hash: bdb4e67-D
Archive Date: 2020/12/10

Higgs boson mass and on-shell width measurements in the four-lepton final state using full Run 2 data

HZZ mass and on-shell width measurements team
CMS collaboration

Abstract

The Higgs boson mass and on-shell width are measured in the $\mathrm{H} \to \mathrm{ZZ}^* \to 4\ell$ ($\ell = e, \mu$) decay channel using data collected by the CMS detector at the LHC at a center-of-mass energy $\sqrt{s} = 13$ TeV during Run 2, corresponding to an integrated luminosity of 137 fb^{-1}.

This box is only visible in draft mode. Please make sure the values below make sense.

PDFAuthor:	Higgs boson mass and on-shell width working group
PDFTitle:	Higgs boson mass measurement in the four-lepton final state using full Run 2 data
PDFSubject:	CMS
PDFKeywords:	CMS, physics, Higgs boson, mass, width, four-lepton

Please also verify that the abstract does not use any user defined symbols

Contents

Sample used

MC samples used are the same as HIG-19-001 [List in backup].
In sync with other groups.

Signal considered: ggF, VBF, VH (WH and Z), ttH

Background considered: qqZZ, ggZZ, Z+X

Data (SingleMuon and SingleElectron) used **only** in the window below 120 GeV.

Objects and selection

The analysis follows the same object definition as in HIG-19-001 for each year.

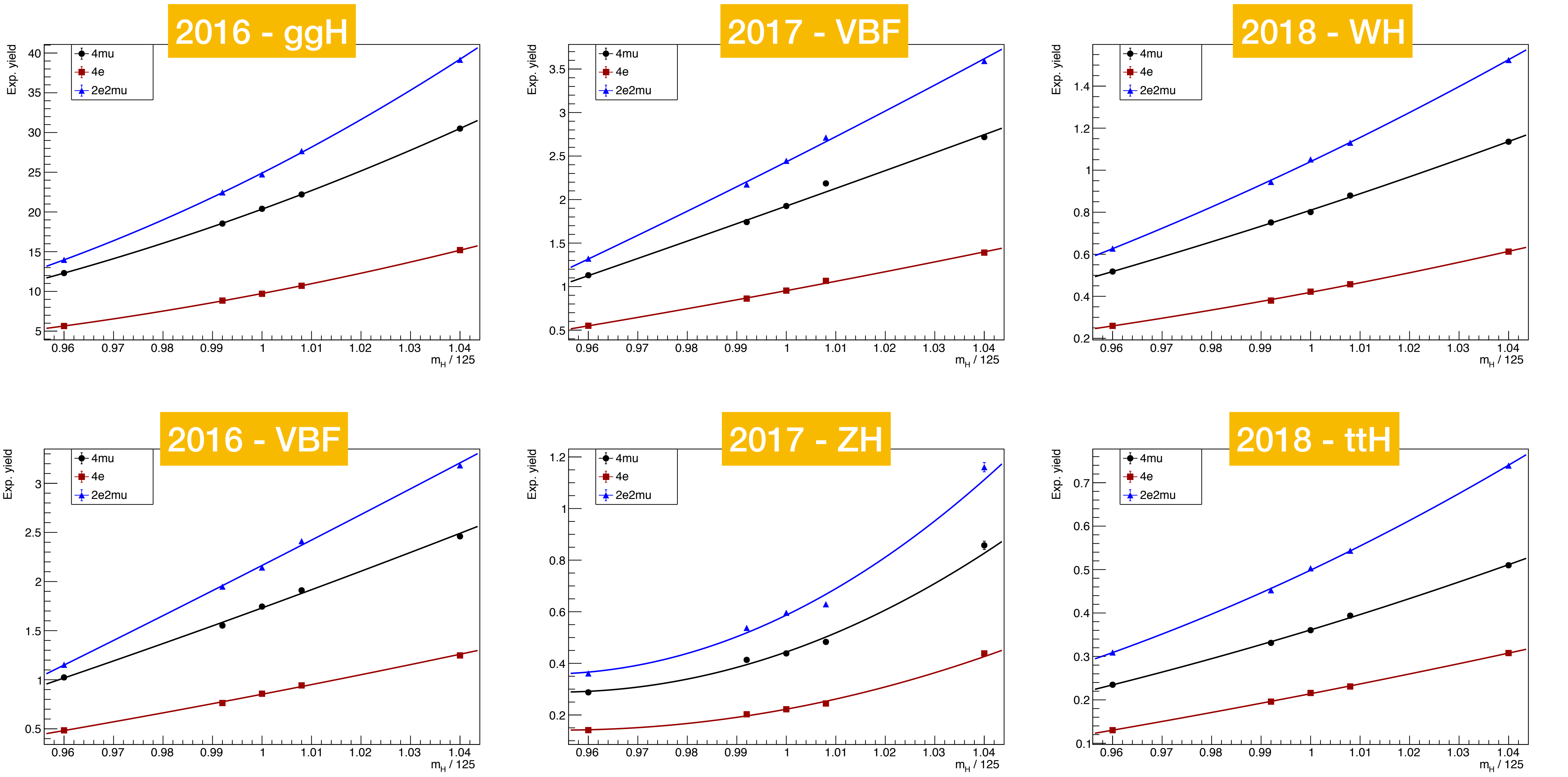
Event selection follows the same step as in HIG-19-001:

- trigger selection
- vertex selection
- selection of the four leptons
- selection of the ZZ candidate.

In case that more than one ZZ candidateis found to fullfil the selection, the one with the highest value of D_{kin} is chosen.

Signal normalisation

The normalisation of the Higgs boson signal is obtained, from simulation, looking at the expected signal yields in the range [105, 140] GeV, using 120, 124, 125, 126 and 130 GeV samples. Fit line is a 2nd order polynomial



Signal parametrisation

The signal lineshape is obtained from the fit of the Higgs boson mass distribution, in the range [105, 140] GeV:

- using a DSCB function for mass measurement [+ Landau for VH]

Fit parameters are derived as a function of mass, using a second order polynomial:

$$param = a + b\ (m_H - 125) + c\ (m_H - 125)^2$$

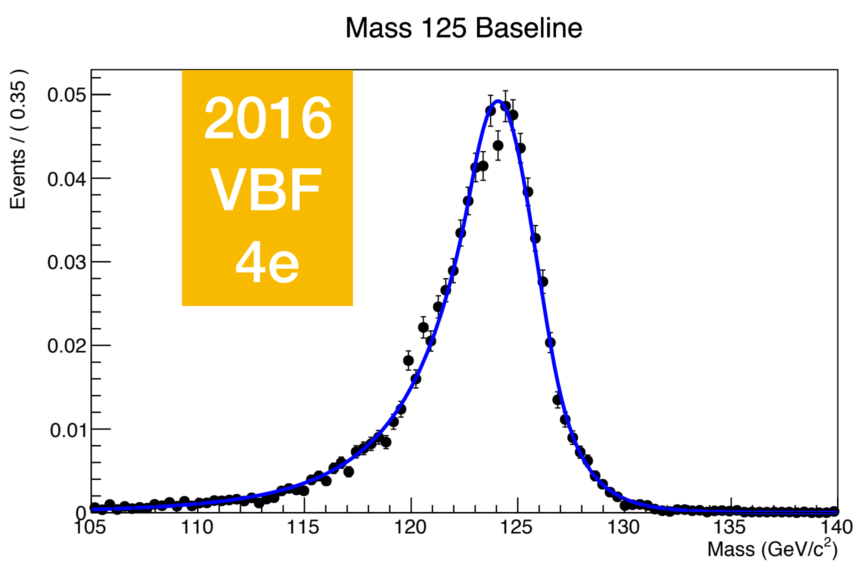
Obtained from the fit of the 125 GeV sample

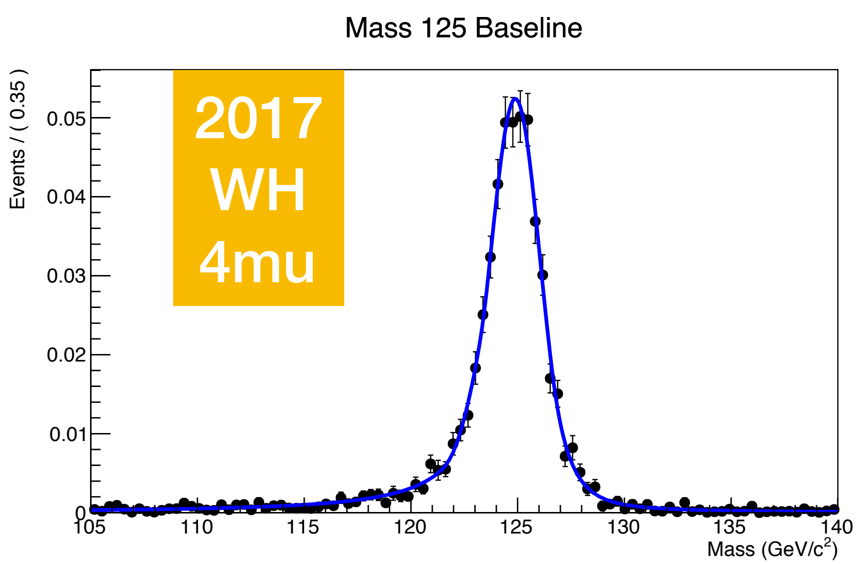
Obtained from the simultaneous fit of all the samples

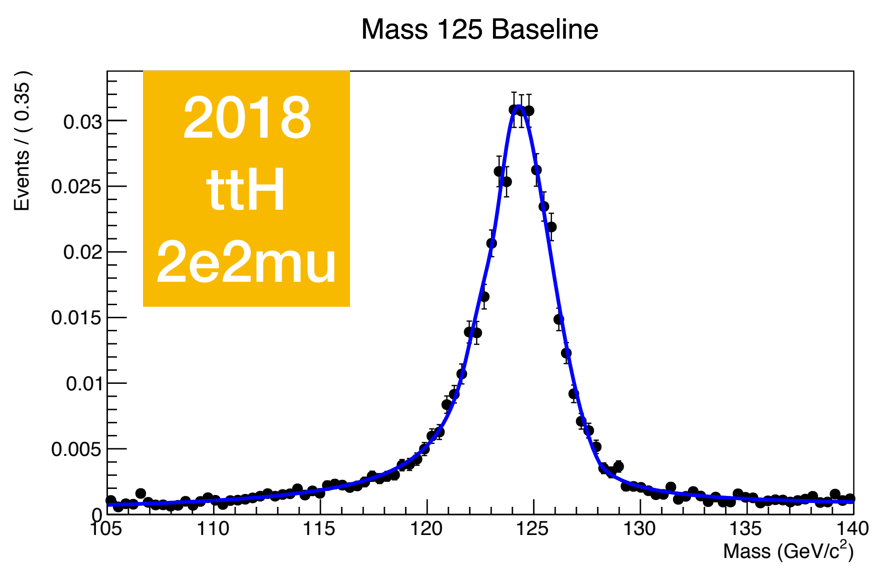
Signal parametrisation

The signal lineshape is obtained from the fit of the Higgs boson mass distribution, in the range [105, 140] GeV:

- using a DSCB function for mass measurement [+ Landau for VH]



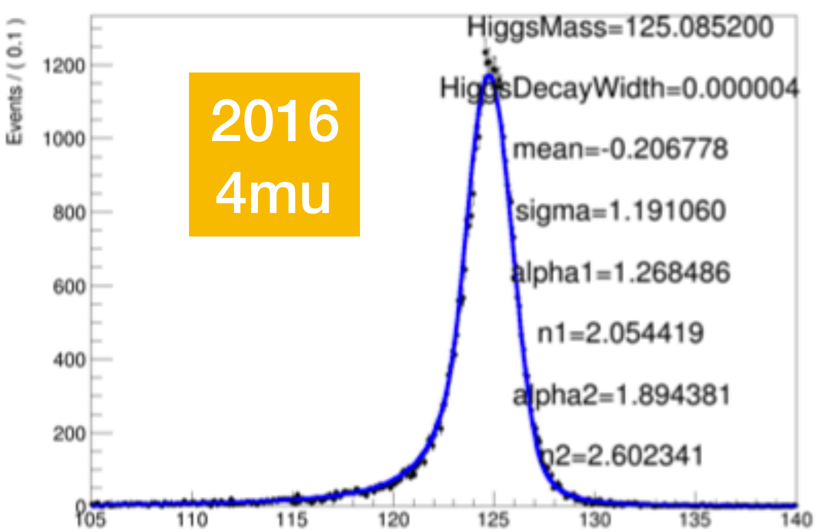


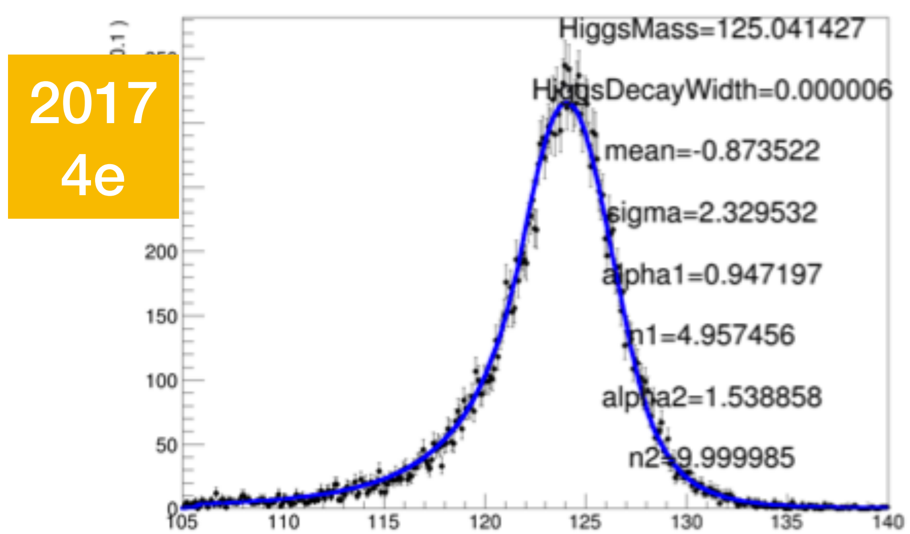


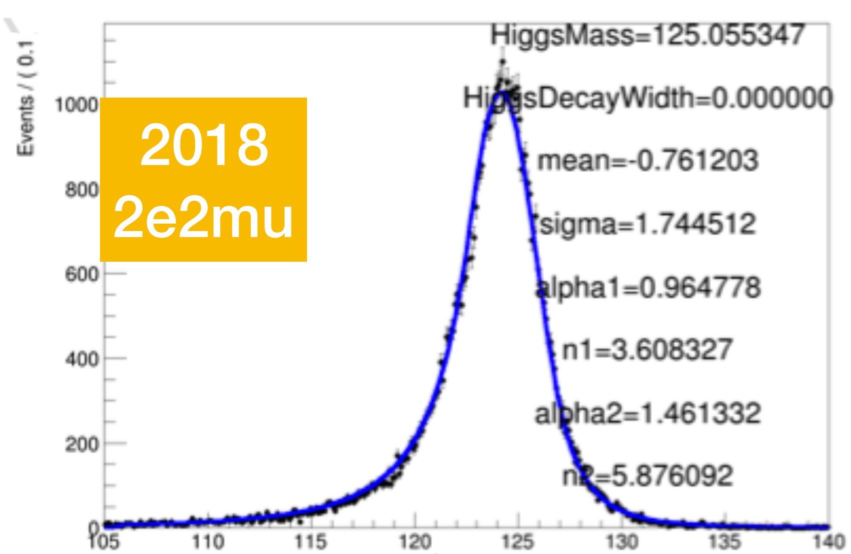
Signal parametrisation

The signal lineshape is obtained from the fit of the Higgs boson mass distribution, in the range [105, 140] GeV:

- using a DSCB function for mass measurement [+ Landau for VH]
- using a convolution of a BW and a DSCB for on-shell width measurement, using **only 125 GeV ggF sample**.







EBE correction

Mass uncertainty is one of the three variables used to build the three-dimensional maximum likelihood used to extract the Higgs boson mass [the other two are the mass itself and the kinematic discriminant D^{kin}_{bkg}].

Lepton uncertainty on momentum measurement is predicted on a per-lepton basis and then propagated to the four-lepton case to predict the **mass error** on an event-by-event (EBE) basis.

Lepton error enters into the mass calculation as:

$$m_0 = F(p_{T1}, \phi_1, \eta_1;\ p_{T2}, \phi_2, \eta_2;\ p_{T3}, \phi_3, \eta_3;\ p_{T4}, \phi_4, \eta_4)$$

$$\delta m_i = F(...;\ p_{Ti} + \delta p_{Ti}, \phi_i, \eta_i;\ ...) - m_0$$

$$\delta m = \sqrt{\delta m_1^2 + \delta m_2^2 + \delta m_3^2 + \delta m_4^2}$$

EBE correction

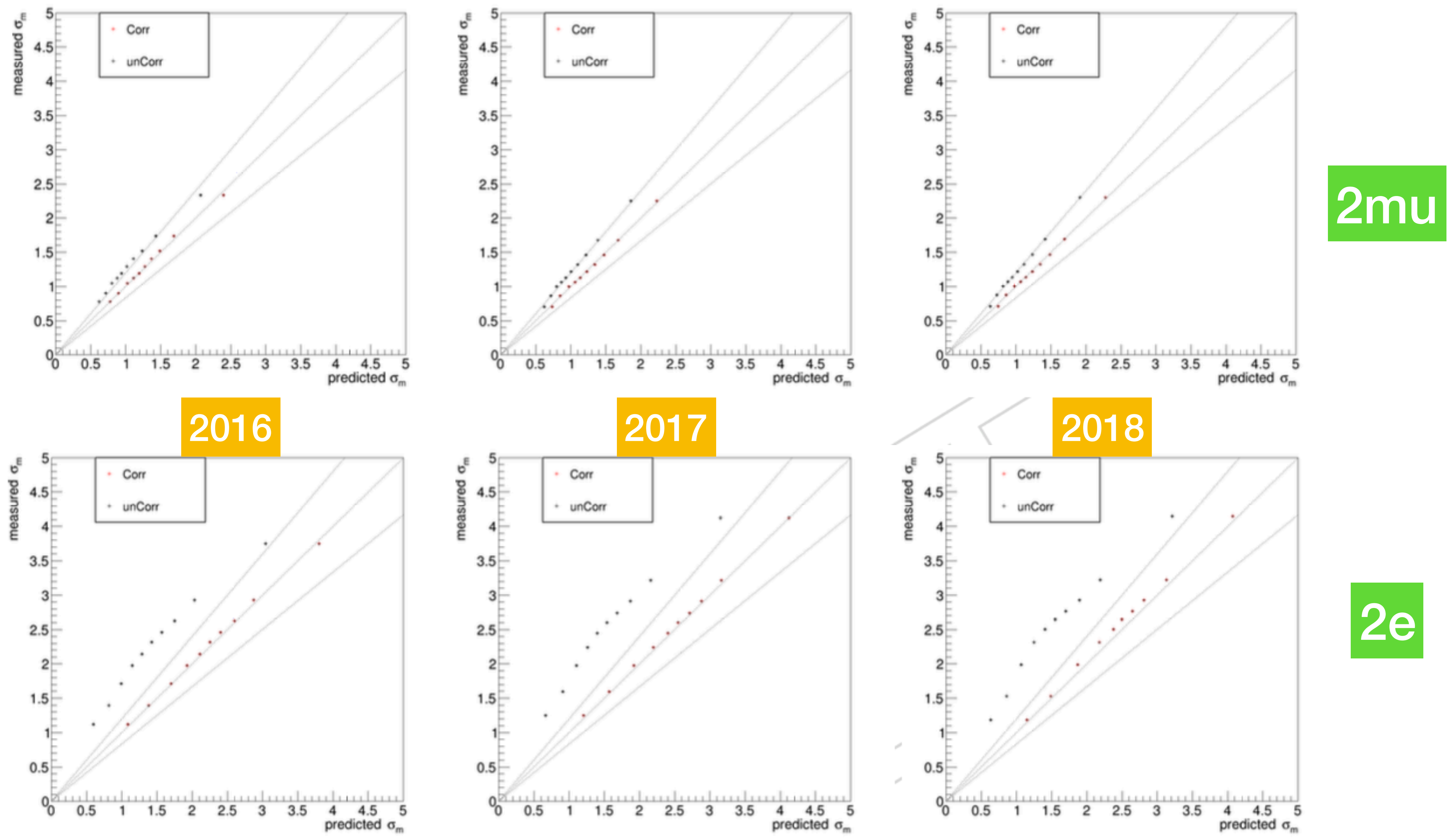
Lepton uncertainty is evaluated in different steps:

1. Fit* the invariant mass distribution of the di-lepton system
2. substitute σ of the Crystall-Ball with λ x δm keeping all the other parameters fixed. Here **λ** is a floated parameter to be fitted and **represents correction of pT error.**
3. re-fit the distribution in order to take the λ correction
4. check the procedure comparing dilepton mass resolution before and after lepton correction

*Function used to fit the distribution:

- Breit-Wigner (mass and Γ are fixed to PDG value) convoluted with a Crystal Ball for the **signal**
- Exponential function for the **background**

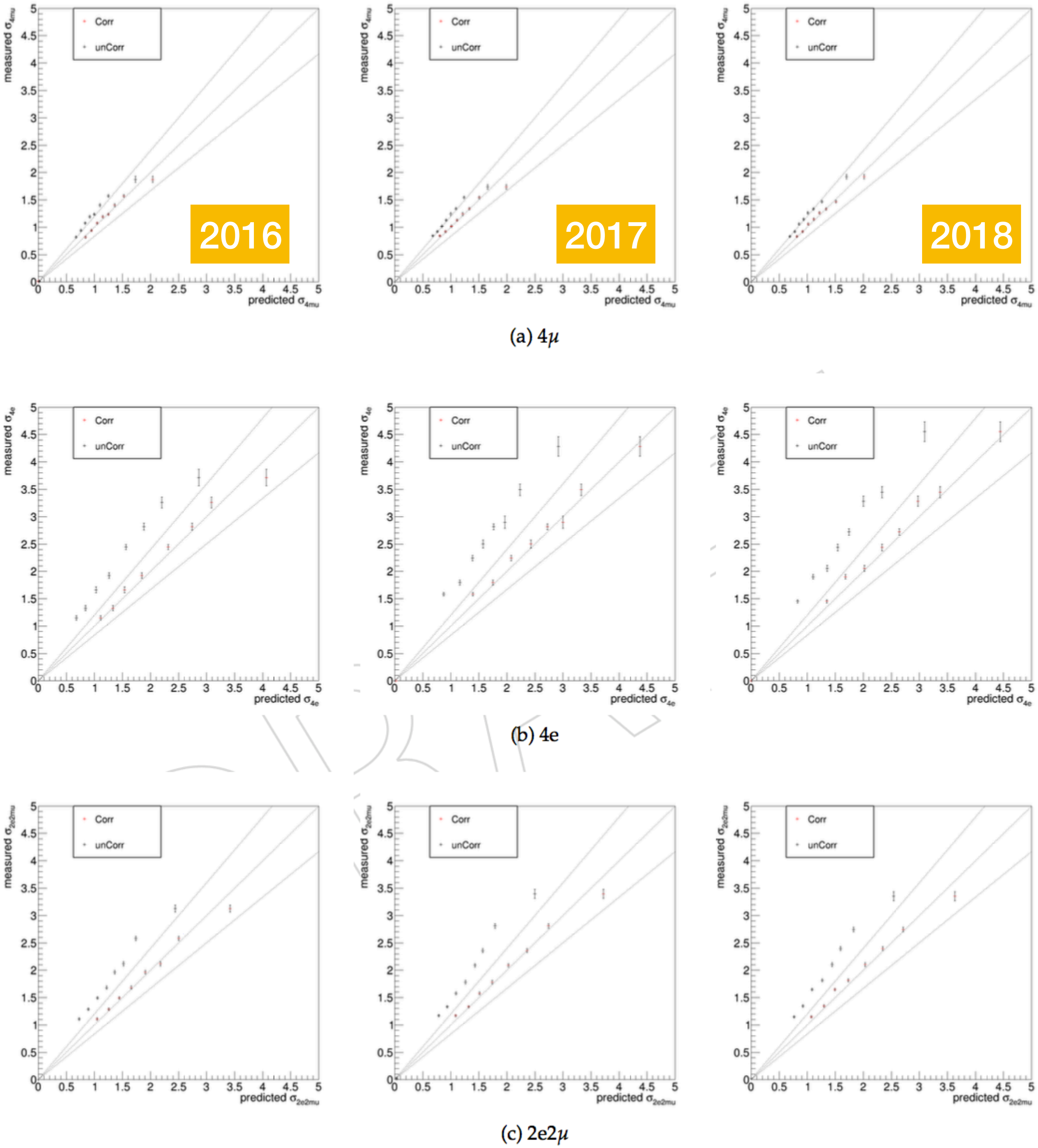
EBE: Z closure test



Z boson mass uncertainty **before** and **after** the event-by-event correction. As we can see, with λ corrections applied, we predict per-event mass uncertainties correctly (better than within +/-10%).

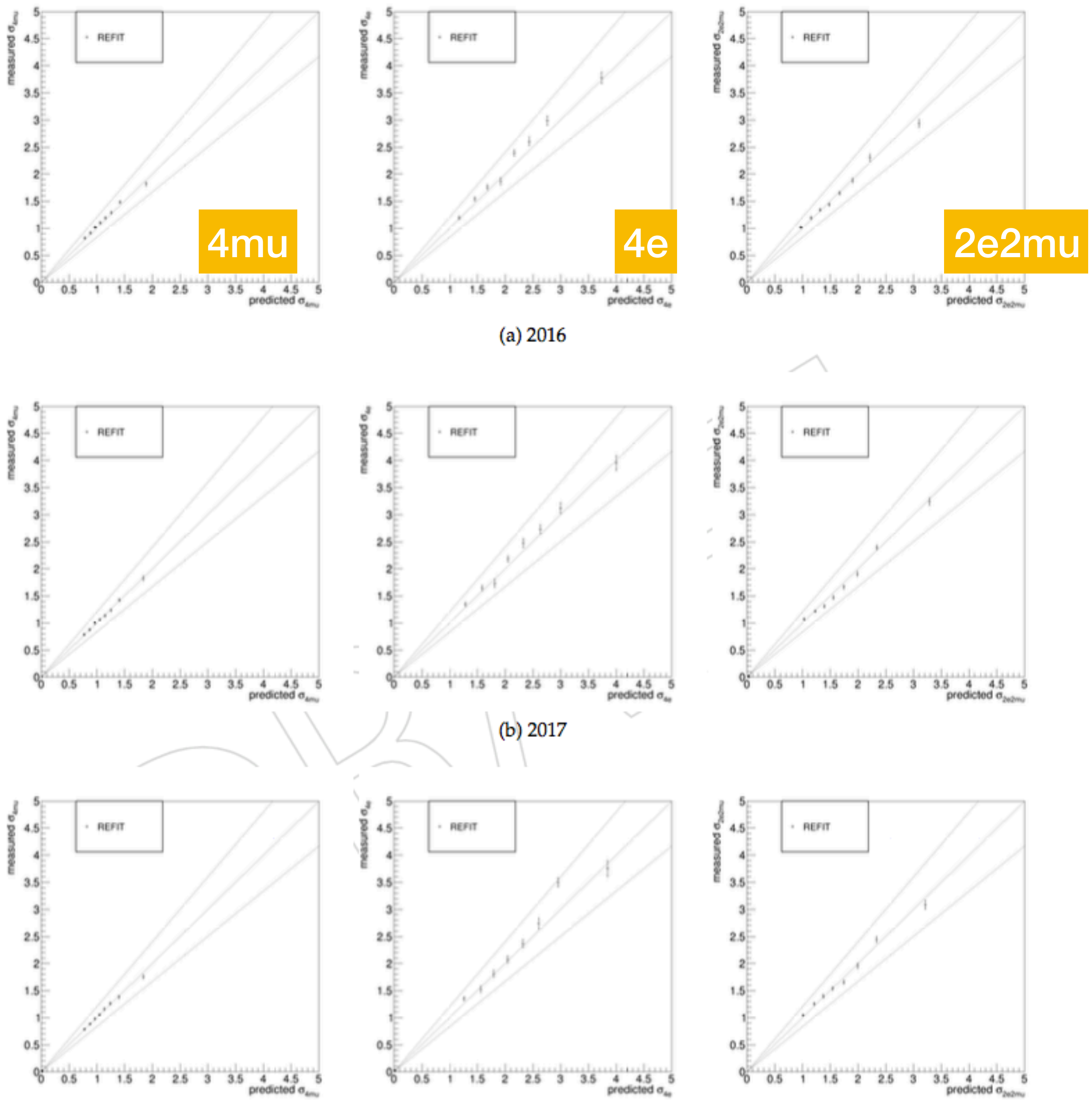
[the dashed lines stands for the 20% uncertainty assigned to the resolution in 2016]

EBE: H closure test



H boson mass uncertainty **before** and **after** the event-by-event correction.
As we can see, the λ correction improves the uncertainty since the measured one is in agreement with the predicted ones.

on-shell Z constraint



(a) 2016

(b) 2017

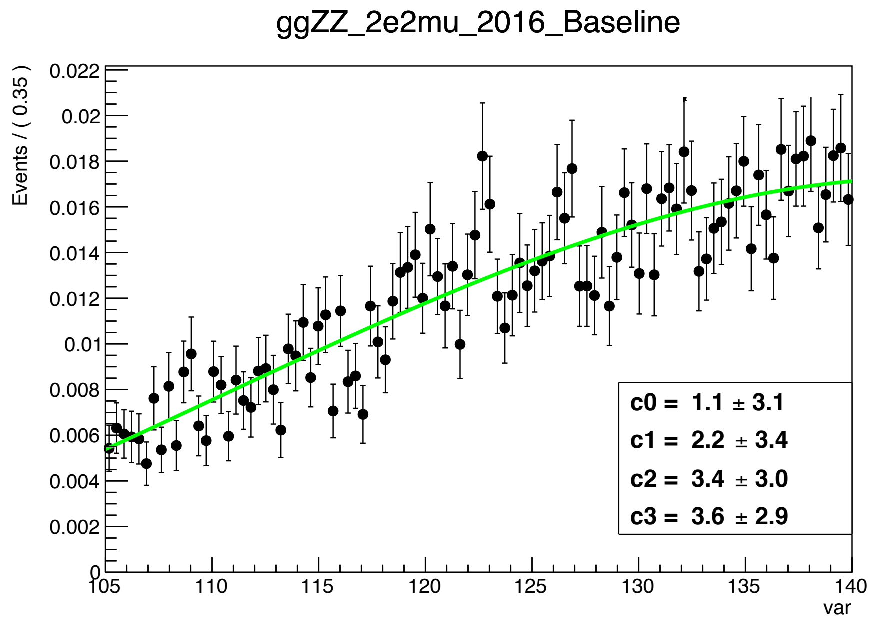
(c) 2018

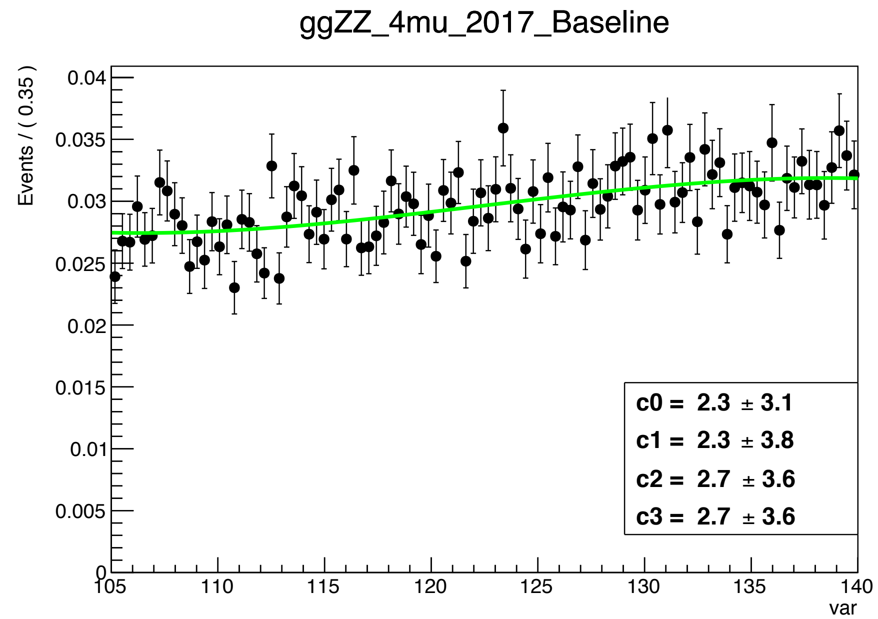
A kinematic fit is performed using a mass constraint on the intermediate on-shell Z resonance in order to improve mass resolution

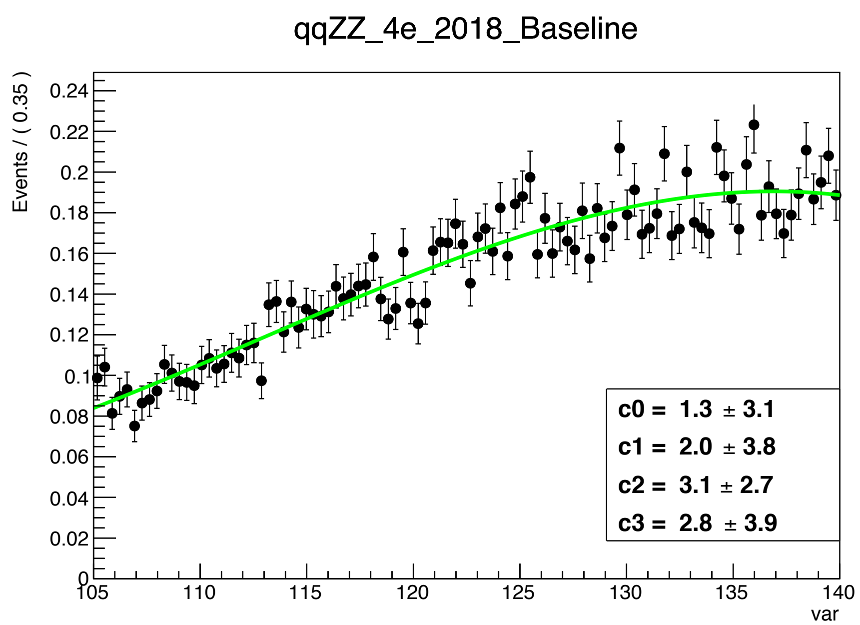
$$\mathscr{L}(p_T^1, p_T^2 \,|\, p_T^{reco1}, \sigma p_T^1, p_T^{reco2}, \sigma p_T^2) = Gauss(p_T^{reco1} \,|\, p_T^1, \sigma p_T^1) \cdot Gauss(p_T^{reco2} \,|\, p_T^2, \sigma p_T^2) \cdot \mathscr{L}(m_{12} \,|\, m_Z, m_H)$$

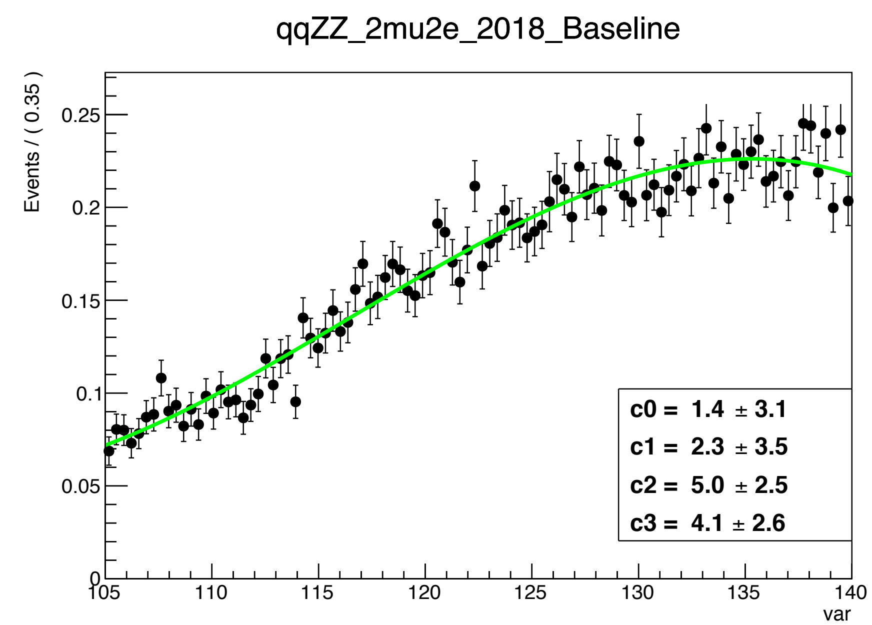
Background estimation

The **irreducible** background shape is estimated for simulation using a Bernstein function of the 3rd order.







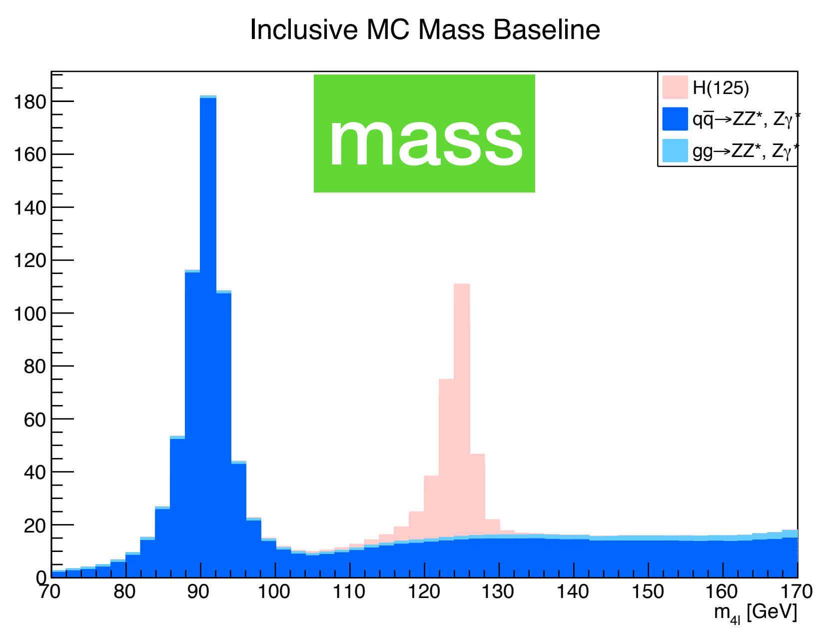


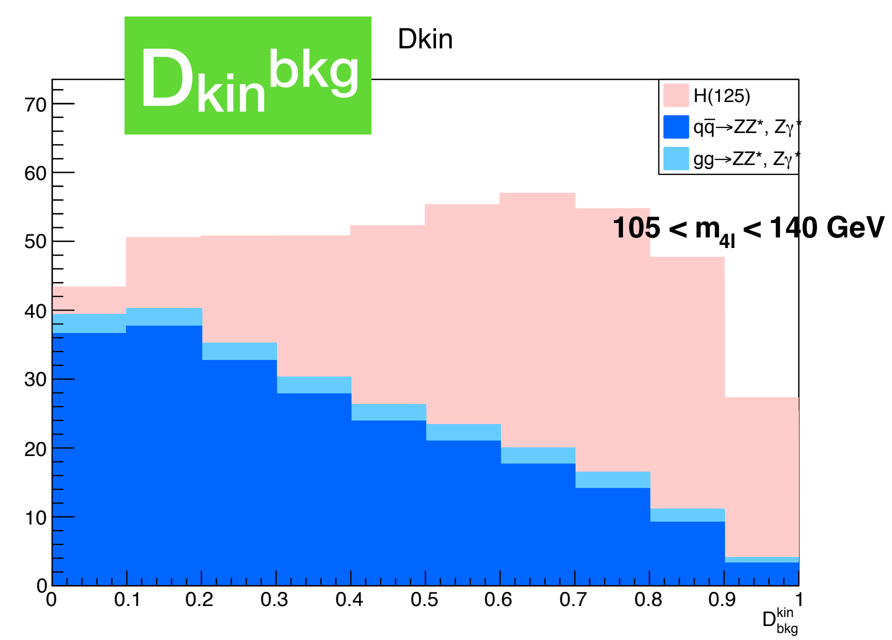
The **reducible** background (Z+X) is currently obtained for 2017 and 2018 scaling according to the luminosity the shape of 2016 obtained in HIG-16-041.

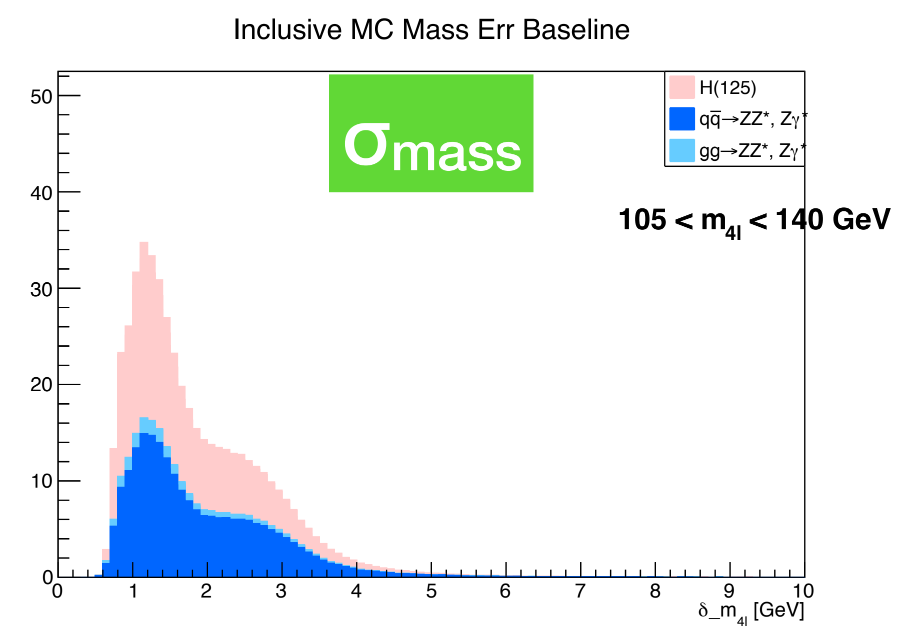
Yield and distributions

[105, 140] GeV

channel	4μ	4e	$2e2\mu+2\mu2e$	inclusive
qqZZ	-	-	-	223.79
ggZZ	-	-	-	22.50
Z+X	-	-	-	136.84
Sum of background	-	-	-	383.13
Signal ($m_H = 125$ GeV)	-	-	-	243.38
Total expected	-	-	-	626.51
Observed	-	-	-	-







Lepton scale uncertainty

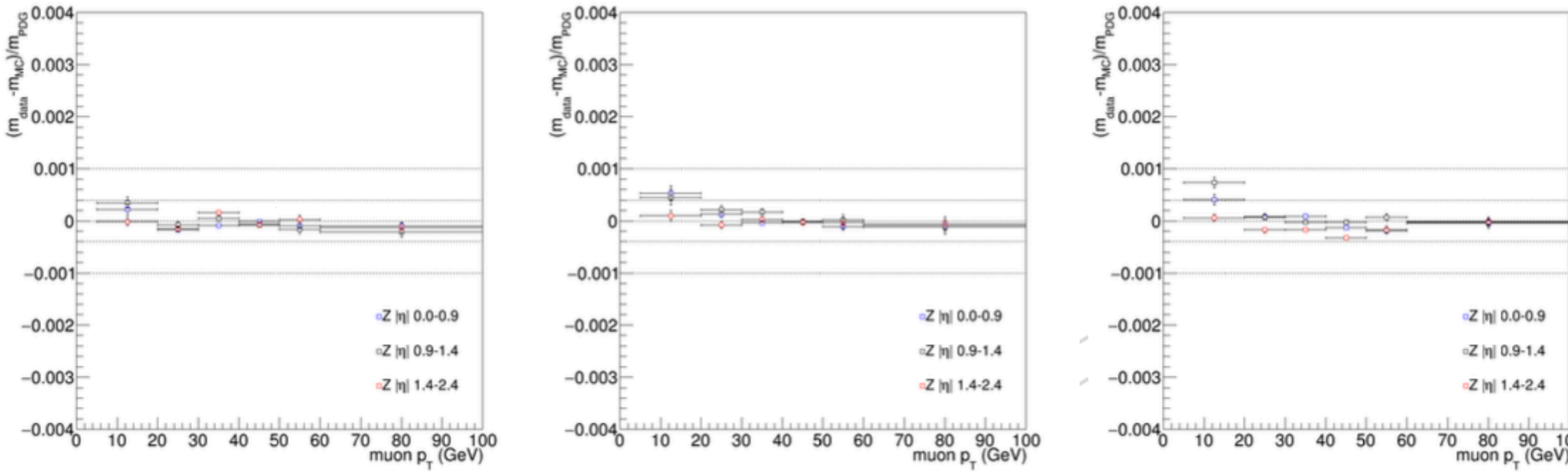
1. Fit Z boson mass in both data and MC (in several pT - eta ranges)

2. In each pT-eta bin, evaluate ($mean_{DATA}$ - $mean_{MC}$) / $mean_{PDG}$

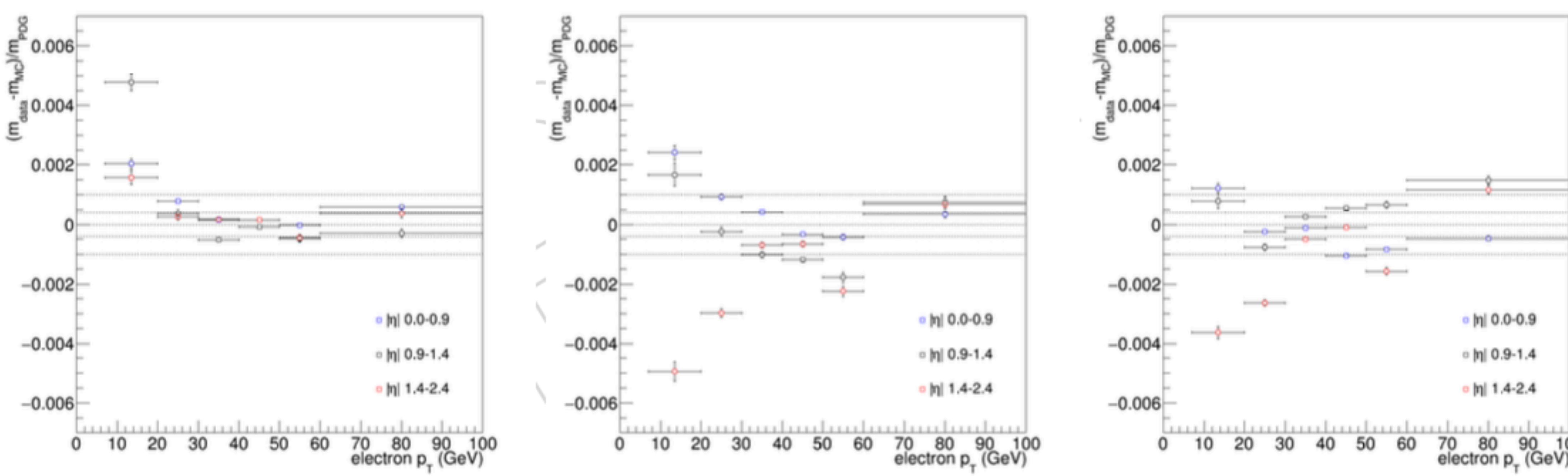
3. Propagate these values to leptons and evaluate again the Higgs boson mass in three configurations:
   A. using nominal pT
   B. using pT*(1 + offset) —> UP
   C. using pT*(1 - offset) —> DOWN

4. Take the max between ($mean\_H_{nom}$ - $mean\_H_{up}$) / $mean\_H_{nom}$ and ($mean\_H_{nom}$ - $mean\_H_{down}$) / $mean\_H_{nom}$

Lepton scale uncertainty



(a) muon



(b) electron

Lepton scale uncertainty

In the electron case, scale and smearing provided by the eGammaPOG have been also taken into account.

4e final state	Lepton scale	Scale corr (POG)	Smearing corr (POG)	TOT
2016	0.08%	0.04%	<< 0.01%	0.09%
2017	0.10%	0.07%	<< 0.01%	0.12%
2018	0.09%	0.03%	<< 0.01%	0.09%
HIG-16-041	0.30%	Not taken into account		0.30%

Systematic used

Dominant systematic uncertainties:

- lepton energy scale:
  - 0.02% (old 0.04%) for muon
  - 0.1-0.15% (old 0.3%) for electron [2016-2017/8]

- lepton energy resolution —> 20%

Other systematic uncertainties used are [**same for all three years**]:

- lepton ID and reco efficiency —> 2.5 - 2.9% depending on the final state

- theory cross section

- luminosity —> 2.6%

- data-driven background —> vary from 36% (4mu) and 43% (4e)

Higgs boson mass result

EXPECTED [in GeV]

Expected uncertainty	4μ	4e	2e2μ	2μ2e	inclusive	(Stat only)
3D model + refit	-	-	-	-	-0.128/+0.127	-0.12/+0.12
3D model	-	-	-	-	-0.136/+0.135	-0.129/+0.130
2D model	-	-	-	-	-0.142/+0.141	-0.135/+0.136
1D model	-	-	-	-	-0.161/+0.159	-0.155/+0.155

Expected uncertainty	HIG-16-041	New
3D model + refit	-0.257/+0.255	-0.128/+0.127
3D model	-0.279/+0.278	-0.136/+0.135
2D model	-0.289/+0.287	-0.142/+0.141
1D model	-0.324/+0.321	-0.161/+0.159

1D model = pdf(m)

2D model = pdf(m, σ_m)

3D model = pdf(m, σ_m, D_{kin})

3D model + refit = pdf(m, σ_m, D_{kin}) + on-shell Z constrain

Conclusion

Higgs boson mass and on-shell width measurements have been presented. Many steps of the analysis have been already done; others are “work in progress”.
Looking at expected results:

- mass measurement —> from 0.258 GeV to 0.128 GeV
- on-shell width measurement —> obtained results but more checks are needed

Started to have a look at **UL samples** (DY and data in m < 120 GeV):

- Rochester muon correction ready —> presented during muon POG (06/12)
- HZZ electron BDT —> which is the status?

Parallel works (**not implemented in the AN**) are still ongoing to further improve the analysis:

- new muon reconstruction —> expect O(10%) improvement on m_H resolution
- lepton energy scale and resolution studies —> resolution from 20%to 10%
- 2D model with σ_M categorisations

Backup

Signal sample used

2016

/GluGluHToZZTo4L_M125_13TeV_powheg2_JHUGenV709_pythia8/RunIISummer16MiniAODv2-PUMoriond17_80X_mcRun2_asymptotic_2016_TrancheIV_v6-v1/MINIAODSIM
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2017

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2018

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Bkg sample used

2016

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2017

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Higgs boson on-shell width result

EXPECTED [in GeV**]**

Obtained very first results: more studies are on-going to double check them

2016 impact plot