HZZ mass and on-shell width analysis status

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on behalf of the
HZZ Mass&(on-shell)width group

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Introduction

Currently working on full Run II UL mass measurement.
First version of the associated AN (**AN_19_248**) circulated within HZZ group. Received and answered first set of questions.

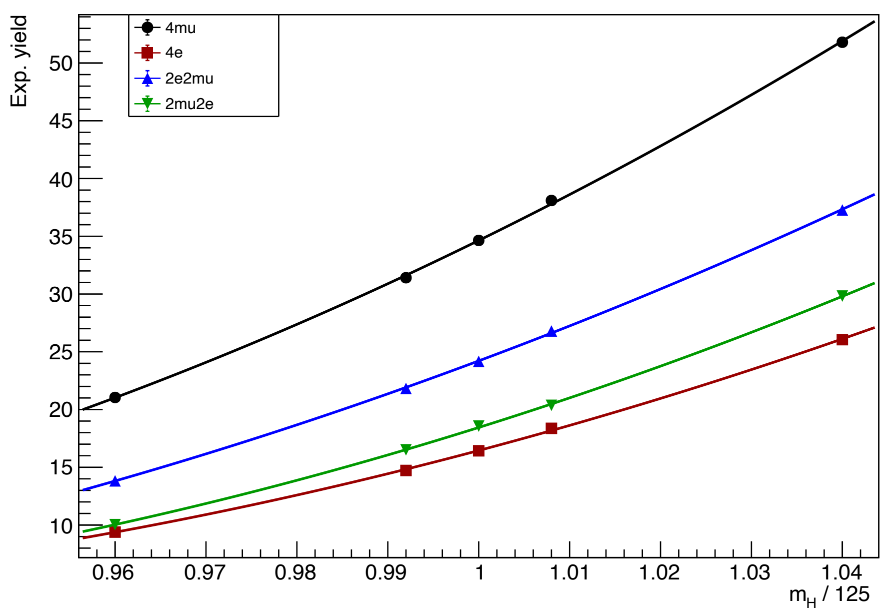
In the following, only MC and expected results will be shown.

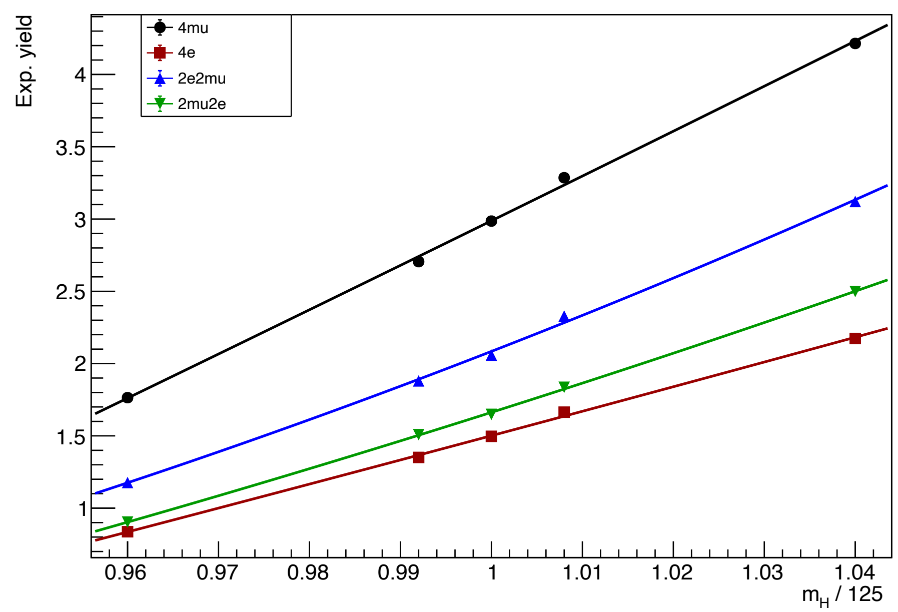
Signal considered: ggH, VBF, VH (WH and ZH), ttH
Background considered:
    MC: qqZZ, ggZZ;
    from DATA: Z+X;
Data used **only** for:
- event-by-event lepton correction (using events around Z boson —> [60, 120] GeV
- evaluation of Z+X contribution

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.

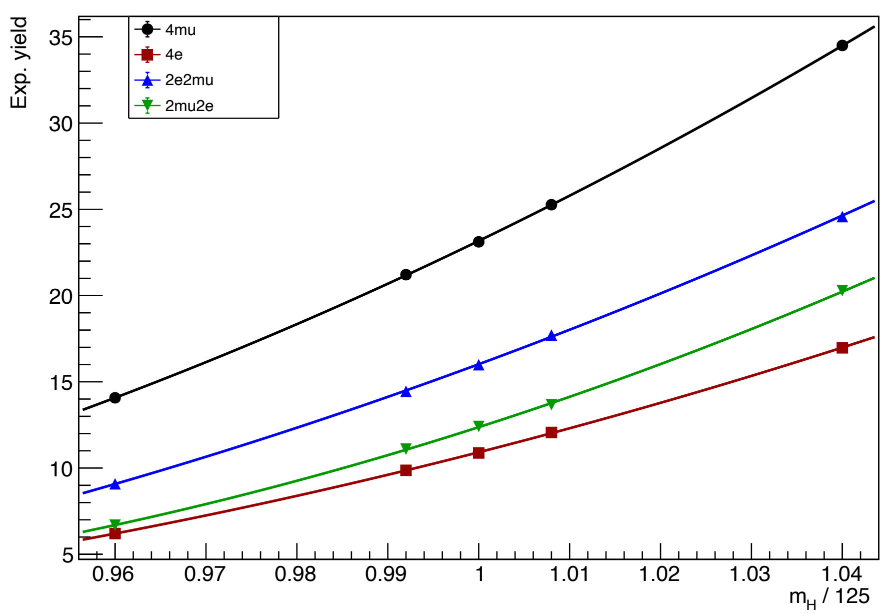
ggH 2018

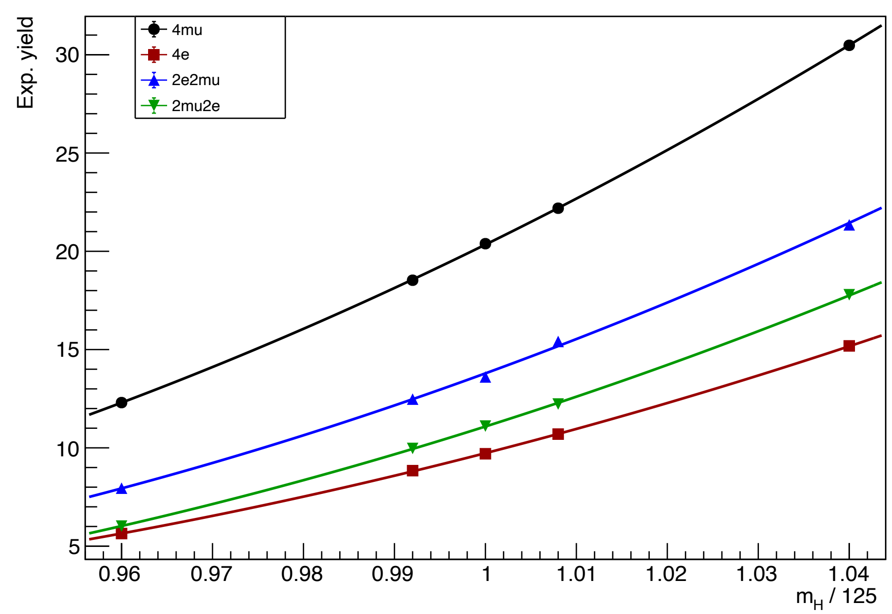




VBF 2018

ggH 2017





ggH 2016

Signal parametrisation

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

- For mass measurement: used a DSCB function [+ Landau for VH & ttH]
- For on-shell width measurement: used a convolution of a BW (μ = 125 GeV and Γ = 0.004 GeV) and a DSCB [+ Landau for VH & ttH]

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

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- Improved thanks to:
  - ✓ the use of beam spot in reconstructing muon
  - ✓ a kinematic fit using a mass constraint on the intermediate mostly on-shell Z1 resonance.

Categorisation

For 2016 results, Higgs boson mass measurement was performed using a 3D (m_H, σ_m, D^{kin}_{bkg}) likelihood.

For full Run II results, categorisation in σ_m/m will be used. This will help in:

- better describing signal shape (**backup**)
- dealing with the correlation existing between σ_m and D^{kin}_{bkg}

Now 9 categories have been created starting from the raw distribution of the relative mass error of the ggH sample @ 125 GeV. The categorisation is done for each final state (4μ, 4e, 2e2μ, 2μ2e) and for each year.

In each category, all ingredients for the mass measurement have been derived independently.

Background estimation

Irreducible background (qqZZ and ggZZ) modelling obtained using a Bernstein function of the 3rd order.

We are currently working on a complete update of Z+X for all years. For now, we use the 2016 estimate and rescale each bin as follow

$$\frac{Z+X_{bin\ i}}{Z+X_{tot}} = \frac{qqZZ_{bin\ i}}{qqZZ_{tot}}$$

The 2017 and 2018 values have been obtained scaling according to the integrated luminosity (~42 and ~60 /fb) 2016 background.

Systematic uncertainties

Lepton momentum scale and lepton momentum resolution are the two systematic uncertainties with the biggest impact on the mass measurement.

The **HIG-16-041 have been used to get a rough idea.**

In parallel, many studies have been done within muon and E/γ POG.
Next results will include new method to evaluate the systematics already approved by POGs.

The values used (foreseen) are:
muon scale = 0.04% (0.01%) and electron scale = 0.3% (<0.15%)
lepton resolution = 20% (<10%)

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CMS

Exp mass measurement uncert (MeV)

From HIG-16-041, scaling according to lumi (3D_refit), expected result is:

140 MeV = 120(stat) ± 73(syst) MeV

New expected results:

135 MeV = 112(stat) ± 75(syst) MeV

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New expected results:

135 MeV = 112(stat) ± 75(syst) MeV

If foreseen systematics are used:

135 MeV = 112(stat) ± **35**(syst) MeV

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Exp mass measurement uncert (MeV)

From HIG-16-041, scaling according to lumi (3D_refit), expected result is:

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New expected results:

135 MeV = 112(stat) ± 75(syst) MeV

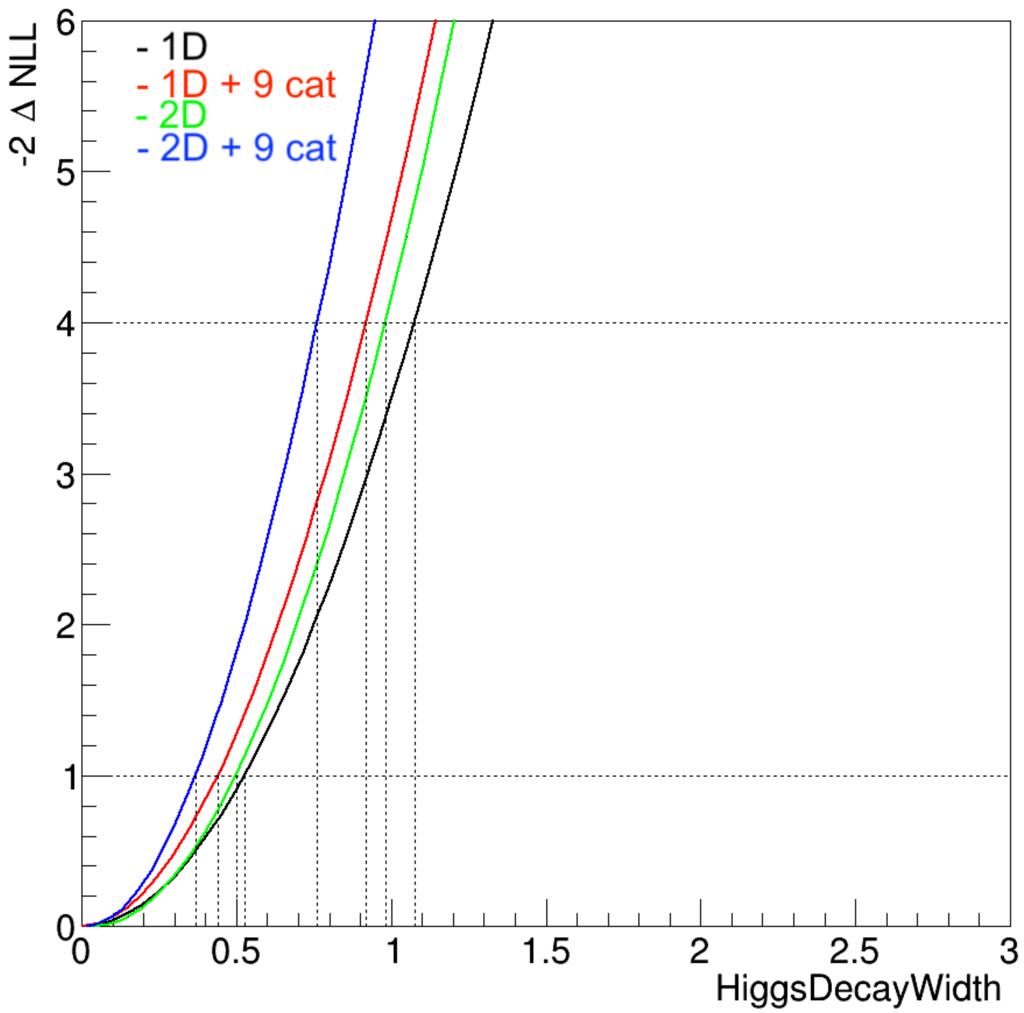
If foreseen systematics are used:

135 MeV = 112(stat) ± **35**(syst) MeV

Optimistic projection at the end of HL-LHC: L = 4500 fb^{-1}

135 MeV = **20**(stat) ± **35**(syst) MeV

Higgs on-shell width



68% C.L.	2016	2017	2018	Full Run II
N-2D′	$0^{+0.61}$	$0^{+0.58}$	$0^{+0.49}$	$0^{+0.37}$
2D′	$0^{+0.74}$	$0^{+0.71}$	$0^{+0.62}$	$0^{+0.50}$
2D′(No syst)	$0^{+0.62}$	$0^{+0.58}$	$0^{+0.47}$	$0^{+0.31}$
2D′(No bkg, No syst)	$0^{+0.39}$	$0^{+0.37}$	$0^{+0.30}$	$0^{+0.19}$
N-2D	$0^{+0.68}$	$0^{+0.64}$	$0^{+0.54}$	$0^{+0.40}$
2D	$0^{+0.84}$	$0^{+0.81}$	$0^{+0.71}$	$0^{+0.56}$
2D(No syst)	$0^{+0.70}$	$0^{+0.66}$	$0^{+0.54}$	$0^{+0.35}$
2D(No bkg, No syst)	$0^{+0.44}$	$0^{+0.41}$	$0^{+0.34}$	$0^{+0.22}$
N-1D′	$0^{+0.73}$	$0^{+0.69}$	$0^{+0.60}$	$0^{+0.44}$
1D′	$0^{+0.80}$	$0^{+0.77}$	$0^{+0.69}$	$0^{+0.53}$
1D′(No syst)	$0^{+0.68}$	$0^{+0.64}$	$0^{+0.54}$	$0^{+0.33}$
1D′(No bkg, No syst)	$0^{+0.39}$	$0^{+0.37}$	$0^{+0.30}$	$0^{+0.19}$
N-1D	$0^{+0.82}$	$0^{+0.77}$	$0^{+0.65}$	$0^{+0.51}$
1D	$0^{+0.92}$	$0^{+0.88}$	$0^{+0.77}$	$0^{+0.60}$
1D(No syst)	$0^{+0.79}$	$0^{+0.73}$	$0^{+0.60}$	$0^{+0.38}$
1D(No bkg, No syst)	$0^{+0.44}$	$0^{+0.41}$	$0^{+0.34}$	$0^{+0.22}$

In 2016 published result, where ggH and VBF categorisation was used:

$\Gamma < 0.75$ GeV (68% C.L.)

VX+BS approach still needs to be implemented.

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Conclusion

Higgs mass and on-shell width measurements have been presented.

Final Full Run 2 expected result for mass uncertainty is:
135 (stat + syst) MeV = 112(stat) ± 35(syst) MeV

Final expected result for width is: **Γ < 0.37 GeV (stat + syst)**

Works in progress:

- Z+X contributions
- VX+BS for width
- UL samples

For Snowmass:

- use full Run 2 UL data cards to extract projection for Snowmass

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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2018

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CMS

Signal parametrisation

The signal line shape 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 & ttH]
- using a convolution of a BW (μ = 125 GeV and Γ = 0.004 GeV) and a DSCB for on-shell width measurement [+ Landau for VH & ttH]

Fit parameters are derived as a function of mass, using a first order polynomial (example in backup):

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

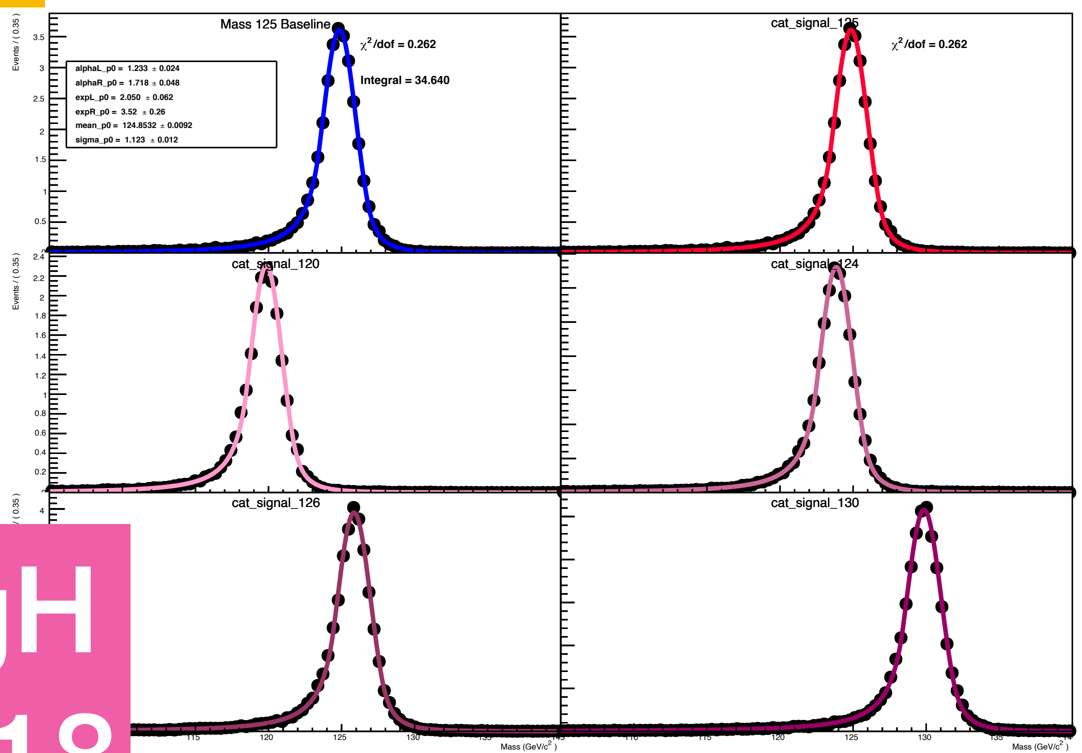
Obtained from the fit of the 125 GeV sample

Obtained from the simultaneous fit of all the samples

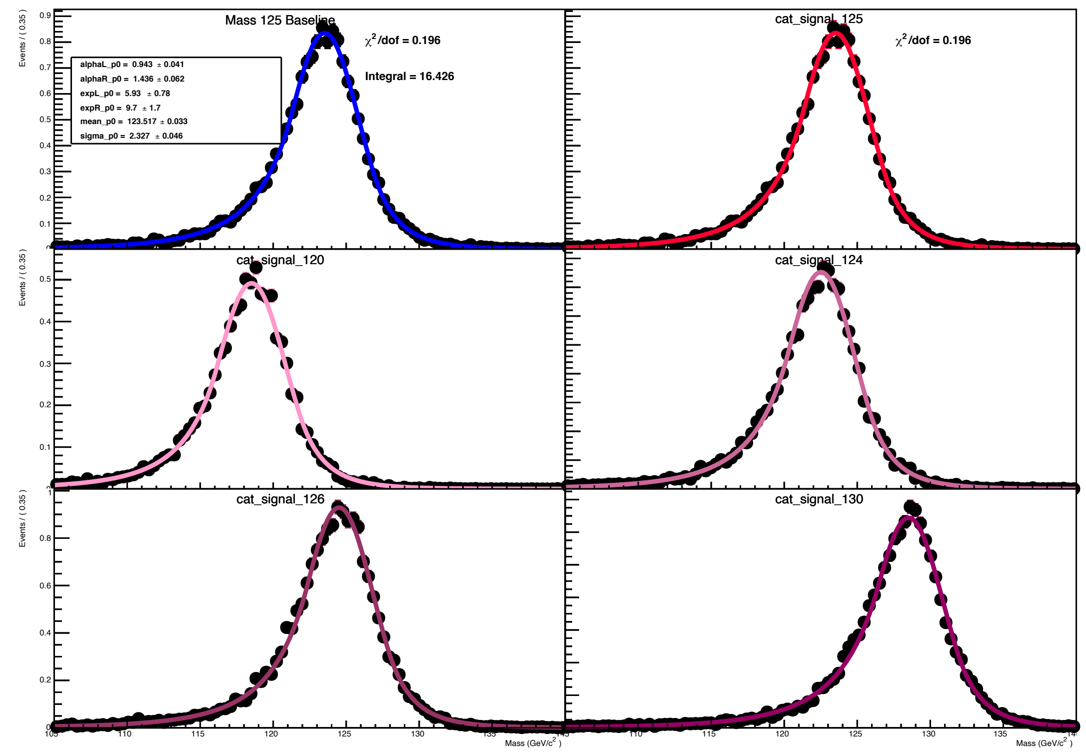
Signal parametrisation

ggH 2018

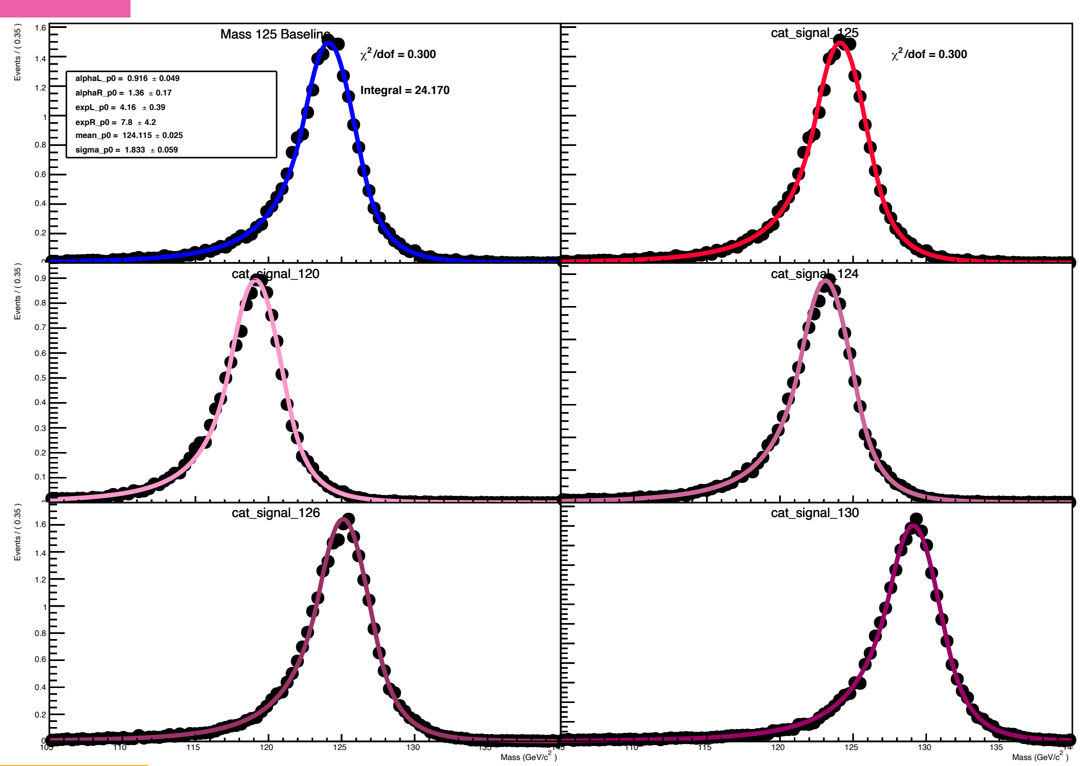
4mu

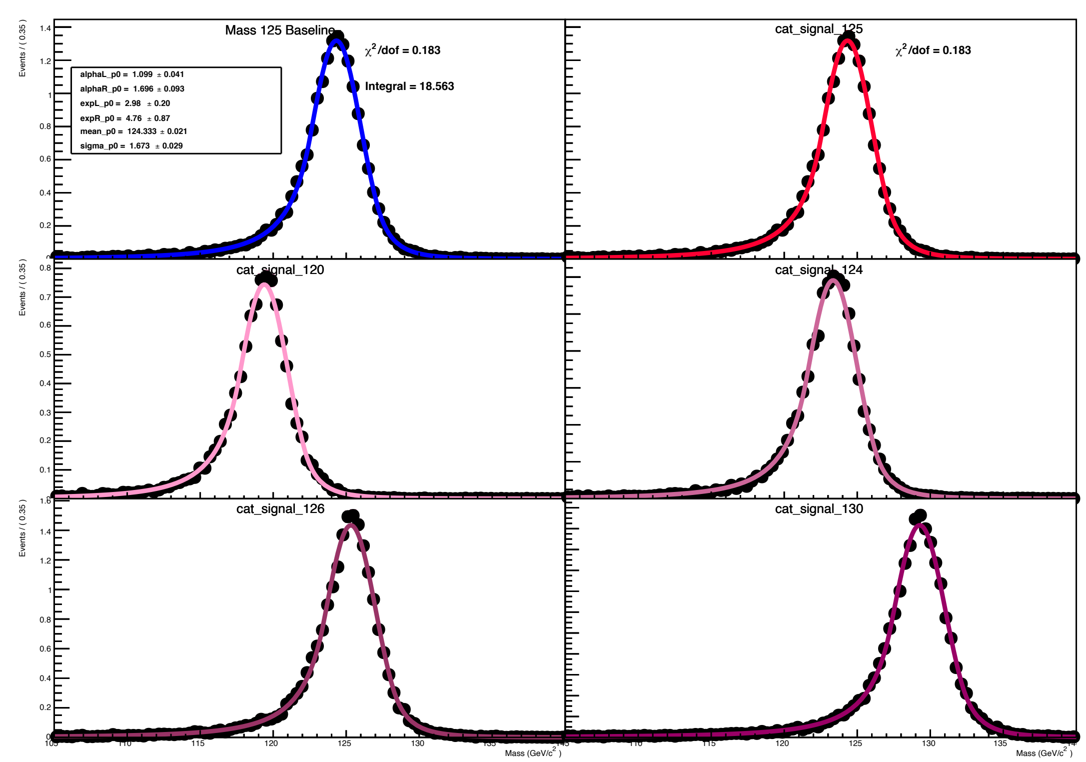


4e



2mu2e





2e2mu

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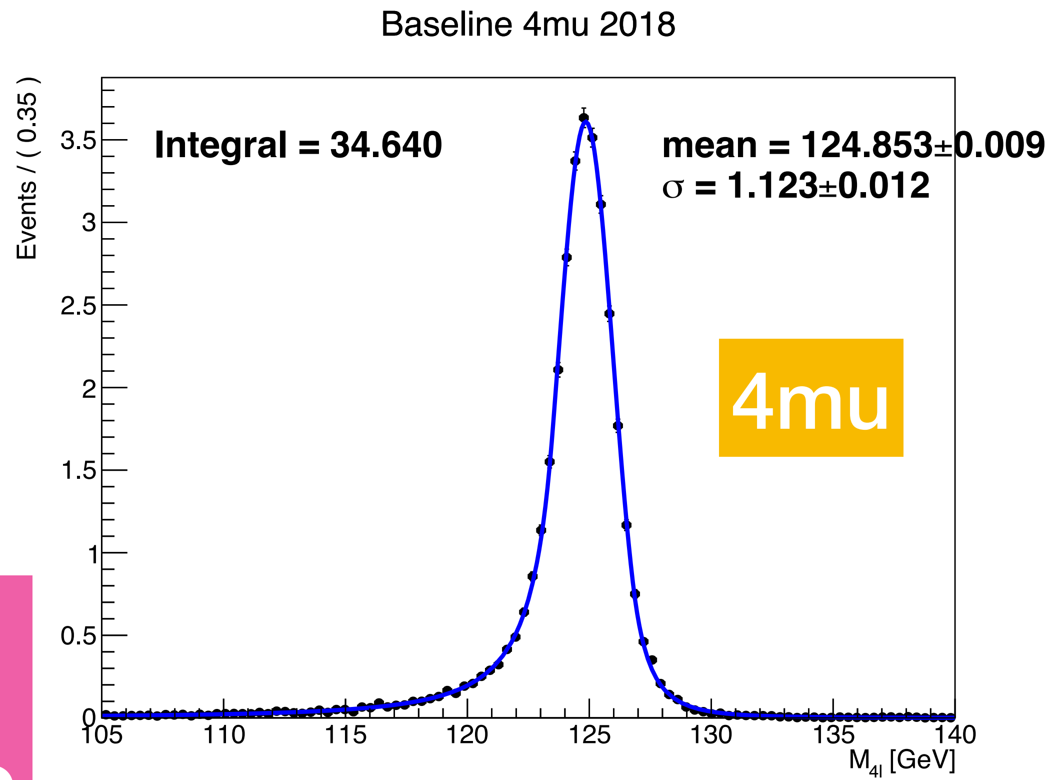
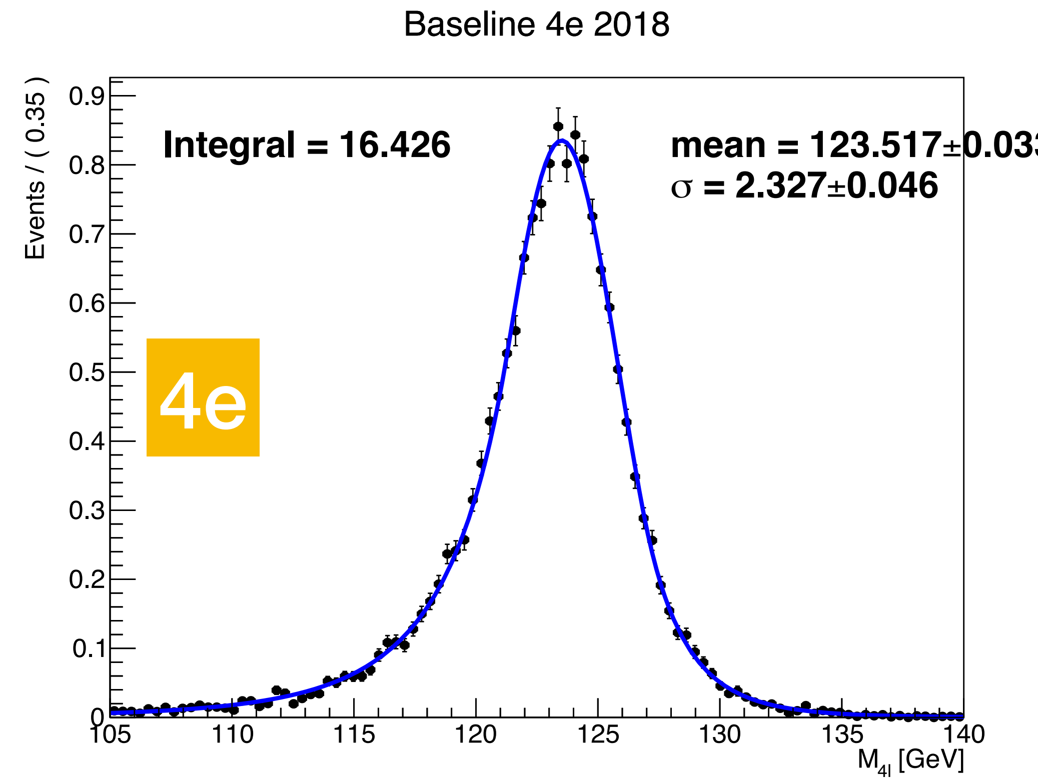
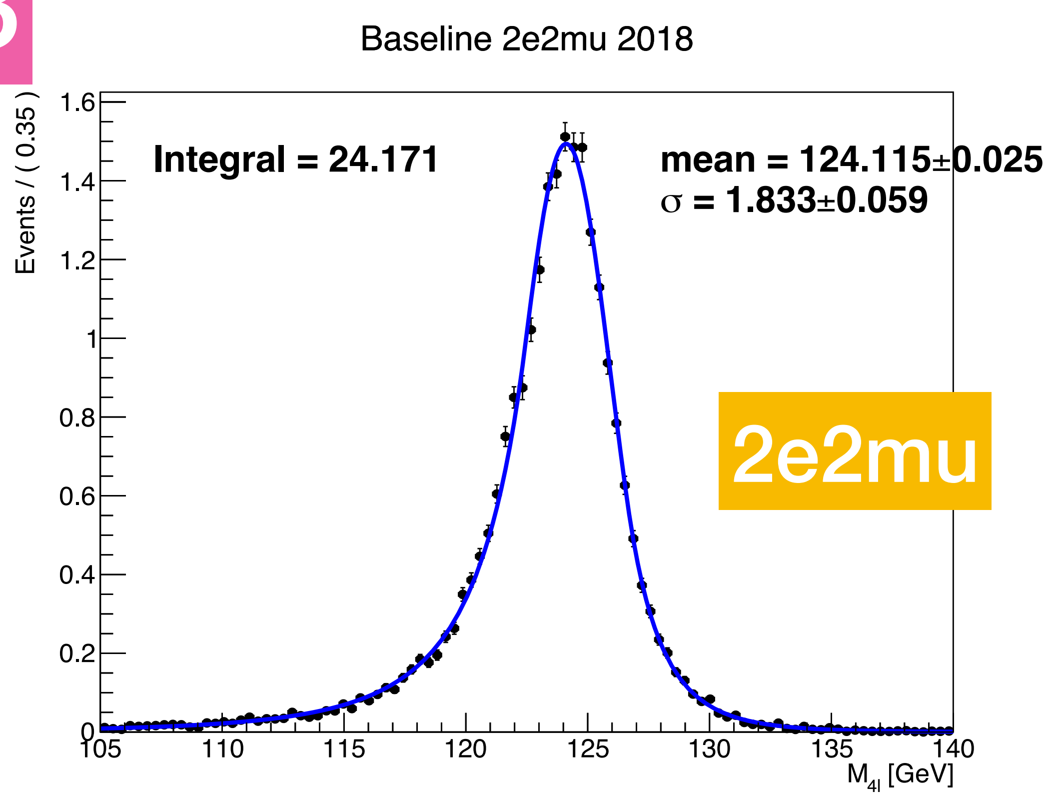
CMS

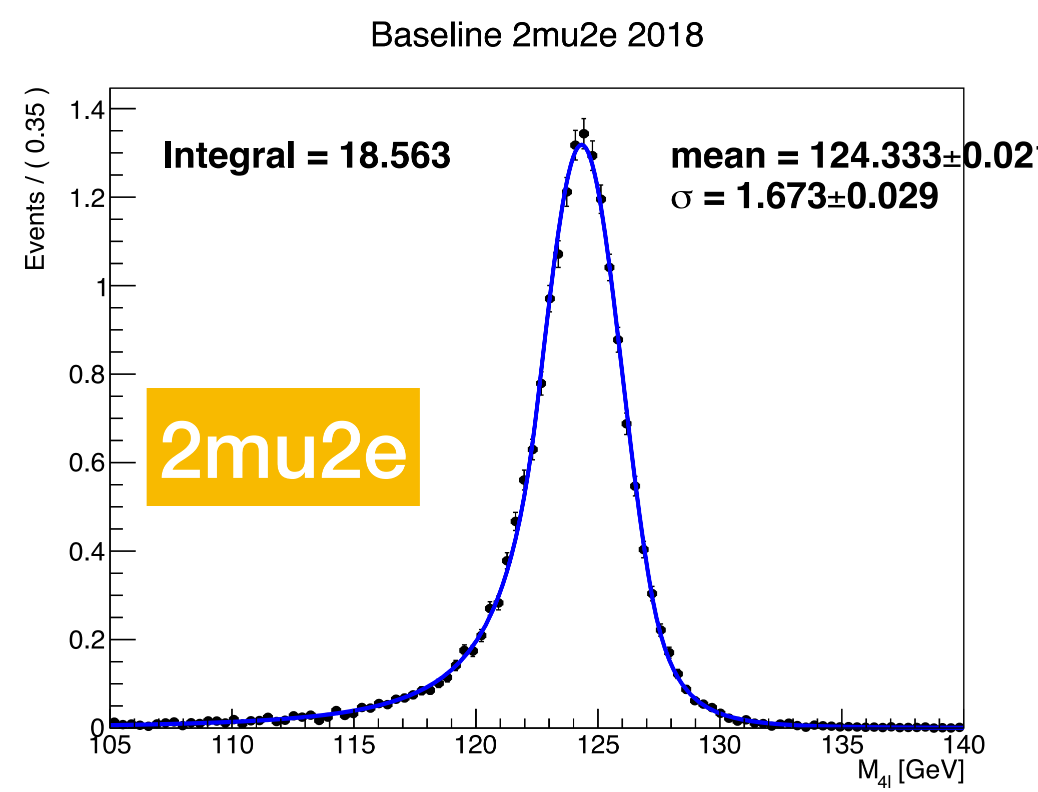
Signal parametrisation

ggH
2018









Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121

VX+BS approach for muon

In the **VX+BS** approach, the system of 4 (2) **muons** is constrained to the beam spot, profits from KalmanVertexFitter (already implemented in CMSSW) and is available at miniAOD level.

This method received **green light from Muon POG** [*].

This method improves Higgs boson mass resolution by roughly 5-7% (depending on the year) in the 4mu final state.

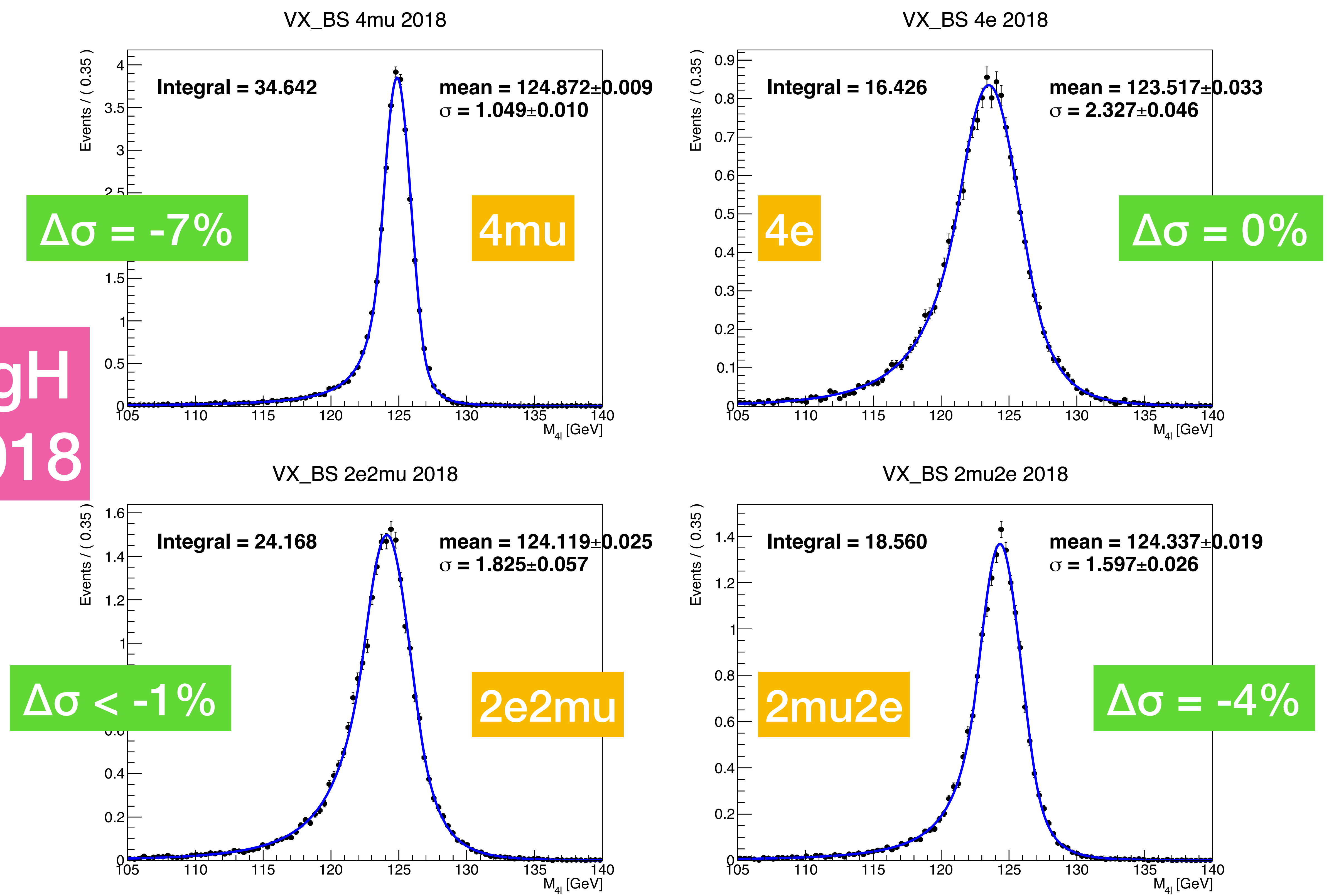
Smaller impact (<5%) in 2e2mu and 2mu2e final state (only muons are constrained).

No impact in 4e final state.

* previous slide

VX+BS approach

ggH
2018



Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
					-4%

EBE correction

Mass uncertainty was one of the variables used to build the maximum likelihood used to extract the Higgs boson mass

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 pT errors enter 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

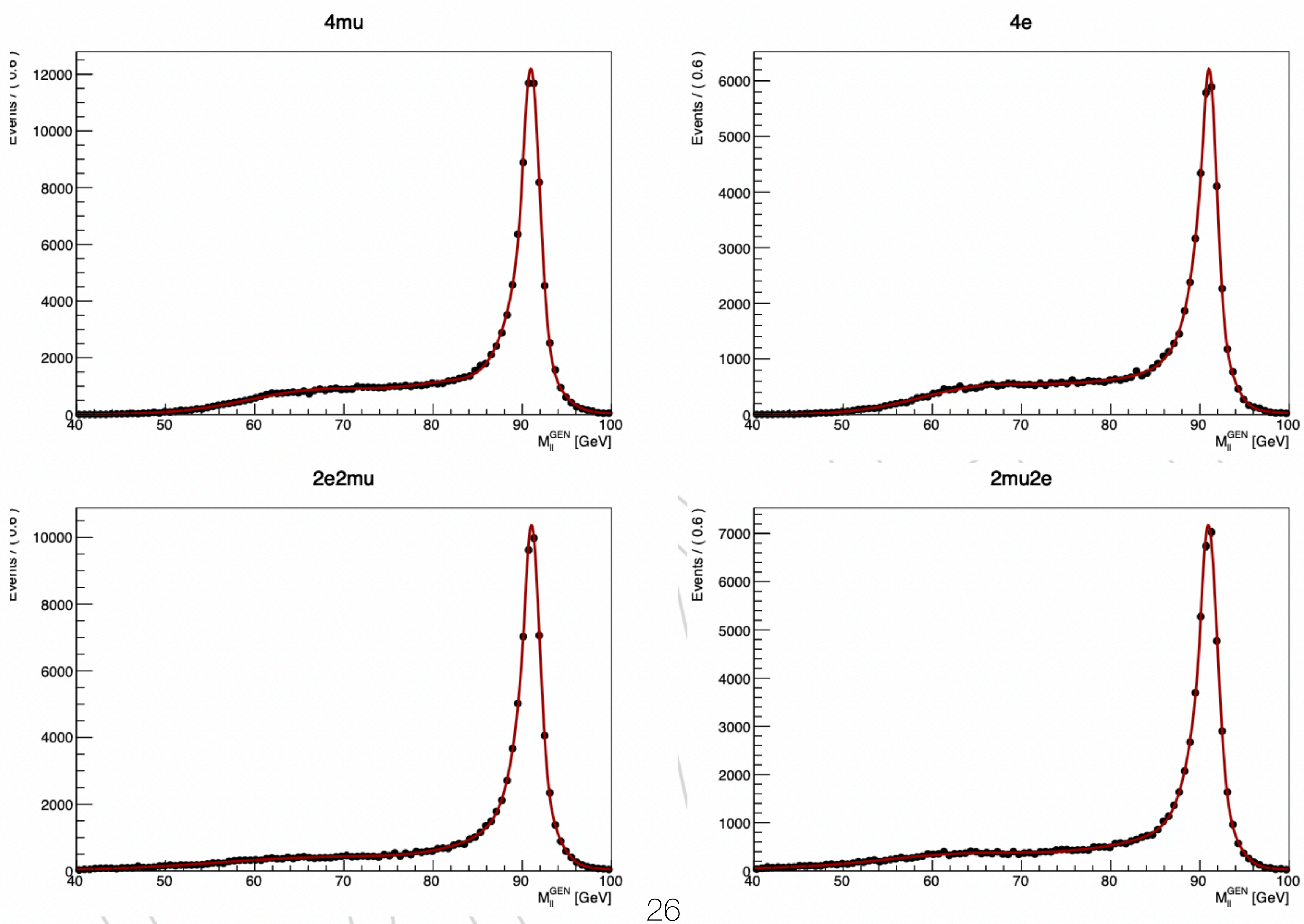
Lepton pT uncertainty is evaluated in different steps:

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 (backup).**

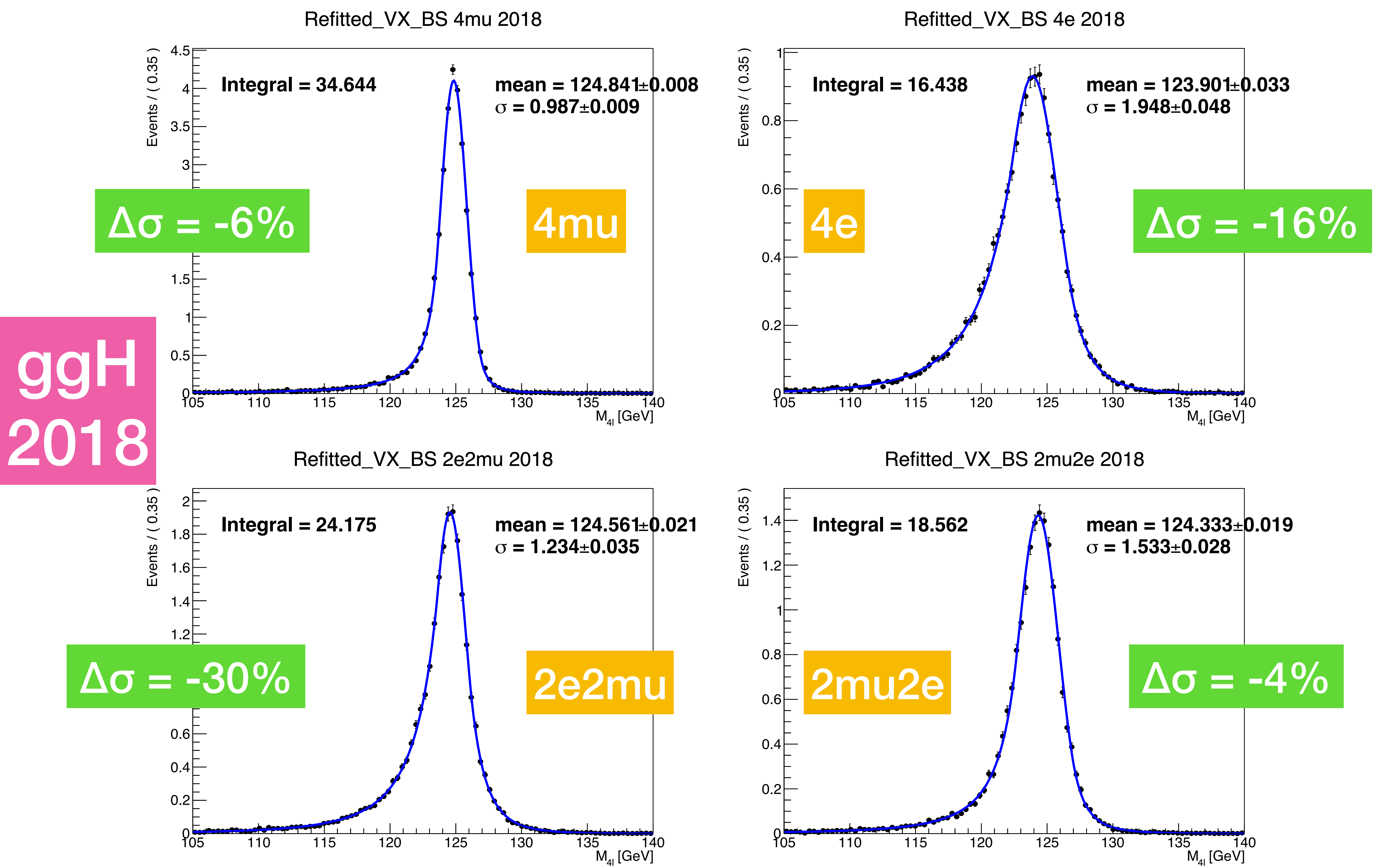
This approach helps to better describe the mass error.

on-shell Z constraint

In order to improve the mass resolution, a kinematic fit is also performed using a mass constraint on the intermediate mostly on-shell Z1 resonance. The basic idea is to re-evaluate the p_T of two leptons forming the Z1 boson of the Higgs candidate, with a constraint on the reconstructed Z mass to follow the Z boson true line shape.



Momentum improvement



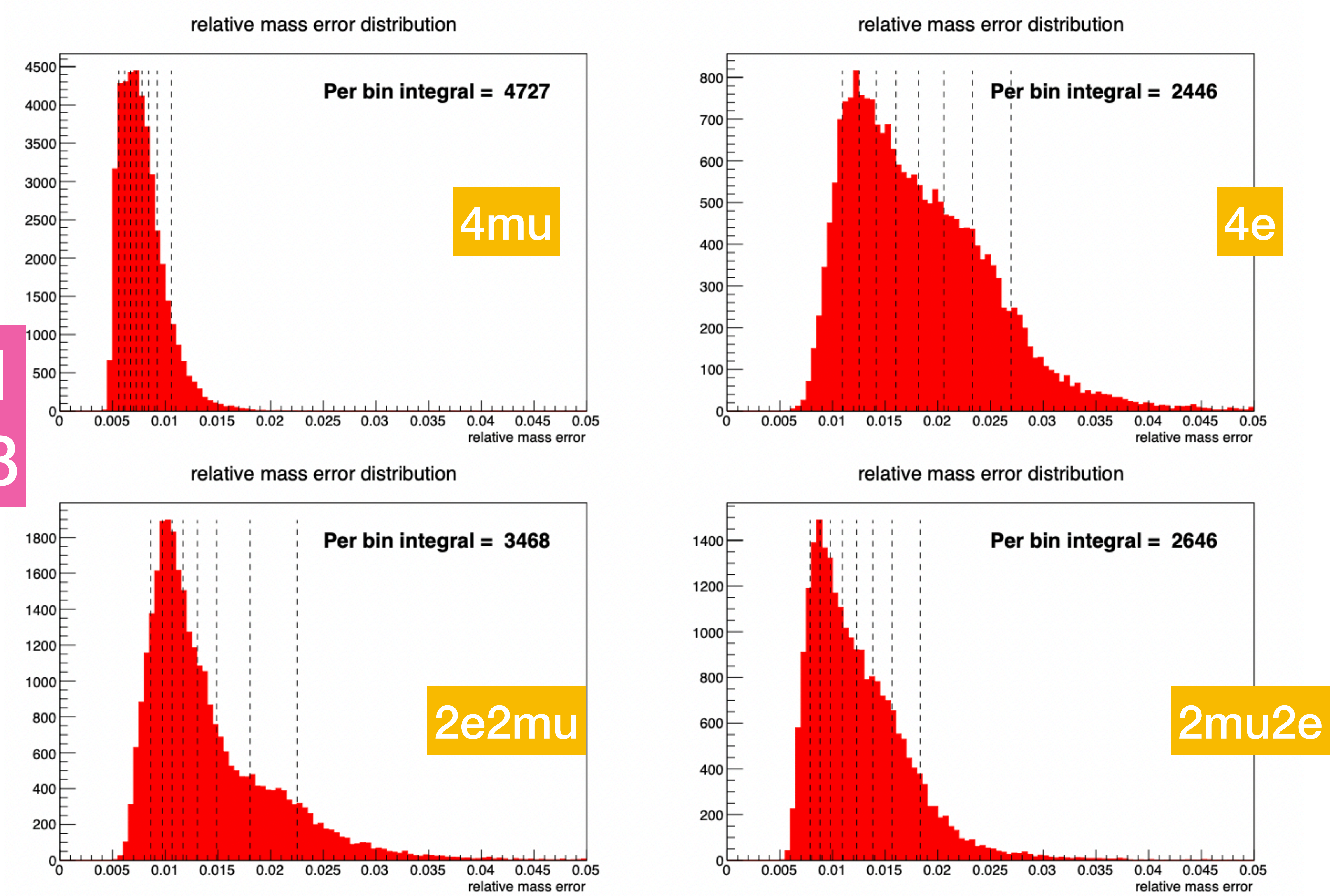
$$\mathscr{L}(p_T^1, p_T^2 | p_T^{reco1}, \sigma p_T^1, p_T^{reco2}, \sigma p_T^2) = Gauss(p_T^{reco1} | p_T^1, \sigma p_T^1) \cdot Gauss(p_T^{reco2} | p_T^2, \sigma p_T^2) \cdot \mathscr{L}(m_{12} | m_Z, m_H)$$

Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
1D+VXBS+Z1	134	424	250	279	105
					-9%

Categorisation

ggH
2018



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Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
1D+VXBS+Z1	134	424	250	279	105
1D+VXBS+Z1+ 9categs	128	371	227	253	98
					-7%

Exp mass measurement uncert (MeV)

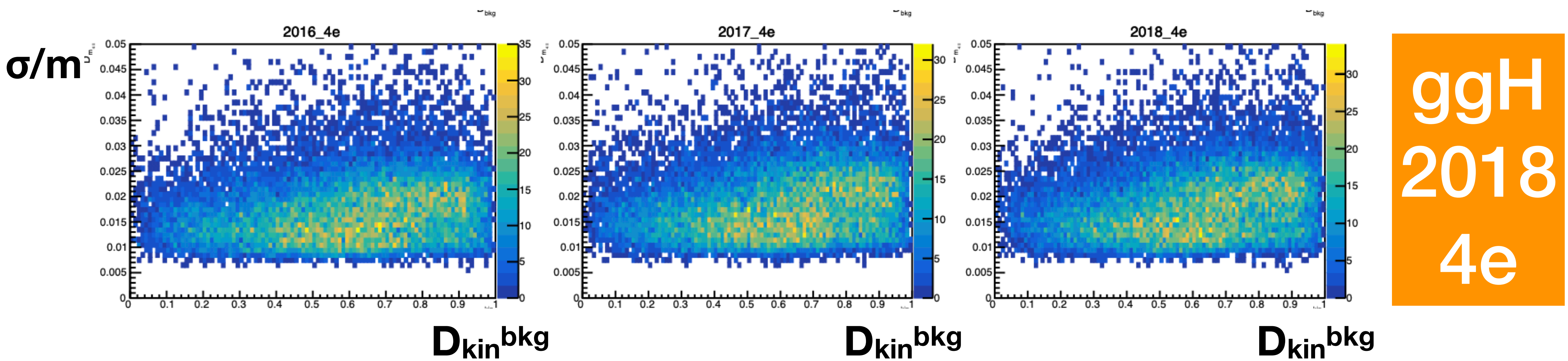
Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
1D+VXBS+Z1	134	424	250	279	105
1D+VXBS+Z1+ 9categs	128	371	227	253	98
1D+VXBS+Z1+ 9categs+Bkg	148	465	276	310	116
					+18%

Kinematic discriminant

The Higgs boson mass measurement was performed using a 3D (m_H, σ_m, D^{kin}_{bkg}) likelihood where correlation was not assumed between last two variables.

It has been shown that this assumption is not really true (*).

Thanks to the categorisation, this correlation is implicitly built-in.



*previous slide

Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
1D+VXBS+Z1	134	424	250	279	105
1D+VXBS+Z1+ 9categs	128	371	227	253	98
1D+VXBS+Z1+ 9categs+Bkg	148	465	276	310	116
2D+VXBS+Z1+ 9categs+Bkg	143	440	266	300	112

-3%

Exp mass measurement uncert (MeV)

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	153	466	315	300	121
1D+VXBS	144	466	313	291	116
1D+VXBS+Z1	134	424	250	279	105
1D+VXBS+Z1+9categs	128	371	227	253	98
1D+VXBS+Z1+9categs+Bkg	148	465	276	310	116
2D+VXBS+Z1+9categs+Bkg	143	440	266	300	112
2D+VXBS+Z1+9categs+Bkg+Syst	154	582	327	354	135

+20%

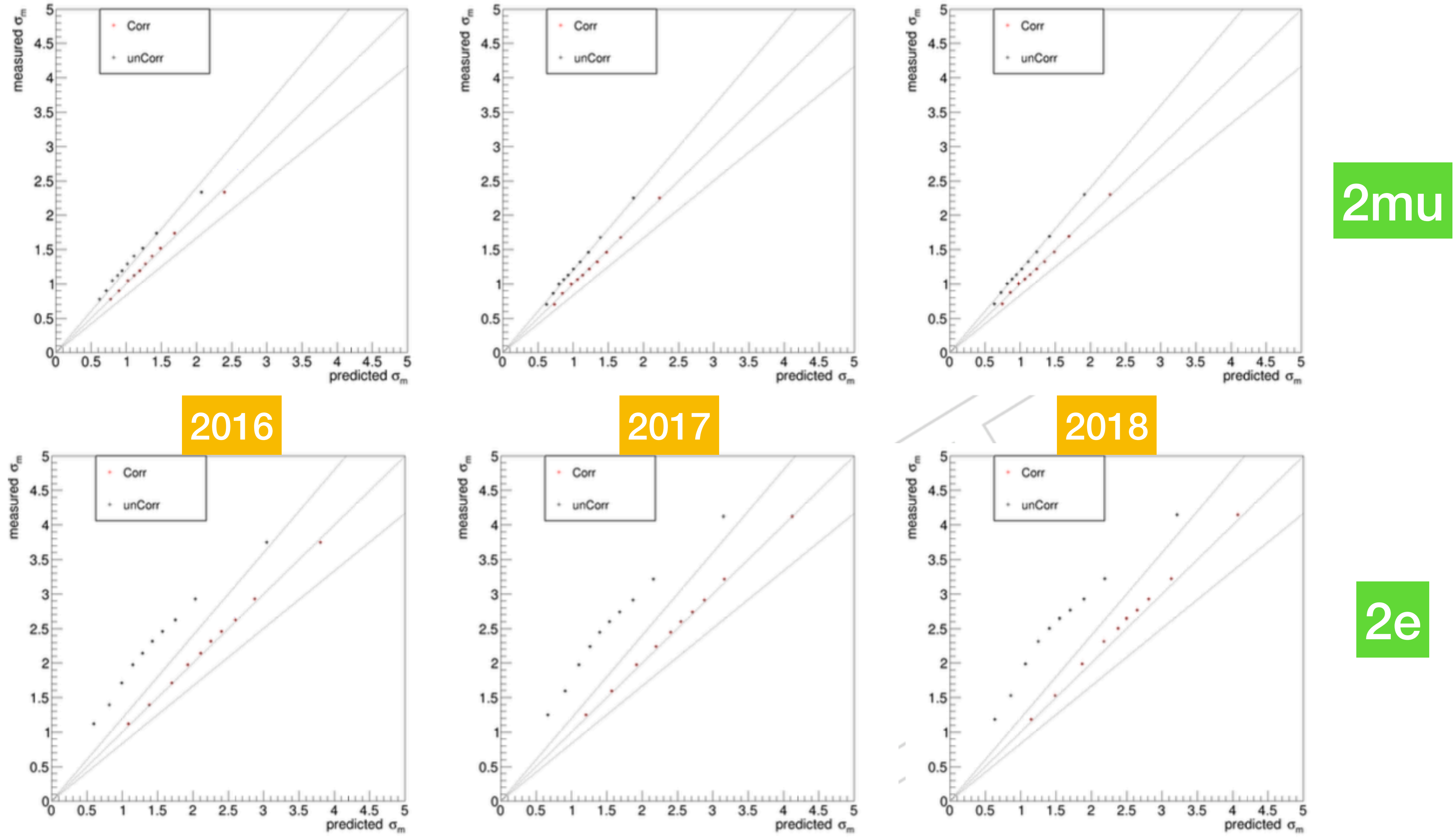
About UL

DY (Summer19 all years) and ggH 2018 (Summer20) samples have been already used for

- muon momentum scale studies —> indeed upcoming presentation will use UL samples (Data and DY)

- VX+BS first check (for green light)

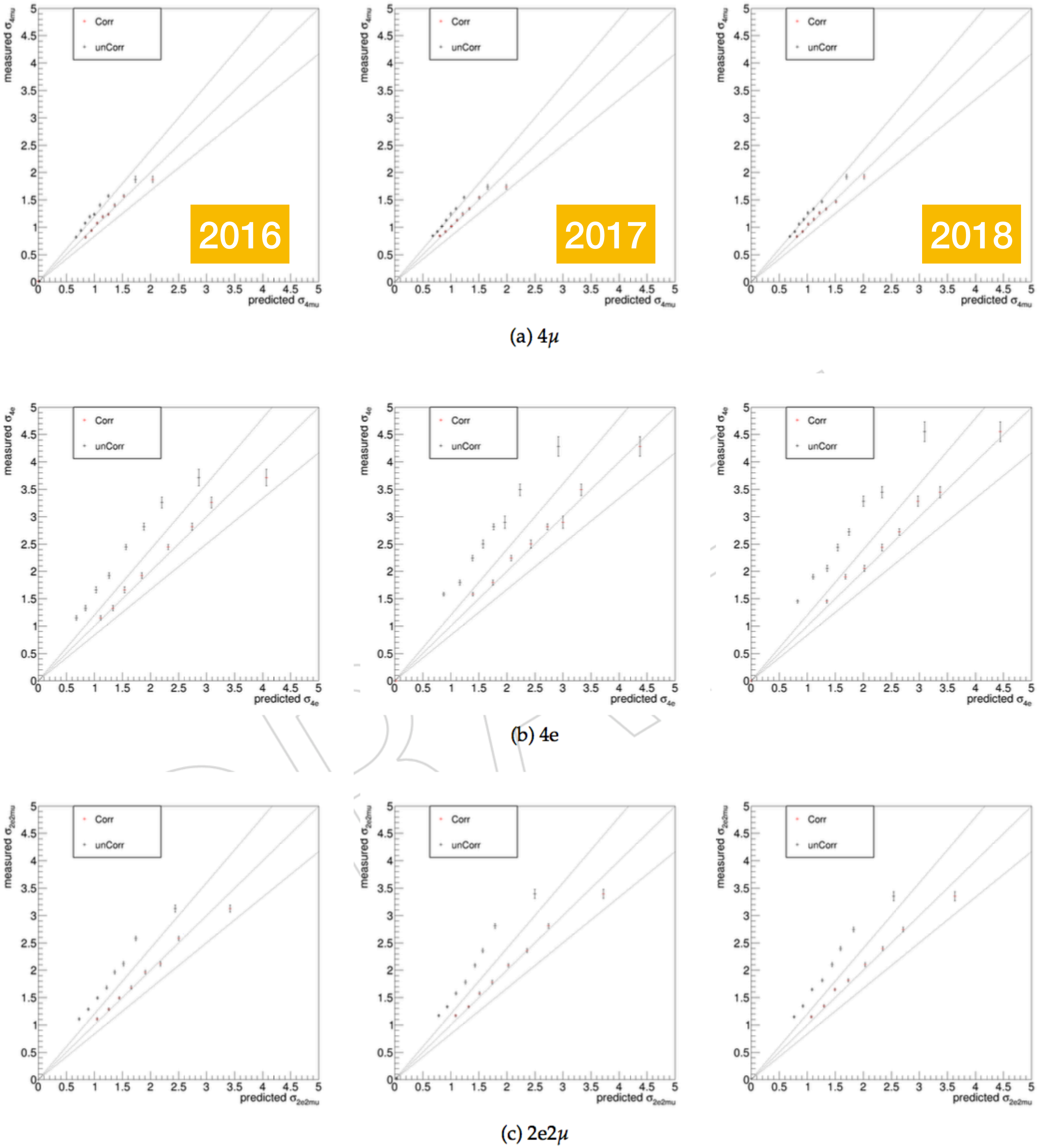
EBE: Z closure test



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%).

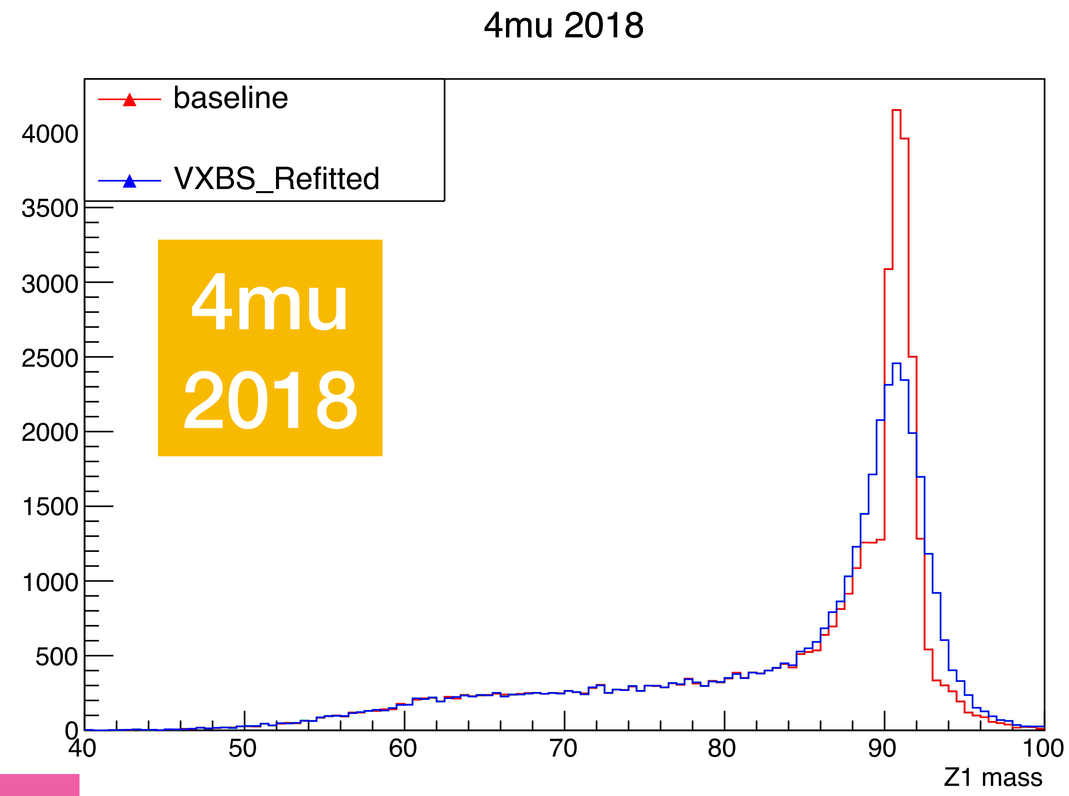
[the dashed lines stands for the 20% uncertainty assigned to the resolution in 2016]

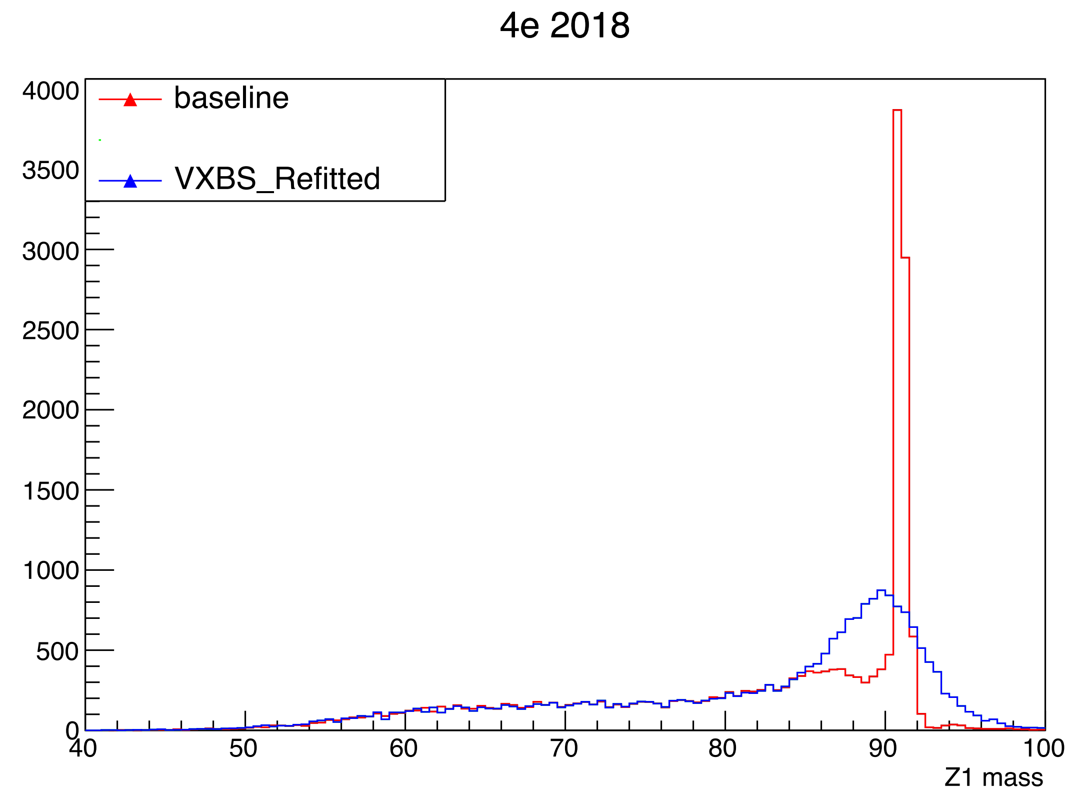
EBE: H closure test



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.

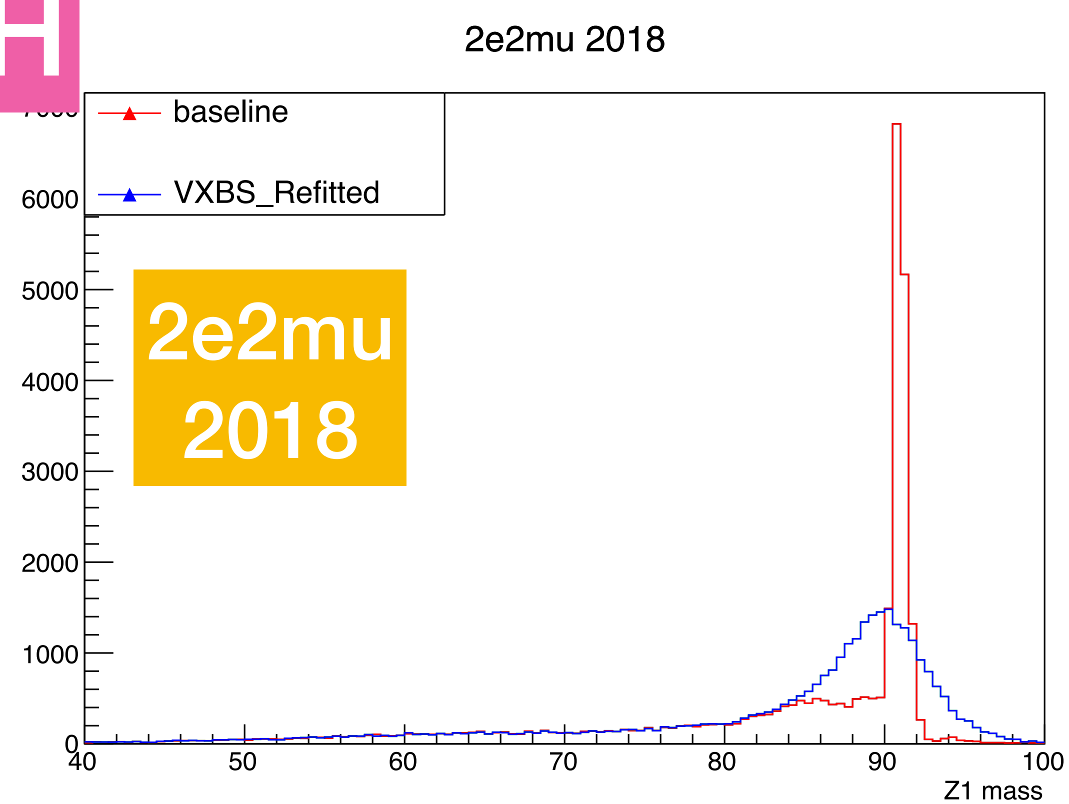
on-shell Z constraint

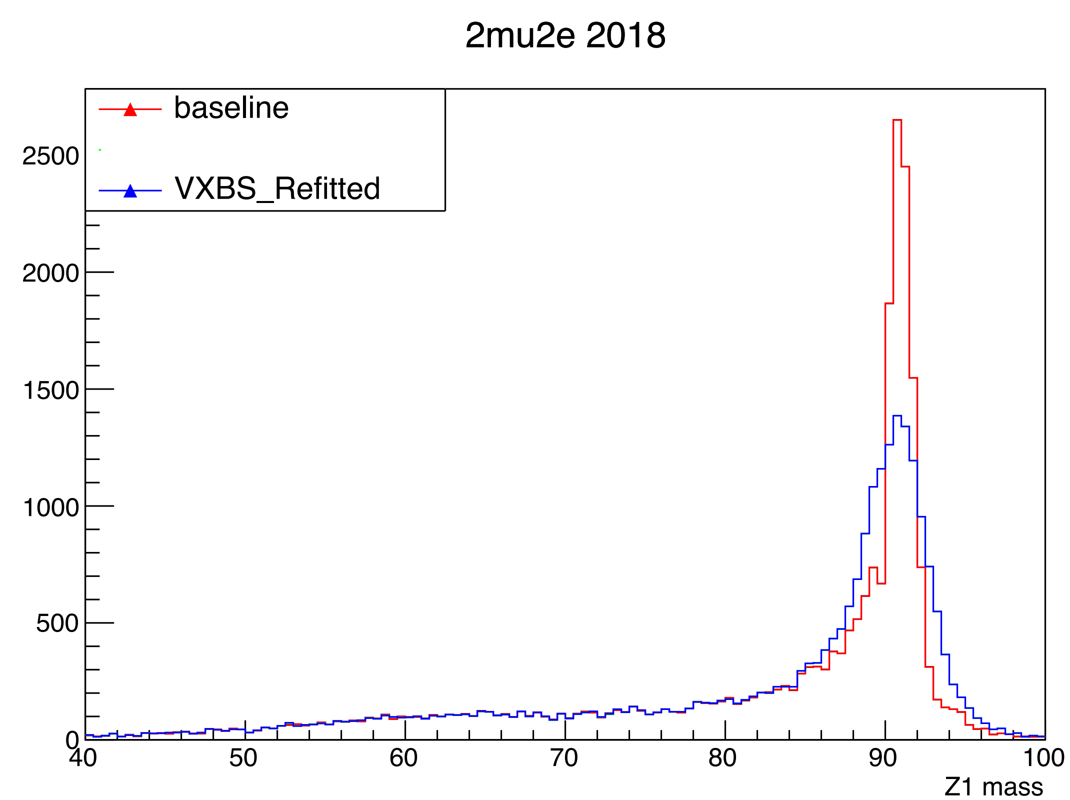




4e
2018

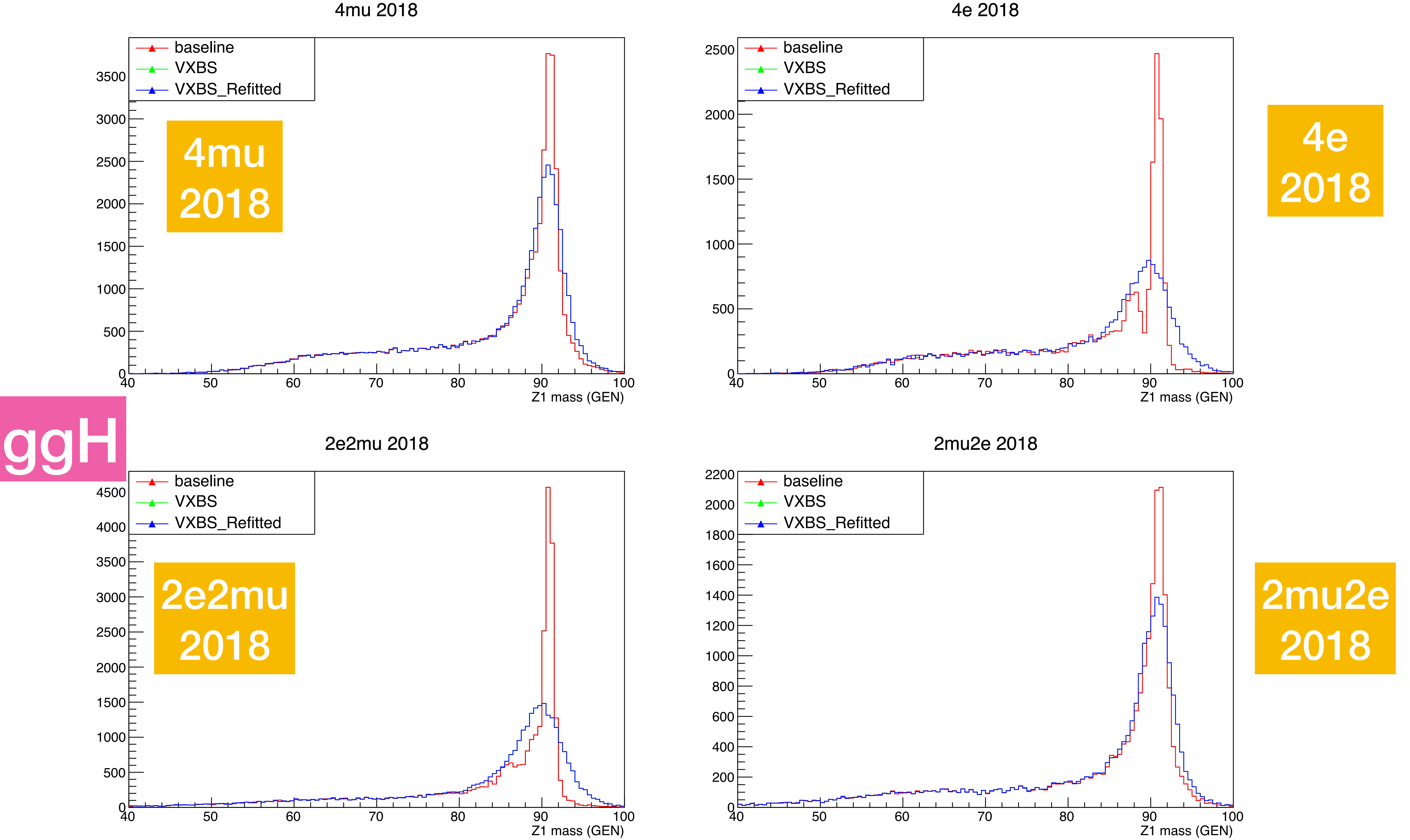
ggH



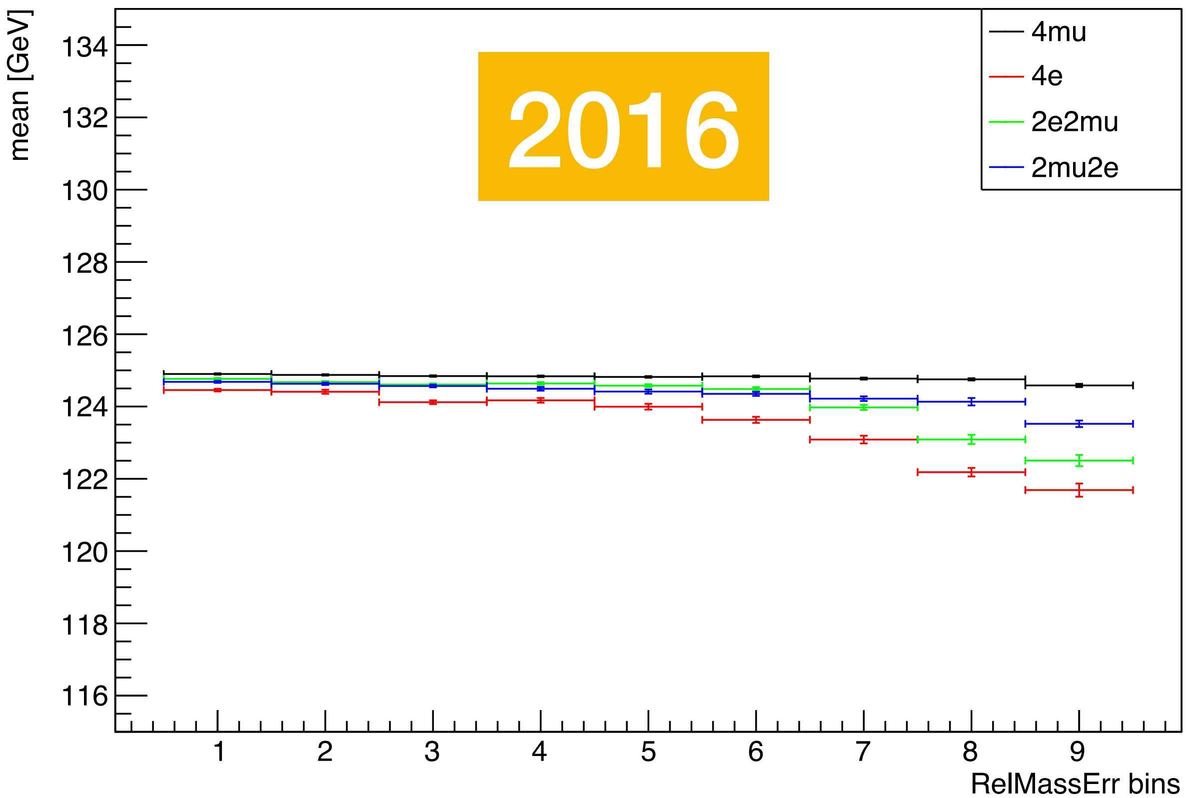


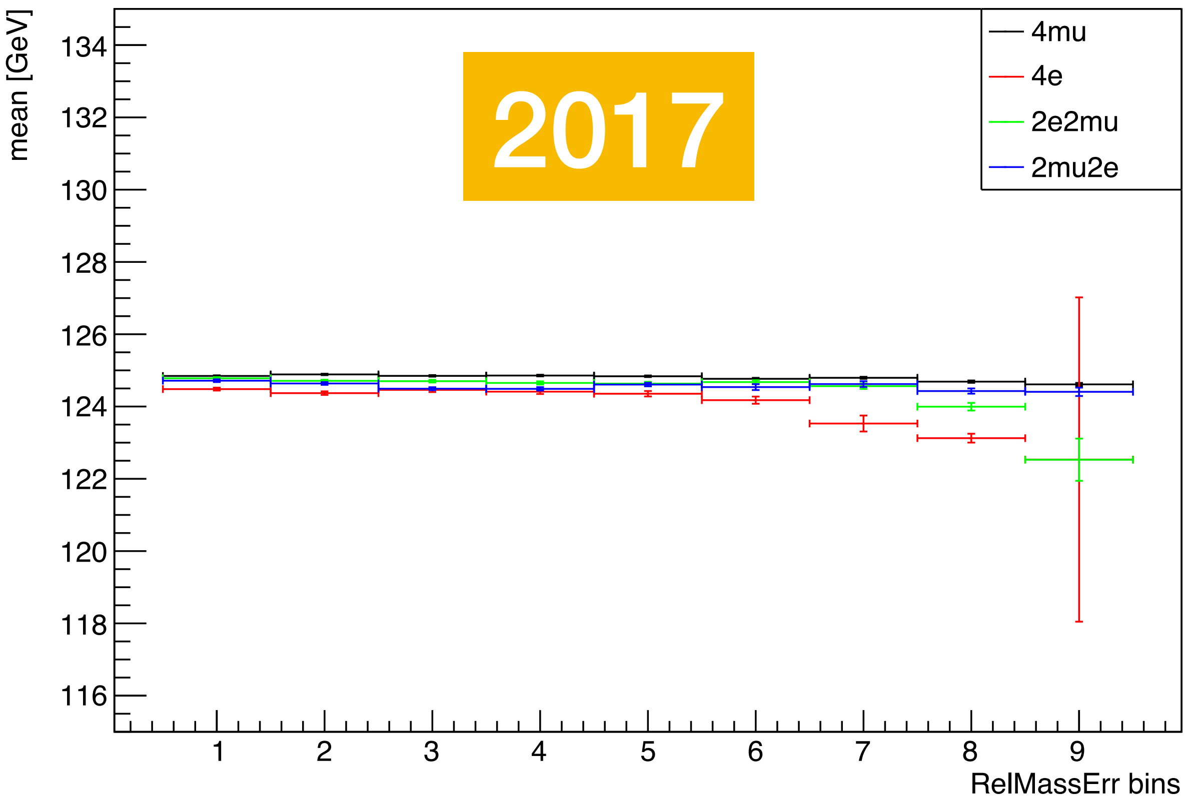
2mu2e
2018

OLD on-shell Z constraint



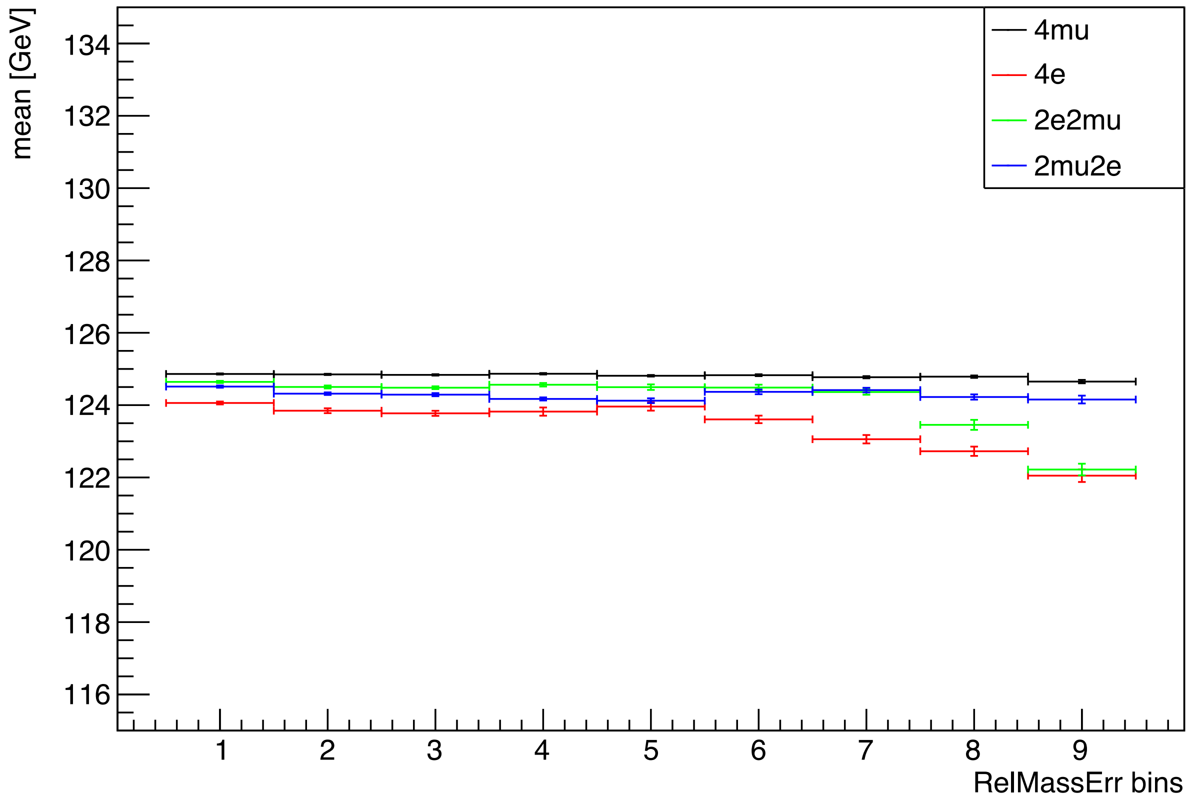
Categorisation



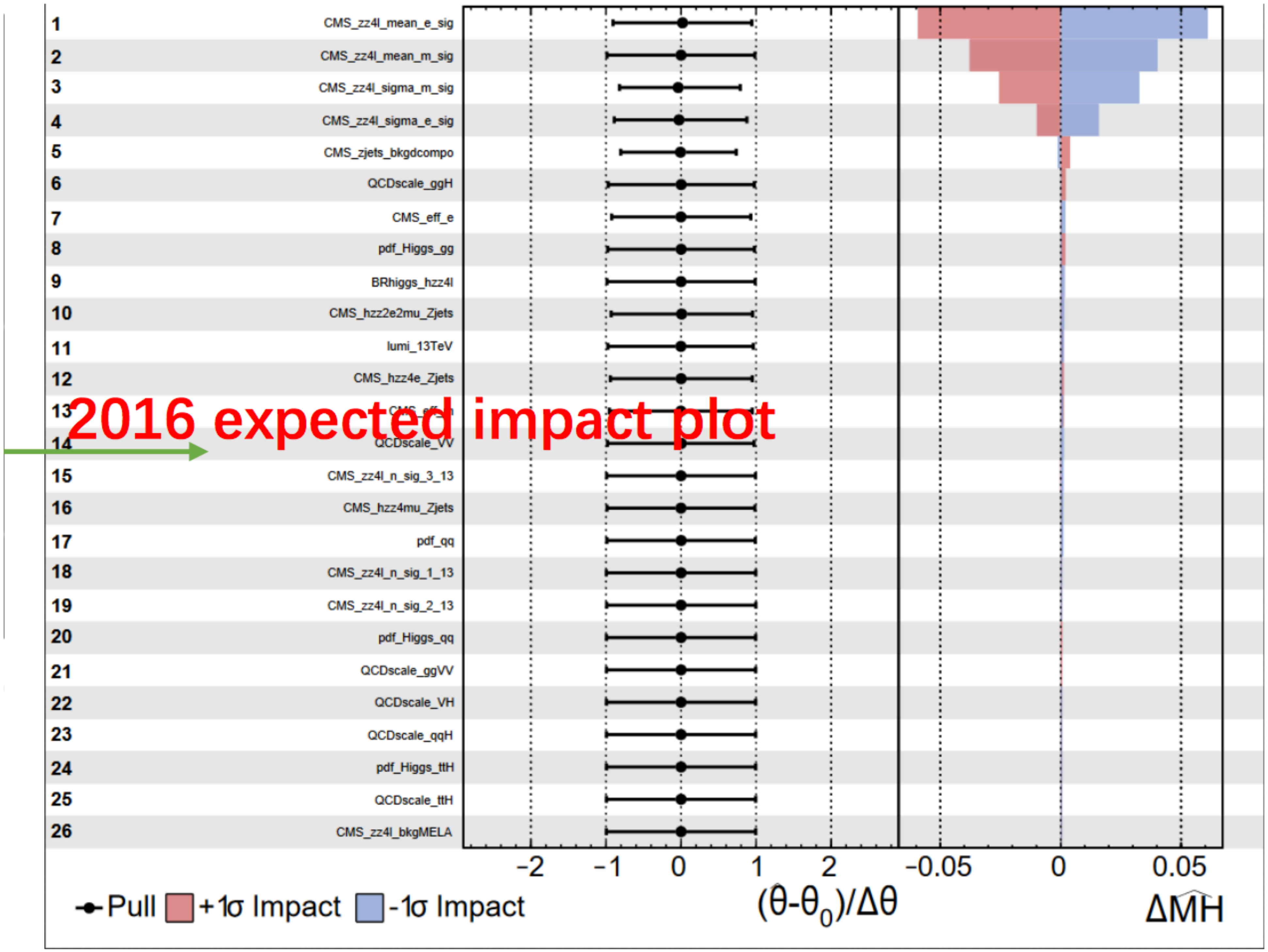


ggH

2018

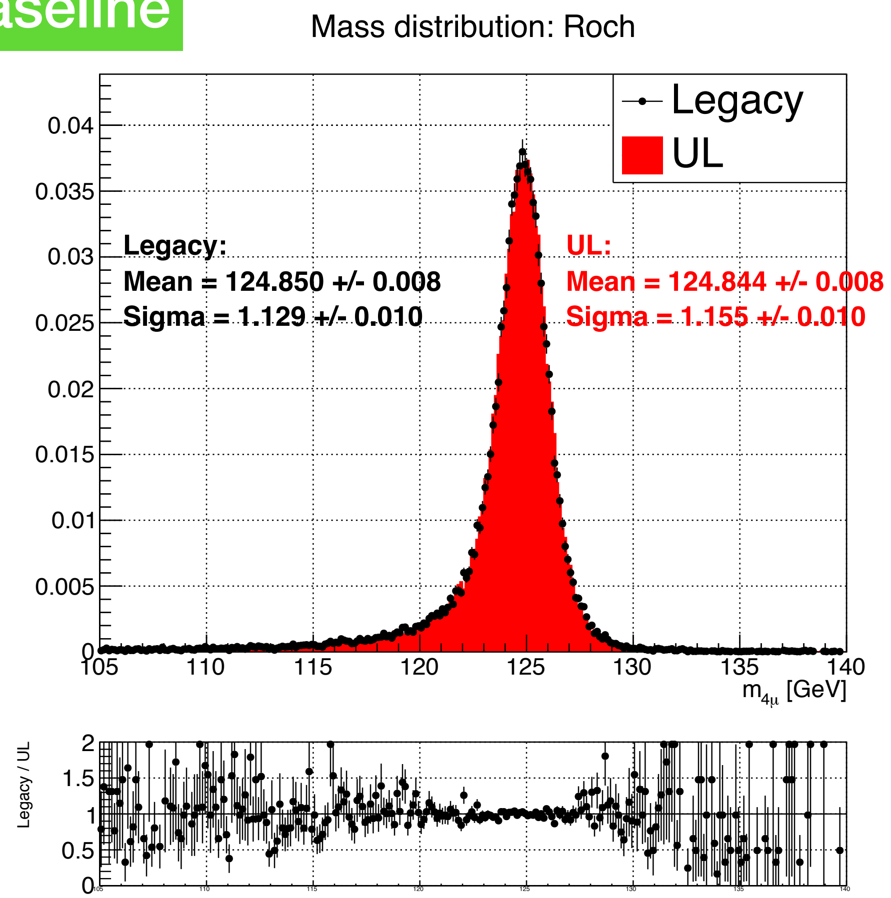


2016 impact plot



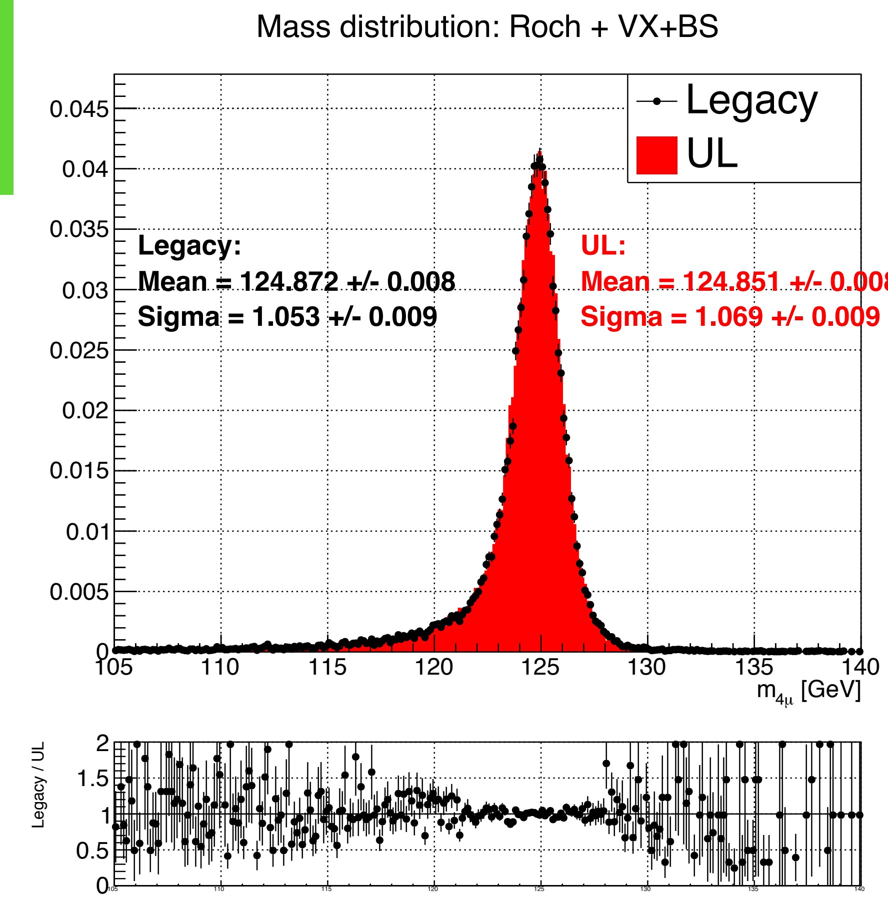
About UL

Baseline



ggH 2018 4mu

Baseline + VX+BS



2016

Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	303	880	590	569	234
1D+VXBS	290	880	586	558	227
1D+VXBS+Z1	268	810	477	533	206
1D+VXBS+Z1 + 9 categs	255	704	433	487	192
1D+VXBS+Z1 + 9 categs + BKG	298	895	532	596	229
2D+VXBS+Z1 + 9 categs + BKG	289	844	511	575	221
2D+VXBS+Z1 + 9 categs + BKG +systt	298	929	547	608	241

2017

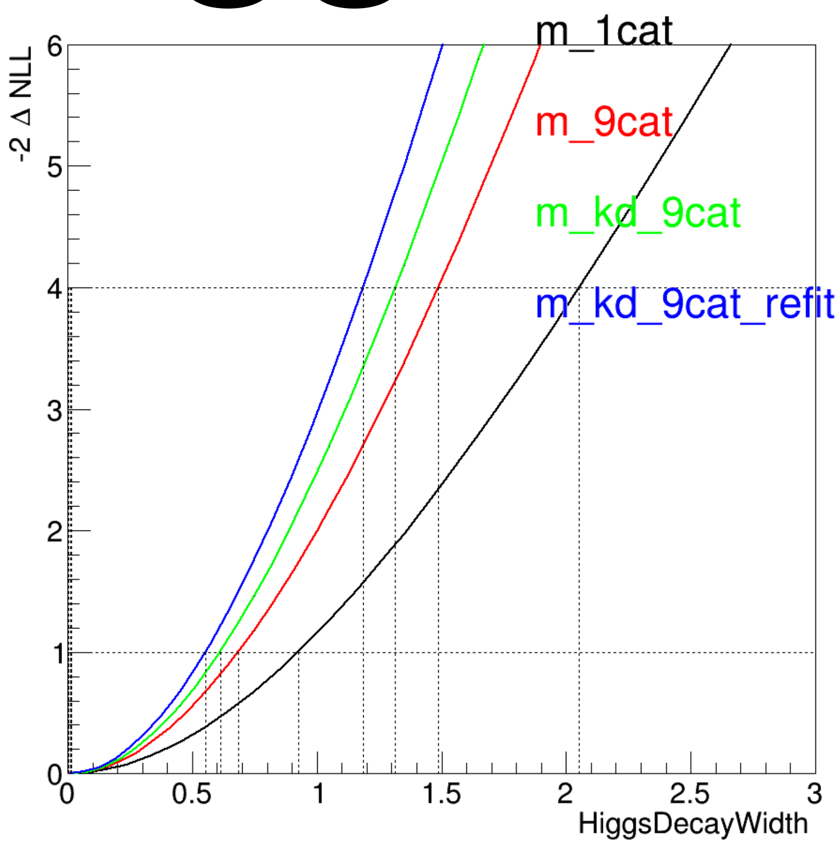
Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	279	877	592	544	222
1D+VXBS	264	877	588	529	212
1D+VXBS+Z1	248	802	473	507	194
1D+VXBS+Z1 + 9 categs	234	687	425	461	180
1D+VXBS+Z1 + 9 categs + BKG	273	868	516	567	214
2D+VXBS+Z1 + 9 categs + BKG	265	820	495	544	206
2D+VXBS+Z1 + 9 categs + BKG +systt	273	906	531	578	226

2018

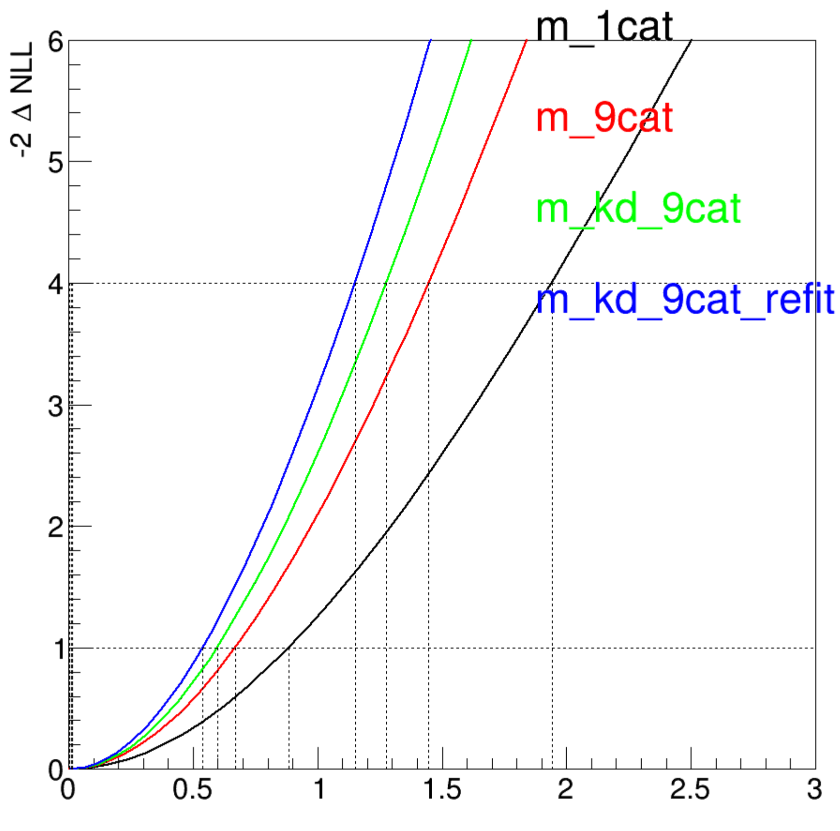
Full Run II Results (MeV)	4mu	4e	2e2mu	2mu2e	Inclusive
1D	229	706	480	466	182
1D+VXBS	213	706	477	448	173
1D+VXBS+Z1	199	642	378	431	157
1D+VXBS+Z1 + 9 categs	190	568	346	388	147
1D+VXBS+Z1 + 9 categs + BKG	217	713	416	475	172
2D+VXBS+Z1 + 9 categs + BKG	210	675	402	456	167
2D+VXBS+Z1 + 9 categs + BKG +systt	219	776	445	496	187

Higgs on-shell width

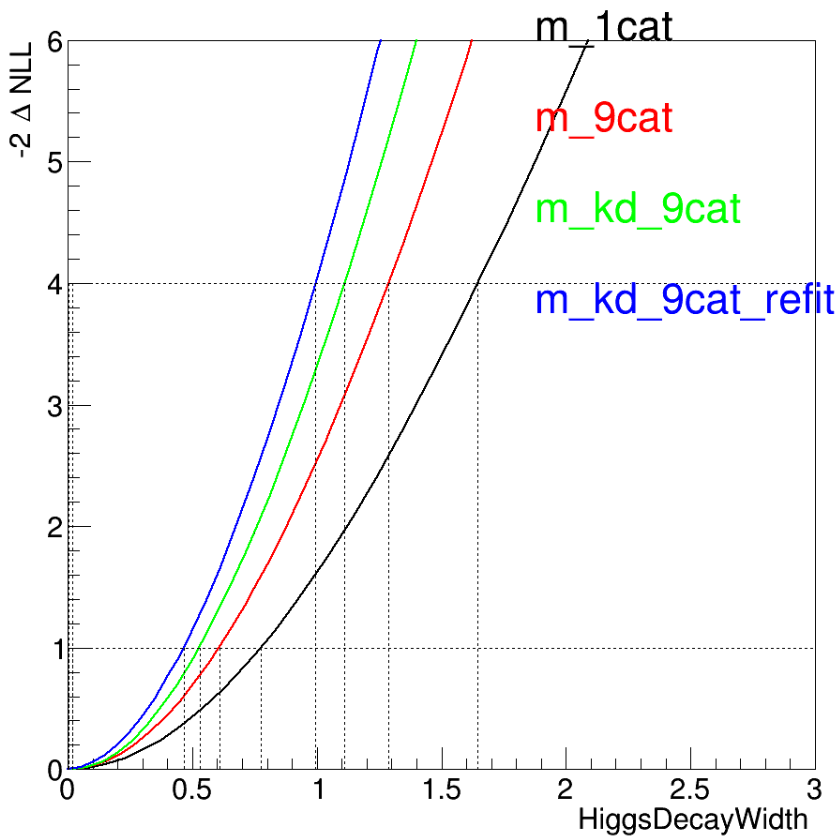
2016



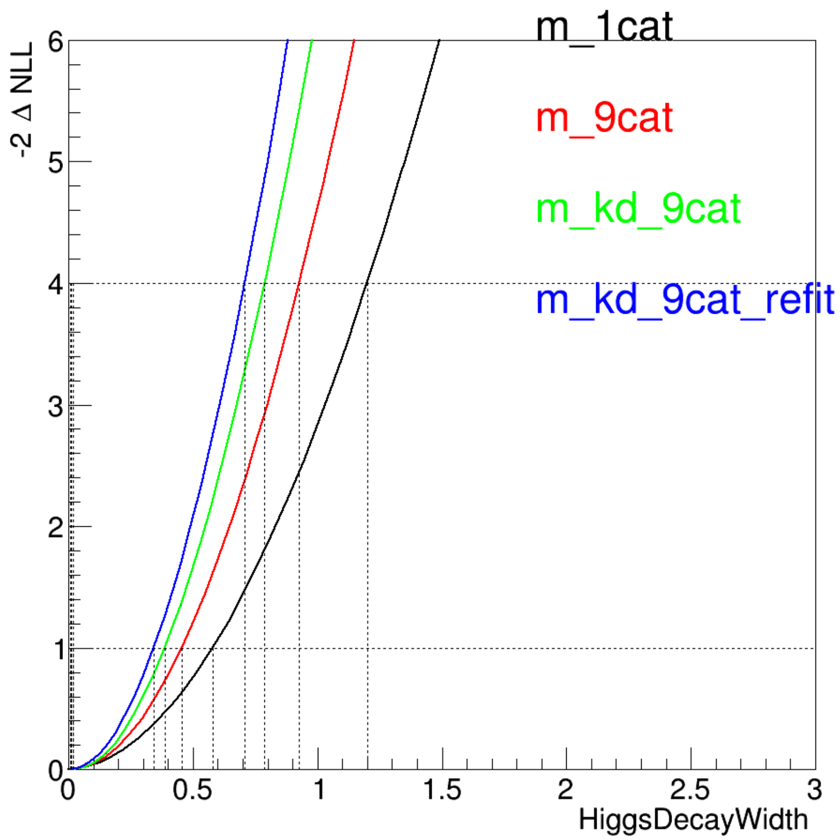
2017



2018



Full Run II



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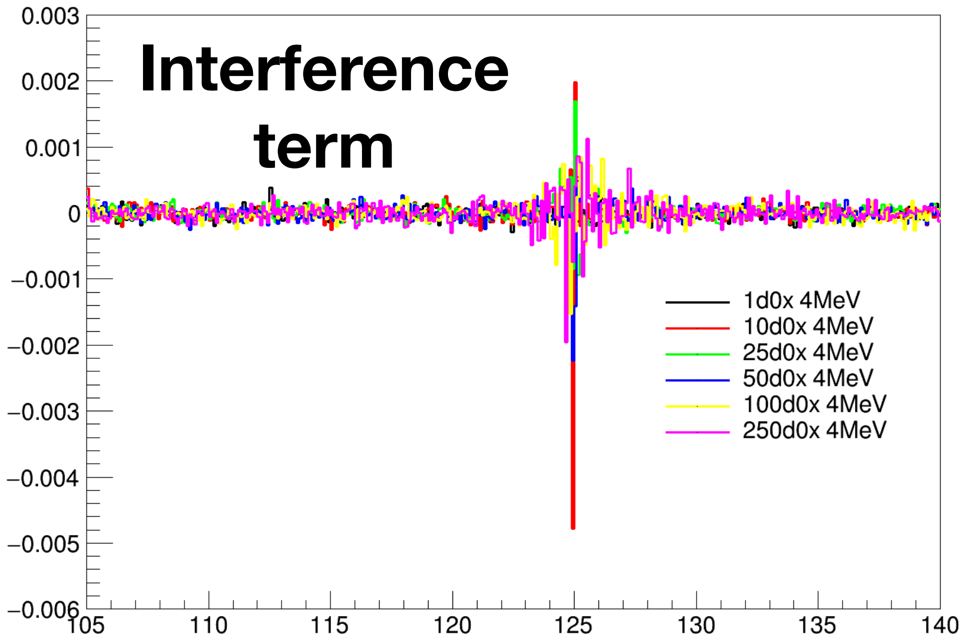
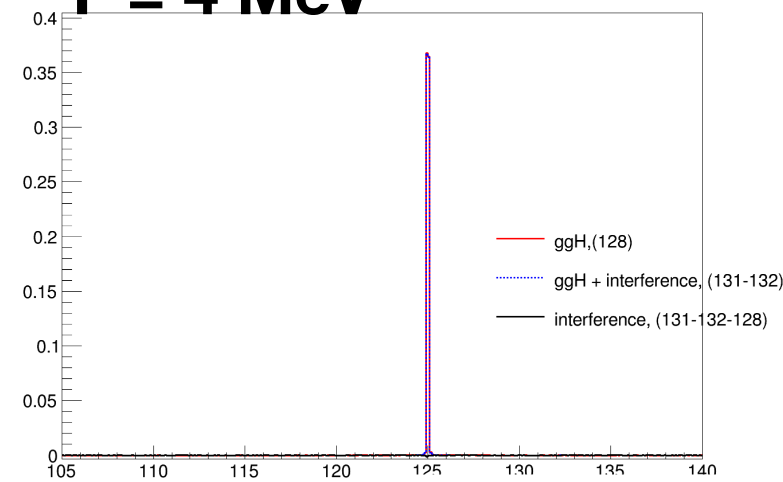
CMS

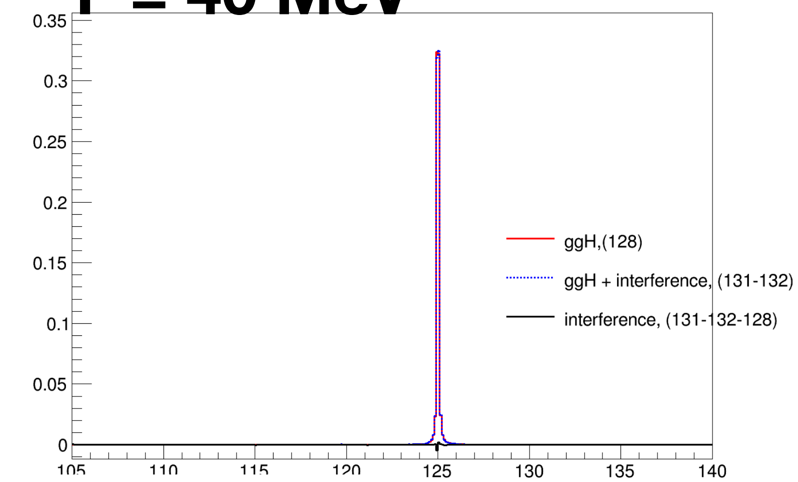
ggZZ Interference



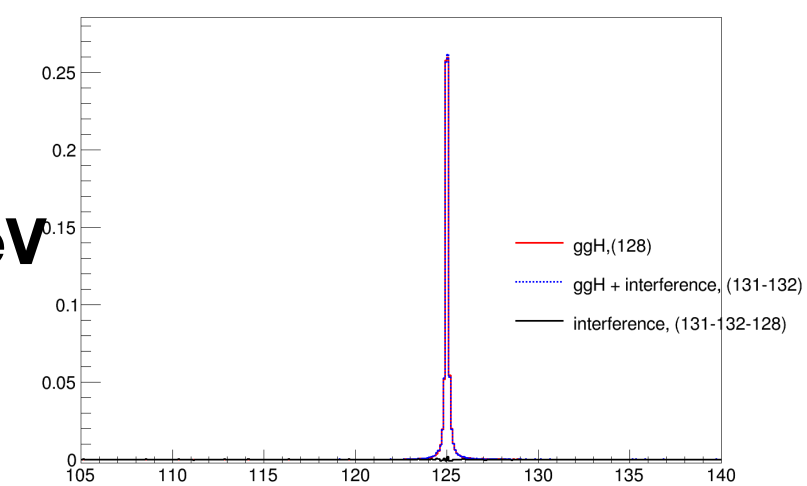
Γ = 4 MeV

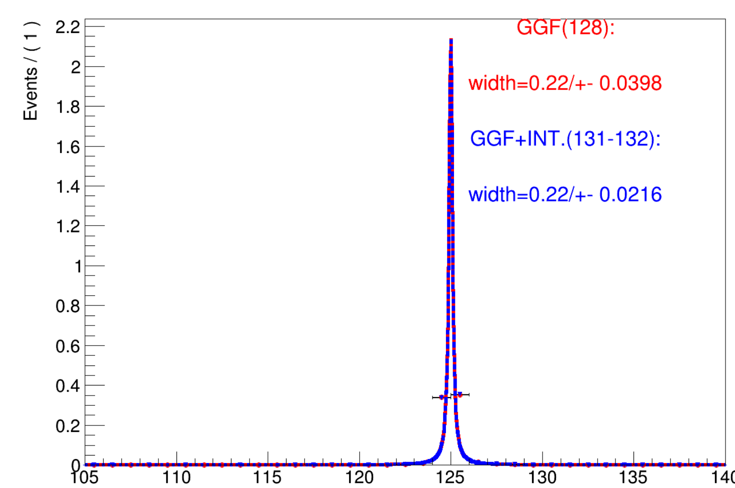


Γ = 40 MeV



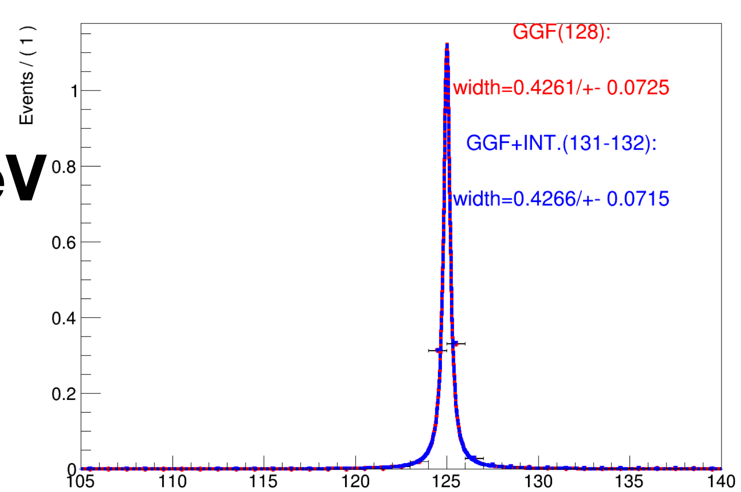
Γ = 100 MeV

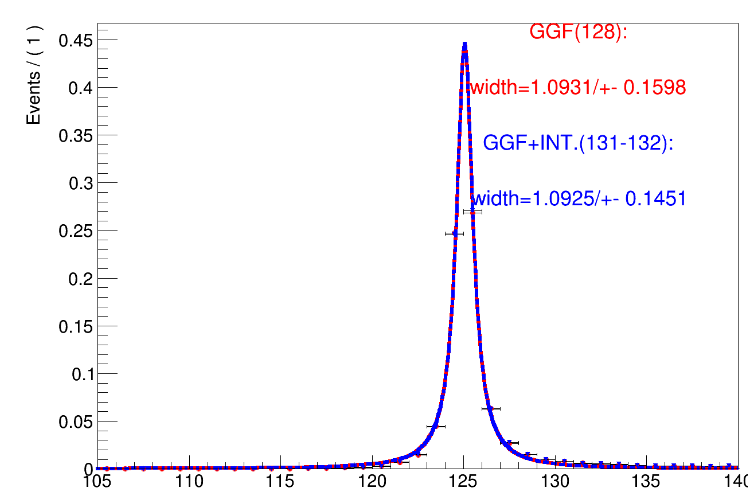




Γ = 200 MeV

Γ = 400 MeV





Γ = 1000 MeV

Higgs mass summary