(Summary)^2 of Moriond EW Interactions 2017

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DESY (Hamburg)

LHC Physics Discussion
DESY, Apr 10, 2017

Remember . . .

I'm just a poor theorist!

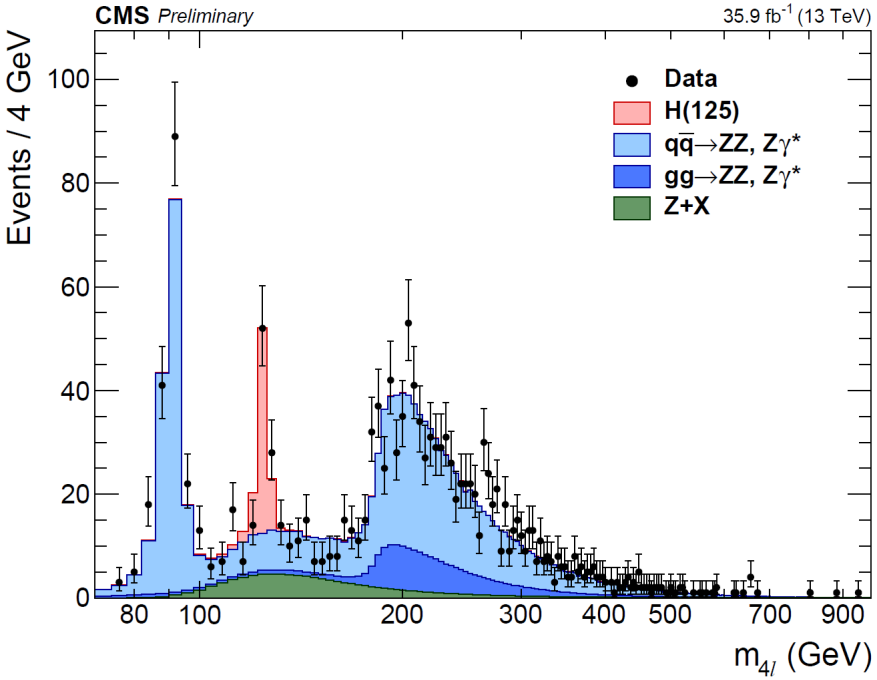
- I work on Higgs physics and on multi-loop calculations come say hi in 2a/308!
- I will present just a small selection mostly related to what I (should) understand better
- My talk mainly focuses on experimental results
- Heavy flavor was a hot topic . . . wait for Matthias' talk, and for LHCb results on Apr 18 @ CERN
- Many interesting presentations left out of this review check the slides!
- I shamelessly ripped off the original slides

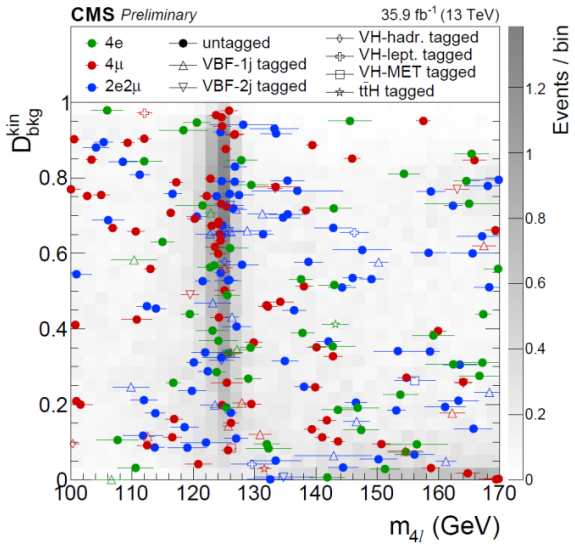
Outline

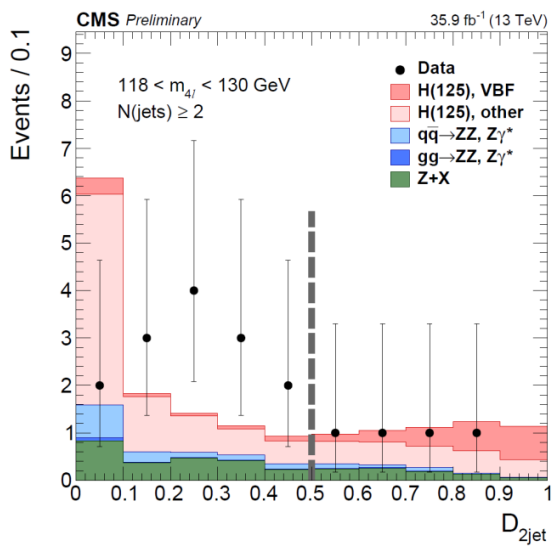
Outline

$h \to ZZ^* \to 4\ell$ by CMS: overview [talk by Oda, CMS-PAS-HIG-16-041]

- Probing 4 (ggH, VBF, VH, ttH) production modes with 7 event categories.
- Make kinematic discriminants using matrix elements with inputs of kinematic properties to reject background events and categorize signal events.

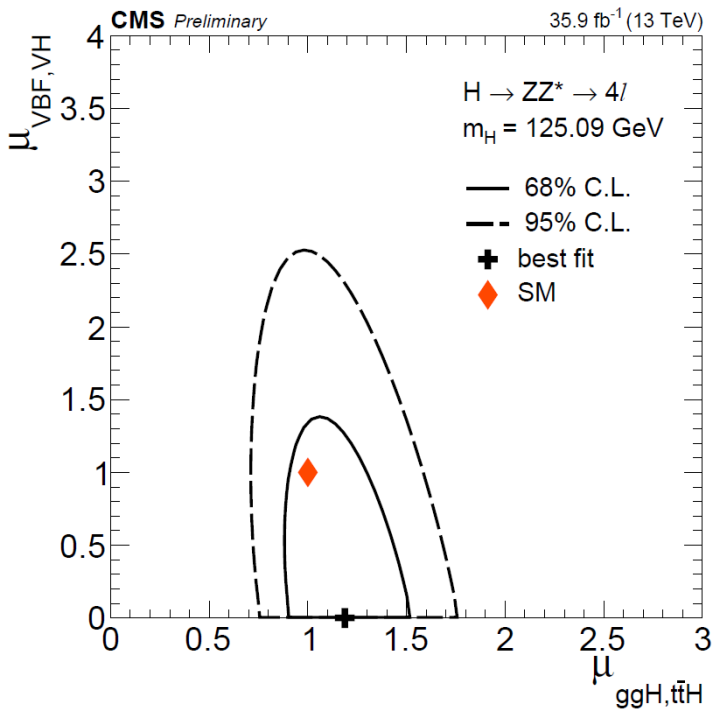


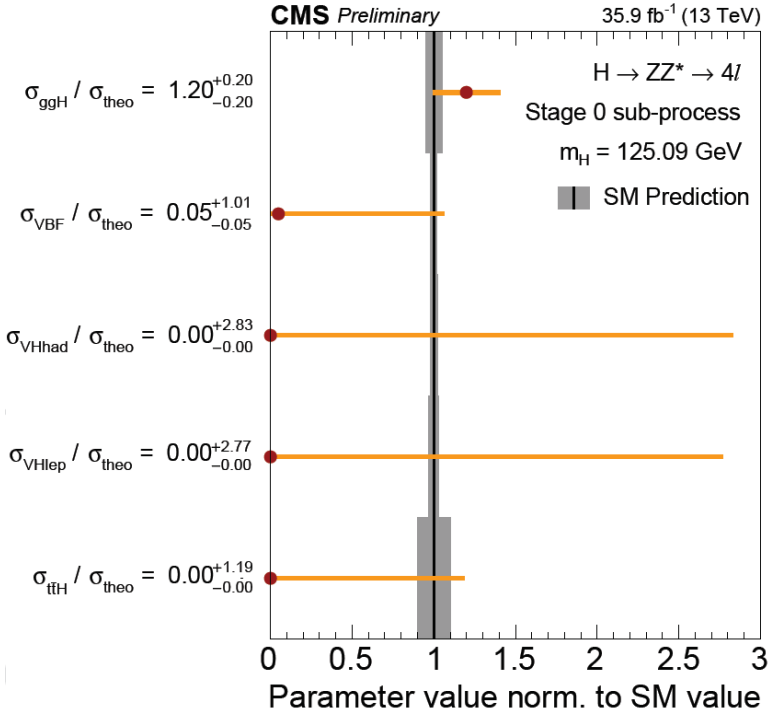




$h \to ZZ^* \to 4\ell$ by CMS: Signal strengths [talk by Oda, CMS-PAS-HIG-16-041]

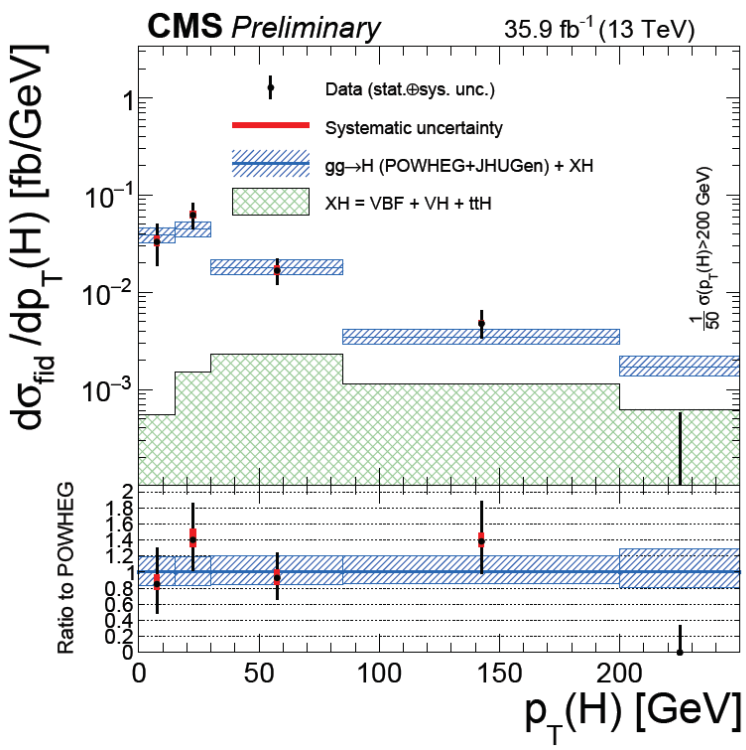
- $\mu = 1.05^{+0.15}_{-0.14}(\text{stat.})^{+0.11}_{-0.09}(\text{syst.})$
  - Combined signal strength at m_H=125.09 GeV.
- Simplified template cross sections for $|y_H|$<2.5.

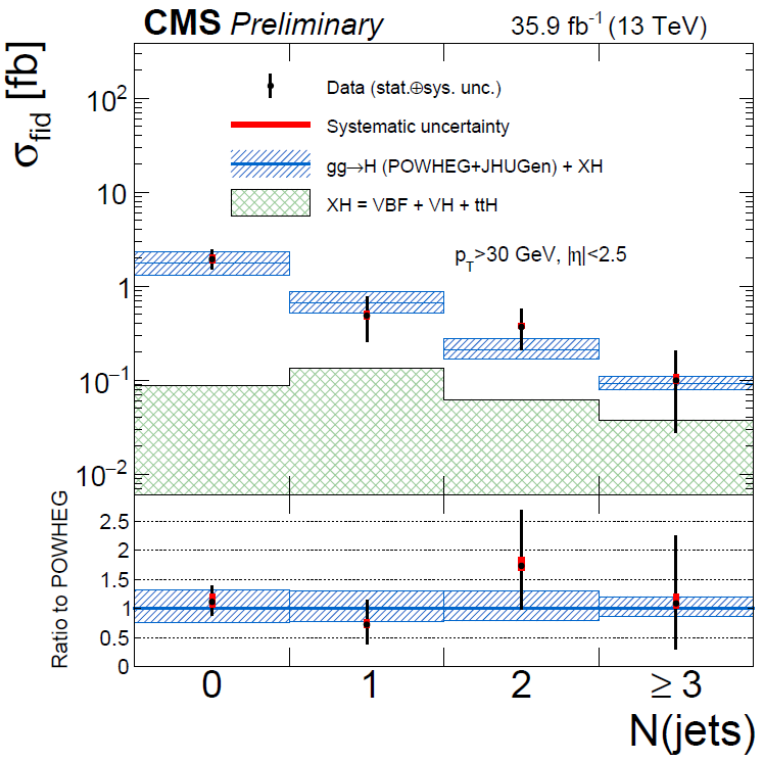




$h \to ZZ^* \to 4\ell$ by CMS: $d\sigma/dp_T$ [talk by Oda, CMS-PAS-HIG-16-041]

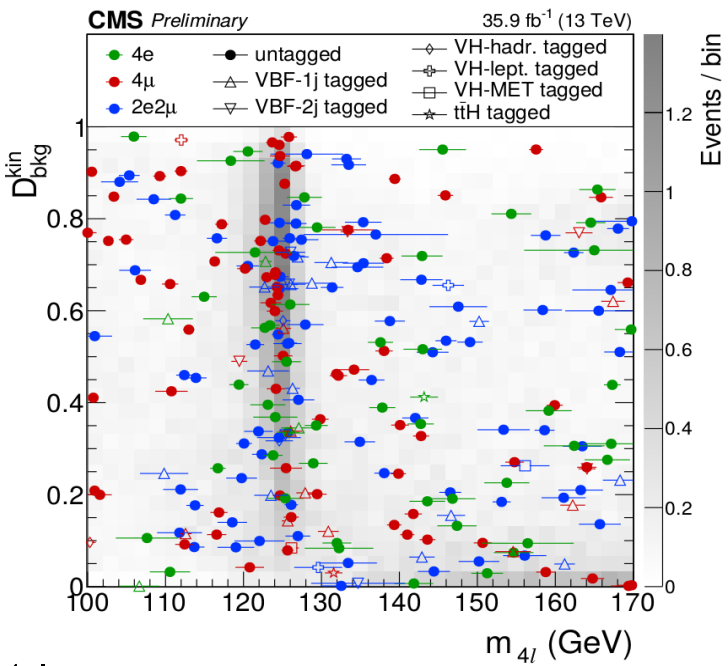
- Differential cross-section with respect to $p_T(H)$ and the number of jets.
- Consistent with the SM expectations within uncertainty.

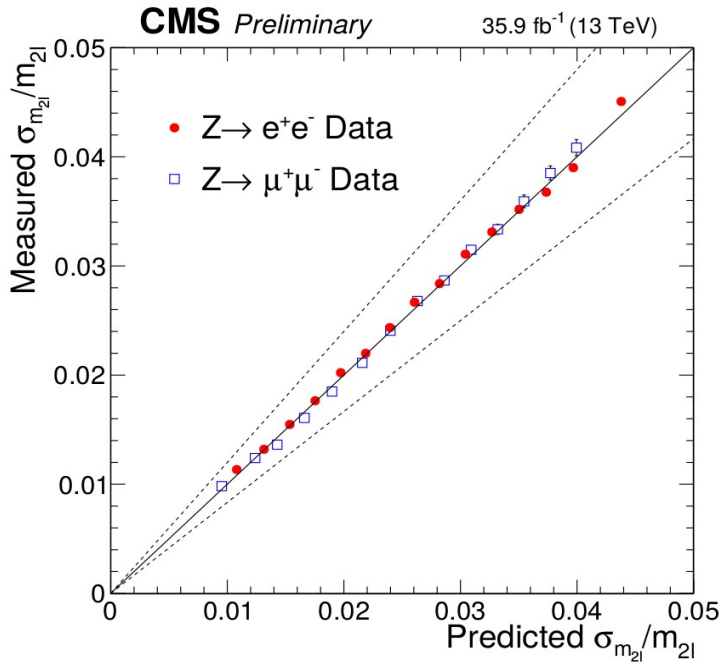




$h \to ZZ^* \to 4\ell$ by CMS: Higgs mass [talk by Mei, CMS-PAS-HIG-16-041]

Mass is determined by 3D measurement with $m(Z_1)$ constraint





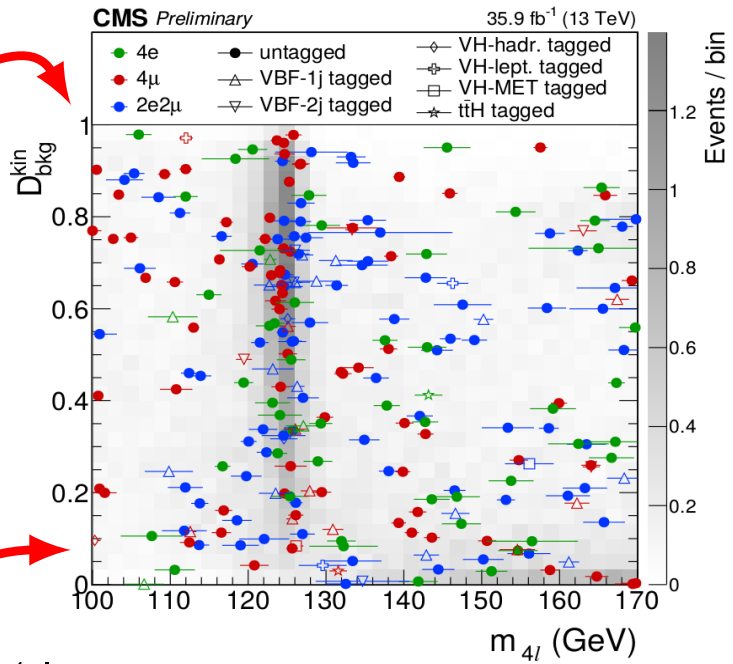
- 4 lepton invariant mass : m_{4l}
- Event-by-event mass uncertainty : $D_{mass} = \sigma_{m_{4l}}/m_{4l}$, propagated from individual lepton p_T resolution (Corrected in data/MC using $Z \to ll$ events)
- Matrix element kinematic discriminant: $\mathcal{D}^{kin}_{bkg} = \left[1 + \frac{\mathcal{P}^{q\bar{q}}_{bkg}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}{\mathcal{P}^{gg}_{sig}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}\right]^{-1}$

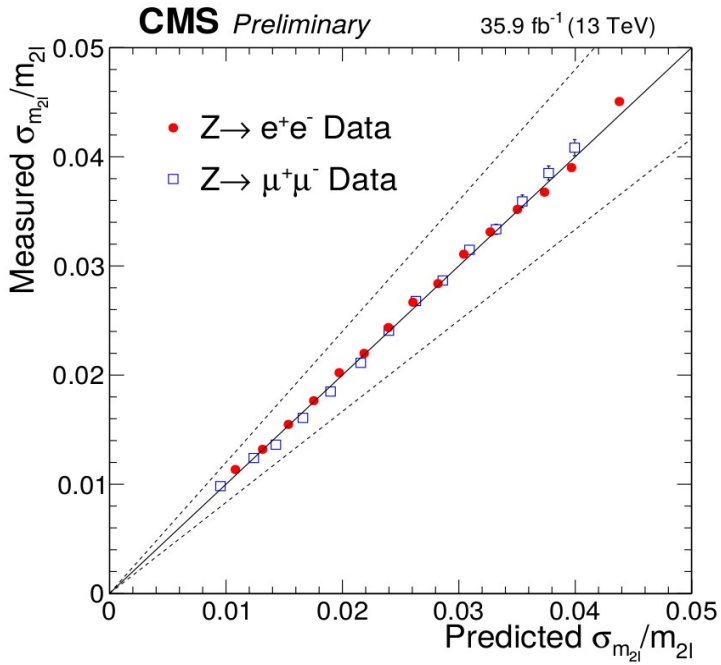
$h \to ZZ^* \to 4\ell$ by CMS: Higgs mass [talk by Mei, CMS-PAS-HIG-16-041]

Mass is determined by 3D measurement with $m(Z_1)$ constraint

sgnl

bckd





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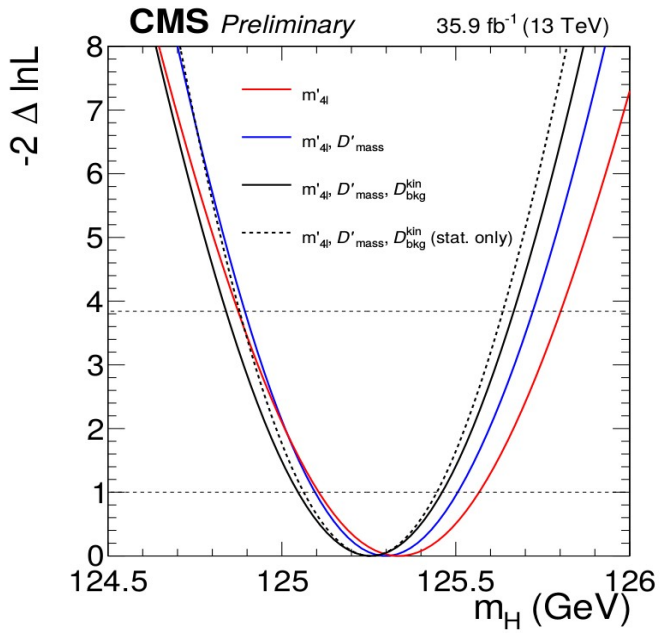
$h \to ZZ^* \to 4\ell$ by CMS: Higgs mass [talk by Mei, CMS-PAS-HIG-16-041]

Result and precision gain

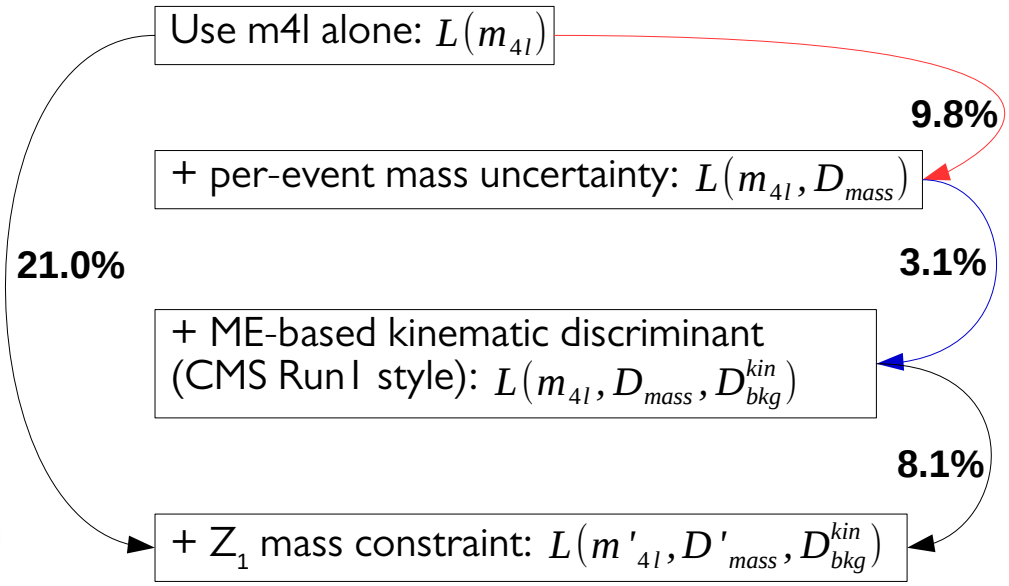
Use per event mass uncertainty + ME-based kinematic discriminant + Z_1 mass constraint:

125.26 ± 0.20 (stat.) ± 0.08 (sys.) GeV

Run I ATLAS+CMS (4l, γγ) combination: 125.09 ± 0.21(stat.)± 0.11(sys.) GeV

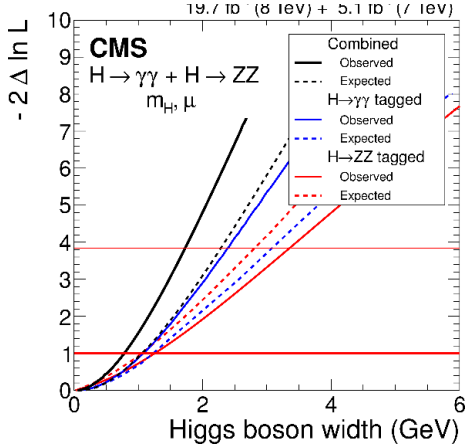


Precision gain in mass measurement:



$h \to ZZ^* \to 4\ell$ by CMS: Higgs width [talk by Oda, CMS-PAS-HIG-16-{041,033}]

- Mass width is measured with two very different methods.
- $\Gamma_H = 0.00^{+0.41}_{-0.00}$ GeV with only on-shell
  - Tighter limit than Run 1
- $\Gamma_H = 10^{+14}_{-10}$ MeV with both on-shell and off-shell
  - With strong theory assumptions
  - With only 12.9 fb^{-1}



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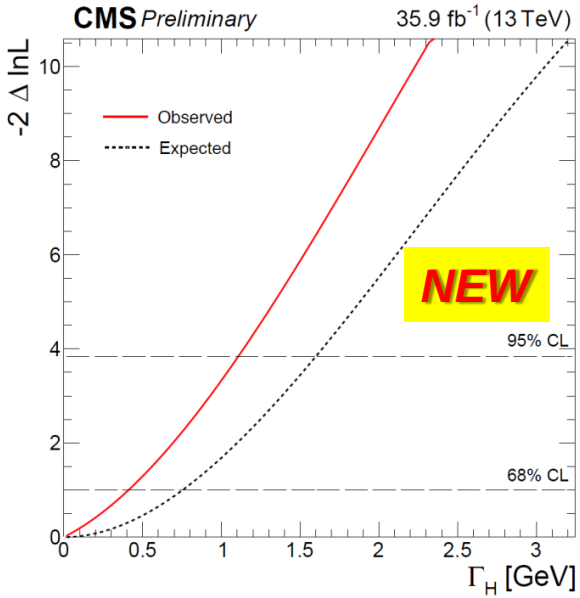

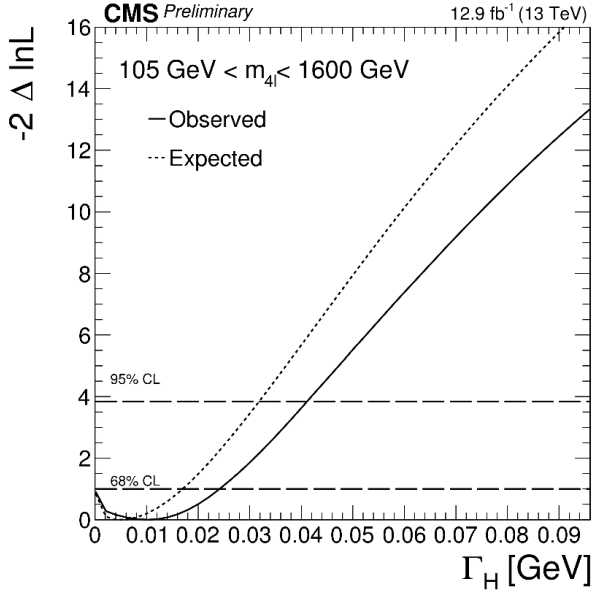

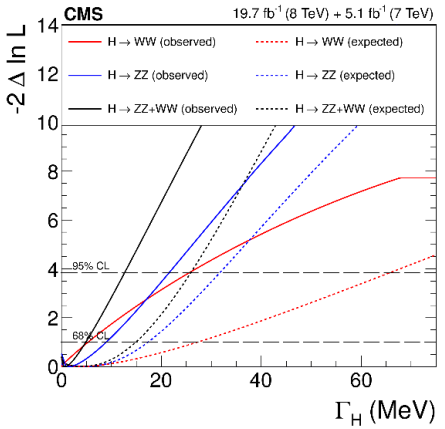

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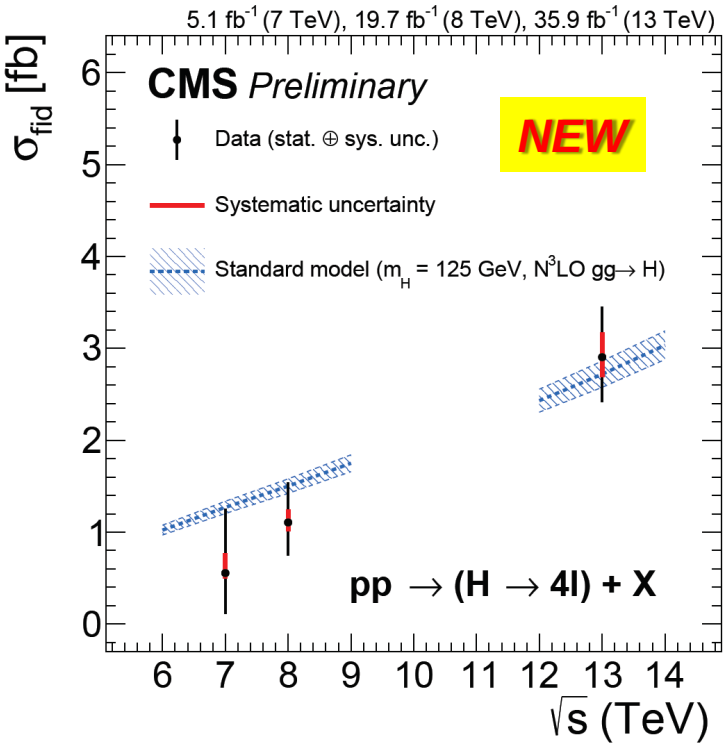
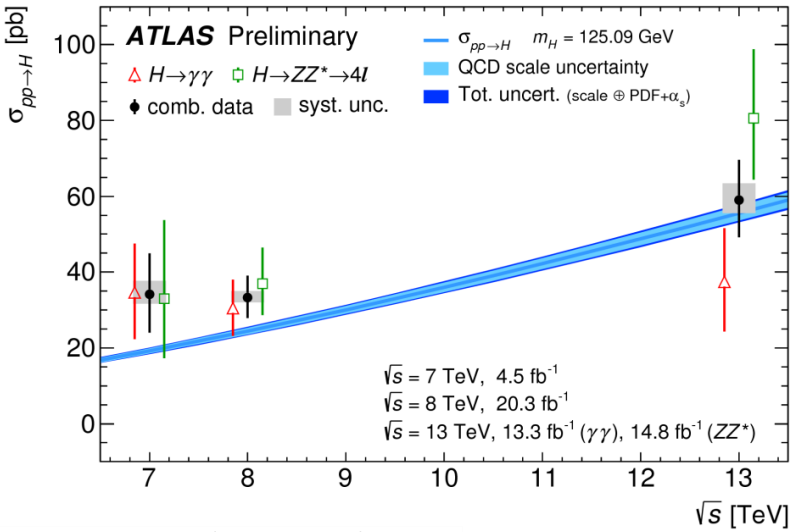
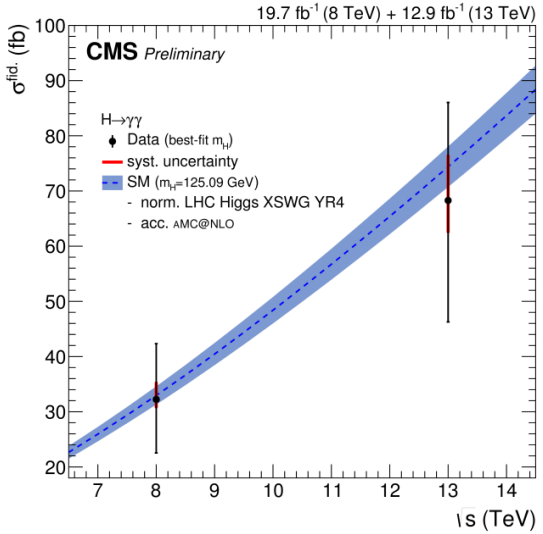
Fiducial cross-section [talk by Oda, ATL-CONF-2016-081; CMS-PAS-HIG-16-{020,041}]

- Total (ATLAS) and fiducial (CMS) cross sections are consistent with N^{3}LO QCD calculation with NLO electroweak corrections.

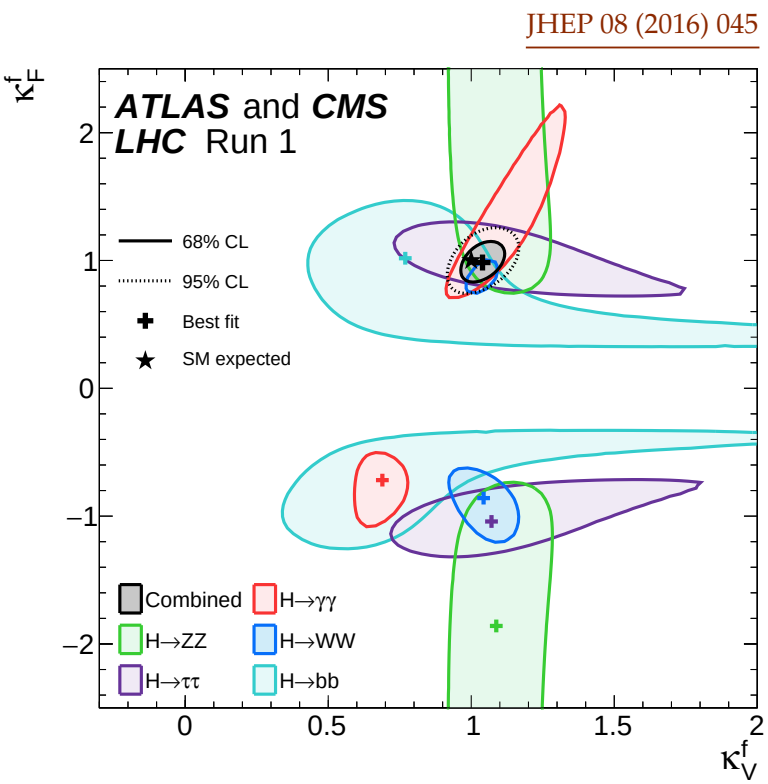




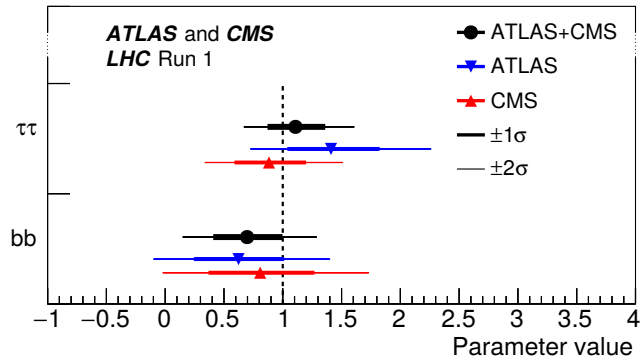


Higgs couplings @ Run-1: κ_V, κ_F [talk by Gaycken]

Couplings to fermions and bosons strongly constrained by Run I measurements.

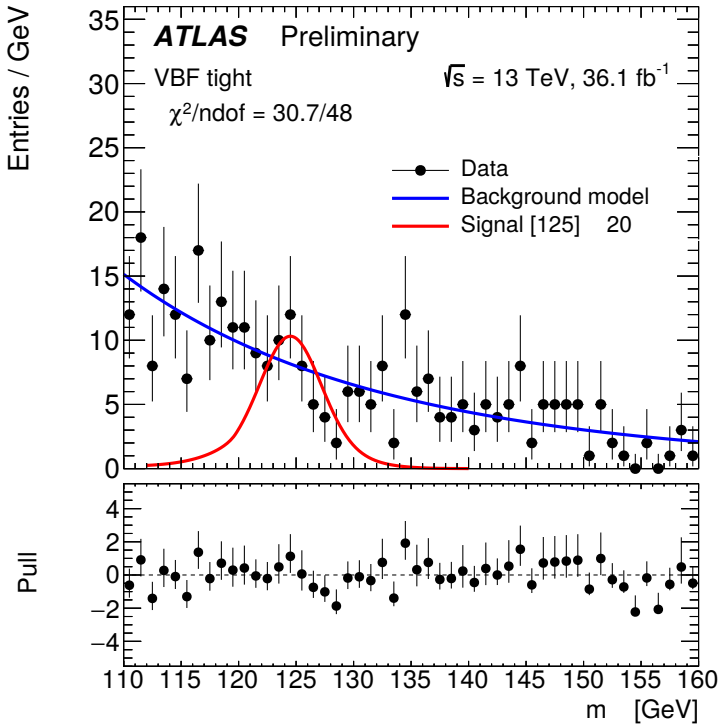


- In combination, search for $H \to \tau^+\tau^-$ exceeds 5σ.
- But, despite being the dominant decay mode, coupling to $b\bar{b}$ not yet observed.



Search for $h \to \mu^+\mu^-$ by ATLAS [talk by Gaycken]

$m_{\mu\mu}$ in VBF tight category



Signalstrength μ extracted from simultaneous fit to $m_{\mu\mu}$ in all categories.

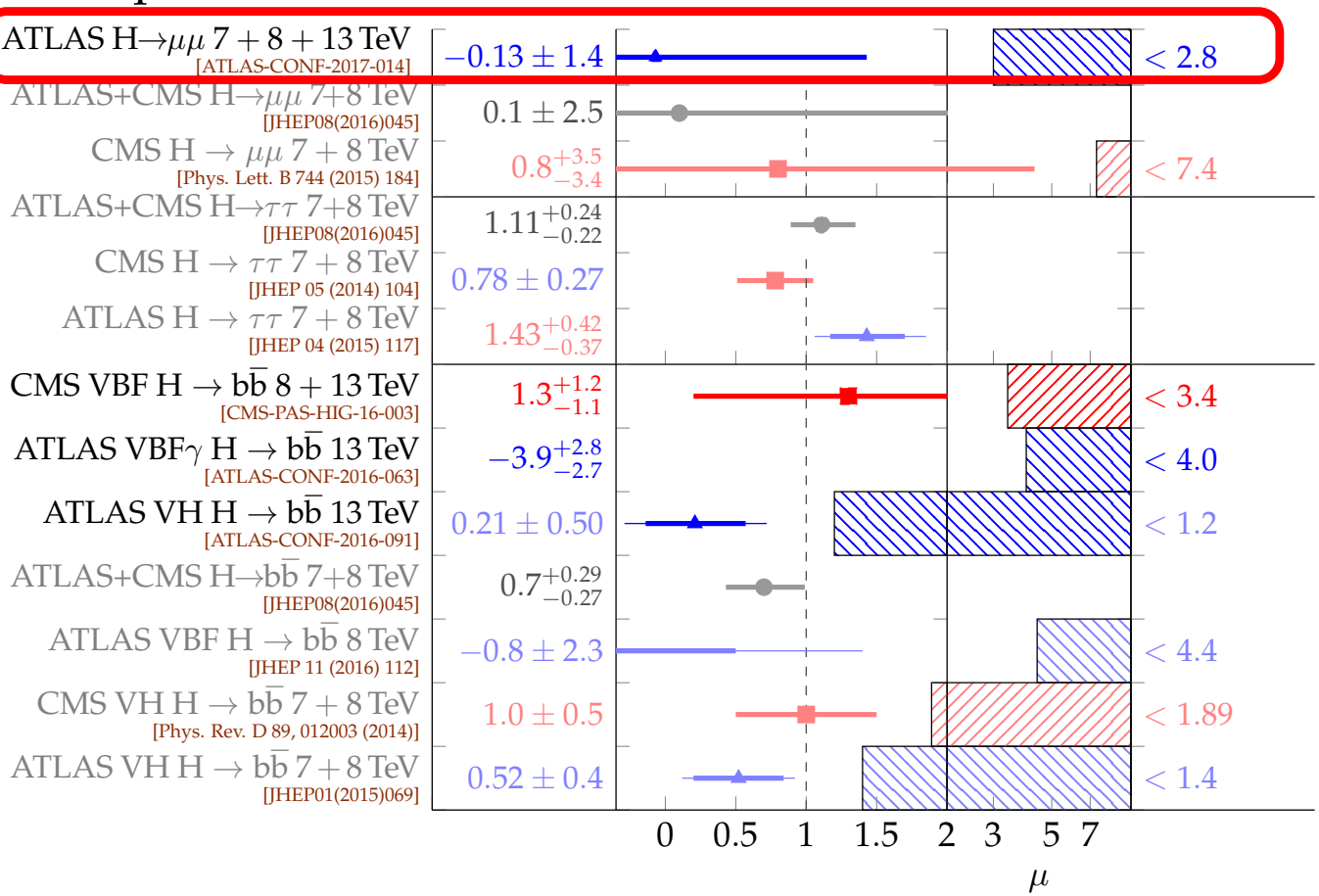
- signal: Crystal-ball +Gaussian
  Shape fixed to prediction of simulation.
- background:
  exponential
  + BW $\otimes$ Gaussian (Z)

ATLAS-CONF-2017-014

Higgs couplings to 2^{nd} & 3^{rd} gen: recap [talk by Gaycken]

Measured signal strength μ and 95% CL limit on $\sigma \times$ Br relative to the SM expectation for $m_{\mathrm{H}} = 125\,\mathrm{GeV}$:

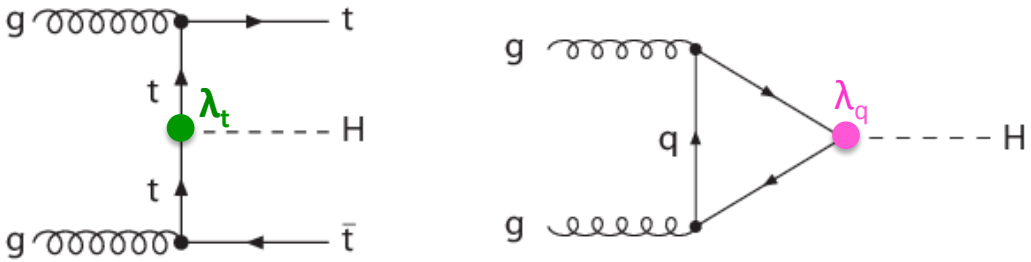
NEW



Towards evidence for ttH at Run-2 [talk by Petrucciani]

overview

- ttH production is the best direct way to probe the coupling between top quark and Higgs boson
  - **tree-level process, cross section prop. to λ_t^2**
  - complementary evidence to loop-induced ggH, which in the SM is also dominated by the λ_t^2 contribution from the top quark loop
- SM ttH cross section at 13 TeV: **507 fb**: ~1/96th of ggH
  - small, but top quarks in the final state provide good handles to trigger and select the events



Towards evidence for ttH at Run-2 [talk by Petrucciani]

Searches can be approximately grouped in:

- **Hadronic**

  $H \to bb$, $H \to \tau_h \tau_h$
- **Leptonic**

  $H \to WW$, $H \to \tau_\ell \tau_{any}$
- **Bosonic:**

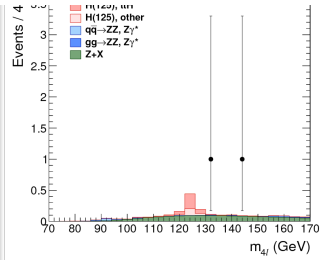
  $H \to \gamma\gamma$, $H \to ZZ^* \to 4\ell$

Towards evidence for ttH at Run-2 [talk by Petrucciani]

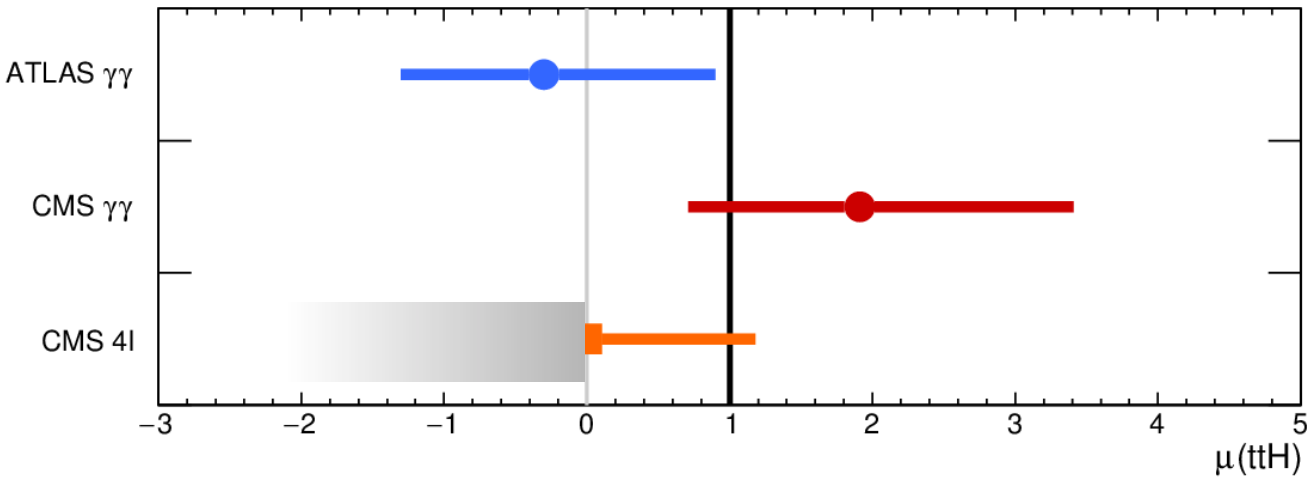
$\gamma\gamma$

	μ	σ(all)	σ(stat)	σ(syst)
ATLAS γγ *CONF-2016-068, **13.3 fb⁻¹***	**−0.3**	**+1.2 −1.0**	+1.2 −1.0	+0.2 −0.2
CMS γγ *PAS HIG-16-020, **12.9 fb⁻¹***	**1.9**	**+1.5 −1.2**		
CMS 4ℓ *PAS HIG-16-041, **35.9 fb⁻¹***	**0.0***	**+1.2* −0.0***		

(*) $-2\Delta\ln L = 1$ interval with $\mu \geq 0$ constraint

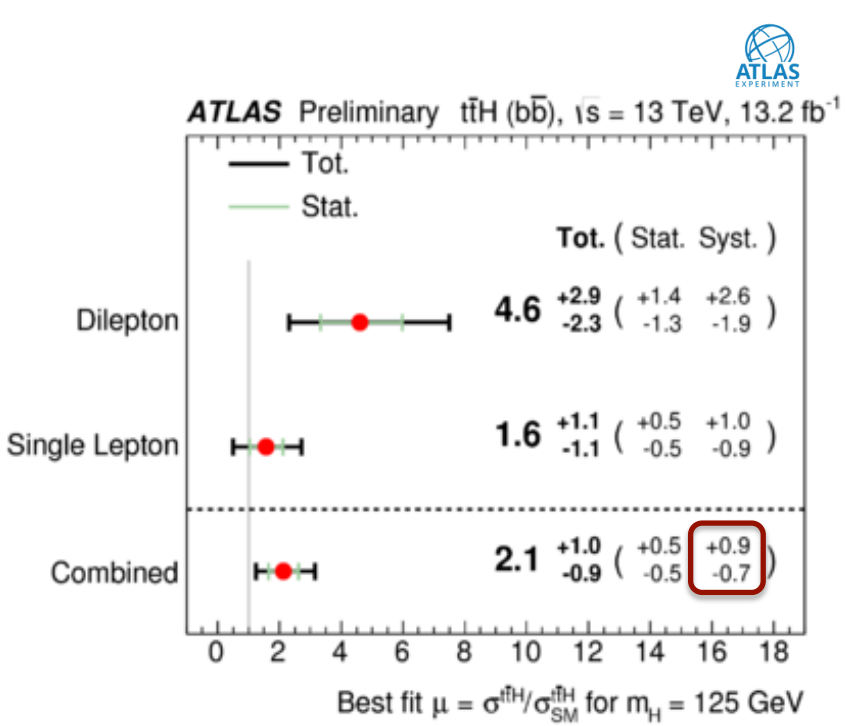


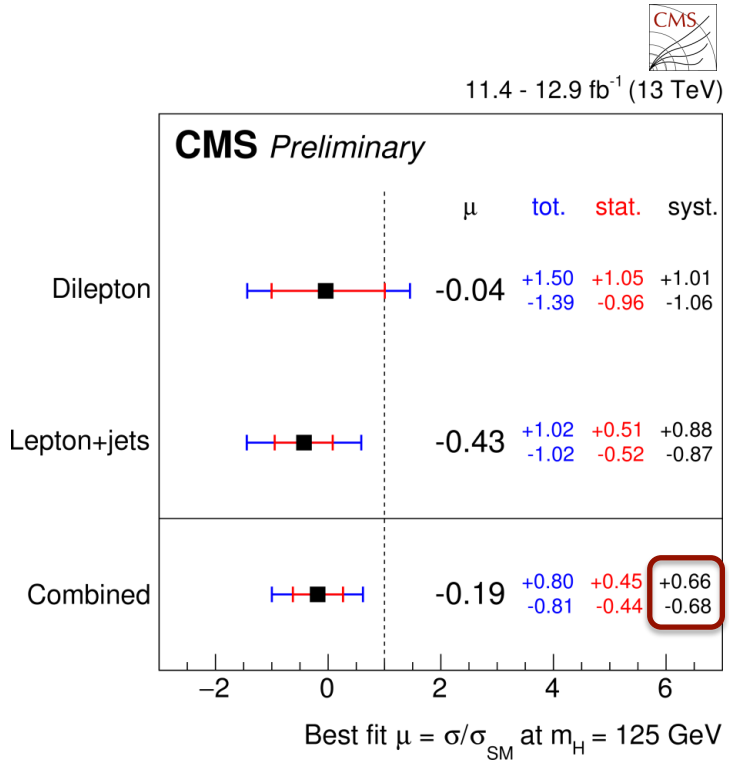
$m_{4\ell}$ [118, 130]	
signal	0.5
bkg.	0.3
data	0



Towards evidence for ttH at Run-2 [talk by Petrucciani]

$b\bar{b}$

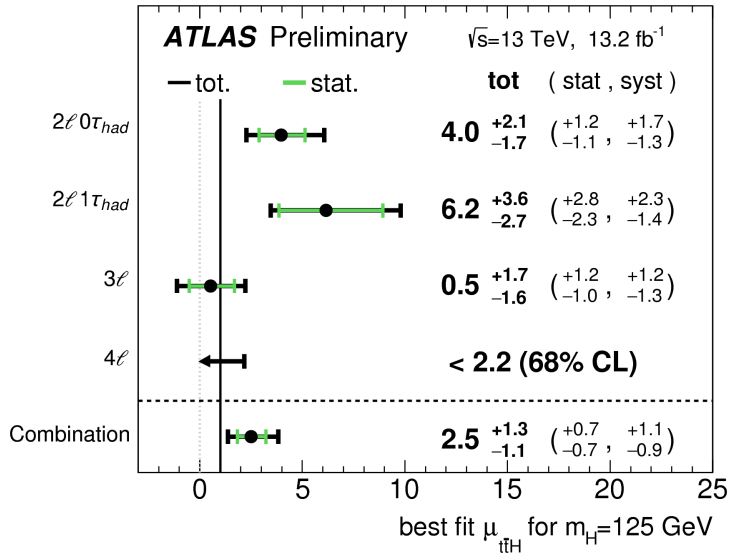


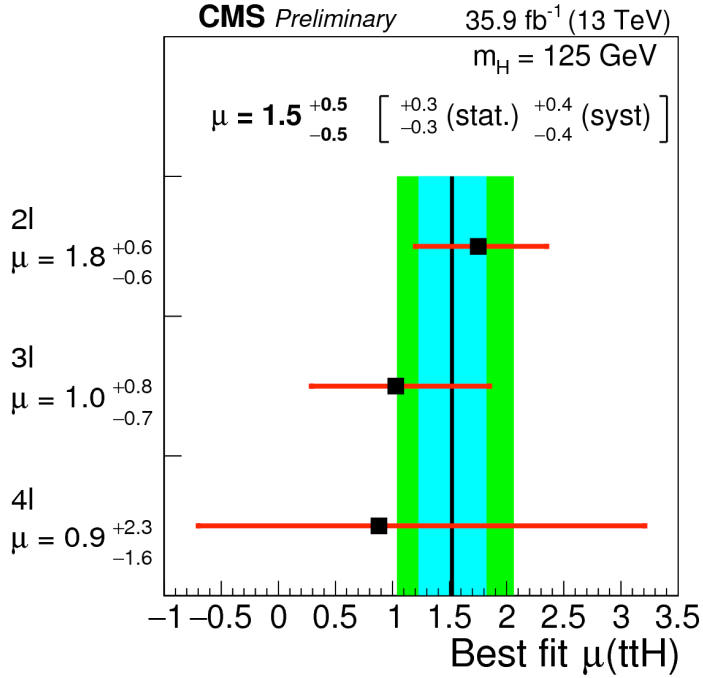


- Sensitivity on μ: ~1·SM, limited by **systematics**
  - dominated by those on tt+(b-)jets background

Towards evidence for ttH at Run-2 [talk by Petrucciani]

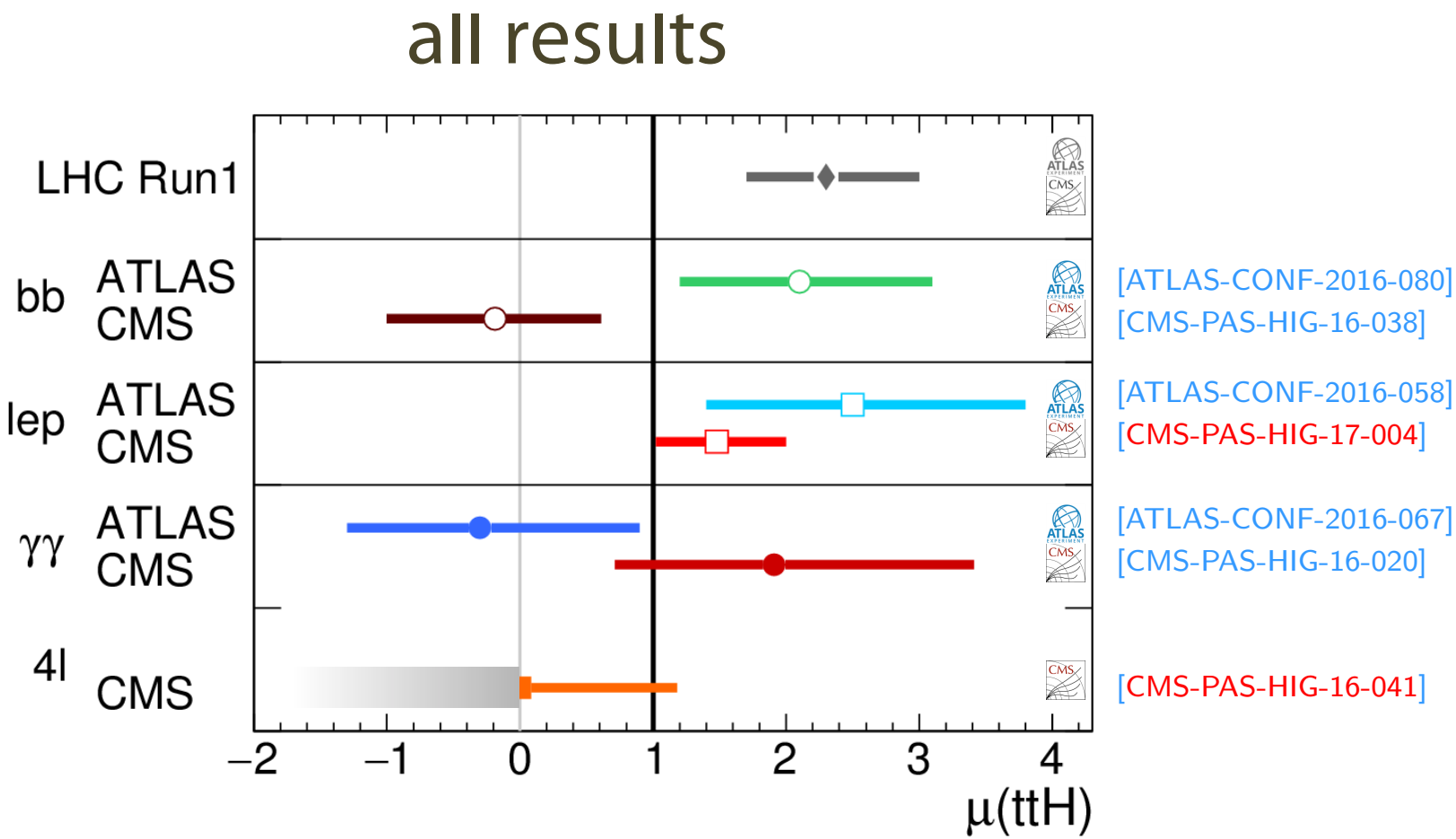
multilepton





- Both results compatible with SM within about 1σ.
- Significance wrt μ(ttH) = 0 hypothesis:
  - ATLAS: 2.2 σ (expected for SM ttH: 1.0 σ)
  - CMS: 3.3 σ (expected for SM ttH: 2.5 σ)

Towards evidence for ttH at Run-2 [talk by Petrucciani]



Towards evidence for ttH at Run-2 [talk by Petrucciani]

Conclusion

- Q: "Evidence for ttH production?"
  A: "Statistically, …"

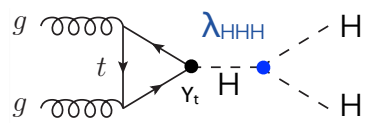
  A combination of ATLAS & CMS ttH results would likely be incompatible with $\mu = 0$

  "… but …"

  there's not yet a single analysis with a strong & unambiguous ttH signal, and it will take time and effort to get there.

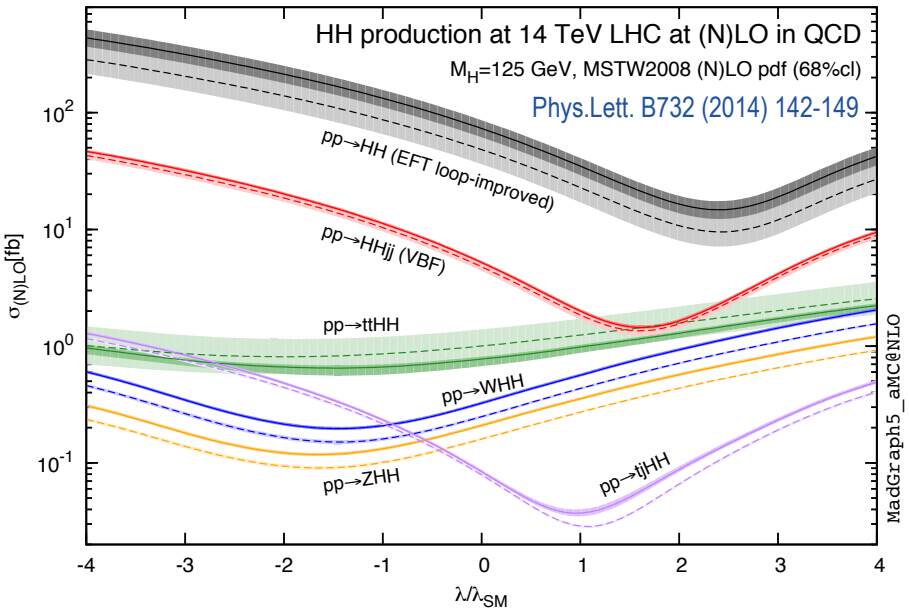
Double Higgs production [talk by Cadamuro]

Non-resonant



$\sigma_{gg\to HH} = 33.49^{+4.3}_{-6.0}$ (scale) ± 2.1 (PDF) ± 2.3 (α_s) fb

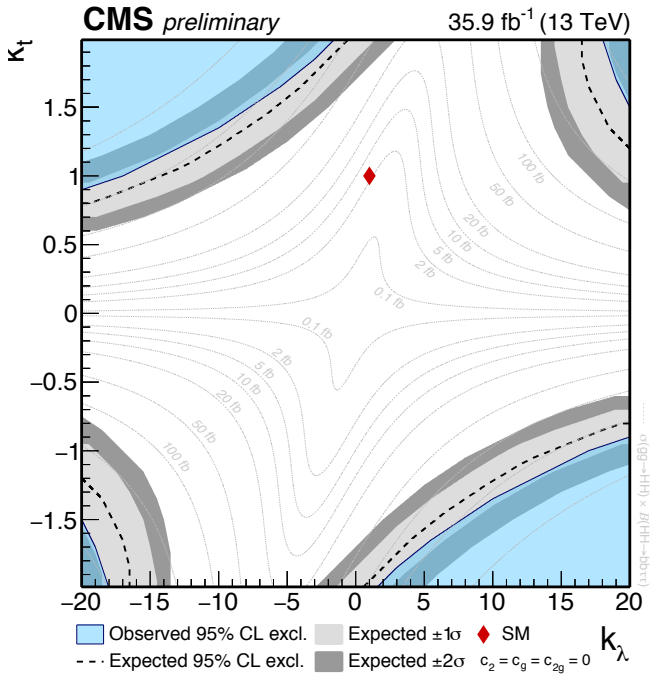
[13 TeV, NNLO + NNLL with top mass effects, HXSWG, arXiv:1610.07922]

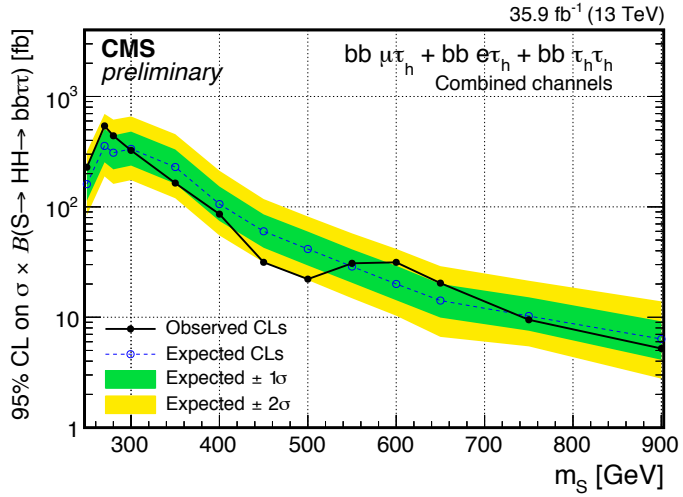


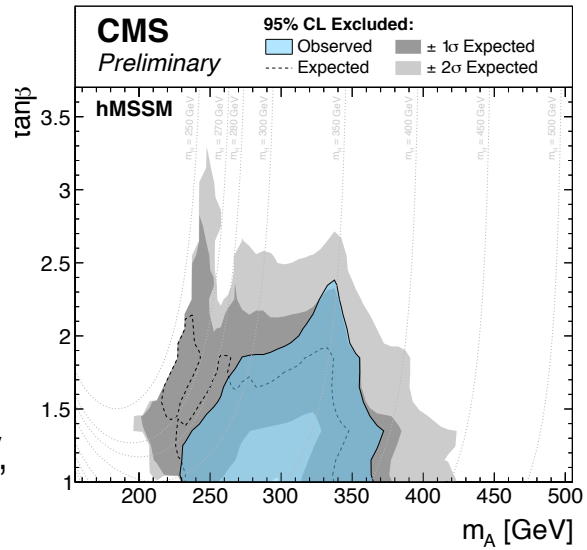
- σ_{HH} : main way to extract Higgs trilinear coupling λ_{HHH}
  - direct information on the shape of the scalar Higgs potential
  - dominated by gg fusion, other production modes out of reach with current data
- Destructive interference of the two diagrams → small σ_{HH}
- Effective lagrangian used to model BSM effects: anomalous λ_{HHH} and y_t couplings and three new contact interactions
  - large modification of σ_{HH}

Double Higgs production [talk by Cadamuro]

NEW: $bb\tau\tau$ by CMS [CMS-PAS-HIG-17-002]



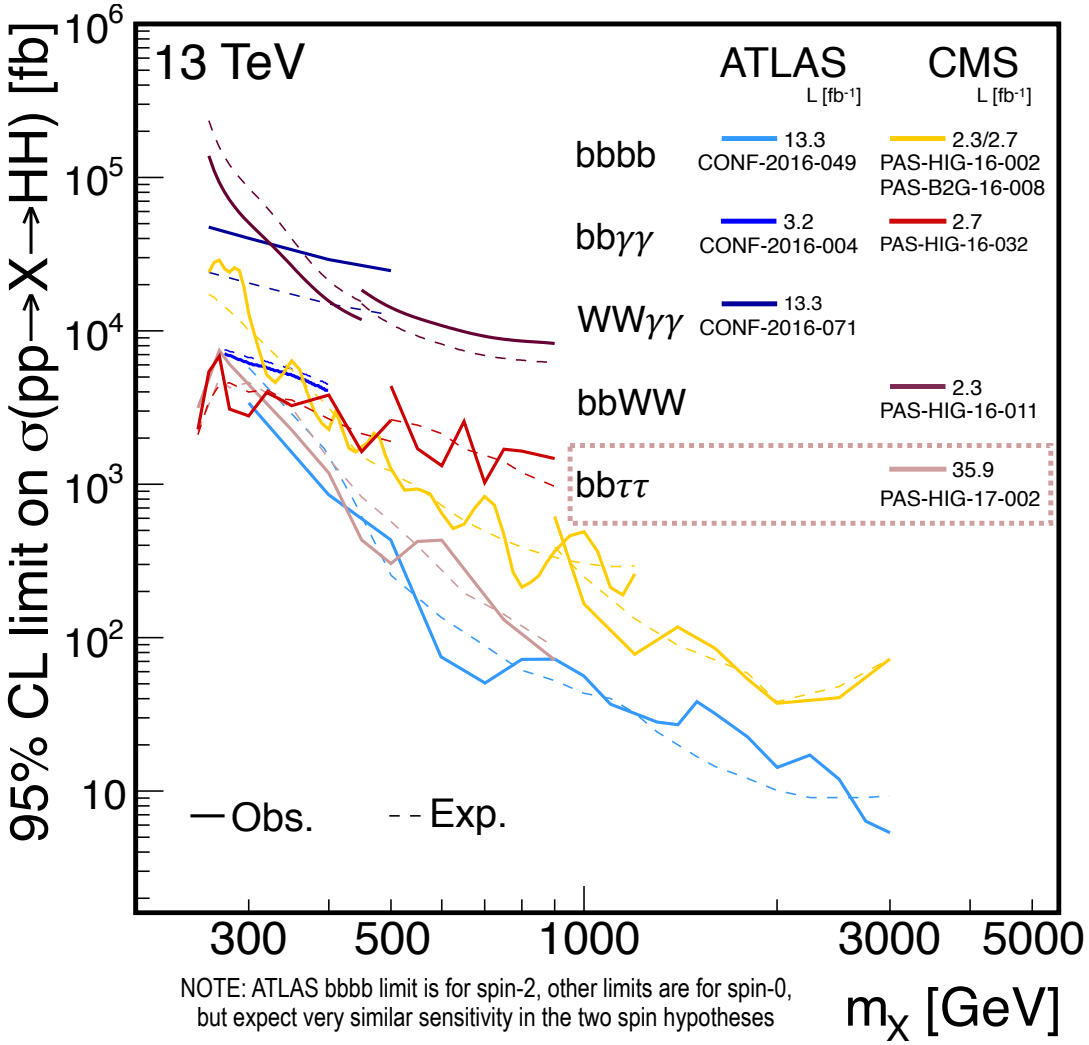




- Non-resonant search excludes 28 times the SM
  - anomalous λ_{HHH} and y_t couplings tested
  - sensitive to the sign of y_t
- Resonant production tested up to m_X = 900 GeV, and interpreted in the hMSSM

Double Higgs production [talk by Cadamuro]

"Analyses doing better than expected: Projections too conservative?"



Chan.	Obs. (exp.) 95% C.L. limit on σ/σ_{SM} ATLAS EXPERIMENT	CMS
bbbb	29 (38)	342 (308)
bbWW	-	410 (227) ⊡
bb$\tau\tau$	-	28 (25) ⊡
bb$\gamma\gamma$	117 (161)	91 (90)
WW$\gamma\gamma$	747 (386)	-

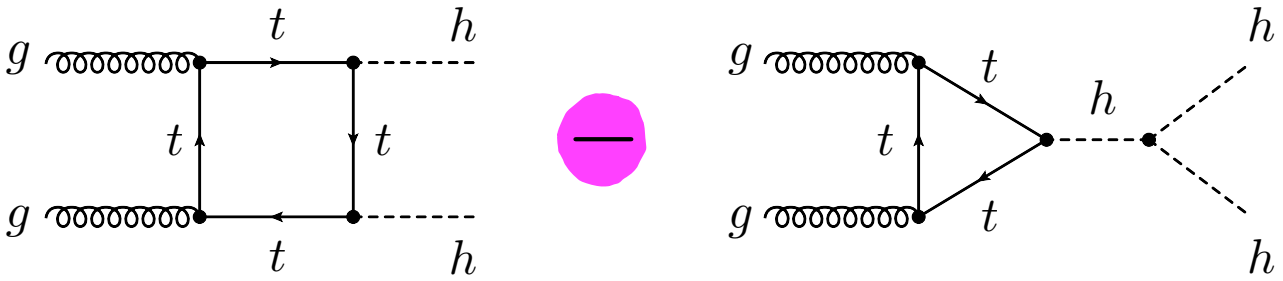
2.3-3.2 fb^{-1} | 13.3 fb^{-1} | 35.9 fb^{-1}

⊡: Test of anomalous HH couplings

- Complementarity in different mass ranges
  - much to gain from a combination!

Double Higgs production & the Higgs self-coupling [talk by Haisch]

μ as a function of the Higgs self-coupling λ



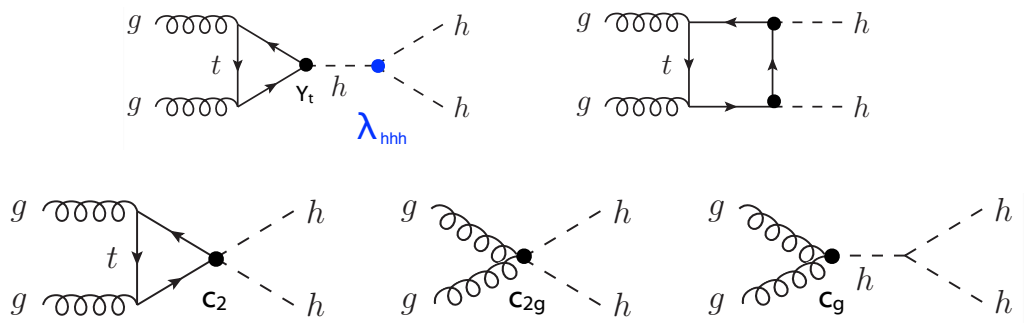
$$R = \frac{\sigma(pp \to hh)}{\sigma(pp \to hh)_{\rm SM}} = 2.1 - 10.8\lambda + 17.2\lambda^2$$

$$R = 1 \implies \lambda_{1,2} = \{\lambda_{\rm SM}, 3.8\lambda_{\rm SM}\}$$

Double Higgs production & BSM [talk by Cadamuro]

More general (and motivated): EFT approach see also [PRD92 (2015) 035001] JHEP04 (2015) 167 , LHCHXSWG-2016-001

- Effective Lagrangian obtained by adding dim-6 operators to the SM Lagrangian
- Results in a modification of the SM λ_{HHH} and y_t couplings and introduces three new contact interactions
  - changing these 5 couplings affect σ_{HH} and the HH kinematics
- Analyses are exploring the 5-dimensional space of these couplings
  - a parametrization of $\sigma_{HH}(\lambda_{HHH}, y_t, c_2, c_g, c_{2g})$ is used



λ from single-Higgs production [talk by Haisch]

LHC Run I, 20.3 fb^{-1} $\longrightarrow$ $\frac{\lambda}{\lambda_{\rm SM}} \in [-14.5, 19.1]$

2γ2b, 1406.5053;
4b, 1506.00285;
2b2τ, 2γ2W, 1509.04670

LHC Run II, 13.3 fb^{-1} $\longrightarrow$ $\frac{\lambda}{\lambda_{\rm SM}} \in [-8.4, 13.4]$

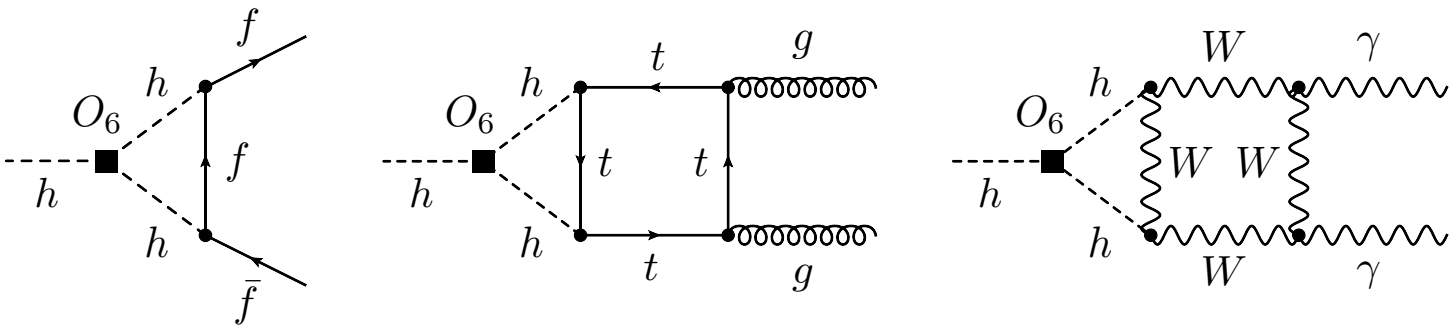
4b, ATLAS-CONF-2016-049

HL-LHC, 3 ab^{-1} $\longrightarrow$ $\frac{\lambda}{\lambda_{\rm SM}} \in [-0.8, 7.7]$

2γ2b, ATL-PHYS-PUB-2017-001

λ from single-Higgs production [talk by Haisch]

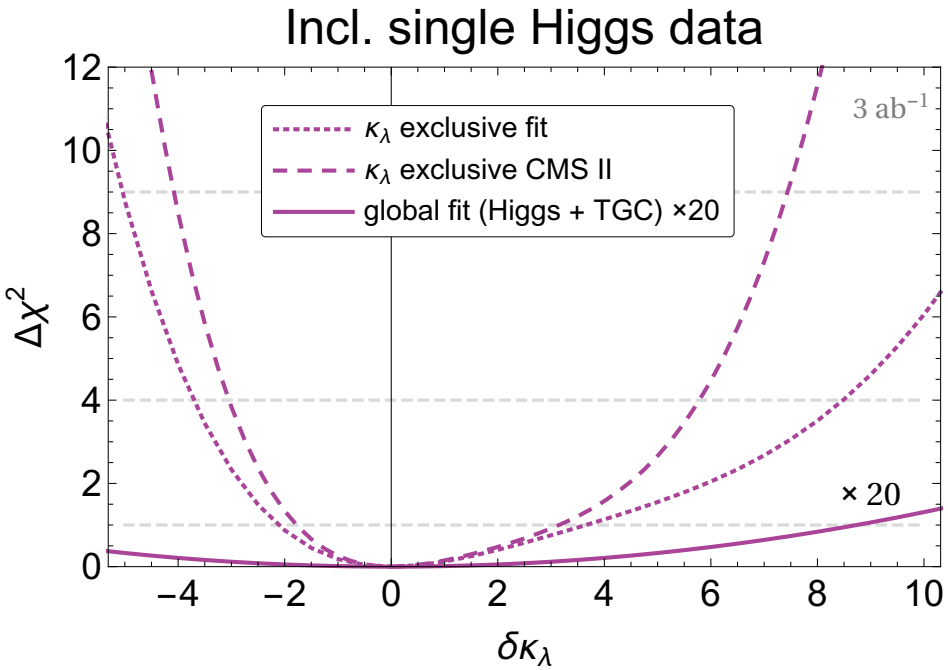
Switch on 1 operator: $\frac{\bar{c}_6}{\Lambda^2}(H^\dagger H)^3 \Rightarrow$ loop-suppressed effect

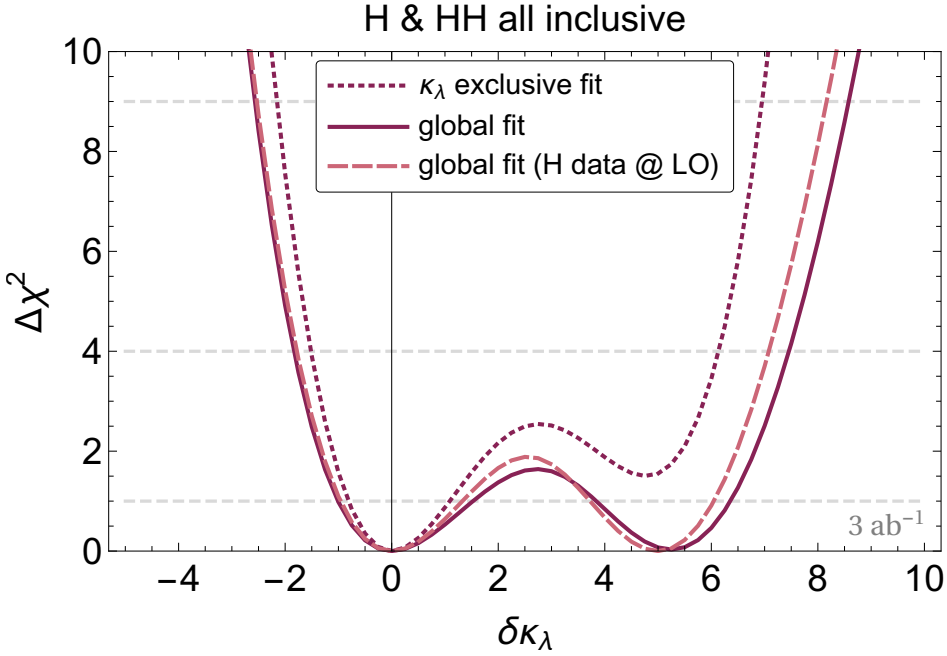


All production & decays channels receive two types of contributions: i) a process dependent one, which is linear in $\bar{c}_6$; ii) a universal one associated to Higgs wave function renormalization, which contains a piece quadratic in $\bar{c}_6$

Gorbahn & UH, 1607.03773; Degrassi et al., 1607.04251; Bizoń, et al., 1610.05771

Warning: a global EFT analysis (w/ 10 unconstrained Higgs-deformations) @ HL-LHC 14 TeV with 3 ab^{-1} shows less optimistic prospects for single-Higgs determinations of $\lambda_{hhh} \equiv \lambda_{hhh}^{\rm SM}(1+\delta\kappa_\lambda)$





Outline

M_W measurement by ATLAS [talk by Andari]

In a traditional template fit analysis, Mw can be extracted from:

➢ Lepton transverse momentum: p_T^l

- insensitive to recoil
- sensitive to pTW modelling, higher order QCD, PDF, W polarisation, charm mass

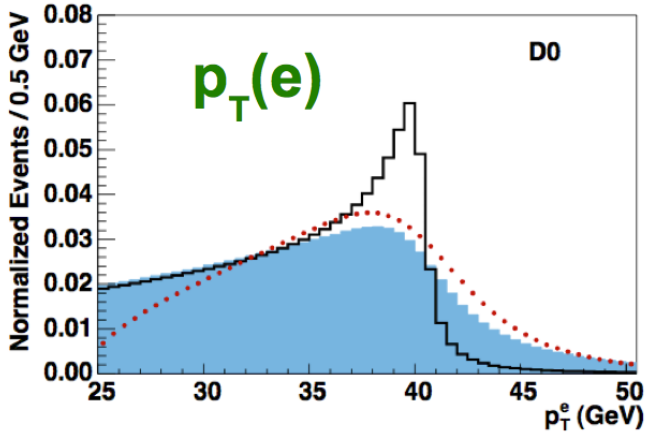
➢ Neutrino transverse mass p_T^ν

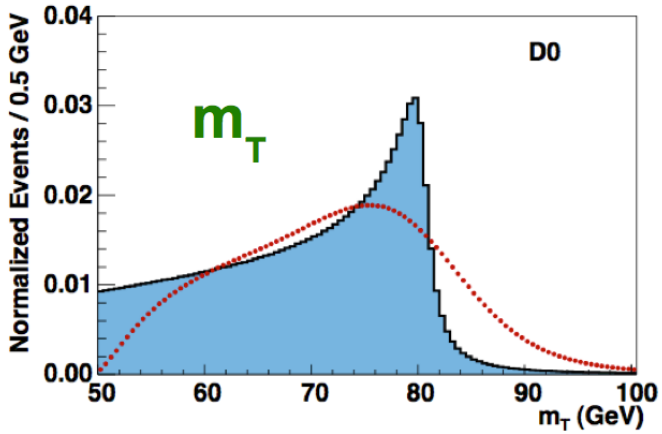
$$\vec{p}_T^{\,\nu} = -(\vec{p}_T^{\,l} + \vec{u})$$

u: the recoil measured as the sum of the energies in topoclusters excluding the lepton itself -->sensitive to pile-up, UE

➢ W transverse mass $m_T = \sqrt{2\, p_T^l p_T^\nu (1 - \cos\Delta\phi(l,\nu))}$

- low sensitivity to pTW, smaller pdf uncertainties
- smaller non-pQCD uncertainties
- Recoil modelling crucial, sensitivity to pile-up, UE





31

Physics modeling

No single generator able to describe all observed distributions.

Start from the Powheg+Pythia8 and apply corrections. Use ancillary measurements of Drell-Yan processes to validate (and tune) the model and assess systematic uncertainties.

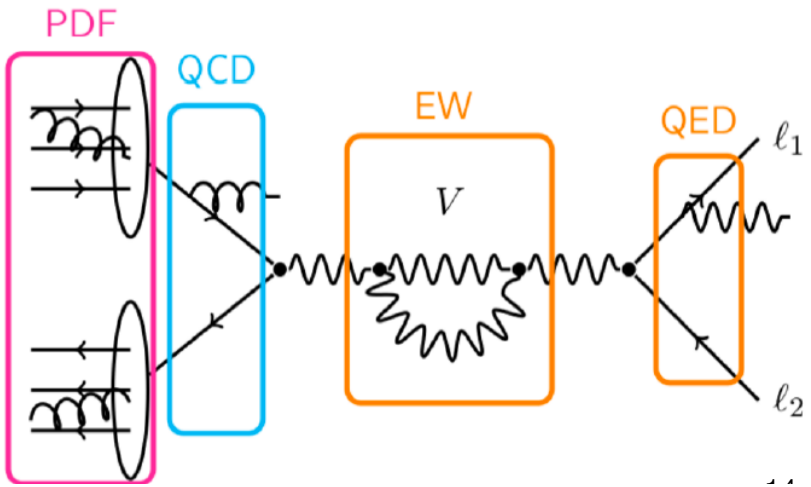
Physics modelling corrections

Electroweak corrections

- *QED FSR and ISR (included)*
- *missing higher order effects and FSR pair production (uncertainties)*

QCD corrections

- *pT distribution*
- *polarisation*
- *rapidity*



M_W measurement by ATLAS [talk by Andari]

Physics modeling uncertainties

W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_{F} with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

QCD

Decay channel	$W \to e\nu$		$W \to \mu\nu$	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

EW

Fixed-order PDF uncertainties are dominant:

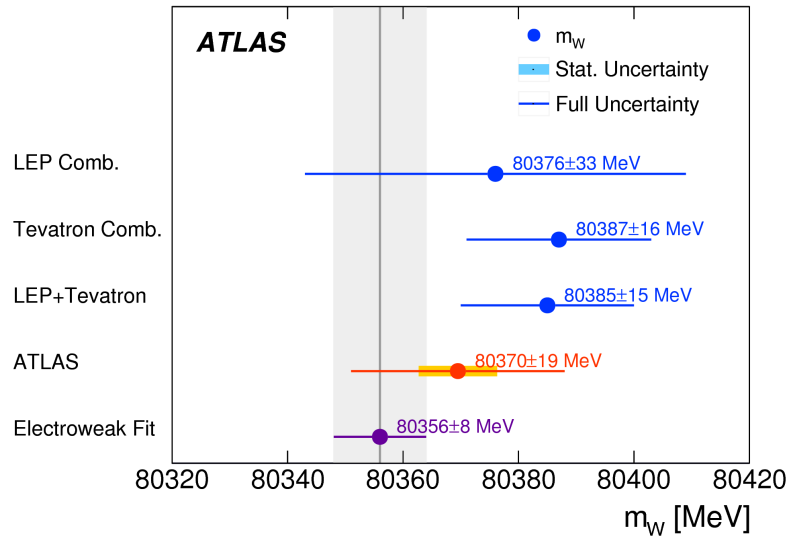
- PDF variations *(25 error eigenvectors)* of CT10nnlo applied simultaneously to the boson rapidity, Ai, and p_T distributions.
- Envelope taken from CT14 and MMHT2014~3.8 MeV

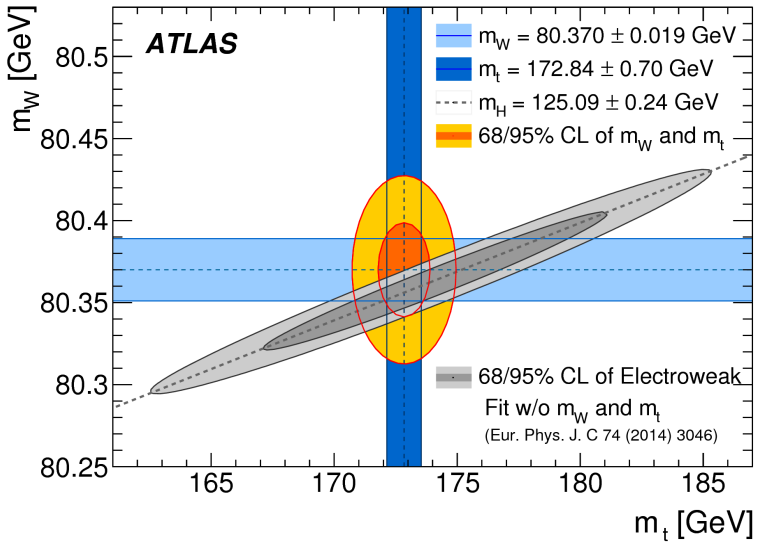
The PDF uncertainties very similar between p_T^l and m_T but strongly anti-correlated between W^+ and W^-

M_W measurement by ATLAS [talk by Andari]

$$
\begin{aligned}
m_W &= 80369.5 \pm 6.8\,\text{MeV(stat.)} \pm 10.6\,\text{MeV(exp. syst.)} \pm 13.6\,\text{MeV(mod. syst.)} \\
&= 80369.5 \pm 18.5\,\text{MeV},
\end{aligned}
$$

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27



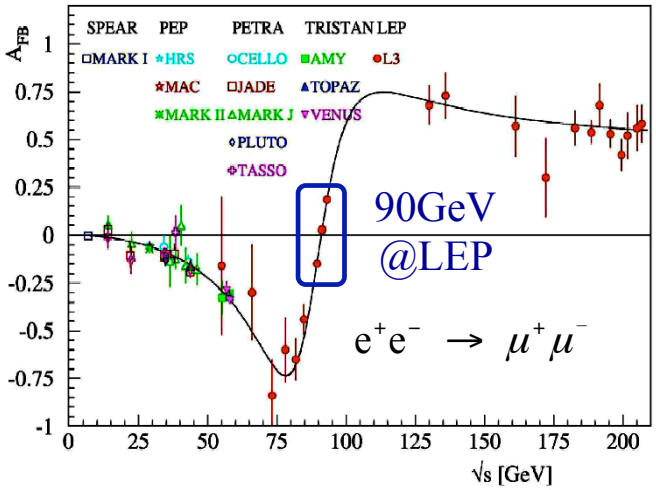


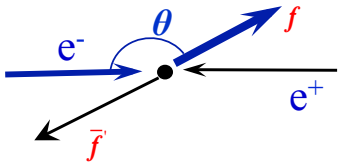
The result is consistent with the SM expectation, compatible with the world average and competitive in precision to the currently leading measurements by CDF and D0

$$f\bar{f} \to Z \to \ell^+\ell^-\text{: } \sin^2\theta^{\text{eff}}_{\text{lept}} \equiv Re[\kappa_\ell(M_Z)]\sin^2\theta \equiv \frac{1}{4|Q_\ell|}\left(1 - \frac{Re[g_V^\ell]}{Re[g_A^\ell]}\right)$$

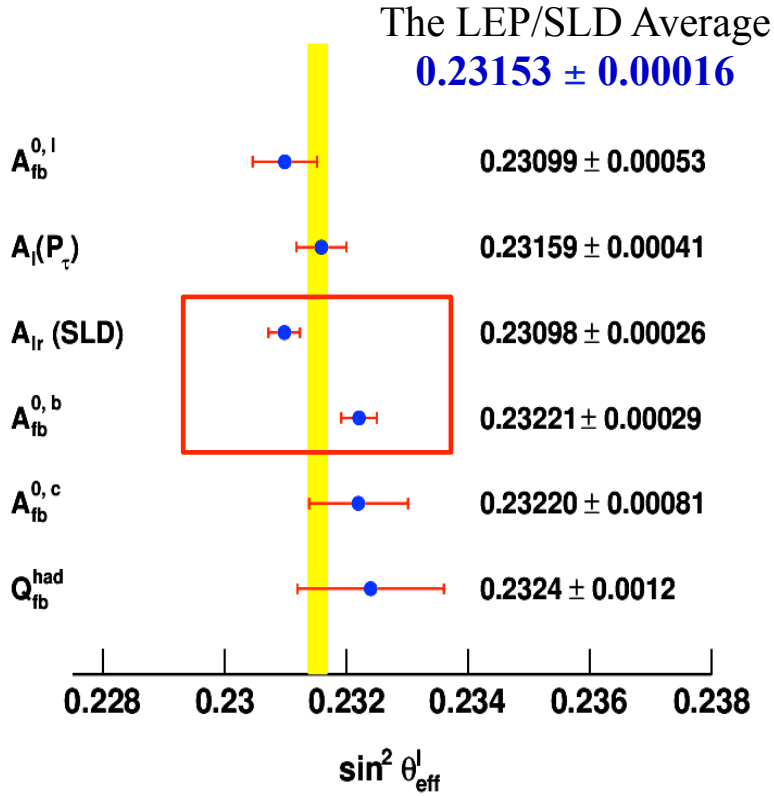
- The most precise results, LEP b-quark $A^{0,b}{}_{fb}$ and SLD beam LR-polarization A_{lr}, differ **3.2**σ

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$





$$\sigma_{F/B} = \int_{0/-1}^{+1/0} \frac{d\sigma}{d\cos\theta} d\cos\theta$$



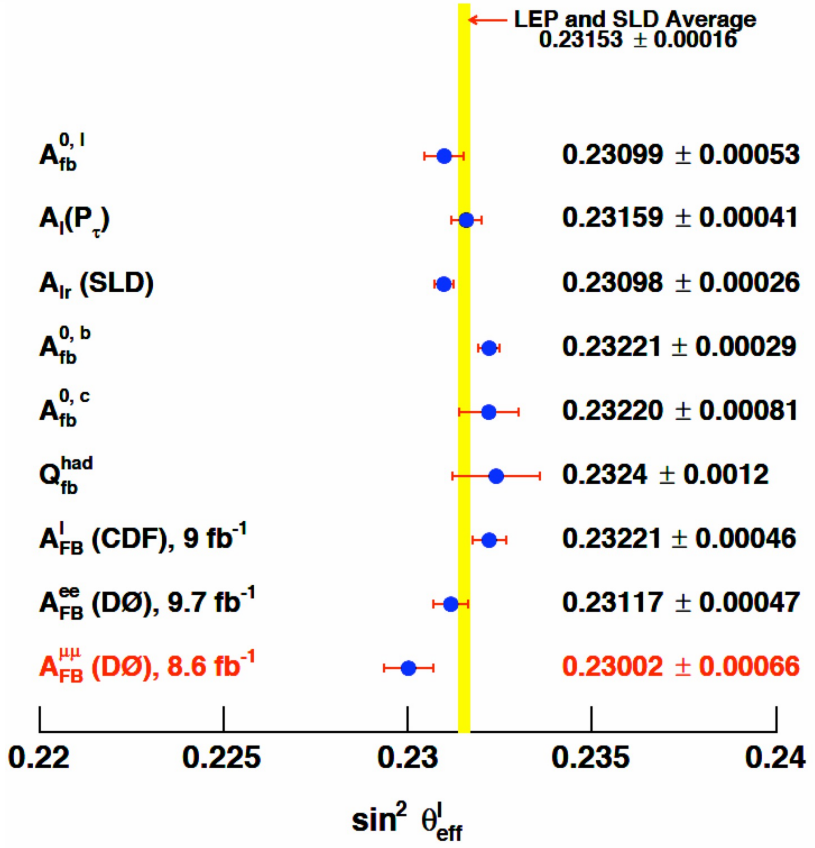
$\sin^2\theta^{\text{eff}}_{\text{lept}}$ in Drell-Yan by D0 [talk by Han]

at Tevatron: reconstruct from Pythia's $\sin\theta^{\text{B(orn)}}$ $\leftrightarrow$ FB charge asymmetry in the distribution of the emission angle of $p_T^{\ell^-}$ relative to the incoming q momentum (in the Collins-Soper frame)

$\sin^2\theta^B_W$	0.22994
Statistical uncertainty	0.00059
Systematic uncertainties	
Momentum calibration	0.00002
Momentum resolution	0.00004
Background	0.00010
Efficiencies	0.00001
Total systematic	0.00011
PDF	0.00027
Total	0.00066

$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23002 \pm 0.00066$$
$$M_W = 80441 \pm 33\ \text{MeV}/c^2$$

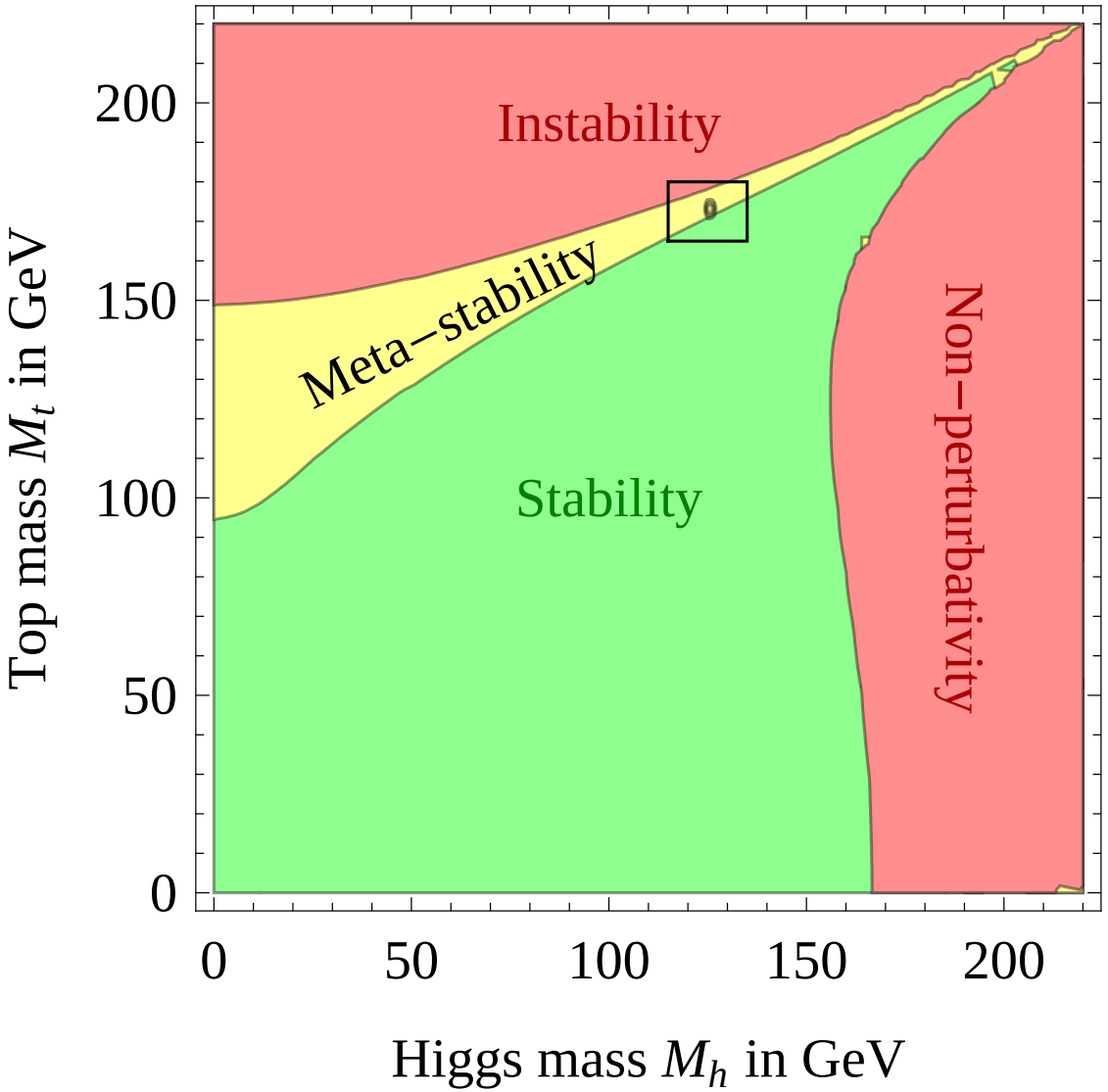
New! **D0 Note 6497-CONF**



* The D0 Z→ee/μμ channels differ ~1.4 σ

Outline

Why the top mass? A matter of life and death :)



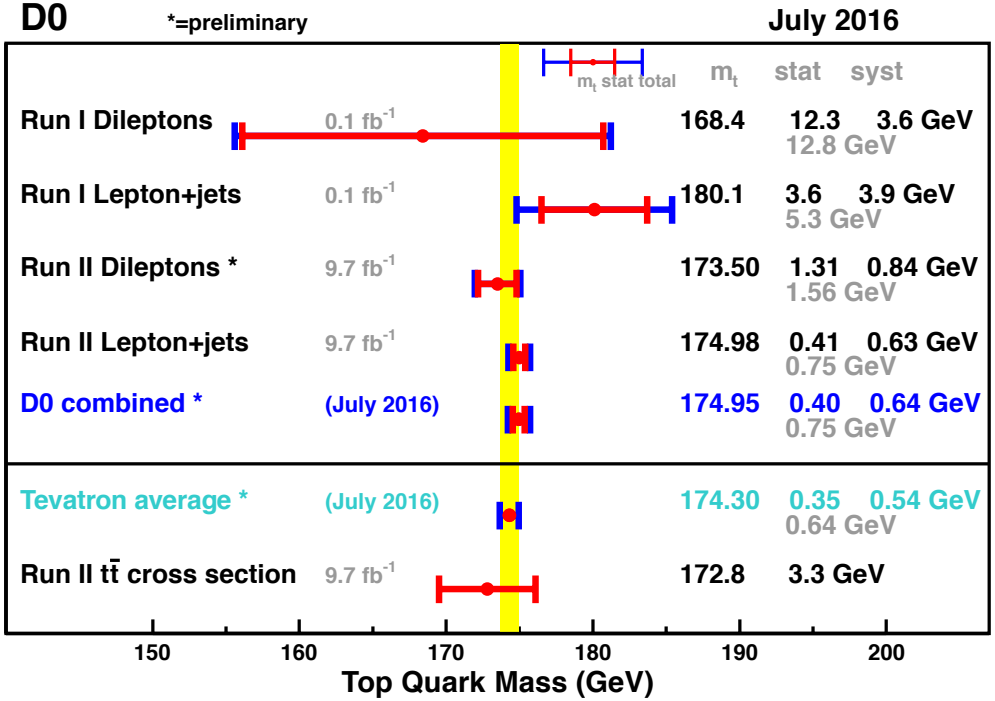
[Degrassi, DV, Elias-Miró, Espinosa, Giudice, Isidori, Strumia 12]

- Higgs pole mass M_h now known with *per mille* accuracy $\Rightarrow \lambda(\mu)$
- Top pole mass $M_t - M_t^{\rm MC} \sim 1$ GeV
- New estimates of renormalon ambiguities, ~ 70 MeV [Beneke et al 16]
- Actually the important quantity is the running Top Yukawa $y_t(\mu)$
- Also $\alpha_s(\mu)$ plays a role

Top Mass combination by D0 [talk by Han, 1703.06994]

Recall world avg 2014: $M_t = 173.34 \pm 0.76$ GeV

- Full D0 combination of Run1 0.1 fb^{-1}and Run2 9.7 fb^{-1}results
- Systematic uncertainties and correlations among channels have been taken into account



	D0 combined values (GeV)
m_t	174.95
In situ light-jet calibration	0.41
Response to b, q, and g jets	0.16
Model for b jets	0.09
Light-jet response	0.21
Out-of-cone correction	< 0.01
Offset	< 0.01
Jet modeling	0.07
Multiple interaction model	0.06
b tag modeling	0.10
Lepton modeling	0.01
Signal modeling	0.35
Background from theory	0.06
Background based on data	0.09
Calibration method	0.07
Systematic uncertainty	0.64
Statistical uncertainty	0.40
Total uncertainty	0.75

174.95 ± 0.75 GeV

Outline

Resonances in VH (W', Z') [talk by Li]

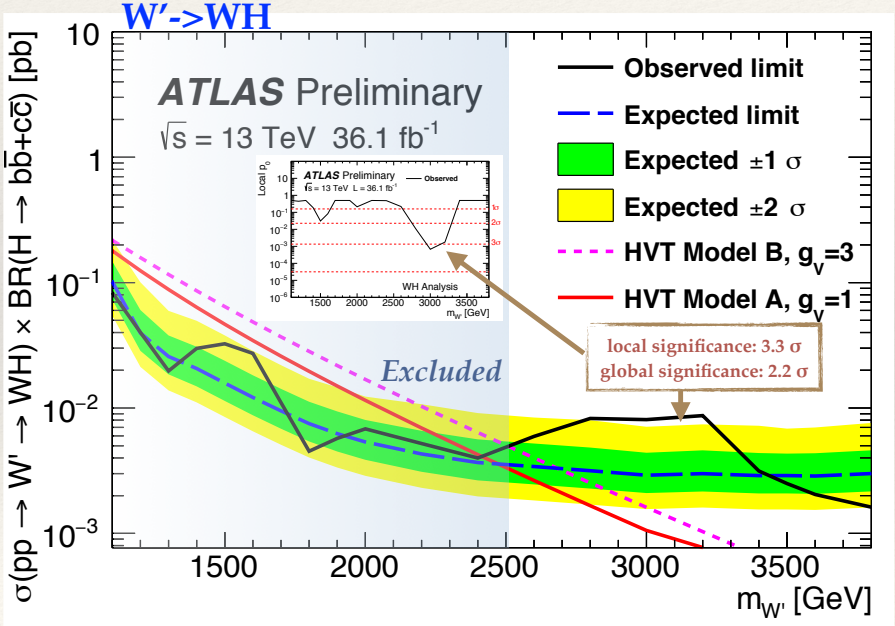
ATLAS-CONF-2017-018

New Results!

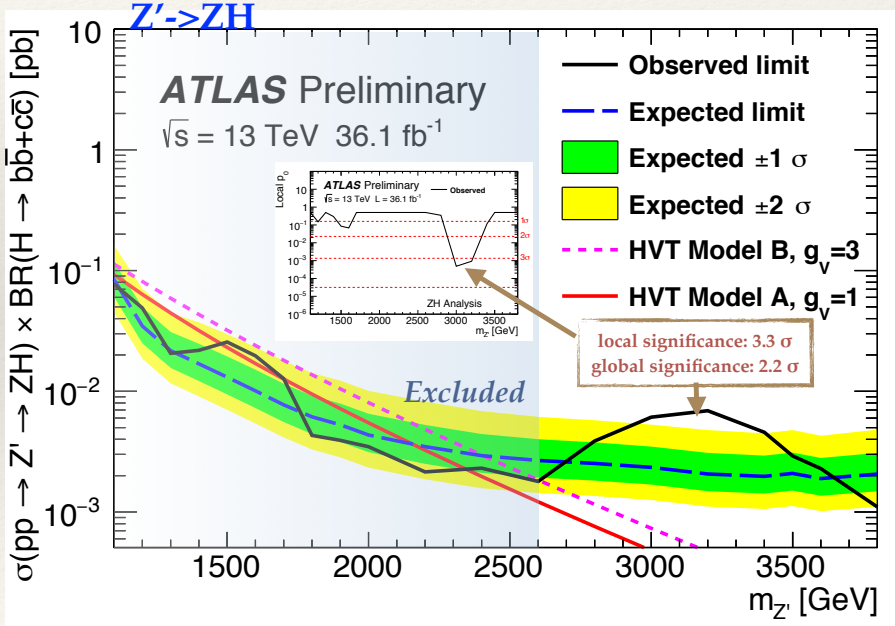
VH, all hadronic, ATLAS

- **Exclusion of HVT Model B(A) mass window 1.10 – 2.5(2.4) TeV for WH, and 1.10 – 2.6(2.3) TeV for ZH.**
- **Largest excess at ~ 3.0 TeV with a local significance of 3.3 σ and a global significance of 2.2 σ.**

W′->WH



Z′->ZH



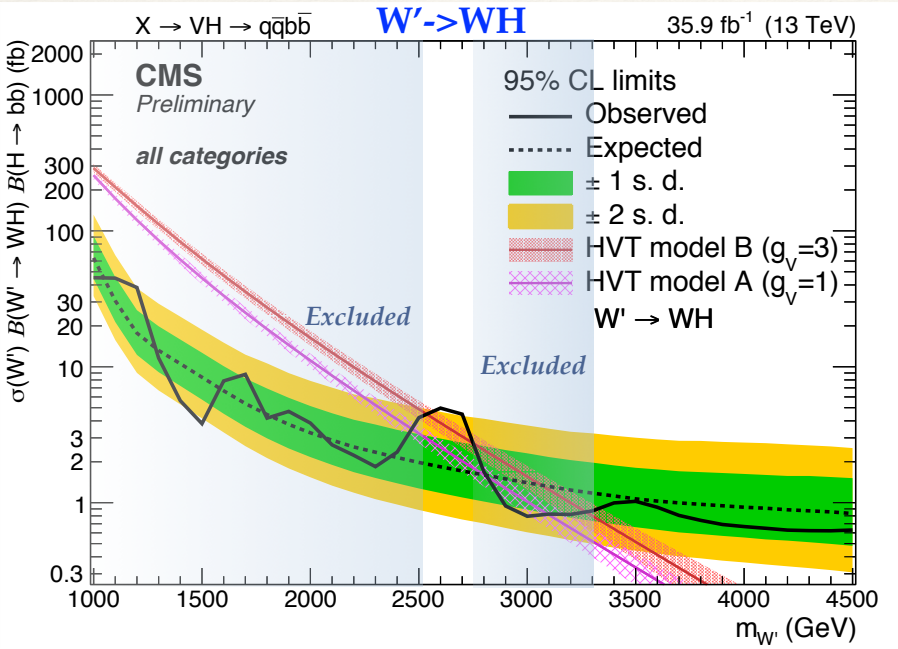
Resonances in VH (W', Z') [talk by Li]

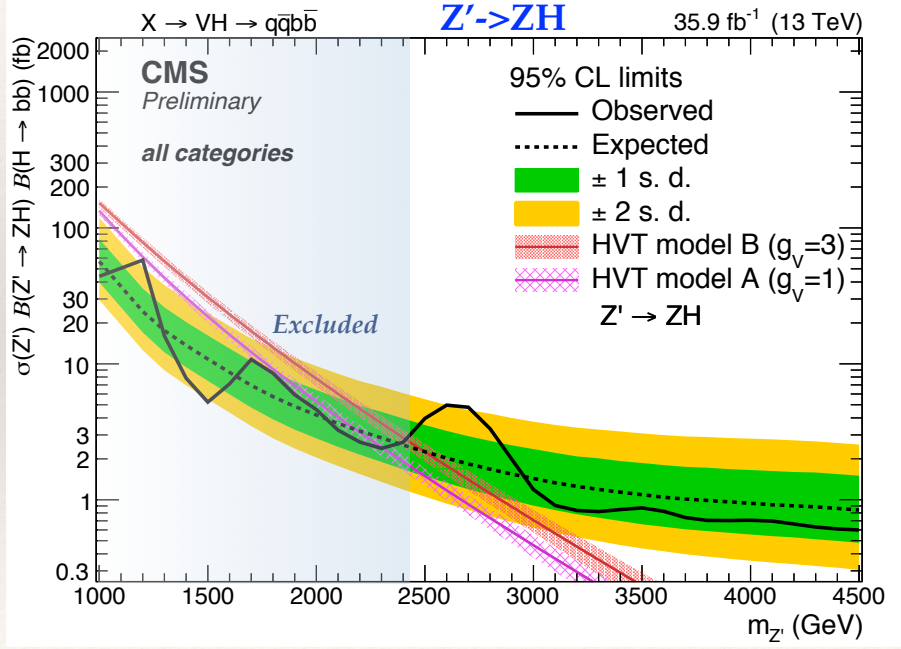
CMS-PAS-B2G-17-002

New Results!

VH, all hadronic, CMS

- Excluded HVT Model B(A) for mass regions 1.0-2.54(2.46) and 2.76(2.82)-3.3(3.1) TeV for WH, and 1.0-2.41(2.31) TeV for ZH.
- The excess observed by ATLAS with a local significance of 3.3 σ at ~3.0 TeV is not observed at CMS.





Summary

- Many interesting new results and nice presentations
- Unique atmosphere, promotes interaction between exp and th
- Precision Higgs physics is now an established, flourishing field. I am eagerly awaiting for new Run-2 results (and for the HL-LHC!)
- LHC becoming competitive with Tevatron for Top and W mass measurements
- Underfluctuation of juicy, unexplained excesses (3TeV in ZH by ATLAS? not by CMS)
- Check out LHCb for news on flavor anomalies!
- The BSM graveyard meanwhile grows ...

Thanks!