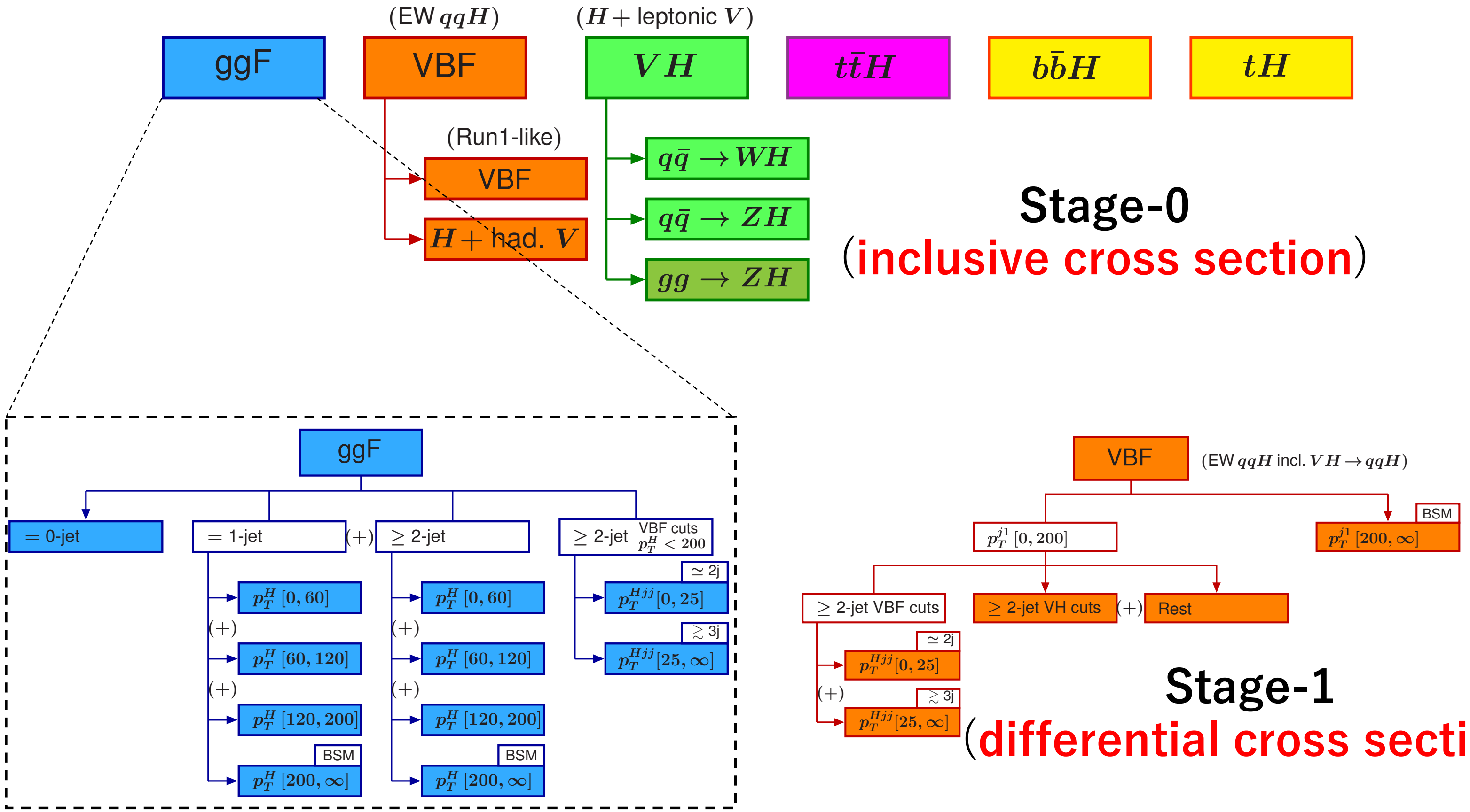
Combined Higgs boson measurements at the ATLAS experiment

Soshi Tsuno
on behalf of ATLAS Collaboration

Simplified Template Cross Section (STXS)

Theorists and Experimentalists agreed on “**common (model-independent) observables**”.

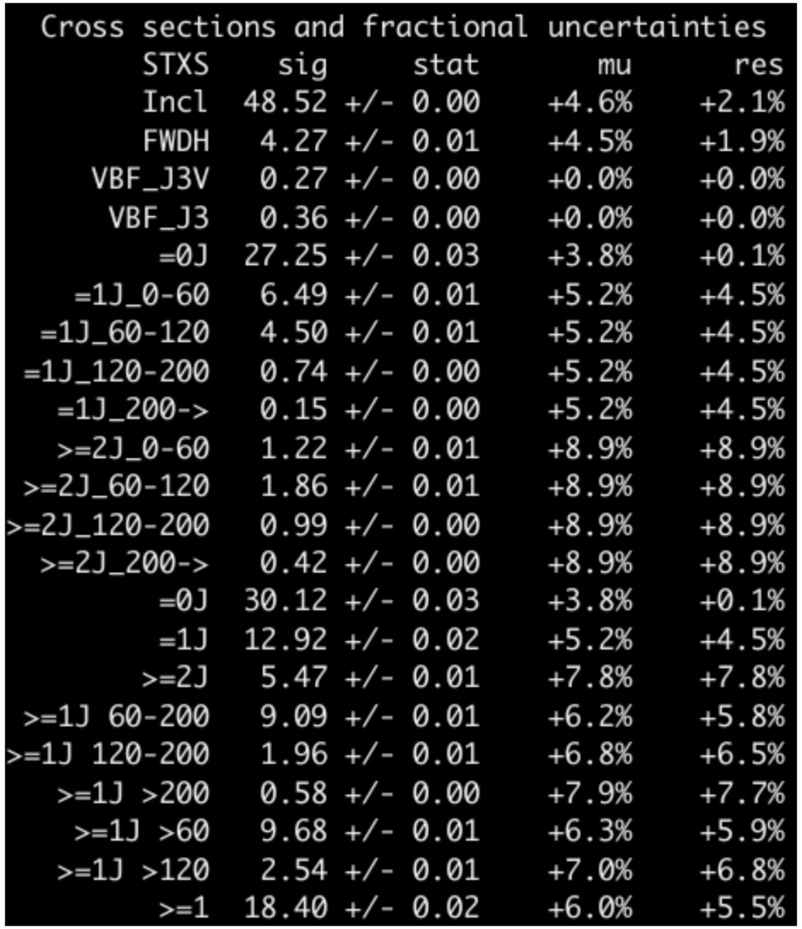
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG



Stage-0
(**inclusive cross section**)

Stage-1
(**differential cross section**)

Theory systematics are provided.



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 Cross sections and fractional uncertainties
        STXS     sig      stat        mu      res
        Incl  48.52 +/- 0.00       +4.6%    +2.1%
        FWDH   4.27 +/- 0.01       +4.5%    +1.9%
     VBF_J3V   0.27 +/- 0.00       +0.0%    +0.0%
      VBF_J3   0.36 +/- 0.00       +0.0%    +0.0%
         =0J  27.25 +/- 0.03       +3.8%    +0.1%
    =1J_0-60   6.49 +/- 0.01       +5.2%    +4.5%
  =1J_60-120   4.50 +/- 0.01       +5.2%    +4.5%
 =1J_120-200   0.74 +/- 0.00       +5.2%    +4.5%
   =1J_200->   0.15 +/- 0.00       +5.2%    +4.5%
   >=2J_0-60   1.22 +/- 0.01       +8.9%    +8.9%
 >=2J_60-120   1.86 +/- 0.01       +8.9%    +8.9%
>=2J_120-200   0.99 +/- 0.00       +8.9%    +8.9%
  >=2J_200->   0.42 +/- 0.00       +8.9%    +8.9%
         =0J  30.12 +/- 0.03       +3.8%    +0.1%
         =1J  12.92 +/- 0.02       +5.2%    +4.5%
        >=2J   5.47 +/- 0.01       +7.8%    +7.8%
 >=1J 60-200   9.09 +/- 0.01       +6.2%    +5.8%
>=1J 120-200   1.96 +/- 0.01       +6.8%    +6.5%
   >=1J >200   0.58 +/- 0.00       +7.9%    +7.7%
    >=1J >60   9.68 +/- 0.01       +6.3%    +5.9%
   >=1J >120   2.54 +/- 0.01       +7.0%    +6.8%
         >=1  18.40 +/- 0.02       +6.0%    +5.5%
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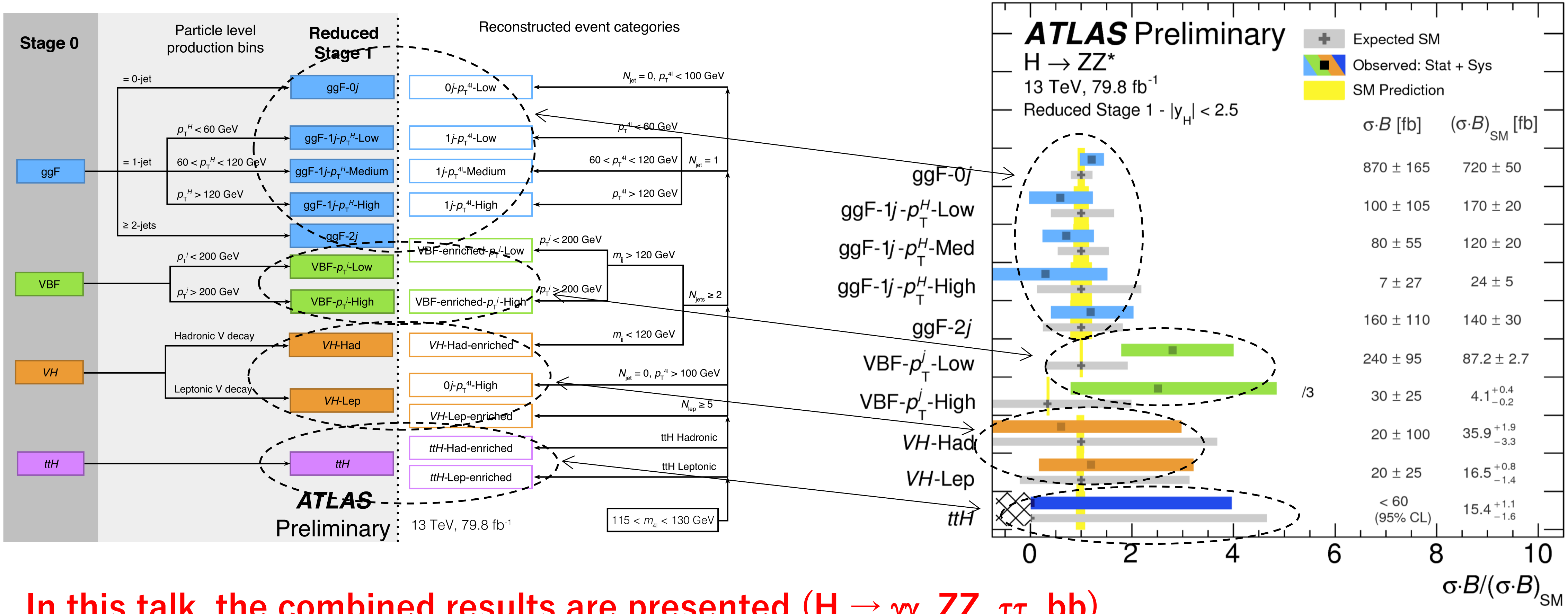
“bin size”, ”categorization” is well defined.

STXS example from individual channel

Example : H → ZZ → 4l channel

ATLAS-CONF-2018-018



In this talk, the combined results are presented (H → γγ, ZZ, ττ, bb)

Statistical combination

Construct profile likelihood :

$$\Lambda(\alpha) = \frac{L(\alpha, \hat{\hat{\theta}}(\alpha))}{L(\hat{\alpha}, \hat{\theta})}$$

θ(α) : nuisance parameters

Systematic uncertainties :

- **ID, JET, MET, TAU**
- **THEORY**

Treated as common across channels.

α : parameter of interests

The α might be the cross section, μ x σ(n_s),

$$n_k^{\text{signal}} = \mathcal{L}_k \sum_i \sum_f (\sigma \times \mathrm{B})_{if} (A \times \epsilon)_{if,k}$$

- Production i = ggF, VBF, WH, ZH, ttH …
- Decay f = γγ, ZZ, WW, ττ, bb

And signal strength μ :

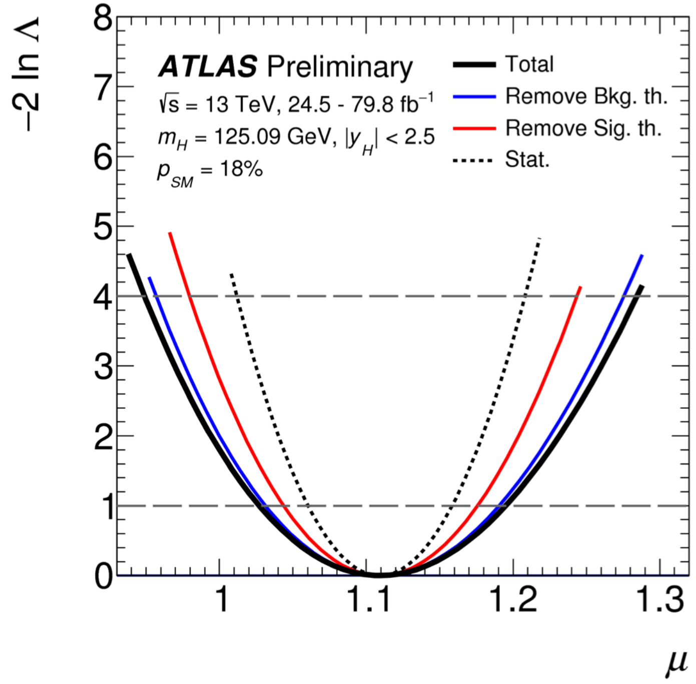
$$\mu_{if} = \frac{\sigma_i}{\sigma_i^{\text{SM}}} \times \frac{\mathrm{B}_f}{\mathrm{B}_f^{\text{SM}}}$$

Maximize -2log(Λ(α)) :

follows χ^2 distribution

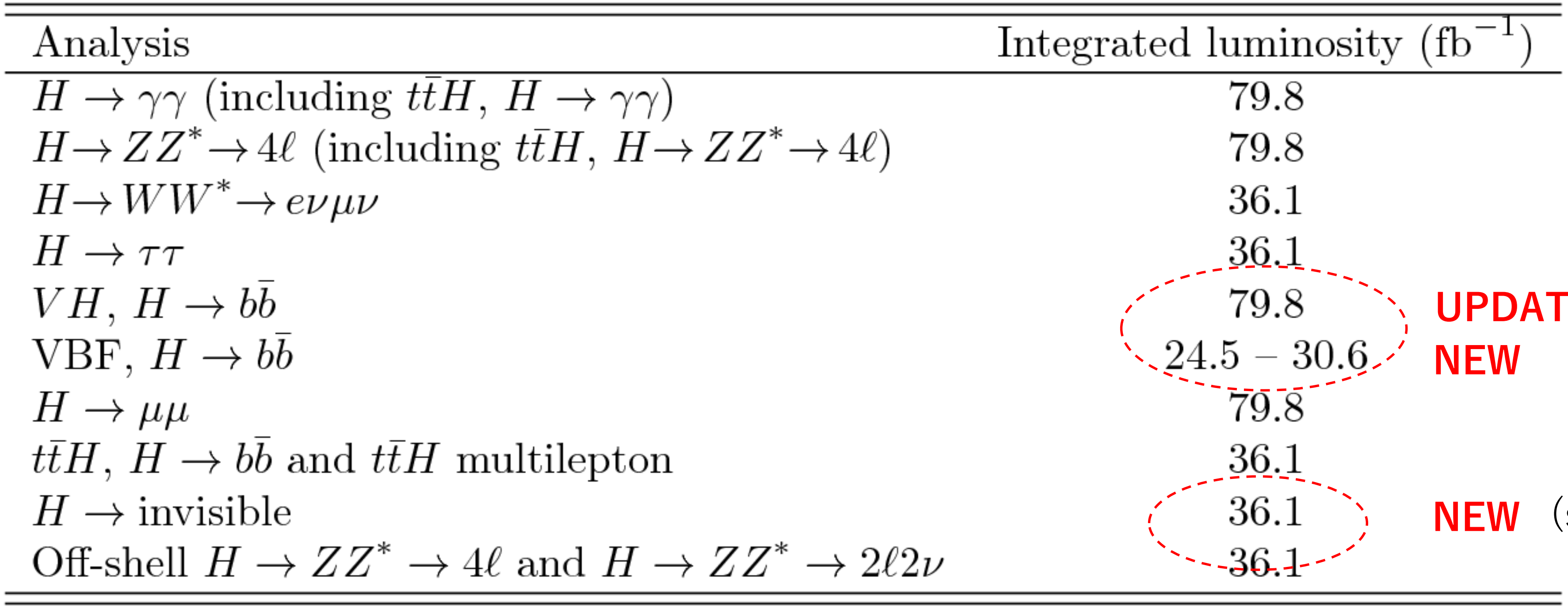
with

- $\hat{\alpha}$, $\hat{\theta}$ is the best fit values
- $\hat{\hat{\theta}}$ is the value at given α



Higgs combination

Reference : ATLAS-CONF-2019-005



Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
VBF, $H \to b\bar{b}$	24.5 – 30.6
$H \to \mu\mu$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$H \to$ invisible	36.1
Off-shell $H \to ZZ^* \to 4\ell$ and $H \to ZZ^* \to 2\ell 2\nu$	36.1

UPDATE (previous: 36.1fb^{-1})

NEW

NEW (see talk by Tulay)

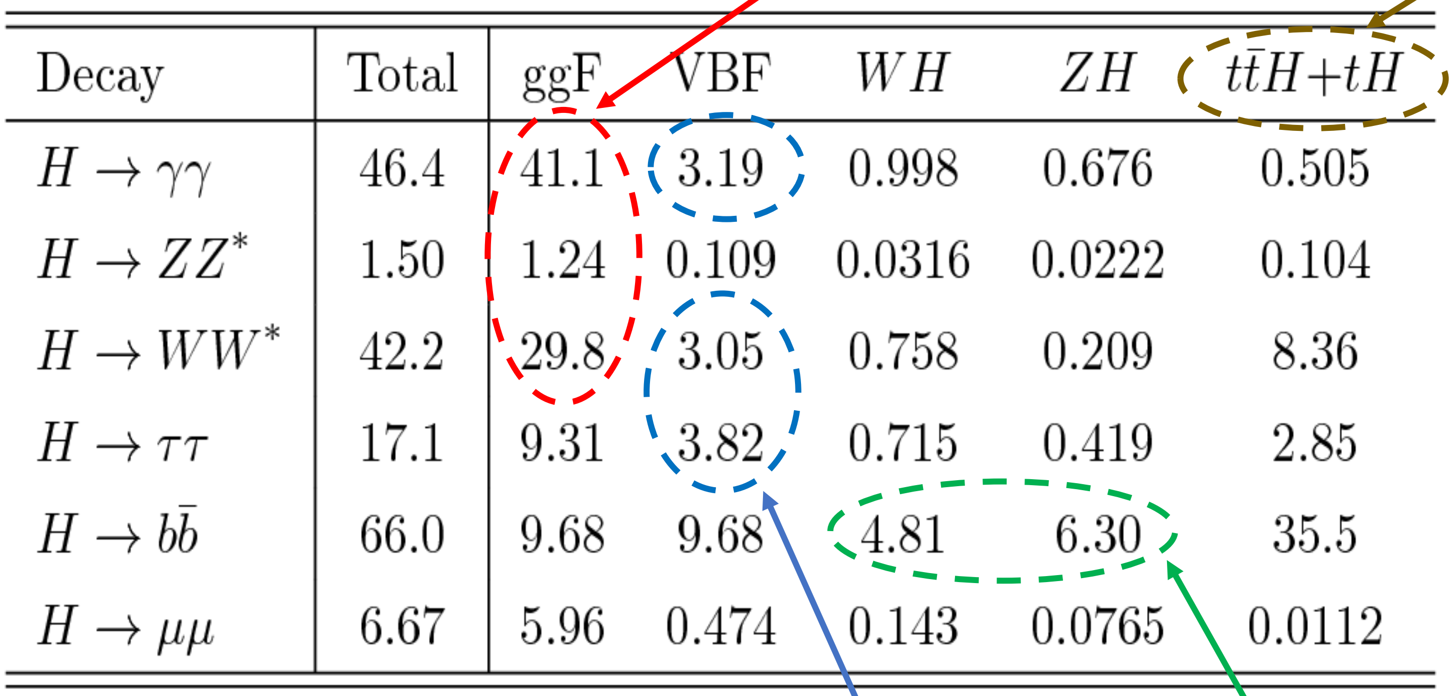
(%) **Signal samples**: gluon-fusion : PowHeg Box NNLOPS, normalized to N^3LO QCD + NLO EW corrections

VBF/VH/ttH : PowHeg Box NLO, normalized to NNLO QCD + NLO EW corrections (except ttH)

w/ PDF4LHC15

Signal yield

Average # of signal per 1fb^{-1}



Decay	Total	ggF	VBF	WH	ZH	$t\bar{t}H+tH$
$H \to \gamma\gamma$	46.4	41.1	3.19	0.998	0.676	0.505
$H \to ZZ^*$	1.50	1.24	0.109	0.0316	0.0222	0.104
$H \to WW^*$	42.2	29.8	3.05	0.758	0.209	8.36
$H \to \tau\tau$	17.1	9.31	3.82	0.715	0.419	2.85
$H \to b\bar{b}$	66.0	9.68	9.68	4.81	6.30	35.5
$H \to \mu\mu$	6.67	5.96	0.474	0.143	0.0765	0.0112

Sensitive to ggH

Direct measurement

Sensitive to VBF

Sensitive to VH

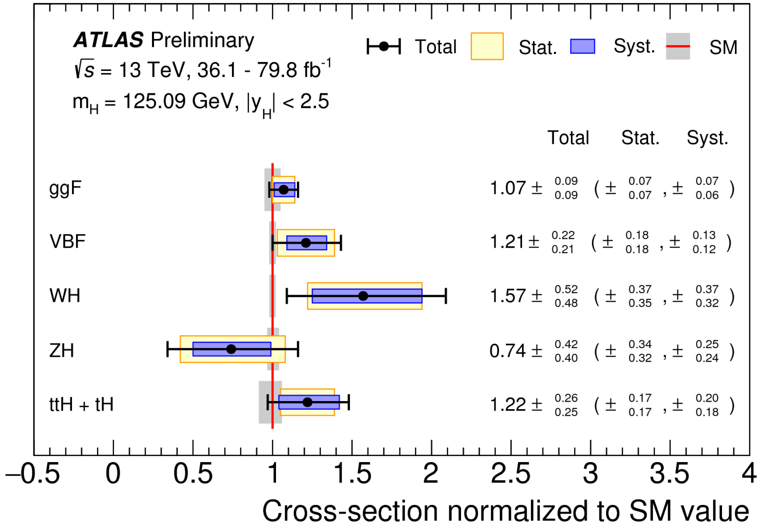
S/sqrt(B)	Reference
~6@79.8fb^{-1}	ATLAS-CONF-2018-028
~9@79.8fb^{-1}	ATLAS-CONF-2018-018
~9.6@36.1fb^{-1}	ATLAS-CONF-2018-004
~6.5@36.1fb^{-1}	ATLAS-CONF-2018-021
~5.4@79.8fb^{-1}	Phys.Lett.B786(2018)59

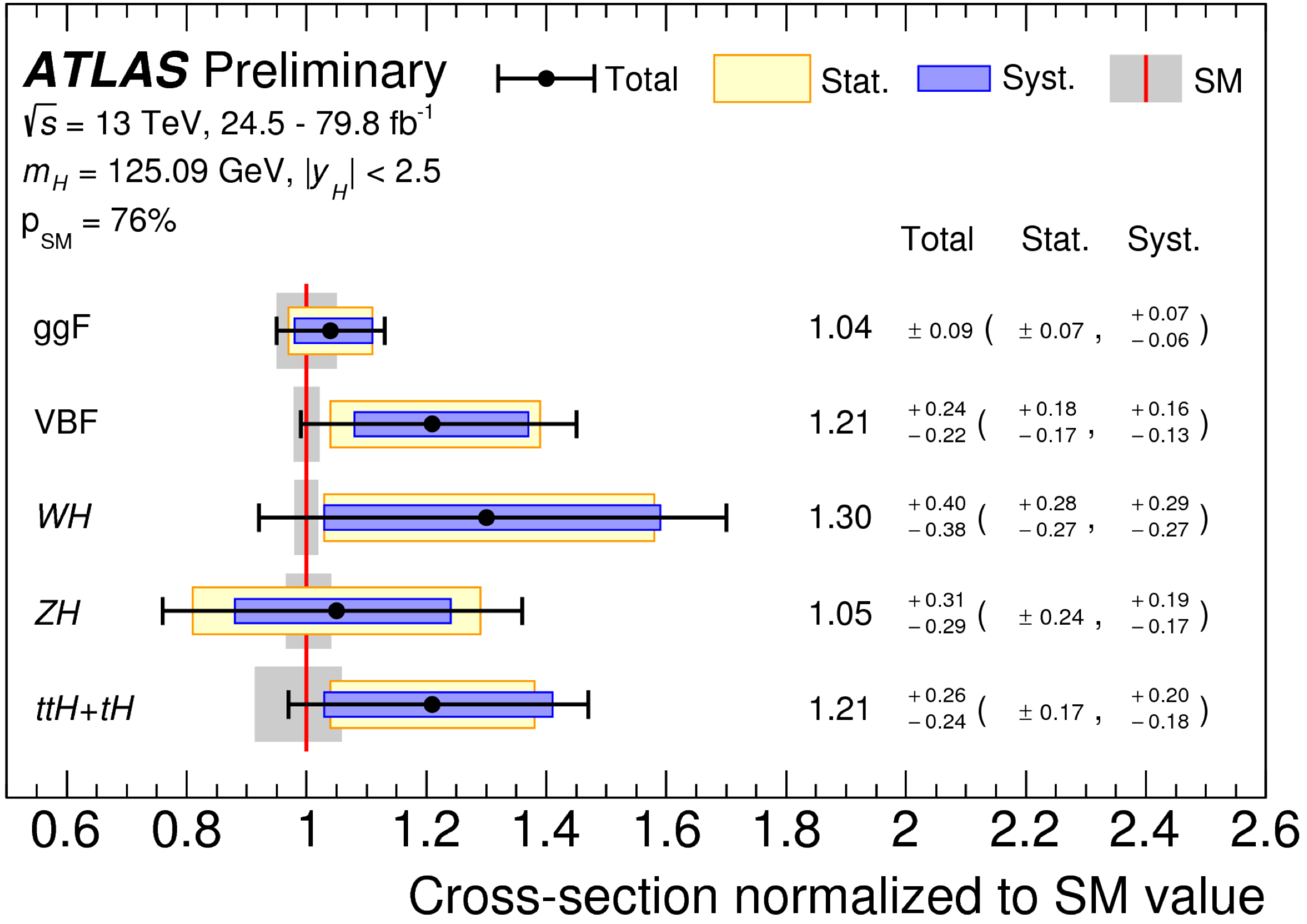
Production cross sections

Increased statistics in VH channel.
($36.1fb^{-1}$ => $79.8fb^{-1}$)

Assuming the SM branching ratio, consistent with SM prediction.

Mild deviation of VBF is from H → ZZ → 4l.



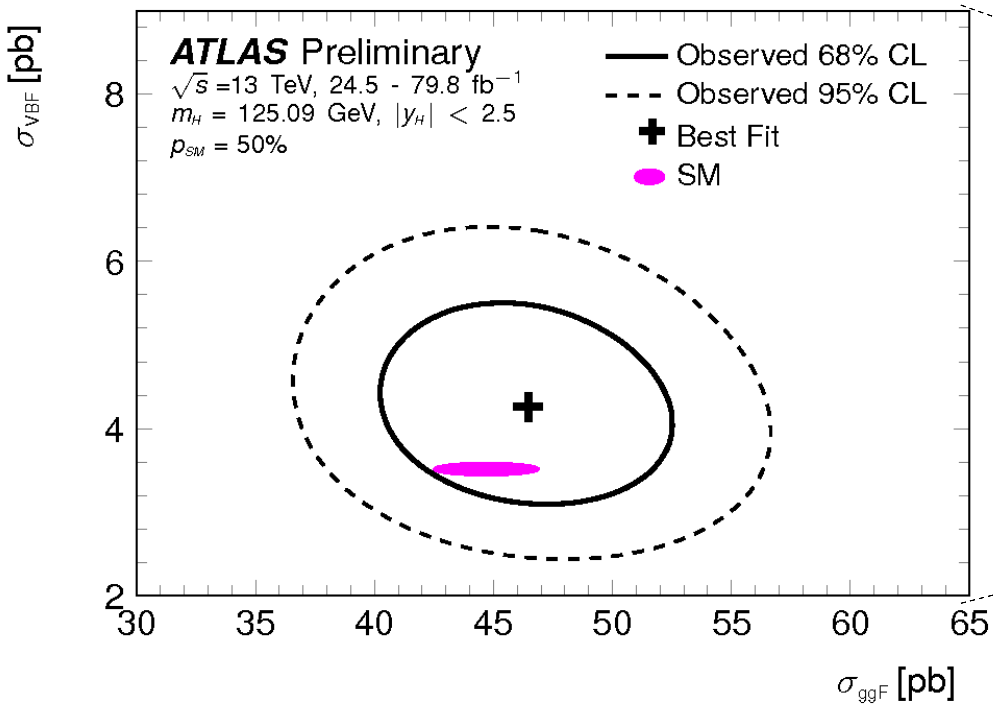


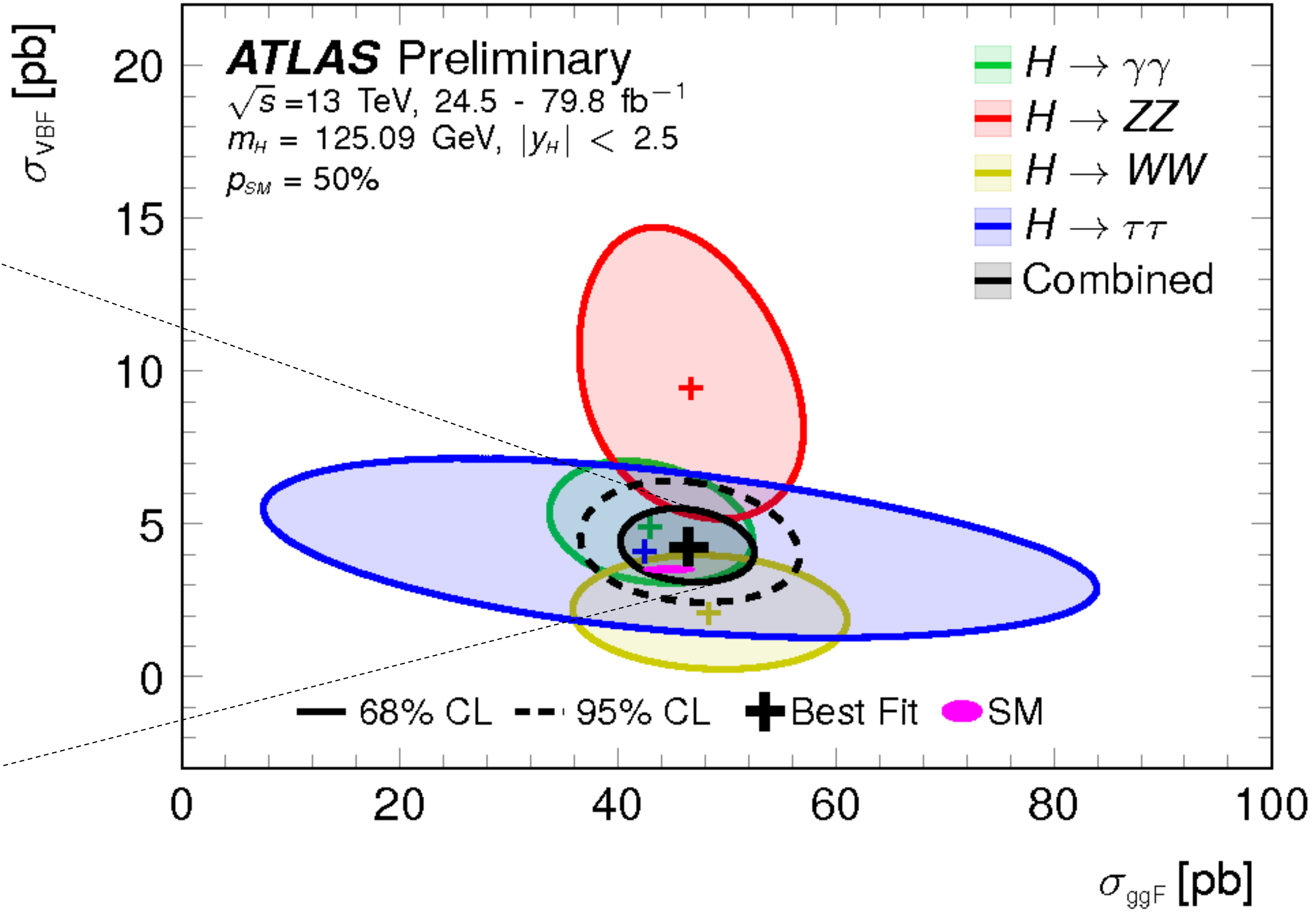
$\sigma_H(SM) = 55.6^{+2.4}_{-3.4}$ pb @ $N^3LO(QCD)+NLO(EW)$

SM compatibility

H → γγ mode is the strongest.

H → ZZ → 4l mode has limited statistics for measuring the VBF production.





Systematic uncertainties

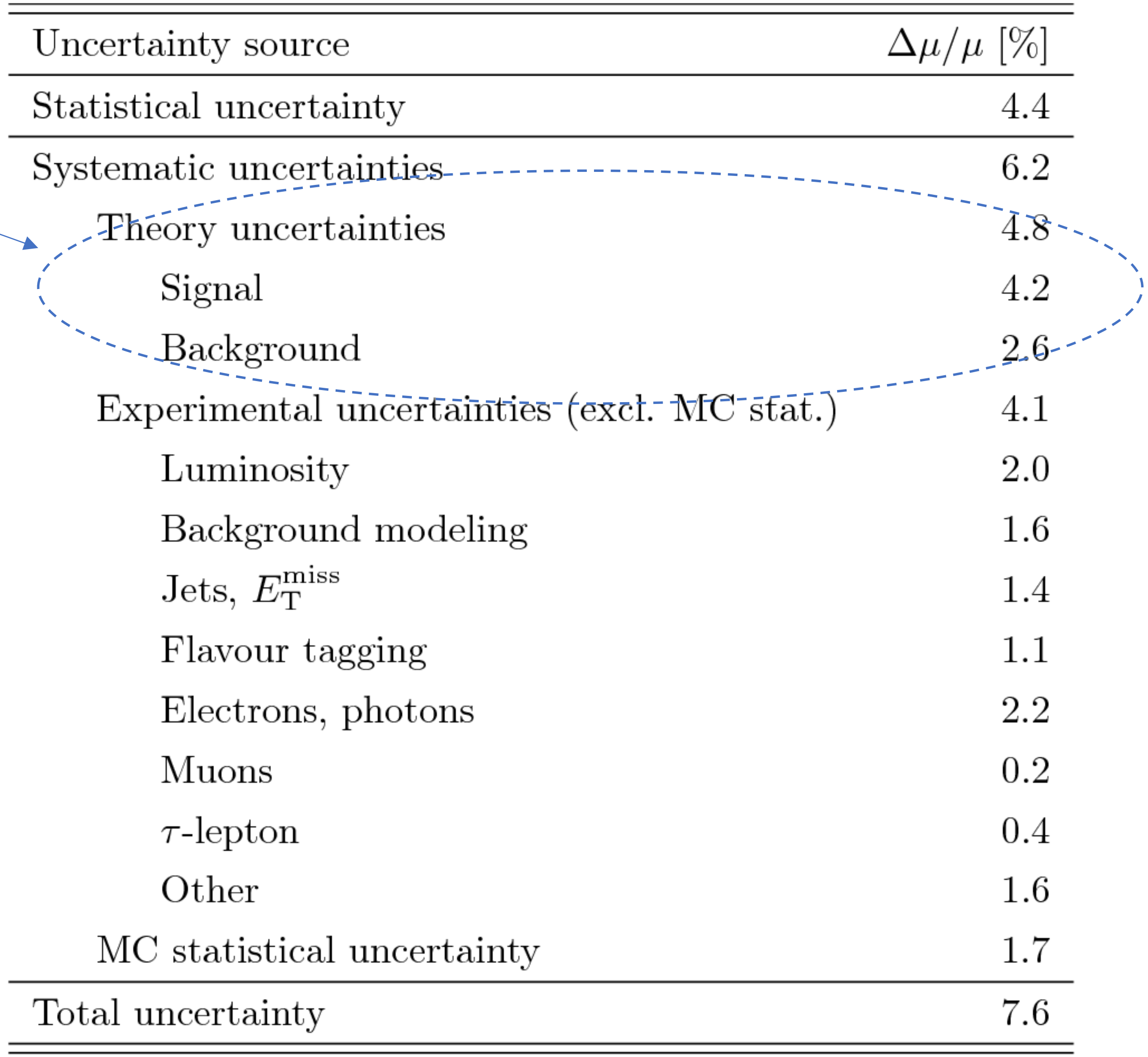
Theory and experimental uncertainties are almost same order (~4-5%).

Luminosity and photon uncertainties are leading source of systematics.

Jet/MET/tau uncertainties are relatively small, since dominant modes are H → $\gamma\gamma$ and ZZ.

If full Run-2 dataset (~140fb^{-1}) is included, the situation might be different.

Thanks for data-driven background estimation method, the background theory uncertainty is under control in 2-3%.



Uncertainty source	$\Delta\mu/\mu$ [%]
Statistical uncertainty	4.4
Systematic uncertainties	6.2
Theory uncertainties	4.8
Signal	4.2
Background	2.6
Experimental uncertainties (excl. MC stat.)	4.1
Luminosity	2.0
Background modeling	1.6
Jets, $E_{\mathrm{T}}^{\mathrm{miss}}$	1.4
Flavour tagging	1.1
Electrons, photons	2.2
Muons	0.2
τ-lepton	0.4
Other	1.6
MC statistical uncertainty	1.7
Total uncertainty	7.6

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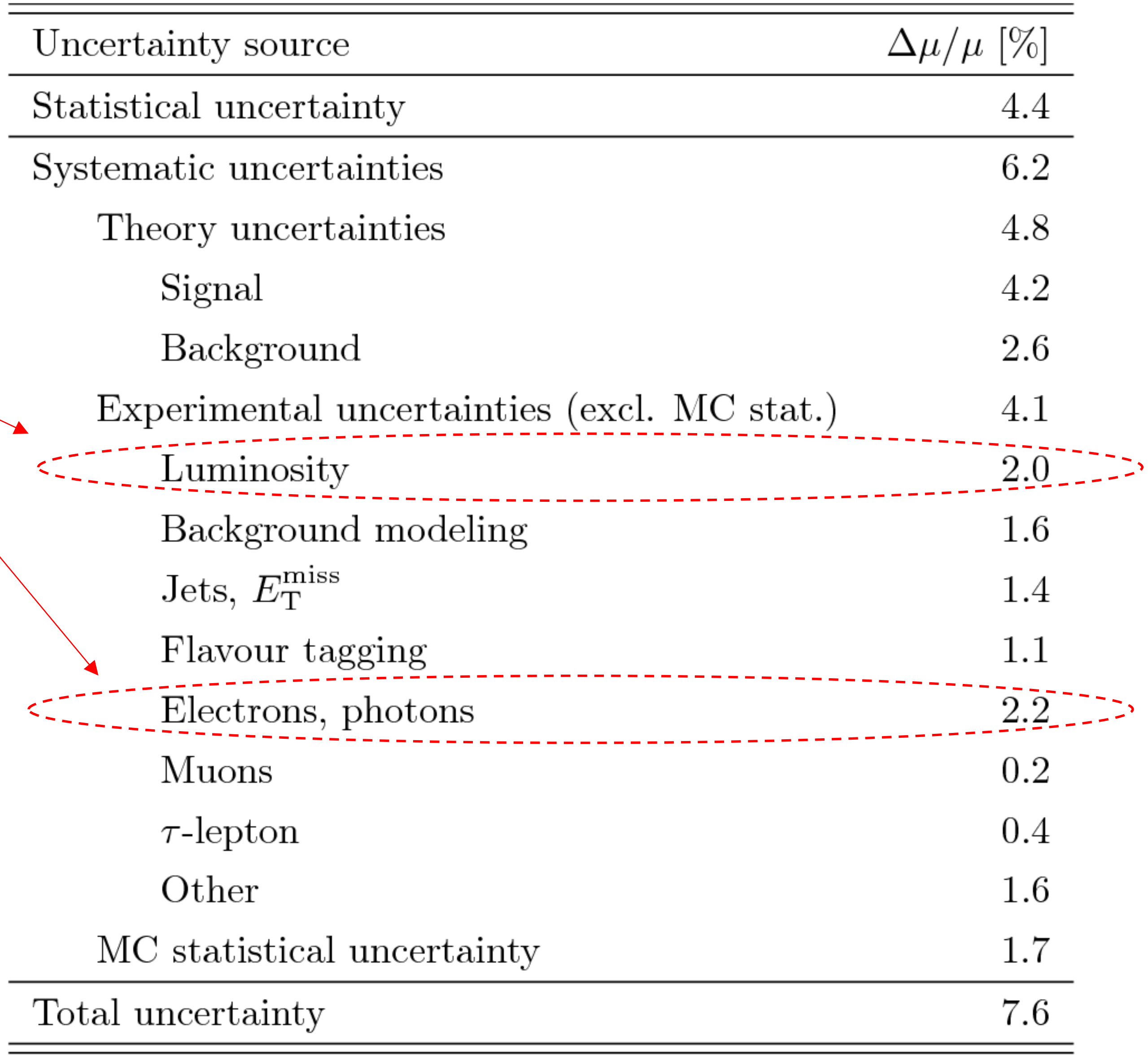

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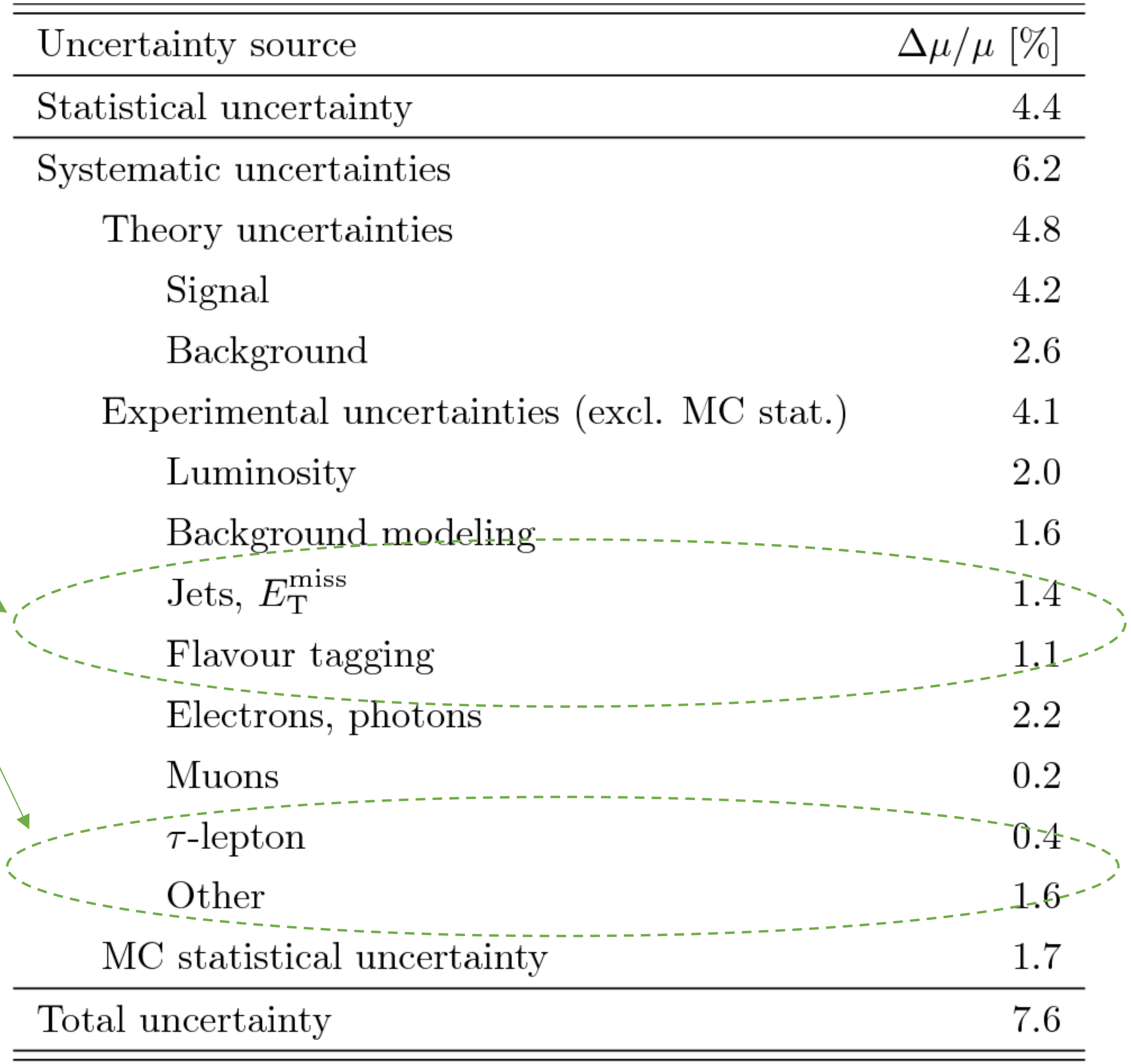

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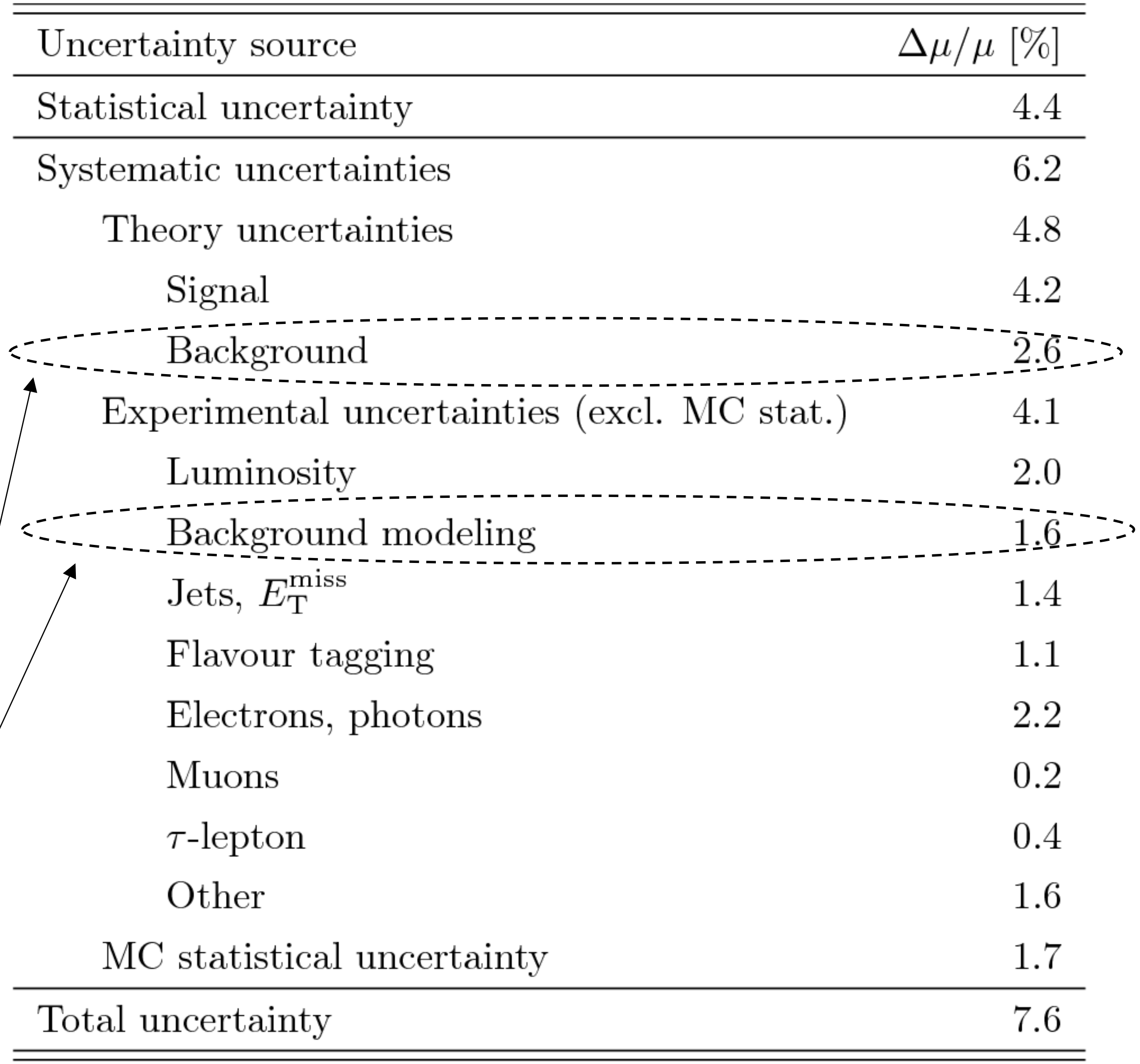

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Further systematic breakdown

Driven by H → γγ, ZZ

H → ττ, WW

H → bb

modeling of top background

Uncertainty source	$\frac{\Delta\sigma_{\mathrm{ggF}}}{\sigma_{\mathrm{ggF}}}$ [%]	$\frac{\Delta\sigma_{\mathrm{VBF}}}{\sigma_{\mathrm{VBF}}}$ [%]	$\frac{\Delta\sigma_{WH}}{\sigma_{WH}}$ [%]	$\frac{\Delta\sigma_{ZH}}{\sigma_{ZH}}$ [%]	$\frac{\Delta\sigma_{t\bar{t}H+tH}}{\sigma_{t\bar{t}H+tH}}$ [%]
Statistical uncertainties	6.4	15	21	23	14
Systematic uncertainties	6.2	12	22	17	15
Theory uncertainties	3.4	9.2	14	14	12
Signal	2.0	8.7	5.8	6.7	6.3
Background	2.7	3.0	13	12	10
Experimental uncertainties (excl. MC stat.)	5.0	6.5	9.9	9.6	9.2
Luminosity	2.1	1.8	1.8	1.8	3.1
Background modeling	2.5	2.2	4.7	2.9	5.7
Jets, $E_{\mathrm{T}}^{\mathrm{miss}}$	0.9	5.4	3.0	3.3	4.0
Flavour tagging	0.9	1.3	7.9	8.0	1.8
Electrons, photons	2.5	1.7	1.8	1.5	3.8
Muons	0.4	0.3	0.1	0.2	0.5
τ-lepton	0.2	1.3	0.3	0.1	2.4
Other	2.5	1.2	0.3	1.1	0.8
MC statistical uncertainties	1.6	4.8	8.8	7.9	4.4
Total uncertainties	8.9	19	30	29	21

Jet/MET

flavor tagging

lepton (e, μ) identification

Ratio respect to $\boldsymbol{\sigma}_{ggF}$ and B_{ZZ}

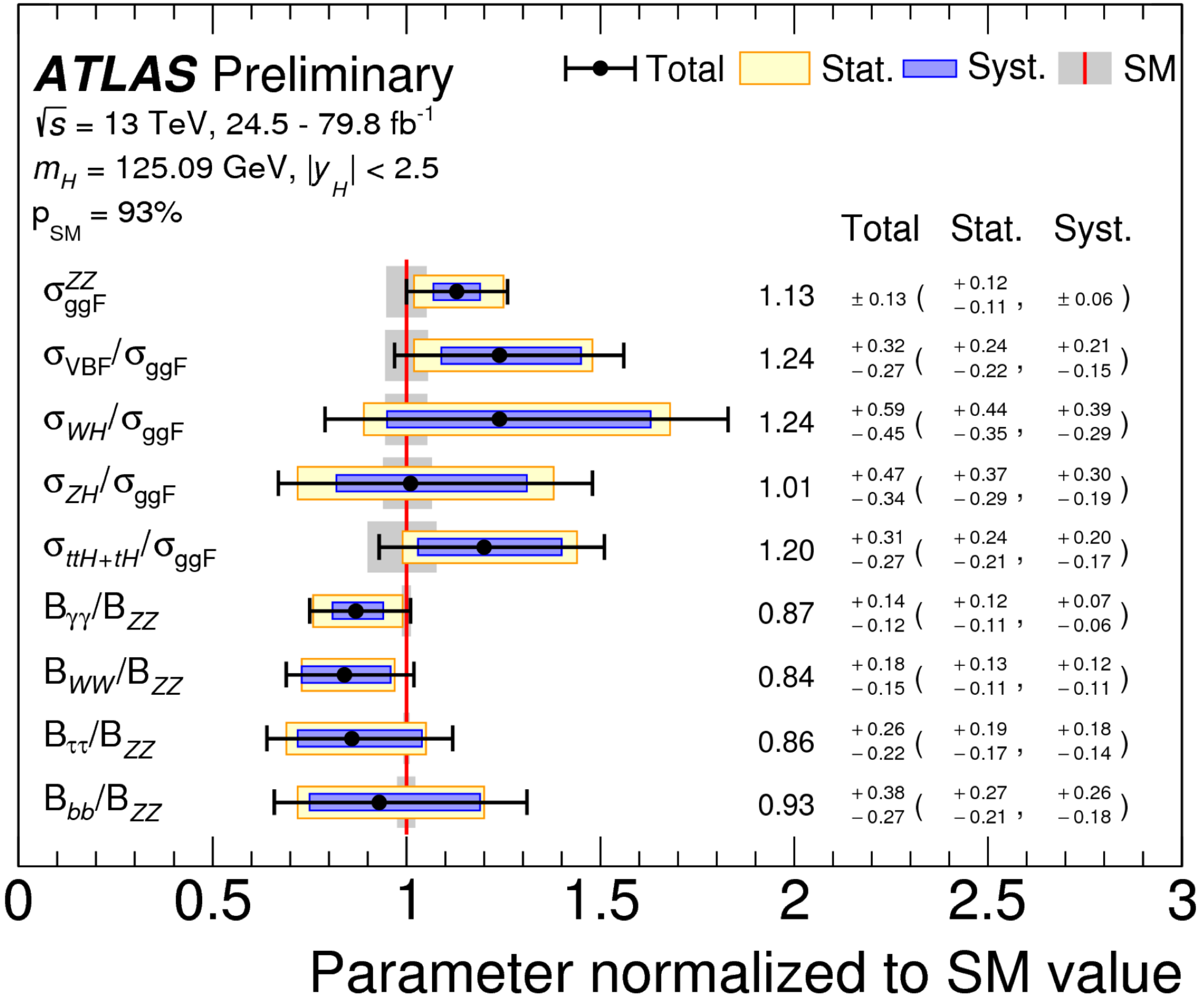
Get the values without SM assumption.

→ **less model-dependent**

Use measured cross section (ggF).

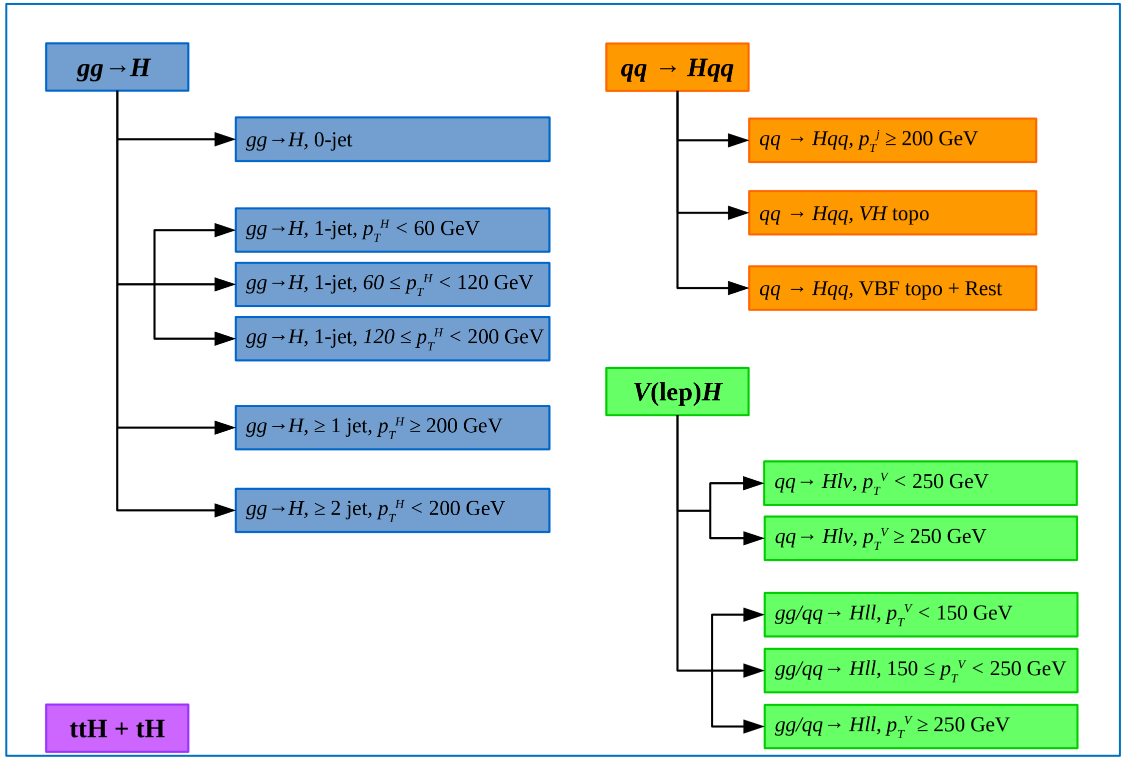
Cancel some systematic uncertainty.

So far, measured B_{ZZ} has higher value than prediction. Thus, ratio of B presents below 1.



STXS : Stage-1 results

Example of 15 exclusive STXS regions



$gg \to H$

- $gg \to H$, 0-jet
- $gg \to H$, 1-jet, $p_T^H < 60$ GeV
- $gg \to H$, 1-jet, $60 \le p_T^H < 120$ GeV
- $gg \to H$, 1-jet, $120 \le p_T^H < 200$ GeV
- $gg \to H$, ≥ 1 jet, $p_T^H \ge 200$ GeV
- $gg \to H$, ≥ 2 jet, $p_T^H < 200$ GeV

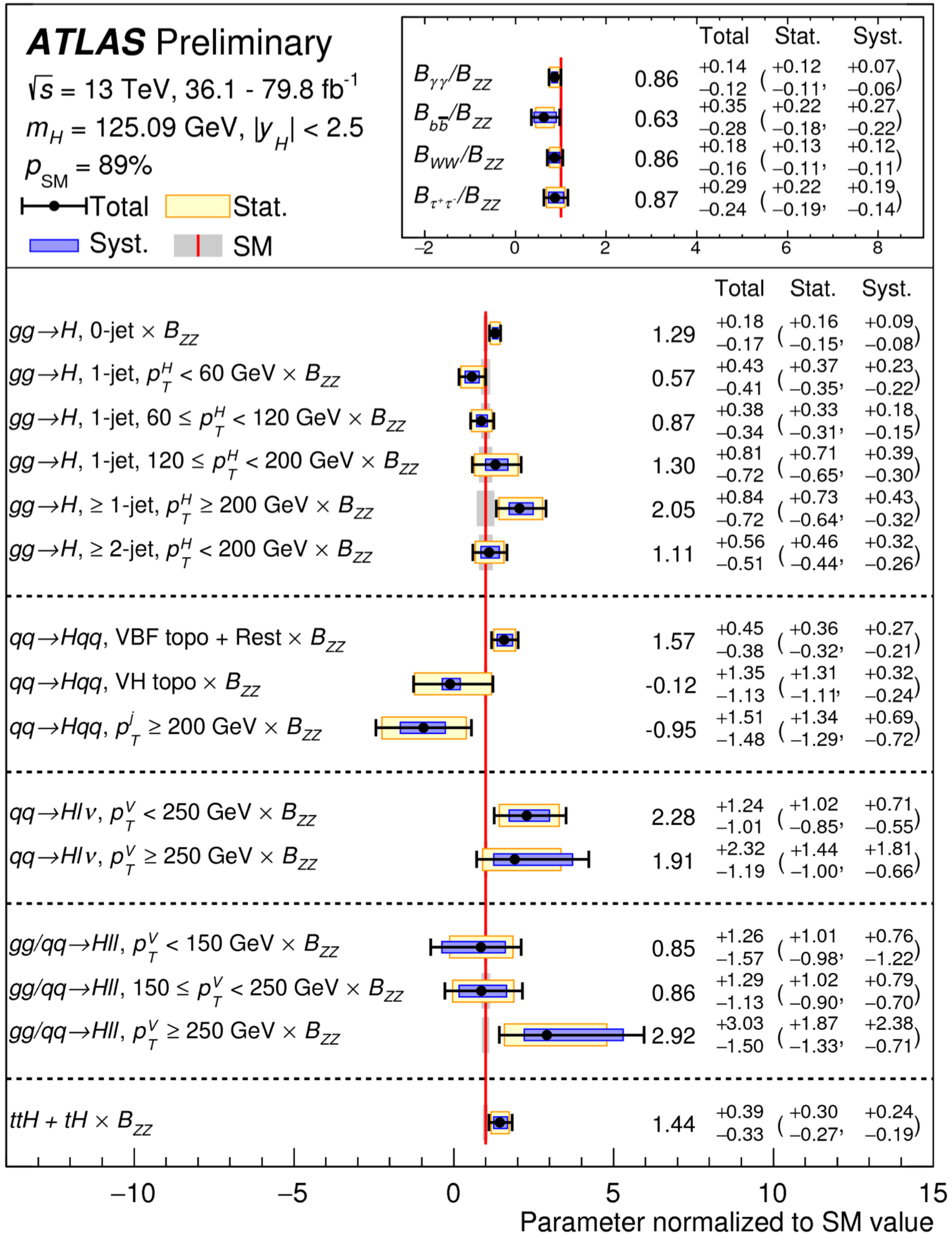
$qq \to Hqq$

- $qq \to Hqq$, $p_T^j \ge 200$ GeV
- $qq \to Hqq$, VH topo
- $qq \to Hqq$, VBF topo + Rest

$V(lep)H$

- $qq \to Hl\nu$, $p_T^V < 250$ GeV
- $qq \to Hl\nu$, $p_T^V \ge 250$ GeV
- $gg/qq \to Hll$, $p_T^V < 150$ GeV
- $gg/qq \to Hll$, $150 \le p_T^V < 250$ GeV
- $gg/qq \to Hll$, $p_T^V \ge 250$ GeV

ttH + tH

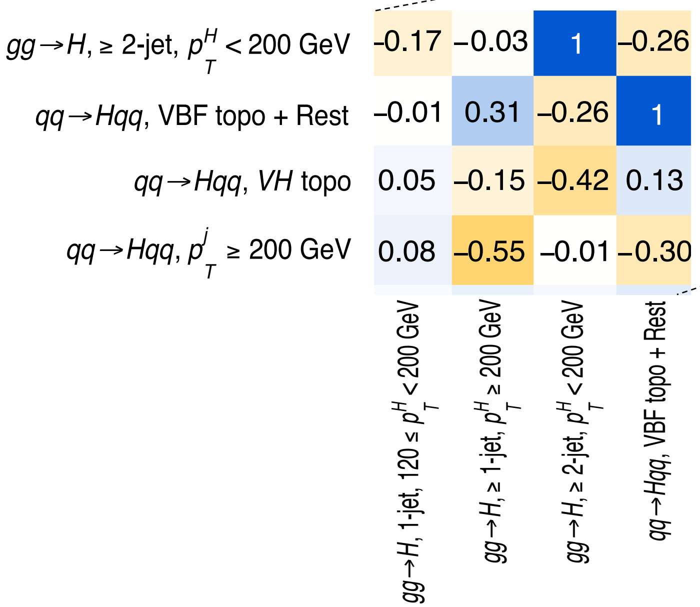


High $p_T(H)$ region is sensitive to BSM signal.

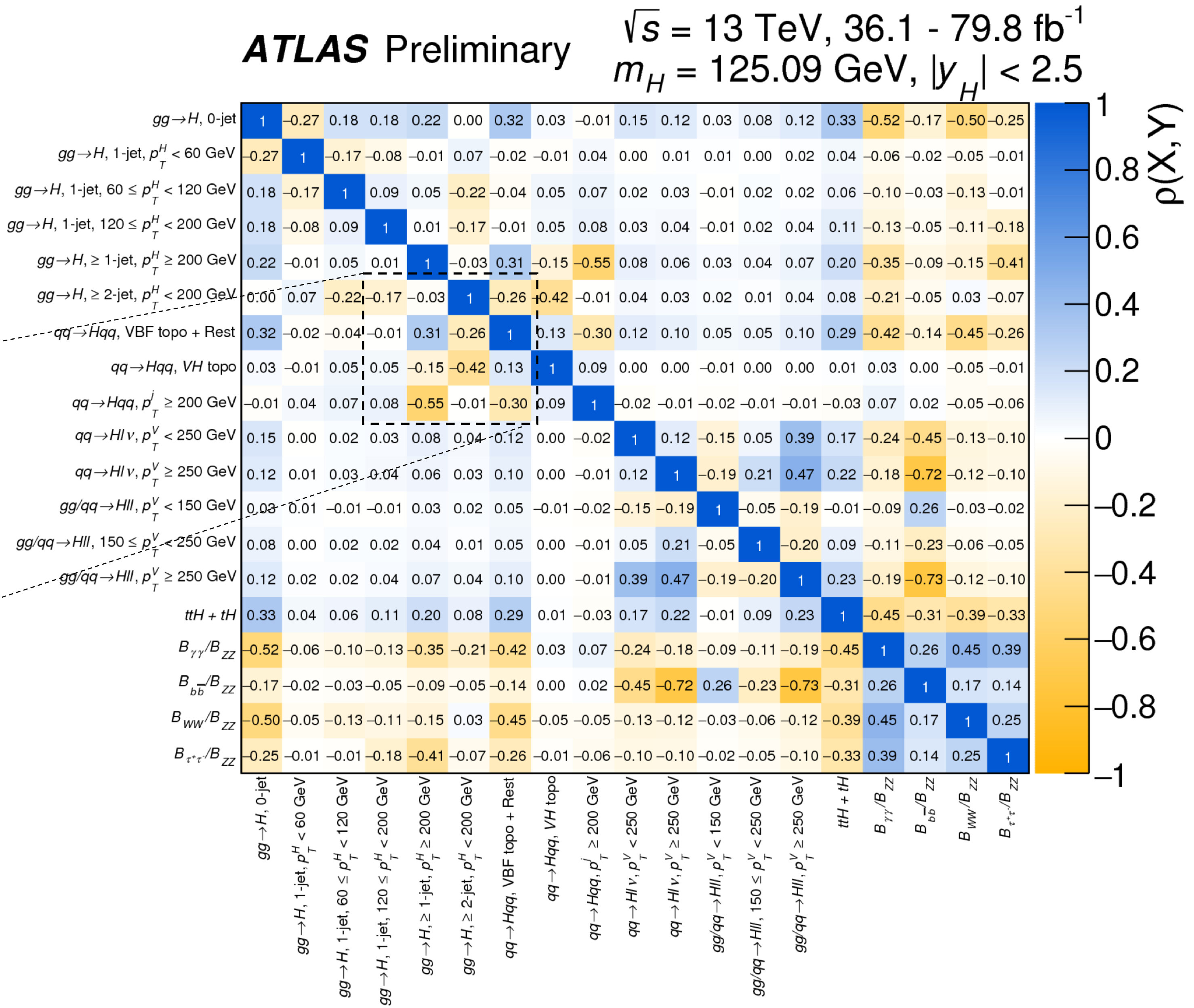
Correlation matrix

Mostly, the correlation is weak.
(each exclusive region is well defined.)

Strong correlation to be understood:

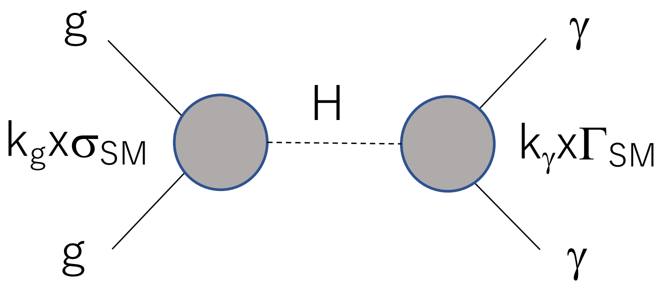


	$gg\to H$, 1-jet, $120 \le p_T^H < 200$ GeV	$gg\to H$, $\ge$ 1-jet, $p_T^H \ge 200$ GeV	$gg\to H$, $\ge$ 2-jet, $p_T^H < 200$ GeV	$qq\to Hqq$, VBF topo + Rest
$gg\to H$, $\ge$ 2-jet, $p_T^H < 200$ GeV	–0.17	–0.03	1	–0.26
$qq\to Hqq$, VBF topo + Rest	–0.01	0.31	–0.26	1
$qq\to Hqq$, VH topo	0.05	–0.15	–0.42	0.13
$qq\to Hqq$, $p_T^j \ge 200$ GeV	0.08	–0.55	–0.01	–0.30



	$gg\to H$, 0-jet	$gg\to H$, 1-jet, $p_T^H < 60$ GeV	$gg\to H$, 1-jet, $60 \le p_T^H < 120$ GeV	$gg\to H$, 1-jet, $120 \le p_T^H < 200$ GeV	$gg\to H$, $\ge$ 1-jet, $p_T^H \ge 200$ GeV	$gg\to H$, $\ge$ 2-jet, $p_T^H < 200$ GeV	$qq\to Hqq$, VBF topo + Rest	$qq\to Hqq$, VH topo	$qq\to Hqq$, $p_T^j \ge 200$ GeV	$qq\to Hl\nu$, $p_T^V < 250$ GeV	$qq\to Hl\nu$, $p_T^V \ge 250$ GeV	$gg/qq\to Hll$, $p_T^V < 150$ GeV	$gg/qq\to Hll$, $150 \le p_T^V < 250$ GeV	$gg/qq\to Hll$, $p_T^V \ge 250$ GeV	$ttH + tH$	$B_{\gamma\gamma}/B_{ZZ}$	$B_{b\bar{b}}/B_{ZZ}$	B_{WW}/B_{ZZ}	$B_{\tau^+\tau^-}/B_{ZZ}$
$gg\to H$, 0-jet	1	–0.27	0.18	0.18	0.22	0.00	0.32	0.03	–0.01	0.15	0.12	0.03	0.08	0.12	0.33	–0.52	–0.17	–0.50	–0.25
$gg\to H$, 1-jet, $p_T^H < 60$ GeV	–0.27	1	–0.17	–0.08	–0.01	0.07	–0.02	–0.01	0.04	0.00	0.01	0.01	0.00	0.02	0.04	–0.06	–0.02	–0.05	–0.01
$gg\to H$, 1-jet, $60 \le p_T^H < 120$ GeV	0.18	–0.17	1	0.09	0.05	–0.22	–0.04	0.05	0.07	0.02	0.03	–0.01	0.02	0.02	0.06	–0.10	–0.03	–0.13	–0.01
$gg\to H$, 1-jet, $120 \le p_T^H < 200$ GeV	0.18	–0.08	0.09	1	0.01	–0.17	–0.01	0.05	0.08	0.03	0.04	–0.01	0.02	0.04	0.11	–0.13	–0.05	–0.11	–0.18
$gg\to H$, $\ge$ 1-jet, $p_T^H \ge 200$ GeV	0.22	–0.01	0.05	0.01	1	–0.03	0.31	–0.15	–0.55	0.08	0.06	0.03	0.04	0.07	0.20	–0.35	–0.09	–0.15	–0.41
$gg\to H$, $\ge$ 2-jet, $p_T^H < 200$ GeV	0.00	0.07	–0.22	–0.17	–0.03	1	–0.26	–0.42	–0.01	0.04	0.03	0.02	0.01	0.04	0.08	–0.21	–0.05	0.03	–0.07
$qq\to Hqq$, VBF topo + Rest	0.32	–0.02	–0.04	–0.01	0.31	–0.26	1	0.13	–0.30	0.12	0.10	0.05	0.05	0.10	0.29	–0.42	–0.14	–0.45	–0.26
$qq\to Hqq$, VH topo	0.03	–0.01	0.05	0.05	–0.15	–0.42	0.13	1	0.09	0.00	0.00	–0.01	0.00	0.00	0.01	0.03	0.00	–0.05	–0.01
$qq\to Hqq$, $p_T^j \ge 200$ GeV	–0.01	0.04	0.07	0.08	–0.55	–0.01	–0.30	0.09	1	–0.02	–0.01	–0.02	–0.01	–0.01	–0.03	0.07	0.02	–0.05	–0.06
$qq\to Hl\nu$, $p_T^V < 250$ GeV	0.15	0.00	0.02	0.03	0.08	0.04	0.12	0.00	–0.02	1	0.12	–0.15	0.05	0.39	0.17	–0.24	–0.45	–0.13	–0.10
$qq\to Hl\nu$, $p_T^V \ge 250$ GeV	0.12	0.01	0.03	0.04	0.06	0.03	0.10	0.00	–0.01	0.12	1	–0.19	0.21	0.47	0.22	–0.18	–0.72	–0.12	–0.10
$gg/qq\to Hll$, $p_T^V < 150$ GeV	0.03	0.01	–0.01	–0.01	0.03	0.02	0.05	–0.01	–0.02	–0.15	–0.19	1	–0.05	–0.19	–0.01	–0.09	0.26	–0.03	–0.02
$gg/qq\to Hll$, $150 \le p_T^V < 250$ GeV	0.08	0.00	0.02	0.02	0.04	0.01	0.05	0.00	–0.01	0.05	0.21	–0.05	1	–0.20	0.09	–0.11	–0.23	–0.06	–0.05
$gg/qq\to Hll$, $p_T^V \ge 250$ GeV	0.12	0.02	0.02	0.04	0.07	0.04	0.10	0.00	–0.01	0.39	0.47	–0.19	–0.20	1	0.23	–0.19	–0.73	–0.12	–0.10
$ttH + tH$	0.33	0.04	0.06	0.11	0.20	0.08	0.29	0.01	–0.03	0.17	0.22	–0.01	0.09	0.23	1	–0.45	–0.31	–0.39	–0.33
$B_{\gamma\gamma}/B_{ZZ}$	–0.52	–0.06	–0.10	–0.13	–0.35	–0.21	–0.42	0.03	0.07	–0.24	–0.18	–0.09	–0.11	–0.19	–0.45	1	0.26	0.45	0.39
$B_{b\bar{b}}/B_{ZZ}$	–0.17	–0.02	–0.03	–0.05	–0.09	–0.05	–0.14	0.00	0.02	–0.45	–0.72	0.26	–0.23	–0.73	–0.31	0.26	1	0.17	0.14
B_{WW}/B_{ZZ}	–0.50	–0.05	–0.13	–0.11	–0.15	0.03	–0.45	–0.05	–0.05	–0.13	–0.12	–0.03	–0.06	–0.12	–0.39	0.45	0.17	1	0.25
$B_{\tau^+\tau^-}/B_{ZZ}$	–0.25	–0.01	–0.01	–0.18	–0.41	–0.07	–0.26	–0.01	–0.06	–0.10	–0.10	–0.02	–0.05	–0.10	–0.33	0.39	0.14	0.25	1

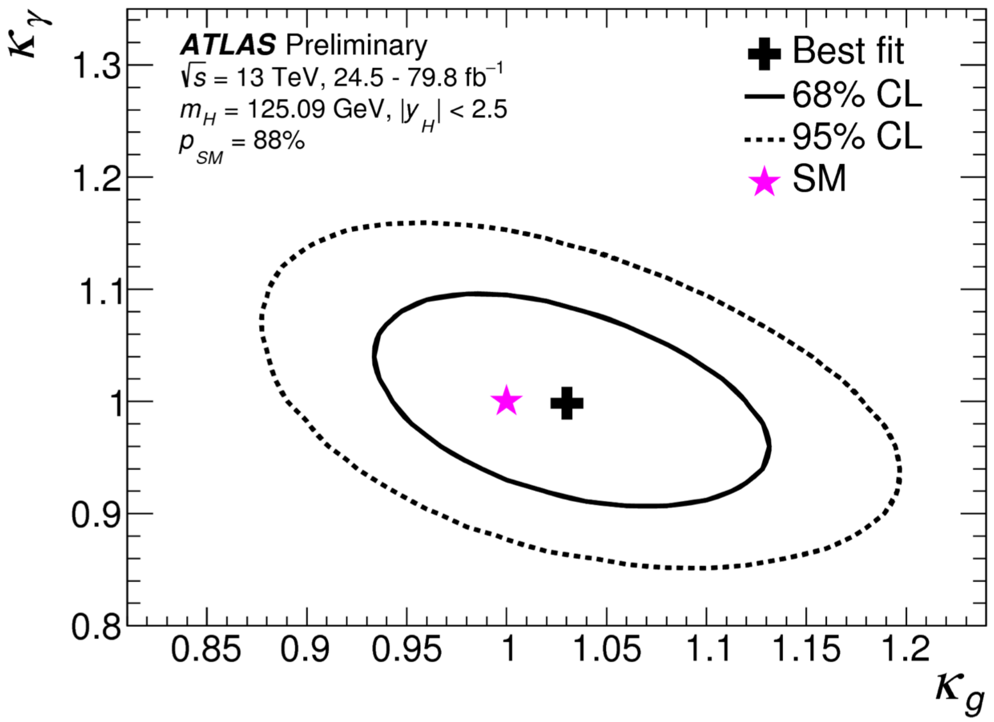
kappa-framework

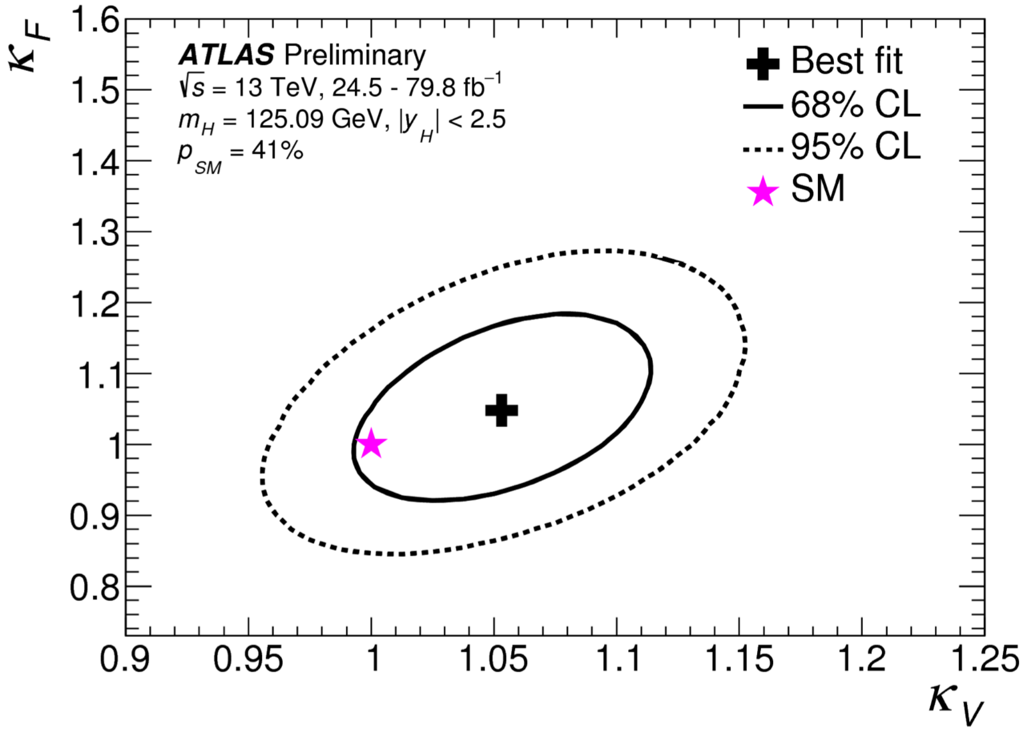


Practical to assess the nature Higgs properties as first order.

Factorize the component by coupling constant.

$$\sigma_i \times \mathrm{B}_f = \frac{\sigma_i(\boldsymbol{\kappa}) \times \Gamma_f(\boldsymbol{\kappa})}{\Gamma_H},$$ where, k_i is coupling strength $\kappa_j^2 = \frac{\sigma_j}{\sigma_j^{\mathrm{SM}}}$ or $\kappa_j^2 = \frac{\Gamma_j}{\Gamma_j^{\mathrm{SM}}}$. (if SM k=1)





Yukawa coupling

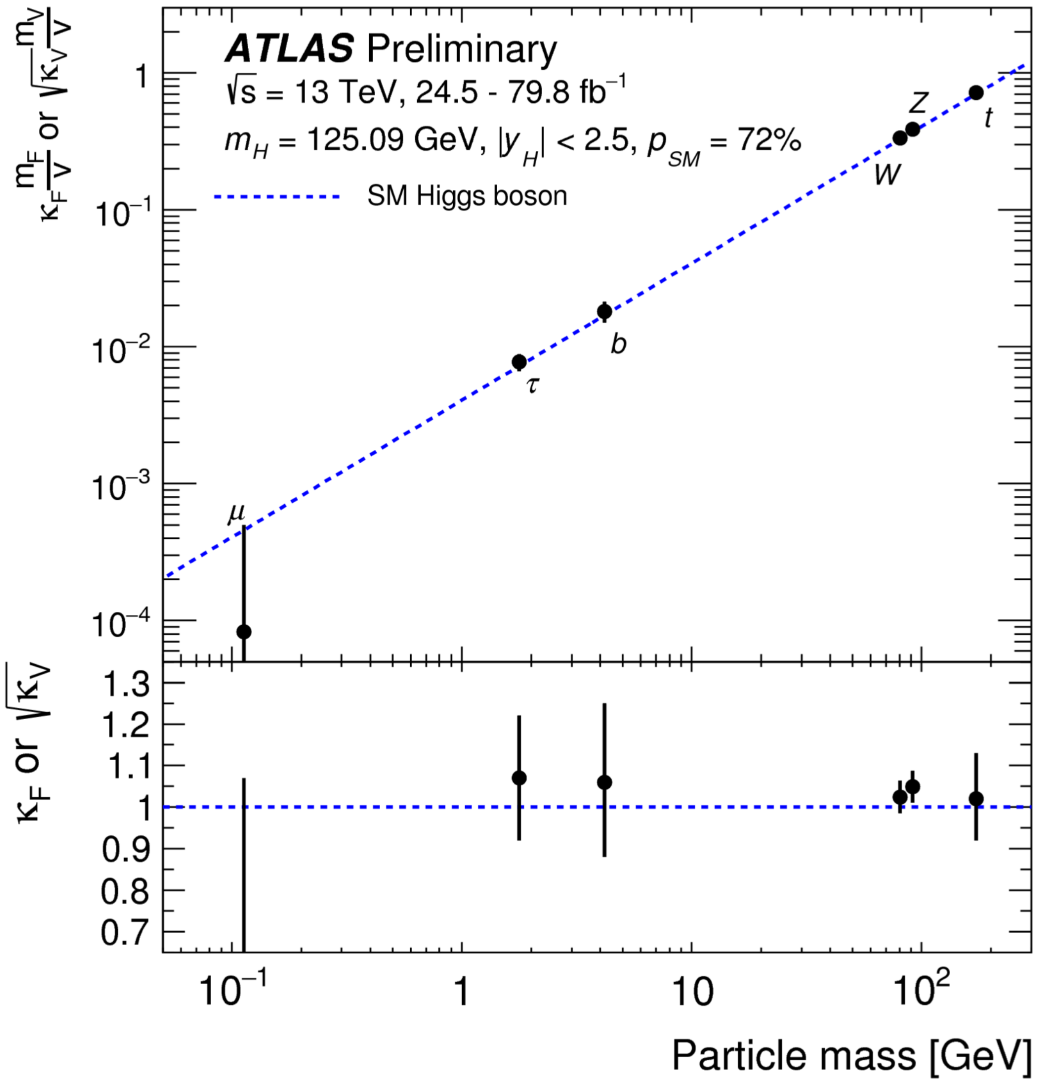
Allow to float individual coupling strength;

(k_Z, k_W, k_b, k_t, k_τ, k_μ)

Yukawa coupling is expressed as:

$$\begin{cases} y_{V,i} = \sqrt{\kappa_{V,i}\frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}}\frac{m_{V,i}}{v} \\ y_{F,i} = \kappa_{F,i}\frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i}\frac{m_{F,i}}{v} \end{cases}$$

Parameter	Result
κ_Z	1.10 ± 0.08
κ_W	1.05 ± 0.08
κ_b	$1.06^{+0.19}_{-0.18}$
κ_t	$1.02^{+0.11}_{-0.10}$
κ_τ	1.07 ± 0.15
κ_μ	< 1.51 at 95% CL.



Constraint to 2HDM / hMSSM

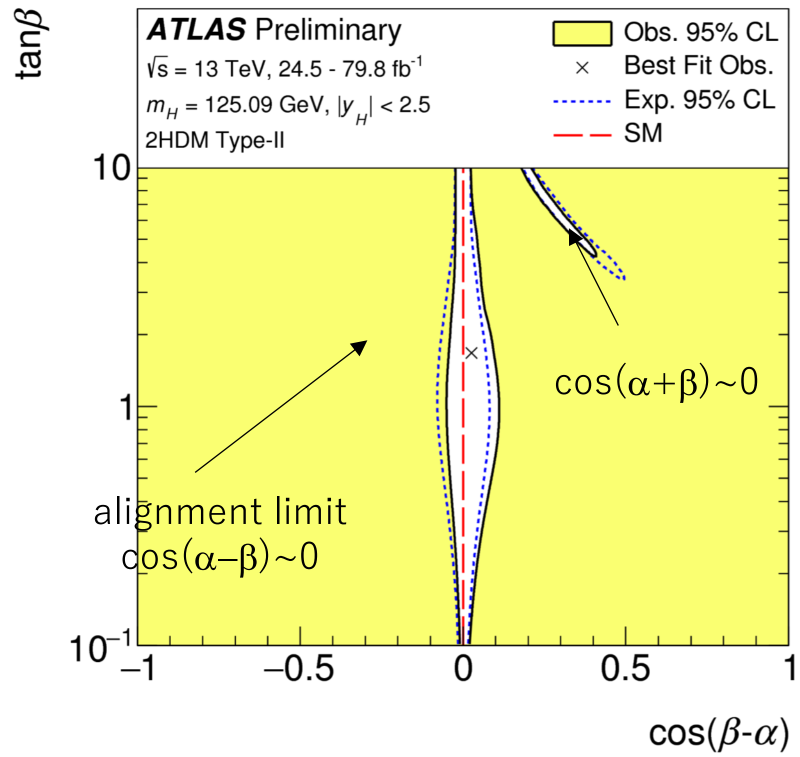
Assume observed Higgs boson

Minimum extension of the SM :

- 5 Higgs bosons : (h, H, A, H^+, H^-)
- 2 mixing parameters : (α, β)

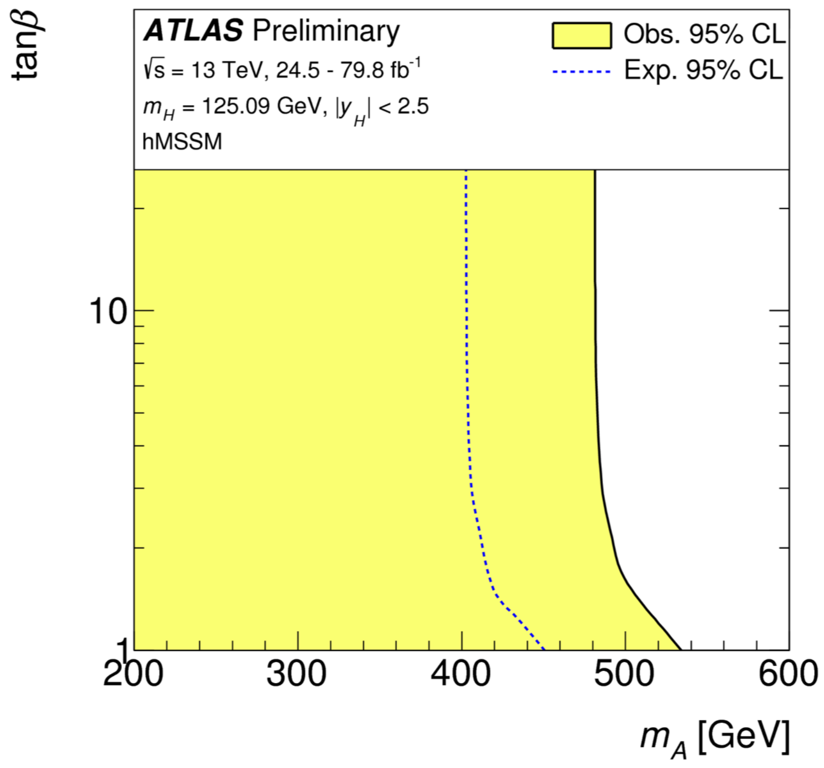
The mixing angle C.L. contour only allows the alignment limits ($\cos(\beta-\alpha)=0$).

At decoupling limit (SM), the CP-odd Higgs mass A is excluded m_A < 480 GeV for any tanβ.



cos($\alpha+\beta$)~0

alignment limit
cos($\alpha-\beta$)~0



Update of HL-LHC perspective

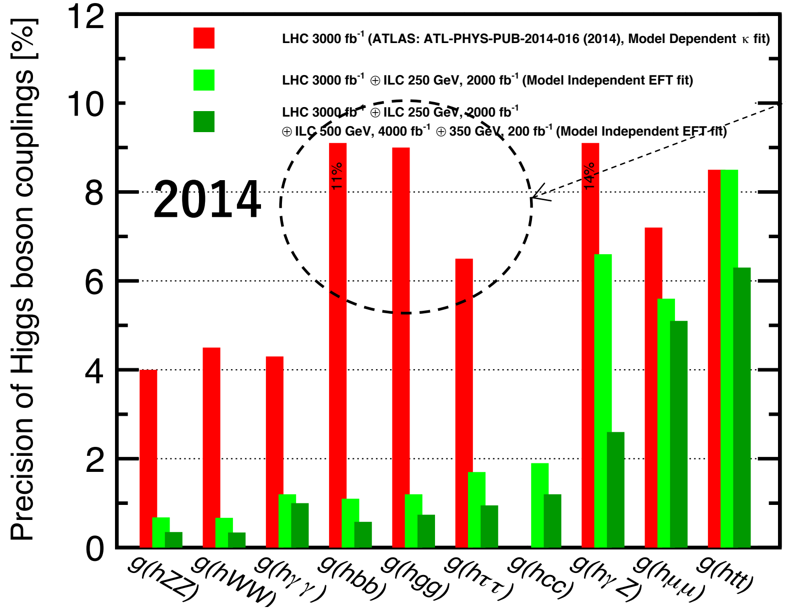
Last update was based on RUN-1 data.

New update uses RUN-2 data.

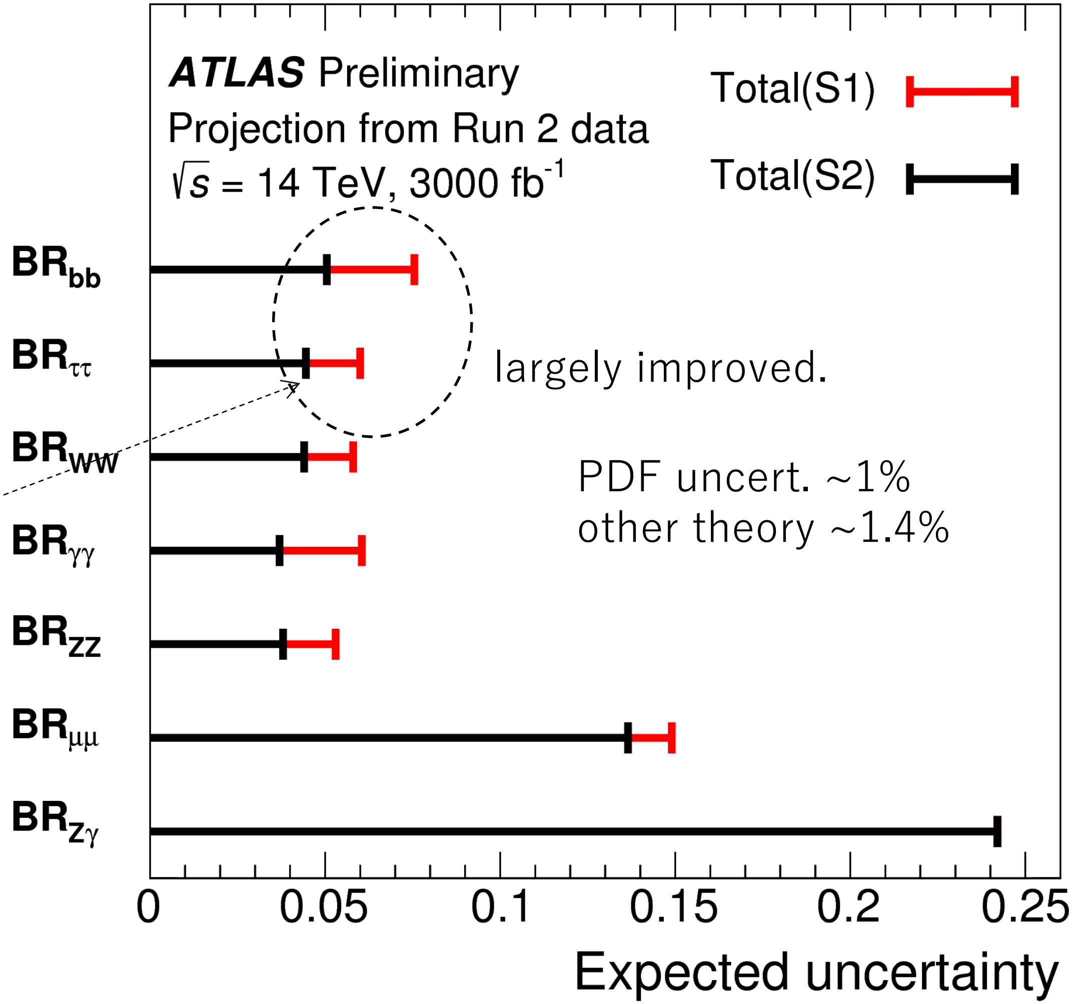
Two “**uncertainty**” scenarios are considered:

S1 : extrapolated from RUN-2 systematics,

S2 : half systematics of RUN-2, except **PDF uncert**.



ATL-PHYS-PUB-2018-054



largely improved.

PDF uncert. ~1%
other theory ~1.4%

Summary

Higgs combination is updated.

Gain of the statistical power in VH → bb process is significant (36.1fb^{-1} => 79.8fb^{-1})

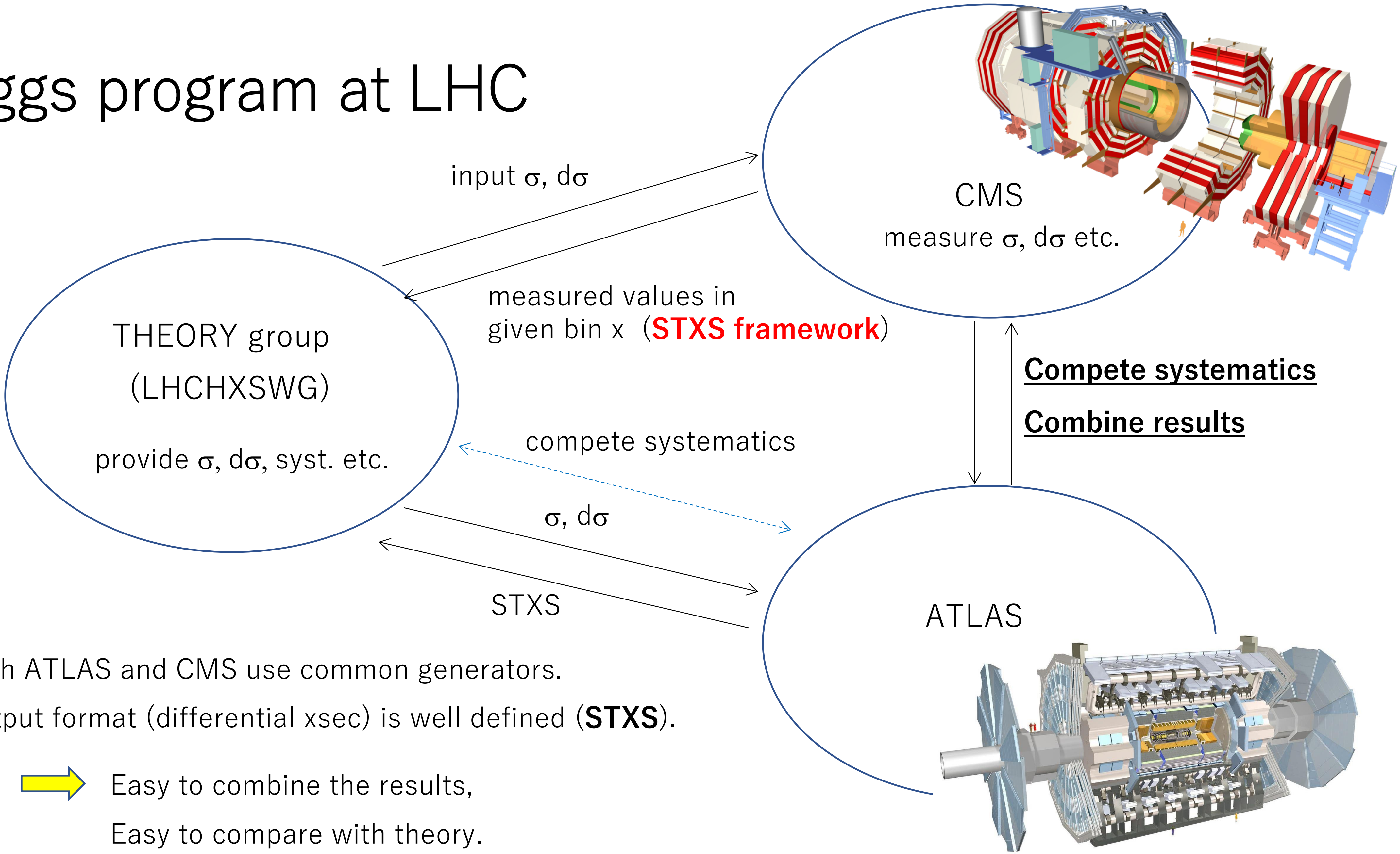
So far, all results are consistent with the SM.

The statistical uncertainty becomes compatible with systematic uncertainties in H → $\gamma\gamma$, WW.

With full RUN-2 dataset (140fb^{-1}), the systematic uncertainty will be more important.

Backup

Higgs program at LHC



input σ, dσ

CMS

measure σ, dσ etc.

measured values in given bin x (**STXS framework**)

THEORY group (LHCHXSWG)

provide σ, dσ, syst. etc.

Compete systematics

Combine results

compete systematics

σ, dσ

STXS

ATLAS

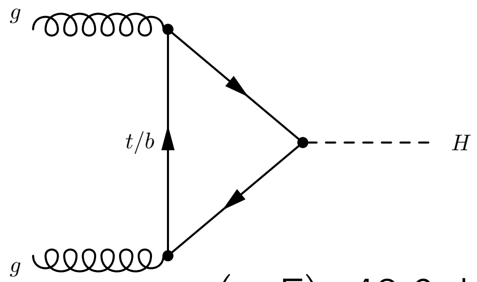
- Both ATLAS and CMS use common generators.
- Output format (differential xsec) is well defined (**STXS**).

⇨ Easy to combine the results,

Easy to compare with theory.

Production cross section

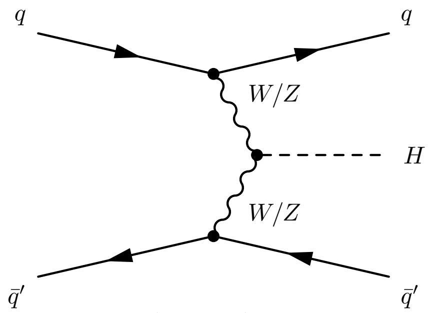
gluon fusion (ggF)



σ(ggF)=48.6pb

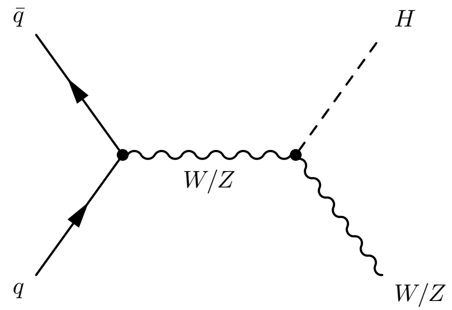
@13TeV, m_H=125GeV

Vector Boson fusion (VBF)



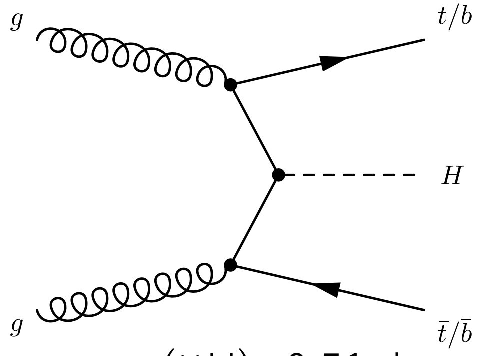
σ(VBF)=3.78pb

Vector Boson association (VH)



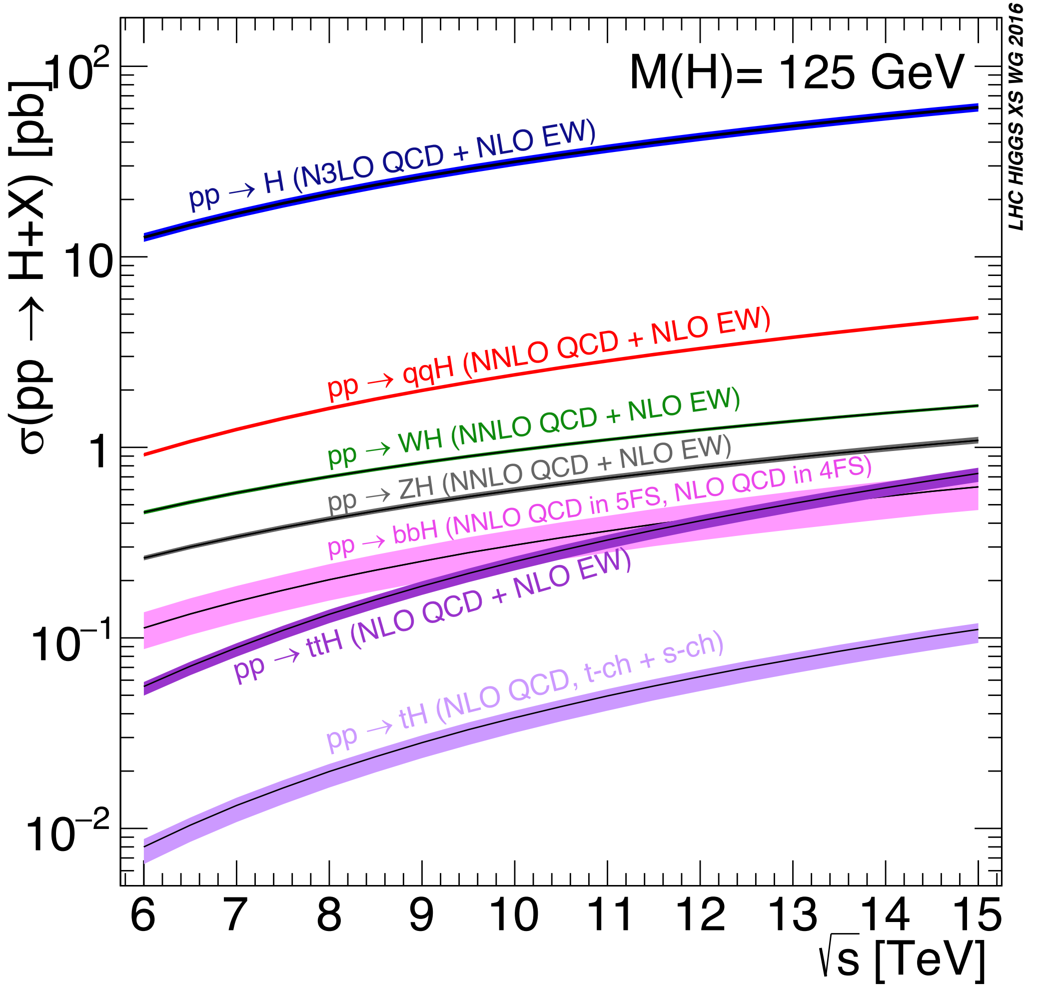
σ(VH)=2.26pb

Top-quark association (ttH)

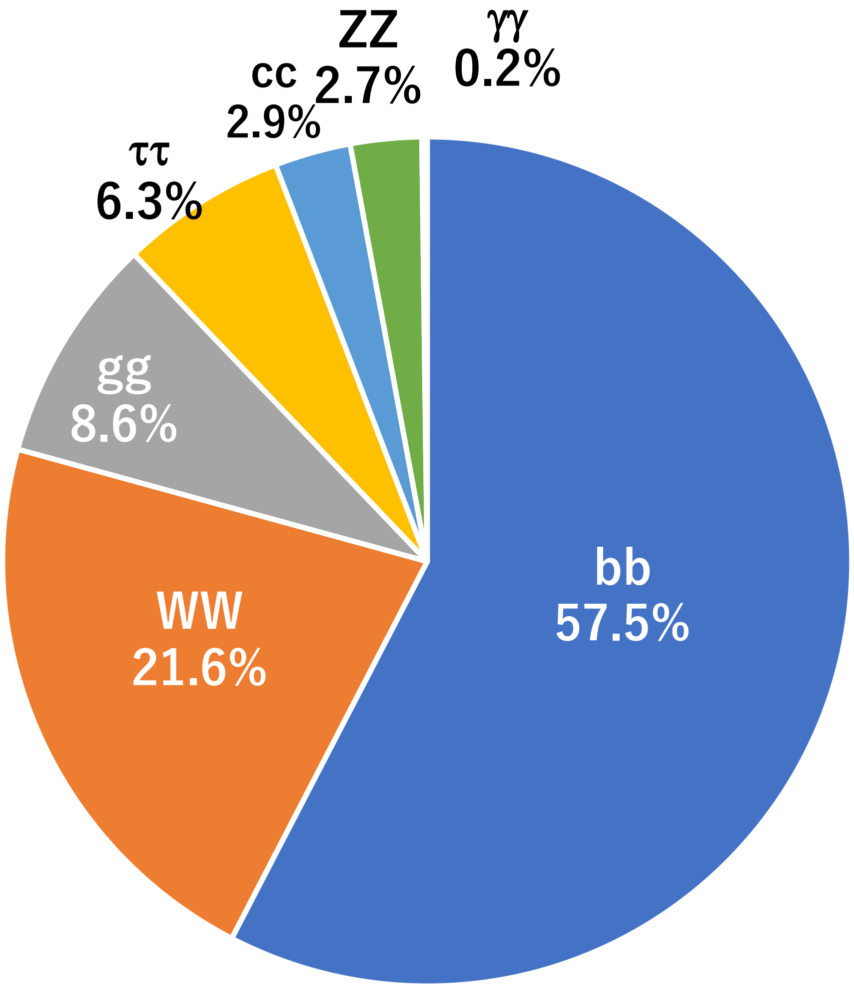


σ(ttH)=0.51pb

σ_H(SM) = $55.6^{+2.4}_{-3.4}$ pb @ N^{3}LO(QCD)+NLO(EW)



Decay mode and analysis channels



γγ, ZZ(4l) : Golden channels. Small BR. but good mass reconstruction, clean signatures

WW(lνlν) : Large BR. Good S/B, but poor mass resolution.

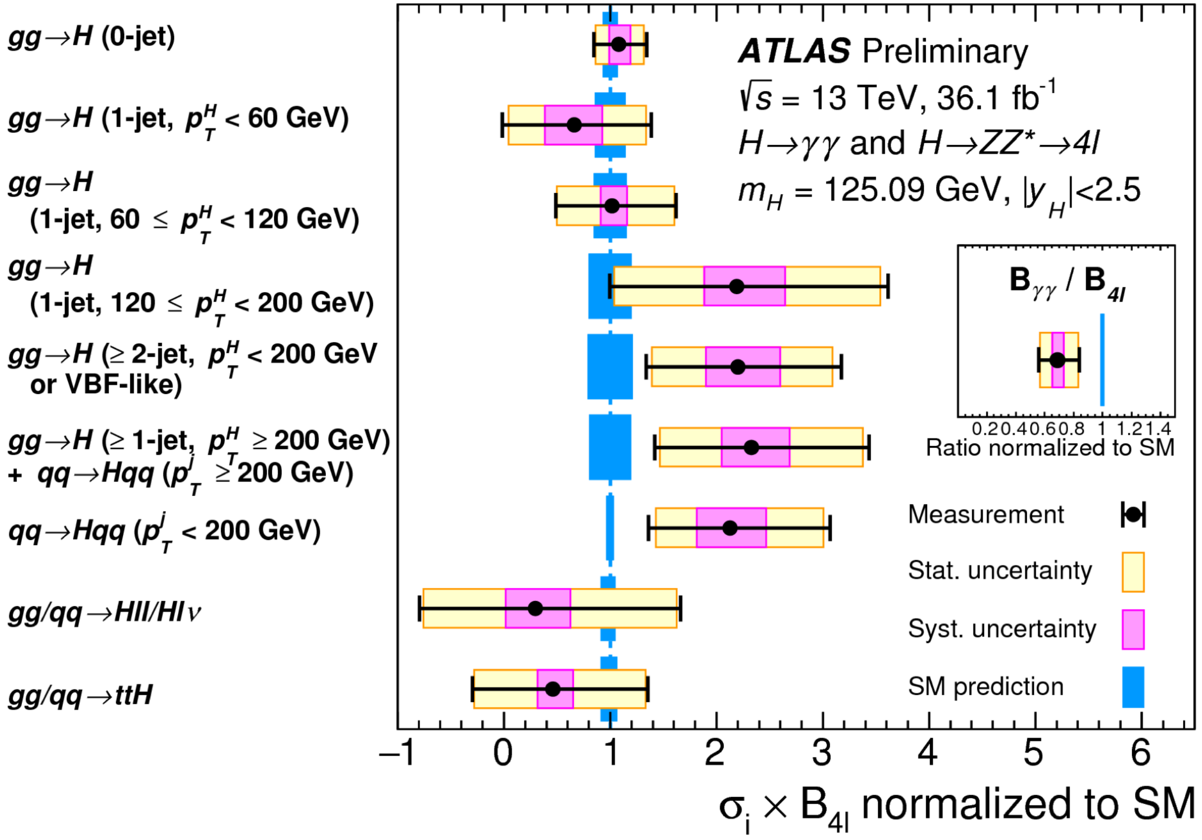
ττ : Reasonable mass reconstruction, Relatively clean signature, reveals fermion mass origin.

bb : Largest BR. Difficult to trigger, large background, The last major channel to be observed.

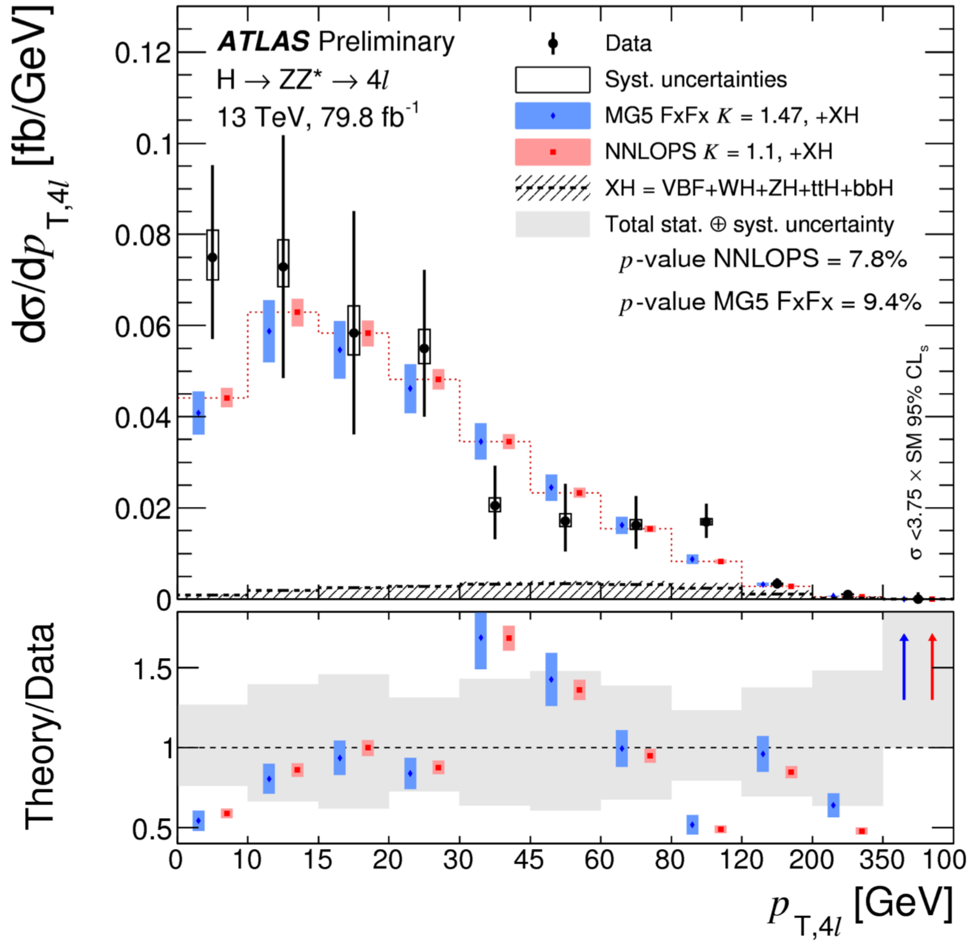
Rare decays (μμ, Zγ, cc) : Small BR, studies as on-going.

STXS and differential cross sections

ATLAS-CONF-2017-047

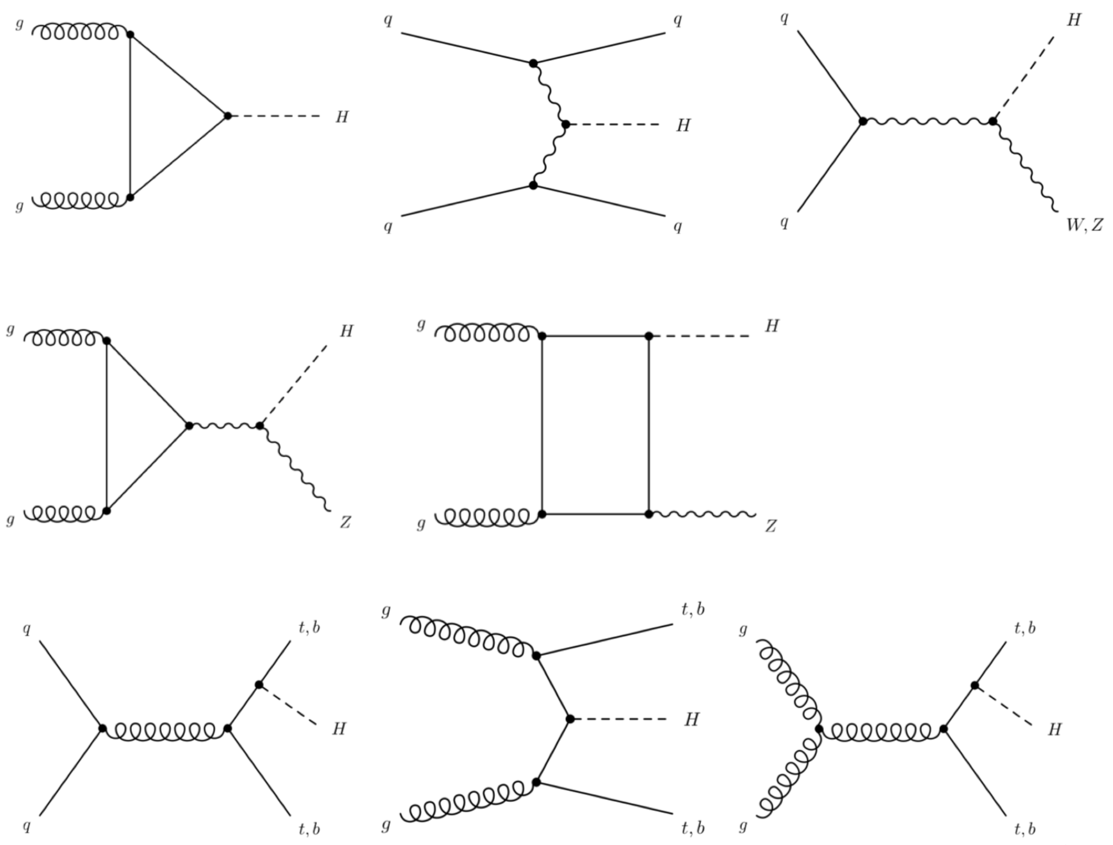


ATLAS-CONF-2018-018



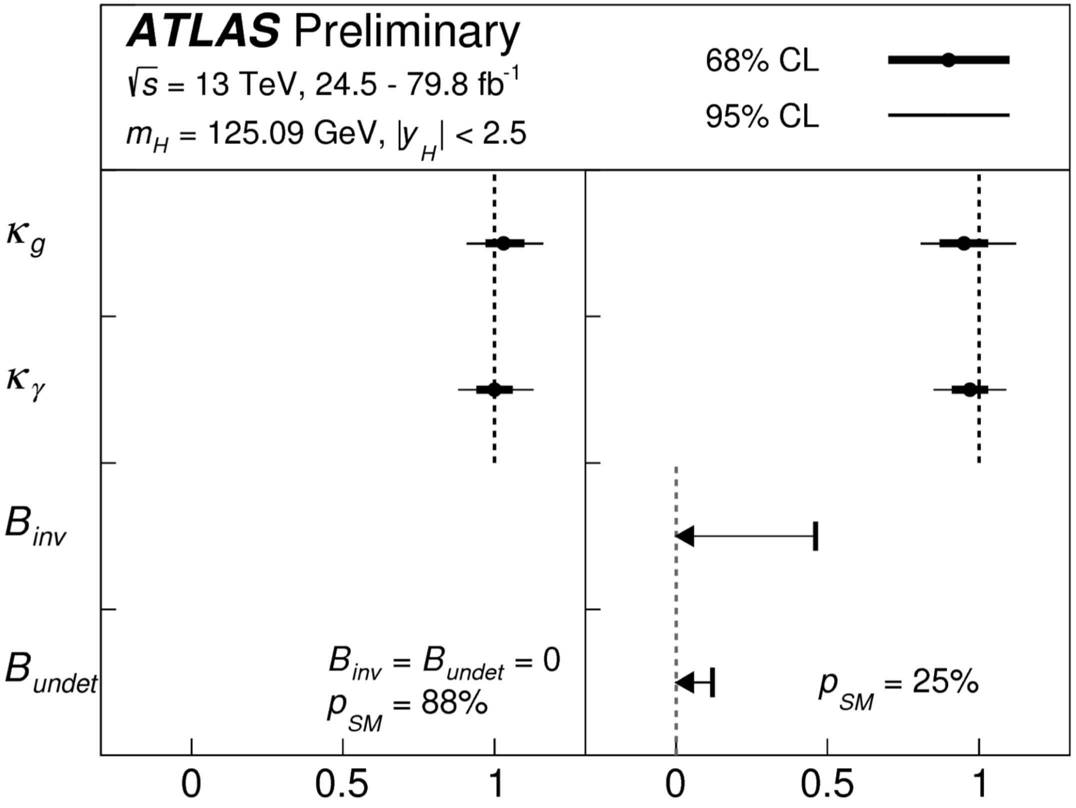
kappa-framework

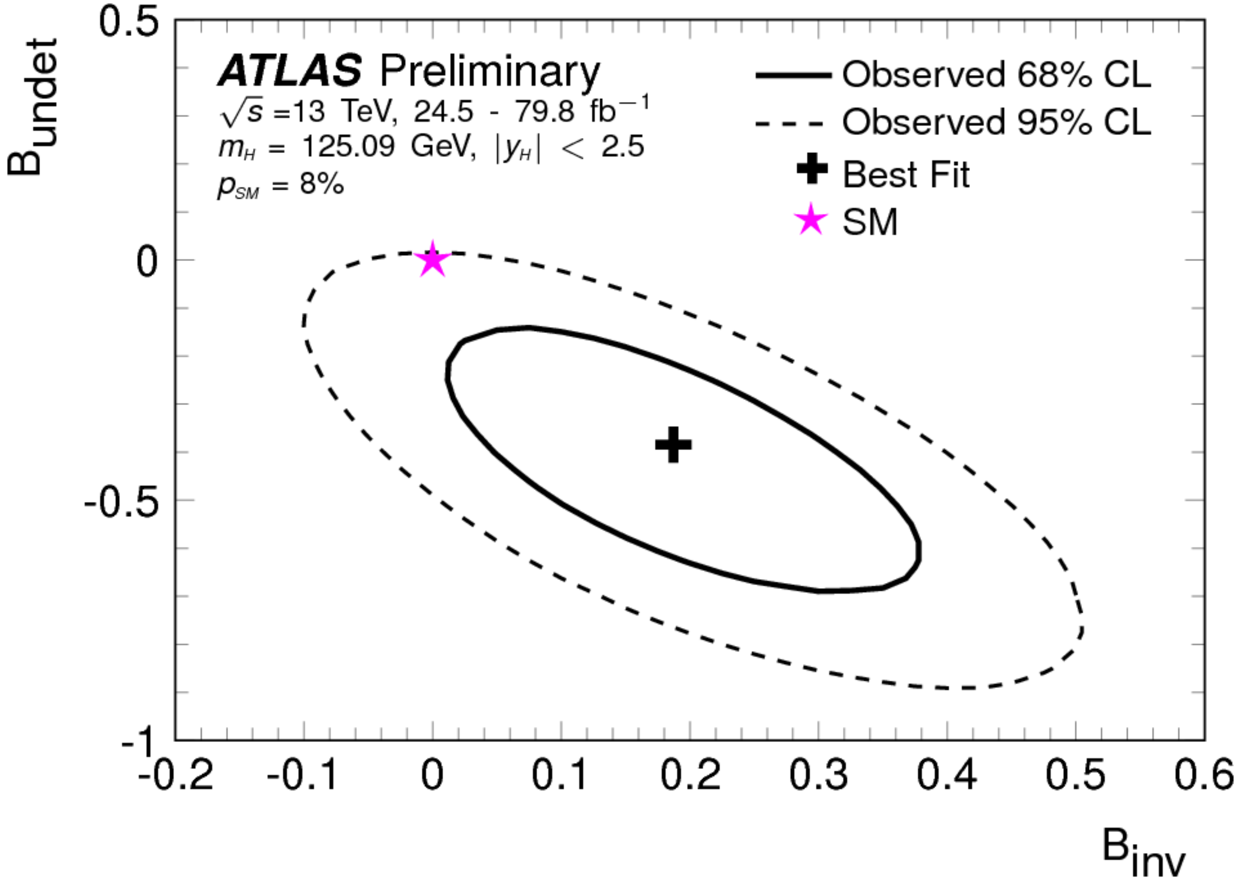
Relation to k_i , example diagrams



Production	Loops	Interference	Effective modifier	Resolved modifier
$\sigma(\text{ggF})$	✓	$t-b$	κ_g^2	$1.04\,\kappa_t^2 + 0.002\,\kappa_b^2 - 0.04\,\kappa_t\kappa_b$
$\sigma(\text{VBF})$	-	-	-	$0.73\,\kappa_W^2 + 0.27\,\kappa_Z^2$
$\sigma(qq/qg \to ZH)$	-	-	-	κ_Z^2
$\sigma(gg \to ZH)$	✓	$t-Z$	$\kappa_{(ggZH)}$	$2.46\,\kappa_Z^2 + 0.46\,\kappa_t^2 - 1.90\,\kappa_Z\kappa_t$
$\sigma(WH)$	-	-	-	κ_W^2
$\sigma(t\bar{t}H)$	-	-	-	κ_t^2
$\sigma(tHW)$	-	$t-W$	-	$2.91\,\kappa_t^2 + 2.31\,\kappa_W^2 - 4.22\,\kappa_t\kappa_W$
$\sigma(tHq)$	-	$t-W$	-	$2.63\,\kappa_t^2 + 3.58\,\kappa_W^2 - 5.21\,\kappa_t\kappa_W$
$\sigma(b\bar{b}H)$	-	-	-	κ_b^2
Partial decay width				
Γ^{bb}	-	-	-	κ_b^2
Γ^{WW}	-	-	-	κ_W^2
Γ^{gg}	✓	$t-b$	κ_g^2	$1.11\,\kappa_t^2 + 0.01\,\kappa_b^2 - 0.12\,\kappa_t\kappa_b$
$\Gamma^{\tau\tau}$	-	-	-	κ_τ^2
Γ^{ZZ}	-	-	-	κ_Z^2
Γ^{cc}	-	-	-	$\kappa_c^2\ (= \kappa_t^2)$
$\Gamma^{\gamma\gamma}$	✓	$t-W$	κ_γ^2	$1.59\,\kappa_W^2 + 0.07\,\kappa_t^2 - 0.67\,\kappa_W\kappa_t$
$\Gamma^{Z\gamma}$	✓	$t-W$	$\kappa_{(Z\gamma)}^2$	$1.12\,\kappa_W^2 - 0.12\,\kappa_W\kappa_t$
Γ^{ss}	-	-	-	$\kappa_s^2\ (= \kappa_b^2)$
$\Gamma^{\mu\mu}$	-	-	-	κ_μ^2
Total width ($\text{B}_{\text{inv}} = \text{B}_{\text{undet}} = 0$)				
Γ_H	✓	-	κ_H^2	$0.58\,\kappa_b^2 + 0.22\,\kappa_W^2$ $+0.08\,\kappa_g^2 + 0.06\,\kappa_\tau^2$ $+0.03\,\kappa_Z^2 + 0.03\,\kappa_c^2$ $+0.0023\,\kappa_\gamma^2 + 0.0015\,\kappa_{(Z\gamma)}^2$ $+0.0004\,\kappa_s^2 + 0.00022\,\kappa_\mu^2$

Constraint to new physics

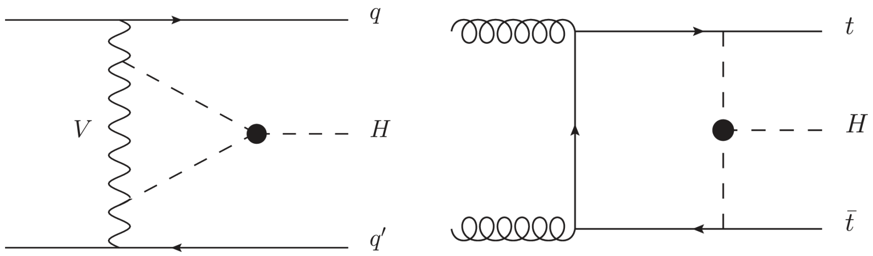




Self coupling

Direct search : previous talk.

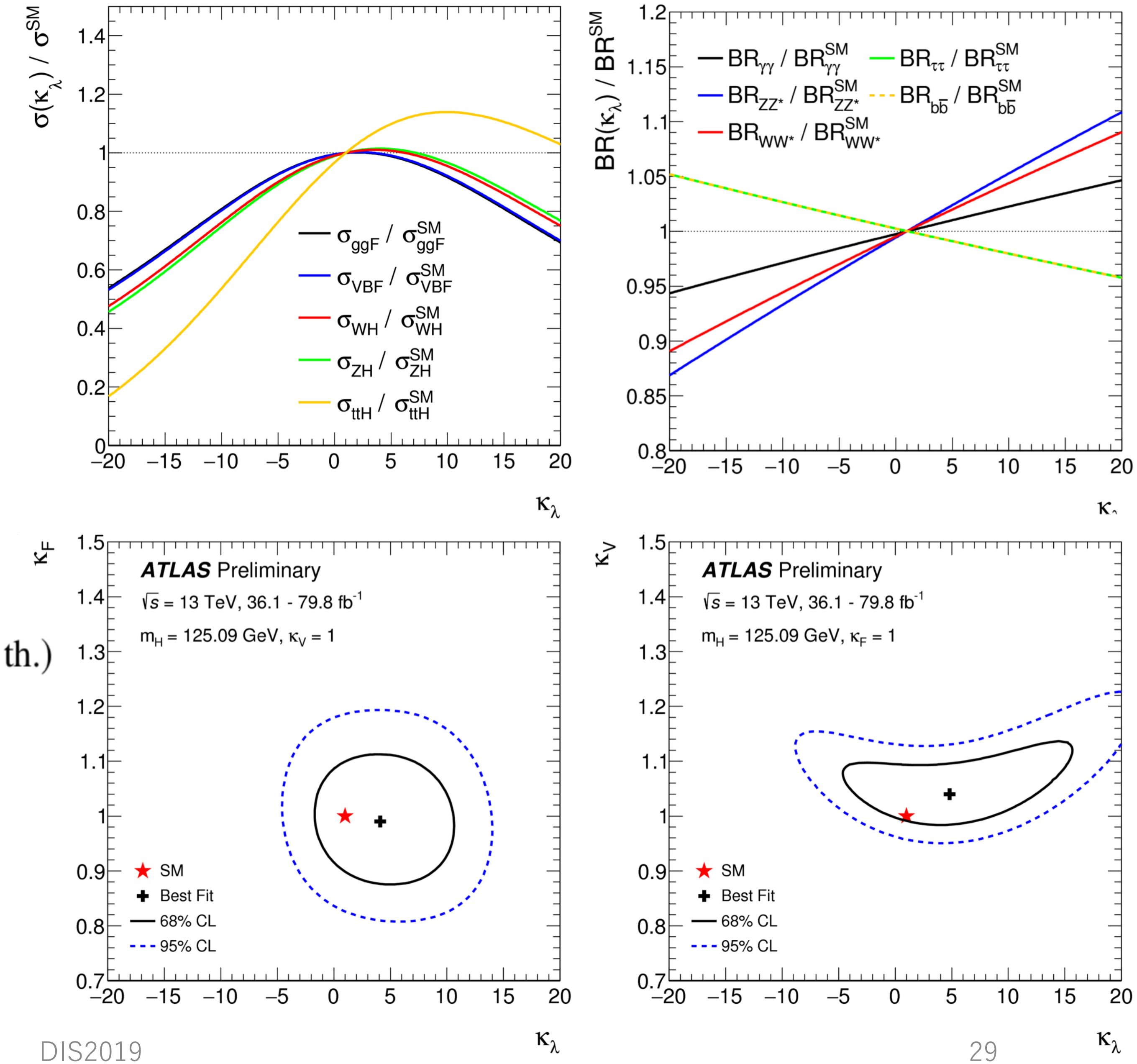
Indirect constraint from loop diagrams



Measured to be ATL-PHYS-PUB-2019-009

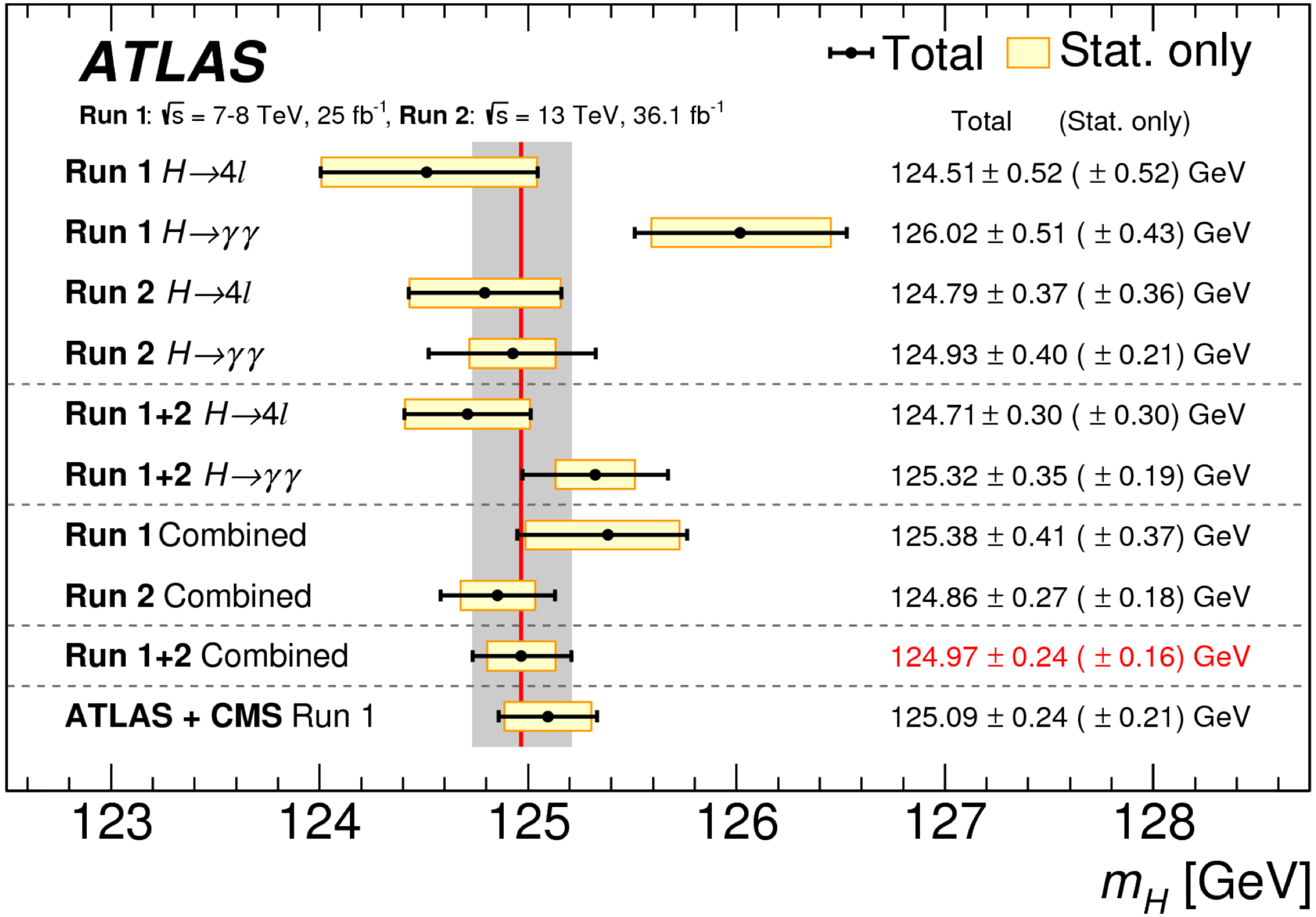
$$\kappa_\lambda = 4.0^{+4.3}_{-4.1} = 4.0^{+3.7}_{-3.6}\,(\text{stat.})\,^{+1.6}_{-1.5}\,(\text{exp.})\,^{+1.3}_{-0.9}\,(\text{sig. th.})\,^{+0.8}_{-0.9}\,(\text{bkg. th.})$$

- ggF production (loop in ttH) is sensitive.
- Large theory uncertainty, assuming new physics only enter in the λ_{HHH} coupling.
- Results is compatible with direct search.

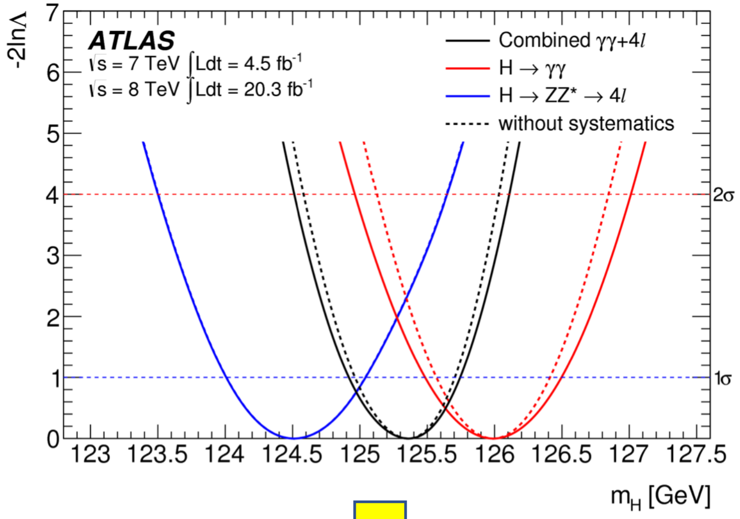


Higgs mass combination

arXiv:1806.00242



Run-1 PRD90(2014)052004



Run-2