Experimental Highlights

Fabio Cerutti – LBNL

Introductory Remarks

- Really interesting conference!
  - right mixture of theoretical and experimental (EXCELLENT) talks with many discussions: having a few slides to introduce them at the end of the talks by the chair person is a **very good IDEA!**
- 3 days full of content: impossible to make justice to all interesting results in 40' !
  - Very successful Young Scientists talks
  - Biased choice of highlights in the following: focus on what is "***new***" or "**intriguing**" or **triggered discussion** (*controversial*) with some more general personal remarks (… but many interesting results are in backup)

THANKS to the organizers!

- I only have one remark … maybe is time to

… change the conference name: the Higgs Hunting season is over ?

THE Higgs (125 GeV) boson

More … Introduction

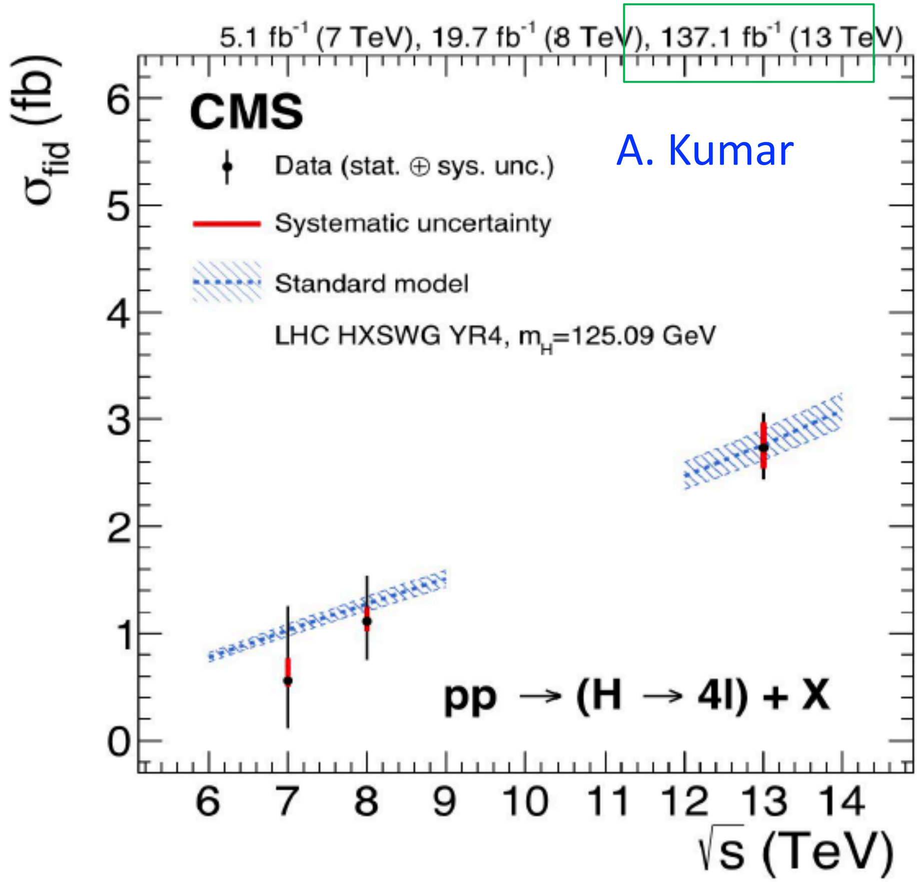
- The Higgs boson and the Brout-Englert-Higgs mechanism play a crucial role in the SM:
  - SM has many "free" parameters: 18 ignoring neutrino masses/mixing and θ_{QCD}, 25 if neutrino are masses+mixing added as Dirac mass terms (not present in original formulation and requires sterile ν_R)
  - Of these 18/25 parameters all but 3 are linked to Higgs interactions:
  - Once also M_H is measured (current accuracy <2 per mill) all free parameters are known with high accuracy:
    - Main testable signature of BEH mechanism → Couplings H-to-SM-particles related to their masses , Higgs self interaction also determined by vev and mass
    - Any measurement at LHC over-constrain hence test the SM model

**Note: Still very little understanding on why we have so many free parameters and the origin of their hierarchy*

Higgs to Boson decays

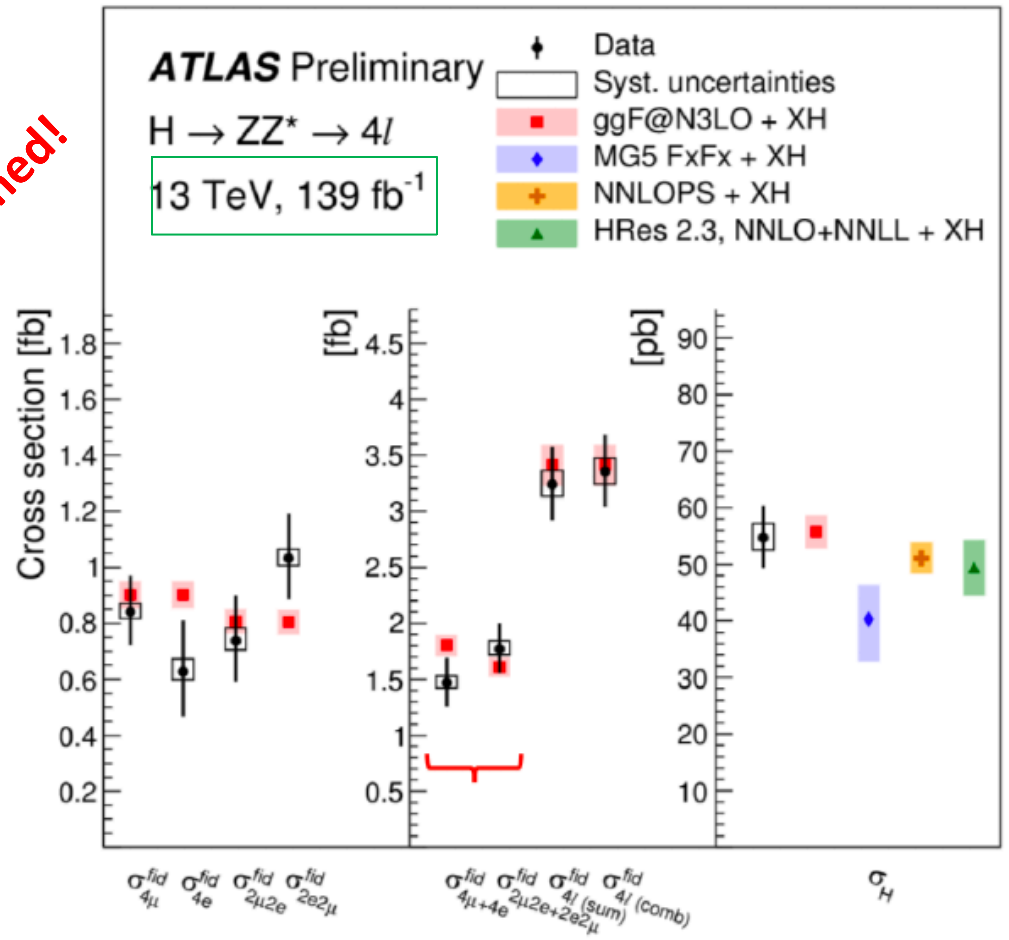
- H->ZZ*-> 4l and H->$\gamma\gamma$ are clearly the cleanest experimental signatures with fully reconstructed final state
  - allow measurement of the mass (2 per mill level)
  - Backgrounds small and/or determined in situ
  - Small BR: need large luminosity!
  - Ideal channels for fiducial differential and STXS measurements
- More challenging H->WW->lνlν
  - Larger BR but systematics on background already playing a major role

H-> 4-leptons updated with full Run2!



10% accuracy reached!

G. Mancini



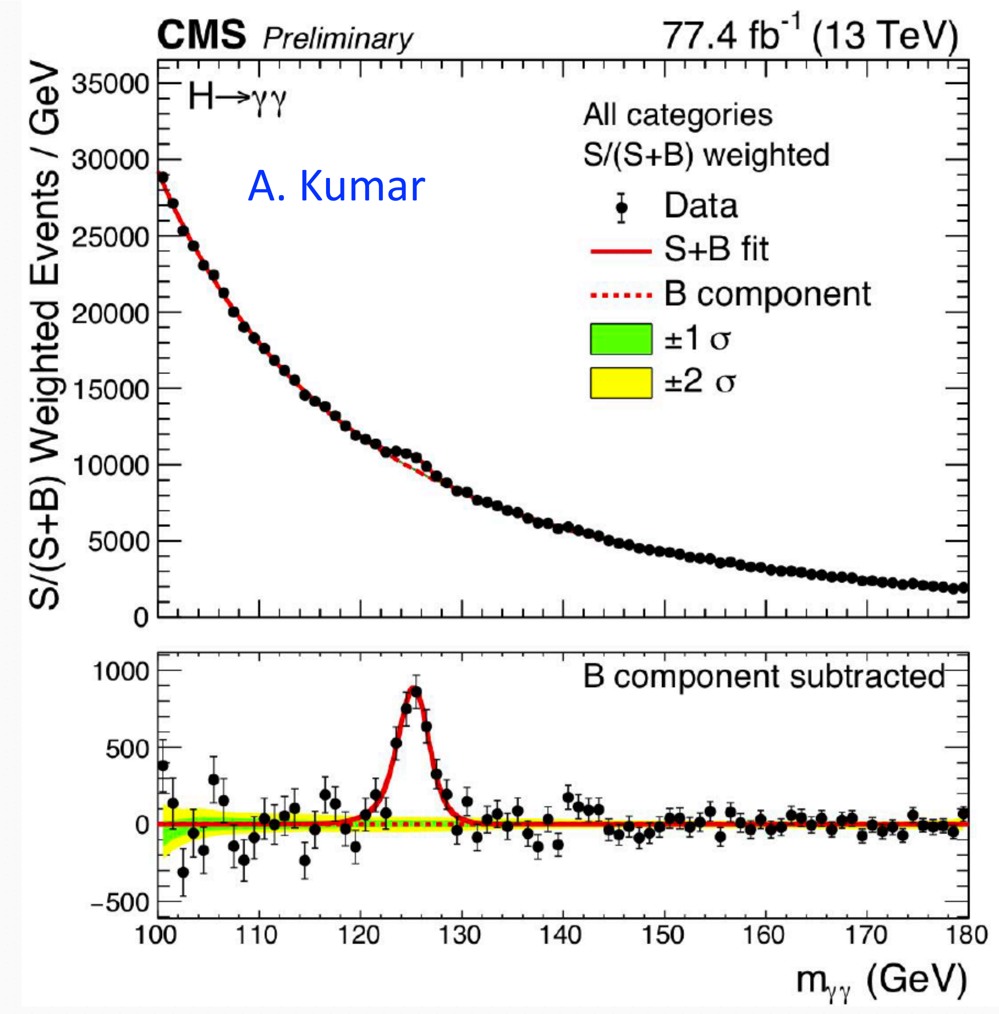
$$\sigma_{\text{fid.}} = 2.73^{+0.30}_{-0.29} = 2.73^{+0.23}_{-0.22}(\text{stat.})^{+0.24}_{-0.19}(\text{syst.})\ \text{fb}$$

$$\sigma^{\text{SM}}_{\text{fid.}} = 2.76 \pm 0.14\ \text{fb}.$$

$$\sigma \cdot \mathcal{B} \equiv \sigma \cdot \mathcal{B}(H \to ZZ^*) = 1.38 \pm 0.11(\text{stat.})^{+0.05}_{-0.03}(\text{exp.}) \pm 0.03(\text{th.})\ \text{pb} = 1.38 \pm 0.12\ \text{pb}.$$

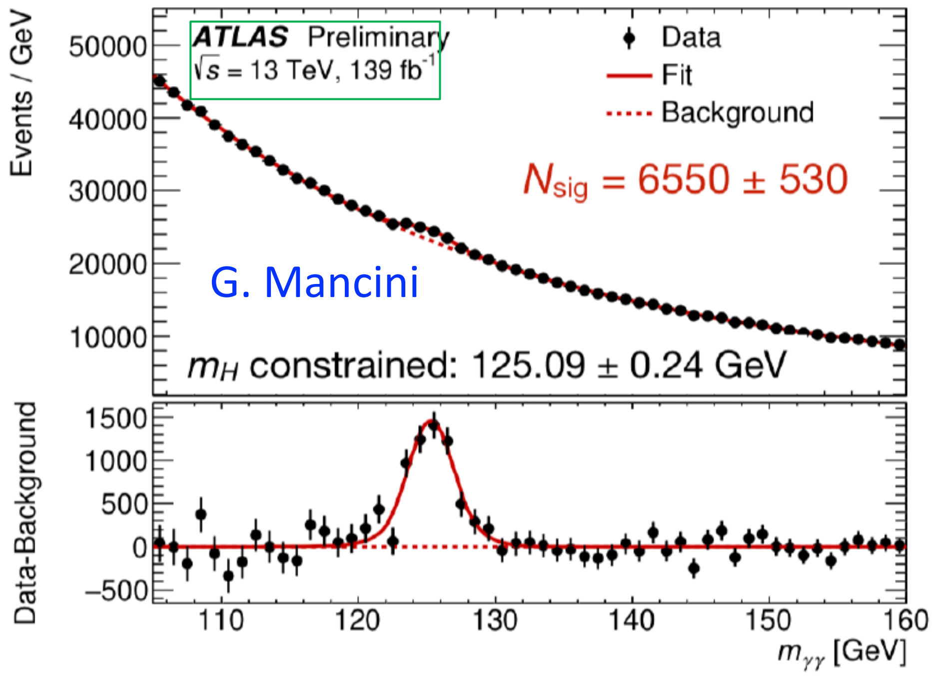
$$(\sigma \cdot \mathcal{B})_{\text{SM}} \equiv (\sigma \cdot \mathcal{B}(H \to ZZ^*))_{\text{SM}} = 1.33 \pm 0.09\ \text{pb}.$$

$H \rightarrow \gamma\gamma$



$$\widehat{\mu} = 1.18^{+0.17}_{-0.14} = 1.18\ ^{+0.12}_{-0.11}\,(\text{stat})^{+0.09}_{-0.07}\,(\text{syst})^{+0.07}_{-0.06}\,(\text{theo})$$

Fiducial XS results with 139 fb^{-1}



$$\sigma_{\text{fid}} = 65.2 \pm 4.5\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 0.3\,(\text{theo.})\ \text{fb}$$

SM prediction: $\sigma_{\text{fid}} = 63.3$ +- 3.3 fb

Also here 10% accuracy achieved with Full Run2 data set

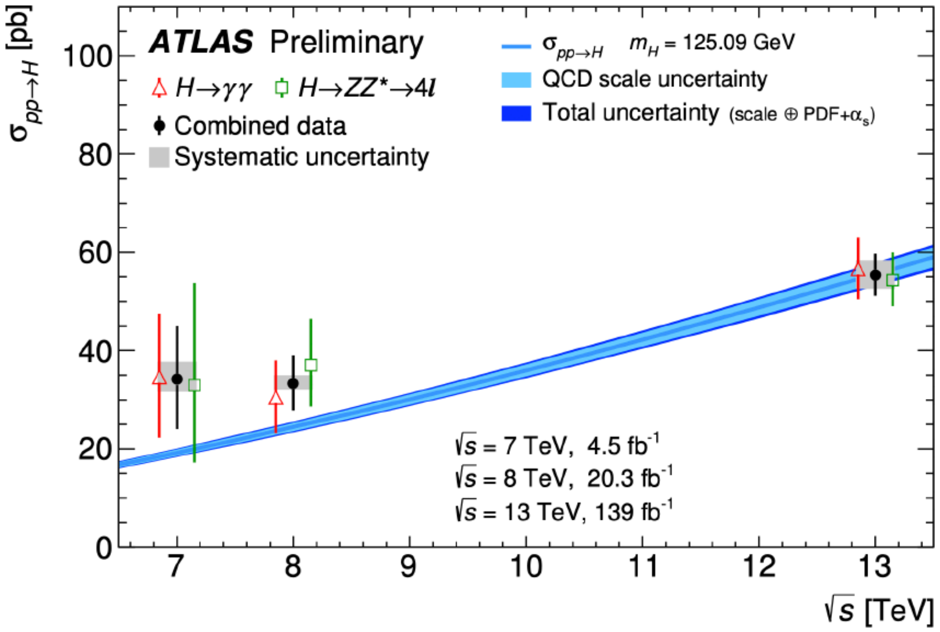
Fiducial cross section immune to theory uncertainties

Updated total combined γγ+4l cross section 139 fb^{-1}

XS: H->γγ and H->ZZ*->4l combination

G. Mancini
Y. Lu

- Results with 139 fb^{-1} @ 13 TeV
- m_H=125.09 GeV
- The cross sections are obtained from the measured event yields, combined accounting for luminosity, detector effects, acceptances, and branching fractions (SM assumptions)



- The measured total Higgs boson production cross section is: $55.4^{+4.3}_{-4.2}$ pb (±3.1(stat.) $^{+3.0}_{-2.8}$(sys.))

Total relative error ~8% in agreement with SM predictions (error ~4.5%)!

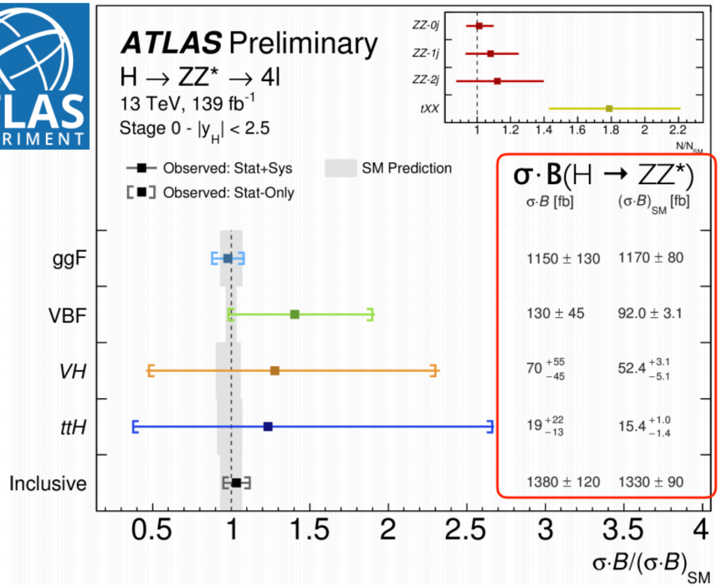
- Agreement with the Standard Model prediction: 55.6 ± 2.5 pb

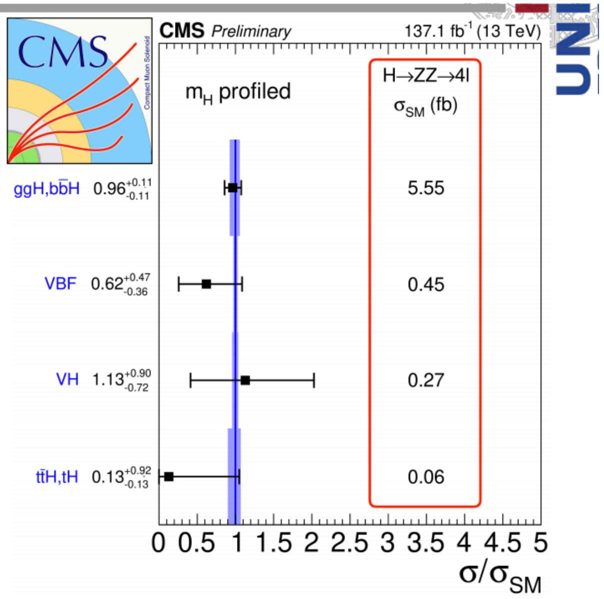
Huge success for experimentalist and theorist

xs per production mode

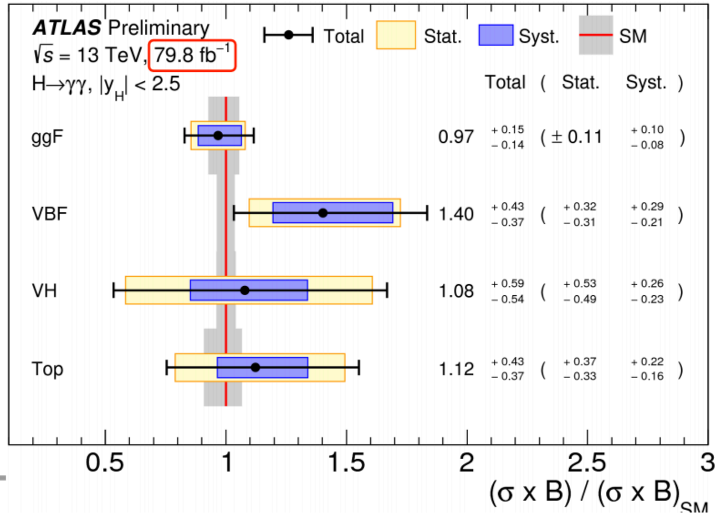
A. Kumar G. Mancini K. Koeneke

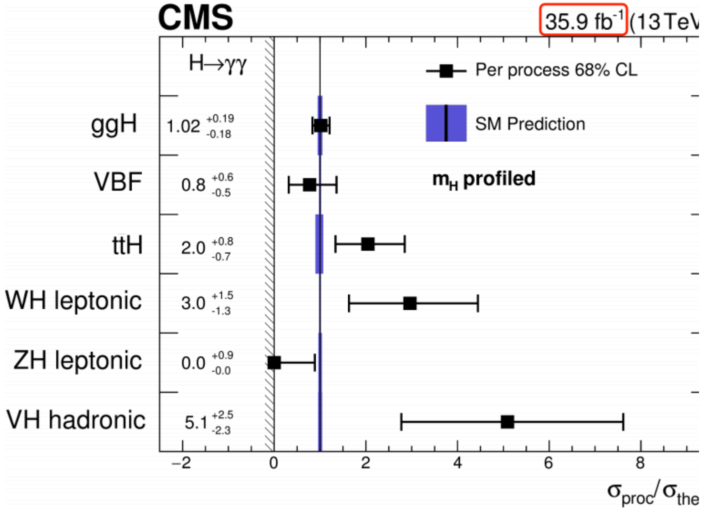
- $H \rightarrow ZZ^* \rightarrow 4\ell$
  - Still statistics limited with 140 fb^{-1}
  - ggF measurement precision reaches precision of SM prediction





- $H \rightarrow \gamma\gamma$
  - Systematics for ggF and VBF similar size as 80 fb^{-1} statistics





Karsten Köneke

- **Theory systematics on signals** starts to play relevant role

Discussion: theory systematics on signal

K. Koeneke

Systematic	ATLAS EXPERIMENT	CMS
μ_R and μ_F	8-point variation: Vary by 0.5 and 2.0; No further constraint	6-point variation: Vary by 0.5 and 2.0; Constrain $0.5 < \mu_R/\mu_F < 2.0$
PDF	PDF4LHC_NLO_30 Hessian eigenvector variations: NNPDF3.0 eigenvectors + alternative nominal (MMHT2014, CT14)	NNPDF eigenvector variations

- Ongoing effort to harmonize theory errors (on both signal and background) in LHC Higgs Combination group (LHCHCWG)
- One of the main motivations of STXS is also to **harmonize (signal) theory uncertainties**: LHCHCSWG documented uncertainties on YR4

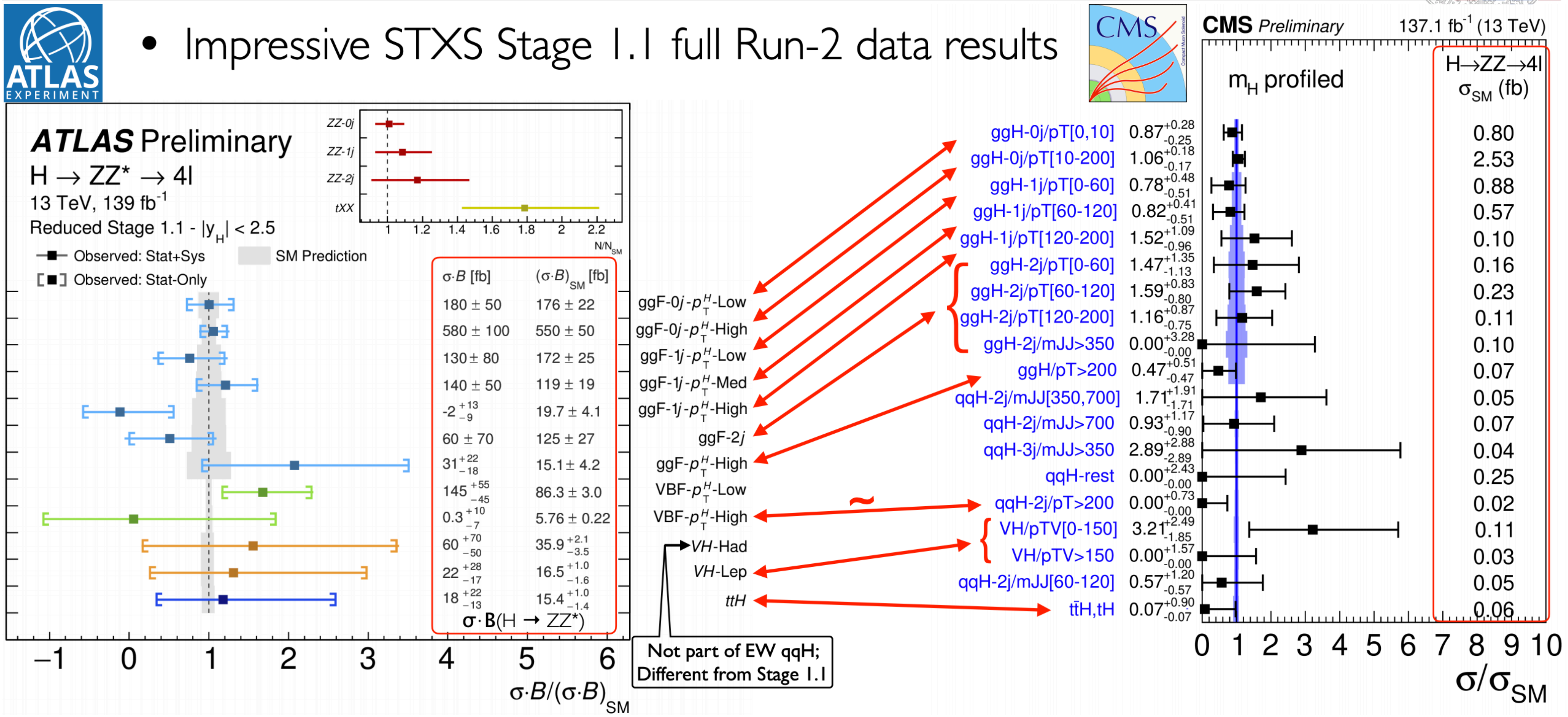
K. Koeneke

A. Kumar

G. Mancini

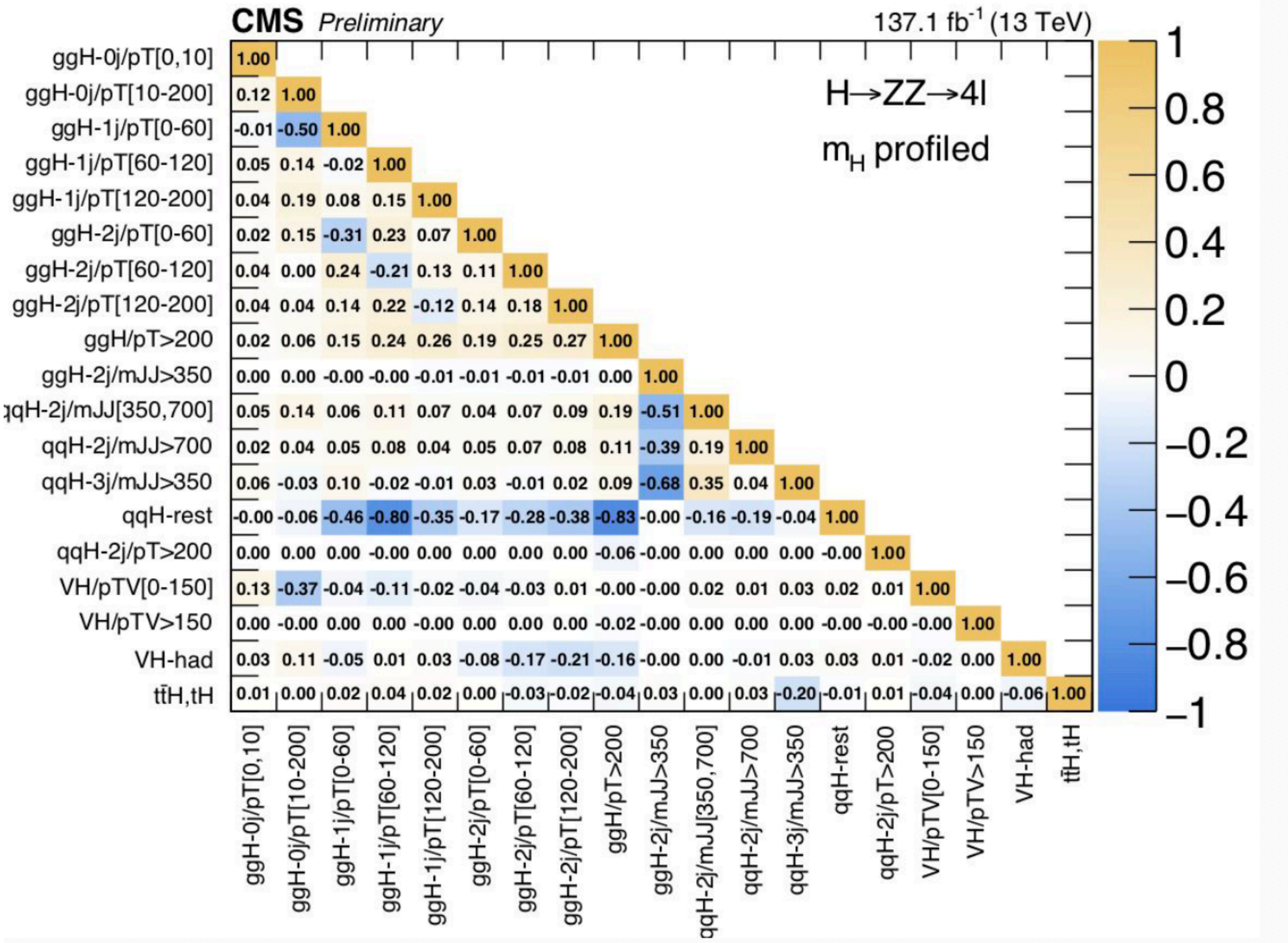
Full Run-2 H → ZZ* → 4ℓ STXS Stage 1.1

- Impressive STXS Stage 1.1 full Run-2 data results



- Very useful for interpretation (EFT) but information diluted, large correlations (need to publish covariance matrix not always easy to determine) and many cases dominated by bkg. Fluctuations … and also check their model dependency

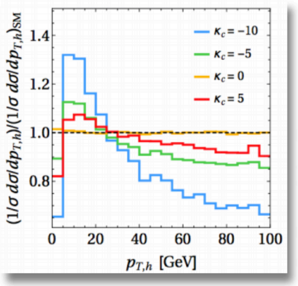
A. Kumar

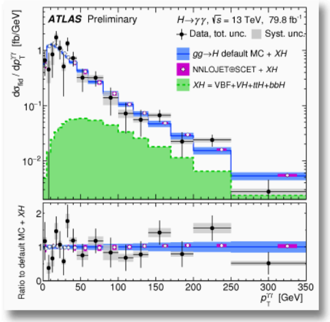


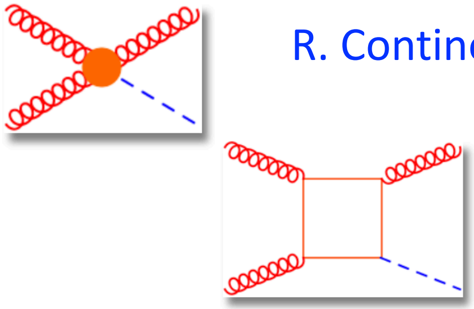
Important to publish (and use) full covariance matrix !

Pt-Higgs measurement

$p_{t,H}$: a major probe for Higgs physics





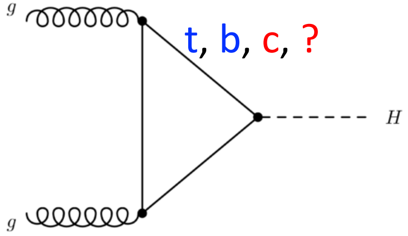


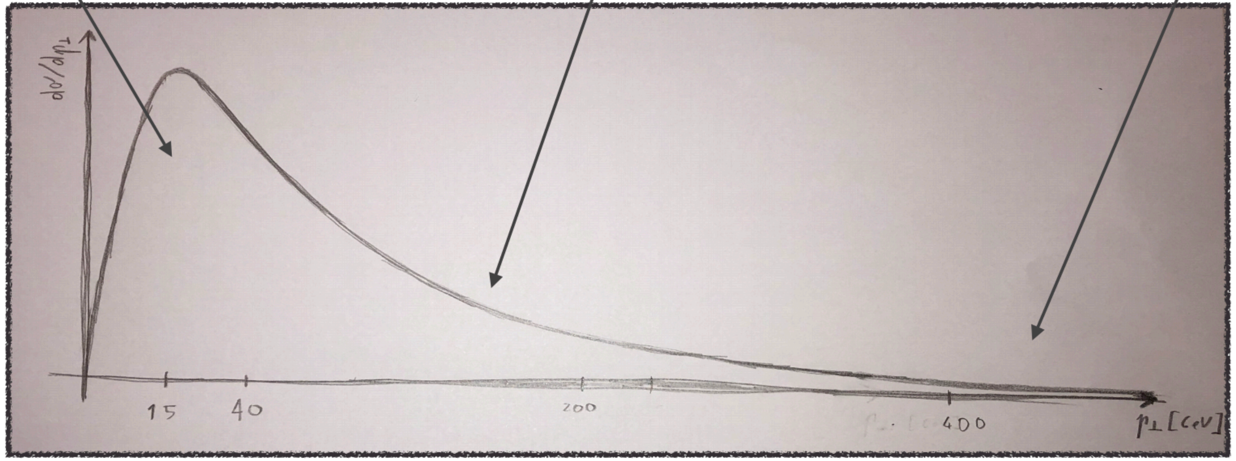
R. Contino

Low p_t
Light Yukawas…

Bulk of the distribution
Highest precision

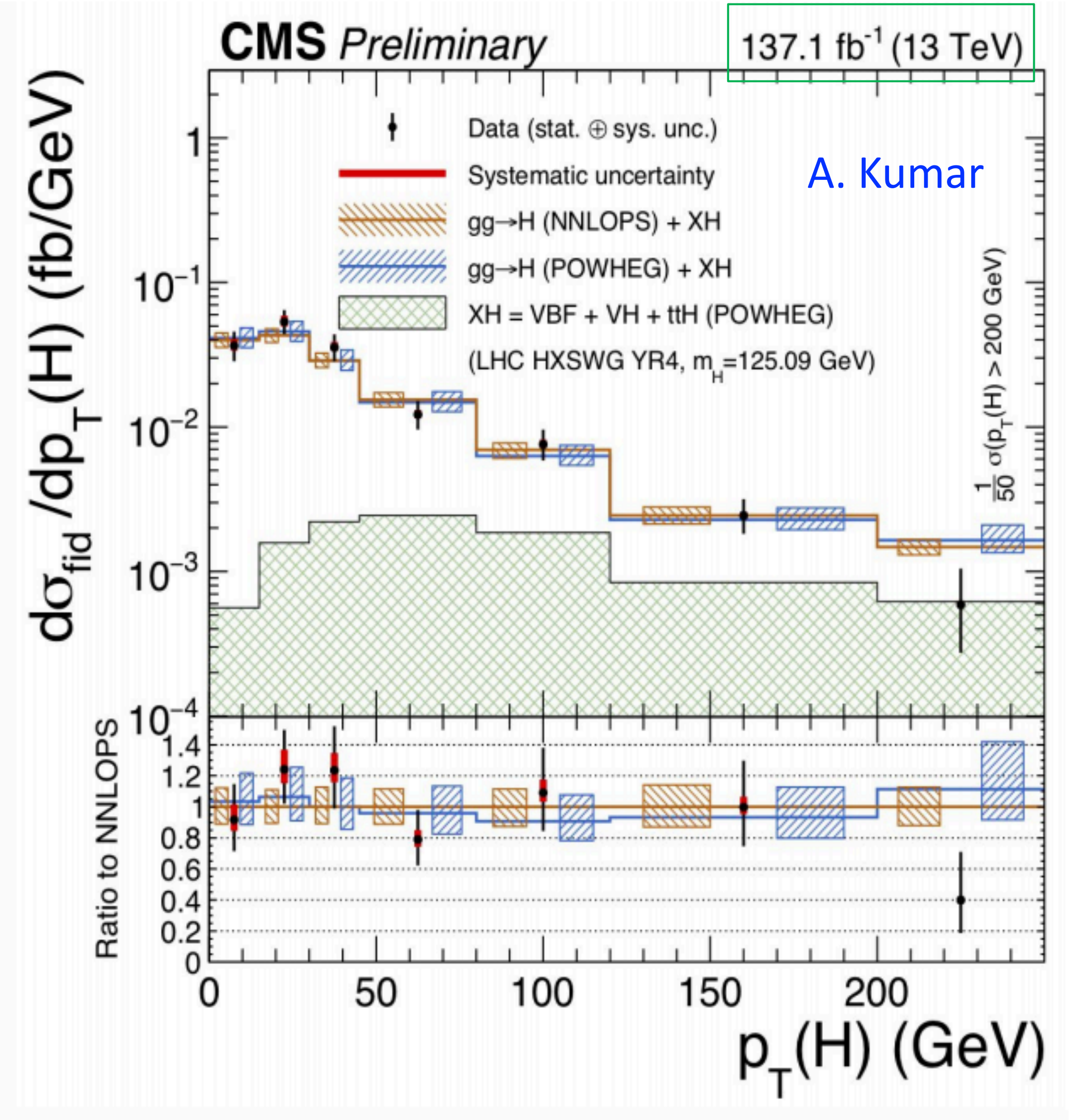
Boosted
ggH vs ttH, EFT…

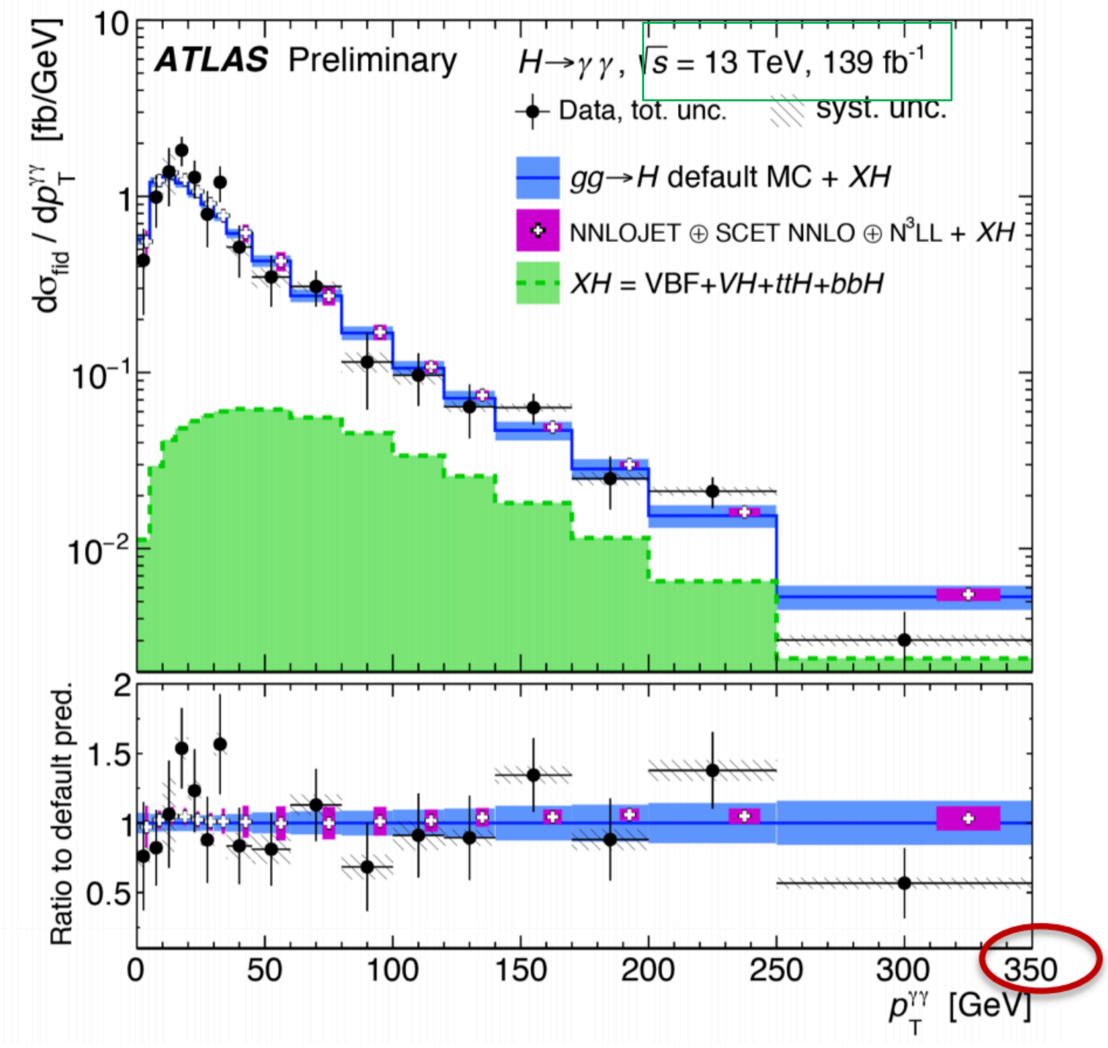




- Higgs Pt spectrum dominated by gluon fusion production (ggF) - not true at very high Pt
- Full range sensitive to several BSM effects:
  - Higgs couplings to charm, bottom, top, BSM Top partners (A.Banfi, A.Martin, V.Sanz ‘13) , EFT operators, …

Fiducial differential cross-sections

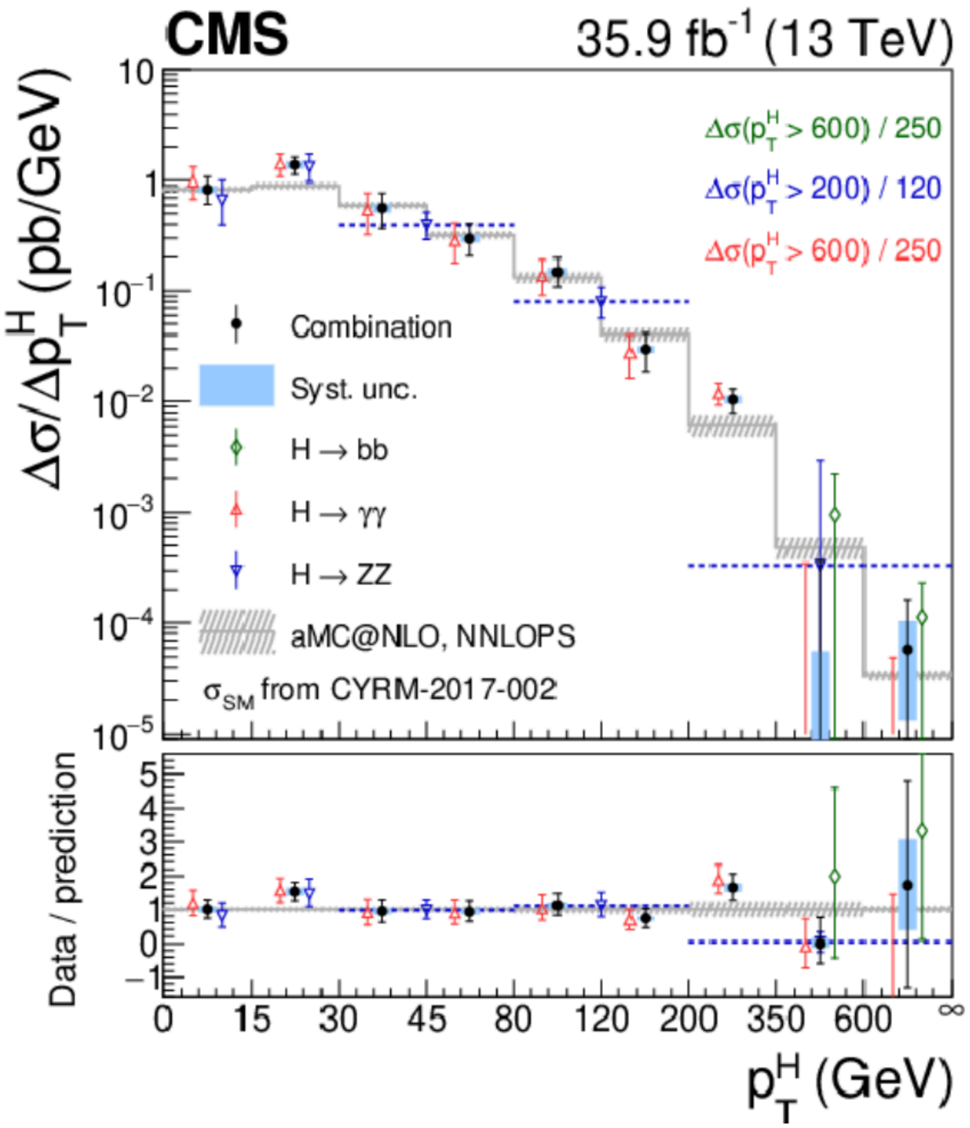


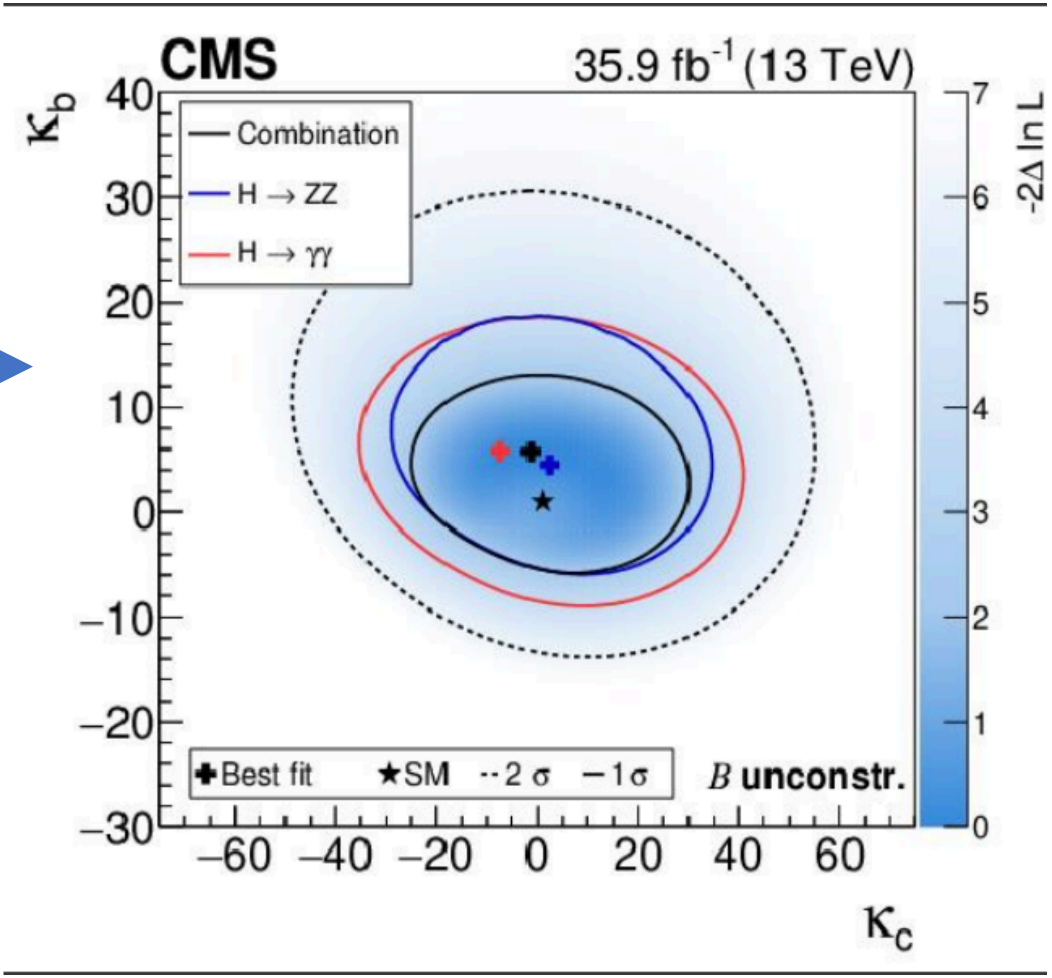


Full Run2 dataset ! The two channels have similar sensitivity

Constraint on charm coupling from PtH

M. Primavera



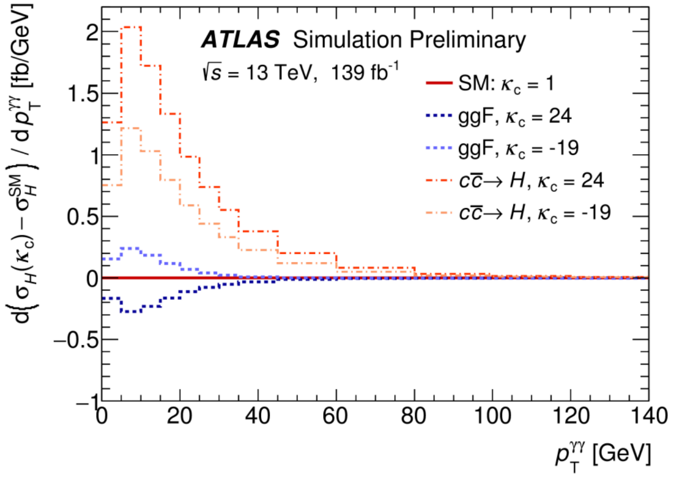


Using only PtH shape information

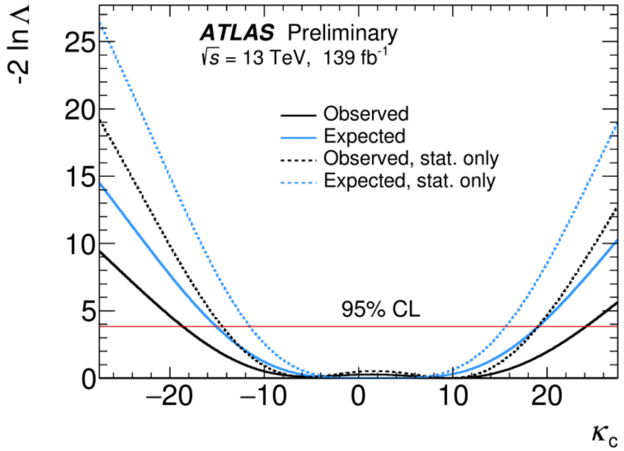
Combining Hγγ+H4l+Hbb channels

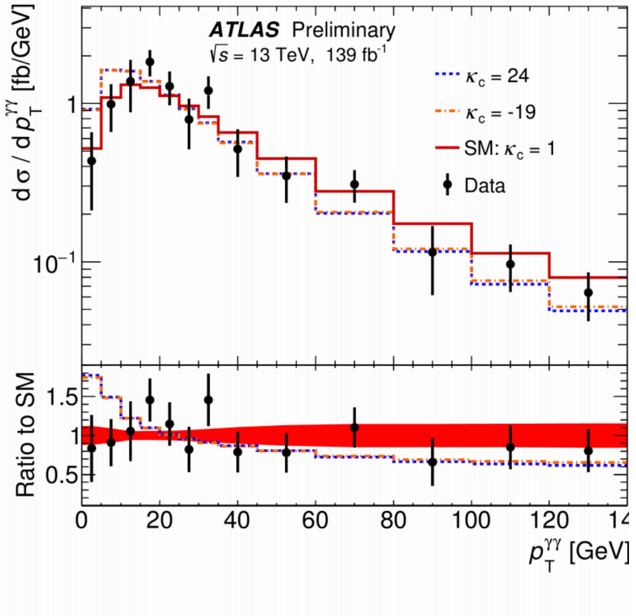
Constraint on charm coupling from PtH

- $gg \to H$
  - Largest change in from top-loop interference with charm-loop
  - Can be positive or negative
- $c\bar{c} \to H$
  - Cross section simply scaled by κ_c^2 in each bin
  - Has stronger contribution to sensitivity



- Shape-only fit $\rightarrow$ reduce model-dependence (Normalization depends on NP modifications to Higgs decay width)
- Measurement statistically limited





Coefficient	Observed 95% CL limit	Expected 95% CL limit
κ_c	$[-19, 24]$	$[-15, 19]$

Larger effect caused by cc->H production
Still worse then with direct search VH→ cc (e.g. see CMS recent limit) but could be complementary (different sensitivity to assumptions)

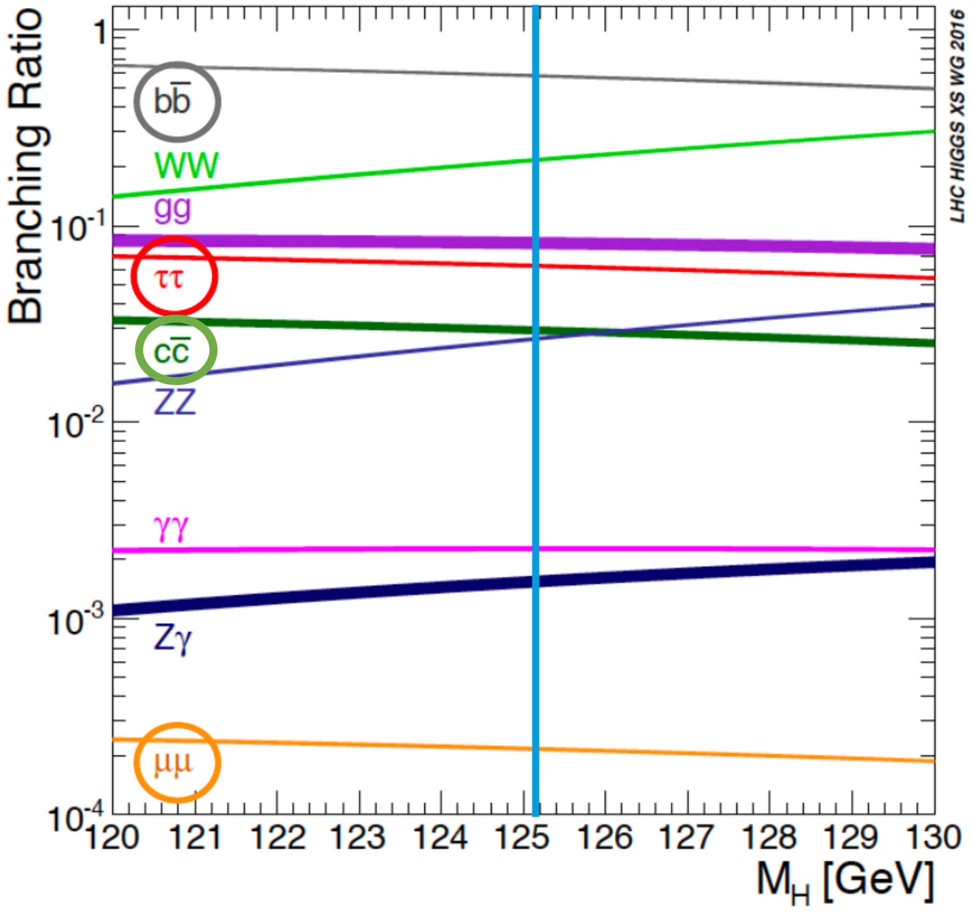
Higgs to Fermion decays

M. Meyer

K. Beker

H. Gray

precise measurements of Higgs Yukawa couplings important test of SM



41.3 fb^{-1} (2017 data)

H → $b\bar{b}$ (BR ~ 58%)
- large background, VH most sensitive production mode

77.4 fb^{-1} (2016 + 2017 data)

H → ττ (BR ~ 6.3%)
- highest experimental sensitivity to Higgs production via VBF

35.9 fb^{-1} (2016 data)

H → μμ (BR ~ 2 * 10^{-2} %)
- high di-muon mass resolution
- probes Yukawa coupling to 2nd-generation fermions

CMS H→ ττ

M. Meyer

H → ττ in ggF & VBF production

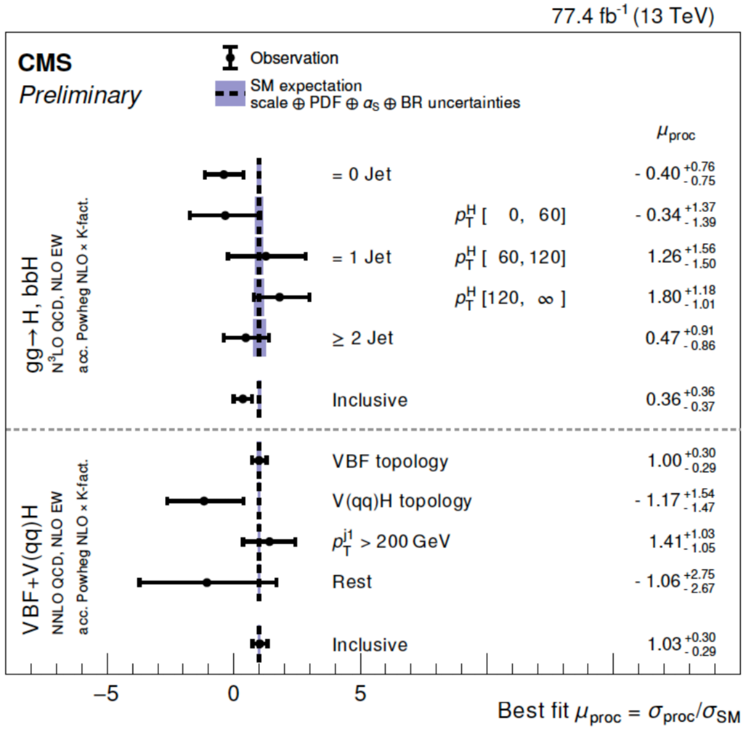
CMS PAS HIG-18-032
NEW!

inclusive measurement:

- best-fit signal strength $\mu = 0.75^{+0.18}_{-0.17}$

cross section measurements split by production modes & different kinematic regimes

- presented as stage-1.0 **simplified template cross sections**, as defined by LHC Higgs Cross Section Working Group
- few categories merged due to low sensitivity



H → ττ: ggF, VBF, VH combination

arXiv:1809.03590, accepted by JHEP

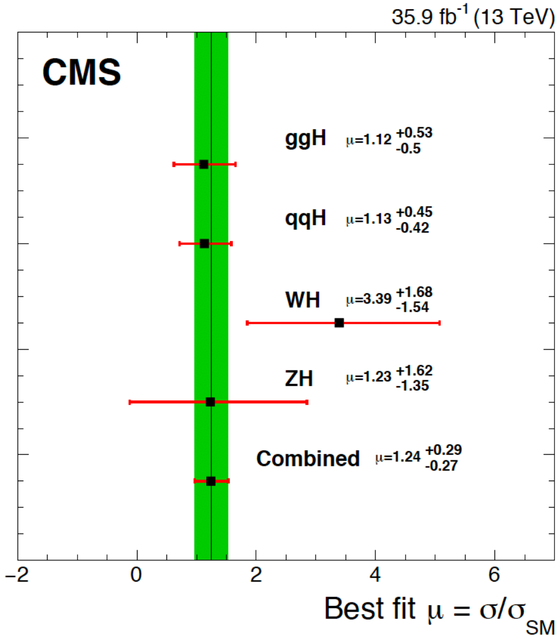
WH / ZH alone:

- best-fit signal strength : $\mu = 2.5^{+1.4}_{-1.3}$
- obs. (exp.) significance of **2.3 σ** (1.0 σ)

combination with ggF & VBF analysis
(**2016 data only**, Phys. Lett. B 779 (2018) 283):

- re-weighting of p_T^H in ggF to spectrum from NNLOPS generator, updated ggF cross section uncertainty
- obs. (exp.) significance of **5.5 σ** (4.8 σ)

➡ **observation level reached with 2016 data alone**



Inclusively ~30% accuracy with only ½ of Run2 data
Start to explore STXS different kinematic per production mode

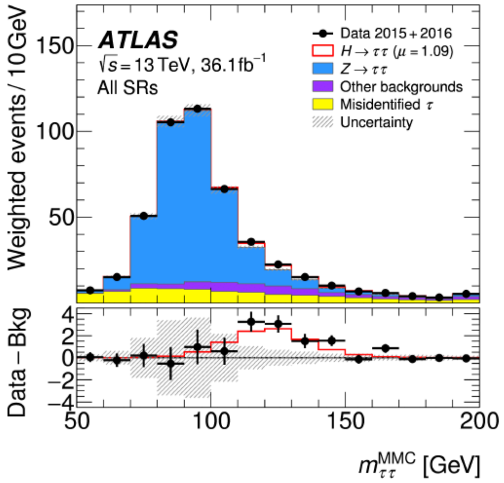
ATLAS H→ ττ

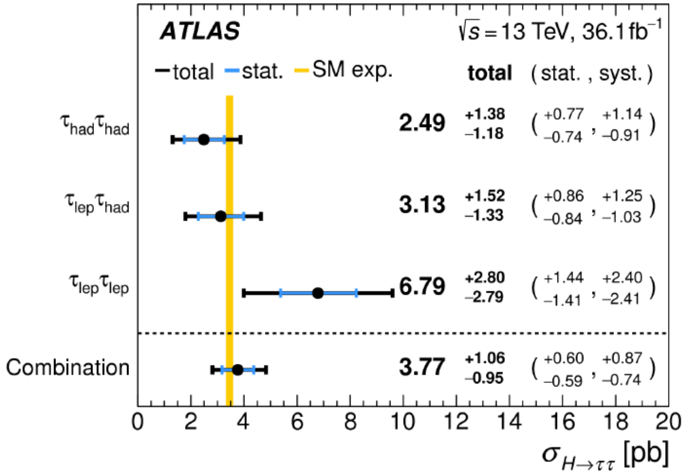
K. Beker

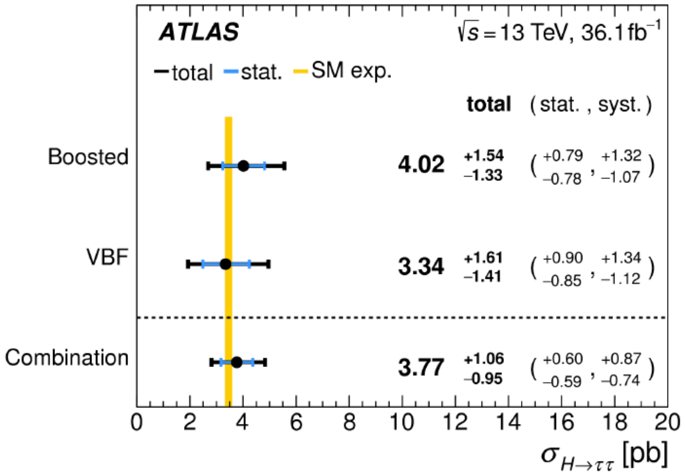
PRD 99 (2019) 072001

36 fb^{-1}
$^1/_4$ of Run 2

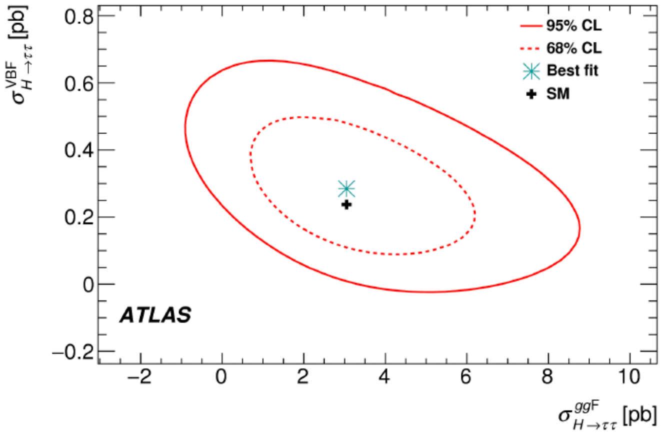
$H \rightarrow \tau\tau$: Results







- Fit of $m_{\tau\tau}^{MMC}$ to extract signal
- Observed significance of 4.4σ (4.1σ exp.)
- **Observation of $H \rightarrow \tau\tau$** when combining with Run 1: 6.4σ (5.4σ exp.)
- Similar contributions from statistical and systematic uncertainties



Kathrin Becker, 29.07.2019

11

Again no significant deviation from SM predictions
Inclusively ~30% accuracy

$H \rightarrow b\bar{b}$: combination

Phys. Rev. Lett. 121 (2018) 121801

CMS $H \rightarrow bb$

M. Meyer

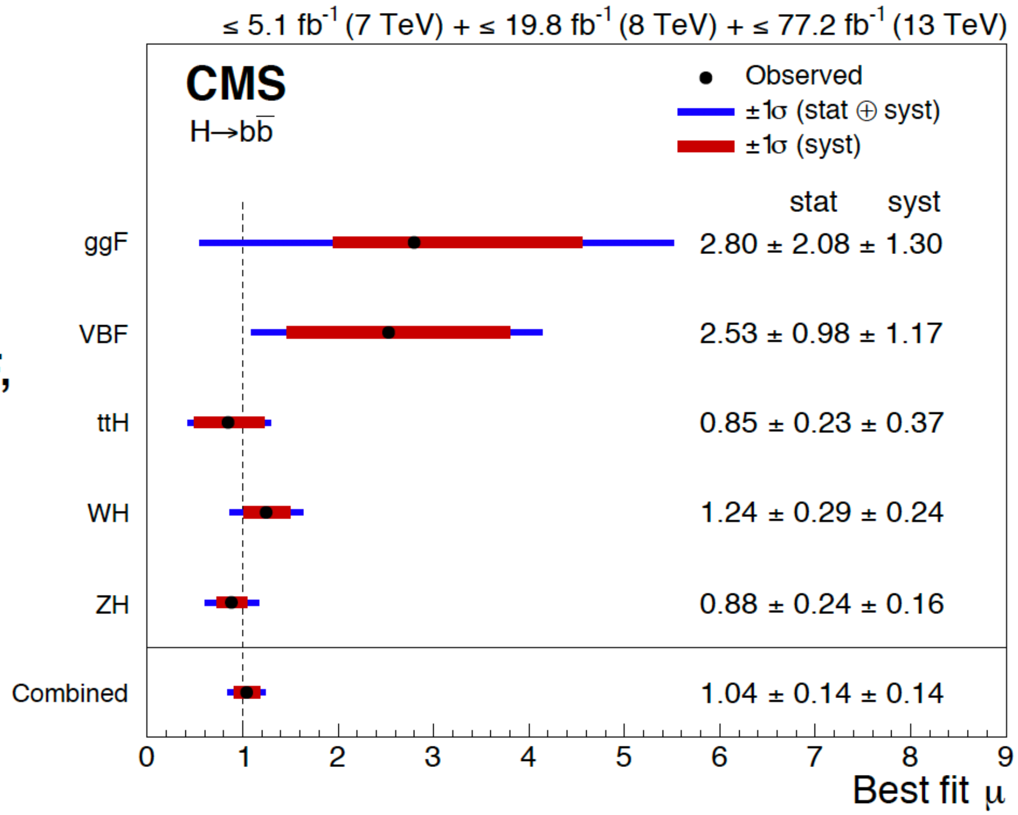
2017 + 2016 + Run I data:

- best-fit signal strength : μ = 1.01 ± 0.22
- obs. (exp.) significance of 4.8 σ (4.9 σ)

combination with analyses targeting ggF, VBF & $t\bar{t}H$ production modes:

- best-fit signal strength : μ = 1.04 ± 0.20
- obs. (exp.) significance of 5.6 σ (5.5 σ)

➡ **observation of $H \rightarrow b\bar{b}$ by CMS**



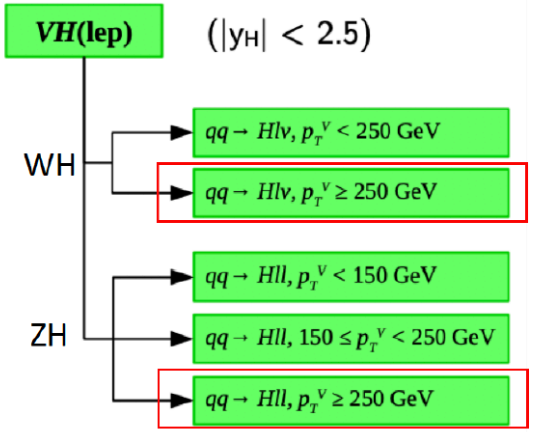
- Also this decay has been observed by both ATLAS and CMS

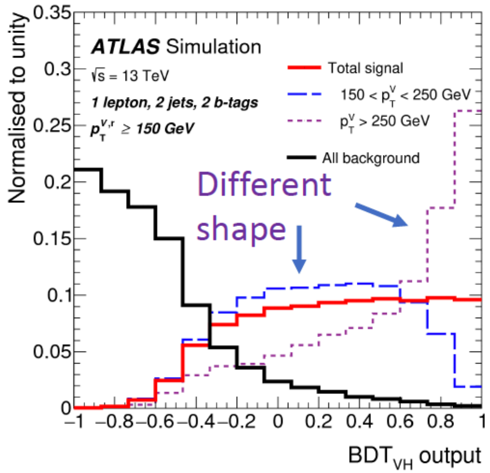
Study VH with $H \to bb$ (STXS)

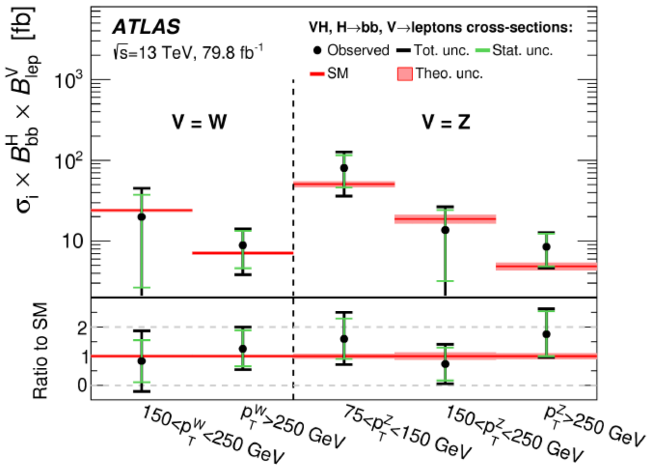
JHEP 05 (2019) 141

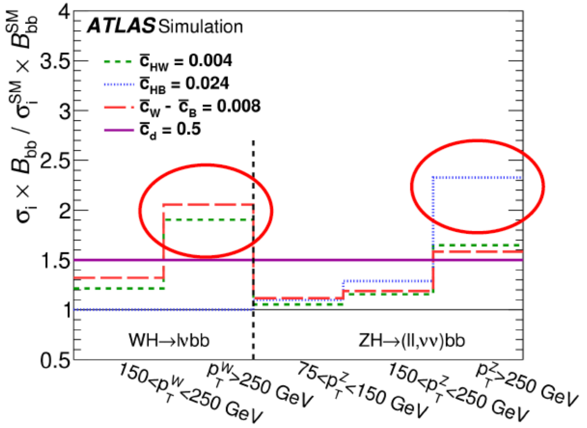
79.8 fb^{-1}
$^{2}/_{3}$ of Run 2

ATLAS H→bb









- Use same BDTs to measure STXS bins as function of $p_T(V)$
- Five cross sections: WH $p_T(V)$: [150-250, > 250] GeV and ZH $p_T(V)$: [75-150, 150-250, > 250] GeV
- All results consistent with SM, still statistics dominated
- Systematics from background modelling and MC statistics
- Impact from signal theory uncertainties small
- Sensitivity to EFT couplings, information on 95% CL limits in the backup

C. Tosciri

K. Beker

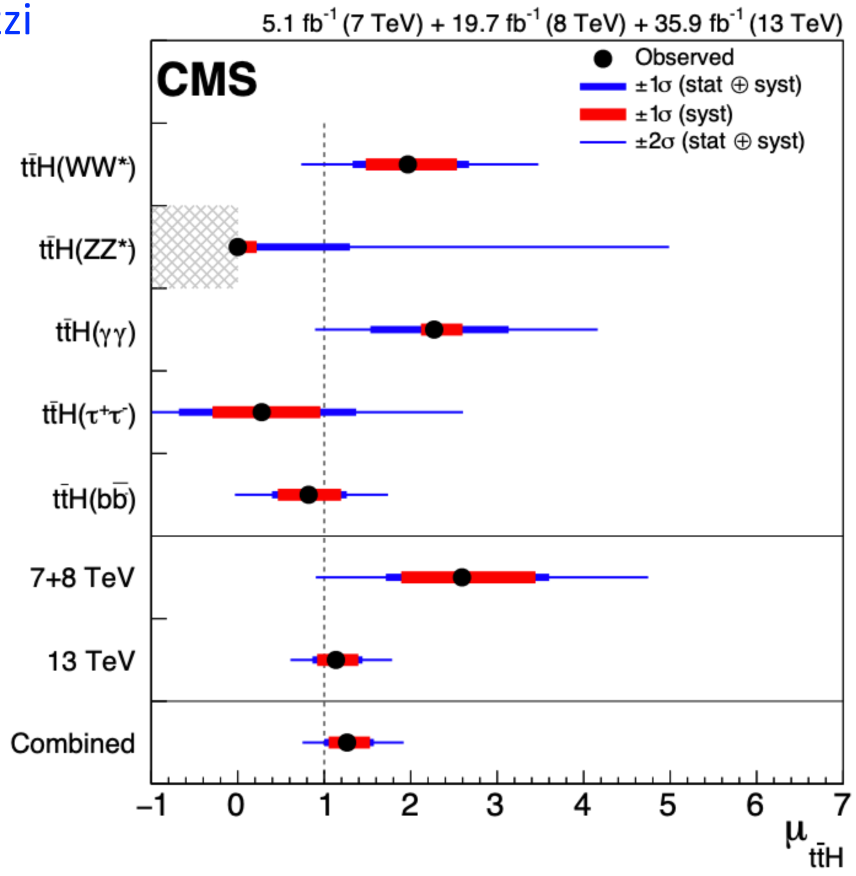
Kathrin Becker, 29.07.2019 8

- Adding STXS measurements and EFT interpretations: High PtV sensitive to new Physics
- **Discussion**: important to check sensitivity/dependence of STXS measurement to BSM effects on signal (and background, e.g. H->WW)

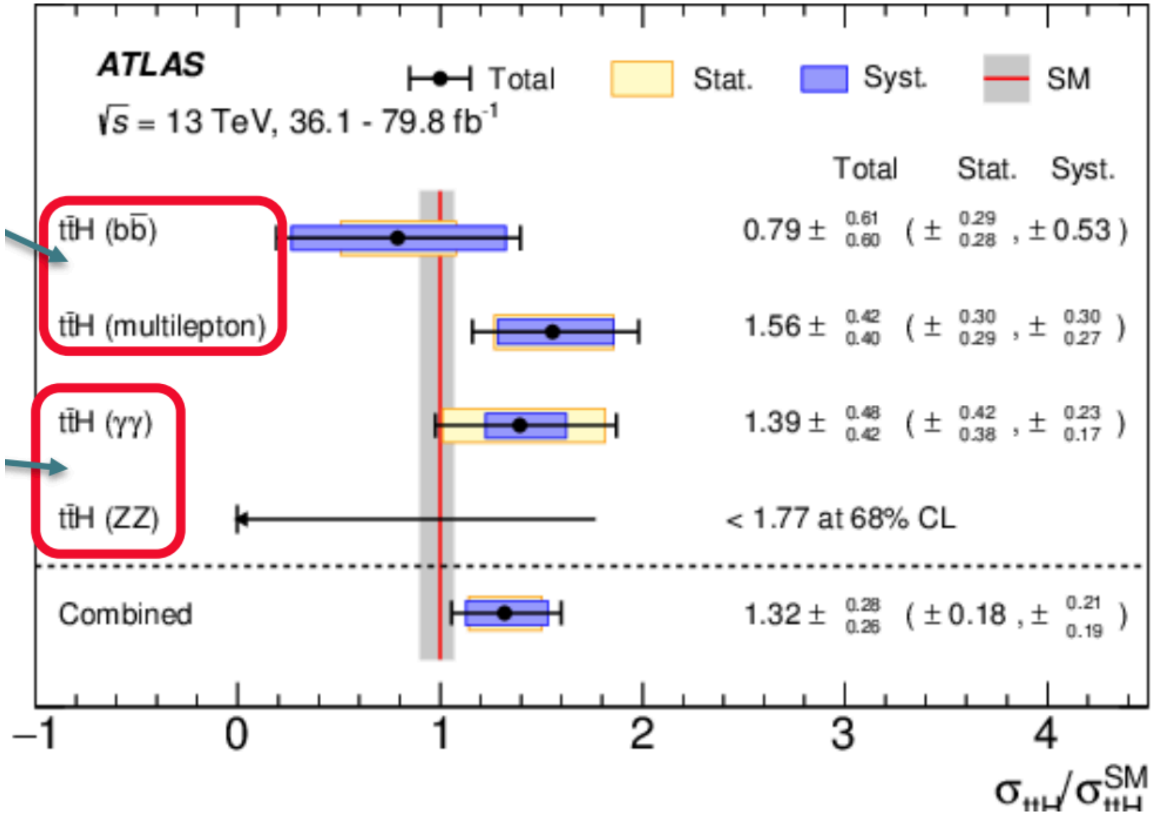
ttH results

M. Peruzzi

B. Li



M. Spalla X. Yang

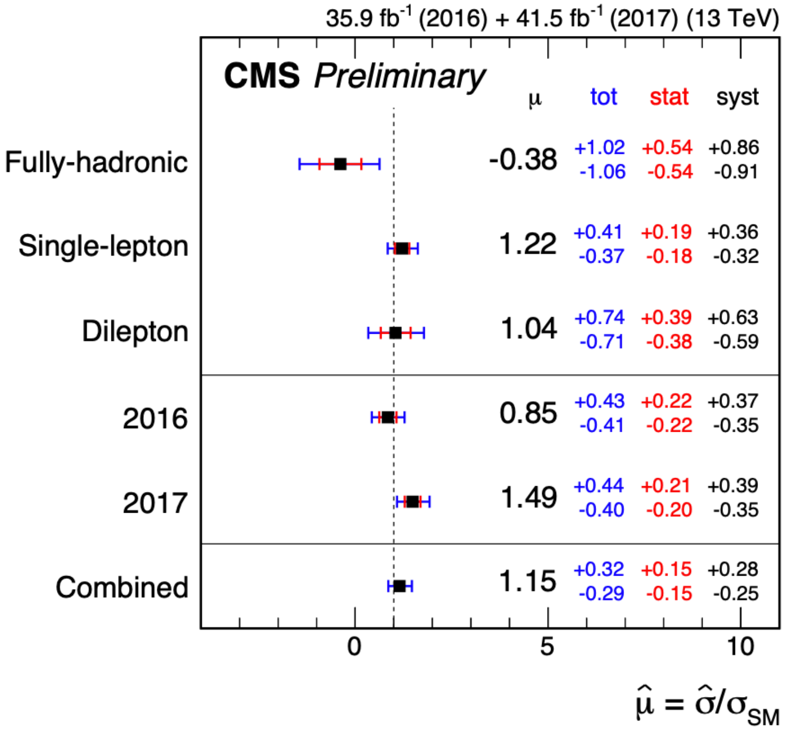


- Observation of ttH was one of the mail goals of LHC Run2:
  - direct observation of Y_{top} (very large coupling ~1!)
- Both CMS and ATLAS observed it in 2018 by combining several decay channels, already achieved ~20% accuracy and measurements in agreement with SM predict.

ttH->bb CMS

M.Peruzzi

CMS PAS HIG-18-030



Uncertainty source	$\Delta\hat{\mu}$
Total experimental	$+0.15/-0.13$
b tagging	$+0.08/-0.07$
jet energy scale and resolution	$+0.05/-0.04$
Total theory	$+0.23/-0.19$
signal	$+0.15/-0.06$
$t\bar{t}$+hf modelling	$+0.14/-0.15$
QCD background prediction	$+0.10/-0.08$
Size of simulated samples	$+0.10/-0.10$
Total systematic	$+0.28/-0.25$
Statistical	$+0.15/-0.15$
Total	$+0.32/-0.29$

- 2017 result: $\mu = 1.49^{+0.44}_{-0.40}$, 3.7σ significance (2.6σ expected)
- **2016+2017 combination: $\mu = 1.15^{+0.32}_{-0.29}$, 3.9σ significance (3.5σ expected)**
- **Very significant improvements in the control of backgrounds result in an impressive boost of the analysis sensitivity**

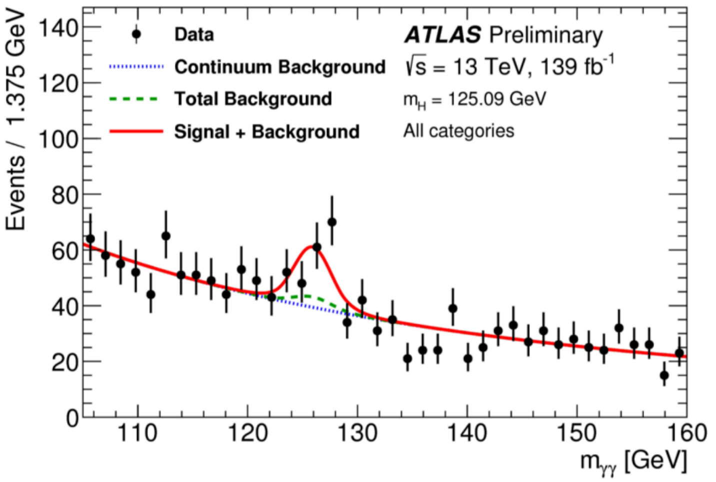
- Update with 2016+2017 data → in CMS ttH->bb is the most precise channel!
- bgk. theory systematics in ATLAS >0.50: quite useful discussion … will continue in LHCHCWG

ttH-> γγ ATLAS

ttH(H→γγ): 139 fb⁻¹ results

M.Spalla

- Maximum Likelihood fit on all categories
  - H mass constrained to experimental value
- ttH observed with 4.9 σ significance
  - Expected: 4.2 σ
- Remains statistically dominated



same size

$$\sigma_{ttH} \times B_{\gamma\gamma} = 1.59\ ^{+0.38}_{-0.36}(\text{stat.})\ ^{+0.15}_{-0.12}(\text{exp.})\ ^{+0.15}_{-0.11}(\text{theo.})\ \text{fb}$$

- Measured cross section still ~1.4 times the Standard Model expectation
  - Remains compatible given the uncertainties

Prediction:

$$\sigma_{ttH} \times B_{\gamma\gamma}\ (\text{SM}) = 1.15\ ^{+0.09}_{-0.12}\ \text{fb}$$

$$\frac{\sigma_{ttH}}{\sigma^{SM}_{ttH}} = 1.38\ \pm^{0.33}_{0.31}\ (\text{Stat.})\ \pm^{0.13}_{0.11}\ (\text{exp.})\ \pm^{0.22}_{0.14}\ (\text{theo.})$$

30% accuracy

- First ttH results with full Run2 data together with CMS and ATLAS H->4l

Higgs → μμ

- One of the major goals for Run3
- Best chance at LHC to measure interactions between Higgs and 2nd generation Fermions
- Main challenge is the very small S/B (at ~2 mill level inclusively);
  - Very important to get correct modelling of background fit with analytic functions to avoid signal biases

ATLAS-CONF-2019-028

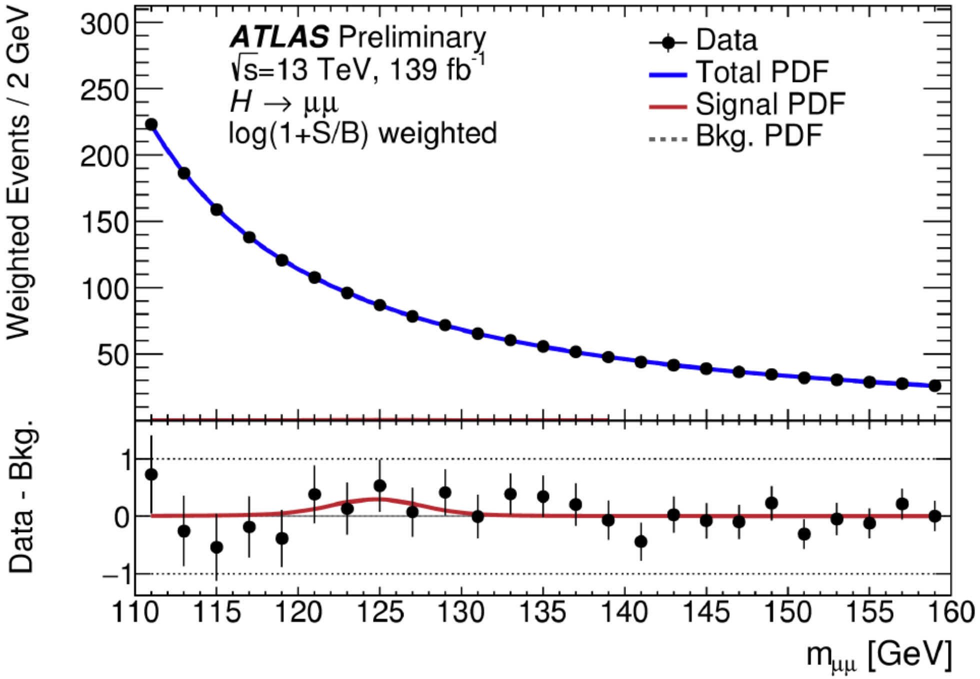
EPS 2019

139 fb^{-1}
Full Run 2

BERKELEY LAB
Lawrence Berkeley National Laboratory

Search for $H \rightarrow \mu\mu$

- Fit to $m_{\mu\mu}$ in 12 categories to extract signal
- Signal modelling: double-sided Crystal Ball
- Background estimation:
  - Important due to very low S/B
    → per mill level description of background
  - $m_{\mu\mu}$ background model parametrized by analytical functions
    - Core function to model DY mass shape
    - Empirical function to correct distortions
- Uncertainties on μ (absolute value):
  - Signal theory: 0.08
  - Signal exp. : 0.07
  - Spurious signal: 0.06
  - Data stat.: 0.7



K. Beker

M. Zgubic

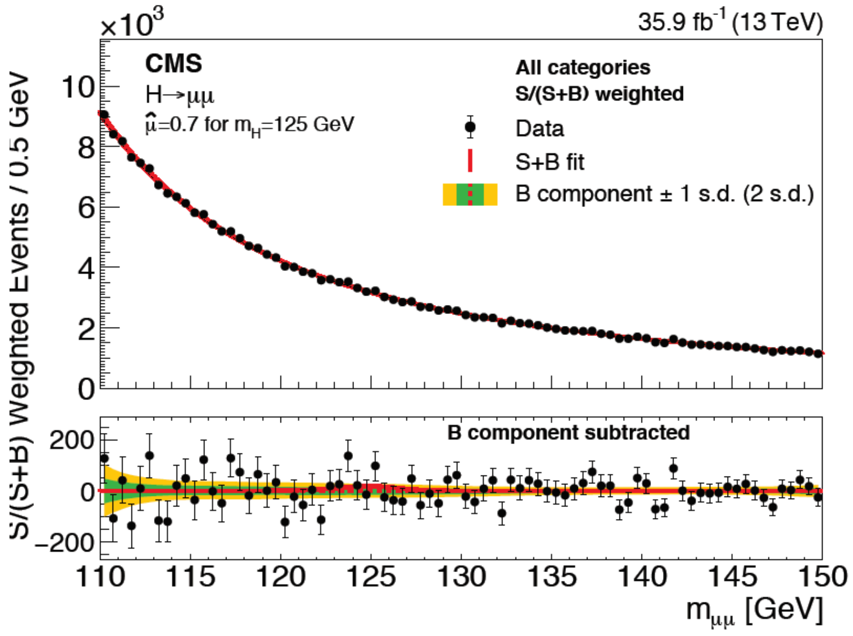
- Results:
  - Upper limits: **1.7 (1.3) x σ_{SM} obs. (exp.)**
  - Signal strength: $\mu = 0.5 \pm 0.7$
  - Significance: 0.8σ (1.5σ) obs. (exp.)

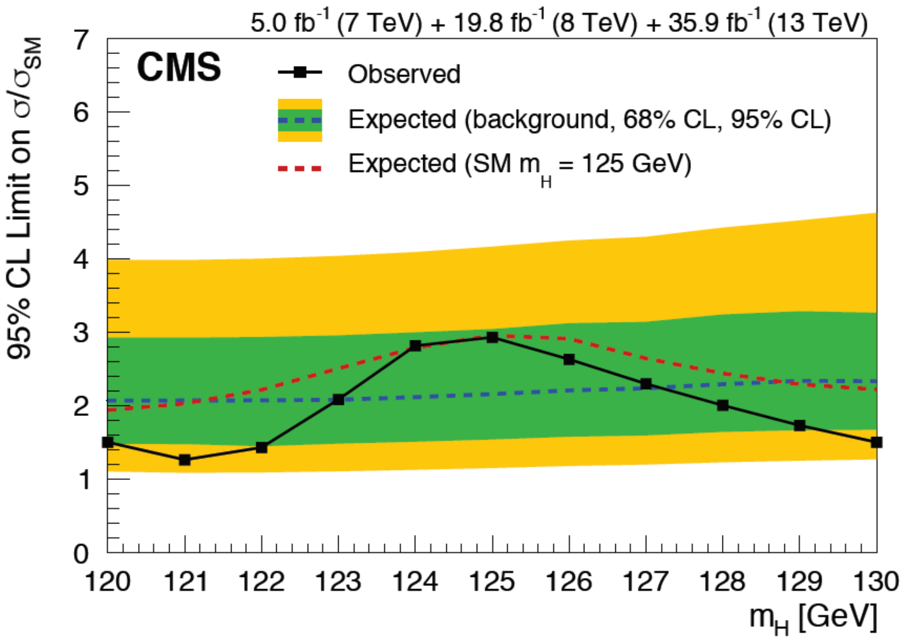
- Preliminary result from ATLAS with full Run2 data reached 1.5σ expected sensitivity!

H → μμ

35.9 fb^{-1} (2016 data)

Phys. Rev. Lett. 122 (2019) 021801





M. Meyer

Y. Gershtein

combined 2016 data + Run I results (at m_H = 125.09 GeV) :

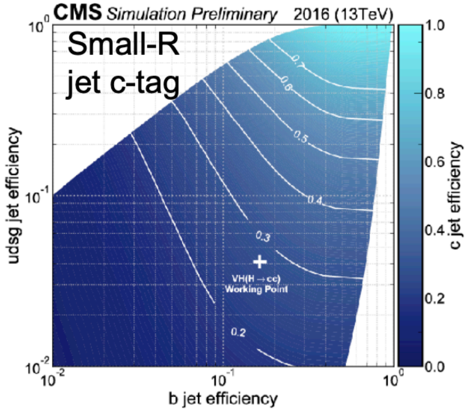
- upper limit on σ/σ_{SM} : 2.9 (2.2) obs. (exp. for μ = 0) at 95% C.L.
- best fit signal strength μ of 1.0 ± 1.0 (stat) ± 0.1 (syst)
- obs. (exp.) significance of 0.9 σ (1.0 σ)

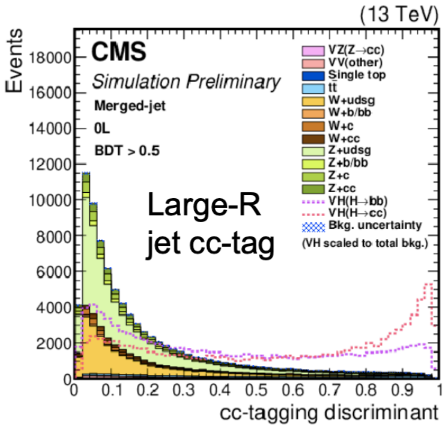
- CMS has ~2 better mass resolution than ATLAS for this signal: should get ~2σ sensitivity with full Run2 dataset

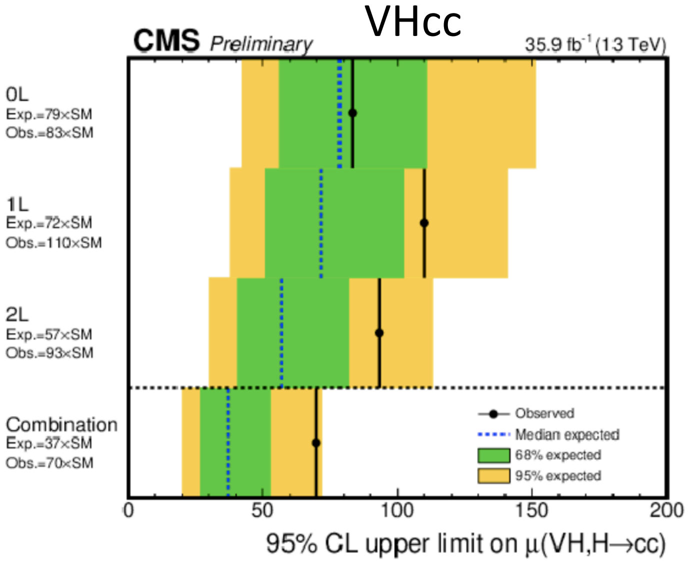
Y. Gershtein L. Gouskos

Higgs → cc (VHcc)

- First CMS search of its kind! See Loukas'es talk on Wednesday





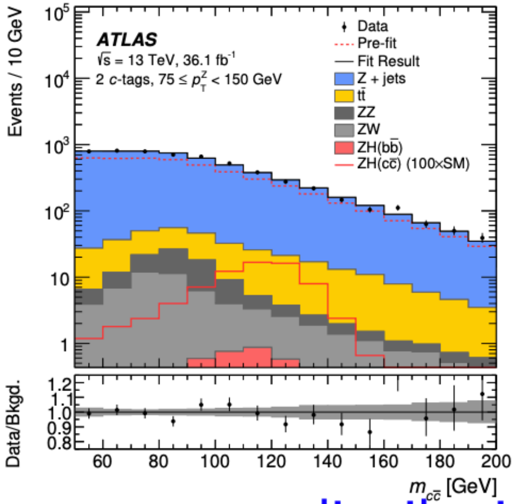


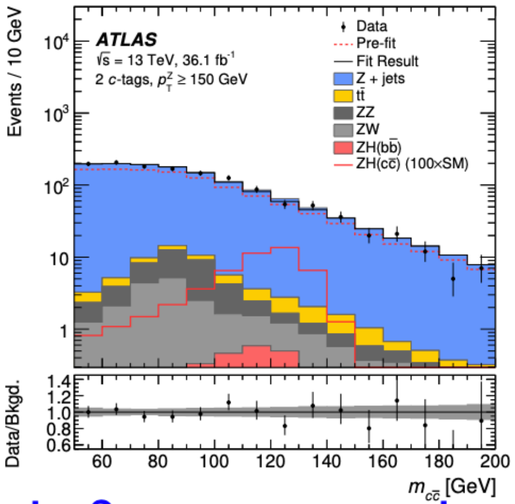
- ~2σ excess
- μ < 70 (μ < 37 expected)

Yuri Gershtein

L. Truong

ZHcc





PRL 120 (2018) 211802

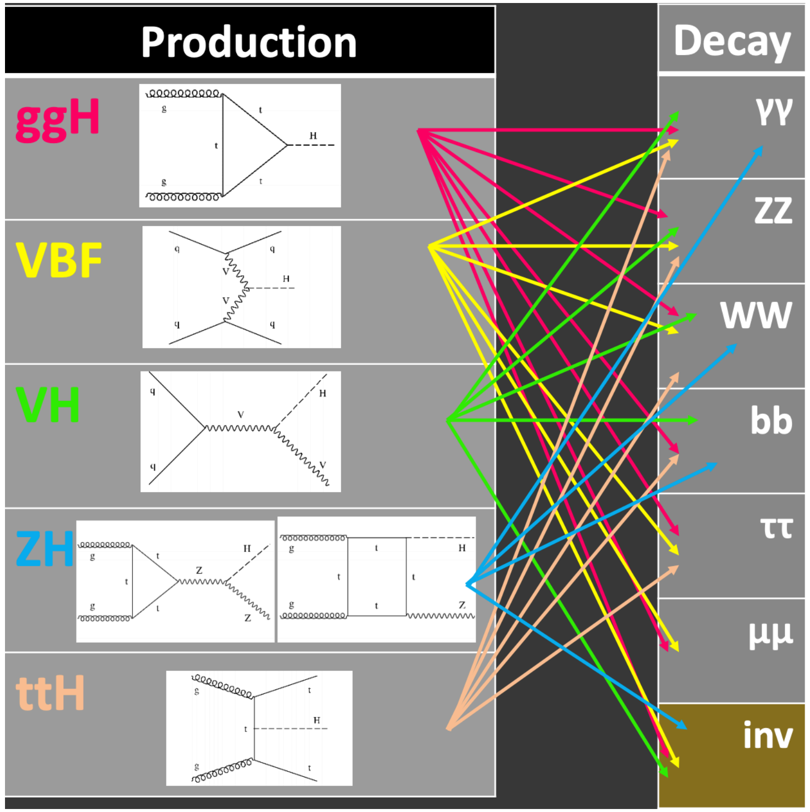
$m_{c\bar{c}}$ distribution in 2 c-tag categories

- Observed (expected) upper limit at 95% CL:
  - on $\sigma(pp \to ZH) \times BR(H \to c\bar{c})$: 2.7 $(3.9^{+2.1}_{-1.1})$ pb. (SM value is 26 fb)
  - or on signal strength: 110 (150^{+80}_{-40})

- Both Experiments will address orthogonality with Hbb analysis and make simultaneous fit Hbb/Hcc fit next round
- CMS also uses 0/1L channels + Merged jets + MVA approach (ATLAS fit to Mcc) :
  - quite striking difference in 2L resolved channel EXPECTED μ sensitivity: 59(CMS) vs 150(ATLAS) !

Channels Combination

M. Primavera



S.Heim

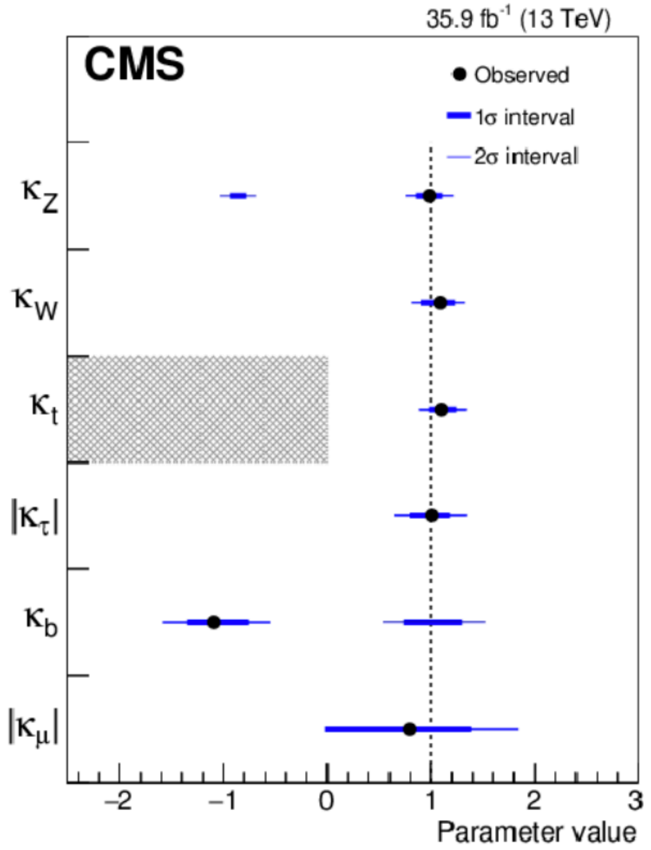
Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
VBF, $H \to b\bar{b}$	24.5 – 30.6
$H \to \mu\mu$	139
$t\bar{t}H$, $H \to b\bar{b}$ 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

- CMS combination based on 36 fb^{-1}
- ATLAS combination based 36-80 fb^{-1} (+139 fb^{-1})

Channels Combination CMS: κ fit

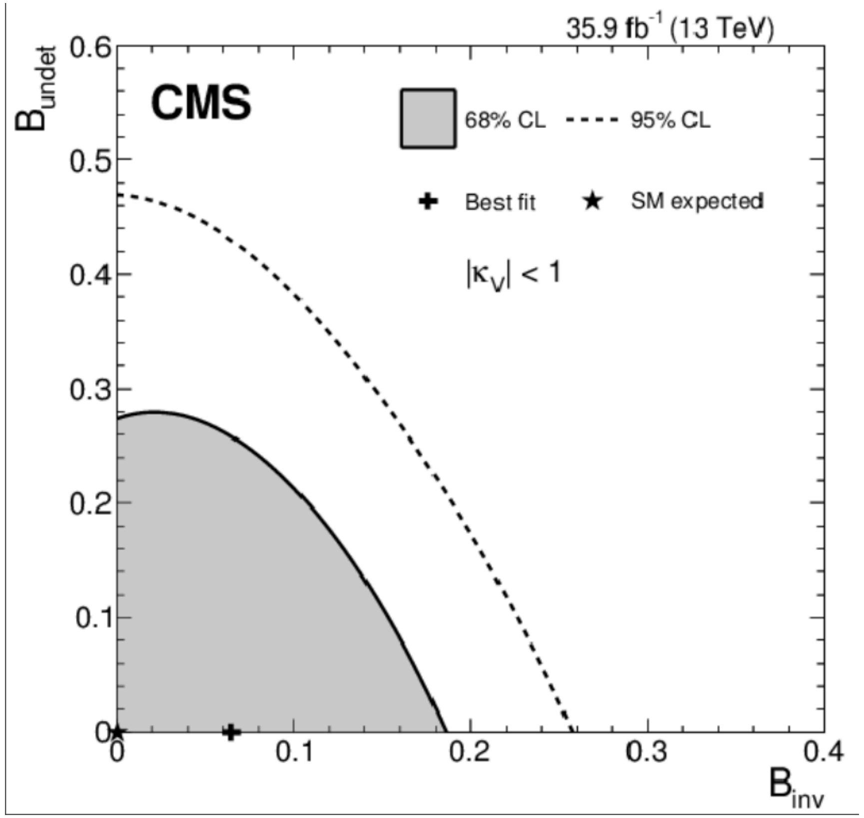
M. Primavera

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\kappa_H^2}{1-(BR_{undet.}+BR_{inv.})}$$



No significant deviations form SM predictions

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\kappa_H^2}{1-(BR_{undet.}+BR_{inv.})}$$



κ fit is a very stringent test of the SM

Combining with invisible Higgs direct search can disentangle "Invisible" from "Undetectable" in κ fit (assuming $|\kappa_V|<1$)

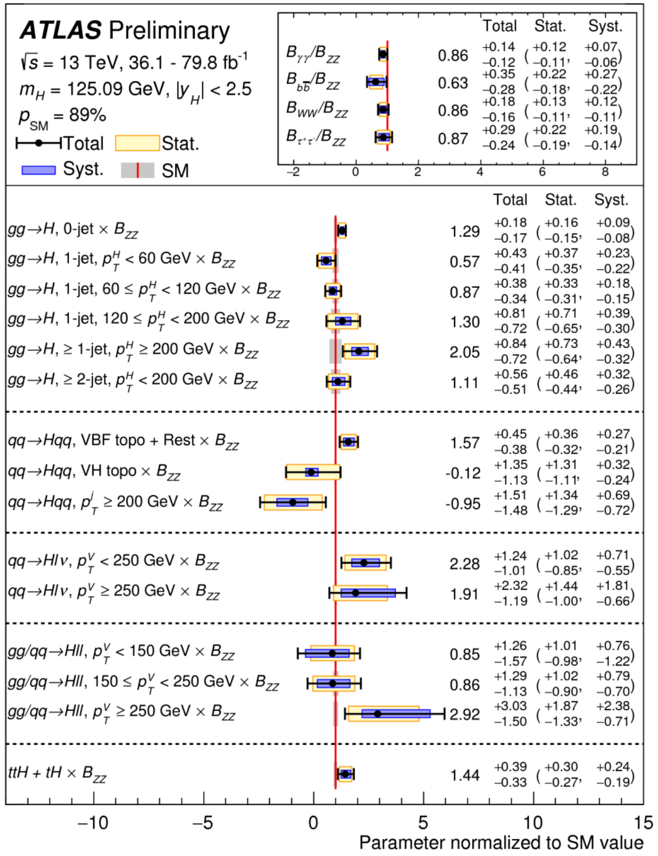
Channels Combination ATLAS

Simplified template cross sections (STXS)

5

19 parameters

- STXS: cross sections binned by production mode and kinematic regions (reduces acceptance uncertainty)
- Parametrization based on cross sections in the H->ZZ channel and ratio of branching ratios
- good compatibility with SM (p = 89%)
- results with higher granularity (full Stage 1) also available



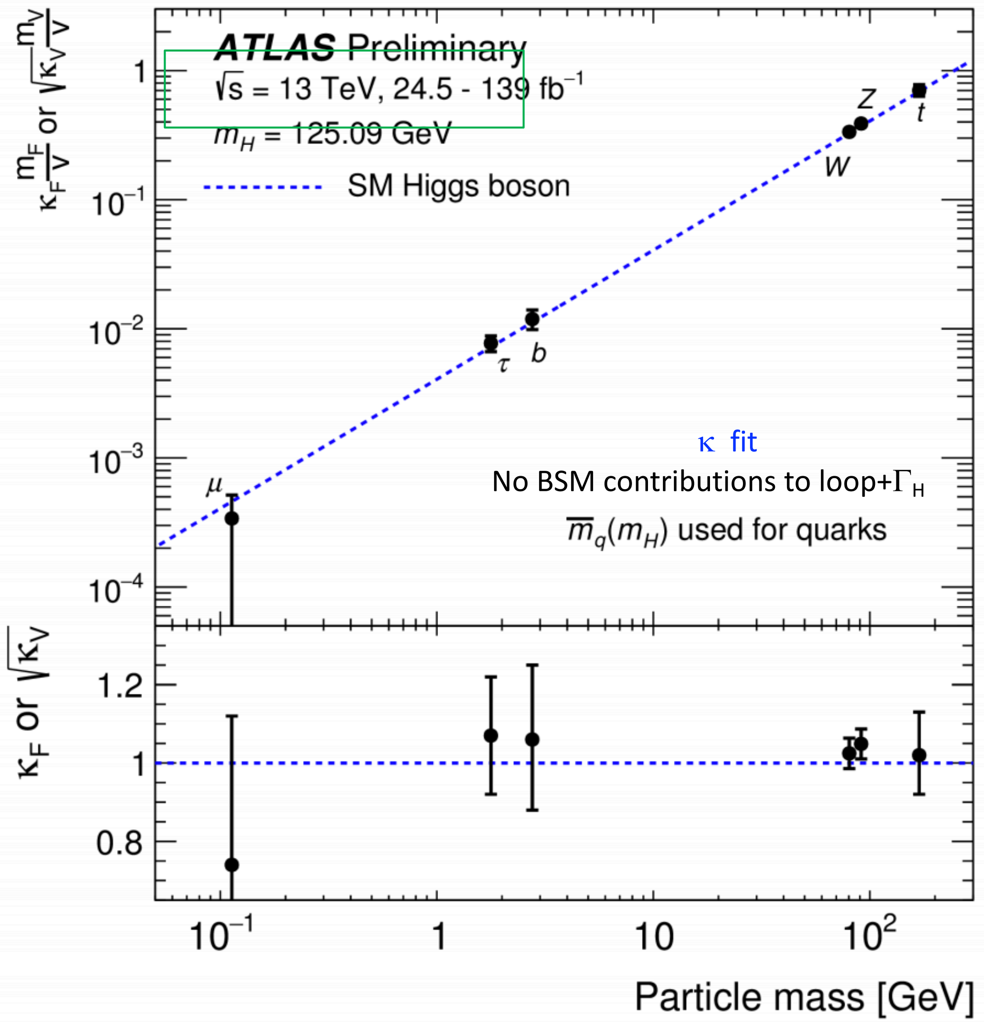
ggH

Hqq

V(lep)H

ttH

S.Heim

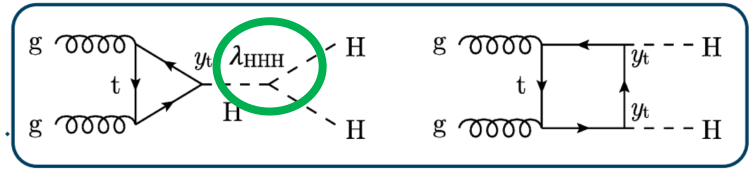


STXS: More model independent way of combining different decay channels that can be used to constraints BSM models

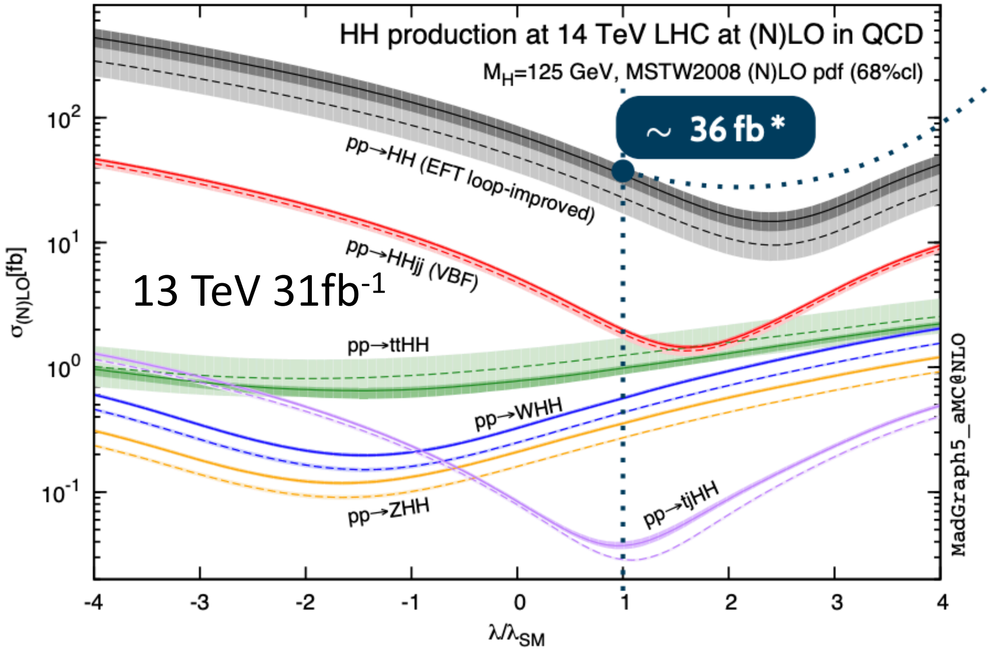
BR ratios introduce large correlations

Justify the change form **A** Higgs boson to **"THE** SM Higgs boson"

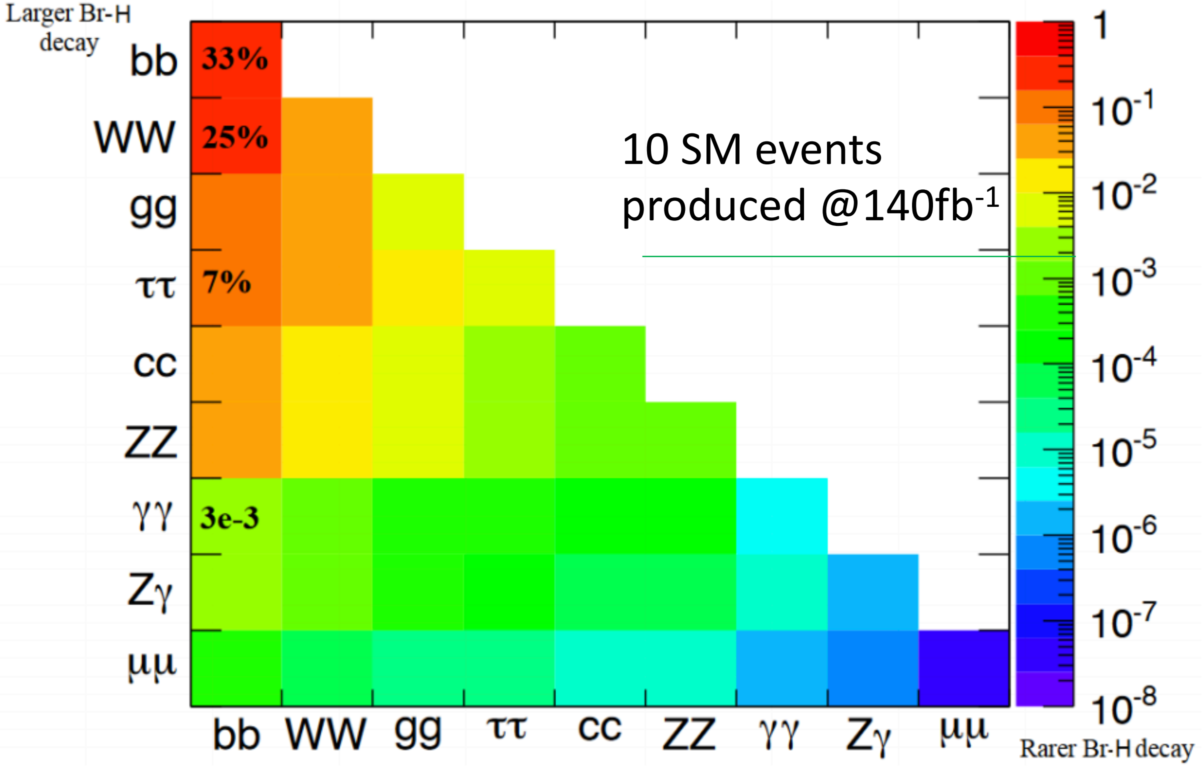
HH and Higgs self-coupling



C. Amendola



S. Shrestha



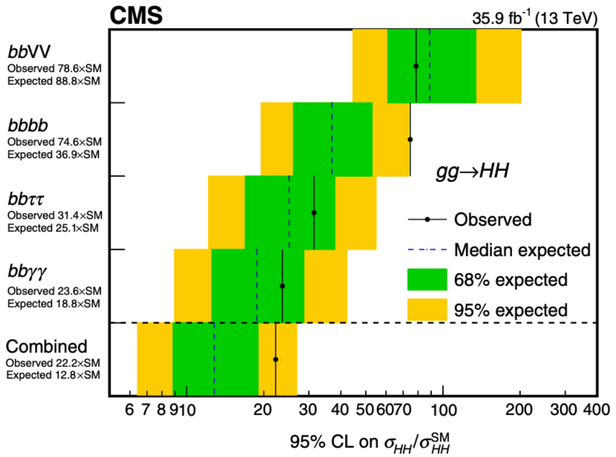
- Once also Higgs Mass is measured SM Higgs interactions fully determined:
  - Higgs potential and self interactions predicted → measure self coupling \ is a fundamental test of the SM
  - Small cross-section - negative interference between the HHH and box diagrams

HH and Higgs self-coupling

C. Amendola

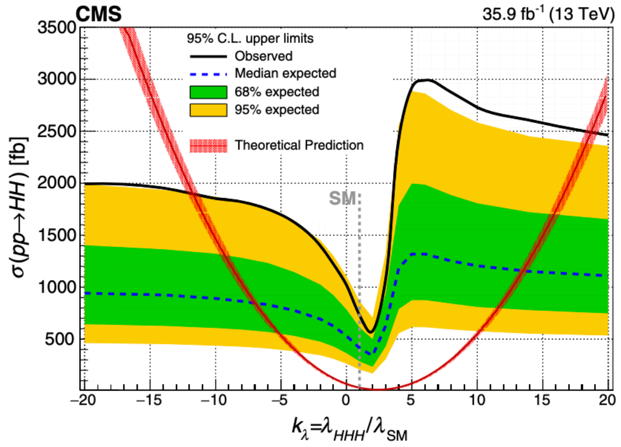
S. Shrestha

SA. Tayloe



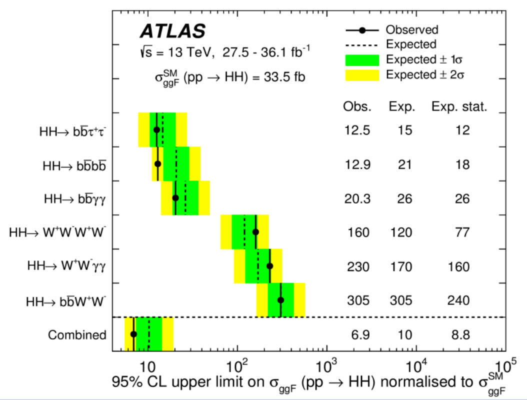
SM combined limit: $22\ (13) \times \sigma_{SM}$

- Run I combination obs (exp) limit: $43\ (46) \times \sigma_{SM}$



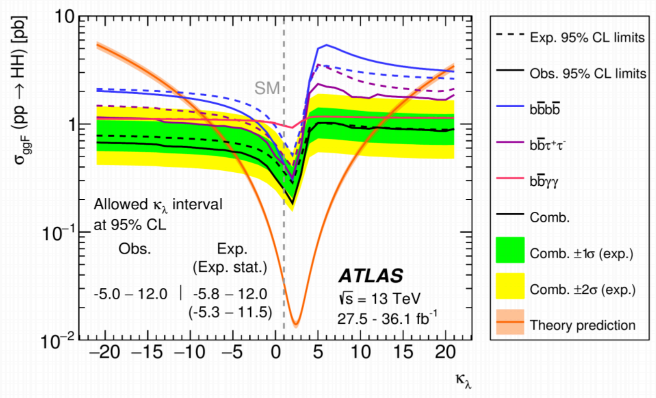
BSM obs (exp) constraints:

$-11.8 < k_\lambda < 18.8\ (-7.1 < k_\lambda < 13.6)$



95% CL limit for $\kappa_\lambda = 1$:

6.9 (10) X SM obs. (exp.)



95% CL confidence intervals:

κ_λ: obs. [-5,12] (exp. [-5.8, 12])

Combining several channels (dominant bbγγ, bbττ, bbbb) Getting closer for HH sensitivity ~10 times SM

Systematic plays important role for bbbb

Self couplings probed using STXS

S.Heim

ATLAS-PUB-2019-009

H Self-interaction from single-H combined measurements ATLAS

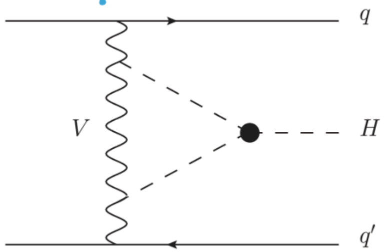
$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 \nu H^3 + \frac{1}{4}\lambda_4 H^4 + \mathcal{O}(H^5)$$

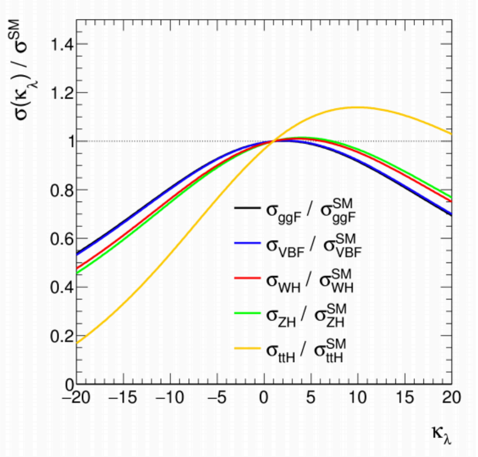
- usually studied in di-Higgs searches
- it is possible to extract the self-coupling in single-Higgs events through NLO EW corrections
- use inclusive XS for ggF, ttH
- use STXS bins for VBF and VH
- assume all single-Higgs couplings to be SM
- fit for $\kappa_\lambda = \frac{\lambda_3}{\lambda_3(\text{SM})}$

κ_λ =[-3.2,11.9] @ 95%CL (di-Higgs: [-5,12])

- results similar to di-Higgs fit

example:





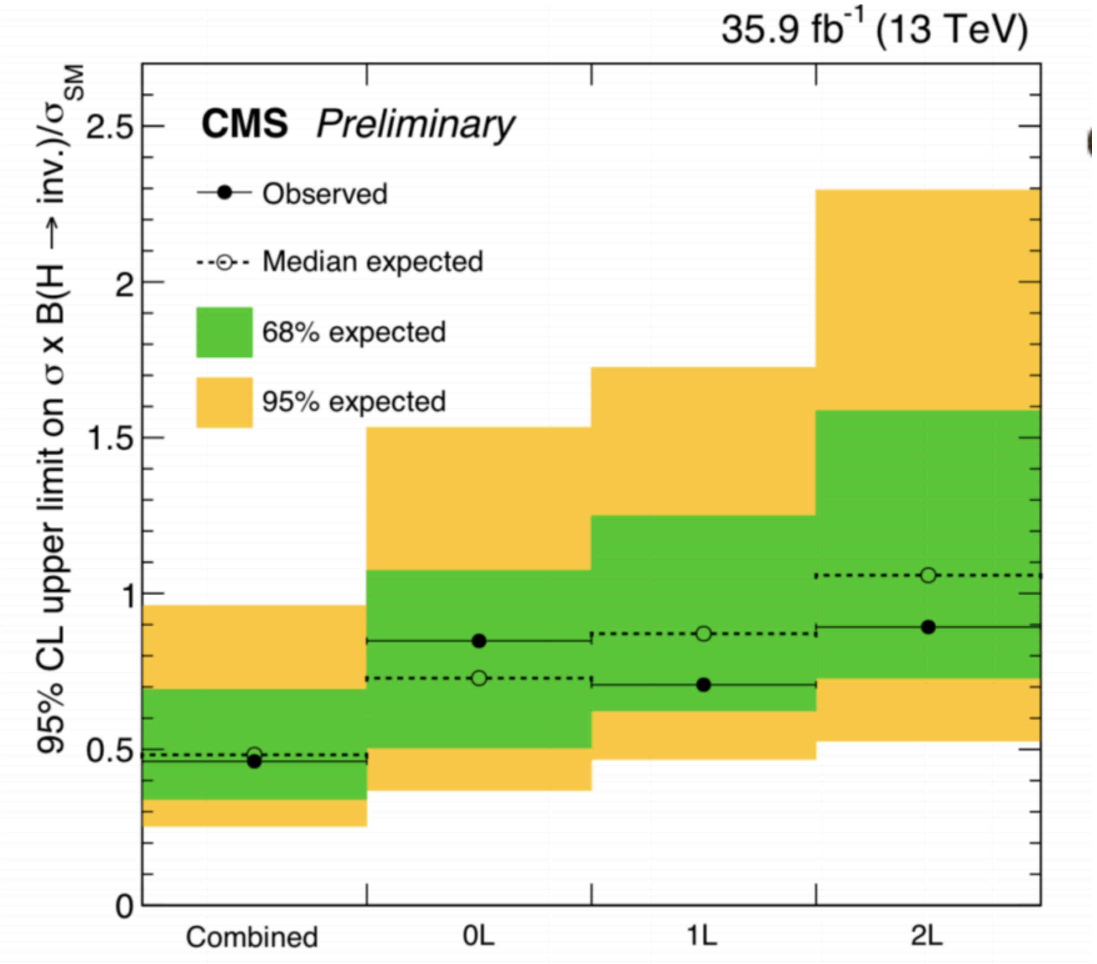
G. Degrassi et al., JHEP 12 (2016 080)
F. Maltoni et al., EPJC 77 (2017) 887

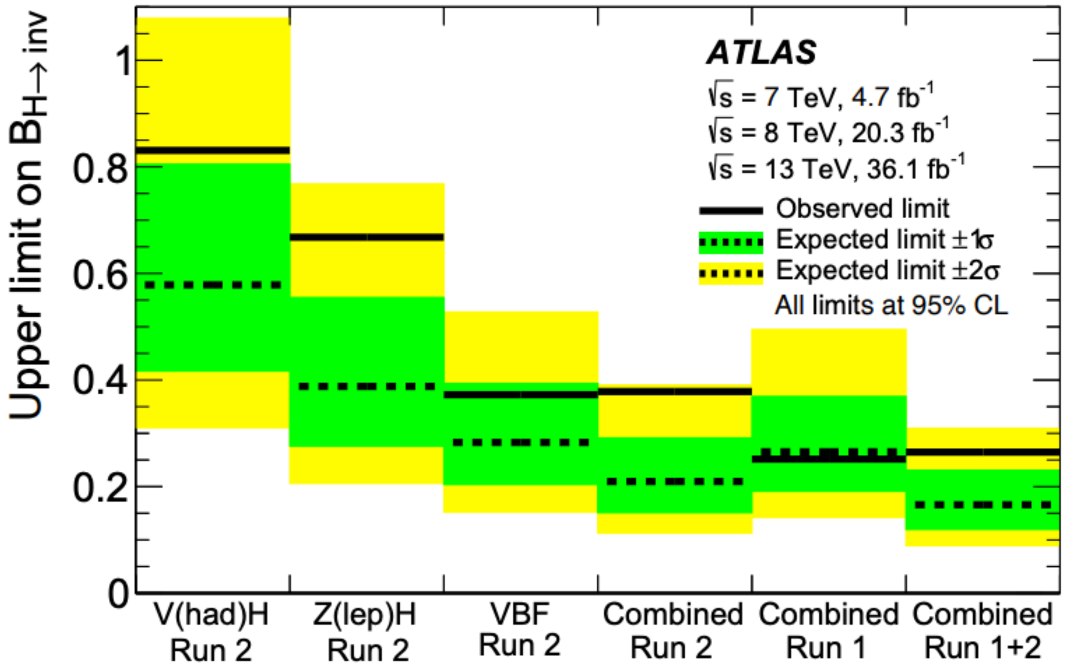
- Interpretation of combined κ fit to constrain λ_3 via Higgs induced EW corrections
- Quite strong assumptions (only BSM effect is λ_3 modification) but complementary to HH search

BSM Higgs

- … since we have observed 1 scalar field it is legitimate to search for additional (pseudo)scalars
- Look also for NON-SM Higgs decay (invisible, LFV, …)

Higgs to Invisible

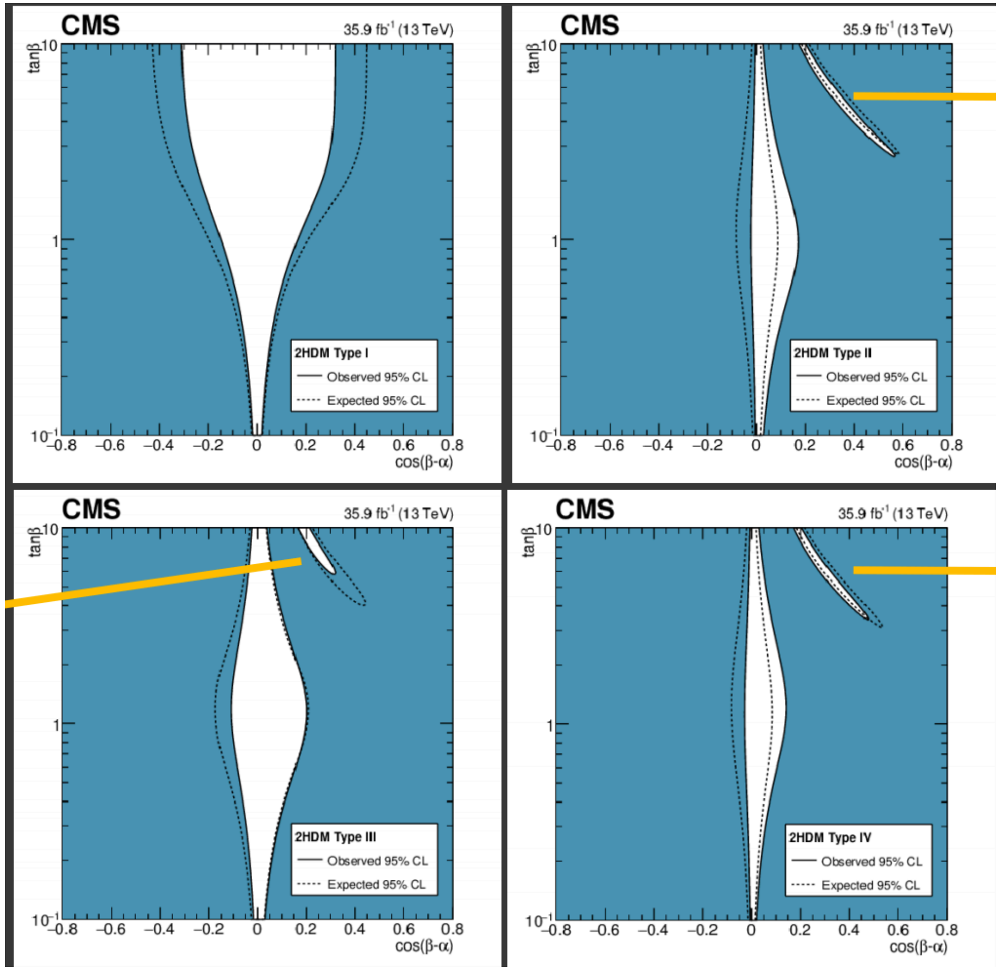


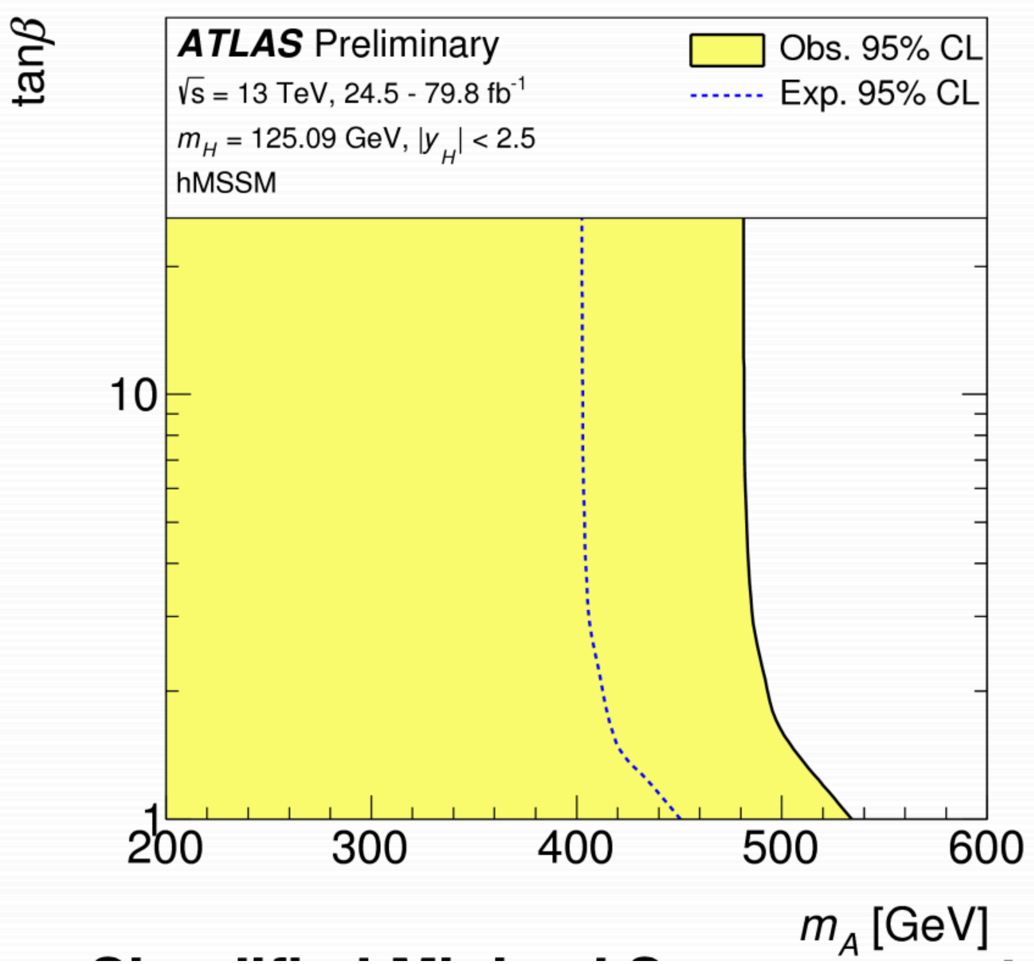


- Upper limit at 95% CL on BR(H→inv) obs(exp) 0.26(0.17)

- SM invisible decay H->ZZ*->4ν very small BR (~1 per mill) no sensitivity to that:
  - Sizeable invisible BR would be a BSM effect
- Important to disentangle other non-detectable contribution to total width

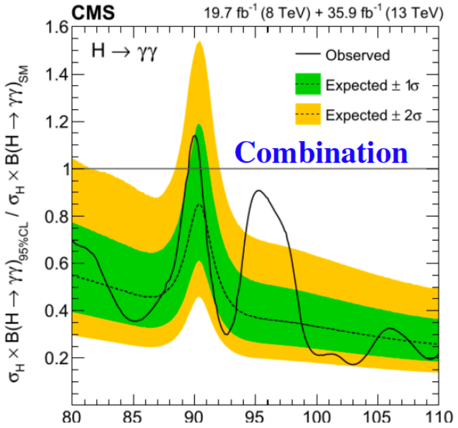
From Channel combination

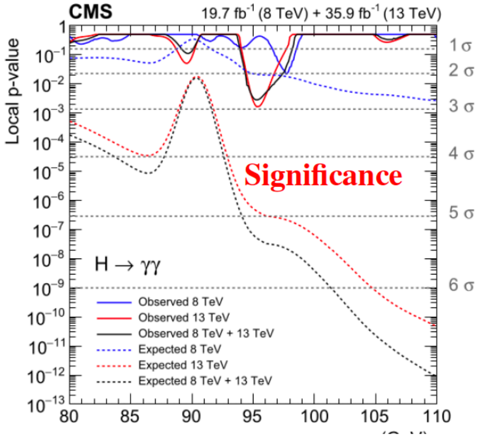




- Quite stringent limits from on-shell Higgs coupling measurements

Low Mass X→γγ search

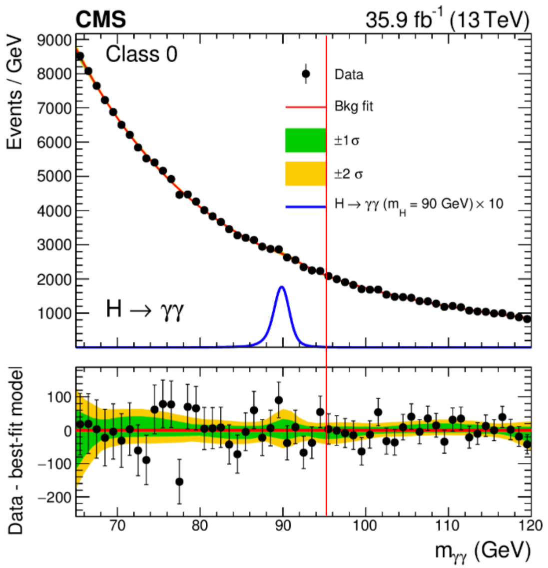


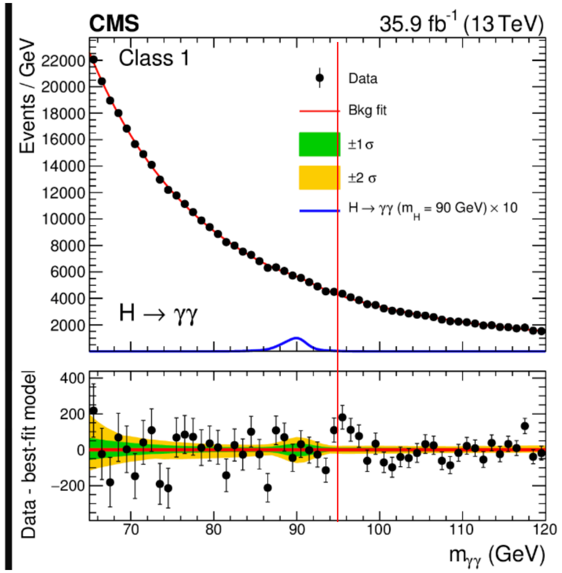


S. Zhang

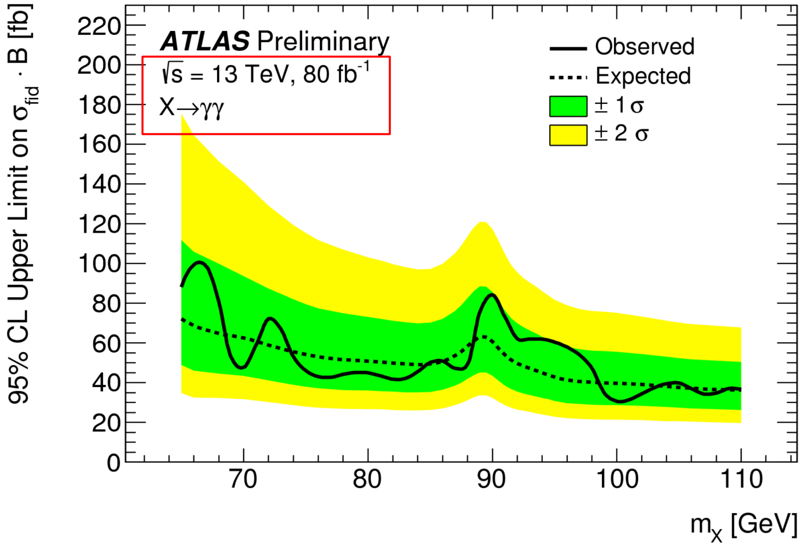
- Normalized **Upper limits on $\sigma \times$ Br**:
  → Minimum (Maximum) Limit: 0.17(1.13) at m_H = 103.0 (90.0) GeV
- Expected and observed **local p-values**:
  → **8 TeV**: Excess with ∼2.0σ local significance at m_H **= 97.6 GeV**
  → **13 TeV**: Excess with ∼ 2.9σ local (1.47σ global) significance at m_H **= 95.3 GeV**
  → **8TeV+13 TeV**: Excess with ∼ 2.8σ local (1.3σ global) significance at m_H **= 95.3 GeV**

♣ More data are required to ascertain the origin of this excess.



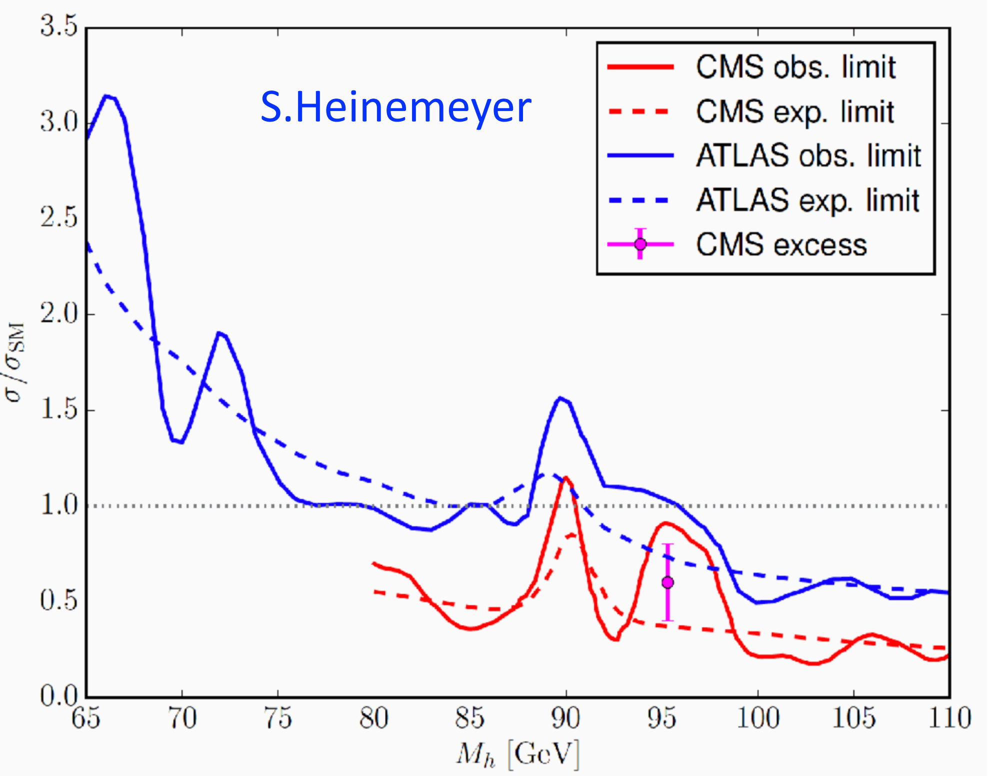


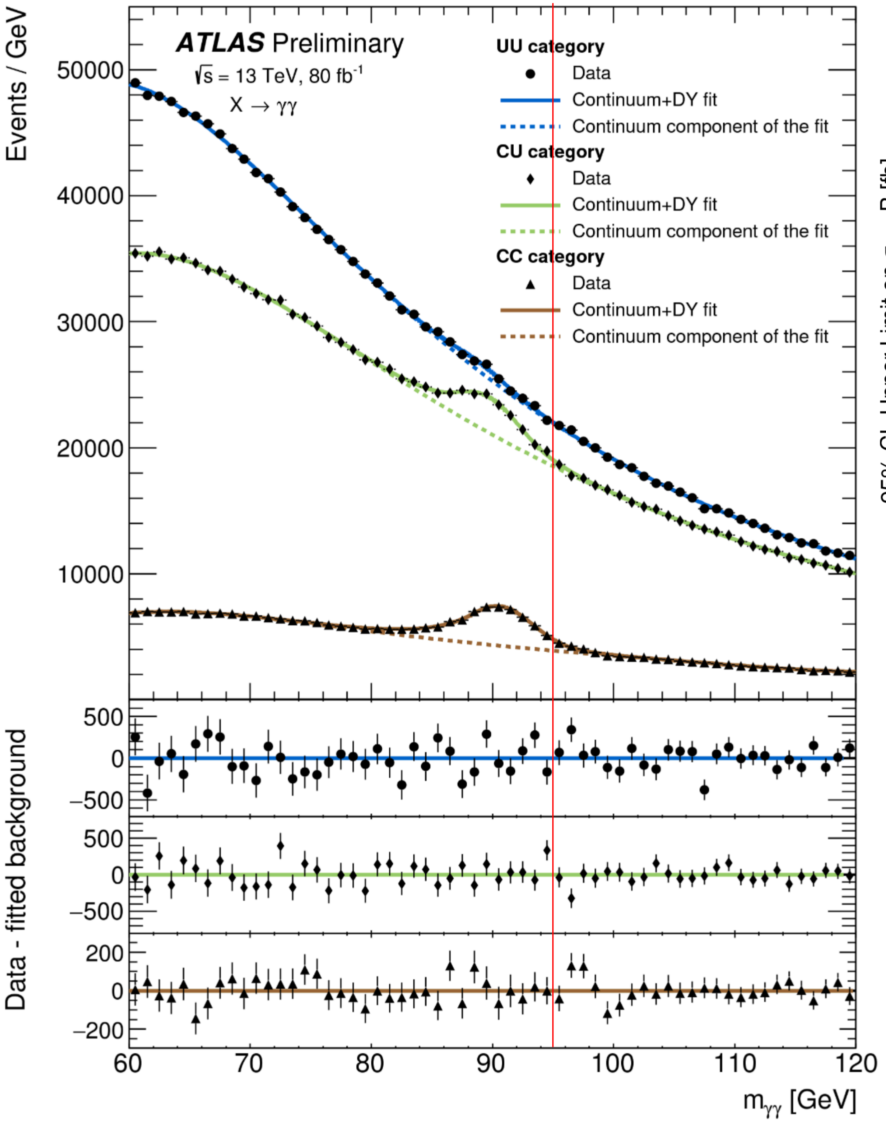
A.Kaczmarska

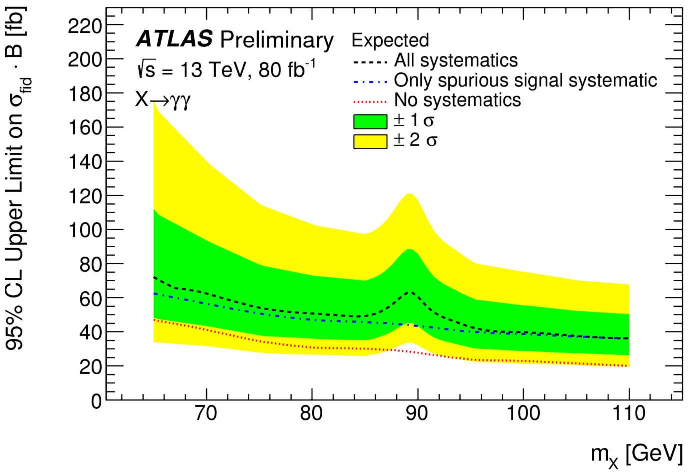


~2.8σ local effects, not confirmed by ATLAS (though lower sensitivity)
Difficult to model Z->ee background since it has a resonant (and distorted) shape

Low Mass X→γγ search







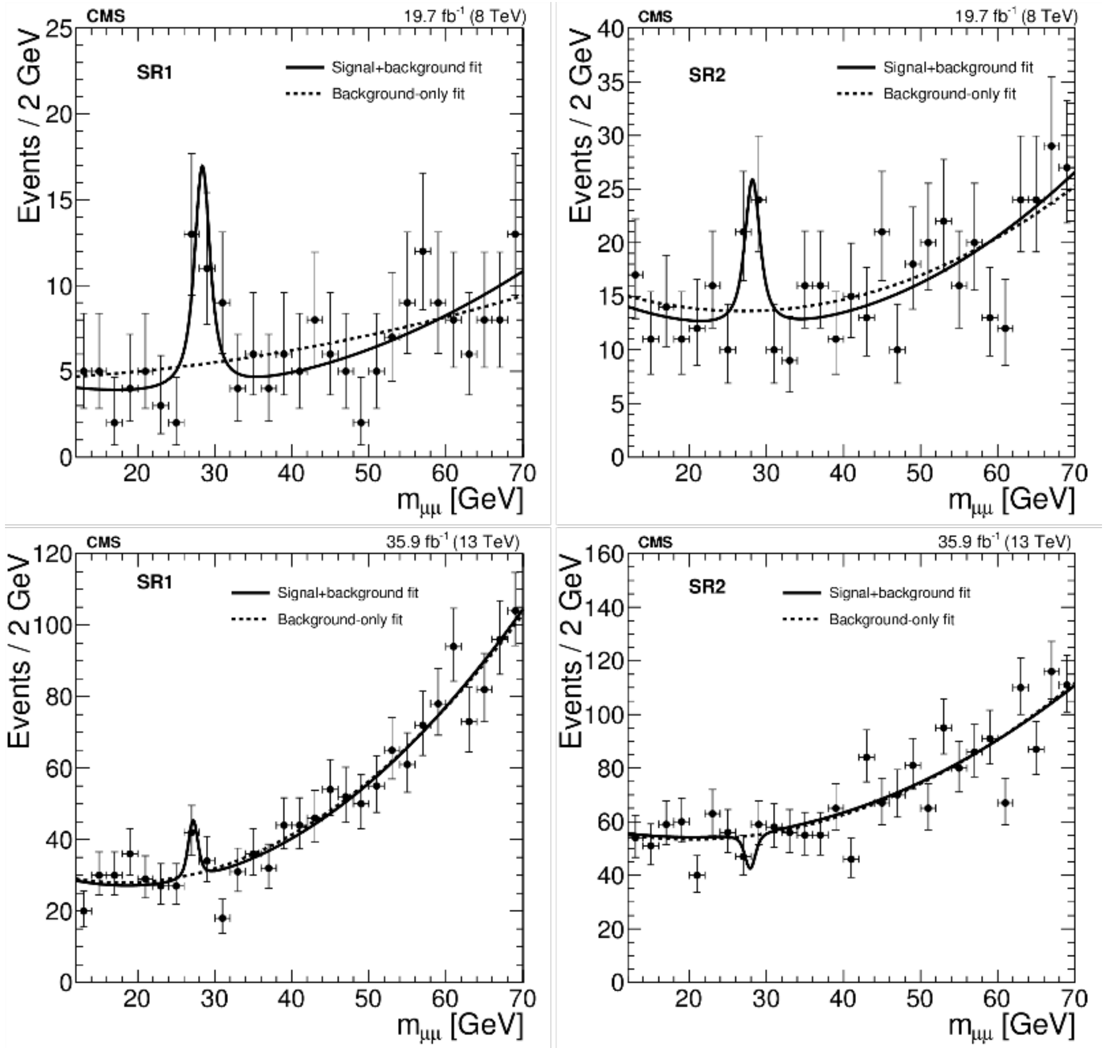
Statistically ATLAS is more powerful since it uses 80fb^{-1} of Data:

Analysis dominated by systematics on bkg. Modelling Spurious Signals (it can be improved with more MC) and Z->ee modelling

μμjb CMS

CMS- HIG-16-017, arXiv:1808.01890 ,
JHEP 11 (2018) 161

- Search $m_{\mu\mu}$={12-70} GeV in 8 TeV (2012) and 13 TeV (2016) data
- Signal region 1: one central b-quark jet + at least one forward jet; Signal region 2: two central jets (at least one b-quark jet) + no forward jets + low pt_{miss}
- 8 TeV: Local excesses of 4.2 (2.9)σ near $m_{\mu\mu}$=28 GeV for SR1(2); 13 TeV: local excess(deficit) of 2.0 (1.4)σ for SR1(2)
- Observed limits exclude scalings consistent with qq (1.5) or gg (2.5) production mechanisms
- More data required for definitive statement

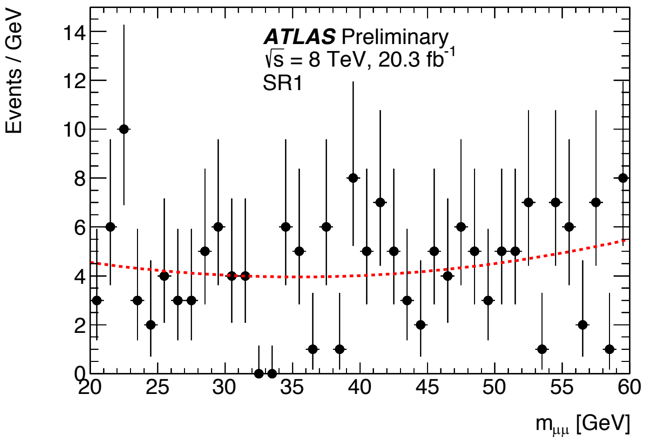


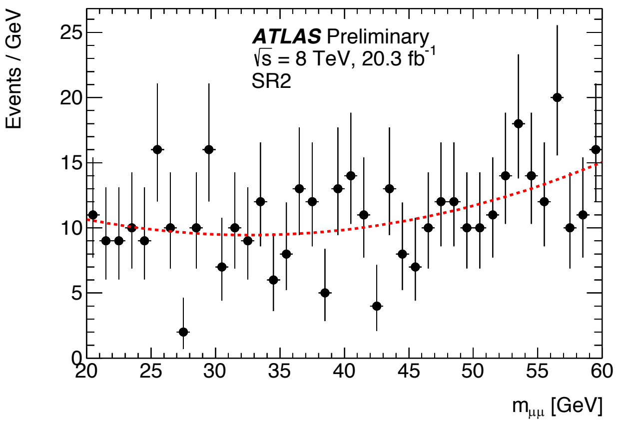
S. Gascon-Shotkin

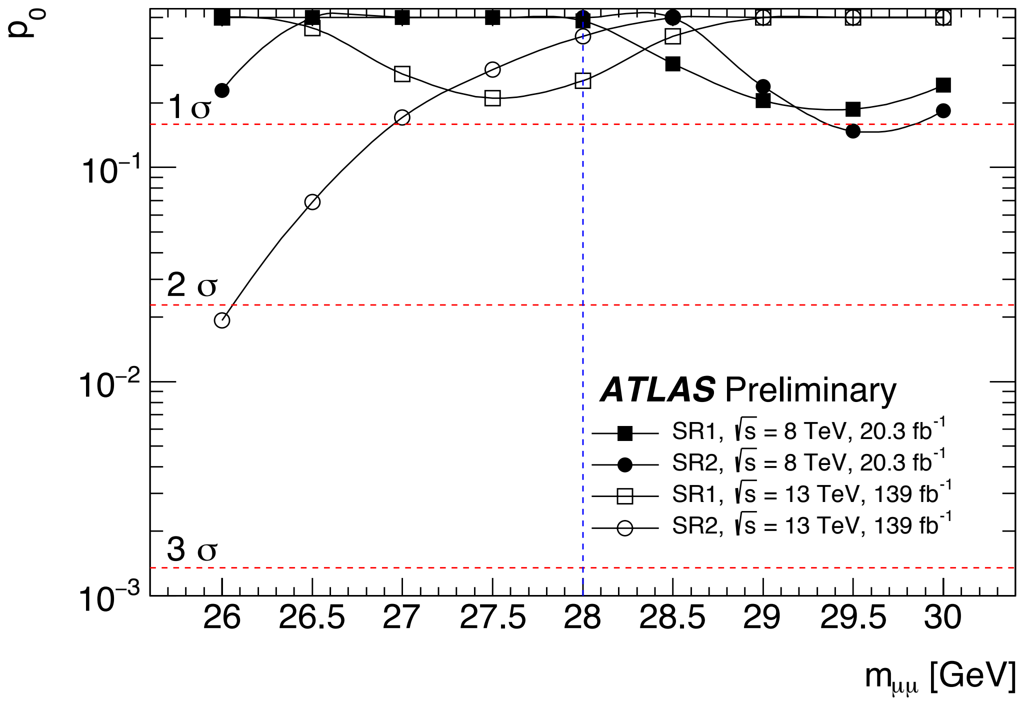
μμjb ATLAS

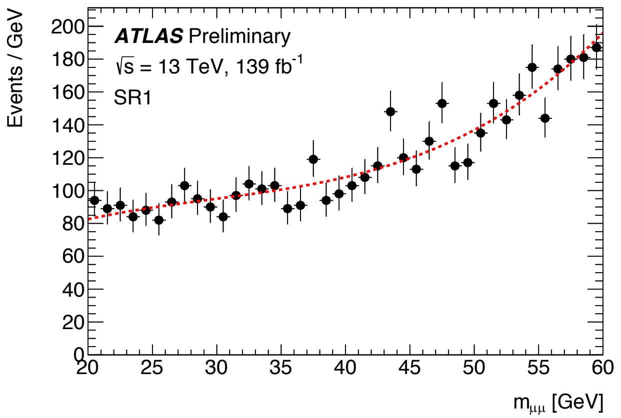
NEW

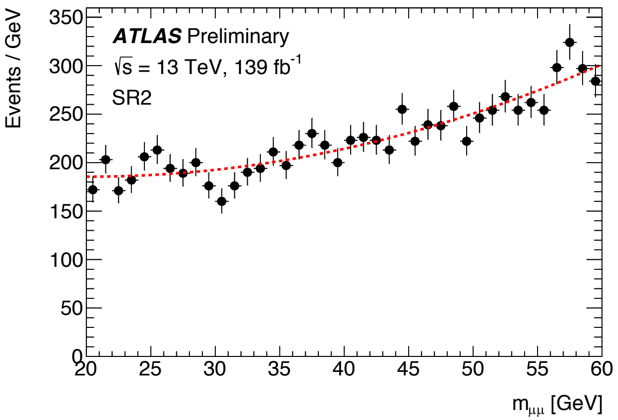
ATLAS-CONF-2019-036











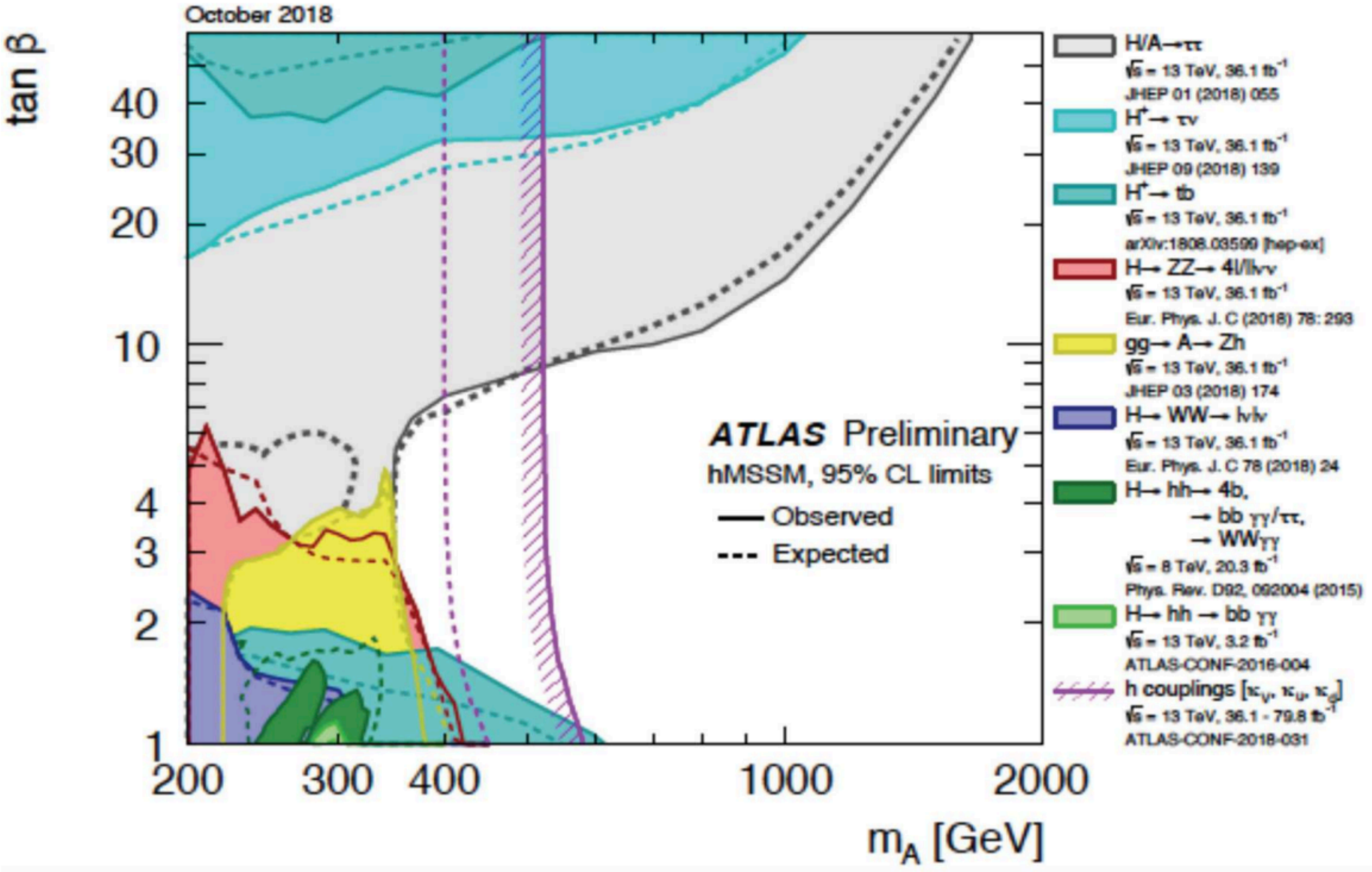
NEW result form ATLAS with **FULL Run1 + Run2** data just released **today**!

Since there is no signal modeling ATLAS selection mimic closely CMS one

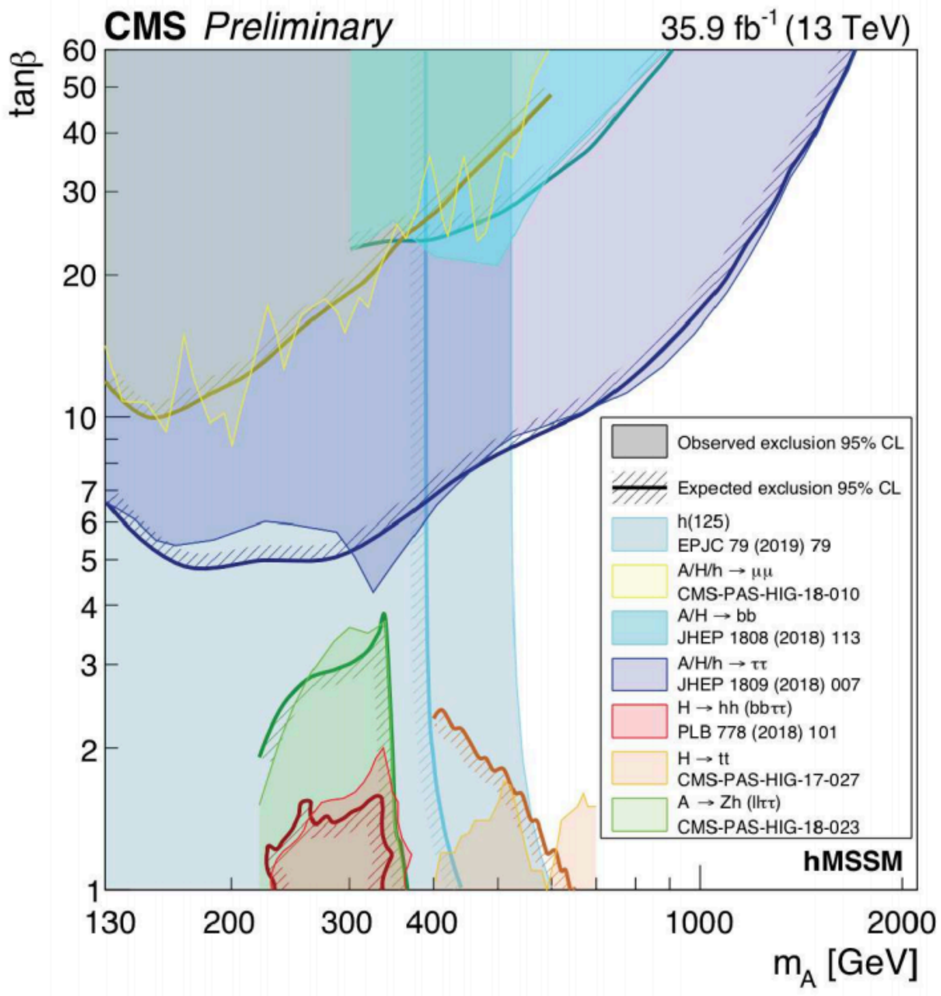
No significant excess observed in the vicinity of 28 GeV

H+/H/A … hMSSM

A.Kaczmarska



S.Gascon-Shotkin



Flavor Anomalies

D. Tou

- 2HDM models predict deviation in R_{D*} and $R_{K^{(*)}}$ measurements.
- LHCb performed precision measurements of SM :
  - R_{D*}, $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau$: 2.1σ
  - R_{D*}, τ three-prong decays : 1.1σ
  - R_K : 2.5σ
  - R_{K*} : 2.2σ at $0.045 < q^2 < 1.1$, 2.4σ at $1.1 < q^2 < 6.0$
- LHCb results consistent with the SM so far. Need better sensitivity to constrain SM and NP.

In general extension of the Higgs sector could strongly impact flavor physics

Closing Remarks

- At 7 years from the discovery we have now a much more clear picture of THE Higgs boson properties:
  - We know it is spin 0 and its interactions with bosons are mainly CP-even
  - We know its mass at 2 per mill accuracy
- Increasing precision in all measurements
  - Bosonic sector:
    - inclusive measurement at ~10% precision
    - differential measurement probing extended phase space with increasing accuracy
  - Interactions with Fermions:
    - 3^{rd} generation (τ, b, t) fully established with uncertainties approaching ~20% level
    - Most promising channel to access couplings to 2^{nd} generation is $H\to\mu\mu$: 3σ sensitivity achievable at the end of Run3 combining ATLAS+CMS: next milestone in Higgs physics
  - Still agreement with SM predictions
  - HH and self-coupling very challenging: we may get close with HL-LHC
- BSM studies: new bosons and non-SM decays
  - very active experimental program but no sign of BSM physics observed up to now
- We have only analyzed a small fraction (~5%) of the expected LHC data:
  - so the best is still to come, and maybe in 10 years form now …

… you'll need to change the conference name AGAIN!

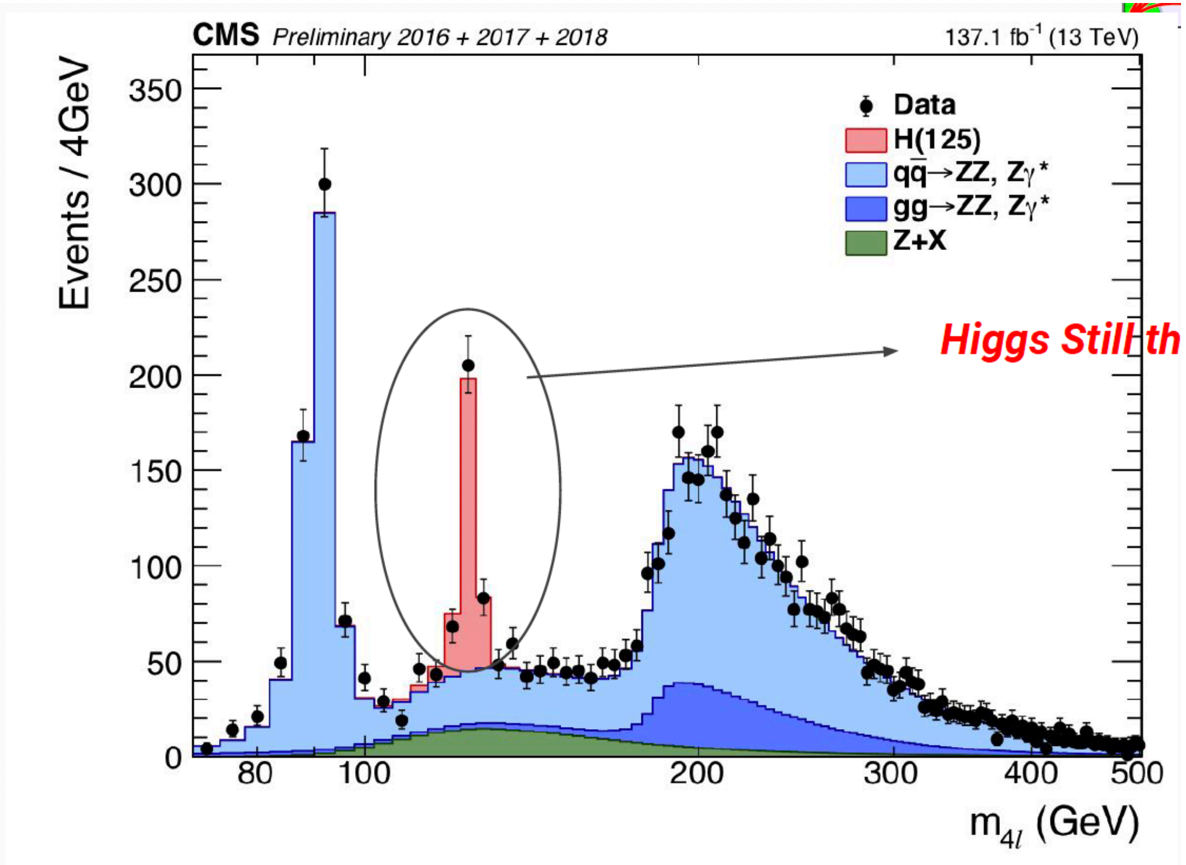
Thank you for your attention !

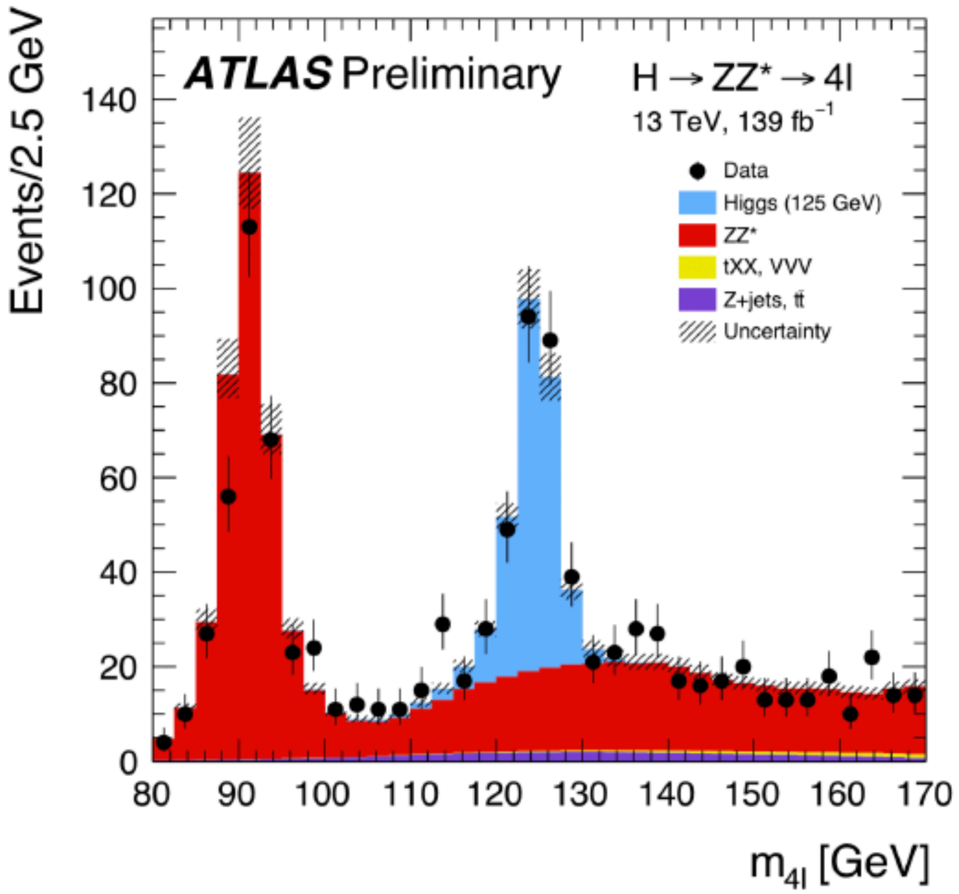
Backup

Higgs to Boson decays

- H->ZZ*-> 4l and H->$\gamma\gamma$ are clearly the best experimental signatures with fully reconstructed final state
  - allow measurement of the mass (< 2 per mill level)
  - Backgrounds small and/or determined in situ (now also true for 4-leptons ALTAS analysis)
  - Small BR: need large luminosity
  - Ideal channels for fiducial differential and STXS measurements
- More challenging H->WW->lνlν
  - Larger BR but systematics on background already playing a major role

H-> 4leptos updated with full Run2!

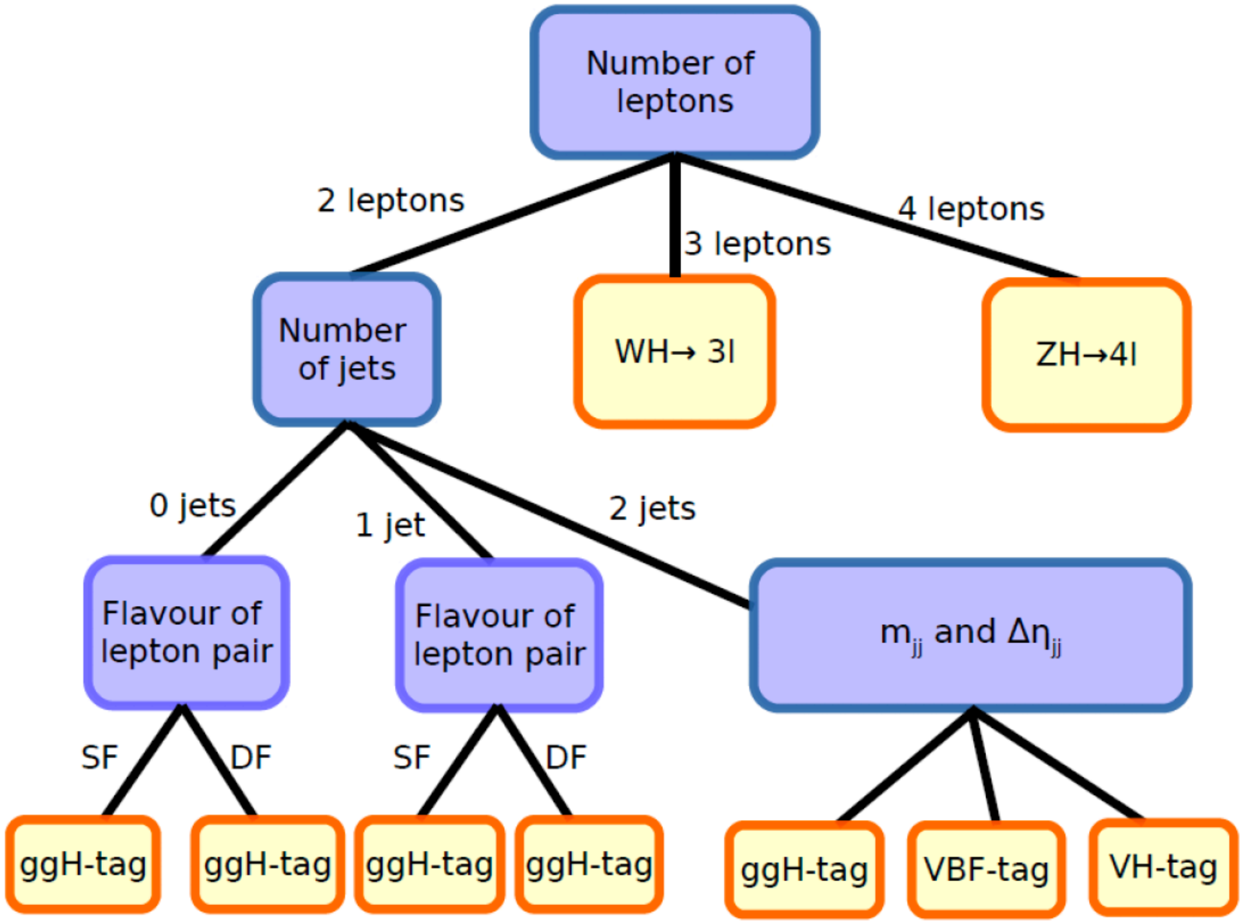




D. Di Croce

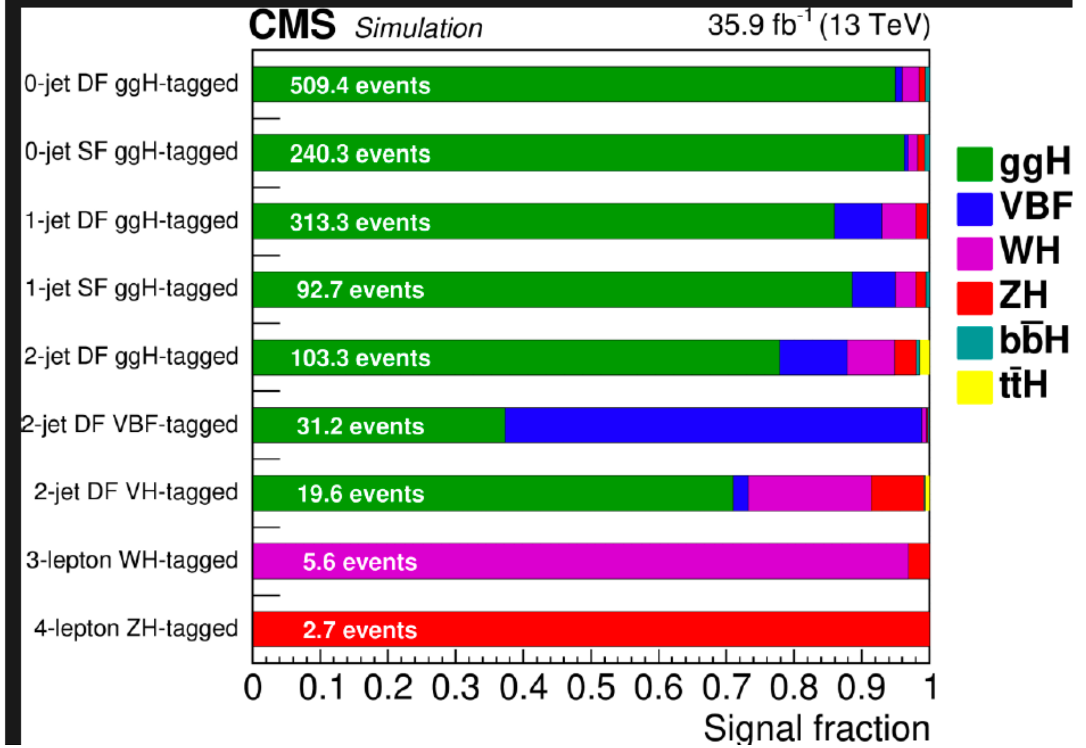
H-> WW

- Events split in 30 categories.



SF: Same Flavour (ee/μμ)
DF: Different Flavour (eμ)

- Opposite charge leptons with $p_T^{lep1} > 25$ GeV and $p_T^{lep2} > 10$ (13) for $\mu(e)$.
- $p_T^{ll} > 30$ GeV and MET > 20 GeV.
- b-tagged jet veto.



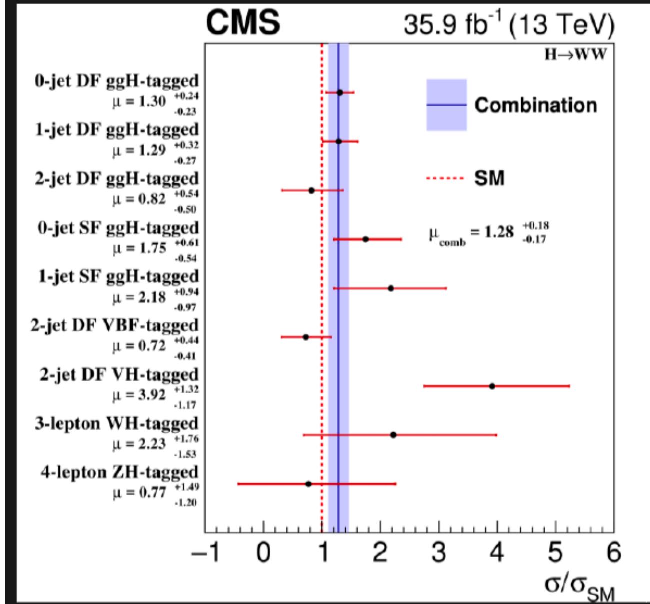
D. Di Croce

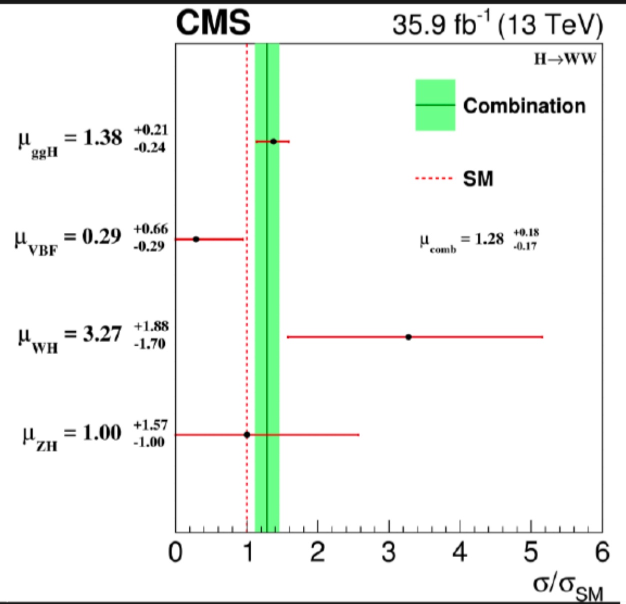
H-> WW

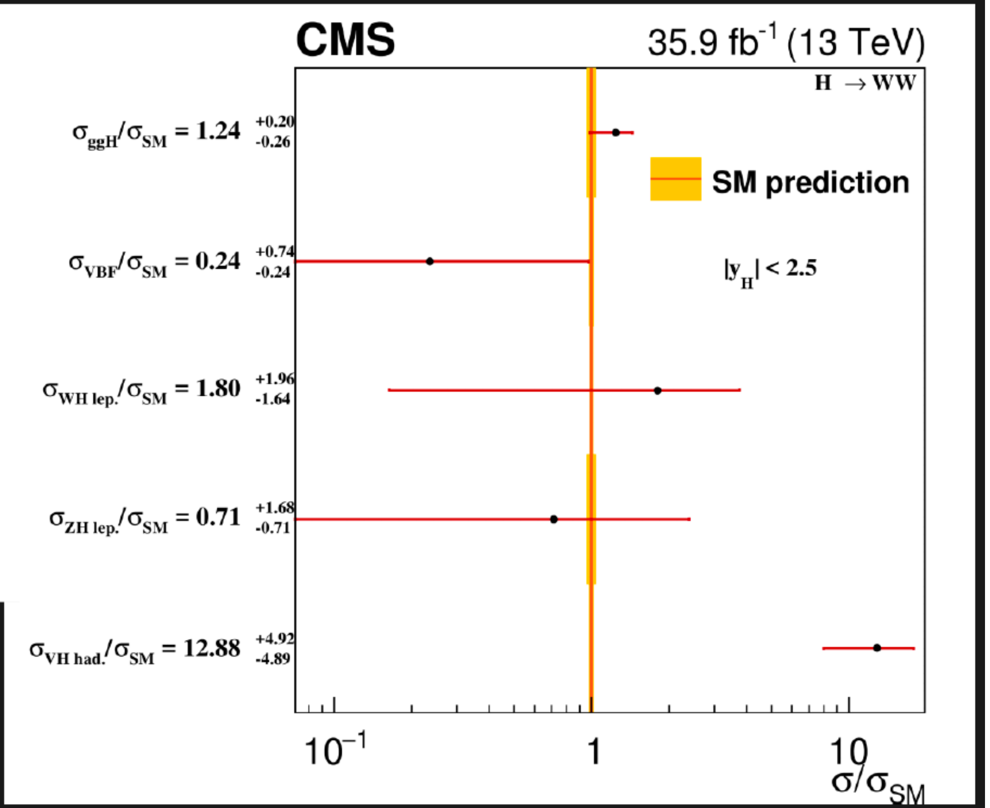
Signal strength measurements

8

- Signal strengths (σ/σ_{SM}) measured from a simultaneous binned likelihood fit of all signal and control regions.







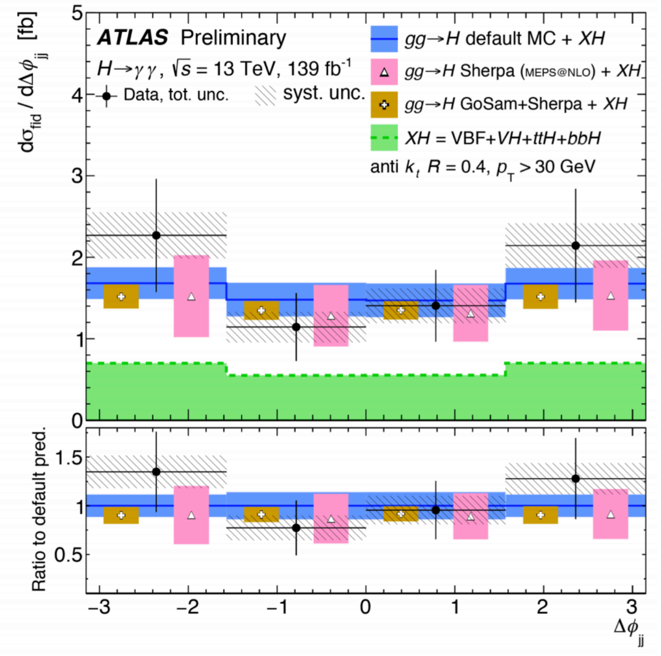
- Limited by lepton reconstruction, background data-driven estimation and ggH theretical uncertainties.
- $\mu = 1.28^{+0.18}_{-0.17}$ at 9.1(7.1) σ observed (expected) significance. First H→WW observation in CMS!!!

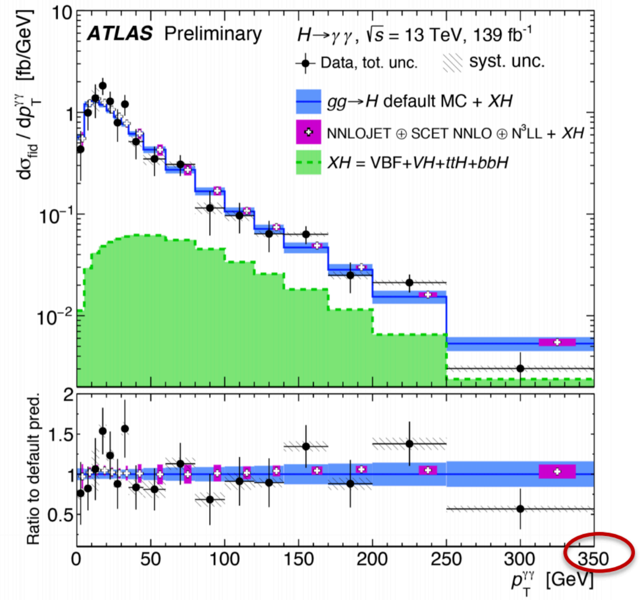
Simplified Template cross-sections

- Proposed at Les Houshe'15 (Proceedings) + LHC Higgs xs working group (YR4)
- Goals:
  - Measure cross-sections per production modes (ggF, VBF, VH, ttH) in different phase space (Signal Templates: PtH, PtV, …) reducing model dependency and maximizing sensitivity to BSM effects
  - Combine different decay channels → increase sensitivity
  - Provide harmonized framework for signal theory uncertainties
- Draw backs:
  - It works well ONLY if signal split matches experimental "categories/sensitivity"
    - *"Staged"* approach matching STXS granularity with experimental sensitivity
  - Up to now kinematic information on decay not considered

Fiducial differential cross-sections

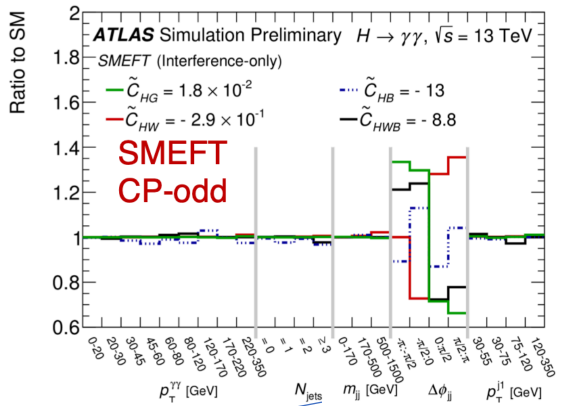
- Fiducial differential cross-sections are the most model independent way to measure Higgs interactions at LHC
- More suitable channels are $H\to\gamma\gamma$ ad $H\to ZZ^*\to$4-leptons:
  - Little impact/dependency of/on subtracted background
  - Fully reconstructed Higgs decay with good experimental resolutions: little sensitivity to "unfolding" (correct for experimental effects) method
- Differential distributions chosen to be sensitive to signal modeling and BSM effects:
  - Production: Pt-Higgs, Higgs-rapidity, Pt-jet, N-jets, N-bjets, $\Delta\phi_{JJ}$, 2D: Pt-Higgs vs N-jets
  - Decay: $\cos(\theta^*)$, $M_{\ell\ell}$, 2D: M_{12} vs M_{34}
- In the following focus on Pt-Higgs, other distributions in *backup*





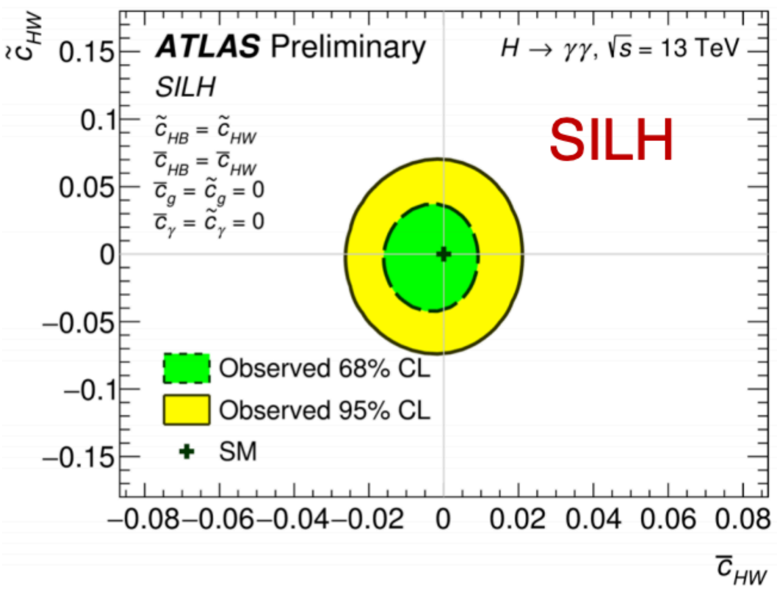
$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SMEFT}} \supset \overline{C}_{HG}O'_g + \overline{C}_{HW}O'_{HW} + \overline{C}_{HB}O'_{HB} + \overline{C}_{HWB}O'_{HWB}$$
$$+\tilde{C}_{HG}\tilde{O}'_g + \tilde{C}_{HW}\tilde{O}'_{HW} + \tilde{C}_{HB}\tilde{O}'_{HB} + \tilde{C}_{HWB}\tilde{O}'_{HWB},$$

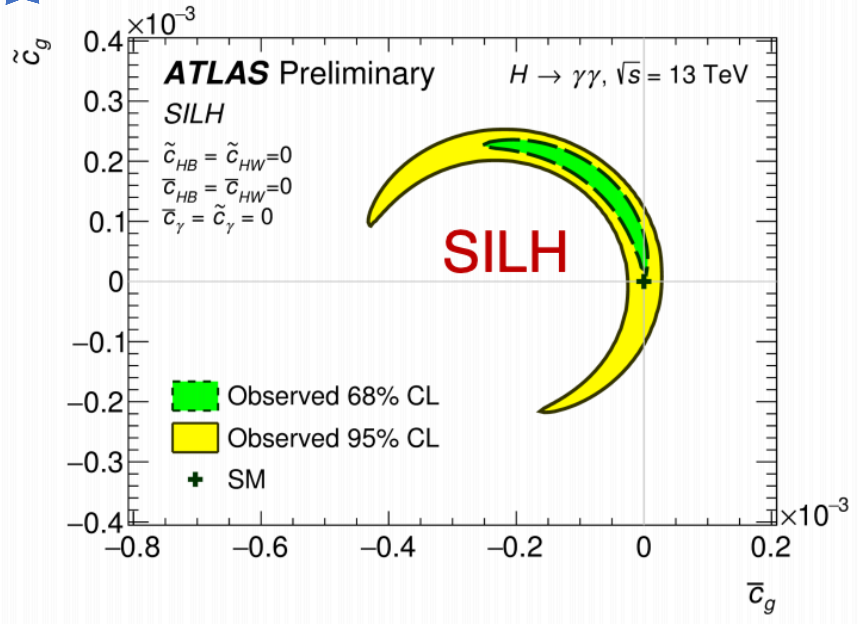
Modify ggF production Modify VBF/VH production and Hγγ decay



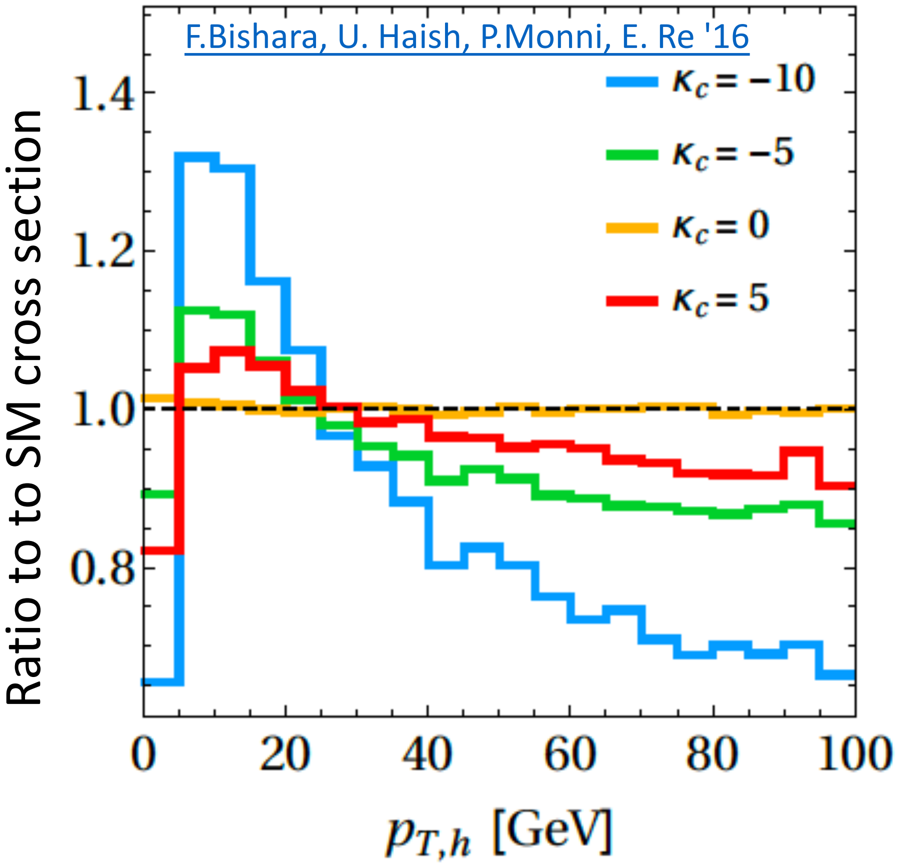
EFT from differential Xs H->γγ

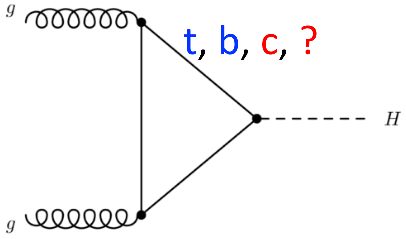
L. Xu

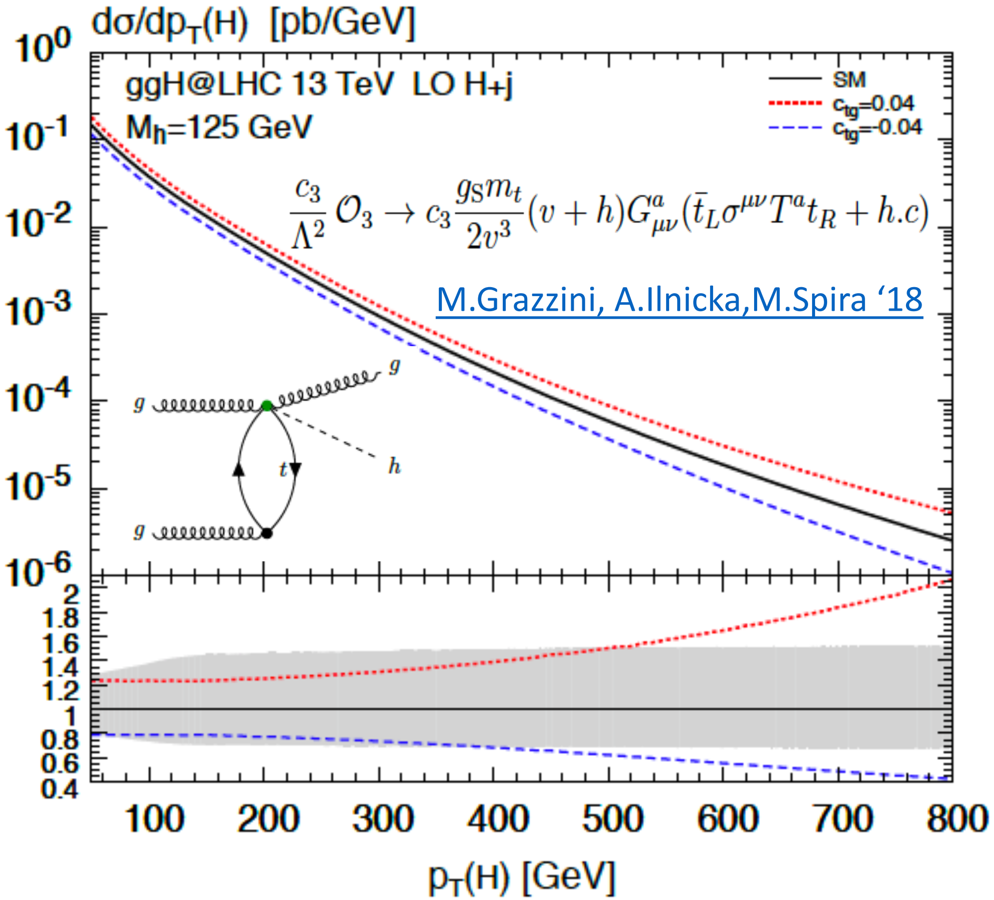




Pt-Higgs in ggF vs BSM physics







- Higgs Pt spectrum dominated by gluon fusion production (ggF) at LHC (not true at very high Pt)
- Full range sensitive to several BSM effects:
  - low Pt: Higgs couplings to charm
  - high Pt: Higgs couplings to top, BSM Top partners (A.Banfi, A.Martin, V.Sanz '13) , EFT operators, …

Comparison of uncertainties …

CMS: 77 fb^{-1}
PAS HIG-18-030

Uncertainty source	$\Delta\hat{\mu}$
Total experimental	+0.15/−0.13
b tagging	+0.08/−0.07
jet energy scale and resolution	+0.05/−0.04
Total theory	+0.23/−0.19
signal	+0.15/−0.06
$t\bar{t}$+hf modelling	+0.14/−0.15
QCD background prediction	+0.10/−0.08
Size of simulated samples	+0.10/−0.10
Total systematic	+0.28/−0.25
Statistical	+0.15/−0.15
Total	+0.32/−0.29

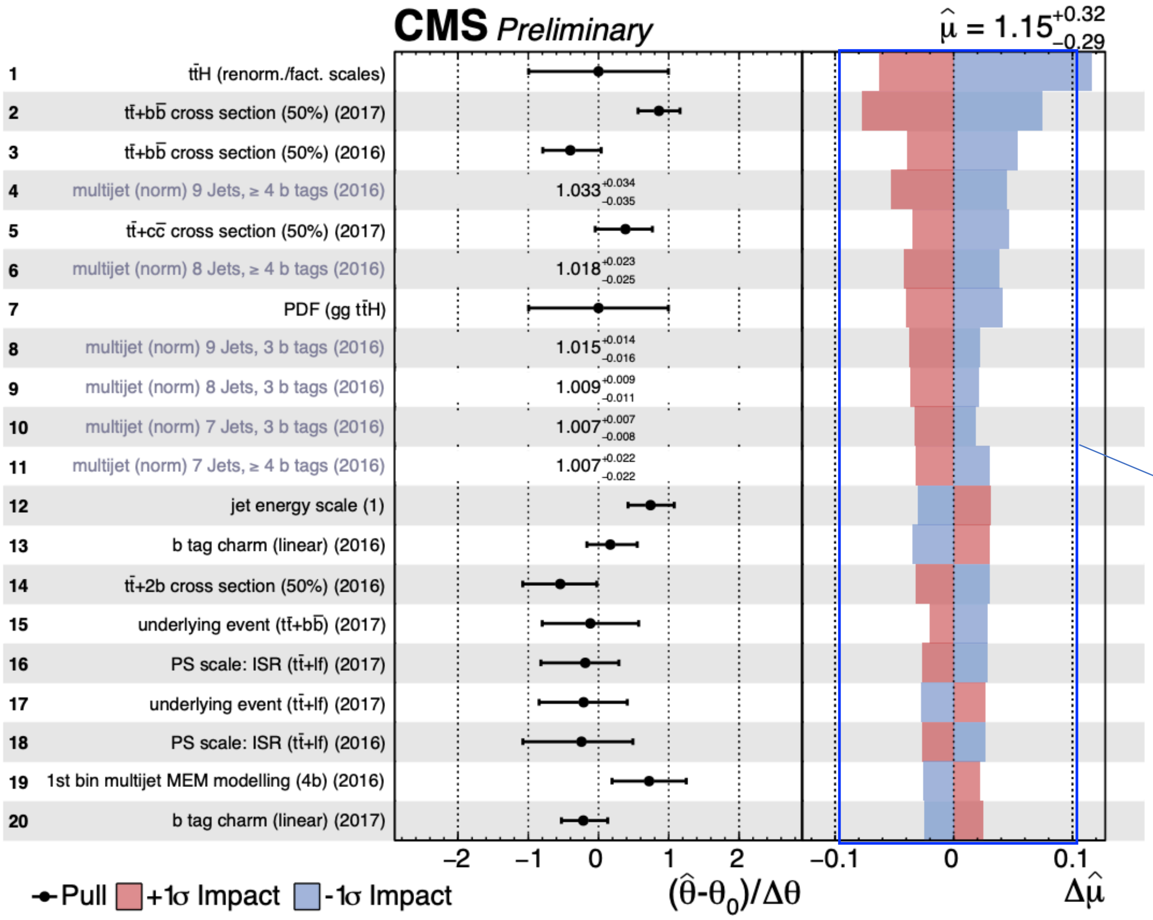
ATLAS: 36 fb^{-1}
arXiv:1712.08895

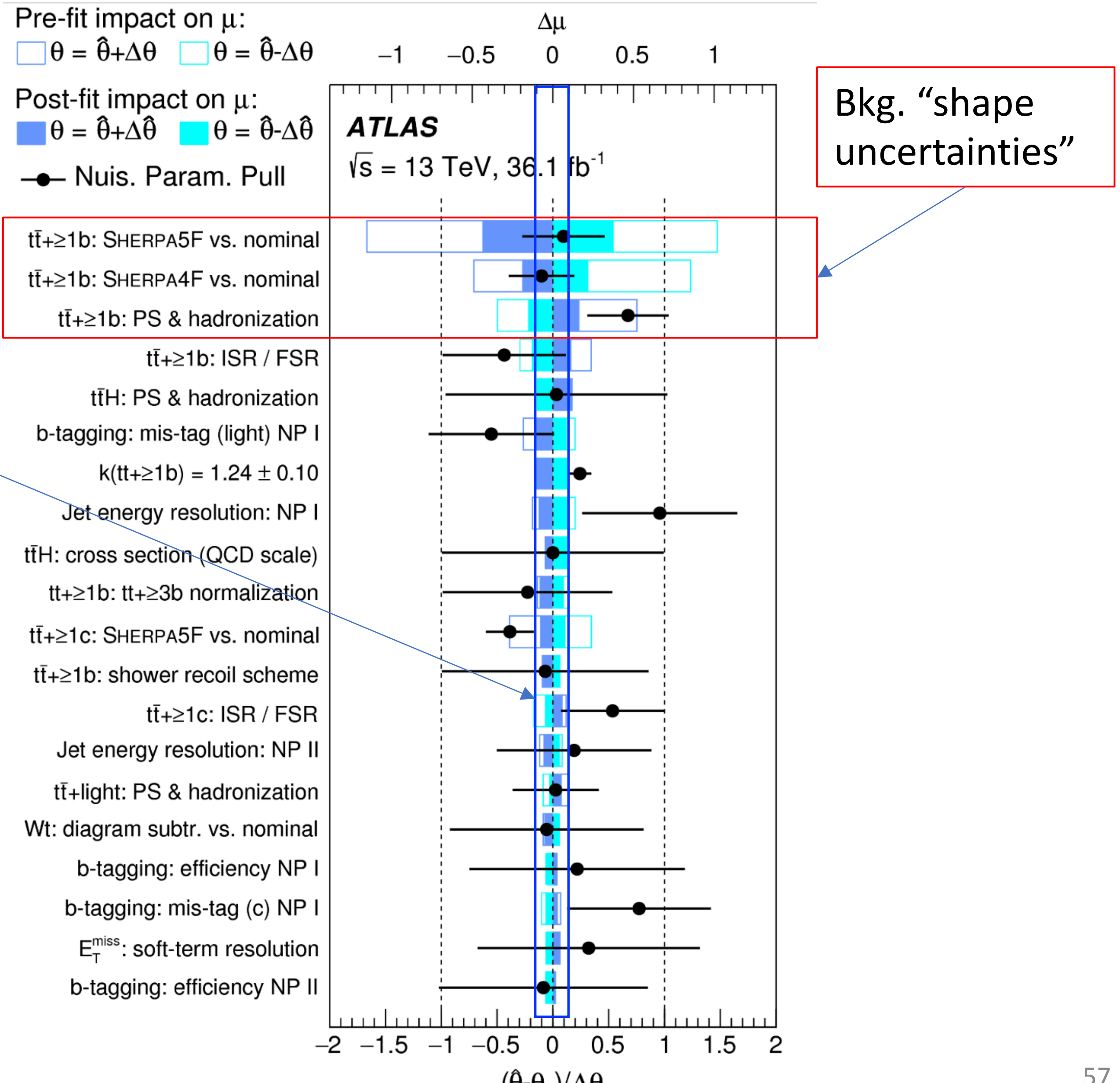
A. David

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modeling	+0.46	−0.46
Background-model stat. unc.	+0.29	−0.31
b-tagging efficiency and mis-tag rates	+0.16	−0.16
Jet energy scale and resolution	+0.14	−0.14
$t\bar{t}H$ modeling	+0.22	−0.05
$t\bar{t}+\geq 1c$ modeling	+0.09	−0.11
JVT, pileup modeling	+0.03	−0.05
Other background modeling	+0.08	−0.08
$t\bar{t}$ + light modeling	+0.06	−0.03
Luminosity	+0.03	−0.02
Light lepton (e, μ) id., isolation, trigger	+0.03	−0.04
Total systematic uncertainty	+0.57	−0.54
$t\bar{t}+\geq 1b$ normalization	+0.09	−0.10
$t\bar{t}+\geq 1c$ normalization	+0.02	−0.03
Intrinsic statistical uncertainty	+0.21	−0.20
Total statistical uncertainty	+0.29	−0.29
Total uncertainty	+0.64	−0.61

- Clearly Large differences!

ttH->bb

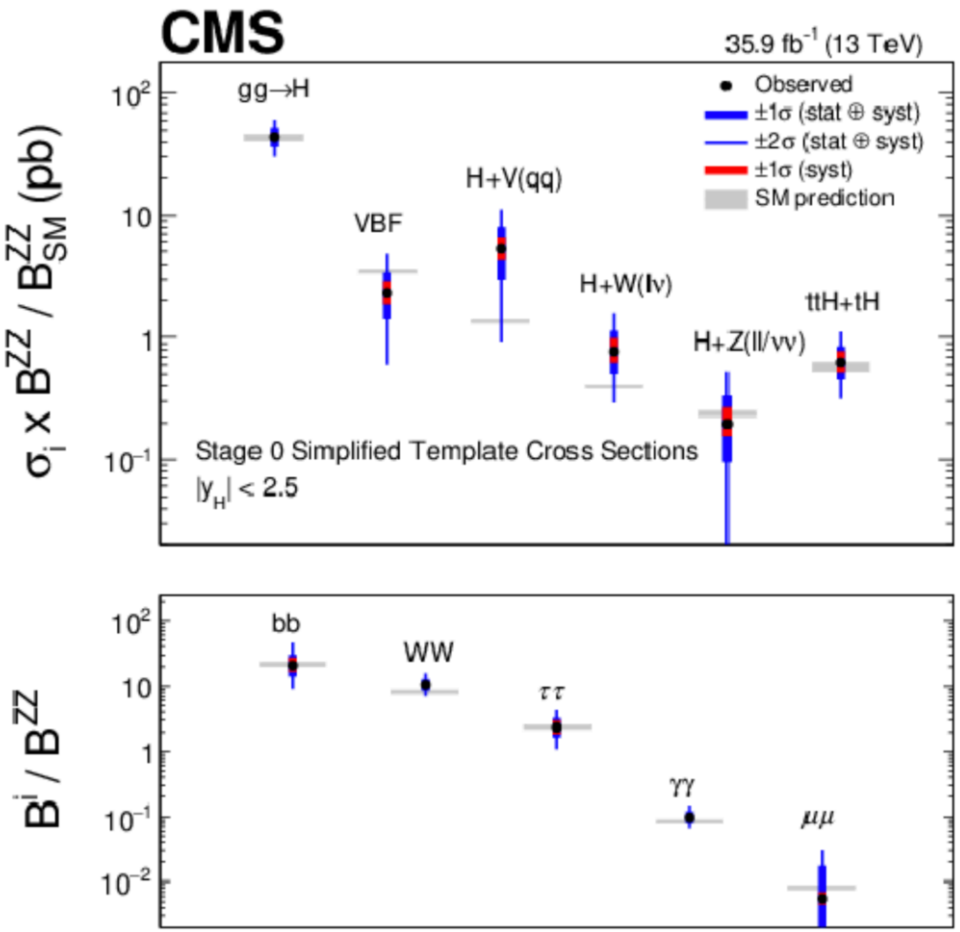




- Side by side comparison

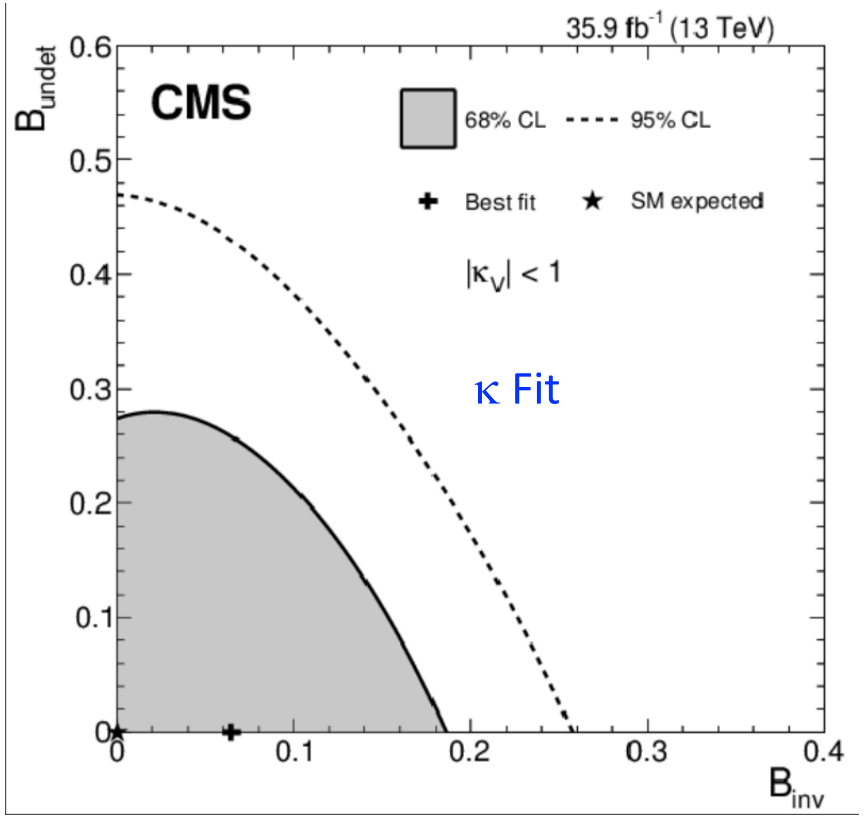
Channels Combination CMS

M. Primavera



No significant deviations form SM predictions

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\kappa_H^2}{1-(BR_{undet.}+BR_{inv.})}$$



Cross sections per production mode (STXS "stage0") separate error of measurement form prediction

Combining with invisible Higgs direct search can disentangle "Invisible" from "Undetectable" in κ fit (assuming $|\kappa_V|<1$)

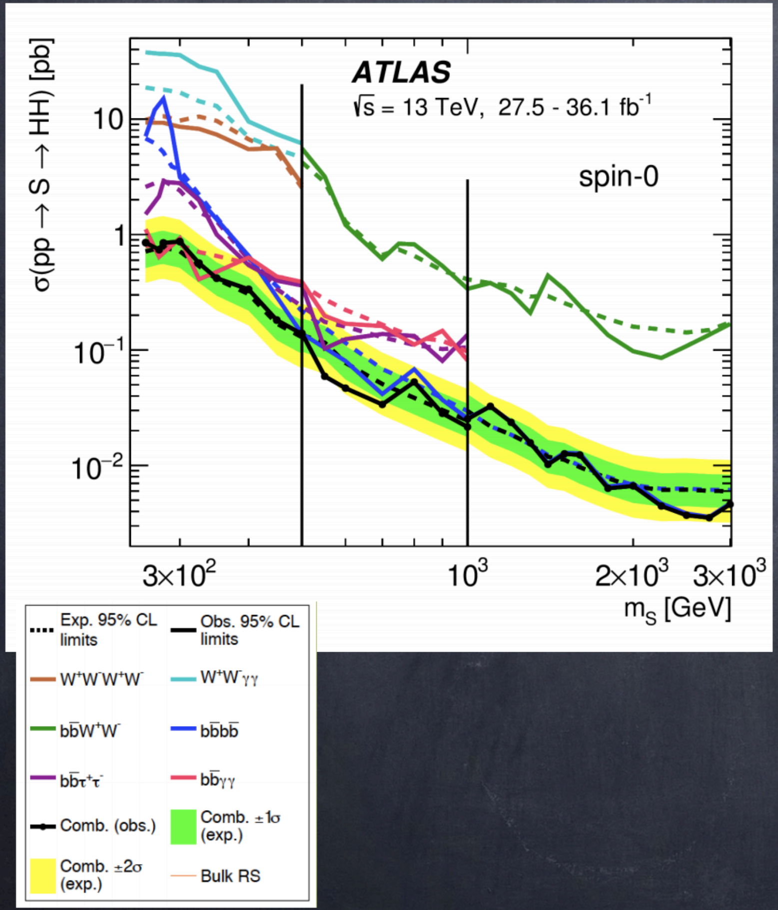
BSM HH resonant production

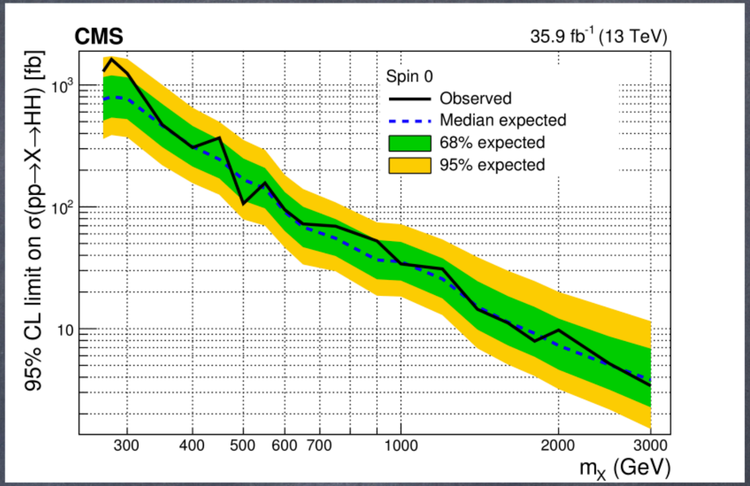
S. Shrestha

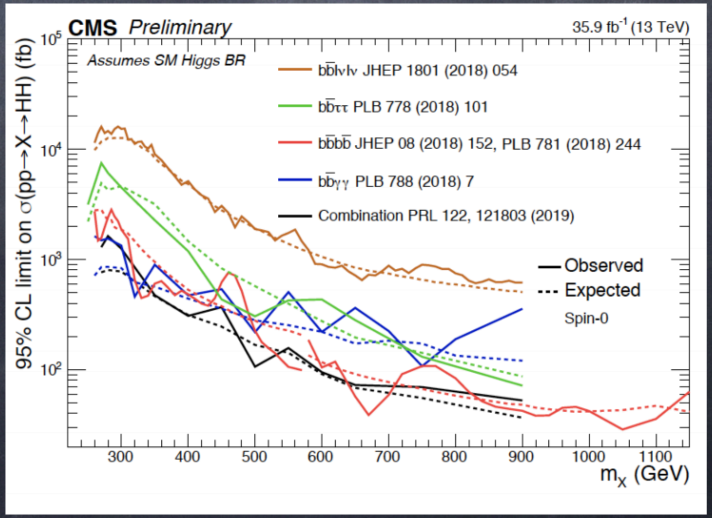
C. Amendola

M. Cepeda

Resonant







Rare decays

Y. Gershtein

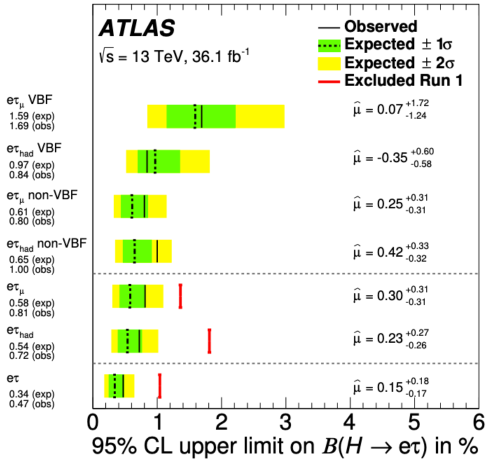
	observed	expected	SM value	ref
H→μμ	$5.7\cdot10^{-4}$	$4.1\cdot10^{-4}$	$2.2\cdot10^{-4}$	CMS-HIG-17-019
H→ee	0.0019	0.0024	$5\cdot10^{-9}$	CMS-HIG-13-007
H→γ J/ψ	$7.6\cdot10^{-4}$	$5.2^{+2.4}_{-1.6}\cdot10^{-4}$	$3\cdot10^{-6}$	CMS-SMP-17-012
H→J/ψJ/ψ	$1.8\cdot10^{-3}$	$1.8^{+0.2}_{-0.1}\cdot10^{-3}$	$1.5\cdot10^{-10}$	CMS-HIG-18-025
H→cc inclusive	2.1	$1.1^{+0.5}_{-0.3}$	0.03	CMS-HIG-18-031
H→YY	$1.4\cdot10^{-3}$	$1.4\pm0.1\cdot10^{-3}$	$2\cdot10^{-9}$	CMS-HIG-18-025
Z→γ J/ψ	$1.4\cdot10^{-6}$	$1.6^{+0.7}_{-0.5}\cdot10^{-6}$	$9\cdot10^{-8}$	CMS-SMP-17-012
Z→J/ψJ/ψ	$2.2\cdot10^{-6}$	$2.8^{+1.2}_{-0.7}\cdot10^{-6}$		CMS-HIG-18-025
Z→YY	$1.5\cdot10^{-6}$	$1.8\pm0.1\cdot10^{-6}$		CMS-HIG-18-025

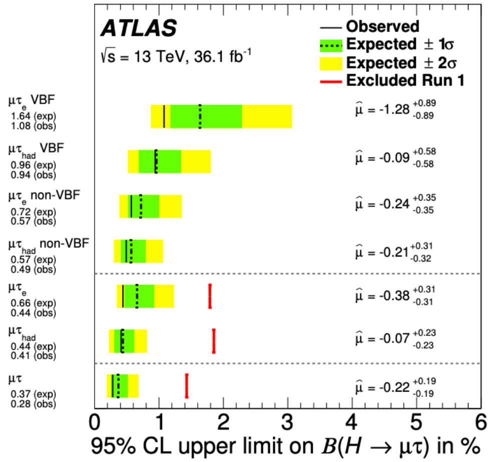
LFV $H\to\ell\tau$ results

L. Truong

	$\mu\tau_e$ non-VBF	$\mu\tau_e$ VBF	$\mu\tau_{had}$ non-VBF	$\mu\tau_{had}$ VBF
Signal	287 ± 23	14.6 ± 1.9	1200 ± 120	25 ± 5
$Z\to\tau\tau$	1860 ± 130	144 ± 26	96100 ± 2000	274 ± 33
Top-quark	1260 ± 130	390 ± 34	1620 ± 210	51 ± 10
Mis-identified	1340 ± 210	41 ± 21	63900 ± 1600	149 ± 33
Other	1180 ± 140	168 ± 18	23000 ± 1000	104 ± 15
Total Bkg.	5640 ± 100	743 ± 29	184500 ± 1200	580 ± 30
Data	5664	723	184508	583

- Observed data agrees with expected background.
- The observed (median) 95% CL limit: 0.47% ($0.34^{+0.13}_{-0.10}$%) and 0.28% ($0.37^{+0.14}_{-0.10}$%) for $H\to e\tau$ and $H\to\mu\tau$



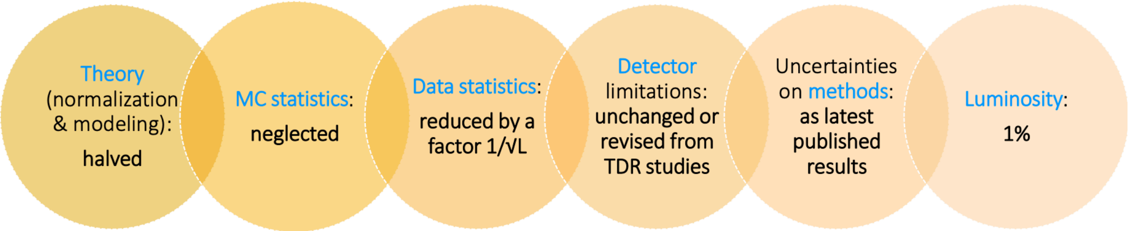


HL-LHC

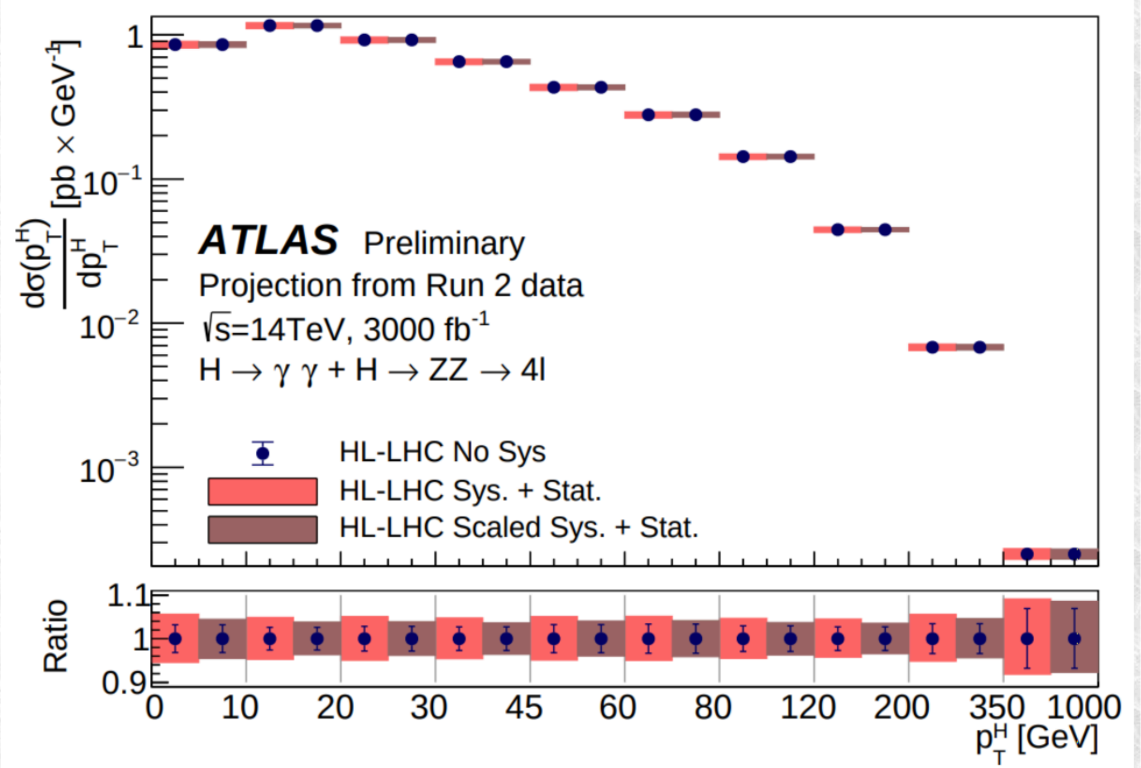
A look to the (near) future HH

B. Murray

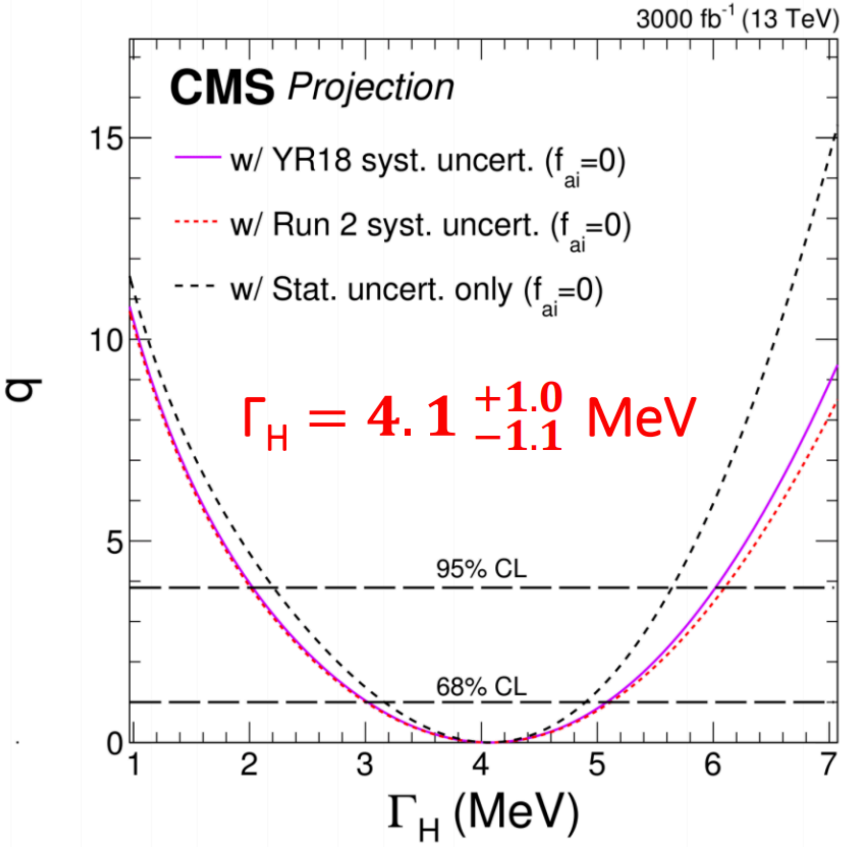
E. Fontanesi



Experimental uncertainties
scaled down with √L until a lower threshold



Better than 10% up to 1 TeV



Combining ZZ on-shell + off-shell

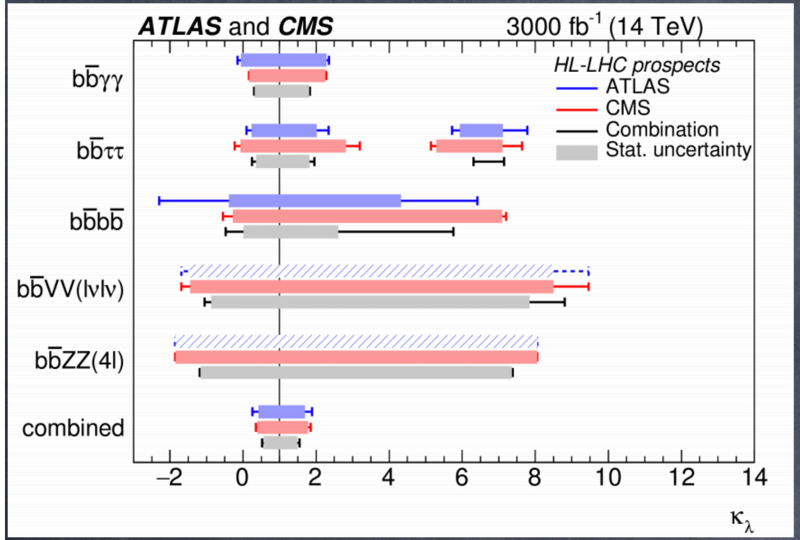
A look to the (near) future HH

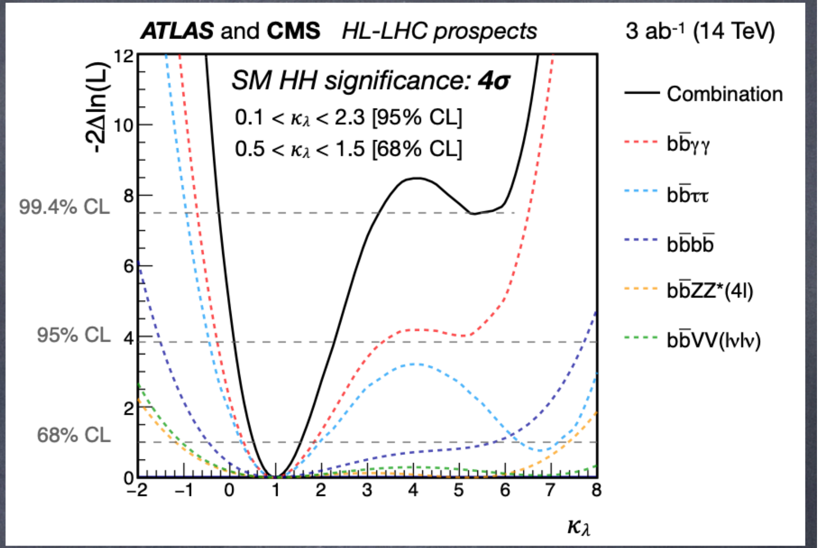
B. Murray

E. Fontanesi

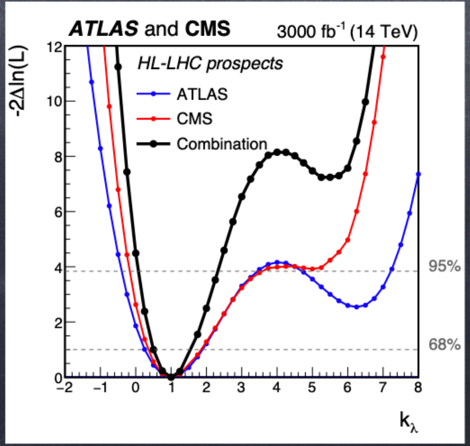
M. Cepeda

HL-LHC?





	Statistical-only		Statistical + Systematic	
	ATLAS	CMS	ATLAS	CMS
$HH \to b\bar{b}b\bar{b}$	1.4	1.2	0.61	0.95
$HH \to b\bar{b}\tau\tau$	2.5	1.6	2.1	1.4
$HH \to b\bar{b}\gamma\gamma$	2.1	1.8	2.0	1.8
$HH \to b\bar{b}VV(ll\nu\nu)$	-	0.59	-	0.56
$HH \to b\bar{b}ZZ(4l)$	-	0.37	-	0.37
combined	3.5	2.8	3.0	2.6
	Combined 4.5		Combined 4.0	



μμjb ATLAS

ATLAS-CONF-2019-036

Preselection	
2 OS muons with $\|\eta\| < 2.1$ and $p_T > 25$ GeV Leading muon $p_T > 27$ GeV (13 TeV dataset only) $m_{\mu\mu} > 12$ GeV $\geq$2 jets with $p_T > 30$ GeV ≥ 1 b-tagged (60%) jet with $\|\eta\| < 2.4$	
SR1	SR2
Exactly one jet with $\|\eta\| < 2.4$ ≥ 1 jet with $2.4 < \|\eta\| < 4.5$	Exactly two jets with $\|\eta\| < 2.4$ No jets with $2.4 < \|\eta\| < 4.5$ $MET < 40$ GeV $\Delta\phi$ (jet,jet)> 2.5

NEW result form ATLAS with **FULL Run1 + Run2** data just released **today**!