Higgs Physics

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base on talks of
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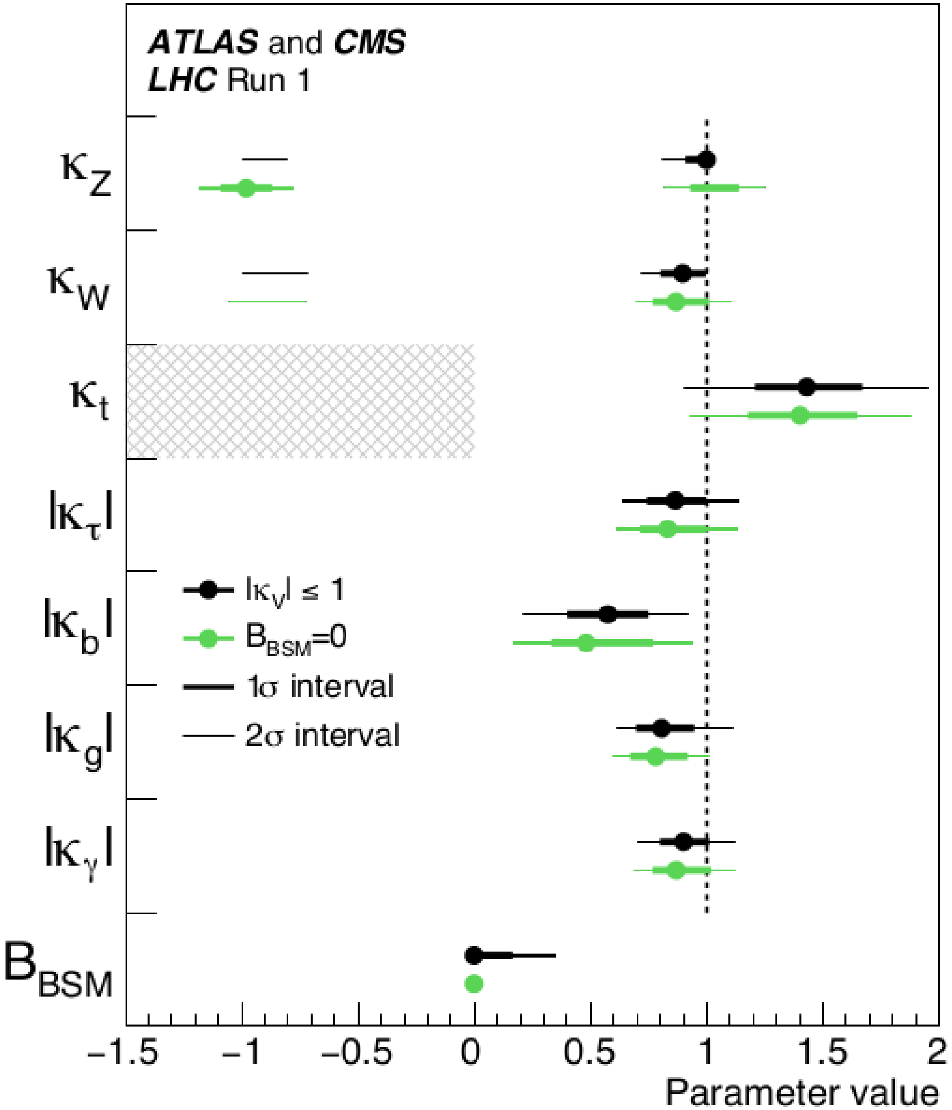
Highlights from GRC, July 13th, Kavli IPMU

Coupling measurements, e.g. with potential BSM in loop : κ_γ, κ_g are coupling modifiers

$\rightarrow B_{BSM} = 0$, no assumption on κ_V, or

$\rightarrow B_{BSM} \geq 0$, $|\kappa_V| \leq 1$



Assuming $|\kappa_V| \leq 1$ (*):

$B_{BSM} < 0.34$ @ 95% CL

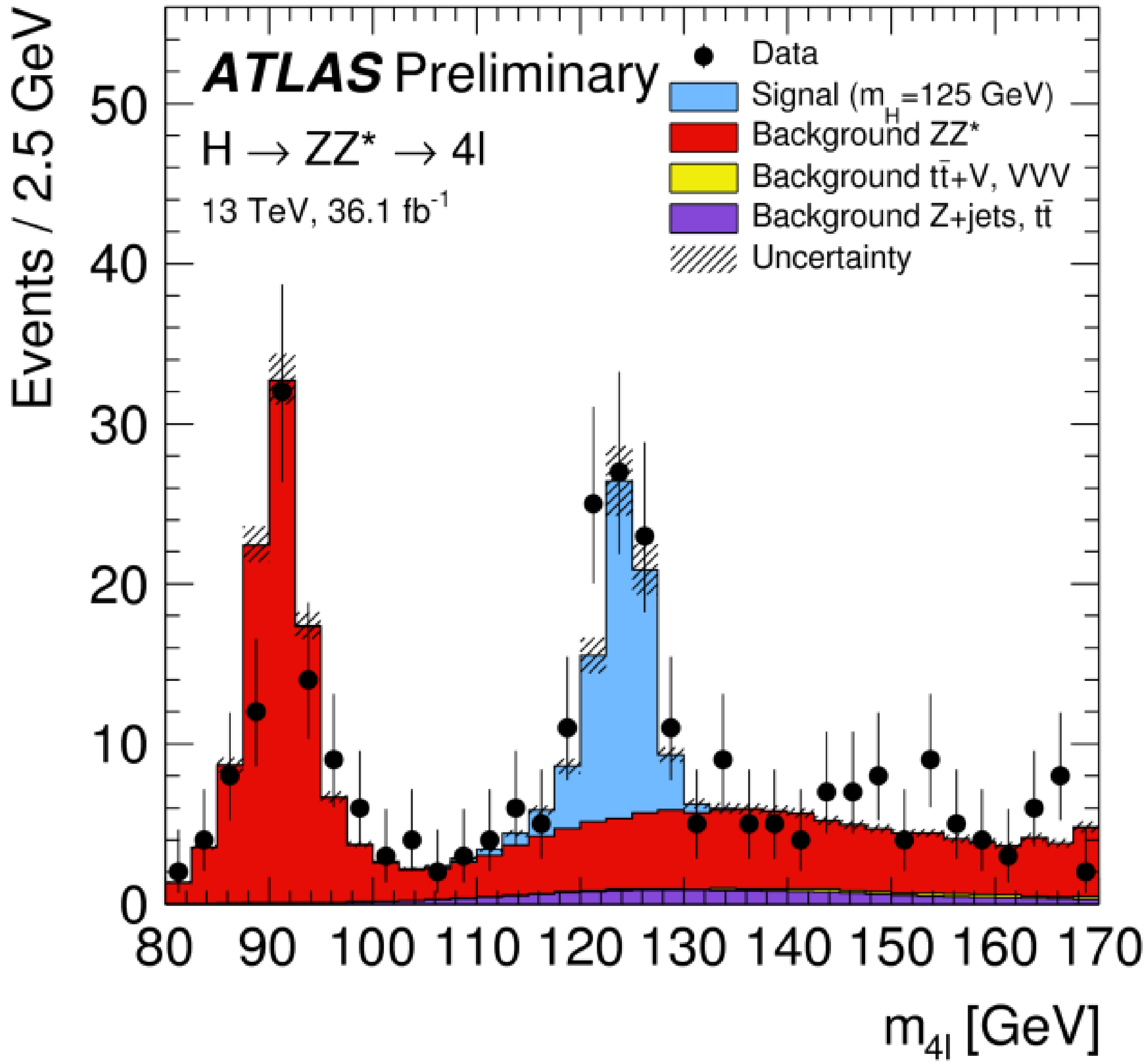
⇒ still plenty of room for New Physics
e.g. invisible decays, decays to
light scalar pairs, light dark vector bosons, etc…

((*) another possible assumption :
equality of on-shell and off-shell couplings
leads to slightly less stringent limit in ATLAS)

(ATLAS Run I, combining with direct
$H \rightarrow$ invisible searches, can remove
assumption on κ_V and get $B_{inv} < 0.23$)

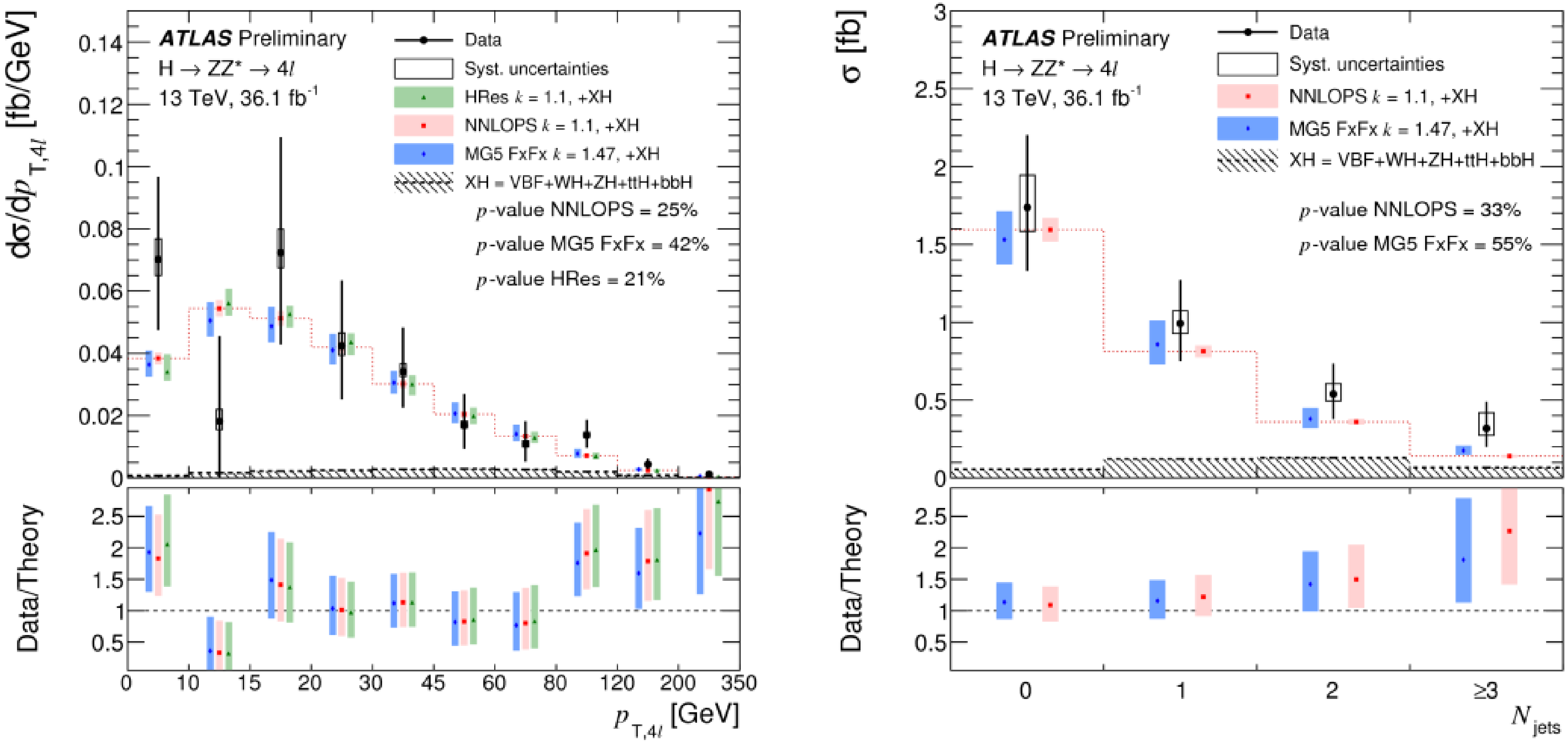
H⟶ZZ*⟶4ℓ

[ATLAS-CONF-2017-032]



H⟶ZZ*⟶4ℓ fiducial differential

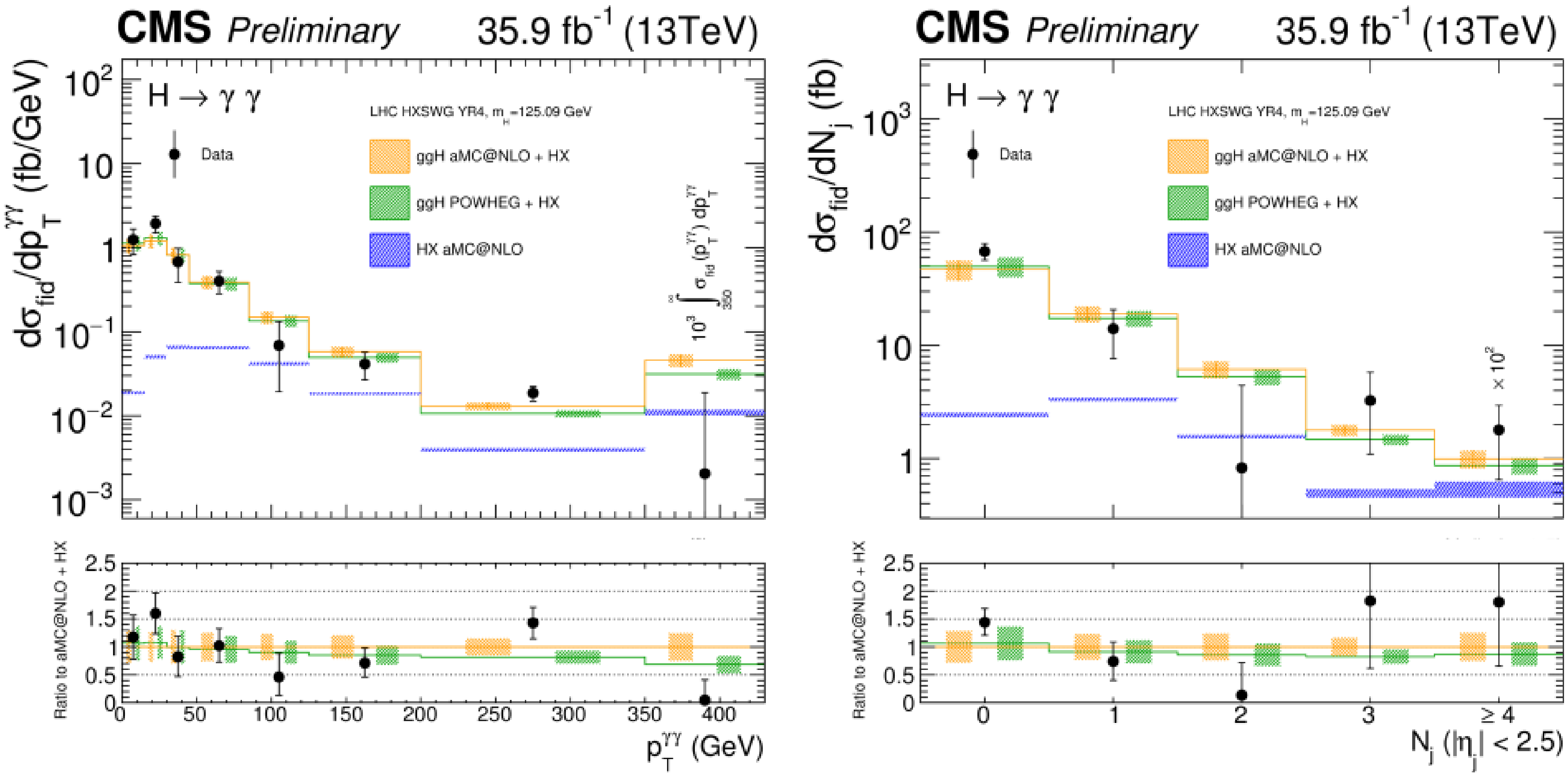
[ATLAS-CONF-2017-032]



□ No particular deviation, cf. some Run 1 fluctuations.

H⟶γγ fiducial differential

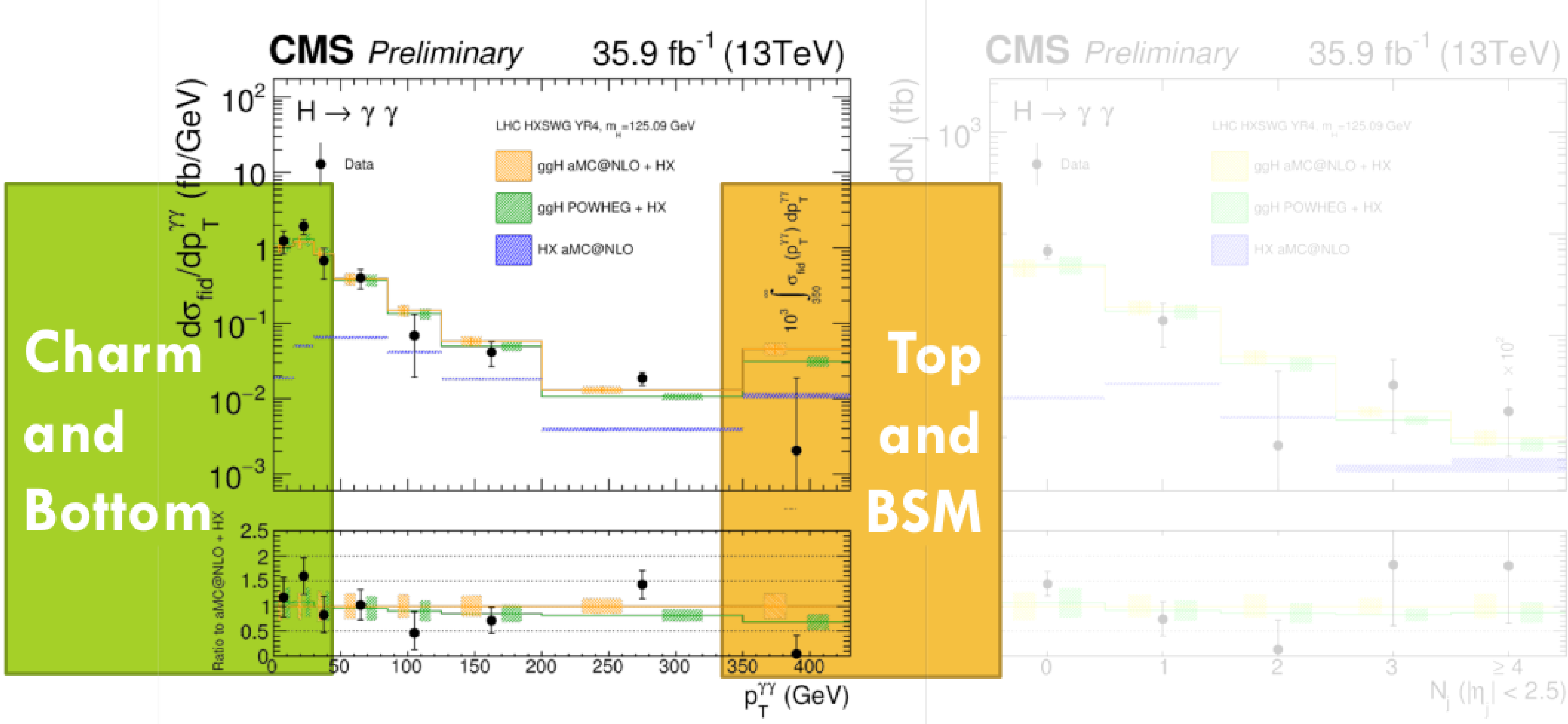
[CMS-PAS-HIG-17-015]



- Unfolding performed by including response matrices in likelihood.
- Nearly no smearing across p_T bins, 10% in N_{jet}.

H⟶γγ fiducial differential

 [CMS-PAS-HIG-17-015]



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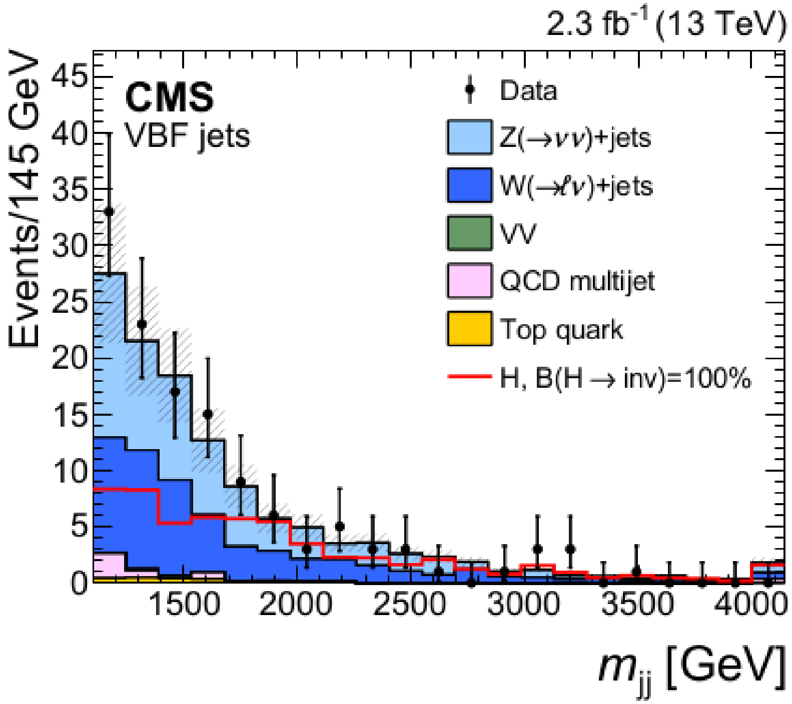
The invisible width of h_{125}

$h_{125} \rightarrow$ invisible tiny in the SM : ~ 0.1% from $h_{125} \rightarrow ZZ \rightarrow 4\nu$
Small SM total width ⇒ could be greatly enhanced by coupling, e.g. to dark matter (neutralinos …)

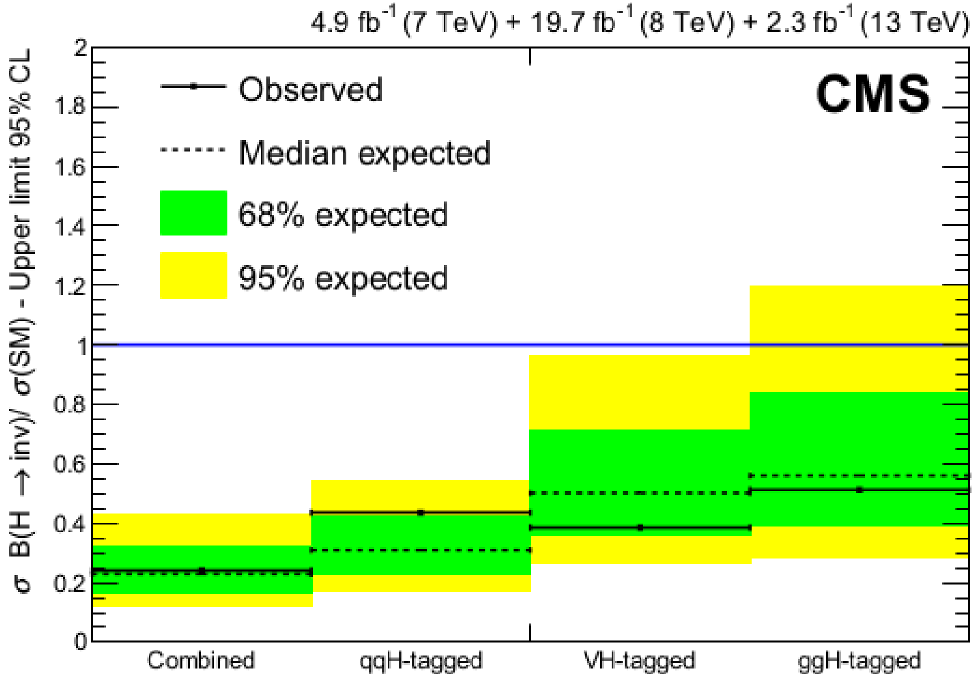
Require associated production to tag it :
⇒ ggH + high p_T jet from ISR, VH with $V \rightarrow qq / \ell\ell$, or VBF topology

Example : CMS VBF, 13 TeV, 2.3 fb^{-1} : large E_T^{miss} (h125 candidate),
two jets with high rapidity separation and invariant mass



Combining 7+8 TeV (25 fb^{-1}) and 13 TeV (2.3 fb^{-1})

$B_{inv} < 0.24$



Additional Heavy Singlet

Simplest extension of the SM : add a scalar SM singlet

⇒ two scalars : h_{125} (assumed to be the lightest) and H

- h_{125} has reduced couplings ($\kappa = \cos\alpha$) to SM wrt H_{SM} $\quad \mu_h = \frac{\sigma_h \times BR_h}{(\sigma_h \times BR_h)_{SM}} = \kappa^2$

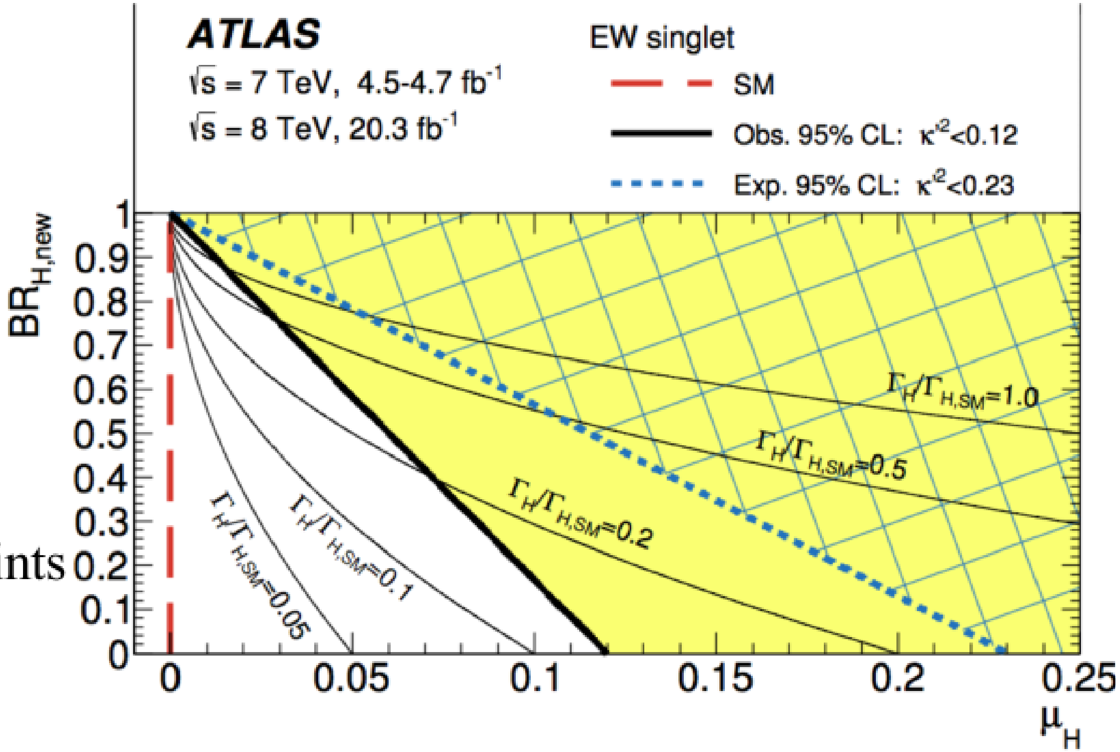
- H couples to SM particles via mixing ($\kappa' = \sin\alpha$) and for $m_H > 250$ GeV/c², $H \to h_{125}h_{125}$ opens up $\quad \mu_H = \frac{\sigma_H \times BR_H}{(\sigma_H \times BR_H)_{SM}} = \kappa'^2 (1 - BR_{H,new})$

Strongly constrained from h_{125} coupling measurements :

e.g. in ATLAS (Run I) :

$$\mu_h = 1.18^{+0.15}_{-0.14}$$

$$\Rightarrow \quad |\sin\alpha| < 0.35$$



⇒ Very important to consider indirect constraints from "precision" Higgs measurements (also from e.g. m_W)

(One) Additional Doublet

Main effort : Two Higgs Doublet Models (2HDM) with CP :
2 CP-even (h/H), 1 CP-odd (A) and a pair of charged ($H^{\pm}$) Higgs bosons,
most important parameters : $\tan\beta = v_2/v_1$ (vev ratio), α : mixing in the CP-even, m_A, m_H, $m_{H\pm}$

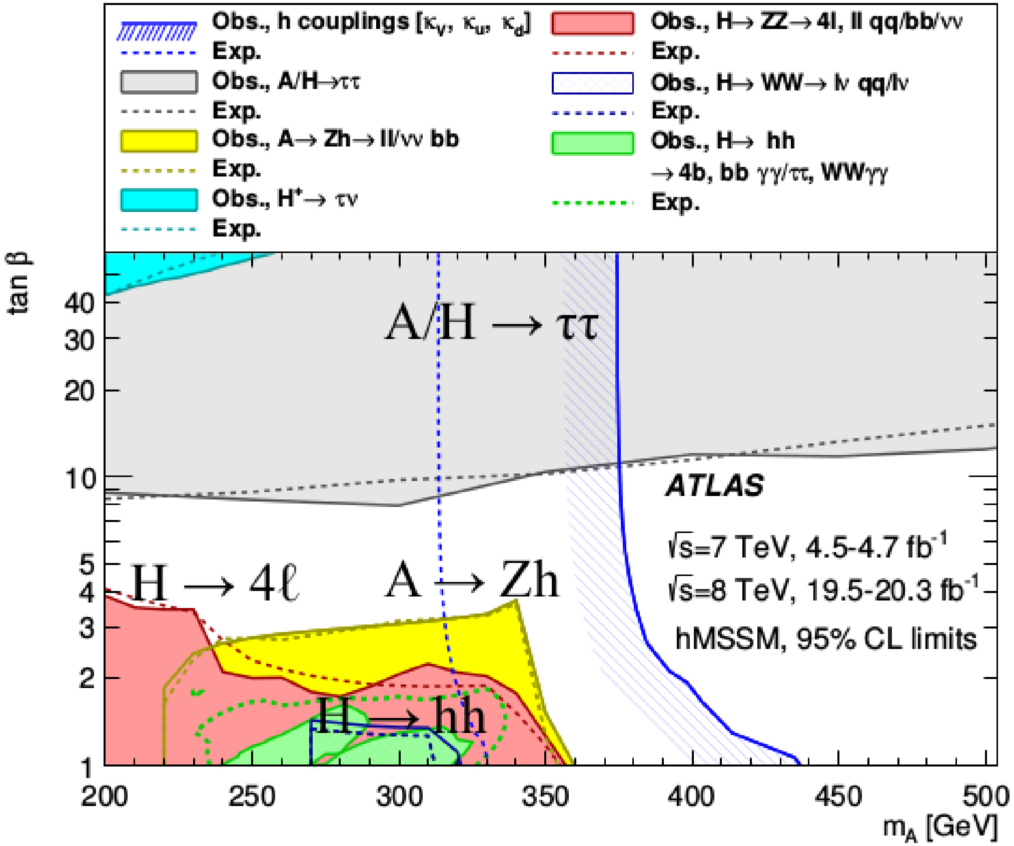
The resonance observed at 125 GeV/c^2 (h) is usually assumed to be the lightest CP-even

Strategy :

→ redundancy : several topologies can cover the same parameter space in given models

→ stay as model independent as possible (e.g. α is often a free parameter, $m_{\mathrm{H}^\pm} \neq \sqrt{m_{\mathrm{A}}^2 + m_{\mathrm{W}}^2}$ ...)

Particular attention to 2HDM-type II (interpretation in the MSSM within the most recent benchmarks)



Higgs boson Flavour Changing Neutral production $t \to qH$

Tiny branching ratio in SM : ~ 10^{-15} / 10^{-17} for q = c / u

⇒ Any observation of such processes is a non ambiguous sign of new physics

Some models predict enhancement by several order of magnitude

Benchmark coupling : *Naturalness limit :* $\lambda_{tcH} \sim 0.086$, $\mathcal{B} \sim 0.2\%$

Both ATLAS and CMS searched for this in top-quark pairs :

$$pp \to t\bar{t} \to W^{+}b\,Hq + c.c.$$

No excess has been observed ⇒ limits :

topology	$H \to \gamma\gamma$ ($W \to \ell\nu/qq$)		multi-leptons	
(%)	q = c	q = u	q = c	q = u
ATLAS	0.79 (0.51)		0.79 (0.54)	0.78 (0.57)
CMS†	0.47 (0.71)	0.42 (0.65)	0.93 (0.89)	-

† unpublished results with better sensitivity than the published analysis ($\mathcal{B}$ < 0.56%)

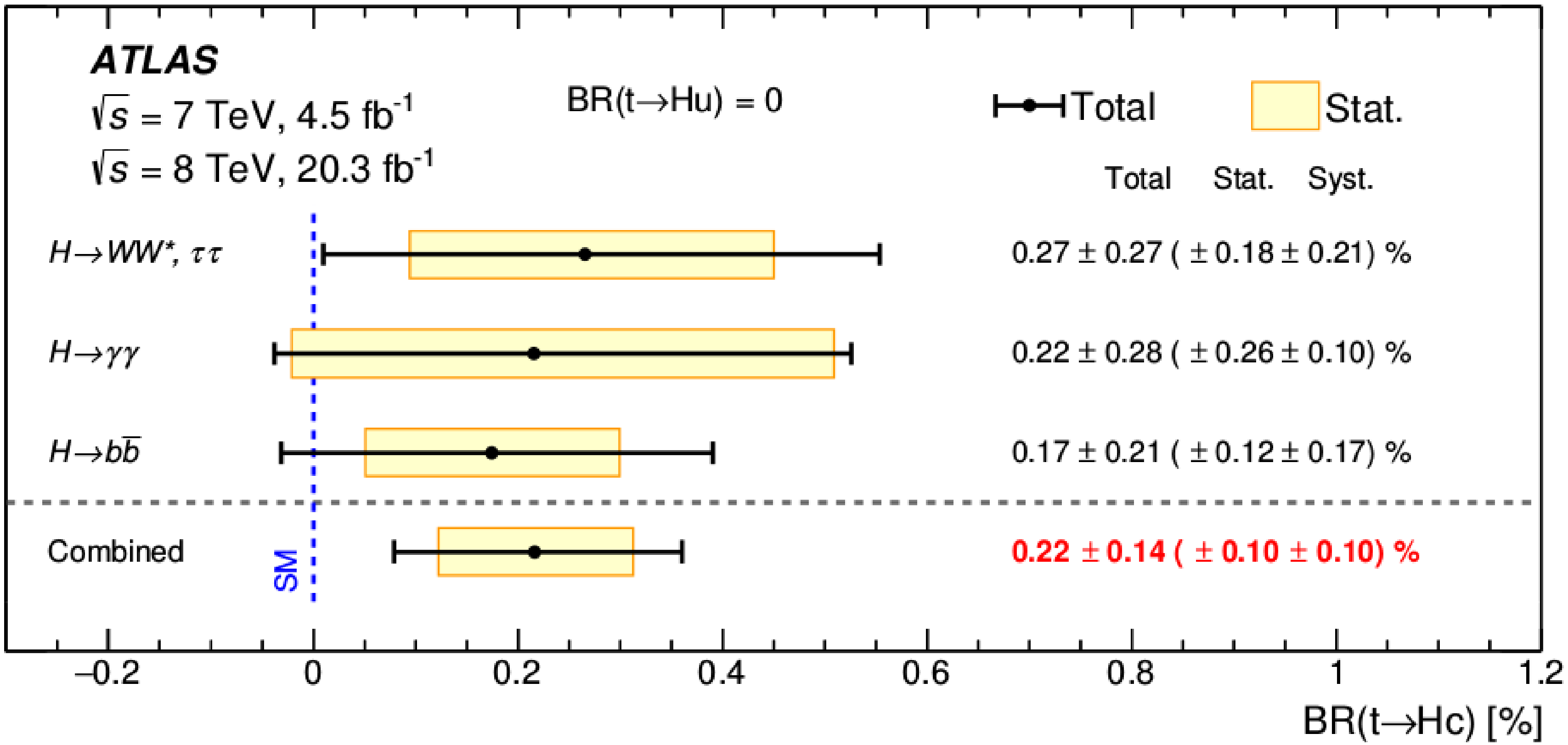
- The ATLAS multi-lepton result is a simple re-interpretation of the SM ttH search in the multi-lepton topology : not optimized for this less busy final state but yet very sensitive !

  ⇒ Might hope for great improvement in run II

Intriguingly the three channels observed a slight excess (and for $H \rightarrow bb$, in the $t \rightarrow cH$ decay) corresponding to a best fit value of

$$\mathcal{B}(t \rightarrow cH) \sim 0.2\%$$

which matches the *naturalness limit* …

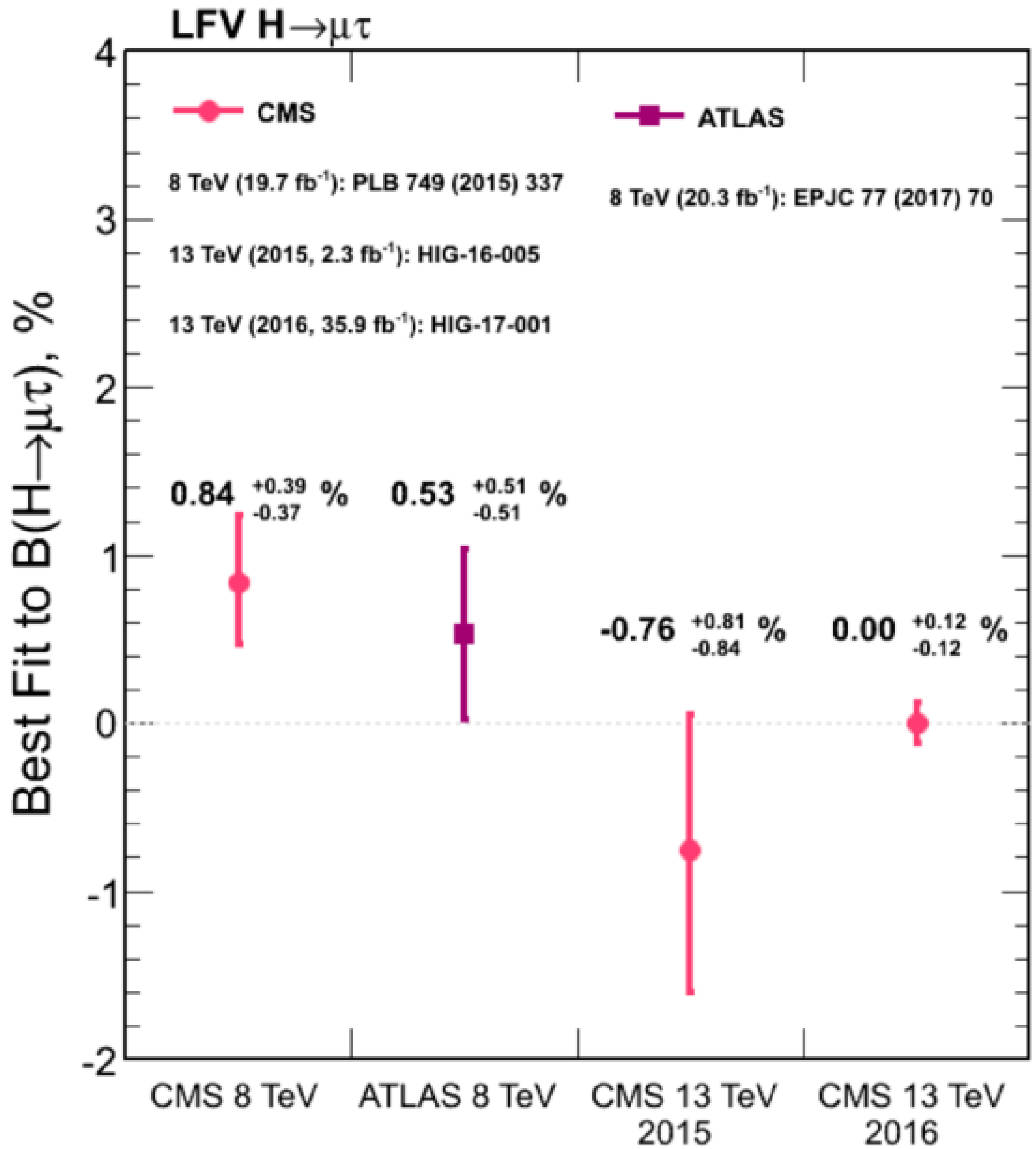


For run II, in the di-photon channel, expect ~ 3.7 events / fb^{-1} for $\mathcal{B} = 0.1\%$:
sensitivity ~ 0.15% with 30 fb^{-1}

⇒ Adding the multi-lepton and bb final state might allow to probe well below the *naturalness limit* before the end of run II

A Run 1 (flavour) puzzle

[CMS-PAS-HIG-17-001]

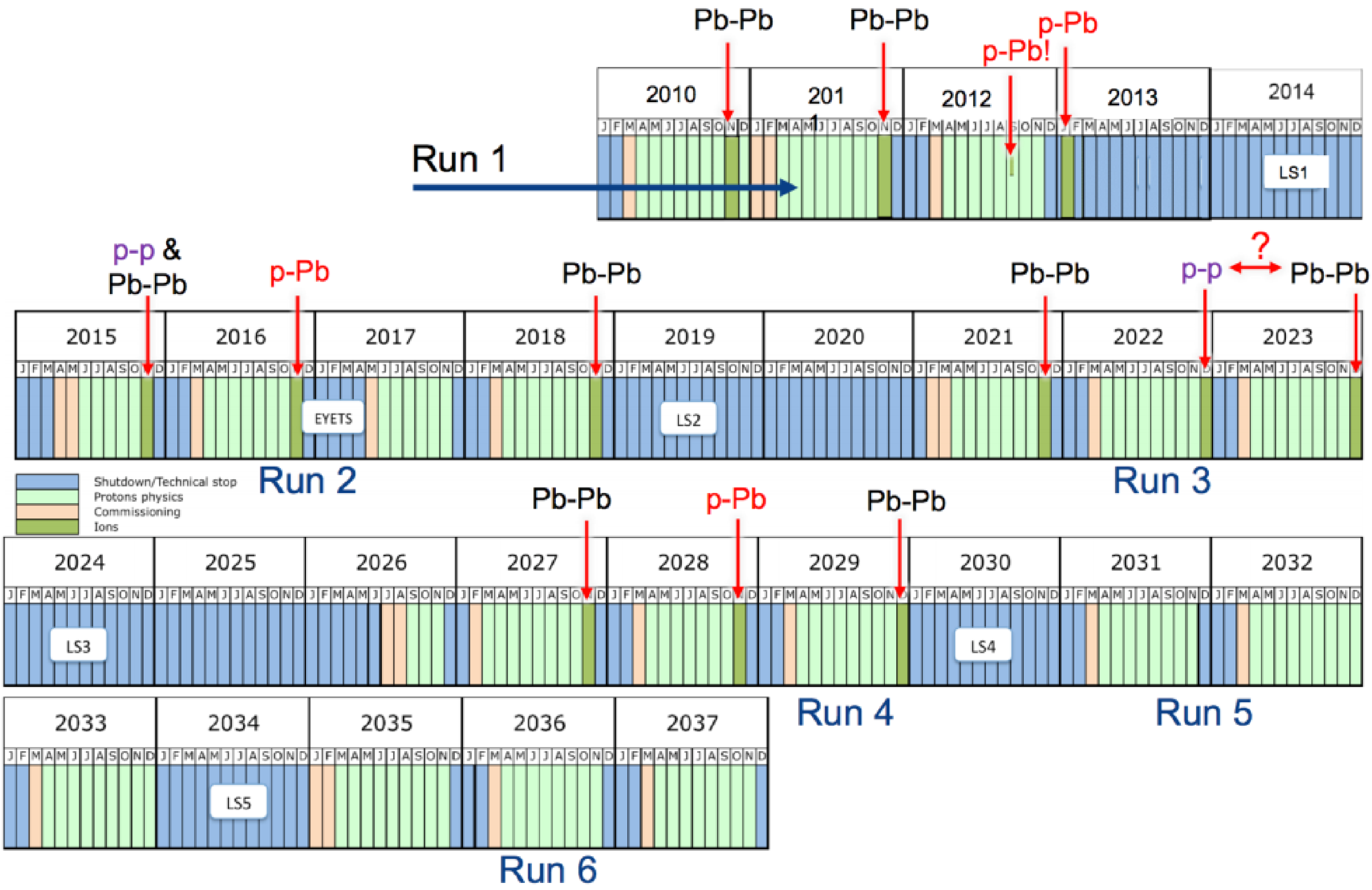


- **Null result.**
- SM wins again.

Summary

- 125 GeV Higgs is like SM Higgs.
- Implications for BSM from the Higgs precision measurements.
- We need wait for more data.

Deeper into the rabbit hole



Deeper into the rabbit hole