10 years of Higgs boson measurements

lessons learned and plans for the future

Roberto Salerno

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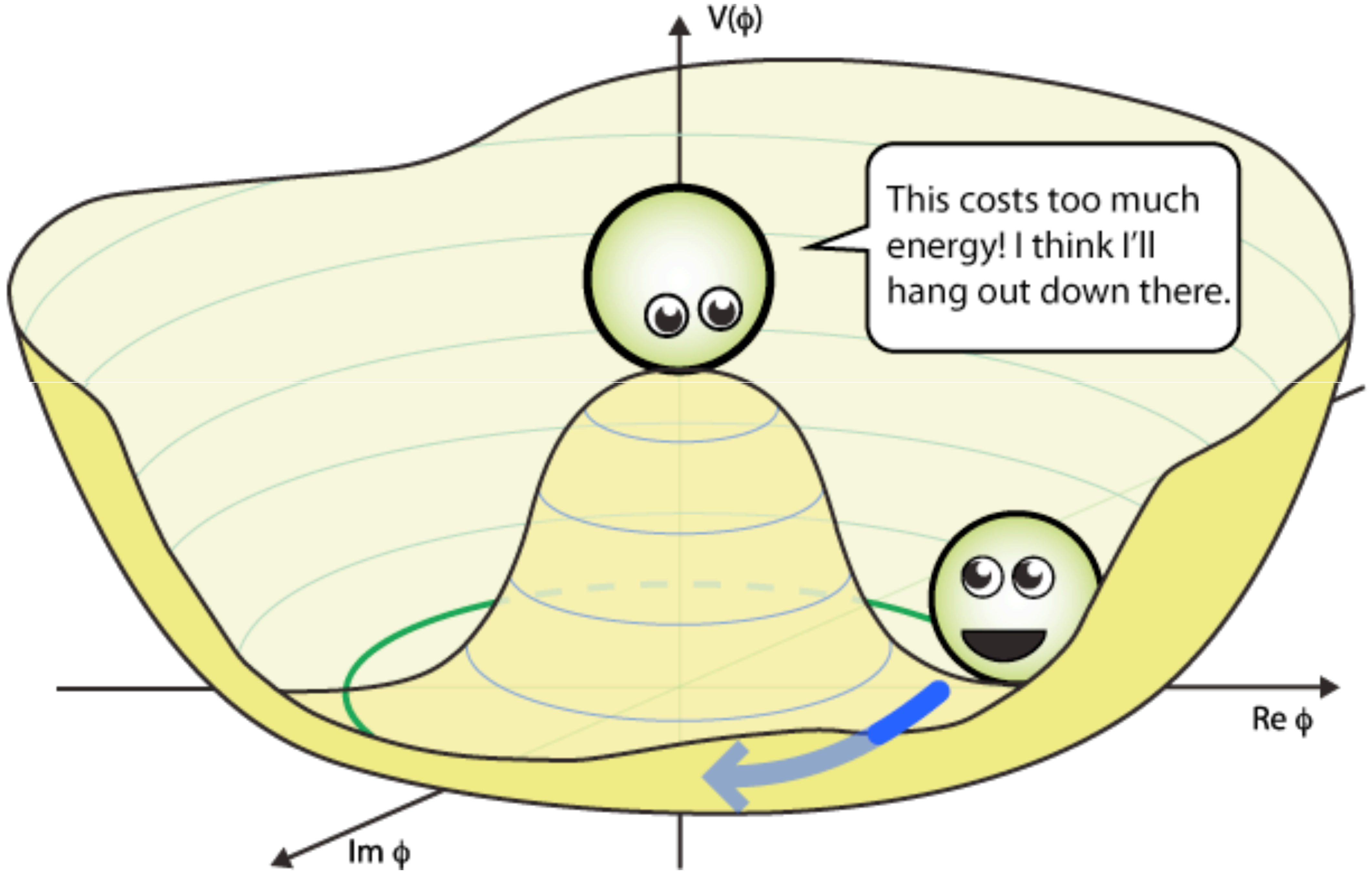
The Brout-Englert-Higgs (BEH) mechanism

"In one slide"

The economical[1)] way to endow fundamental particles with mass while keeping the theory gauge invariant and predictive

The field is responsible for the spontaneous breaking of electroweak symmetry



PRL 13, 321-323 (1964) Englert and Brout
PRL 13, 508-509 (1964) Higgs
PRL 13, 585-587 (1964) Guralnik, Hagen, Kibble

1) less economical (Higgs doublets, families of Higgses, ...) or more complicated (Higgs-less solutions, Technicolor, ...) routes exist

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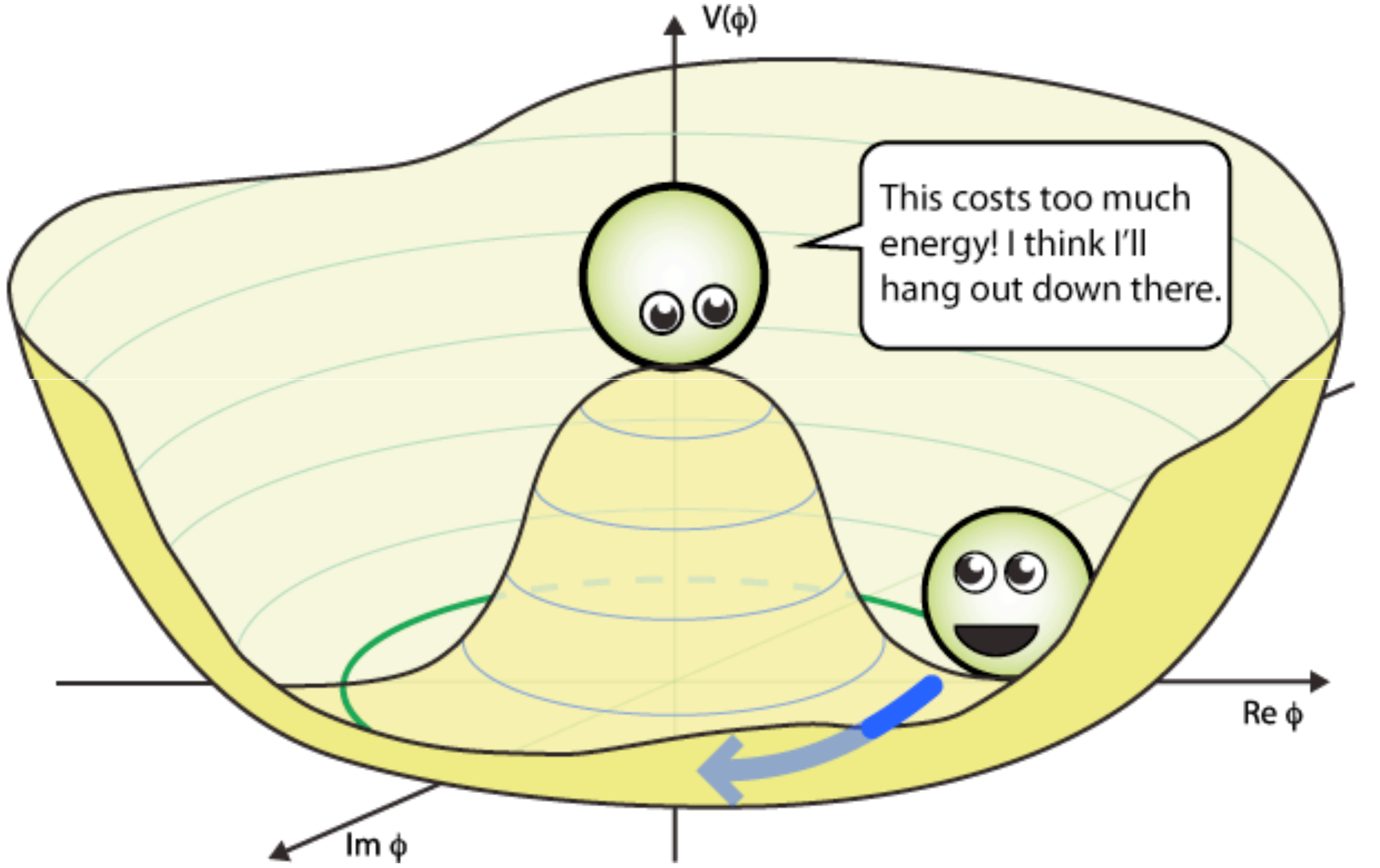

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The economical[1)] way to endow fundamental particles with mass while keeping the theory gauge invariant and predictive

The field is responsible for the spontaneous breaking of electroweak symmetry

"Only"

1 new particle **the Higgs boson (H)**

1 unknown **the Higgs boson mass (m_H)**

1) less economical (Higgs doublets, families of Higgses, ...)
or more complicated (Higgs-less solutions, Technicolor, ...) routes exist

The Higgs boson is special

It is a fundamental scalar particle (spin 0) and
its theory is unlike anything else has been seen in Nature!

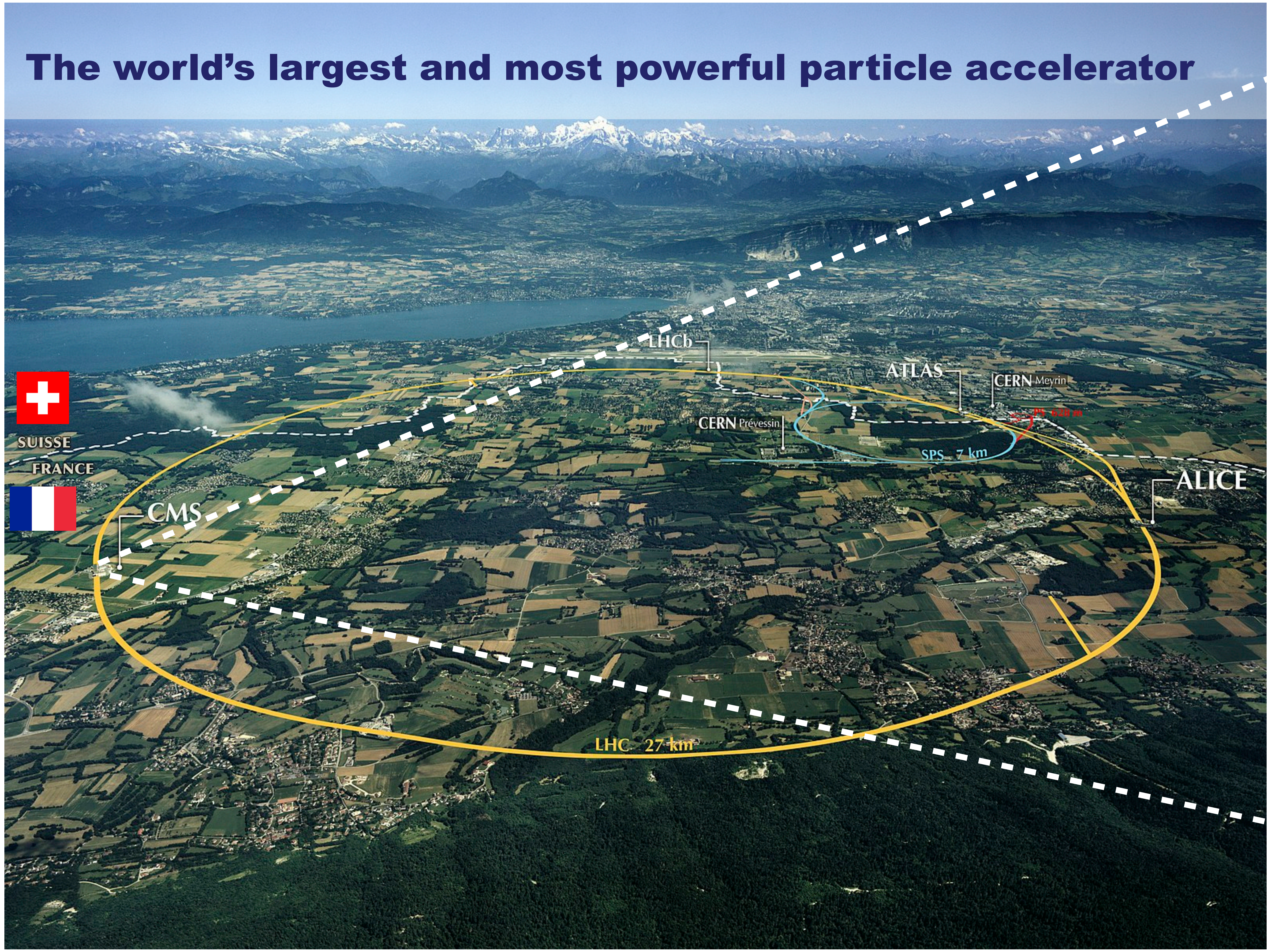
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \psi_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$

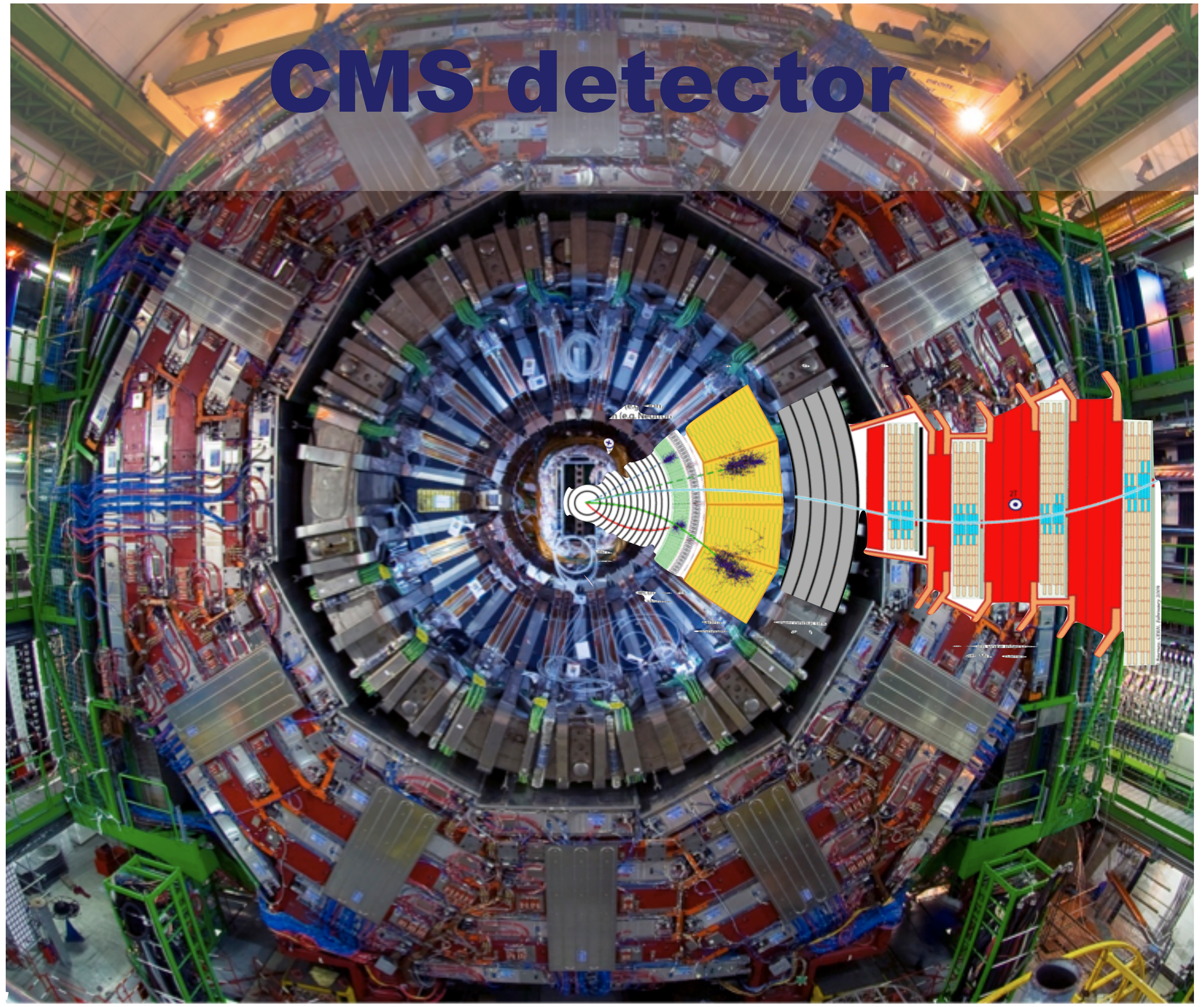
A gauge interaction
with vector bosons

A Yukawa interaction
with the fermions

A potential $V(\phi) \sim -\mu^2(\phi\phi^\dagger)+\lambda(\phi\phi^\dagger)^2$
the keystone of the BEH
mechanism and SM

LHC : a new dimension in particle physics

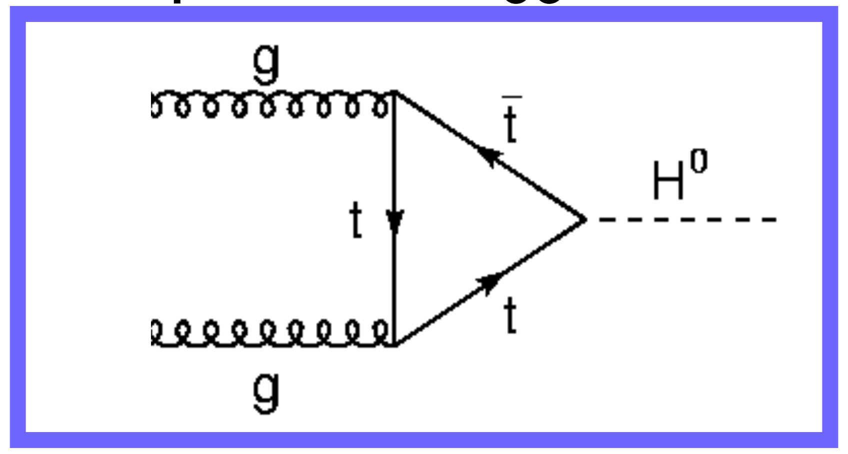




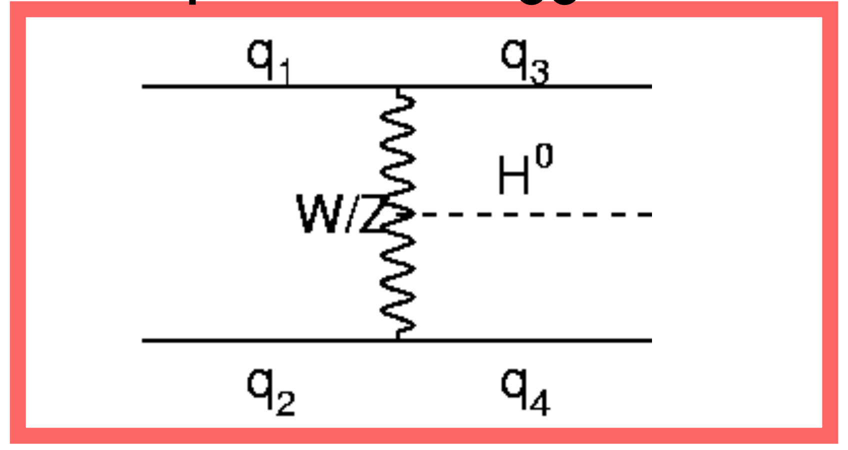
14000-tonne weight
21 metres long, 15 metres wide and 15 metres high
4 Tesla field (~10^6 times the magnetic field of the Earth)

The Higgs boson production and decay *"just a reminder"*

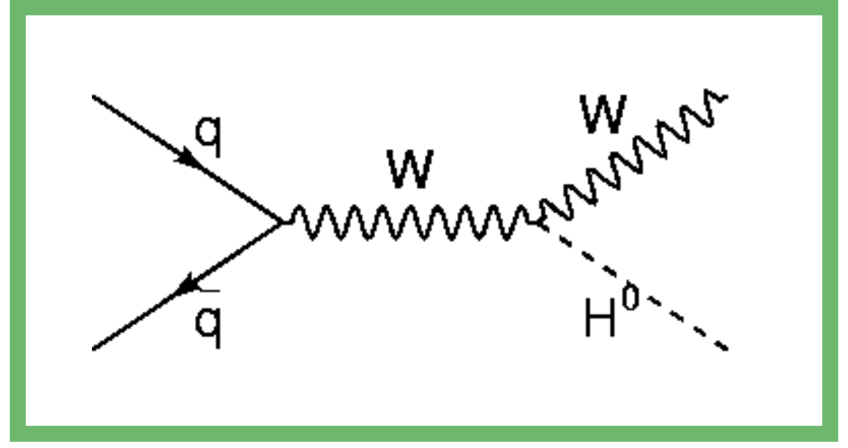
σ=49 pb / 6.9M Higgs in 140fb^{-1}



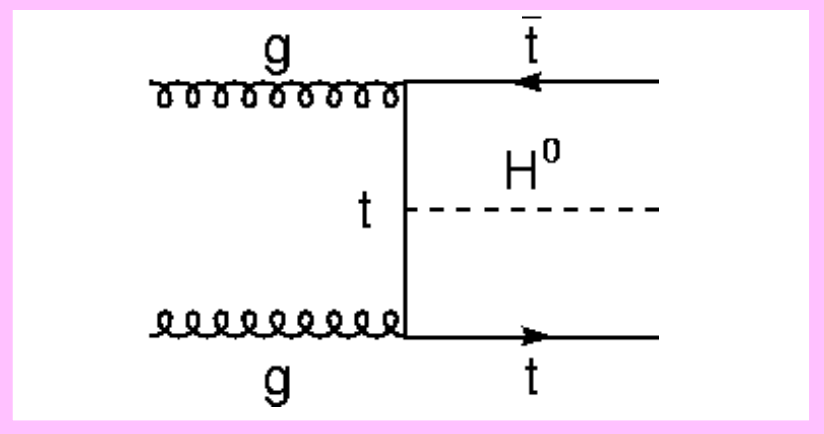
σ=3.8 pb / 520k Higgs in 140fb^{-1}

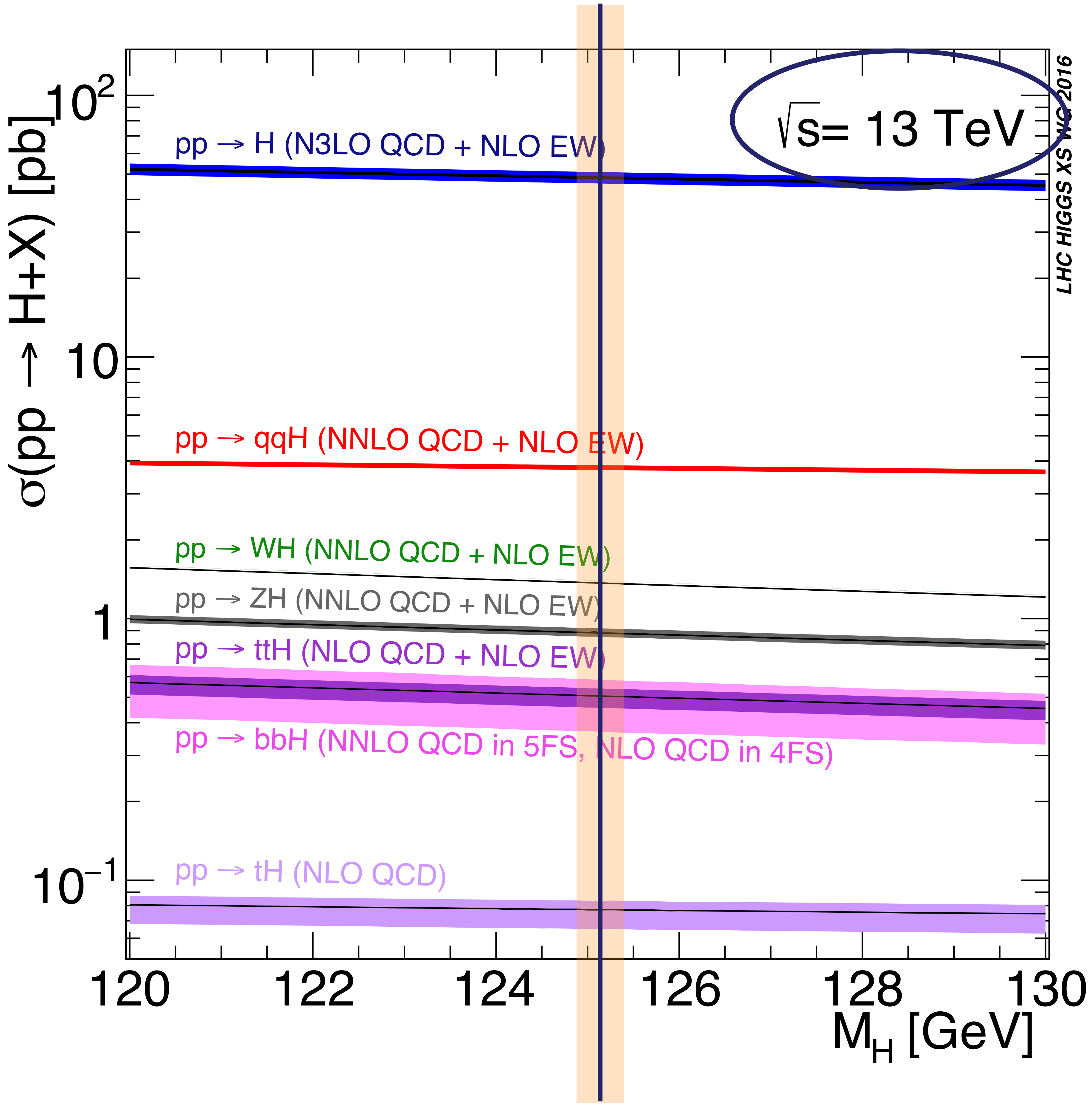


σ=2.3 pb / 320k Higgs in 140fb^{-1}

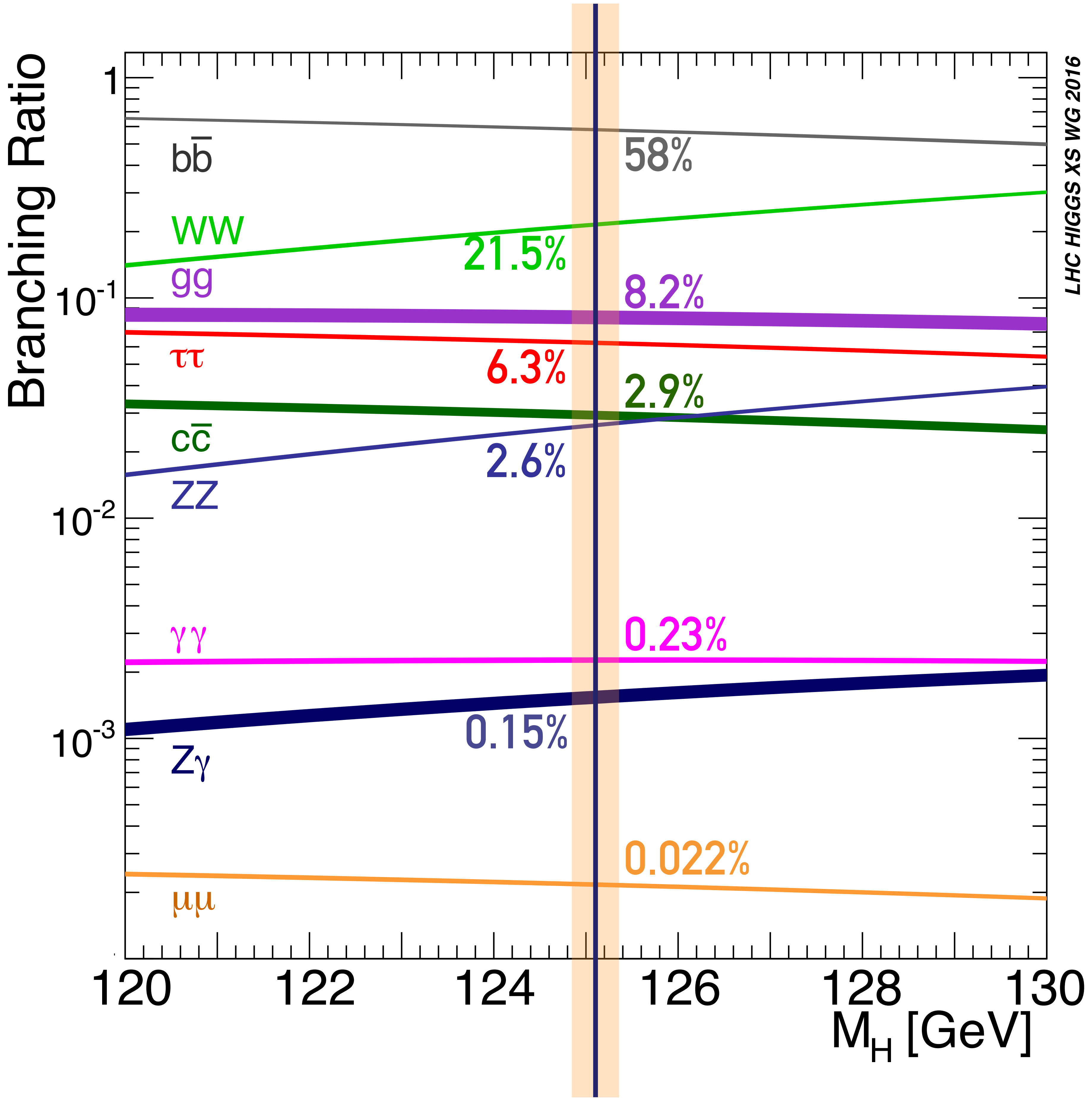


σ=0.5 pb / 70k Higgs in 140fb^{-1}





125.09 ± 0.24 GeV
LHC Run1 measurement



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LHC Run1 measurement

The Higgs boson timeline at LHC

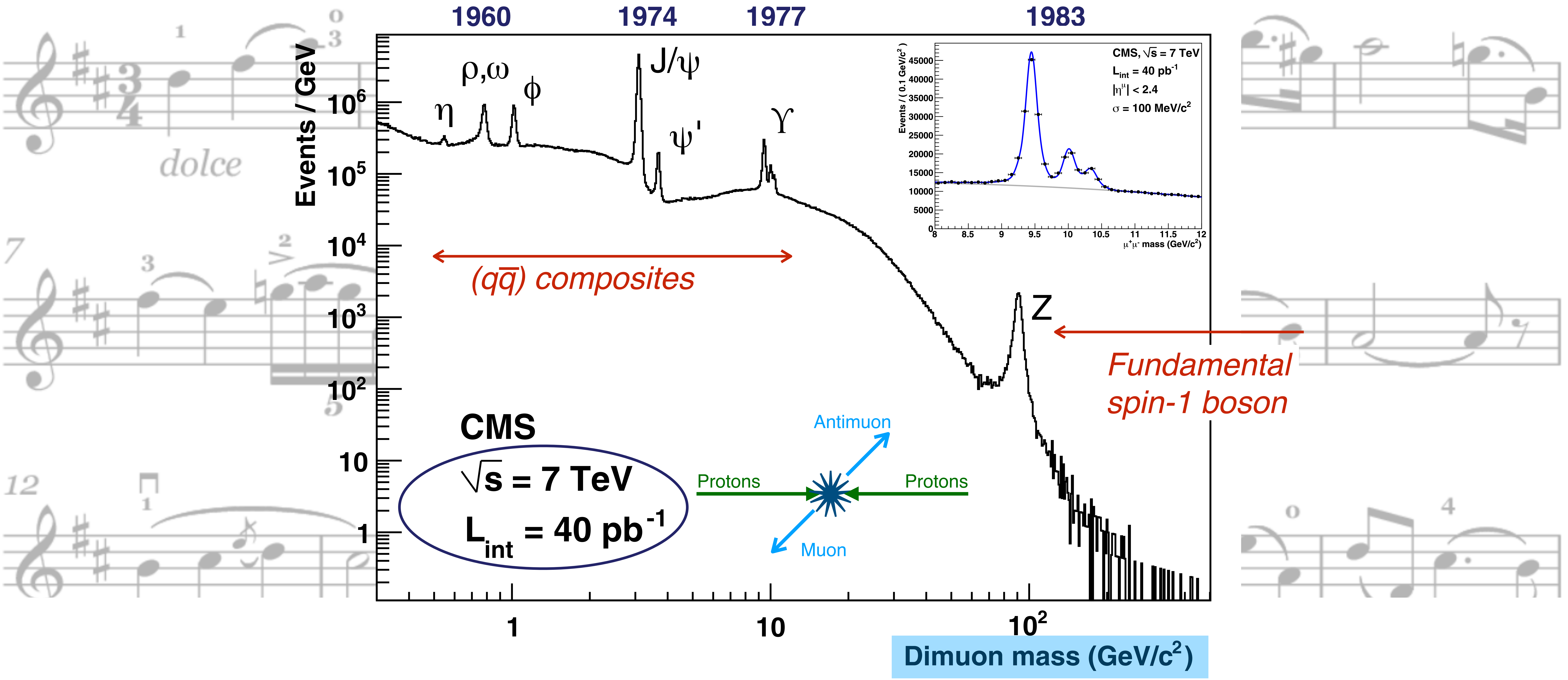
Years of unprecedented moments in HEP

“Intermezzo”

In 2010 LHC started to deliver proton-proton collisions

"Intermezzo"

In 2010 LHC started to deliver proton-proton collisions
50 years of particle physics … in few weeks of data taking



The Higgs boson timeline at LHC

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The Higgs boson timeline at LHC

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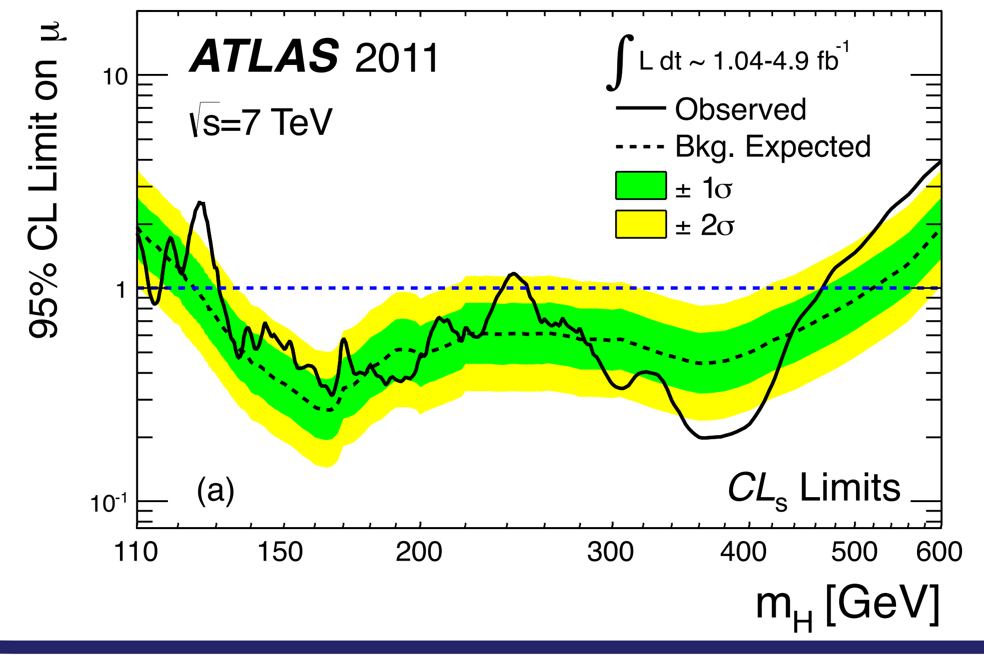
Few highlights

Higgs boson searches

"if the SM Higgs boson exists, is most likely to have a mass constrained to 115-130 GeV "



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LHC

Run1 ~25/fb — 7TeV 8TeV

Run2 ~150/fb — 13TeV

Run3 — 13.6TeV

High Luminosity LHC

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 …2038

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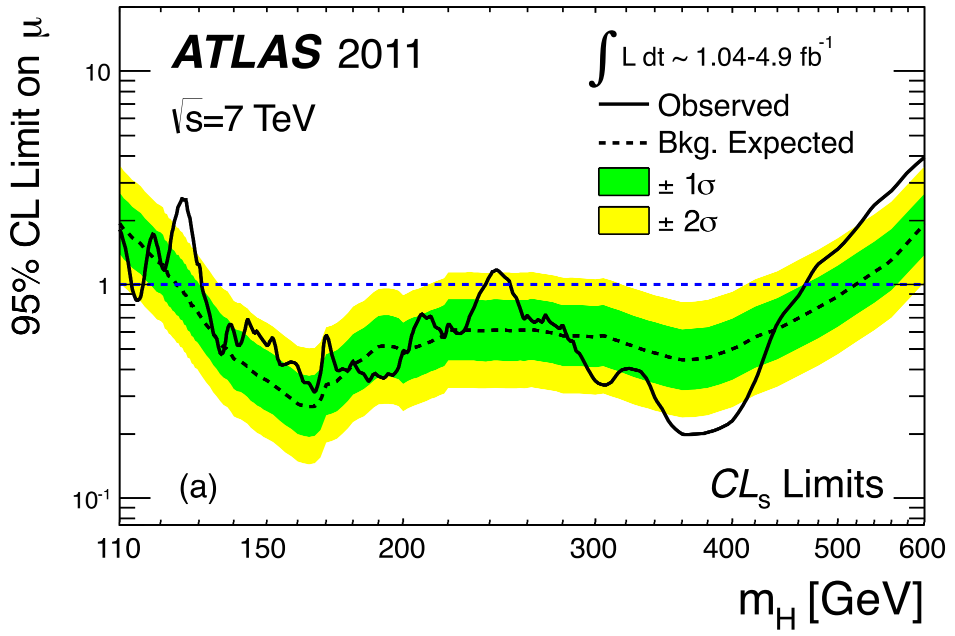
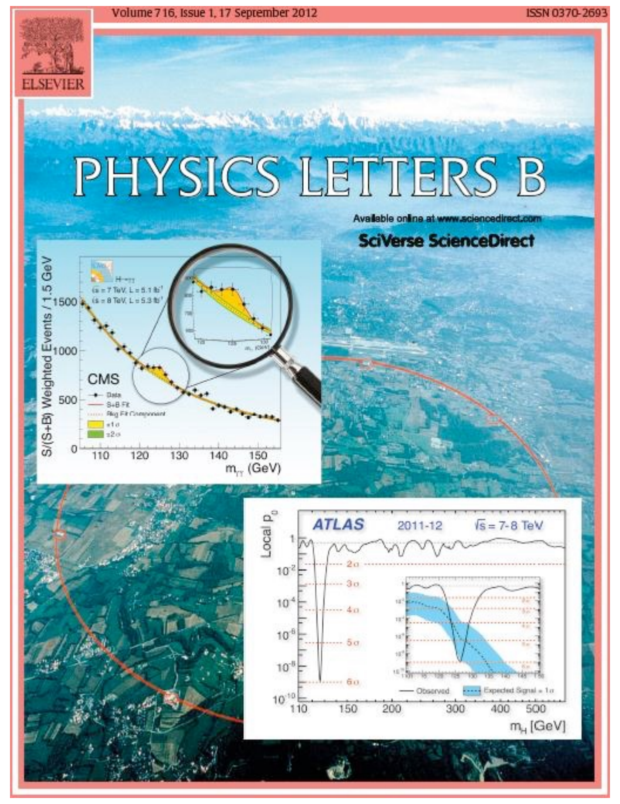
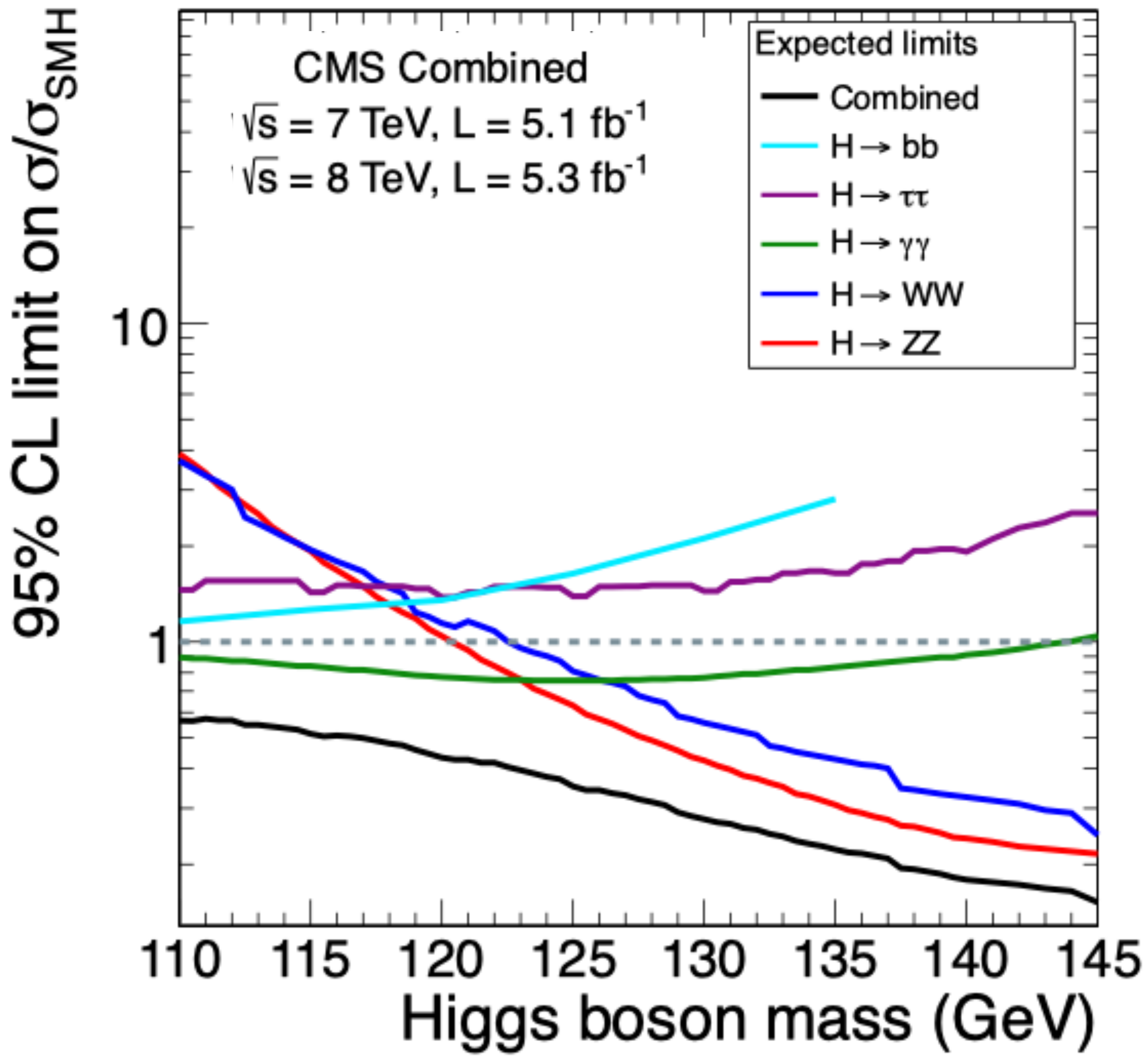


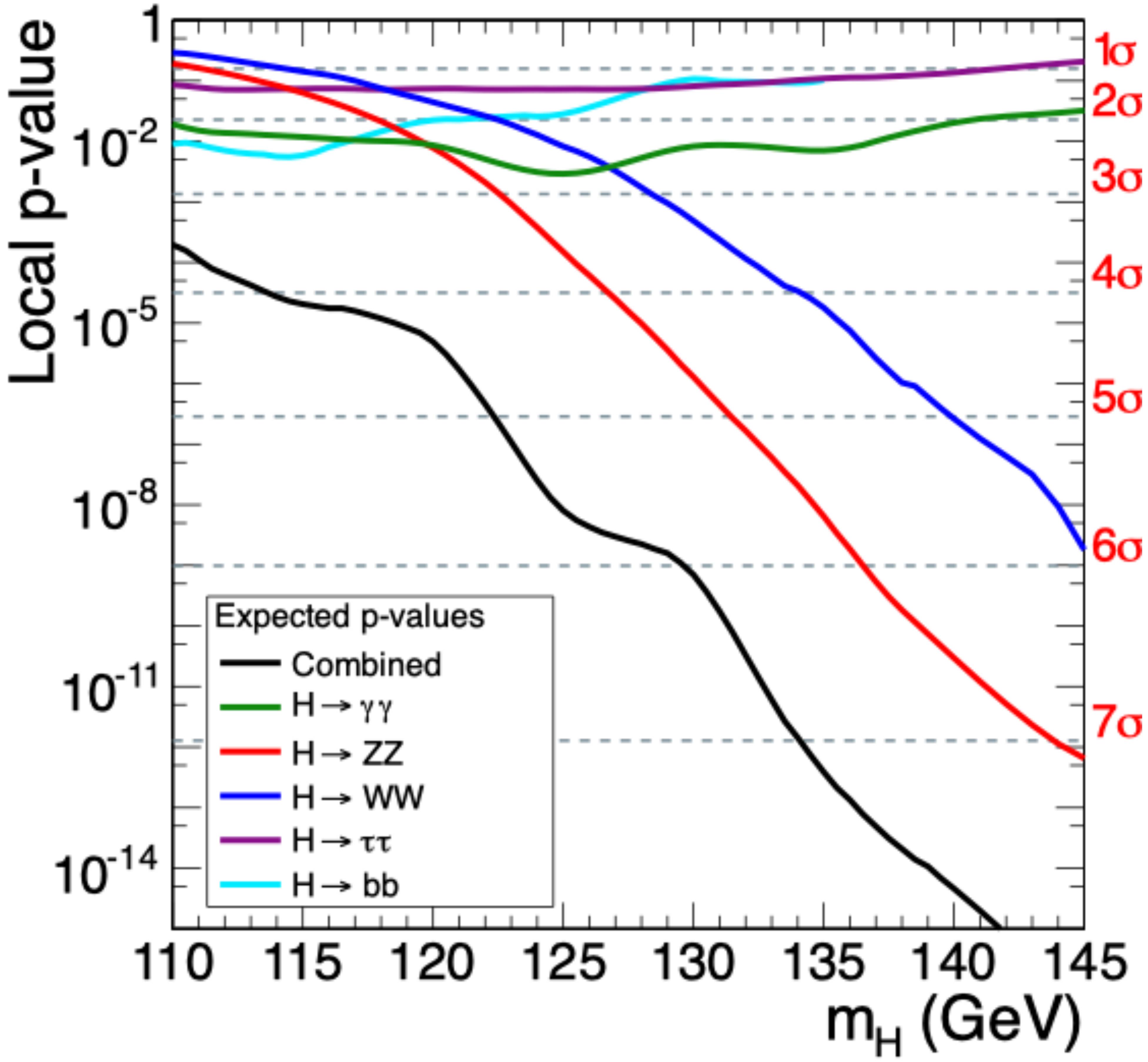
Higgs boson observation



The big five

Expected results



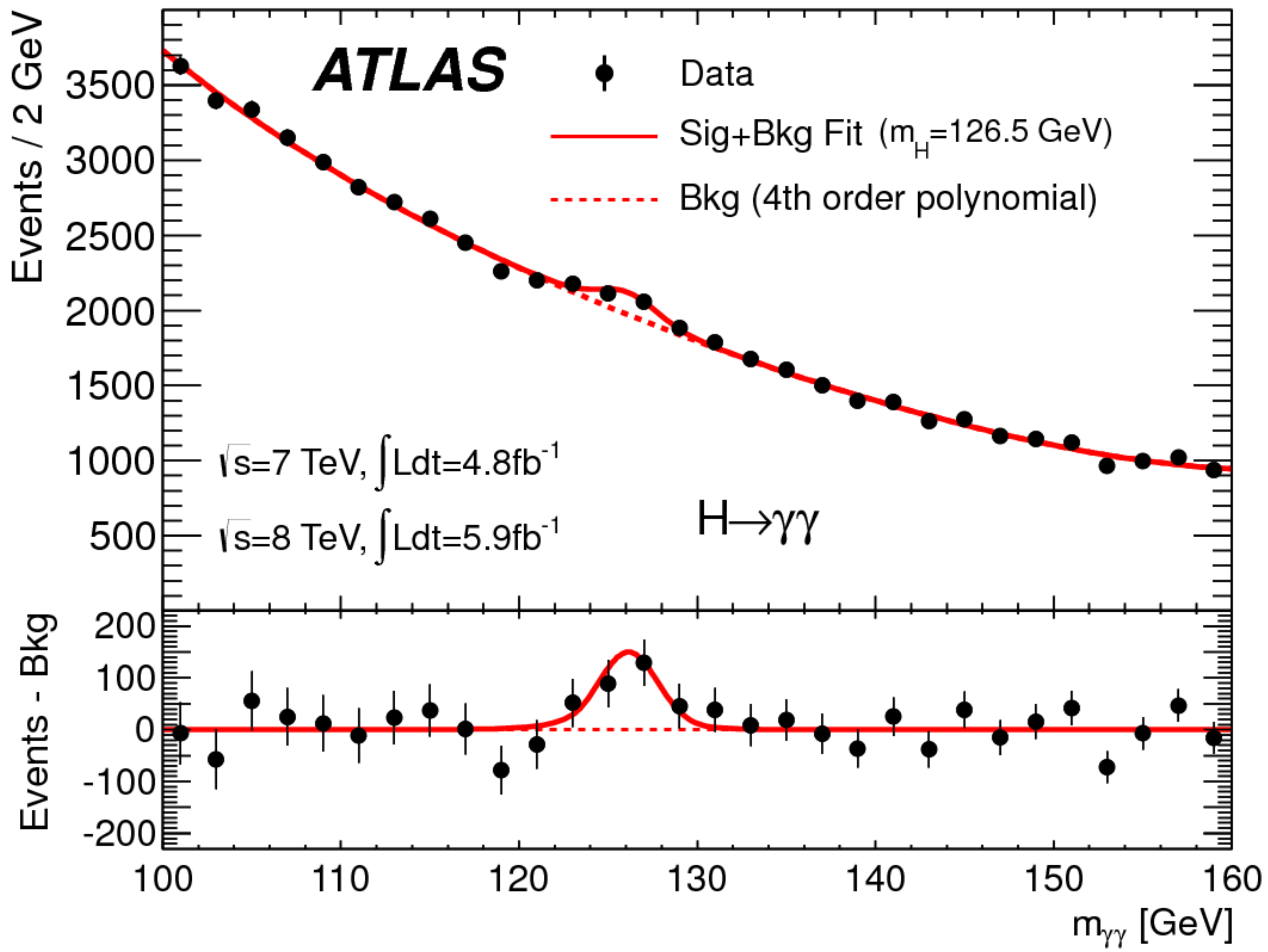


High mass resolution decay modes: **H →ZZ** / **H →γγ**

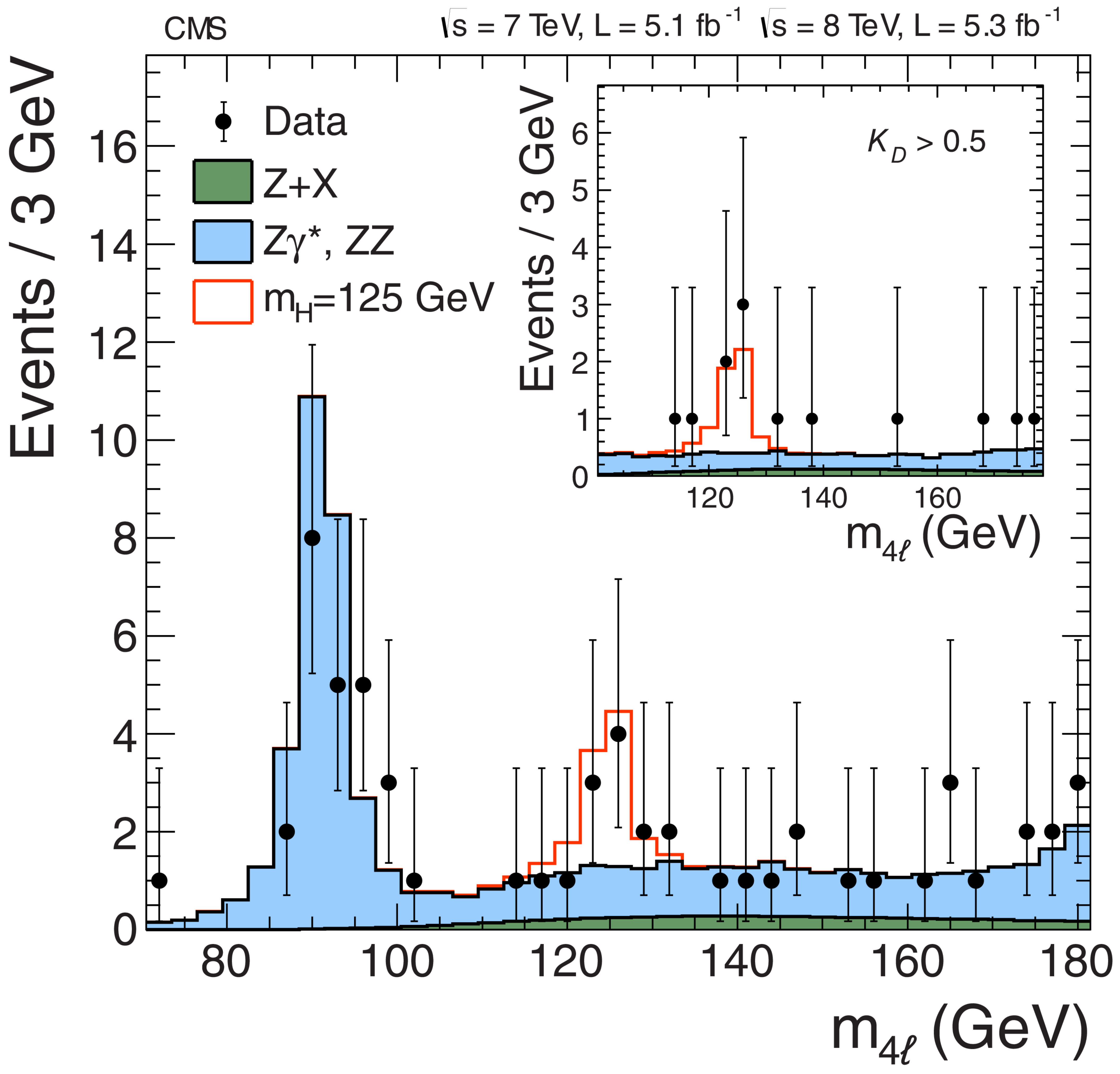
Lower mass resolution decay modes: **H →WW** / **H →bb** / **H→ττ**

Discovery of a new particle

$H \rightarrow \gamma\gamma$

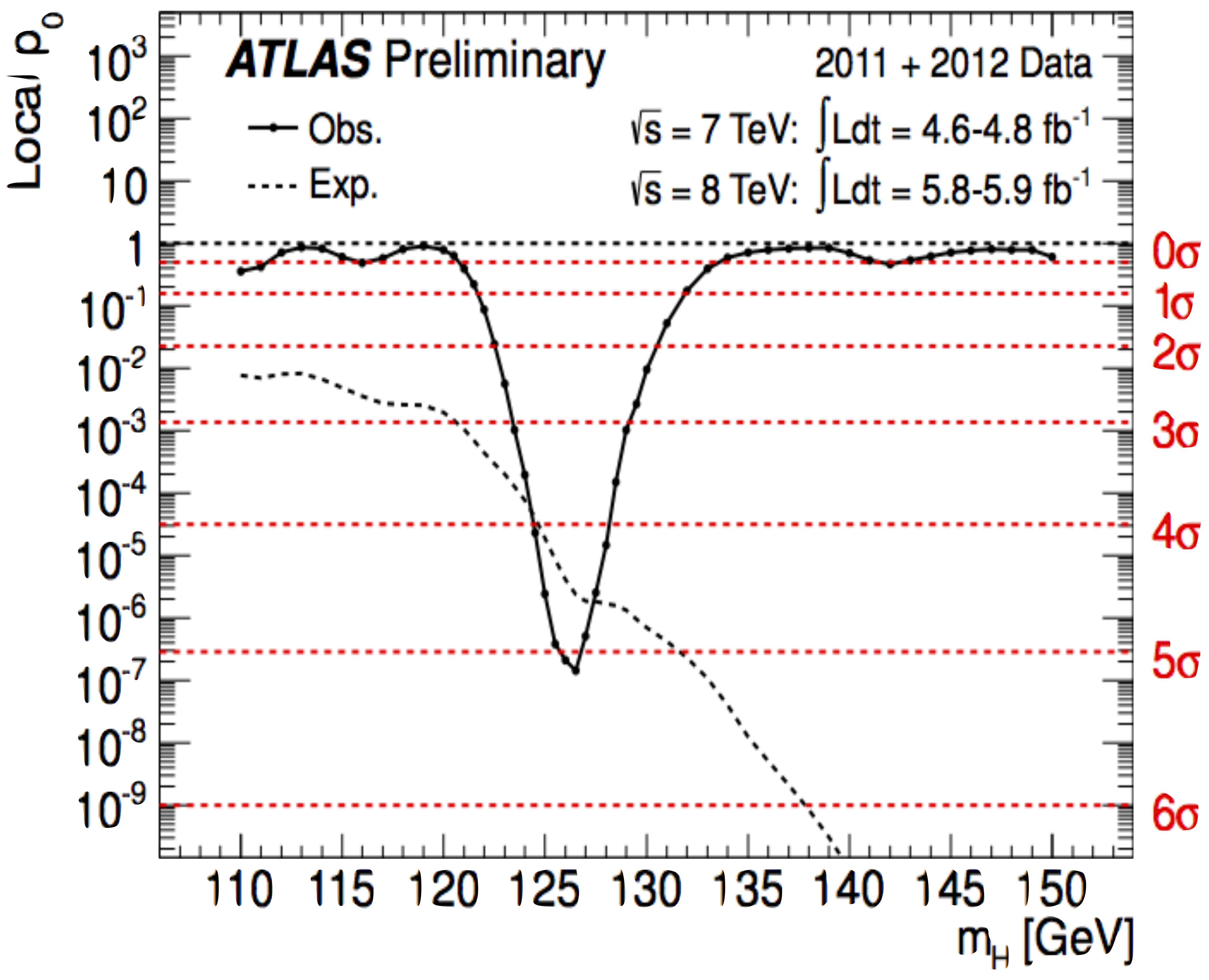


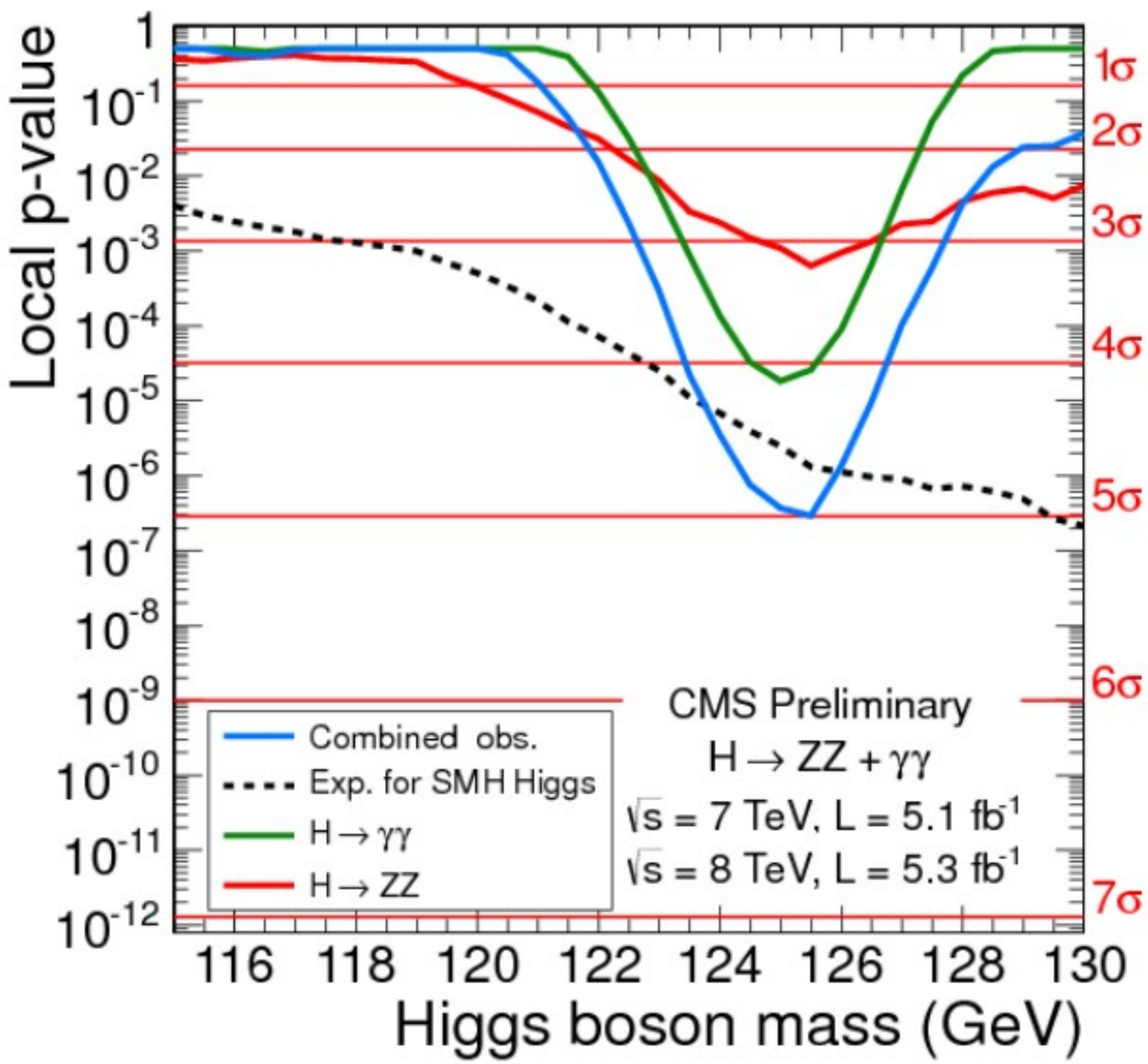
$H \rightarrow ZZ$



Discovery of a new particle

The open boxes on July 4th 2012





Discovery of a new particle

More than a billion people saw the news on TV, on five thousand broadcasts on a thousand TV stations

Ten thousand news articles in a hundred countries

Discovery of a new particle

July 2013
European Physics Society HEPP Prize

"**Discovery** of a Higgs boson, a scalar particle whose associated field breaks electroweak symmetry and generates mass" awarded to the **ATLAS and CMS Collaborations**

October 2013
Nobel Prize

"For the **theoretical discovery** of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, **by the ATLAS and CMS experiments at CERN's LHC**" awarded jointly to **François Englert and Peter W. Higgs**

The Higgs boson timeline at LHC

Years of unprecedented moments in HEP

LHC | Run1 ~25/fb | 7TeV | 8TeV | Run2 ~150/fb | 13TeV | Run3 | 13.6TeV | High Luminosity LHC

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | …2038

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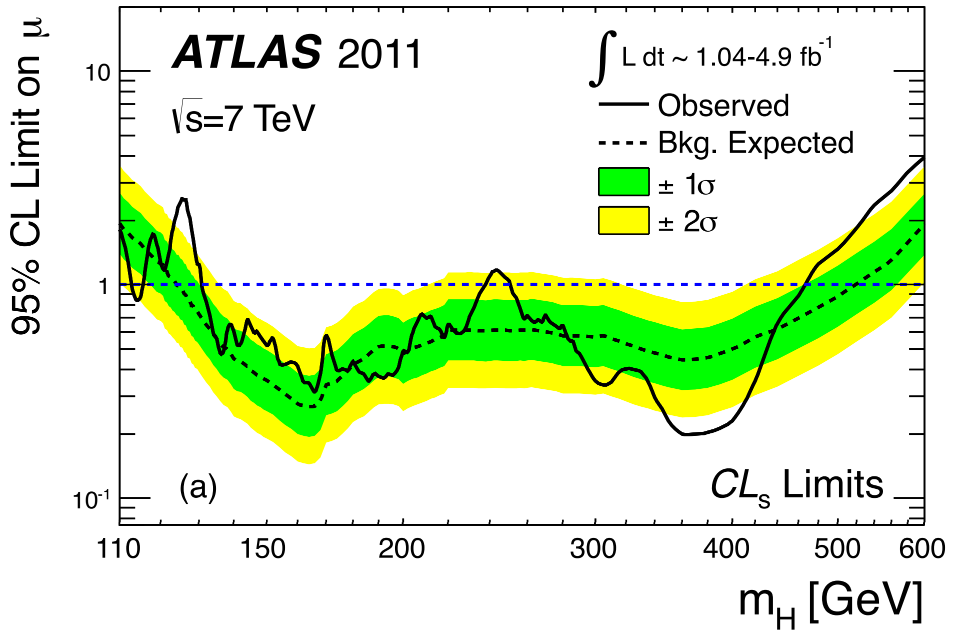

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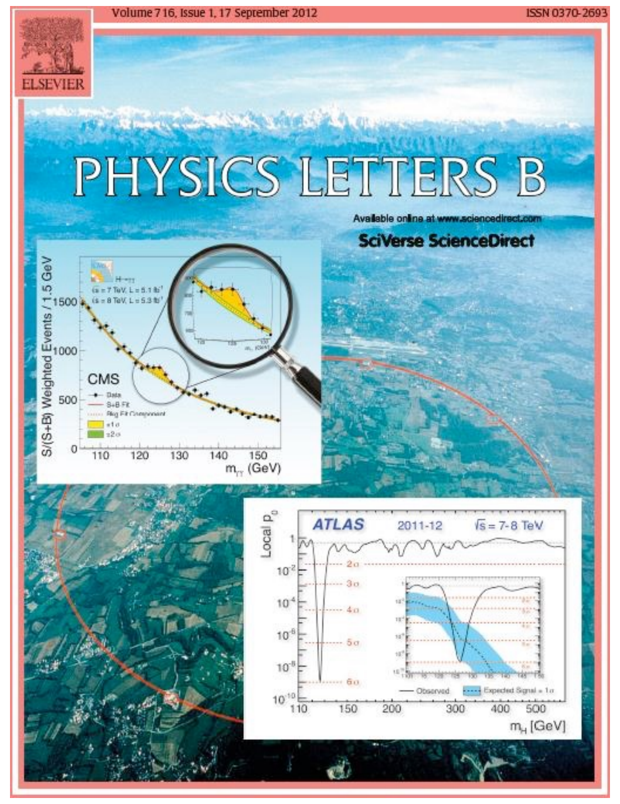

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LHC — Run1 ~25/fb: 7TeV, 8TeV (2010–2012)

Run2 ~150/fb: 13TeV (2015–2018)

Run3: 13.6TeV (2022–)

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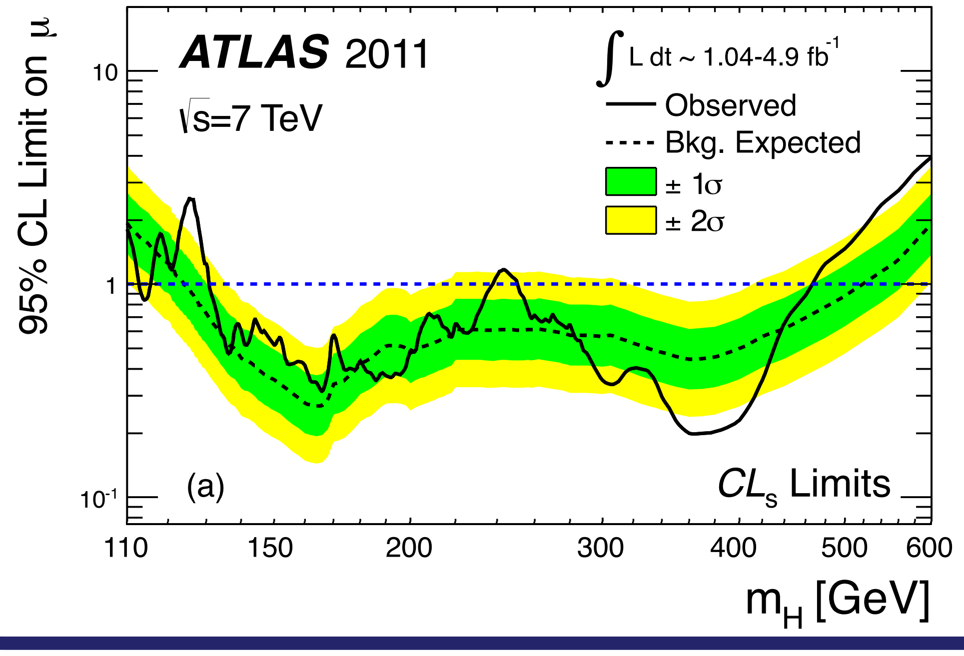
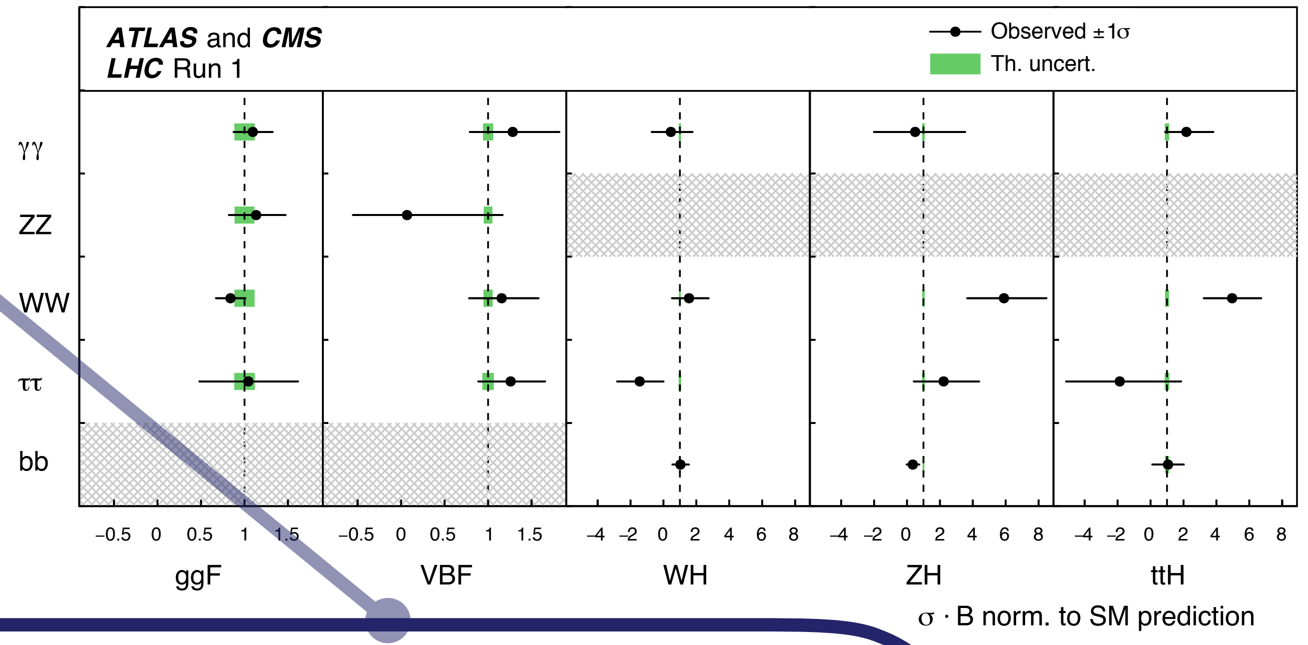


LHC combination

In one word "SM like"



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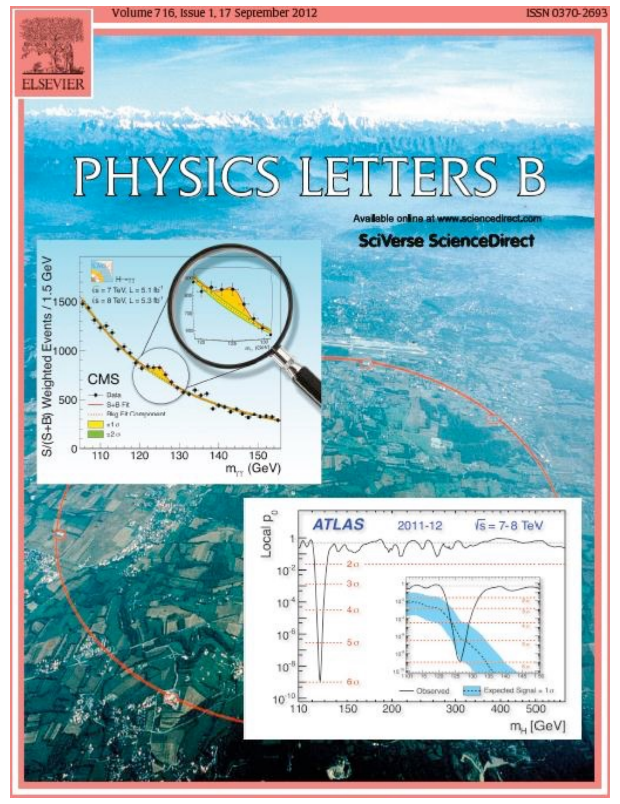

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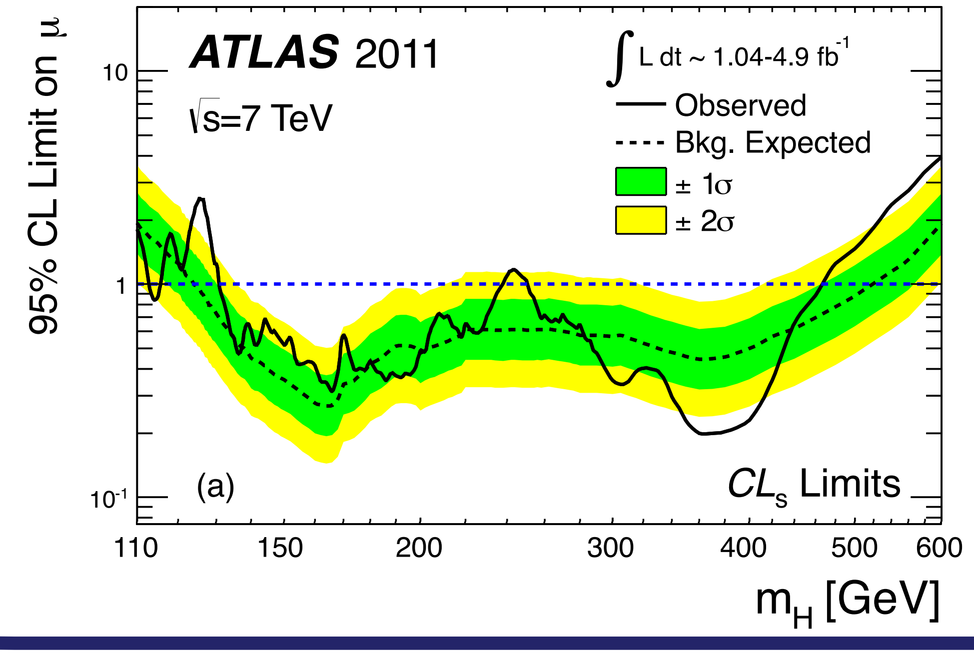

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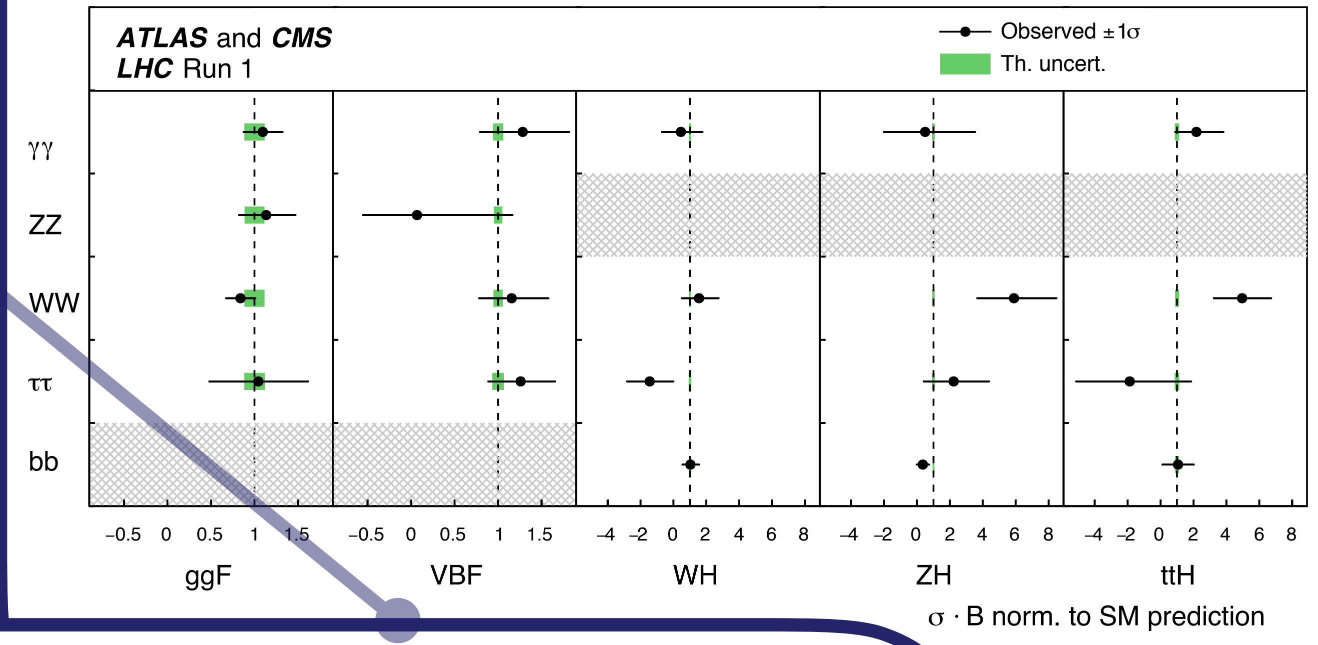

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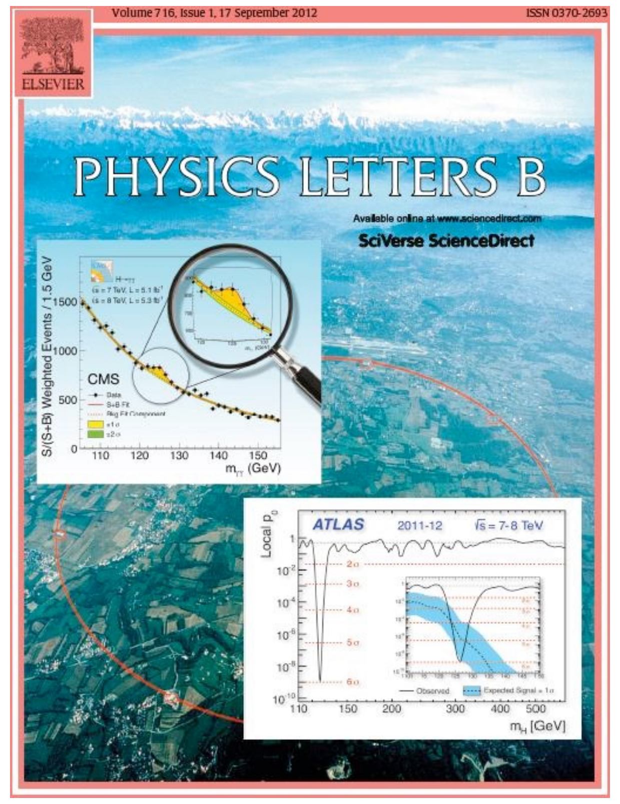

Towards the precision physics era

A huge landscape of possibilities opens

A huge landscape of possibilities opens

Complete characterisation of the Higgs boson profile

(exploiting both H-Z, H-W, and H-γ interactions and its couplings with 3rd/2nd-family fermion)

A huge landscape of possibilities opens

Study of the Higgs boson self-coupling

Complete characterisation of the Higgs boson profile

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A huge landscape of possibilities opens

The Higgs boson as a tool to reveal the mysteries of Universe
(Dark matter, BSM, ...)

Study of the Higgs boson self-coupling

Complete characterisation of the Higgs boson profile
(exploiting both H-Z, H-W, and H-γ interactions and its couplings with 3rd/2nd-family fermion)

The experimental H profile

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

H^0

$J = 0$

In the following H^0 refers to the signal that has been discovered in the Higgs searches. Whereas the observed signal is labeled as a spin 0 particle and is called a Higgs Boson, the detailed properties of H^0 and its role in the context of electroweak symmetry breaking need to be further clarified. These issues are addressed by the measurements listed below.

Concerning mass limits and cross section limits that have been obtained in the searches for neutral and charged Higgs bosons, see the sections "Searches for Neutral Higgs Bosons" and "Searches for Charged Higgs Bosons ($H^{\pm}$ and $H^{\pm\pm}$)", respectively.

H^0 MASS

VALUE (GeV)	*DOCUMENT ID*	*TECN*	*COMMENT*
125.25±0.17 OUR AVERAGE	Error includes scale	factor of 1.5.	See the ideogram below.
125.46±0.16	[1] SIRUNYAN 20L	CMS	pp, 13 TeV, $\gamma\gamma$, $ZZ^* \to 4\ell$

The Higgs boson mass: “is not” vs. “is”

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✔ The Higgs boson mass **is not** a prediction of the theory but the Higgs boson mass **is** free input parameter of the theory

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- **Higgs boson observables : couplings, branching ratios, width**
- **Electroweak observables : mass of the W boson, mass of the top quark, effective weak mixing angle, ….**

1) I would argue that is the most important

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- **Higgs boson observables : couplings, branching ratios, width**
- **Electroweak observables : mass of the W boson, mass of the top quark, effective weak mixing angle, ….**

✔ The Higgs boson mass value **is** connected to the Fermi and the Planck scales and ultimately with the vacuum stability

1) I would argue that is the most important

m_H and effects on EWK observables

hep-ph/0311148

Approximated parametrisation for the mass of W boson (m_W) :

$$M_W = M_W^0 - c_1\,\mathrm{dH} - c_2\,\mathrm{dH}^2 + c_3\,\mathrm{dH}^4 + c_4(\mathrm{dh}-1) - c_5\,\mathrm{d}\alpha + c_6\,\mathrm{dt} - c_7\,\mathrm{dt}^2 - c_8\,\mathrm{dH}\,\mathrm{dt} + c_9\,\mathrm{dh}\,\mathrm{dt} - c_{10}\,\mathrm{d}\alpha_s + c_{11}\,\mathrm{dZ},$$

where

$$\mathrm{dH} = \ln\left(\frac{M_H}{100\ \mathrm{GeV}}\right), \quad \mathrm{dh} = \left(\frac{M_H}{100\ \mathrm{GeV}}\right)^2, \quad \mathrm{dt} = \left(\frac{m_t}{174.3\ \mathrm{GeV}}\right)^2 - 1,$$

$$\mathrm{dZ} = \frac{M_Z}{91.1875\ \mathrm{GeV}} - 1, \quad \mathrm{d}\alpha = \frac{\Delta\alpha}{0.05907} - 1, \quad \mathrm{d}\alpha_s = \frac{\alpha_s(M_Z)}{0.119} - 1,$$

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where

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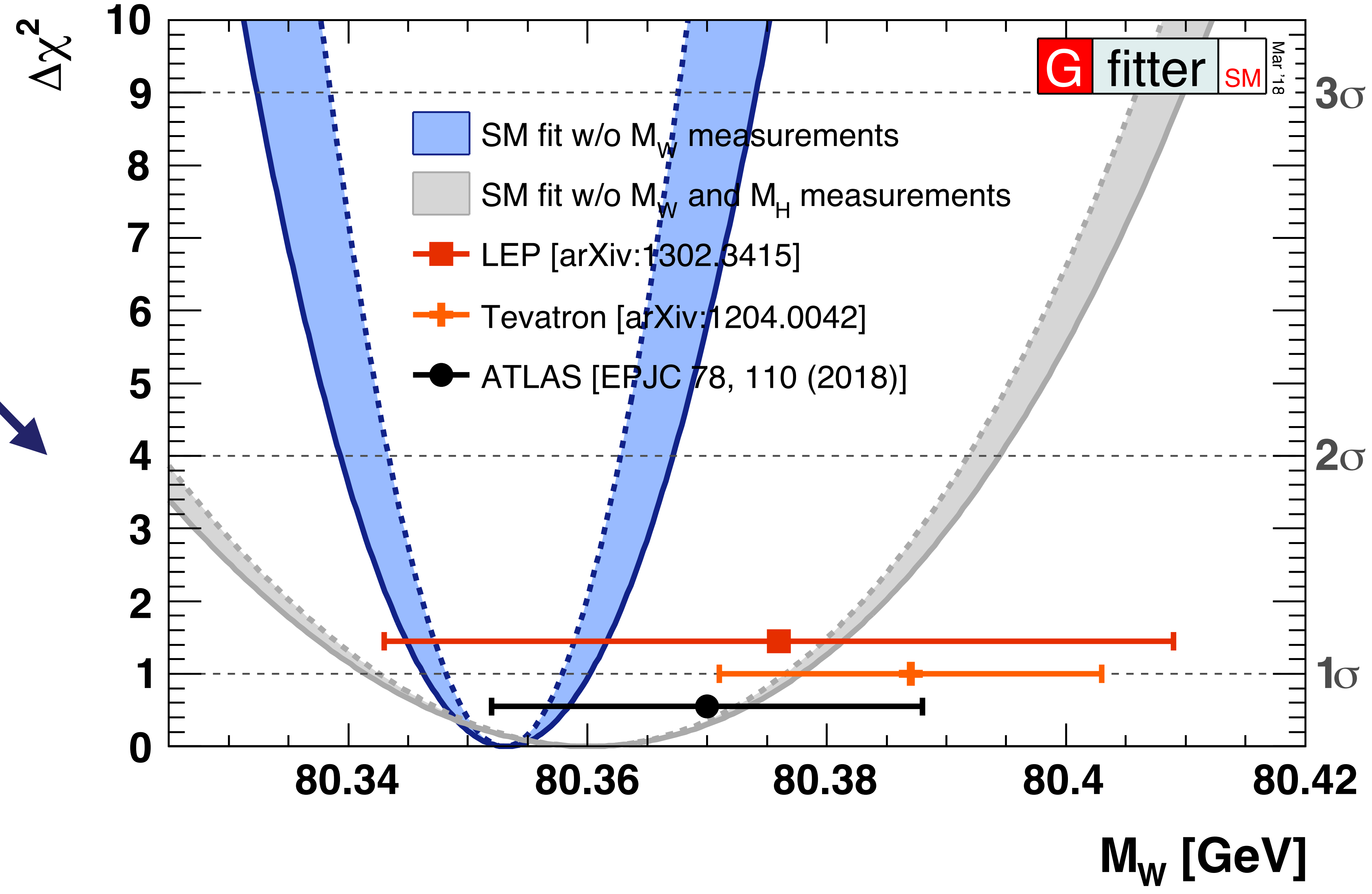


Significant one loop corrections growing like the logarithm of m_H.

The m_H measurement

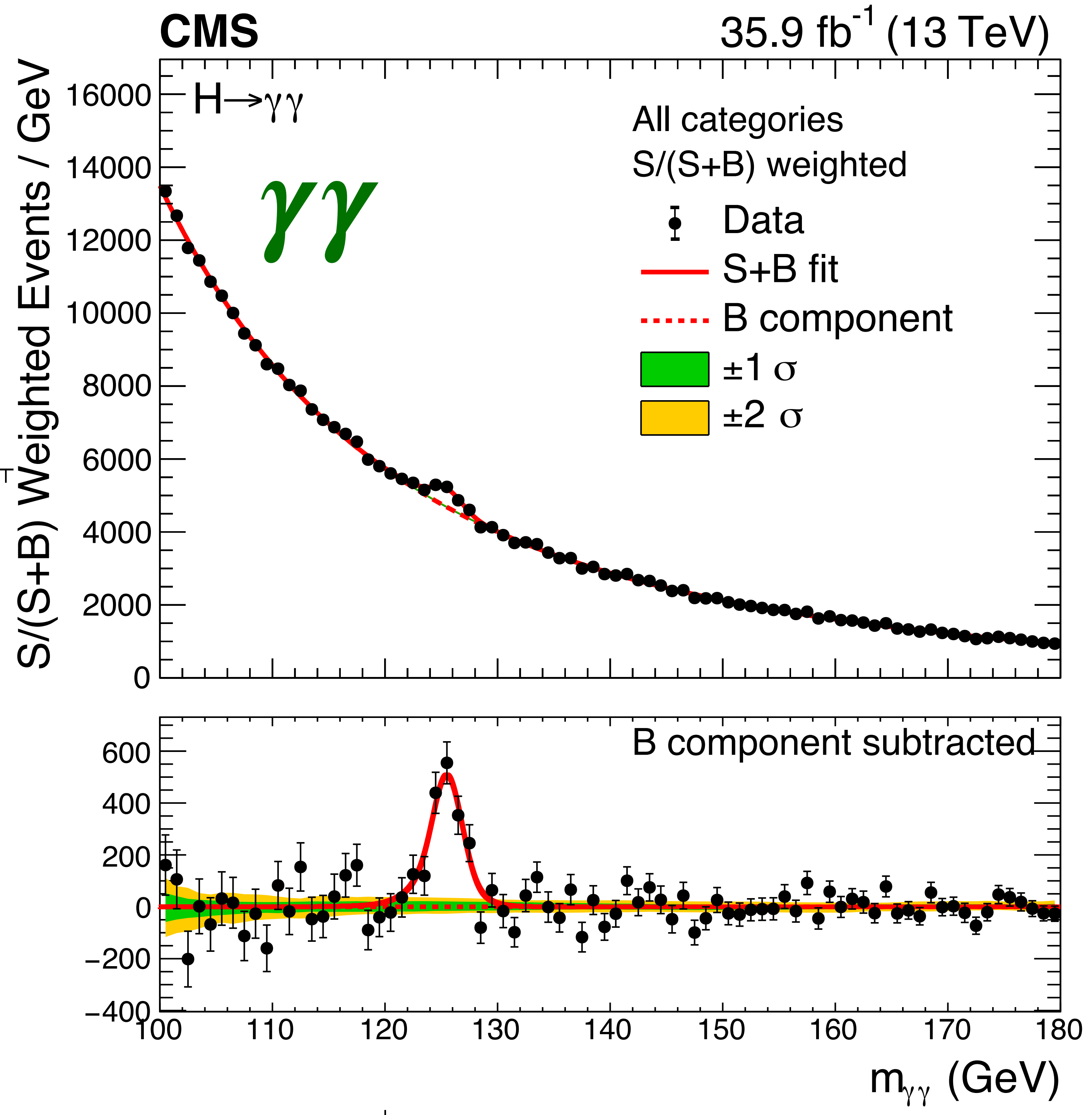
The concept oversimplified

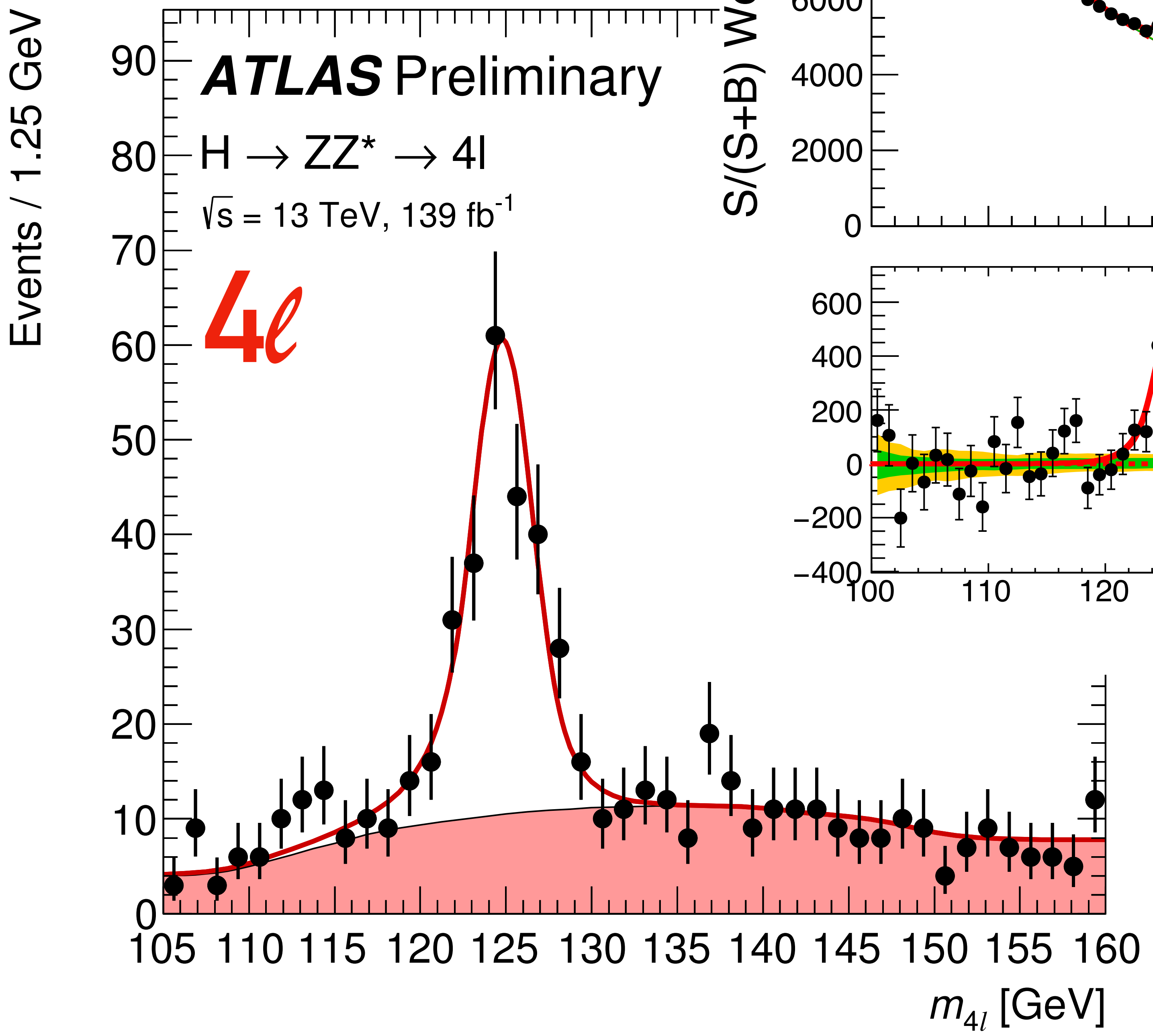
The m_H measurement

The concept oversimplified

"Mass Peaks"

using high resolution channels (4ℓ+γγ)





The m_H measurement

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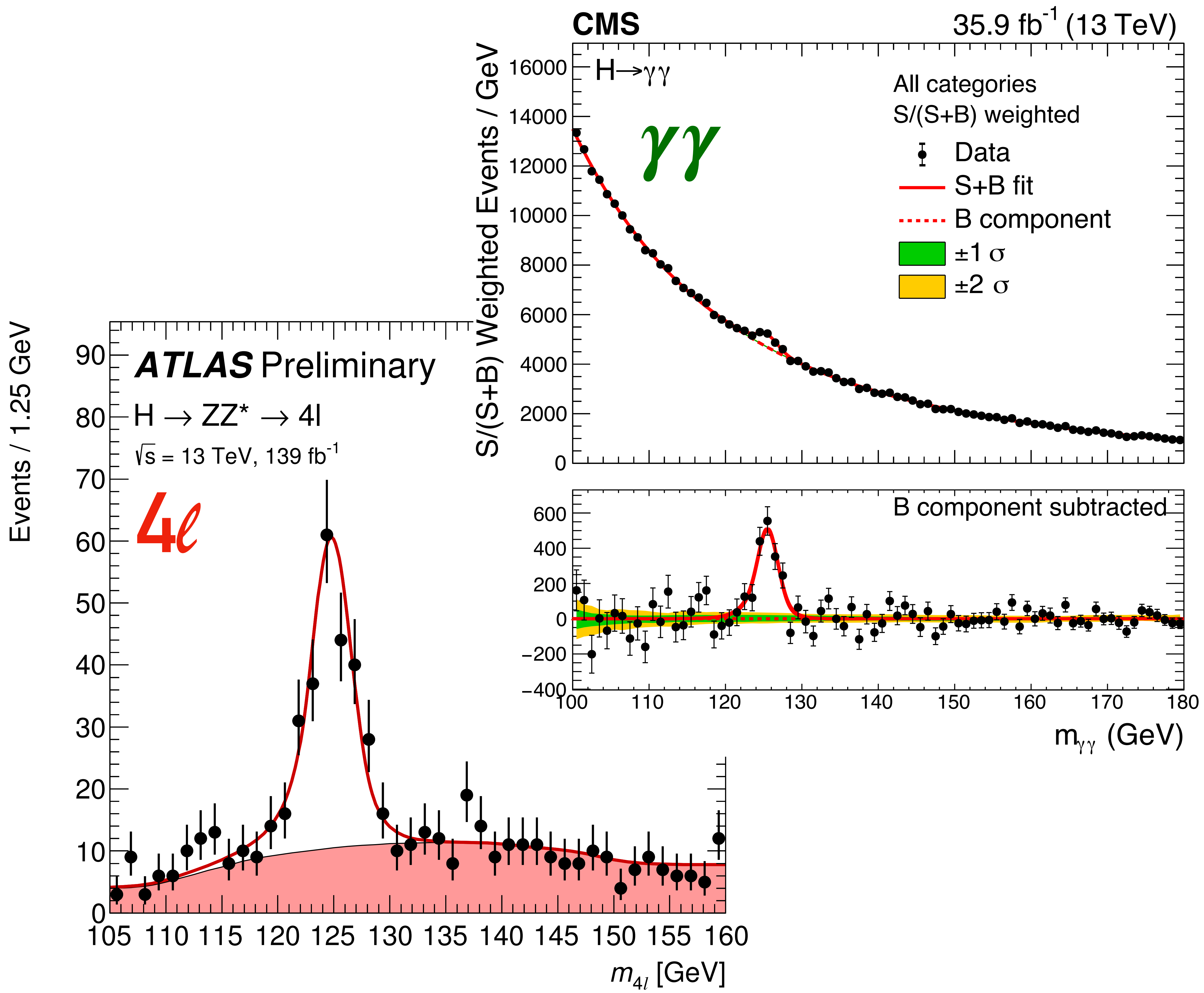
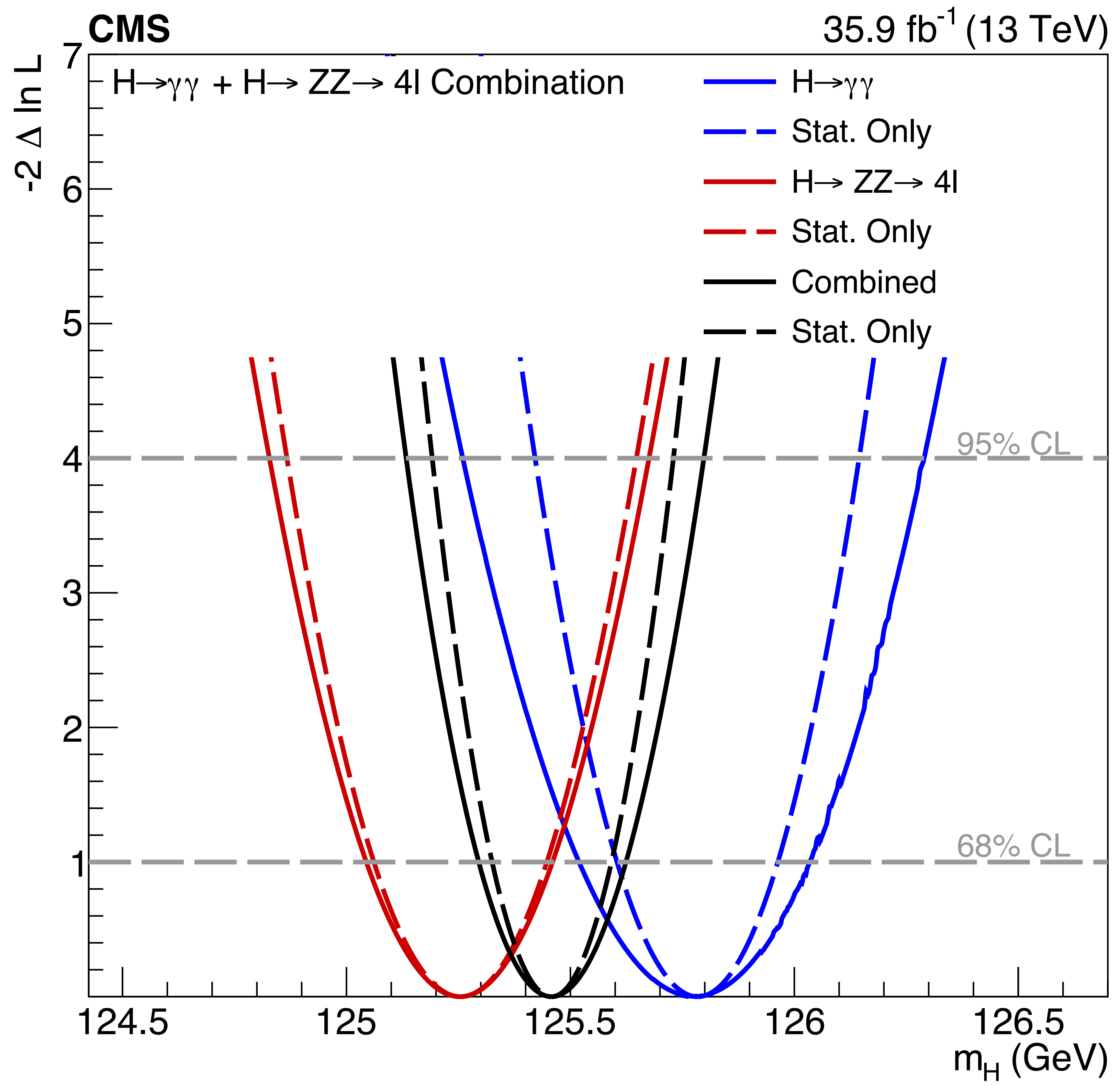
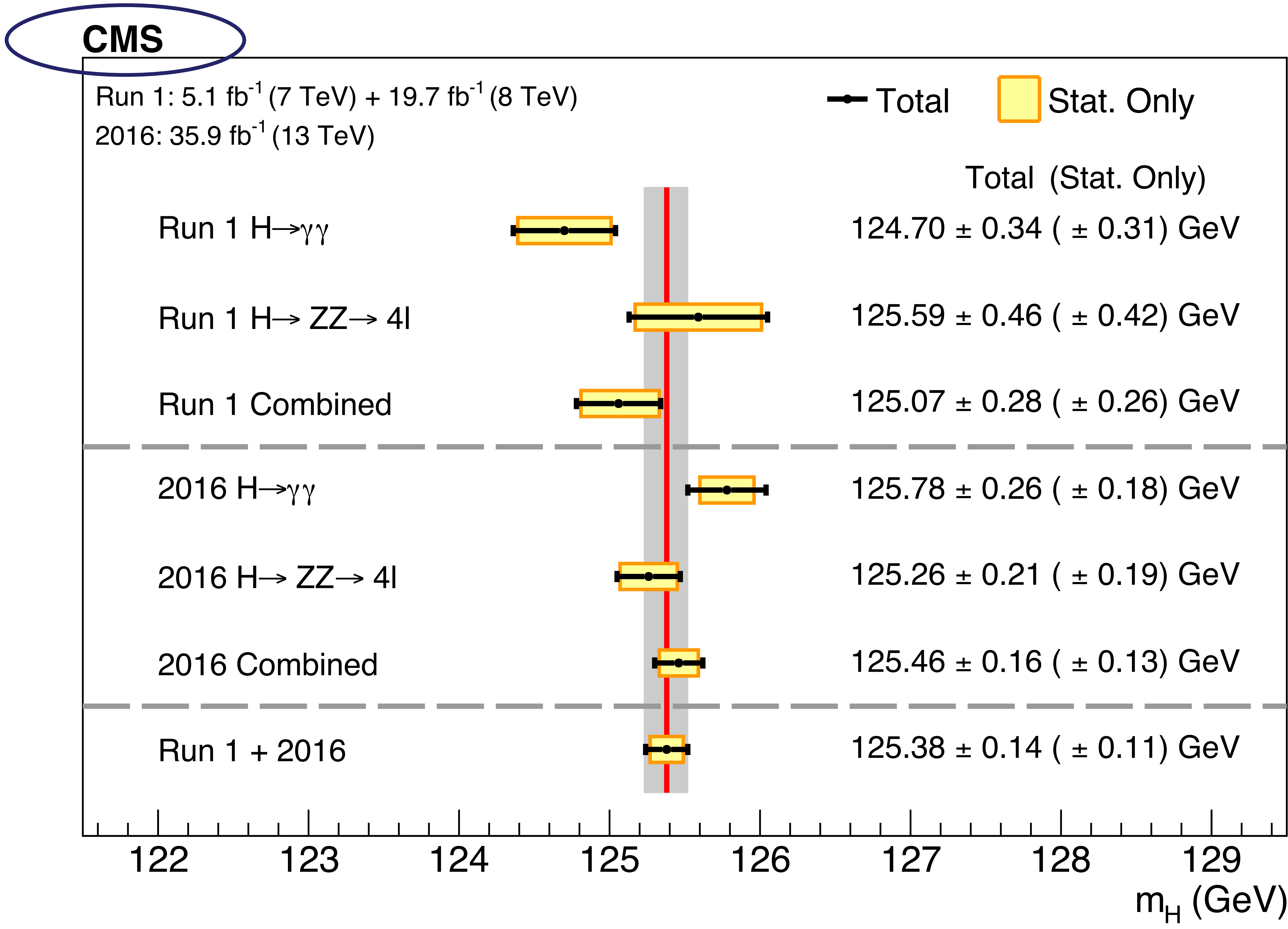


"Mass Measurements"



m_H : best precision to date

Combination of channels



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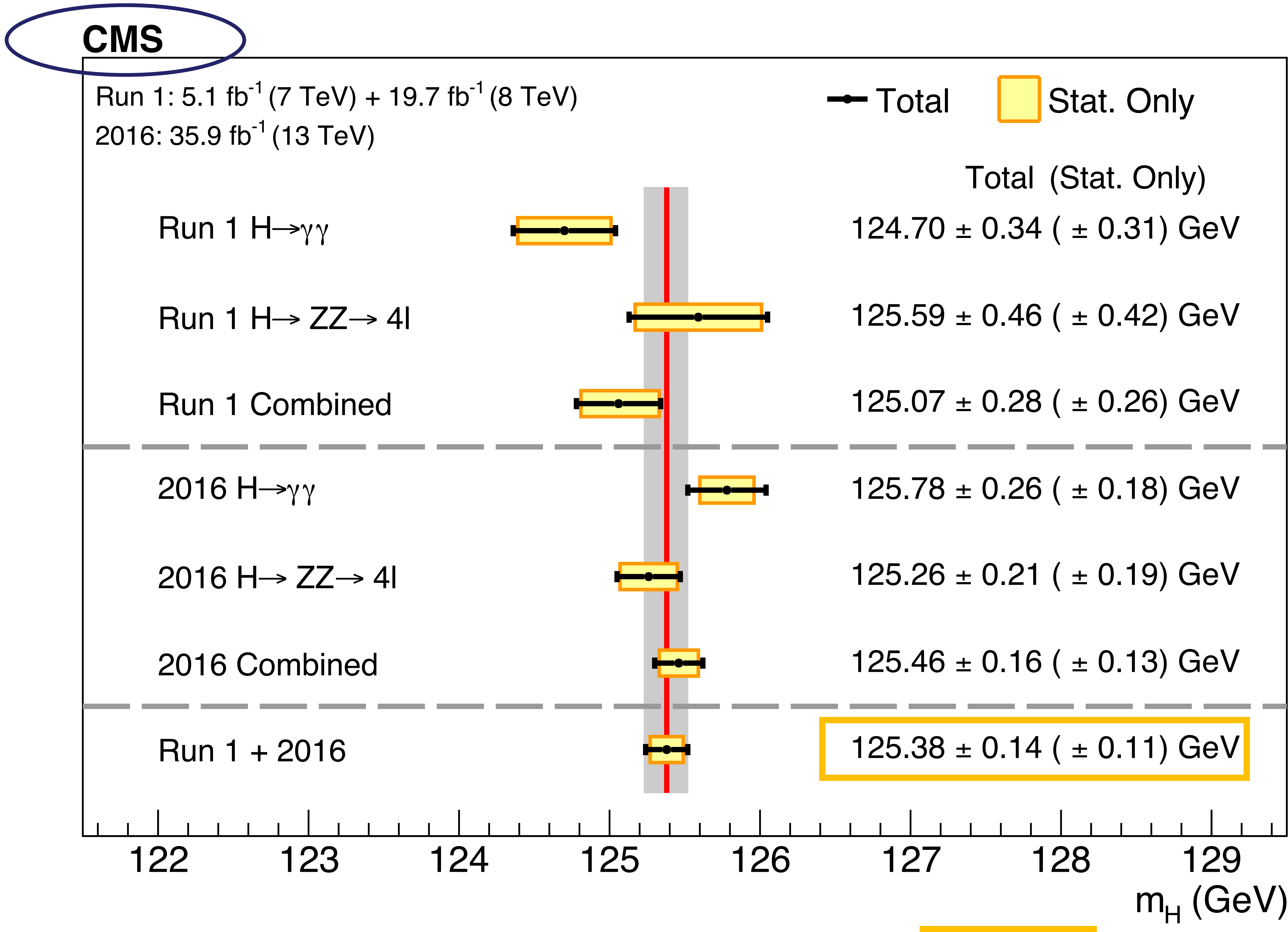


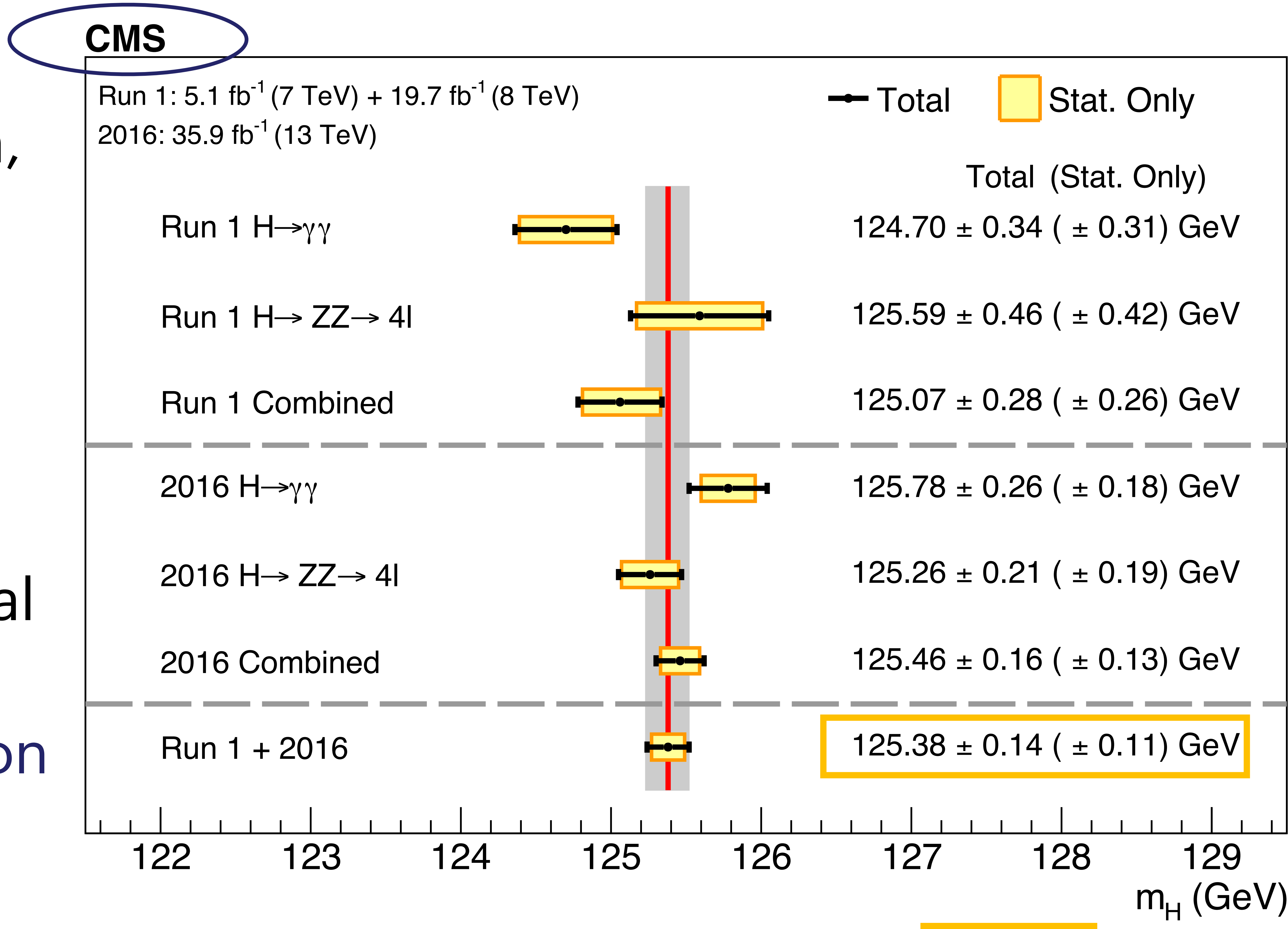
Uncertainty 140 MeV (0.11%)

m_H : best precision to date

Precision driven by statistics, but photon, electron and muon scale and resolution systematics will soon become limiting!

Some measurements still based on partial Run 2 datasets: more improvements to come, and ATLAS+CMS mass combination

Combination of channels



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Projections on m_H

hopes & wishes — High Luminosity LHC

at the High-Luminosity LHC with the CMS detector

Expected m_H measurement uncertainty, given in MeV, in the two different scenarios: *Optimistic* and *Pessimistic*

$m_{4\ell}$ expected uncertainty (MeV)	inclusive	4μ	4e	$2e2\mu$	$2\mu 2e$
Optimistic					
Total	26	30	105	60	67
Syst impact	16	11	64	31	32
Stat only	22	28	83	51	59
Pessimistic					
Total	30	32	206	107	112
Syst impact	20	15	189	94	95
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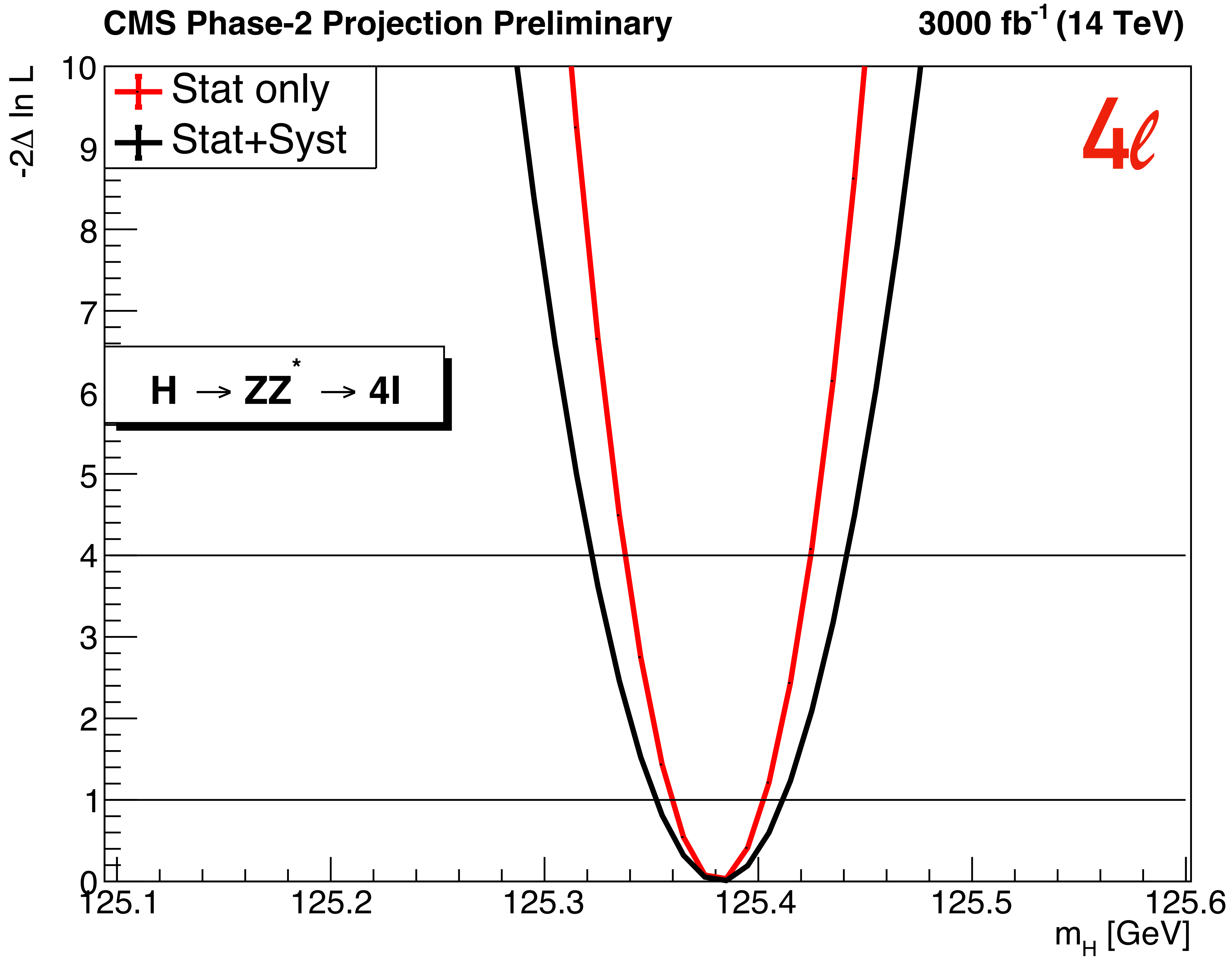
Stat>Syst but same magnitude



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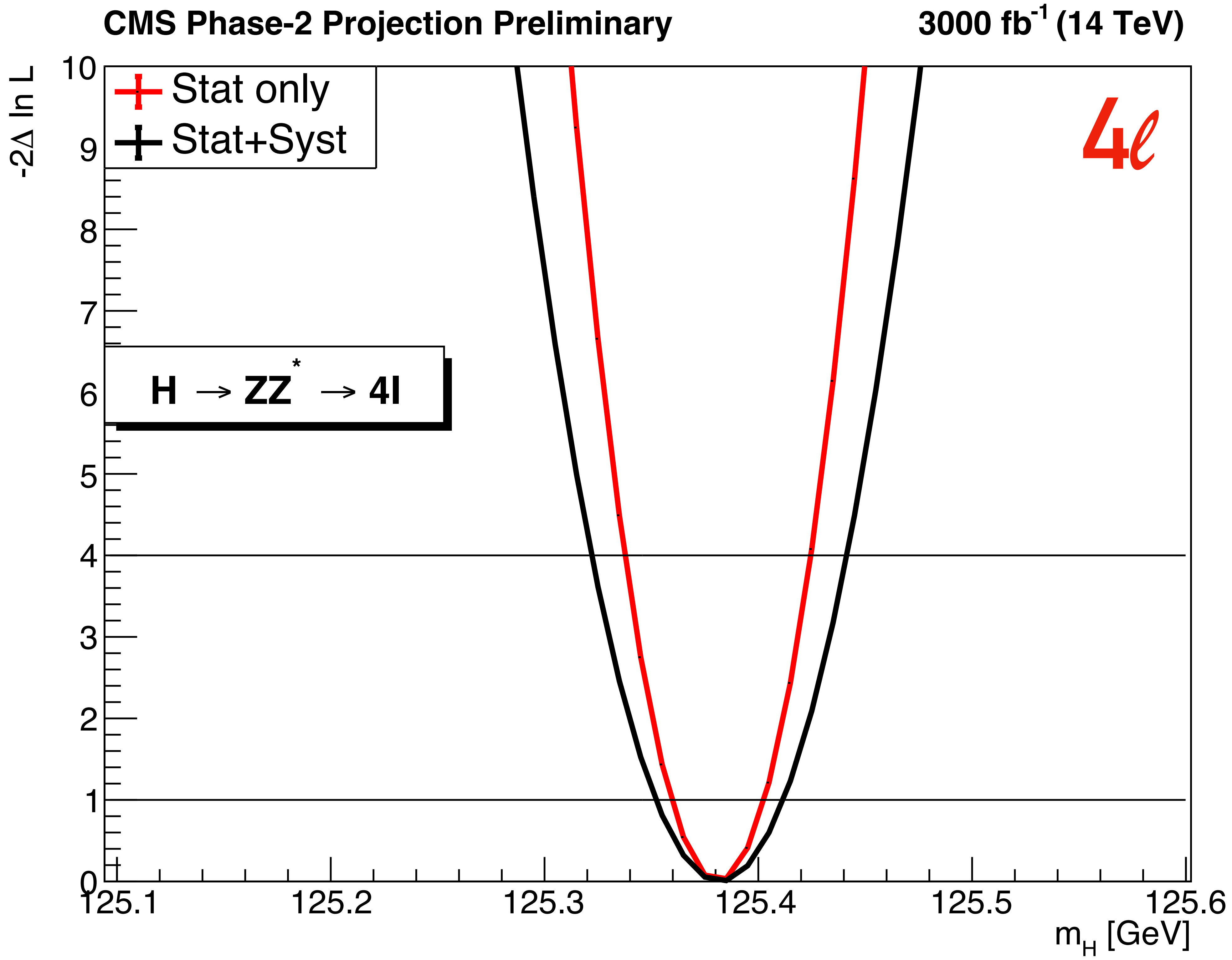
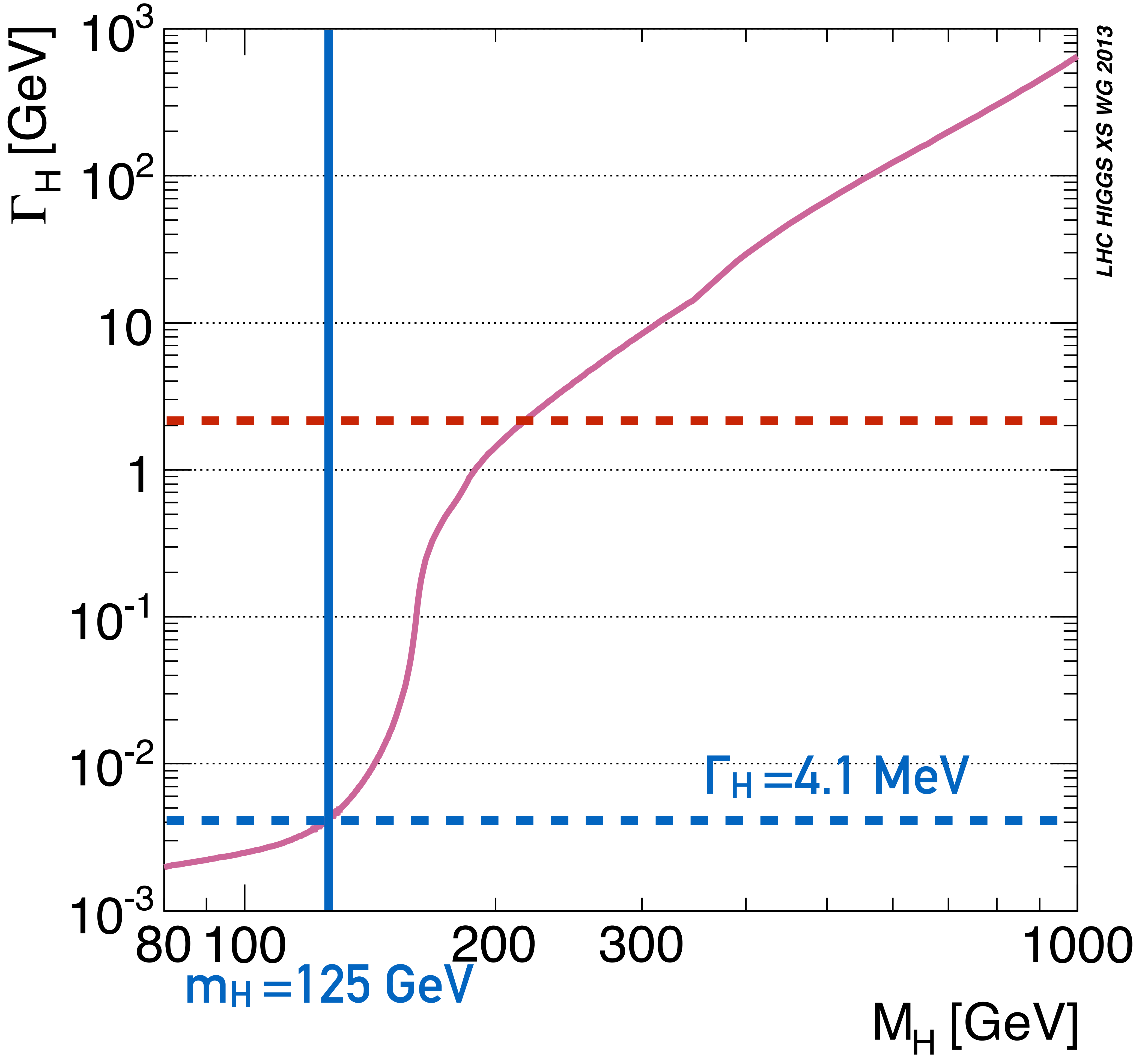


> than a factor 7 (210 MeV ⇒ 26-30 MeV) compared to the 4l current measurement

Improvements due to: a factor 10 in luminosity, the new tracker with less material, the precision and stability of the HGCal, the improvements to the barrel calorimeters, and the pileup suppression provided by the new MTD.

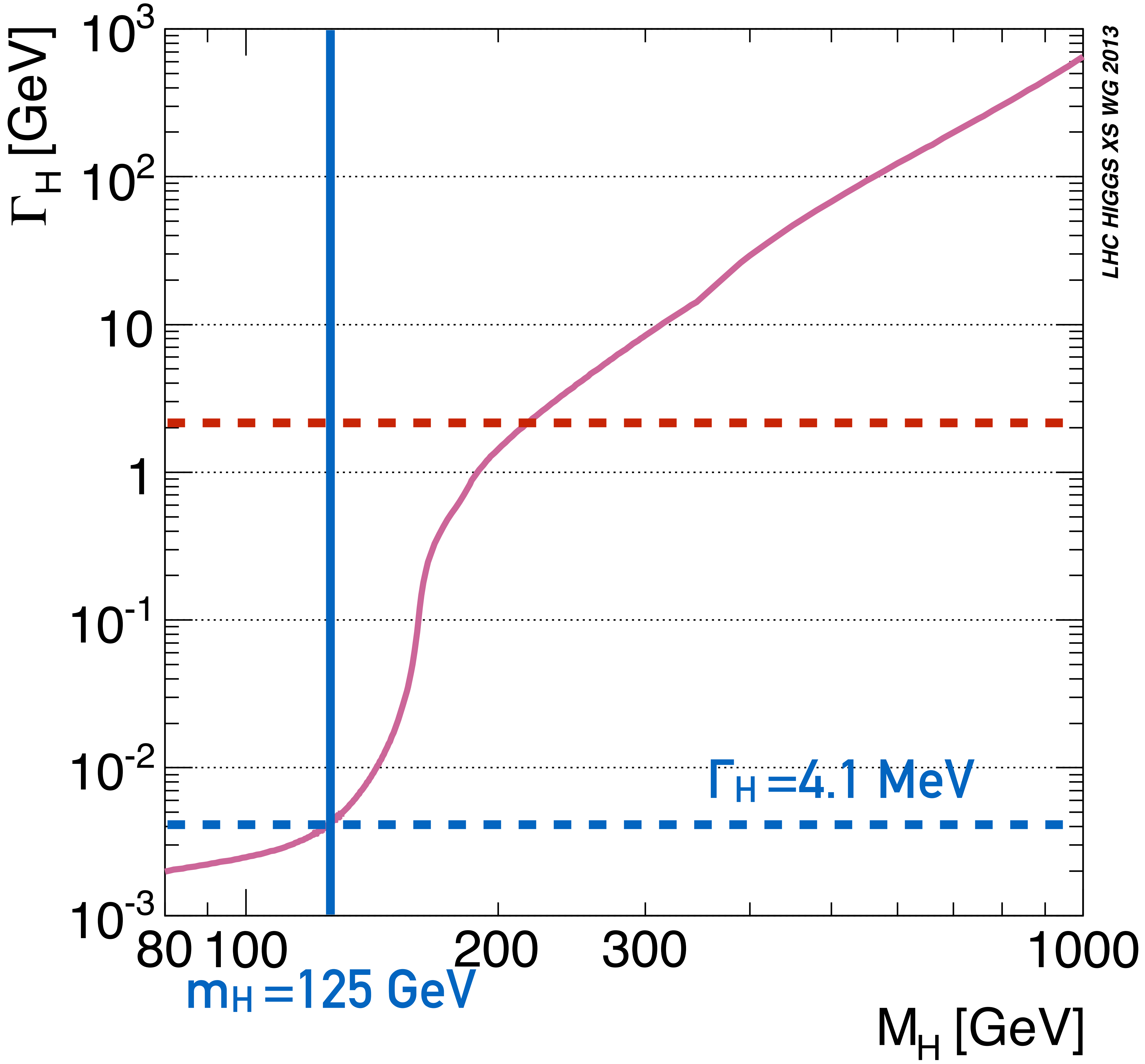
The Higgs boson width



A crucial parameter for BSM searches, in SM $c\tau_H = 48$ fm, small width $\Gamma_H = 4.1$ MeV

We have long experience with heavy EW bosons (W and Z). However, their width is $\Gamma_H \sim 2$ GeV !

The Higgs boson width



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We have long experience with heavy EW bosons (W and Z). However, their width is $\Gamma_H \sim 2$ GeV !

The direct measurements it is extremely hard! In addition, the total width is the sum of all the partial widths, on the contrary of LEP, at LHC only σxBR can be measured.

The Higgs boson width : strategies

Direct measurements

- on-shell line shape
- lifetime

Indirect measurements

- couplings
- off-shell production

The Higgs boson width : strategies

Direct measurements

on-shell line shape

lifetime

Limited by detector resolutions

Indirect measurements

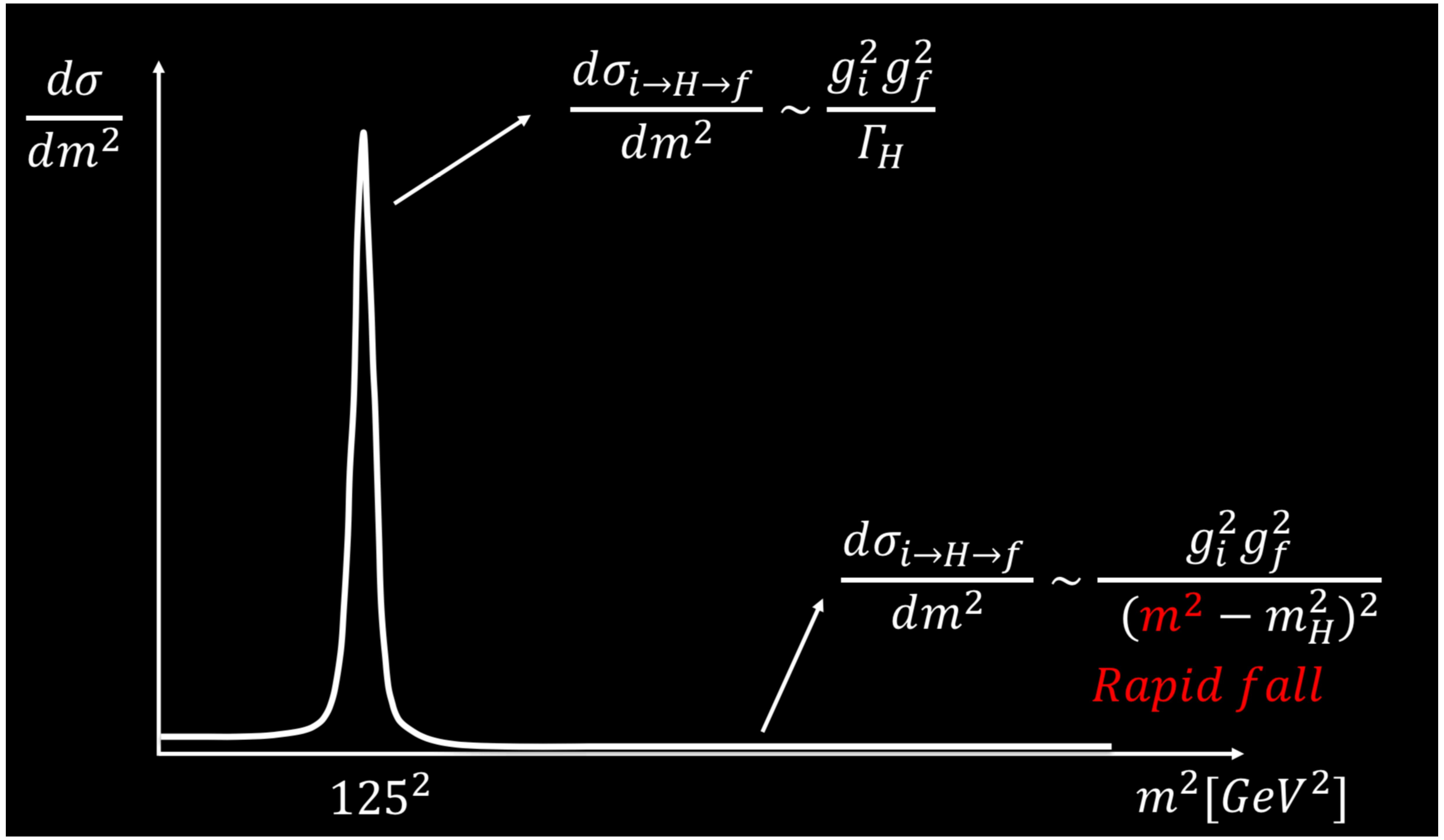
couplings

off-shell production

The way out

From off-shell production

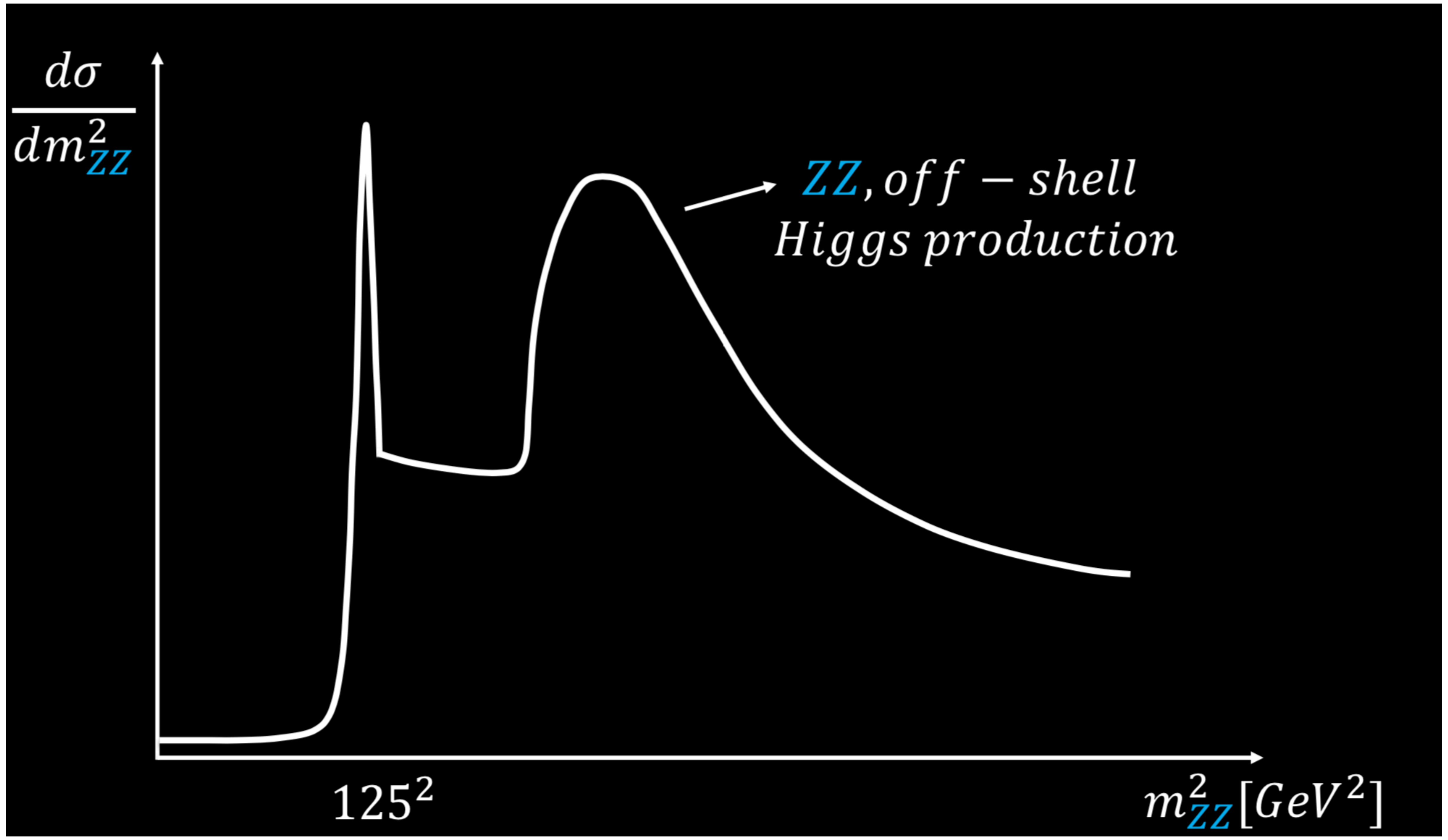
Indirect measurement



The fixed-width Breit-Wigner scheme is generally good in describe the inclusive differential ($d\sigma/dm^2$) Higgs boson production

… but …

From off-shell production



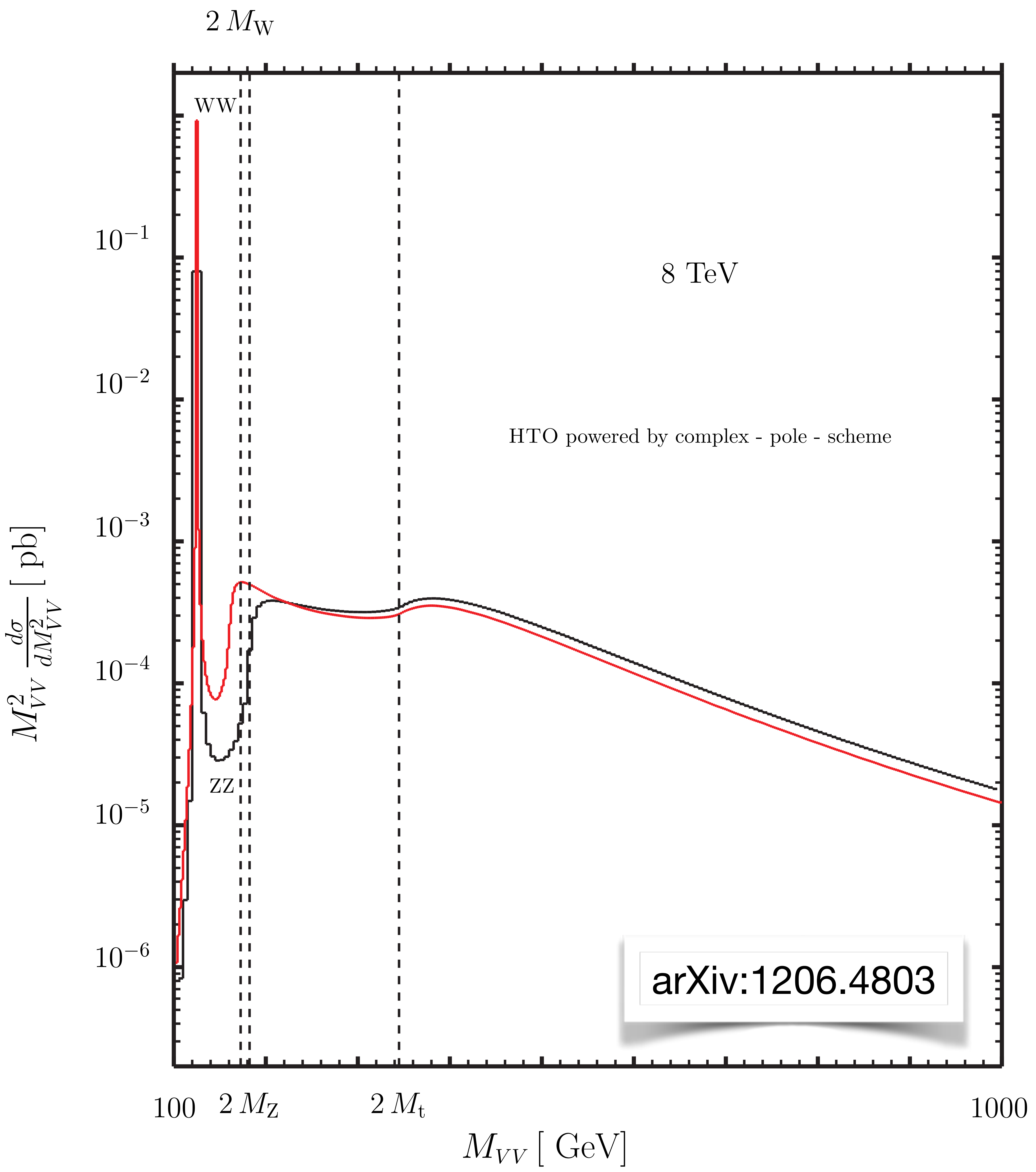
The fixed-width Breit-Wigner scheme is generally good in describe the inclusive differential ($d\sigma/dm^2$) Higgs boson production

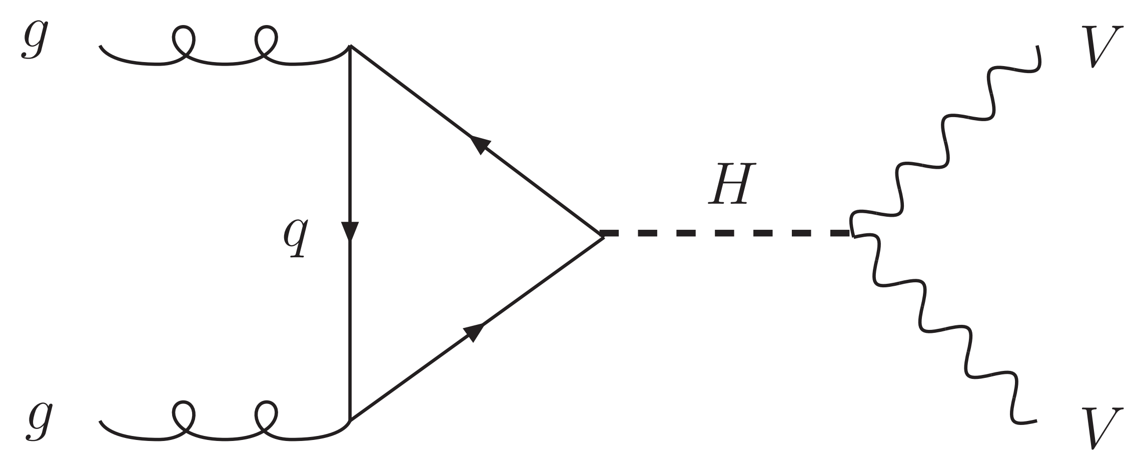
... but ...

... as soon as we restrict to VV decay channel there is a large off-shell contribution above the VV threshold (high Higgs virtuality), it means that two q^2 propagators compensate and the cross section is enhanced.

From off-shell production

Indirect measurement





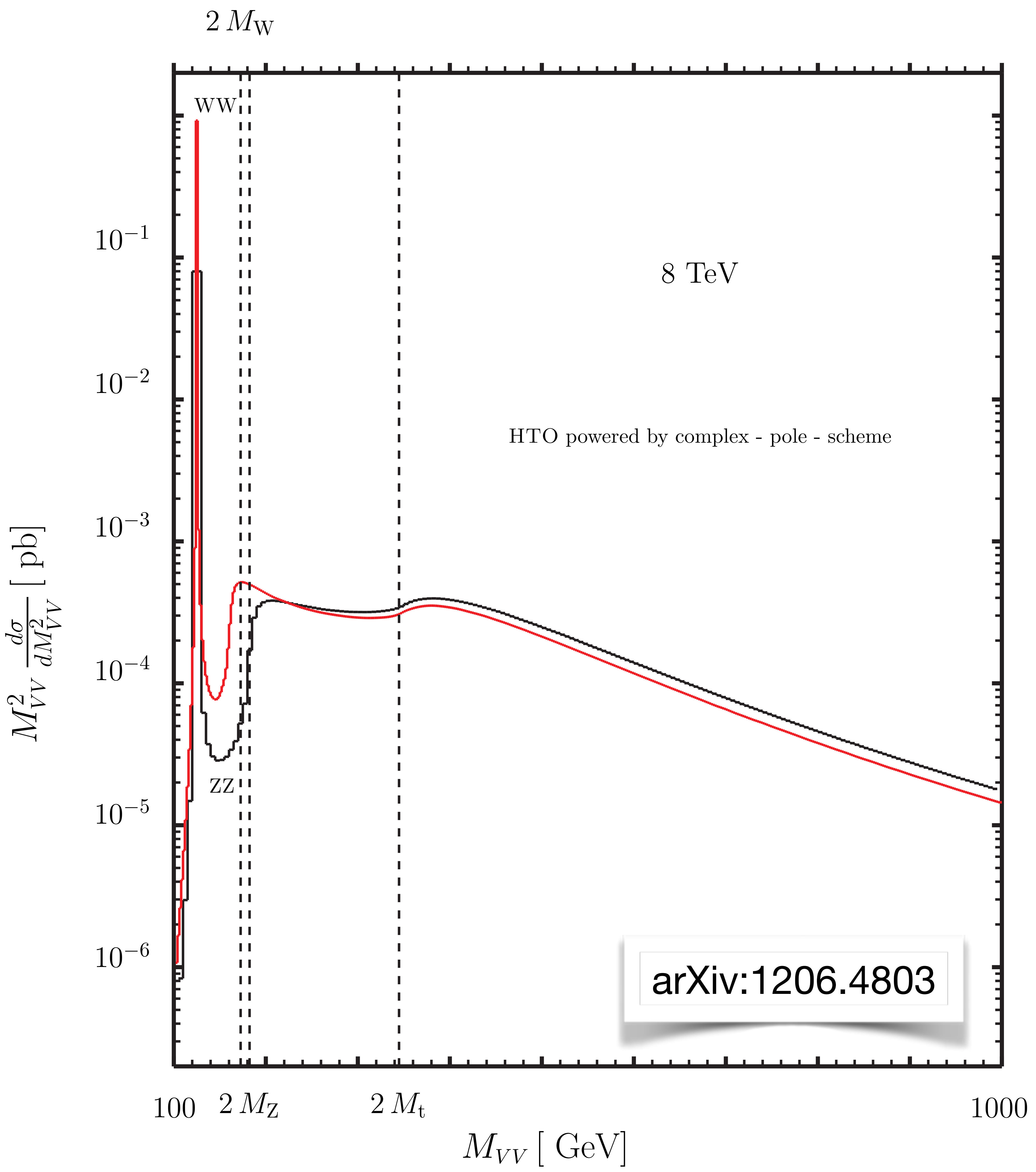
The NNLO **ZZ (black)** and **WW (red)** invariant mass distributions in gg→VV for m_H =125GeV

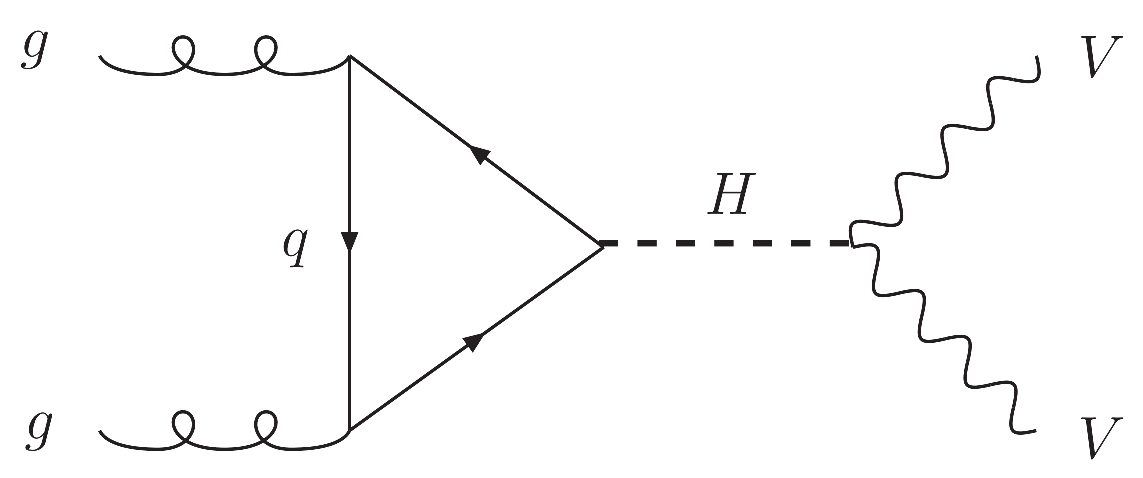
$$\sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \frac{g^2_{ggH}g^2_{HZZ}}{m_H\Gamma_H}$$

$$\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \frac{g^2_{ggH}g^2_{HZZ}}{(2m_Z)^2}$$

From off-shell production

Indirect measurement





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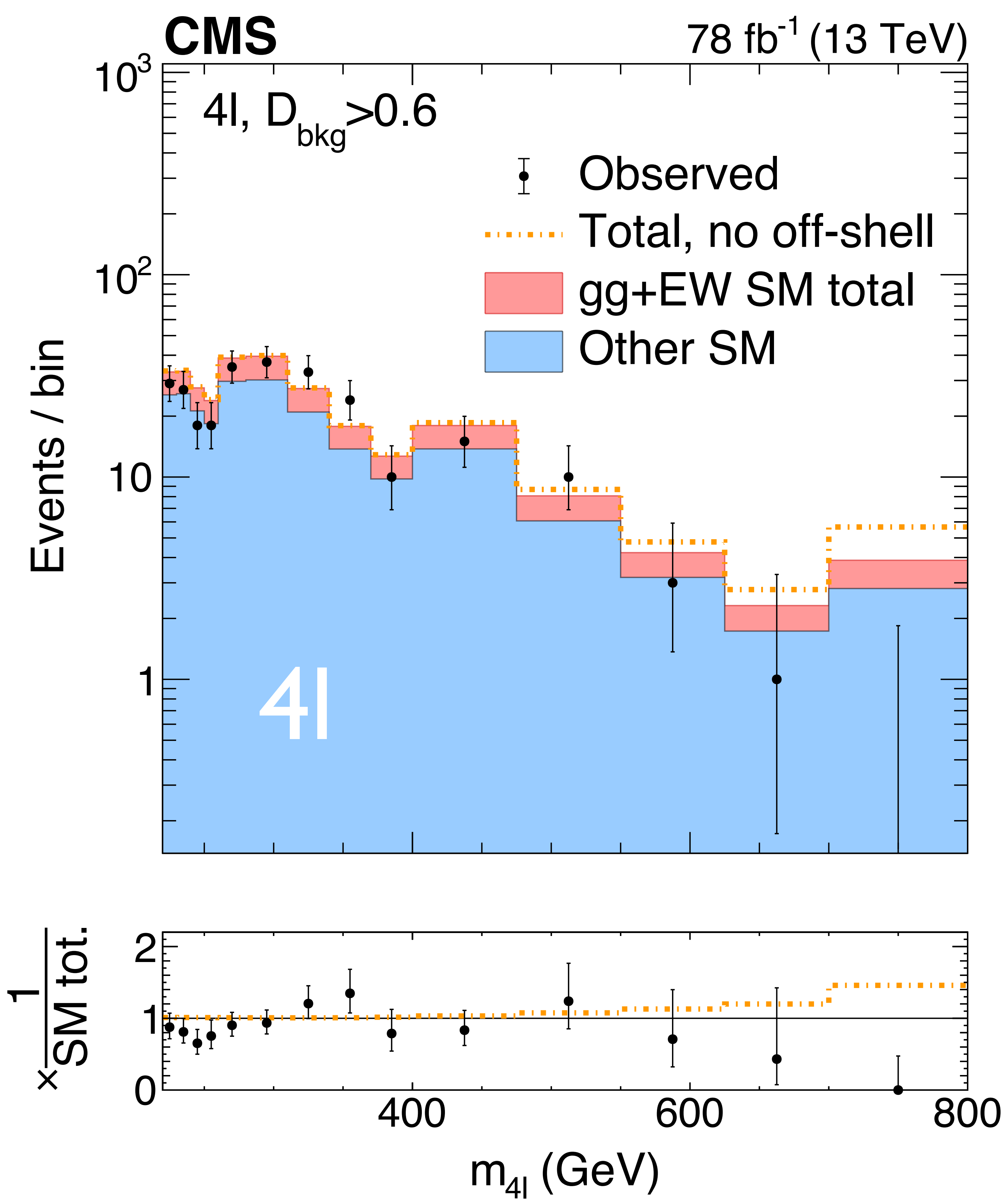
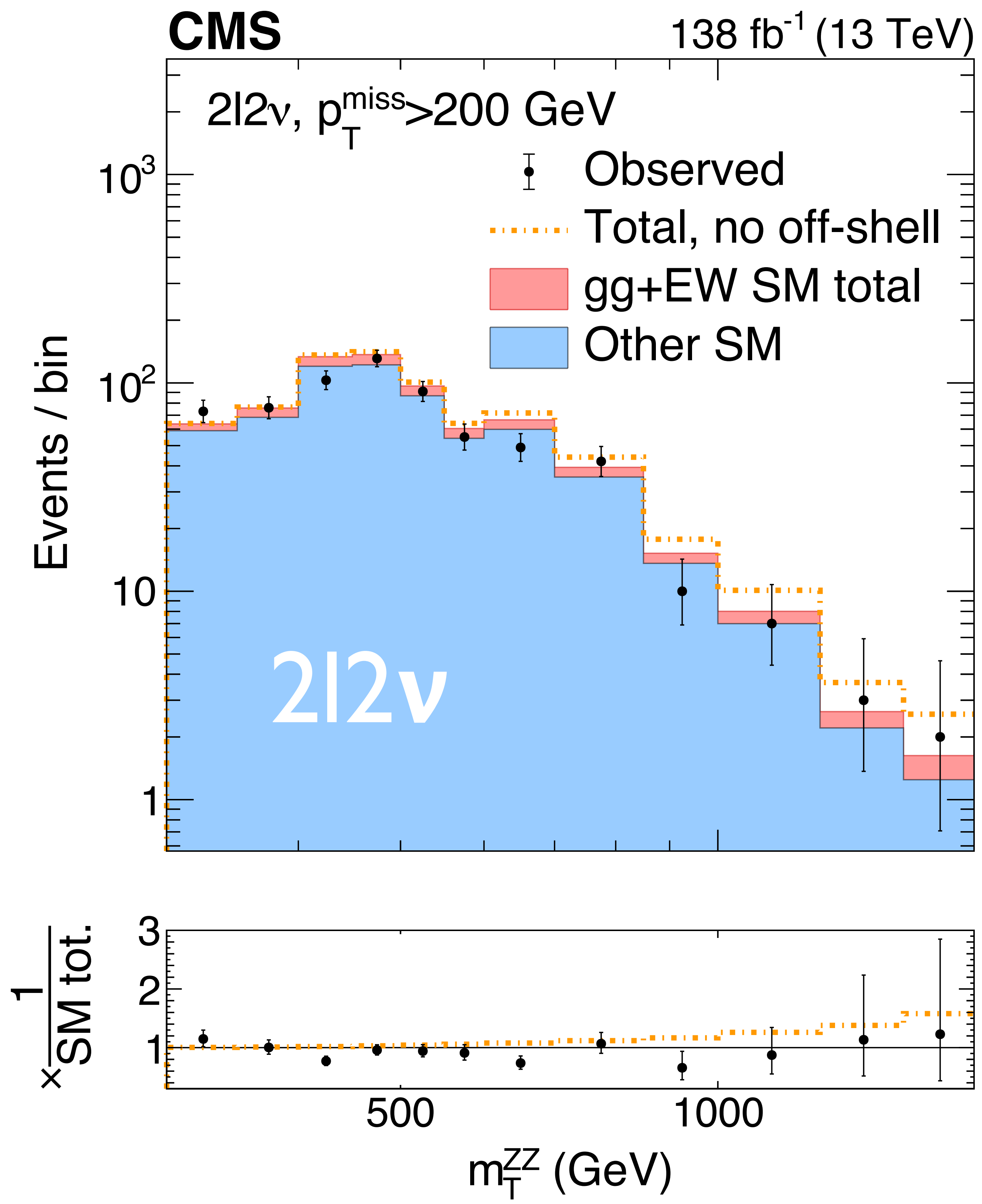
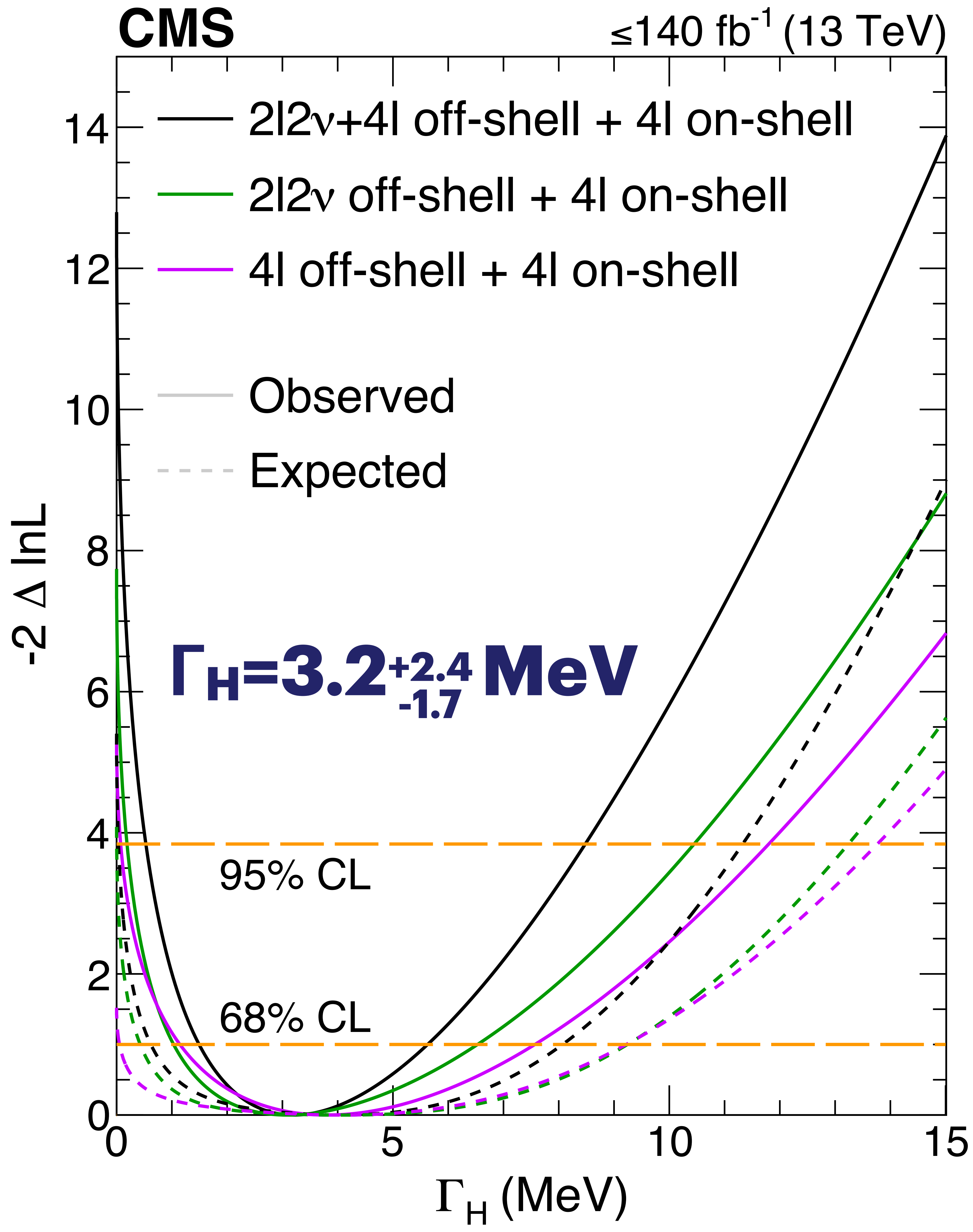
$$\frac{\sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \dfrac{g^2_{ggH} g^2_{HZZ}}{m_H \Gamma_H}}{\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \dfrac{g^2_{ggH} g^2_{HZZ}}{(2m_Z)^2}}$$

Idea: make the ratio between the two cross sections and measure Γ_H

Measurement of the Higgs boson width







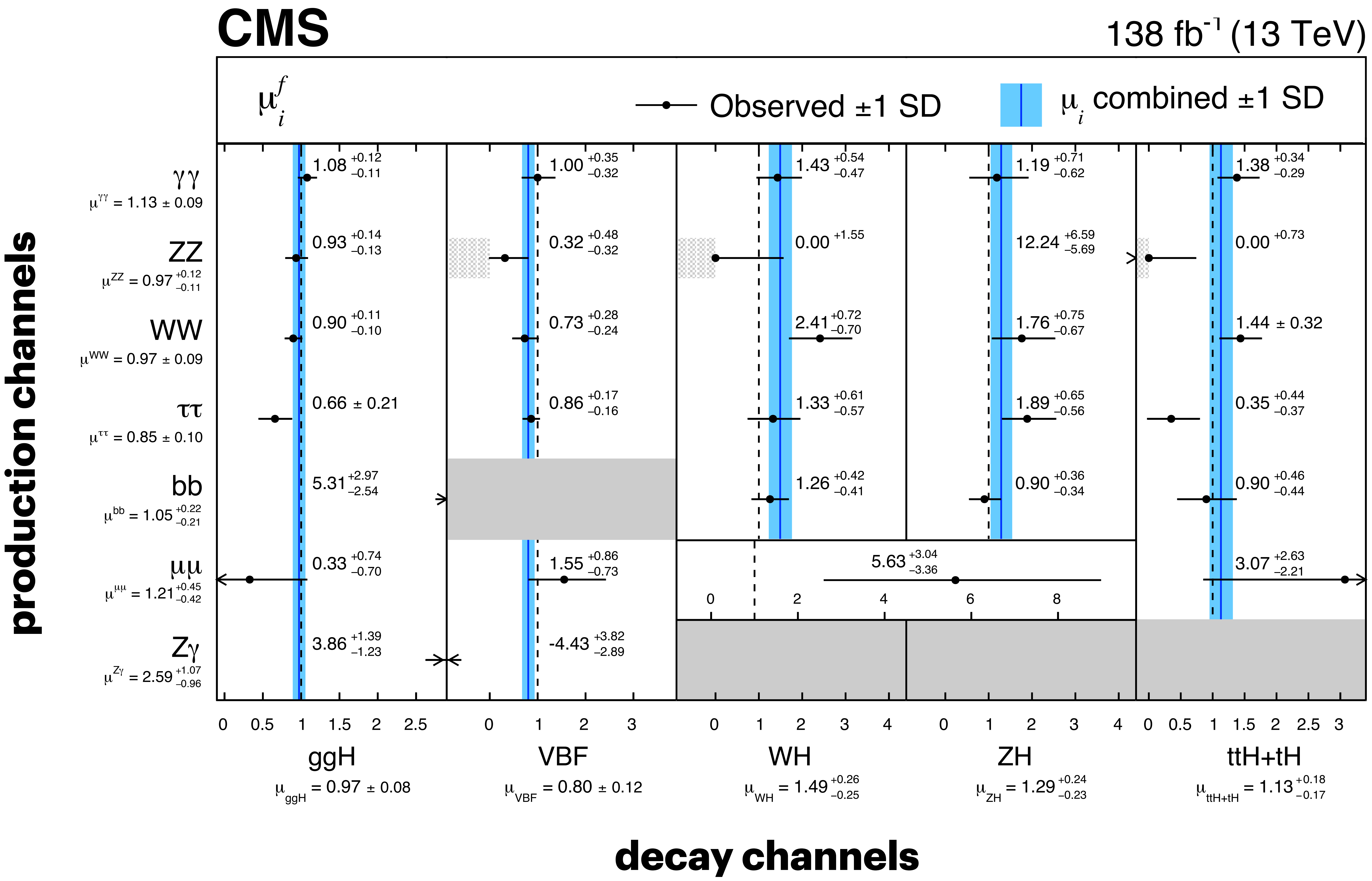
$\Gamma_H = 3.2^{+2.4}_{-1.7}$ **MeV**

No off-shell scenario ($\mu^{\text{off-shell}}=0$) excluded >99.9% CL

⇒ **3.6σ for evidence for off-shell H production**

Higgs boson couplings

After 10 years many signal strength modifiers[1] measured

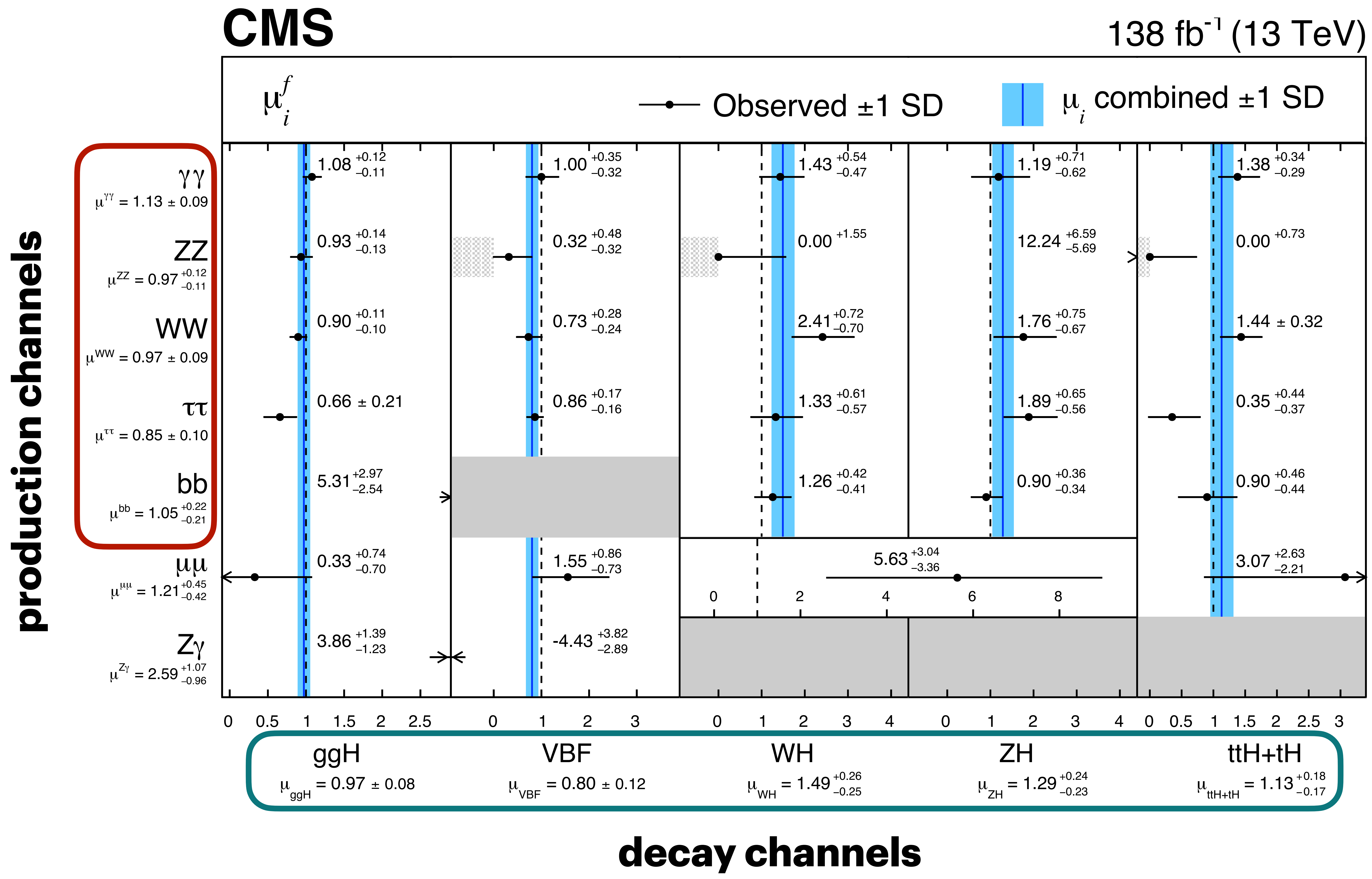


1) μ scale cross sections and branching fractions relative to the SM

Higgs boson couplings

After 10 years many signal strength modifiers[1)] measured

5 main production channels and **5 main** decay channels are observed



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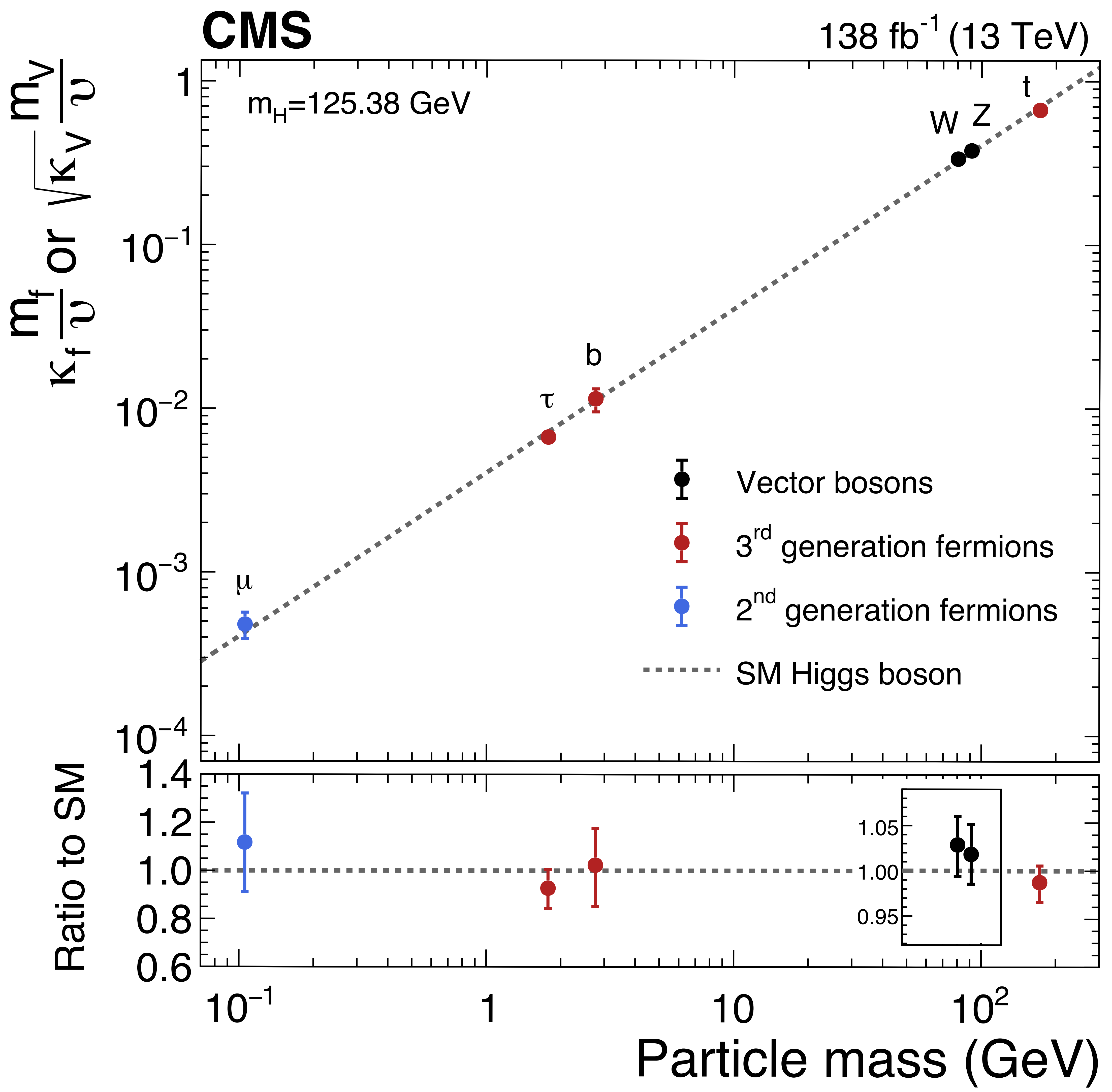
Higgs boson couplings vs. mass

Remarkable agreement with the predictions of the BEH mechanism over 3 orders of magnitude of mass!



Coupling modifier k_j : parameterisation of inclusive production and decay rates
e.g. $k_j^2 = \sigma/\sigma_{SM}$

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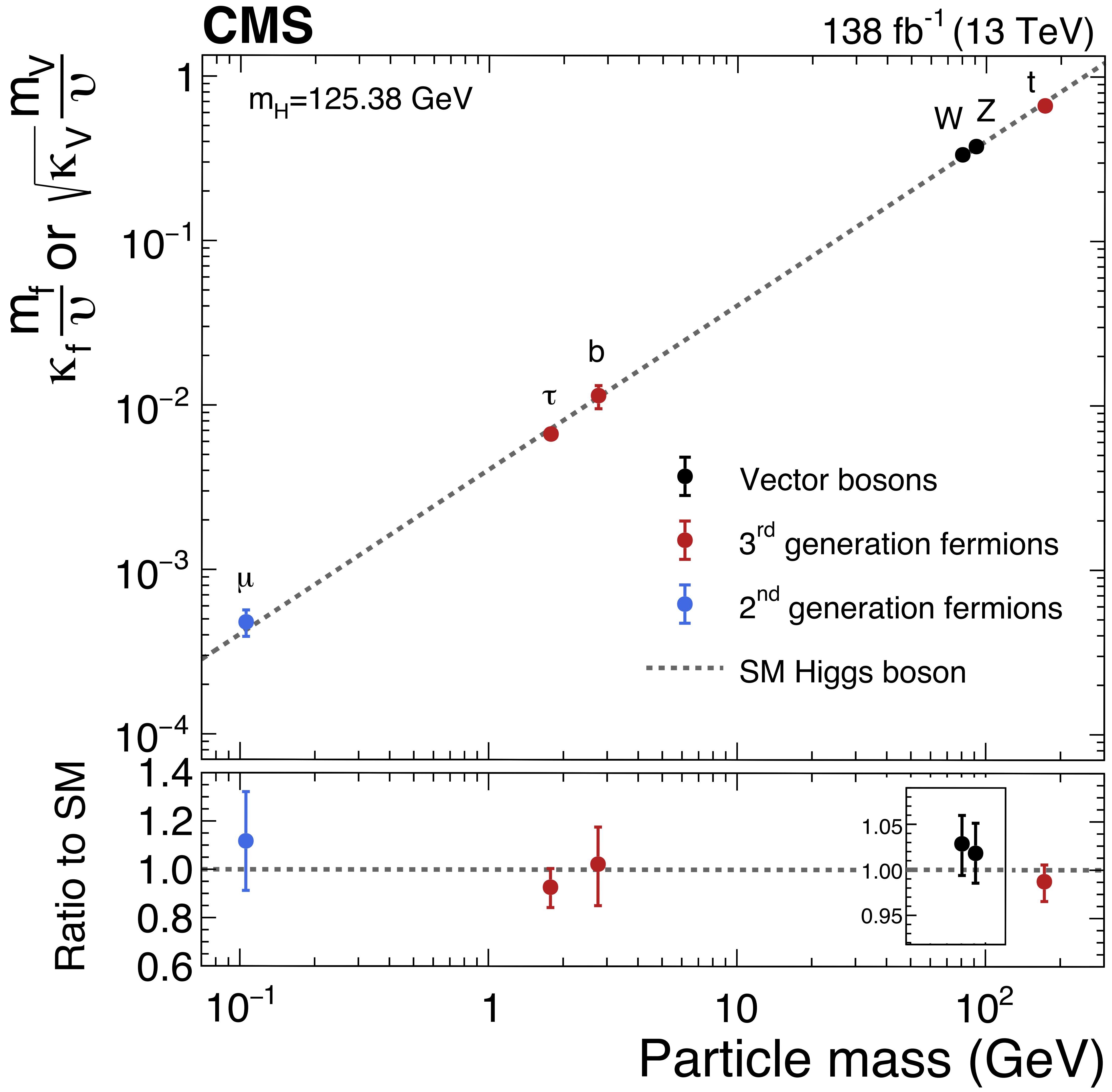
~5% precision on k_V

Observation (>5σ) of coupling with 3rd gen.

Evidence (>3σ) of coupling with 2nd gen.



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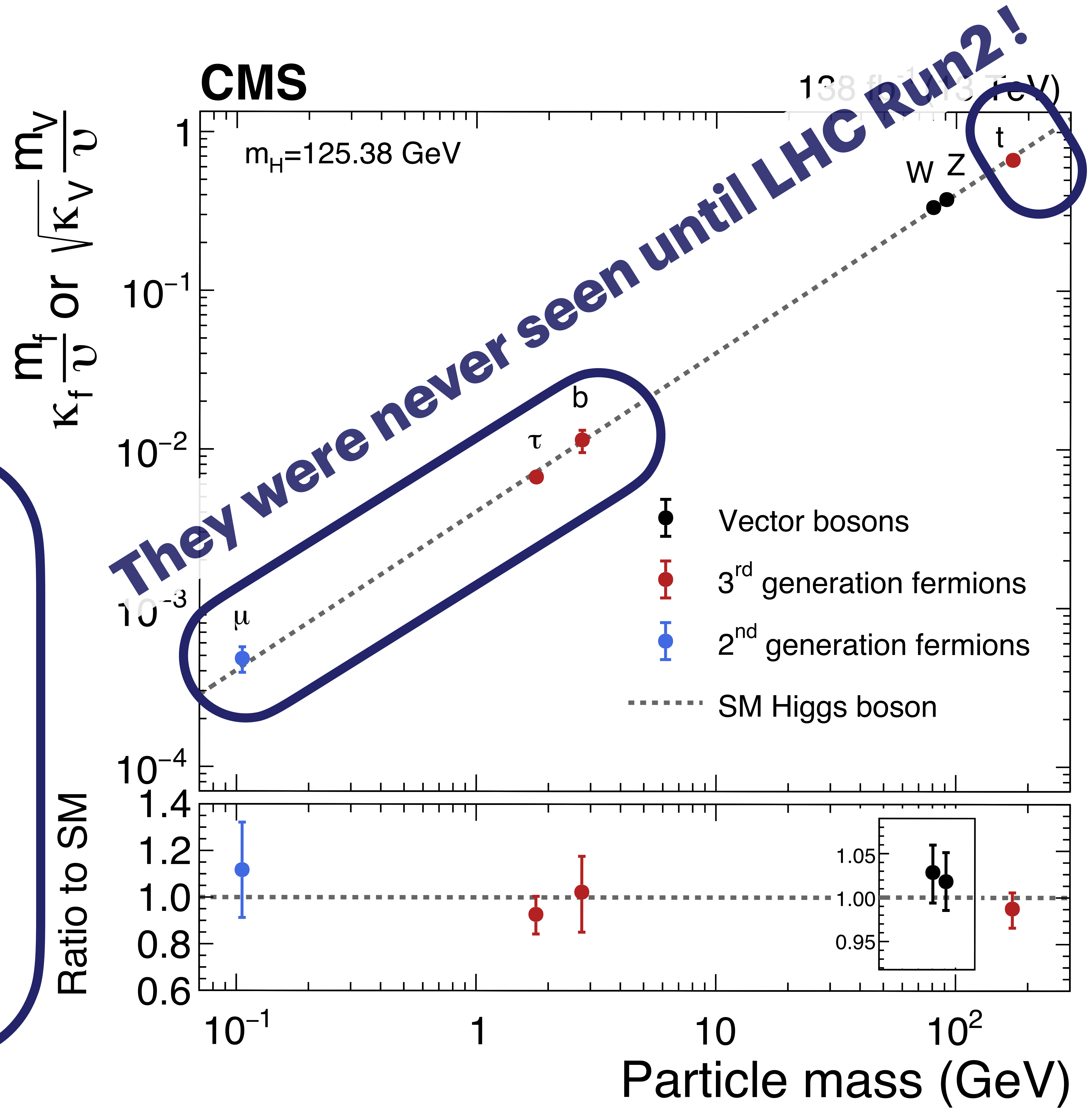
Observation of fundamental interaction (the Yukawa) is important as observation of a fundamental particle.



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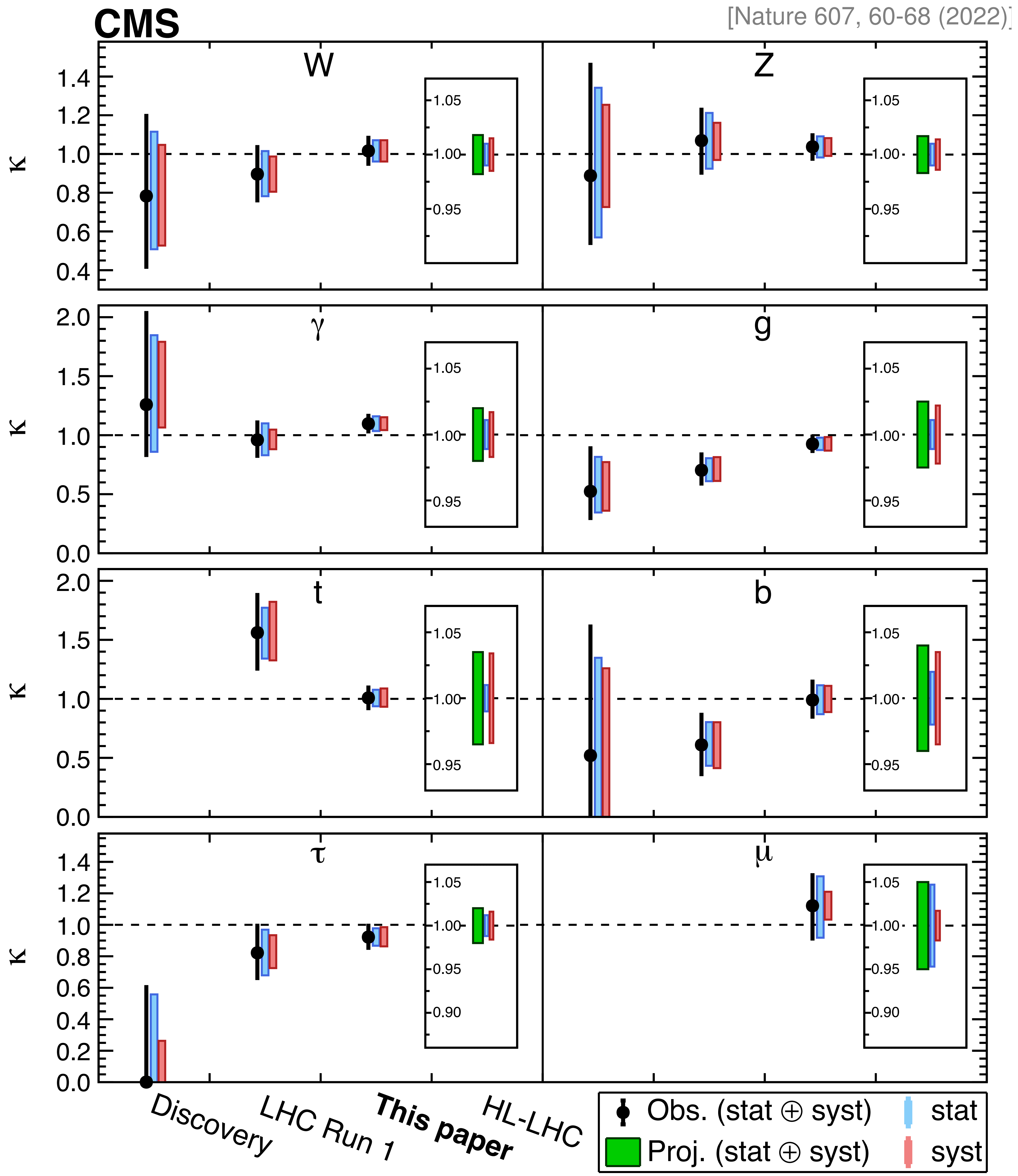
e.g. $k_j^2 = \sigma/\sigma_{SM}$

Projections of H couplings

hopes & wishes

High Luminosity LHC

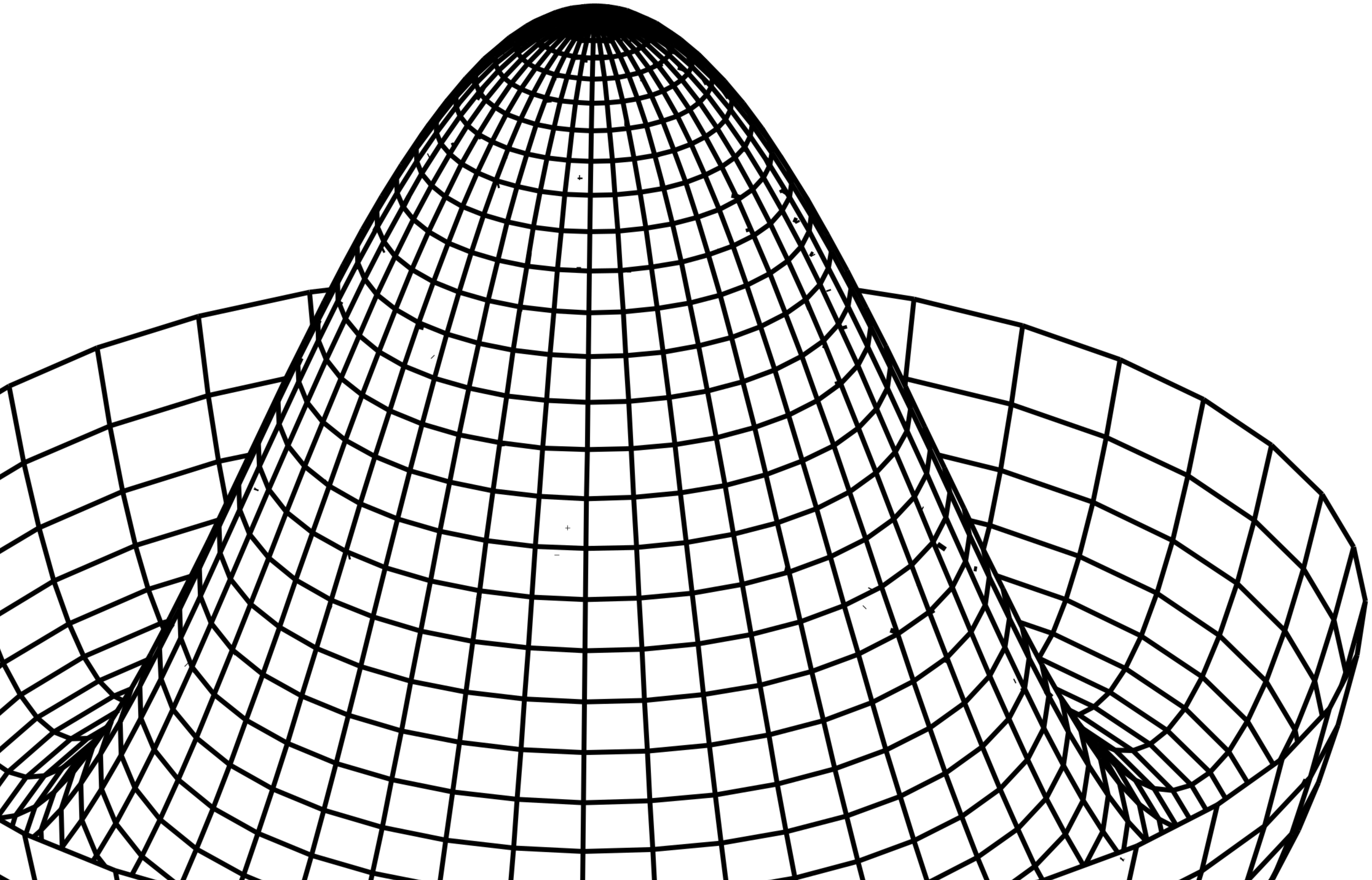


Many beyond SM scenarios predict only %-level deviations from SM !

About 20× more Higgs bosons expected from Run3 and High-Luminosity LHC

→ Harsher experimental conditions require upgrades of our detectors

H boson self-interaction



Does the Higgs boson interact with itself?

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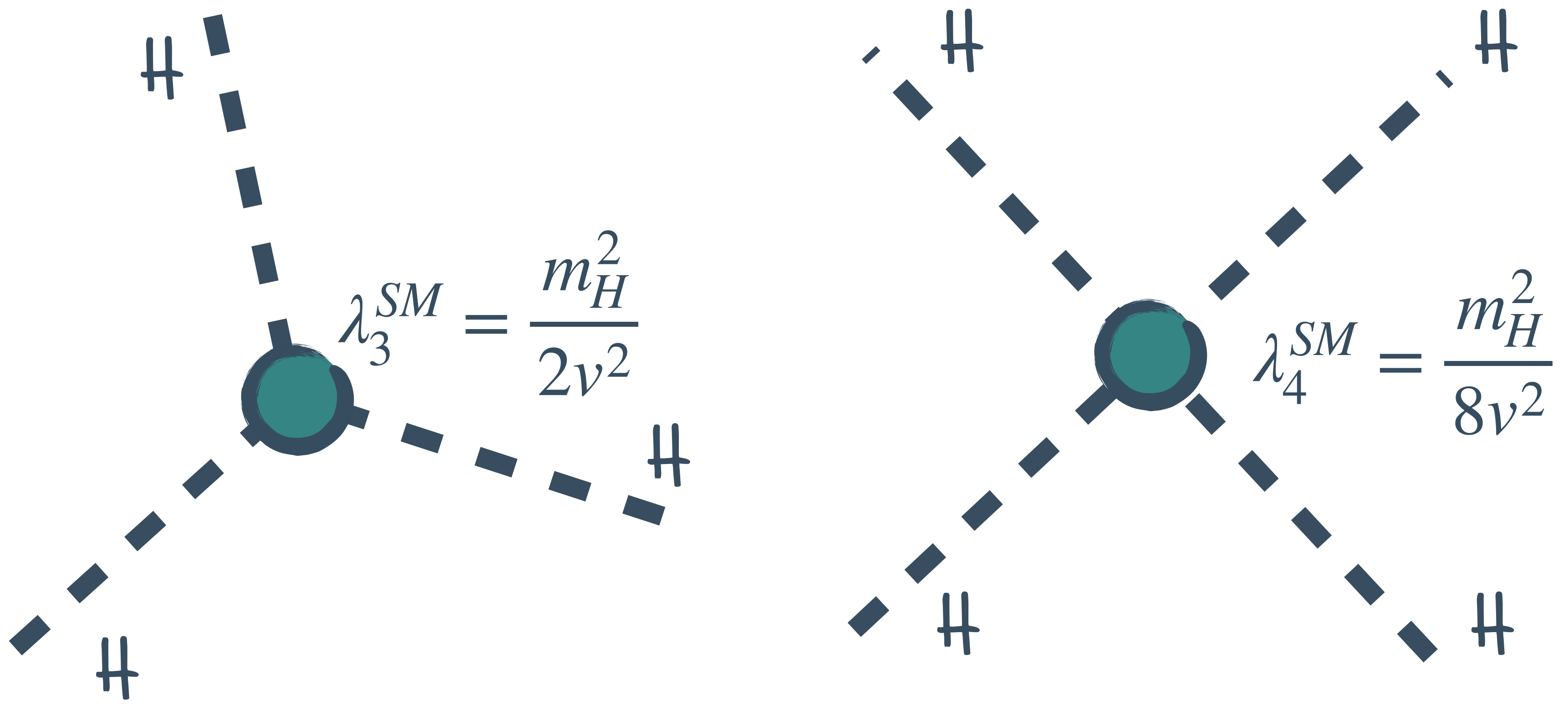
A self-interacting Higgs (as SM predicts) would be unlike anything yet seen in nature.
All other interactions change particle identity.

The Higgs boson **cubic** (λ_3^{SM}) and **quartic** (λ_4^{SM}) couplings are the keys to check the EWSB. The Higgs boson potential is :

$$\mathscr{L} \subset -\frac{m_h^2}{2}h^2 - \lambda_3^{SM} v h^3 - \lambda_4^{SM} h^4$$



Direct test of cubic coupling only **with HH** production

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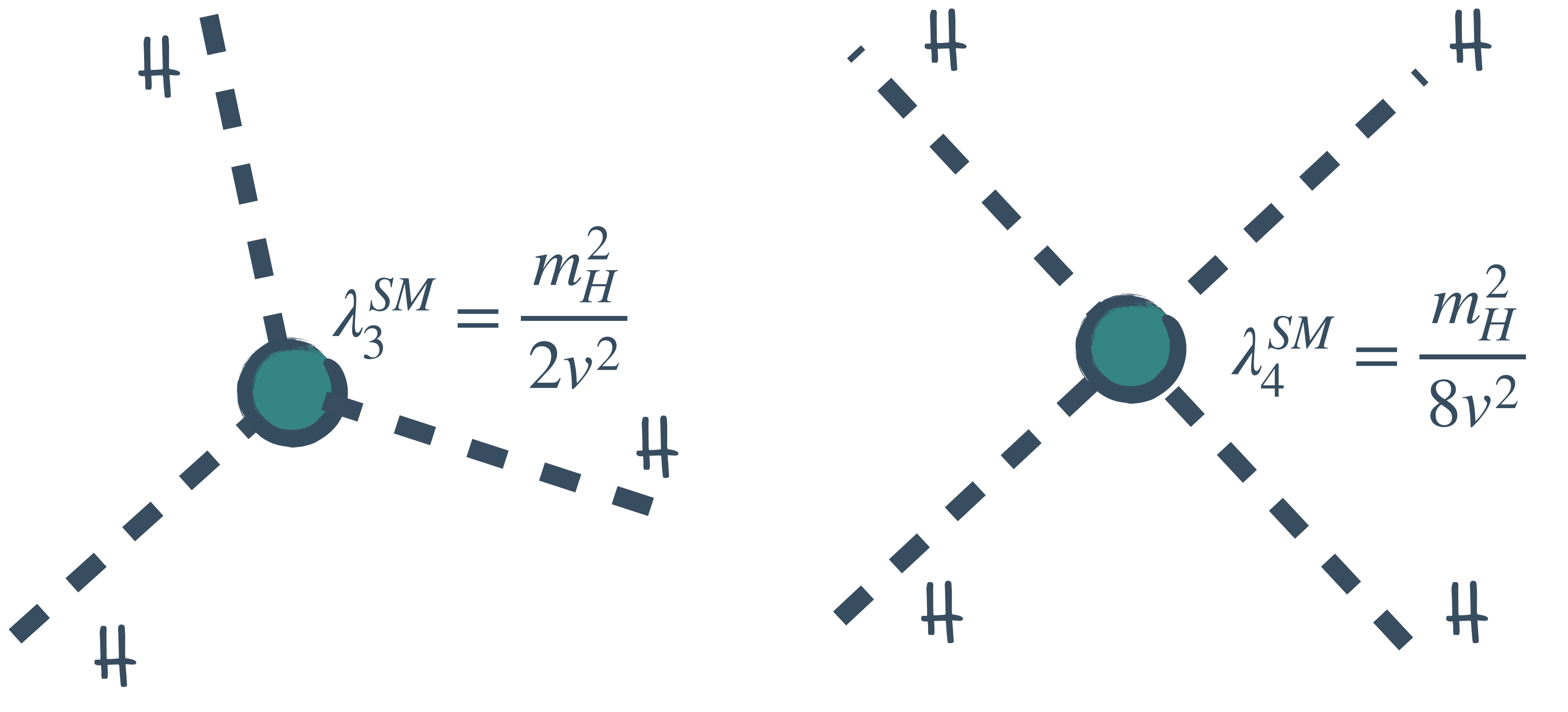
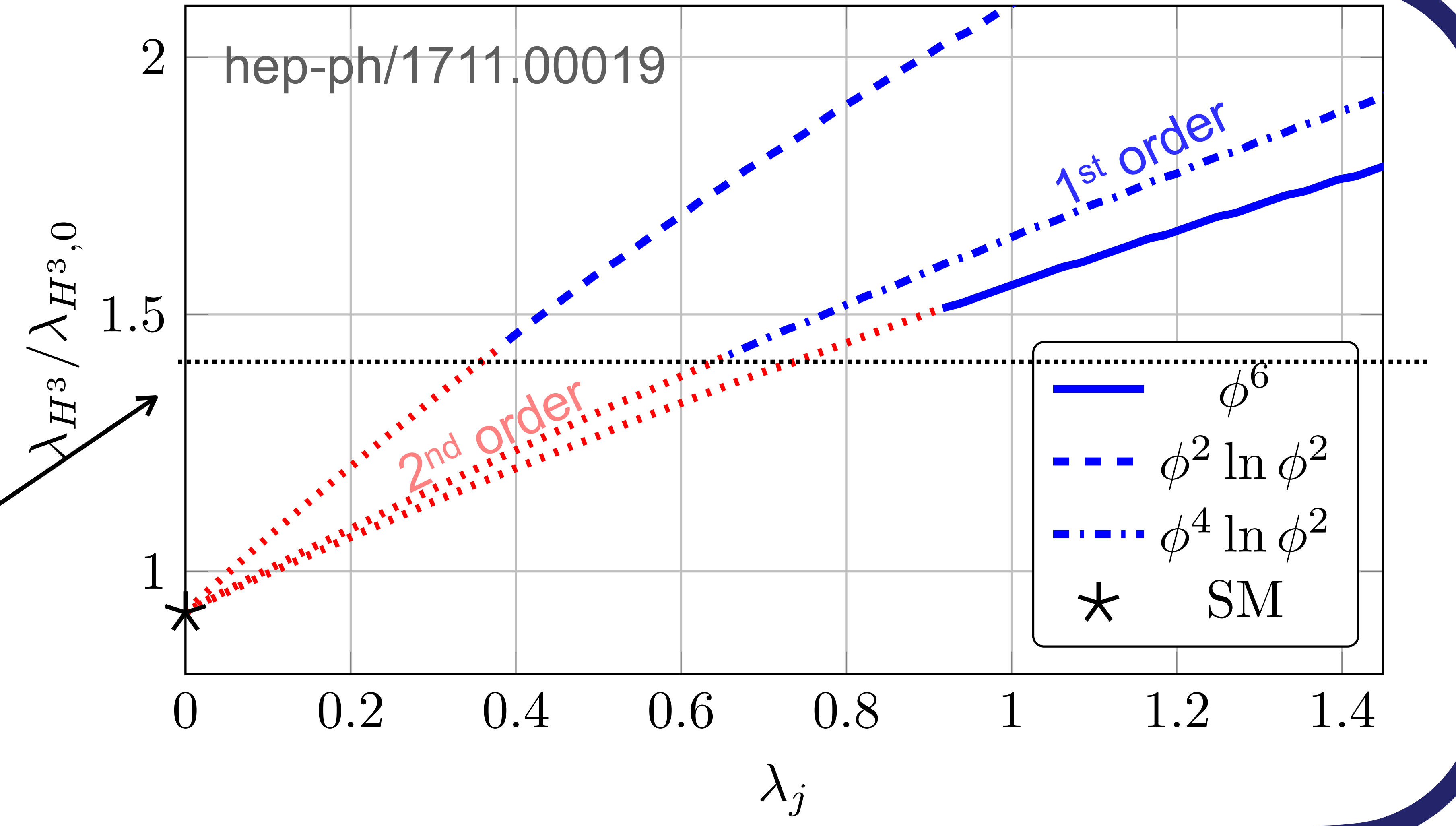


Direct test of cubic coupling only **with HH** production

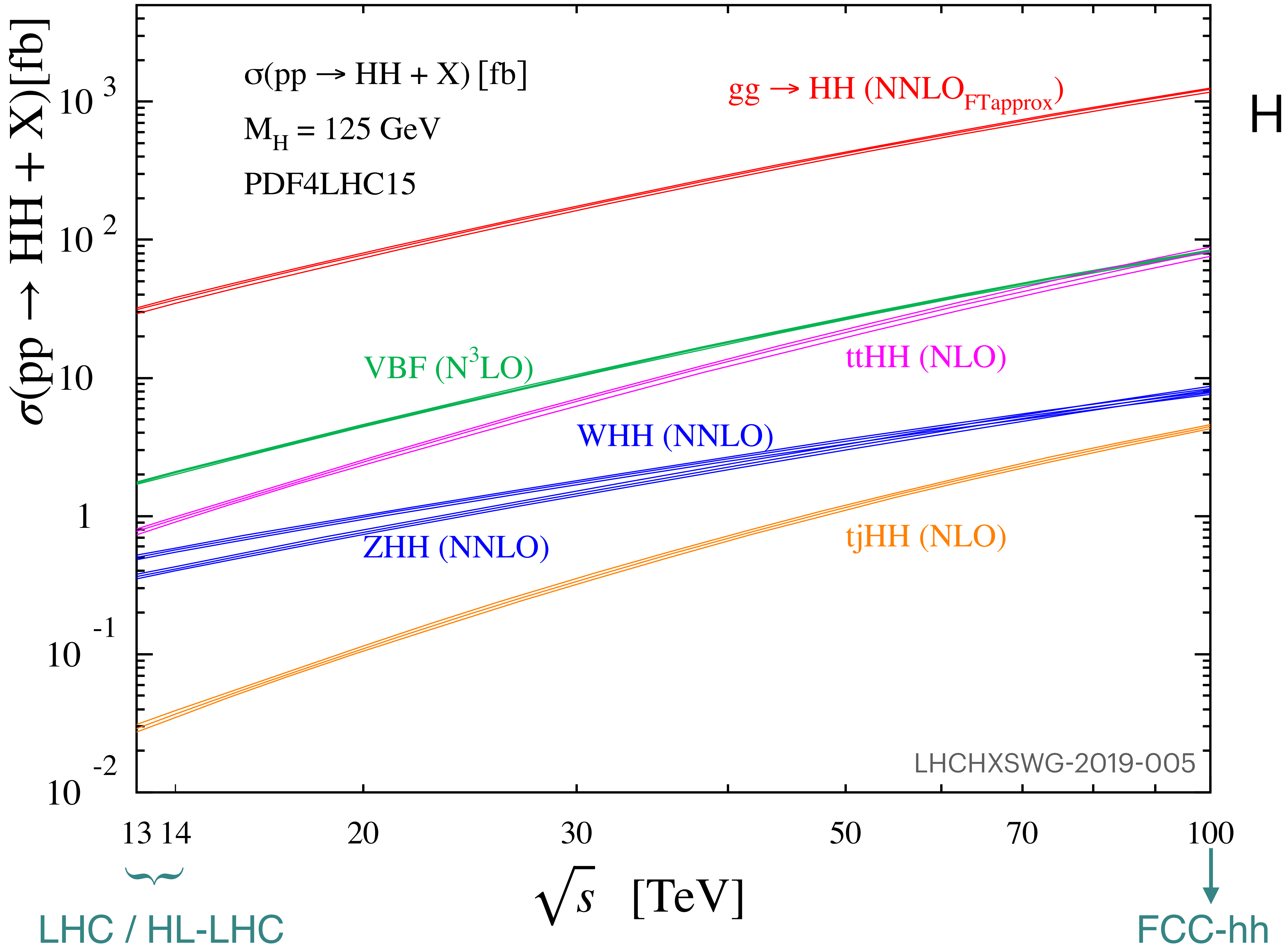
The thermal history of the Universe

Deviations from SM Higgs boson self-coupling cause a modified potential that allows **first-order electroweak phase transition** and hence an explanation of the observed matter vs anti-matter asymmetry!



We need to probe size of modification down to 1.4,
the expected uncertainty of the measurement should be $\mathcal{O}(10\%)$

HH production cross sections within SM



HH production channels similar to H production, **but** there is a very important difference

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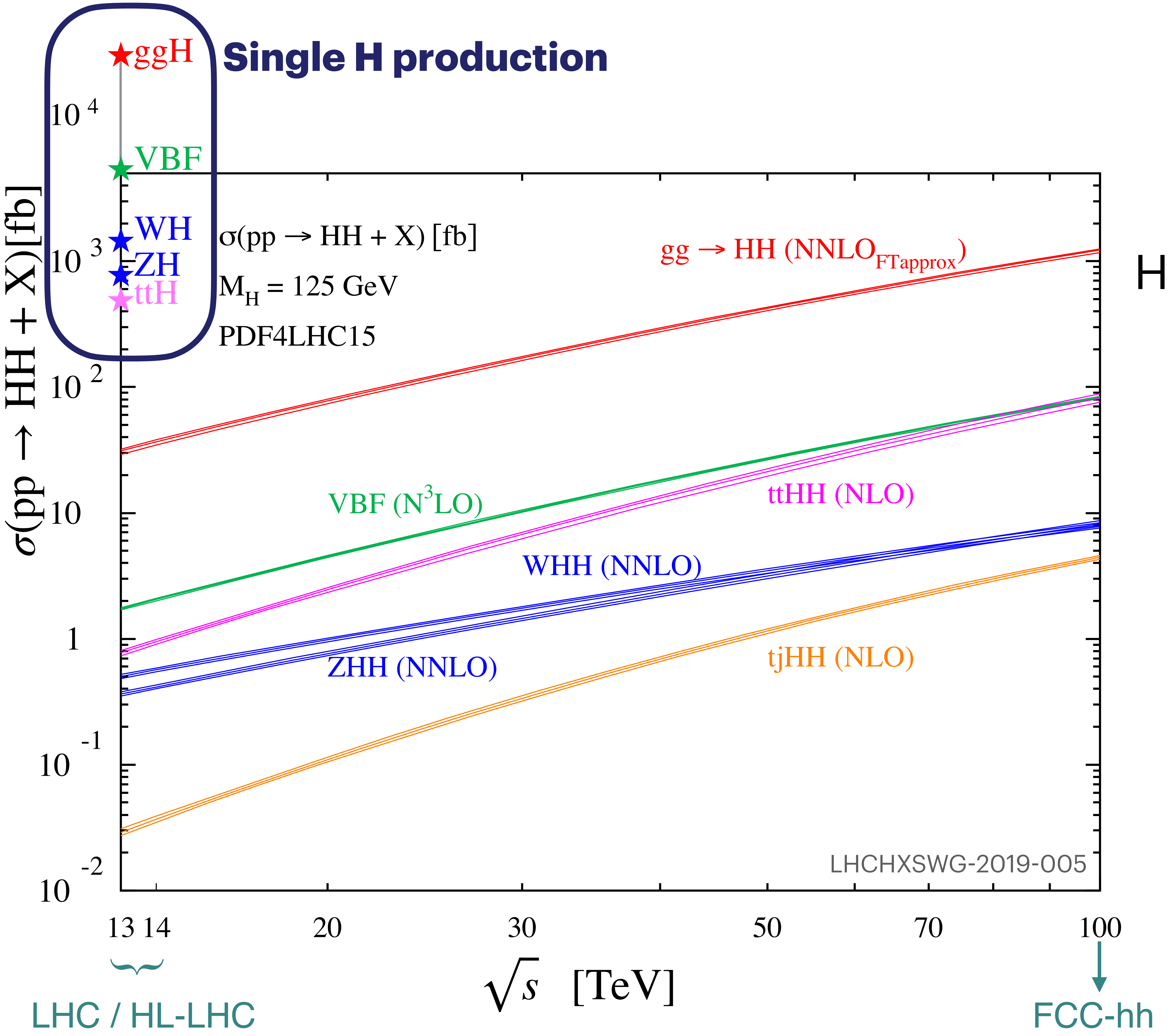


HH production channels similar to H production,

but there is a very important difference

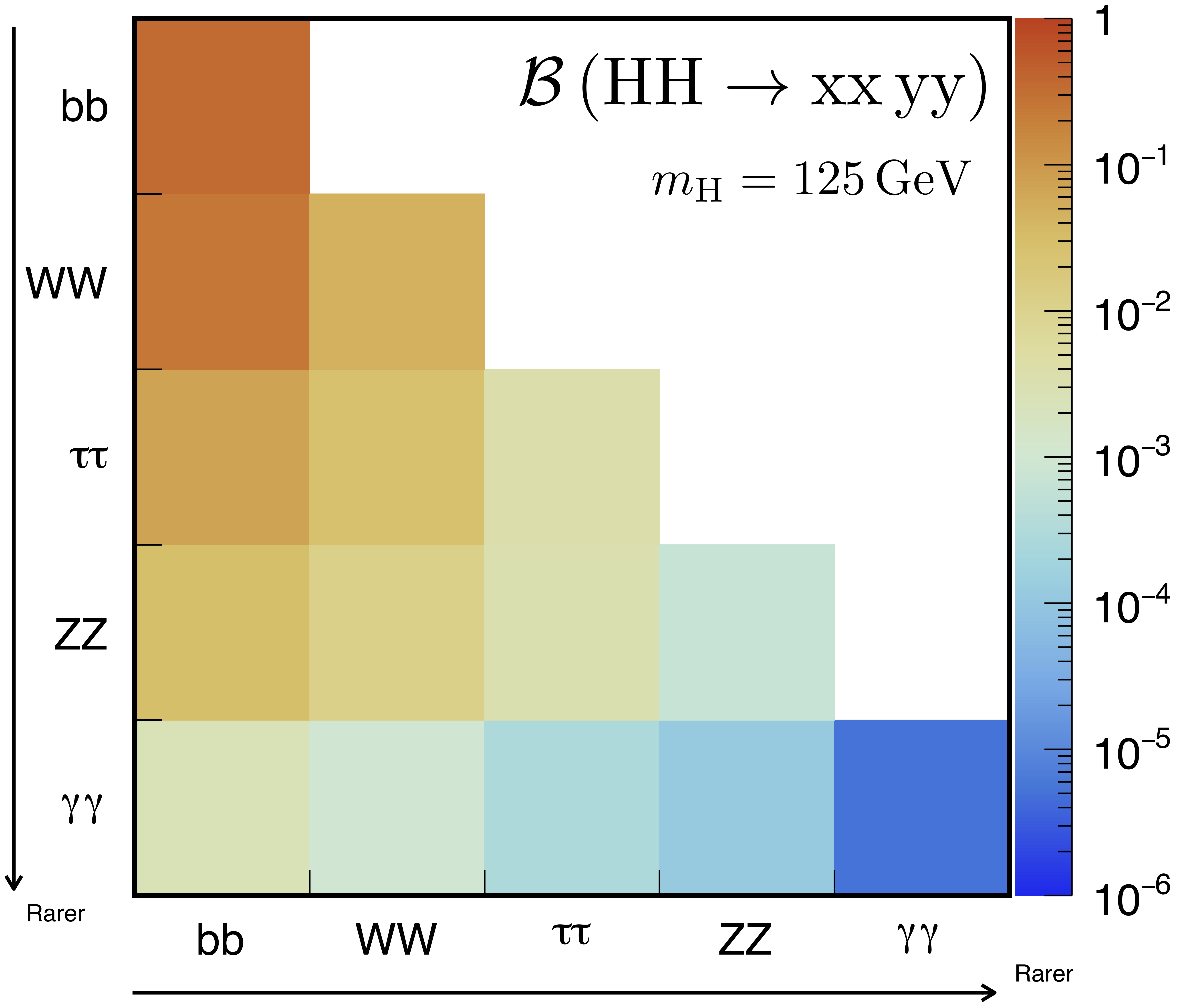
$$\sigma(pp \to HH) \sim \frac{\sigma(pp \to H)}{1000}$$

Higgs boson pairs are predicted to be 1000× rarer than single Higgs

HH final states within SM

A **very** rich set of final states

ATLAS/CMS results with LHC Run 2 covers



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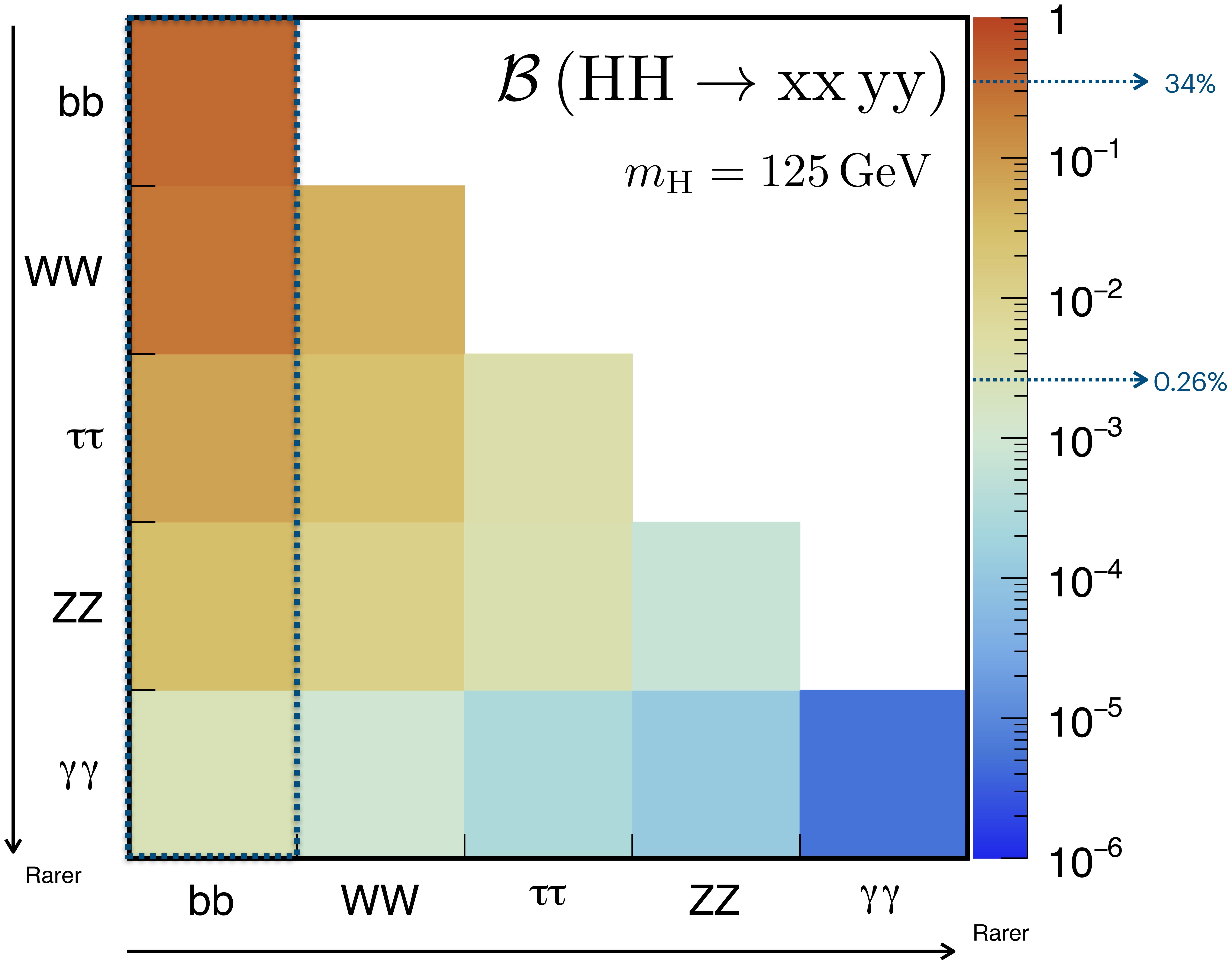
≥ 1 H decaying to b quarks channels



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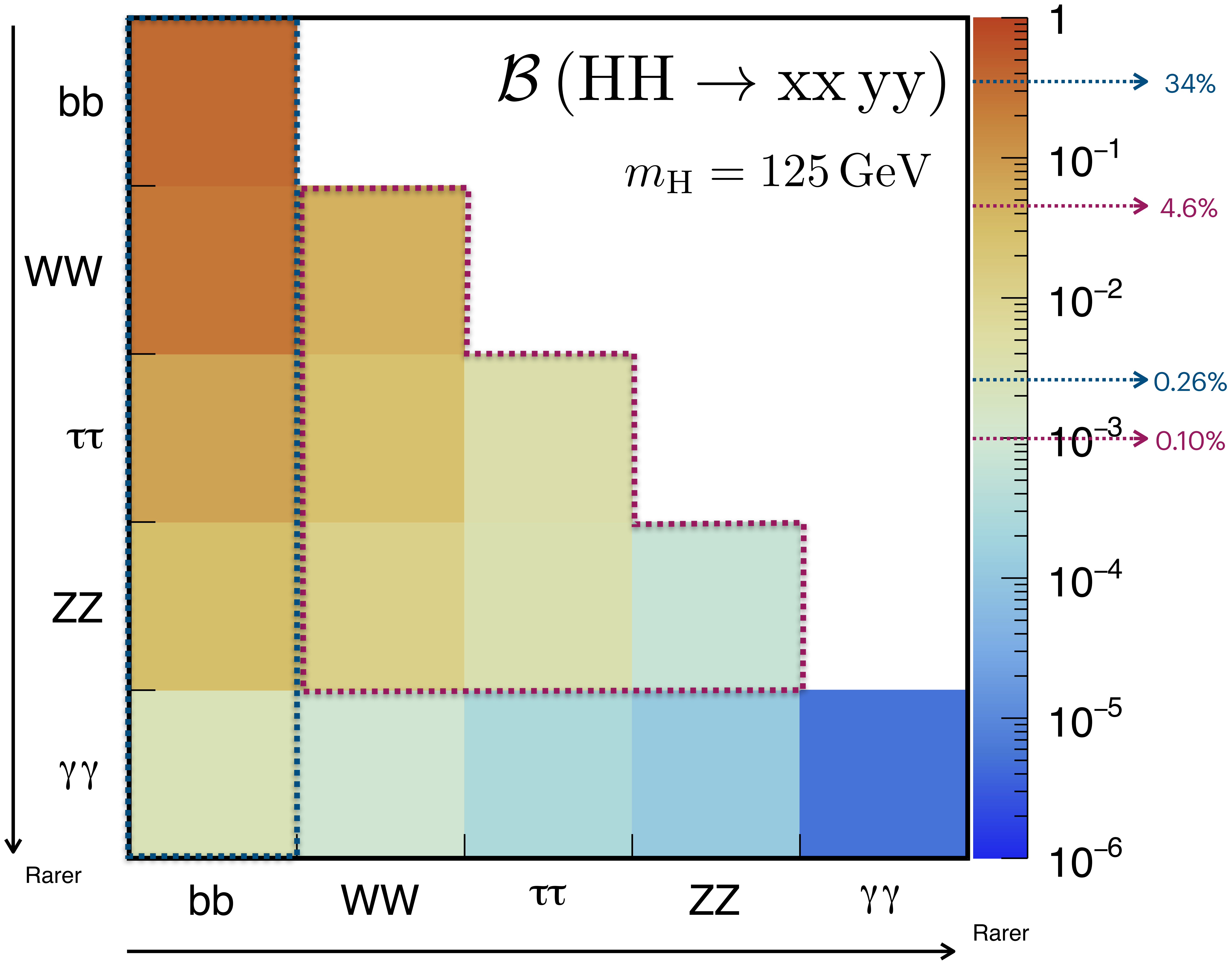


HH final states within SM

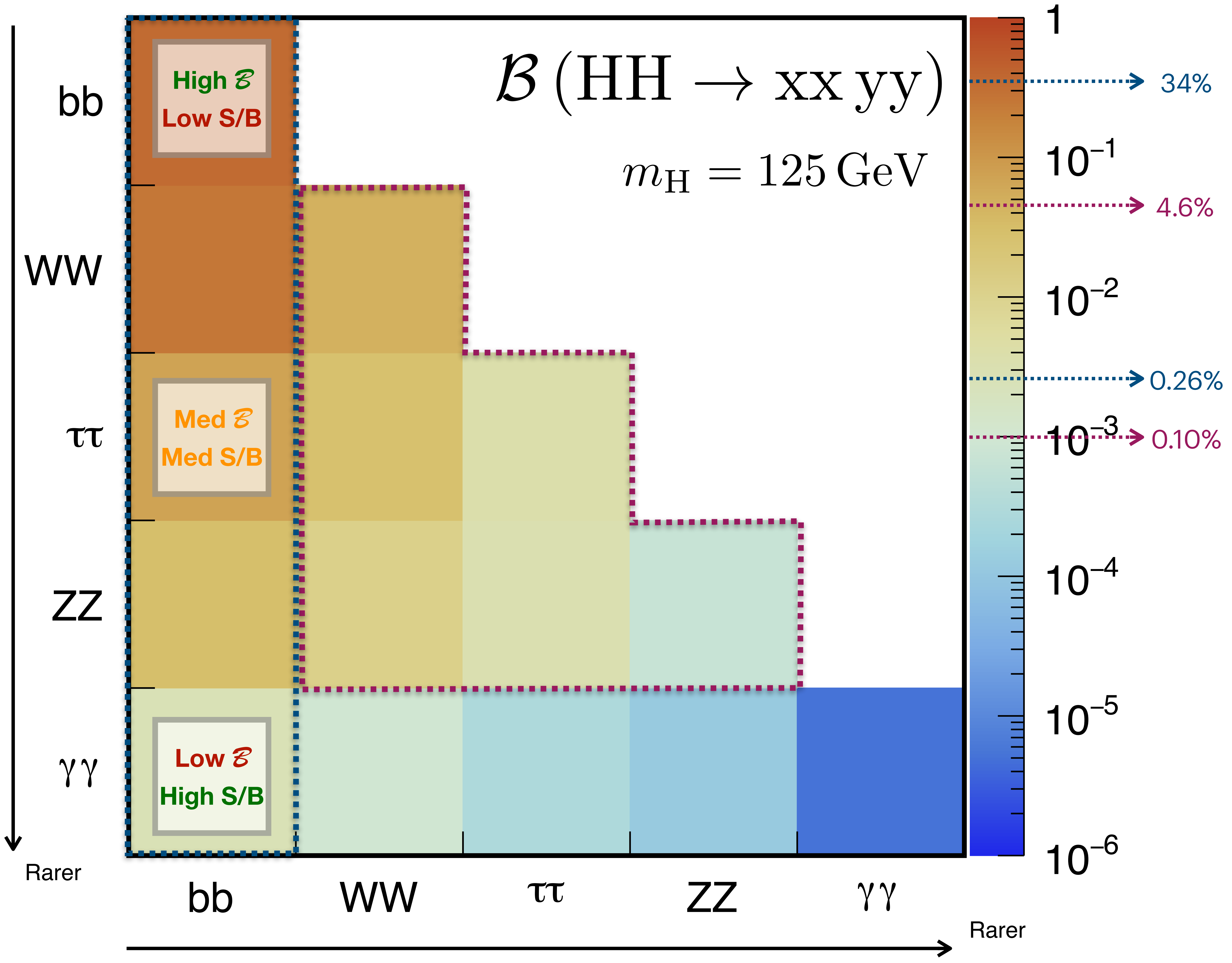
A **very** rich set of final states

ATLAS/CMS results with LHC Run 2 covers

≥ 1 H decaying to b quarks channels

multilepton channels

Not a single **“golden”** channel
but (at least) three **“silver”** bullets



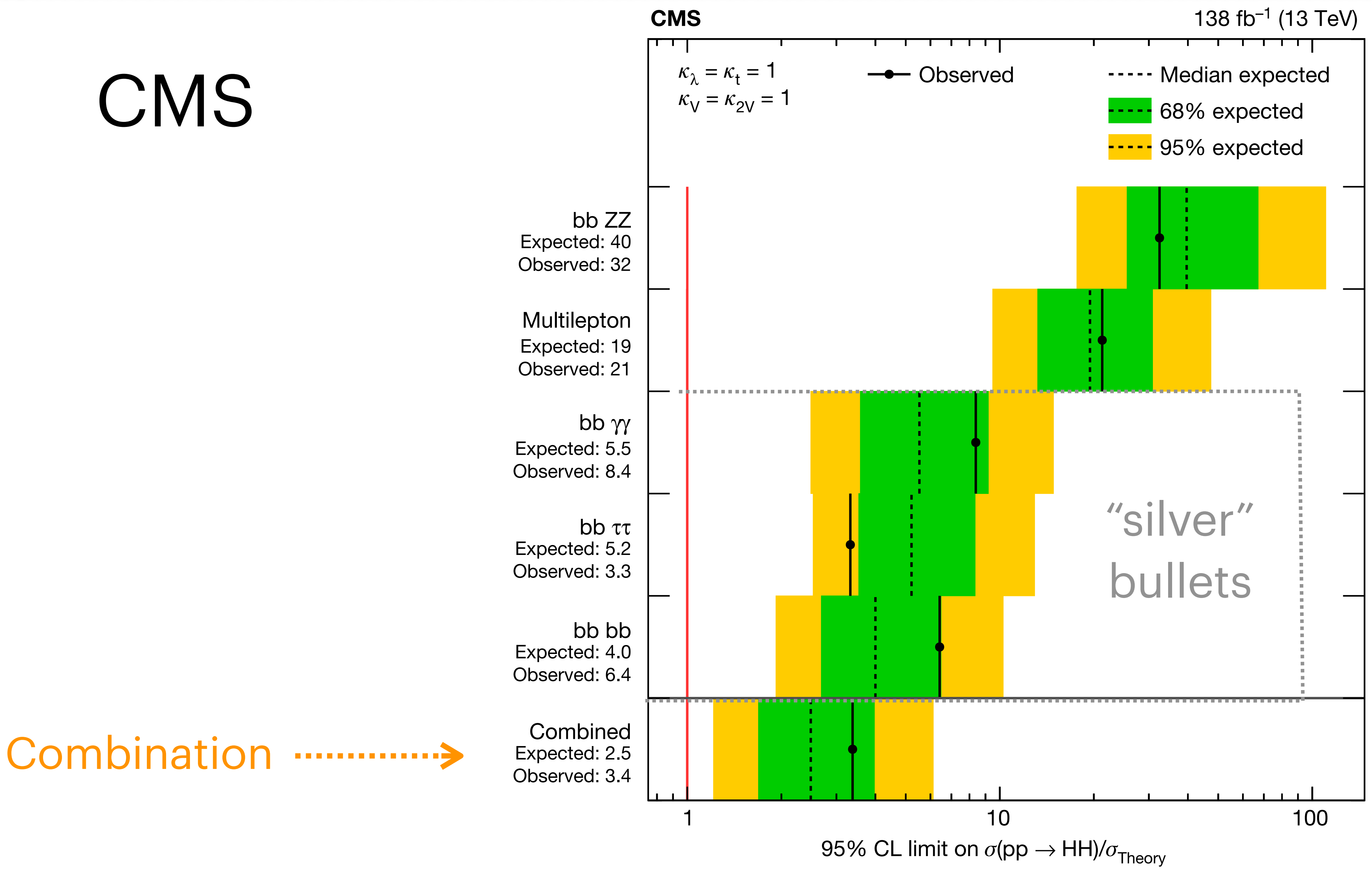
Putting all together

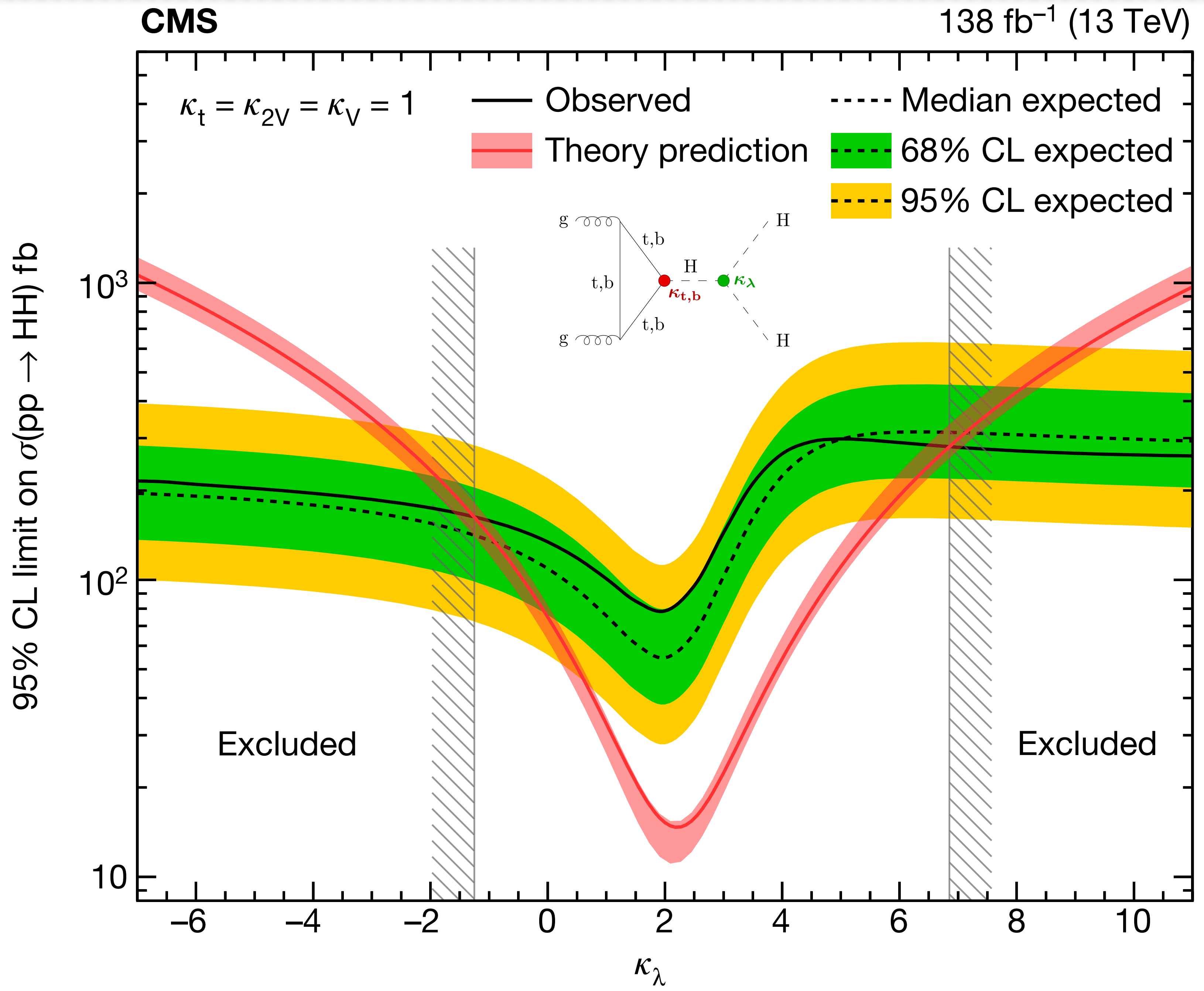
Not a single "golden" channel but various contributions to the overall sensitivity $\Rightarrow$ Combinations are key

Putting all together : HH production

Not a single "golden" channel but various contributions to the overall sensitivity ⇒ Combinations are key

CMS





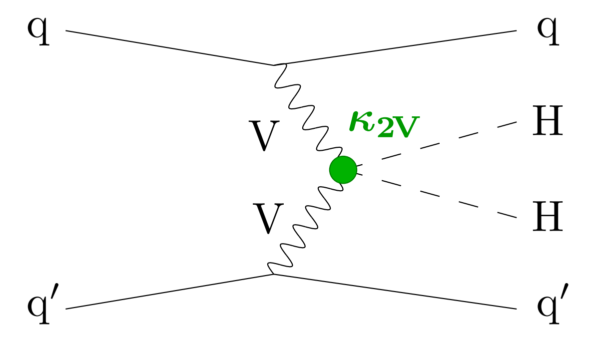
ATLAS

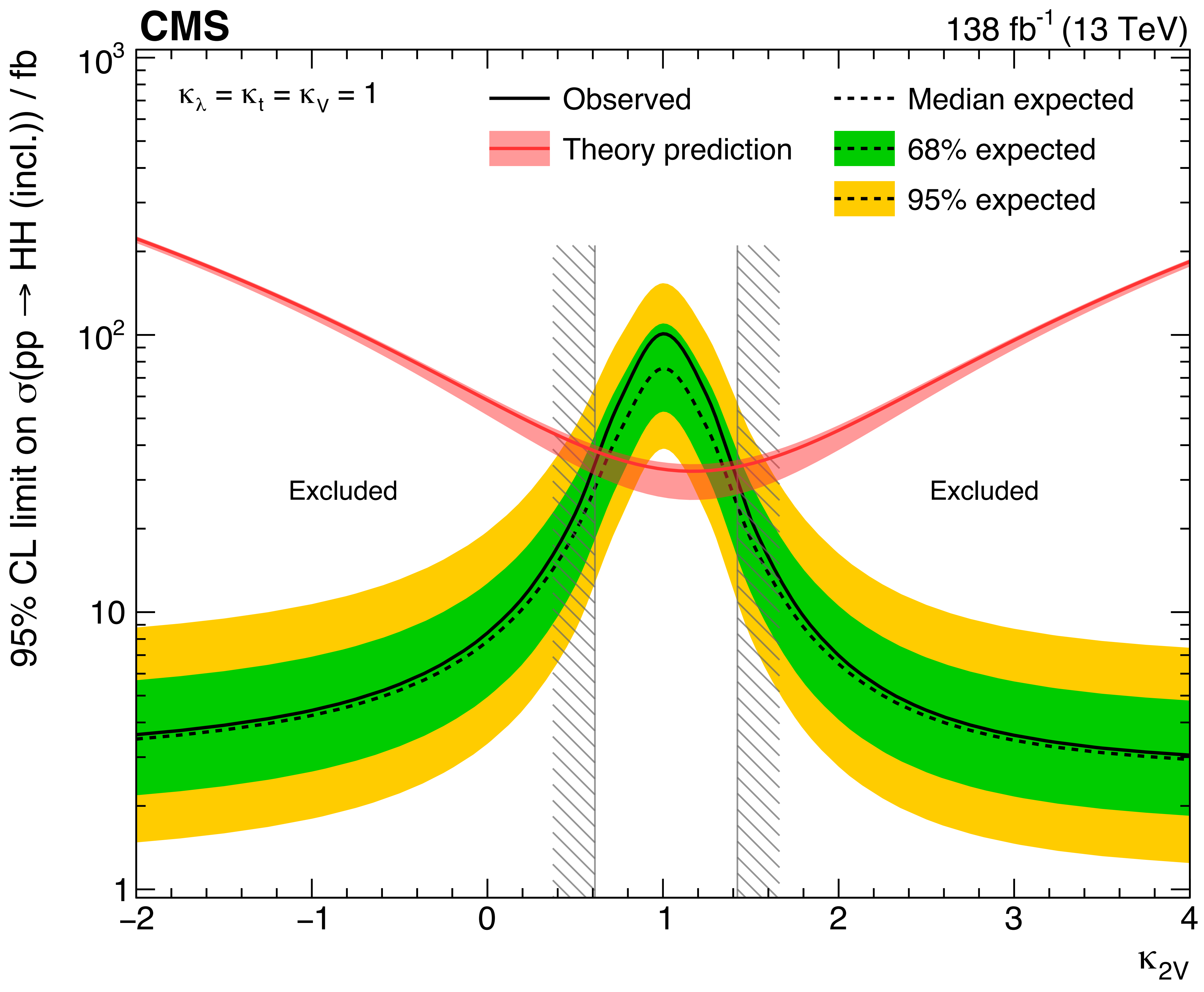
95% CL limit on $\sigma_{HH}/\sigma^{SM}_{HH}$ 2.4(2.9) obs.(exp.)

95% CL limit on $k_\lambda \in [-0.6; +6.6]$

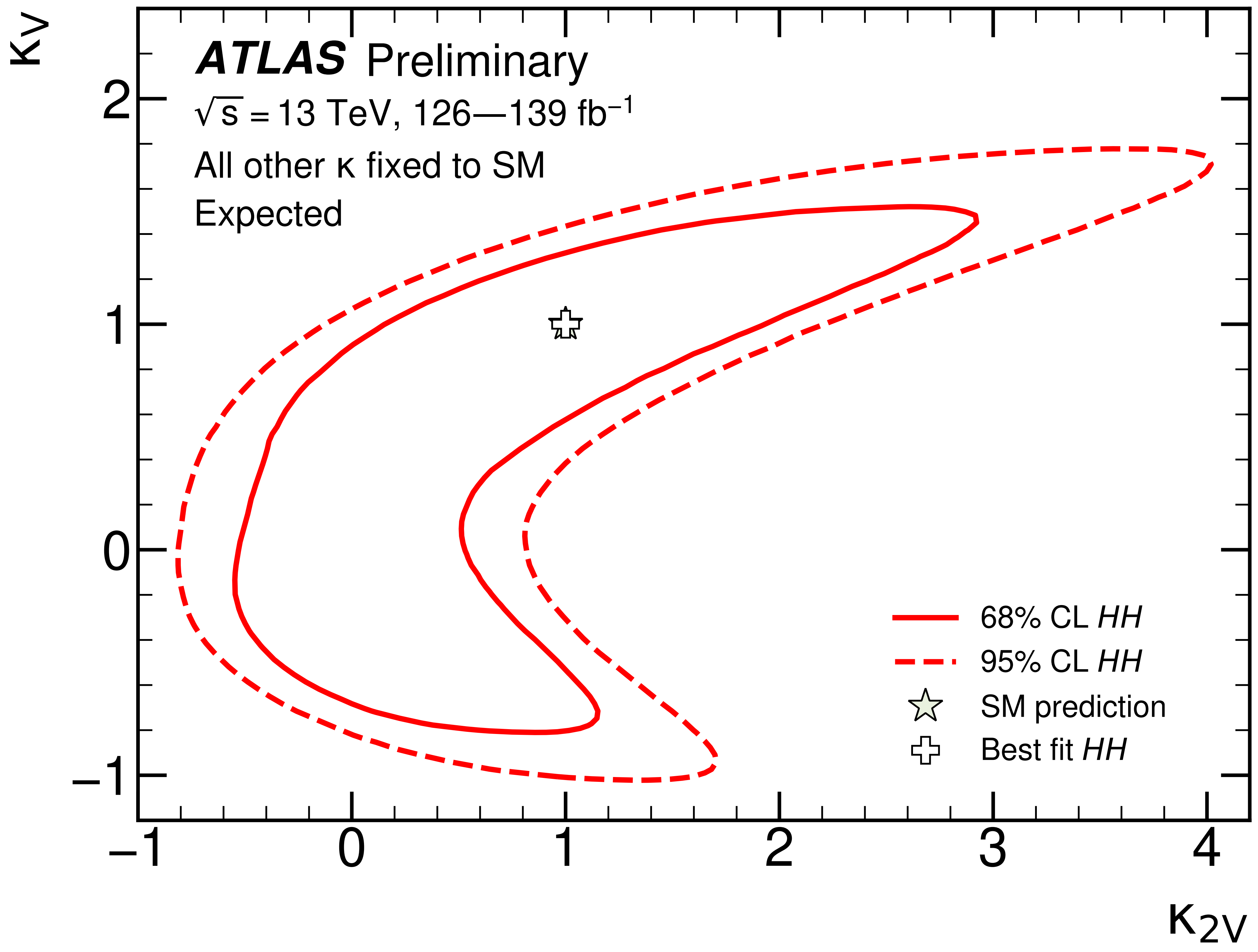
ATLAS: ATLAS-CONF-2022-050 CMS: Nature 607, 60-68 (2022)

Putting all together : VVHH interaction





$k_{2V} = 0$ is excluded, with a significance of 6.6 s.d. assuming all other couplings to be SM



Constrained in the k_V and k_{2V} plane

ATLAS: ATLAS-CONF-2022-050 CMS: Nature 607, 60-68 (2022)

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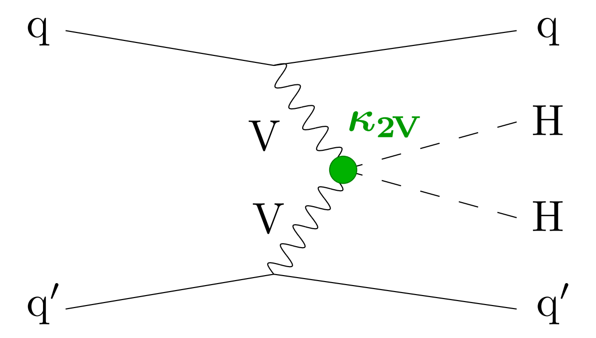

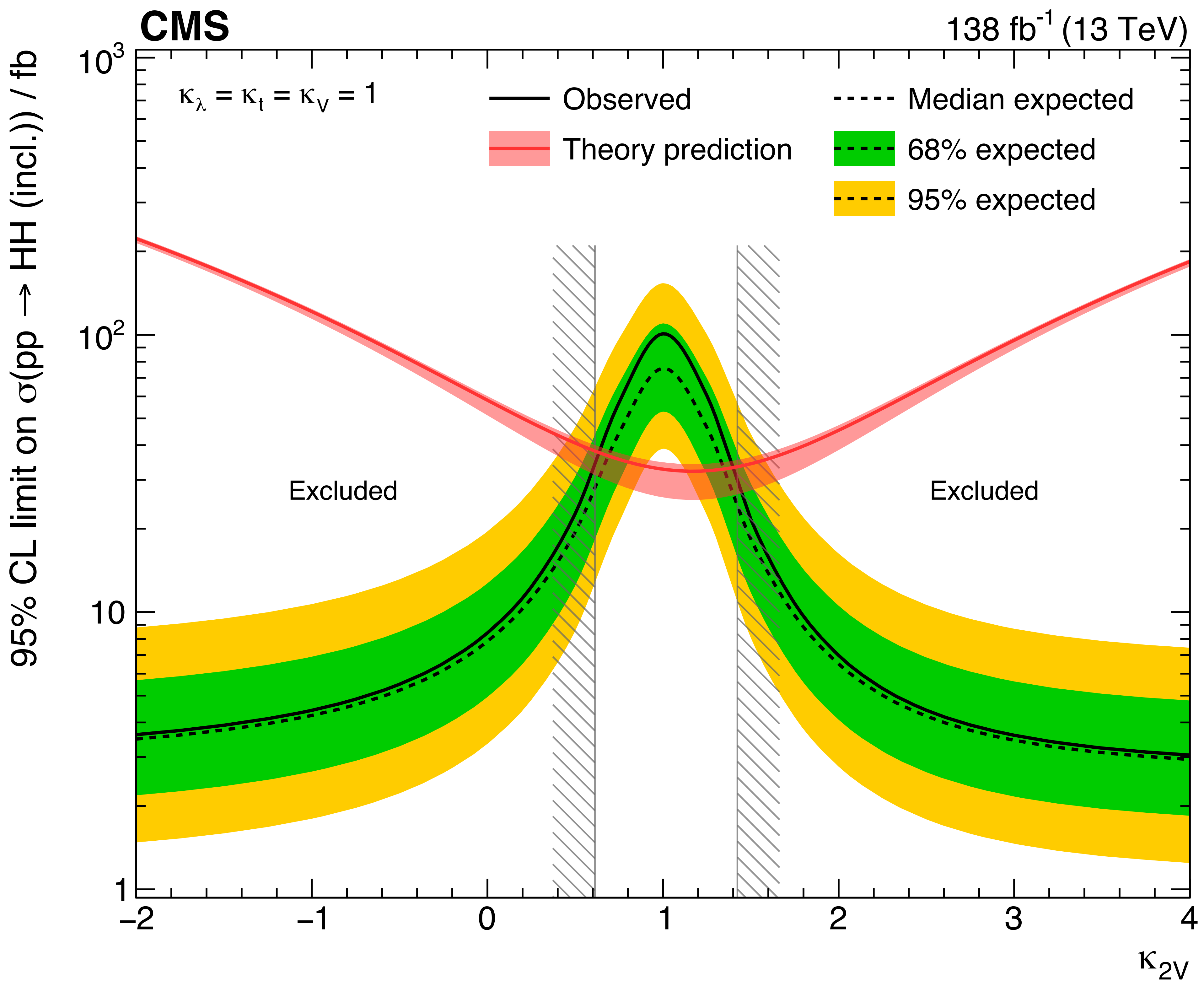

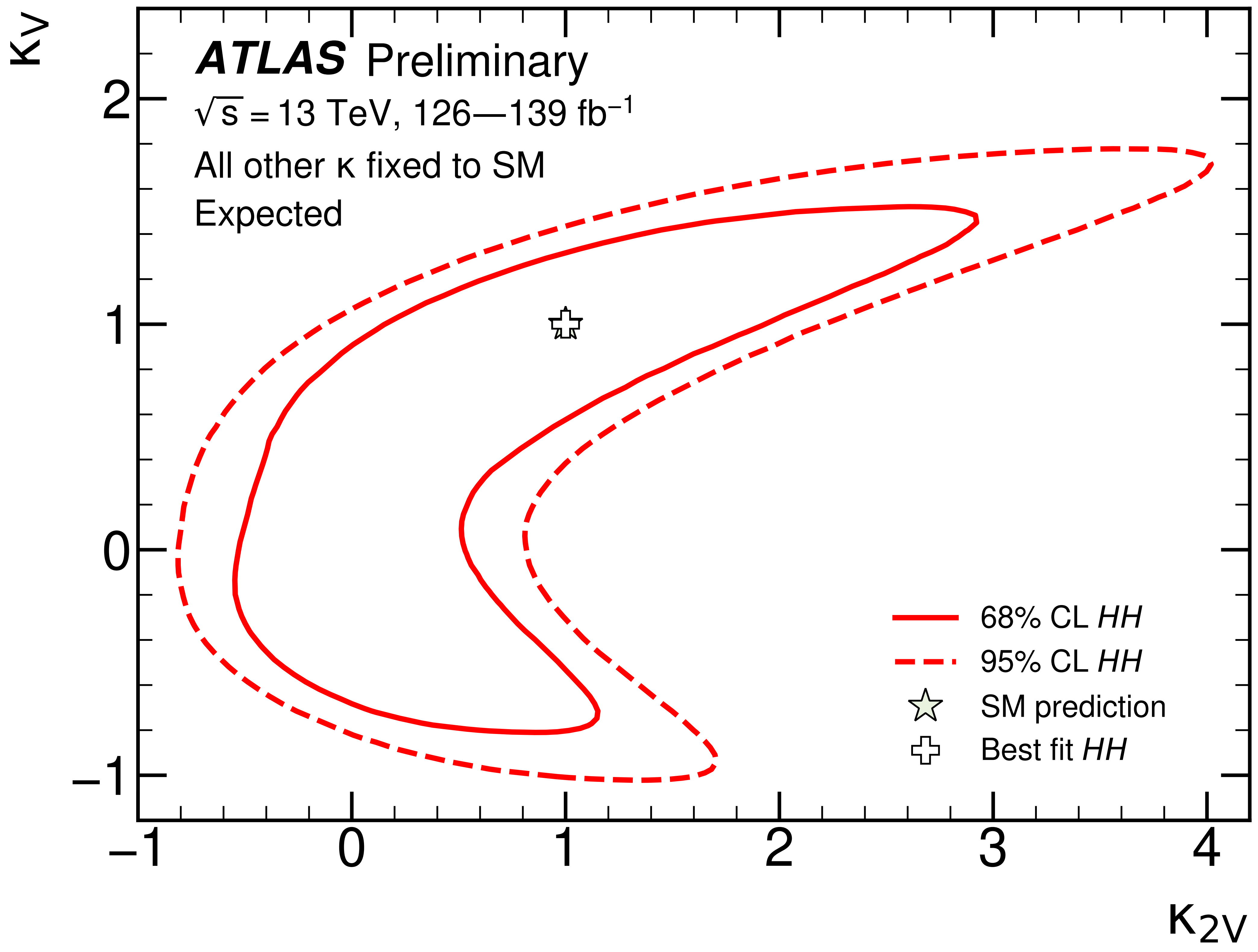

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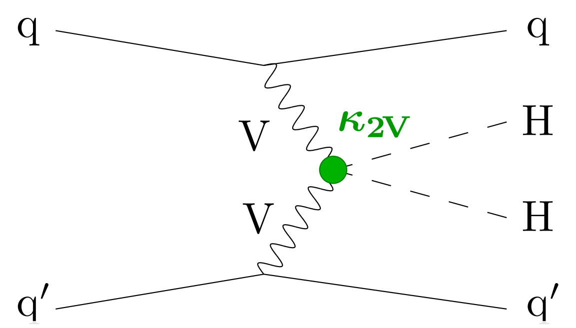
Constrained in the k_V and k_{2V} plane

Establishing the existence of the quartic coupling **VVHH**

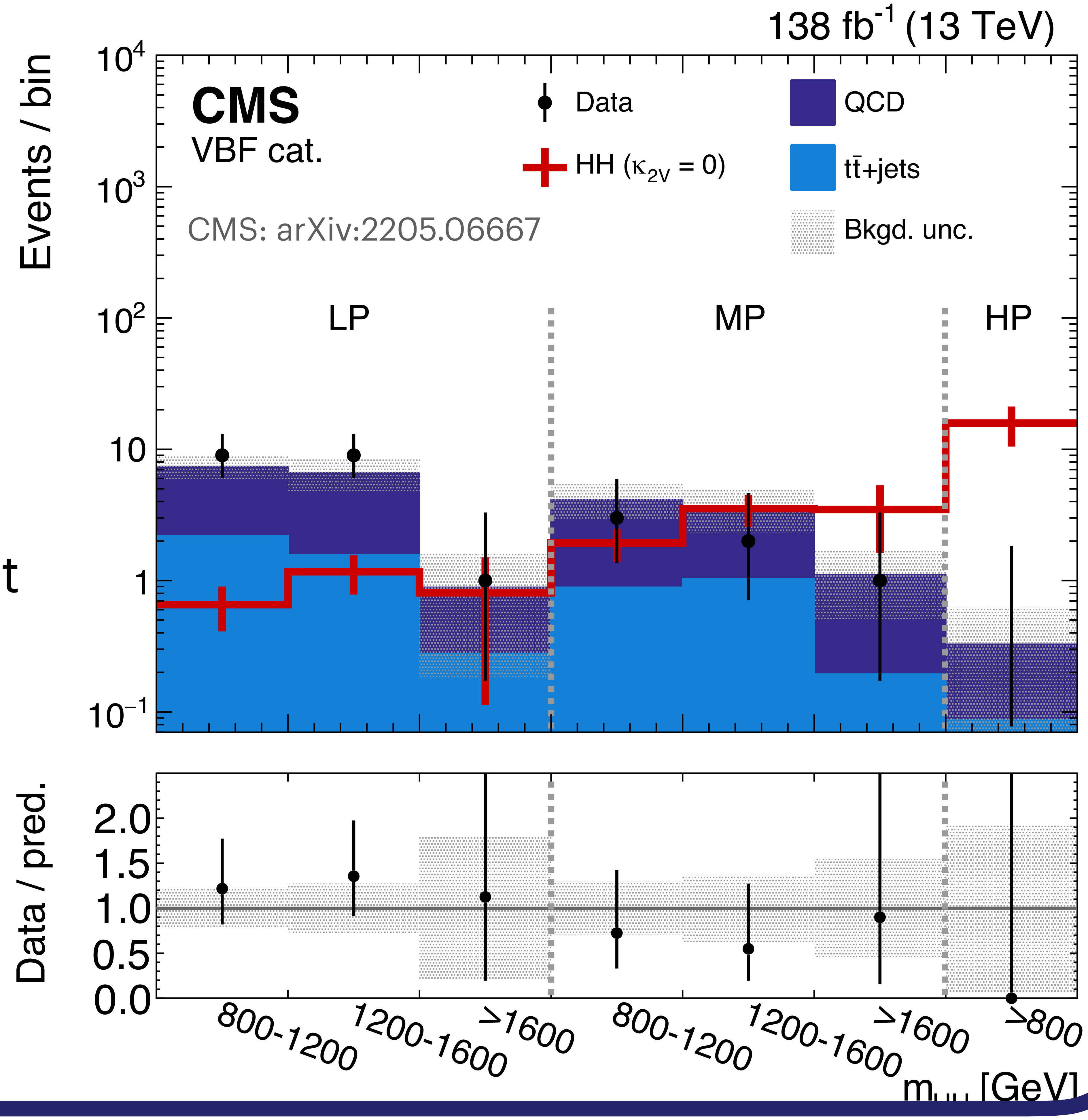
Key role of (HH→bbbb) boosted searches and ML for H→bb decay ID

ATLAS: ATLAS-CONF-2022-050 CMS: Nature 607, 60-68 (2022)

Putting all together : VVHH interaction



The distributions of the invariant mass of the HH system after a background-only fit to the data, for the VBF categories of the HH→bbbb channel



Establishing the existence of the quartic coupling **VVHH**

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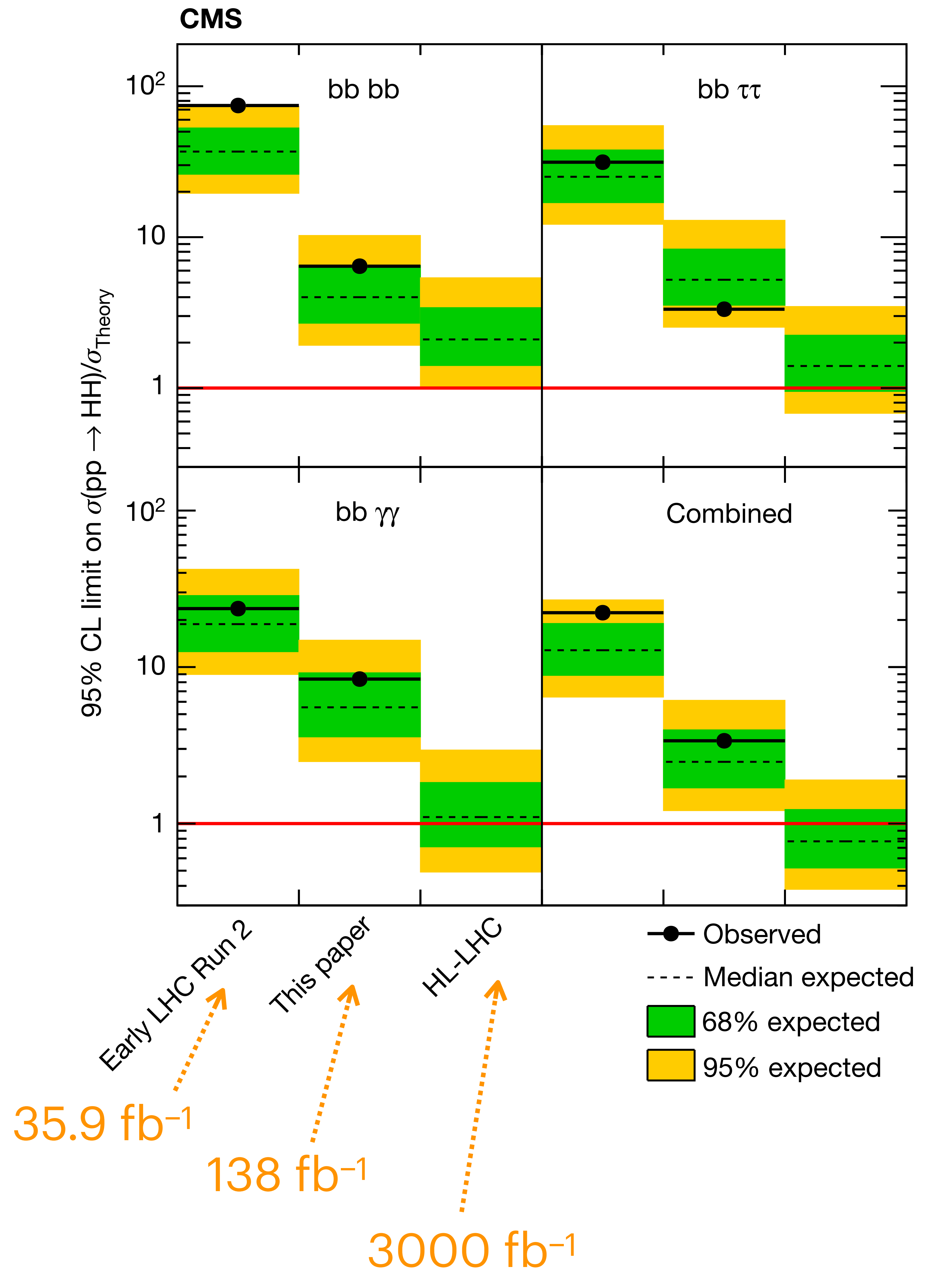
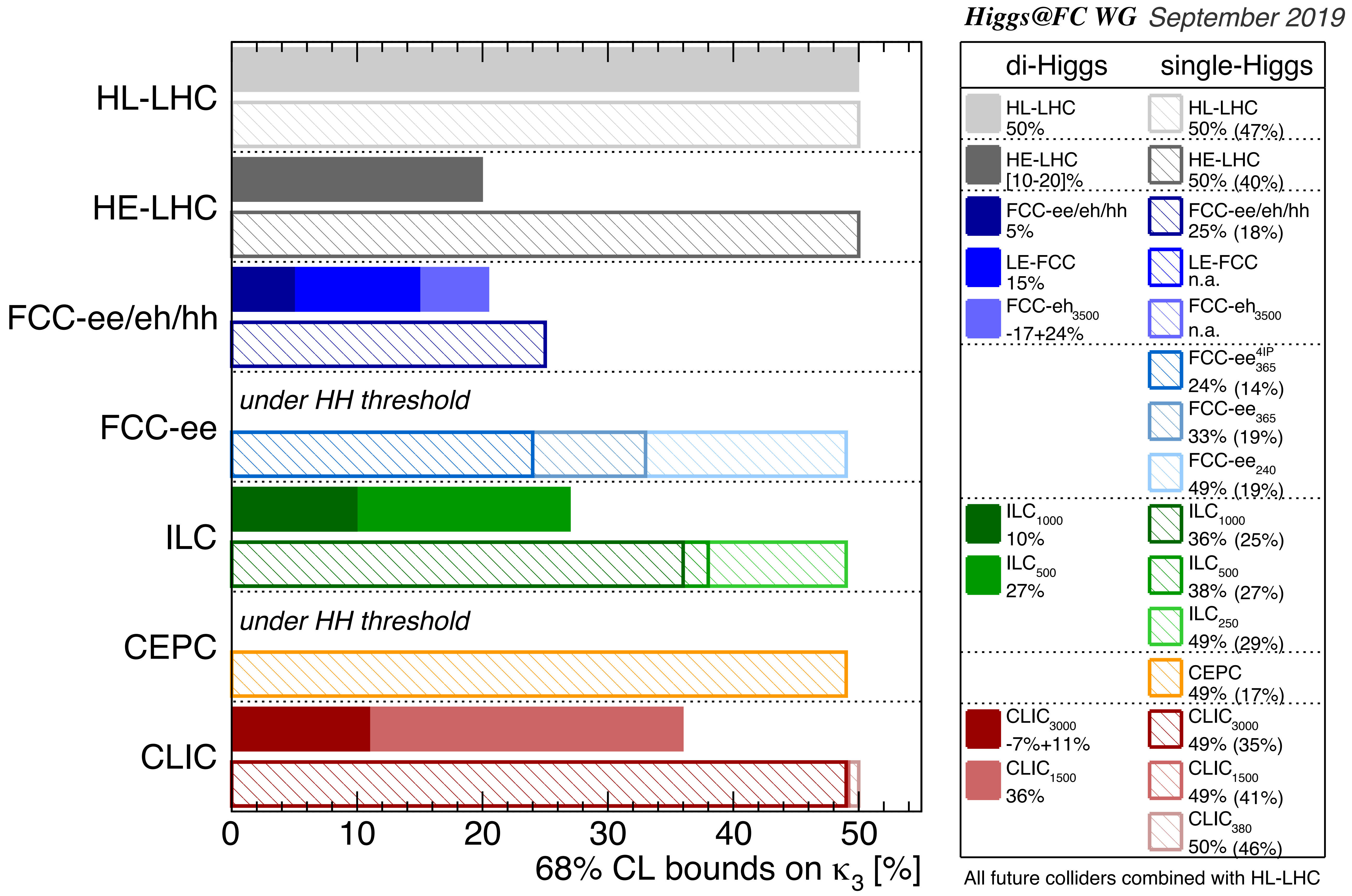
The future : HL-LHC and beyond

hopes & wishes

High Luminosity LHC

Exp. and obs. limits on HH production in different datasets



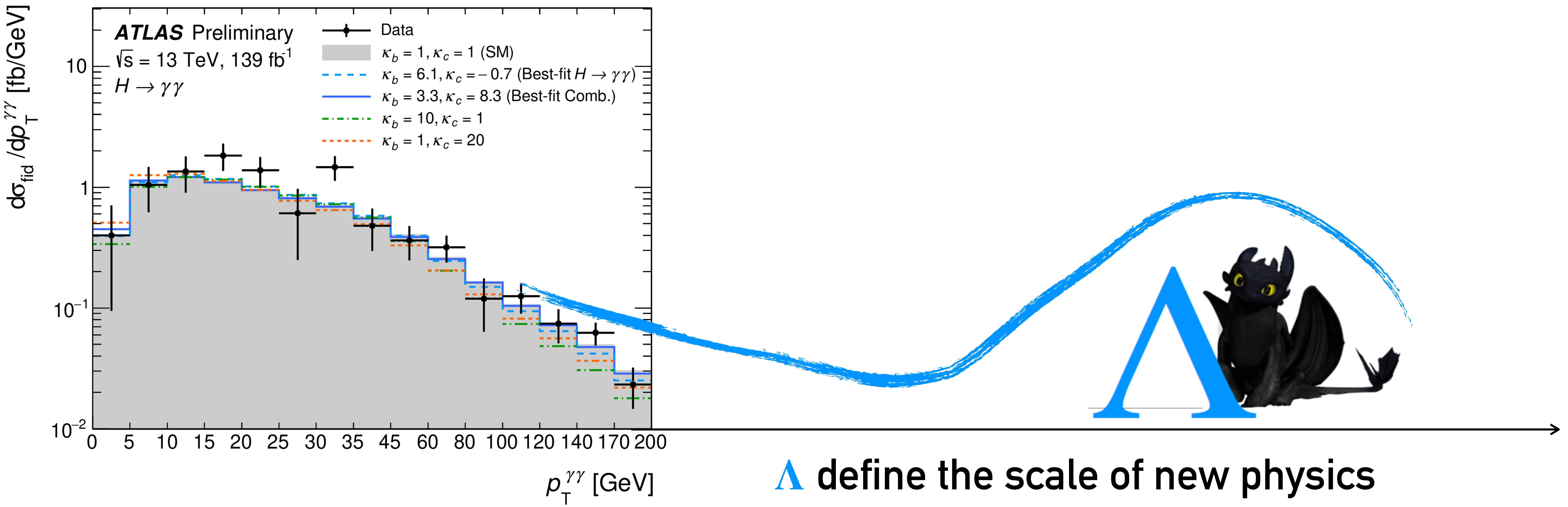


Key legacy of HL-LHC:

unmatched precision over the next ≥30 years

CMS: Nature 607, 60-68 (2022)

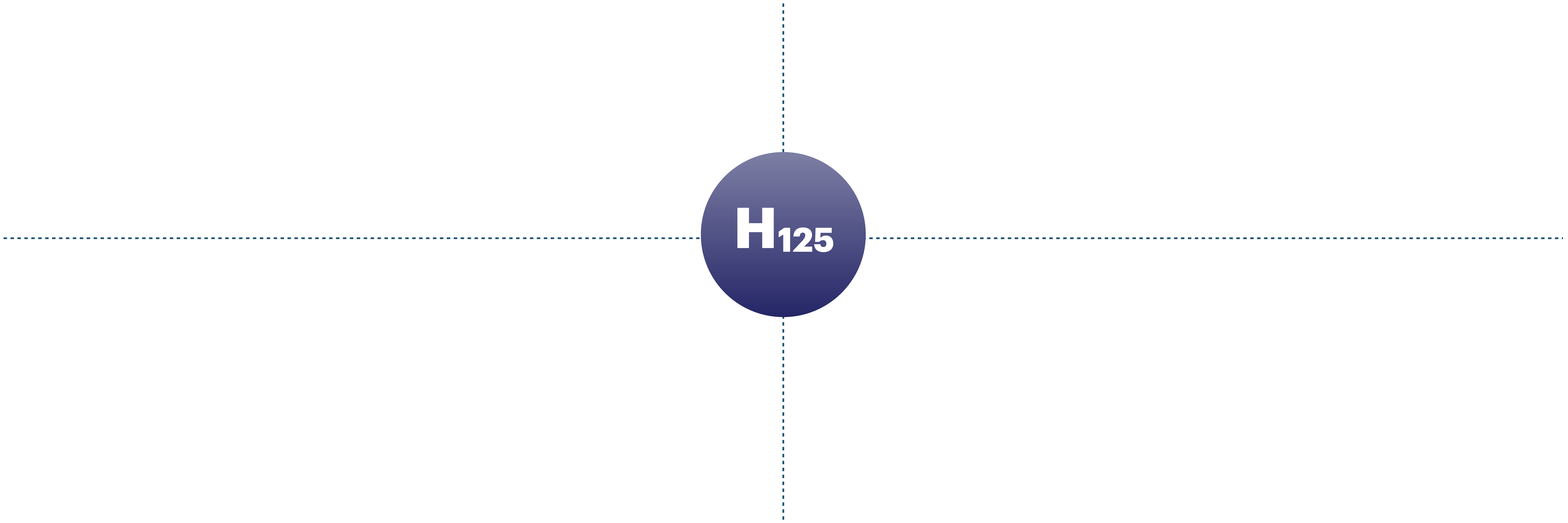
Higgs boson in BSM searches



Λ define the scale of new physics

The role of H in searches for BSM

Few examples



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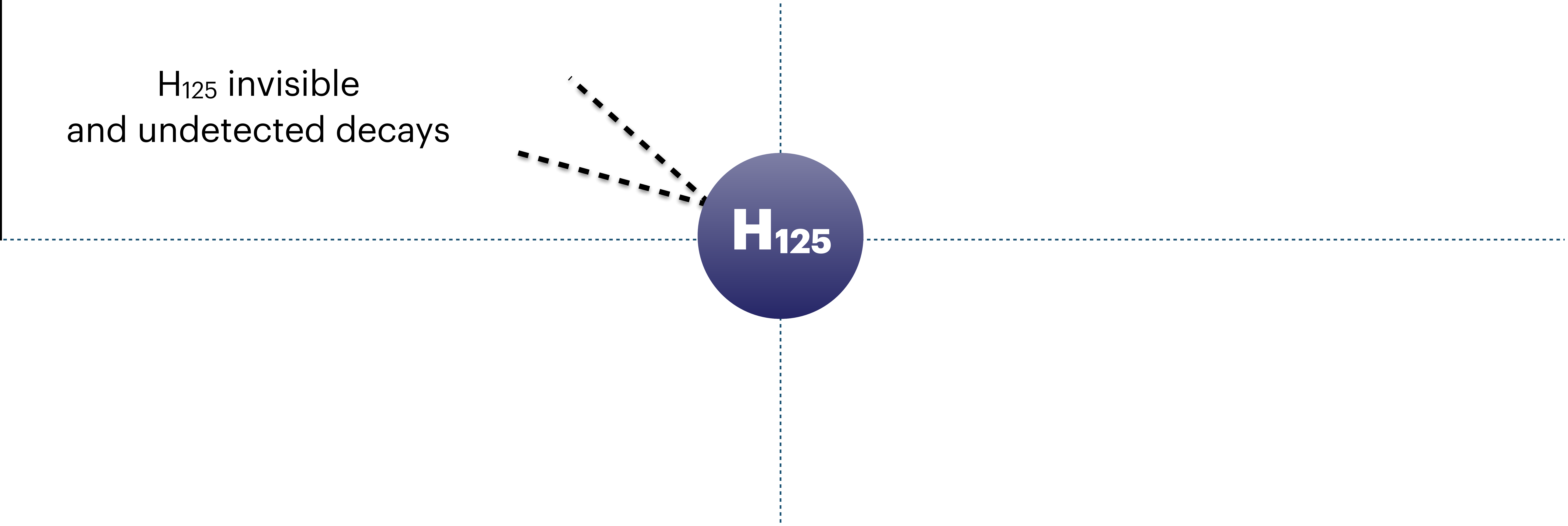
invisible decay



The role of H in searches for BSM

Few examples

invisible decay

H_{125} invisible
and undetected decays

flavour violating decays

H_{125} flavour violating
decays

The role of H in searches for BSM

Few examples

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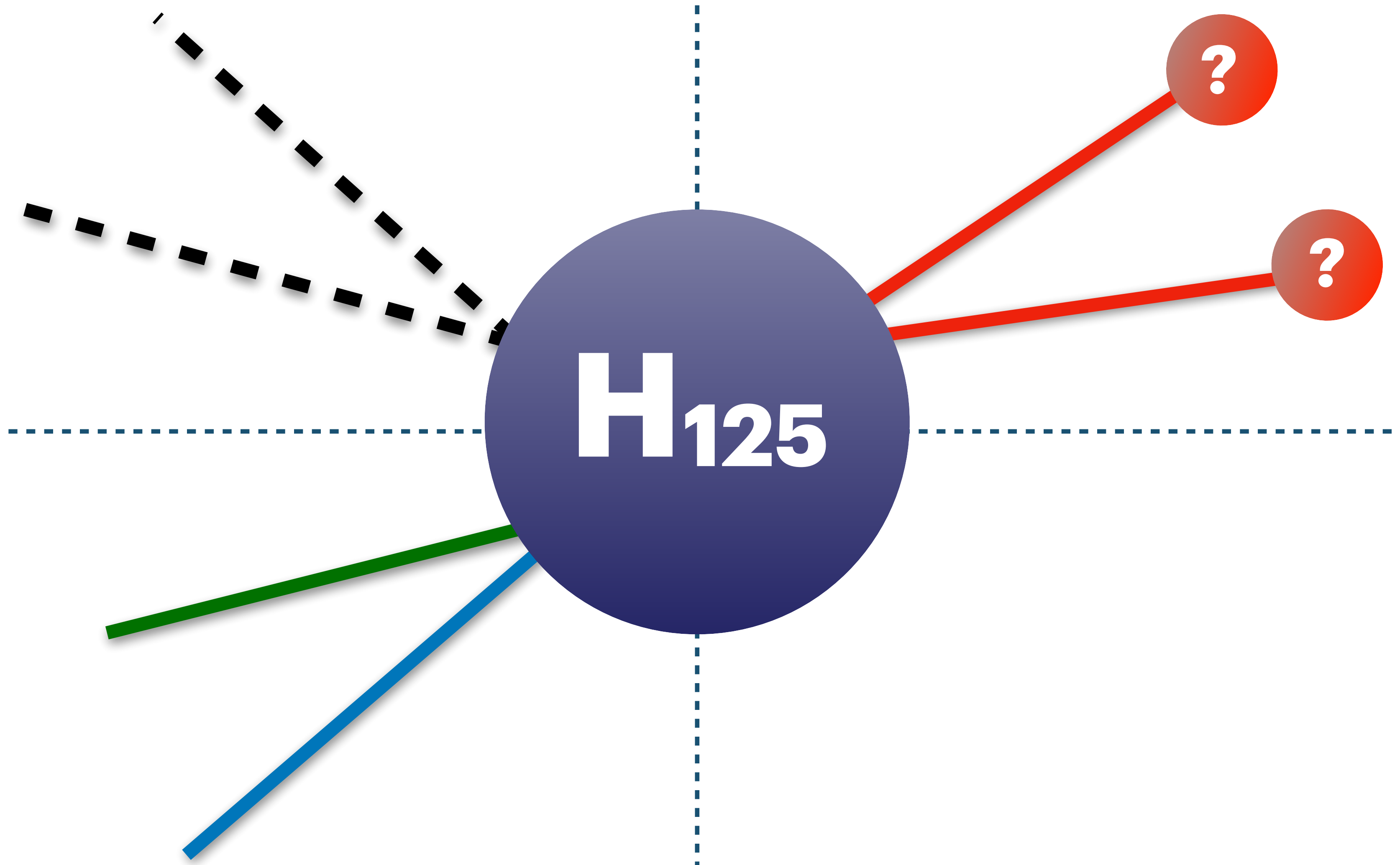

H_{125} exotic decays

exotic decays

flavour violating decays

H_{125} flavour violating
decays

The role of H in searches for BSM

Few examples

Higgs boson to invisible decay

The expected SM H branching fraction to invisible decay ($\mathscr{B}_{\text{inv}}$) is 0.12% due to $H \to ZZ* \to \nu\bar{\nu}\nu\bar{\nu}$

Several BSM scenario $\Rightarrow$ anomalous and sizeable values, $\mathscr{B}_{\text{inv}}$ is significantly enhanced.

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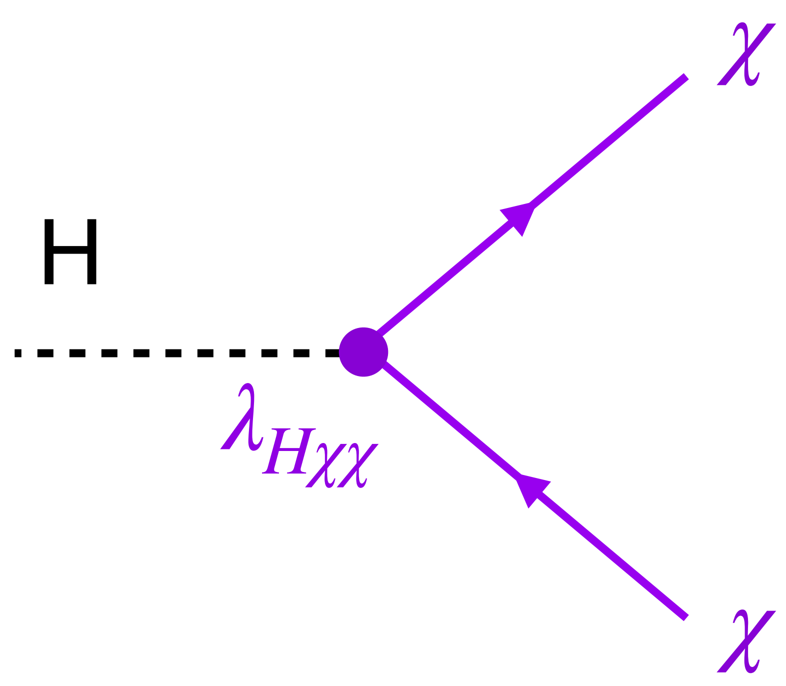
In one class of models H decay in a pair of stable WIMPs.
They represent a simple extension of the SM to provide a Dark Matter (DM) candidate and are able to predict the observed relic DM density via s-channel $\chi\chi \to f\bar{f}$ annihilation.



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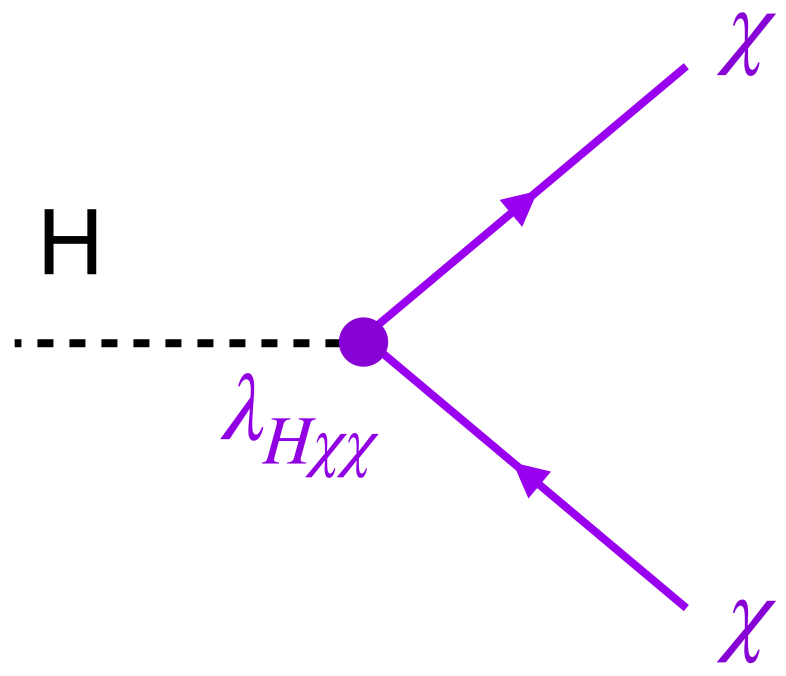
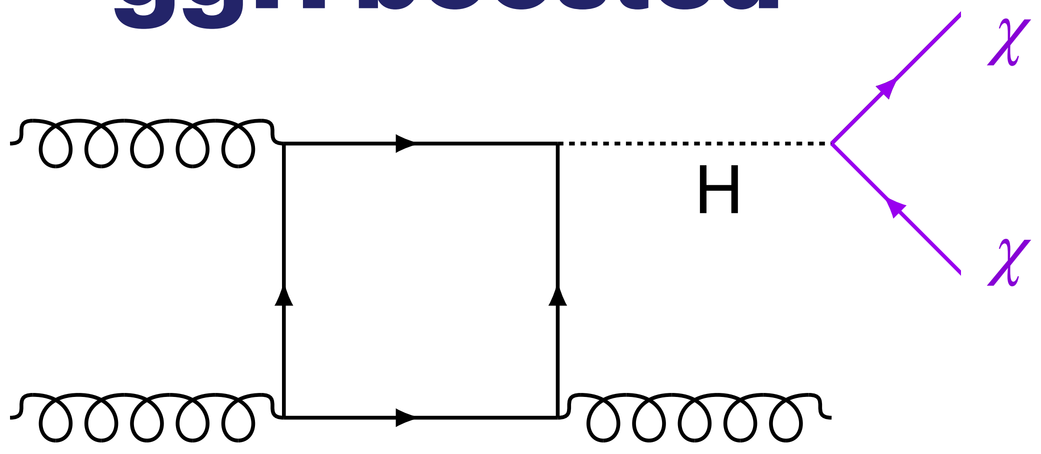


The solution of the DM problem could be found within the Higgs sector.

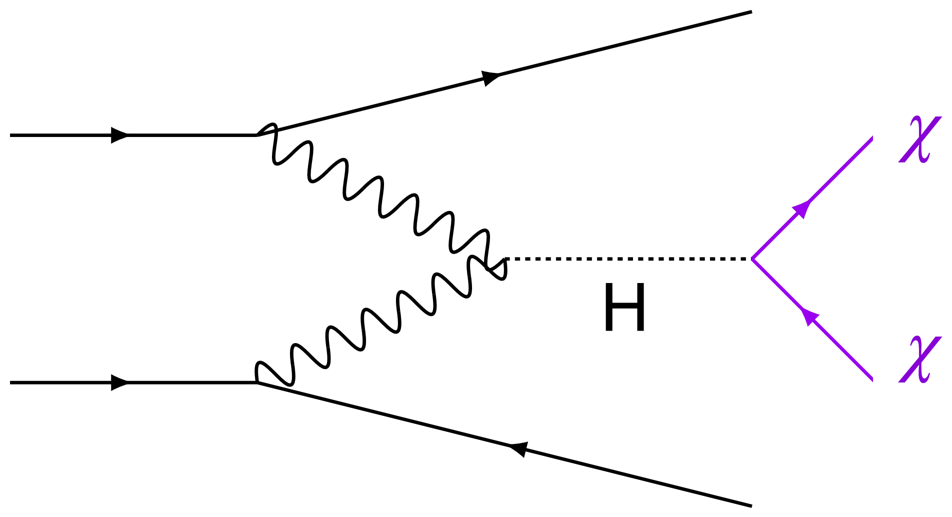
Common signature : significant missing transverse momentum from the Higgs boson decay.
Identify the event : profit of visible particles recoiling against the Higgs boson.

Search for Higgs boson to invisible decay

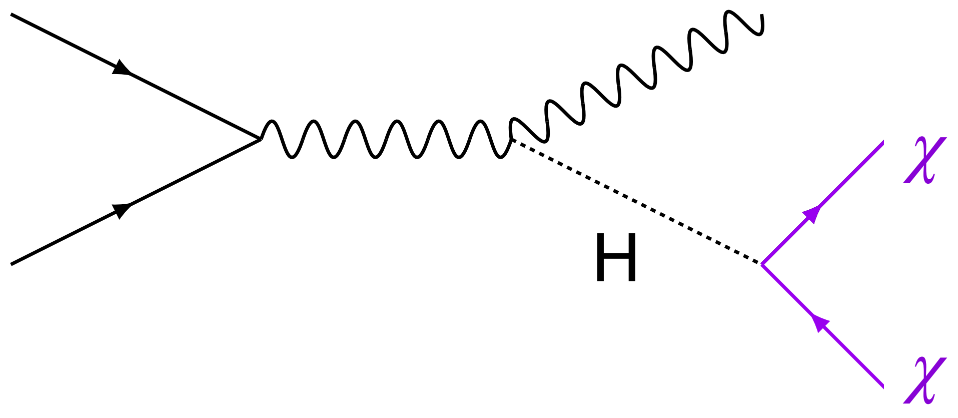
ggH boosted



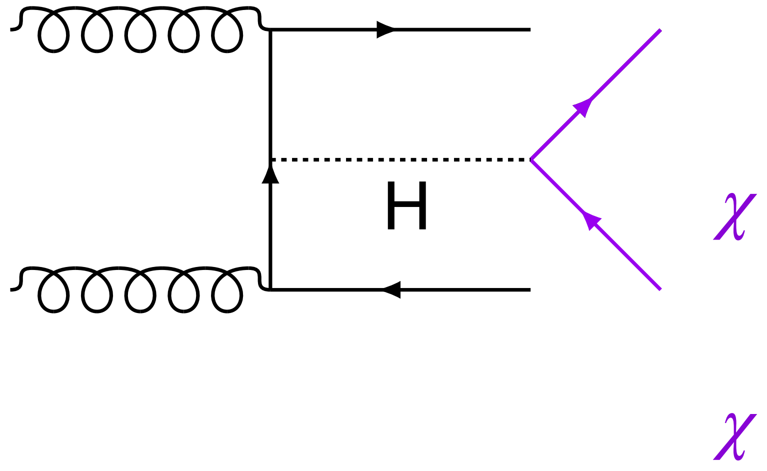
VBF



Associated production



ttH



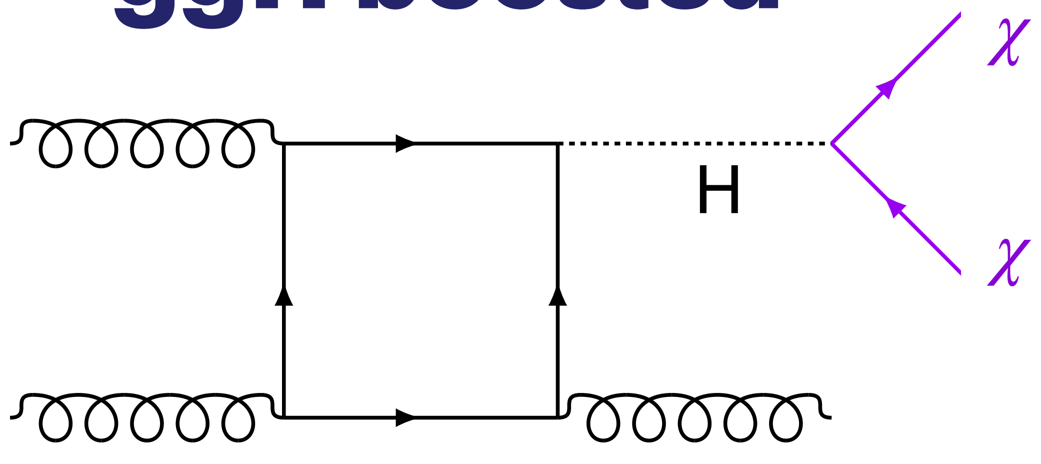
ATLAS and CMS probe all production mechanisms

Run2 analyses

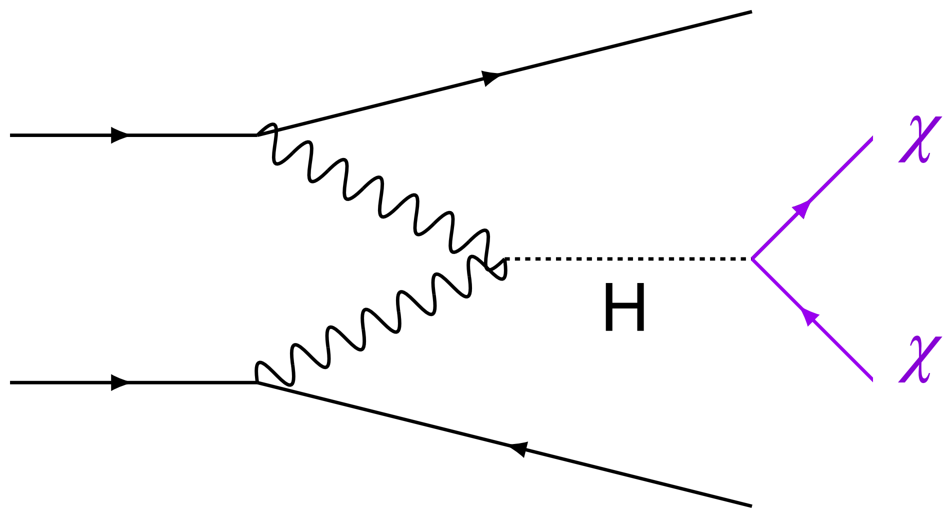
	ggH boosted	VBF	Associated production	ttH
ATLAS	Phys.Rev.D 103 (2021) 11, 112006	arXiv:2202.07953 Eur.Phys.J.C 82 (2022) 2, 105	Phys.Lett.B 829 (2022) 137066	ATLAS-CONF-2022-007
CMS	JHEP 11 (2021) 153	Phys.Rev.D 105 (2022) 092007	Eur.Phys.J.C 81 (2021) JHEP 11 (2021) 153	

Search for Higgs boson to invisible decay

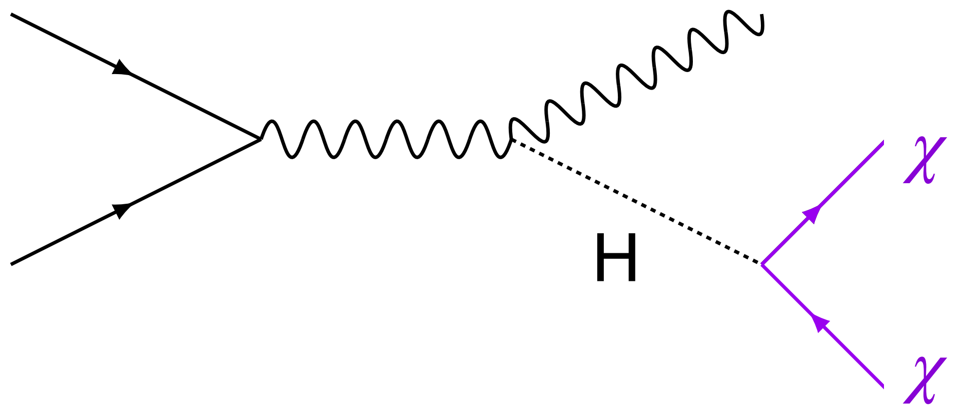
ggH boosted



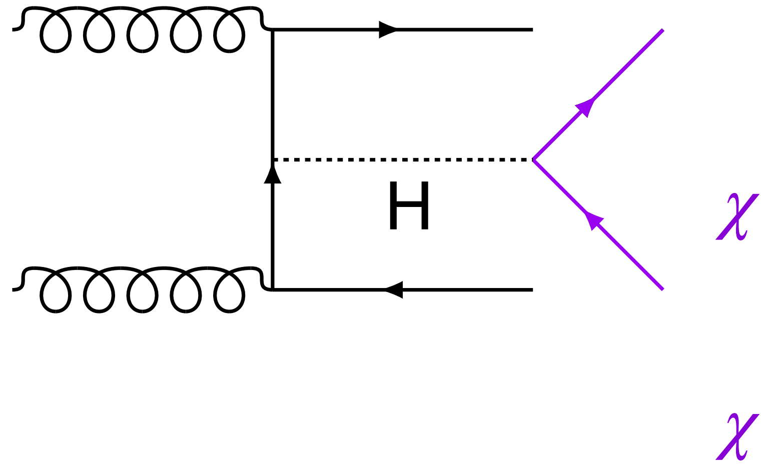
VBF



Associated production



ttH



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The VBF production mechanism drives the overall sensitivity in the direct search for invisible decays of the Higgs boson, thanks to its large production cross section and **distinctive event topology**

VBF Higgs boson to invisible decay

ATLAS arXiv:2202.07953

CMS Phys.Rev.D 105 (2022) 092007

Strategy

2 jets with large angular separation $\Delta\eta_{jj}$ and large invariant mass m_{jj}

Veto on other objects (leptons/photons)

High missing transverse momentum (trigger constraint) → reject QCD

Low $|\Delta\phi_{jj}|$ → reject QCD

⇒ Main remaining backgrounds: $Z(\nu\nu) + \text{jets}$ and $W(l\nu) + \text{jets}$ (strong and VBF productions)

VBF Higgs boson to invisible decay

arXiv:2202.07953
Phys.Rev.D 105 (2022) 092007

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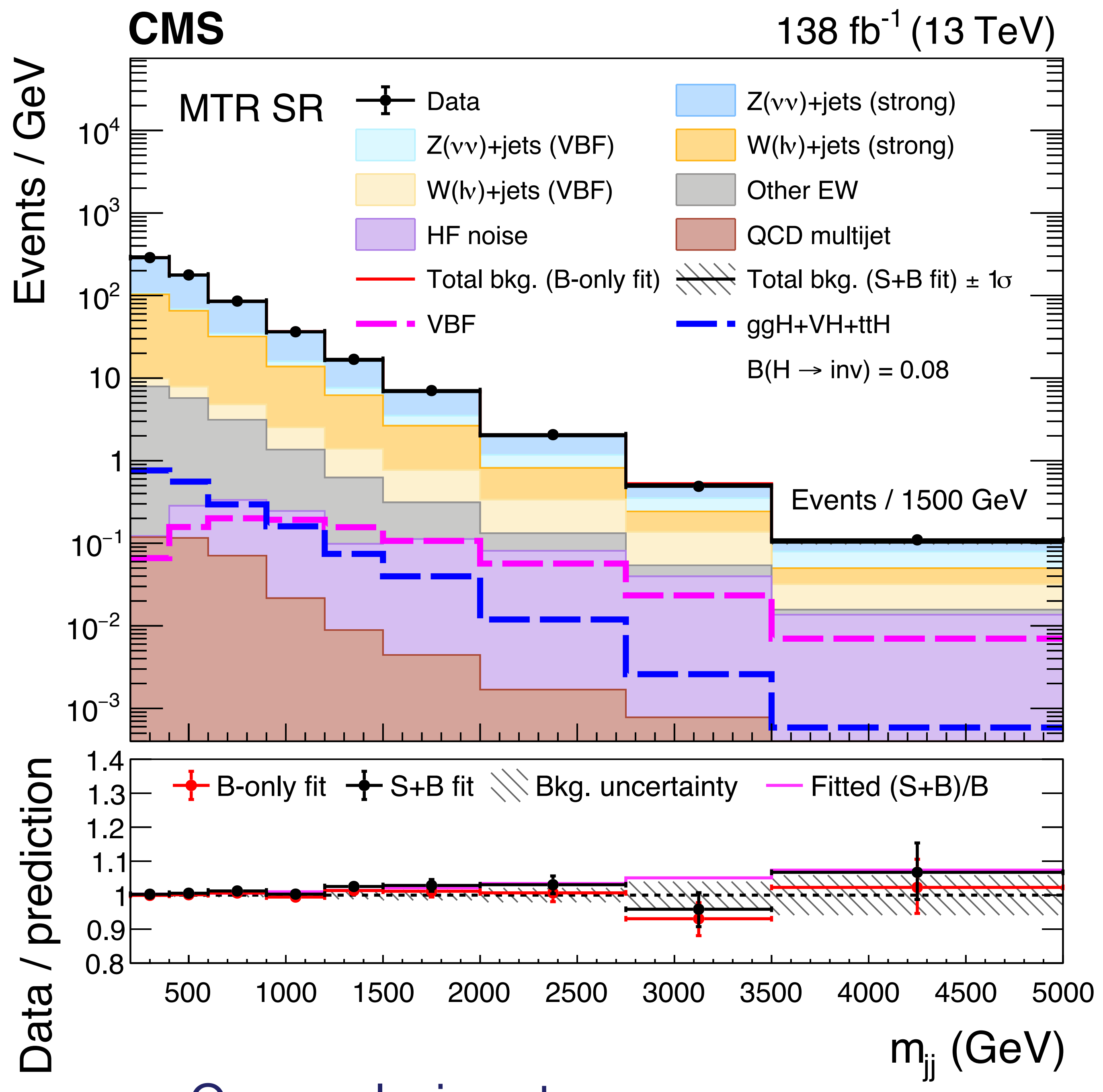

One analysis category

VBF Higgs boson to invisible decay

arXiv:2202.07953
Phys.Rev.D 105 (2022) 092007

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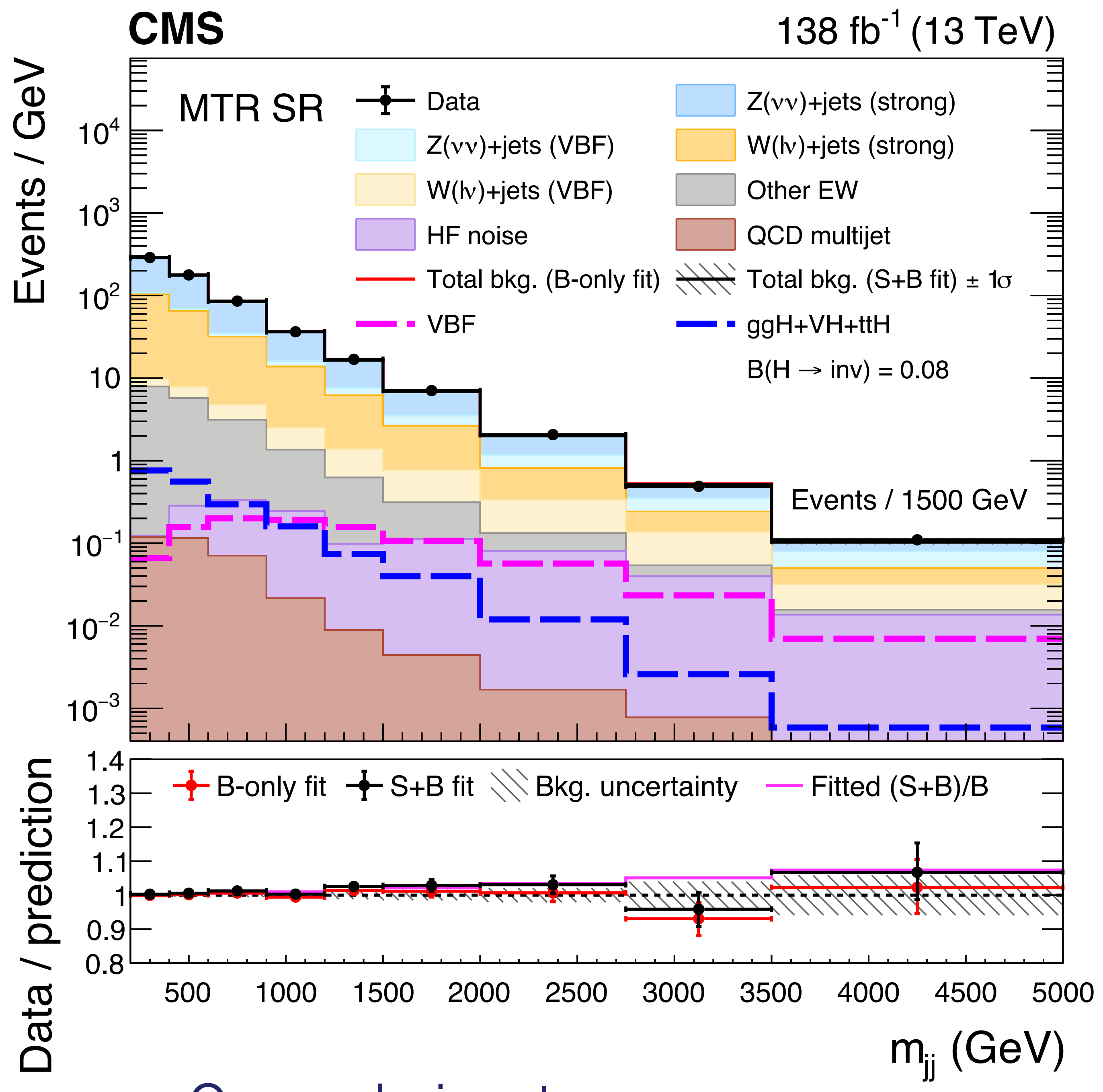

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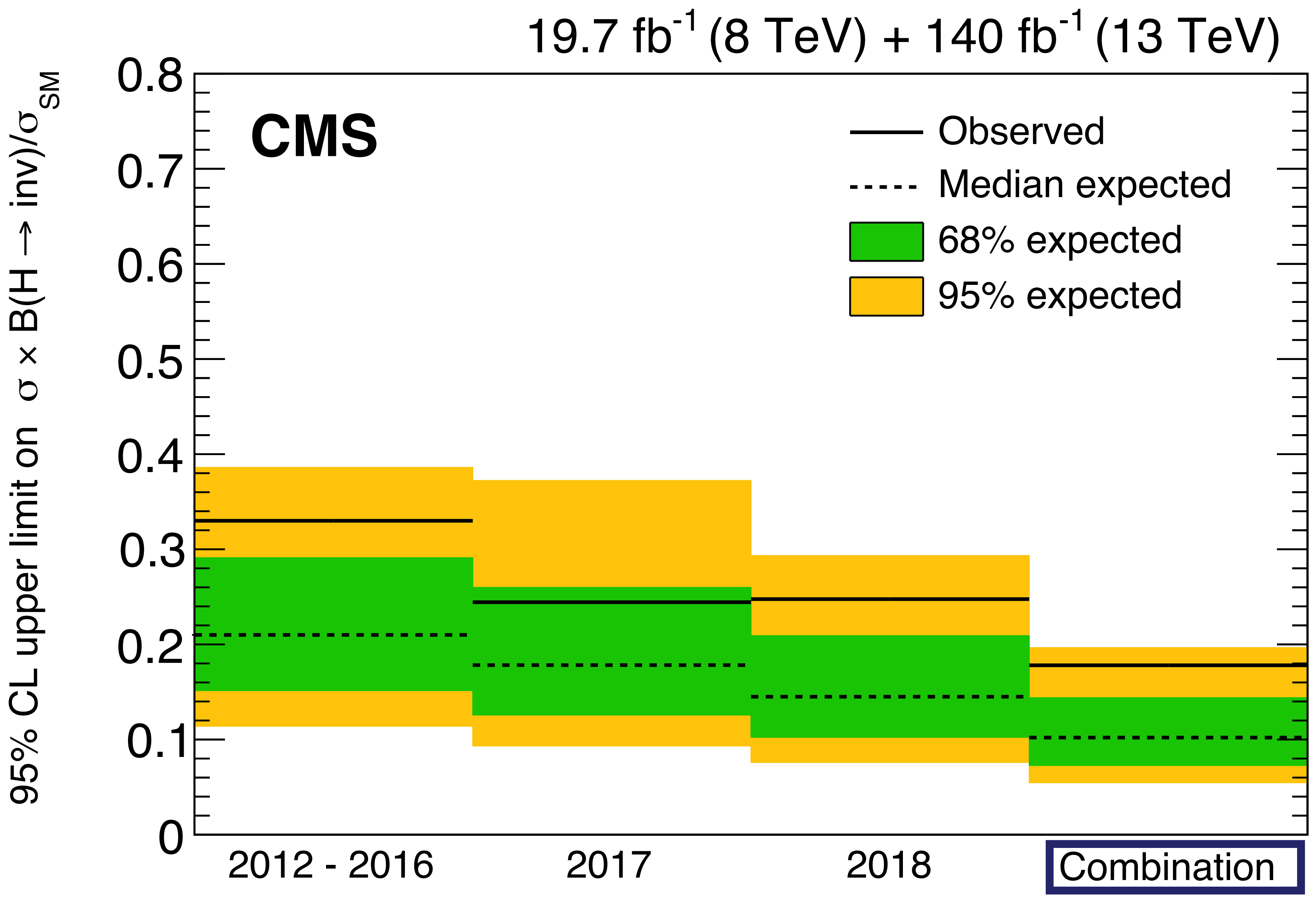


Results

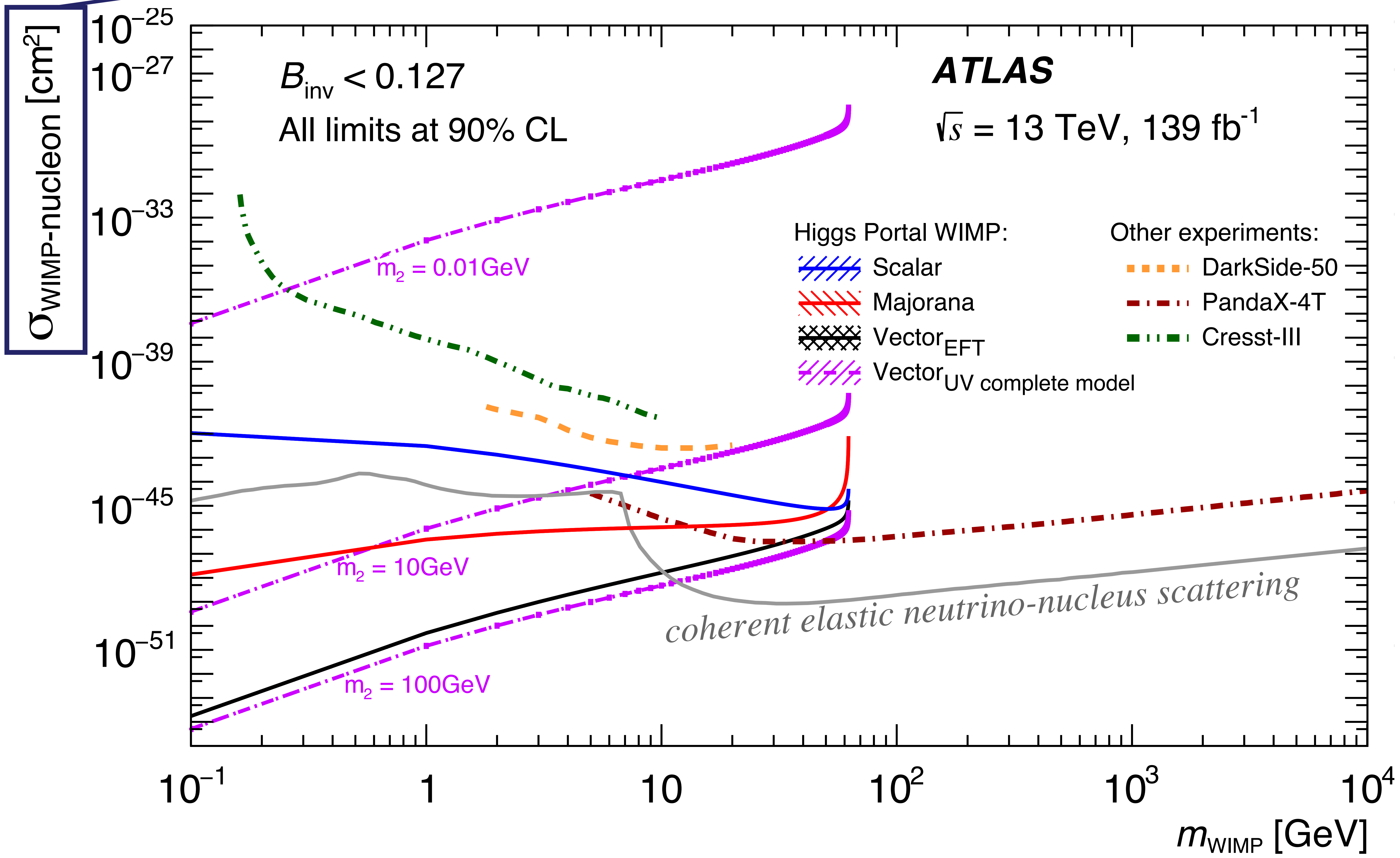
	obs(ext) UL on $\mathscr{B}_{inv}$
ATLAS	0.145(0.103)
CMS	0.18(0.10)

Interpretations

arXiv:2202.07953

Phys.Rev.D 105 (2022) 092007

Upper limits on the spin-independent **WIMP–nucleon cross section**



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arXiv:2202.07953
Phys.Rev.D 105 (2022) 092007

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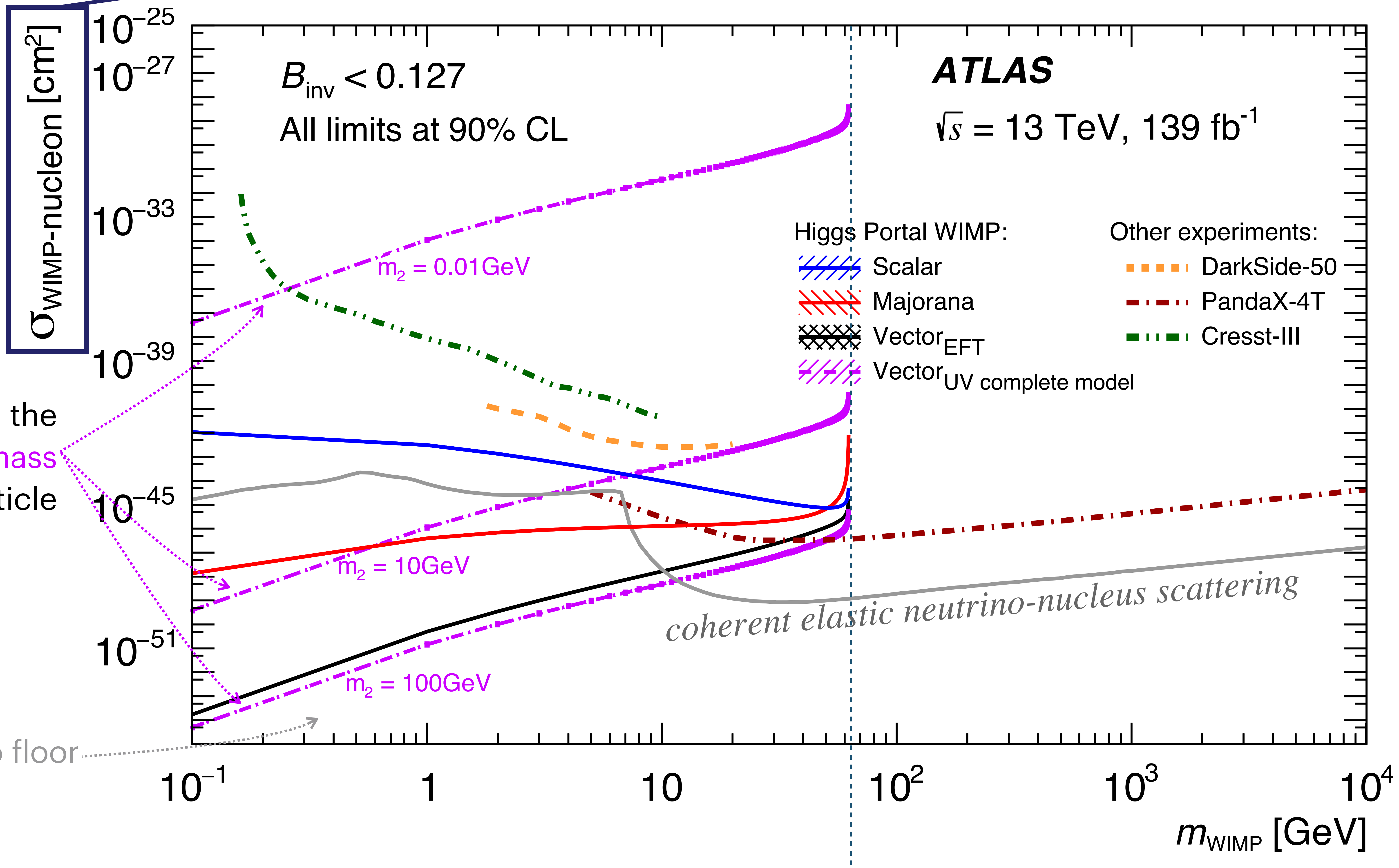

For the vector$_{\text{UV}}$ models, the dependence on the mass m_2, new scalar particle

Down in the neutrino floor

Kinematical threshold
$m_{\text{WIMP}} = m_{\text{DM}} = m_{H/2}$ = 62.5 GeV

Outperforms direct searches experiments for low m_{DM}

Lepton-Flavour Violating decays

$H \to e\mu/\mu\tau/e\tau$ are forbidden in the SM but takes place through the LFV Yukawa couplings $Y_{ij} \neq (m_i/v)\delta_{ij}$ arising in two Higgs doublet models, extra dimensions, models with flavor symmetries, models of compositeness, …

$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ & Y_{\mu\mu} & Y_{\mu\tau} \\ & & Y_{\tau\tau} \end{pmatrix}$$

Lepton-Flavour Violating decays

Phys.Rev.D 104 (2022) 032013

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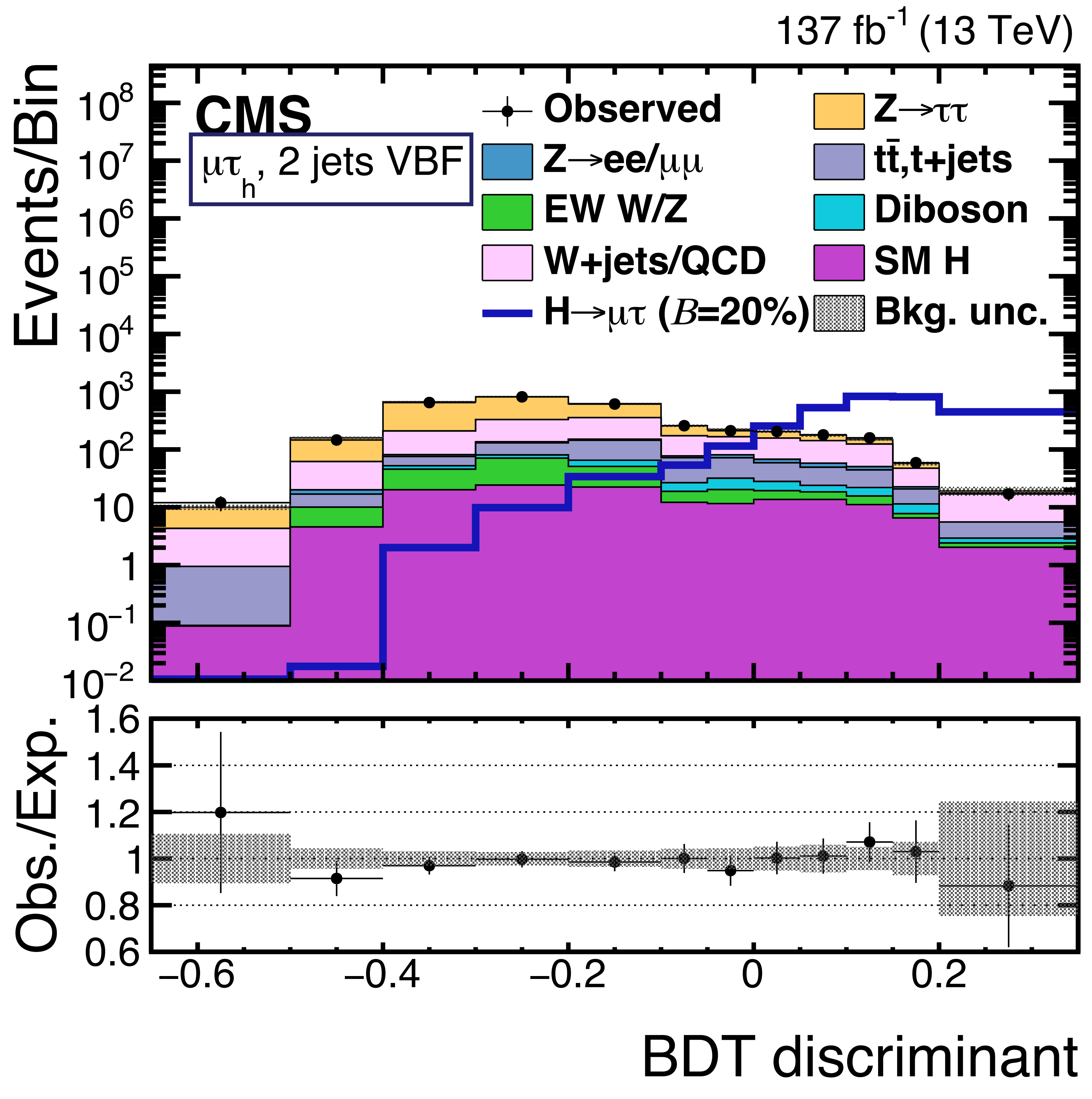
Focus on $Y_{e\tau}$ and $Y_{\mu\tau}$ ($Y_{e\mu}$ strongly constrained by $\mu \to e\gamma$)



Channels: $e\tau_h$, $e\tau_\mu$, $\mu\tau_h$, $\mu\tau_e$

Jet categories: 0j, 1j, 2j (ggH), VBF

BDTs to discriminate signal

Joint fit to BDT outputs

Most sensitive category

Lepton-Flavour Violating decays

Phys.Rev.D 104 (2022) 032013

$H \to e\mu/\mu\tau/e\tau$ are forbidden in the SM but takes place through the LFV Yukawa couplings $Y_{ij} \neq (m_i/v)\delta_{ij}$ arising in two Higgs doublet models, extra dimensions, models with flavor symmetries, models of compositeness, ...

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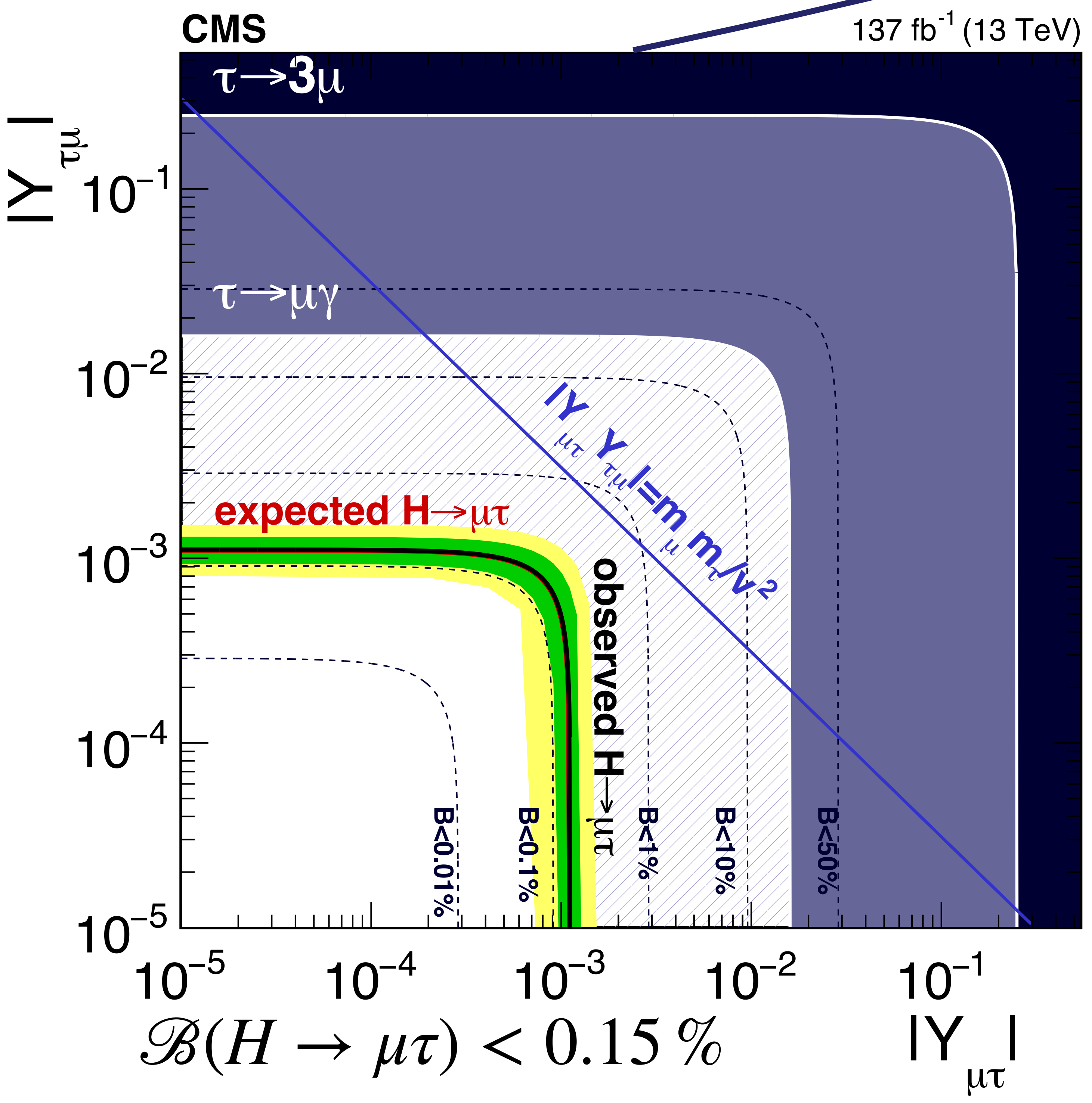
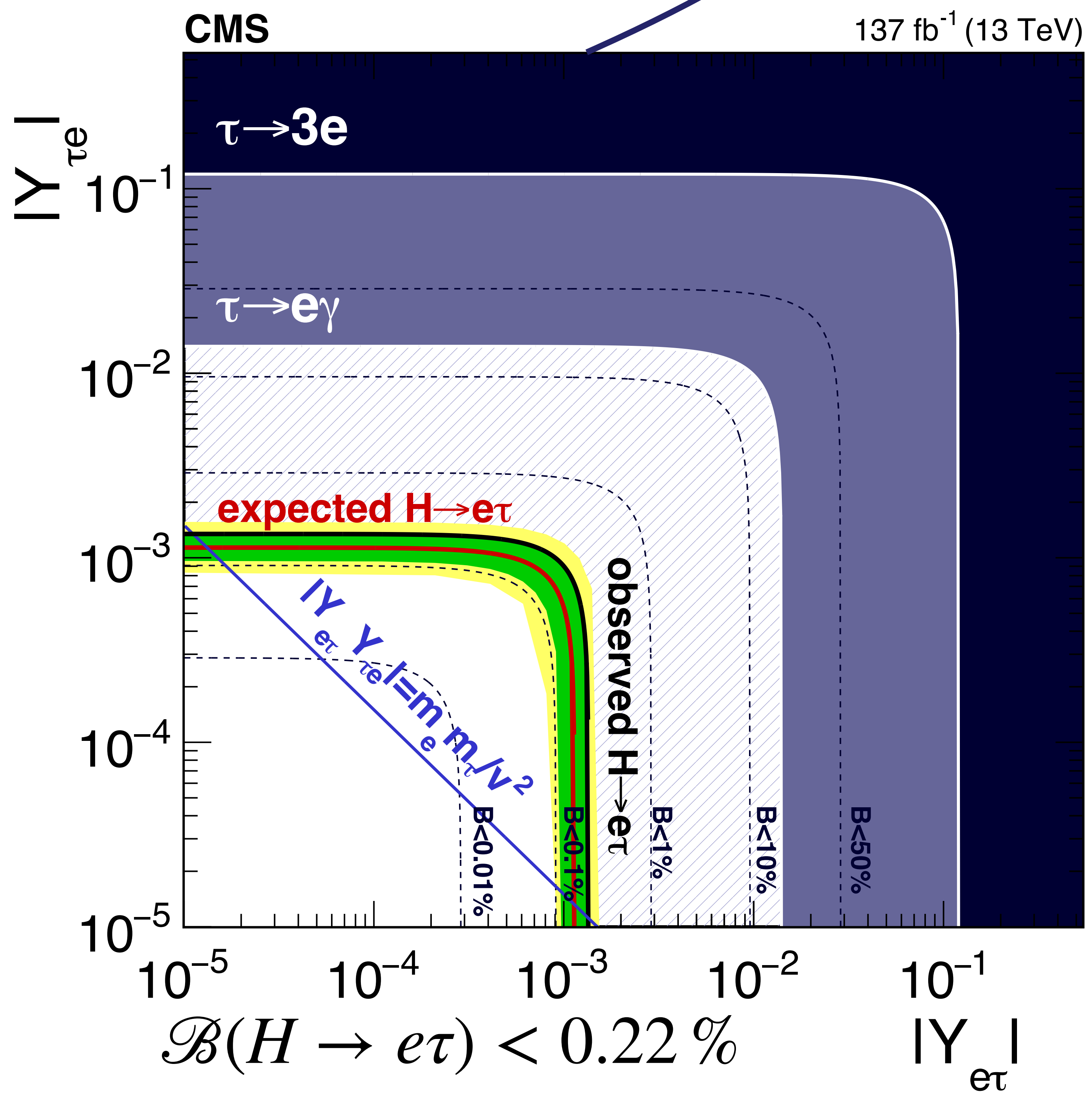
Focus on $Y_{e\tau}$ and $Y_{\mu\tau}$ ($Y_{e\mu}$ strongly constrained by $\mu \to e\gamma$)

The upper limits on $\mathscr{B}(H \to e\tau)$ and $\mathscr{B}(H \to \mu\tau)$ are used to put constraints on $Y_{e\tau}$ and $Y_{\mu\tau}$

Better than constraints from other experiments and for $Y_{\mu\tau}$ within the naturalness limit $|Y_{\mu\tau}Y_{\tau\mu}| < \frac{m_\mu m_\tau}{v^2}$



$\mathscr{B}(H \to \mu\tau) < 0.15\,\%$



$\mathscr{B}(H \to e\tau) < 0.22\,\%$

10 years

we have only started with the Higgs boson

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A fundamentally different kind of particle, a new player in our team probing Nature.

10 years

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A fundamentally different kind of particle, a new player in our team probing Nature.

We have steadily accrued knowledge about this Higgs boson.
The Higgs boson **remains** compatible with SM predictions.

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The Higgs boson **remains** compatible with SM predictions.

The coming decades are crucial to understand it and make use of it in exploring nature.