The 690 GeV resonance

Maurizio Consoli
INFN, Sezione di Catania

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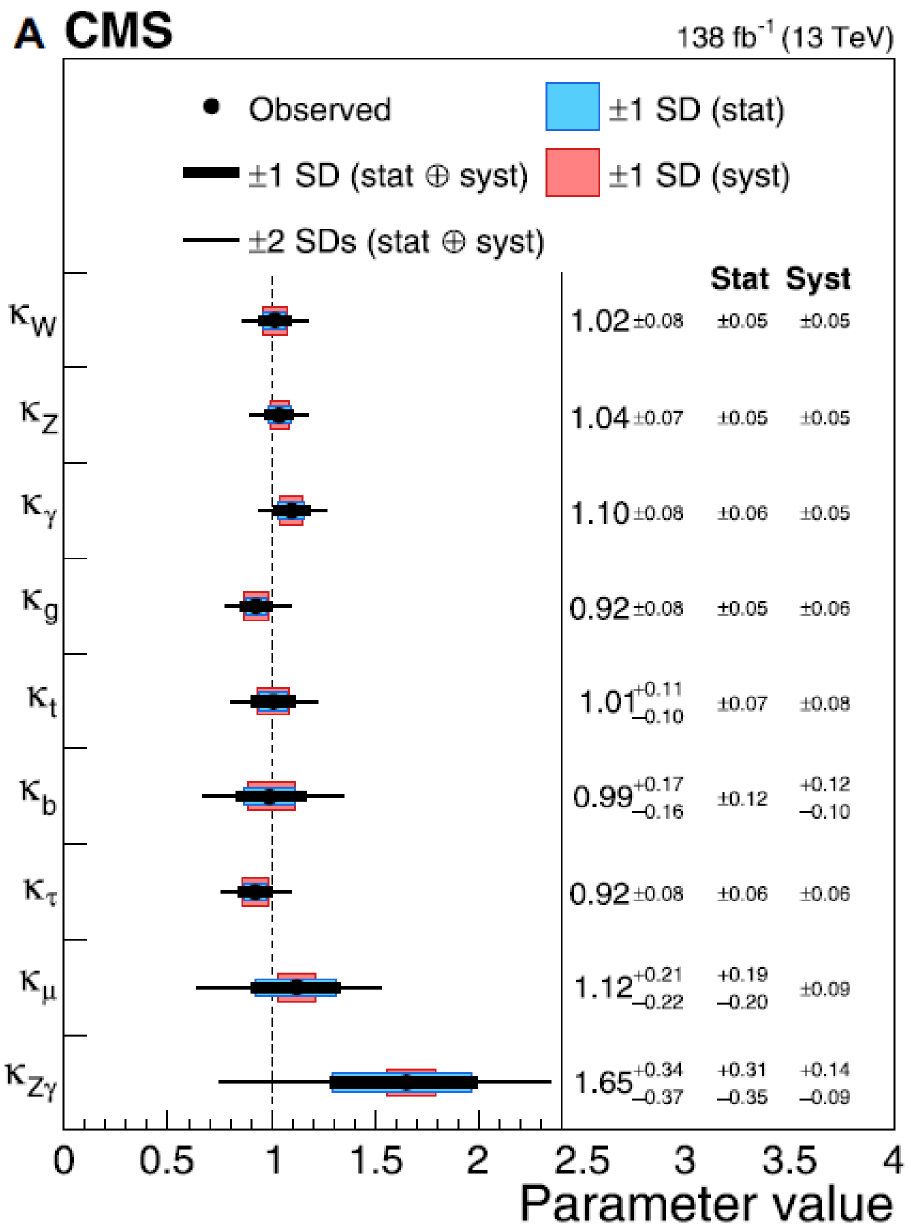
Abstract

1) Theoretical arguments + lattice simulations indicate that, besides the known resonance with $\mathbf{m_h=125\ GeV}$, the SM Higgs field may exhibit a heavy, but relatively narrow, second resonance with $\mathbf{(M_H)^{Theor} \approx 690(30)\ GeV}$

2) Several indications from LHC for a new scalar resonance in the predicted region of mass

3) The observed deviations cannot be simple statistical fluctuations. The combined value $\mathbf{(M_H)^{comb} \approx 685(10)\ GeV}$ is in very good agreement with the theoretical prediction



Higgs boson interactions

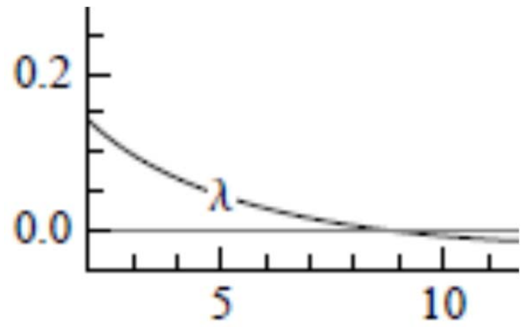
(in units of the expected values)

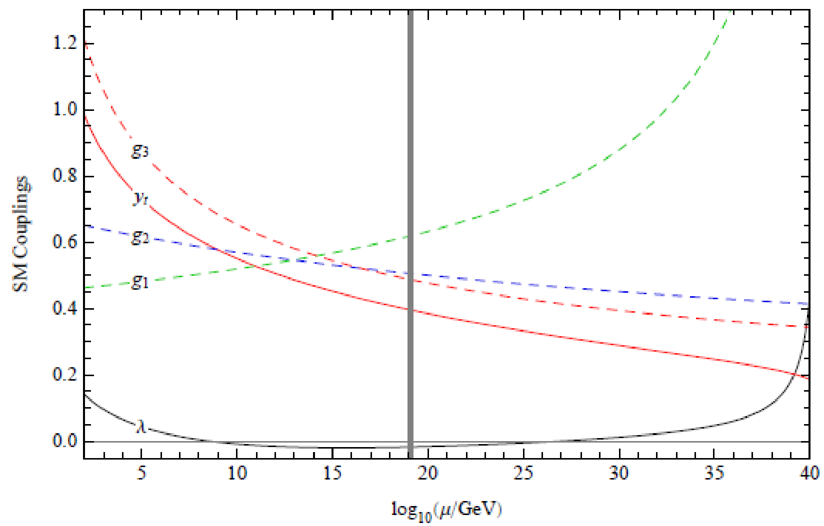
Theory → $\kappa=1$

- G. Ortona, Frontiers in Physics, September 2023

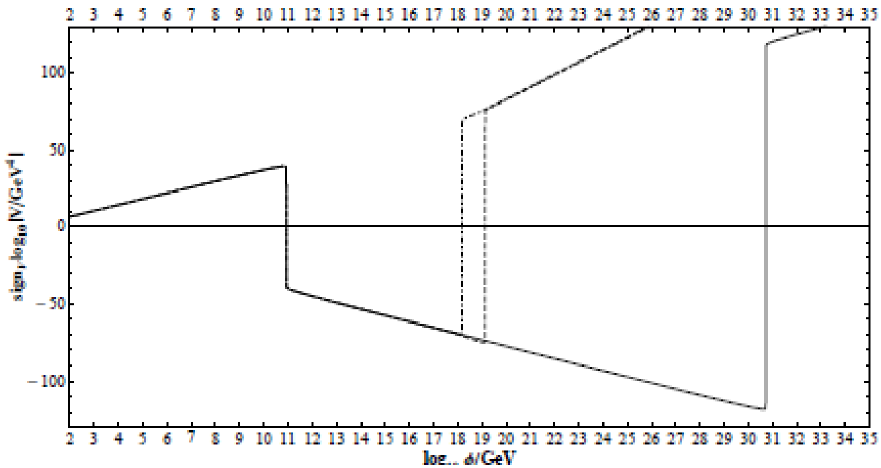
But an instability of the perturbative effective potential

- The perturbative scalar coupling $\boldsymbol{\lambda^{pert}(\phi)}$ becomes negative at Log(ϕ/GeV) $\approx$10
- Fig: from Gabrielli et al. PRD 89(2014)





- As a consequence, the absolute minimum of the potential V$\boldsymbol{(\phi)\approx\lambda^{pert}(\phi)\ \phi^4}$ is for Log(ϕ/GeV) $\approx$ 31 and is much deeper than the SM vacuum
- Fig: from Branchina and Messina PRL111(2013)



A metastable electroweak vacuum?

- In principle, the new minimum could coexist with the SM vacuum since the tunneling time is much larger than the age of the Universe, see Isidori, Ridolfi, Strumia, Nucl. Phys. B **609** (2001) 387; Degrassi, et al. JHEP **08** (2012) 098
- Yet, the problem requires a cosmological perspective because, otherwise, in an infinitely old Universe, even an infinitesimal tunneling probability would be incompatible with our existence
- Then, in view of the extreme conditions of the early Universe, the survival of the tiny electroweak minimum is somewhat surprising, which suggests that either we live in a very special and exponentially unlikely corner or new physics must exist below 10^{10} GeV (Espinosa, Giudice, Riotto, JCAP (2008) **05**)

An alternative view

- A non-perturbative description of SSB?
- Hardly to be done with the full (scalar + gauge + fermion) structure of the theory
- Adopt the early SM perspective: SSB originates in the $\mathbf{\Phi^4}$ sector ($\rightarrow$ showing, **a posteriori**, that the other couplings introduce just small corrections).
- Now, after 50 years, theoretical and numerical studies of $\mathbf{\Phi^4}$ indicate:

  1) SSB should represent a weak 1st-order phase transition

  2) a continuum limit with a Gaussian structure of Green's functions ("triviality")

  1) + 2) $\rightarrow$ 3)

  3) Exploring the infinite Gaussian-like approximations to the effective potential, where

$$\mathbf{V_{eff}(\phi) = \text{'}\underset{\text{background}}{\underset{\uparrow}{V_{class}(\phi)}}\text{'} + \text{'}\underset{\textbf{Zero-Point-Energy}\text{ of free-field-like fluctuations}}{\underset{\uparrow}{ZPE(\phi)}}\text{'}}$$

SSB is then an **infinitesimally weak** 1st-order phase transition (Coleman–Weinberg 1-loop calculation being the prototype of this class of approximations). Notice the difference with the perturbative large-ϕ form $V(\phi) \approx \boldsymbol{\lambda^{pert}(\phi)\,\phi^4}$

SSB in cutoff Φ^4 is a weak first-order phase transition

(NOT second-order as with $V_{pert}(\phi)$)

- In the standard picture (classical double-well potential + perturbative corrections) SSB is a 2nd-order phase transition
- But lattice simulations of **cutoff Φ^4** give instead a (weak) 1st order phase transition
- Magnetization as function of temperature→ See e.g. Akiyama et al. PRD 100(2019) 054510

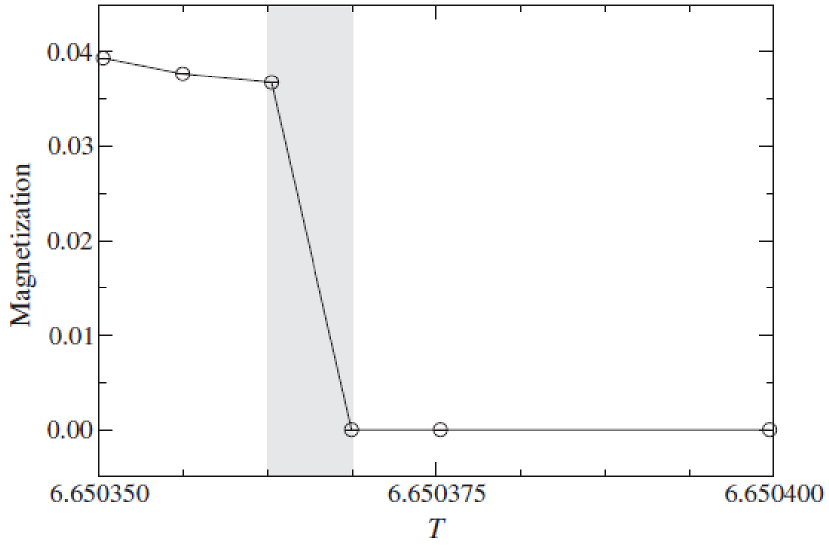


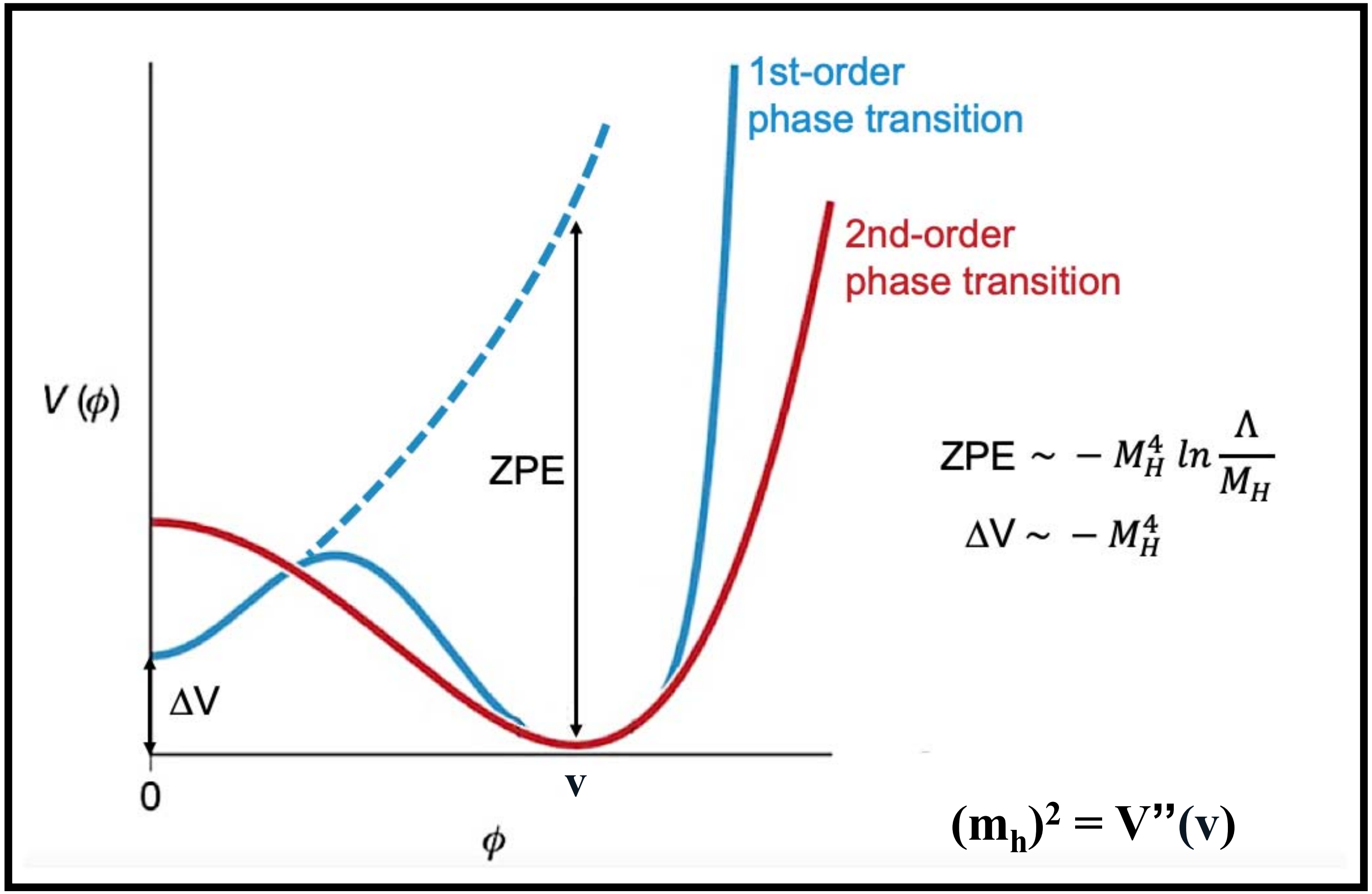
FIG. 7. Spontaneous magnetization in the thermodynamic limit with $D_{\mathrm{cut}} = 13$. Error bars, provided by extrapolation, are within symbols. $T_{\mathrm{c}}(D_{\mathrm{cut}} = 13)$ estimated by $X^{(n)}$ of Eq. (15) is within the gray band.

SSB: 2nd-order vs. 1st-order

1^{st}-order scheme

$m_h = 125$ GeV

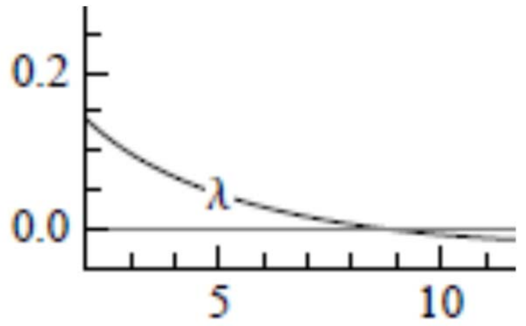
$M_H = ?$



Different views of the scalar self-coupling at the Fermi scale

- In a perturbative view (with gauge + yukawa contributions) the scalar self-coupling, at the Fermi scale **v ≡ 246 GeV**
- $\boldsymbol{\lambda^{p}(v) \equiv \lambda_{PDG} = 3\,(m_h/v)^2}$

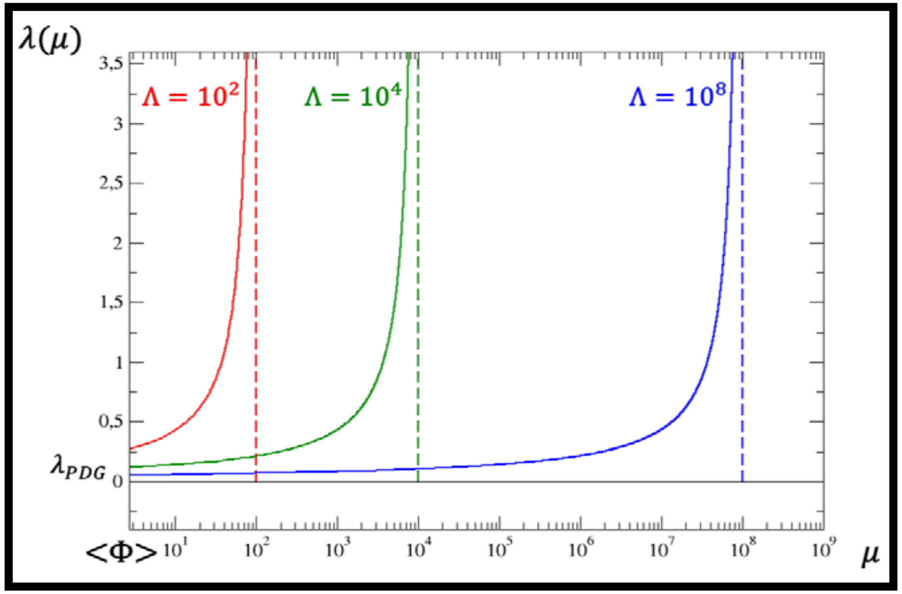
  evolves as in figure and becomes negative



- Within pure $\boldsymbol{\Phi^4}$ theory, the same coupling now depends on the Landau pole

  $$\boldsymbol{\lambda(v) \equiv \lambda_{PDG} = 3\,(m_h/v)^2 \approx L^{-1}}$$

  with $\mathbf{L \approx \ln(\Lambda/v)}$
- With experiments at the Fermi scale, the different evolution of $\lambda^{p}(\mu)$ and $\lambda(\mu)$ at large μ remains unobservable
- To minimize the **Λ**-dependence, consider all theories (Λ,λ), (Λ',λ'), (Λ'',λ'')… and a **RG** equation for $\mathbf{V_{eff}(\phi)}$, in particular for $|\mathbf{V_{eff}(v)}| \approx (\mathbf{M_H})^4 \approx (\mathbf{T_c})^4$



RG-analysis → different meaning of the two masses in Φ^4

- The mass scale $\mathbf{m_h}$ fixes the quadratic shape of the potential and the coupling $\lambda(v) = 3(m_h/v)^2 \approx L^{-1}$ between the fluctuations of the SSB vacuum **where we are living** (Higgs field and Goldstone bosons). These **observable** interactions produce deviations from a pure Gaussian structure of Green's functions and, by "triviality", should vanish when $\mathbf{L=Ln(\Lambda/v) \to \infty}$, i.e.
- $$(m_h)^2 \approx L^{-1} v^2$$
- Instead $\mathbf{M_H}$ contains the information on those **collective, unobservable** interactions between the quanta of the symmetric phase that have produced our SSB vacuum. Critical temperature to restore the symmetry is $\mathbf{T_c \approx M_H}$ however $\mathbf{M_H \approx K\, v}$ is NOT a measure of observable interactions in the broken phase.
- This reflects into a different scaling with the ultraviolet cutoff $\mathbf{\Lambda}$

$$M_H \approx K\, v \approx L^{1/2}\, m_h \gg m_h$$

- Thus the tree-level couplings for a standard Higgs boson with mass $\mathbf{M_H}$ become
- $\lambda_0 = 3(M_H/v)^2 \approx 3\, K^2 \quad \to \quad \lambda = (m_h/M_H)^2\, \lambda_0 \approx \lambda_0 \cdot L^{-1}$
- $g_0 = (M_H)^2 / v \approx K^2\, v \quad \to \quad g = (m_h/M_H)\, g_0 \approx g_0 \cdot L^{-1/2}$

Two-mass structure of the propagator

- **Scalar propagator** from the **Gaussian Effective Action** (GEA), both for the one-component and O(N) invariant Φ^4 theory, **interpolates between** $\mathbf{m_h}$ and $\mathbf{M_H}$
- Indeed, in terms of $\mathbf{L=Ln(\Lambda/v)}$ one finds

$$\mathbf{G^{-1}(p) = p^2 + (M_H)^2 \; A(p)}$$

with $\mathbf{A(p) \approx L^{-1}}$ for $\mathbf{p \rightarrow 0}$ so that $\mathbf{G^{-1}(p=0) = (m_h)^2 \approx L^{-1} (M_H)^2}$

with $\mathbf{A(p) \approx 1}$ **at large** $\mathbf{p^2}$ so that $\mathbf{G^{-1}(p) \approx p^2 + (M_H)^2}$

- Note that the continuum theory $L \rightarrow \infty$ has to become free-field

$$\mathbf{G^{-1}(p) \rightarrow p^2 + (M_H)^2}$$

with the only exception of a discontinuity in the zero-measure set **p=0**. However, in a cutoff theory, the two masses can coexist. Example, for $\Lambda \approx 10^{19}$ GeV $\rightarrow$ $\mathbf{L^{1/2} \approx 6}$

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PHYSICS AFTER THE DISCOVERY
OF THE HIGGS BOSON*

J.J. van der Bij

Institut für Physik, Albert-Ludwigs-Universität Freiburg, Germany

- «Renormalizability, however, does not imply that one must have a single Higgs particle peak. Fundamental QFT tells us only that the Higgs field must have a Källén–Lehmann spectral density [14,15]. This density must fall off fast enough at infinity, since otherwise the theory is not renormalizable. Since in some sense the Higgs field is considered to be different from other fields, it is not unreasonable to expect a non-trivial density. The premier scientific goal regarding electroweak symmetry breaking is thus to measure the Källén–Lehmann spectral density of the Higgs propagator».

- **G(p)** has not a simple one-mass structure? → **Check with lattice simulations**

- Fitting to a free-field propagator one can extract $\mathbf{m_h}$ from $[G(p)]_{latt}$ for p→0 and $\mathbf{M_H}$ from $[G(p)]_{latt}$ at larger $\mathbf{p^2}$

- We thus checked the logarithmic scaling and extracted the coefficient $\mathbf{c_2}$

$$\mathbf{M_H \approx m_h L^{1/2} c_2^{-1/2}} \qquad\qquad [\mathbf{c_2^{-1/2}}]_{\mathbf{latt}} = \mathbf{0.67 \pm 0.03}$$

Then, by combining $\mathbf{(m_h)^2 = (\lambda/3)\, v^2}$ and $\mathbf{\lambda \approx (16\,\pi^2/3) \cdot L^{-1}}$

one finds the two relations

$$\mathbf{m_h \approx (4\,\pi/3)\, v\, L^{-1/2} \approx 1.03\ TeV \cdot L^{-1/2}}$$

$$\mathbf{M_H \approx K\, v} \qquad\qquad \text{with} \quad K = (4\,\pi/3)\, [c_2^{-1/2}]_{latt}$$

or $$\mathbf{(M_H)^{Theor} \approx 690\ (30)\quad GeV}$$

- Given the estimate

$$(M_H)^{Theor} \approx 690\ (30) \quad \mathrm{GeV}$$

one can now understand the agreement with the old upper bound

$$(m_h)^{max} \approx 690\ (50) \quad \mathrm{GeV}$$

(Lang 670(80) GeV + Heller 710(60) GeV, 1993)

Indeed, from $m_h \approx 1.03\ \mathrm{TeV} \cdot L^{-1/2}$ $\quad (m_h)^{max} \rightarrow (L^{1/2})_{min} = 1.5 \pm 0.1$

so that from $M_H \approx m_h\ L^{1/2}\ c_2^{-1/2}$ $\quad$ and $[c_2^{-1/2}]_{latt} = 0.67 \pm 0.03$

$$(M_H)^{Theor} \approx (m_h)^{max}\ (1.5 \pm 0.1)\ (0.67 \pm 0.03) \approx (m_h)^{max}\ (1.00 \pm 0.08)$$

With such heavy M_H, **a posteriori**, ZPE of gauge and fermion fields are just a small correction → $[6(M_w)^4 + 3(M_z)^4] / (M_H)^4 \approx 0.002$ and $12(m_t)^4/(M_H)^4 \approx 0.05$

Basic phenomenology of the 690 GeV resonance

- The interactions with the Goldstone bosons (representing now the longitudinal Ws and Zs) are strongly suppressed by the ratio $\mathbf{(m_h/M_H)^2} \approx$ 0.032. This means that the large conventional width $\Gamma^{\mathbf{conv}}$ ($H \rightarrow WW+ZZ$) $\approx$ 150 GeV is reduced to about $\Gamma(H \rightarrow WW+ZZ) \approx 5$ GeV.
- Altogether, for $(M_H)^{Theor} =$ 690 (30) GeV , the total width is expected in the range $\Gamma(H \rightarrow all) \approx 25 \div 35$ GeV with a main branching ratio into top-quark pairs $\approx 75 \div 80$ % and the other main decay modes $B(H \rightarrow ZZ) = 0.053(12)$, $B(H \rightarrow WW) = 0.11(2)$, $B(H \rightarrow hh) = 0.05(1)$
- Finally, due to its weak coupling to longitudinal Ws and Zs, H-production at LHC through Vector-Boson Fusion (VBF) is negligible as compared to gluon-gluon-Fusion (ggF) with typical cross section $\sigma^{ggF}(pp \rightarrow H) = 1100(170)$ fb.
- Example: $\sigma^{\mathbf{peak}}(pp \rightarrow H \rightarrow ZZ) = 58(15)$ fb and $\sigma^{\mathbf{peak}}(pp \rightarrow H \rightarrow hh) = 55(10)$ fb.
- ATLAS bkg: $\langle \sigma^{\mathbf{bkg}}(pp \rightarrow ZZ) \rangle \approx$ 50 fb (E=665÷720 GeV)
- ATLAS bkg : $\langle \sigma^{\mathbf{bkg}}(pp \rightarrow hh) \rangle \approx$ 80 fb (E=650÷700 GeV)

$$\langle S/B \rangle = 1 + \langle \sigma^{\mathbf{peak}}/\sigma^{\mathbf{bkg}} \rangle \approx \mathbf{1.6 \div 2.2}$$

But things are not so simple (interference, binning of the data…). Besides, **we even don't know if there is a new resonance**. **Then, how could we know its production mechanisms?** Before any definite assumption, **we need a simplest scheme** (some background + resonating amplitude) to describe the basic phenomenology.

Background + resonance: excess/defect sequences

We have adopted the model of a resonance interfering with a background $\sigma_B(E)$.
This produces a total cross section ($s = E^2$ and $\Gamma_H = \Gamma(H \to \text{all})$)

$$\sigma_T(E) \;=\; \sigma_B(E) + \sigma_{\rm BW}(E) + \sigma_{\rm int}(E) \;,$$

where

$$\sigma_{\rm int}(E) \;=\; 2\sqrt{\sigma_B(E)\sigma_{\rm peak}}\,\frac{(M_H^2 - s)}{\Gamma_H M_H}\,R(E)$$

and

$$\sigma_{\rm BW}(E) = \sigma_{\rm peak}\cdot R(E)$$

$$R(E) \;=\; \frac{(\Gamma_H M_H)^2}{(s - M_H^2)^2 + (\Gamma_H M_H)^2} \;.$$

- If Breit-Wigner peak is comparable to (or smaller than) the BKG (otherwise easy to see it...). Then, sizeable interference. Example: $\Gamma/M=0.03$ and $\sigma_{peak}/\sigma_b(M) = 0.7$. For a bin size ΔE,
  . $\Delta E = \Gamma$ $\Delta E=2\Gamma$ $\Delta E= 2\Gamma$
- [M −3Γ/2, M – Γ/2] → **S/B =1.80** & [M −3Γ, M – Γ] → **S/B =1.44** & [M −5Γ/2, M – Γ/2] → **S/B = 1.60**
- [M – Γ/2, M + Γ /2] → **S/B =1.54** & [M − Γ, M + Γ] → **S/B =1.39** & [M −Γ/2, M + 3Γ/2] → **S/B =1.03**
- [M + Γ/2, M + 3Γ/2] → **S/B = 0.47** & [M + Γ, M + 3Γ] → **S/B =0.61** & [M+3Γ/2, M +7Γ/2] → **S/B = 0.65**

Note that, if the binning is asymmetric with respect to M, you could see NO enhancement in that bin which includes the mass. This is why **excess/defect sequences** become more important than the height of the peak itself. Look for such sequence in different channels

Remarks (before considering the data)

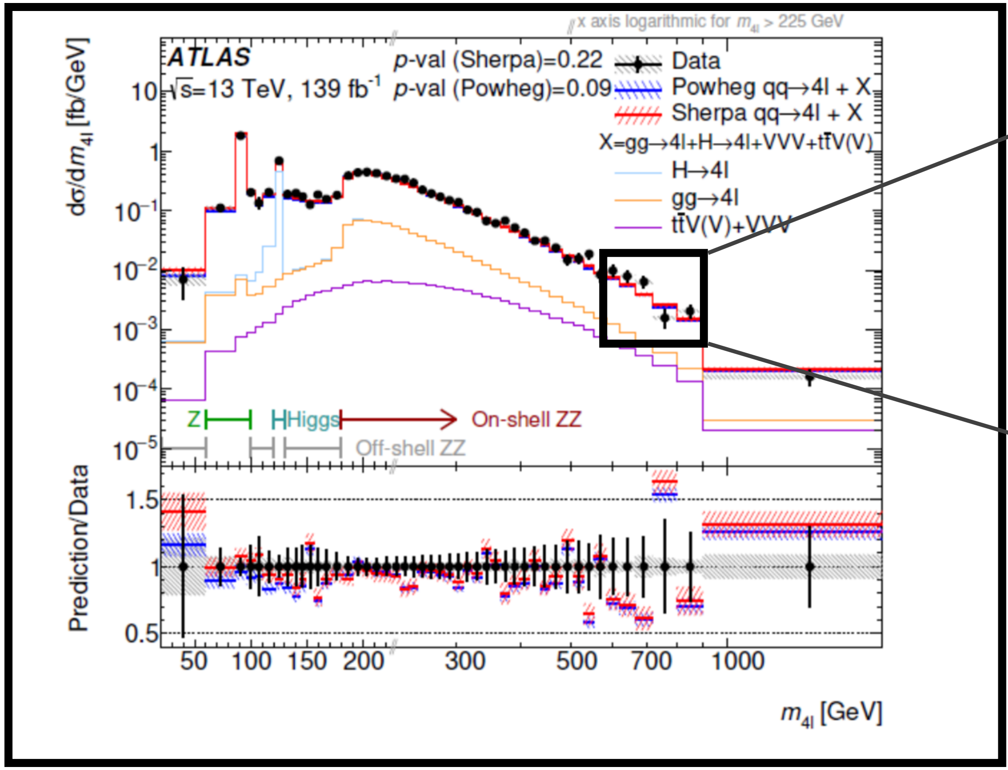
- With a definite mass prediction of 690 (30) GeV, one should look for deviations from the background nearby, say in the region 600 ÷ 800 GeV, so that **local deviations cannot be downgraded** by the so called “Look Elsewhere” Effect (LEE).

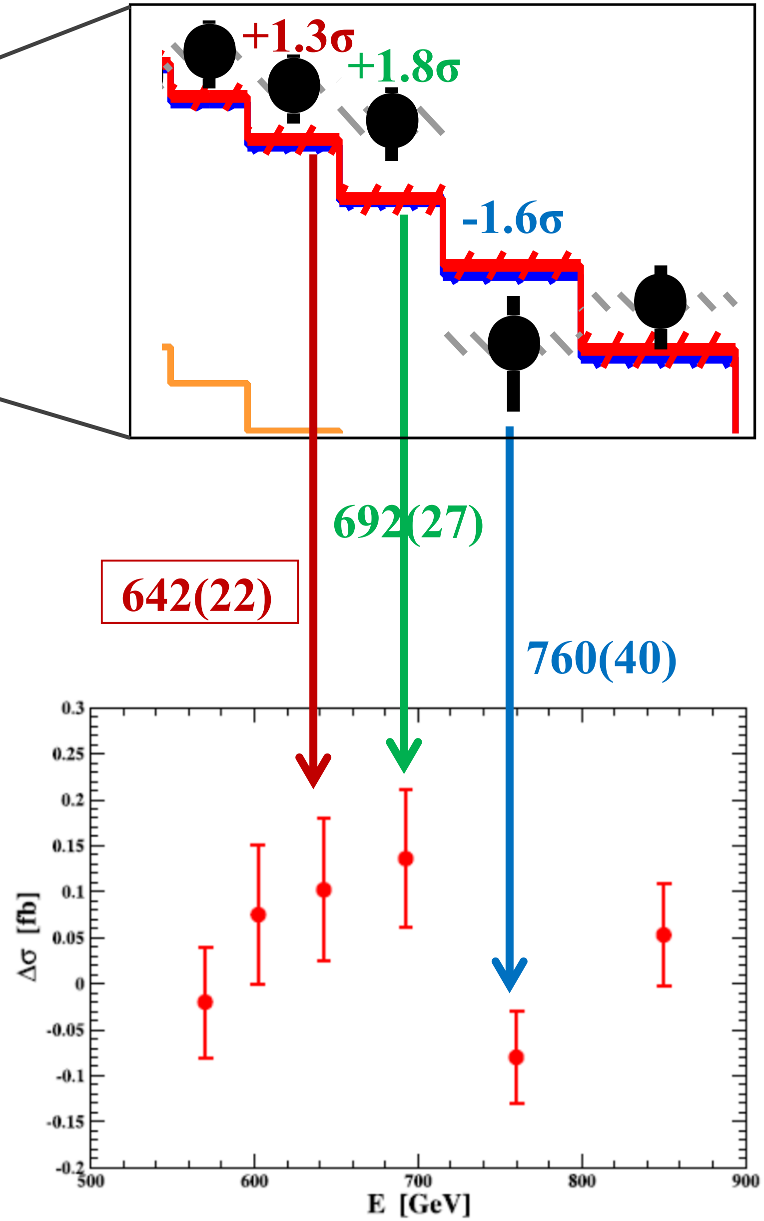
- With the present energy and luminosity of LHC, the second resonance is too heavy to be seen unambiguously by both collaborations in all possible channels.

- The **statistical significance of deviations** from the background should be evaluated by taking into account the phenomenology of **a resonance that can produce both excesses and defects of events.**

ATLAS charged 4-lepton cross-section m_{4l} = 600÷900 GeV

see Fig.5 of JHEP 07(2021)005; arXiv:2103.01918v1 [hep-ex]





Bin [GeV]	σ_{EXP} [fb]	σ_{B} [fb]	$(\sigma_{\mathrm{EXP}} - \sigma_{\mathrm{B}})$ [fb]
555–585	0.252 ±0.056	0.272 ± 0.023	−0.020 ± 0.060
585–620	0.344 ± 0.070	0.259 ± 0.021	+0.085 ± 0.075
620–665	0.356 ± 0.075	0.254 ± 0.023	+0.102 ± 0.078
665–720	0.350 ± 0.073	0.214 ± 0.019	+0.136 ± 0.075
720–800	0.126 ± 0.047	0.206 ± 0.018	−0.080 ± 0.050
800–900	0.205 ± 0.052	0.152 ± 0.017	+0.053 ± 0.055

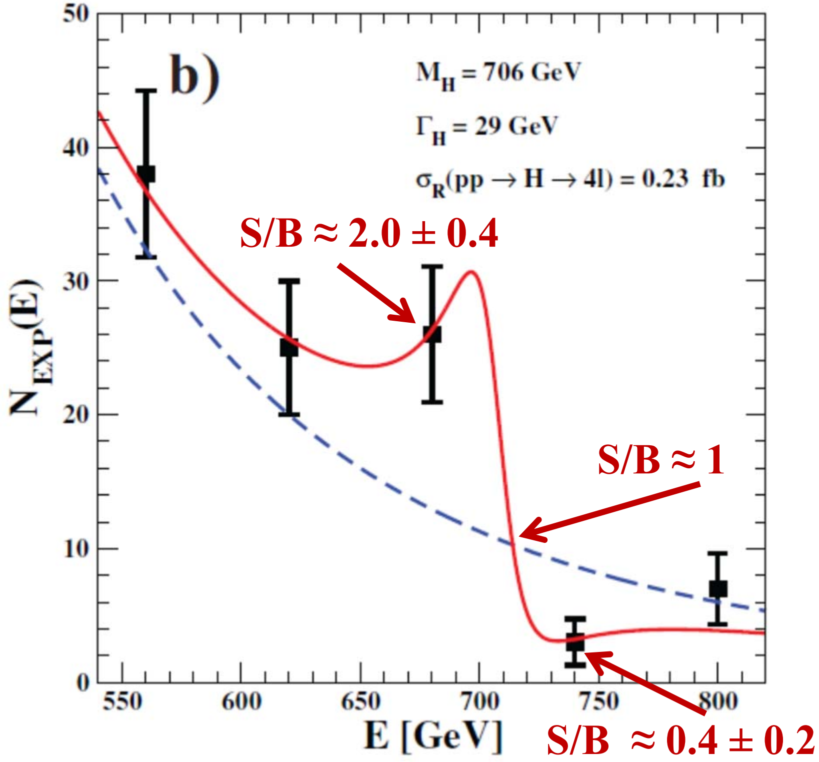
ATLAS ggF-low charged 4-lepton events

EPJC **81** 332 (2021)

- The dominant ATLAS ggF-low events grouped in large bins, here 60 GeV, as for the previous cross section plot N.B. average acceptance ≈ 0.38

- Fitted mass and width :
- **M= 706(25) GeV** and **Γ = 29(20) GeV**
- **Γ/M ≈ 0.04 ± 0.03**
- Full red curve and blue dashed background coincide for E ≈ M

- From cross section data (symmetric error bars):
- **M=677(22) GeV** and **Γ ≈ 21(16) GeV**
- **Γ/M ≈ 0.03 ± 0.02**



Fit with interference of a background + resonance

ATLAS 4-leptons (including llνν events)

EPJC **81** 332 (2021)

- Including llνν events the same excess-defect pattern is confirmed (although with lower statistical significance)
- Our fitted averages, from cross-section data and ggF-low 4-lepton events, are
- **‹M› ≈ 691 GeV** and **‹Γ› ≈ 25 GeV** **‹Γ/M › ≈ 0.036**
- Compare with ATLAS by averaging

  $\Gamma/M = 0.01$ and 0.05

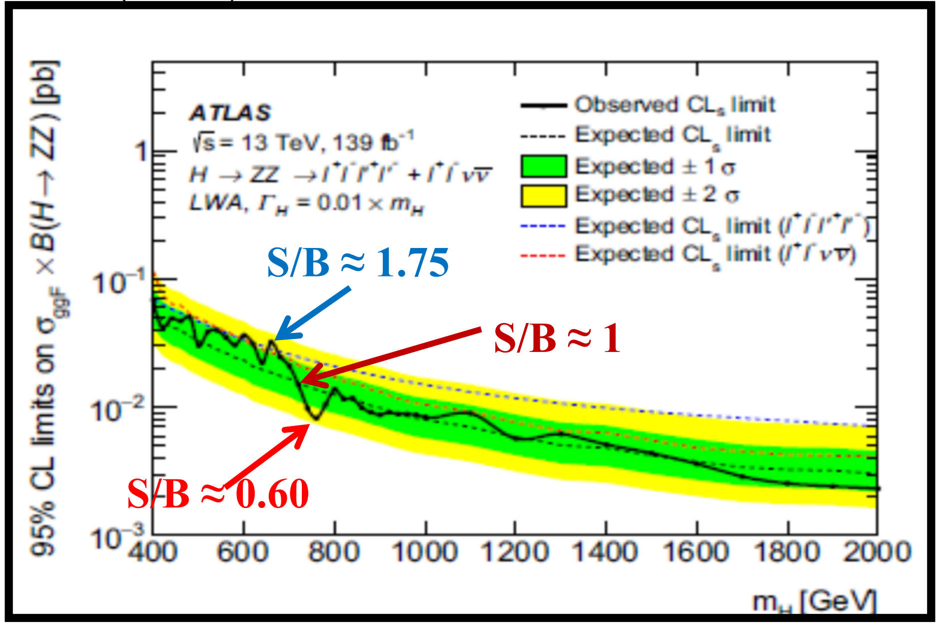
- E ≈ 650 GeV → **‹S/B› ≈ 1.60**
- E ≈ 700 GeV → **S/B ≈ 1**
- E ≈ 750 GeV → **‹S/B› ≈ 0.62**

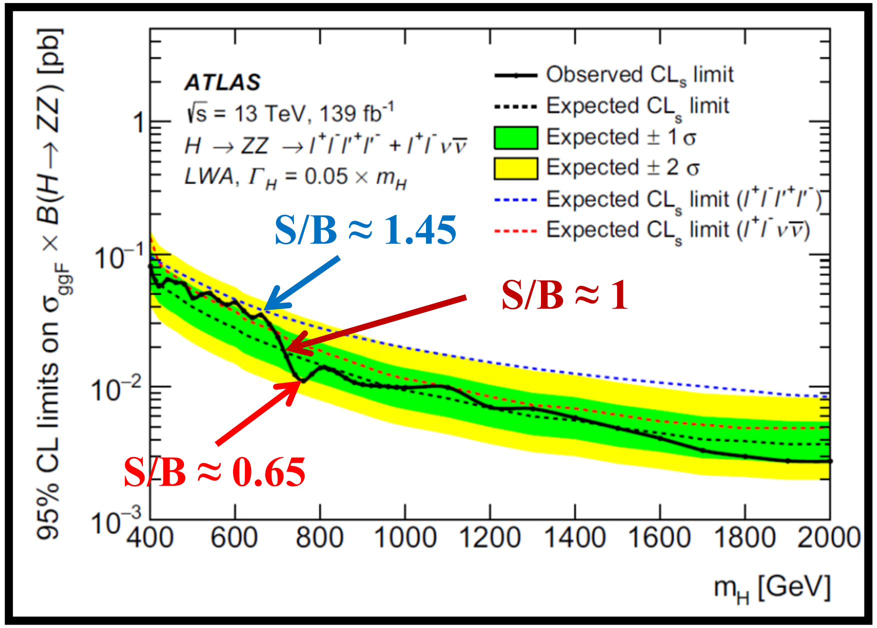
$$\Delta E = 2\Gamma$$

$[M - 5\Gamma/2,\ M - \Gamma/2] \rightarrow S/B = 1.60$

$[M - \Gamma/2,\ M + 3\Gamma/2] \rightarrow S/B = 1.03$

$[M + 3\Gamma/2,\ M + 7\Gamma/2] \rightarrow S/B = 0.65$



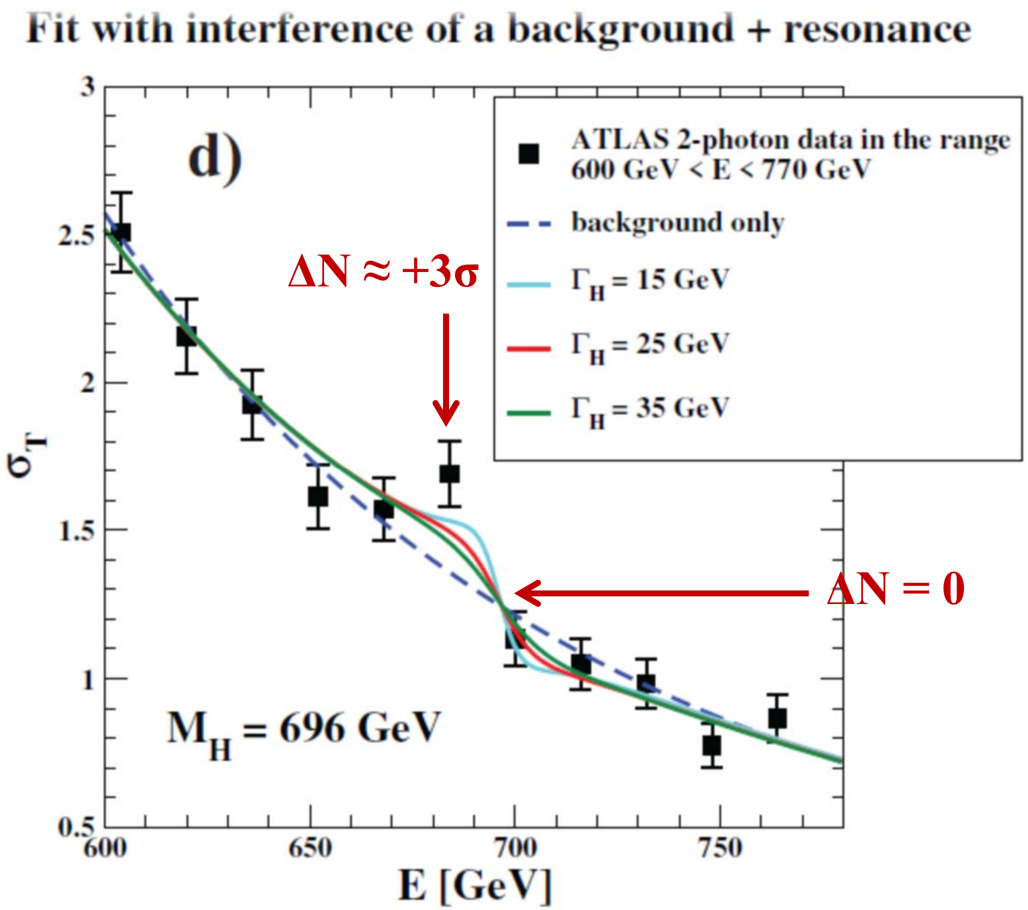


ATLAS high mass γγ events

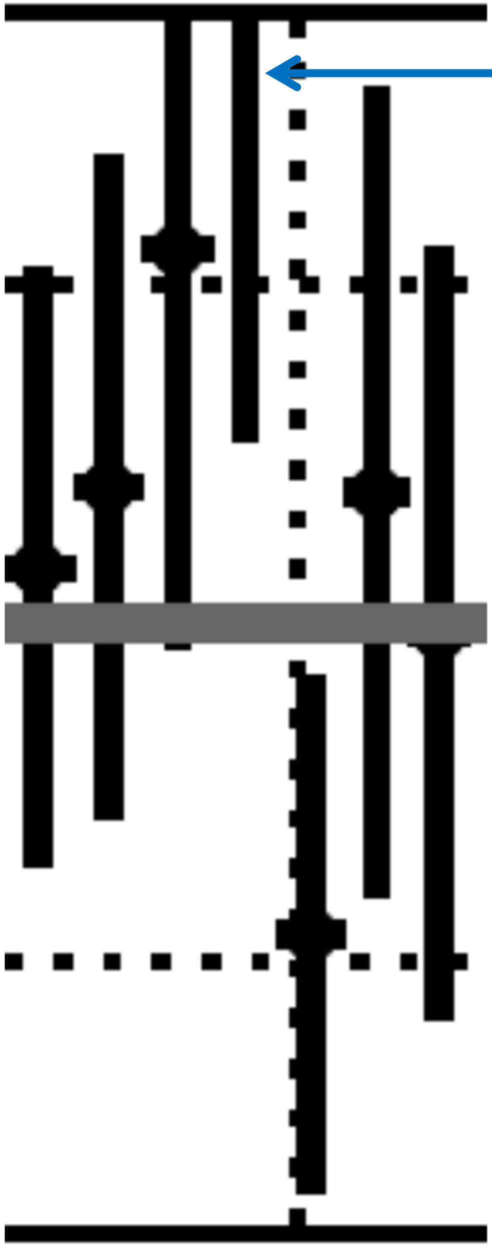
- Fit to the ATLAS data including
  Background + Interference

- All curves coincide with the background for the fitted mass M=696(12) GeV where interference vanishes

- This is because, here, background is much larger than the pure BW term



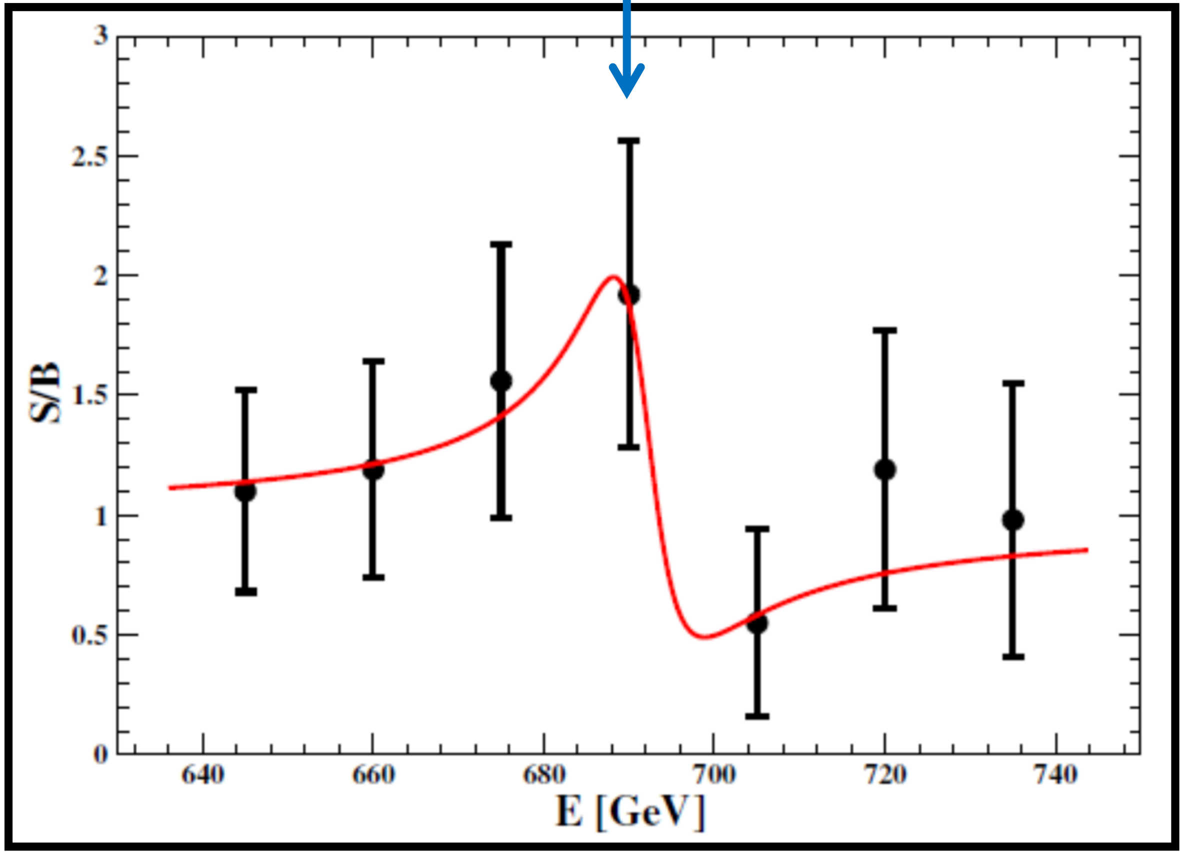
CMS 4-lepton data: S/B from 640 to 740 GeV



690 GeV

690 GeV

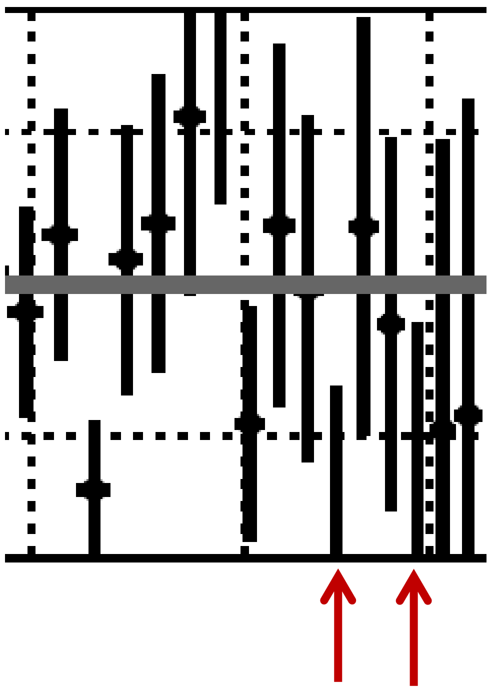
- **M = 692(15) GeV** **$\Gamma = 10_{-8}^{+16}$ GeV**



CMS 4-lepton data: S/B ratio

(CMS PAS HIG-24-002 - July 2024)

M_H = 692 GeV (and various widths)



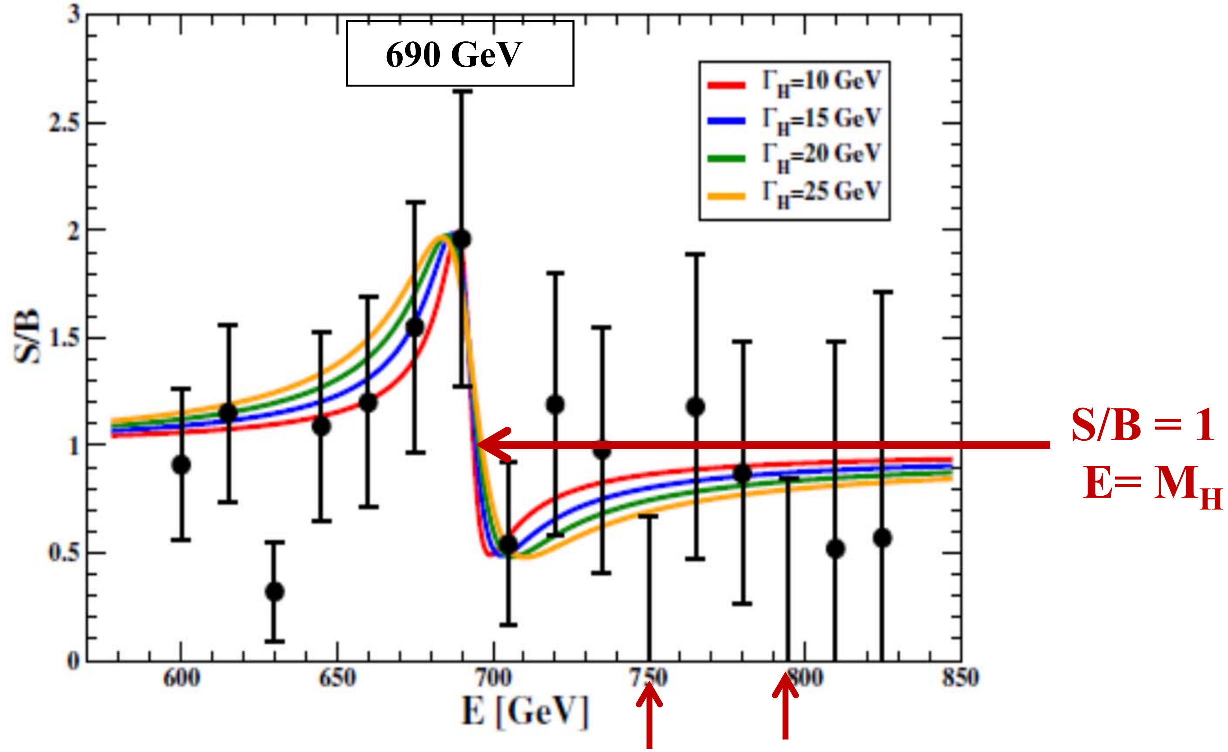


Figure 4. Comparing the CMS S/B ratios to eq. (5.2), for $M_H = 692$ GeV, $N_R = 0.55$, and four different widths.

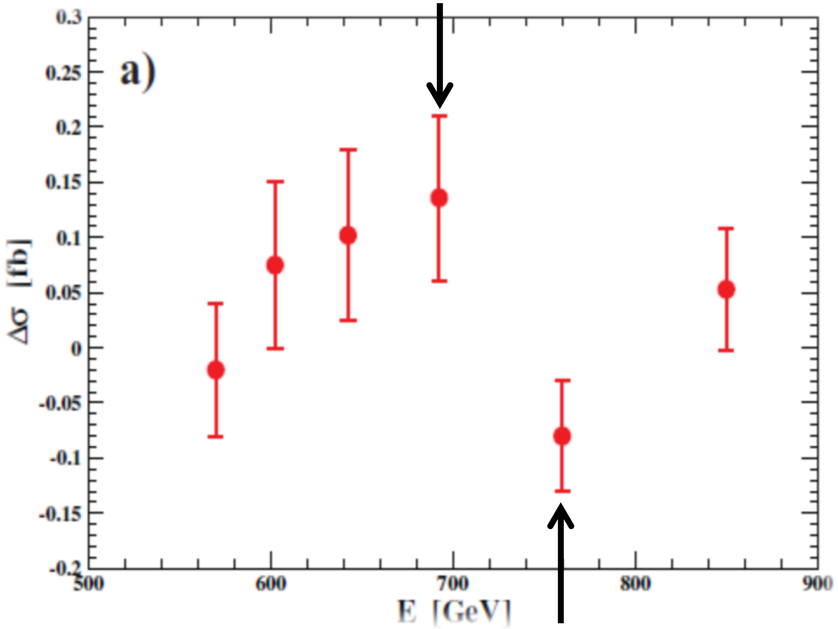
empty bins

4-lepton channel: ATLAS + CMS

ATLAS 4-lepton cross section

JHEP **07**(2021)005

- **$\Delta\sigma(E) = \sigma^{exp}(E) - \sigma^{bkg}(E)$**
- **692(27) GeV   ‹S/B› = 1.64 ± 0.34**

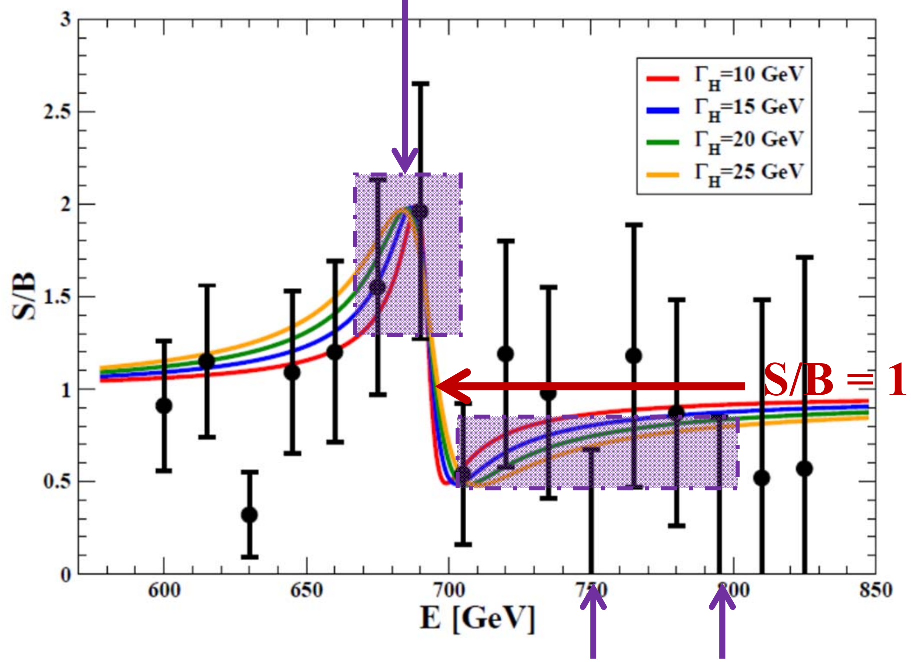


- **760(40) GeV   ‹S/B› = 0.61 ± 0.23**

CMS 4-lepton data

- **682 (15) GeV**

‹S/B› = 1.70 ± 0.45



- **‹S/B› = 0.65 ± 0.15**
- **Empty bins at 750 and 795 GeV are crucial**

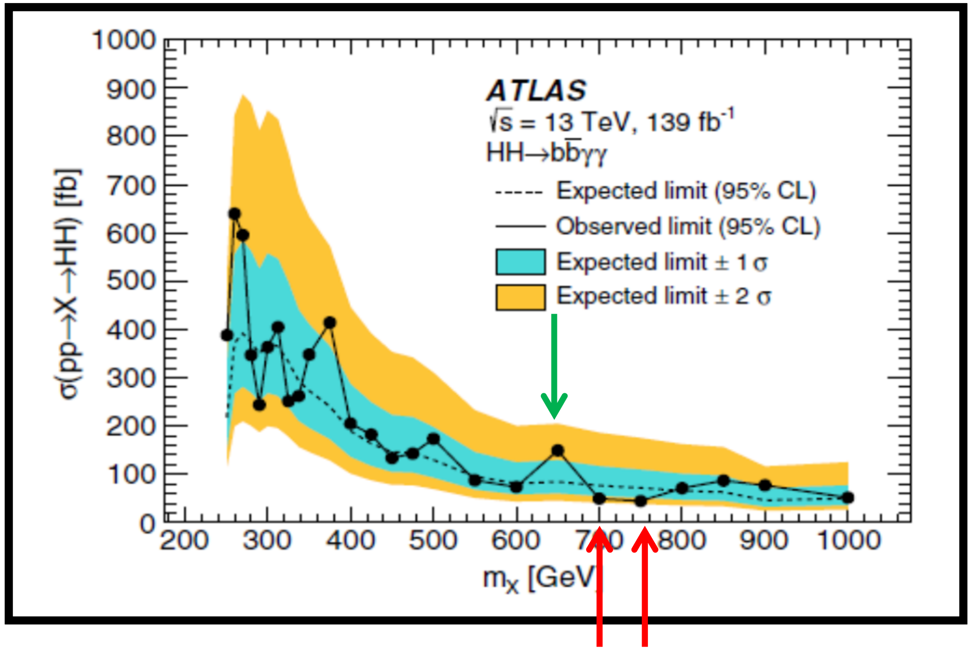
The ATLAS bb+γγ data

PRD **106** (2022) 052001

- Limits for the cross section σ(pp→X→hh). Large uncertainties, but simply **shift the central values up and down.** Important discrepancies
- The differences in consecutive energy bins (j=1, 2…6 → 550, 600...800 GeV)

$$\Delta\,(j+1, j) = \sigma(j+1) - \sigma\,(j)$$

cannot be explained. The pairs (4,3) and (6,5) give combined deviation from background of about **3.8σ.** The pairs (3,2) and (6,5) give a slightly smaller **3.3σ**



j	σ^{obs}(j) [fb]	σ^{expected}(j) [fb]
1	87.5 (15.6)	${95.1^{+50.4}_{-26.6}}^{+137.3}_{-44.1}$
2	73.6 (14.3)	${81.1^{+43.3}_{-22.7}}^{+119.0}_{-37.6}$
3	149.3 (20.3)	${84.4^{+44.4}_{-23.6}}^{+120.1}_{-39.1}$
4	49.4 (12.0)	${76.5^{+40.0}_{-21.4}}^{+109.6}_{-35.4}$
5	44.5 (12.0)	${71.7^{+37.6}_{-20.0}}^{+103.3}_{-33.2}$
6	71.0 (14.0)	${65.8^{+35.1}_{-18.4}}^{+96.5}_{-30.5}$

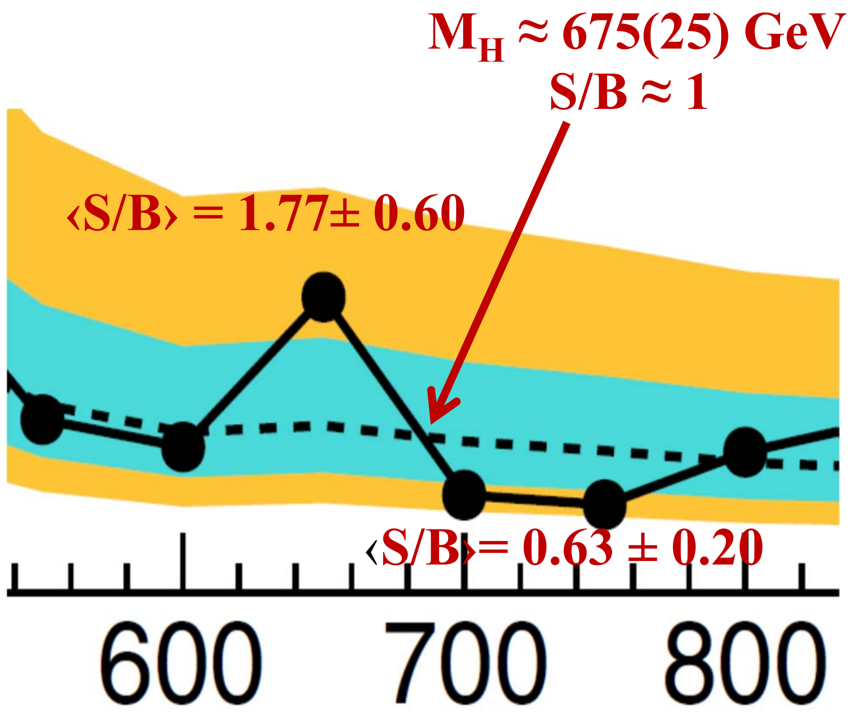
≈ 3

$\Delta^{\text{obs}}(2,1) = -13.9 \pm 21.1$	$\Delta^{\text{expected}}(2,1) = -19.9 \pm 12.4$
$\Delta^{\text{obs}}(3,2) = +75.7 \pm 24.8$	$\Delta^{\text{expected}}(3,2) = +3.1 \pm 1.4$
$\Delta^{\text{obs}}(4,3) = -99.9 \pm 23.6$	$\Delta^{\text{expected}}(4,3) = -11.4 \pm 7.2$
$\Delta^{\text{obs}}(5,4) = -4.9 \pm 17.0$	$\Delta^{\text{expected}}(5,4) = -6.8 \pm 4.2$
$\Delta^{\text{obs}}(6,5) = +26.5 \pm 18.4$	$\Delta^{\text{expected}}(6,5) = -7.9 \pm 4.7$

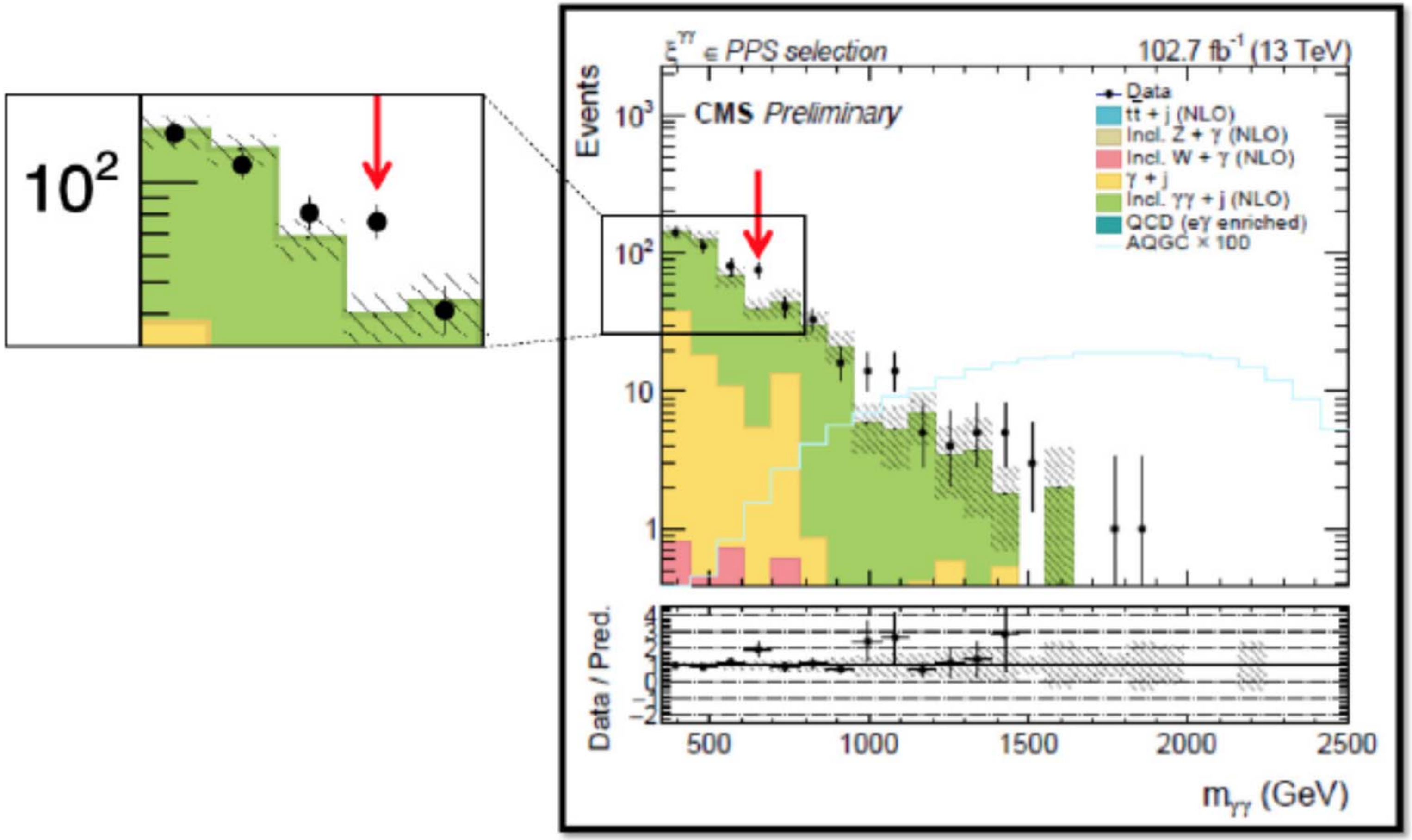
The same excess/defect trend

below 700 GeV		above 700 GeV	
‹S/B› = 1.64 ± 0.34	→	‹S/B› = 0.61 ± 0.23	ATLAS 4-leptons
‹S/B› = 1.70 ± 0.45	→	‹S/B› = 0.65 ± 0.15	CMS 4-leptons
‹S/B› = 1.77 ± 0.60	→	‹S/B› = 0.63 ± 0.20	ATLAS (bb+γγ)

A new resonance H around 700 GeV with B(H→ZZ) ≈ B(H→hh)



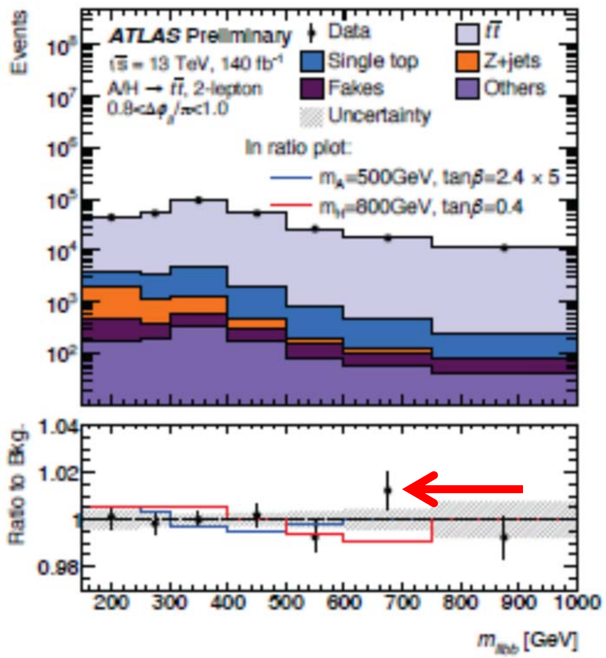
CMS-TOTEM analysis of γγ pairs produced in pp diffractive scattering (CMS-PAS-EXO-21-007)



- For a m(γγ)= 650(40) GeV → 76(9) OBSERVED vs. 40(9) EXPECTED
- In the most conservative case this is a 3 σ effect (the only significant excess)

ATLAS top-quark pair production

- Large B(H→t $\bar{t}$) ≈ 75% is expected
- Small 1% excess observed near 675 GeV
- The 1% level is **precisely as expected** because the **signal** for a 700 GeV Higgs is about **1 pb**, to be compared with a **background** cross section of about **100 pb** (CMS: JHEP 02 (2019) 149)



(e) $0.8 < \Delta\phi_{\ell\ell} < 1.0$

Table 12: The measured differential cross section and bin boundaries for each bin of the normalized and absolute measurements of the $t\bar{t}$ differential cross section at parton level in the full phase space as a function of $m_{t\bar{t}}$ are tabulated.

$m_{t\bar{t}}$ [GeV]	$\frac{1}{\sigma}\frac{d\sigma}{dm_{t\bar{t}}}$ [GeV $^{-1}$]	$\frac{d\sigma}{dm_{t\bar{t}}}$ [pb/GeV]
[300, 380]	$(1.981 \pm 0.036 \pm 0.18) \times 10^{-3}$	$1.664 \pm 0.031 \pm 0.163$
[380, 470]	$(3.992 \pm 0.049 \pm 0.183) \times 10^{-3}$	$3.354 \pm 0.041 \pm 0.324$
[470, 620]	$(2.009 \pm 0.023 \pm 0.057) \times 10^{-3}$	$1.688 \pm 0.019 \pm 0.122$
[620, 820]	$(6.363 \pm 0.108 \pm 0.355) \times 10^{-4}$	$0.535 \pm 0.009 \pm 0.038$
[820, 1100]	$(1.438 \pm 0.041 \pm 0.105) \times 10^{-4}$	$0.121 \pm 0.003 \pm 0.012$
[1100, 1500]	$(2.72 \pm 0.106 \pm 0.206) \times 10^{-5}$	$(2.285 \pm 0.089 \pm 0.21) \times 10^{-2}$
[1500, 2500]	$(2.45 \pm 0.24 \pm 0.464) \times 10^{-6}$	$(2.059 \pm 0.201 \pm 0.383) \times 10^{-3}$

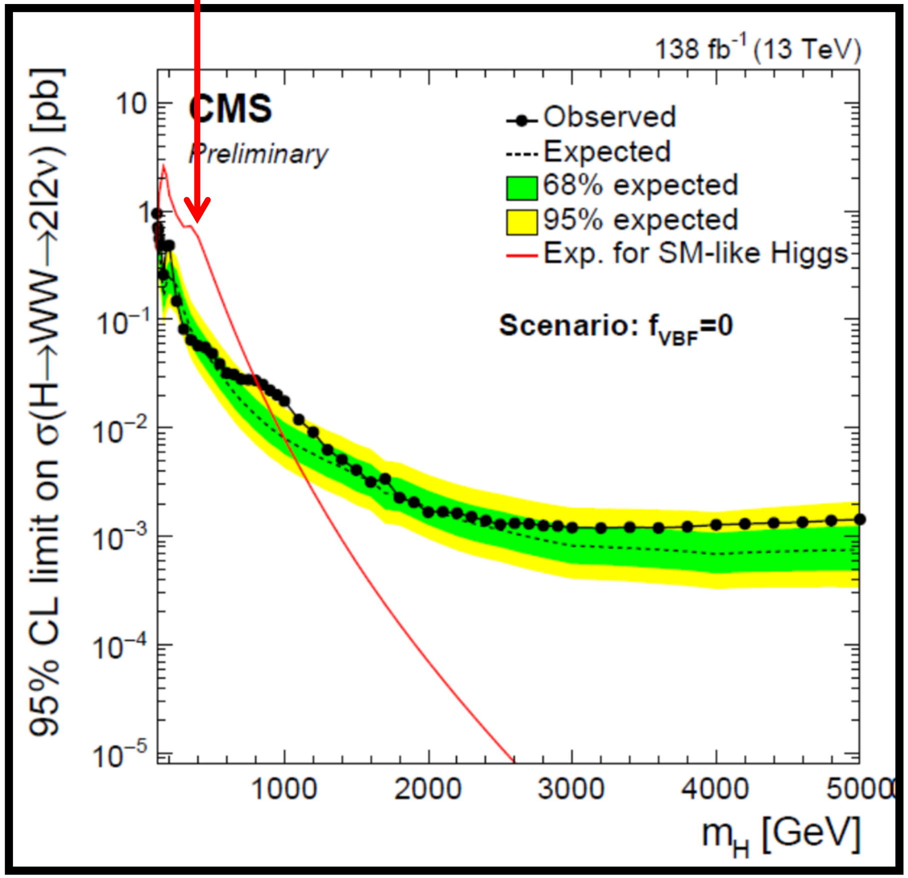
σ ≈ 107 ± 7.6 pb

- Overall consistency with other searches for new heavy resonances H
- Two examples:
- 1) CMS search for H→WW→2l2ν (expected effect too small to be seen)
- 2) CMS search for H→hh→bbWW (interesting trend of the observed S/B)

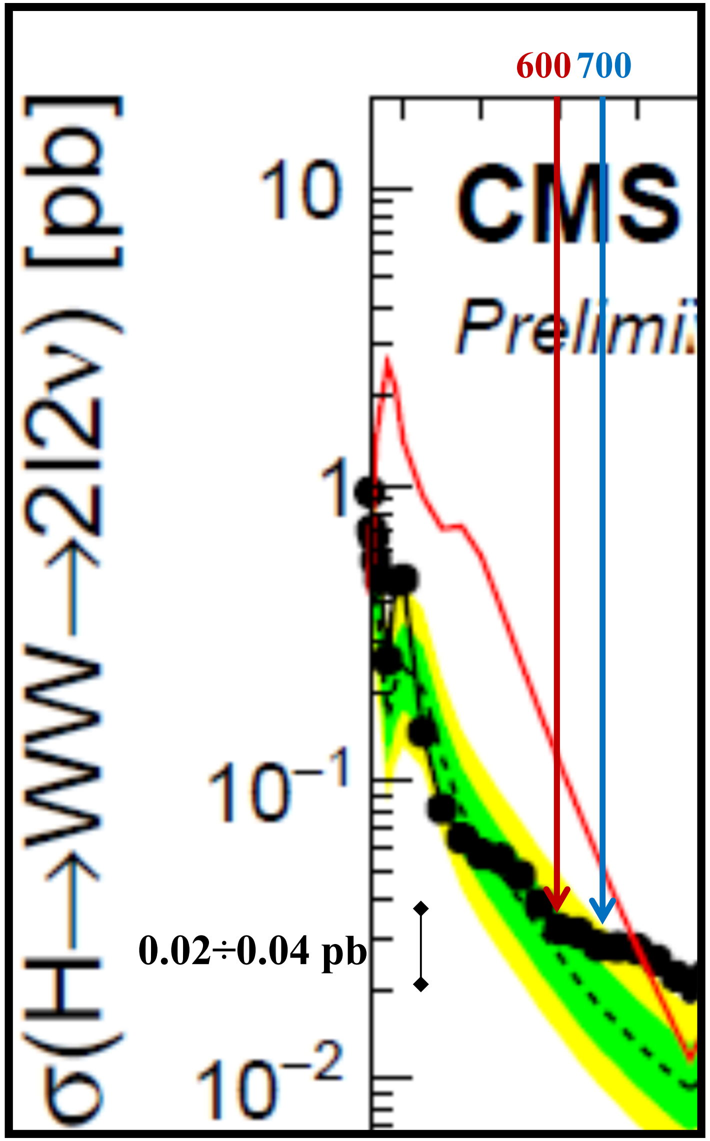
CMS search for heavy scalar H→WW→2l2ν

CMS-PAS-HIG-20-016, March 2022

SM-like Higgs



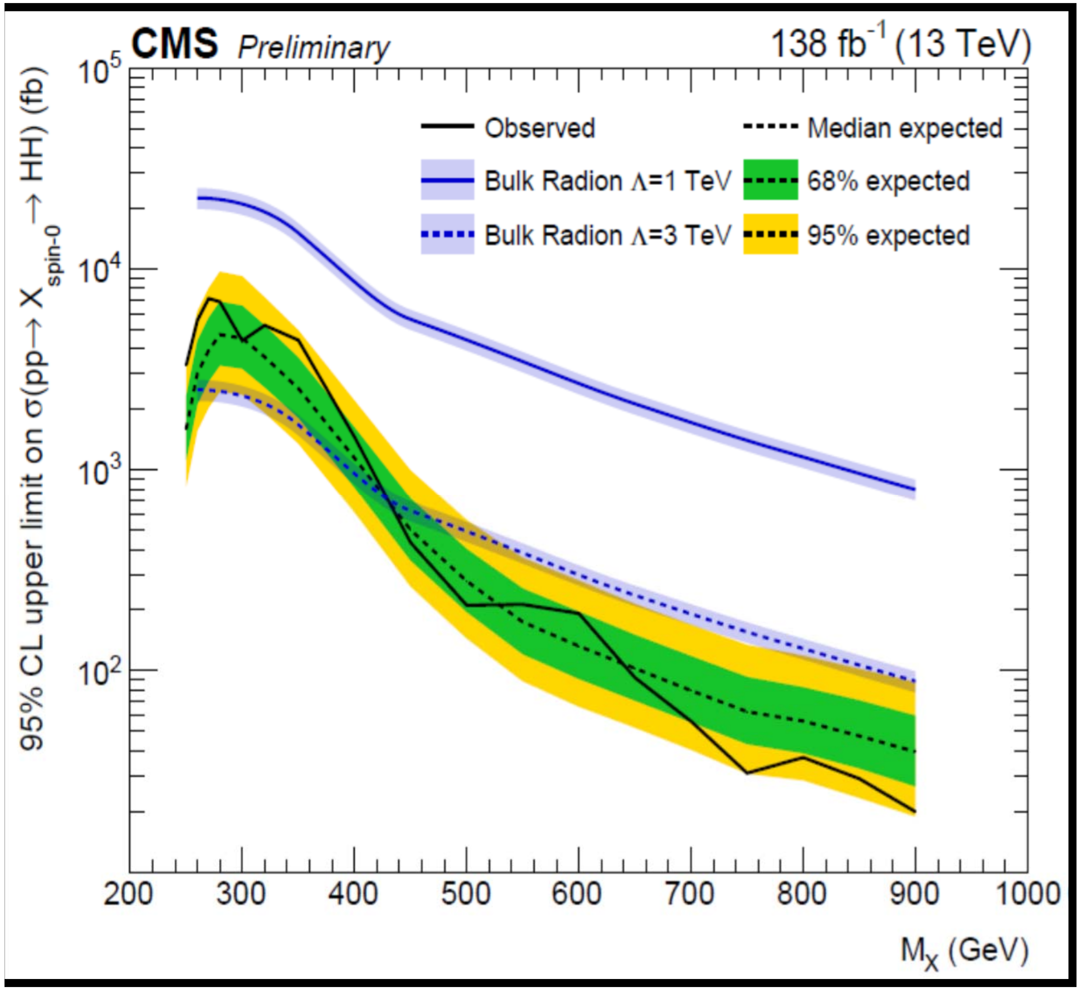
700 GeV second resonance σ(pp→H→WW→2l2ν) ≈ 0.005 pb



H→WW→2l2ν   NO VBF production

CMS search for heavy scalar X→hh→bbWW

CMS-PAS-HIG-21-005, March 2023

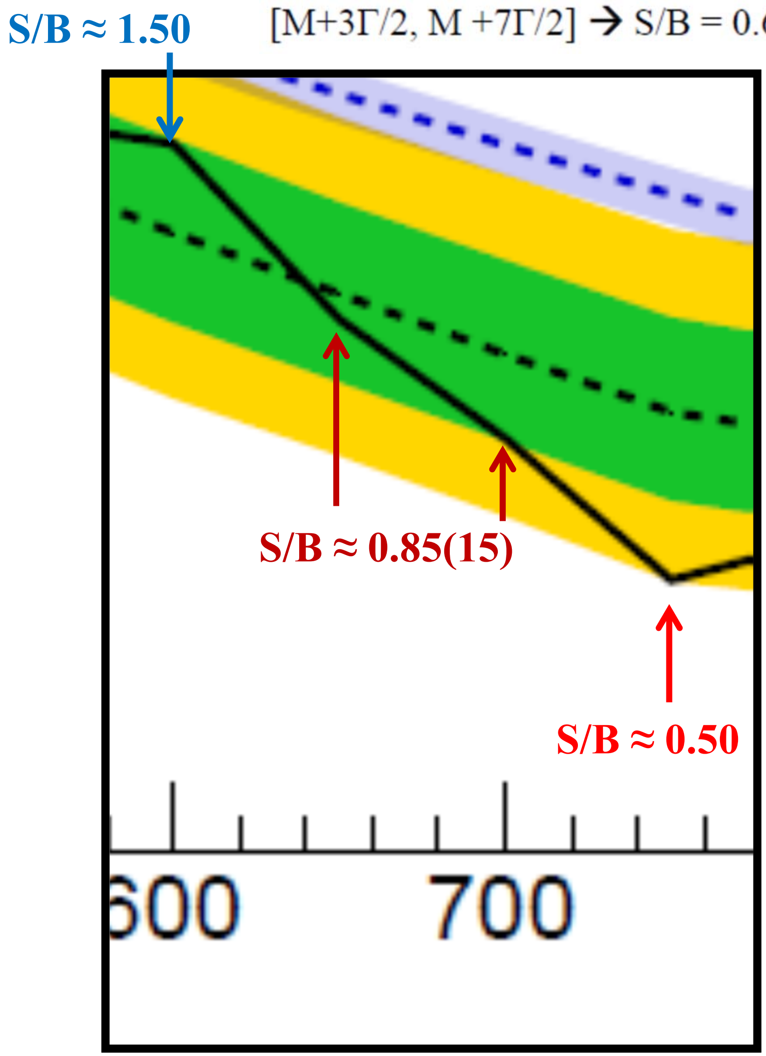


$\Delta E = 2\Gamma$

$[M - 5\Gamma/2,\ M - \Gamma/2] \rightarrow S/B = 1.60$

$[M - \Gamma/2,\ M + 3\Gamma/2] \rightarrow S/B = 1.03$

$[M + 3\Gamma/2,\ M + 7\Gamma/2] \rightarrow S/B = 0.65$



Conclusions

The determinations of $\mathbf{M_H}$ from the 6 data sets, with symmetric error bars, and the **combined excess/defect deviation** from the expected values (LEE downgrade is not applicable with a definite theoretical prediction)

- $\mathbf{(M_H)^{EXP} \approx 677\ (22)\ GeV}$ ATLAS 4-lepton cross section data $\approx 3\sigma$
- $\mathbf{(M_H)^{EXP} \approx 696\ (12)\ GeV}$ ATLAS inclusive $\gamma\gamma$ events $\approx 3\sigma$
- $\mathbf{(M_H)^{EXP} \approx 692\ (15)\ GeV}$ CMS 4-lepton S/B data $\approx 2\sigma$
- $\mathbf{(M_H)^{EXP} \approx 675\ (25)\ GeV}$ ATLAS (bb+$\gamma\gamma$) events $\approx 3.8\sigma$
- $\mathbf{(M_H)^{EXP} \approx 675\ (75)\ GeV}$ ATLAS top-quark pairs $\approx 1\sigma$
- $\mathbf{(M_H)^{EXP} \approx 650\ (40)\ GeV}$ CMS-TOTEM $\gamma\gamma$ in pp diffractive $\approx 3\sigma$
- $\mathbf{(M_H)^{COMB} \approx 685\ (10)\ GeV}$

compare with

- $\mathbf{(M_H)^{THEOR} = 690\ (30)\ GeV}$
- Besides the agreement of the mass value, the overall statistical evidence is above the traditional 5-sigma level, thus excluding an interpretation as simple statistical fluctuations
- Finally, the low **S/B ≈ 0.64 (15)** observed in the ATLAS and CMS 4-lepton channel, in the range 700÷800 GeV, is the same **S/B ≈ 0.63(20)** obtained from the defect of ATLAS (bb+$\gamma\gamma$) events in the same region of invariant mass. This points toward a new resonance H with $B(H \rightarrow ZZ) \approx B(H \rightarrow hh)$, as for the second resonance