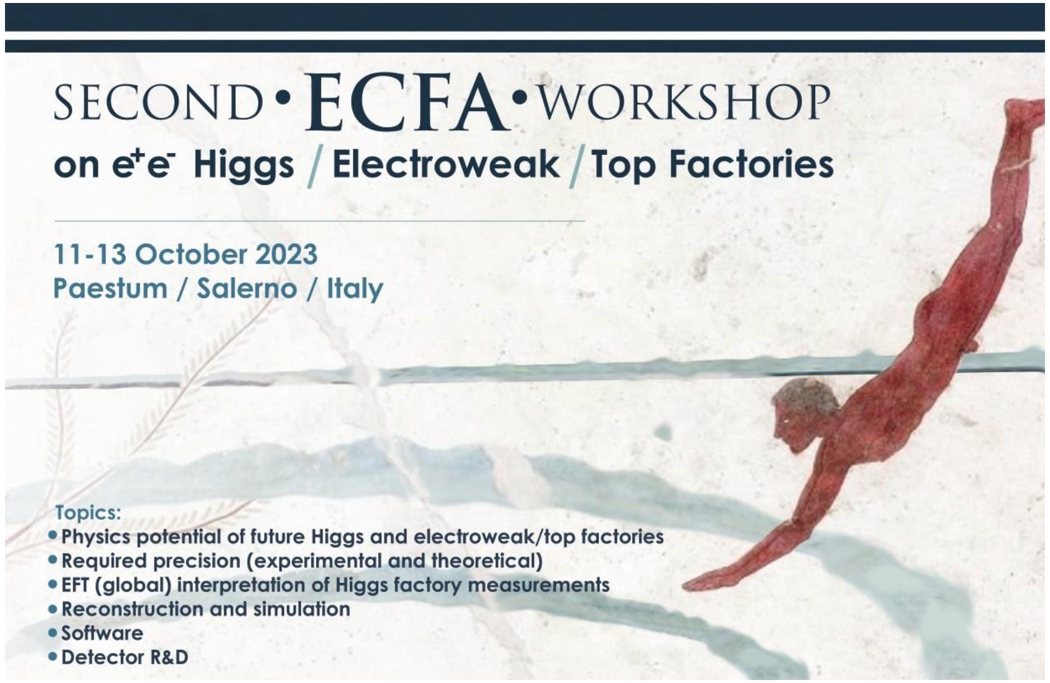
A plea for H(650)

WG1-SRCH



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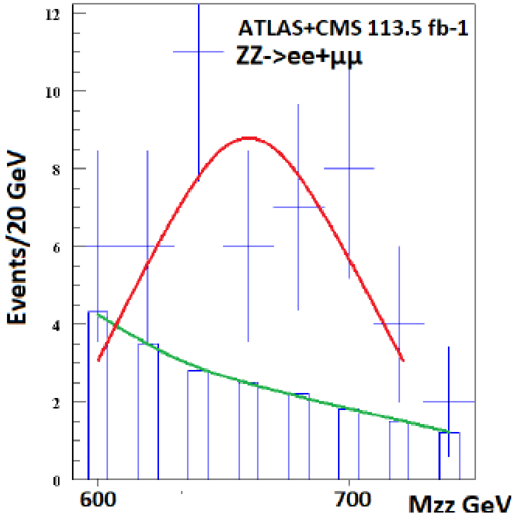
Introduction I



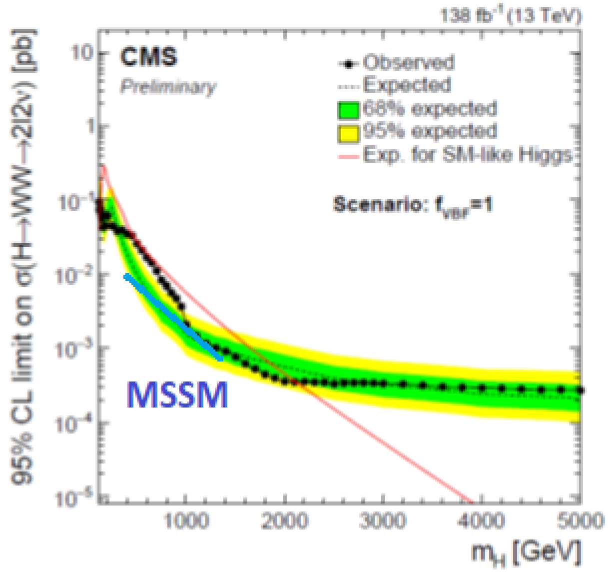
- With RUN2 data there has been growing evidence for a wide resonance with **M=650 GeV** and **Γtot=100 GeV**
- Note that the SM Higgs width would be 150 GeV at this mass
- Historically this work started in 2018 *1806.04529* with the mode ZZ, confirmed by *2103.01918*, then came WW *2104.04762* and **h(95)h(125)** *2310.01643*
- Note in passing the connection between h(95) and H(650)
- Putting them together, one reaches **6 s.d. global** (Fisher method)
- Question: how to interpret this resonance in the context of existing phenomenology ?
- Caveat : one cannot exclude that this resonance is a **tensor** (under investigation)

Introduction II

- To make a story short, an interpretation was not possible within present phenomenology
- Hence the low popularity of this channel and our attempt to go beyond the usual 2HD+scalar models
- Including triplets seems viable provided one goes beyond the Georgi Machacek model (one doublet + 2 triplets) by adding a **second doublet to** GM
- In particular GM predicts ZZ/WW~2 while observation gives ~ten times less
- Reminds us the story of going from **SM to SUSY** which required a second doublet
- Such a **SUSY extension** has been developed by the Spanish groups (Quiros et al. *1308.4025*)

Model independent statement

- Here I would like to emphasize a **model independent** aspect of this resonance: the fact that it couples to W+W- with ~ the same strength as h(125) which breaks down a **unitarity sum rule (SR) due to Haber et al.** Phys. Rev. D43, 904 (1991
- There is no remedy for this in 2HD+singlets while models with **triplets** offer the possibility of a compensation through an **H++** (**u channel exchange** of opposite sign)
- One therefore **predicts** the appearance of **H++->W+W+** with a coupling ~ H(600)W+W-
- **Major result which would kill the 2HD models**



CMS PAS HIG-20-016

Sum Rule I

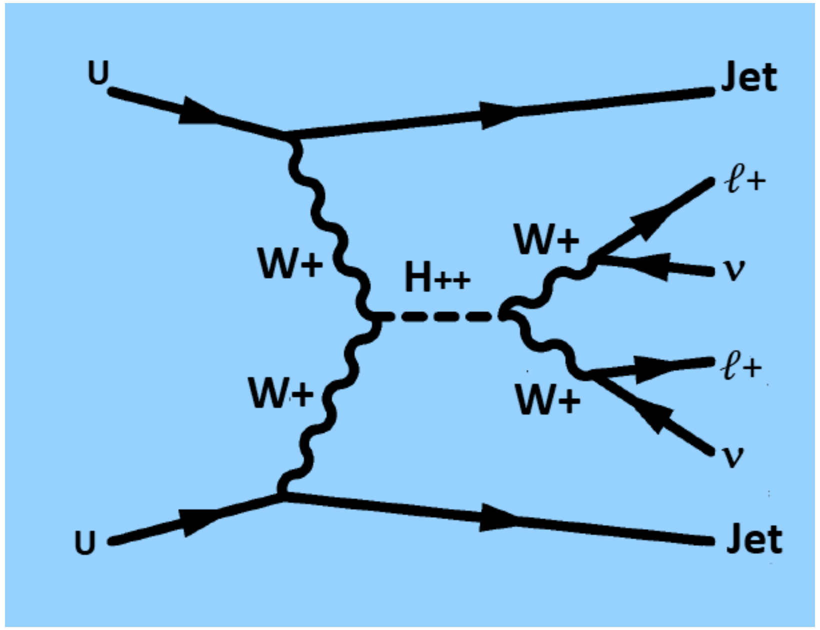
- **W+W- ->W+W-** Haber et al. in [*P.R.D* 43 (1991) 904-912]

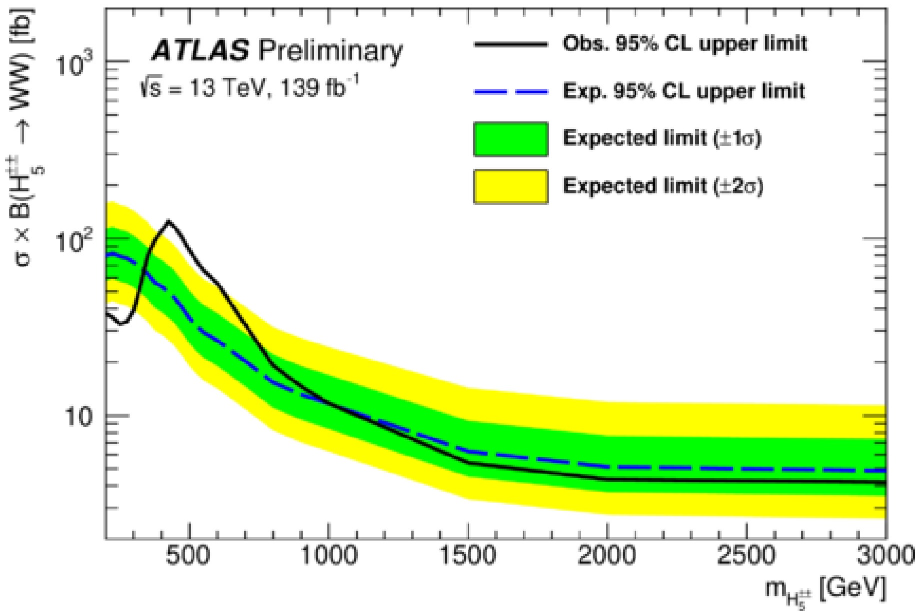
$$g^2(4m_W^2 - 3m_Z^2 c_W^2) \overset{\rho\simeq 1}{\simeq} g^2 m_W^2 = \sum_k g^2_{W^+W^-H_k^0} - \sum_l g^2_{W^+W^+H_l^{--}}$$

- So-far we have been able to measure H(650)W+W- and (*2302.07276*) h(95)W+W-
- There are other candidates like h(151) and H(330) where these measurements are unavailable, but we have ideas on how to deal with them (2308.12180 and ***https://indico.cern.ch/event/1253605/***
- H(650) alone forces to have a contribution of H++->W+W+ with a coupling ~ SM=gmW

First hint from LHC

- Recently at the Belgrade ATLAS meeting: **H++(450)->W+W+**
- **[ATLAS-CONF-2023-023/]()**
- 3.2 s.d. local, 2.5 s.d. global





Sum Rule II

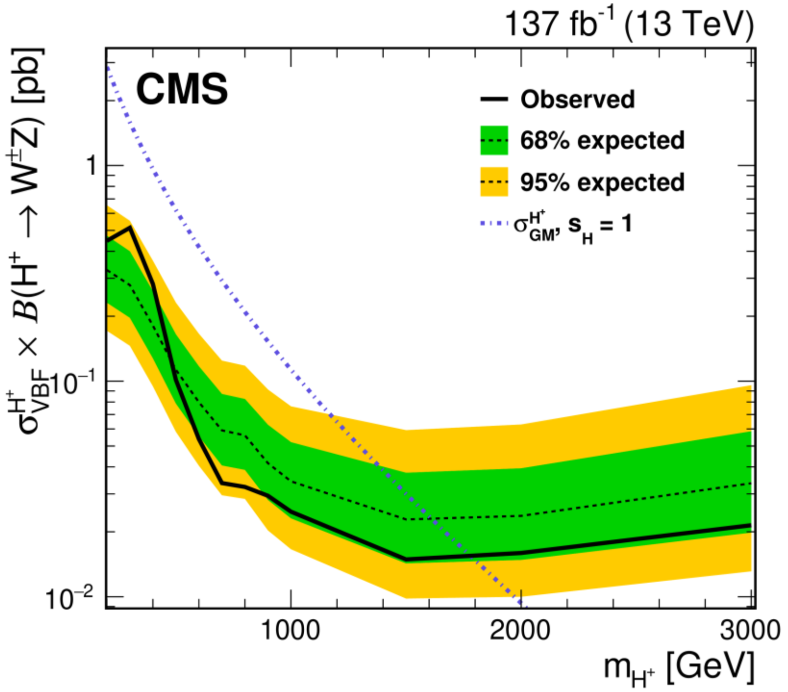
- **W+W- -> ZZ** allows a similar SR

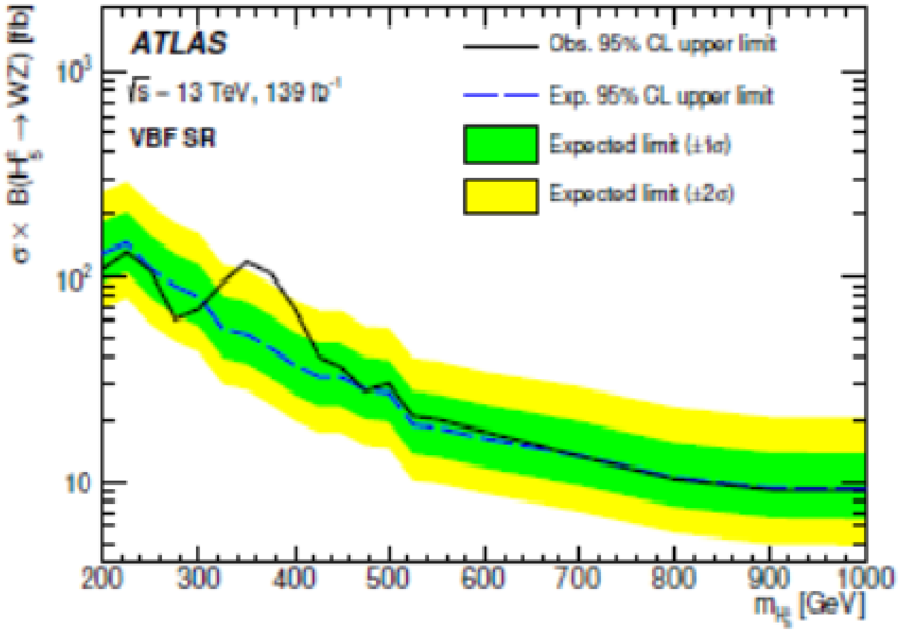
$$\frac{g^2 m_Z^4 c_W^2}{m_W^2} \overset{\rho\simeq 1}{\simeq} g^2 m_Z^2 = \sum_k g_{W^+W^-H_k^0} g_{ZZH_k^0} - \sum_l g^2_{W^+ZH_l^-}$$

- This forces a strong coupling for **H+->ZW+** which should be observed at LHC
- Note that the result depends on the **signs** of the coupling constants which are not known from present measurements
- h95ZZ is known from LEP2 (but not its sign !)

Evidence for H+ -> ZW+

2207.03925





- Coincident excess at mH5+~375 GeV for ATLAS (2.8sd) & CMS 3.5 s.d. global
- In GM H5++ and H5+ are mass degenerate which is almost true (see for e-GM 2111.14195)
- Obviously H(650) does not have the same content as H5 in GM

Quantitative interpretations

- Combining H++ and H+ gives 4.3 s.d. global.
- Quantitatively, SR predicts $\Gamma_{\mathbf{H{+}{+}\text{->}W{+}W{+}}}$ and the measured cross section allows to deduce the BR(W+W+) and the total width $\Gamma_{\mathbf{H{+}{+}\text{->}W{+}W{+}}}$ /BR(W+W+)

Resonance	u GeV	s_H	BR %	Total width GeV	σ_{VBF} nb
H++(450)->W+W+	70±11	0.80±0.12	9±3	180±60	770±250
H+(375)->ZW	59±10	0.67±0.11	18±6	50±16	450±170

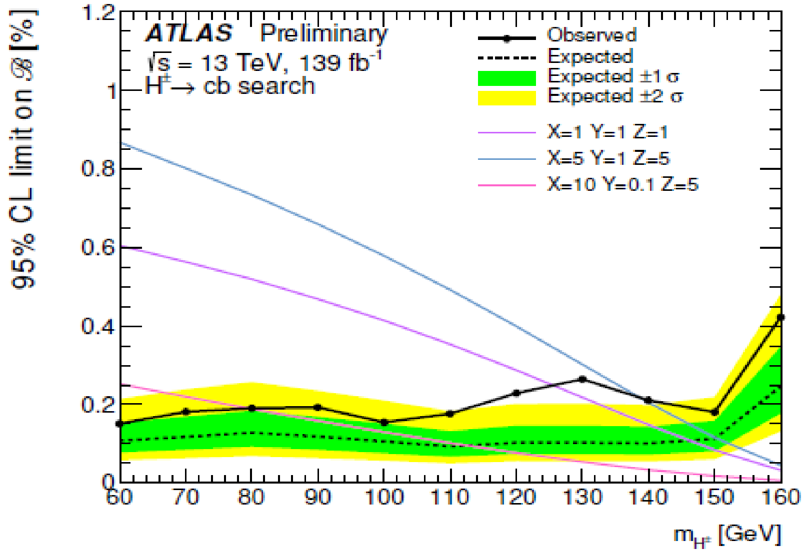
➔ **u=70 GeV** comes as a surprise: usual lore was BR(W+W+)=1 and u<25 GeV

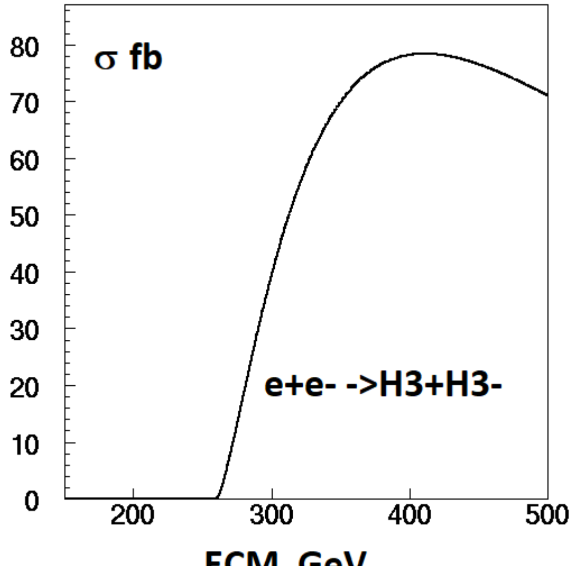
➔ BR(W+W+)~10% requires other modes like H'+W+ or even H'+H'+ (ZH'+ for H+)

➔ **A light (or several) light H'+ predicted**

A light H'+ ?

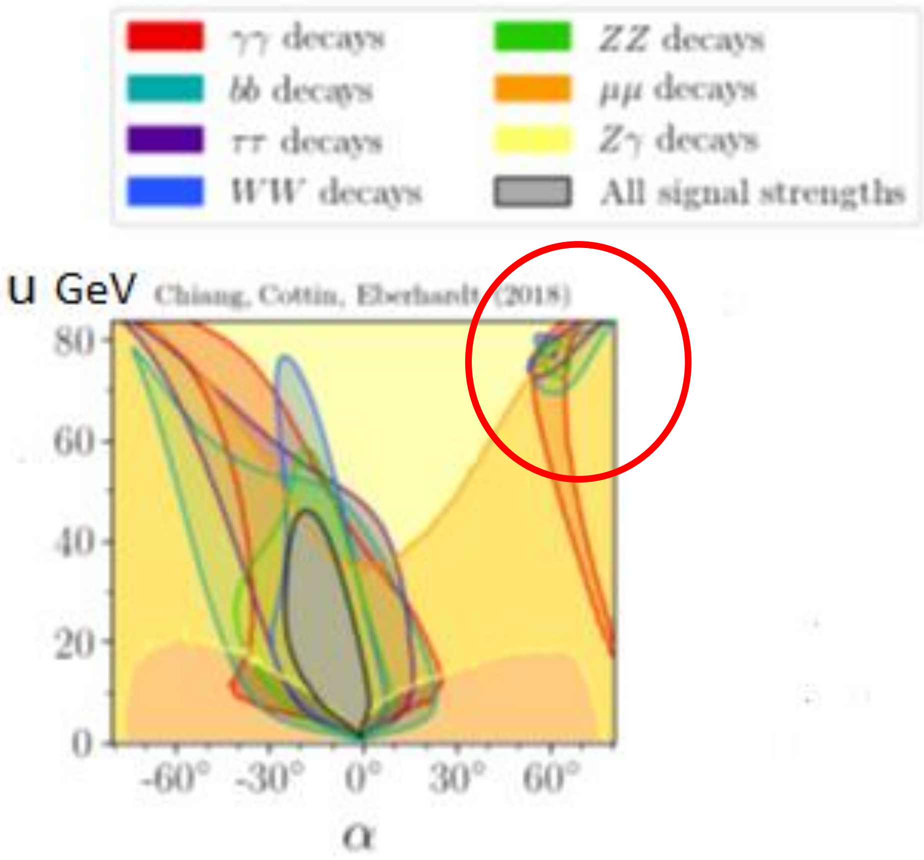
- There are few hints for this
- B decays into Dτ and $\Lambda\tau$ are reduced by 1.6 and 1.4 s.d. [2305.00614](2305.00614) suggesting mH+~200 GeV
- ATLAS has searched for t->bH+->bbc and found a 3 s.d. local (2.5 global) excess around 130 GeV *2302.11739*
- Not allowed in 2HD models for type II 1702.04571 but allowed for tanβ>2 in type I
- Good news for all Higgs factories !
- e-GM predicts on top of H5+, H3+, an extra H2+ which could also be light (blind regions for searches ?)





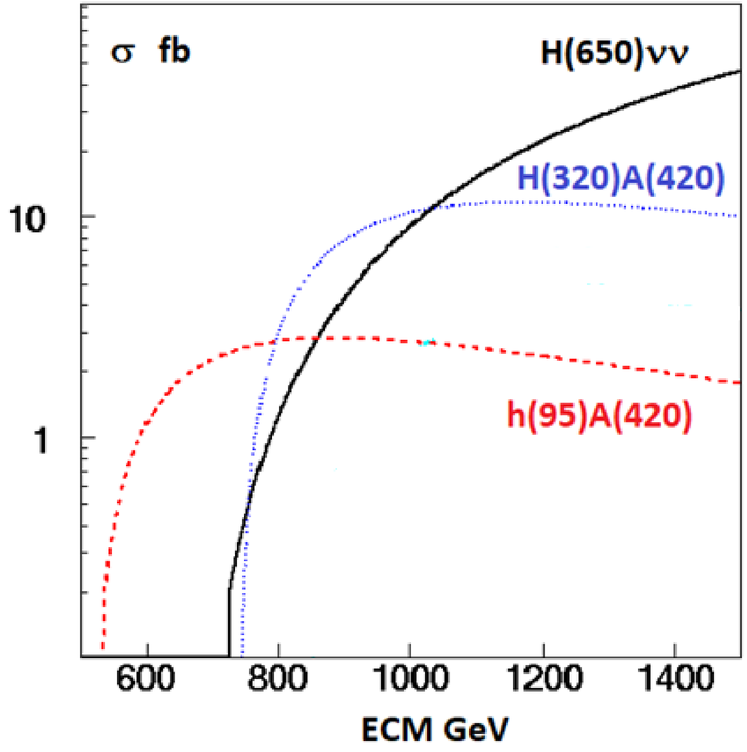
Precision Measurements

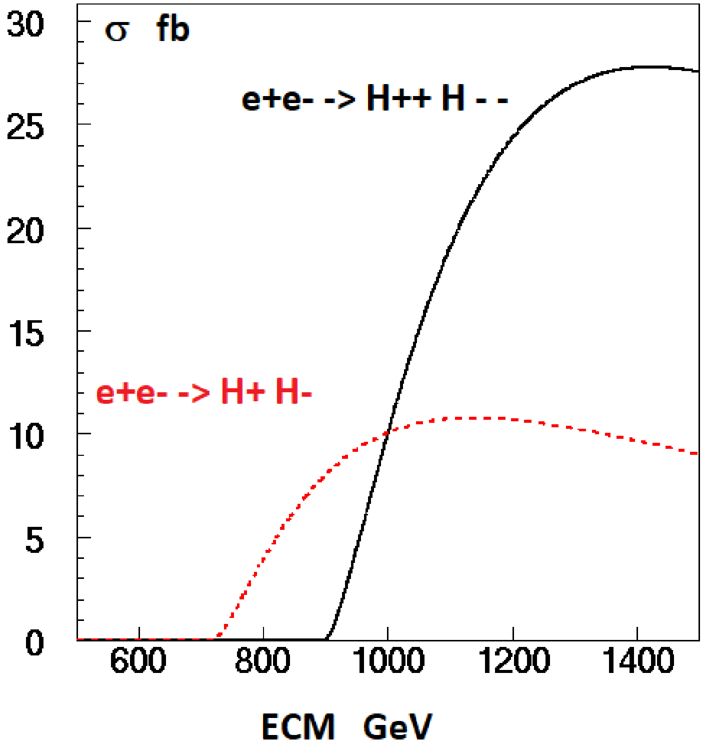
- u=70 GeV deduced from the sum rules seems incompatible with PM
- There is however a GM solution with **large** α=60° and u=v_ξ=v_χ=75 GeV which satisfies PM for h(125)
- Implies that h can have a **large triplet component**, unnoticed, still passing PM
- True for **h->hh ?** We need to understand V(h)
- μ95γγ~0.3 does not seem to originate from the charged Higgs sector, given that μ125γγ~1, meaning that H'+(130) does not seem to affect h125

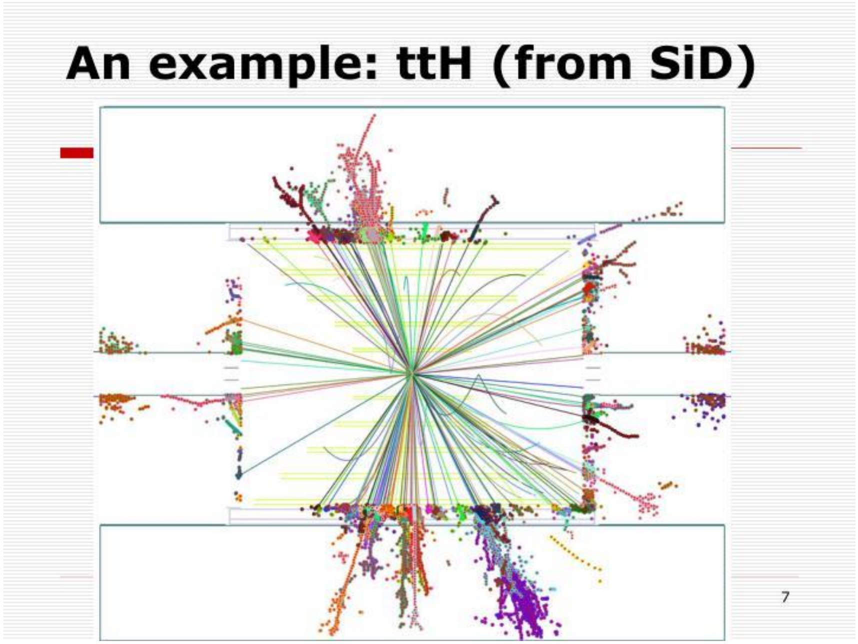


1807.10660

TeV collider reach







- ILC would provide 8000 fb-1 at 1 TeV
- The final states are complex modes (~ttH) requiring the **highest $\mathcal{L}$** and an **almost ideal detector**
- **H(650)** mainly produced through VBF (beam polarisation allows a factor ~2 gain, not included)
- Using a **e-e- collider** one could also produce H $^{--}$ through VBF with polarized beams ~100 fb at 1 TeV

Conclusions

- Growing confidence that **BSM physics** is **– at last ! –** showing up with strong synergy between H(650), H++(450) and H+(375)->ZW and several neutral scalars including h(95)
- This BSM physics does not fit in existing 2HD+S schemes
- Needs an extended version of GM, **e-GM** or/and a **Tensor scenario** (in progress)
- **Final consolidation for 650 GeV** resonance should come soon from CMS with **ZZ**
- As expected from e-GM, several other signals are lying around, not discussed here
- Very rich prospects for HEP !
- Read our papers and a recent talk at ECFA WG1-SRCH:

2211.11723 , 2308.12180 and *https://indico.cern.ch/event/1253605/*

- Stay tuned !

Additional slides

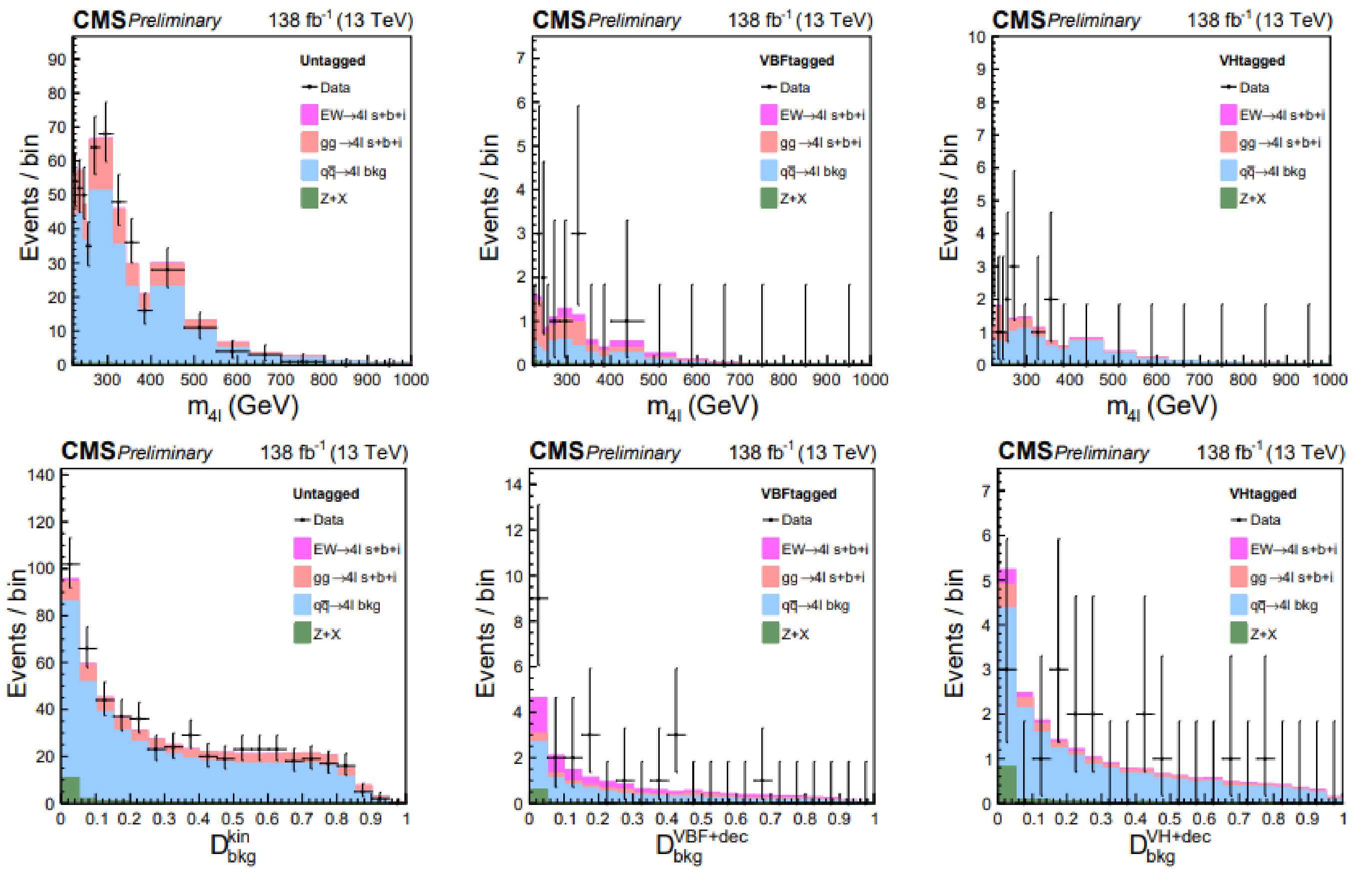
A tensor scenario ?

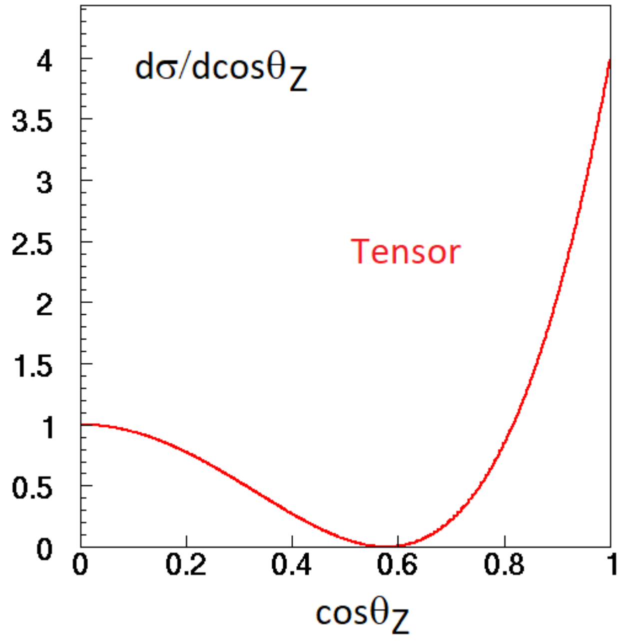
- Seems viable despite several **complexities** (renormalizability, high energy behaviour, need for unitarization) which can perhaps be mastered as shown in *1511.00022*
- The large width can be interpreted as due to a **2J+1** factor instead of assuming a replica of the SM Higgs coupling
- **ZZ/WW=0.5** instead of 2 in GM ~agrees with observation within errors
- Could be clearly distinguished from a scalar decay through its **angular distribution** which is forward peaked
- Doubly charged candidates could be scalars or due to an **isotensor** giving T++, T+ and T0(650)
- Haber et al **sum rule** still apply ? Uncertain but not excluded
- Recently CMS has proposed an interpretation of X(650) as a **bulk KK graviton** *2310.01643*
- The **large width** seems to disfavour such an interpretation *9909255*

Results from CMS

CMS-PAS-HIG-21-019

- Selecting a scalar solution in ZZ->4l , D_{bkg}>0.6, CMS finds:





Tensor decay in ZZ

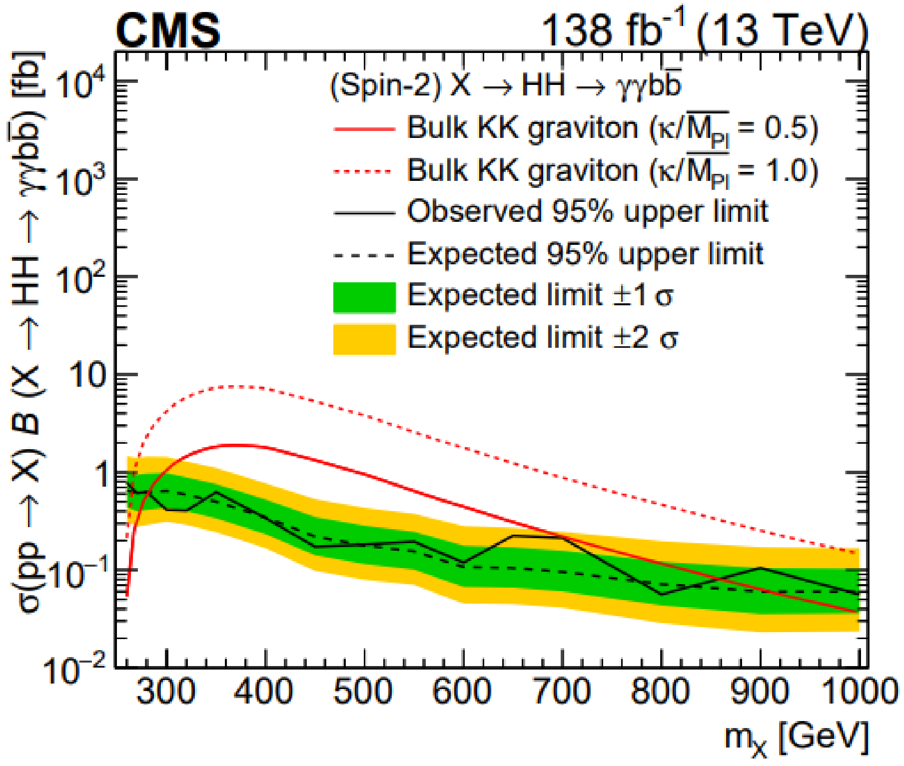
- No sign of an excess at ~650 GeV in this subsample
- A tensor resonance, fwd peaked, removed by this selection ?

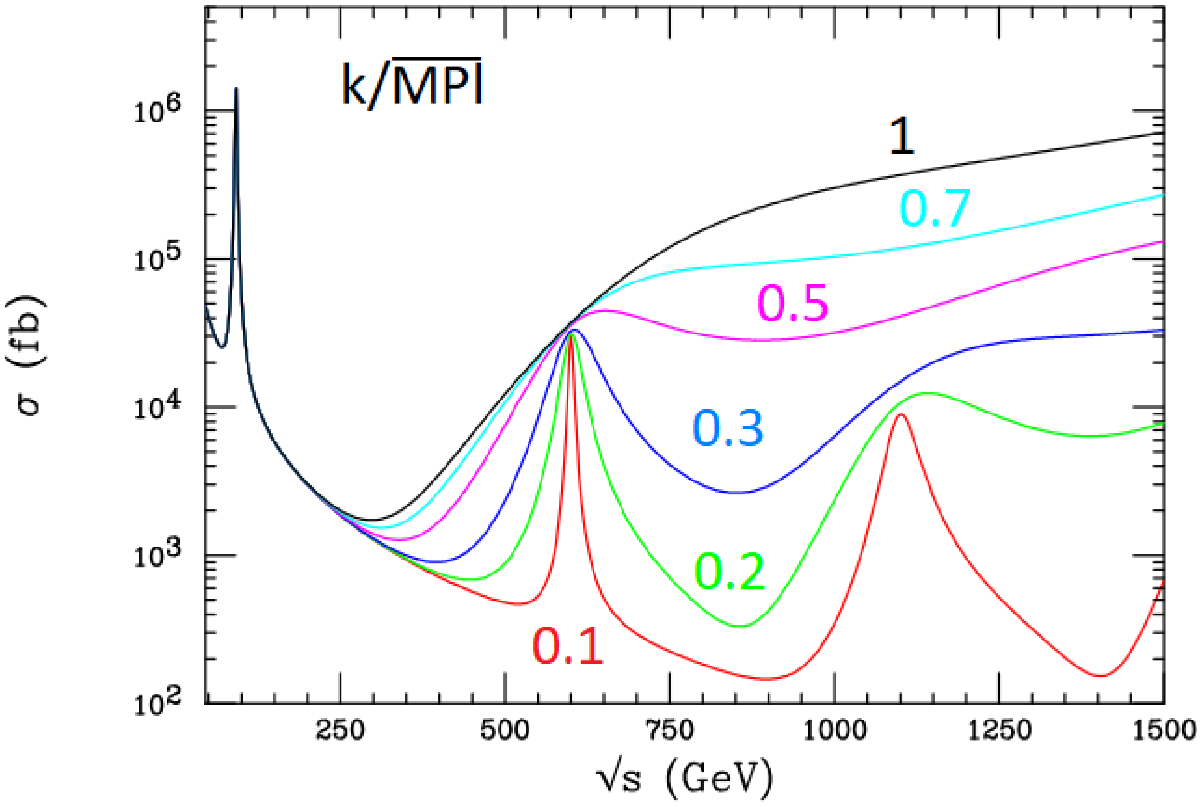
Bulk KK graviton ?

2310.01643

9909255 e+e- -> $\mathcal{G}_{KK}$(600) -> μ+μ- versus k/Mplanck

(just for illustration since e+e- is unlikely to couple to $\mathcal{G}_{KK}$)





b->sγ constraint on mH+

- Light H+ excluded for 2HDM II, not for 2HDM I with tanβ>2 [1702.04571]

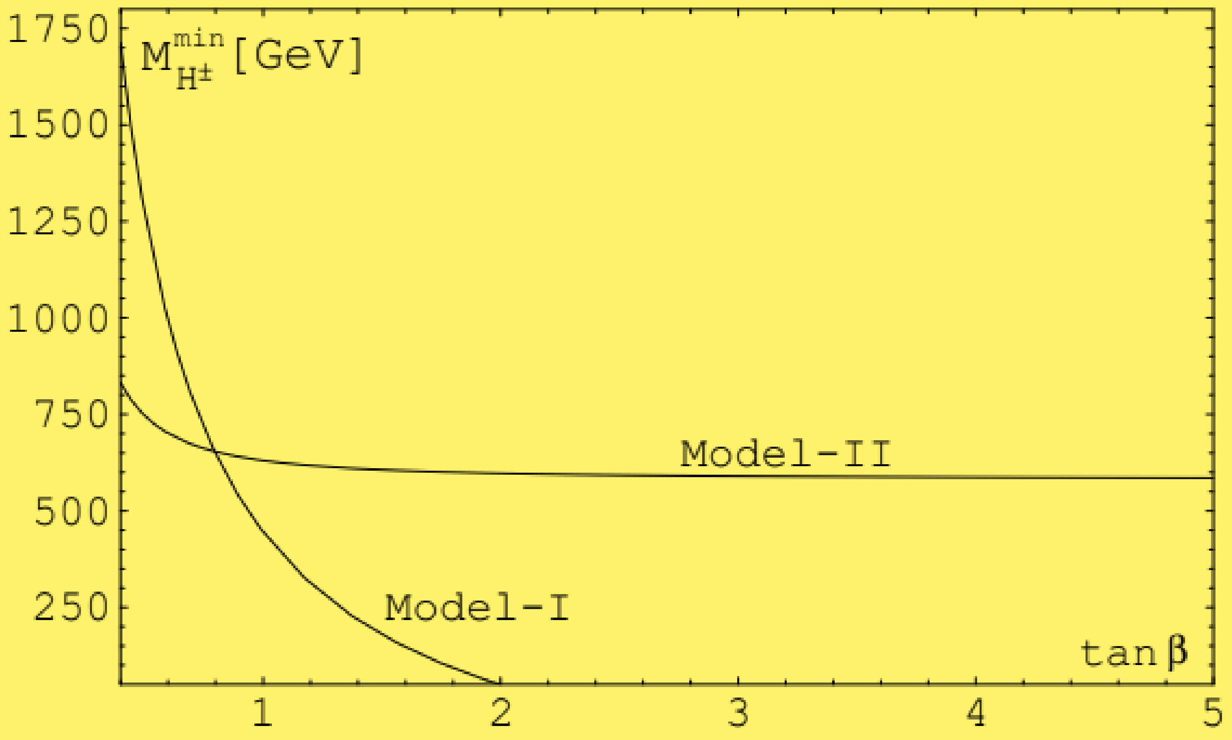


Figure 4: 95% C.L. lower bounds on $M_{H^\pm}$ as functions of $\tan\beta$.

How to derive the missing couplings ?

- There are indications for several neutral scalars candidates on the market, with unknown couplings to WW/ZZ
- Can one derive them taking into account the present measurements ?
- The answer seems positive assuming there is no CP violation and using available measurements

Process	Channels	References	# s.d. glob. (local)	Michelin
H650	WW/ZZ ggF/VBF h95h125	1806.04429 2009.14791 2103.01918 CMS PAS HIG-20-016 CMS-PAS-HIG-21-011	6.1	**
A400	tt ZH320->Zh125h125	1908.01115 ATLAS-CONF-2022-043	5	*
h95	$\gamma\gamma$ $\tau\tau$ bb (LEP)	0306033 1811.08159 1803.06553 CMS-PAS-HIG-20-002 ATLAS-CONF-2023-035	3.9	~*
h151	$\gamma\gamma$ +ETmiss	2109.02650	4.8	?
H+375	ZW	ATLAS-CONF-2022-005 2104.04762	(3.5)	
H++450	W+W+	ATLAS-CONF-2023-023 2104.04762	(3.9)	
H+160	bc	*EPS-HEP2021, 631*	(3)	
h146	μe	CMS-PAS-HIG-22-002	(3.8)	

The neutral sector in e-GM

- e-GM comprises two doublet fields $\phi1$, $\phi2$ with vev **v1 and v2** and two triplet fields χ, ξ with the same vev **u**
- For the neutral sector one writes:

$$\begin{pmatrix} h_{95} \\ h_{125} \\ H_{320} \\ H_{650} \end{pmatrix} = \mathscr{X}_{4\times4} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \\ \chi^0 \\ \xi^0 \end{pmatrix}$$

where the matrix is 4X4 unitary **real** (no CPV) with 16-4-6=**6 free parameters** requiring the **unitary vectors** to be **orthogonal**

- In total there are 6+3 (v1, v2, u) free parameters and 14 observables from LHC measurements
- One needs to choose between various **Yukawa coupling patterns** and we find that **type I** (all fermions having the same coupling) gives a reasonable agreement with the data

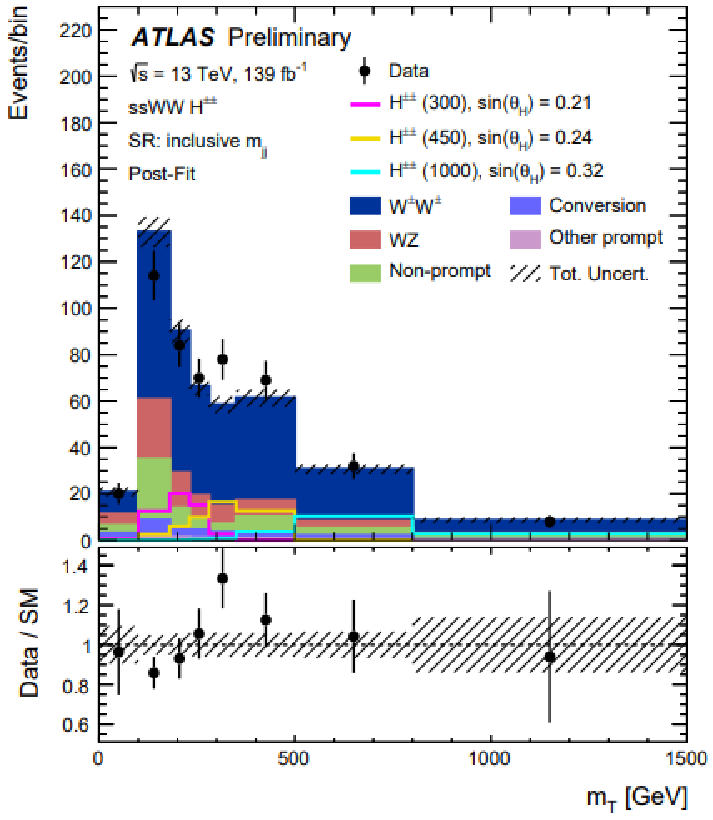
Example of a solution

	1	2	3	4	htt/SM	ZZ/SM	WW/SM
	$\phi 1$	$\phi 2$	χ	ξ			
H95	0.08	-0.56	0	0.82	- 0.96	- 0.34	0.59
H125	0.58	0.58	0.47	0.33	0.99	0.99	1.1
H320	0.31	0.30	-0.88	0.17	0.52	- 1.29	- 0.38
H650	0.74	-0.52	0	-0.43	- 0.90	- 0.43	- 0.91

- **v1=-30 v2=102 u=69.5 GeV   Type I Yukawa**
- Coloured squares have unknown couplings except for h95WW which ~agrees with measurements
- H125~cos$\alpha\phi$ as predicted by PM of Chiang et al. *1807.10660*
- H650 dominated by doublets is produced mainly by ggF contrary to H5
- Predicts μ95$\gamma\gamma$~1 while ATLAS+ CMS measure **$\mu\gamma\gamma$=0.27+0.1-0.09** (*2302.07276*)
- There exist another solution with $\mu\gamma\gamma\sim 0.3$ w/o H+ contributions
- H320->ZZ should be large: excluded unless H320->hh is very large

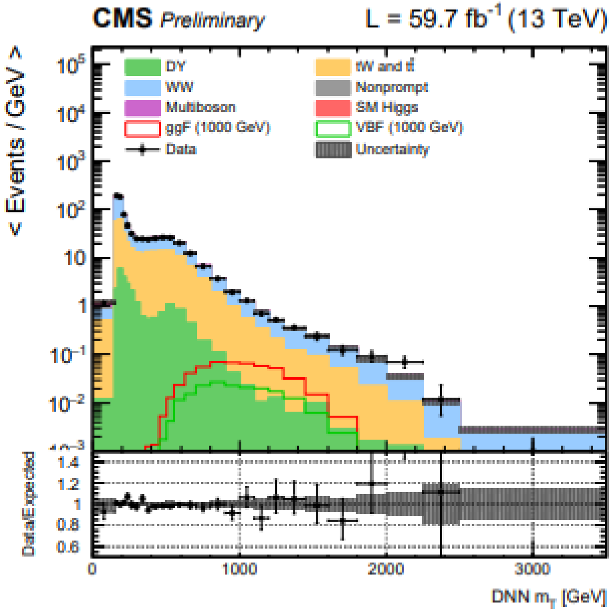
W+W- with b jet veto > 50 times larger W+W+ due to tt background

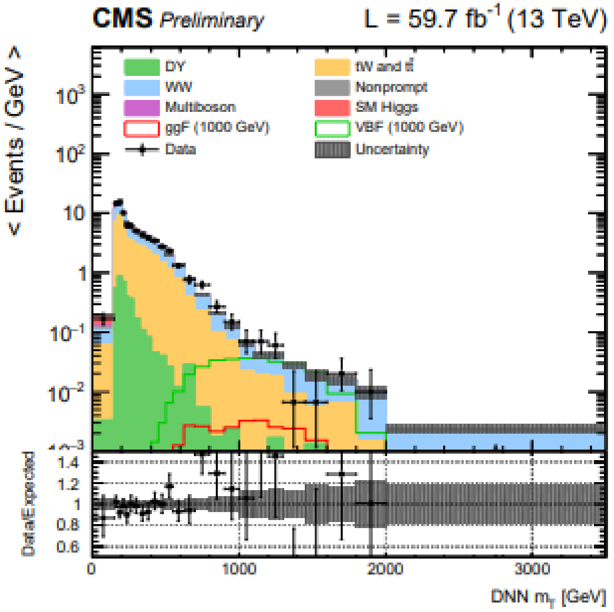
VBF W+W-



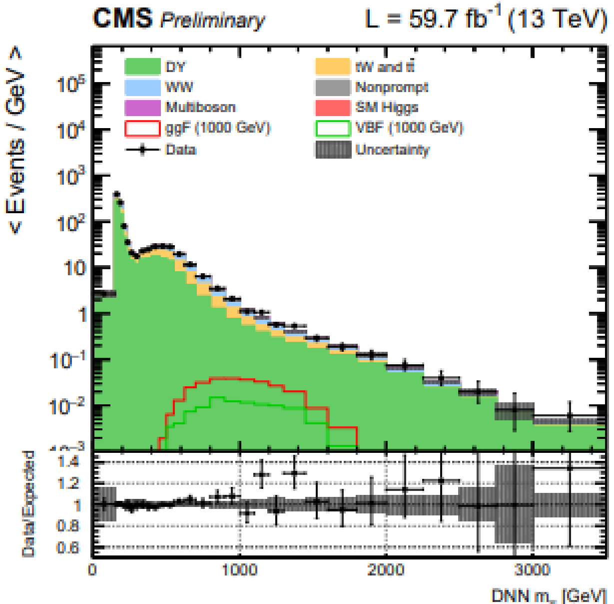
VBF W+W+

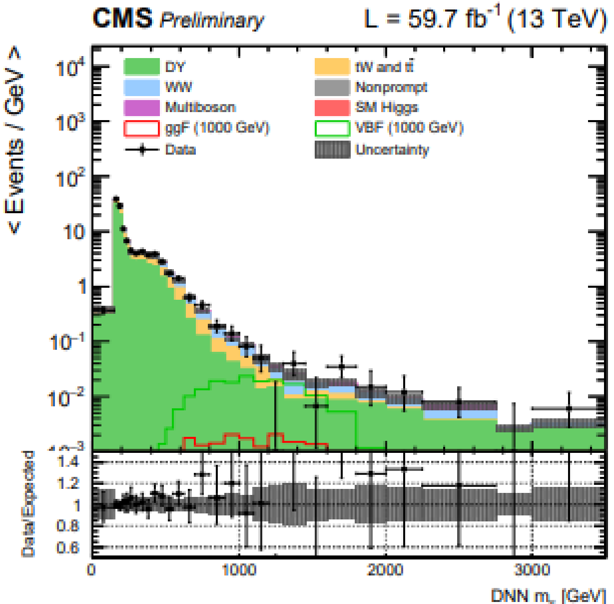
μe





μ+μ-



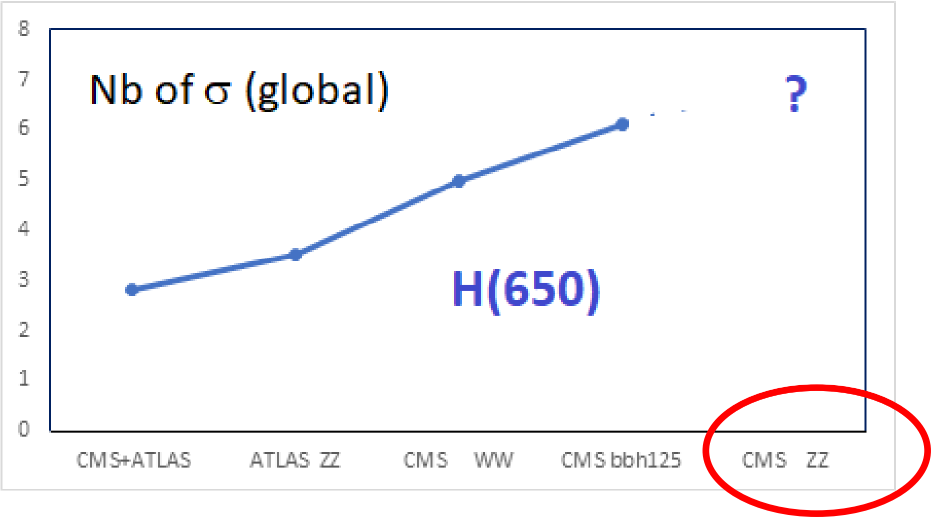


Scalars for sum rules

Scalar	Channels	References	# s.d. glob.
H650	WW/ZZ ggFVBF h95h125	1806.04529 2009.14791 2103.01918 CMS-PAS-HIG-20-016 CMS-PAS-HIG-21-011	6.1
h95	$\gamma\gamma$ $\tau\tau$ bb (LEP2)	0306033 1811.08159 1803.06553 CMS-PAS-HIG-20-002 ATLAS-CONF-2023-035	3.9
H++450	W+W+	ATLAS-CONF-2023-023 2104.04762	2.6
H+375	ZW	2207.03925 2104.04762	2.7
H++ & H+			4.3

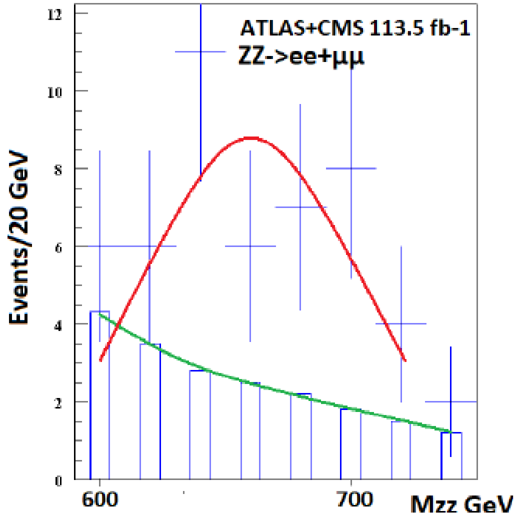
Historical progress of H(650)

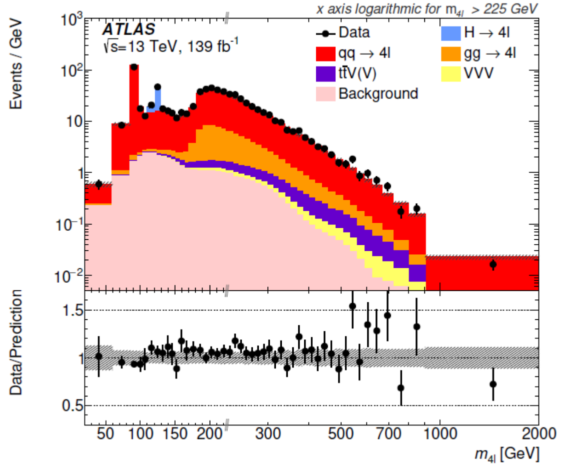
Steps	Mode	Origin	Local sd	Remark	Global sd
0	ZZ->4ℓ	ATLAS+CMS from [7]	3.8	ATLAS+CMS 113.5 fb-1 Defines mass & width	2.8
1	ZZ->4ℓ	From ATLAS	3.5	From histogram	3.5
2	WW->ℓνℓν	From CMS	3.8	Official statement	5
3	h(95)h(125)->bbγγ	From CMS	3.8	Official statement	6.1

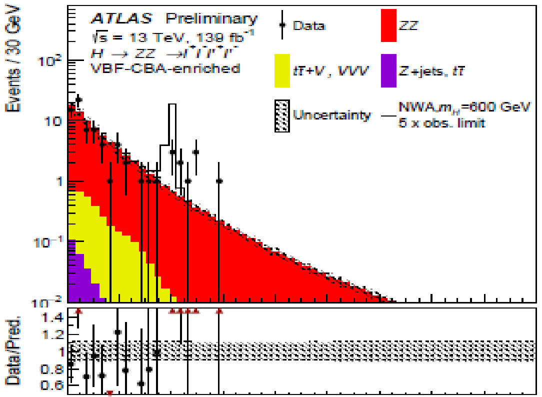


1^{st} indication : H->ZZ into 4 leptons

- The **cleanest channel** for discoveries
- From a combination of published histograms [1806.04529]() with 113.5 fb^{-1} from **CMS (2/3) and ATLAS (1/3)** one observes a peak with M_H~660 GeV Γ_H~100 GeV, σ~90±25 fb with s/b=46/20 ~3.8 s.d. local significance (5.8 Bayesian), 2.8 s.d. global
- With 139 fb-1 ATLAS ~3.2 s.d. effect at the same mass [2103.01918]()
- With 139 fb-1, with **sequential cuts**, an excess is observed at the same mass, s/b=9/2 ~2.1 s.d., for VBF->H(660)->ZZ ~30±10 fb (~2 times smaller with a **MVA analysis**) [2009.14791]()
- The VBF cross section is well below the inclusive cross section ~90fb implying a **dominant ggF contribution**
- CMS analyses into four leptons, ggF nor VBF, are not yet published
- These results call for a combination of both analyses before one can draw a valid conclusion
- Could stop here but…



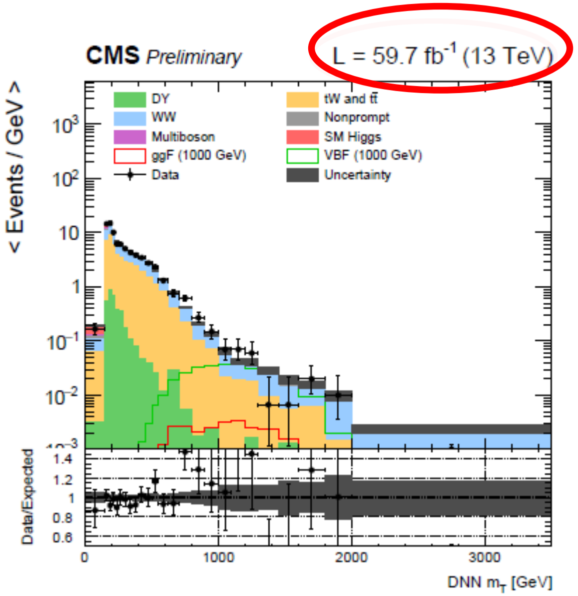




Evidence for VBF->H(650)->W+W- ->$\ell\ell\nu\nu$

CMS PAS HIG-20-016

- Large top background even after b-jet vetoing
- **Wide signal** with ±50% mass resolution
- VBF->H(650)->$\ell\ell\nu\nu$ (μμ, ee and μe) favoured with 3.8 s.d. local (2.6 global) significance
- The **VBF** cross section ~**160±50 fb**, close to SM, is >5 times larger than ZZ, **inconsistent with GM** which predicts for the scalar **H5 WW/ZZ=0.5** !
- Within **2HD**, h(125)WW from CMS gives **sin²(α–β)~0.97±0.09** meaning that **H(650)WW~cos²(α–β)~(0.03± 0.09)SM**
- **2HD 2 s.d. upper limit shown by the blue line**
- Both interpretations are inconsistent !
- An attempt from ATLAS does not reach the same sensitivity (only μe) [ATLAS-CONF-2022-066]



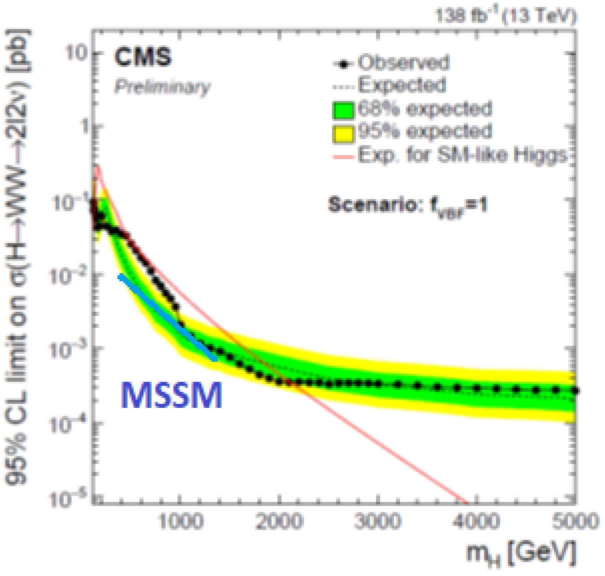
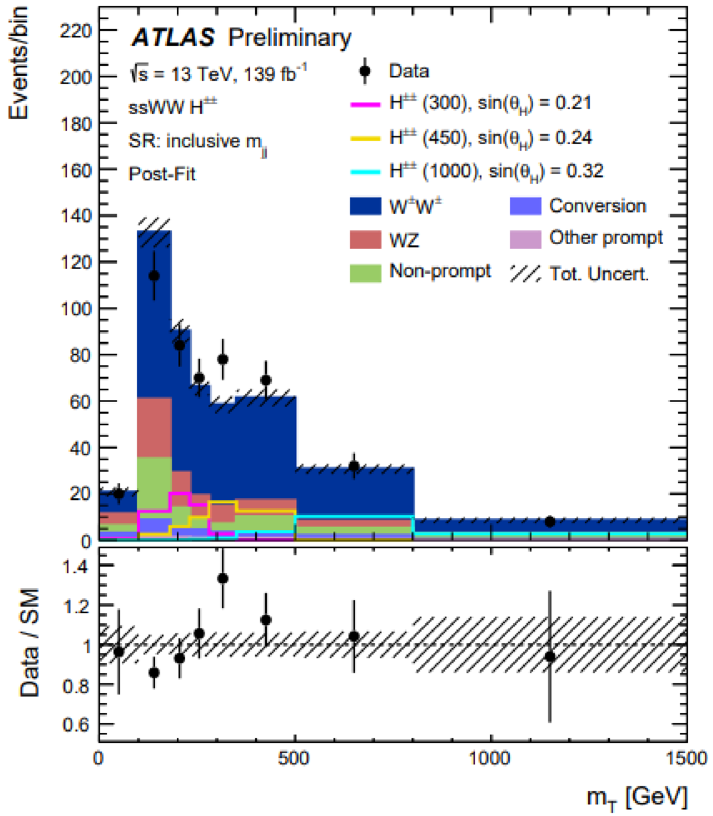


Table 3: Summary of the signal hypotheses with highest local significance for each f_{VBF} scenario. For each signal hypothesis the resonance mass, production cross sections, and the local and global significances are given.

Scenario	Mass [GeV]	ggF cross sec. [pb]	VBF cross sec. [pb]	Local signi. [σ]	Global signi. [σ]
SM f_{VBF}	800	0.16	0.057	3.2	1.7 ± 0.2
$f_{VBF} = 1$	650	0.0	0.16	3.8	2.6 ± 0.2
$f_{VBF} = 0$	950	0.19	0.0	2.6	0.4 ± 0.6
floating f_{VBF}	650	2.9×10^{-6}	0.16	3.8	2.4 ± 0.2

W+W- with b jet veto > 50 times larger W+W+ due to tt background

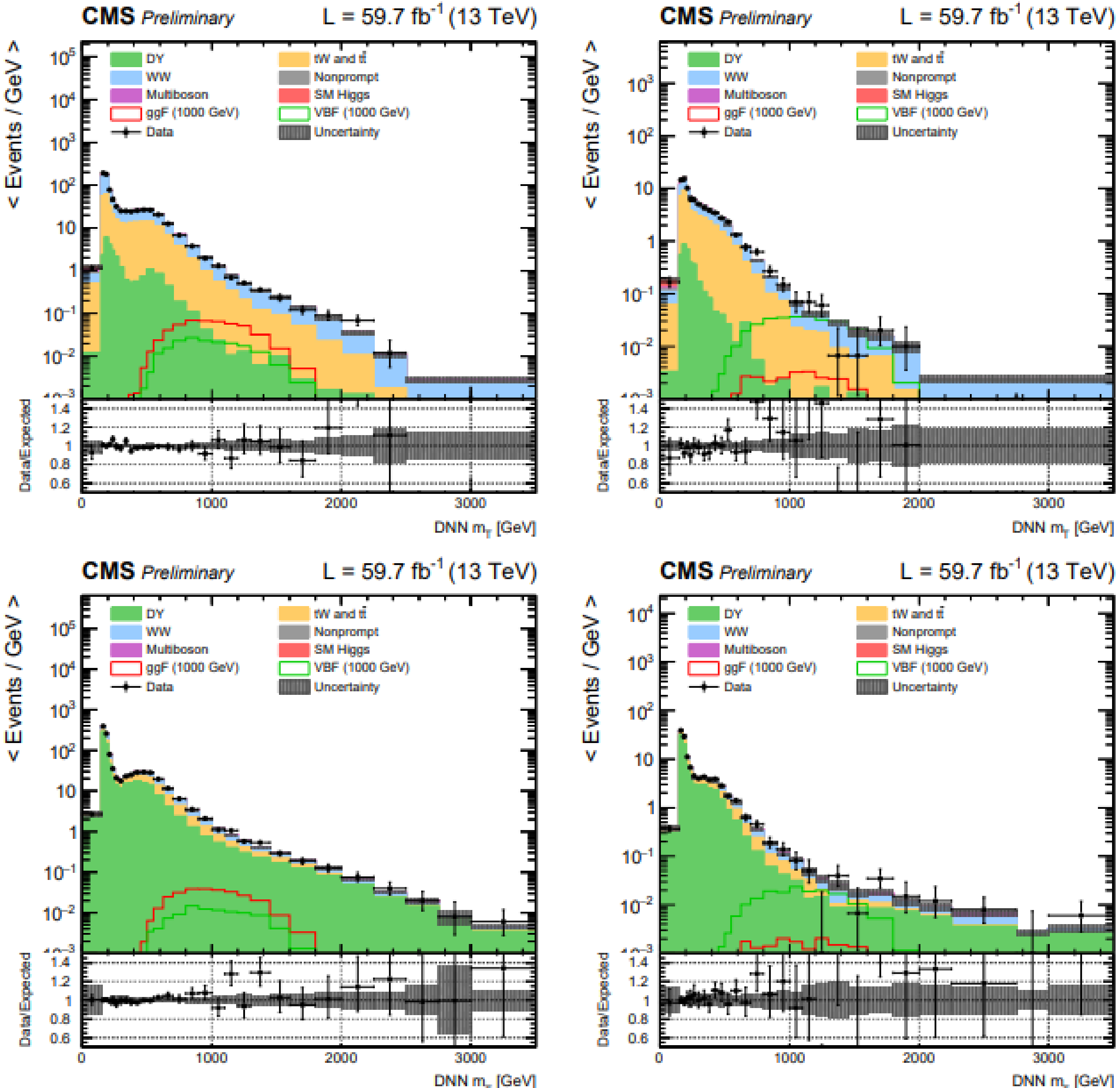
VBF W+W-



VBF W+W+

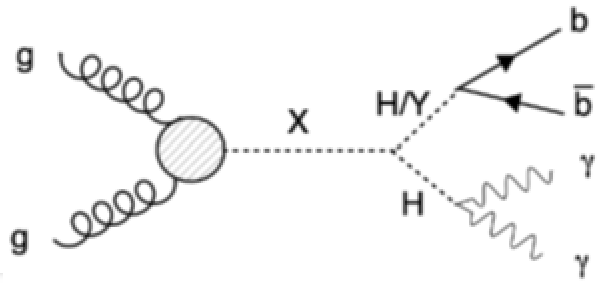
μe

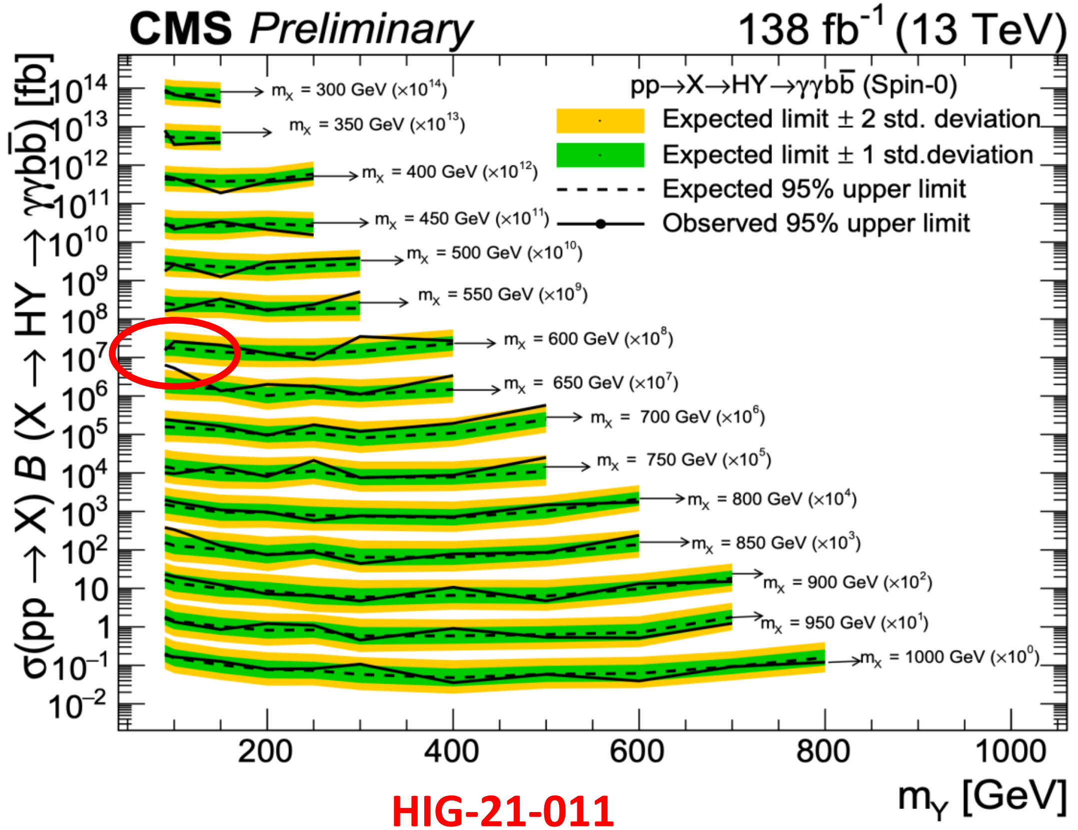
μ+μ-



Evidence for gg+VBF->H(650)->Y(90)+h(125)->bb+γγ

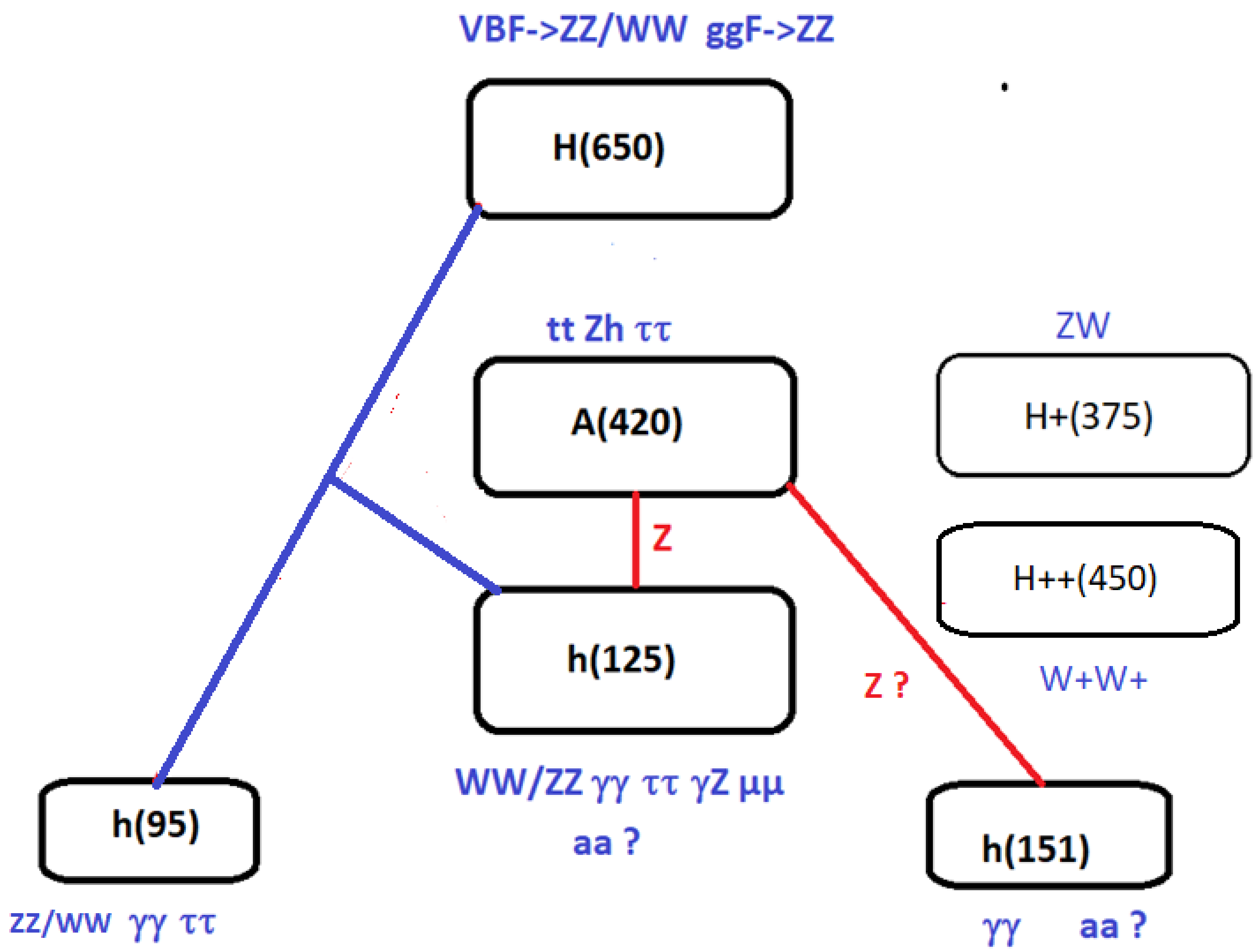
- 3.8 s.d. for mH=650 GeV and mY=90 GeV shown at ICHEP22
- Mass resolution on Y does not allow to distinguish between Z and h(95) which is by now a “good old friend”
- CP says that bb cannot come from Z->bb but could be h(95) which is another strong candidate seen in 3 channels 2203.13180 +2302.07276
- The cross section is dominant over all other indications **~200 fb** but it includes ggF+VBF





HIG-21-011

SUMMARY OF BSM CANDIDATES



Scalars for sum rules

Scalar	Channels	References	# s.d. glob.
H650	WW/ZZ ggFVBF h95h125	1806.04529 2009.14791 2103.01918 CMS-PAS-HIG-20-016 CMS-PAS-HIG-21-011	6.1
h95	$\gamma\gamma$ $\tau\tau$ bb (LEP2)	0306033 1811.08159 1803.06553 CMS-PAS-HIG-20-002 ATLAS-CONF-2023-035	3.9
H++450	W+W+	ATLAS-CONF-2023-023 2104.04762	2.6
H+375	ZW	2207.03925 2104.04762	2.7
H++ & H+			4.3

LHC inputs for our work

- We choose to select * combined searches with **> 4 s.d. global significance** with the exception of h151 which results from an **unofficial combination** of CMS & ATLAS data
- This keeps 4 neutral scalars and one pseudo scalar
- No change of significance after a CMS update of h(95)->2γ with RUN1 and RUN2 after some cleaning against Z->e+e-
- ATLAS claims 1.7 s.d. on h95->2γ
- Recent progress for H++ from ATLAS

Process	Channels	References	# s.d. glob. (local)	Michelin
H650	WW/ZZ ggF/VBF h95h125	1806.04429 2009.14791 2103.01918 CMS PAS HIG-20-016 CMS-PAS-HIG-21-011	6.1	**
A400	tt ZH320->Zh125h125	1908.01115 ATLAS-CONF-2022-043	5	*
h95	$\gamma\gamma$ $\tau\tau$ bb (LEP)	0306033 1811.08159 1803.06553 CMS-PAS-HIG-20-002 ATLAS-CONF-2023-035	3.9	~*
h151	$\gamma\gamma$ +ETmiss	2109.02650	4.8	?
H+375	ZW	ATLAS-CONF-2022-005 2104.04762	(3.5)	
H++450	W+W+	ATLAS-CONF-2023-023 2104.04762	(3.9)	
H+160	bc	*EPS-HEP2021, 631*	(3)	
h146	μe	CMS-PAS-HIG-22-002	(3.8)	

Georgi-Machacek for pedestrians

- Allows I=2, H++, without violating ρ=**$M^2w/Mz^2cos^2\theta w=1$** at tree level
- Is achieved by combining 1 isospin doublet (v_ϕ) + 2 triplets, one real the other imaginary, with the same vacuum expectations :

$$\rho = \frac{\tilde{v}_\phi^2 + 4\tilde{v}_\chi^2 + 4\tilde{v}_\xi^2}{\tilde{v}_\phi^2 + 8\tilde{v}_\chi^2} = \frac{v^2}{v^2 + 4(\tilde{v}_\chi^2 - \tilde{v}_\xi^2)}.$$

=1 with v_χ=v_ξ=u

- Predicts a **5-plet** of physical states H5++ H5+ H50 H5- H5- - **Fermiophobic** only produced by **VBF**
- **+ 3-plet** H3+ H30 (CP-odd) -> **A(400)**
- **Mass degeneracy** inside multiplets usually assumed but **unnecessary** for $\rho=1$ see 2111.14195
- + **Singlets h** and h' **mixing angle α**

The GM model for advanced

- GM is constituted by one doublet ϕ and two triplets, one complex χ and one real ξ, with the same vacuum expectations to get $\rho=1$

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \quad \chi = \begin{pmatrix} \chi^{++} \\ \chi^+ \\ \chi^{0*} \end{pmatrix}, \quad \xi = \begin{pmatrix} \xi^+ \\ \xi^0 \\ \xi^- \end{pmatrix}$$

Y=1/2 T=1/2 $v\phi$ Y=1 T=1 $v\chi$ Y=0 T=1 $v\xi=v\chi$ $\rho=1$

$$\rho = \frac{\tilde{v}_\phi^2 + 4\tilde{v}_\chi^2 + 4\tilde{v}_\xi^2}{\tilde{v}_\phi^2 + 8\tilde{v}_\chi^2} = \frac{v^2}{v^2 + 4(\tilde{v}_\chi^2 - \tilde{v}_\xi^2)}.$$

- Only ϕ couples to fermions
- They form the following physical states, dominantly triplet r
- $s_H=2\sqrt{2}v\chi/v$

$$\begin{aligned}
H_5^{++} &= \chi^{++}, \\
H_5^{+} &= \frac{(\chi^+ - \xi^+)}{\sqrt{2}}, \\
H_5^0 &= \sqrt{\frac{2}{3}}\xi^0 - \sqrt{\frac{1}{3}}\chi^{0,r}, \\
H_3^+ &= -s_H\phi^+ + c_H\frac{(\chi^+ + \xi^+)}{\sqrt{2}}, \\
H_3^0 &= -s_H\phi^{0,i} + c_H\chi^{0,i}.
\end{aligned}$$

- H1 and H1' have following composition

$$\begin{aligned}
H_1^0 &= \phi^{0,r}, \\
H_1^{0\prime} &= \sqrt{\frac{1}{3}}\xi^0 + \sqrt{\frac{2}{3}}\chi^{0,r}.
\end{aligned}$$

- The physical states are

$$\begin{aligned}
h &= \cos\alpha\, H_1^0 - \sin\alpha\, H_1^{0\prime}, \\
H &= \sin\alpha\, H_1^0 + \cos\alpha\, H_1^{0\prime}.
\end{aligned}$$

- Common wisdom: the mixing angle α **has to be small** to avoid altering the doublet properties of the SM h(125)
- Also $v\xi=v\chi$ small while SR says that $v\xi=v\chi=70$ GeV

SGM: a SUSY version of GM

1308.4025

$$\Sigma_{-1} = \begin{pmatrix} \frac{\chi^-}{\sqrt{2}} & \chi^0 \\ \chi^{--} & -\frac{\chi^-}{\sqrt{2}} \end{pmatrix}, \quad \Sigma_0 = \begin{pmatrix} \frac{\phi^0}{\sqrt{2}} & \phi^+ \\ \phi^- & -\frac{\phi^0}{\sqrt{2}} \end{pmatrix}, \quad \Sigma_1 = \begin{pmatrix} \frac{\psi^+}{\sqrt{2}} & \psi^{++} \\ \psi^0 & -\frac{\psi^+}{\sqrt{2}} \end{pmatrix}$$

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}, \quad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

- GM does not necessarily mean compositeness
- SGM provides all the “goodies” of SUSY:

  Perturbativity, computability
- EWSB naturally triggered
- Mh predicted with less “tension” on stop masses with extra contributions to RC
- Two doublets as needed to interpret H320 and the ZZ/WW decays of H(650)
- DM candidate
- Complex/rich world with ~20 Higgs scalars

TeV projects

SNOWMASS

D. Schulte
Higgs Hunting 23

+ CEPC-ee 0.24 TeV
SPPC-pp 100 TeV

	CME [TeV]	Lumi per IP [$10^{34}cm^{-2}s^{-1}$]	Years to physics	Cost range [B$]	Power [MW]
FCC-ee	0.24	8.5	13-18	12-18	290
ILC	0.25	2.7	<12	7-12	140
CLIC	0.38	2.3	13-18	7-12	110
ILC	3	6.1	19-24	18-30	400
CLIC	3	5.9	19-24	18-30	550
MC	3	1.8	19-24	7-12	230
MC	10	20	>25	12-18	300
FCC-hh	100	30	>25	30-50	560

Snowmass Paper

arXiv:2203.07622

Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole		Upgrades	
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ^*_{z}	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ^*_{x}	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	138	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [26]. *): For operation at the Z-pole additional beam power of 1.94/3.88 MW is necessary for positron production.