Evidence for BSM physics in the scalar sector

ECFA WG1-SRCH

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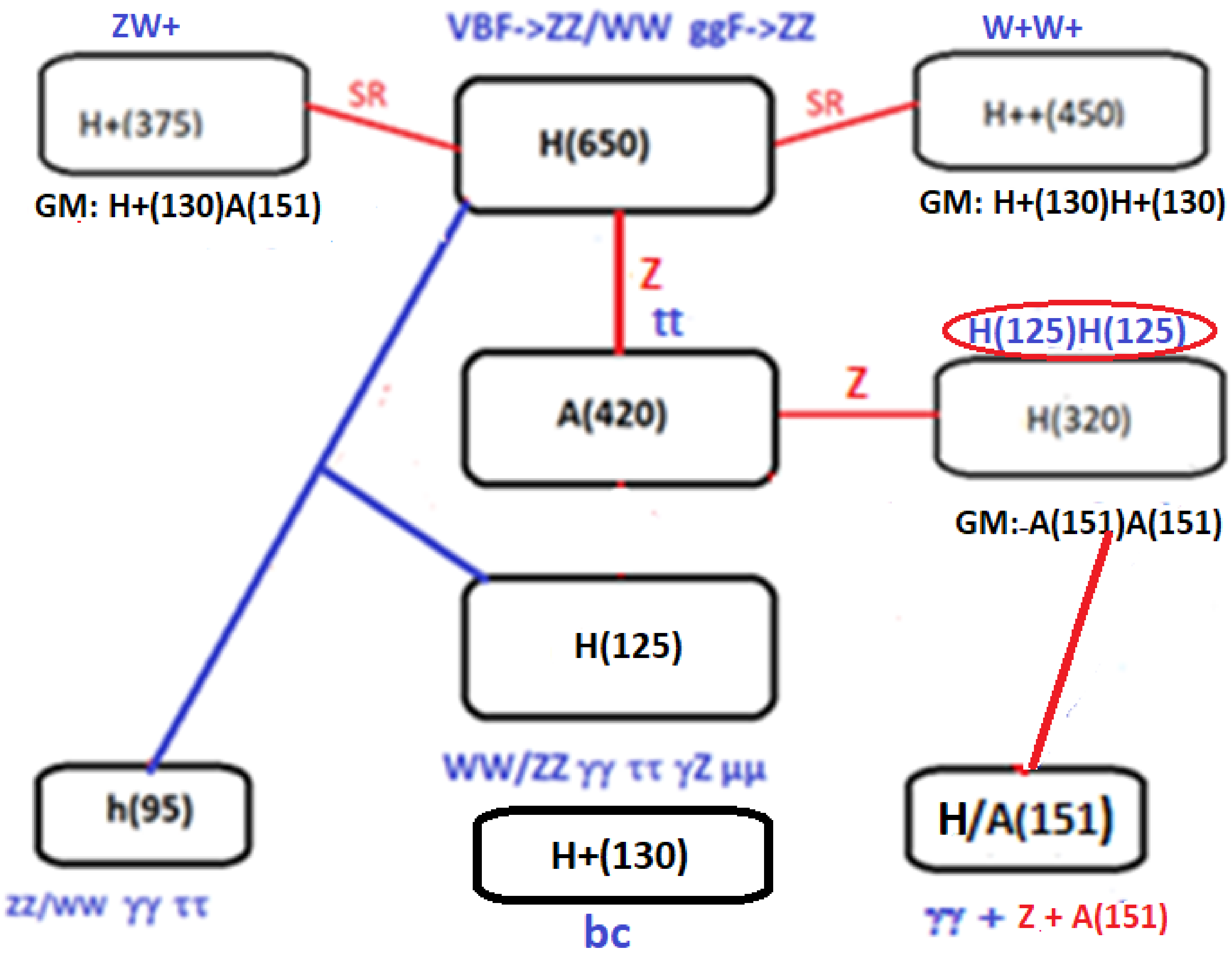
Introduction

- **LHC results will** have a major influence on our choice for future machines
- **Direct discoveries** are needed to justify these costly projects
- **Our only compass is LHC !**
- ATLAS & CMS show a plethora of indications for BSM physics in the sector of scalars
- None reaches by itself the 5 s.d. level , e.g., H(650) achieves this goal by combining 4 channels (**ZZ/WW/Hh/ttZ**)
- Indications for **H++->W+W+ and H+->ZW+** suggest going beyond two doublet/singlet models interpretations
- This talk tries to make sense out of them to converge to **a phenomenological explanation** which can confirm some and exclude others
- Having elected an explanation, it predicts **further signals**, additional decay modes which will consolidate or exclude this type of explanation
- It will also look into the consequences for e+e- colliders under consideration

SUMMARY OF BSM SCALAR CANDIDATES



A Georgi Machacek interpretation

- This copious list of candidates does not fit within MSSM nor even NMSSM
- **H++->W+W-/H+->ZW** predicted by GM and W+W-/ZZ unitarity sum rules would constitute the **strongest case for GM**
- GM is a minimal model which can be extended in many ways 2111.14195
- E.g. H(650) requires adding a second doublet 2211.11723

GM	**Isosinglet**	**h95**	**h125**
	Isotriplet	**A151->γγ**	**H+130->bc**
	Isofiveplet	**H320->hh**	**H+375->ZW+ H++450->W+W+**
e-GM +1 isodoublet		**A420->ZH320**	**H650 H+->ttW ?**

- All boxes among the **9 e-GM predicted scalars** have a candidate indicated by LHC data
- Predicts that X(151) seen in γγ +tags is CP=-1
- There is a candidate **H+->A(420)W+ -> ttW+** 2001.04770
- Physical states differ substantially from the GM Isospin states as expected 2111.14195

Predicting H++ and H+->ZW+

- **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 is H(320) where these measurements are unavailable, but we have ideas on how to deal with them (matrix method)
- H(650) alone forces to have a contribution of H++->W+W+ with a coupling ~ SM=gmW
- This predicted state has been observed in W+W+
- The same is true for H+->ZW predicted from **WW->ZZ**
- Both predict that W+W+ and ZW+ are subdominant

Predicting the missing couplings

- e-GM comprises two doublet fields $\phi 1$, $\phi 2$ with vev **v1 and v2** and two triplet fields χ, ξ with the same vev **u**
- For the neutral sector one writes:

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

- 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 7 observables from LHC measurements, u from SR + constraint $v1^2+v2^2+4u^2=(174\text{ GeV})^2$
- 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

A matrix solution

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

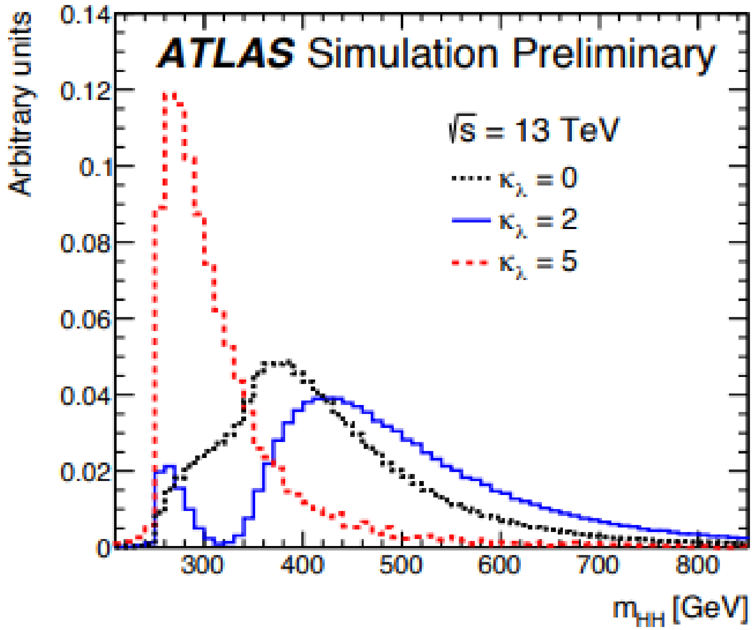
$$H_5^0 = \sqrt{\frac{2}{3}}\xi^0 - \sqrt{\frac{1}{3}}\chi^{0,r},$$

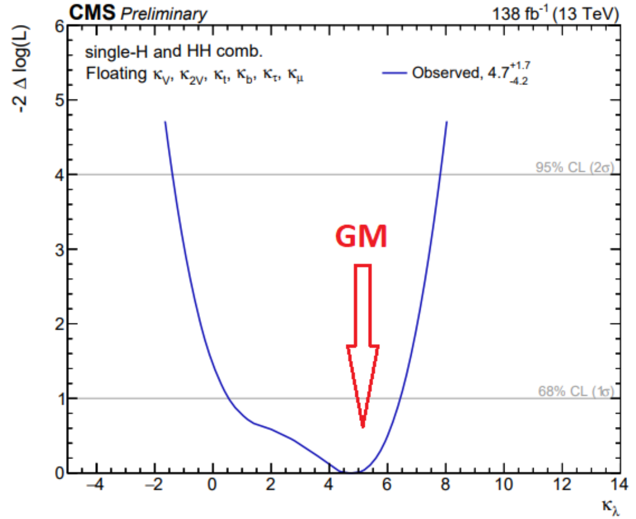
	1	2	3	4	htt/SM	ZZ/SM	WW/SM
	ϕ1	ϕ2	χ	ξ			
H95	0.08	-0.56	0	0.82	- 0.96	- 0.34	0.59
H125	0.58	0.58	0.47	0.33	0.99	0.99	1.1
H320	0.31	0.30	-0.88	0.17	0.52	- 1.29	- 0.38
H650	0.74	-0.52	0	-0.43	- 0.90	- 0.43	- 0.91

- Coloured squares have unmeasured couplings which can be **predicted** by this approach
- Neutral scalars do not coincide with GM isospin states H1, H3 and H5, as predicted *2111.14195*
- **H125=0.58(ϕ1+ϕ2)+0.58H'1** ~ **pure singlet** fulfils SM predictions *1807.10660*
- **h95 =-0.56ϕ2 +0.5 H^{0}'1+0.7H^{0}5** comprises a **large fiveplet** component H5
- ρ, mH and mixings are not predictable within GM (divergent at loop level)
- h95->WW measured by a combination of ATLAS+CMS, agrees with this prediction 2302.07276
- **H320** has **doublet components** hence its coupling to HH, forbidden with the H5 component
- H320->ZZ predicted width ~5 GeV is subdominant with respect to $\Gamma_{H320\to AA}$ **~ 100 GeV**

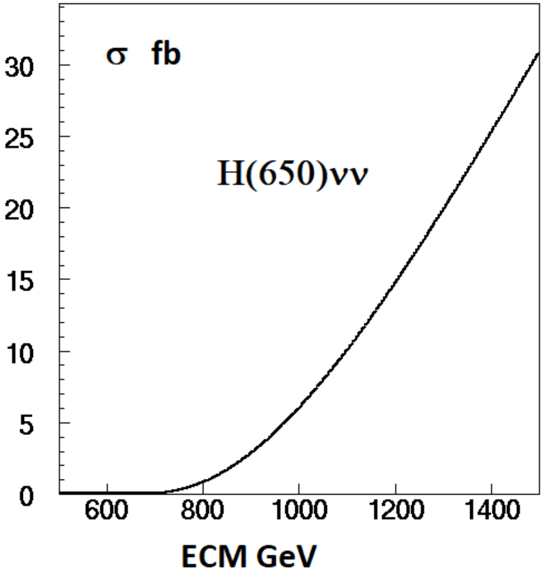
Predicting the triple Higgs coupling

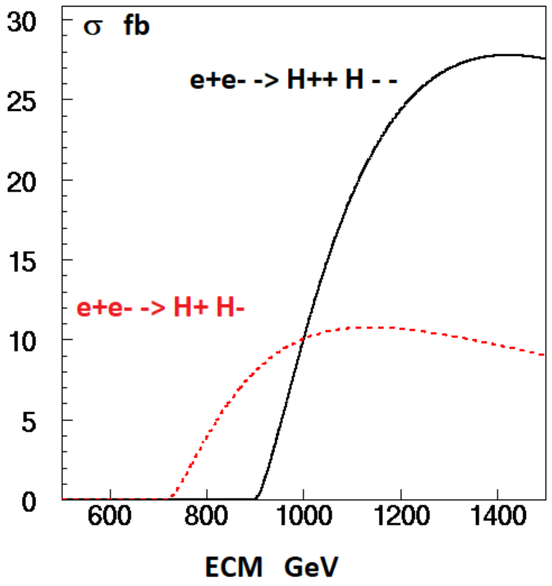
- Major effort of ATLAS & CMS, the **‘holy grail’** of HEP
- Very challenging with a SM cross section ~30 fb
- H(320)->HH contribution has > ten times larger cross section and could perturb
- It and simulate κ_λ ~5
- Wide signal not incompatible with data
- **H(320)->A(151)A(151)** is predicted as the dominant decay and should be detected in A(420)->ZH(320) producing the most convincing BSM signal
- **Strong prediction of e-GM !**

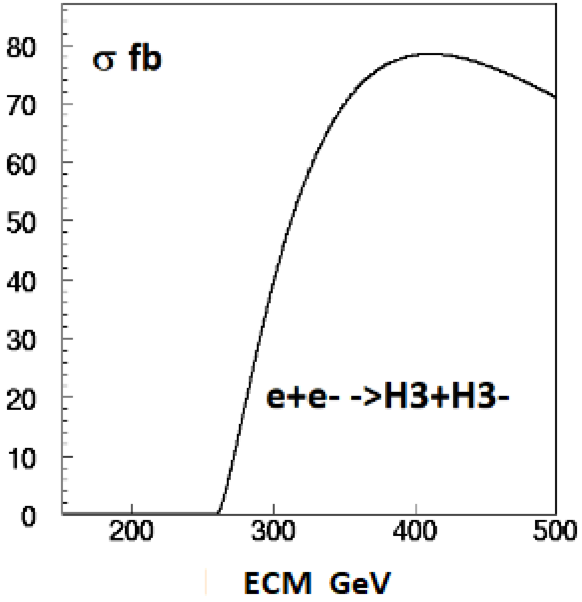


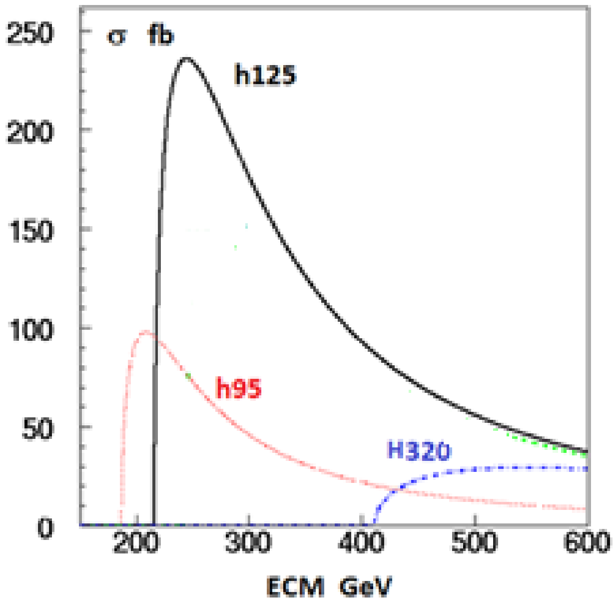


e+e- collider reach









- ILC would provide **8000 fb-1 at 1 TeV,** needed to cover H++, H(650) and H(320)
- Heavy final states are complex modes (~ SM ttH) requiring the **highest $\mathcal{L}$** and an **almost ideal detector with forward coverage for b jet ID**
- **H(650)** mainly produced through VBF (beam polarisation allows a factor ~2 gain, not included) benefits from an increased energy
- A(420) and A(151) can be seen through cascades like H(650)->ZA(420), H+(375)->A(151)W+, H(320)->A(151)A(151)
- Using an **e-e- collider** one could also produce H $^{--}$ through VBF with polarized beams gives ~100 fb at 1 TeV
- Circular machine can access to h95 and H+(130)

Summary and conclusions

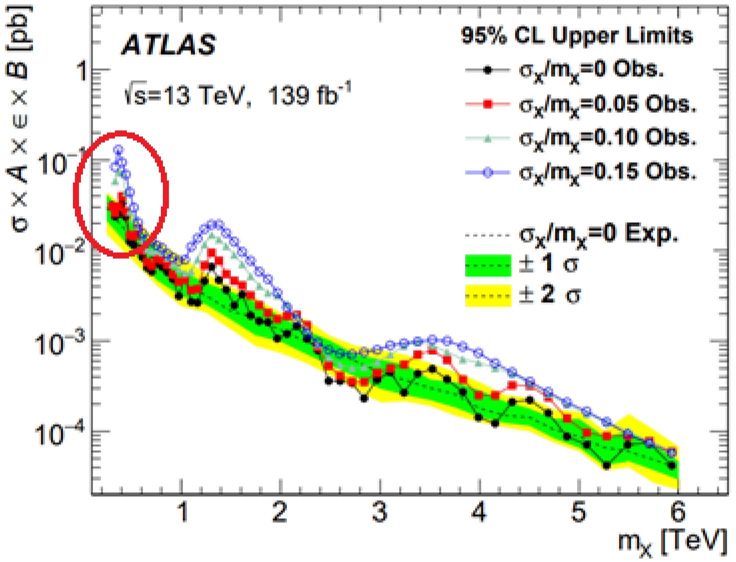
- An avalanche of indications for BSM scalars is observed at LHC
- The table of **e-GM predicted states** can be filled with these various indications provided by LHC predicting a **third H+** in H+->ttW+ also observed in 2311.04033
- Eagerly awaiting for a confirmation of H(650)->ZZ by CMS, a basis for H++ prediction through unitarity sum rules, which would constitute a **major progress** for our work
- H(320)->H(125)H(125) should contribute to **the H*->HH** SM measurements
- A global interpretation based on GM+SR predicts a **triple discovery** for A(420), A(151), H(320) with A(420)->H(320)Z->A(151)A(151)Z, achievable with RUN2 data
- The **matrix method** shows that the neutral candidates strongly differ from the isospin pure states predicted by GM, as expected in 2111.14195
- All these scalars could be precisely measured at an LC reaching 1 TeV
- Read our papers : 2404.09827 the most recent and **2308.12180**

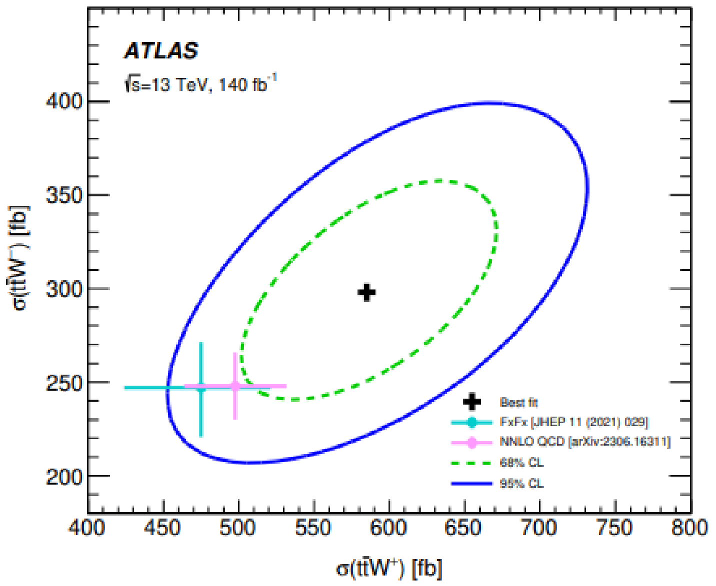
constantly updated

Additional slides

Predicting an extra H+

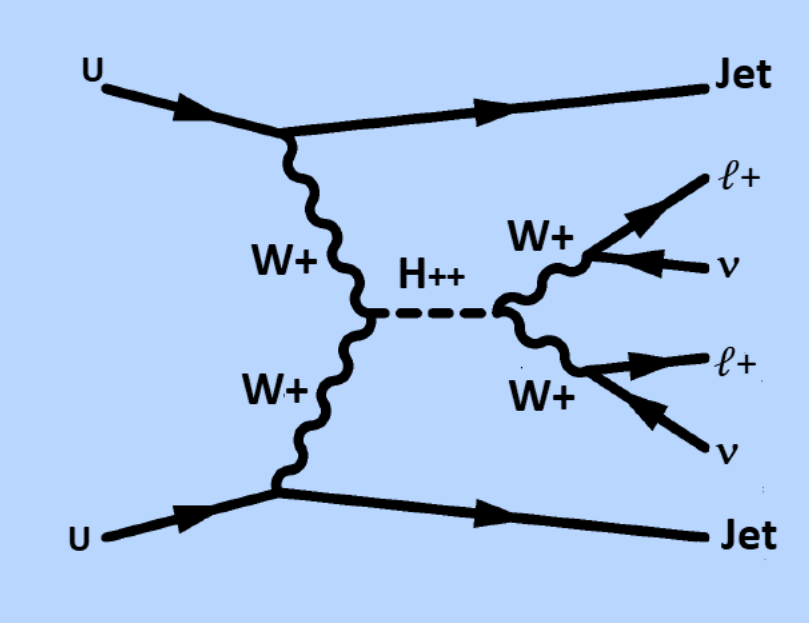
- An e-GM scheme requires an extra H+ related to H(650)
- By analogy with H(650)->A(420)Z->ttZ, one expects that **H+->A(420)W+->ttW+**
- An inclusive search for heavy jet-jet masses associated to a high pT lepton provides such a candidate [2001.04770](2001.04770)
- ATLAS and CMS observe an excess in the inclusive measurement of ttW+/- [2401.05299](2401.05299)
- Seems to proceed through ZW fusion to explain the charge asymmetry (p->u->W+ : factor 2)
- One should therefore observe H+->ZW
- No such effect in ttZ, which is not yet understood



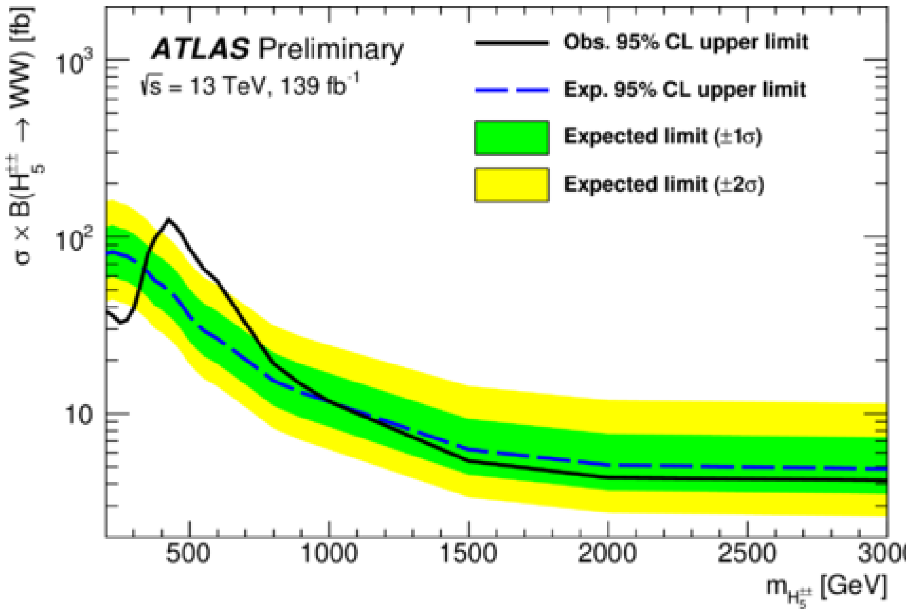


First hint for H++

- Recently at the Belgrade ATLAS meeting: **H++(450)->W+W+**
- LHC is ideally suited for this measurement:



- 3.2 s.d. local, 2.5 s.d. global
- The reconstruction efficiency of CMS is a factor 2 below that of ATLAS 2312.00420



Sum Rule II

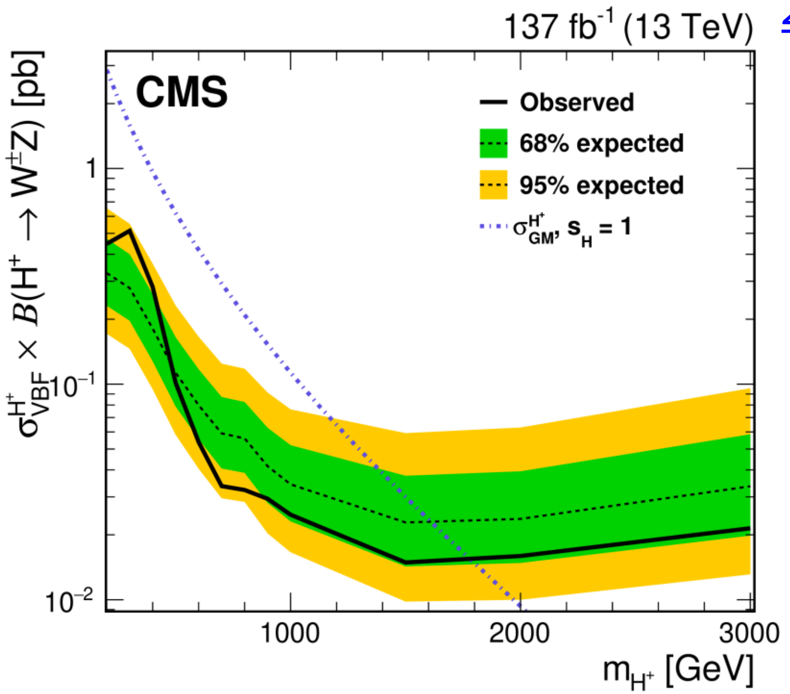
- **W+W- -> ZZ** allows a similar SR

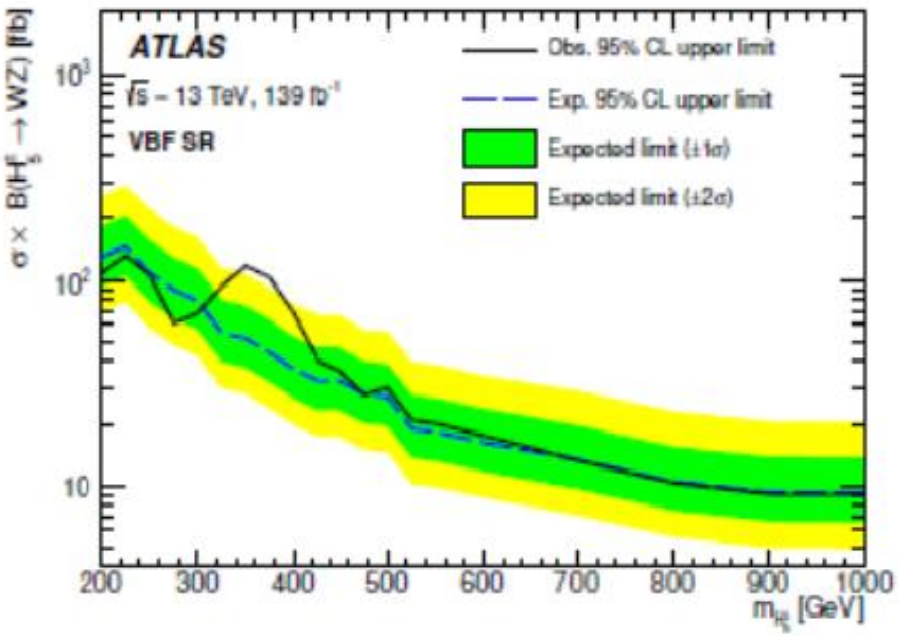
$$\frac{g^2 m_Z^4 c_W^2}{m_W^2} \overset{\rho\simeq 1}{\simeq} g^2 m_Z^2 = \sum_k g_{W^+W^-H_k^0} g_{ZZH_k^0} - \sum_l g^2_{W^+ZH_l^-}$$

- This forces a strong coupling for **H+->ZW+** which should be observed at LHC
- Note that this 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 excesses at mH5+~375 GeV for ATLAS & CMS
- **ATLAS** claims 2.8 s.d. local
- In GM H5++ and H5+ are mass degenerate which is almost true (see for e-GM 2111.14195)
- H(650) cannot fulfil the requirements of a neutral candidate of H5 but H(320) is more appropriate

Model independent results

- From these and the SR, one can deduce the total cross section, the elastic BR and the total widths as given in the following table:

Channel	**σ_{VBF} fb**	**σ_{VBF} VV fb**	**BR(VV) %**	**Γtot GeV**
H++(450)	830	75	9±4	160
H+(375)	810	125	15±8	80

- These predictive results only rely on the validity of the sum rule approach, which seems legitimate given that VV final states at the LHC energy scale agree with the SM predictions
- They call for lighter charged scalers to provide VH and HH contributions

GM interpretation

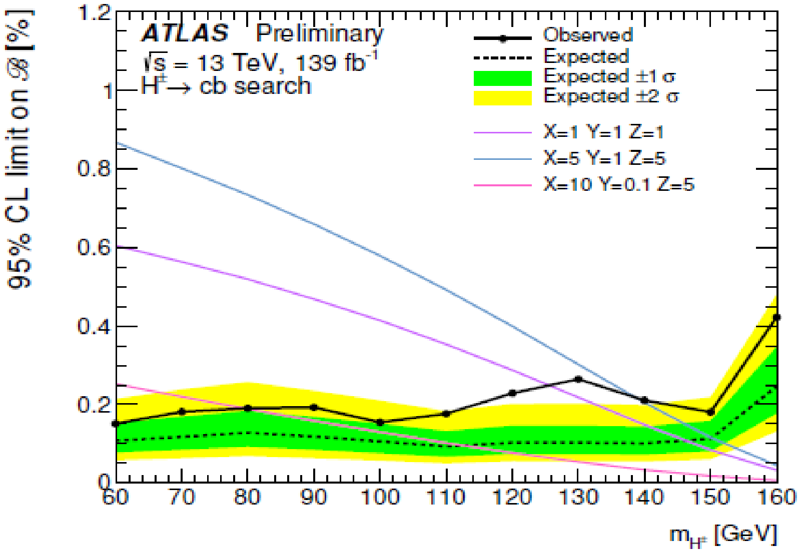
- Quantitatively, SR predicts $\Gamma_{\mathbf{H{+}{+}\text{->}W{+}W{+}}}$ and the measured cross section allows to deduce the BR(W+W+) and the total width $\Gamma_{\mathbf{H{+}{+}\text{->}W{+}W{+}}}$ /BR(W+W+)

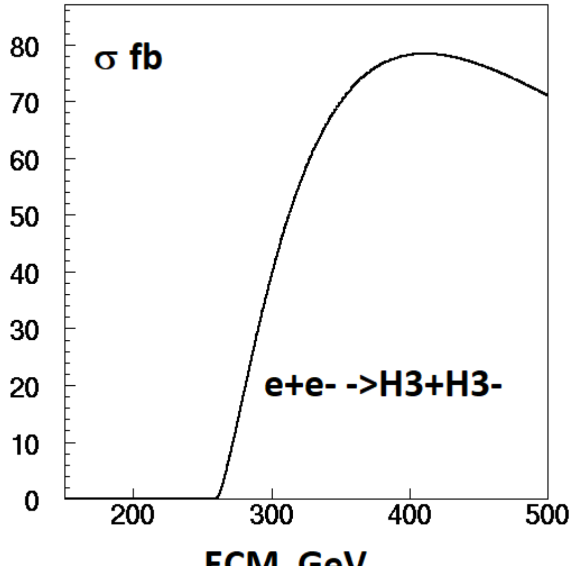
Channel	u GeV	s_H	BR(VV) %	BR(VH) %
H++	70±12	0.80±0.1	9	12.5
H+	80±13	0.90±0.2	15	17

- **u=70 GeV** comes as a surprise: usual lore is BR(W+W+)=1 and u<25 GeV
- This large value is inconsistent with models with only one triplet (*2312.17314*) requiring u much smaller to fulfill **ρ~1**
- BR(W+W+)~10% requires other modes like H'+W+ or even **H'+H'+** (ZH'+ for H+)
- **A light (or several) H'+ predicted**

A light H'+ ?

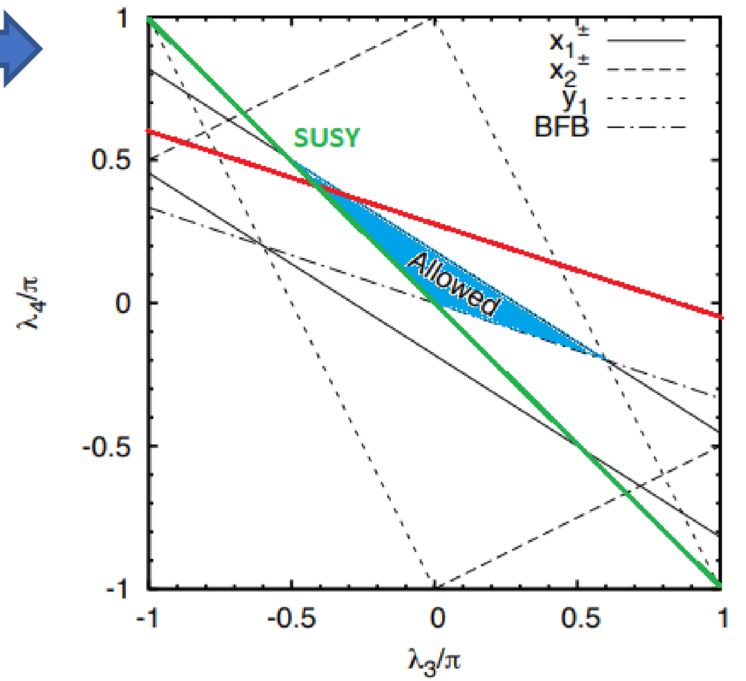
- There are few indirect hints for this
- B decays into Dτ and $\Lambda\tau$ are reduced by 1.6 and 1.4 s.d. 2305.00614 suggesting mH+~200 GeV
- ATLAS has searched for t->bH+->bbc and found a 3 s.d. local (2.5 global) excess around 130 GeV 2302.11739
- Not allowed in 2HD models for type II 1702.04571 but allowed for tanβ>2 in type I
- One predicts A mass degenerate which can feed into H+(375)->AW+ (could be A(151) seen into 2γ)
- Works quantitatively to explain the observed BR of H++ and H+(375) into H'+H'+ and H'+A
- Good news for circular colliders





Towards a full GM solution ?

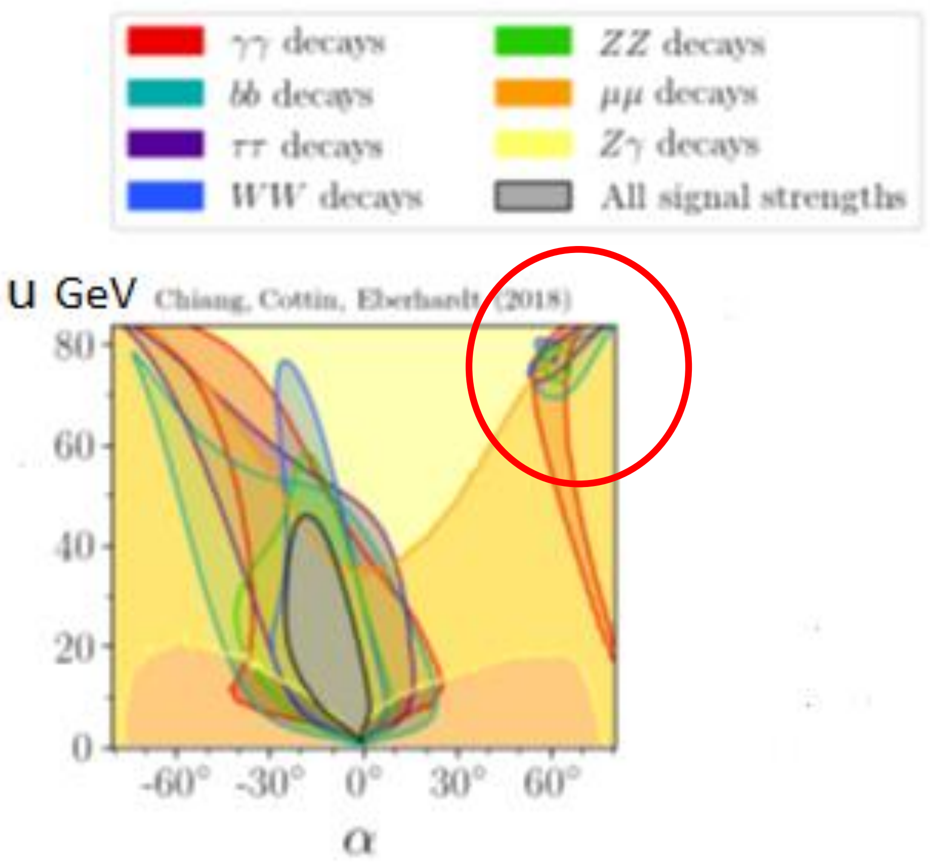
- From the properties of the GM candidates one can deduce the dimensionless couplings $\lambda 1$ $\lambda 2$ $\lambda 3+3\lambda 4$
- Adding unitarity and BFB condition gives $\lambda 3$ and $\lambda 4$
- One uses the total widths derived from the SR to extract the missing widths of H++ into **H+(130)H+(130)** and H+ into H+(130)A3(151) assuming that there are to other decay modes
- With this additional constraint one gets **M1, M2 and $\lambda 5$**
- To compute quantities involving h(95) and h(125), like $\mu 95\gamma\gamma$, one needs to determine a **mixing parameter α**
- To determine α, **we impose that $\mu 125\gamma\gamma \sim 1$**



u GeV	m5 GeV	$\lambda 1$	$\lambda 2$	$\lambda 3$	$\lambda 4$	$\lambda 5$	M1 GeV	M2 GeV
70	400	0.07	-1.4	-1.06	1.25	-6.3	950	400

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** still passing PM
- Not necessarily true for **h->hh** or **Zγ**
- **μ95γγ~0.3** differs from the matrix prediction ~1, perhaps due to the charged Higgs sector while μ125γγ~1 could be due to an accidental cancellation



1807.10660

H(320) as a partner of H++ ?

- The **H5 multiplet** containing H++ needs to be completed by a neutral scalar, which cannot be H(650) which is doublet dominated
- Given its mass, H(320) seems appropriate and its dominant content in triplet fields (see matrix) reinforces this hypothesis
- However, its decay into bbbb interpreted as h(125)h(125) seems to violate GM
- Note that h(125) and h(95) also carry triplet components which allows H(320)->hh
- H(320) most probably decays into **A(151)A(151)** which feeds into bbbb, experimentally indistinguishable from hh
-

b->sγ constraint on mH+

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

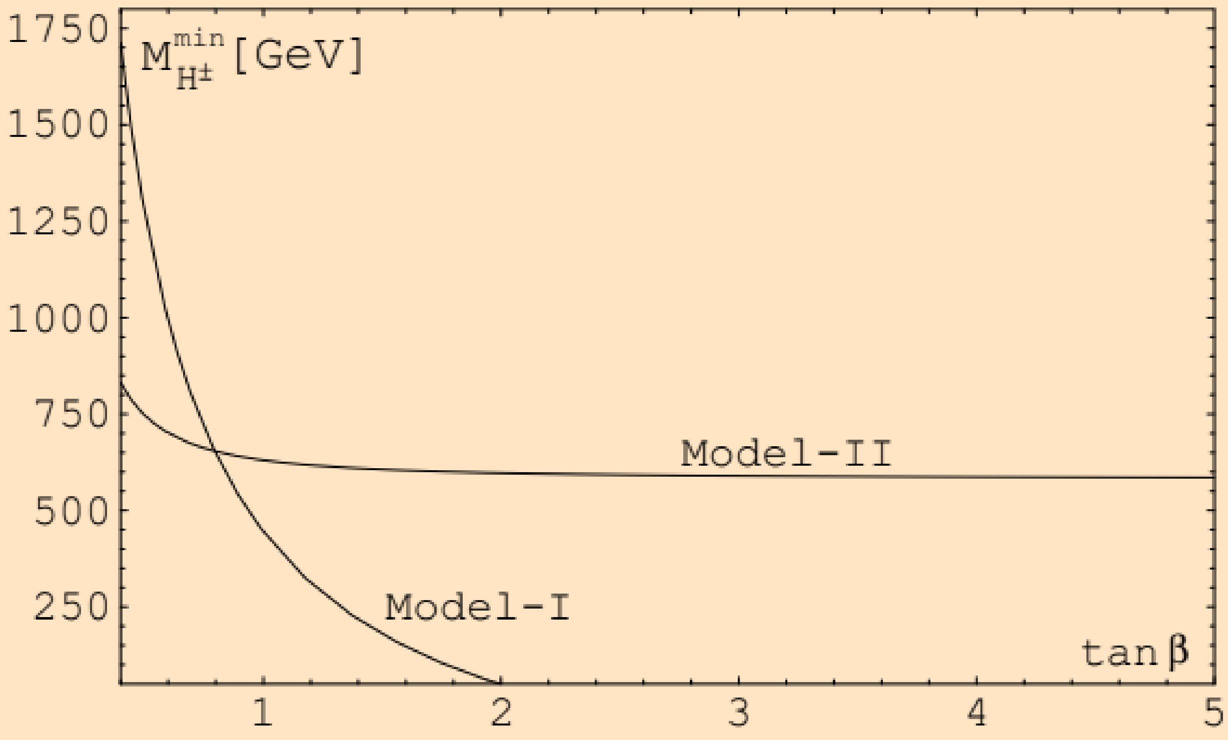
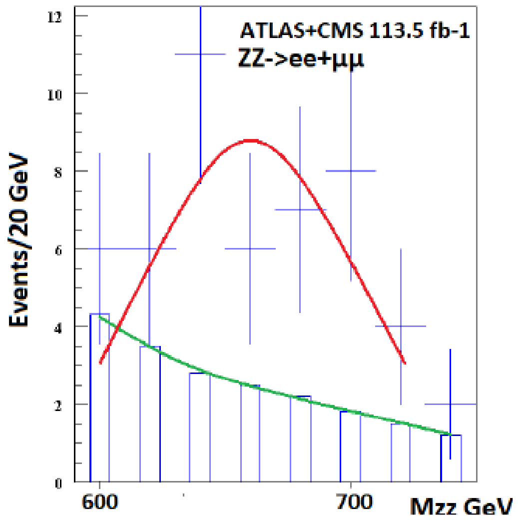
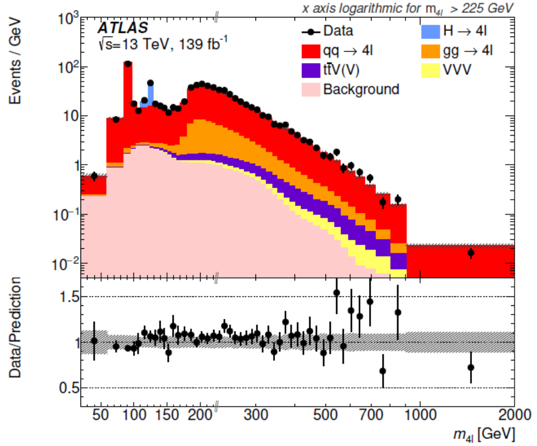


Figure 4: 95% C.L. lower bounds on $M_{H^\pm}$ as functions of $\tan\beta$.

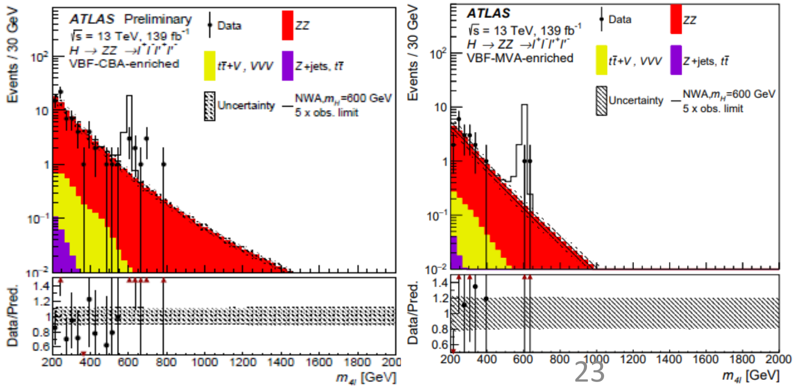
1st indication : H->ZZ into 4 leptons



- The **cleanest channel** for discoveries
- From a combination of published histograms [1806.04529](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, with **sequential cuts**, an excess is observed at the same mass, s/b=9/2 ~2.1 s.d., for VBFBR(ZZ)->H(660)->ZZ ~34±20 fb (~2 times smaller with a **MVA analysis**) [2009.14791](2009.14791) and 3 sd 150±60 fb for ggFBR(ZZ)

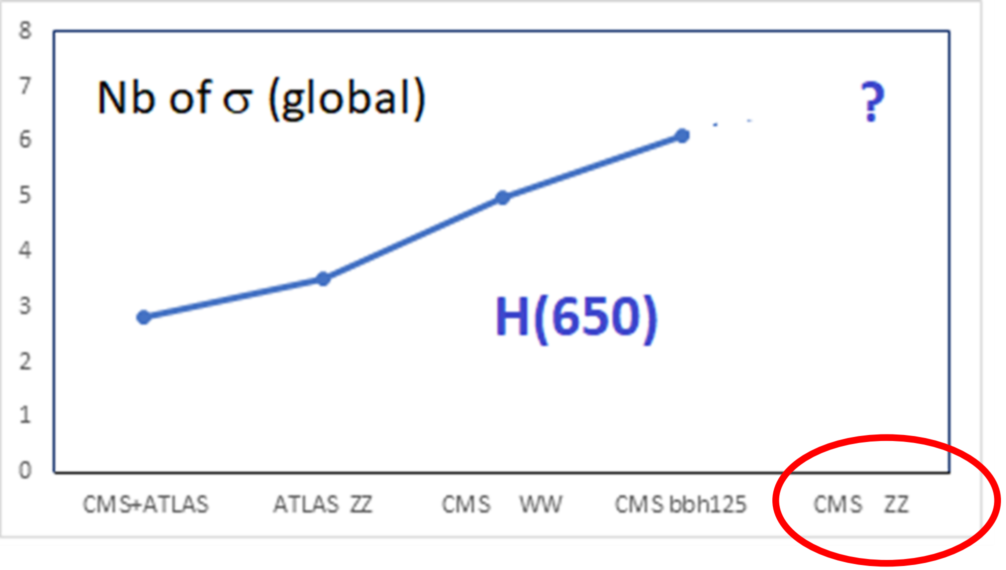


- The MVA analysis gives ggFBR(ZZ)<50 fb MVA + **ℓ+ℓ-νν**
- CMS analyses into four leptons are not yet published
- These results call for a combination of both analyses before one can draw a valid conclusion
- Could stop here but…



Historical progress of H(650)

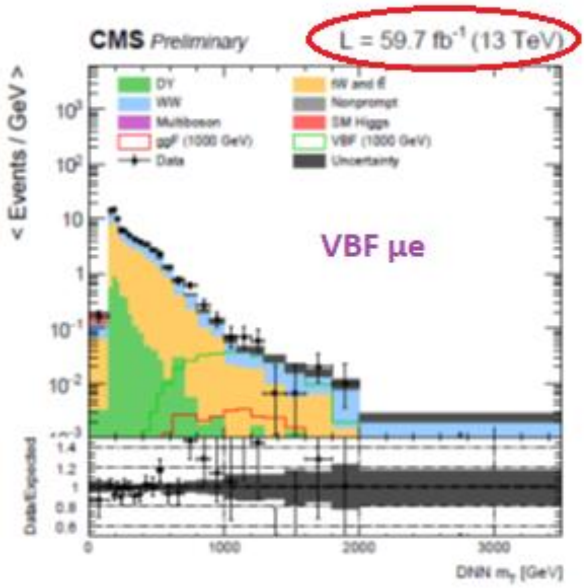
Steps	Mode	Origin	Local sd	Remark	Global sd
0	ZZ->4ℓ	ATLAS+CMS from [7]	3.8	ATLAS+CMS 113.5 fb-1 Defines mass & width	2.8
1	ZZ->4ℓ	From ATLAS	3.5	From histogram	3.5
2	WW->ℓνℓν	From CMS	3.8	Official statement	5
3	h(95)h(125)->bbγγ	From CMS	3.8	Official statement	6.1



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

- ggF has a large top background even after b-jet vetoing and using **μe** (against DY)
- **Wide signal** with ±50% mass resolution
- **VBF->H(650)->$\ell\ell\nu\nu$** allows to see a signal
- This **VBF** cross section ~**160±50 fb**, close to SM, is ~3 times larger than VBF->ZZ, inconsistent with **GM** which predicts for the scalar **H5 WW/ZZ=0.5**
- **2 HD excluded** (bue line) h(125)WW predicts **sin²(α–β)~0.97±0.09** meaning that **H(650)WW~cos²(α–β)~(0.03± 0.09)SM**
- Both GM and 2HD excluded !
- An attempt from ATLAS does not reach the same sensitivity (only μe) ATLAS-CONF-2022-066

μe



CMS PAS HIG-20-016

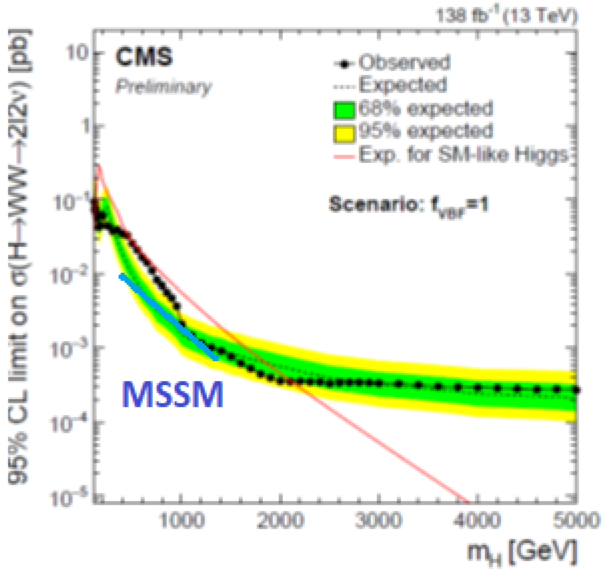
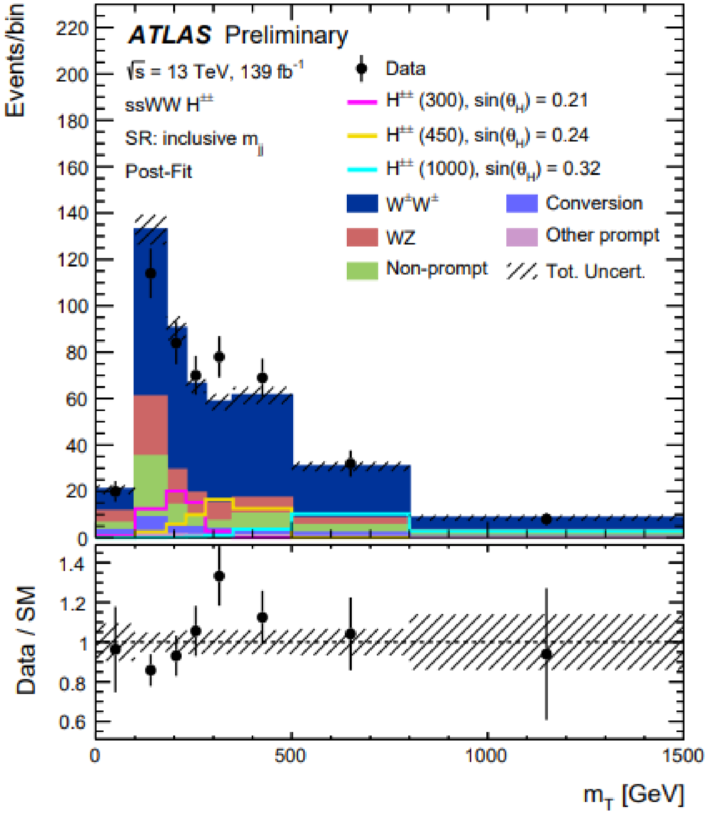


Table 3: Summary of the signal hypotheses with highest local significance for each f_{VBF} scenario. For each signal hypothesis the resonance mass, production cross sections, and the local and global significances are given.

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 than W+W+ due to tt and DY backgrounds



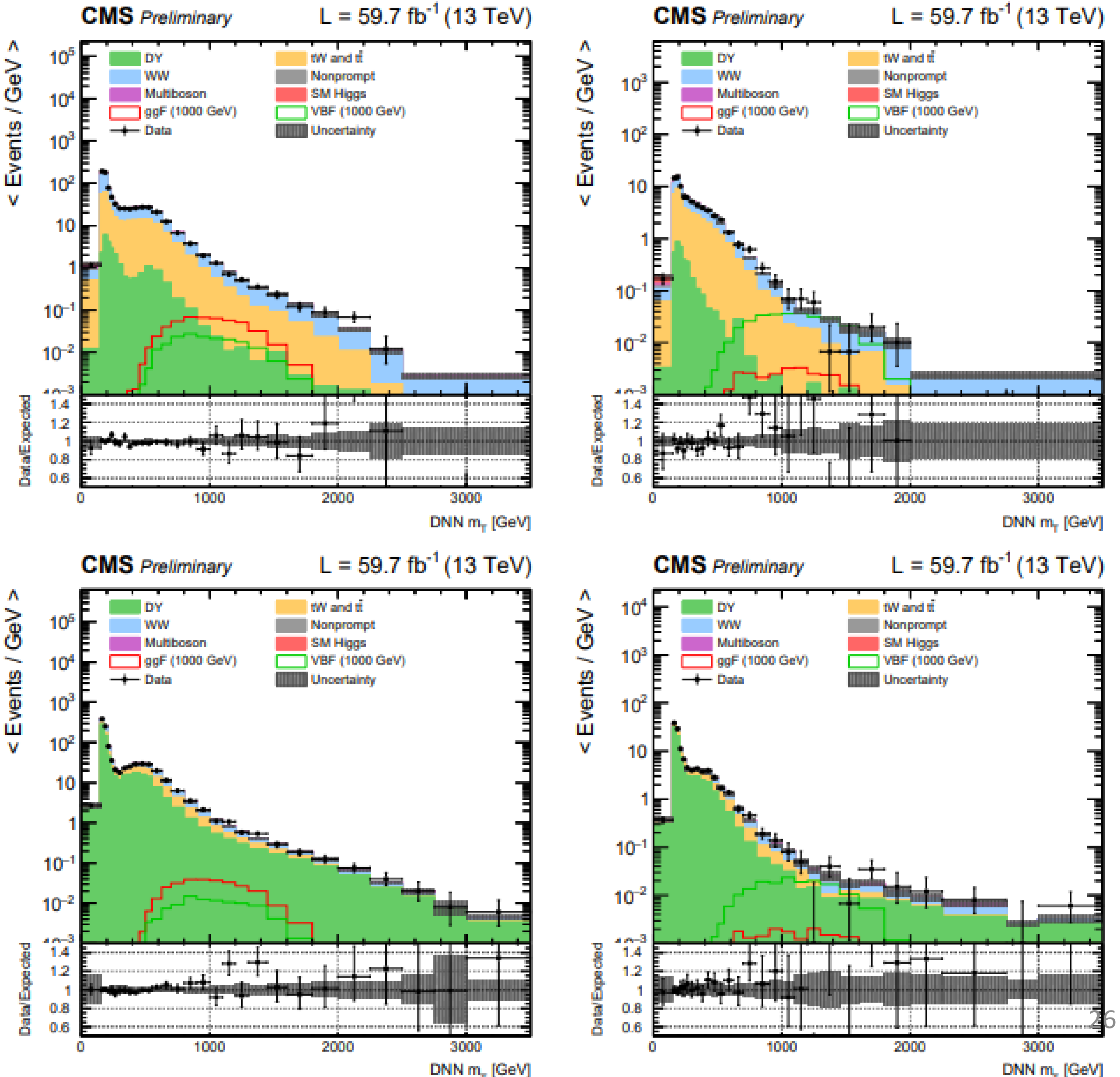
W+W+ much easier

ggF->W+W-

VBF W+W-

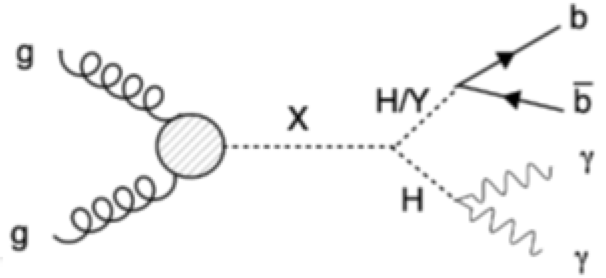
μ+e-

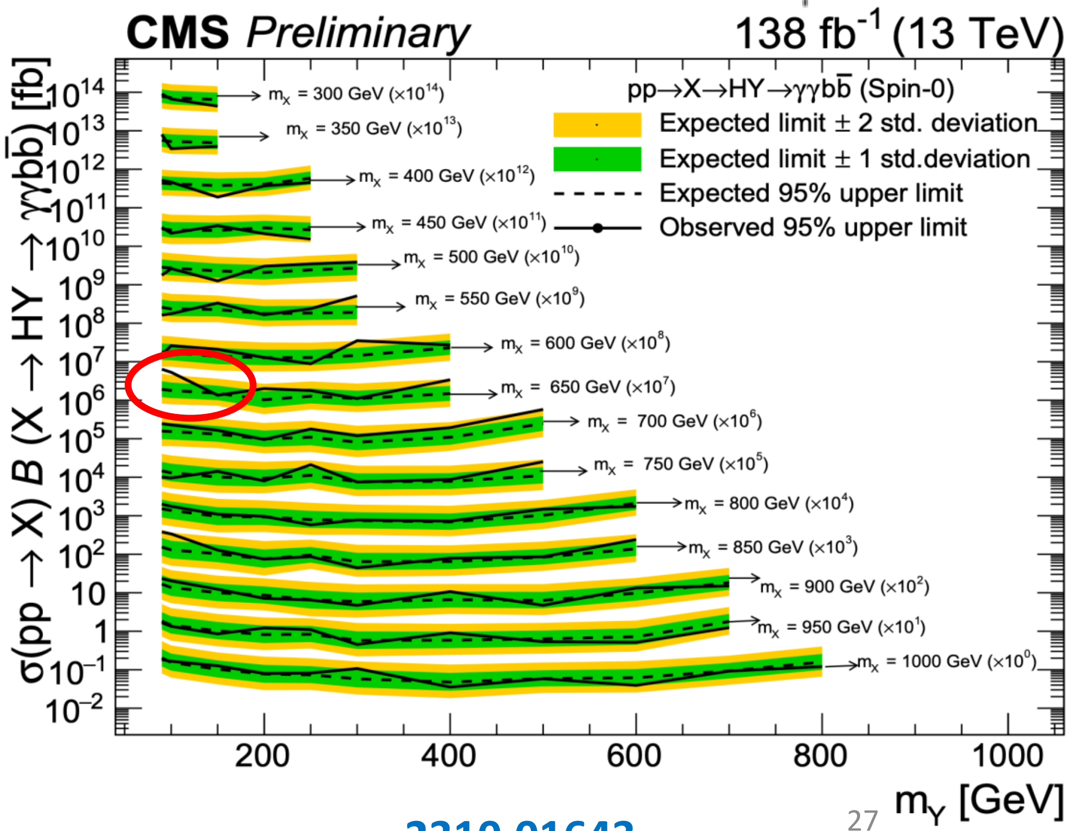
μ+μ-



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 scalar candidate seen in 3 channels [2203.13180](2203.13180) +[2302.07276](2302.07276)
- The cross section is dominant over all other indications **~190+90-70 fb** but it includes ggF+VBF
- Also interpreted by CMS as a **tensor particle**

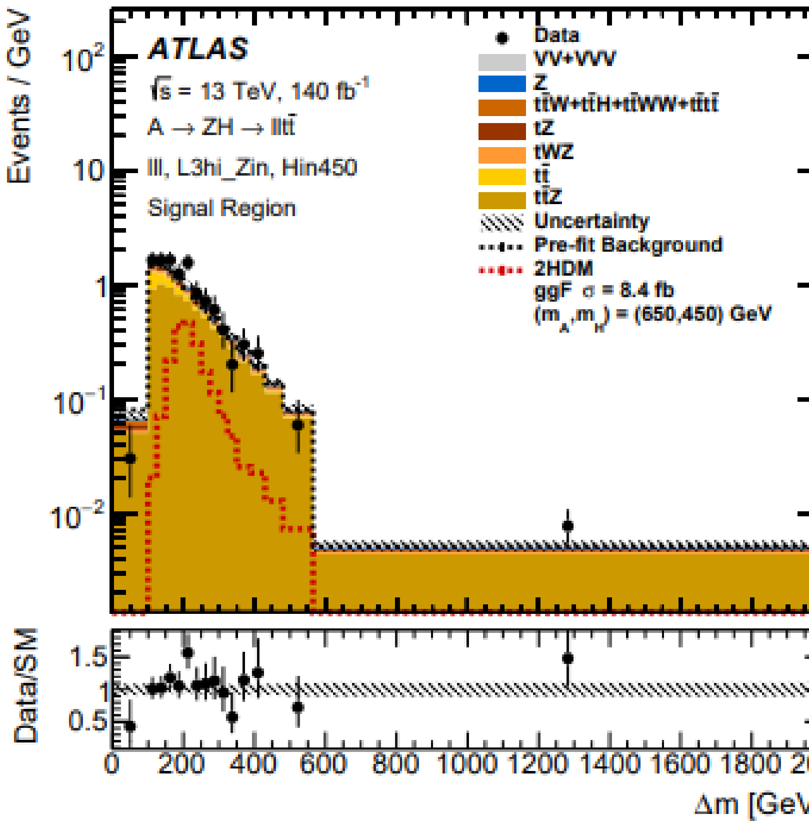




[2310.01643](2310.01643)

Evidence for H(650)->A(450)Z

- ATLAS sees a 2.85 s.d. excess in ttZ in A(650)->H(450)Z->ttℓ+ℓ- 2311.04033
- Also compatible with **H(650)->A(450)Z->ttℓ+ℓ-**
- Reinforces the case for H(650)
- The CP=-1 candidate A(420)->tt 1908.01115 is compatible given the poor mass resolution
- A third observation was in A(420)->H(320)Z->hhZ ATLAS-CONF-2022-043
- In this context, there is no need to invoke the LE criterion which would justify the word 'insignificant' for this new indication easily accommodated within GM



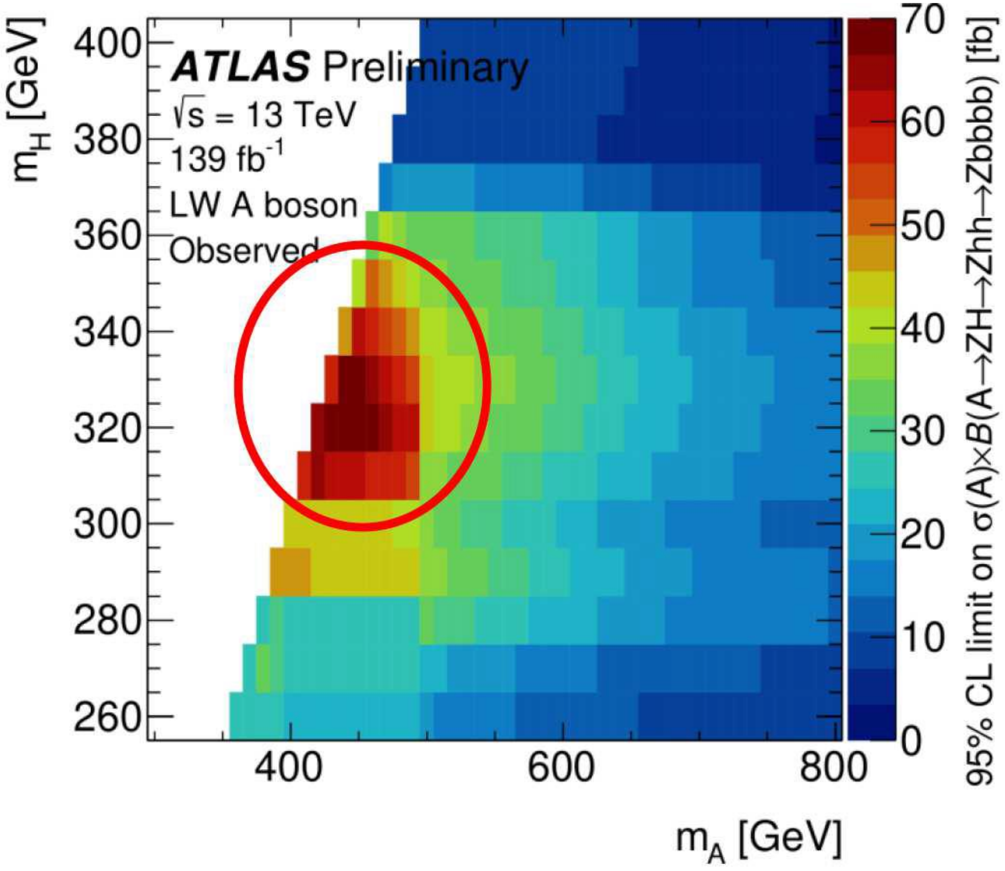
Δm=m(ttℓ+ℓ-)-m(tt)

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

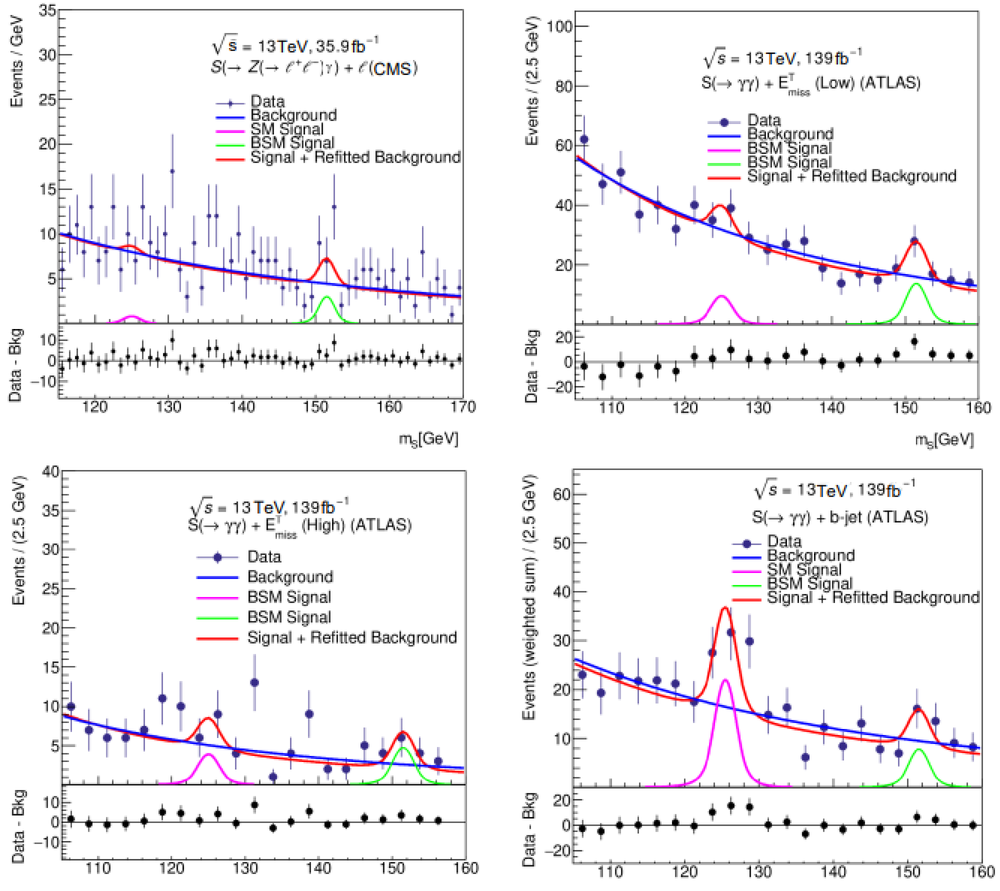
Evidence for H(320) and A(420)

- ATLAS has observed **A(420)->ZH(320)** with H(320)->h(125)h(125)->bbbb
- The bb mass resolution is too poor to exclude contributions from h(95) or A(130)
- The significance is 3.8 s.d. local [*2210.05415*]
- This decay sits close to the kinematical limit meani that H(320) could be heavier and complete the GM **H5 multiplet**, together with H+(375), H++(450)
- Recall that H(320)->hh is forbidden only if h is a pu singlet and H pure triplet, which is not the case
- Note finally that this indication constitutes the **3d evidence** for a CP odd A, together with A->tt and H(650)->AZ



Evidence for h/A(151)->γγ+ tag

- A second γγ+Zγ peak appears when requiring extra tag Etmiss or b jet
- 2109.02650 claims ~4 sd by combining ATLAS and CMS data
- GM predicts that ggF->H(320) has a cross cross section of 2000 fb, 2/3 going into A(151)A(151) with **A->bb, ττ** providing the tagging ingredient
- One predicts **BR(A(151)->γγ)~1.310-3**



Georgi-Machacek for pedestrians

- Allows I=2, H++, without violating **$\rho = M^2_W / M_Z^2 \cos^2\theta_W = 1$** 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 $v_\chi = v_\xi = u$**
- 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 **ρ=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 vϕ Y=1 T=1 vχ Y=0 T=1 vξ=vχ ρ=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
- They form the following physical states, dominantly triplet r
- $s_H = 2\sqrt{2} v_\chi / v$

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

- H1 and H1' have following composition

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

- The physical states are

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

- Common wisdom: the mixing angle α **has to be small** to avoid altering the doublet properties of the SM h(125)
- Also vξ=vχ are predicted small while SR says that vξ=vχ=70 GeV

SGM: a SUSY version of GM

1308.4025

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

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

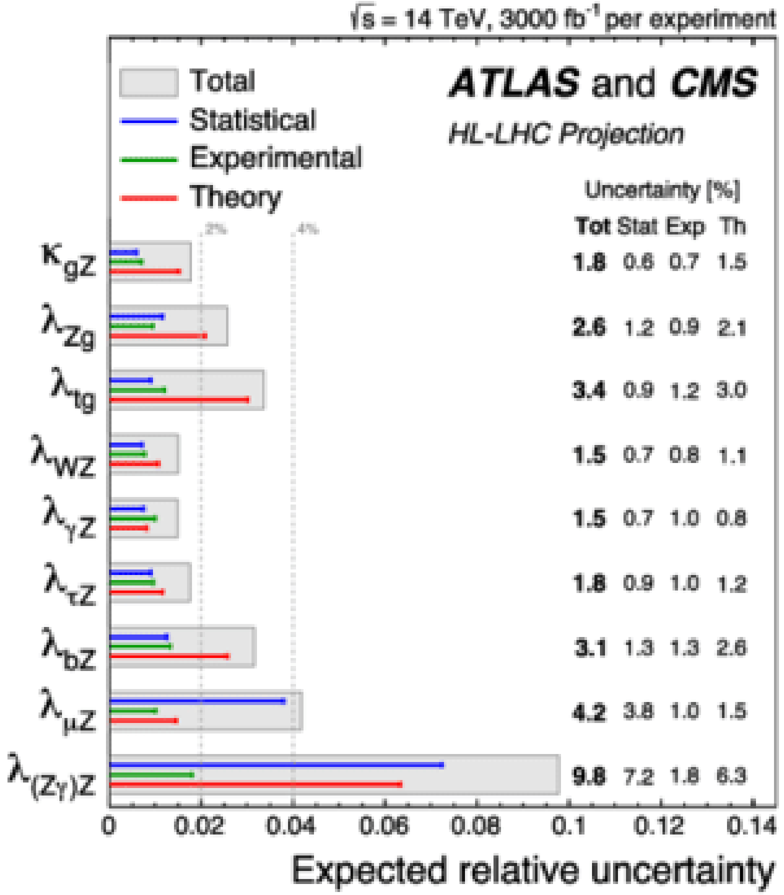
- GM does not necessarily mean compositeness

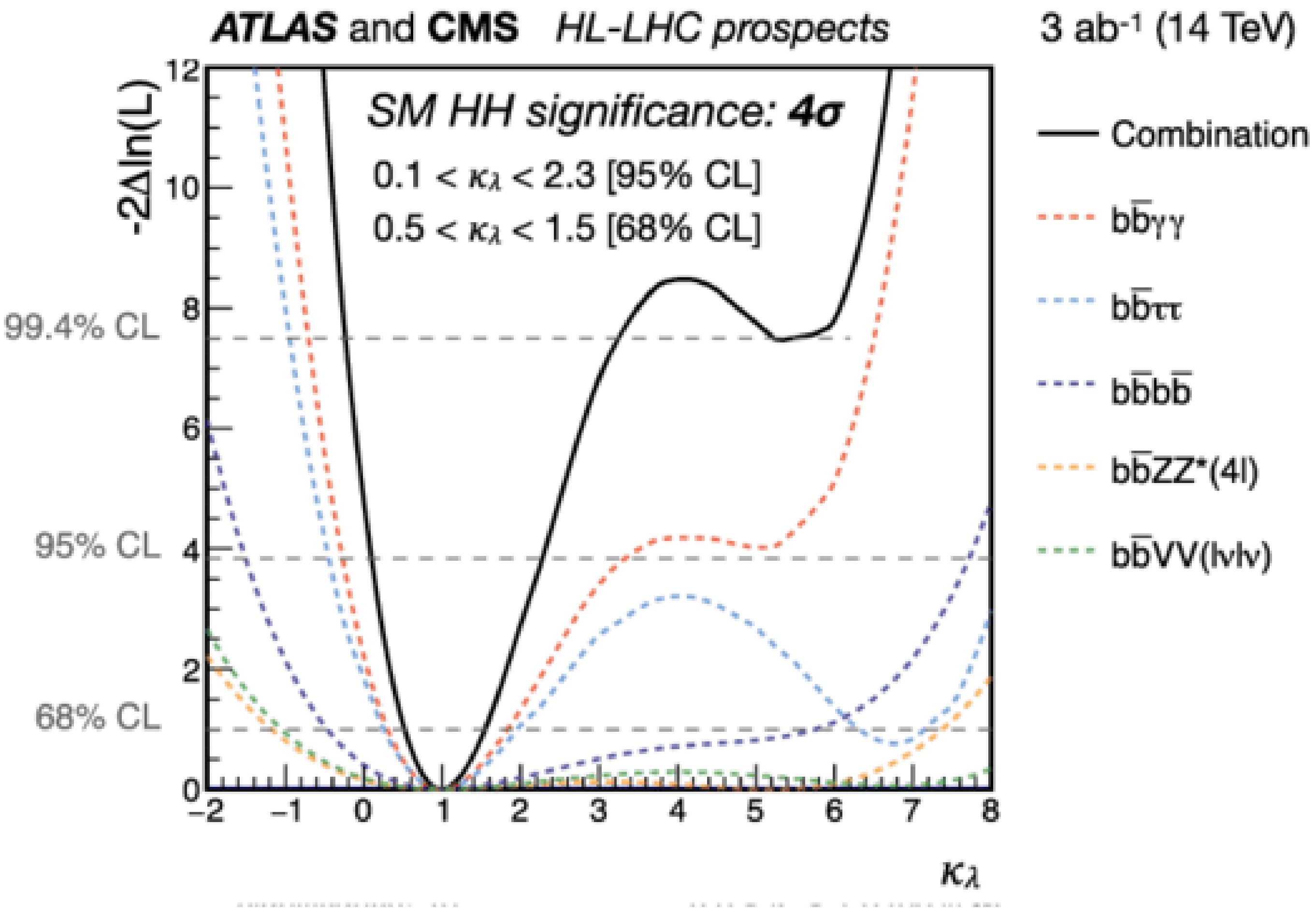
SGM provides all the “goodies” of SUSY:

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

Expected HL-LHC accuracies





TeV projects

SNOWMASS

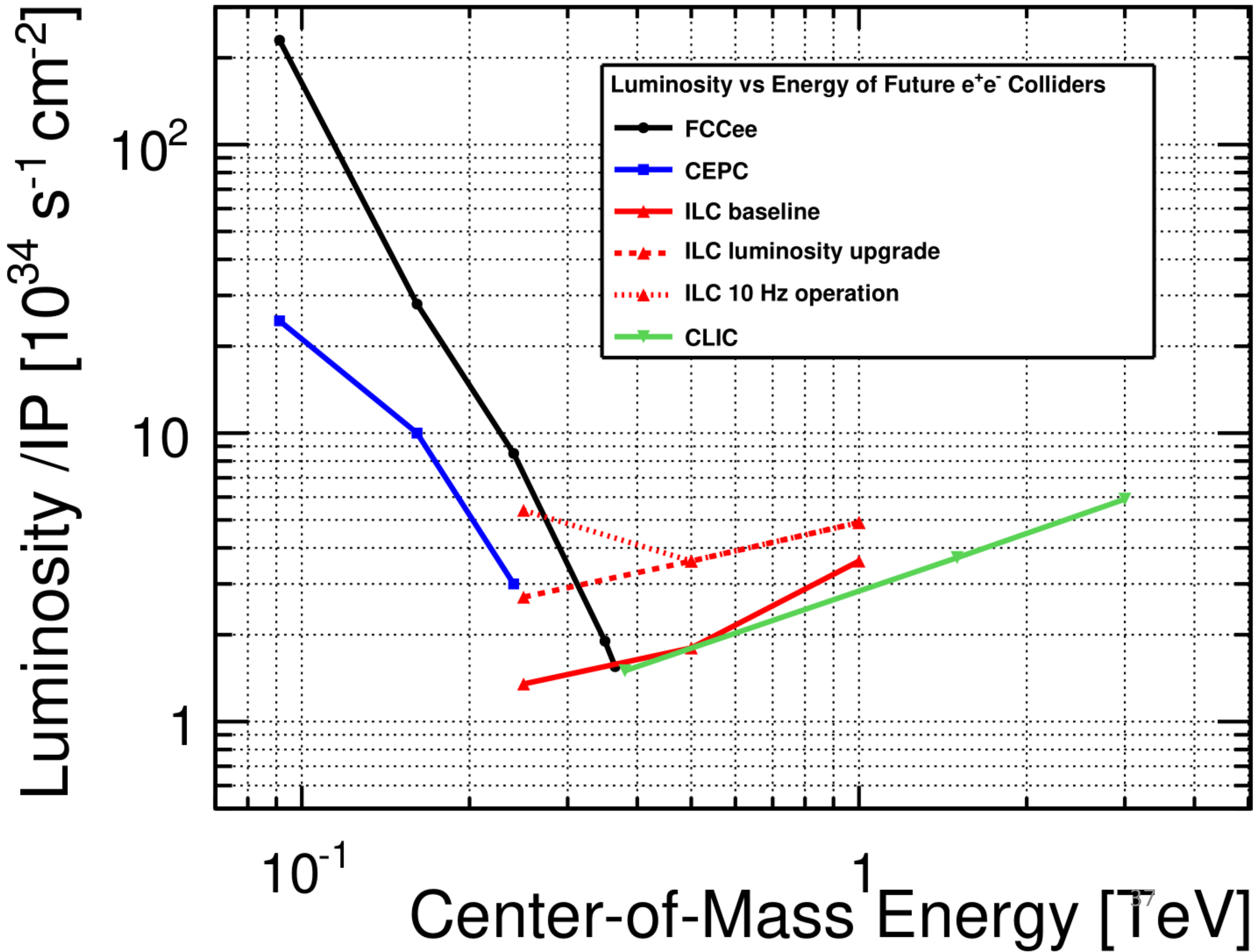
D. Schulte
Higgs Hunting 23

+ 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

LUMINOSITY at 1 TeV

- In reference *1903.01629* a running scenario of ILC at **1 TeV collecting 8000 fb-1** has been envisaged
- Beneficial for **Higgs self-coupling** measurement
- Discoveries at LHC would boost these studies at ILC and CLIC
- Convert ILC into an ERL 2105.11015 and 2203.06476



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.