Word from KTHH

HIPPO meeting, 231206

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Introduction

The KTH di-Higgs team is 5 strong: Jonas (faculty), Olle (Post-doc), Magda (PhD), Renske (PhD – just joining!) and Christian (faculty – joining slowly)

So far in Run 2 we have worked on the 2022 HH→bb$\gamma\gamma$ analysis as well as the not-yet published Run 2 SH→ bb$\gamma\gamma$ analysis (together with the SU group)

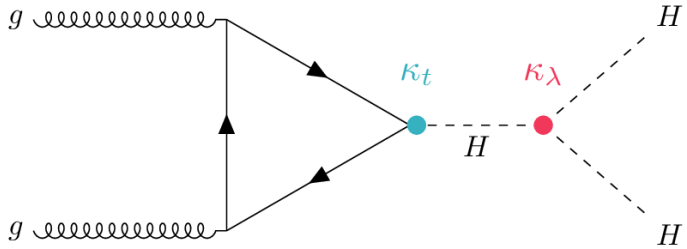
As David has already neatly covered SH I will

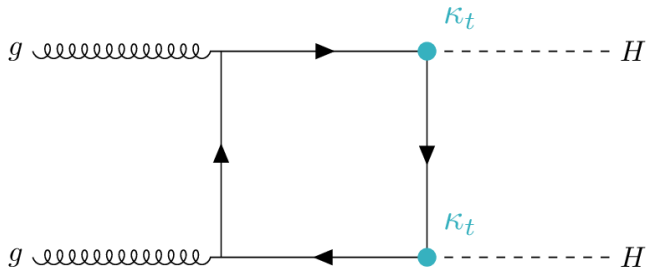
- Say a few words on the bb$\gamma\gamma$ final state in general
- Mention the *resonant* HH combination paper that just came out
- Show some plots of what *others* are doing in searches for the SH

On di-Higgs searches in general

Higgs: The most enigmatic SM particle:

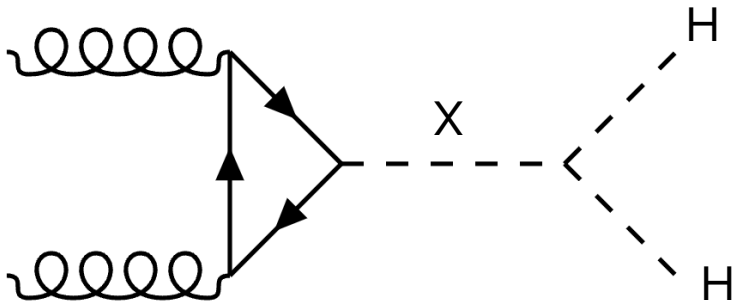
- Is it THE SM Higgs we've found?
- Is it even just one particle?





Searches in the Di-Higgs channels **essential** to answer those questions:

- Di-Higgs searches allows probing the trilinear Higgs coupling λ_{HHH} (more standard notation $\kappa_\lambda = \lambda_{HHH} / \lambda_{HHH, SM}$)
- Can also be used to search for potential new *heavy resonances* which appear in many BSM scenarios (2HDM, SUSY, TRSM… - even potentially spin-2 resonances)



Non-resonant $HH \rightarrow b\bar{b}\gamma\gamma$

arXiv:2310.12301

Just recently out: "Legacy" Run 2 (140 fb^{-1}) search

Branching ratio not so impressive but:

- Excellent trigger and reco efficiency for photons
- Excellent $m_{\gamma\gamma}$ resolution

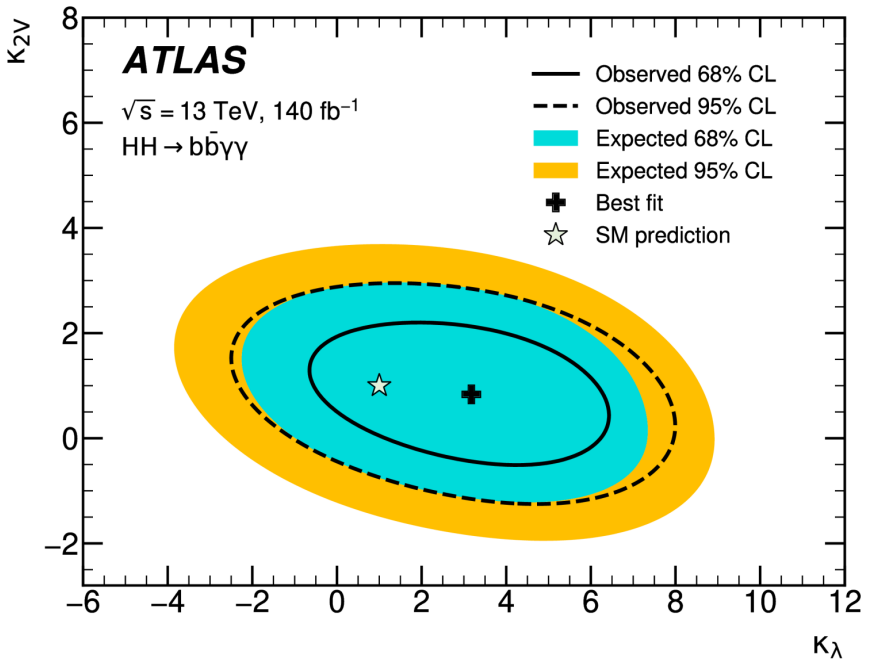
→ Channel provides unique handle at low $m_{bb\gamma\gamma}$: sensitive to triangle diagram!

Analysis looks for events w. 2 photons in H mass window – split in high and low $m_{bb\gamma\gamma}$ region

Improvements since last:

- VBF selection included (handle on κ_{2V})
- Improved bg discrimination → >10% more sensitive than last analysis: -1.4 < κ_λ < 6.9
- Limits for the first time in HEFT and SMEFT

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%



Run 3: $ZH \rightarrow b\bar{b}\gamma\gamma$?

Cross section of HH tiny: three orders of magnitude smaller than H - hence unlikely discovery in Run 3

Slightly less tiny cross section: σ x BR ~ **4 times larger**

Measuring this in the bb$\gamma\gamma$ - experimentally interesting:

- Provides constraints to a large background in the HH analysis (as well as SH, near $m_S = m_Z$)
- ZH Discovery would provide *method validation* already in Run 3 of the method → hopefully go on to HH discovery in HL regime.

Also experimentally challenging: Lower mass of Z means higher background regime.

Branching Ratios
H → bb 58%
Z → bb 15%
H → $\gamma\gamma$ 0.023%
Z → $\gamma\gamma$ O(10^{-5})

Prod Cross Sections
σ(HH) ~ 0.031 pb
σ(ZH) ~ 0.88 pb

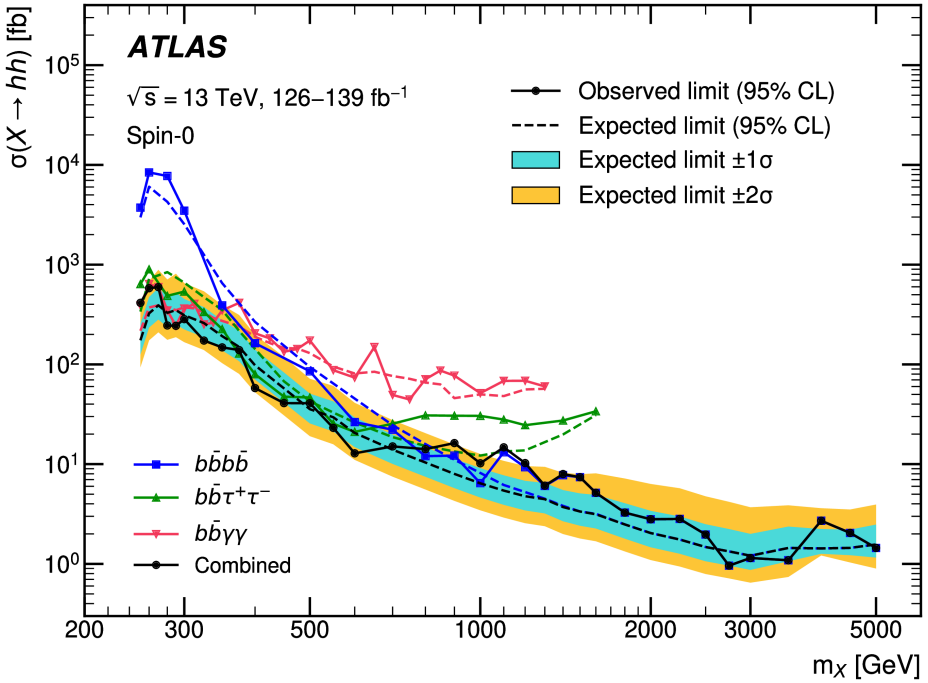
arXiv:2311.15956

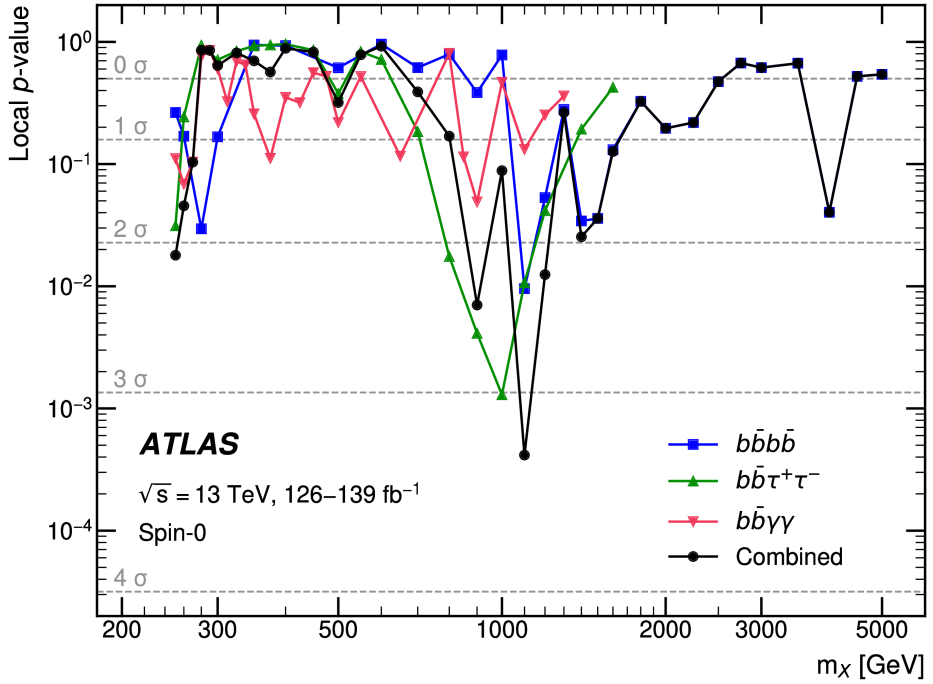
Di-Higgs: Resonant Combination

A combined likelihood calculated by combining the likelihoods of three analyses – the individual signal regions have negligible overlap, and thus are statistically independent

No significant excess! Limits set! Largest combined deviation of 3.3 (2.1)σ at 1.1 TeV

$b\bar{b}\gamma\gamma$ strongest at low, $b\bar{b}\tau^+\tau^-$ at intermediate and $b\bar{b}b\bar{b}$ at high m_X





Di-Higgs: Combination

Interpretation:
Type-I Two-Higgs Doublet Model

Extension of SM with three neutral Higgs bosons

In this context assumed:

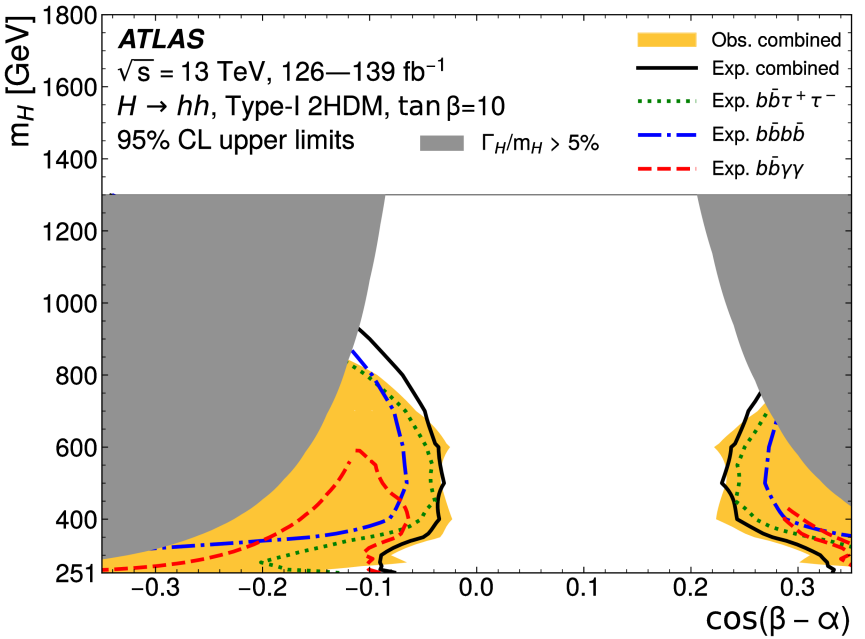
- The resonance decaying to Higgs pair corresponds to heavy CP-even *H* decaying to two light CP-even *h*
- All parameters assumed fixed except cos(β-α), m_H and tan(β)

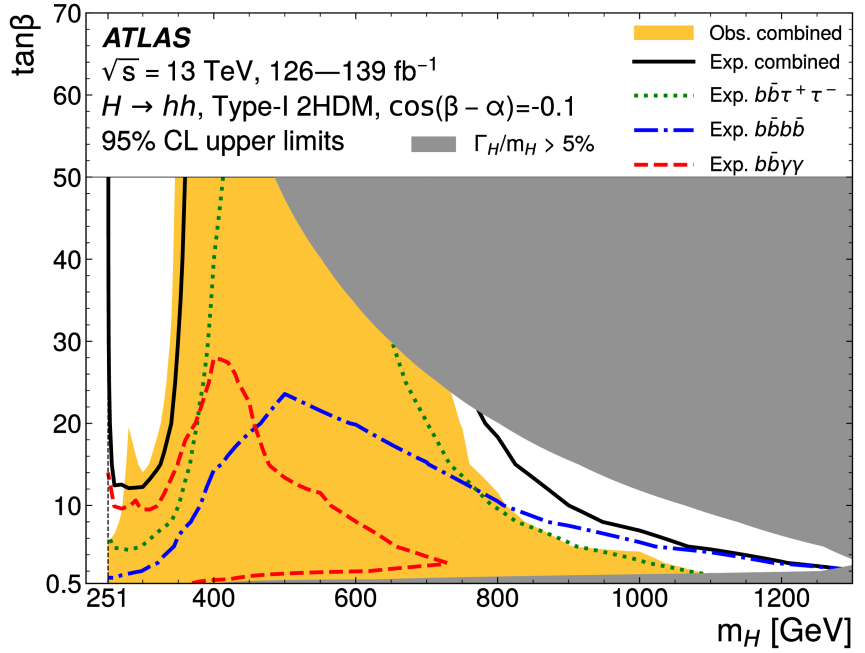
The non-fixed parameter form planes in which we can set exclusion limits

Exludes certain regions still allowed by Higgs boson coupling measurements

MSSM interpretation in backup!

arXiv:2311.15956





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$X \rightarrow SH$

If *several new scalar particles* (beyond the 125 GeV one) are avaliable to the LHC, AND if weakly coupled to SM particles would make X→SH (or even X→SS) preferred

TRSM, complex 2HDM, NMSSM…

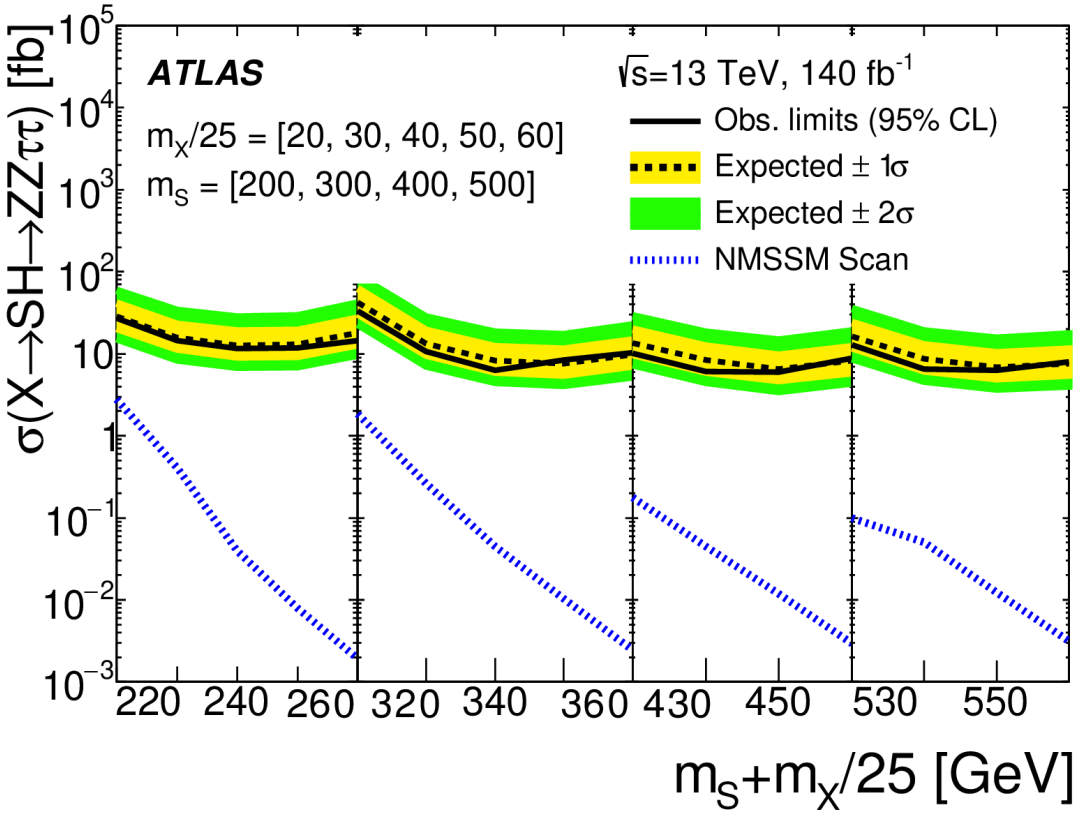
ATLAS currently:

- SH→VV$\tau\tau$

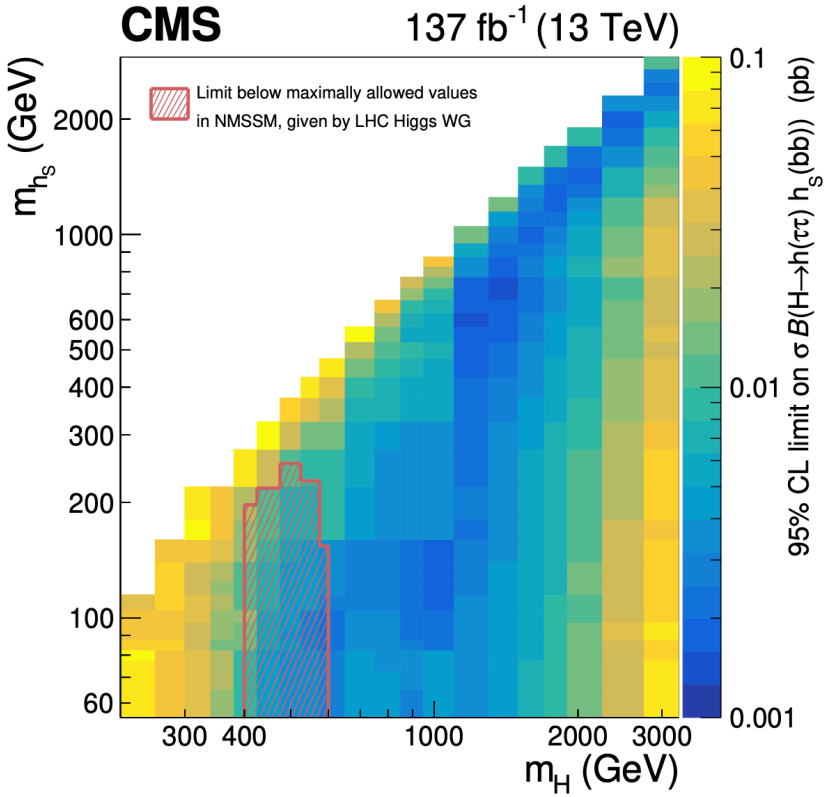
CMS currently

- SH→bb$\gamma\gamma$, SH→bbbb, SH->bb$\tau\tau$

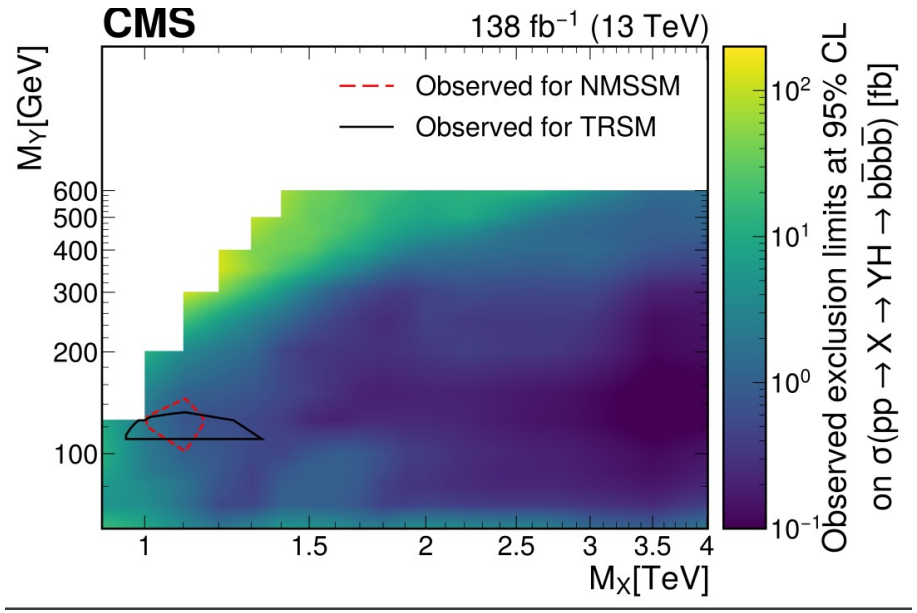
Keep your eyes open for new publications!
Especially those with b-quarks and photons!



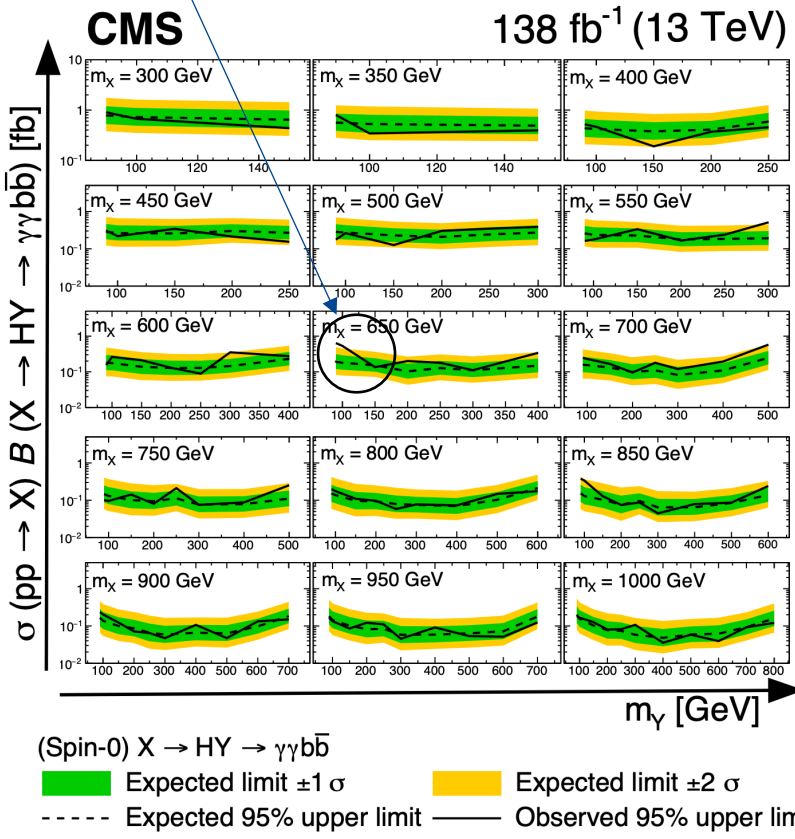
$X \rightarrow SH$ from CMS



JHEP11(2021)057



Phys. Lett. B 842 (2023)



arXiv:2310.01643

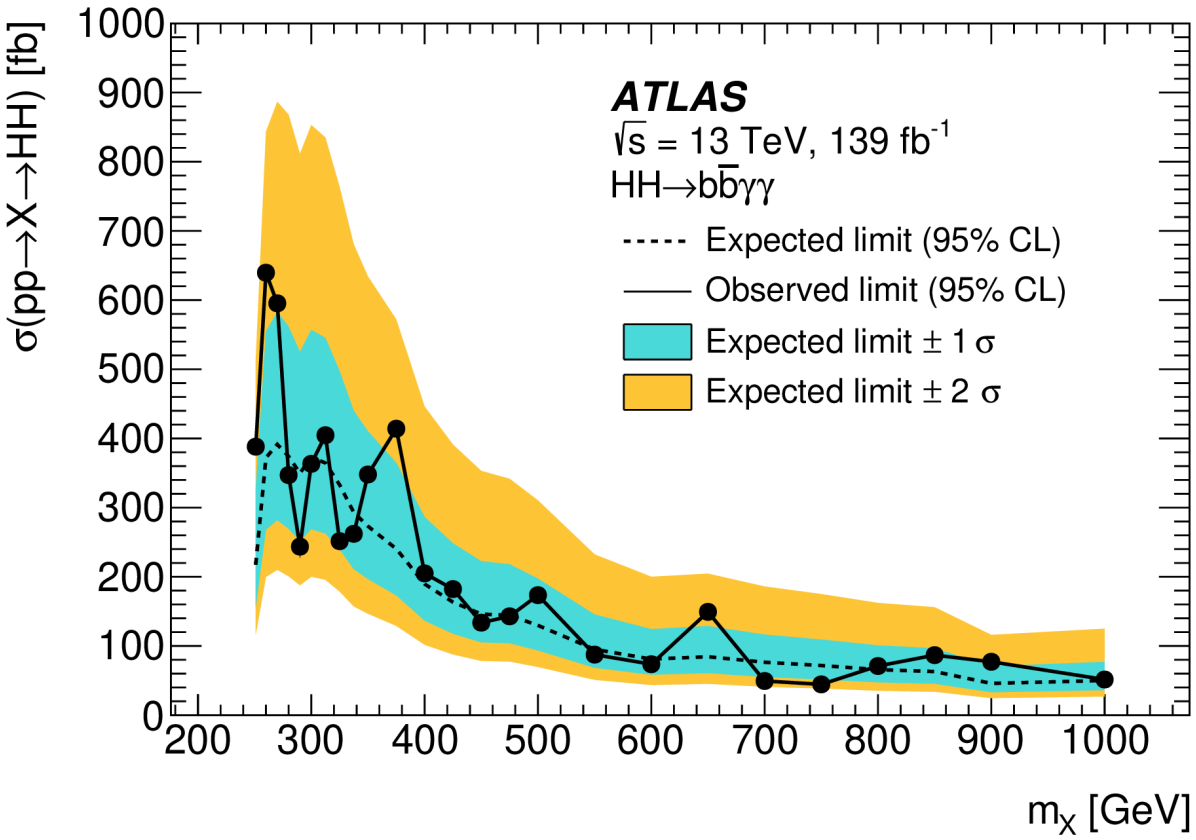
Run 2+3

- Maintain presence in bb$\gamma\gamma$ final state analyses – kicked off very recently so still finding their shape
- Publication schedule might steer us a bit, but
  - ”Discovering” ZH would be fun
  - Finding ways to improve the SH analysis (the one that comes out is the first ATLAS attempt after all) would also be an interesting challenge

Backup

Phys. Rev. D 106 (2022) 052001

Di-Higgs: $X \rightarrow HH \rightarrow b\bar{b}\gamma\gamma$



m_X [GeV]	BDT threshold	Efficiency [%]
251	0.70	6.6
260	0.75	5.7
270	0.80	5.1
280	0.85	4.5
290	0.85	4.7
300	0.85	4.9
312.5	0.85	5.2
325	0.85	5.2
337.5	0.85	5.5
350	0.85	5.8
375	0.90	5.5
400	0.80	7.6
425	0.85	7.6
450	0.85	8.1
475	0.80	9.1
500	0.75	9.9
550	0.60	11.6
600	0.45	12.9
700	0.20	14.9
800	0.10	16.2
900	0.20	19.4
1000	0.05	20.0

Di-Higgs: Combination

Interpretation:
Type-I Two-Higgs Doublet Model

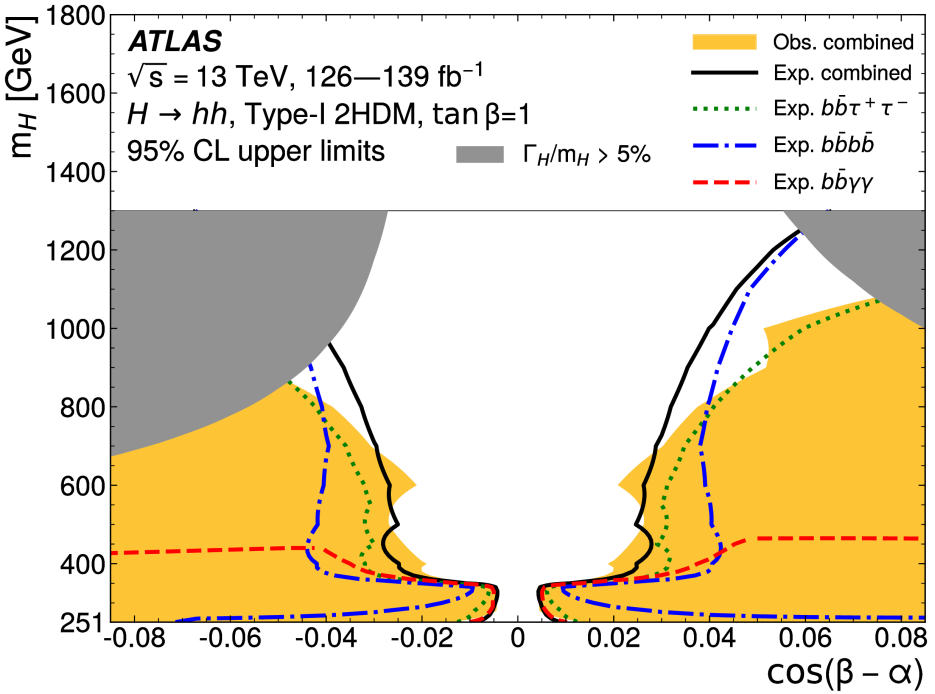
Extension of SM with three neutral Higgs bosons

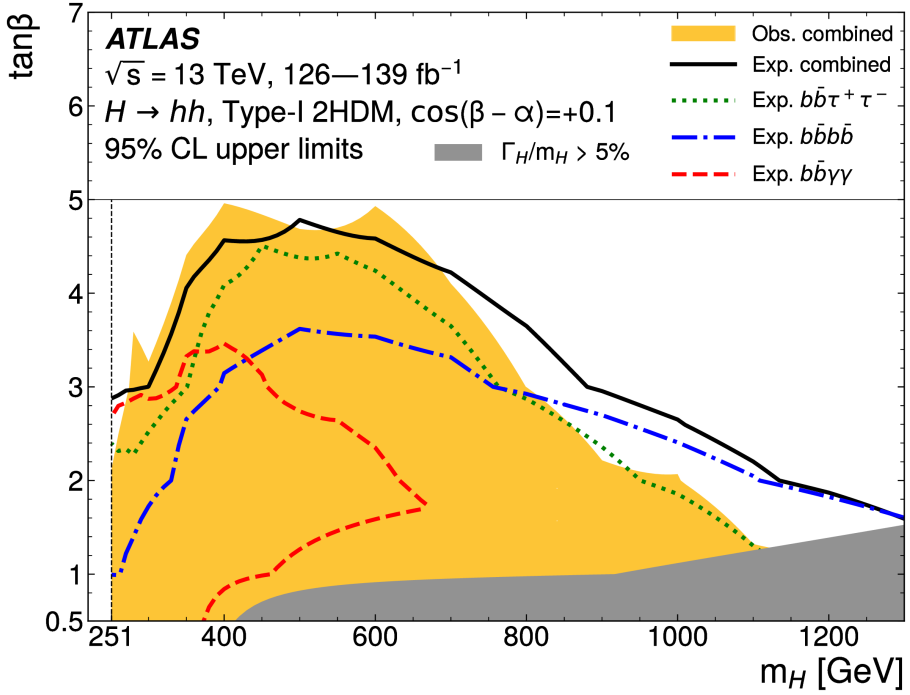
In this context assumed:

- The resonance decaying to Higgs pair corresponds to heavy CP-even *H* decaying to two light CP-even *h*
- All parameters assumed fixed except cos(β-α), m_H and tan(β)

The non-fixed parameter form planes in which we can set exclusion limits

Stronger limits in certain regions of cos(β-α) than provided by Higgs boson coupling measurements





Di-Higgs: Combination

Interpretation:
Minimal Supersymmetric Standard Model

Has Higgs sector of Type-II 2HDM – includes same parameters as previous interpretation

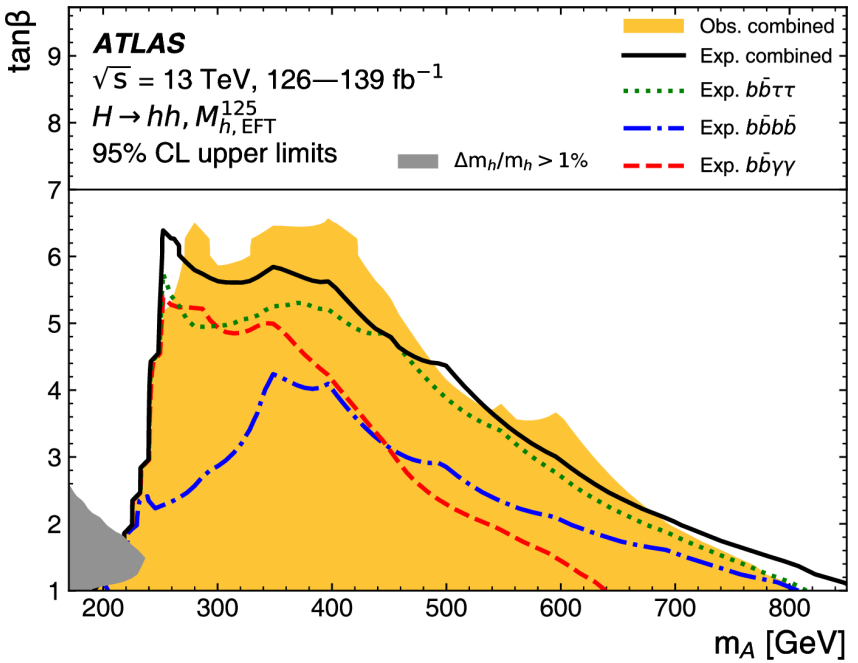
Supersymmetry constrains free Higgs sector parameters to only m_H and $\tan(\beta)$ – plane in which limits are set

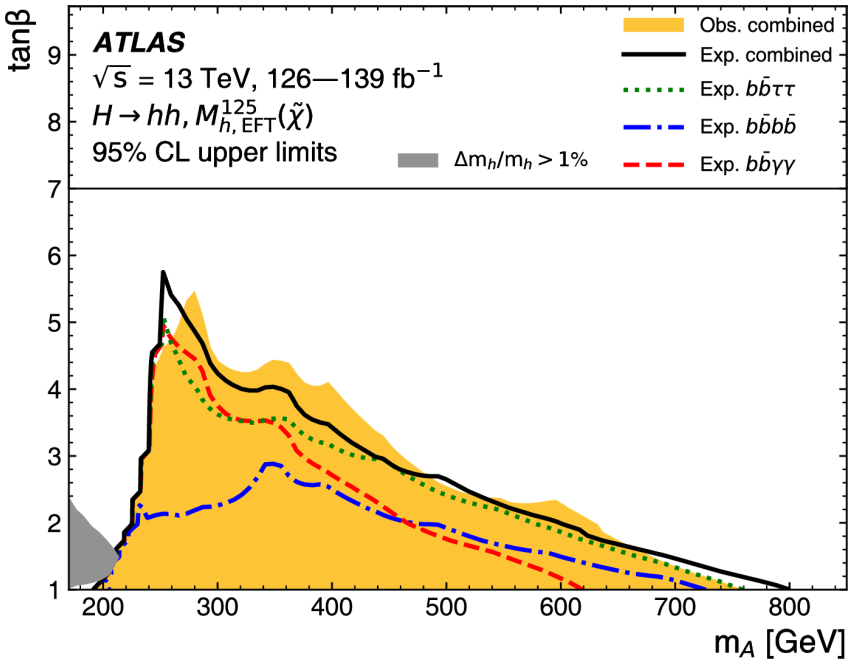
2 scenarios:

(i) Mass scales very high

(ii) Neutralinos and charginos are accessible

Excludes region around $\tan(\beta)$ ~2 and ~5 not probed by otherwise sensitive probes to this parameter space





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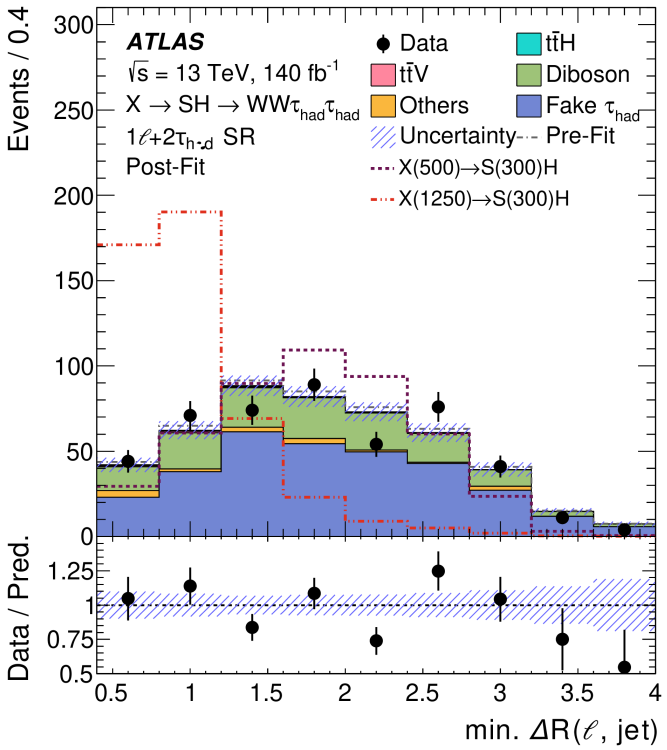
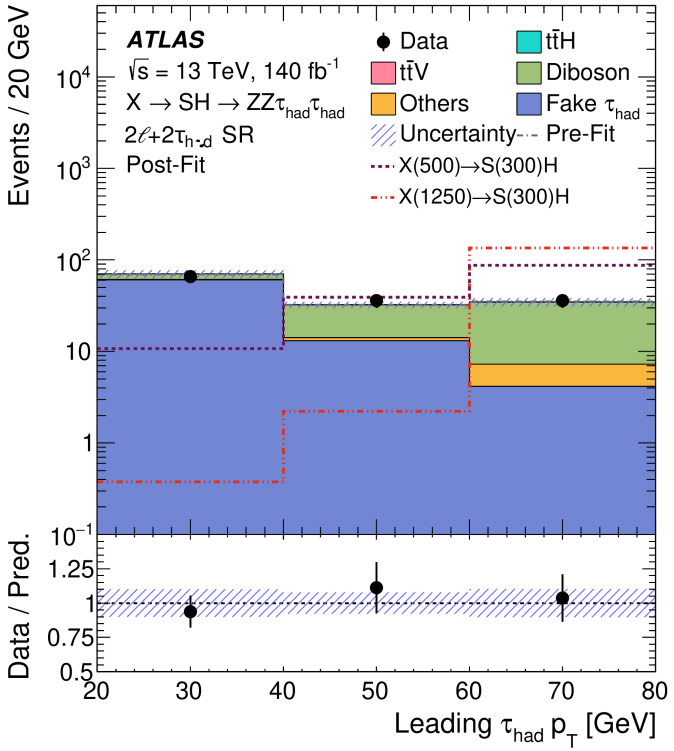
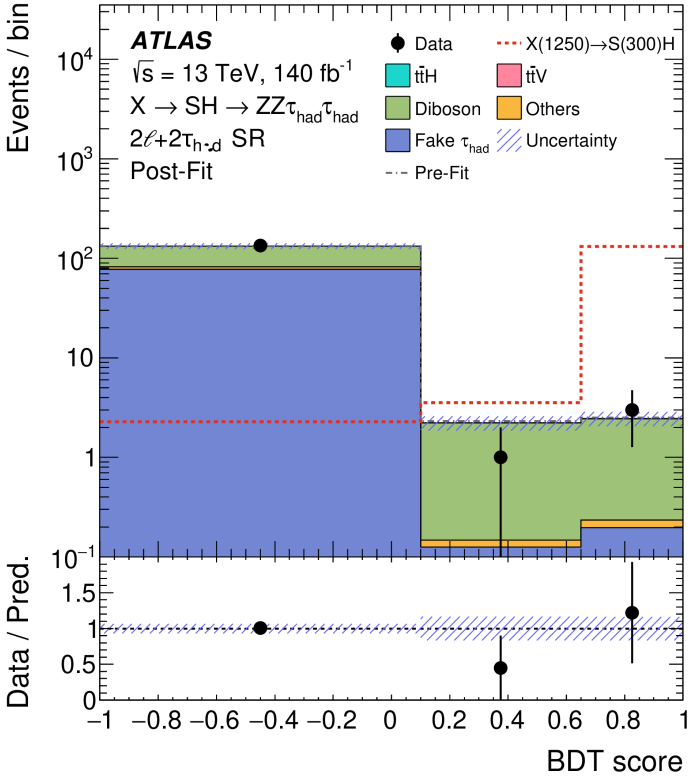
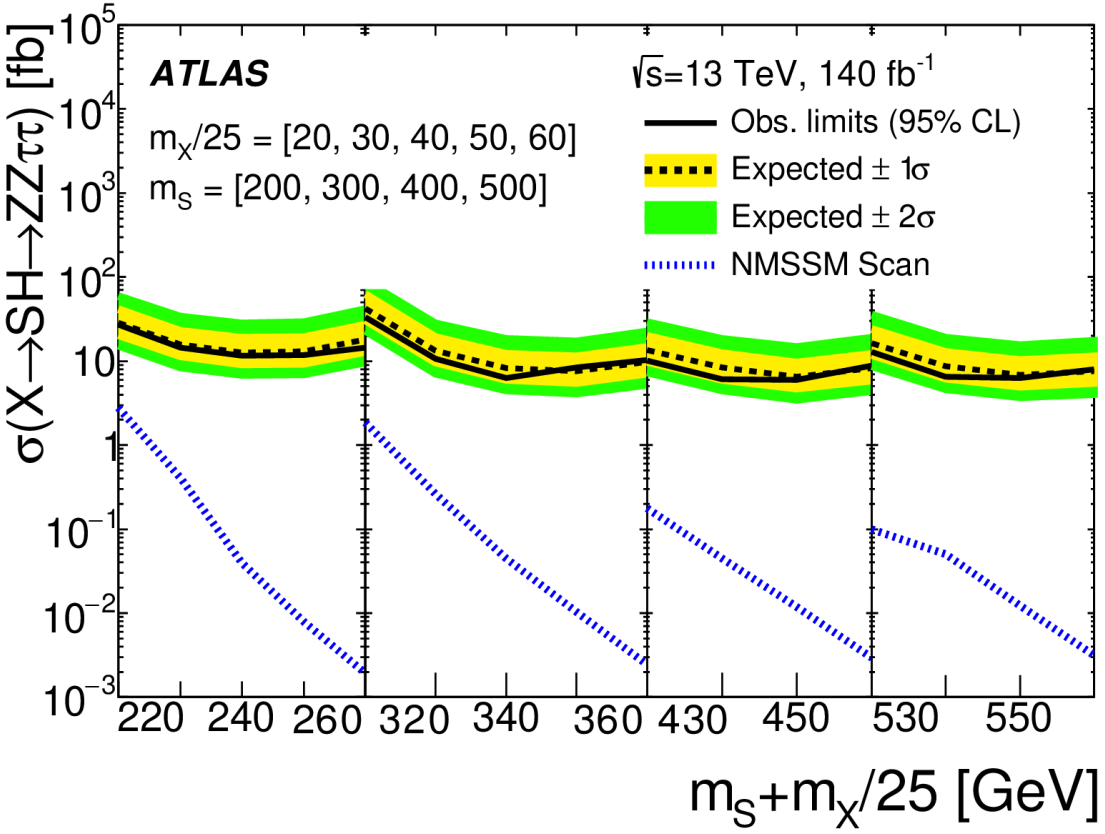
SH: $\rightarrow VV\tau^{+}\tau^{-}$

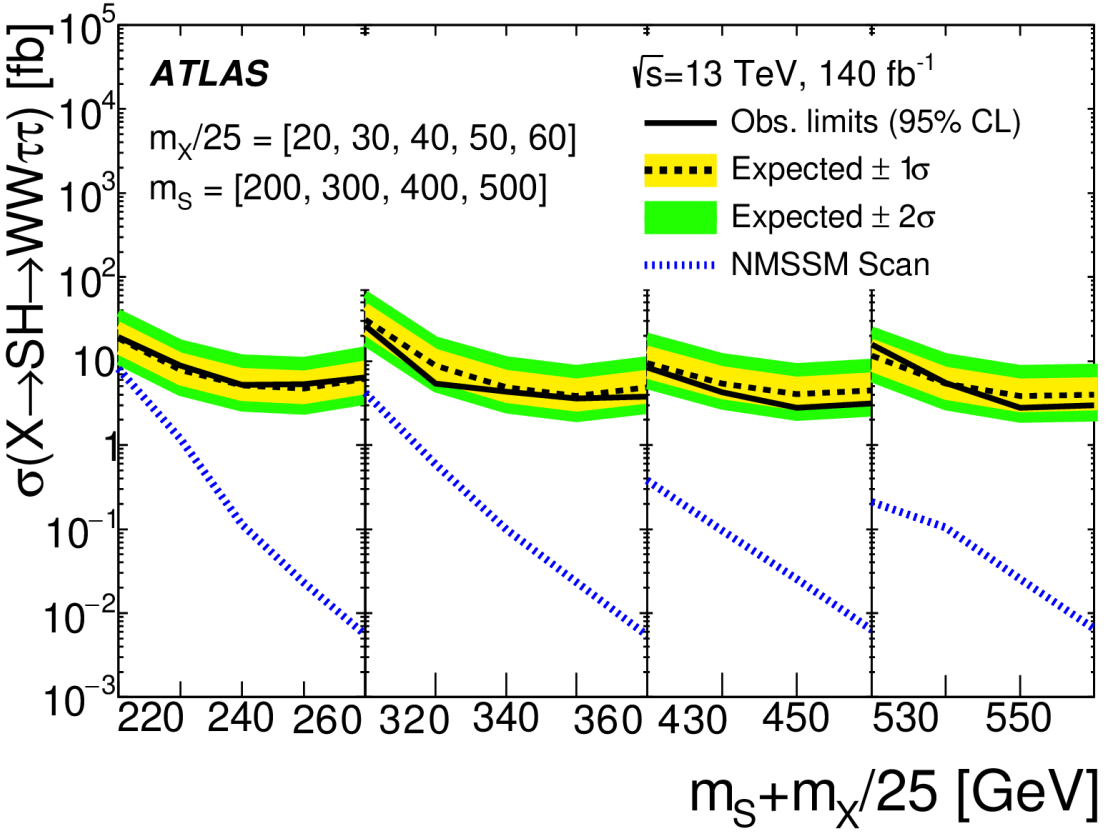






SH: $\rightarrow VV\tau^+\tau^-$





SH: $\rightarrow VV\tau^{+}\tau^{-}$