

What is the '650' GeV resonance made of ?



IRN Terascale @ IJCLab Orsay

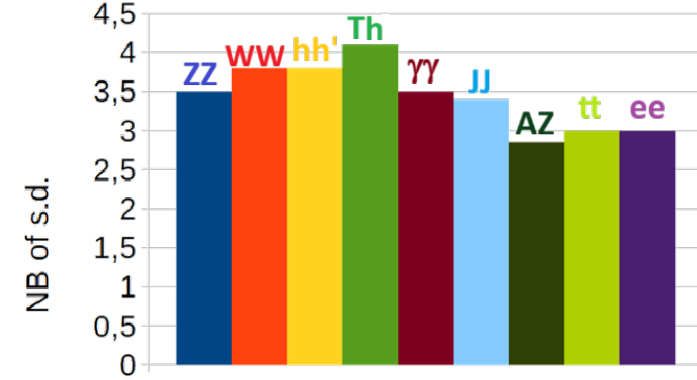
20-22 april 2026
Auditorium P. Lhemann
Building 200

 **UC**Lab
Irène Joliot-Curie
Laboratoire de Physique
des 2 Infinis

 **CNRS** NUCLÉAIRE
& PARTICULES

 **université**
PARIS-SACLAY
Université
Paris Cité

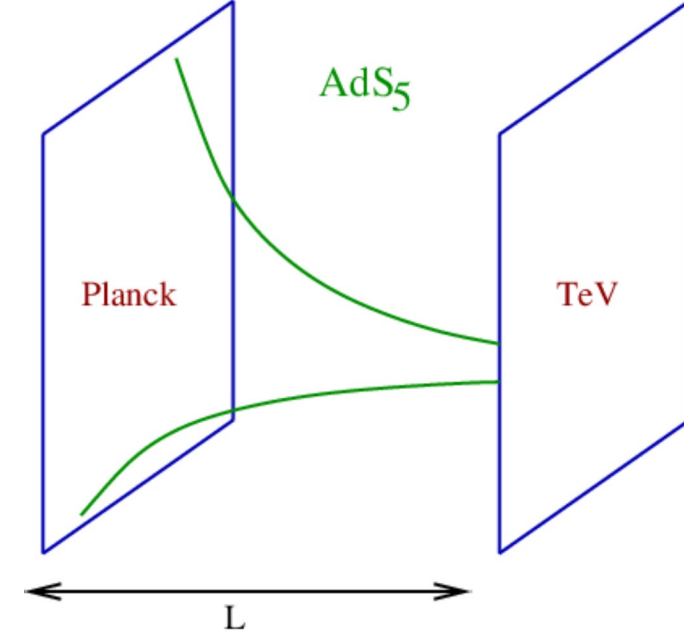
INTRODUCTION



- For many years there has been growing evidence for indications around 650 GeV both in ATLAS and CMS
- Presently there are **9 such indications, each reaching ~3 sd**. When statistically combined they give a **global evidence ~6 sd** ! RUN3 should allow to reach individually 5 sd for some of them
- Coming after the 750 GeV episode, they provoke, at best, polite skepticism
- Today we come to the conclusion that the alleged 750 GeV in 2 photons first seen by ATLAS belongs to the same family, the shift in mass being presumably due to a **mis-calibrated detector + an initial positive fluctuation** in the ATLAS sample

What is it ?

- Interpretations of this effect went through different phases but, at present, the best interpretation of these indications is given by the **Randall Sundrum** model



- However it is fair to add that various observations do not coincide with the strict predictions of this model, in particular the **absence of coupling to gluons** which considerably reduces the production rate for this resonance and explains that it takes so long to reach a full confirmation in spite of its low mass
- We understand the reason for this absence, invoking the classical **dual picture** where the RS 5D is dual to a 4D world where resonances are **composite objects**. In this picture the SM Higgs is itself made of **colorless/neutral preons** which therefore do not couple directly to **gluons** nor **photons**. The same would be true for KK gravitons which can only couple to gluons through top loops

References

[1] New resonances at LHC

Alain Le Yaouanc (IJCLab, Orsay), François Richard (IJCLab, Orsay) (Jun 11, 2025)

e-Print: 2506.09490

[2] $X_{650} \rightarrow ZZ/WW/H_{125}H_{95}/A_{450Z}$ -- scalar, tensor or both ?

Alain Le Yaouanc (IJCLab, Orsay), (IJCLab, Orsay), François Richard (IJCLab, Orsay) (Aug 22, 2024)

Contribution to: 3rd ECFA workshop on e+e- Higgs, Electroweak and Top Factories

e-Print: 2408.12178

[3] Triple Higgs coupling

Alain Le Yaouanc (IJCLab, Orsay), (IJCLab, Orsay), François Richard (IJCLab, Orsay) (Apr 15, 2024)

Contribution to LCWS24

e-Print: 2404.09827

[4] As a consequence of $H(650) \rightarrow W+W-/ZZ$, one predicts $H_{++} \rightarrow W+W+$ and $H_{+-} \rightarrow ZW+$, as indicated by LHC data

Alain Le Yaouanc (IJCLab, Orsay), François Richard (IJCLab, Orsay) (Aug 23, 2023)

Contribution to: 2nd ECFA Workshop on e+e- Higgs/EW/Top Factories

e-Print: 2308.12180

[5] Searches for scalars at LHC and interpretation of the findings Anirban Kundu (Calcutta U.),

Alain Le Yaouanc (IJCLab, Orsay), Poulami Mondal (Calcutta U.), François Richard (IJCLab, Orsay)

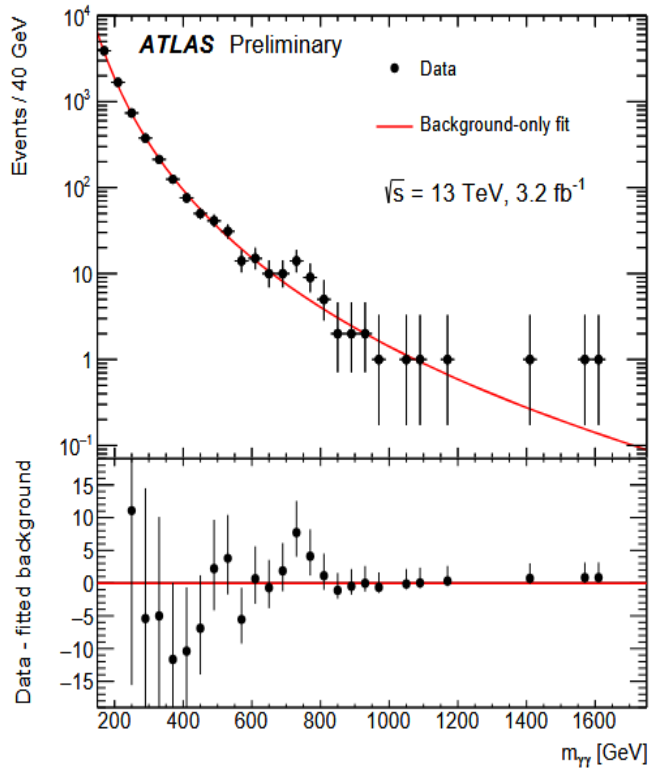
Contribution to 2022 ECFA Workshop on e+e- Higgs/EW/TOP factories

e-Print: 2211.11723

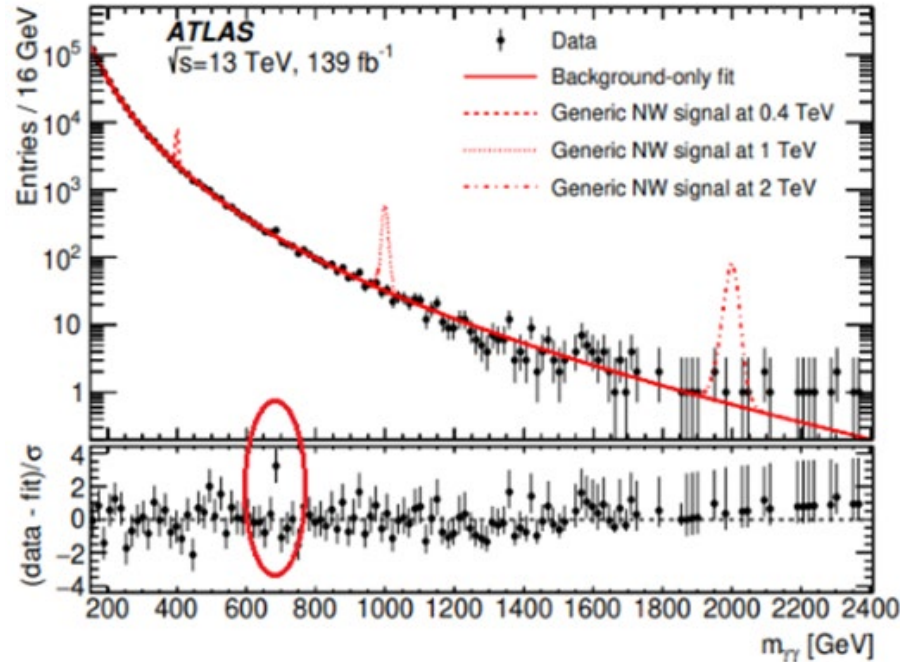
The two photon story

Yesterday: 750 GeV wide

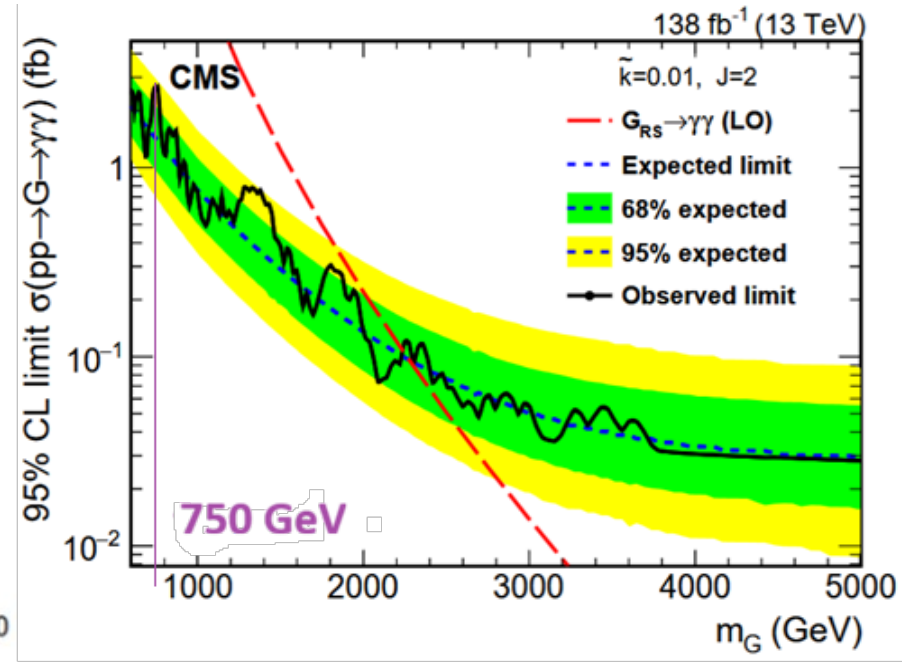
Today: 700-750 GeV narrow



[ATLAS-CONF-2015-081](#)



[2102.13405](#)

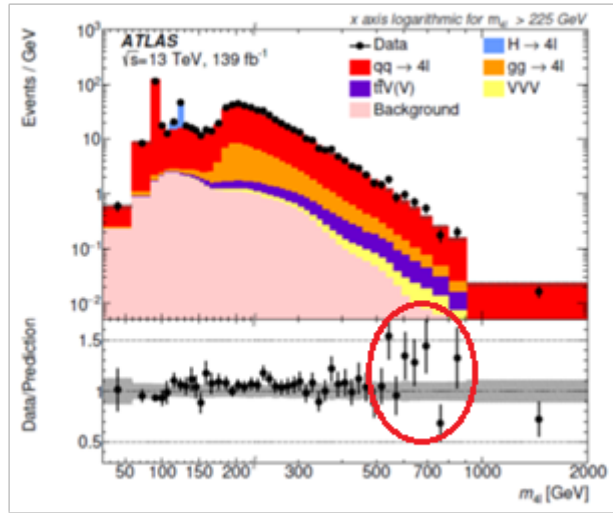


[2405.09320](#)

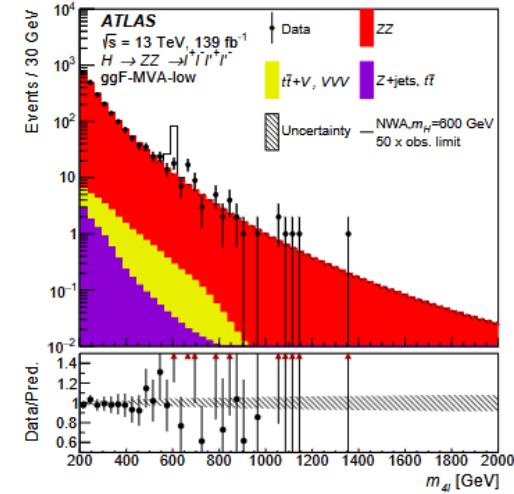
X700->ZZ->e⁺e⁻e⁺e⁻ J=2 or J=0 ?

- Naive cut based analysis

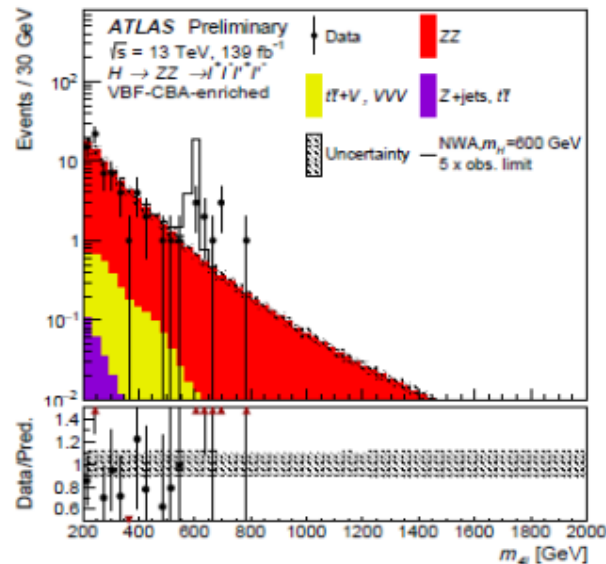
- Selecting a scalar against DY



ggF+VBF

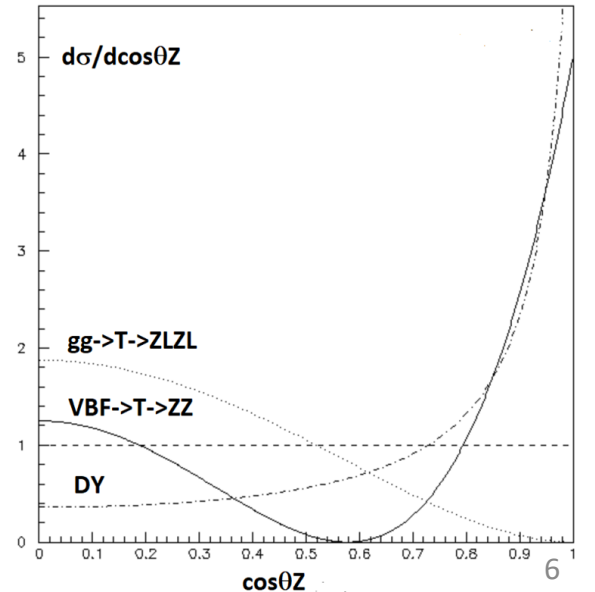
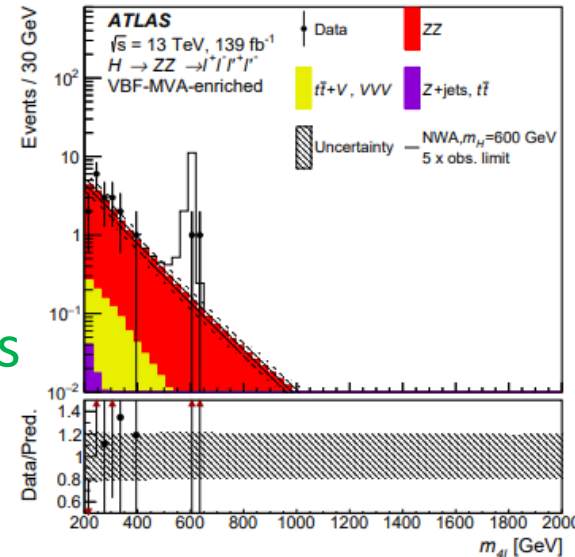


[2009.14791](#)



VBF

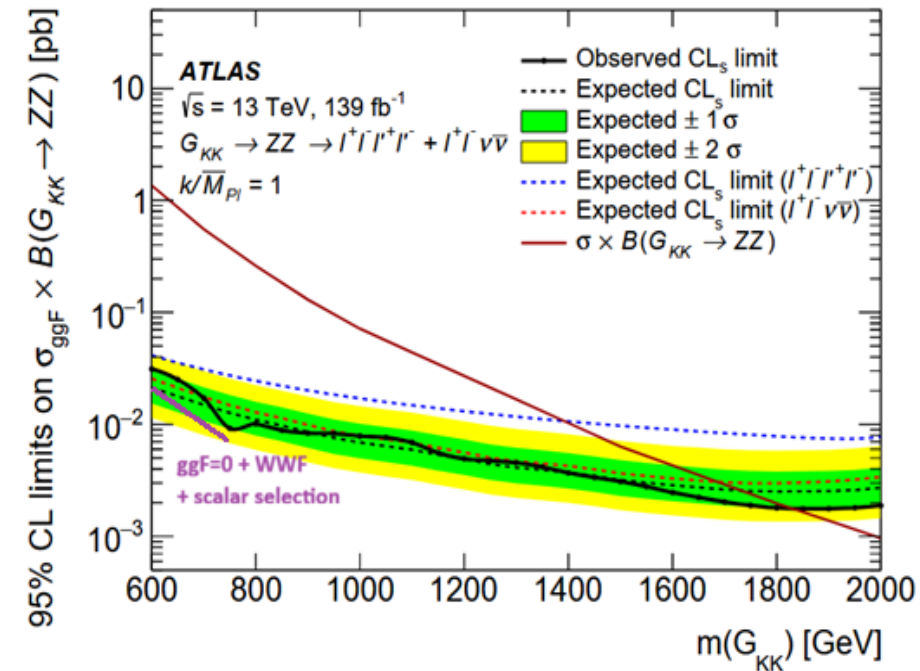
9 evts -> 2 evts



Only produced through VBF

- Both ATLAS and CMS lose the **ZZ channel** with scalar selections even w/o the VBF selection
- ggF should not suffer from a scalar selection !
- Same observation in the **WW channel** by CMS which concludes that this signal comes mainly from VBF and not from ggF
- Goes against RS standard predictions !
- Invalidates mass limit from ATLAS
- Explains why we need so much luminosity to observe a sub-TeV resonance

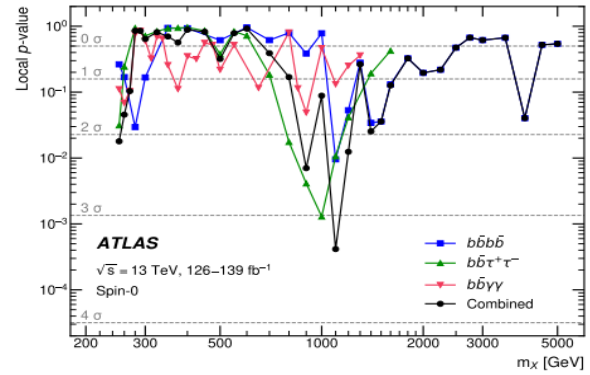
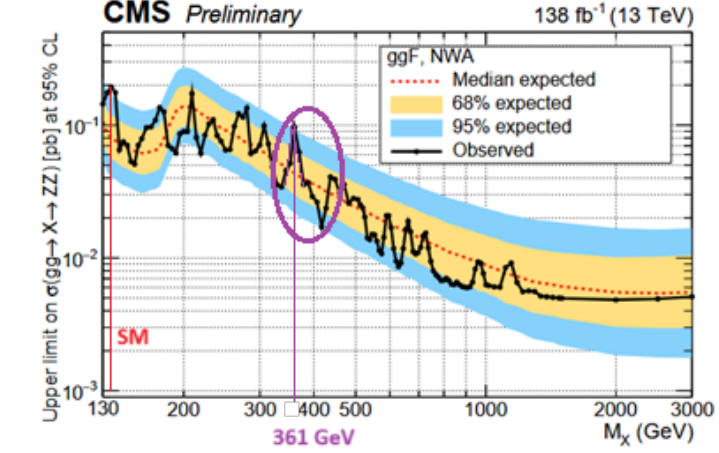
[2009.14791](#)



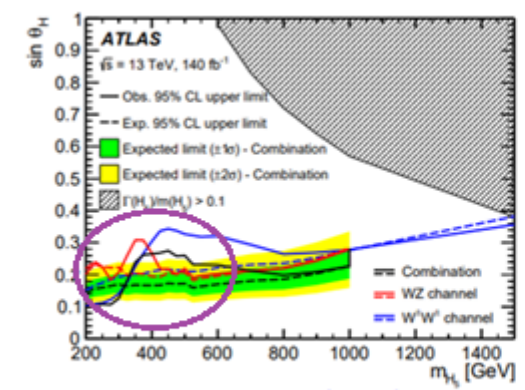
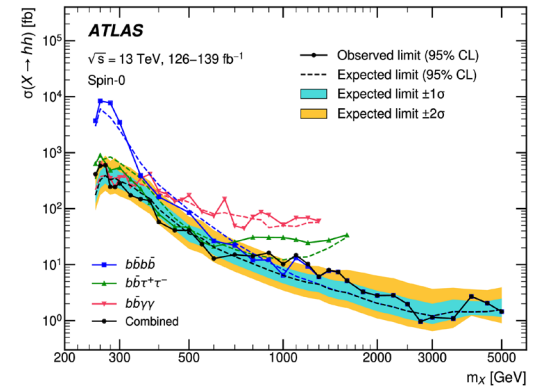
RS predictions

- RS predicts: **T380 T700 T1100 GeV** given by zeros of **Bessel function** (geometry)
- We have 5 indications compatible with T380 hence a significance of ~ 4 s.d.
- Explains the **width of T700 ~ 20 GeV** instead of ~ 3 GeV for T380
- Indication in **hh at 1000 GeV** from ATLAS
- **Perturbative unitarity** predicts that there could be **W^+W^+ and ZW** resonances to avoid early violation which seems true for the first sequence **T380**

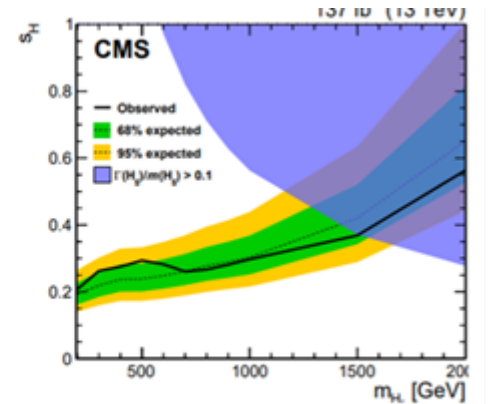
$$g^2(4m_W^2 - 3m_Z^2 c_W^2)^{\rho \approx 1} \simeq g^2 m_W^2 = \sum_k g_{W^+W^-H_k^0}^2 - \sum_l g_{W^+W^+H_l^-}^2$$



Phys. Rev. Lett. 132 (2024) 231801



Phys. Lett. B 860 (2025) 139137

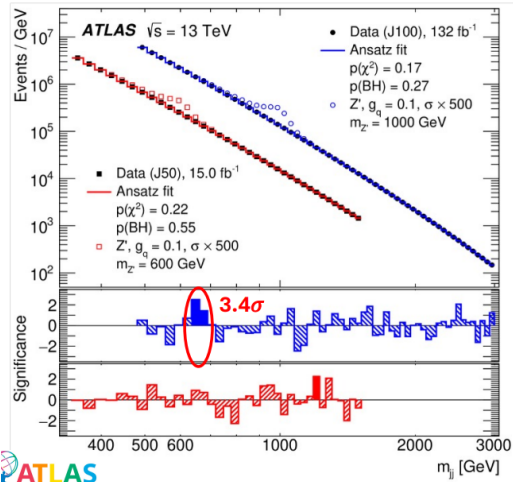


Eur. Phys. J. C 81 (2021) 723

Other evidences for 650 GeV

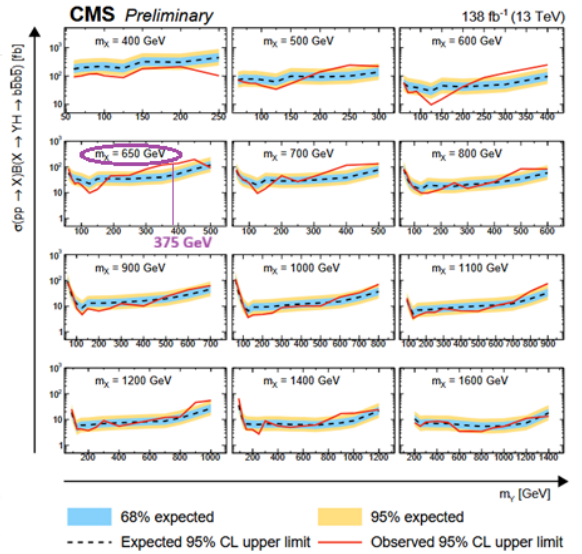
[2509.01219](#)

CERN-EP-2025-194, in submission



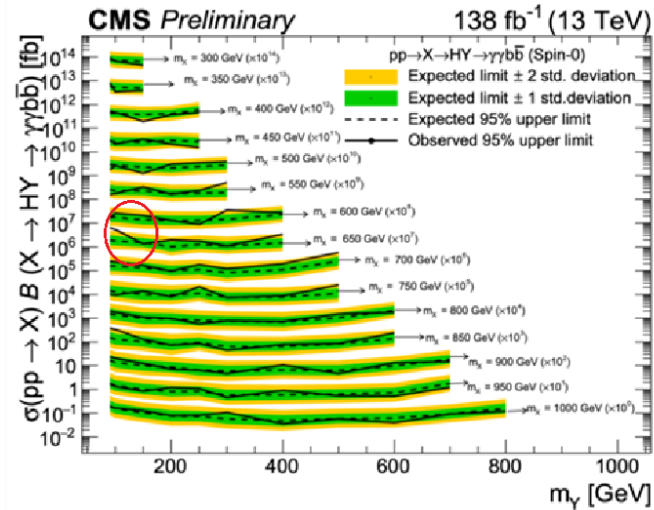
X650->2 Jets

[CMS-PAS-HIG-20-012](#)



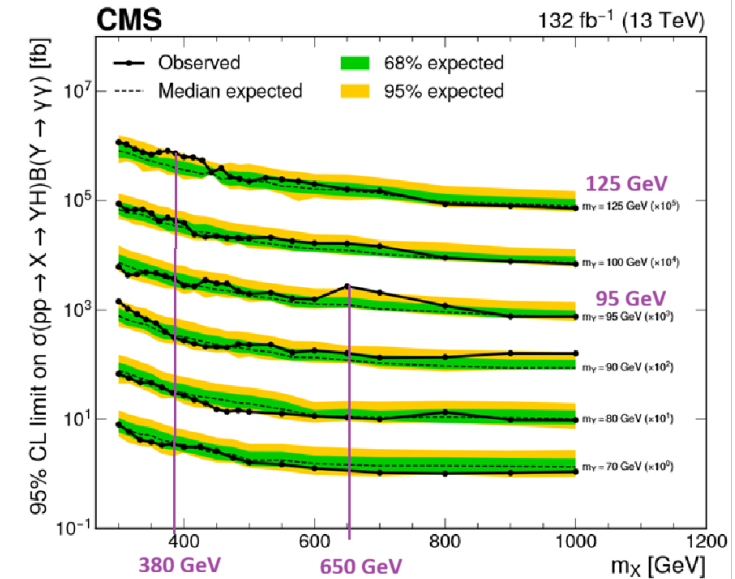
X650->Y375+h125->bb+bb

[2310.01643](#)



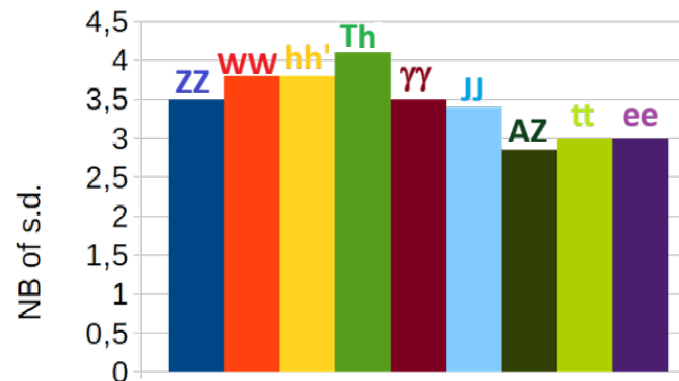
X650-> h125h95 -> γγ + bb

[2505.23012](#)

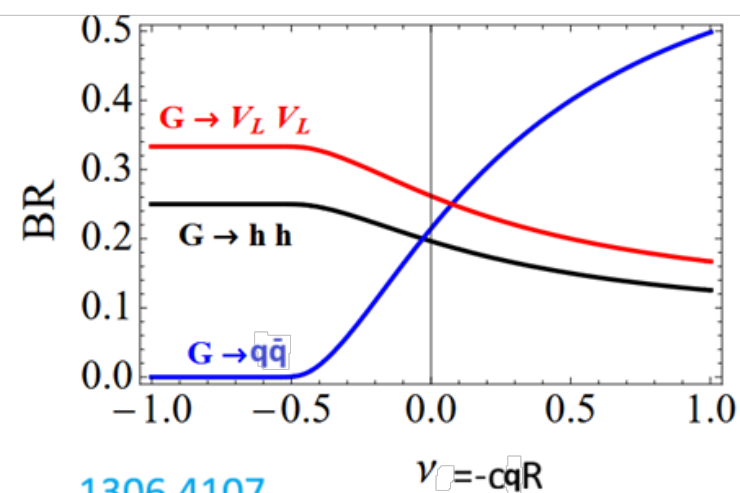
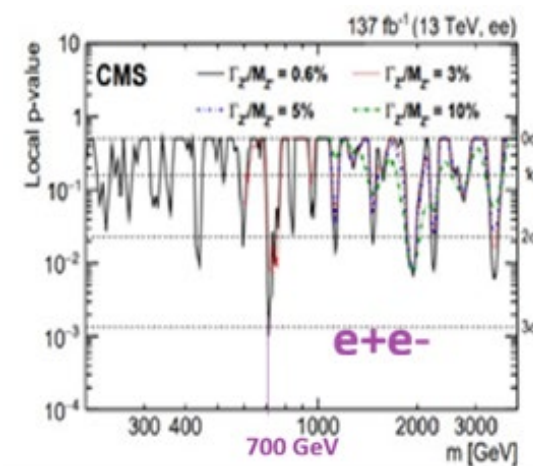


X650-> h125h95 -> γγ+ττ

T380-> h125h125->γγ+ττ

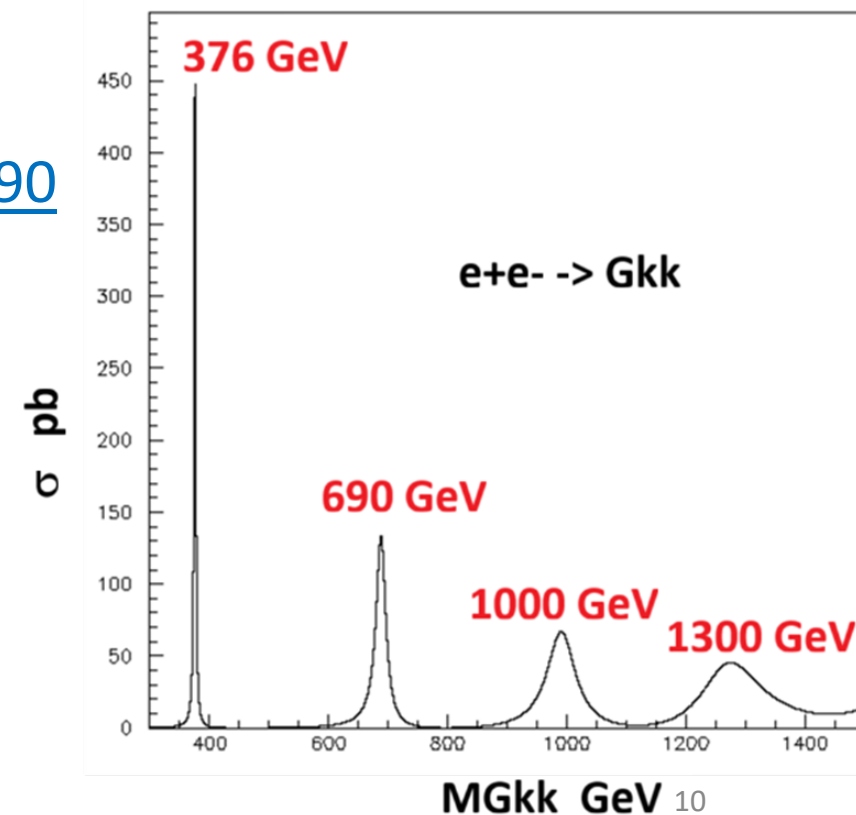


Open questions



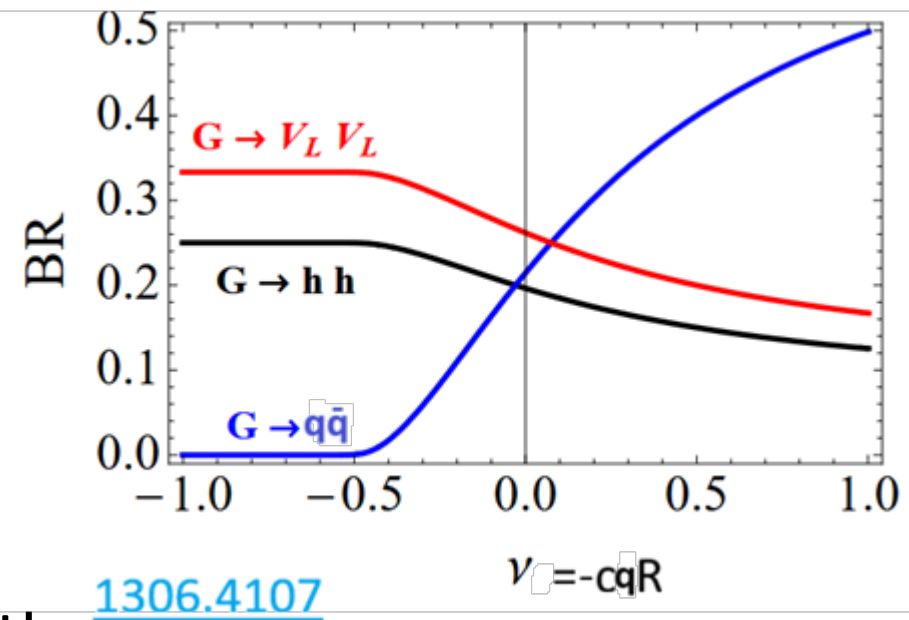
1306.4107

- Where are the other KK states like Z_{KK} etc... ?
- Two mechanisms are proposed to explain why G_{KK} could be the lightest KK state [1603.06980](#) [2506.09490](#)
- Is it coupled to $e+e-$? $BR(G_{KK} \rightarrow ee) = 0.25\%$ from ATLAS/CMS is compatible with $\sin^2\theta_{eff}$ from LEP/SLD if Z_{KK} is much heavier than G_{KK}
- Essential point: $BR(ee) \sim 0.25\%$ would predict **Giga graviton factories** at $e+e-$ colliders

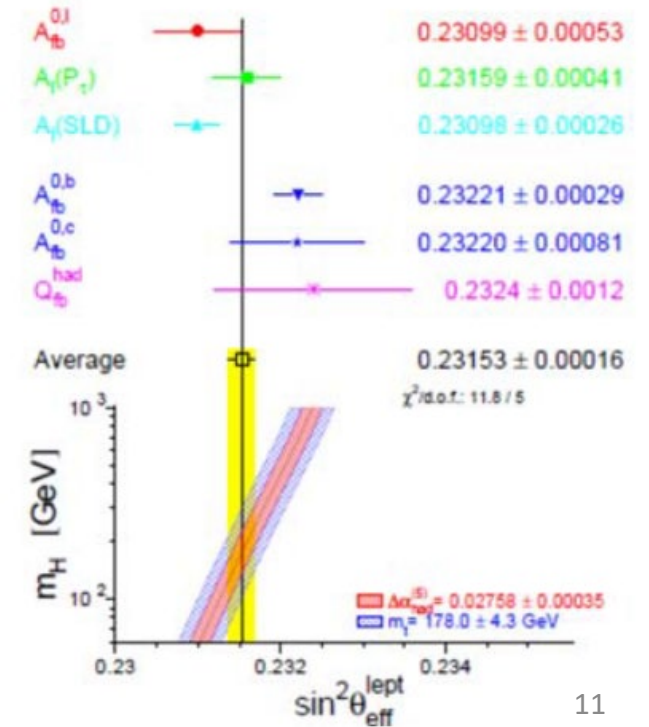


LEP precision measurements

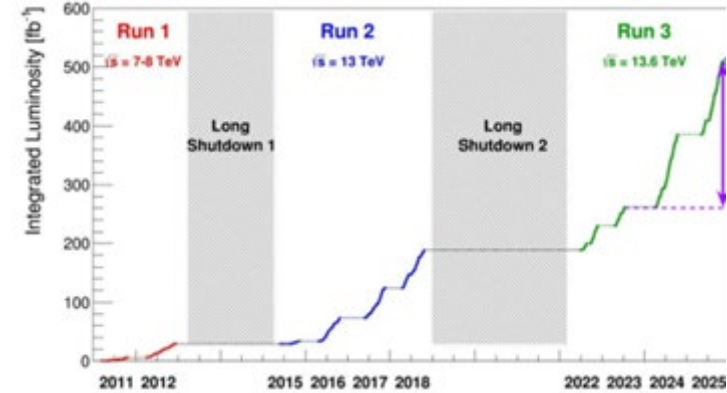
- In the RS model Z_{KK} can influence LEP PM
- AFB_b, ALR show signs of deviations which can be fixed within a LR extension of the RS model
- So far a KK mass of **0.3TeV/sinθ'** was assumed, with $\sin\theta' > 0.1$ (to keep perturbativity), see [0610173](#), hence **ceR=0.56** which gives a negligible $BR(G_{KK} \rightarrow ee)$
- If this mass is of order **2.5TeV/sinθ'**, ALR implies that **ceR=0.45**
- This solution implies **BR(ee)~0.25%** compatible with ATLAS and CMS as suggested by the figure from [1306.4107](#)



[1306.4107](#)



SUMMARY



- '650' and '750' are probably not distinct !
- ZZ and WW suggest a **J=2 state** produced by **VBF** with seven more indications
- This resonance is accompanied by two other indications which suggest the **RS sequence T380 T700 T1000** which provides an explanation for the width and strengthen our interpretation
- Absence of coupling to **gluons** suggest G_{KK} is a **composite particle** made of **colorless partons** similarly to the Higgs boson
- T380, accompanied by T++ and T+, allows to push **perturbative unitarity limit > 29 TeV**
- To interpret LEP precision measurements and **BR(ee)~0.25%** KK gravitons should be much lighter than KK Z
- Implies **Gigafactories for e+e- colliders with ECM>400 GeV**
- **RUN2+RUN3** should provide enough data to confirm/reject this signal and its interpretations

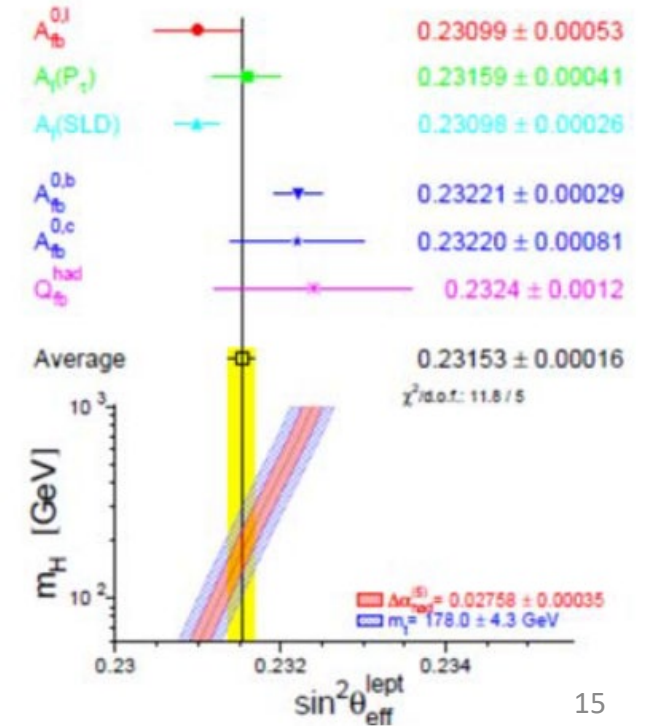
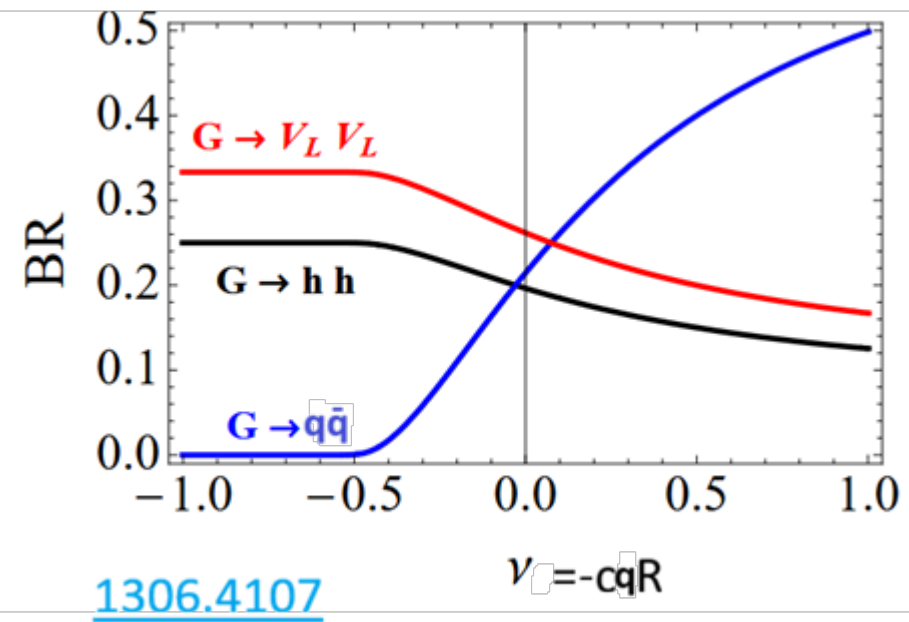
Acknowledgements

- Thanks to **Andreas Höcker** and **Gautier Hamel de Monchenault** for their encouragements in this task
- Useful and pleasant exchanges with **Abdelhak Djouadi**, **Ulrich Ellwanger**, **Adam Falkowski** and **Gilbert Moulataka** are gratefully acknowledged
- Thanks to **Roman Poeschl**, **Guillaume Unal** and **Louis Fayard** for useful exchanges
- Thanks to **Kaustub Agashe** and **Severin Lüst** experts on the RS model

Additional slides

LEP precision measurements

- In the RS model Z_{KK} can influence LEP PM
- AFB_b, ALR show signs of deviations which can be fixed within a LR extension of the RS model
- So far a KK mass of **0.3TeV/sinθ'** was assumed, with $\sin\theta' > 0.1$, see [0610173](#), hence **ceR=0.56** which gives a negligible BR($G_{KK} \rightarrow ee$)
- If this mass is of order 2.5TeV/sinθ', ALR implies that **ceR=0.45**
- This implies **BR(ee)~0.25%** compatible with ATLAS and CMS as suggested by the figure from [1306.4107](#)

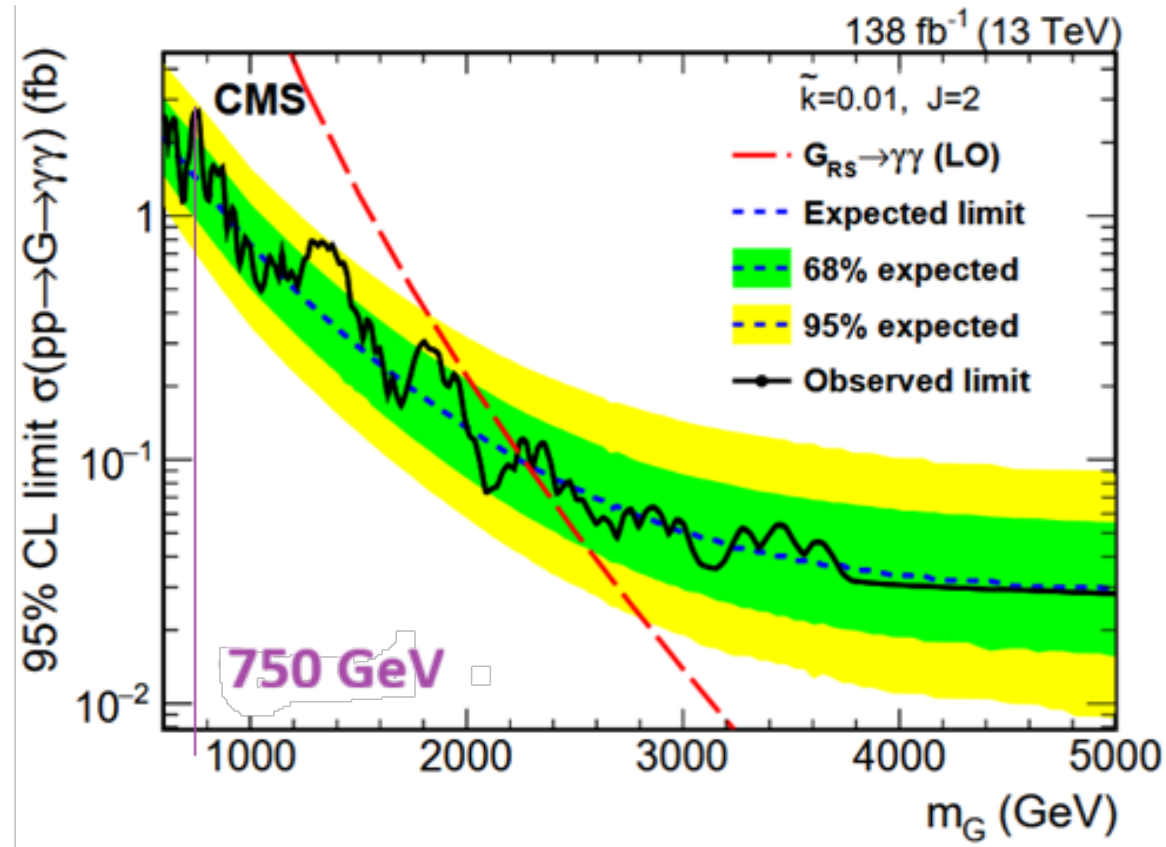


Can G_{KK} be much lighter than Z_{KK} ?

- In [1603.06980](#) a mechanism is recalled where bulk fields develop localized corrections to the **kinetic terms** which can modify the phenomenological predictions
- **Large brane kinetic terms** allows to create a hierarchy between the diverse KK families
- A more radical way out is to invoke an **analogue of the Higgs mechanism**. As longitudinal degrees of freedom of Z and W come from the SM Higgs doublet, the additional degrees of freedom for the massive graviton KK modes (5 in the massive vs 2 in the massless case) would come from one vector and one scalar KK mode. Experimentally, these “eaten” vectors and scalar degrees of freedom are not visible as individual particles. The same thing could also happen for the fermionic KK modes in a SUSY theory. They can become the missing degrees of freedom of the massive gravitino KK modes.
- We are indebted towards Severin Lüst for suggesting this mechanism.

CMS on $G_{KK} \rightarrow 2\gamma$

- ATLAS has found a xsection of ~ 2 fb at ~ 700 GeV
- There is also an indication by CMS in [2405.09320](#)



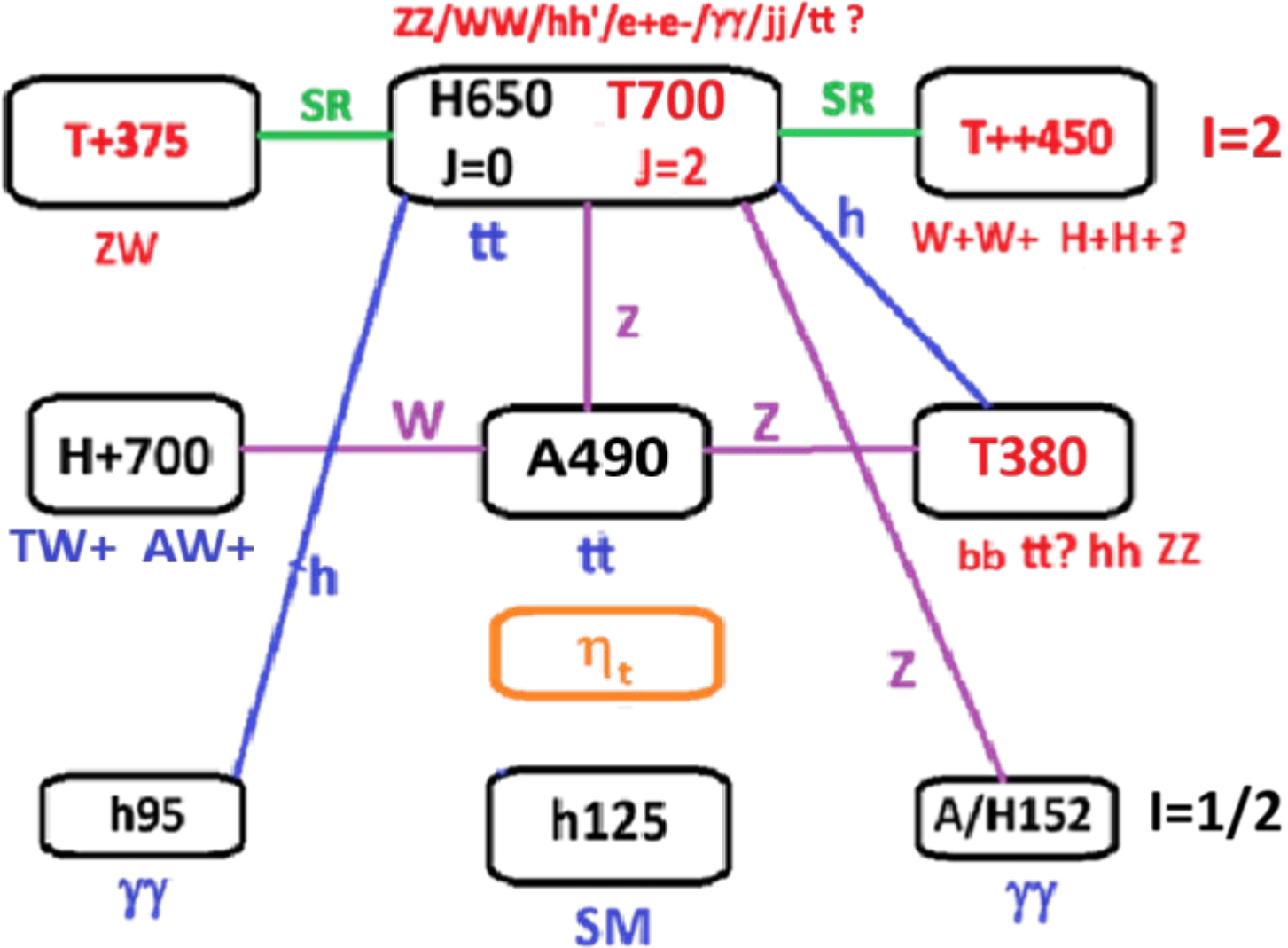
Sum Rules

- **Perturbative Unitarity** requirements predict sum rules for **scalar couplings**
- $W_L^+ W_L^- \rightarrow W_L^+ W_L^-$ Haber et al. in *P.R.D* 43 (1991) 904-912
- They are satisfied by the SM and heavy scalar doublet (decoupling) contributions
- In the Georgi Machacek model one has compensation due to H^{++} (u exchange term)

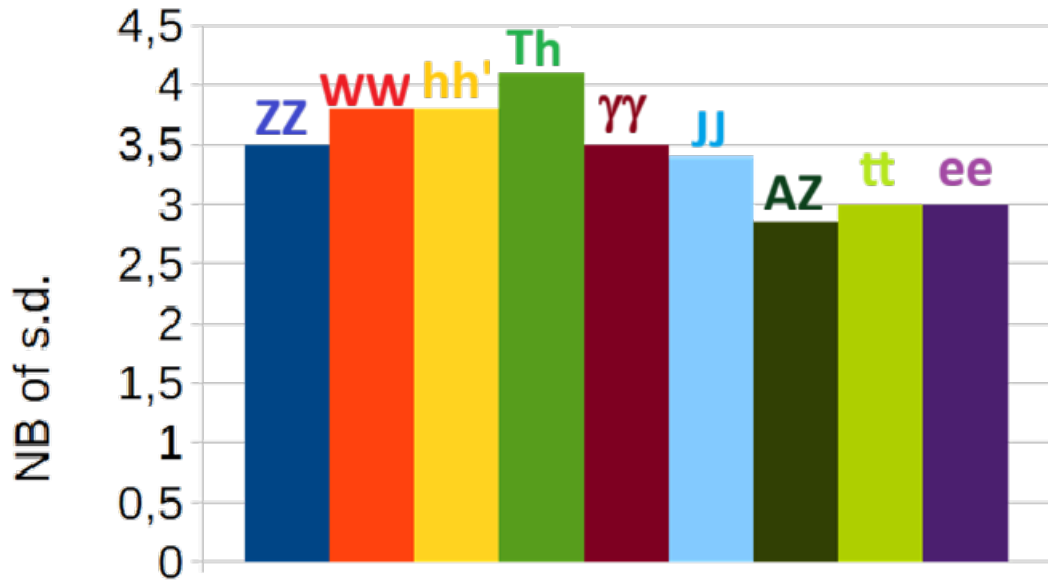
$$g^2(4m_W^2 - 3m_Z^2 c_W^2)^{\rho \simeq 1} \simeq g^2 m_W^2 = \sum_k g_{W^+ W^- H_k^0}^2 - \sum_l g_{W^+ W^+ H_l^{--}}^2$$

- KK J=2 gravitons have a **different angular distribution** but could be compensated by doubly charged tensors $T^{++} \rightarrow W^+ W^+$ giving u exchange contributions
- In the same way $ZZ \rightarrow WW$ forces us to expect $T \rightarrow ZW$
- They are indicated by LHC data for the first KK recurrence at 380 GeV
- They could also appear at 700 GeV for the second KK recurrence

Summary diagram

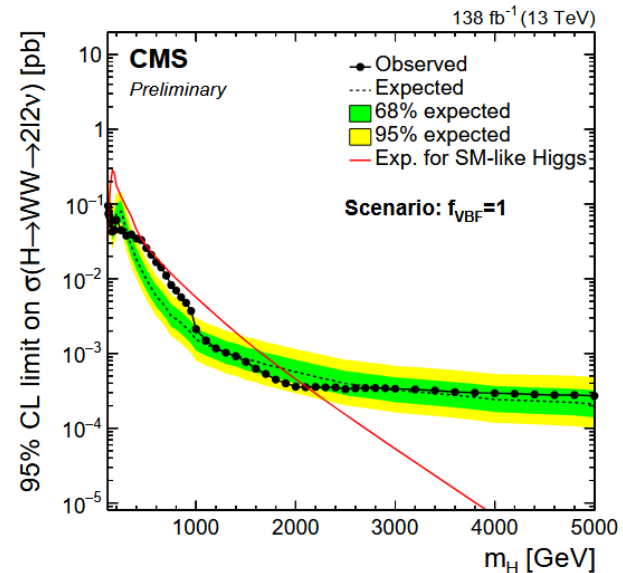
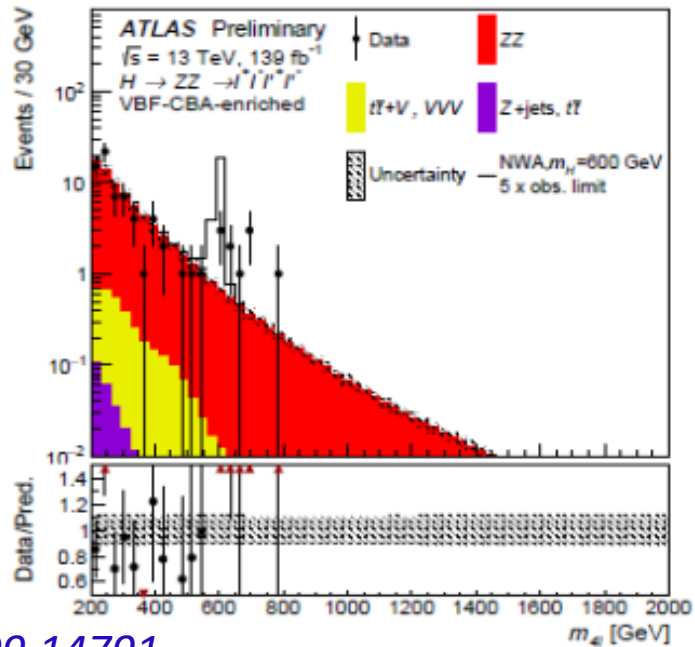
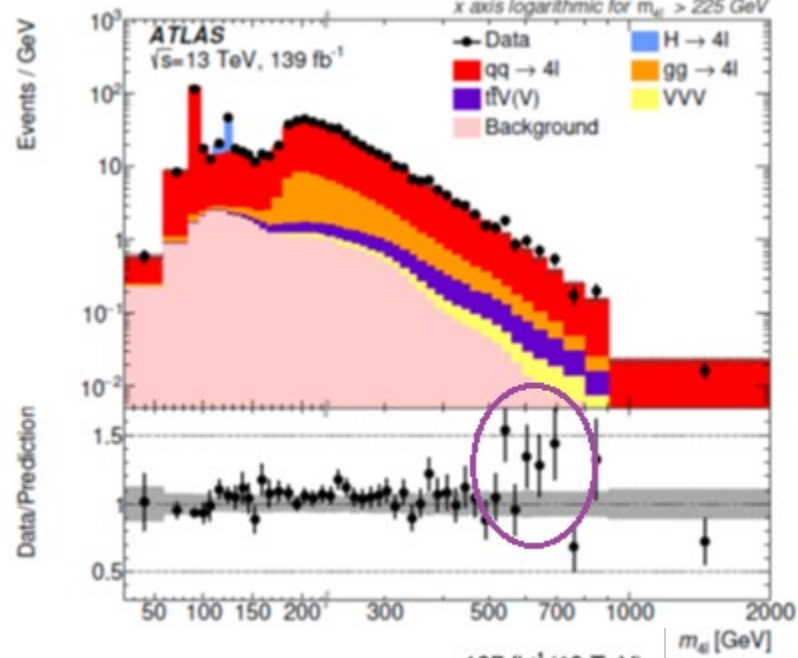


Evidences for ~ 650 GeV resonance(s)



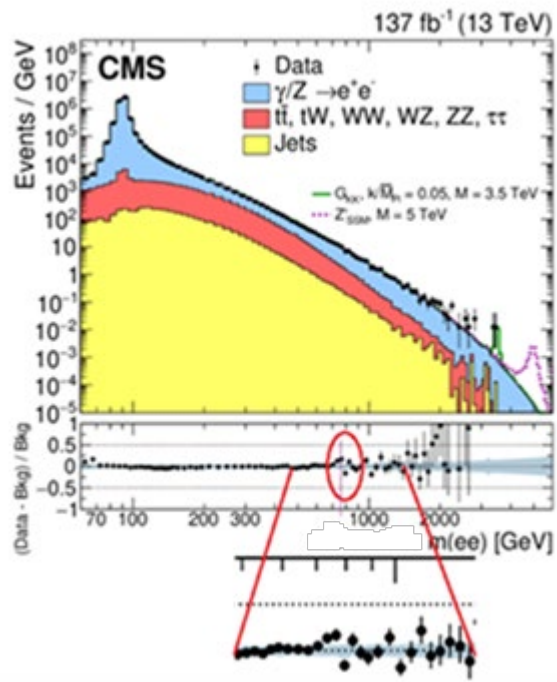
~ 6 sd global significance

Channel	Significance s.d.	Reference
ZZ 4 leptons	3.8 ggF+VBF 2.8 VBF	ATLAS 2009.14791
WW 2leptons	3.8 VBF	CMS-PAS-HIG-20-016
h95h125 bb/ $\tau\tau$ $\gamma\gamma$	3.8	CMS 2310.01643 CMS 2506.23012
T380h125 bbbb	4.1	CMS-PAS-HIG-20-012
$\gamma\gamma$	3.5	ATLAS 2102.13405
JJ	3.4	ATLAS 2509.01219
AZ tt 2leptons	2.85	ATLAS 2311
e+e-	3	ATLAS 1903.06248 CMS 2103.02708
tt	3	ATLAS 2404.18986 CMS 2507.05119

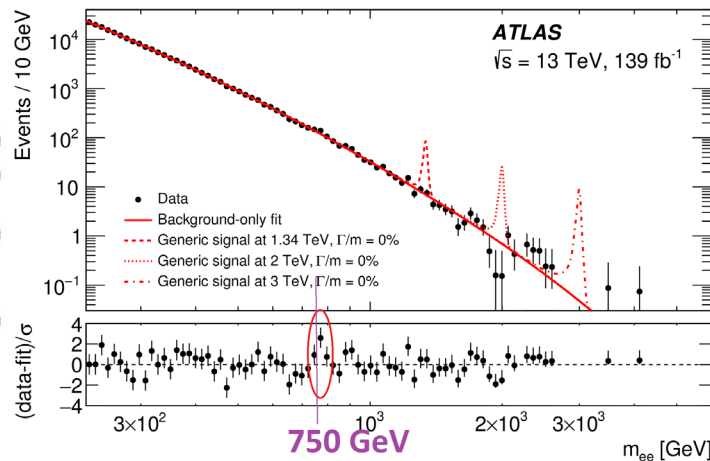
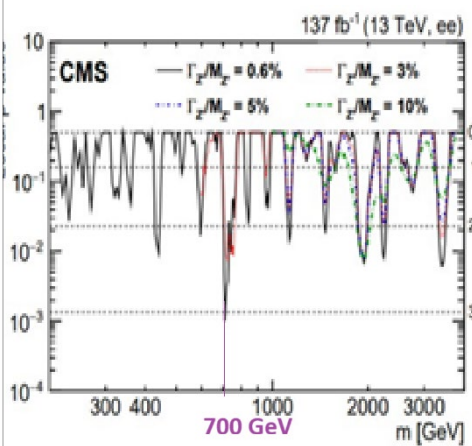


CMS-PAS-HIG-20-016

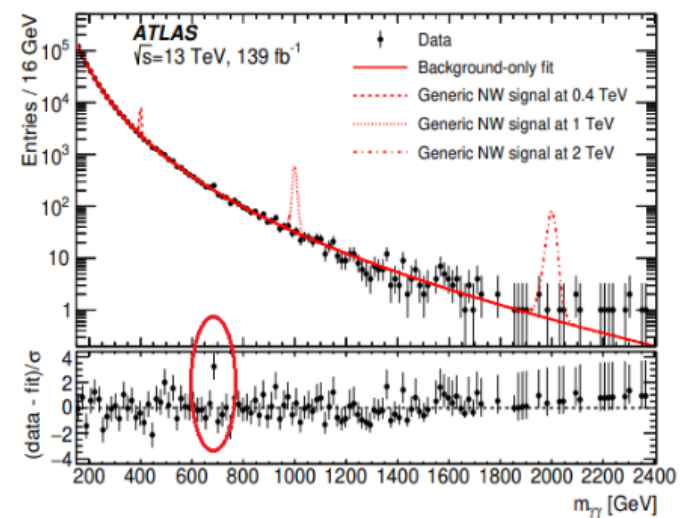
2009.14791



2103.02708



1903.06248

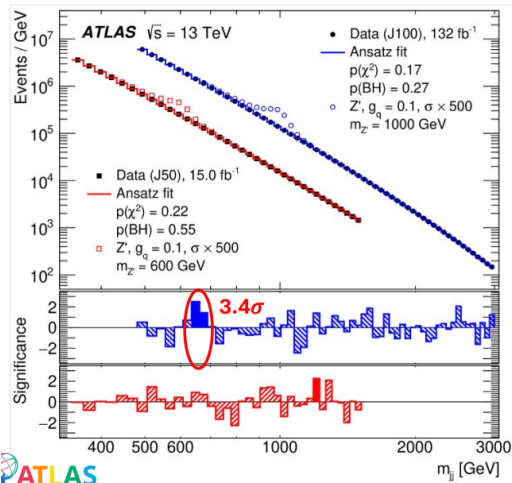


2102.13405

Complex modes

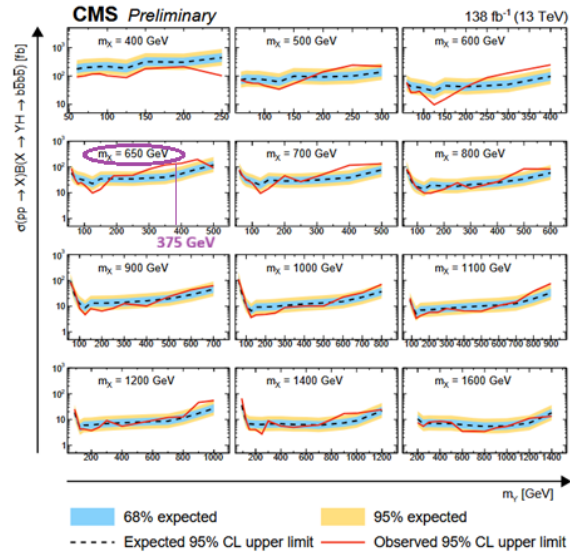
2509.01219

CERN-EP-2025-194, in submission



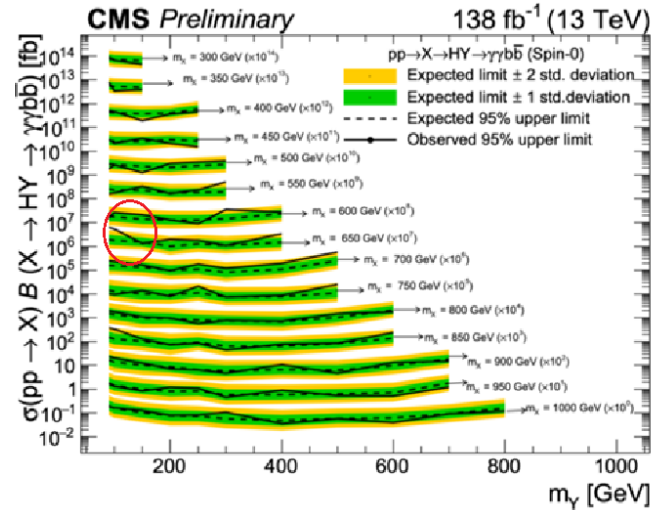
X650->2 Jets

CMS-PAS-HIG-20-012



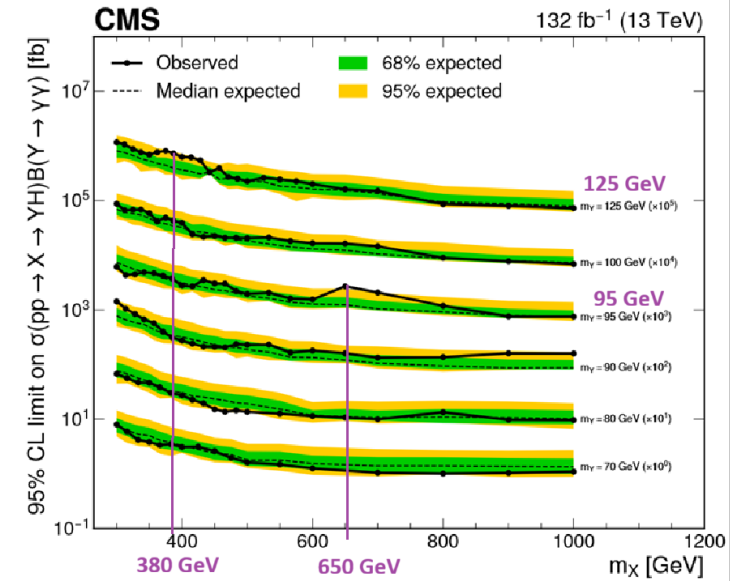
X650->Y375+h125->bb+bb

2310.01643



X650-> h125h95 -> gamma gamma + bb

2505.23012



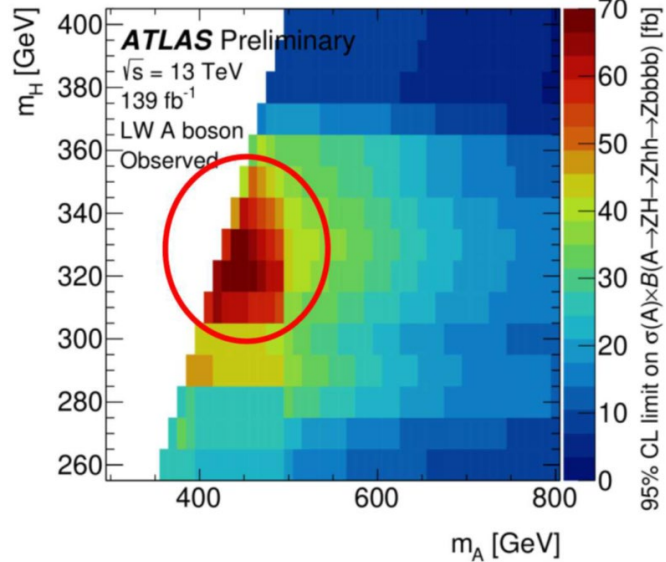
X650-> h125h95 -> gamma gamma + tau tau

T380-> h125h125->gamma gamma + tau tau

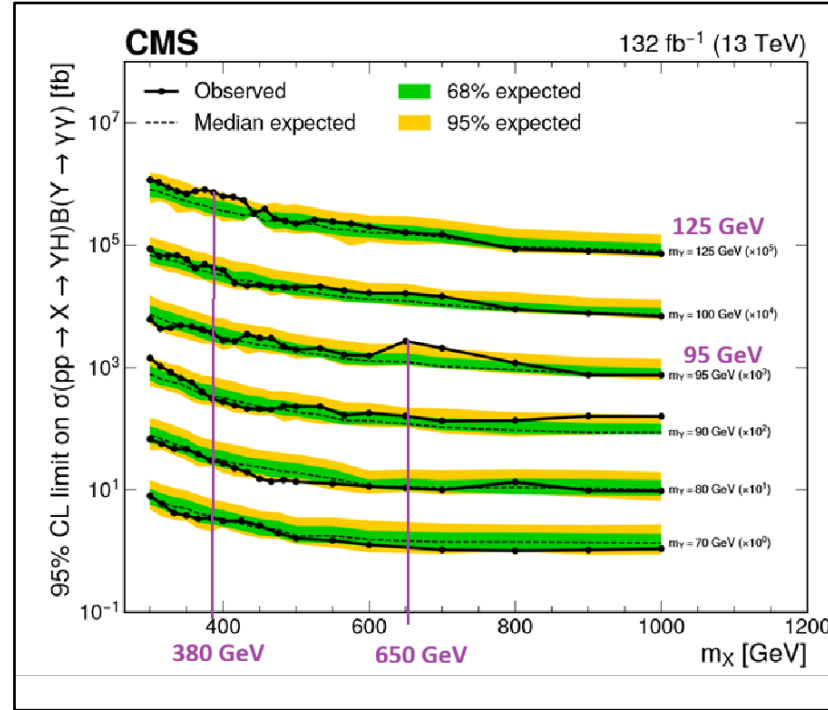
Next best candidate to T700 ?

[CMS 2506.23012](#)

[2210.05415](#)



A490 \rightarrow T380Z \rightarrow bbbbZ



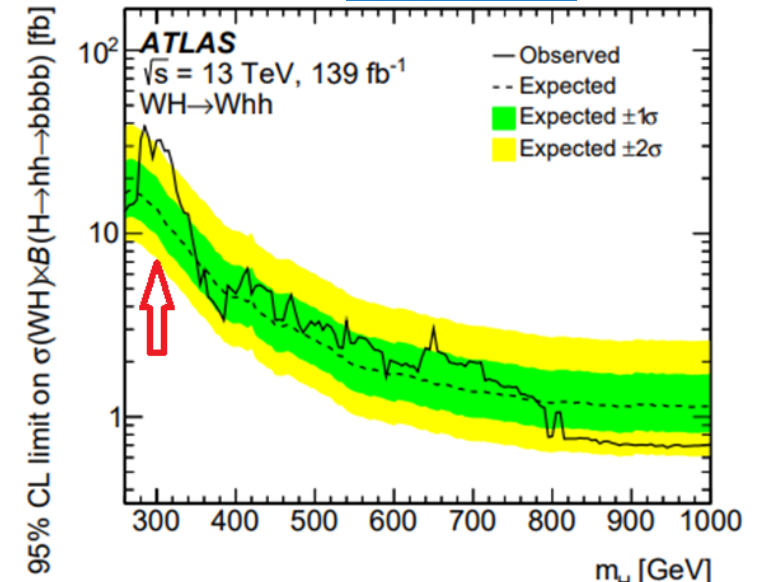
T380 \rightarrow hh \rightarrow $\tau^+ \tau^- + \gamma\gamma$

T700 \rightarrow T380h \rightarrow bb+bb

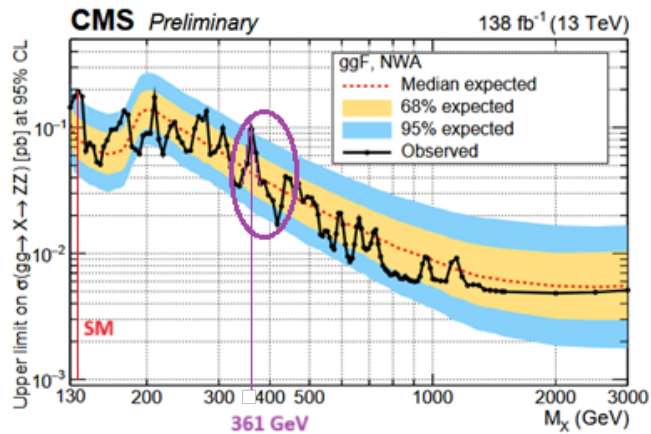
[CMS-PAS-HIG-20-012](#)

\rightarrow 4 s.d. SIGNIFICANCE

[2210.05415](#)

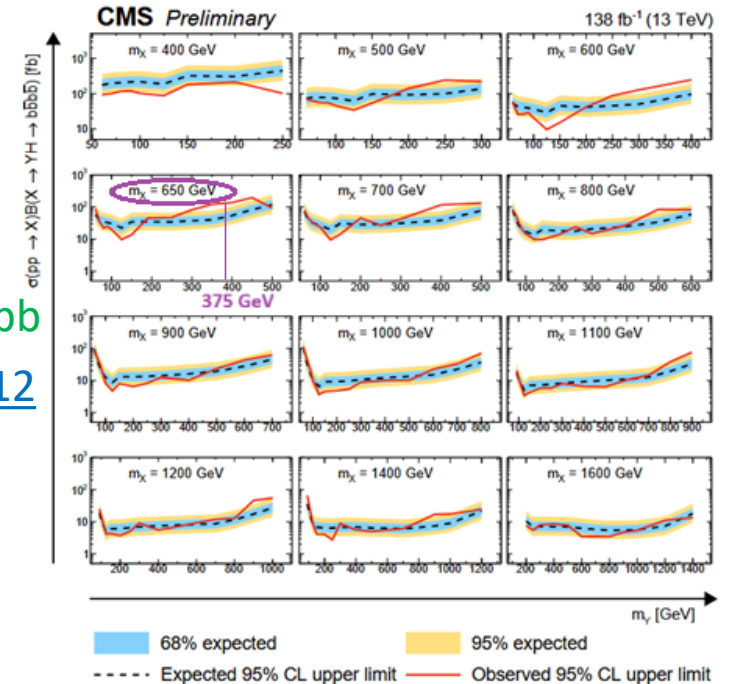


H+ \rightarrow T380+W \rightarrow hh+W \rightarrow bbbb+W



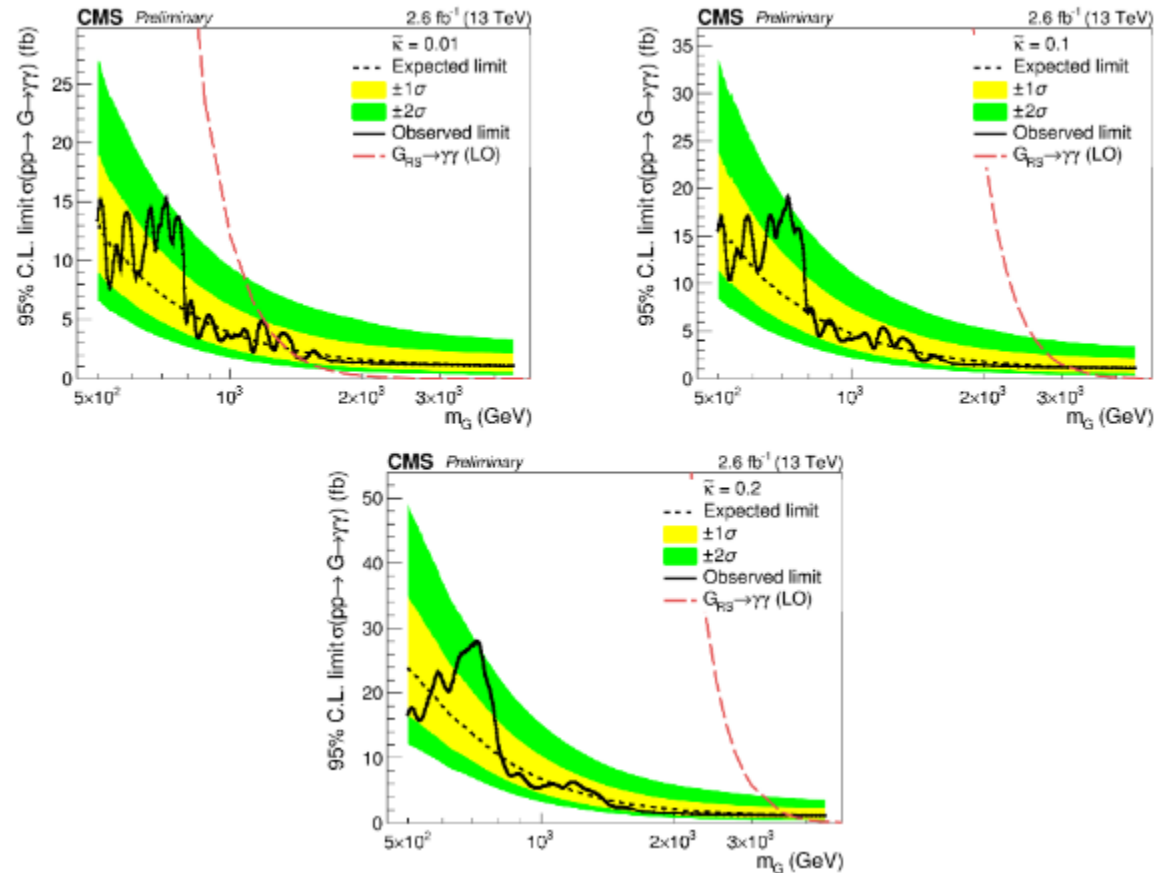
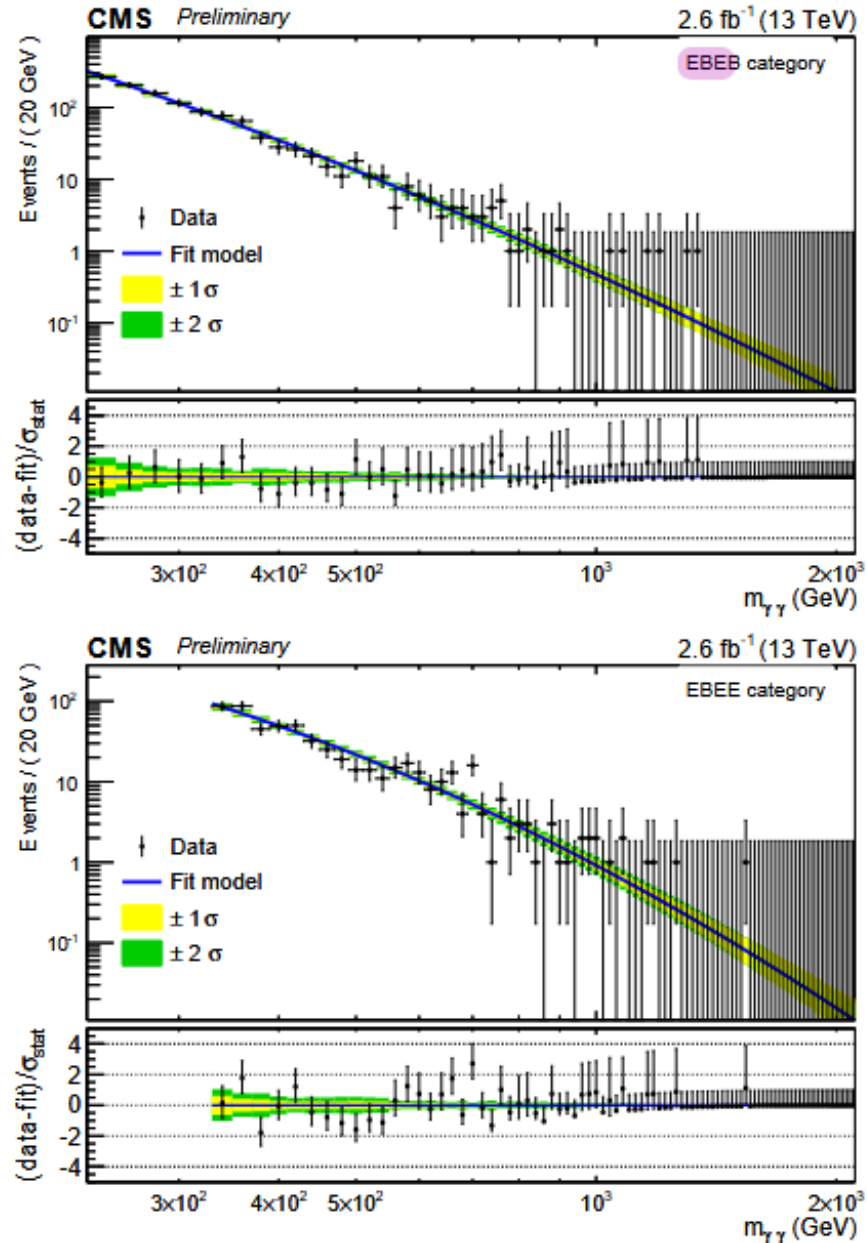
T380 \rightarrow ZZ \rightarrow $l^+ l^- l'^+ l'^-$

[CMS-PAS-HIG-24-002](#)



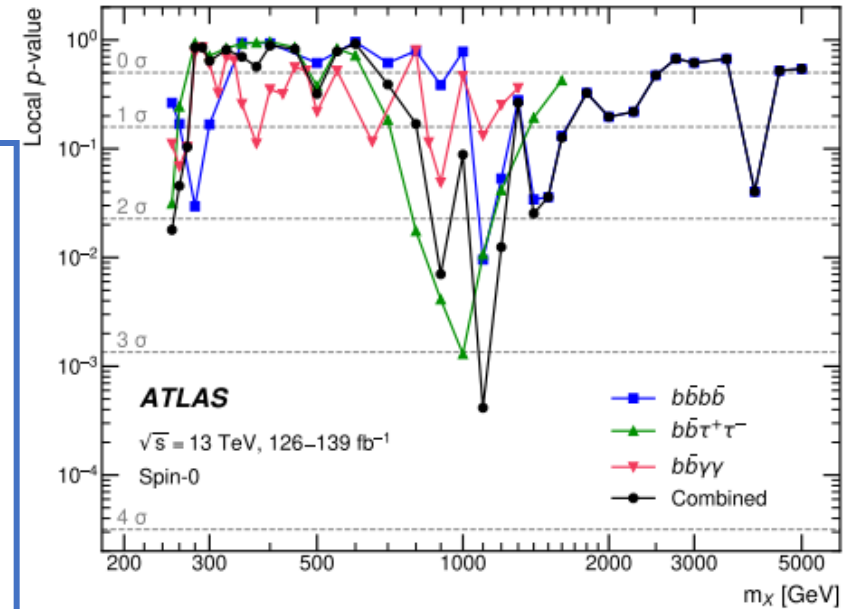
CMS results

<https://cds.cern.ch/record/2114808/files/EXO-15-004-pas.pdf>

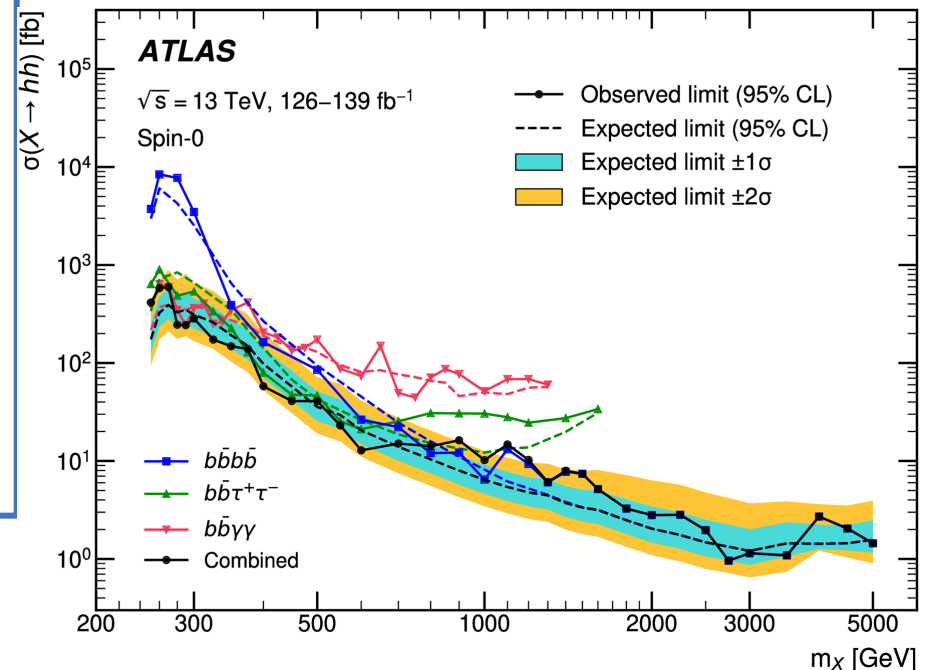


Graviton recurrences ?

- T700 seems a valid tensor candidate
- In the Randall Sundrum (RS) model, graviton KK resonances G_{iKK} have masses which go like $m_i \sim 100x_i^G$ in GeV, where $x_i^G = 3.8, 7.0, 10.2, 13.3 \dots$ and widths which go like $\Gamma \sim 0.06(x_i^G)^3$
- These numbers which govern the RS model are of **geometric origin**, simply given by the zeros of the Bessel function $J_1(x)$
- Assuming that **T700 is the second KK resonance**, one predicts **T380** as the first one, as observed and the third one **T1000**, which seems indicated by ATLAS searches for $h_{125}h_{125}$
- The next one should be T1300



Phys. Rev. Lett. 132 (2024) 231801



A preliminary interpretation of these indications

J=0
I=1/2

J=2
I=2

HD1	h125 → SM	WL	ZL
HD2	h95 → 2γ	t → H⁺130 b → bcb	A152 → 2γ+Z/W
HD3	H650 → A490Z → ttZ	H⁺700 → A490W⁺	A490 → T380Z → hhZ
TQ1	T⁺⁺450 → W⁺W⁺	T⁺375 → ZW⁺	T380 → hh,bb,tt
TQ2	T700 → ZZ/WW/h125h95/tt/2γ/e+e-		
TQ3	T1000 → ZZ/WW/h125h125		

Weinberg Model
Gauge Theory of CP violation, Phys. Rev. Lett, 37 (1976) 657.

Randall Sundrum
MTQ1=380
MTQ2=700
MTQ3=1000

Effective Field Theory: Why and why not?

- No signs for NP at LHC thus far

- Most likely: $\Lambda_{NP} \gtrsim 1 \text{ TeV}$

- Expansion in: $v^2/\Lambda_{NP}^2 \ll 1$

Effective Field Theory (EFT):

- Model independent
- Valid at energies E below Λ_{NP}

But:

- How small does E/Λ_{NP} need to be? Validity for (non-)resonant processes?
- Huge number of free parameters \Rightarrow Analysis with all couplings unfeasible

\Rightarrow EFTs: powerful but complicated

X \rightarrow WZ

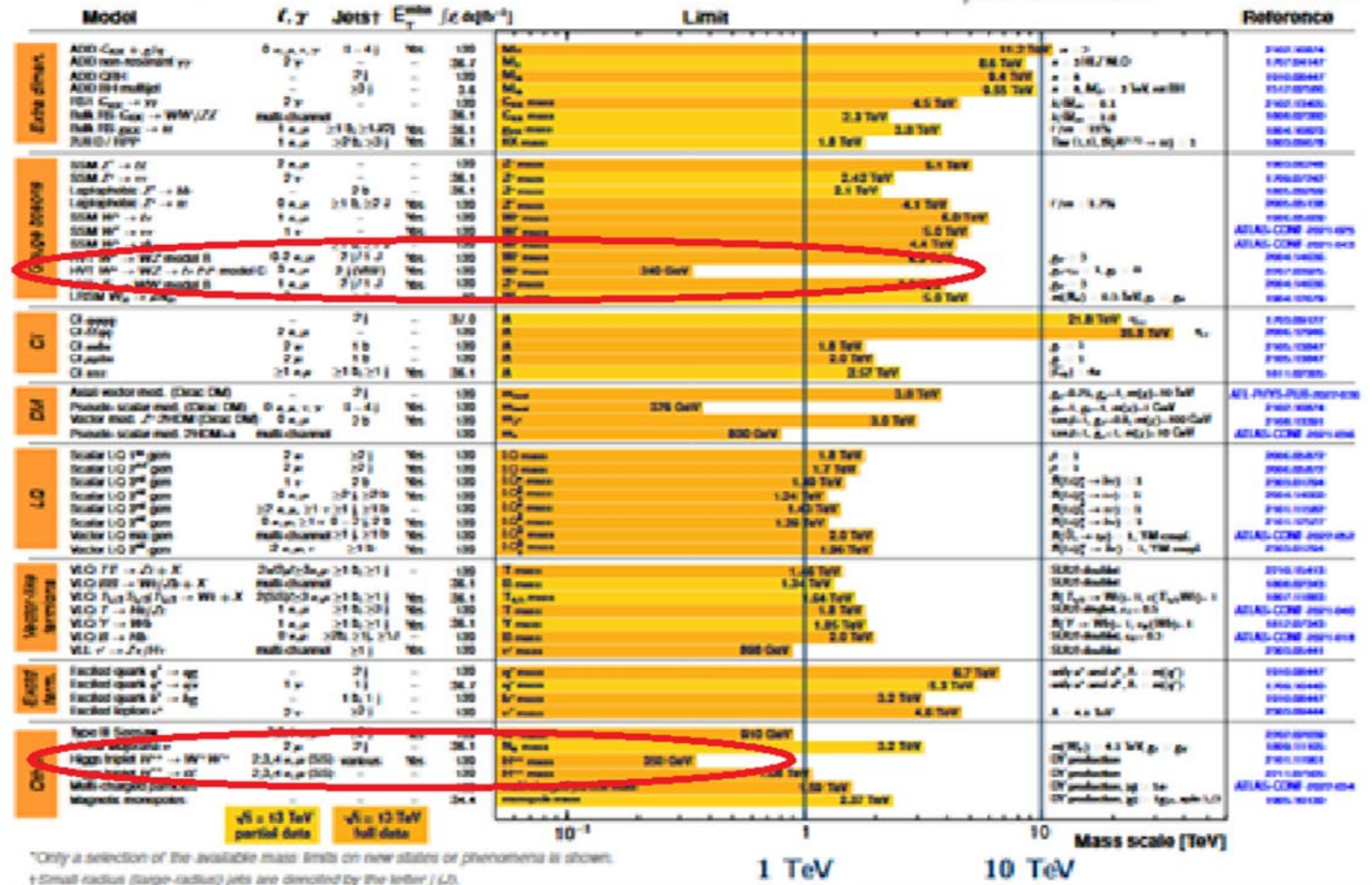
H $^{++} \rightarrow$ W+W+

ATL-PHYS-PUB-2023-008

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

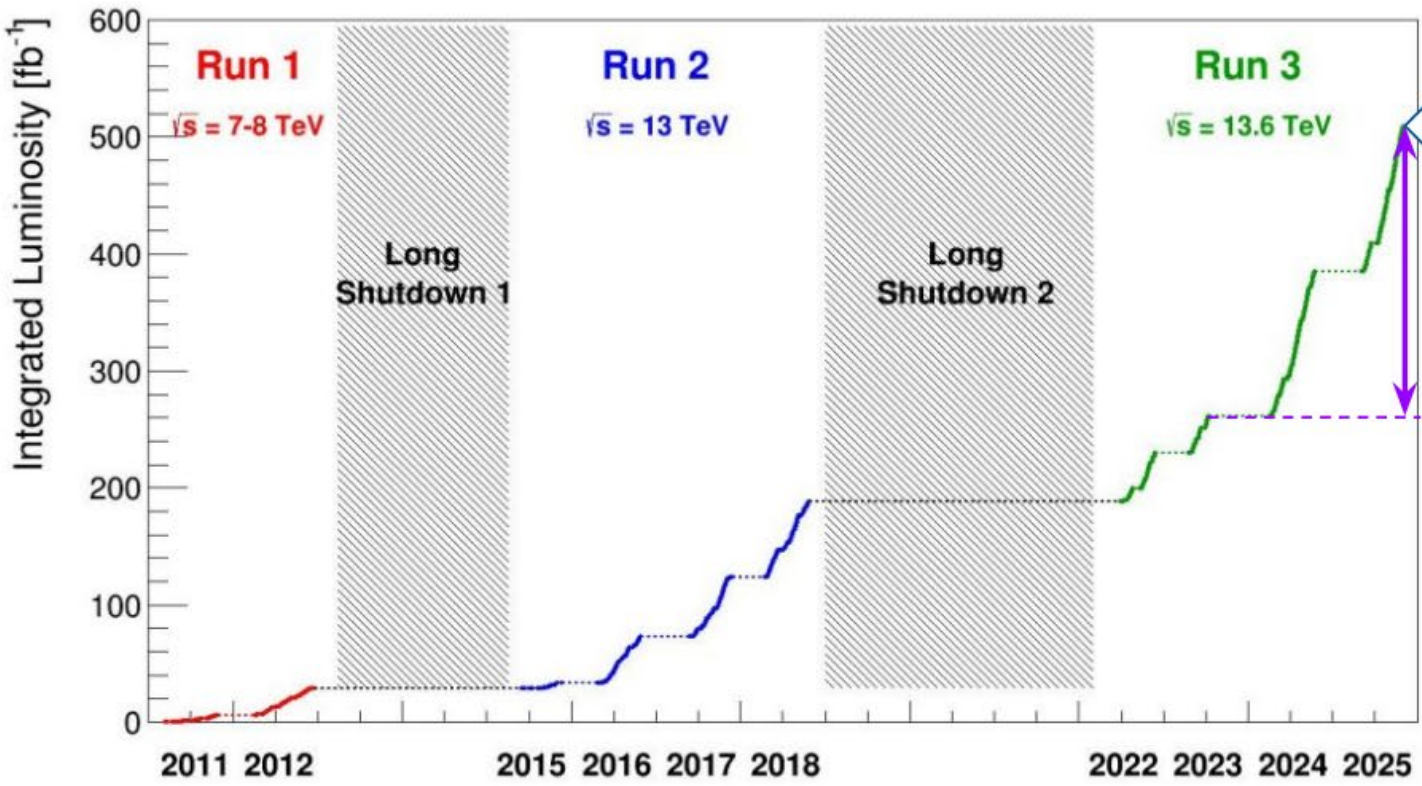
Status: March 2023

ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$
 $\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$



entering the attobarn era

Michi Hostettler Moriond 2026



0.51 ab⁻¹
("x2" for ATLAS + CMS)

~50% of which delivered in the past 2 years...

+30 fb⁻¹ in 2026

