BOSTON UNIVERSITY

Recent results in prompt searches at CMS

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LHCp 2024,

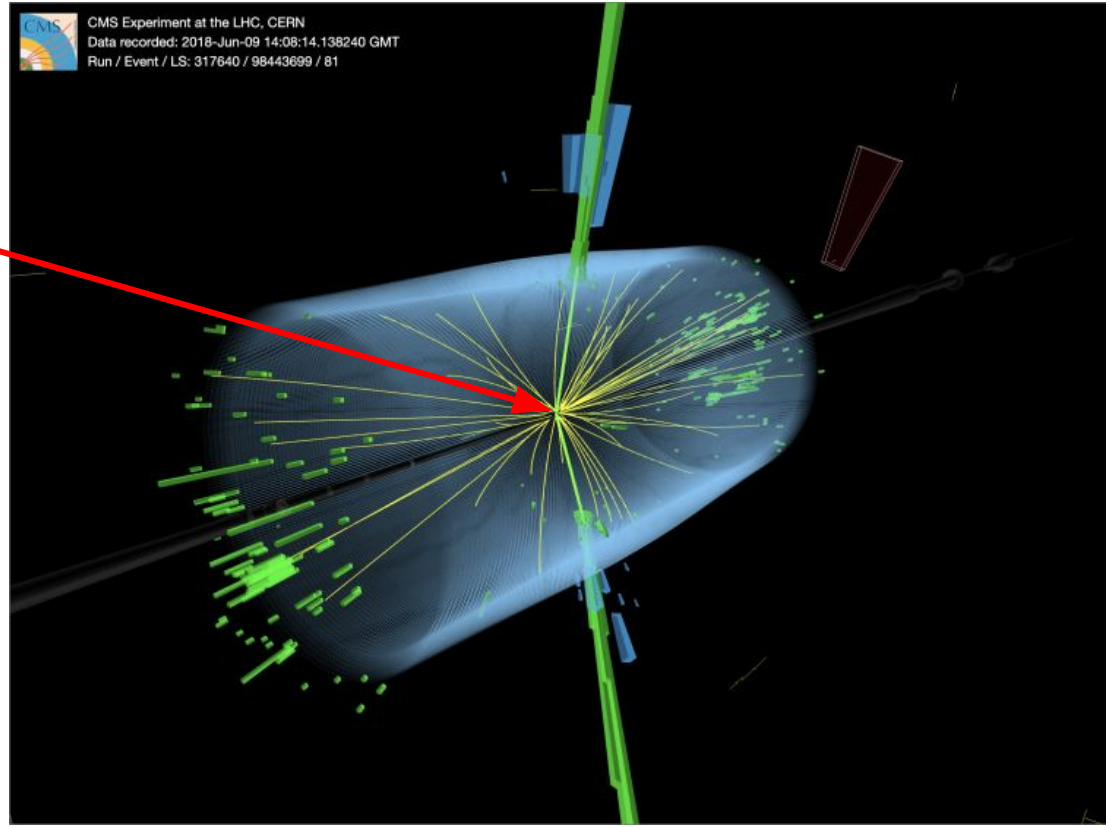
June 3rd 2024, Boston

Introduction

"Prompt searches": those in which the **main interaction happens next to the collision point**:

- Very extensive prompt search program at CMS: around 500 papers published so far!

- New searches require us to push boundaries and go out of the trodden path: **ingenuity is the main characteristic of current prompt searches**.



From JHEP 07 (2021) 208

What is novel? (topics in this talk)

Using advanced reconstruction and identification techniques:

- X→ZH→(ee/μμ/νν)+J, CMS-PAS-B2G-23-008.
- High mass γγ, arXiv:2405.09320.

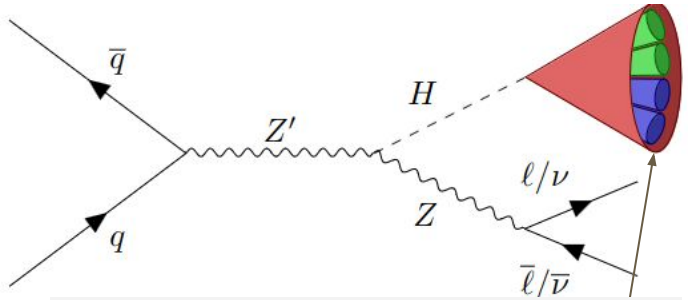
Improving our background estimations:

- RPV SUSY with jet scaling patterns, CMS-PAS-SUS-23-015.
- Excited τ, CMS-PAS-EXO-22-007.

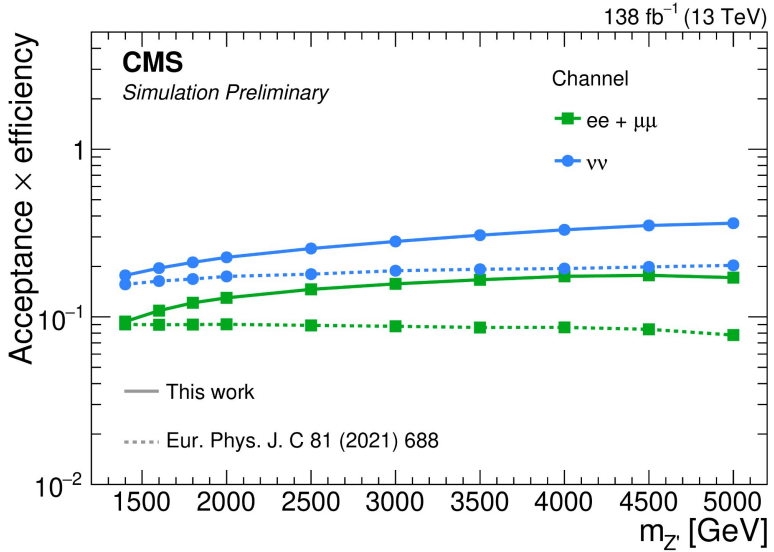
X→ZH→(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

Back-to-back boosted jet + dilepton (ee/μμ) or p_T^{miss} (νν) system.

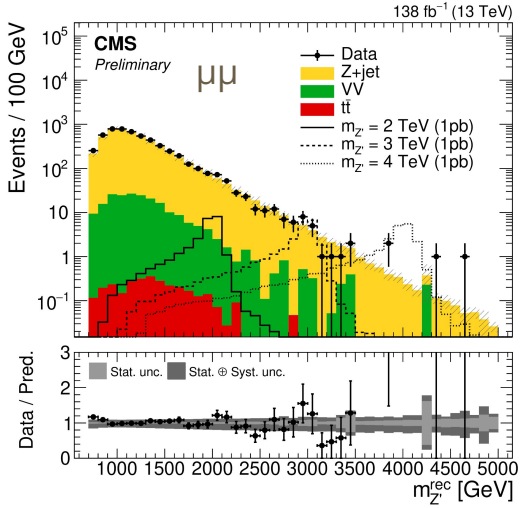
- Boosted jet required to **not contain** 2 b-tagged sub-jets.
- Target is to improve on the ZH search EPJ C 81 (2021) 688 with higher sensitivity to non-bb Higgs decays:
  - Use **ParticleNet** (imaging with gCNN for jet tagging, link) for the identification of the H cluster.

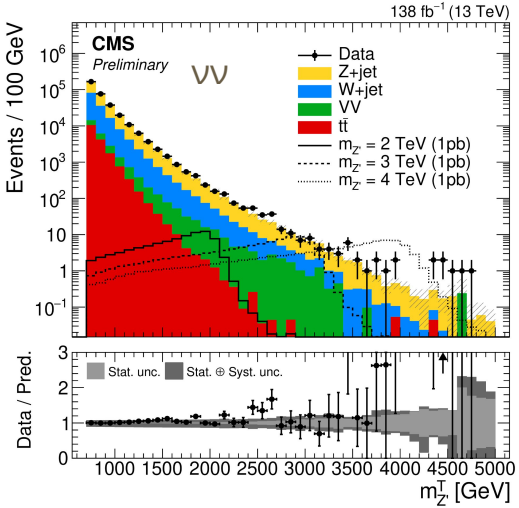


Target H→VV→qqqq and H→cc decays



Reconstructed (transverse) mass of the system



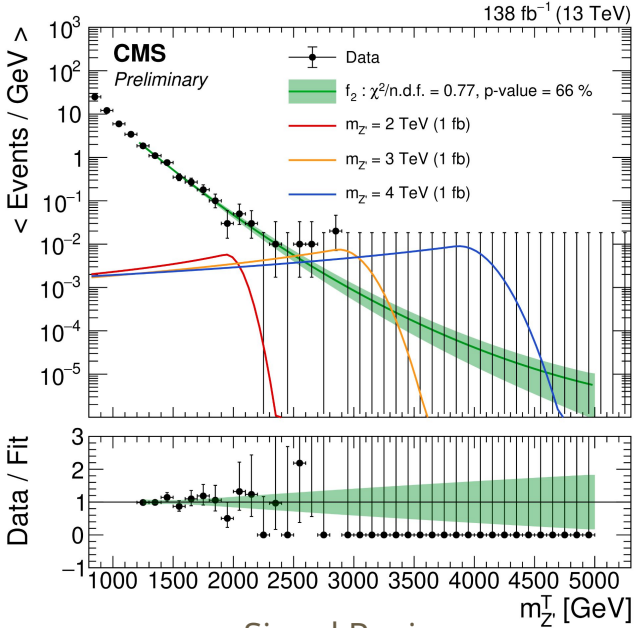


X⟶ZH⟶(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

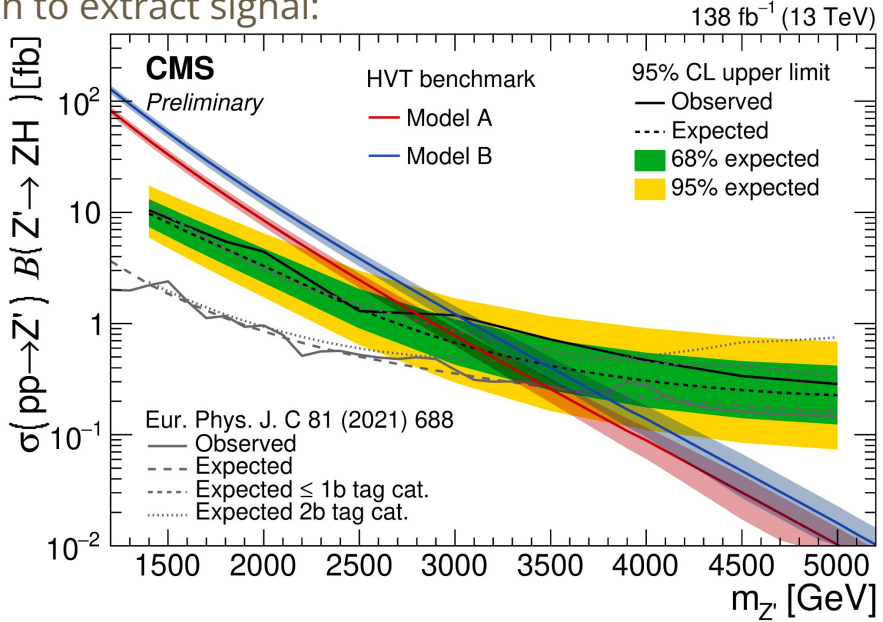
$$f_N(x) = \exp\left(\sum_{i=0}^{N} p_i x^i\right)$$

Validation regions/ Signal regions separated by the tightness on the reconstructed H criteria:

- Use validation region to validate falling background analytical fit + set order of fitting function.
- Signal region is then fit with resulting function to extract signal:



νν Signal Region

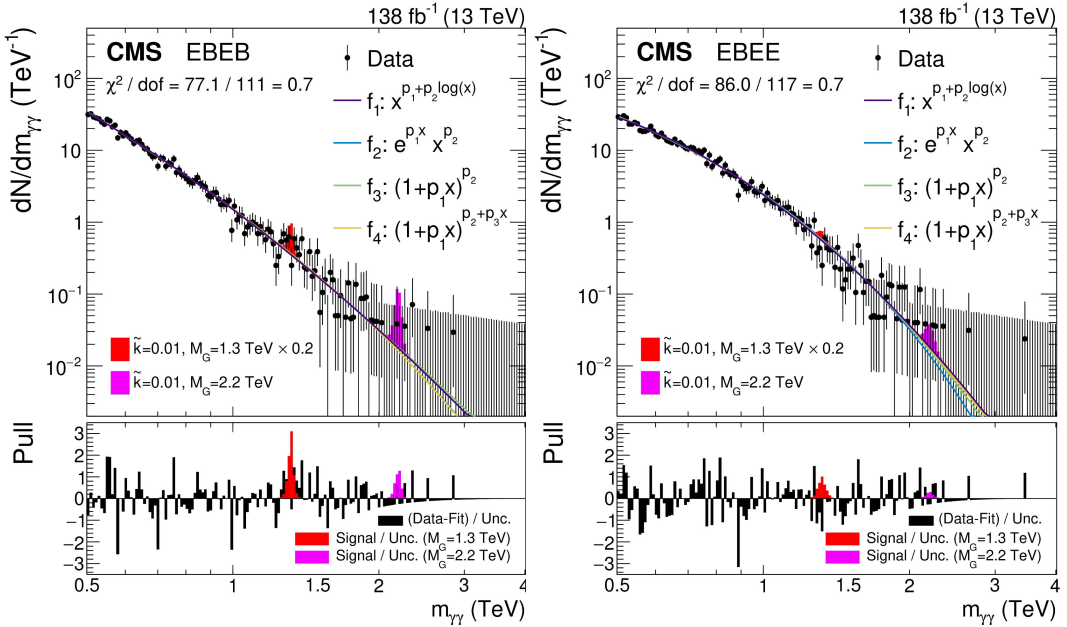


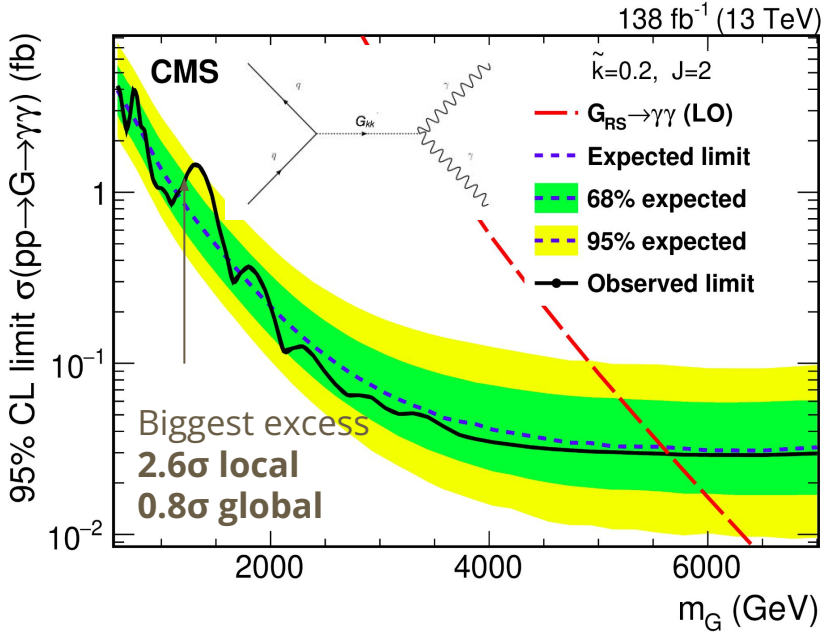
Notice the improvement with respect to <2b category in EPJ C 81 (2021) 688.

High mass γγ - arXiv:2405.09320 (sub. to JHEP)

Diphoton resonant search:

- Uses the bump hunt technique with discrete profiling.
- Dedicated high p_T photon ID designed for high mass resonances.
- Two channels based on whether a photon is in the ECAL endcap.





Not seen by ATLAS (PLB 822 (2021) 136651)

High mass γγ - arXiv:2405.09320 (sub. to JHEP)

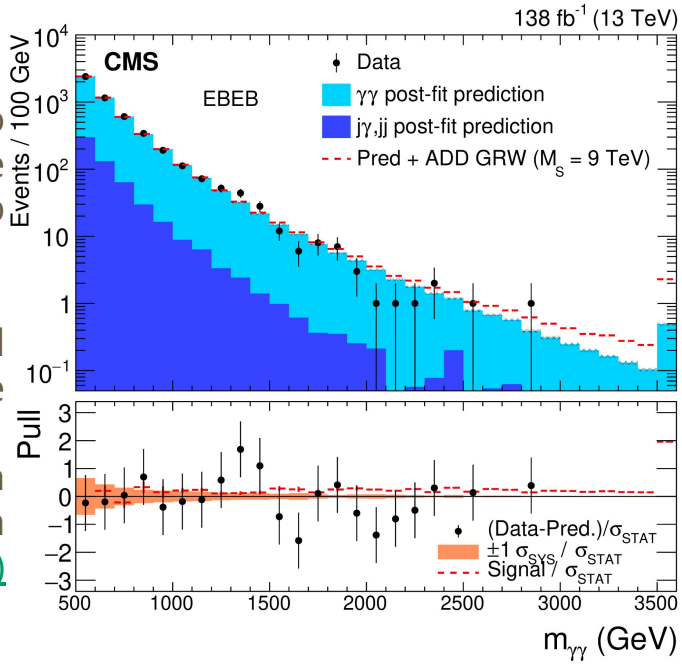
Diphoton **non-**resonant search in the same paper with the same target of high p_T photons:

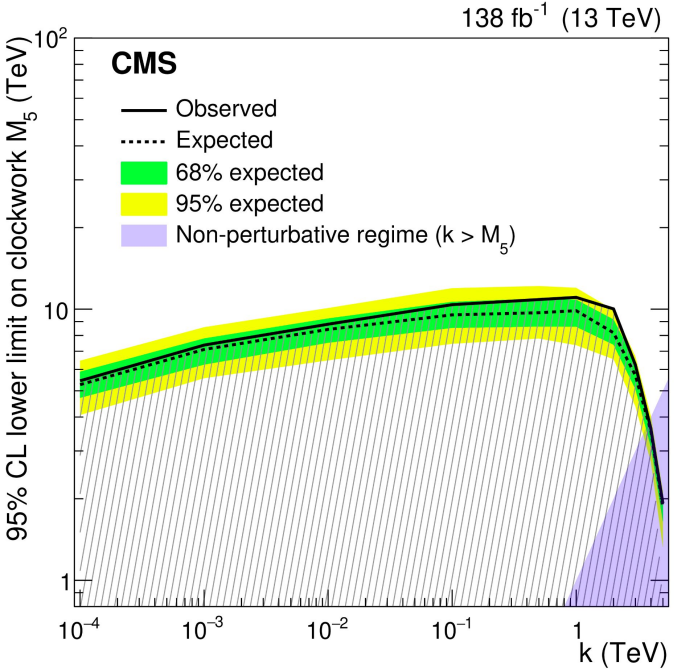
- Rely on MC for γγ background modelling. Tight-to-loose method for non prompt γ
- Signal predictions from additional ADD (extra dimensions)/clockwork predict deviations at the high mass tails.

Fit performed on two categories, based on the presence of and endcap photon.

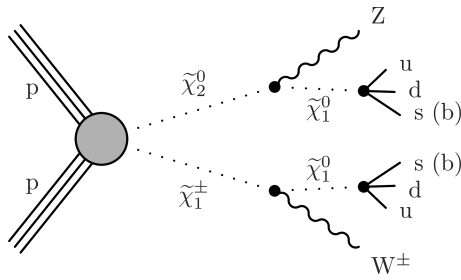
Results exclude a broad piece of parameter space for the CW model:

- Consistent with recent results from ATLAS (JHEP 10 (2023) 079).





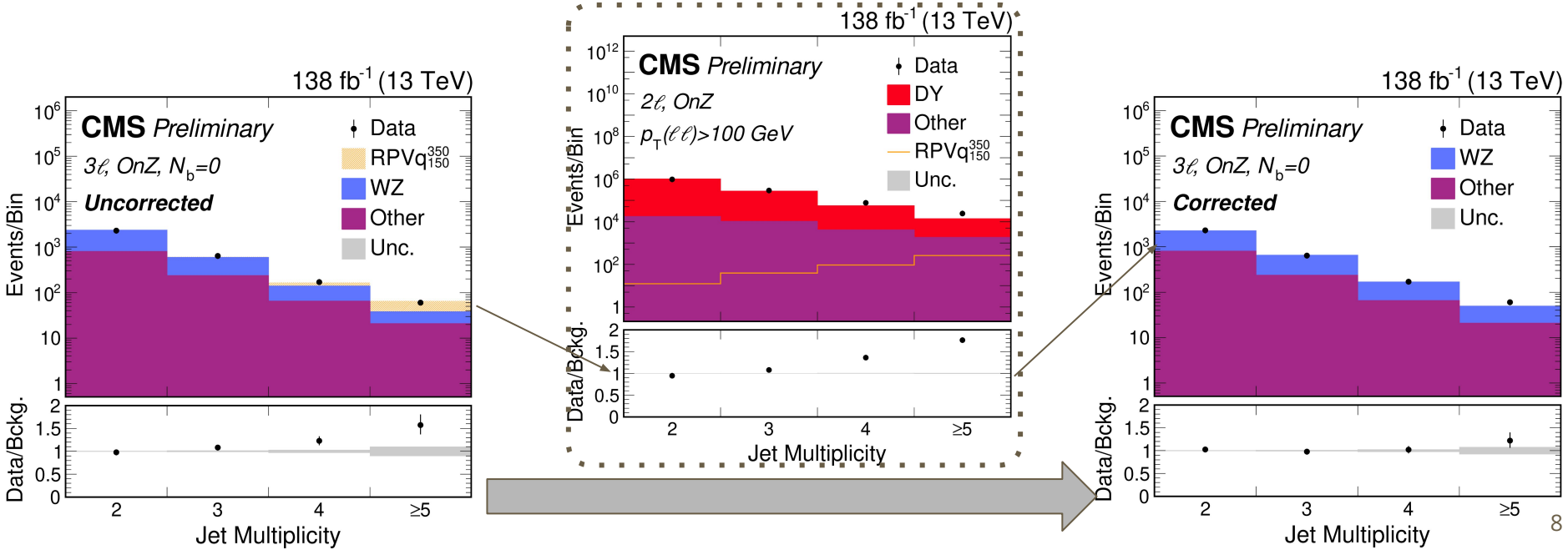
RPV SUSY with jet scaling patterns - CMS-PAS-SUS-23-015



A search in final states 3 light leptons + multiple (b-)jets

Its main challenge is the modelling of ttZ and WZ:

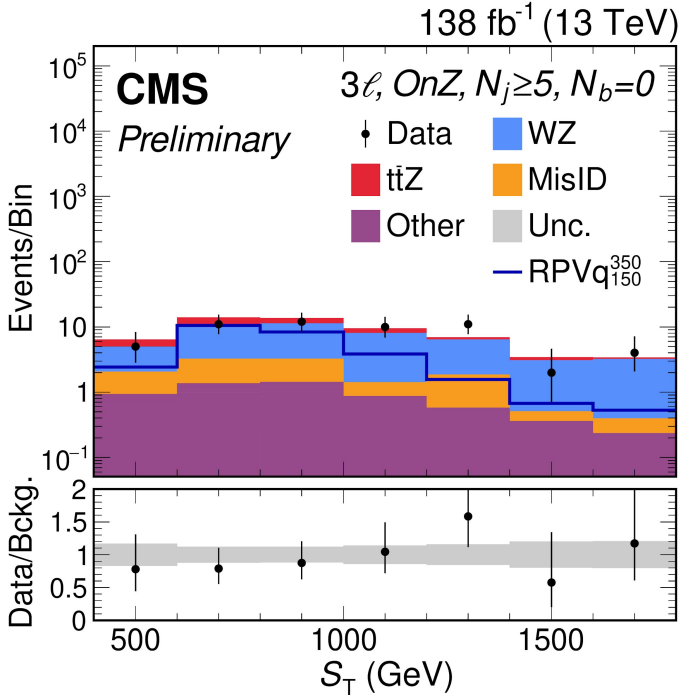
- Parton showering is known to not model high N_{jet} regions well.
- Instead of relying in pure MC, jet multiplicity corrections are derived from data in sidebands where jets are produced by similar processes.

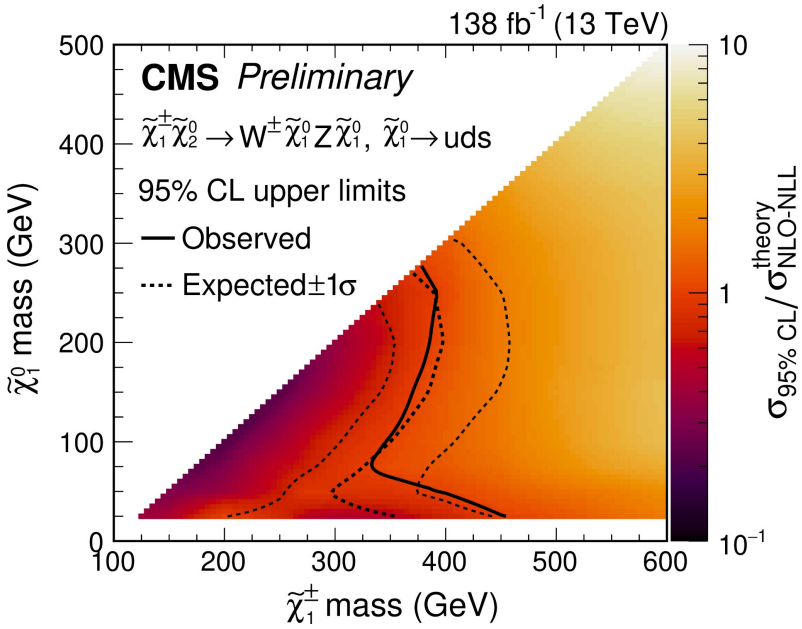


RPV SUSY with jet scaling patterns - CMS-PAS-SUS-23-015

The S_T variable (scalar sum of the p_T of all leptons, jets and p_T^{miss}) is used as a discrimination variable:

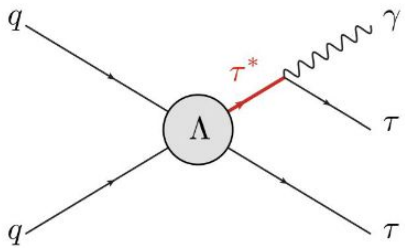
- In 2 different categories with/without b tagged jets.
- And 4 different regions of increasing Jet multiplicity.



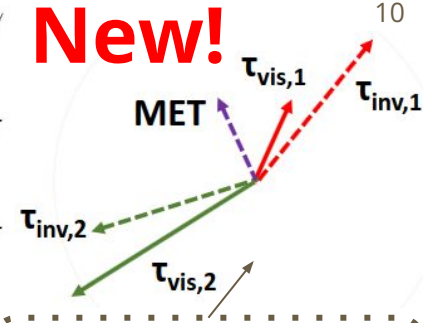


First result on prompt hadronic RPV decays for electroweakino production!

Excited τ - CMS-PAS-EXO-22-007



New!

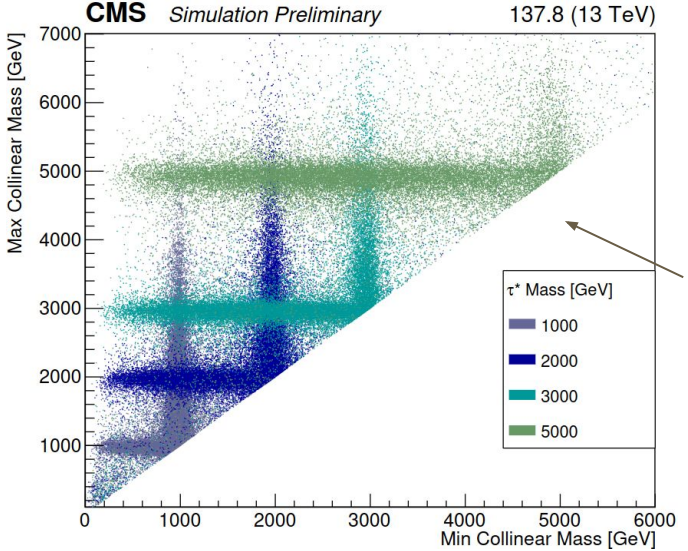


CI model that predicts a ττ + high p_T γ final state.

Several steps to reconstruct the mass of the τ* in $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$

- "Collinear approximation": assume that ν_τ is collinear with the visible part of the τ decay (either of τ_h, e, μ).

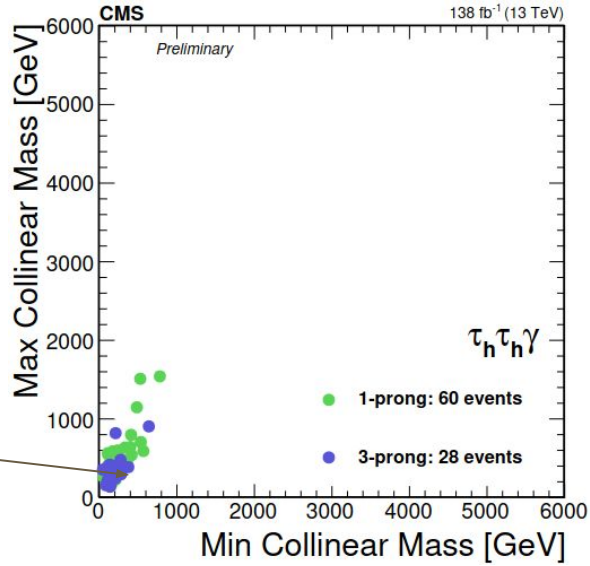
Split p_T^{miss} into components from each τ



Both τ-γ masses are built

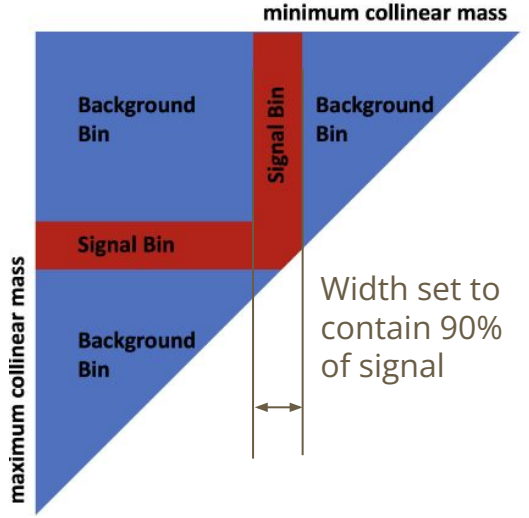
Signal populates a region in which either mass is compatible with m_{τ^*}.

Data is much more spread out.



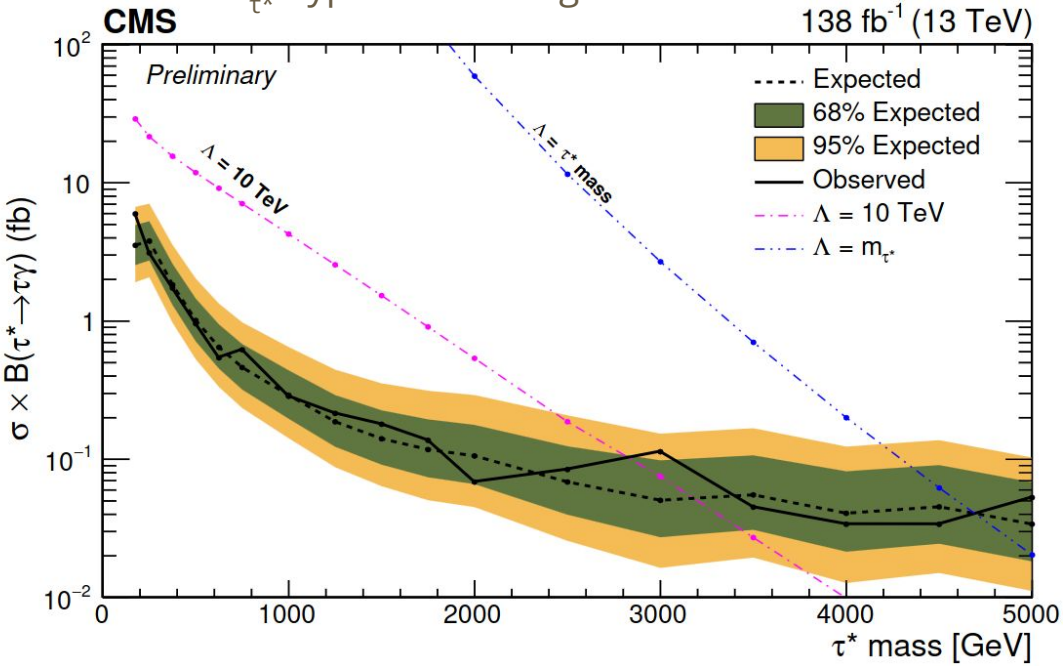
Excited τ - CMS-PAS-EXO-22-007

New!



The peculiarity of the L shape is used to define a parametric SR selection:

- Same data is used for all signal interpretations but binning depends on the m_{τ^*} hypothesis being tested.

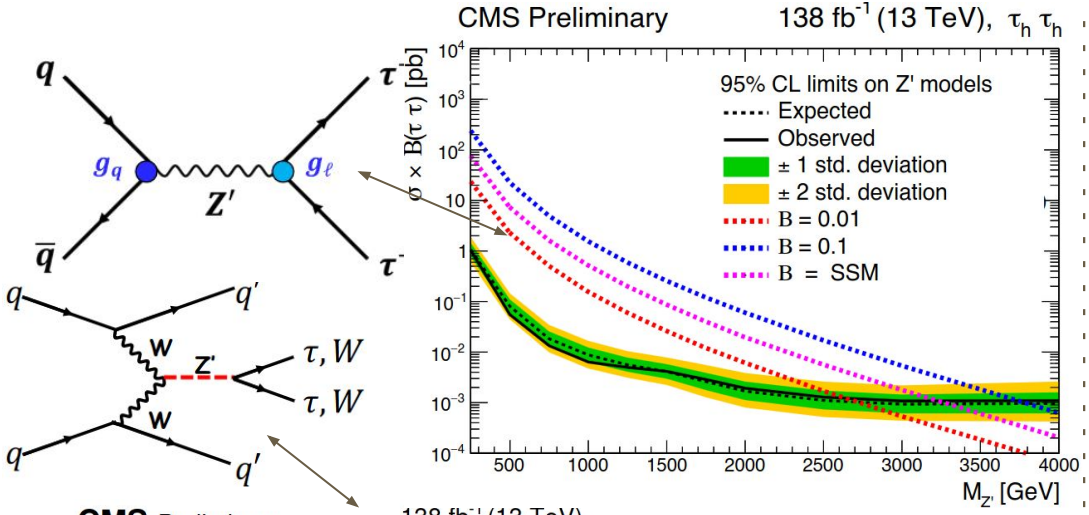


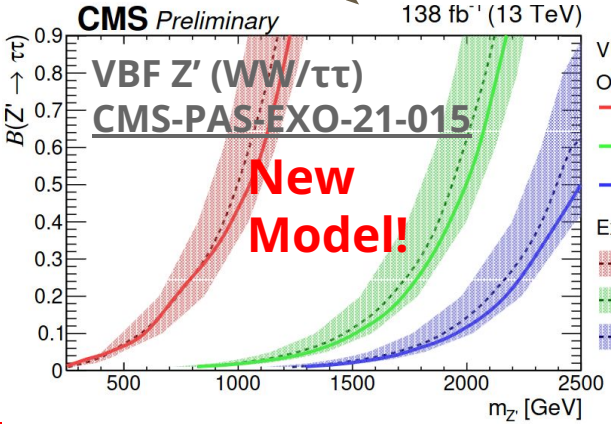
Setting upper limits on the mass on m_{τ^*} of 2.7/4.8 TeV depending on the assumptions on the CI energy scale.

Similar performance to the results obtained by ATLAS in JHEP 06 (2023) 199 (with a different strategy based on ττjj).

Other new prompt searches not in this talk

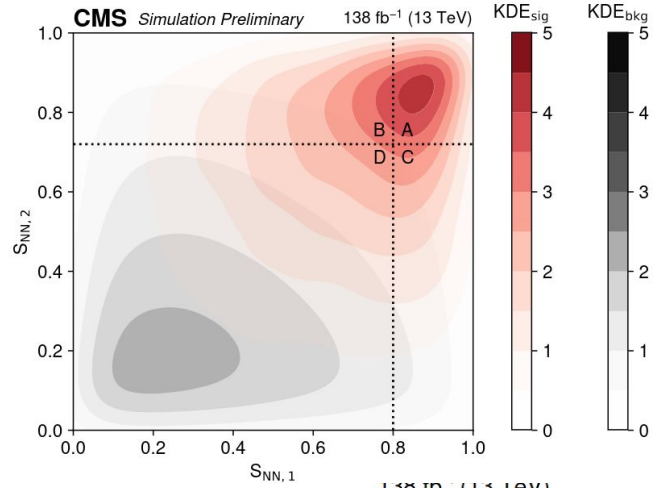
Not covered on this talk but just released:

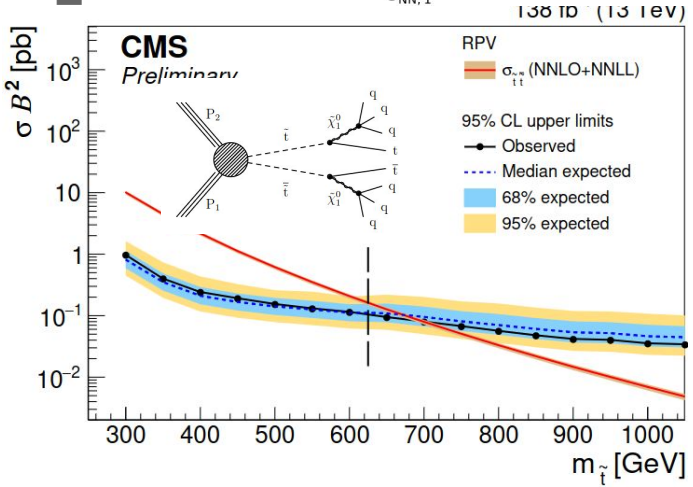




Check out Matia's talk!

RPV SUSY with ABCDISCO
CMS-PAS-SUS-23-001





See Weijie's talk!

Summary

Prompt searches are a pillar of the CMS search program with a very broad range of signatures being explored:

- We are in era where we need to push the boundaries to increase our sensitivity:
  - Developing new reconstruction and identification techniques…

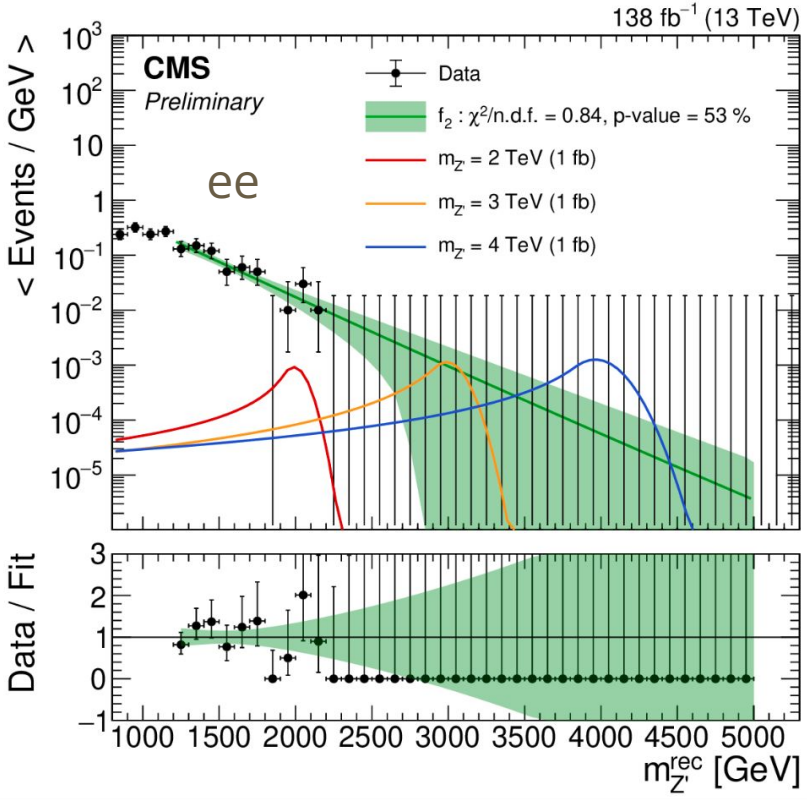
    … and new background estimation methods.

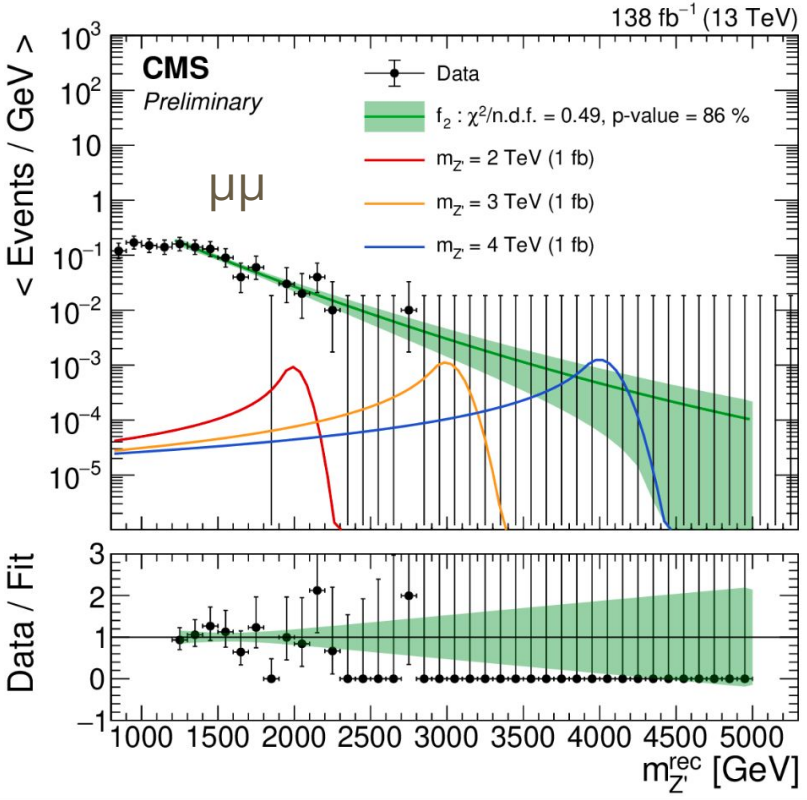
  - Allow us to probe BSM even further.

- Stay tuned for the coming new results!

Backup

X→ZH→(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

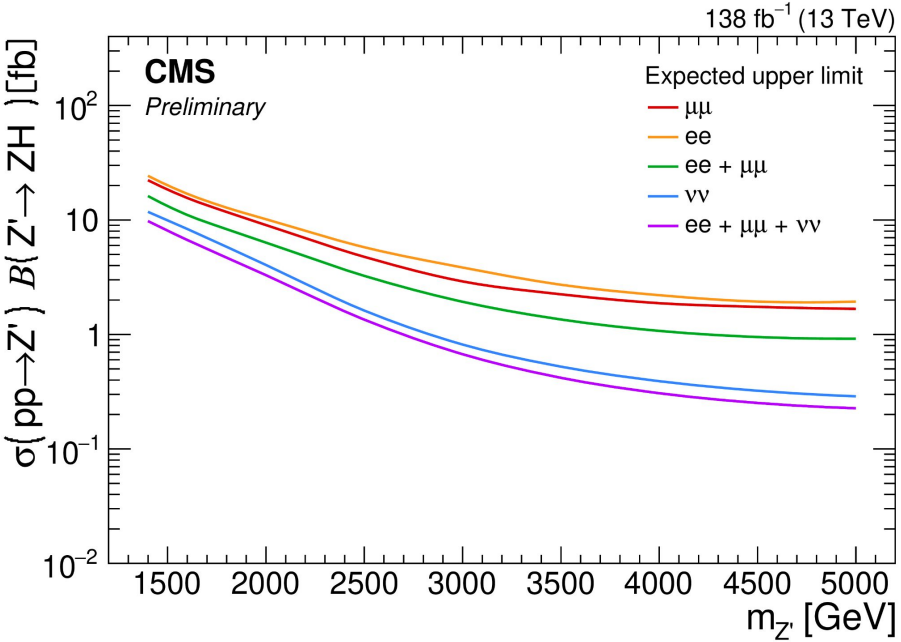




Signal region fits for charged lepton channels

X→ZH→(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

Expected upper limit per channel

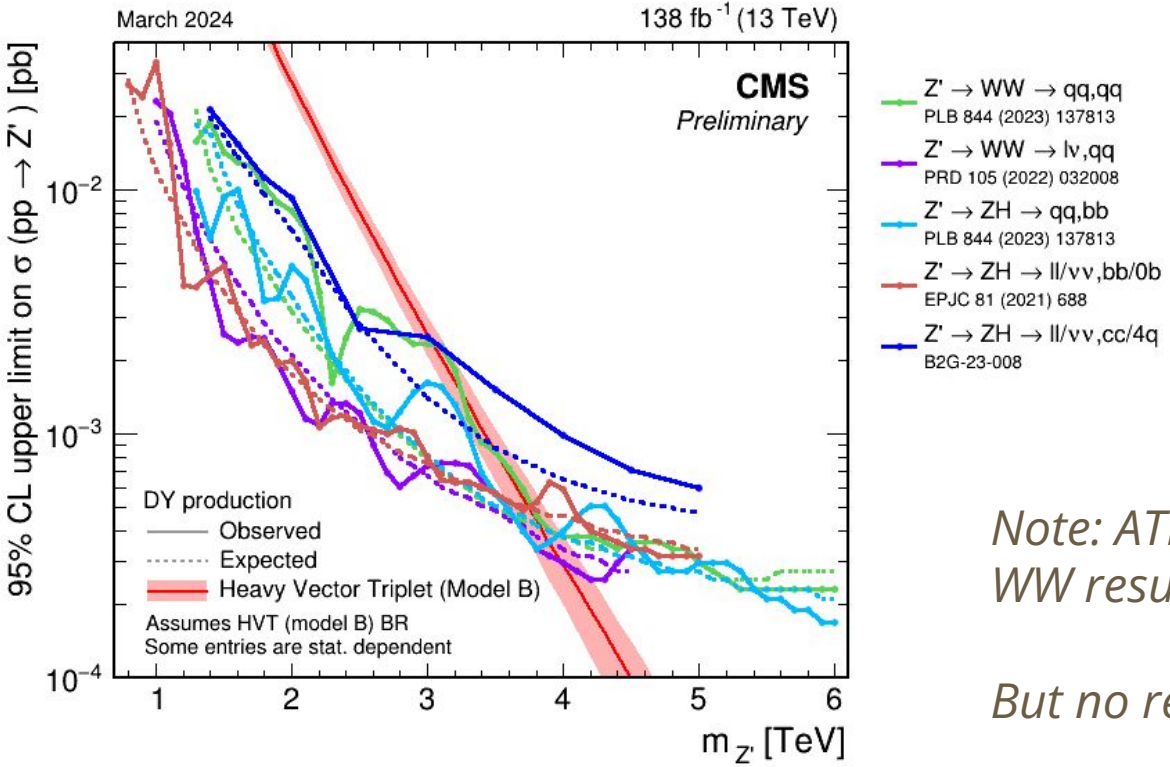


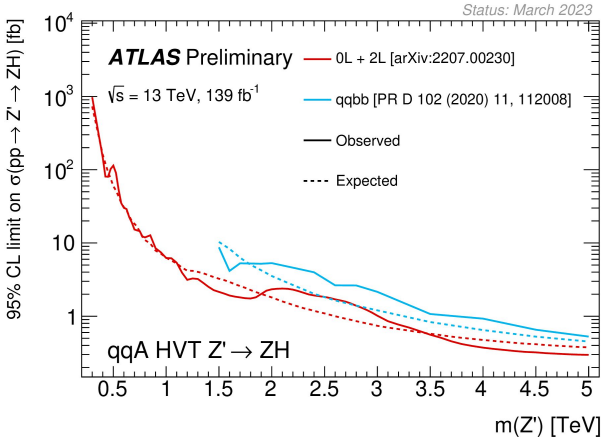
X→ZH→(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

Uncertainty breakdown in the analysis (effects on signal):

Source	uncertainty	Source	uncertainty
H jet identification	2.0–5.0%	Trigger	0.9–1.5%
b tagging veto	0.4–1.0%	Muon identification	0.1–0.3%
Jet energy scale and resolution	0.2–2.0%	Electron identification	5.2–5.9%
Pileup	0.3–1.8%	Lepton reconstruction	0.9–1.7%
Luminosity	1.6%	PDF	0.3–13.4%
Prefiring	0.3–0.8%	QCD scales	6.6–17.2%

X→ZH→(ee/μμ/νν)+J - CMS-PAS-B2G-23-008

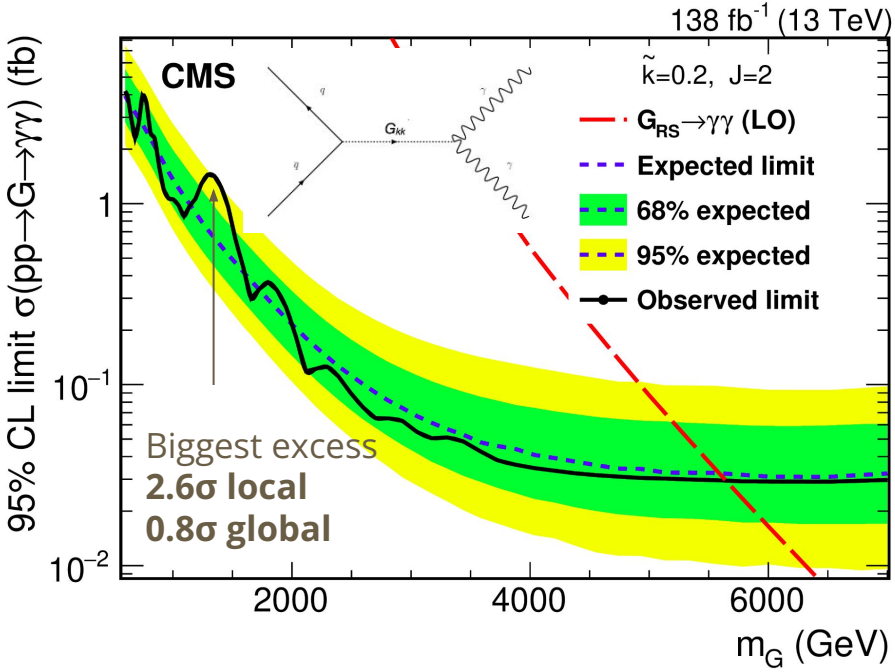




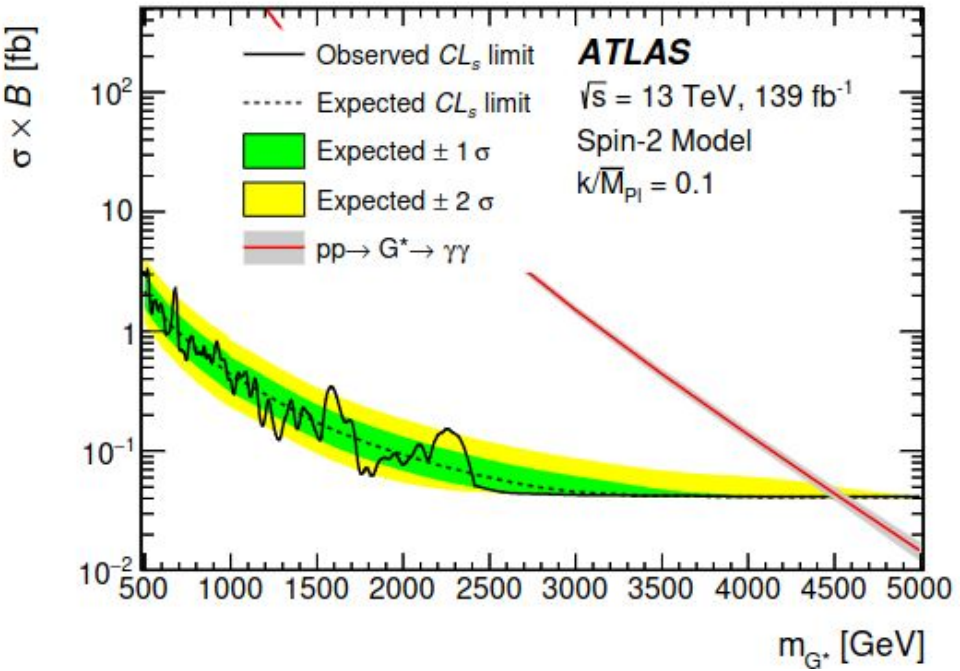
Note: ATLAS has the corresponding WW results but in a separate plot.

But no result in the H→cc/4q decay.

High mass γγ - arXiv:2405.09320 (sub. to JHEP)

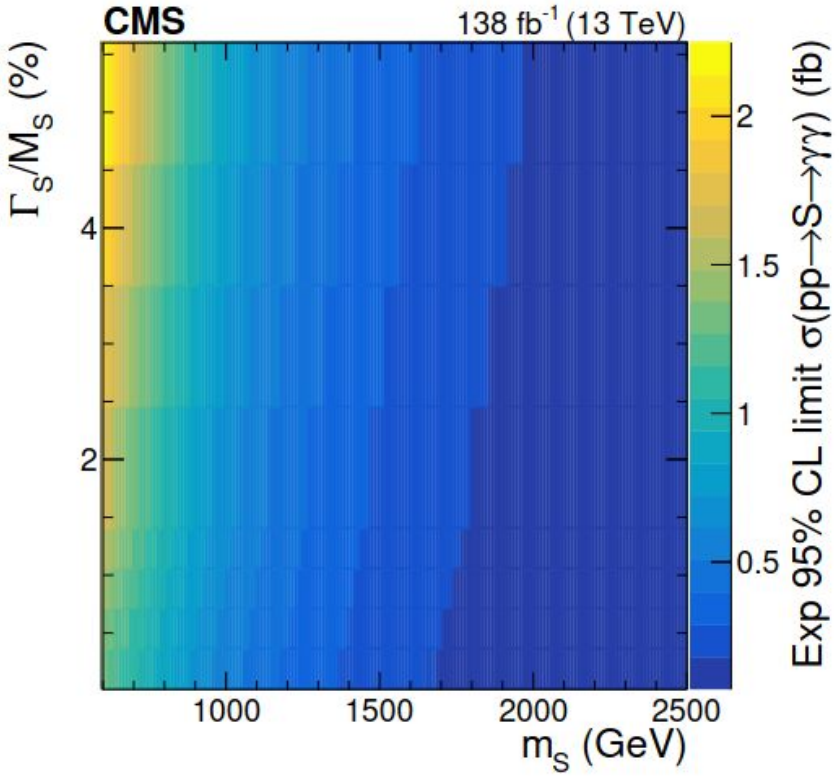


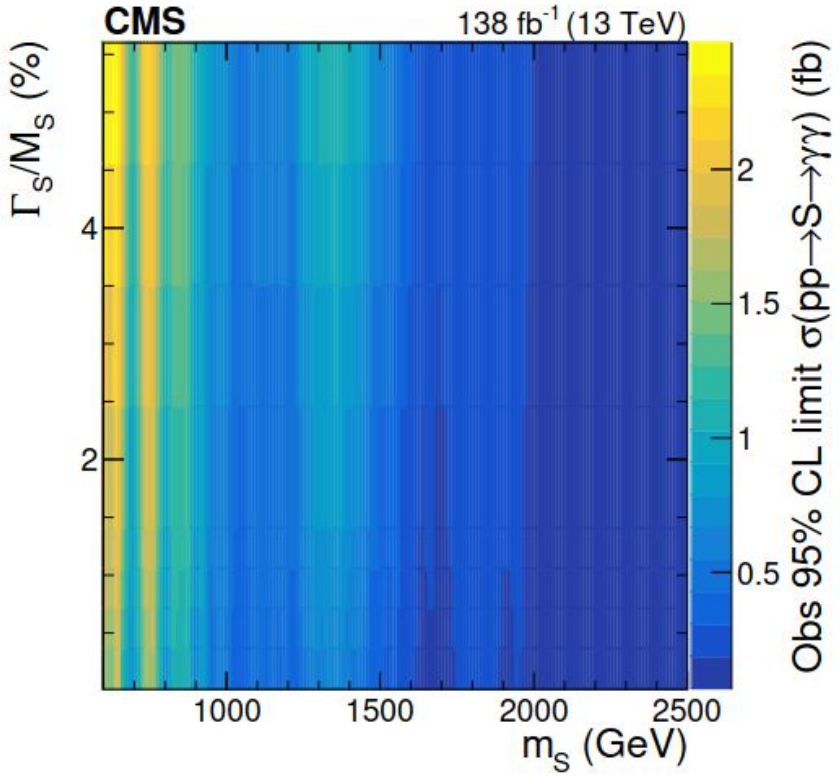
CMS result



ATLAS (PLB 822 (2021) 136651)

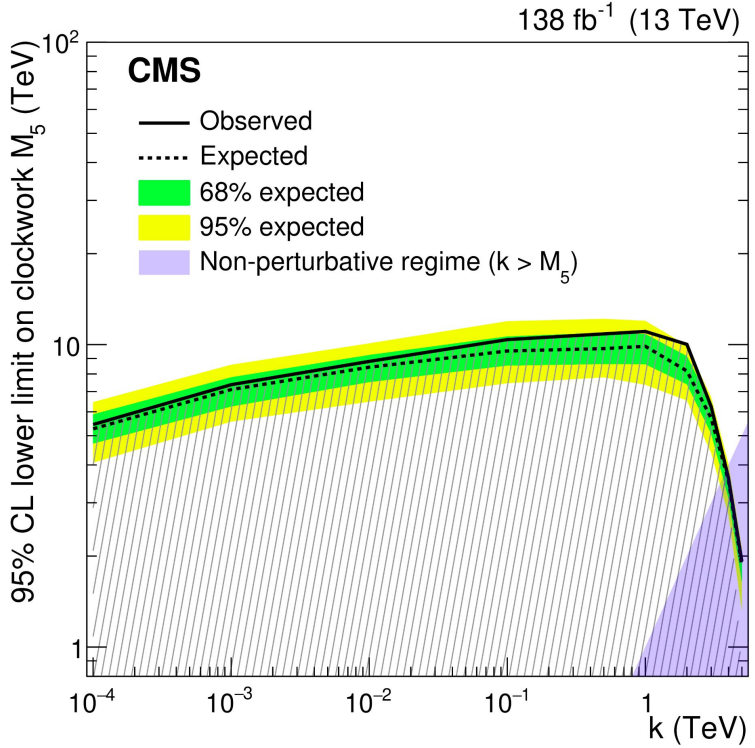
High mass γγ - arXiv:2405.09320 (sub. to JHEP)



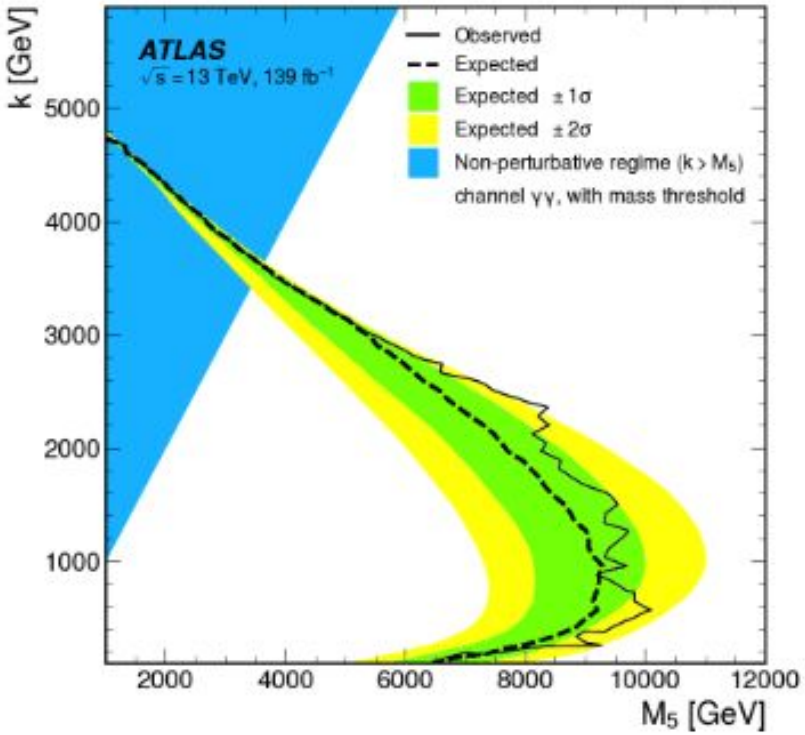


Resonant search, scalar model

High mass γγ - arXiv:2405.09320 (sub. to JHEP)

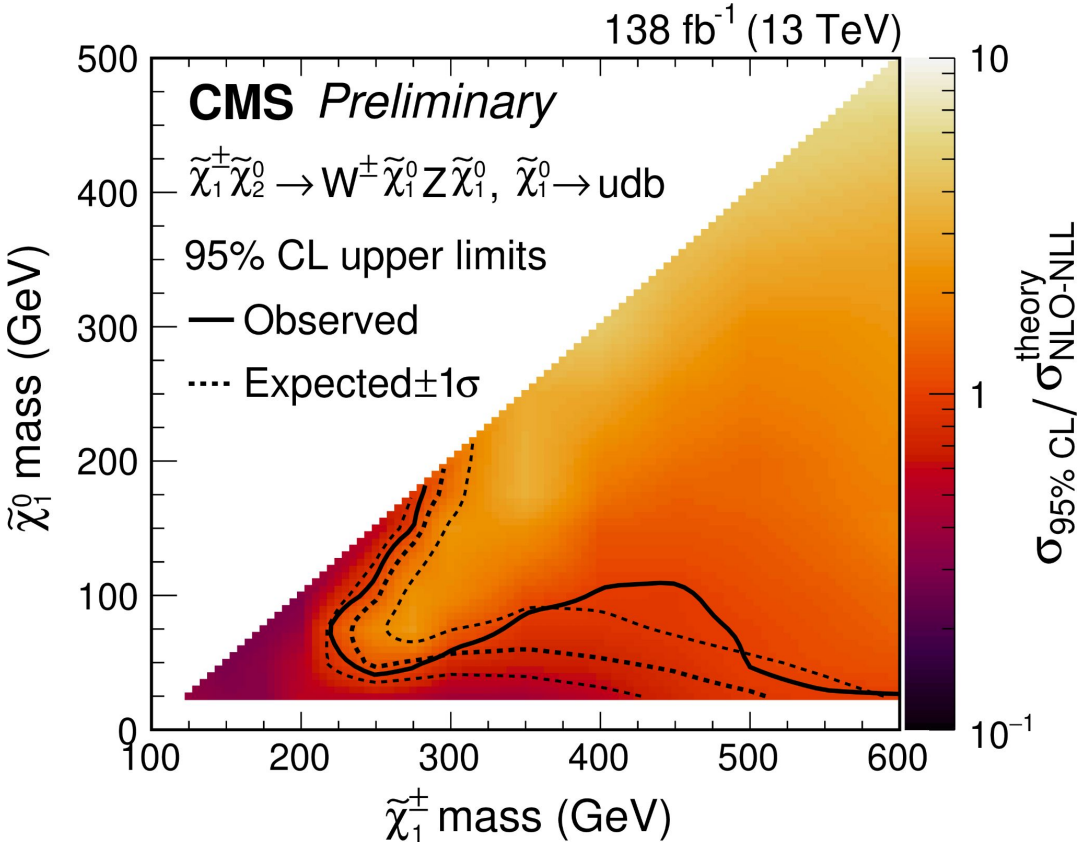


CMS result



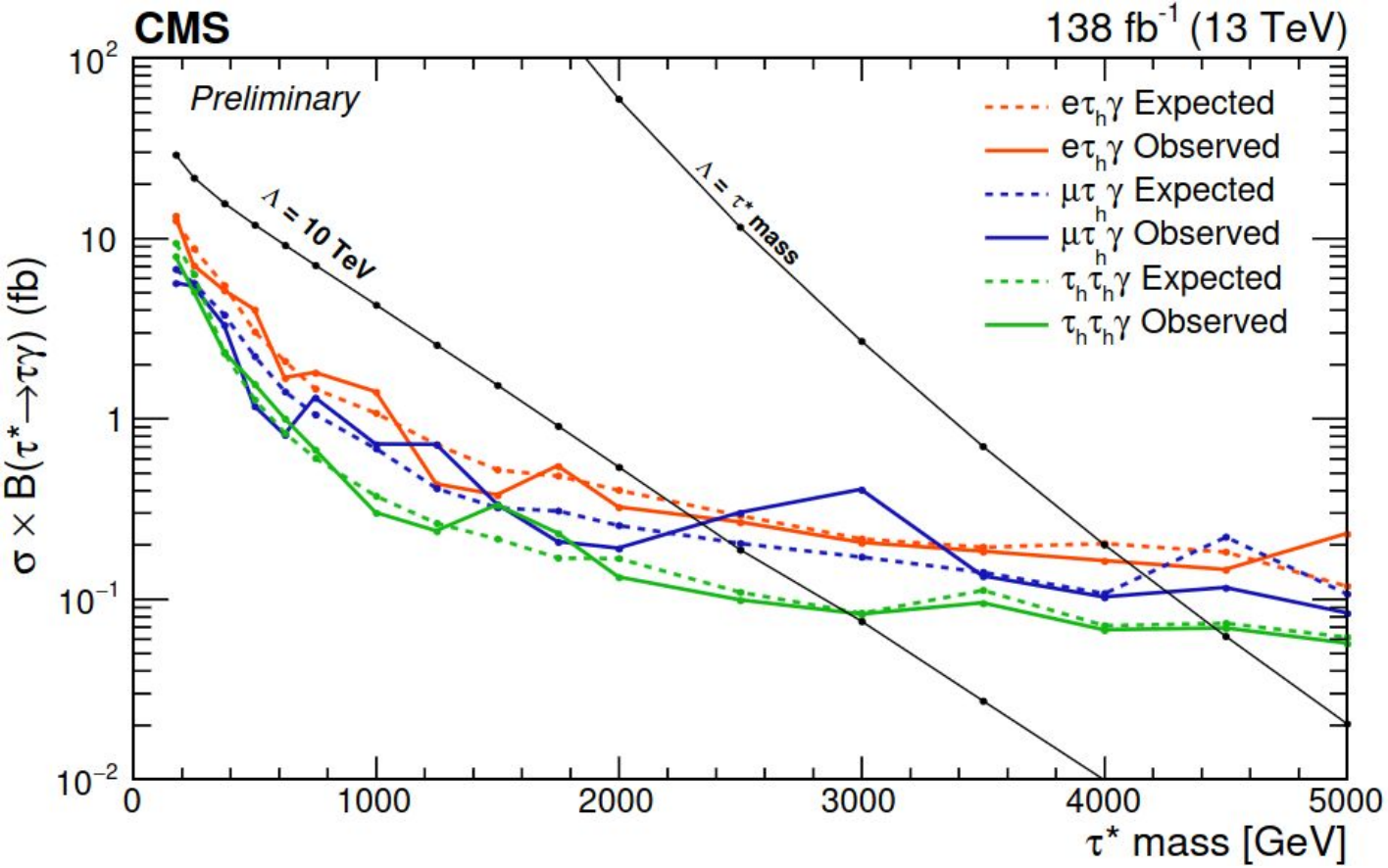
ATLAS (JHEP 10 (2023) 079)

RPV SUSY with jet scaling patterns - CMS-PAS-SUS-23-015



Excited τ - CMS-PAS-EXO-22-007

New!



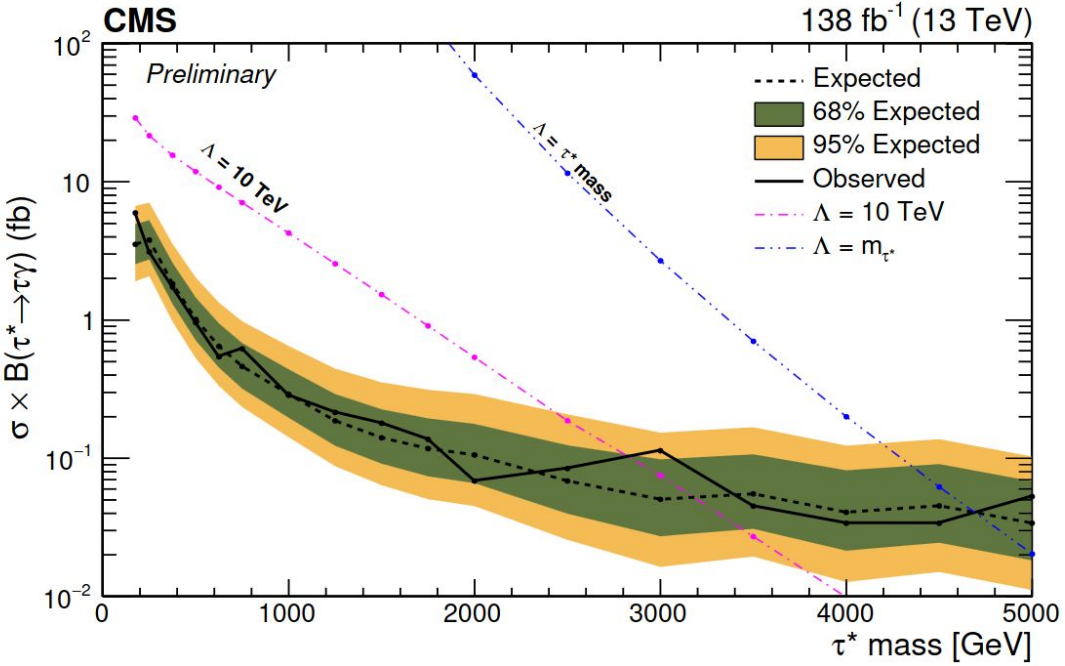
Excited τ - CMS-PAS-EXO-22-007

New!

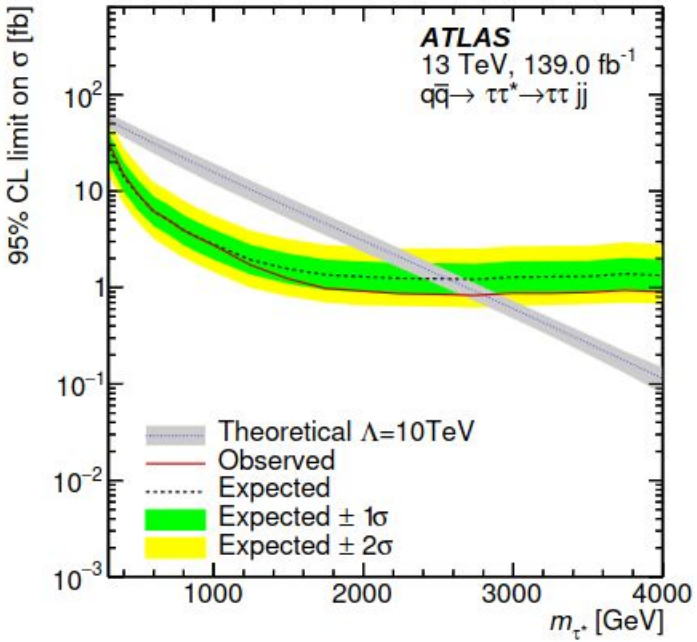
Source	$ee\gamma$	$\mu\mu\gamma$	$e\mu\gamma$	$e\tau_h\gamma$	$\mu\tau_h\gamma$	$\tau_h\tau_h\gamma$
Luminosity	2.0	2.1	2.1	2.1,2.1	2.0,2.1	2.1,2.1
DeepTau anti-jet 1-prong	-	-	-	3.5,9.4	3.7,8.7	9.0,19
DeepTau anti-jet 3-prong	-	-	-	1.4,1.5	1.2,1.1	2.8,2.6
$\tau_h\tau_h$ trigger 1-prong	-	-	-	-,-	-,-	8.2,11
$\tau_h\tau_h$ trigger 3-prong	-	-	-	-,-	-,-	2.2,1.2
τ_h energy scale	-	-	-	0.3,0.1	0.5,0.1	2.0,0.0
e id	0.9	-	0.6	0.8,1.3	-,-	-,-
γ id	5.5	5.7	4.6	2.1,14	2.1,13	2.8,14
$e\mu$ trigger	-	-	1.1	-,-	-,-	-,-
b-tagging	-	-	-	1.1,0.0	1.0,0.0	-,-
PDF sets	-	-	-	-,23	-,22	-,24

Excited τ - CMS-PAS-EXO-22-007

New!



CMS-PAS-EXO-22-007

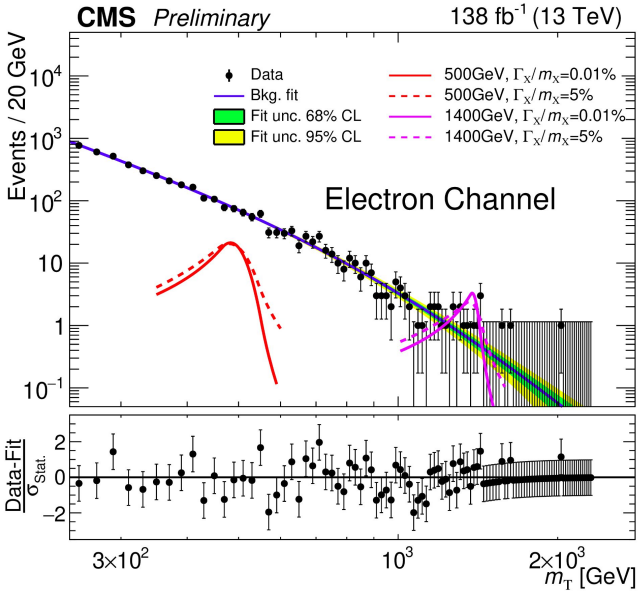


JHEP 06 (2023) 199

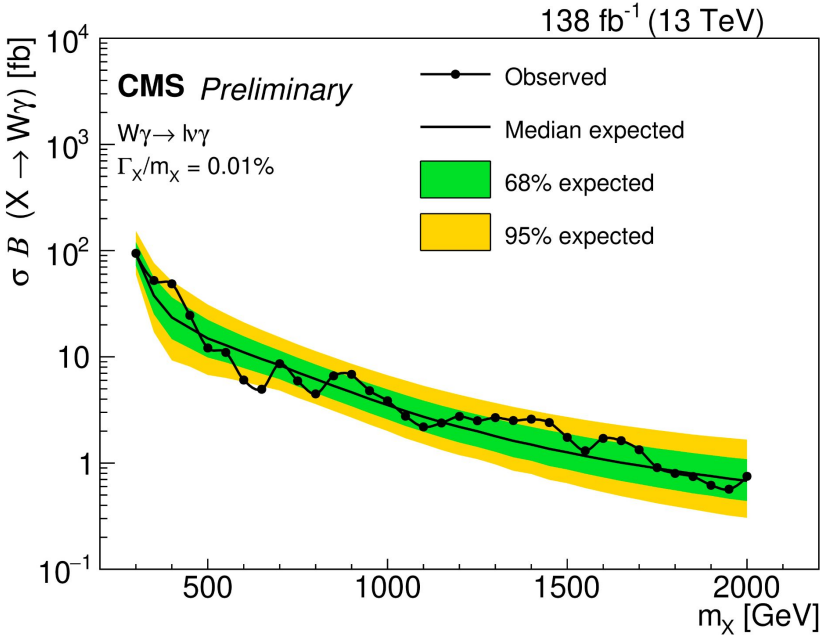
Other recent prompt analysis

Resonant W(→lν)+γ - CMS-PAS-EXO-21-017

Electron channel fit



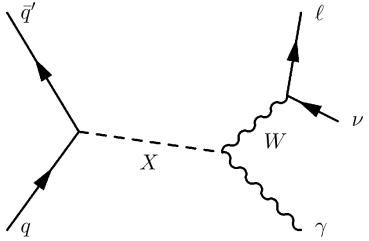
Results from purely leptonic fit

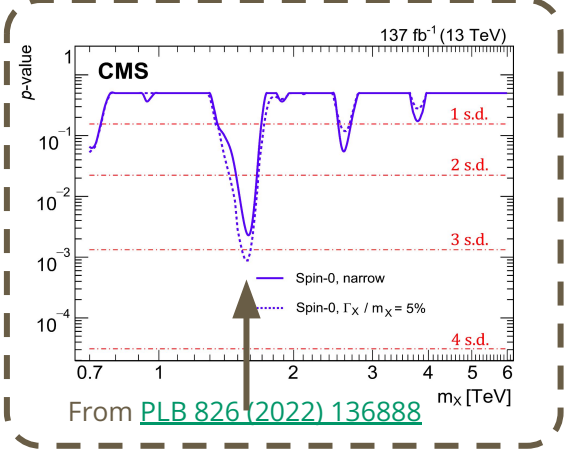


Resonant W(→lν)+γ - CMS-PAS-EXO-21-017

- The hadronic version of the analysis (PLB 826 (2022) 136888) had a (local) ~3σ excess.

- Leptonic analysis provides a cleaner final state to cross-check with the drawback of less statistical power.



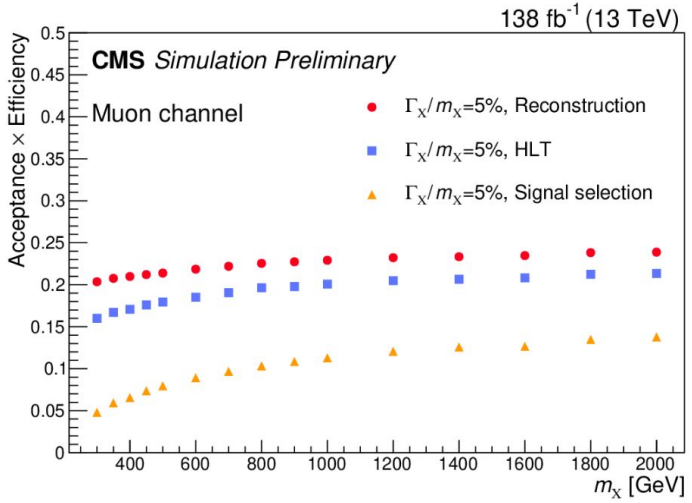


From PLB 826 (2022) 136888

- Very inclusive selection leading to broad -and flat at high m_X- signal efficiency.

Key anti-bkg. criteria against tt and Wγ

Selections	Electron channel	Muon channel
Lepton p_T	> 35 GeV	> 30 GeV
$m_{\ell\gamma}$ mass	$\lvert m_{e\gamma} - 91.0\rvert > 20$ GeV	—
Lepton ID	Tight	
Photon p_T	$0.4m_T < p_T(\gamma) < 0.55m_T$	
p_T^{miss}	$p_T^{miss} > 40$ GeV	
Photon η	$\lvert\eta\rvert < 1.44$	
Photon ID	Medium	
b jet veto	0 medium-tagged b jets	



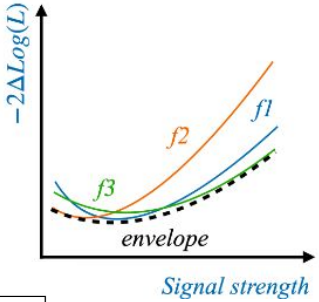
Resonant W(→lν)+γ - CMS-PAS-EXO-21-017

- Search strategy uses the "bump hunt" technique over the m_T(l+γ) variable in both muon and electron channels: background modelling uses the "envelope" method.

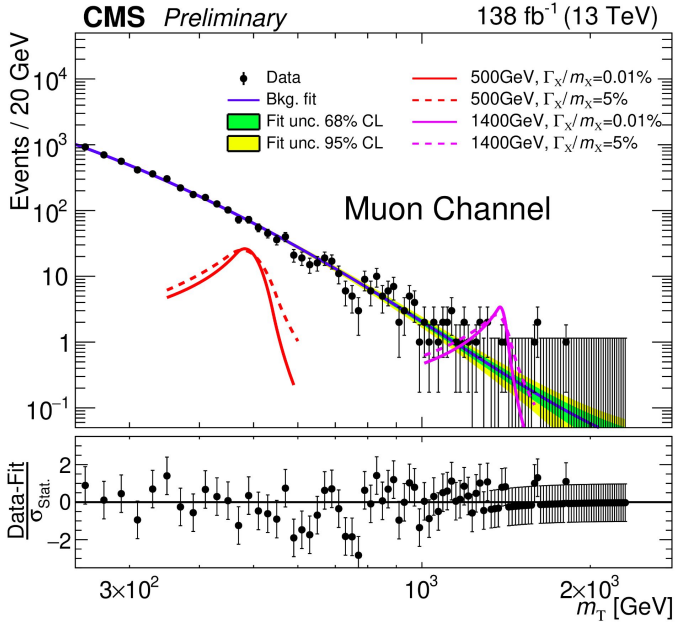
$$p_0 \times x^{\sum_{i=1}^{N} p_i \times \log^{i-1}(x)}$$

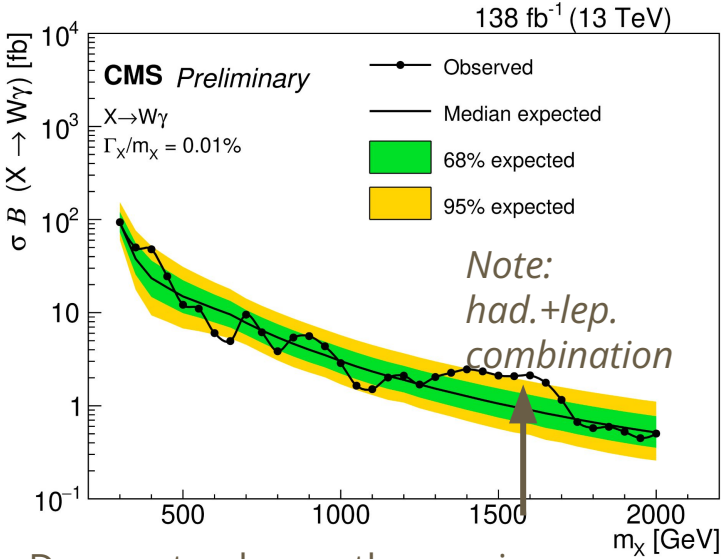
$$p_0 \times \frac{(1-x)^{p_1}}{x^{\sum_{i=2}^{N} p_i \times \log^{i-2}(x)}}$$

$$p_0 \times e^{p_1 x} x^{\sum_{i=2}^{N} p_i \times \log^{i-2}(x)}$$



- Results improve hadronic analysis up to a 50%.

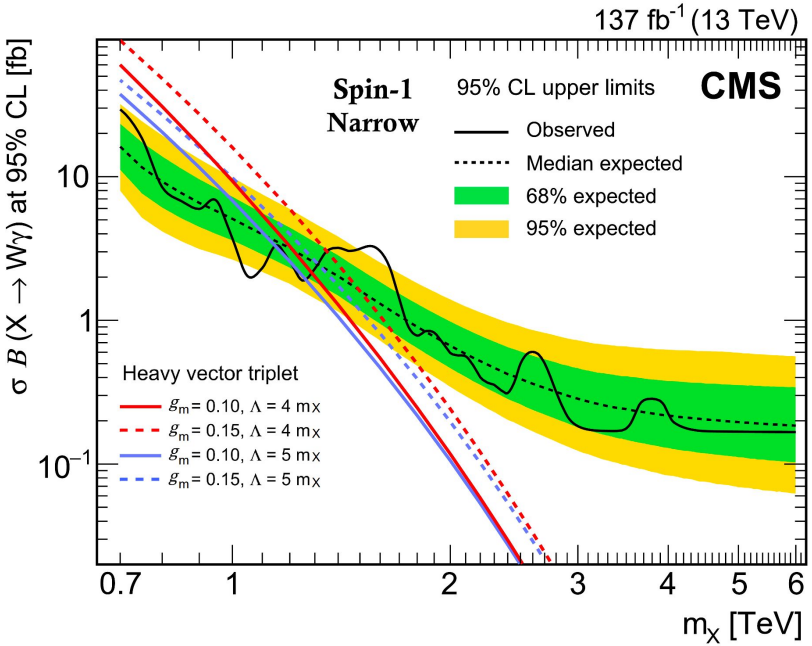




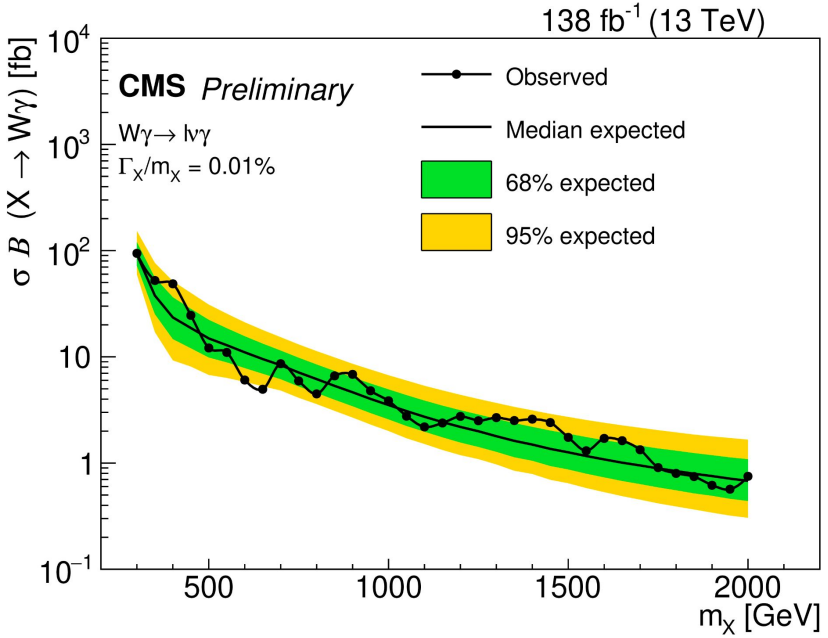
Does not enhance the previous excess.
Combined local significance drops to 2σ.
ATLAS (JHEP07(2023)125, had.) sees no effect either.

Resonant W(→lν)+γ - CMS-PAS-EXO-21-017

CMS, had. (PLB 826 (2022) 136888)



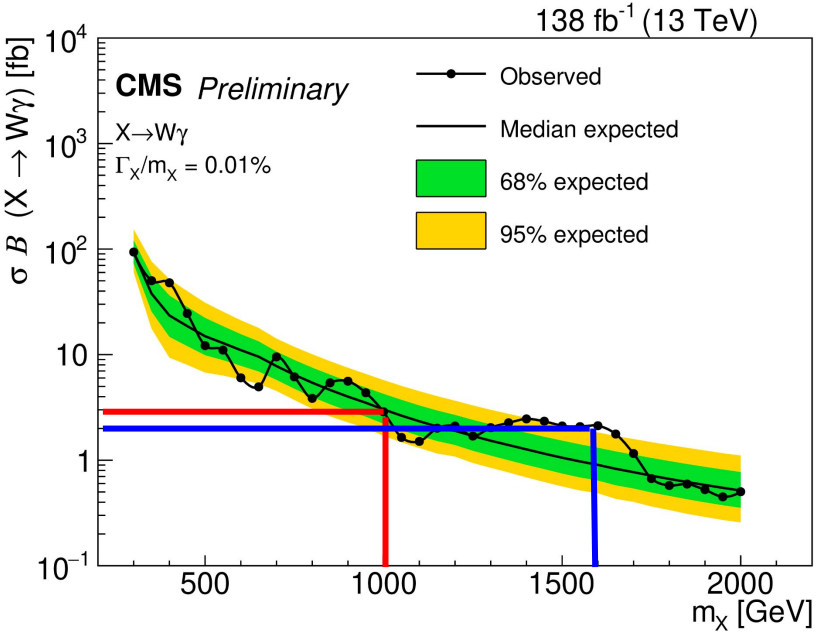
CMS, lep.



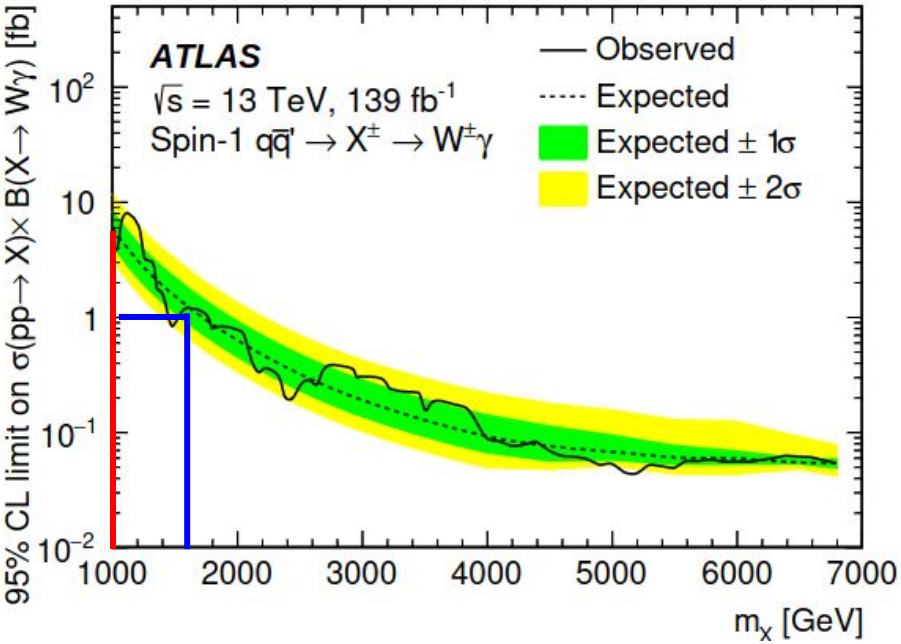
Note that the leptonic search provides the most improvement at lower masses, at higher masses (> 2 TeV) starts to get closer in performance.

Resonant W(→lν)+γ - CMS-PAS-EXO-21-017

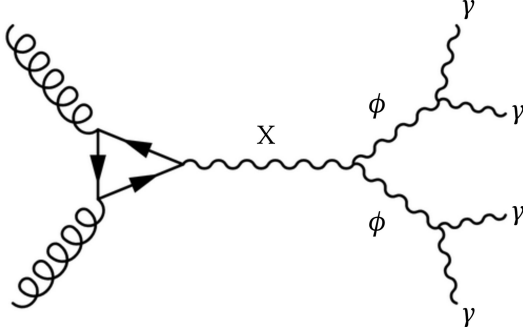
CMS, had. + lep. combined



ATLAS, **only** had. JHEP07(2023)125



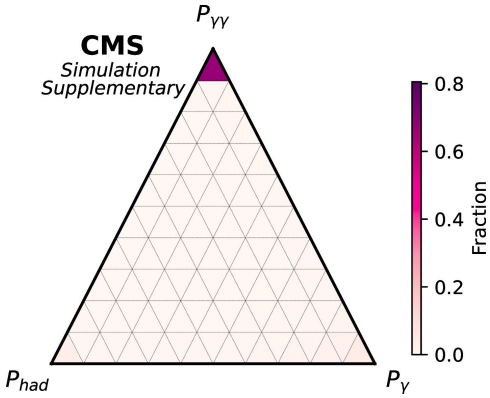
Merged photons - arXiv:2405.00834 (sub. to PRL)

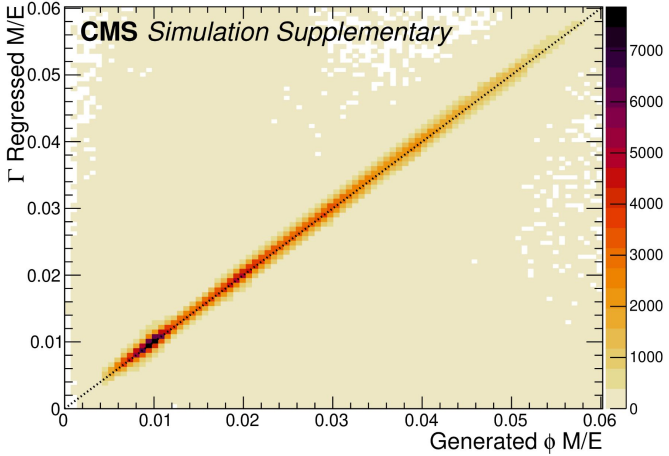


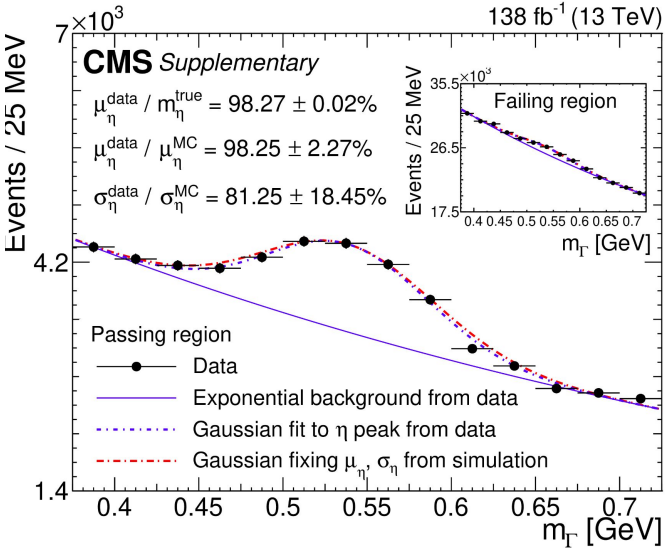
In a chain of two resonances (X/ϕ) such that $m_X >> m_\phi$ can lead to pairs of very boosted ϕ which in turn produce photon pairs to merge:

- Designed a merged photon reconstruction + identification algorithm based on imaging techniques over ECAL hits.
- Includes both a classifier (γγ/γ/jet) and a mass regressor:

Validated in η meson decays





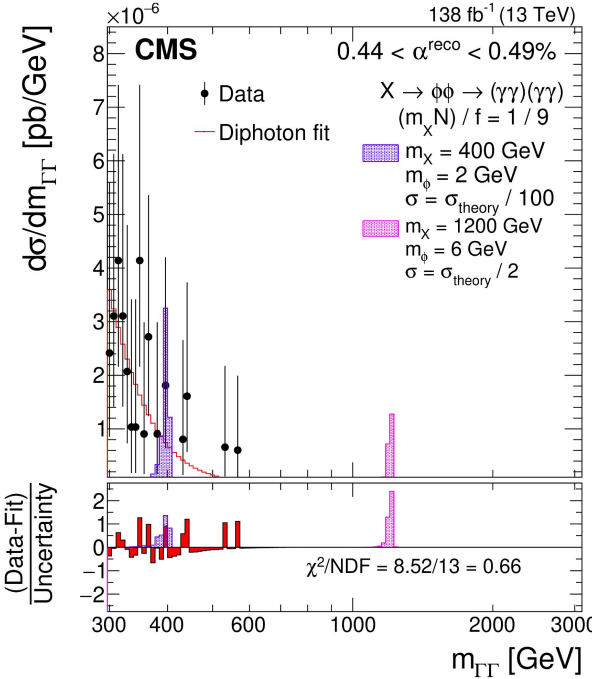


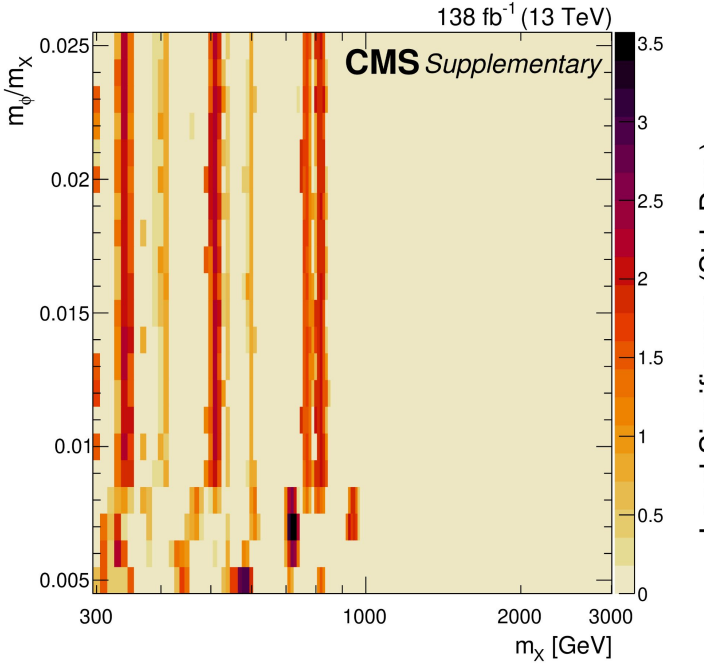
Performance plots for true merged photons

Merged photons - arXiv:2405.00834 (sub. to PRL)

Search is based on a bump hunt over the $m_{\gamma\gamma}$ distribution.

- Discrete profiling is used to model the SM background.
- The fit is performed in multiple slices of $\alpha=m_{\gamma}/m_{\gamma\gamma}$:





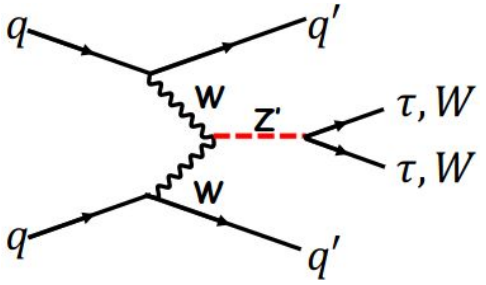
Largest excess for m_X~720 GeV m_ϕ~5 GeV

Corresponding to 3.57σ (1.07σ) local (global) significance

First search of its kind! No ATLAS equivalent yet.

VBF Z' (WW/ττ) - CMS-PAS-EXO-21-015

New!



Search in the eμ, $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states, with emphasis on 3rd generation final states as preferred by the B anomalies:

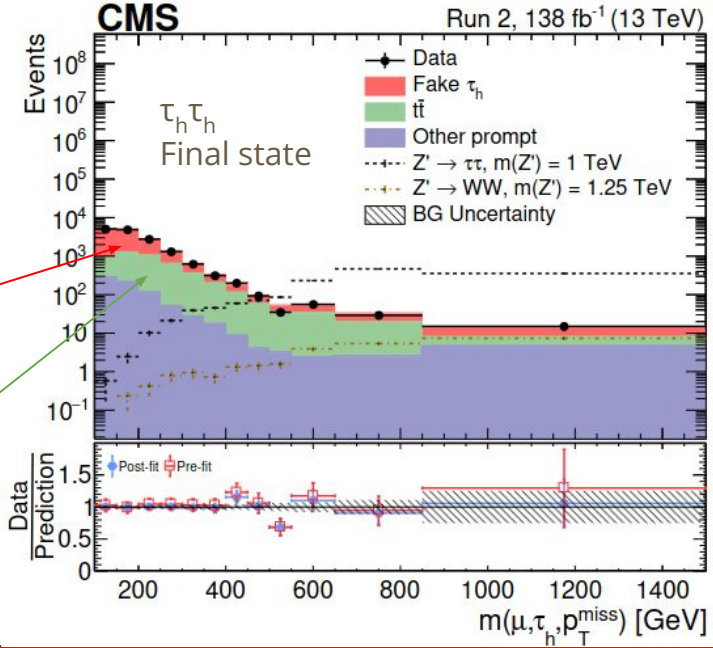
- Leverage the VBF topology to tighten the selection by requiring a pair of well separated ($|\Delta\eta_{jj}| > 4.2$) jets with high mass ($m_{jj} > 500$ GeV).
- Boost to the Z' => p_T^{miss} from τ decay is collinear with Z' => Reco $m_{Z'}$ closer to real one:

$$m_{Z'}^{reco} = \sqrt{(E_{\ell 1} + E_{\ell 2} + p_T^{miss})^2 + (\vec{p}_{\ell 1} + \vec{p}_{\ell 2} + \vec{p}_T^{miss})^2}$$

General background estimation follows similar strategy for all regions:

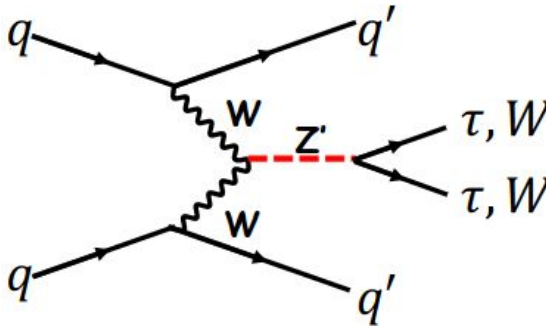
- Non prompt leptons estimated using the loose-to-tight method from non-isolated lepton sidebands.

- Leading prompt backgrounds shape estimated from MC and normalized from data.



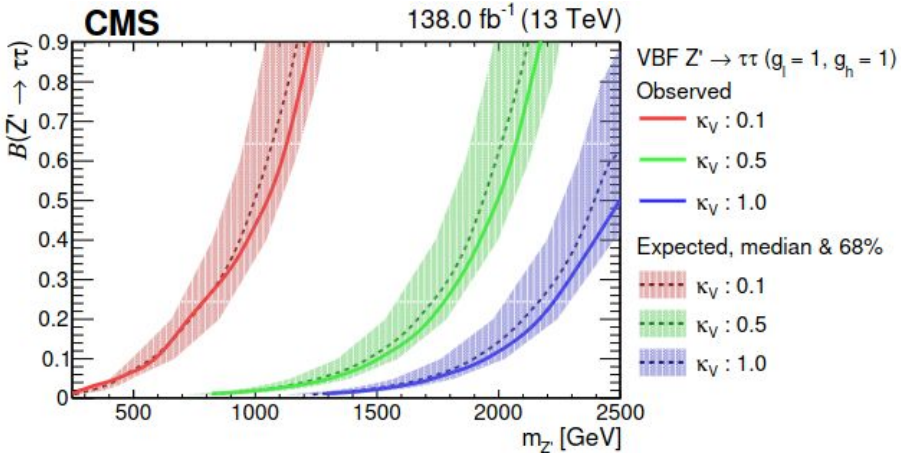
VBF Z' (WW/ττ) - CMS-PAS-EXO-21-015

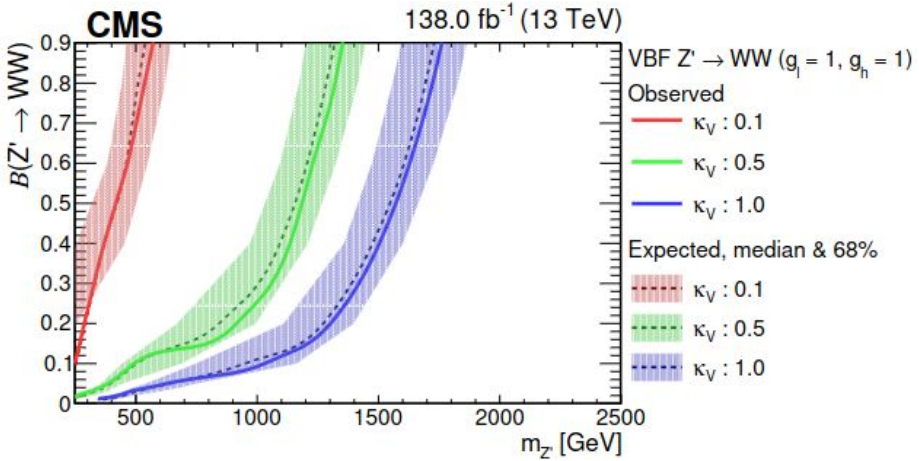
New!



Interpretation relies on the Sequential Standard Model and four independent parameters:

- Independent couplings of the Z' to 1st+2nd (g_l) and 3rd (g_h) generations.
  - Several hypothesis changing the relative sensitivity of each channel.
- Coupling to W (k_V) and Z' mass ($m_{Z'}$) can be varied independently.





First interpretations of VBF produced Z' at the LHC
Already provident limits in masses ranging from 300 GeV to 3 TeV

Prompt searches in other talks

Many more talks related to prompt searches in CMS, be sure to check them!

- Recent results on dark sectors in CMS
- HNLs in CMS
- Physics of dark sectors in CMS
- Resonant Searches for Dark Matter Mediators with CMS
- Leptoquark Searches with 3rd Generation Final States in CMS
- Leptoquark Searches with Electrons and Muons in the Final State in CMS
- Searches for New Massive Scalars in CMS
- Exotic Higgs decays with CMS
- Searches for BSM in top final states in CMS
- Exotic tops: anomalous interactions, non-standard decays in CMS
- Searches for VLQs in CMS
- Searches for VLLs in CMS