Searches for New Physics with multiboson final states

Rafael Coelho Lopes de Sá (Fermilab)
For the CMS collaboration

MBI 2016: Multiboson Interactions
UW Madison

Introduction

- CMS has performed many analysis searching for new physics with dibosons.
- There is no time to discuss them all here in details. I will give an overview of the results related to searches for which an EFT approach would not work (since we've explored EFT-related measurements so much already in this meeting).
- I will conceptually separate the measurements in categories:
  - Resonant X→HH searches
  - Resonant X→VV searches (V=W/Z)
  - Non-resonant ("SUSY-like") VV+E_T^{miss} and VH+E_T^{miss} searches
  - X→γγ and X→Zγ searches (including m_X ~ 750 GeV)

- These searches are performed in CMS by many different groups (HIG, EXO, B2G, SUS).

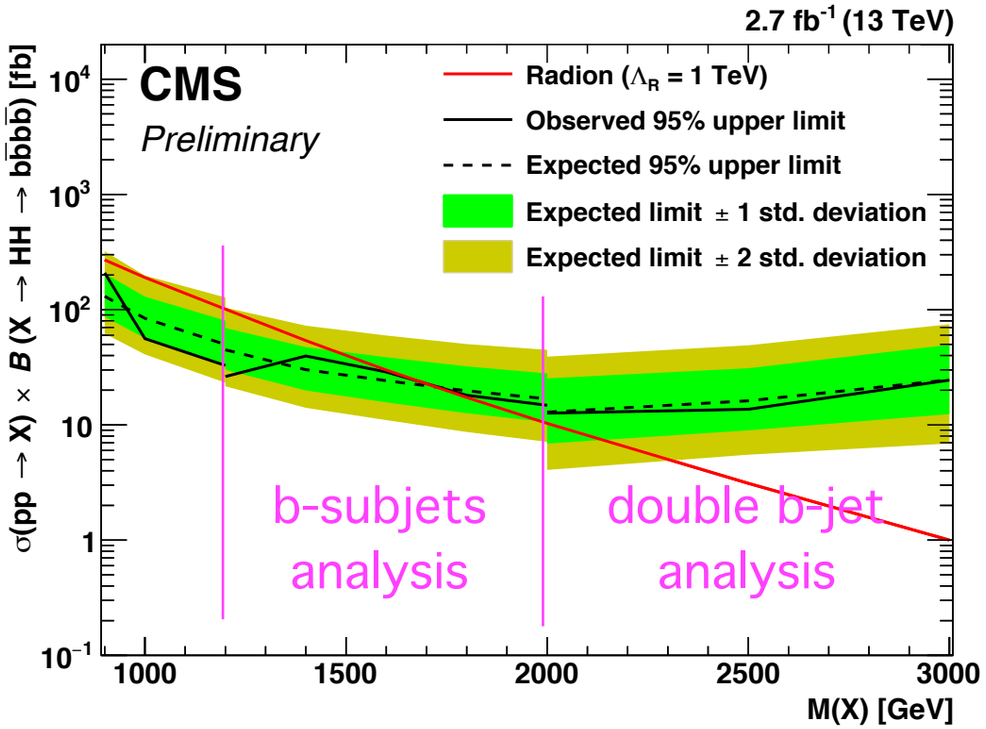
✓ Different techniques that can be used for different kinematical regimes (resolved jets, merged jets, large E_T^{miss}, ...)

✗ Different ways to interpret the results (graviton models, SUSY simplified models, heavy Higgs models, ...). I will try to be as generic as possible in this presentation.

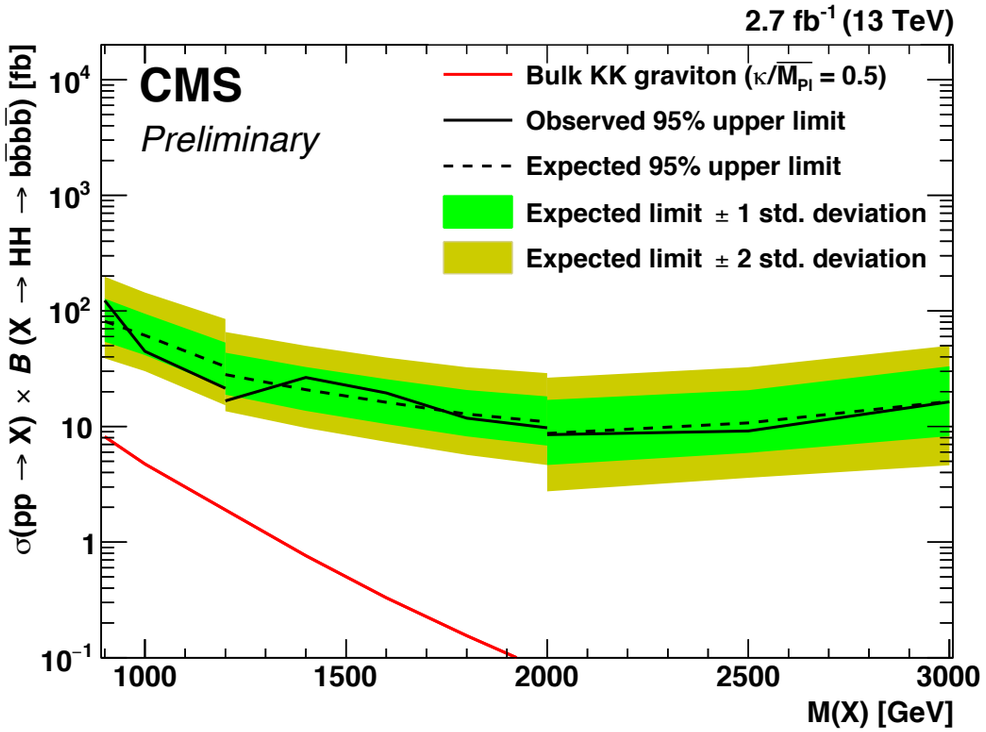
Resonant HH search

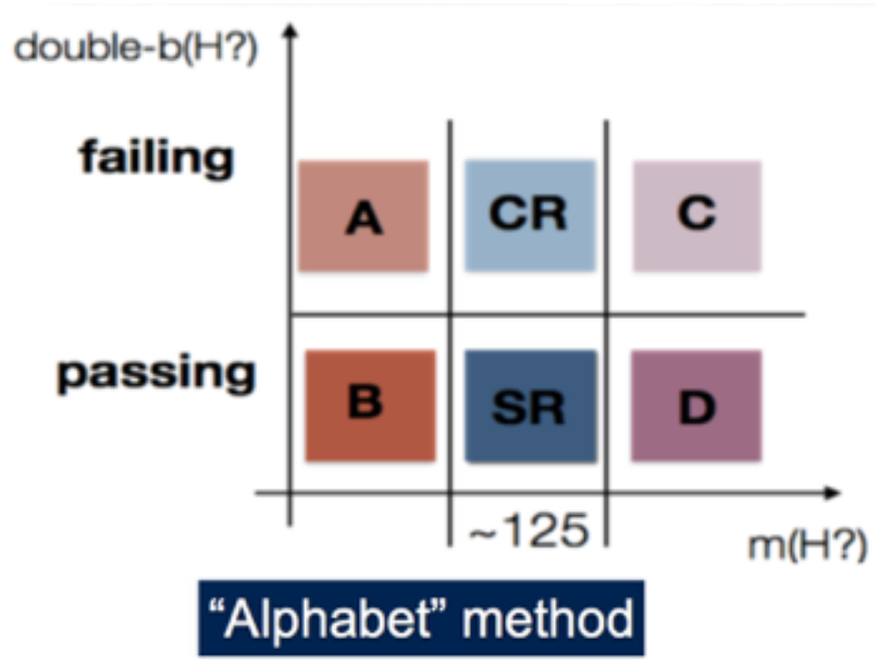
- B2G-16-008: X → H(→J[bb])H(→J[bb])

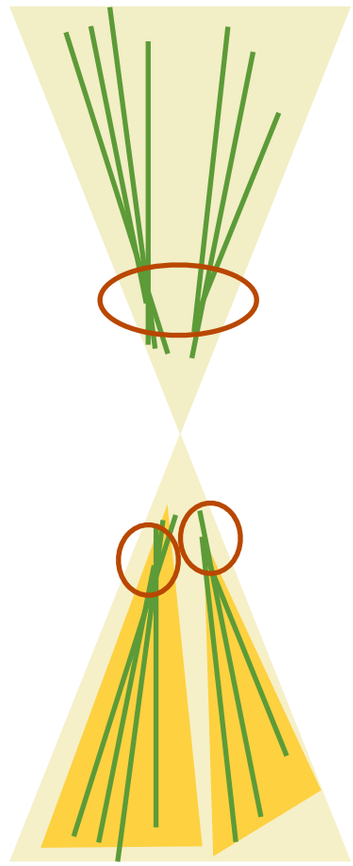
spin 0 hypothesis



spin 2 hypothesis







Two ID strategies for large-R jets with substructure

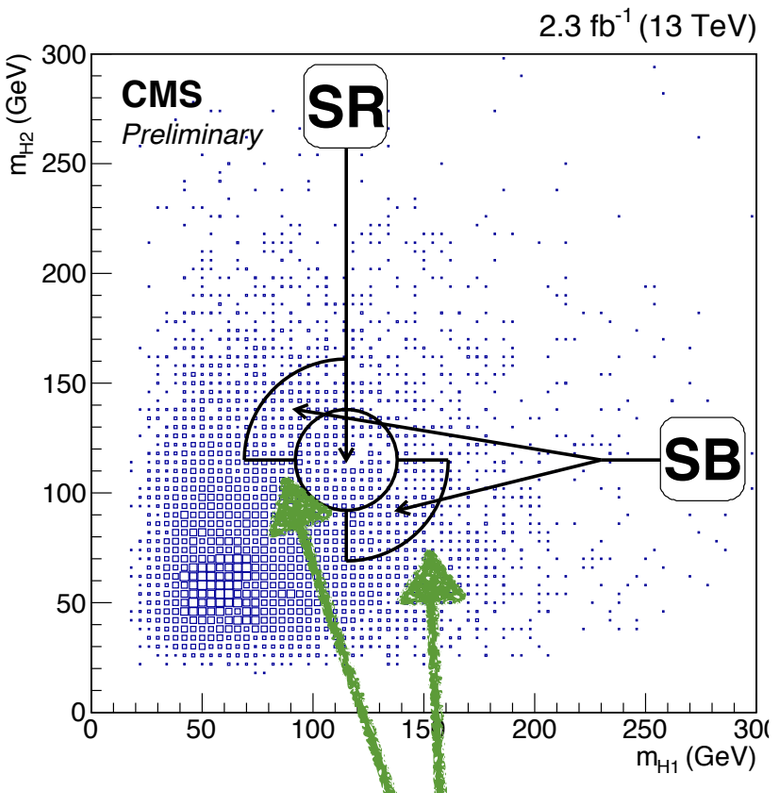
1. Identify subjets and b-tag each of the 4 subjets individually (analysis requires 3 or 4 b-subjets)
2. Dedicated double b-tagger

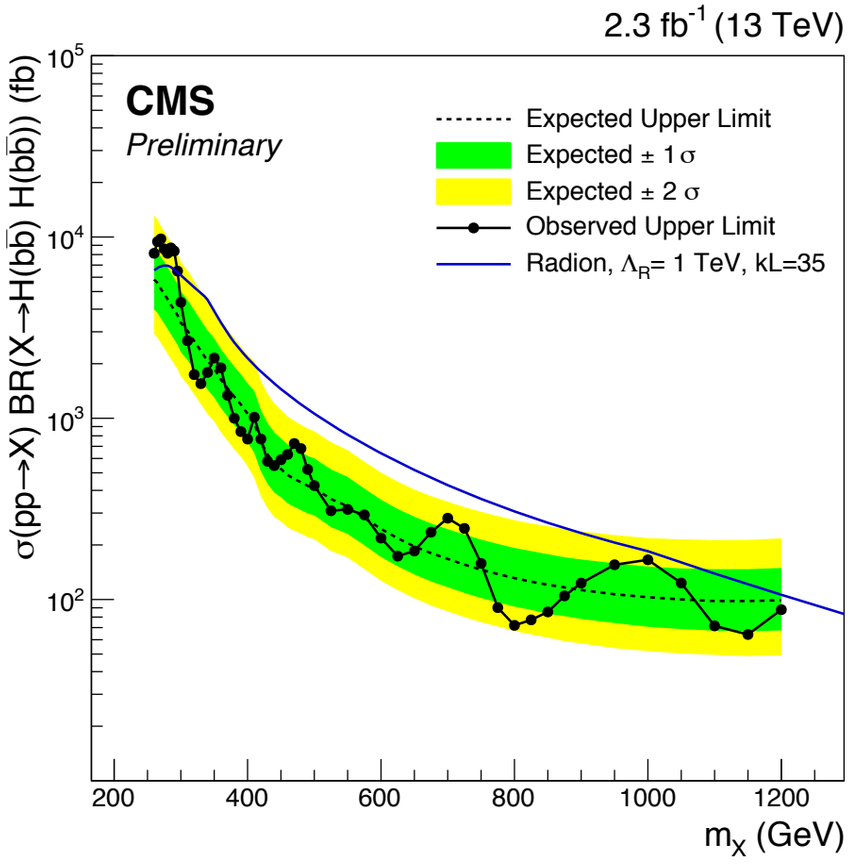
Resonant HH search

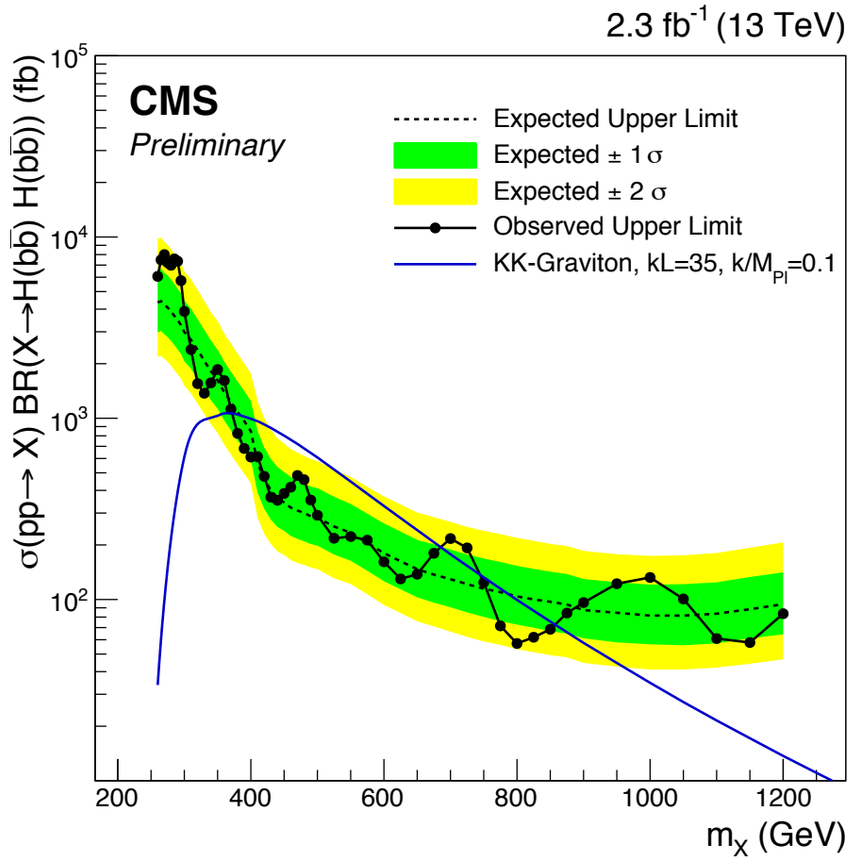
- HIG-16-002: X → H(→bb)H(→bb)
- Requires 4 b-tagged jets with mass consistent with SM H boson. Complementary to the high-mass merged analysis, covering low values of m_X.

spin 0 hypothesis

spin 2 hypothesis





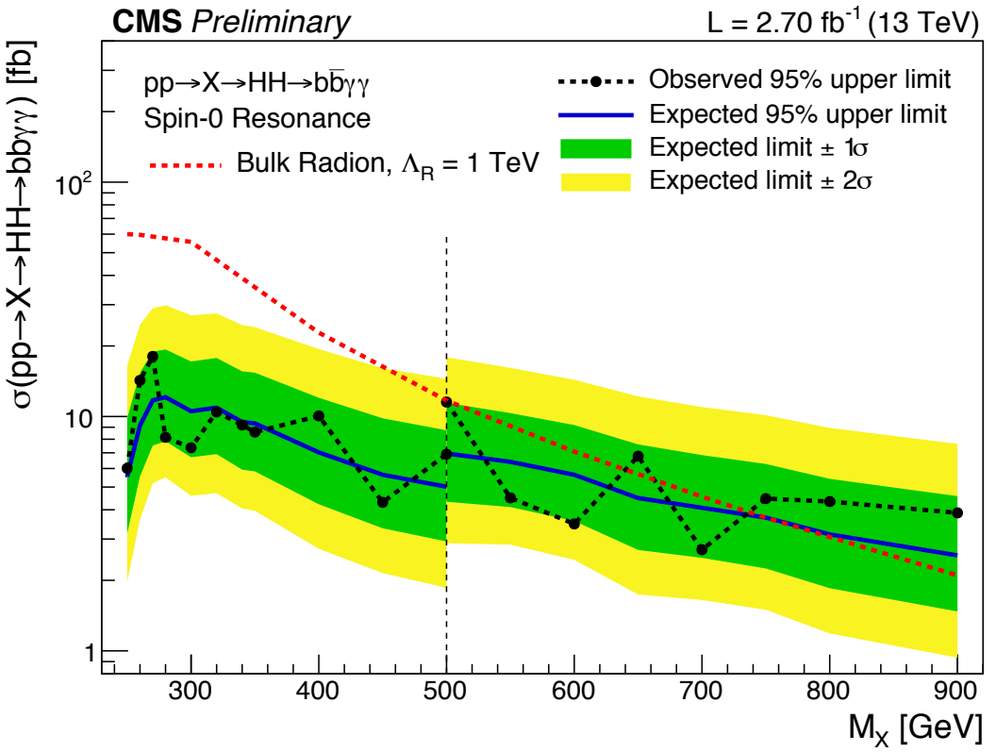


Asymmetric SB to properly describe trigger turn-on

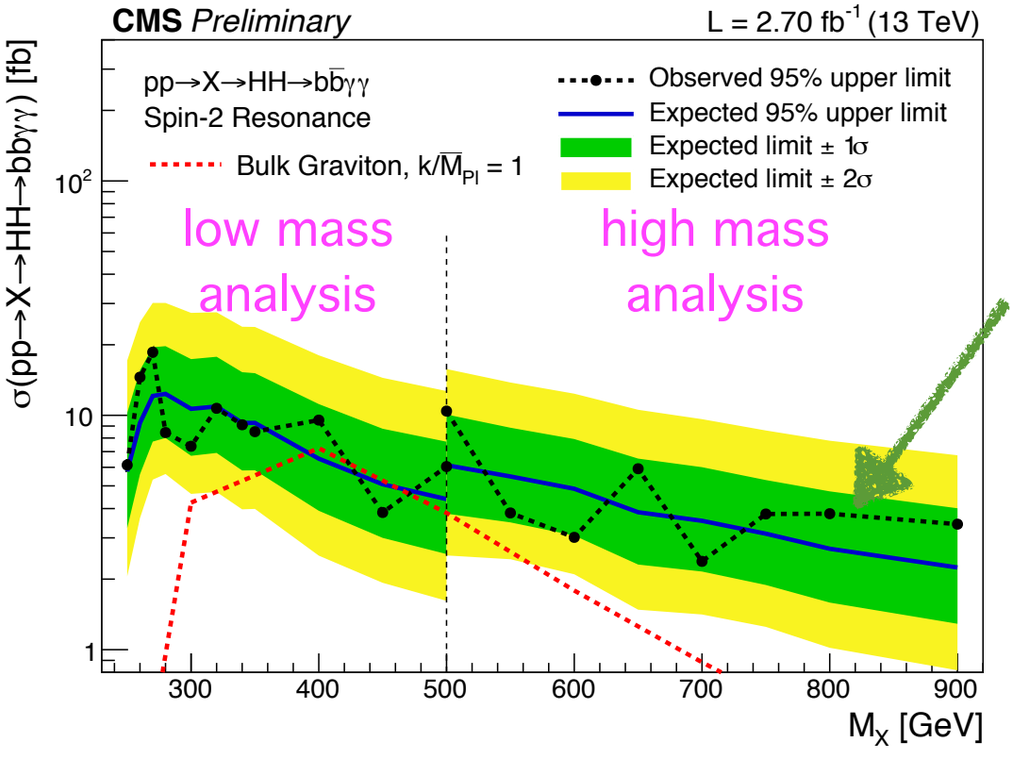
Resonant HH search

- HIG-16-032: X → H(→γγ) H(→bb)

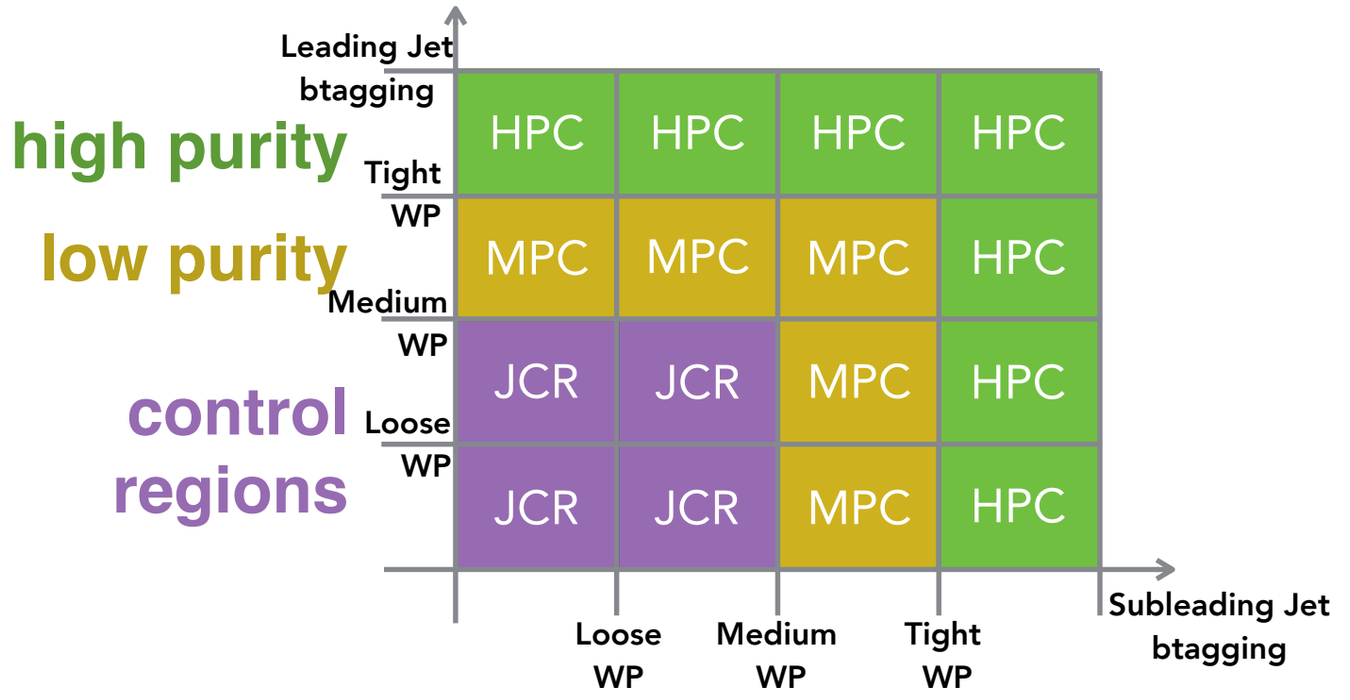
spin 0 hypothesis



spin 2 hypothesis



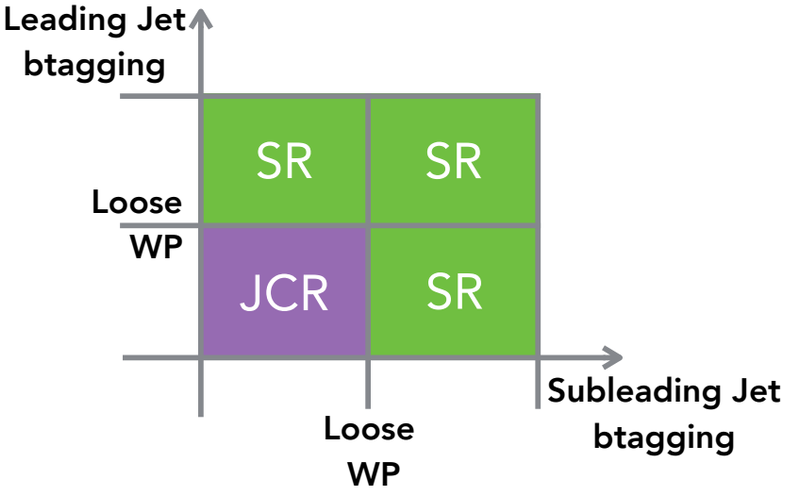
Low-mass signal regions (m_{JJ} < 500 GeV)



High-mass signal regions (m_{JJ} > 500 GeV)

Non-smooth limits due to different m_X cut in each point (small point-to-point correlation)

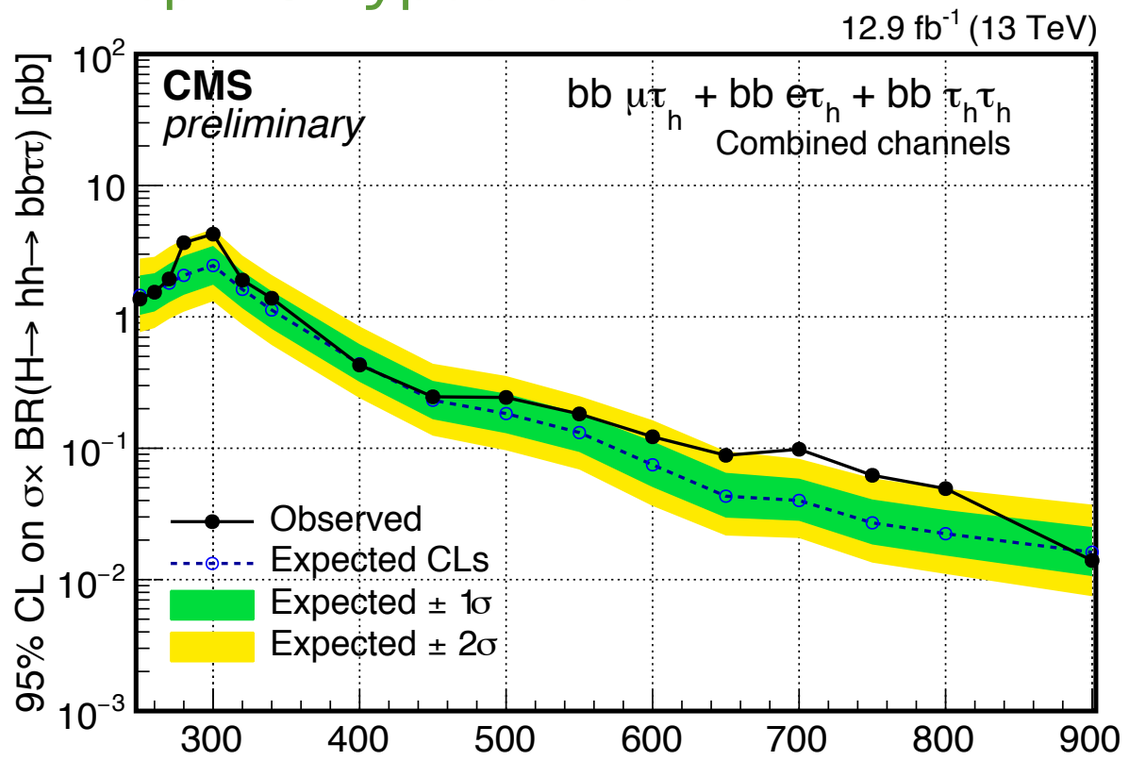
Limits obtained from m_{bb}x$m_{\gamma\gamma}$ fits

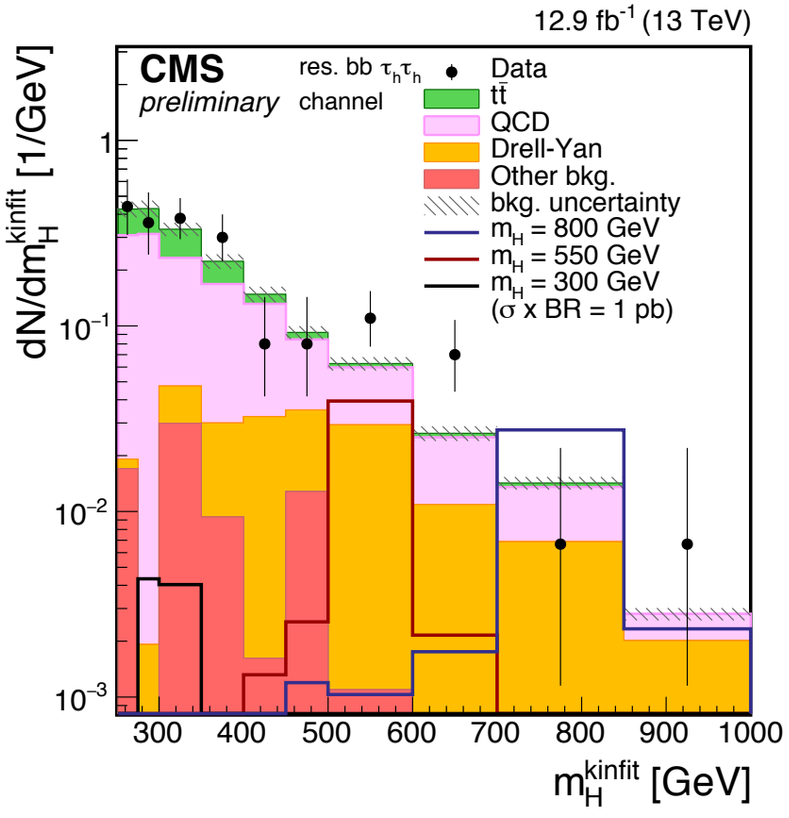


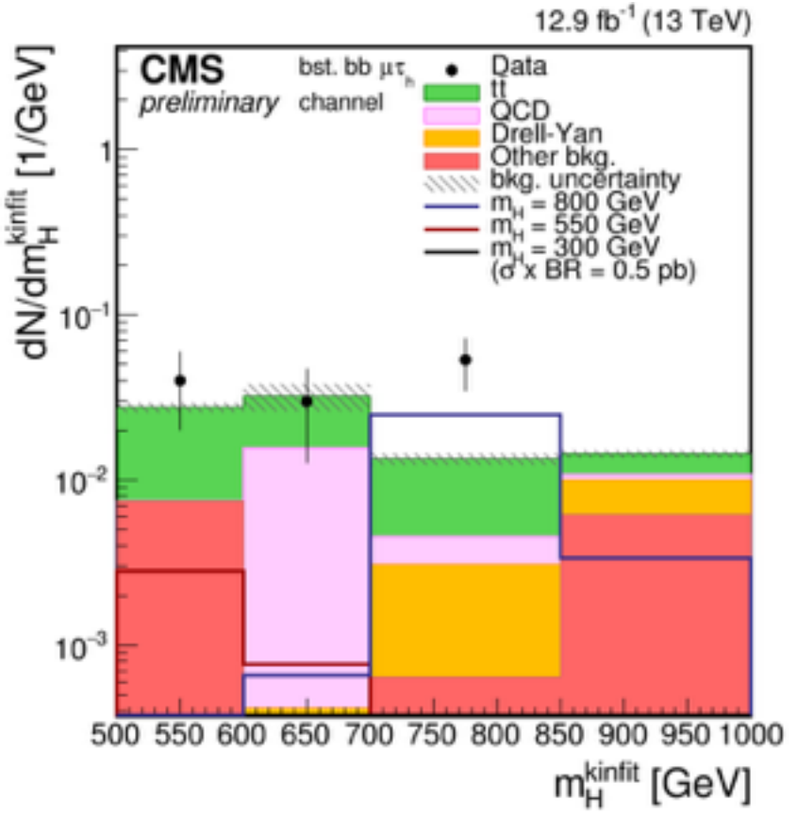
Resonant HH search

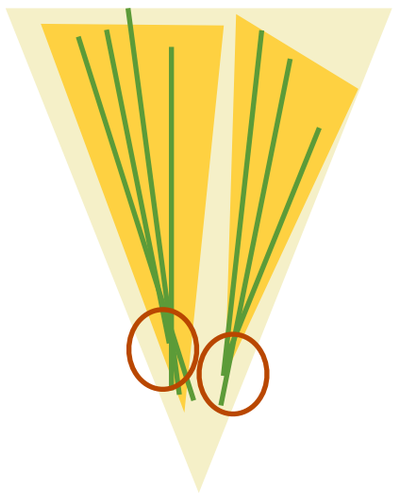
- HIG-16-029: X → H(→bb) H(→ττ)
- Analysis in $e\tau_h/\mu\tau_h/\tau_h\tau_h$ channels.
- In the $e\tau_h/\mu\tau_h$ channels, also consider "merged" X→H(→J[bb])H(→ττ)
- Use the large-R jet not to identify events, but for a better estimate of m_{bb}.

spin 0 hypothesis







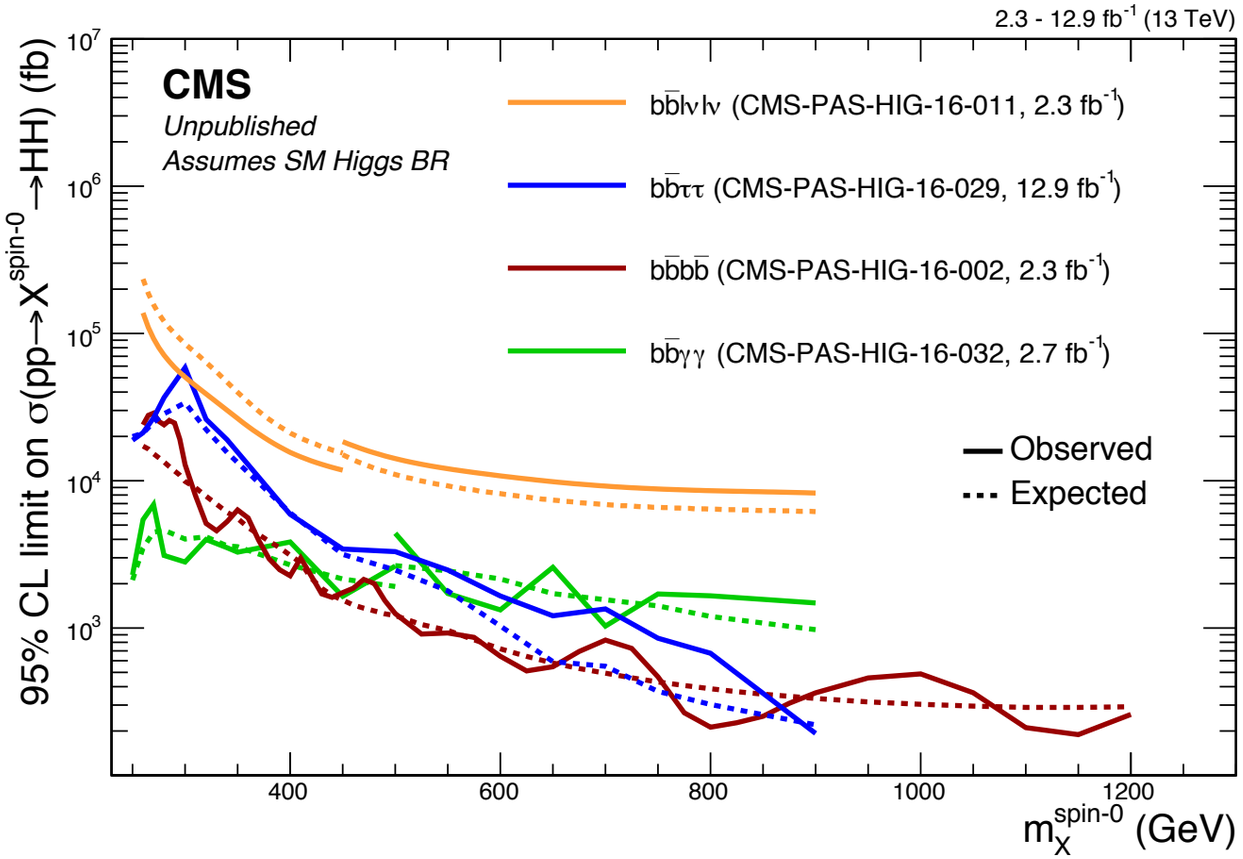


Requires one of the two b-tagged subjets of the R=0.8 jet to be matched to a R=0.4 jet.

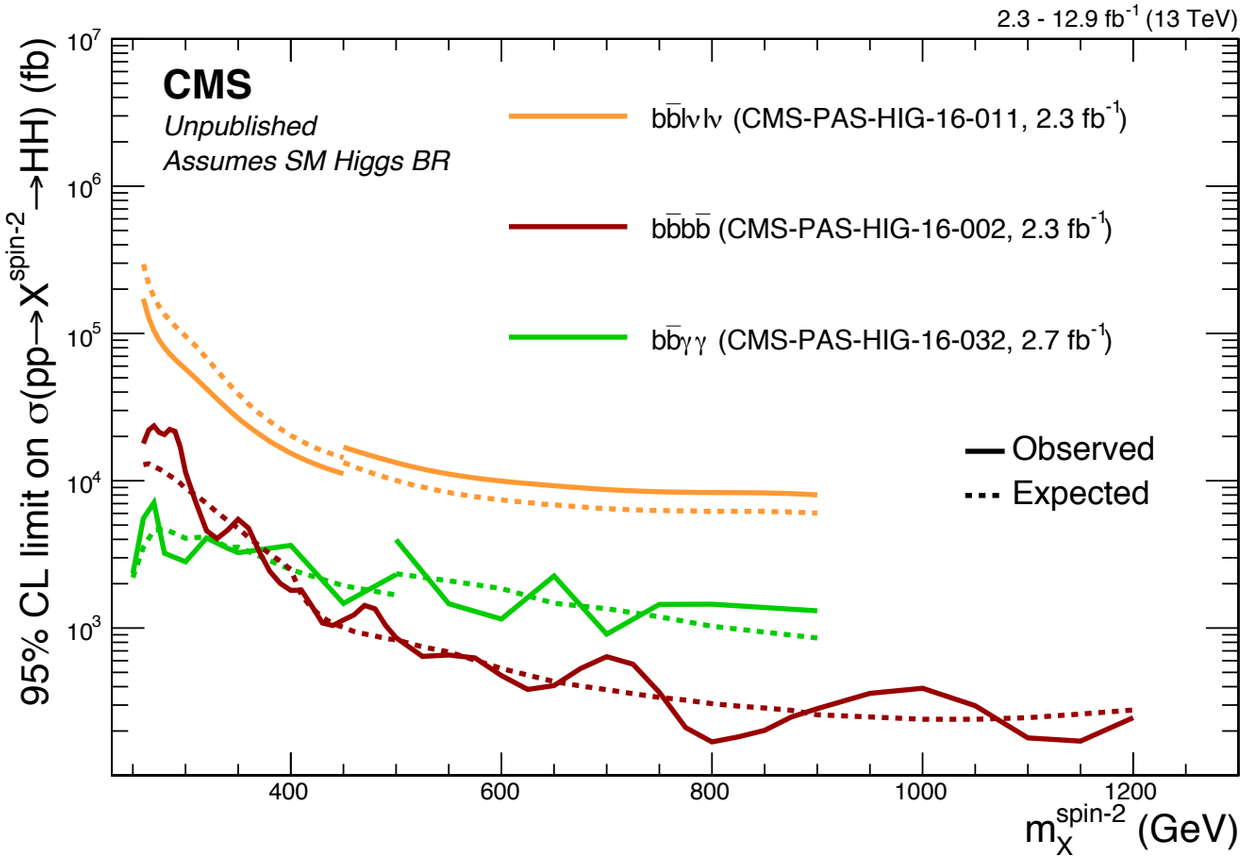
Resonant HH search : summary

- We can assume the SM H branching ratios to compare the analyses
- Comparison at low mass m_X < 1.2 TeV.
- At high m_X mass, limits come only from the merged X→HH→4b analysis.

spin 0 hypothesis

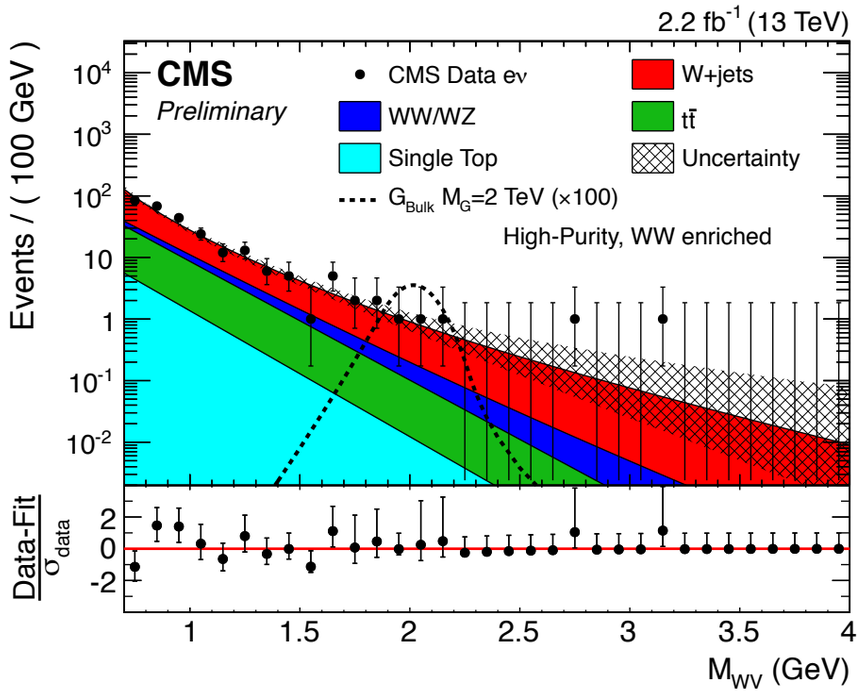


spin 2 hypothesis

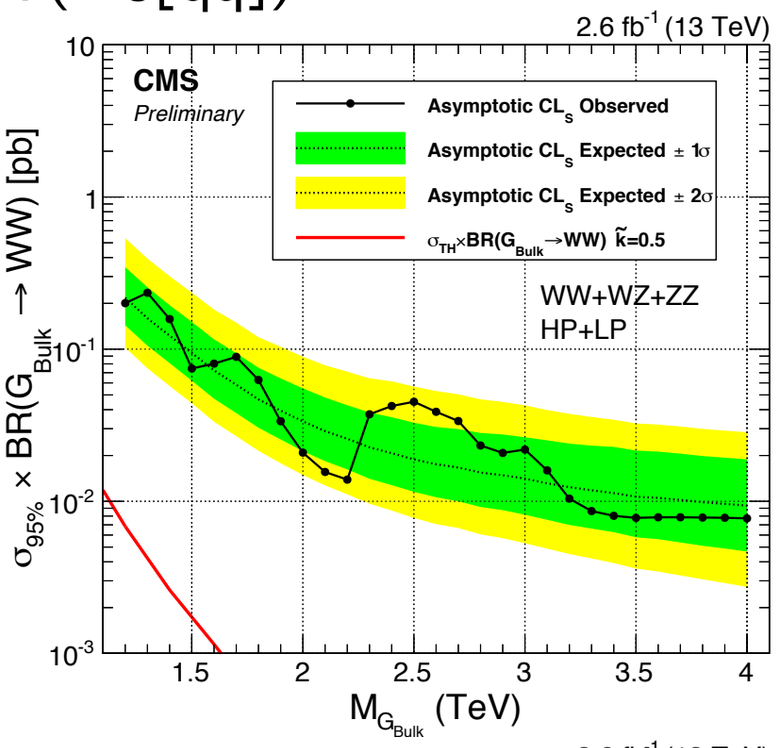


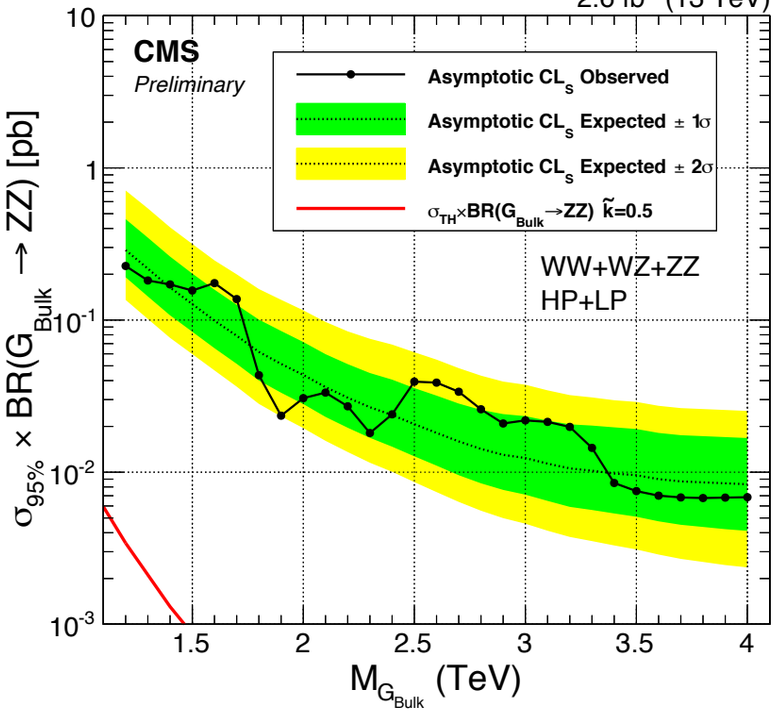
Resonant VV searches

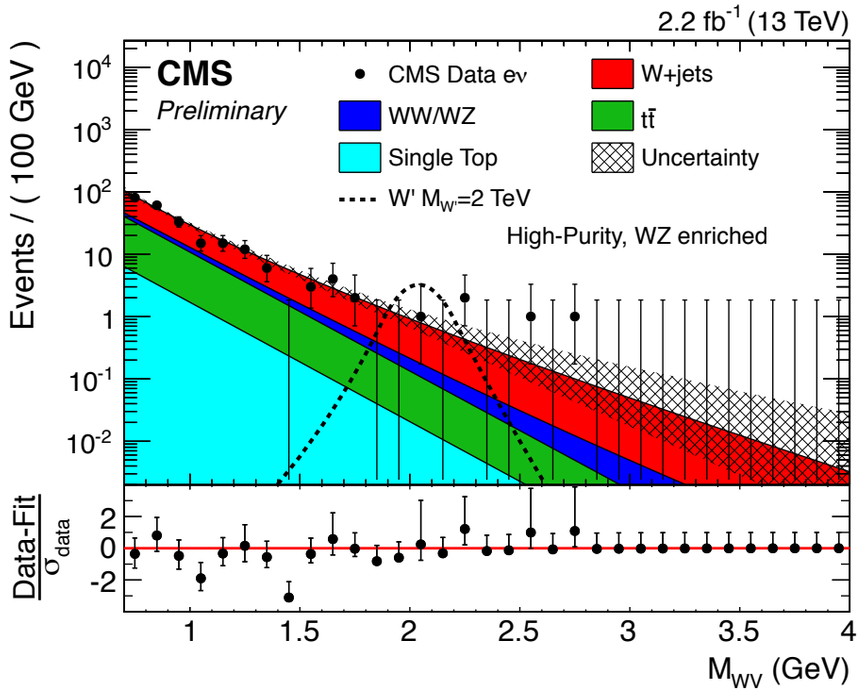
- EXO-15-002: X → V(→J[qq])V(→J[qq])



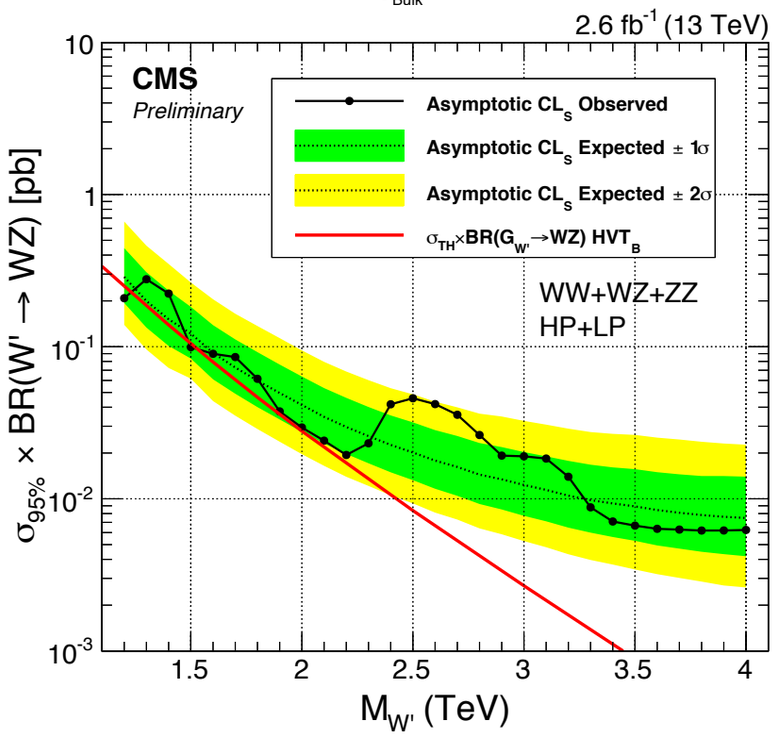
spin 2 hypothesis

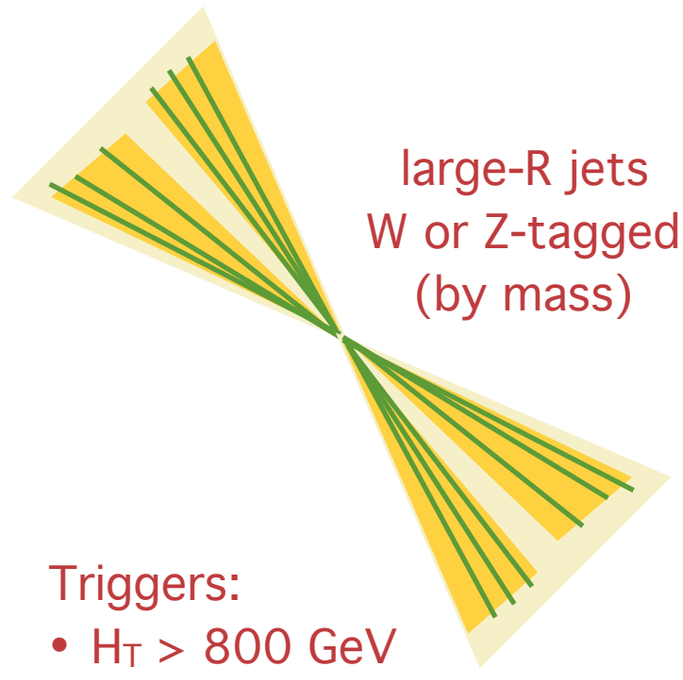






spin 1 hypothesis

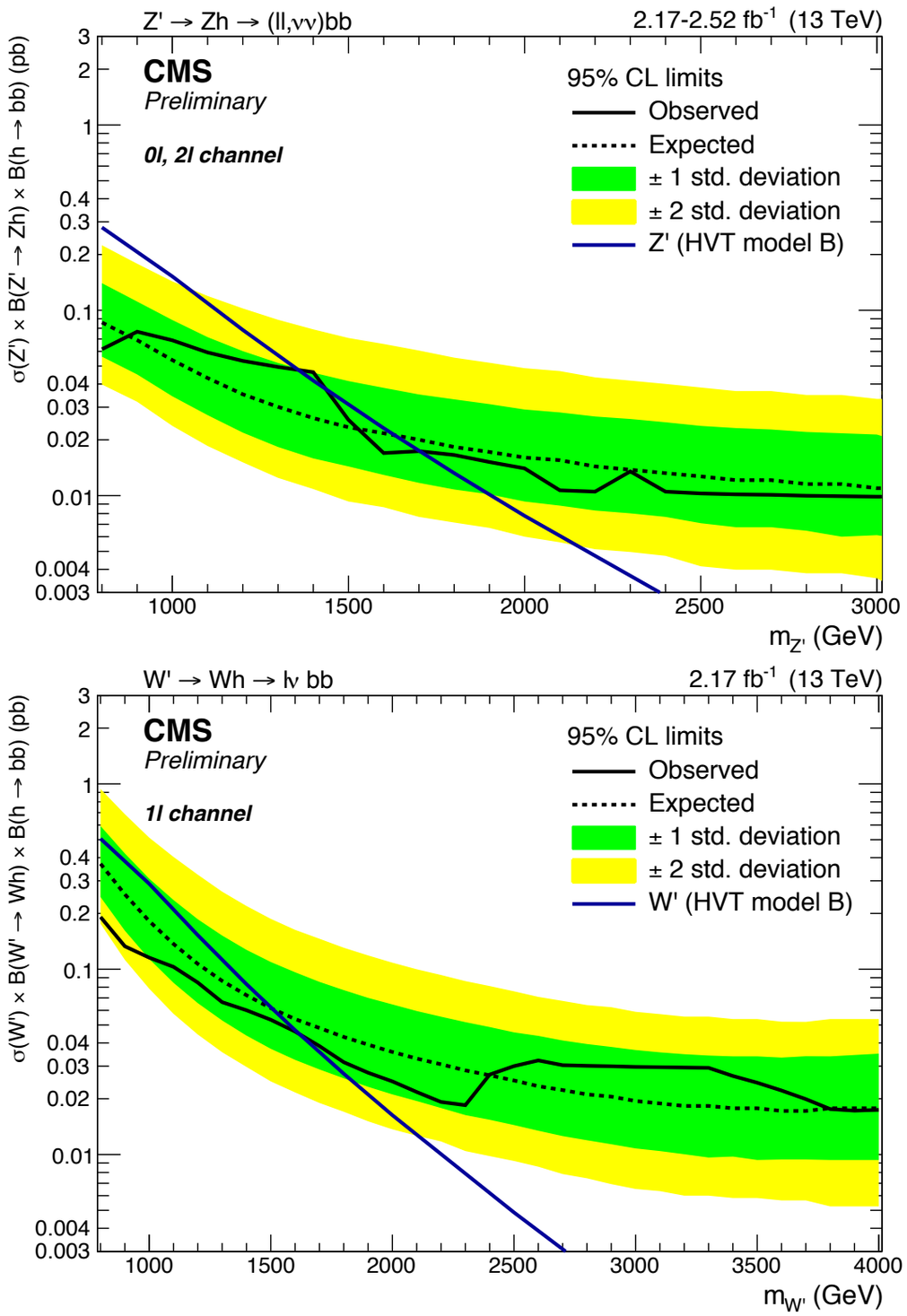


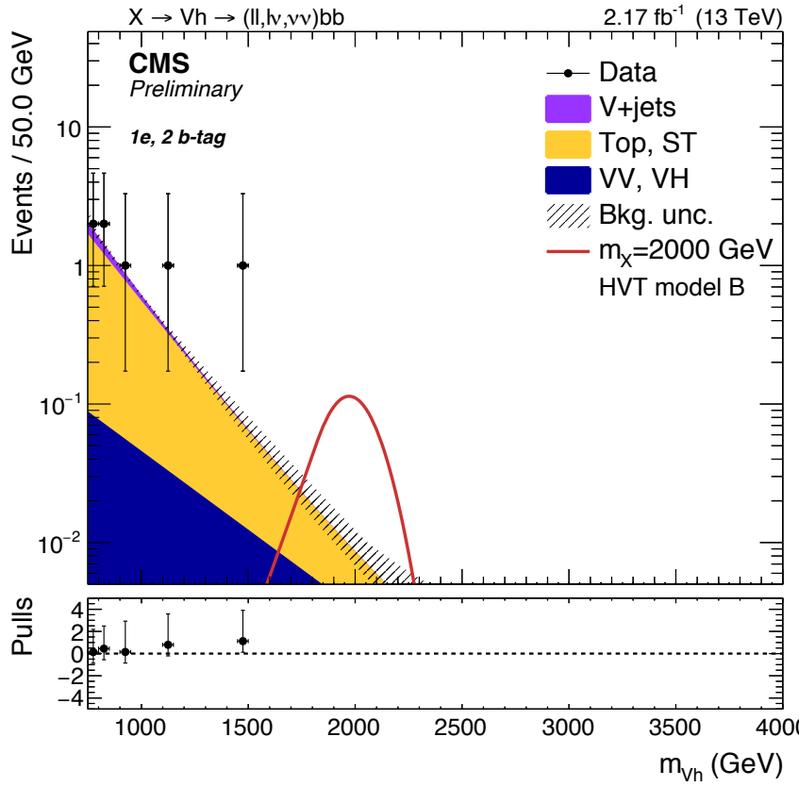


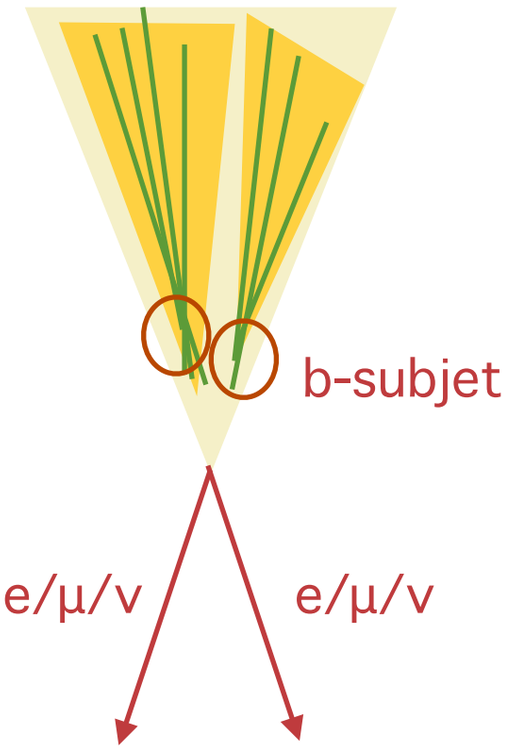
Triggers:
- H_T > 800 GeV
- p_T^{jet} > 360, m_{jet} > 30 GeV

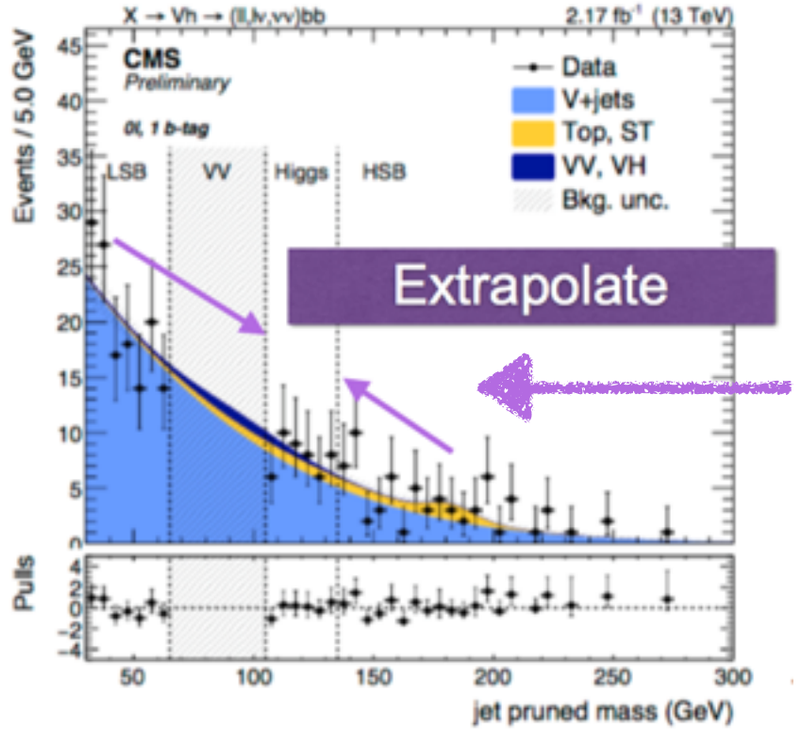
Resonant VV searches

- B2G-16-003: X → V(→ℓℓ/ℓν/νν)H(→J[bb])





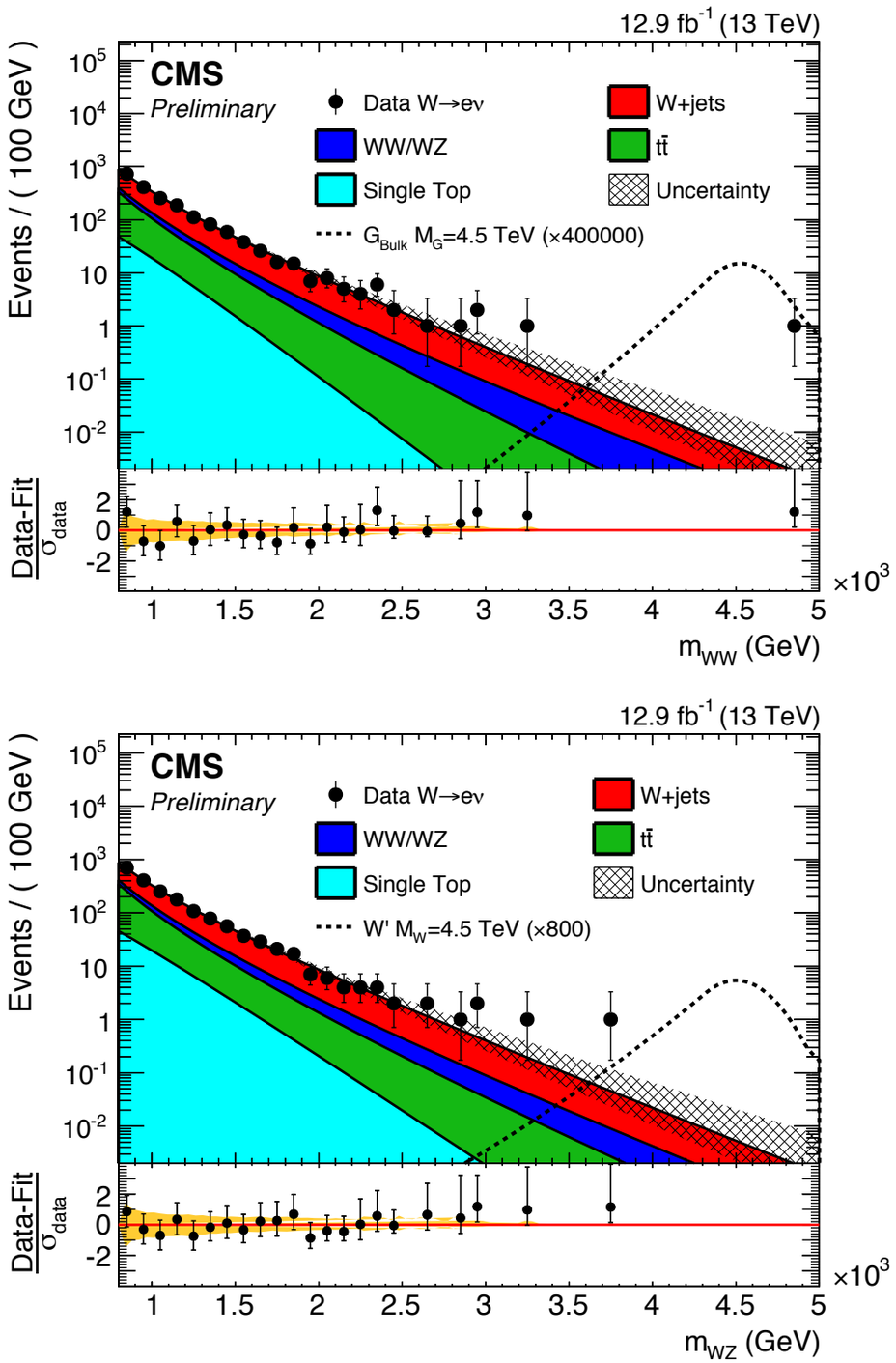




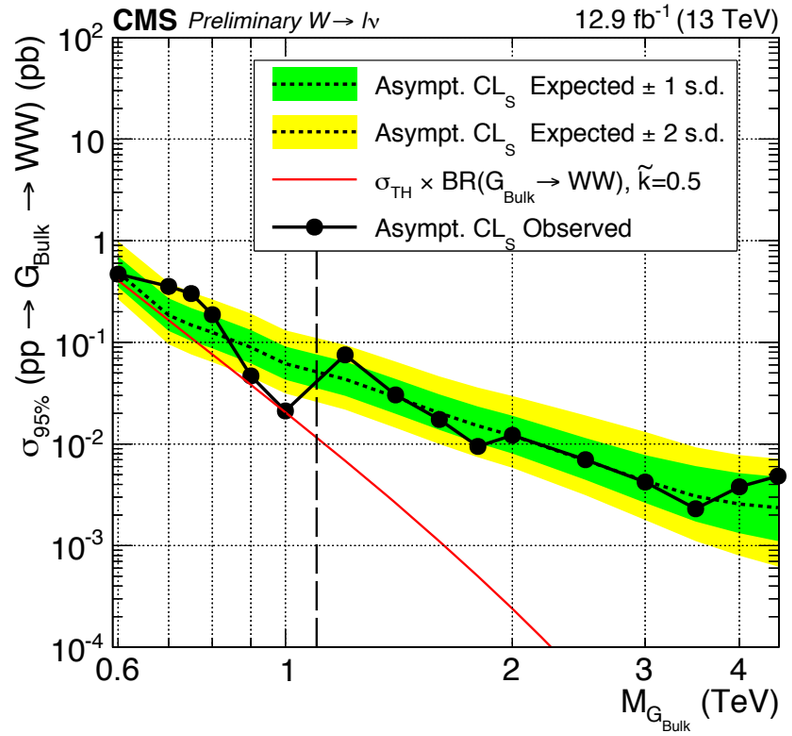
The VV region is not used as SB since the same method is used for $Z_{lep}V$ and $W_{lep}V$ searches (next slides)

Resonant VV searches

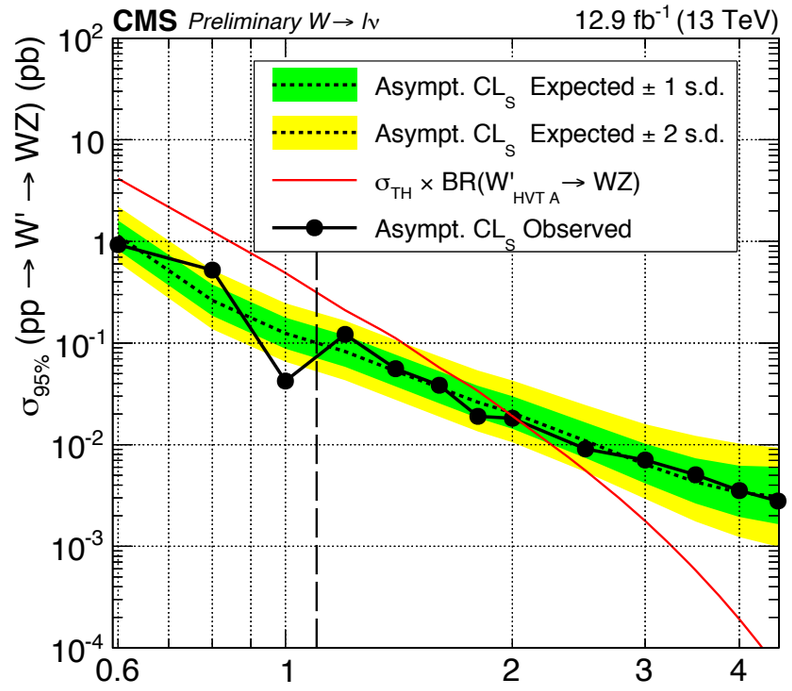
- B2G-16-020: X → W(→ℓν)V(→J[qq])



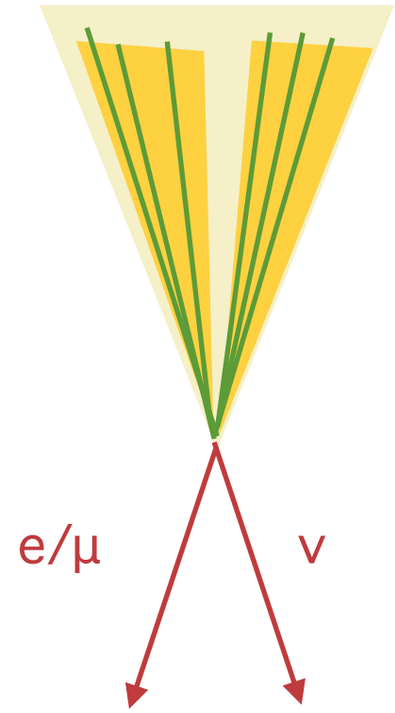
spin 2 hypothesis



spin 1 hypothesis

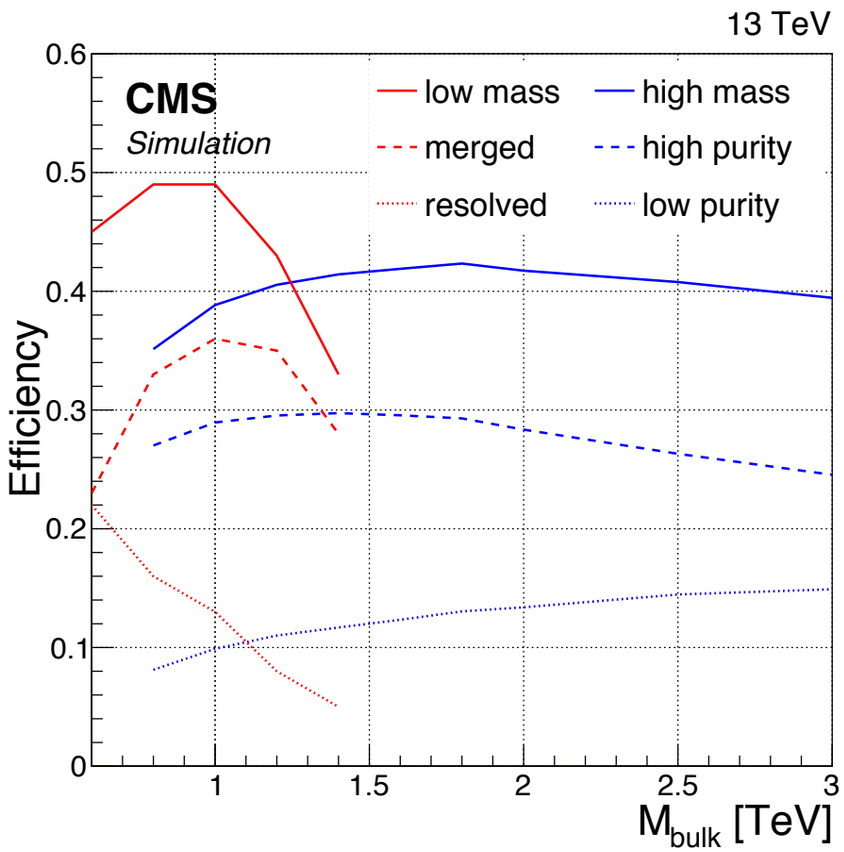


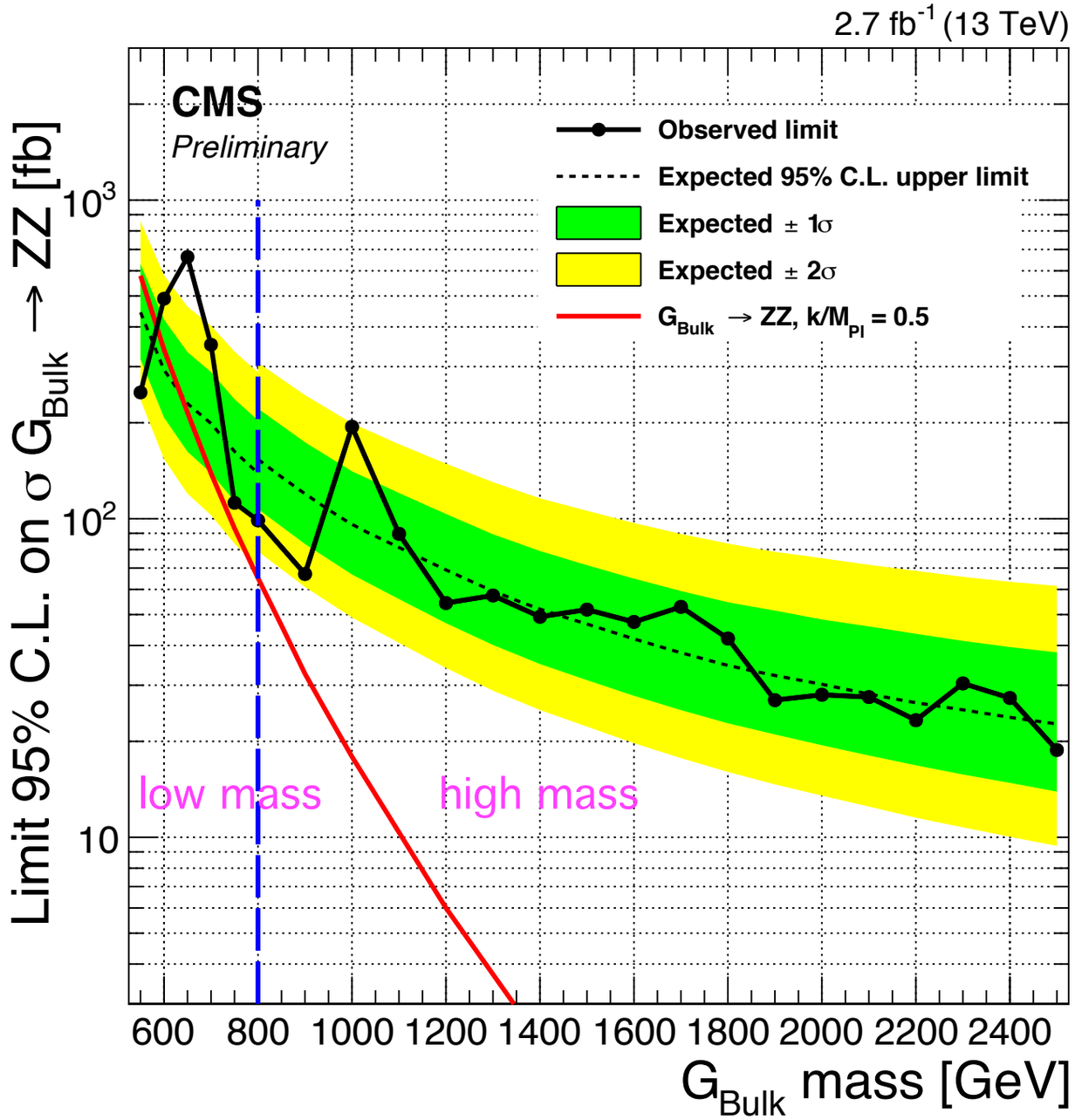
large-R jet
W or Z-tagged



Resonant VV searches

- B2G-16-010: X → Z(→ℓℓ)V(→qq)



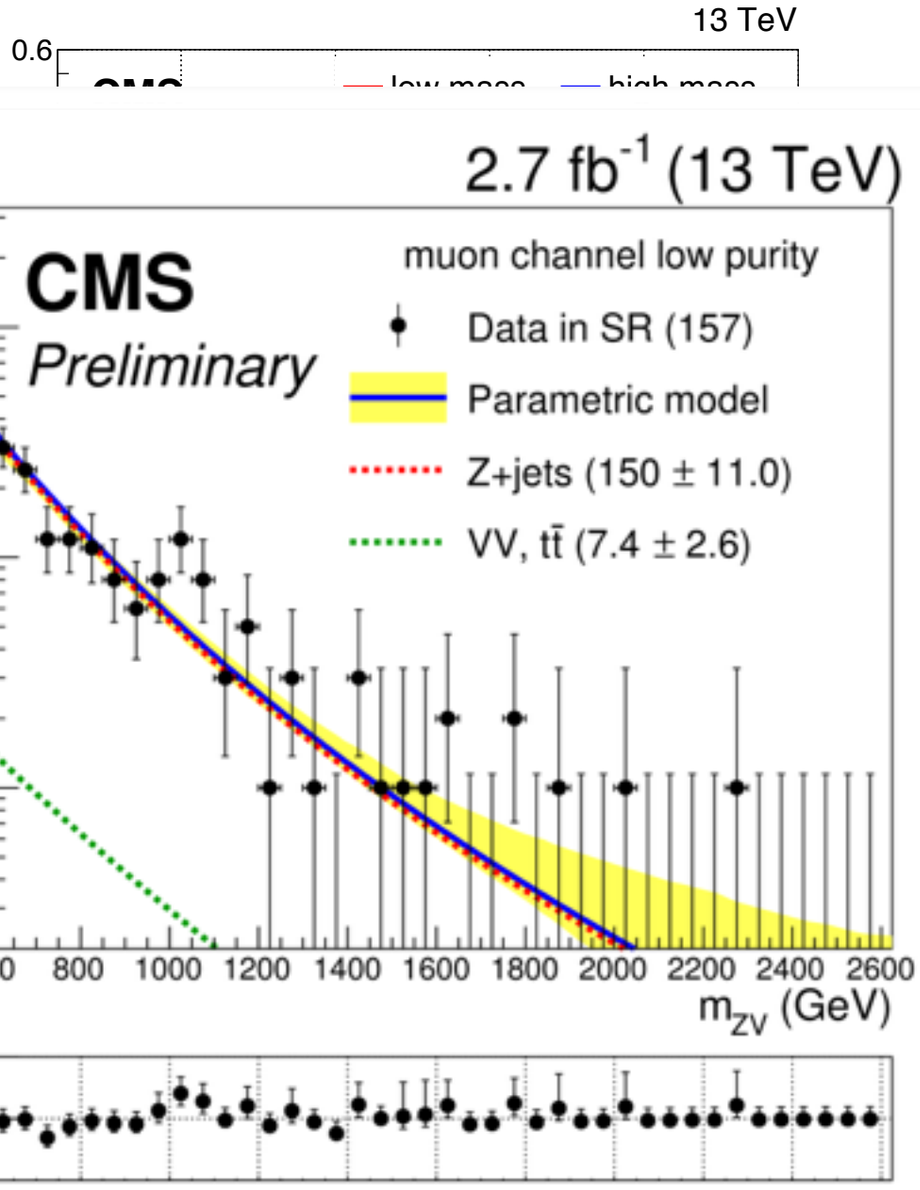


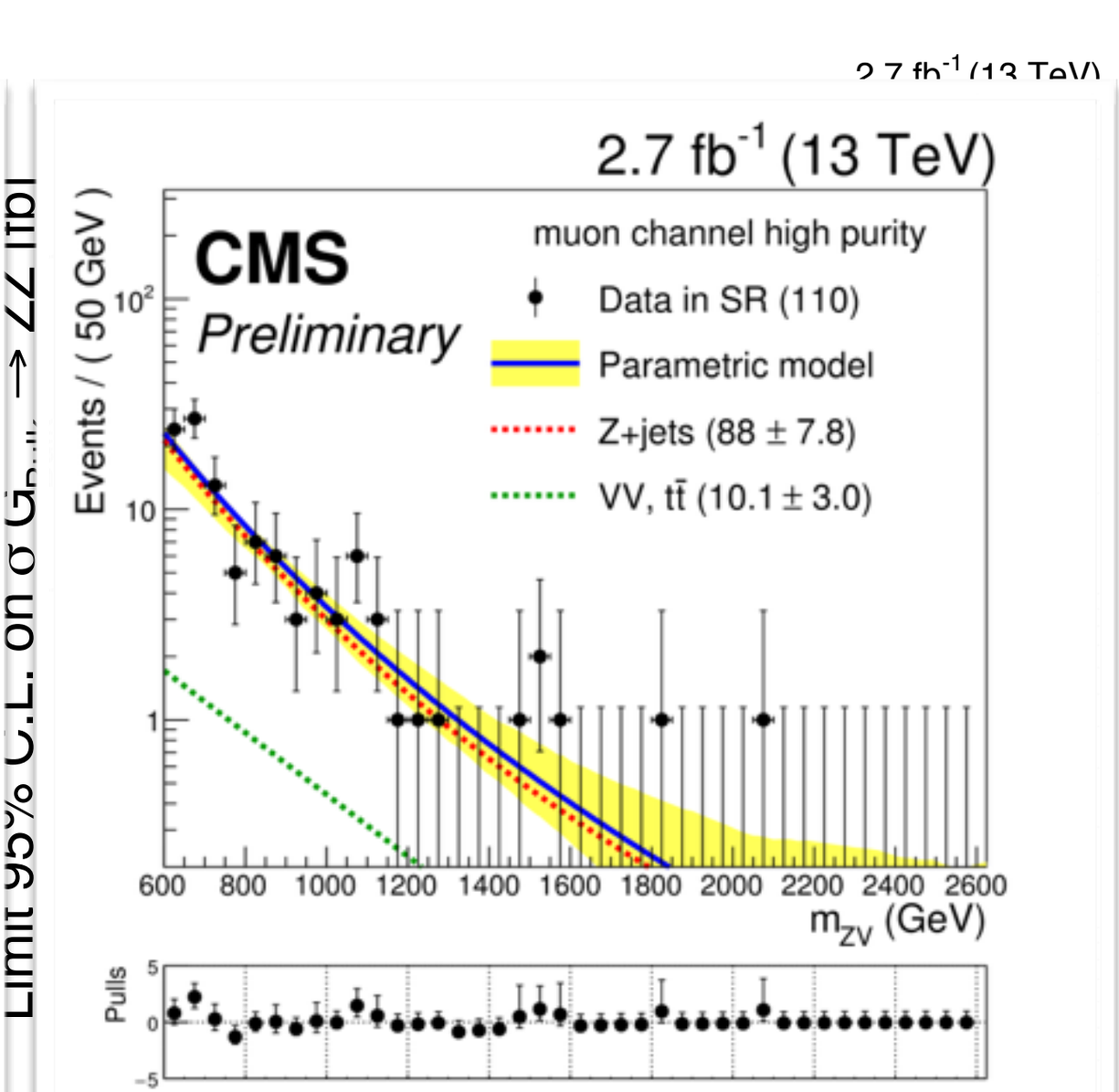
Two strategies to increase sensitivity

1. At low mass, reconstruct merged and resolved hadronic V. In each category separate b-tagged (high purity) and non b-tagged (low purity) jets.
2. At high mass, separate low (high purity) and high (low purity) n-subjetiness (τ_{21})

Resonant VV searches

- B2G-16-010: X → Z(→ℓℓ)V(→qq)



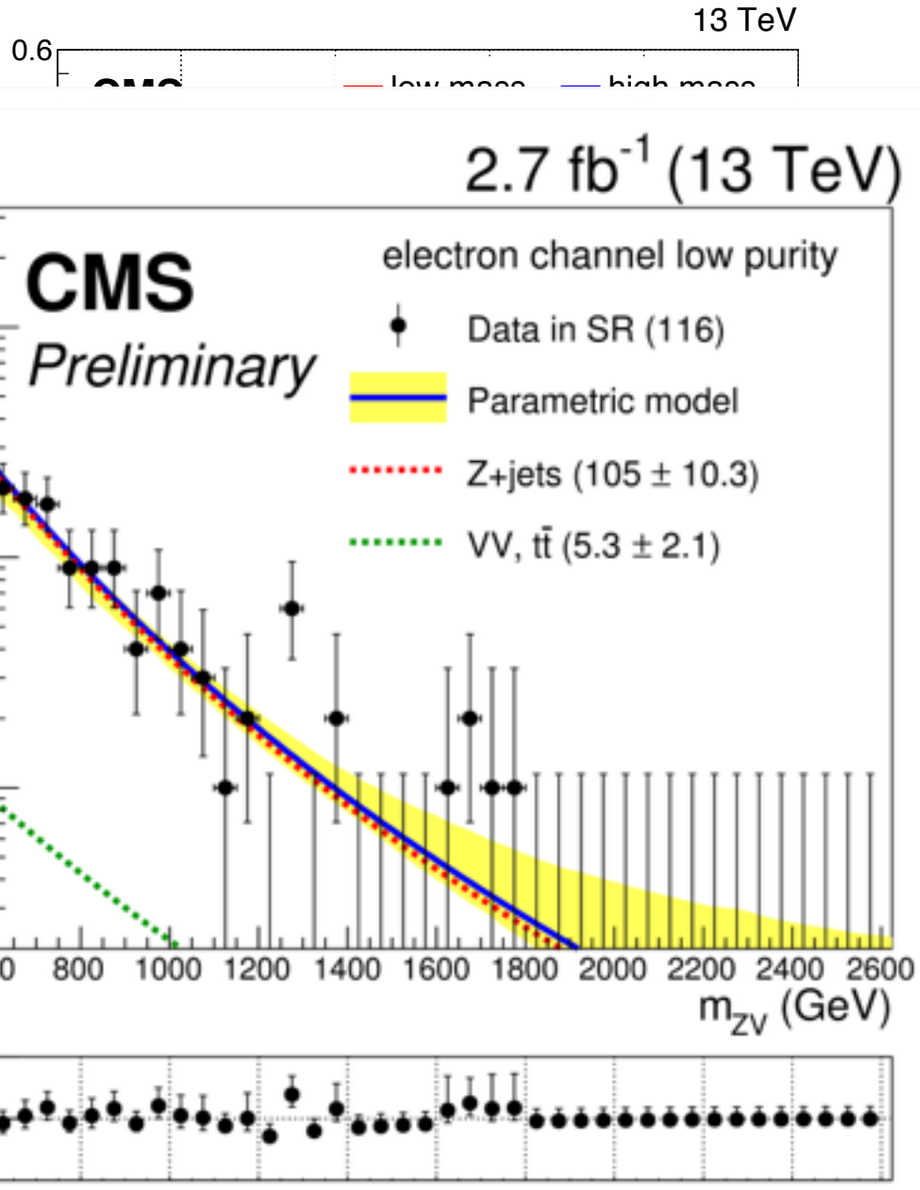


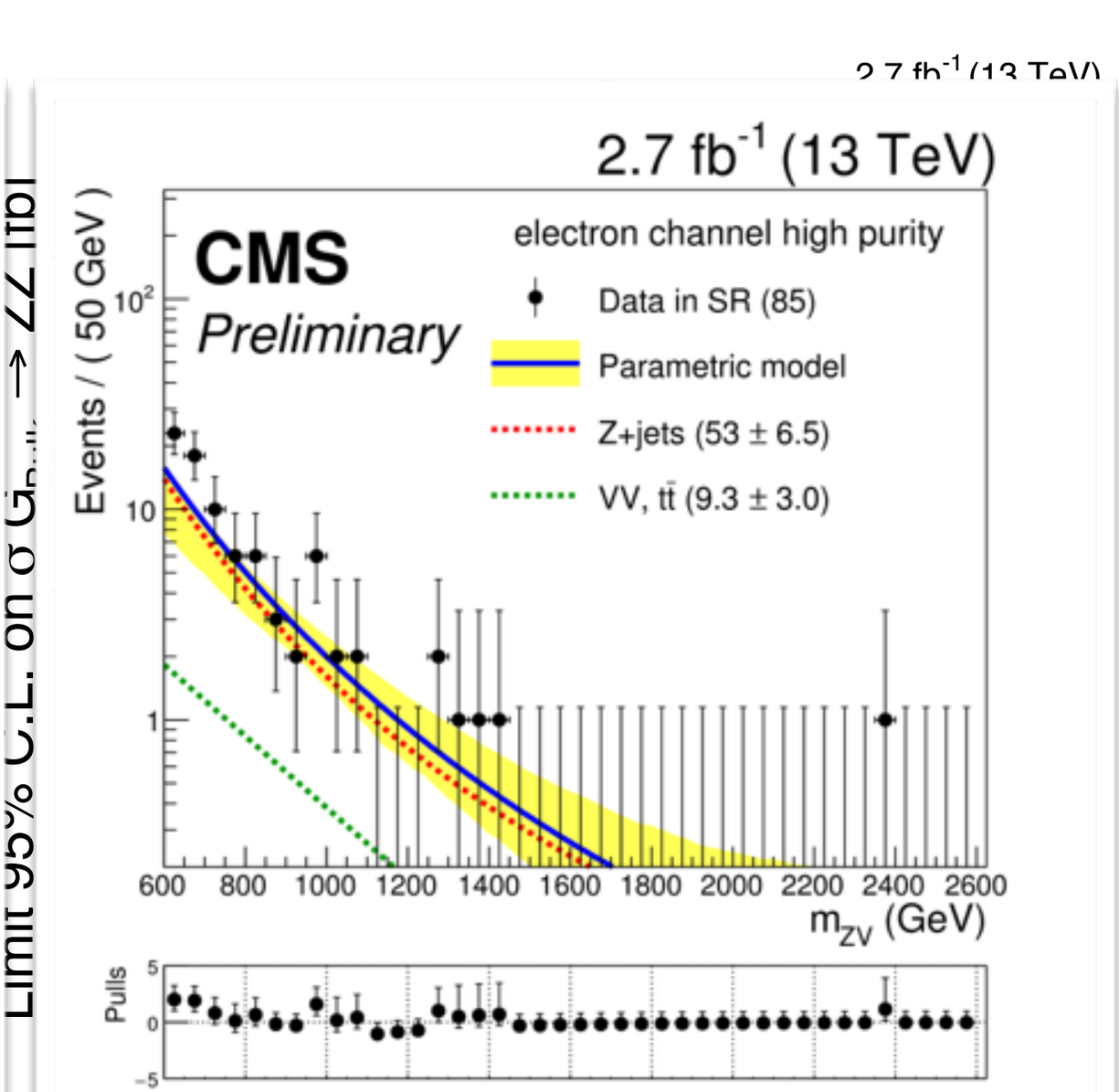
1

2. At high mass, separate low (high purity) and high (low purity) n-subjetiness (τ_{21})

Resonant VV searches

- B2G-16-010: X → Z(→ℓℓ)V(→qq)





Limit 95% C.L. on σ G... → ZZ [fb]

600 800 1000 1200 1400 1600 1800 2000 2200 2400

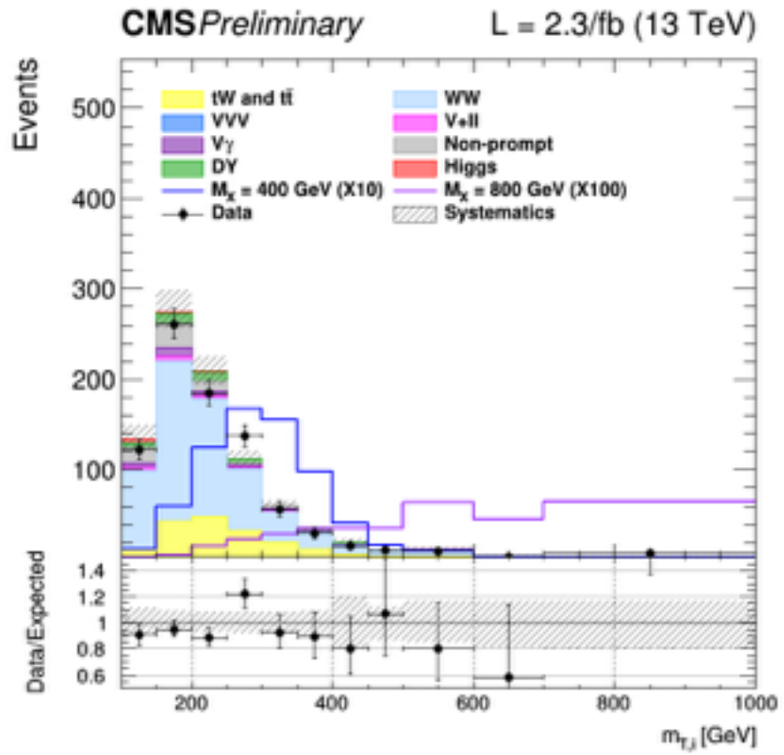
G_{Bulk} mass [GeV]

1. tagged (low purity) jets.
2. At high mass, separate low (high purity) and high (low purity) n-subjetiness (τ_{21})

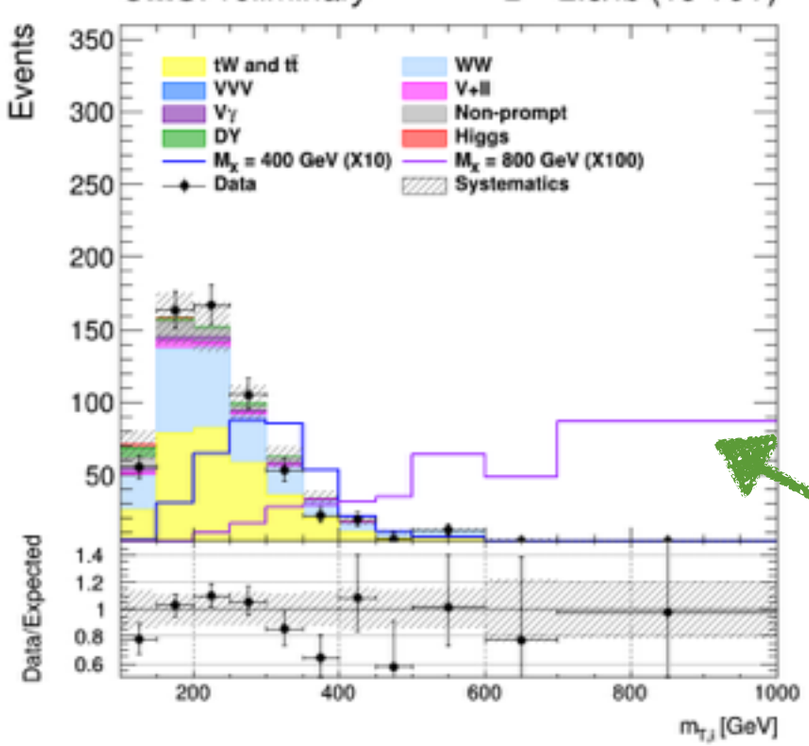
Resonant VV searches

- HIG-16-023: X → W(→ℓν)W(→ℓν)

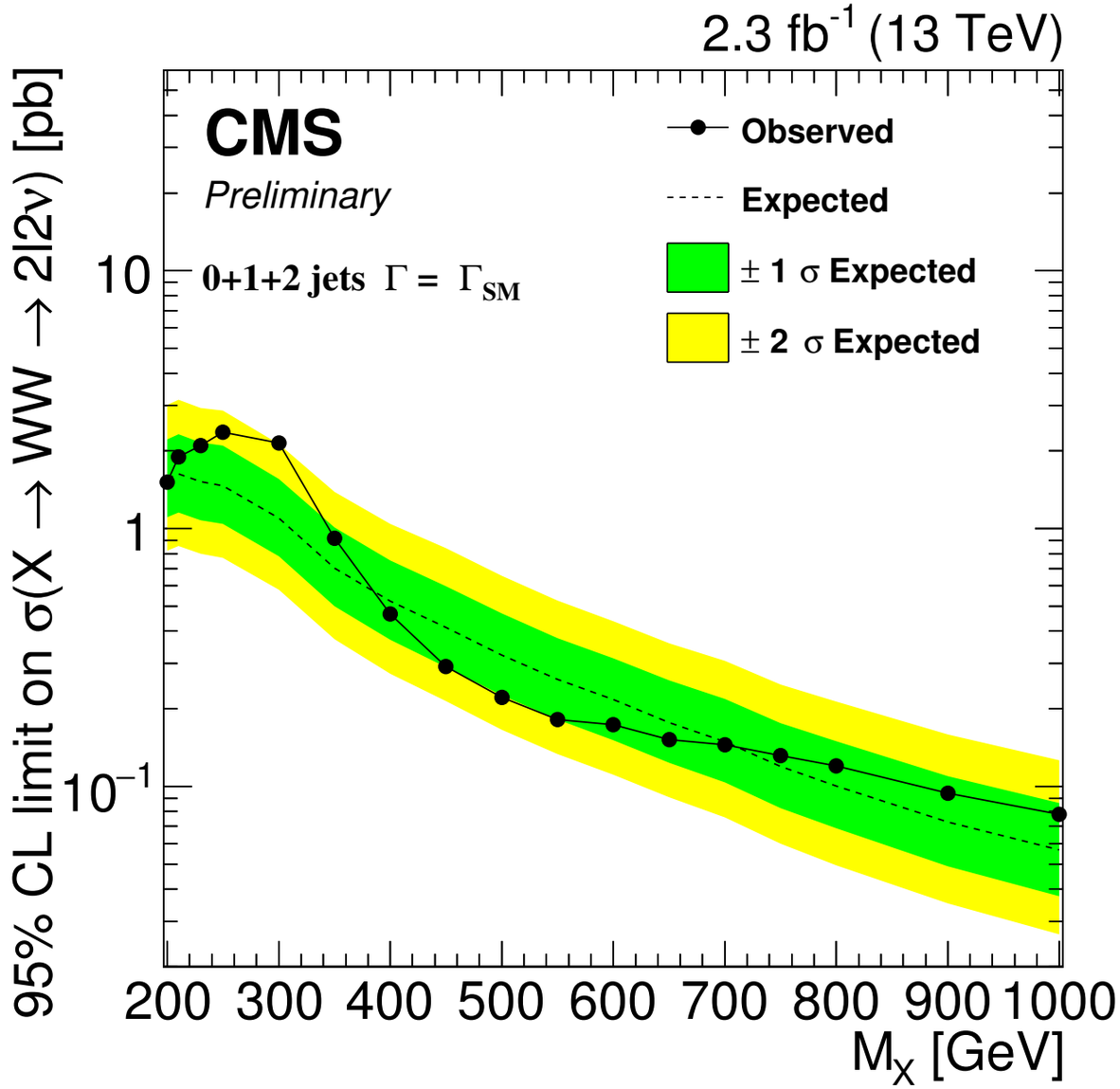
"ggF" signal region



"VBF" signal region



spin 0 hypothesis

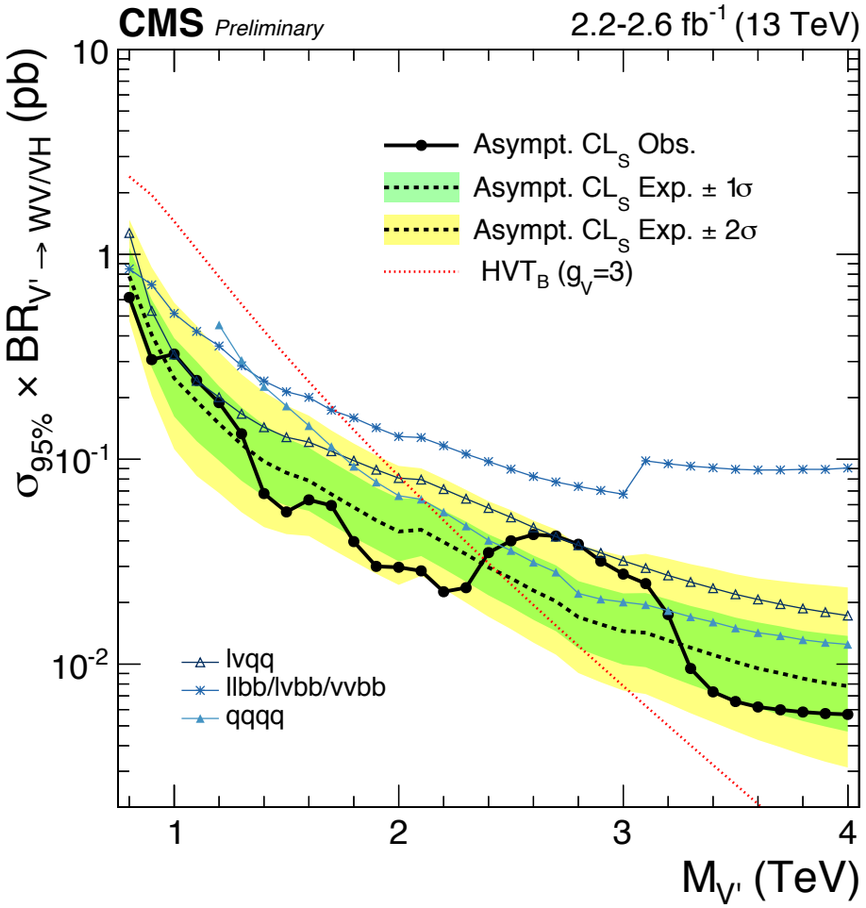


This analysis assumes gg-produced X resonance. Important contribution from interference with SM higgs gg→H→WW and box gg→WW production.

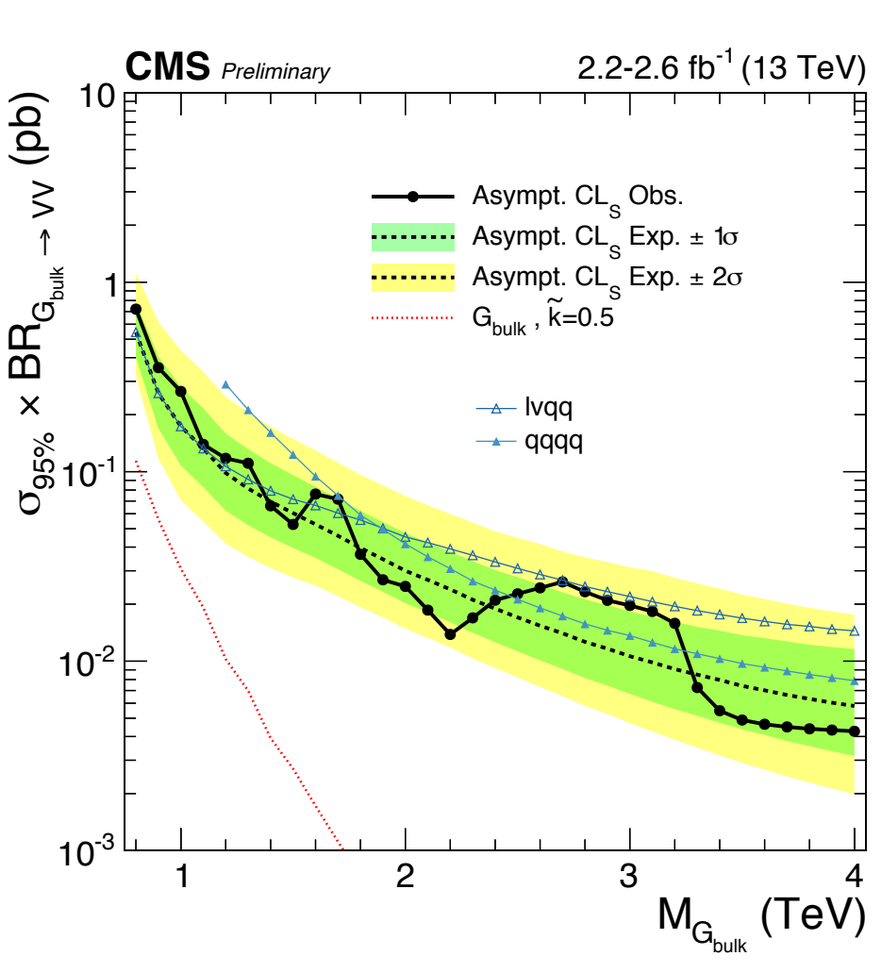
Resonant VV searches: summary

- B2G-16-007: combination
- We combine searches assuming a Higgs Vector Triplet model (spin 1) and a bulk graviton model (spin 2).
- No excess above background consistent with the decay of a resonance with $m_X \sim 2$TeV.

spin 1 hypothesis

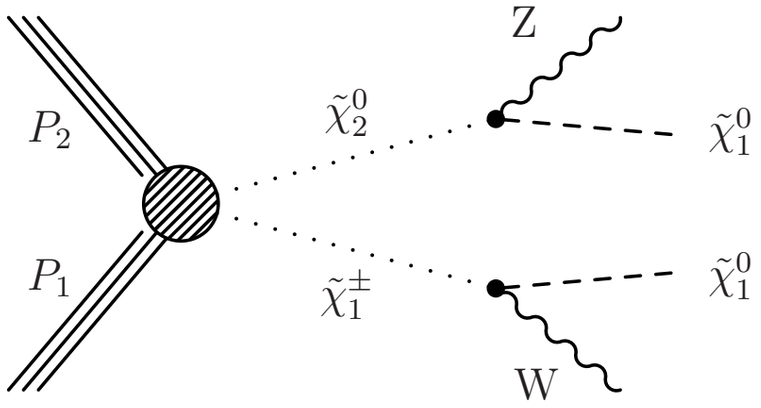


spin 2 hypothesis

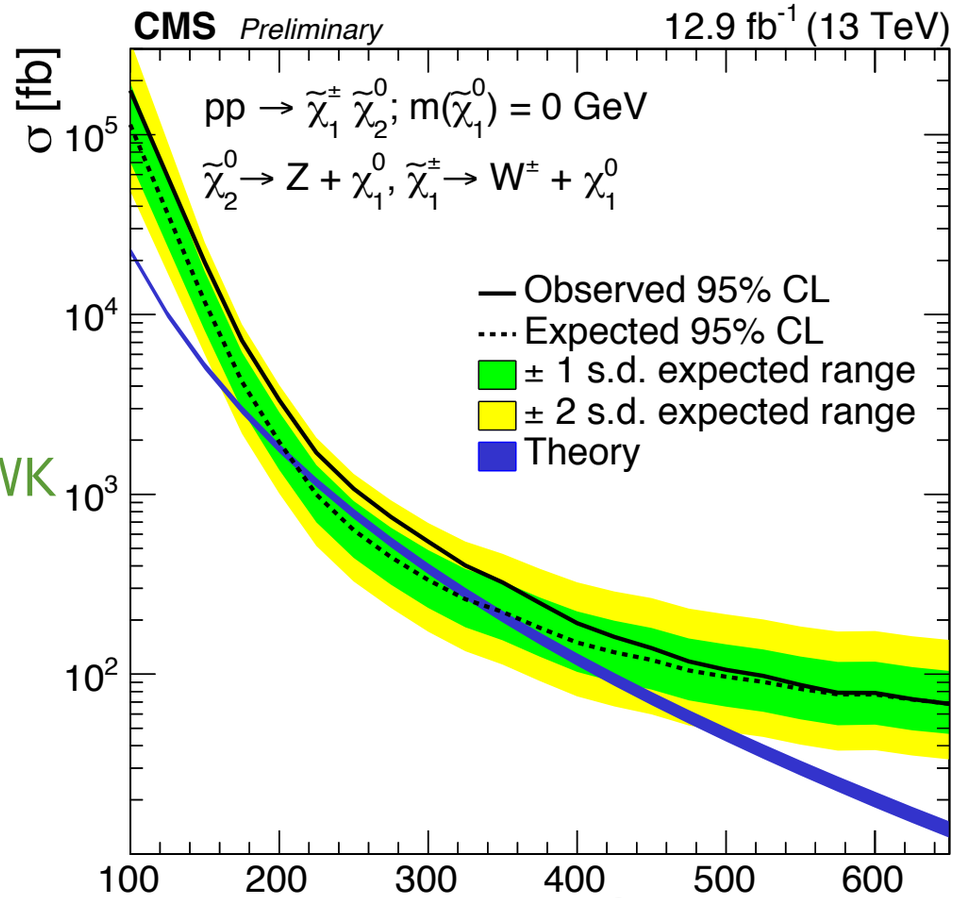


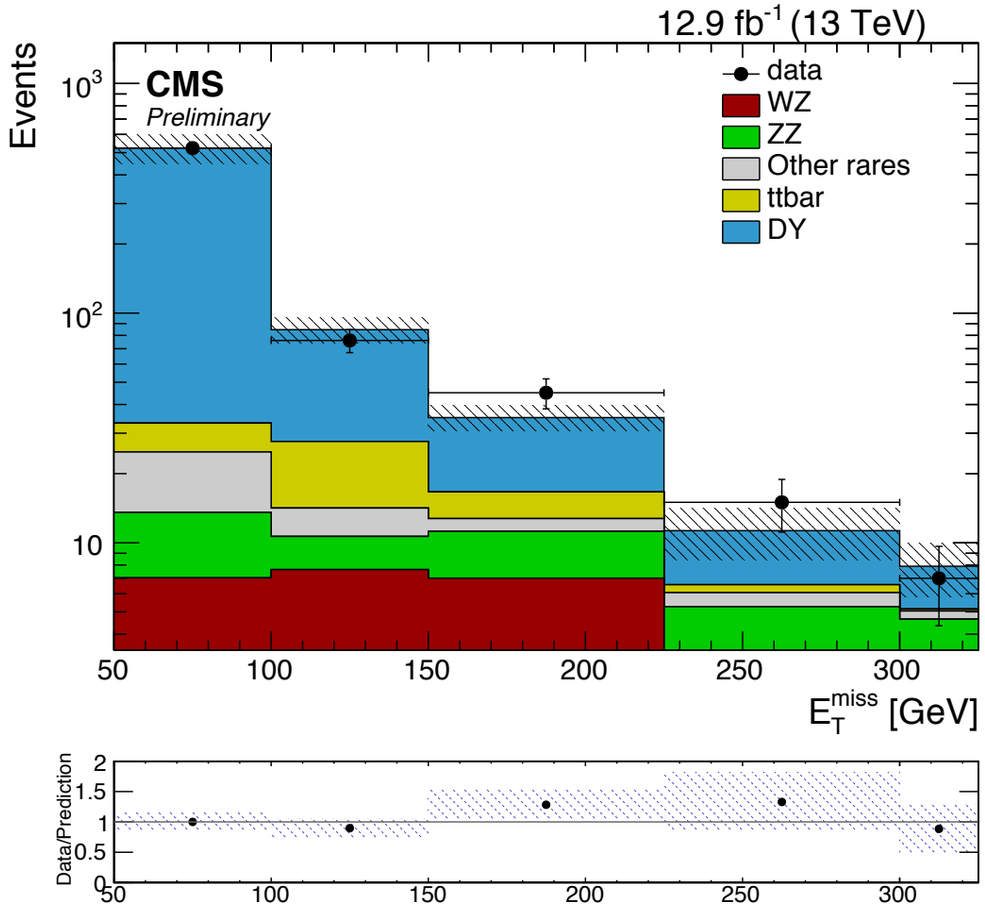
Non-resonant VV searches

- SUS-16-021: $Z(\rightarrow \ell\ell)W(\rightarrow qq) + E_T^{miss}$



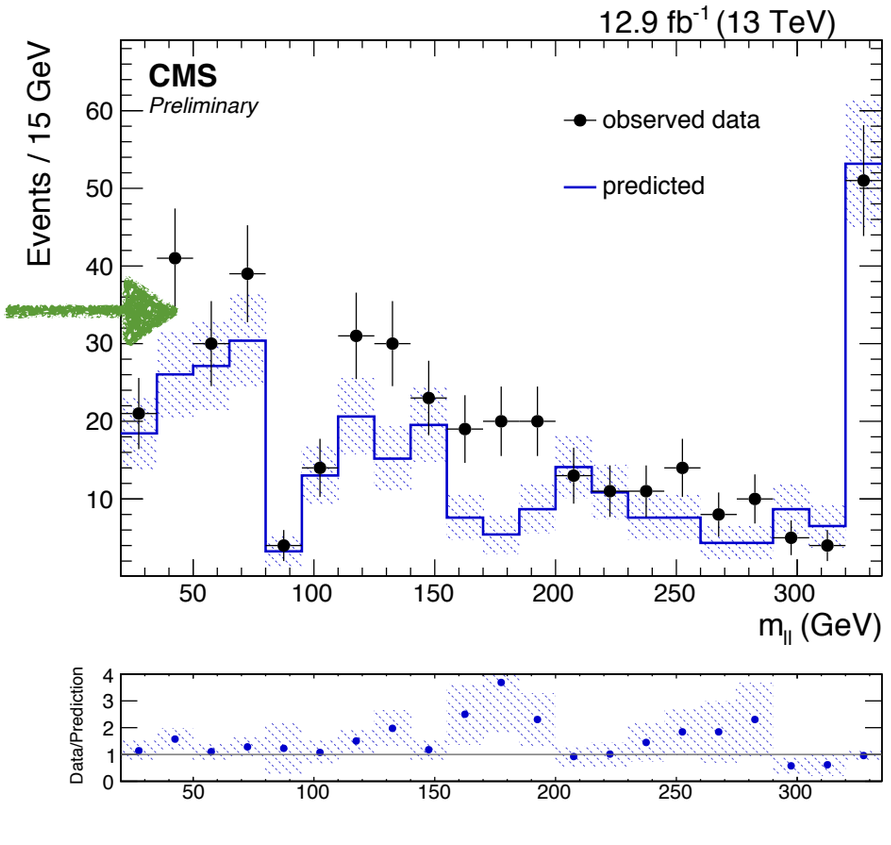
Motivated by and targeting models of EWK production of SUSY





But...

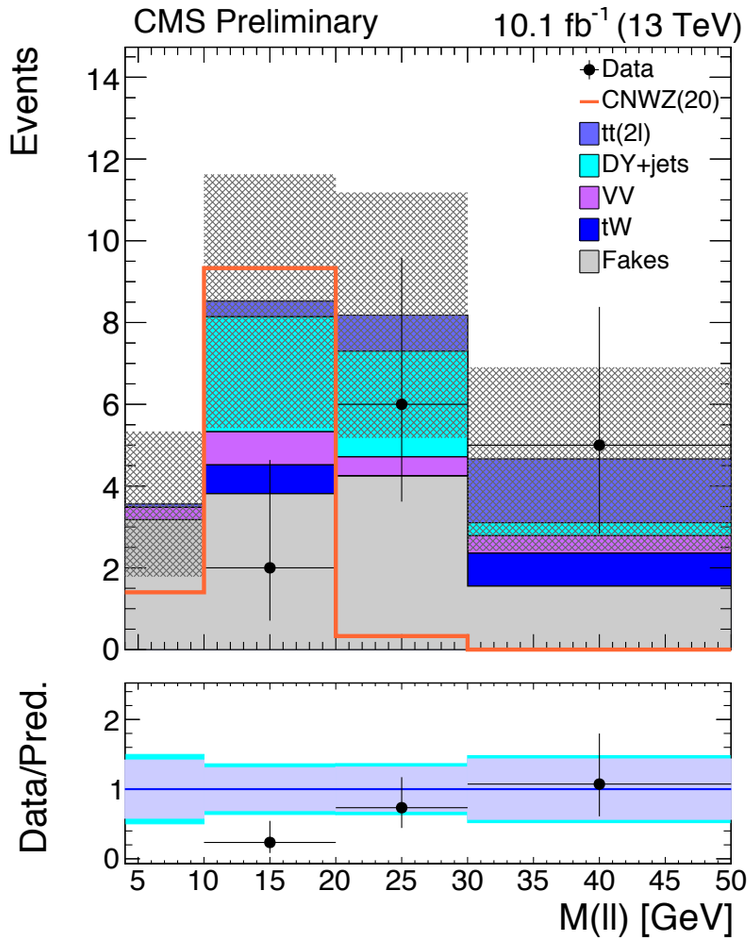
EWK analysis rejects $t\bar{t}$ background requiring zero b-jets and $M_{T2} > 80$ GeV. This analysis builds a likelihood based on $L(\Sigma m_{\ell b}, \Delta\phi^{\ell\ell}, p_T^{\ell\ell}, E_T^{miss})$ to veto $t\bar{t}$ events.



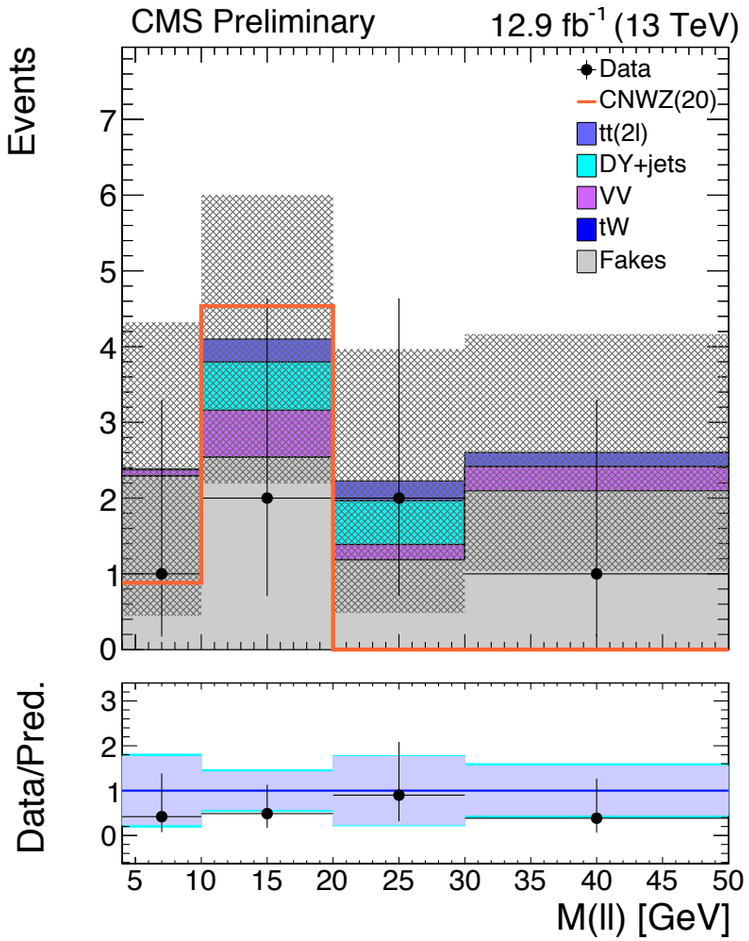
Non-resonant VV searches

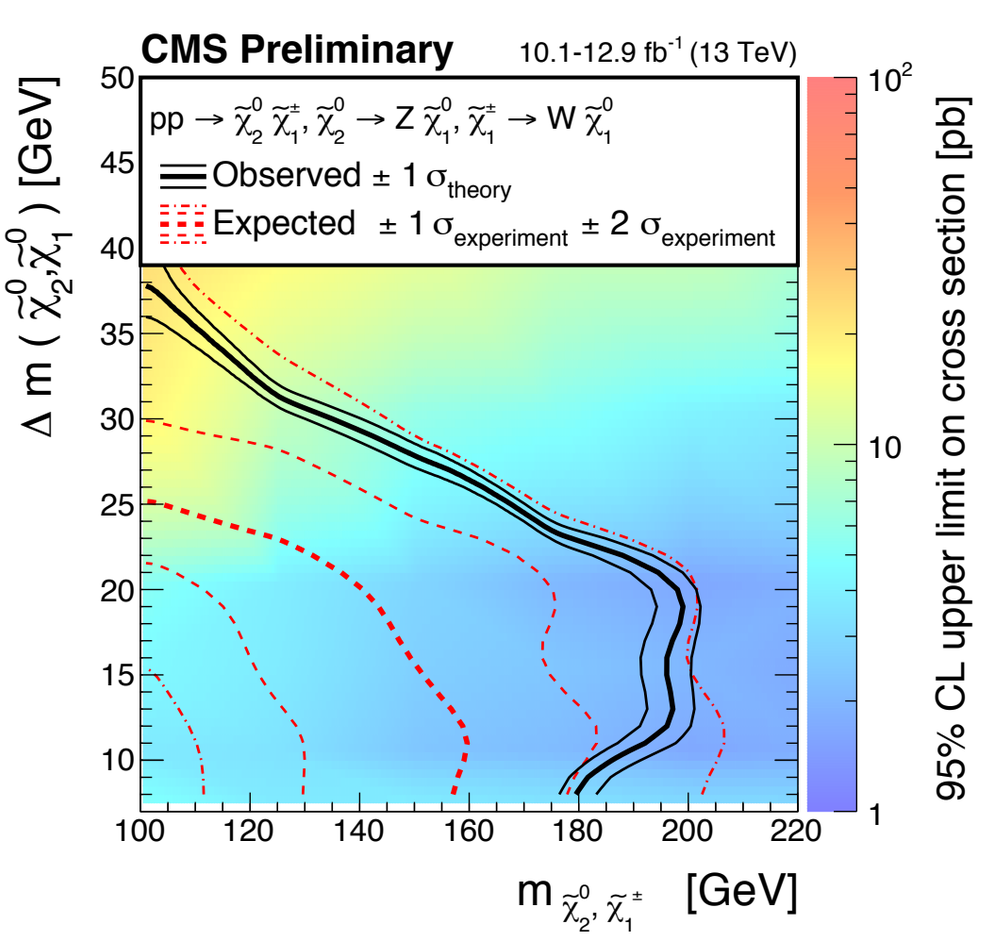
- SUS-16-025: $Z(\rightarrow \ell \not{\ell})W(\rightarrow \ell \nu) + E_T^{miss}$
- Search for two opposite-sign soft leptons optimized for the case in which the vector bosons are produced very off-shell (compressed spectrum).
- Dedicated low-momentum $2\mu + E_T^{miss}$ trigger developed for this analysis.
  - $p_T^{\mu} > 3$ GeV
  - $E_T^{miss} > 50$ GeV

$125 < E_T^{miss} < 250$ GeV



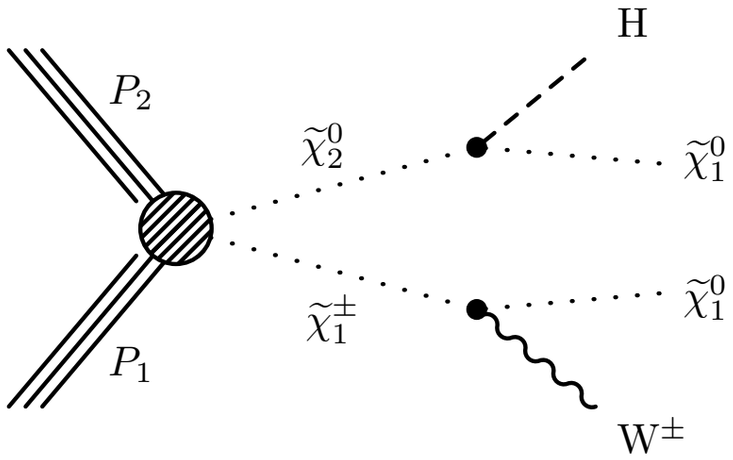
$E_T^{miss} > 250$ GeV

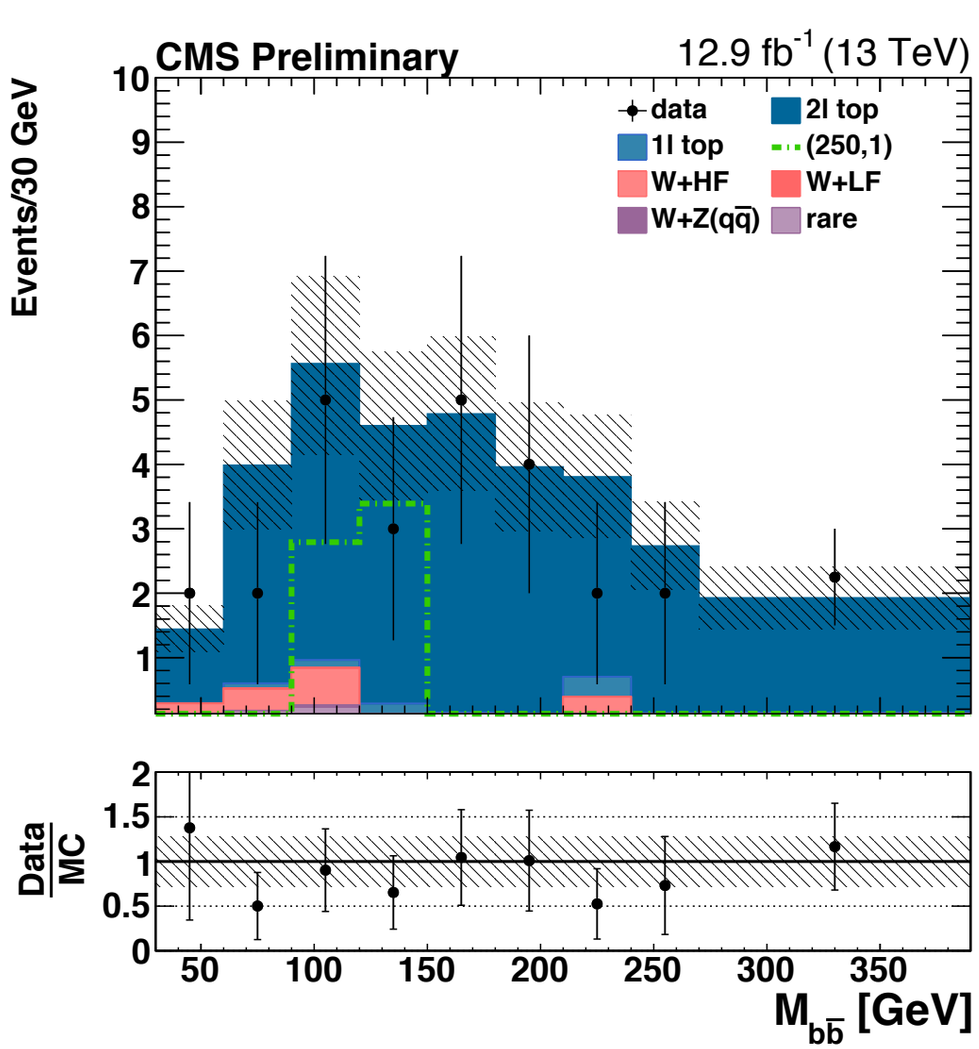


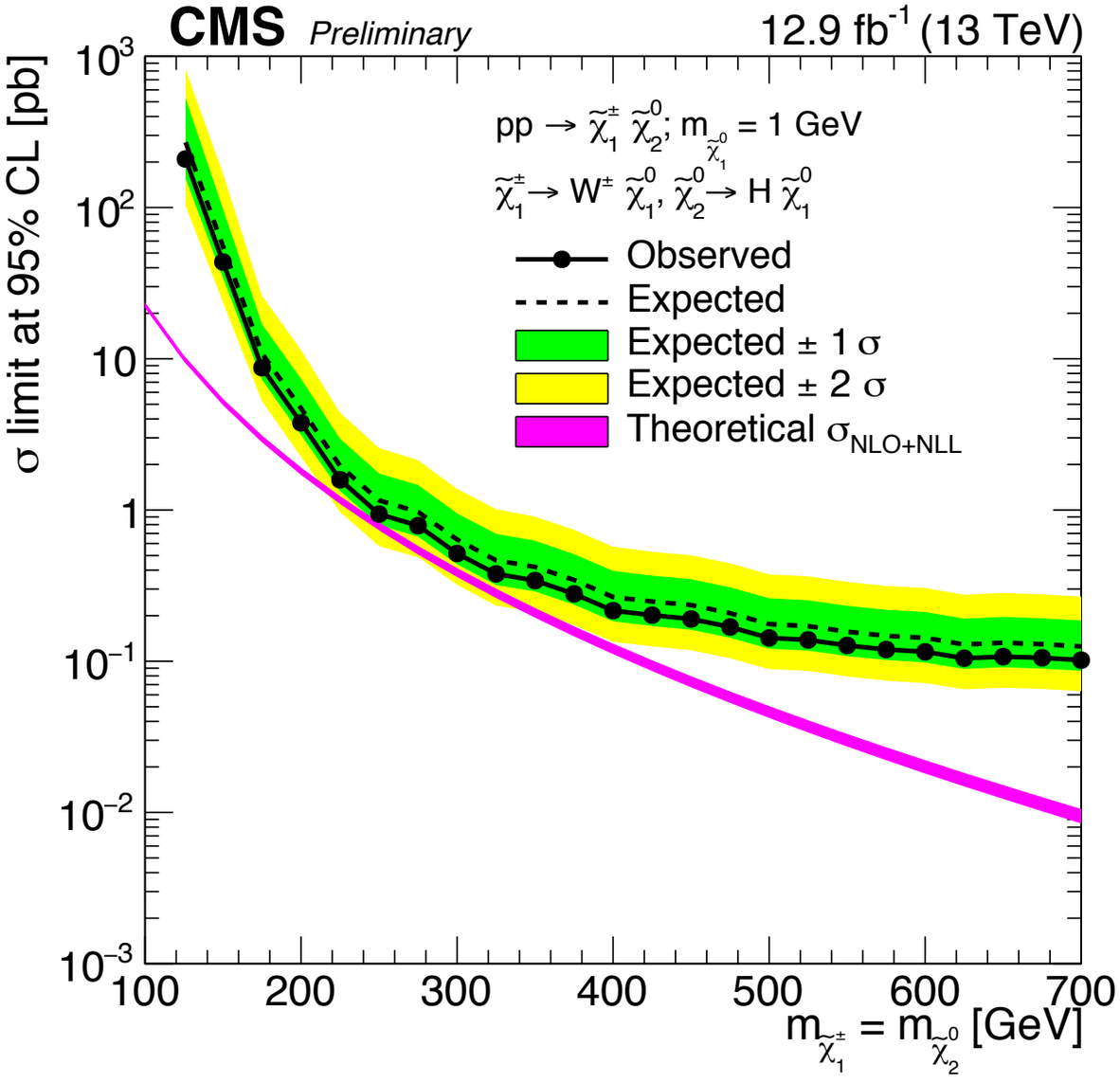


Non-resonant VV searches

- SUS-16-026: $W(\rightarrow \ell\nu)H(\rightarrow bb) + E_T^{miss}$

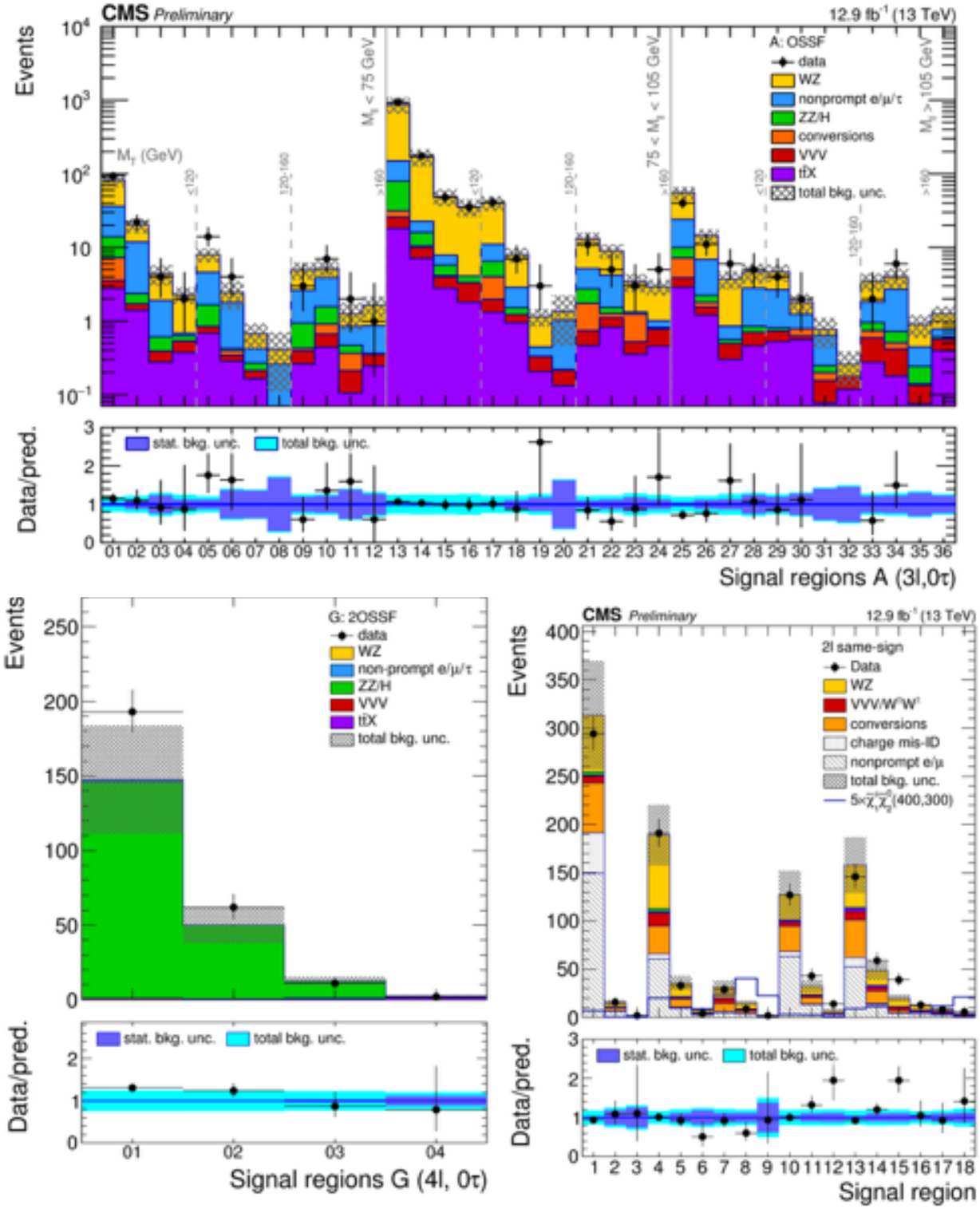


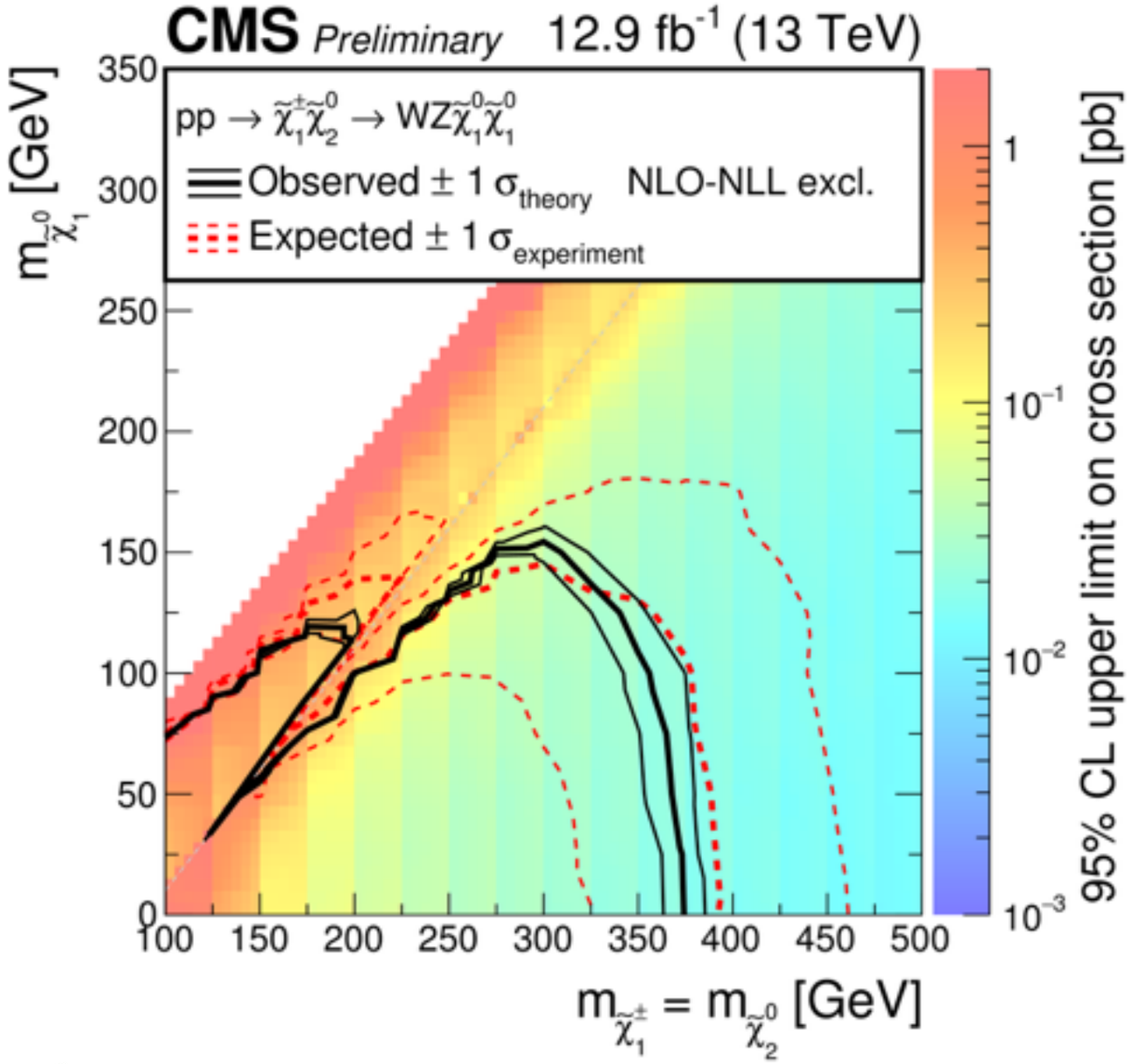




Non-resonant VV searches

- SUS-16-024: $Z(\rightarrow \ell\ell)W(\rightarrow \ell\nu)$ + E_T^{miss} and $Z(\rightarrow 2\ell)Z(\rightarrow 2\ell)$ + E_T^{miss}





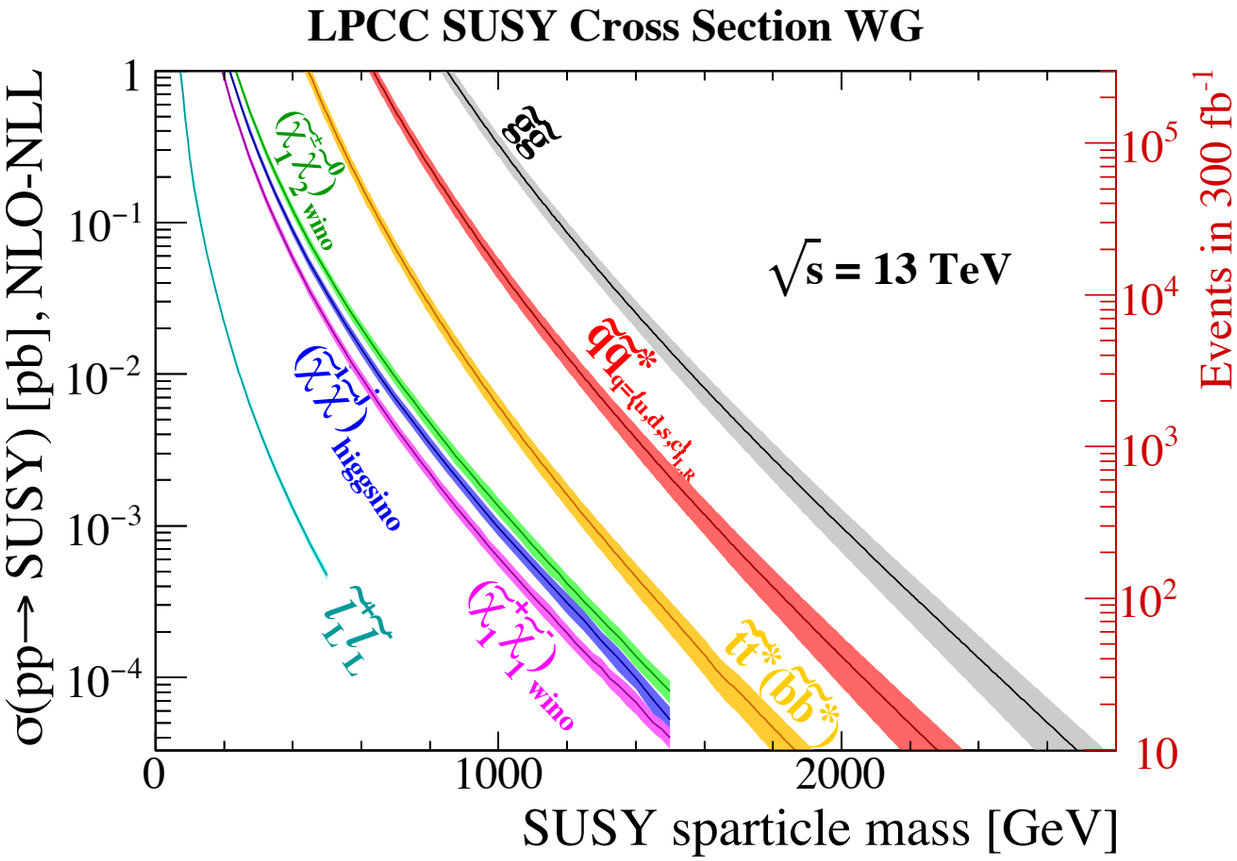
Same-sign dilepton signal regions for compressed spectra

MBI 2016

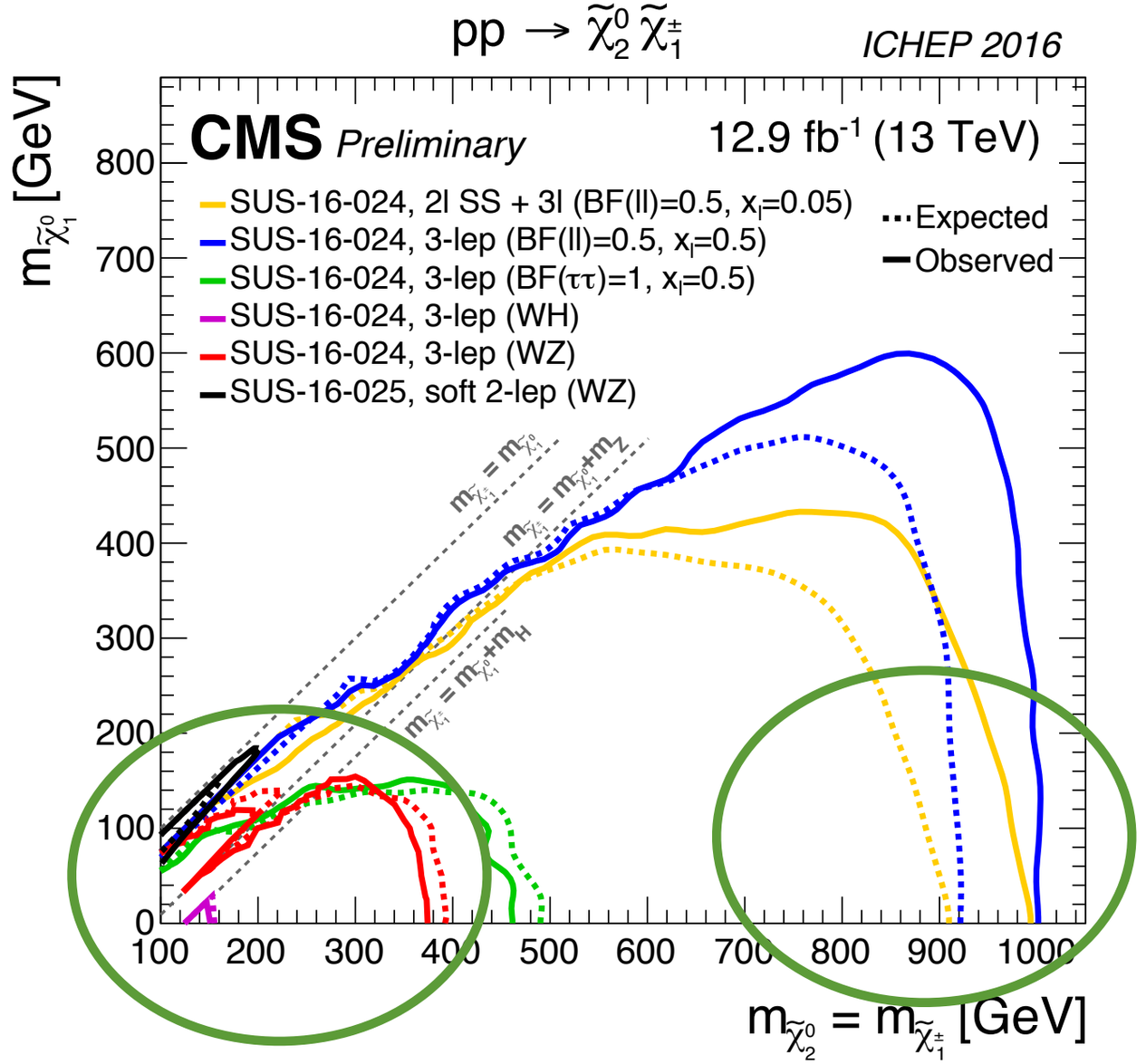
Non-resonant VV searches: summary

- Interpreted as a SUSY simplified model of neutralino+chargino direct production
- Strongest limits comes from slepton decays (not discussed here)

Largest "electroweakino" cross section



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1407.5066

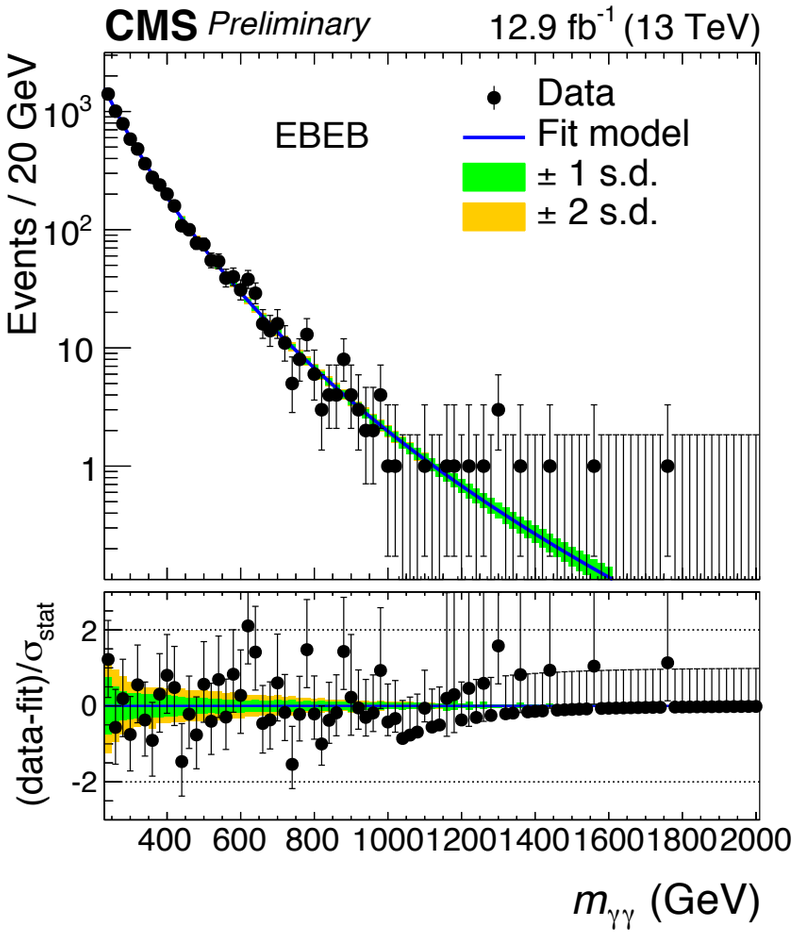


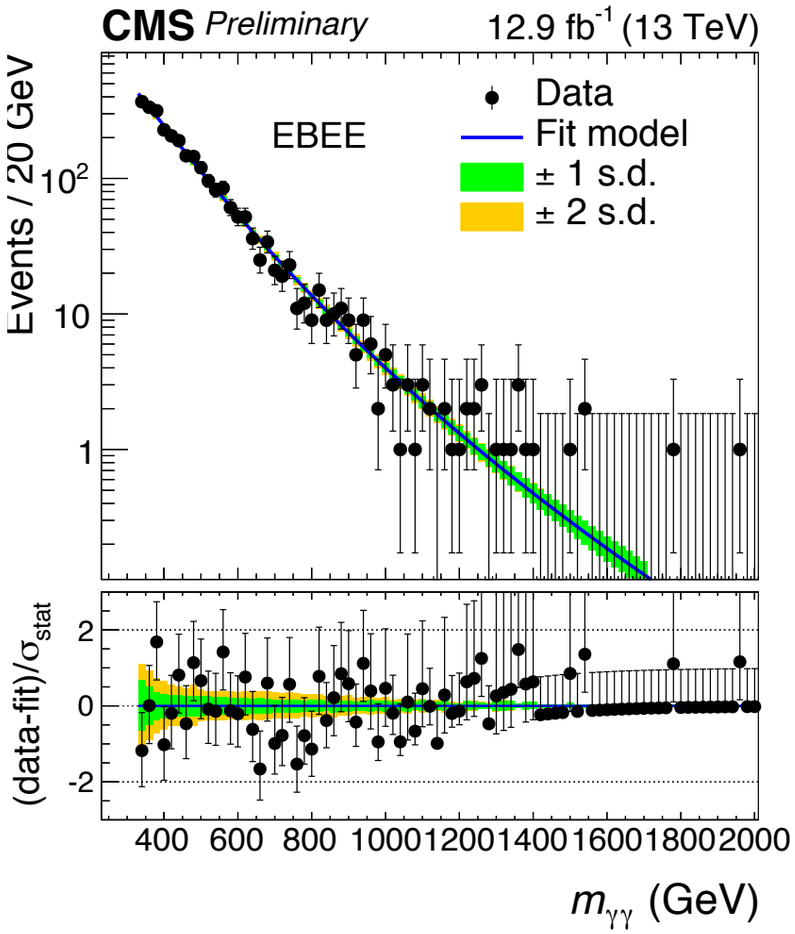
WZ+E_T^{miss} searches

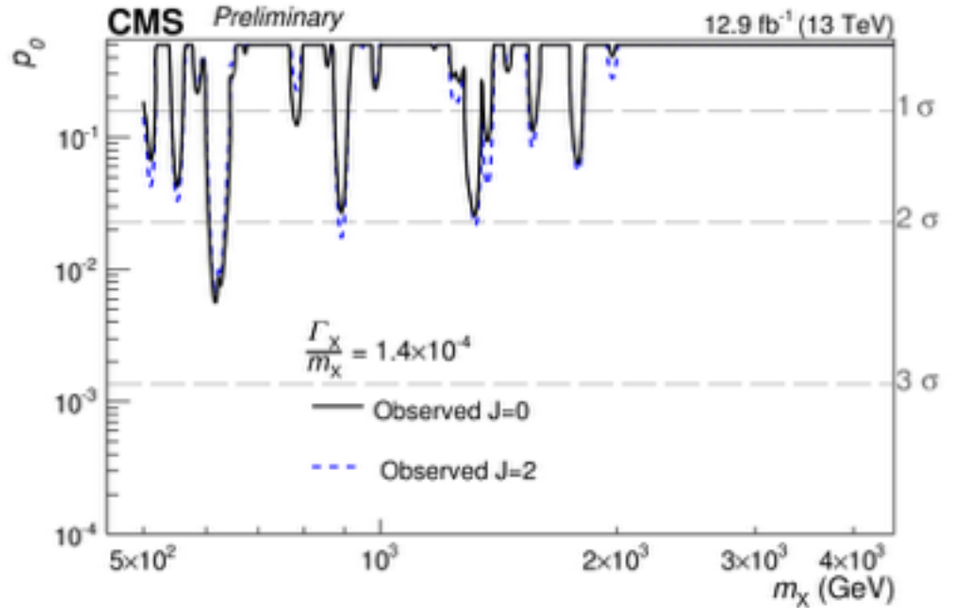
sleptons searches

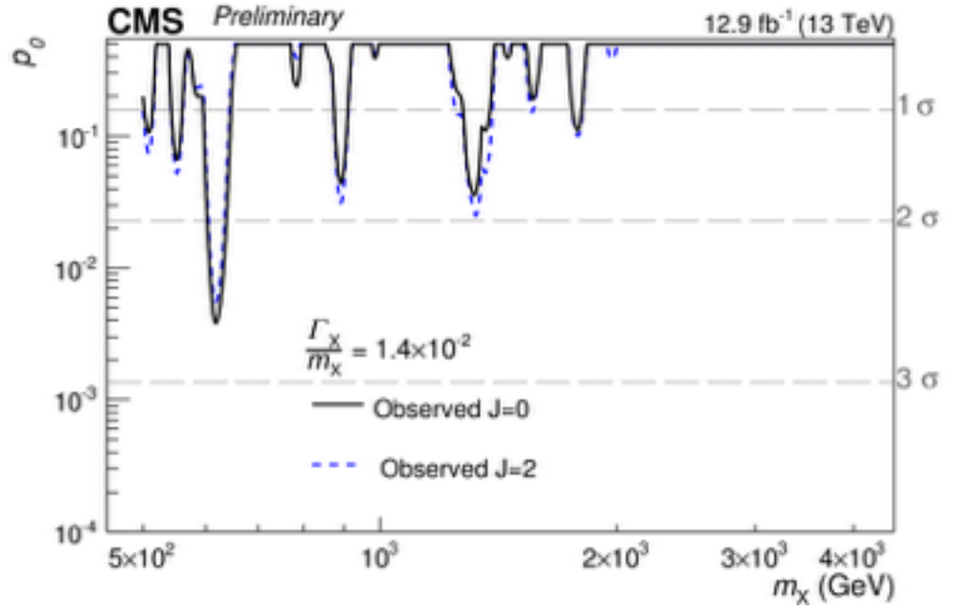
Resonant γγ and Zγ searches

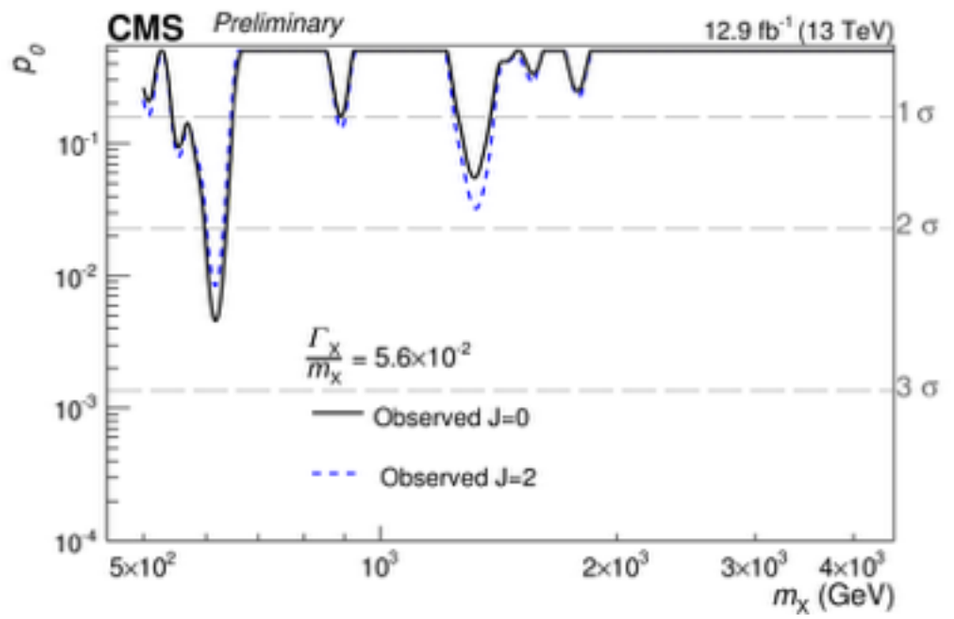
- EXO-16-027: X → γγ





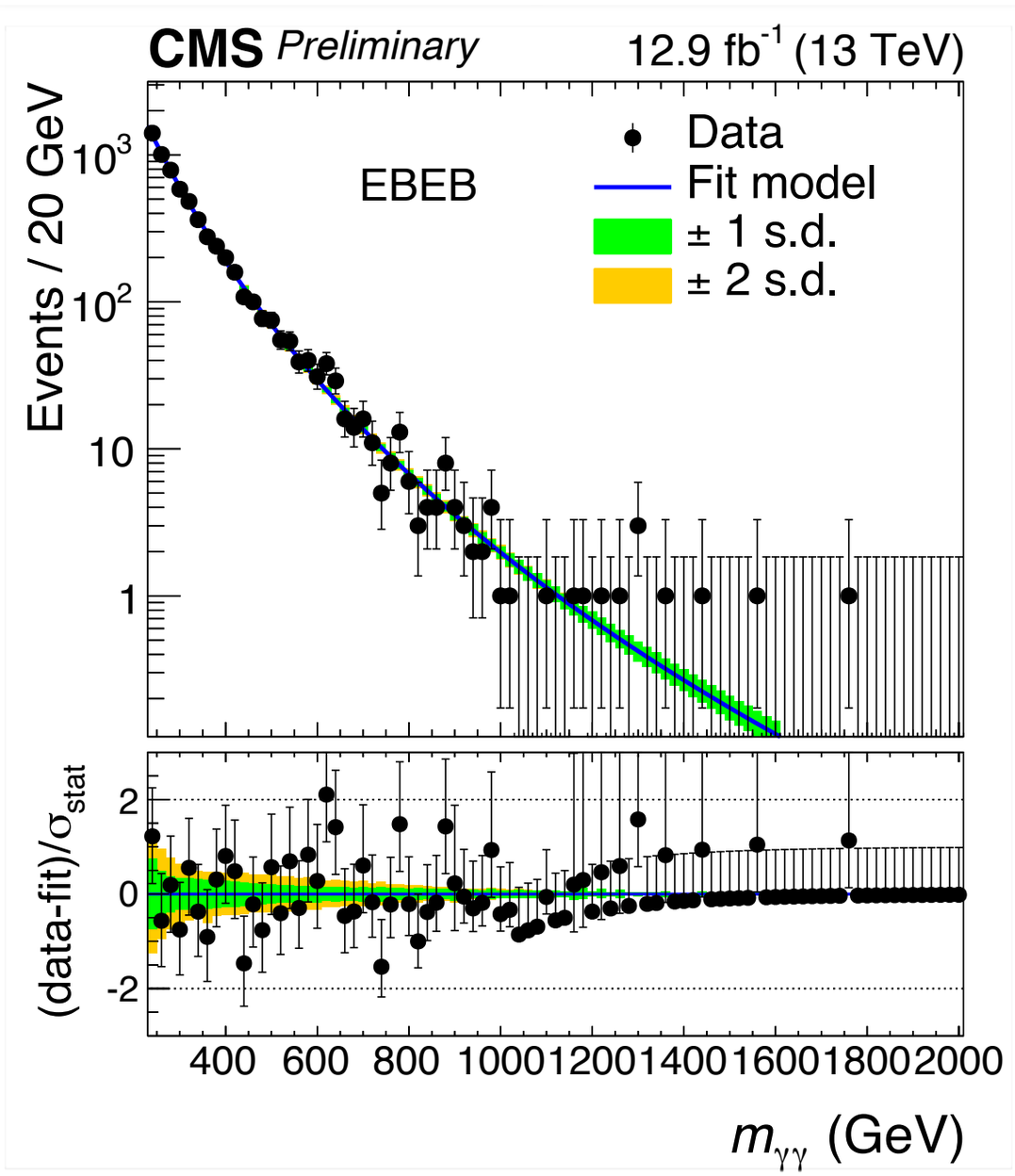


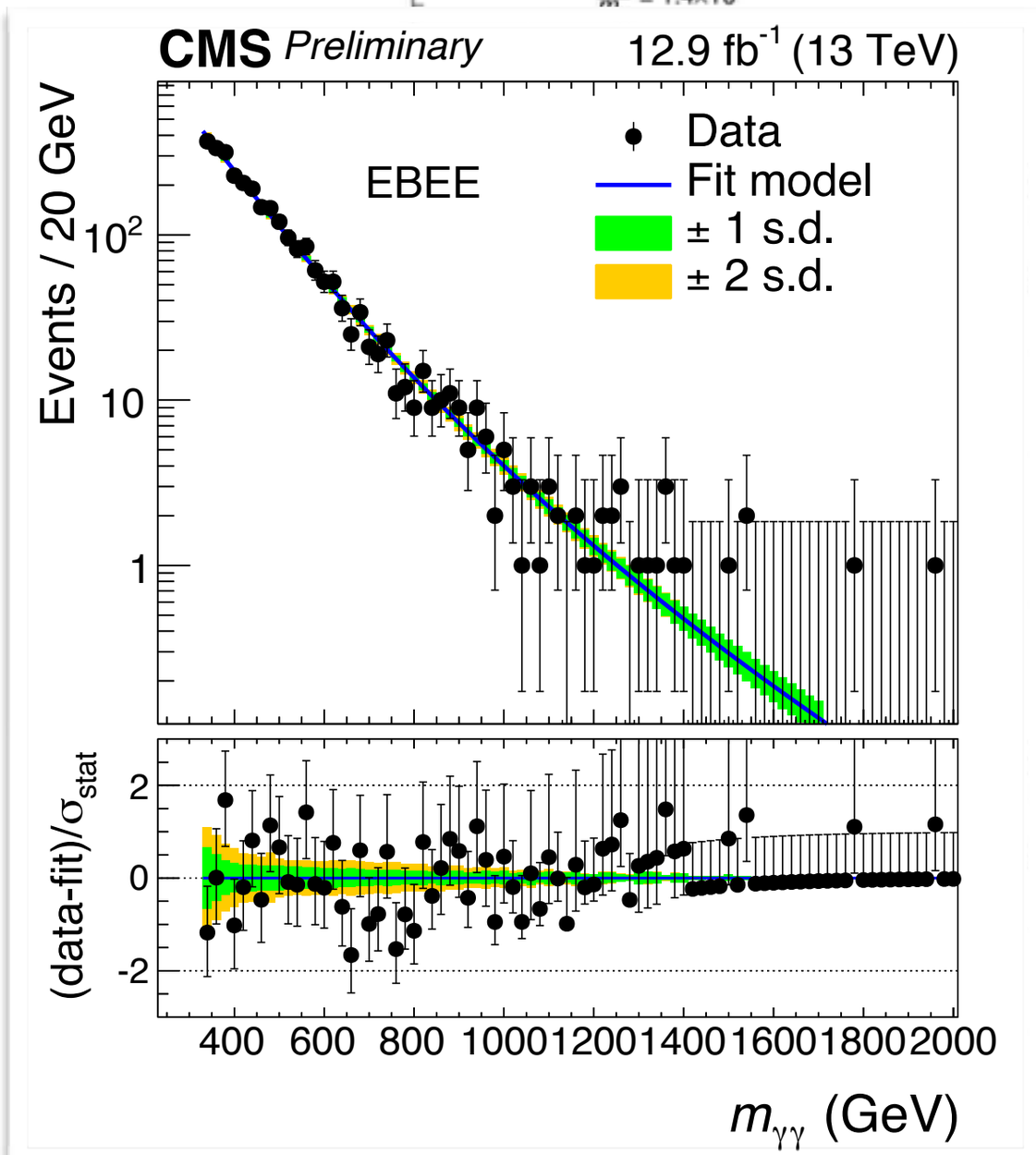




Resonant γγ and Zγ searches

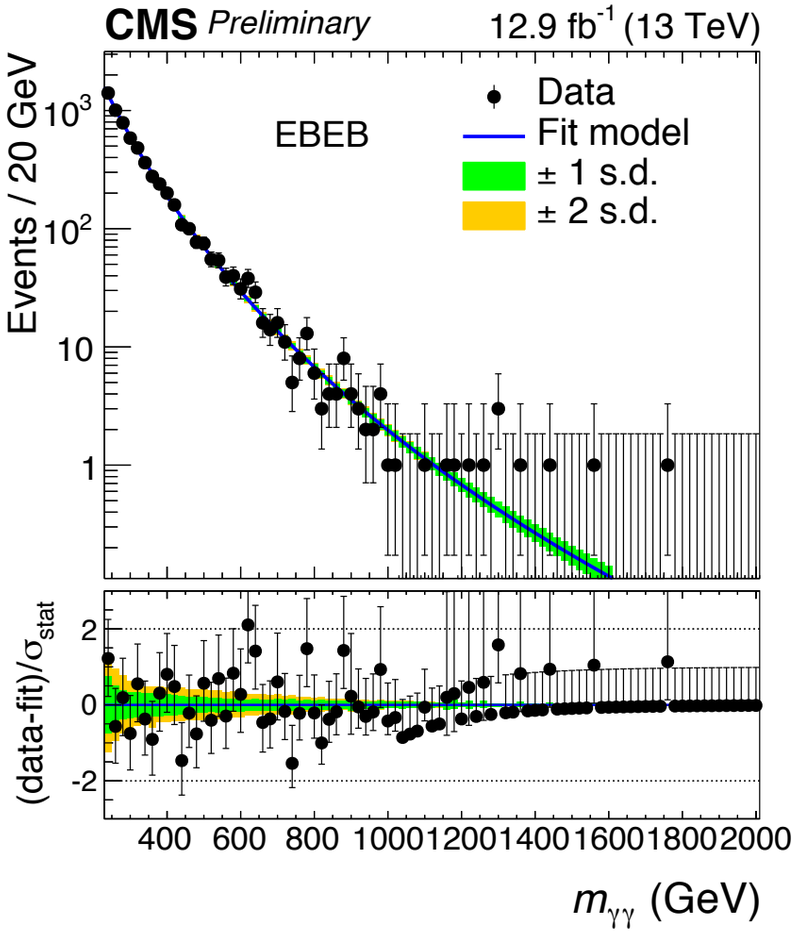
- EXO-16-027: X → γγ

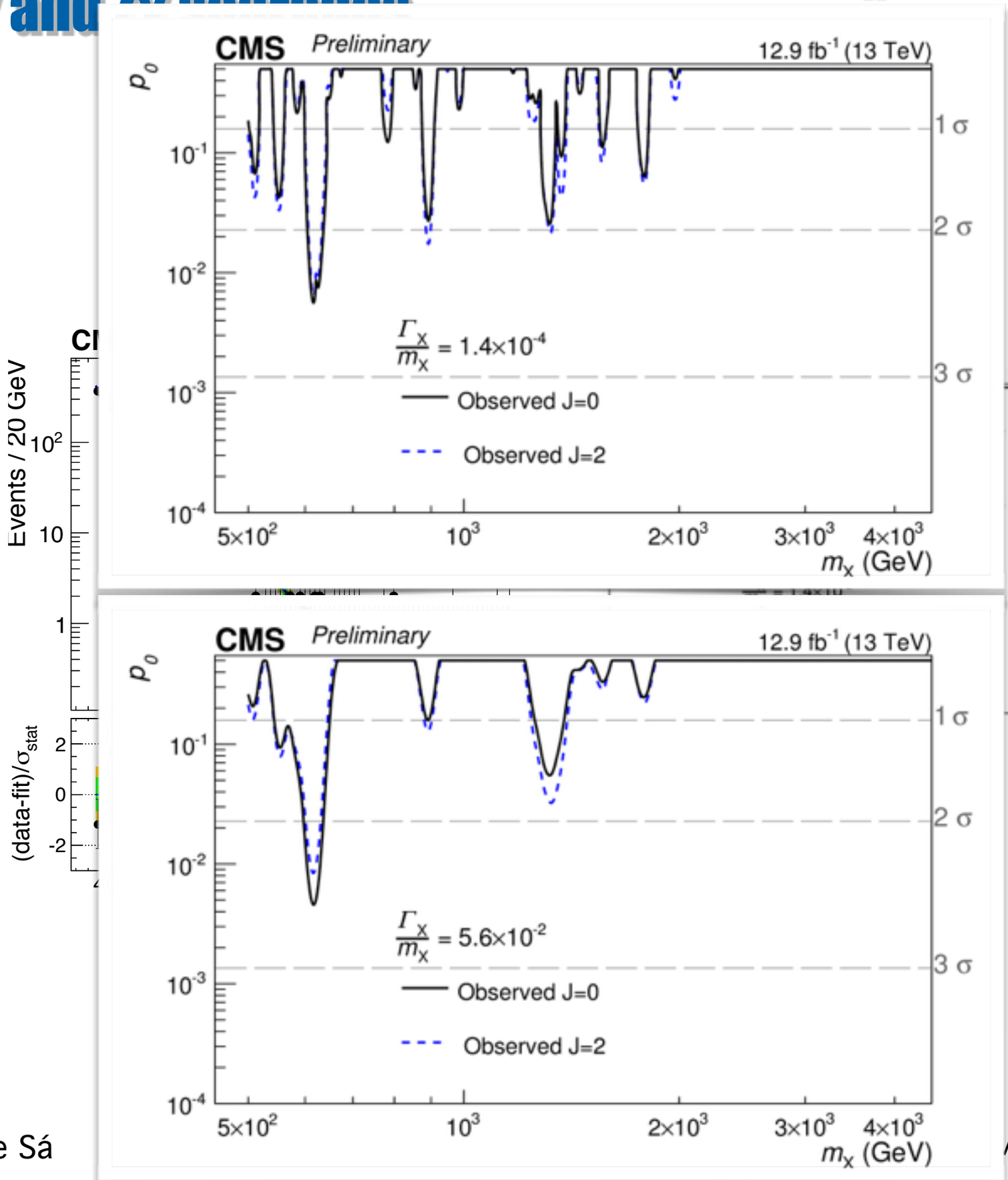




Resonant γγ and Zγ searches

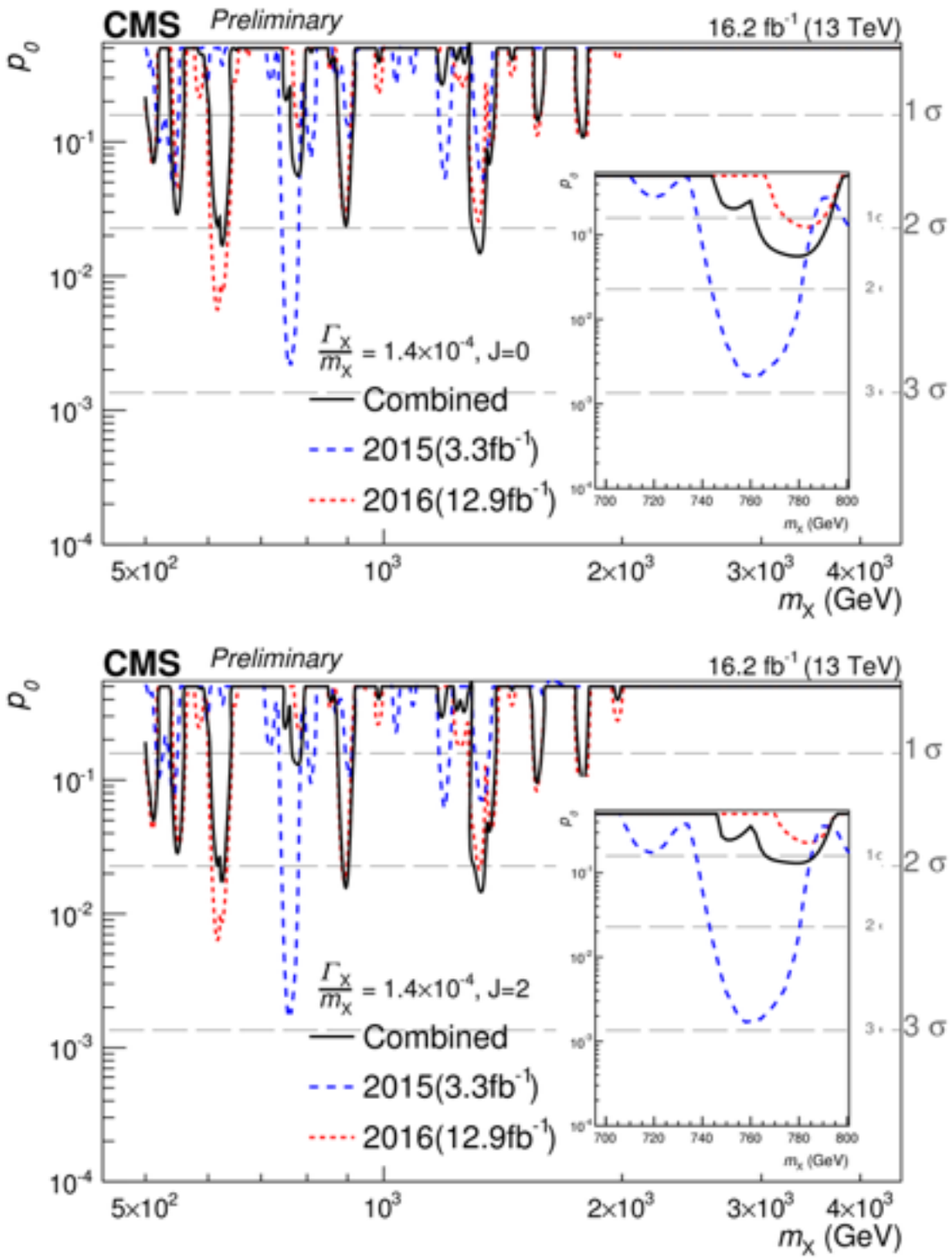
- EXO-16-027: X → γγ

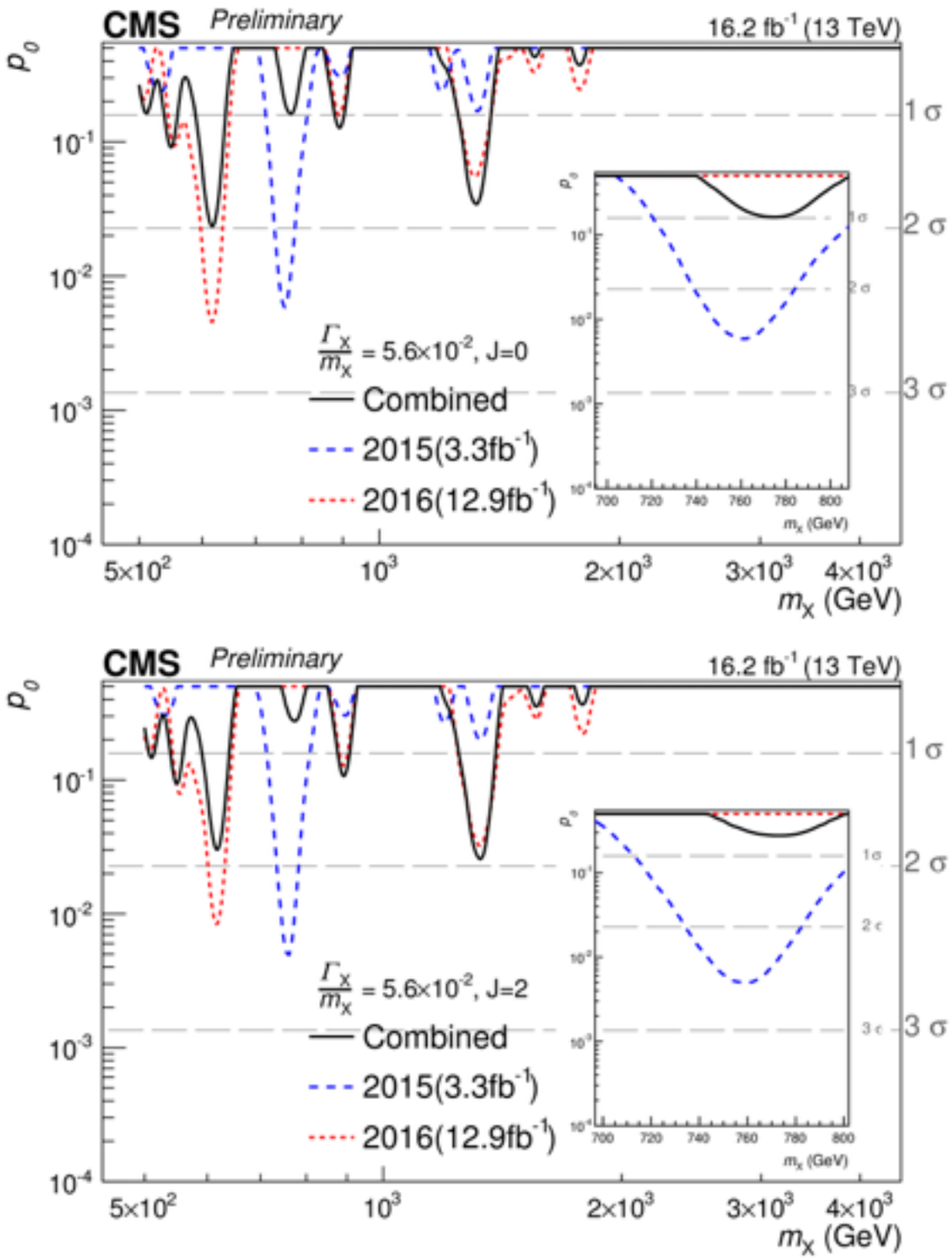




Resonant γγ and Zγ searches

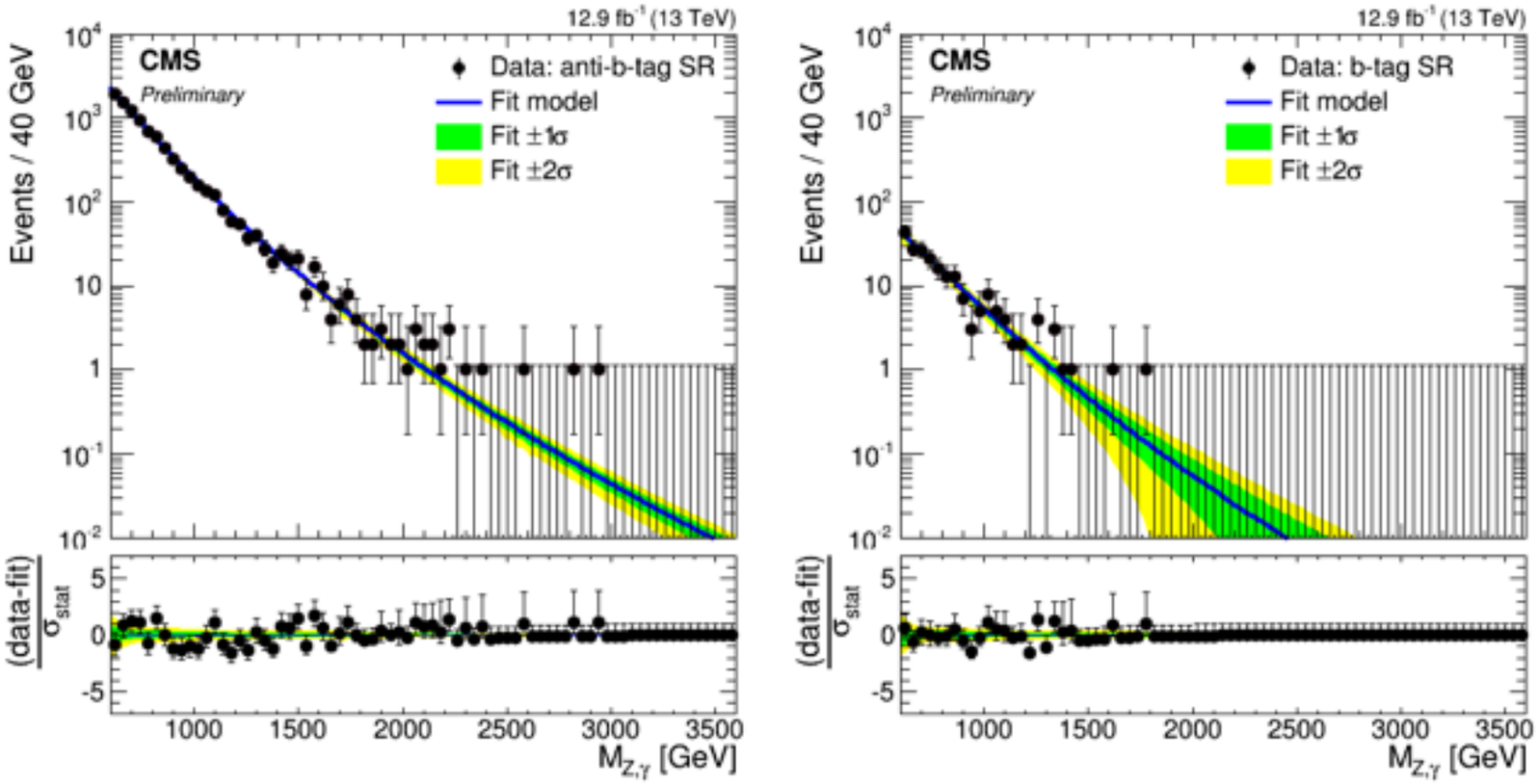
- Comparison of 2015 and 2016 X→γγ searches

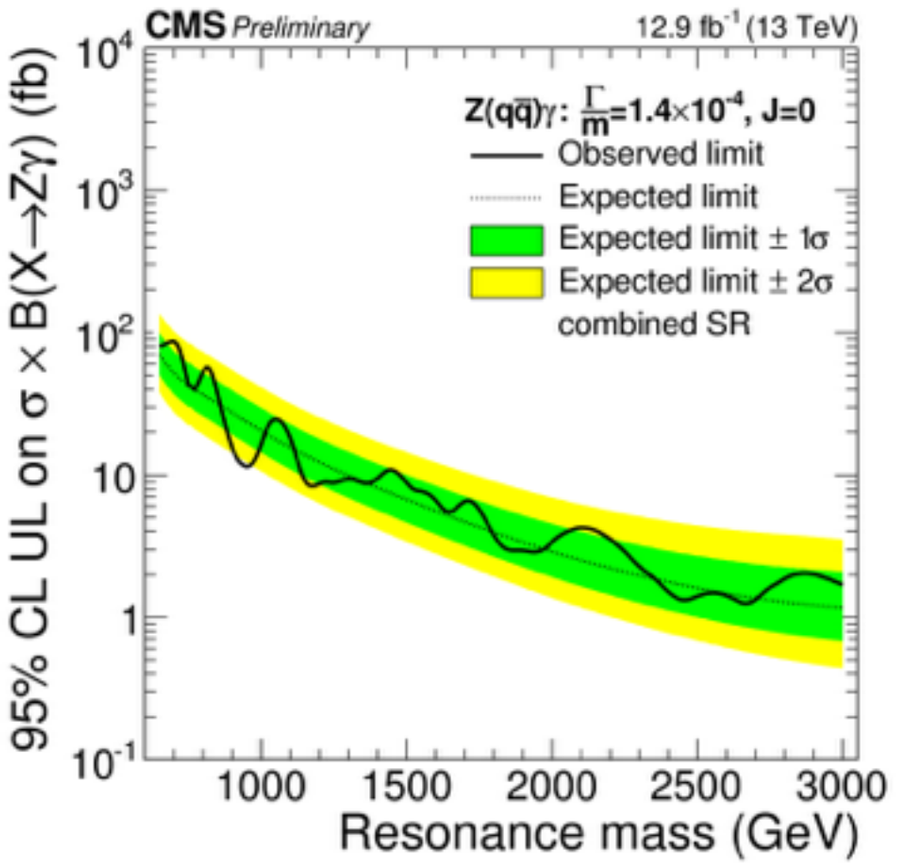




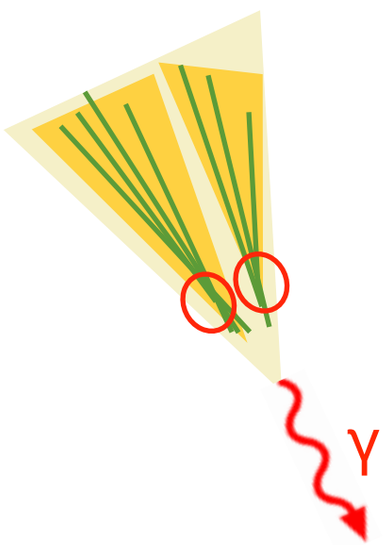
Resonant γγ and Zγ searches

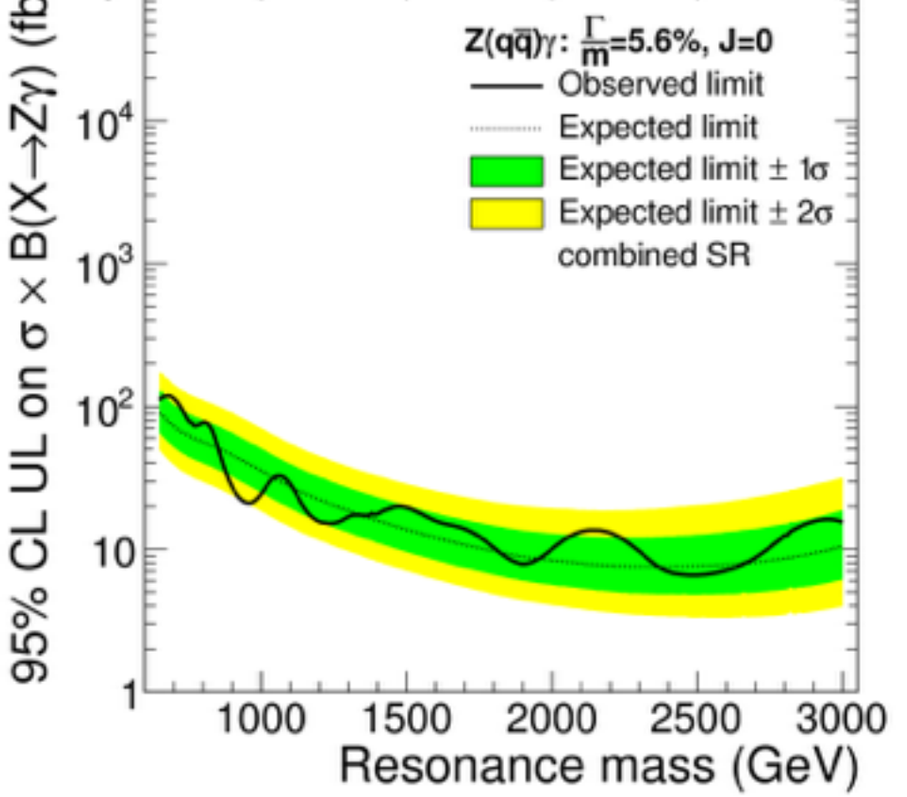
- EXO-16-035: X → Z(→J[qq])γ





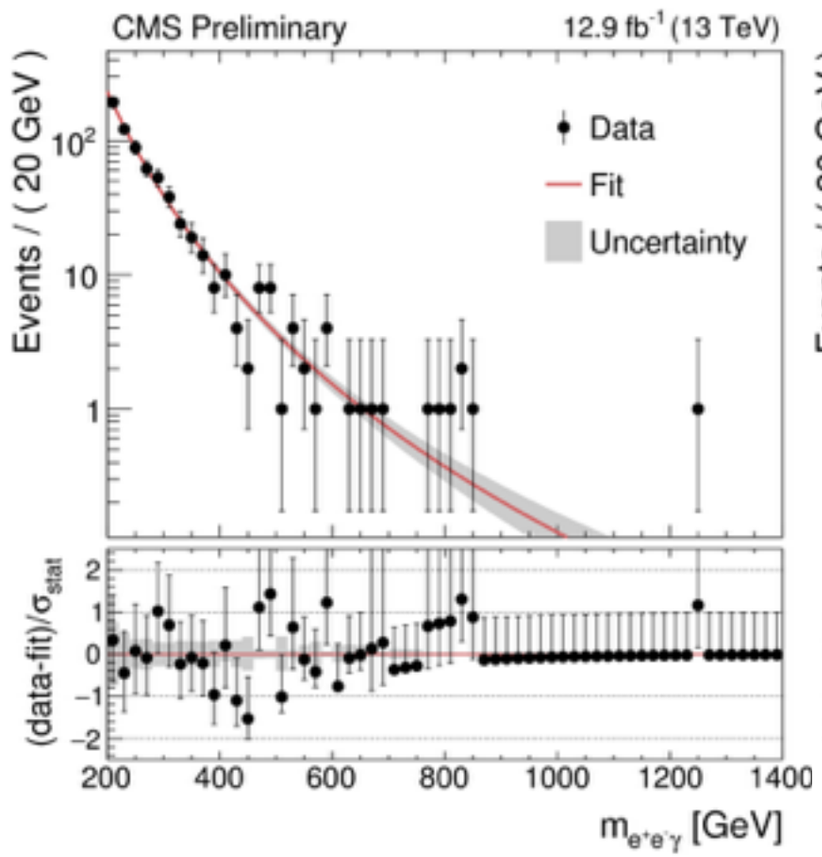
- Analysis performed in the merged regime.
- To improve sensitivity, the search is performed separately when at least one of the subjets is b-tagged (high purity) and when neither are (low purity).

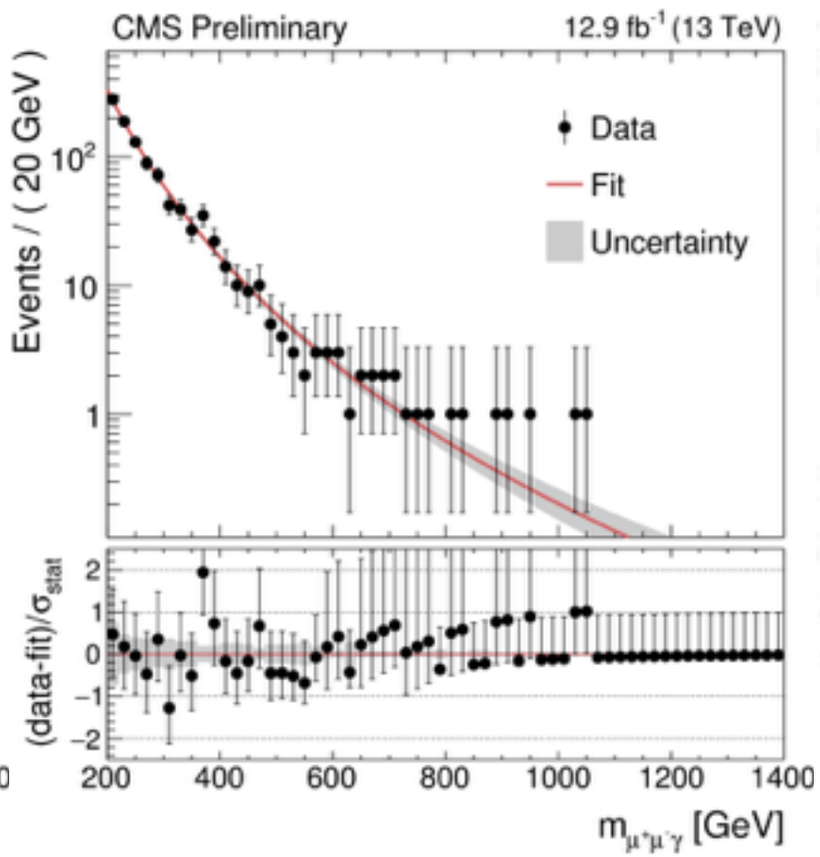


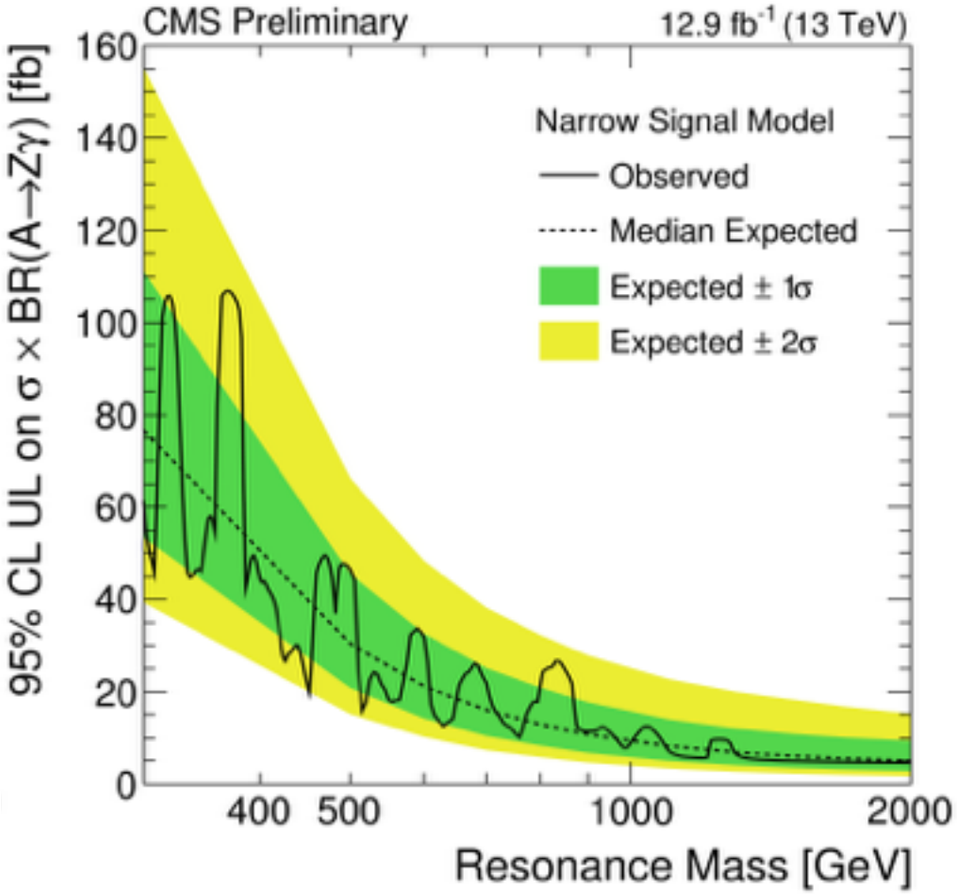


Resonant γγ and Zγ searches

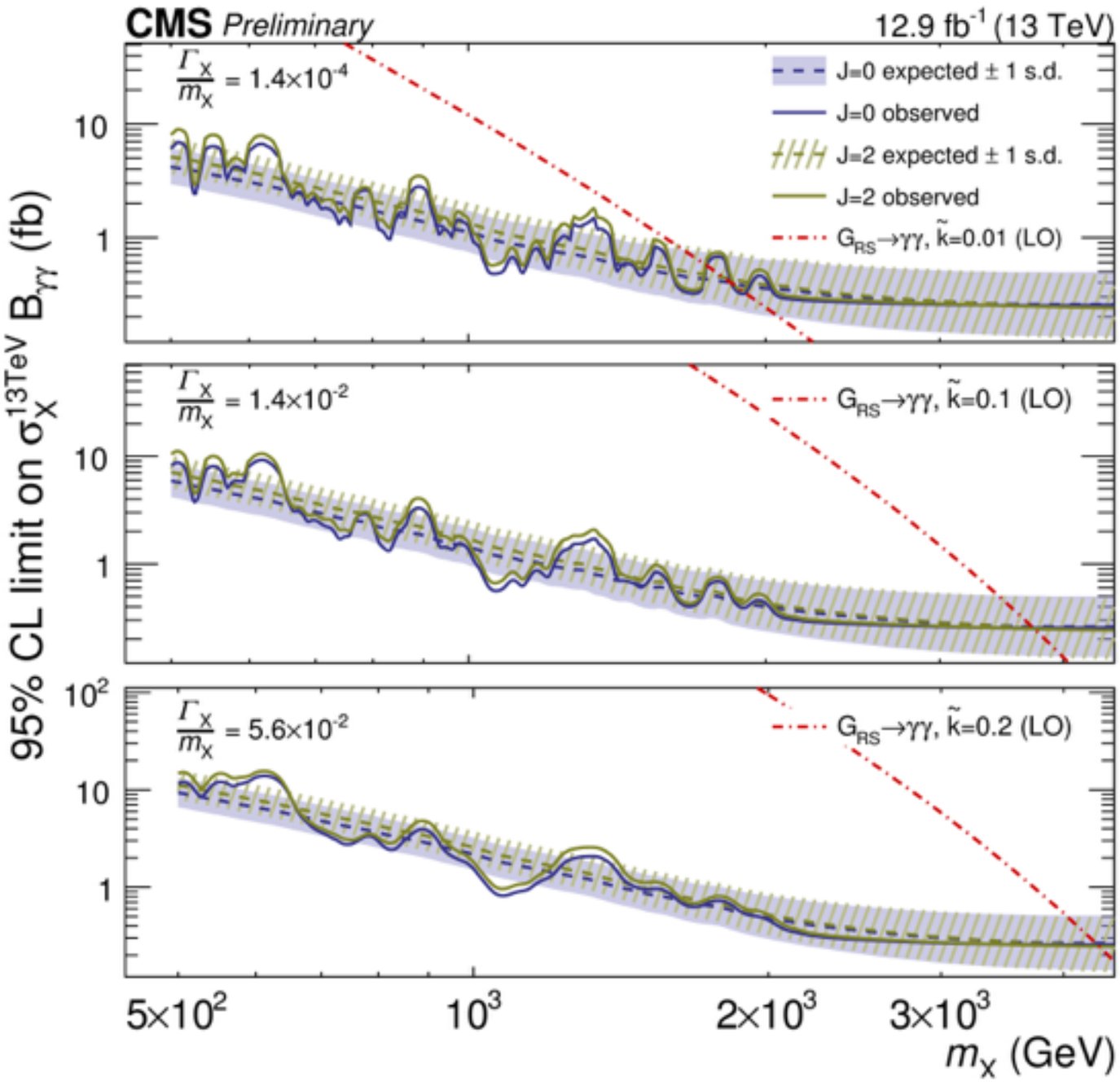
- EXO-16-034: $X \rightarrow Z(\rightarrow \ell\ell)\gamma$

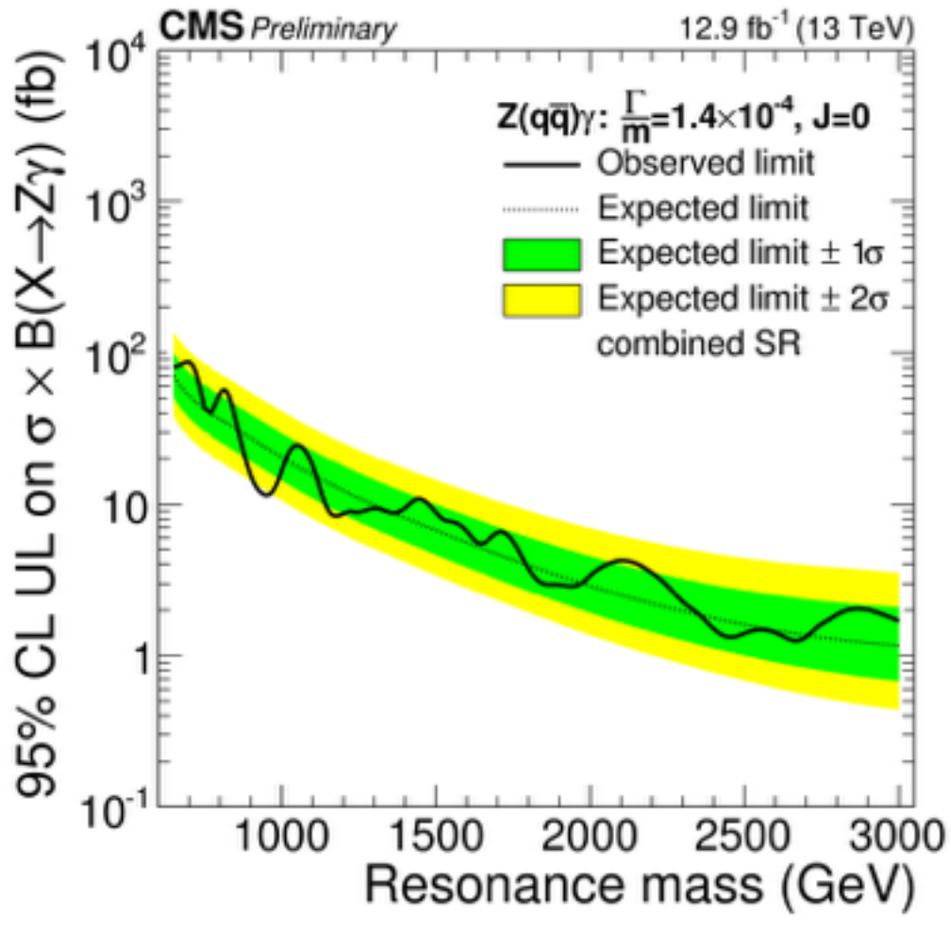


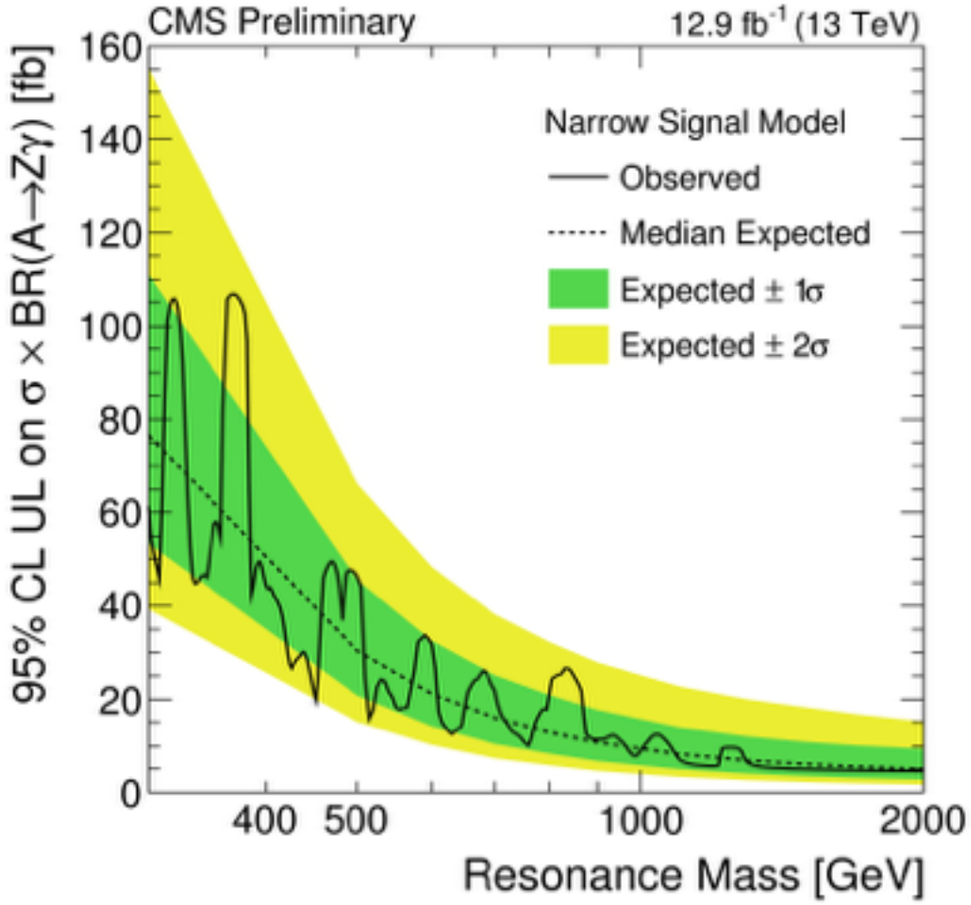




γγ and Zγ searches: summary







Conclusions 1/2

- We presented searches for new physics in final states with dibosons using the 13 TeV dataset CMS collected in 2015 and 2016.
- We discussed (some of the most recent) searches for new resonances decaying to HH, VV, γγ, and Zγ.
- No significant excess observed above background in any channel.

- In particular, using 12.9 fb^{-1} of integrated luminosity collected in 2016 with the CMS detector, no significant excess above background is observed in the diphoton final state consistent with the decay of a resonance with $m_X \sim 750$ GeV.
- Also, no significant excess above background consistent with a decay $X \rightarrow V(\rightarrow J[qq])V(\rightarrow J[qq])$ with $m_X \sim 2$TeV.

- We discussed new searches for non-resonant $WZ+E_T^{miss}$ and $WH+E_T^{miss}$ final states in the context of electroweak SUSY. No significant excess is observed.
- With 12.9 fb^{-1} of integrated luminosity collected in 2016, certain regions of the neutralino+chargino direct production phase-space can already be excluded.

Conclusions 2/2

- The LHC has already delivered over 25 fb^{-1} of integrated luminosity this year. Many new and more powerful results will be present soon in the search for new physics with dibosons.
- There are many more searches that are not ready but are already feasible with the dataset we currently have. Usually they just require more time to understand the data we collected.

Stay Tuned