BSM searches in resolved di-boson topologies

MBI 2017

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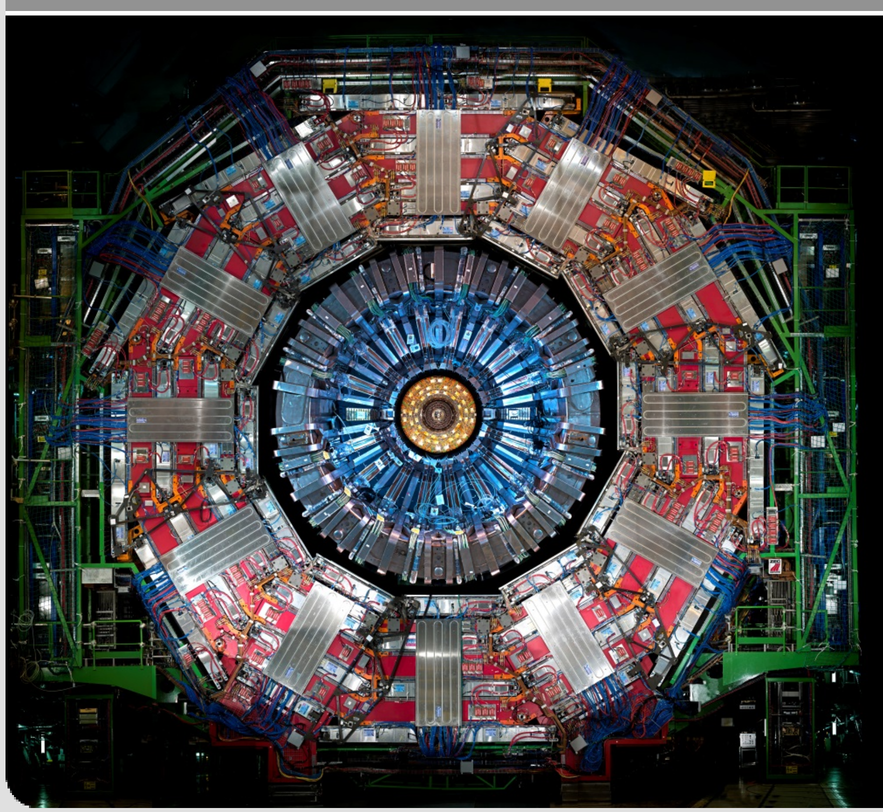

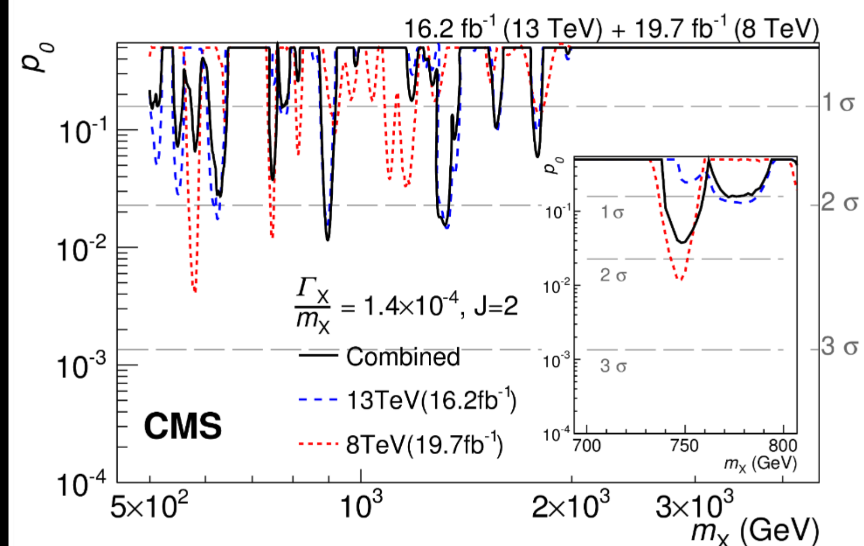

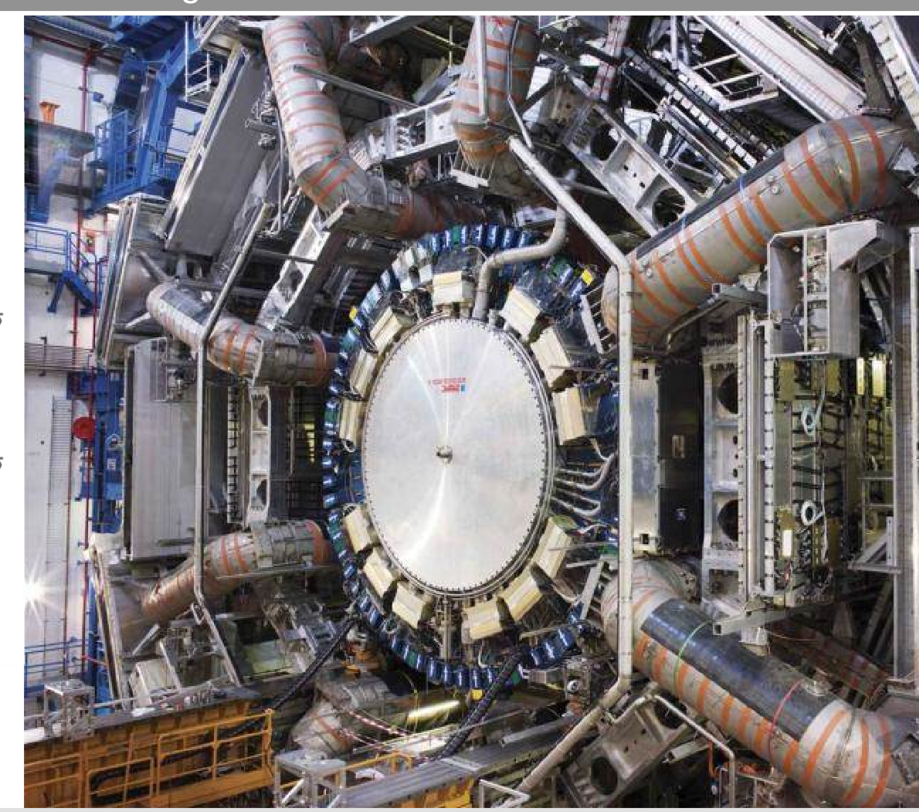

Motivation

- New Physics searches in di-boson channels don't have unified motivation
  => common theme is hierarchy problem:
  => why is the ewk scale so much lower the Plank scale

- Potential answers

	spin-0	spin-1	spin-2
⇒ extra-dimensions (ADD, RS-models)	Radion	-	Graviton
⇒ extended gauge groups (partial compositeness)	-	Z',W'	-
⇒ extended Higgs sectors (2HDM, scalar mixing…)	$H^{\pm}$ A,H	-	-

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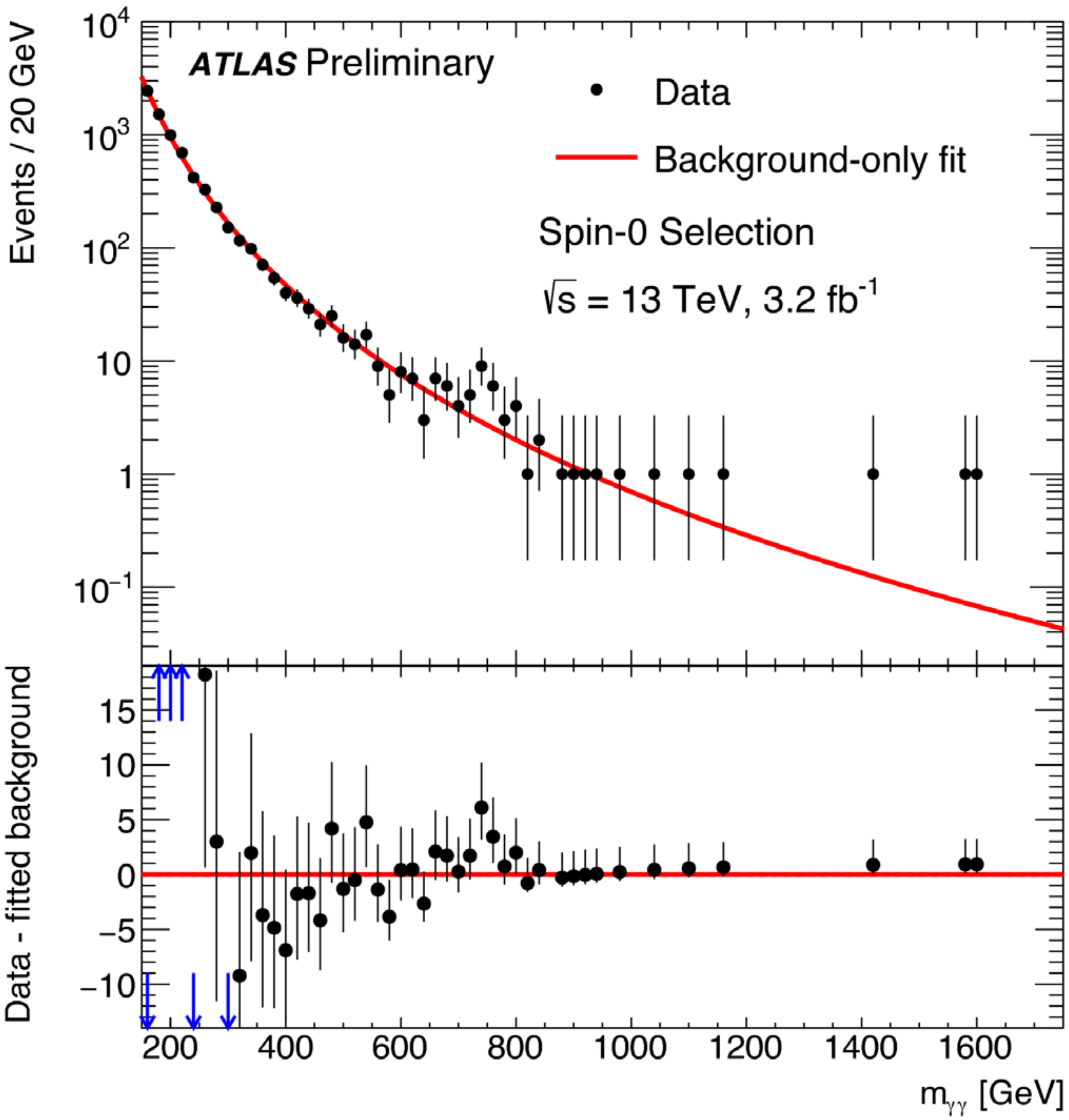


[ATLAS-CONF-16-018]

- Explicit models are a nice starting point for BSM searches
- But need to prepared for the unexpected
- Example: 750 GeV "signal"
- Doesn't really fit any of the models discussed above
- Still generated ~500 theory papers explaining the excess

Keep your eyes open for surprises!

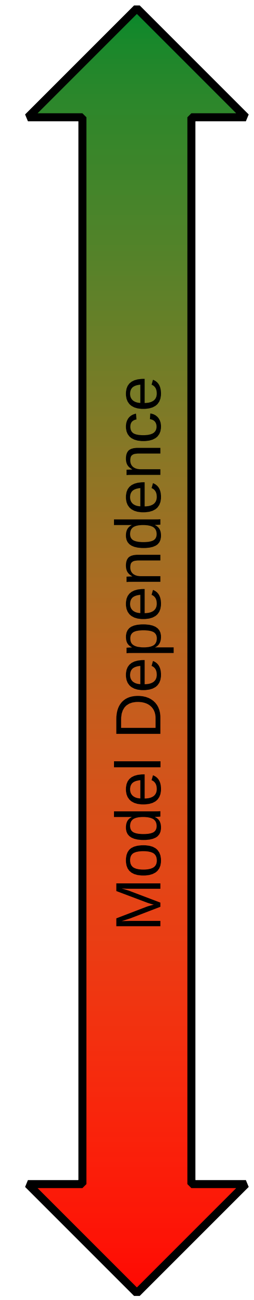
Analysis Strategies

- Simple “bump hunt”

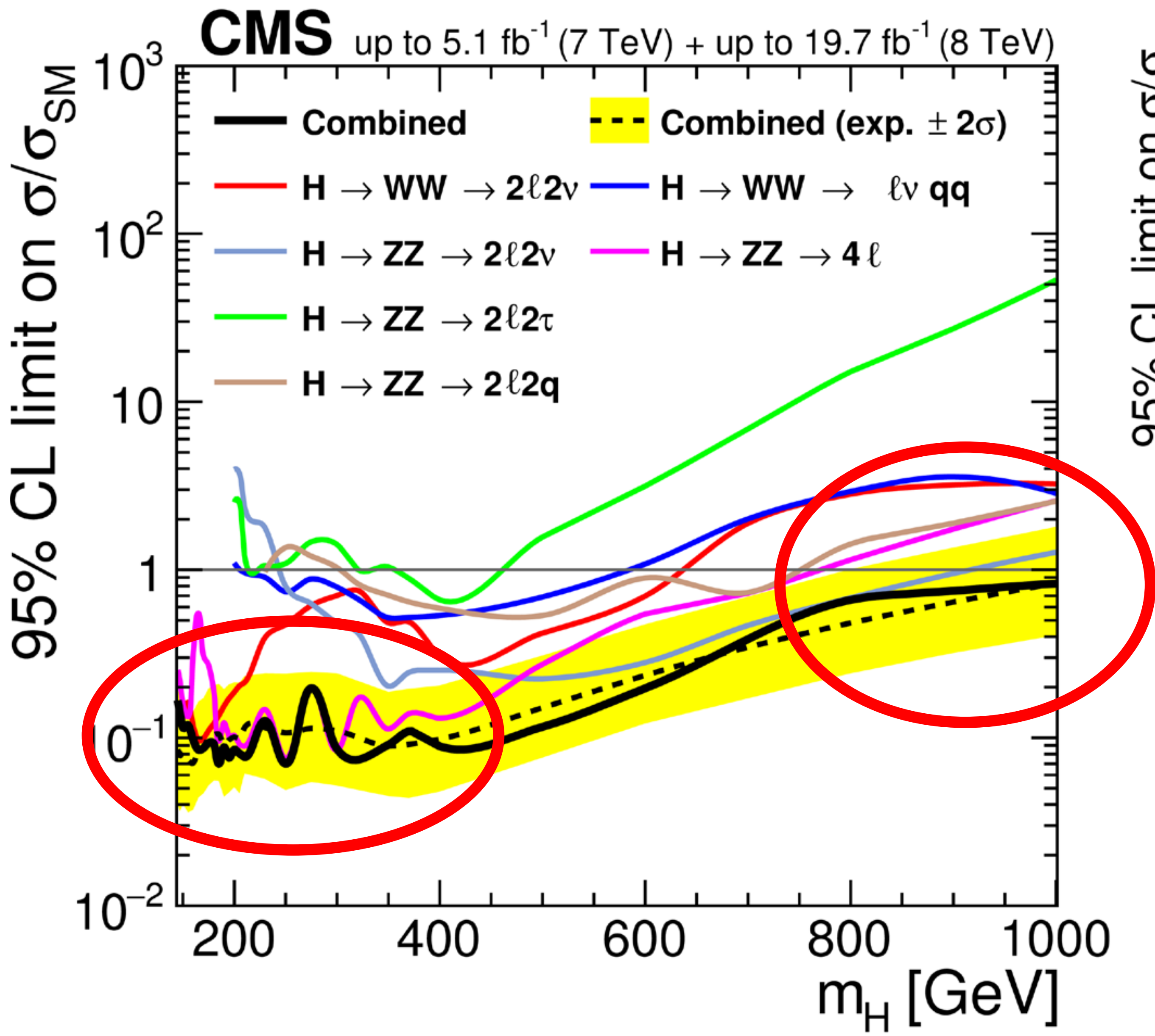
- Signal/background interference effects

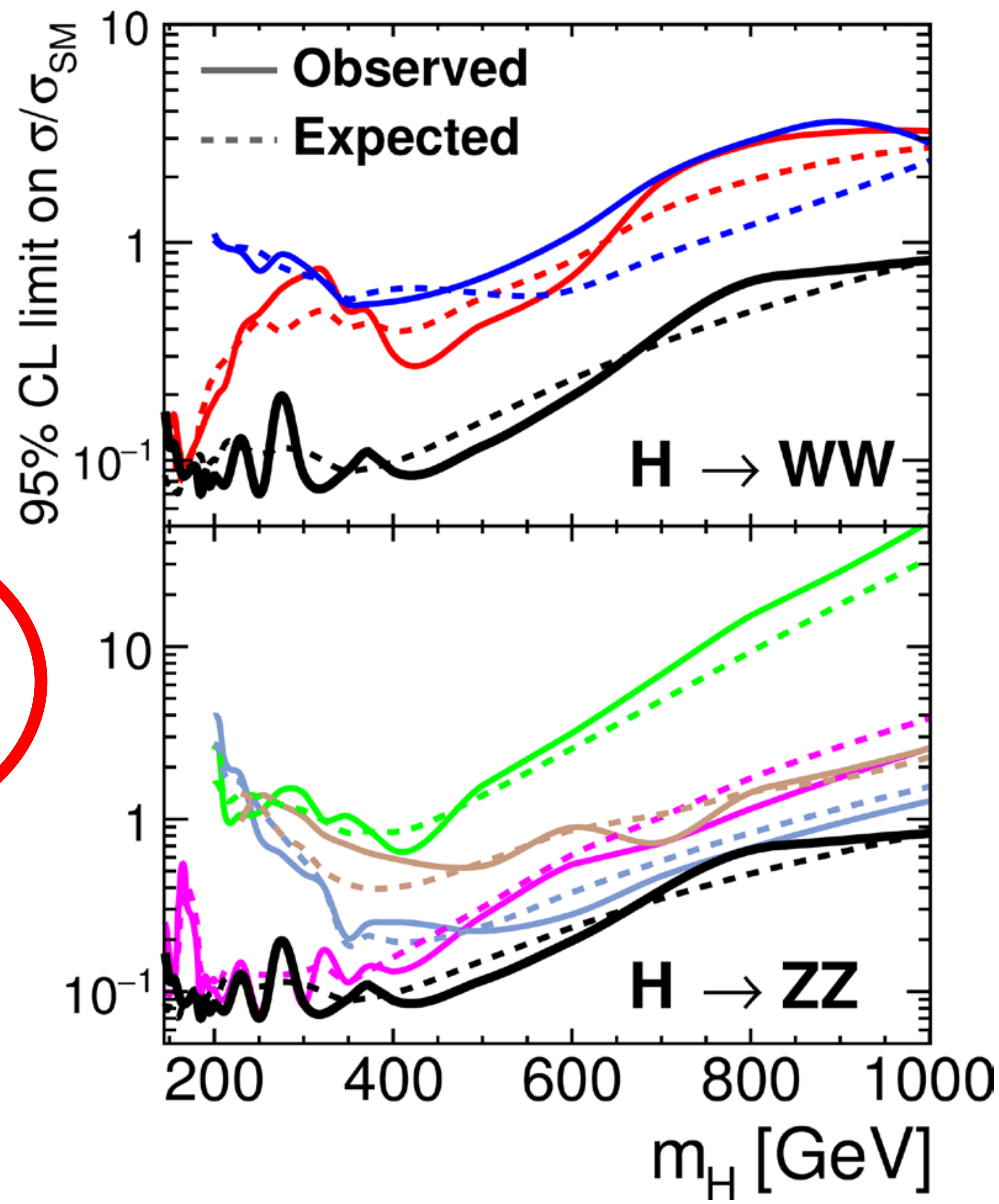
- VBF vs qq vs gg initial states
  => additional jet tags
  => final state distributions dependent on initial state

- Likelihood discriminants
  multivariate discriminators
  deep learning



Boosted vs Resolved





[JHEP 10 (2105) 144]

Low masses:
Background suppression is key
=> leptonic channels

High masses:
low signal cross sections,
needs highest branching ratios
=> hadronic decays

Channels to Consider

Results from LHC on:

- $\gamma\gamma$
- $Z\gamma$
- WW
- ZZ
- WZ

Not covered:

- Boosted Hadronic decays (see Zhaoxu‘s talk)
- Final states with Higgs bosons (see Pascal‘s talk)
- Run I (8 TeV) data

Results + Conclusion

- No BSM physics discovered
- Come back next year to more data

Backup

Di-Photon Searches

Continuation of controversial 750 GeV excess analysis

Two spin-hypotheses:

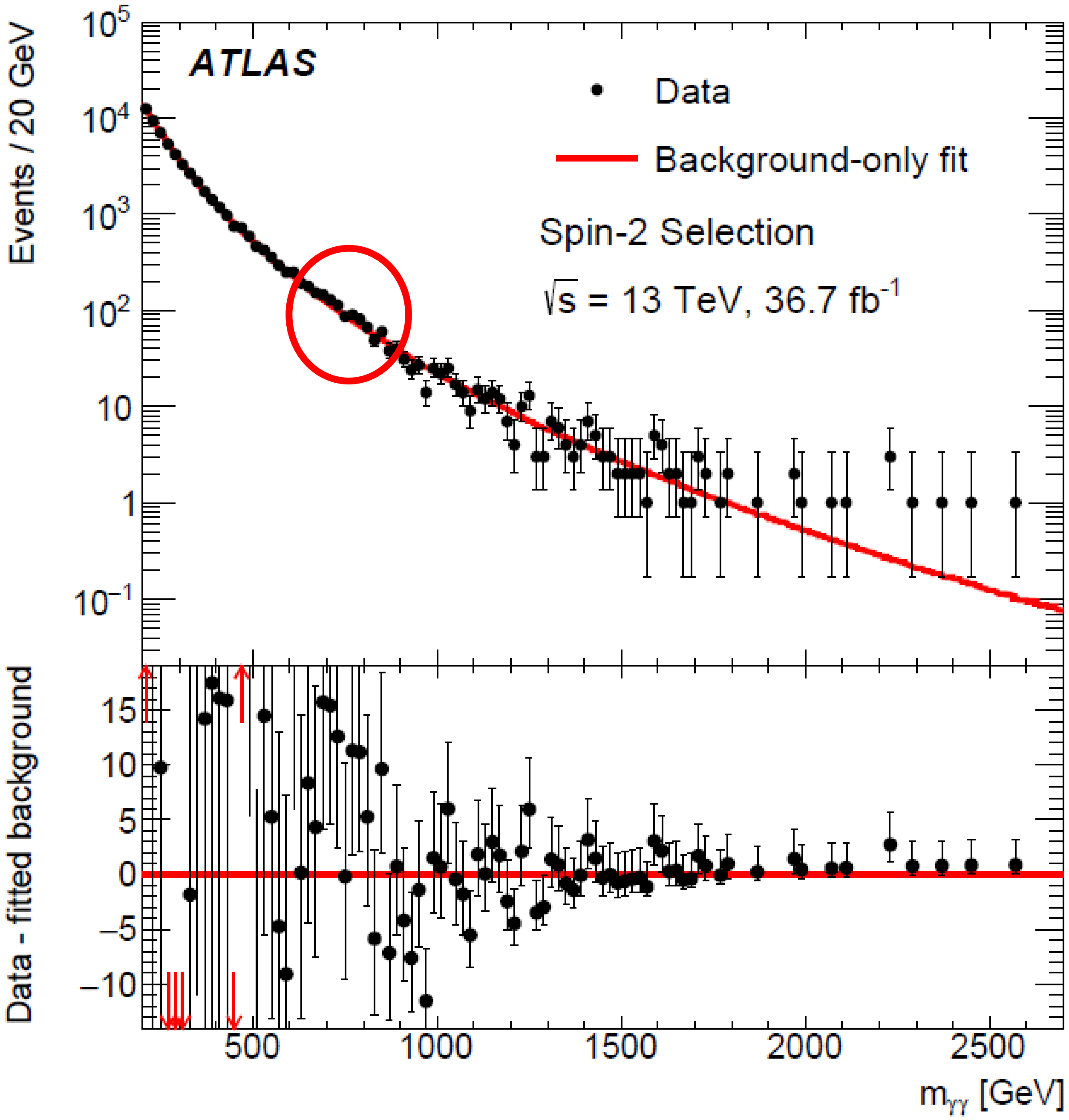
Spin 0: $pt_\gamma > 0.4/0.3\ m_{\gamma\gamma}$ => very central

Spin 2: flat pt_γ cut (55GeV)

Interesting feature:

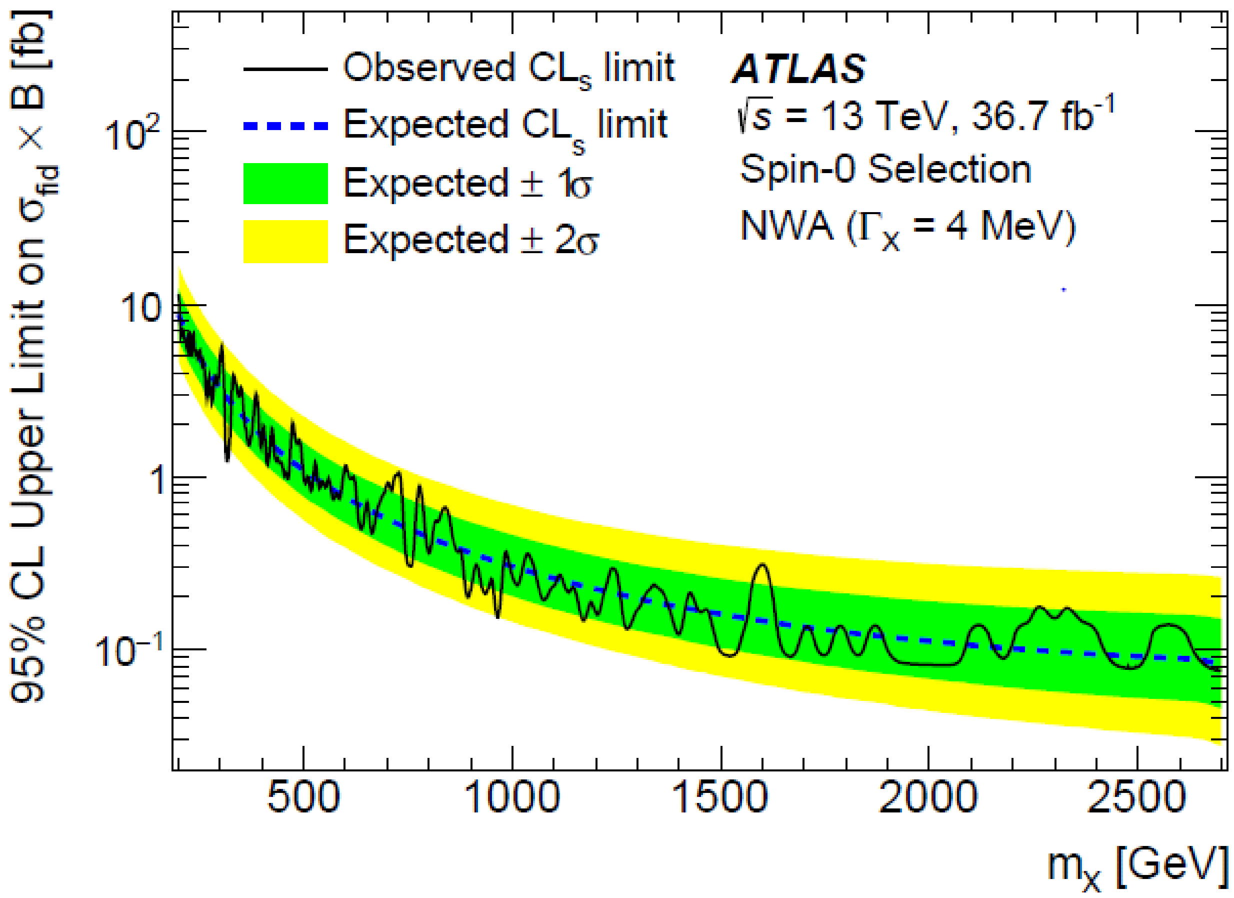
Includes search for non-resonant high mass enhancement

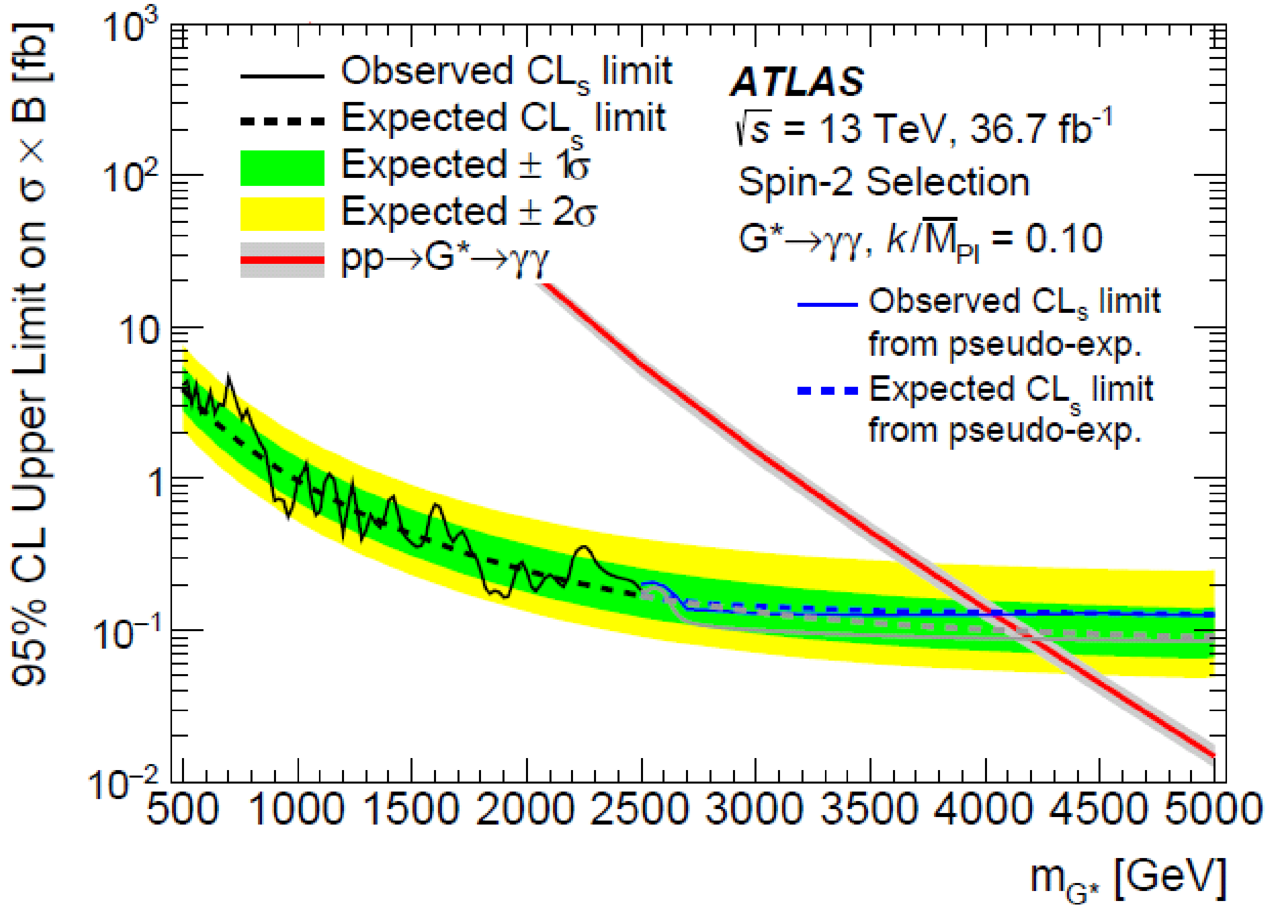
Interpreted in ADD extra dimension mode



[arxiv:170-04147]

Diphoton limits





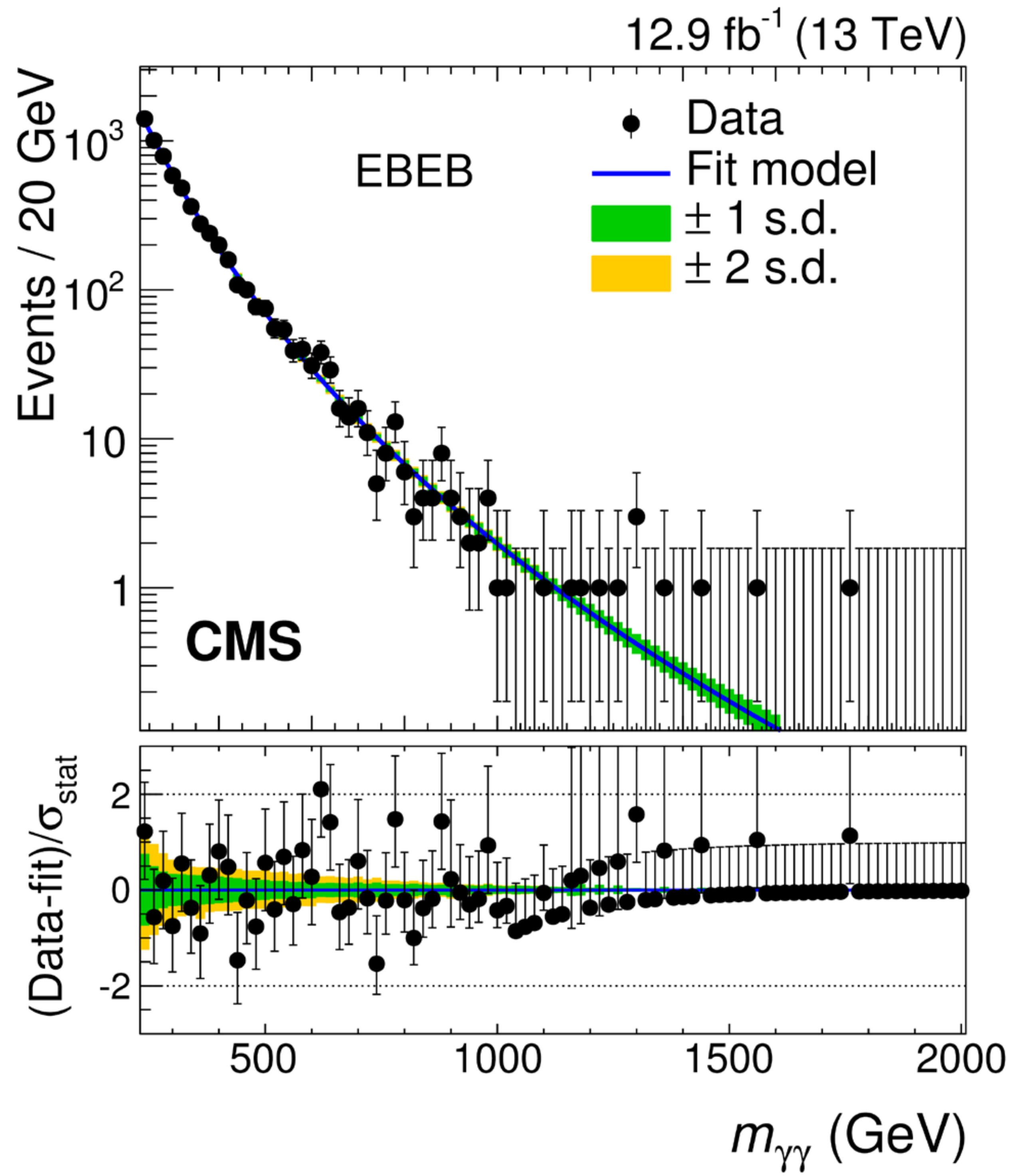
- Still some excess around 700 GeV (2.8σ for 2016 data)
- 10x integrated luminosity compared to 2015 data
  =>would expect significance to grow in case of real signal

[arxiv:170-04147]

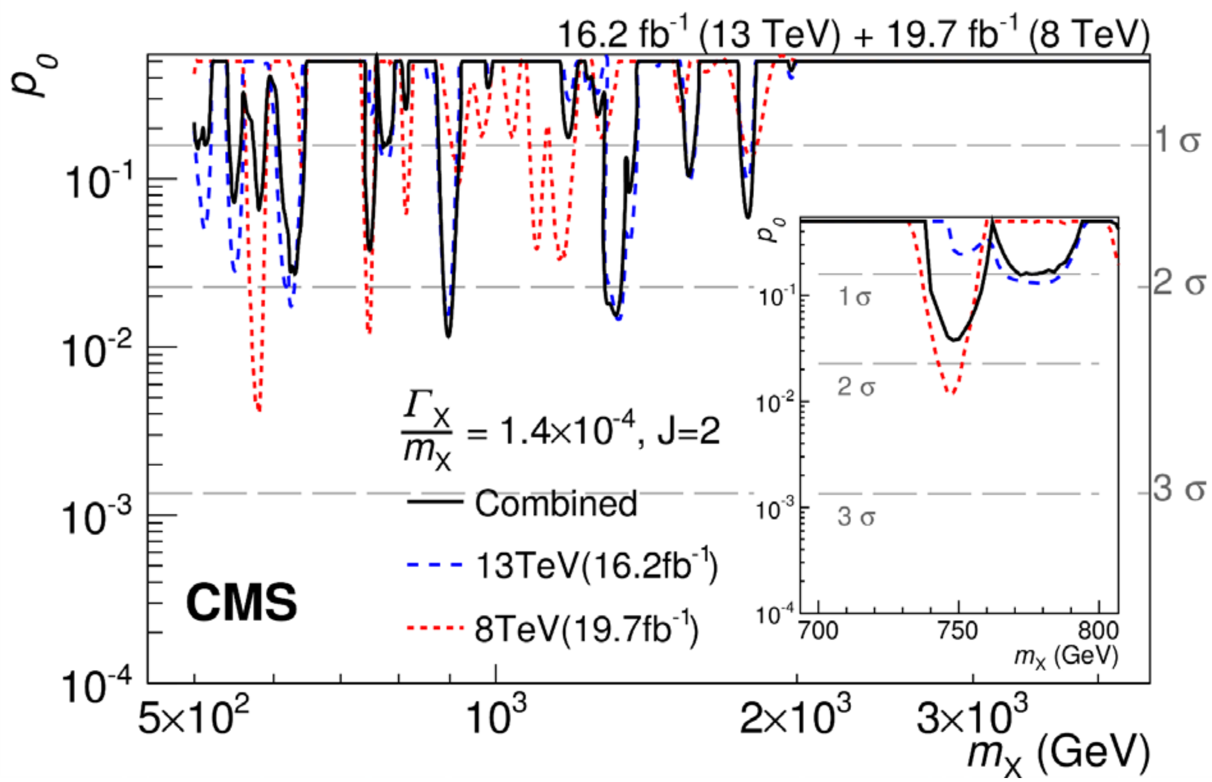
Di-Photon Searches

Similar analysis in CMS
Very straight forward:
→ no signal dependent categories
→ simple bump hunt o smoothly falling
  background
=> Aids in potential re-interpretation

No excess observed

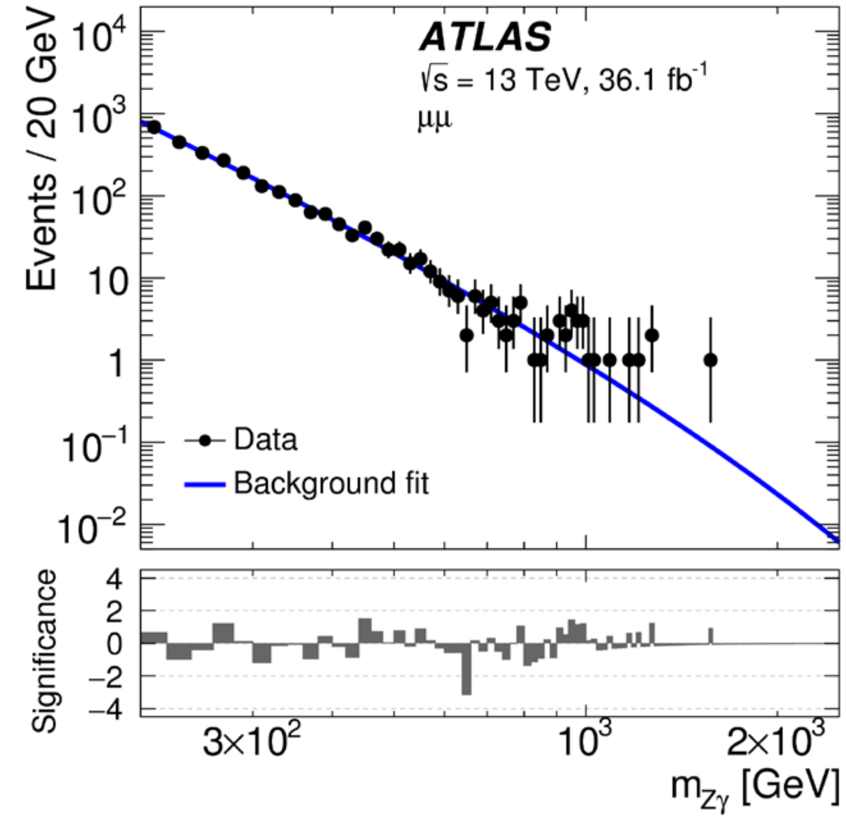


[PLB 767 (2017) 147]

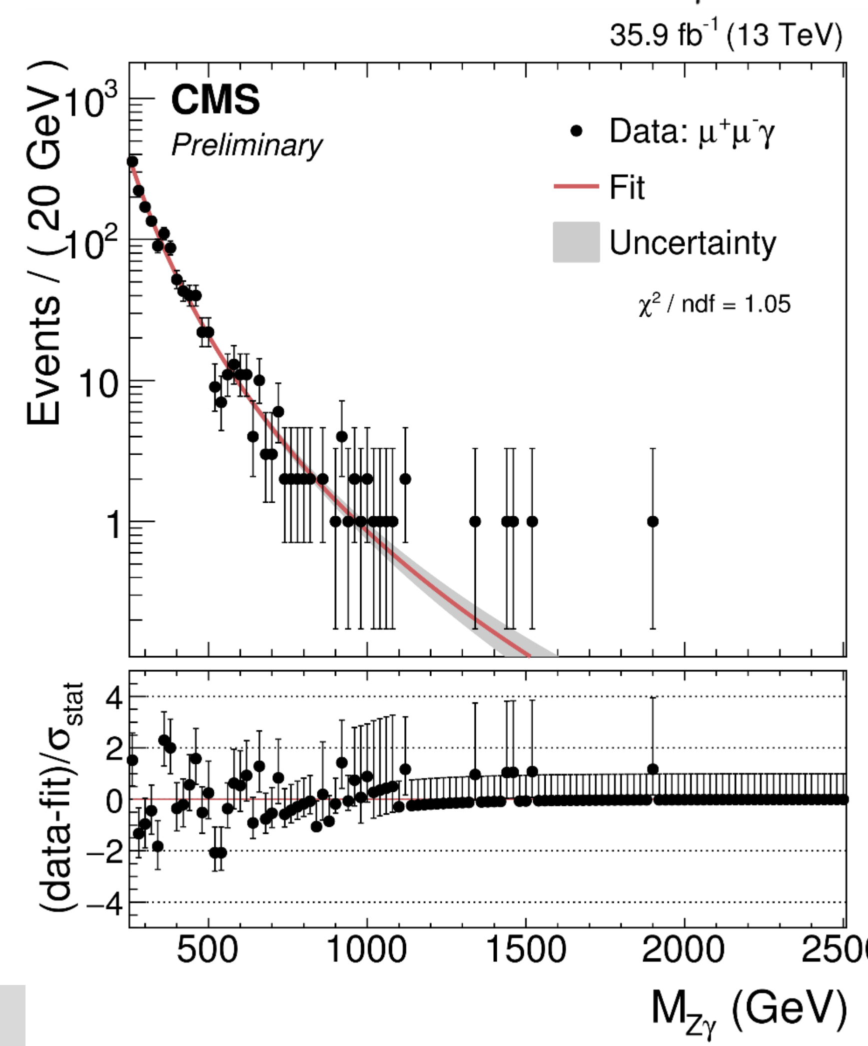


Zγ

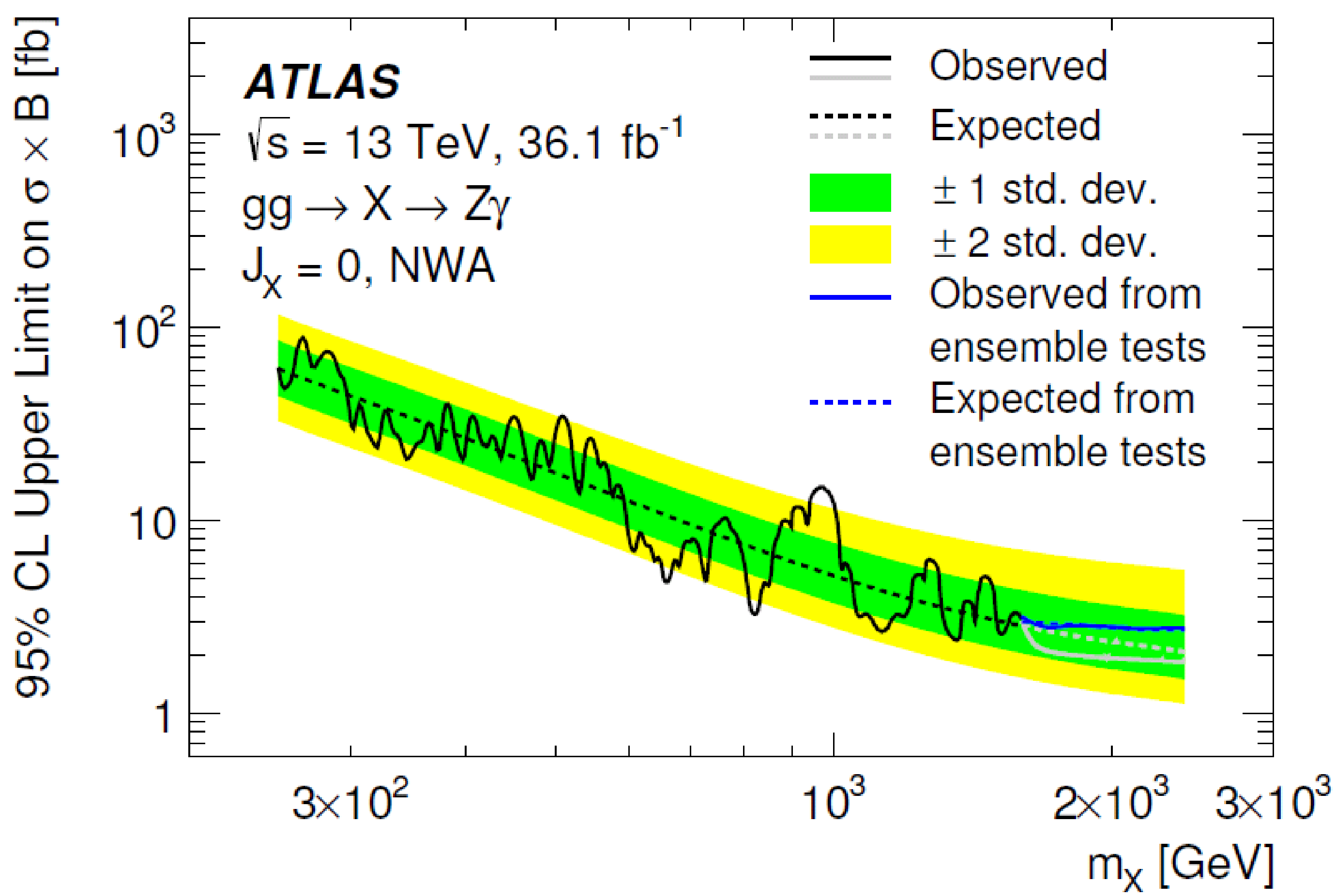
- Immediately related to γγ by ewk symmetry breaking
  => sensitive to similar models
  => Spin 0 Higgs-like hypothesis
  => KK Graviton
- Compatible with SM



[arxiv:1708-00212]



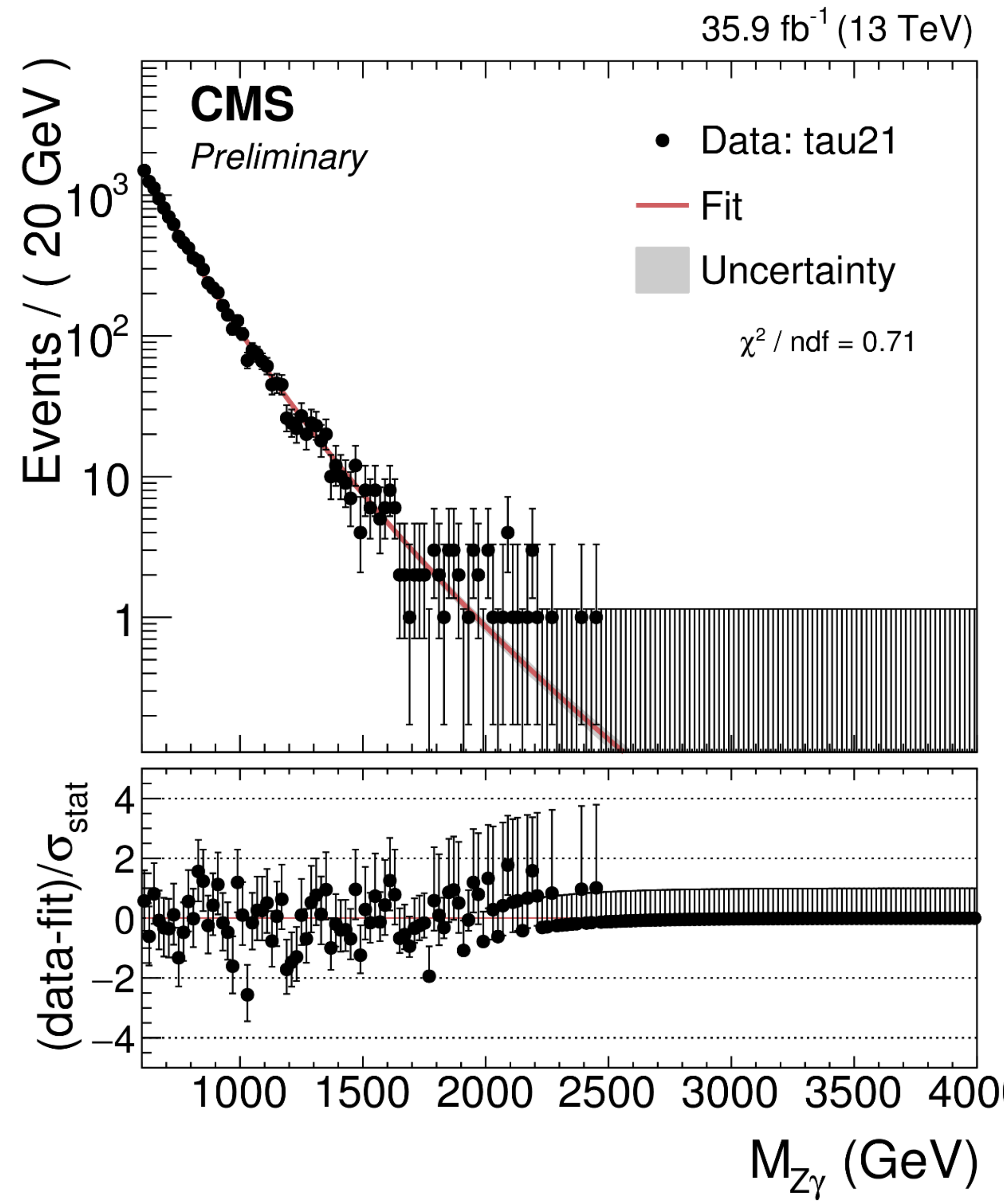
[CMS-EXO-17-005]

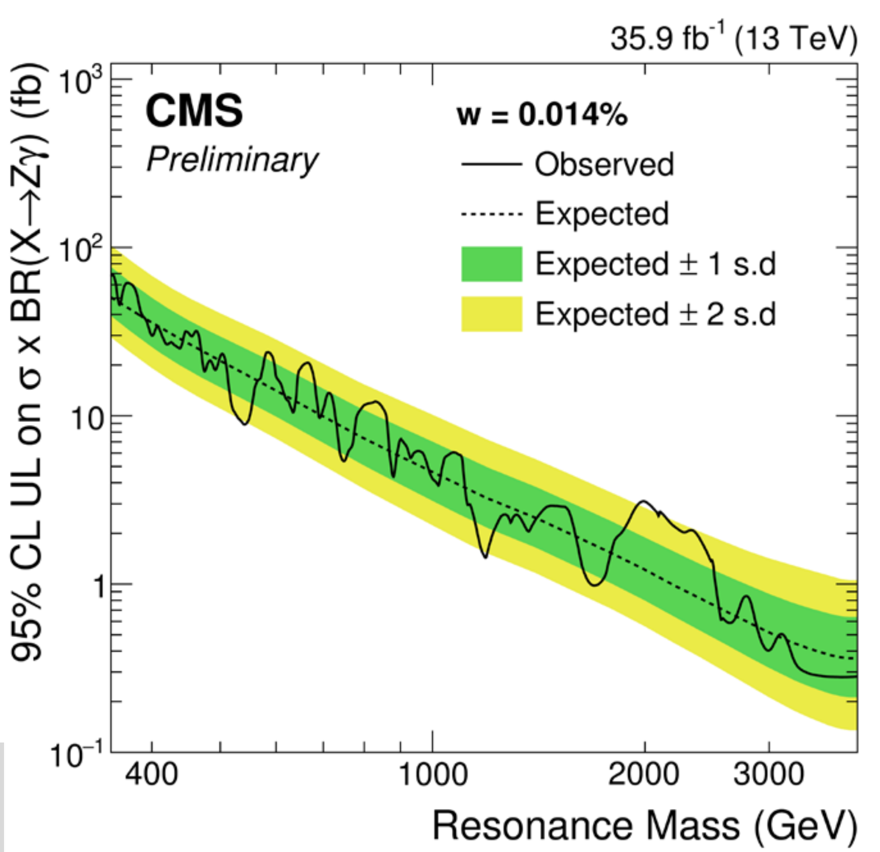


Zγ

- At high mass, limits driven by signal acceptance: low Z→ℓℓ branching fraction
  => Add hadronic Z decays for high mass

- Use a number of discriminants to enrich Z (see Zhaoxu's talk for details)
  => jet mass
  => 2-prong substructure (N-subjettiness)
  => subjet b-tags

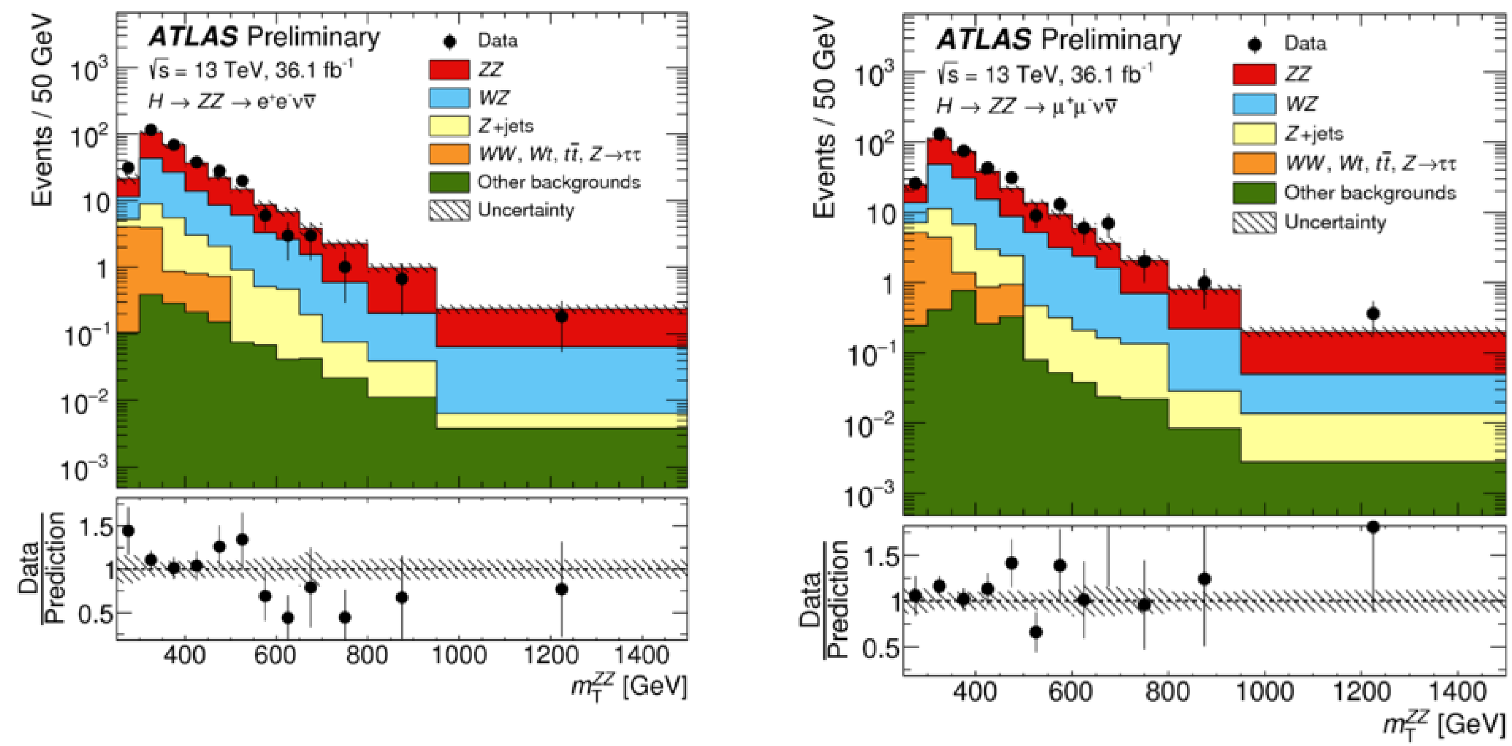




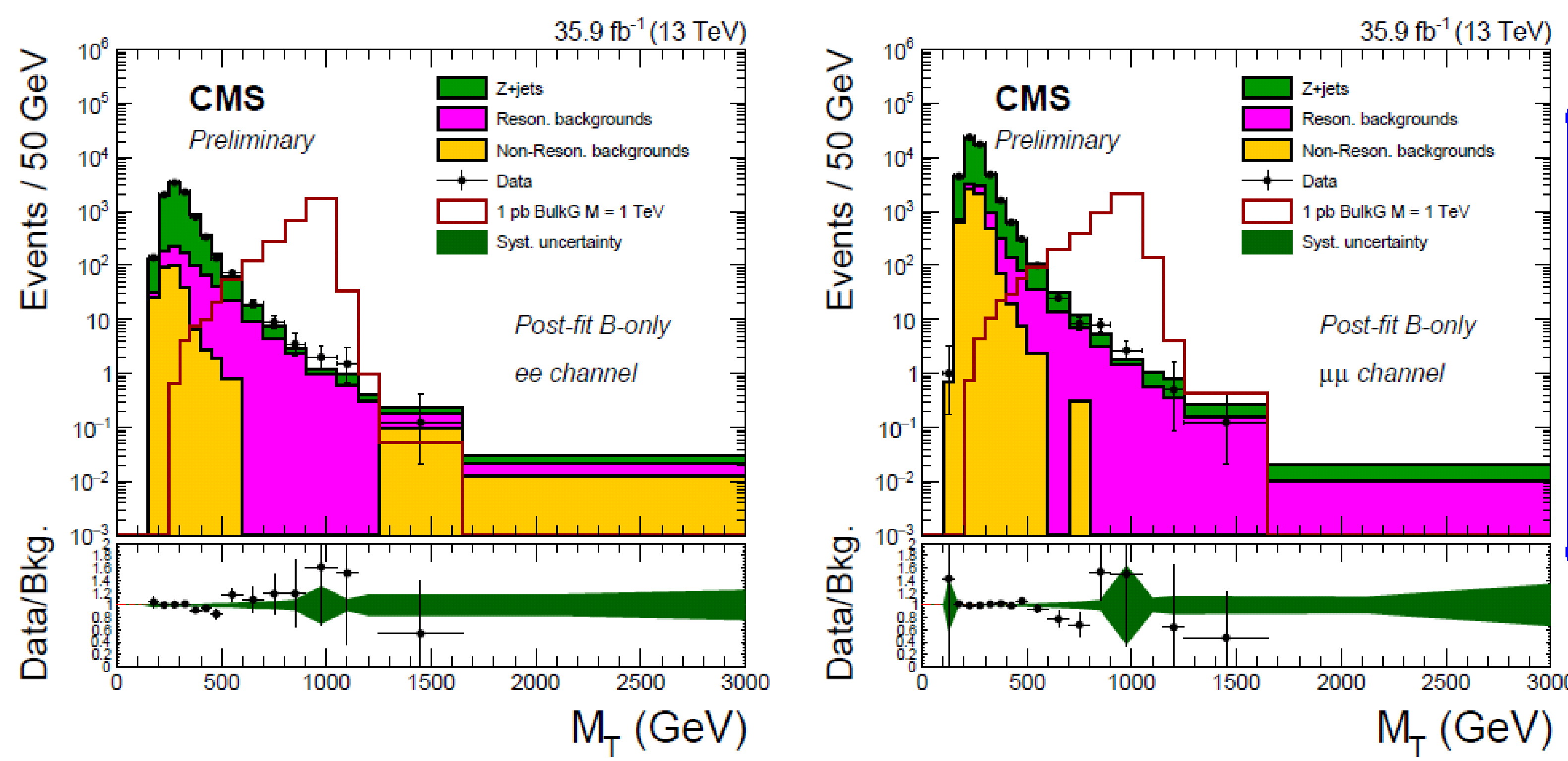
[CMS-EXO-17-005]

ZZ → ℓℓνν

- Good compromise between branching ratio and background
- Largest background from SM diboson production
- Major effort to understand MET mismeasurements, determine MET corrections
- Cannot reconstruct resonance mass
  => use transverse mass
  => still poor resolution
- Looking for Bulk Graviton and 2HDM



[ATLAS-CONF-2017-058]

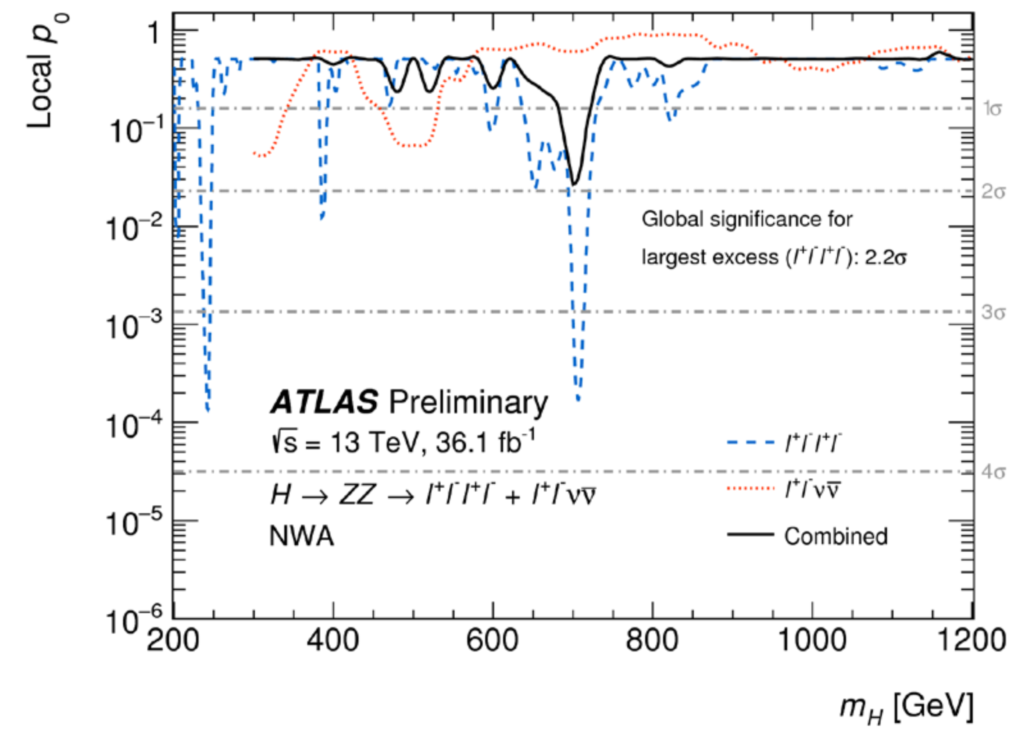


[CMS-B2G-16-023]

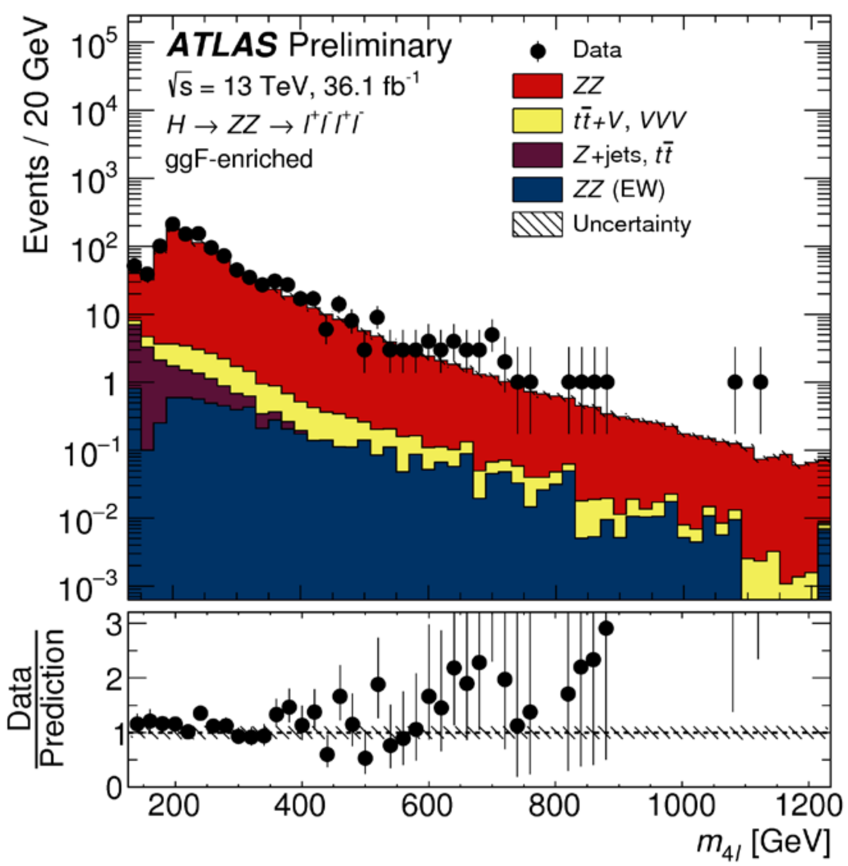
ZZ → 4ℓ

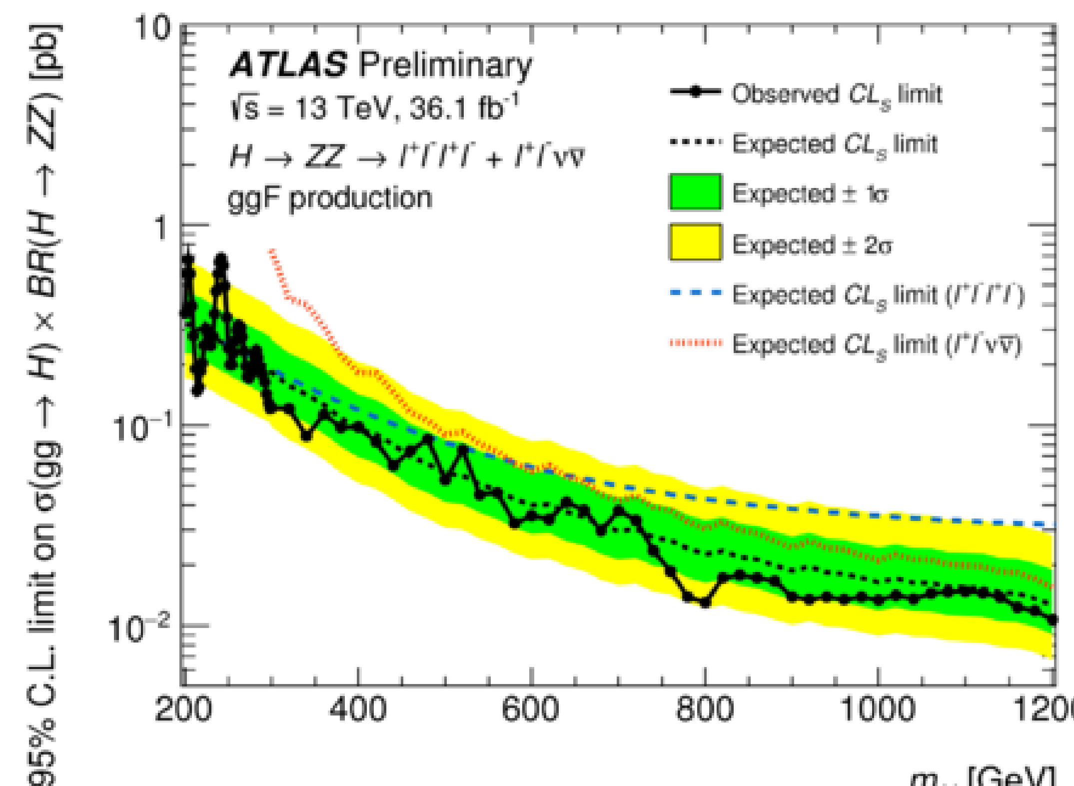
Karlsruher Institut für Technologie

- Combined by ATLAS with 4ℓ channel
- Very low background, but lacks signal acceptance at high mass
- Analysis similar to Run I high mass Higgs search
  => VBF category
  => interference effect sin signal shape
- Particularly useful for 2HDM
- Some excess in 4ℓ channel, but not significant in combination with ℓℓνν



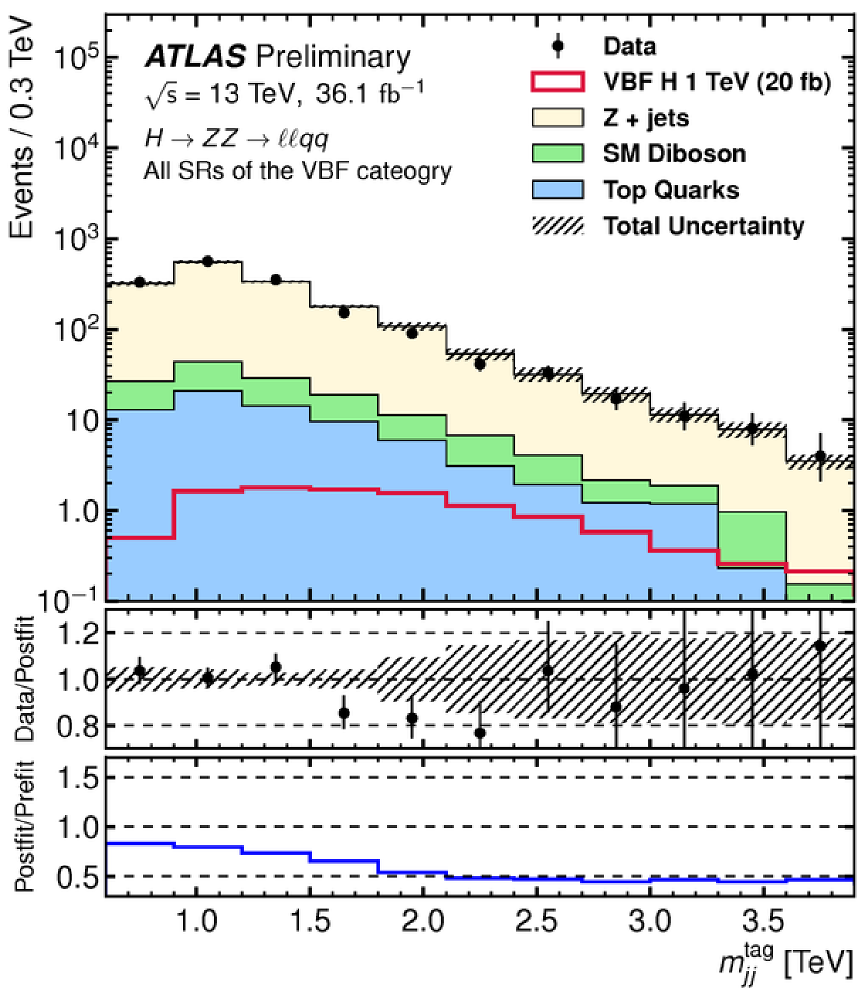
[ATLAS-CONF-2017-058]



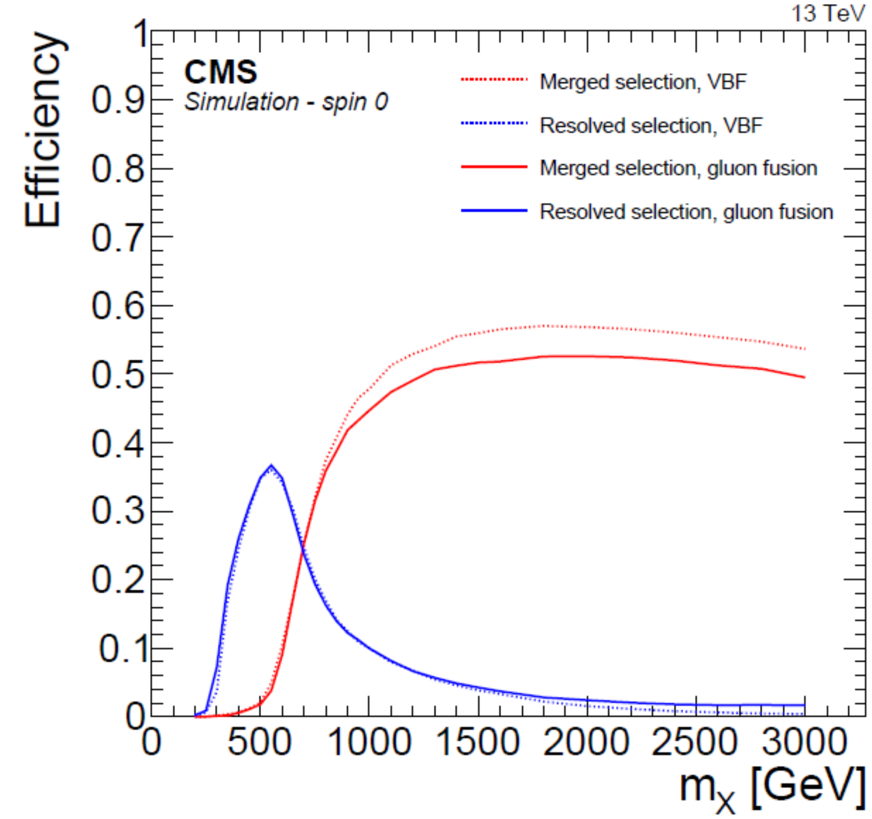


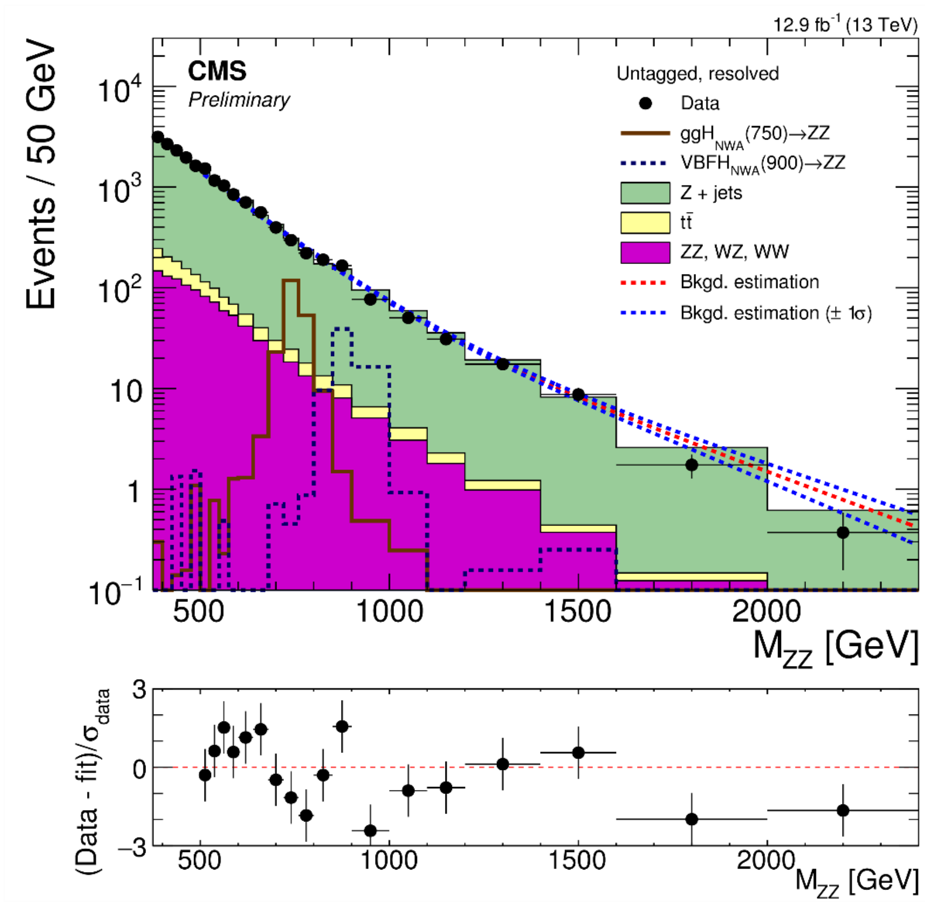
ZZ → 2ℓ2q

- High branching ratio, but high backgrounds
- Boosted at high mass, but needs resolved (dijet) analysis to reach lower masses
- Interpretation in Higgs-like (ATLAS+CMS) and Graviton Models (CMS), HVT (ATLAS)
- Includes VBF categories, b-tags (for Z → qq)



ATLAS-TOP-SECRET

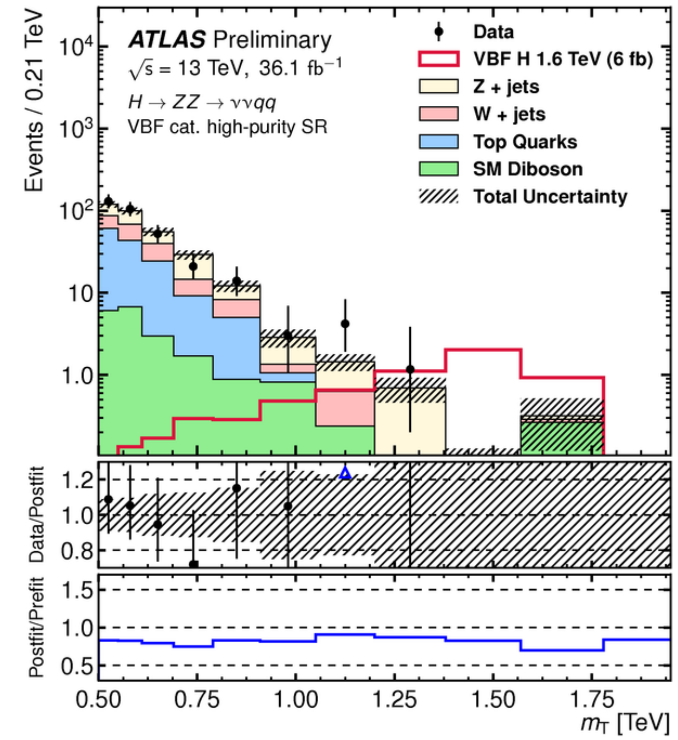




[CMS-HIG-16-034]

ZZ → 2q2ν

- 2ℓ2q analysis combined with 2q2ν by ATLAS
- Similar Analysis in CMS using only boosted FS
- Not easy to have proper combined VBF + DY-like analysis
  => requires assumptions on relative coupling strengths (increased model dep.)
  => requires calculation of DY-like resonance production + 2jets (ideally in NLO) to compute feed-down



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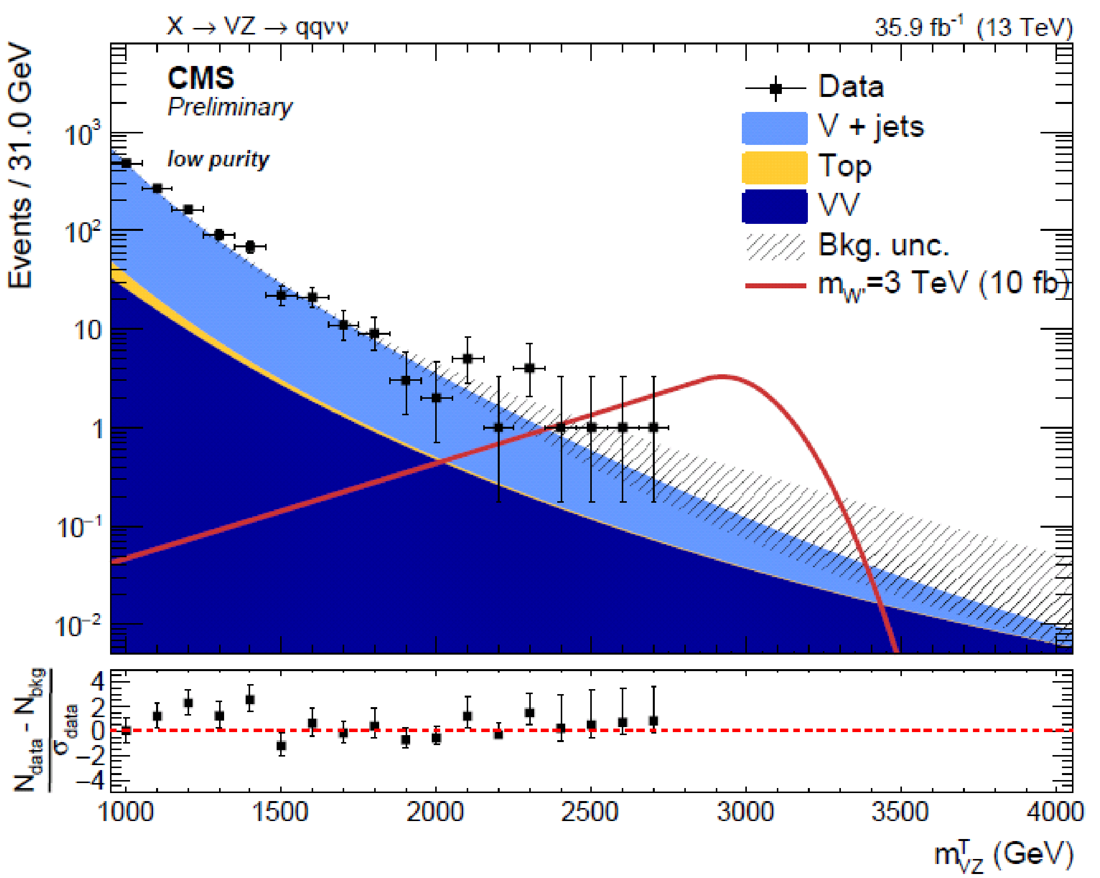
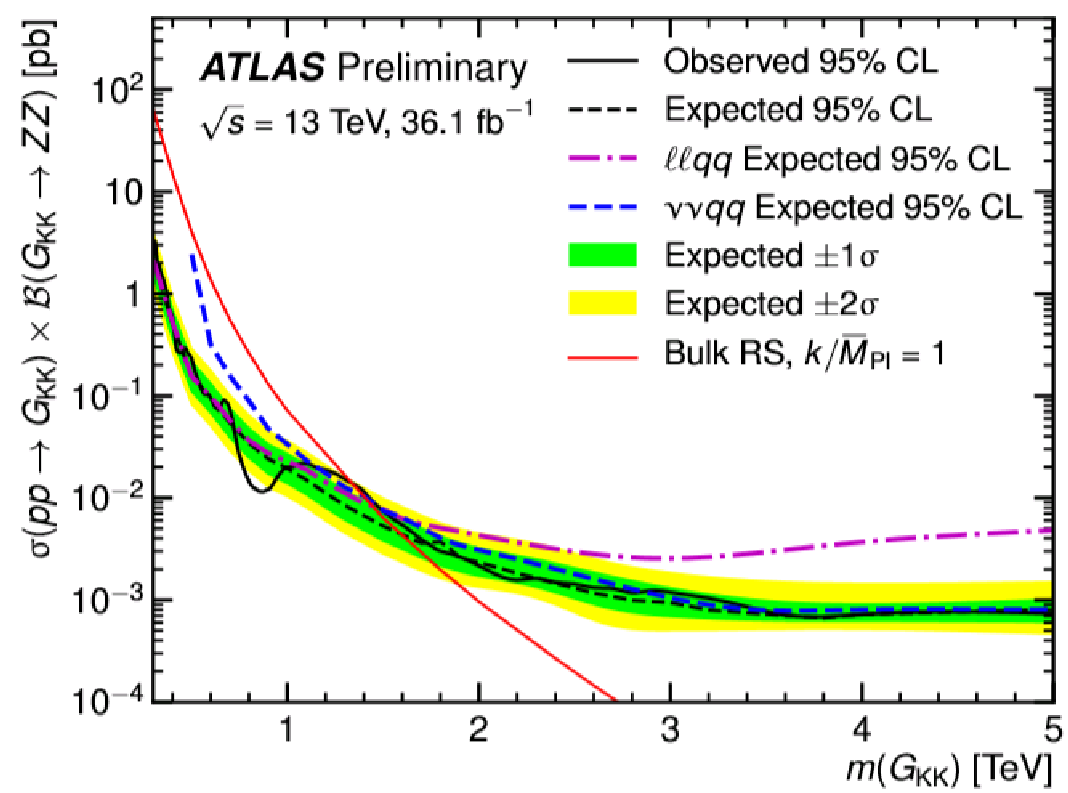


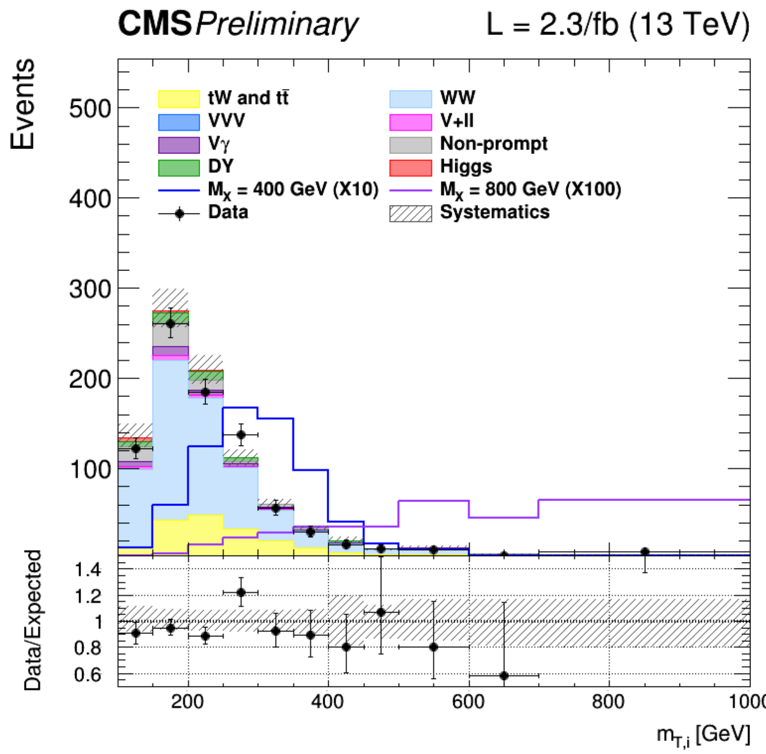
[CMS-B2G-17-005]



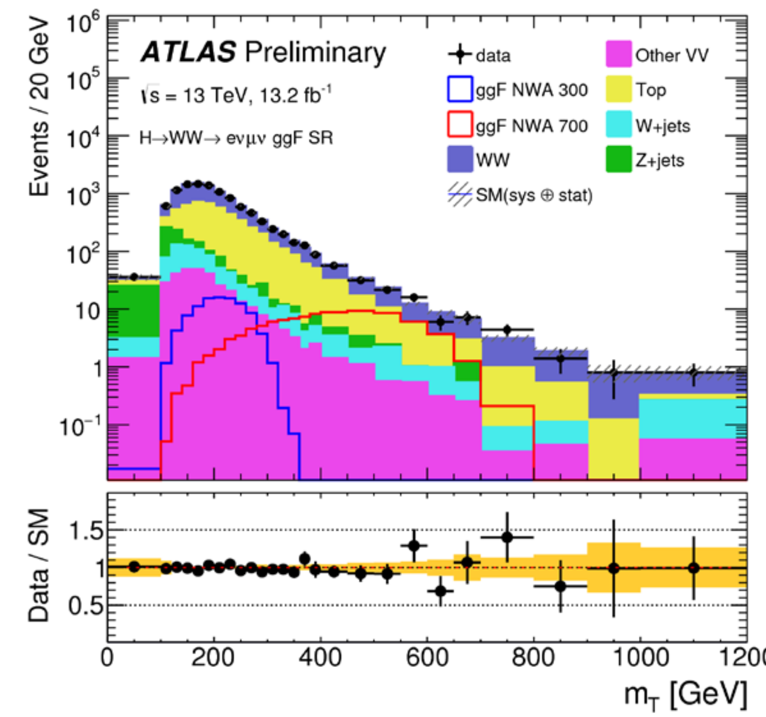
WW → $\ell\nu\ell\nu$

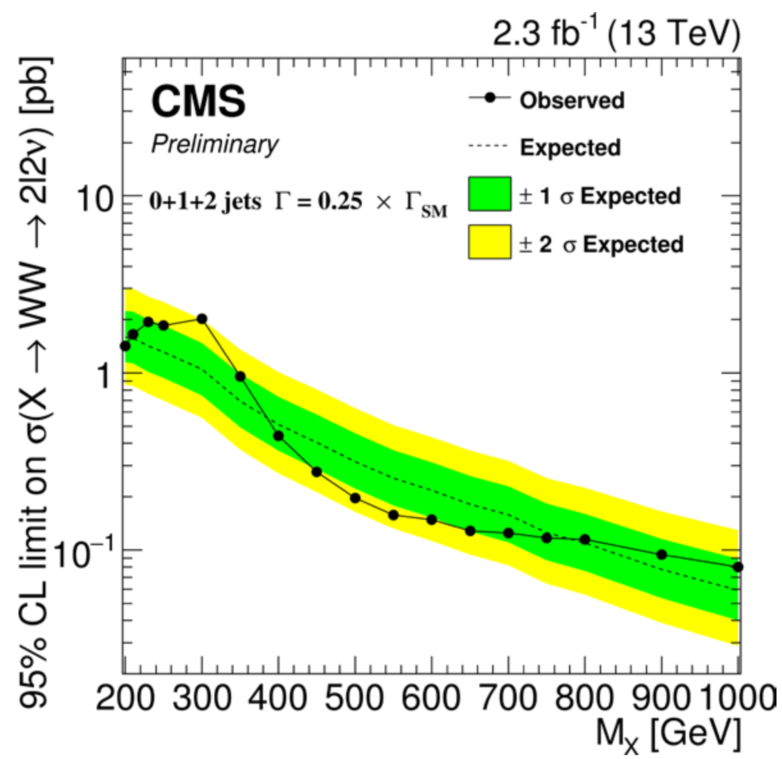
- analysis closely follow Run I high mass Higgs boson searches
- Categories in lepton flavor (top background)
- categories in jet multiplicities to suppress top backgrounds and tag VBF production
- Sophisticated signal parameterization including interference effects
- Looking for ewk singlet interference model
- Limits set for a number of signal width hypothesis

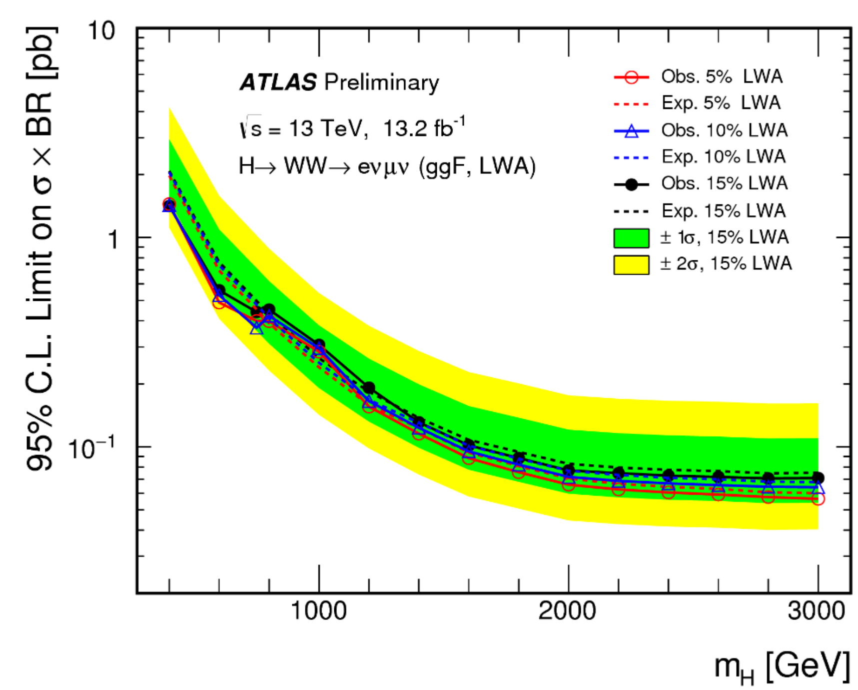
[CM-HIG-16-023]



[ATLAS-CONF-2016-074]

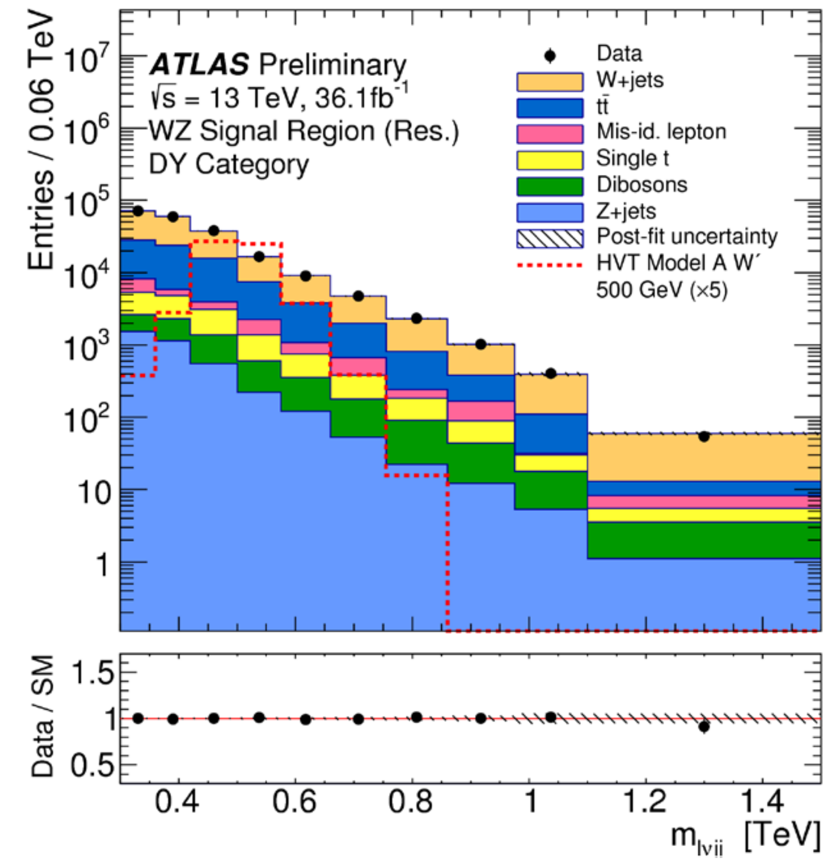




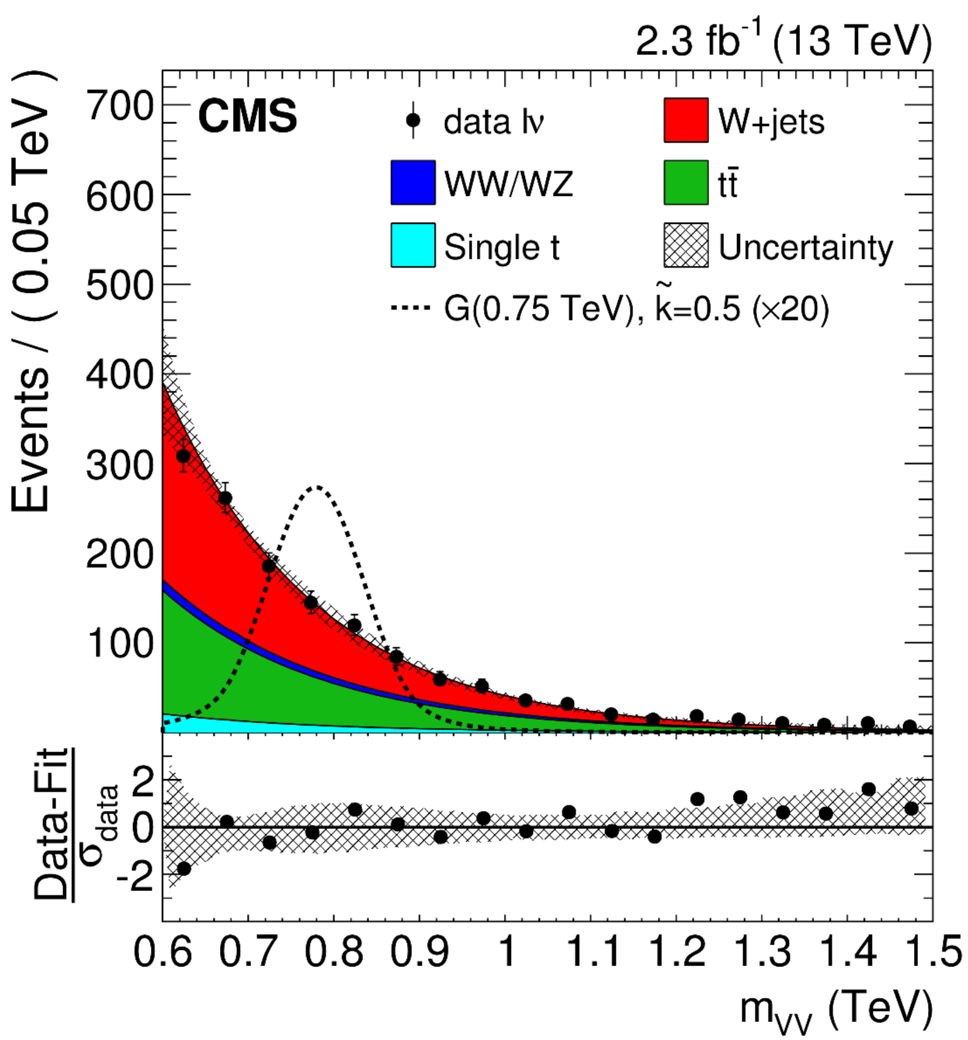


WW → ℓνqq

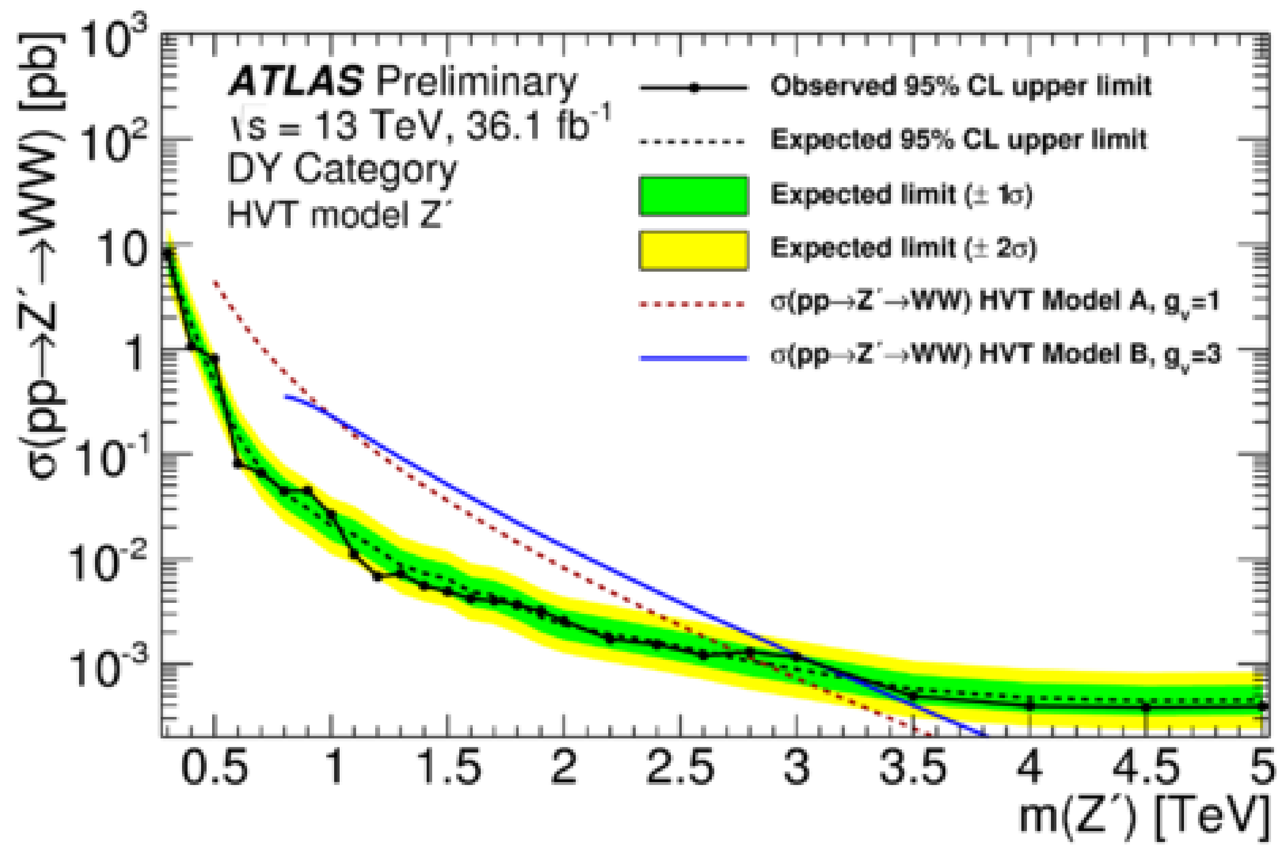
- Very similar to ZZ → 2ℓ2q
  => similar analysis techniques
  => similar interpretation (Graviton, HVT)
- ATLAS study contains VBF channel
  => no combined limit



[ATLAS-CONF-2017-051]



[JHEP 03 (2017) 162]

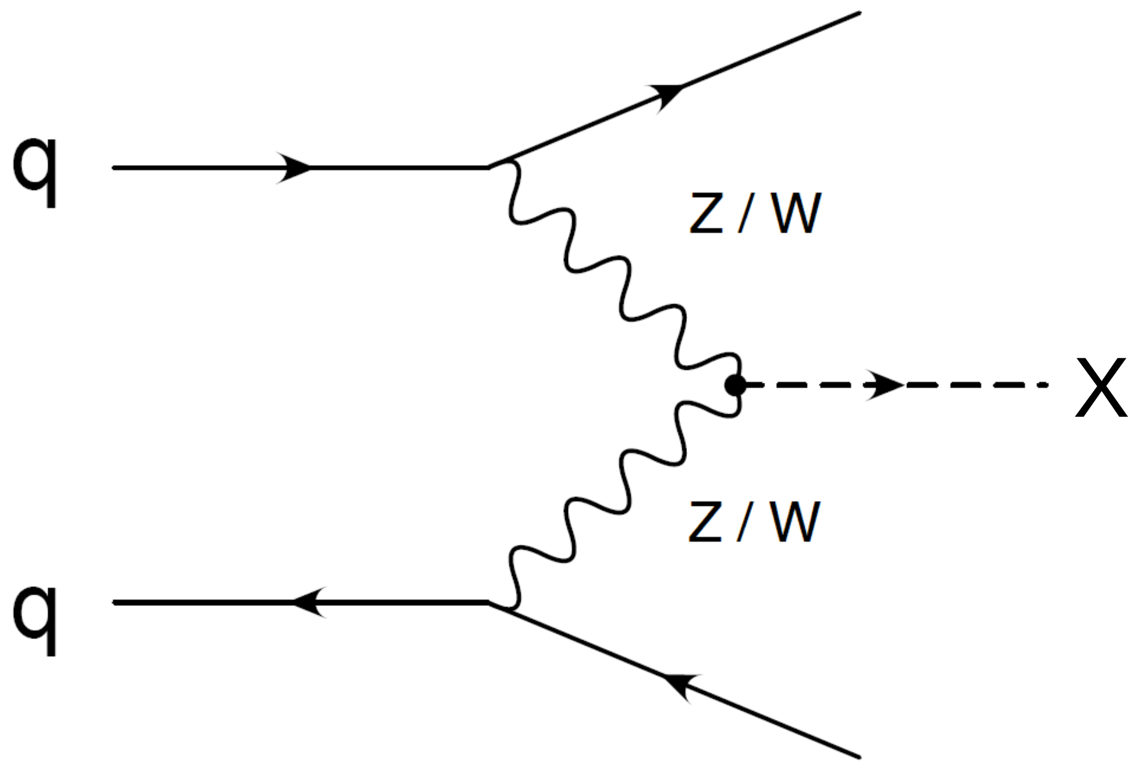


VBF-Only searches

- What if new physics ONLY couples to electroweak sector?
  => no tree-level production from quarks/gluons
  => even loop-induced couplings suppressed for gluon initial states

- VBF processes become dominant production mode
  => search for resonances in VBF modes

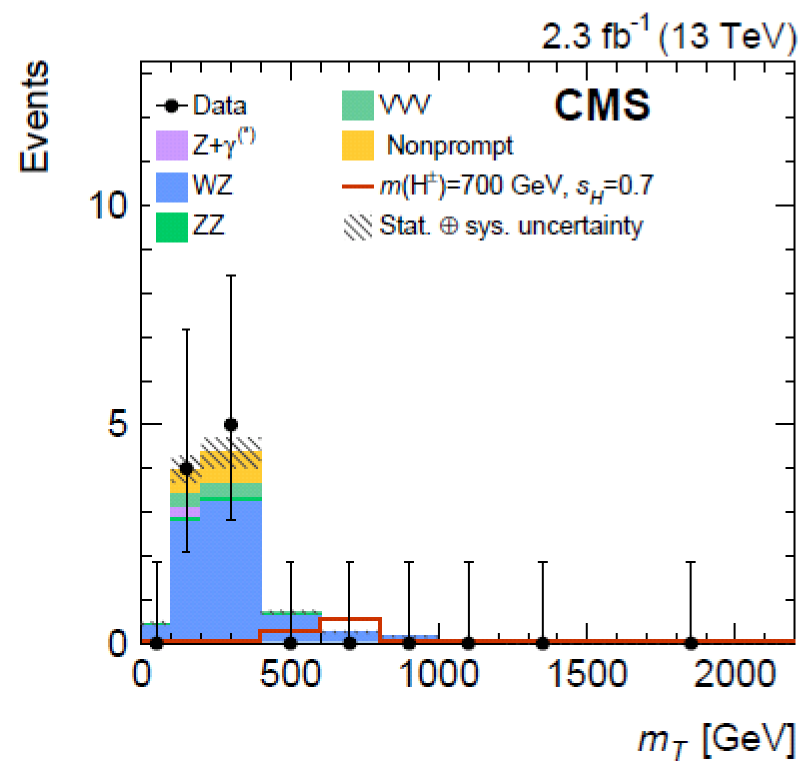
- strategies similar to typical Higgs searches in VBF
  => require two additional jets
  => wide separation in angle
  => high dijet invariant mass

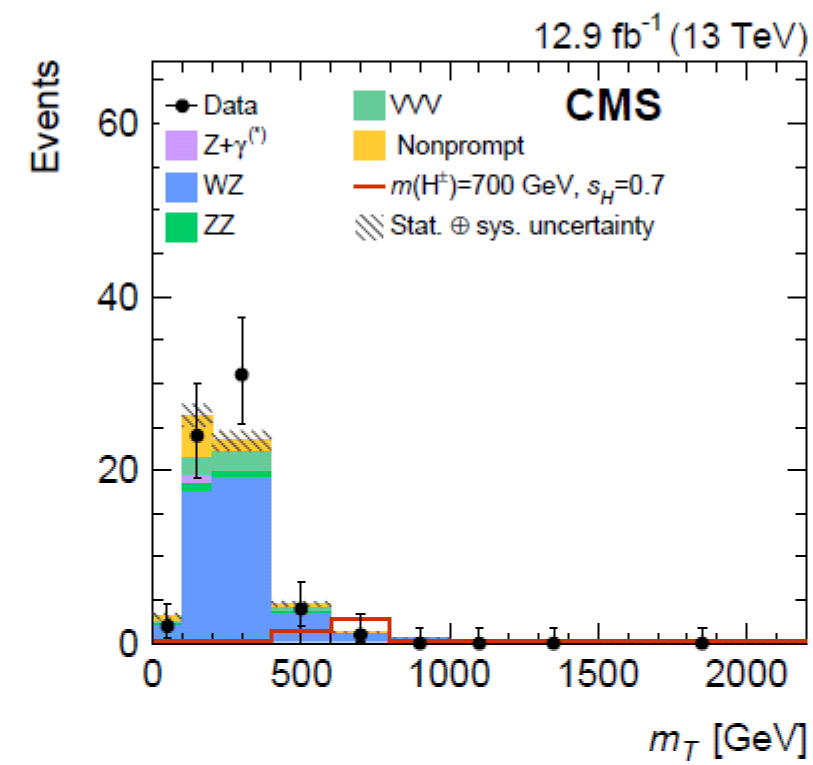


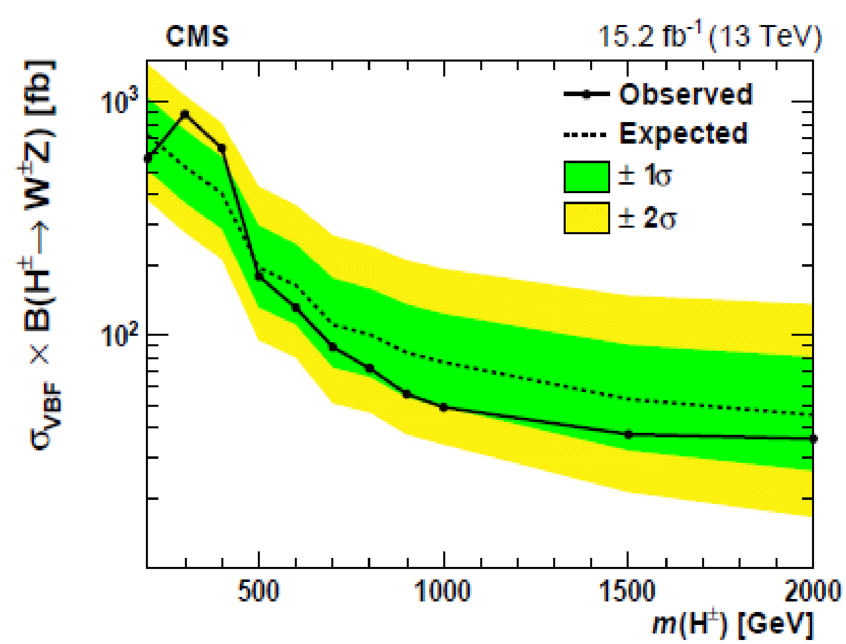
$H^{\pm} \rightarrow WZ$ (VBF)

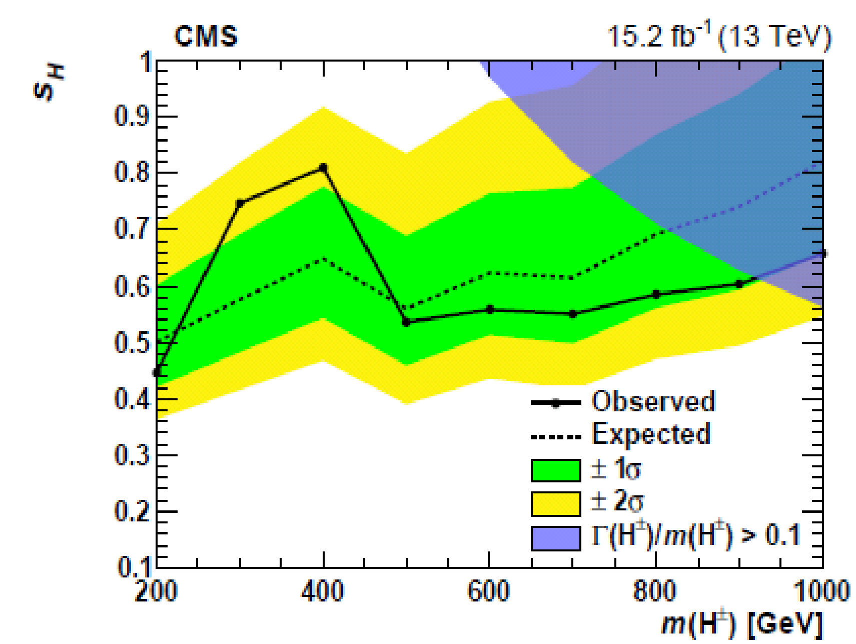
[arxiv:1705-02942]

- Usual 2HDM $H^{\pm}$ still has substantial coupling to fermions
- Looking for charged member of additional SU(2) triplet, e.g. (Georgi-Machacek)
- Cross-section governed by contribution of triplet vev to boson mass: $\sin\vartheta_H$





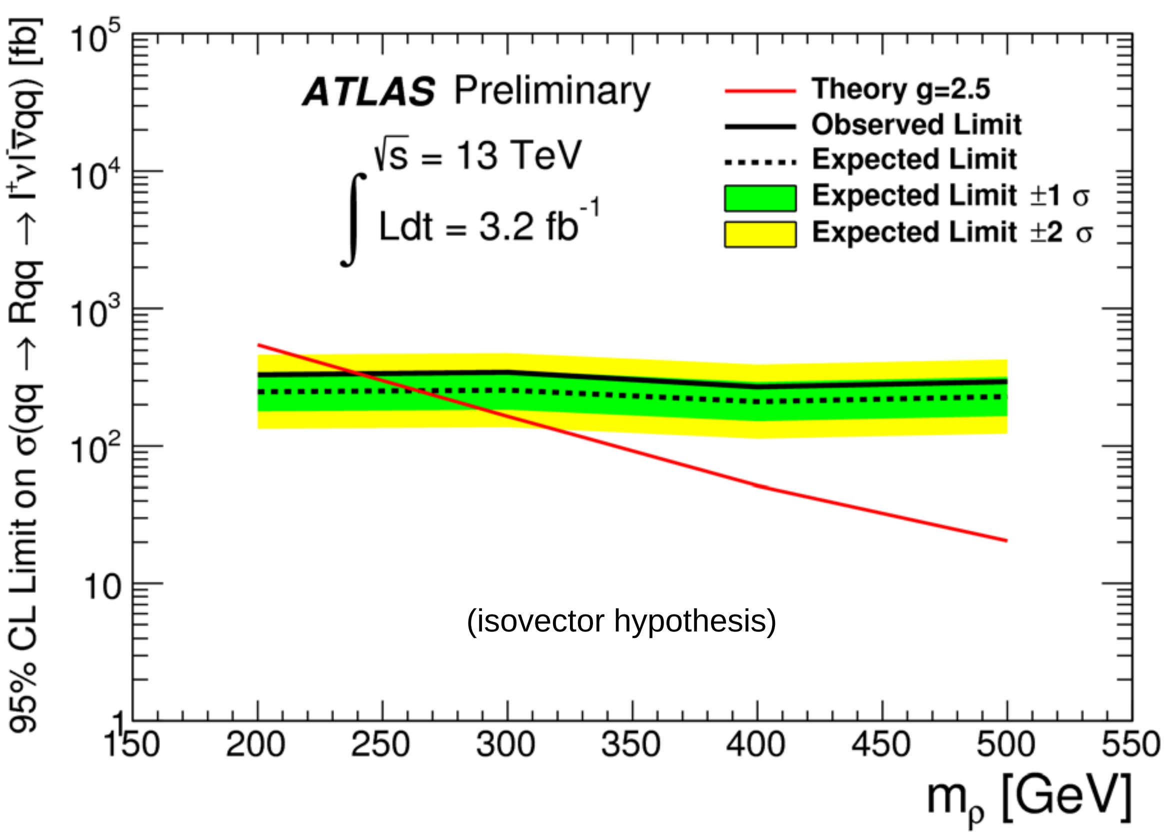


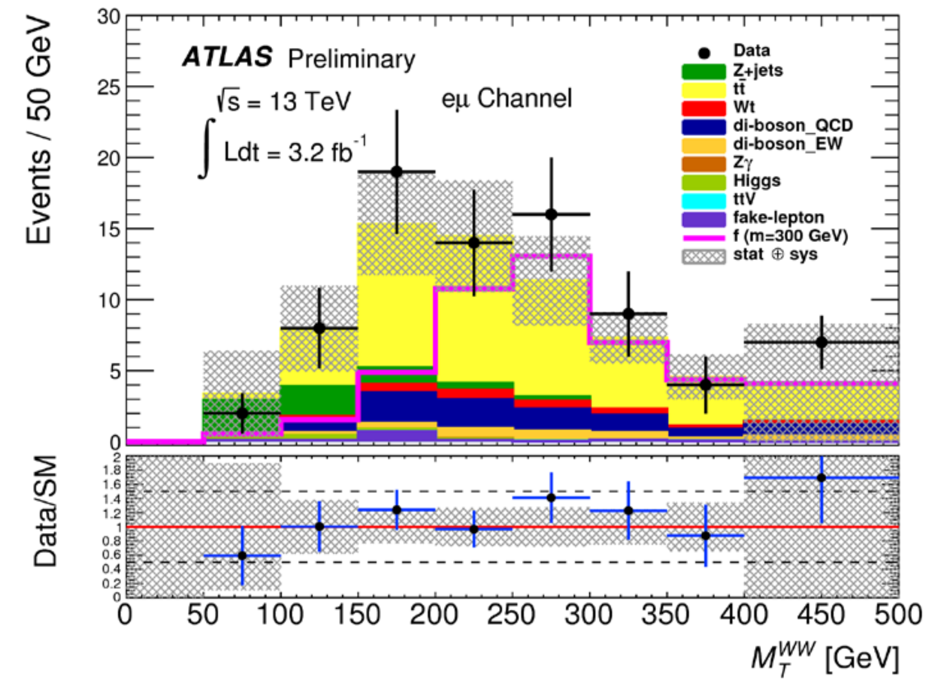


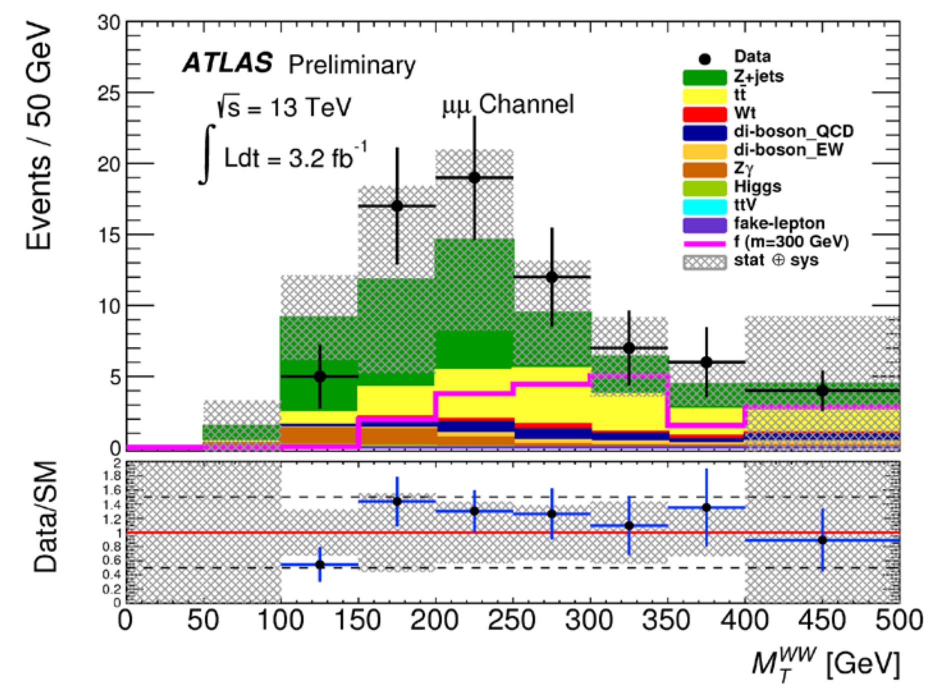
WW → ℓνℓν (VBF)

[ATLAS-CONF-2016-053]

- Very generic resonance parameterization (effective chiral Lagrangian) according to spin / isospin, coupling to longitudinal boson components
- Very wide for high masses and observable couplings
  => limits search range to <500GeV







Results + Conclusion II

- No BSM physics discovered
- Come back next year to more data

- Large number of final states covered
- Many searches reasonably generic, possible to reinterpret in generic resonance scenarios

- Up to the TeV range, limits are now very strong, limiting options for BSM physics:
  => could hide by being weakly coupled
  => could hide by being very heavy

- Expect some more good results soon: 2016 data analysis not yet all finished
  => jump in centre-of-mass energy 8 →13TeVdrives gain in sensitivity for
  Run II vs Run I
  => less dramatic improvements expected for 2017 vs 2016 data