Ricerca di risonanze in due corpi

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ATLAS and CMS Run II Public results

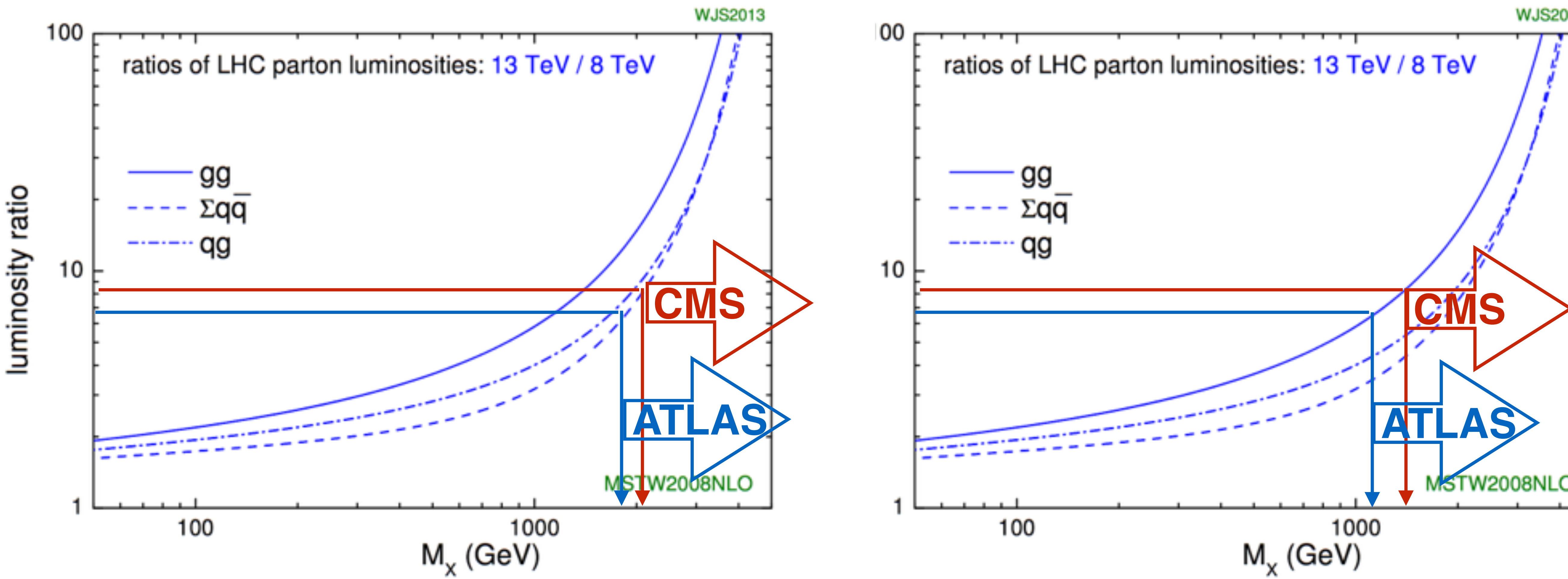
Analysis	ATLAS	CMS	in this talk
Dijet production	arxiv:1512.01530	arXiv:1512.01224	✓
Dijet angular distribution	arxiv:1512.01530	PAS EXO-15-009	Backup
b-jet pairs	arxiv:1603.08791		✓
Diphoton	ATLAS-CONF-2016-018	PAS EXO-16-018	✓
Z+photon	ATLAS-CONF-2016-010	PAS EXO-16-019*	Backup
Photon+jet	arxiv:1512.05910		Backup
VV → qqqq	ATLAS-CONF-2015-073	PAS EXO-15-002	✓
VV → ℓνqq	ATLAS-CONF-2015-075	PAS EXO-15-002	✓
VV → ννqq	ATLAS-CONF-2015-068		✗
VV → $\ell\ell$qq	ATLAS-CONF-2015-071		✗
Vh->$\ell\ell$bb, $\ell\nu$bb, ννbb	ATLAS-CONF-2015-074		✓
Dilepton	ATLAS-CONF-2015-070	PAS EXO-15-005	Backup
eμ final states	ATLAS-CONF-2015-072	PAS EXO-16-001	✗
W′ → e/μ+MET	ATLAS-CONF-2015-063	PAS EXO-15-006	Backup
W′ → τ+MET		PAS EXO-16-006	✗

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

* only leptonic channel

Run II Analyses

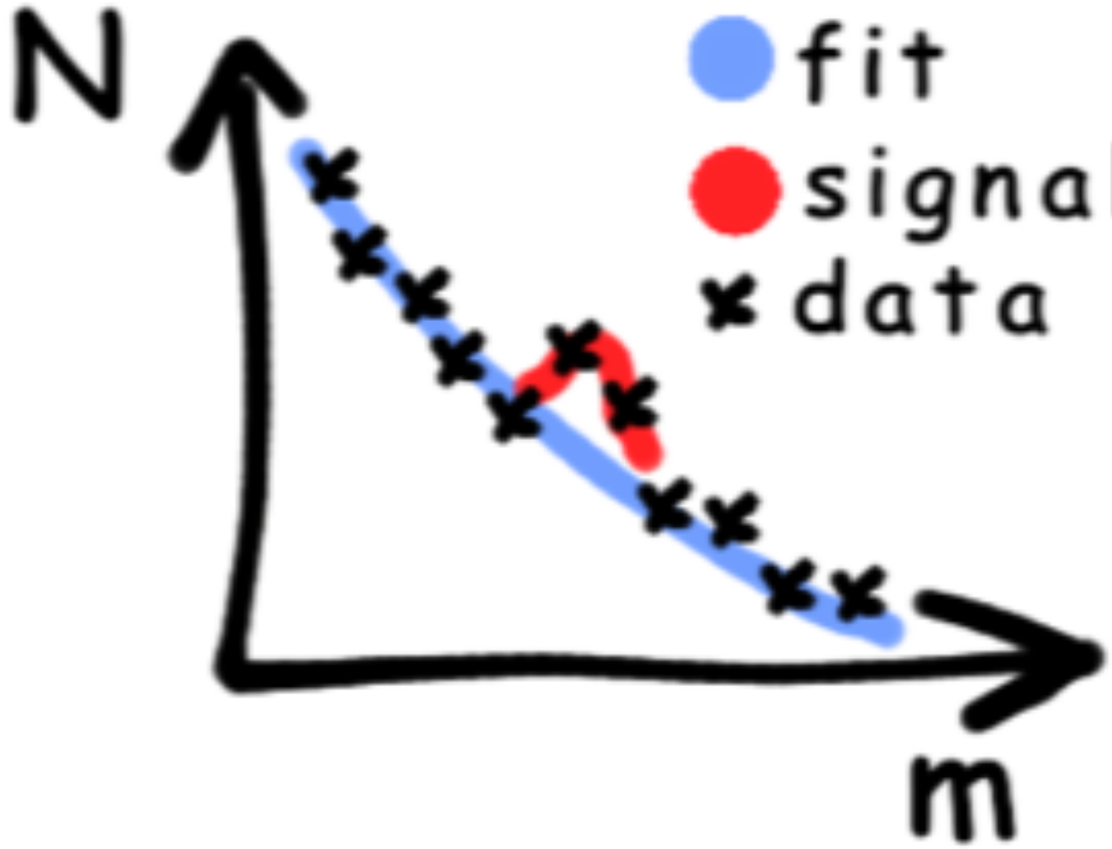
Min M_X value for qq and gg production at which 8 TeV analysis ≈ 13 TeV analysis



- Run I integrated lumi. **ATLAS: 20.3/fb** , **CMS: 19.7/fb**
- Run II integrated lumi. **ATLAS: 3.2/fb** , **CMS: 2.7/fb (3.8T)+0.6/fb (0T)**
- Increase in energy compensate the lower luminosity
- Effectively, the new dataset should be comparable to what we saw in Run I

http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

How new resonances arise



Beyond SM physics can show up in many different ways

Resonance models:

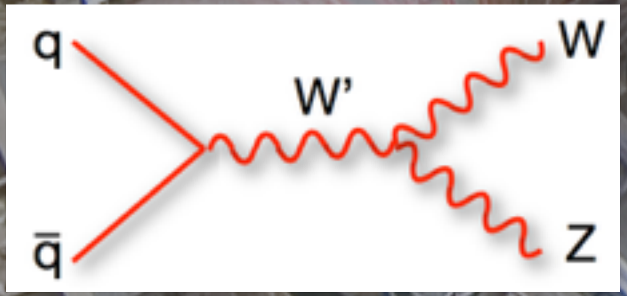
- Sequential Standard Model (Z′,W′, spin-1);
- Randall-Sundrum graviton (RS G*, spin-2);
- Bulk RS graviton (Bulk G*, spin-2):couples more with heavy particles;
- HVT Model
- extended Higgs sectors (spin-0).

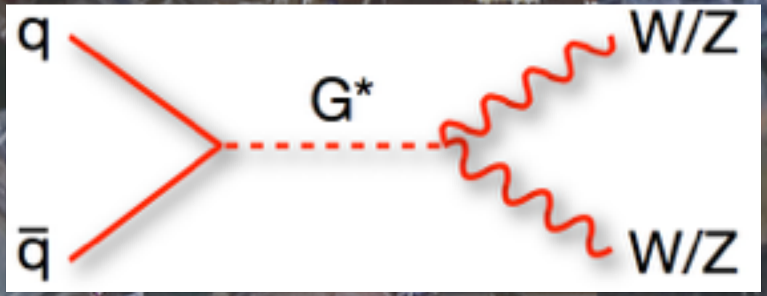
BSM signatures involve a combination of **leptons**, **photons**, **bosons**, and **jets**.

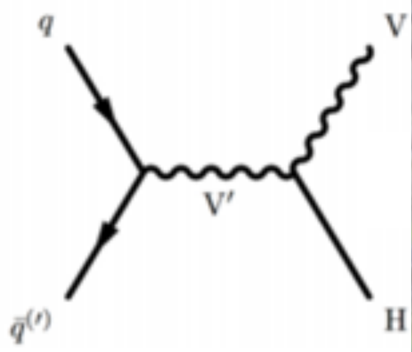
Experimental strategy:

- Bumps over a continuous background
- functional forms fitted on data for background model
- final states including partons often dominate
- Although small x-sections, channels w/ leptons and photons provide the cleanest signature

Diboson

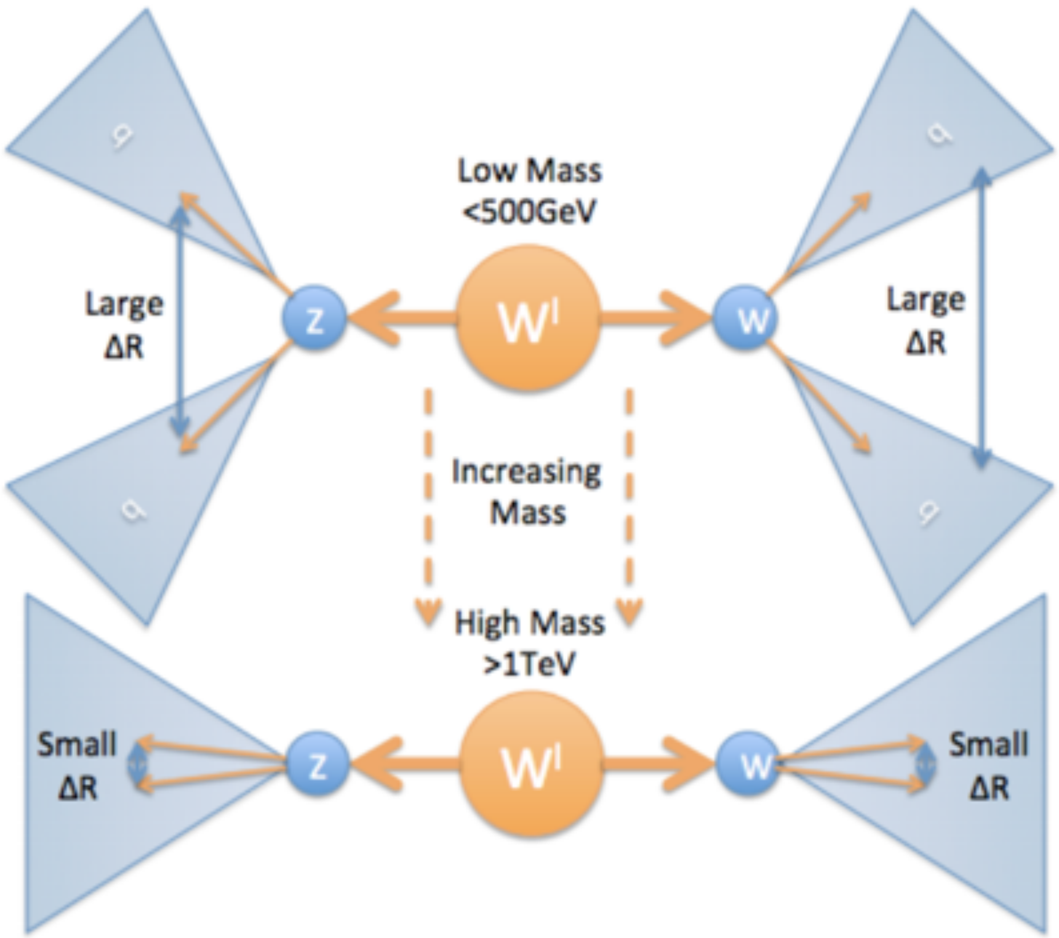




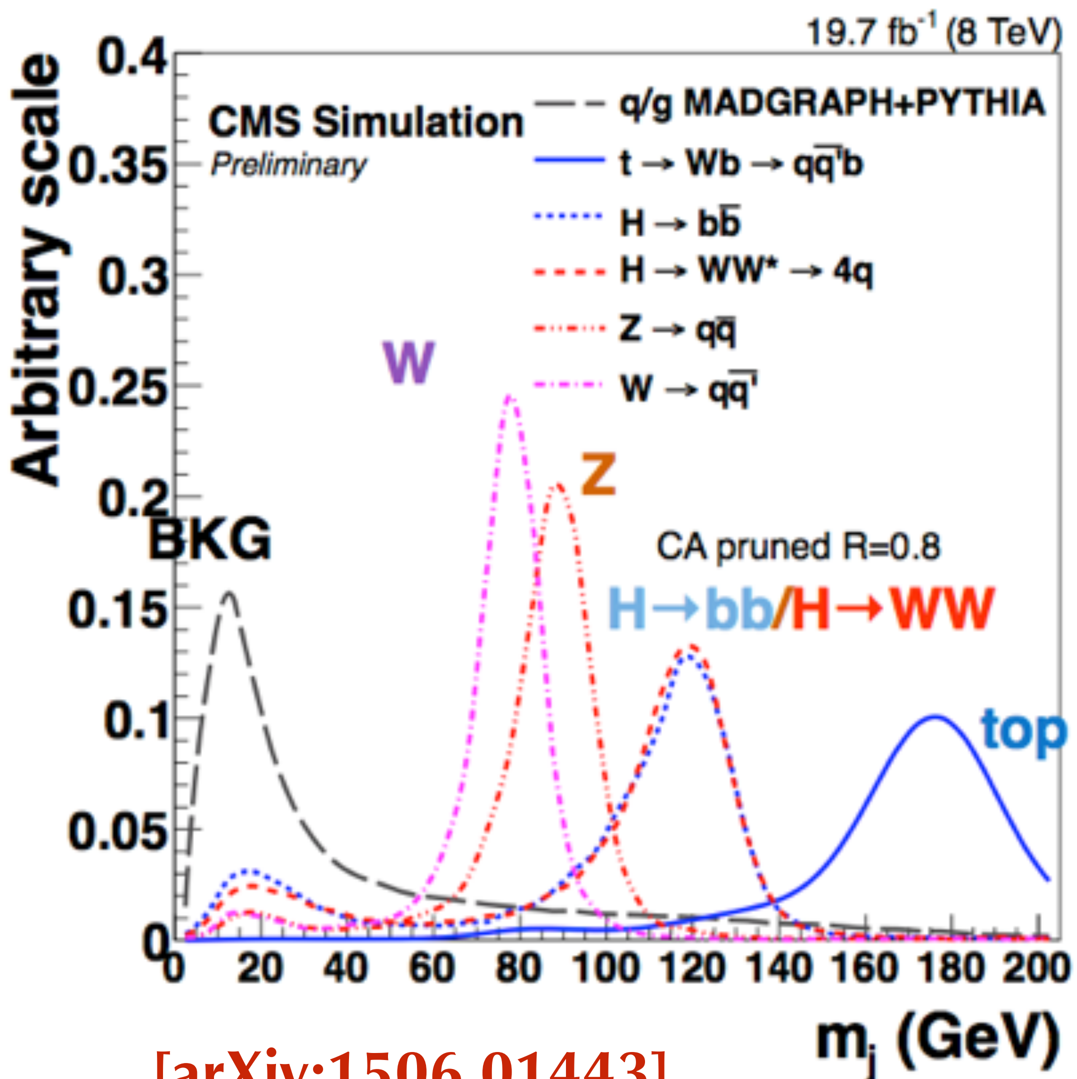


Boosted bosons

- Heavy resonances decay results in boosted bosons, hadronic decays enhancing the rates.
- Crucial to identify boosted V→qq decays
  - for large enough p_T, decay products merge into a single massive jet
  - jet mass and jet-substructure quantities main tool for discriminating signal vs background



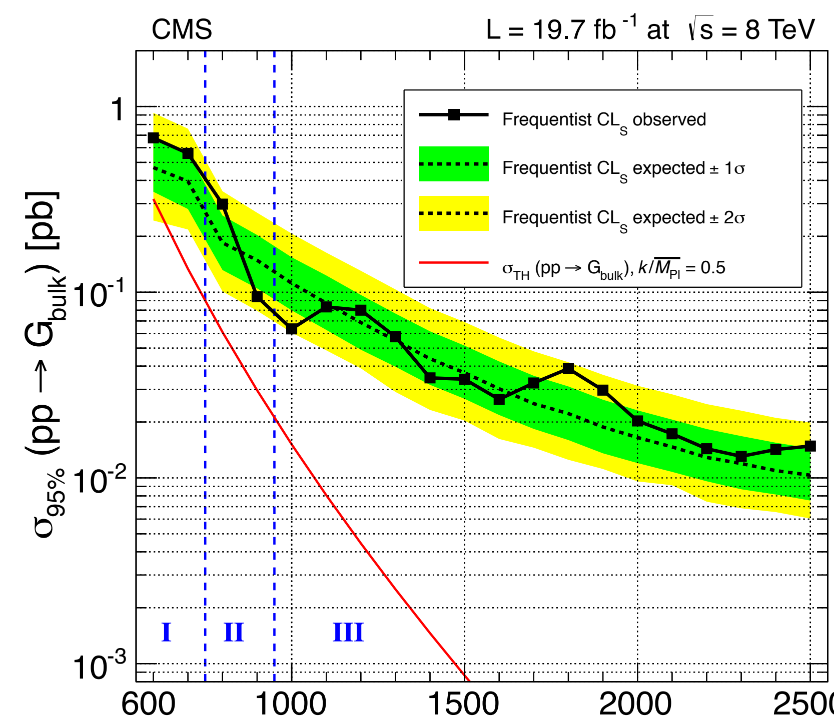
Cartoons by A. Martyniuk



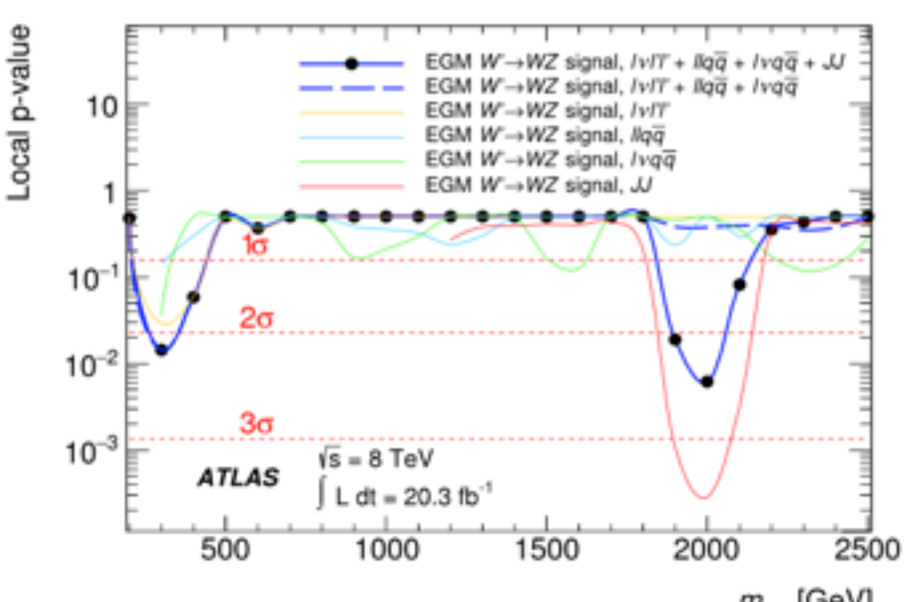
[arXiv:1506.01443]

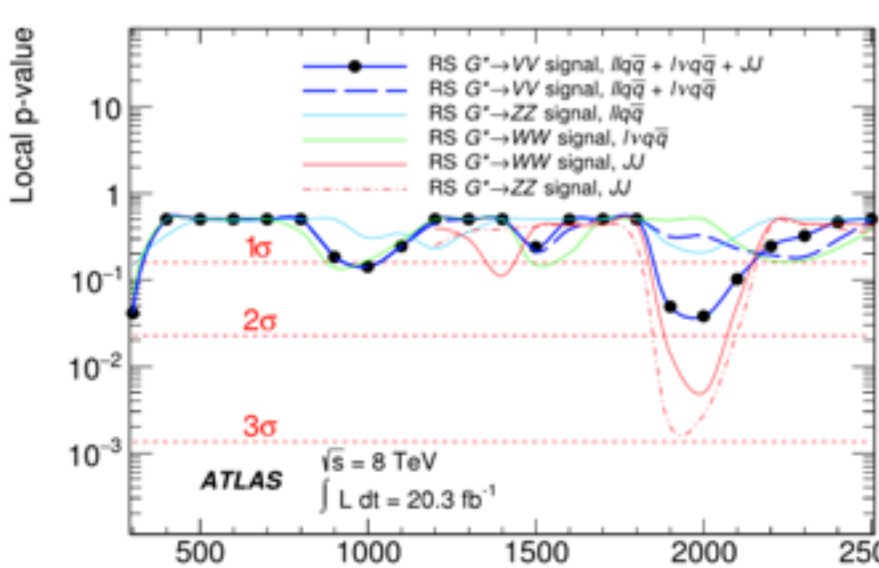
Diboson status @ 8 TeV

- **ATLAS**
  - excess at ~2 TeV in the Run I **fully hadronic Diboson** search [arXiv:1506.00962]
  - local significance 3.4σ (WZ →jj)
  - global significance 2.5σ (WW+WZ+ZZ →jj)
- **CMS:**
  - CMS no excesses with significances > 2σ observed (**ℓℓ+jet, ℓν+jet, jj**)
  - **H(bb)W(ℓν)** 2.9σ local significance at ~1.8 TeV in electron channel, nothing in the muon channel → combination gives 2σ



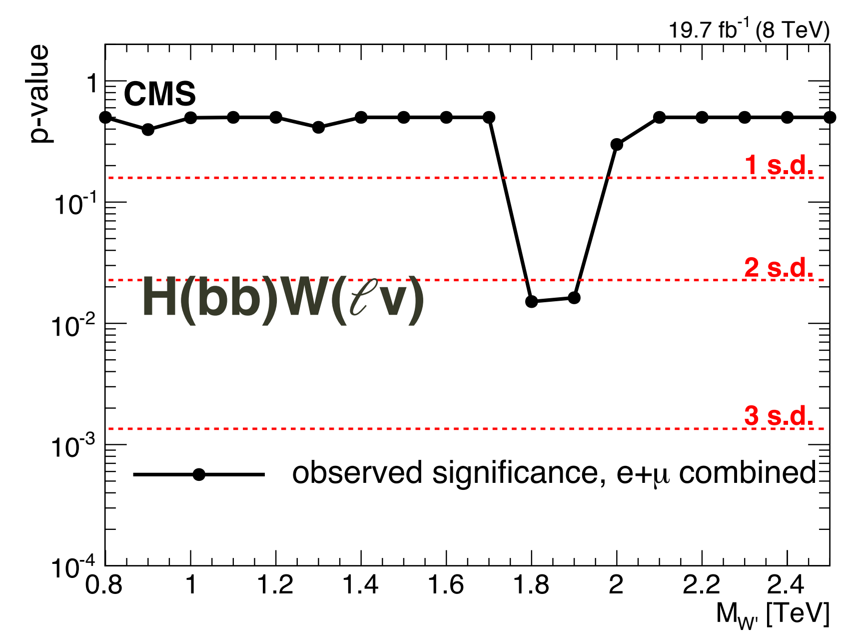
[arXiv:1405.3447]





m_{G^*} [GeV]

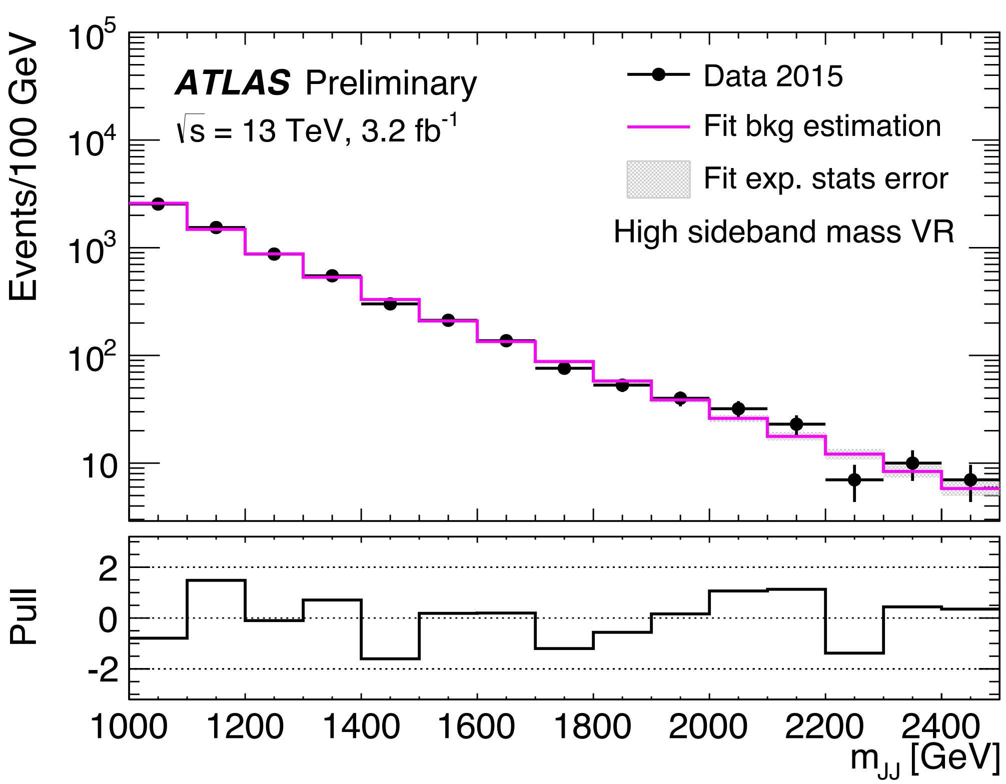
[arXiv:1512.05099]



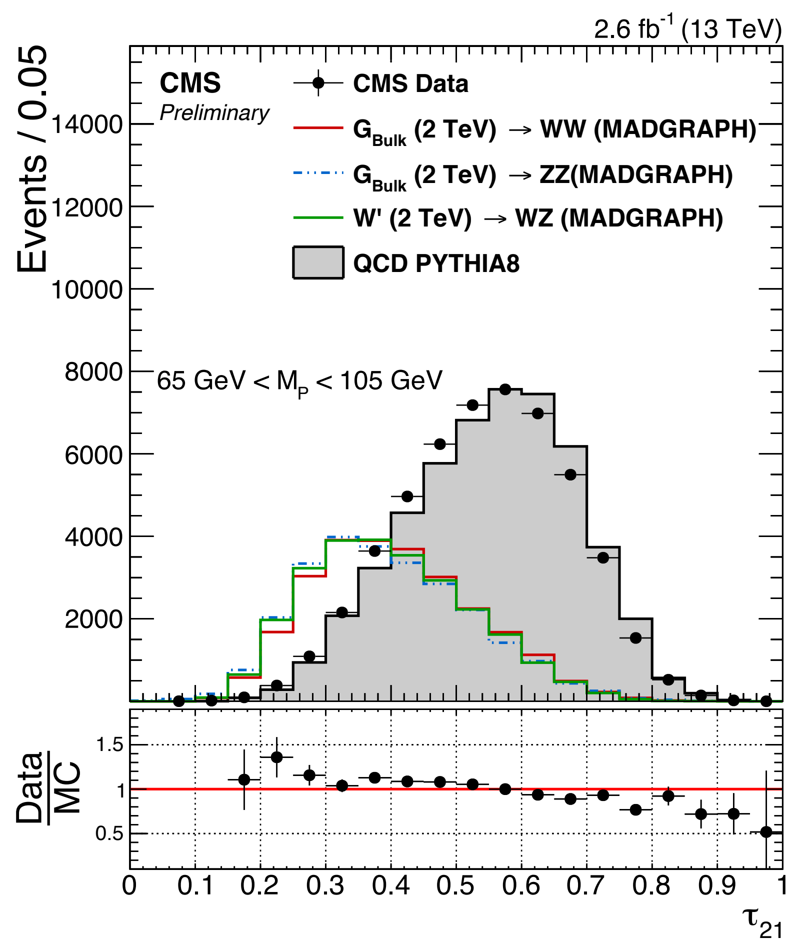
[arXiv:1601.06431]

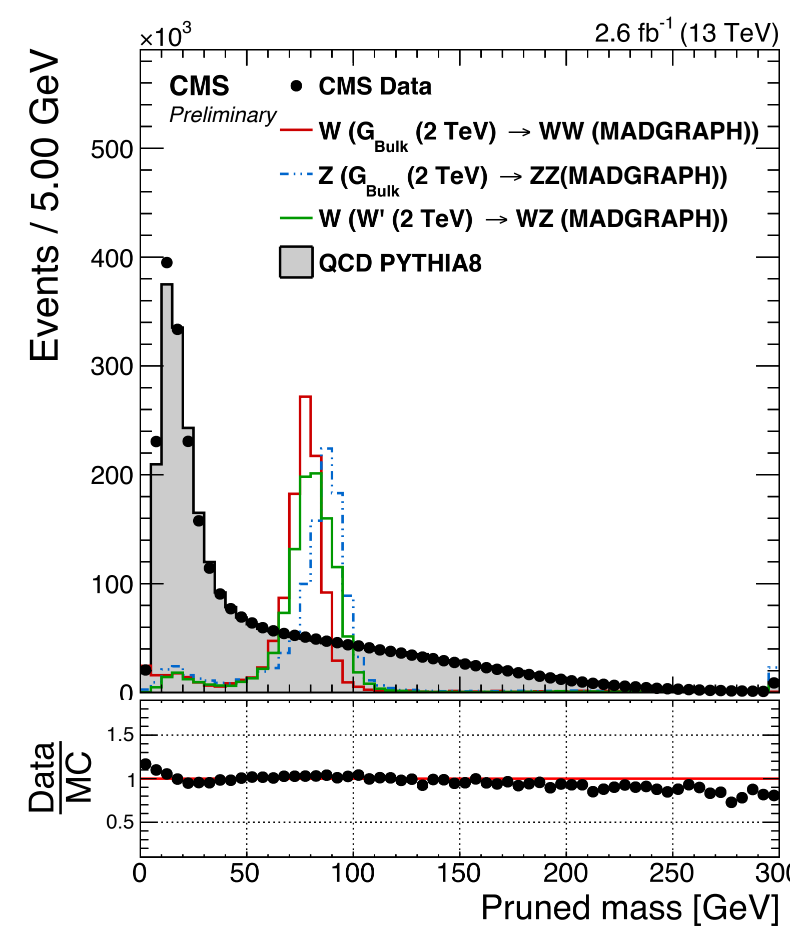
WW, WZ, ZZ → dijet

- **ATLAS**
  - V→qq tagger based on energy correlation (D_2), m_j and tracks
- **CMS**
  - V→qq tagger based on N-subjettiness (τ_{21}), m_j and tracks
- Main background from di-jets events modeled with a power-law function validated in MC and data control regions



[ATLAS-CONF-2015-073]

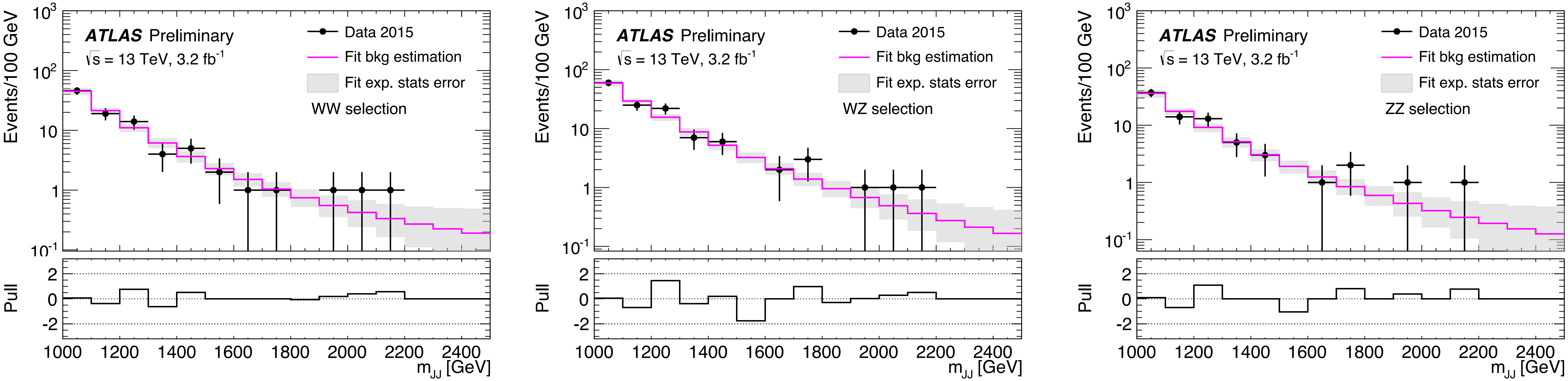


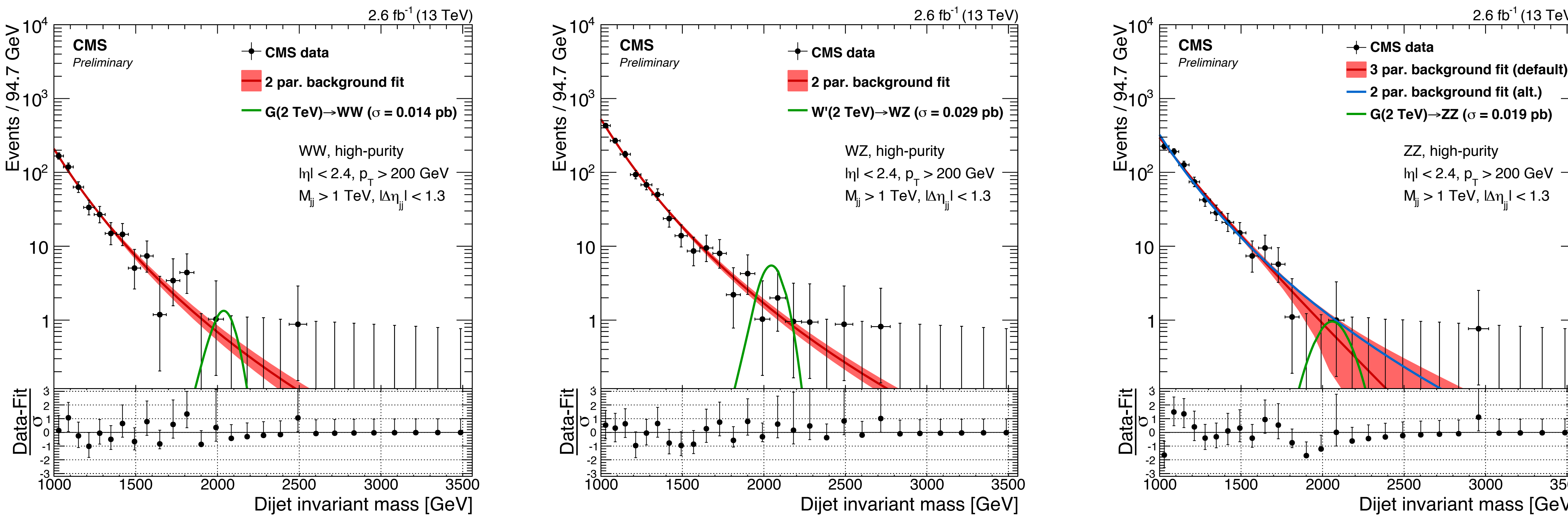


CMS-PAS-EXO-15-002

WW, WZ, ZZ → dijet

[ATLAS-CONF-2015-073]

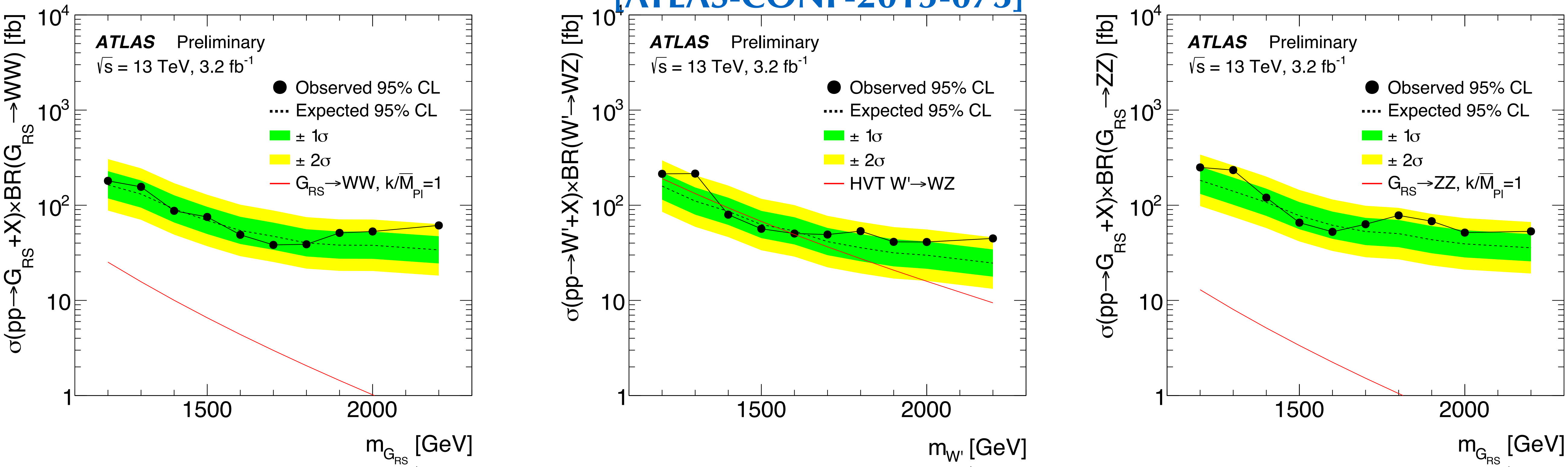


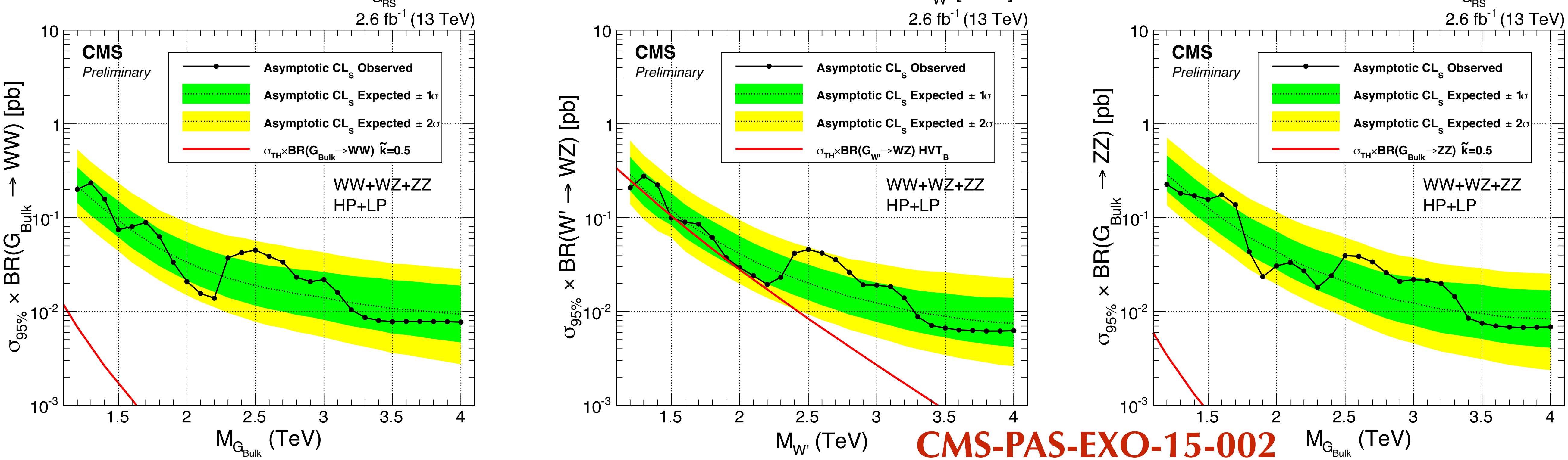


CMS-PAS-EXO-15-002

WW, WZ, ZZ → dijet

[ATLAS-CONF-2015-073]



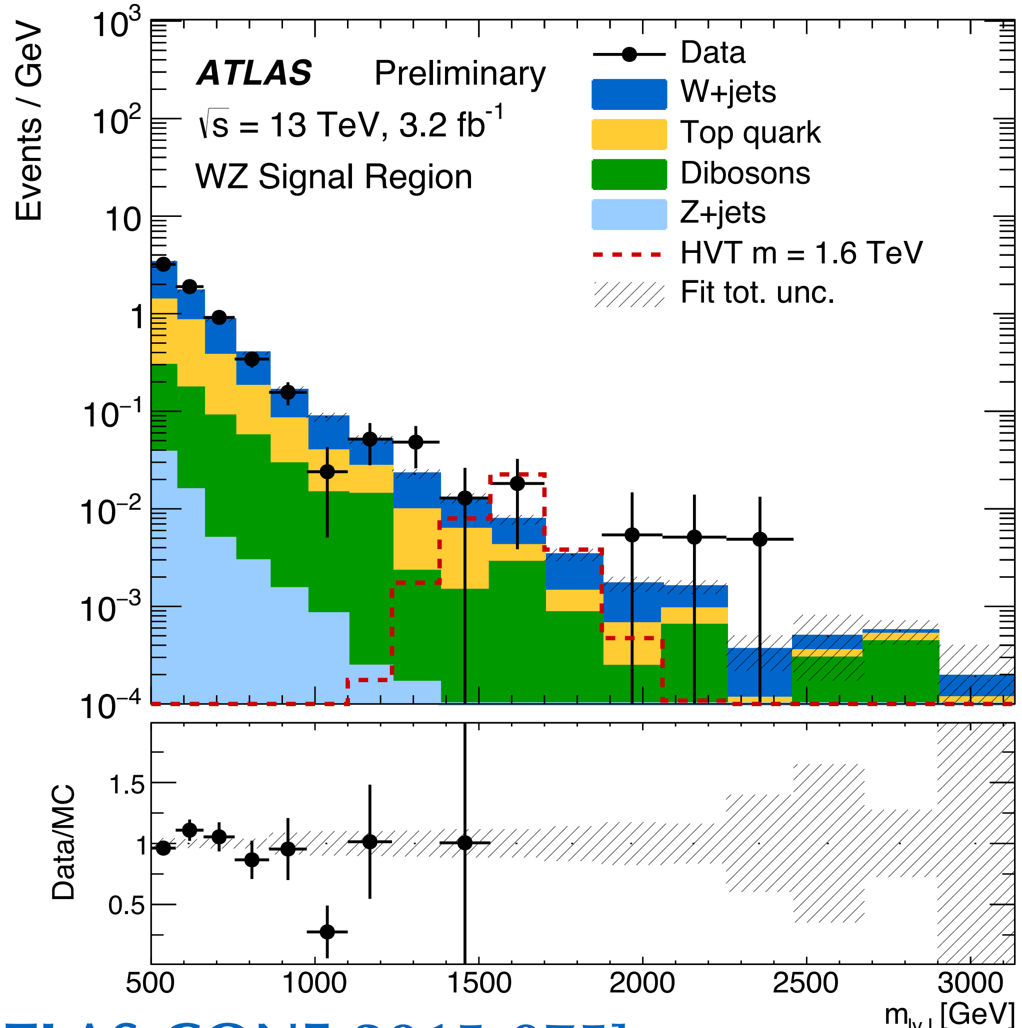


CMS-PAS-EXO-15-002

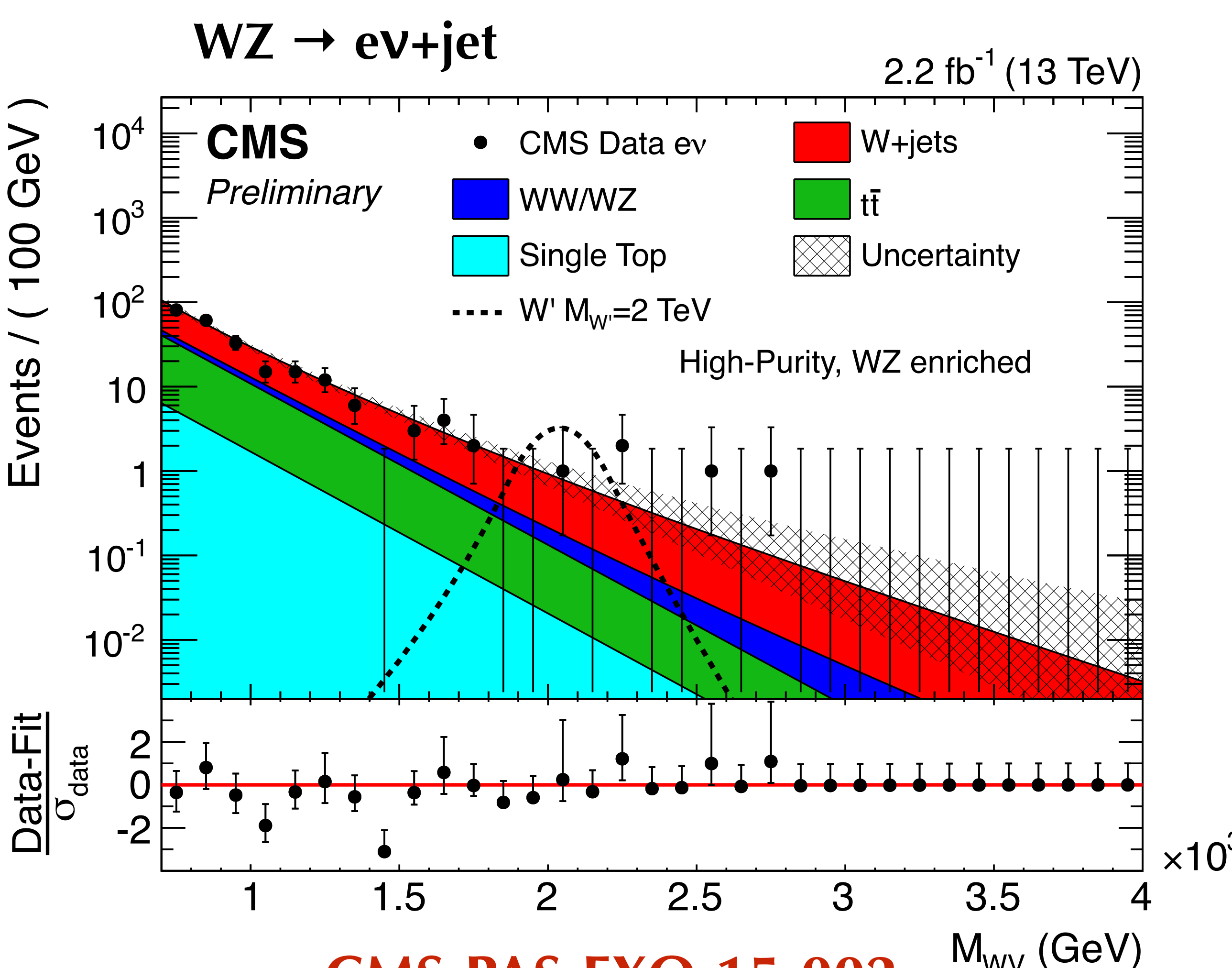
Very similar results. **Still, not enough lumi to exclude the Run I excess or to confirm it.**

WW, WZ → ℓν+jet

- Main backgrounds from W+jets and ttbar
- **ATLAS**
  - bkg. from MC, normalized to data
- **CMS**
  - bkg. normalized in control regions, prediction shape from the sideband and extrapolated to signal region

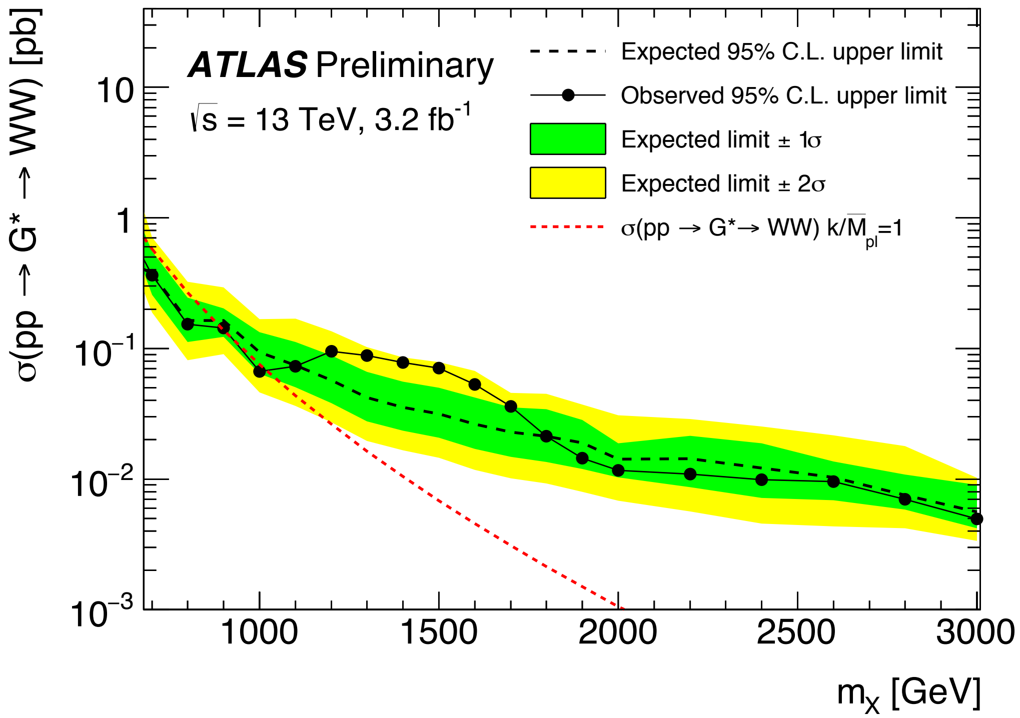


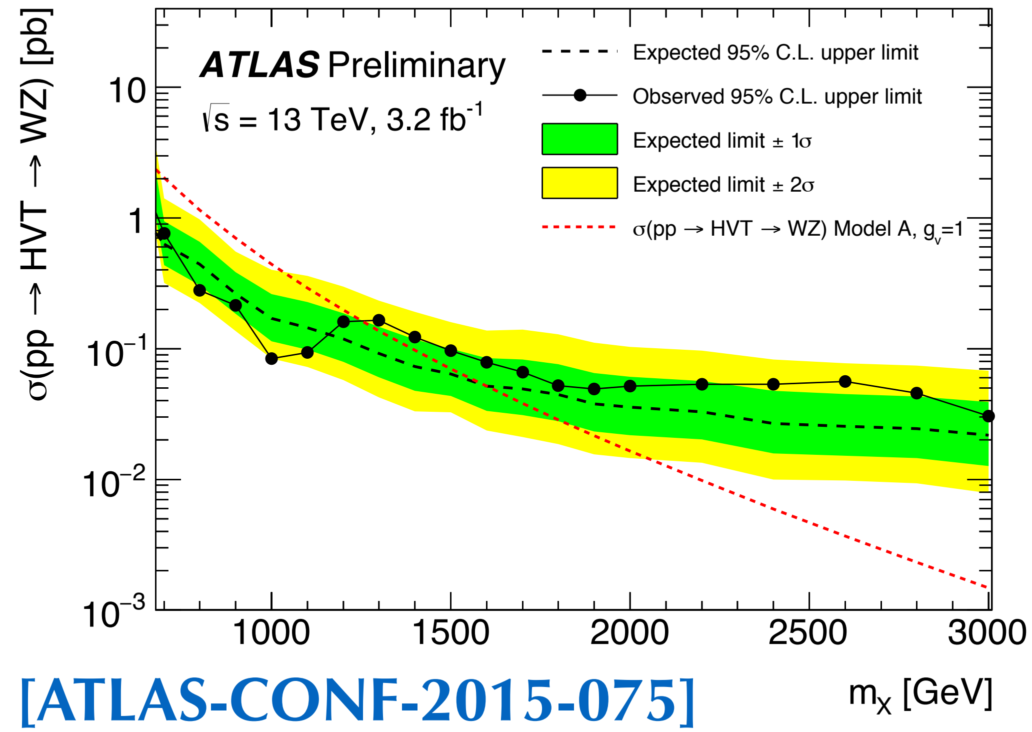
[ATLAS-CONF-2015-075]



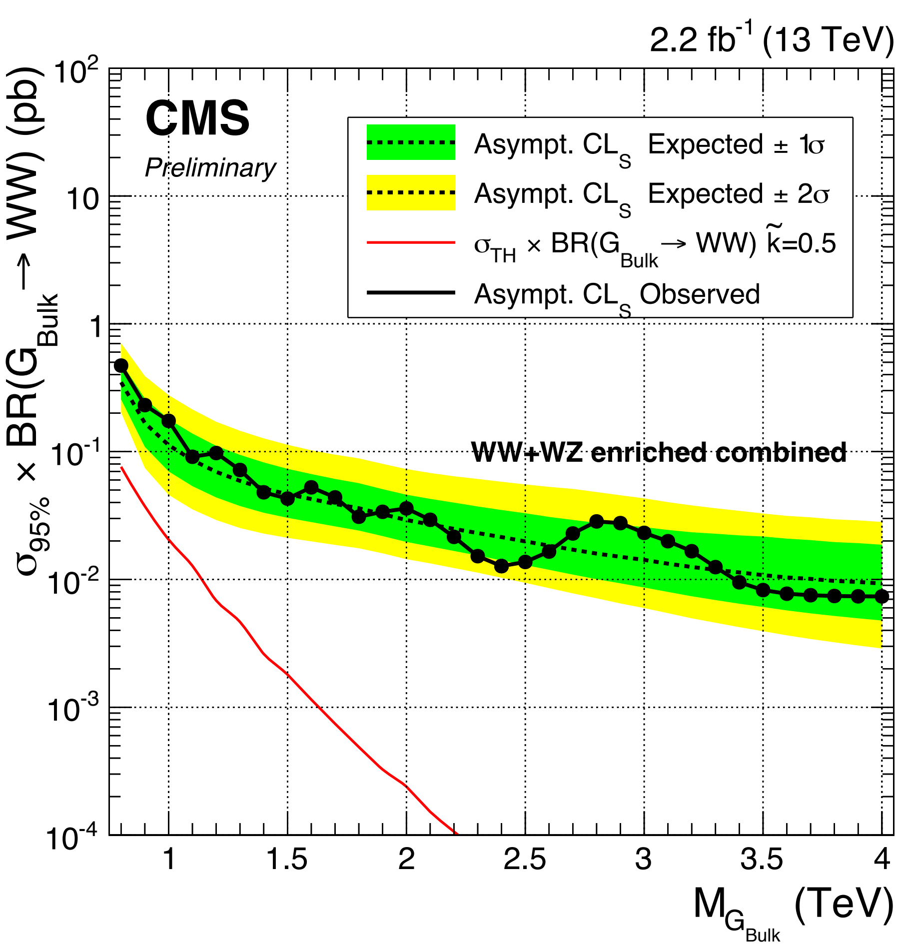
CMS-PAS-EXO-15-002

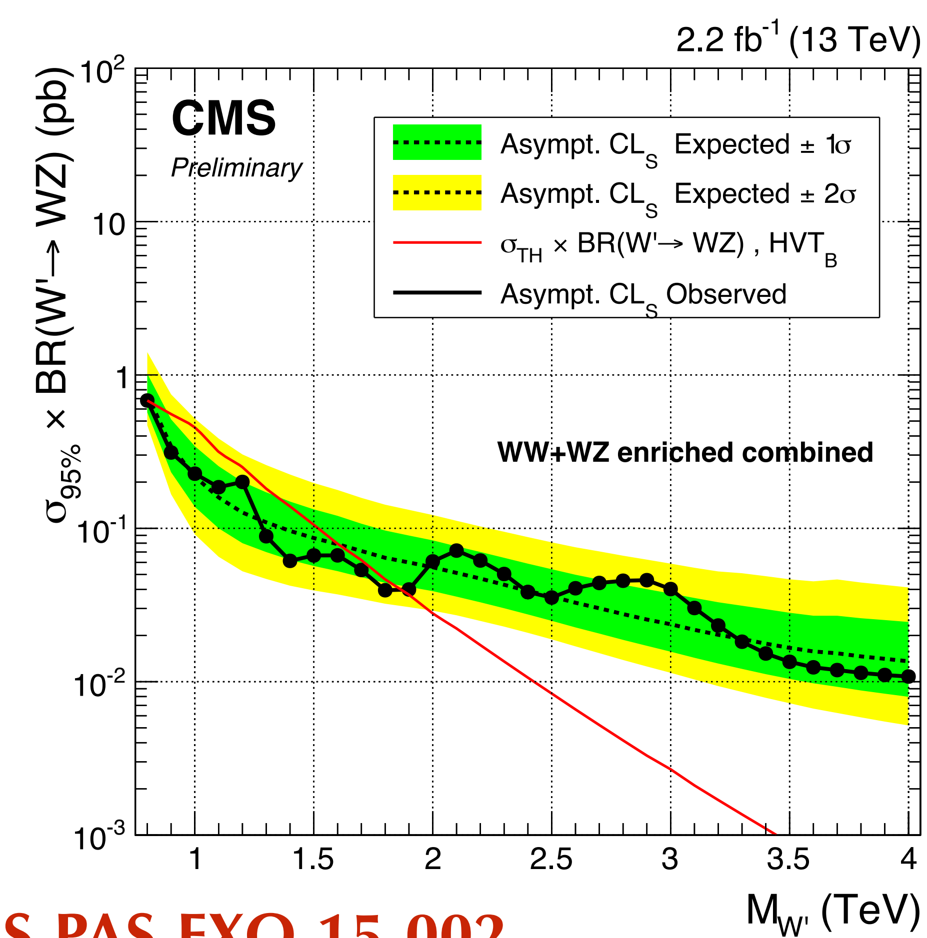
WW, WZ → $\ell\nu$+jet





[ATLAS-CONF-2015-075]



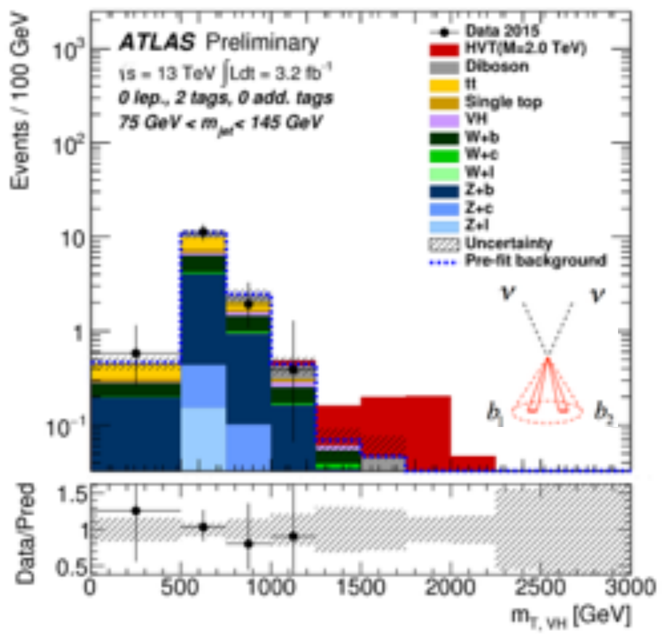


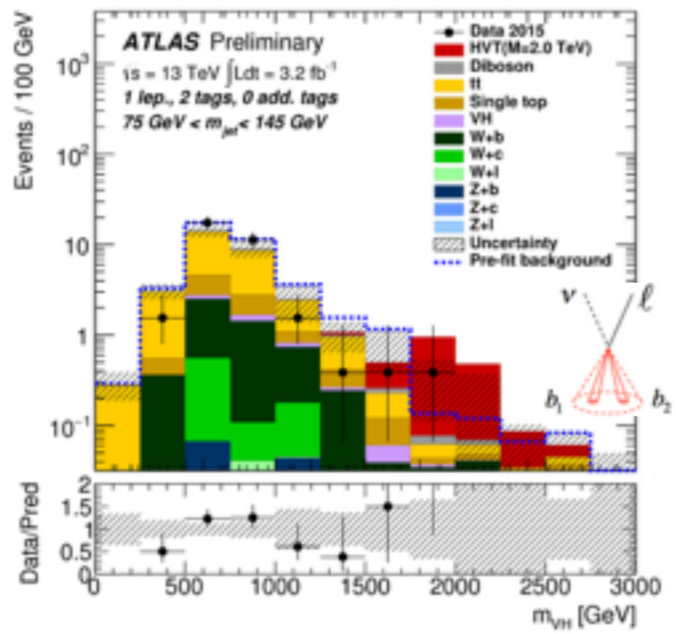
No evidence for resonant diboson production.

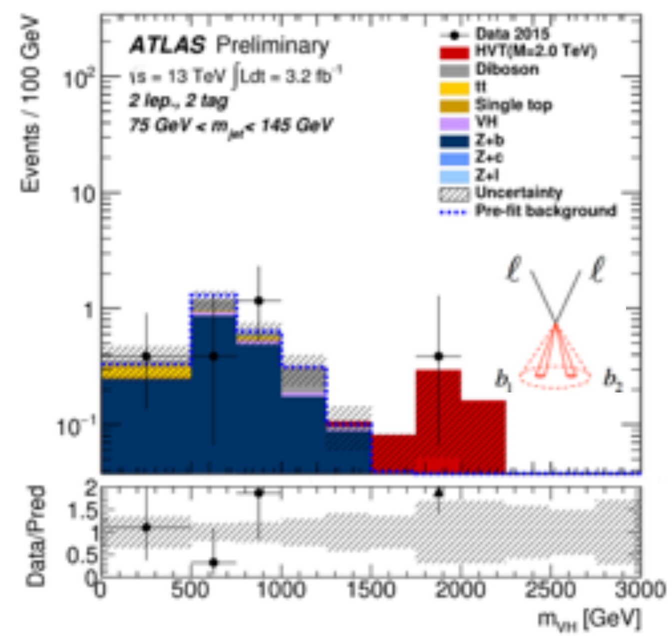
CMS-PAS-EXO-15-002

Other Diboson analyses by ATLAS

- VV → $\ell\ell$qq [ATLAS-CONF-2015-071]
- VV → ννqq [ATLAS-CONF-2015-068]
- **Vh->$\ell\ell$bb, $\ell\nu$bb, ννbb** [ATLAS-CONF-2015-074]

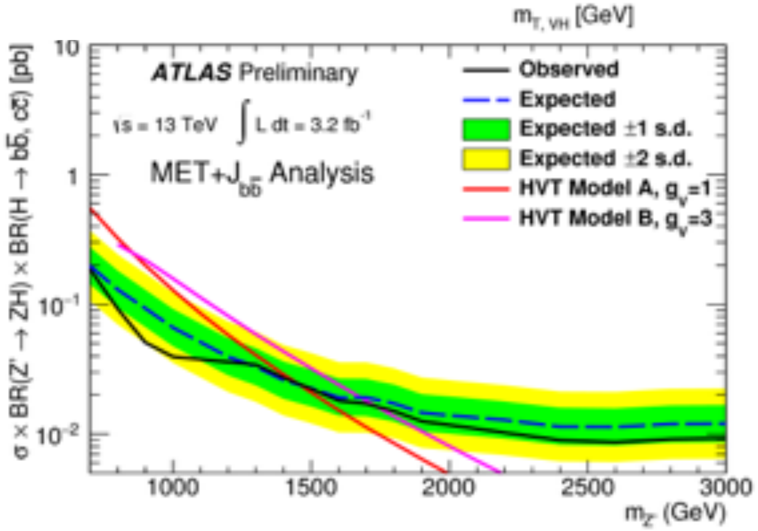


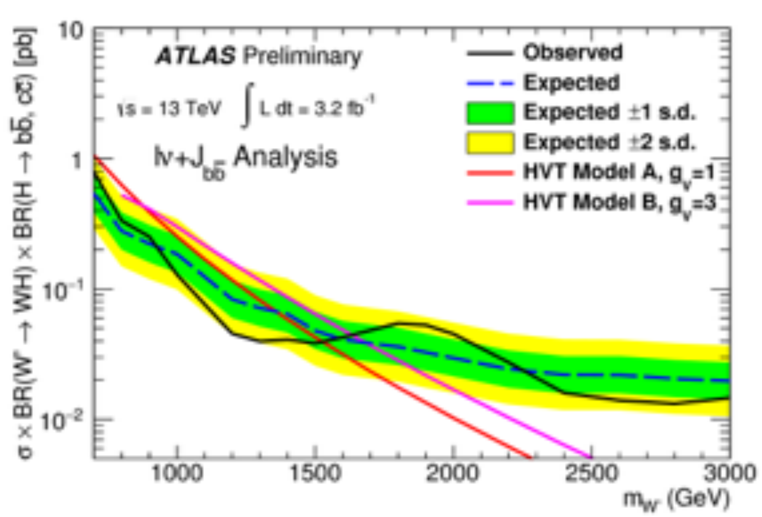


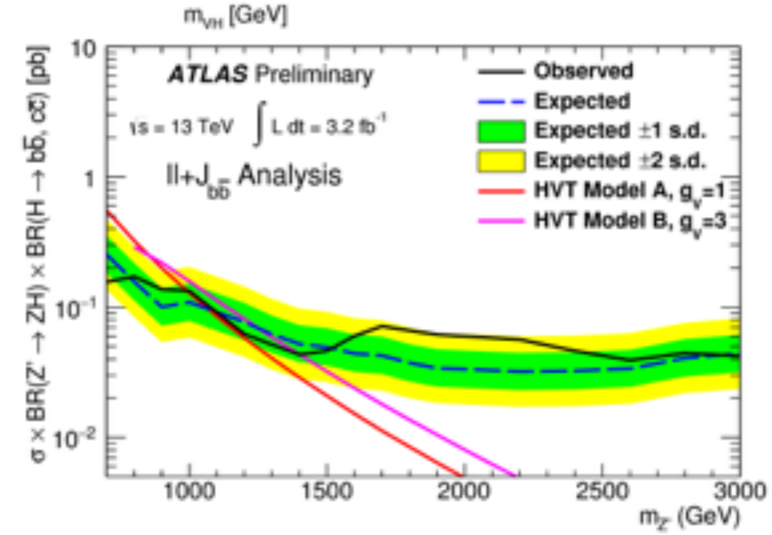


No confirmation of the excess seen by CMS @ 8 TeV.

Still, not enough luminosity.

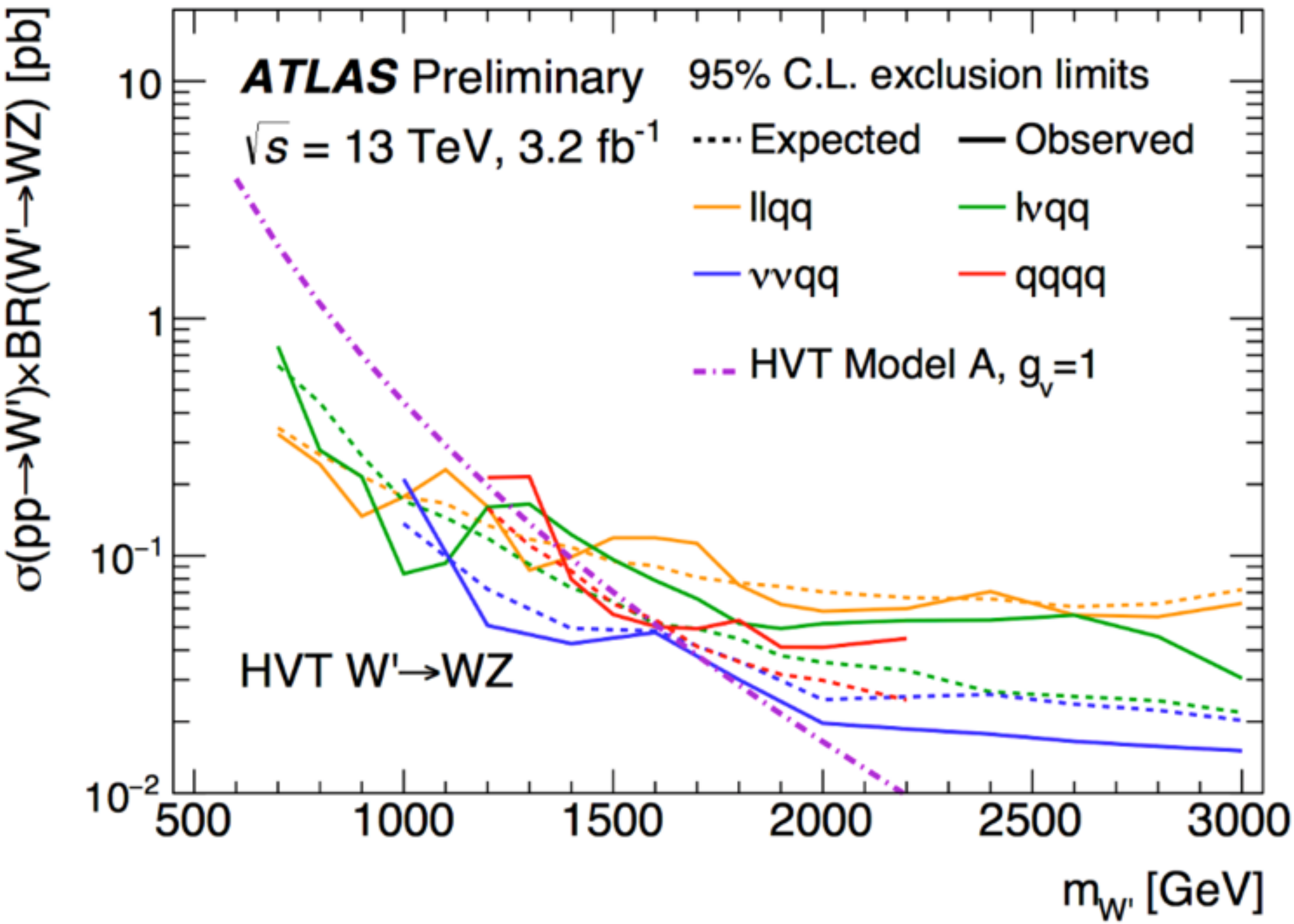






[ATLAS-CONF-2015-074]

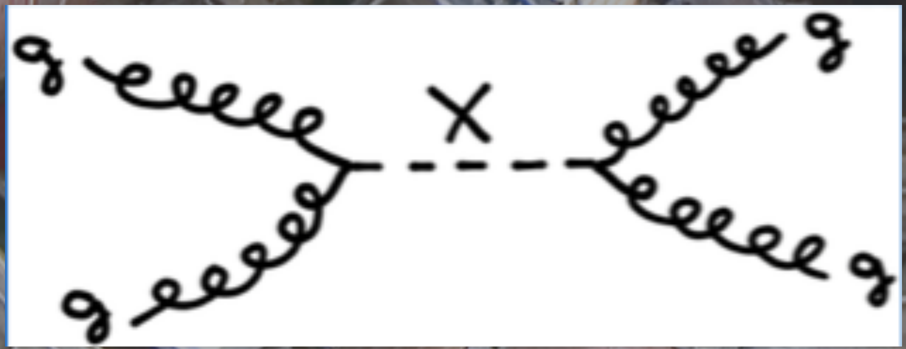
Other Diboson analyses by ATLAS

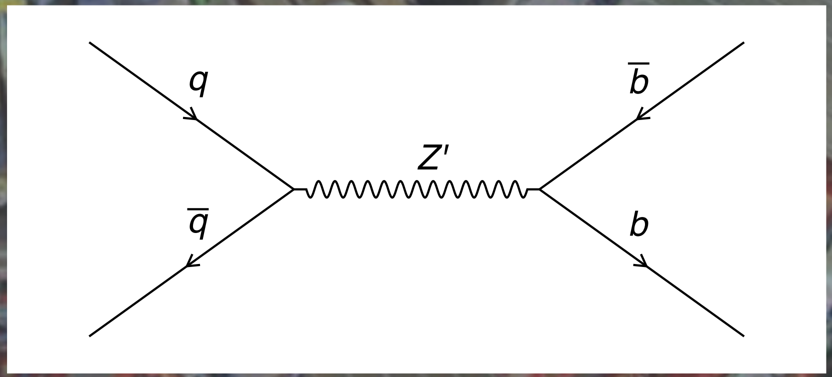


VV → $\ell\ell$qq and VV → ννqq not public in CMS

No evidence for resonant disobey production.

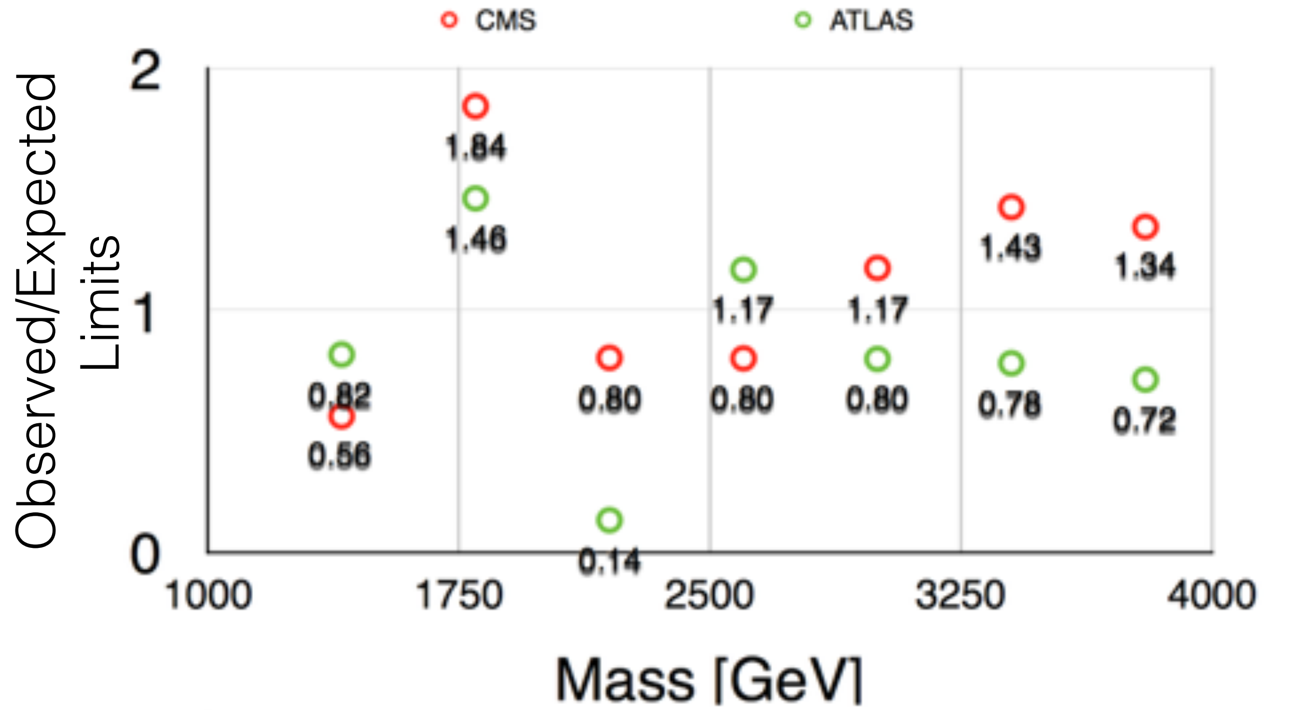
Dijet

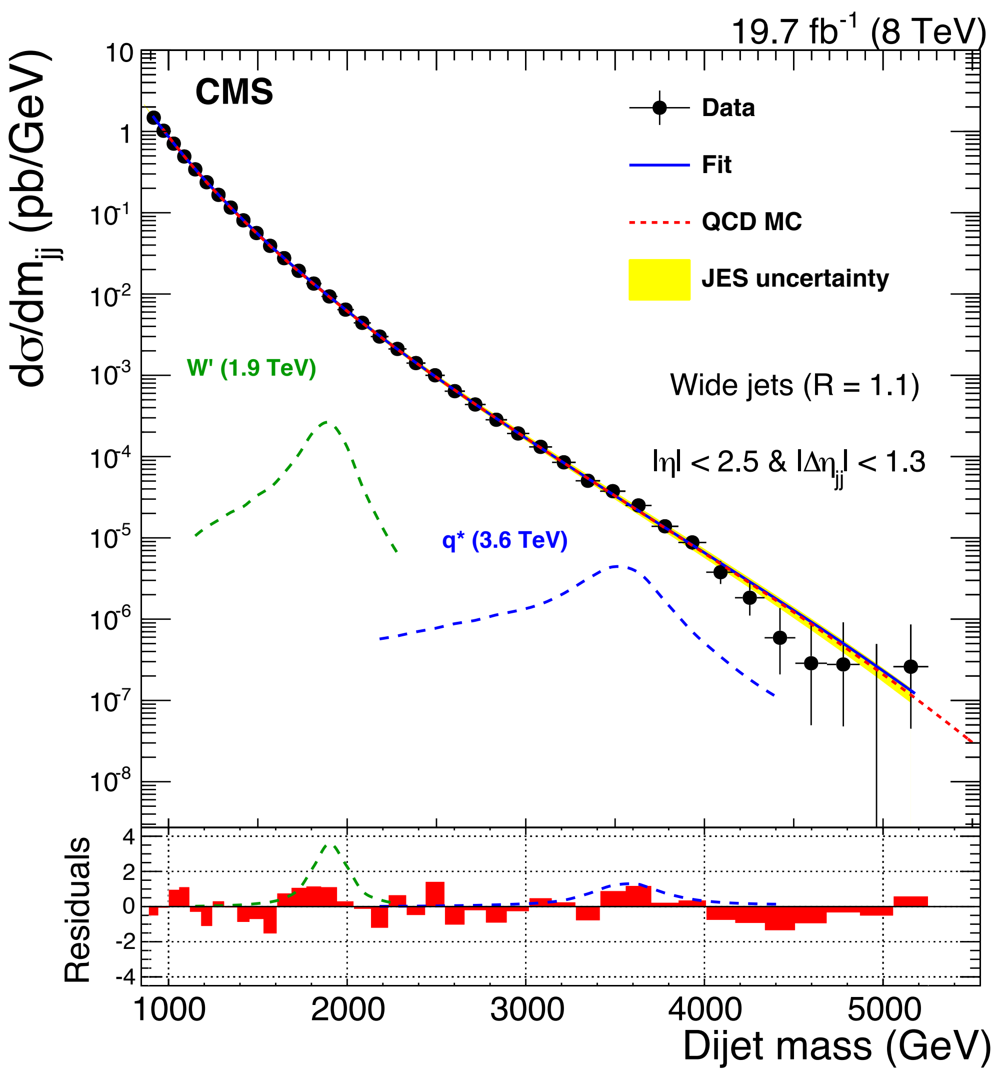




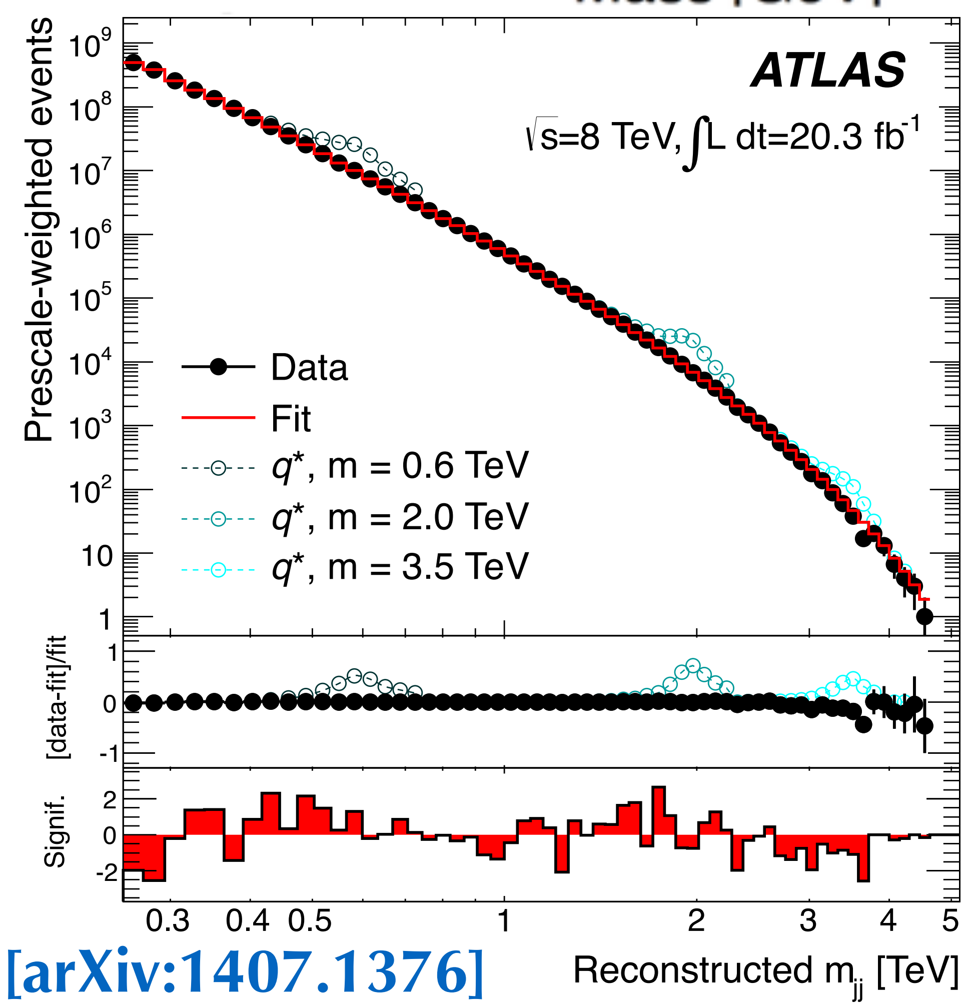
Dijet status @ 8 TeV

- **CMS** ~2sigma (local) excess at ~1.8 TeV
- **ATLAS** much smaller Obs/Exp limit
- Only place where both experiments have observed limit > expectation





[arXiv:1501.04198]

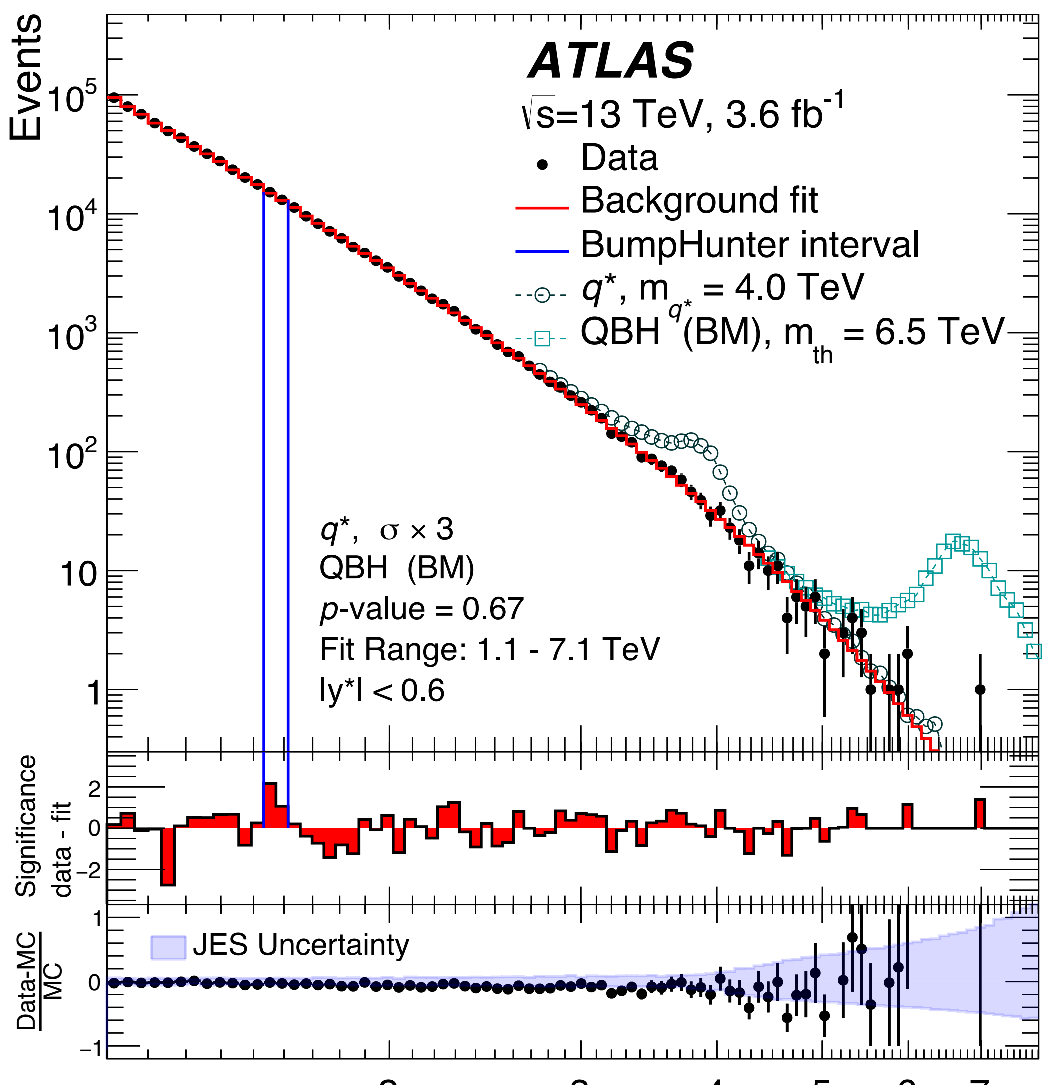


[arXiv:1407.1376]

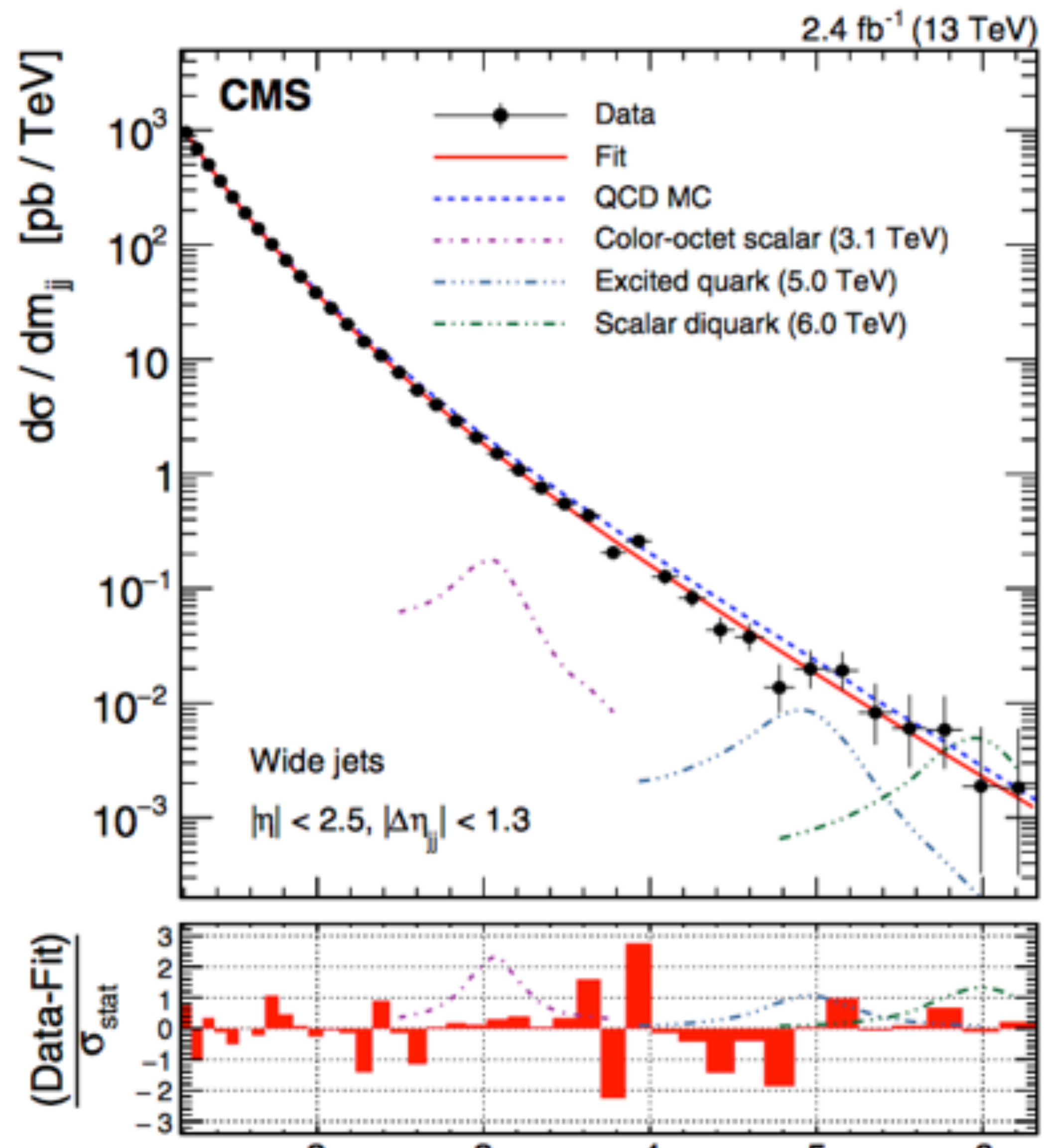
Dijet

Search for (narrow) dijet resonances & new phenomena in dijet angular distributions

- discriminant: m_{jj} and rapidity difference
- Background dominated by QCD multi-jet events
  - modeled with a functional form fitted on data



[arxiv:1512.01530]



[arXiv:1512.01224]

Moderate excess around 1.8 TeV. Dijet Run II results confirm the Run I picture

Dijet

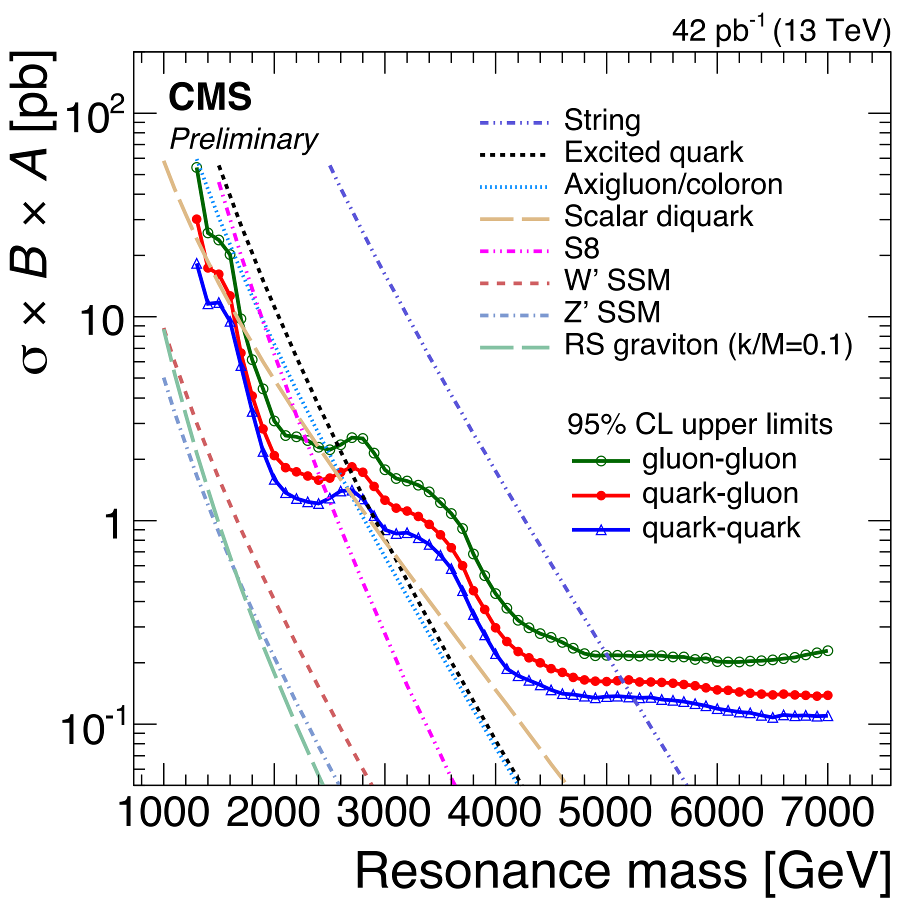
ATLAS

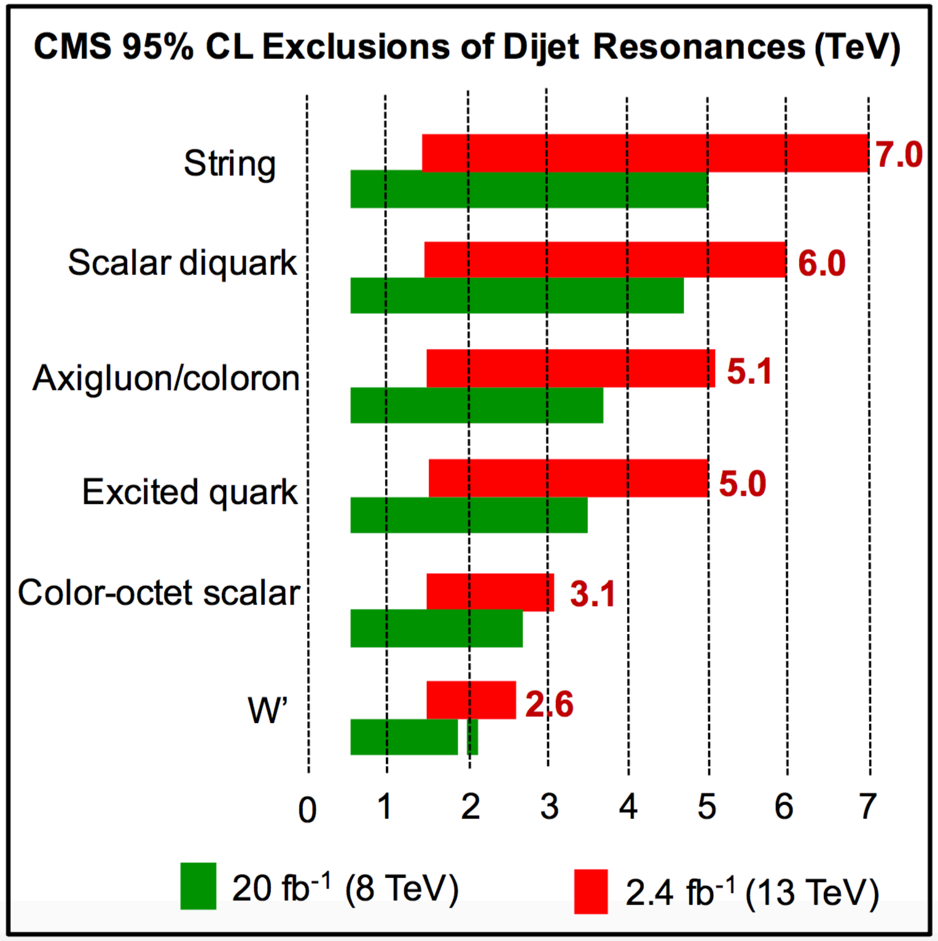
Model	95% CL Exclusion limit		
	Run 1 Observed	Observed 13 TeV	Expected 13 TeV
Quantum black holes, ADD (BLACKMAX generator)	5.6 TeV	8.1 TeV	8.1 TeV
Quantum black holes, ADD (QBH generator)	5.7 TeV	8.3 TeV	8.3 TeV
Quantum black holes, RS (QBH generator)	–	5.3 TeV	5.1 TeV
Excited quark	4.1 TeV	5.2 TeV	4.9 TeV
W'	2.5 TeV	2.6 TeV	2.6 TeV
Contact interactions (η_{LL} =+1)	8.1 TeV	12.0 TeV	12.0 TeV
Contact interactions (η_{LL} =−1)	12.0 TeV	17.5 TeV	18.1 TeV

[arxiv:1512.01530]

No signal found, both analysis significantly extended limits w.r.t 8 TeV

[arXiv:1512.01224]

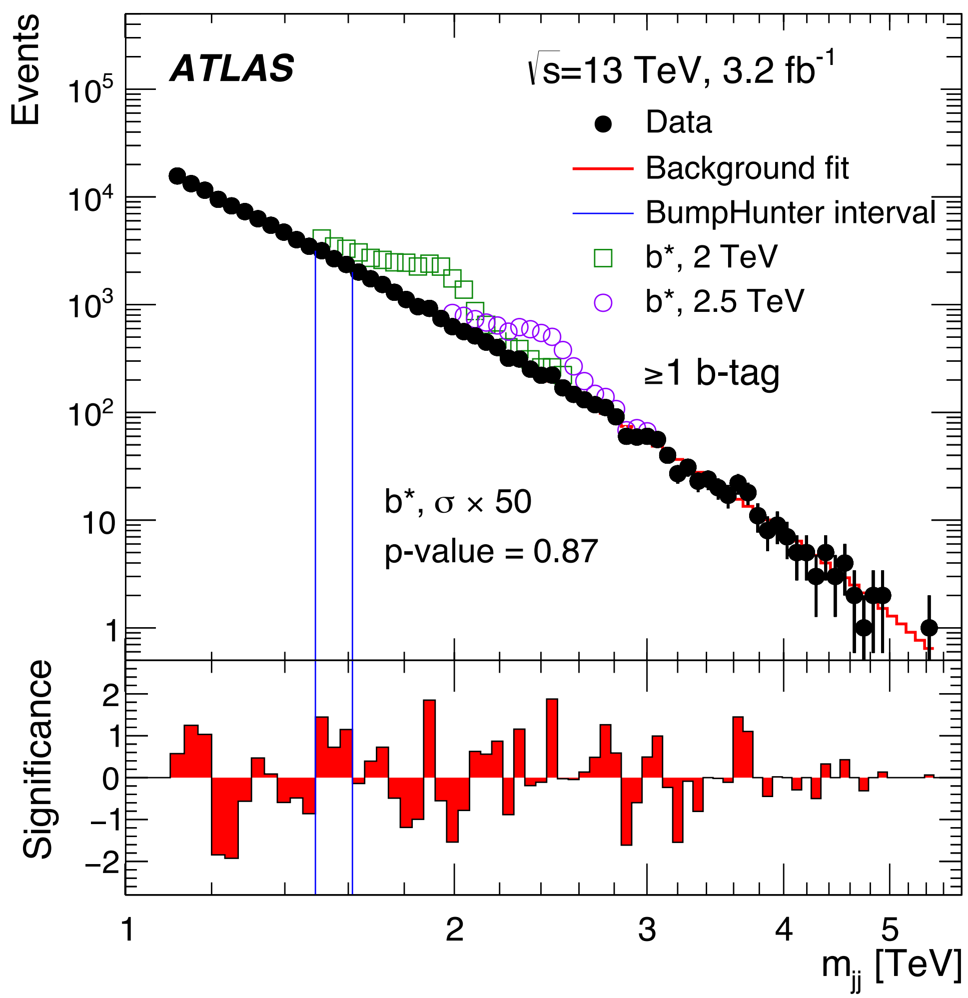


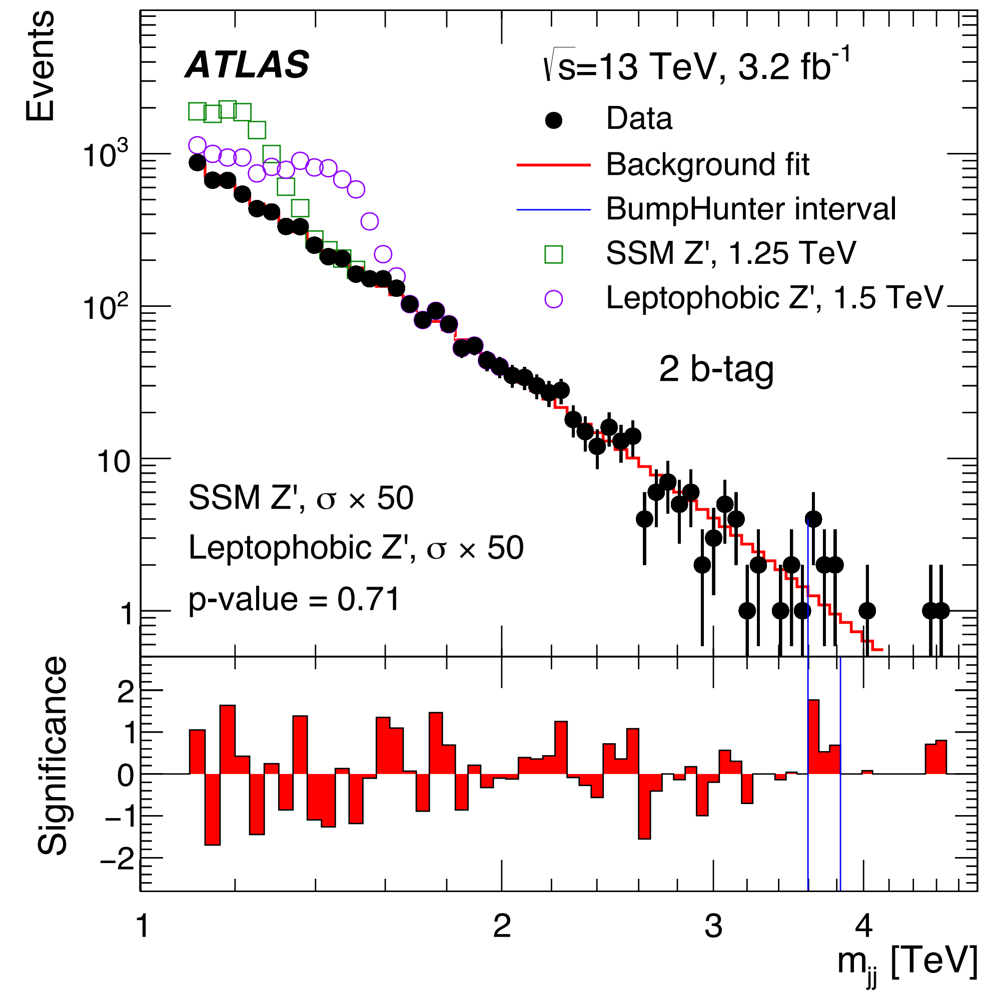


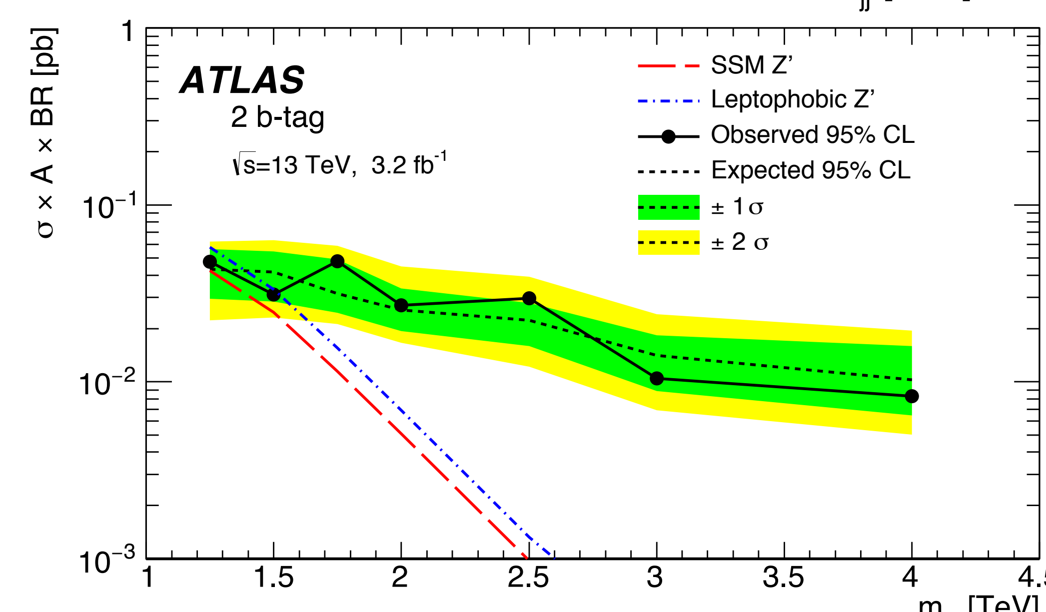
Di-b-jet by ATLAS

- **Single and double b-tag categories** sensitive to different signal hypotheses
- Use same background estimation method as di-jet analysis

[arXiv:1603.08791]

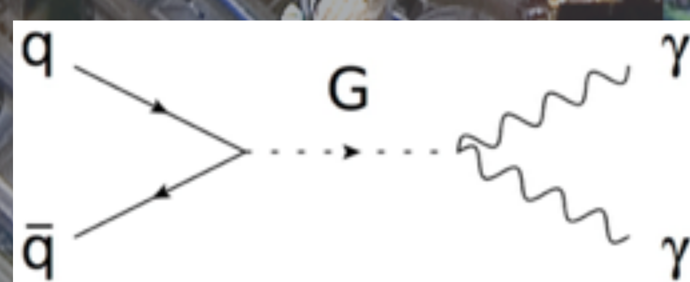


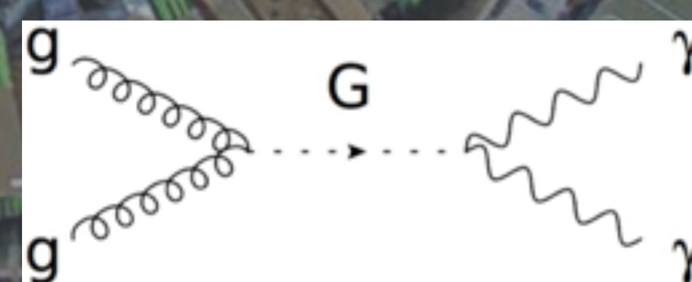




Exclude leptophobic $Z' \rightarrow bb$ model up to 1.5 TeV. No yet sensitive to Z'_{SSM}

Diphoton

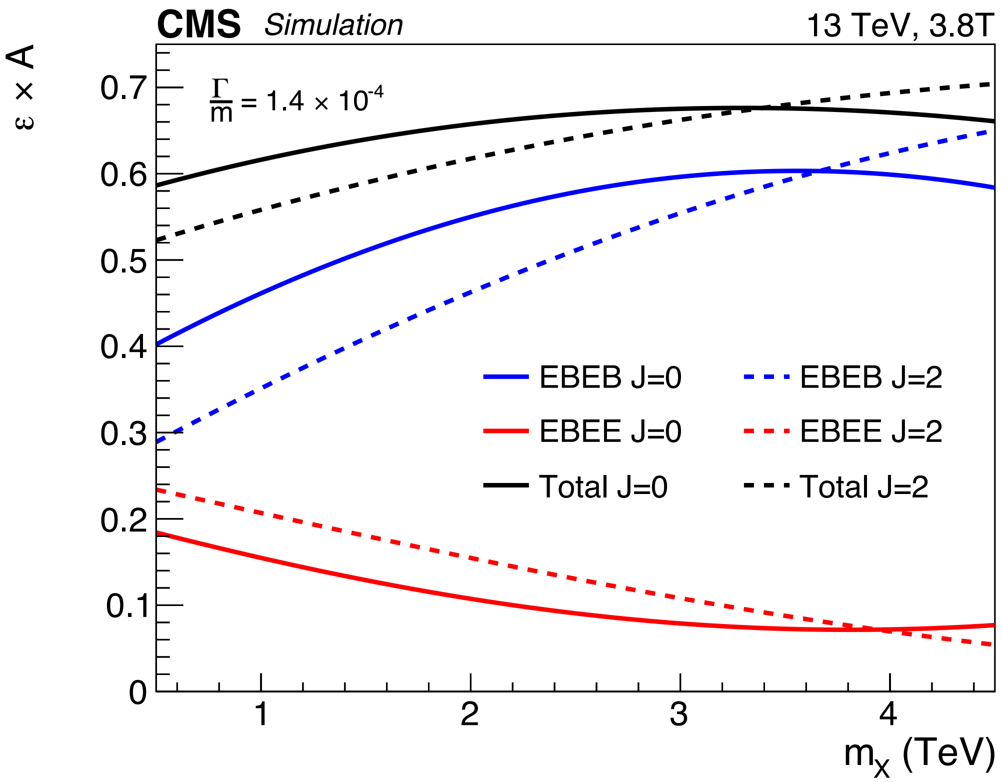




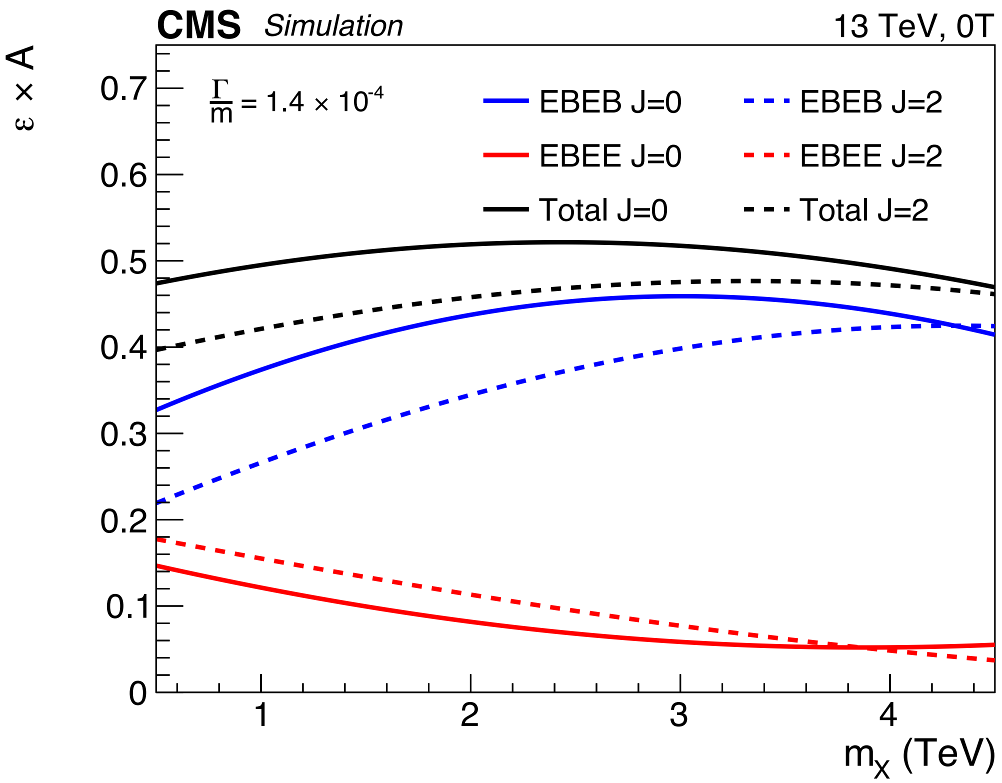
General Strategy

[PAS EXO-16-018]

- **Clear final state:**
  - two high pt photons reconstructed as high energy deposit in EM calorimeters
  - isolated: no additional activity in the direction of the two photons



- **ATLAS**
  - **different selection** for **spin-0** (optimized for Higgs-like signal) and **spin-2** (optimized for $G \rightarrow \gamma\gamma$)
- **CMS**
  - categorize events in **barrel-barrel** (EBEB) and **barrel-endcaps** (EBEE)
  - **B=0 T data** (0.6/fb) analyzed



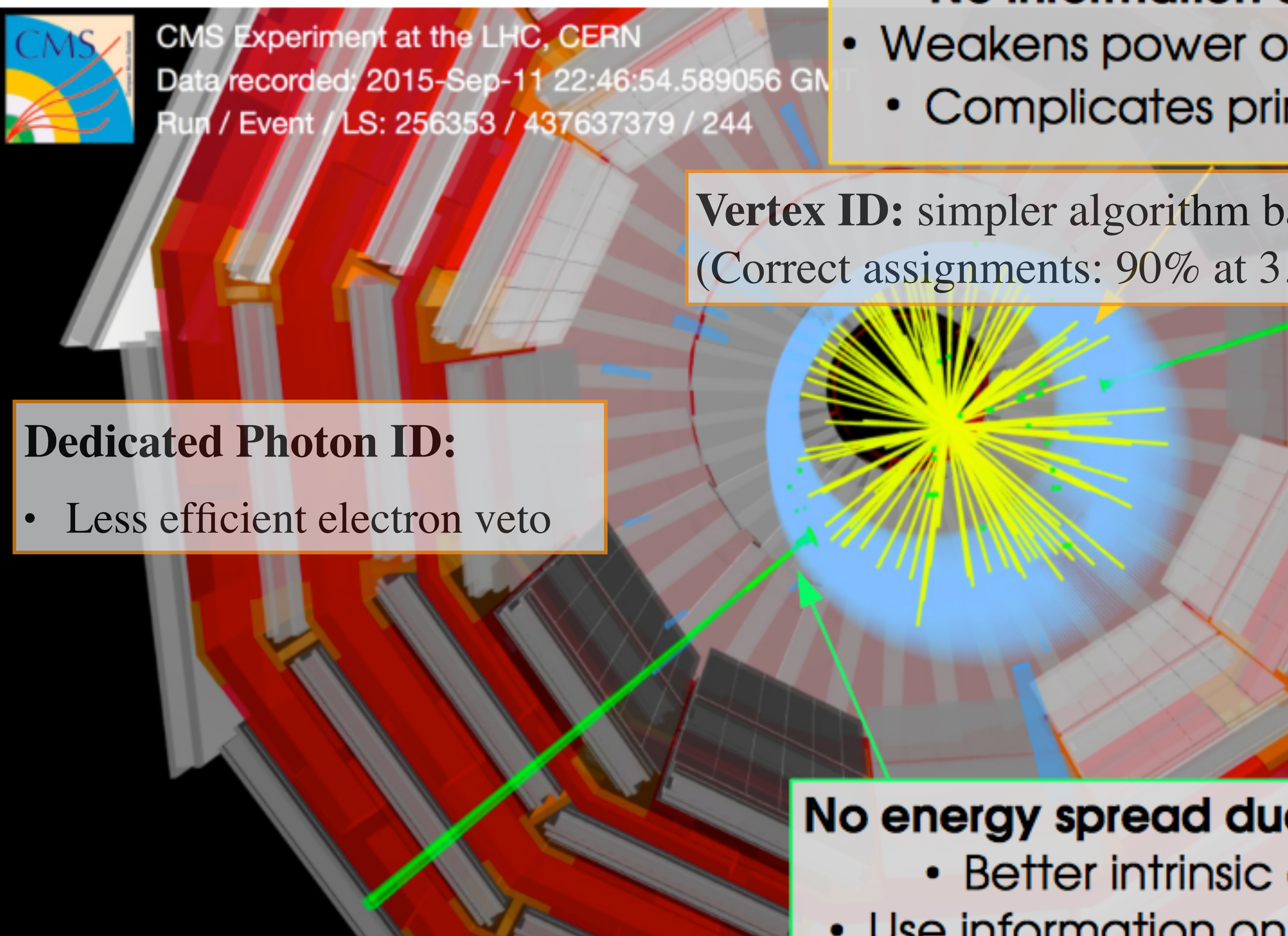
0T data challenge

Significant re-thinking of the analysis needed to use data without magnetic field

No information on tracks` Momenta

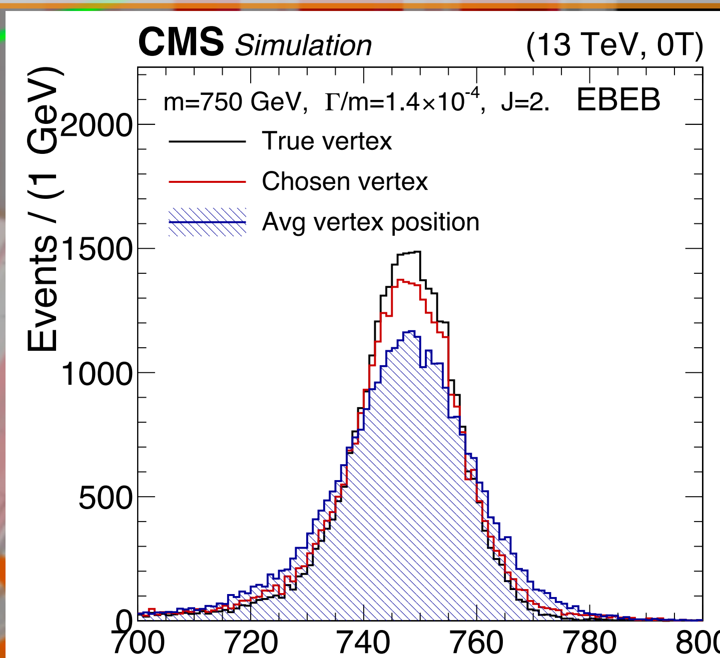
- Weakens power of isolation requirements
  - Complicates primary vertex selection

Vertex ID: simpler algorithm based on **track-counting**
(Correct assignments: 90% at 3.8T, 60% at 0T)



Dedicated Photon ID:

- Less efficient electron veto



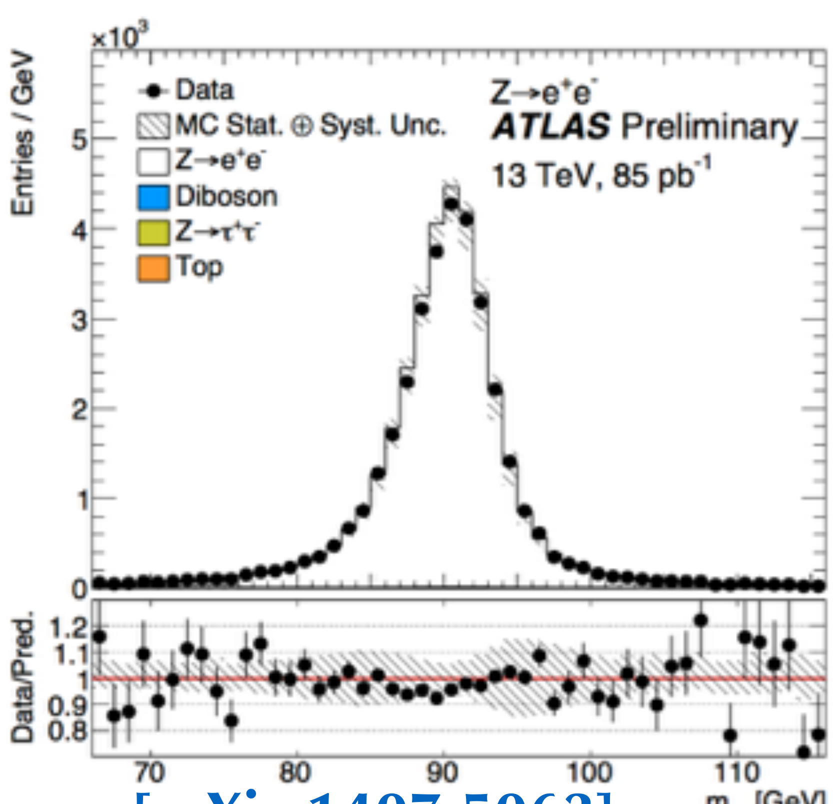
[PAS EXO-16-018]

No energy spread due to brem/conversions

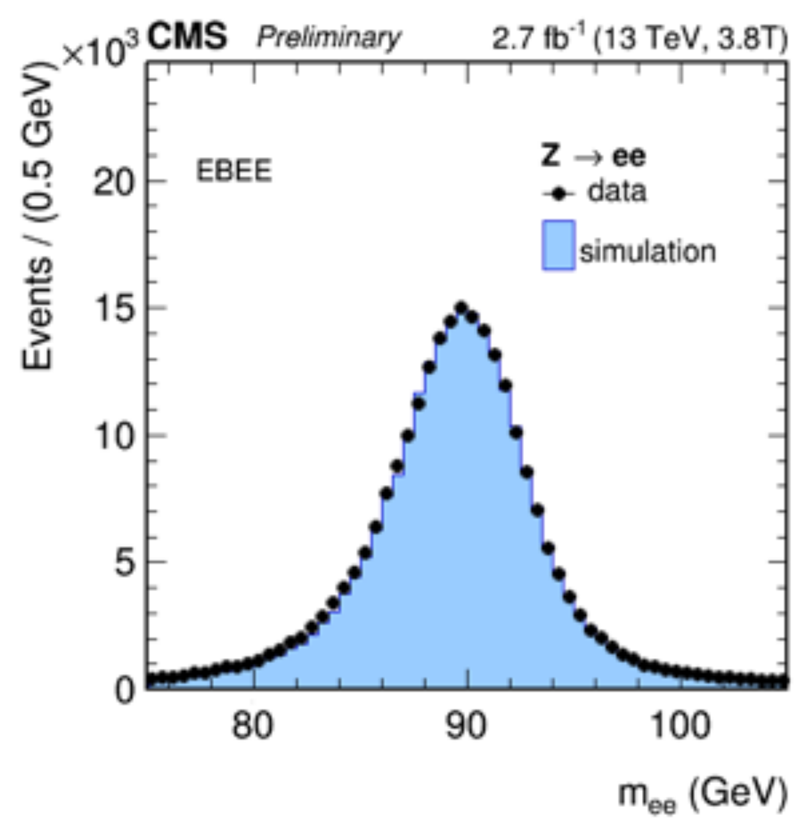
- Better intrinsic energy resolution
- Use information on lateral shower profile.

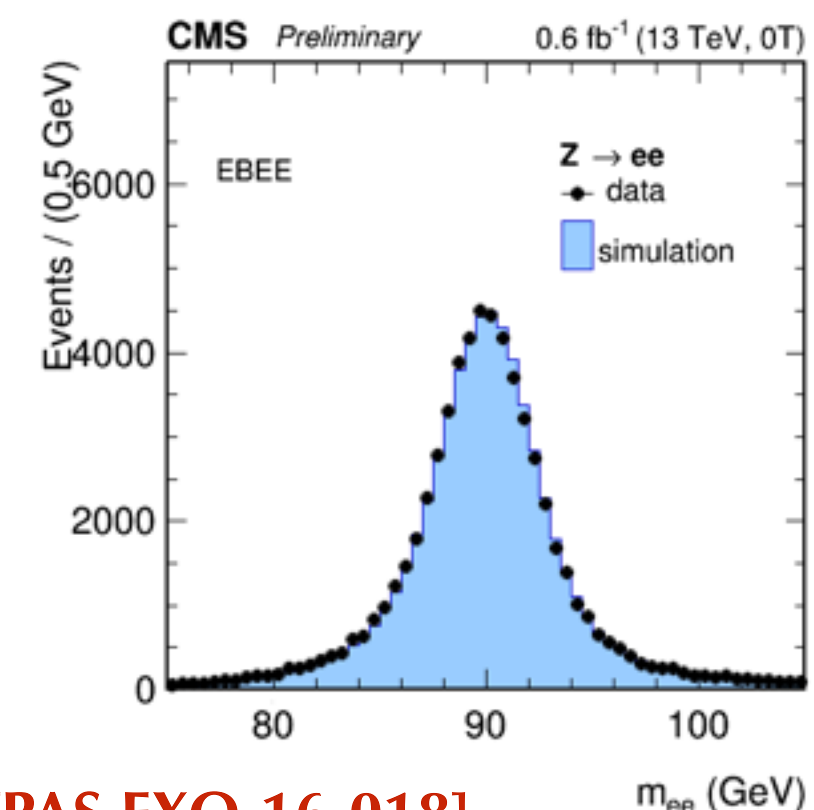
ID and Energy calibration

- Measure **efficiency** in data (using Z→ee and Z → $\ell\ell\gamma$)
- **ATLAS**
  - **photon ID eff.** 85% (E_T ~50 GeV) - 95% (E_T ~200 GeV)
- **CMS**
  - **photon ID eff.** in the **barrel**: 90(85)% at 3.8(0)T.
  - **photon ID eff.** in the **endcaps**: 85(70)% at 3.8(0)T.
- **Energy scale and resolution** corrections, from **MV regression** to calibrate photon energy, **validated with Z → ee events**



[arXiv:1407.5063]



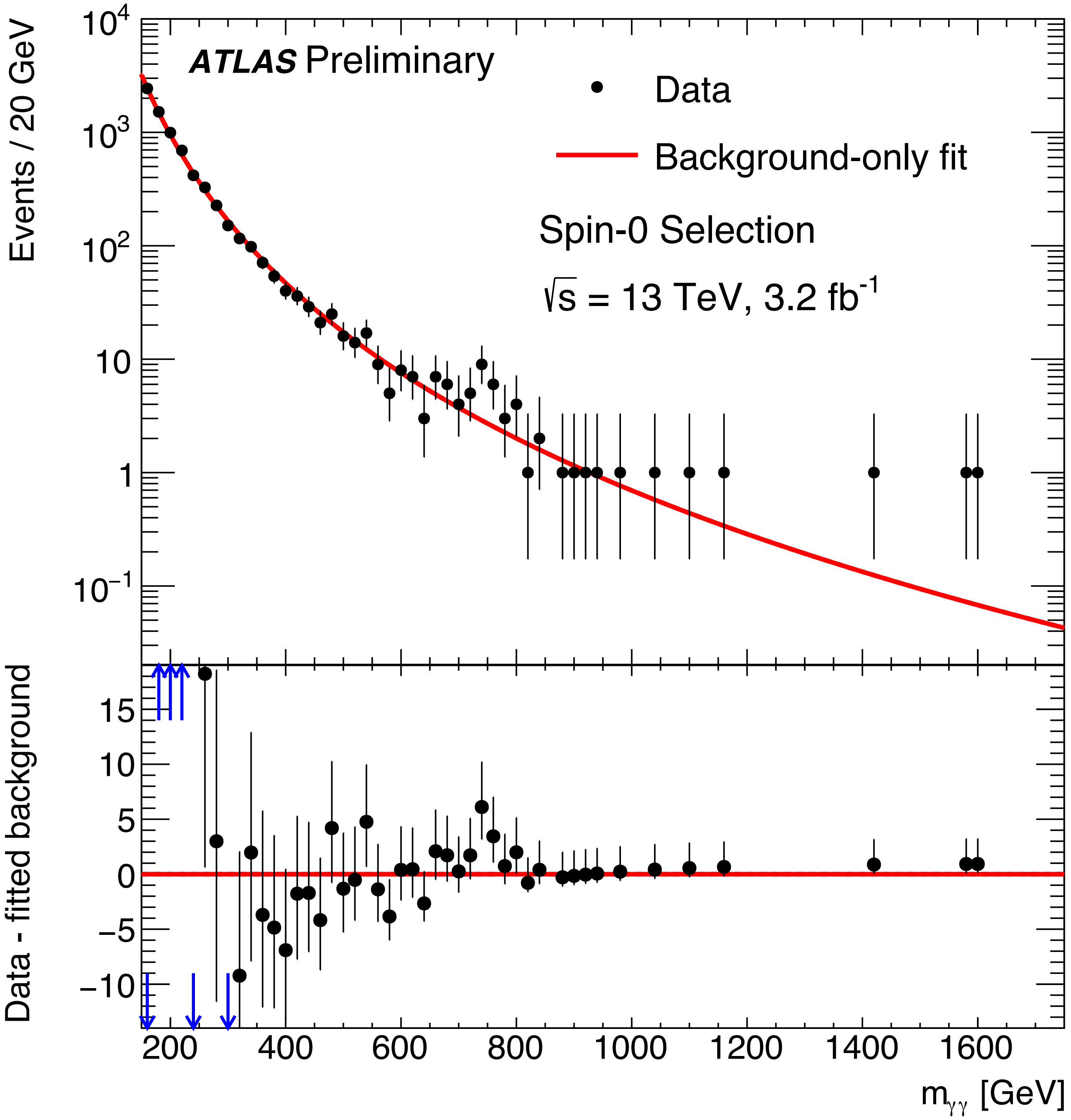


[PAS EXO-16-018]

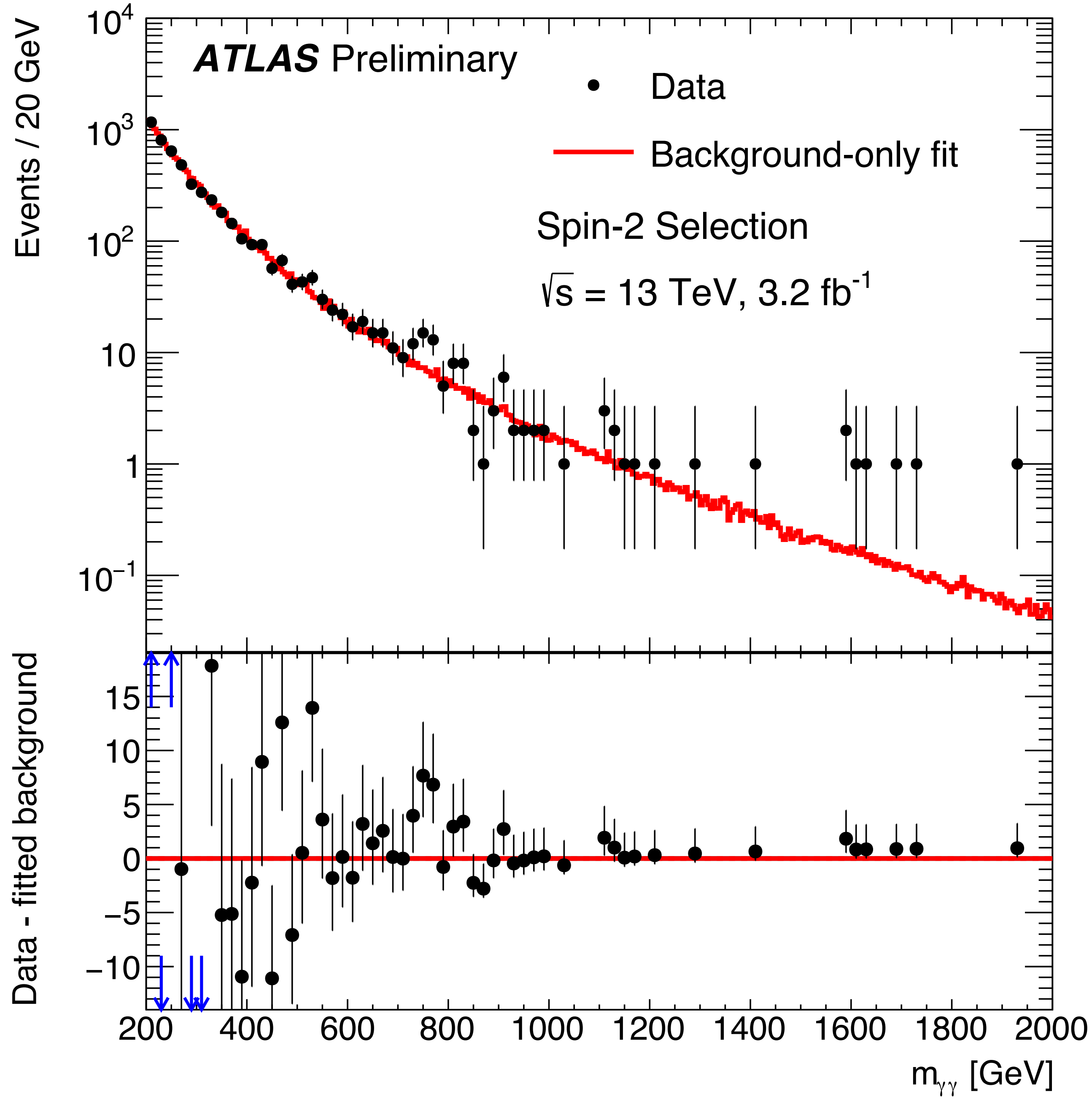
Mass Spectra ATLAS

[ATLAS-CONF-2016-018]

SPIN 0



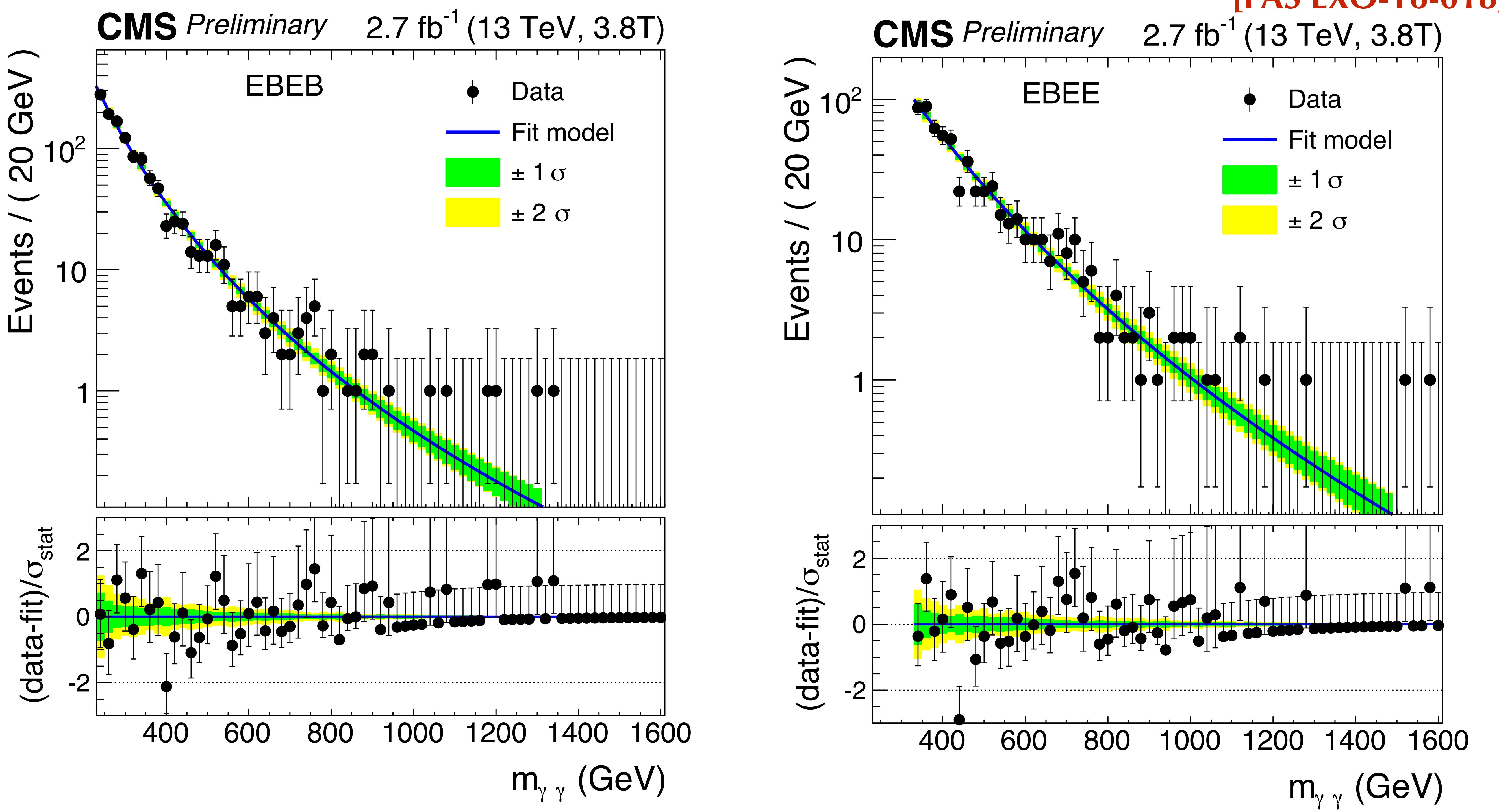
SPIN 2



Parametrize background mass spectrum from data or from bkg template (ATLAS spin 2)

Mass Spectra CMS @3.8T

[PAS EXO-16-018]

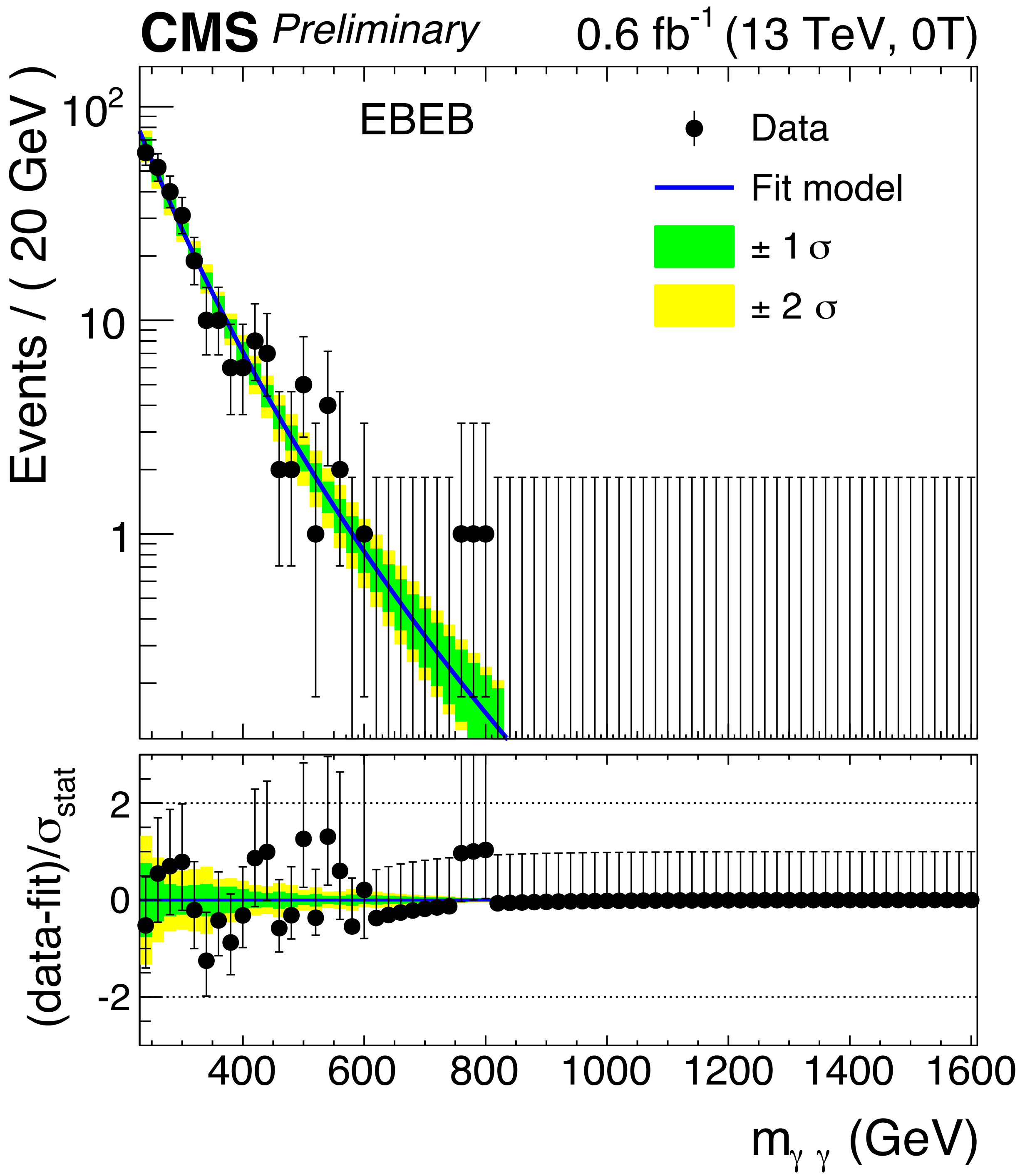


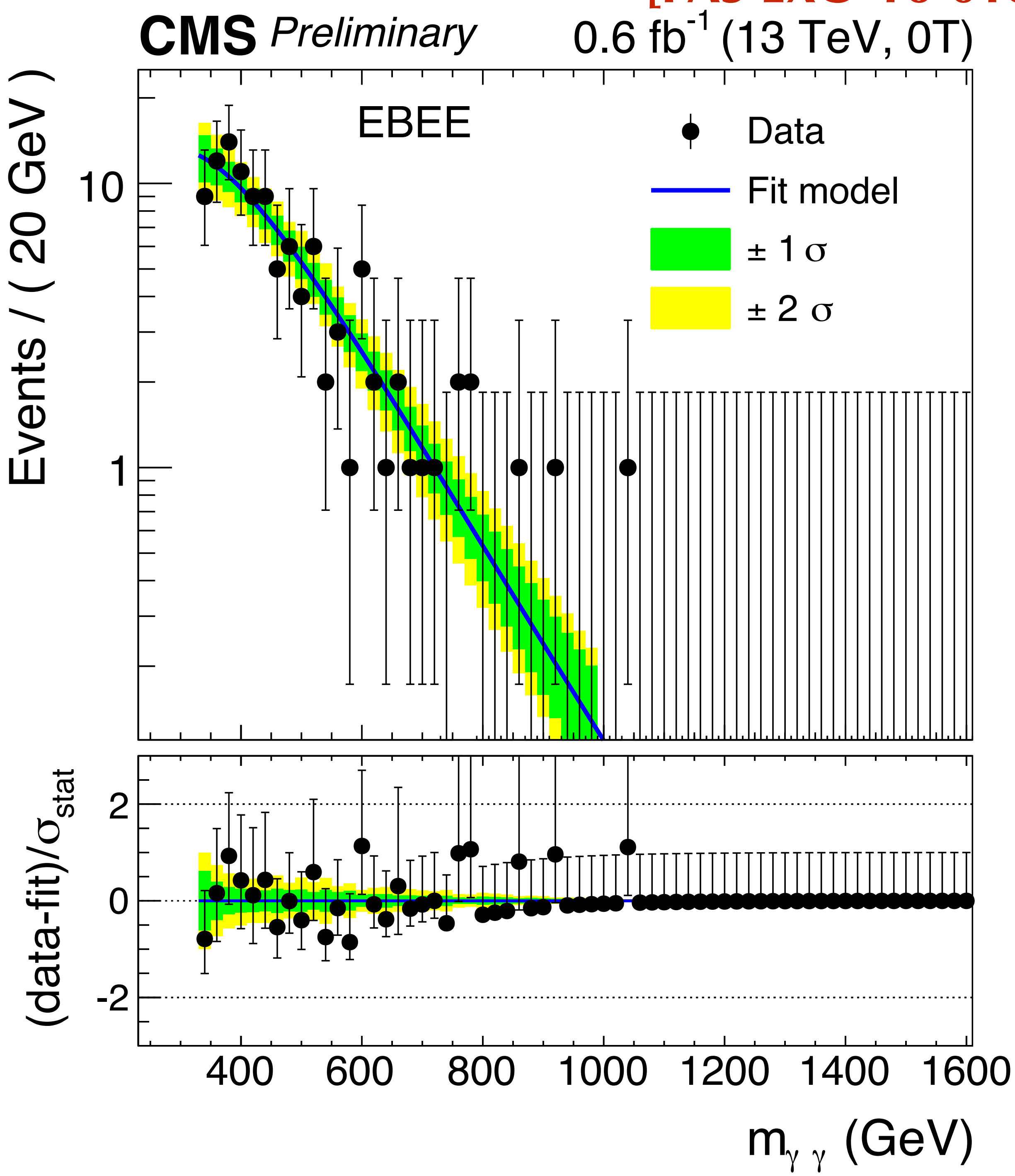
Parametrize background mass spectrum from data (independent shape for each category).

Possible mismodelling studied on simulation and explicit uncertainty added to the fit.

Mass Spectra CMS @0T

[PAS EXO-16-018]





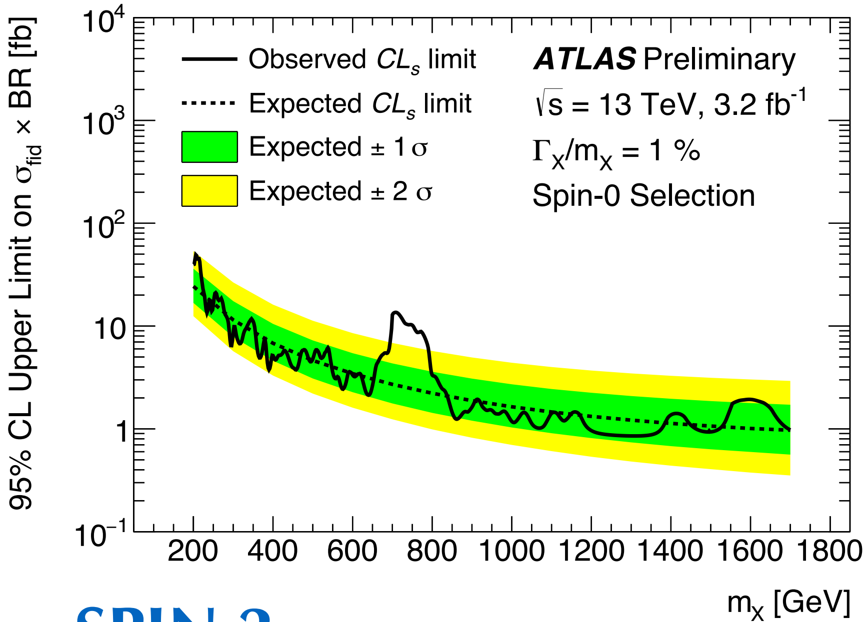
Parametrize background mass spectrum from data (independent shape for each category).

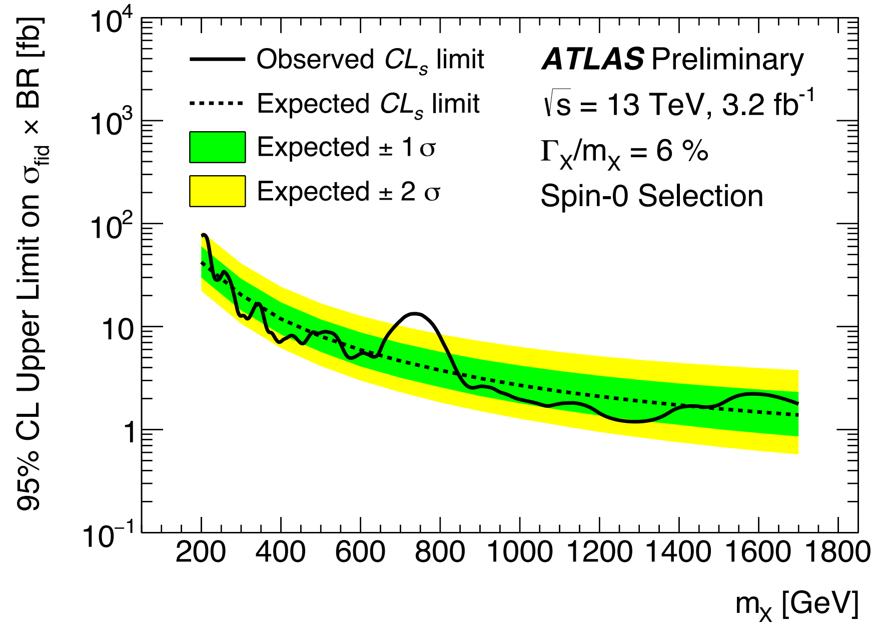
Possible mismodelling studied on simulation and explicit uncertainty added to the fit.

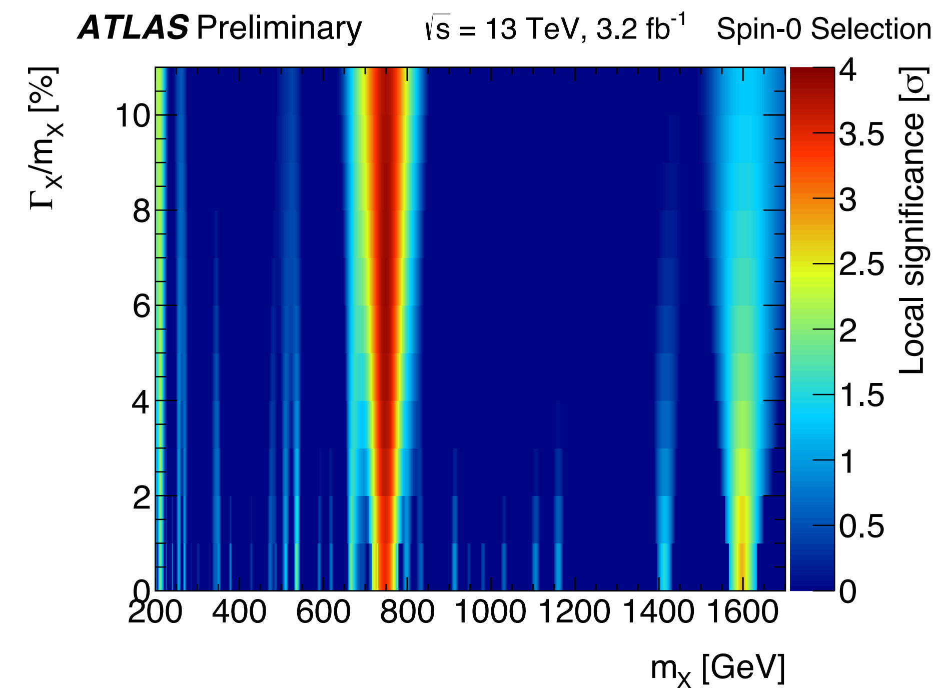
Upper Limits & p-values ATLAS

[ATLAS-CONF-2016-018]

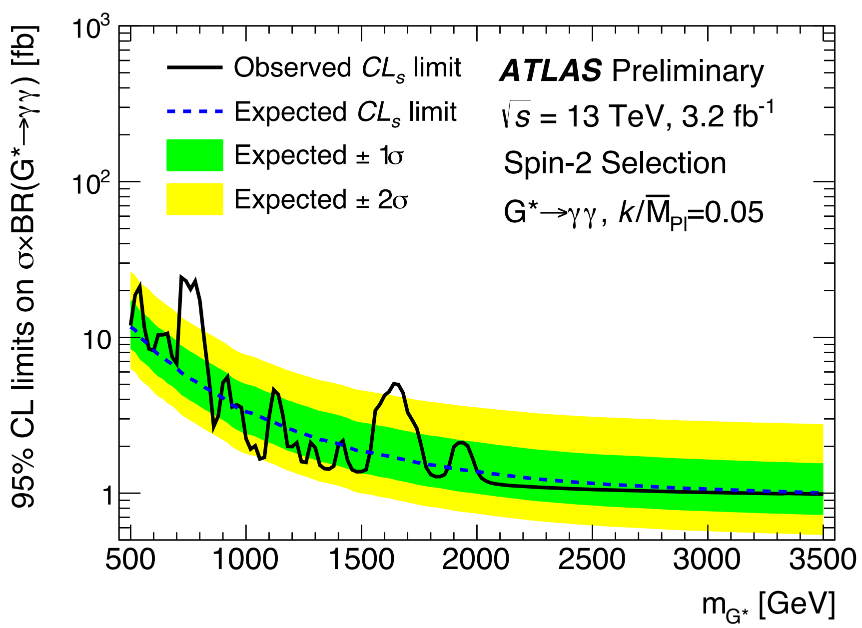
SPIN 0

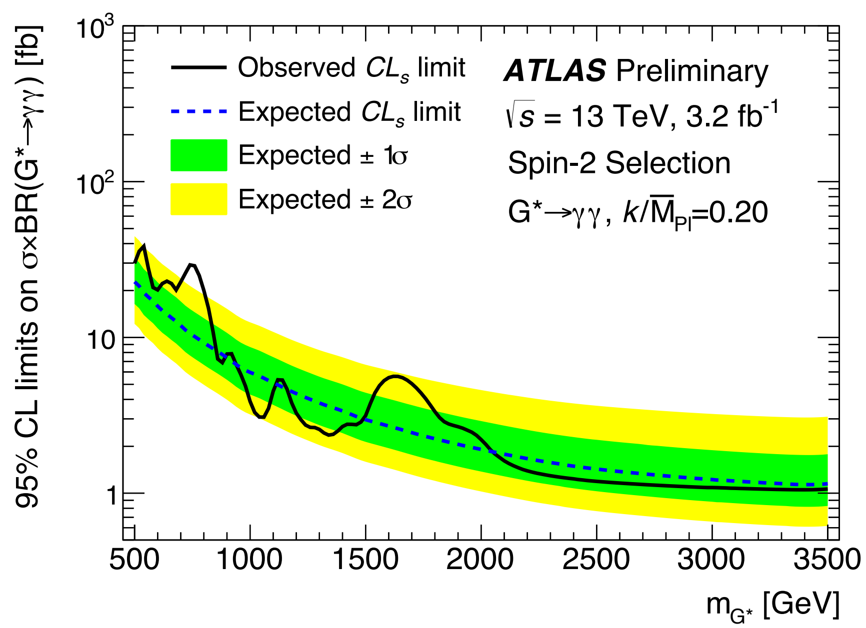


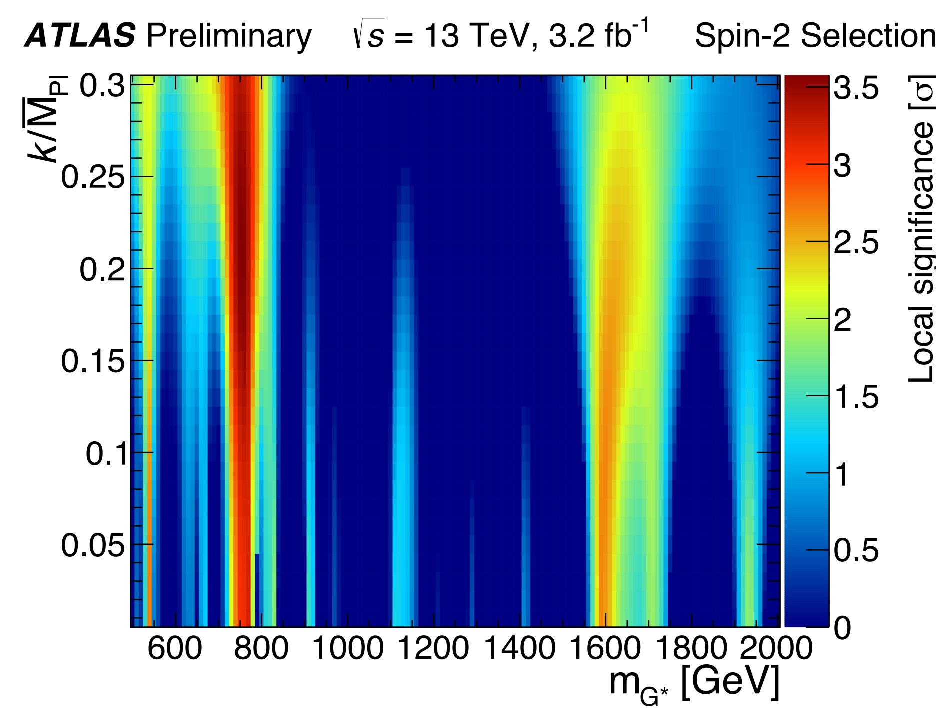




SPIN 2





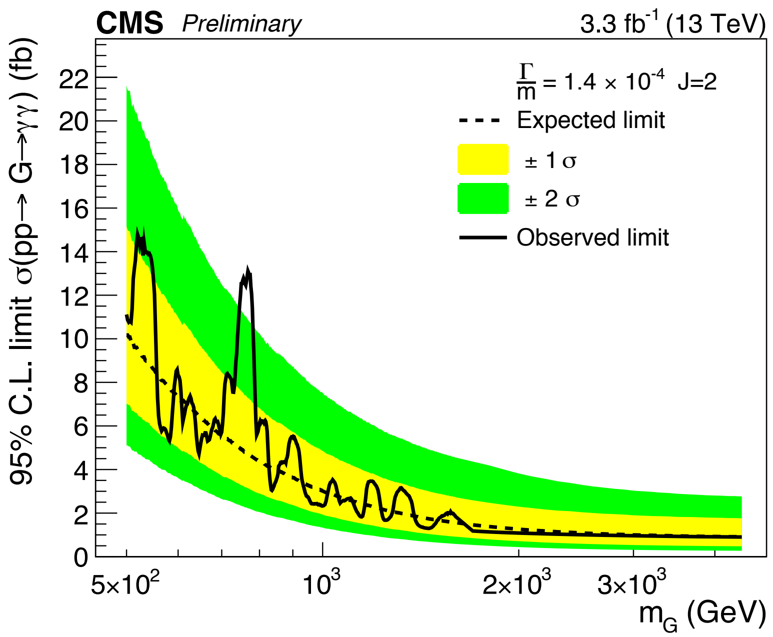


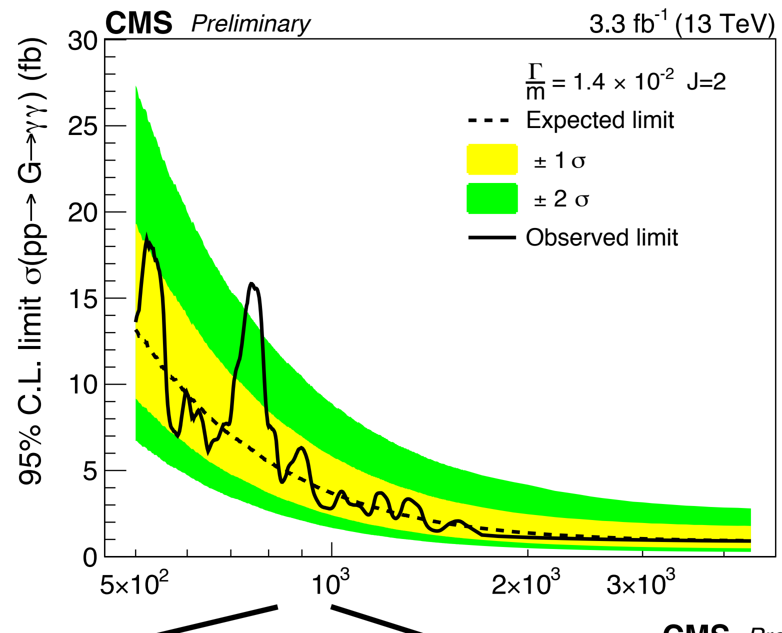
Largest deviations ~ 750 GeV

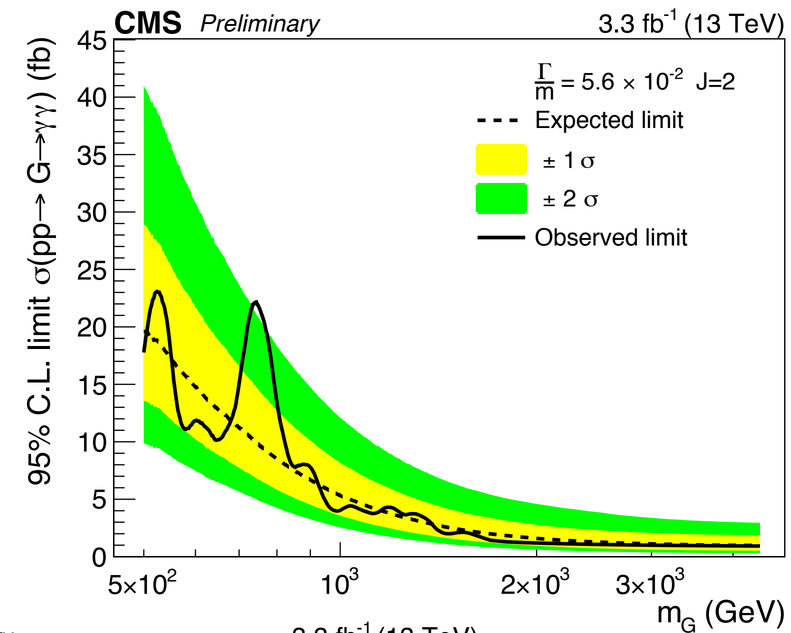
- **spin 0** and Γ_X = 45 GeV (6%): 3.9σ local significance, z-global =2.0σ
- **spin 2** and k/M_{Pl}=0.2 (Γ_G = 6% m_G), 3.6σ local significance, z-global =1.8σ

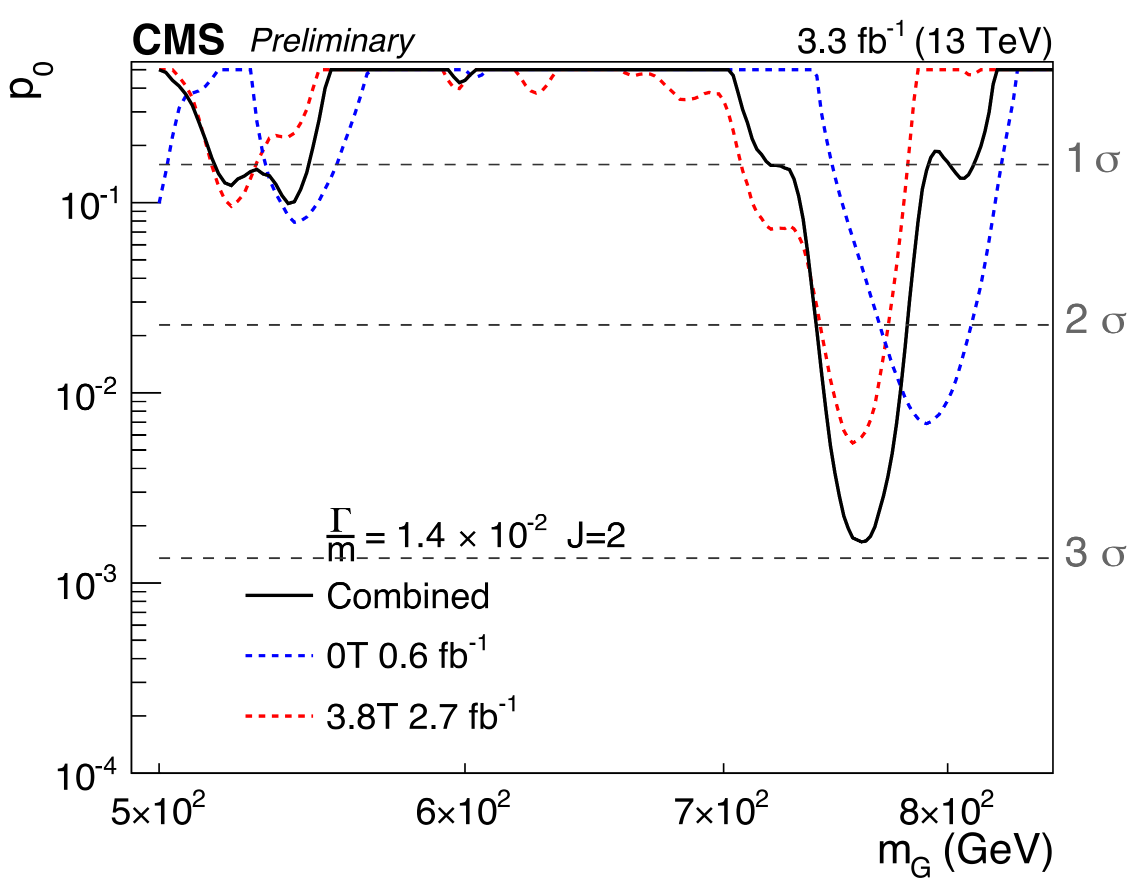
Upper Limits & p-values CMS

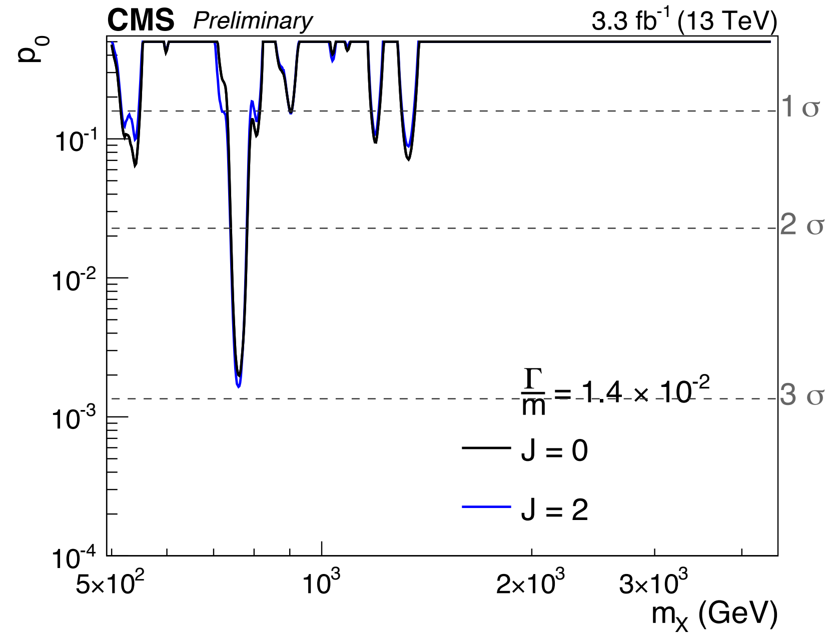
Narrow width **[PAS EXO-16-018]** **Wide width**











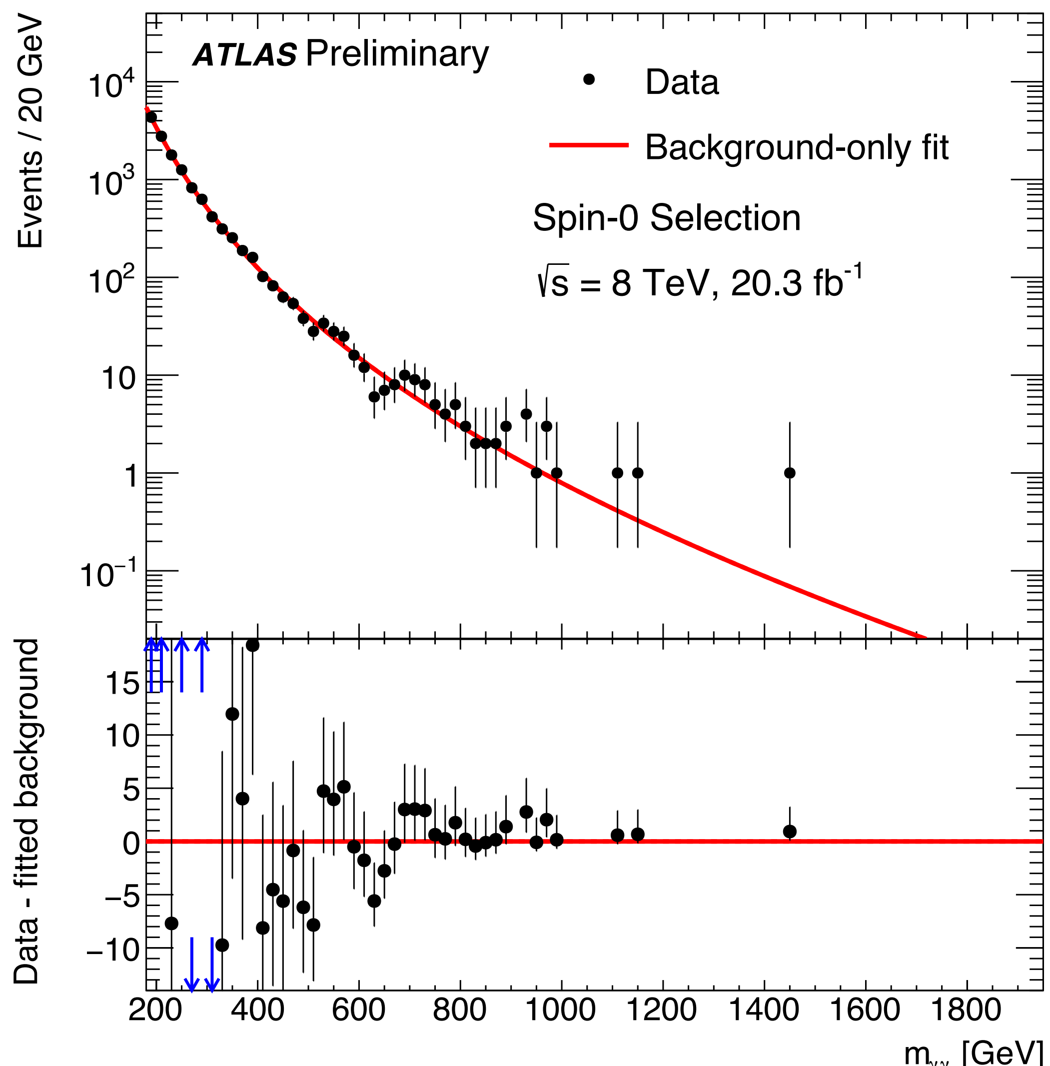
Largest deviations ~ 760 GeV

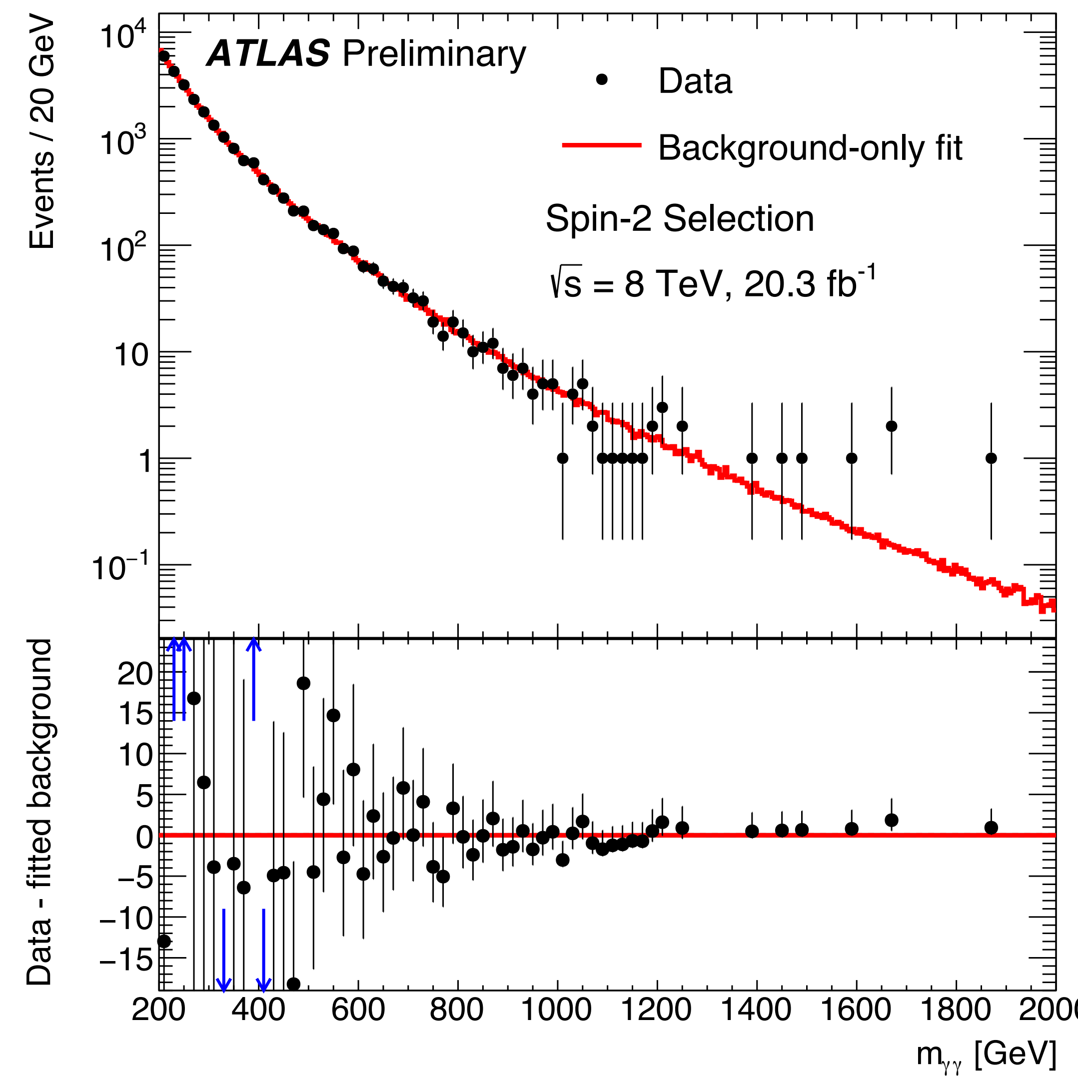
- **spin 2** and Γ/m=1.4%, 2.9σ local significance (2.8σ, spin 0), global significance <1σ
- comes mostly from EBEB categories, driven by 3.8T

Compatibility with 8 TeV ATLAS

8 TeV data re-analyzed: latest Run I calibration + same Run I selections + 13 TeV analysis methods

SPIN 0 **[ATLAS-CONF-2016-018]** **SPIN 2**





- 1.9σ at 750 GeV, Γ/m=6%
- Compatibility with 13 TeV scalar
  - gg (scaling: 4.7) →compatibility: 1.2σ
  - qq (scaling: 2.7)→compatibility: 2.1σ

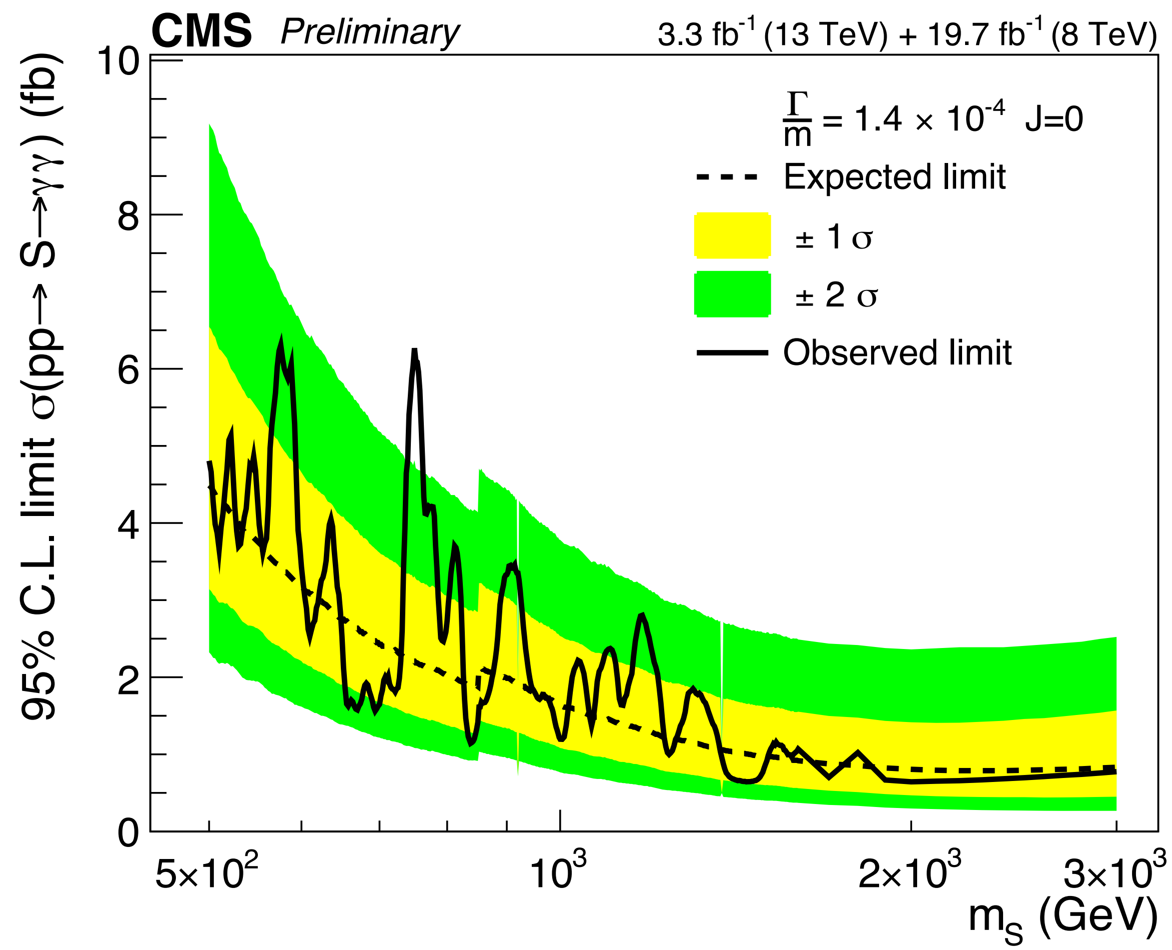
- No significant excess
- Compatibility with 13 TeV graviton
  - gg→compatibility: 2.7σ
  - qq→compatibility: 3.3σ

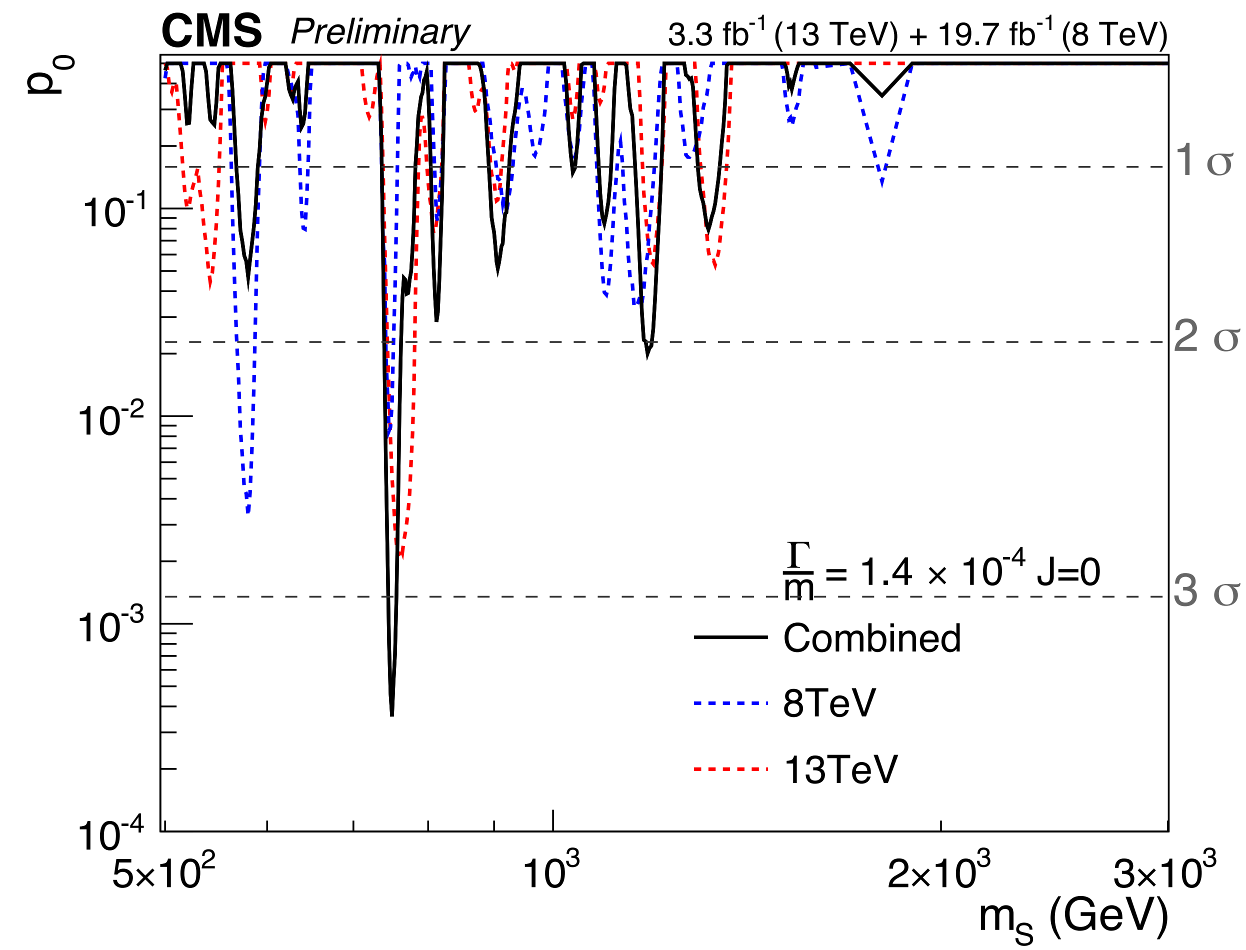
Combination with 8 TeV CMS

[PAS EXO-16-018]

Two searches for diphoton resonances at 8TeV.

- **HIG14006**: search range 150-850GeV
- **EXO12045**:search range 500-3000GeV
- Combination in all 6 signal hyp. tested at 13TeV (at each mass, pick most sensitive analysis)





Largest excess observed at 750 GeV and for narrow width.

- Local significance: 3.4σ
- Taking into account mass range 500-3000 GeV (and all signal hyp.), global significance becomes 1.6σ

Summary

- **Interesting situation overall**
- **Diboson** analysis
  - Not excess observed in Run II
  - Still, not enough lumi to exclude the Run I excess or to confirm it
- **DiJet** Run II results confirm the Run I picture, more lumi needed
- **Diphoton** "750 thing" very exciting
  - ATLAS and CMS use different data categorization
  - excess seen for different width hypothesis in ATLAS and CMS
  - CMS results more significant when Run I is added
  - ATLAS Run II compatibility w.r.t. Run I estimated
  - The theory community shows immediate interest on the "750 thing"
- **Analyses fully dominated by the statistical uncertainty**
  - not easy to compare ATLAS and CMS (more in the discussion)

2016 data will be fundamental

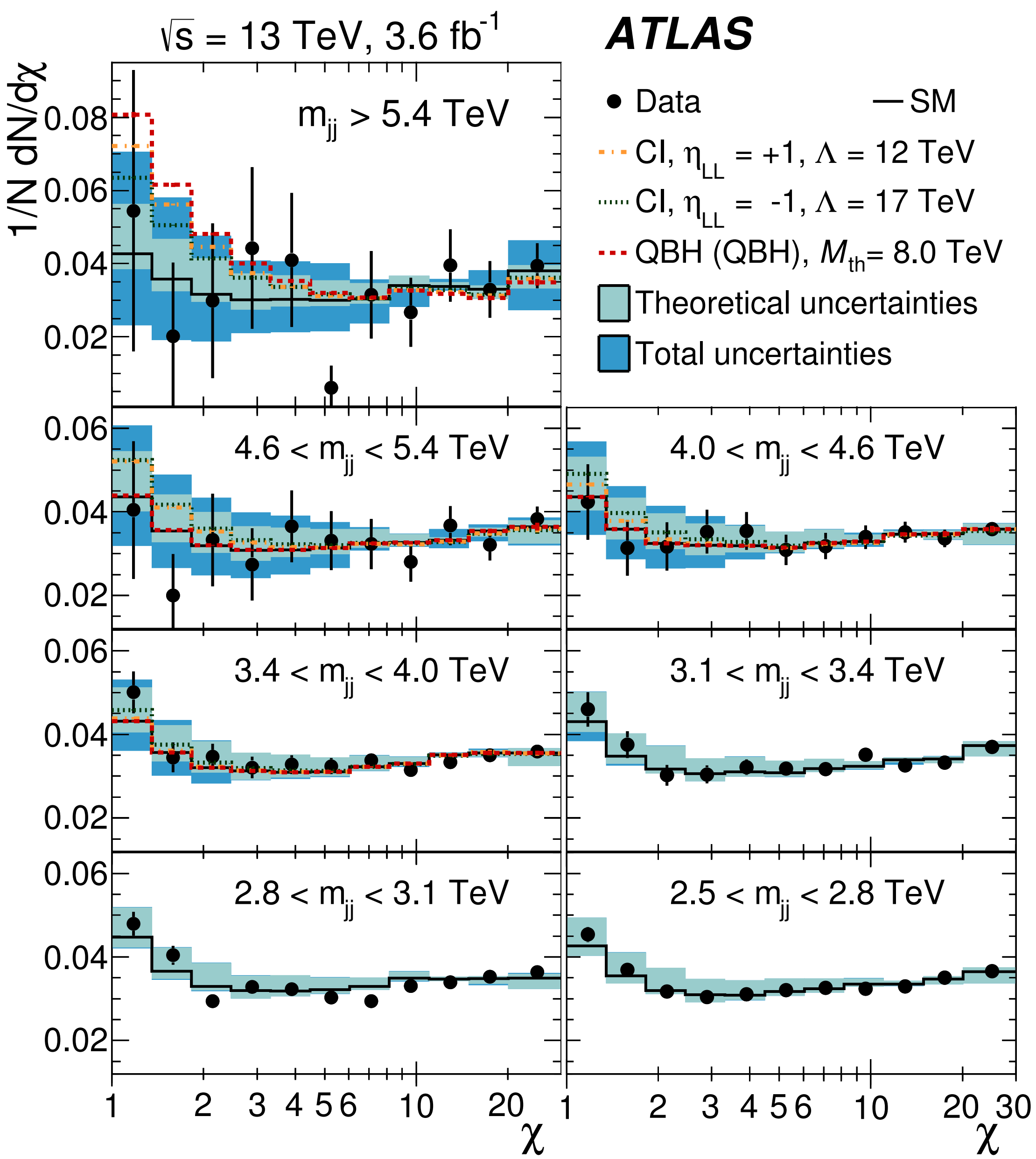
BACKUP

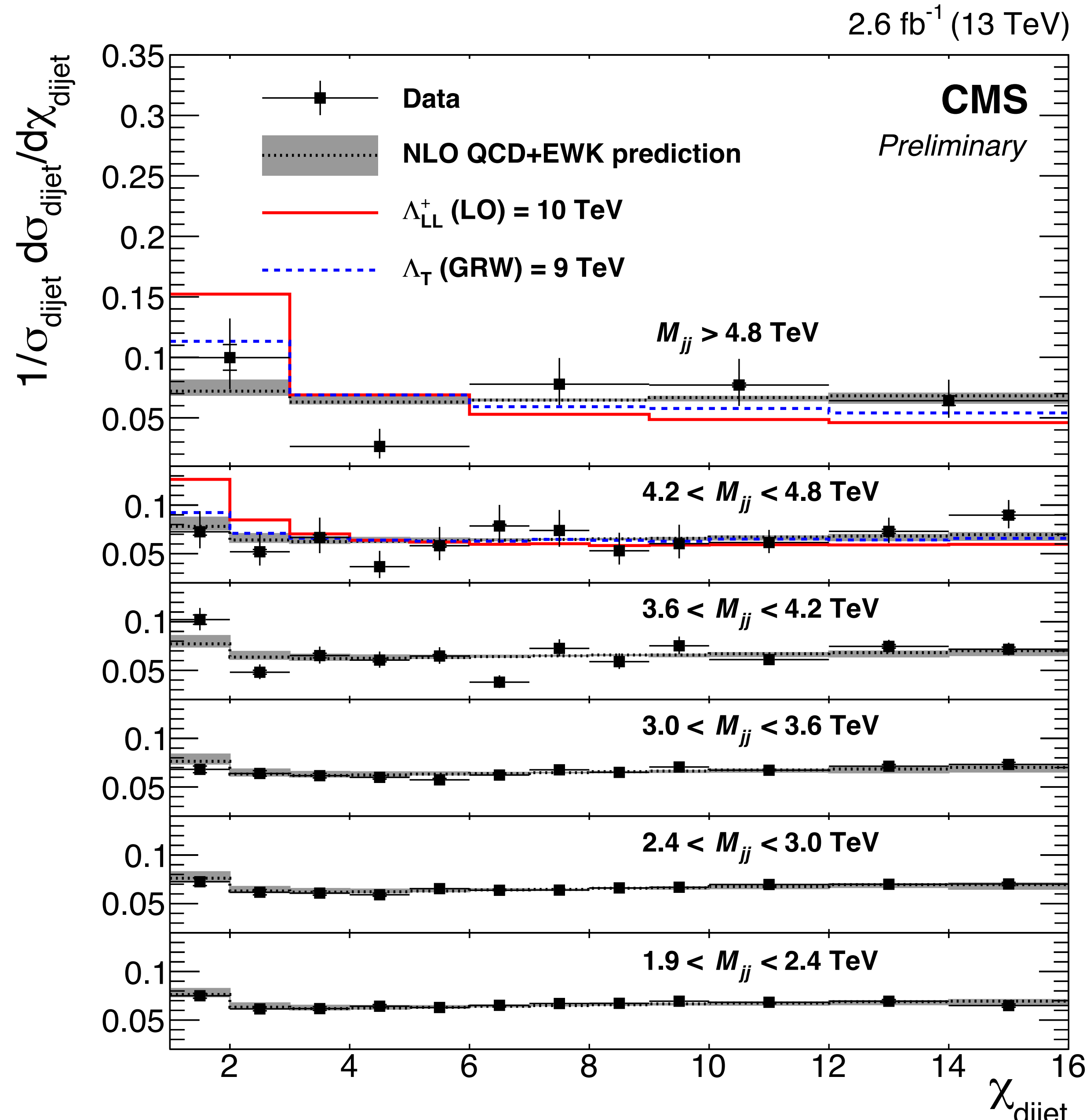
Dijet angular distributions

Many theories BSM predict activity at large angles with respect to the beam.

- Polar angle in the dijet center of mass frame:
- bkg from MC normalized to data.

$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$



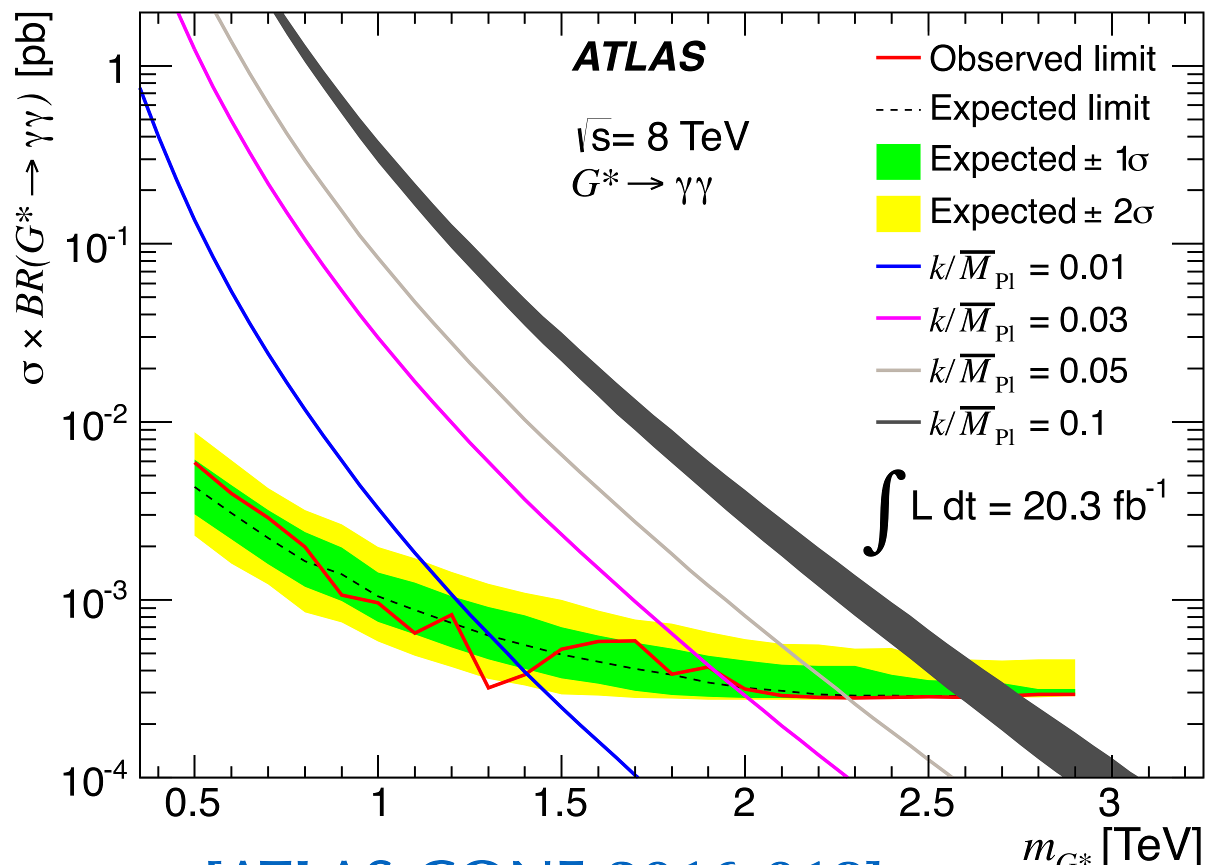


[arxiv:1512.01530]

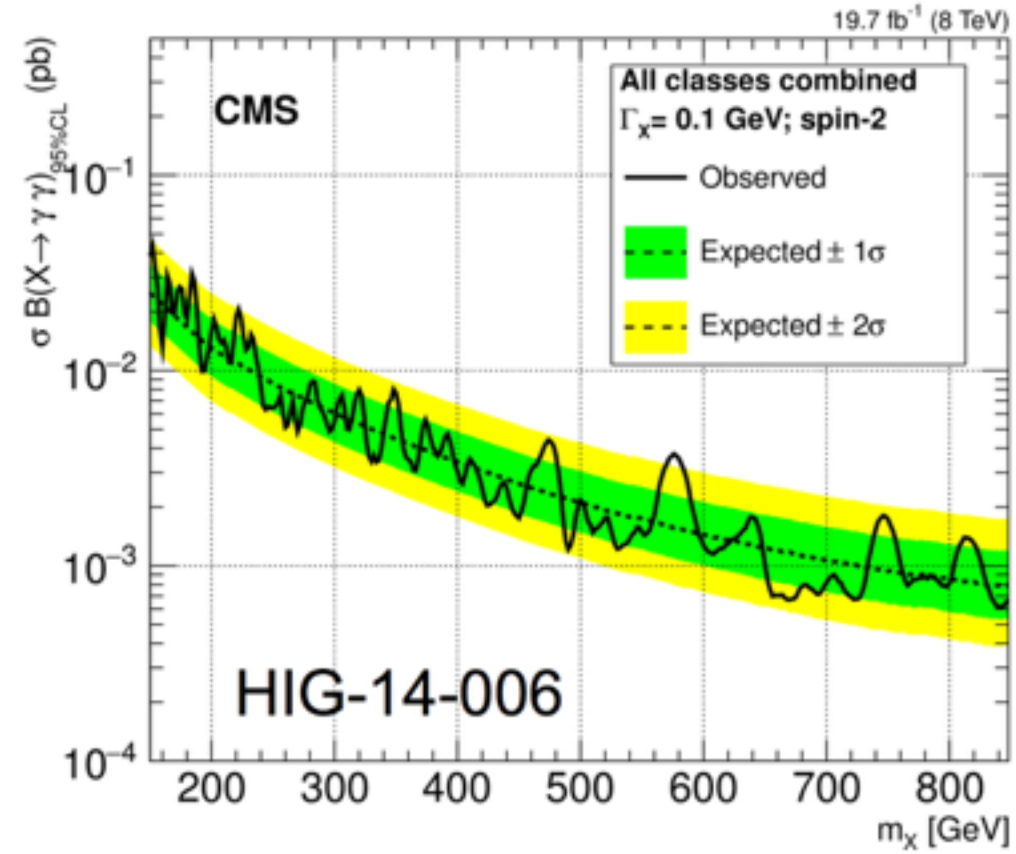
[PAS EXO-15-009]

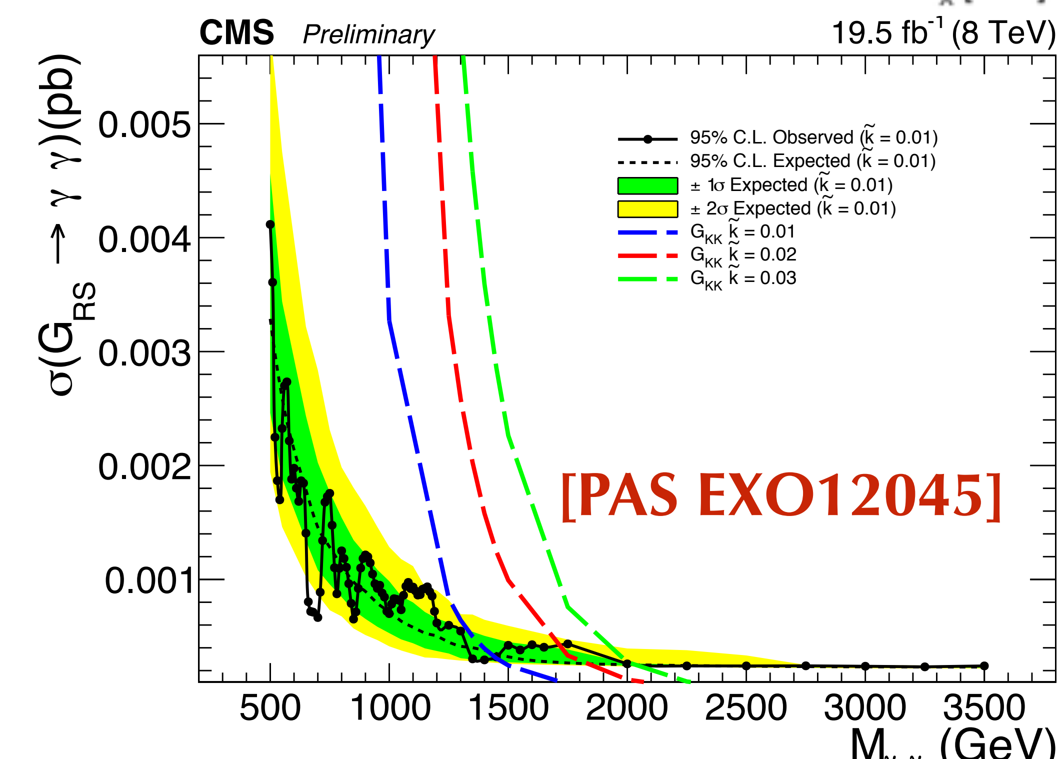
Data are compared to NLO predictions in different dijet mass bins.

Diphoton status at 8 TeV

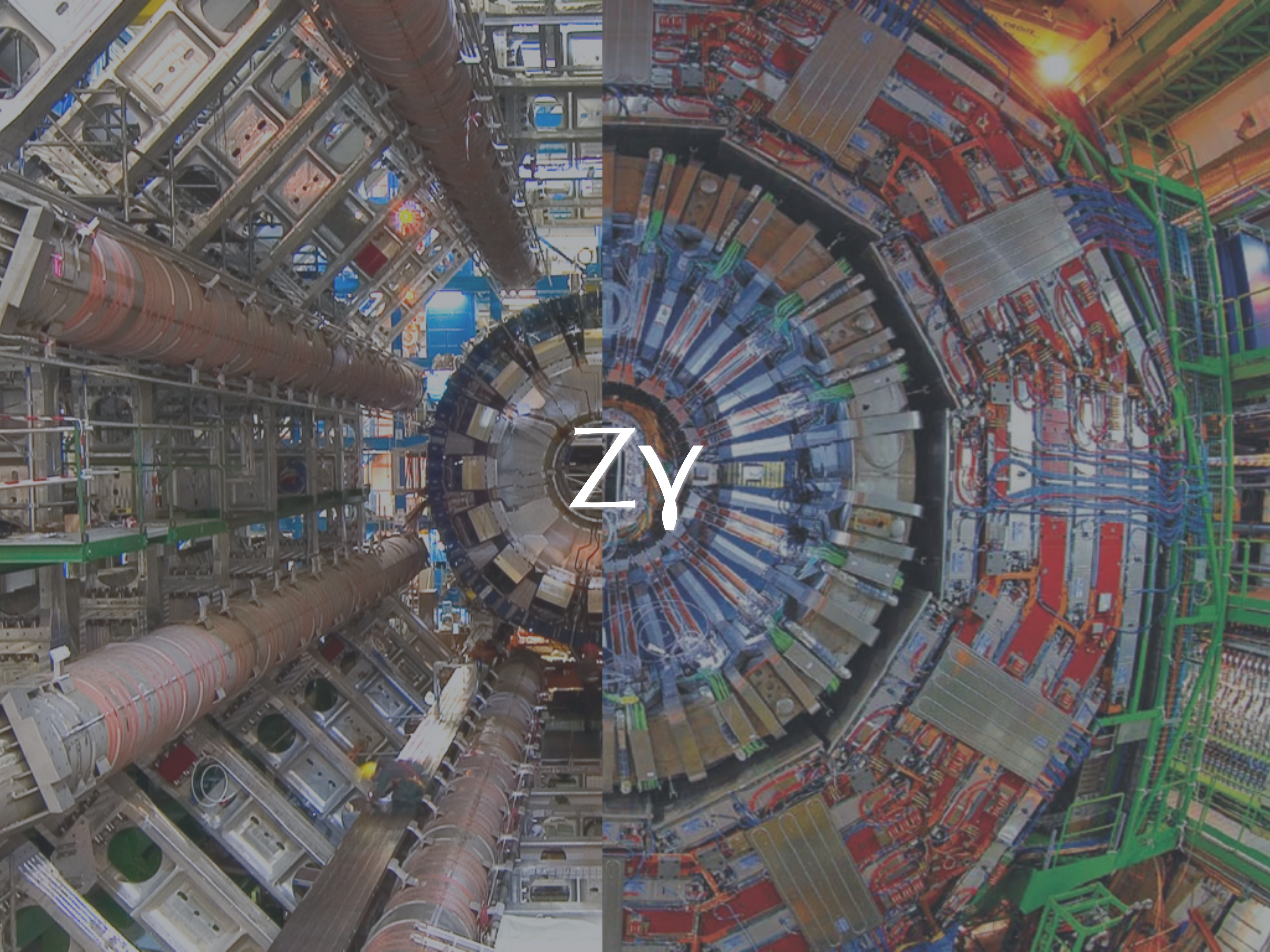


[ATLAS-CONF-2016-018]





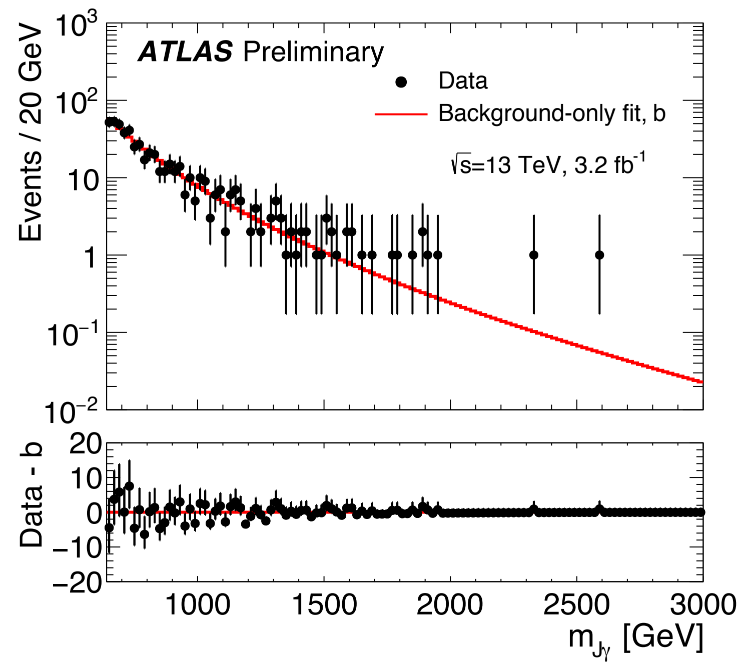
[PAS EXO12045]

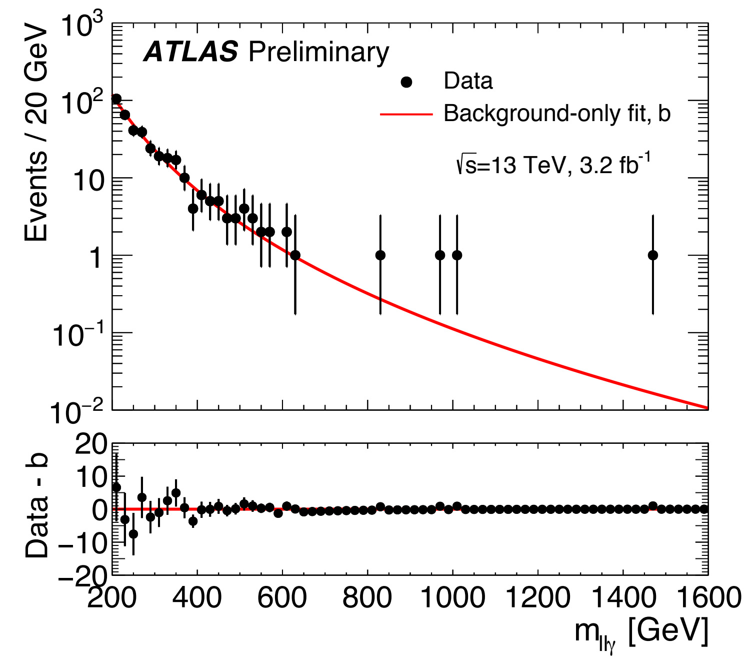

Zγ

Zγ

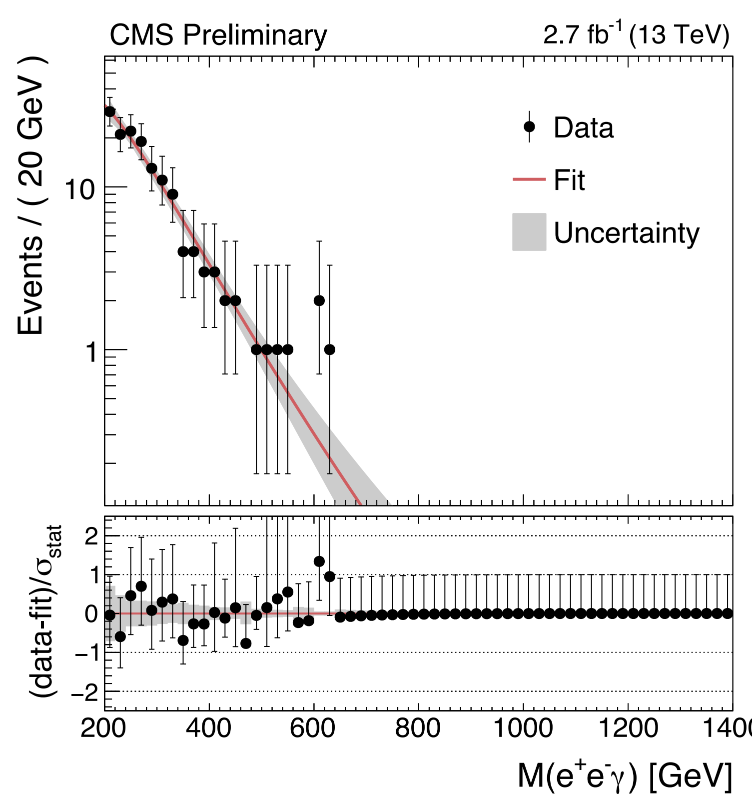
- **Leptonic Analysis** (Z → ee, μμ)
- **Hadronic Analysis** (Z → qq), in boosted regime
- main background:
    - LA: non-resonant Z+γ, Z+jet with jet->γ mis ID
    - HA: γ+jet, multi-jet; V+jet bkg
- Bkg functional form fitted to data

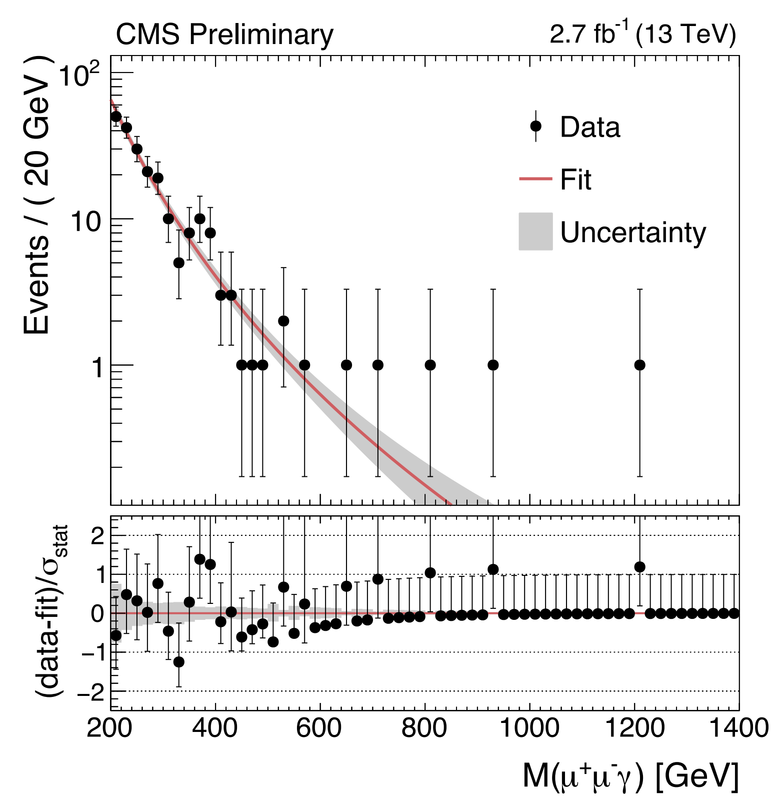
[ATLAS-CONF-2016-010]

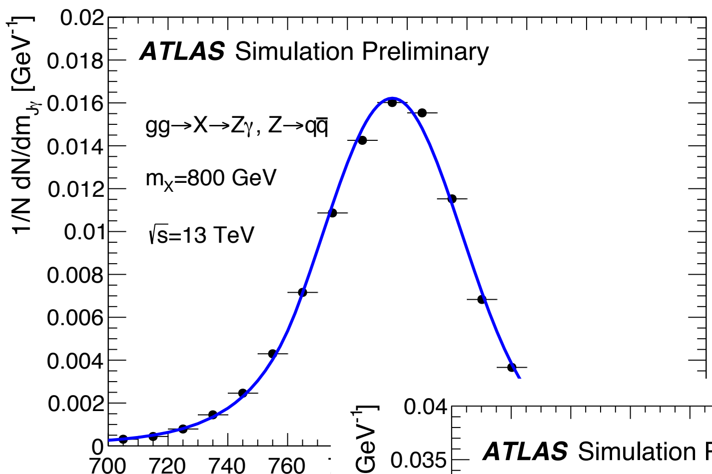


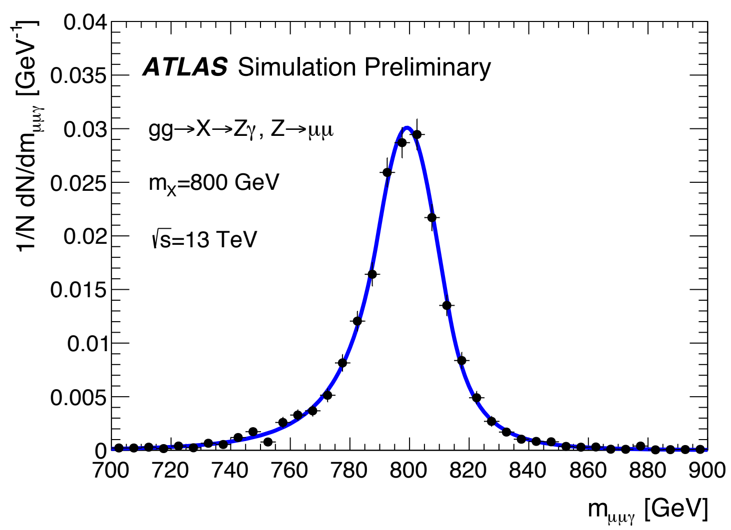


[PAS EXO-16-018]



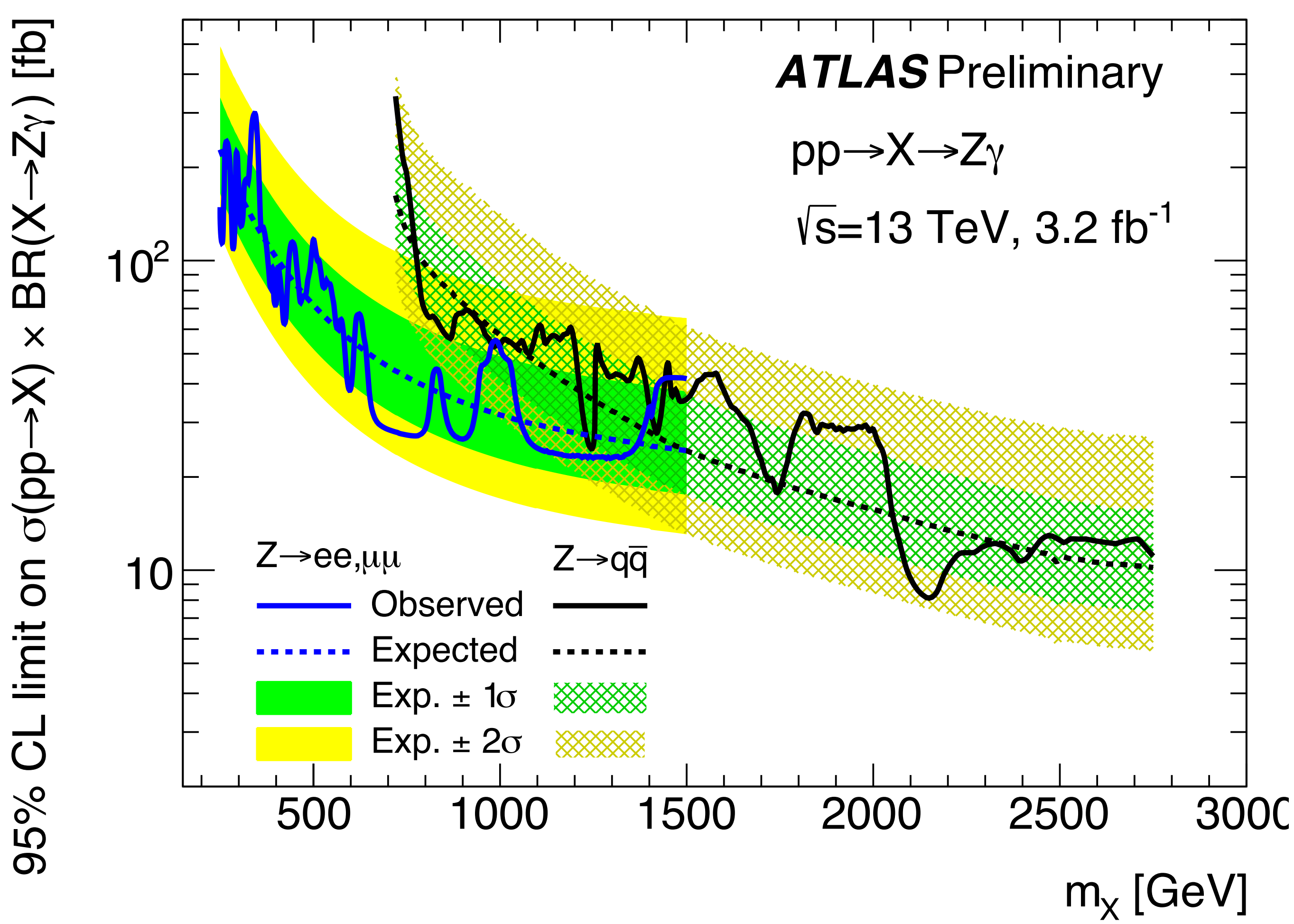




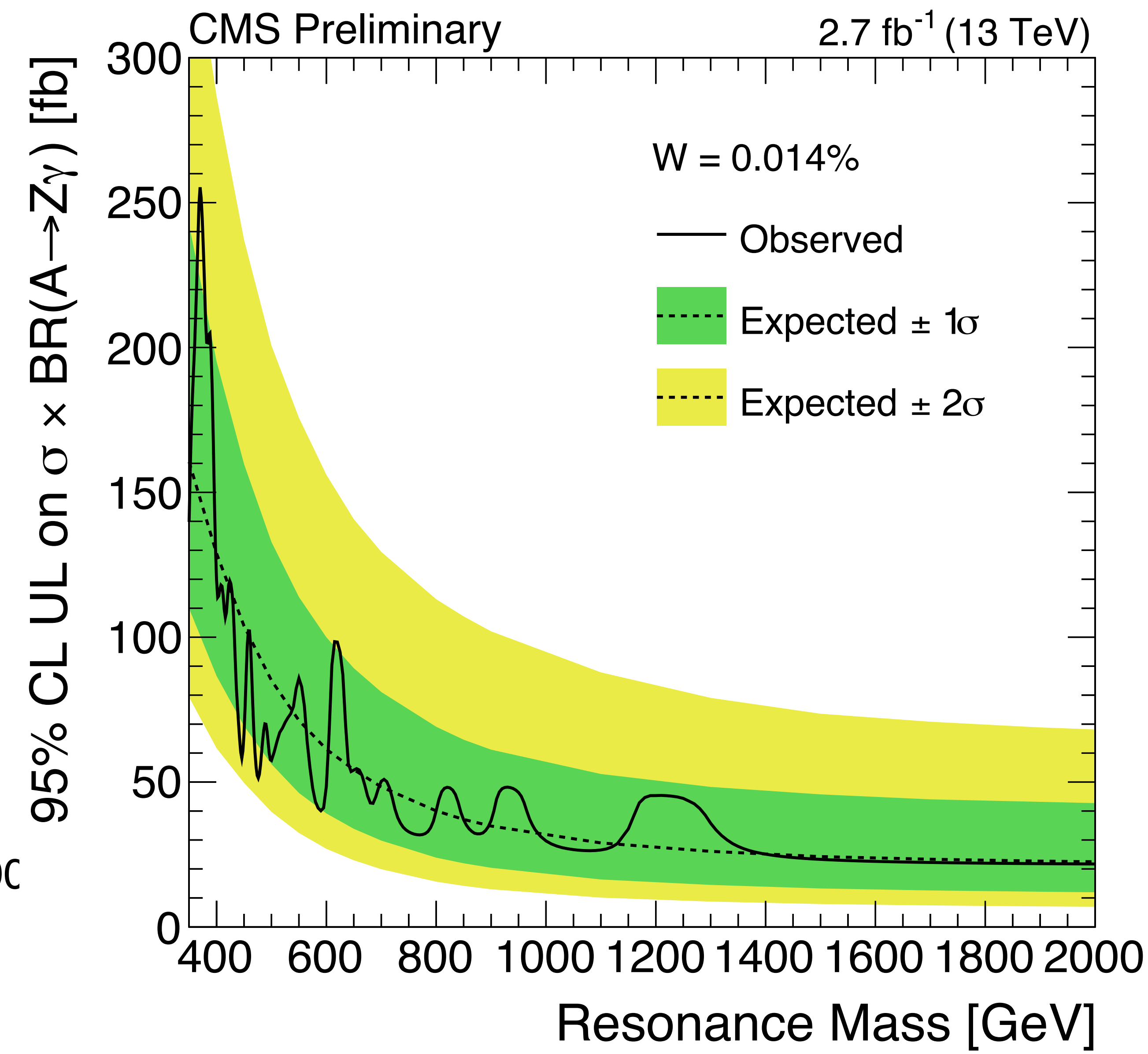


Zγ

[ATLAS-CONF-2016-010]



[PAS EXO-16-018]



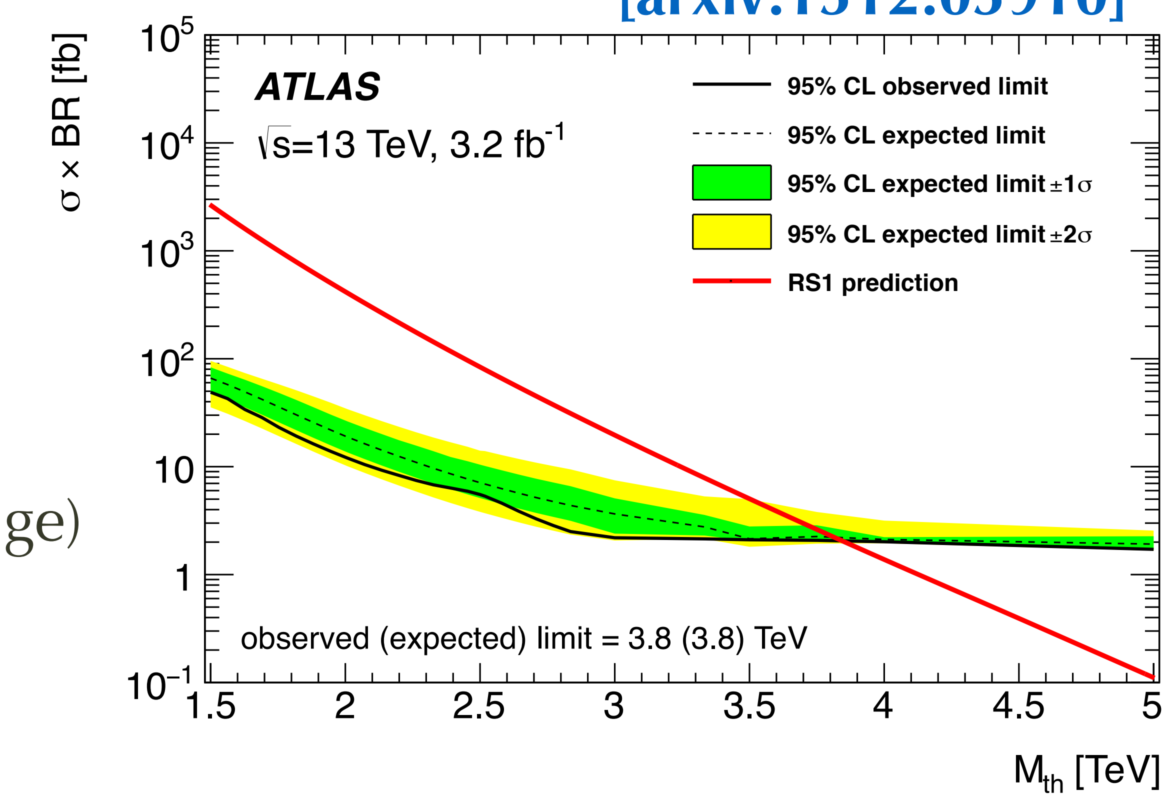
No significant excess in data in the invariant mass distribution was found over SM expectation.

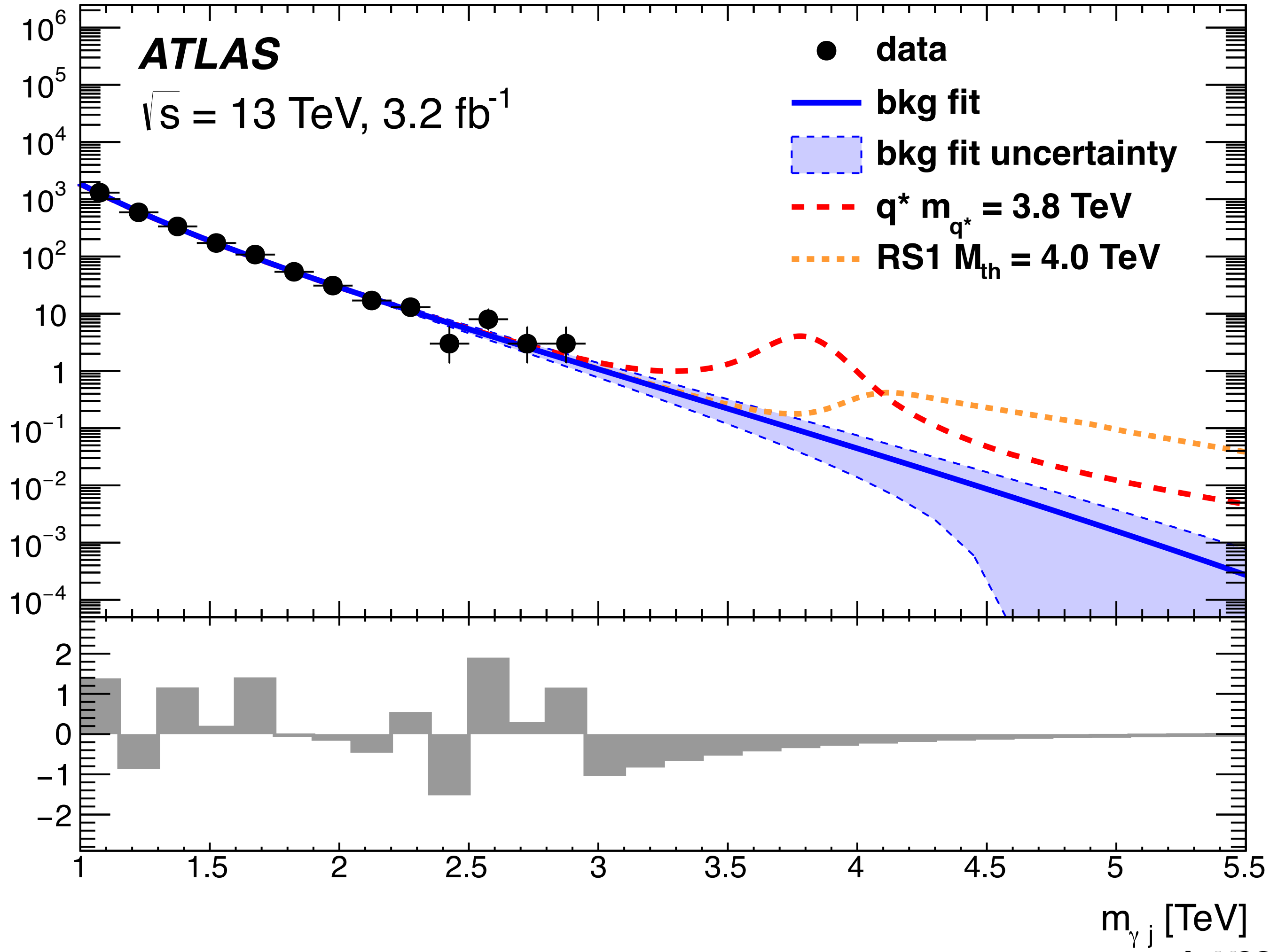

γ+jet

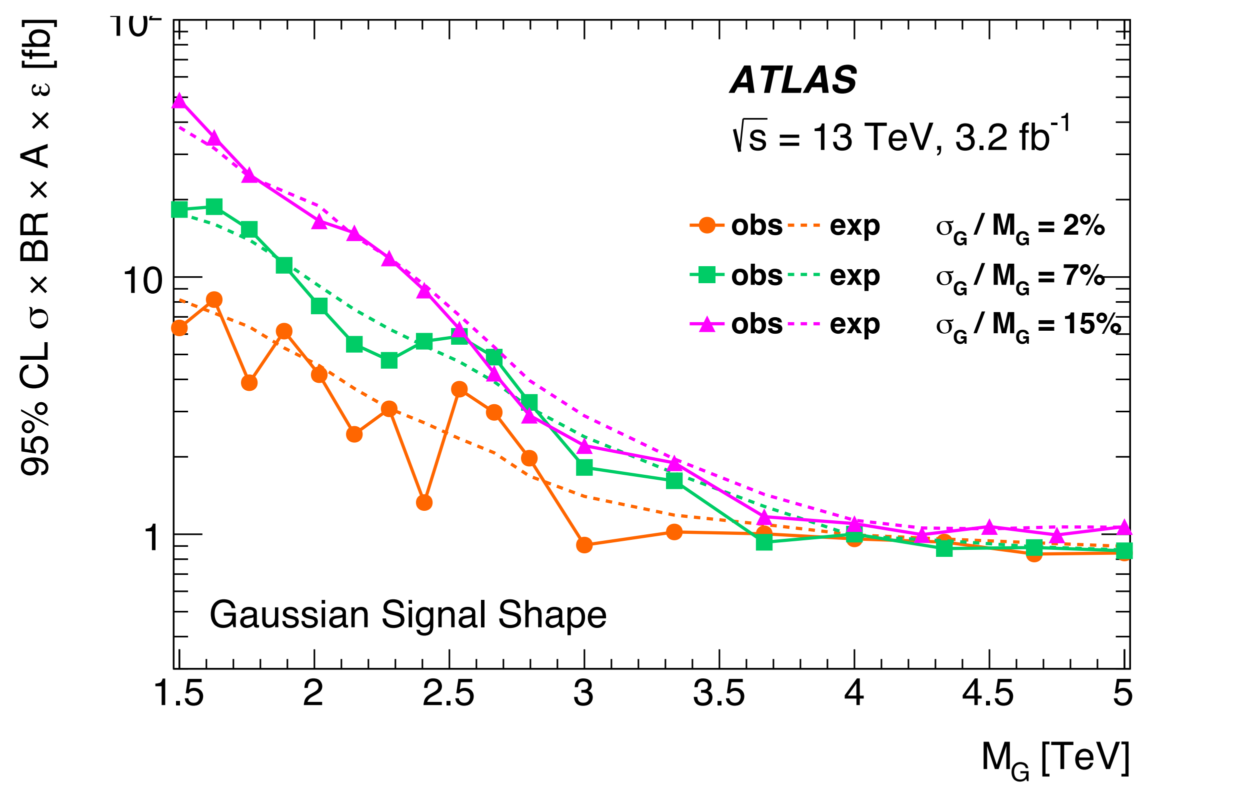
γ+jet by ATLAS

[arxiv:1512.05910]

- Search for localized excess in γ+jet mass
- Background: SM prompt γ+jet, produced by QCD Compton scattering.
    - data-driven background model (validated on MC)
    - functional form fitted on data (major problem: modelling of the background over a wide mass range)







Limit on visible cross section for generic-peak search

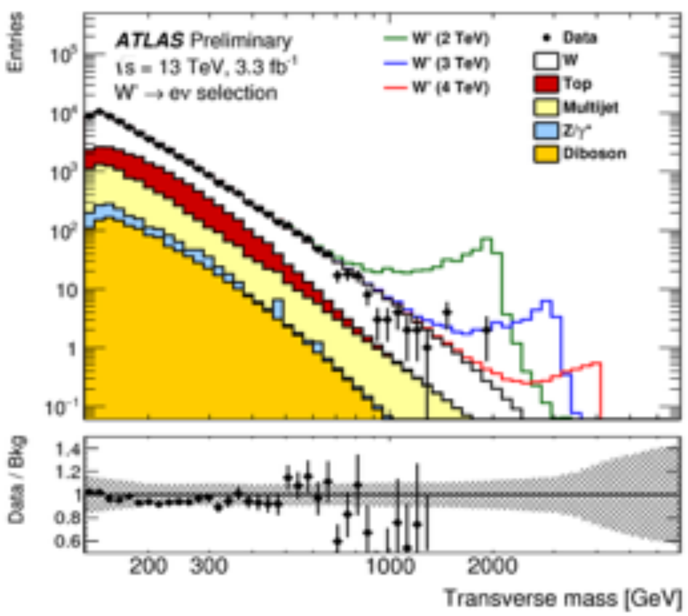
Leptonic W′/Z′

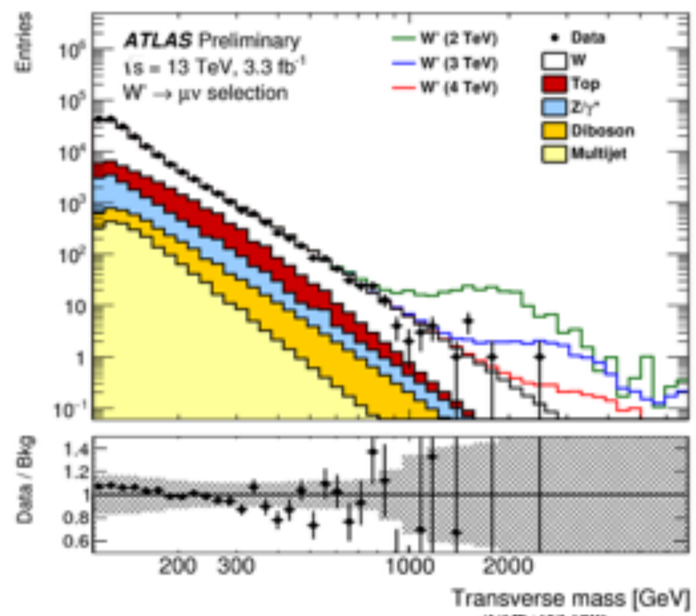
$W' \to \ell\nu$

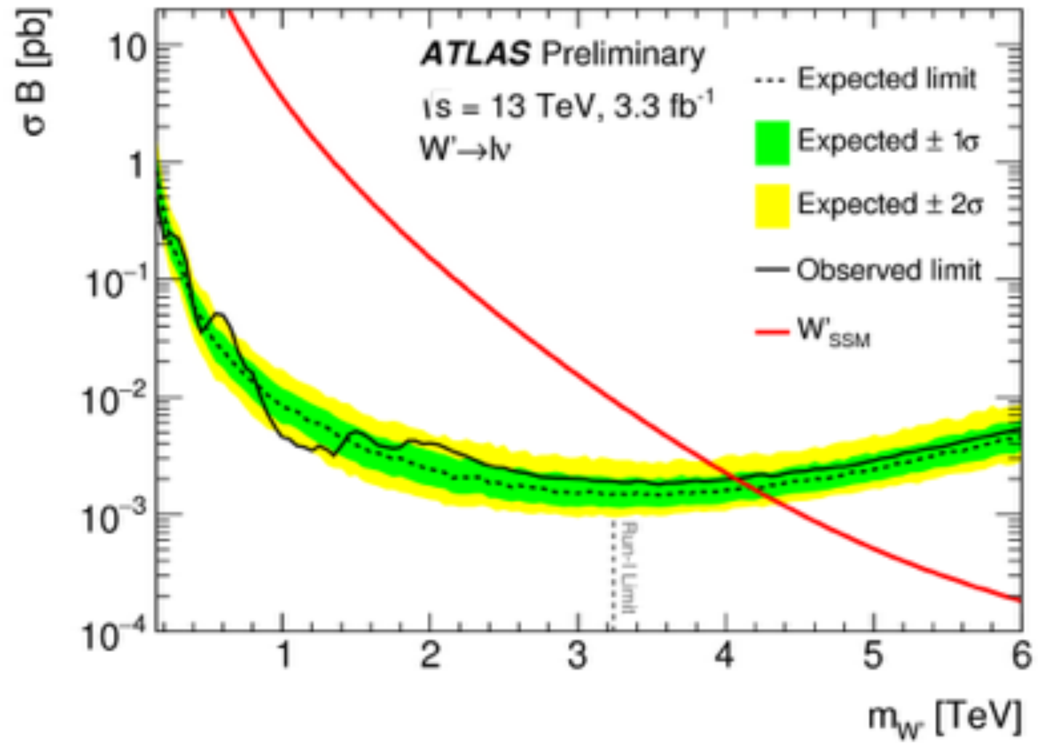
W′ search for discrepancies above background in the transverse mass distribution:

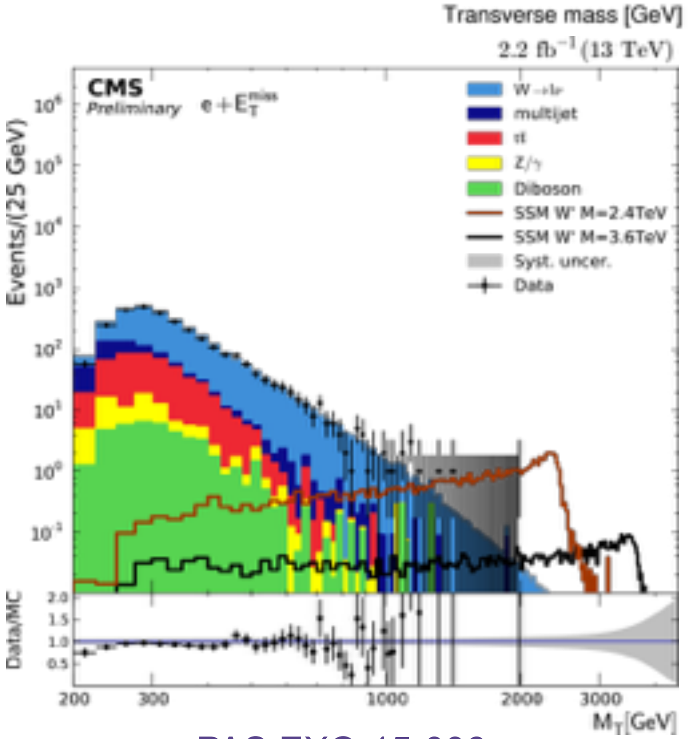
$$M_T = \sqrt{2p_T^l E_T^{\text{miss}}(1-\cos[\Delta\phi(\vec{p}_T^{\,l}, \vec{p}_T^{\,\text{miss}})])}$$

ATLAS-CONF-2015-063

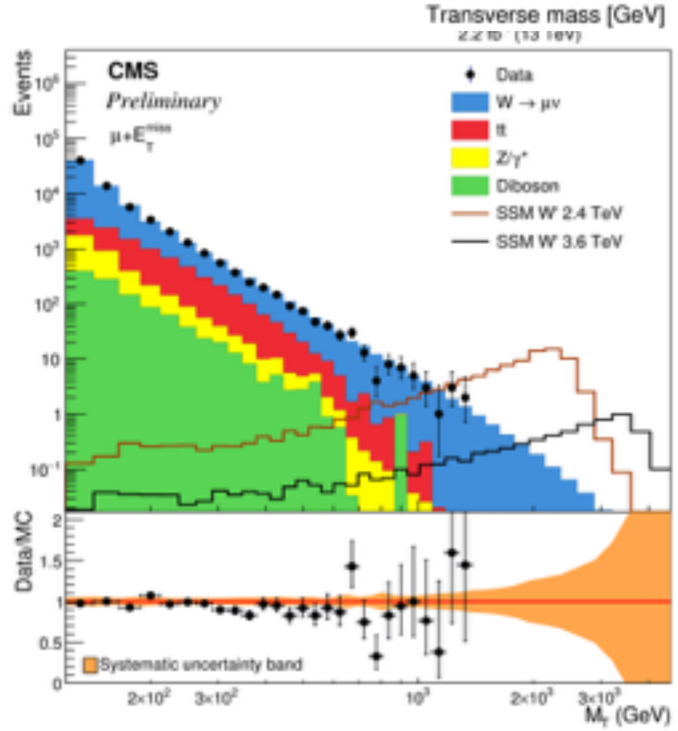


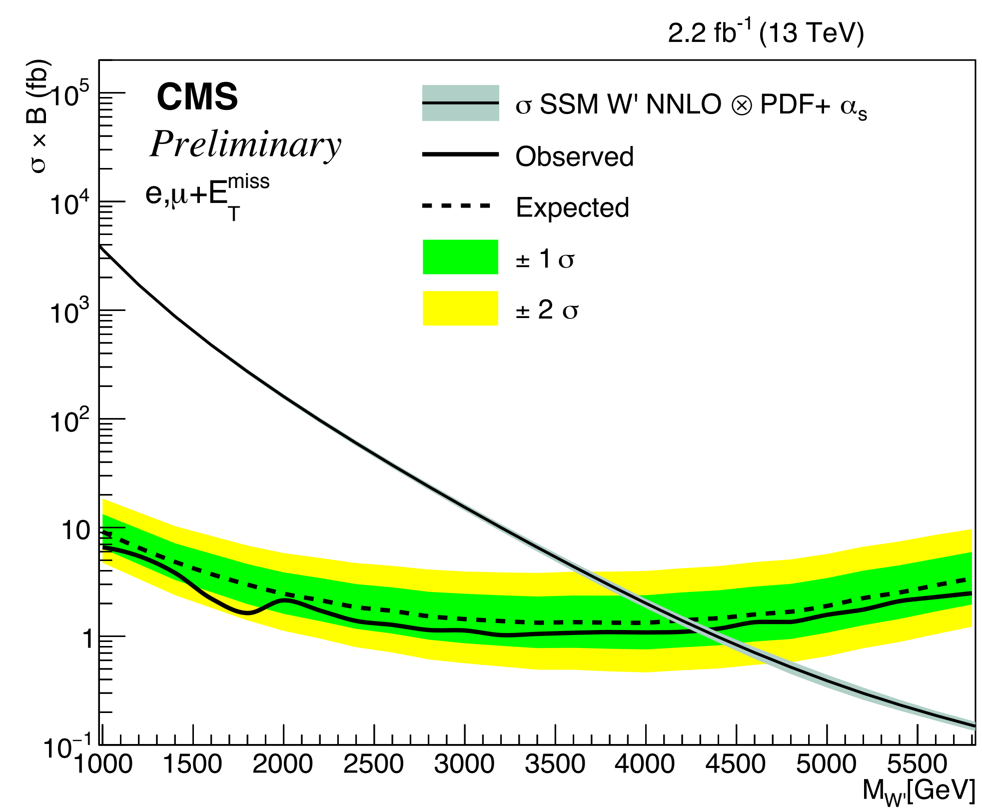






PAS EXO-15-006

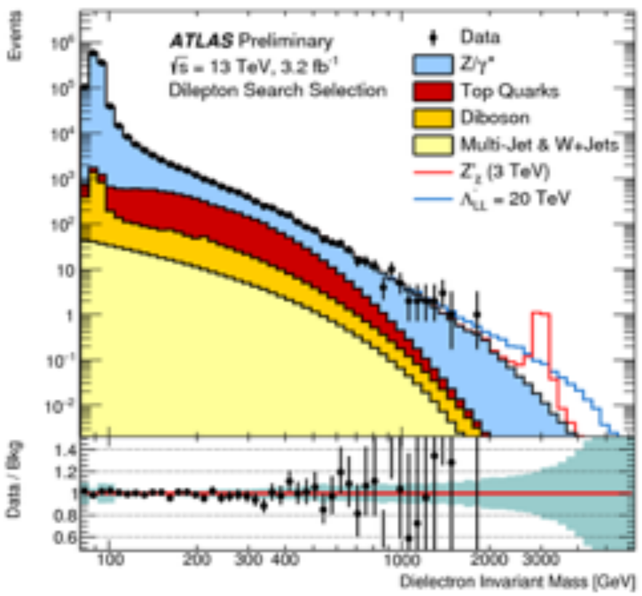


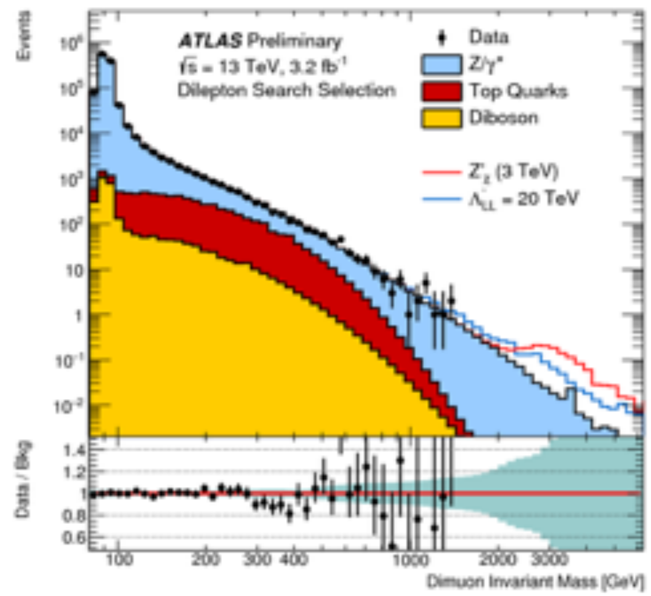


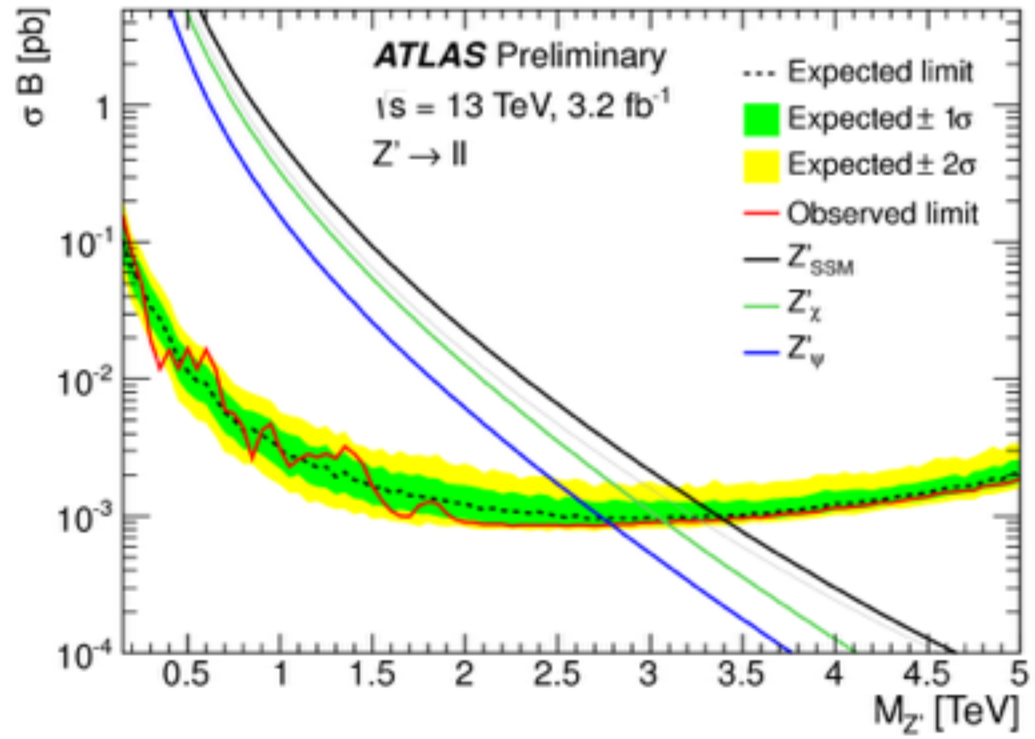
$Z' \to \ell\ell$

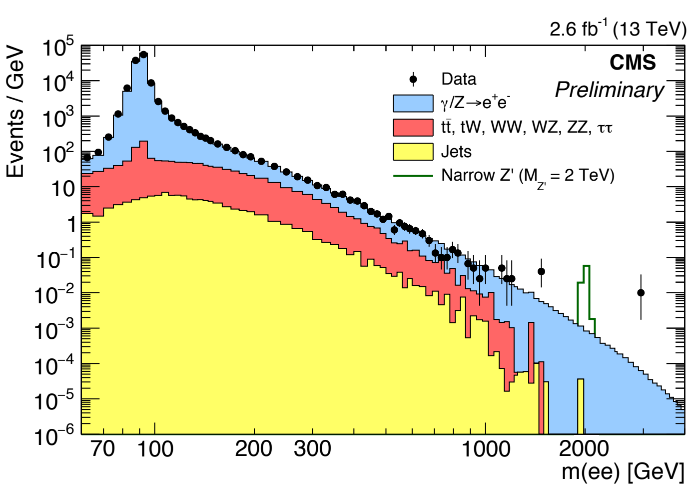
Z' search for narrow resonances in the di-lepton invariant mass distributions (ee, mu mu)

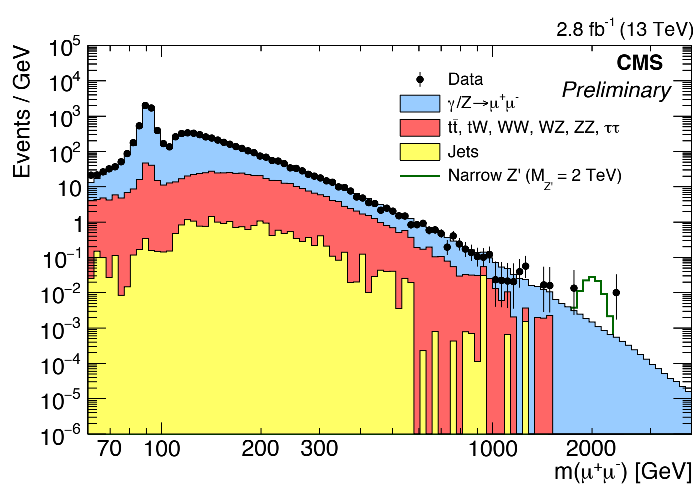
ATLAS-CONF-2015-070











PAS EXO-15-005