Experimental results on di-photon, ZZ and WW resonances from ATLAS and CMS

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on behalf of the ALTAS and CMS collaborations

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Institute of High Energy Physics

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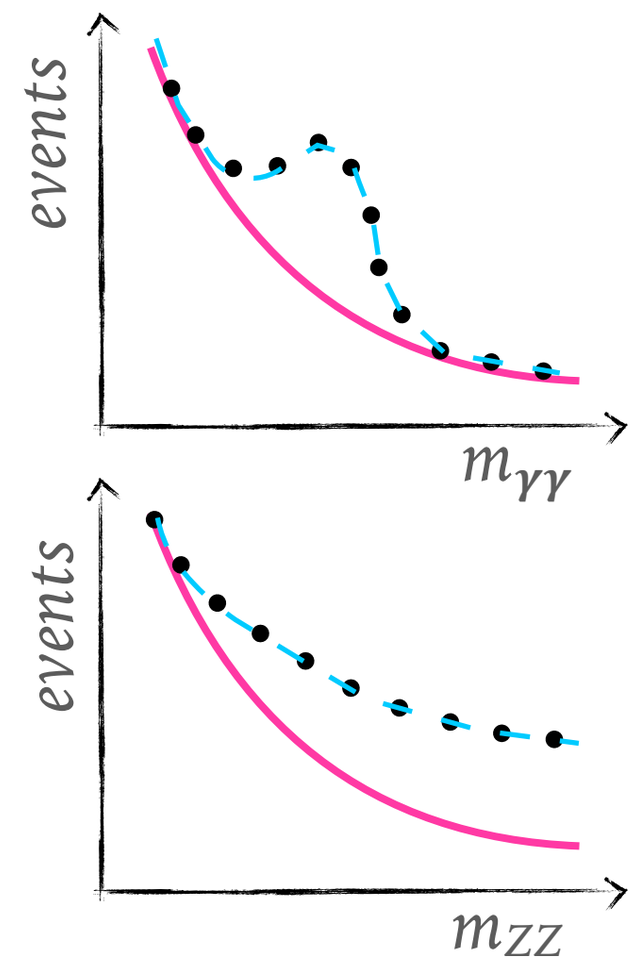
Introduction

- Motivation:
  - many BSM Physics models predict new resonances decaying into $\gamma\gamma$/ZZ/WW
  - searching for heavy resonances is the most direct way to probe new physics at TeV scale
- Strategy:
  - if no E_T^{miss}: search for a peak over discriminant
  - if with E_T^{miss}: observe a flat event excess over discriminant
- Benchmark signal models to interpret the experimental results:
  - heavy H in models with extended higgs sector
  - warped ED models predicting gravitons
  - heavy vector triplet (HVT) predicting W'/Z'



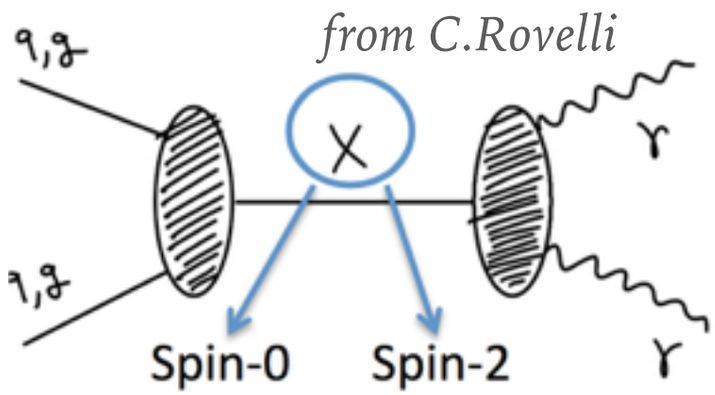
Content

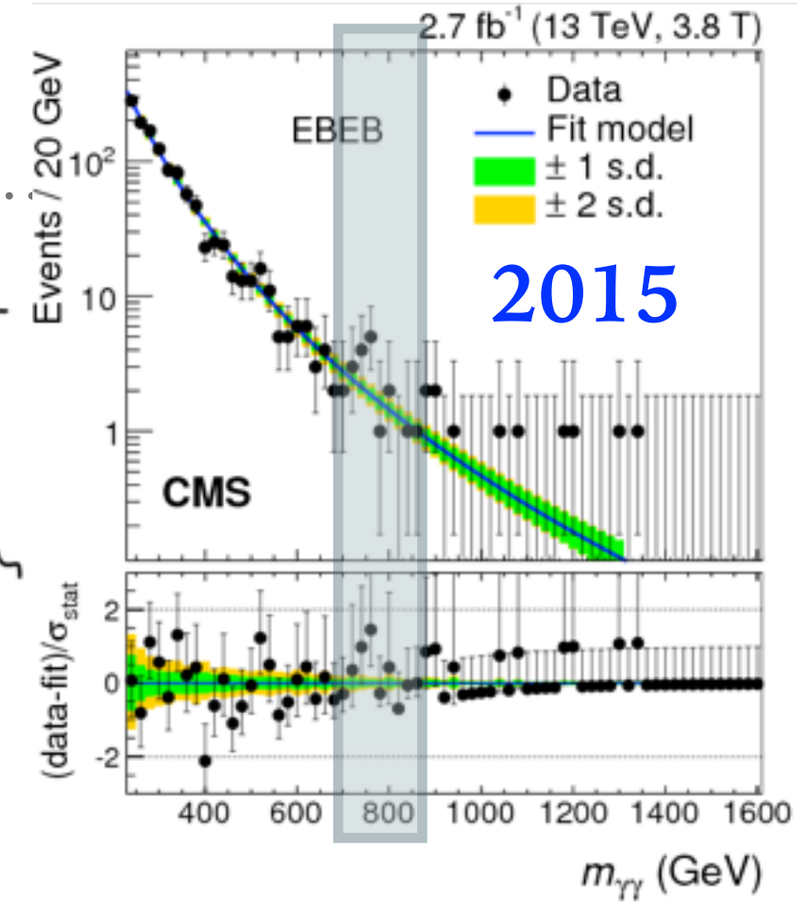
- **X → γγ**
  - Excess at 750GeV disappeared with 13TeV results
    2015: CERN-EP-2016-120/PRL 117, 051802 (2016)
    2016: ATLAS-CONF-2016-059/CMS-PAS-EXO-16-027
- **X → ZZ/WW**
  - all hadronic decay: (search for new resonance from 1.2/0.8 to 3/4TeV)
    - **VV → qqqq** ATLAS-CONF-2016-055/CMS-PAS-EXO-15-002
  - all leptonic decay:
    - Examples: (search for new resonance up to 1 TeV)
      ZZ → 4l ATLAS-CONF-2016-079/CMS-PAS-HIG-16-033
      ZZ → llvv ATLAS-CONF-2016-056/CMS-PAS-HIG-16-001
    - other channels available:
      WW → llvv *ATLAS-CONF-2016-056/CMS-PAS-HIG-16-023*
  - semi-leptonic decay:
    - Example: (search for new resonance from 0.5/0.6 to 5.0/4.5 TeV)
      WW → lvqq ATLAS-CONF-2016-062/CMS-PAS-B2G-16-020
    - other channels available:
      ZV → llqq *ATLAS-CONF-2016-082/CMS-PAS-B2G-16-010*
      ZV → vvqq *ATLAS-CONF-2016-082*

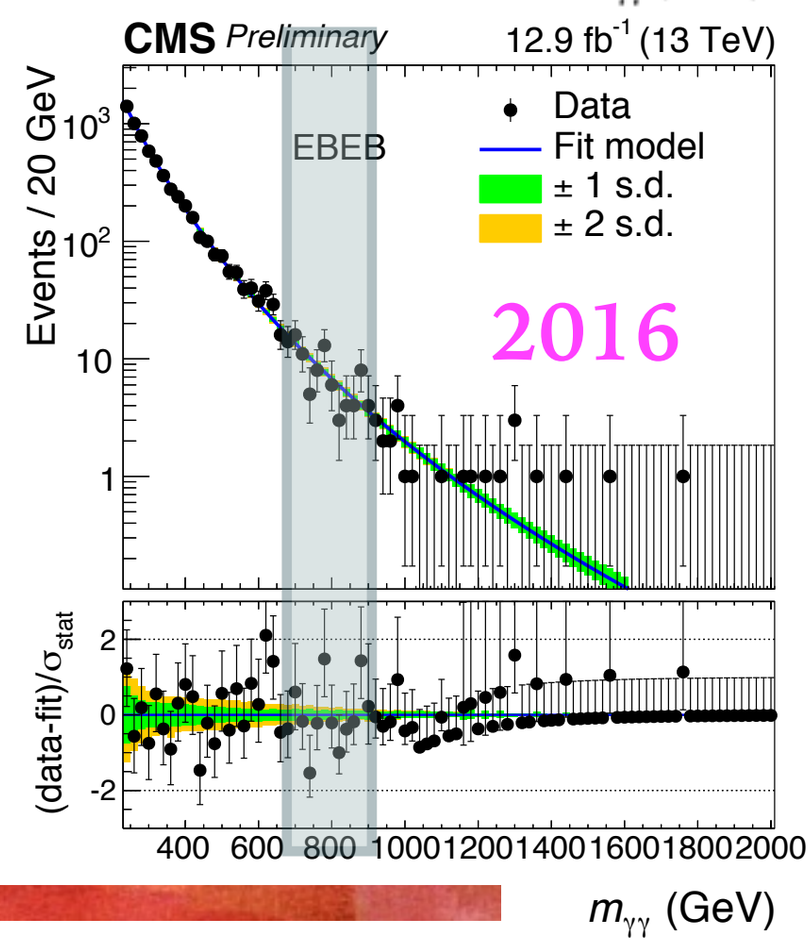
$X \rightarrow \gamma\gamma$: Overview

2015: PRL 117, 051802 (2016)
2016: CMS-PAS-EXO-16-027

- Simple but robust channel for resonance search:
  - predicted by many theoretical models;
  - relatively low background and low systematic uncertainties at hadron collider;
  - good mass resolution.
- Analysis strategy:
  - 2 well-reconstructed isolated energetic photons (central preferred) with large $m_{\gamma\gamma}$
  - Signal: convolution of instrinsic line-shape and detector response (i.e. efficiencies, energy scale and resolution).
  - Background: simultaneous fit to $m_{\gamma\gamma}$ distribution with an empirical function.

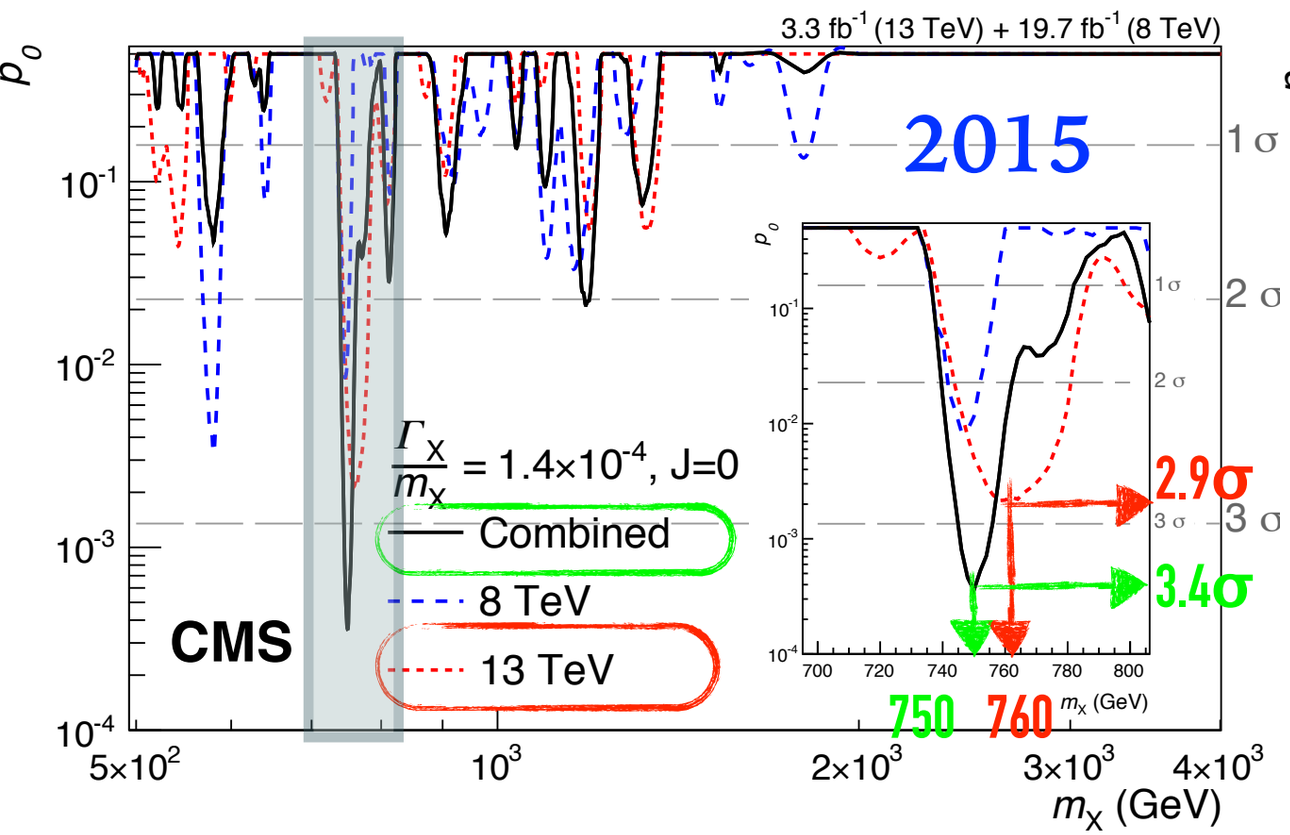


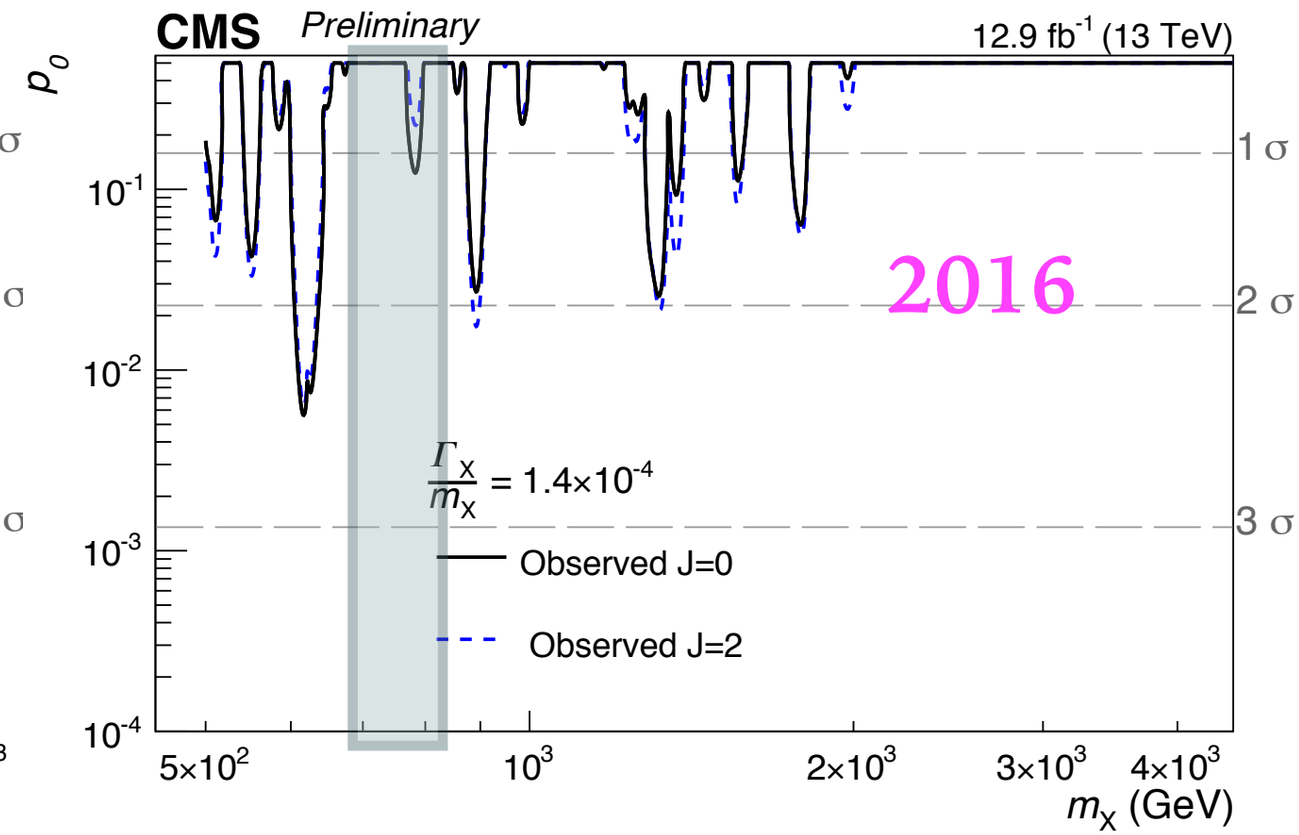




$X \rightarrow \gamma\gamma$: Excess at 750GeV disappeared

2015: PRL 117, 051802 (2016)
2016: CMS-PAS-EXO-16-027



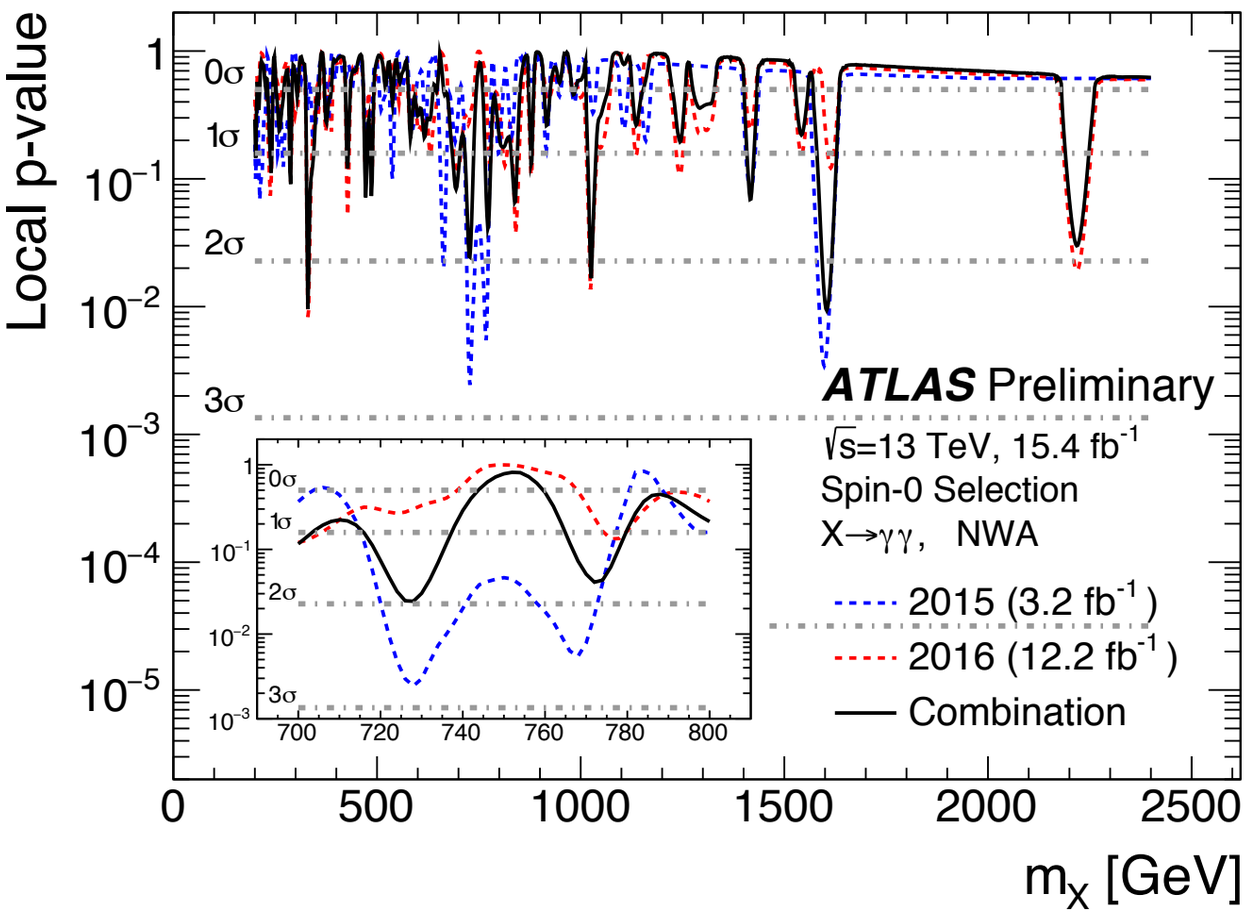


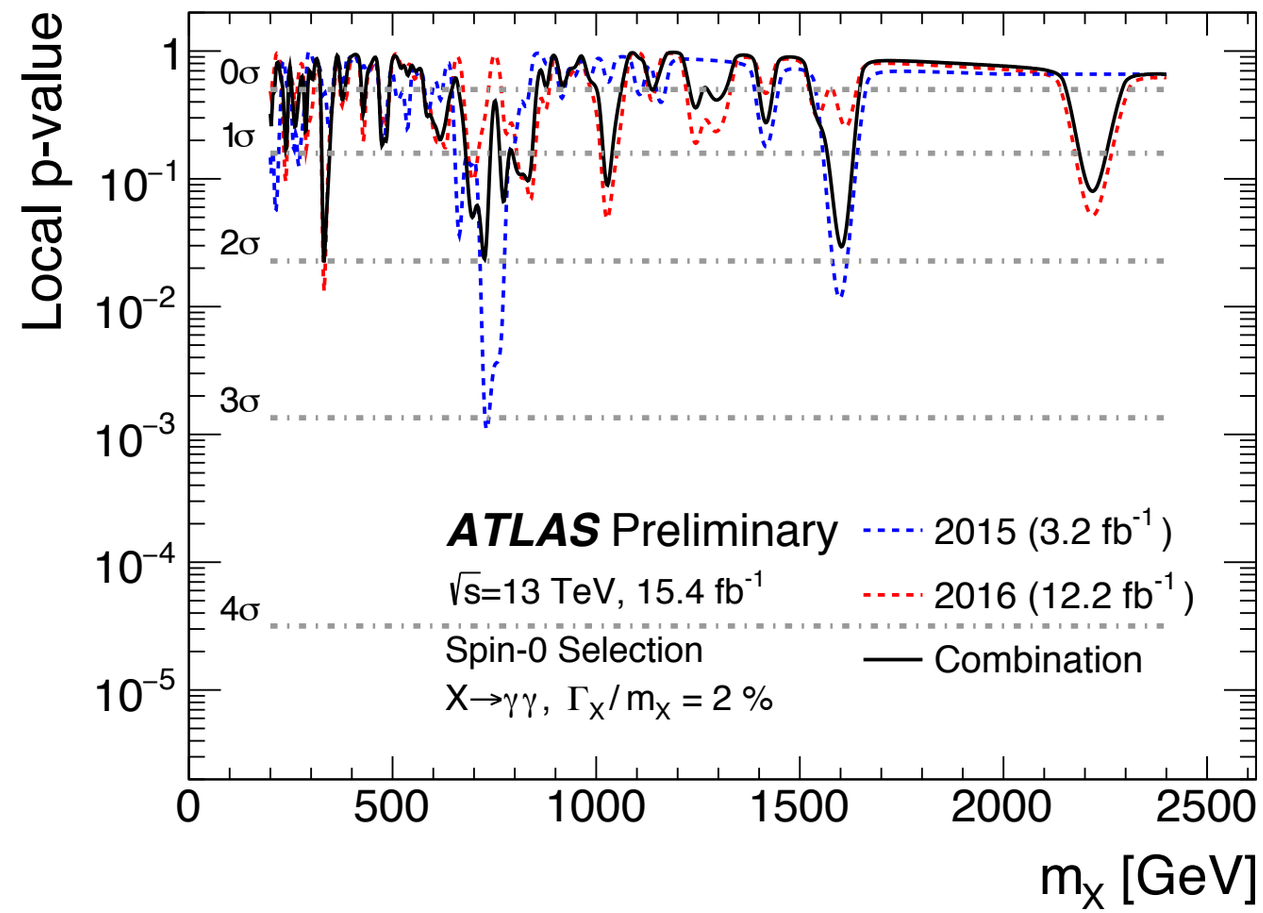
- a significant excess appeared around 750 with combined 8 TeV and 13 TeV results
- for narrow width:
  — local 3.4σ
  — global 1.6σ

- largest excess now observed at ~620 GeV with local significance (narrow width) of ~2.4-2.7 σ
- **NO** siginificant excess at ~750 GeV

$X \rightarrow \gamma\gamma$: Excess at 750GeV disappeared

ATLAS-CONF-2016-059



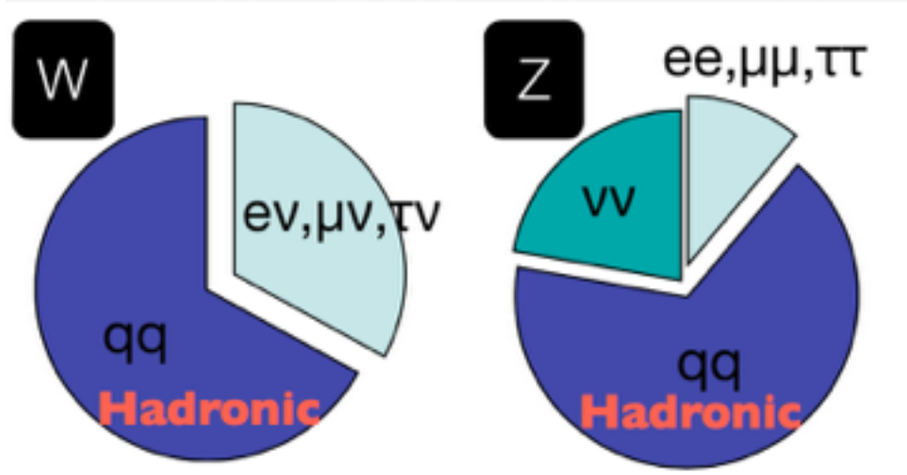


- largest significance at 1.6 TeV for an assumed narrow width:
  local 2.4σ
  global <1σ

- largest significance in mass range of 700-800 with a relative width of 20%:
  local 2.3σ

X → ZZ/WW

- All hadronic decay (e.g. ZZ/WW → qqqq)
  - high branching ratio
  - high background at hadron collider
  - search for a resonance peak over transverse mass



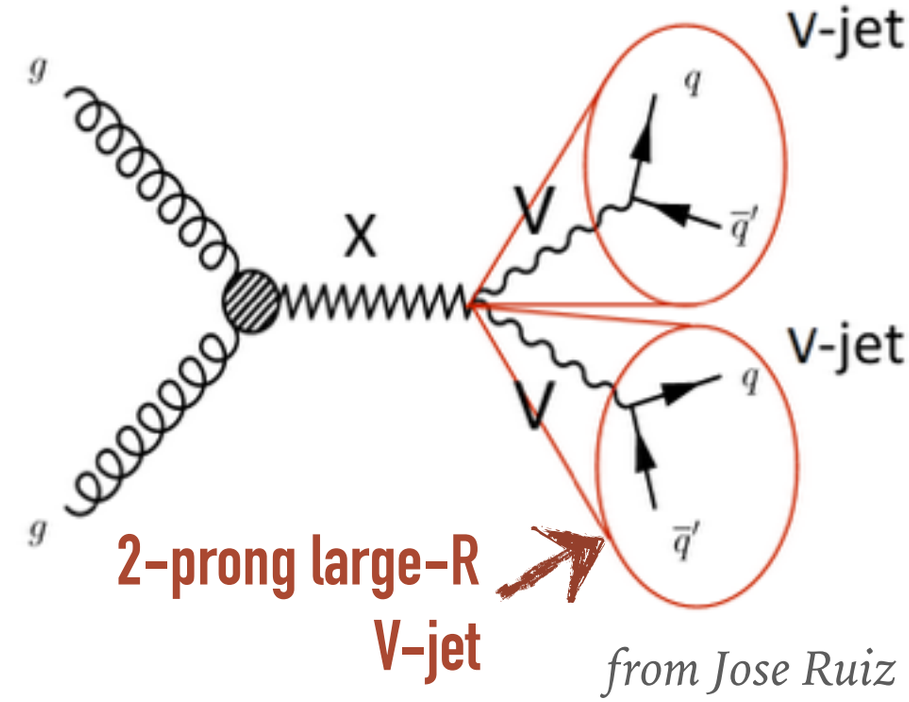
from S. Mukherjee

- All leptonic decay (e.g. ZZ → llνν)
  - low branching ratio
  - low background at hadron collider
  - no sharp peak: very small dependence of mass width assumption
- Semi-leptonic decay (e.g. WW → lνqq)
  - combine the experimental strengths of the above two channels

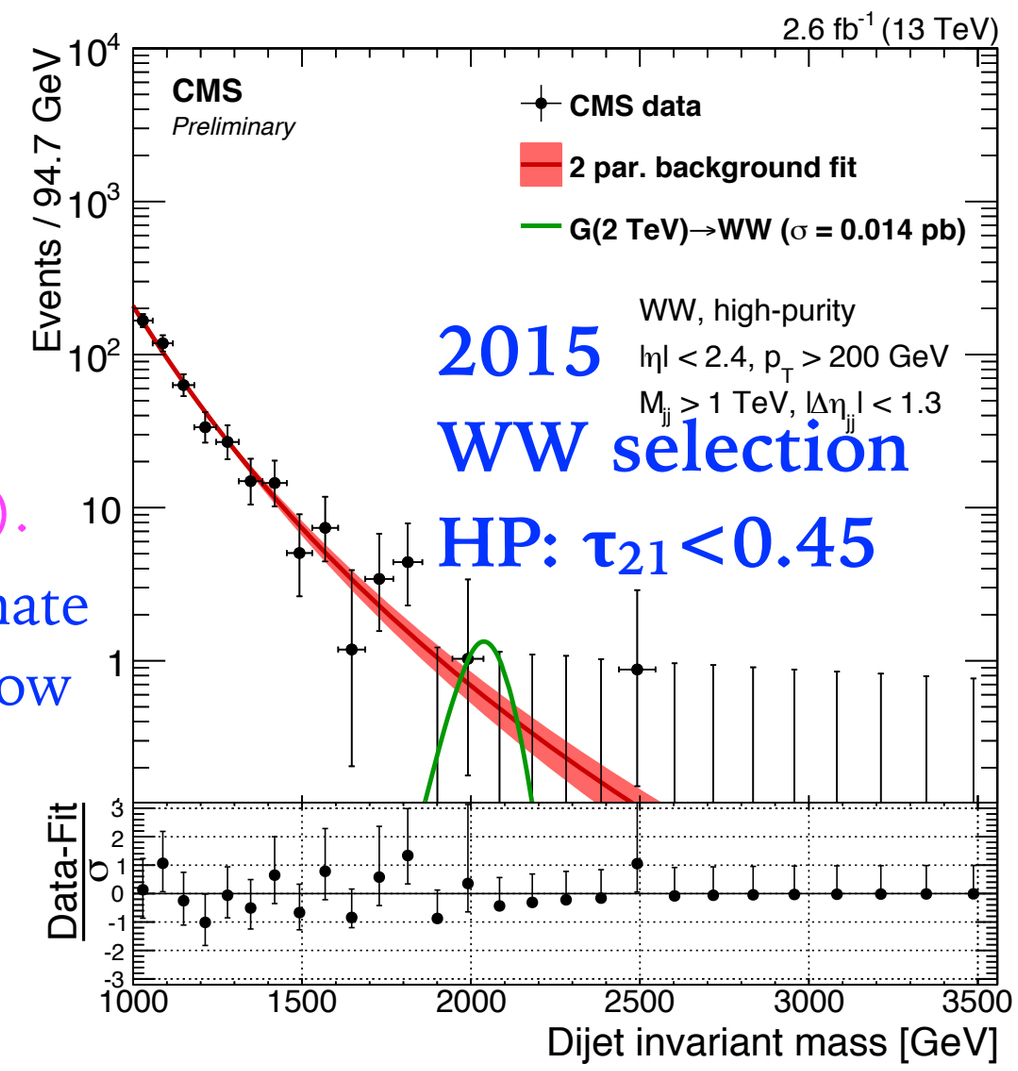
X → ZZ/WW → qqqq

ATLAS-CONF-2016-055
CMS-PAS-EXO-15-002

- Better performance in high mass region where backgrounds fall off.
- Target at TeV scale new resonance (m_{JJ}>1TeV).
- Pruned/trimmed jets: mitigate soft radiation and underlying event contributions and other noise.
- Boosted W/Z: 2 hadronic decay products collinear → jet substructure and jet mass to identify V-jet
- **Event selection:**
  - 2 back-to-back V-jets (on-shell) with large p_T and $|\eta|$<2.0/2.4 (ATLAS/CMS);
  - **ATLAS:** p_T asymmetry to lower t-channel QCD; N_{tracks}<30 to reject glon jet (+~30% sensitivity).
  - **CMS:** V-jet identification variable, τ_{21} (discriminate signal from background), used to define High/Low Purity regions.
- Signal: convolute line-shape and detector response
- Backgrounds: simultaneous fit to m_{JJ} distribution with an empirical function.



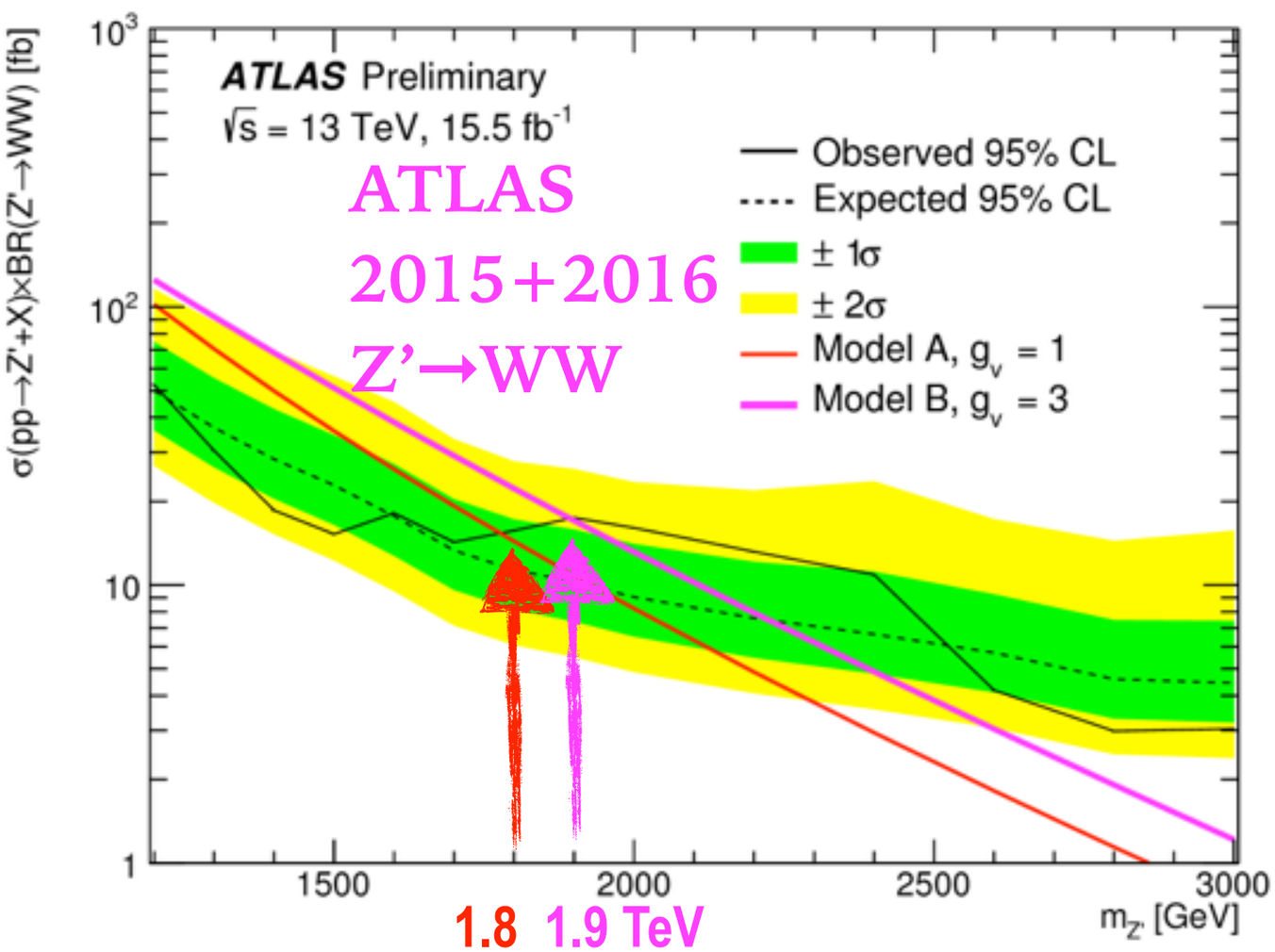
from Jose Ruiz

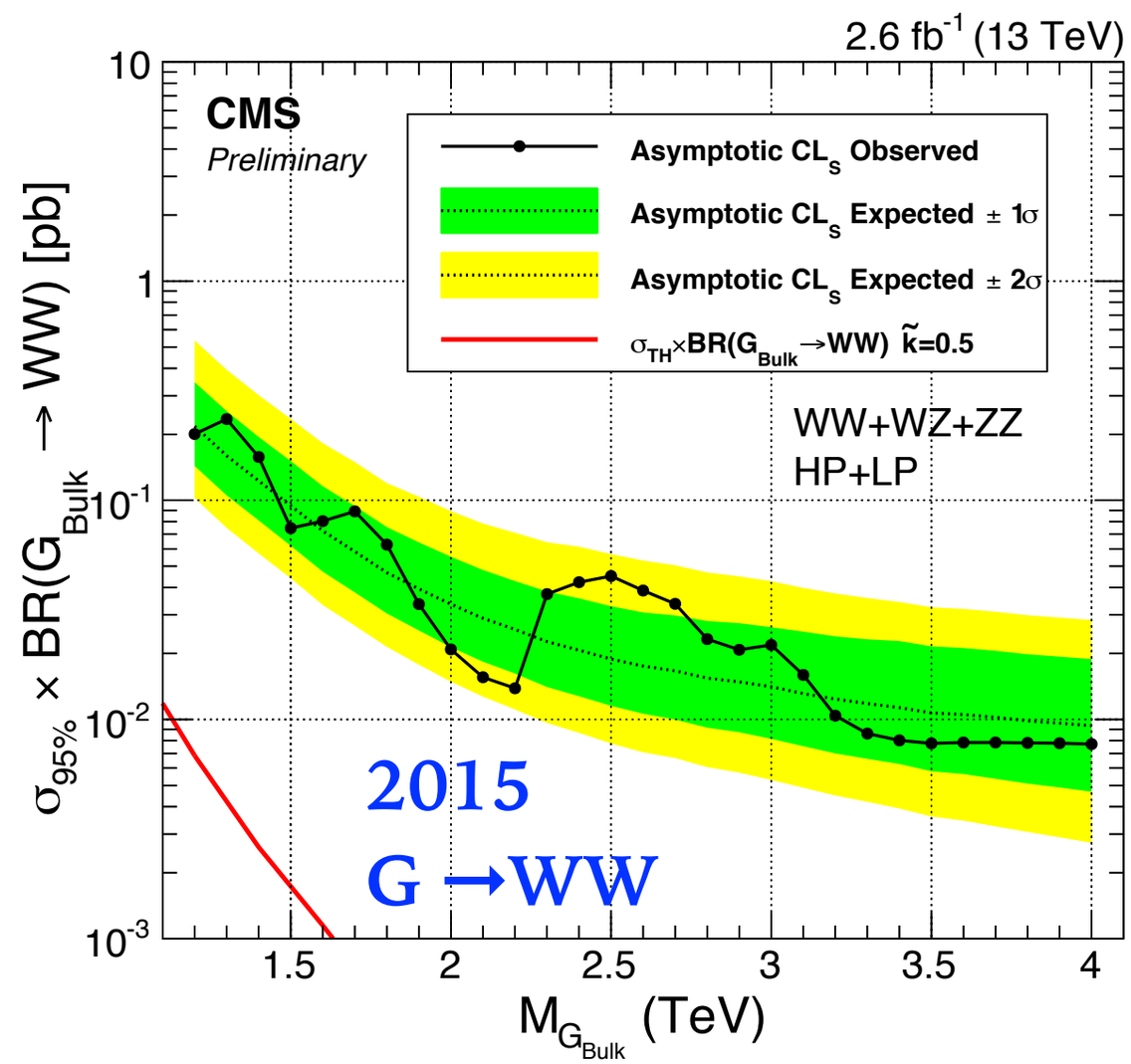


X → ZZ/WW→ qqqq

ATLAS-CONF-2016-055
CMS-PAS-EXO-15-002

- ATLAS:
  - less sensitive in bulk-graviton model;
  - HVT model shown (Z' →WW as example): exclude Z' mass from 1.2 TeV up to 1.8(1.9)TeV, depending on the coupling strength g_v .
- CMS: for ZZ/WW final state, only bulk-graviton model available.

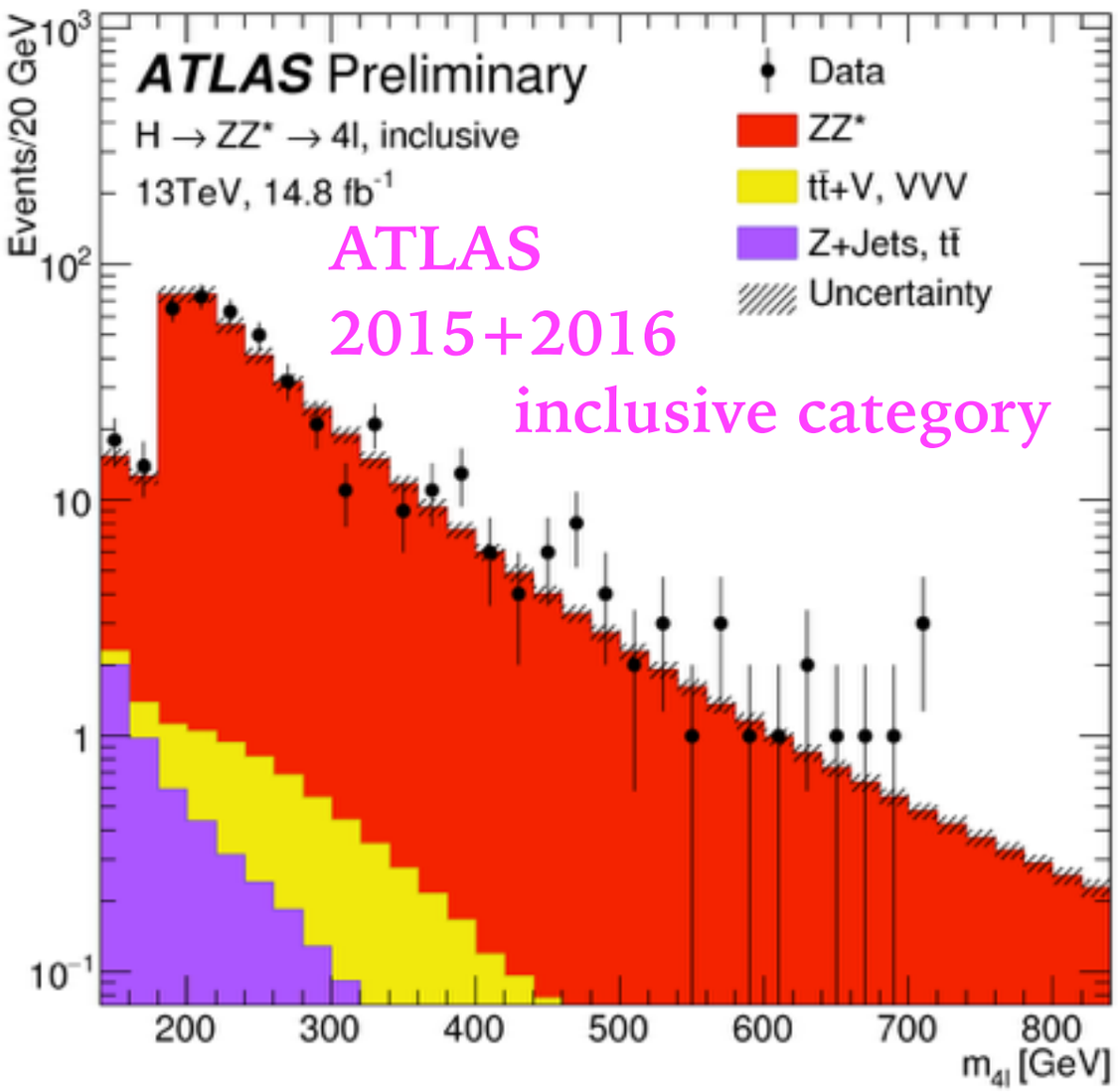


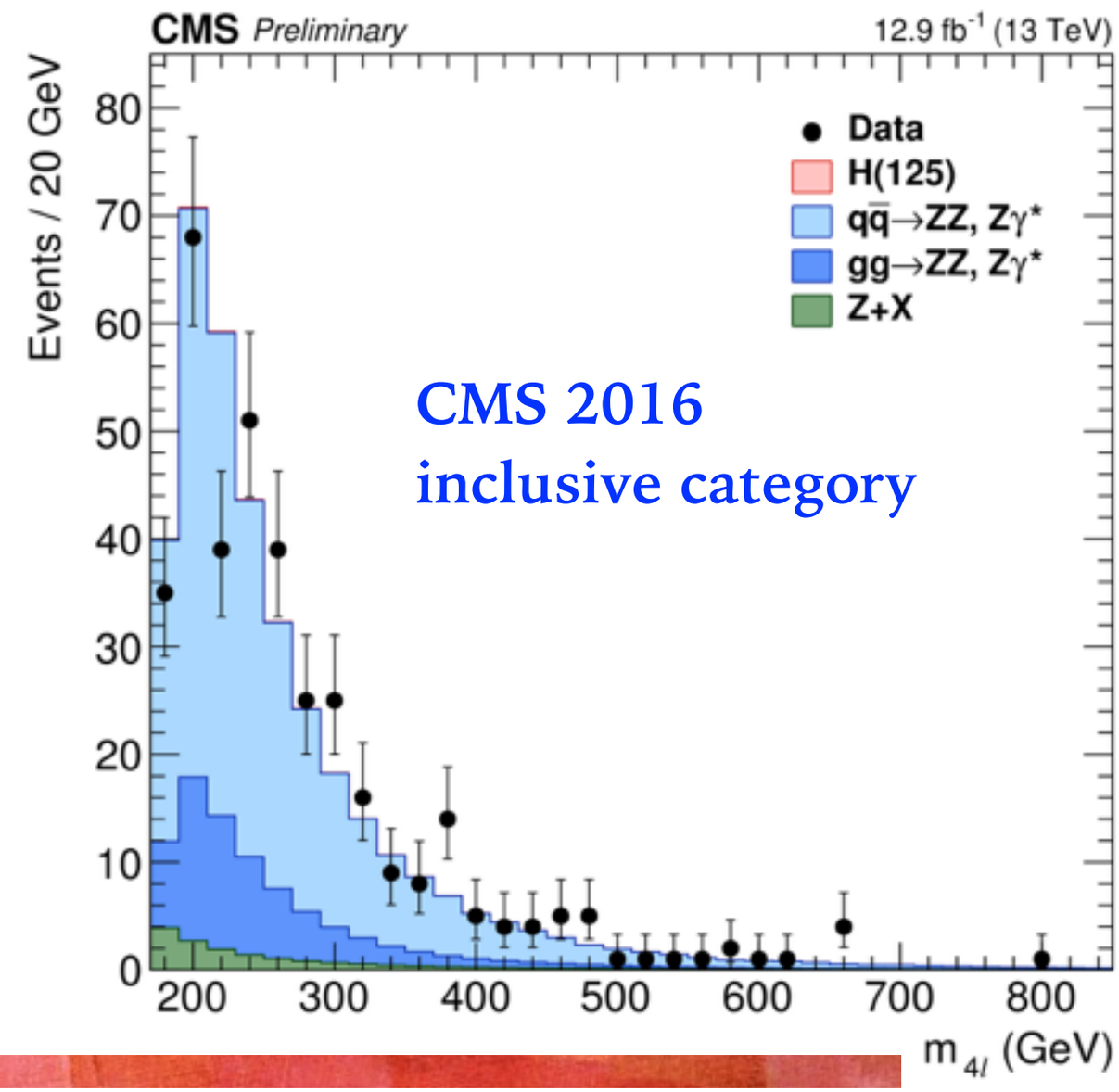


$H^* \rightarrow ZZ \rightarrow 4l$

ATLAS-CONF-2016-079
CMS-PAS-HIG-16-033

- Analysis strategy:
  - select 2 on-shell Z bosons reconstructed from e^+e^- or $\mu^+\mu^-$, categorized in VBF and ggF.
  - backgrounds:
    - irreducible: ZZ from MC
    - reducible: Z+jets from 2 independent data-driven methods
- No events observed beyond m_{4l}=850GeV

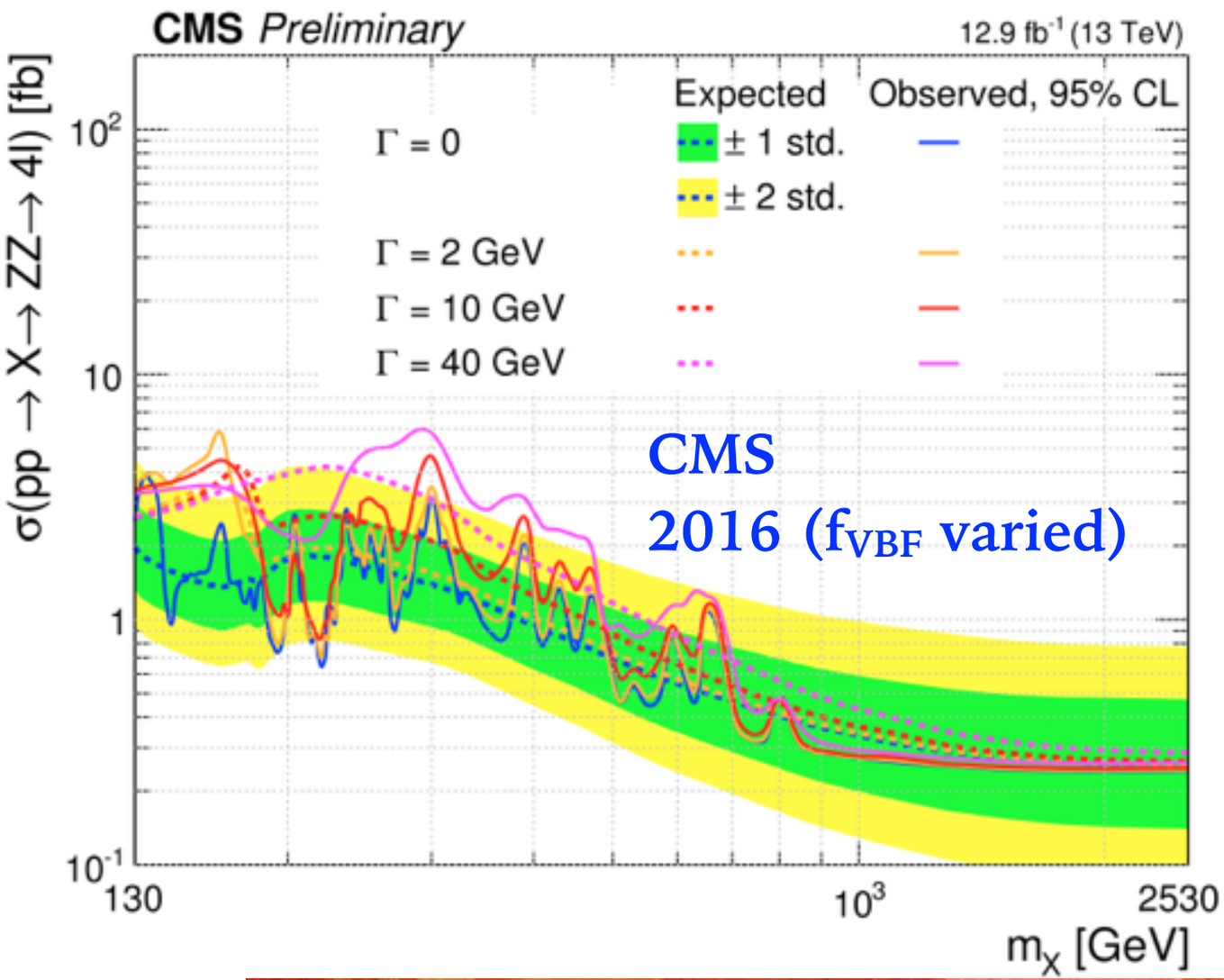


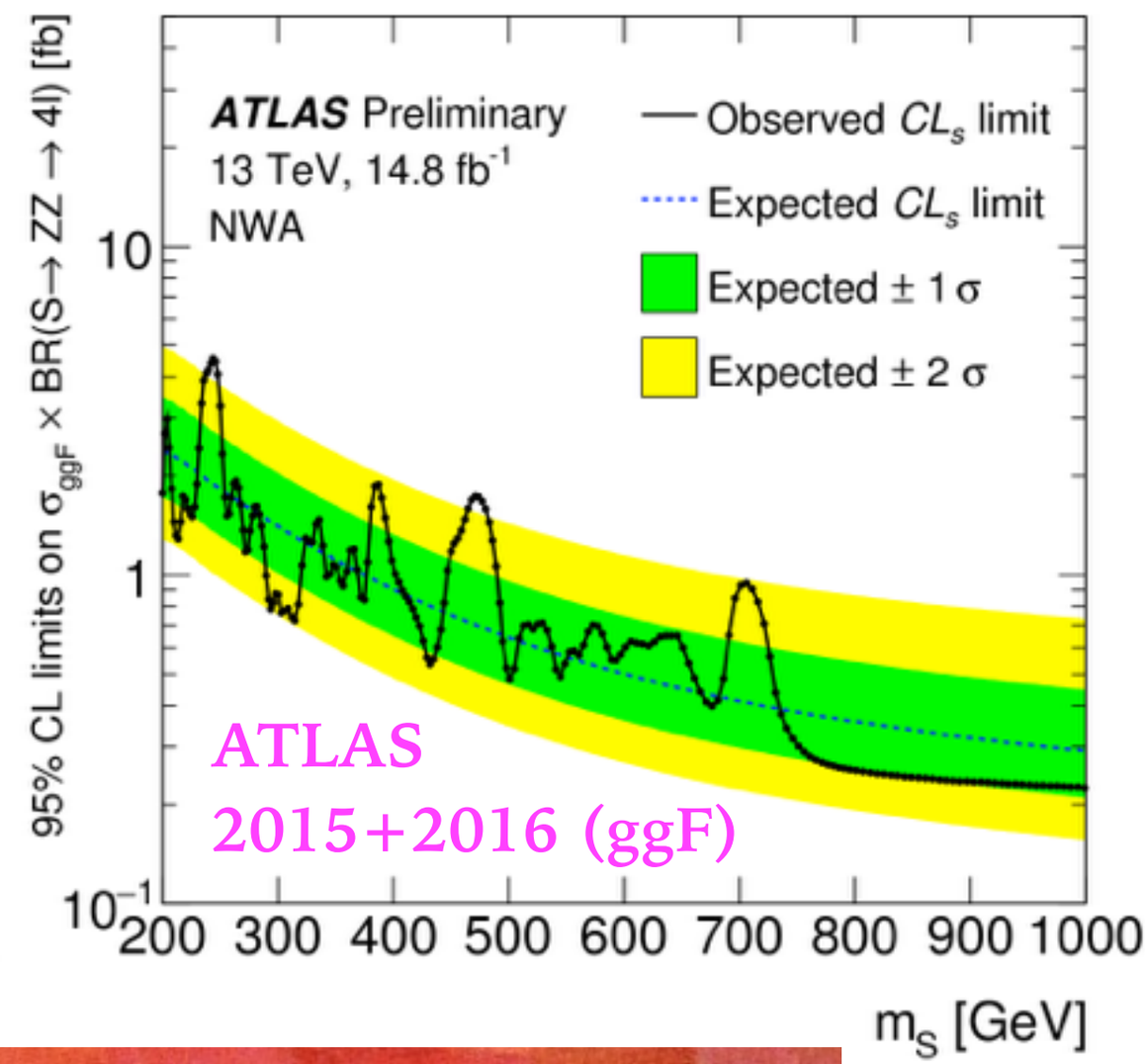


H* → ZZ → 4l

ATLAS-CONF-2016-079
CMS-PAS-HIG-16-033

- No excess claimed, thus results interpreted as limits on X → ZZ → 4l with a narrow width approximation
- CMS: the fraction of VBF and VH production, f_{VBF}, can be either varied or fixed in the fit → less model dependent; various widths shown.
- ATLAS: ggF category result shown with Γ/m_S=0.5%





$X \rightarrow ZZ \rightarrow llvv$

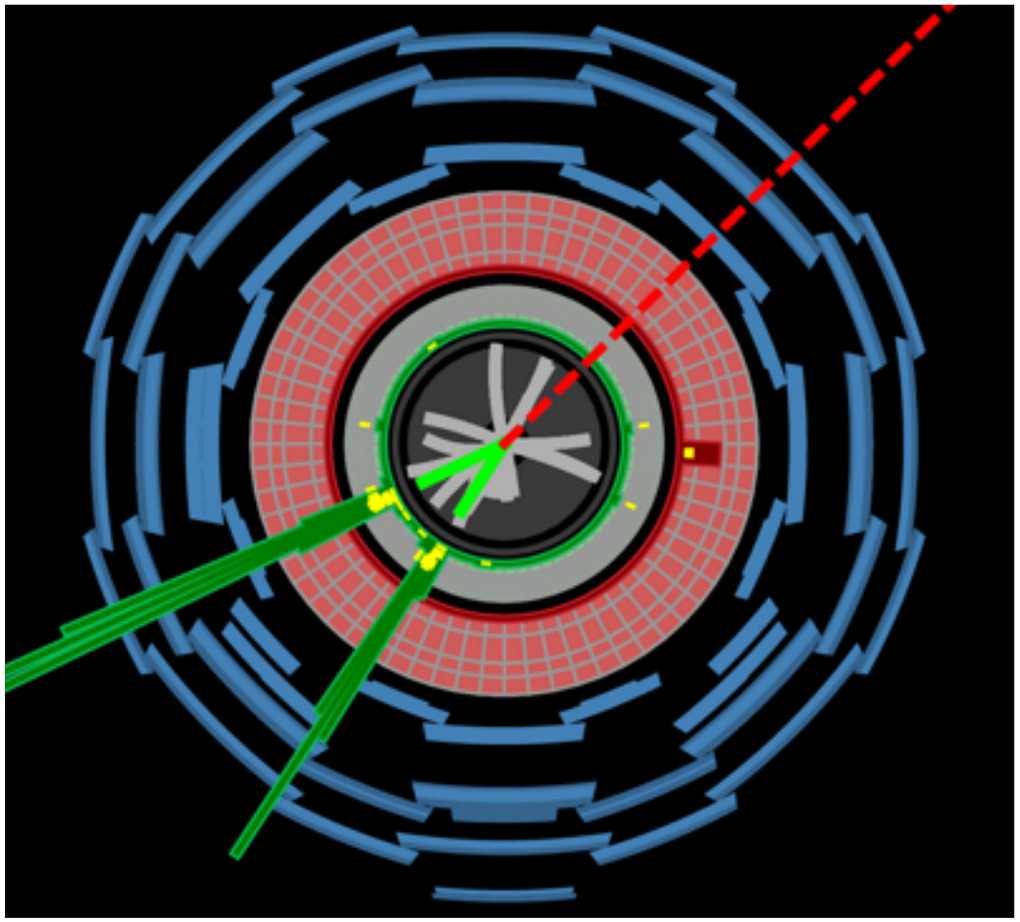
ATLAS-CONF-2016-056
CMS-PAS-HIG-16-001

Event Selection

— 2 well-identified isolated leptons originated from an energetic Z boson decay
— large E_T^{miss}
— to suppress fake E_T^{miss} background:
  jet far from E_T^{miss}
  +further customised cuts (ATLAS)
— top background suppression: b-jet veto
— WZ background suppression:
  3rd lepton veto
— VBF/ggF event categories

Background

Different background composite and estimate method:
— ZZ/ZVV: MC
— WZ: MC (CMS); 3l control region (ATLAS)
— Z+jets: γ+jet data-driven (CMS)
  ABCD data-driven (ATLAS)
— non-resonant-ll: eμ data-driven
— W+jets: fake factor from data (ATLAS)



X → ZZ → llνν

ATLAS-CONF-2016-056
CMS-PAS-HIG-16-001

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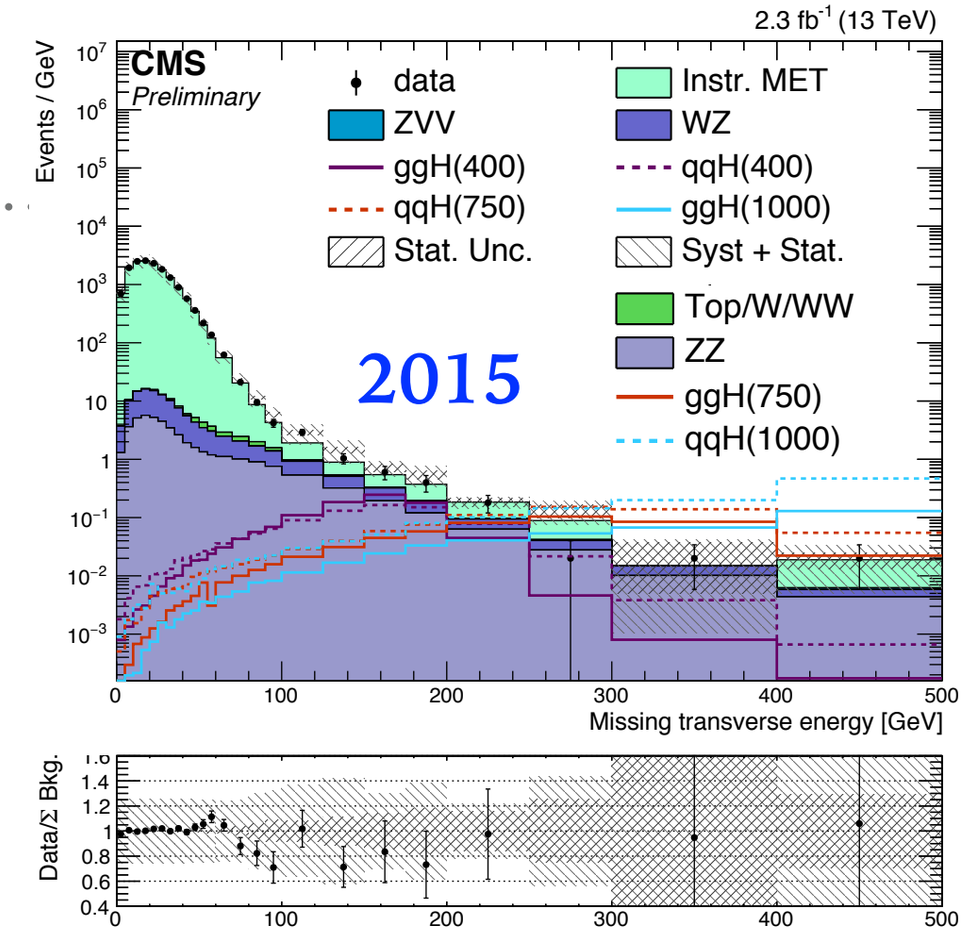
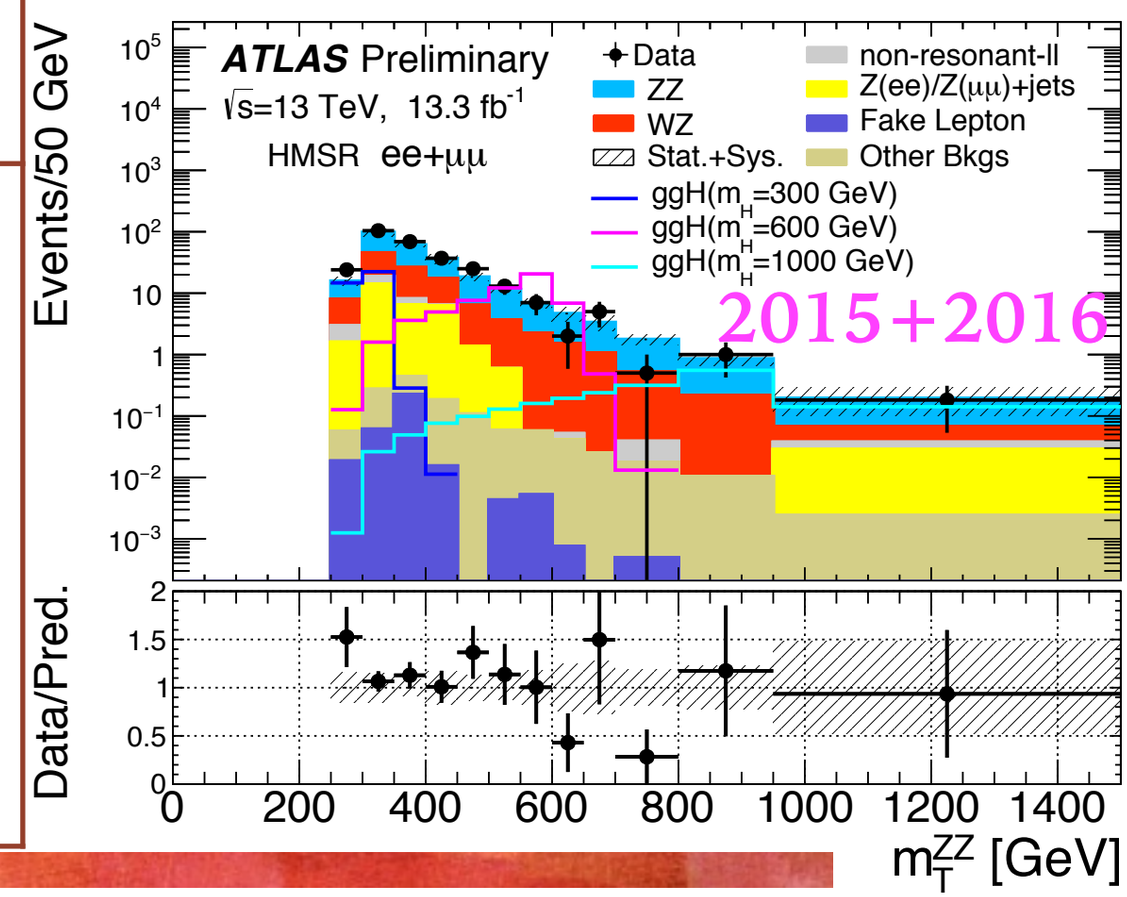
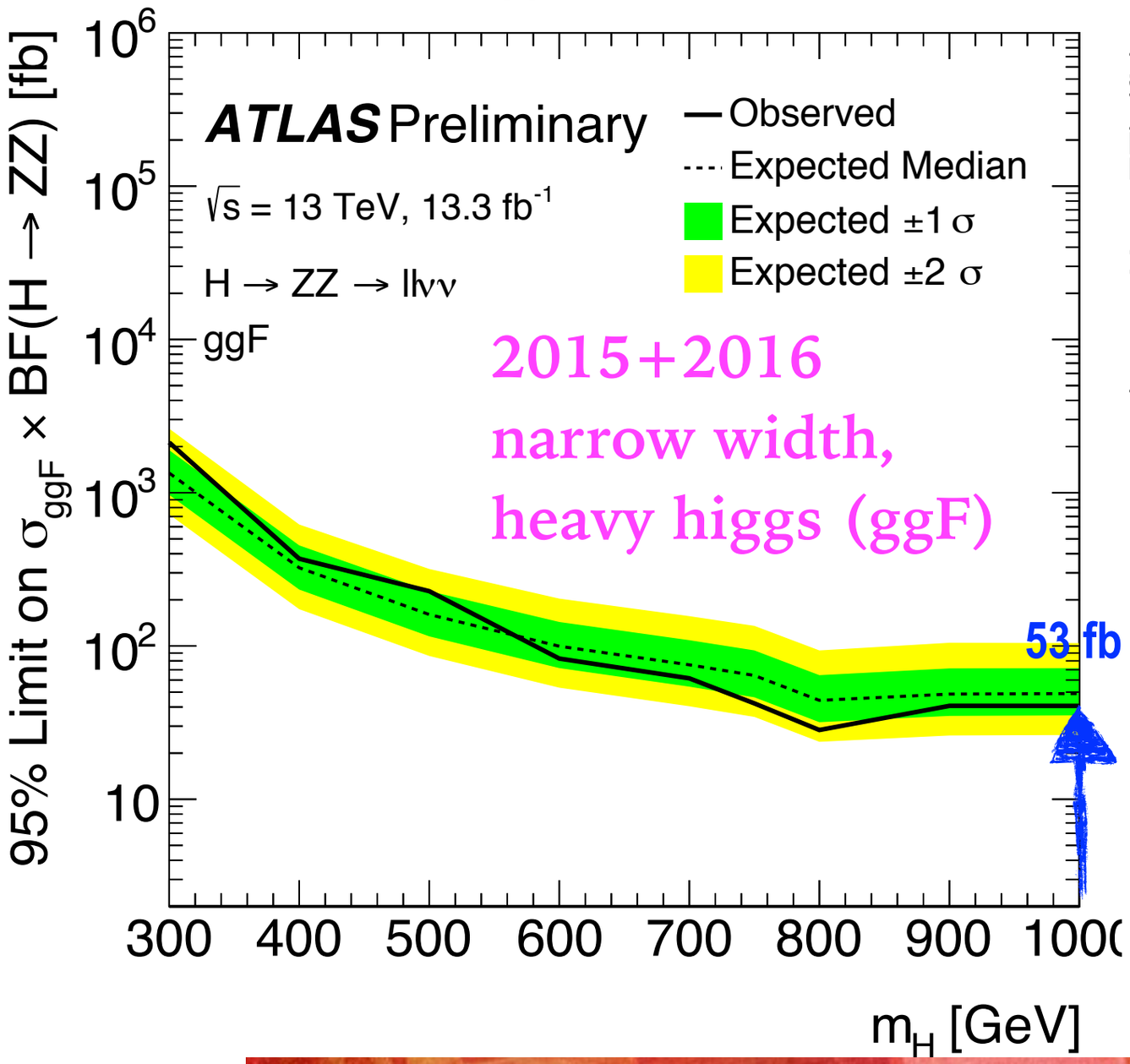


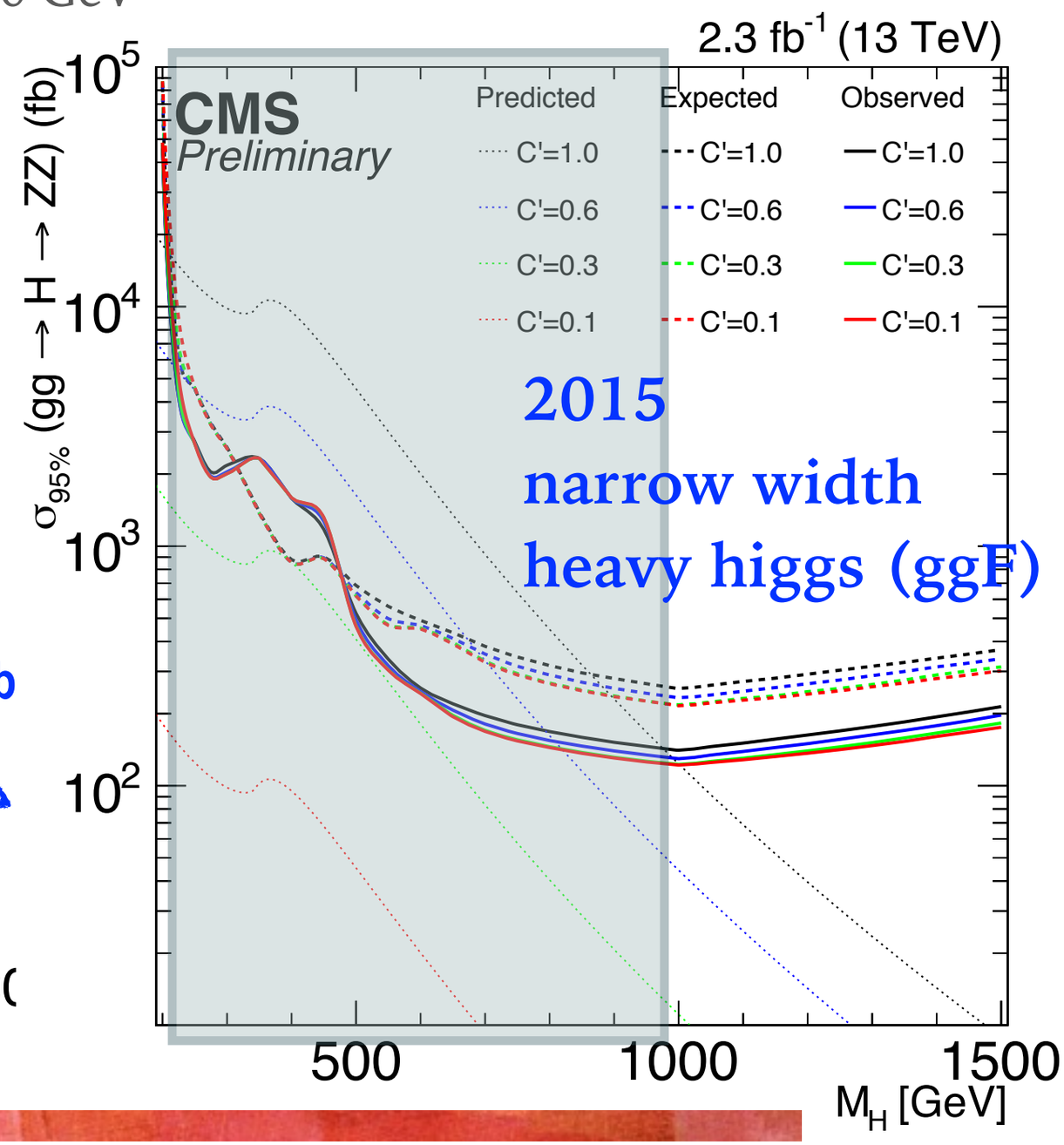


X → ZZ → llνν

ATLAS-CONF-2016-056
CMS-PAS-HIG-16-001

- No significant excess seen, improved limits w.r.t. Run1
- ATLAS: exclude cross section of H* → ZZ production at m_H=1TeV up to 53 fb
- CMS: the most stringent limit given by the EW signlet model with mixing parameter C'=1, exclude higgs mass from ~210 to ~980 GeV

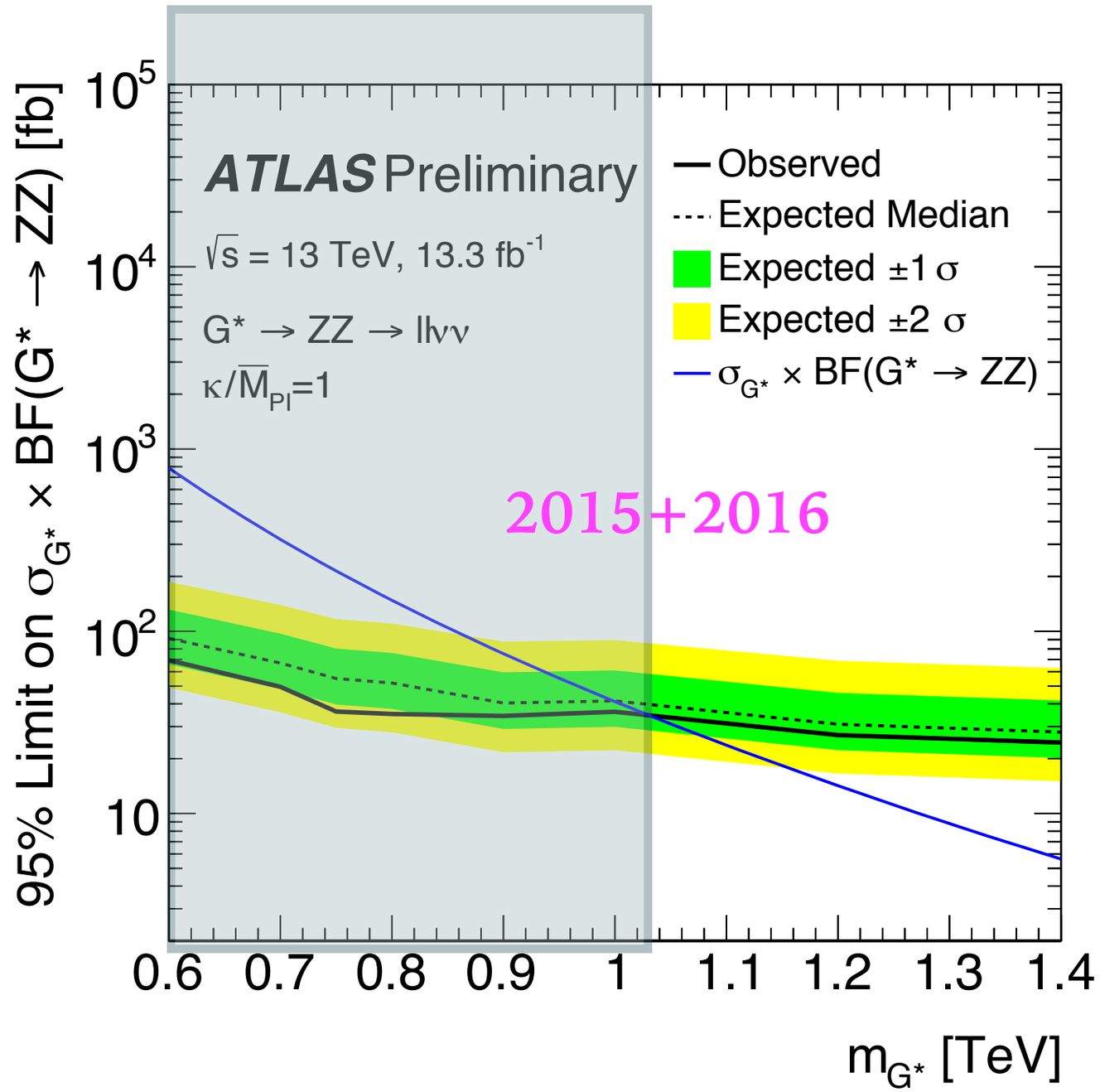




X → ZZ → llνν

ATLAS-CONF-2016-056

- Limits also interpreted to RS graviton produced with coupling constant $k/M_{Pl} = 1$
- RS graviton excluded from 600 GeV up to 1.03 TeV

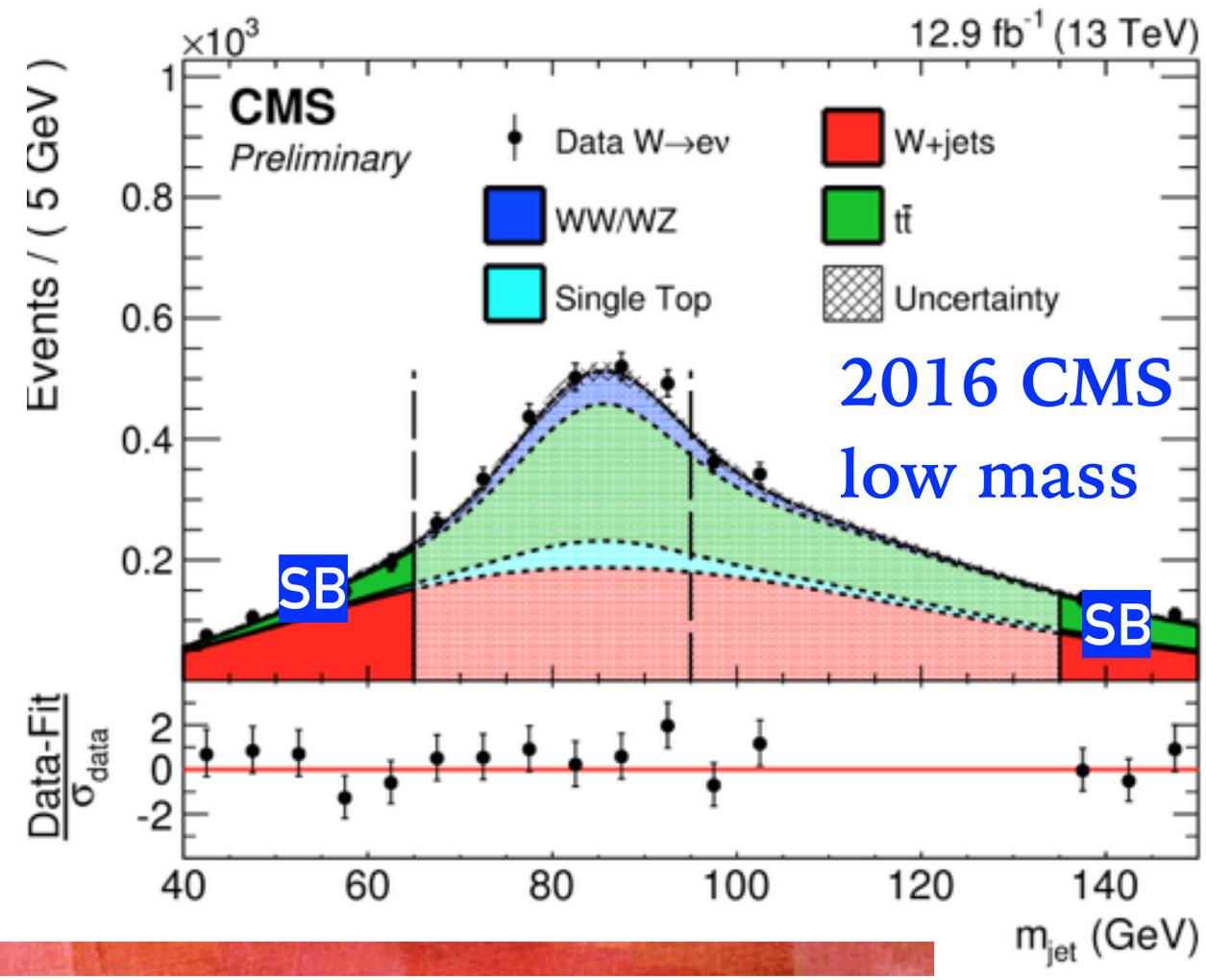


X → WV → lvqq

ATLAS-CONF-2016-062
CMS-PAS-B2G-16-020

Analysis strategy:

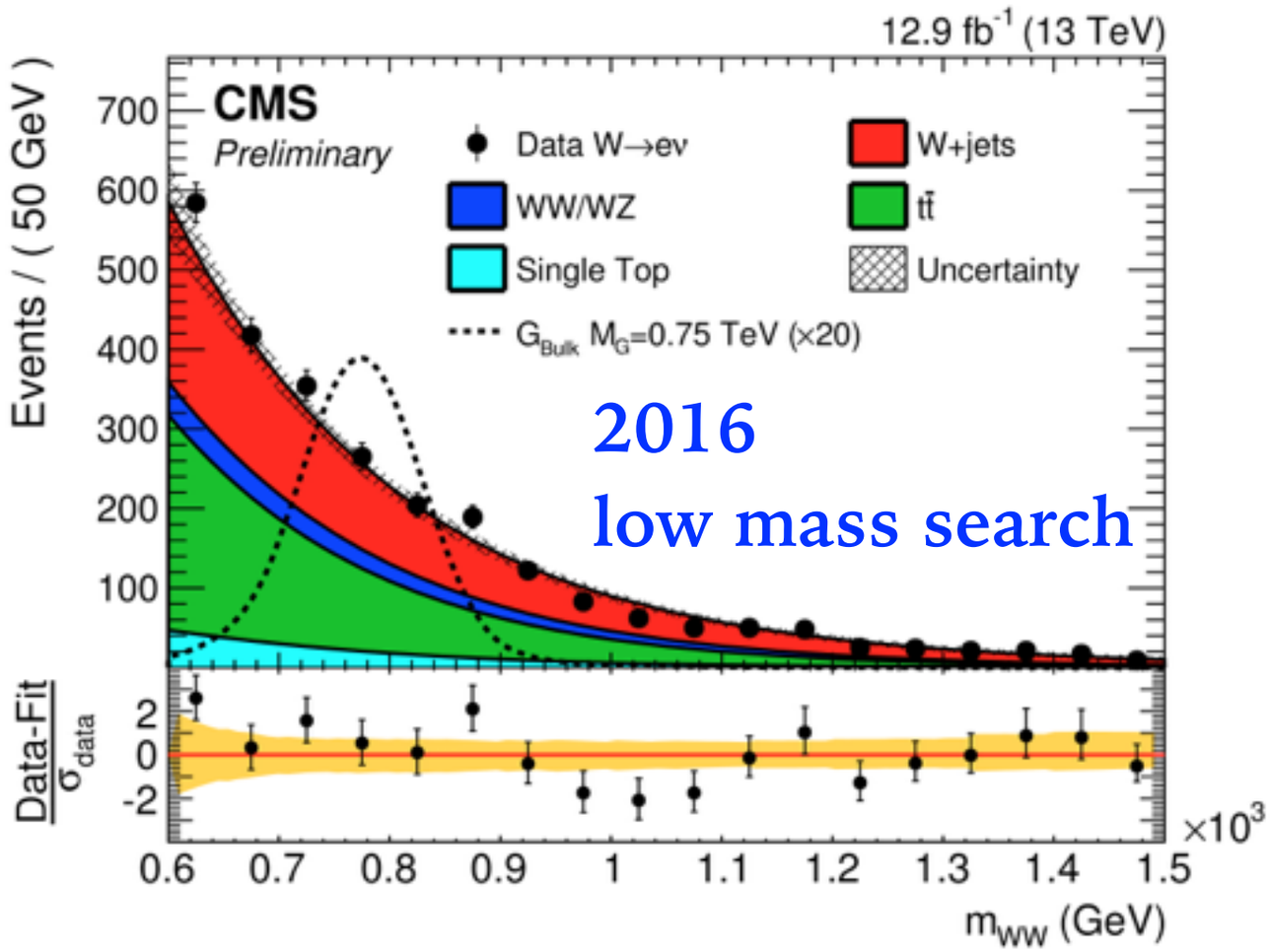
- Selections:
  - W → lv: large E_T^{miss} with a well-reconstructed energetic lepton;
  - V → qq: boson tagged jet (mass pruned/trimmed) with large p_T;
  - τ_{21} cut optimized for **low/high mass resonance searches;**
    2-prong boson jet cut separates **high/low purity regions.**
- Background:
  - ttbar CR: b-jet veto reverted
    - MC shape normalized by scale factor from CR
  - W+jet CR: boson jet mass sideband (SB)
    - both shape and yield extrapolated from SB.
  - MC shape normalized by a simultaneous fit to signal and all control regions.

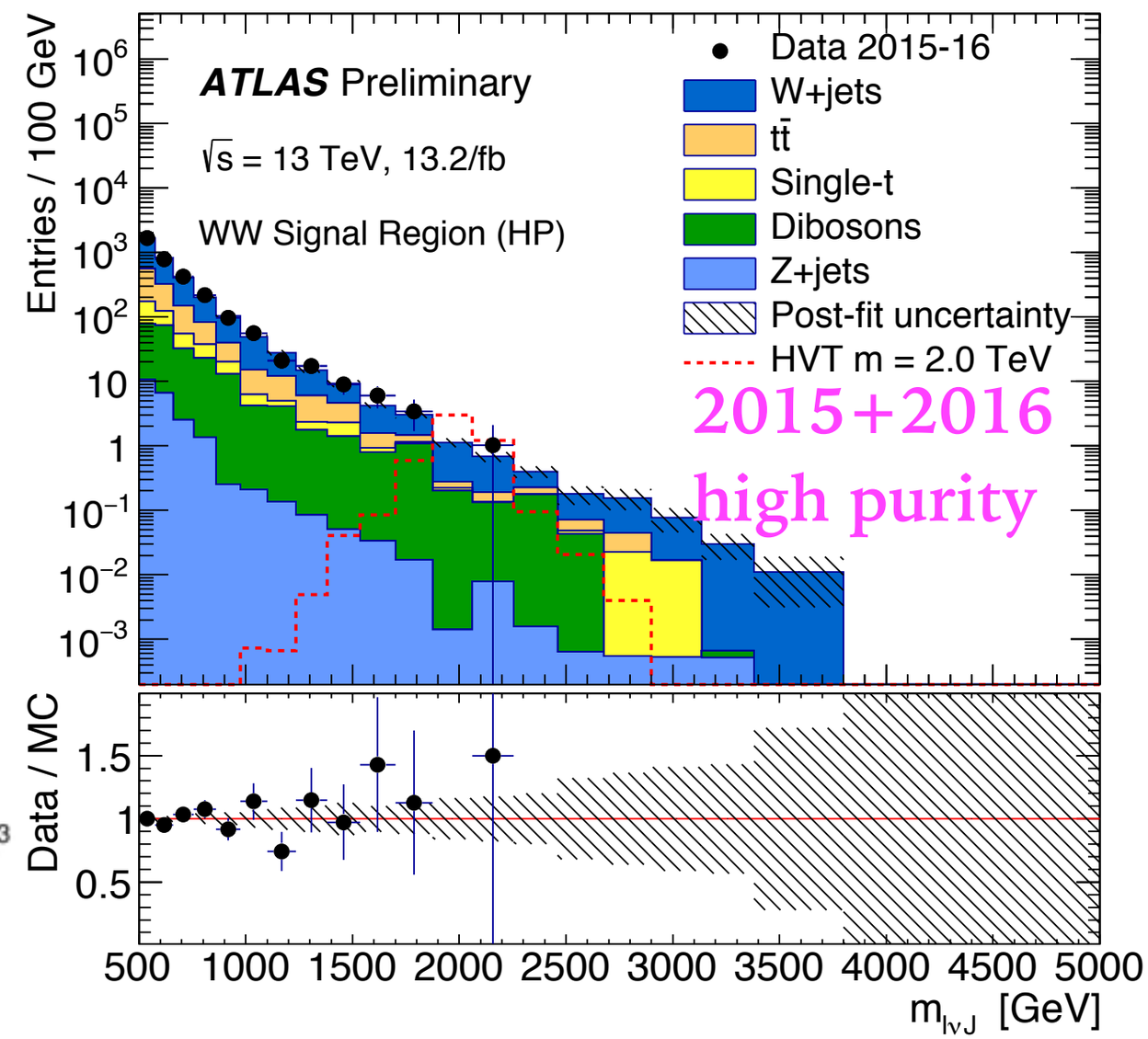


X → WV → lvqq

ATLAS-CONF-2016-062
CMS-PAS-B2G-16-020

- No evidence for a signal found

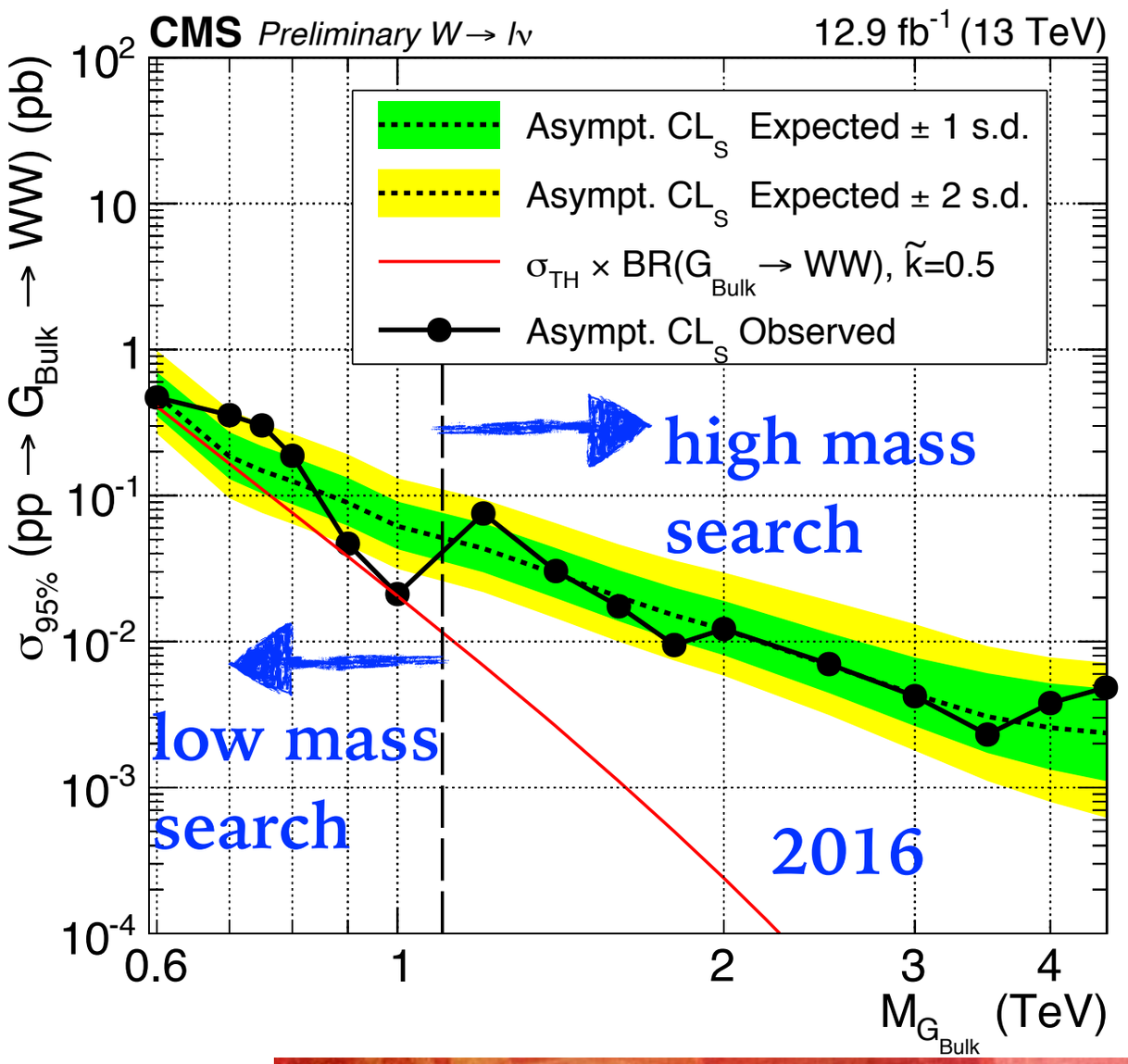


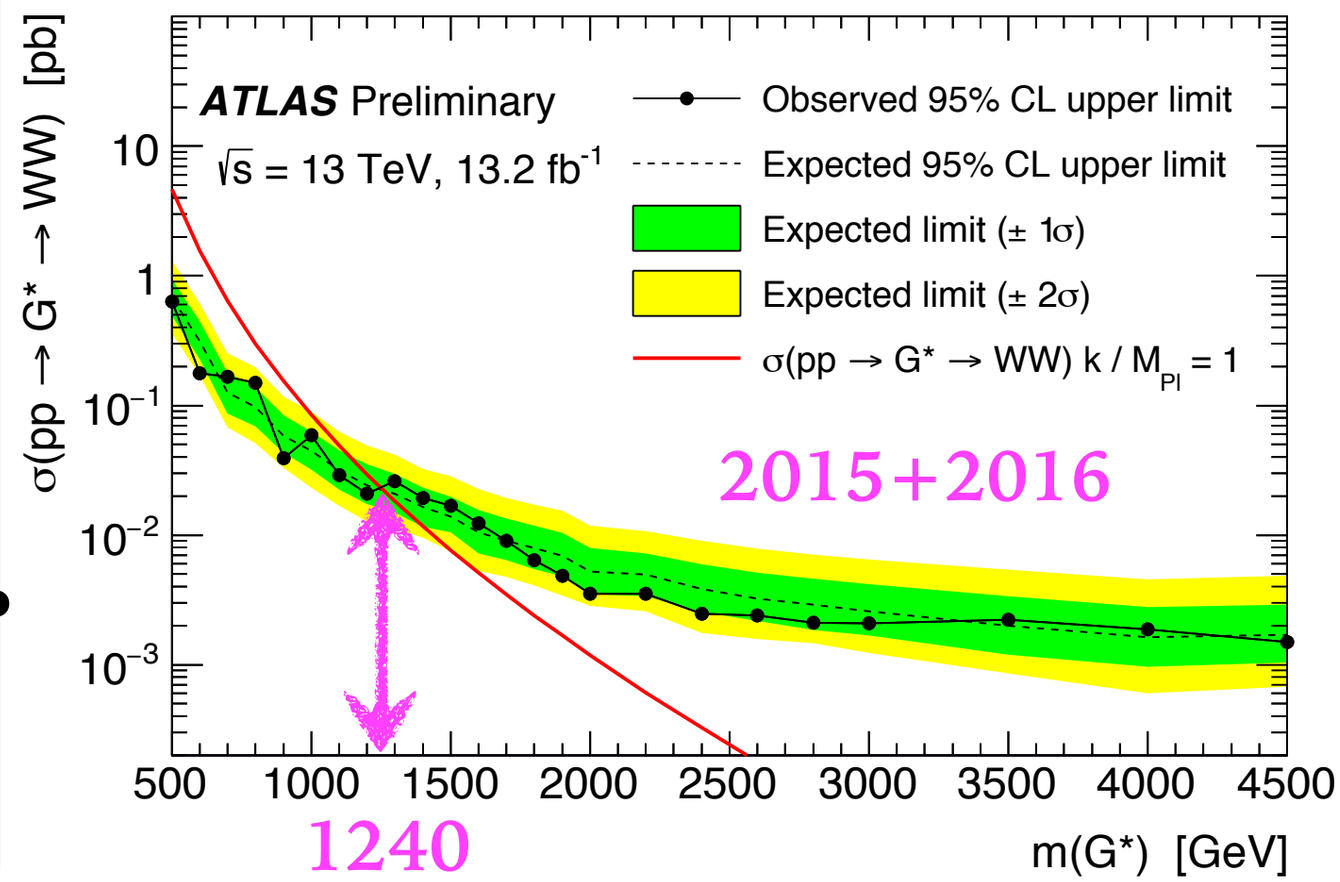


X → WV → lvqq

ATLAS-CONF-2016-062
CMS-PAS-B2G-16-020

- Thus results are interpreted as limits on various models
- Limits set on the production of $G_{bulk} \rightarrow WW$ w.r.t. graviton mass:
  - for coupling constant $k/M_{PL}=1/0.5$ (ATLAS/CMS)
  - ATLAS is able to exclude the RS graviton up to 1240 GeV

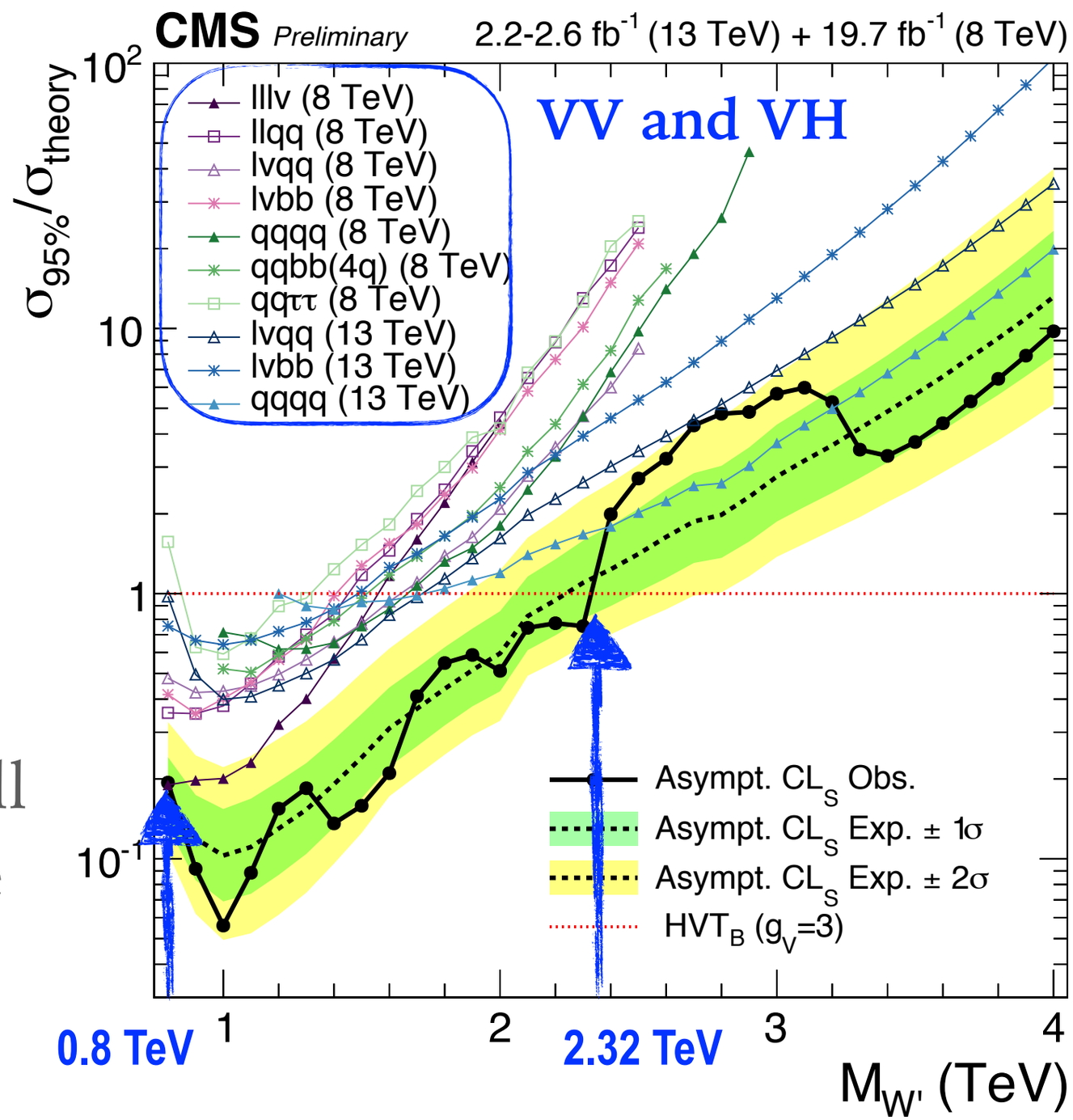




8+13 TeV (2015) Grand Combination

CMS-PAS-B2G-16-007

- 2015 data only
- Combined results interpreted to:
  — HVT with W'/Z' predicted;
  — warped extra dimension graviton decaying to WW/ZZ.
- Combine many channels (all the available ones when the paper was prepared).

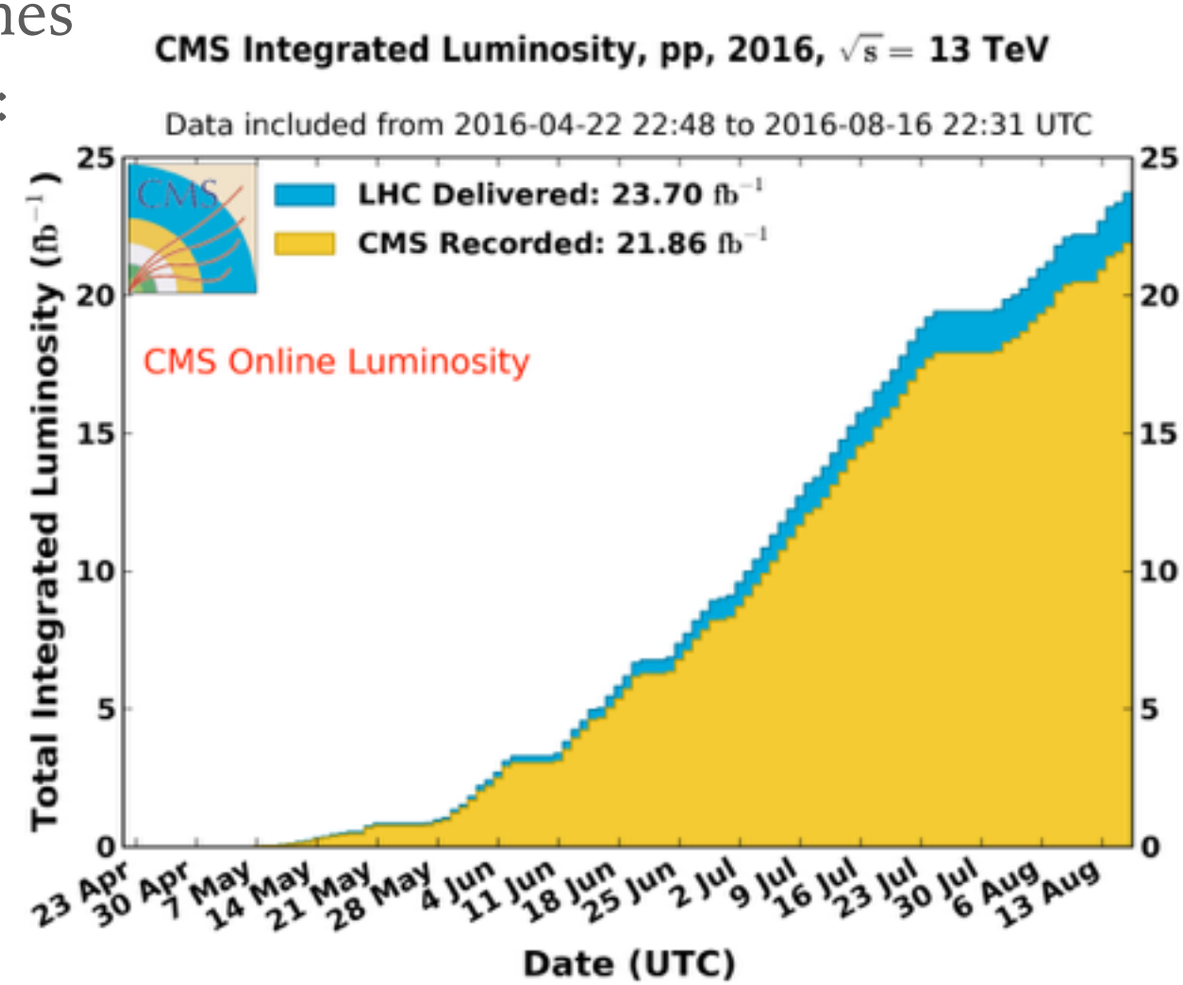


Summary

- Lack in luck for ATLAS and CMS:
  — 750 seems a statistical fluctuation and no confirmation from other bosons
  — no significant excess found so far with 13 TeV data

Good to use for physics
17.2 /fb
up to 16 August

- However, di-photon/Z/W resonance searches remain sensitive to the frontiers in energy:
  - Promising channel:
    — low SM background,
    — clean signal region,
    — great lepton/photon performance
  - Still challenging to improve:
    — e.g. background estimate technique
  - More 2016 data to study!



- In conclusion:
  looking forward to the upcoming excitement!

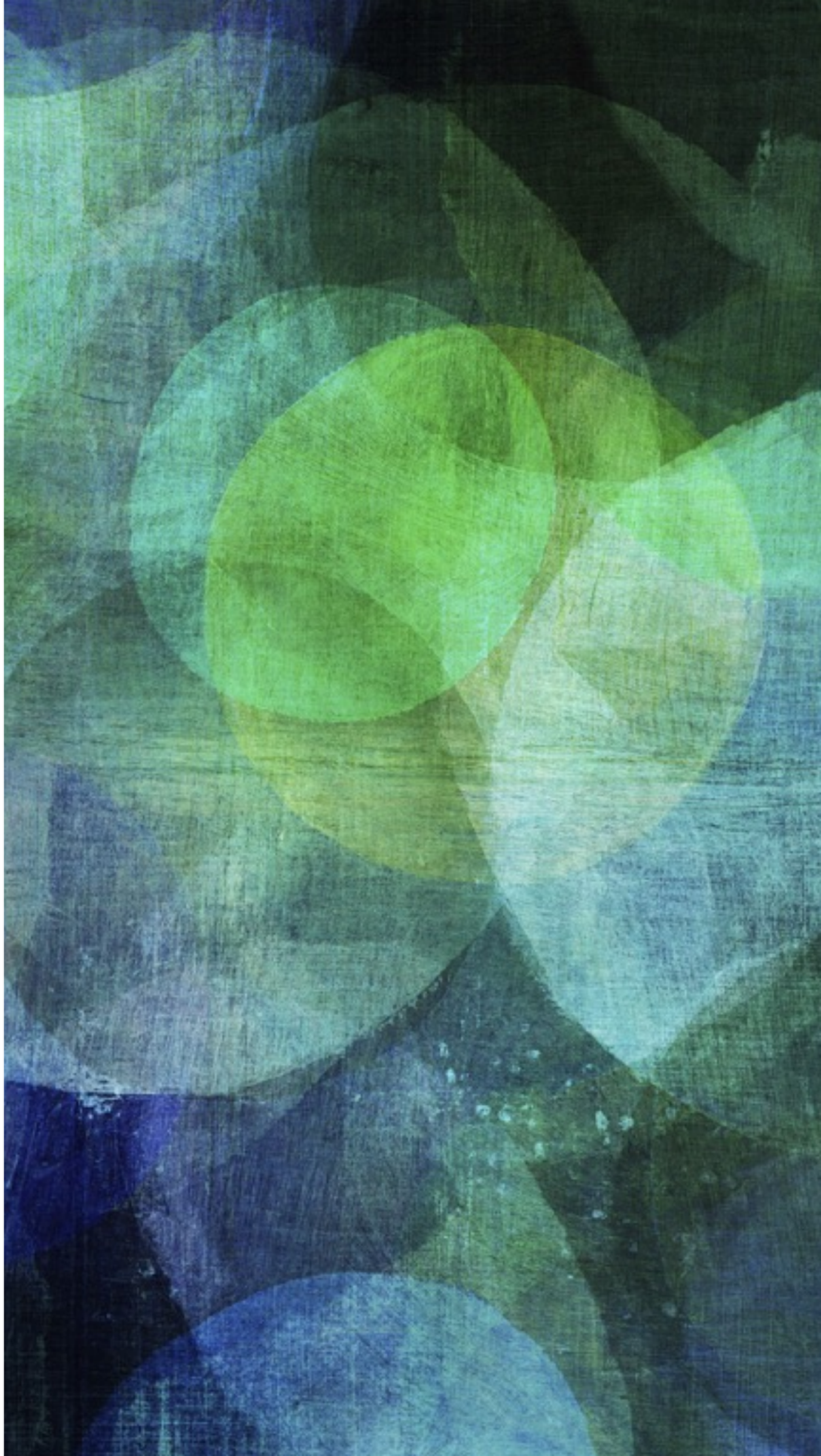
谢谢！

VIELEN DANK!

THANK YOU VERY MUCH!!

Backup

everybody needs a backup ;)



Boson jet tagging

ATL-PHYS-PUB-2015-033, ATL-PHYS-PUB-2014-004
CMS-PAS-JME-13-006

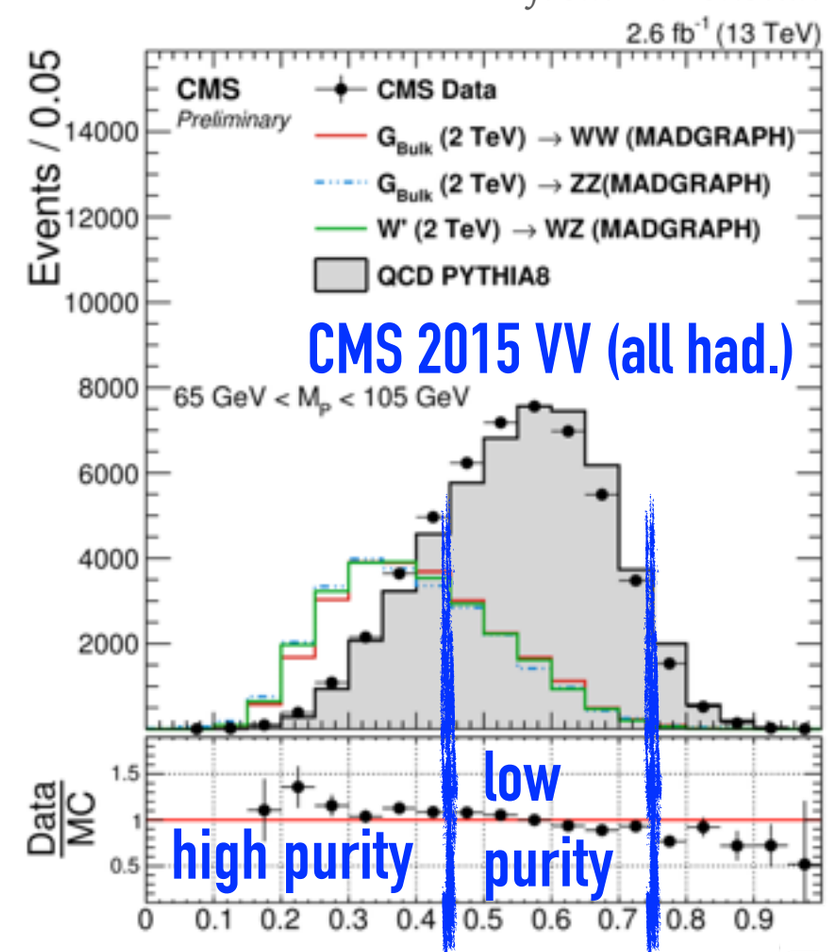
Jet grooming to miminize pile-up impact:

- ATLAS mainly uses 'jet trimming' arXiv:0912.1342
- CMS mainly uses 'jet pruning' arXiv:0912.0033

from N.Konstantinidis

V-jet tagging:

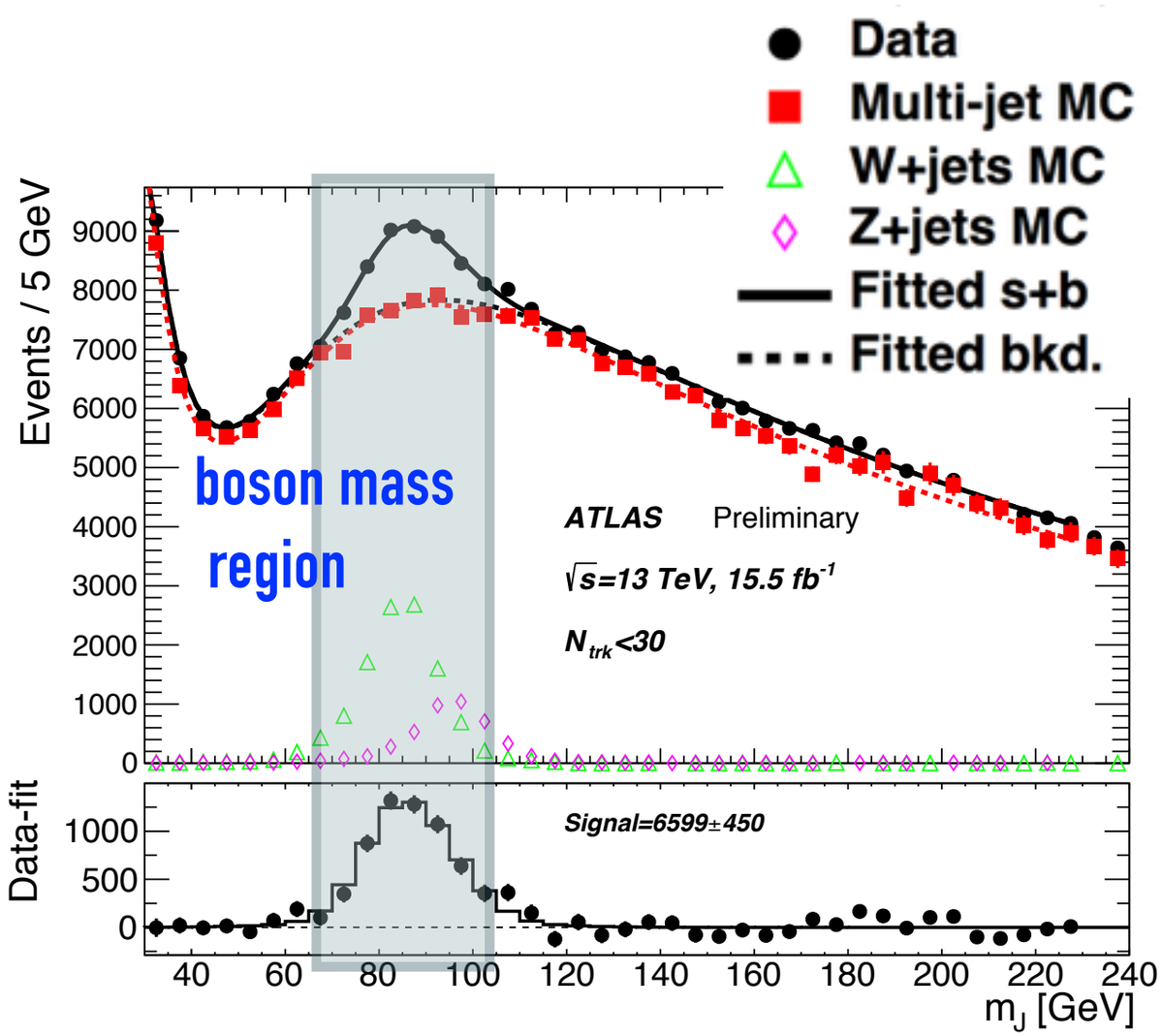
- jet mass cut (within W/Z mass window)
- jet substrcture cut to reject one-prong jet from single-quark or gluon background jet
  - $D_2^{(\beta=1)}$ used in ATLAS: a variation on the ratio of energy correlations. (arXiv:1409.6298, 1507.03018)
  - τ_{21} used in CMS: jet shape variable to measure consistency of jet to have N subjets. (arXiv:1011.2268)

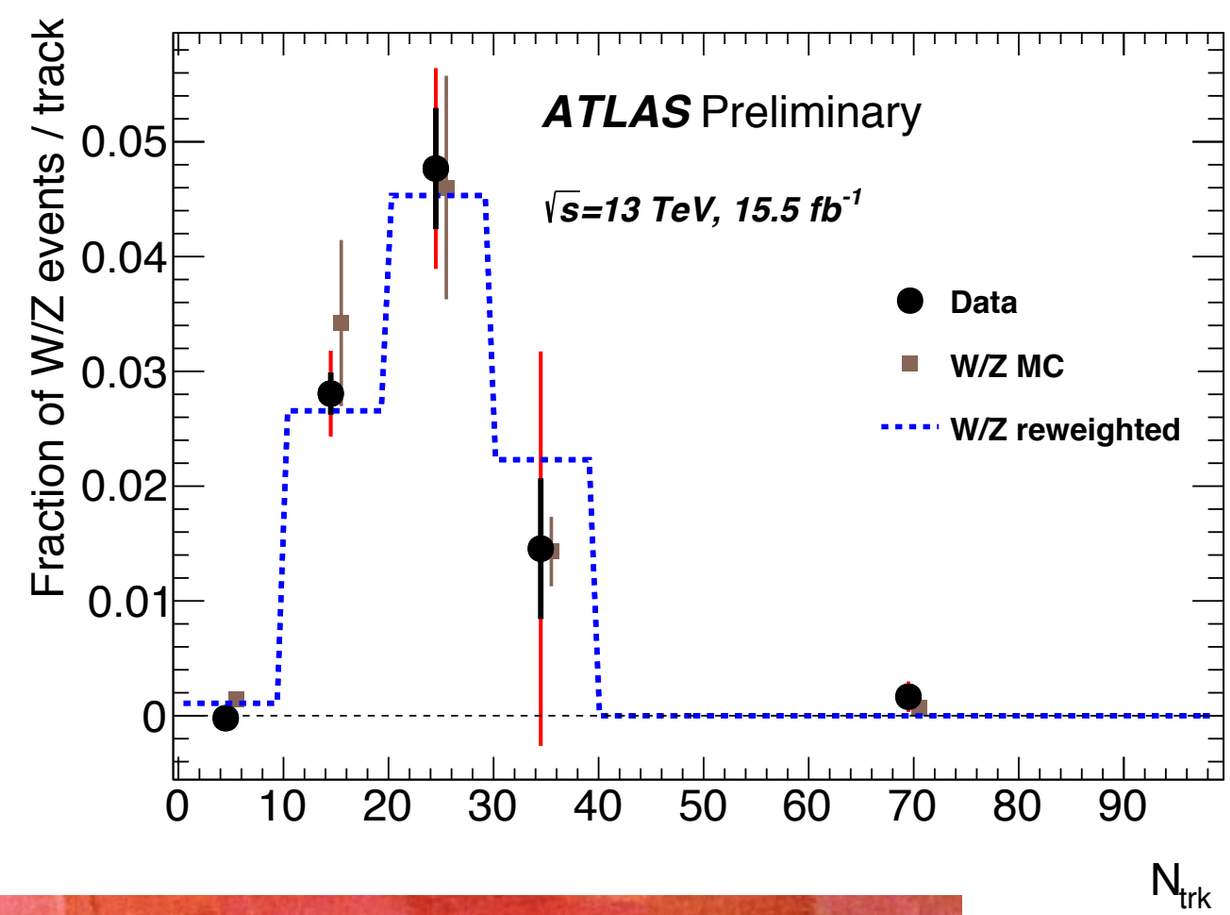


Cut on jet ghost tracks @ ATLAS (VV →qqqq)

- Discriminate boson jets from background jets by using $N_{trk}<30$
- N_{trk}: the number of charged-particle tracks pointing to the primary vertex with $p_T > 0.5$ GeV associated to the ungroomed jet through ghost-association

ATLAS-CONF-2016-055





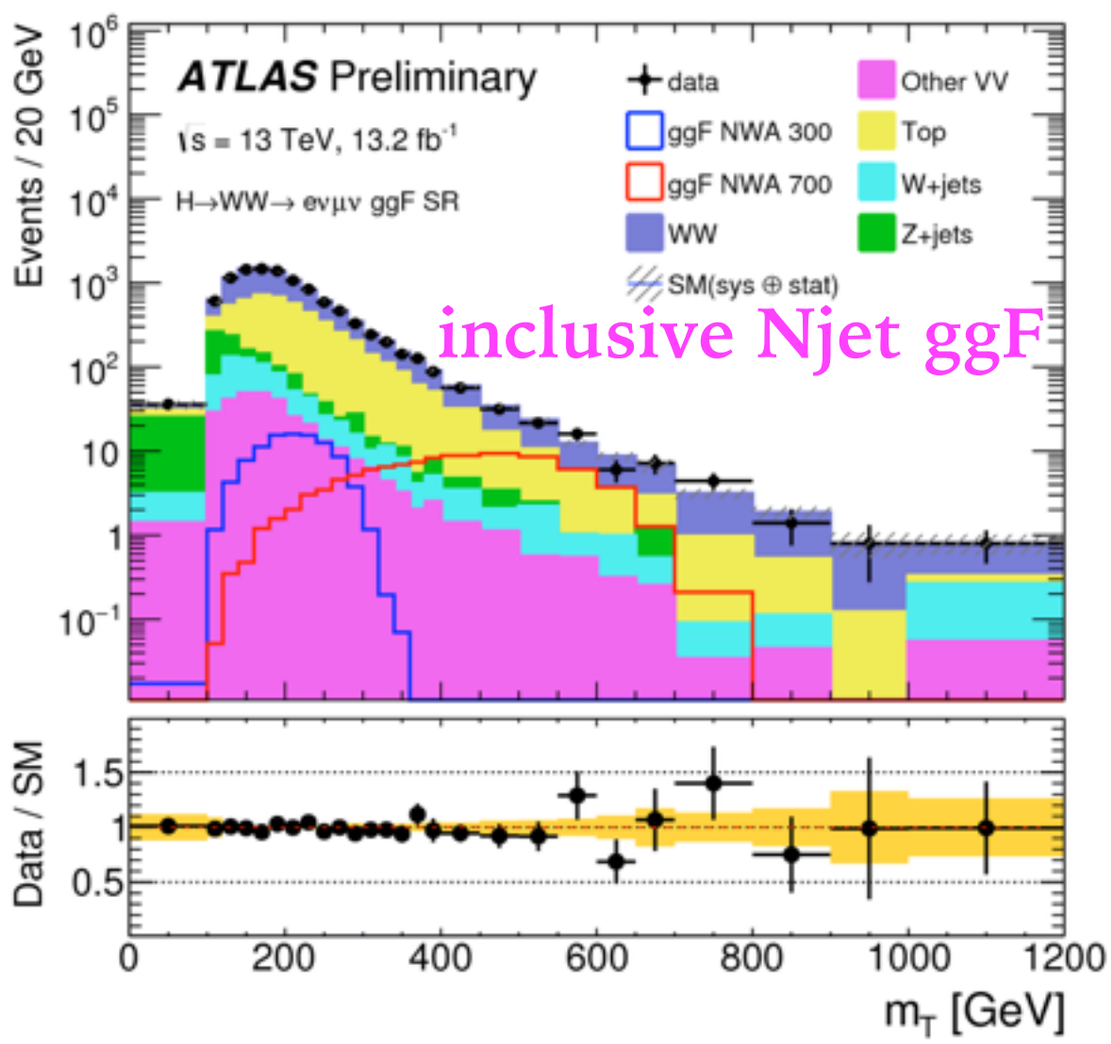
X → WW → lνlν

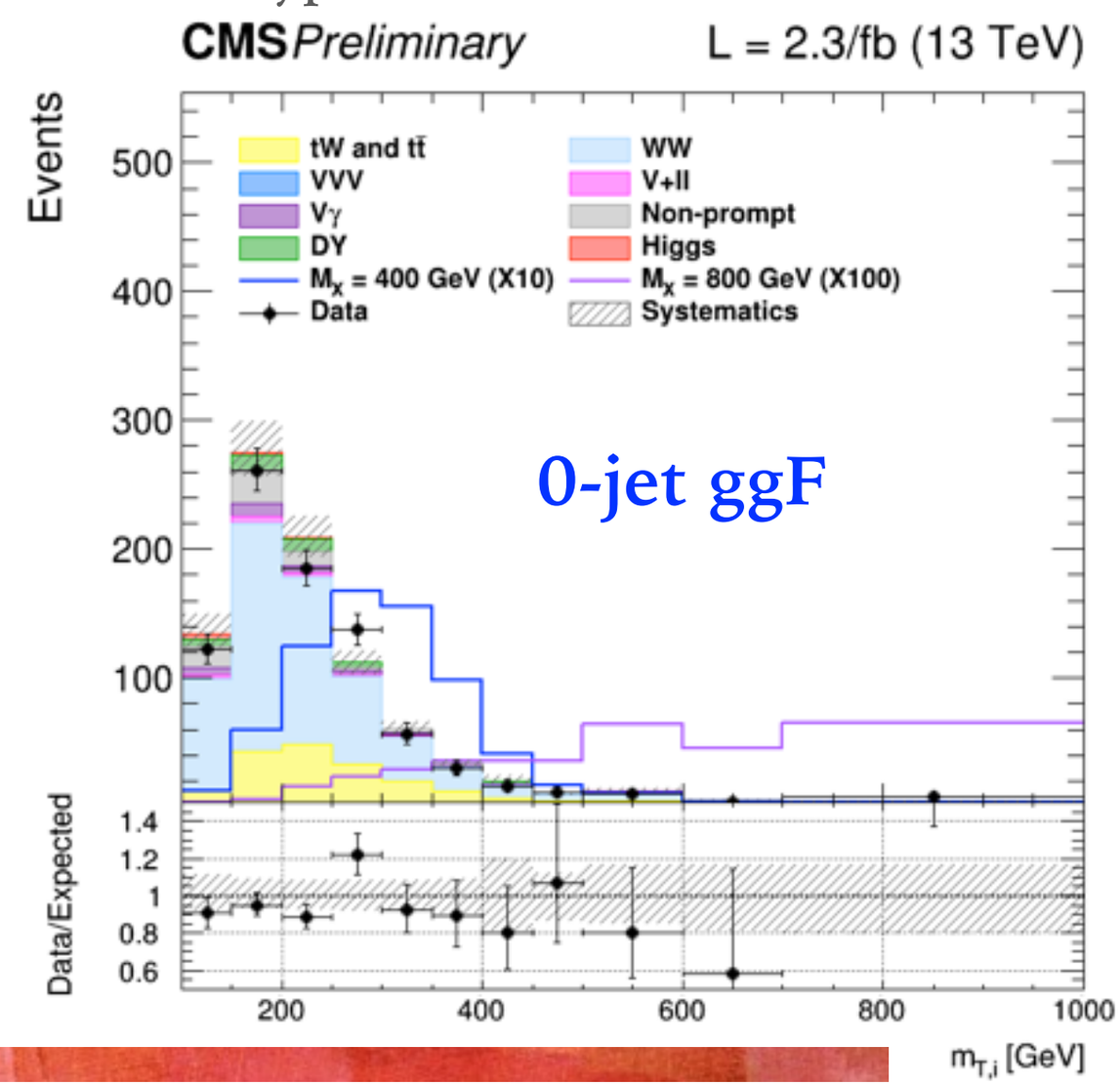
ATLAS-CONF-2016-074
CMS-PAS-HIG-16-023

- CMS: 2015 data only; ATLAS: 2015+2016 data
- search for heavy scalar mass in a range of $0.2 < M_X < 1$TeV
- categorized by ggF and VBF
- "improved" m_T computation: using real four-momentum

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{miss}|^2}$$

+ **better** discriminate among different signal mass hypotheses

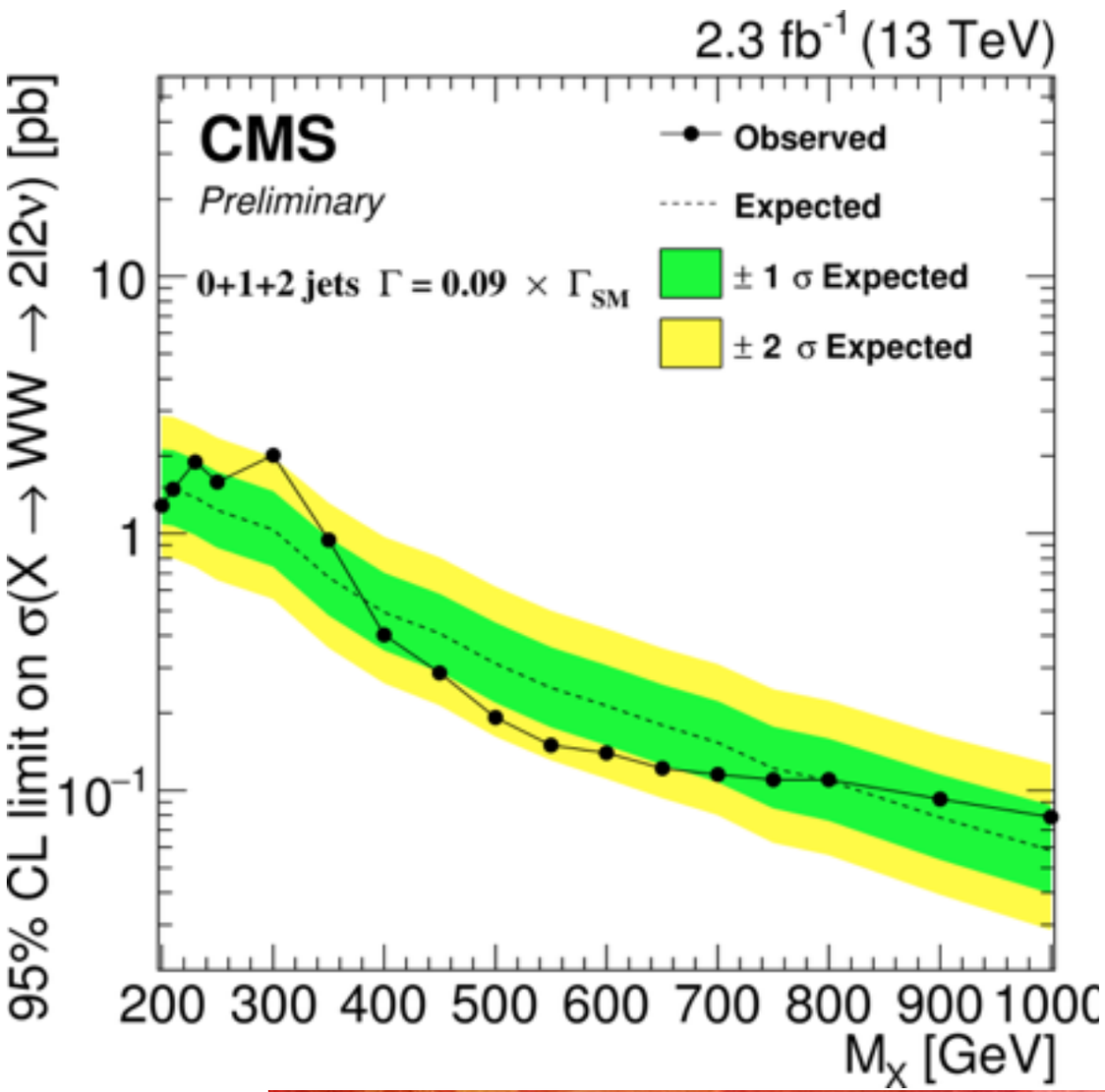


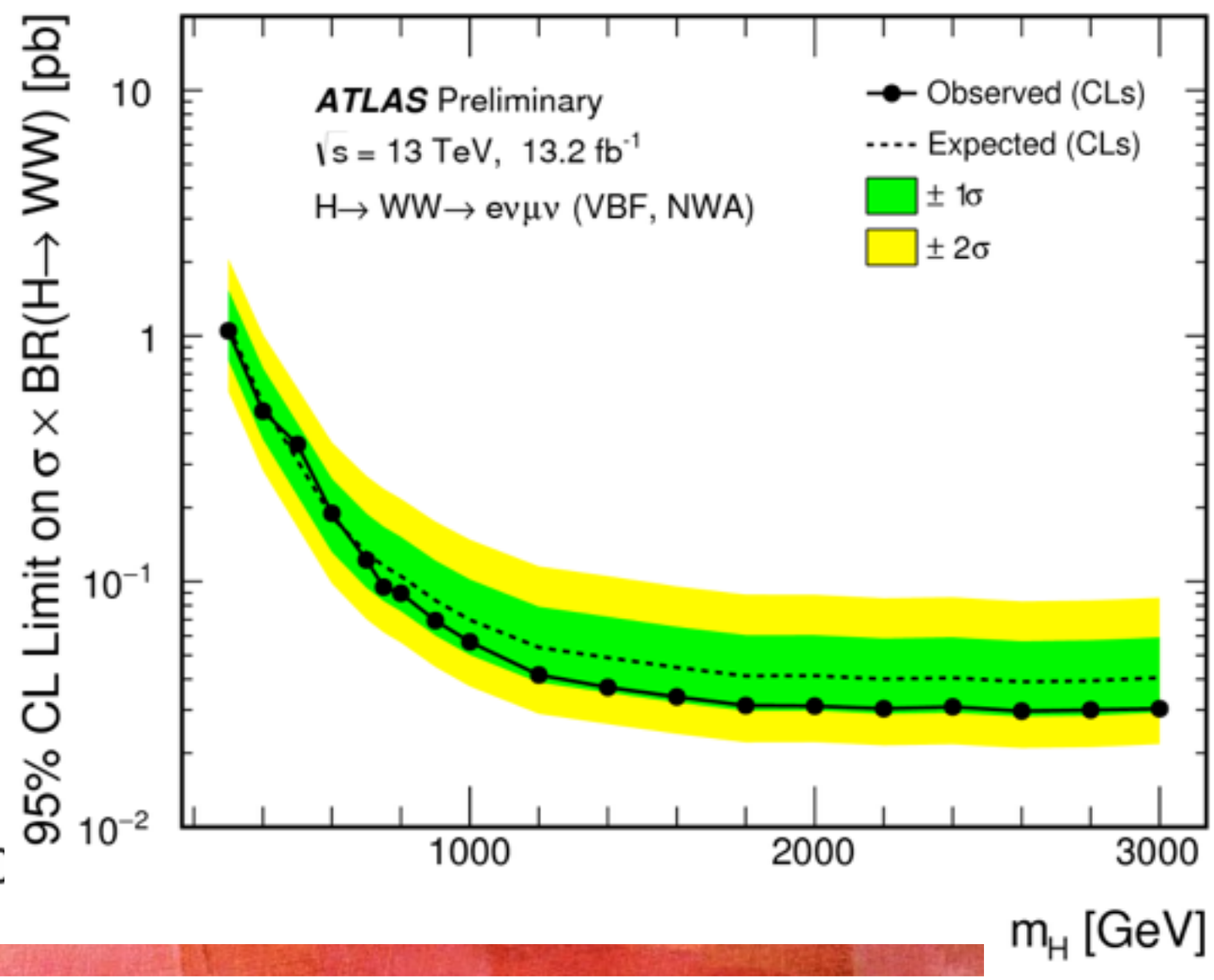


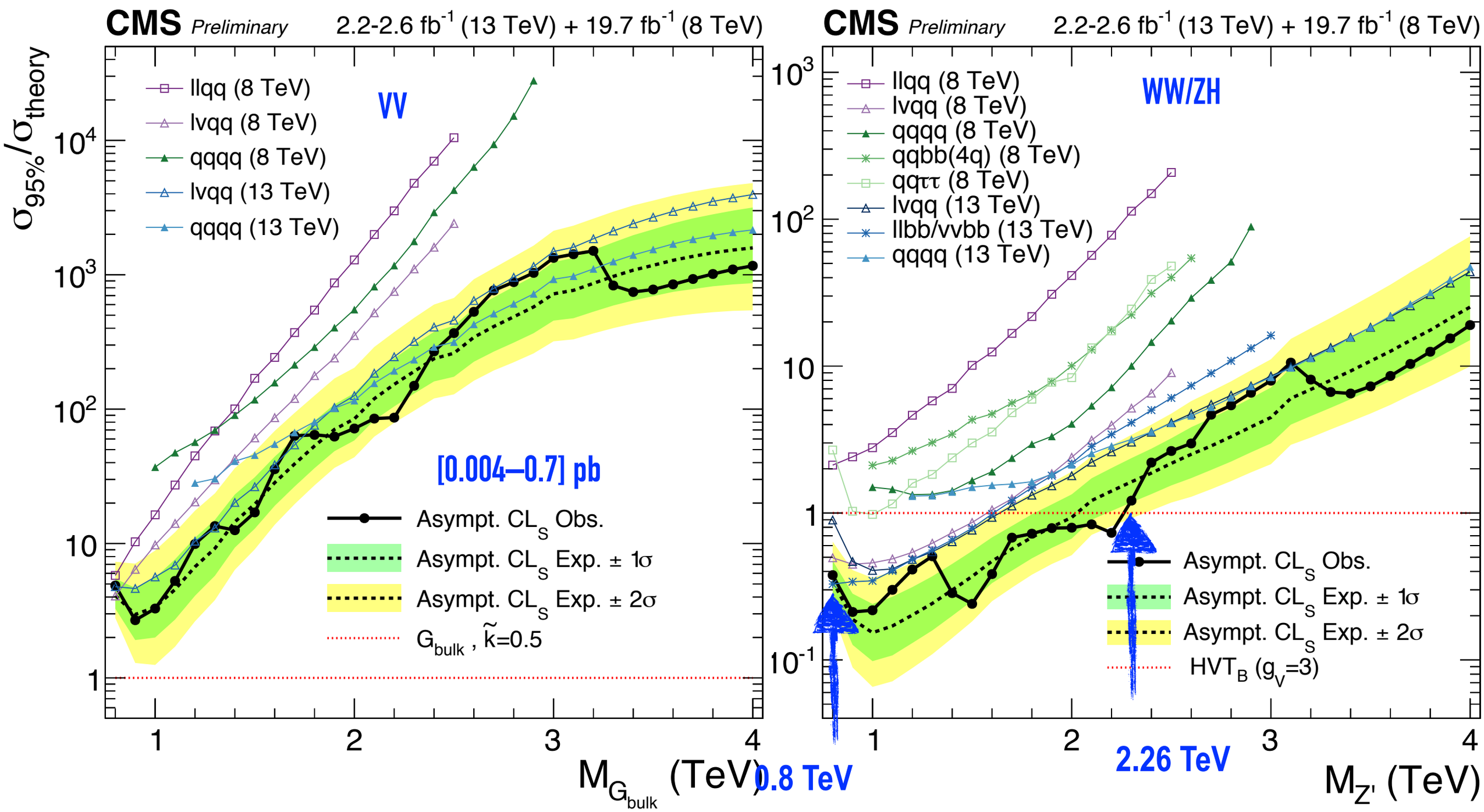
X → WW → lνlν

ATLAS-CONF-2016-074
CMS-PAS-HIG-16-023

- Exclusion limits set
  - CMS: on the sum of ggF and VBF cross sections times BR(WW) for difference widths with m_X from 200GeV to 1TeV;
  - ATLAS: on the ggF or VBF cross section times BR(WW) for different widths with m_H from 300GeV (4.3pb) to 3TeV (0.051pb)





8+13 TeV (2015) Grand Combination

CMS-PAS-B2G-16-007