ATLAS Searches for VV/Zγ Resonances

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On behalf of ATLAS collaboration

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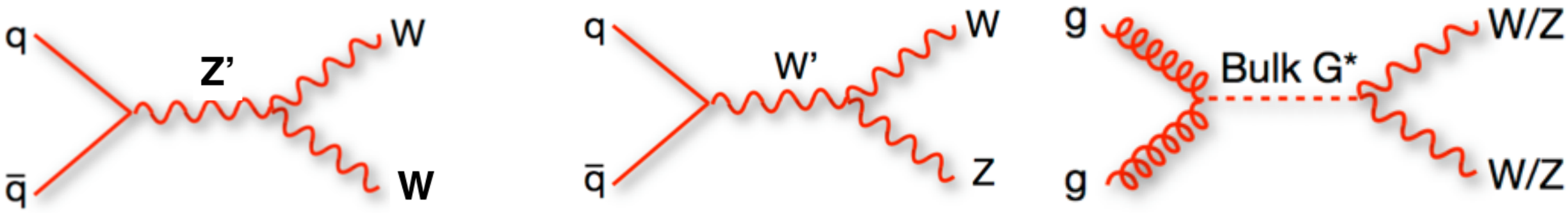
Introduction

- Many BSM theories predict heavy resonances decaying to heavy quarks or bosons
  - Spin-0
    - 2HDM, additional scalar singlets
  - Spin-1
    - Heavy Vector Triplets, Composite Higgs
  - Spin-2
    - Randall-Sundrum (RS) graviton mode



- Di-boson resonance searches highly motivated !

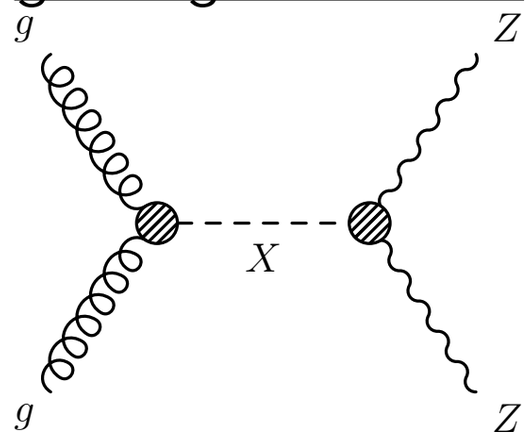
✓ This talk covers VV and Vγ (V = W/Z) decay modes

<u>NEW results in LHC-ATLAS Run2 with 36.1 fb^{-1}</u>

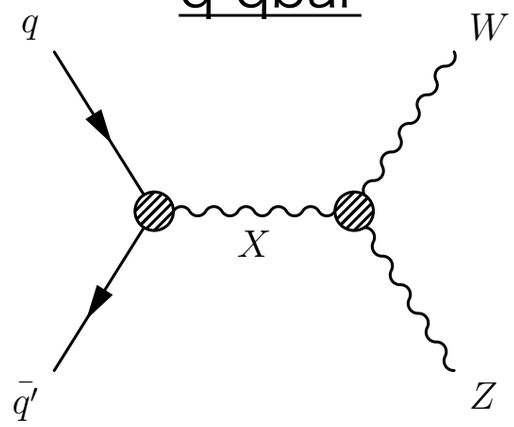
High mass object searches with VV

- Production
  - Gluon-gluon fusion (ggF)
  - Quark-antiquark interaction (qqbar)
  - Vector-boson fusion (VBF)
    - 2 forward jets tagged

gluon-gluon fusion



q-qbar



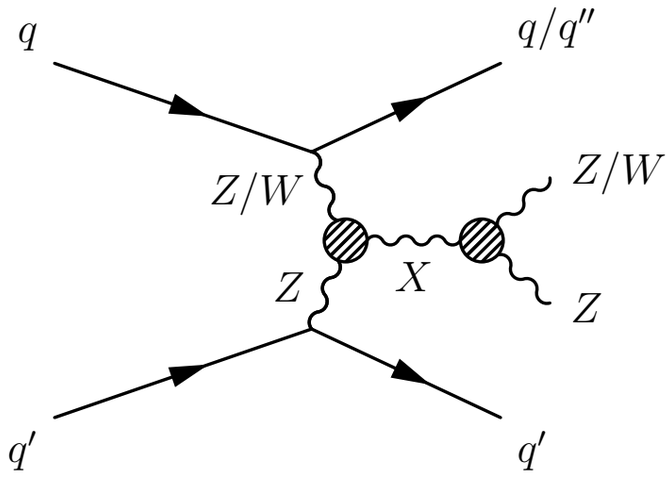
- Decay channels of vector boson

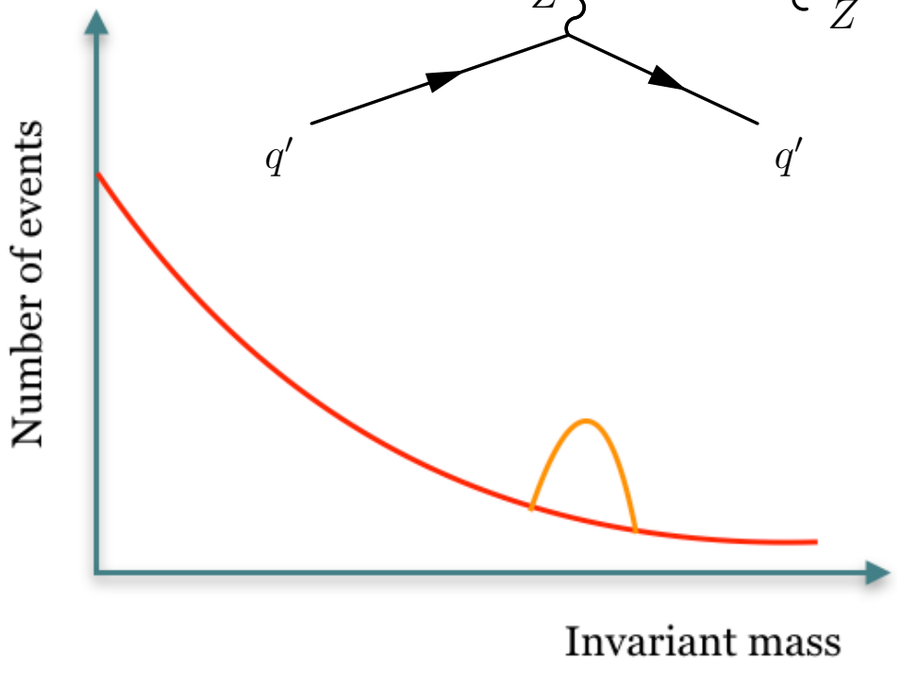
	W	Z
$\ell\,\nu$ / $\ell\,\ell$ (ℓ =e, μ)	10.7 % x2	3.3% x2
$\tau\,\nu$ / $\tau\,\tau$	11.4%	3.3%
$\nu\,\nu$	-	20.0%
qq(')	67.4%	69.9%

  - Leptonic decays
    - Small branching fractions
    - Clean final states
  - Hadronic decays
    - Large branching fractions
    - More backgrounds from QCD events
      - **Boson tagging with large-R jets**

- Methodology
  - To search for excesses above backgrounds in the VV invariant mass distribution

vector-boson fusion

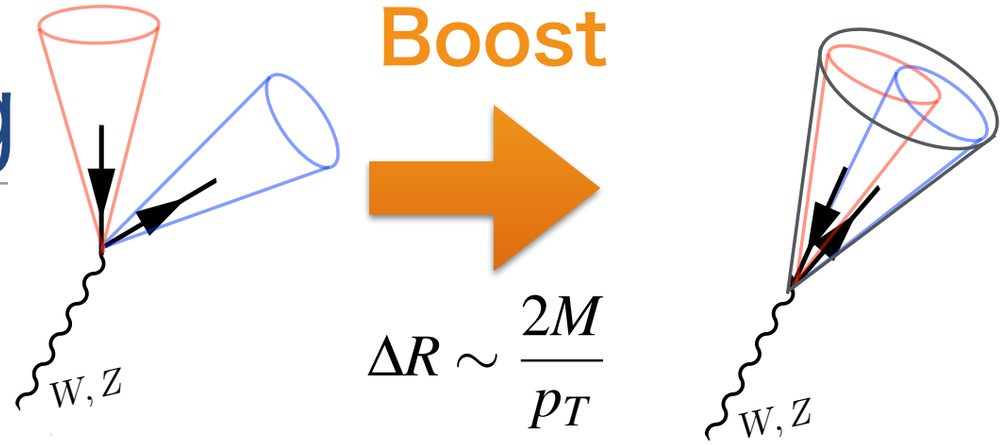


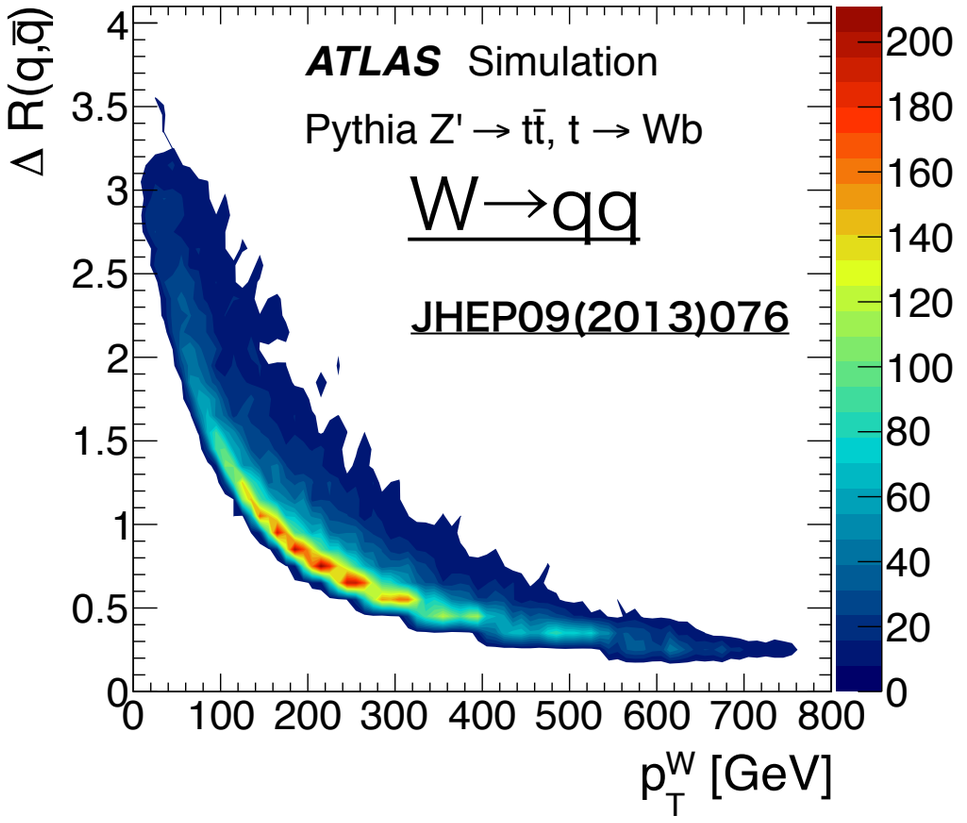


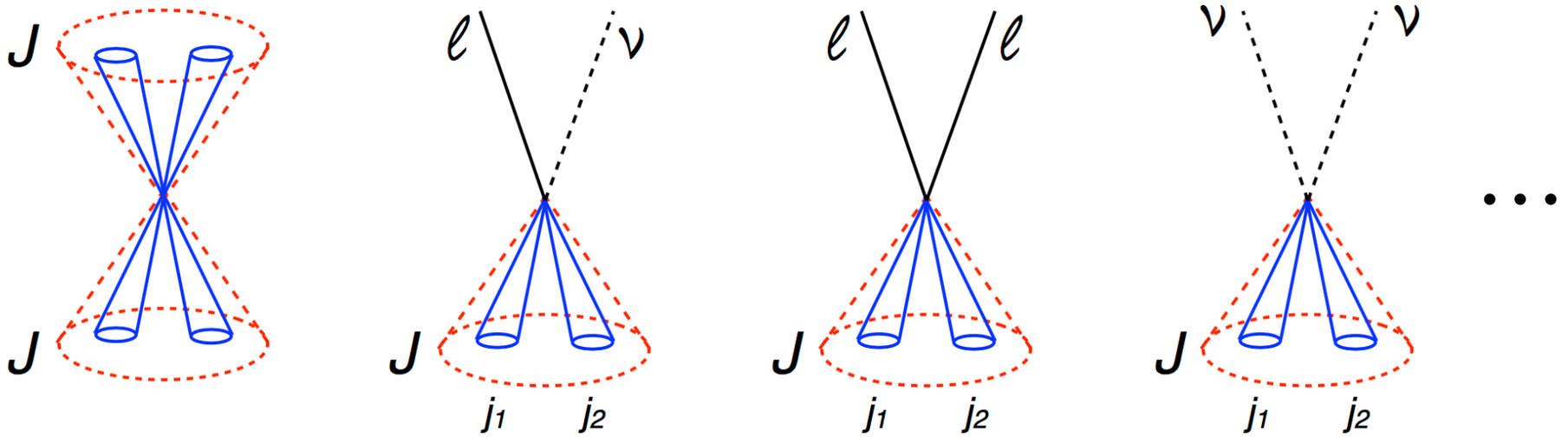
Boosted vector boson tagging

- Event categories
  - Resolved
    - Small-R jet (R=0.4) : j
  - Merged (boosted)
    - Large-R jet (R=1.0) : **J**
      - New techniques developed for boosted-V ID
        - ✓ Combinations with jet mass and jet-substructure variables

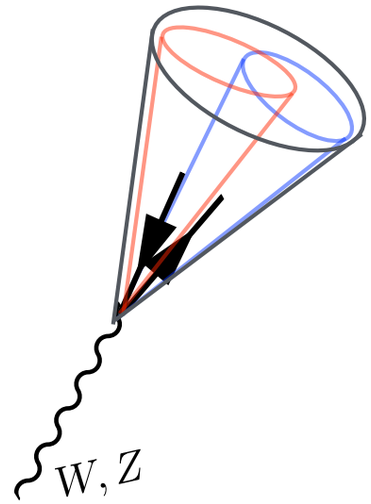
- Decay channels
  - **All hadronic**
  - **Semi-leptonic**
    - 0/1/2 leptons
  - All leptonic
    - $ZZ \to 4\ell$, $2\ell 2\nu$, $WW \to \ell\nu\ell\nu$



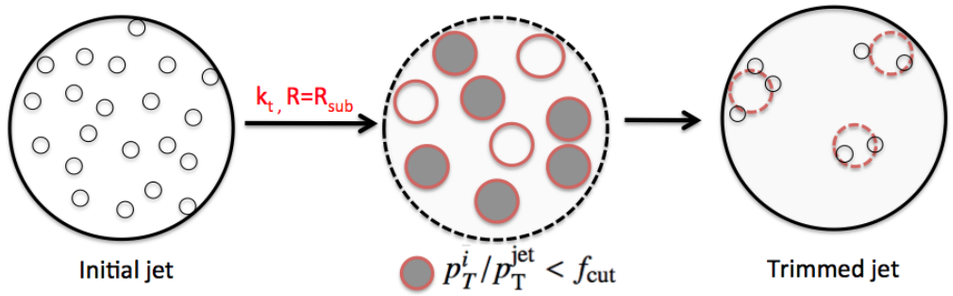


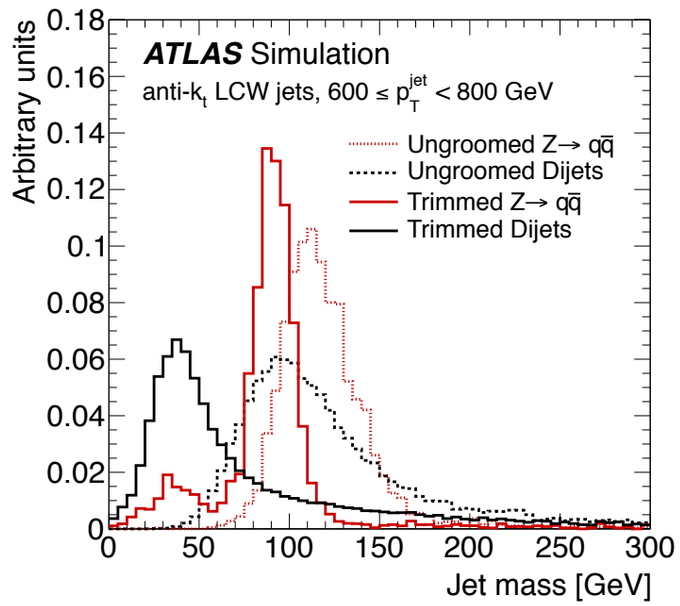


Boosted vector boson tagging

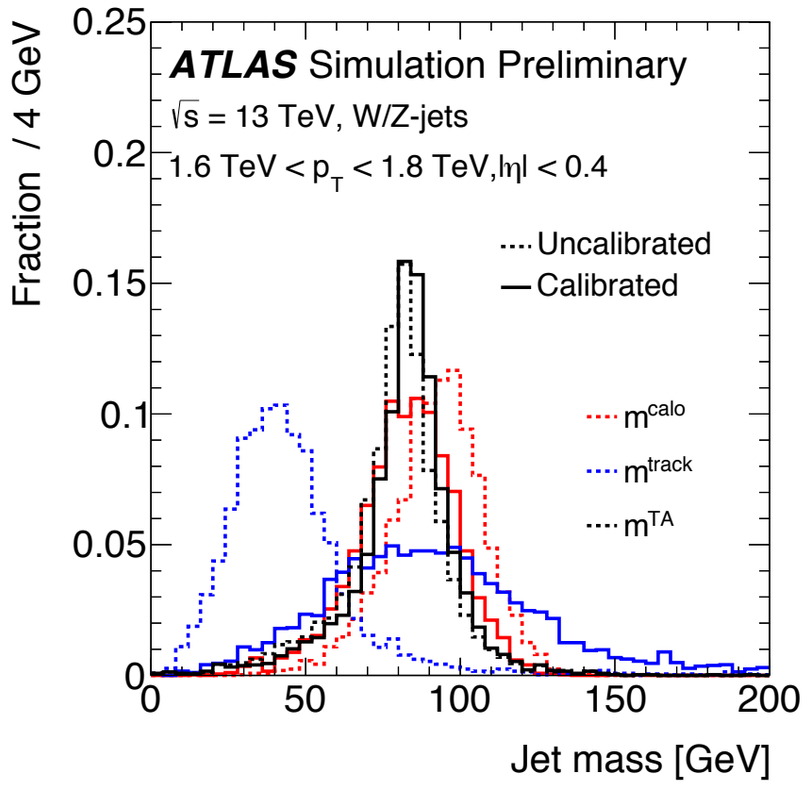


- Trimming of large-R jet
  - Remove constituents with pT(const)/p_T(jet)< 5%





- Track-assisted jet-mass
  - $m^{\text{TA}} = m^{\text{track}} \times \frac{p_T^{\text{calof}}}{p_T^{\text{track}}}$



- Substructure variable
  - "D2"
    - for 2-pronginess

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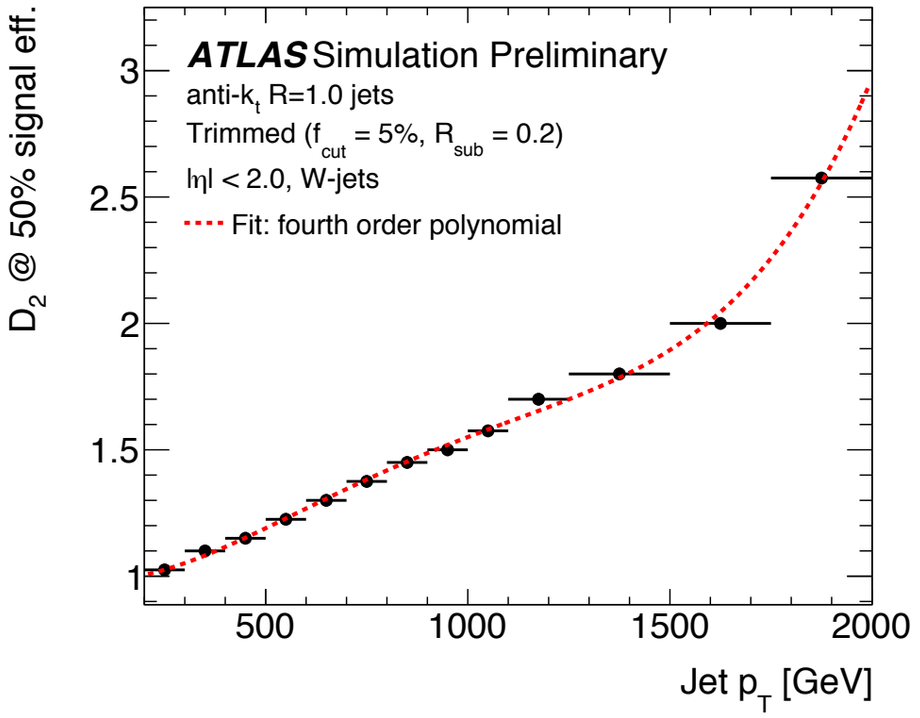


WW/WZ → ℓ ν qq searches

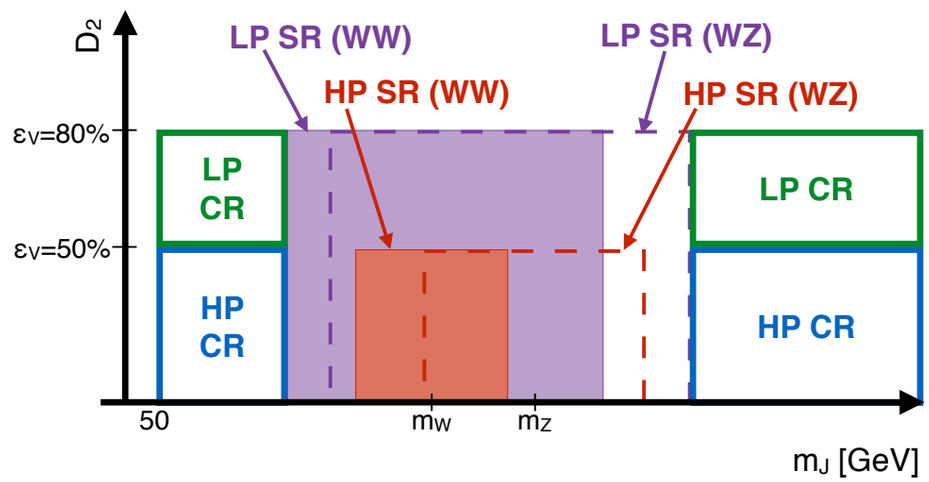
arXiv:1710.07235

- Hadronic decaying boson
  - Merged (J)
    - V → large-R jet
  - Resolved (jj)
    - added to extend sensitivity to the low mass regions

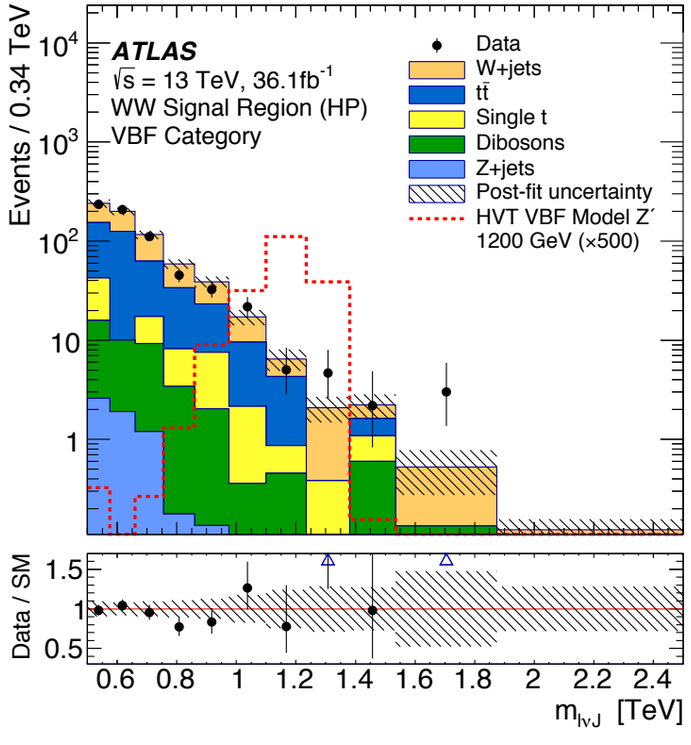
- Sub-categories in the merged
  - High/Low purity (HP/LP) regions
    - 50/80 % working point with D2
  - Large-R jet mass

- Backgrounds
  - W+jets (main), ttbar, SM diboson, Z+jets, QCD (resolved)

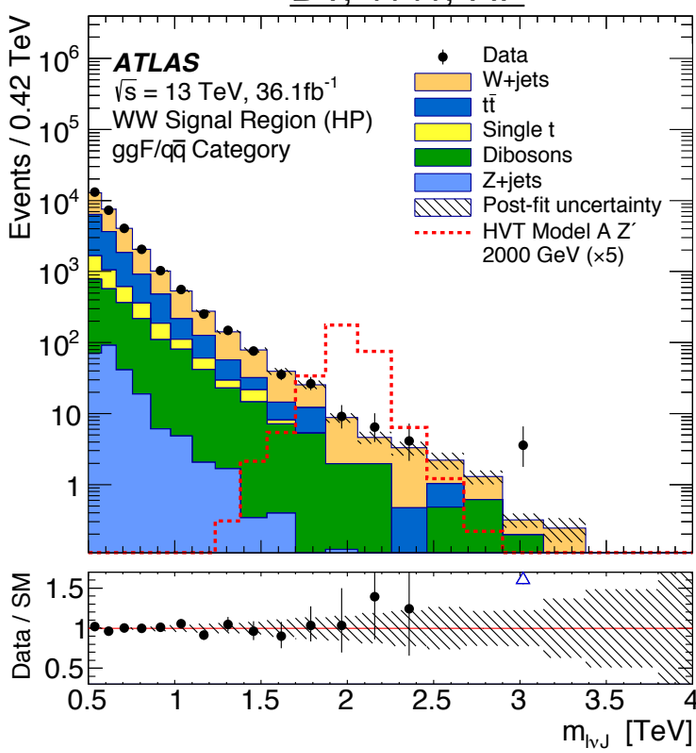
- Systematic uncertainties
  - Jet energy/mass scale
  - jet-substructure



VBF, WW, HP



DY, WW, HP

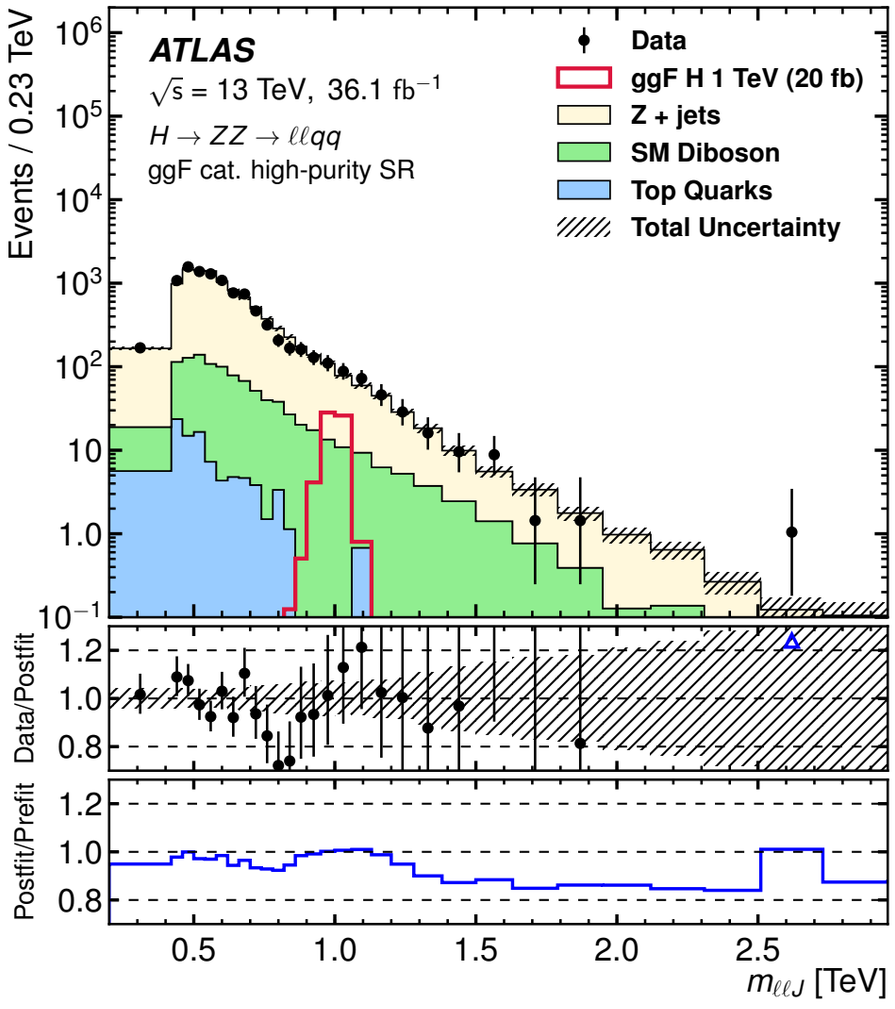


ZZ/ZW → $\ell\ell$qq / $\nu\nu$qq searches

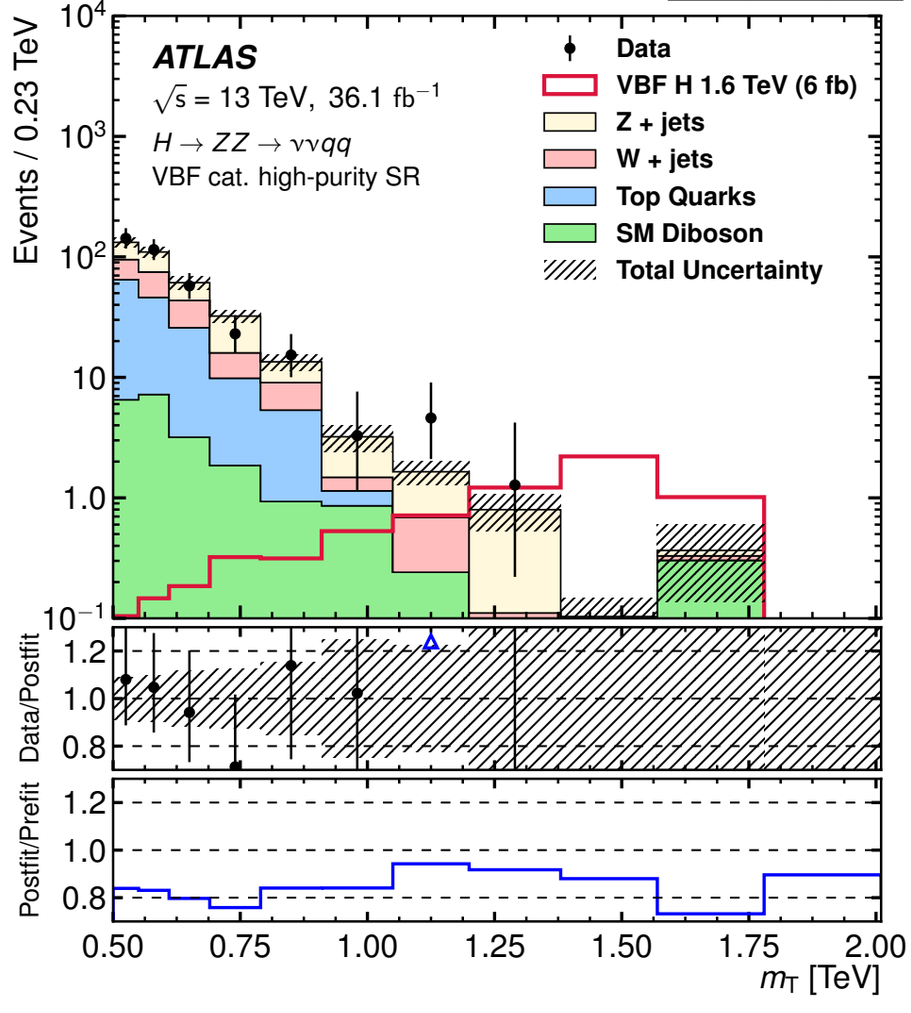
arXiv:1708.09638

- Models
  - Spin-0/1/2 interpretations tested
- Production
  - VBF: requiring additional 2 small-R jet with respect to ggF
- Event categories
  - Resolved : V → 2 small-R jets (used only for $\ell\ell$qq)
  - Merged : V → 1 large-R jet
- Backgrounds
  - Z+jets, W+jets, ttbar, SM VV
- Systematic uncertainties
  - Jet energy scale, jet mass scale, jet-substructure,
  - $\ell\ell$qq : Z+jets modeling, $\nu\nu$qq : W+jets modeling

ggF, ZZ, HP



VBF, ZZ, HP

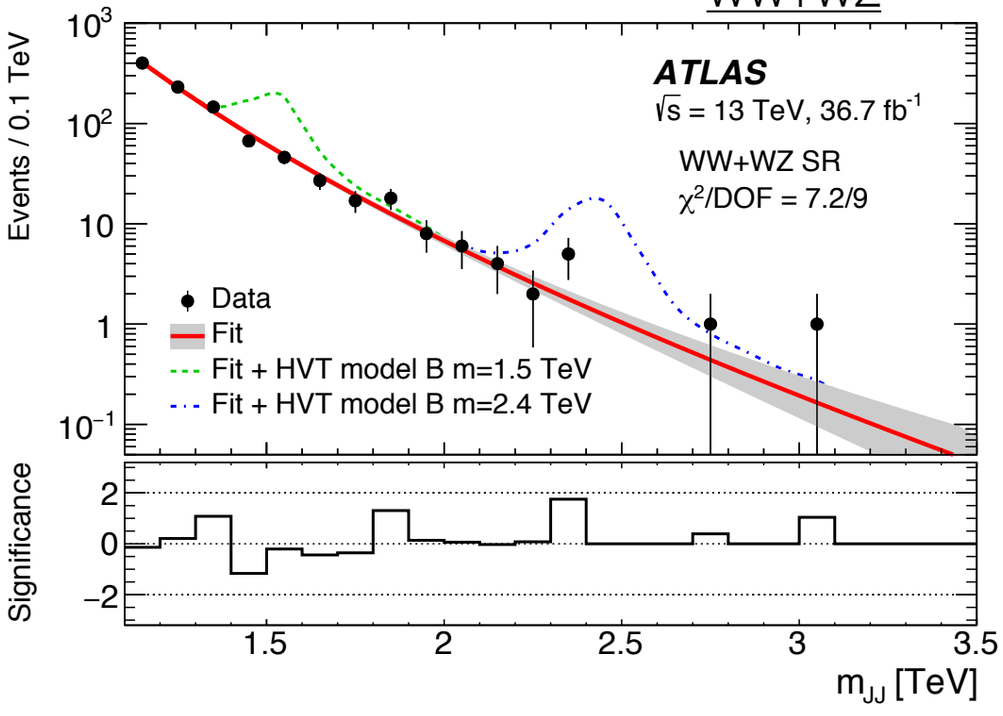


VV → qqqq search

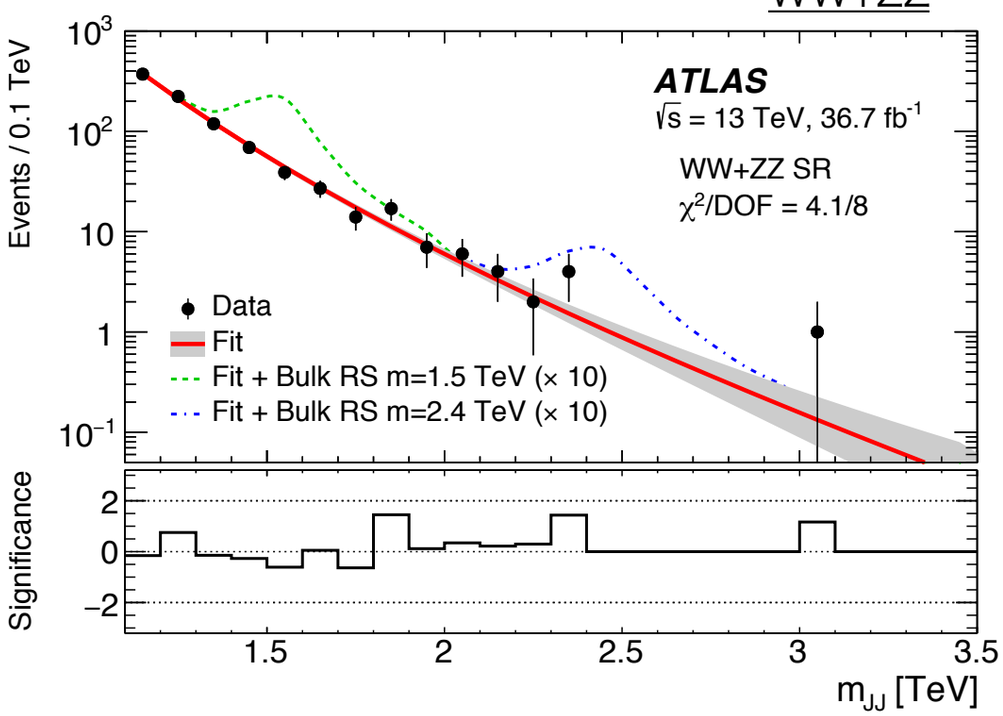
arXiv:1708.04445

- Event selection
  - 2 large-R jets
  - Missing E_T < 250 GeV
- Background estimation
  - Multi-jet QCD events dominate
    - ✓ High purity signal regions only
  - Modeling
    - $\frac{d\eta}{dx} = p_1(1-x)^{(p_2-\xi p_3)}x^{-p_3}$
    - x = $m_{JJ}/\sqrt{s}$
    - p_1: normalization, p_2 - p_3: shape parameters
    - ξ: to remove the correlation between p_2 and p_3 in the fitting

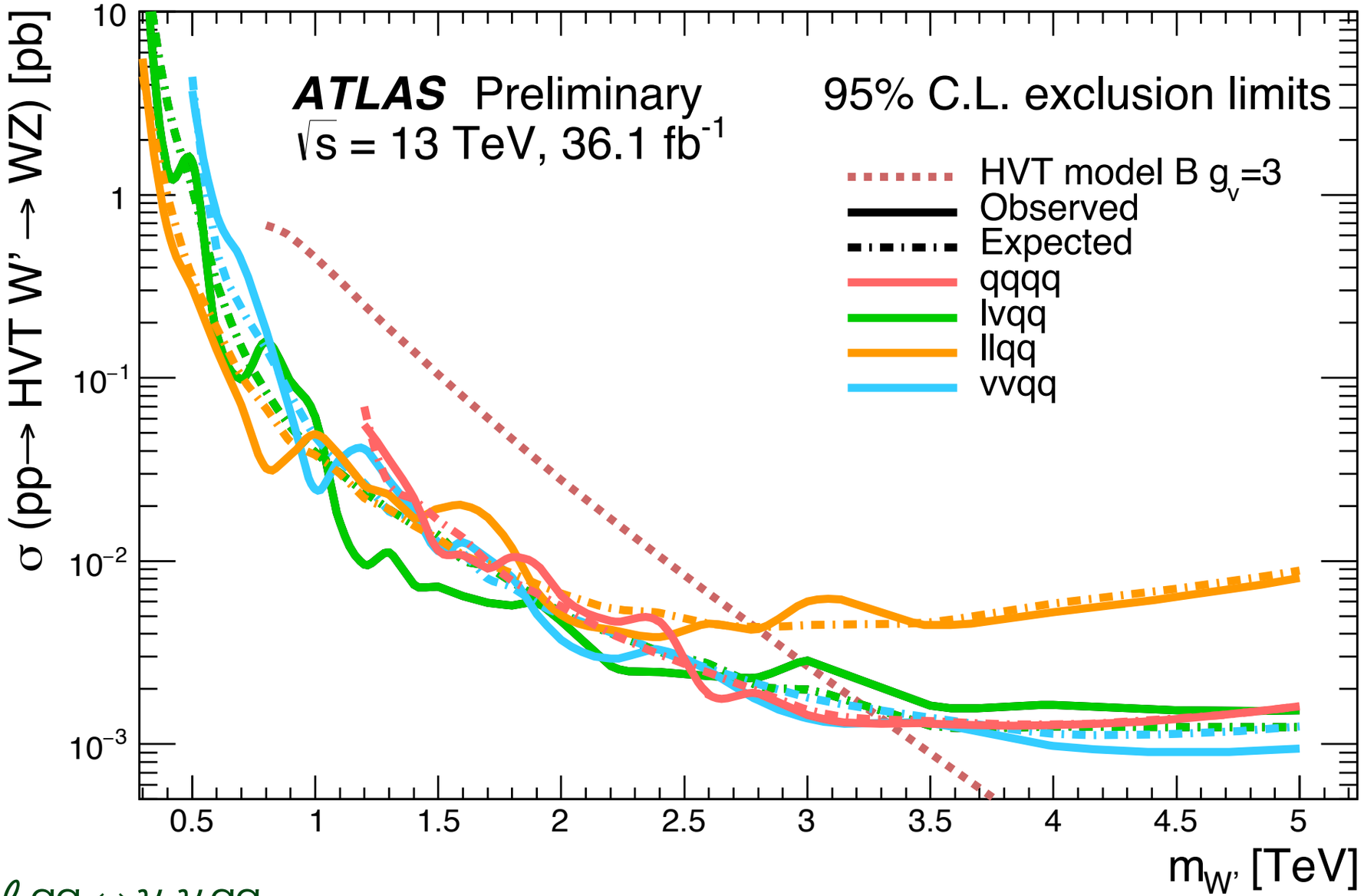
WW+WZ



WW+ZZ



Summary : Hadronic W'→WZ searches



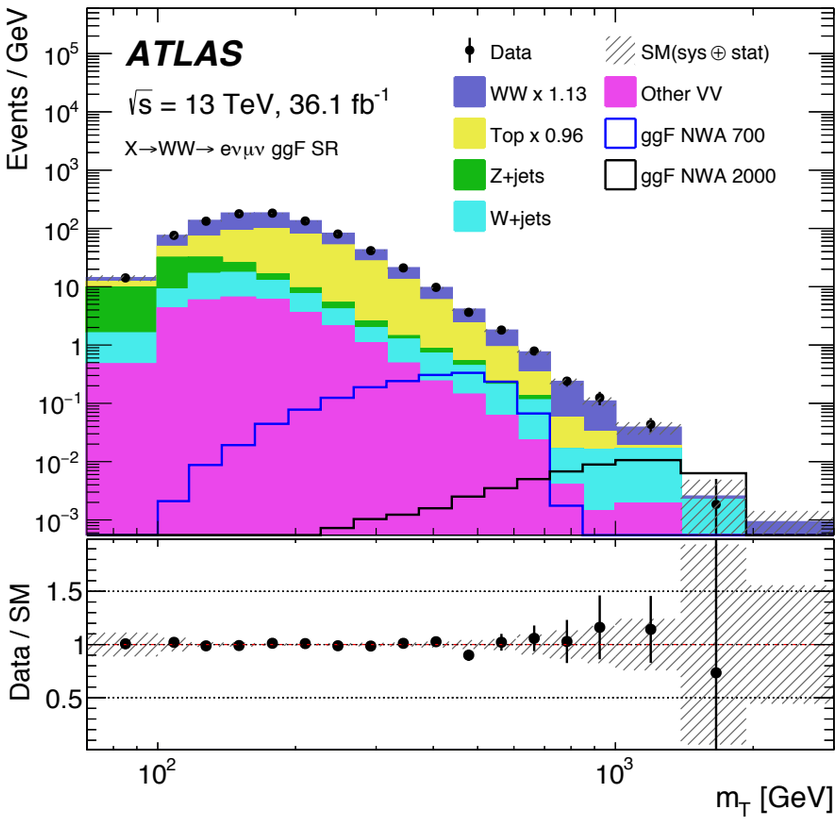
- $\ell\ \ell$ qq ↔ $\nu\ \nu$ qq
  - low mass region
    - Good / bad mass resolution
  - high mass region
    - Statistically limited / high statistics
- l ν qq
  - Good sensitivity in wide mass region
- qqqq
  - Low mass region
    - QCD background
  - High mass region
    - JES uncertainty

WW → eνμν search

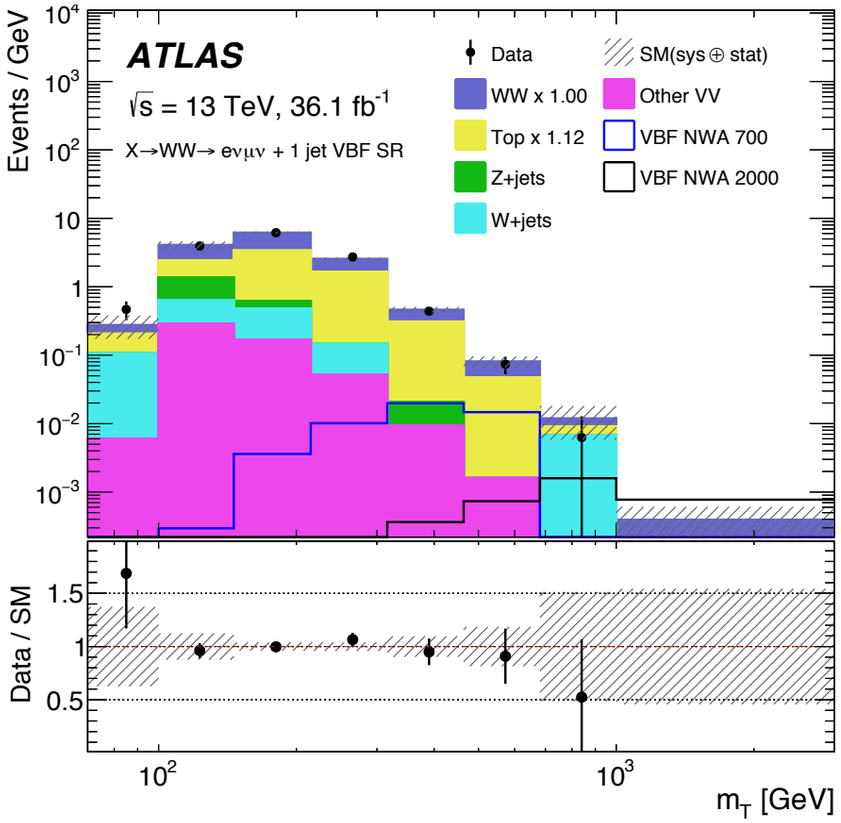
arXiv:1710.01123

- Event selections
  - single lepton triggers
  - leptons
    - tight identification, isolation
    - opposite sign electron and muon pair
  - Number of jets
    - ggF: 0 jets
    - VBF: 1 or 2 jets
- Backgrounds
  - SM WW (main for ggF), ttbar (main for VBF)

ggF



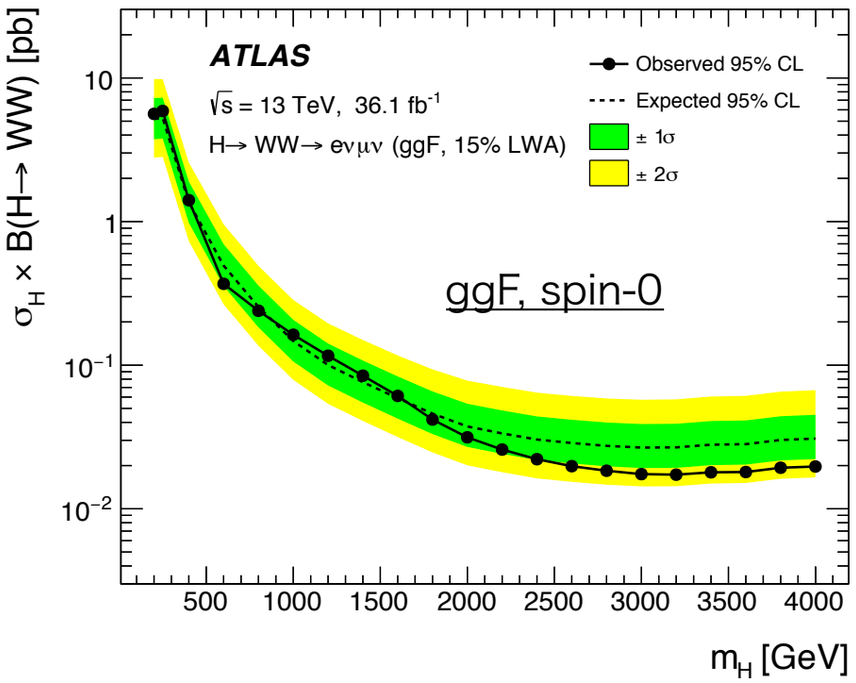
VBF

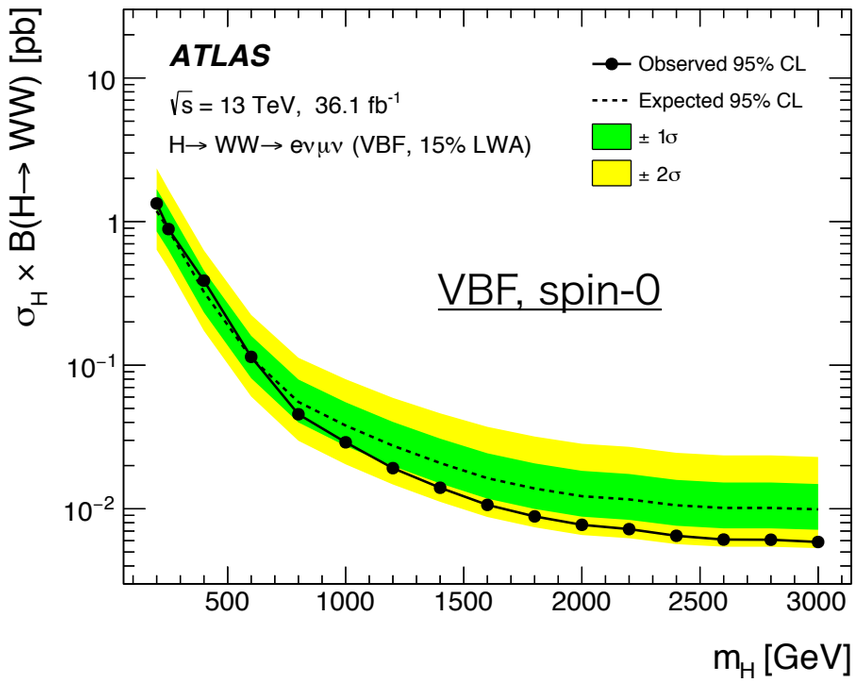


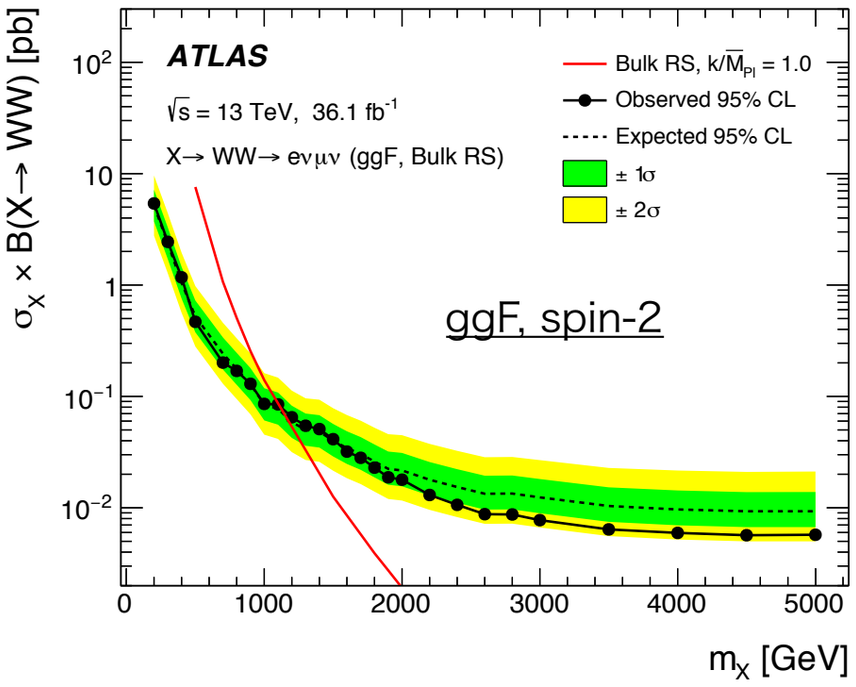
WW → eνμν search

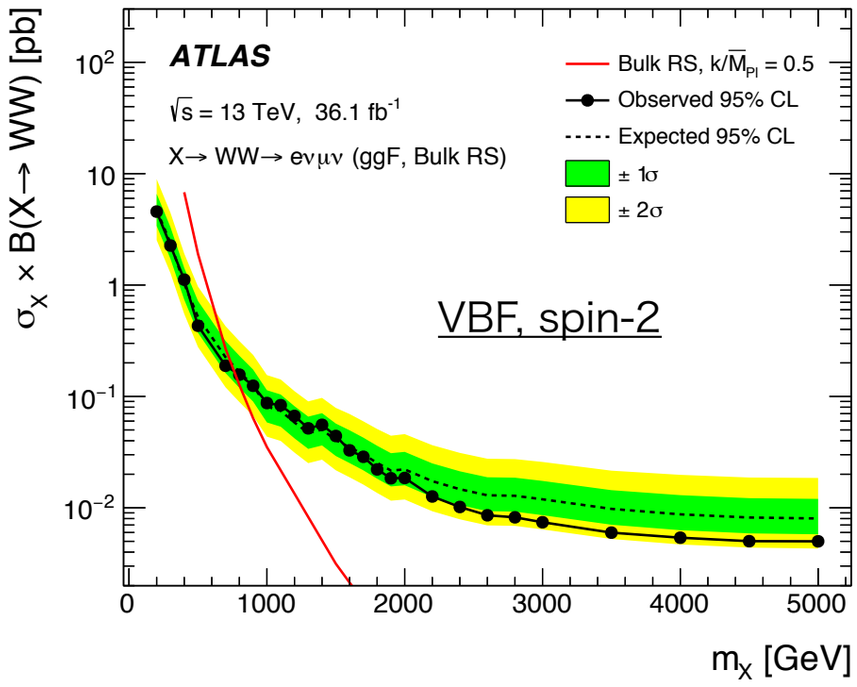
arXiv:1710.01123

- Result
  - No excess in spin-0/2 analyses









$ZZ \to 4\ell / \ell\ell\nu\nu$ searches

- $ZZ \to 4\ell$
  - Signal selections
    - single lepton triggers
    - leptons
      - tight identification, isolation
      - opposite sign leptons for 4ℓ , 2e2μ
    - Z-mass window
  - Backgrounds
    - SM ZZ(main), ttbar+V, VVV, Z+jets

- $ZZ \to \ell\ell\nu\nu$
  - Signal selections
    - single lepton triggers
    - leptons
      - tight identification, isolation
      - N=2, opposite sign,
    - Z-mass window
    - Missing E_T > 120 GeV
  - Backgrounds
    - SM ZZ(main), WZ, Z+jets

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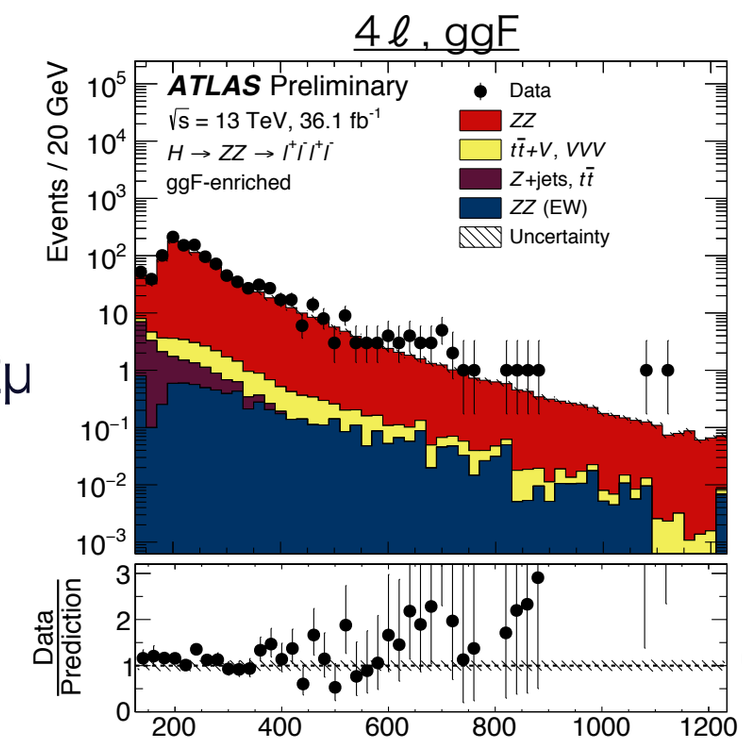
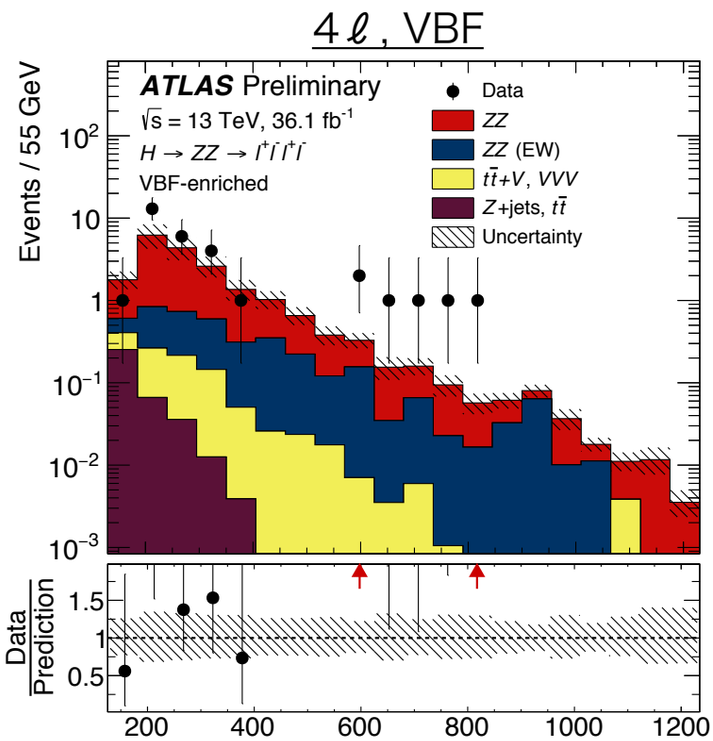
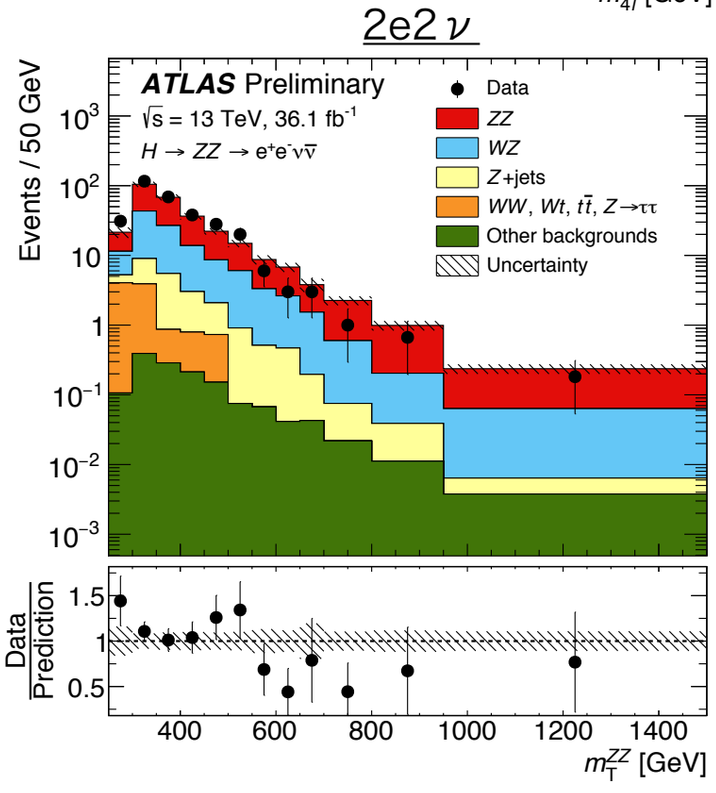
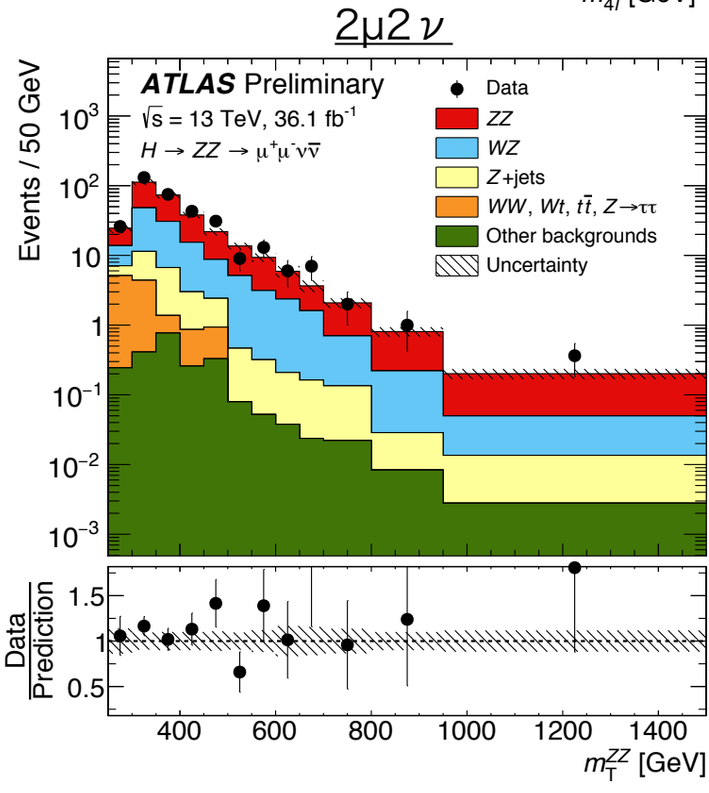


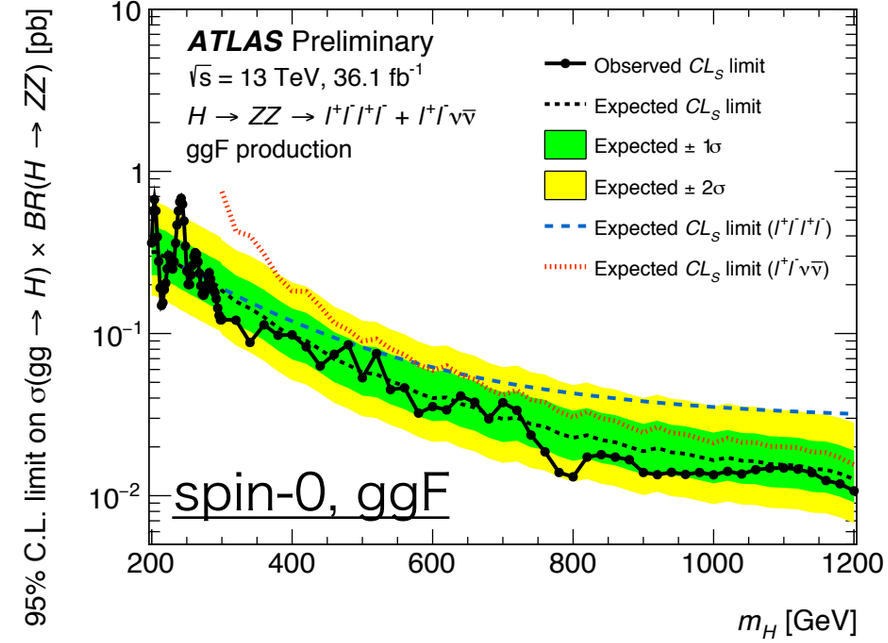


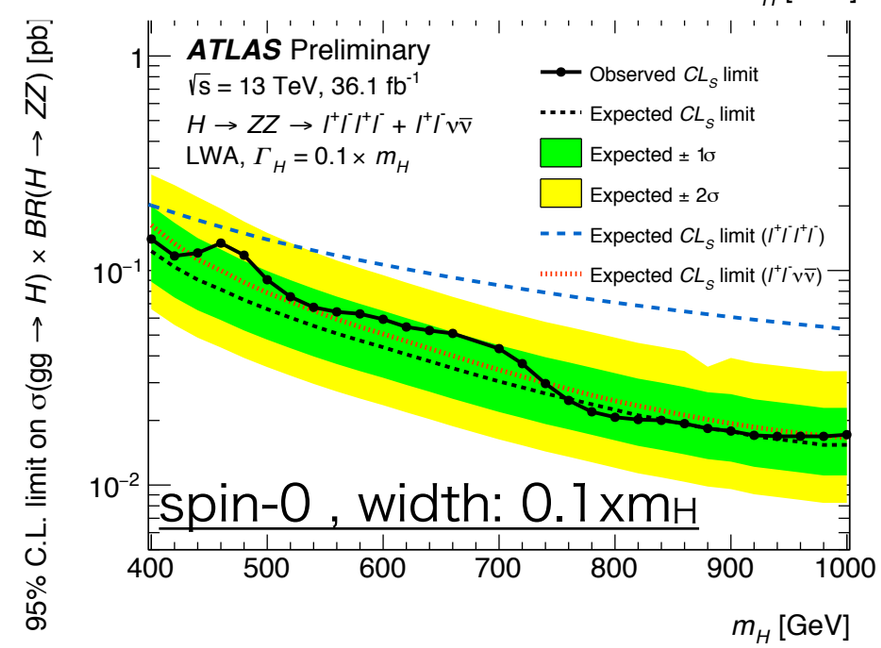


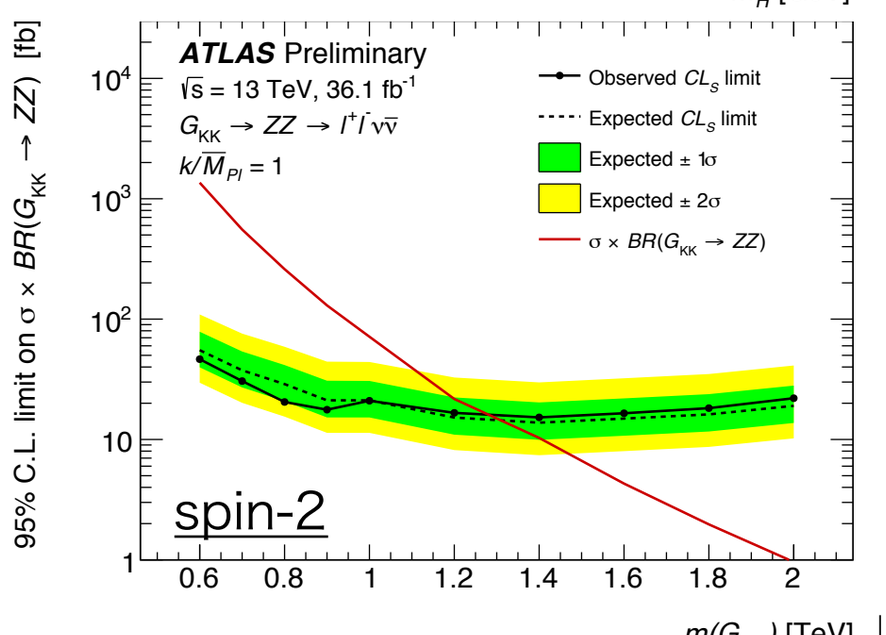


$ZZ \to 4\ell / \ell\ell\nu\nu$ searches

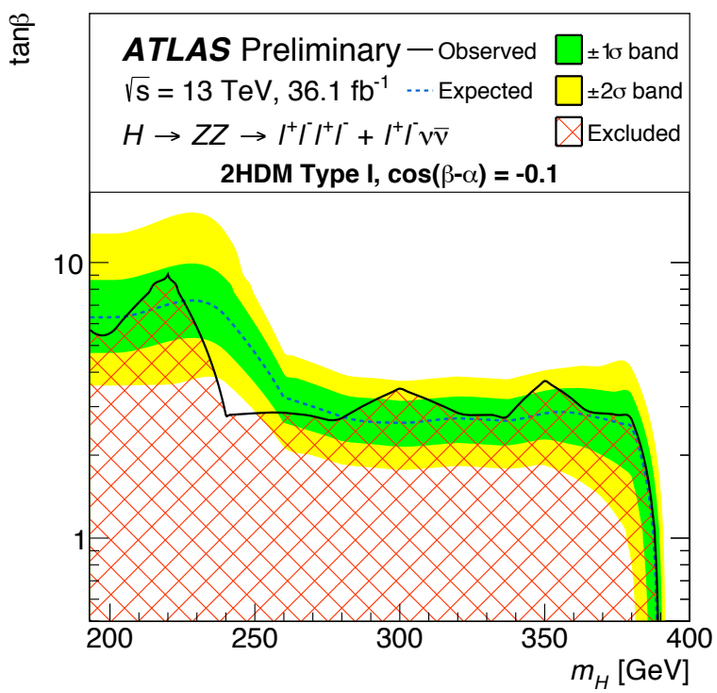
- Results
  - No significant excess observed
  - Limits set for 2HDM Type I / II



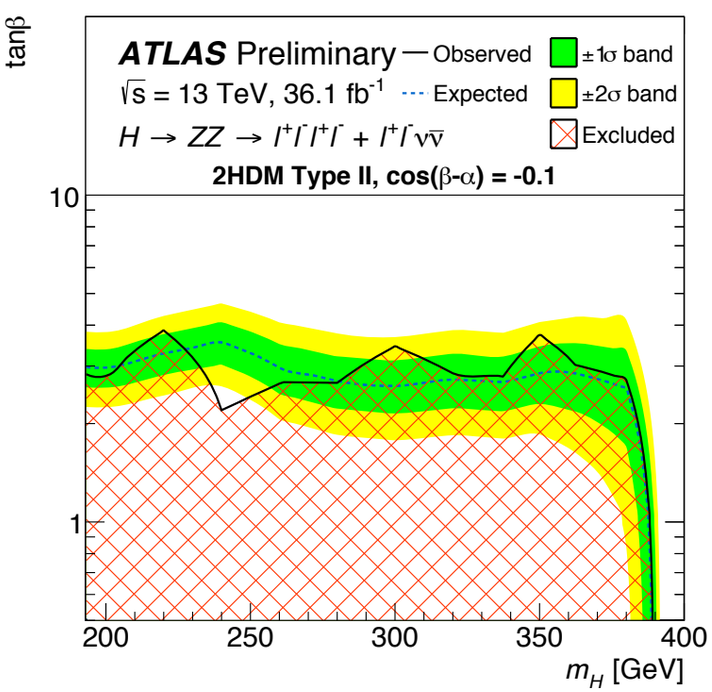




2HDM Type-I



2HDM Type-II



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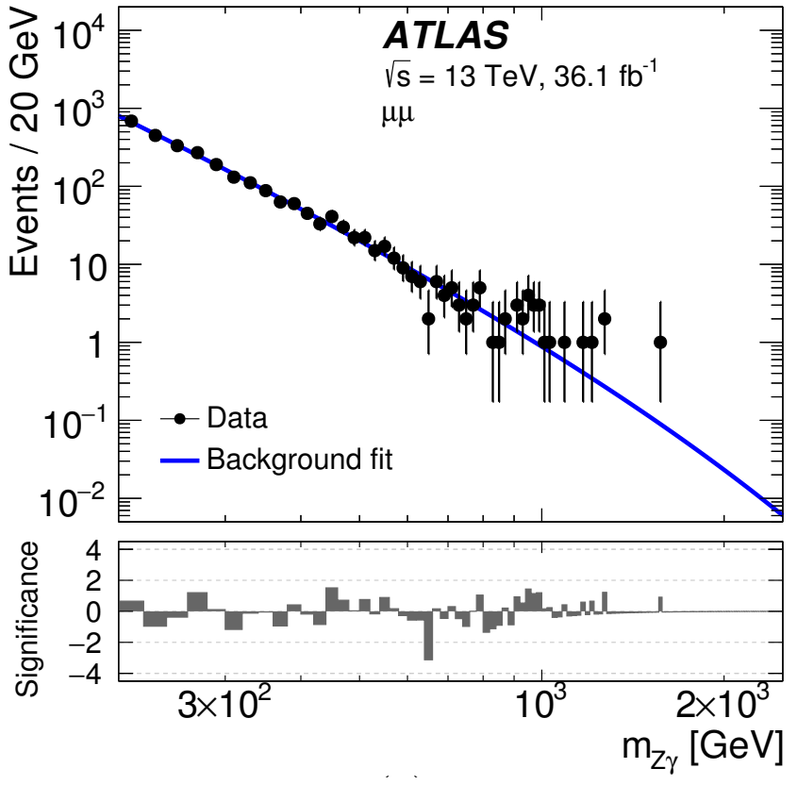
High mass $Z\gamma$ resonance search

- Performed in parallel with the SM Higgs decay
  - $H(X) \to Z\gamma \to \ell\ell\gamma$
- Event selection
  - Triggers
    - Single / di-lepton triggers
  - Photons
    - Tight identification
  - Leptons (ee or μμ)
    - Tight identification and isolation
  - Z boson
    - 2 leptons
    - Mass window: 91.2 ± 15 GeV

- Signal modeling
  - narrow spin-0/2 resonance
- Backgrounds
  - SM $Z+\gamma$, $Z+$jet events with fitting



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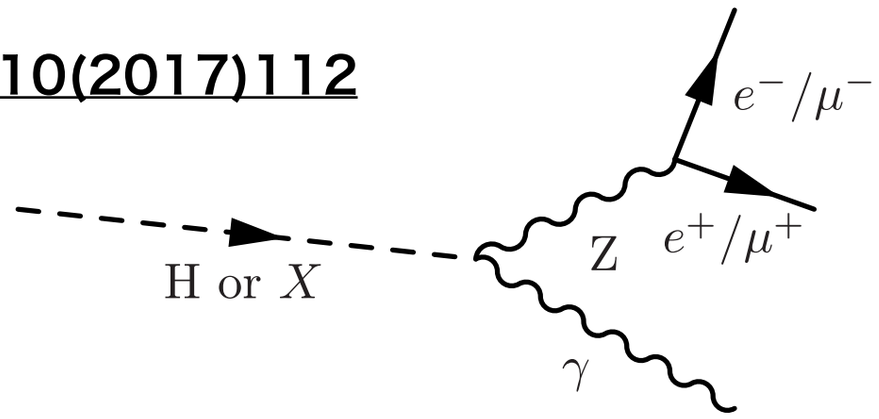
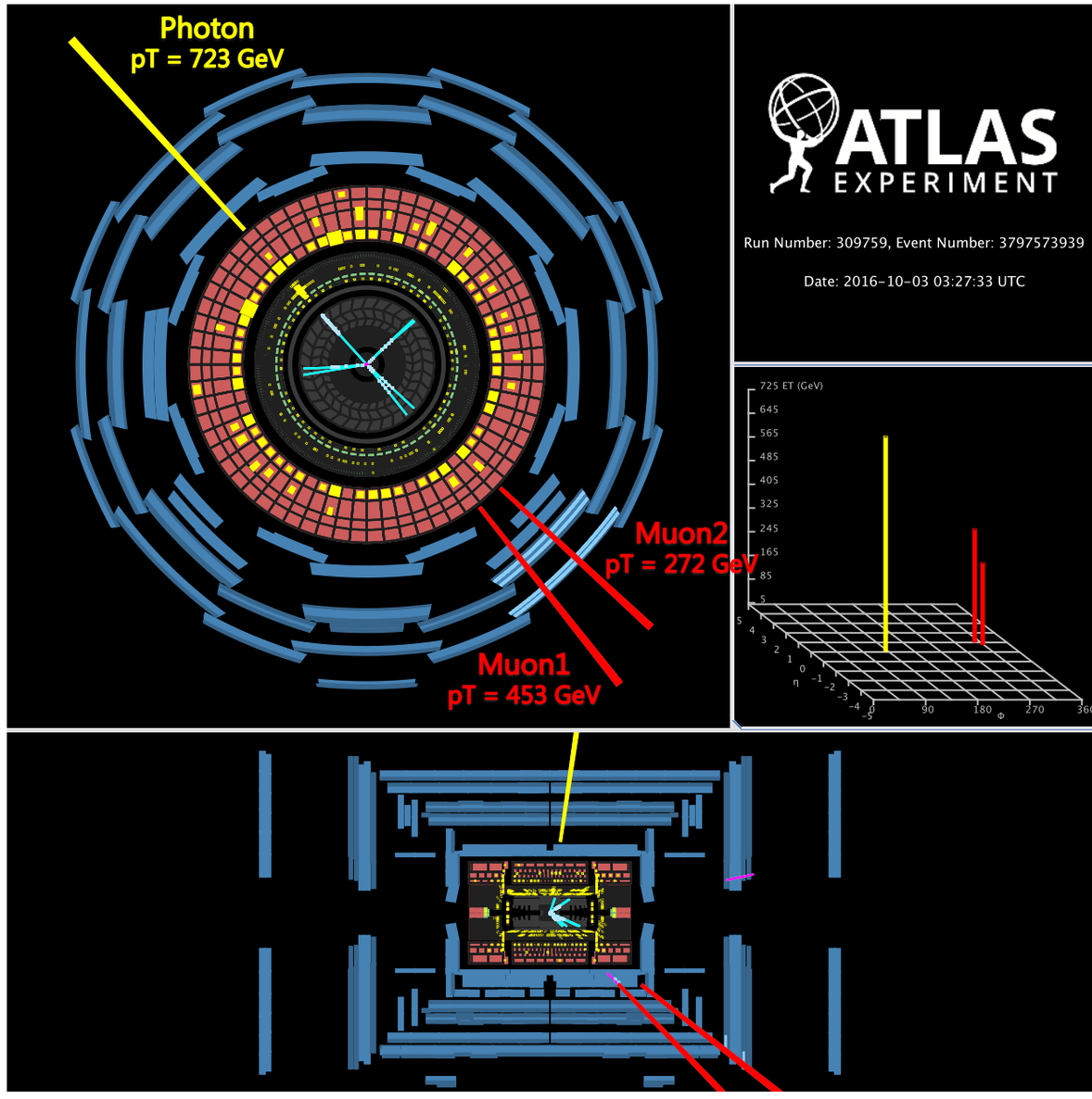
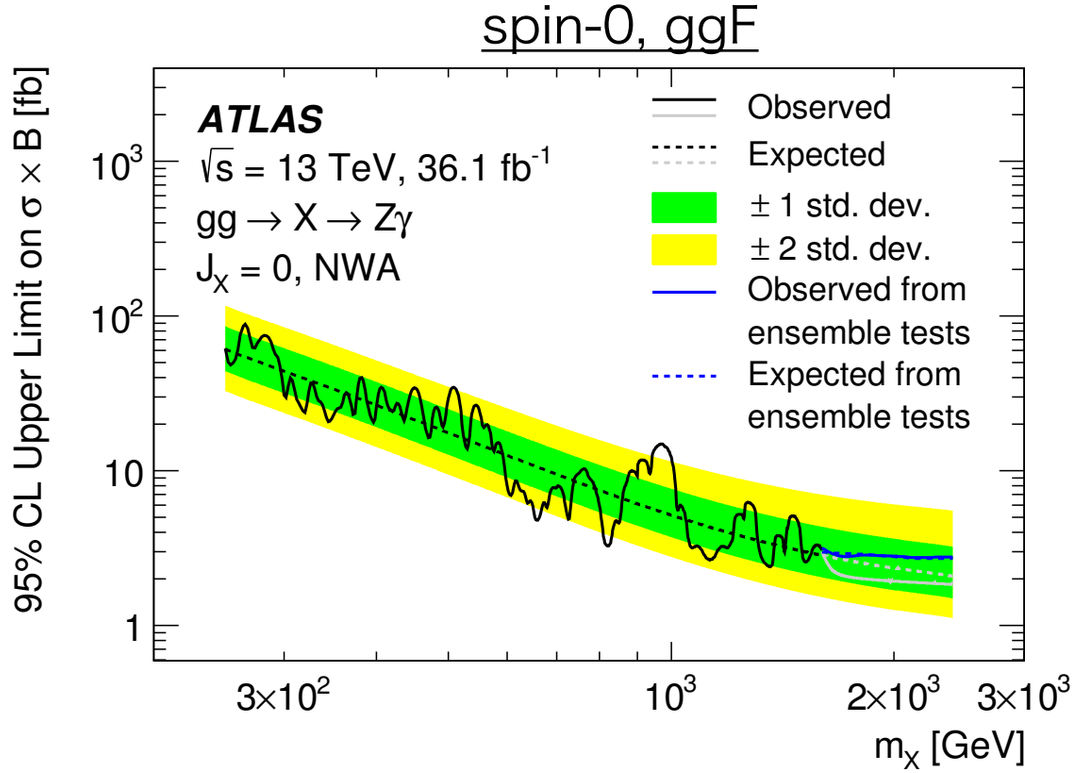


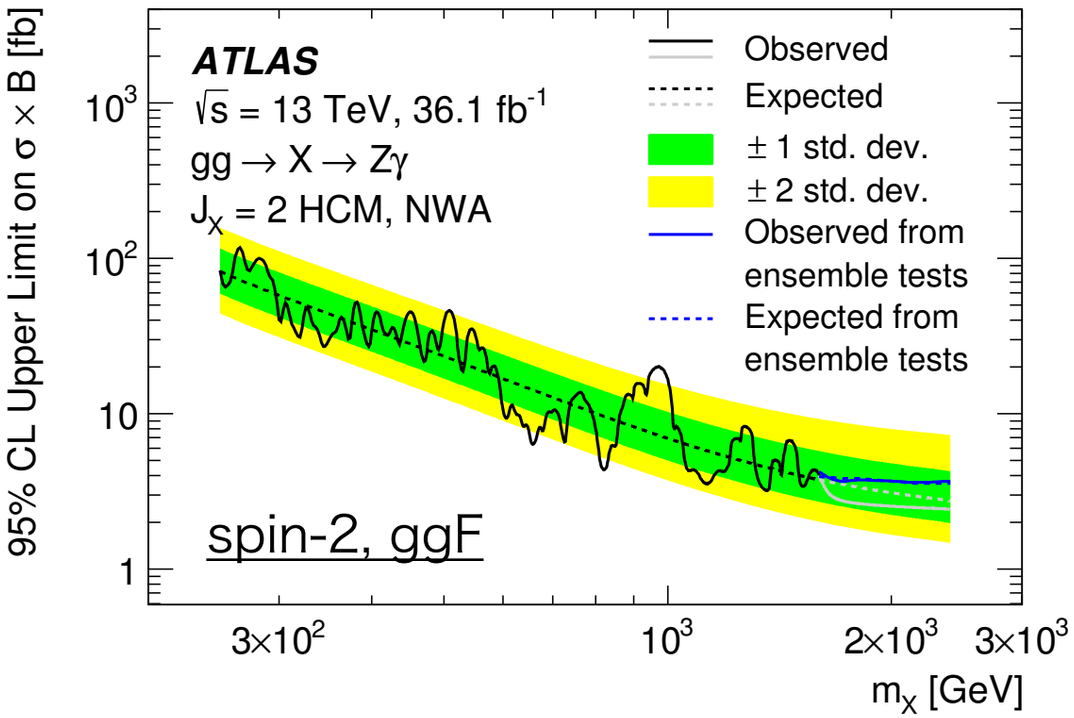


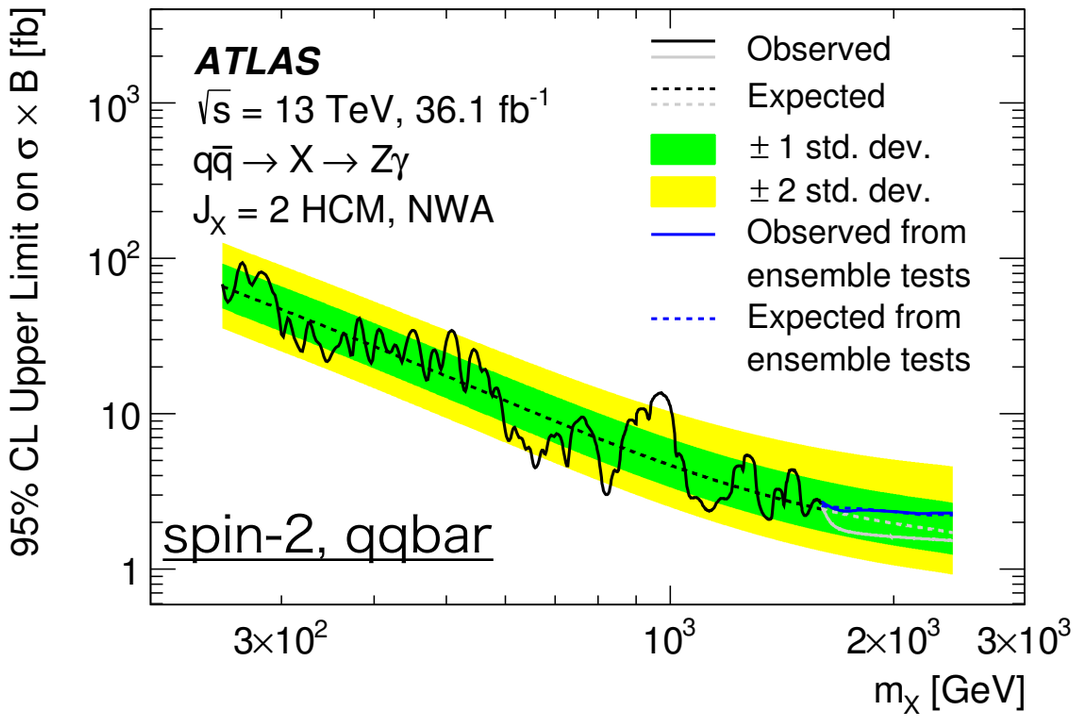
High mass $Z\gamma$ resonance search

JHEP10(2017)112

- Results
  - Data consistent with Standard Model background-only hypothesis
  - Largest deviation
    - local (global) significance of 2.7(0.8) σ at 960 GeV
  - Main uncertainties
    - e/γ resolution
      - 4 - 30 % on signal width
    - background bias
      - 0 - 6 % on signal yield







Summary

- Di-boson resonance searches in ATLAS

  - High mass state motivated by multiple BSM models
    - Direct way to explore the TeV scale

  - Experimentally challenging
    - Highest energy/momentum measurement
    - Boosted object tagging with large-R jet

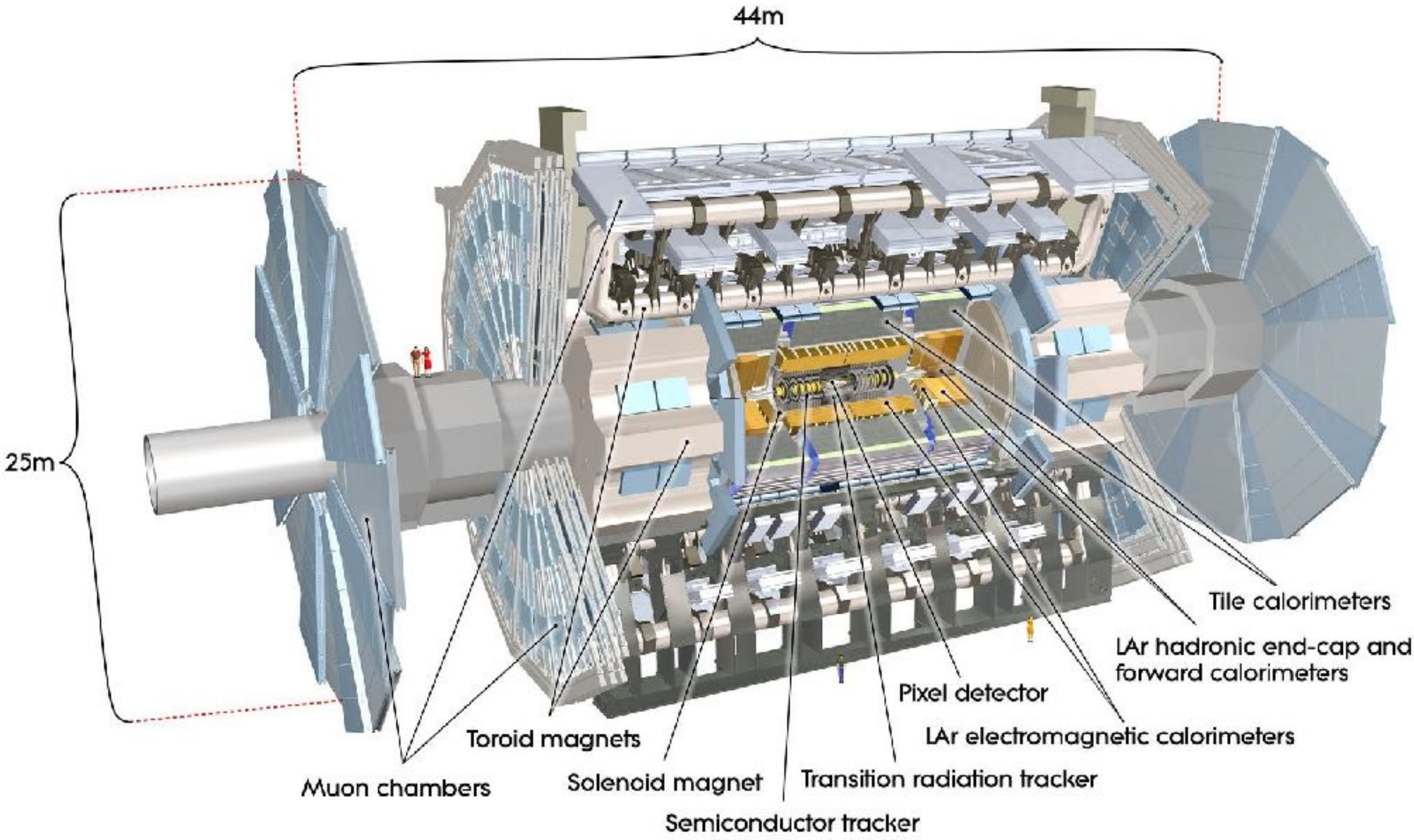
  - Results
    - No statistically significant excess observed in ATLAS

      - ✓ **Much more data coming in Run2 for more strict limits, or discoveries. Stay tuned!**

Backup

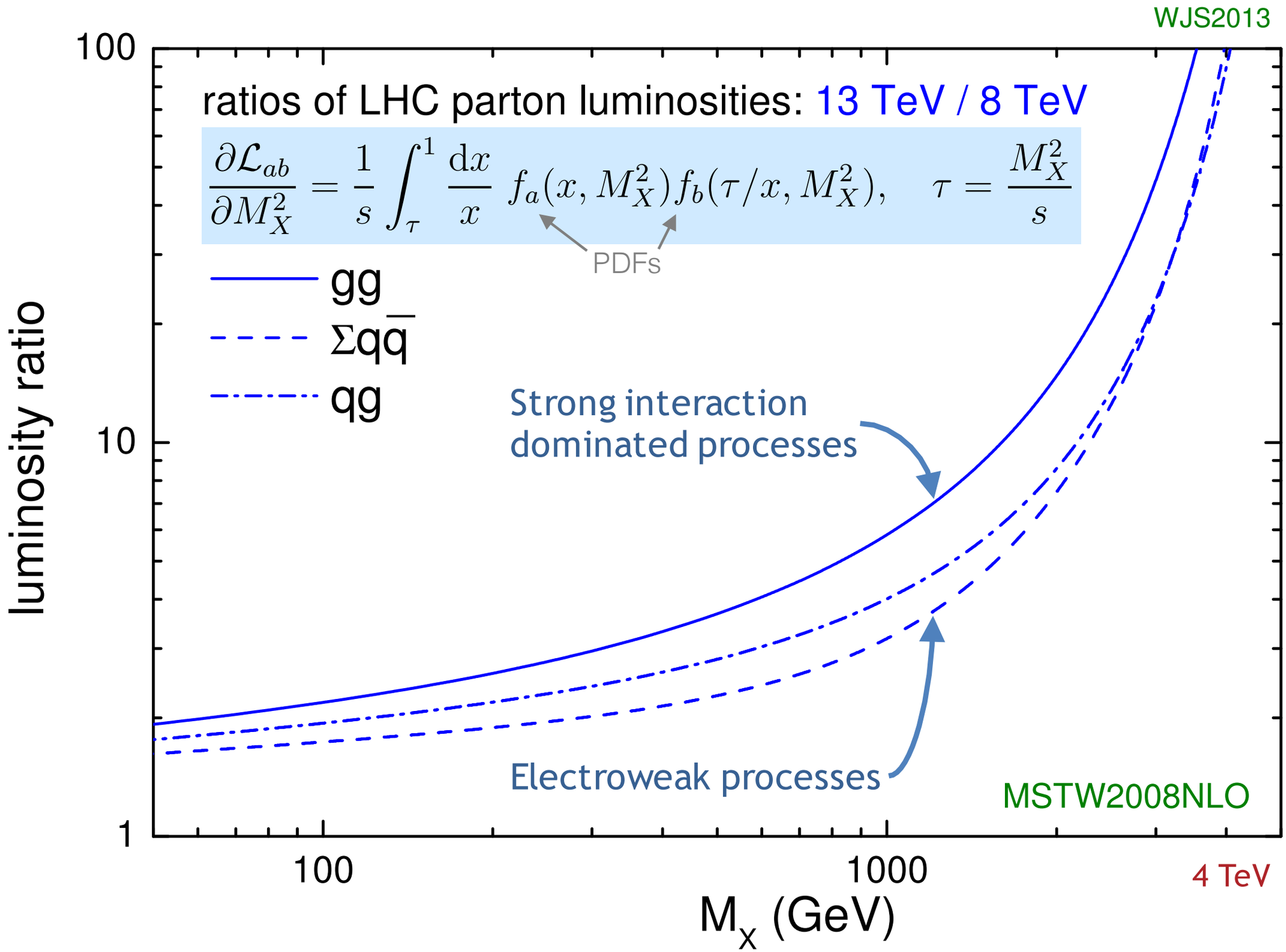
Experimental apparatus

The ATLAS detector



CERN-GE-0803012

13 TeV / 8 TeV inclusive parton luminosity ratio



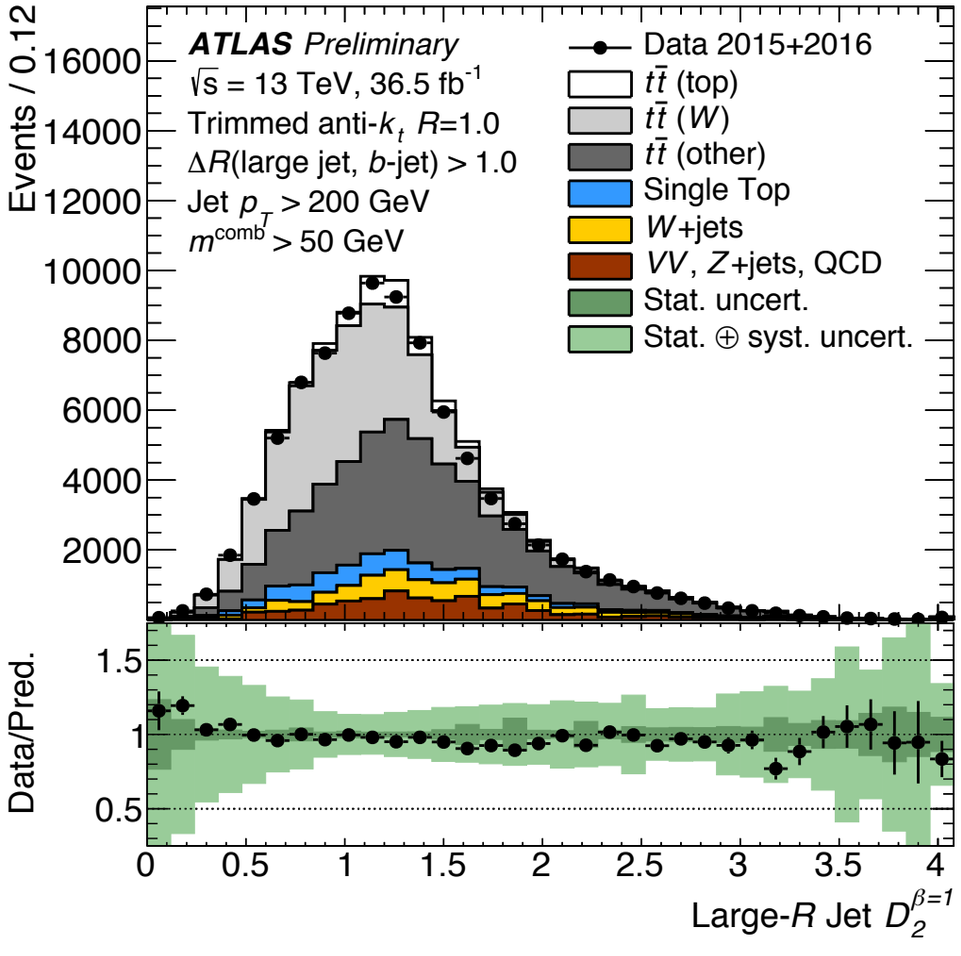
Substructure variable

- Definitions

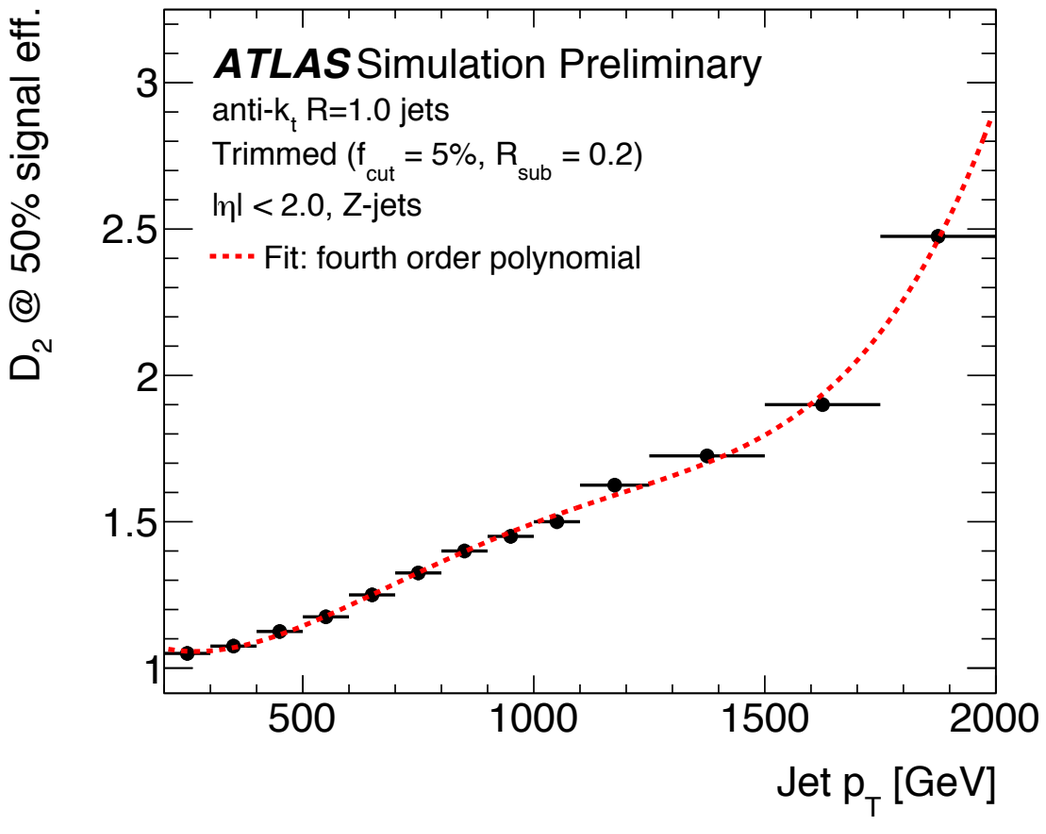
$$\mathrm{ECF}(N,\beta) = \sum_{i_1<i_2<\ldots<i_N\in J} \left(\prod_{a=1}^{N} E_{i_a}\right)\left(\prod_{b=1}^{N-1}\prod_{c=b+1}^{N} \theta_{i_b i_c}\right)^{\beta}$$

$$D_2^{\beta=1} = ECF(3)\left(\frac{ECF(2)}{ECF(1)}\right)^3$$

JETM-2017-004



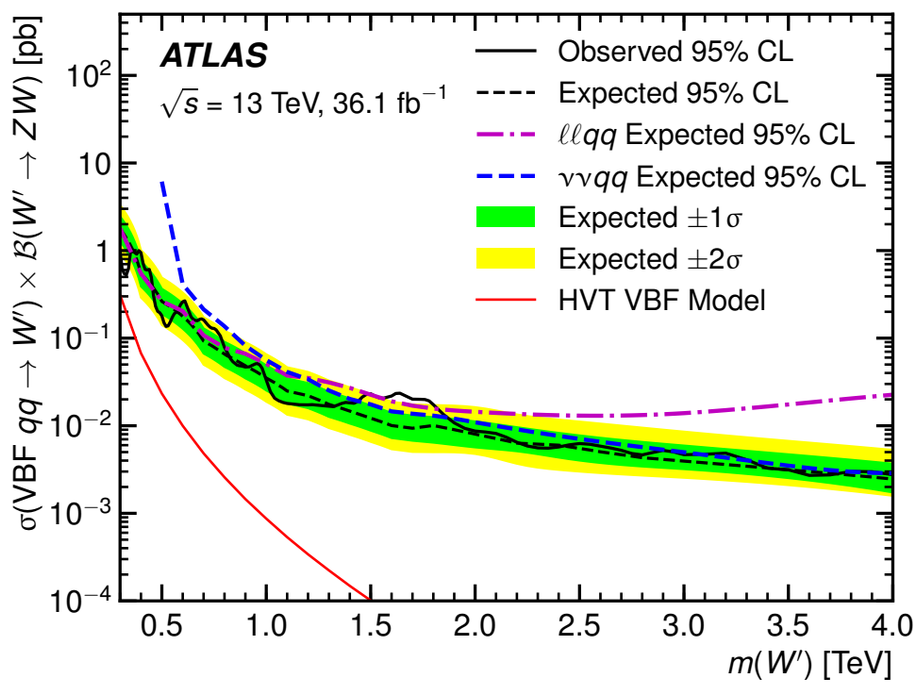
ATL-PHYS-PUB-2015-033

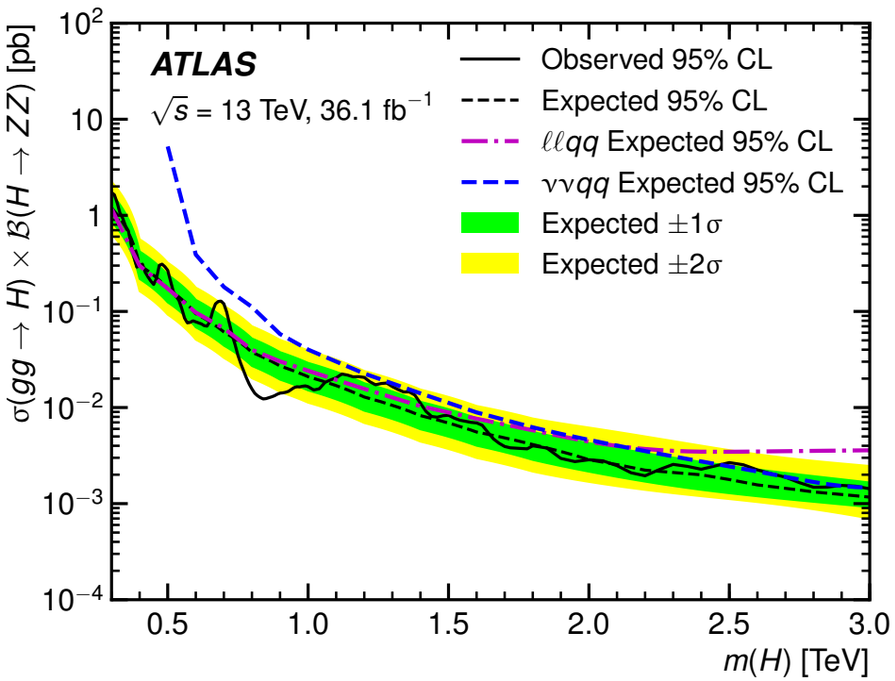


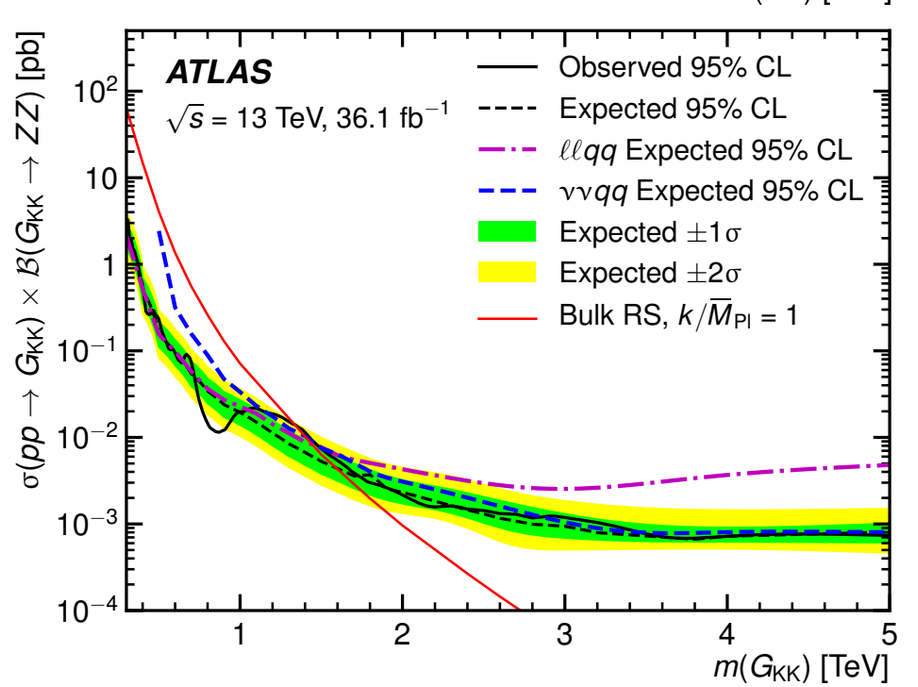
ZZ/ZW → ℓ ℓ qq / ν ν qq searches

arXiv:1708.09638

- Results
  - no significant excess
    - qqbar, ggF, VBF productions
    - Scalar, vector triplet, graviton interpretations



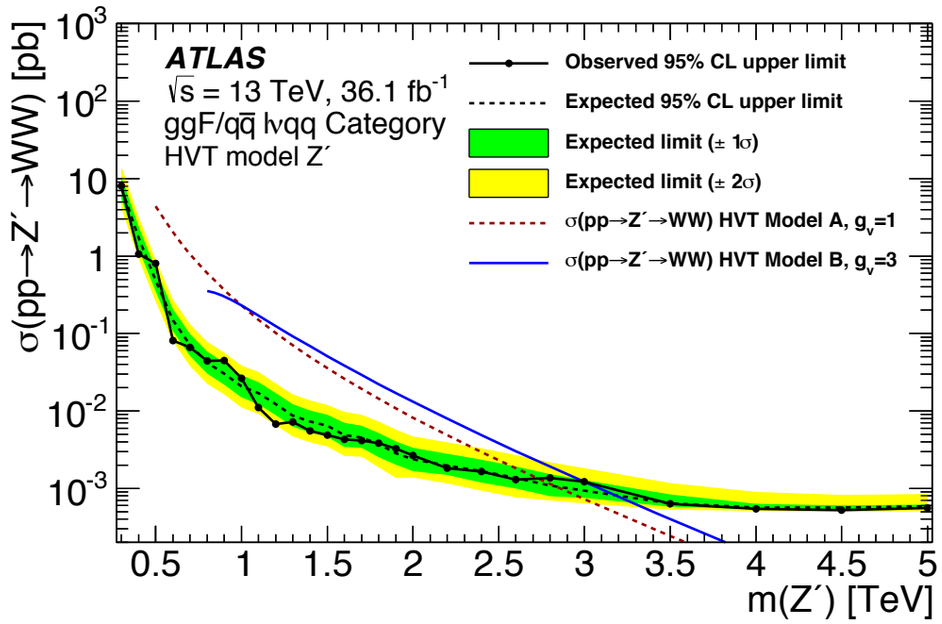


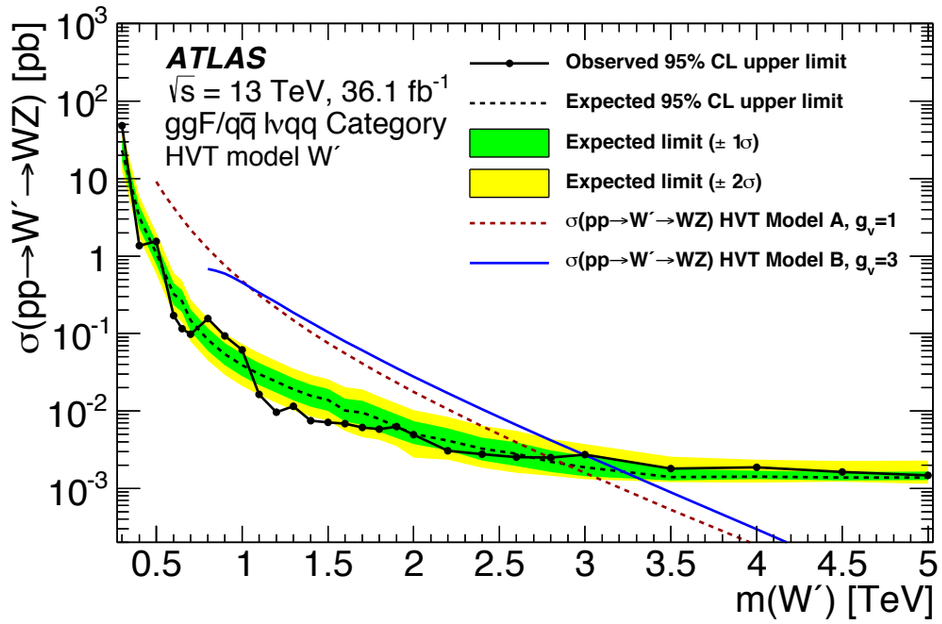


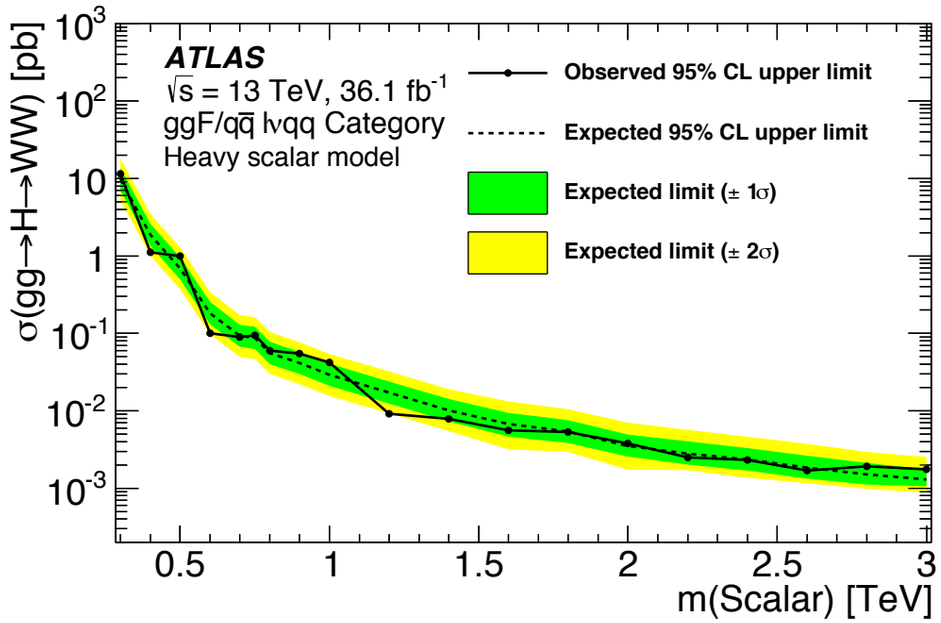
WW/WZ → ℓ ν qq searches

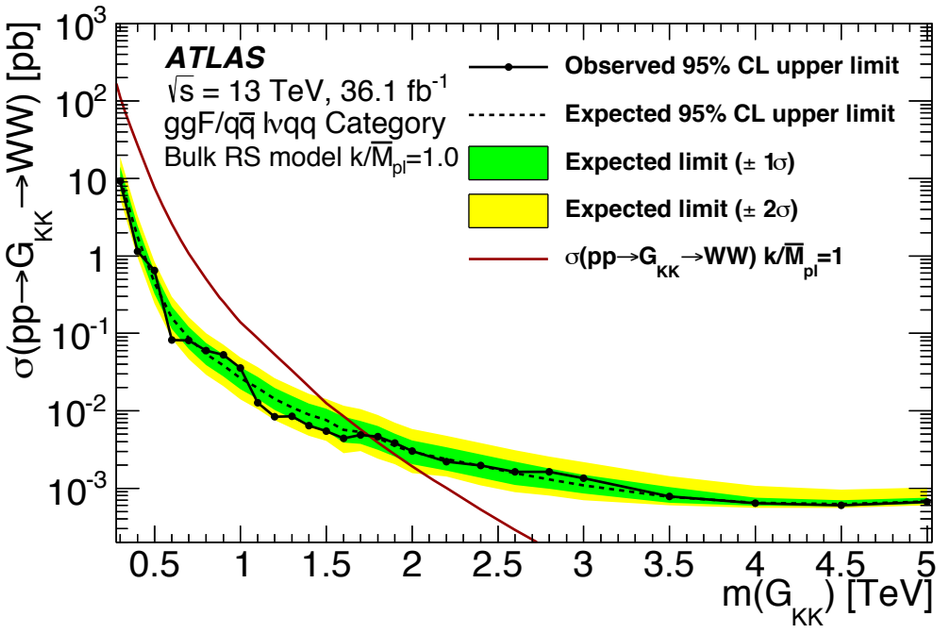
- Result
  - Consistent BG estimate with data
- HVT Model A
  - Triplet model similar to SSM, dominant couplings to fermions
- HVT Model B
  - Triplet model similar to composite Higgs, ggF suppressed

arXiv:1710.07235





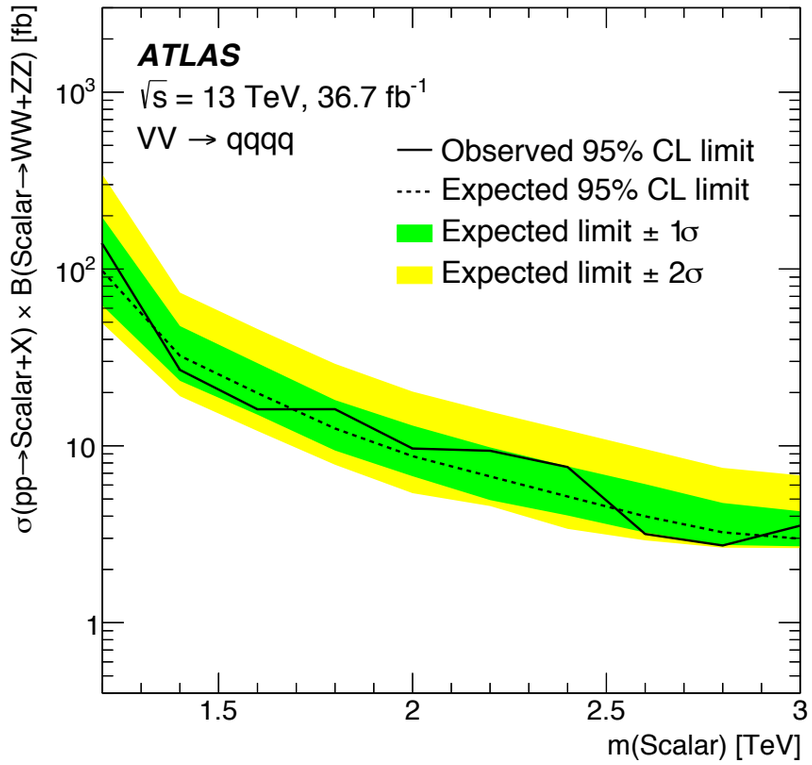


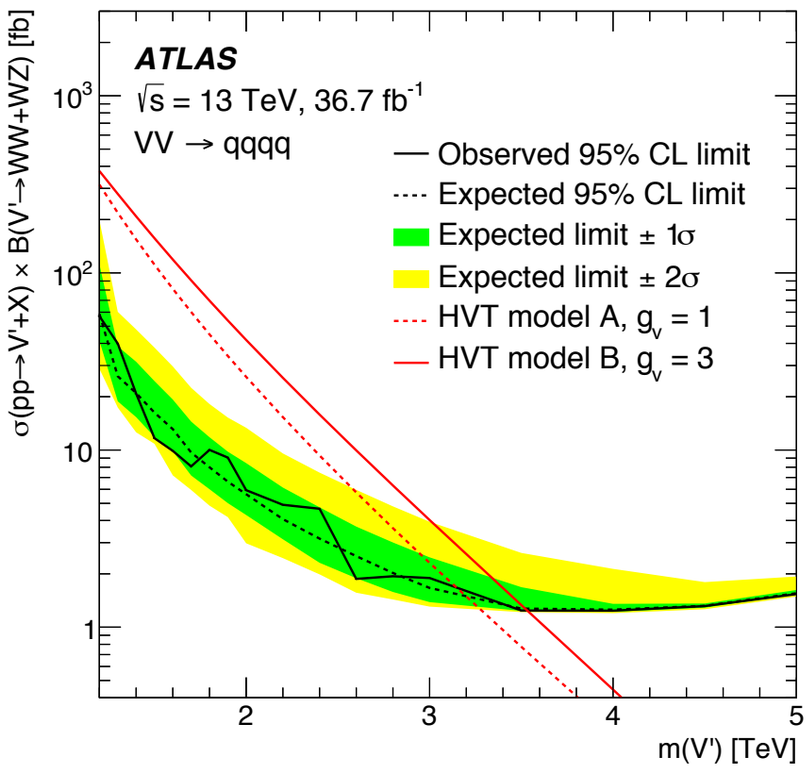


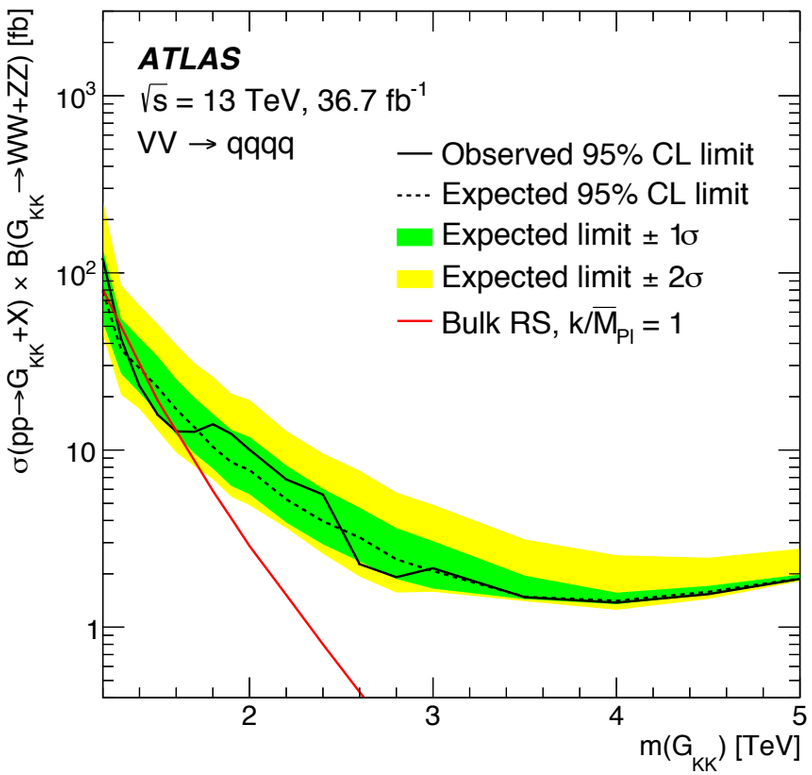
VV → qqqq search

arXiv:1708.04445

- Results
  - No significant excess observed
    - Interpretations: scalar, vector triplets, bulk gravitons







References

- "Search for diboson resonances with boson-tagged jets in pp collisions at √s =13 TeV with the ATLAS detector"
  - https://arxiv.org/abs/1708.04445
    - submitted to PLB

- "Searches for heavy ZZ and ZW resonances in the $\ell\ell$qq and $\nu\nu$qq final states in pp collisions at √s =13 TeV with the ATLAS detector"
  - https://arxiv.org/abs/1708.09638
    - submitted to JHEP

- "Search for WW/WZ resonance production in $\ell\nu$qq final states in pp collisions at √s = 13 TeV with the ATLAS detector"
  - https://arxiv.org/abs/1710.07235
    - submitted to JHEP

- "Search for heavy resonances decaying into WW in the e$\nu\mu\nu$ final state in pp collisions at √s =13 TeV with the ATLAS detector"
  - https://arxiv.org/abs/1710.01123
    - submitted to EPJC

- "Search for heavy ZZ resonances in the $\ell^+\ell^-\ell^+\ell^-$ and $\ell^+\ell^-\nu\nu$ final states using proton-proton collisions at √s =13 TeV with the ATLAS detector"
  - http://cds.cern.ch/record/2273874
    - ATLAS-CONF-2017-0589

- "Searches for the Zγ decay mode of the Higgs boson and for new high-mass resonances in pp collisions at √s = 13 TeV with the ATLAS detector"
  - https://link.springer.com/article/10.1007/JHEP10(2017)112