# Search for electroweak production of supersymmetric particles in final states with two boosted hadronically decaying bosons and missing transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV

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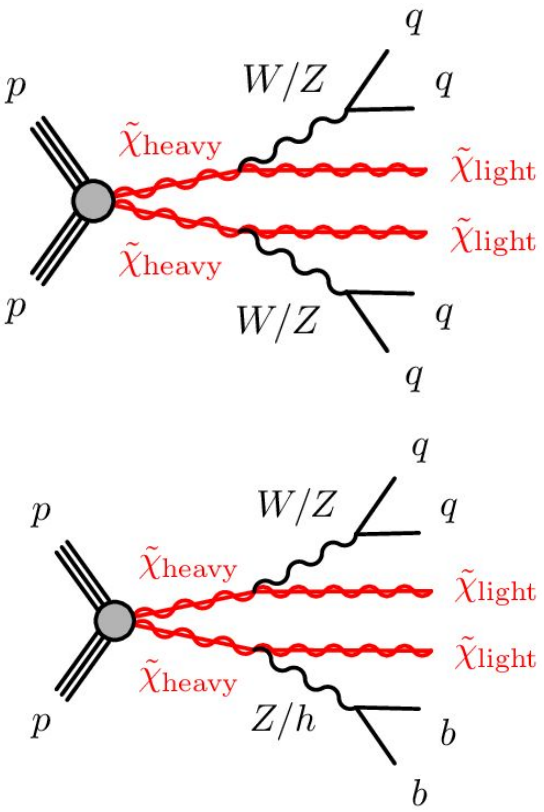
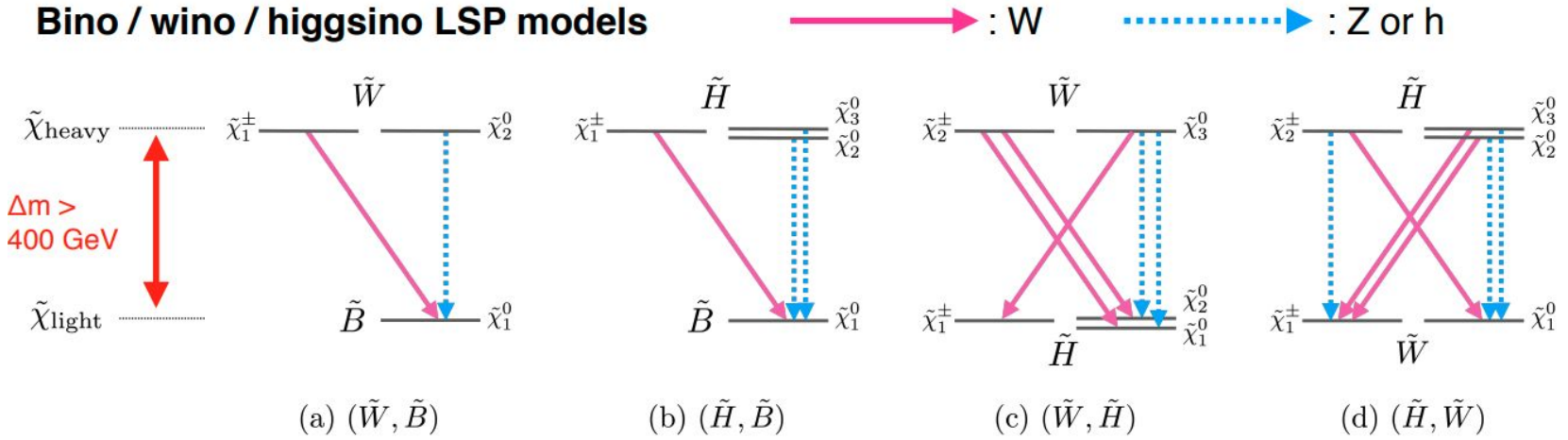
# Introduction

- Target neutralino and chargino production with large Δm.
  - Δm = 400 GeV ~ 1 TeV
- Signature
  - 2 boosted W/Z/h + MET
    - Fully hadronic final states (qqqq or bbqq)
      - Large branching ratio
        - Compared to leptonic final states which are more explored conventionally
        - Allows for increased signal
  - Increased signal -> increased background
    - Z+jets
    - Need to be able to suppress this.
      - Boosted bosons are reconstructed
        - ΔR = 1.0 (Large-R jets)
        - Jet substructure
      - Tight kinematic selection
  - This is a new signature in ATLAS/CMS



# Introduction - Target Models

- Baseline MSSM scenario
- Wino or Higgsino production
- Both simplified (100% BR) models and more general cases are considered.



# Boson Tagging

W/Z -> qq tagging (https://cds.cern.ch/record/2724149)

- Cuts in three variables with $p_T$-dependant cut values
  - Mass window
  - Upper cut on $D_2$ - 2 prongness (calculated using the energy correlation function)
  - Upper cut on $n_{trk}$ - track multiplicity
- Working point was reoptimized - loosened $n_{trk}$
  - Mass and $D_2$ at official 50%WP
  - Rejection is about 10-100 per jet
    - Asking 2 bosons improves S/N by ~O(1000).

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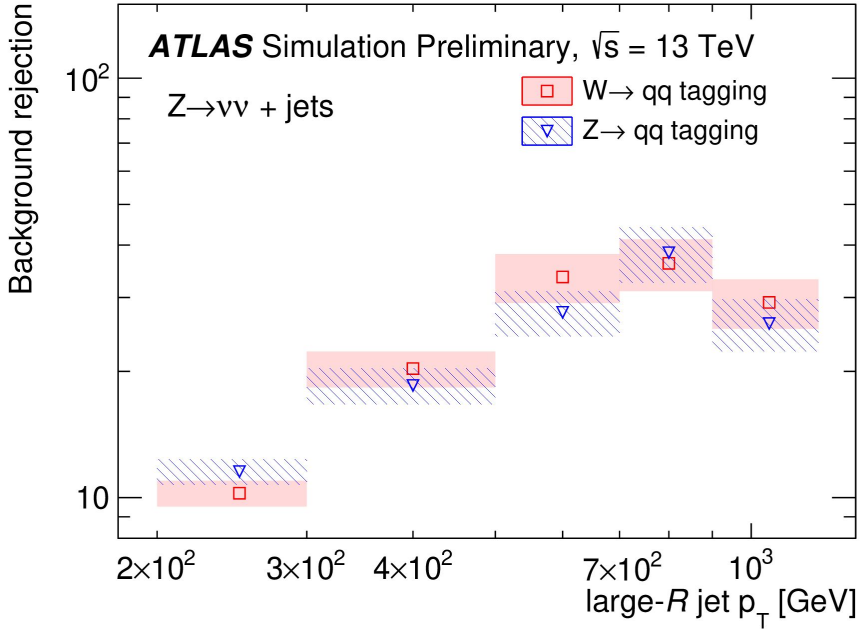
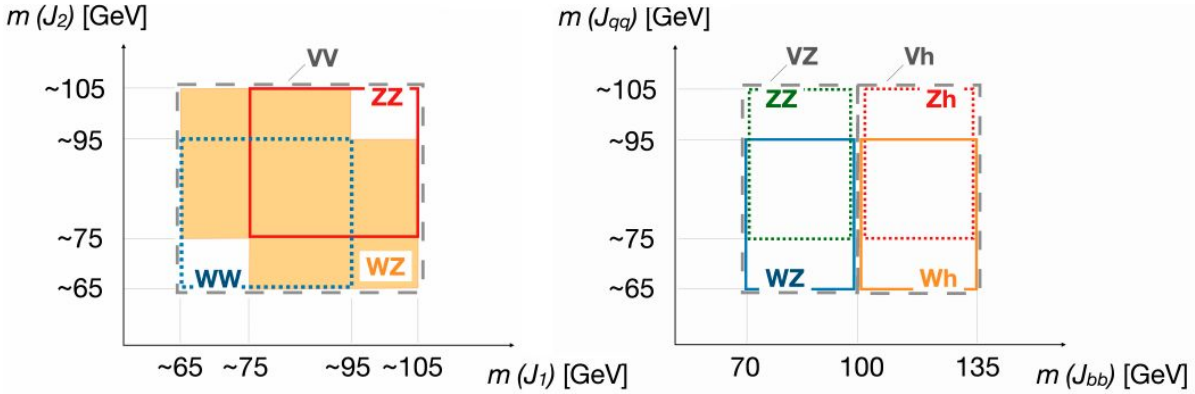


# Event Selection - Analysis Strategy

- Preselection:
  - n(large-R jets) ≥ 2, $n_{lepton}$=0, MET>200 GeV
  - Cleaning cuts (e.g. non-collision BG veto)
- 2 categories
  - 4Q : (W/Z)(W/Z) -> qqqq
  - 2B2Q : (W/Z)(Z/h) -> qqbb
    - Split is based on presence or absence of 2b tagged large-R jet.

- 10 SRs are defined
  - This accommodates WW/WZ/Wh/ZZ/Zh final states.
- Aimed to minimize model dependence.
  - Especially on BRs.



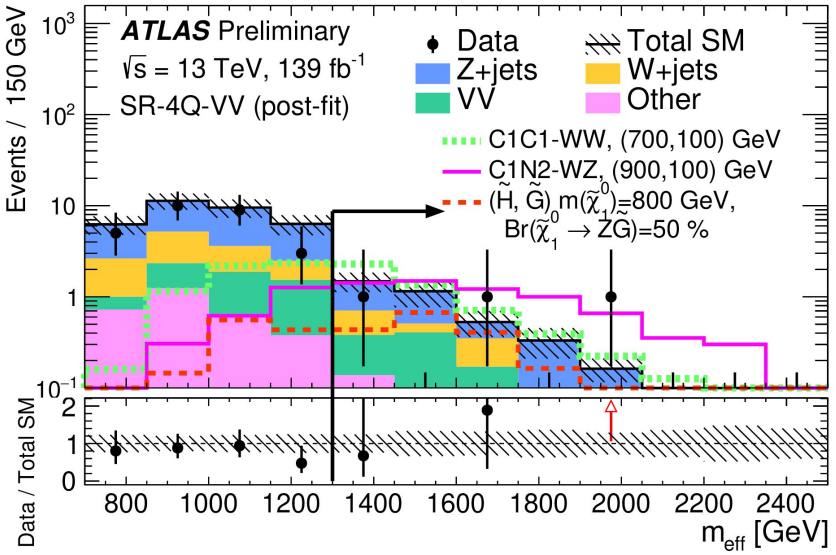
# Event Selection

Further BG rejection cuts:

- Veto b-jets outside of large-R jets
- min$\Delta\phi$(j,MET)>1.0
  - Selects spherical event topology
- $m_{eff}$ cut (scalar sum of MET, $J_1$, and $J_2$ $p_T$)
  - Selects events with hard kinematics

Cuts are found by optimizing at (Wino, Bino) = (800, 100) GeV.

- Shown on the right, optimizing $m_{eff}$.

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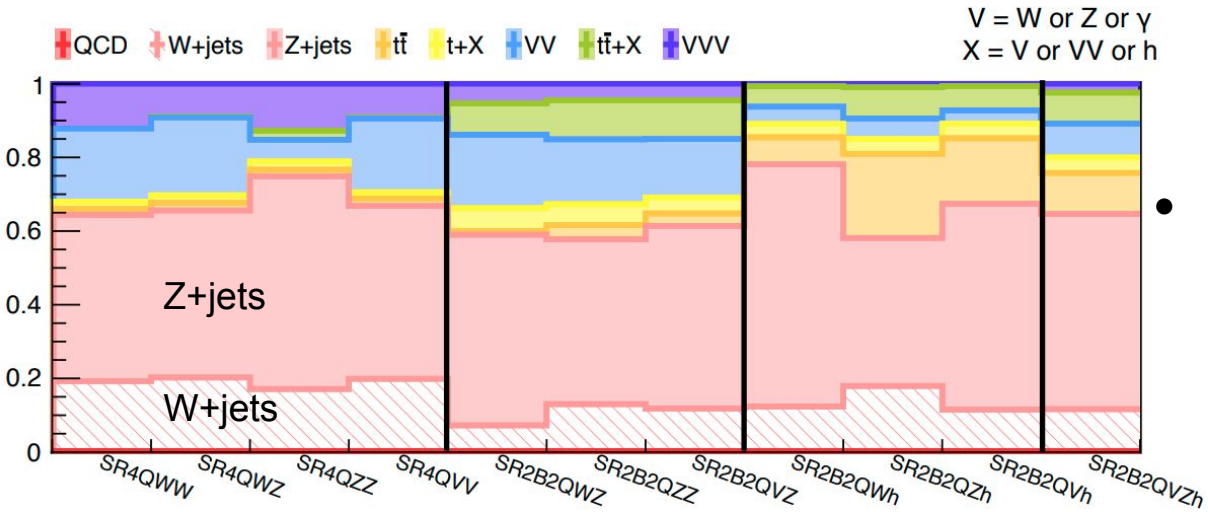
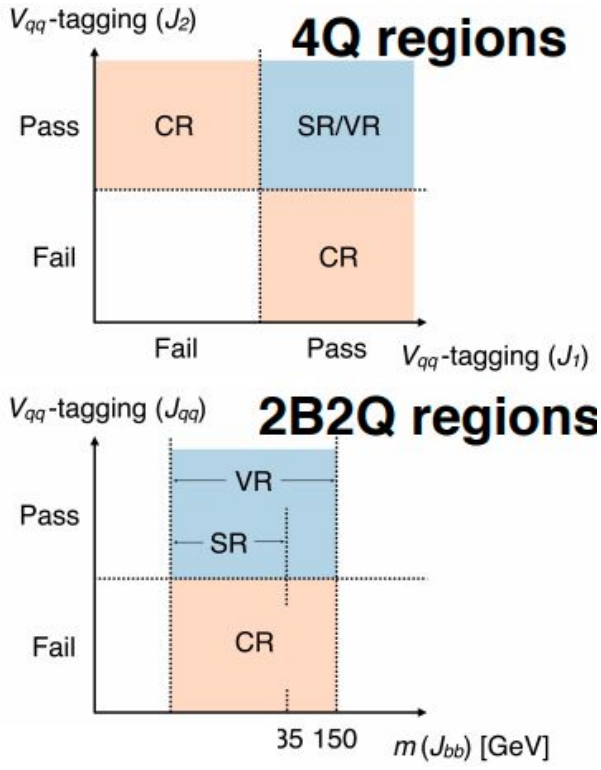
# Background Composition




- Reducible BG account for 90%
  - V+Jets
    - 2 ISR fat jets
  - VV, ttbar, single-top
    - 1 ISR and 1 real boson jet
- Irreducible BG account for 10%
  - tt+X, VVV
    - 0 ISR and 2 real boson jets

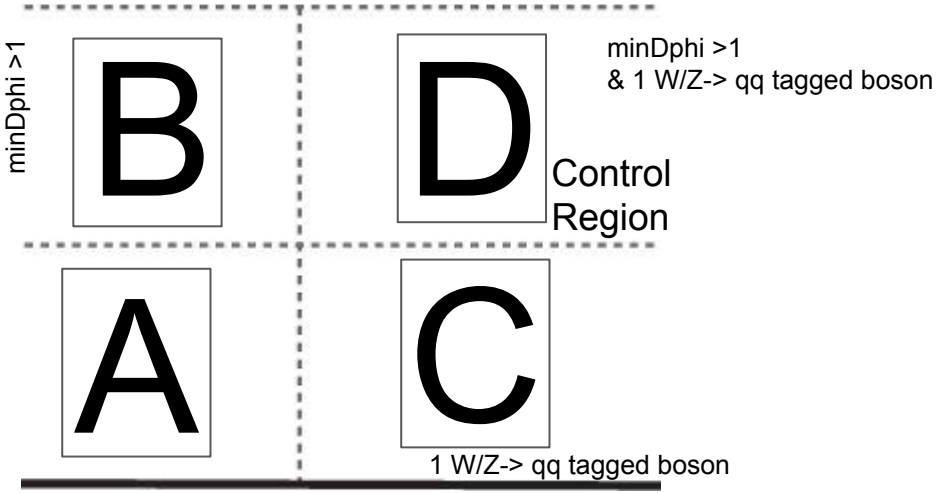
# Background Estimation - Reducible backgrounds

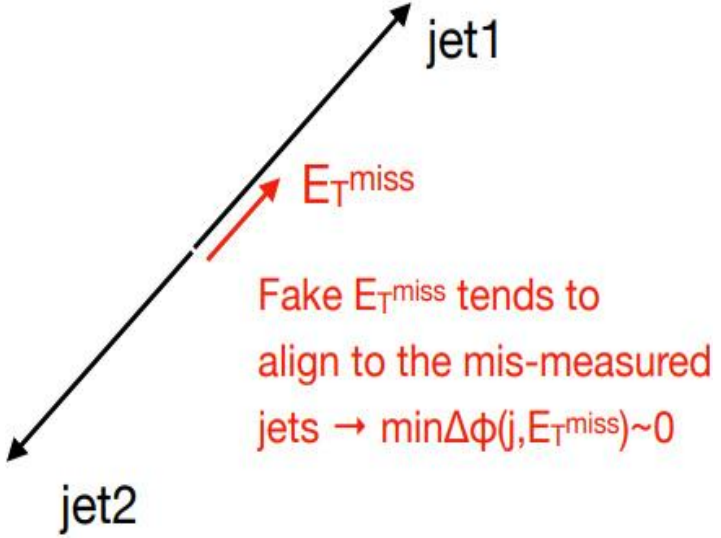



- Reducuble BGs include a “Fake Boson” originating from ISR jets
  - All have similar jet compositions
    - Therefore they are treated as a single BG component
- Semi-data driven method
  - CR is defined by inverting the W/Z tagging of the SR.
  - MC used to extrapolate CR->SR
- MC extrapolation is validated using kinematically equivalent 1L/1Y regions
  - Dominant BG in each region has a similar shape
    - Z(->vv) in 0L ~ W(->lv) in 1L ~ y+jets in 1Y
    - Therefore TFs are also similar
      - Confirmed by MC and data
- So validate modeling in TF(1L/1Y) ~ validating modeling of in TF(0L).

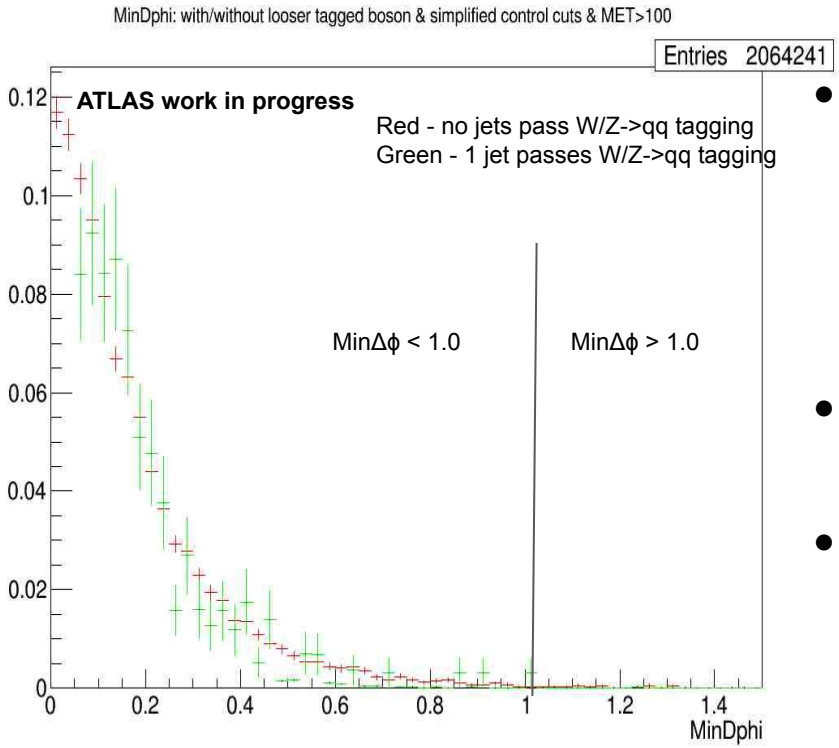
# Multijet Background

- Characterized by a fake MET from mismeasured jet energy
  - Low minΔϕ
- Multi-jet is very difficult to estimate.
  - Believed to be very small though.
- ABCD method
  - Use W/Z->qq tagging and minΔϕ as ABCD variables.
  - Cuts are minΔϕ>1.0 and tagged boson>1.



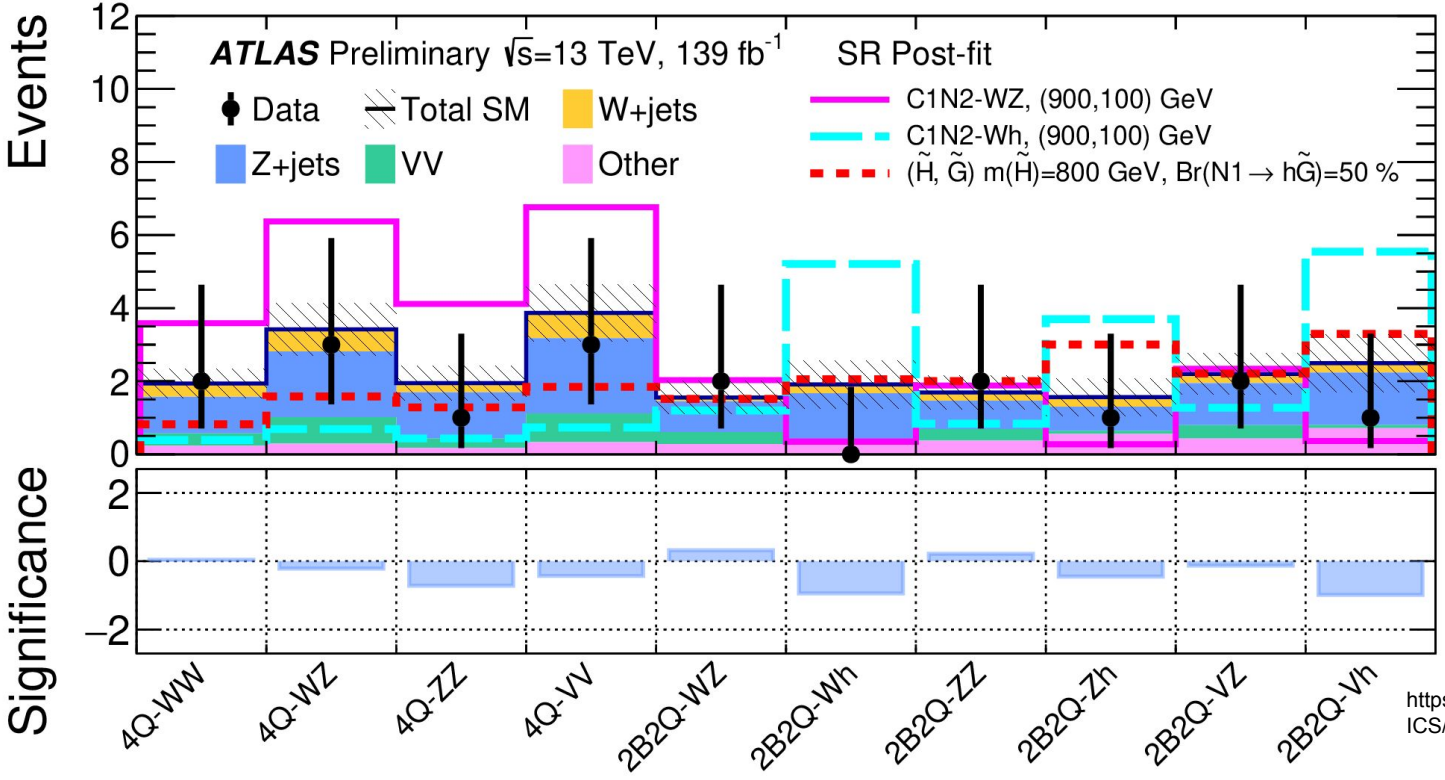



# Multijet Background




- Due to low statistics in Data and MC prediction was made for CR.
  - This has higher statistics than SR
  - Relative fraction will not change much from CR to SR.
    - Only need to show negligible contribution in CR.
- For MET>200 GeV this was found to be nearly negligible.
  - -1.61 ± 1.80 for MET>200 GeV
  - -0.950± 0.96 for MET>300 GeV
- Multijet is negligible in the CR therefore must be negligible in SR.

# Results - Unblinded SRs




- No significant data excess was found.

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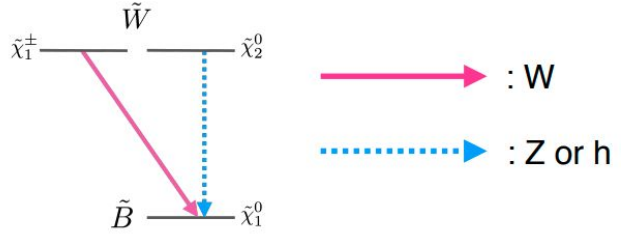
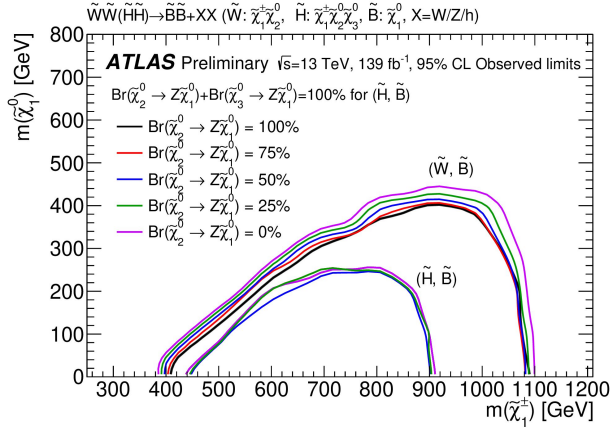
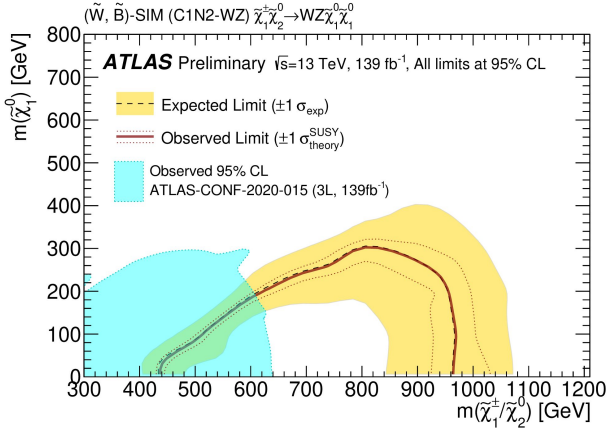
# Results

- Unprecedented limits for large Δm.
  - 300-400 GeV improvement in the benchmark simplified models compared to best limits by ATLAS/CMS.
  - Up to 1050 (900) GeV excluded for wino (higgsino) production.
    - Confirmed with various LSP types and BR assumptions

$(\tilde{W}, \tilde{B})$ simplified model

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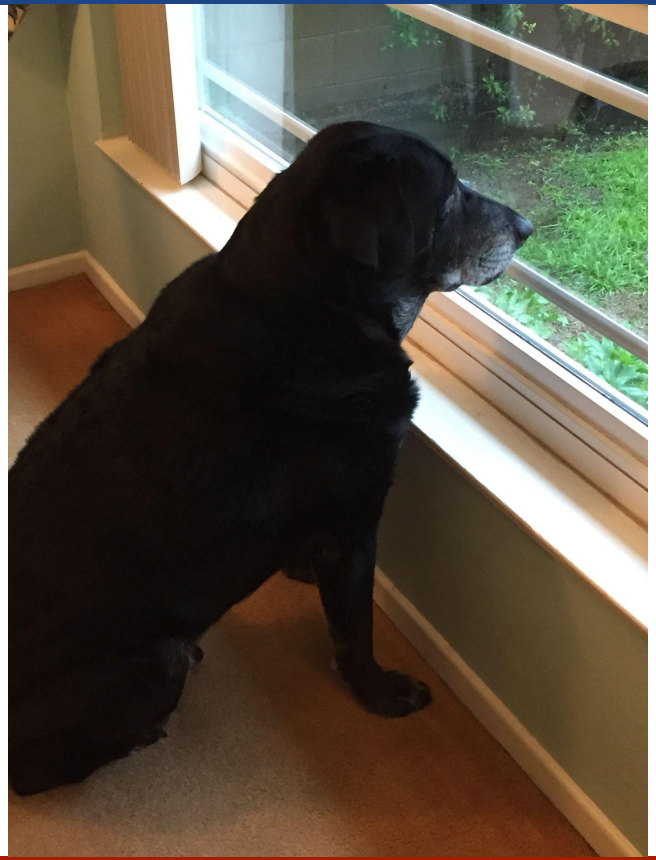
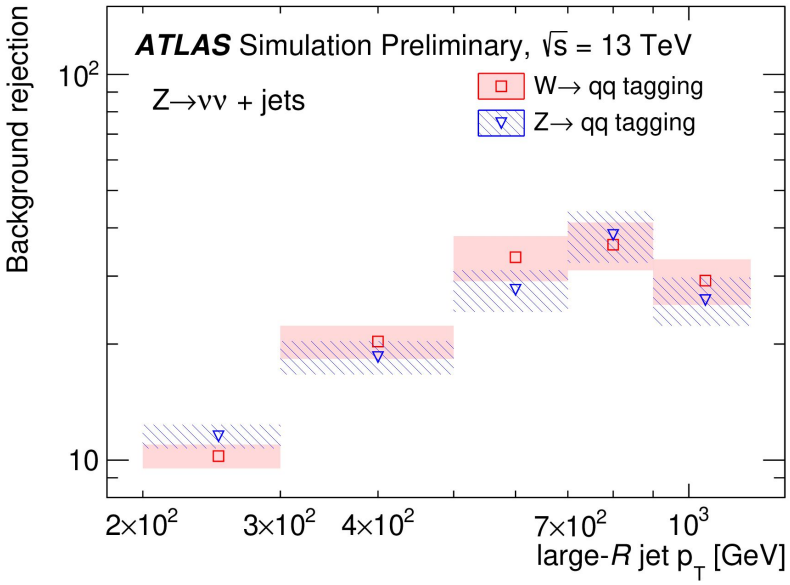
# Conclusion

- Boosted di-boson+MET using full Run 2 data.
  - Fully hadronic final states give large Branching Ratios.
  - Boson reconstruction using large-R jets and jet substructure.
    - Allows for strong BG reduction
  - New signature in ATLAS/CMS SUSY search.
- Covered a variety of models, including:
  - Conventional Wino-NLSP/Bino-LSP simplified models.
  - Models with various production modes, LSP types, and BR assumptions.
- **No data excess in the SRs**
- **Most stringent limits set for scenarios with large Δm.**
  - 300-400 GeV improvement
  - Up to 1050 (900) GeV is excluded in the wino (higgsino) mass.

# Backup

# Z/h->bb tagging

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Z/h -> bb tagging (https://cds.cern.ch/record/2268678)

- B-tagged VR track jet used as b-multiplicity in large-R jet.
- $J_{bb}$ mass is corrected by leading muon $p_T$
- Selections:
  - 2 VR track jets pass 85% eff. WP within large-R jet
  - Mass window