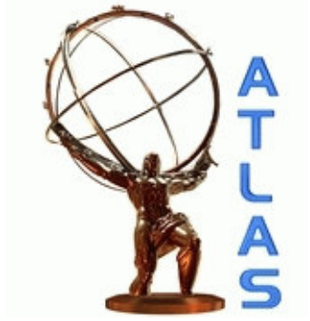
Exotica Searches at the LHC



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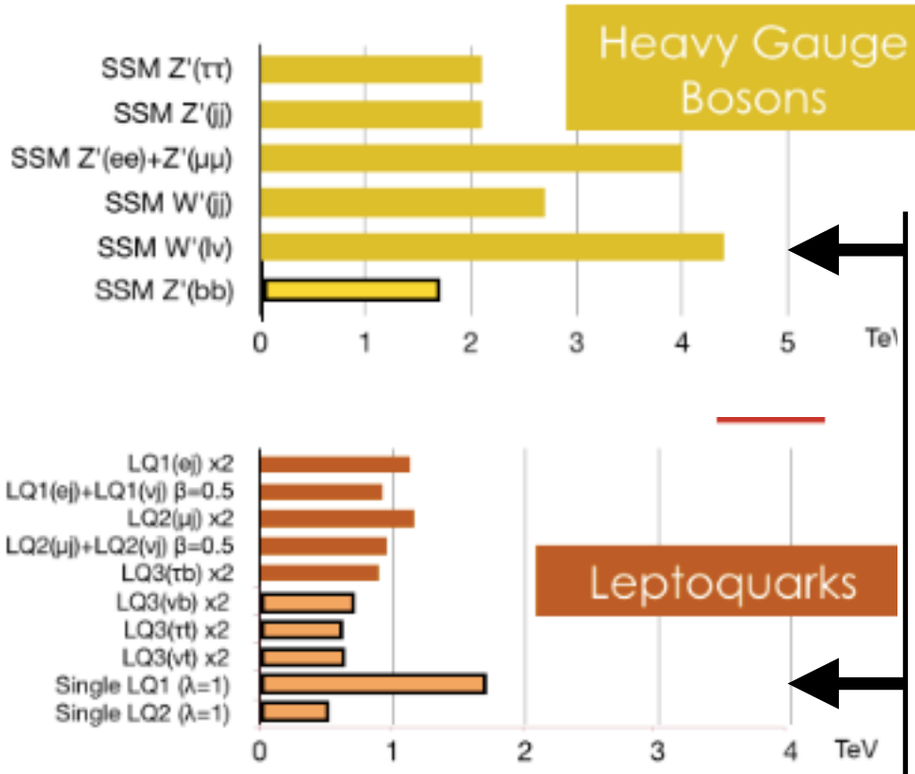
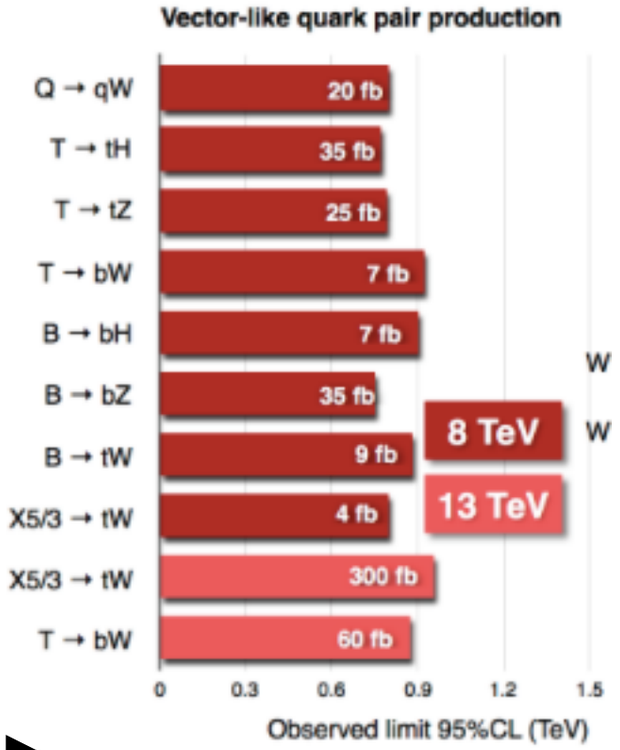
On Behalf of ATLAS and CMS Collaborations

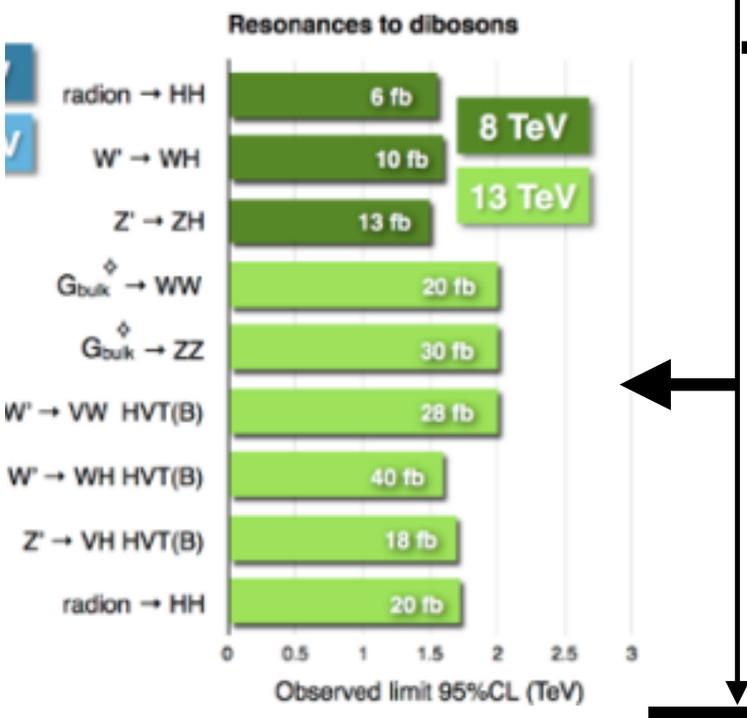
CLHCP2017, Nanjing, Jiangsu Province
Dec 22-24, 2017

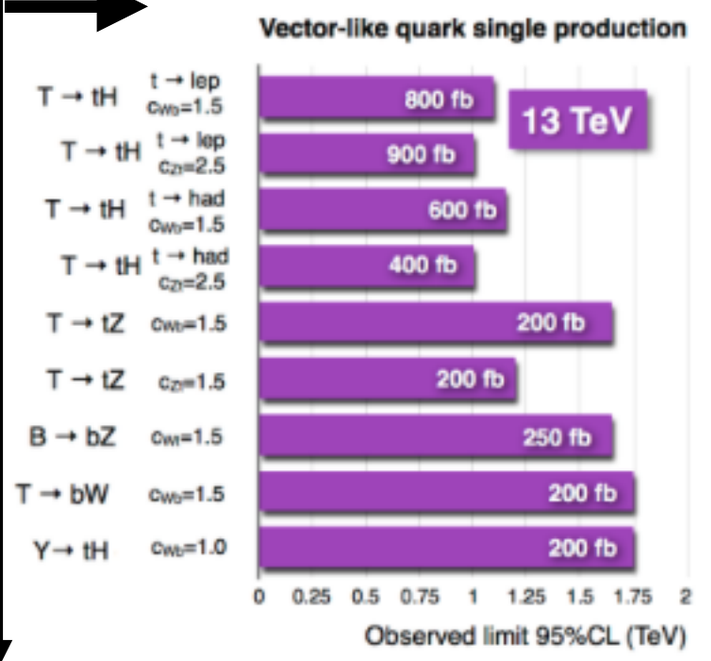
Outline

- Introduction
- Exotica searches
  - Heavy Bosons
  - Leptoquarks
  - Heavy Neutrinos
  - Vector Like Quarks
  - Diboson Resonance
  - Dark Matter
- Conclusion









Dark Matter

Introduction

- **Discovery of a scalar boson consistent with SM Higgs**
  - Is it SM Higgs or something else ?
  - new window for physics beyond SM

- **Exotica searches**
  - cover wide range of final states
  - numerous models (extension of SM):
    - hierarchy problem
    - neutrino mass
    - dark matter

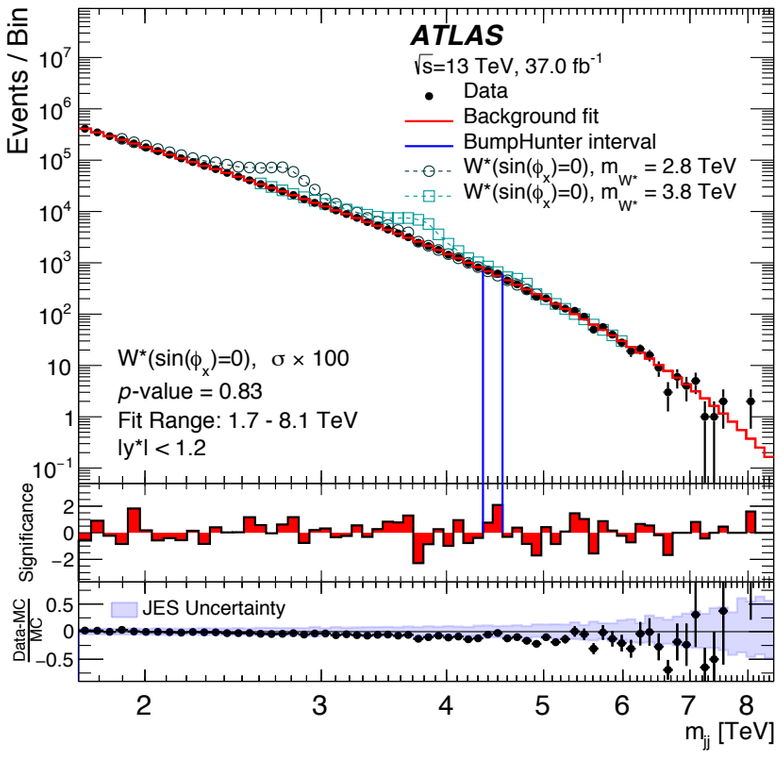
- **Search strategies:**
  - direct searches: look for resonance
  - indirect searches: look for any disagreement

Heavy Boson Search

Di-jet resonance

- **Probe numerous BSM models: String, Axigluons/Colorons, Color-octet scalar, W'/Z' bosons, RS …**
- **Search for bumps on the smoothly falling di-jet invariant mass spectrum.**

Phys.Rev.D 96.052004



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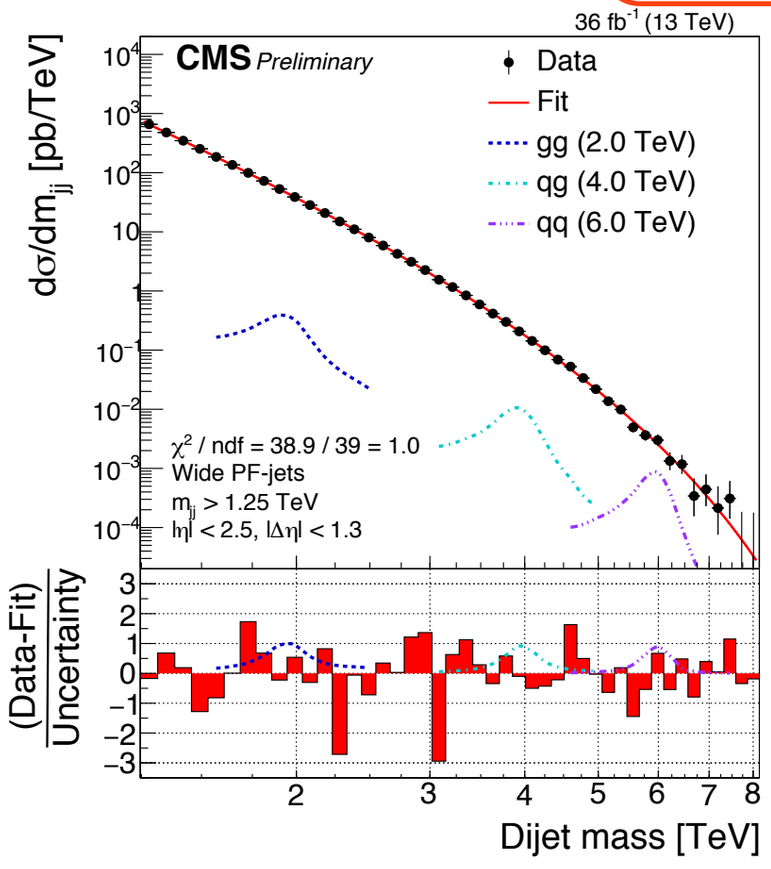

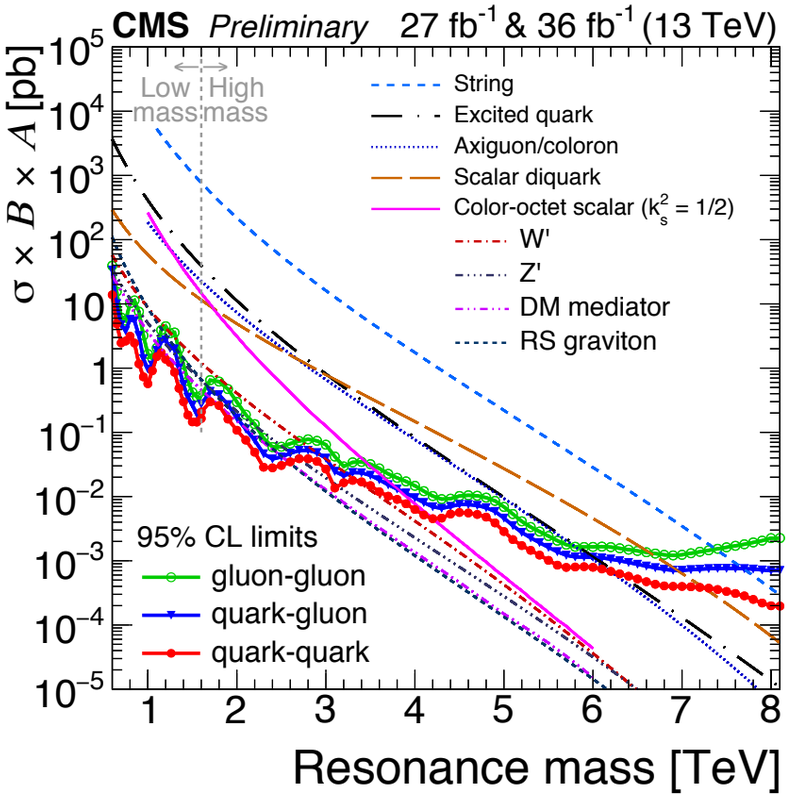

No significant excess observed in 36-37 fb^{-1}.

Lower limits up to 7.7 TeV for different models.

$Z' \to l^+ l^-$

- Generally, all new particles that can decay to dilepton called Z'
- Many BSM theories predict $Z' \to l^+ l^-$
  - extension of SM in Grand Unification (e.g Z'_{ψ})
  - some SUSY models predict new spin-0 resonance
  - sequential SM predict Z'_{SSM}

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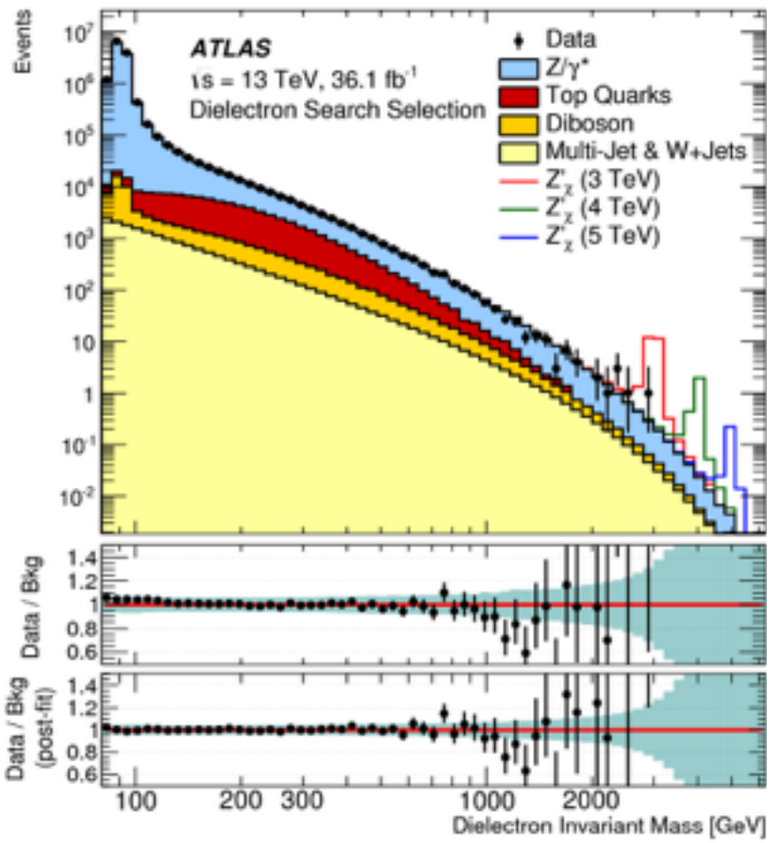
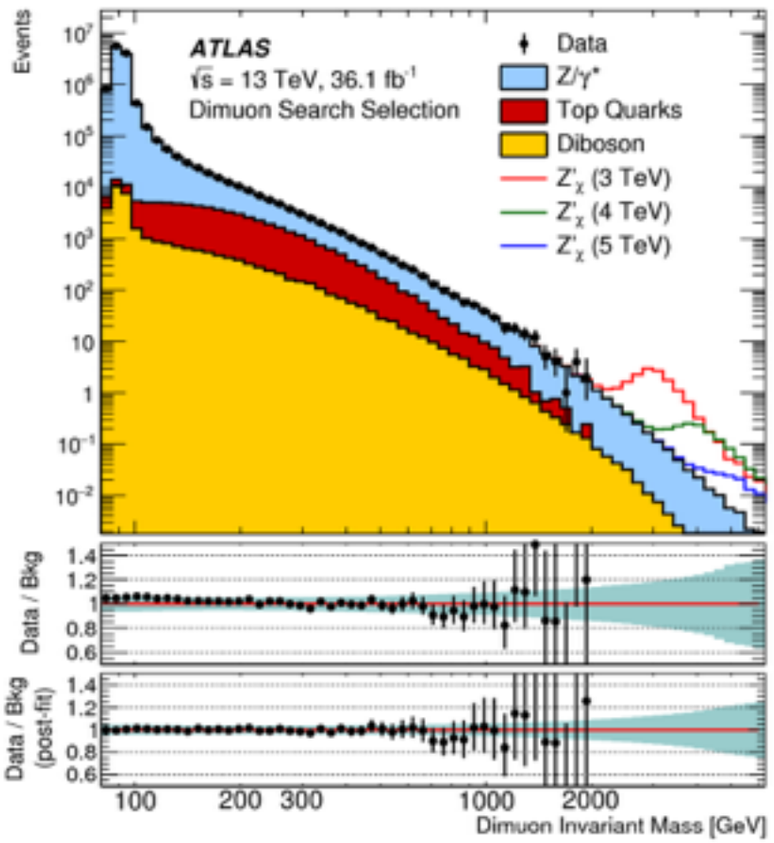




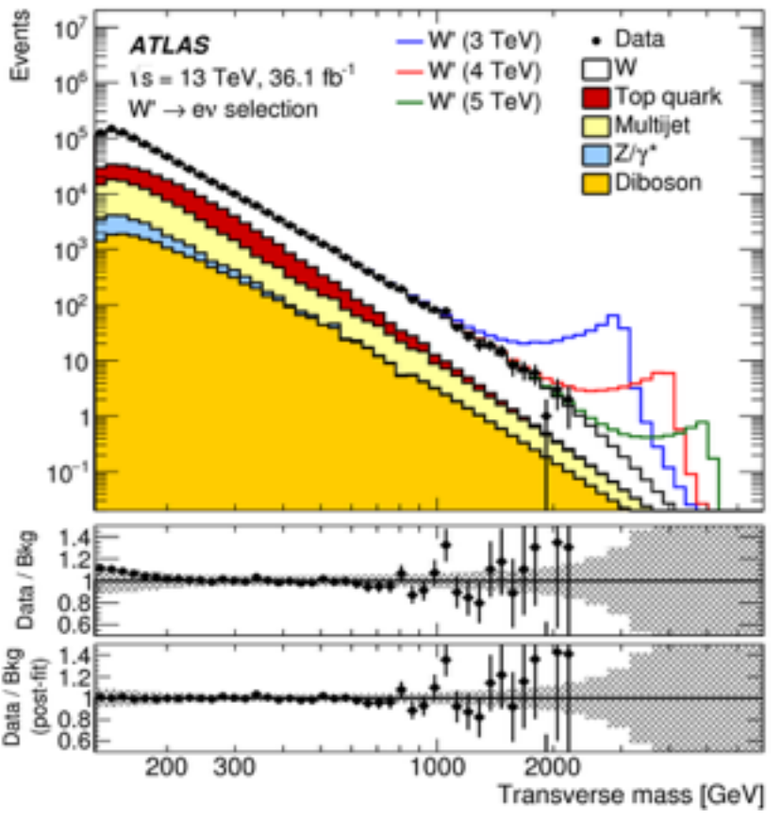
Excellent modelling for all data up to 3TeV.

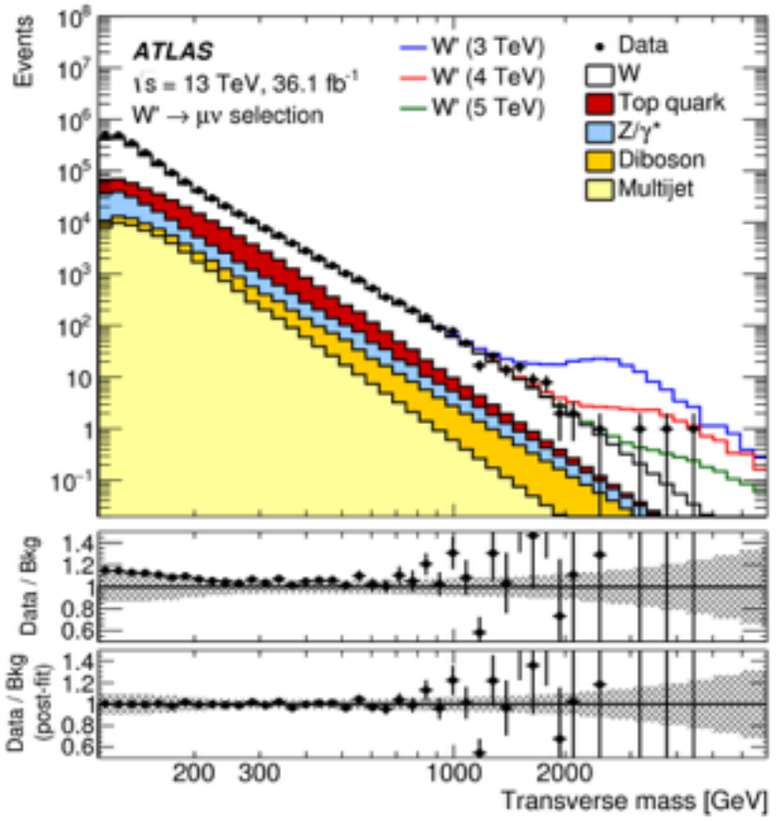
Limit can reach 5TeV by all Run 2 data: 100 fb^{-1}.

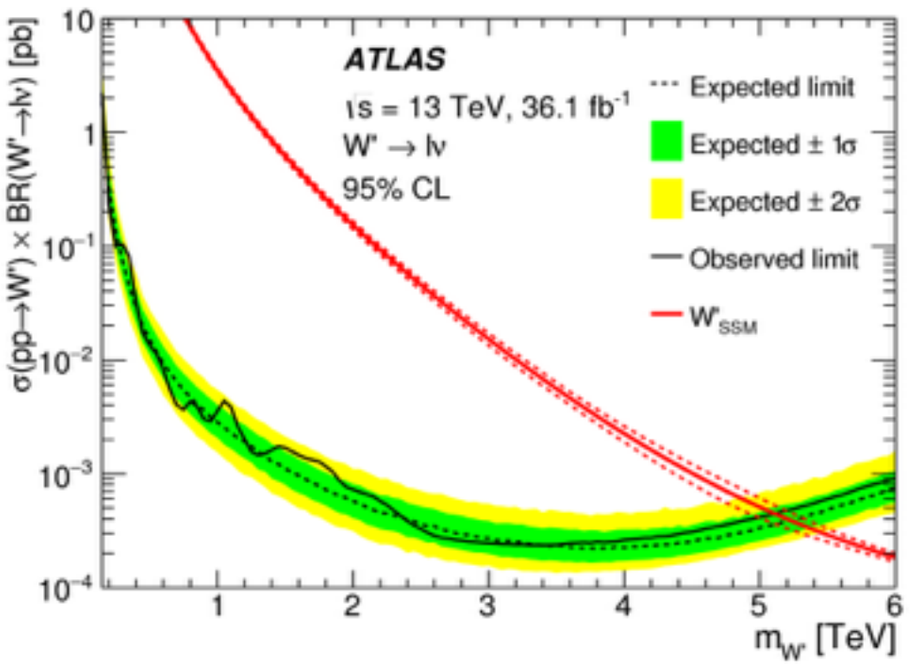
$W' \rightarrow l\nu$

- **Search for heavy boson with lepton+MET signature.**
- **Look for excess on the transverse mass distribution.**
- **Dominant backgrounds coming from: W+jets, Top, QCD, Z, multi-bosons**

arXiv: 1706.04786







Assuming W' boson with the same coupling as the SM W boson, W' masses below 5.1TeV are excluded at 95% CL.

$W' \rightarrow tb$

- **Search for heavy boson with $tb \rightarrow bblv$ signature.**
- **Directly probe the W' coupling to 3rd generation quark, can be enhanced w.r.t lighter quarks in some models.**
- **Complement search for W' $\rightarrow lv$ and W' $\rightarrow VV$**
- **Unlike W' $\rightarrow lv$, the W' $\rightarrow tb \rightarrow bblv$ allows W' mass to be fully reconstructed up to a quadratic ambiguity.**

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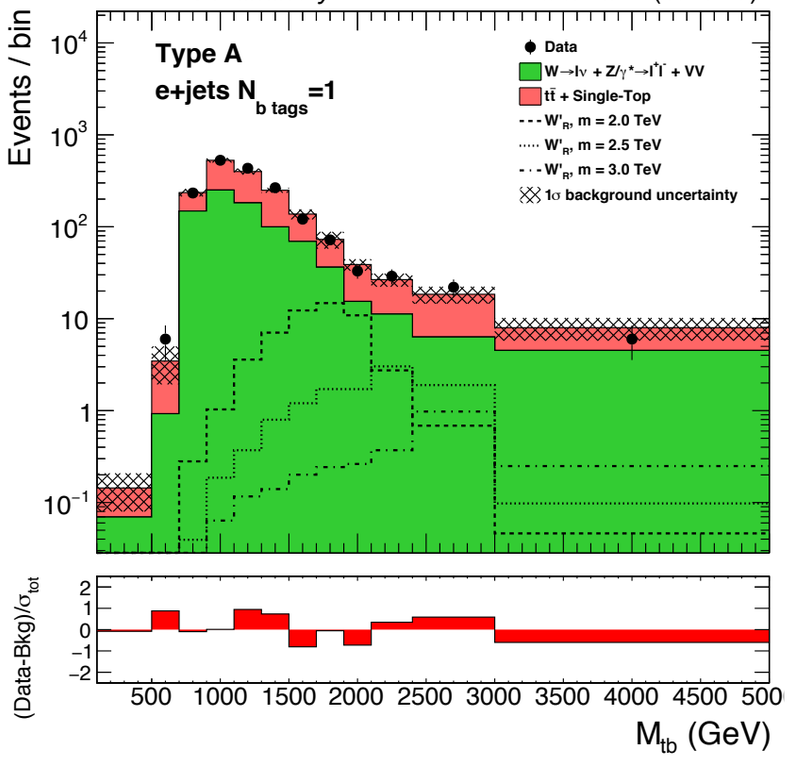
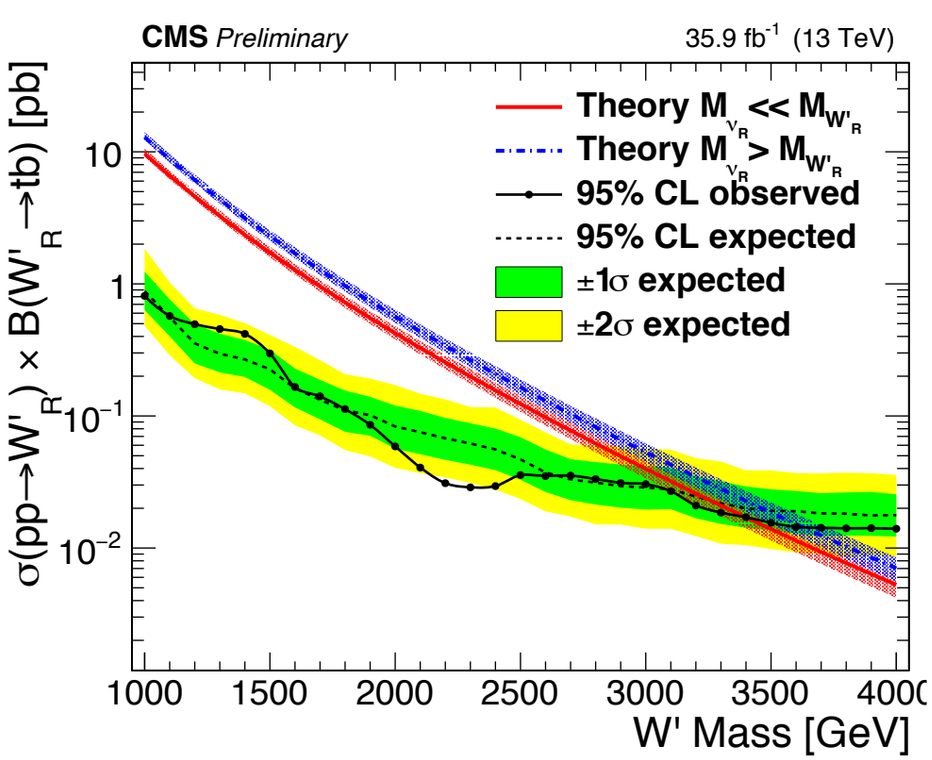
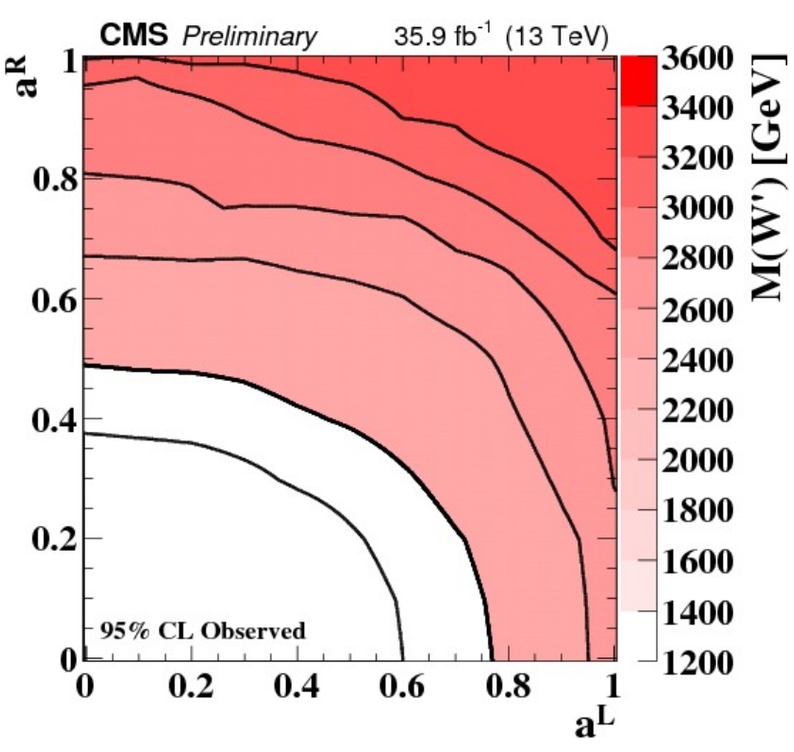


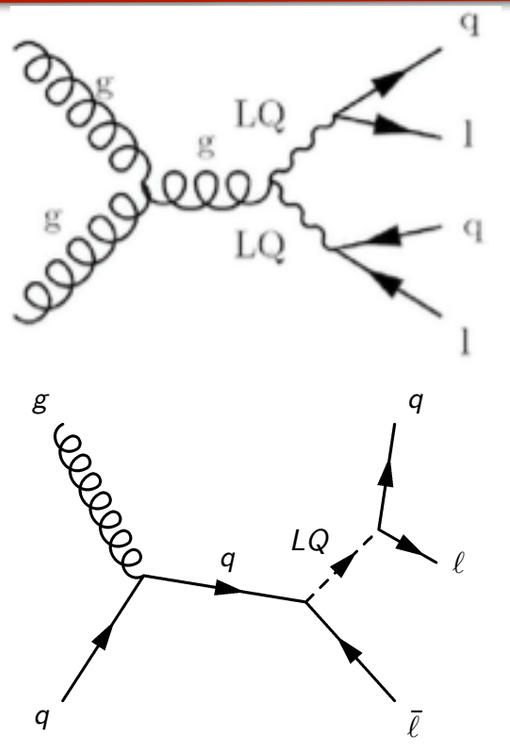




Exclude right-handed W' boson below 3.4TeV if $M_{W_R'} \gg M_{\nu_R}$ and 3.6TeV if $M_{W_R'} < M_{\nu_R}$

Leptoquark Search

Leptoquarks



- **Leptoquarks (LQs) arise in many models, such as grand unified theories, compositeness models and superstring theories.**
- **LQs: carry colour charge, fractional electric charge, and both lepton and baryon quantum numbers.**
- **If exist, decay into a lepton and a quark. Search for resonance of lepton+jet in experiment.**

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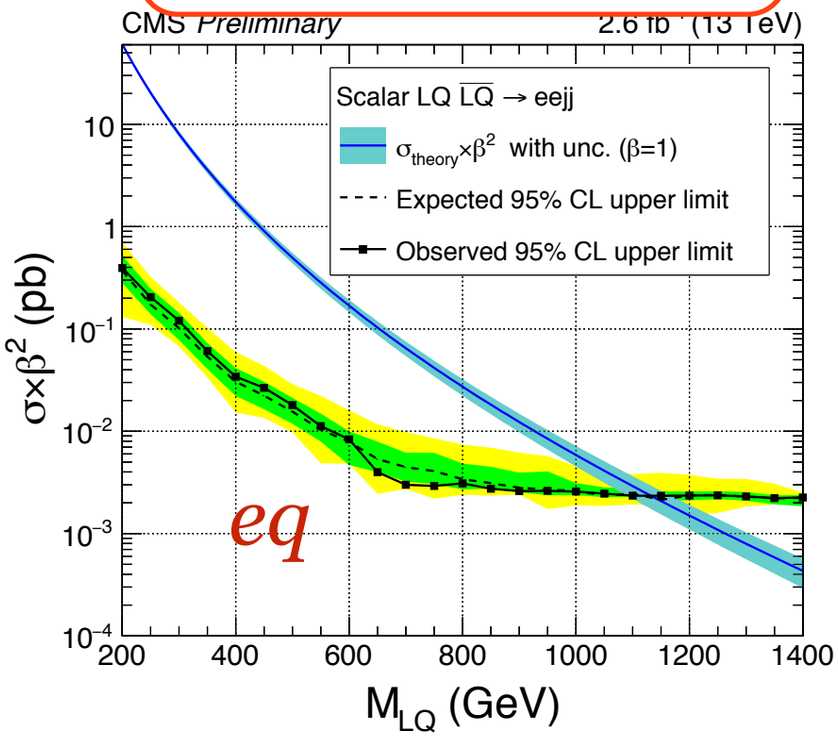
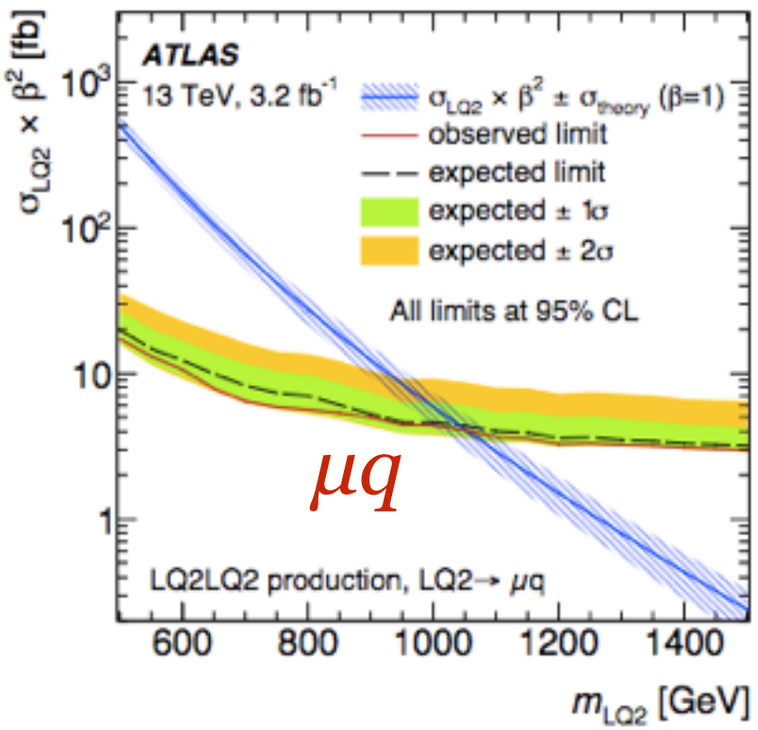


New J. Phys. 18(2016)093016



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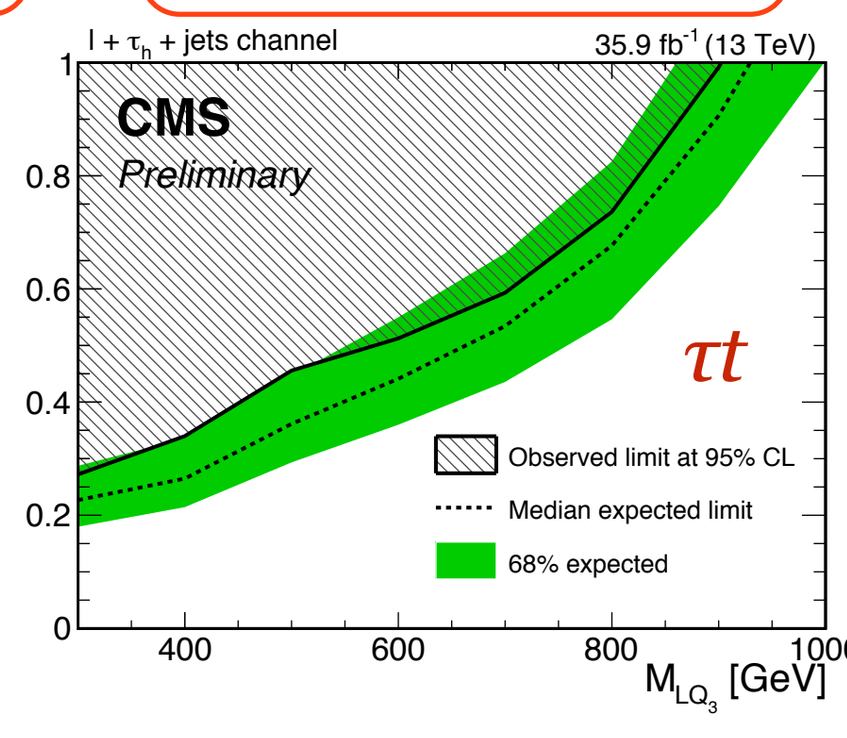
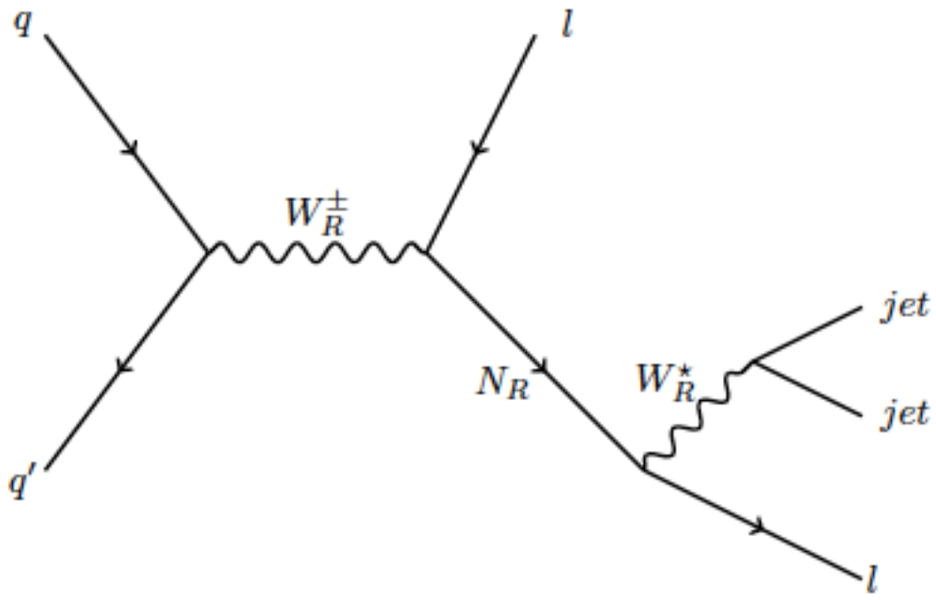


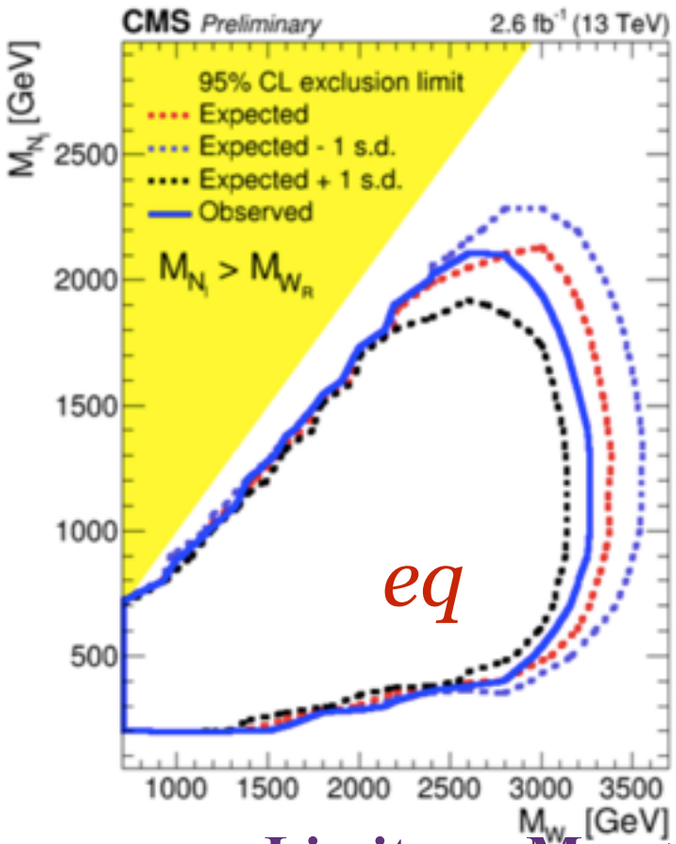
No significant excess observed in 2~36fb^{-1}. Results in terms of β = BR(LQ→*lq*)

Heavy Neutrinos

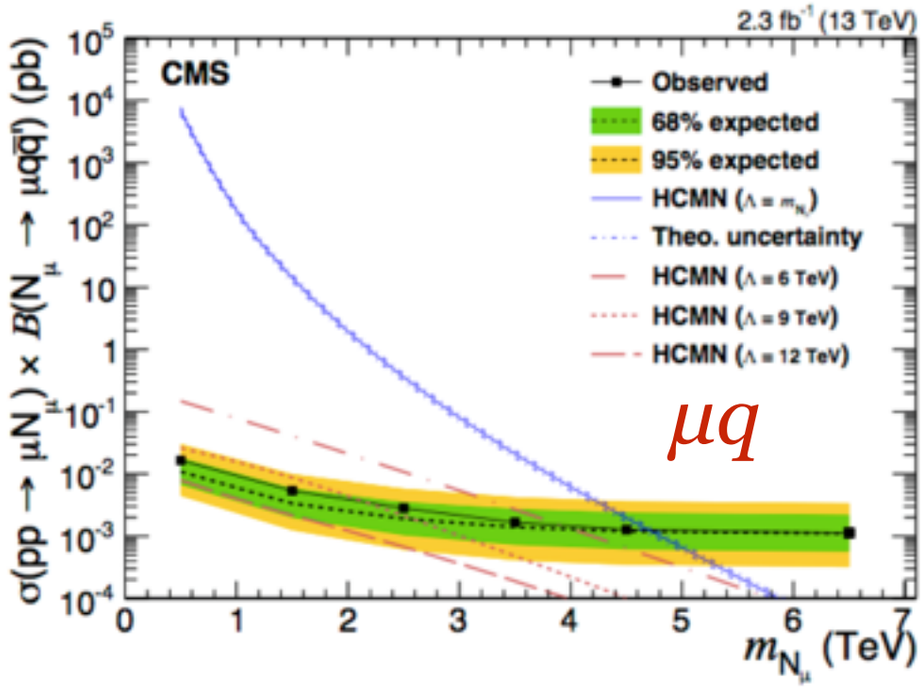


- **Heavy Neutrinos predicted in Seesaw models, LRSM and composite lepton models**
- **Those theories provide explanation for SM neutrino masses.**
- **Seesaw/LRSM also have W_R, signatures: $l^+l^- j\,j$**

CMS-PAS-EXO-16-045



Phys.Lett.B 2017.11.001



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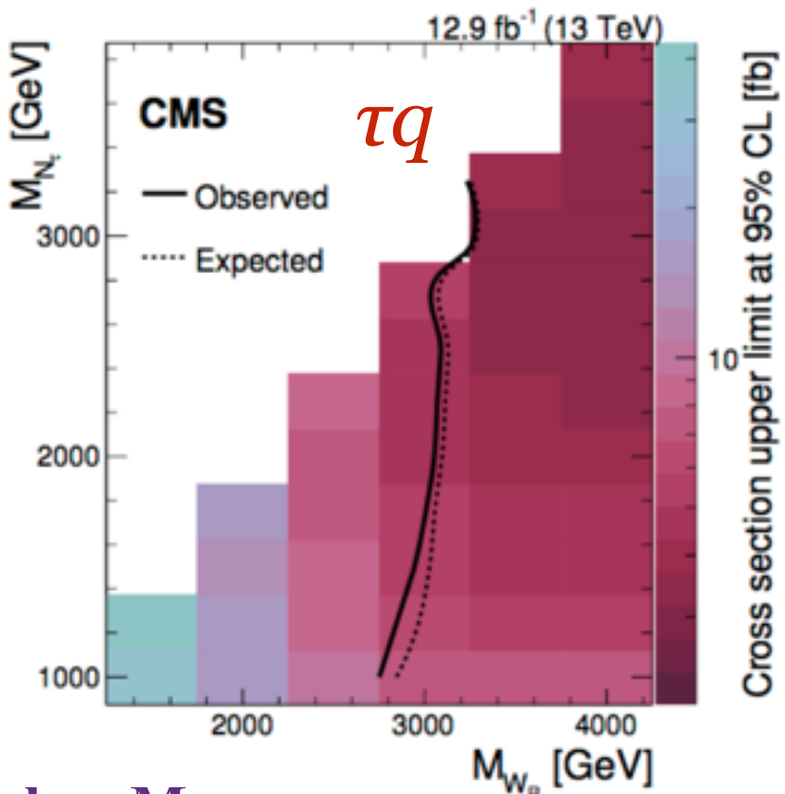
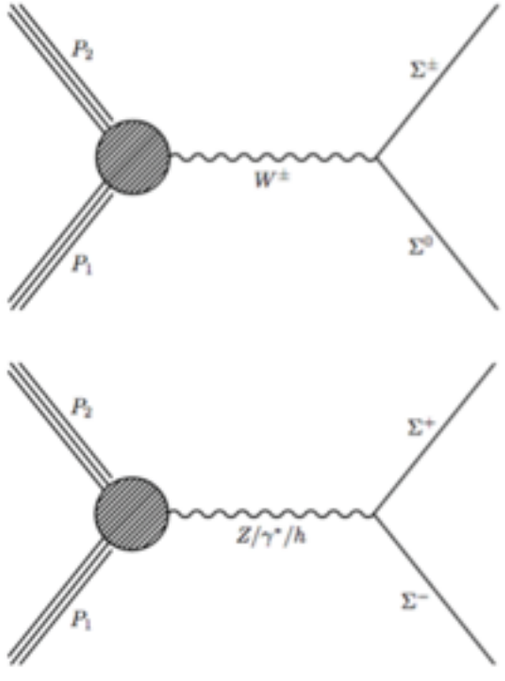


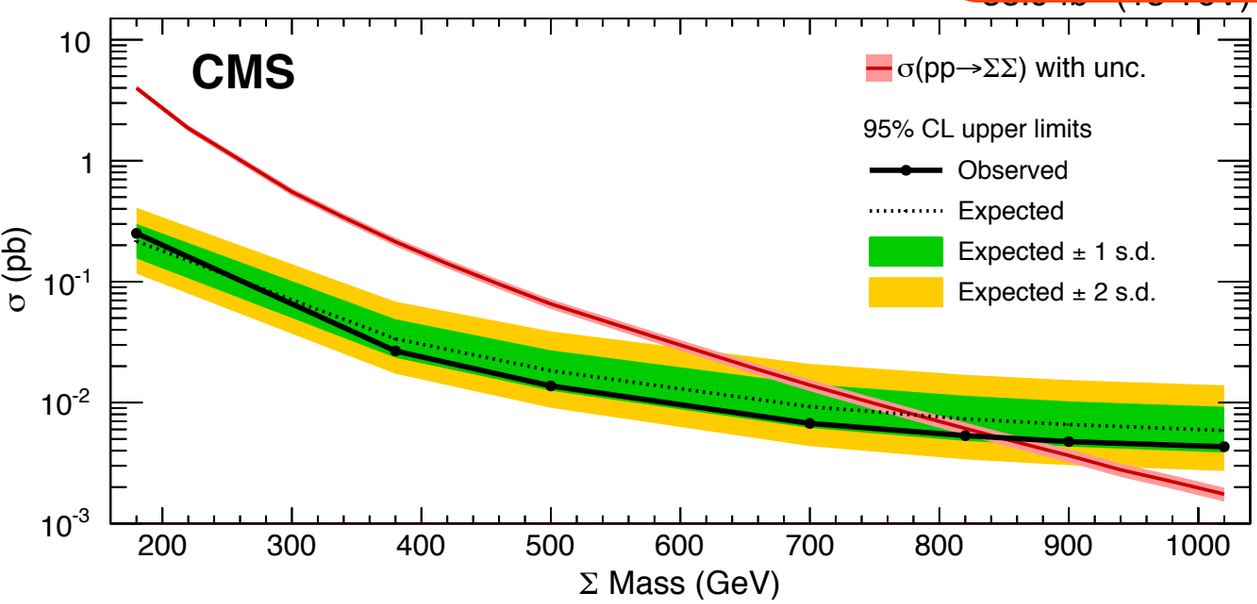
Limits on $M_{WR} > 3$TeV for a wide range of M_{NI} values below M_{WR}.

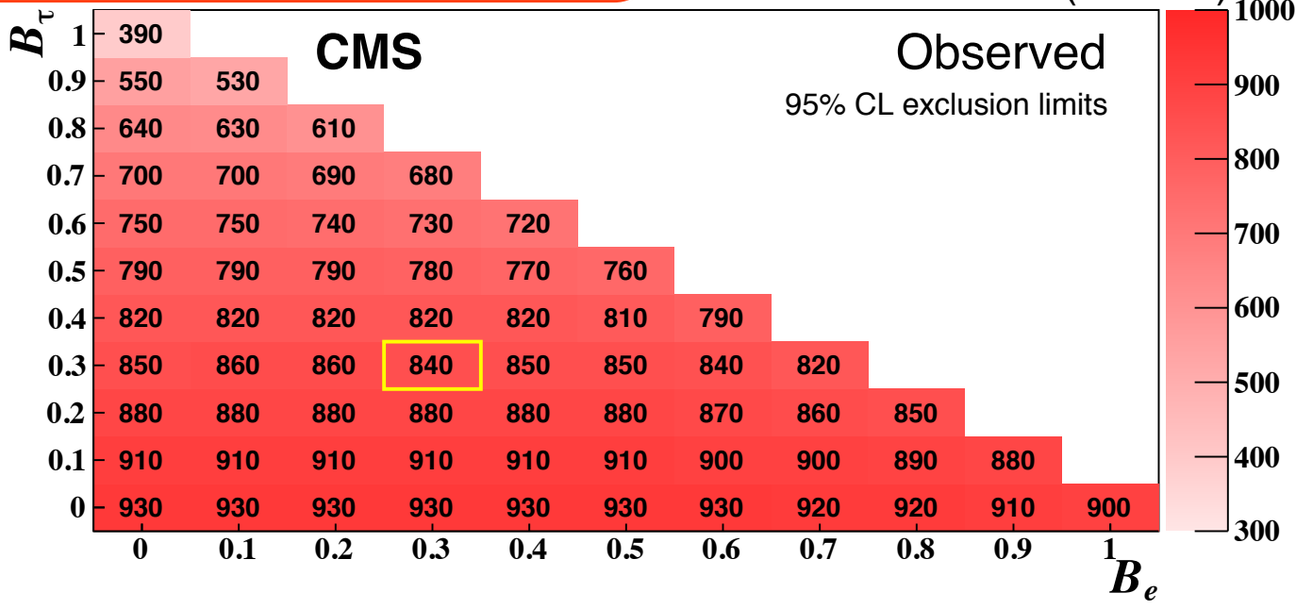
Type III Seesaw



- **Similar as Type I SS. But neutrino mass arises from mediation of massive SU(2) triplet $\Sigma^{\pm}$, Σ^0**
- **Decay through** $\Sigma^{\pm} \to W^{\pm}\nu, \Sigma^{\pm} \to Z\ell^{\pm}, \Sigma^{\pm} \to H\ell^{\pm}$, $\Sigma^0 \to W^{\pm}\ell^{\mp}, \Sigma^0 \to Z\nu, \Sigma^0 \to H\nu$,
- **$\Sigma^{\pm}\Sigma^0, \Sigma^{\pm}\Sigma^{\mp} \to \geq 3\ \ell^{\pm}$, search with multi lepton final states**

Phys.Rev.Lett. 119(2017)221802





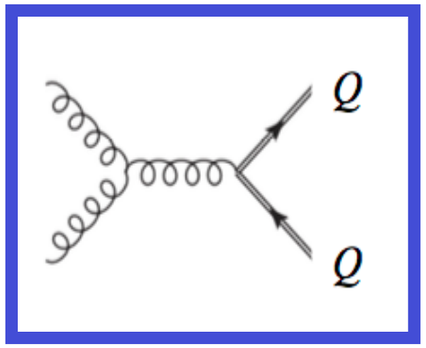
Most sensitive probe to date of the type III seesaw mechanism:

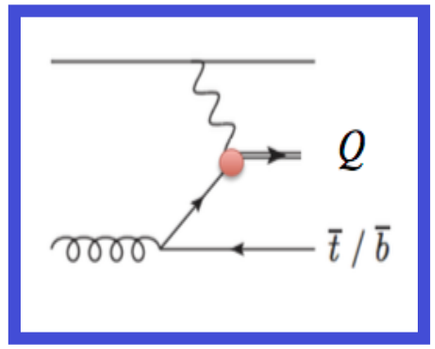
exclude the heavy fermions < 840GeV

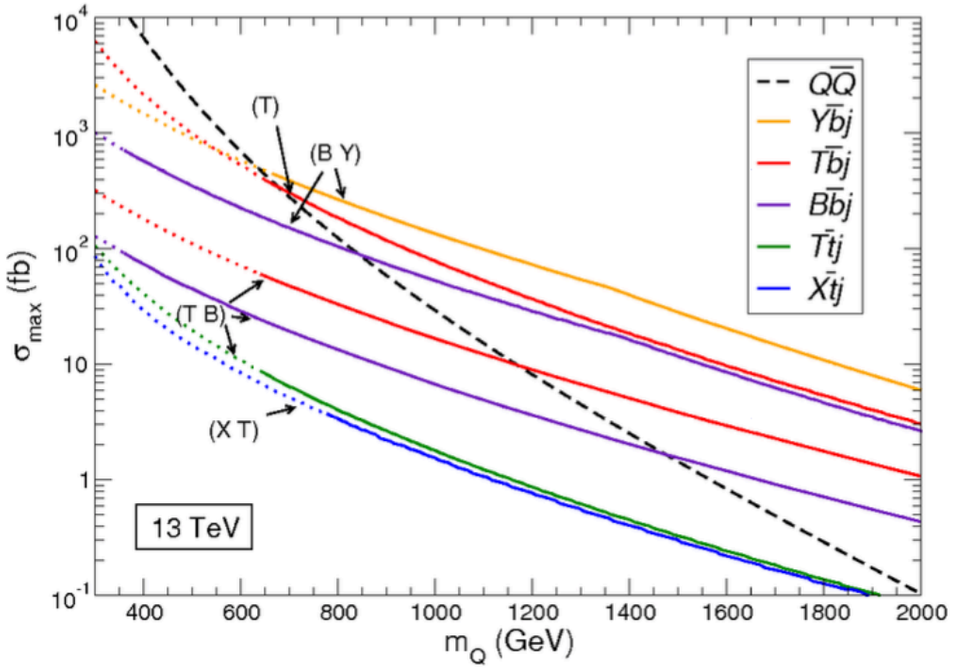
Vector-Like Quarks Search

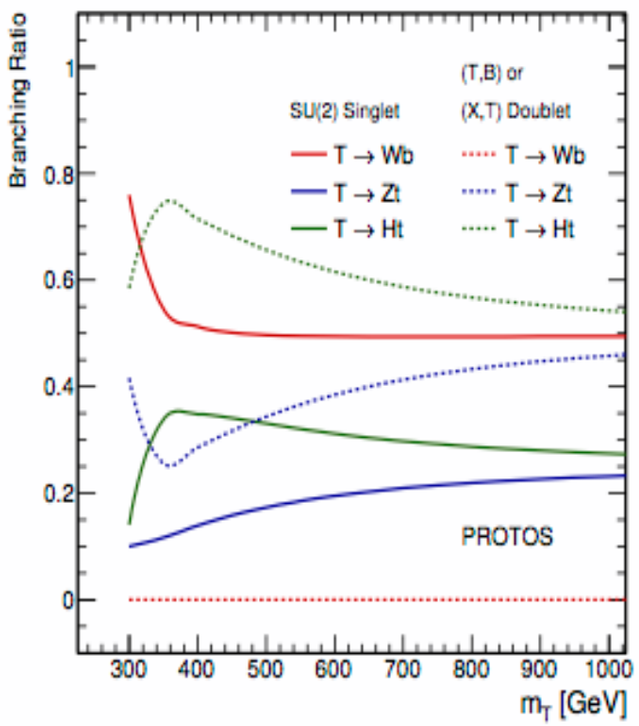
Vector-Like Quarks

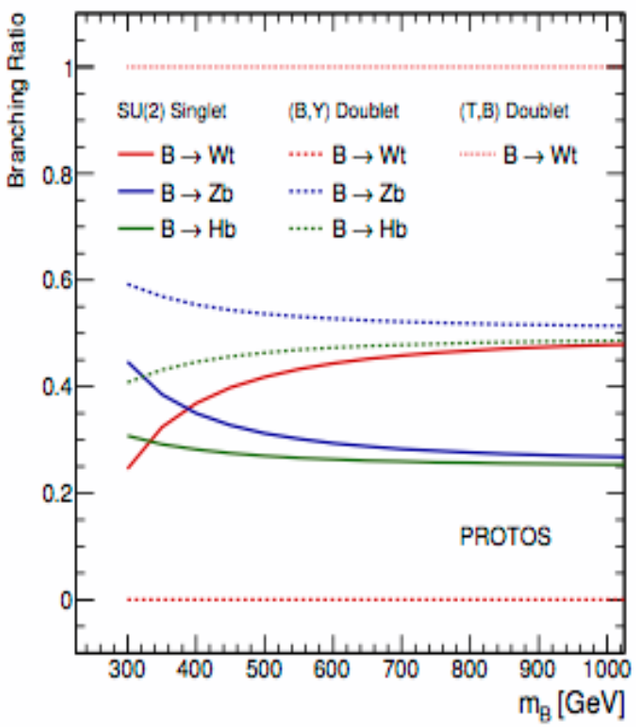
- Extra family of spin 1/2 quarks
  - symmetric vector-like coupling to W/Z
  - Mass from direct mass term
  - Can solve hierarchy problem
- Pair production from strong interaction
  - Model independent
- Single production from electroweak
  - Depends mixing with SM quarks
- Decays to boson+heavy quark



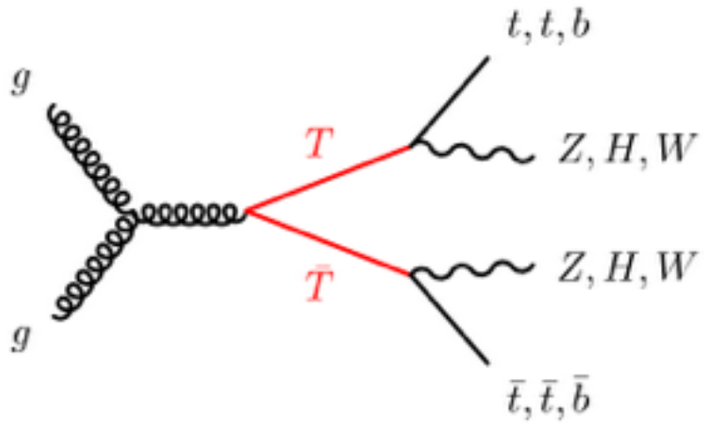








Pair-Produced VLQ



- **Search with final state Wb:**
  - **both T decay to Wb**
  - **one W decay to lv**
  - **one W decay to qq**
- **Neutrino constrained by W mass**

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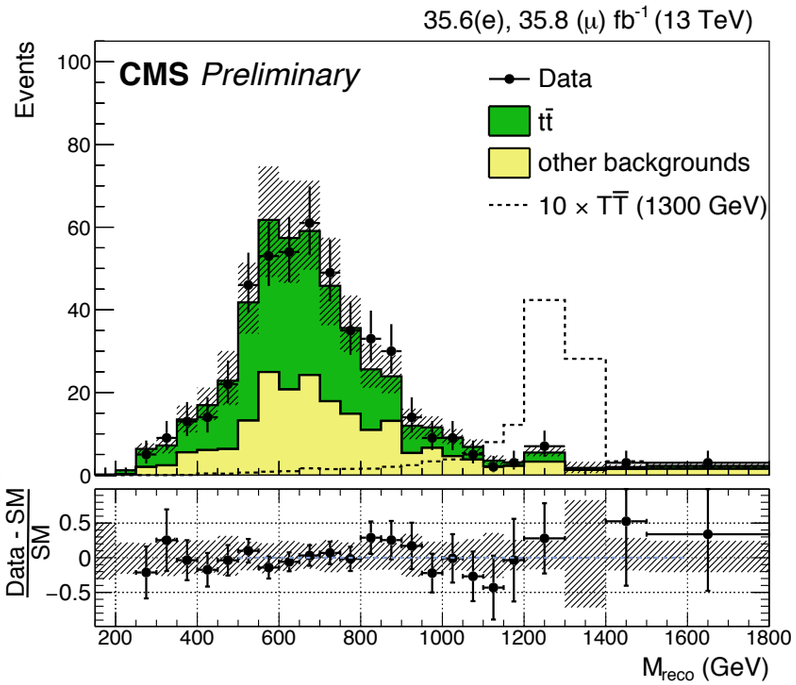

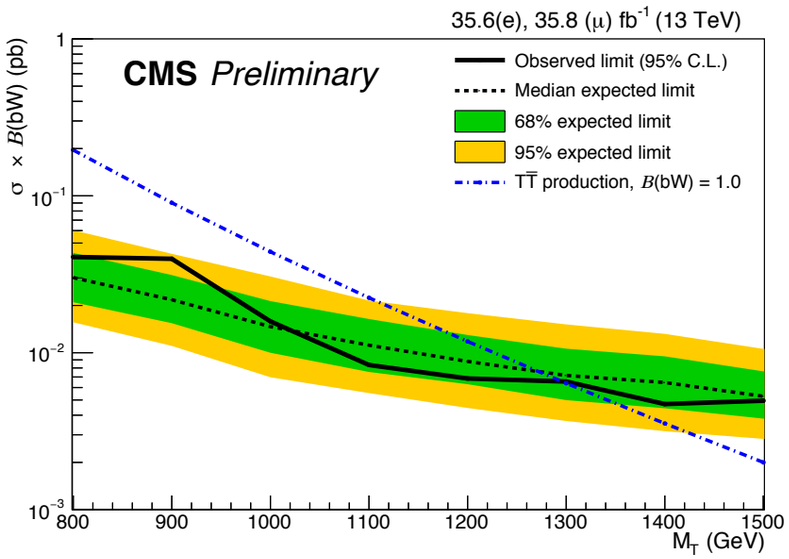

Limit for M_T at 1295 GeV if BR(T→Wb) =1

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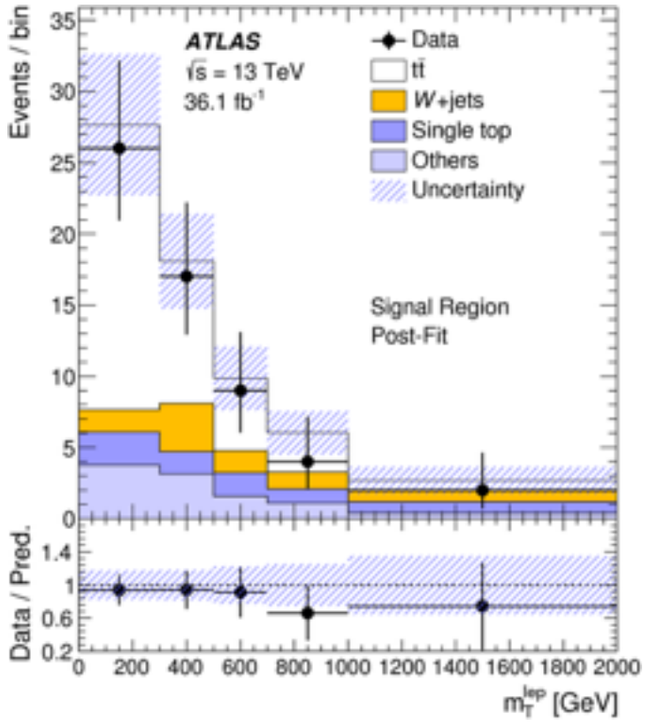
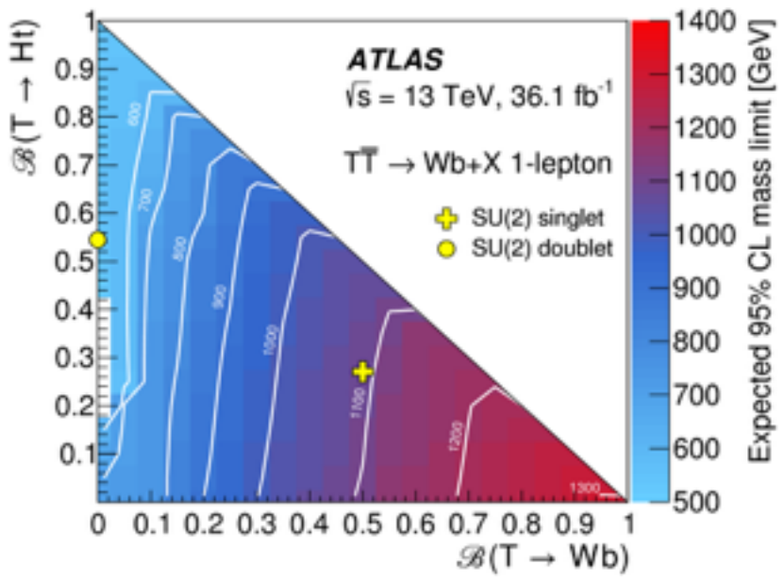
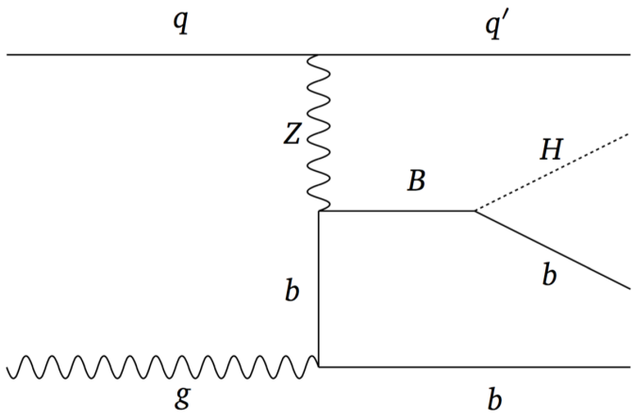


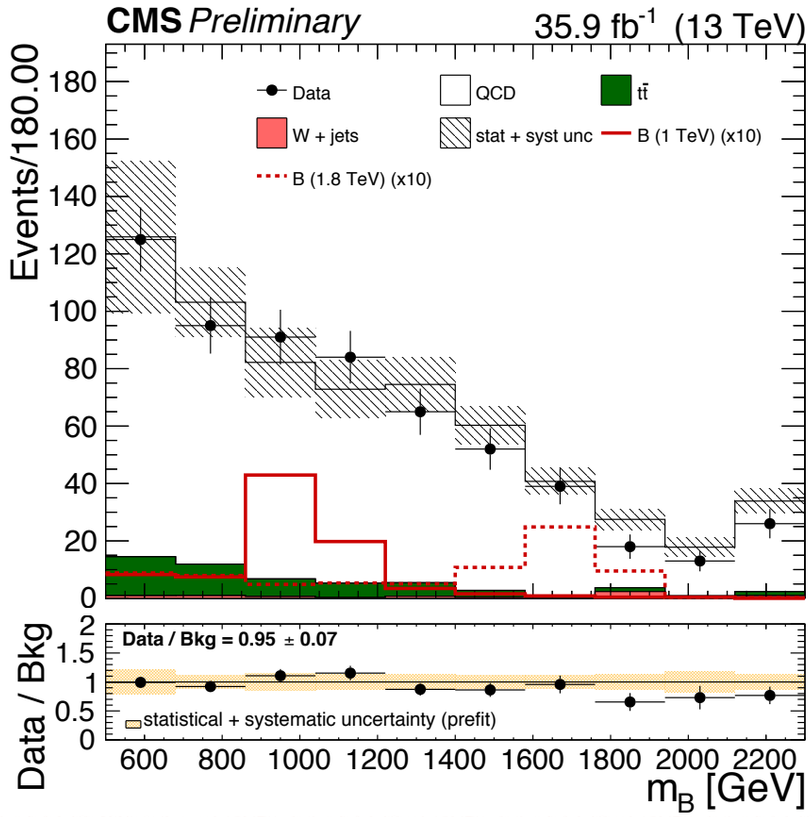


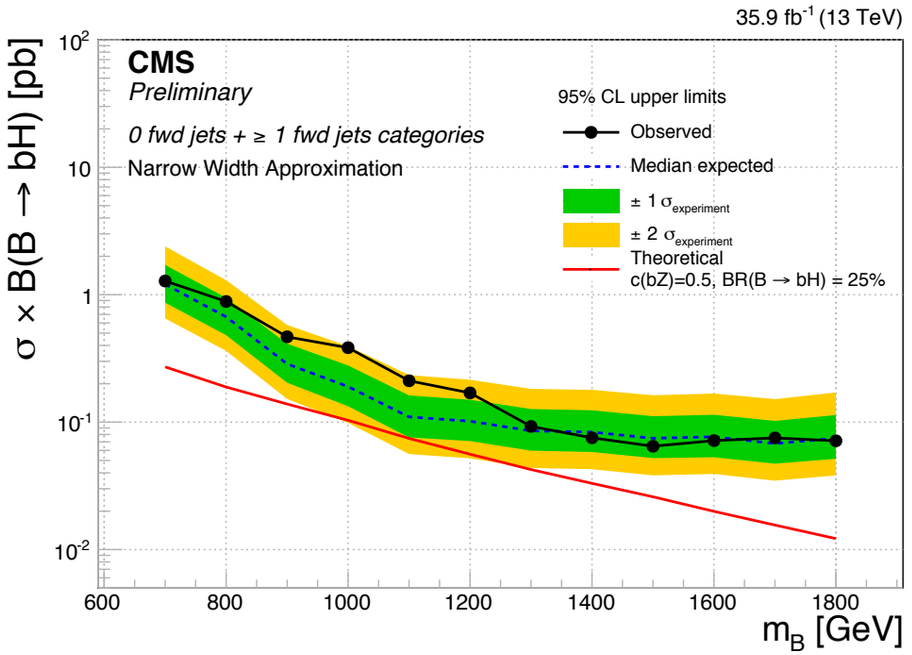
Limit for M_T at 1350 GeV if BR(T→Wb) =1

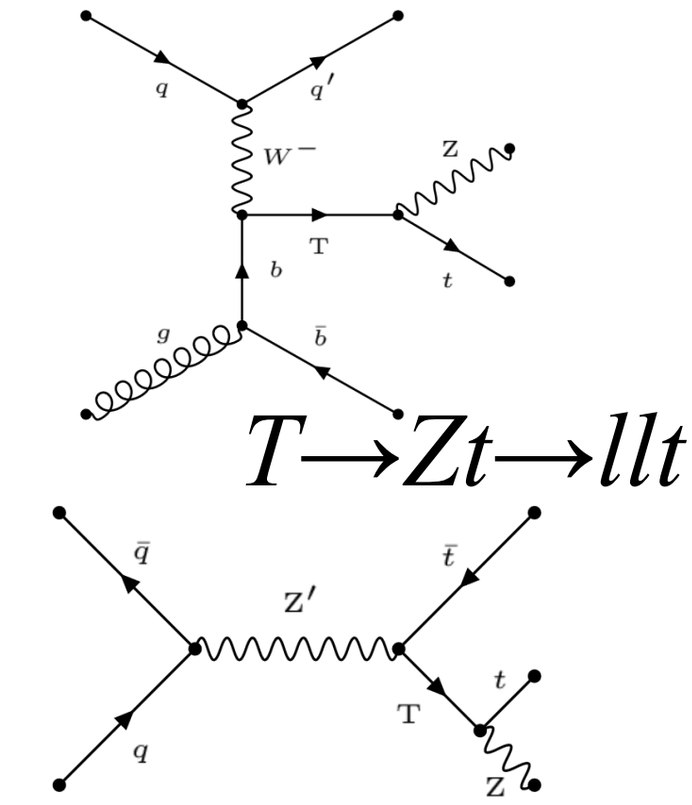
Singly Produced VLQ



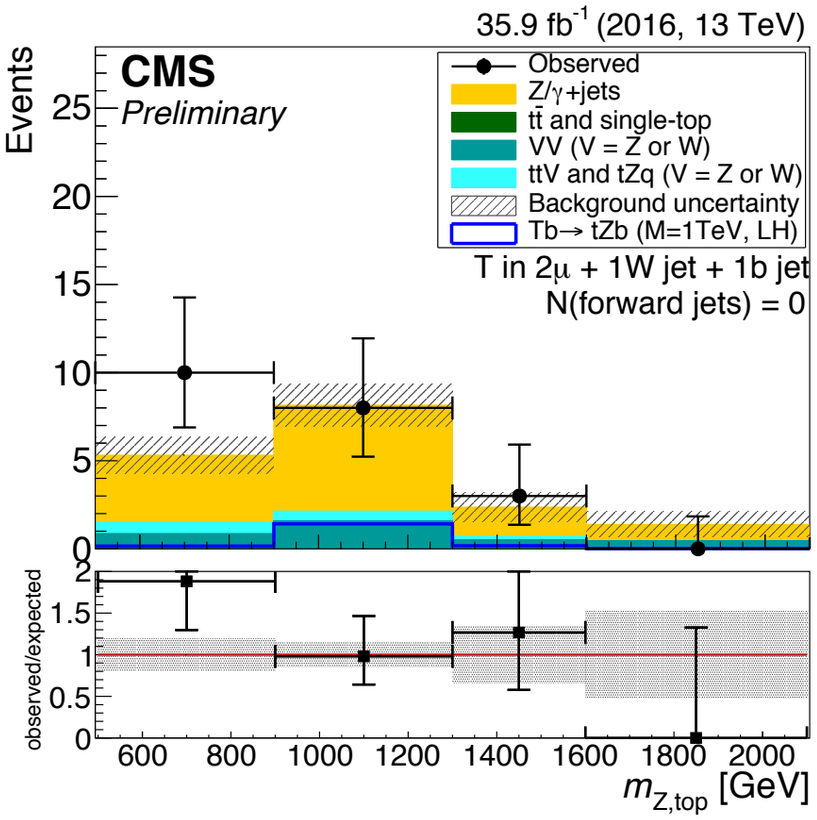
$B \rightarrow Hb \rightarrow bbb$

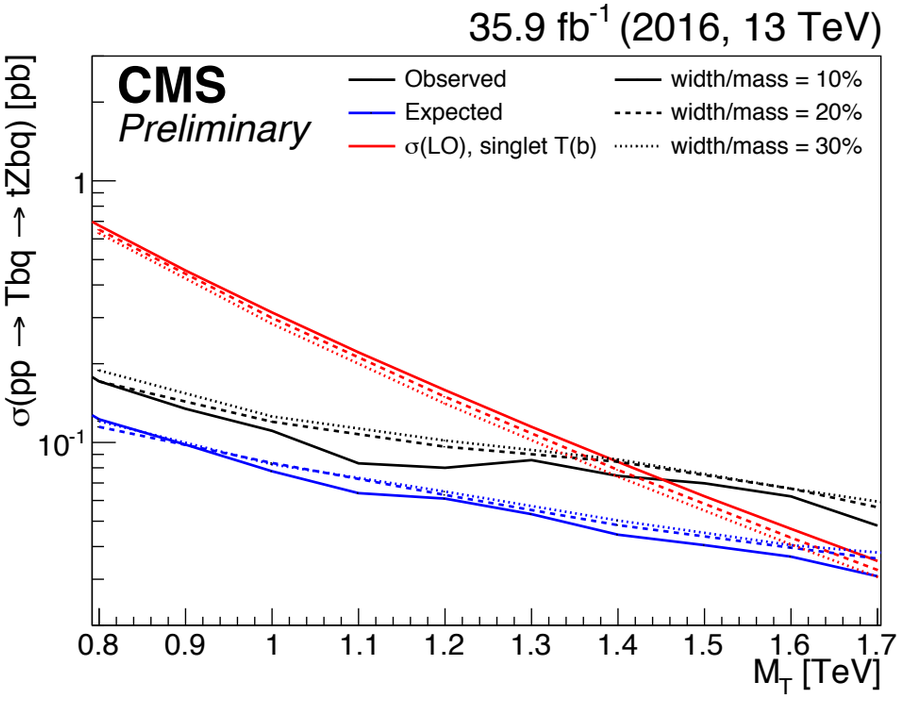






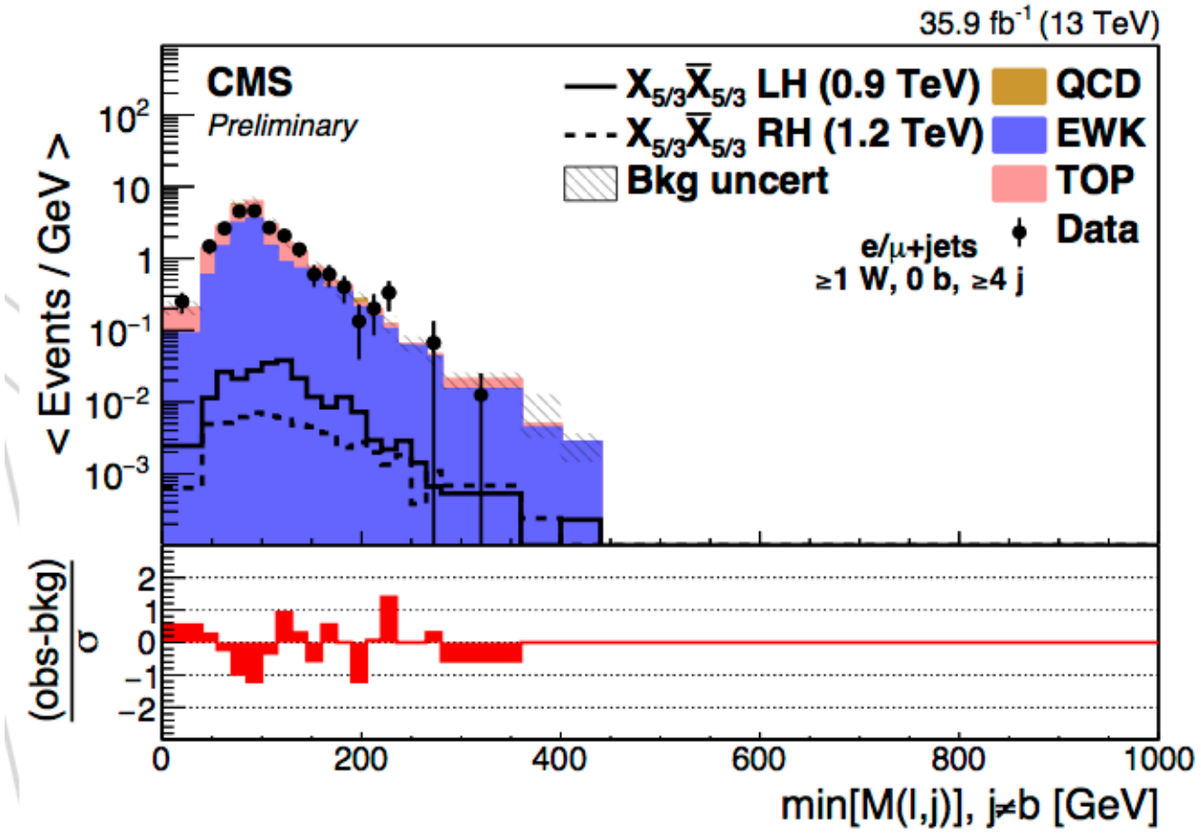
$T \rightarrow Zt \rightarrow llt$





Pair Produced $X_{5/3}$

- Heavy vector-like top quark partner
  - Exotic 5/3 charge, decay to tW
- FS: 1 lep + >= 4jets + MET
- Analyse 8 cat. based on
  - Number of tagged W, t and bjets



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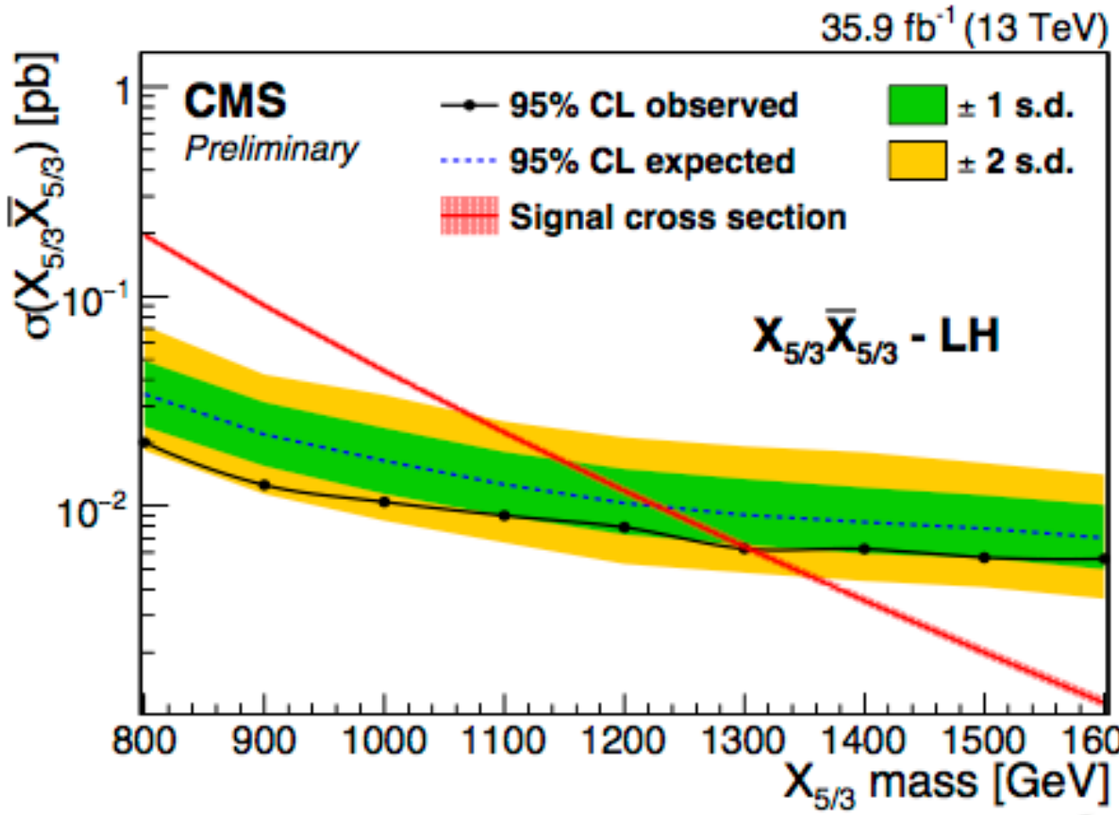
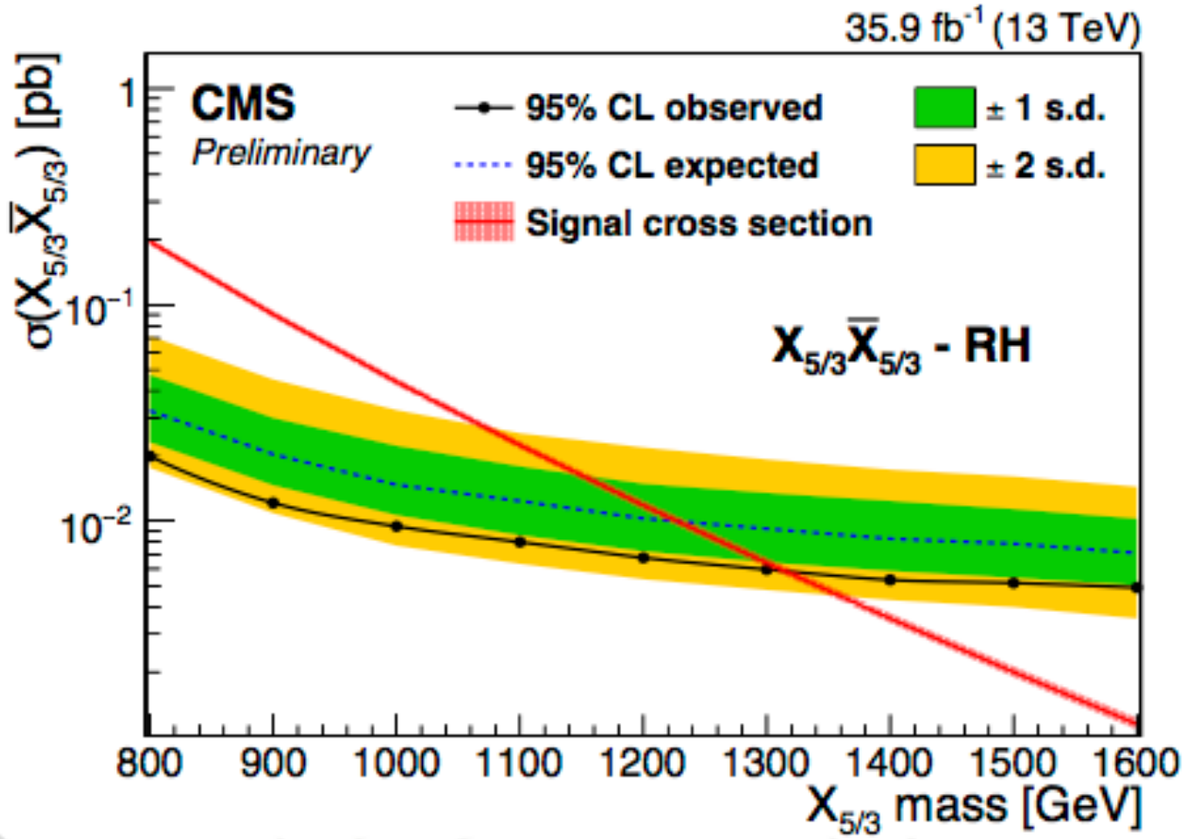


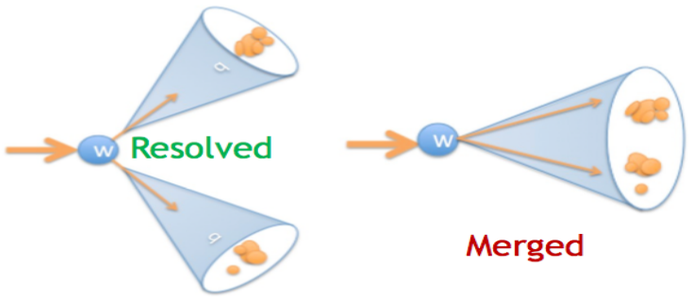


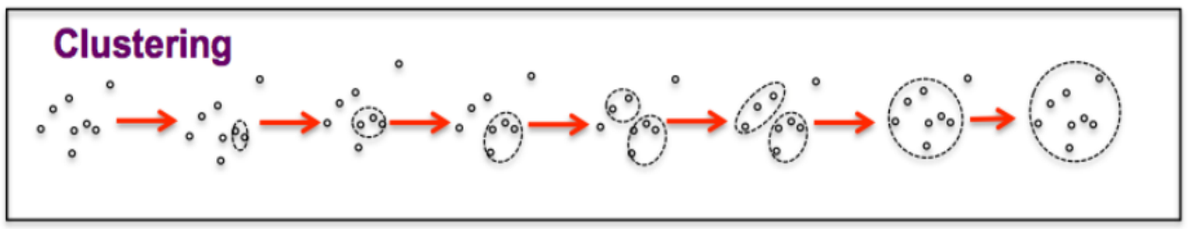
Di-boson Resonance Searches

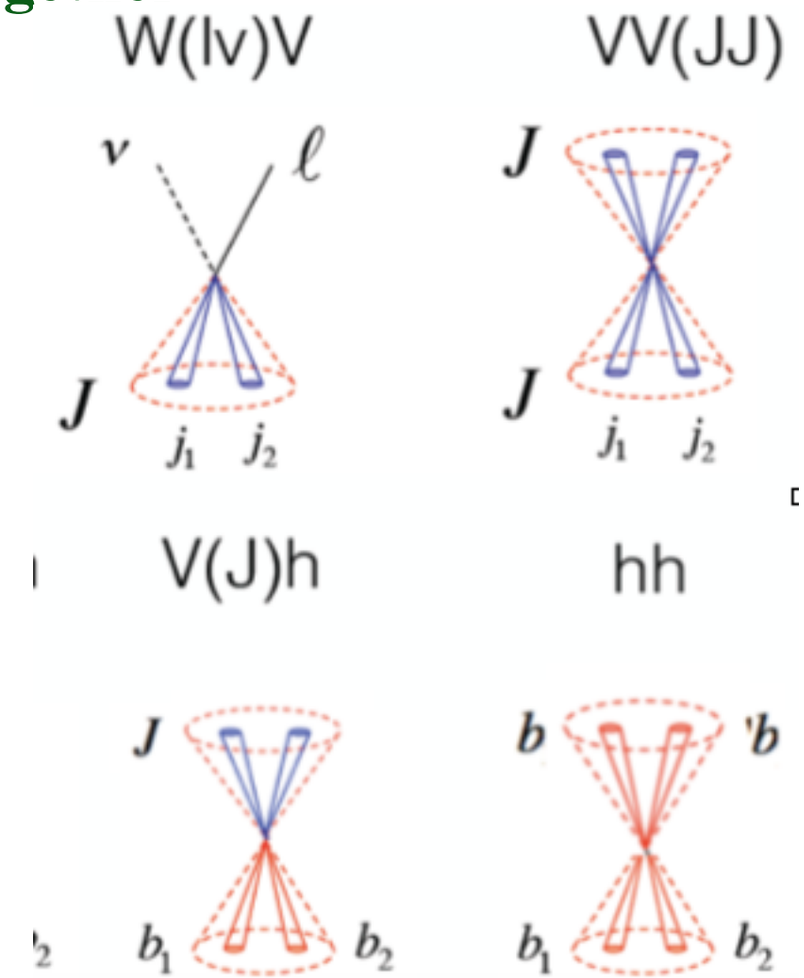
Diboson Resonance

- Rich program of diboson resonance search
  - Spin 0: S/H → WW/ZZ: extended Higgs sectors, scalar singlet
  - Spin 1: V' → VH/VV: Heavy Vector Triplet
  - Spin 2: G* → VV: Extra dimensions
- Unable to cover all the final states in this talk. Only select a few recent results.

- Highly boosted W/Z/H decay products are merged together
- Use jet sub-structure algorithm to tag boosted object

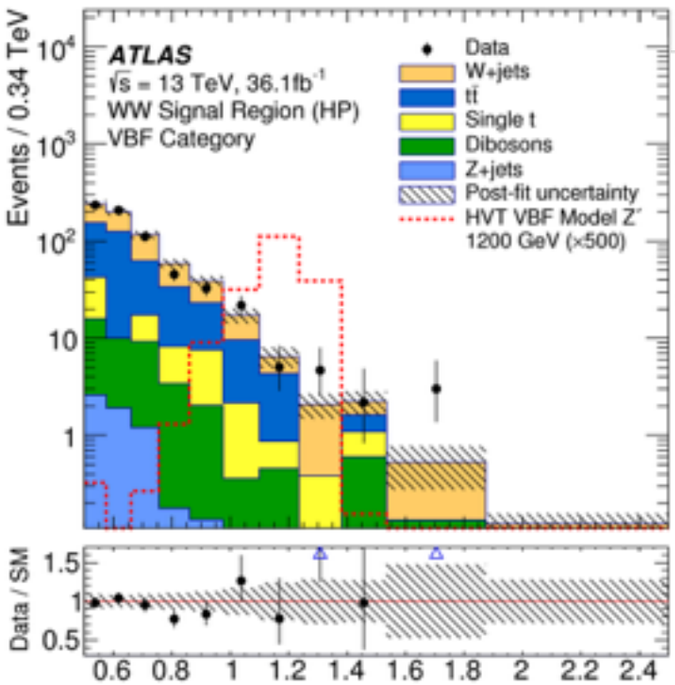


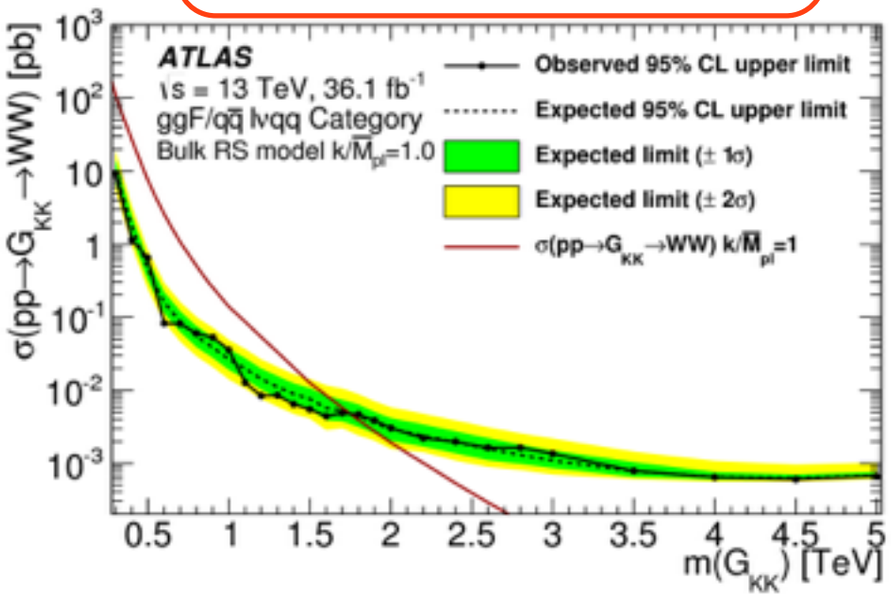


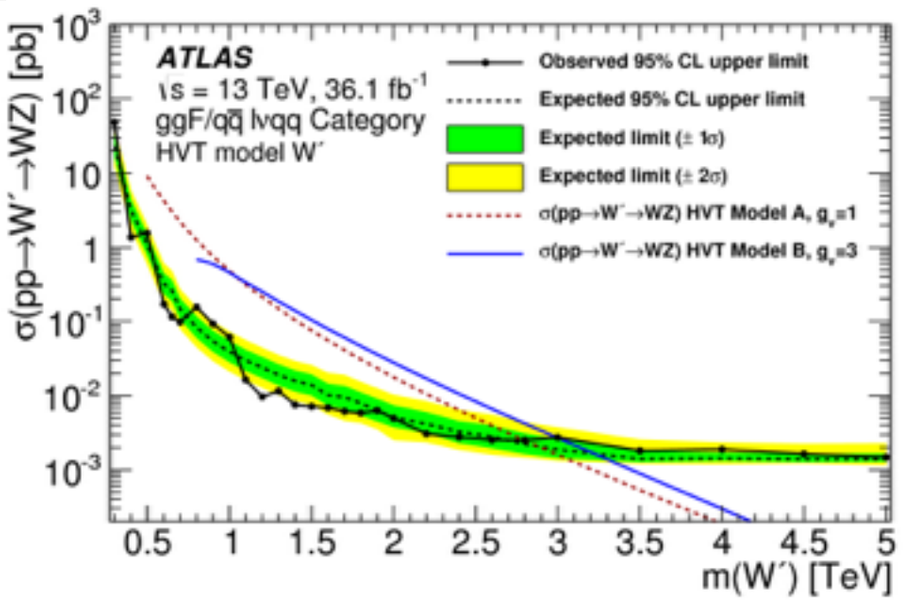


WW/WZ → lvqq

arXiv:1710.07235







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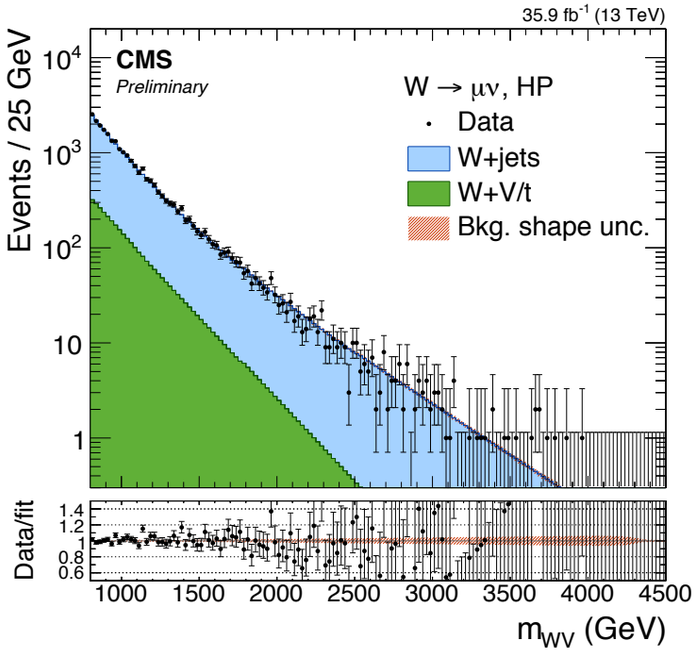
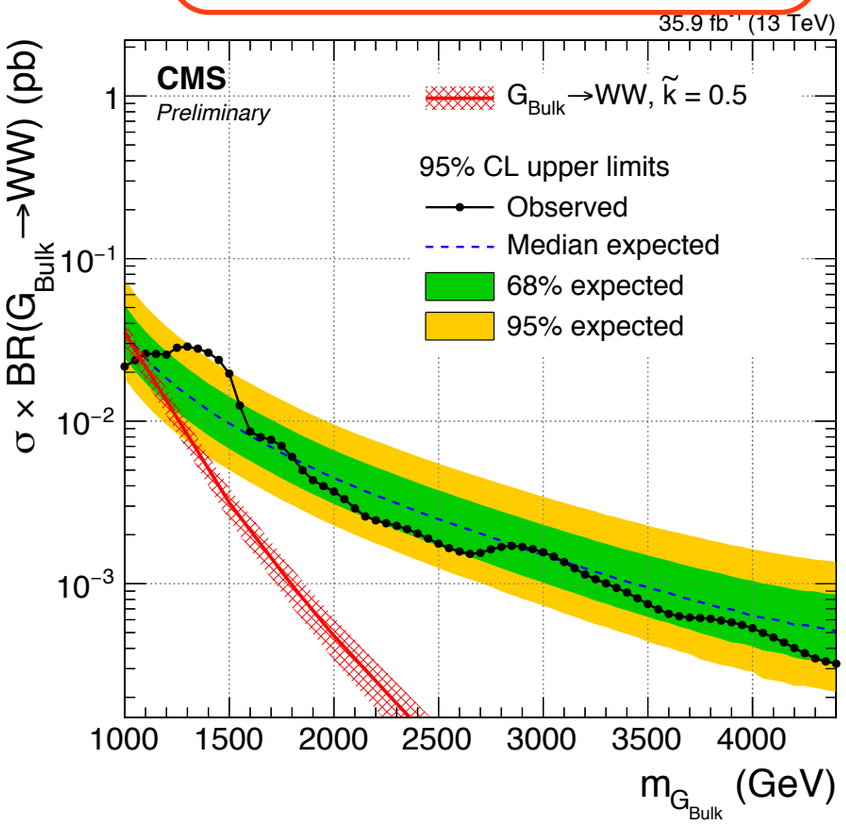
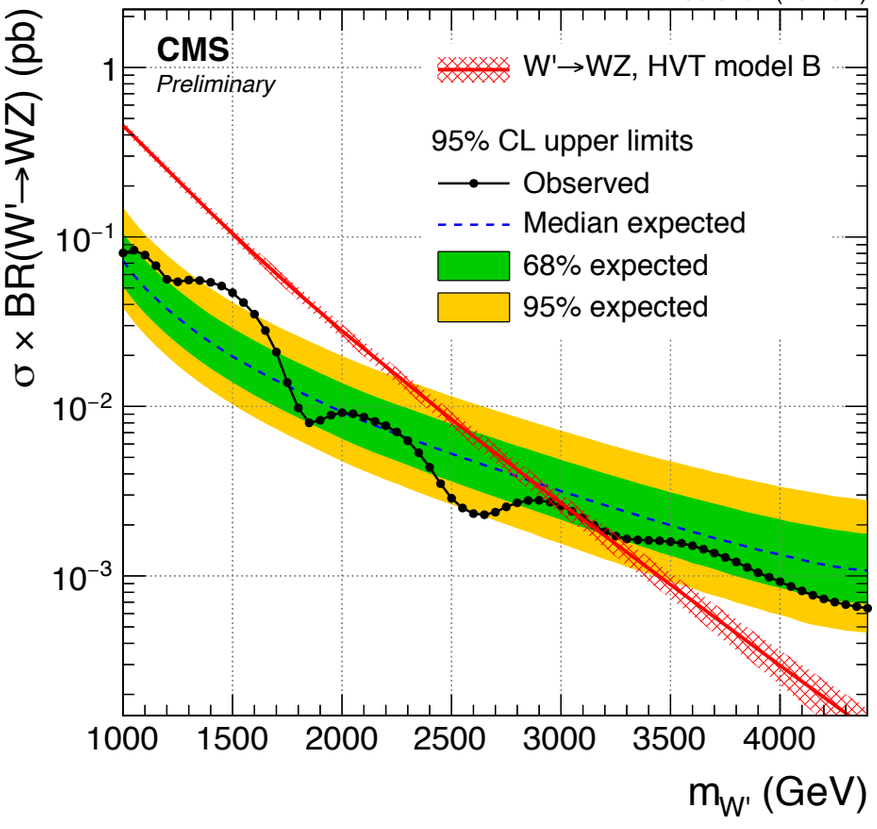


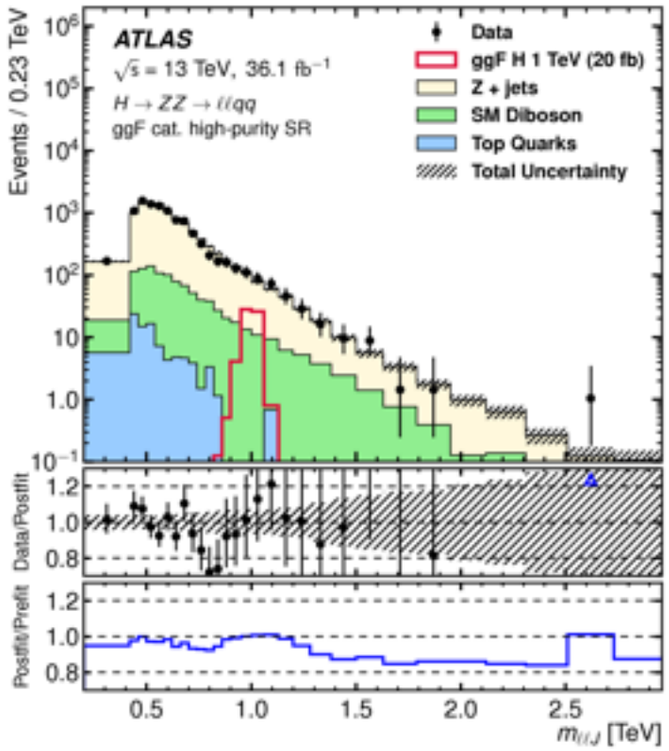


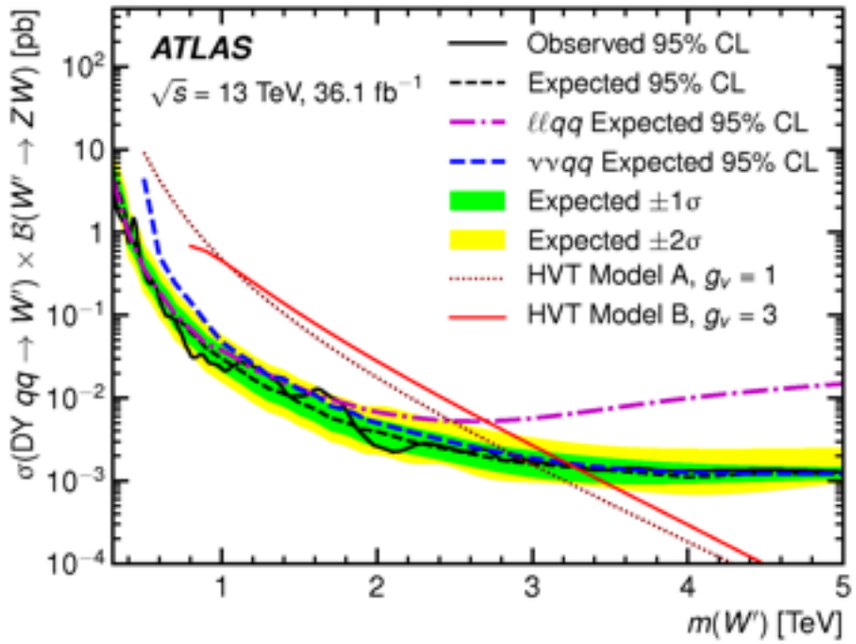


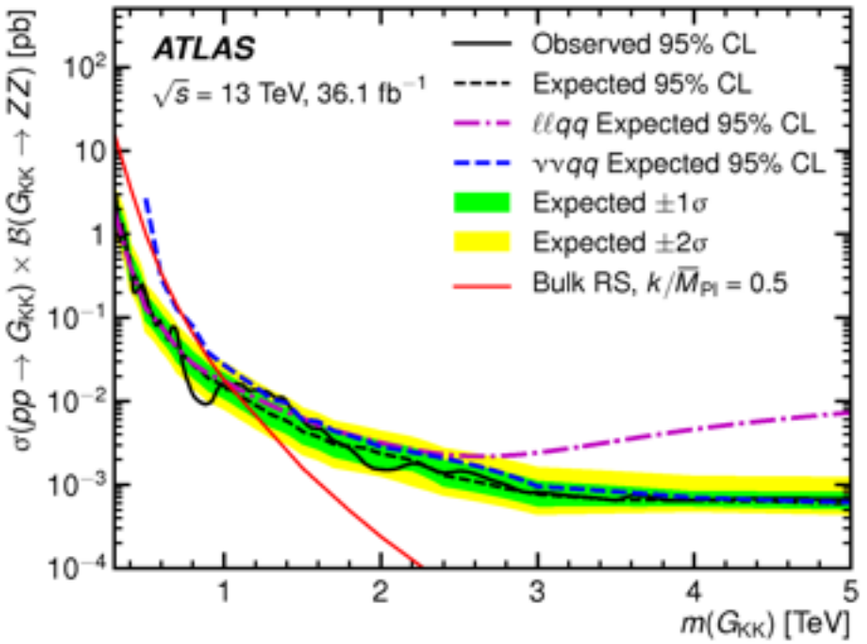
Limits for Bulk Graviton > 1TeV, while limits for HVT model W' ~ 3TeV

ZW/ZZ → llqq/vvqq

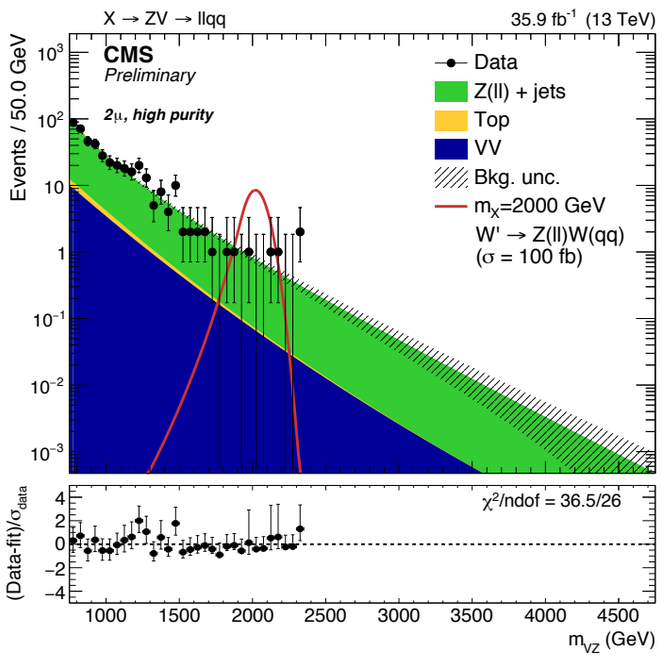
arXiv: 1708.09638

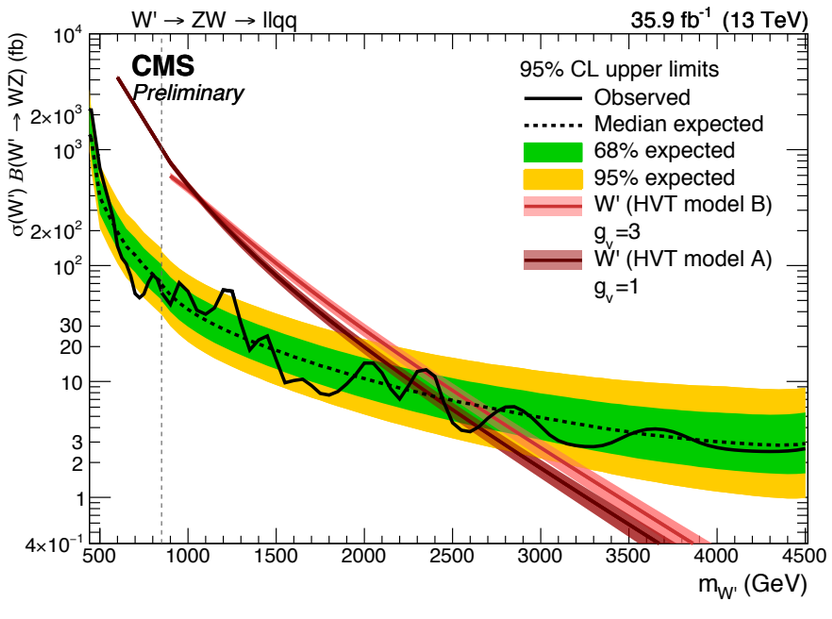


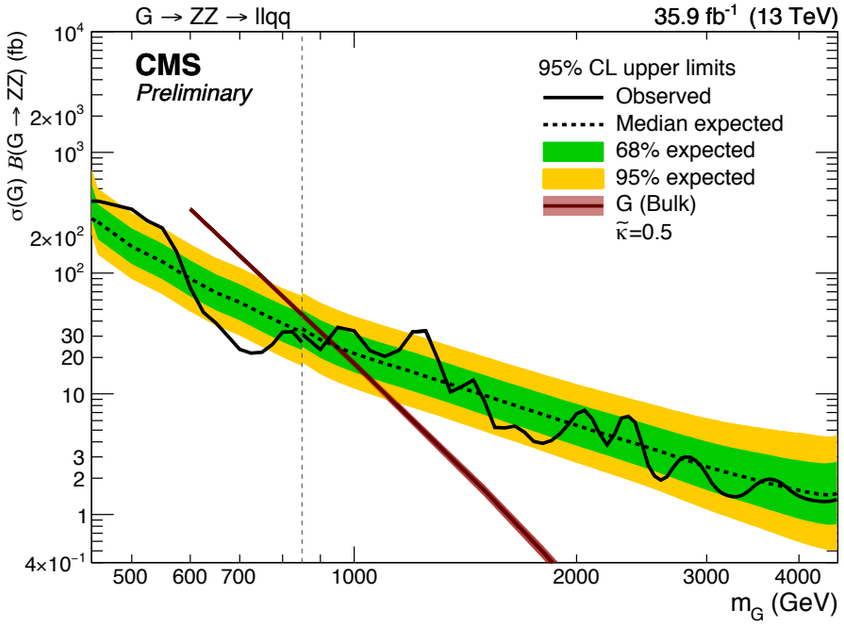




CMS-PAS-B2G-17-013

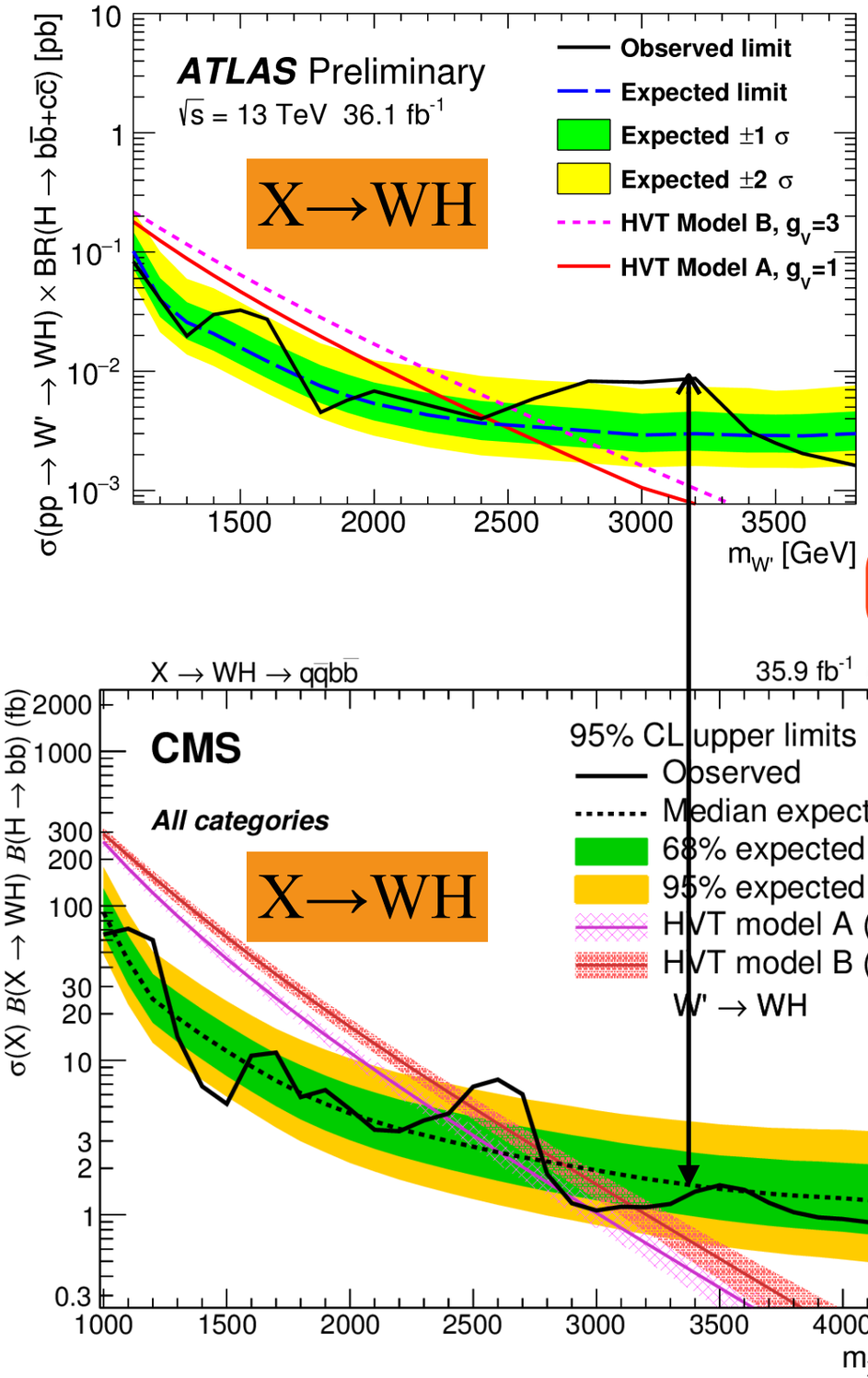


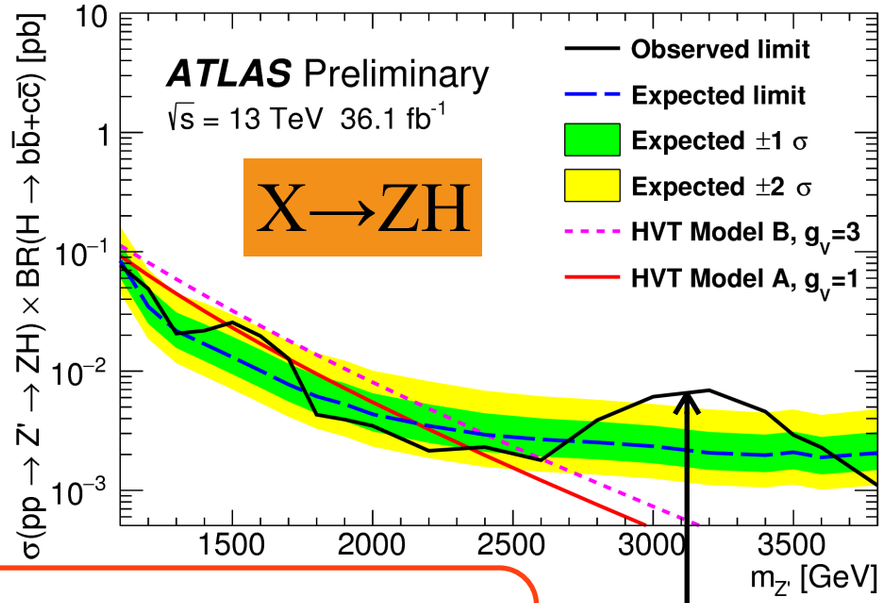




Limits for Bulk Graviton > 1TeV, while limits for HVT model W' ~ 2.5 TeV

$VH \rightarrow qqbb$





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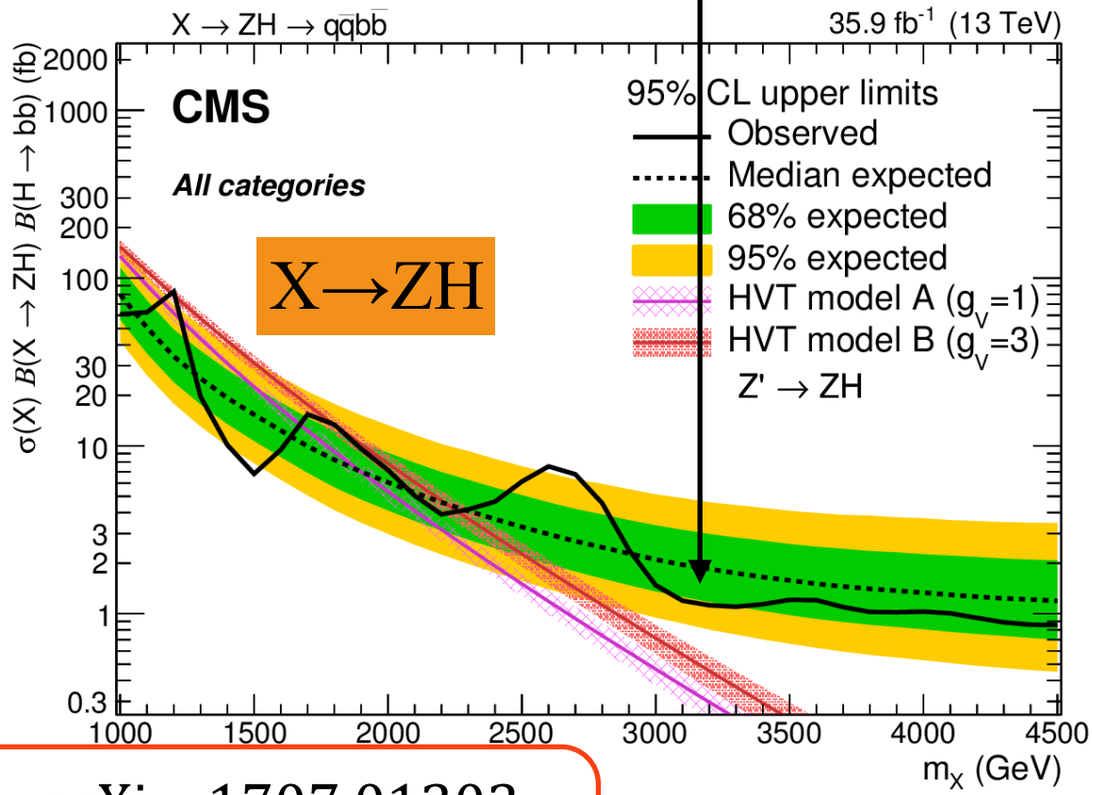


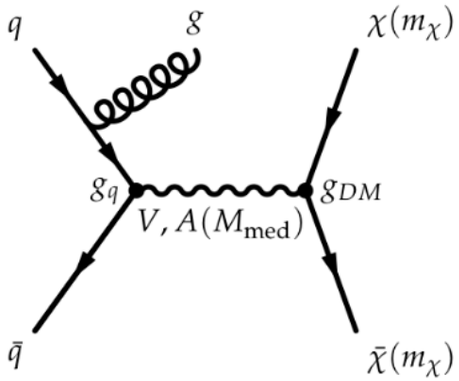
arXiv: 1707.01303

No significant excess found. Limits set on bench mark models and coupling plane.

Dark Matter Searches

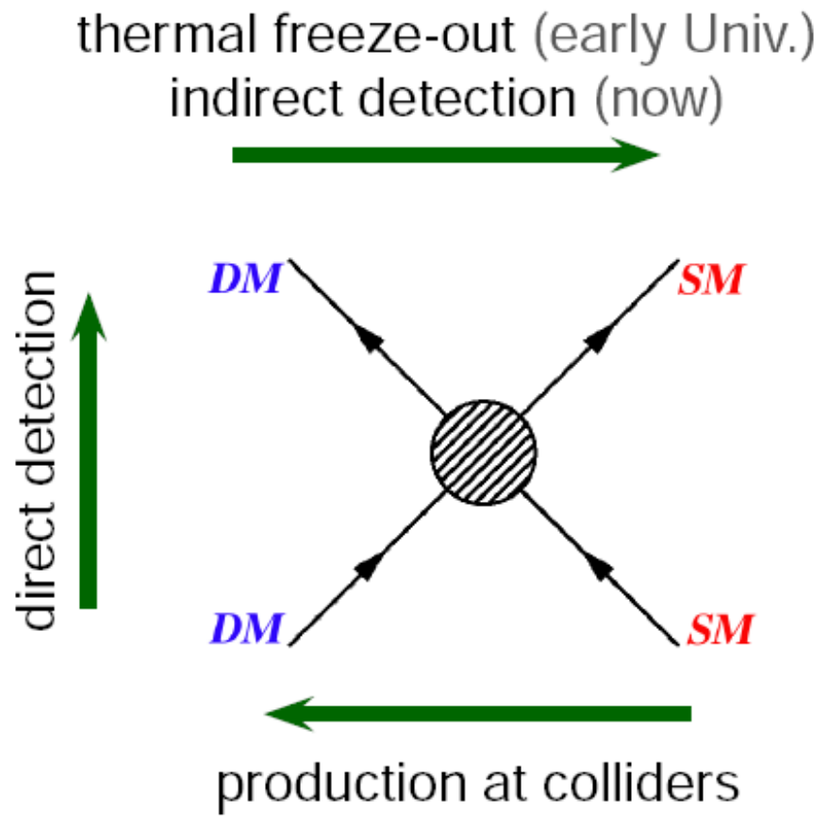
Dark Matter Bench Mark Models at LHC

- **Keep the mediator information.**
- **Simplified model with parameters of**
  - **$M_{mediator}$, M_{χ}, gq, g_{χ}**

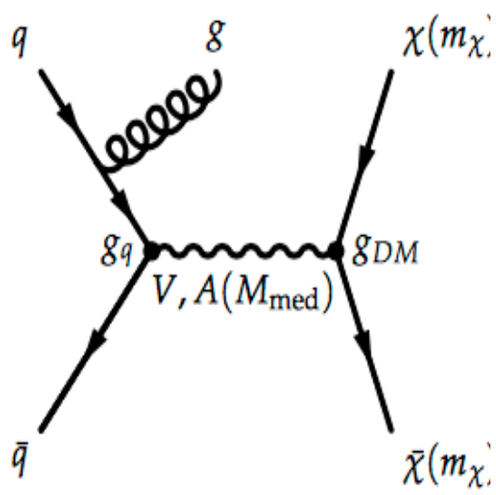


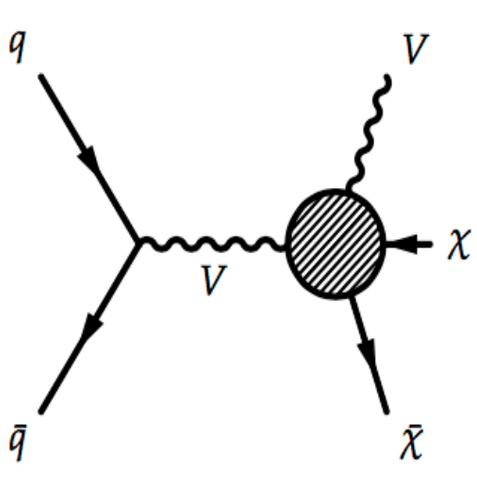
$$\mathcal{L}_{\text{vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$

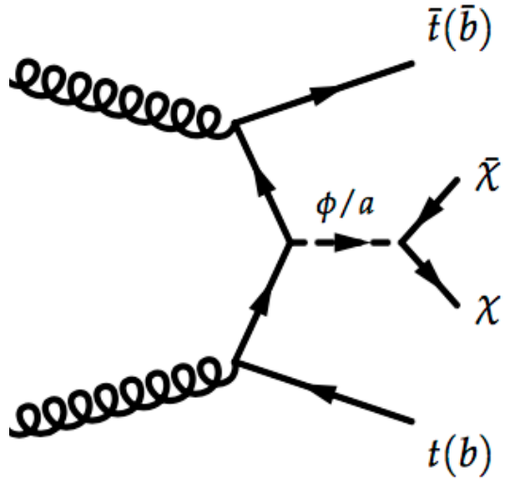
$$\mathcal{L}_{\text{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu\gamma^5 \chi$$

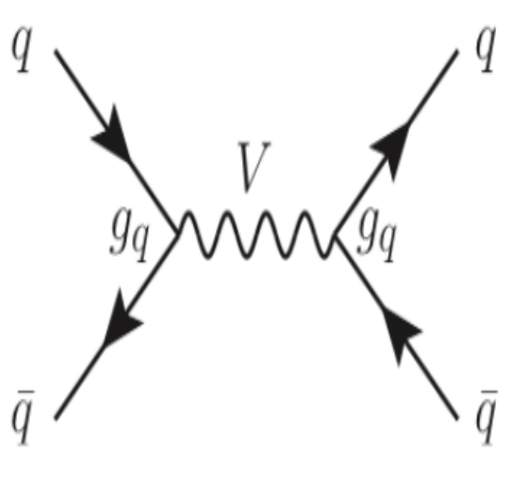


- **Searches with MET+X or mediator**

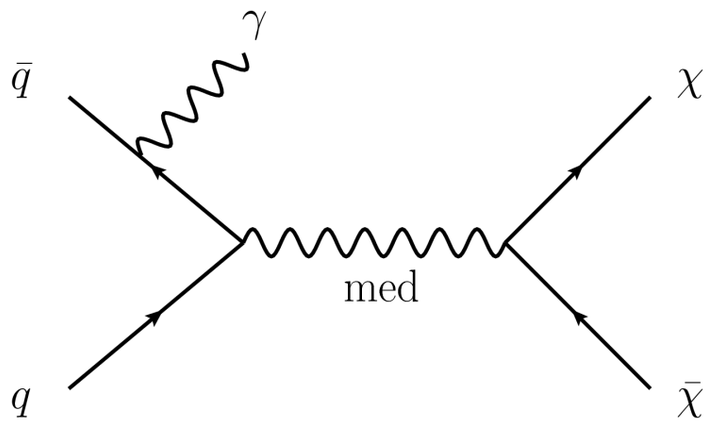


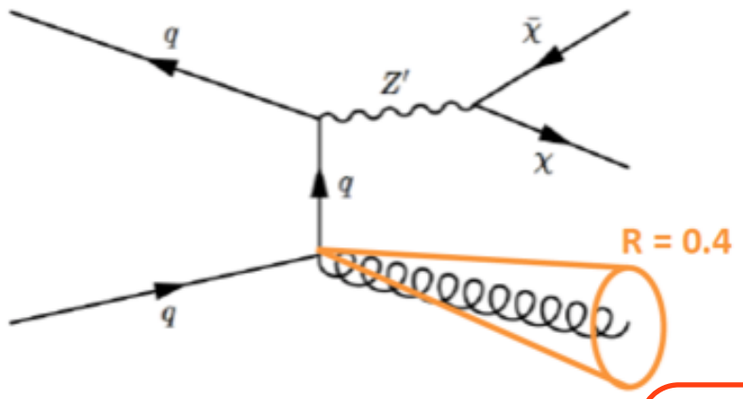


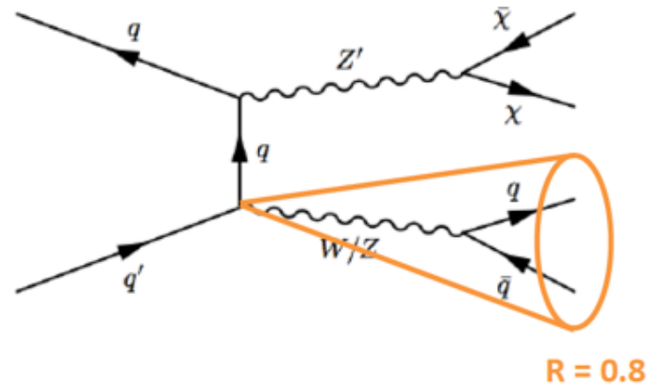




Mono- γ/jet/V + MET







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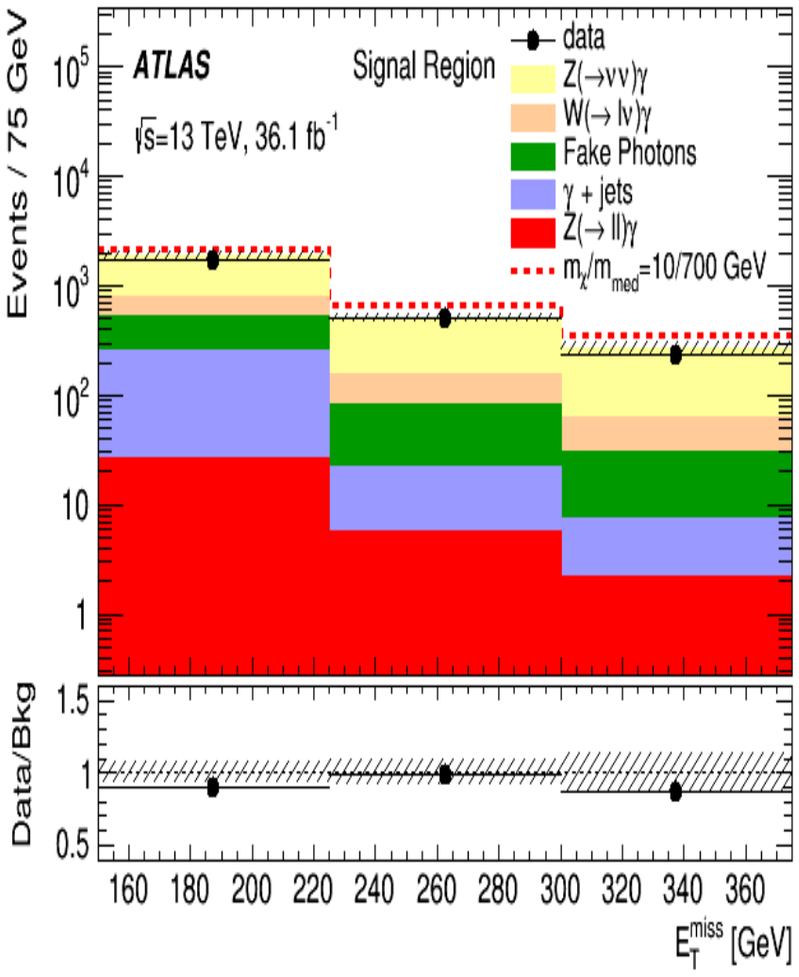
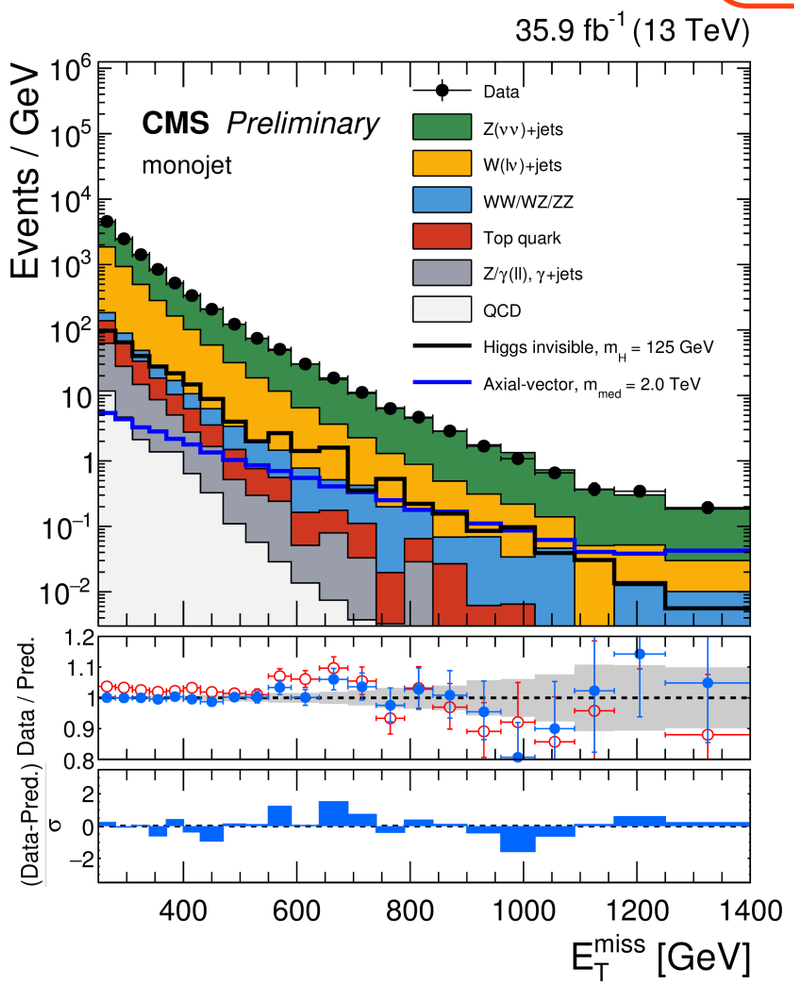
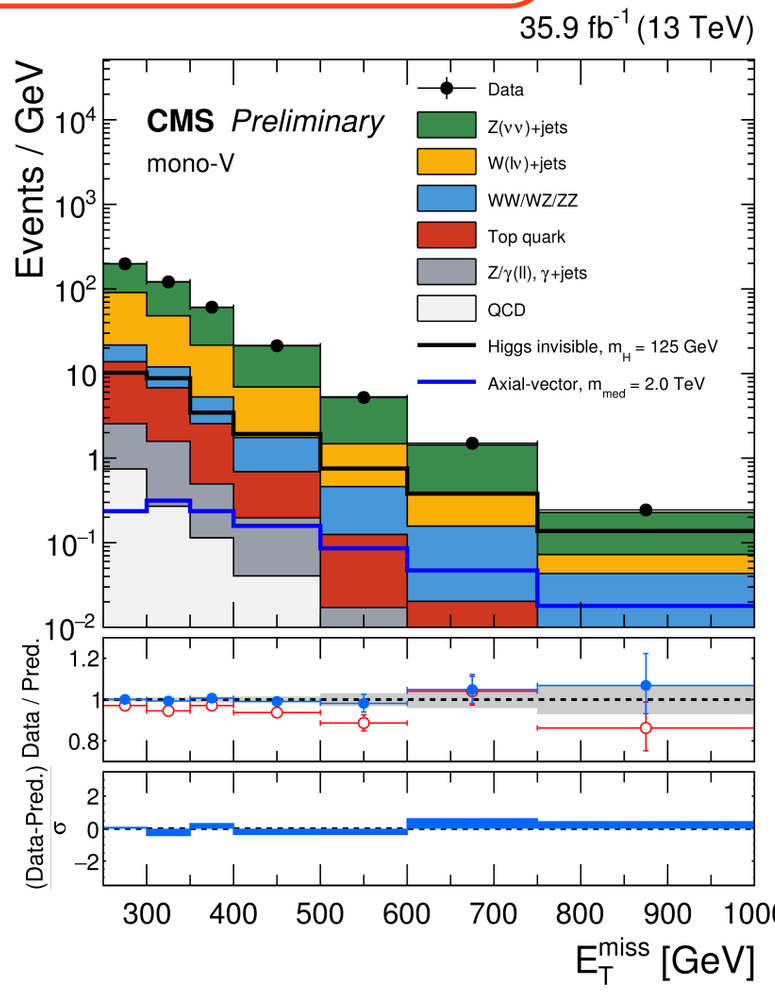
CMS-PAS-EXO-16-048

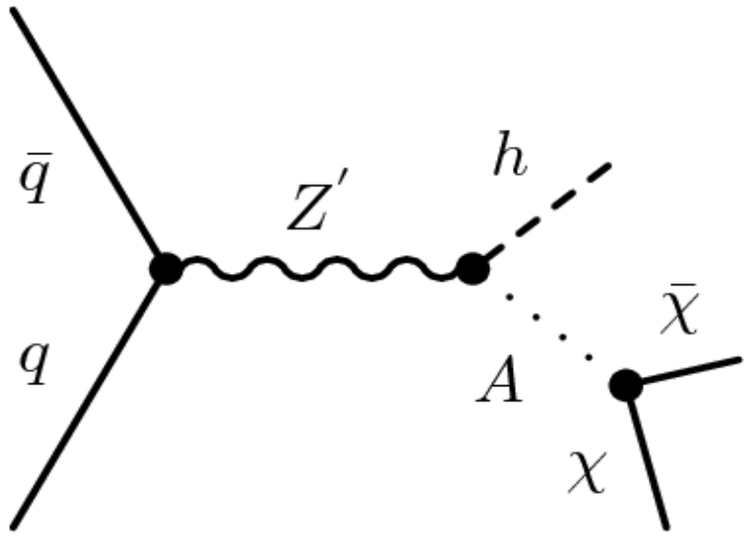






Search for excess in the MET spectrum after Mono-object selection

Mono Higgs (bb)



- Higgs produced with DM pair
  - Z' - 2HDM
- Higgs decays to bb
  - both boosted and resolved
- Dominant backgrounds
  - Z+jets, W+jets, Top, di-boson

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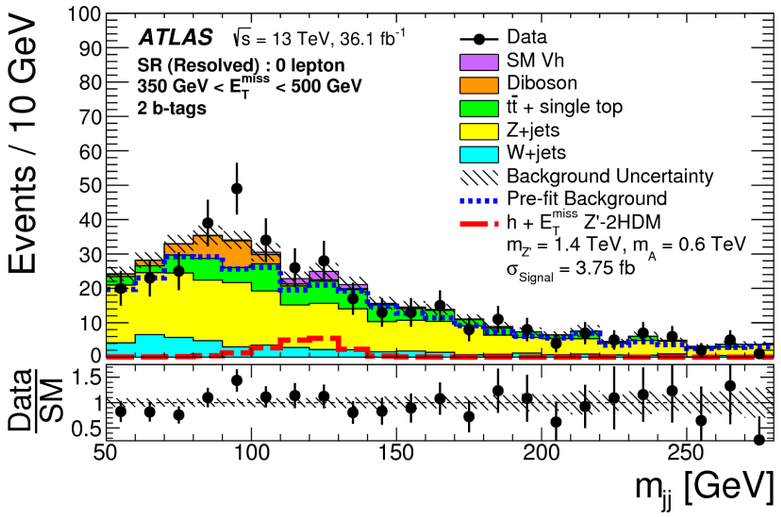
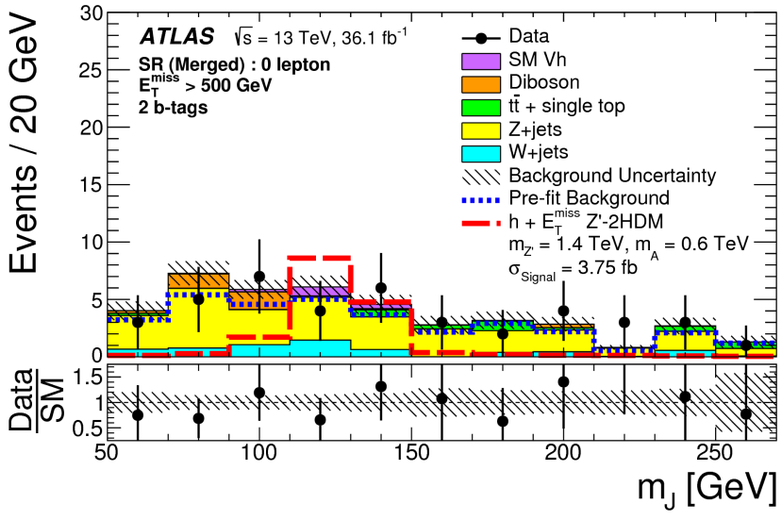
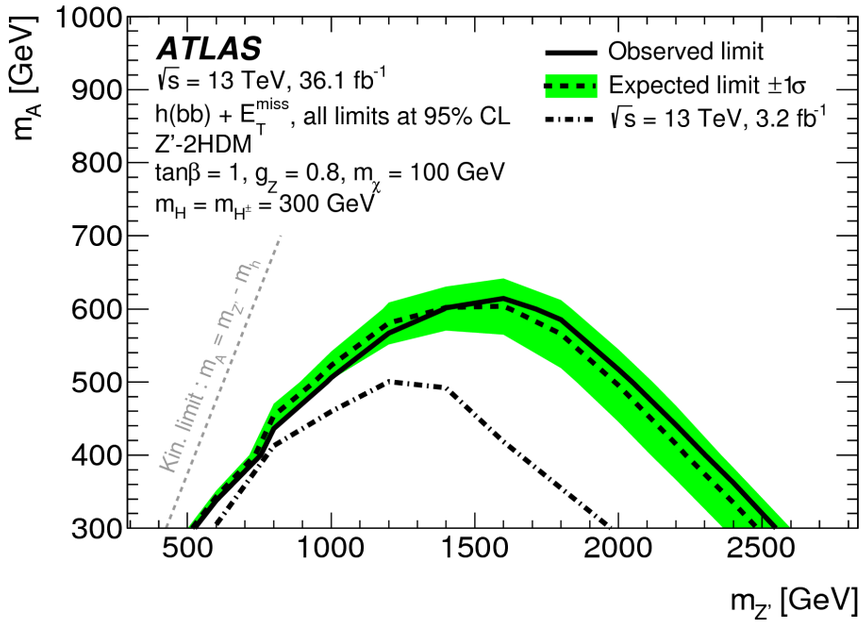


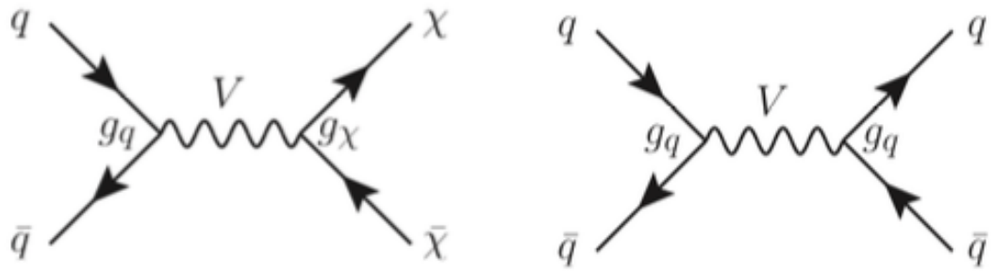
Resolved



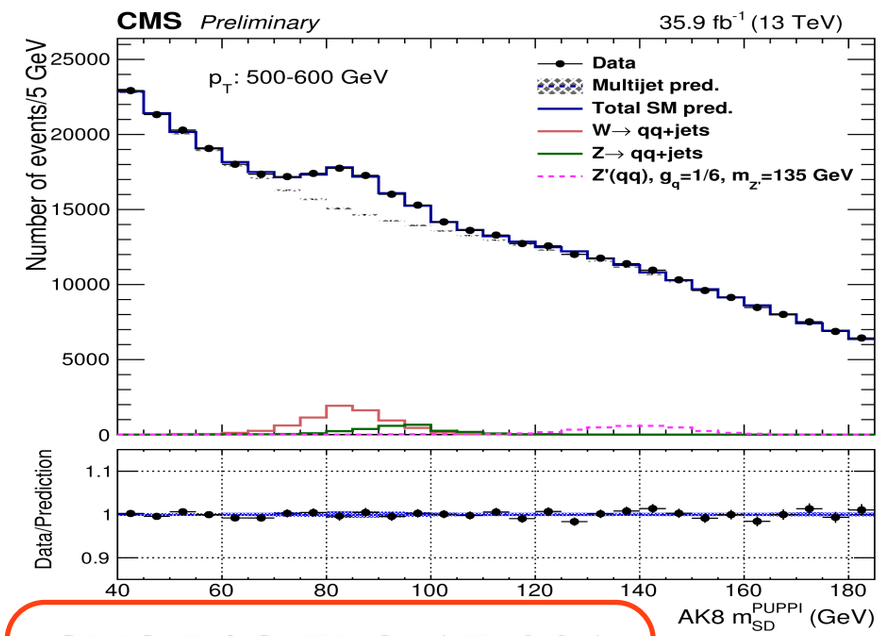
Boosted



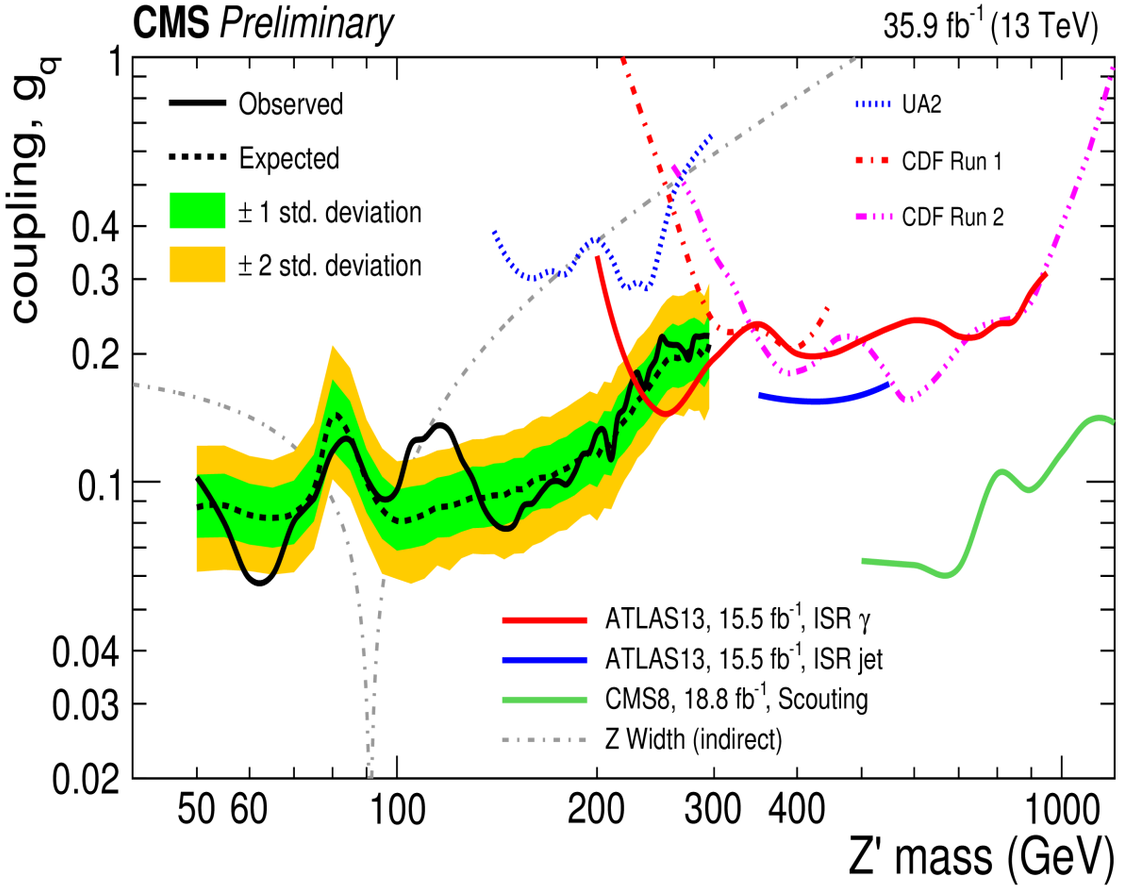
Mediator Searches in di-jets

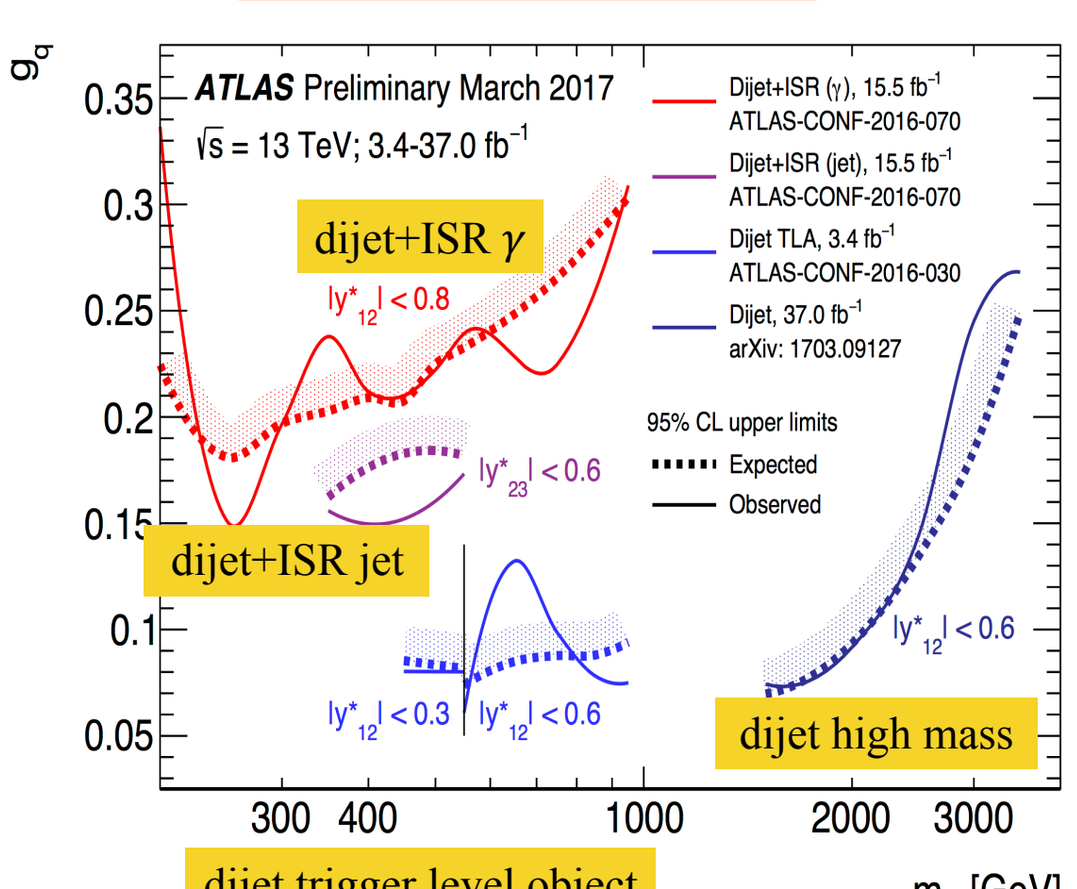


- Based on di-jets resonances searches
  - Both high mass / low mass regions



CMS-PAS-EXO-17-001



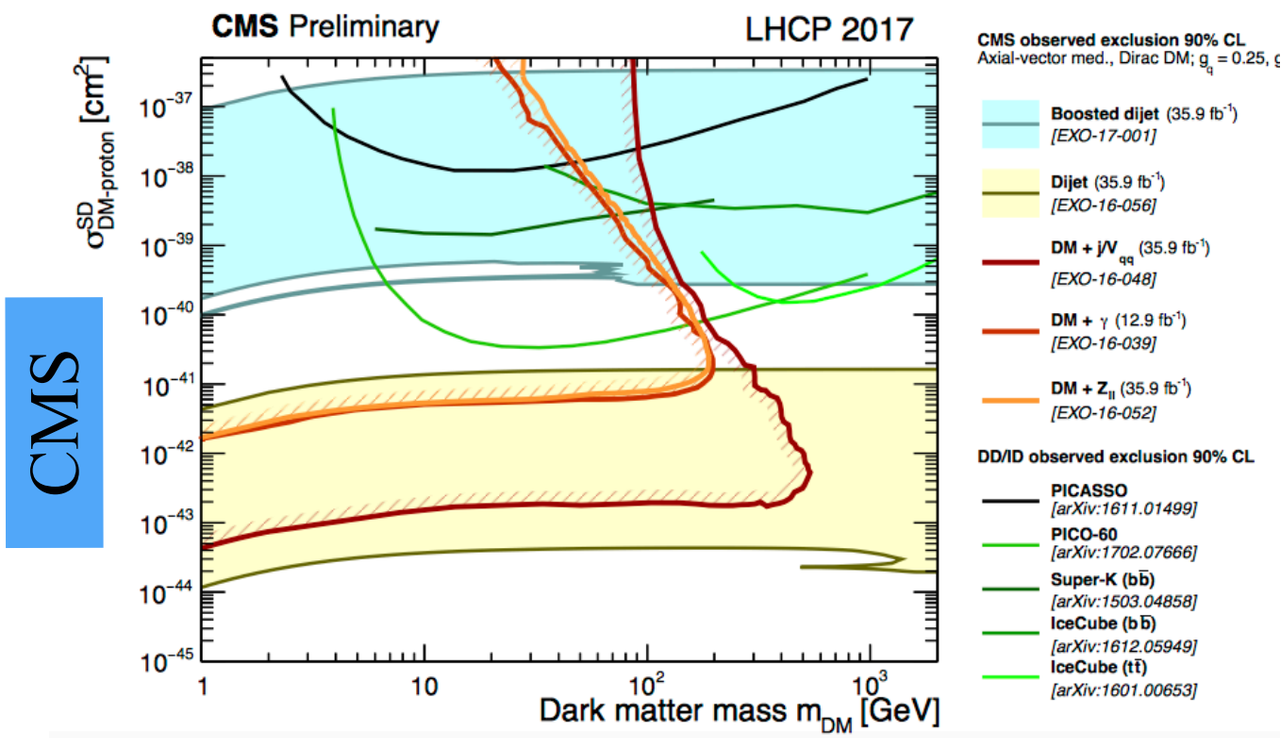


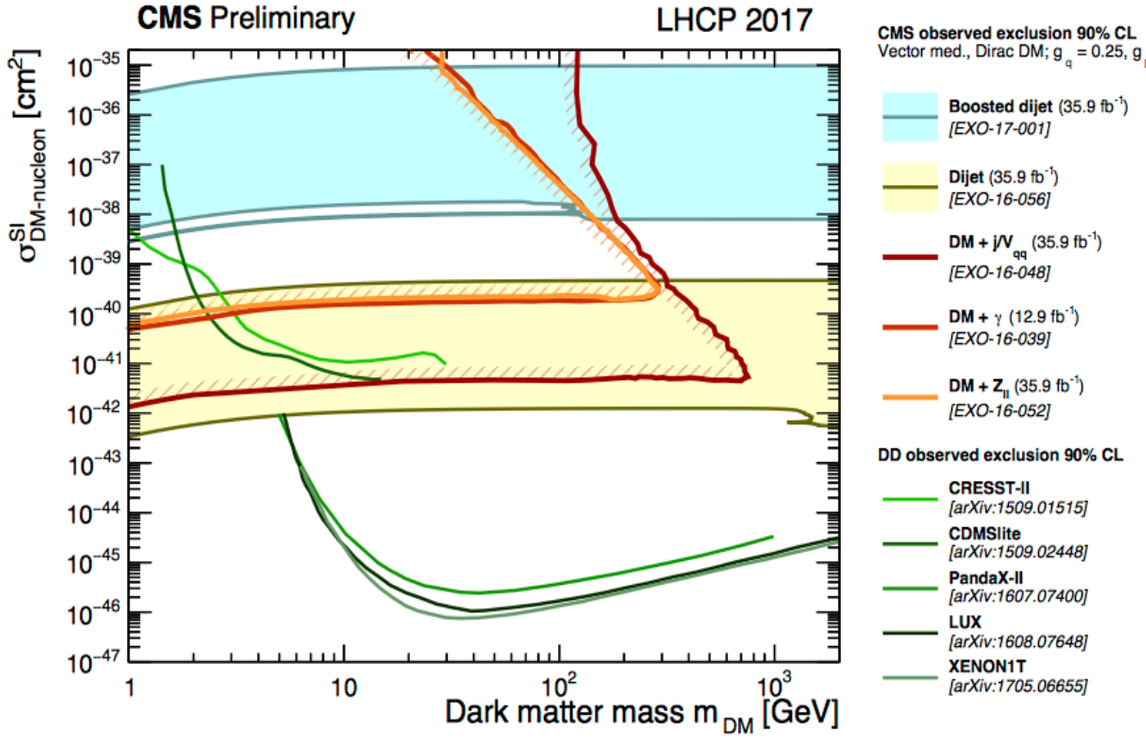
Dark Matter Search Summary

Spin Dependent

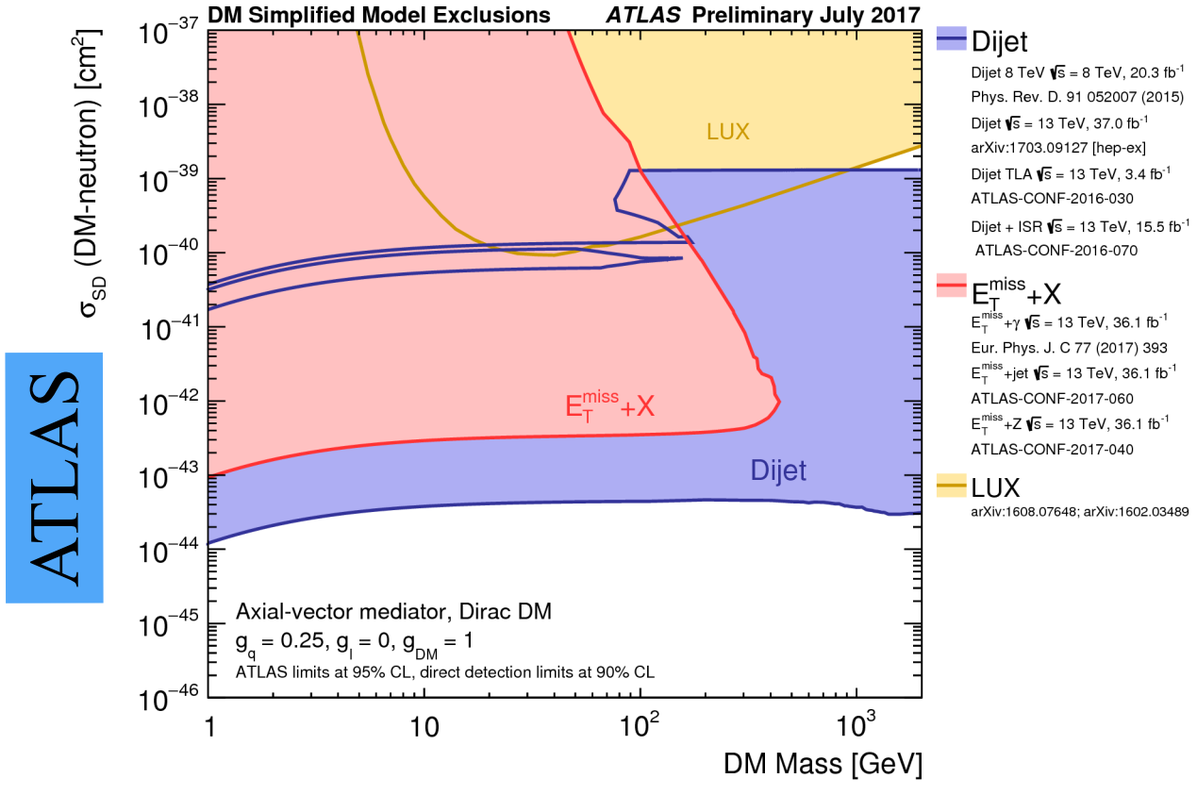
Spin Independent

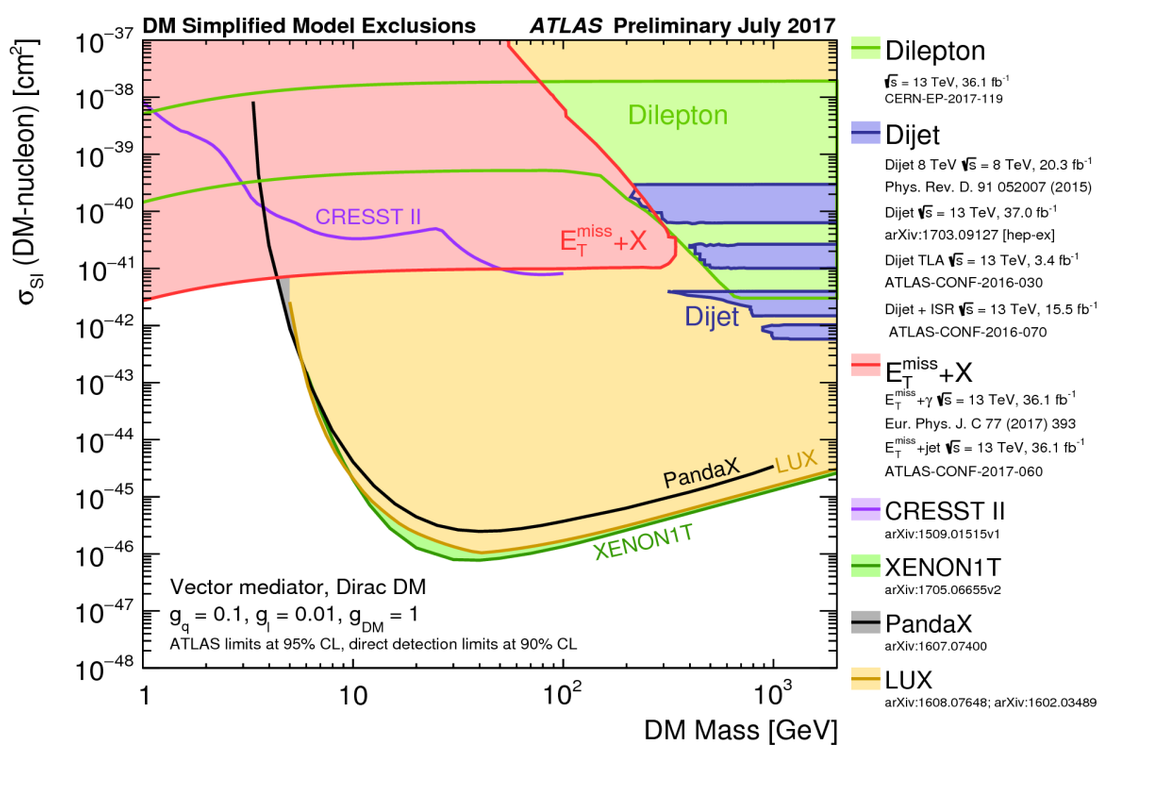
CMS





ATLAS





Conclusion

- **Exotica search very active field**
  - large variety of analyses
  - large potential to make a discovery

- **Rich results are produced**
  - only a small fraction of results shown in this talk
  - tight constraints to heavy resonance or dark matter

- **No sign for new physics found yet!**

- **Still lots of analyses ongoing based on 13 TeV data. Looking forward to more exciting results!**

- backup