

EXOTICS SEARCHES

KEVIN BLACK
BOSTON UNIVERSITY
FOR THE ATLAS AND CMS
COLLABORATIONS



OVERVIEW

- ✱ New Gauge Bosons
- ✱ New Quarks and Leptons
- ✱ Dark Matter
- ✱ Generic Topological Searches

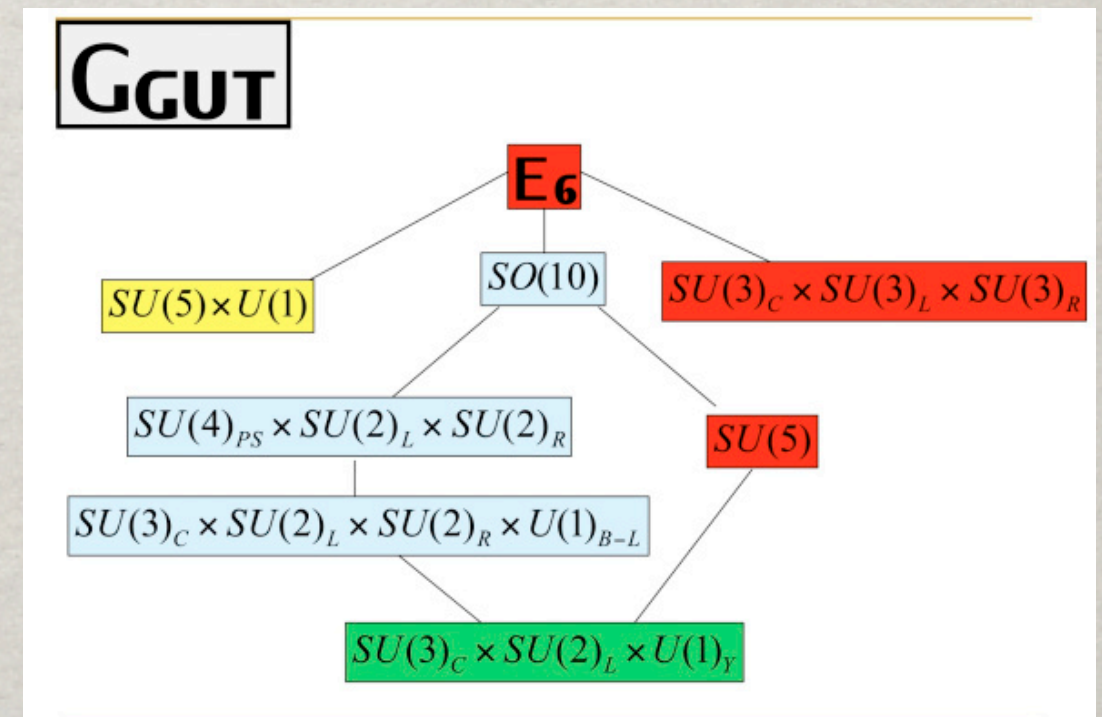
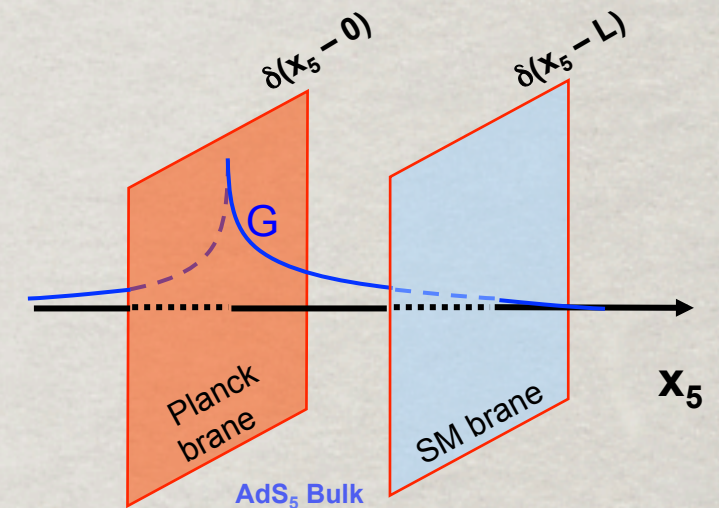


What will new physics look like?

collisions.org.au

NEW GAUGE BOSONS

- Many extensions of the SM predict new bosons that come from the enlarged symmetry groups proposed:
 - Sequential Standard Model (SSM)
 - GUTs: $E_6 \rightarrow SO(10) \times U(1)$ $SU(5) \times U(1) \times U(1)$
 - Left-Right symmetric models
 - Extra-Dimensions

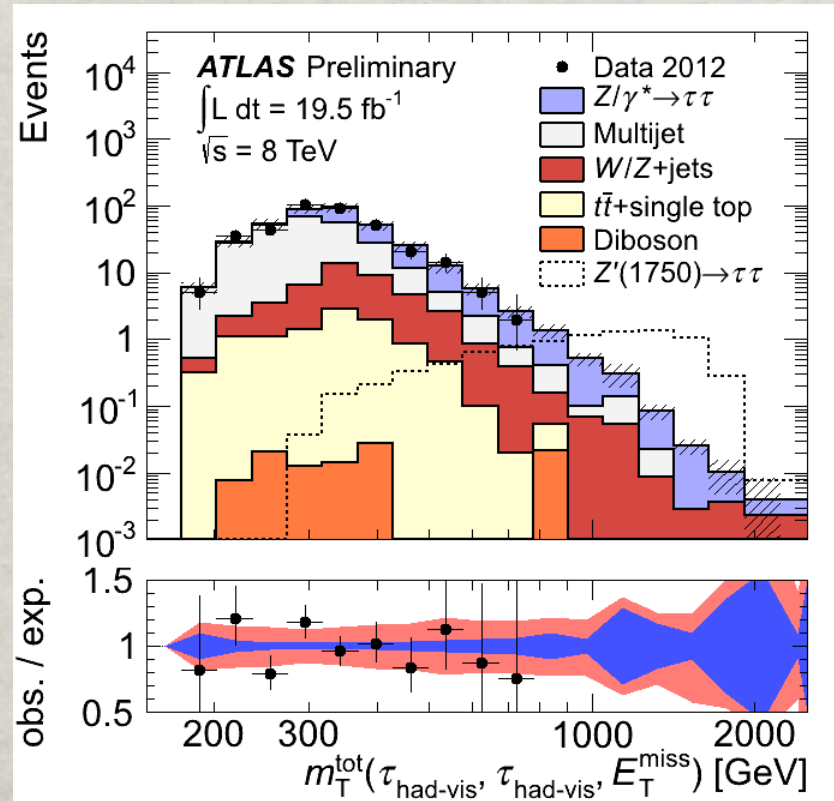
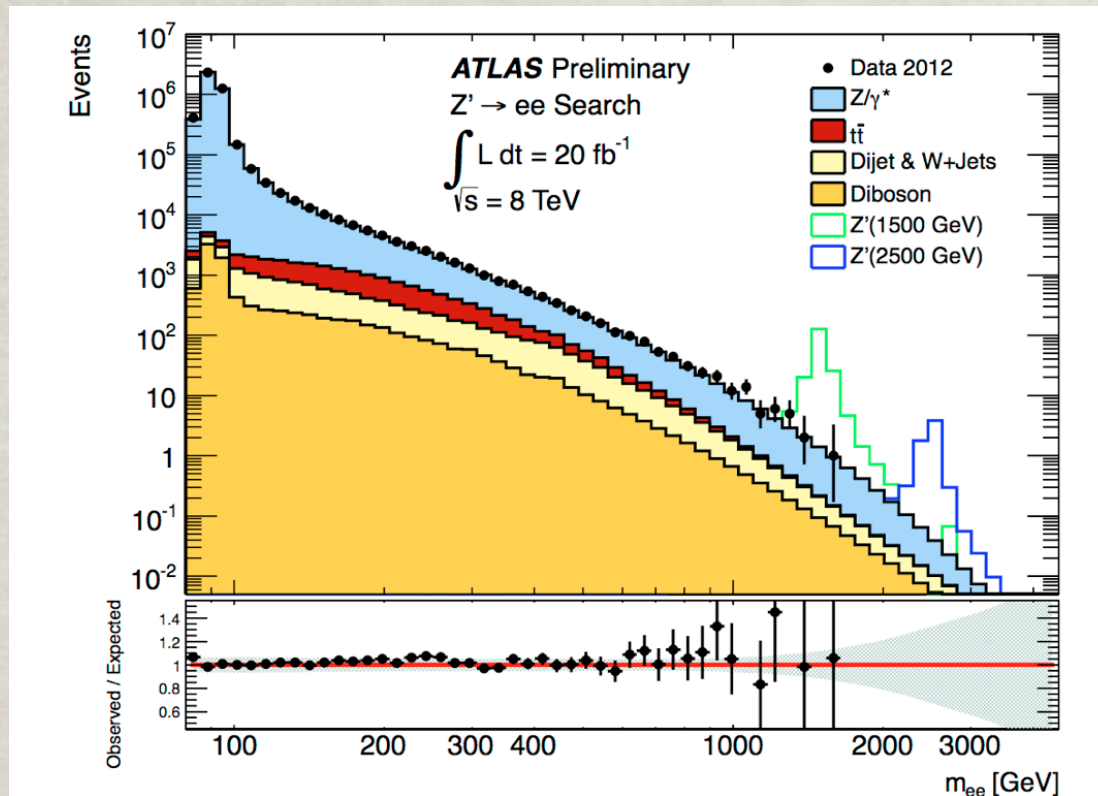


DILEPTON RESONANCES

ATLAS-CONF-2013-017

- Search for resonance in dilepton invariant mass (like heavier version of Z)
- If like the SM - most likely place to find it from the dilepton and dimuon channel
- However, could have preferred coupling to the 3rd generation and hence not show up there. Look for ditau resonances (top decays covered previously)

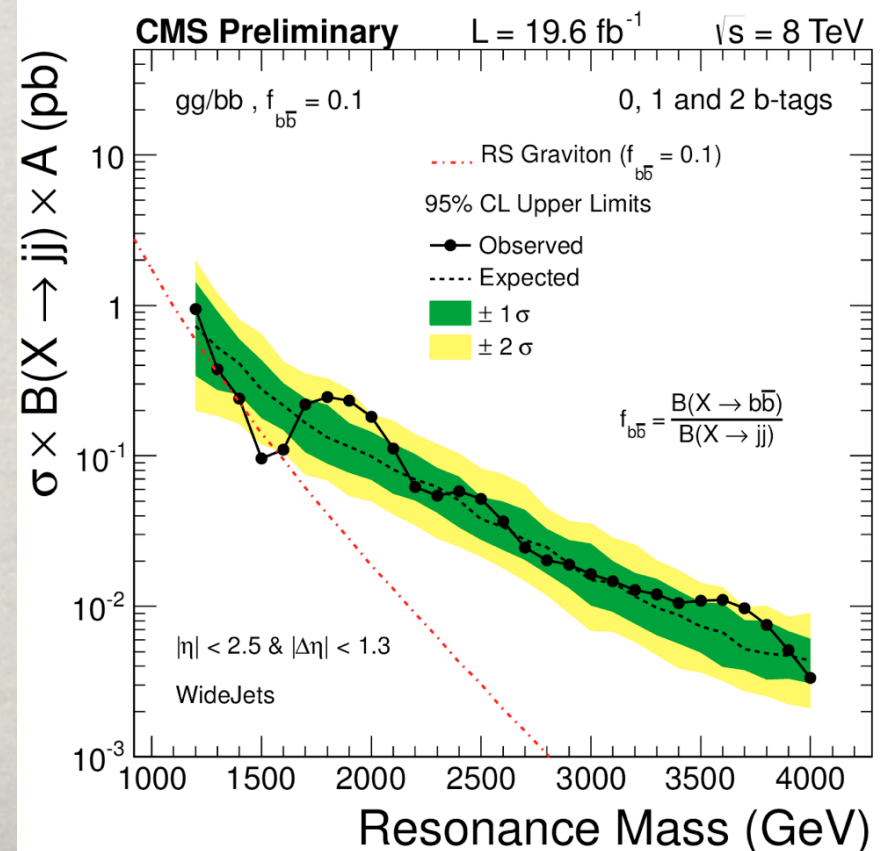
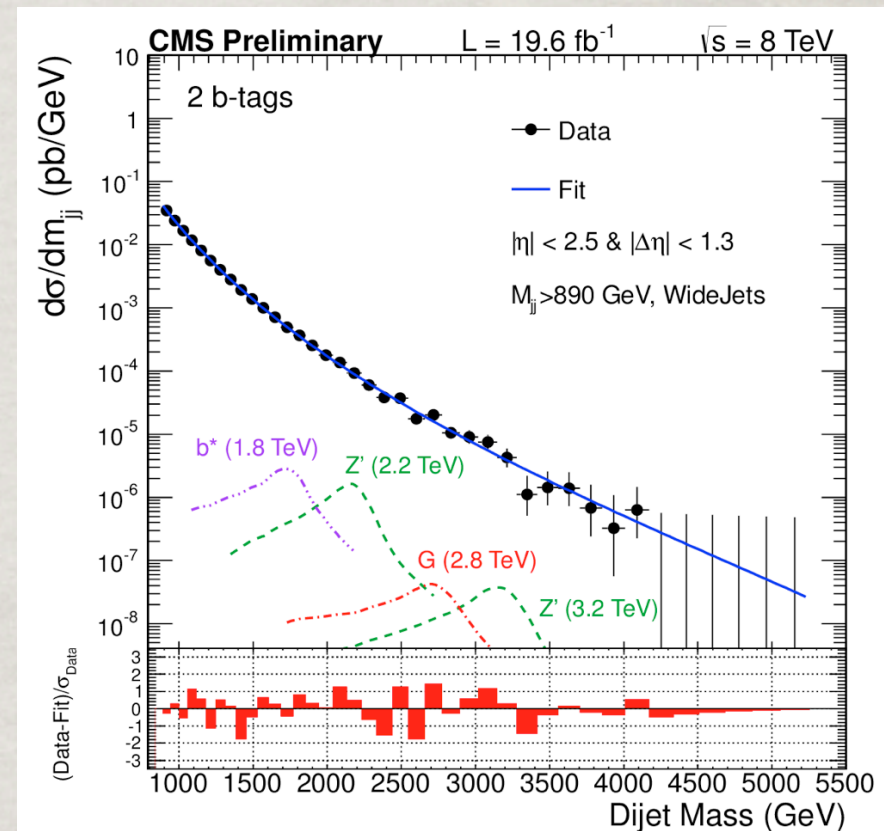
ATLAS-CONF-2013-066



DIJET RESONANCES

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EXO12023

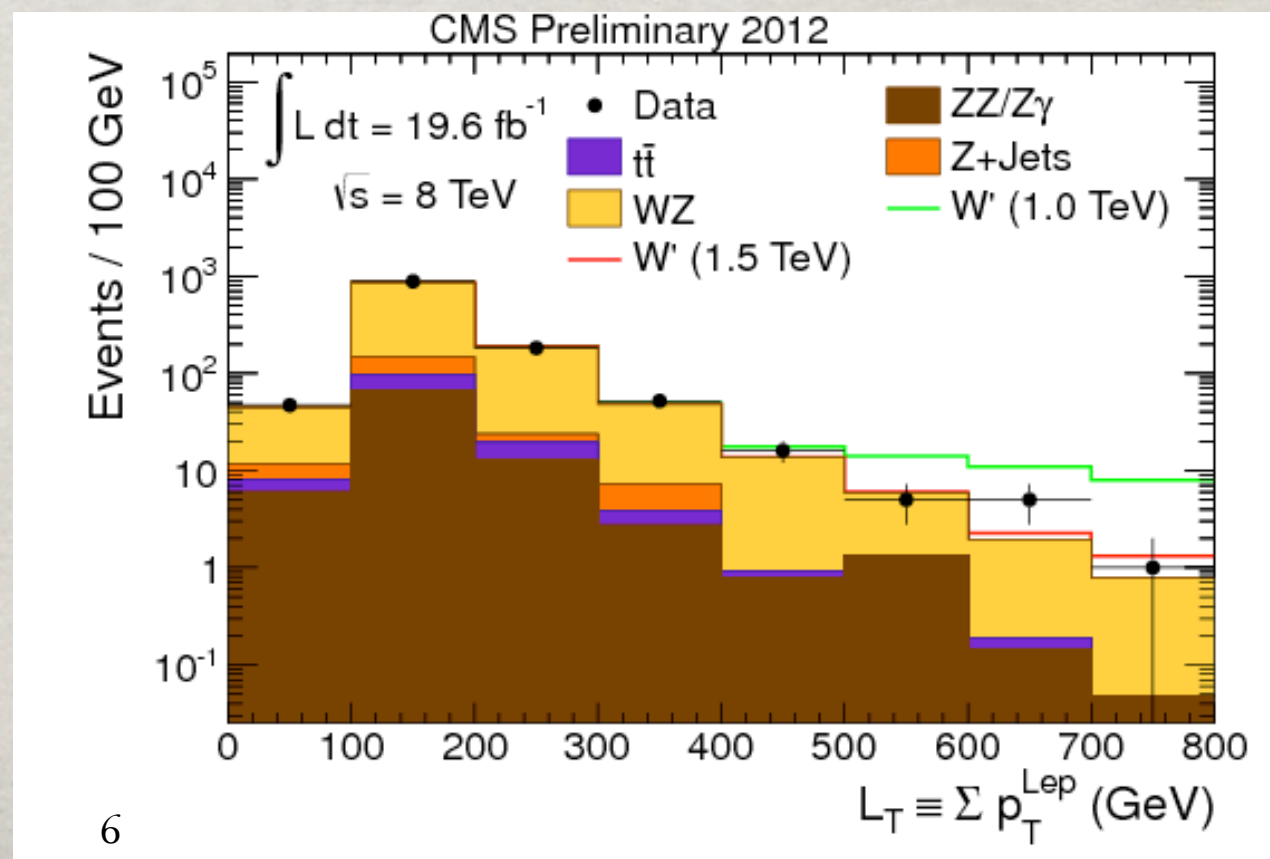
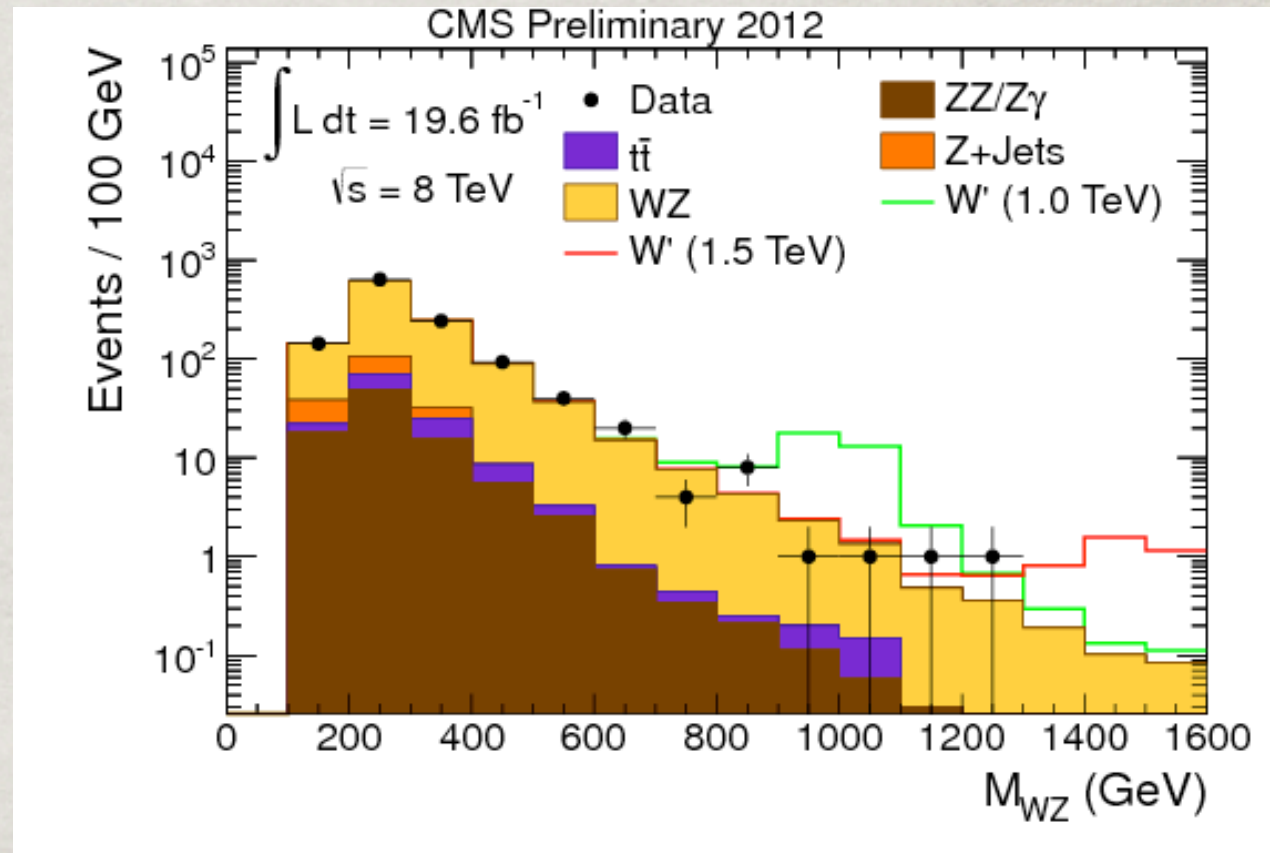
- For new particle that couples strongly to quarks, look at dijet channel
- Larger backgrounds but also larger branching ratios for some searches
- Look also for decays into heavy flavor jet pairs



DIBOSON RESONANCE

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EXO12025

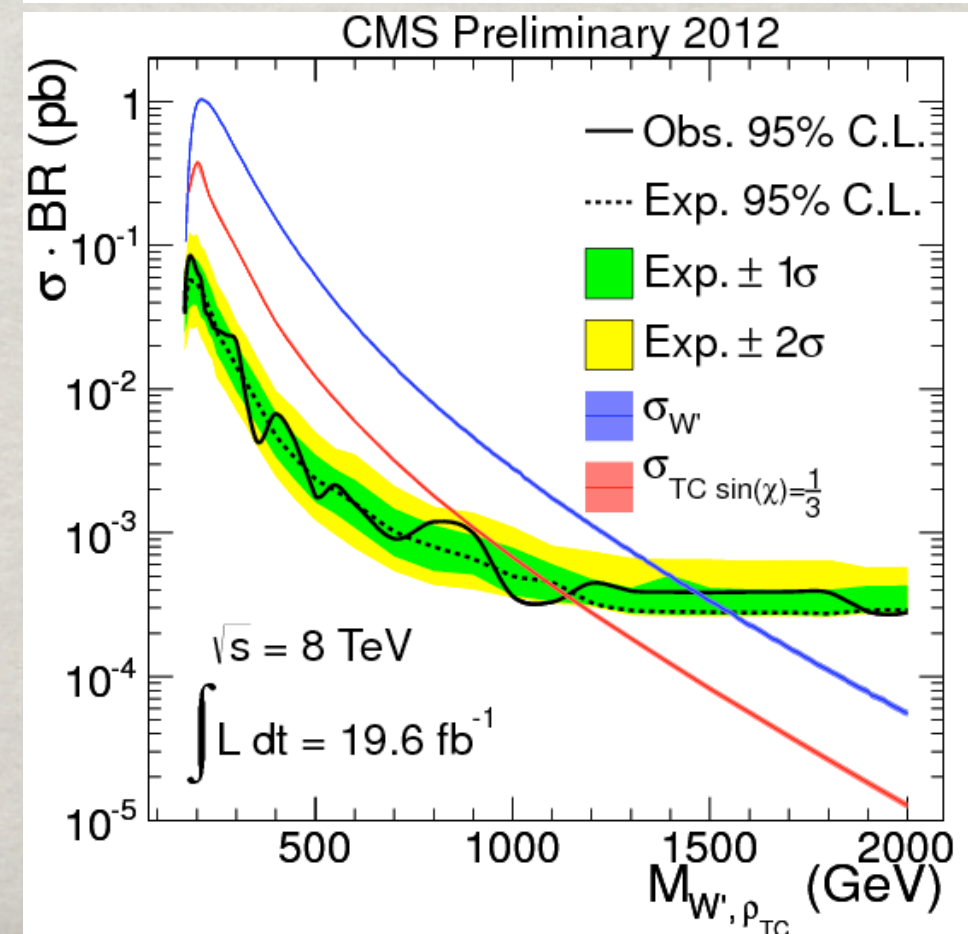
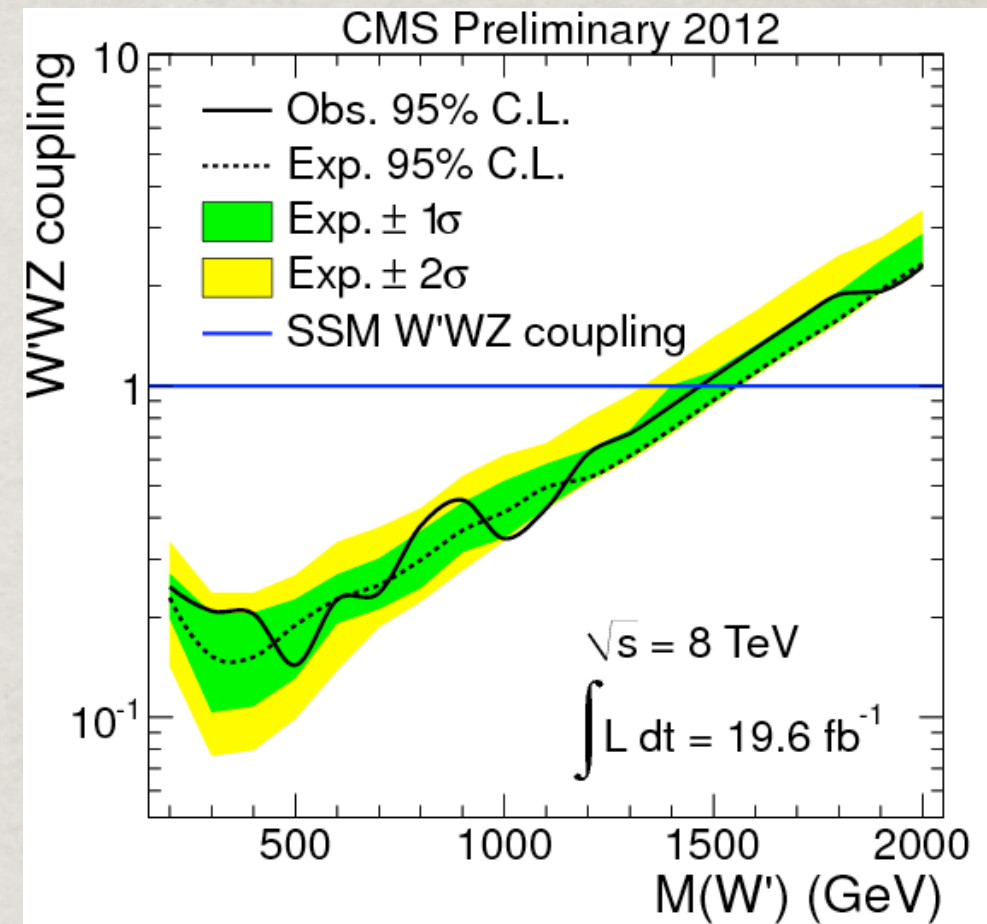
- Search for W' in diboson channel, technicolor
- W and Z decay leptonically
- Use invariant mass and sum of lepton p_T



DIBOSON RESONANCES

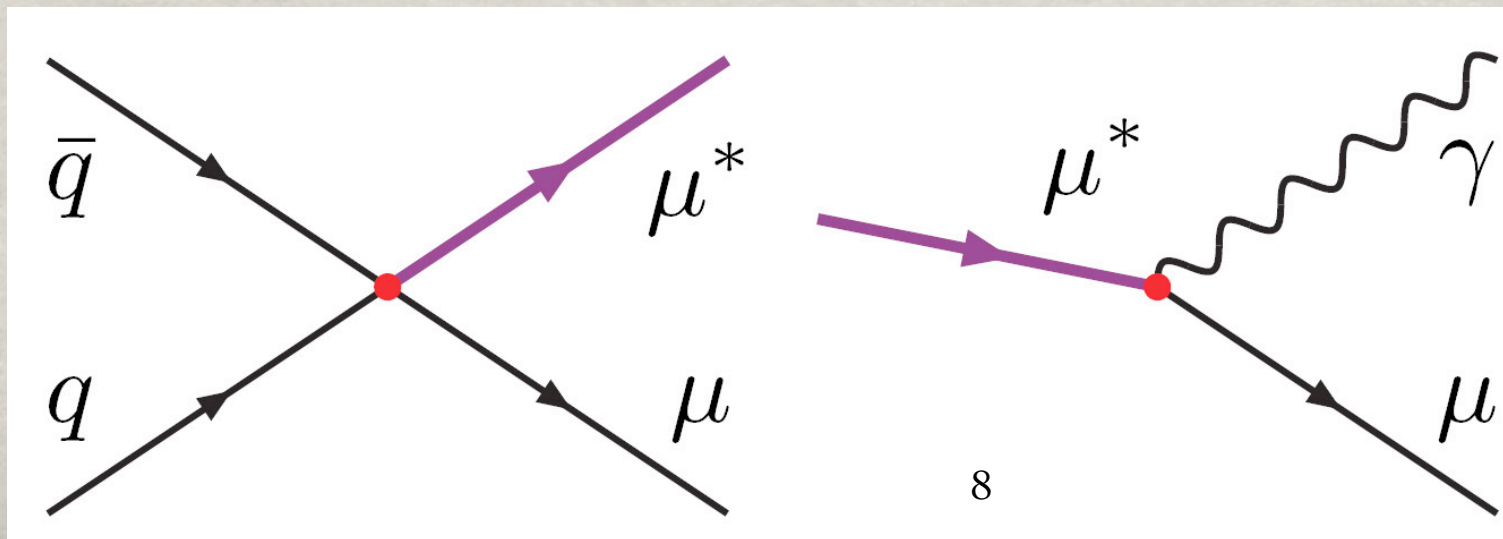
PAS
EXO12025

- ✱ Limits on both the mass and coupling as a function of mass of W'
- ✱ Techni rho exclusion up to ~ 1 TeV
- ✱ All experimental channels covered



NEW FERMIONS

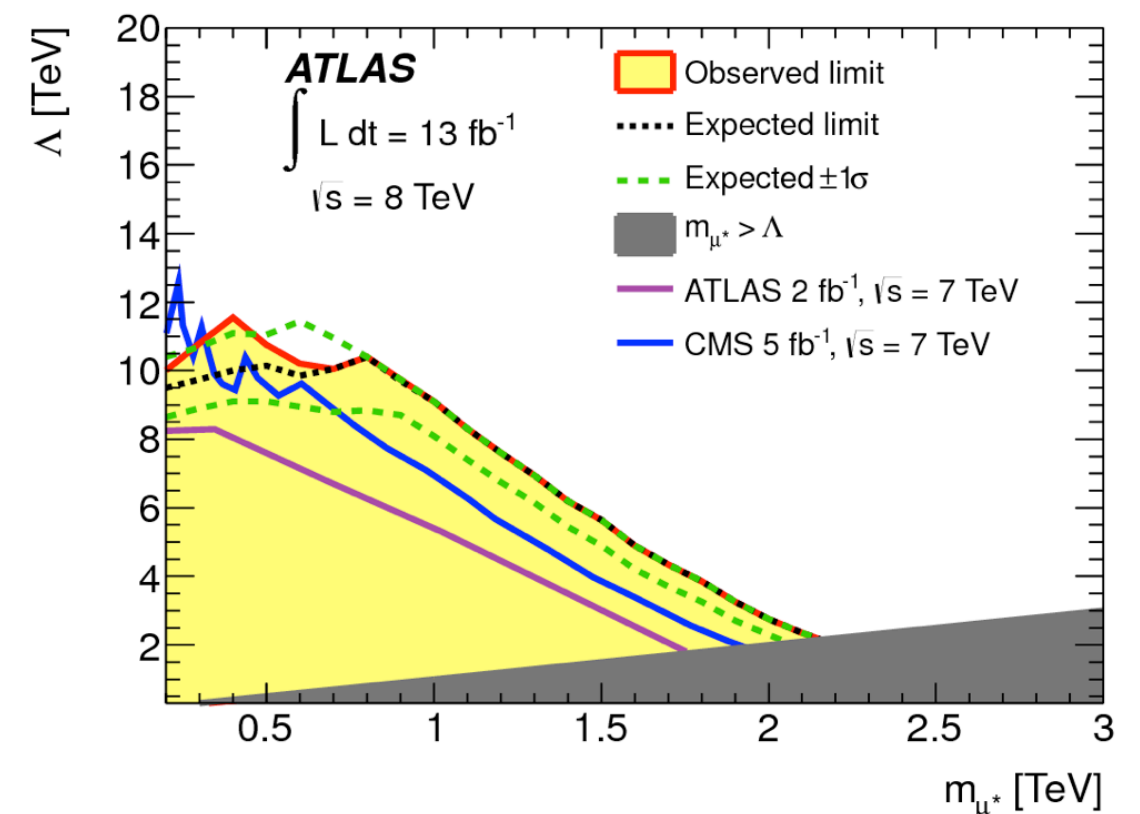
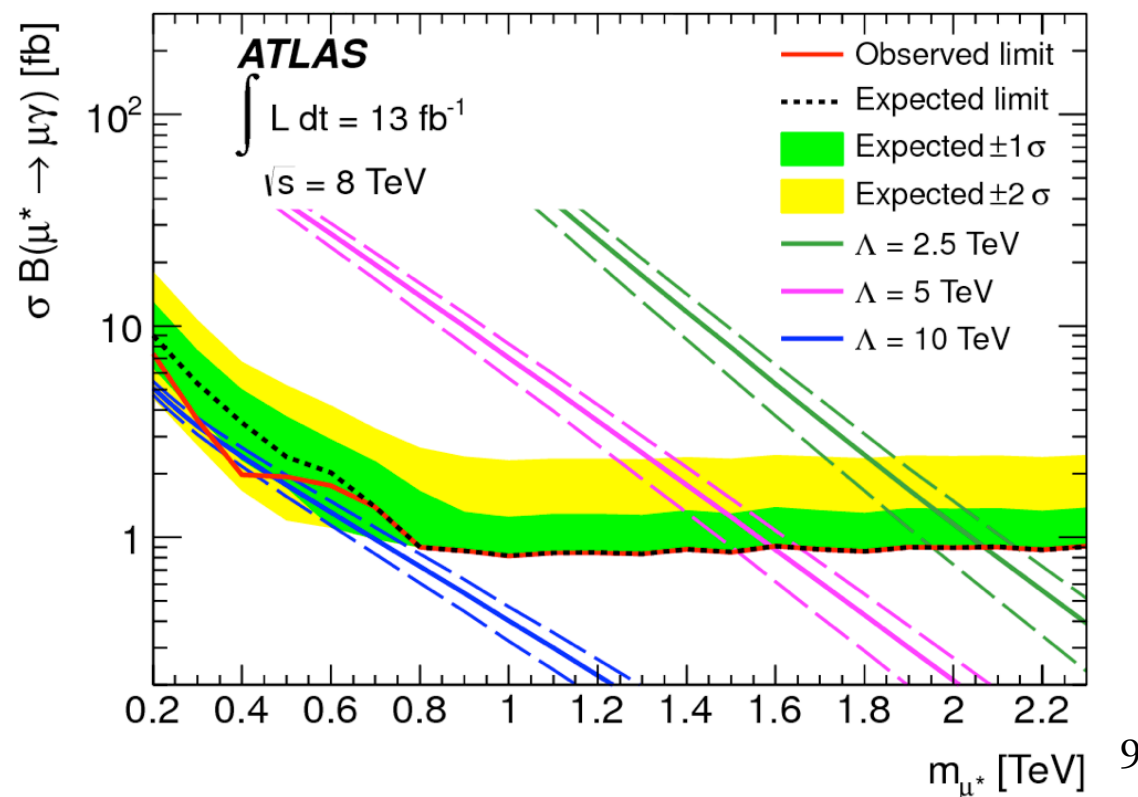
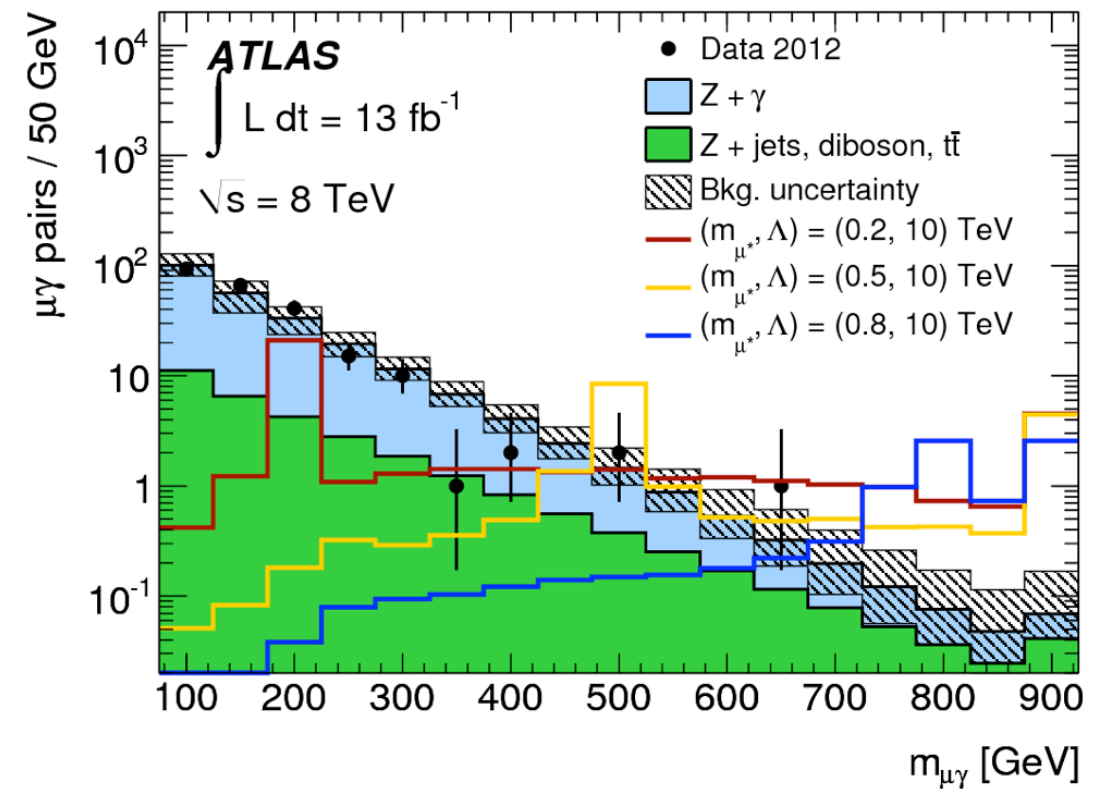
- ✿ In the SM leptons and quarks are fundamental particles
- ✿ If this is incorrect - and they have substructure - should be able to see excited states of the composite particles
- ✿ Search for excited leptons by decay in either single lepton or dilepton+photon resonance



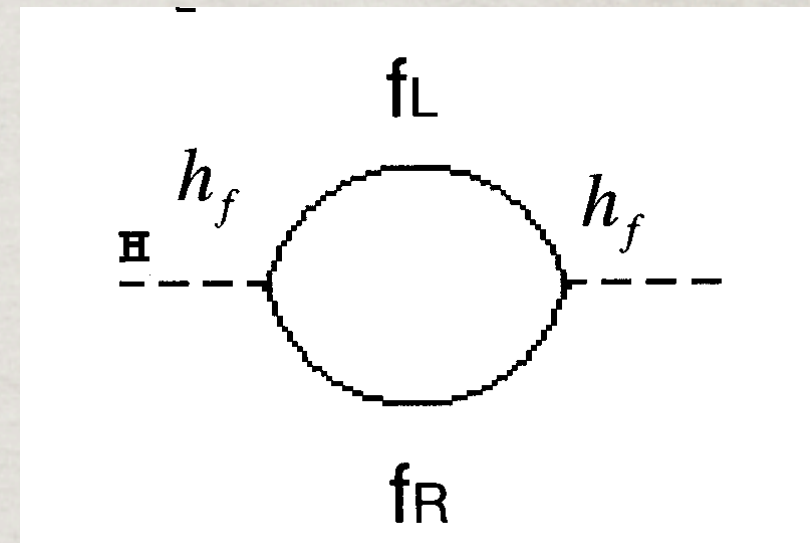
NEW FERMIONS

☼ Search in lepton+photon
and dilepton + photon

[arXiv:1308.1364](https://arxiv.org/abs/1308.1364)



VECTOR-LIKE QUARKS



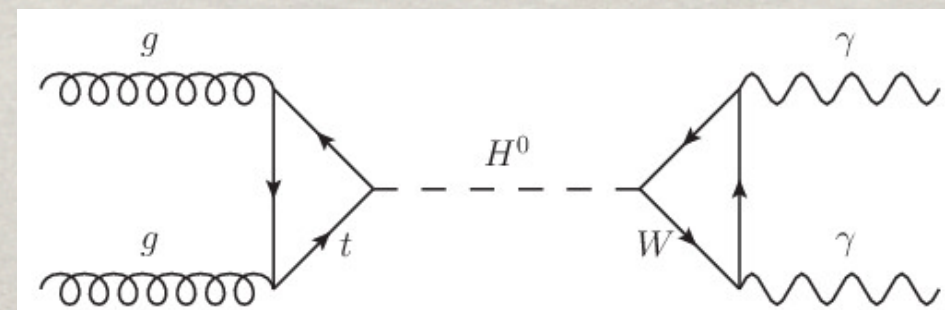
- ✿ To cancel the quadratic divergences to the Higgs boson mass introduce new top partner at ~ 1 TeV
- ✿ Chiral 4th Generation highly disfavored as it would, for example, naively enhance the Higgs cross-section by a factor of ~ 9

$$\begin{pmatrix} t'_L \\ b'_L \end{pmatrix} \quad t'_R, b'_R$$

$$g\bar{\psi}_L\phi\psi_R \rightarrow m\bar{\psi}_L\psi_R$$

EWSB

2.4 MeV/c ² 2/3 1/2 u up	1.27 GeV/c ² 2/3 1/2 c charm	172.5 GeV/c ² 2/3 1/2 t top	? 2/3 1/2 t' ?
4.8 MeV/c ² -1/3 1/2 d up	104 MeV/c ² -1/3 1/2 s strange	4.2 GeV/c ² -1/3 1/2 b bottom	? -1/3 1/2 b' ?
< 2.2 eV/c ² 0 1/2 ν _e electron neutrino	< 0.17 MeV/c ² 0 1/2 ν _μ muon neutrino	< 15.5 MeV/c ² 0 1/2 ν _τ tau neutrino	? 0 1/2 ν ₄ ?
0.511 MeV/c ² -1 1/2 e electron	105.7 MeV/c ² -1 1/2 μ muon	1.777 GeV/c ² -1 1/2 τ tau	? -1 1/2 l ₄ ?
0 0 1 γ photon	0 0 1 g gluon	80.4 GeV/c ² ±1 1 W [±] W boson	91.2 GeV/c ² 0 1 Z ⁰ Z boson



VECTOR-LIKE QUARKS

- ✱ A SM chiral quark couples only to the left-handed charged current (V-A) interaction

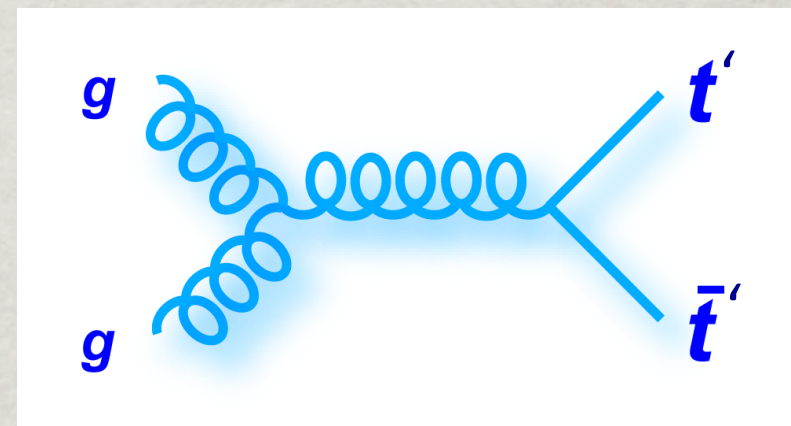
$$\begin{aligned} J_L^{\mu+} &= \bar{u}_L \gamma^\mu d_L = \bar{u} \gamma^\mu (1 - \gamma^5) d = \mathbf{V} - \mathbf{A} \\ J_R^{\mu+} &= 0 \end{aligned}$$

- ✱ Vector like quarks would couple to both the left handed and right-handed charged current

$$J^{\mu+} = J_L^{\mu+} + J_R^{\mu+} = \bar{u}_L \gamma^\mu d_L + \bar{u}_R \gamma^\mu d_R = \bar{u} \gamma^\mu d = \mathbf{V}$$

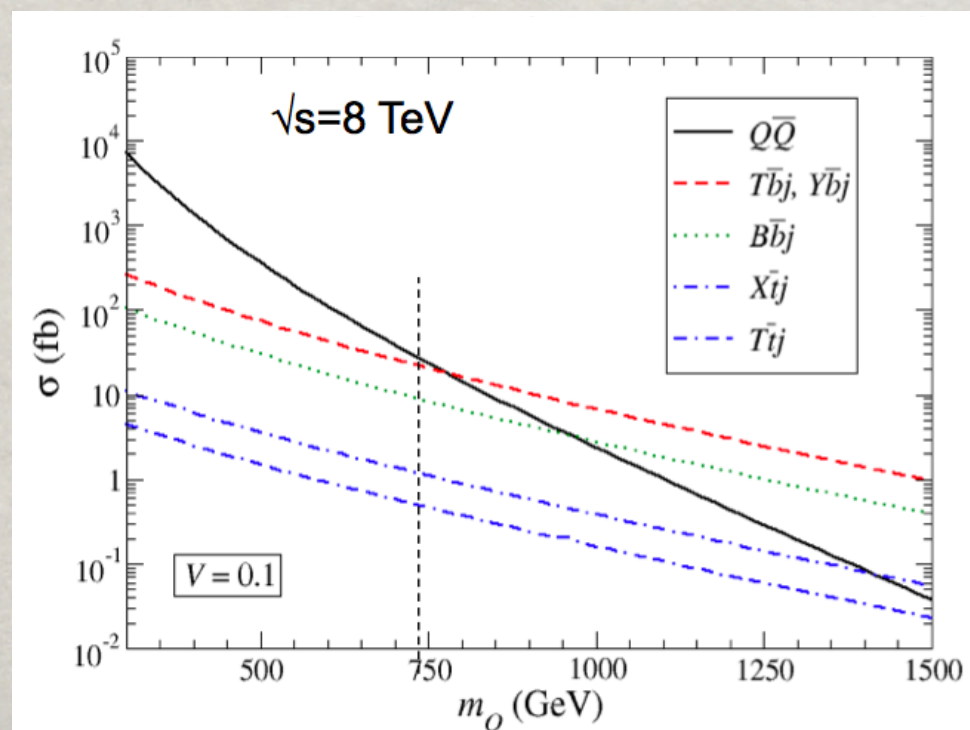
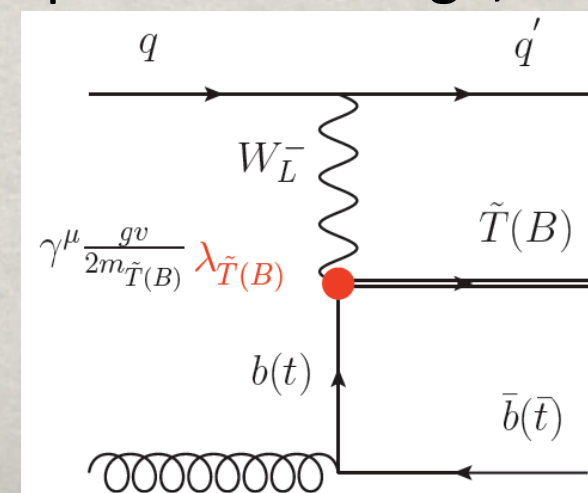
Pair Production

(like heavy $t\bar{t}$)



Single Production

(depends on charge, coupling)



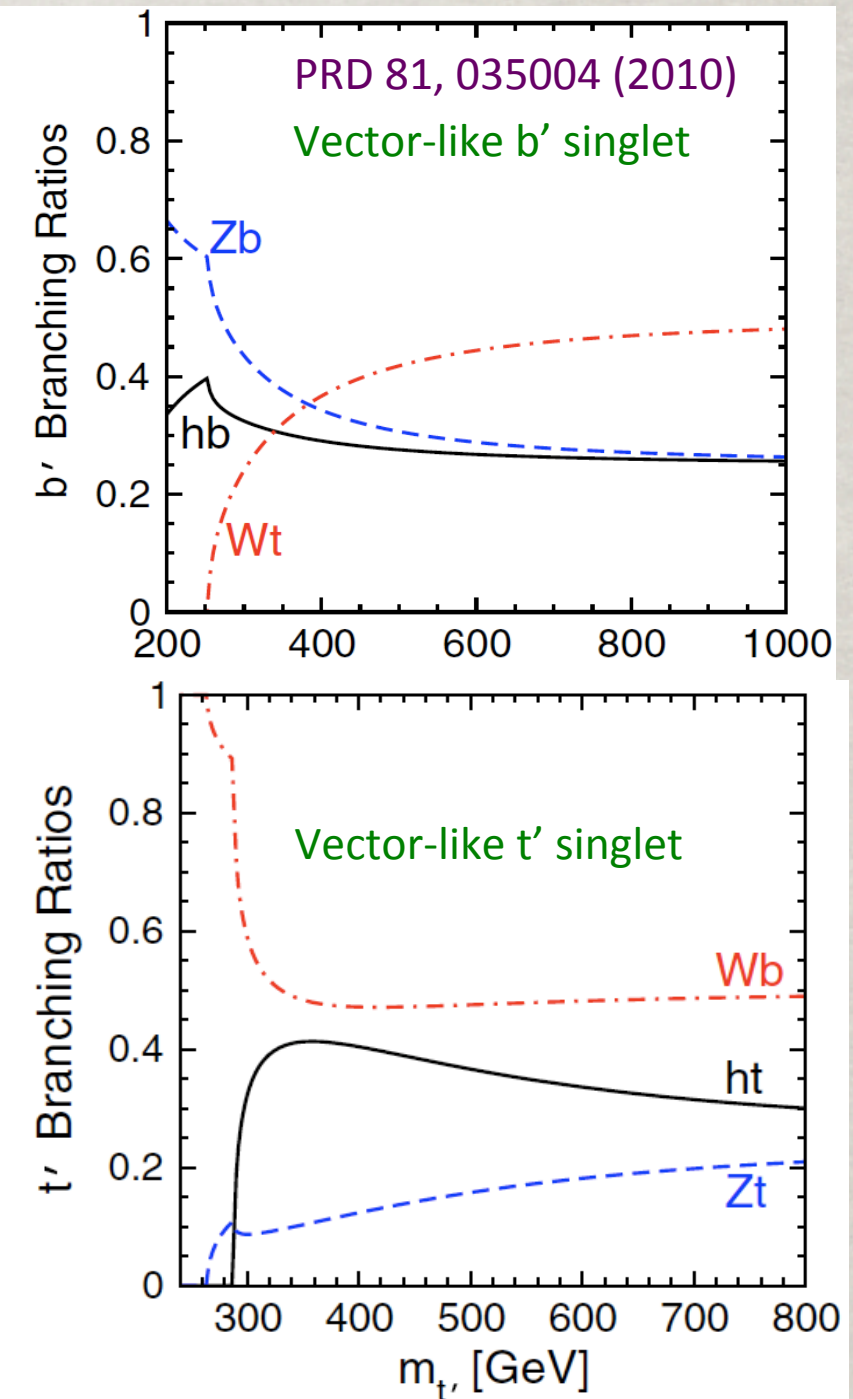
VLQ PROPERTIES

- **Vector-like:** left and right handed component quantum numbers are the same, e.g. :

Vector-like singlets t'_L t'_R

Vector-like doublets $\begin{pmatrix} t'_L \\ b'_L \end{pmatrix}$ $\begin{pmatrix} t'_R \\ b'_R \end{pmatrix}$

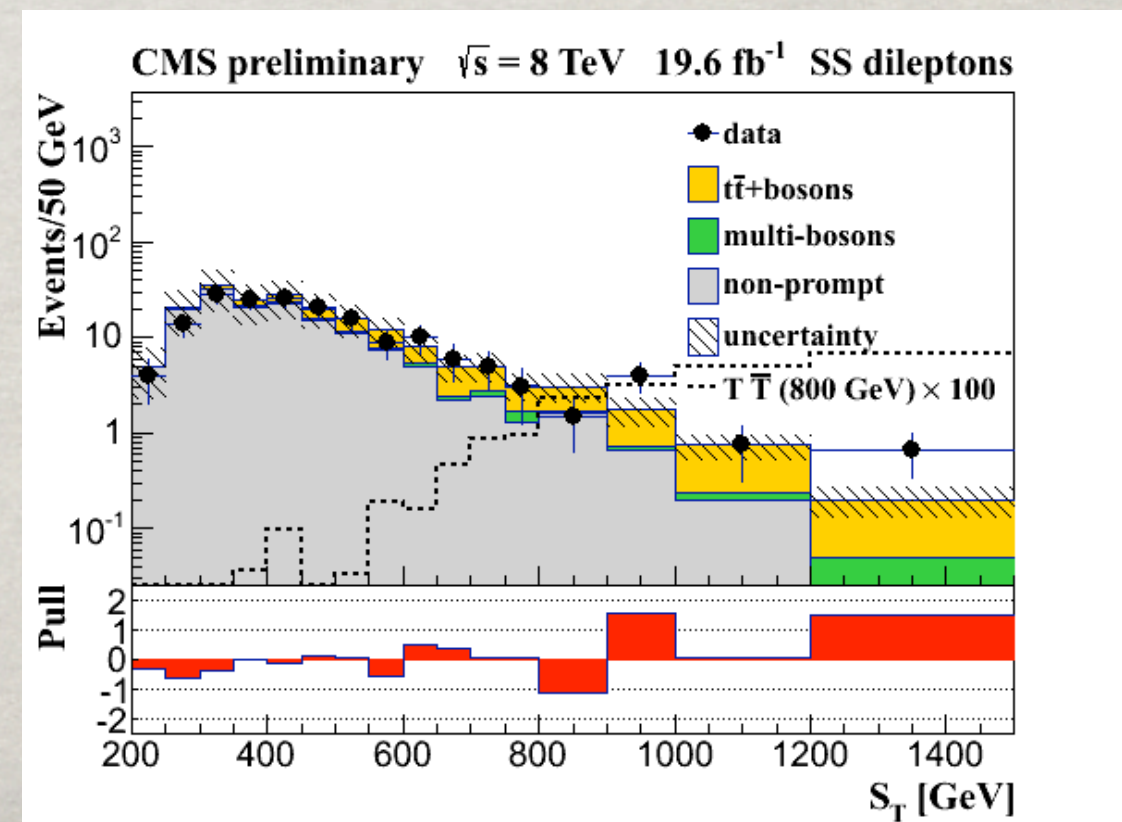
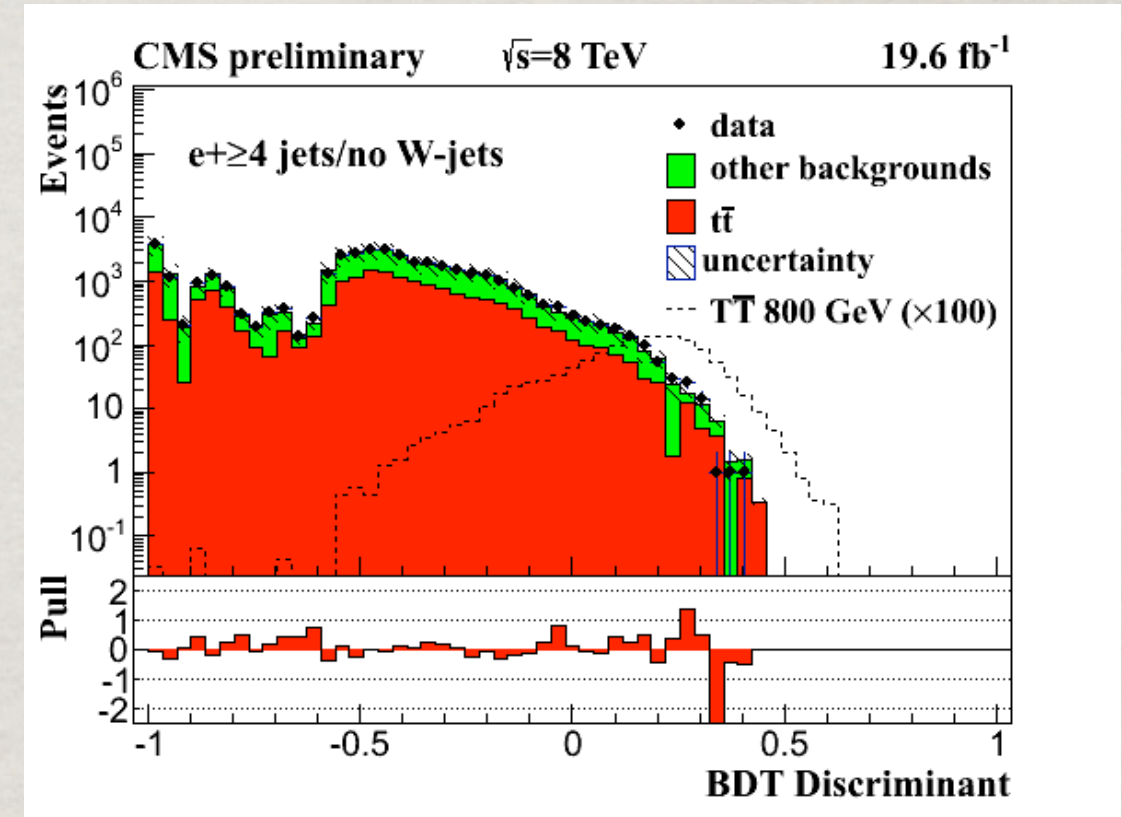
- Gauge invariant mass term independent of the SM Higgs $M\bar{\psi}_L\psi_R$
- Mixing of weak eigenstates w/ different isospin breaks GIM and induces tree level FCNC.
- Mixing with 3rd generation generally preferred in most models (though caveats exist), and is experimentally less well constrained.
- Present in many BSM models: Little Higgs, Composite Top/Higgs, Extra Dims., GUTs, extended SUSY, ...



PAS
B2G-12-015

☼ Inclusive search in
single lepton and
dilepton (same sign)

☼ Use BDT in single
lepton with larger
background to get
optimal separation

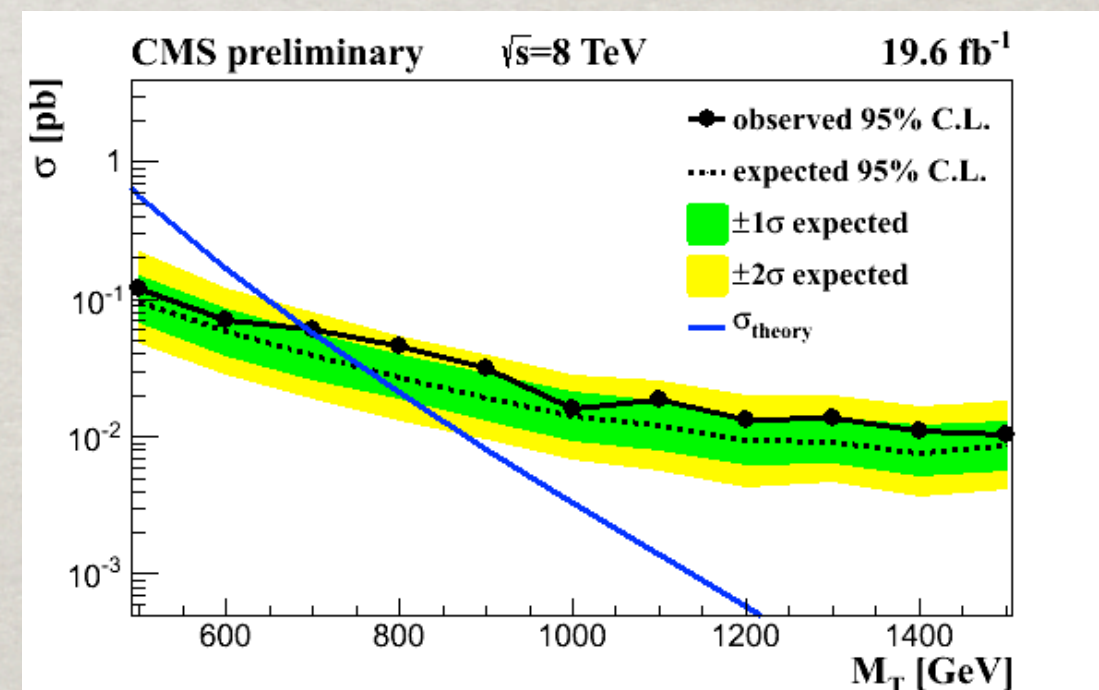
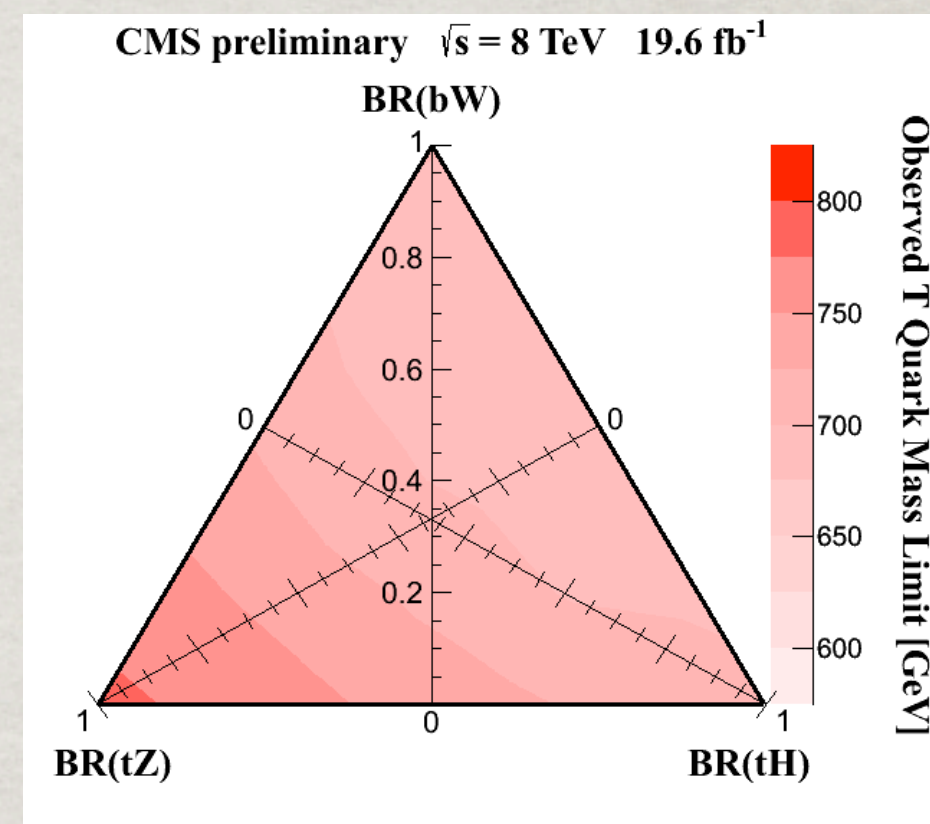


VLQ LIMITS

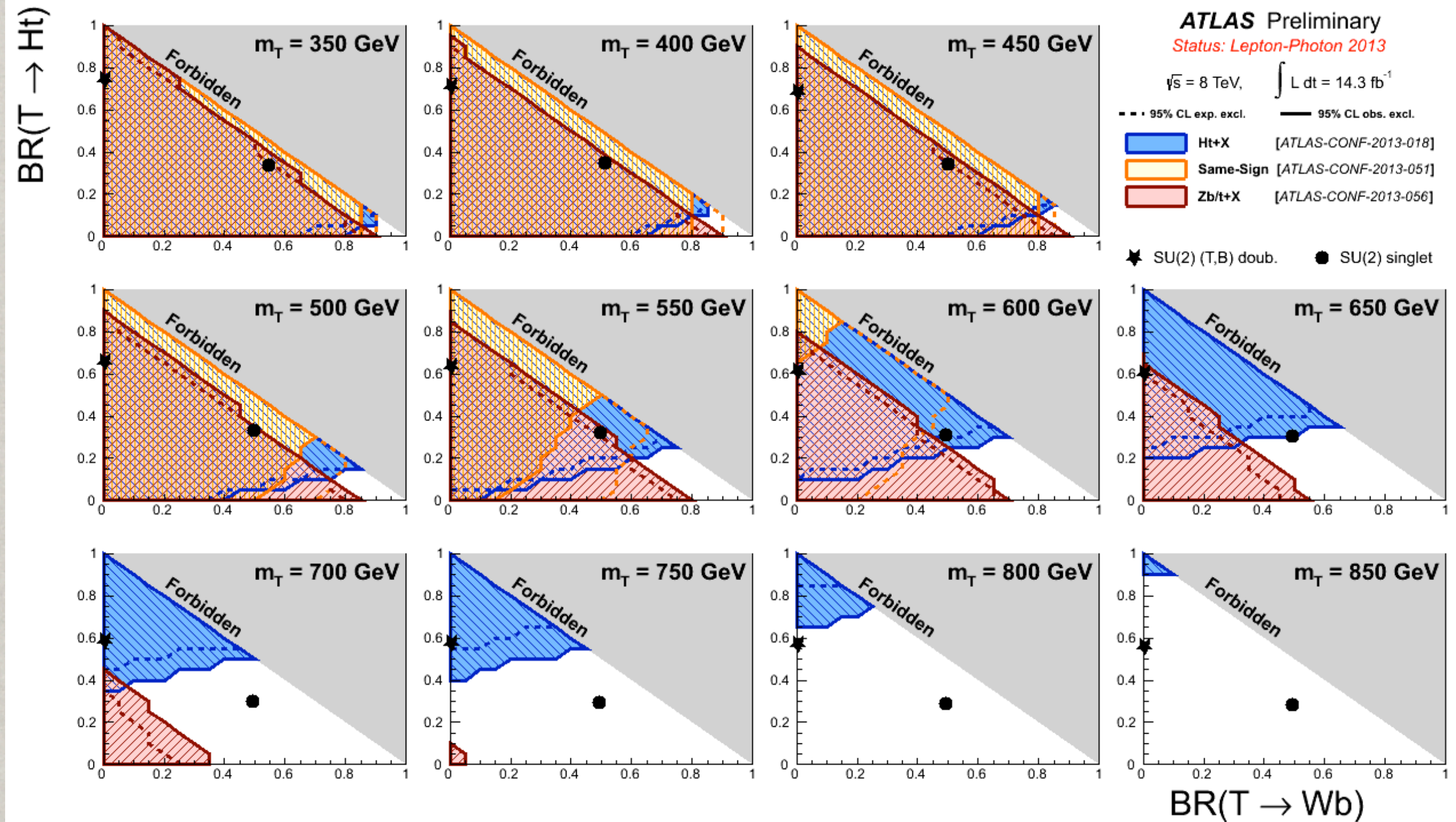
- Plot as a function of heavy top mass with assumed branching ratios
- Set limits on mass for different branching ratios in triangle (assuming only 3 decay modes)

PAS

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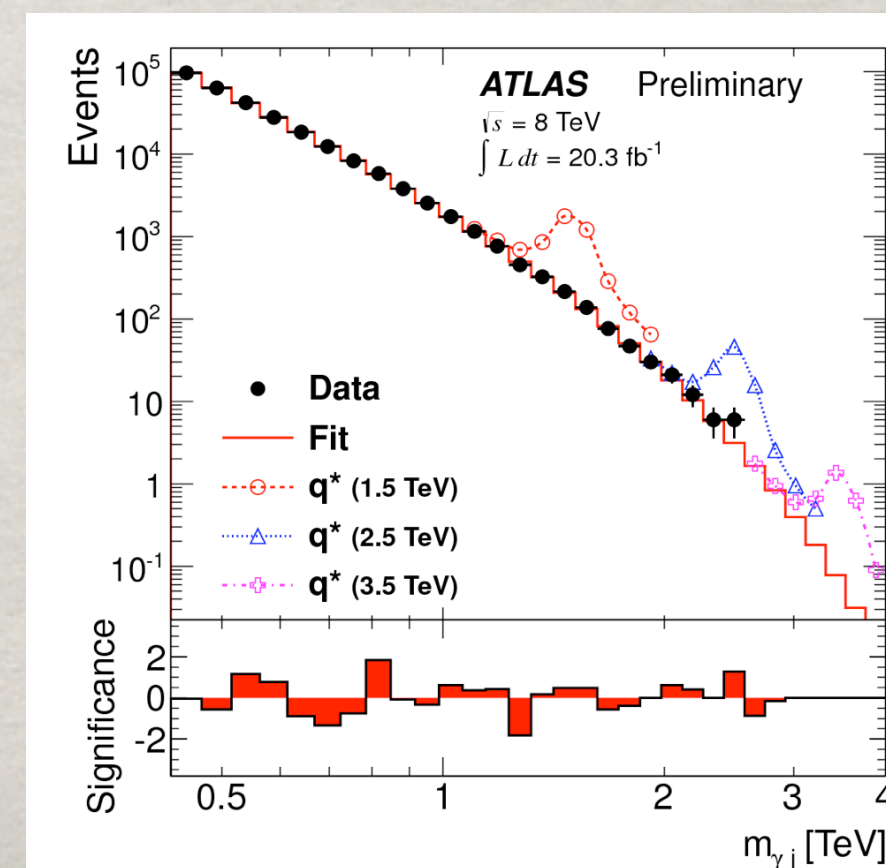
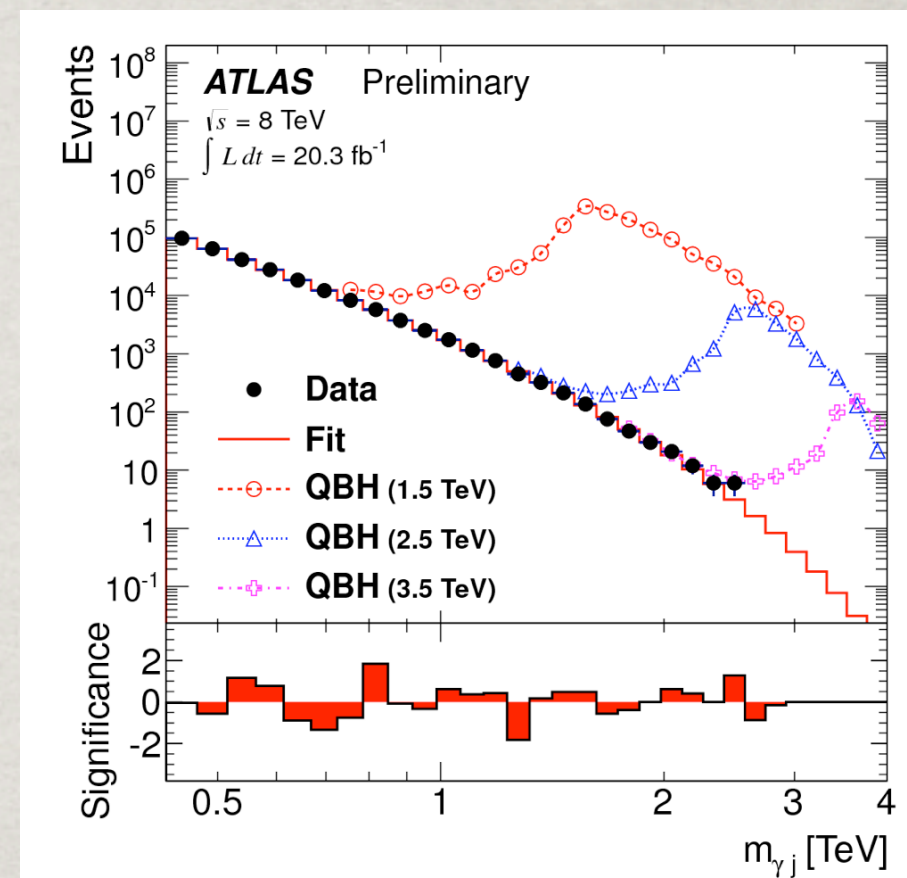


ATLAS VLQ SUMMARY

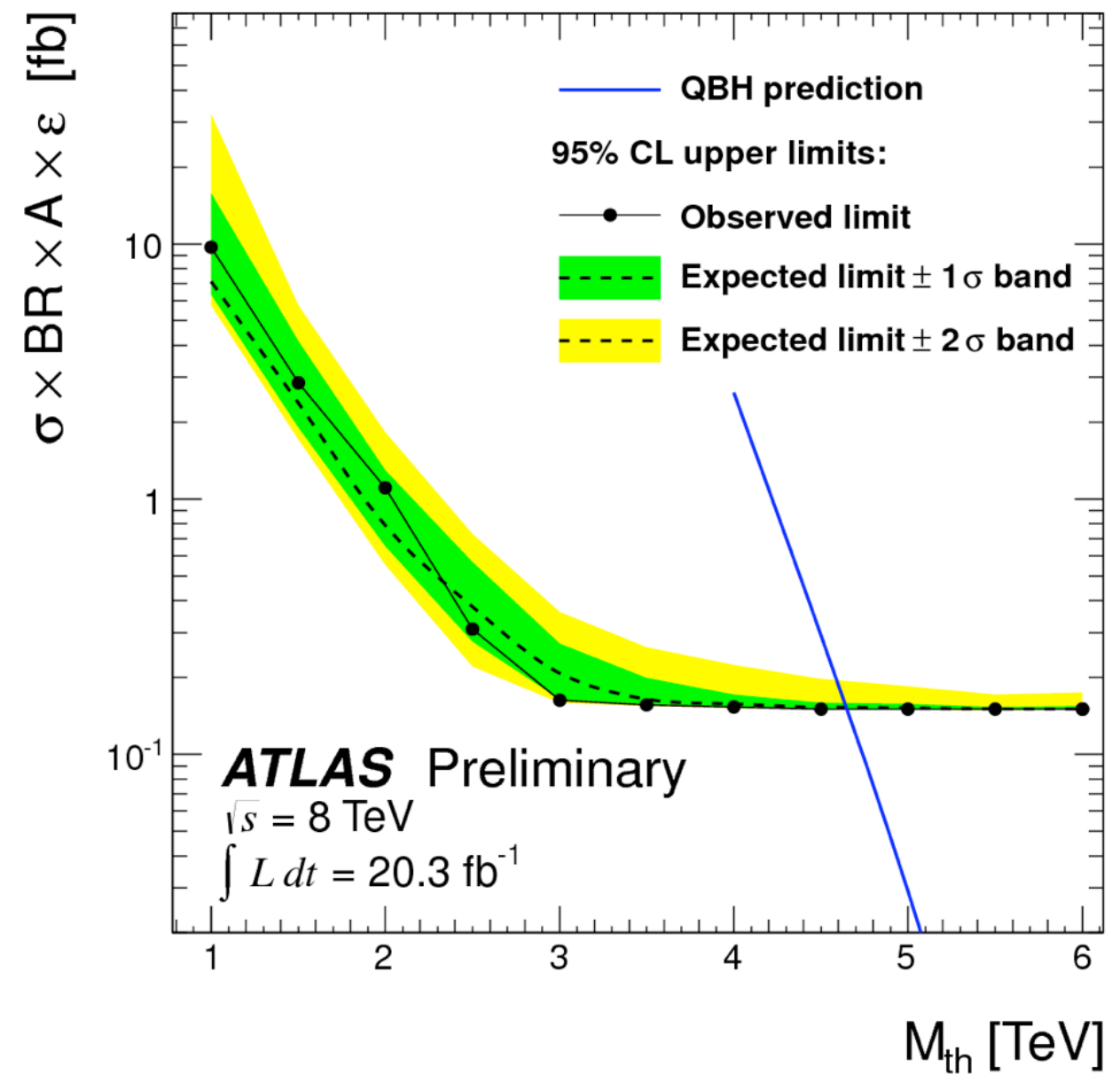
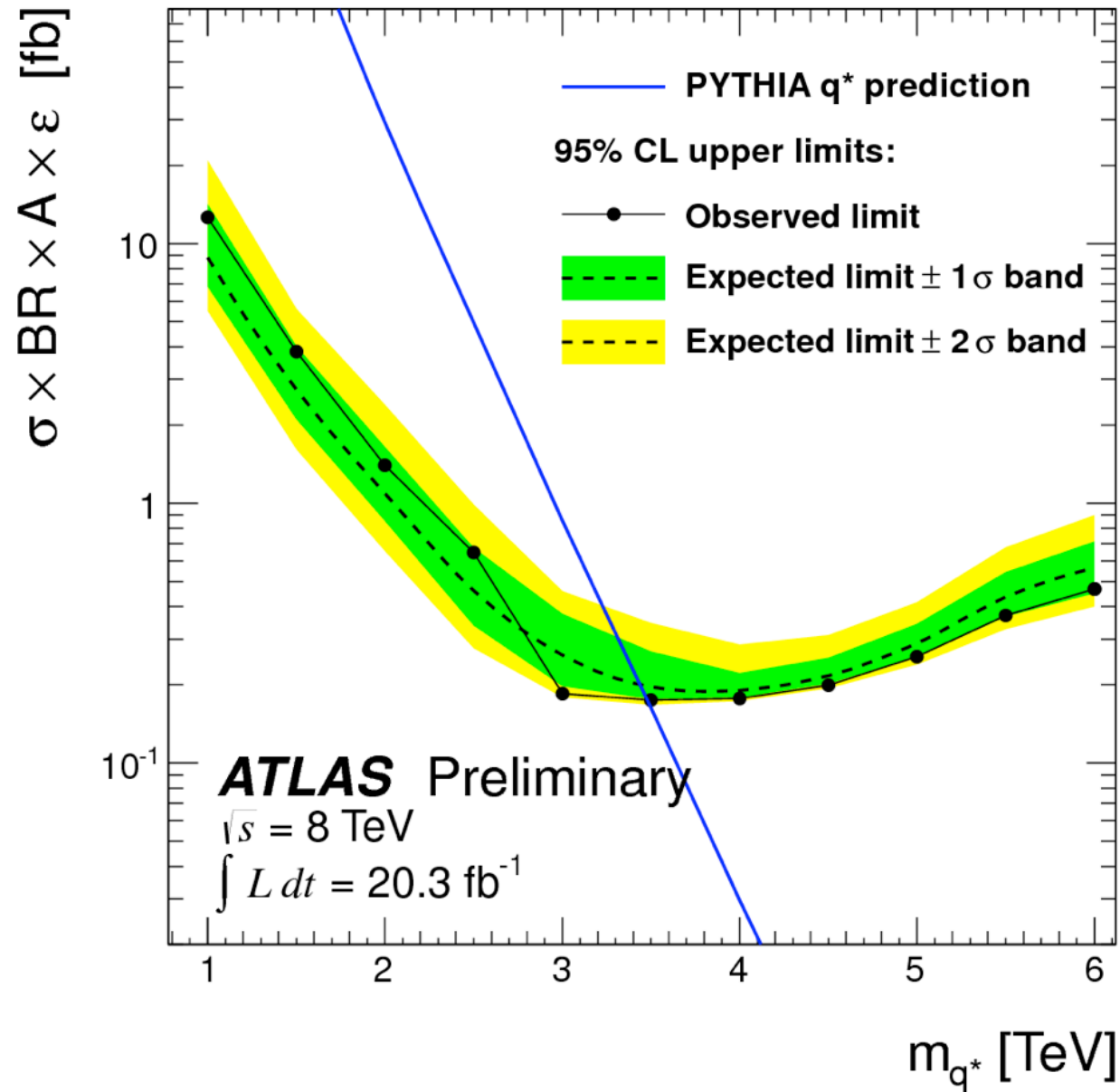


EXCITED QUARKS

- Similar to excited leptons, if quarks are composite expect to see excited states
- Could decay into a quark and a photon
- Search for events with one high pt jet and photon

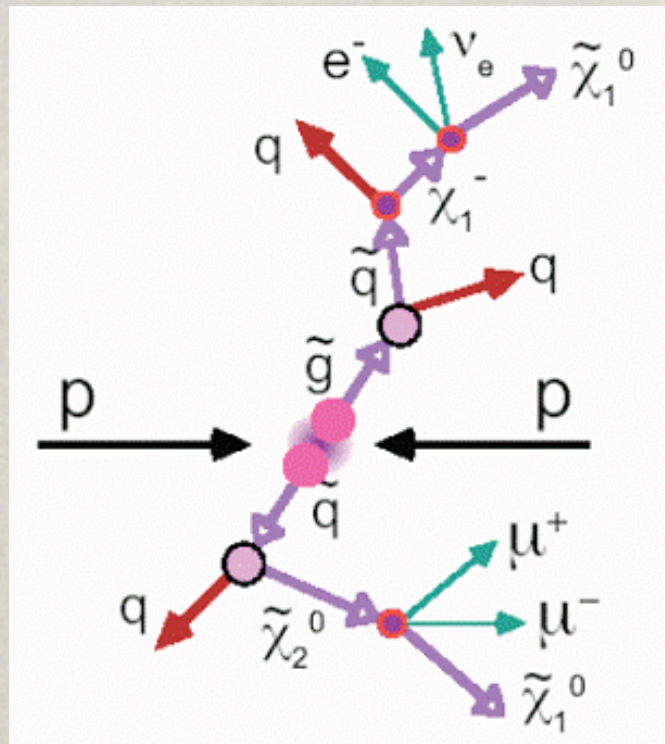


EXCITED QUARK LIMITS



DARK MATTER SEARCHES

- ✱ Direct Searches: Look for DM-nucleus scattering
- ✱ Indirect Searches: Look for astrophysical of DM production or annihilation
- ✱ Collider Searches - Search for missing energy signature of dark matter candidate escaping

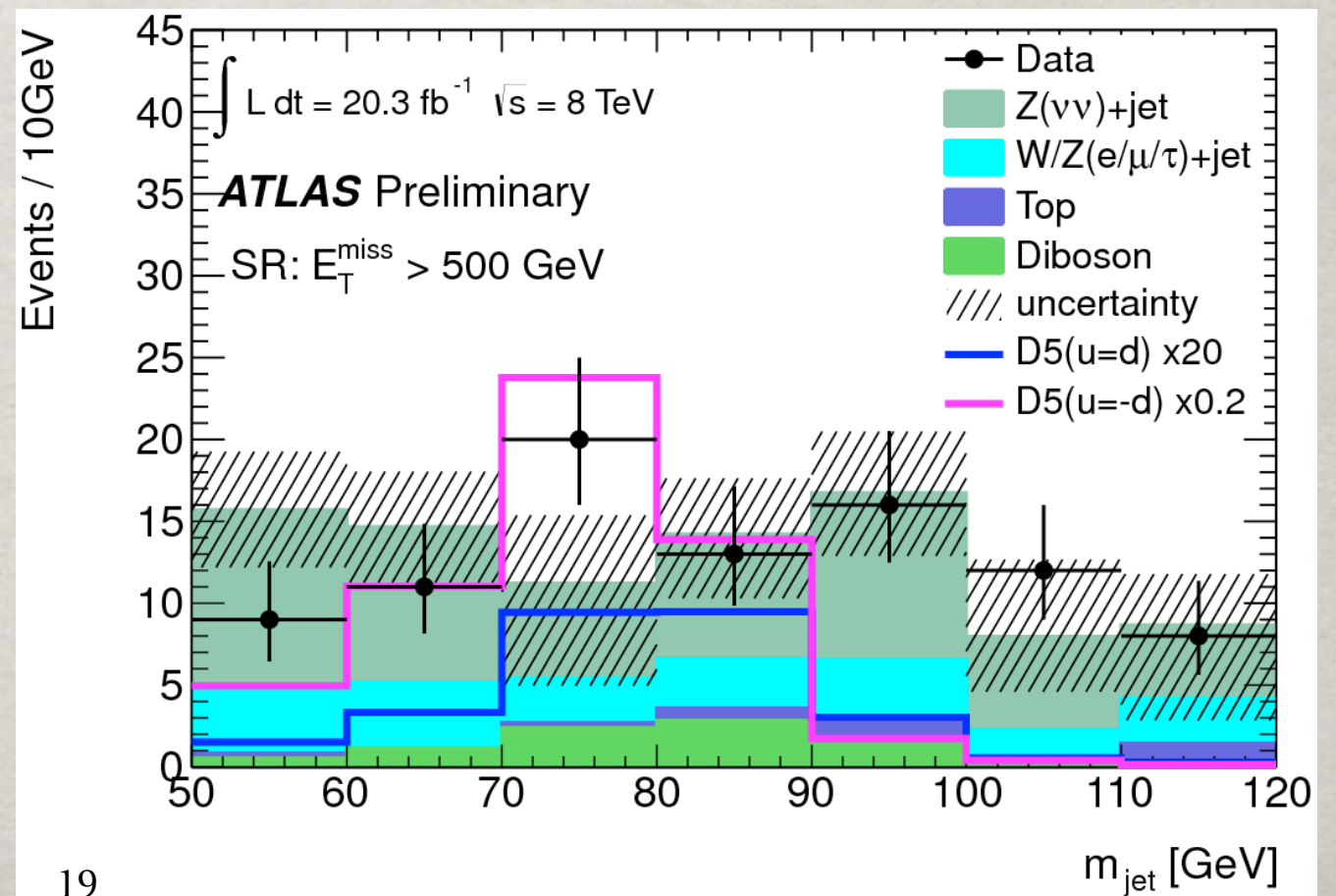
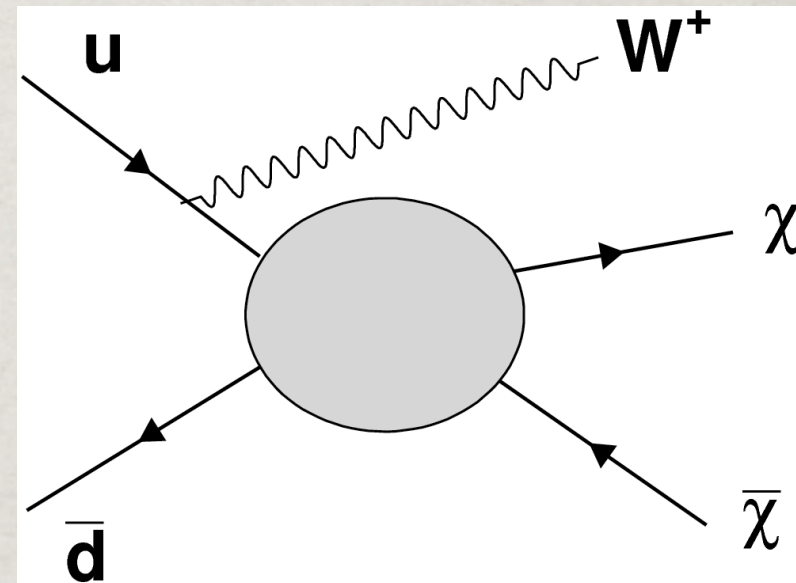


W AND Z BOSON

ATLAS-CONF-2013-073

- Search for mono-W or Z decaying hadronically with large missing energy

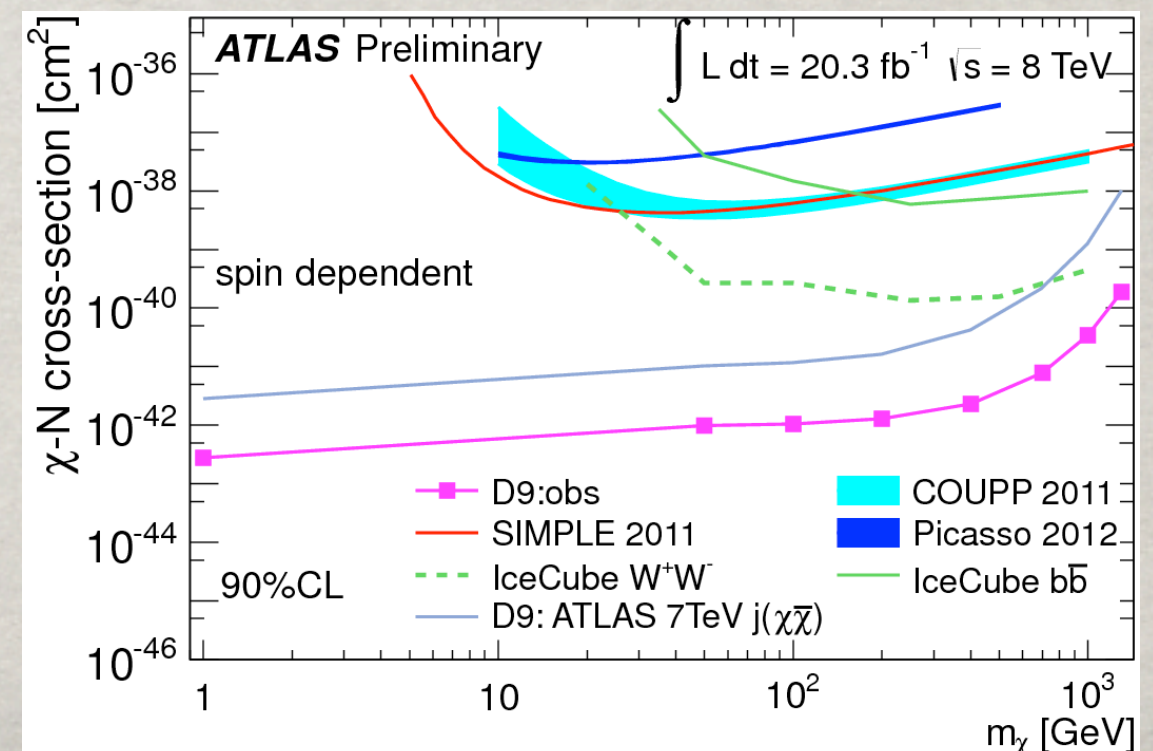
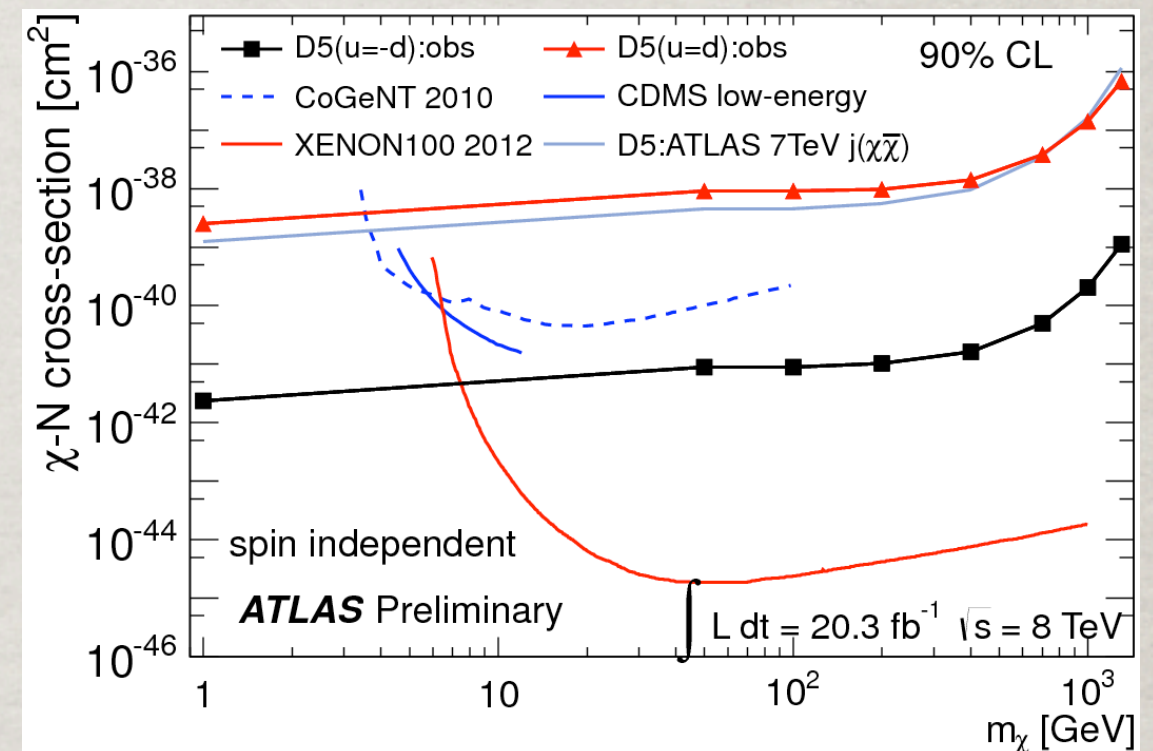
- Divide into several control regions and signal regions to maximize sensitivity to different scenarios



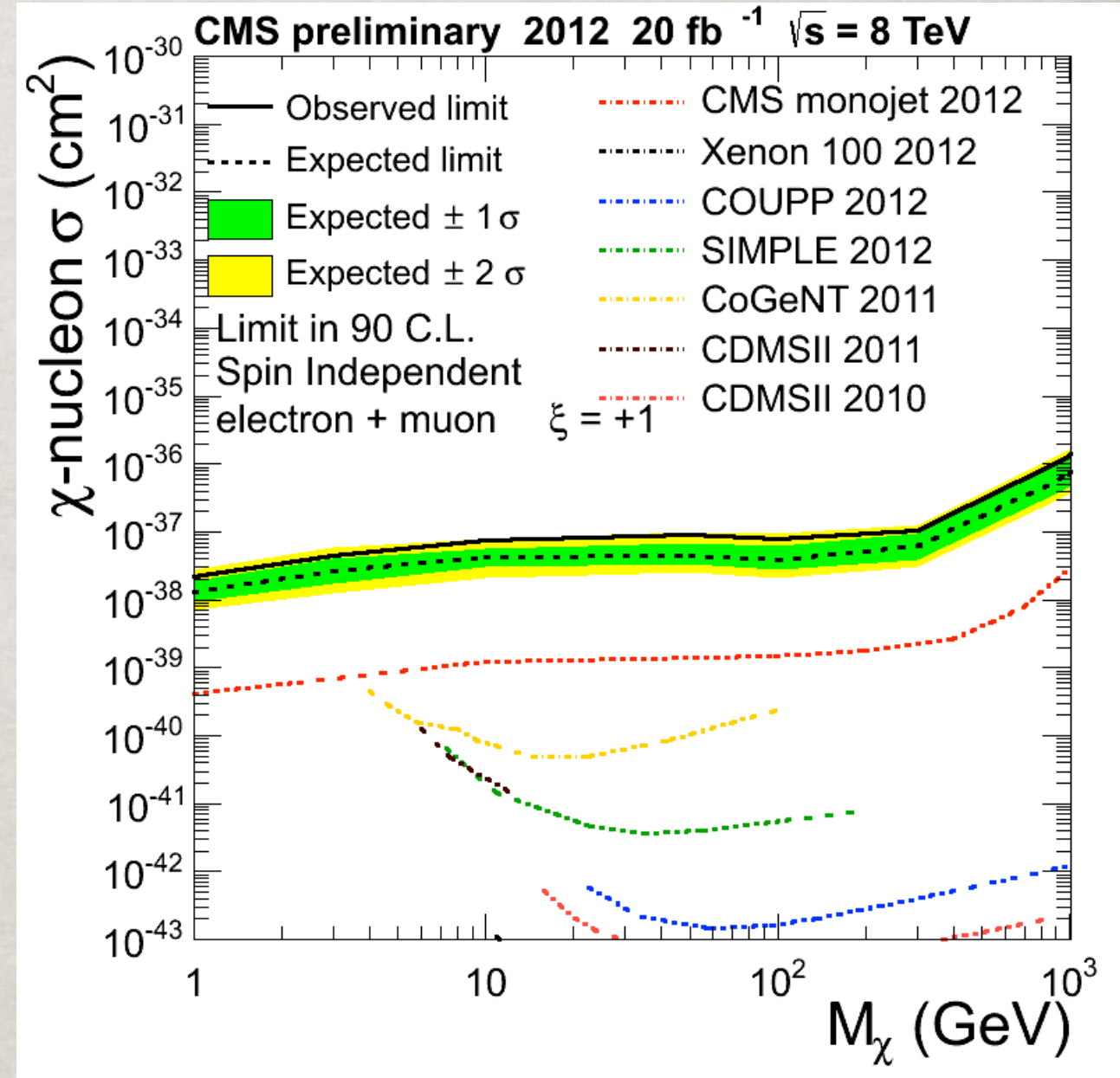
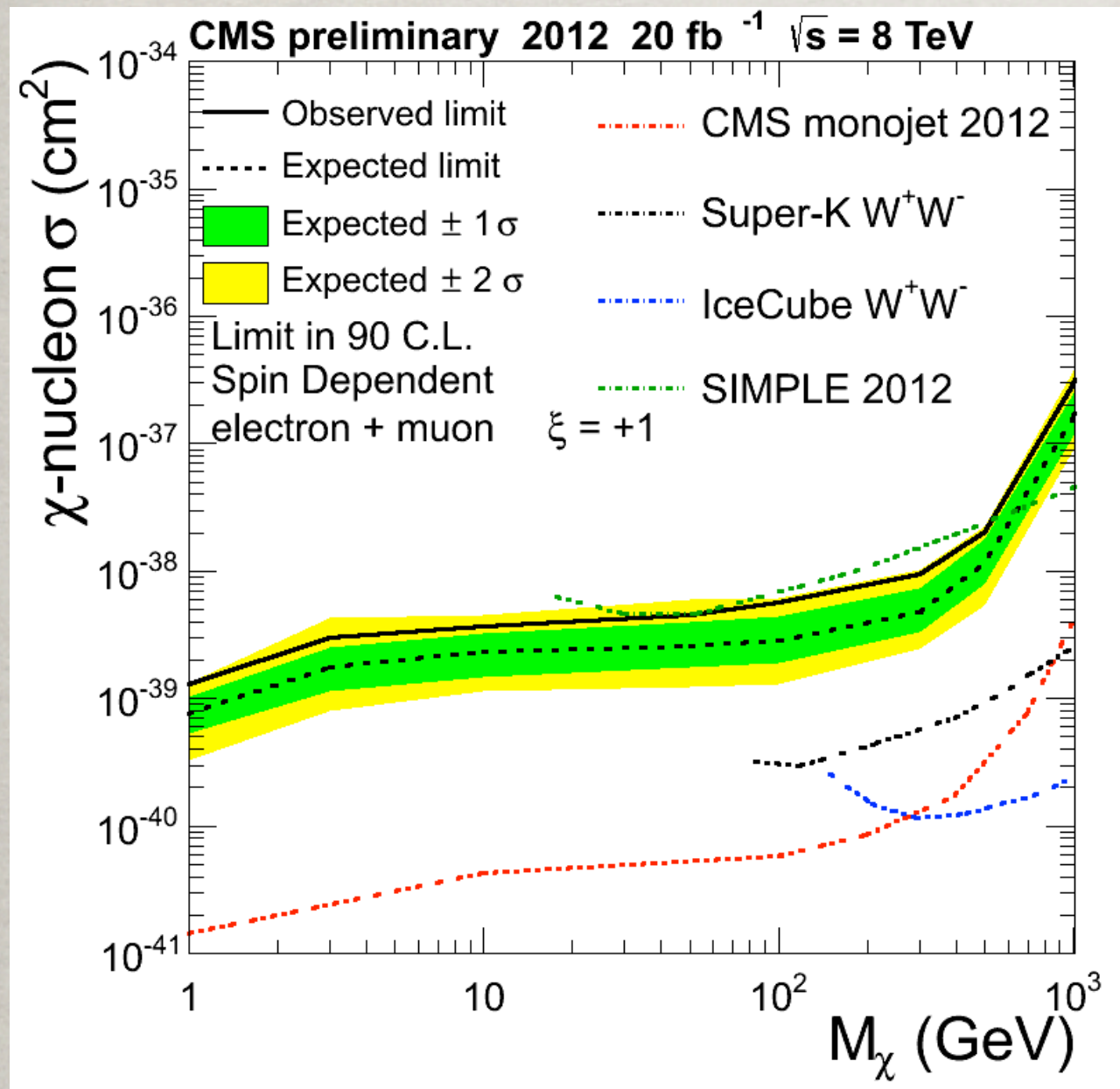
DARK MATTER LIMITS

ATLAS-CONF-2013-073

- Parameterize by different EFT operators
- Worlds best limits for spin dependent operators
- Note that constructive interference between u and d diagram leads to enhancement for monoW leading to best limits for D5



MONO W LIMITS



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EXO13004

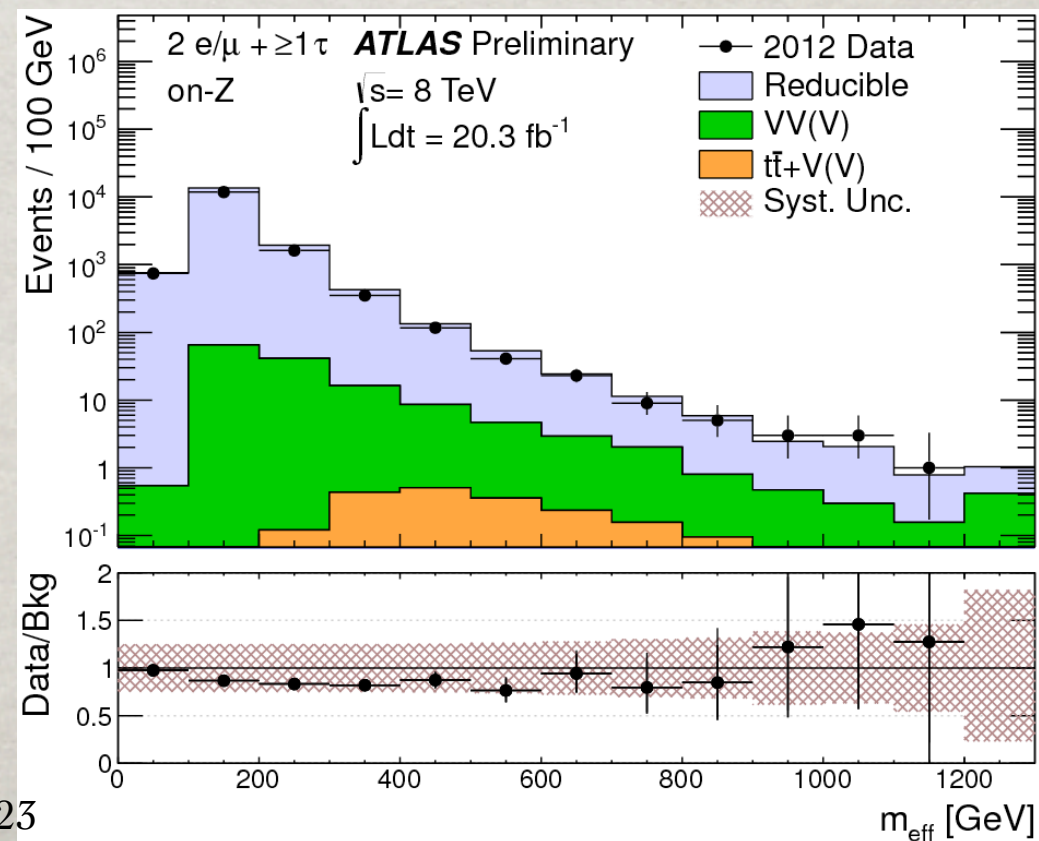
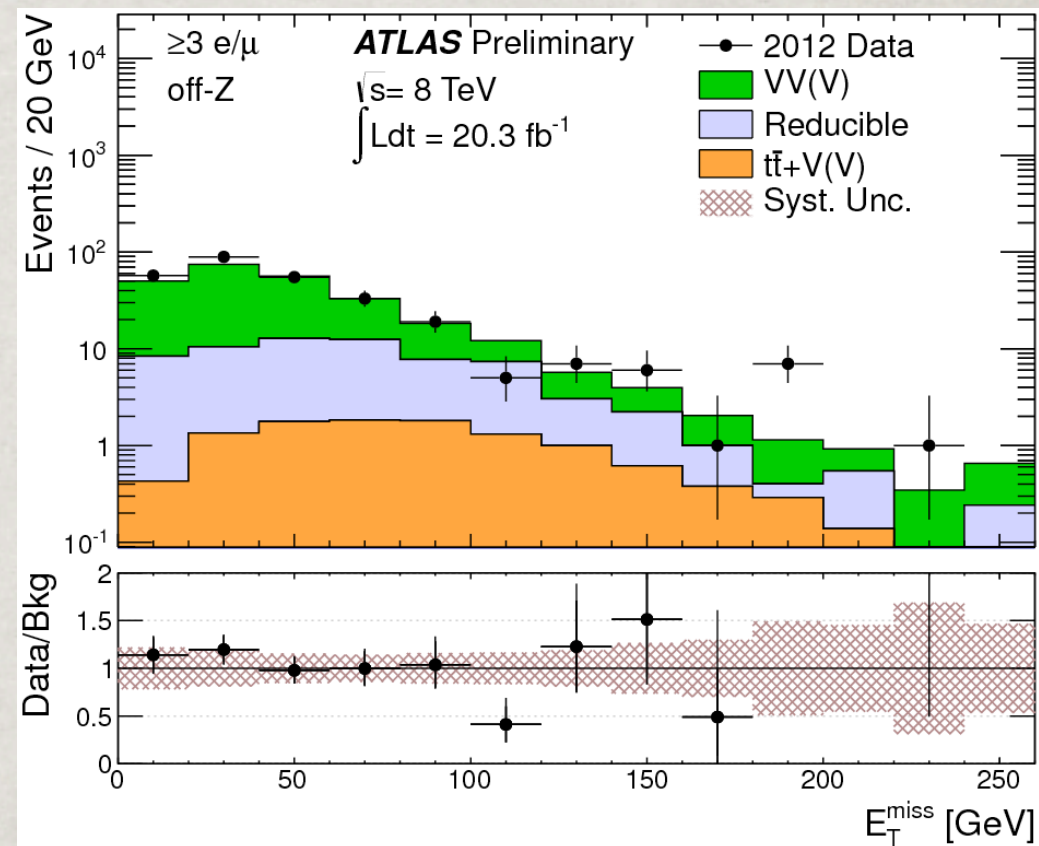
MODEL INDEPENDENT SEARCHES

- ✱ Look for anomalous production over a wide variety of final states
- ✱ Strip model dependent assumptions out of analysis
- ✱ Present results in most general way we can

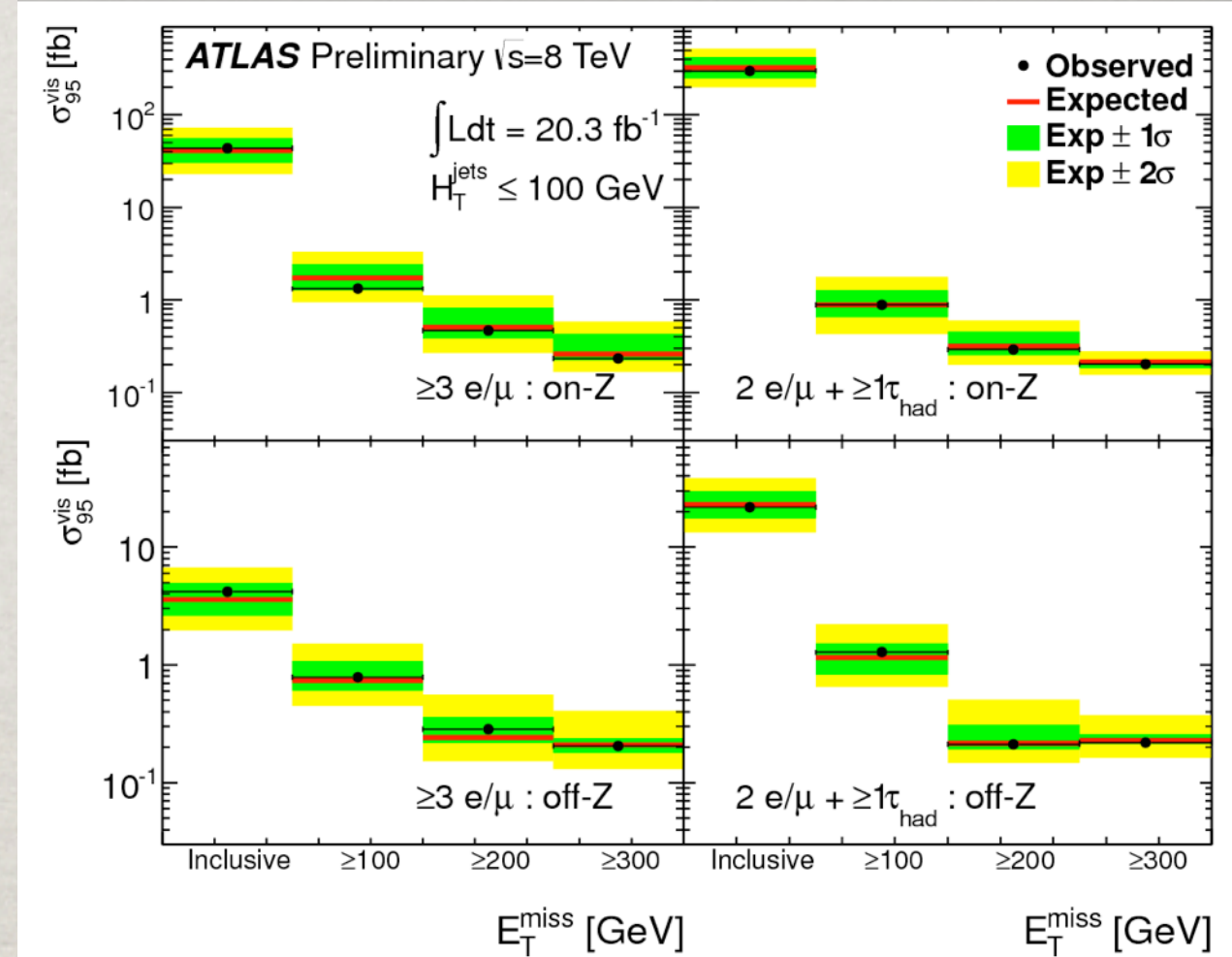
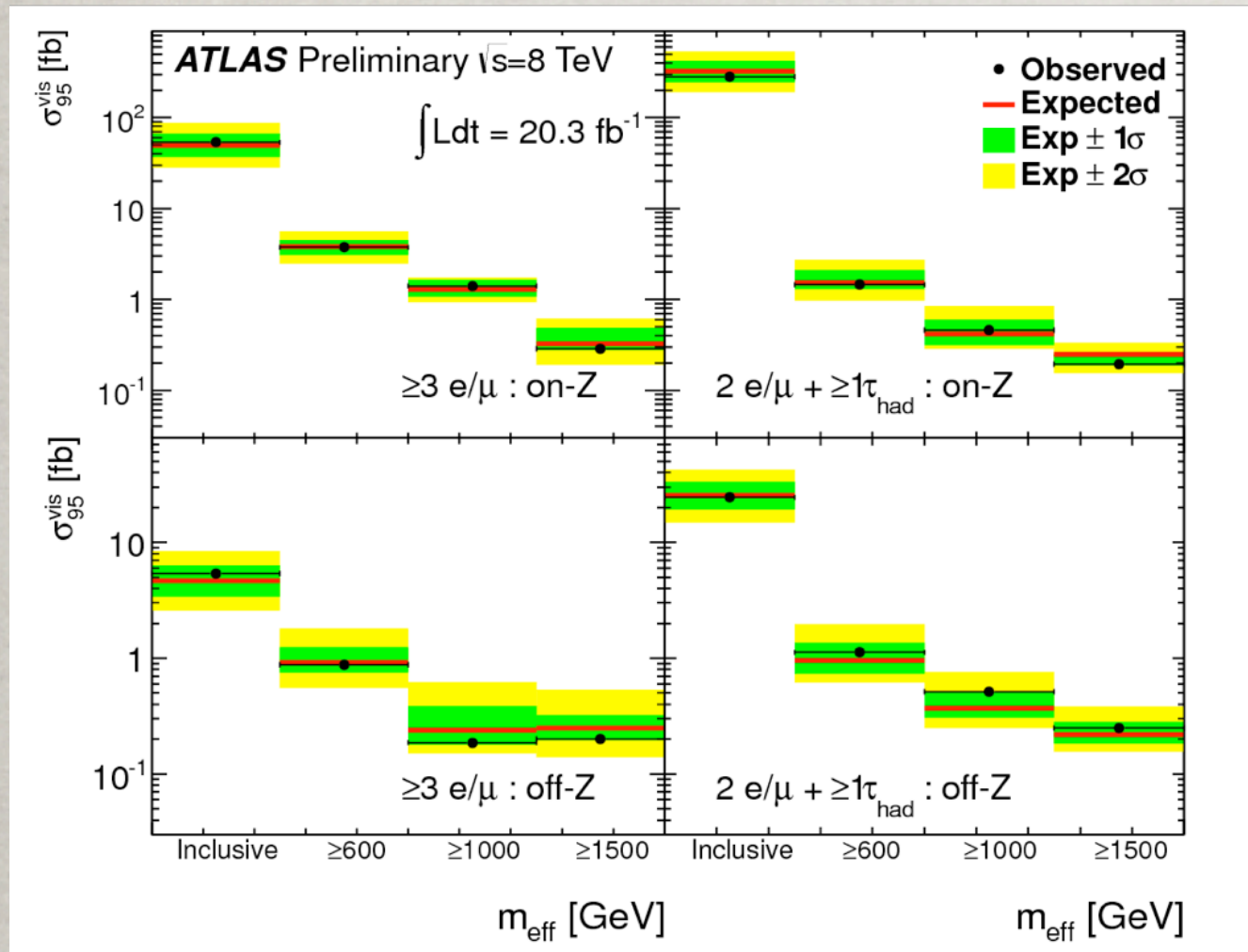
TRILEPTONS

ATLAS-CONF-2013-070

- Look in trilepton final state
- Examine several kinematic variables and place model independent limit on cross-section for new physics contributions



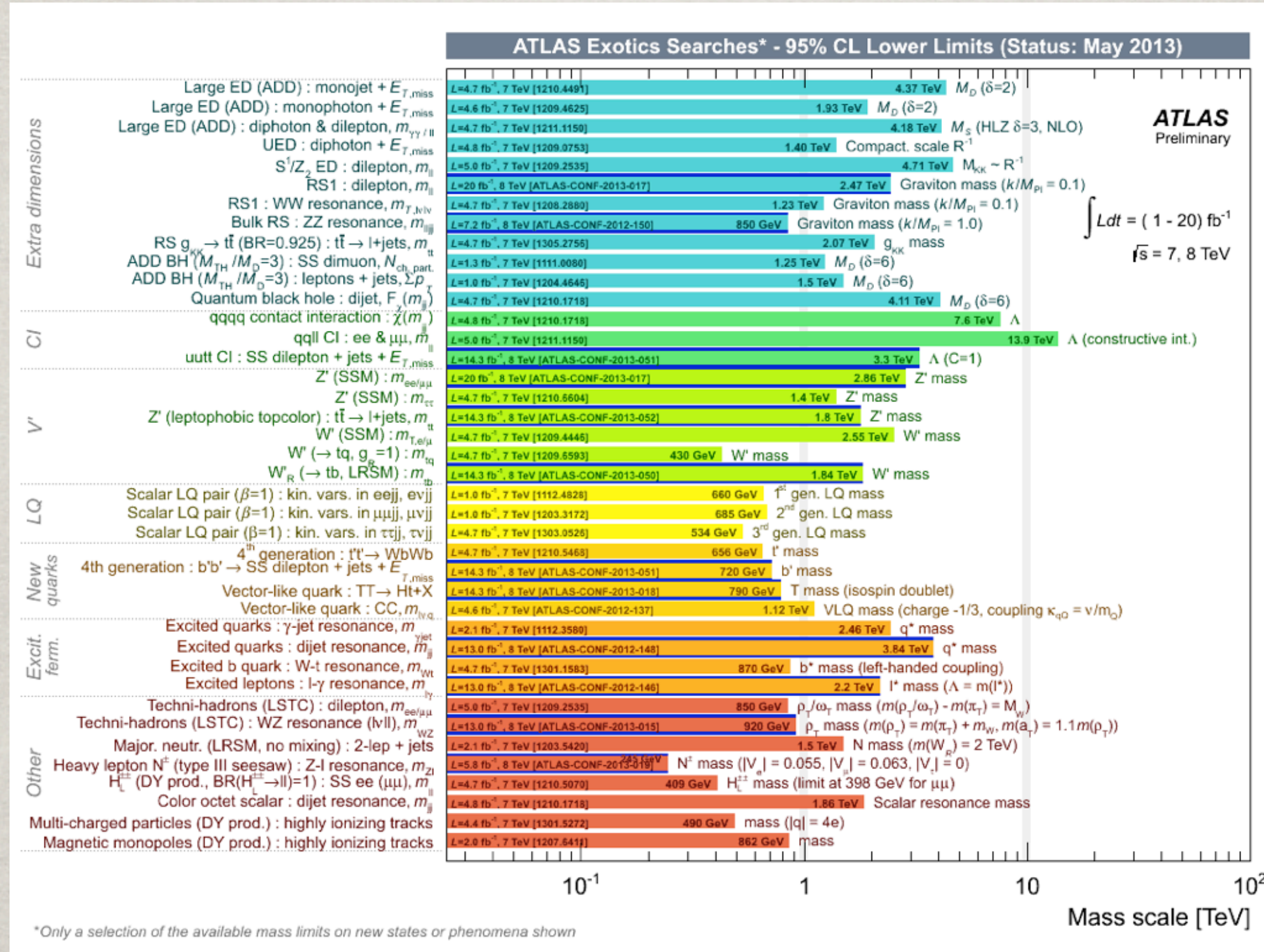
MODEL INDEPENDENT LIMITS



ATLAS-CONF-2013-070

MANY MORE RESULTS

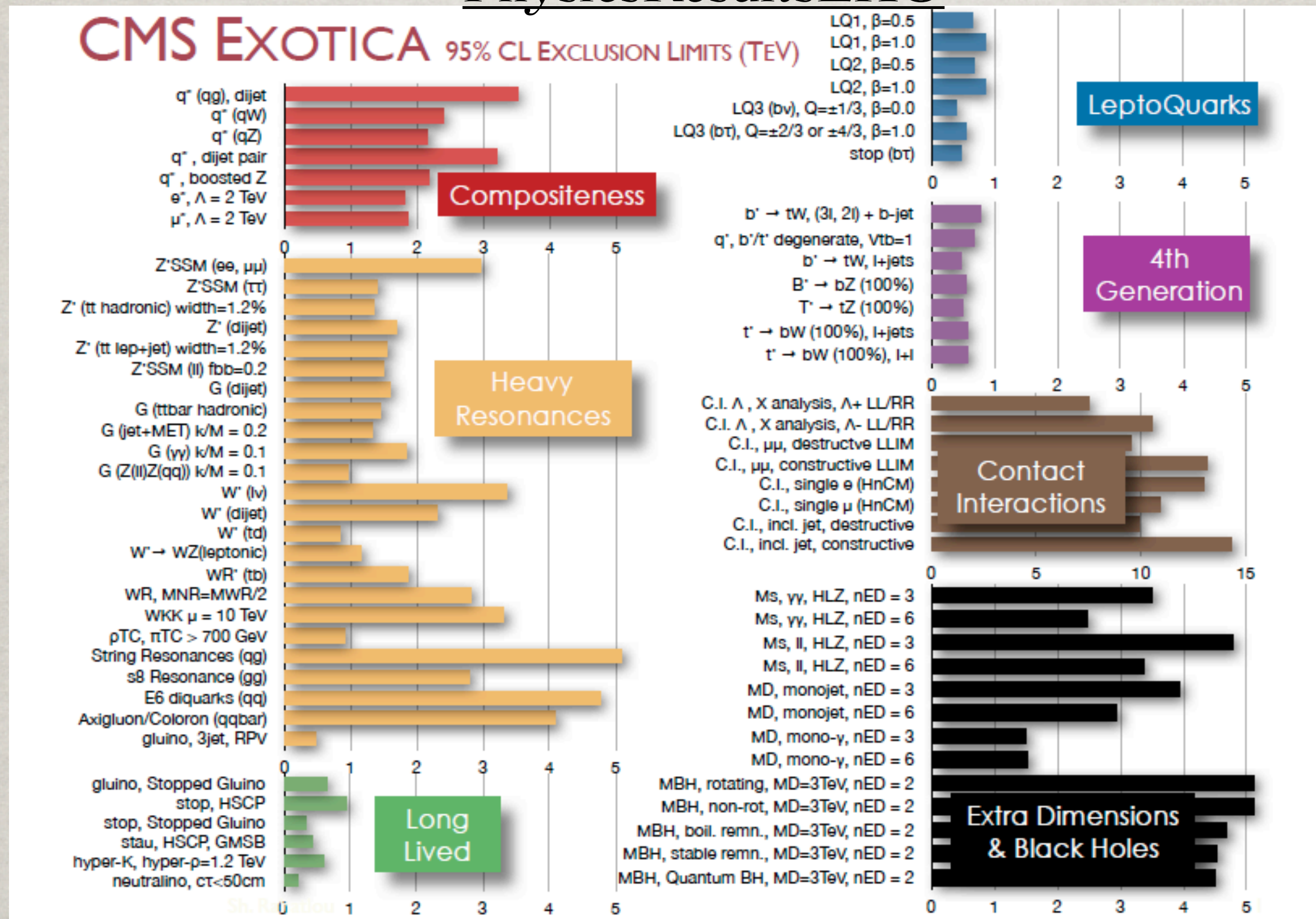
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults>



STILL MORE!

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>

PhysicsResultsEXO



SUMMARY

- ✱ Unfortunately - no significant signs of exotic physics yet in Run I of LHC
- ✱ Limits on heavy gauge bosons (2-3 TeV), heavy new quarks (~ 700 -800 GeV) , and model independent limits on contributions to new physics
- ✱ Expect slew of new results soon as many analysis finishing adding the complete run I datasets!

BACKUP

✱ Dilepton Search:

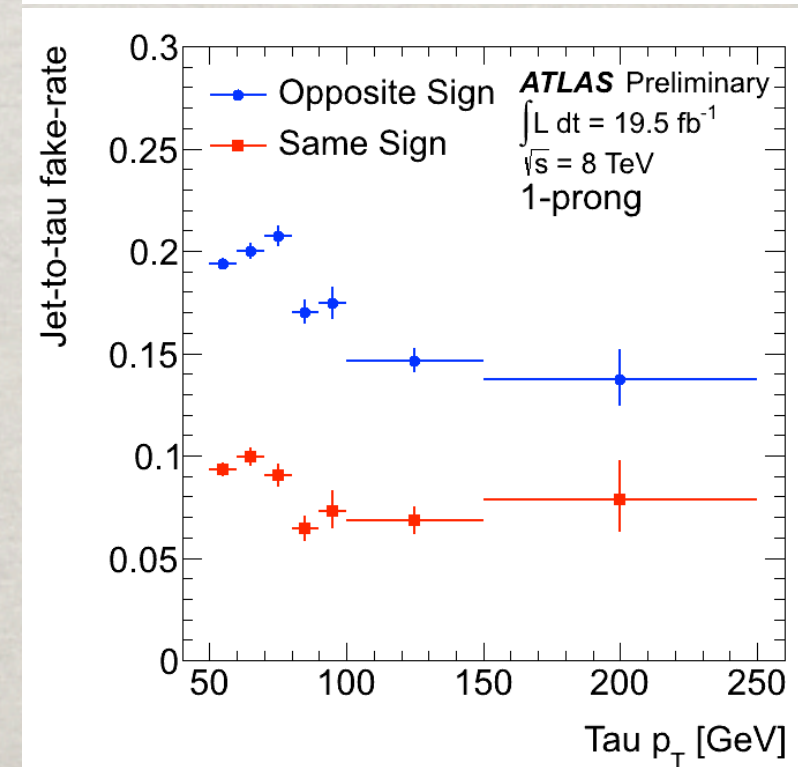
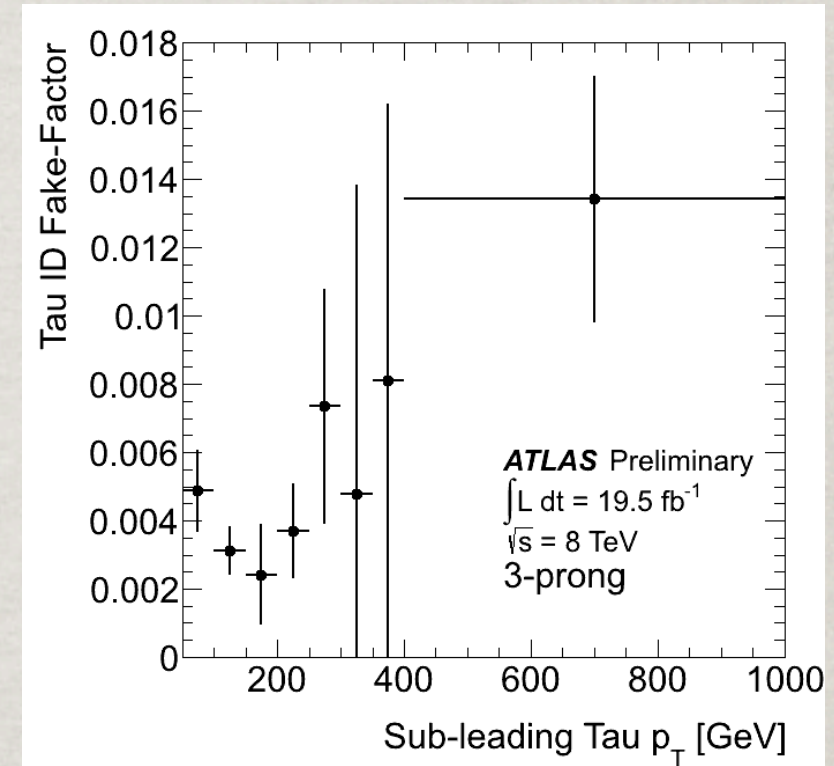
- ✱ Two electrons with $E_t > 40$ (30 GeV), trigger with diphoton trigger with (35,25 GeV thresholds)
- ✱ Relative Isolation cut less than $0.7\% + 5 \text{ GeV}$ ($2\% + 6.0 \text{ GeV}$)
- ✱ Two muons with $p_t > 25 \text{ GeV}$, or of 24 and 36 GeV single muon trigger, 5% relative isolation

DITAU SEARCH

- ✱ BDT using shower shape, tracking information for hadronic tau reconstruction
- ✱ Require two hadronic taus with $P_t > 50 \text{ GeV}$, no electrons or muons reconstructed
- ✱ High P_t tau for trigger $> 150 \text{ GeV}$ (leading tau offline)
- ✱ use total transverse mass as search variable

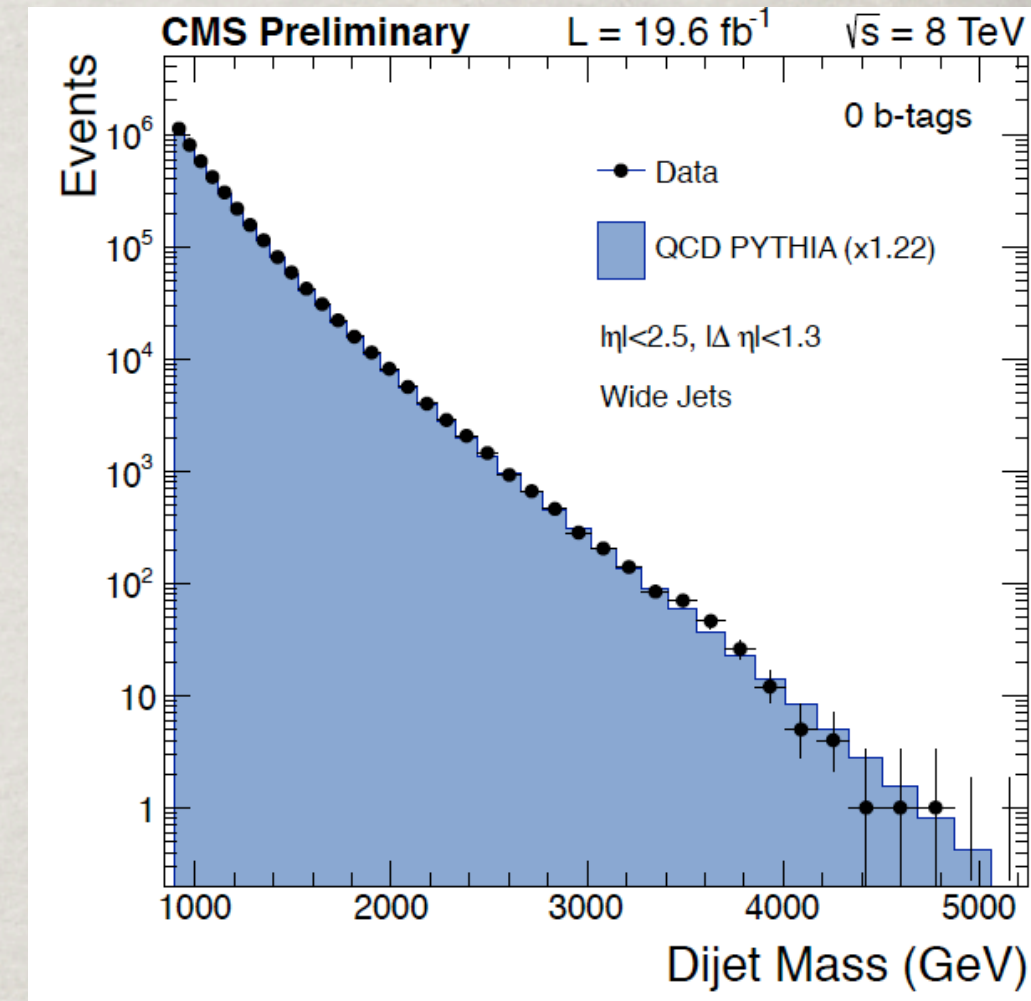
BACKGROUNDS

- ✱ Z to tau tau and multijet main backgrounds
- ✱ Use fake factor method to estimate backgrounds from multijet and W +jet backgrounds



- ✱ Fit dijet spectra to parameterized function
- ✱ Search for resonance structure not well fit by this function
- ✱ Set single limit on :

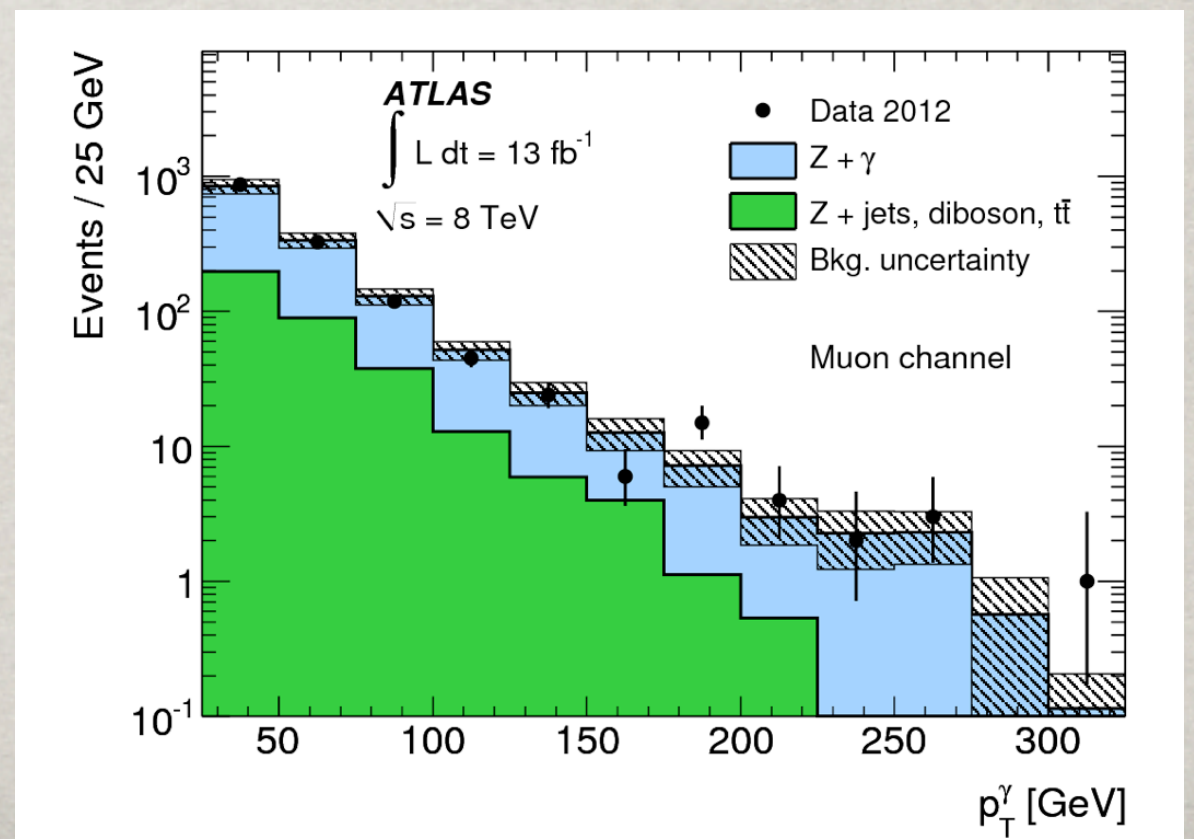
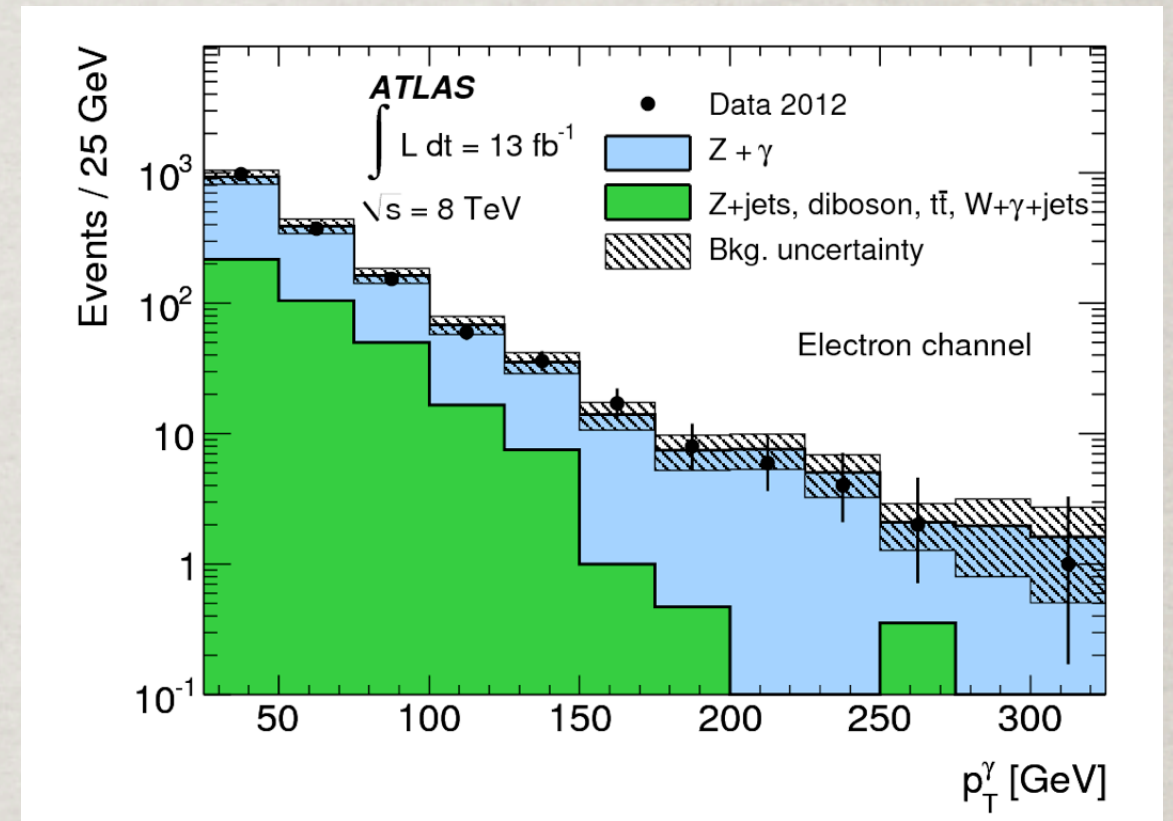
$$f_{b\bar{b}} = \frac{B(X \rightarrow b\bar{b})}{B(X \rightarrow jj)}$$



$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3} \ln(x)}$$

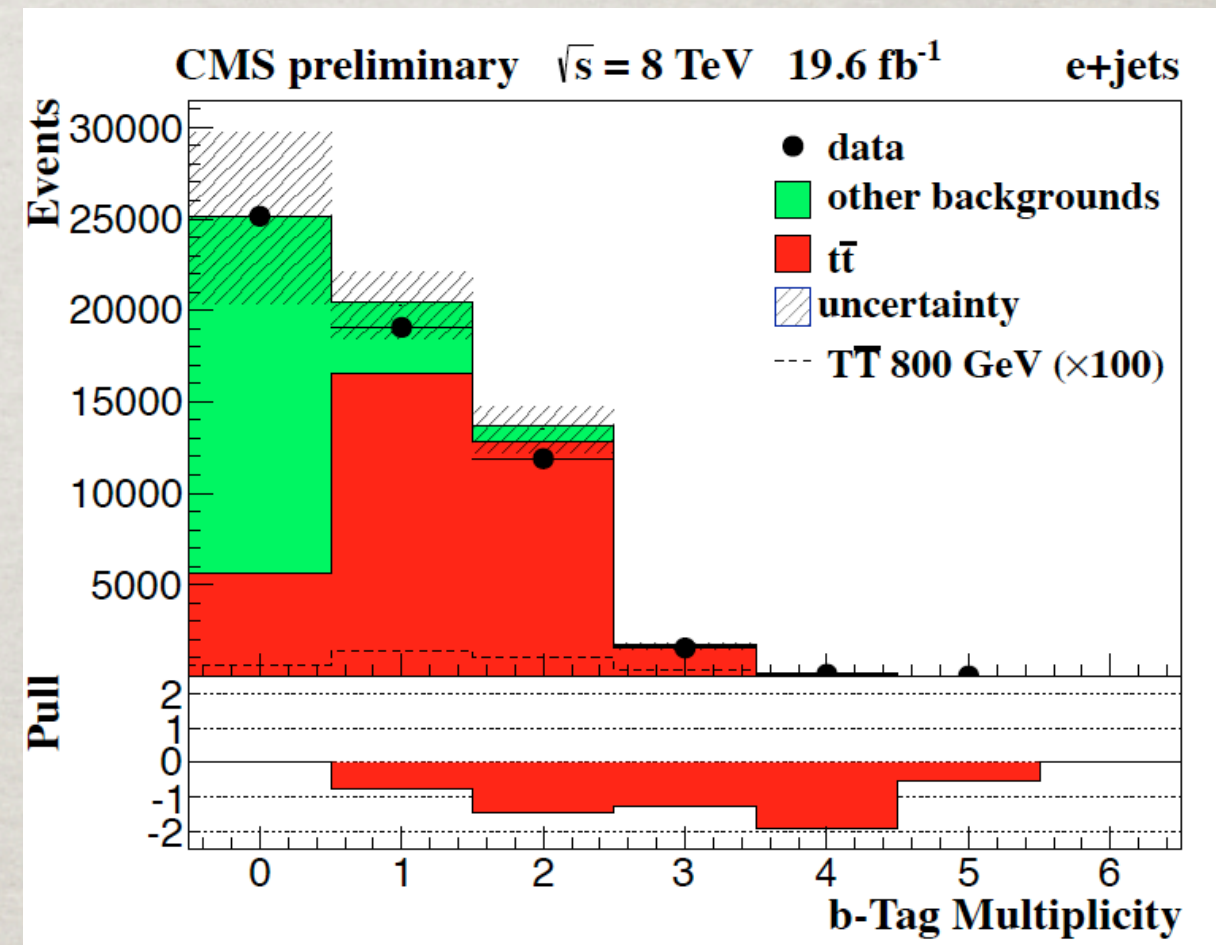
EXCITED LEPTONS

- ✱ Z+photon is major background (taken from simulation)
- ✱ Z+jet backgrounds are normalized from data in a control region near the Z mass where the signal contamination is $\sim 2\%$ or less



VLQ CMS

- ✱ Define control region dominated by $t\bar{t}$ and w +jets
- ✱ scale to get best agreement in control region as a function of b-tags
- ✱ scale drell-yan prediction to observed z peak



☼ Multileptons: VLQ CMS

- ☼ Divided into 4 mutually exclusive categories
 - ☼ opposite sign (A) - $bWbW$ final state ($H_t > 300$, $S_t > 900$, with invariant mass of b-jet and lepton < 170 GeV)
 - ☼ opposite sign (B) - Zt final state, $H_t > 500$, $S_t > 1000$, 5 jets with two leptons from Z
 - ☼ same sign: two same sign leptons $H_t > 500$, $S_t > 700$,
 - ☼ trilepton: three leptons with same H_t and S_t requirement as same sign