Exotics Searches

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For the ATLAS and CMS Collaborations

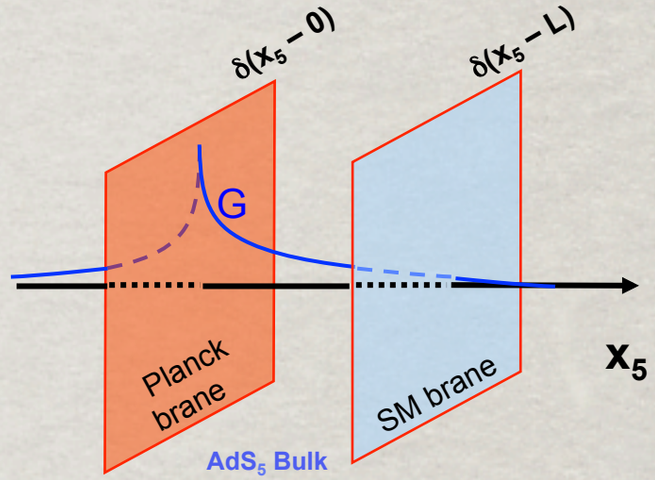
BOSTON UNIVERSITY

Overview

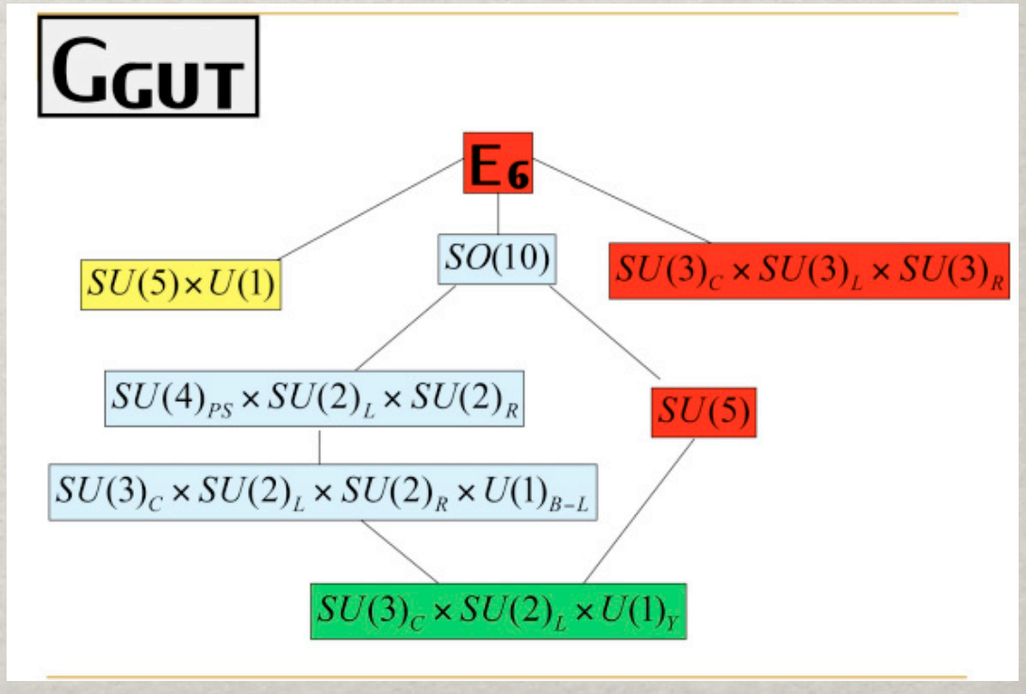
- New Gauge Bosons
- New Quarks and Leptons
- Dark Matter
- Generic Topological Searches

What will new physics look like?
collisions.org.au

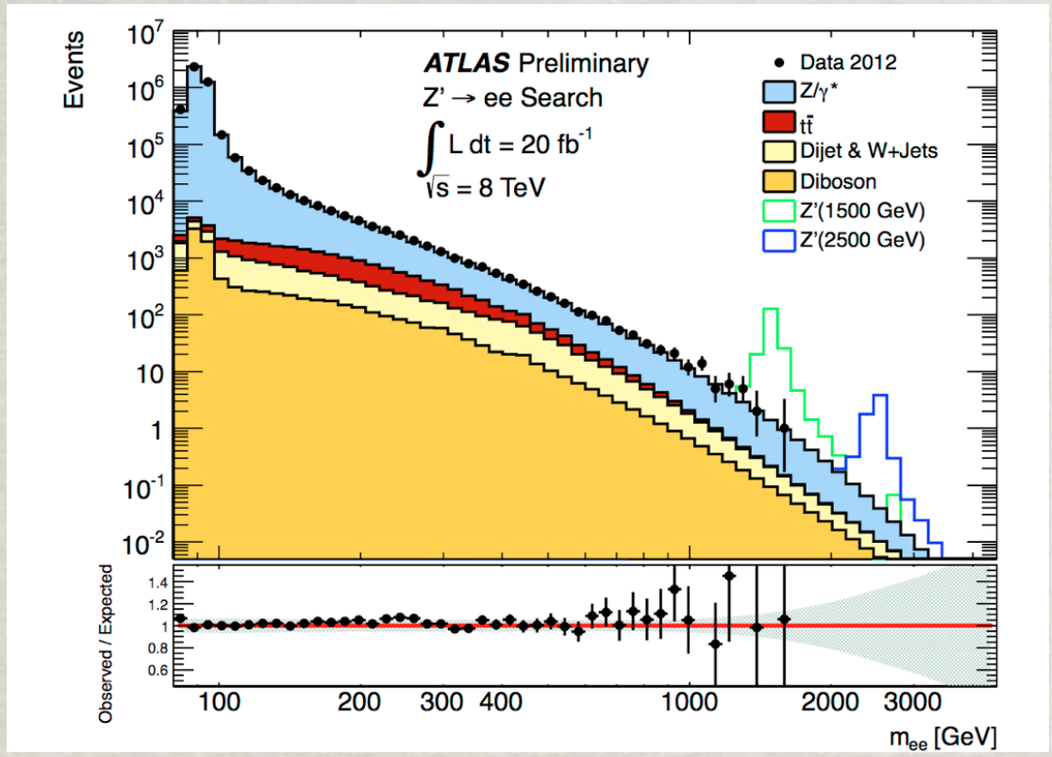
New Gauge Bosons

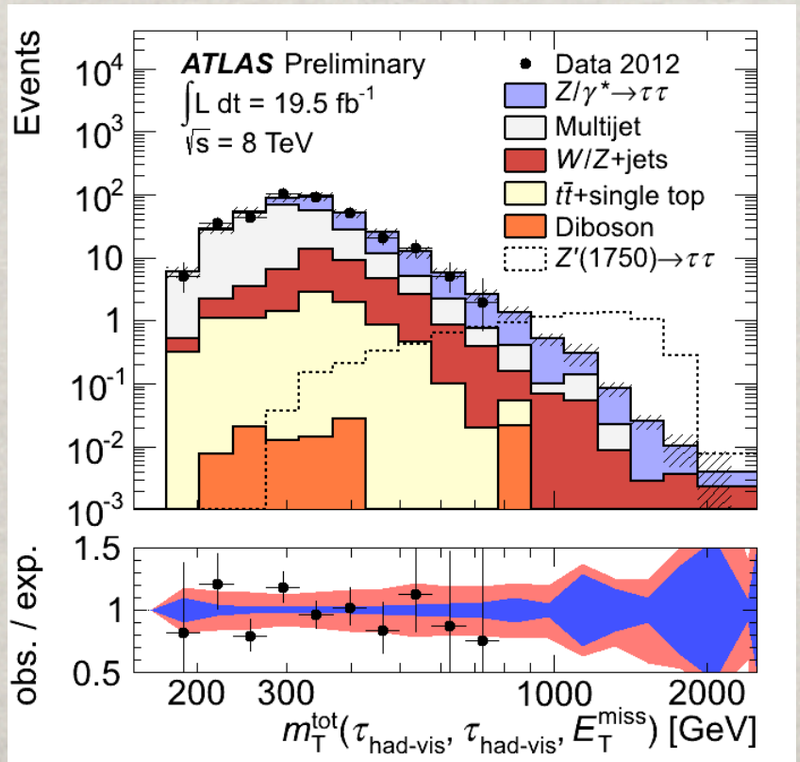


- Many extensions of the SM predict new bosons that come from the enlarged symmetry groups proposed:
  - Sequential Standard Model (SSM)
  - GUTs: E6 ->SO(10)×U(1) SU(5)×U(1)×U(1)
  - Left-Right symmetric models
  - Extra-Dimensions



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 dilectron 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)

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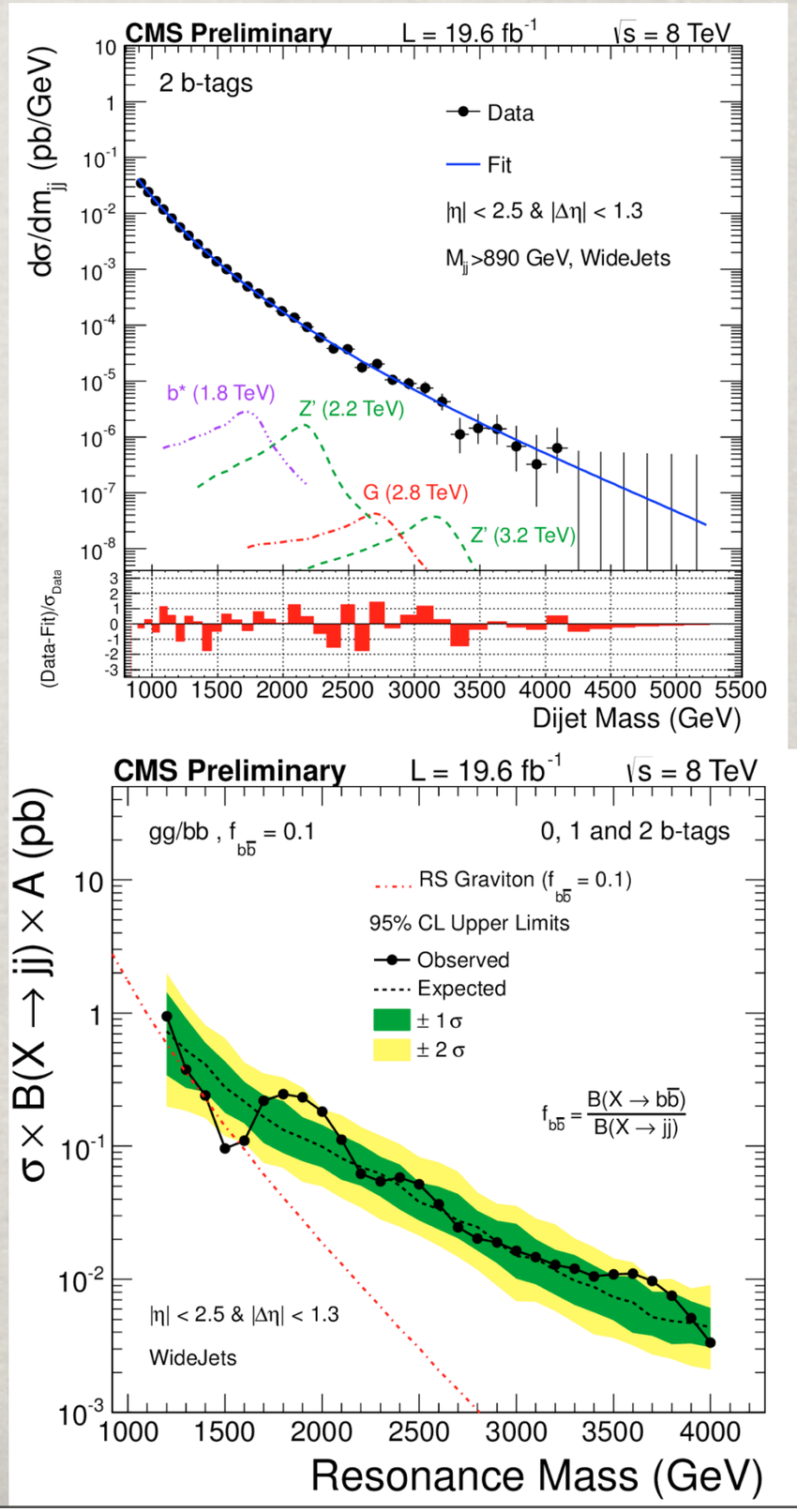
Dijet Resonances

PAS
EXO12023

- For new particle that couples strongly to quarks , look at dijet channel

- Larger backgrounds but also larger branching ratios for some searches

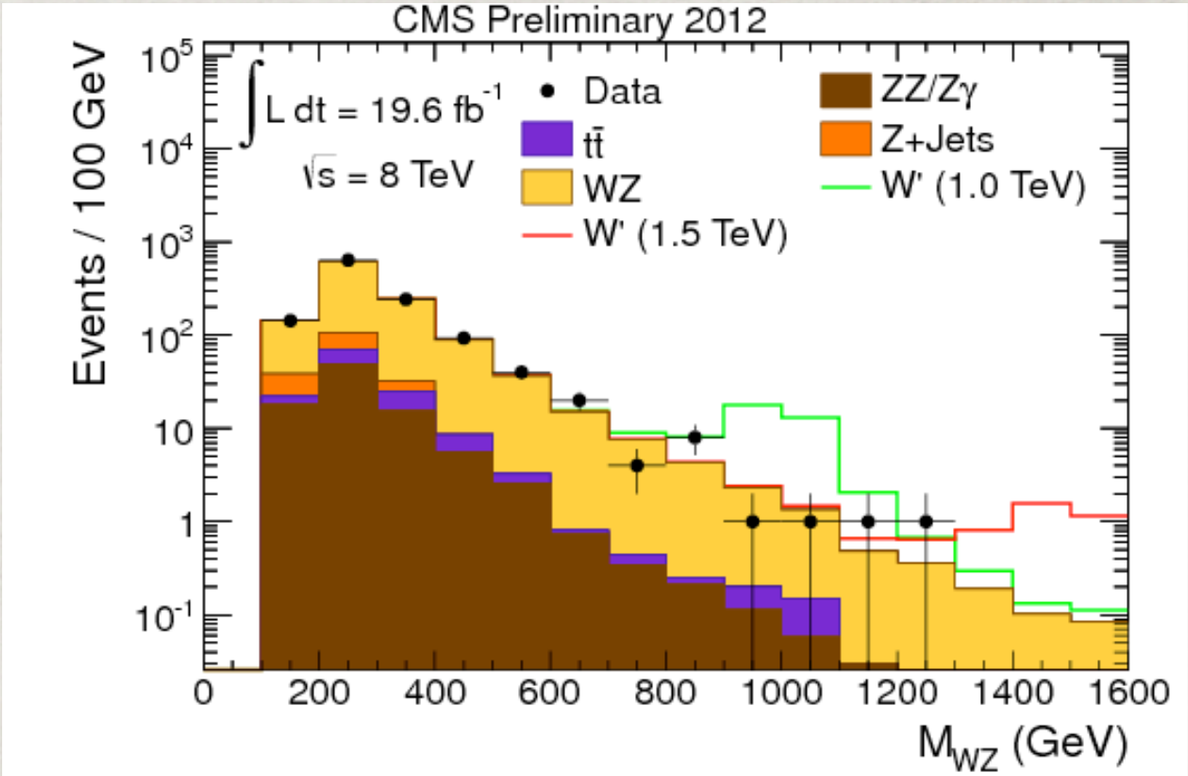
- Look also for decays into heavy flavor jet pairs

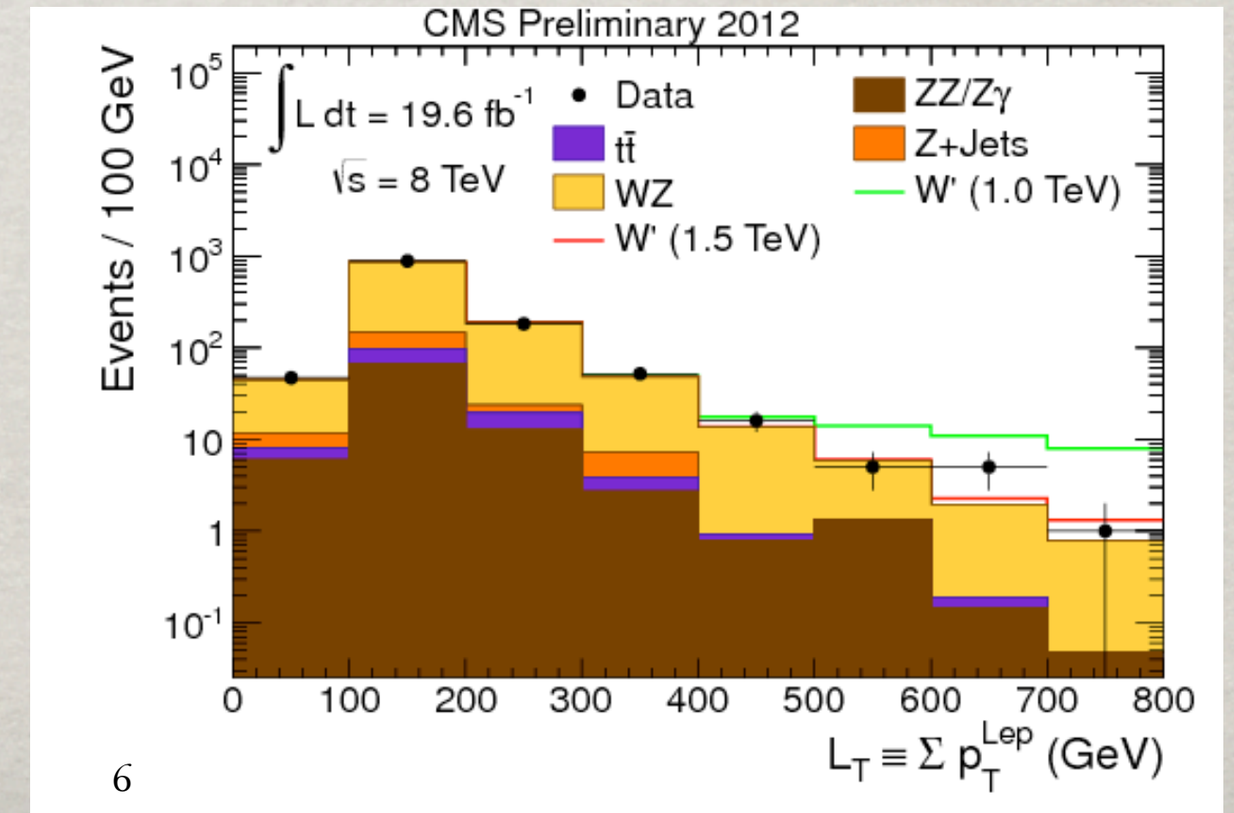


Diboson Resonance

PAS
EXO12025

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

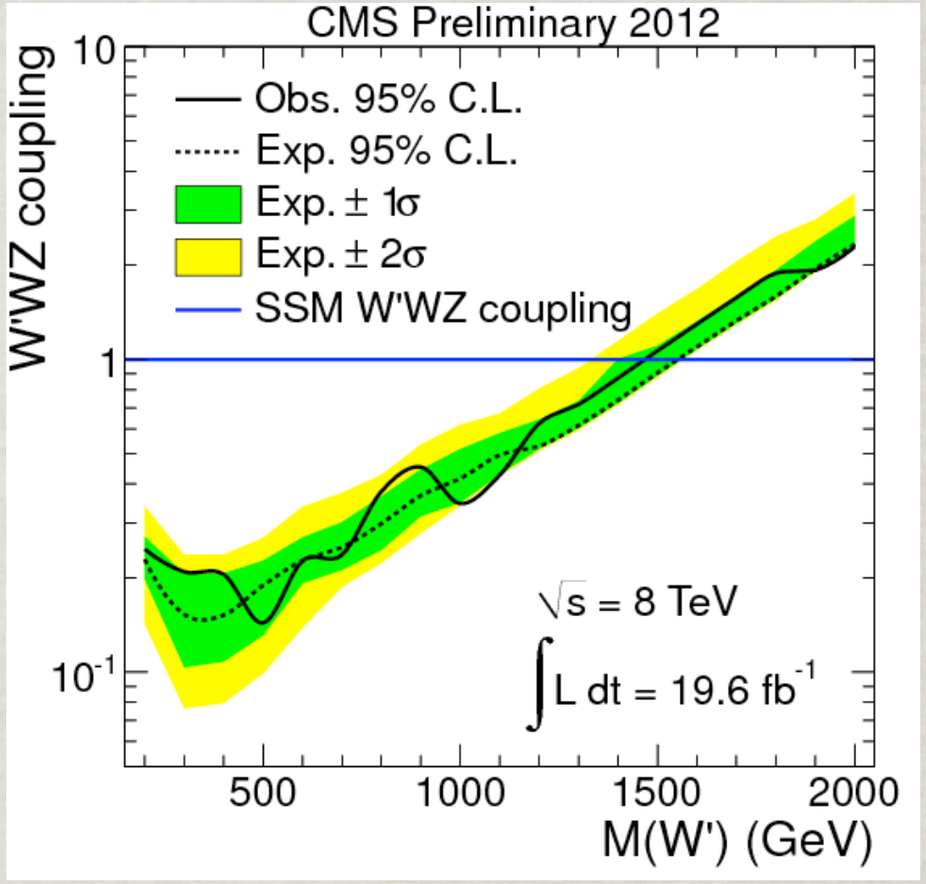


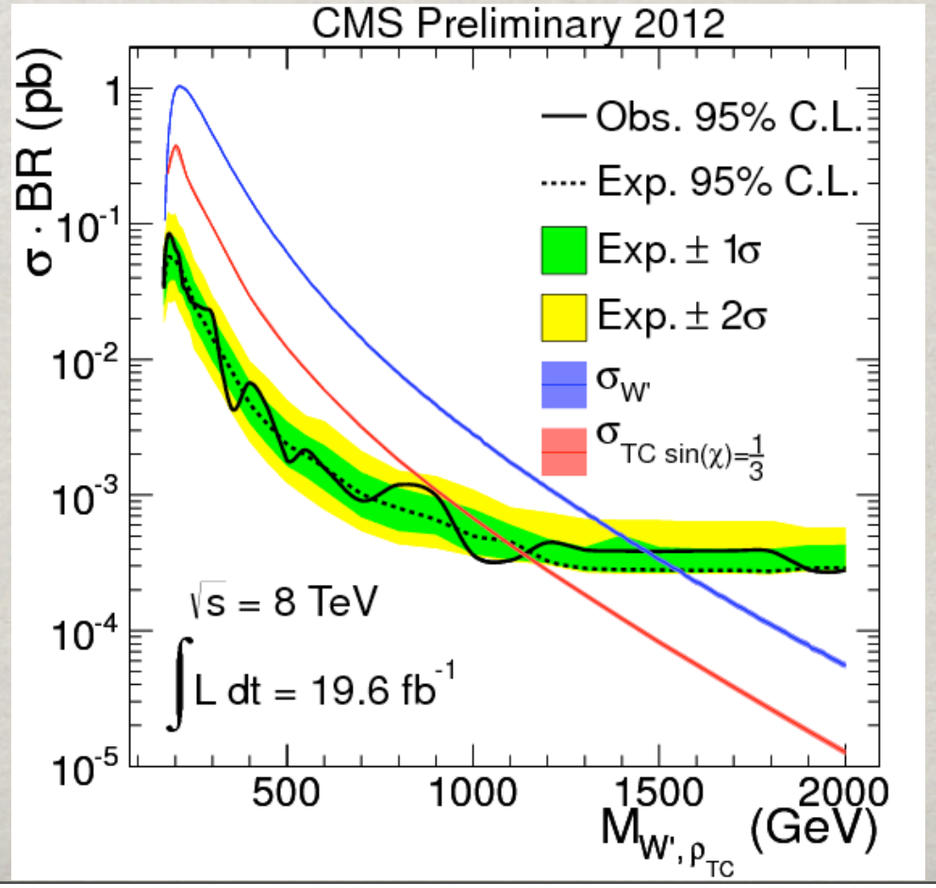


Diboson Resonances

PAS
EXO12025

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



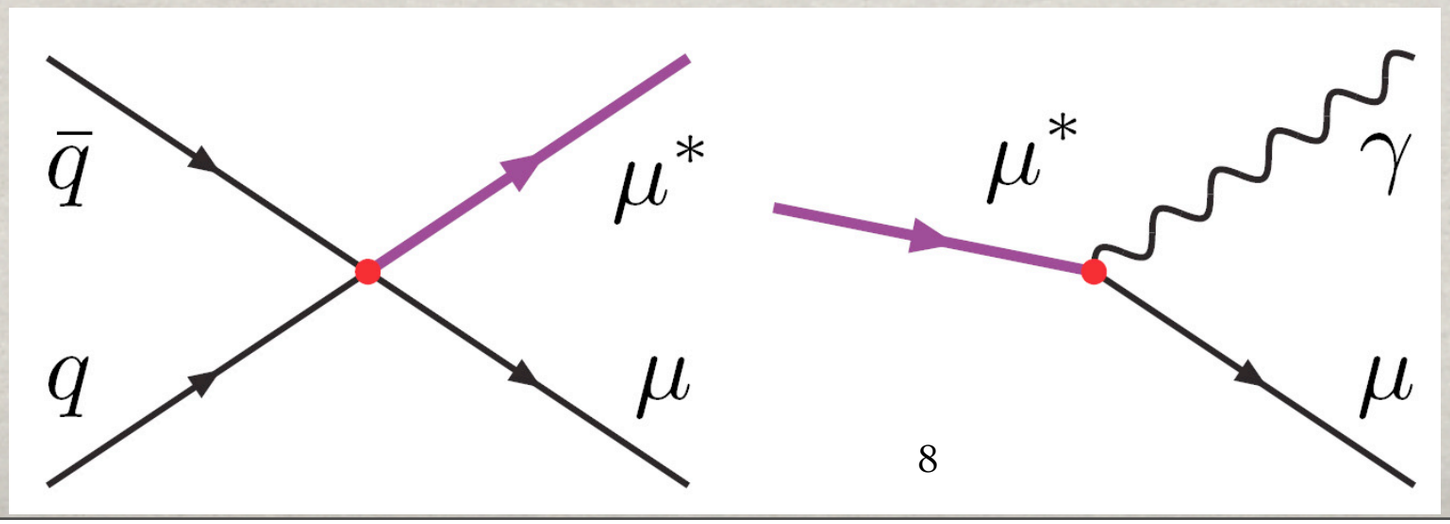


New Fermions

- 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

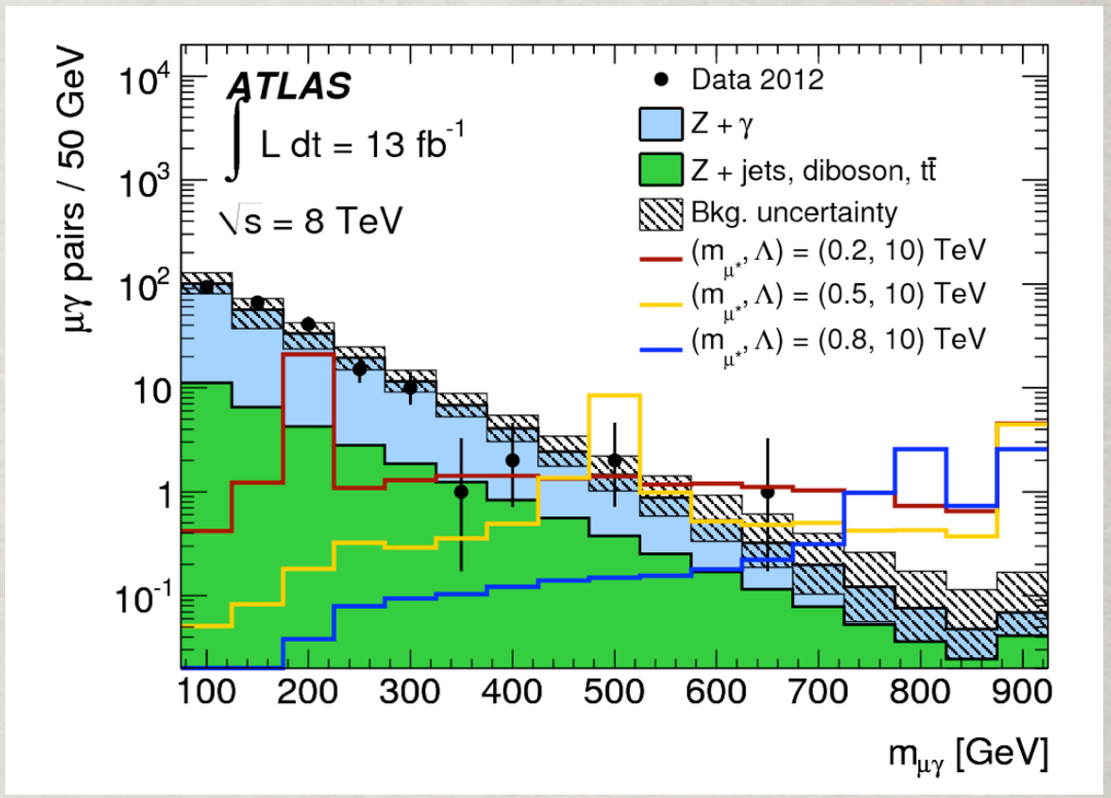
- Search for excited leptons by decay in either single lepton or dilepton+photon resonance

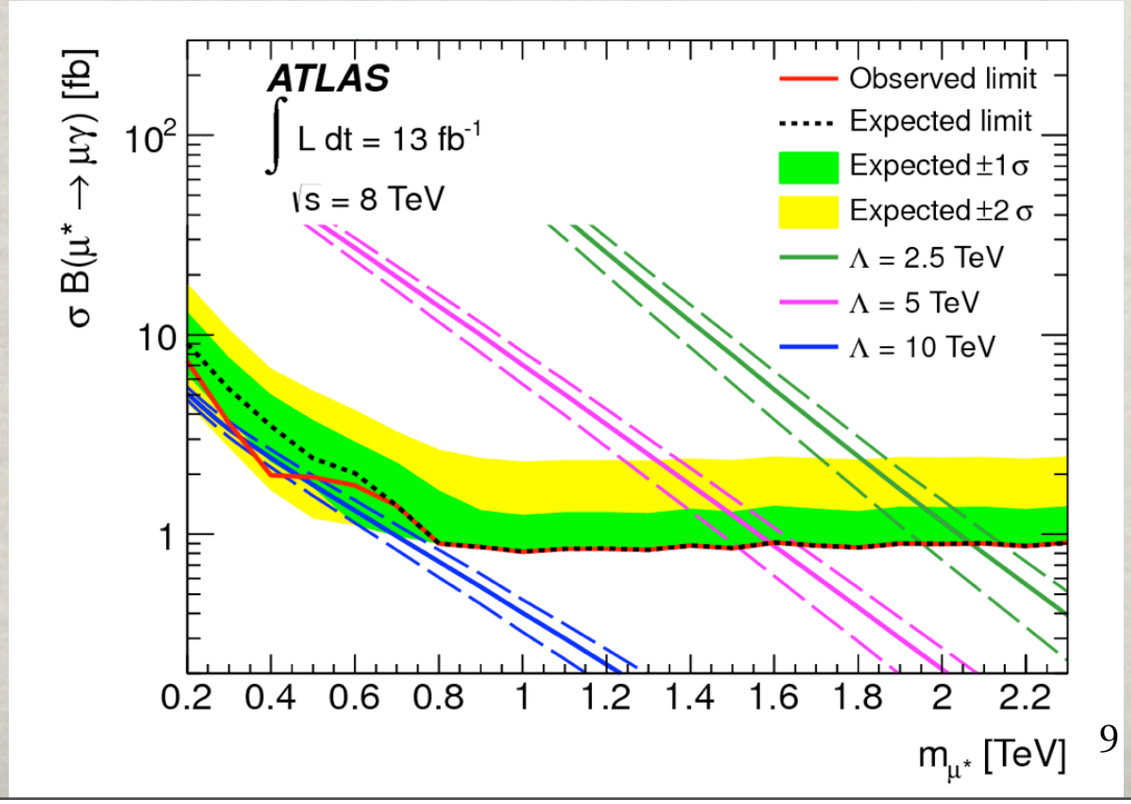


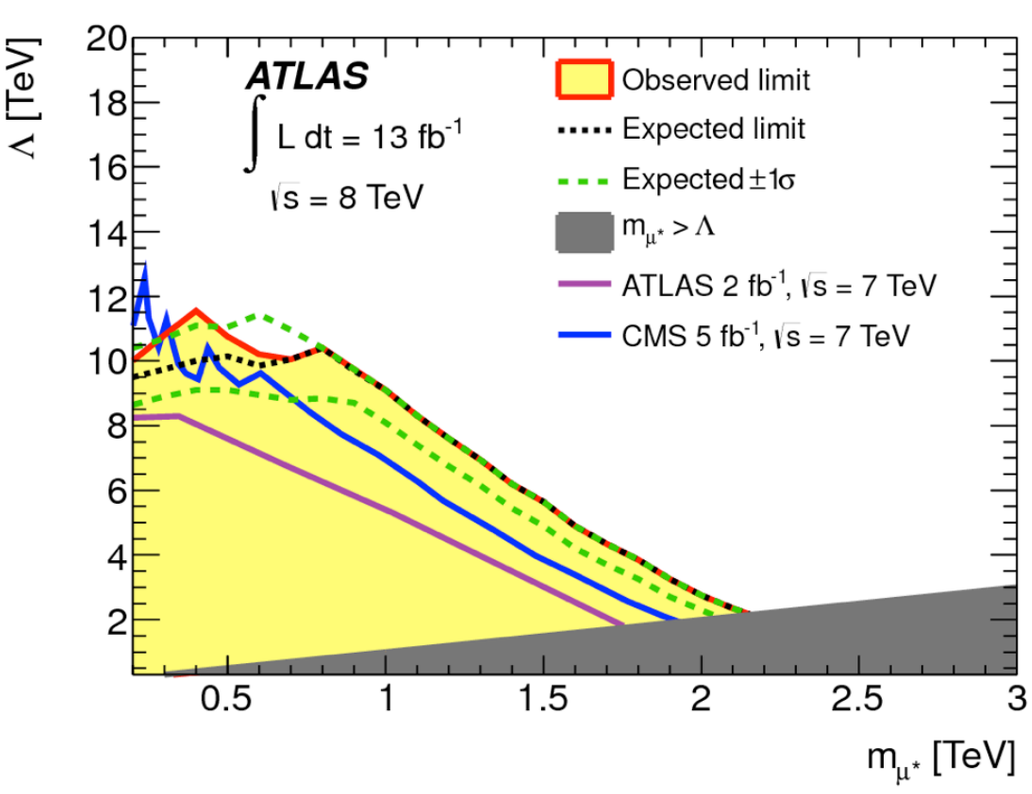
New Fermions

- Search in lepton+photon and dilepton + photon

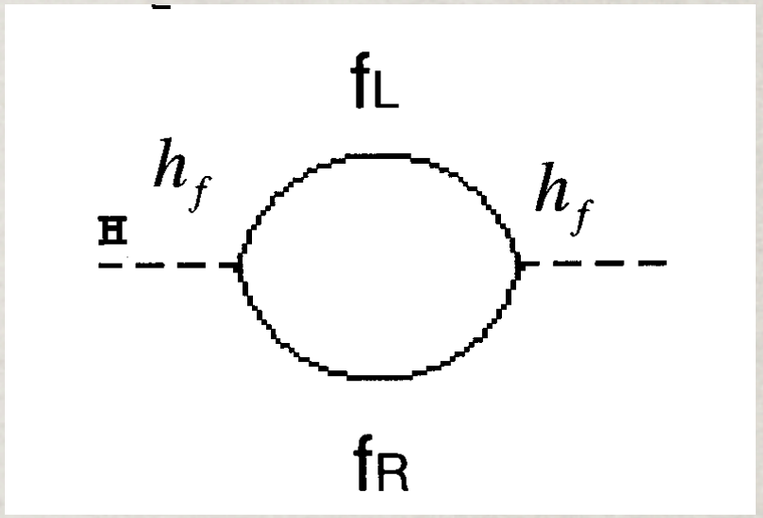
arXiv:1308.1364







Vector-Like Quarks



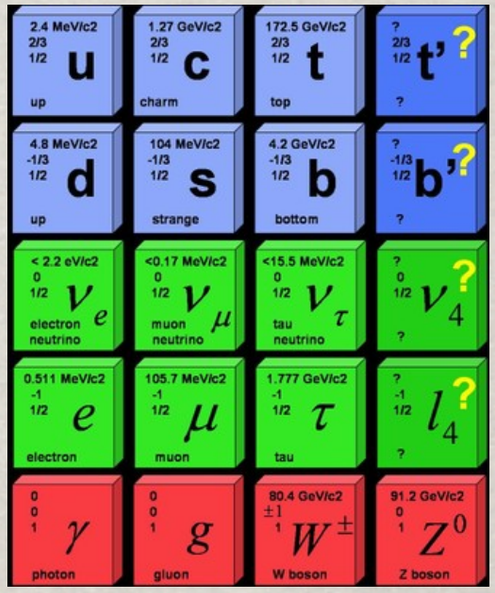
- To cancel the quadratic divergences to the Higgs boson mass introduce new top partner at ~1 TeV

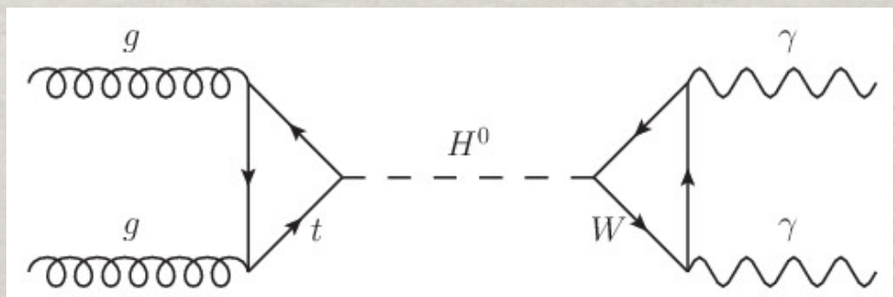
$$\begin{pmatrix} t'_L \\ b'_L \end{pmatrix} \quad t'_R, b'_R$$

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

EWSB

- Chiral 4th Generation highly disfavored as it would, for example, naively enhance the Higgs cross-section by a factor of ~9





Vector-Like Quarks

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

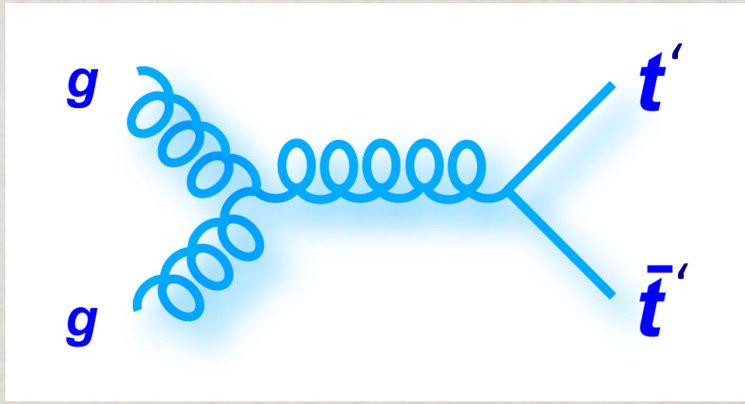
$$J_L^{\mu+} = \bar{u}_L \gamma^\mu d_L = \bar{u}\gamma^\mu(1-\gamma^5)d = V - A$$
$$J_R^{\mu+} = 0$$

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

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

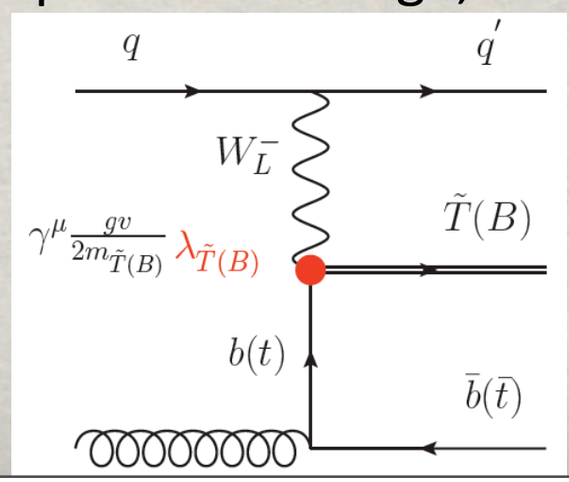
Pair Production

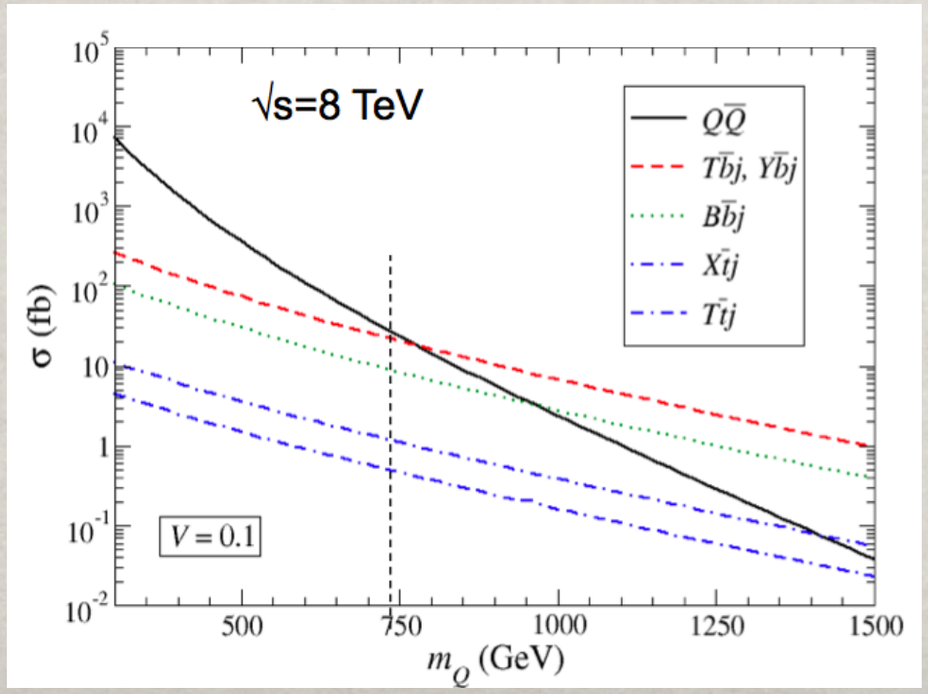
(like heavy $t\bar{t}$)



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

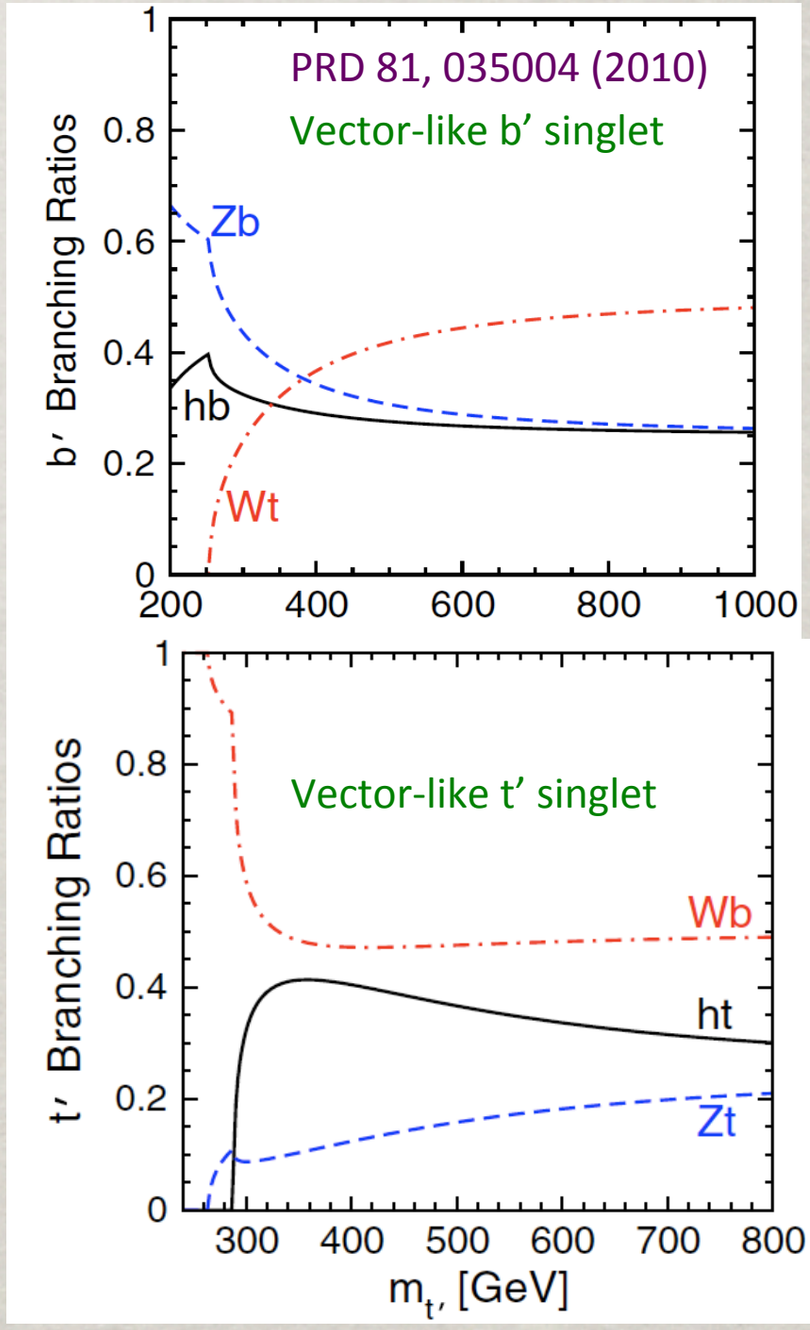
Vector-like doublets $\begin{pmatrix} t'_L \\ b'_L \end{pmatrix}$ $\begin{pmatrix} t'_R \\ b'_R \end{pmatrix}$

- 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, …

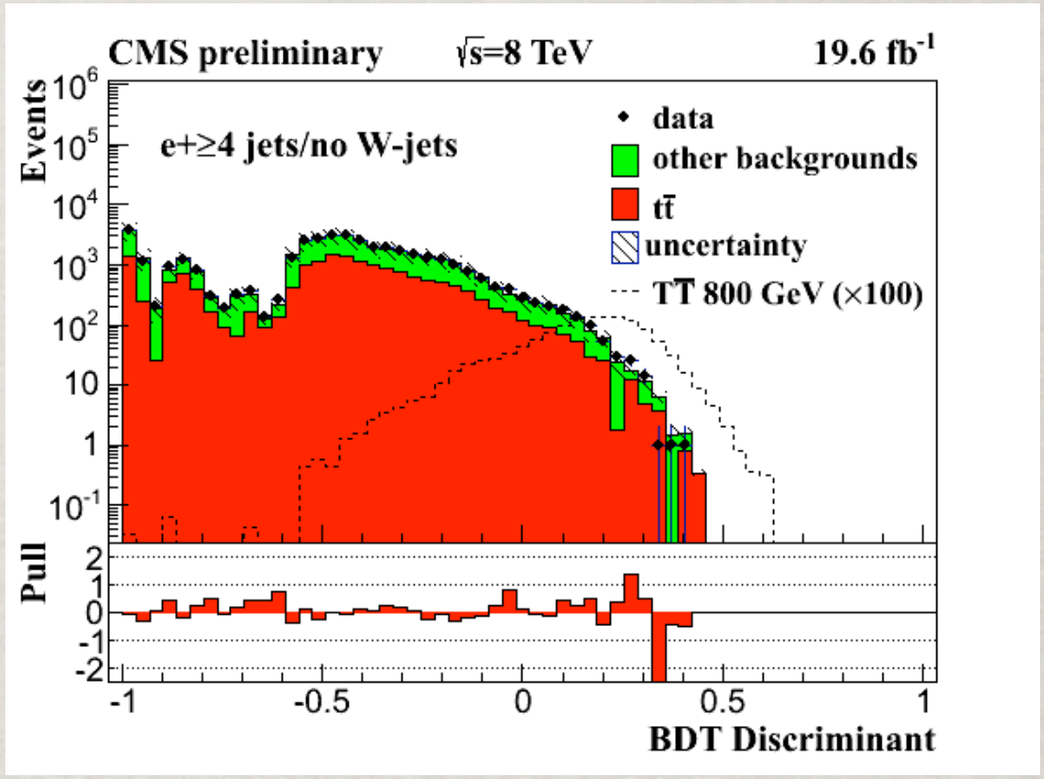


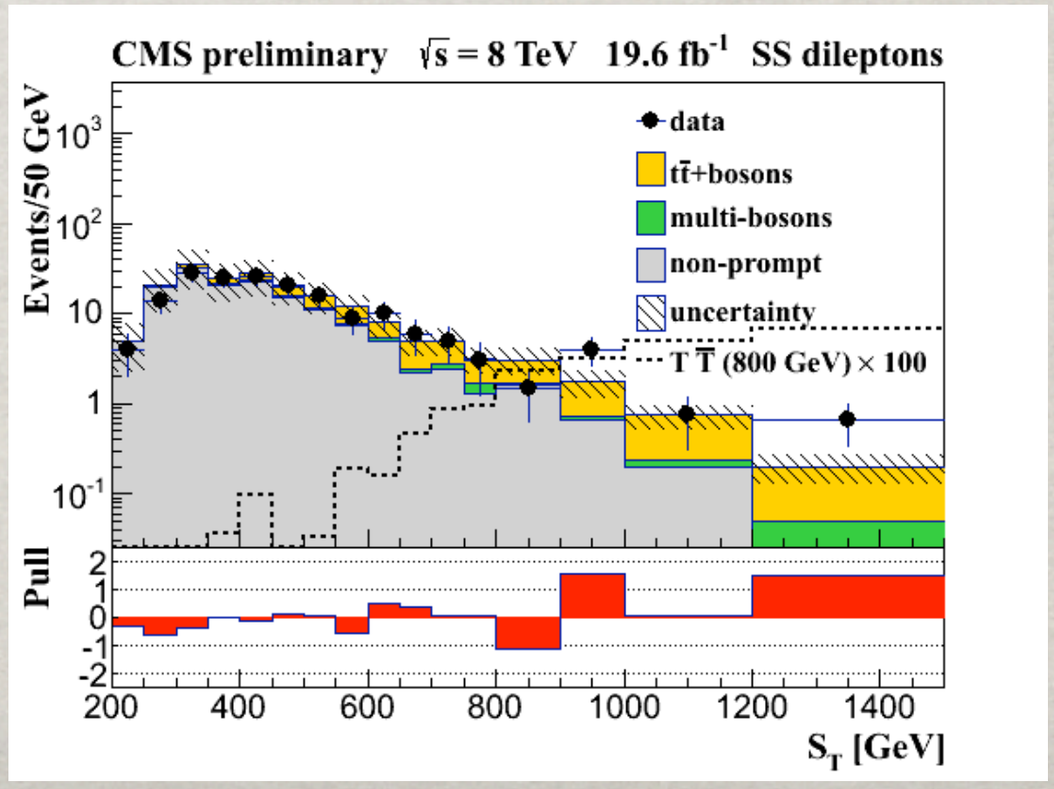
VLQ

PAS
B2G-12-015

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

- Use BDT in single lepton with larger background to get optimal seperation

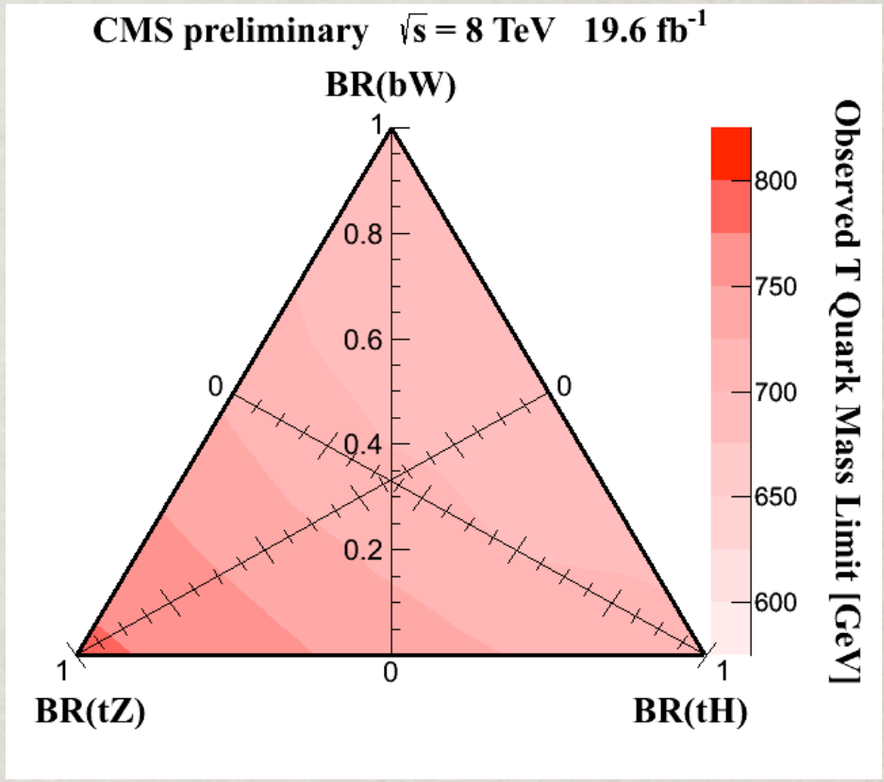




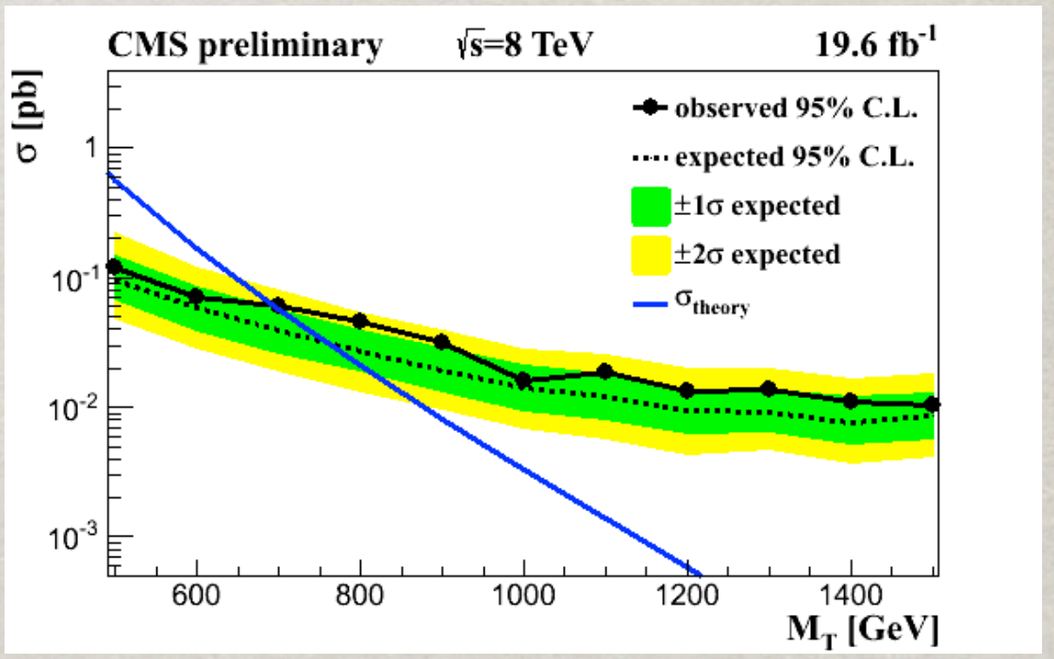
VLQ Limits

- Plot as a function of heavy top mass with assumed branching ratios

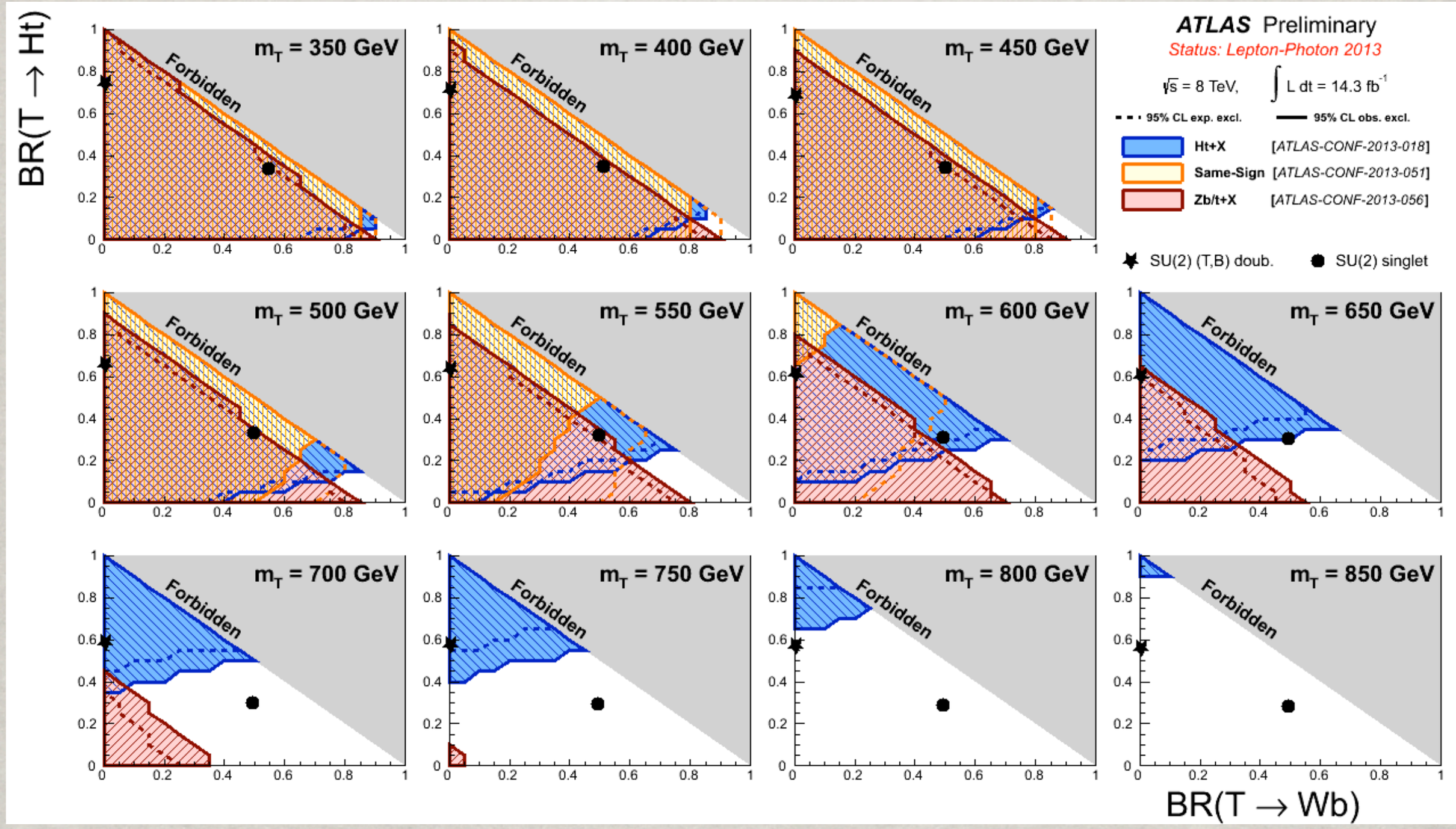
PAS B2G-12-015



- Set limits on mass for different branching ratios in triangle (assuming only 3 decay modes)

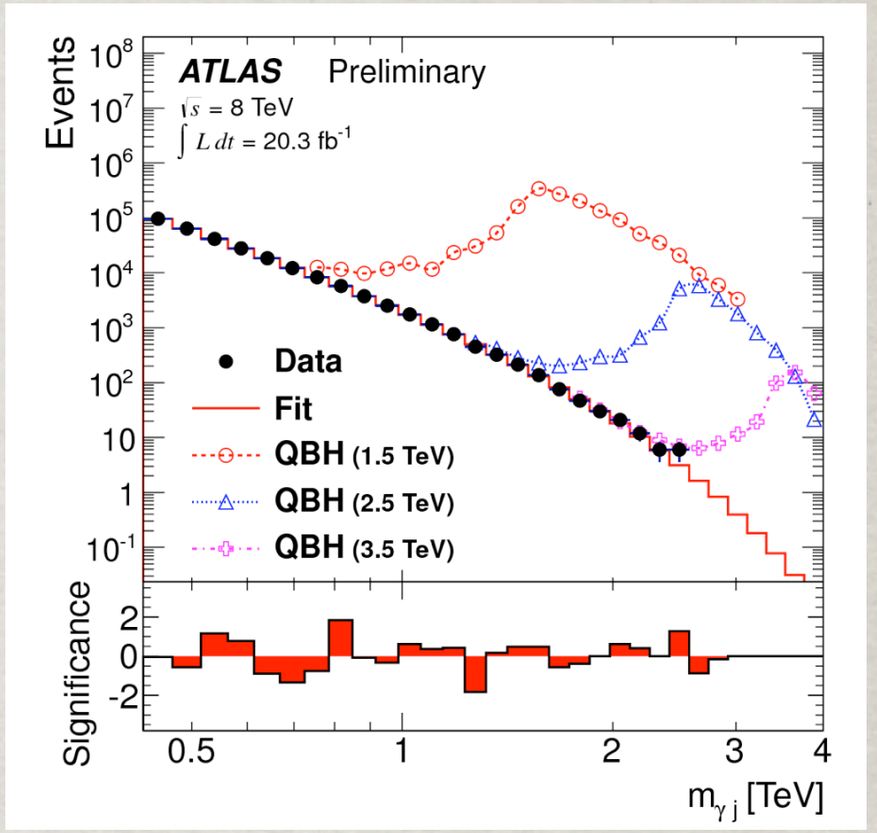


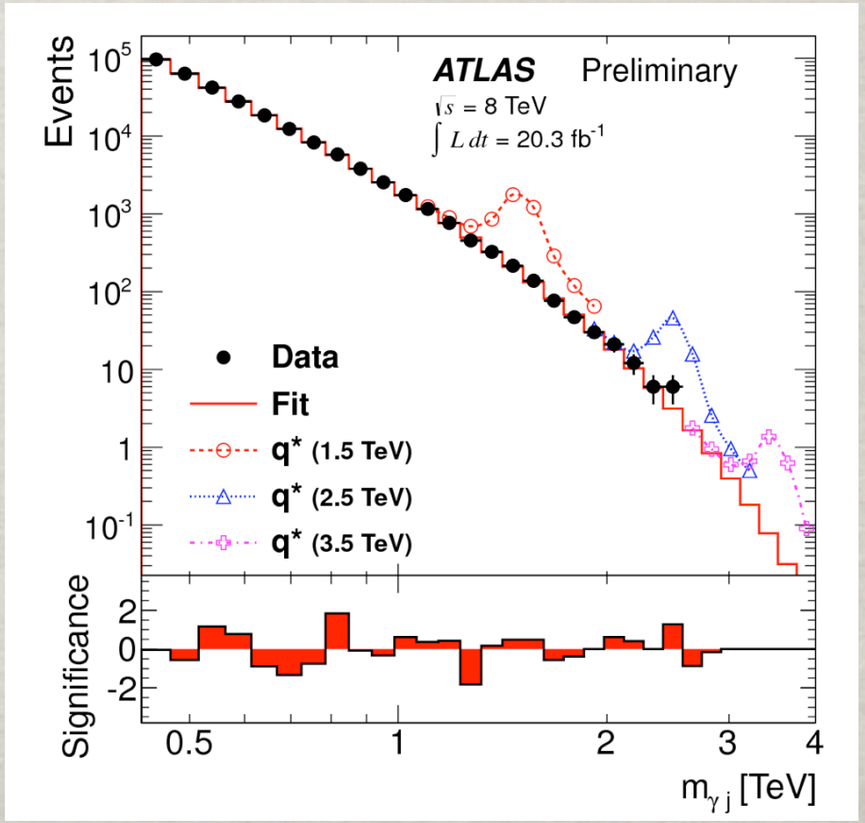
ATLAS VLQ Summary



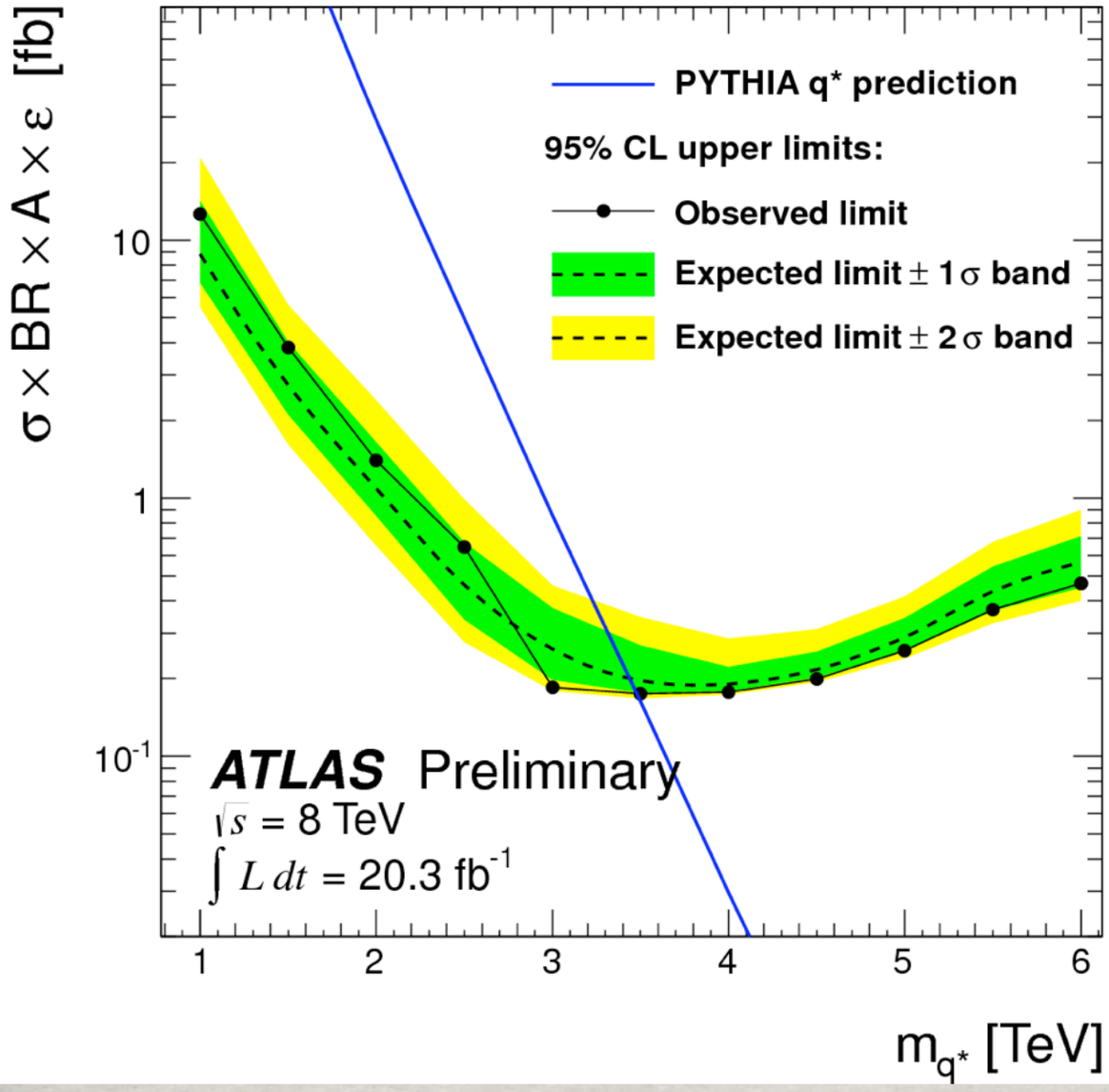
Excited Quarks

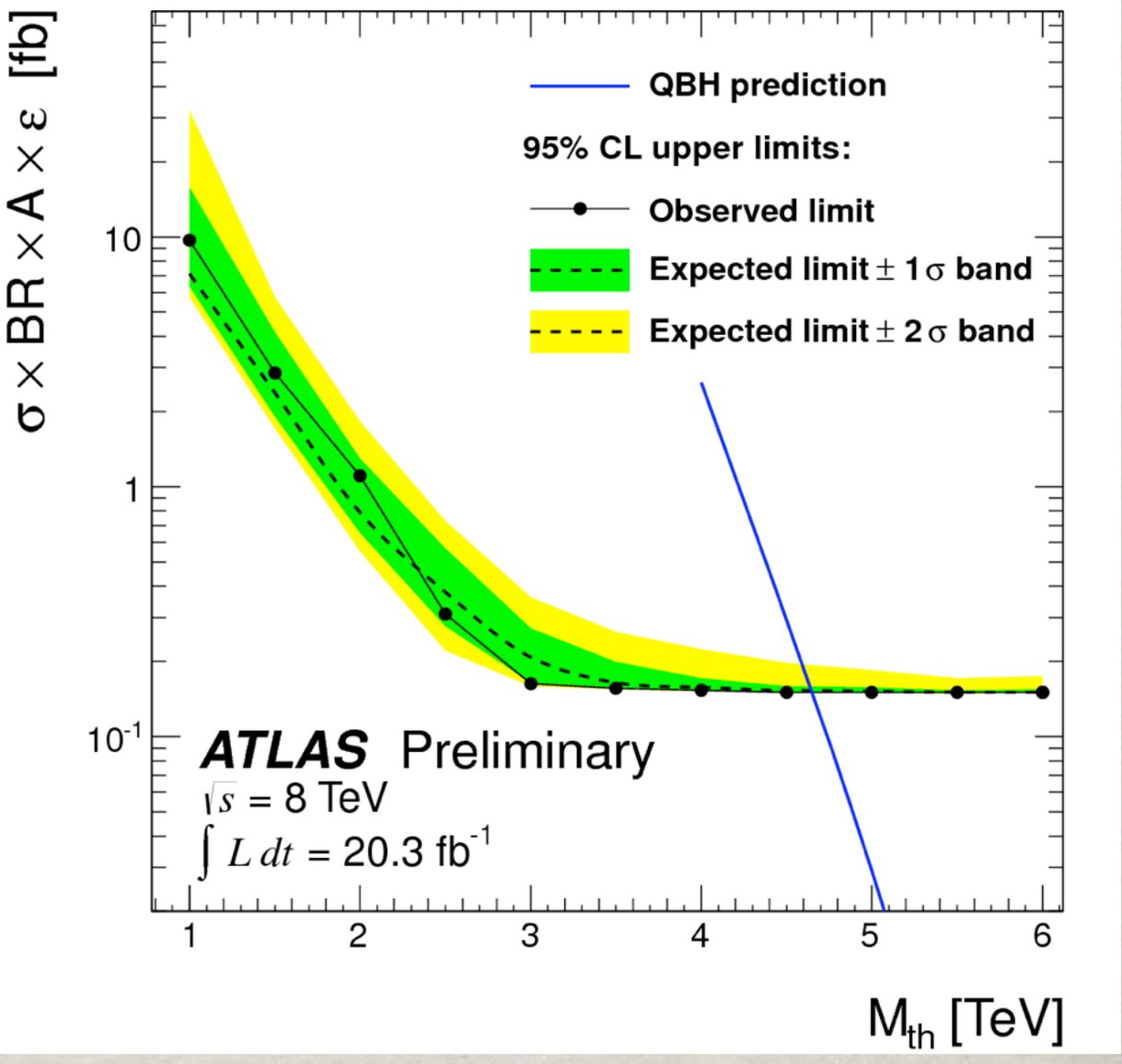
- Similar to excited leptons, if quarks are composite expect to see excited states
- Could decay into a quark and a photon
- Search for events with one high pt jet and photon





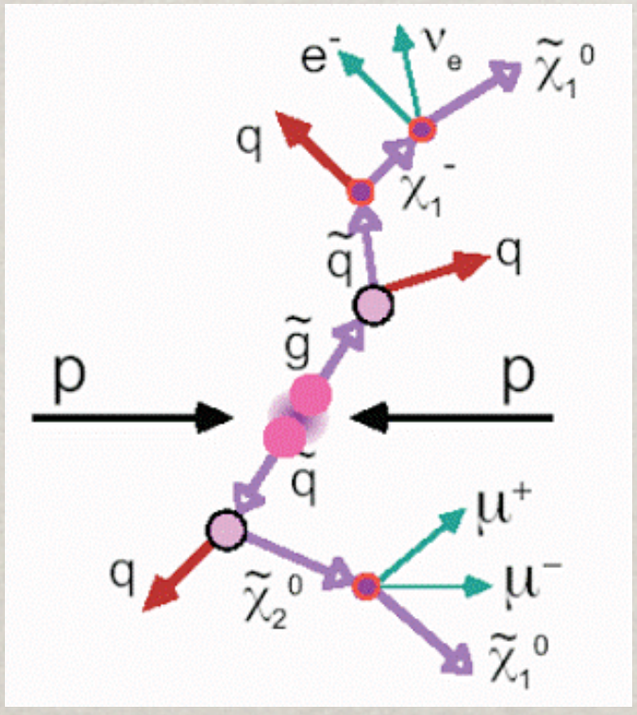
Excited quark limits





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

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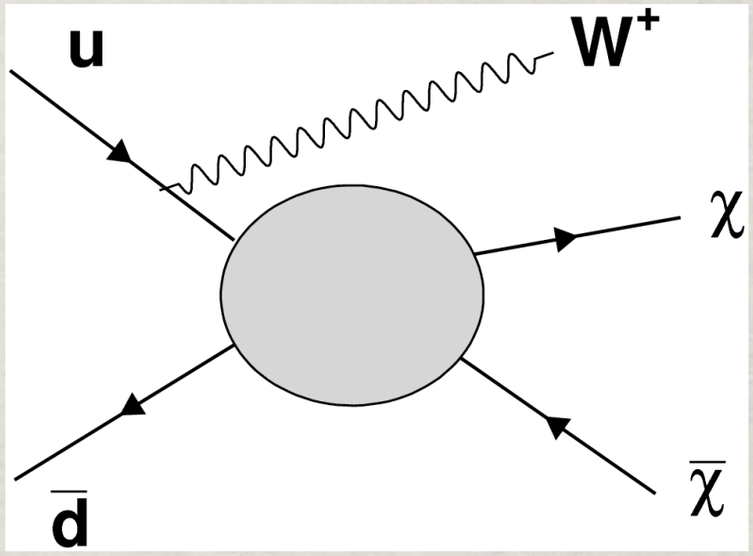
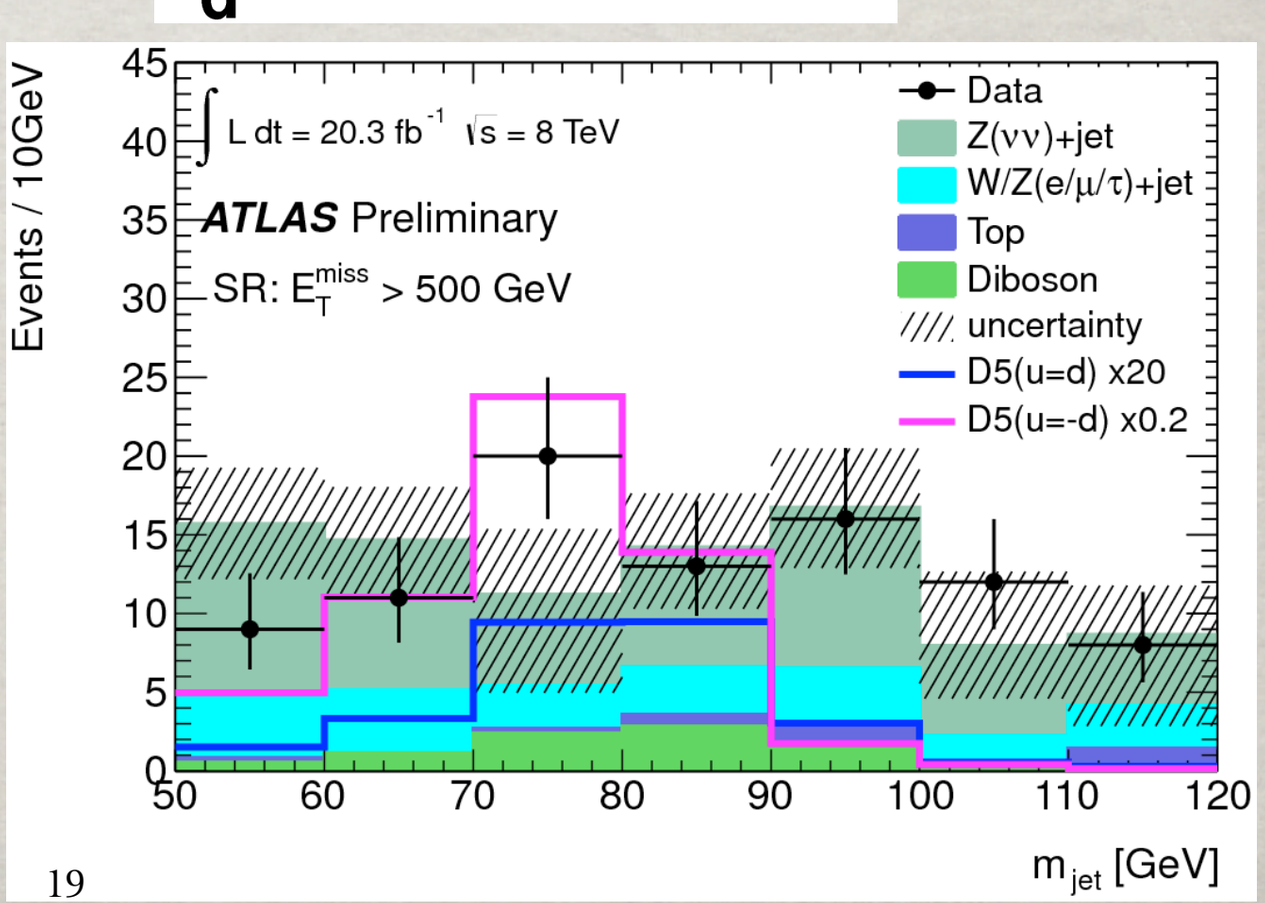
- Search for mono-W or Z decaying hadronically with large missing energy
- Divide into several control regions and signal regions to maximize sensitivity to different scenarios





Dark Matter Limits

- 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

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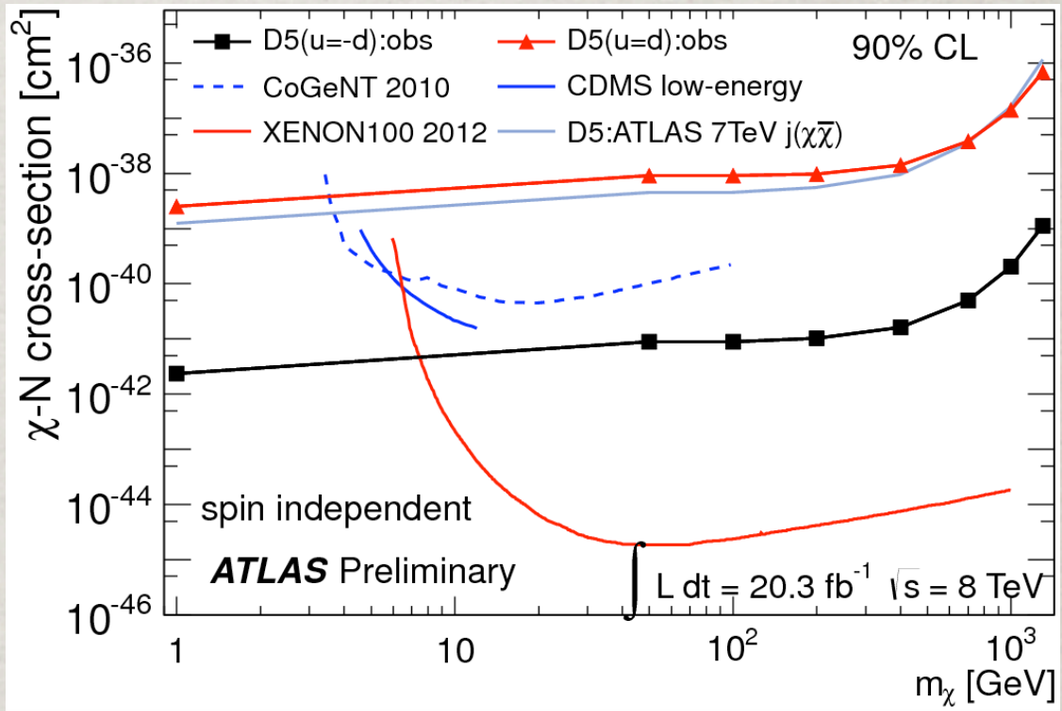
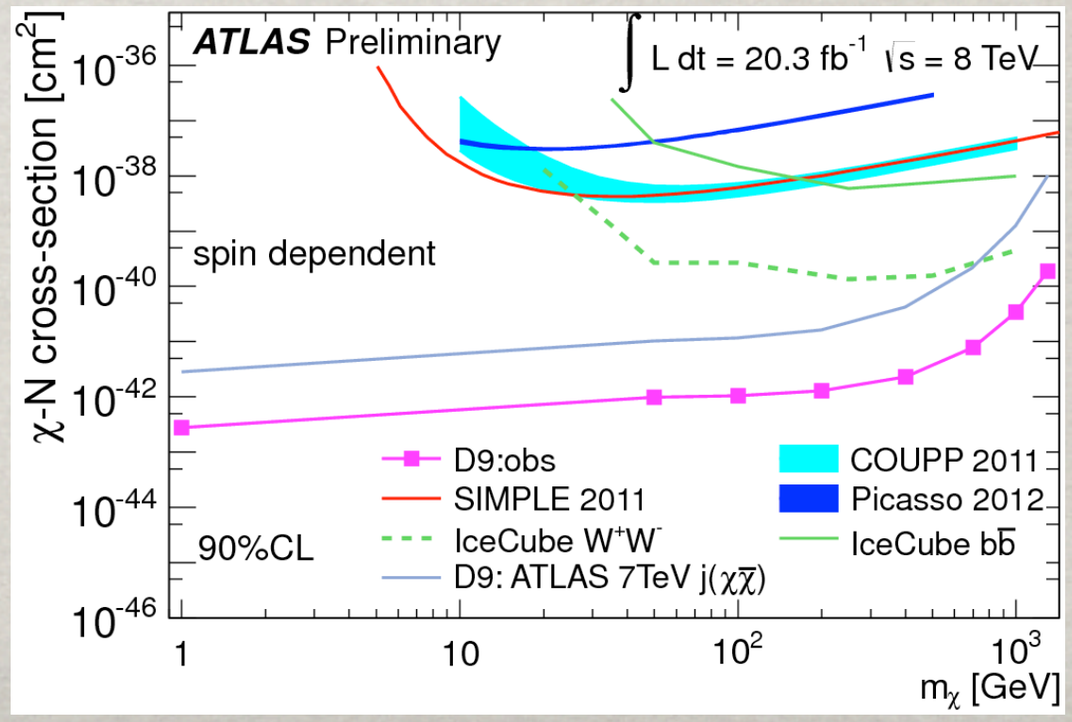
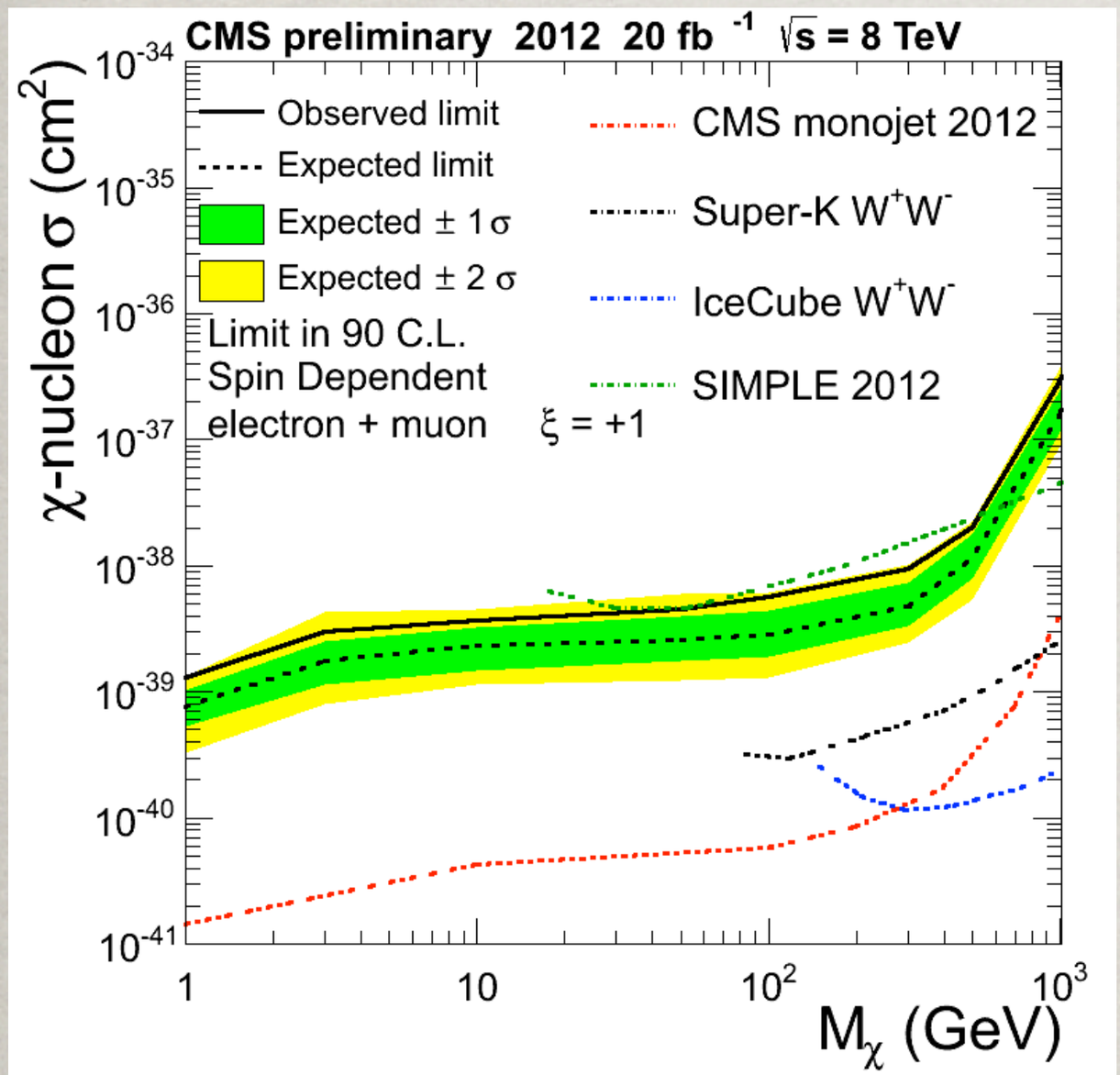
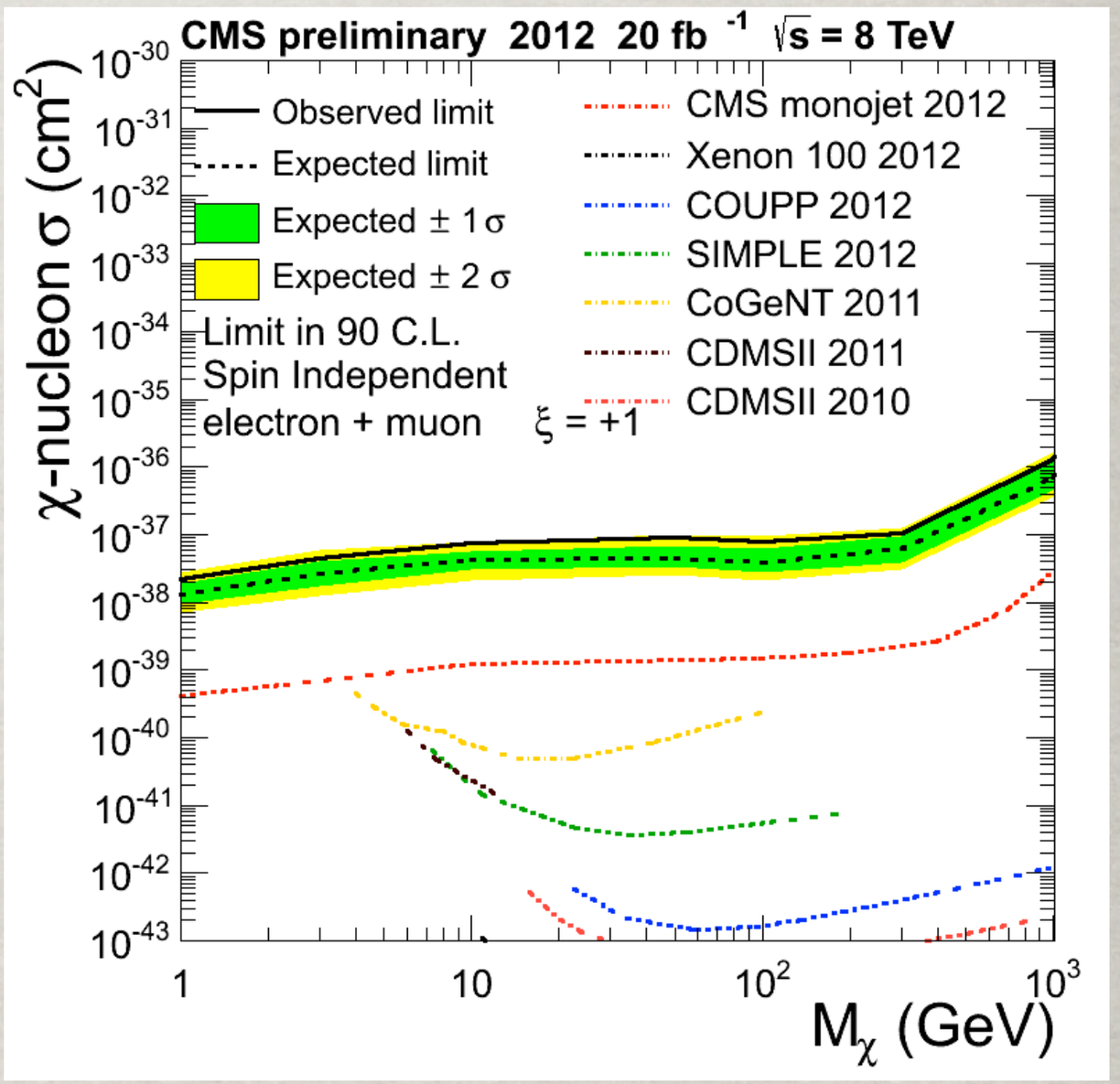




Mono W limits





PAS EXO13004

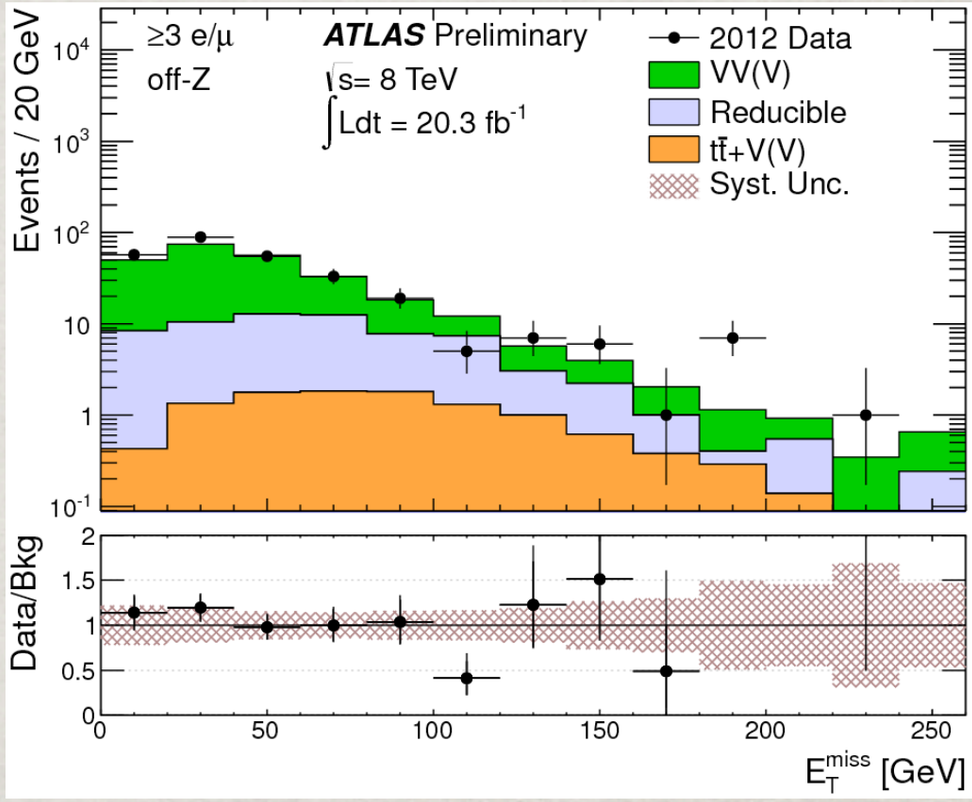
Model independent searches

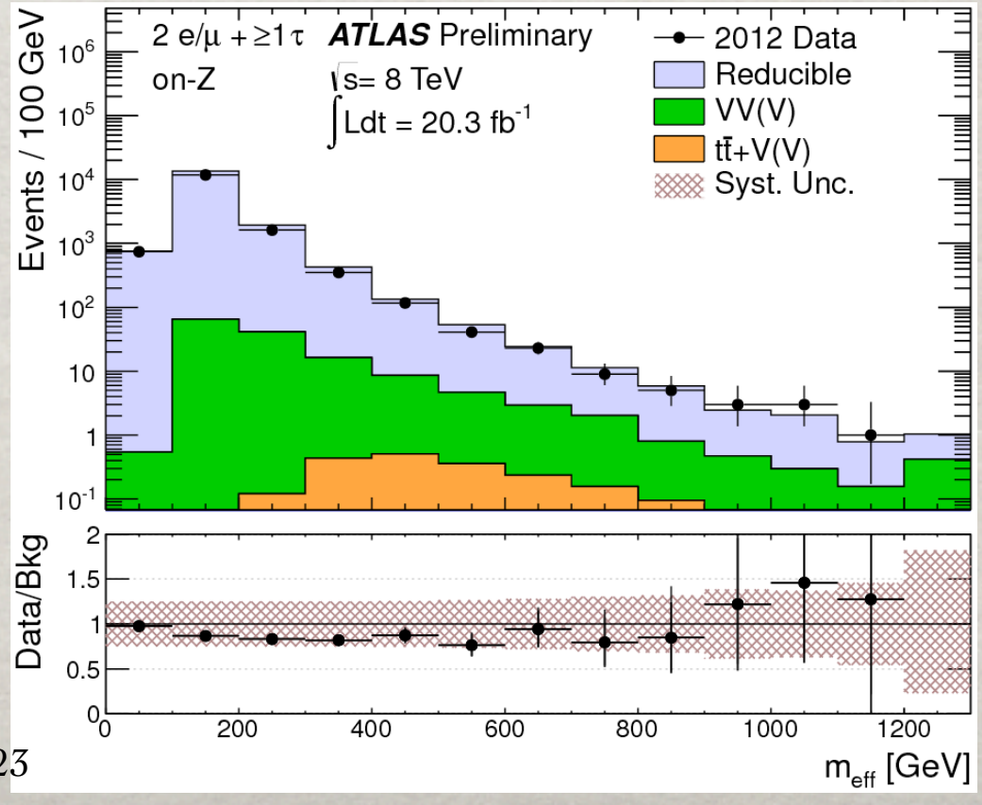
- Look for anomalous production over a wide variety of final states
- Strip model dependent assumptions out of analysis
- Present results in most general way we can

Trileptons

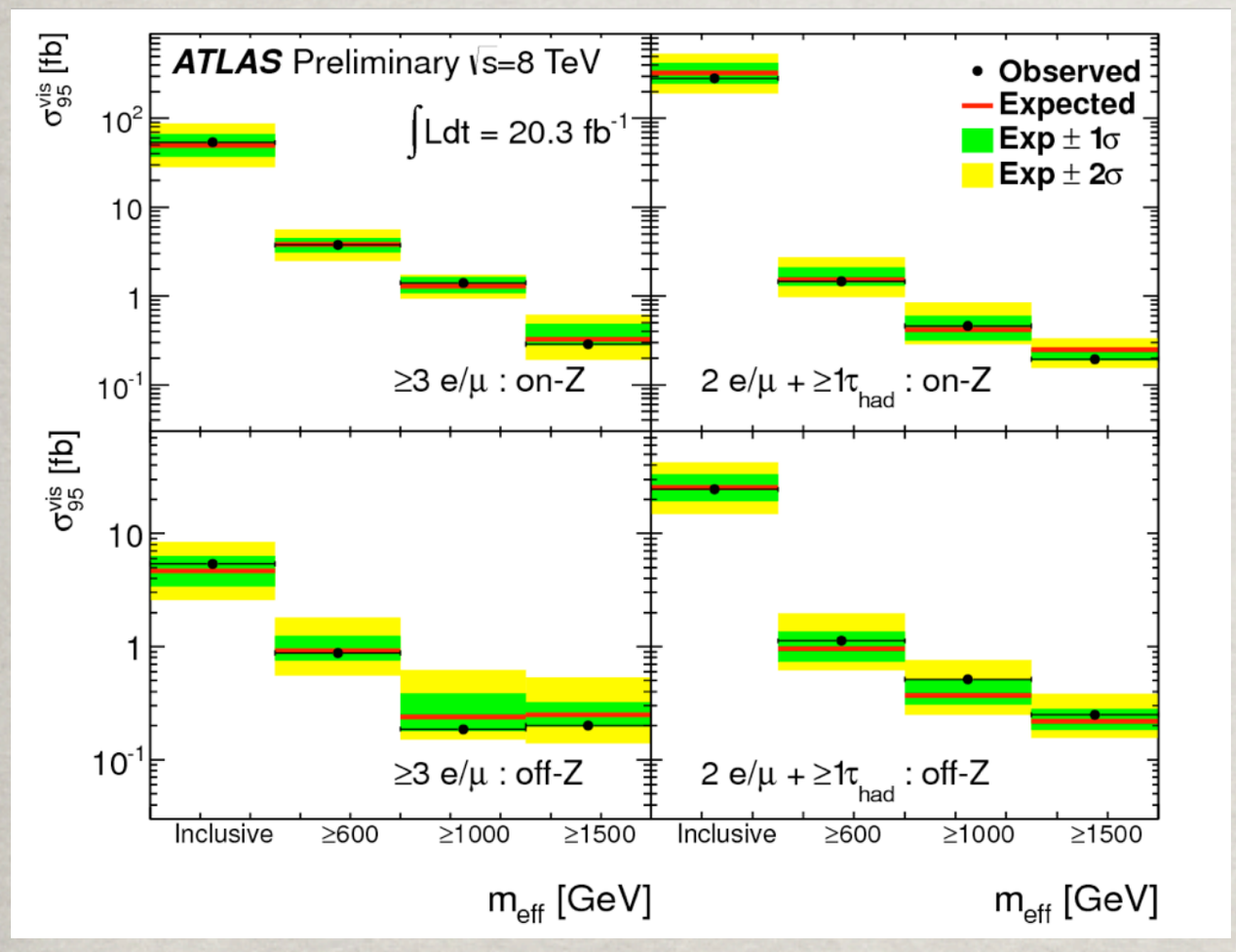
ATLAS-CONF-2013-070

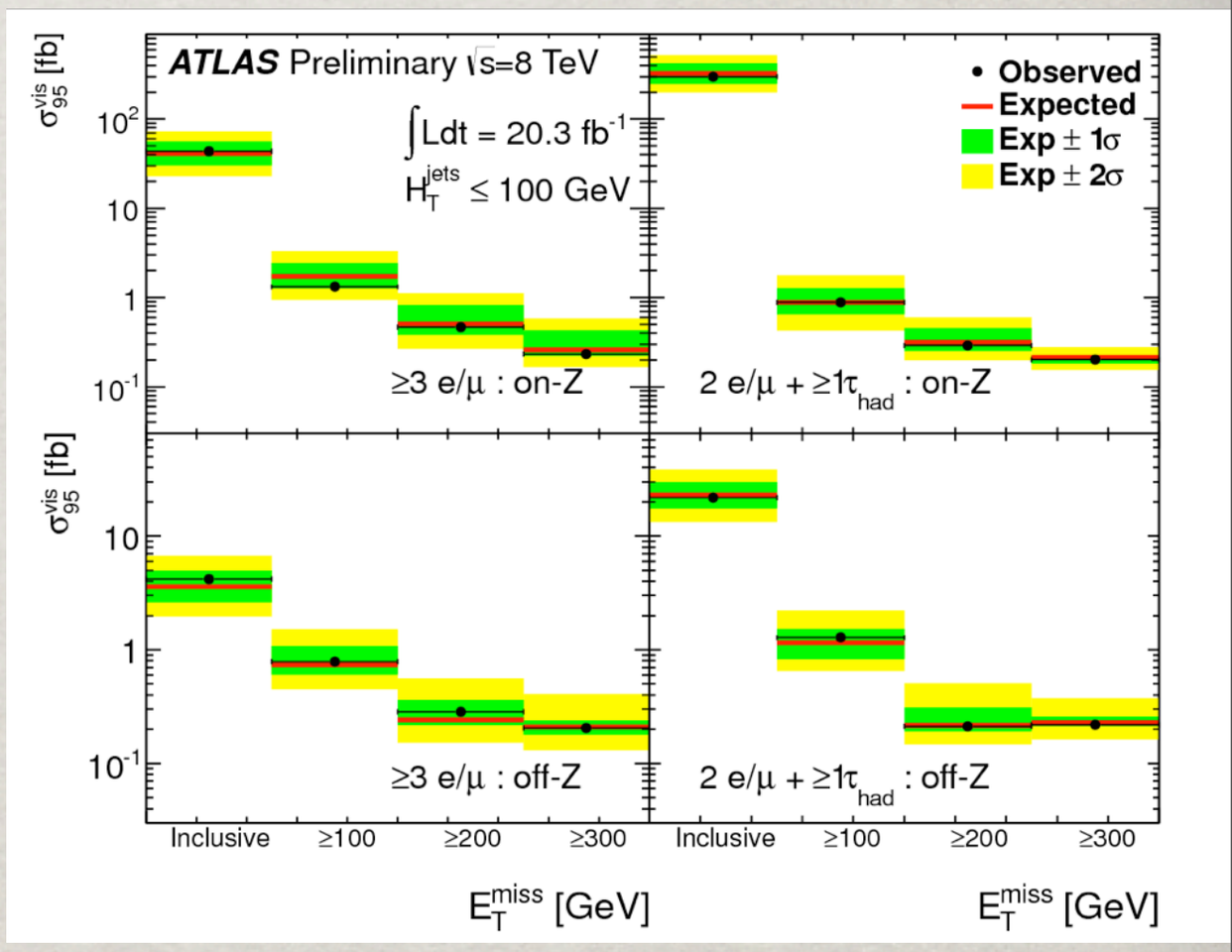
- Look in trilepton final state
- Examine several kinematic variables and place model independent limit on cross-section for new physics contributions





Model independent limits





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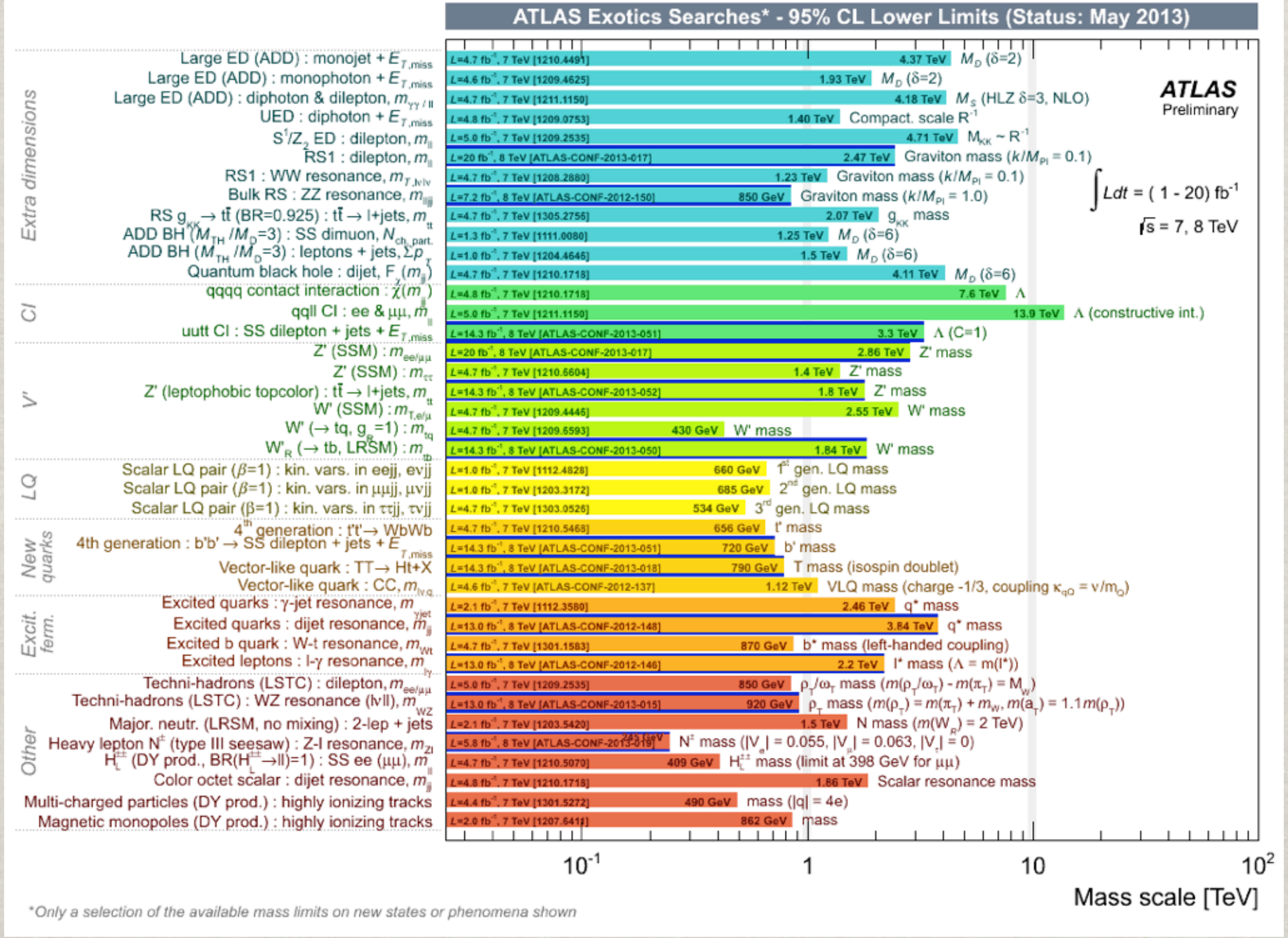
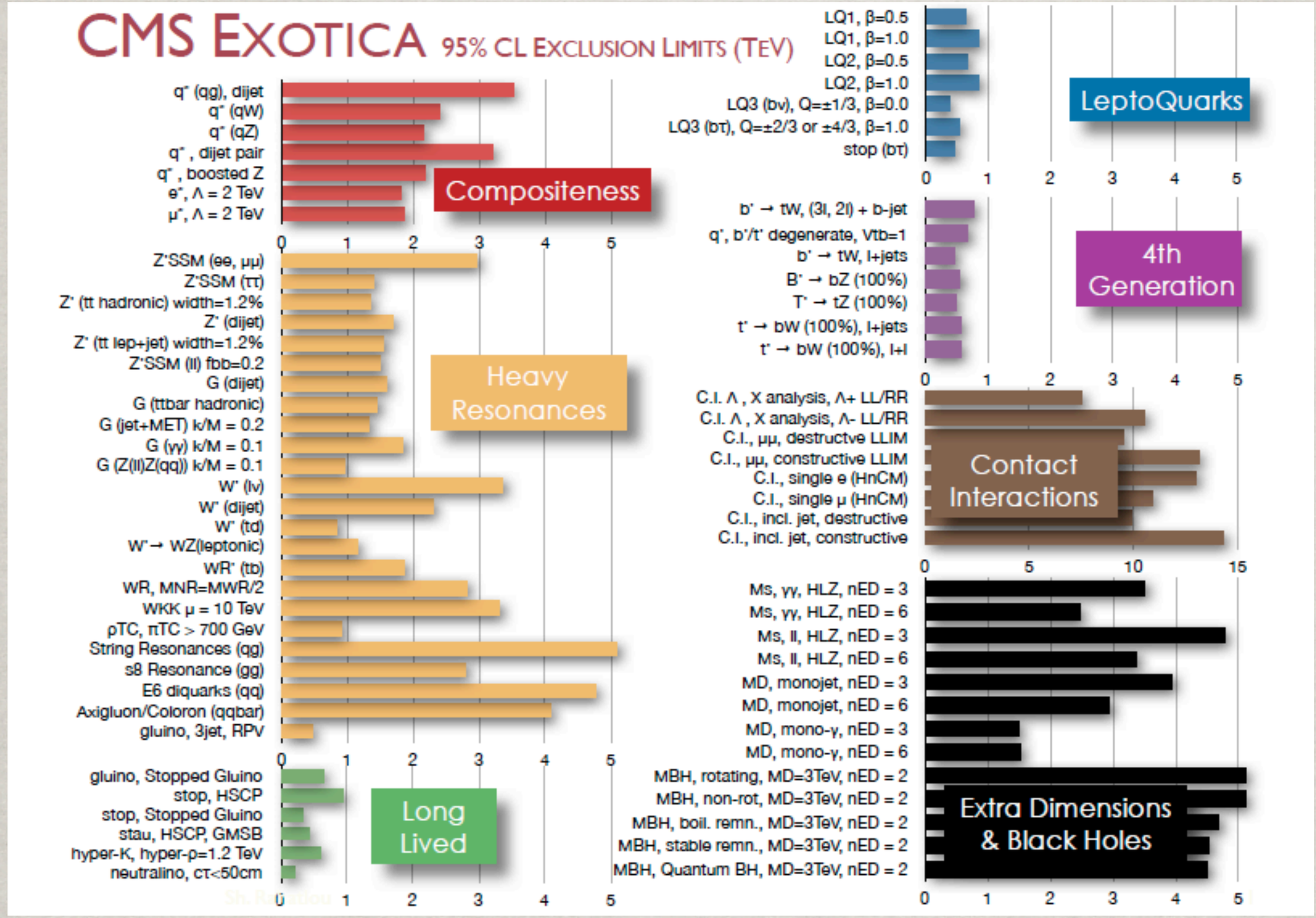
MANY MORE RESULTS



*Only a selection of the available mass limits on new states or phenomena shown

Still More!


CMS Exotica 95% CL Exclusion Limits (TeV)
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lν)
W' (dijet)
W' (td)
W'→ WZ(leptonic)
WR' (tb)
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Heavy Resonances
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
neutralino, cτ<50cm
Long Lived
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bν), Q=±1/3, β=0.0
LQ3 (bτ), Q=±2/3 or ±4/3, β=1.0
stop (bτ)
LeptoQuarks
b' → tW, (3l, 2l) + b-jet
q*, b'/t' degenerate, Vtb=1
b' → tW, l+jets
B' → bZ (100%)
T' → tZ (100%)
t' → bW (100%), l+jets
t' → bW (100%), l+l
4th Generation
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
Contact Interactions
Ms, γγ, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 3
Ms, ll, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-γ, nED = 3
MD, mono-γ, nED = 6
MBH, rotating, MD=3TeV, nED = 2
MBH, non-rot, MD=3TeV, nED = 2
MBH, boil. remn., MD=3TeV, nED = 2
MBH, stable remn., MD=3TeV, nED = 2
MBH, Quantum BH, MD=3TeV, nED = 2
Extra Dimensions & Black Holes

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!