

Searches for Exotica at the LHC

Moriond QCD 2013

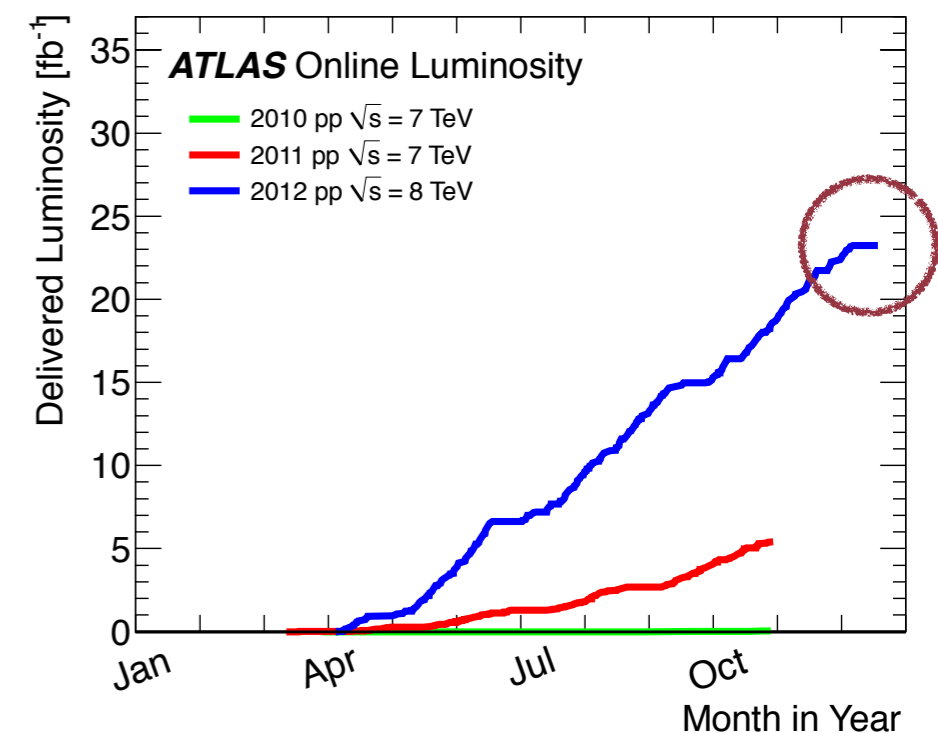
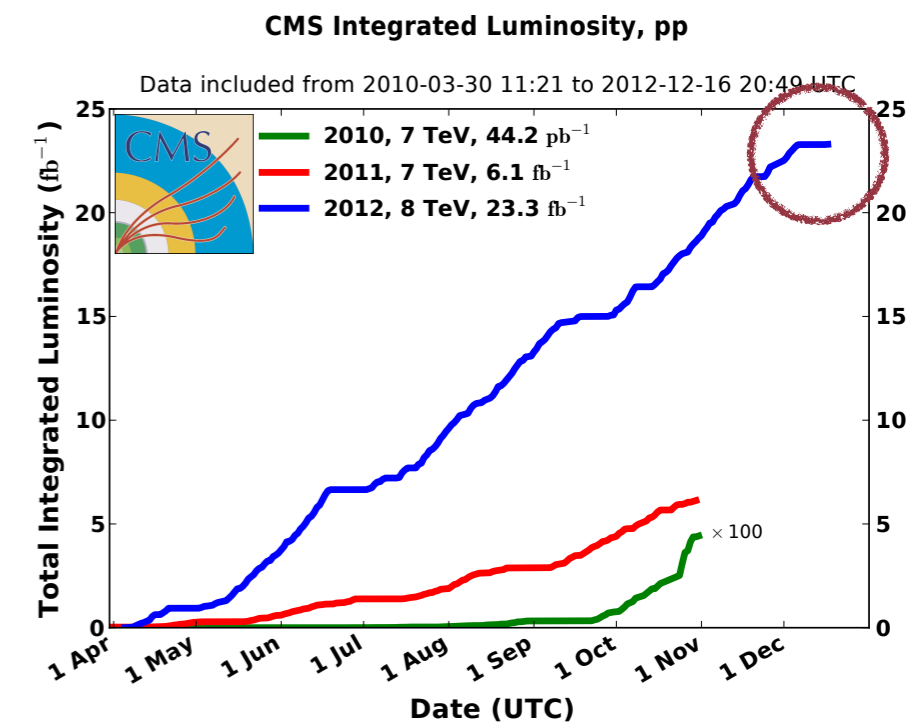
John Paul Chou
Rutgers University

Monday, March 11th, 2013



Exclusive focus on new 8 TeV (~9-20/fb) results from the LHC!

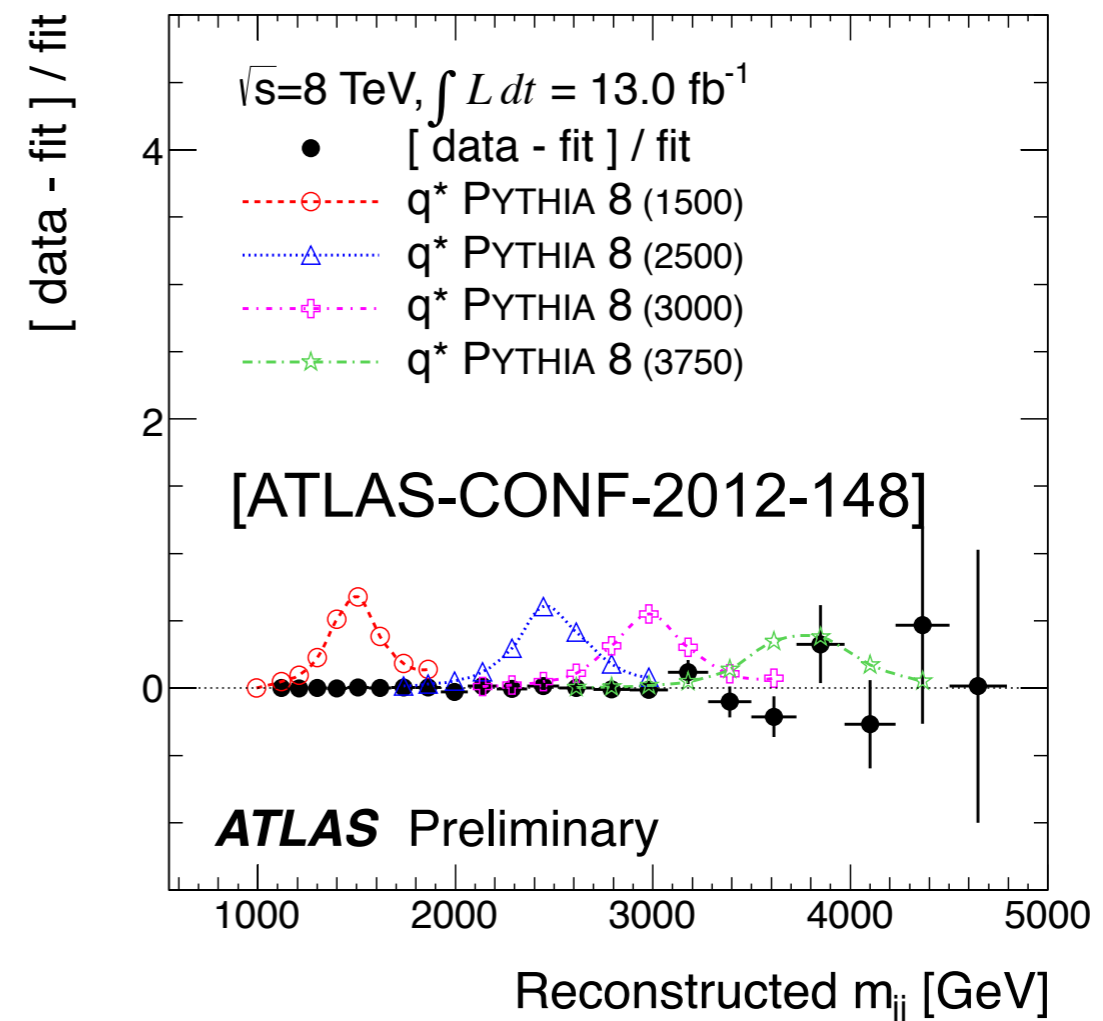
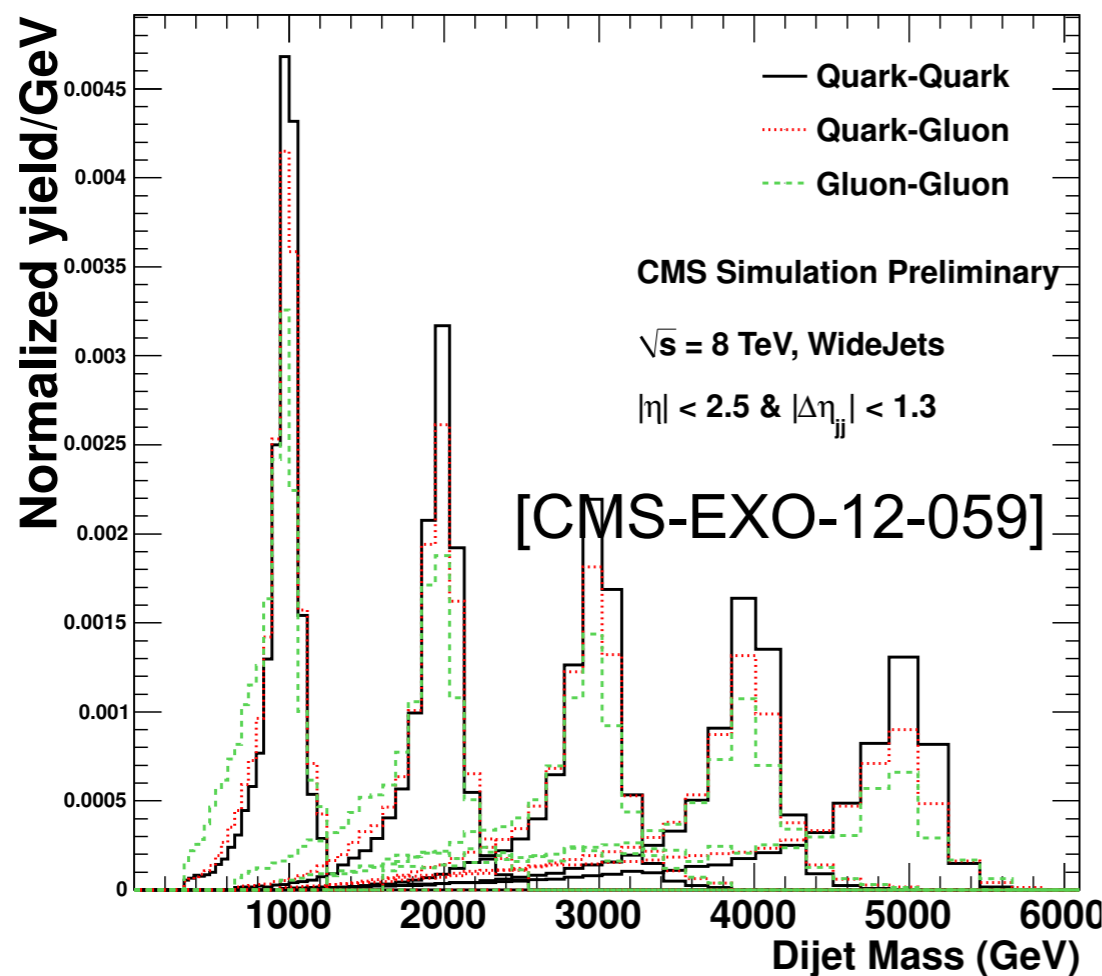
- 8 TeV Results
 - Dijets Resonances (CMS+ATLAS)
 - Top Partners (CMS)
 - T-Prime (ATLAS)
 - B-Prime (CMS)



DIJET RESONANCES



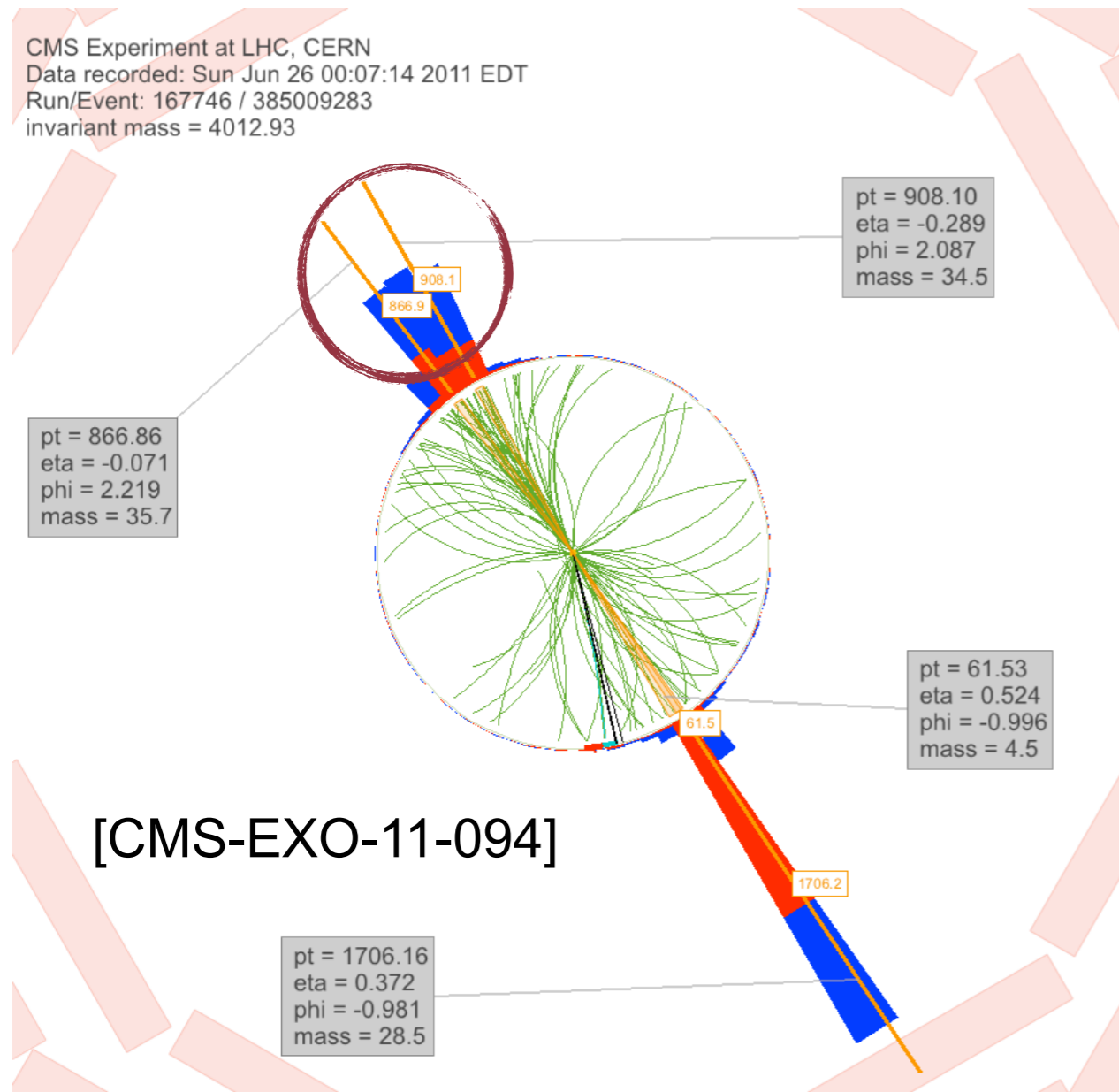
- Generic search for new physics in the dijet spectrum
 - look for **central** resonances (ATLAS: $|\Delta y| < 1.2$; CMS: $|\Delta \eta| < 1.3$)
 - CMS separates searches by final state (qq, qg, gg)
 - ATLAS provides simplified Gaussian models ($\sigma/M=0.07, 0.10, 0.15$)



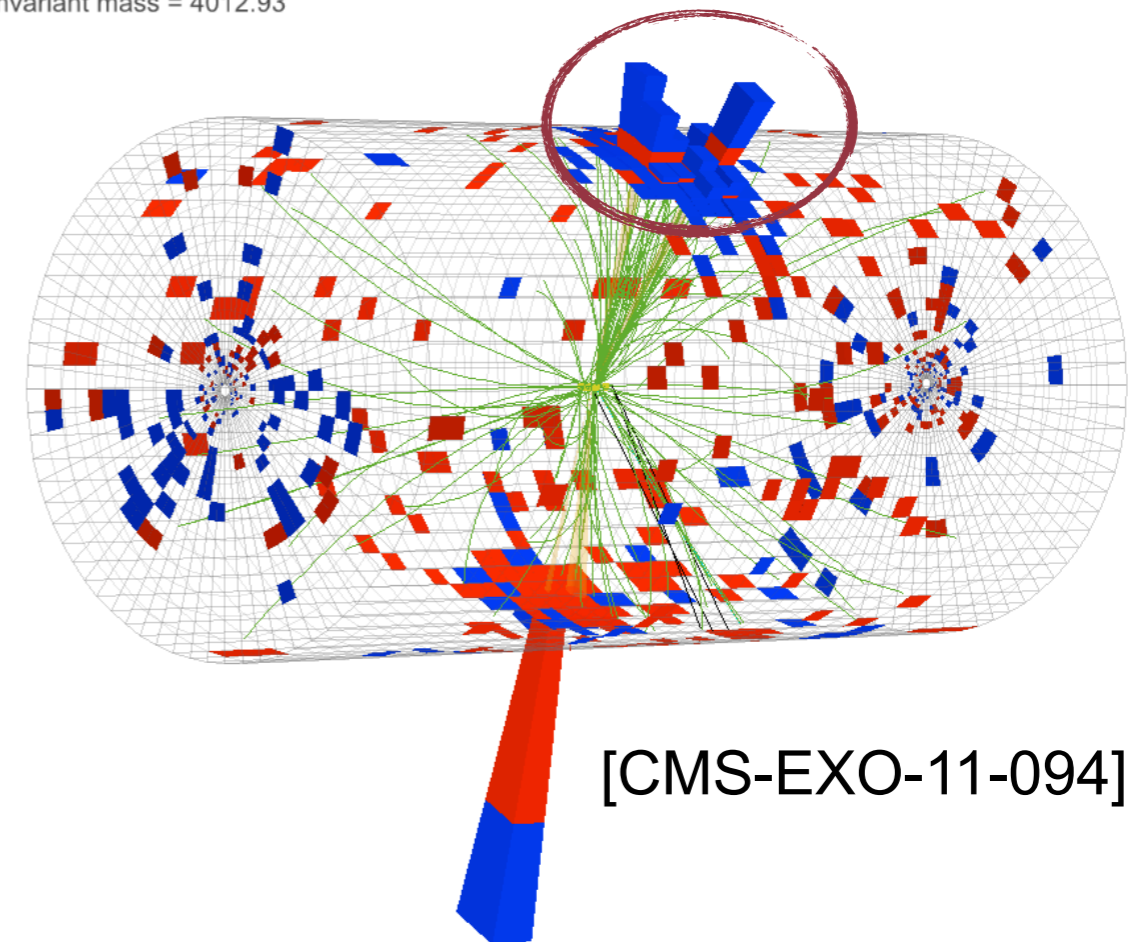
WIDE-JET ALGORITHM



- CMS uses an FSR-recovery technique by combining anti- k_T 0.5 jets within $\Delta R < 1.1$



CMS Experiment at LHC, CERN
Data recorded: Sun Jun 26 00:07:14 2011 EDT
Run/Event: 167746 / 385009283
invariant mass = 4012.93

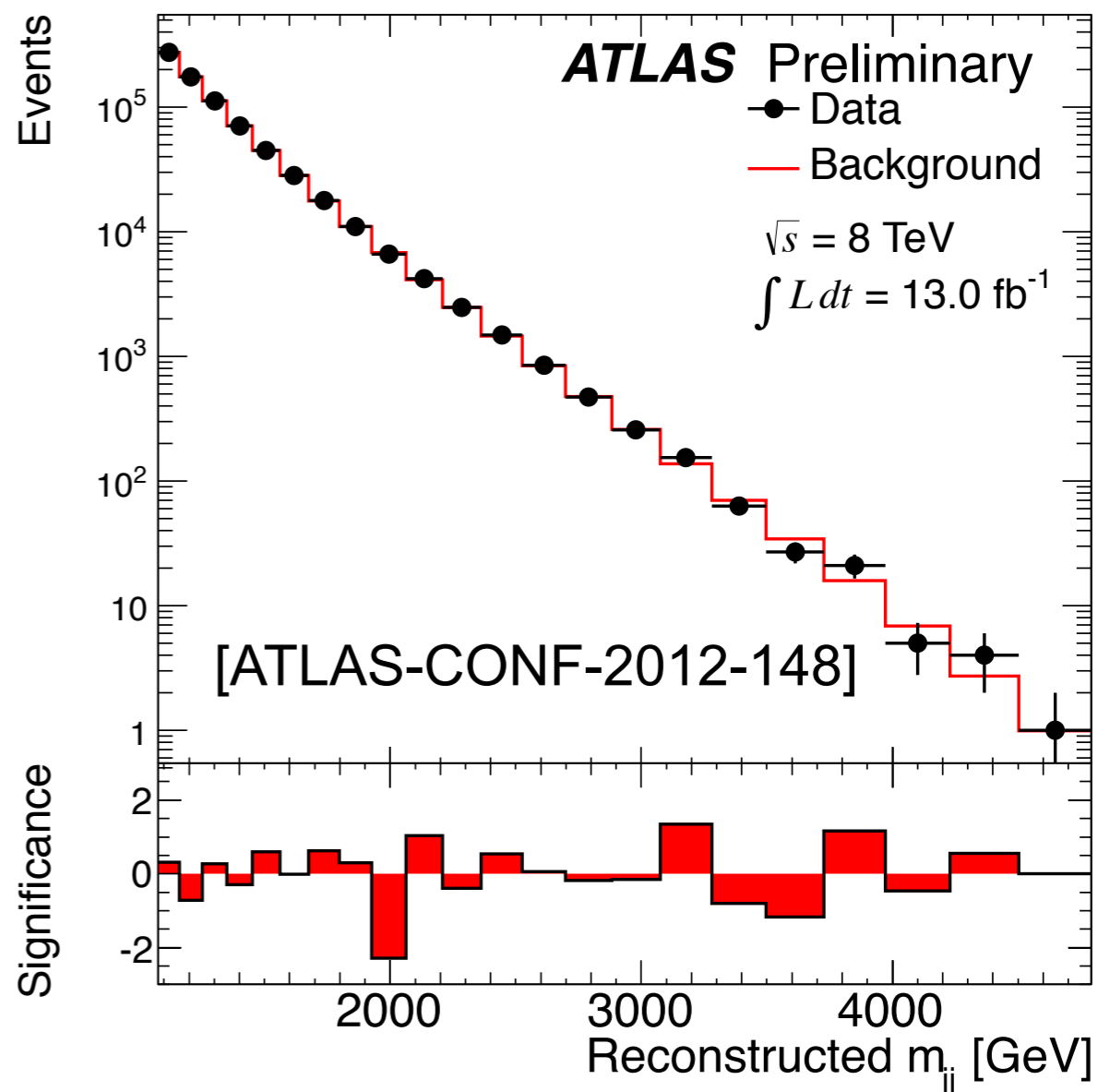
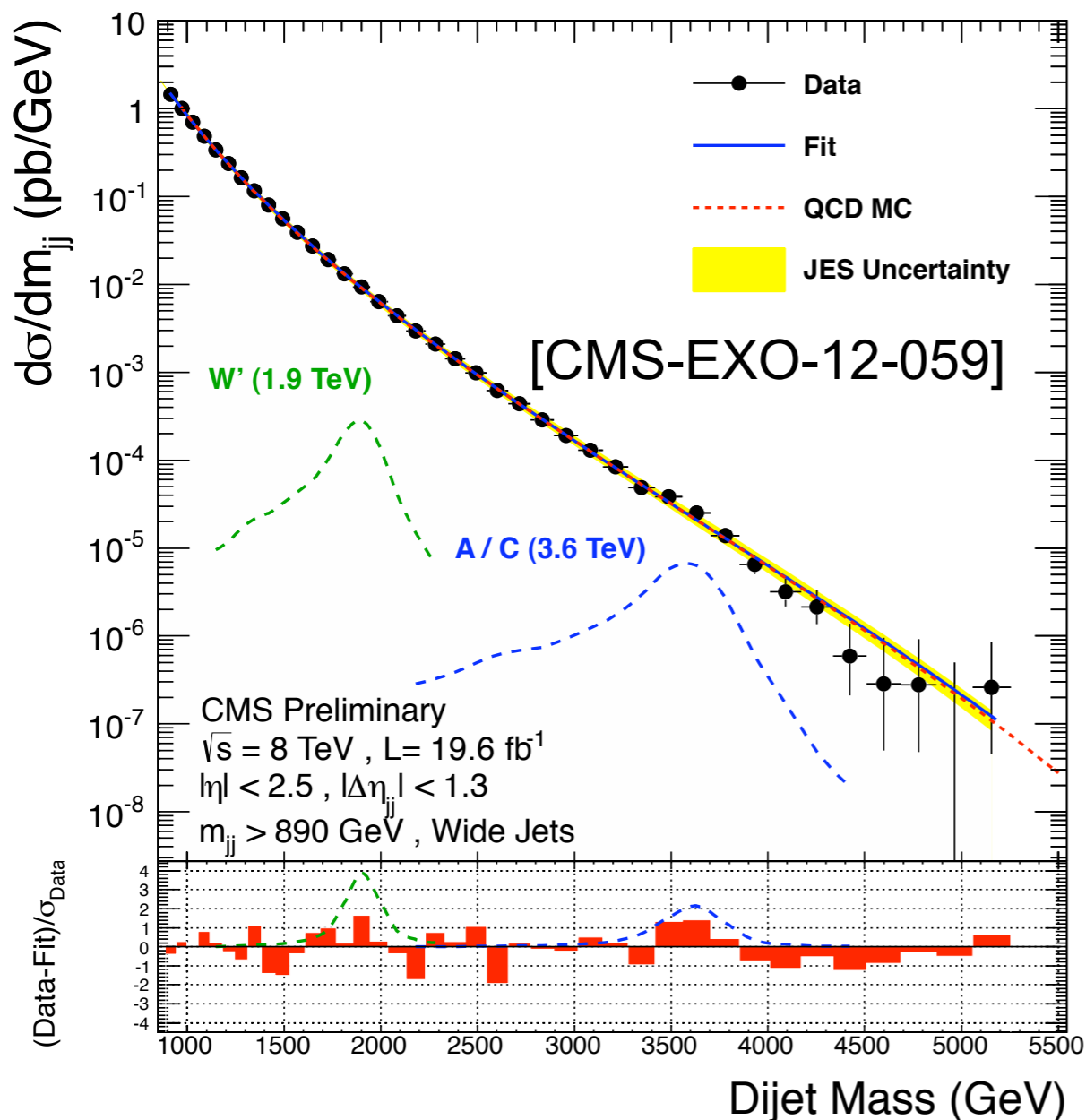


DIJET BACKGROUND TECHNIQUE



- CMS and ATLAS fit to a smooth, steeply falling function

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3} \ln(x)}; \quad x \equiv m_{jj}/\sqrt{s}$$

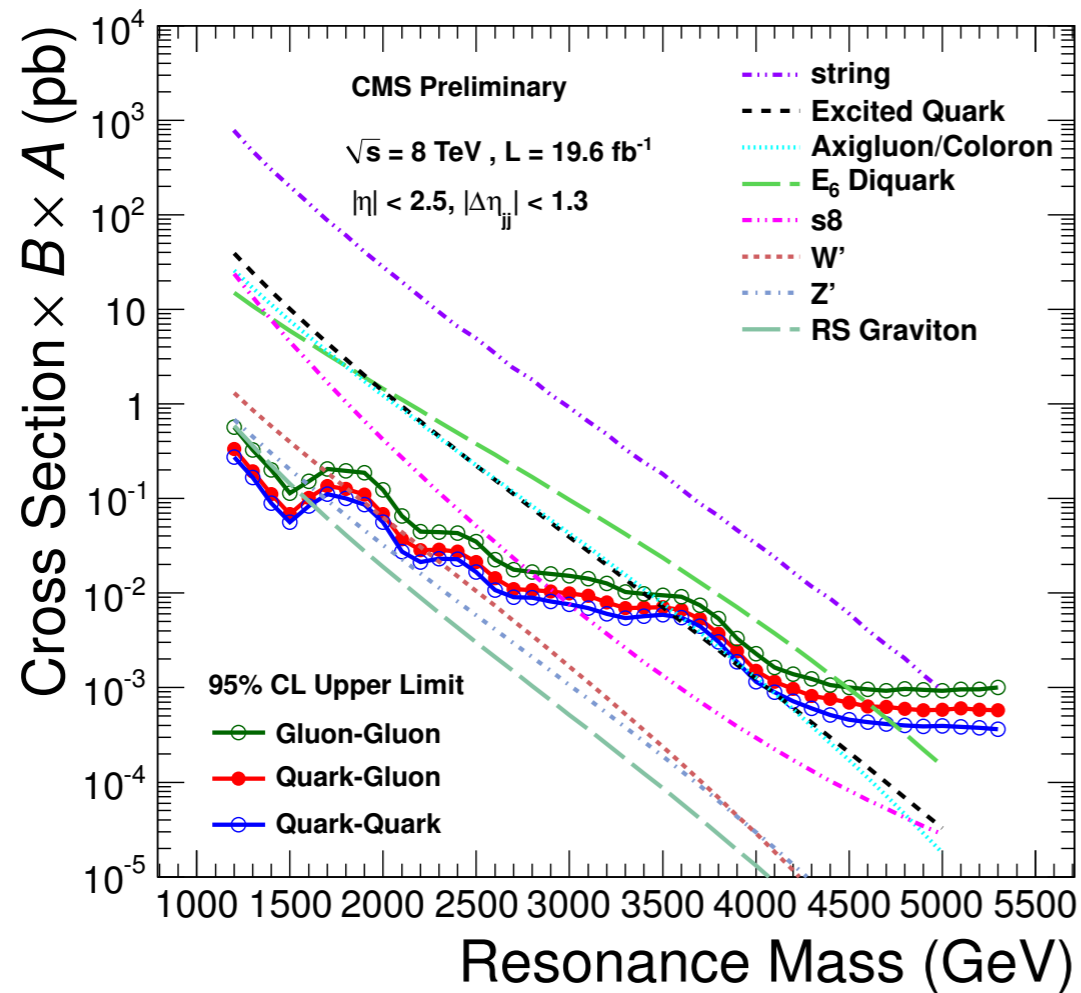


DIJET LIMITS

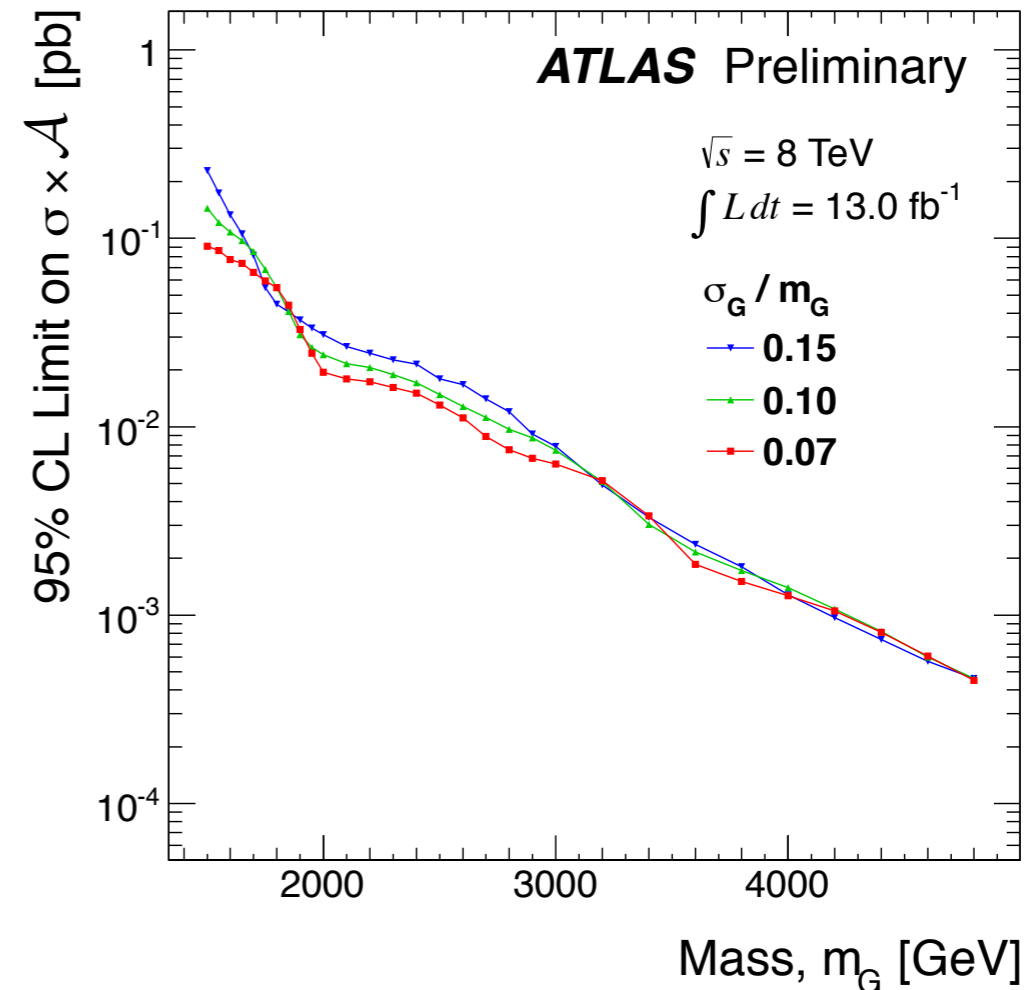


- Exclusions

- CMS excludes e.g. SSM Z' [1.20 TeV, 1.68 TeV] (+ many more)
- ATLAS excludes excited quark [1.50 TeV, 3.84 TeV]



[CMS-EXO-12-059]

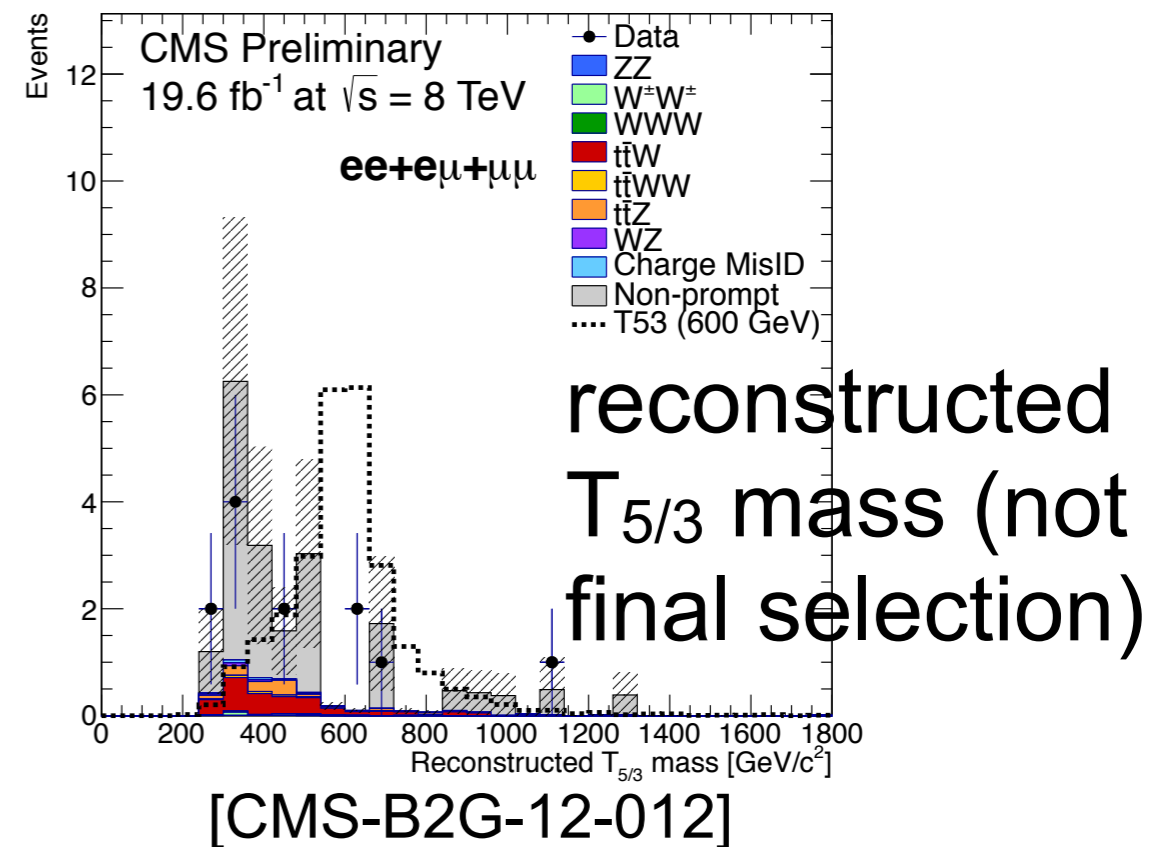
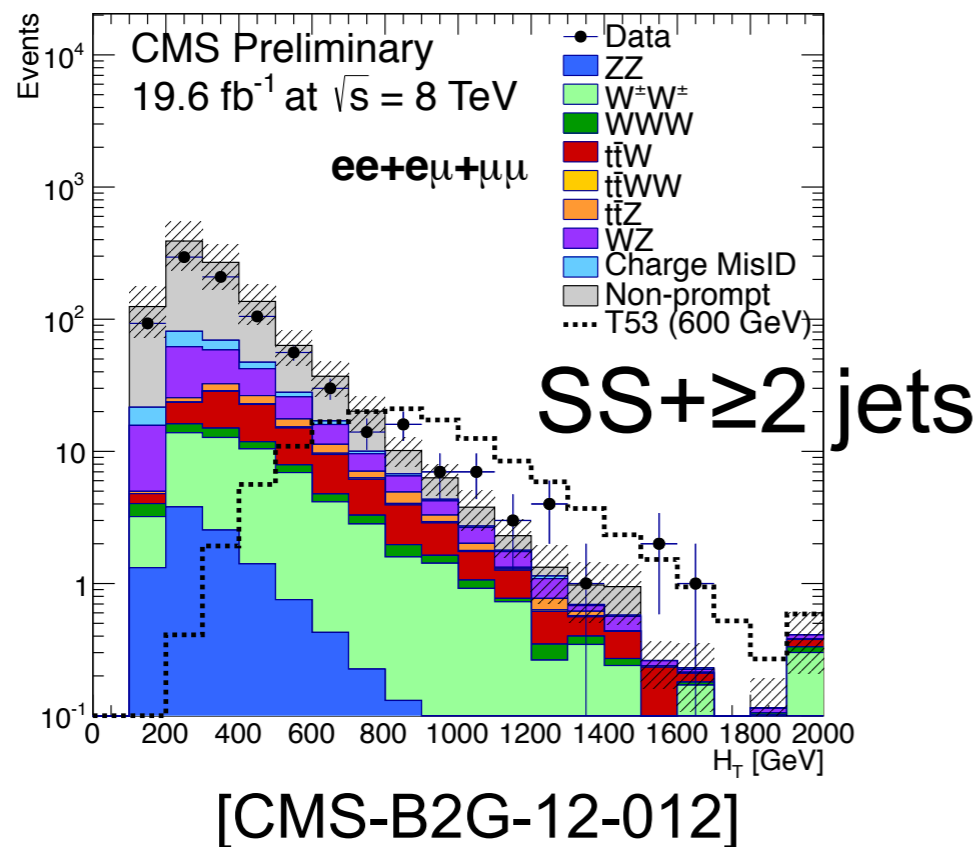
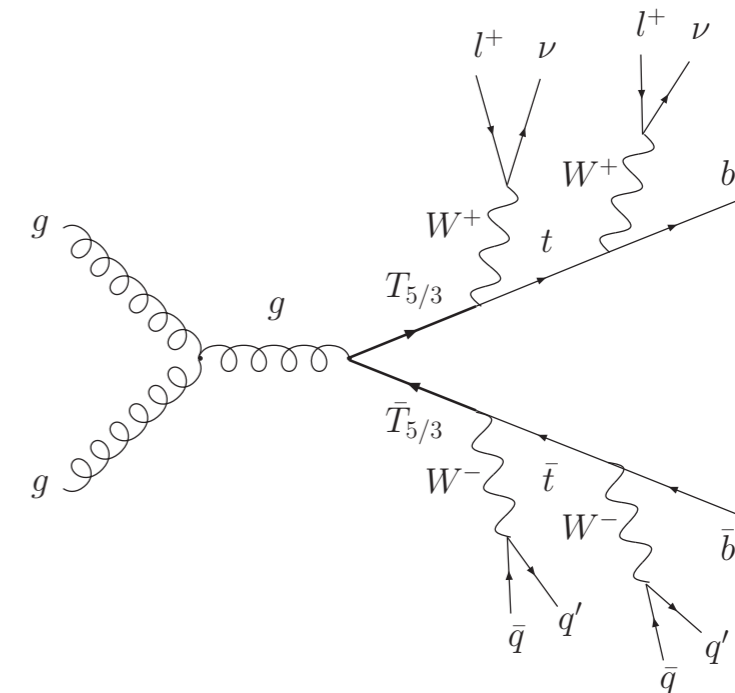


[ATLAS-CONF-2012-148]

TOP PARTNERS



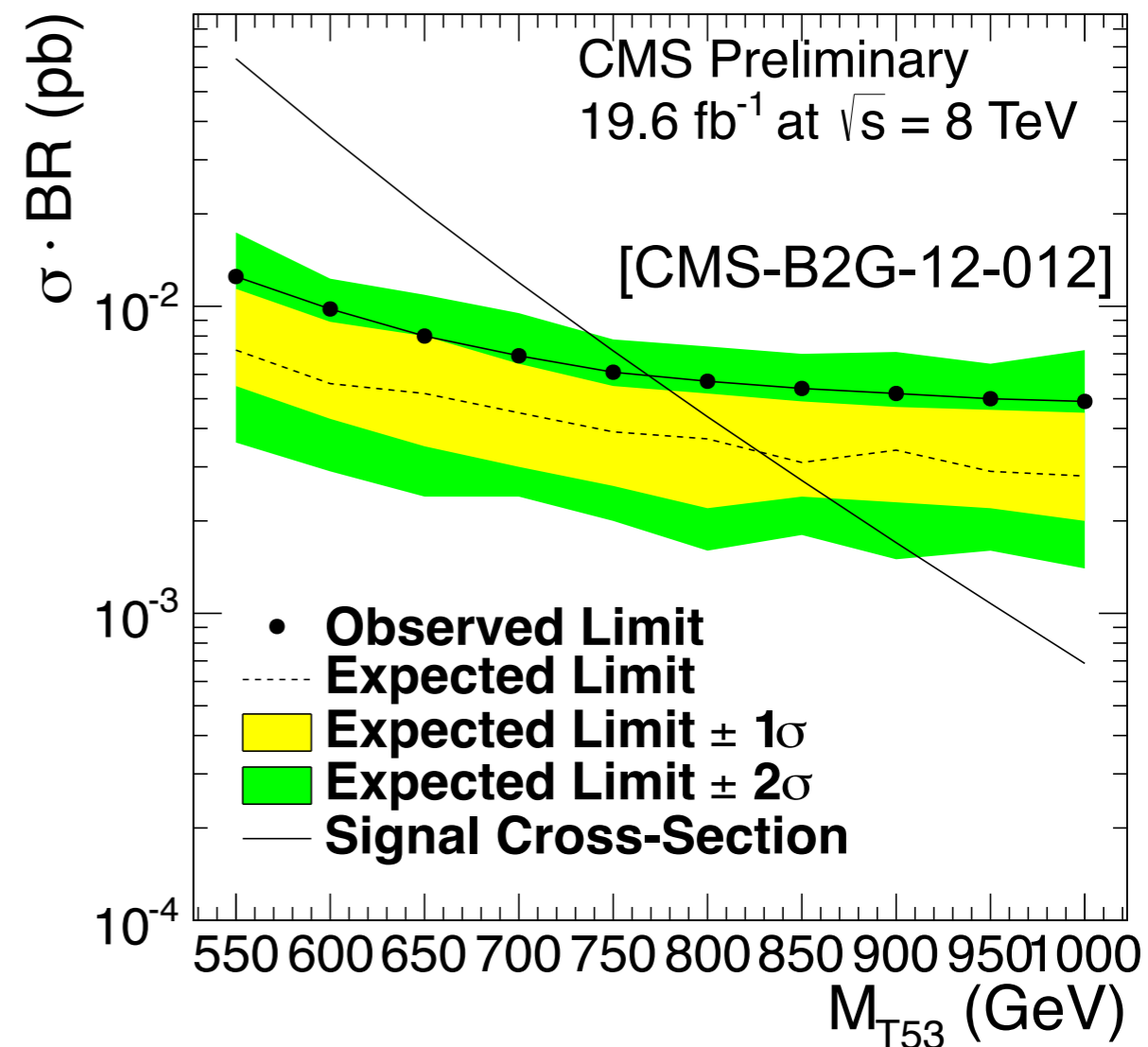
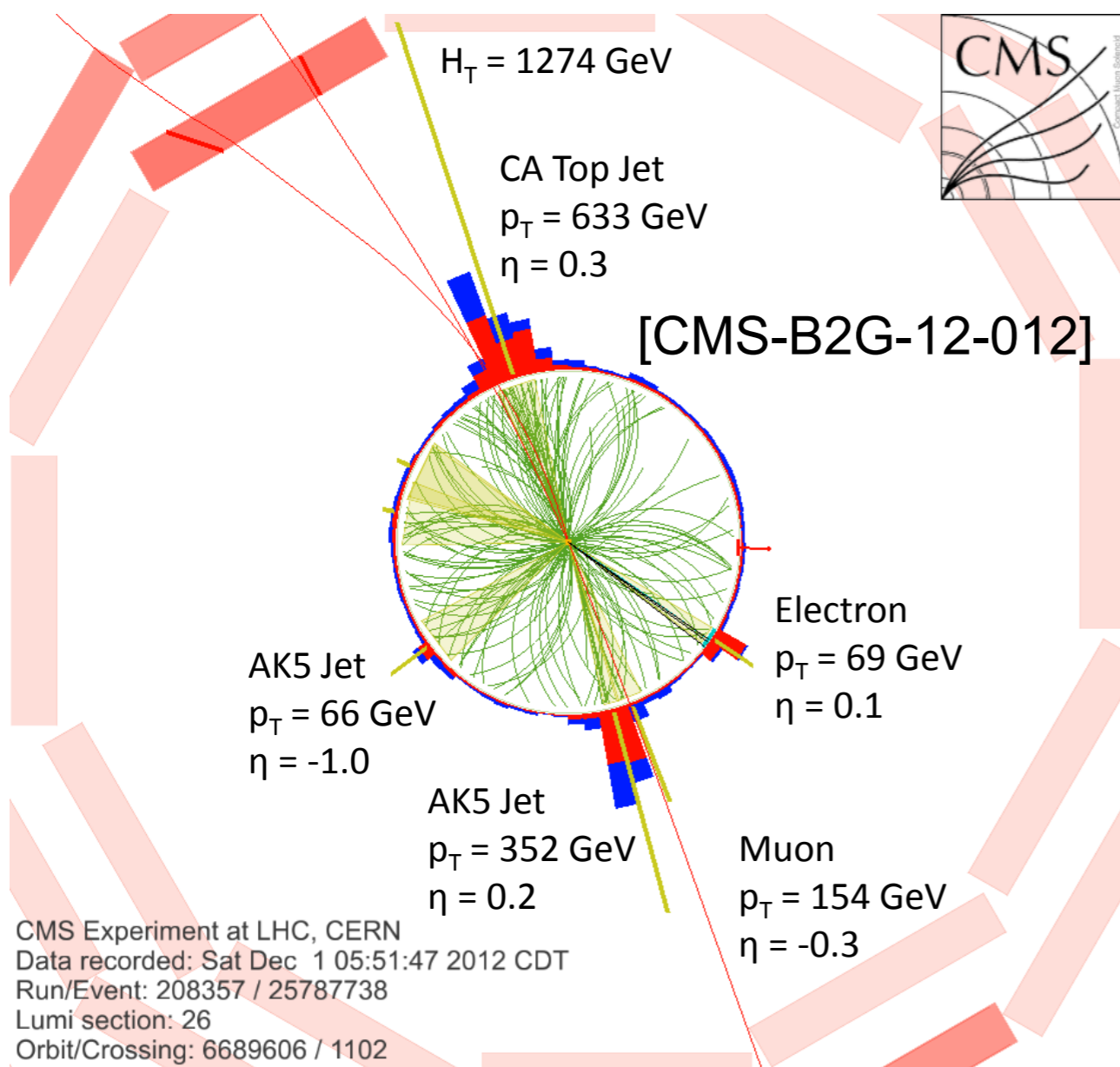
- Search for pair production of charge 5/3 top partner decaying 100% to Wt
 - Final state signature: **same-sign leptons** outside Z window + **$H_T > 900$ GeV**
 - Require ≥ 5 “constituents” in addition to two SS leptons
 - constituent=lepton, jet, V -tagged jet (2), or top-tagged jet (3)



TOP PARTNER LIMITS



- In final selection, observe 11 events against 6.6 ± 2.0 expected
 - Exclude 5/3 Top Partners with masses up to 770 GeV



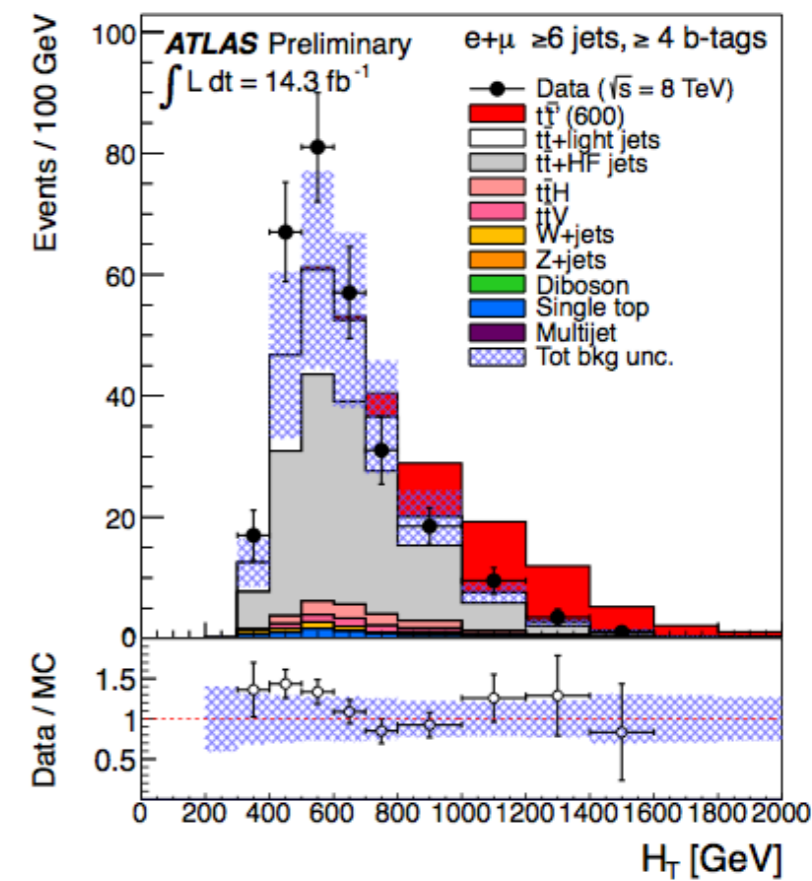
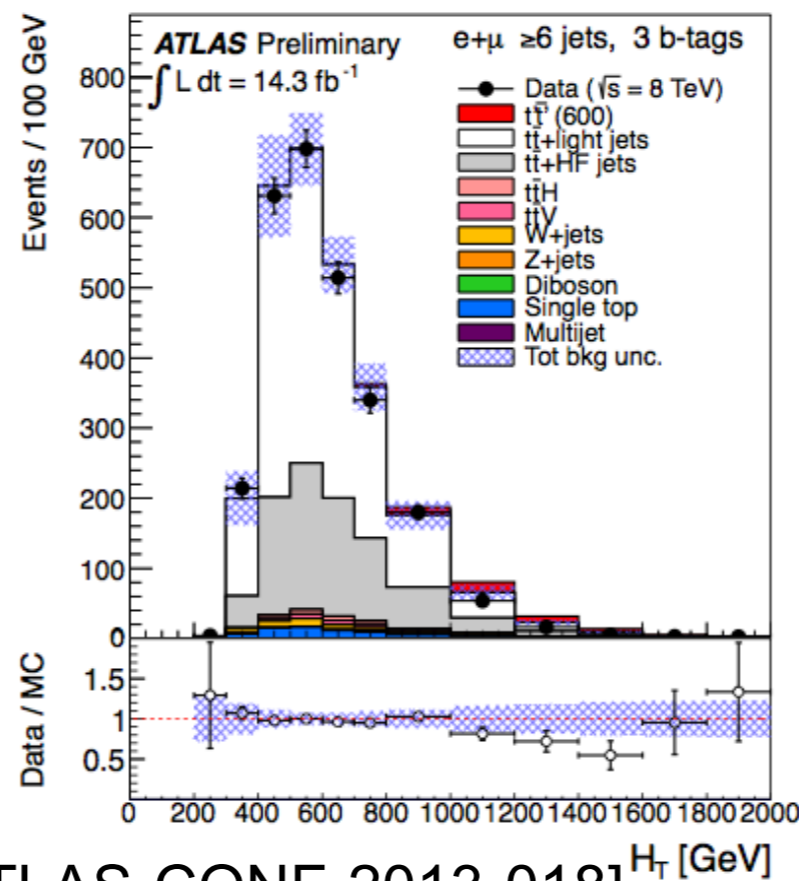
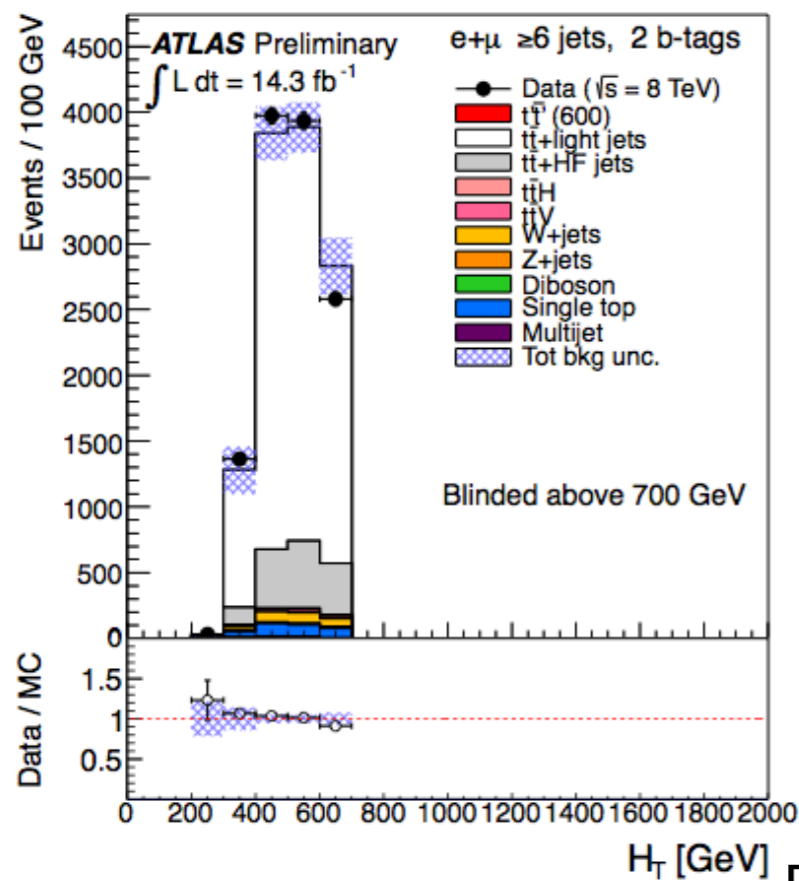
VECTOR-LIKE T-PRIME SEARCH



- Inclusive search for pair production of T'
 - consider decays to Wb , Zt , and Ht
- $=1$ lepton + ≥ 6 jets + MET + M_T
 - bin in number of b-tags

(N.B. ATLAS $H_T = \sum p_T$ of all objects)

- Use control ($H_T < 700$ GeV) regions to fit for $t\bar{t} + \text{LF}$ and $t\bar{t} + \text{HF}$

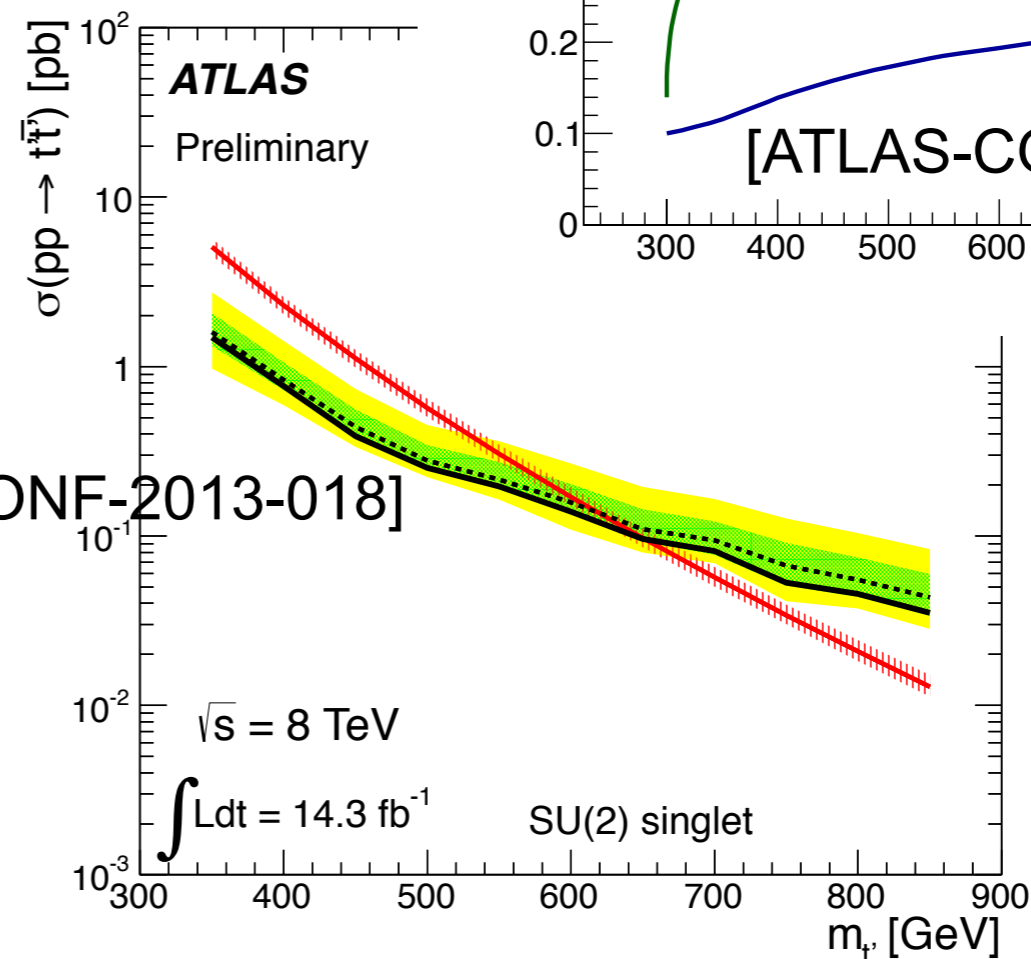
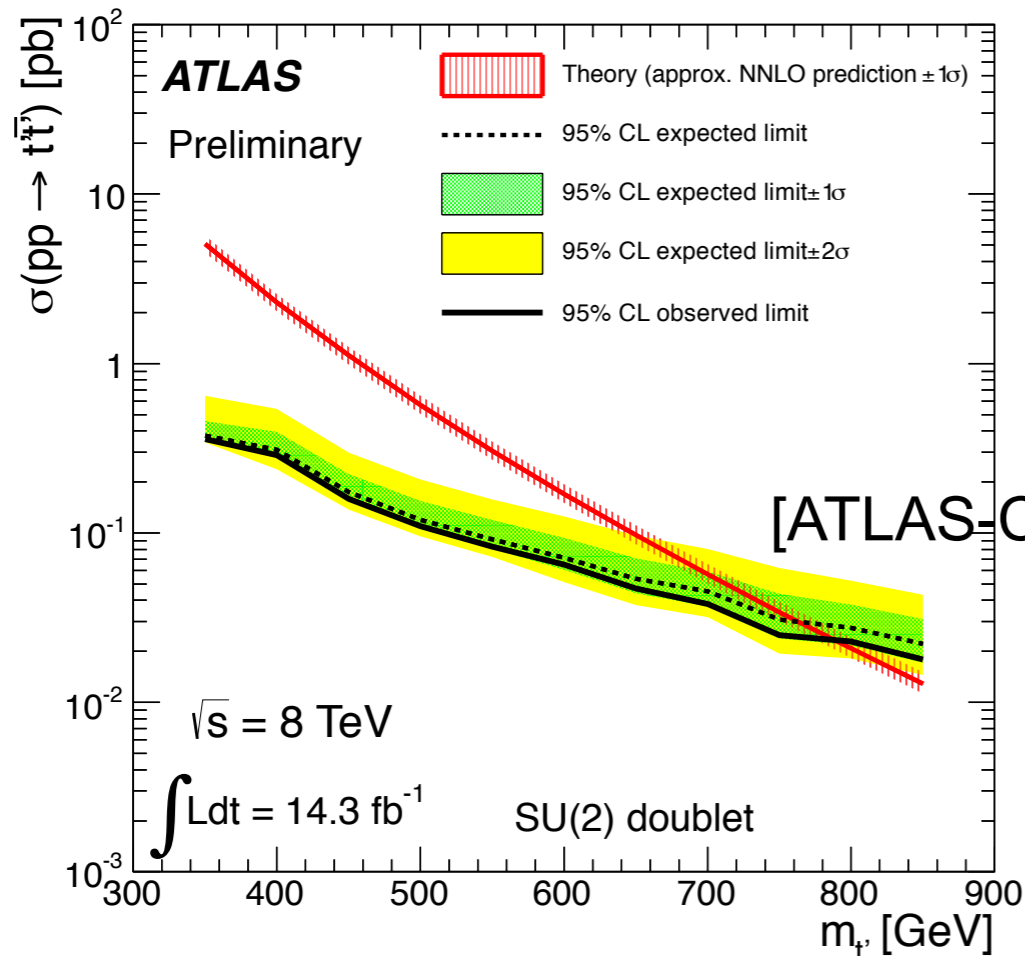
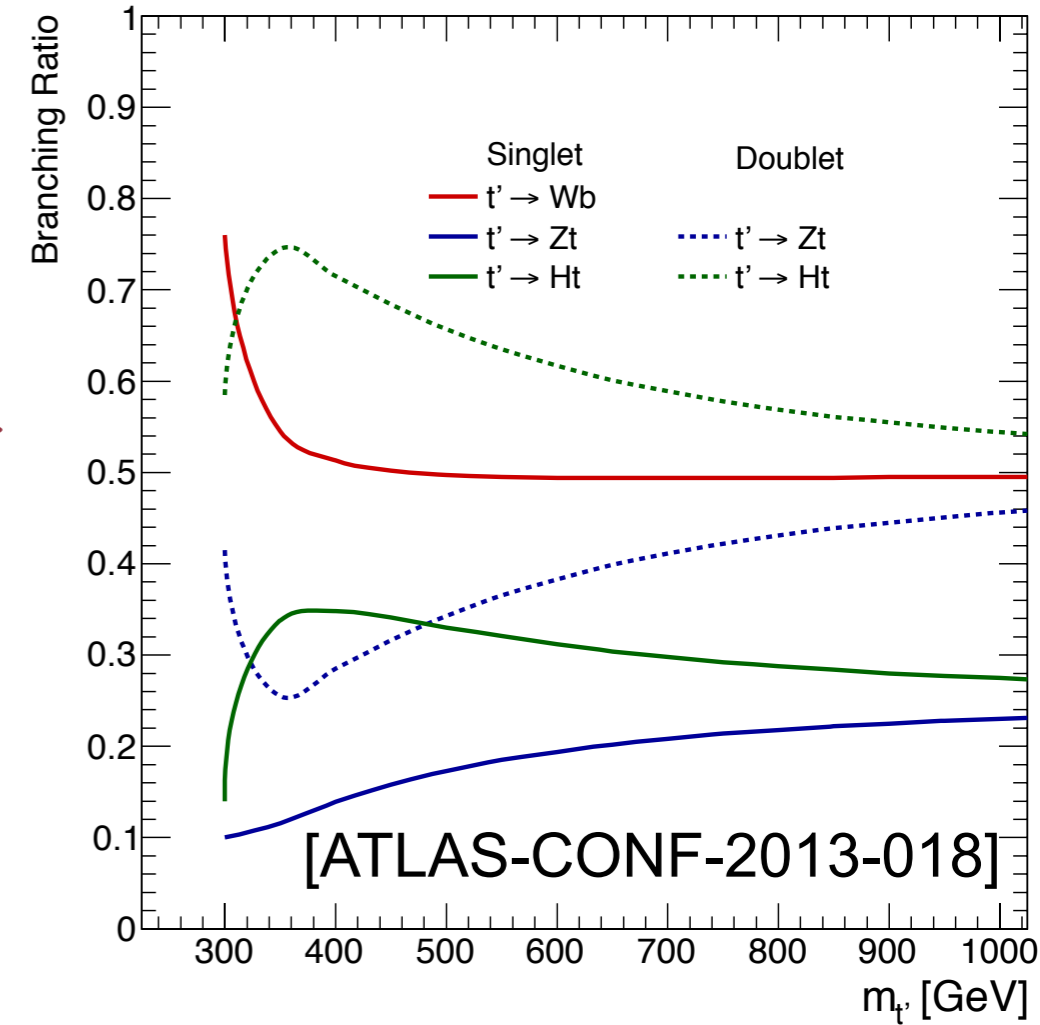


[ATLAS-CONF-2013-018]

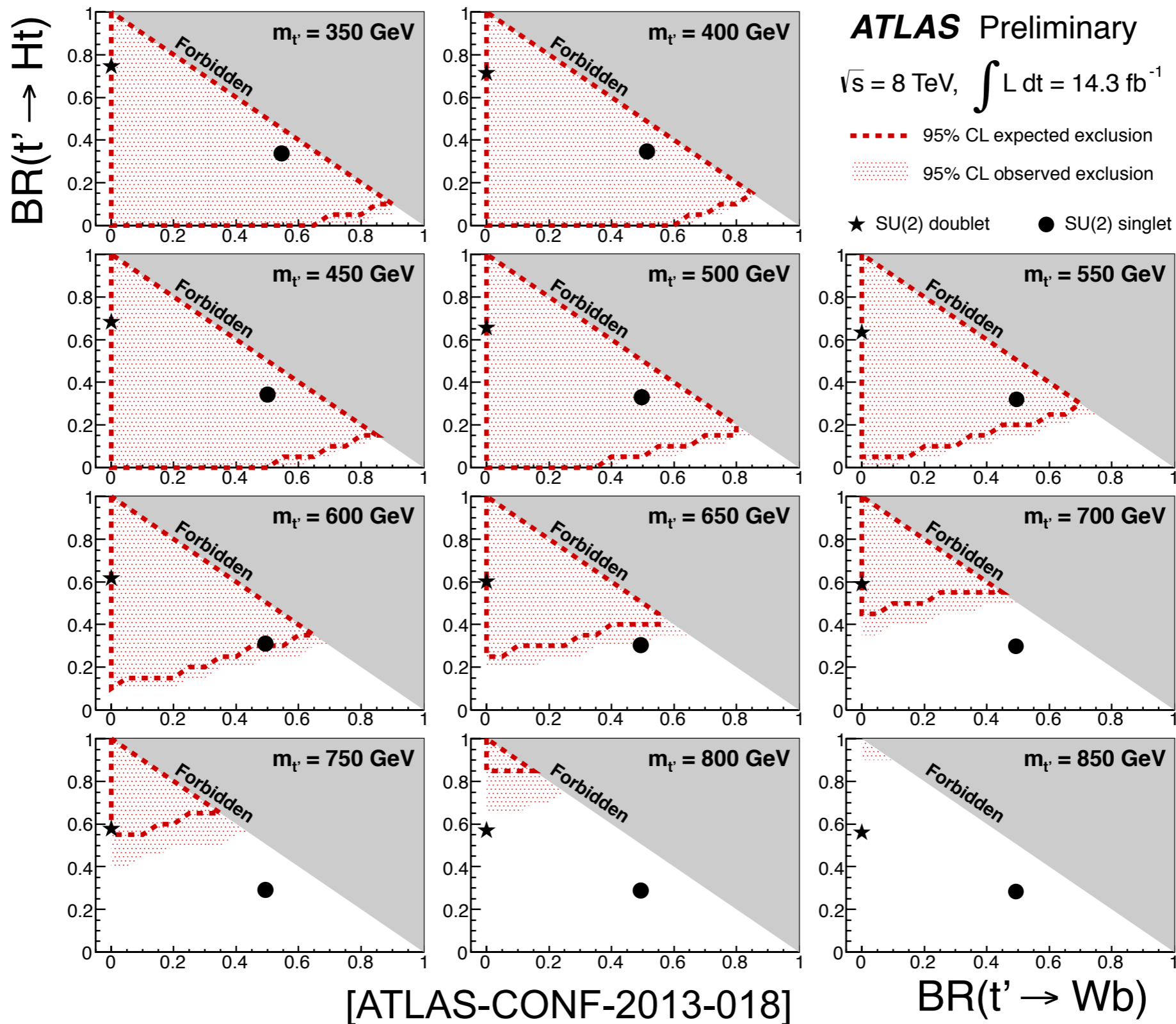
T-PRIME LIMITS



- Set limits on weak-isospin doublet and singlet models
 - specific BRs to Wb , Zt , and Ht as a function of mass
 - Exclude $T' < 790$ (640) GeV for a doublet (singlet)



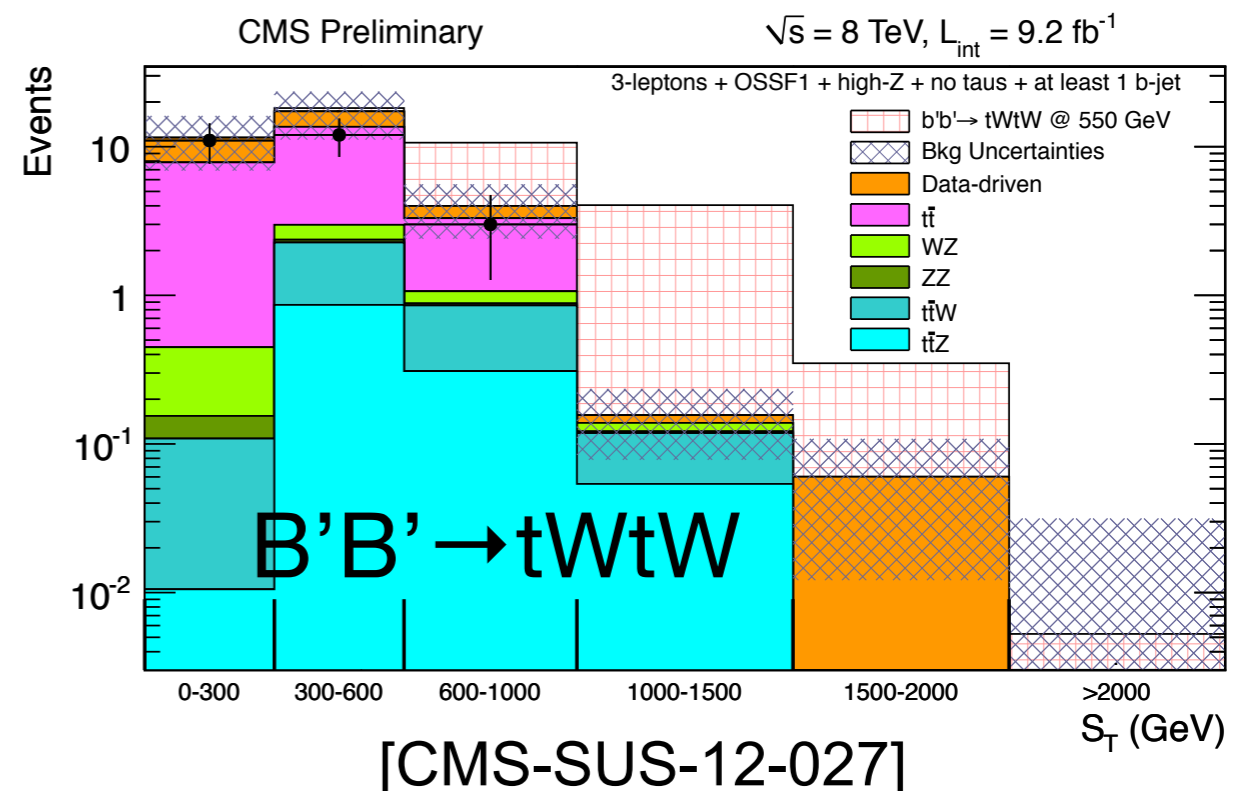
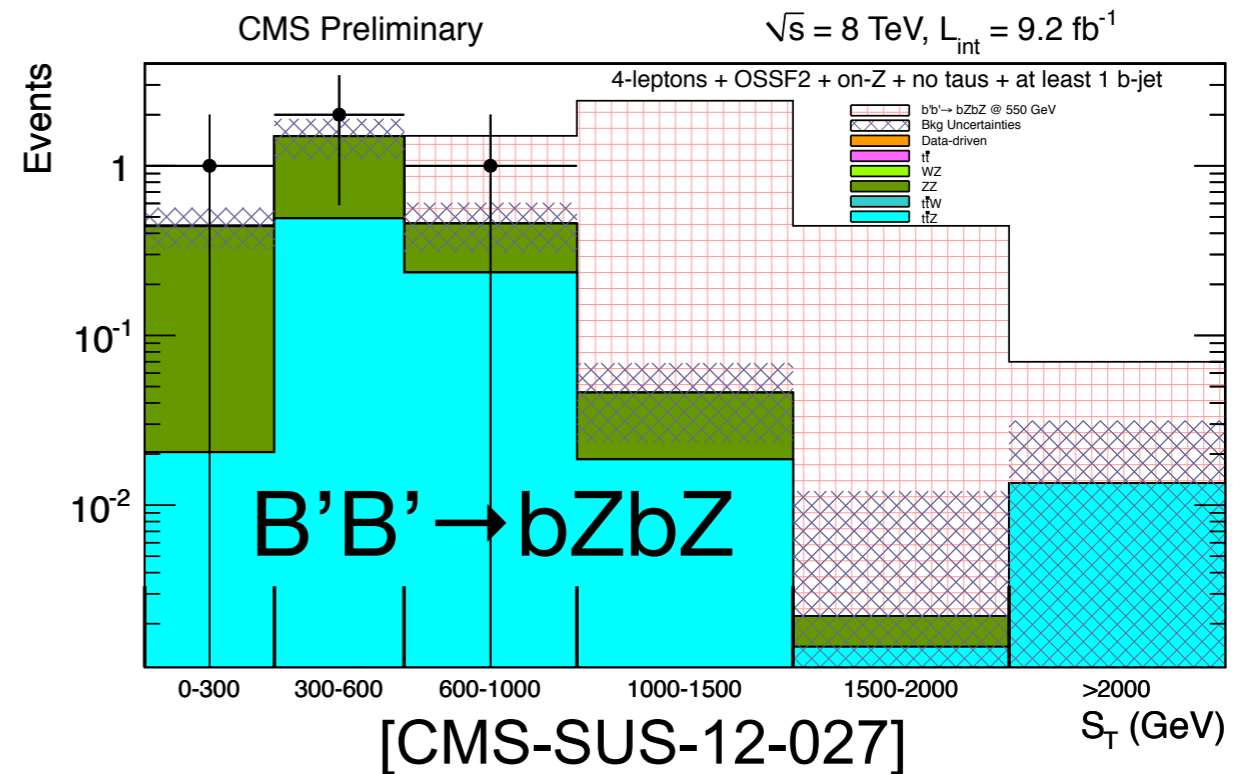
T-PRIME LIMITS BY BRANCHING RATIO



B-PRIME SEARCH WITH MULTILEPTONS



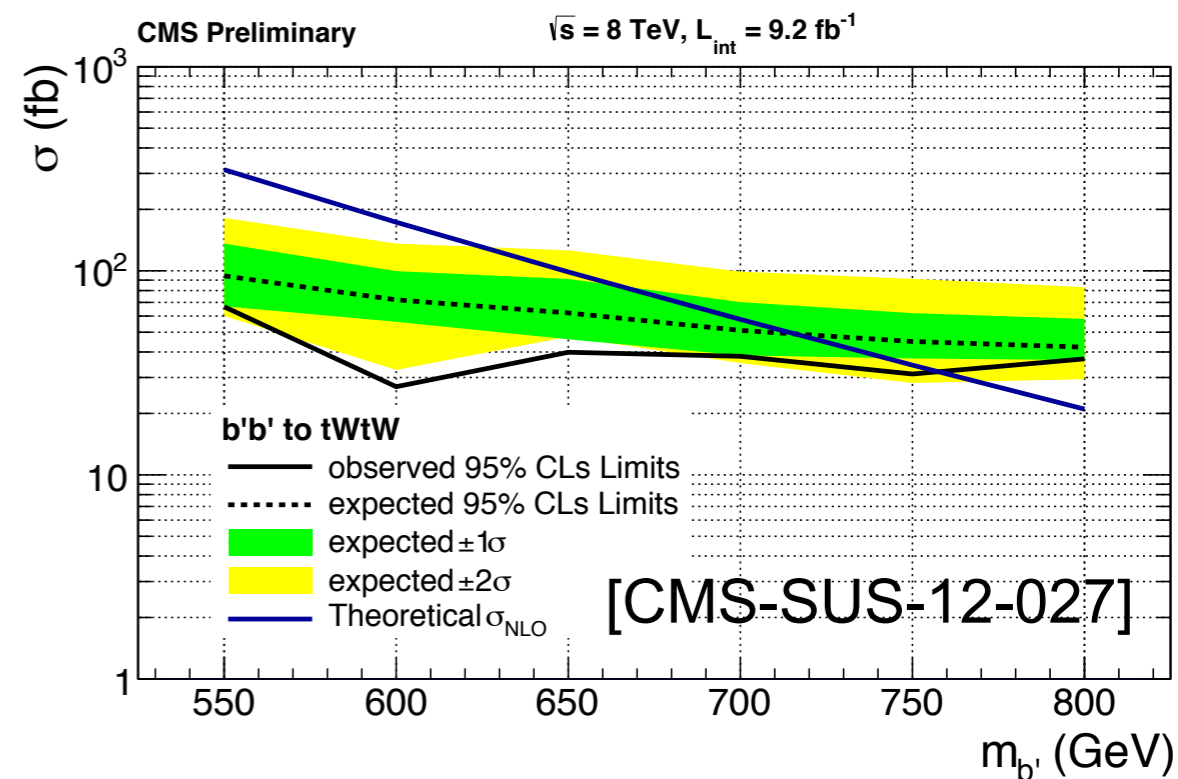
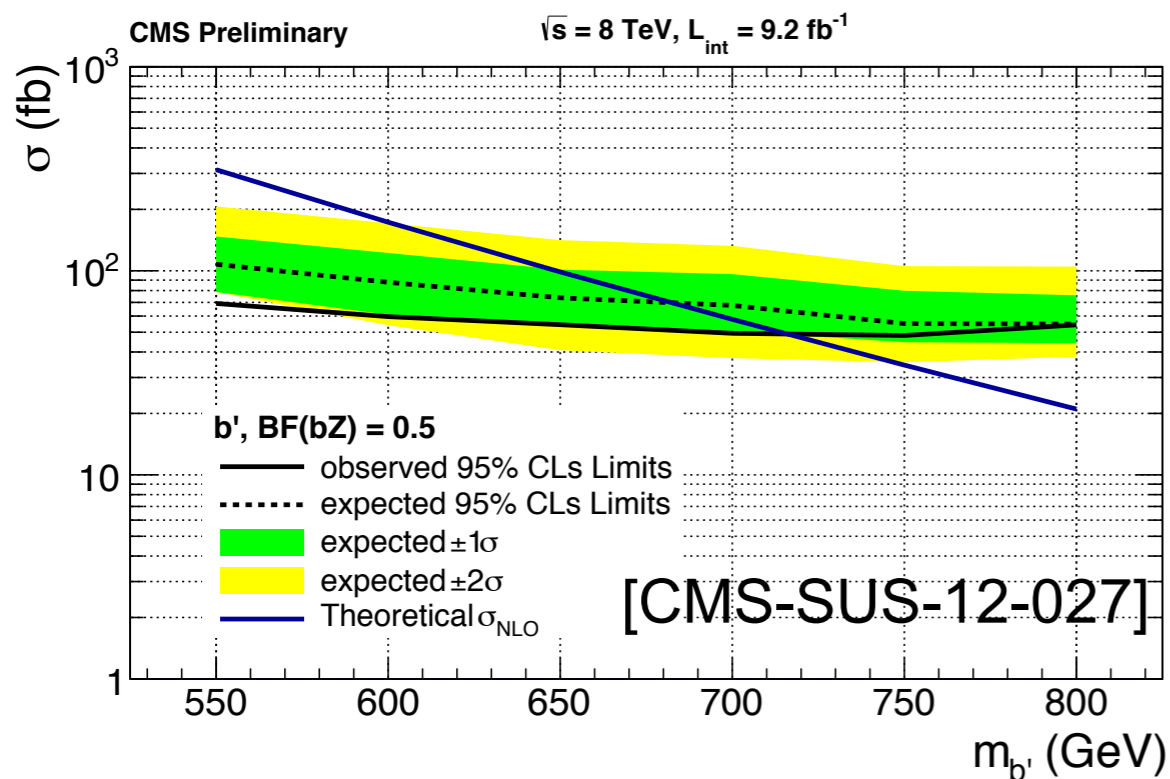
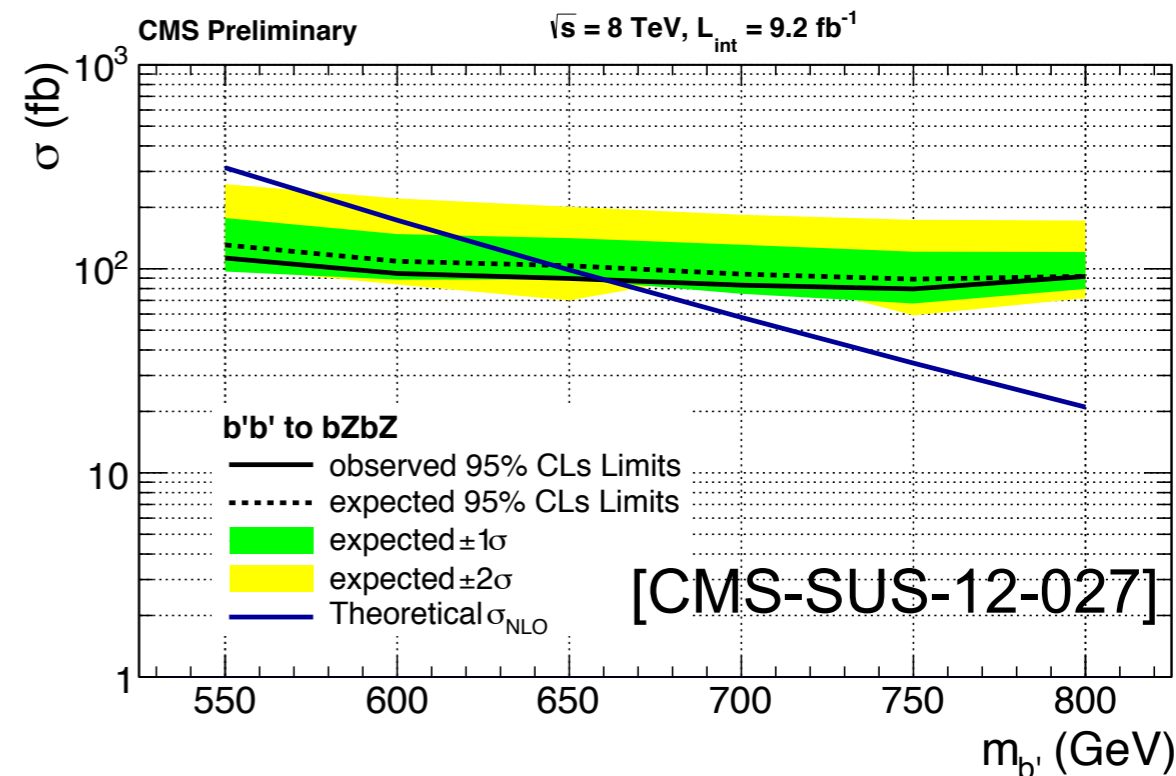
- Re-interpret search for RPV SUSY with ≥ 3 leptons as search for vector-like B'
 - RPV SUSY search considers 100's of bins
 - $S_T = H_T + L_T + MET$
 - number of leptons
 - number of taus
 - number of b tags
 - # of opposite-sign same flavor lepton pairs
 - on/off shell Z



B-PRIME LIMITS



- Exclude B' with 100% BR to bZ
 - $m_{B'} > 660$ GeV @ 95% CL
- Exclude B' with 100% BR to tW
 - $m_{B'} > 760$ GeV @ 95% CL
- Exclude B' with 50% BR to bZ
 - $m_{B'} > 715$ GeV @ 95% CL



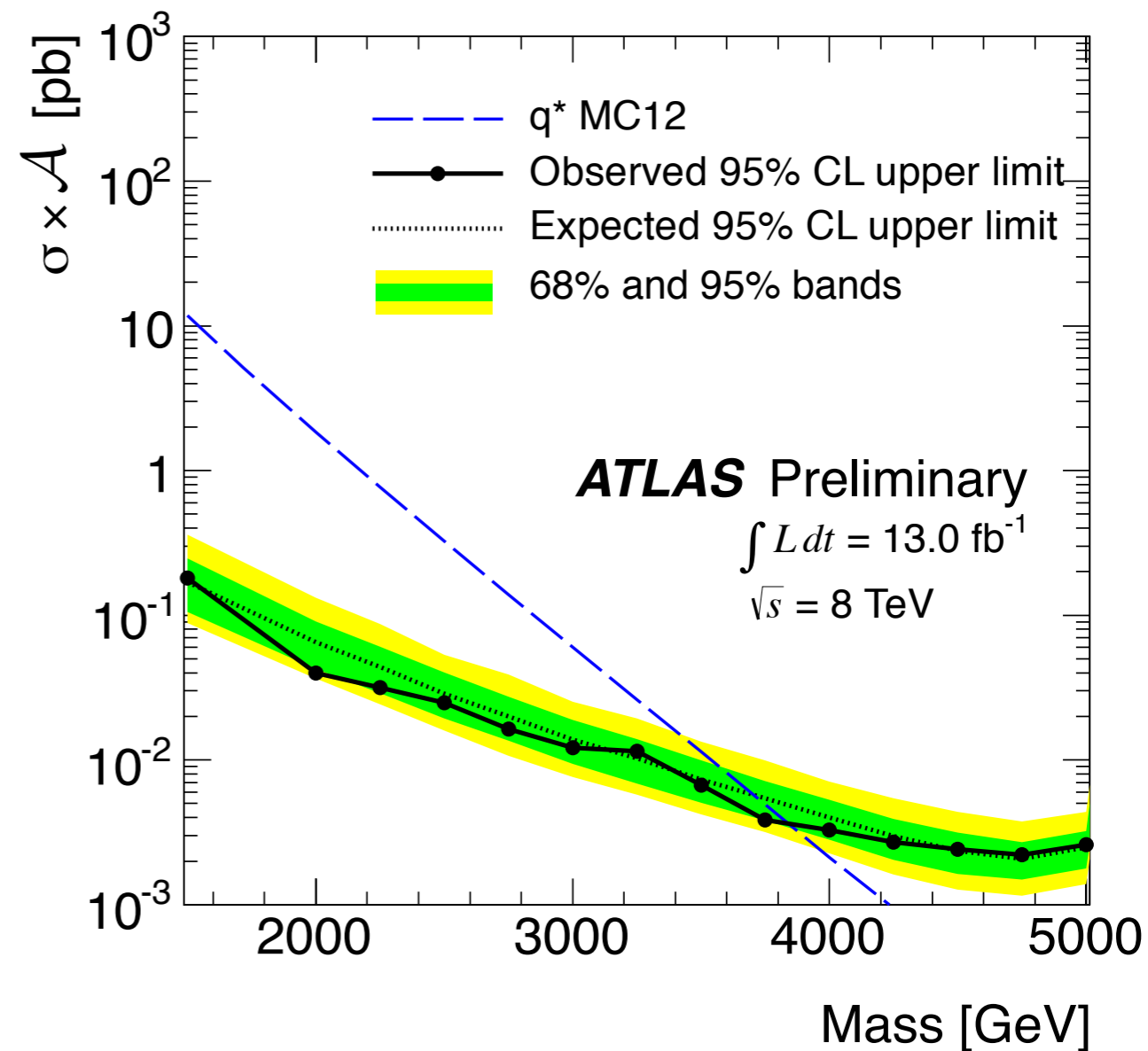
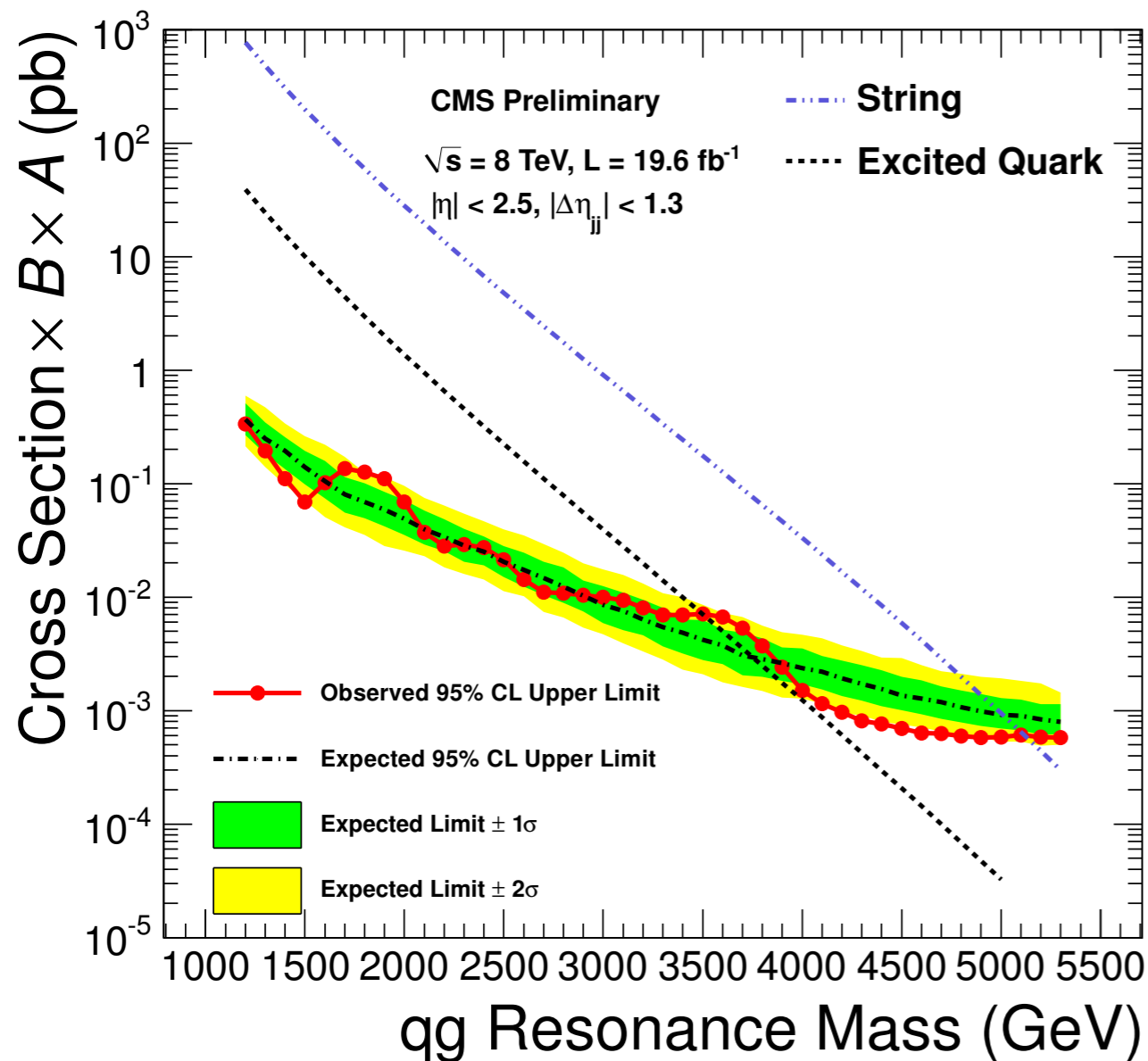
CONCLUSIONS



- LHC has completed its first run
- We've found something BEHGHK-like, **but the search for New Physics has just begun**
 - CMS and ATLAS have only just begun exploring and exploiting the full 8 TeV dataset
 - We've learned a lot about where New Physics isn't, and where it still could be
- Lots of places new physics **could still be hiding**
 - Long-lived particles, multijet final states, top-like final states, etc.
 - Be prepared for many more results in the coming months
- Stay tuned!

BACKUP

LIMITS ON EXCITED QUARKS



ATLAS Exotics Searches* - 95% CL Lower Limits (Status: HCP 2012)

ATLAS
Preliminary

$\int L dt = (1.0 - 13.0) \text{ fb}^{-1}$
 $\sqrt{s} = 7, 8 \text{ TeV}$

Extra dimensions

CI

V'

LQ

New quarks

Excit. ferm.

Other

| | | | |
|---|--|----------|--|
| Large ED (ADD) : monojet + $E_{T,miss}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.4491]}$ | 4.37 TeV | $M_D (\delta=2)$ |
| Large ED (ADD) : monophoton + $E_{T,miss}$ | $L=4.6 \text{ fb}^{-1}, 7 \text{ TeV [1209.4625]}$ | 1.93 TeV | $M_D (\delta=2)$ |
| Large ED (ADD) : diphoton & dilepton, $m_{\gamma\gamma} / ll$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1211.1150]}$ | 4.18 TeV | $M_S (\text{HLZ } \delta=3, \text{ NLO})$ |
| UED : diphoton + $E_{T,miss}$ | $L=4.8 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-072]}$ | 1.41 TeV | Compact. scale R^{-1} |
| S^1/Z_2 ED : dilepton, m_{ll} | $L=4.9-5.0 \text{ fb}^{-1}, 7 \text{ TeV [1209.2535]}$ | 4.71 TeV | $M_{KK} \sim R^{-1}$ |
| RS1 : diphoton & dilepton, $m_{\gamma\gamma} / ll$ | $L=4.7-5.0 \text{ fb}^{-1}, 7 \text{ TeV [1210.8389]}$ | 2.23 TeV | Graviton mass ($k/M_{Pl} = 0.1$) |
| RS1 : ZZ resonance, $m_{llll} / lljj$ | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1203.0718]}$ | 845 GeV | Graviton mass ($k/M_{Pl} = 0.1$) |
| RS1 : WW resonance, $m_{T,lvlv}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1208.2880]}$ | 1.23 TeV | Graviton mass ($k/M_{Pl} = 0.1$) |
| RS $g_{KK} \rightarrow tt$ (BR=0.925) : $tt \rightarrow l+jets$, $m_{tt,boosted}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-136]}$ | 1.9 TeV | g_{KK} mass |
| ADD BH ($M_{TH}/M_D=3$) : SS dimuon, $N_{ch.part.}$ | $L=1.3 \text{ fb}^{-1}, 7 \text{ TeV [1111.0080]}$ | 1.25 TeV | $M_D (\delta=6)$ |
| ADD BH ($M_{TH}/M_D=3$) : leptons + jets, $\Sigma \rho_T$ | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1204.4646]}$ | 1.5 TeV | $M_D (\delta=6)$ |
| Quantum black hole : dijet, $F(m_{jj})$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.1718]}$ | 4.11 TeV | $M_D (\delta=6)$ |
| qqqq contact interaction : $\chi(m_{jj})$ | $L=4.8 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-038]}$ | 7.8 TeV | Λ |
| qqll CI : ee & $\mu\mu$, m_{ll} | $L=4.9-5.0 \text{ fb}^{-1}, 7 \text{ TeV [1211.1150]}$ | 13.9 TeV | Λ (constructive int.) |
| uutt CI : SS dilepton + jets + $E_{T,miss}$ | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1202.5520]}$ | 1.7 TeV | Λ |
| Z' (SSM) : $m_{ee/\mu\mu}$ | $L=5.9-6.1 \text{ fb}^{-1}, 8 \text{ TeV [ATLAS-CONF-2012-129]}$ | 2.49 TeV | Z' mass |
| Z' (SSM) : $m_{\tau\tau}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.6604]}$ | 1.4 TeV | Z' mass |
| W' (SSM) : $m_{T,e/\mu}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1209.4446]}$ | 2.55 TeV | W' mass |
| W' ($\rightarrow tq, g_R=1$) : m_{tq} | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1209.6593]}$ | 430 GeV | W' mass |
| W'_R ($\rightarrow tb, \text{SSM}$) : m_{tb} | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1205.1016]}$ | 1.13 TeV | W' mass |
| W* : $m_{T,e/\mu}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1209.4446]}$ | 2.42 TeV | W* mass |
| Scalar LQ pair ($\beta=1$) : kin. vars. in eejj, evjj | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1112.4828]}$ | 660 GeV | 1 st gen. LQ mass |
| Scalar LQ pair ($\beta=1$) : kin. vars. in $\mu\mu jj, \mu\nu jj$ | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1203.3172]}$ | 685 GeV | 2 nd gen. LQ mass |
| Scalar LQ pair ($\beta=1$) : kin. vars. in $\tau\tau jj, \tau\nu jj$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [Preliminary]}$ | 538 GeV | 3 rd gen. LQ mass |
| 4 th generation : $tt' \rightarrow WbWb$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.5468]}$ | 656 GeV | t' mass |
| 4 th generation : $b'b' (T_{5/3}, T_{5/3}) \rightarrow WtWt$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-130]}$ | 670 GeV | b' ($T_{5/3}$) mass |
| New quark b' : $b'b' \rightarrow Zb+X$, m_{Zb} | $L=2.0 \text{ fb}^{-1}, 7 \text{ TeV [1204.1265]}$ | 400 GeV | b' mass |
| Top partner : $TT \rightarrow tt + A_0 A_0$ (dilepton, M_{T2}) | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1209.4186]}$ | 483 GeV | T mass ($m(A_0) < 100 \text{ GeV}$) |
| Vector-like quark : CC, m_{lvq} | $L=4.6 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-137]}$ | 1.12 TeV | VLQ mass (charge -1/3, coupling $\kappa_{qQ} = v/m_Q$) |
| Vector-like quark : NC, m_{llq} | $L=4.6 \text{ fb}^{-1}, 7 \text{ TeV [ATLAS-CONF-2012-137]}$ | 1.08 TeV | VLQ mass (charge 2/3, coupling $\kappa_{qQ} = v/m_Q$) |
| Excited quarks : γ -jet resonance, $m_{\gamma jet}$ | $L=2.1 \text{ fb}^{-1}, 7 \text{ TeV [1112.3580]}$ | 2.46 TeV | q* mass |
| Excited quarks : dijet resonance, m_{jj} | $L=13.0 \text{ fb}^{-1}, 8 \text{ TeV [ATLAS-CONF-2012-148]}$ | 3.84 TeV | q* mass |
| Excited lepton : l- γ resonance, $m_{l\gamma}$ | $L=13.0 \text{ fb}^{-1}, 8 \text{ TeV [ATLAS-CONF-2012-146]}$ | 2.2 TeV | l* mass ($\Lambda = m(l^*)$) |
| Techni-hadrons (LSTC) : dilepton, $m_{ee/\mu\mu}$ | $L=4.9-5.0 \text{ fb}^{-1}, 7 \text{ TeV [1209.2535]}$ | 850 GeV | ρ_T/ω_T mass ($m(\rho_T/\omega_T) - m(\pi_T) = M_W$) |
| Techni-hadrons (LSTC) : WZ resonance (νll), $m_{T,WZ}$ | $L=1.0 \text{ fb}^{-1}, 7 \text{ TeV [1204.1648]}$ | 483 GeV | ρ_T mass ($m(\rho_T) = m(\pi_T) + m_W, m(a_T) = 1.1 m(\rho_T)$) |
| Major. neutr. (LRSM, no mixing) : 2-lep + jets | $L=2.1 \text{ fb}^{-1}, 7 \text{ TeV [1203.5420]}$ | 1.5 TeV | N mass ($m(W_R) = 2 \text{ TeV}$) |
| W_R (LRSM, no mixing) : 2-lep + jets | $L=2.1 \text{ fb}^{-1}, 7 \text{ TeV [1203.5420]}$ | 2.4 TeV | W_R mass ($m(N) < 1.4 \text{ TeV}$) |
| $H_L^{\pm\pm}$ (DY prod., BR($H_L^{\pm\pm} \rightarrow ll$)=1) : SS ee ($\mu\mu$), m_{ll} | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.5070]}$ | 409 GeV | $H_L^{\pm\pm}$ mass (limit at 398 GeV for $\mu\mu$) |
| $H_L^{\pm\pm}$ (DY prod., BR($H_L^{\pm\pm} \rightarrow e\mu$)=1) : SS e μ , $m_{e\mu}$ | $L=4.7 \text{ fb}^{-1}, 7 \text{ TeV [1210.5070]}$ | 375 GeV | $H_L^{\pm\pm}$ mass |
| Color octet scalar : dijet resonance, m_{jj} | $L=4.8 \text{ fb}^{-1}, 7 \text{ TeV [1210.1718]}$ | 1.86 TeV | Scalar resonance mass |

10^{-1}

1

10

10^2

Mass scale [TeV]

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

CMS EXOTICA 95% CL EXCLUSION LIMITS (TeV)

