Search for single production of vector-like quarks decaying into a W-boson and a b-quark at 13 TeV

Dustin Biedermann

Humboldt-Universität zu Berlin

Top 2016
Olomouc, 20th September 2016

Vector-like Quarks

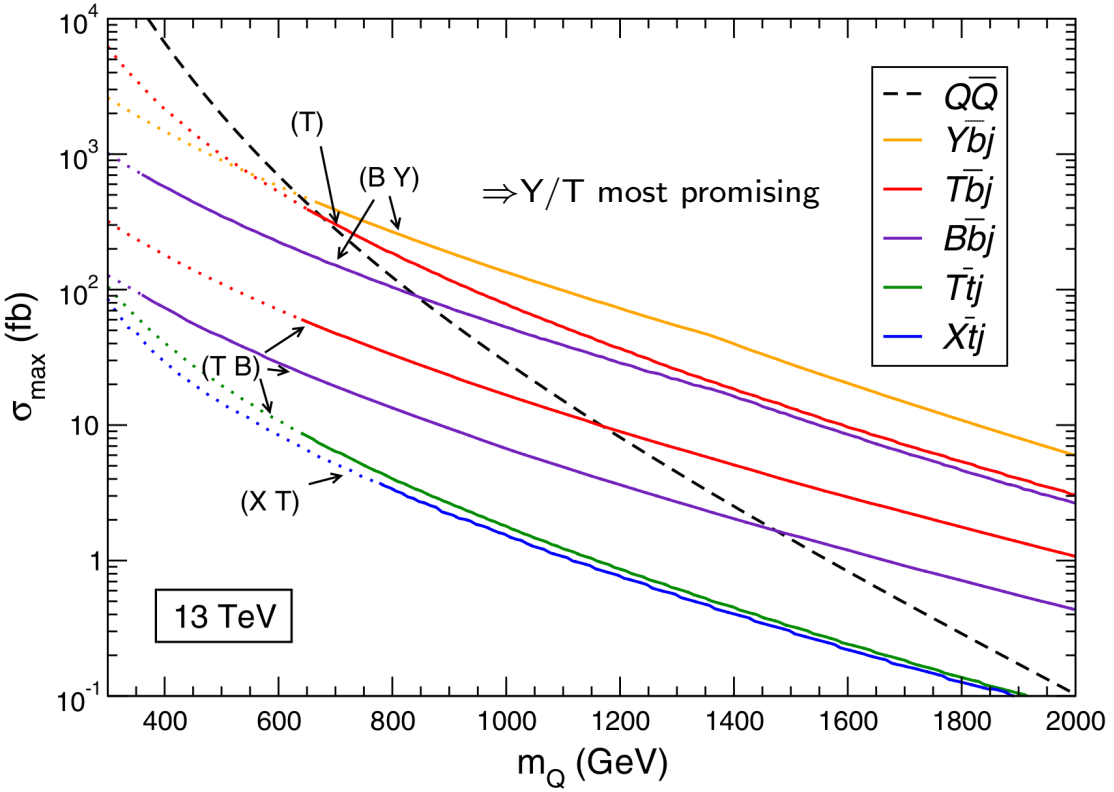
Vector-like Quarks (VLQ) predicted by several BSM models (little Higgs, composite Higgs, ...) addressing Hierarchy problem, tension in A_{FB}^{b}, ...

Appear in different SU(2) multiplets:

- Singlets: T, B
- Doublets: (XT), (TB), (BY)
- Triplets: (XTB), (TBY)

Pair production: mass constraints ($m(T/Y) \gtrsim 800 - 900$ GeV)

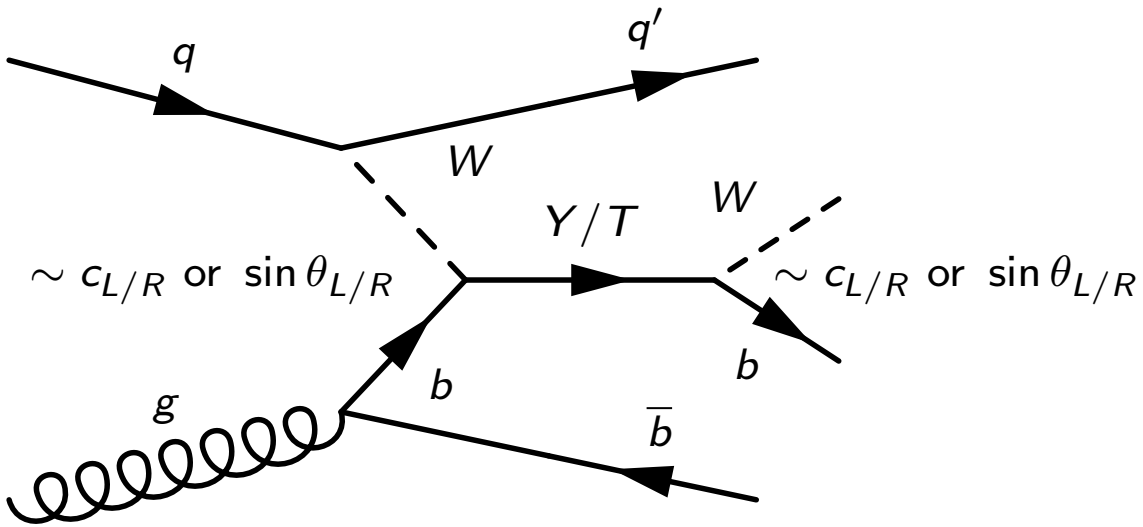
Single production: coupling constraints



Maximally allowed single production cross sections from electro-weak bounds
Phys.Rev. D88.9 (2013) 094010

Principal analysis idea

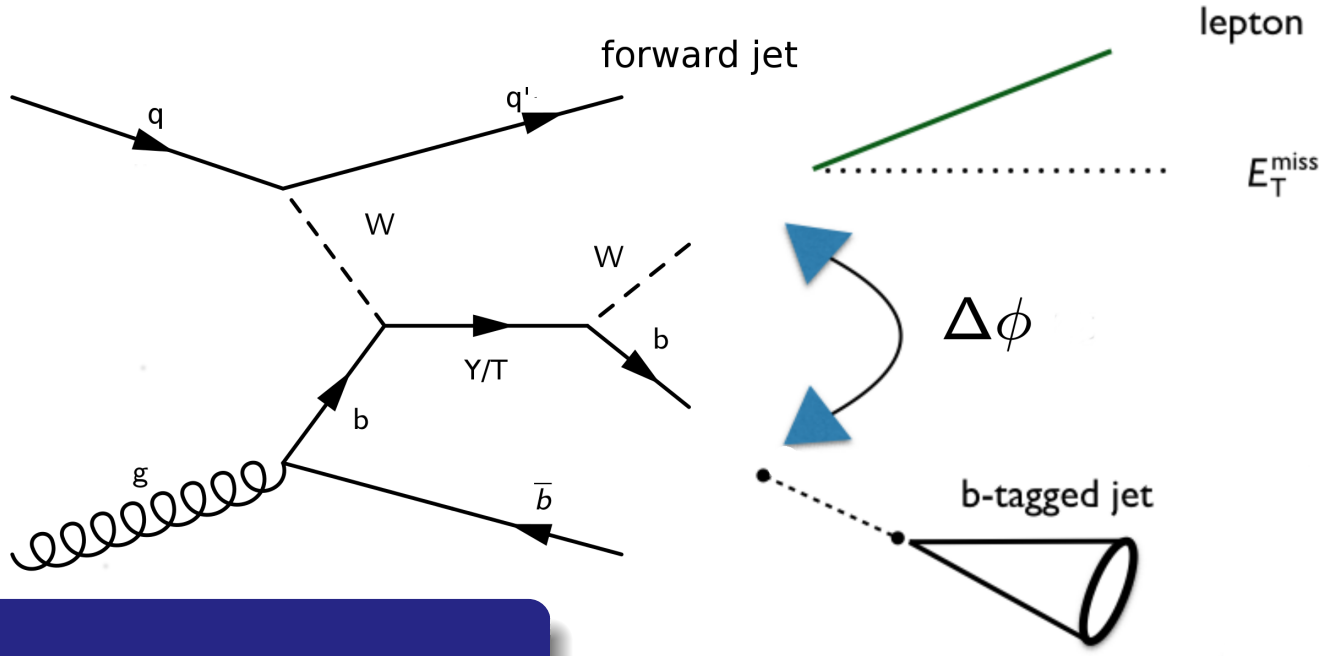
- Singly-produced VLQ $Y^{-\frac{4}{3}}$ and $T^{\frac{2}{3}}$ (2015 data, 3.2 fb^{-1})
- Production: Weak t-channel bW fusion
- Decay process: $Y/T \to Wb$
- $BR(Y \to Wb) = 100\%$; T-singlet: $BR(T \to Wb) \approx 50\%$ at high masses



Measure/set limits on single production cross-section and couplings ($c_{L/R}$, $\sin\theta_{L,R}$)

$c_{L/R}$: Matsedonskyi, Panico and Wulzer, JHEP 12 (2014) 097
$\sin\theta_{R/L}$: Aguilar-Saavedra et al., PRD 88.9 (2013) 094010

Analysis Strategy



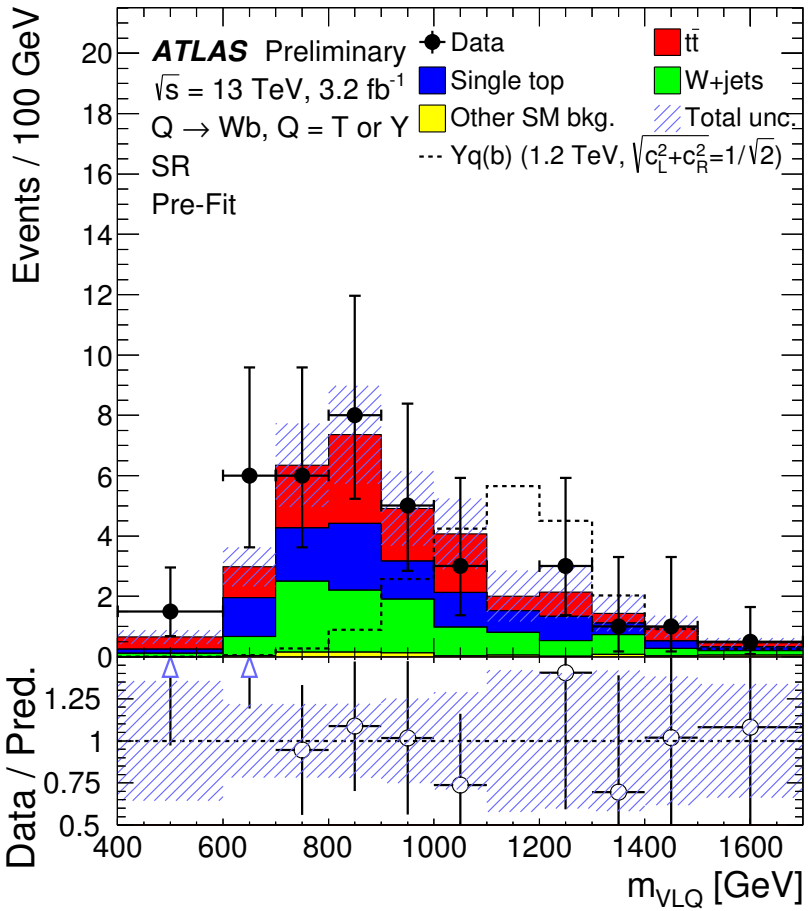
Strategy

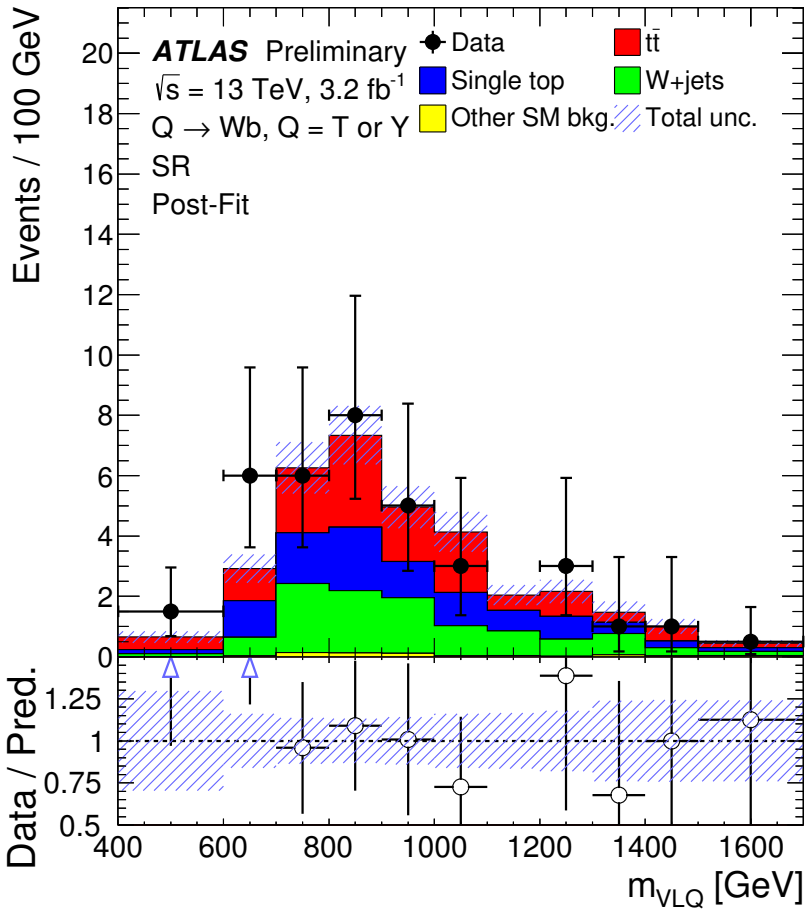
- Exactly one e or μ
- $E_T^{miss} > 120$ GeV
- b-tagged jet ($R = 0.4$) $p_T > 350$ GeV
- Large $|\Delta\phi$(l,b-jet)$|$
- Veto hard central jets ($|\eta| < 2.5$, $p_T > 75$ GeV)
- Forward jet ($2.5 < |\eta| < 4.5$)

Discriminant: $m(\mathrm{VLQ}) = \sqrt{\left(\sum_i^{l,\nu,b} p_i\right)^2}$

Main backgrounds: W+jets, $t\bar{t}$, single top

Signal extraction with profile likelihood fit in m_{VLQ}

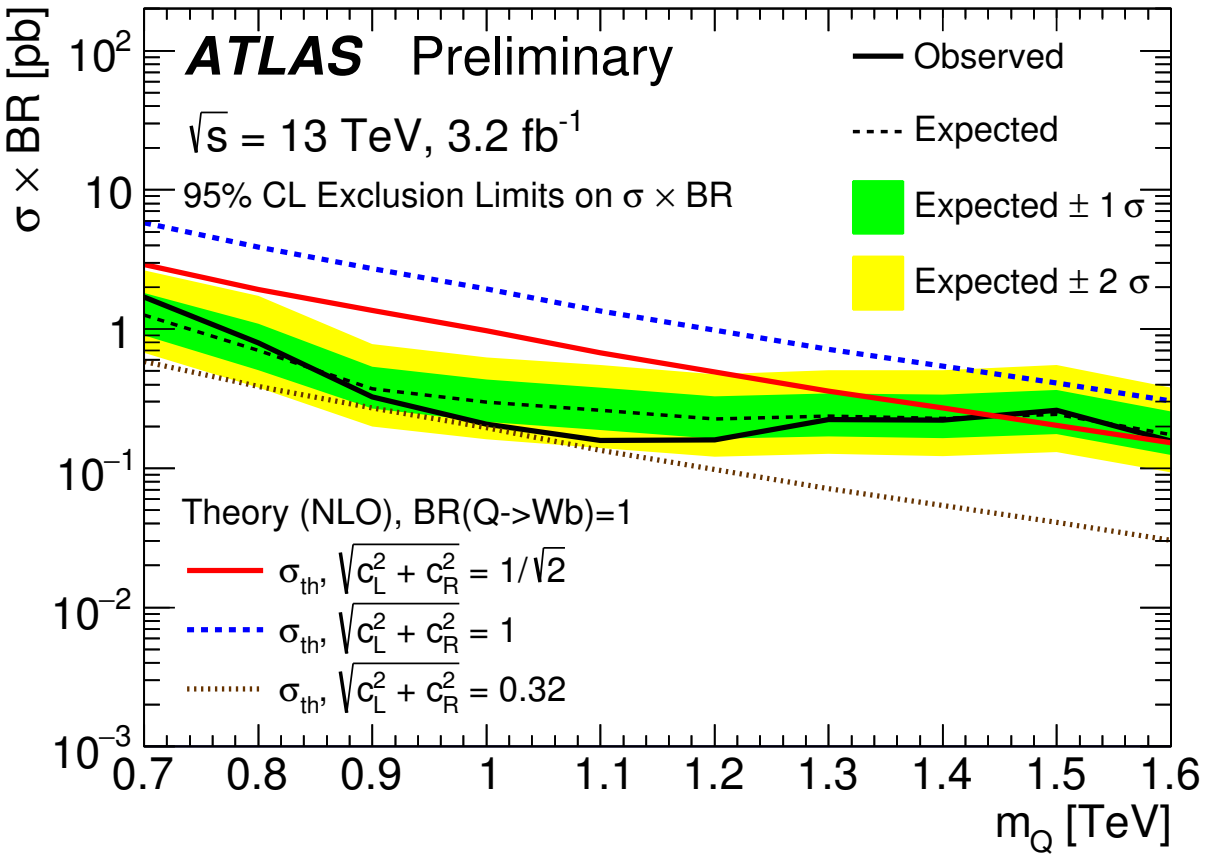




Good data/MC agreement in SR and in ttbar and W+jets CR (backup)
Good data/MC agreement in other distributions too (backup)

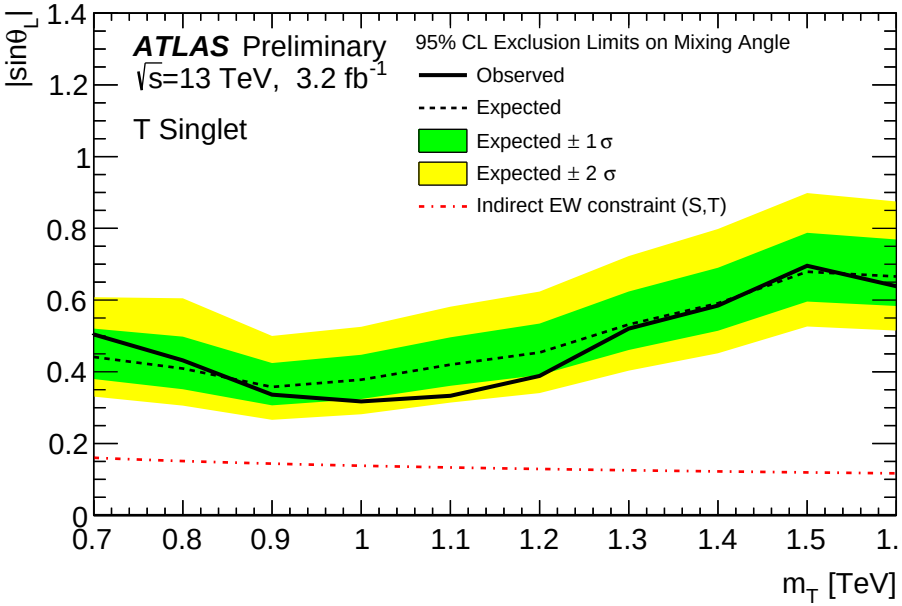
No significant excess observed $\Rightarrow$ limit setting

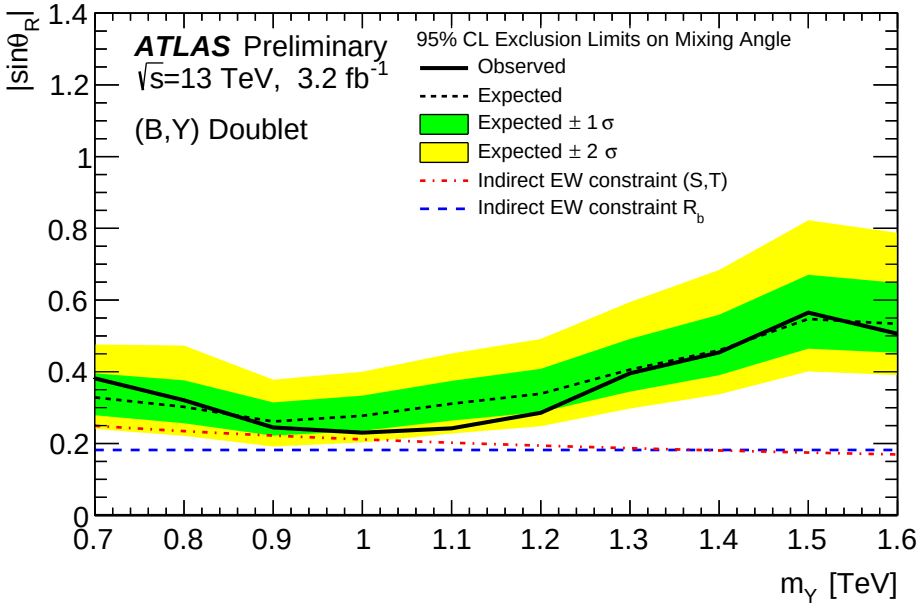
Limit on cross section times branching ratio for Y and T



$m(Y) < 1.44$ TeV excluded at 95% CL for $\sqrt{c_L^2 + c_R^2} = 1/\sqrt{2}$

Limits on couplings





Limits are close to electro-weak precision bounds for Y masses between 900 and 1100 GeV

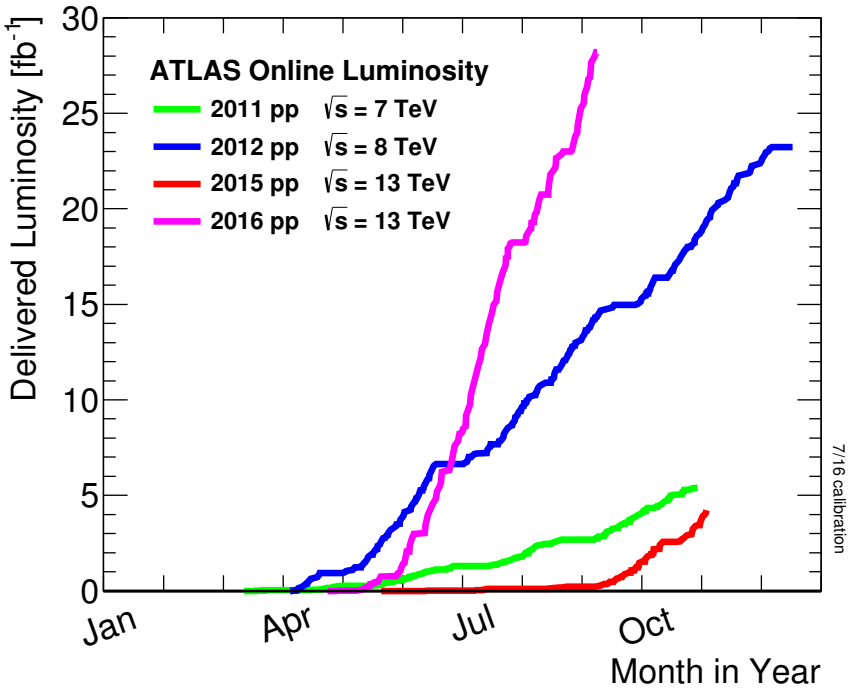
(More coupling limits in backup slides)

Conclusion

Summay

- Search for singly produced Y/T VLQs using 3.2 fb^{-1} ($\sqrt{s} = 13$ TeV)
- Observed limit for Y/T($m = 900$ GeV): $\sigma < 0.33$ pb
- Y mass exclusion for $\sqrt{c_L^2 + c_R^2} = 1/\sqrt{2}$: m(Y)<1.44 TeV
- $\sin\theta_R$ limits for (BY) doublet close to EW precision bounds
- Results are public: ▸ ATLAS-CONF-2016-072

More data is coming in fast
$\Rightarrow$ perhaps VLQs are discovered soon!



Thank you!

Backup

Couplings

Model-independent aproach (JHEP 12 (2014) 097)

$$L_W = \frac{g}{2}\left(c_L \overline{Q}_L \gamma_\mu W^\mu b_L + c_R \overline{Q}_R \gamma_\mu W^\mu b_L\right) + ... \tag{1}$$

$$\Rightarrow \sigma_{\text{sing}}(Q\overline{b}) = \left(c_L^2 + c_R^2\right)\sigma_{\text{Wb}}(M) \tag{2}$$

$$\Rightarrow \sqrt{\frac{\sigma_{limit}}{\sigma_{theory}(\sqrt{c_L^2 + c_R^2} = 1)}} = \sqrt{c_L^2 + c_R^2} \tag{3}$$

Model-specific aproach (PRD 88.9 (2013) 094010)

$$L_W = \frac{g}{\sqrt{2}}\left(V_{Qb}^L \overline{Q}_L \gamma_\mu W^\mu b_L + V_{Qb}^R \overline{Q}_R \gamma_\mu W^\mu b_L\right) + ... \tag{4}$$

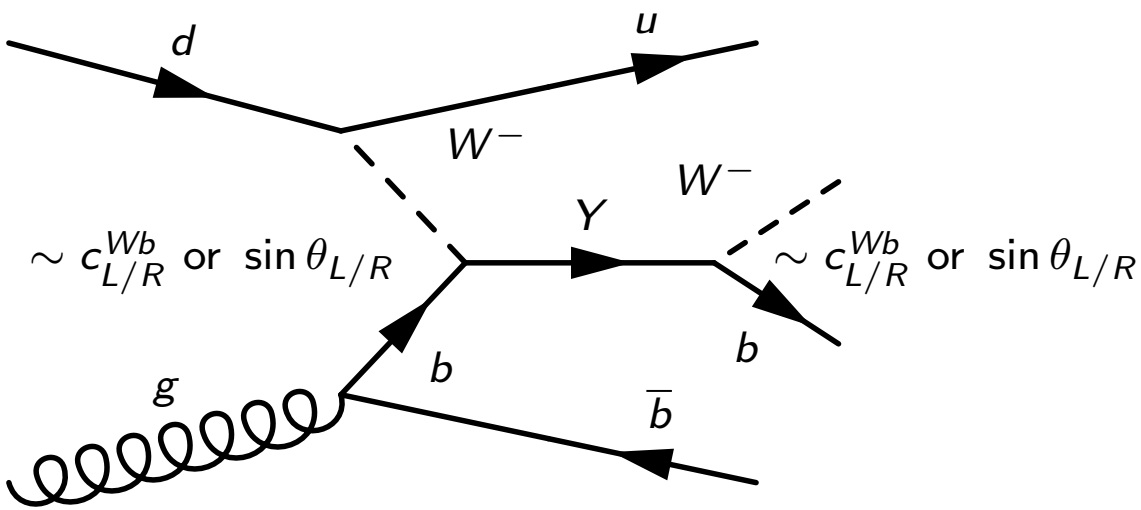
The mixing V depends on the multiplett, e.g. for (BY) it is $V_{Yb}^{R/L} = -\sin\theta_{R/L} e^{i\phi}$

$\Rightarrow$ possible to translate limit on $\sqrt{c_L^2 + c_R^2}$ to model specific mixing parameter $\sin\theta_{R/L}$

Coupling determination in single production

Single production cross section is coupling dependent

Strong Pair production ⇒ mass constraints (less model-dependent)
Electroweak Single production ⇒ coupling constraints (more model-dependent)



Models considered in this analysis:

- Matsedonskyi, Panico and Wulzer, JHEP 12 (2014) 097
  'Model-independent' non-renormalizable Lagrangian w/o specific multiplet structure
  Couplings: $c_{L/R}^{Wb}$
- Aguilar-Saavreda et al., PRD 88.9 (2013) 094010
  Renormalizable Lagrangian, multiplet realizations, also limits from EW precision obs.
  Couplings: $\sin\theta_{L/R}$ with $\sin\theta_L = f(\sin\theta_R)$

Translation: $c_{L/R}^{Wb} = \sqrt{2}\sin\theta_{L/R}$

Systematics

Considered Systematics

- JES/JER
- E_T^{miss}
- Electron / muon
- Lepton SF
- Flavour tagging
- $t\bar{t}$ generator, shower/hadronisation, ISR/FSR
- Single top generator, shower/hadronisation, ISR/FSR
- Luminosity uncertainty: 2.1%
- V+jets and Diboson cross section: 5%
- Single top cross section : 6.8%
- Top pair production cross section: $+5.7\%$ and -5.3%
- Fakes: 50% (flat)
- PDF systematics for W+jets and signals

Selection cuts

Preselection

- Exactly one e or mu (single lepton trigger)
- Number of j4 ($p_T > 25$ GeV): > 1, leading jet (lj): $|\eta| < 2.5$
- Veto events with fwd jets ($2.5 < |\eta| < 4.5$) of $p_T < 40$ GeV
- $E_T^{\text{miss}} > 120$ GeV

Y/T signal region

- lj: b-tagged
- lj: $p_T > 350$ GeV
- veto hard central jet (hj) ($p_T > 75$ GeV) with $\Delta R(\text{hj,lj}) < 1.2$ and $\Delta R(\text{hj,lj}) > 2.7$
- $|\Delta\phi(\text{lep,lj})| > 2.5$
- number of fwd. jet ≥ 1

Wjets control region

Same cuts as in SR except:

- lj: not b-tagged
- lj: $p_T > 250$ GeV

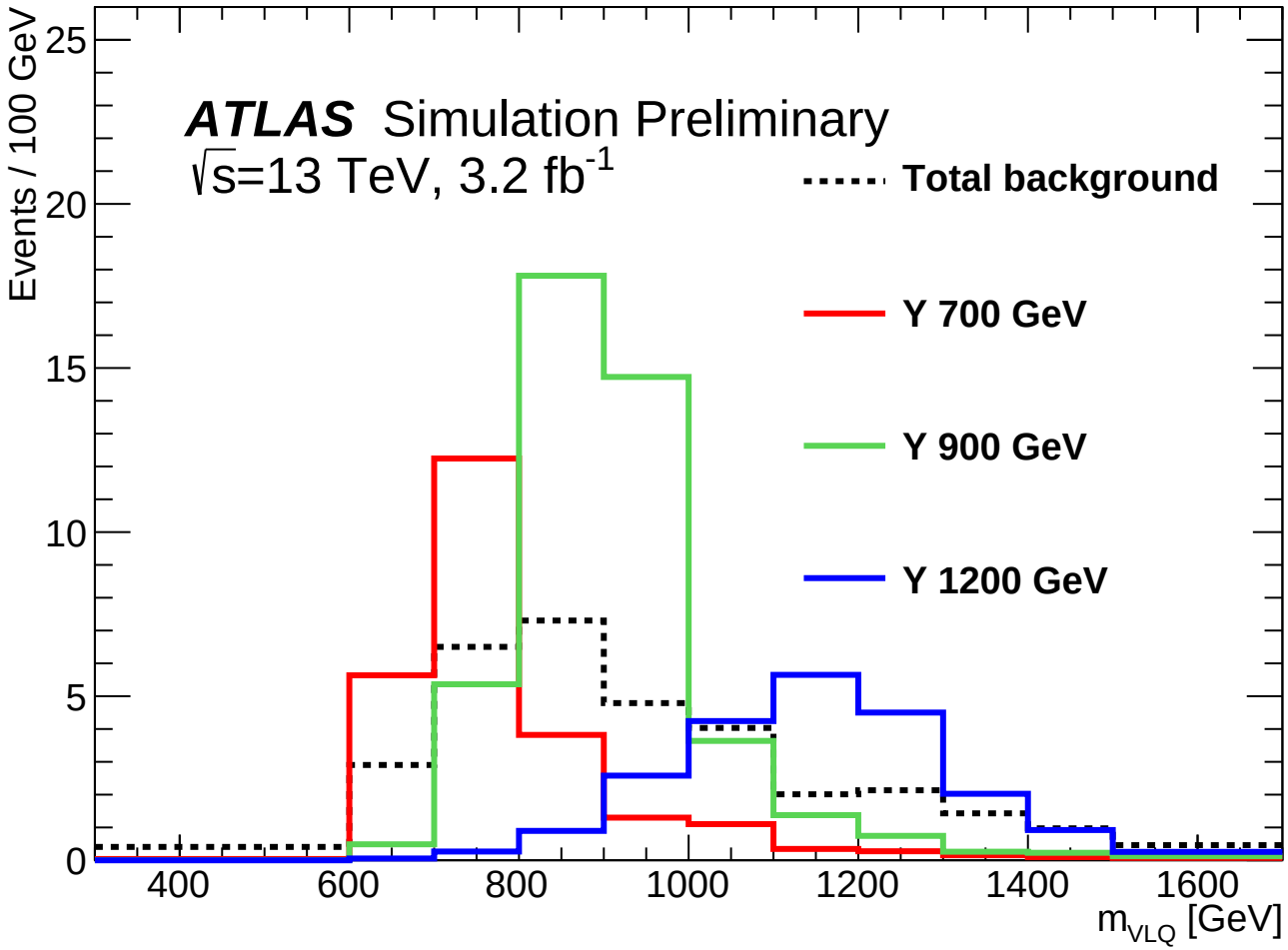
ttbar control region

Same cuts as in SR except:

- lj: $p_T > 200$ GeV
- Require at least one hj with $\Delta R(\text{hj,lj}) < 1.2$ or $\Delta R(\text{hj,lj}) > 2.7$

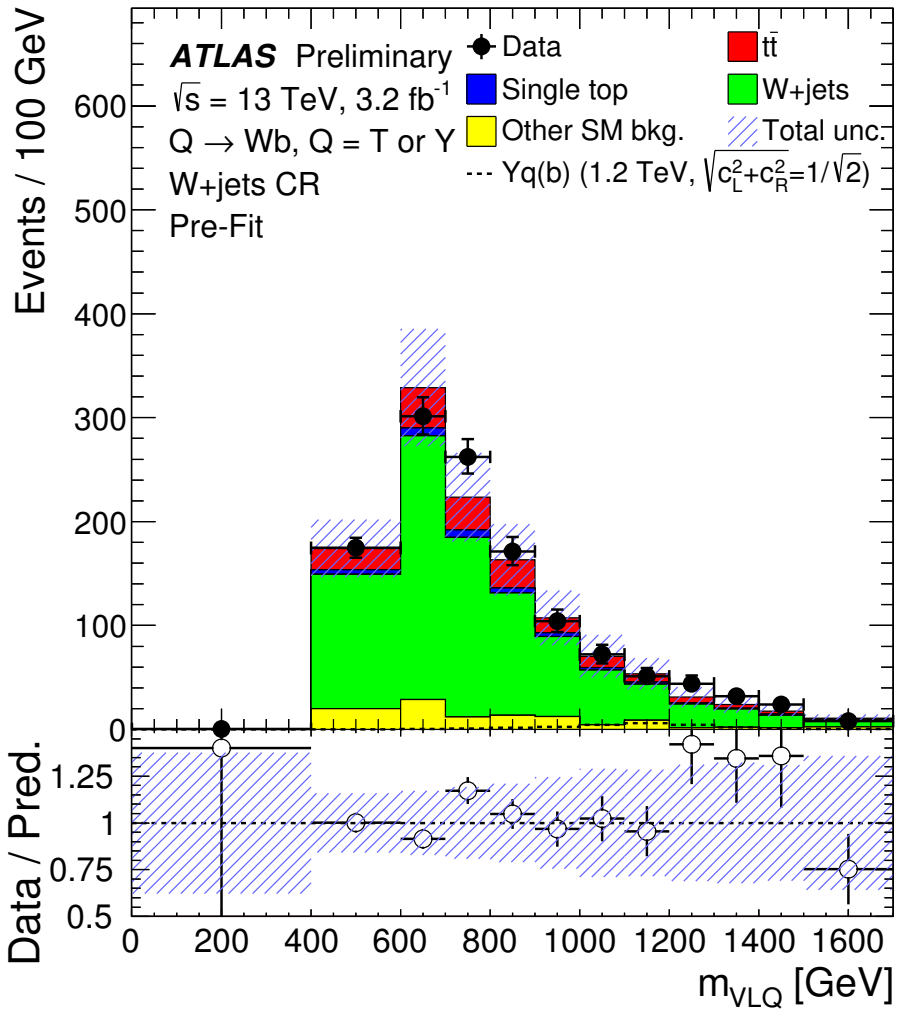
Cuts are optimized to obtain maximal $S/\sqrt{B}$ for $m(Y) = 900$ GeV in SR

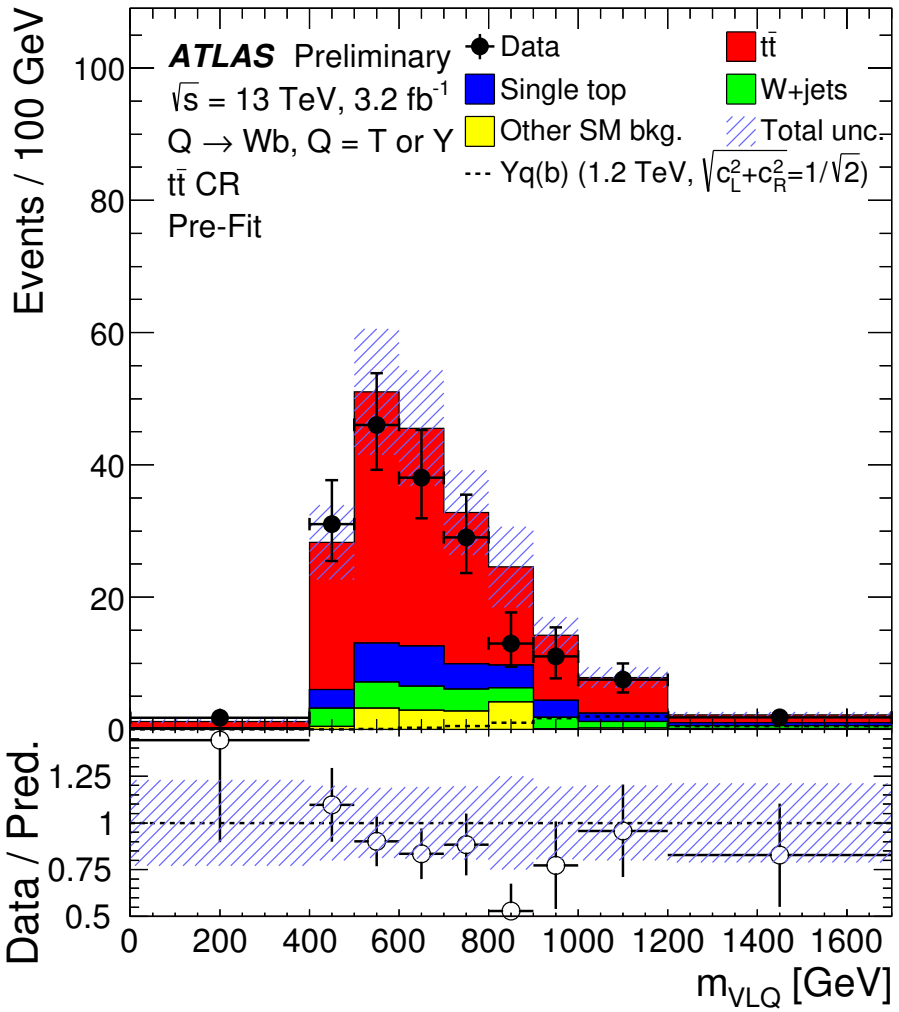
Signals in signal region



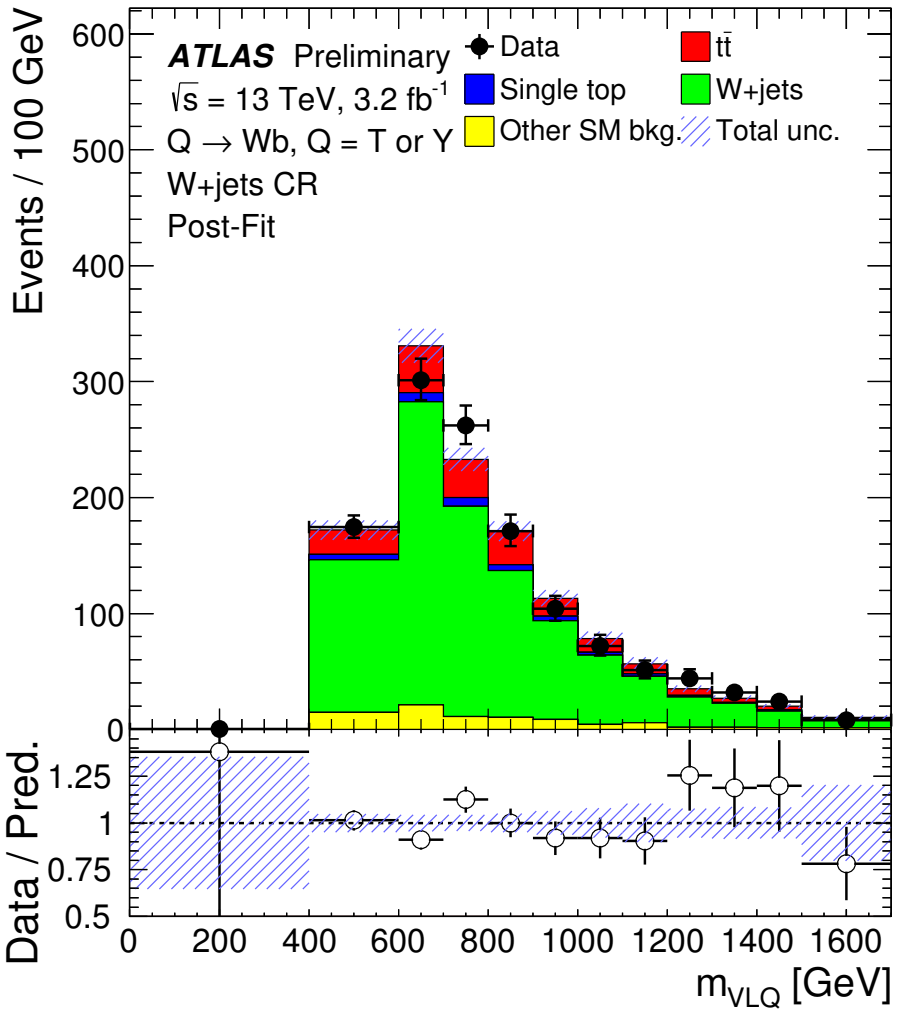
Assumed coupling for all three signals is $\sqrt{c_L^2 + c_R^2} = 1/\sqrt{2}$

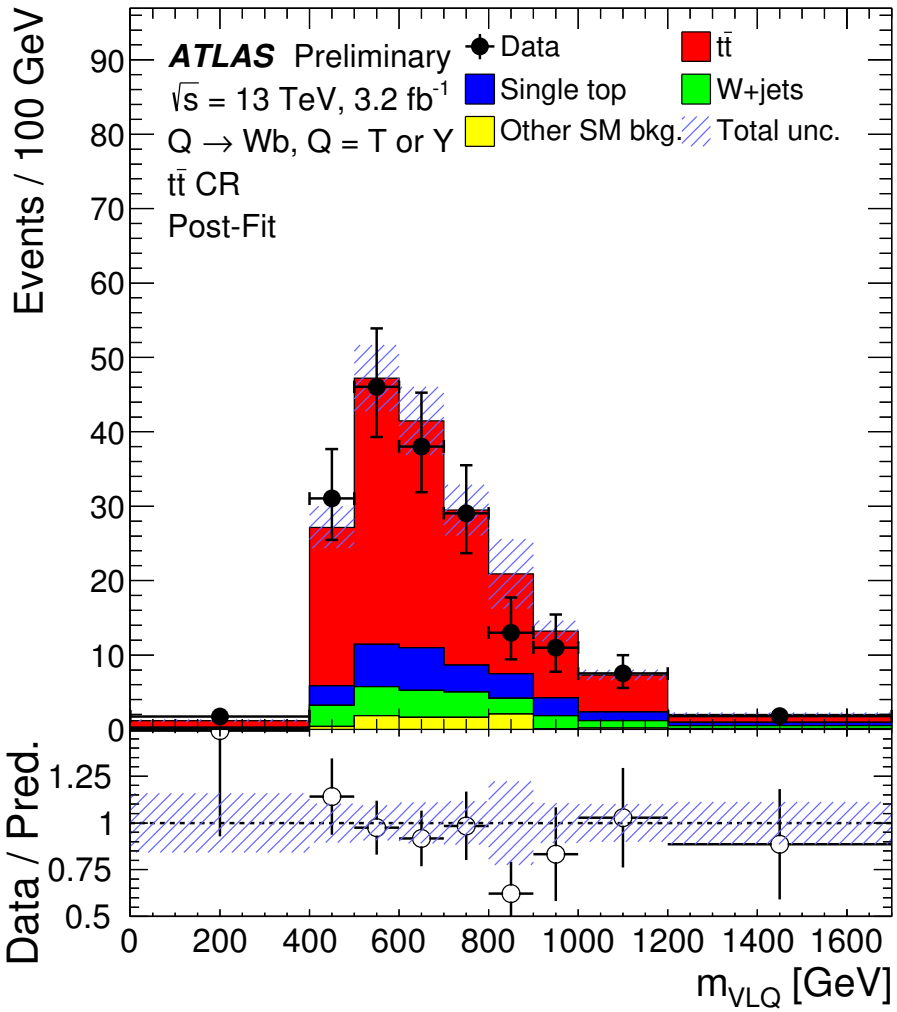
Control regions - Data/MC - Pre-fit





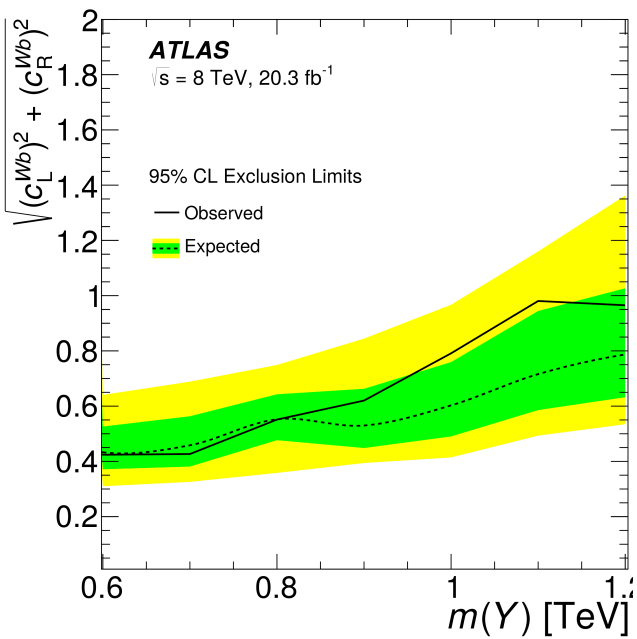
Control regions - Data/MC - Post-fit



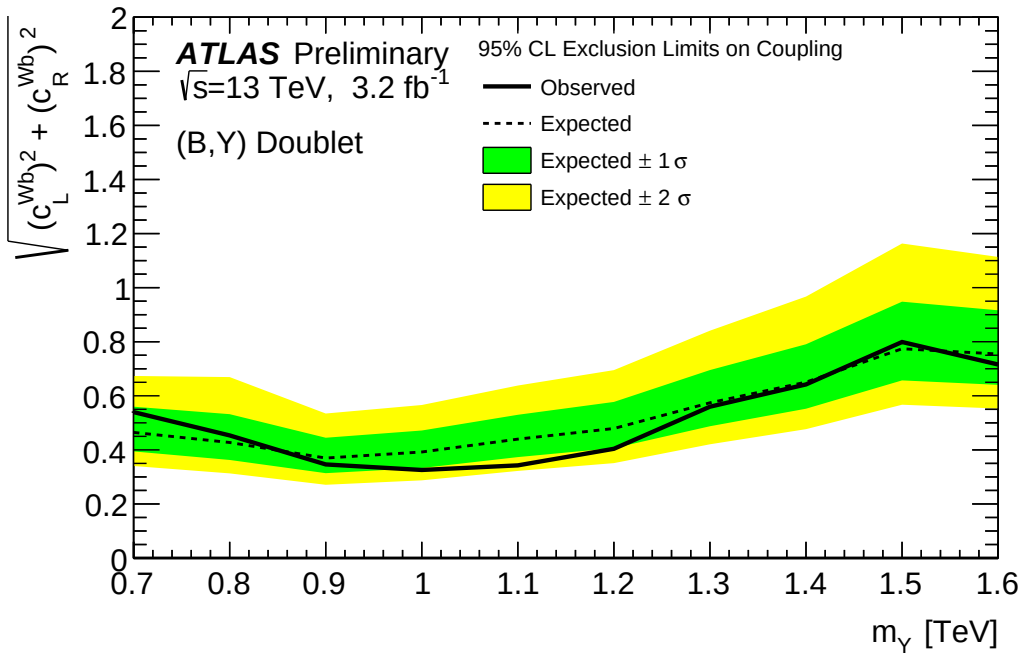


Limit on YbW coupling ('model independent')

8 TeV

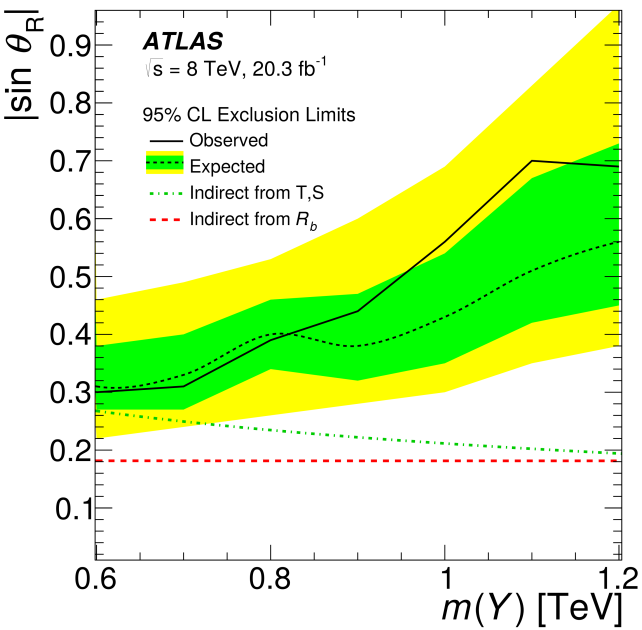


13 TeV

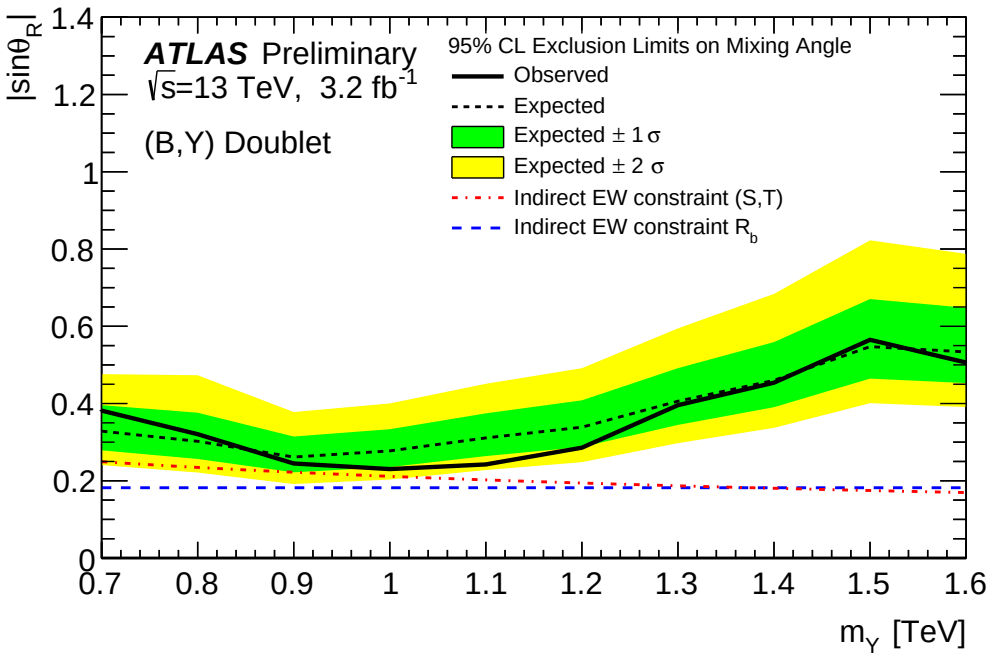


Limit on YbW coupling in a BY-doublet model

8 TeV

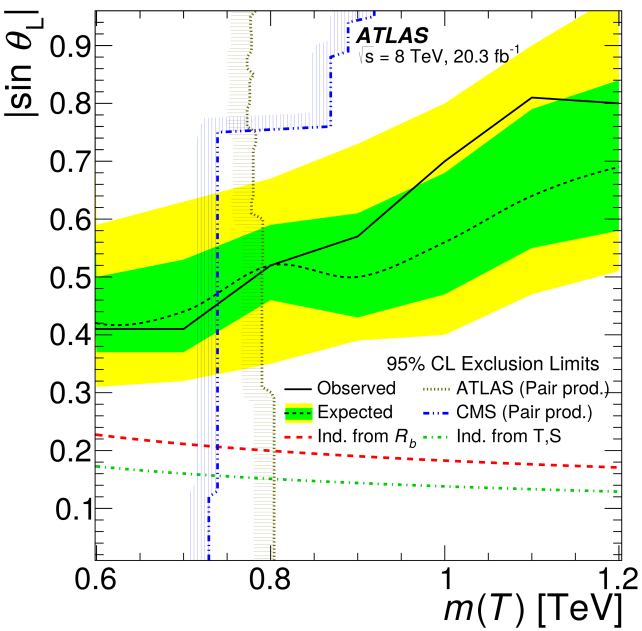


13 TeV

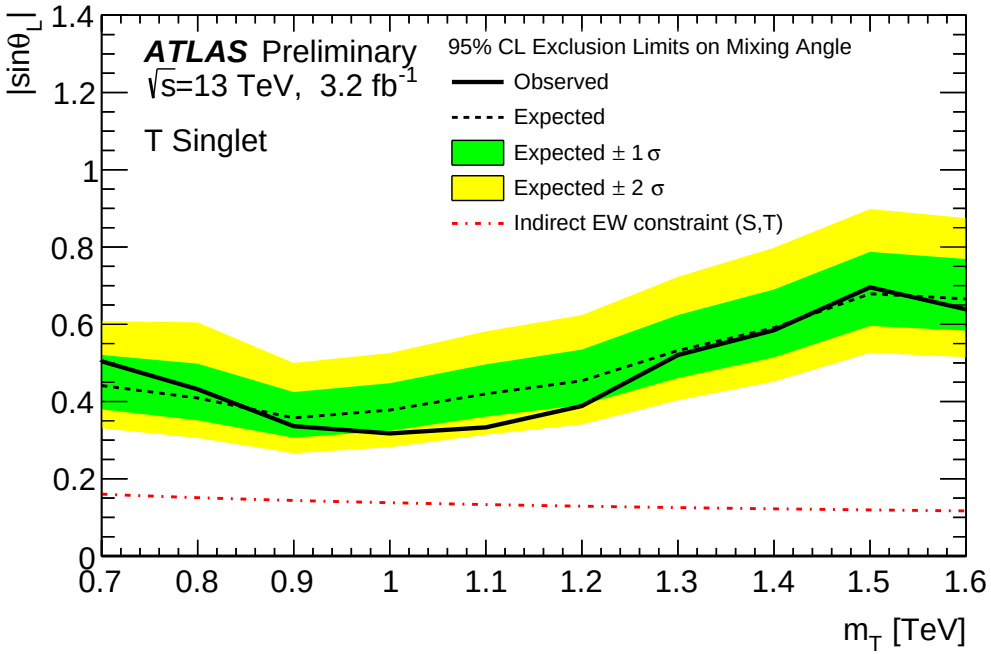


Limit on TbW coupling (for a T singlet)

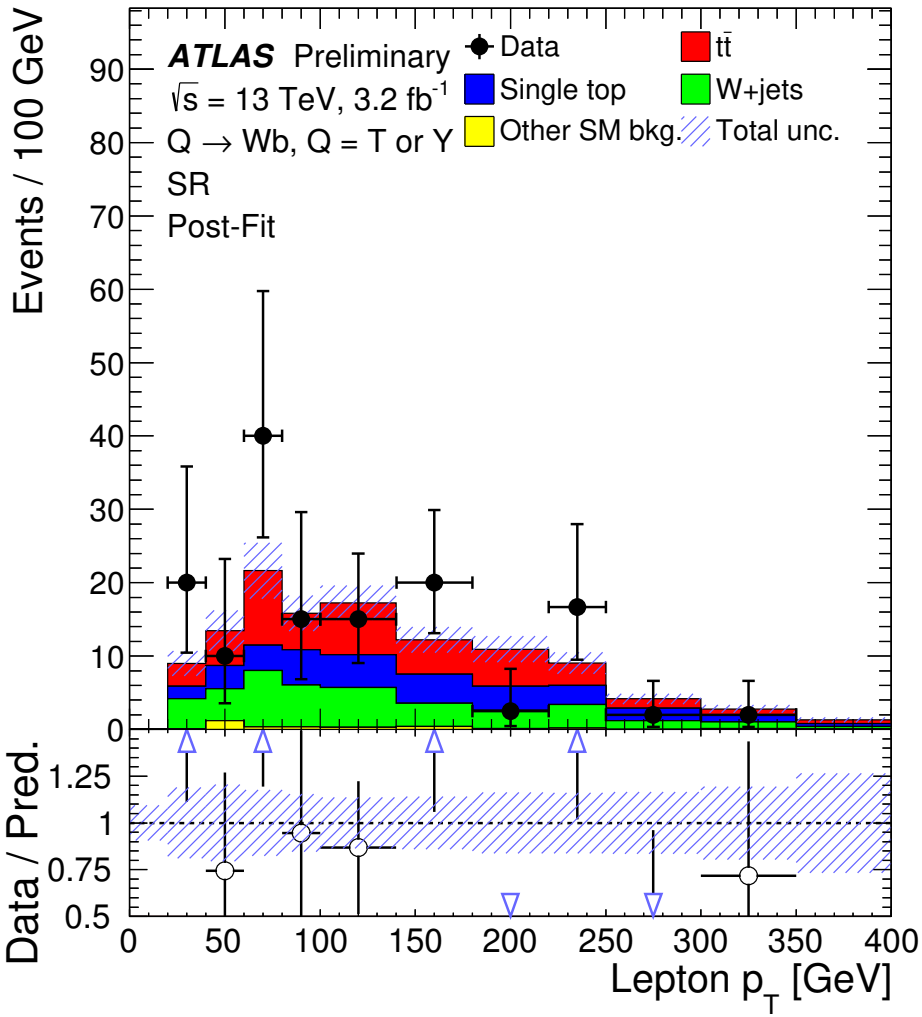
8 TeV

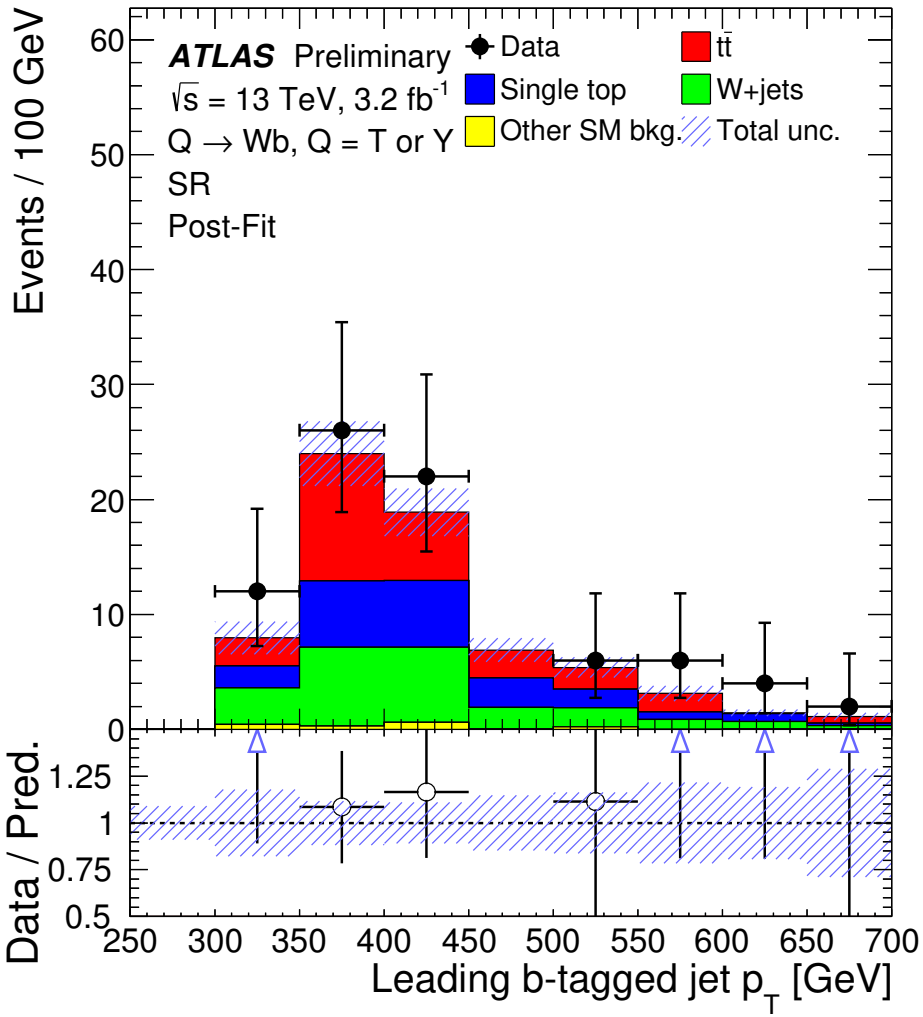


13 TeV



Kinematic variabels - I





Kinematic variabels - II