Single Top Production

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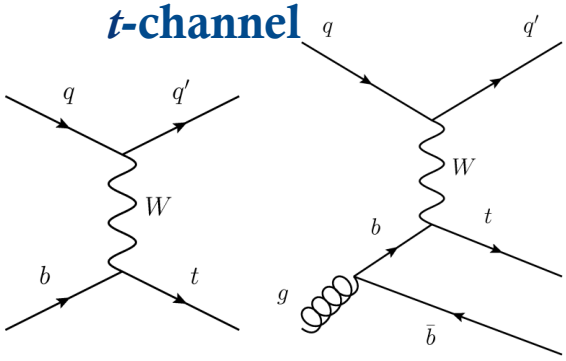
for the ATLAS, and CMS Collaborations
PANIC2014, Hamburg

Outline

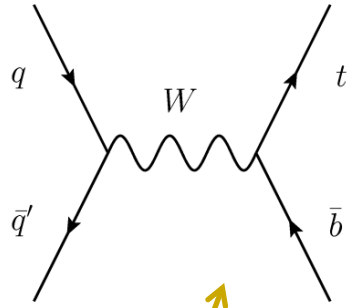
- Motivation and General selection requirements
- *t*-channel
  - Couplings derived from t-channel events
- Associated W+t production
  - b* search (in backup)
- $|V_{tb}|$
- s-channel
  - W' search
- FCNC searches (if time permits)

Production Modes & Observables

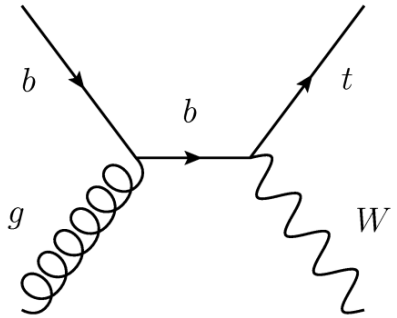
t-channel



s-channel



Wt-channel

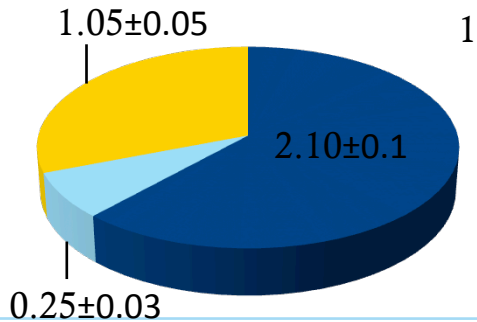


What can we measure?

- Cross-sections for each channel (σ_t, σ_s, and σ_{Wt})
- Matrix Element / Couplings (V_{tb}, anomalous)

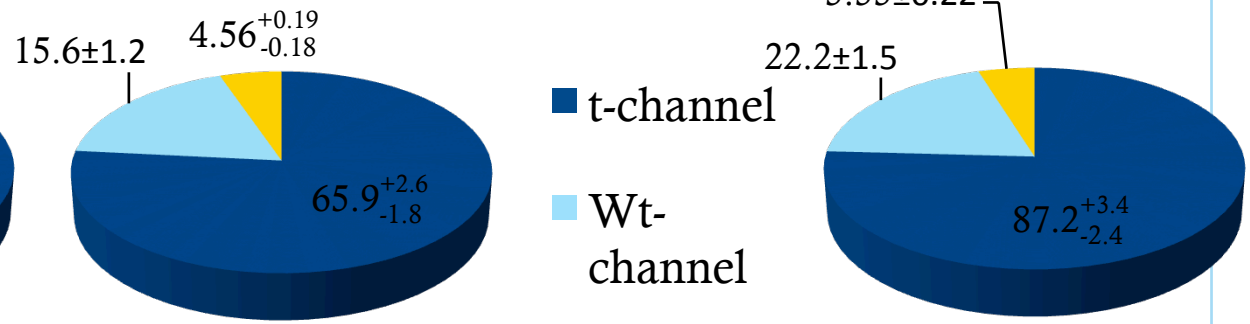
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

TeVatron (1.96TeV)



Haefner, arXiv:1210:7813 [hep-ex]

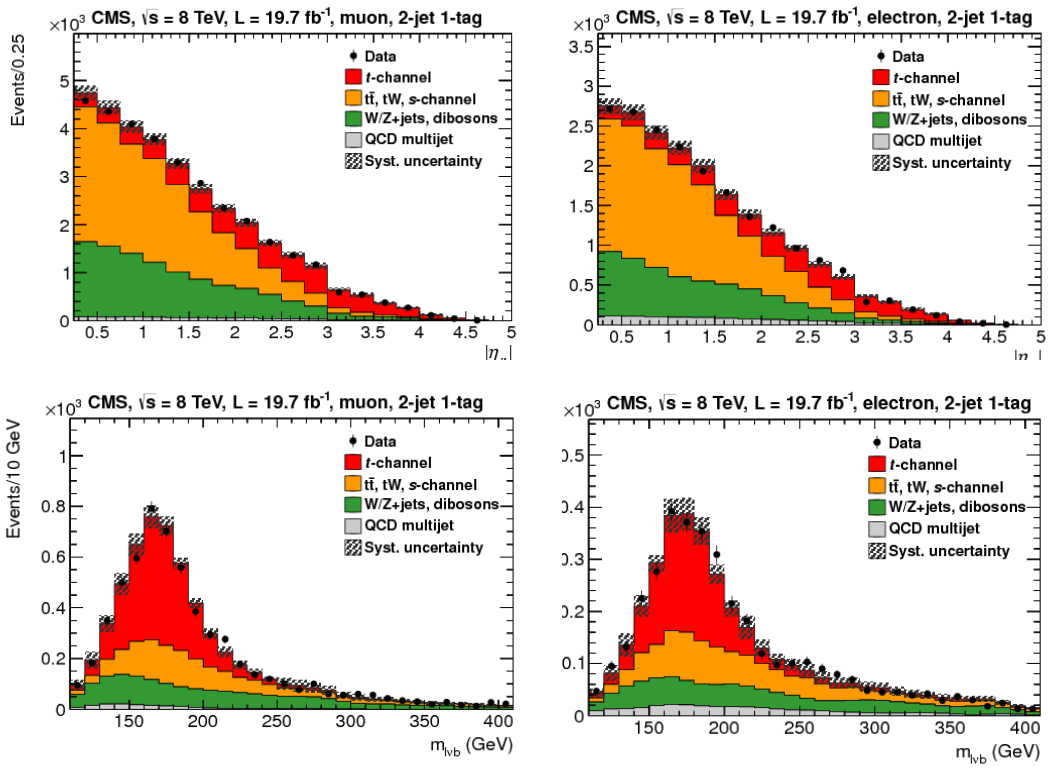
LHC: 7 TeV (L), 8TeV (R)



Kidonakis, arXiv:1210:7813 [hep-ph]

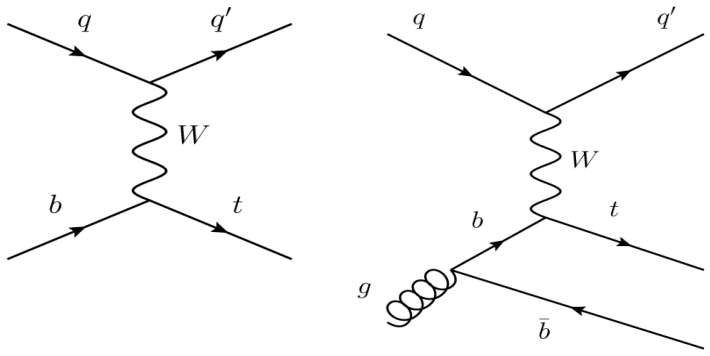
General Selection Criteria

- Leptonic W decay
  - Single e and μ triggers, p_T, |η|, and isolation cuts
  - Missing E_T, transverse mass
- A few analyses use hadronic W decay
- Jets:
  - p_T, |η| cuts
  - b-tagging
- MultiVariateAnalysis
  - Neural Net, Boosted Decisions Tree



J. High Energy Phys. 06 (2014) 090
arXiv:1403.7366
CERN-PH-EP-2014-032

t-Channel Single Top Production

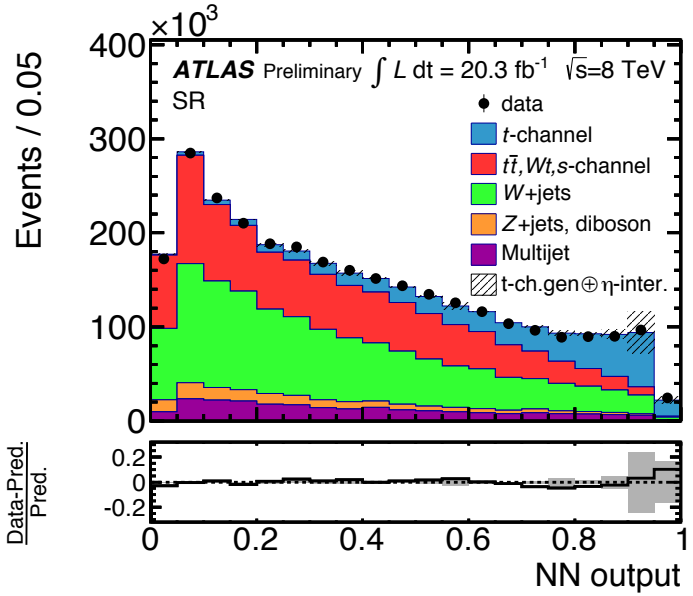


Dominant contribution to single-top production

Can extract $|V_{tb}|$ from cross section.
Polarized top quark,
Probe for anomalous couplings.

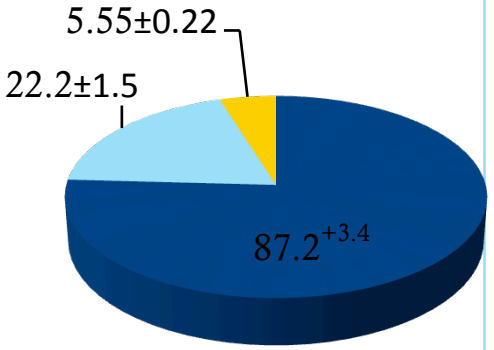
t-channel's high-p_T forward jet helps identification

Dominant backgrounds: $t\bar{t}$ production, W+jets



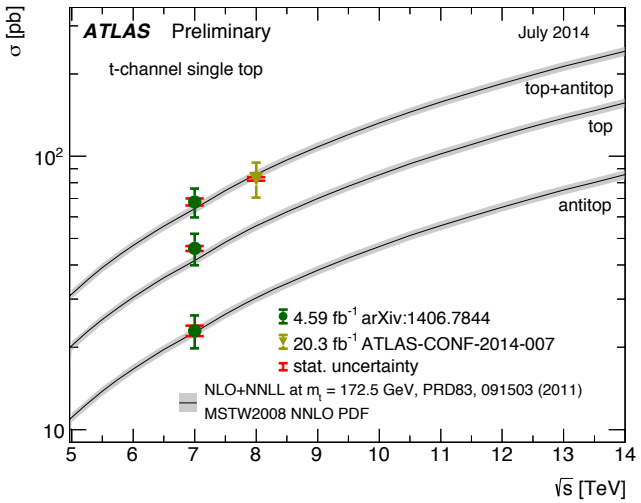
ATLAS-CONF-2014-007

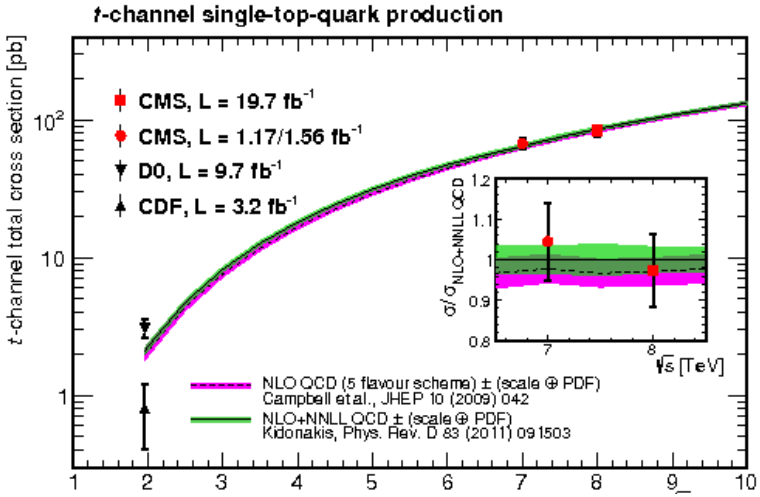
LHC (8 TeV)



Kidonakis, arXiv:1210:7813 [hep-ph]

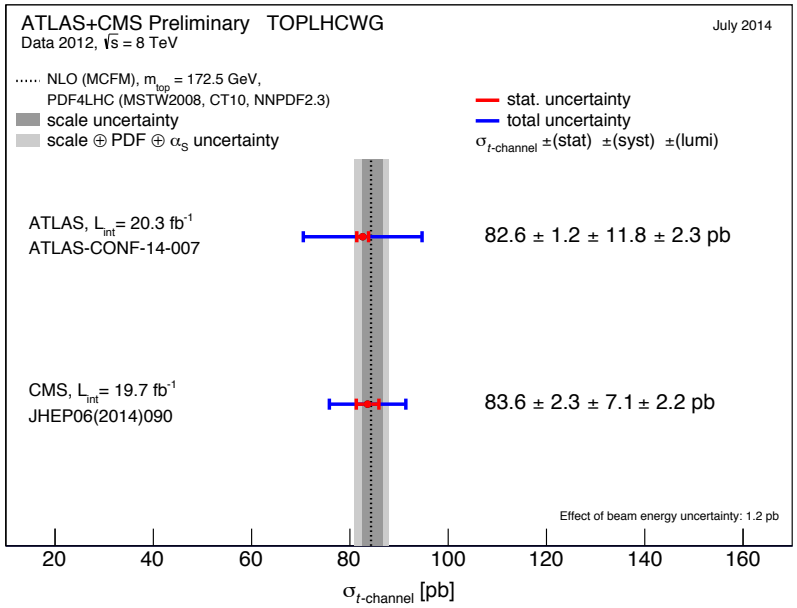
Extracted Cross Sections





CMS: JHEP 12 (2012) 035 (7-TeV)
JHEP 06 (2014) 090 (8-TeV)
ATLAS: arXiv:1406.7844 (7-TeV)
ATLAS-CONF-2014-007 (8-TeV)

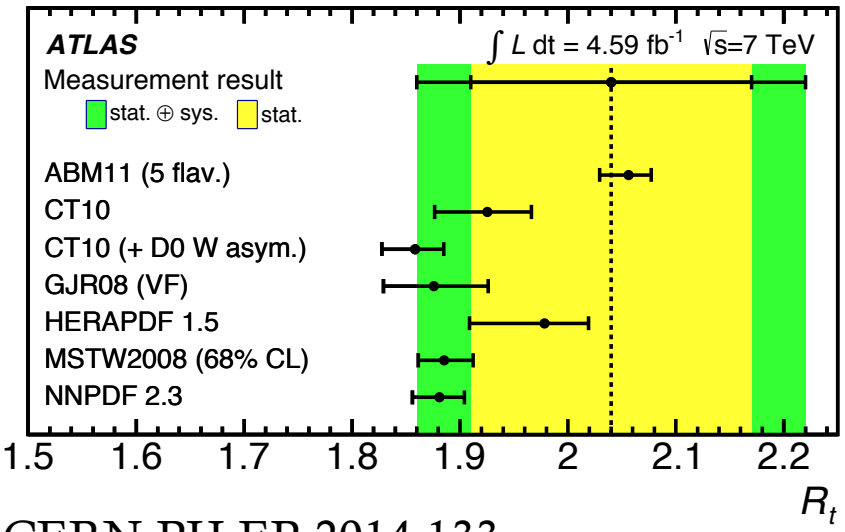
Largest Systemactics, 8TeV:
CMS: t-channel generator,
W+h.f background
ATLAS: t-channel generator,
JES η -intercalibration



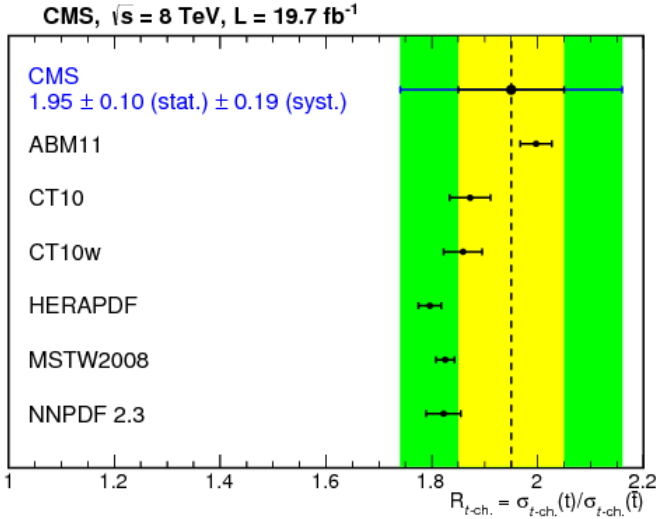
Ratio of top anti-top Cross-Section

$R_t = \sigma_t/\sigma_{\bar{t}}$ Sensitive to PDFs and new physics.

Many systematics cancel



CERN-PH-EP-2014-133
arXiv:1406.7844
Submitted to Phys Rev D.



J. High Energy Phys. 06 (2014) 090
CERN-PH-EP-2014-032
arXiv:1403.7366

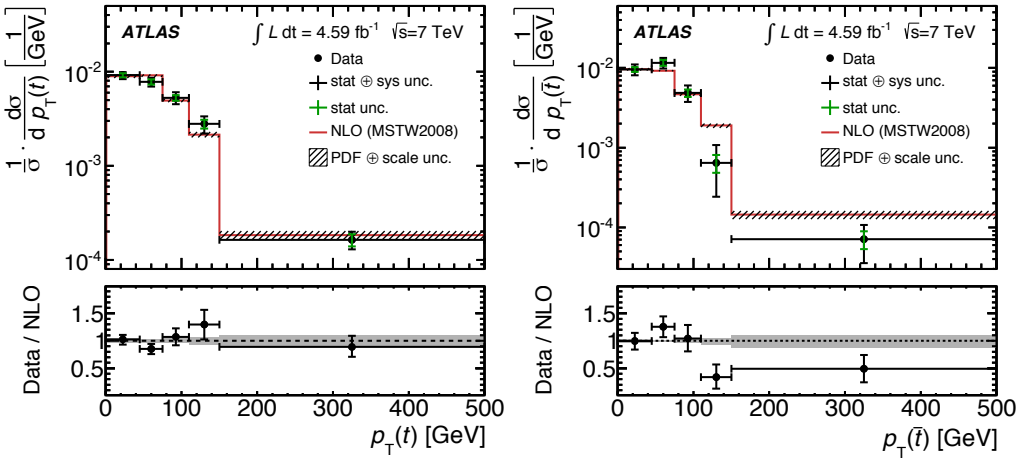
Largest systematics:

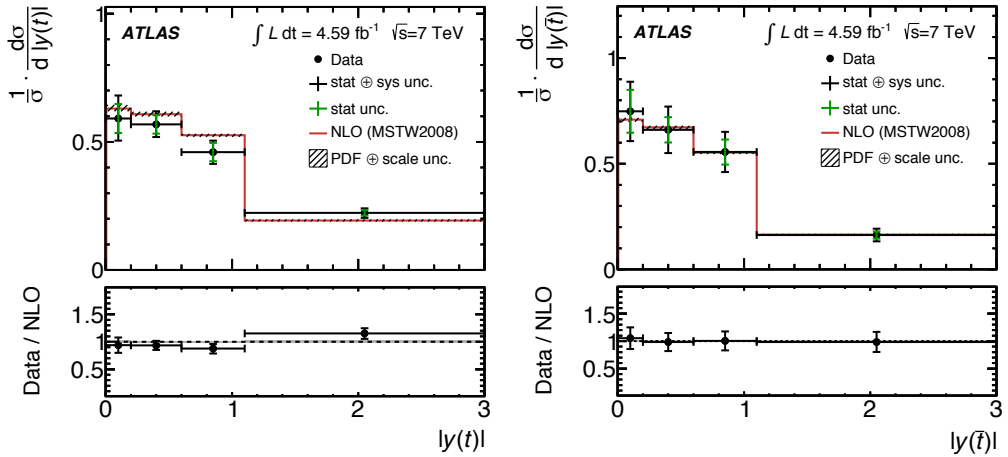
MC statistics, PDF variation

PDF variation, Signal modeling

Differential Cross Sections

t $\bar{t}$





ATLAS: arXiv:1406.7844 (7-TeV)

Differential cross sections also measured vs p_T and $|y|$, for top and anti-top separately.

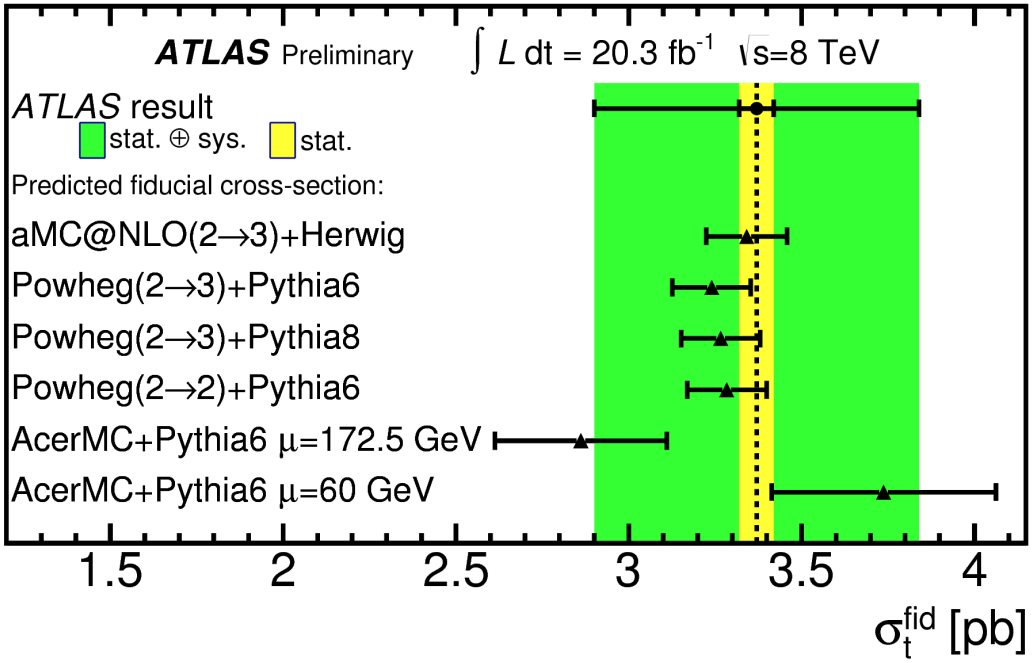
Normalized differential cross sections reduce systematic uncertainties.

NLO predictions consistent with measurements.

t-Channel Fiducial Cross section

Reduce uncertainties due to generator dependent extrapolation to total cross section.

Fiducial region defined in terms of (truth) particle quantities
to measure the x-section in a phase space close to the phase space of the reconstructed and selected data events (see backup).



ATLAS-CONF-2014-007

$\sigma_{fid} = 3.37 \pm 0.05(stat.) \pm 0.47(syst.) \pm 0.09(lumi.)$ pb

Main uncertainties: JES η -intercalibration, t-channel generator.

t-Polarization: CMS

If Θ_l is the angle between the spectator jet and the lepton in the top-frame,

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{1}{2} + A_l \cos\theta_l$$

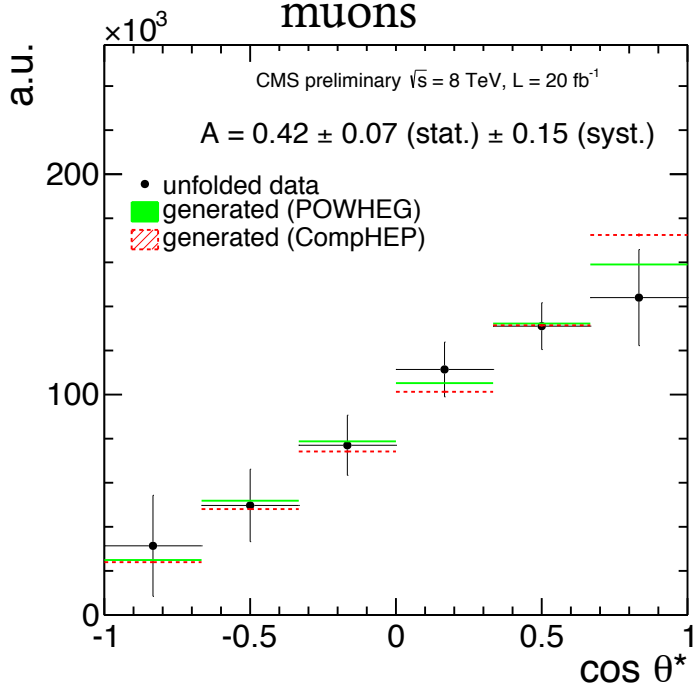
$A_l = 1/2\ P\ \alpha_l$

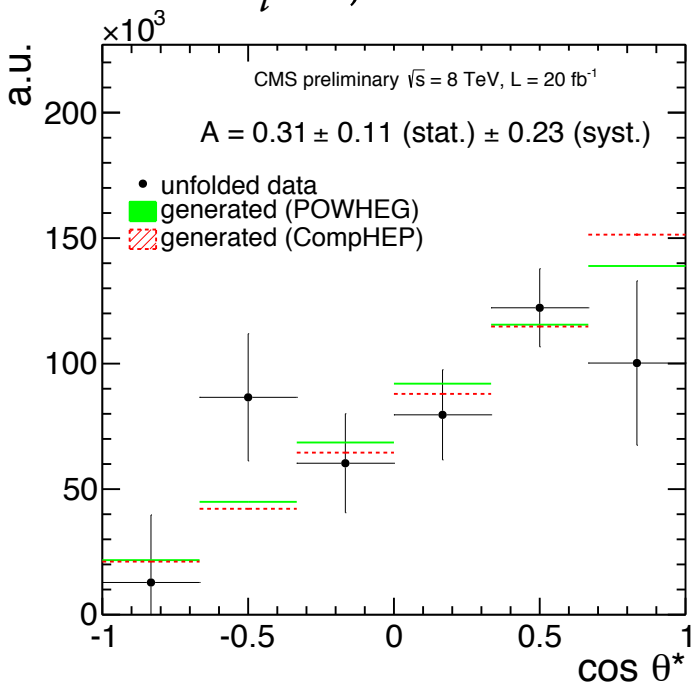
CMS PAS TOP-13-001

$A_l = 0.41 \pm 0.06 \pm 0.16$ (combined)

In SM $\alpha_l = 1$, $\Rightarrow P = 0.82 \pm 0.12 \pm 0.32$

muons





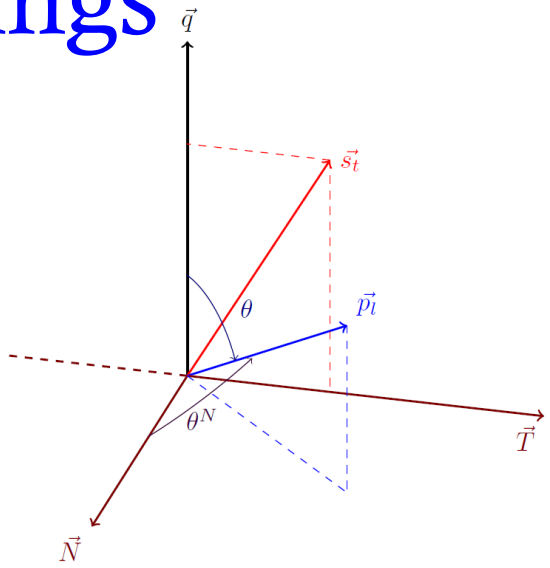
electrons

Anomalous Couplings

CMS measures decay angle of lepton in *W* rest-frame w.r.t. *W* in *t* rest frame in t-channel sample.
ATLAS measures forward backward asymmetry of lepton along perpendicular direction (*N*).

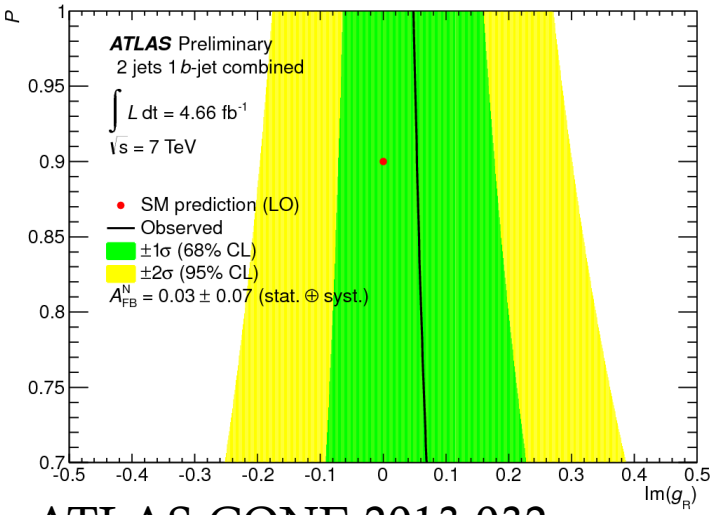
$$\vec{N} = \vec{s} \times \vec{q}$$

Limits set on anomalous couplings.

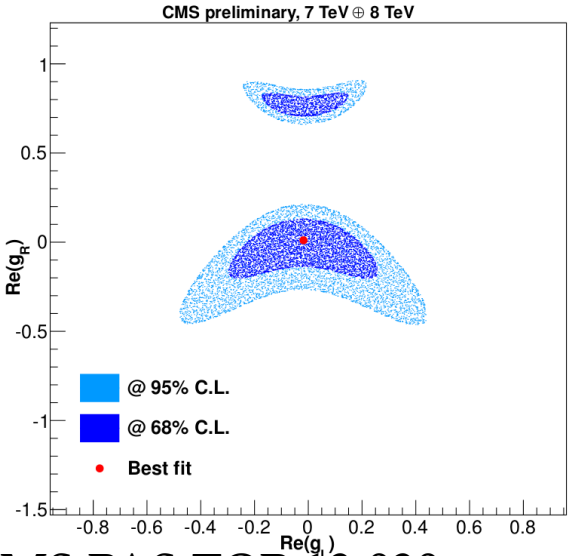


$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_{\mathrm{L}}P_{\mathrm{L}} + V_{\mathrm{R}}P_{\mathrm{R}}\right)tW^{-}_{\mu} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_{\mathrm{L}}P_{\mathrm{L}} + g_{\mathrm{R}}P_{\mathrm{R}}\right)tW^{-}_{\mu} + \mathrm{h.c.}$$

CMS analysis sensitive to real part of anomalous couplings.
ATLAS analysis sensitive to imaginary part.



ATLAS-CONF-2013-032

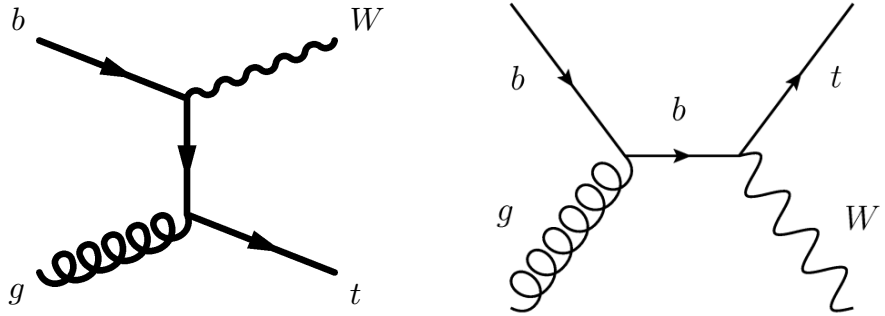


CMS-PAS-TOP-12-020

Associated *W-t* Production

Dominant background is $t\bar{t}$

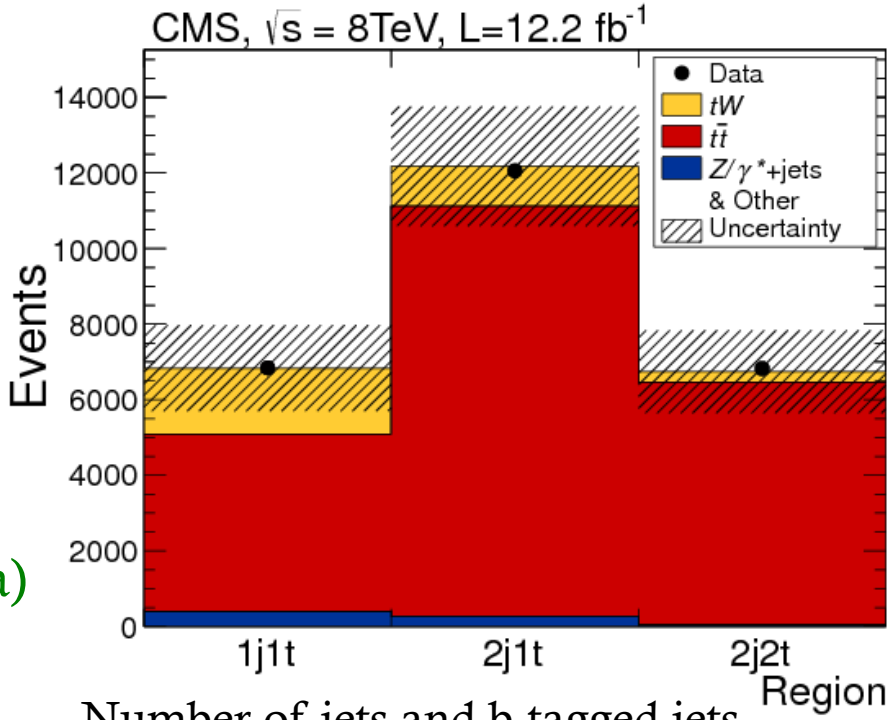
In fact, at NLO, the signal $tW\bar{b}$,
Mixes with $t\bar{t}$
Theoretical calculation removes resonant diagrams.



Require exactly 2 leptons, one or two jets and b-tagging.
1-jet tagged has less background.

Observation:
CMS: σ_{tW}=23.4 ± 5.4 pb (6.1 sigma)
PRL 112 (2014) 231802 (8-TeV)

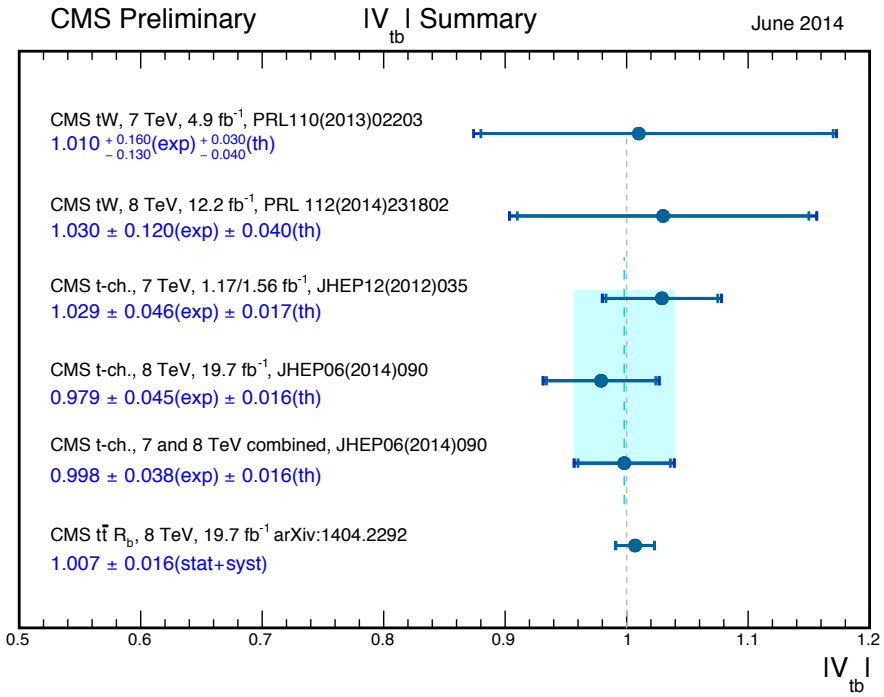
ATLAS: σ_{tW}=27.2±5.8 pb (4.2 sigma)
ATLAS-CONF-2013-100 (8 TeV)



Number of jets and b-tagged jets

Extracted $|V_{tb}|$

CMS



ATLAS

$|V_{tb}| = 1.03^{+0.16}_{-0.19}$ Wt 7-TeV

Phys. Lett. B 716 (2012) 142-159

$|V_{tb}| = 1.10 \pm 0.12$ Wt 8-TeV

ATLAS-CONF-2013-100

$|V_{tb}| = 1.02 \pm 0.07$ t-ch 7-TeV

arXiv:1406.7844

$|V_{tb}| = 0.97^{+0.09}_{-0.10}$ t-ch 8-TeV

ATLAS-CONF-2014-007

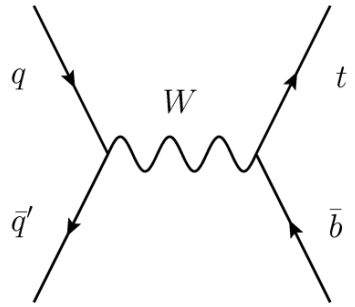
s-Channel Single-Top Production

Feb. 2014: D0+CDF announced first observation of single-top-quark production in the s-channel by combining results from both experiments.

$$\sigma = 1.24^{+0.26}_{-0.24}\ \text{pb}$$

(6.3 sigma observation)

Phys. Rev. Lett. 112, 231803 (2014)
arXiv:1402.5126 [hep-ex]



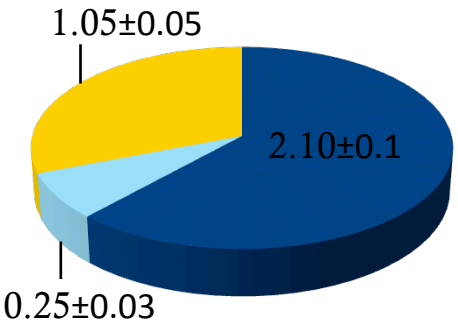
Best LHC result: CMS 8-TeV data

$$6.2^{+8.0}_{-5.1}\ \text{pb}$$

<11.5 @95% CL
CMS-PAS-TOP-13-009

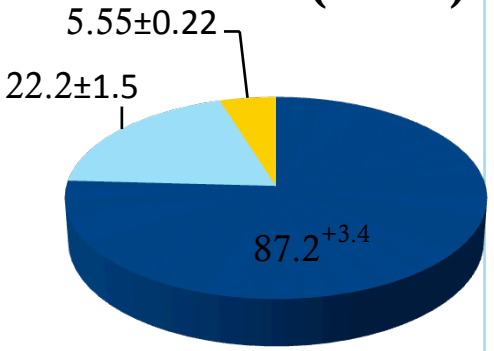
ATLAS 7-TeV: < 26.5 pb
ATLAS-CONF-2011-118

TeVatron (1.96TeV)



Haefner,
arXiv:1210:7813 [hep-ex]

LHC (8 TeV)

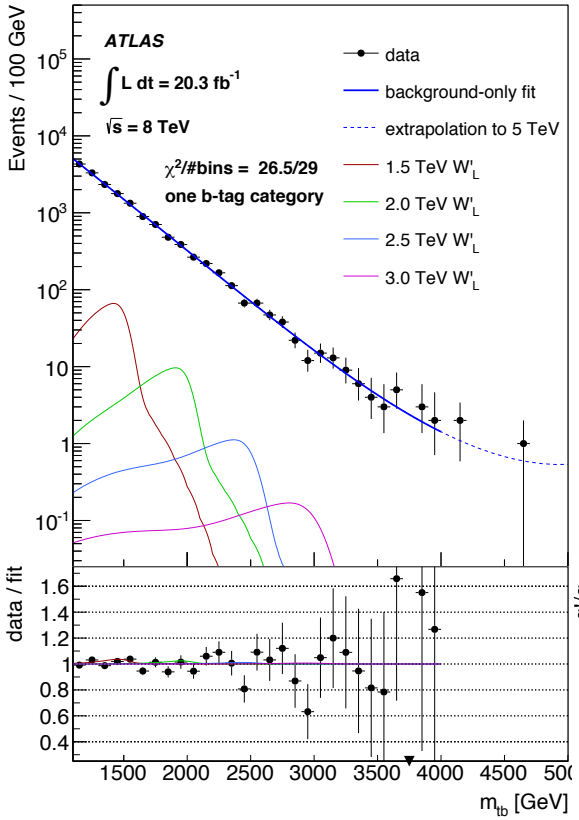


Kidonakis,
arXiv:1210:7813 [hep-ph]

W' Search

In addition to the SM s-channel search, one can look for a heavier object.

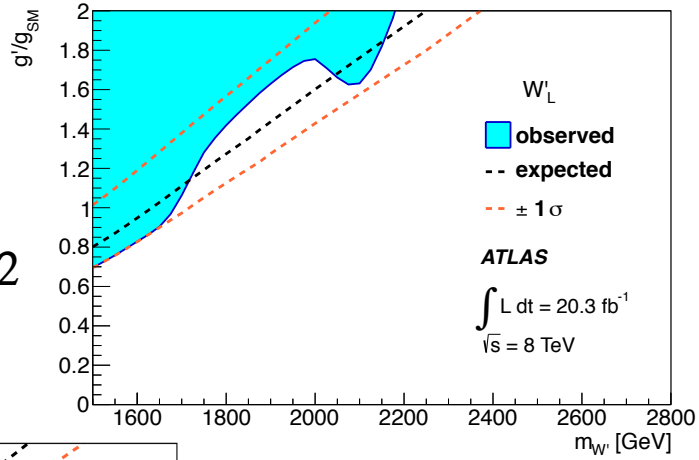
$$W' \rightarrow t\bar{b} \rightarrow jjb\bar{b}$$

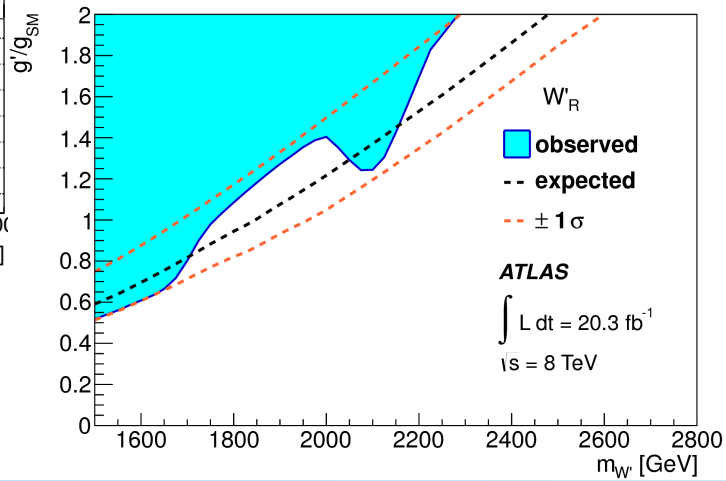


One tagged b-jet

Limits are set on W' mass/couplings

CERN-PH-EP-2014-152
arXiv:1408.0886
submitted to EPJ C

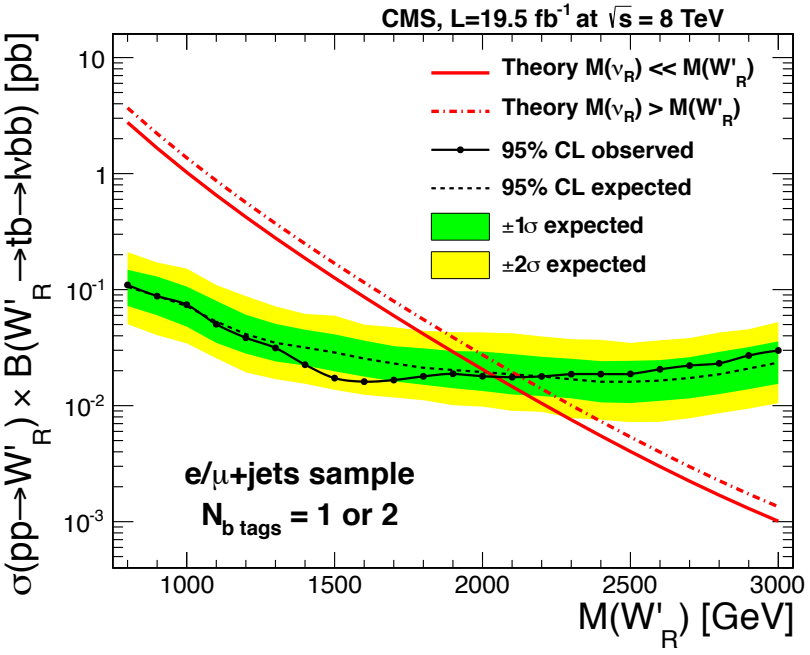




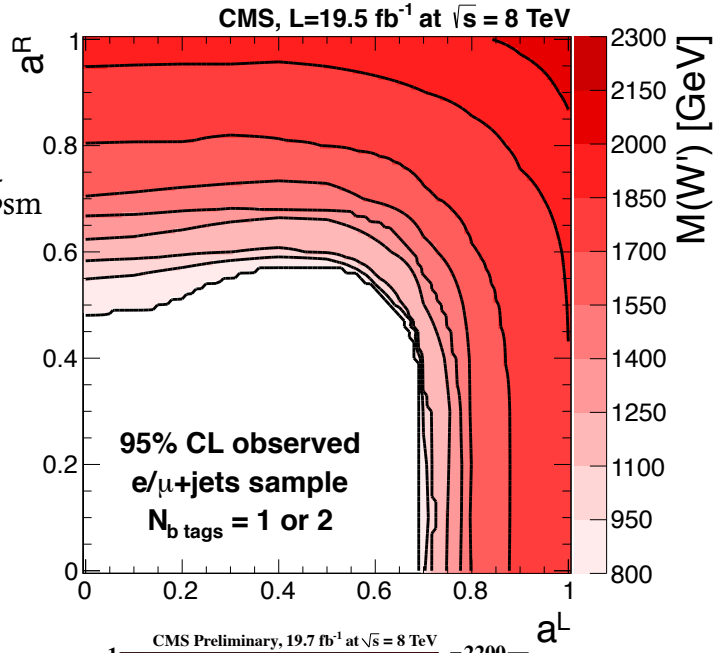
CMS Results

$W' \to t\bar{b} \to l\nu b\bar{b}$

CMS PAS B2G-14-010



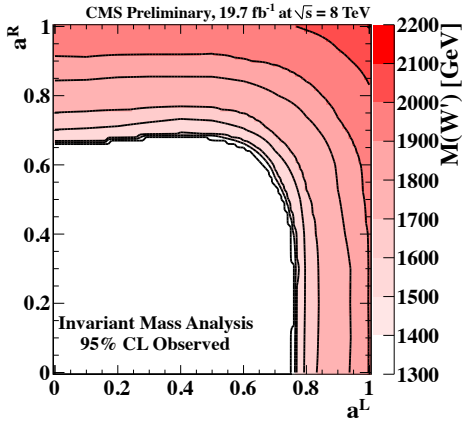
$a^R = g_r/g_{sm}$



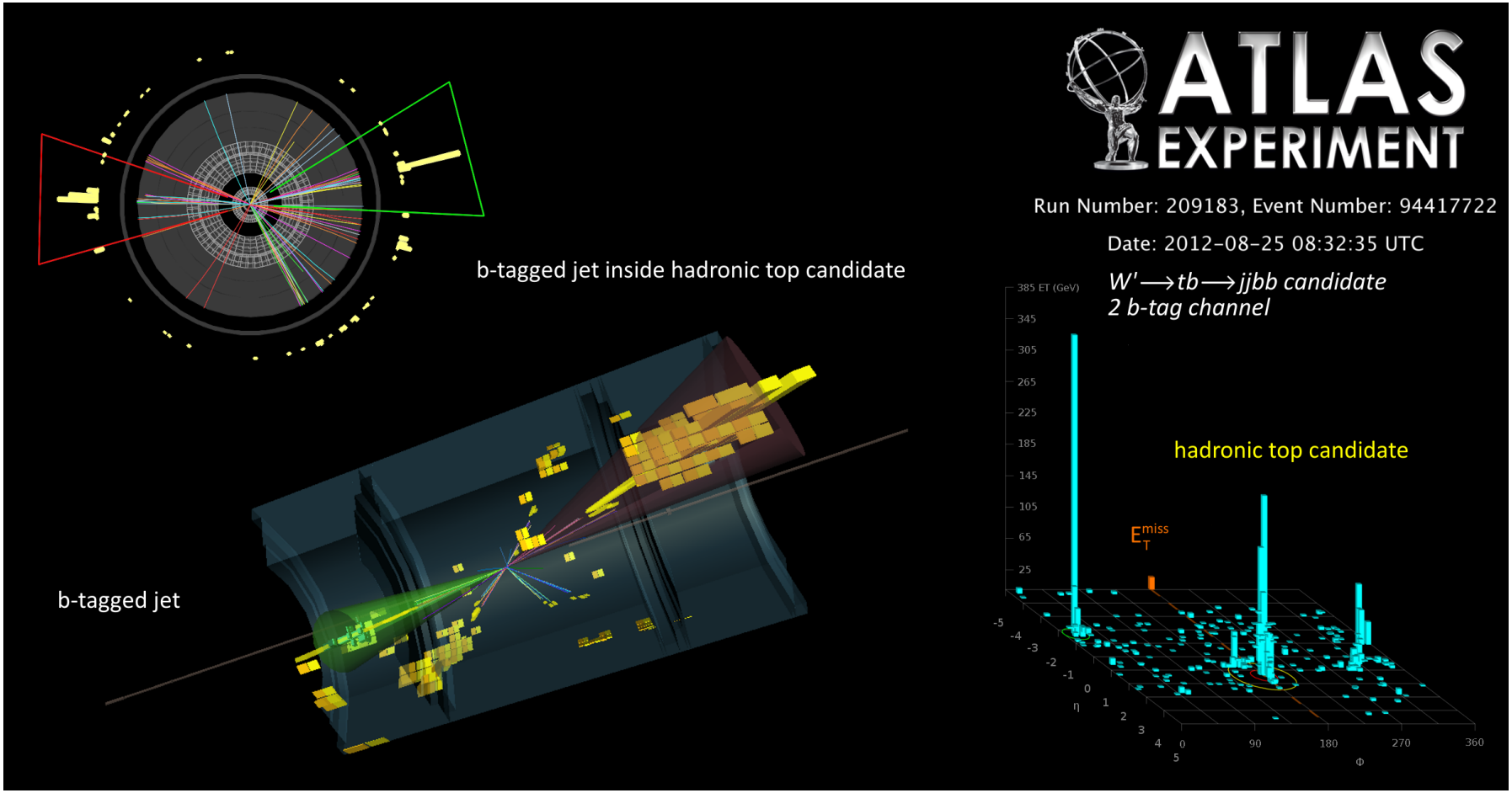
Most stringent limit so far

CMS PAS B2G-14-009

$W' \to t\bar{b} \to jjb\bar{b}$

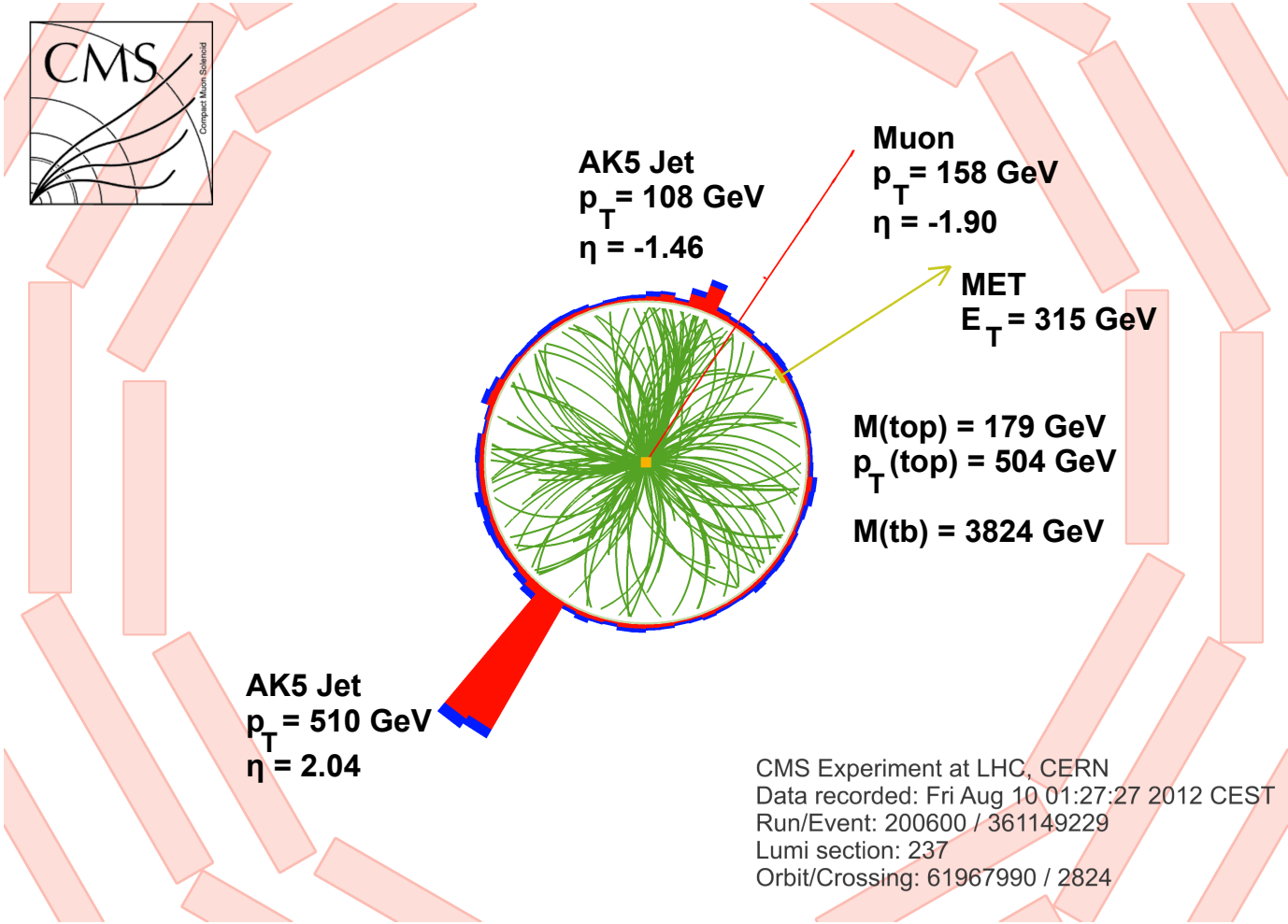


High Mass W' Candidate ATLAS

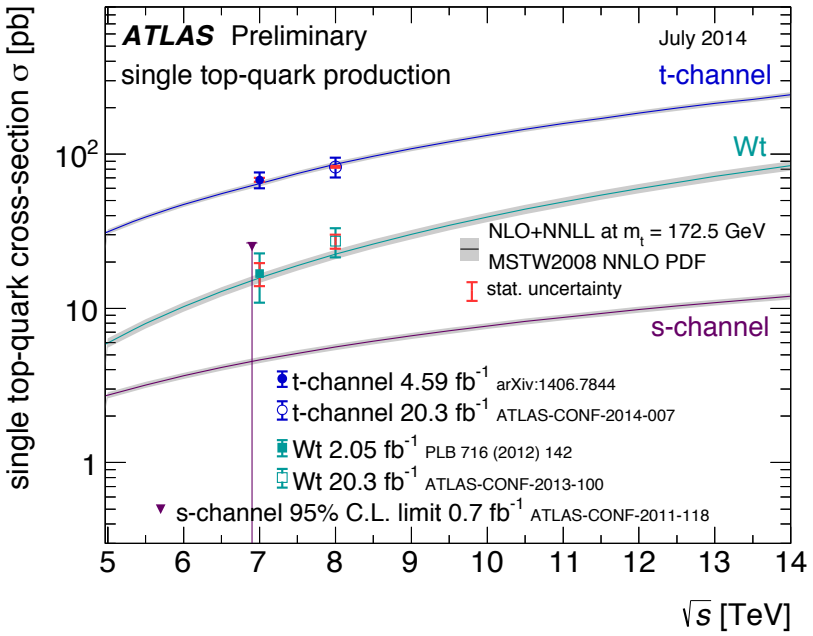


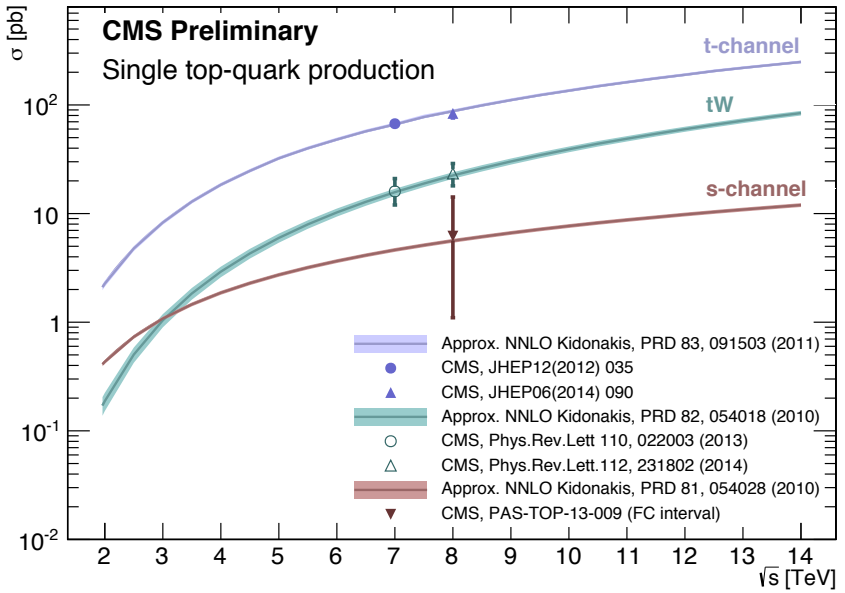
M_{tb}=3.3 TeV, p_T(top)=790 GeV, p_T(b)=520 GeV

High Mass W' Candidate CMS



Summary of Cross Sections

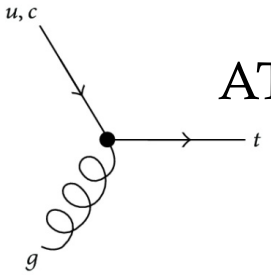




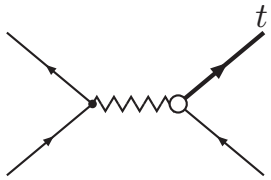
- *t*-channel process now becoming tool for studying precise couplings, BSM.
- Associated *W*+*t* production now observed (6.1 sigma CMS, 4.2 ATLAS)
- *s*-channel observed at Tevatron. More work/data needed to observe at LHC.

Searches for Flavor Changing Neutral Currents

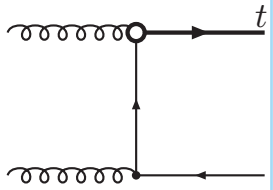
Many different searches



ATLAS-CONF-2013-063

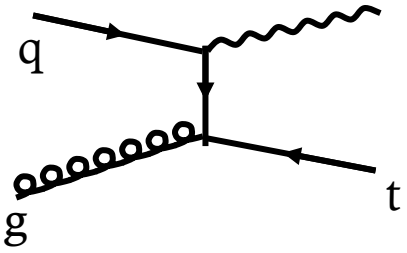


$q\bar{q} \to t\bar{c}$

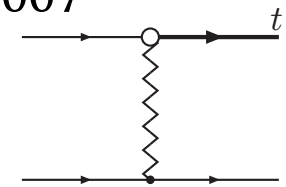


$gg \to tc$

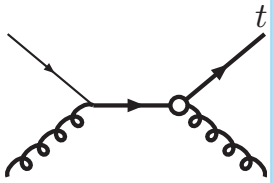
CMS PAS TOP-14-007



CMS PAS TOP-14-003
CMS PAS TOP-12-021



$c\bar{q} \to t\bar{q}$



$cg \to tg$

Same basic Lagrangian

$$\mathcal{L} = \sum_{q=u,c} \left[\sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a (f_q^L P_L + f_q^R P_R) q \, G^a_{\mu\nu} + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{Zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} (\hat{f}_q^L P_L + \hat{f}_q^R P_R) q \, Z_{\mu\nu} \right] + \text{h.c.}$$

Lots of Upper Limits

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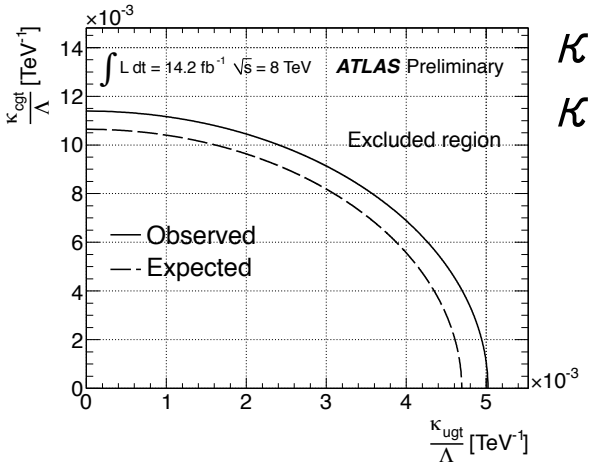


$\kappa_{gut}/\Lambda < 0.0051$ TeV^{-1}

$\kappa_{gct}/\Lambda < 0.011$ TeV^{-1}

CMS PAS TOP-14-003

CMS PAS TOP-12-021

$\kappa_{gut}/\Lambda < 0.10$ TeV^{-1}

$\kappa_{gct}/\Lambda < 0.35$ TeV^{-1}

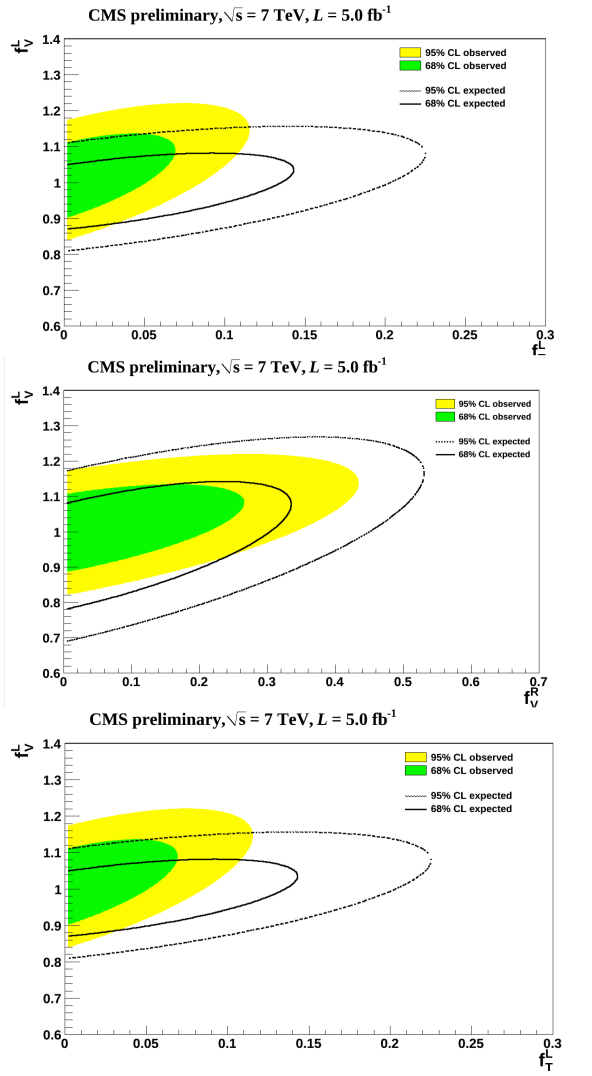
$\kappa_{Zut}/\Lambda < 0.45$ TeV^{-1}

$\kappa_{Zct}/\Lambda < 2.27$ TeV^{-1}

$\kappa_{tu\gamma}/\Lambda < 0.028$ TeV^{-1}

$\kappa_{tc\gamma}/\Lambda < 0.094$ TeV^{-1}

CMS PAS TOP-14-007



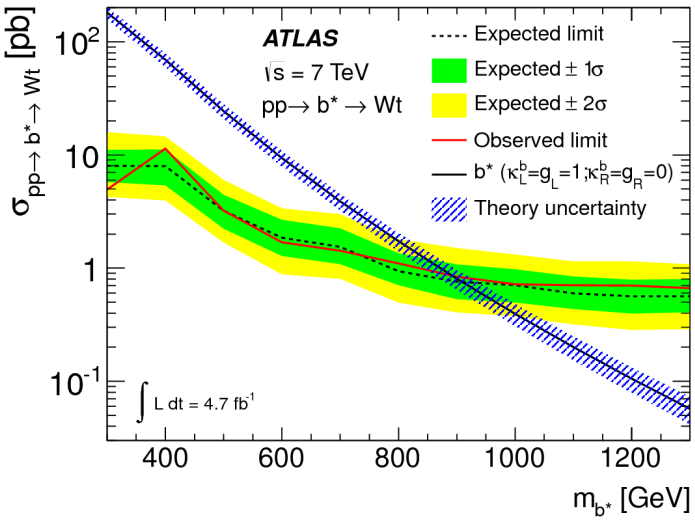
Summary

- Observations of *t*-channel and *W*+*t* single-top production. Upper limits on s-channel at LHC, but observed at Tevatron.
- Limits set on b^*, W', anomalous couplings, as well as FCNC.
- These are complicated analyses; not all analyses of Run 1 data complete yet.
- New data will be taken in 2015 at higher energies
  - Larger cross sections, More integrated luminosity.
  - Greater reach for b*,W' searches.

Stay tuned.

Backup

ATLAS $b^* \rightarrow Wt$ Search



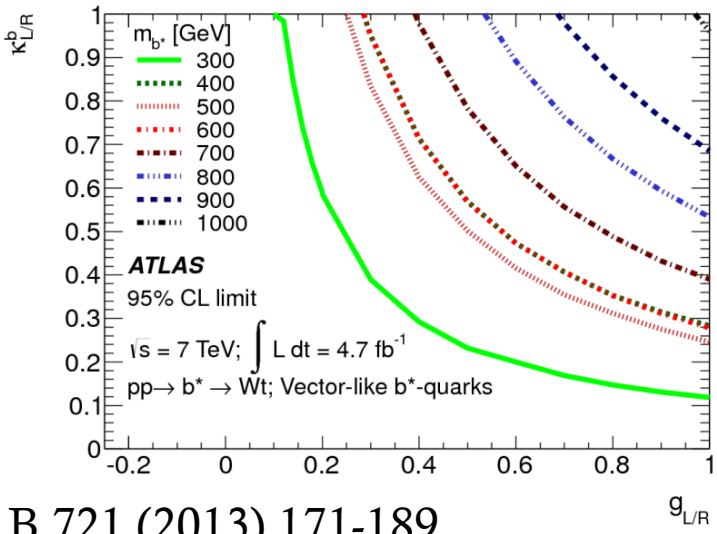
- L, R or vector-like couplings

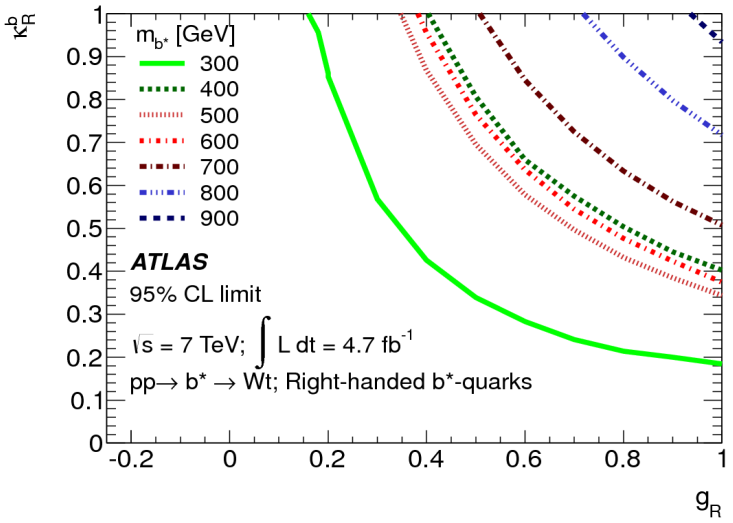
$$\mathcal{L} = \frac{g_s}{2\Lambda} G_{\mu\nu}\, \bar{b}\, \sigma^{\mu\nu} \left(\kappa_L^b P_L + \kappa_R^b P_R \right) b^* + \text{h.c.}$$

- Wt-channel decay signature

$$\mathcal{L} = \frac{g_2}{\sqrt{2}} W_\mu^+ \, \bar{t} \gamma^\mu \left(g_L P_L + g_R P_R \right) b^* + \text{h.c.}$$

$$m_{b^*} > 870\,\text{GeV}\ (\kappa_L^b = g_L = 1)$$





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t-Channel Fiducial Cross section: Fiducial Selection Cuts

Object	Cut
Electrons	$p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$
Muons	$p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$
Jets	$p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 4.5$
	$p_{\mathrm{T}} > 35$ GeV, if $2.75 < \lvert\eta\rvert < 3.5$
Lepton (ℓ), Jets (j_i)	$\Delta R(\ell, j_i) > 0.4$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV
Transverse W-boson mass	$m_{\mathrm{T}}(W) > 50$ GeV
Lepton (ℓ), jet with the highest p_{T} (j_1)	$p_{\mathrm{T}}(\ell) > 40$ GeV $\left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$