Single Top Quark Production Cross Section and Properties Using the ALTAS Detector at the LHC

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on behalf of the ATLAS Collaboration

4th International Conference on New Frontiers in Physics
Kolymbari, Crete, Greece 26.08.2015

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Outline

- Why Study Single Top Processes?
- Single Top Quark Phenomenology
- Measurements
  - t-channel
  - Wt channel
- Searches
  - s-channel
  - Heavy Gauge Bosons (W')
  - Monotops
  - FCNC

Why Study Single Top Processes?

Massive
- most massive elementary particle…that we know of
- Higgs mass corrections
- hierarchy problem

Decay Before Hadronization
- only opportunity to observe bare parton

Background in Other Searches
- background to Higgs, SUSY, etc…

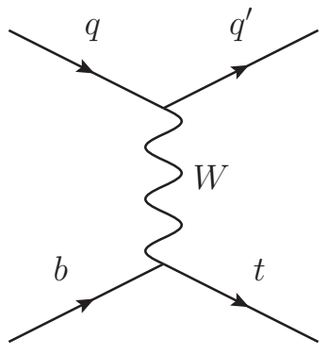
Unique Tests of Standard Model
- ratio of u and d quark PDF
- unitarity test of CKM matrix, $|V_{tb}|$ extraction
- top quark polarization, W boson helicity, etc…

Beyond the Standard Model Probe
- *Wtb* anomalous couplings
- flavor changing neutral currents
- heavy gauge bosons
- dark matter

Single Top Quark Phenomenology

t-channel generic selection

- 2 high p_T jets
  - 1 forward light jet
  - 1 central b-jet
- 1 isolated, high p_T lepton
- E_T^{Miss}



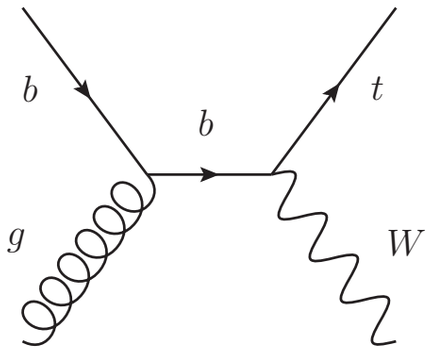
$$\sigma^{\text{theory}}_{t\text{-ch}} = 64.57^{+2.63}_{-1.74}\ \text{pb @ 7 TeV}$$

$$\sigma^{\text{theory}}_{t\text{-ch}} = 87.76^{+3.44}_{-1.91}\ \text{pb @ 8 TeV}$$

Phys. Rev. D 83, 091503 (2011)

Wt-channel generic selection

- 1 high p_T central b-jet
- 2 isolated, high p_T leptons
- E_T^{Miss}



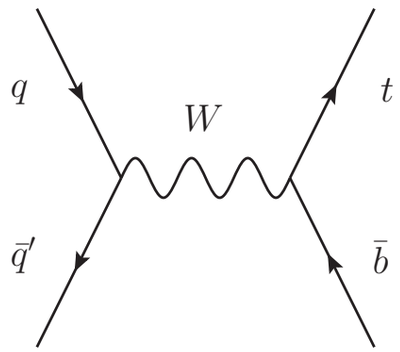
$$\sigma^{\text{theory}}_{Wt\text{-ch}} = 15.74^{+1.17}_{-1.21}\ \text{pb @ 7 TeV}$$

$$\sigma^{\text{theory}}_{Wt\text{-ch}} = 22.37 \pm 1.52\ \text{pb @ 8 TeV}$$

Phys. Rev. D 82, 054018 (2010)

s-channel generic selection

- 2 high p_T central b-jets
- 1 isolated high p_T lepton
- E_T^{Miss}



$$\sigma^{\text{theory}}_{s\text{-ch}} = 4.63^{+0.20}_{-0.18}\ \text{pb @ 7 TeV}$$

$$\sigma^{\text{theory}}_{s\text{-ch}} = 5.61 \pm 0.22\ \text{pb @ 8 TeV}$$

Phys. Rev. D 81, 054028 (2010)

* calculations made assuming a top mass of 172.5 GeV and using the MSTW 2008 NNLO PDF

t-chan Cross Section Measurements

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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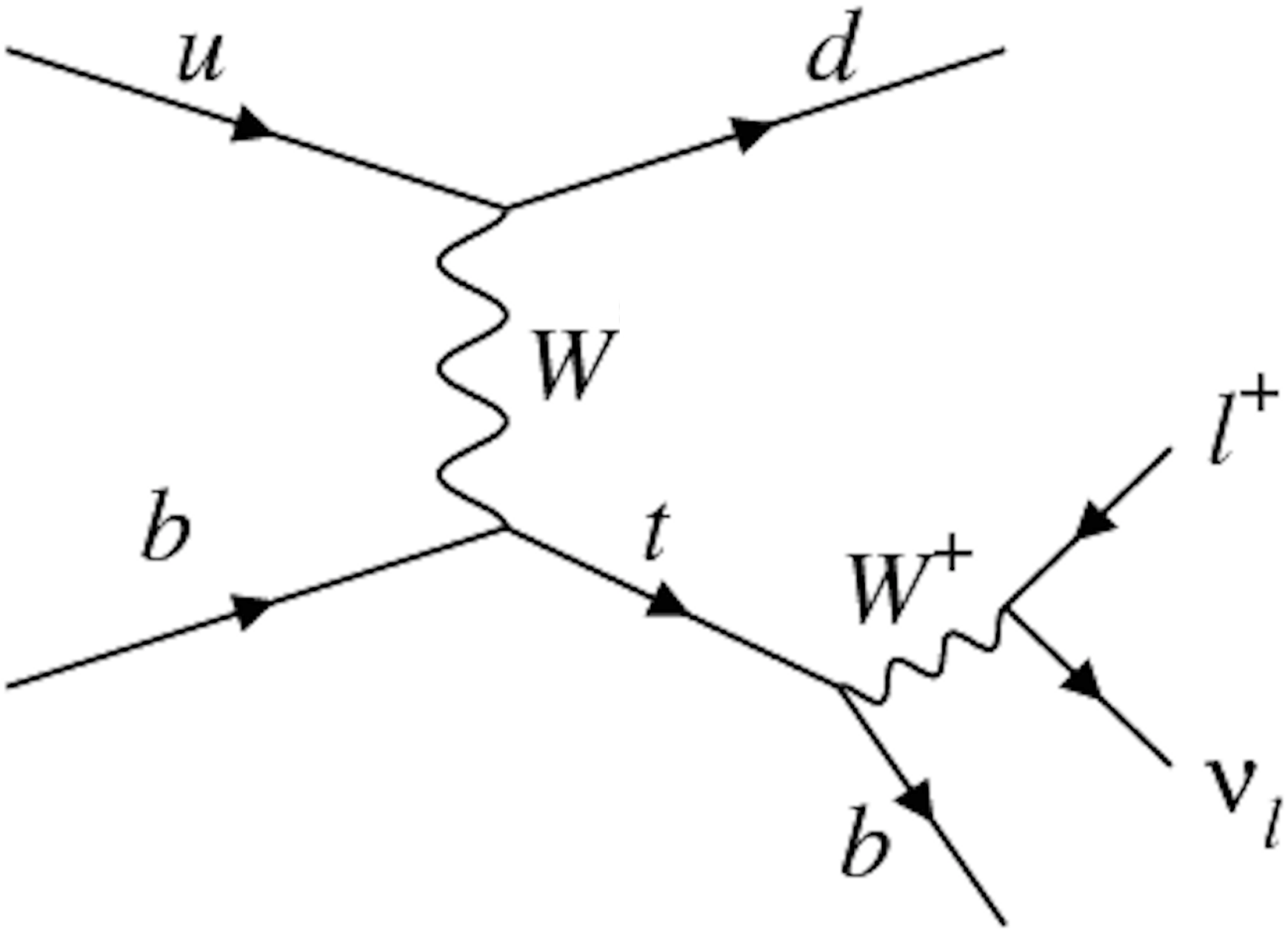
$\sqrt{s}$ = 7 TeV, 4.6 fb^{-1}

Phys. Rev. D. 90, 112006

t-channel Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Final State Selection

- 1 light quark, 1 b-jet, 1 electron or muon, E_T^{Miss}



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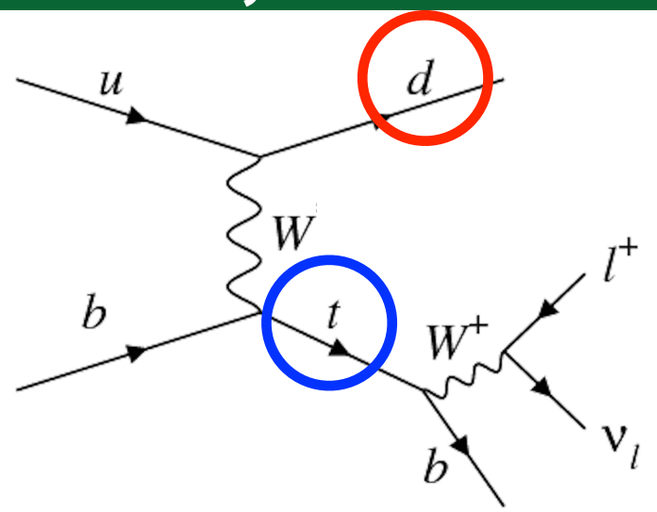
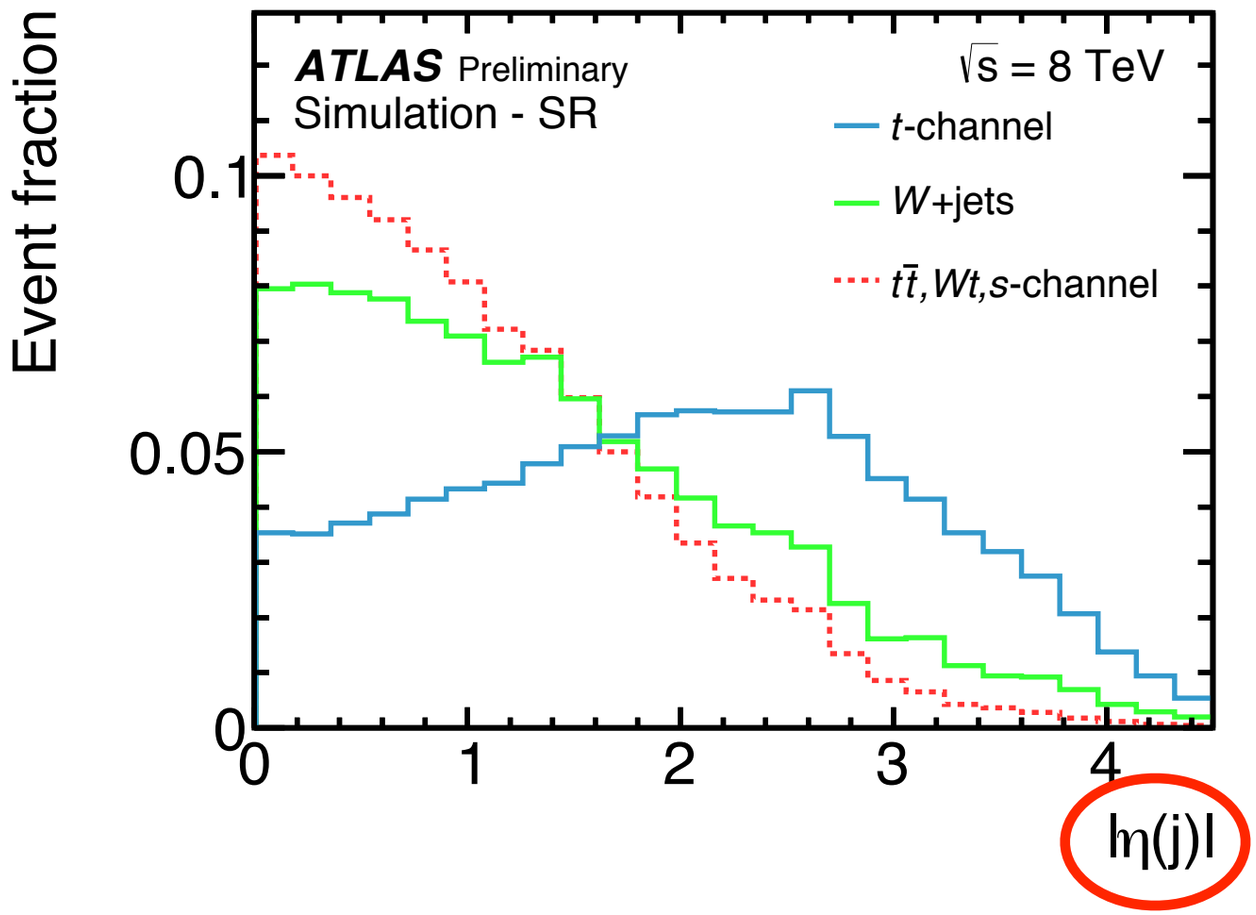
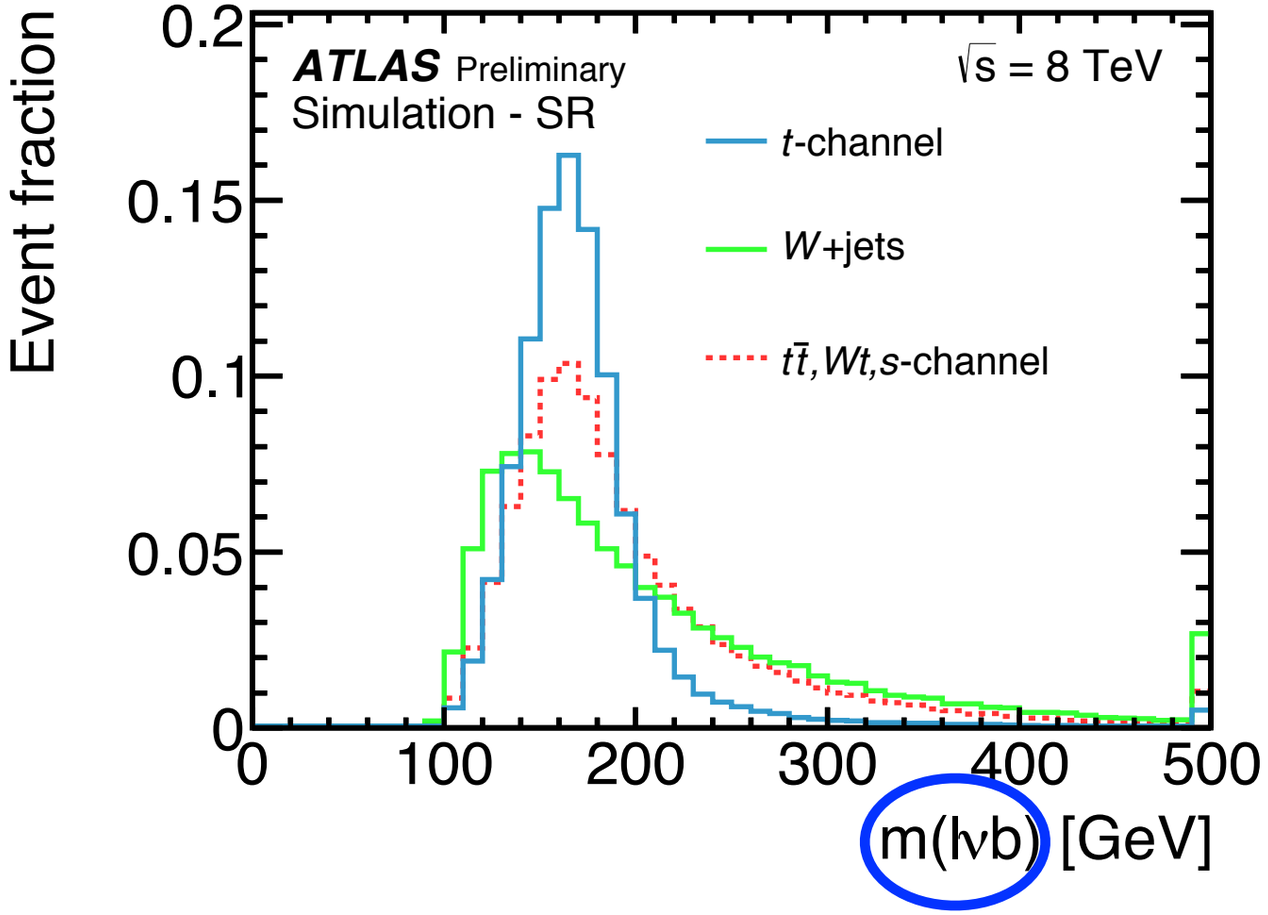
t-channel Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Signal Discrimination

- Neural Network
- most discriminating variables: |η(j)| and m(lvb)







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Signal Discrimination

- Neural Network
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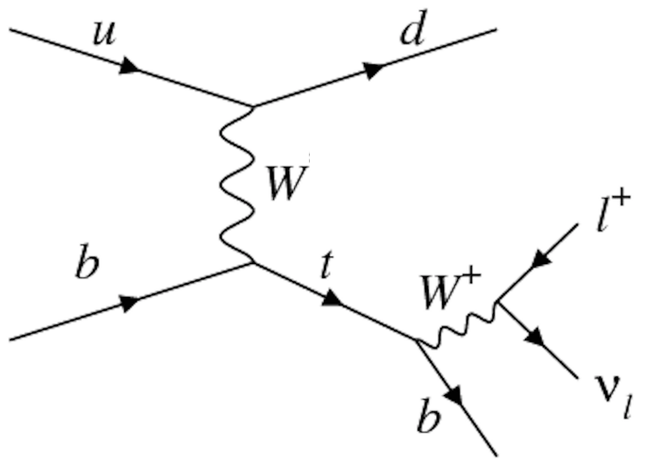

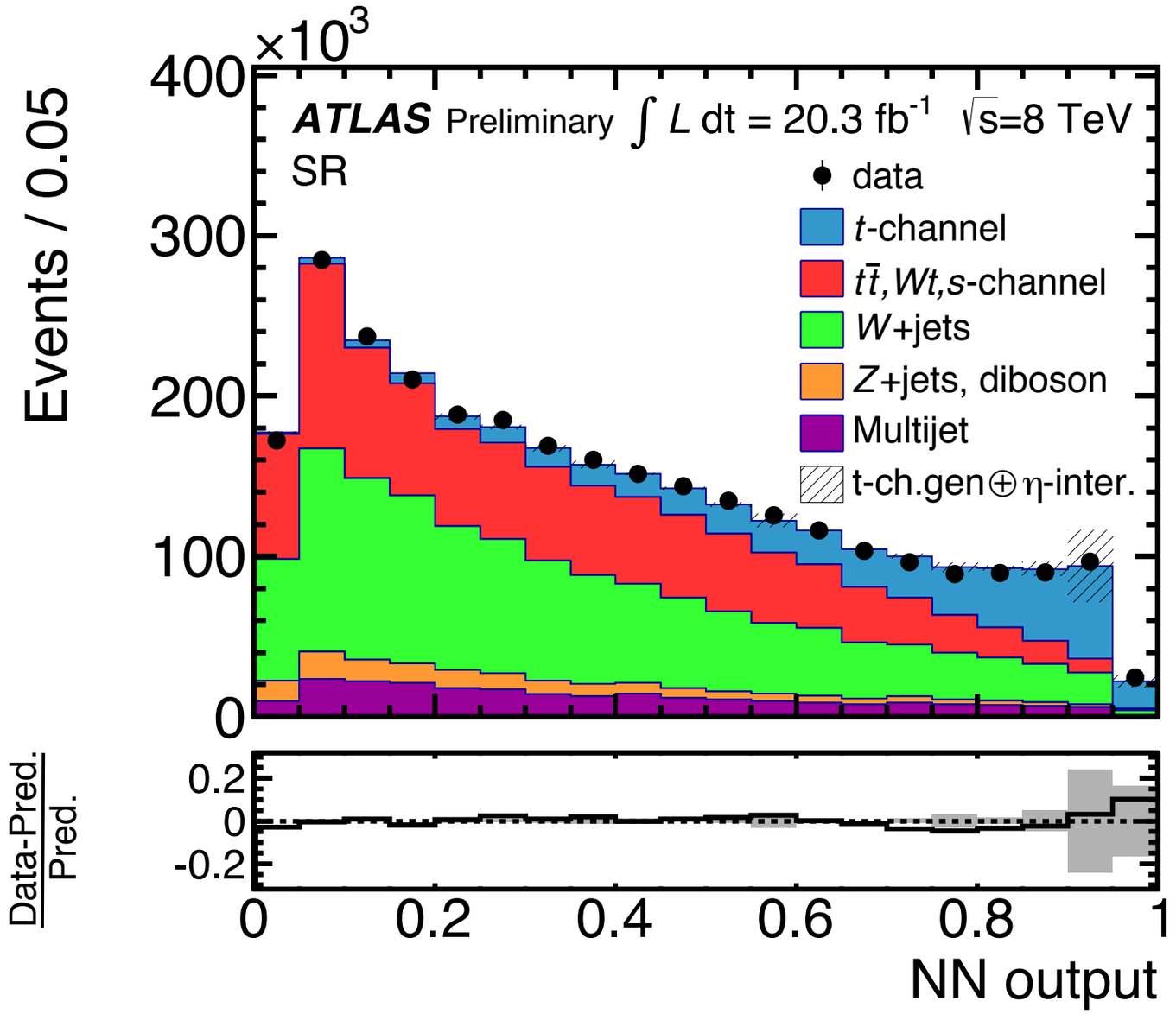

includes t-channel generator and JES uncertainties

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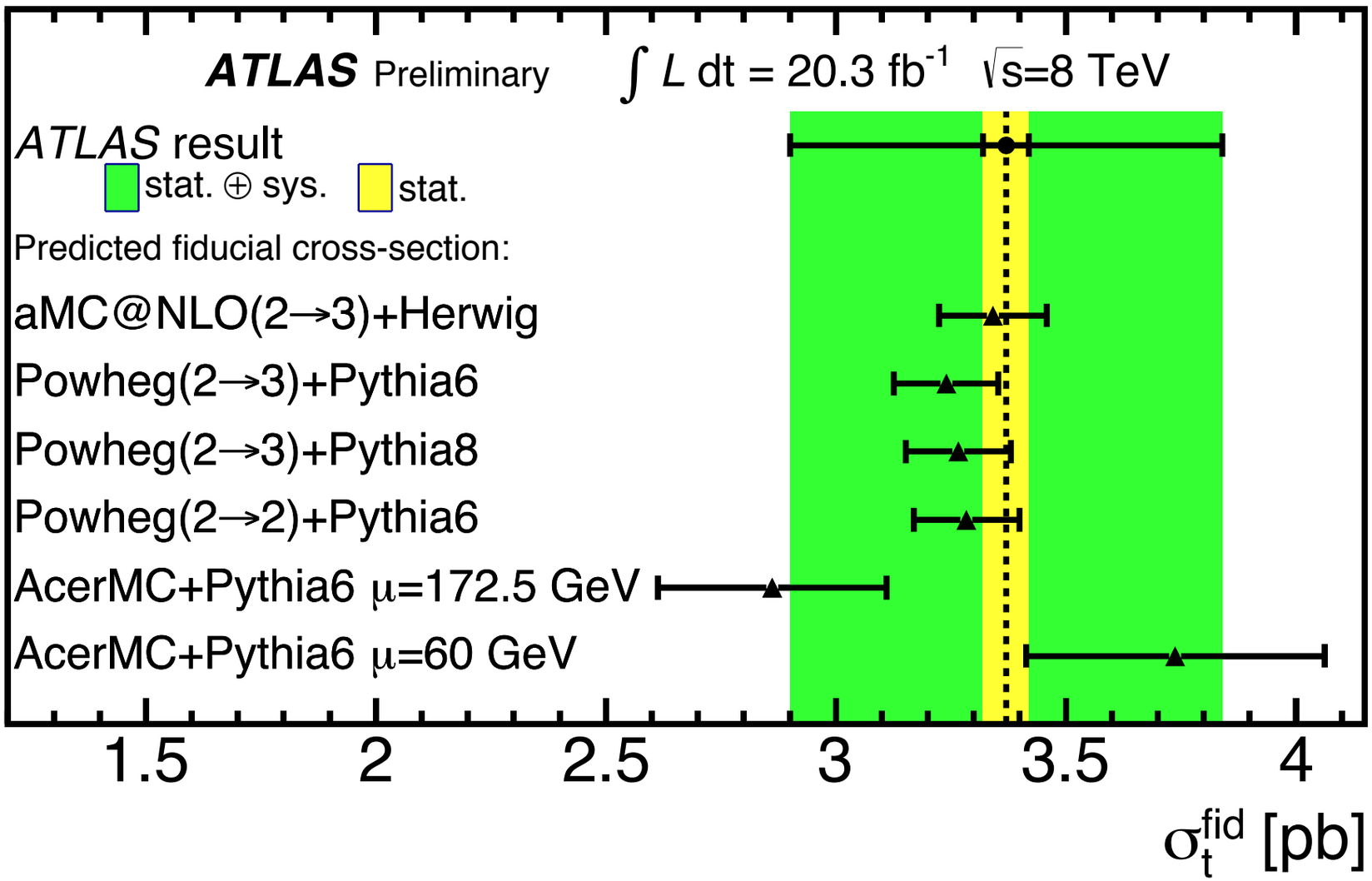
Cross Section Determination (fiducial)

- cross section in region of phase-space visible by ATLAS
- easier theoretical interpretation
- reduced sensitivity to theoretical uncertainties

dominated by JES and generator modeling uncertainties

$$\sigma_{\text{fid}} = 3.37 \pm 0.05(\text{stat}) \pm 0.48(\text{syst})\ \text{pb}$$



$$\frac{\delta\sigma_{\text{fid}}}{\sigma_{\text{fid}}} = 14\%$$

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t-channel Inclusive Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

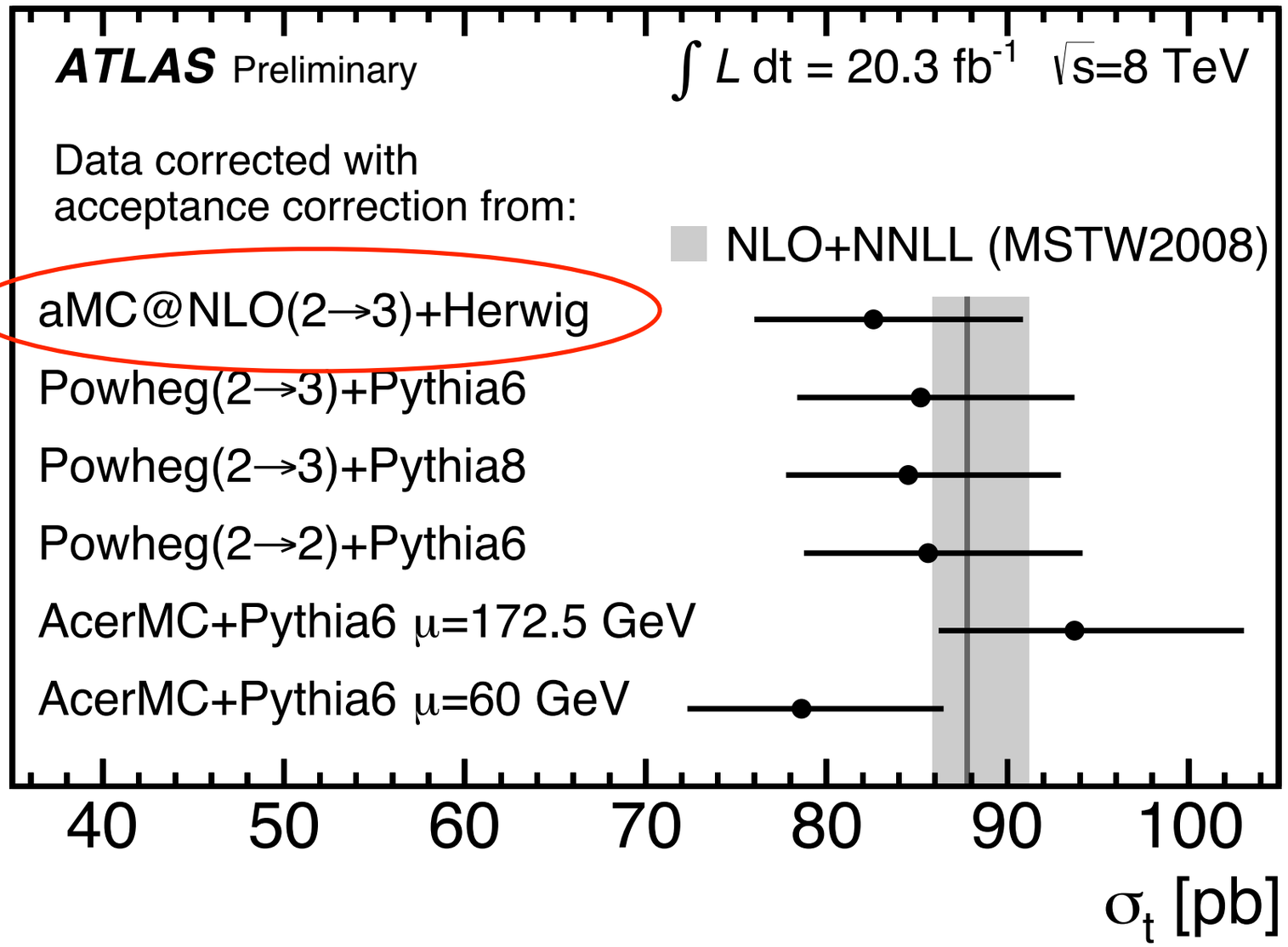
Cross Section Determination (inclusive)

- uses acceptance of different MC generators
- selection cuts of fiducial volume in backup

$$\sigma_{\rm inc} = \frac{1}{\epsilon_{\rm fid}}\sigma_{\rm fid}$$

$$\sigma_{\rm inc} = 82.6 \pm 1.2({\rm stat}) \pm 12.0({\rm syst})\ {\rm pb}$$

$$\frac{\delta\sigma_{\rm inc}}{\sigma_{\rm inc}} = 15\%$$



$$\sigma_{t\text{-ch}}^{\rm theory} = 87.76^{+3.44}_{-1.91}\ {\rm pb}$$

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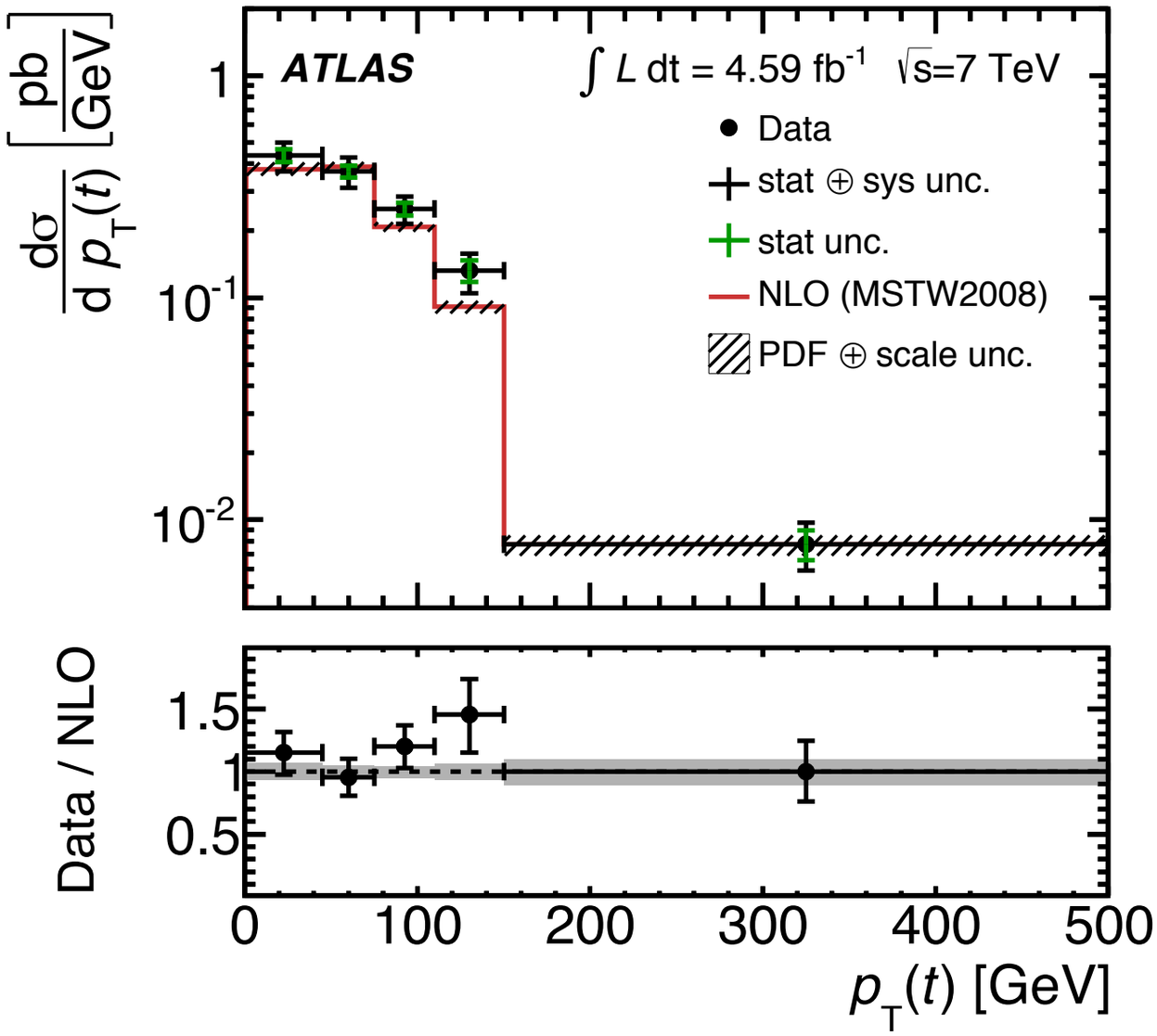
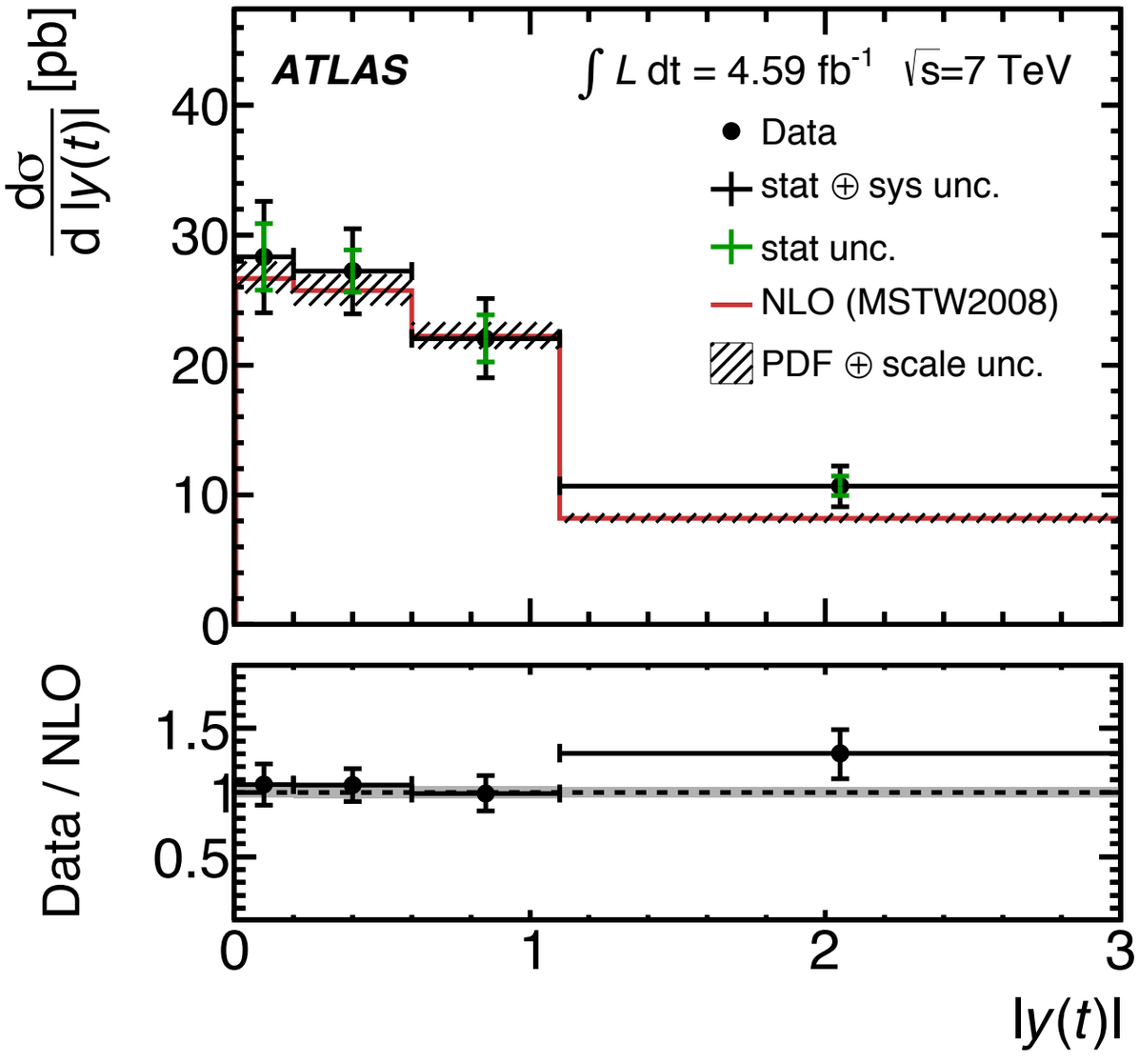
t-channel Differential Cross Section ($\sqrt{s}$ = 7 TeV, 4.6 fb^{-1})

Cross Section Determination (differential)

- first differential cross section measurements
- given in both $p_T(t)$ and $|y(t)|$



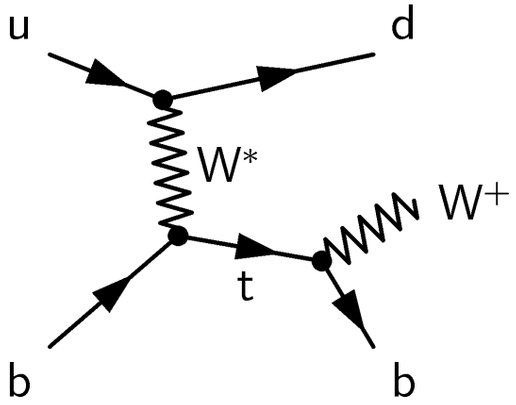


Phys. Rev. D. 90, 112006 (2014)

t-channel Cross Section Ratio, R_t ($\sqrt{s}$ = 7 TeV, 4.6 fb^{-1})

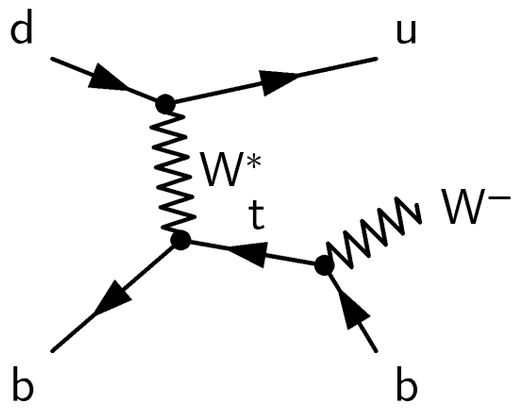
Top vs Antitop Production, R_t

- standard model test
- u and d quark in PDFs



$\sigma_{\text{t-chan}}\,(t) = 46 \pm 1(\text{stat}) \pm 6(\text{syst})$ pb

$\sigma^{\text{theory}}_{t\text{-chan}}\,(t) = 41.9^{+1.8}_{-0.9}$ pb

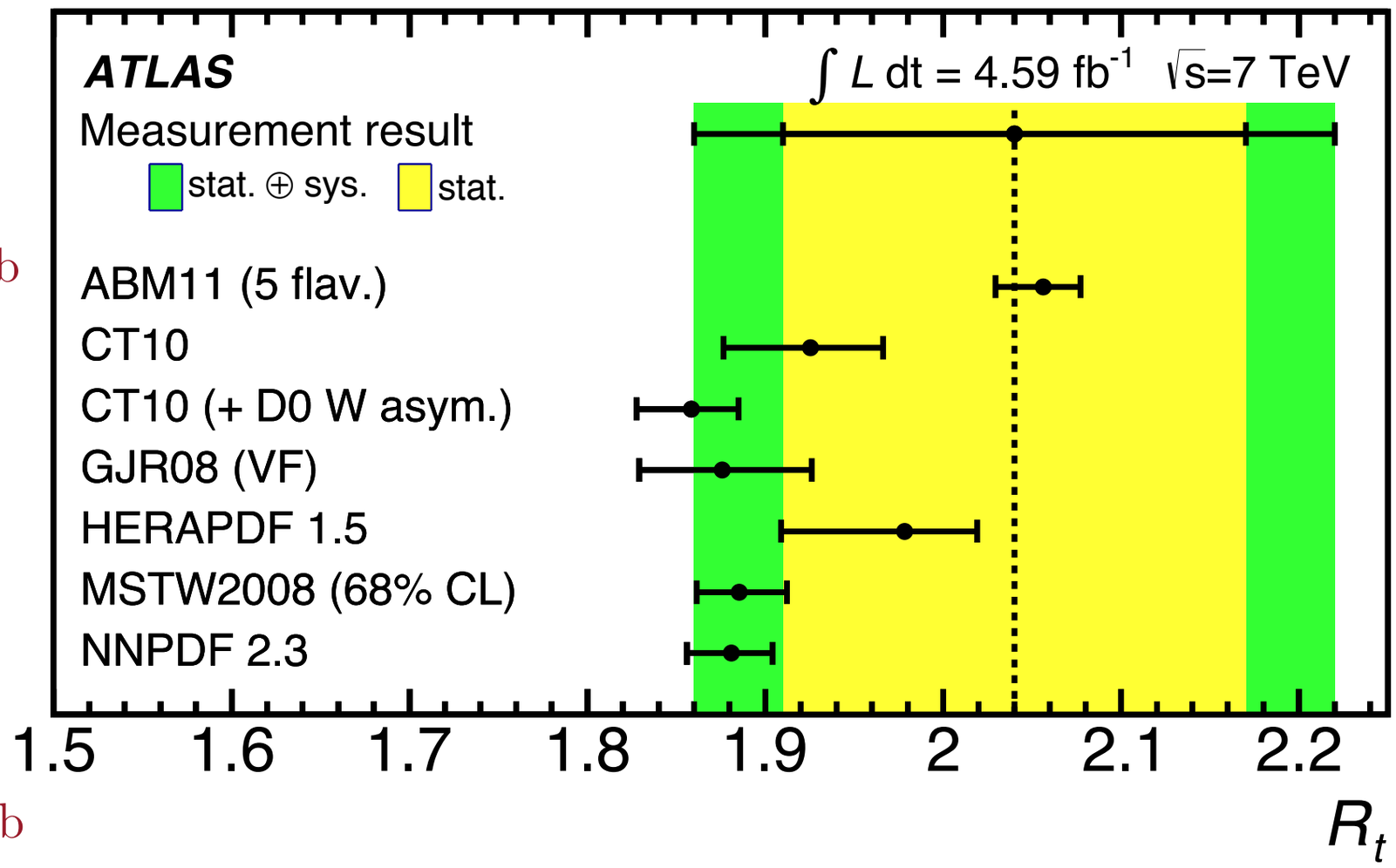


$\sigma_{\text{t-chan}}\,(\bar{t}) = 23 \pm 1(\text{stat}) \pm 3(\text{syst})$ pb

$\sigma^{\text{theory}}_{t\text{-chan}}\,(\bar{t}) = 22.7^{+0.9}_{-1.0}$ pb

dominated by JES, generator modeling, and b-tagging efficiency uncertainties

$$R_t = \frac{\sigma\,(t)}{\sigma\,(\bar{t})} = 2.04 \pm 0.13(\text{stat}) \pm 0.12(\text{syst}) \qquad \frac{\delta R_t}{R_t} = 9\%$$



Phys. Rev. D. 90, 112006 (2014)

Wt-chan Cross Section Measurement

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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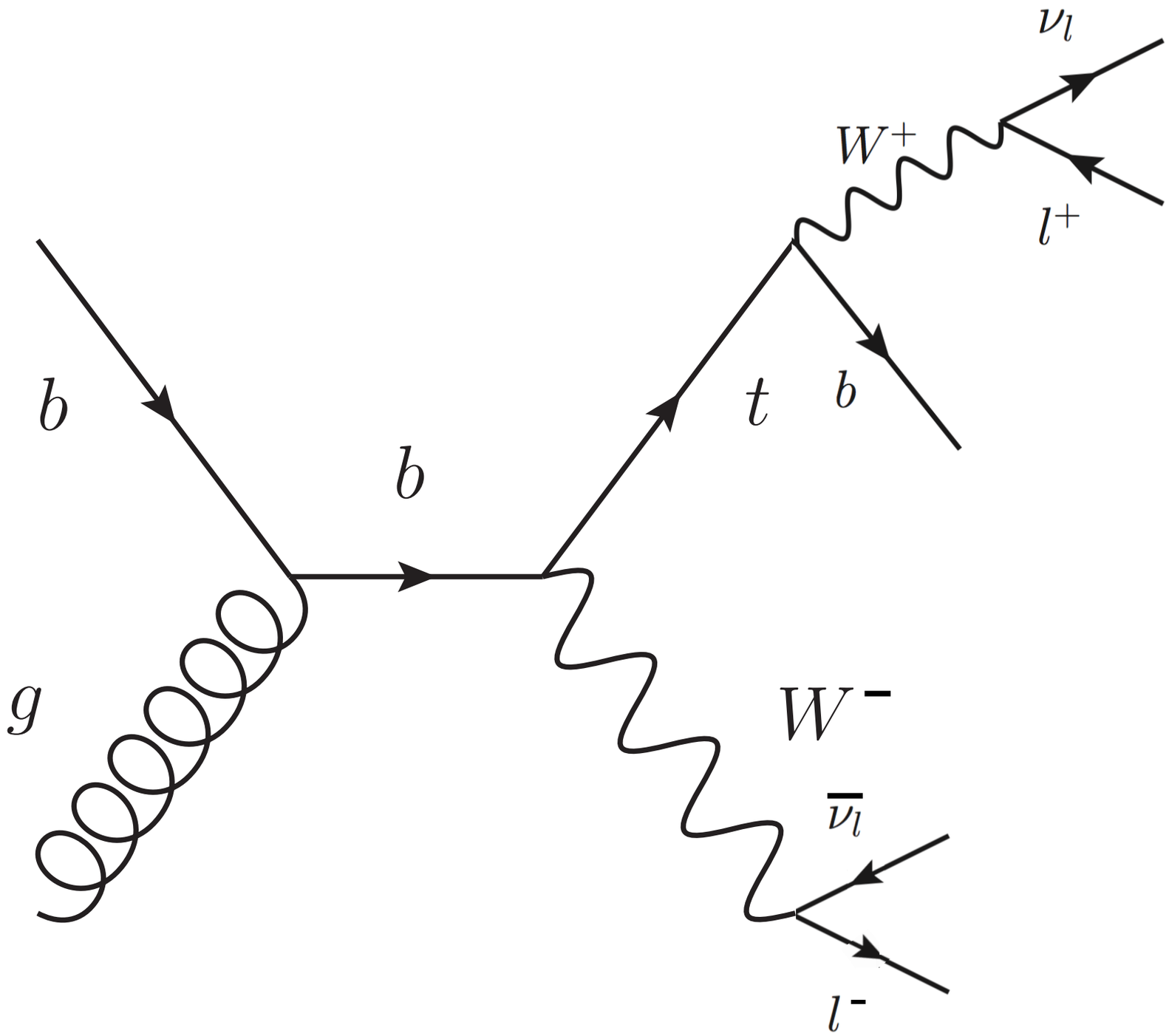
Wt-channel Inclusive Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Final State Selection

- 1 electron, 1 muon (opposite sign), E_T^{Miss}, 1 or 2 jets (≥1 b-tagged)



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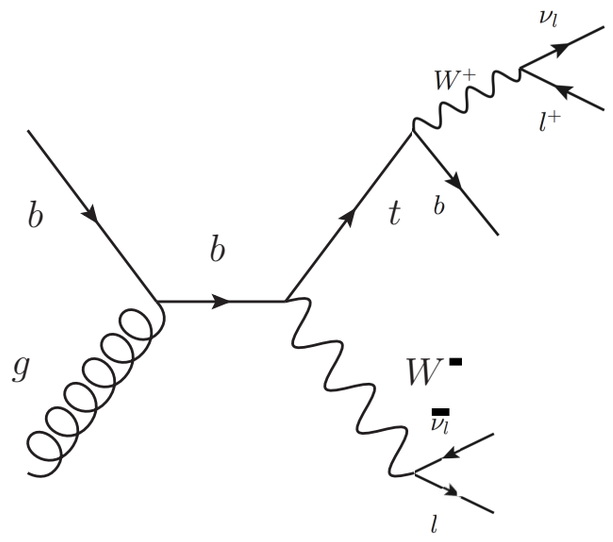
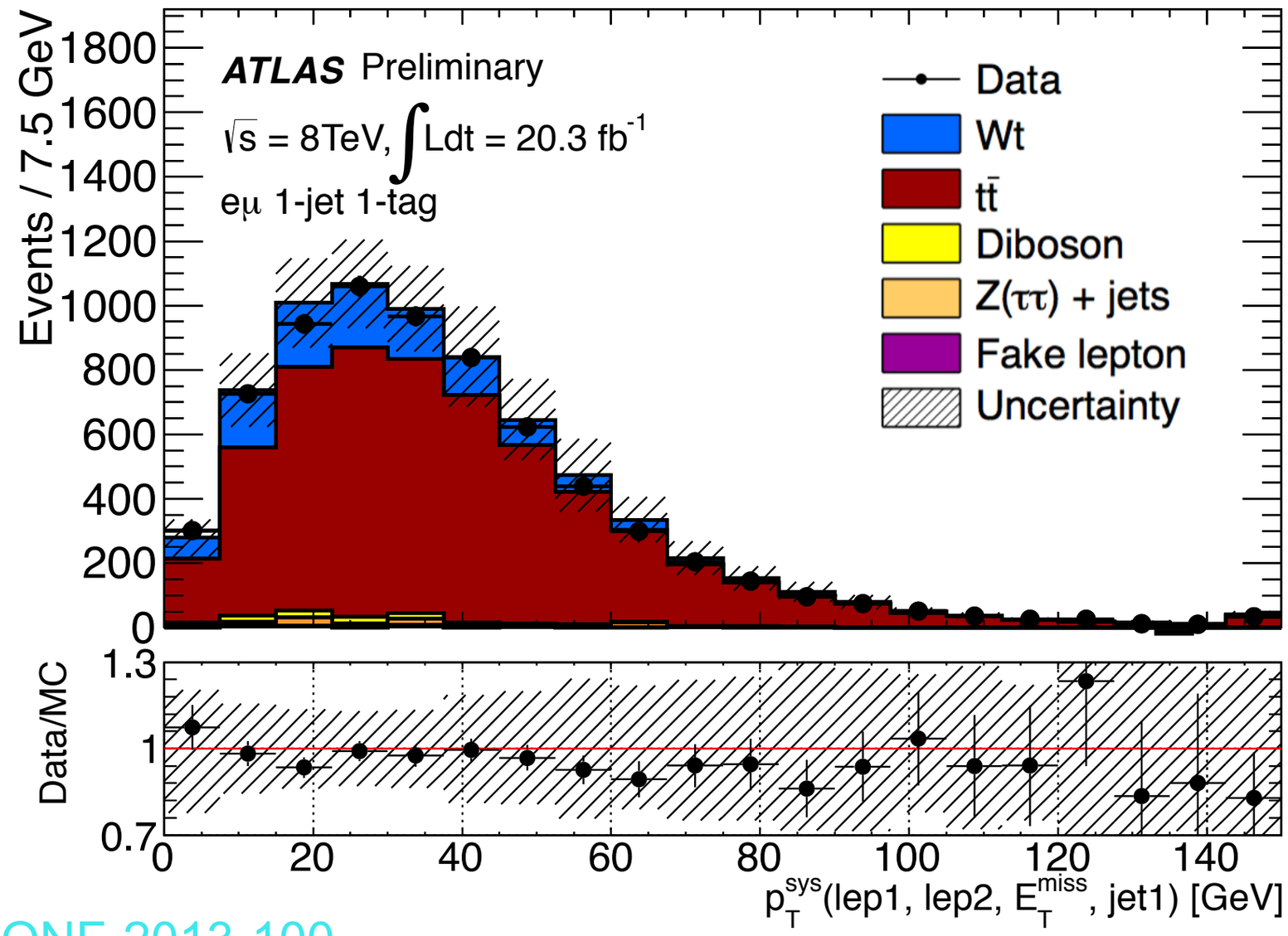
Wt-channel Inclusive Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Signal Discrimination

- Boosted Decision Trees
- classifiers defined for 1-jet and 2-jet events
- most discriminating variables: p_T^{sys}





includes all systematic uncertainties

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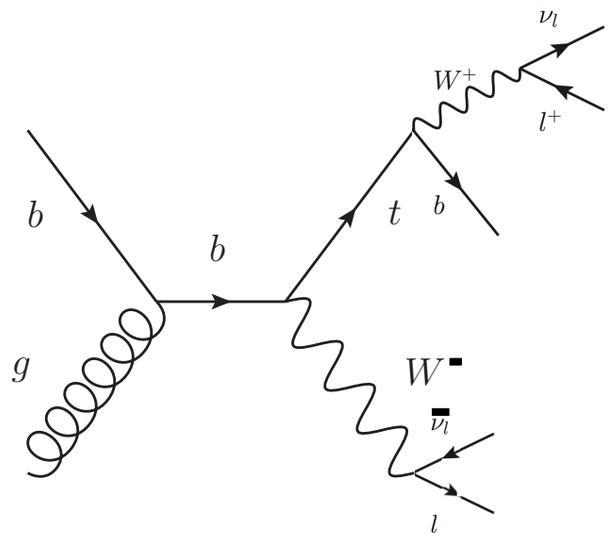
Wt-channel Inclusive Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

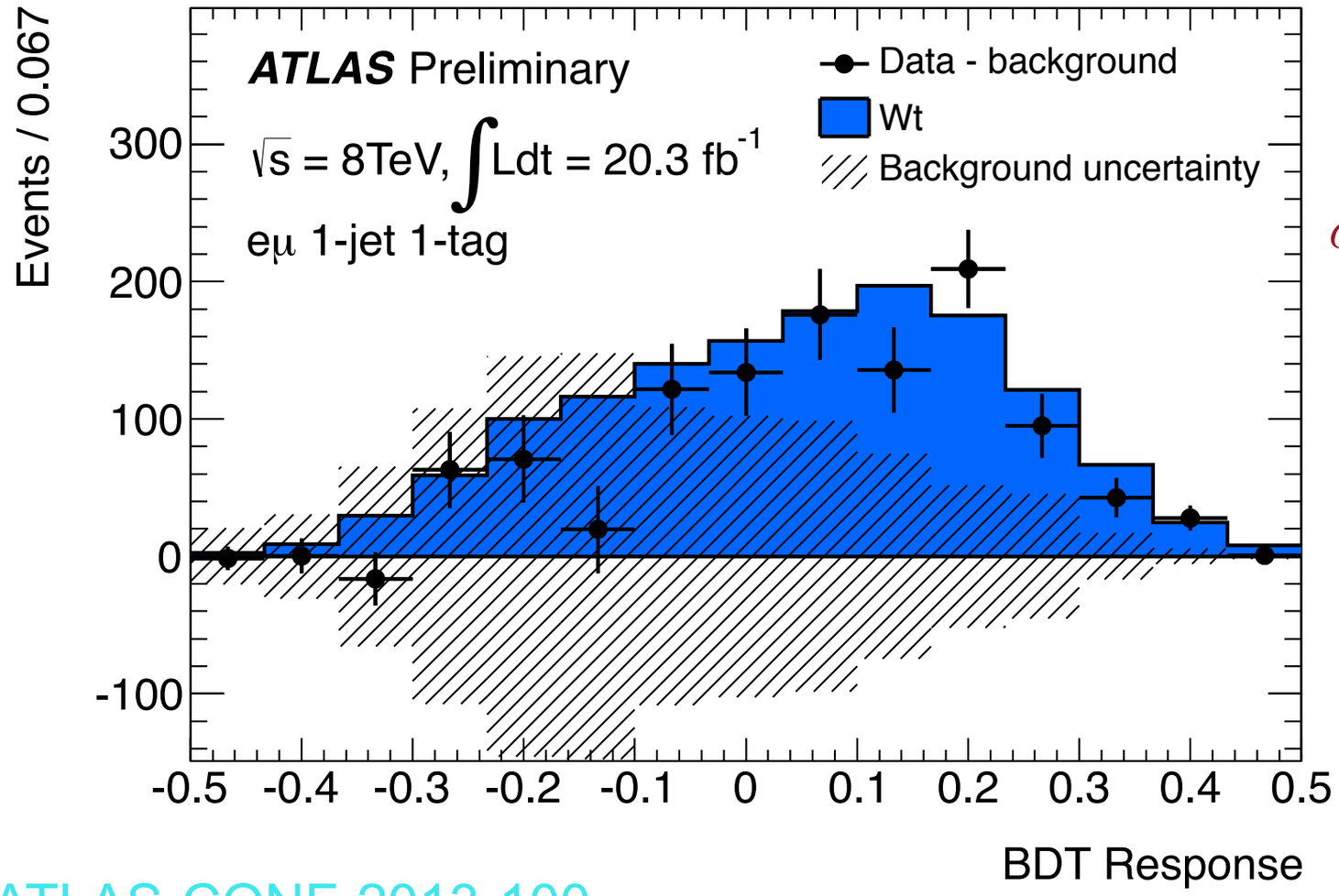
Cross Section Determination

- maximum-likelihood fit to BDT distributions



Results

- observed (expected) significance of 4.2σ (4.0σ)
- inclusive cross section
- CKM matrix element $|V_{tb}|$ with lower limit (later slide)



$$\sigma_{\text{inc}} = 27.2 \pm 2.8(\text{stat}) \pm 5.4(\text{syst}) \text{ pb}$$

$$\frac{\delta\sigma_{\text{inc}}}{\sigma_{\text{inc}}} = 22\%$$

$$\sigma^{\text{theory}}_{Wt\text{-ch}} = 22.37 \pm 1.52 \text{ pb}$$

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Wt- and t-chan $|V_{tb}|$ Measurements

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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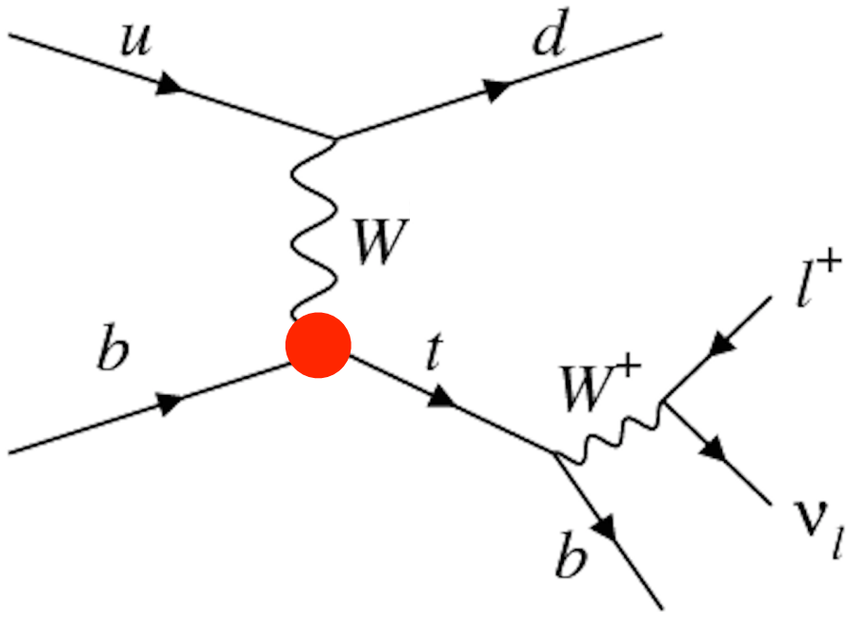
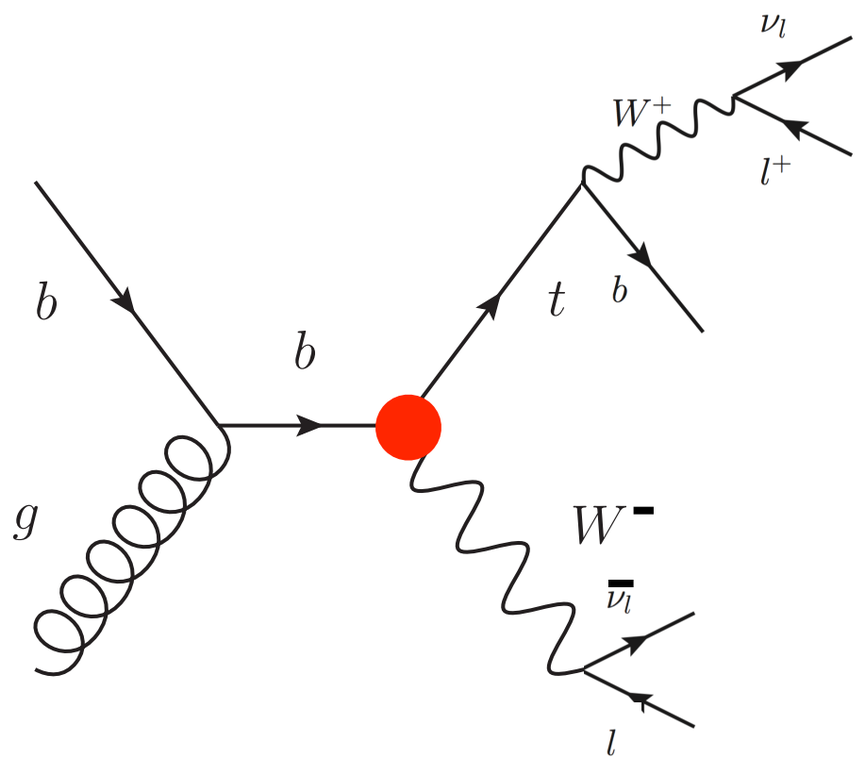
Assumptions NOT made

- unitarity of CKM matrix
- number of quark generations





t-channel

$$|V_{tb}| = 0.97^{+0.09}_{-0.10} \quad \frac{\delta|V_{tb}|}{|V_{tb}|} = 9\%$$

$$|V_{tb}| > 0.78 \text{ at } 95\% \text{ CL}$$

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Wt-channel

$$|V_{tb}| = 1.10 \pm 0.12 \quad \frac{\delta|V_{tb}|}{|V_{tb}|} = 11\%$$

$$|V_{tb}| > 0.72 \text{ at } 95\% \text{ CL}$$

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s-chan Search
$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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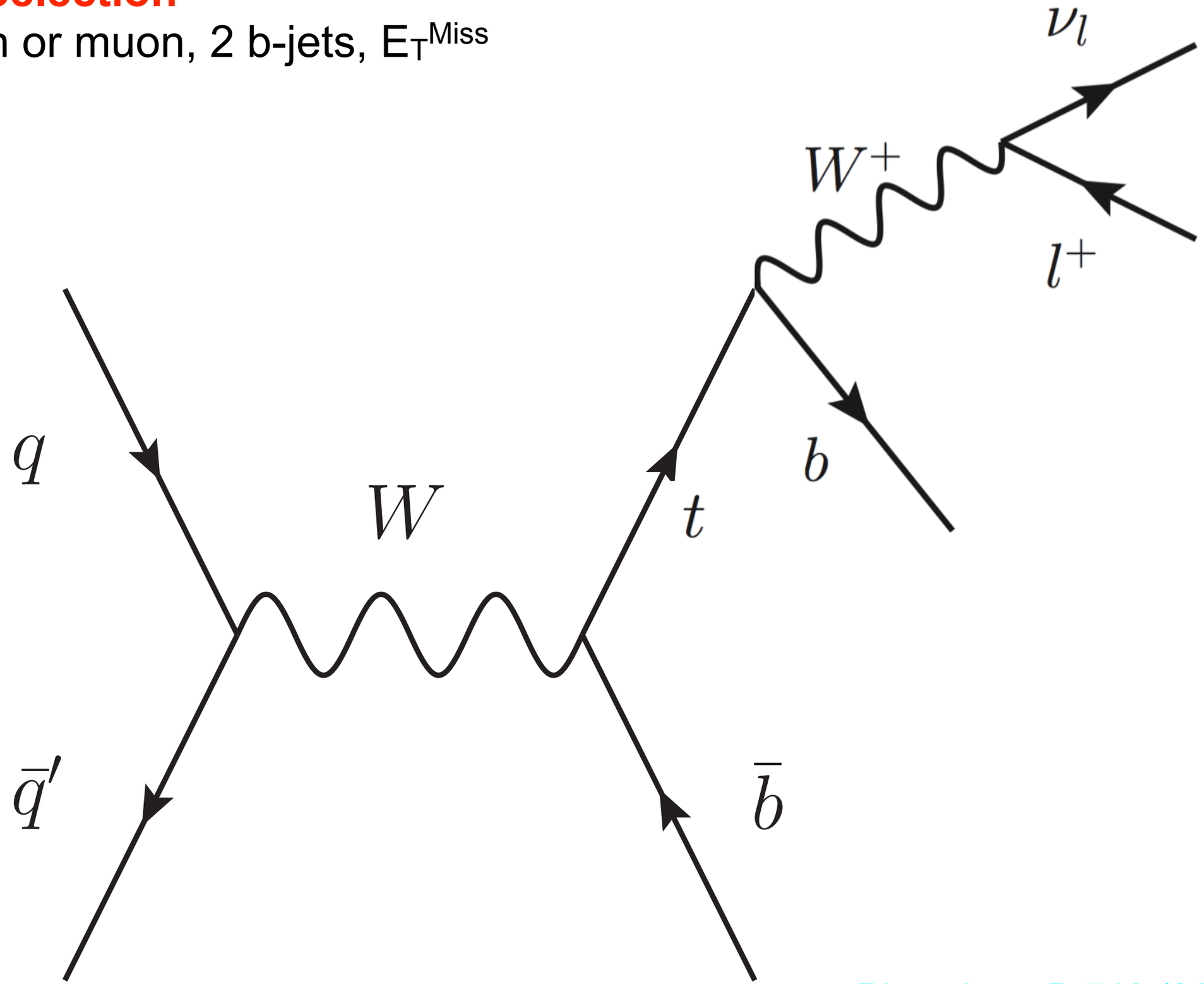
Final State Selection

- 1 electron or muon, 2 b-jets, E_T^{Miss}



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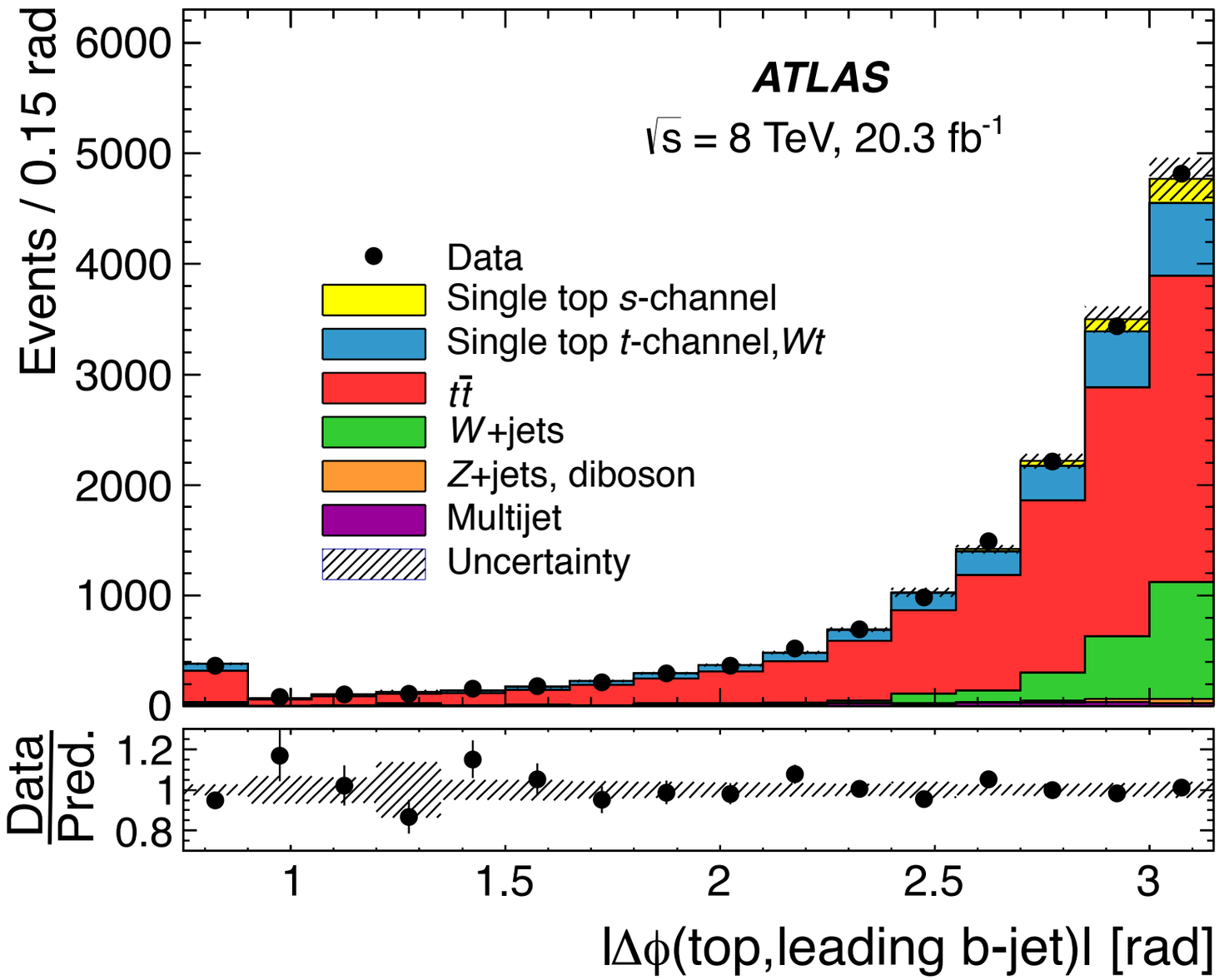
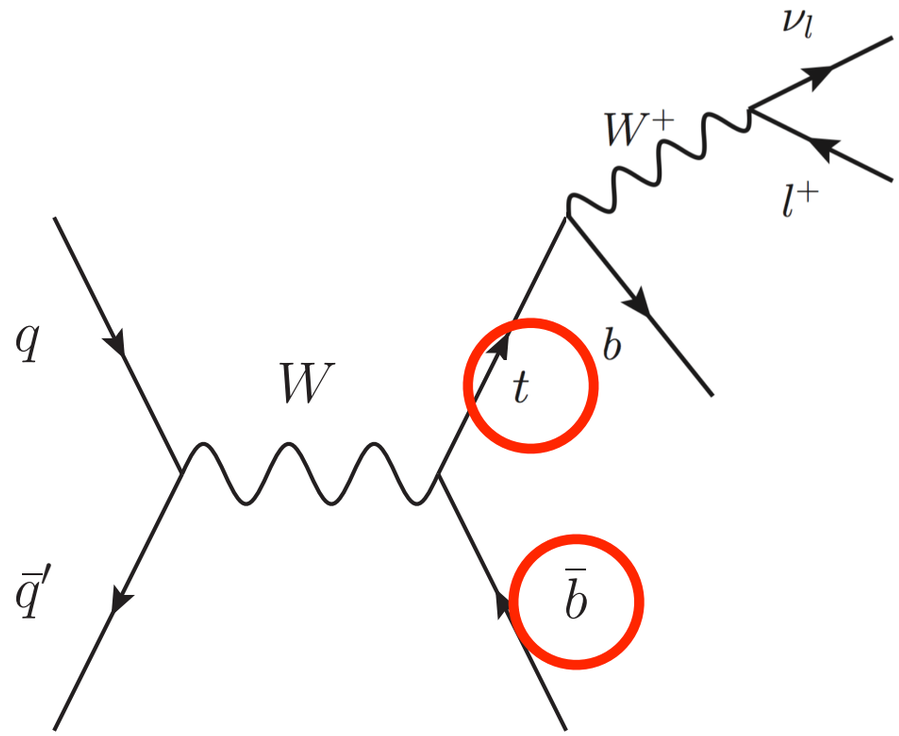
Signal Discrimination

- Boosted Decision Tree
- most discriminating variables: $|\Delta\varphi(b,t)|$ and $H_T(lep+E_T^{Miss})$





includes background normalization and statistical uncertainties

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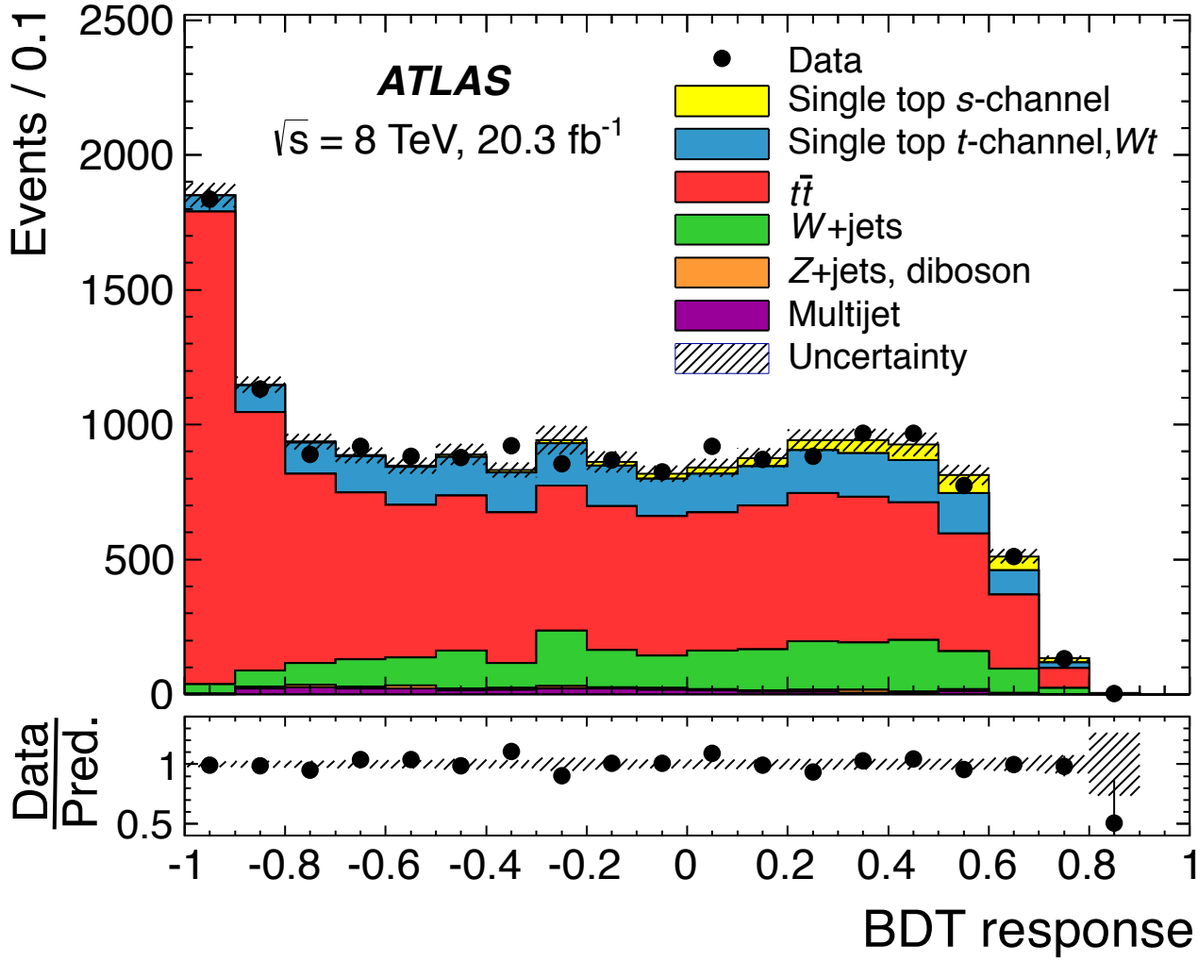
s-channel Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Cross Section Determination

- maximum-likelihood fit to classifier distributions

Results

- observed (expected) significance of 1.3σ (1.4σ)
- upper limit of 14.6 pb on production cross section at 95% CL
- limited by systematic uncertainties



dominated by E_T^{Miss} scale and JES uncertainties

$$\sigma_s = 5.0 \pm 1.7(\text{stat}) \pm 4.0(\text{syst})\ \text{pb}$$

$$\sigma_{s\text{-ch}}^{\text{theory}} = 5.61 \pm 0.22\ \text{pb}$$

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Search for W'→tb̄

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

Phys. Lett. B 743 (2015)

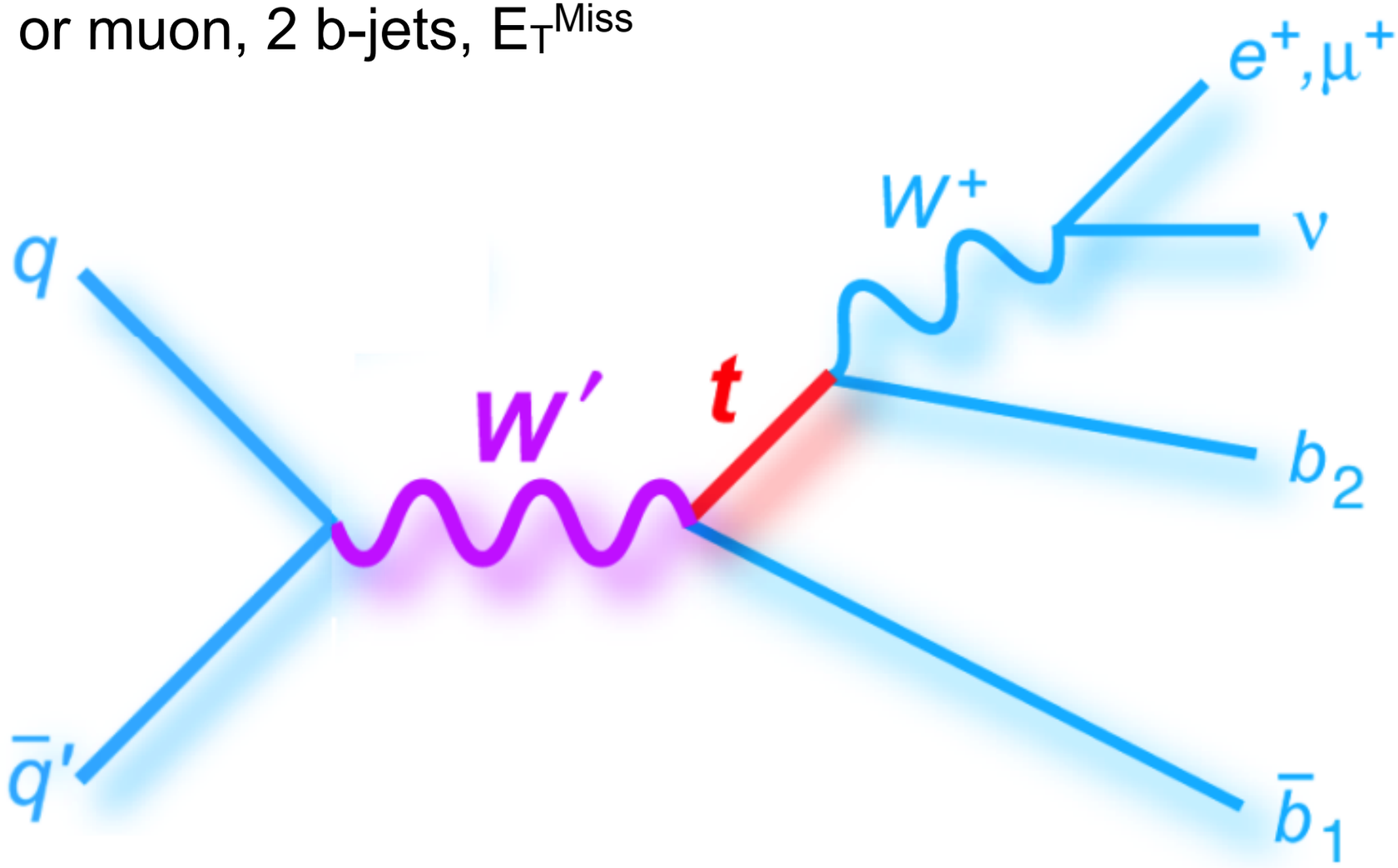
W' Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

BSM Search

- search for new vector currents mediated by heavy gauge boson (W')
- left/right handed W' bosons are searched for between 0.5 and 3 TeV

Final State Selection

- 1 electron or muon, 2 b-jets, E_T^{Miss}

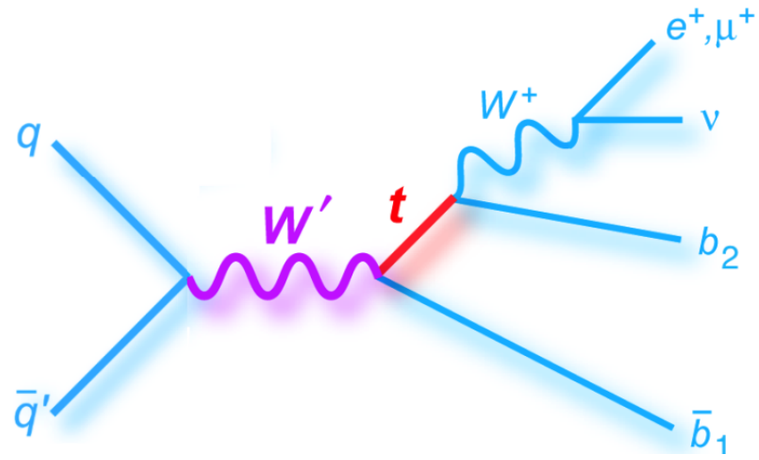


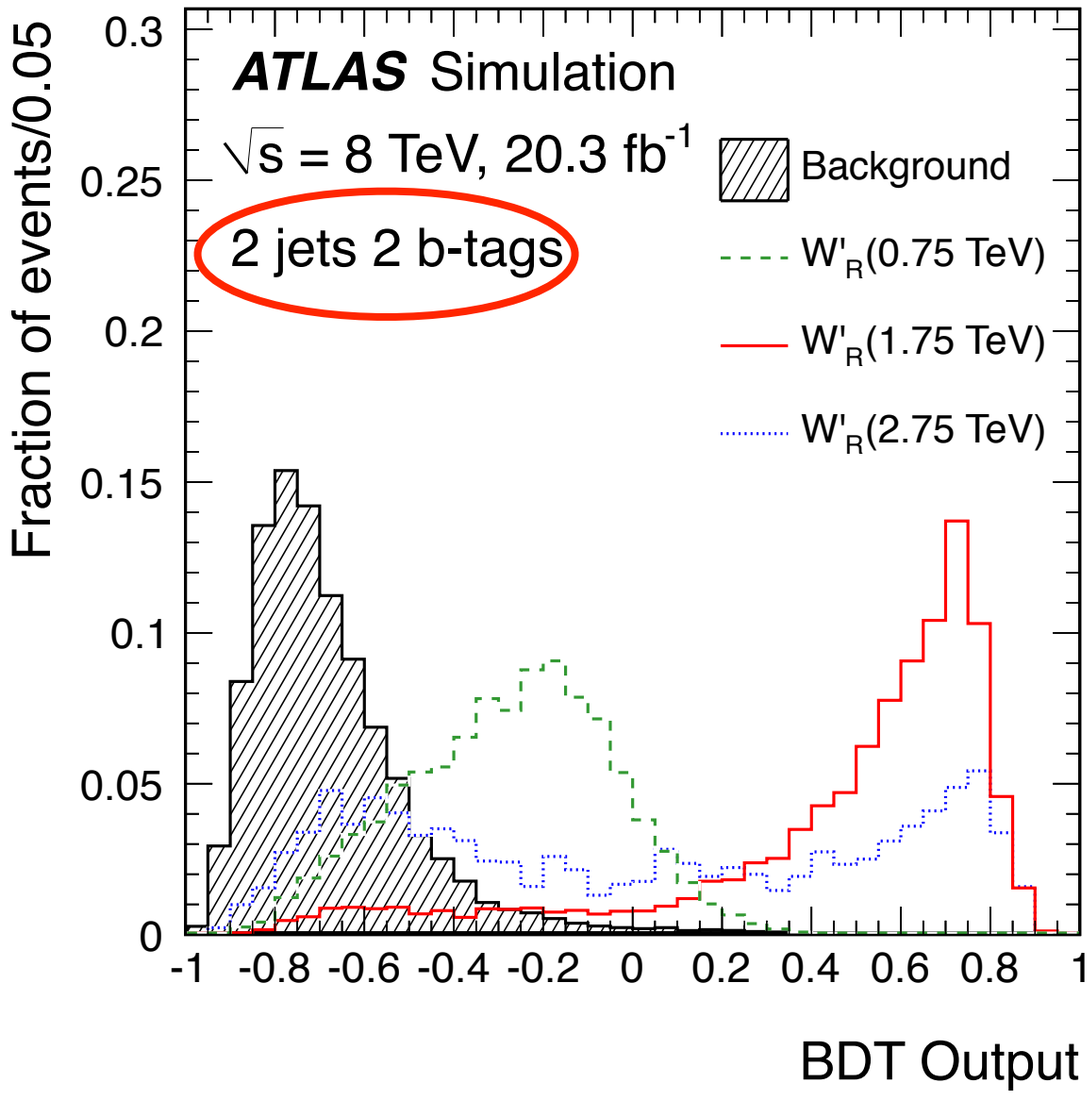
Phys. Lett. B 743 (2015) 235-255

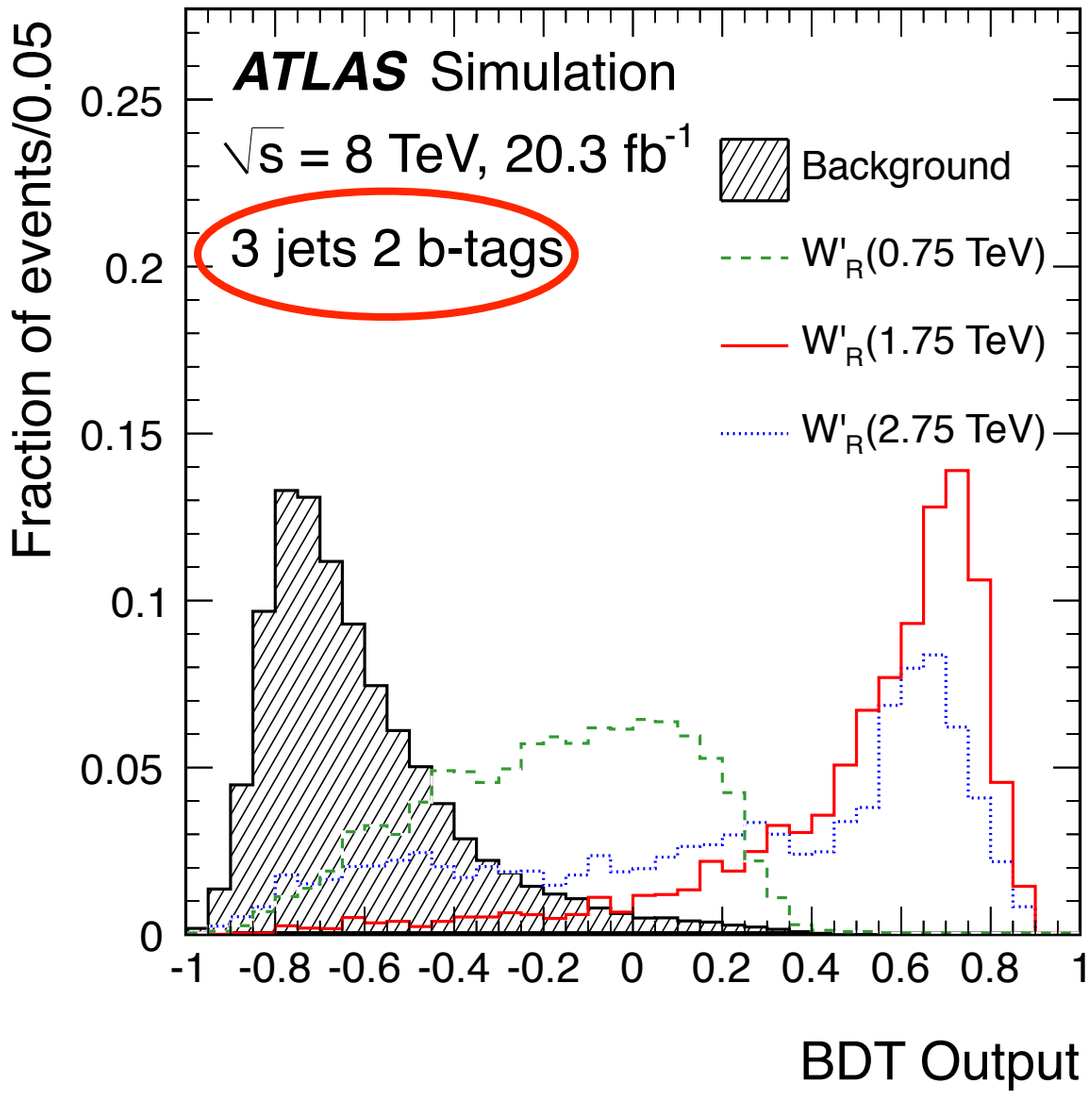
W' Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Signal Discrimination

- Boosted Decision Trees
- left and right handed W' in 2-jet and 3-jet regions







Phys. Lett. B 743 (2015) 235-255

W' Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

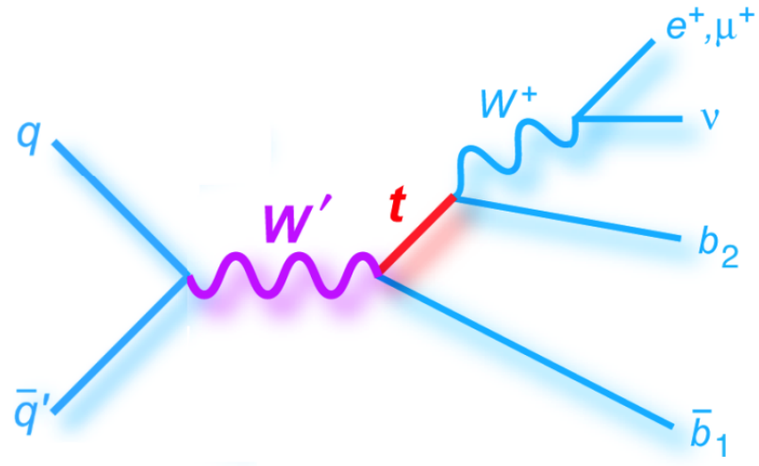
Results

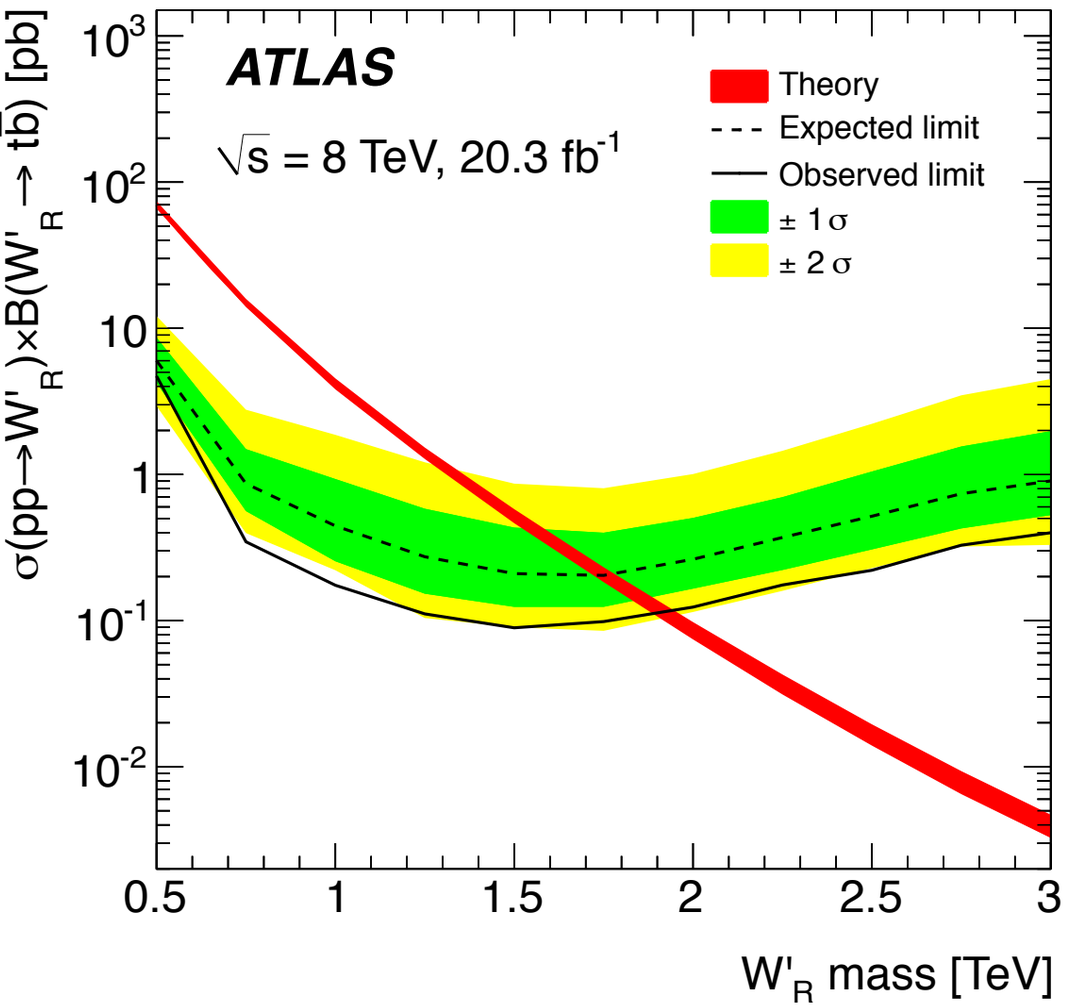
- limits set on W'$_R$ and W'$_L$ masses

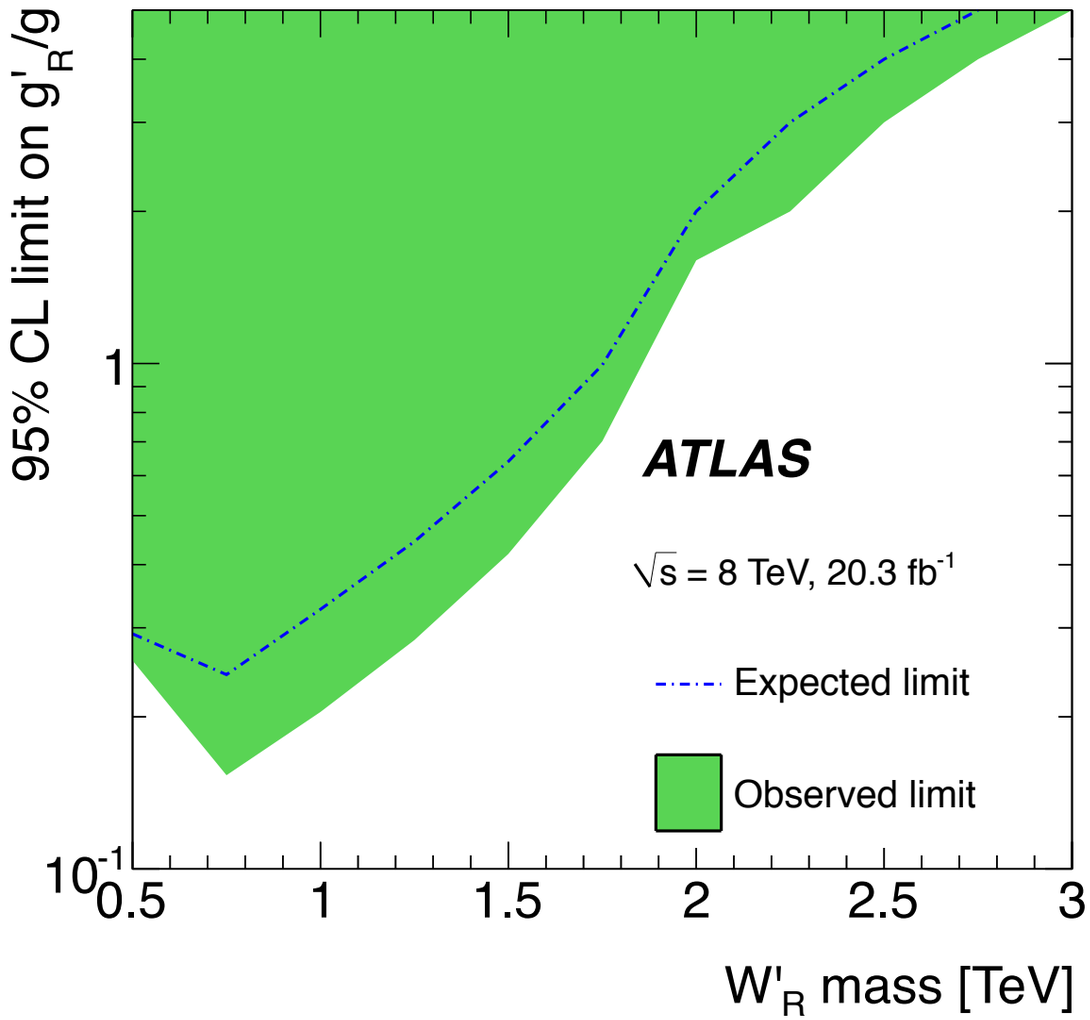
$$m\,(W'_L) > 1.70 \text{ TeV at } 95\% \text{ CL}$$

$$m\,(W'_R) > 1.92 \text{ TeV at } 95\% \text{ CL}$$

*in backup







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Search for Monotops
$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

Eur. Phys. J. C 75 (2015) 79

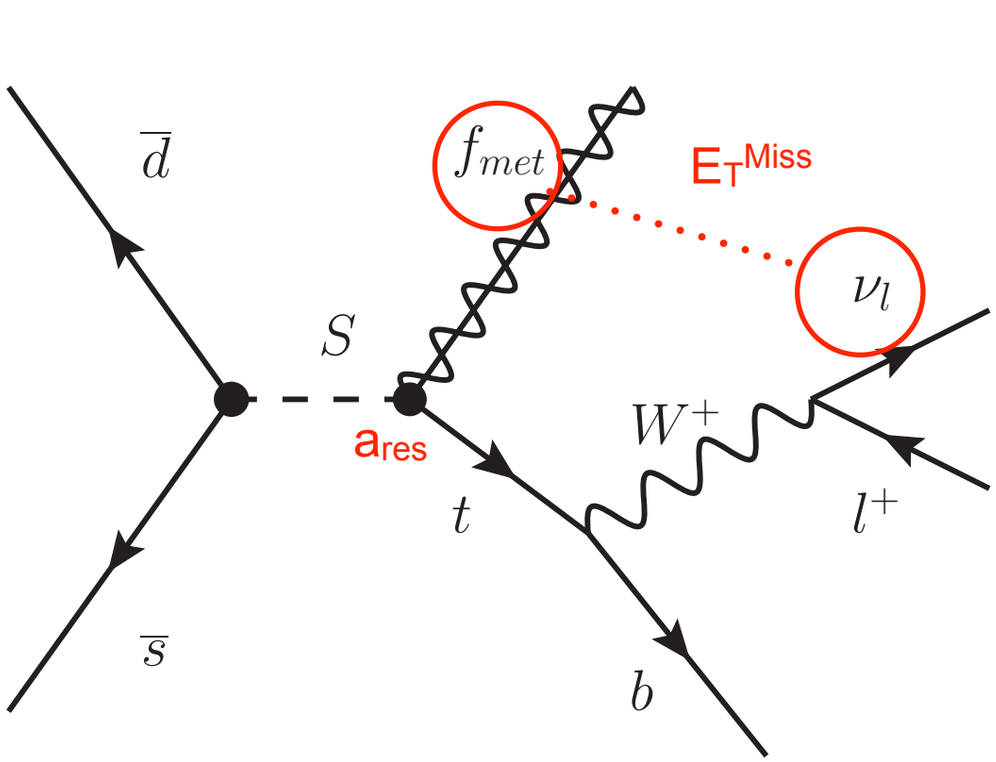
Monotop Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

BSM Search

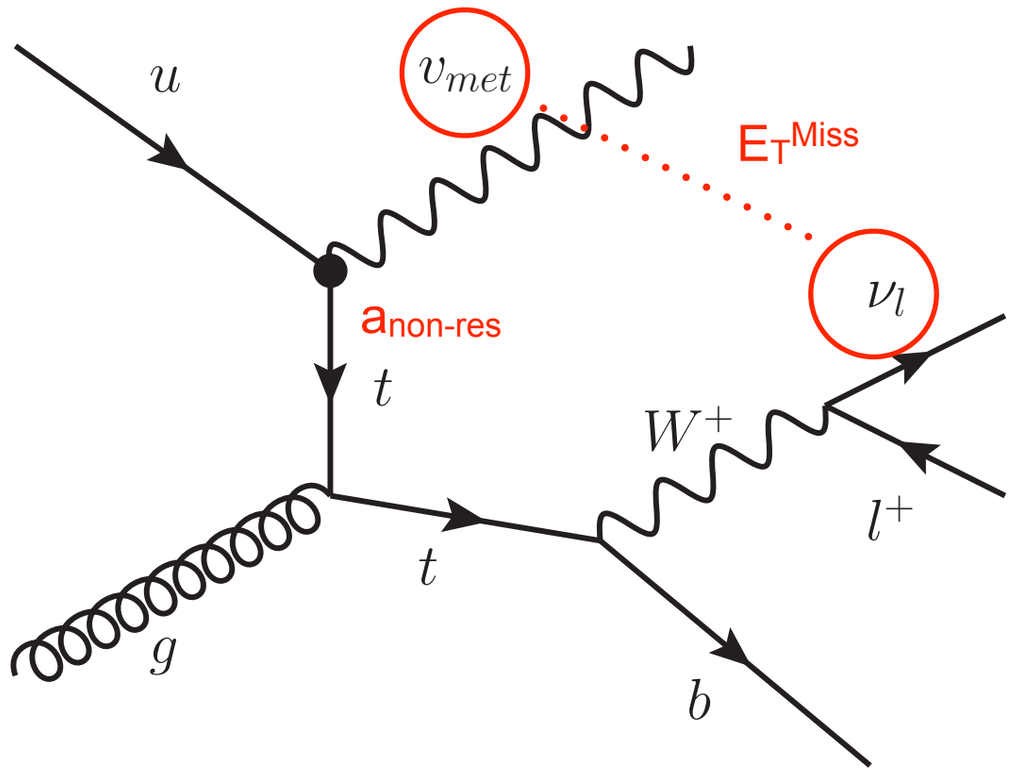
- search for single top quarks produced with large E_T^{Miss}
- dark matter candidate search
- resonant and non resonant production models

Final State Selection

- 1 electron or muon, 1 b-jet, E_T^{Miss}



resonant production



non-resonant production

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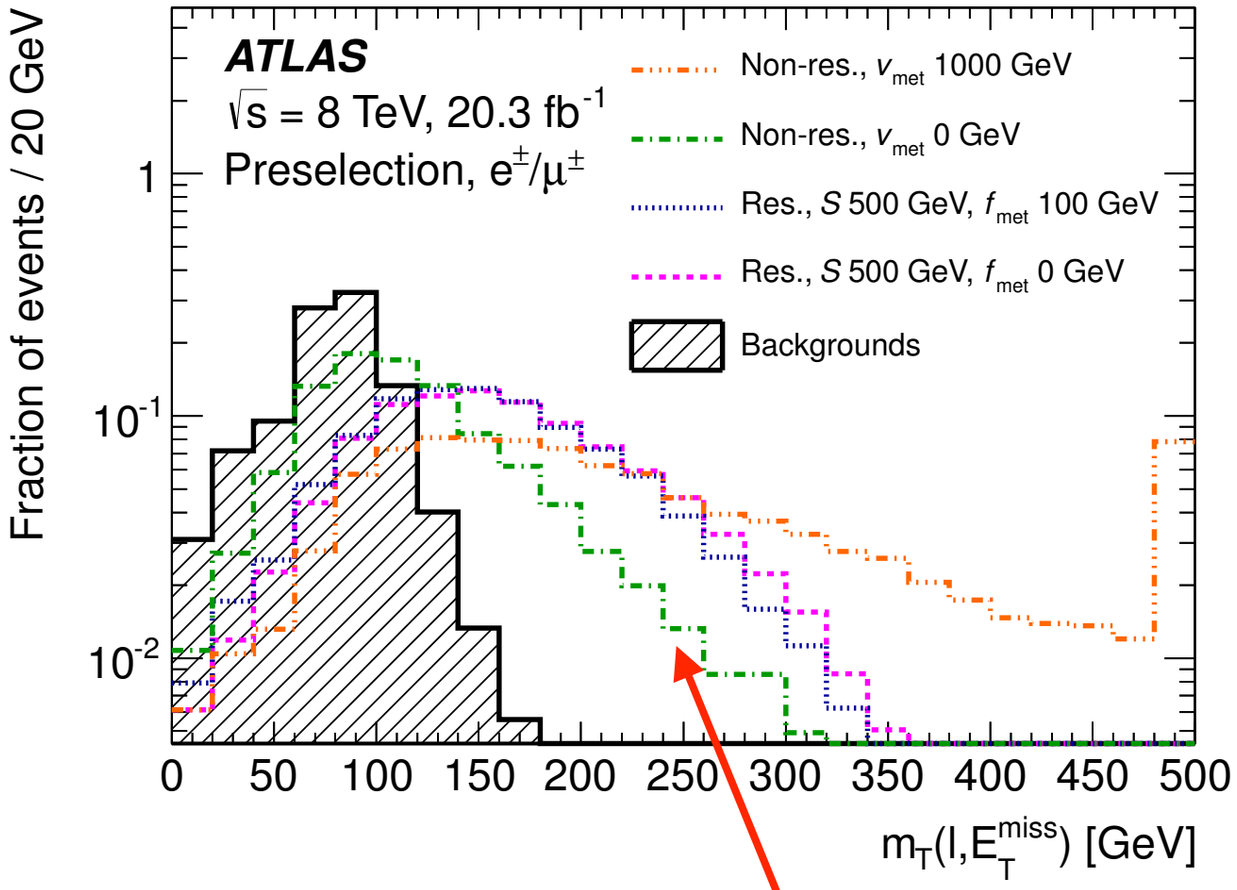
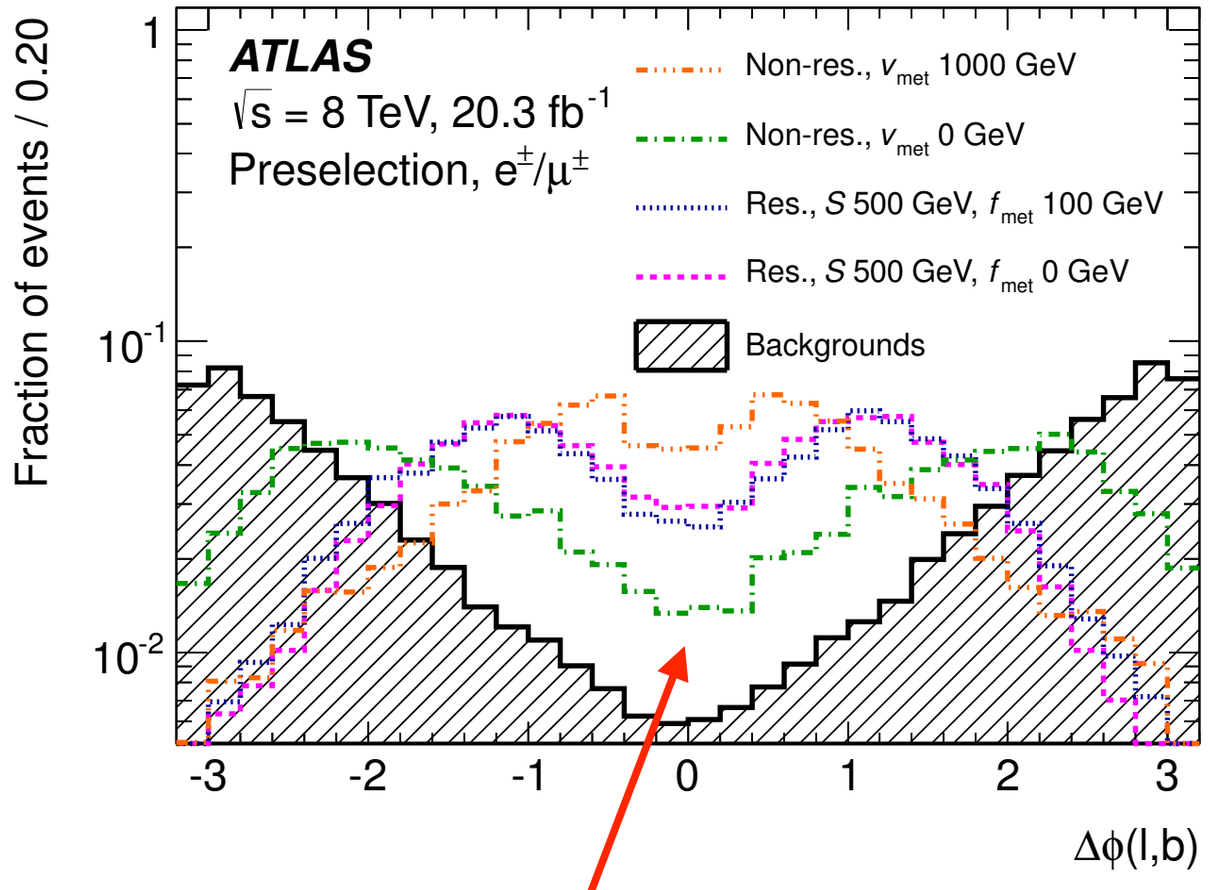
Signal Discrimination

- cut based approach using $M_T(l,E_T^{Miss})$ and $|\Delta\varphi(l,b)|$
- optimization done to maximize expected limits





excellent discriminating power

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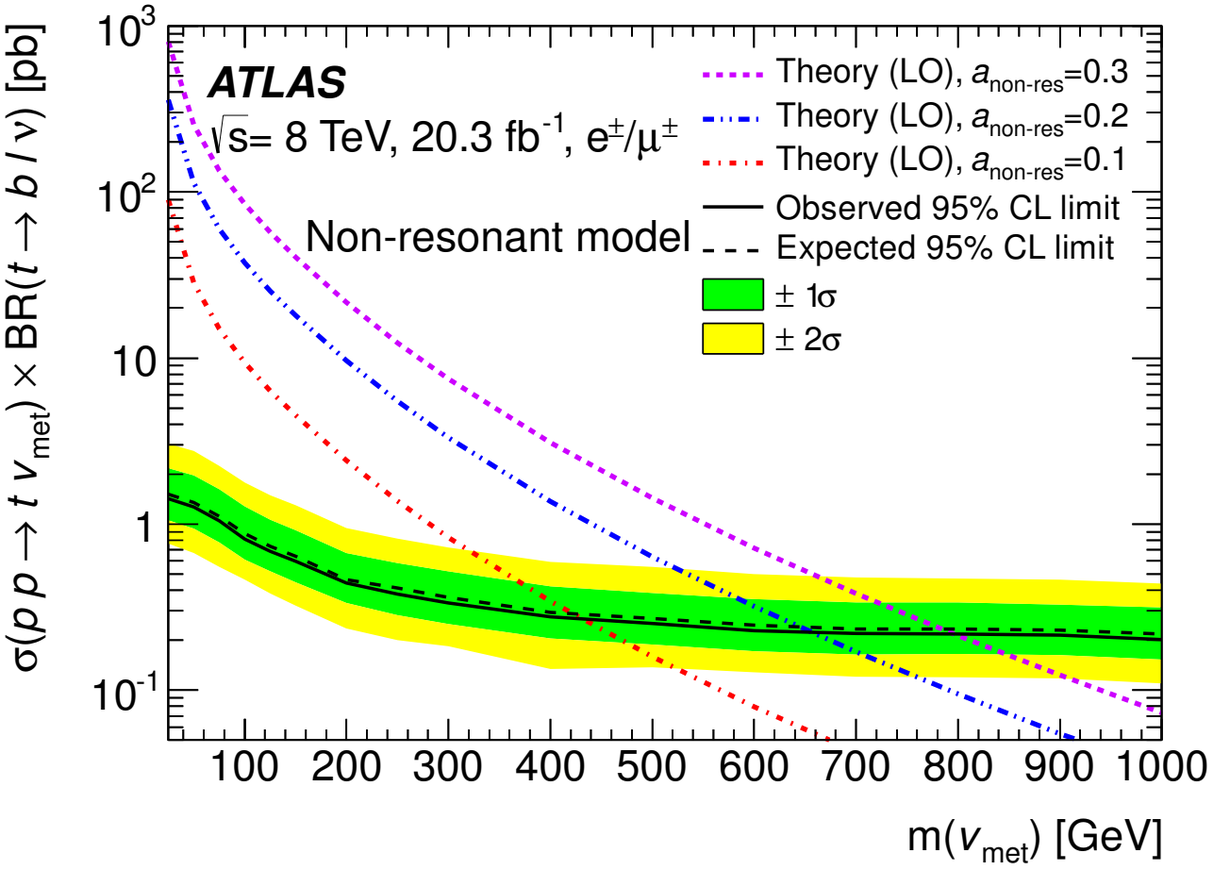
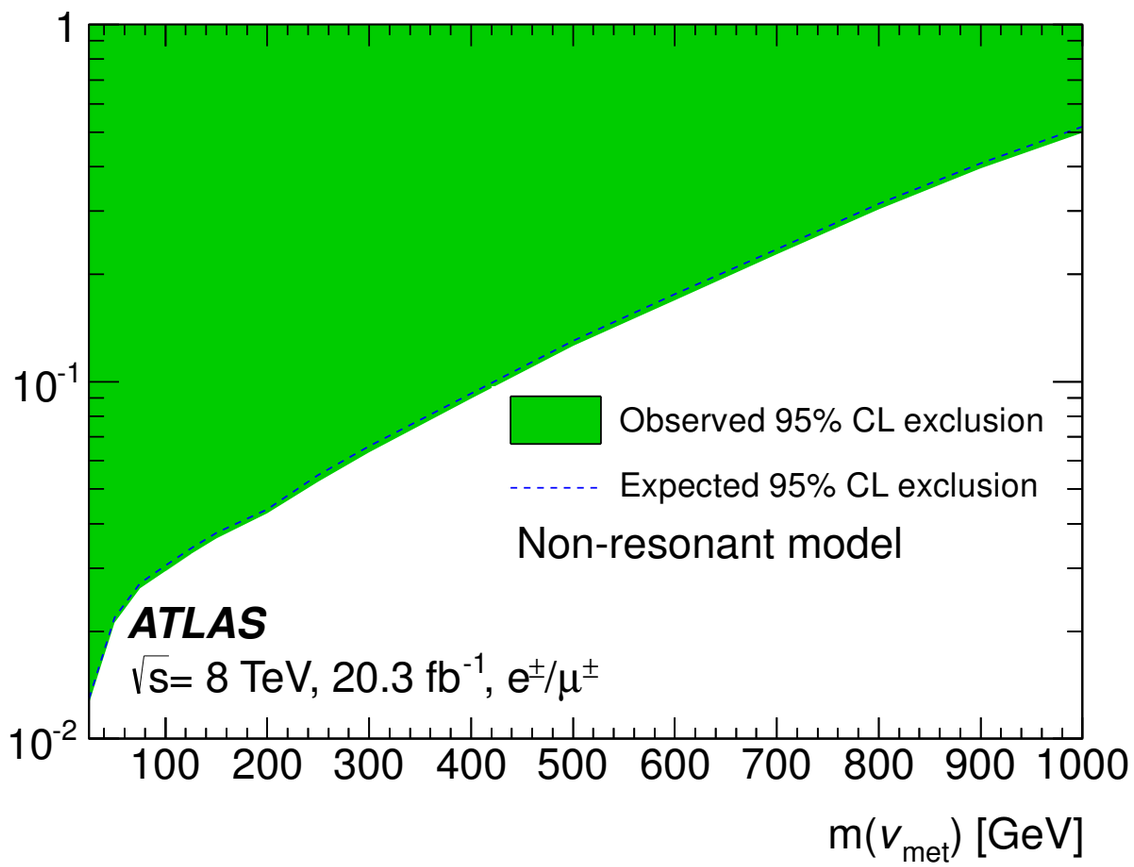
Monotop Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Results

- limits set on effective coupling strength
- limits set on m(v_{met}) and m(f_{met})





$$\text{for } a_{\text{non-res}} = 0.2,\ m\left(v_{\text{met}}\right) > 657 \text{ GeV at } 95\% \text{ CL}$$

$$\text{for } a_{\text{res}} = 0.2,\ m\left(f_{\text{met}}\right) > 100 \text{ GeV at } 95\% \text{ CL}$$ *in backup

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Single Top via FCNC

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

TOPQ-2014-13

Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

BSM Search

- search for single top quarks via FCNC in production vertex
- QCD multijet background makes search in the t → gq decay vertex challenging

Final State Selection

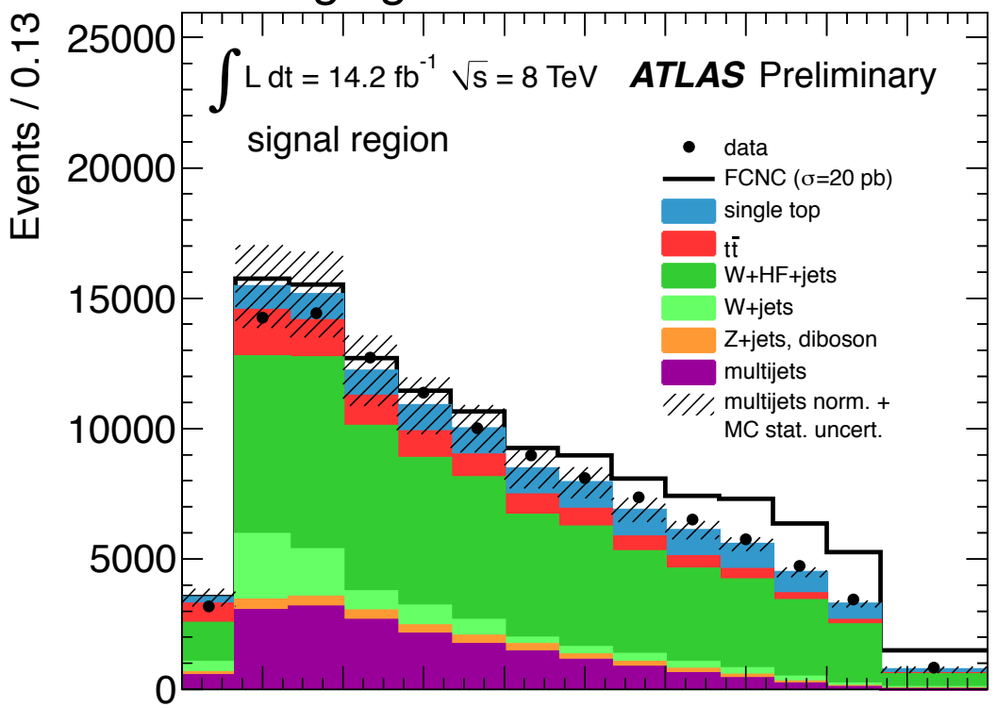
- 1 electron or muon, 1 b-jet, E_T^{Miss}

Signal Discrimination

- Neural Network

Main Systematics

- JES/JER
- PDF uncertainties
- b/c-tagging efficiencies



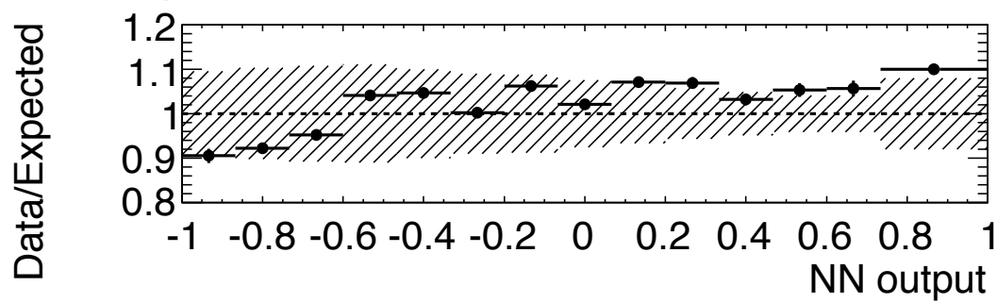
Results

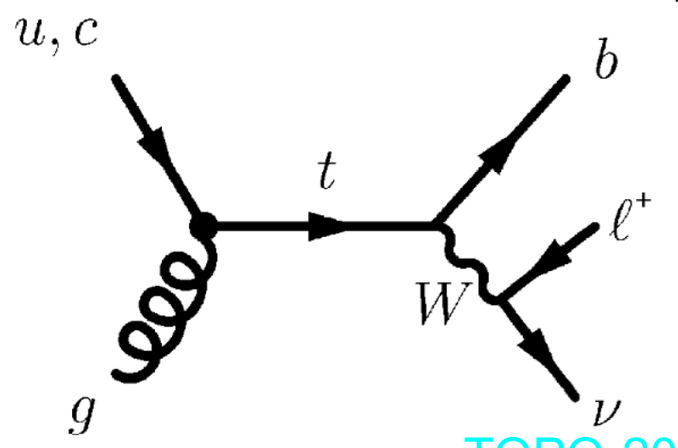
- limits set on coupling parameters κ_{ugt} and κ_{cgt}
- limits set on $\mathcal{BR}$(t → cg) and $\mathcal{BR}$(t → ug)

$$\mathcal{L}_{\text{eff}} = g_s \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{t}\, \sigma^{\mu\nu} T^a (f_q^L P_L + f_q^R P_R)\, q\, G^a_{\mu\nu} + h.c.,$$

$$\frac{\kappa_{ugt}}{\Lambda} < 5.8 \times 10^{-3}\ \text{TeV}^{-1} \qquad \mathcal{B}(t \to ug) < 4.0 \times 10^{-5}$$

$$\frac{\kappa_{cgt}}{\Lambda} < 13 \times 10^{-3}\ \text{TeV}^{-1} \qquad \mathcal{B}(t \to cg) < 17 \times 10^{-5}$$





TOPQ-2014-13

Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

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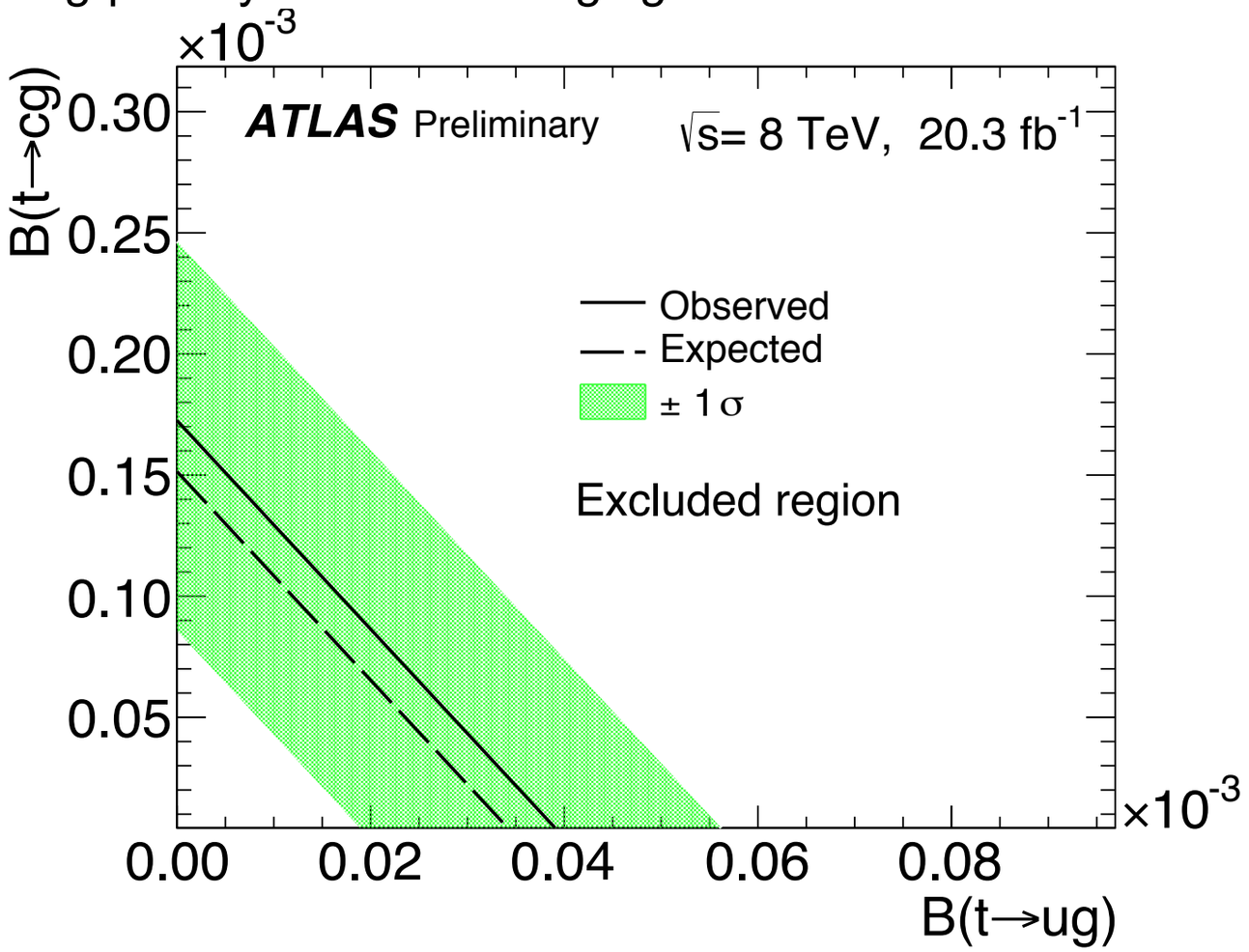
- limits set on $\mathcal{BR}$(t → cg) and $\mathcal{BR}$(t → ug)



$$\mathcal{L}_{\text{eff}} = g_s \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{t}\, \sigma^{\mu\nu} T^a (f_q^L P_L + f_q^R P_R)\, q\, G^a_{\mu\nu} + h.c.,$$

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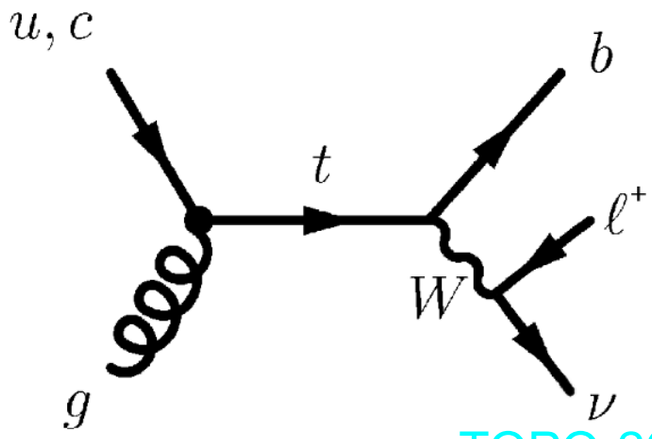
$$\frac{\kappa_{cgt}}{\Lambda} < 13 \times 10^{-3}\ \text{TeV}^{-1} \qquad \mathcal{B}(t \to cg) < 17 \times 10^{-5}$$



TOPQ-2014-13

Summary

- ATLAS is performing a wide range of studies involving single top quark
- Cross section measurements for t- and Wt-channels were presented
- Presented search results for s-channel analysis
- Showed $|V_{tb}|$ matrix element extractions
- Latest limits on BSM searches were shown
- Measurements and additional searches underway for Run-II
- Visit our public page for up-to-date results

13 TeV t-channel single top event display

E_T^{Miss}
(~ 30 GeV)

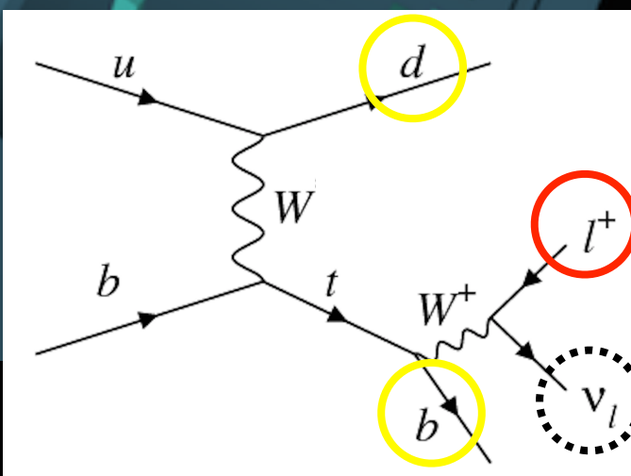
ATLAS EXPERIMENT

Run: 267073
Event: 279124678
2015-06-05 02:24:03 CEST

forward light quark jet
(p_T ~ 30 GeV)

reconstructed muon
(p_T ~ 30 GeV)

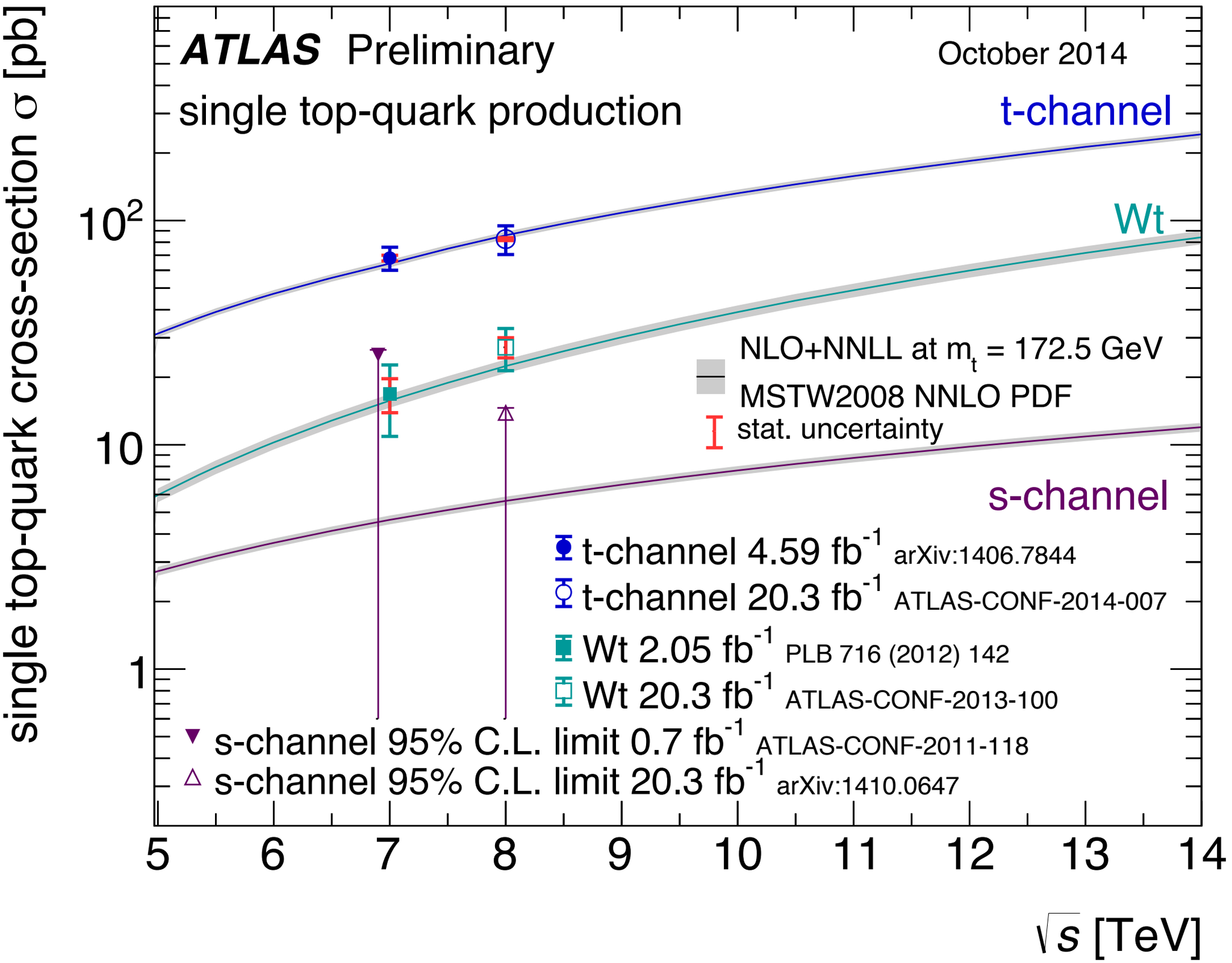
central b-jet
(p_T ~ 50 GeV)



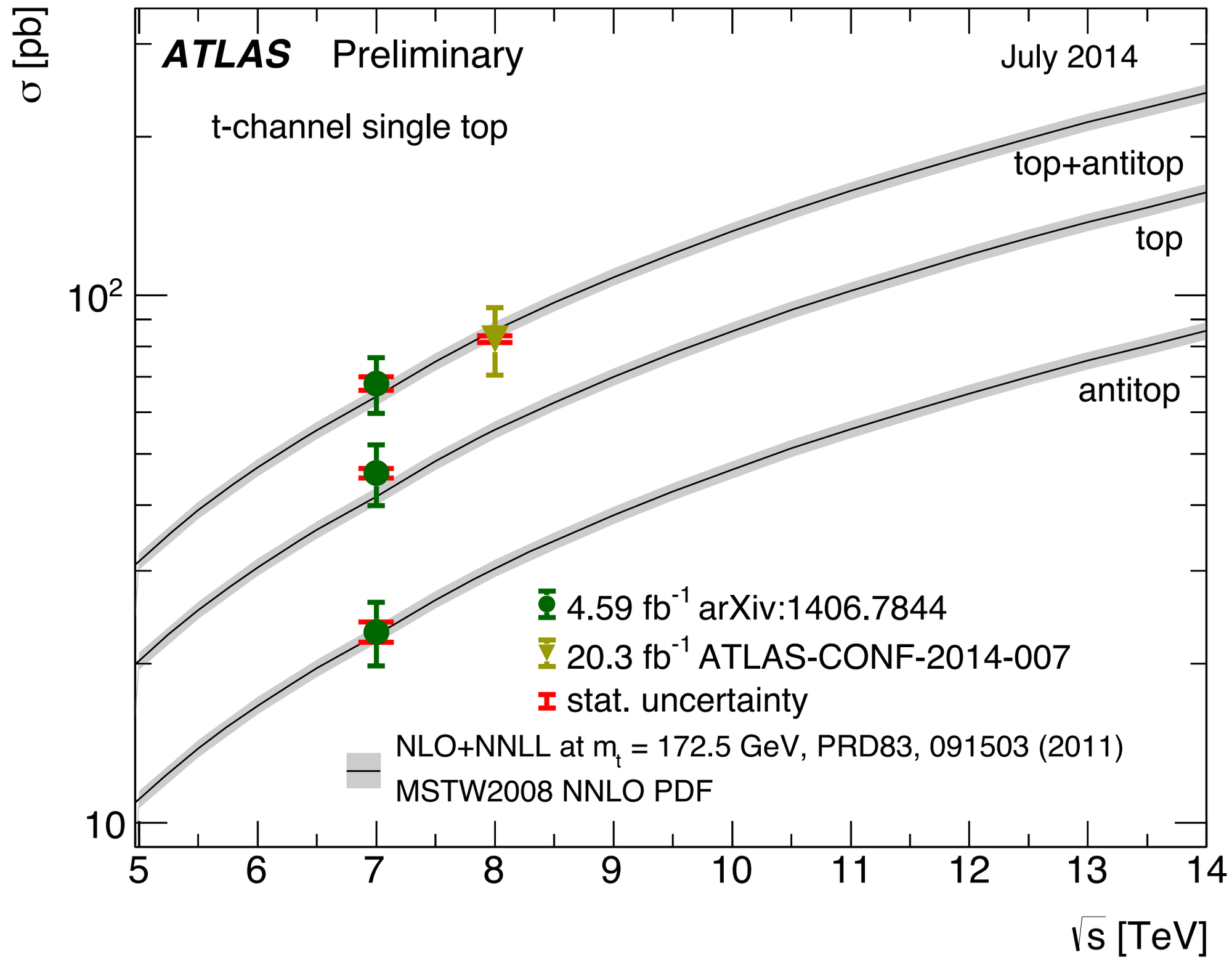
BACKUP

Summary Plots

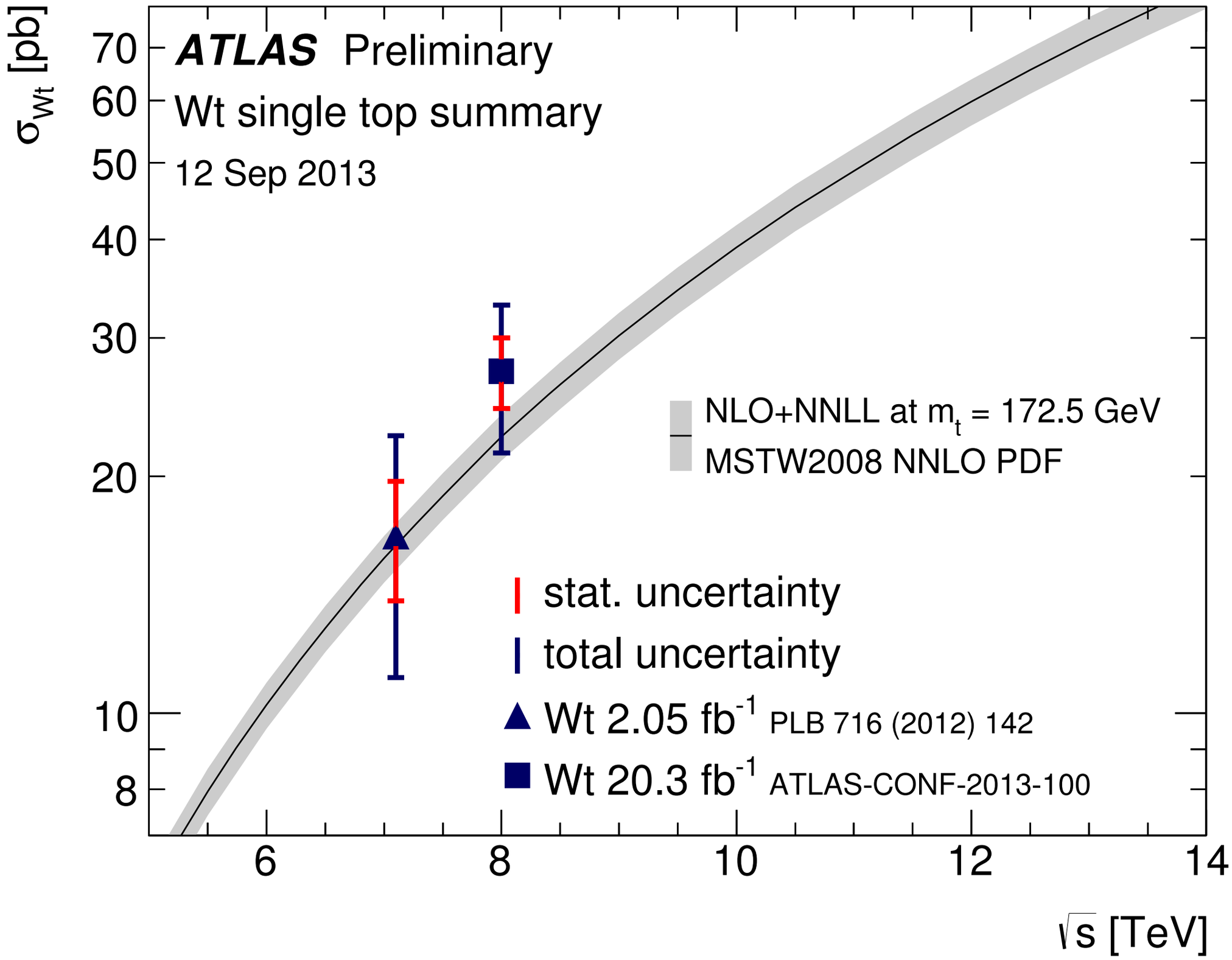
Single Top Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



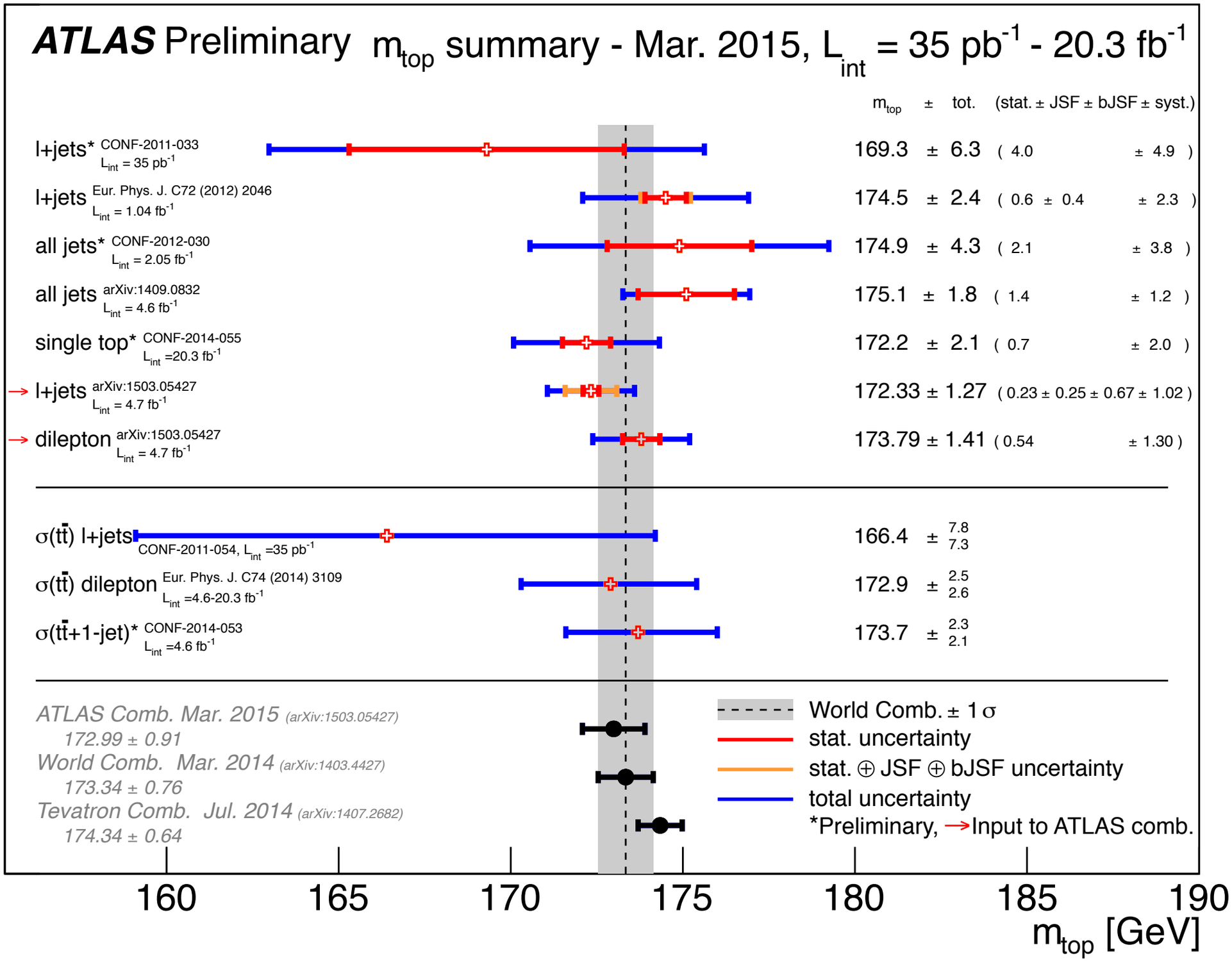
t-channel Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



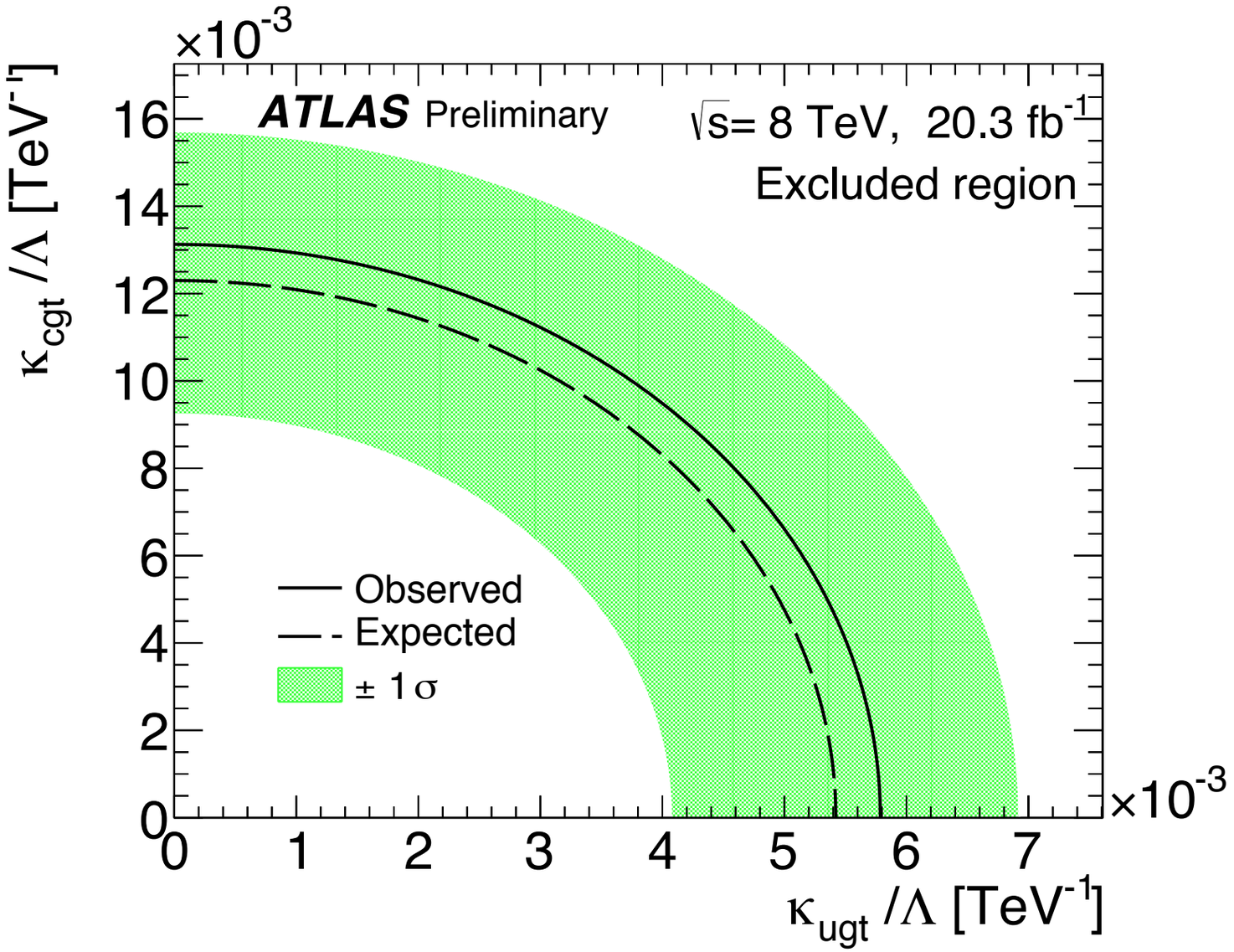
Wt-channel Cross Section ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



Top Mass Summary ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



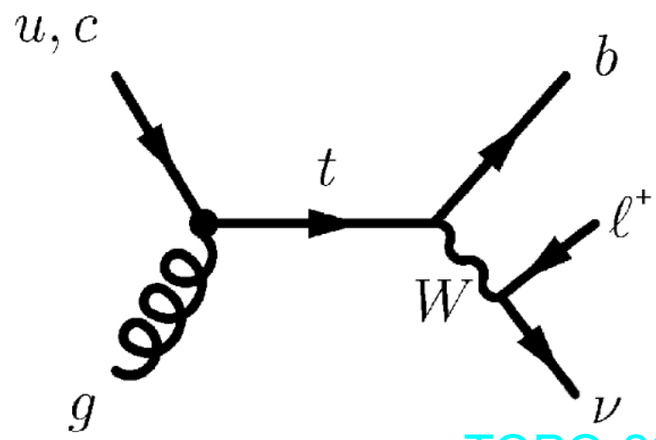
Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



$$\mathcal{L}_{\text{eff}} = g_s \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{t}\, \sigma^{\mu\nu} T^a (f_q^L P_L + f_q^R P_R)\, q\, G^a_{\mu\nu} + h.c.,$$

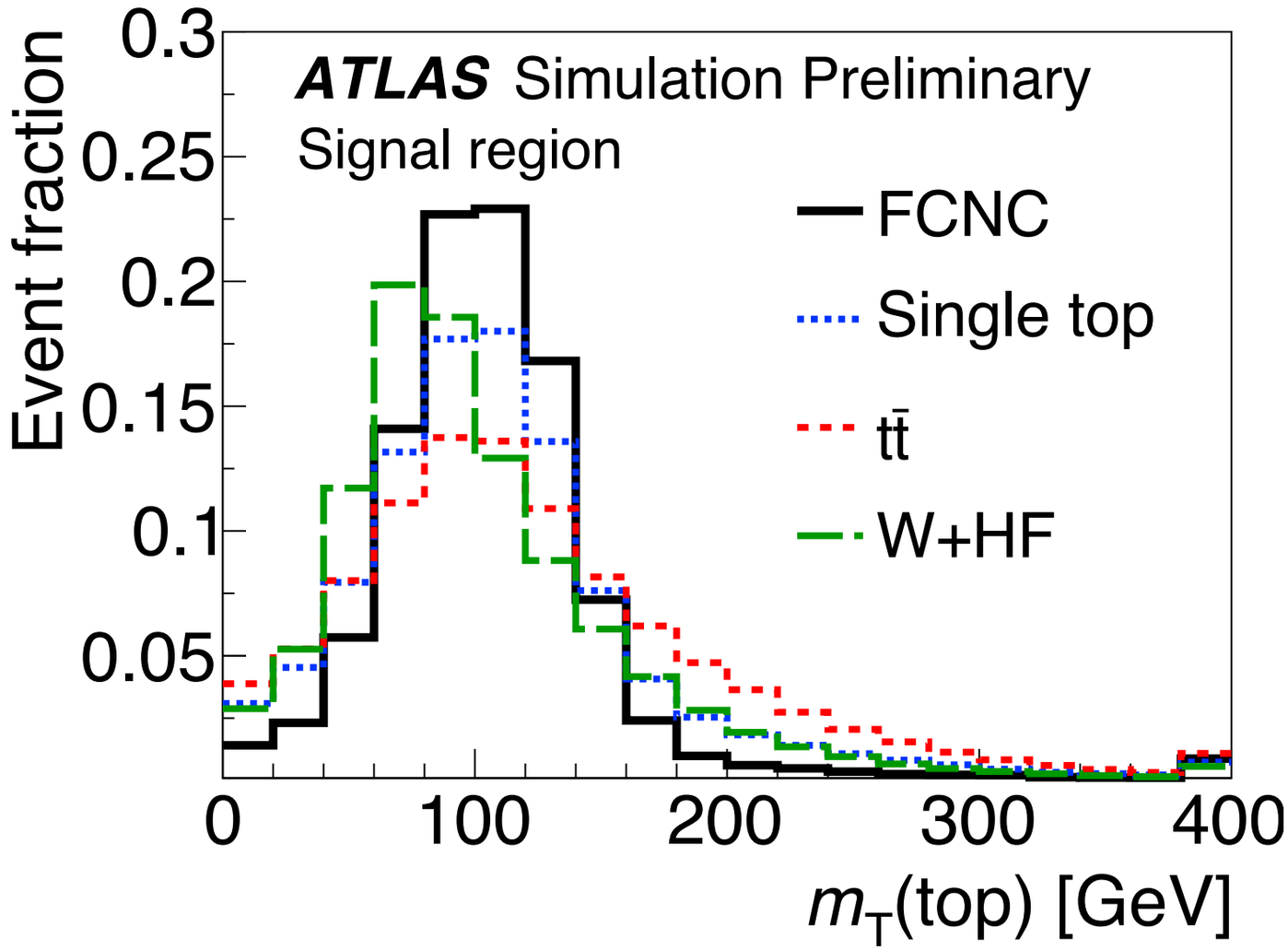
$$\frac{\kappa_{ugt}}{\Lambda} < 5.8 \times 10^{-3}\ \text{TeV}^{-1} \qquad \mathcal{B}(t \to ug) < 4.0 \times 10^{-5}$$

$$\frac{\kappa_{cgt}}{\Lambda} < 13 \times 10^{-3}\ \text{TeV}^{-1} \qquad \mathcal{B}(t \to cg) < 17 \times 10^{-5}$$



TOPQ-2014-13

Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



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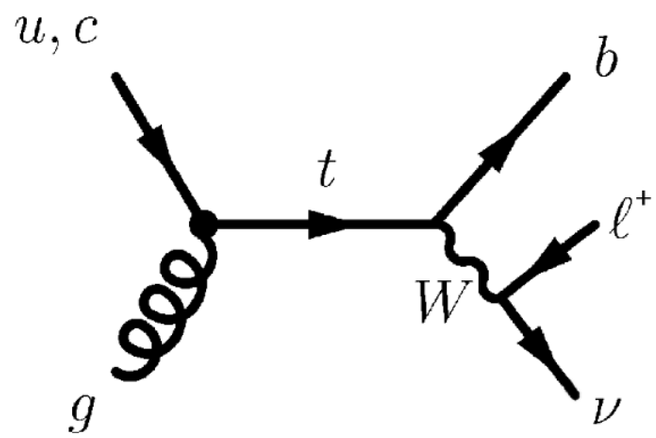
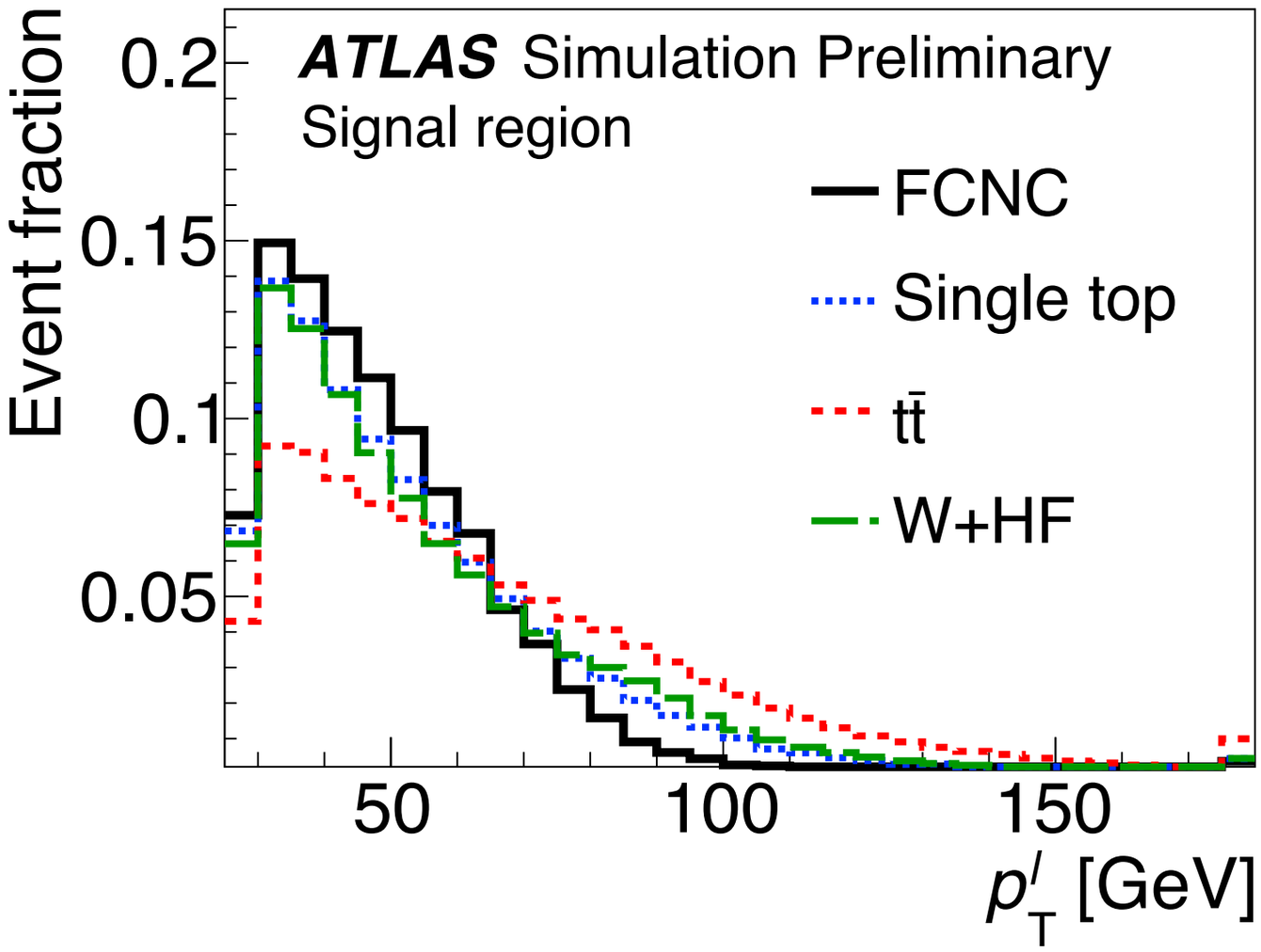


TOPQ-2014-13

Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



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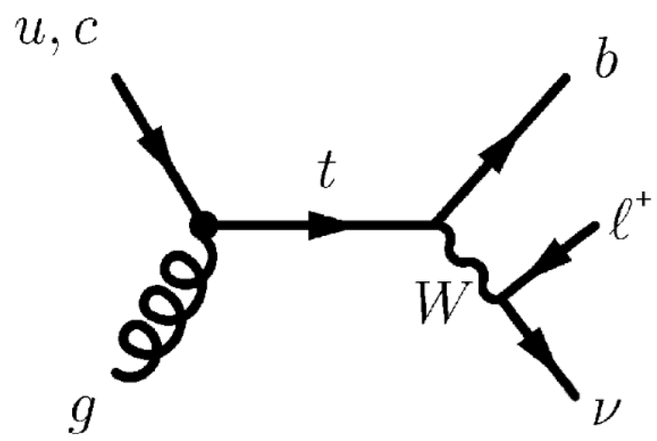
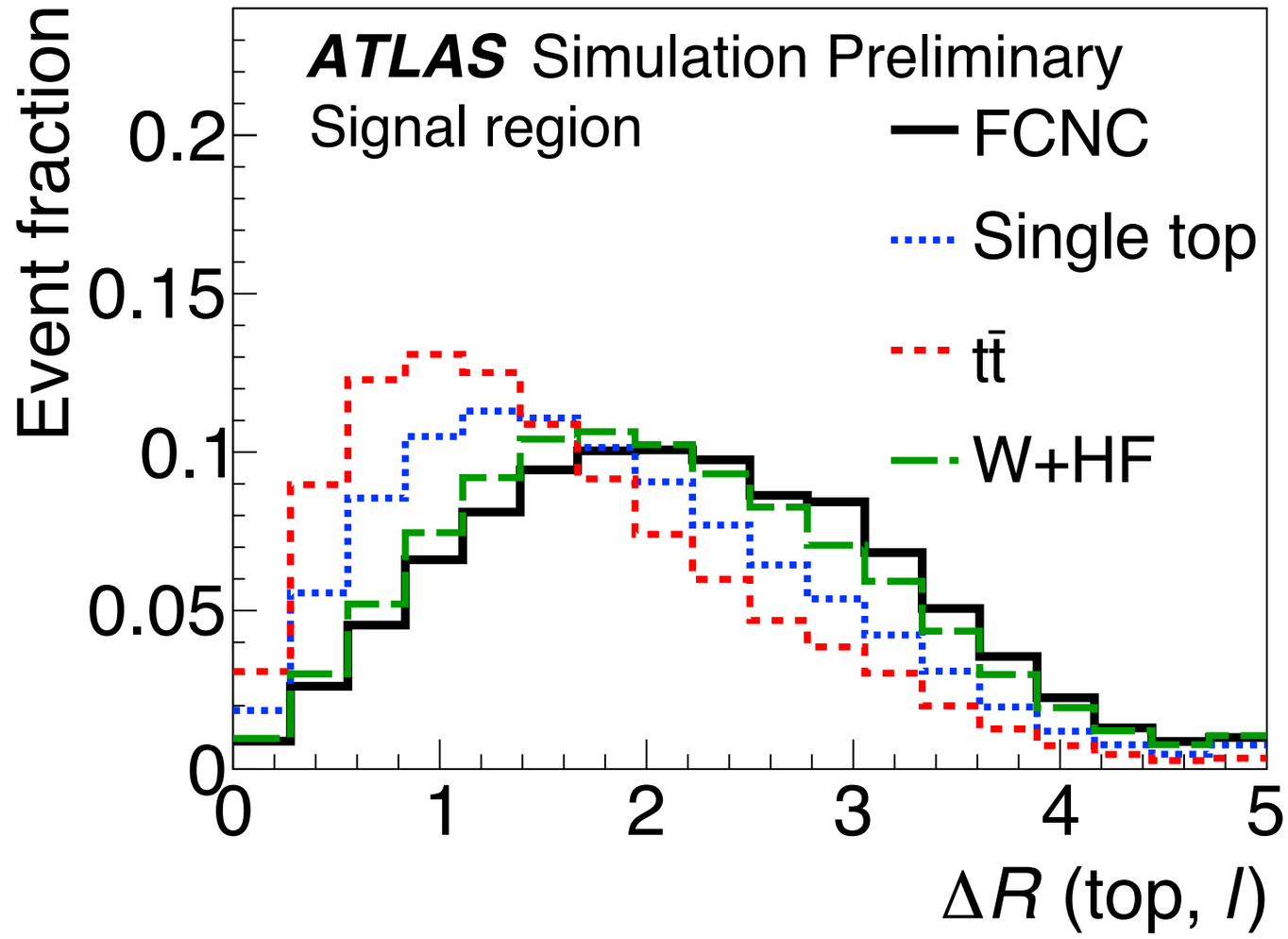


TOPQ-2014-13

Single Top via FCNC Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})



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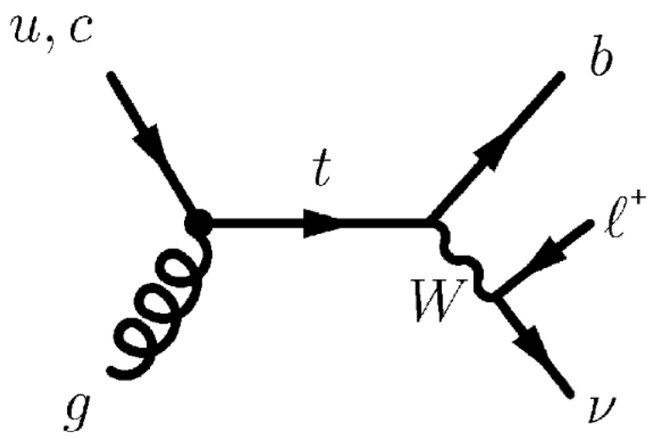


TOPQ-2014-13

t-chan Cross Section Measurements

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

ATLAS-CONF-2014-007

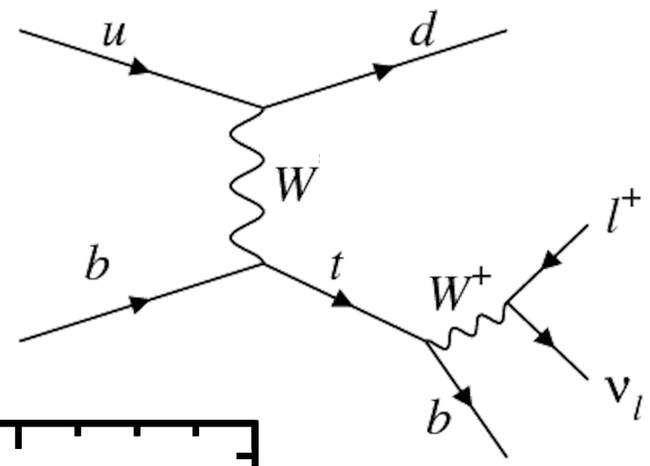
Selection Cuts in Fiducial Volume

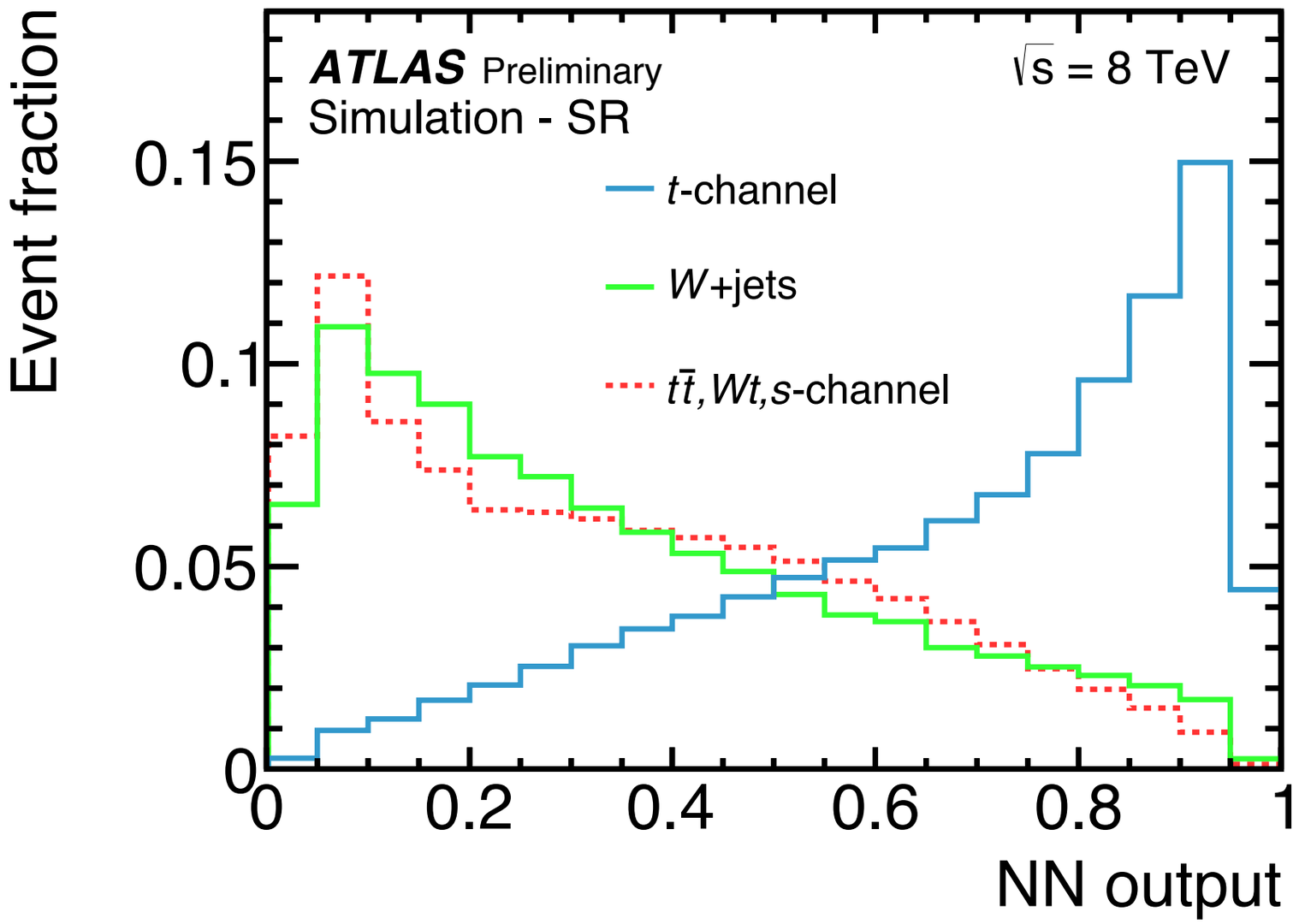
Object	Cut
Electrons	$p_T > 25$ GeV and $\|\eta\| < 2.5$
Muons	$p_T > 25$ GeV and $\|\eta\| < 2.5$
Jets	$p_T > 30$ GeV and $\|\eta\| < 4.5$
	$p_T > 35$ GeV, if $2.75 < \|\eta\| < 3.5$
Lepton (ℓ), Jets (j_i)	$\Delta R(\ell, j_i) > 0.4$
E_T^{miss}	$E_T^{miss} > 30$ GeV
Transverse W-boson mass	$m_T(W) >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

- stable particles; mean lifetime > 30ps
- lepton from W boson decay
- lepton dressed with photons within a cone of ΔR<0.1
- E_T^{Miss} vectorial sum of neutrinos form W boson decay
- AKT4 jets used
- overlap removal; reject events with ΔR(lep,b-jet)<0.4

Signal Discrimination

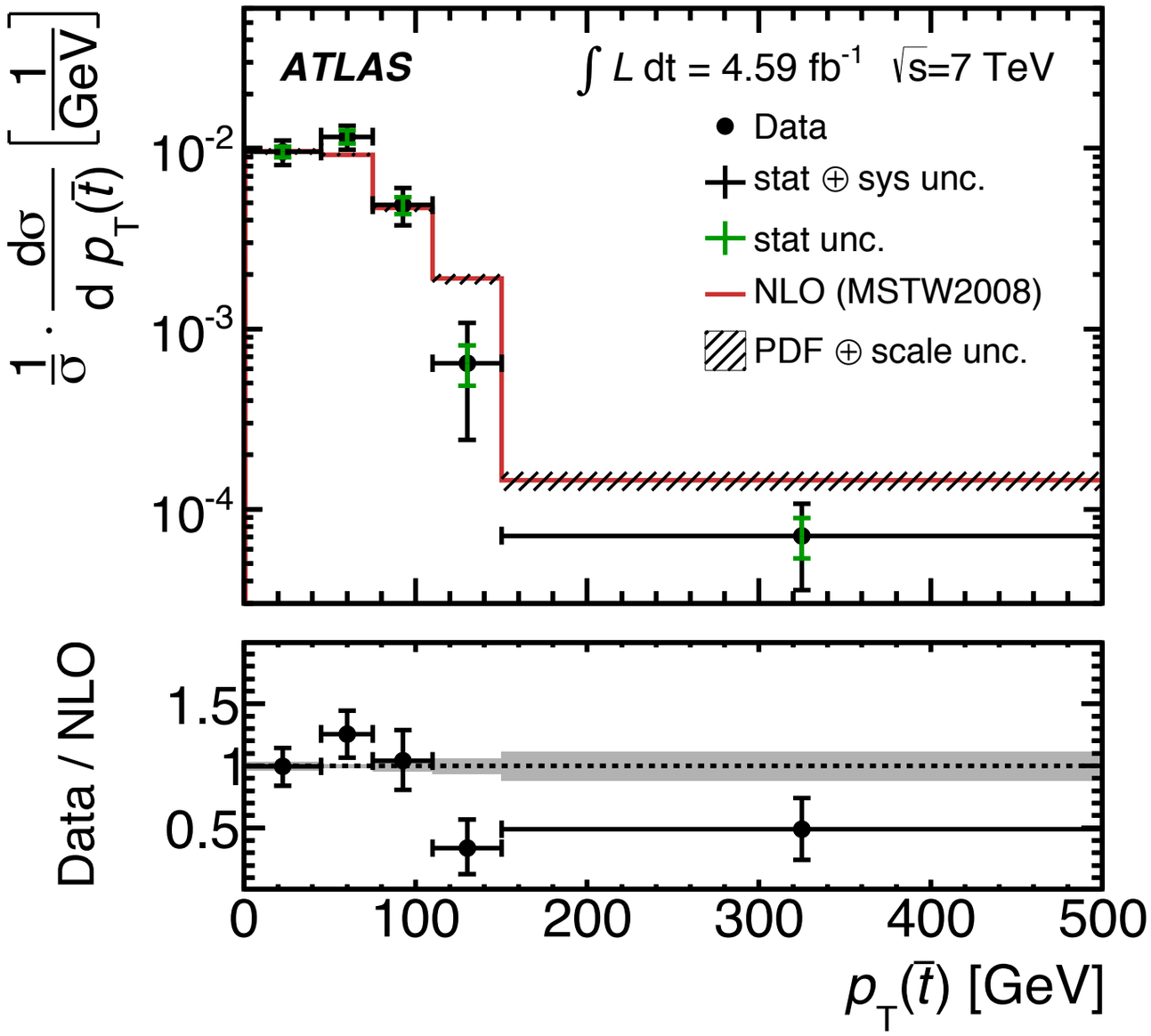
- Neural Network
- most discriminating variables: |η(j)| and m(lvb)





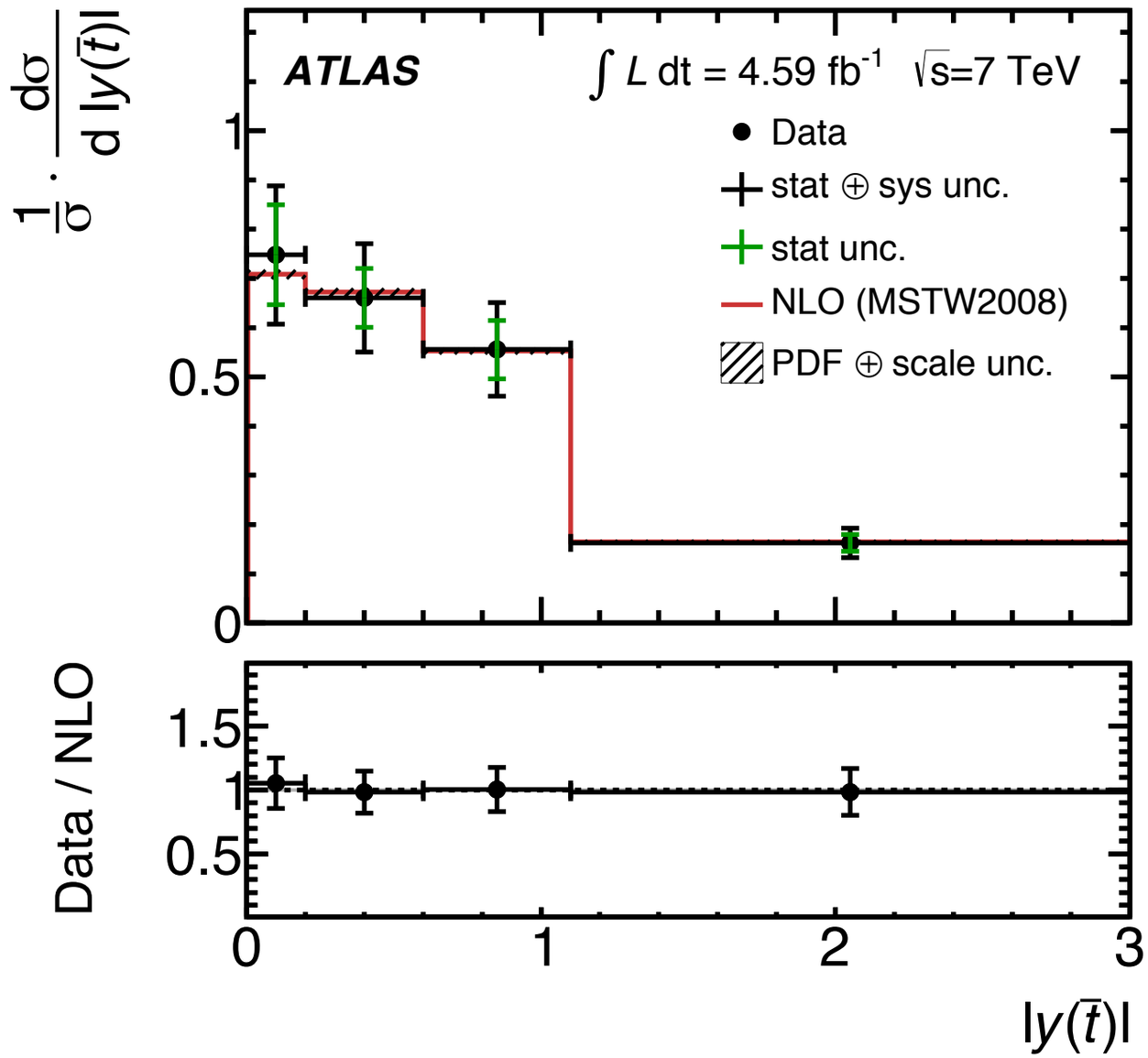
ATLAS-CONF-2014-007

t-channel Differential Cross Section ($\sqrt{s}$ = 7 TeV, 4.6 fb^{-1})



$p_T(\bar{t})$ [GeV]	$\frac{d\sigma}{dp_T(\bar{t})}$ [$\frac{fb}{GeV}$]	total [%]	stat. [%]	syst. [%]
[0, 45]	190 ± 50	± 28	± 12	± 25
[45, 75]	230 ± 40	± 18	± 8.2	± 17
[75, 110]	97 ± 27	± 27	± 13	± 24
[110, 150]	13.0 ± 9.7	± 74	± 26	± 70
[150, 500]	1.4 ± 0.9	± 59	± 26	± 53

t-channel Differential Cross Section ($\sqrt{s}$ = 7 TeV, 4.6 fb^{-1})



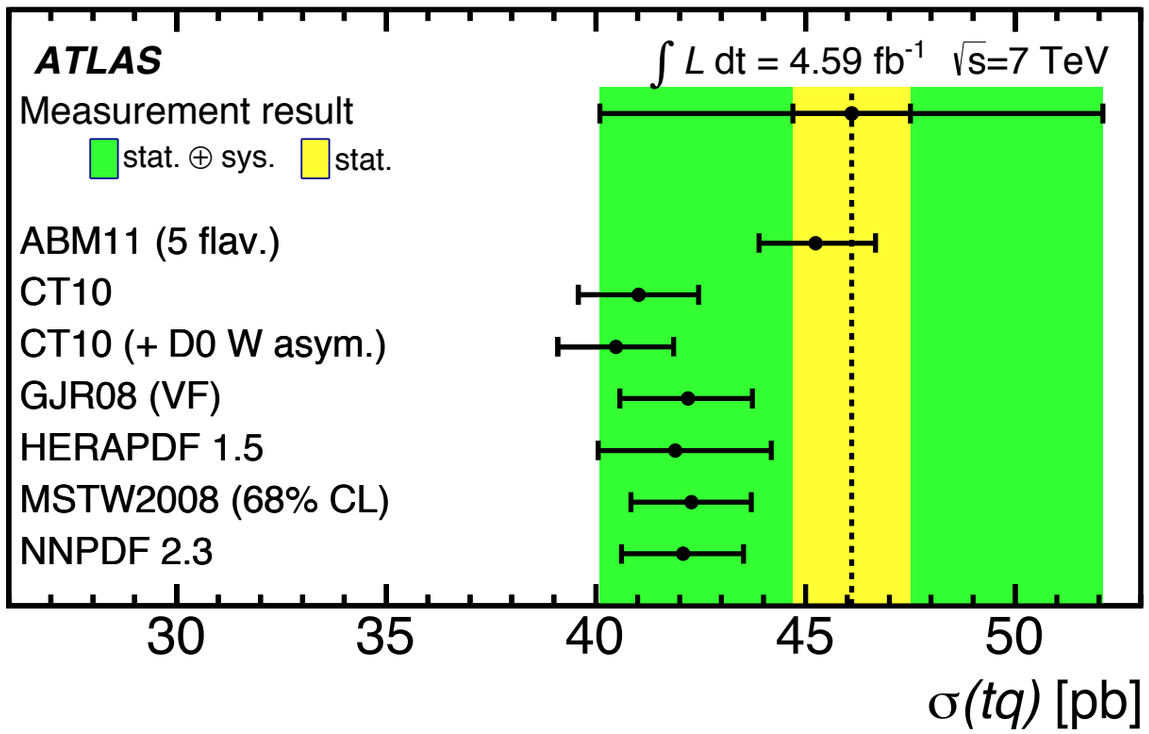
$\lvert y(\bar{t})\rvert$	$\frac{d\sigma}{d\lvert y(\bar{t})\rvert}$ [pb]	total [%]	stat. [%]	syst. [%]
[0, 0.2]	15.0 ± 3.4	±23	±13	±18
[0.2, 0.6]	13.3 ± 3.3	±25	±9.5	±23
[0.6, 1.1]	11.2 ± 2.6	±23	±11	±20
[1.1, 3.0]	3.3 ± 0.9	±29	±13	±25

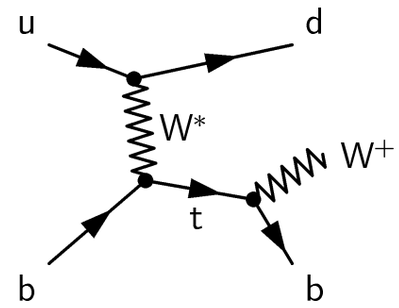
t-channel R_t Measurement

$\sqrt{s}$ = 7 TeV, 4.6 fb^{-1}

Phys. Rev. D. 90, 112006

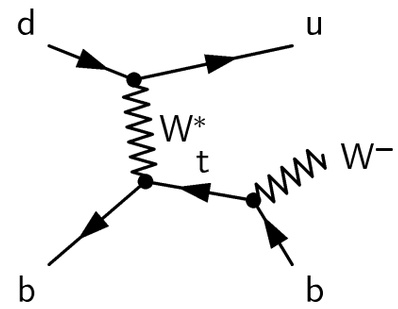
t-channel R_t Measurement ($\sqrt{s}$ = 7 TeV, 4.6 fb^{-1})





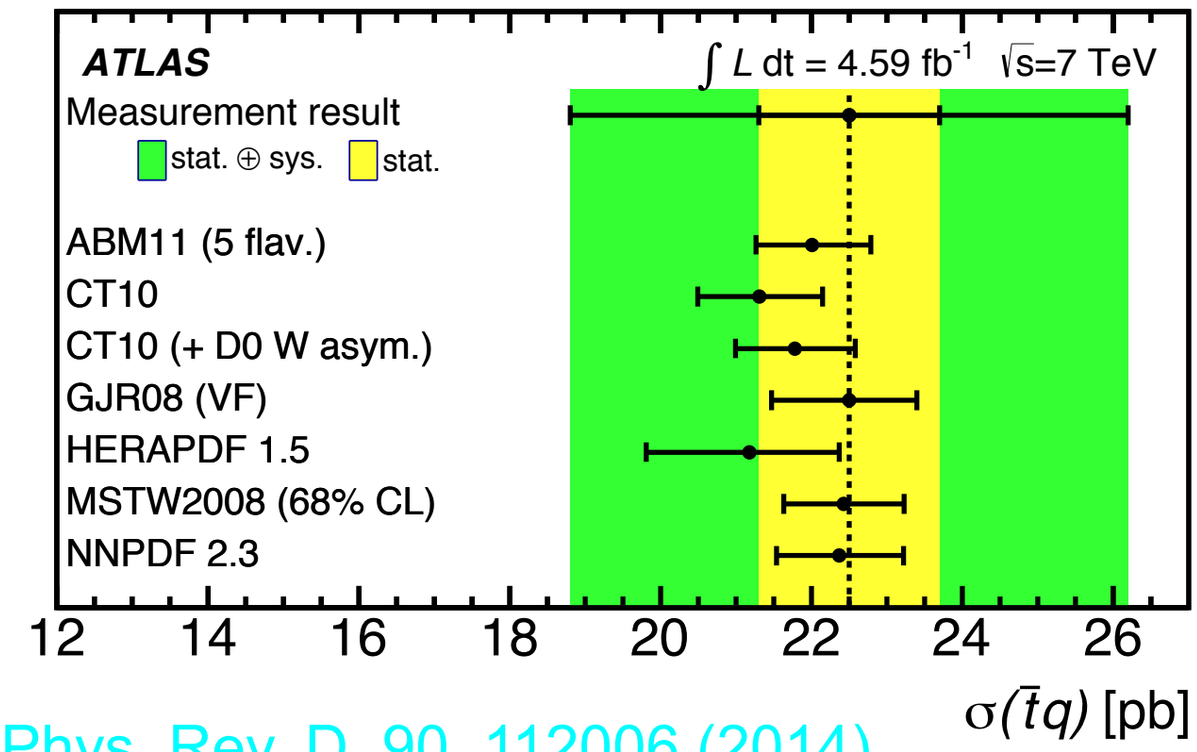
$$\sigma_{\text{t-chan}}\,(t) = 46 \pm 1(\text{stat}) \pm 3(\text{syst})\ \text{pb}$$

$$\sigma^{\text{theory}}_{t\text{-chan}}\,(t) = 41.9^{+1.8}_{-0.9}\ \text{pb}$$



$$\sigma_{\text{t-chan}}\,(\bar{t}) = 23 \pm 1(\text{stat}) \pm 3(\text{syst})\ \text{pb}$$

$$\sigma^{\text{theory}}_{t\text{-chan}}\,(\bar{t}) = 22.7^{+0.9}_{-1.0}\ \text{pb}$$



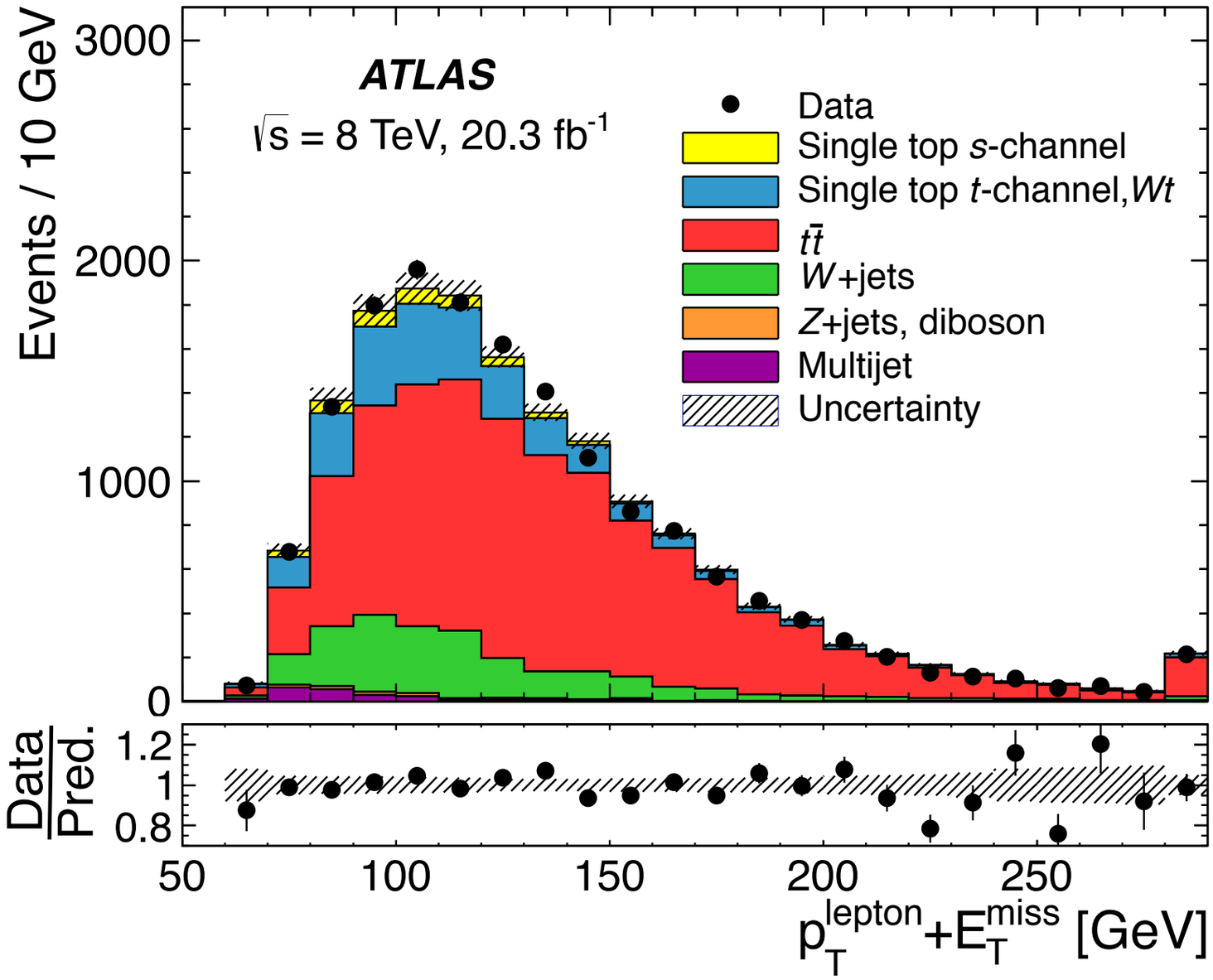
Phys. Rev. D. 90, 112006 (2014)

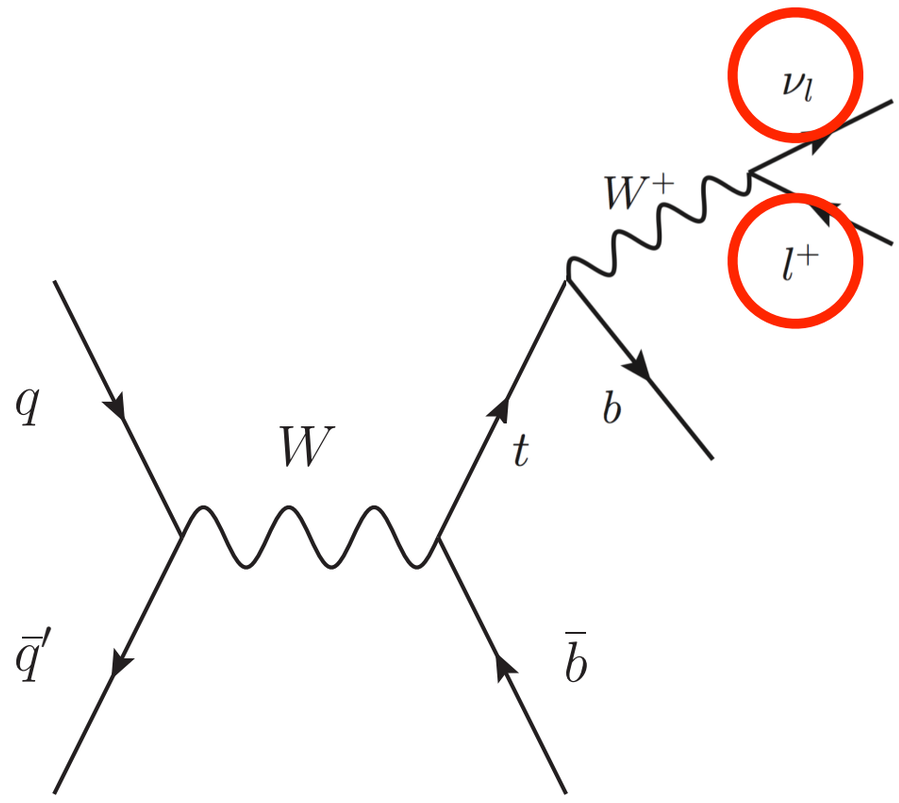
s-chan Search
$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

Phys. Lett. B 740 (2015) 118

Signal Discrimination

- Boosted Decision Tree
- most discriminating variables: $|\Delta\varphi(b,t)|$ and $H_T(lep+E_T^{Miss})$





Phys. Lett. B 740 (2015) 118

Search for W'→tb̄

$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

Phys. Lett. B 743 (2015)

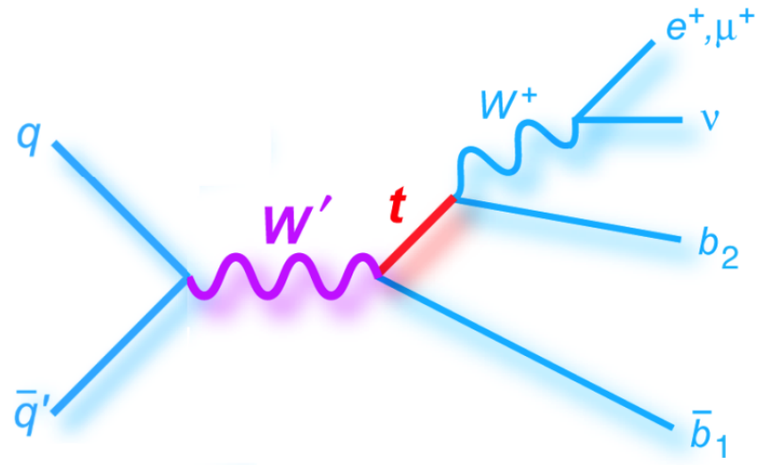
W' Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

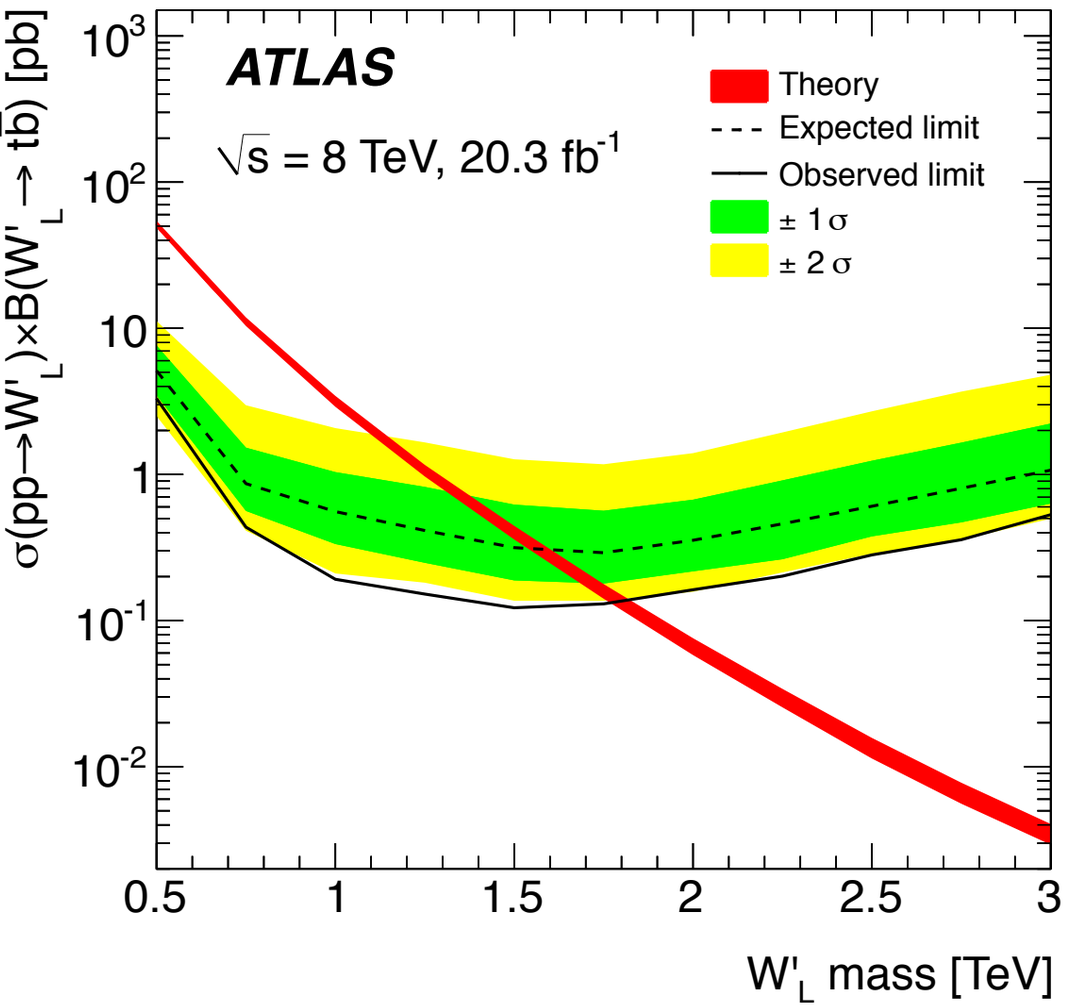
Results

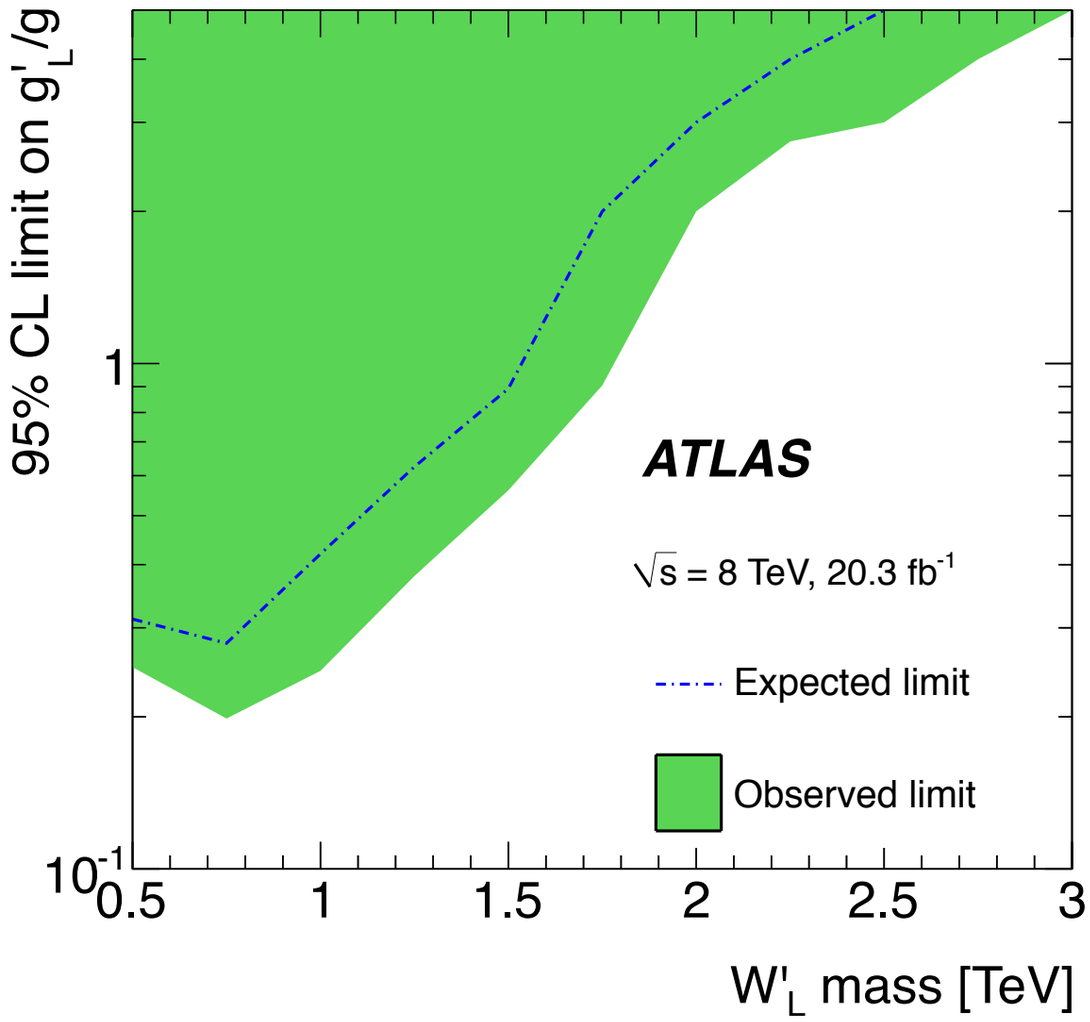
- limits set W'$_R$ and W'$_L$ masses

$$m\left(W'_L\right) < 1.70 \text{ GeV at 95\% CL}$$

$$m\left(W'_R\right) < 1.92 \text{ GeV at 95\% CL}$$





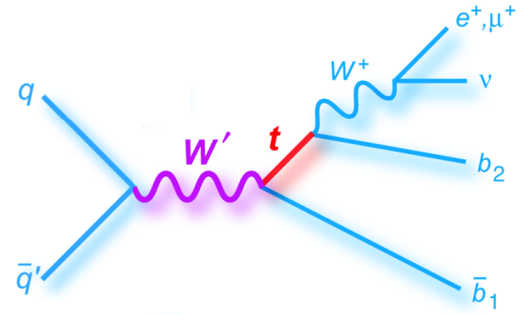


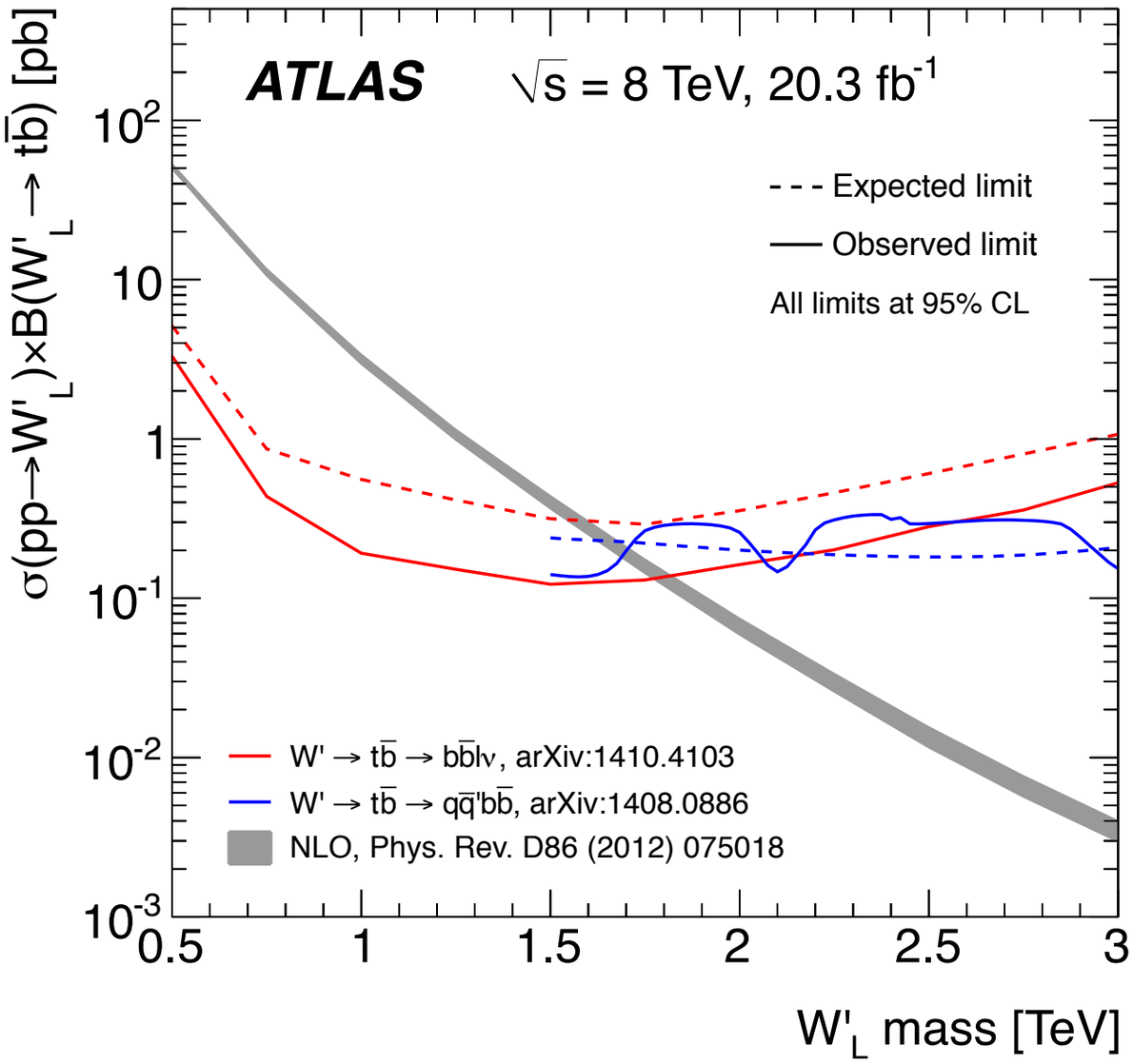
Phys. Lett. B 743 (2015) 235-255

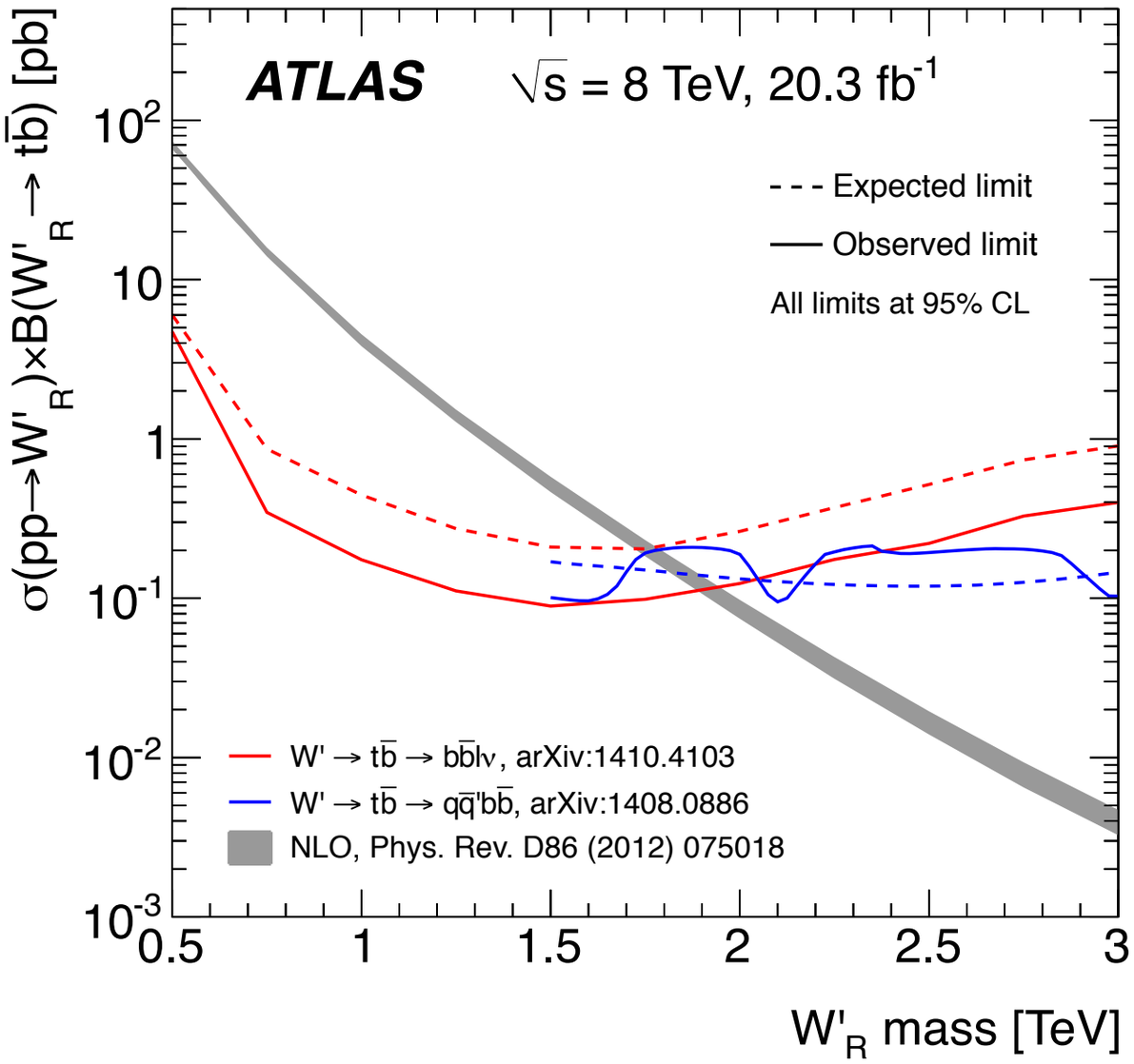
W' Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Results

- limits combined with hadronic analysis







Phys. Lett. B 743 (2015) 235-255

Search for Monotops
$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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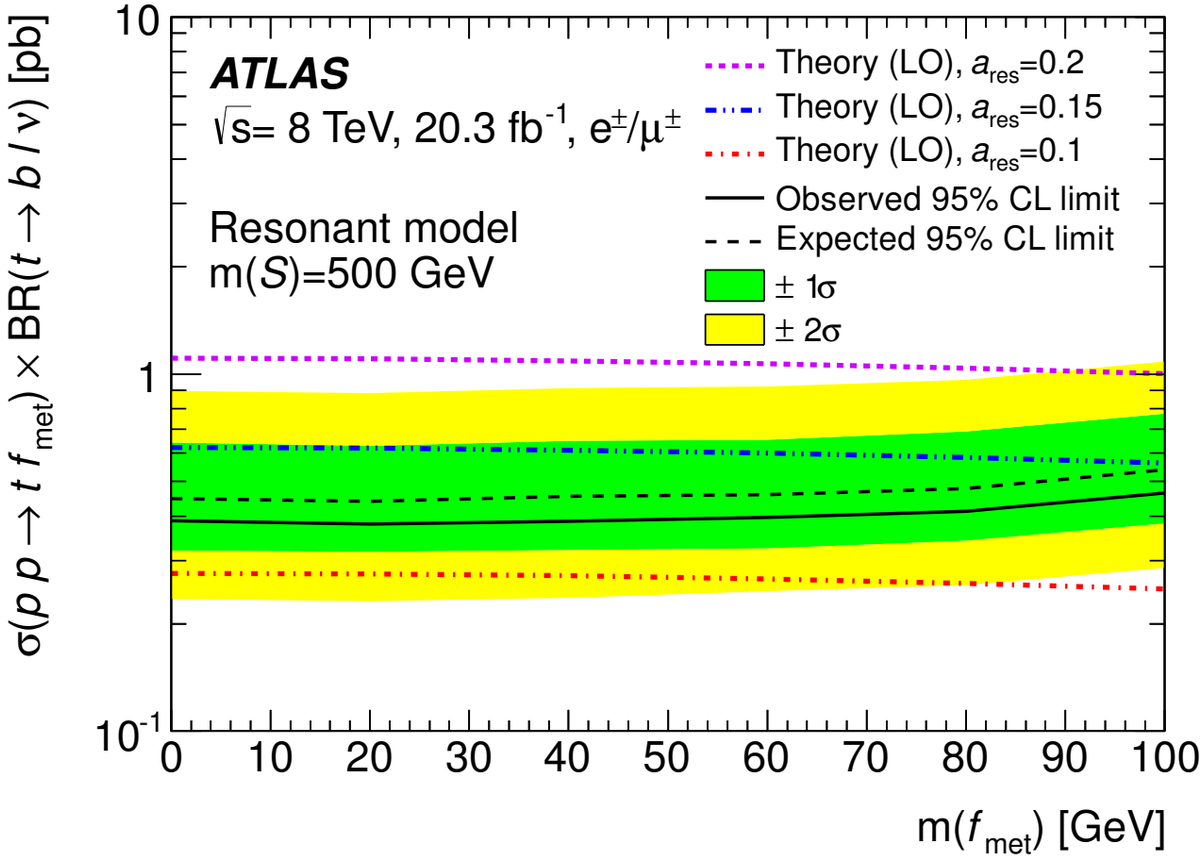
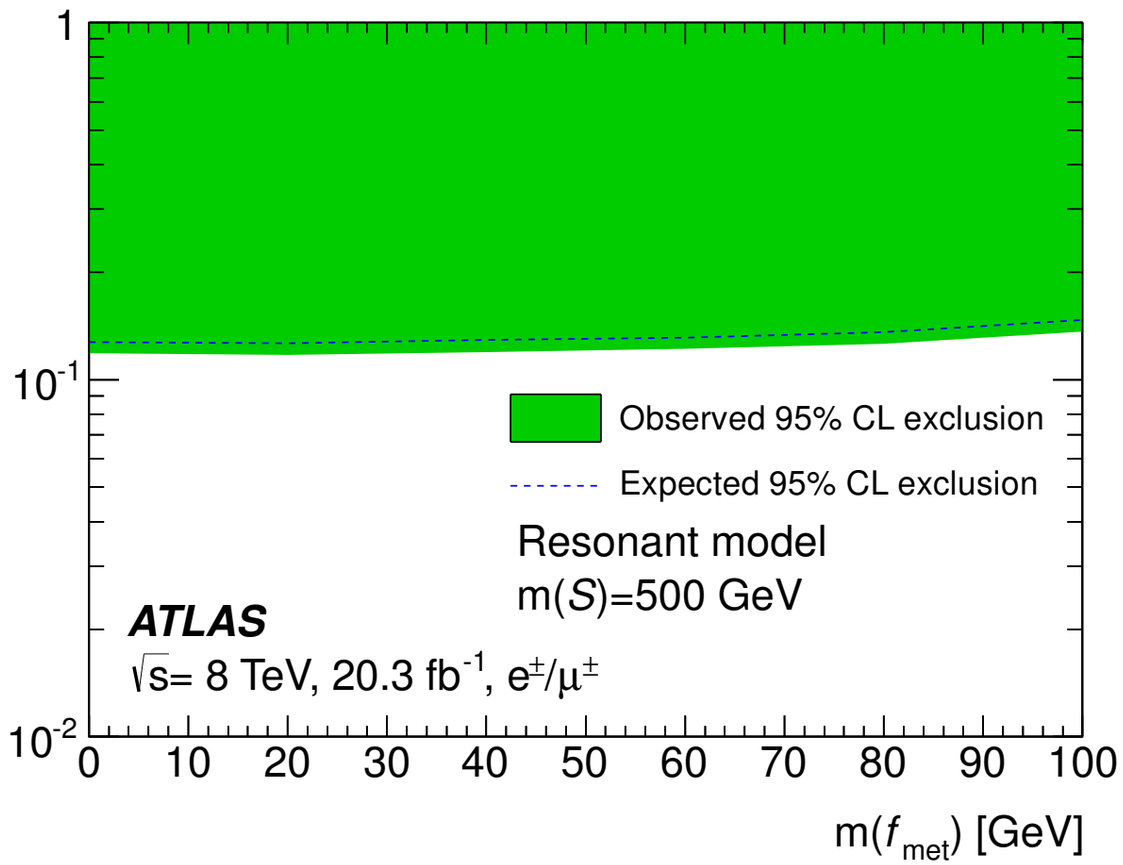
Monotop Search ($\sqrt{s}$ = 8 TeV, 20.3 fb^{-1})

Results

- limits set on effective coupling strength
- limits set on m(v_{met}) and m(f_{met})





$$\text{for } a_{\text{res}} = 0.2,\ m\left(f_{\text{met}}\right) > 100 \text{ GeV at } 95\% \text{ CL}$$

$$\text{for } a_{\text{non-res}} = 0.2,\ m\left(v_{\text{met}}\right) > 657 \text{ GeV at } 95\% \text{ CL}$$

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Anomalous Couplings

$\sqrt{s}$ = 7 TeV, 4.6 fb^{-1}

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Anomalous Couplings ($\sqrt{s}$ = 7 TeV, 4.66 fb^{-1})

BSM Search

- search for $\mathcal{CP}$ violation in the decay of single top quarks
- measures the forward-backward asymmetry
- a non-zero value is indicative of $\mathcal{CP}$ violating contribution to *Wtb* vertex

Final State Selection

- 1 electron or muon, 1 b-jet, E_T^{Miss}

$$A_z \equiv \frac{N_{\text{evt}}(\cos\theta > z) - N_{\text{evt}}(\cos\theta < z)}{N_{\text{evt}}(\cos\theta > z) + N_{\text{evt}}(\cos\theta < z)}$$

Signal Discrimination

- cut and count analysis

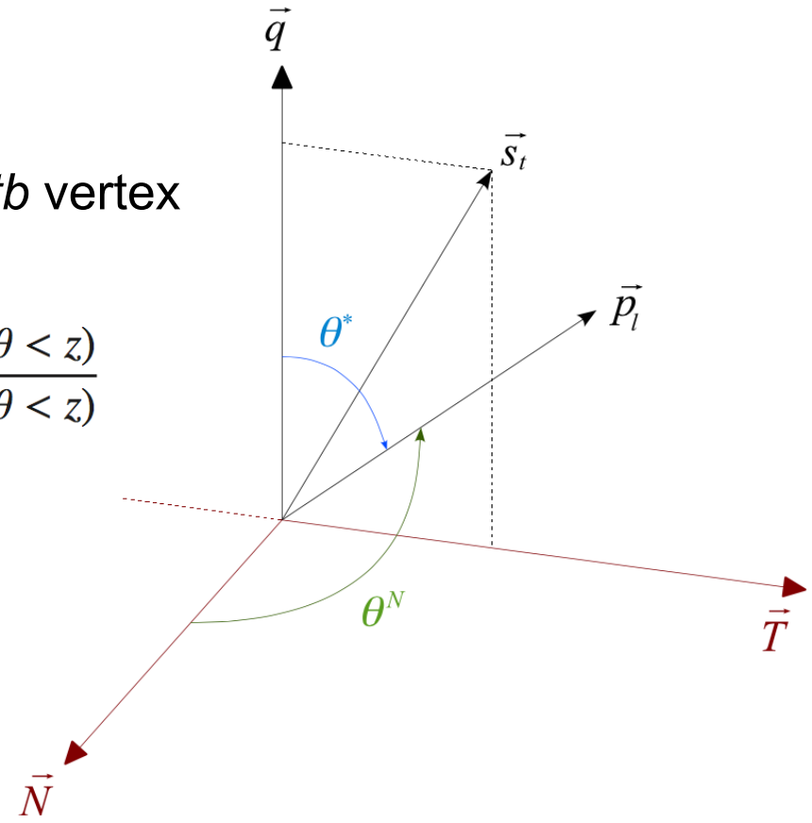
$$A_{\text{FB}}^{\text{N}} = 0.64\, P\, \mathbb{I}(g_{\text{R}})$$

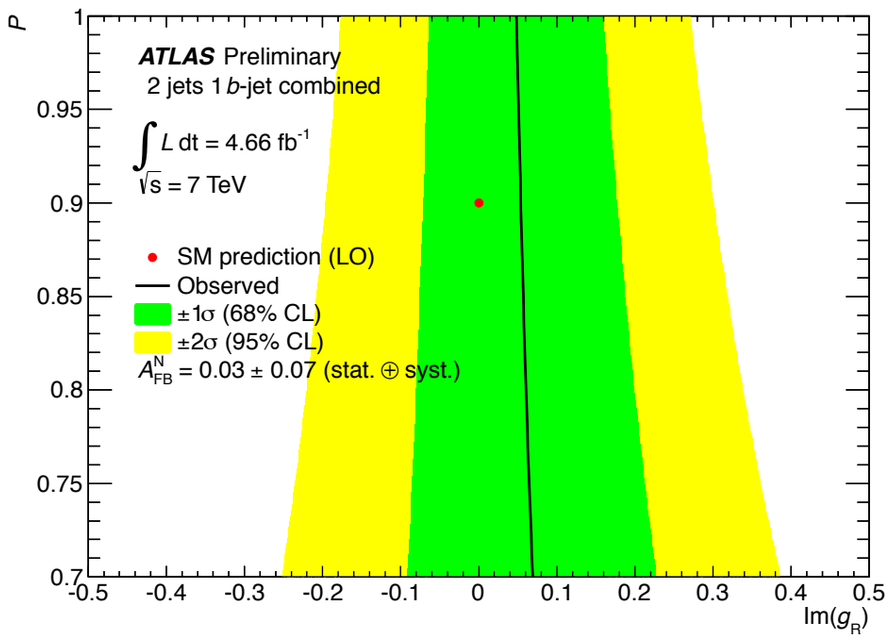
Main Systematics

- generator modeling uncertainties
- parton shower
- JES/JER

Results

- forward-backward asymmetry
- limits on Im(g_R)
- good agreement with SM





$$A_{\text{FB}}^{\text{N}} = 0.031 \pm 0.065(\text{stat})^{+0.029}_{-0.031}(\text{syst})$$

$$-0.20 < \text{Im}\,(g_R) < 0.30 \;@\; 95\%\ \text{CL}$$

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