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Recent Results On Top Physics In Atlas

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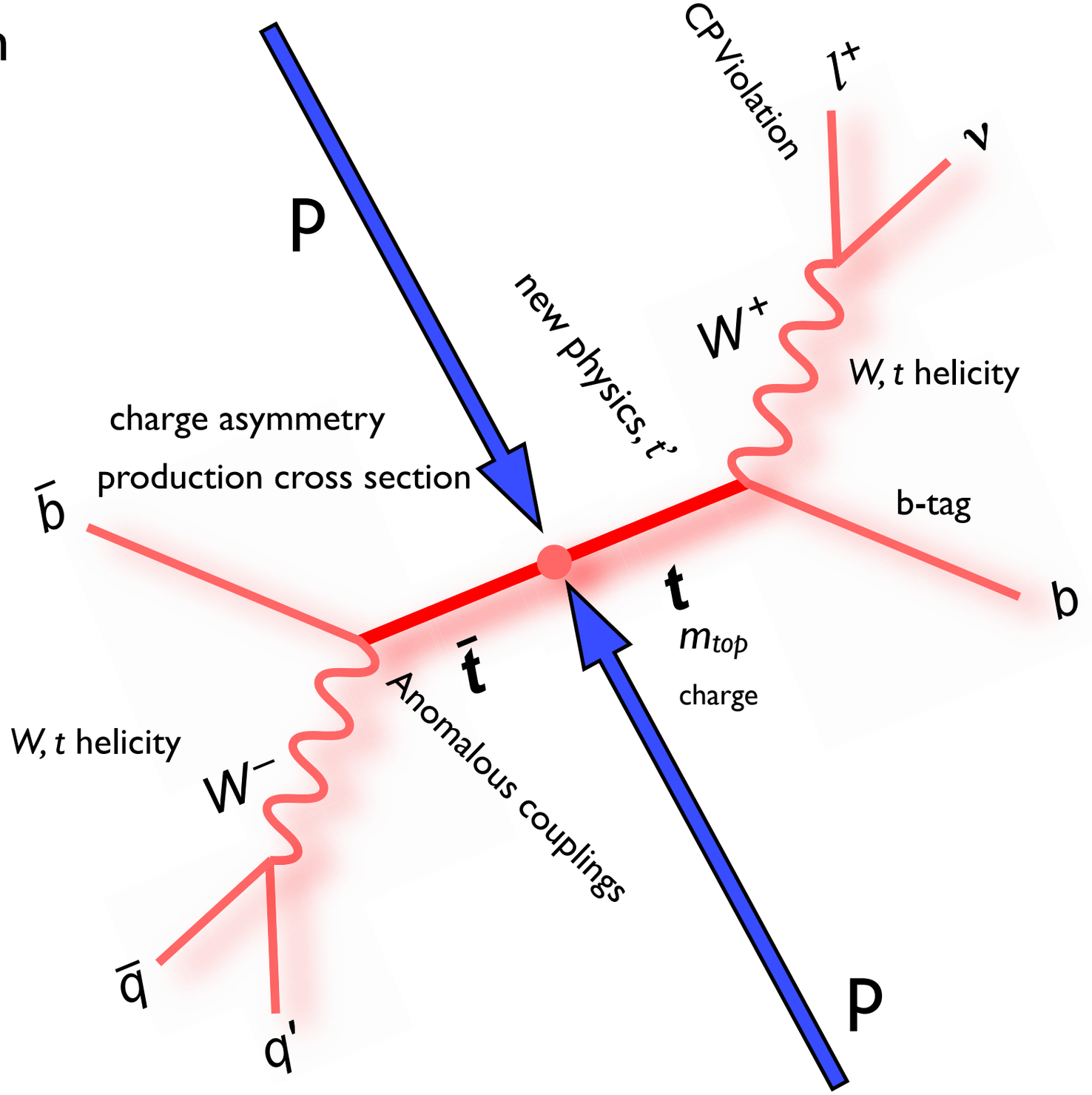
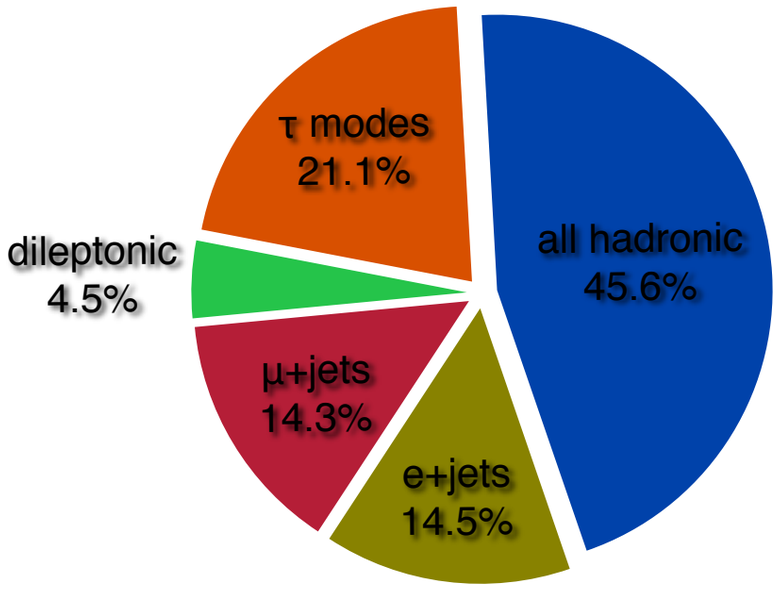
Outline

- Introduction
- $t\bar{t}$ cross section production
- Single top production
- Top Properties
- Beyond the S.M. searches
- Conclusion

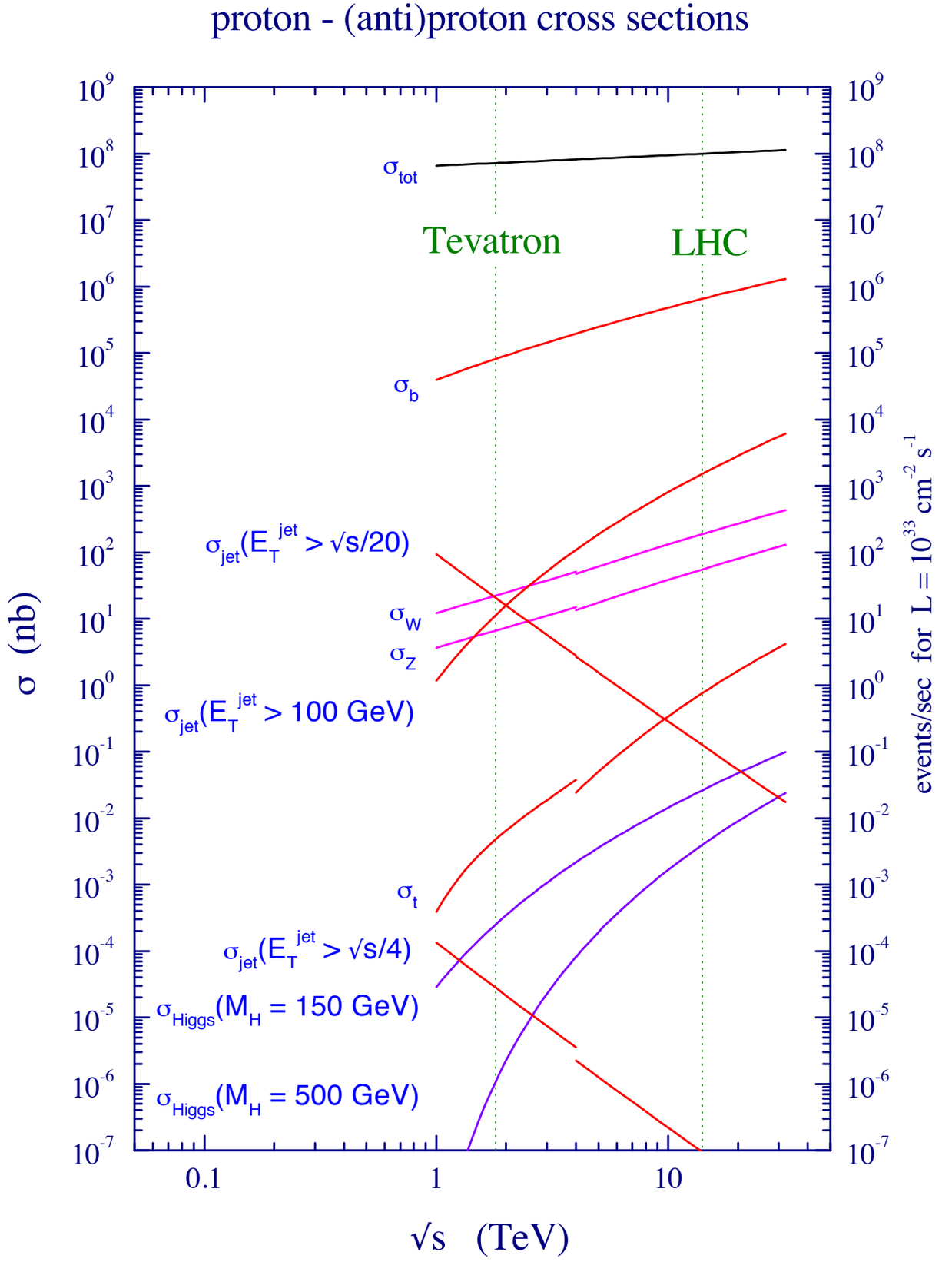


LHC: top factory machine

- Top Production at LHC:
  - $t\bar{t}$ pairs
  - Single top
- Leading Order diagrams
  - $q\bar{q} \rightarrow t\bar{t}$ *(15% at* $\sqrt{s}$ = 7 TeV)
  - $gg \rightarrow t\bar{t}$ *(85% at* $\sqrt{s}$ = 7 TeV)



- Top production per experiment
  - 5 fb^{-1} $\sqrt{s}$ = 7 TeV and 20 fb^{-1} $\sqrt{s}$ =8 TeV
  - 5.6× 10^6 $t\bar{t}$ events for
  - 2.7 × 10^6 Single top events



$t\bar{t}$ production cross section

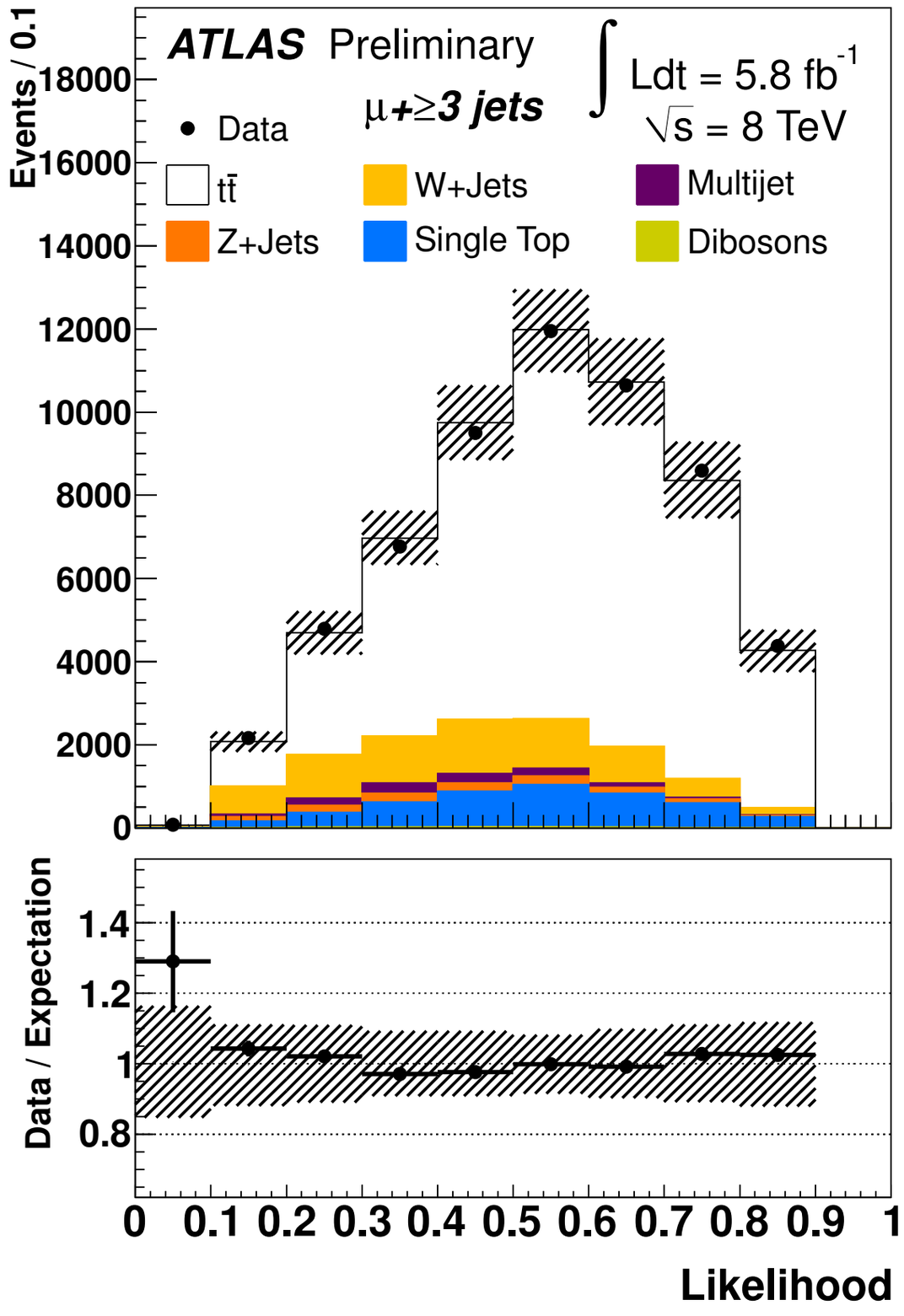
$t\bar{t} \rightarrow l$+jets | $5.8\ \text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV ATLAS-CONF-2012-149

- First Atlas inclusive cross section at 8 TeV
  - single lepton channel
  - N(jets) ≥ 3
  - N(b^{tag})≥ 1 (70% opp. point)

- Likelihood binned fit
  - discriminant: ratio of likelihood, L,

$$D(\eta_l, A'|\sigma_{t\bar{t}}) = \frac{L^s}{L^s + L^b}$$

  - lepton pseudo rapidity η_l
  - transformed aplanarity $A' = e^{-8A}$
    - ✦ $A = {}^3/_2\ \lambda_3$, smallest eigenvalue normalized momentum
    - ✦ $A \rightarrow A'$ increases the separation power

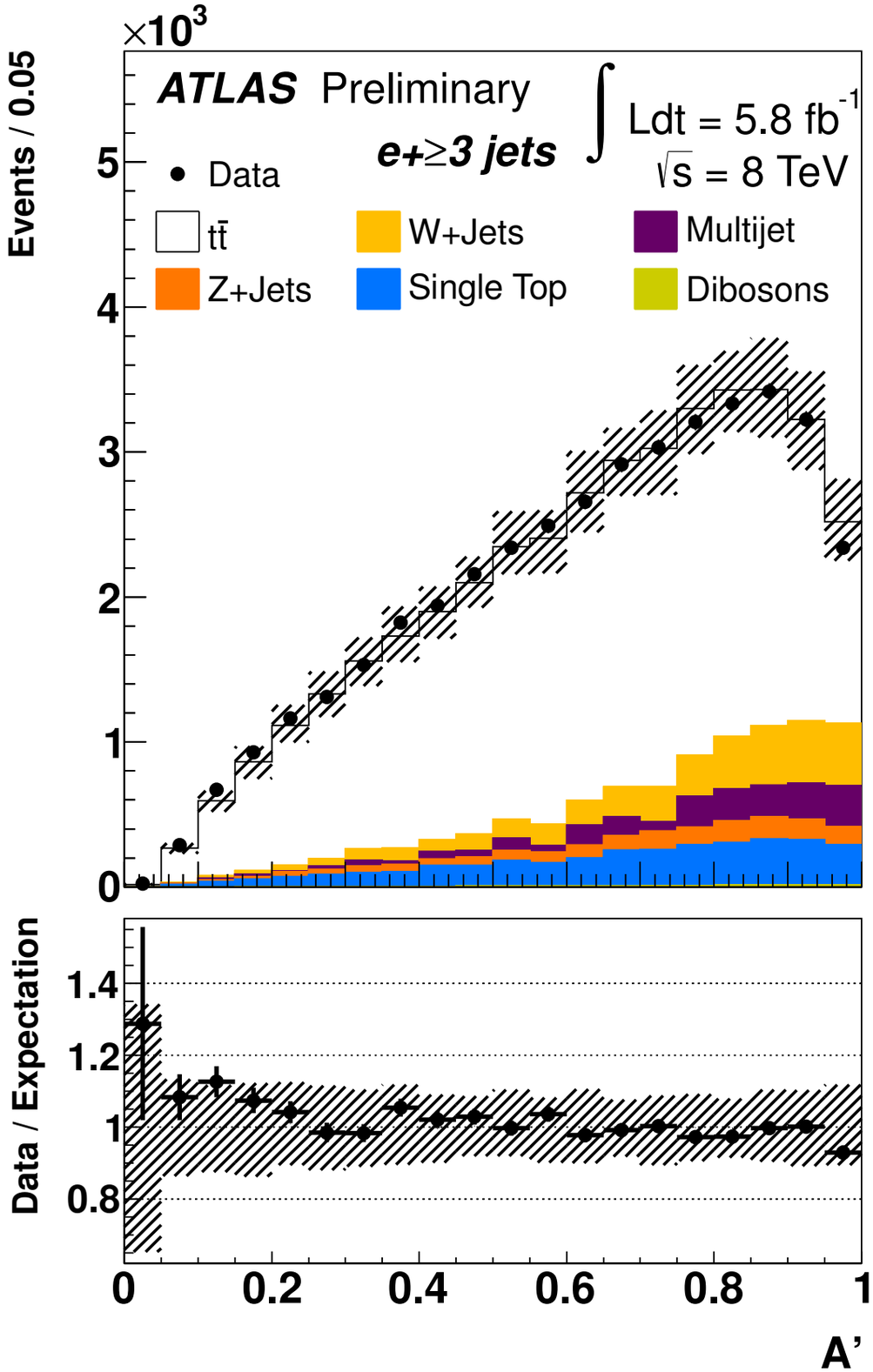


- Simultaneous over e, μ fit:
  - per channel fit of *W*+*j*

Channel	$N_{t\bar{t}}$	$\sigma_{t\bar{t}}$ (pb)
e+≥3 jets	31050±350	239±3
μ+≥3 jets	45000±400	242±2
l+≥3 jets	76000±500	241±2

- Good Agreement with theoretical prediction:

$$\sigma_{t\bar{t}} = 241 \pm 2\ (\text{stat}) \pm 31\ (\text{syst}) \pm 9\ (\text{lumi})\ \text{pb}$$



  - Dominant Systematics: MC modeling of the signal (11%) and Jet/E_T^{miss} reconstruction/calibration (~6%)

$$\sigma_{t\bar{t}}^{\text{theor}} = 238^{+22}_{-25}\ \text{pb}$$

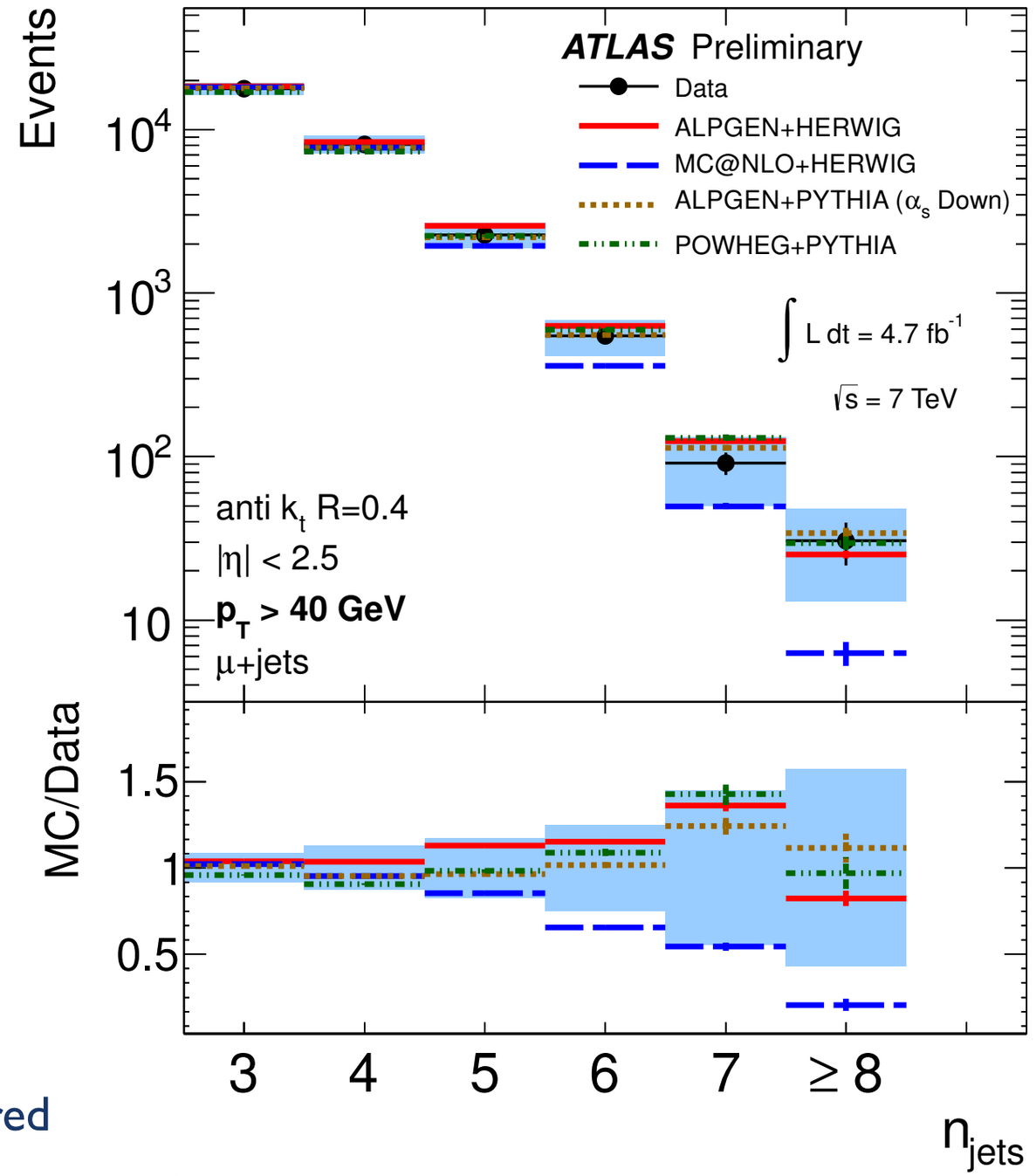
    - ✦ top mass @172.5 GeV
    - ✦ approximate NNLO QCD HATHOR
  - Most recent calculation: M. Czakon et Al (CERN-PH-TH/2013-056, TTK-13-08)

$$\sigma_{t\bar{t}}^{\text{theor}} = 245.8^{+6.2}_{-8.4}\ \text{pb}$$

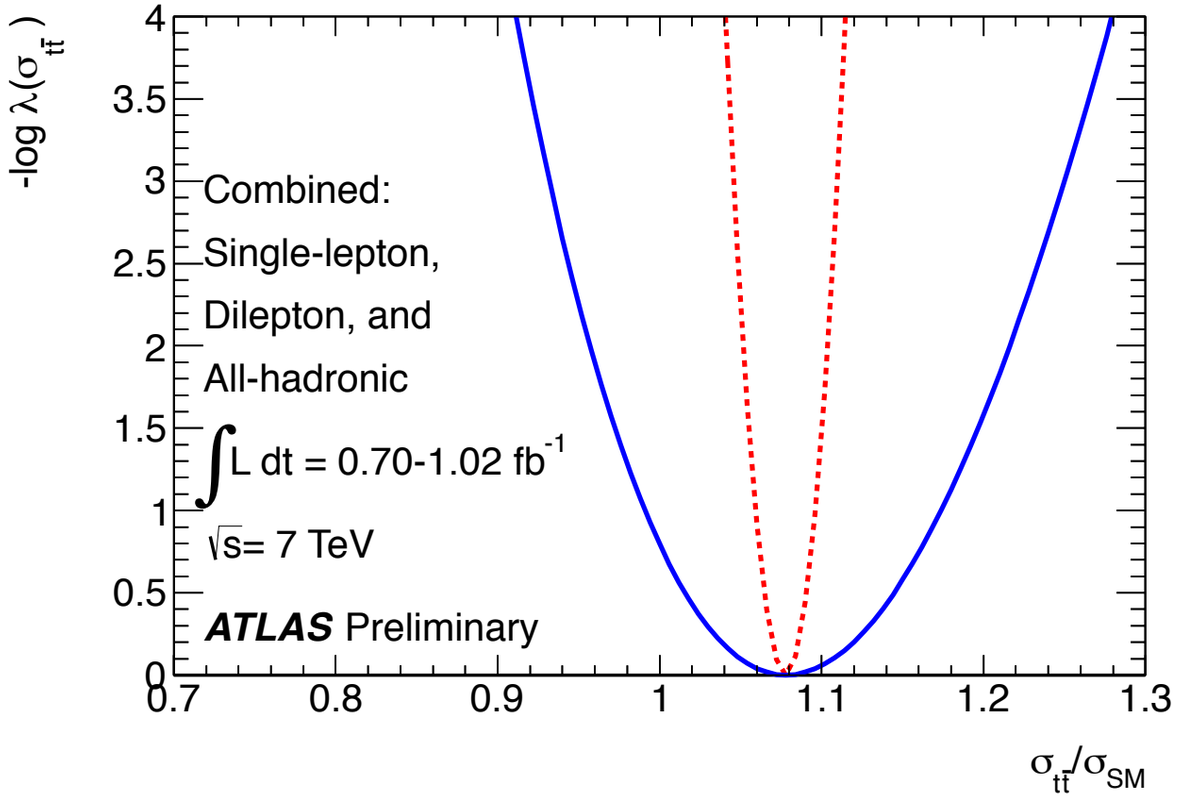
    - ✦ NNLO QCD corrections

$t\bar{t}$ Jet Multiplicity 4.7 fb^{-1} $\sqrt{s}$ = 7 TeV ATLAS-CONF-2012-155

- Measuring *N*(jets) as function of p_T
  - constrains ISR/FSR models at m_{top} scale
  - tests of perturbative QCD
- Measurement in single lepton channel
  - p_T thresholds of: 25, 50, 60 and 80 GeV
  - correction of detector effects with unfolding
  - Systematics:
    - ✦ background modeling at low *N*(jets)
    - ✦ jet energy scale at high *N*(jets)
- MC@NLO
  - disfavored by data
    - ✦ lower multiplicity prediction
    - ✦ softer jets
- ALPGEN
  - with Pythia showering upward α_s variation disfavored
  - with Herwig/Pythia consistent with data (within uncertainty)
- Powheg
  - with Pythia consistent with data (within uncertainty)



$\sigma_{t\bar{t}}$ Summary ATLAS-CONF-2012-024



- Combination at 7 TeV:

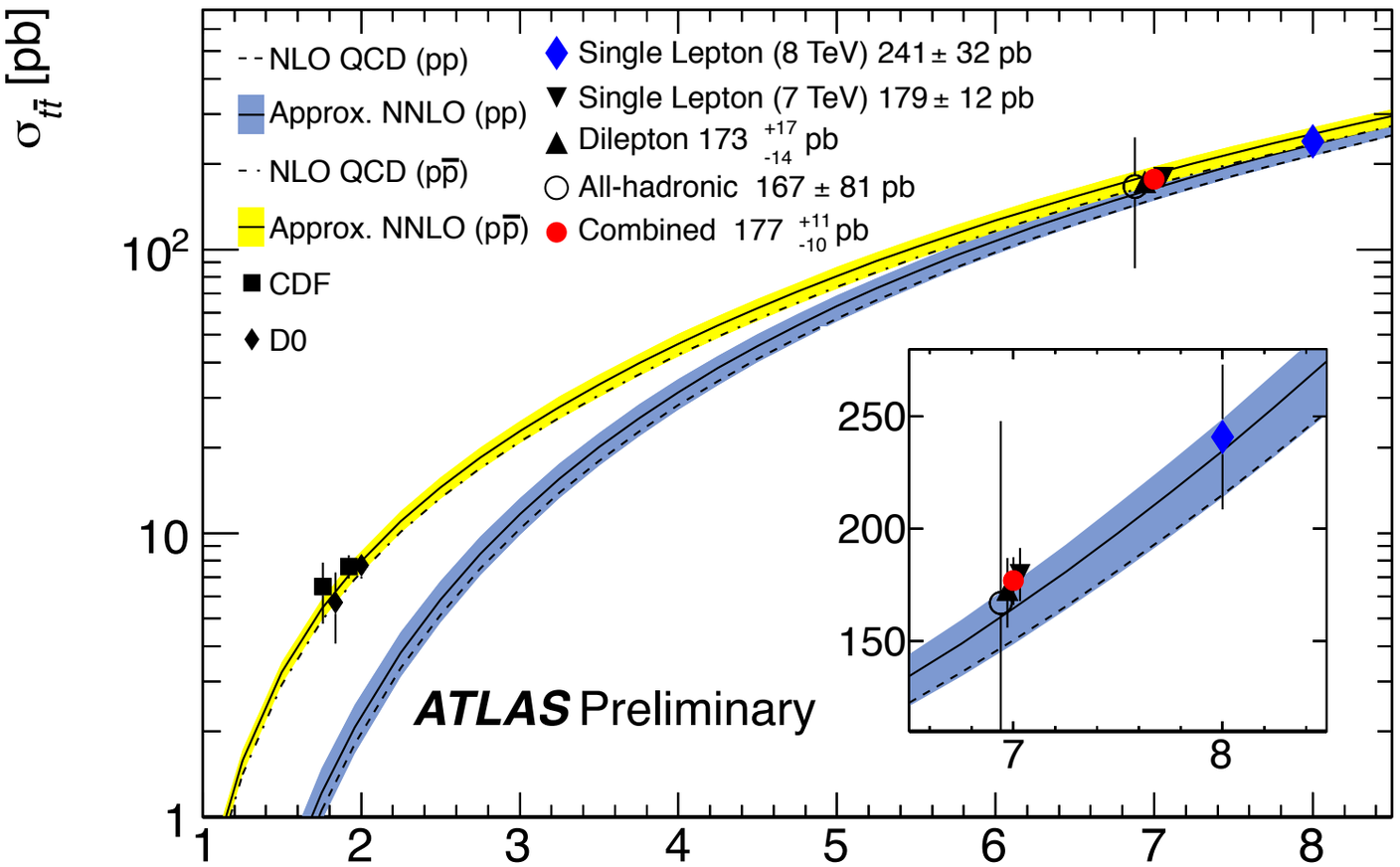
$$\sigma_{t\bar{t}}\ (\ 7\ \mathrm{TeV}) = 177^{+11}_{-10}\ \mathrm{pb}$$

  - Combined likelihood parametrization
    - ✦ profile likelihood ratio estimator
  - 6 measurements combination
  - full correlation of shared uncertainties

- Single lepton channel at 8 TeV

$$\sigma_{t\bar{t}}\ (\ 8\ \mathrm{TeV}) = 241 \pm 32\ \mathrm{pb}$$

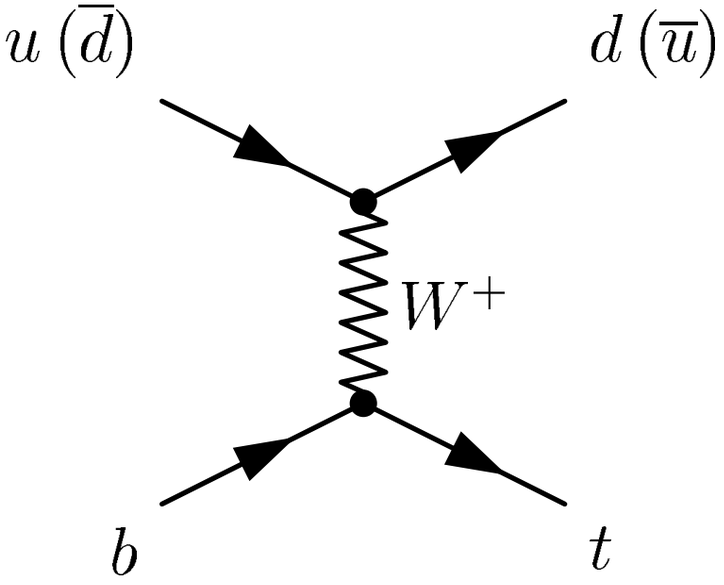
- Good Agreement with NNLO S.M. calculation for both C.M. energies



Single Top

Single Top cross section

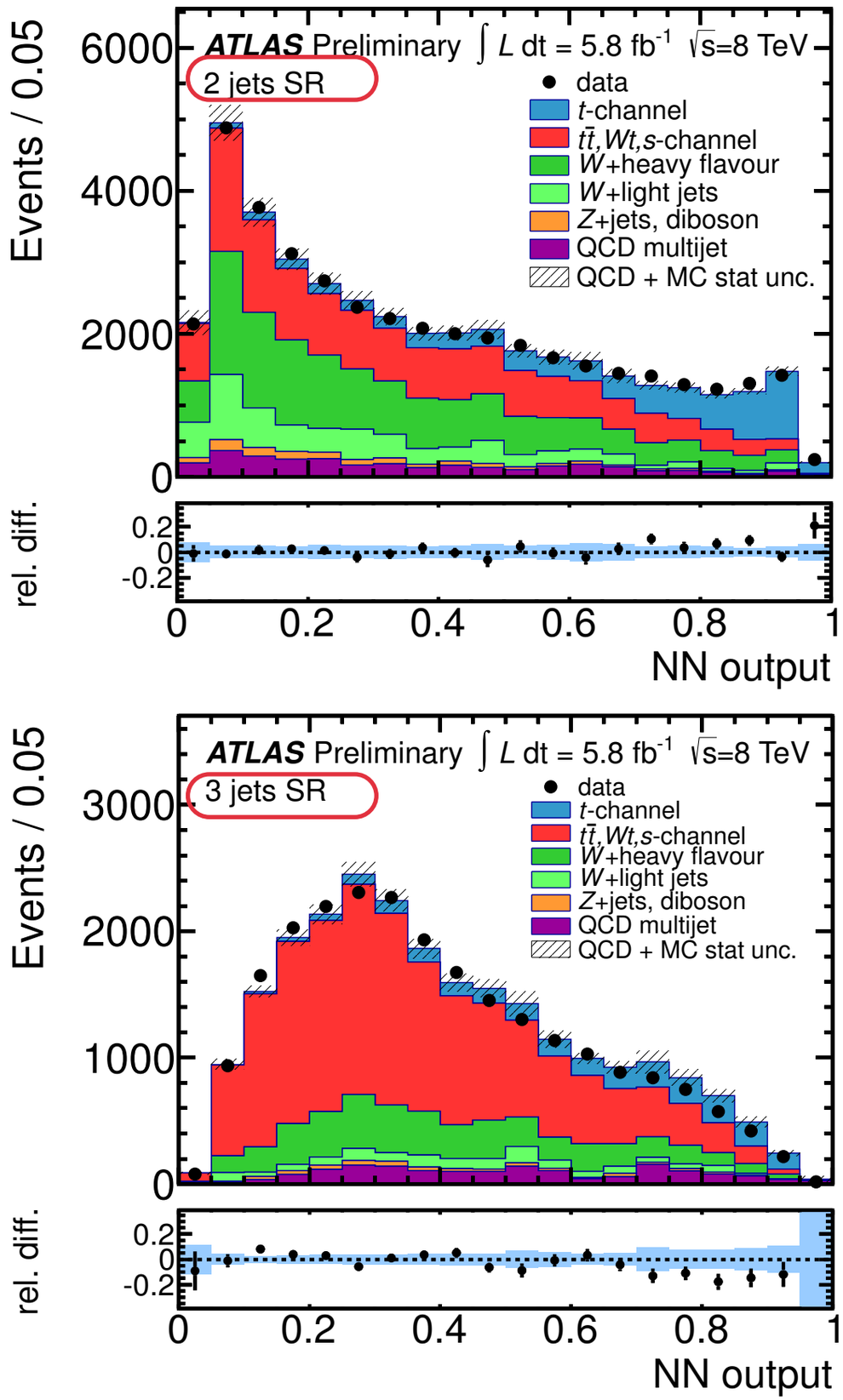
- Production via electroweak, charged-current interactions.



  - at $\sqrt{s}$ = 8 TeV $\sigma_t \simeq {}^1/_2\ \sigma_{t\bar{t}}$
  - Dominant *t-channel* via virtual *W* boson
- Motivations:
  - sensitivity to new physics
  - constrain $|V_{tb}|$, no assumption on number of quark generations
  - *b-quark PDF* measurement
- Previous ATLAS measurements:
  - *t* channel at $\sqrt{s}$ = 7 TeV σ_t=83 ± 20 pb Observation of 7.2 σ (Phys. Lett. B 717 (2012) 330-350)
    - ✦ N.N. (analysis similar to 8 TeV)
    - ✦ Systematics: b-tagging eff, jet modeling, ISR/FSR
    - ✦ $|V_{tb}| > 0.75$ at 95% C.L.
  - t channel $\sigma_t / \sigma_{t\bar{t}} = 1.81^{+0.23}_{-0.22}$ at $\sqrt{s}$ = 7 TeV (ATLAS-CONF-2012-056)
  - W_t production at $\sqrt{s}$ = 7 TeV σ_{Wt}= 16.8 ± 2.9 (stat) ± 4.9 (syst) pb (Phys. Lett. B 716 (2012) 142-159)
    - ✦ 3.3 σ Evidence
  - *s-channel* production σ_t < 26.5 pb (95% Upper Limit) (ATLAS-CONF-2011-118)

Single Top cross section $5.8\ \text{fb}^{-1}$, at $\sqrt{s} = 8$ TeV, ATLAS-CONF-2012-132 LC2013

- Selection:
  - semi-leptonic channel
- W+jets main background
  - W+*H.F.*-jets same signature
  - *W+light-jets* due to misidentification on b-jets
- N.N. discrimination
  - kinematic variables
    - 11 variables: m_{jb} m_{lvb}, η_j
- cross section extraction: likelihood fit
  - extraction of β scale factors
    - N(events) = β × expectation
  - combined fit in 2 and 3 jet bins



Single Top cross section *5.8* fb^{-1} at $\sqrt{s}$ = *8* TeV ATLAS-CONF-2012-132 LC2013

- cross section

$$\sigma_{\mathrm{t}} = 95 \pm 2(\mathrm{stat}) \pm 18(\mathrm{syst})\ \mathrm{pb}$$

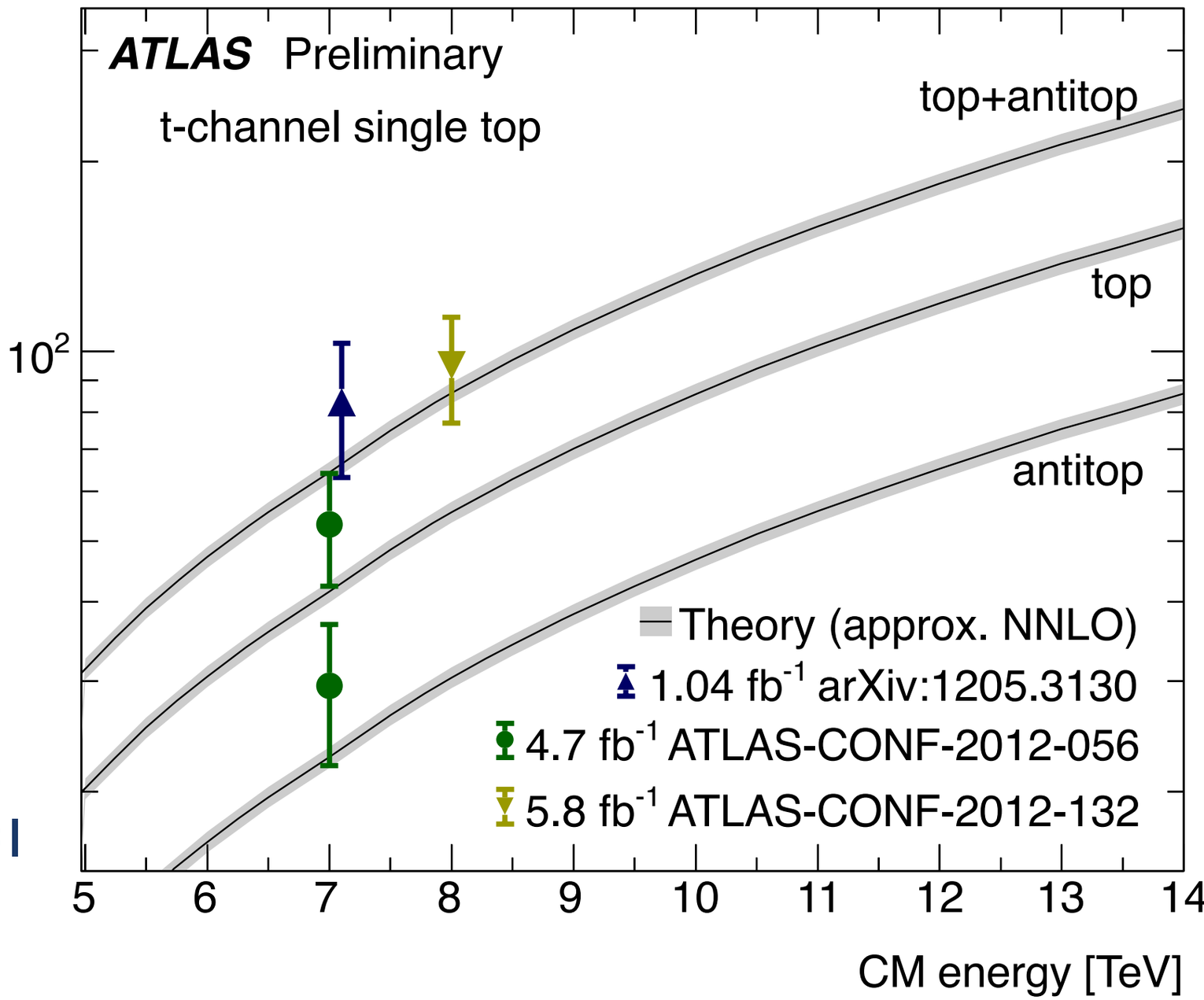
- coupling at the *W-t-b* vertex

$$|V_{\mathrm{tb}}| = 1.04\ ^{+0.10}_{-0.11}$$

- Agreement with S.M. NNLO:

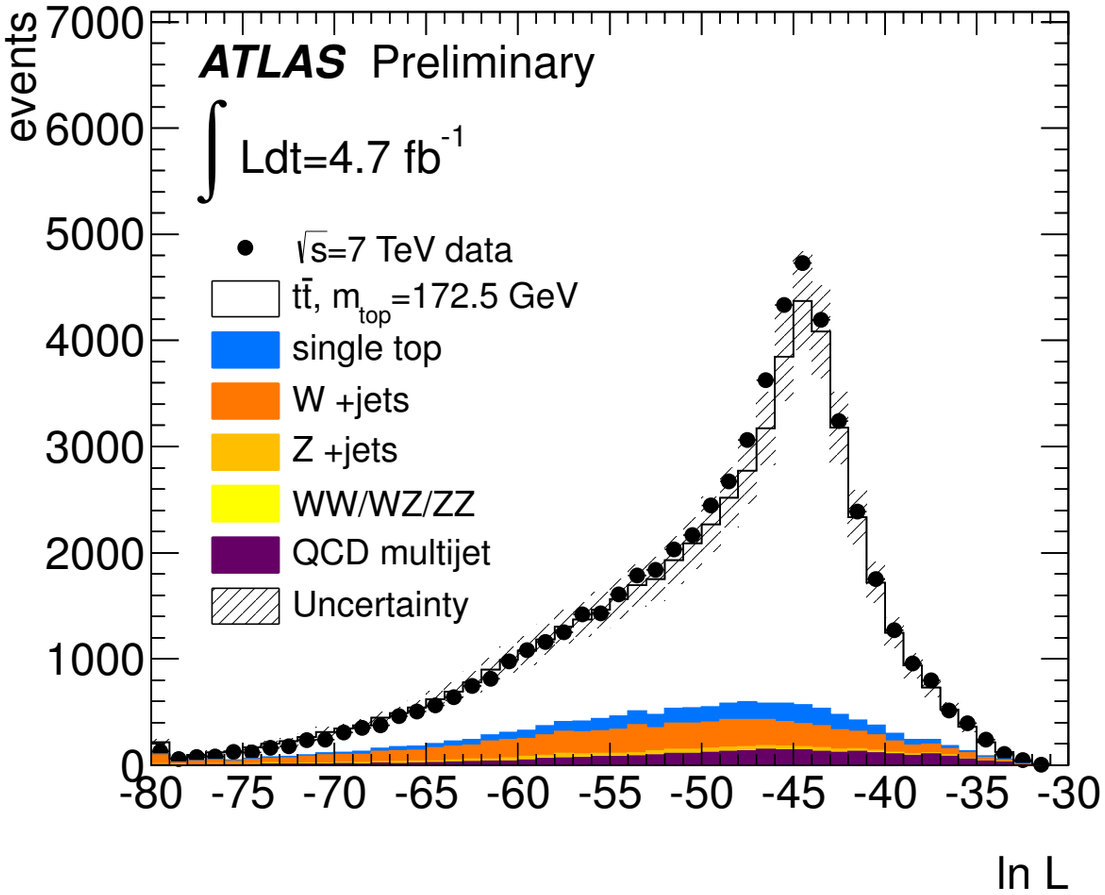
$$\sigma_{\mathrm{t}}^{\mathrm{theor}} = 87.8^{+3.4}_{-1.9}\ \mathrm{pb}$$

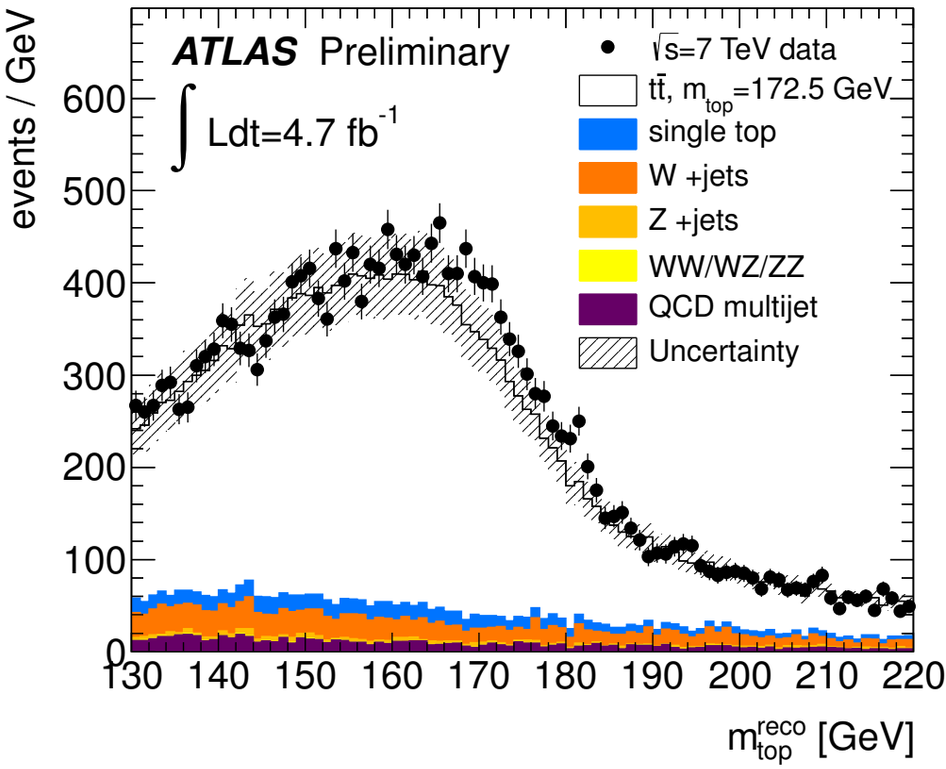
- 95% C.L. $|V_{tb}|$ at 0.80 for $|V_{tb}|$=1



Properties of the top quark

- kinematic reconstruction with a likelihood fit using KLFitter
  - Reconstruction to parton mapping response: transfer functions
  - Γ_{top} and Γ_W Breit Wigner constraints for m_{top}^{reco} and m_W^{reco}
  - b-tag information included for correct jet permutation assignment





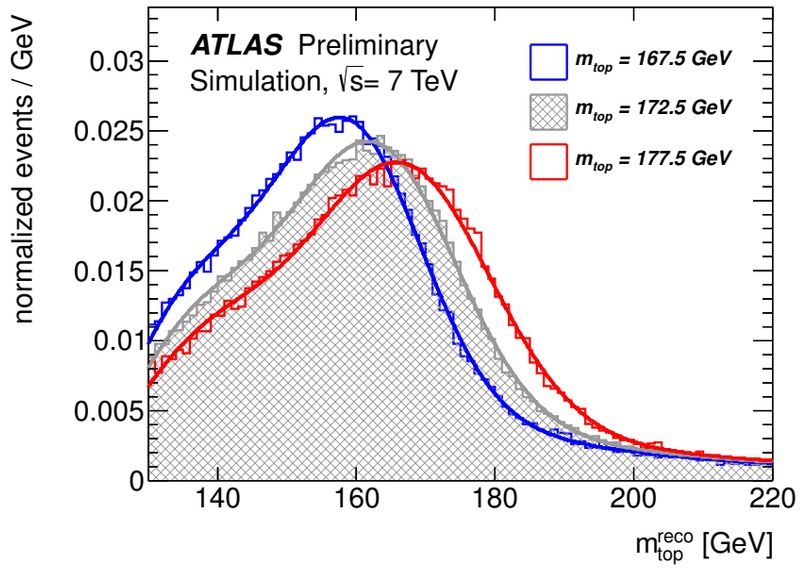
(c) $m_{\text{top}}^{\text{reco}}$

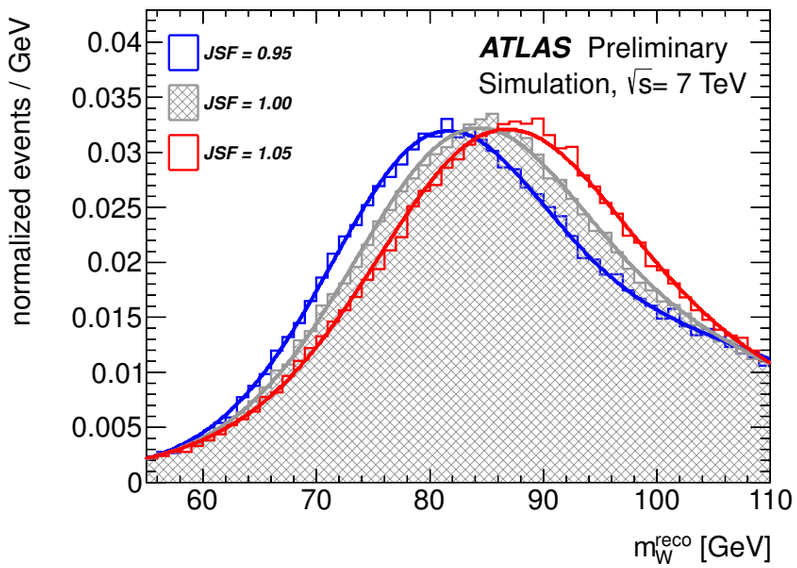
$$
\begin{aligned}
L \;=\; & \mathcal{T}\left(E_{\text{jet}_1}|\hat{E}_{b_{\text{had}}}\right)\cdot\mathcal{T}\left(E_{\text{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\text{jet}_3}|\hat{E}_{q_1}\right)\cdot \\
& \mathcal{T}\left(E_{\text{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\text{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\text{miss}}|\hat{p}_{y,\nu}\right)\cdot \\
& \left\{\begin{array}{ll} \mathcal{T}\left(E_e|\hat{E}_e\right) & \text{e+jets} \\ \mathcal{T}\left(p_{\text{T},\mu}|\hat{p}_{\text{T},\mu}\right) & \mu\text{+jets} \end{array}\right\}. \\
& \mathcal{B}\left[m(q_1\,q_2)|m_W,\Gamma_W\right]\cdot\mathcal{B}\left[m(\ell\,\nu)|m_W,\Gamma_W\right]\cdot \\
& \mathcal{B}\left[m(q_1\,q_2\,b_{\text{had}})|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot \\
& \mathcal{B}\left[m(\ell\,\nu\,b_\ell)|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot W_{\text{btag}}\,.
\end{aligned}
$$

Top Mass: II $_{4.7\ fb^{-1},\ \sqrt{s}\ =\ 7\ TeV,\ ATLAS\text{-}CONF\text{-}2013\text{-}046}$ LC2013

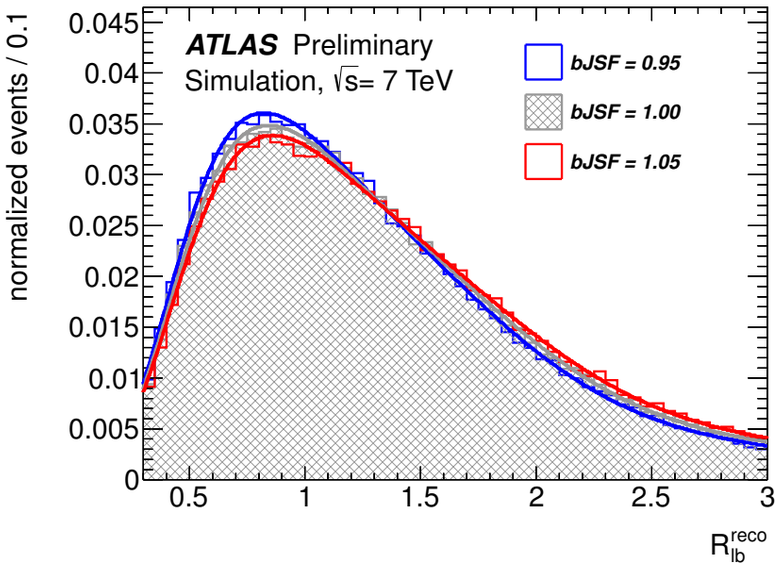
- First Implementation of 3D analysis for m_{top} extraction
- Observables:
  - m_{top}: main observable
  - m_W^{reco}:sensitivity to jet energy scale (JES)
  - R_{lb}^{calo}: sensitivity to b-to light jets energy changes (bJES)

$$R_{\mathrm{lb}}^{\mathrm{calo}} = \begin{cases} \dfrac{\Sigma p_{\mathrm{T}}^{\text{b-tag}}}{\Sigma p_{\mathrm{T}}^{\text{light-jets}}}, & 2\ \text{b-tags} \\ \dfrac{p_{\mathrm{T}}^{\text{b-tag}}}{\frac{1}{2}\Sigma p_{\mathrm{T}}^{\text{light-jets}}}, & 1\text{-btag} \end{cases}$$





- Parametrization:
  - Fit function: Gaussian plus Landau for m_{top} and R_{lb}^{reco}
  - Separation for 1-tag, ≥2b- tags for sensitivity
  - Simultaneous fit to all templates.



Top Mass: III $4.7\ \text{fb}^{-1}$, $\sqrt{s} = 7$ TeV, ATLAS-CONF-2013-046

- Uncertainties:
  - b-tagging, residual JES dependence
  - statistical component of bJSF determination.

- Improvements w.r.t to $1\ \text{fb}^{-1}$ 2d :
  - The total systematic uncertainty is reduced by 40%
  - Better modeling of underlying partonic quantities

- Result:

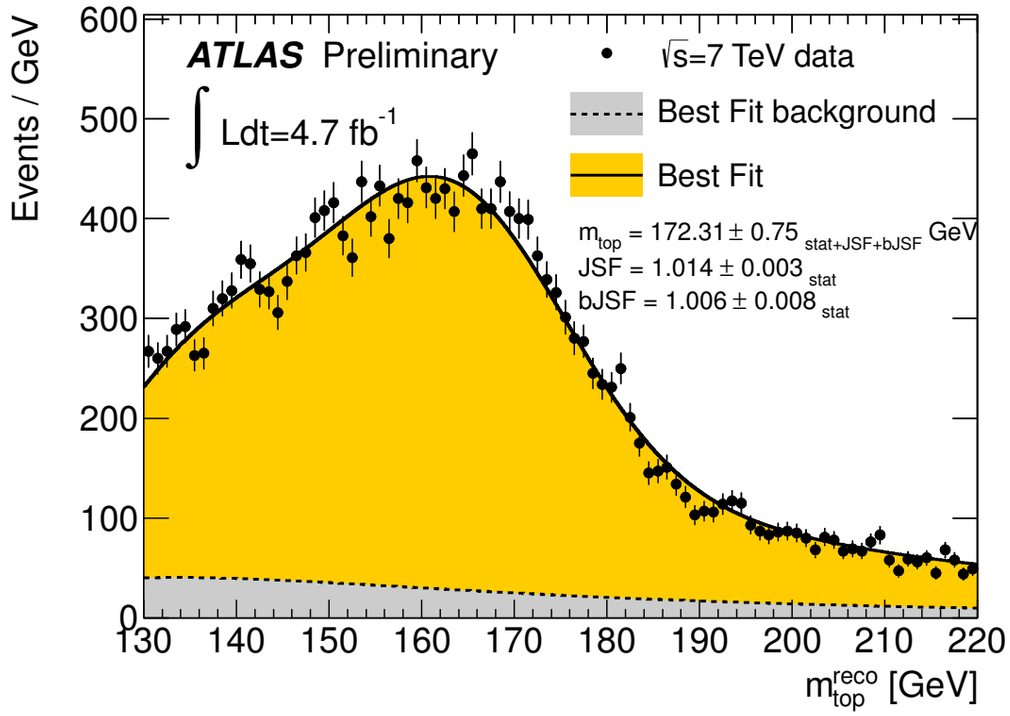
$$m_{\text{top}} = 172.31 \ \pm 0.75(\text{stat+JSF+bJSF}) \ \pm 1.35(\text{syst}) \ \text{GeV}$$

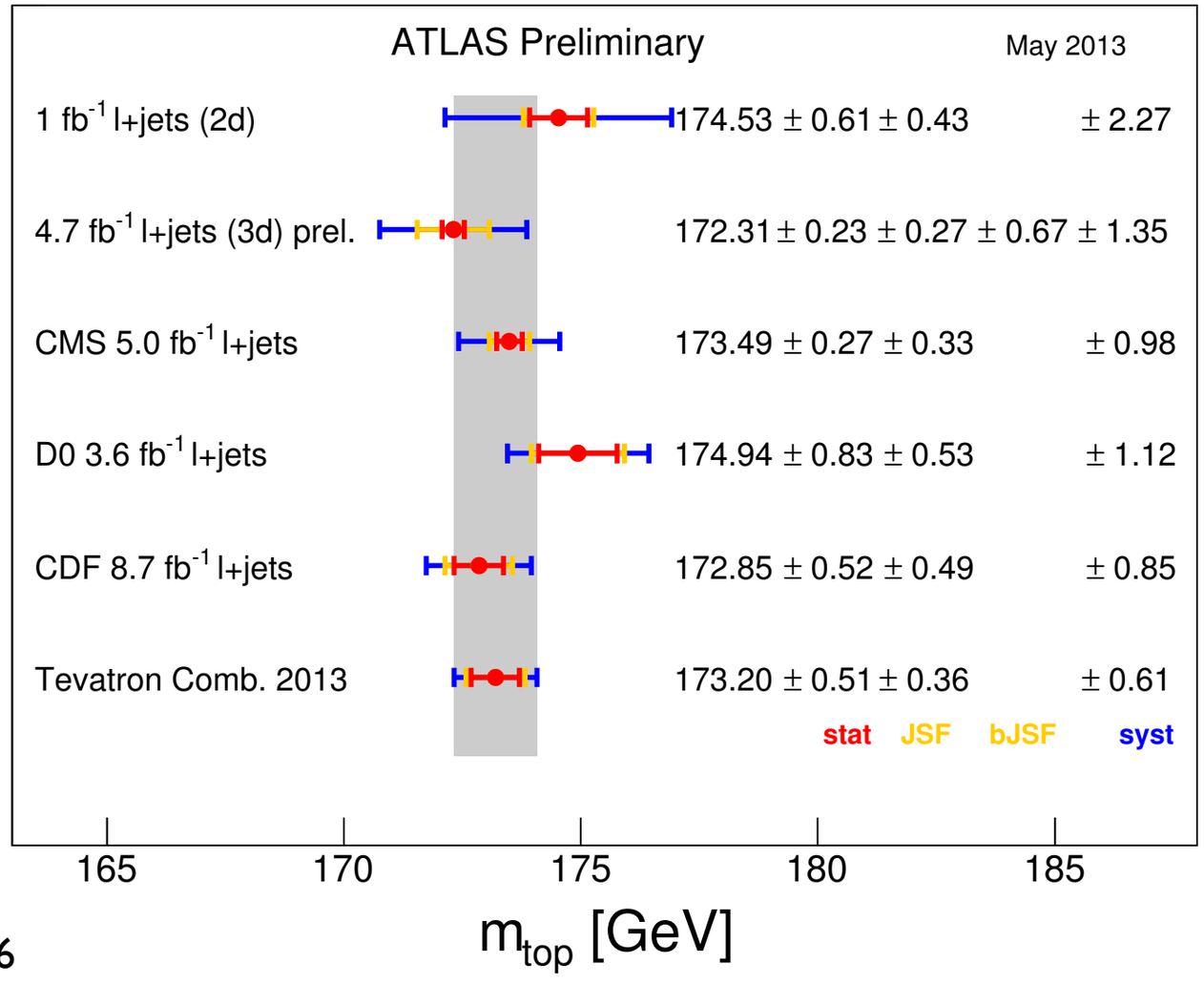
  - Nuisances:
    - ✦ jet energy scale factor:

$$\text{JSF} = 1.014 \pm 0.003(\text{stat}) \ \pm 0.021(\text{syst})$$

    - ✦ b-jet-to-light jet fraction:

$$\text{bJSF} = 1.006 \pm 0.008(\text{stat}) \ \pm 0.020(\text{syst})$$

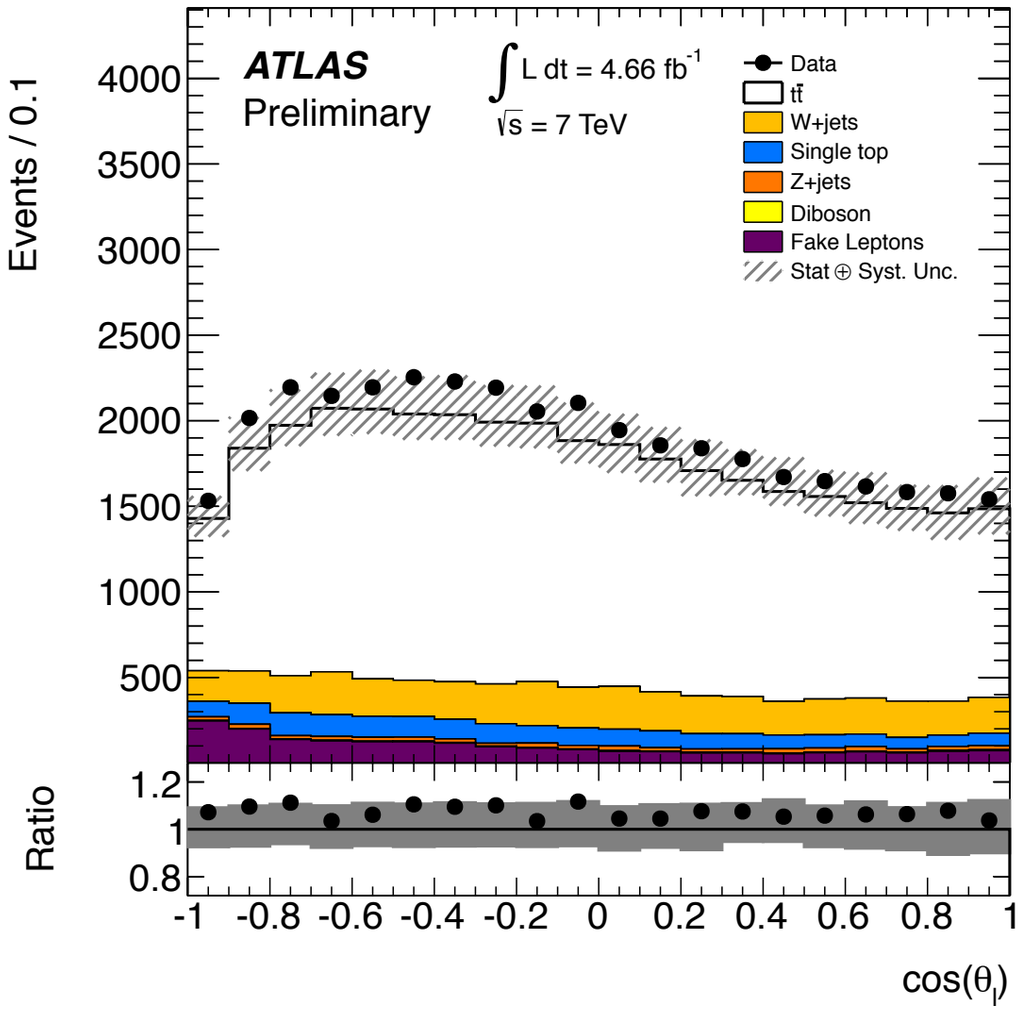


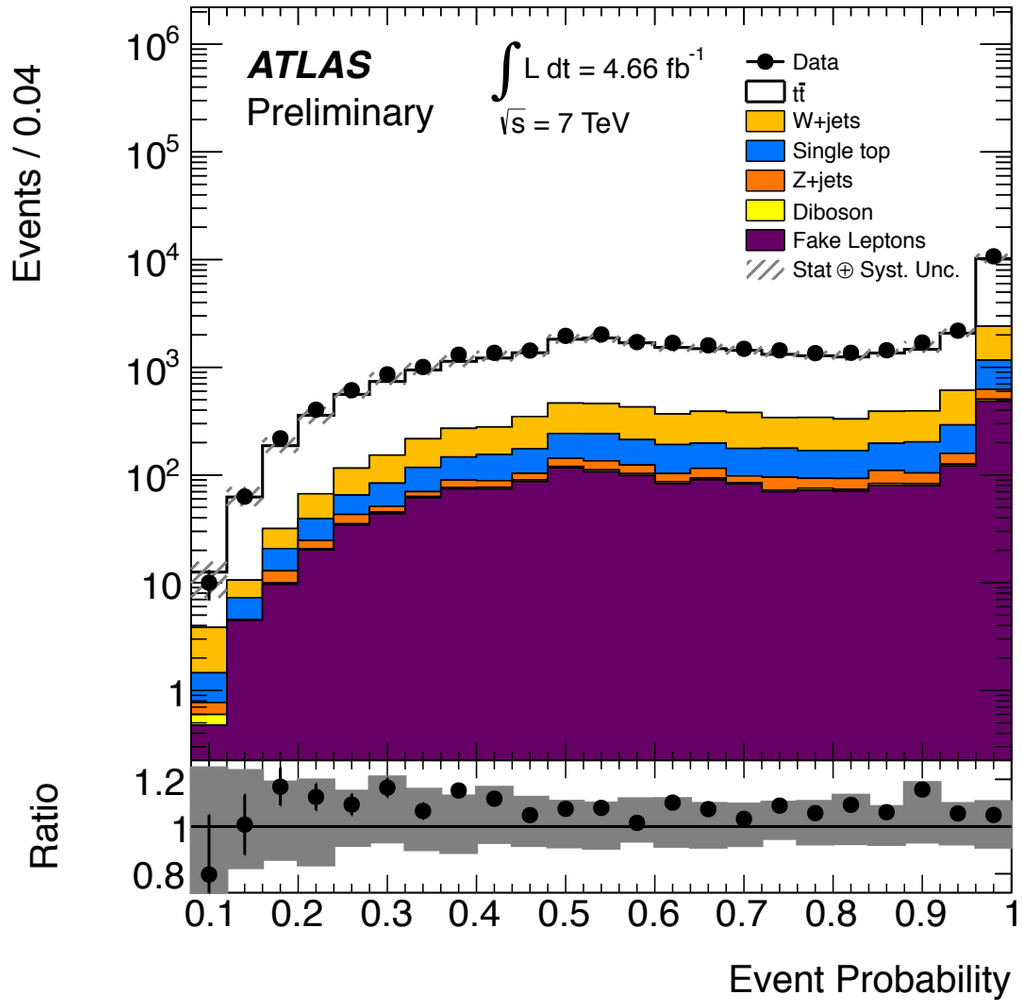


Top Polarization I $_{4.7\ \text{fb}^{-1}\ \sqrt{s}\ =\ 7\ \text{TeV}\ \text{ATLAS-CONF-2012-133}}$

- Motivations:
  - the top (anti-top) produced almost unpolarized in $t\bar{t}$ production
  - In BSM models polarized top quarks can be produced
- Method and Extraction
  - lepton polar angle (top rest frame) θ_i :

$$f = \frac{1}{2} + \frac{N(\cos(\theta_i) > 0) - N(\cos(\theta_i) < 0)}{N(\cos(\theta_i) > 0) + N(\cos(\theta_i) < 0)}$$





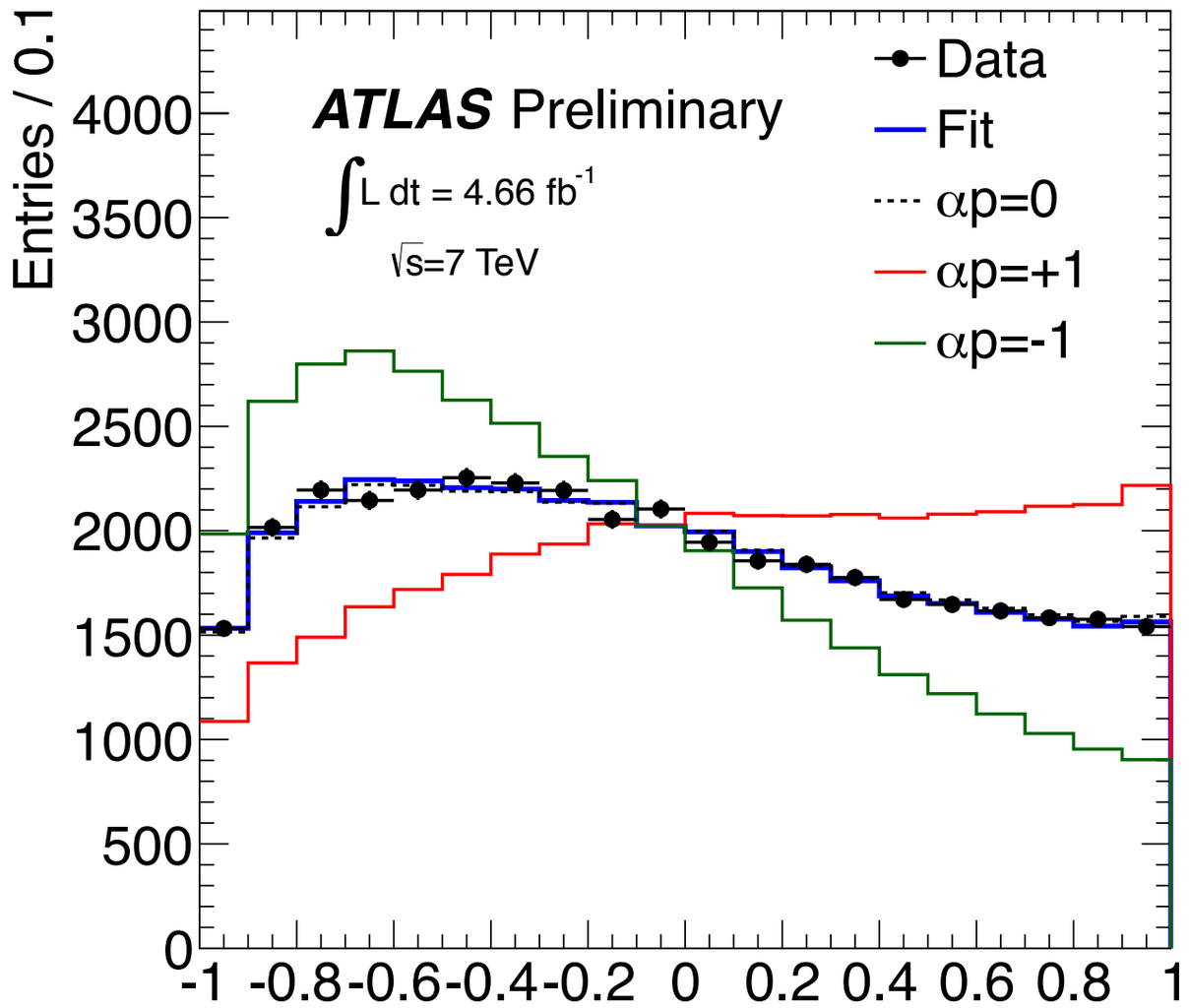
Top Polarization II $4.7\ \text{fb}^{-1}$, $\sqrt{s} = 7$, TeV ATLAS-CONF-2012-133 LC2013

- Template fit :
  - extraction of degree of polarization:

$$\alpha p = 2f - 1$$

  - templates:
    - ✦ fully positive and negative polarization
- Systematic Uncertainties:
  - Resolution and Calibration scales
  - Leading Jet reconstruction

Source	Δf	
Lepton reconstruction	+0.002	-0.003
Jet reconstruction	+0.018	-0.028
$E_{\text{T}}^{\text{miss}}$ reconstruction	+0.001	-0.003
Signal modelling	+0.011	-0.012
W+jets shape	+0.004	-0.004
Fake lepton shape	+0.004	-0.005
Monte Carlo background cross section	+0.002	-0.002
Template statistical uncertainty	+0.004	-0.004
Total systematic	+0.023	-0.032



- Results:

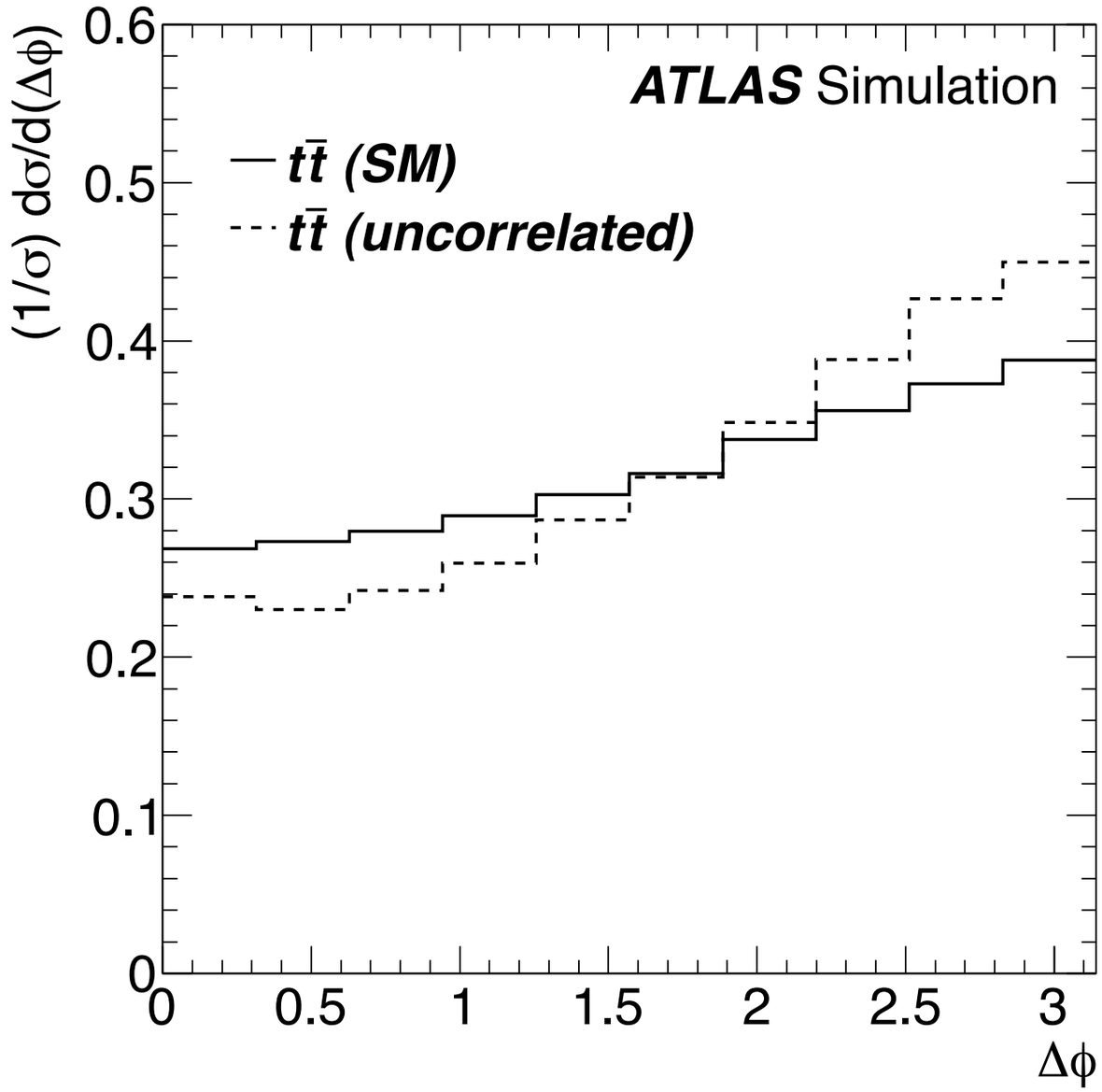
$$f = 0.470 \pm 0.009(\text{stat}) \, ^{+0.023}_{-0.032}(\text{syst})$$

$$\alpha p = -0.060 \pm 0.018(\text{stat}) ^{+0.046}_{-0.064}(\text{syst})$$

  - Consistent with S.M. prediction of $f = 0.5$

$t\bar{t}$ Spin Correlation I 2.1 fb^{-1} $\sqrt{s}$ = 7 TeV PRL 108, 212001 (2012)

- $\tau_{top} < O(1)$ of α_s time scale, decay before hadronization:
  - spin at production transferred to decay products.
  - t and $\bar{t}$ spins for $t\bar{t}$ production correlated under the S.M.
  - The $t\bar{t}$ decay in $W^+W^-b\bar{b}\,b^+ \rightarrow l^+\nu\, l^-\nu\, b\bar{b}\,b^+$ channel produces charged leptons
  - correlations in azimuthal angle, $\Delta\varphi$, in the laboratory frame



- Analysis extracts degree of correlation :
  - fractional difference in number of aligned and anti aligned events top quarks

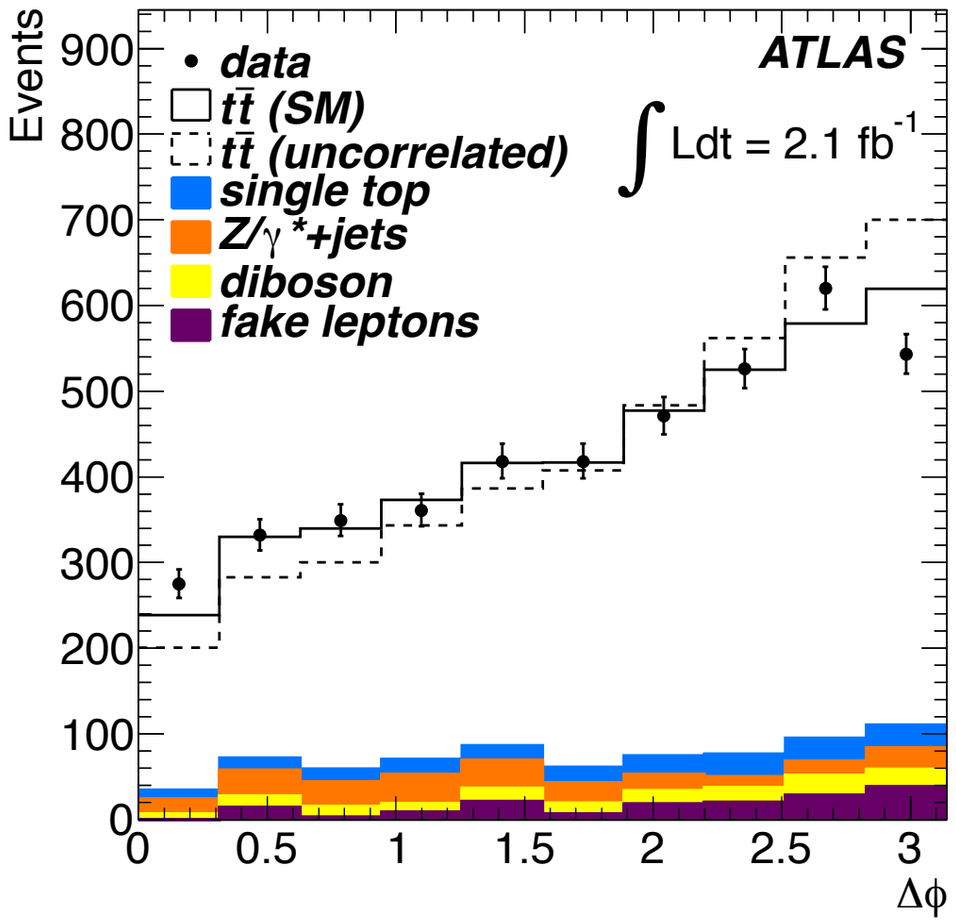
$$A \equiv \frac{N(\uparrow\uparrow)+N(\downarrow\downarrow)-N(\uparrow\downarrow)-N(\downarrow\uparrow)}{N(\uparrow\uparrow)+N(\downarrow\downarrow)+N(\uparrow\downarrow)+N(\downarrow\uparrow)}$$

$t\bar{t}$ Spin Correlation II 2.1 fb^{-1} $\sqrt{s}$ = 7 TeV PRL 108, 212001 (2012)

- Template fit on $\Delta\phi$ distributions

$$A_{\text{measured}} = A^{\text{SM}} \cdot f^{\text{SM}}$$

  - linear superposition of template modeling the correlated (f^{SM}) and uncorrected (1- f^{SM}) hypotheses



- Result projected in helicity basis:

  - helicity base (quark direction of flight in the C.M.)

$$A_{\text{helicity}} = 0.40 \pm 0.04(\text{stat}) \, ^{+0.08}_{-0.07}(\text{syst})$$

  - Consistent with S.M. prediction

$$A^{\text{theor}}_{\text{helicity}} = 0.31$$

- First Observation

  - No correlation hypothesis excluded at 5.1σ

Uncertainty source	Δf^{SM}
Data statistics	±0.14
MC simulation template statistics	±0.09
Luminosity	±0.01
Lepton	±0.01
Jet energy scale, resolution and efficiency	±0.12
NLO generator	±0.08
Parton shower and fragmentation	±0.08
ISR/FSR	±0.07
PDF uncertainty	±0.07
Top quark mass	±0.01
Fake leptons	+0.16/−0.07
Calorimeter readout	±0.01
All systematics	+0.27/−0.22
Statistical + Systematic	+0.30/−0.26

W_{tb} vertex probes

- Top physics:
  - direct probe of couplings in the W_{tb} vertex
- Most general S.M. Lagrangian at tree level:

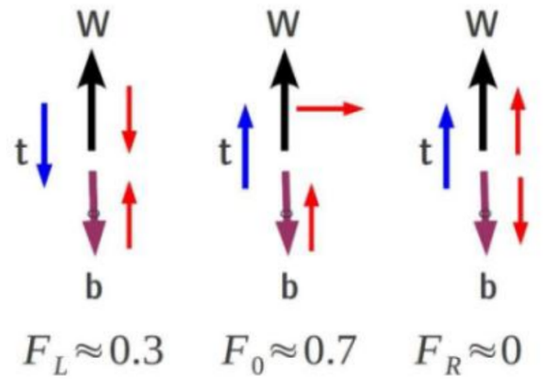
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_{\mathrm{L}}P_{\mathrm{L}} + V_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_{W}}\left(g_{\mathrm{L}}P_{\mathrm{L}} + g_{\mathrm{R}}P_{\mathrm{R}}\right)tW_{\mu}^{-} + \mathrm{h.c.}$$

  - $V_L \sim V_{tb} \sim 1$
  - while the anomalous couplings $V_R = g_{R,L} = 0$
- Deviations from:
  - W polarization fractions
  - Lepton Angular asymmetries from the W decay

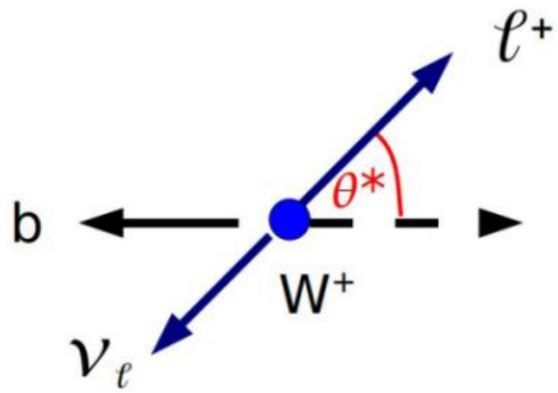
W helicity I 1.04 fb^{-1} $\sqrt{s}$ = 7 TeV JHEP 1206 (2012) 088) LC2013

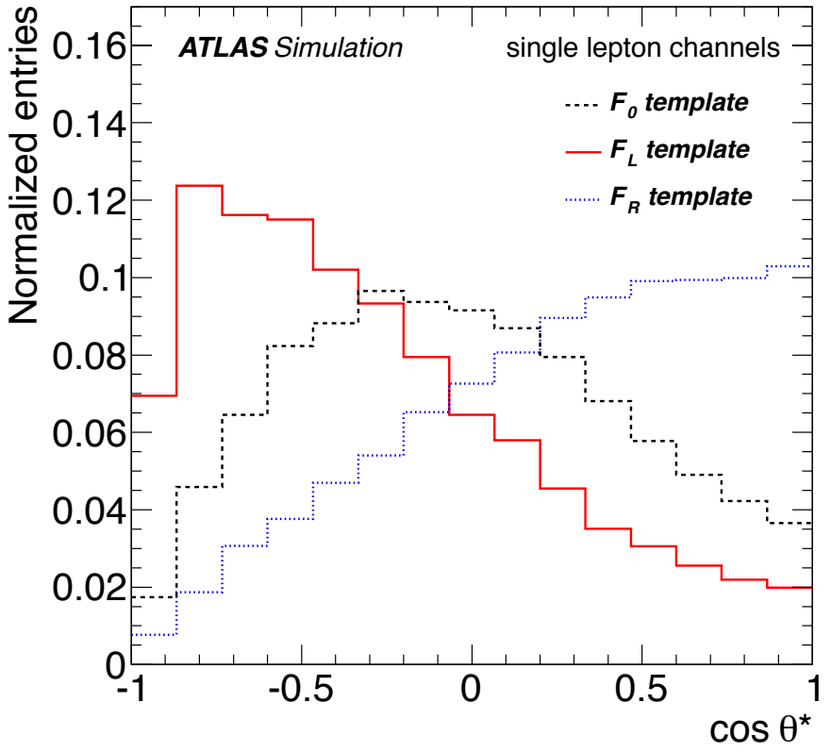
- W polarization can be longitudinal, left or right-handed
- Angular distribution:

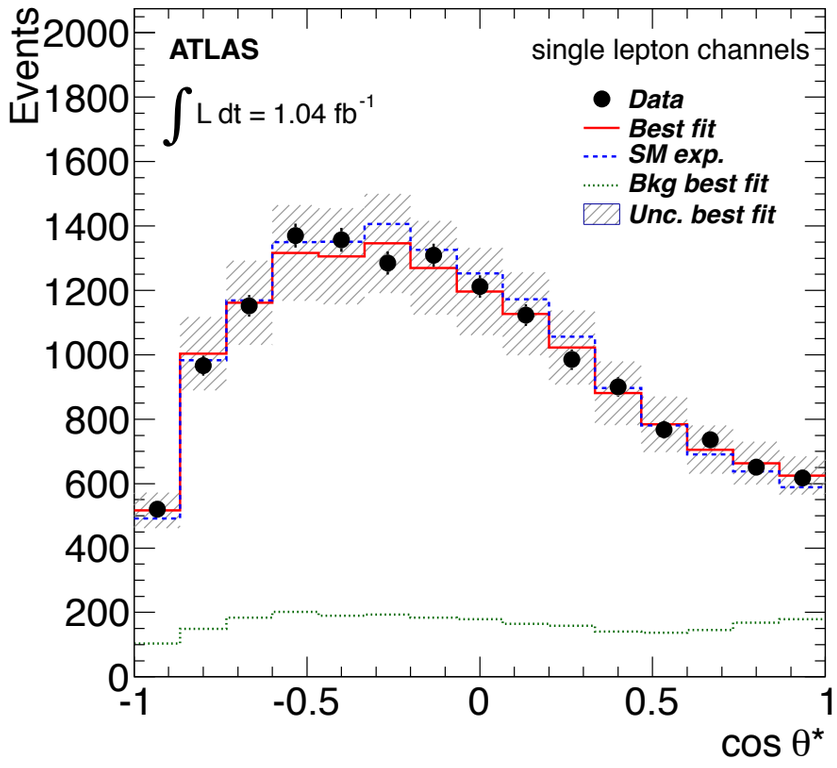
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_{\rm L} + \frac{3}{8}(1+\cos\theta^*)^2 F_{\rm R}$$

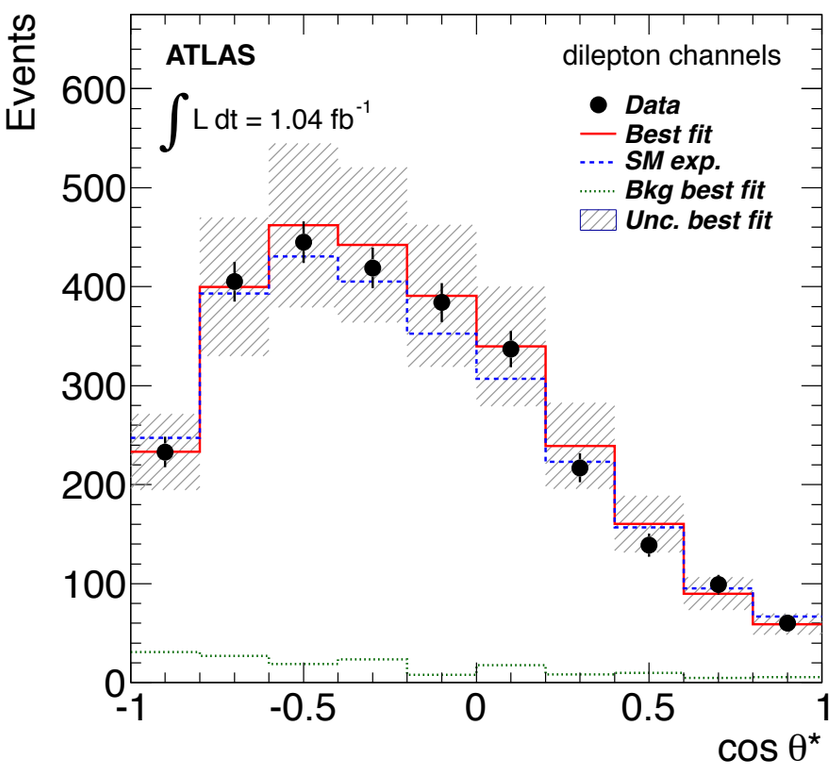


- Method I: *W* helicity states templates from cosθ*









W helicity II 1.04 fb^{-1} $\sqrt{s}$ = 7 TeV JHEP 1206 (2012) 088) LC2013

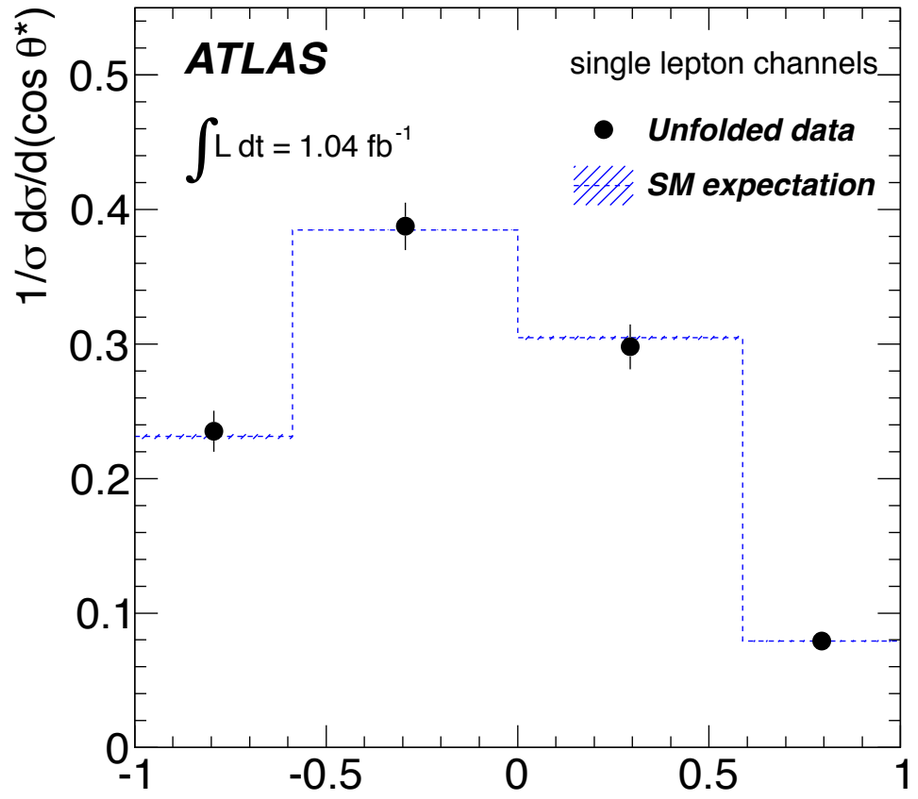
- Method II: Measurement of angular distributions

$$A_{\pm} = \frac{N(cos\theta^* > z_{\pm}) - N(cos\theta^* < z_{\pm})}{N(cos\theta^* > z_{\pm}) + N(cos\theta^* < z_{\pm})}; \quad z_{\pm} = \pm(1 - 2^{2/3})$$

- χ^2 minimization in reconstruction of single lepton events:

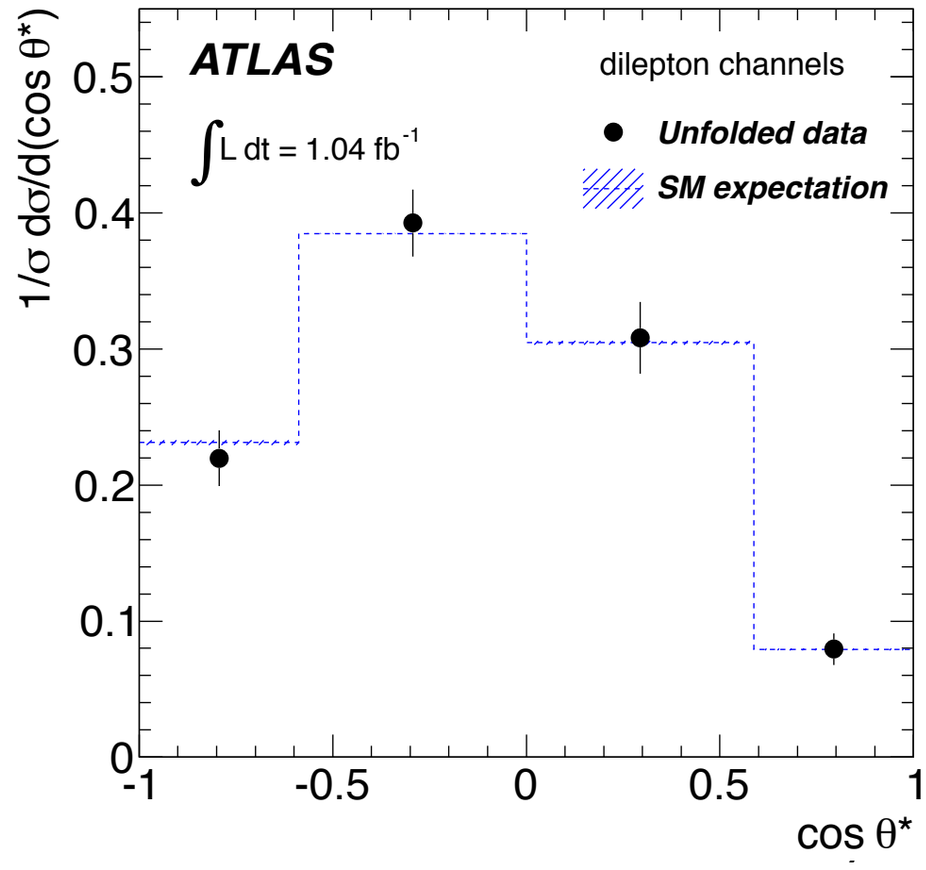
$$\chi^2 = \frac{(m_{\ell\nu j_a} - m_t)^2}{\sigma_t^2} + \frac{(m_{j_b j_c j_d} - m_t)^2}{\sigma_t^2} + \frac{(m_{\ell\nu} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_c j_d} - m_W)^2}{\sigma_W^2}$$

  - σ_t=14 GeV σ_W=10 GeV



  - Four non-uniform bins in $A^{\pm}$
  - Count events above and below z
  - Correction factors: selection and reconstruction effects
  - Conversion to W helicity fraction:

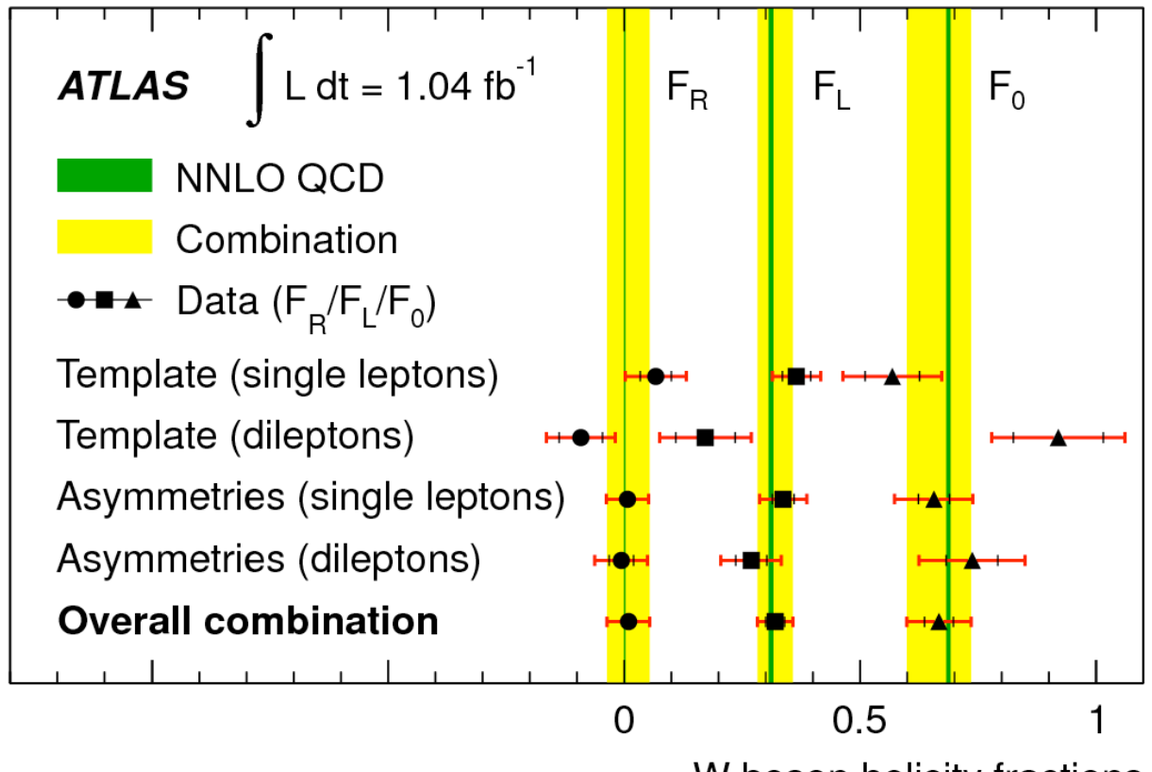
$$\beta = (2^{\frac{1}{3}} - 1)$$
$$A_+ = 3\beta\,[F_0 + 1(1+\beta)F_{\mathrm{R}}]$$
$$A_- = -3\beta\,[F_0 + 1(1+\beta)F_{\mathrm{L}}]$$



W helicity III 1.04 fb^{-1} $\sqrt{s}$ = 7 TeV JHEP 1206 (2012) 088

- Combination
  - Including correlated effects
  - Agreement with S.M. prediction

Channel	F_0	F_L	F_R
W boson helicity fractions from the template fit			
Single leptons	$0.57 \pm 0.06 \pm 0.09$	$0.37 \pm 0.03 \pm 0.04$	$0.07 \pm 0.03 \pm 0.06$
Dileptons	$0.92 \pm 0.10 \pm 0.10$	$0.17 \pm 0.06 \pm 0.07$	$-0.09 \pm 0.05 \pm 0.06$
Combination	$0.66 \pm 0.06 \pm 0.07$	$0.33 \pm 0.03 \pm 0.03$	$0.01 \pm 0.03 \pm 0.06$
F_R fixed	$0.66 \pm 0.03 \pm 0.04$	$0.34 \pm 0.03 \pm 0.04$	0 (fixed)
W boson helicity fractions from the angular asymmetries			
Single leptons	$0.66 \pm 0.03 \pm 0.08$	$0.33 \pm 0.02 \pm 0.05$	$0.01 \pm 0.01 \pm 0.04$
Dileptons	$0.74 \pm 0.06 \pm 0.10$	$0.27 \pm 0.03 \pm 0.05$	$-0.01 \pm 0.03 \pm 0.05$
Combination	$0.67 \pm 0.04 \pm 0.07$	$0.32 \pm 0.02 \pm 0.04$	$0.01 \pm 0.02 \pm 0.04$
Overall combination	$0.67 \pm 0.03 \pm 0.06$	$0.32 \pm 0.02 \pm 0.03$	$0.01 \pm 0.01 \pm 0.04$

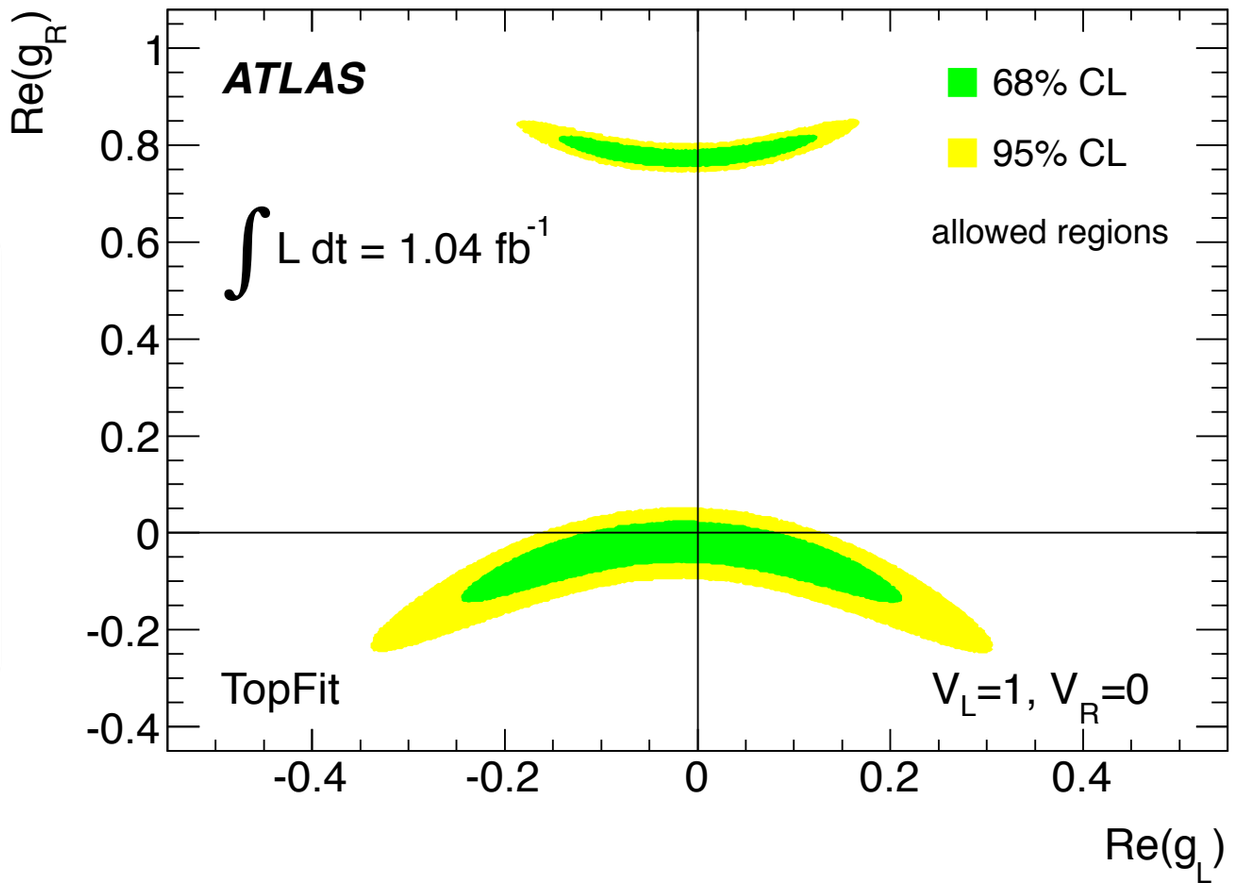


- No deviations in anomalous couplings from the Standard Model:

$$\mathrm{Re}\,(V_\mathrm{R}) \in [-0.20, 0.23] \rightarrow \frac{\mathrm{Re}\,(C^{33}_{\phi\phi})}{\Lambda^2} \in [-6.7, 7.8] \quad \mathrm{TeV}^{-2}$$

$$\mathrm{Re}\,(g_\mathrm{L}) \in [-0.14, 0.11] \rightarrow \frac{\mathrm{Re}\,(C^{33}_{dW})}{\Lambda^2} \in [-1.6, 1.2] \quad \mathrm{TeV}^{-2}$$

$$\mathrm{Re}\,(g_\mathrm{R}) \in [-0.08, 0.04] \rightarrow \frac{\mathrm{Re}\,(C^{33}_{uW})}{\Lambda^2} \in [-1.0, 0.5] \quad \mathrm{TeV}^{-2}$$



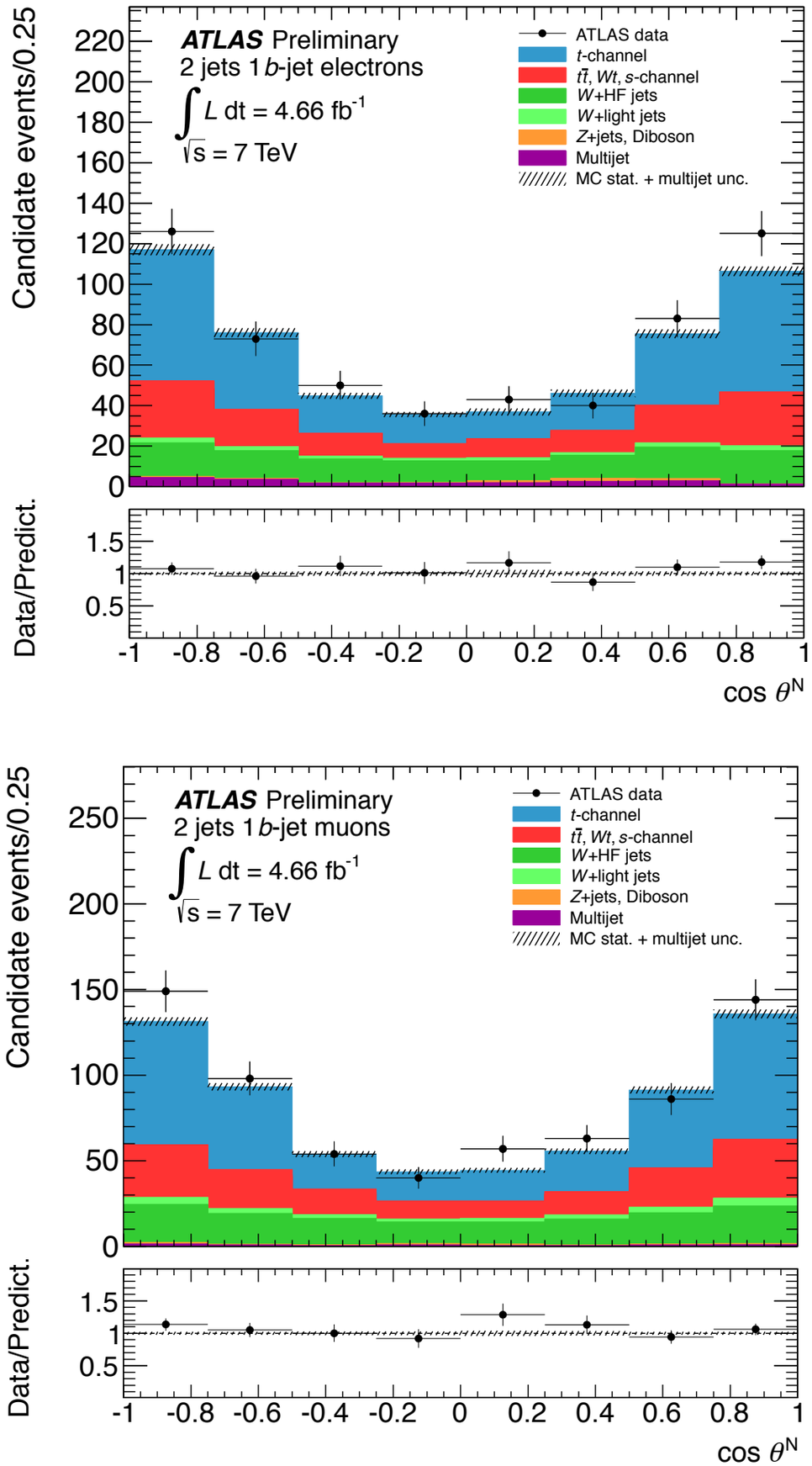
Single Top *CP* Violation 4.66 fb^{-1}, $\sqrt{s}$ = 7 TeV, ATLAS-CONF-2013-032 LC2013

- Limits on the Wtb vertex in $t\bar{t}$ events
  - Not sensitive to all anomalous couplings, especially if CP-violating component
  - Non-SM contributions have sizable CP-violating components
- Asymmetry:
  - Forward/Backwards asymmetry:

$$A_{\mathrm{FB}}^{\mathrm{N}} = \frac{3}{4} P (F_{\mathrm{R}}^{N} - F_{\mathrm{L}}^{N})$$

    - ✦ cos θ^{N} w.r.t to the plane of $p(W)$ and top polarization
    - ✦ Full Reconstruction of top and W needed
  - A_{FB} relates to $I(g_R)$

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

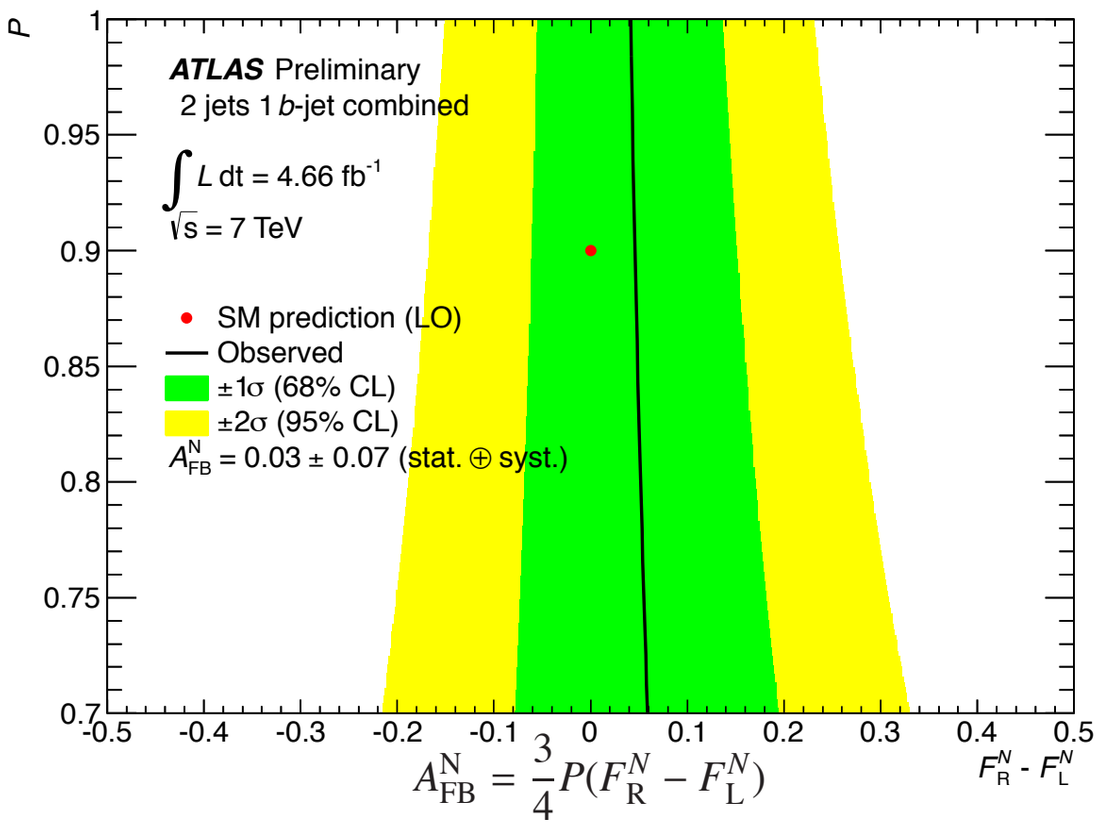


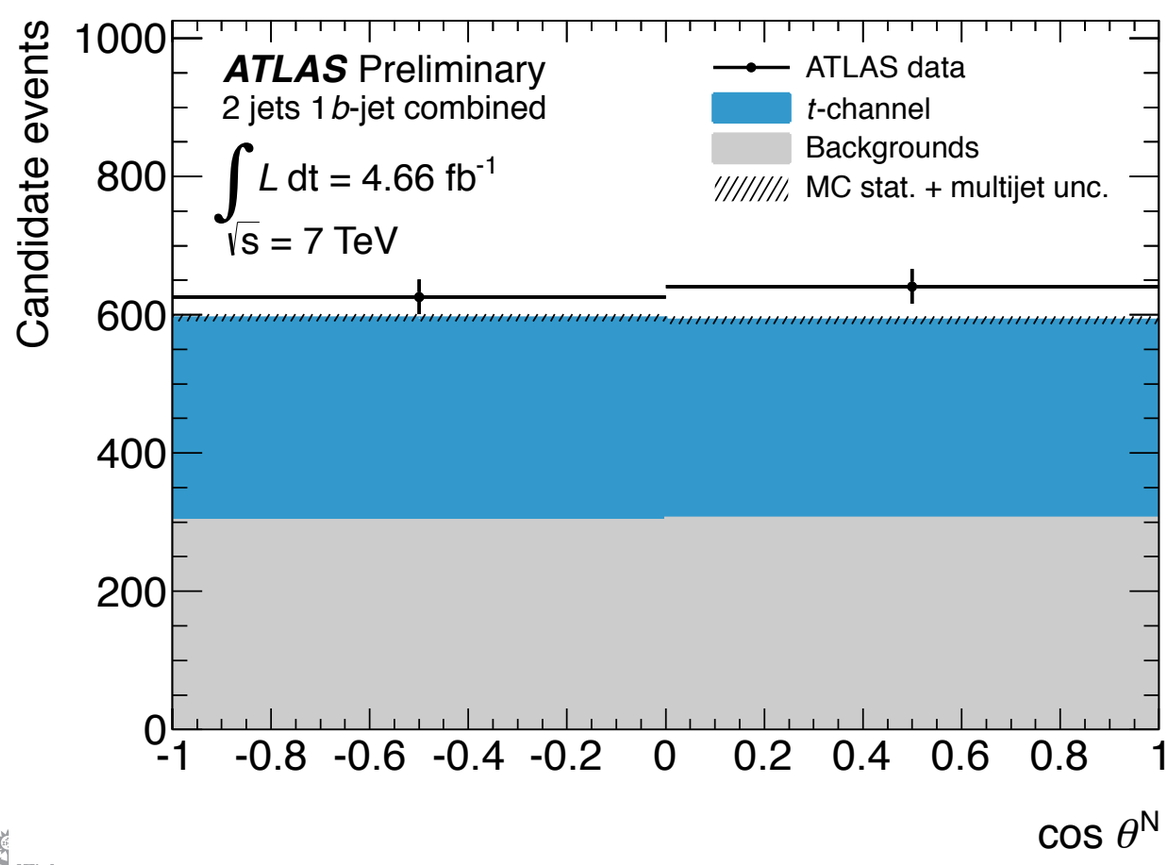
Single Top *CP* Violation 4.66 fb^{-1}, $\sqrt{s}$ = 7 TeV, ATLAS-CONF-2013-032

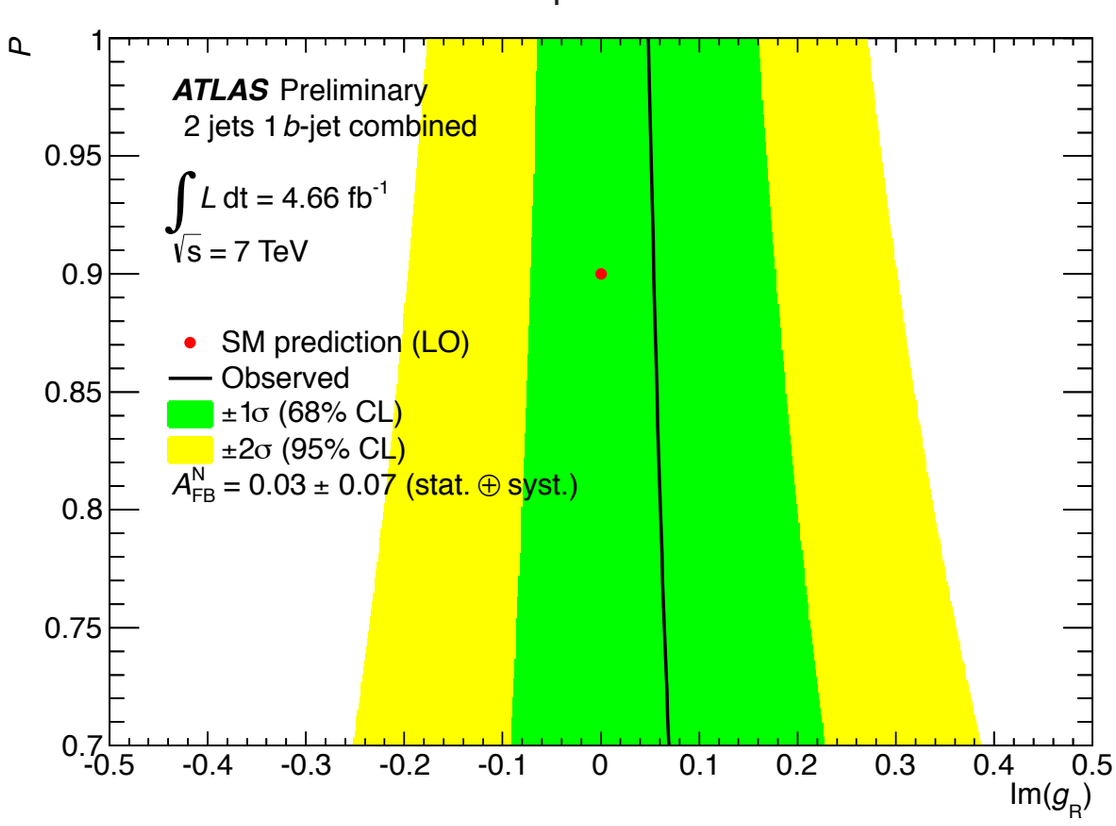
- Consistent with *CP* invariance in top quark decays (A^N_{FB} = 0).

$$A_{\mathrm{FB}}^{\mathrm{N}} = 0.032 \pm 0.065(\mathrm{stat})\ ^{+0.029}_{-0.031}(\mathrm{syst})$$

  - [−0.20, 0.30] 95% C.L. on I(g_R)
    - ✦ 0.9 top quark polarization *P*
- Consistent with SM predictions:
  - leading order
  - including one loop E.W. corrections
- Leading Systematics: *t*-channel and $t\bar{t}$ generators







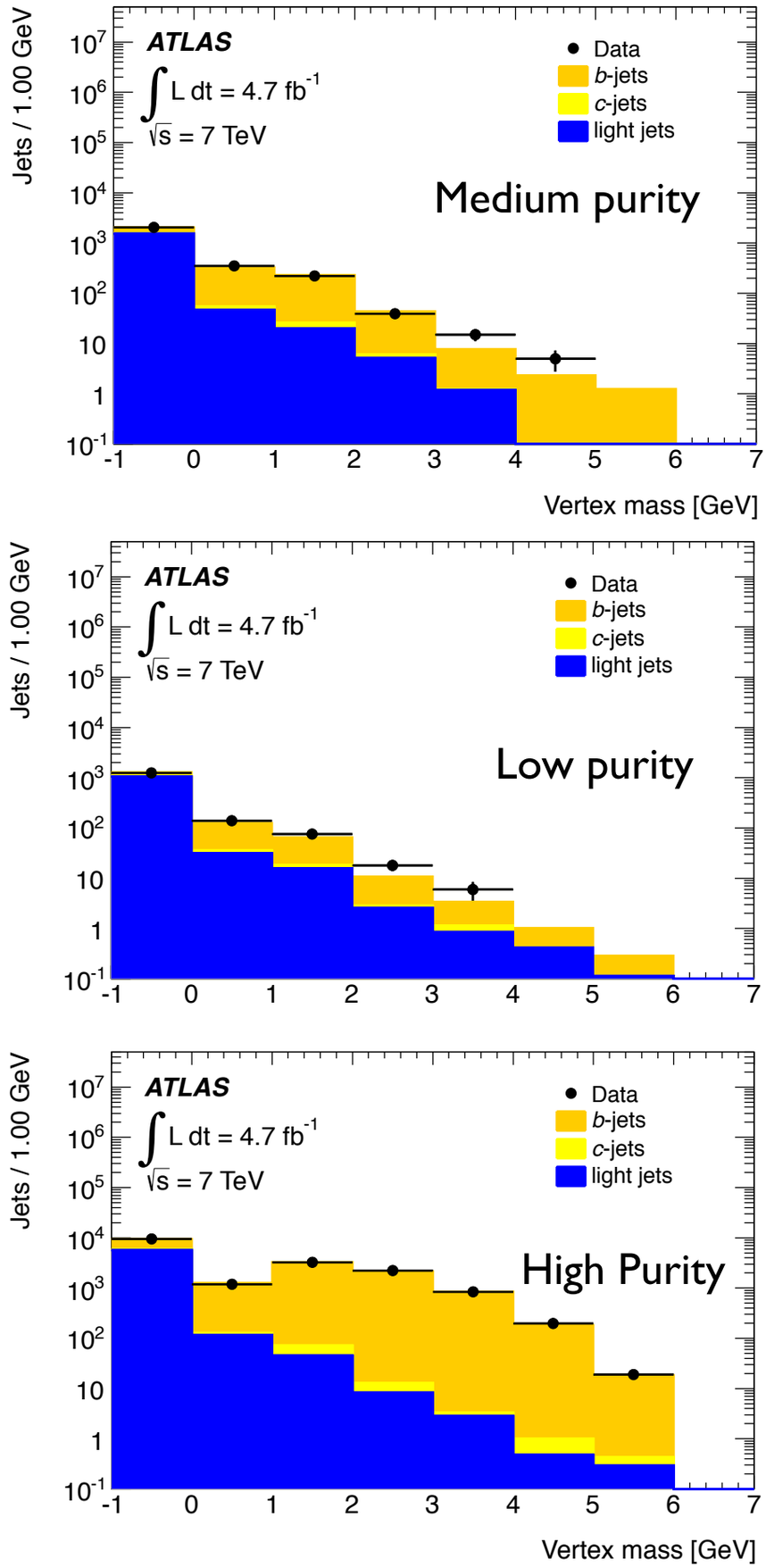
$$A_{\mathrm{FB}}^{\mathrm{N}} = 0.64\ P\ \mathbb{I}(g_{\mathrm{R}})$$

$t\bar{t}$+ HF | 4.7 fb^{-1} $\sqrt{s}$ = 7 TeV sub. PRD. CERN-PH-EP-2013-030 LC2013

- Search for $t\bar{t}$ associated with heavy-flavor (HF) quarks:
  - $t\bar{t} + b + X, t\bar{t} + c + X$
  - production via gluon splitting from ISR/FSR
  - HF of proton can lead to $t\bar{t}$ with at least one b (c) quark
- Motivations:
  - Main irreducible background to $H \to t\bar{t}$ and $H \to b\bar{b}$
  - Constrain models of HF production at the scale of the top quark mass
  - Composite Higgs Models
- Strategy:
  - Search in dilepton channel with at least three b-tagged jets
    - two jets originate from W decay
    - main background light flavor jets
  - Extract ratio of fiducial cross sections R= $\sigma(t\bar{t}+HF) / \sigma(t\bar{t}+j)$
    - $\sigma(t\bar{t}+j)$: at least 3 (2) jets (b-tagged jets)

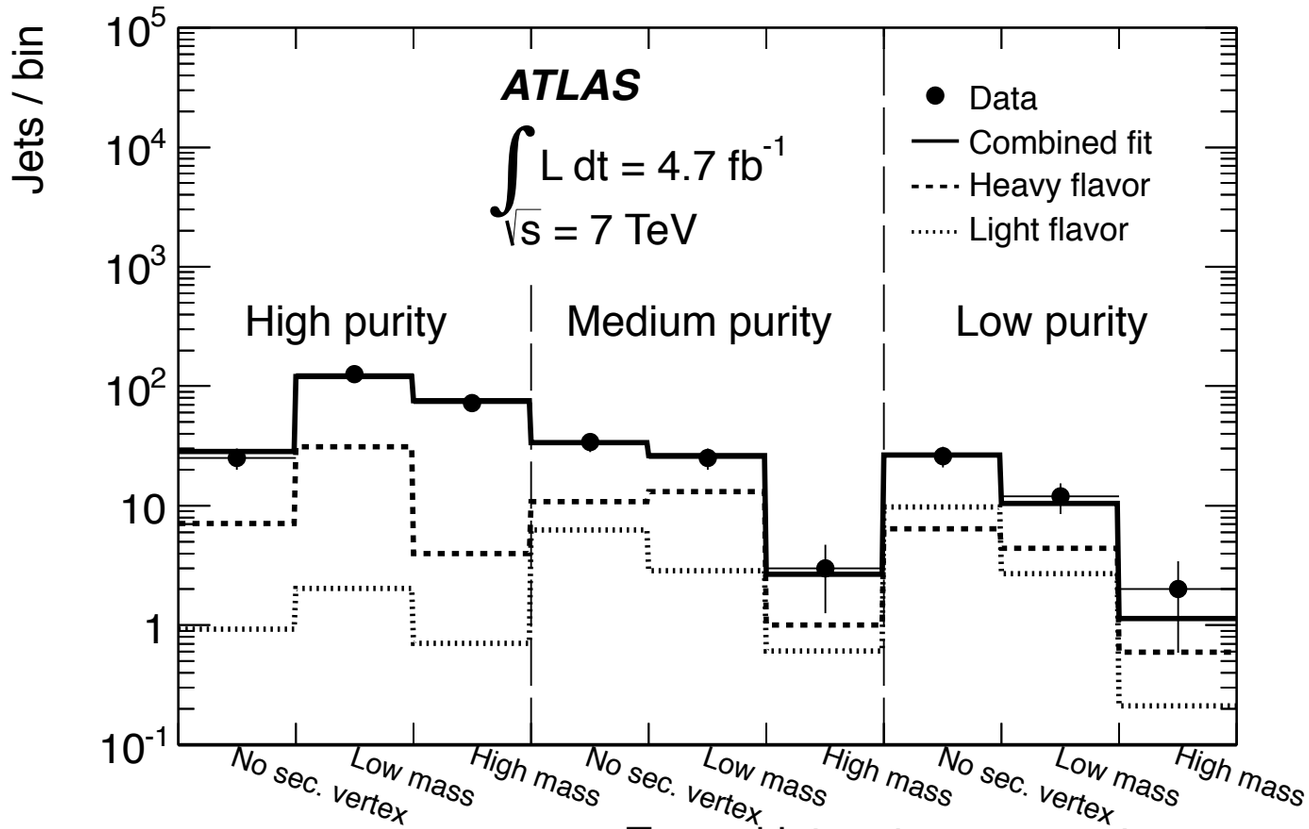
b-purity	b-jet efficiency	c-jet efficiency	light-flavor rejection
Tight	60%	17%	230
Medium	10%	7%	100
Low	5%	6%	75

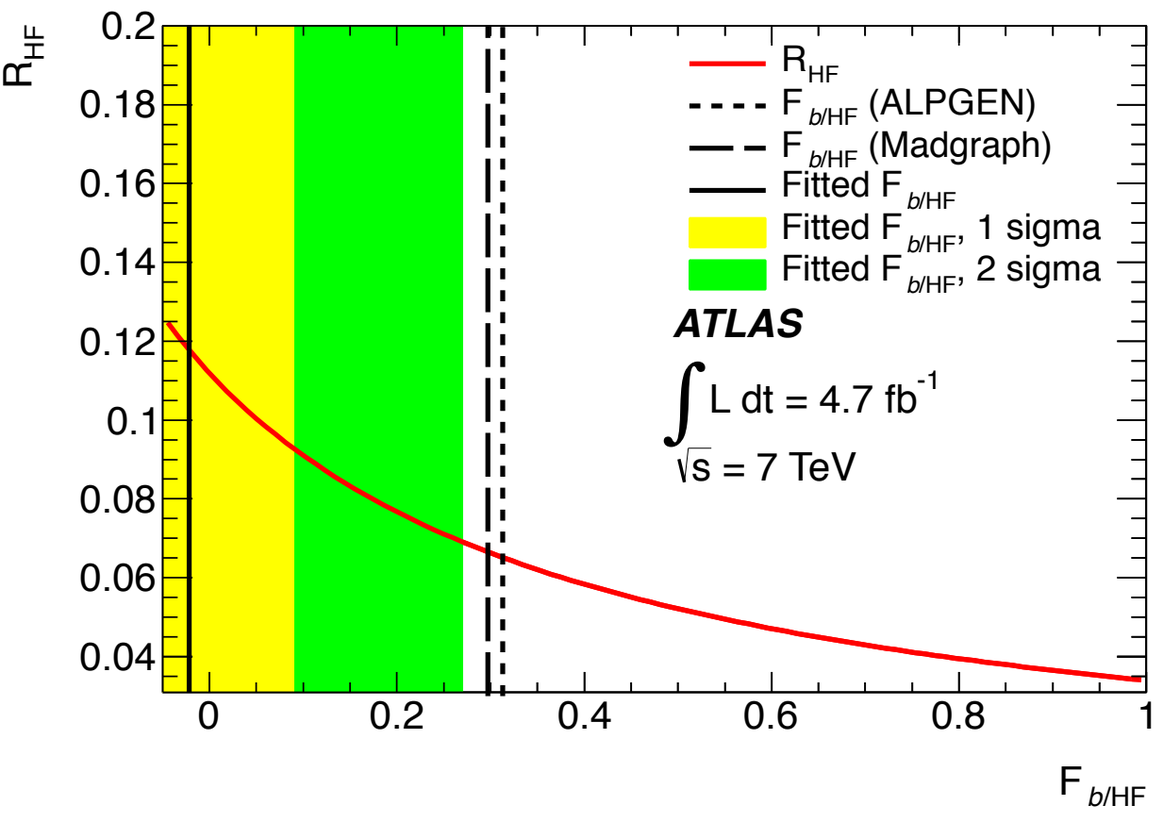
  - Classify three purity bins
    - tagger operating point
    - mutually exclusive



$t\bar{t}$+ HF II 4.7 fb^{-1} $\sqrt{s}$ = 7 TeV sub. PRD. CERN-PH-EP-2013-030

- Template fit over jet vertex mass
  - determine $\sigma(t\bar{t}+HF)$
  - discrimination of light/heavy flavor portion
  - 2D templates:
    - ✦ jet vertex mass and jet p_T
  - Combined fit on purity bins
- Results
  - Dominant Systematic: flavor composition





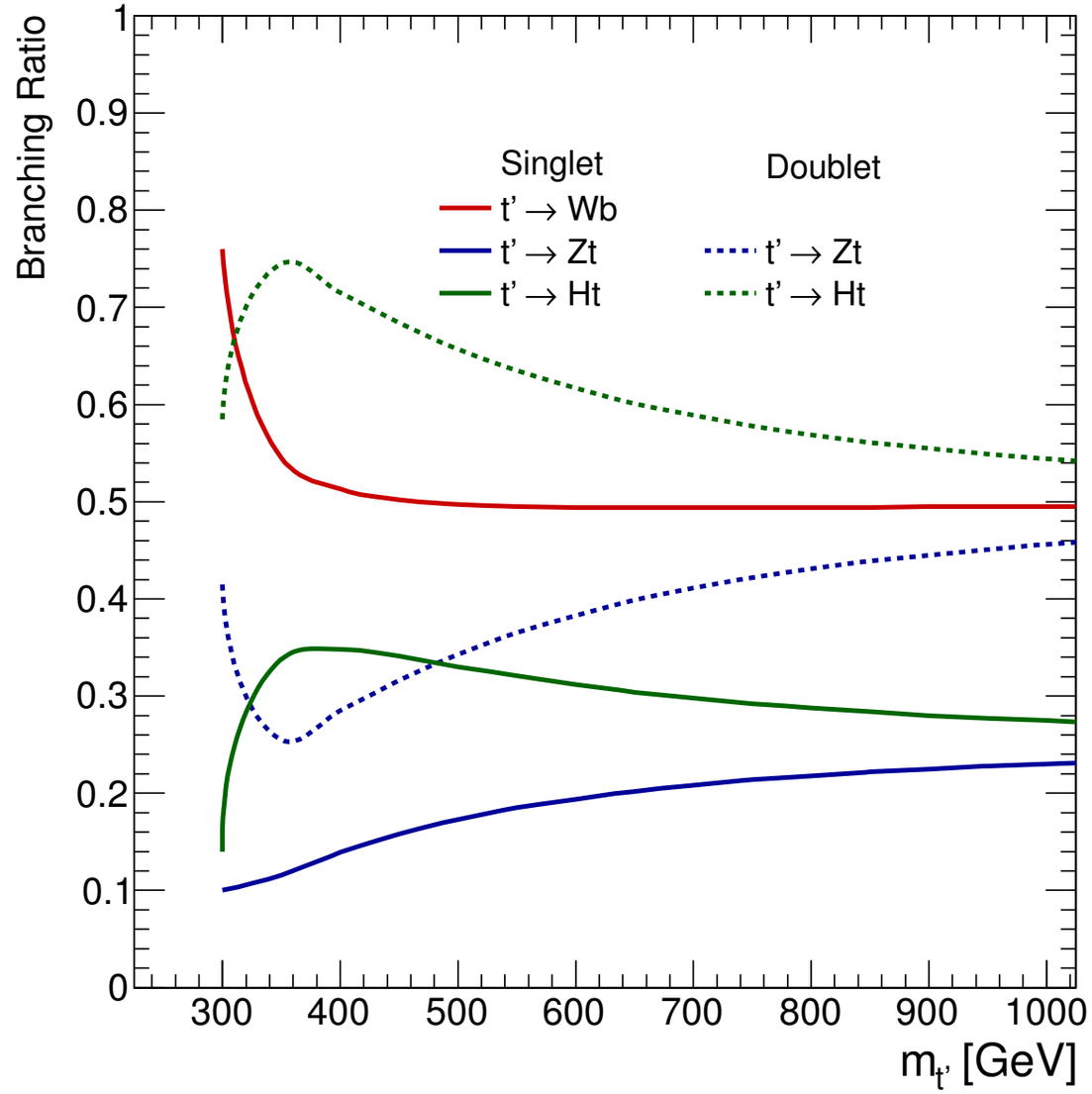
$$R_{\mathrm{HF}} = \left[7.1 \ \pm 1.3(\mathrm{stat}) \ ^{+5.3}_{-2.0}(\mathrm{syst})\right] \%$$

- LO (ALPGEN+HERWIG) 3.4 ± 1.1%, 1.4 σ agreement
- $t\bar{t}$ NLO plus LO jets 5.2 ± 1.7 % 0.6 σ agreement

B.S.M. physics

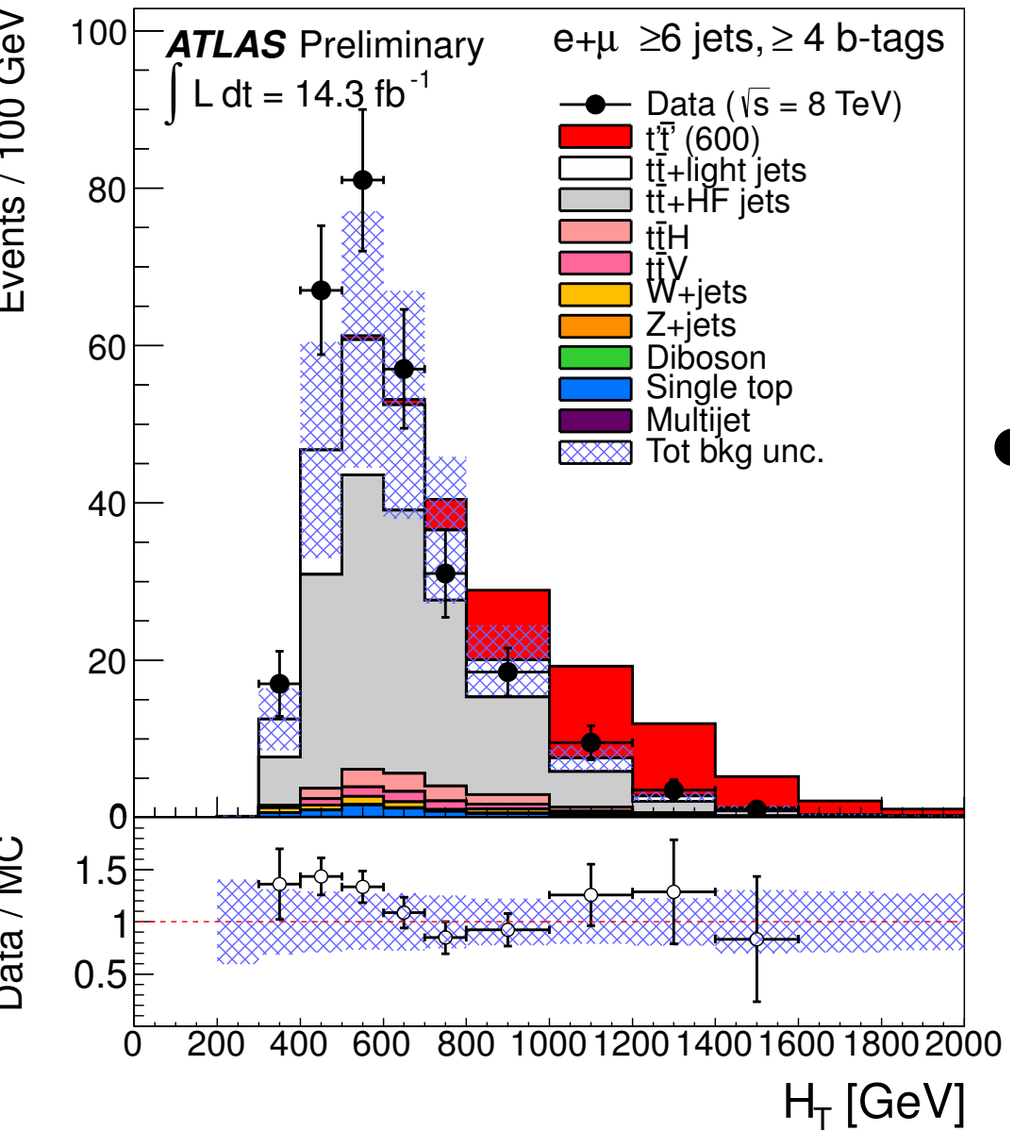
Heavy top-like in l+j

- Addition to Standard Model of doublets (triplets) of vector-like quarks
  - both chiralities transform *SU(2)×U(1)*
  - extensions of S.M.: Little Higgs, extra dimensional models
    - ✦ solve Higgs mass top correction hierarchy
- LHC expected production:
  - pairs for *O(m < 1* TeV*)*: clean signature high cross sections
  - for *O(m > 1* TeV*)*: singlet E.W. production can dominate
- Preference coupling with 3^{thd}gen quarks
  - mixing dependent of S.M. quarks
  - *t' → Wb, t' → Zt, t' → Ht*
- *W'* searches in association with top production

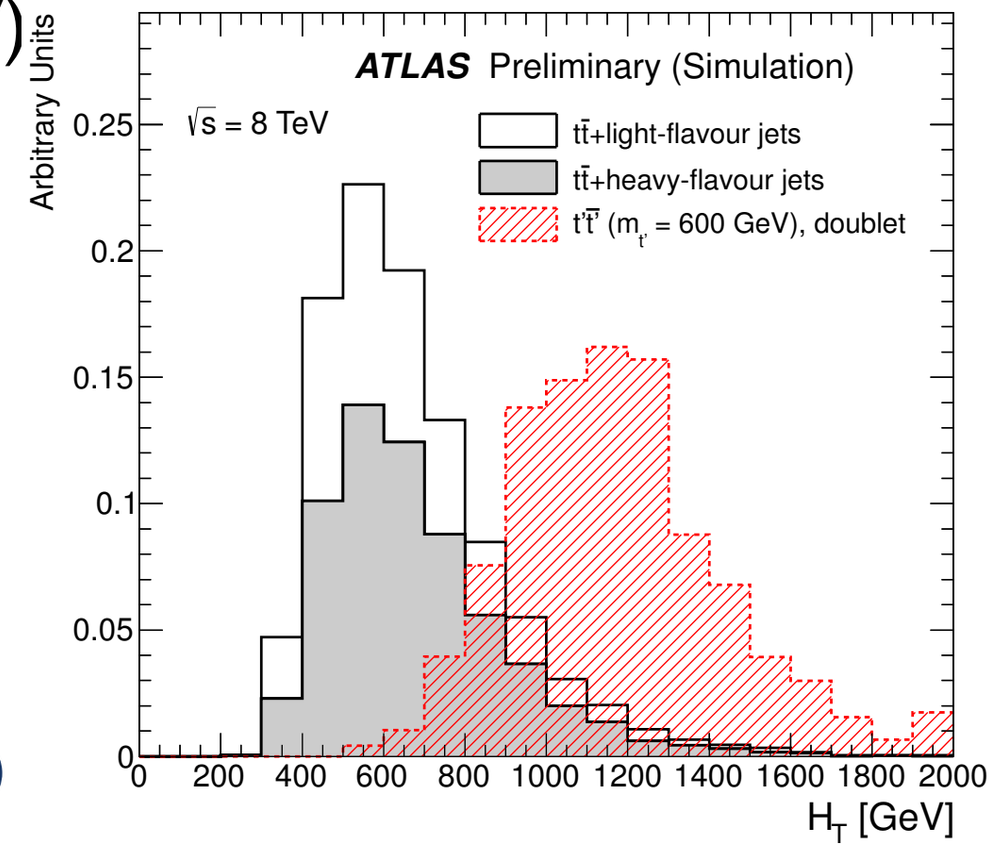


$t' \rightarrow Ht$ l 14.3 fb-1 $\sqrt{s}$ = 8 TeV ATLAS-CONF-2013-018

- Heavy quark t' decay in S.M Higgs (m_H=125 GeV)
  - $H \rightarrow b\bar{b}, t\bar{t} \rightarrow l$+jets
  - Isolated lepton
  - large E_t^{miss}

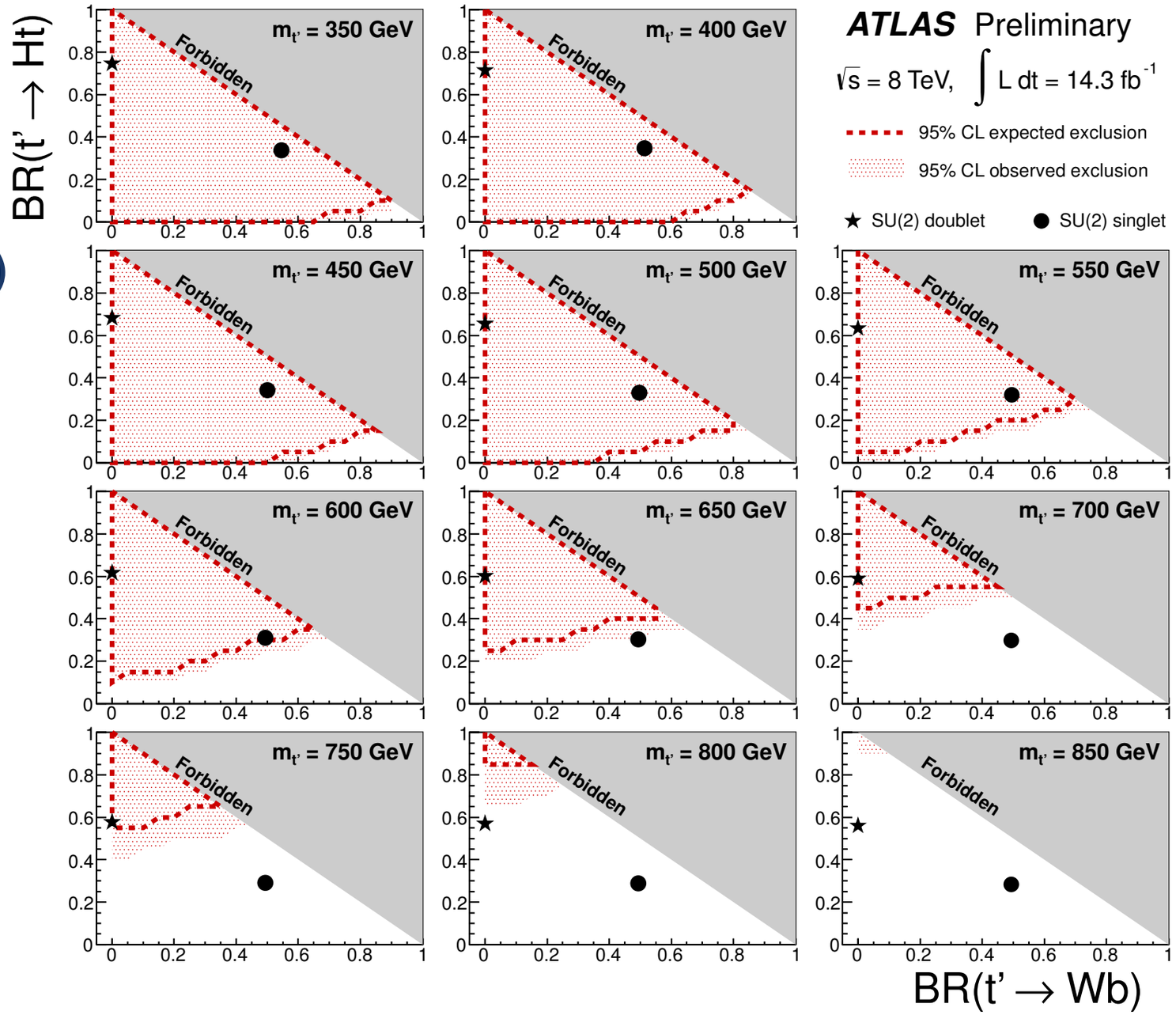


- Selection:
  - exclusive 1 lepton
  - ≥ 6 jets, N(b^{tag}) ≥2
- Strategy:
  - channel splitting in N(b^{tag}) bins
    - ≥4 golden
    - < 4 calibrate background constrain systematics
  - H_T discriminant distribution
    - Exploit large $m_{t'}$.
    - independent of decay mode



$t' \to Ht\,l$ 14.3 fb-1 $\sqrt{s}$ = 8 TeV ATLAS-CONF-2013-018

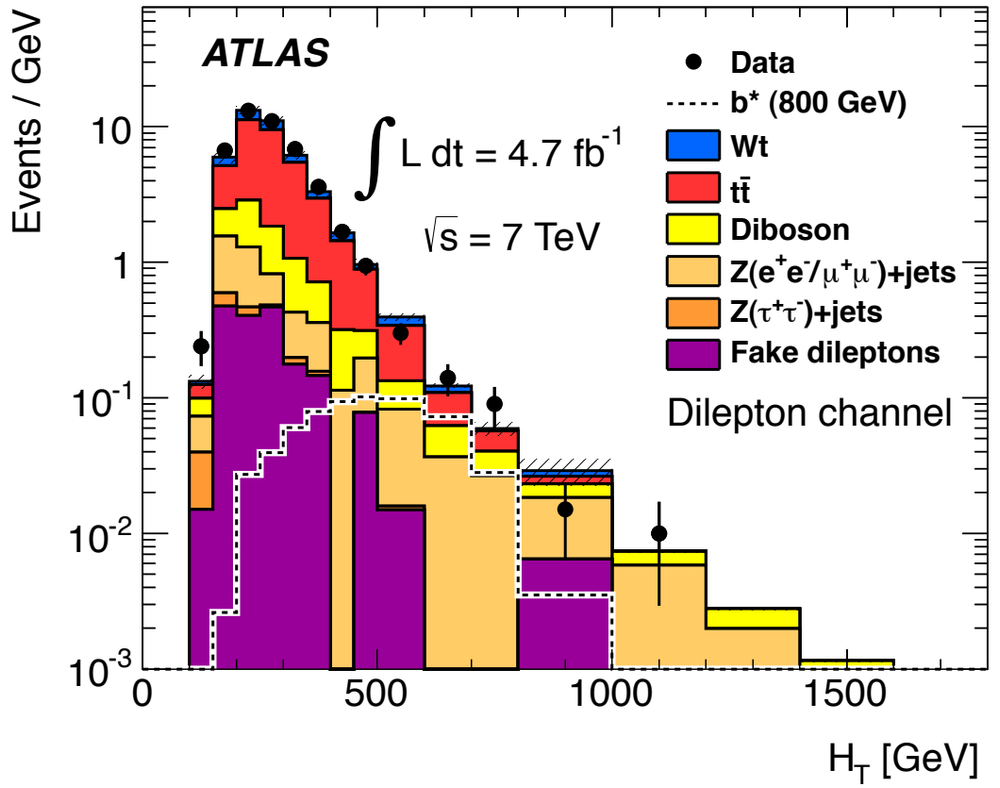
- No observation, 95% C.L. exclusions for the weak isospins:
  - doublet: an observed (expected) $m_{t'} > 790$ (745) GeV
    - ✦ most stringent limit to date
  - singlet: the observed (expected) $m_{t'} > 640$ (615) GeV

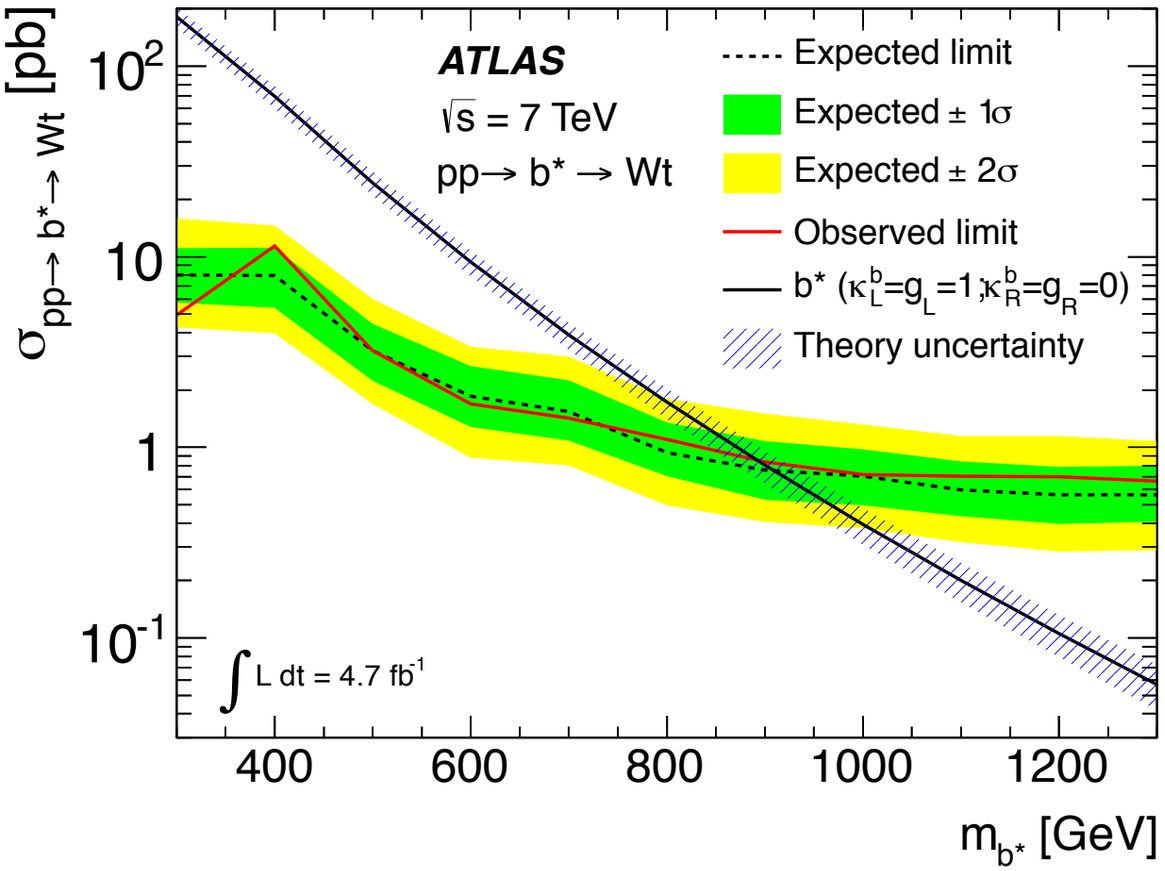


- Derive limits on vector-like t′ quark production:
  - different values of $m_{t'}$ as f unction of $BR(t' \to Wb)$ and $BR(t' \to Ht)$.
  - $BR(t' \to Zt) = 1 - BR(t' \to Wb) - BR(t' \to Ht)$

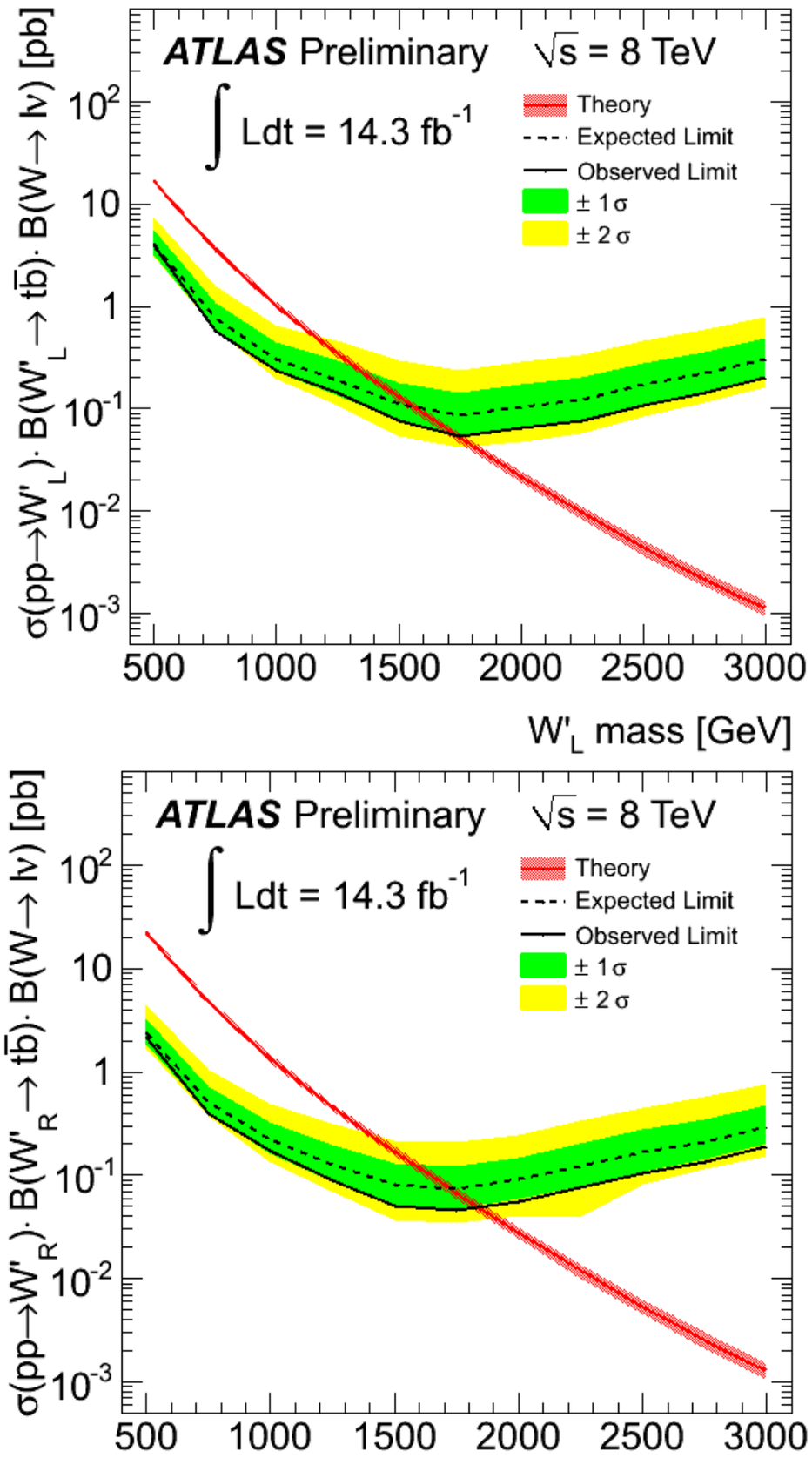
b^*-quark production 4.7 fb-1 $\sqrt{s}$ = 7 TeV Phys. Lett. B 721 (2013) 171-189 LC2013

- b*→Wt first search for excited quarks coupling to 3thd gen. fermions
  - Randall–Sundrum models (strong interaction)
  - with a heavy gluon partner (ex. composite Higgs models)
- Dilepton channel:
  - two opposite charge lepton, one jet, no b-tag
  - H_T discriminant
- semi-leptonic:
  - one lepton N(b-tag) ≥ 1
  - reconstructed mass
- left-handed models
  - unit strength chromo- magnetic coupling
  - $m_{b^*} < 870$ GeV excluded at 95% C.L.
- right handed models:
  - vector-like b^* couplings
  - $k_L^b = g_L = 0$, $k_R^b = g_R = 1$ $m_{b^*} < 920$ GeV excluded at 95%
  - $k_L^b = g_L = k_R^b = g_R = 1$, $m_{b^*} < 920$ GeV excluded at 95%

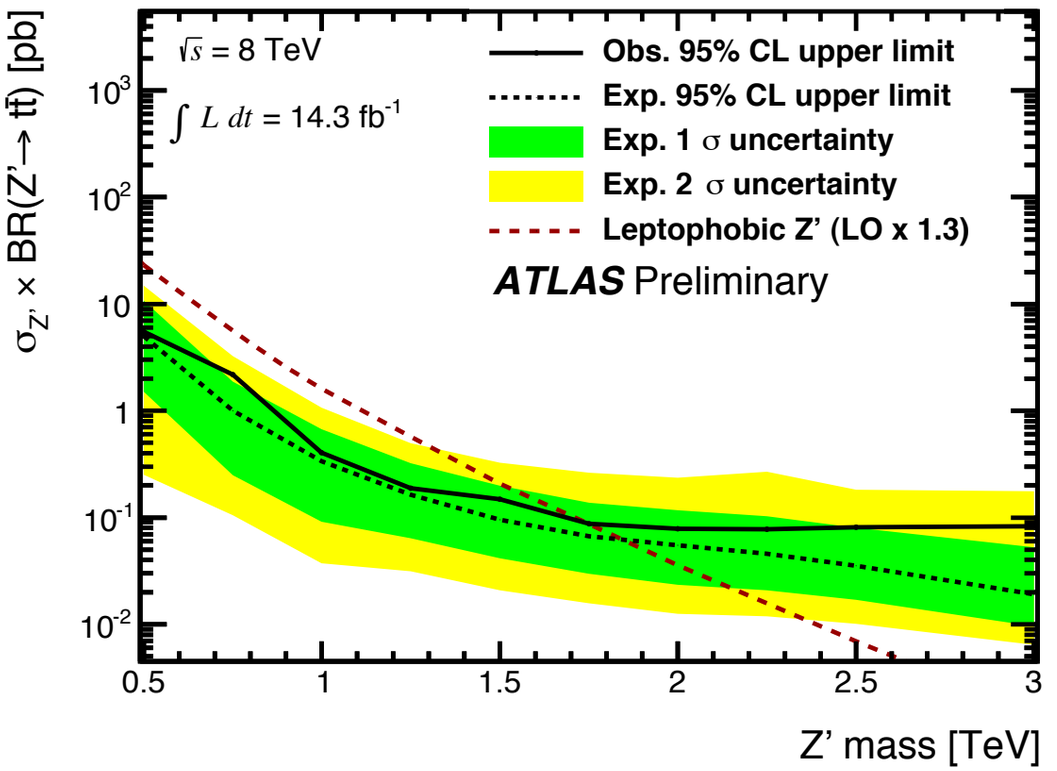


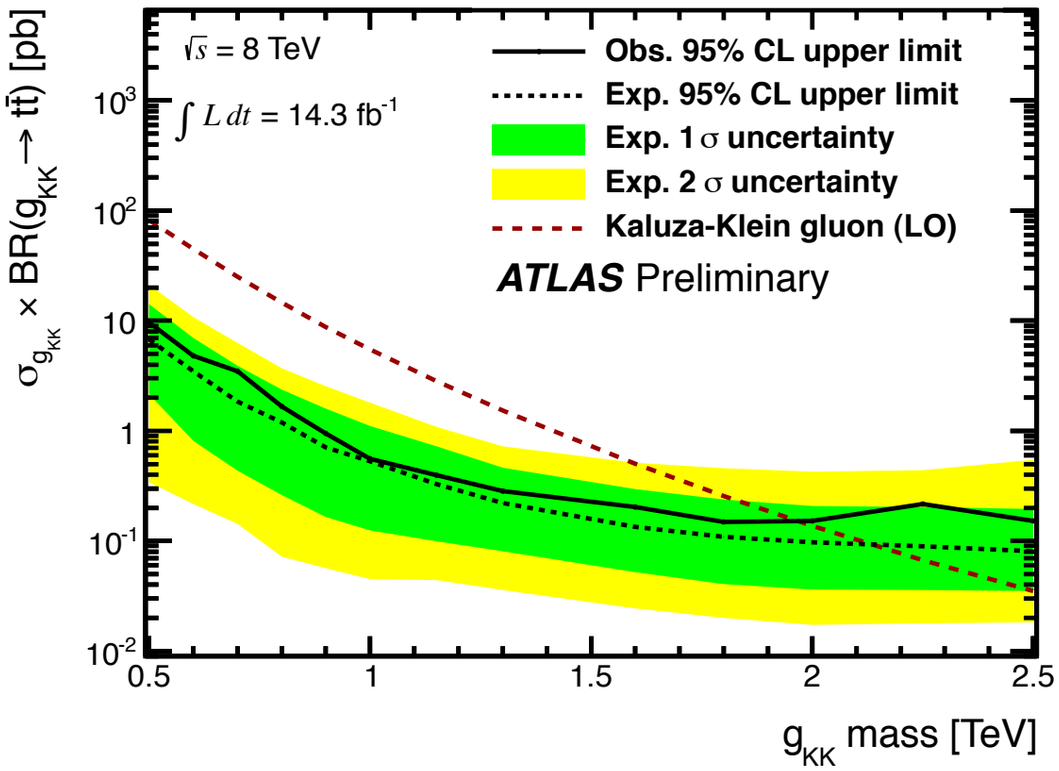


- *W'* top searches
  - heavily coupling with 3thd gen. quarks
  - $t\bar{b}$ reconstruction allows for peak hunting in invariant mass spectrum
  - assumed same coupling strength as for W
- Analysis based on BDT
  - training with kinematic variables
    - ✦ separately for 2-jet and 3-jet events
  - signal $m_{W'}$ = 1.75 TeV for best exclusion limit
- Systematics:
  - b-tag performance,Jet Energy Scale
  - monte carlo generator, ISR/FSR
- No deviation observed, 95% C.L. on $m_{W'}$
  - Left Handed model: 1.74 TeV
  - Right handed model: 1.56 TeV



- Resonances predicted by topcolor assisted technicolor Phys. Lett. B345 (1995) 483–489
  - leptophobic Z'
  - Randall–Sundrum warped extra-dimension
    - bulk Kaluza–Klein (color-octet)
- Search for excesses in $m_{t\bar{t}}^{reco}$
  - boosted: high-mass $t\bar{t}$
    - collimated decay products,
    - no ambiguity
    - single jet reconstruction with R=1.0
  - resolved: hadronic top identification
    - small radius jets (R=0.4)
    - χ^2 for best jet assignment to leptonic and hadronic top
- Dominant systematic: $t\bar{t}$ cross section
- No deviation, 95% C.L. exclusions derived
  - Narrow $Z' \rightarrow t\bar{t}$: 0.5 TeV for $\sigma_{Z'}$= 5.3 to 3 TeV for $\sigma_{Z'}$ = 0.08 pb
  - broad color octet $g_{kk} \rightarrow t\bar{t}$: 0.5 TeV for σ_{kk}= 9.6 to 2.5 TeV for σ_{kk} = 0.152 pb





Conclusions

- Status:
  - Concluded many measurements with 7 TeV and 8 TeV data
  - 20 fb^{-1} awaiting to be further analyzed

$\sigma_{t\bar{t}}$ (7 TeV) $= 177^{+11}_{-10}$ pb

$\sigma_{t\bar{t}}$ (8 TeV) $= 241 \pm 32$ pb

$\sigma_{t} = 95 \pm 2(\text{stat}) \pm 18(\text{syst})$ pb

$A_{\text{helicity}} = 0.40 \pm 0.04(\text{stat})\ ^{+0.08}_{-0.07}(\text{syst})$

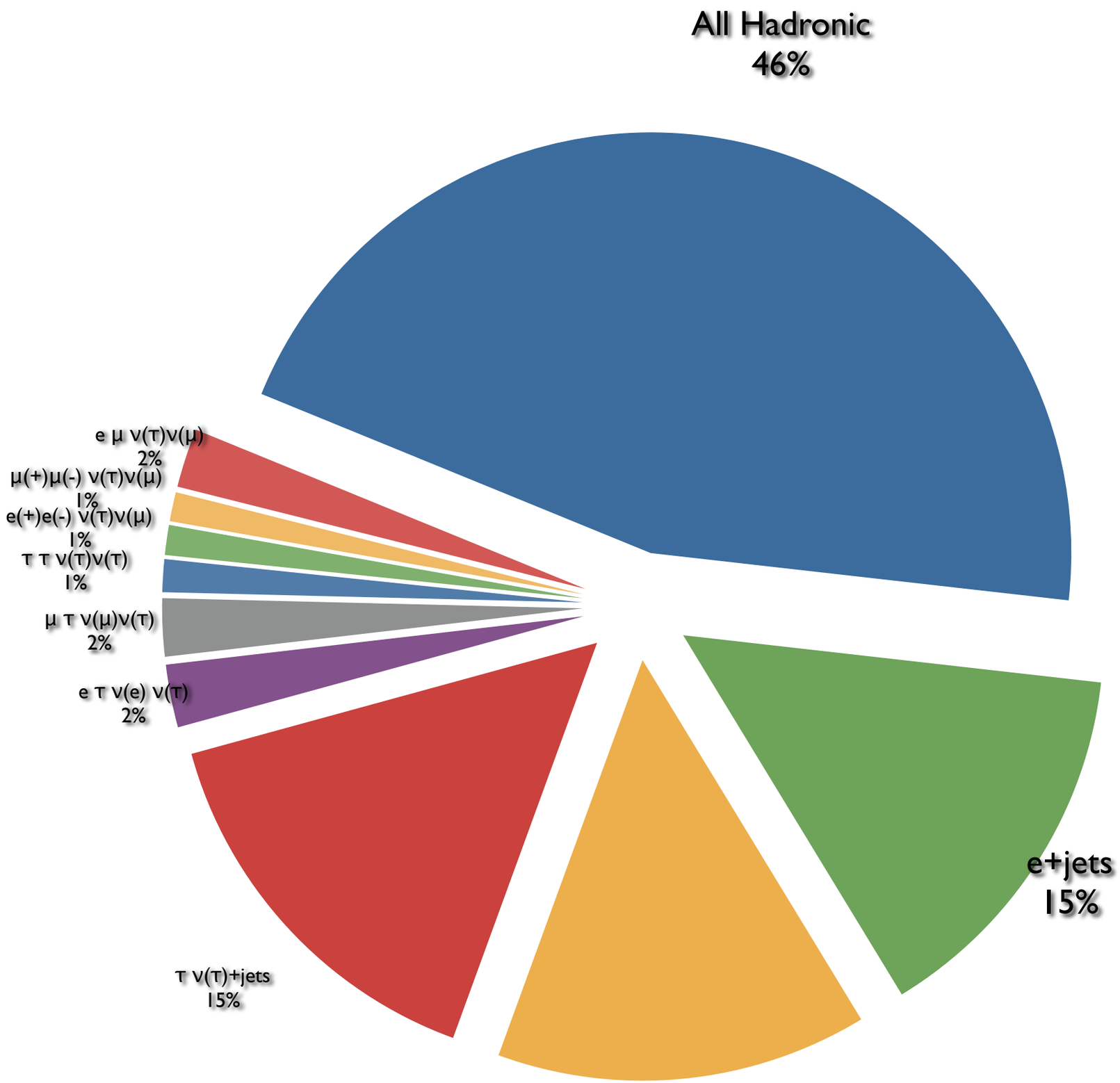
$A^{\text{N}}_{\text{FB}} = 0.032 \pm 0.065(\text{stat})\ ^{+0.029}_{-0.031}(\text{syst})$

$R_{\text{HF}} = \left[7.1 \pm 1.3(\text{stat})\ ^{+5.3}_{-2.0}(\text{syst})\right]\ \%$

- top physics:
  - Constraints to Standard Model trough its properties
  - Aperture in search for new physics phenomena
- Good agreement with standard model
  - No new physics observed, stringent limits
- The full set of top results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

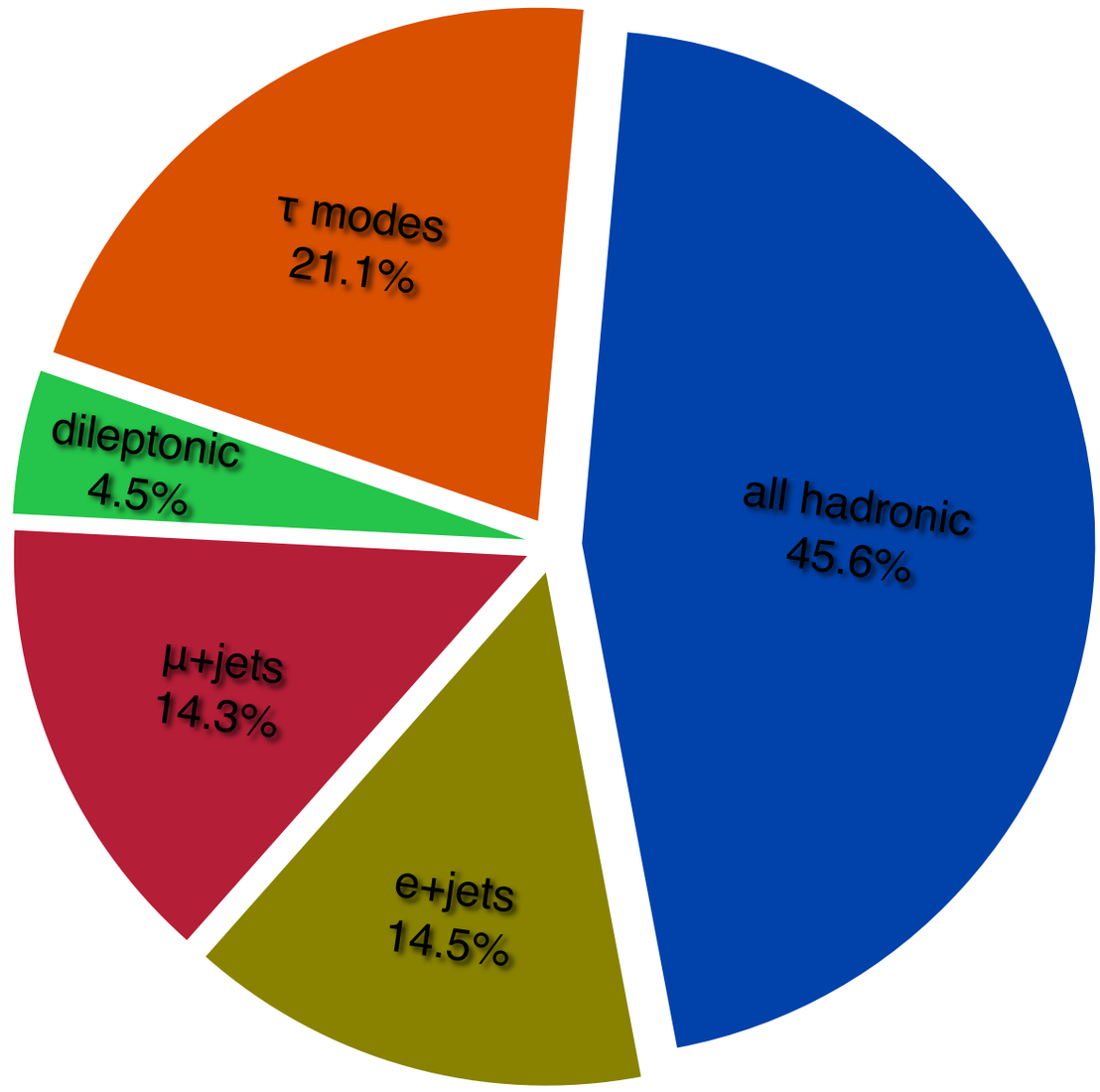
Additional Material

Top Decay Modes



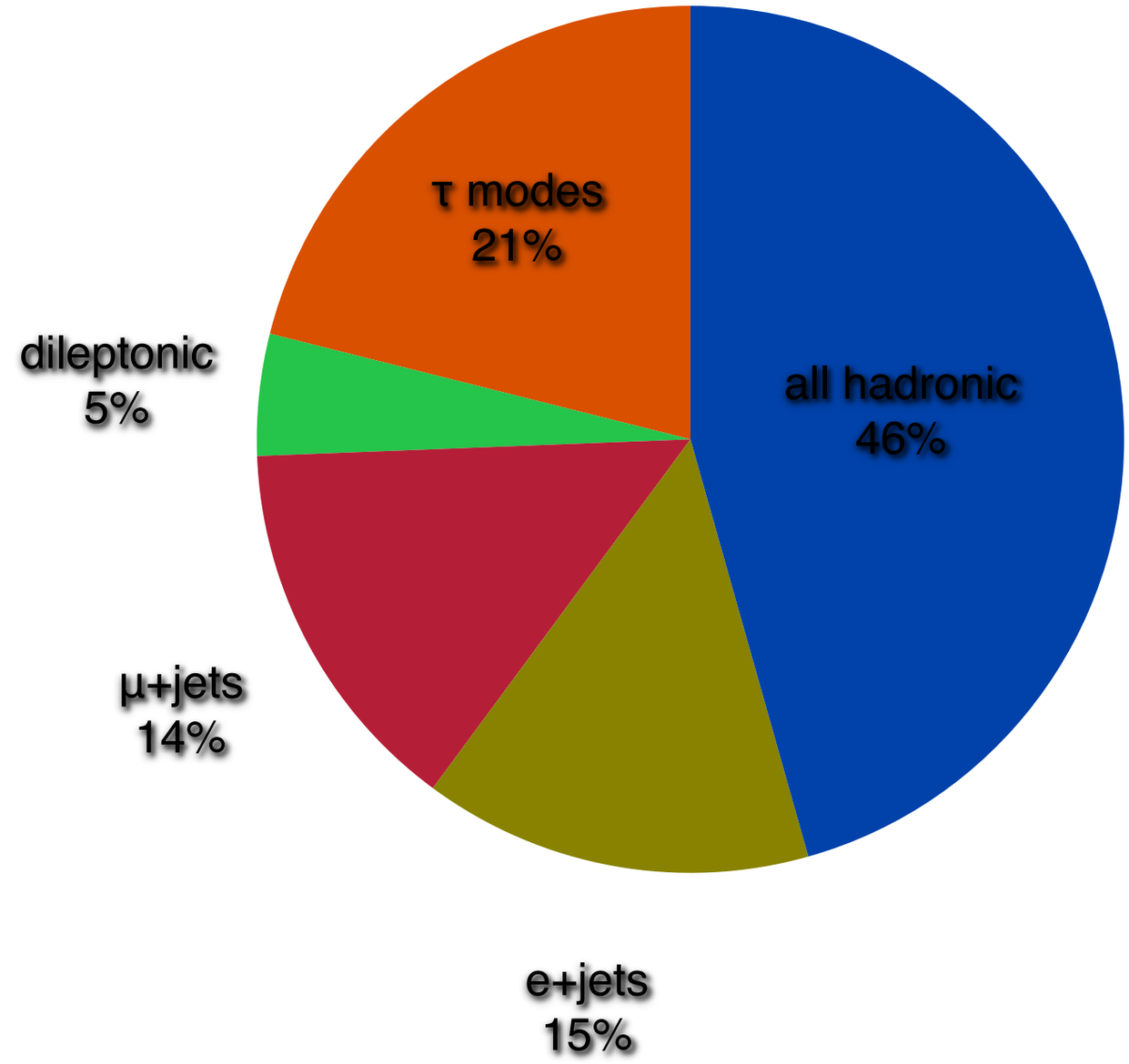
Motivations for Top Physics

- Probe Standard Model
  - top mass measurement
  - top EM couplings: $t\bar{t}\gamma$, $t\bar{t}Z$
  - Single Top production
- Precise tests of perturbative QCD
- Important background for many searches
  - New physics: SUSY, ..
  - Higgs searches in: $t\bar{t}H$, ...
- Searches for new physics:
  - vector like heavy new quarks



Top Decay Modes

- All hadronic:
  - high background
- Lepton plus jets
  - best compromise
    - statistics
    - signal/background
- Dilepltonic
  - low rate

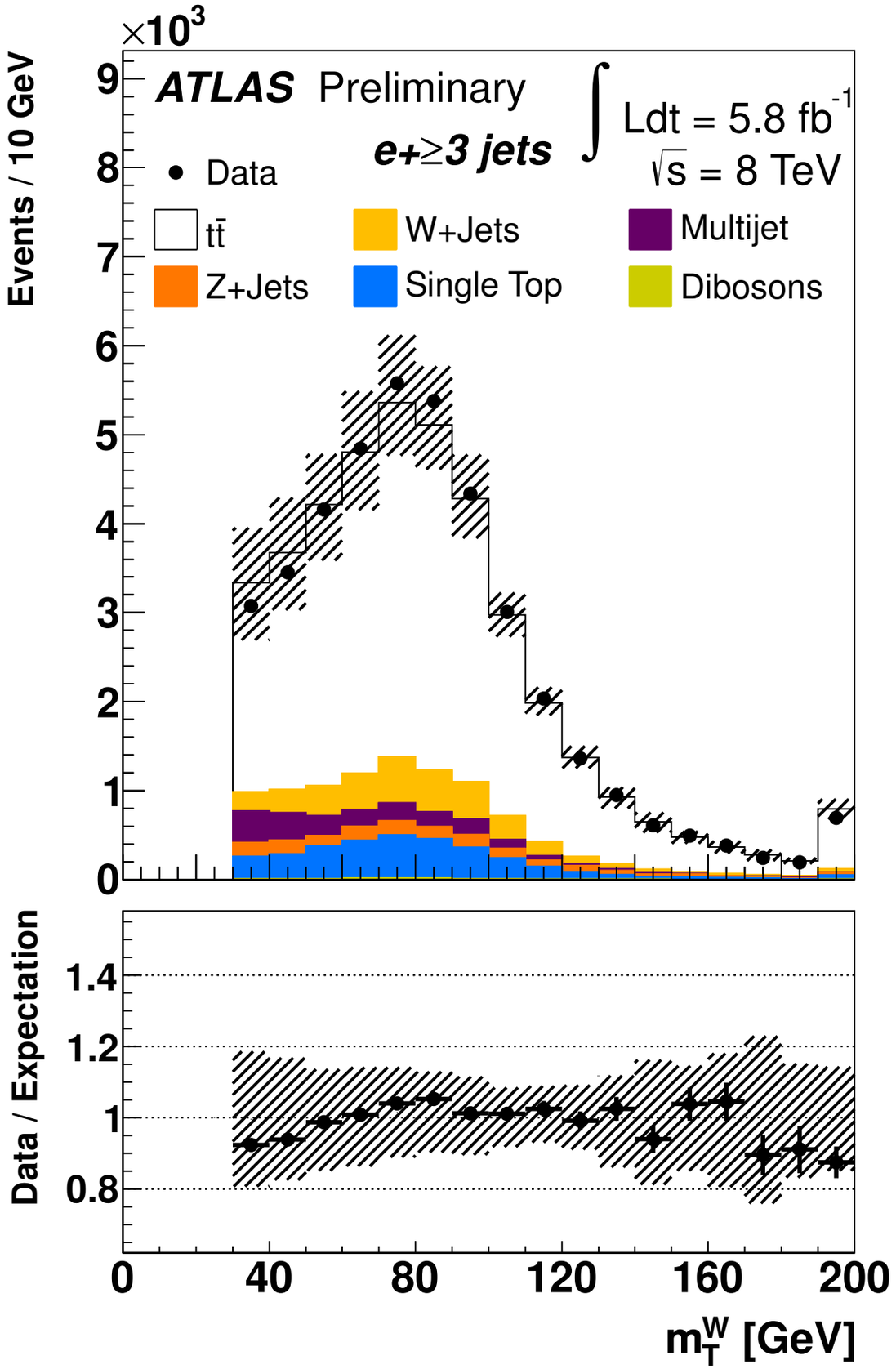


Object Definition

- Electrons:
  - EM cluster with track matched
  - Isolation in tracker and calorimeter E_T > 25 GeV, |η| <1.37 or 1.52< |η| <2.47
- Muons:
  - Tracks in both Inner detector and muon spectrometer
  - Track and calorimeter Isolation p_T > 20 GeV |η| <2.5
- Jets:
  - Reconstructed from topological clusters using the anti-k_T algorithm (R = 0.4)
    - p_T > 25 GeV, |η| <2.5
  - η and p_T dependent correction
    - factors derived from simulation and validated with data
- Missing transverse energy:
  - Vector sum of energy deposits in calorimeter
  - Corrected for identified objects
- b-tagging:
  - Neural network based b-tagging (MV1 algorithm)
    - b-tagging efficiency of ~70%
    - light jet rejection factor ~140

Event Selection

- Leptons:
  - electron (muon) trigger with threshold > 20 (18) GeV
  - exclusively single reconstructed electron (muon) with p_T > 25 (20) GeV
- Missing transverse energy:
  - E_T^{miss} > 25 GeV in the muon channel
  - E_T^{miss} +m_T^W >60 GeV in the electron channel
- Jets:
  - At least 2 (4) jets with p_T > 25 GeV and |η| <2.5 for single top (t t) analyses
  - At least one jet must be tagged as a b-jet
- l+jets:
  - lepton trigger, exactly one lepton, ≥3 or 4 jets, b-tagged jets, E_T^{miss}
- Di-lepton:
  - lepton trigger, two opposite charge leptons, ≥2 jets, b-tagged jets, E_T^{miss}, Z veto
- Full hadronic:
  - mixed jet triggers, ≥5 jets (p_T >55 GeV) + 1 (p_T > 30 GeV) , b-tagged jets ≥2

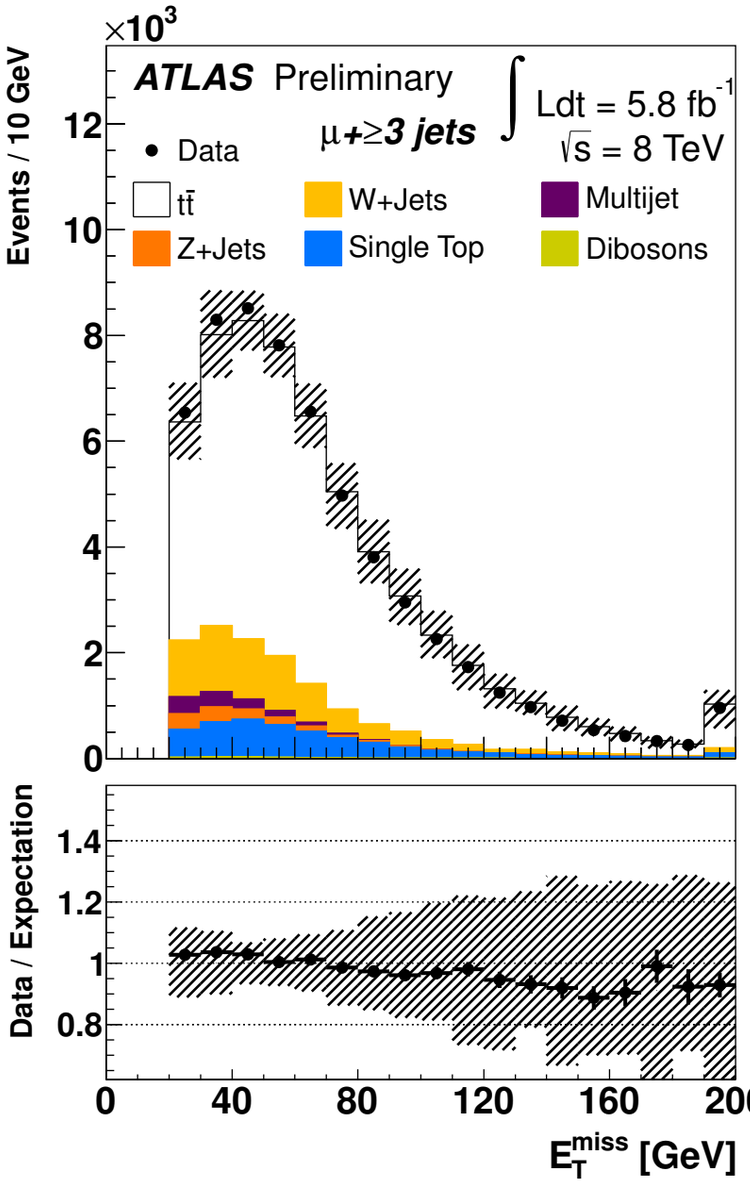


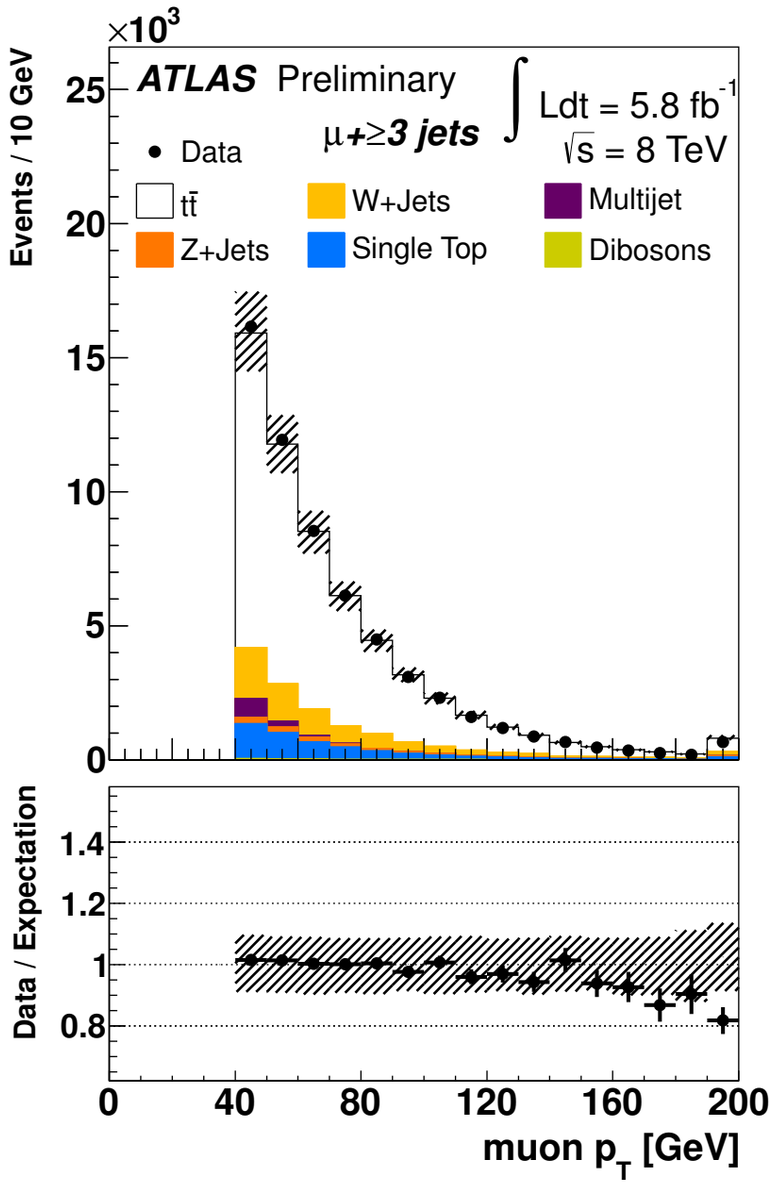
Main Systematics

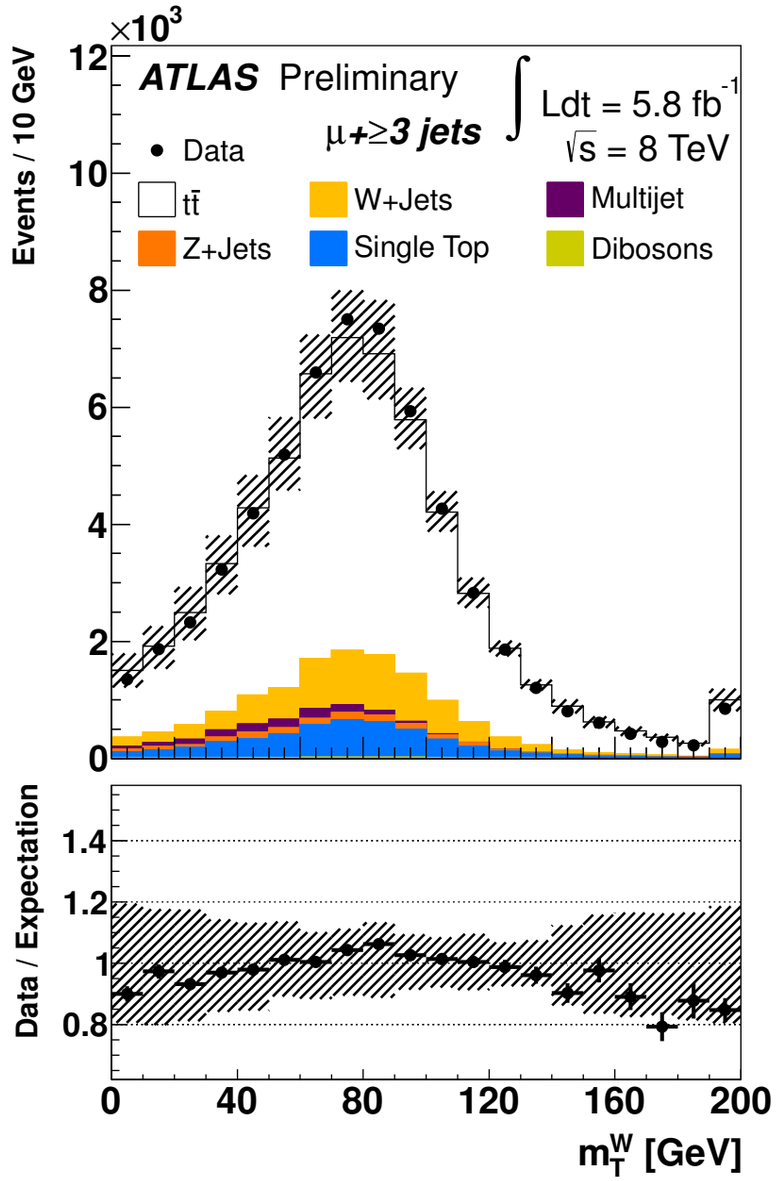
- Signal Systematics
  - M.C. Generator: comparison of generators.
    - ✦ maximum deviation between samples
  - Parton Shower/Hadronization uncertainty
    - ✦ comparison of cluster fragmentation and string fragmentation
- Leptons:
  - Reconstruction efficiency:
    - ✦ D.D. scale factors from tag & probe with $Z \rightarrow ee\ (\mu\mu)$
    - ✦ variations according to uncertainties
  - Scale and resolution:
    - ✦ MC smearing in correction factors
    - ✦ shift energy (momentum) scales to cp groups
- Jets:
  - reconstruction efficiency:
    - ✦ track jets match to calo jets / N(jets) .
    - ✦ in situ calibration error
  - scale and resolution:
    - ✦ single hardon response (in situ) and single pion (test beam), material budget, electronic noise
  - b-jet efficiency, miss-tag rate
    - ✦ N.N. response

Event Selection

- muon channel data / mc compairison

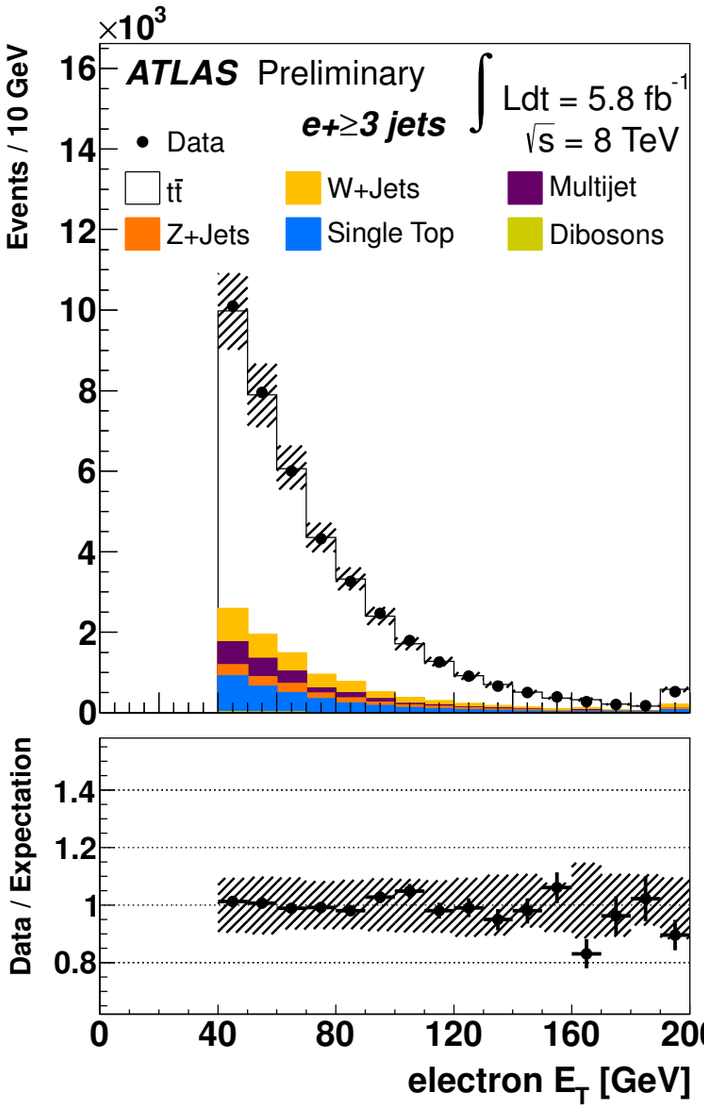


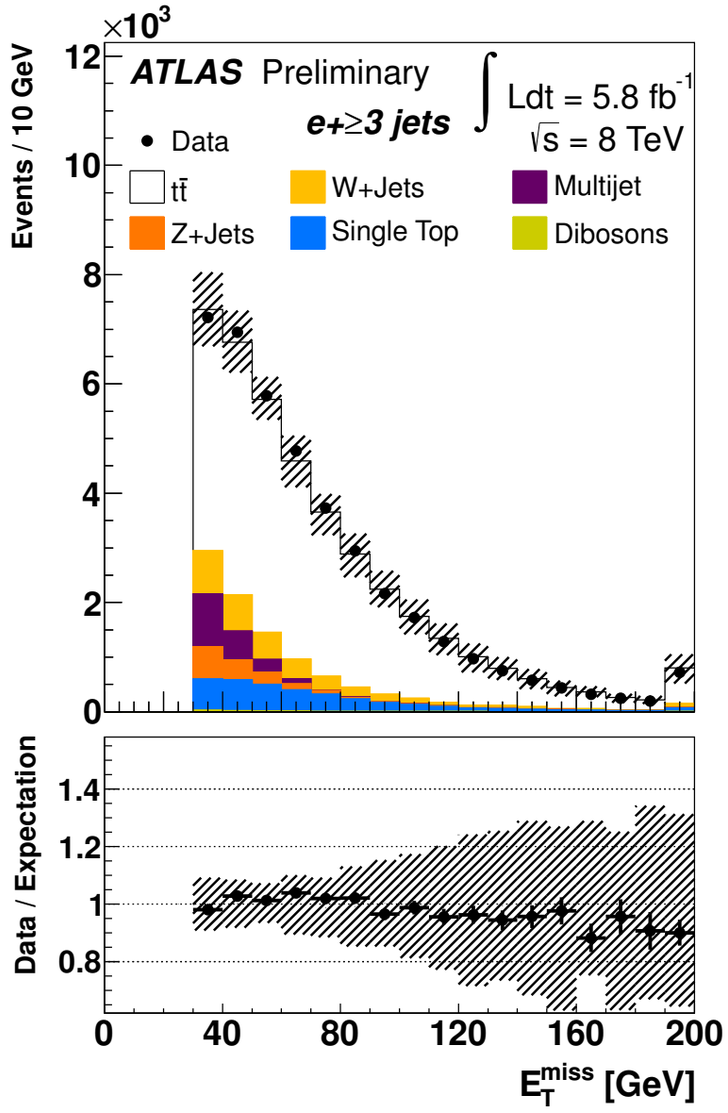




Event Selection

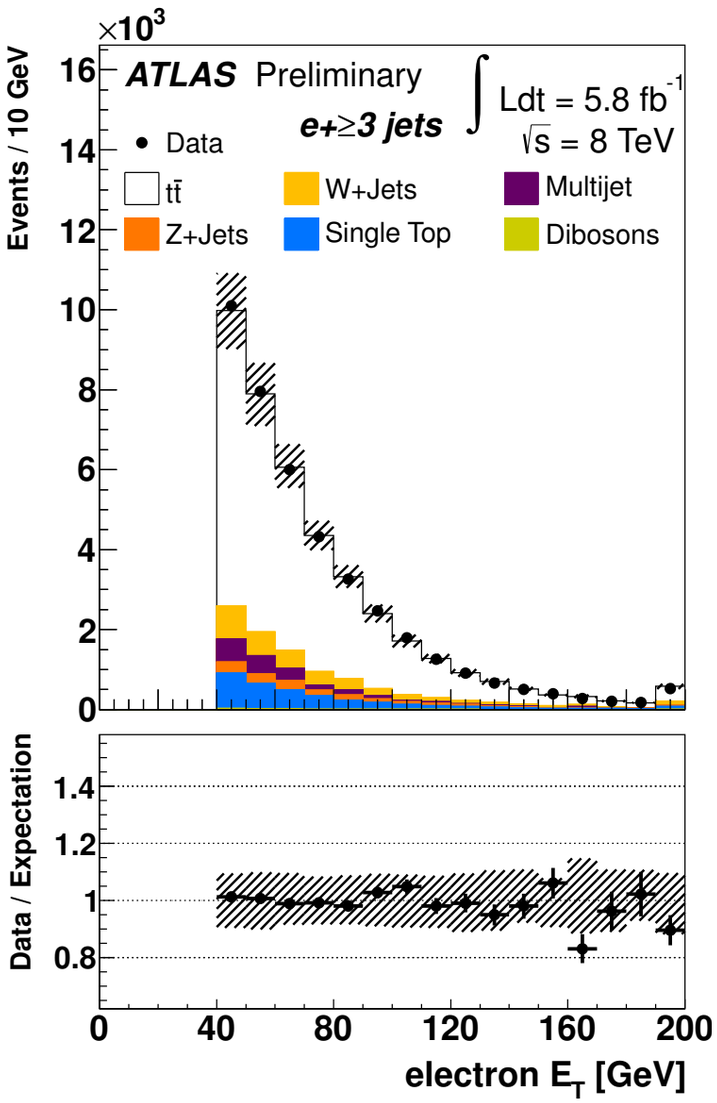
- electron channel data / mc comparison

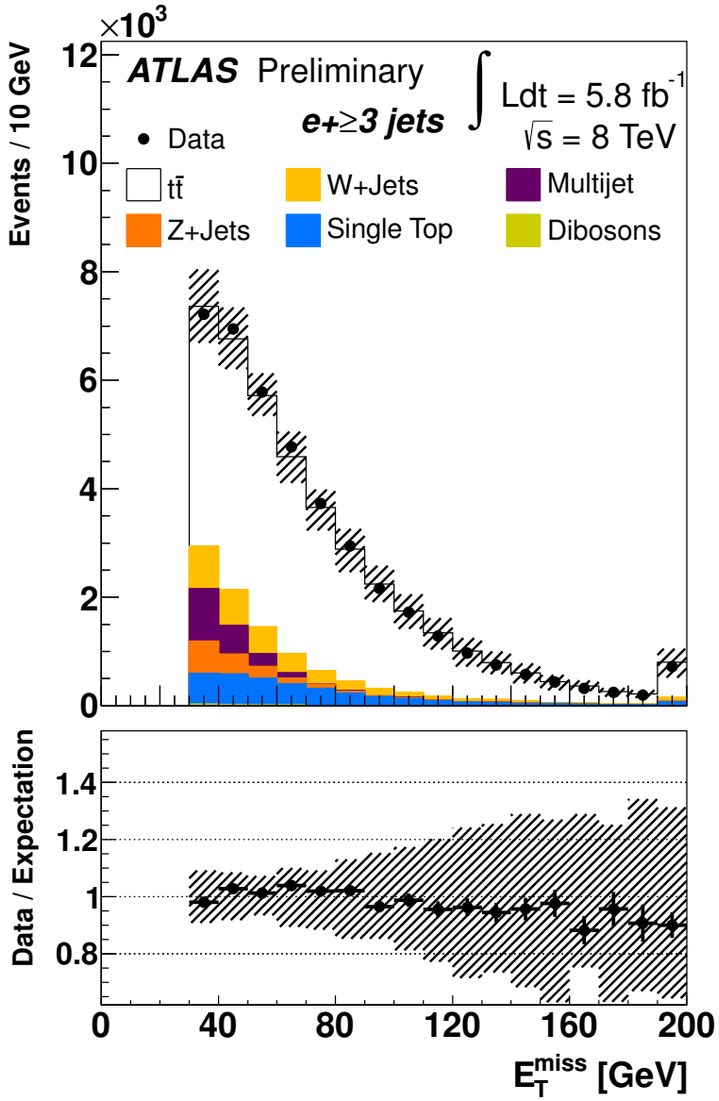


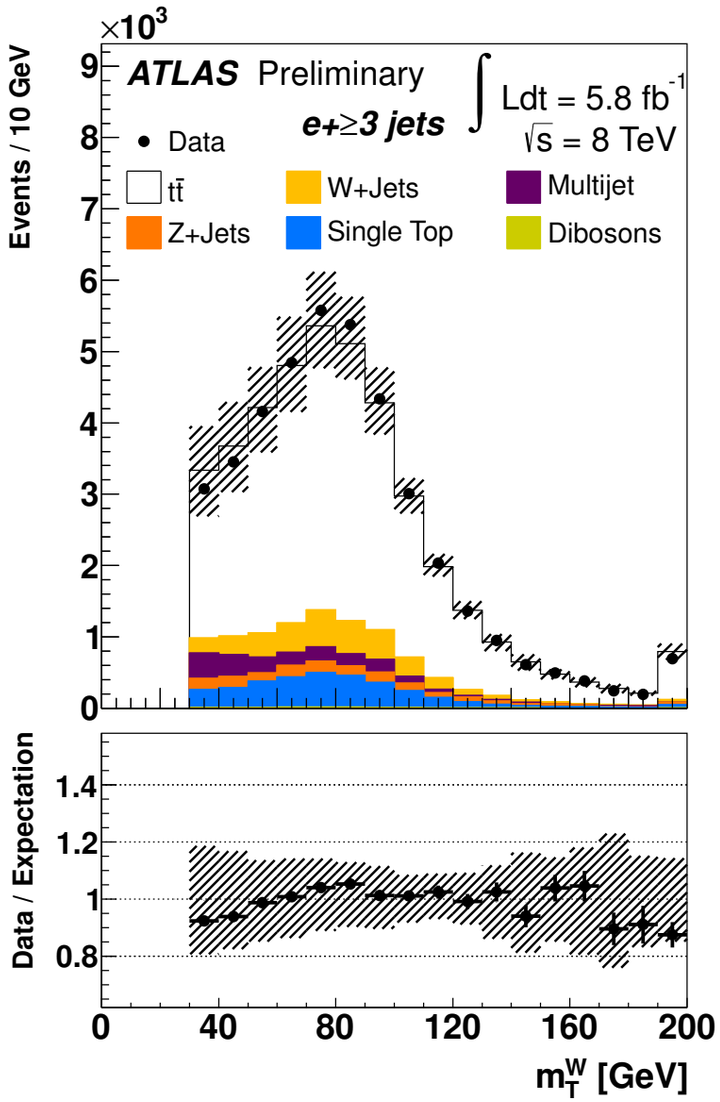


- Inclusive cross section at 8 TeV
  - single lepton jets channel
- Selection Optimized for Multijets backgrounds
- Main backgrounds:
  - Multijets, W+jets, Z+jets, SignleTop, Dibosons (ZZ, WW)

	e+≥3 jets	μ+≥3 jets
$t\bar{t}$	31000^{+2900}_{-3100}	44000±4000
W+jets	5700±2400	9000±4000
Multijet	1900± 900	1100± 500
Z+jets	1400± 600	1200± 500
Single top	3260± 160	4610± 230
Dibosons	115± 6	158± 8
Total Expected	43000±4000	61000±6000
Data	40794	58872





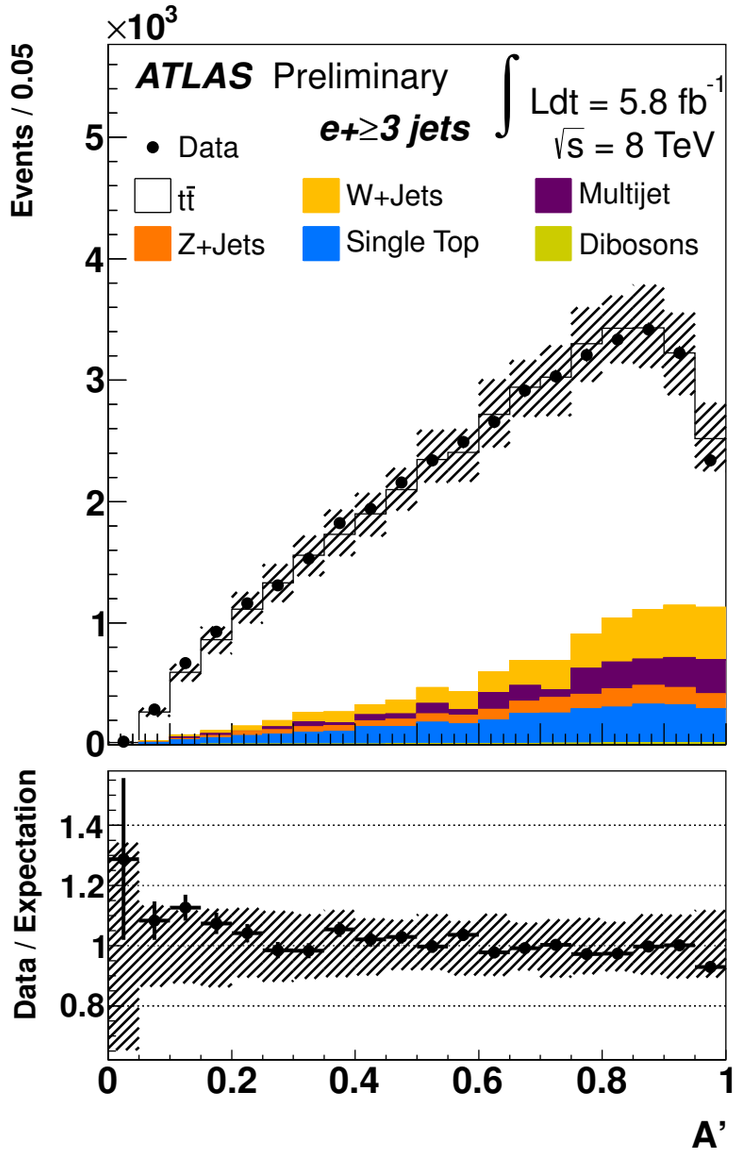


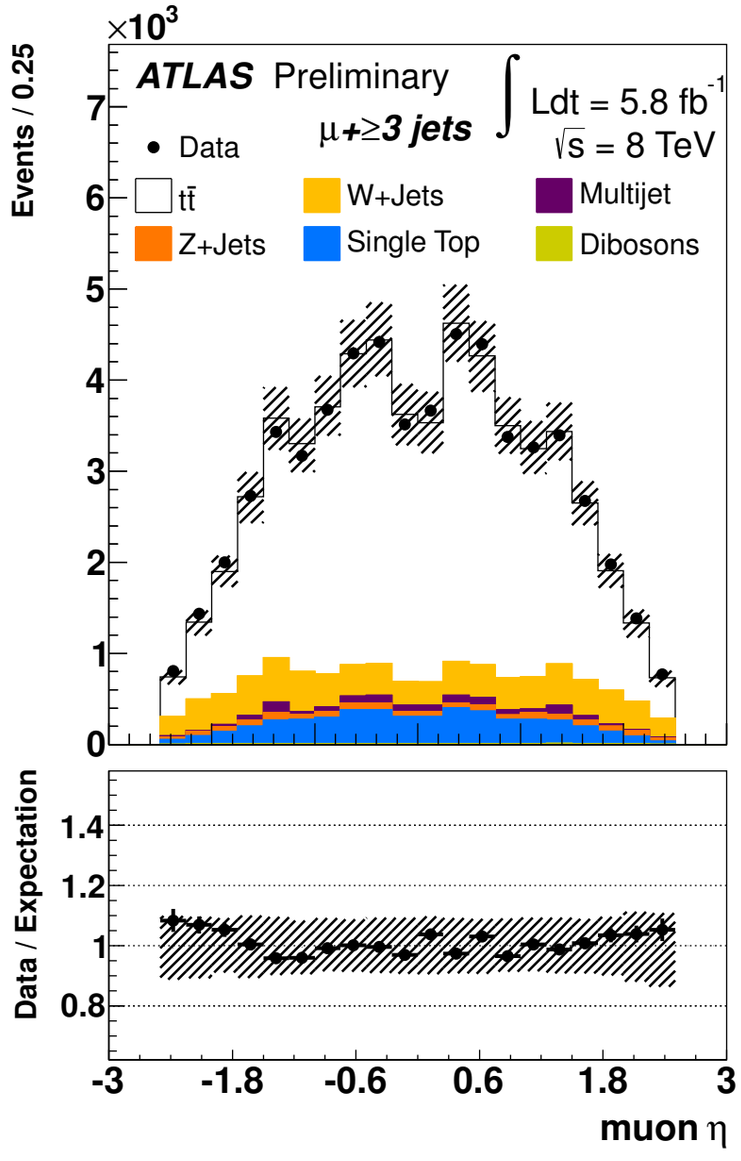
- Selection:
  - single electron(muon) trigger fired
  - A primary vertex with at least five tracks
  - Njets (p_T > 25 GeV) ≥ 3 and |η| < 2.5
  - Reconstructed electron (muon) of p_T with E_T > 40 GeV matching the corresponding high level trigger object
  - No second electron (muon) with E_T > 25 GeV (p_T > 25 GeV)
  - E_T^{miss} > 30 GeV for the electron channel m_T^W > 30 GeV;
  - in the μ+jets channel: E_T^{miss} > 20 GeV and $m_T^W + E_T^{miss}$ > 60 GeV;
  - at least one b tagged jet
- Systematics

Source	e+ ≥3 jets	μ+ ≥ 3 *jets*	combined
Jet/MET reconstruction, calibration	6.7, -6.3	5.4, -4.6	5.9, -5.2
Lepton trigger, identification and reconstruction	2.4, -2.7	4.7, -4.2	2.7, -2.8
Background normalization and composition	1.9, -2.2	1.6, -1.5	1.8, -1.9
b-tagging efficiency	1.7, -1.3	1.9, -1.1	1.8, -1.2
MC modelling of the signal	±12	±11	±11
Total	±14	±13	±13

$t\bar{t}$ → *l*+jets Variables $5.8\ \text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV ATLAS-CONF-2012-149

- lepton η:
  - leptons from $t\bar{t}$ are more central than *W+J*

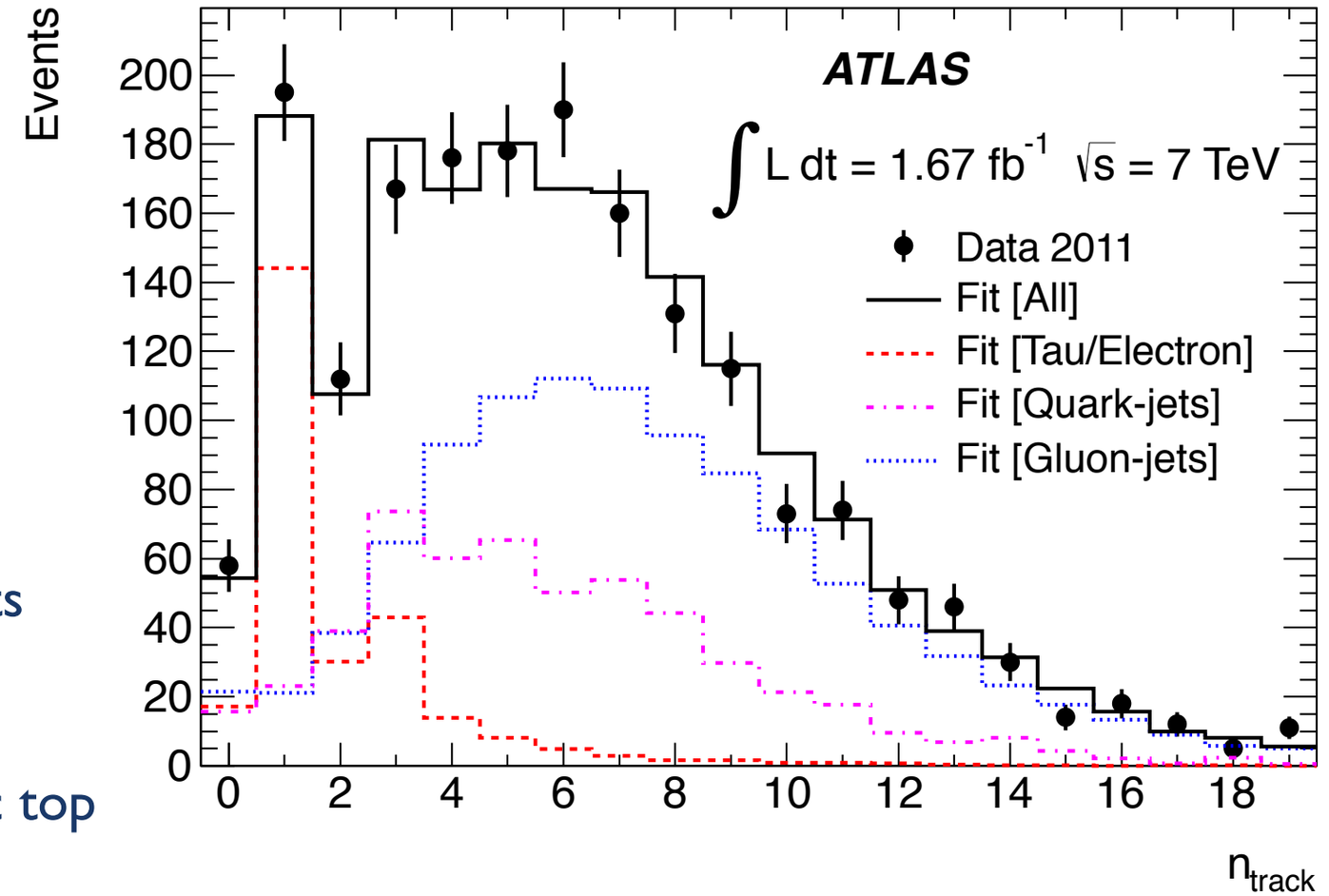




- Event Aplanarity:
  - transformed aplanarity A'= e-8A
  - A = 3/2 λ3, smallest eigenvalue normalized momentum
  - A → A′ increases the separation power
  - $t\bar{t}$ more isotropic than W+j

$\sigma_{t\bar{t}} \rightarrow \tau$+jets *4.7 fb^{-1} $\sqrt{s}$ = 7 TeV Eur. Phys. J. C, 73 3 (2013) 2328* LC2013

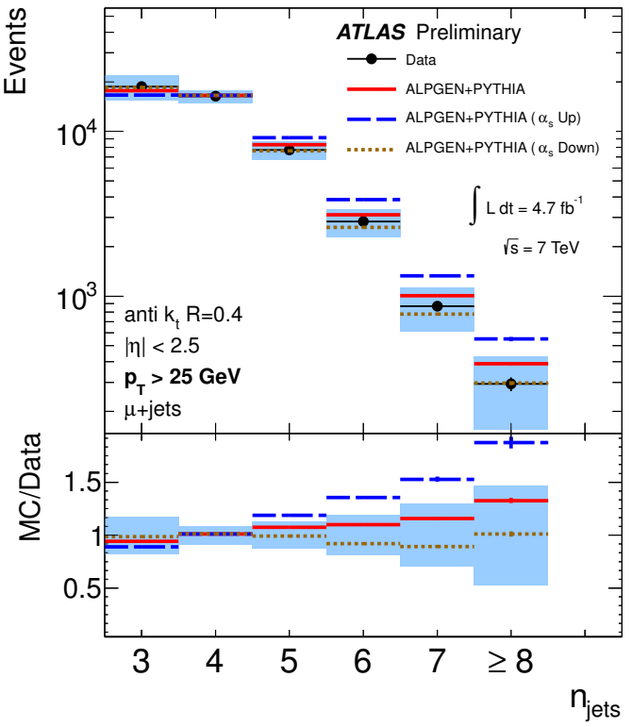
- Hadronically: $t\bar{t} \rightarrow b\tau_{had}\nu_\tau\, bqq$
- Motivations:
  - Probe flavour - dependent effects in top decays
  - In BSM searches: dominant background
  - If charged Higgs enhancement of $\sigma_{t\bar{t}}$
- Backgrounds:
  - multi-jets, jet faking τ_{had}, single top, W+jets
- Strategy:
  - require $\geq$ 5 jets, N(b^{tag})$\geq$2: 4 for hadronic top jets identification 1 for τ_{had} candidate
    - p_T > *20* GeV, $|\eta|$<*2.5*, $p_T(\tau)$ > 40 GeV
  - template fit to number of tracks associated to τ_{had}
  - Systematics: ISR/FSR(15%), b-tag (9%), Jet energy scale (5%)

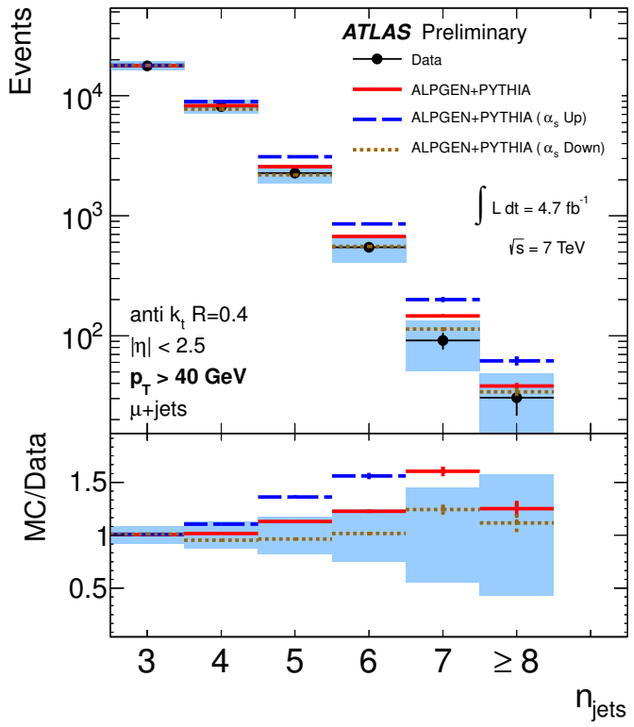


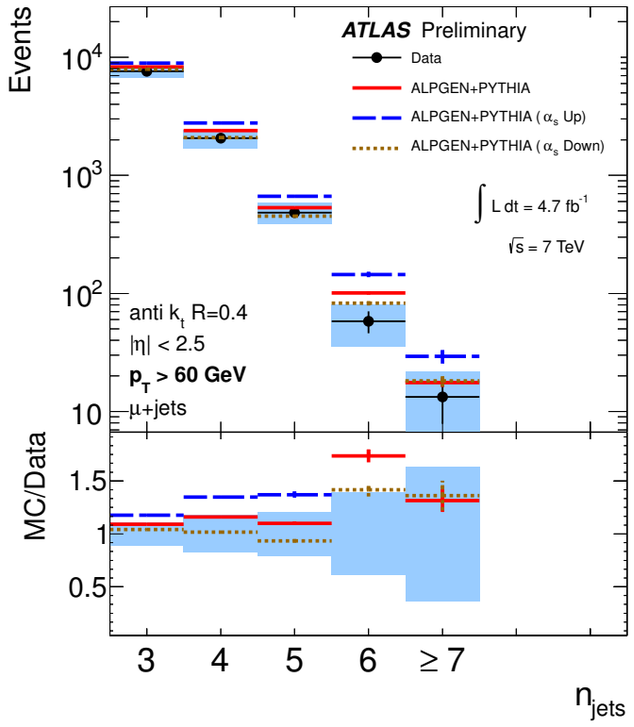
- Result in τ+jets $\sigma_{t\bar{t}} = 194 \pm 18(\text{stat}) \pm 46(\text{syst})$ pb
  - compare/include τ+e(μ) $\sigma_{t\bar{t}} = 186 \pm 13(\text{stat}) \pm 20(\text{syst}) \pm 7(\text{lumi})$ pb Phys. Lett. B 717(2012) 89-108)
  - Good agreement with the theory: $\sigma_{t\bar{t}}^{\text{theor}} = 167^{+17}_{-18}$ pb

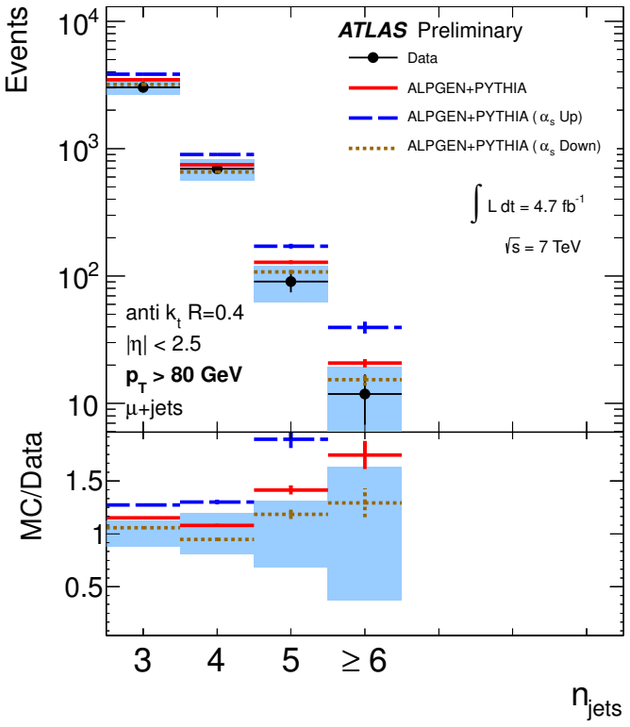
$t\bar{t}$ Jet Multiplicity II 4.7 fb^{-1} $\sqrt{s}$ = 8 TeV ATLAS-CONF-2012-155

LC2013

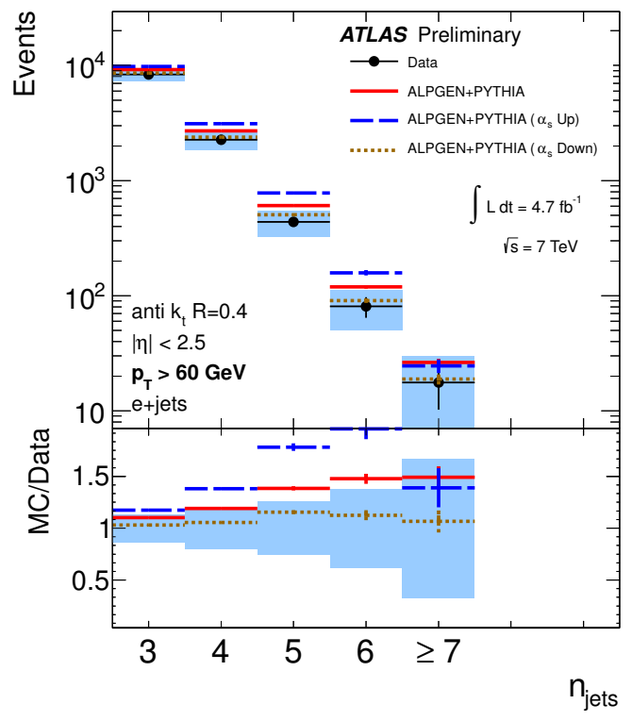


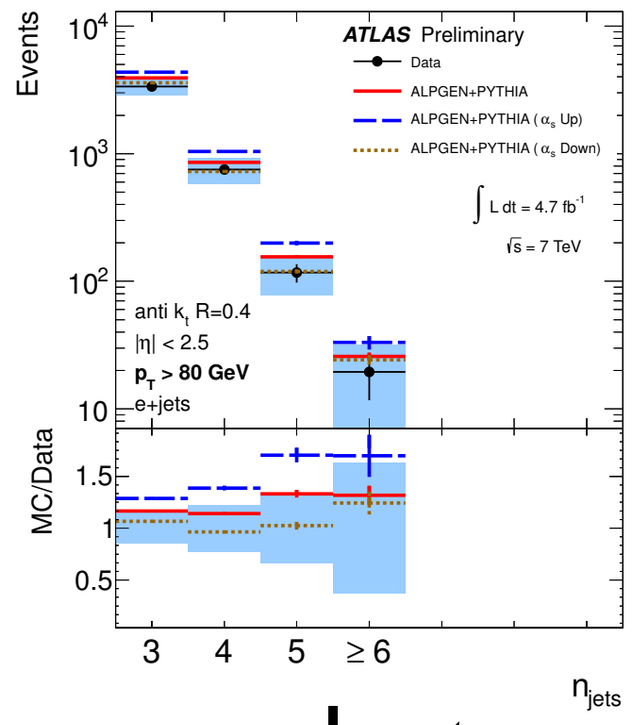


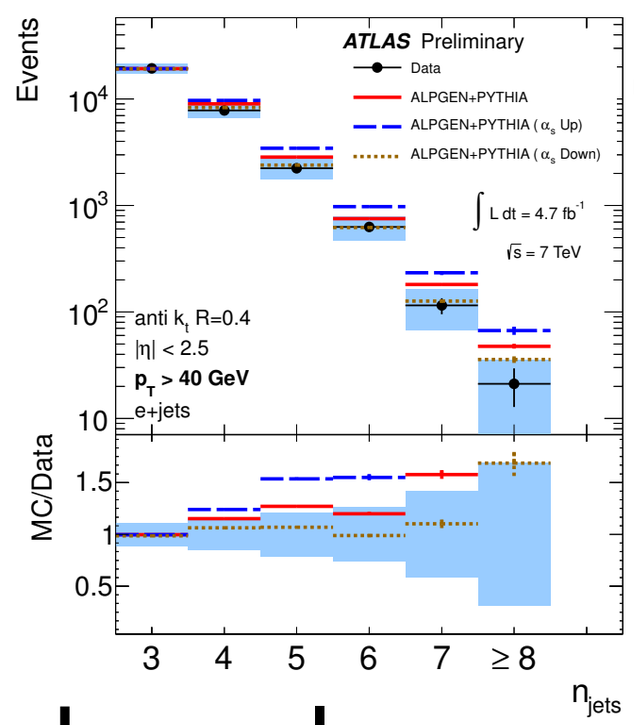


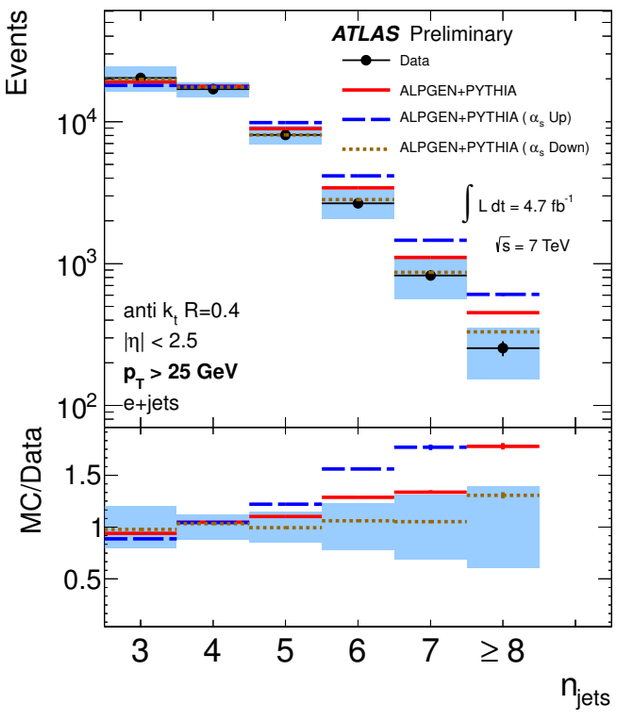


muon channel





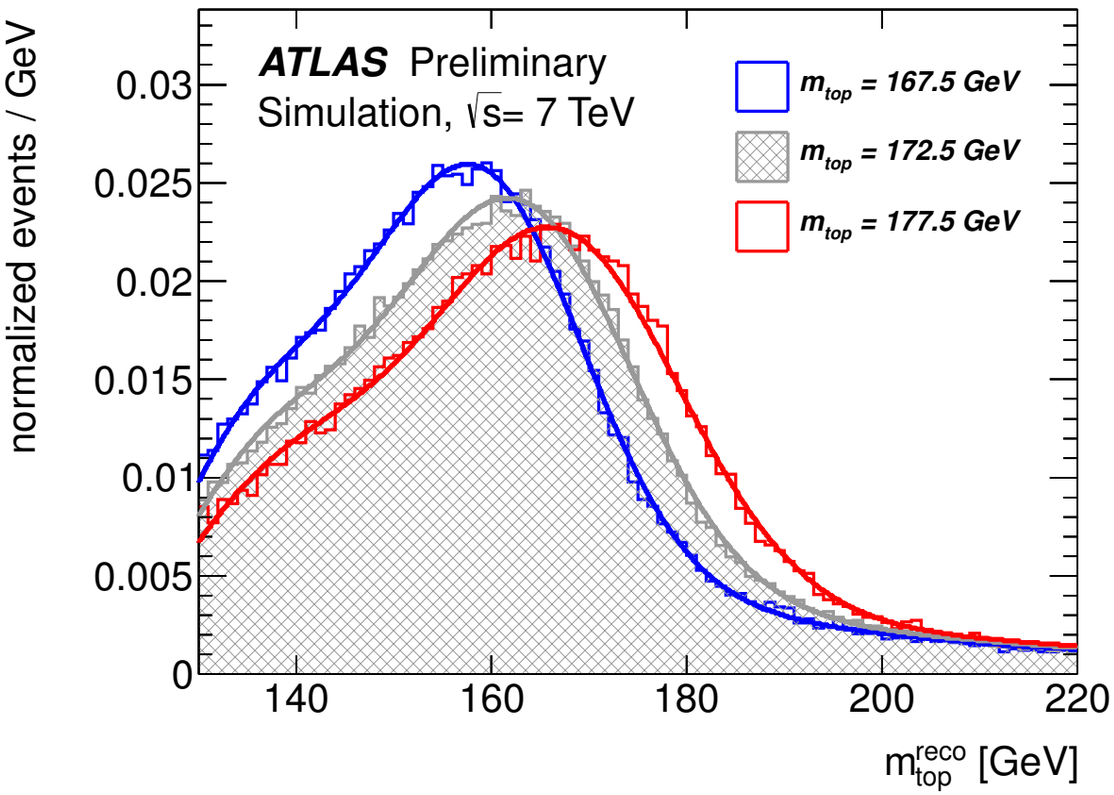


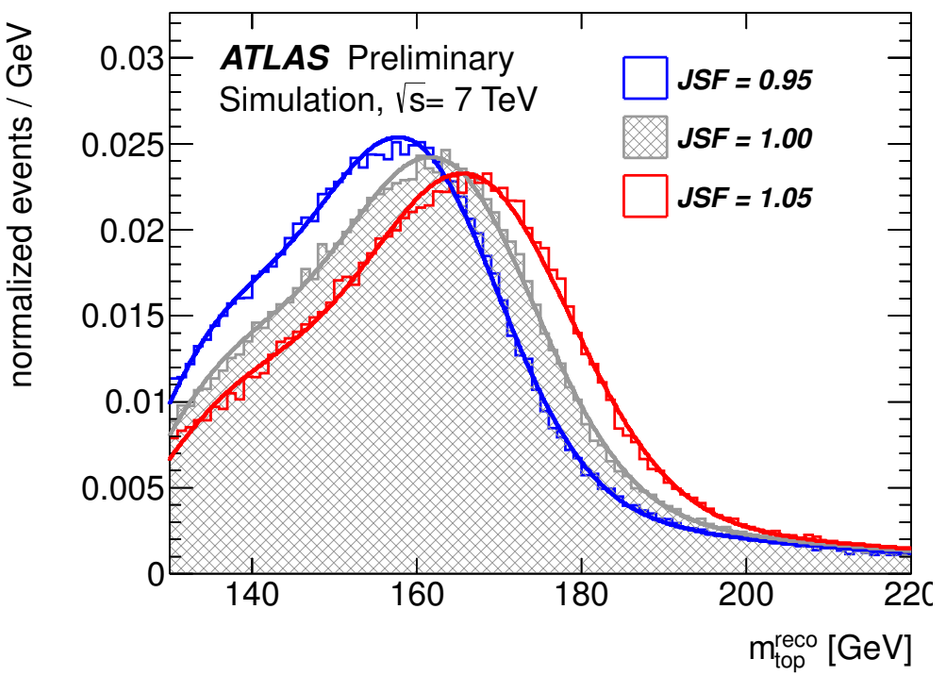


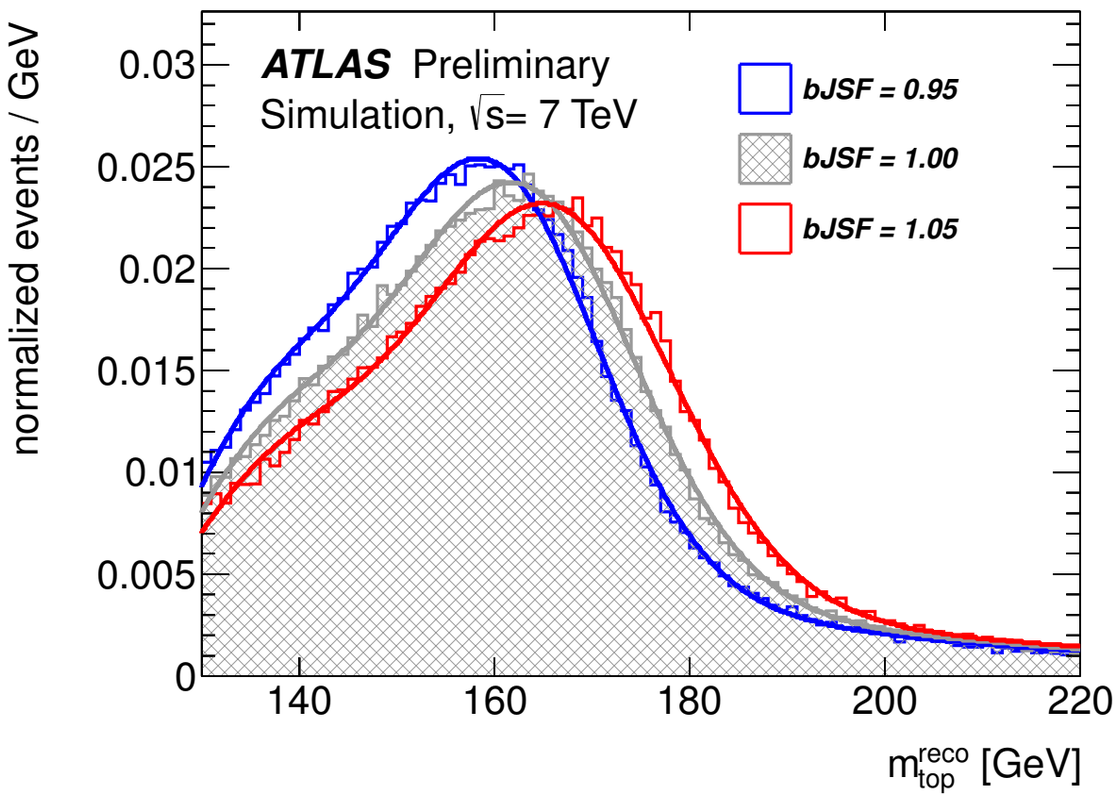
electron channel

Top Mass: II $4.7\ fb^{-1}$, $\sqrt{s} = 7$ TeV, ATLAS-CONF-2013-046

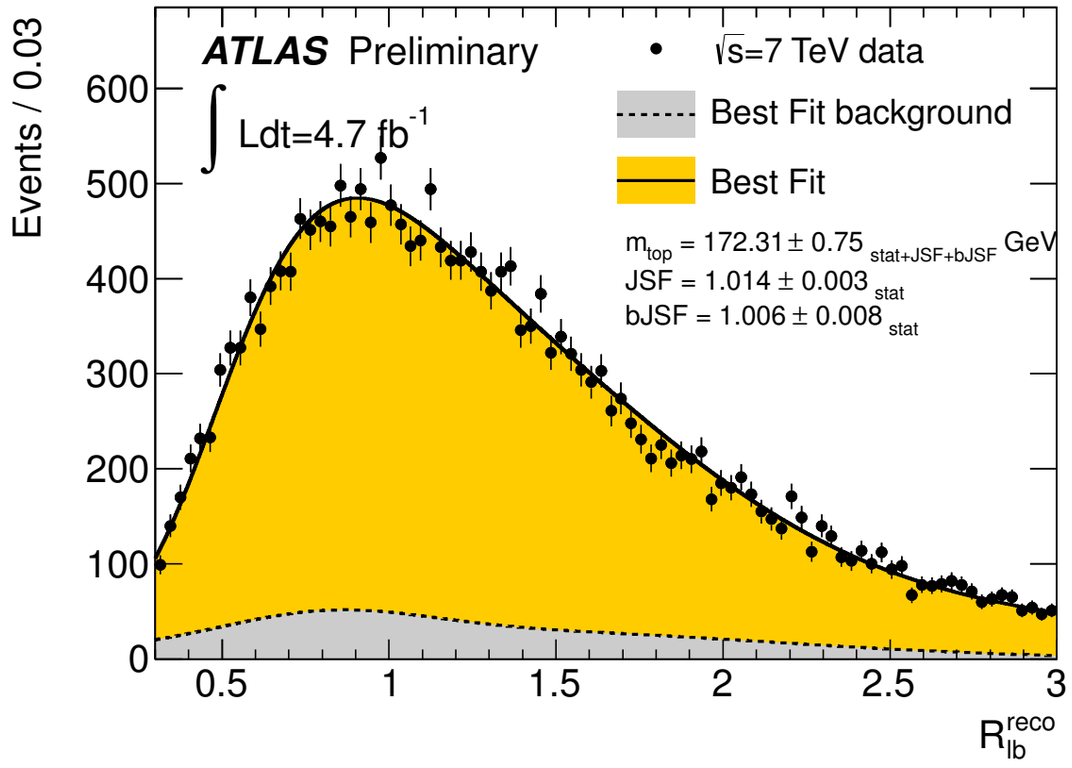
- Observables:
  - m_{top}: main observable
  - m_W^{reco}:sensitivity to jet energy scale (JES)
  - R_{lb}^{calo} sensitivity to b-to light jets energy changes (bJES)
    - ✦ H.F. momenta / light jets momenta
- Parametrization:
  - separation for 1-tag, ≥2b- tags for sensitivity
  - simultaneous fit to all templates.

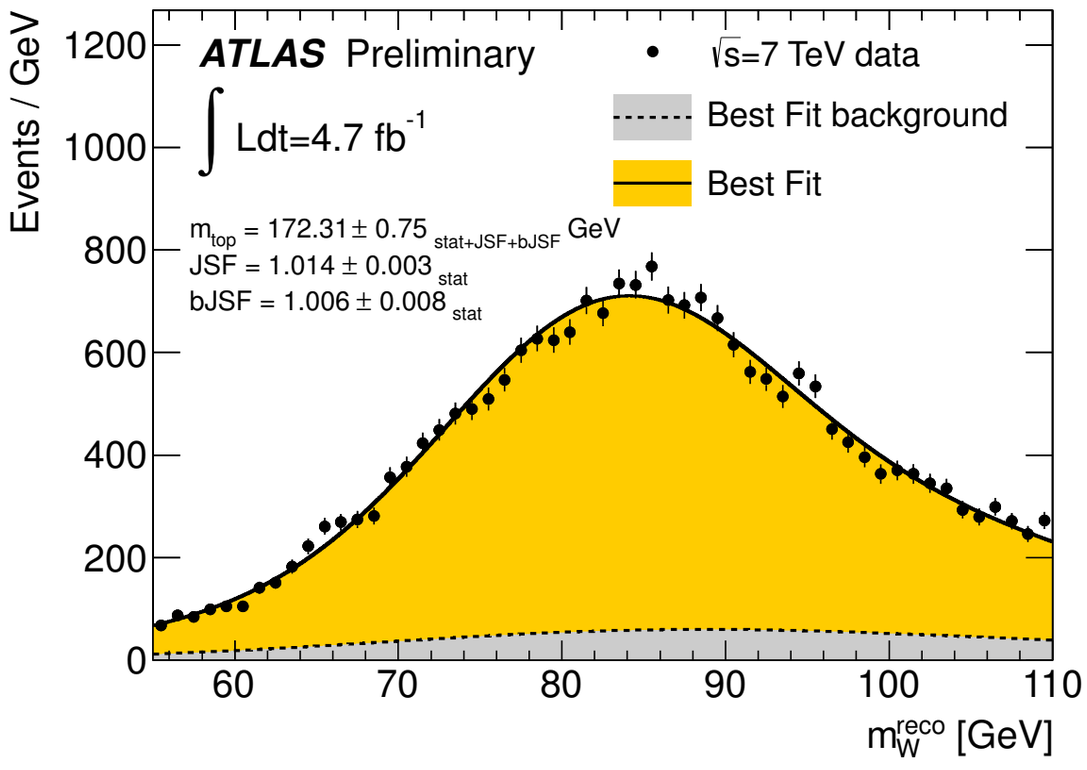






Top Mass: 3D Template Fit II



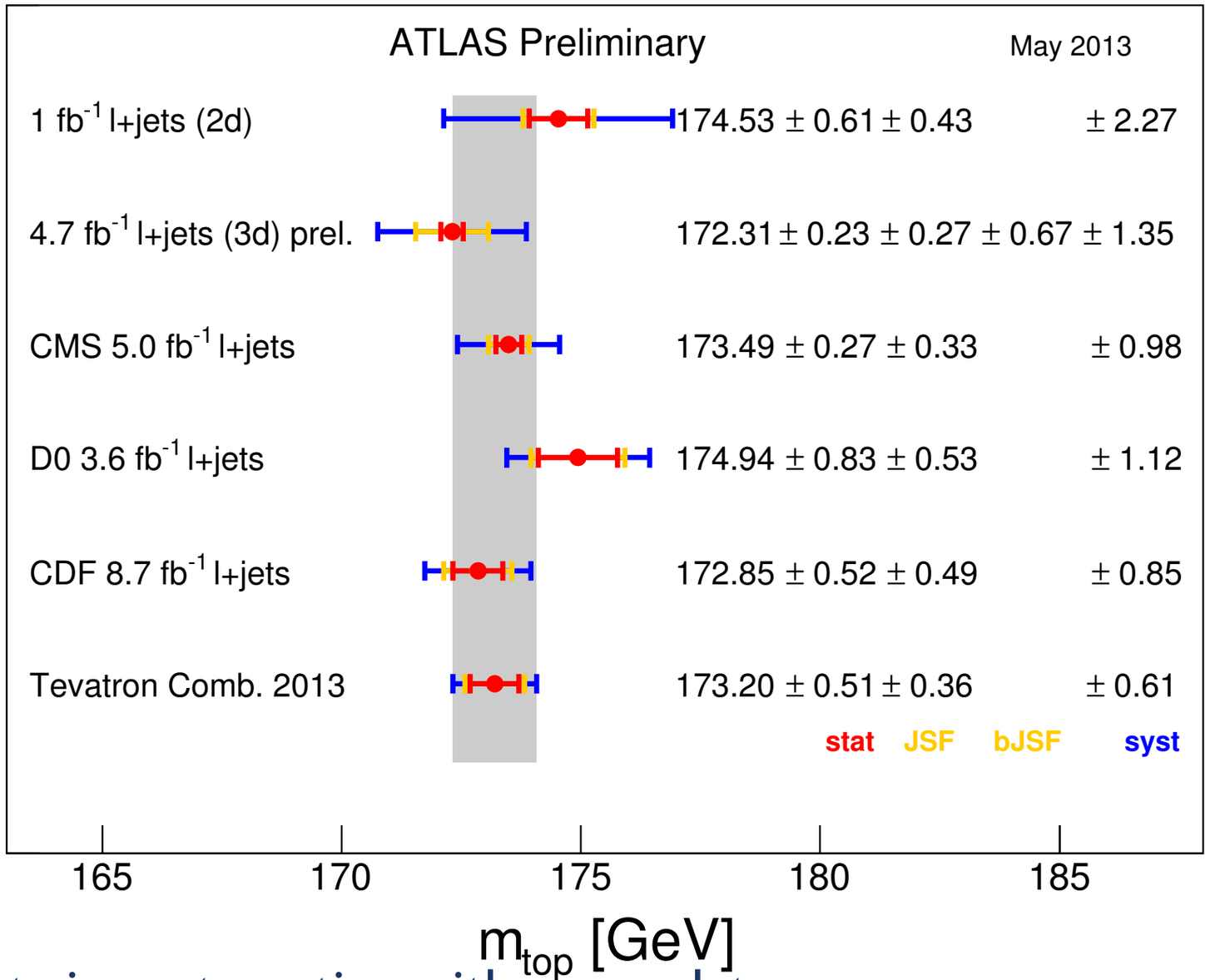


	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

Top Mass $4.7\ \text{fb}^{-1}$, $\sqrt{s} = 7$ TeV, ATLAS-CONF-2013-046

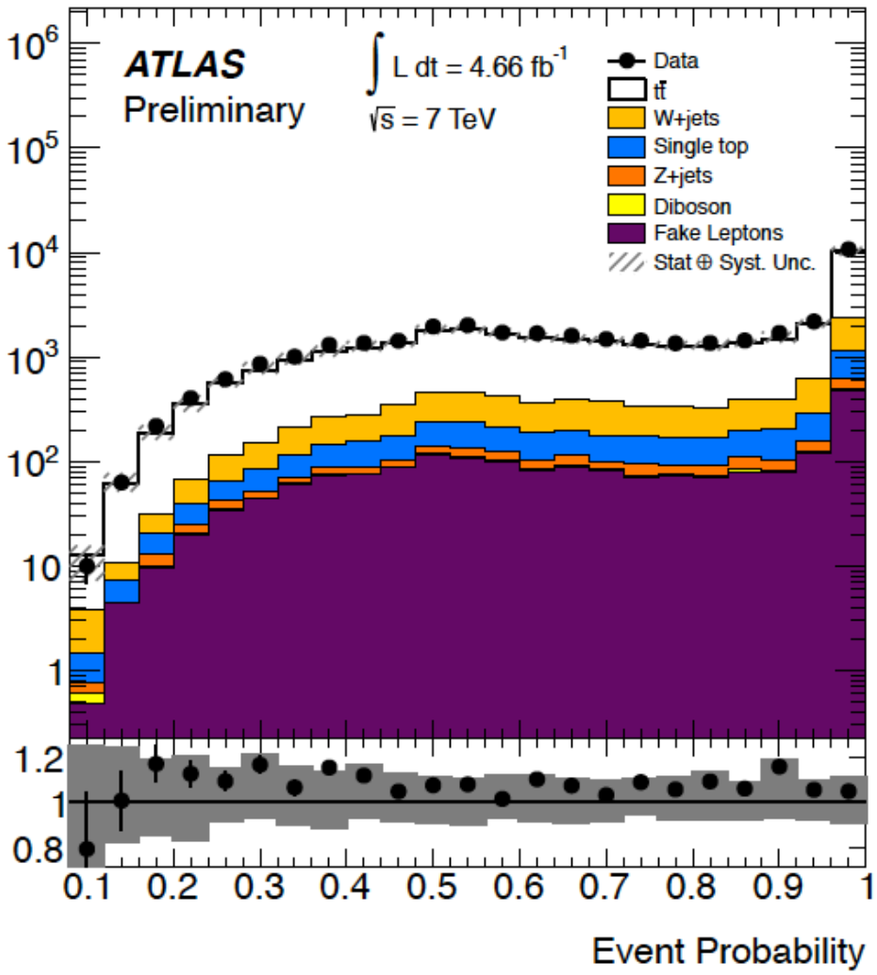
- Improvements:
  - Sensitivity to m_{top} improved by 20%.
  - The total systematic uncertainty is reduced by 40%
    - ✦ bJES strongly reduced
  - Better modeling of underlying partonic quantities
    - ✦ tails of the transfer functions
- Future improvements
  - better understanding b-tagging systematics
  - reduction of statistical components in systematics with more data
  - Determination of JSF in kinematic regions.
- Result:

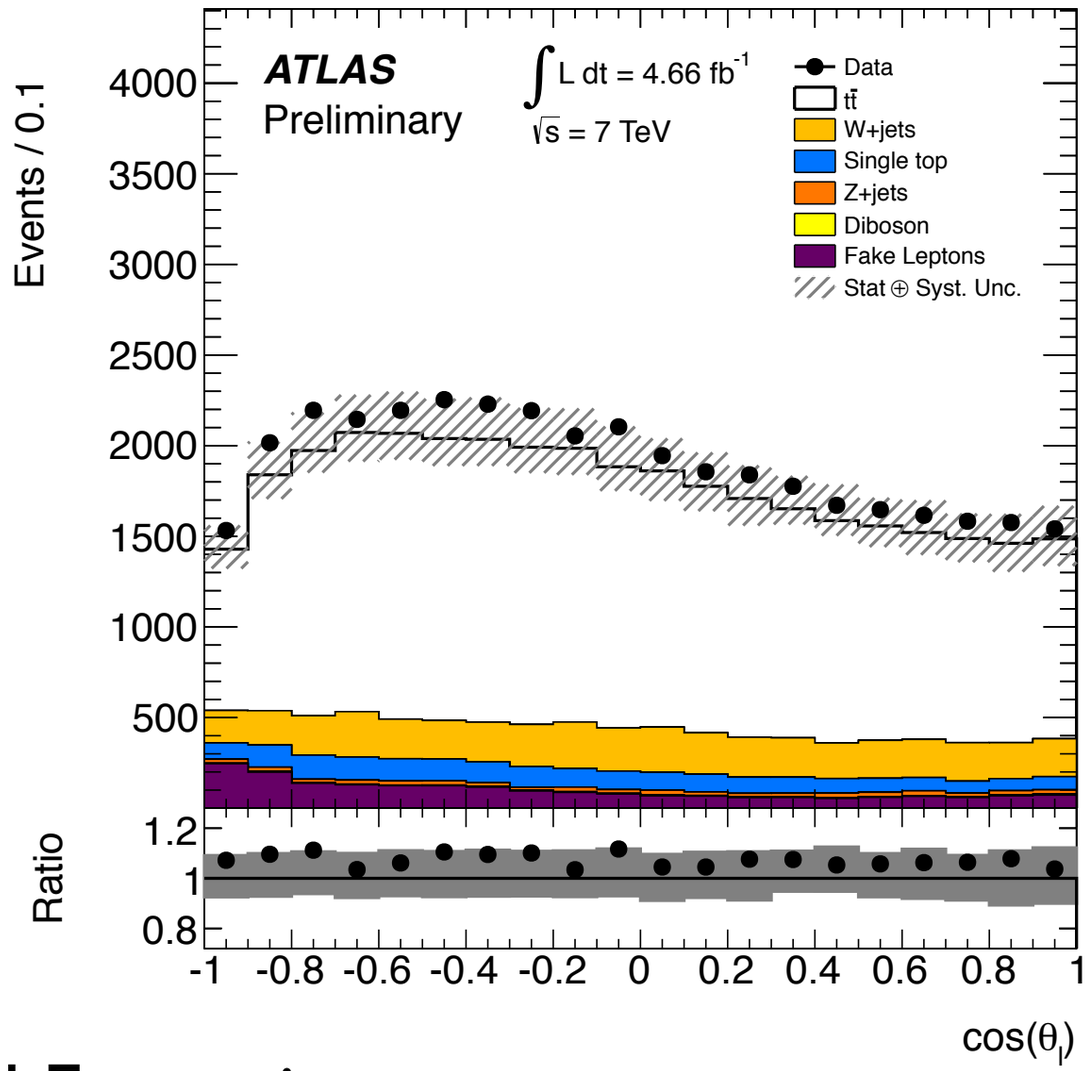
$$m_{\text{top}} = 172.31 \ \pm 0.75(\text{stat+JSF+bJSF}) \ \pm 1.35(\text{syst}) \ \text{GeV}$$



Top Polarization I $_{4.7\ fb^{-1}\ \sqrt{s}\ =\ 7\ TeV\ ATLAS\text{-}CONF\text{-}2012\text{-}133}$ LC2013

- Motivations:
  - Unpolarized Standard Model top
  - Some BSM models, top quarks are produced polarized





- Method and Extraction
  - lepton polar angle (top rest frame) (θ_i) :

$$f = \frac{1}{2} + \frac{N(\cos(\theta_i) > 0) - N(\cos(\theta_i) < 0)}{N(\cos(\theta_i) > 0) + N(\cos(\theta_i) < 0)}$$

- Simultaneous over e, μ fit:
  - per channel fit of *W*+*j*
    - ✦ uncertainties absorption by *W*+*j* fraction

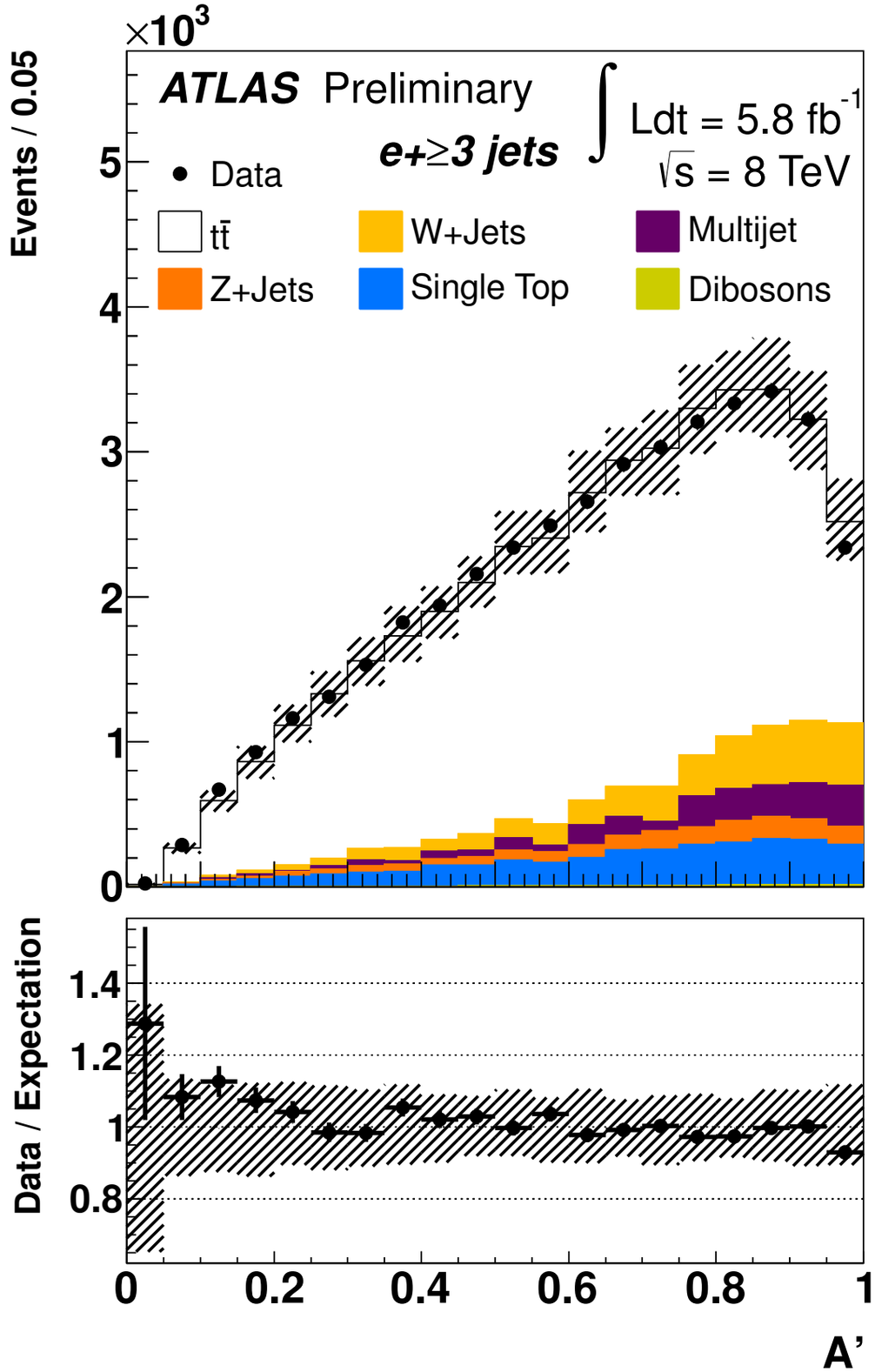
Channel	$N_{t\bar{t}}$	$\sigma_{t\bar{t}}$ (pb)
e+≥3 jets	31050±350	239±3
μ+≥3 jets	45000±400	242±2
l+≥3 jets	76000±500	241±2

- Good Agreement with theoretical prediction:

$$\sigma_{t\bar{t}} = 241 \pm 2\ (\text{stat}) \pm 31\ (\text{syst}) \pm 9\ (\text{lumi})\ \text{pb}$$

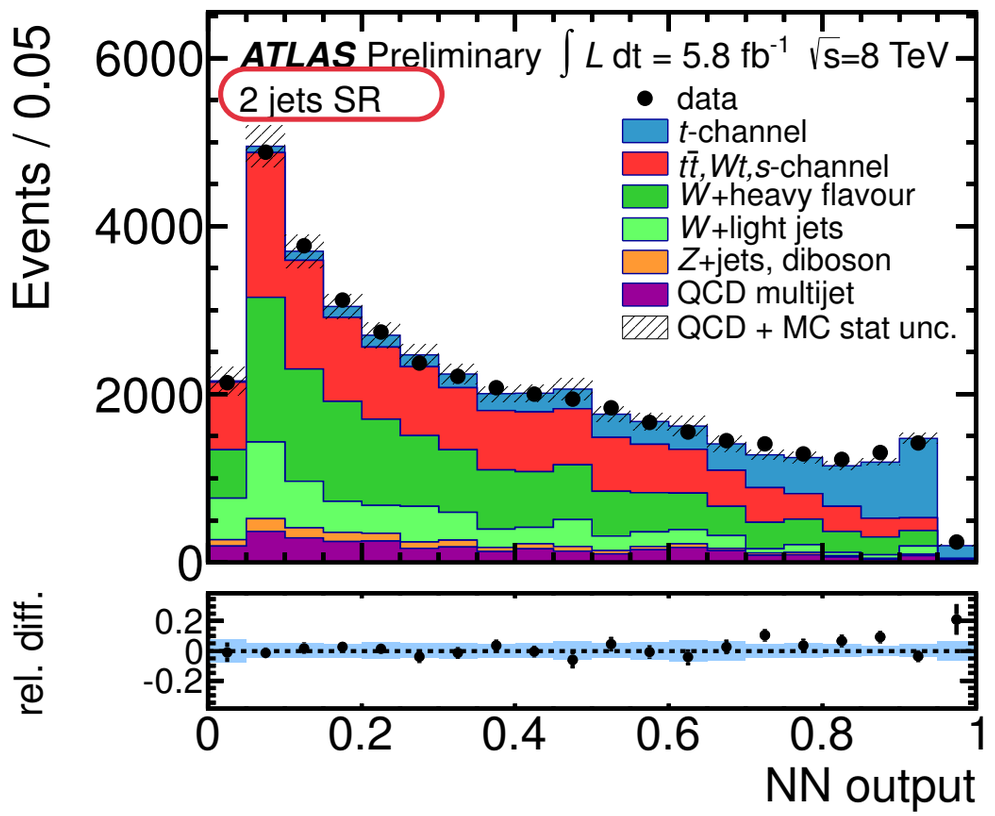
$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{theor}} = 238^{+22}_{-25}\ \text{pb}$$

  - ✦ top mass @172.5 GeV
  - ✦ and NNLO QCD HATHOR



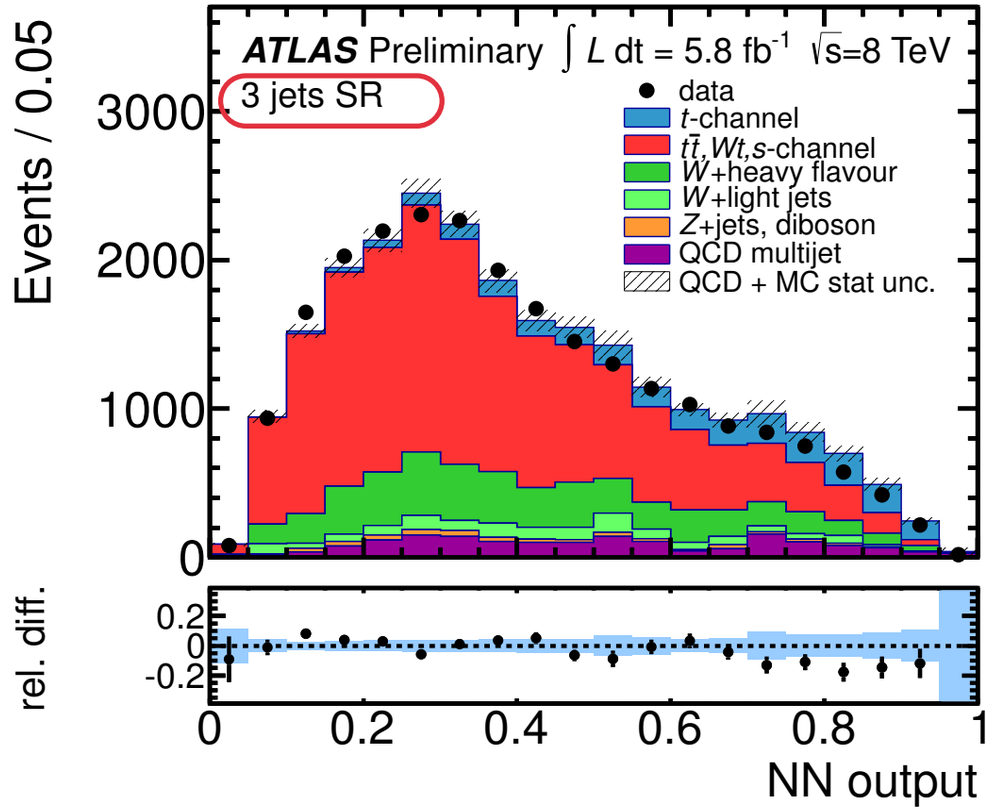
Single Top cross section $5.8\ \text{fb}^{-1}$, at $\sqrt{s} = 8$ TeV, ATLAS-CONF-2012-132 LC2013

- Selection:
- N.N. discrimination
  - min $|p_z(\nu)|$ for quadratic solution choice
- cross section extraction: likelihood fit
  - extraction of β scale factors
    - ✦ N(evt) = β × expectation
  - combined fit in 2 and 3 jet bins



Process	$\hat{\beta}$
t channel	1.08 ± 0.03
W+ heavy flavour	1.04 ± 0.03
W+ light jets	0.93 ± 0.04
Z+ jets, diboson	0.94 ± 0.10
$t\bar{t}$, Wt, s channel	0.88 ± 0.01

statistical errors only



$t\bar{t}$ Spin Correlation 2.1 fb^{-1} $\sqrt{s}$ = 7 TeV PRL 108, 212001 (2012)

- Template fit on $\Delta\phi$ distributions

$$A_{\text{measured}} = A^{\text{SM}} \cdot f^{\text{SM}}$$

  - linear superposition of template modeling the correlated (f^{SM}) and uncorrected (1- f^{SM}) hypotheses

- Results projected in two basis:

  - helicity base (quark direction of flight in the C.M.)

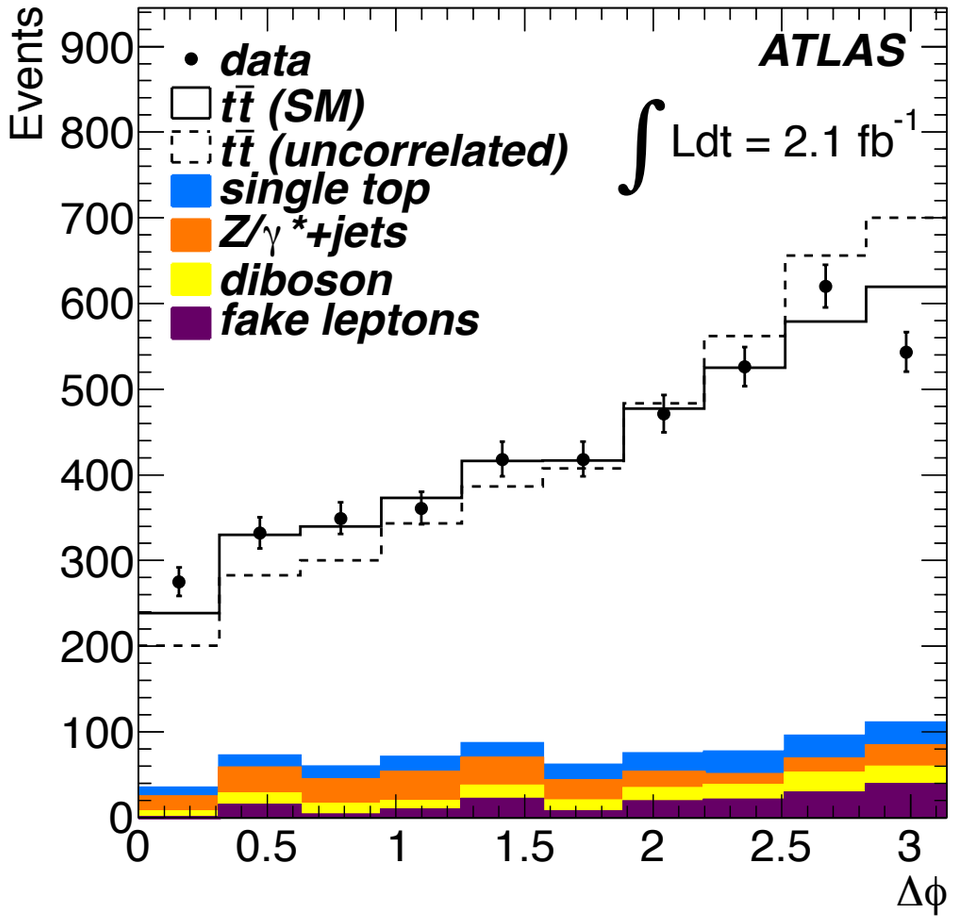
$$A_{\text{helicity}} = 0.40 \ \pm 0.04(\text{stat}) \ ^{+0.08}_{-0.07}(\text{syst})$$

  - maximal basis (optimized for $\bar{t}t$ production from gg)

$$A_{\text{maximal}} = 0.57 \ \pm 0.06(\text{stat}) \ ^{+0.12}_{-0.10}(\text{syst})$$

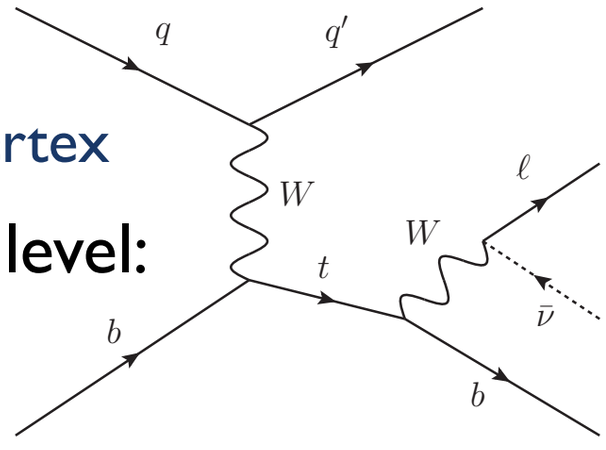
  - Consistent with S.M. prediction
    - ✦ $A_{helicicy}$=0.31 and $A_{maximal}$= 0.44

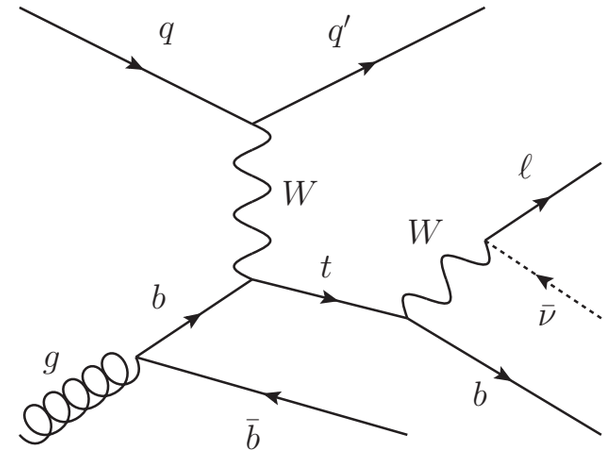
- First Observation
  - No correlation excluded at 5.1σ



Uncertainty source	Δf^{SM}
Data statistics	±0.14
MC simulation template statistics	±0.09
Luminosity	±0.01
Lepton	±0.01
Jet energy scale, resolution and efficiency	±0.12
NLO generator	±0.08
Parton shower and fragmentation	±0.08
ISR/FSR	±0.07
PDF uncertainty	±0.07
Top quark mass	±0.01
Fake leptons	+0.16/−0.07
Calorimeter readout	±0.01
All systematics	+0.27/−0.22
Statistical + Systematic	+0.30/−0.26

- Single Top production
  - direct probe of couplings in the W_{tb} vertex
- most general S.M. lagrangian at tree level:





  - $V_L \sim V_{tb} \sim 1$: $\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right) t W_{\mu}^{-} + \text{h.c.}$
  - while the anomalous couplings V_R and $g_{L,R} = 0$
- Deviations from:
  - W polarization fractions
  - Lepton Angular asymmetries from the W decay
- For unpolarised top quark production
- only meaningful reference direction: momentum (q) of the *W* boson in the top quark rest frame (helicity basis)
  - corresponding angle θ^{*}
  - In top quark decays θ angle between the direction of the lepton from the W decay in the W boson rest frame and a certain reference direction.

W helicity

1.04 fb^{-1} $\sqrt{s}$ = 7 TeV JHEP 1206 (2012) 088)

- Method II: Measurement of angular distributions

$$A_{\pm} = \frac{N(cos\theta^* > z_{\pm}) - N(cos\theta^* < z_{\pm})}{N(cos\theta^* > z_{\pm}) + N(cos\theta^* < z_{\pm})}; \quad z_{\pm} = \pm(1 - 2^{2/3})$$

$$\beta = (2^{\frac{1}{3}} - 1)$$

$$A_+ = 3\beta\,[F_0 + 1(1+\beta)F_{\rm R}] \qquad F_R = \frac{1}{1-\beta} + \frac{A_- - \beta A_+}{3\beta(1-\beta^2)},$$

$$A_- = -3\beta\,[F_0 + 1(1+\beta)F_{\rm L}] \qquad F_L = \frac{1}{1-\beta} - \frac{A_+ - \beta A_-}{3\beta(1-\beta^2)},$$

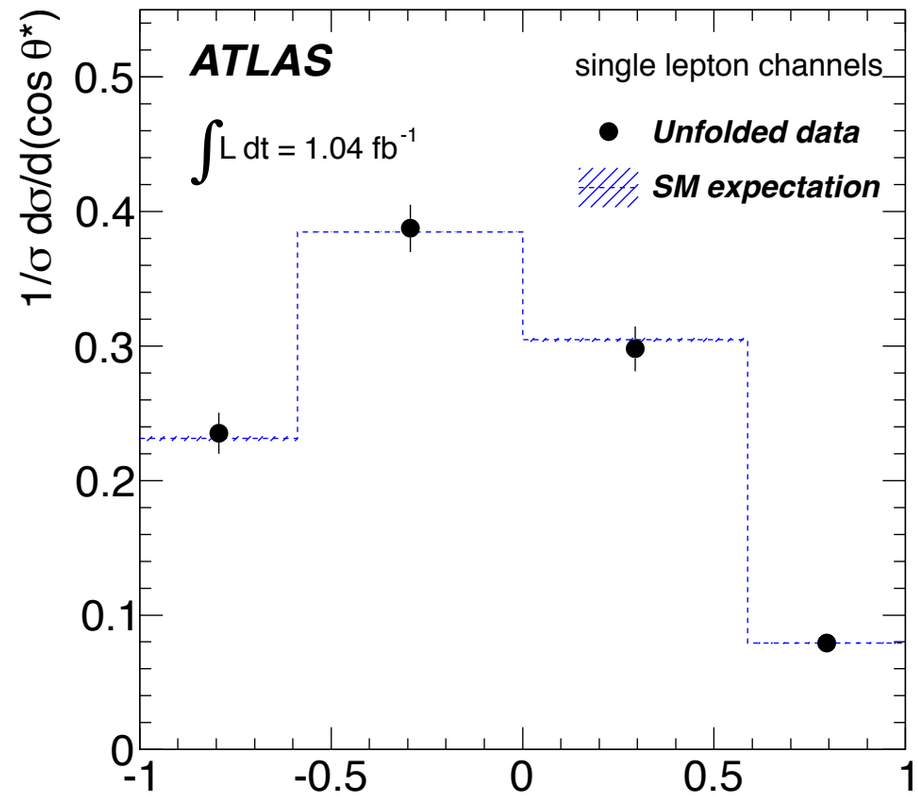
$$F_0 = -\frac{1+\beta}{1-\beta} + \frac{A_+ - A_-}{3\beta(1-\beta)}.$$

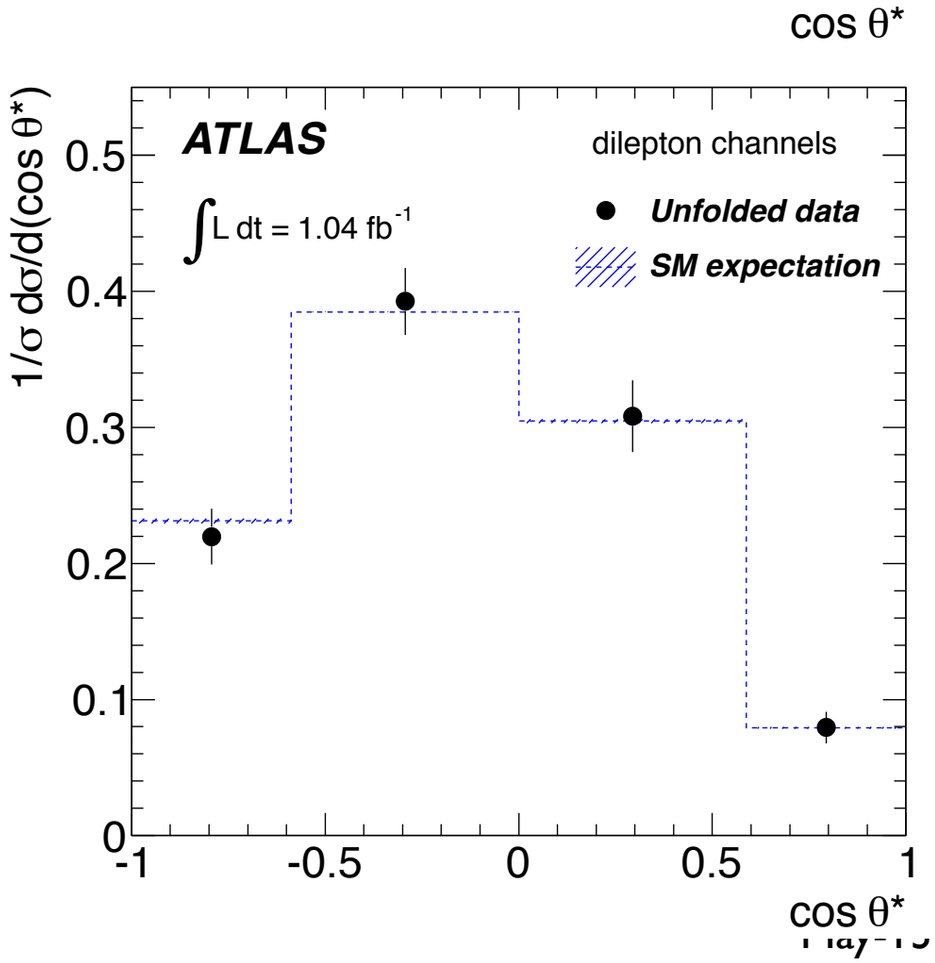
  - S.M. values:
    - ✦ $A_+ \sim 0.548 \pm 0.010$
    - ✦ $A_- \sim -0.8397 \pm 0.0033$

- χ^2 minimization in reconstruction of single lepton events:

$$\chi^2 = \frac{(m_{\ell\nu j_a} - m_t)^2}{\sigma_t^2} + \frac{(m_{j_b j_c j_d} - m_t)^2}{\sigma_t^2} + \frac{(m_{\ell\nu} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_c j_d} - m_W)^2}{\sigma_W^2}$$

  - σ_t=14 GeV σ_W=10 GeV

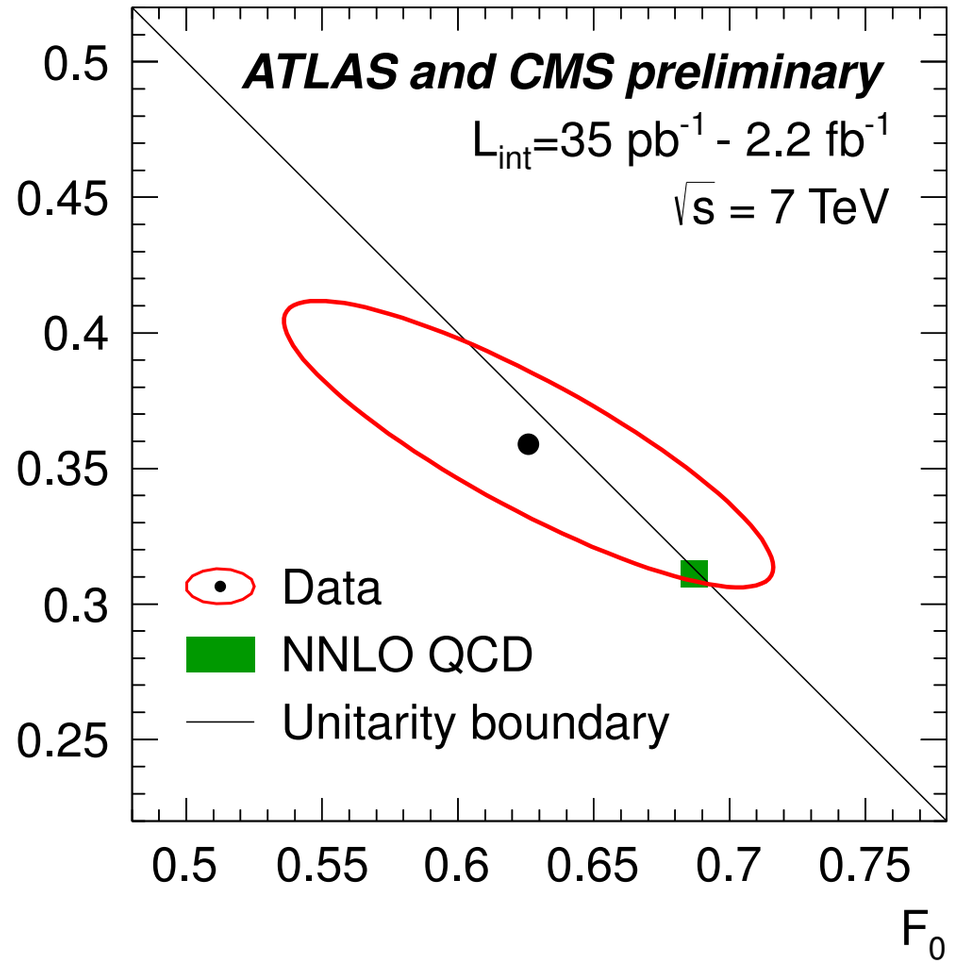




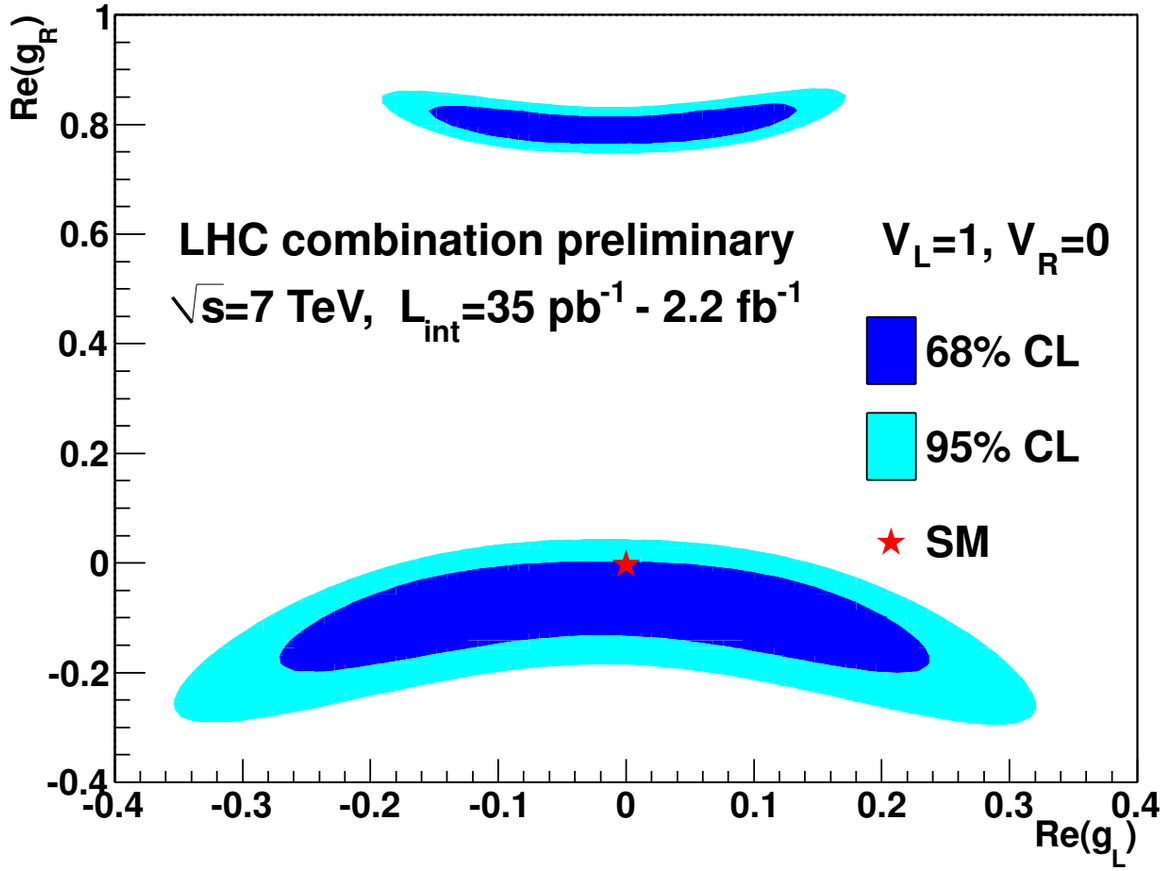
- Combination of F_0, F_R
  - $F_R = 1 - F_0 - F_L$
- All results before combination:

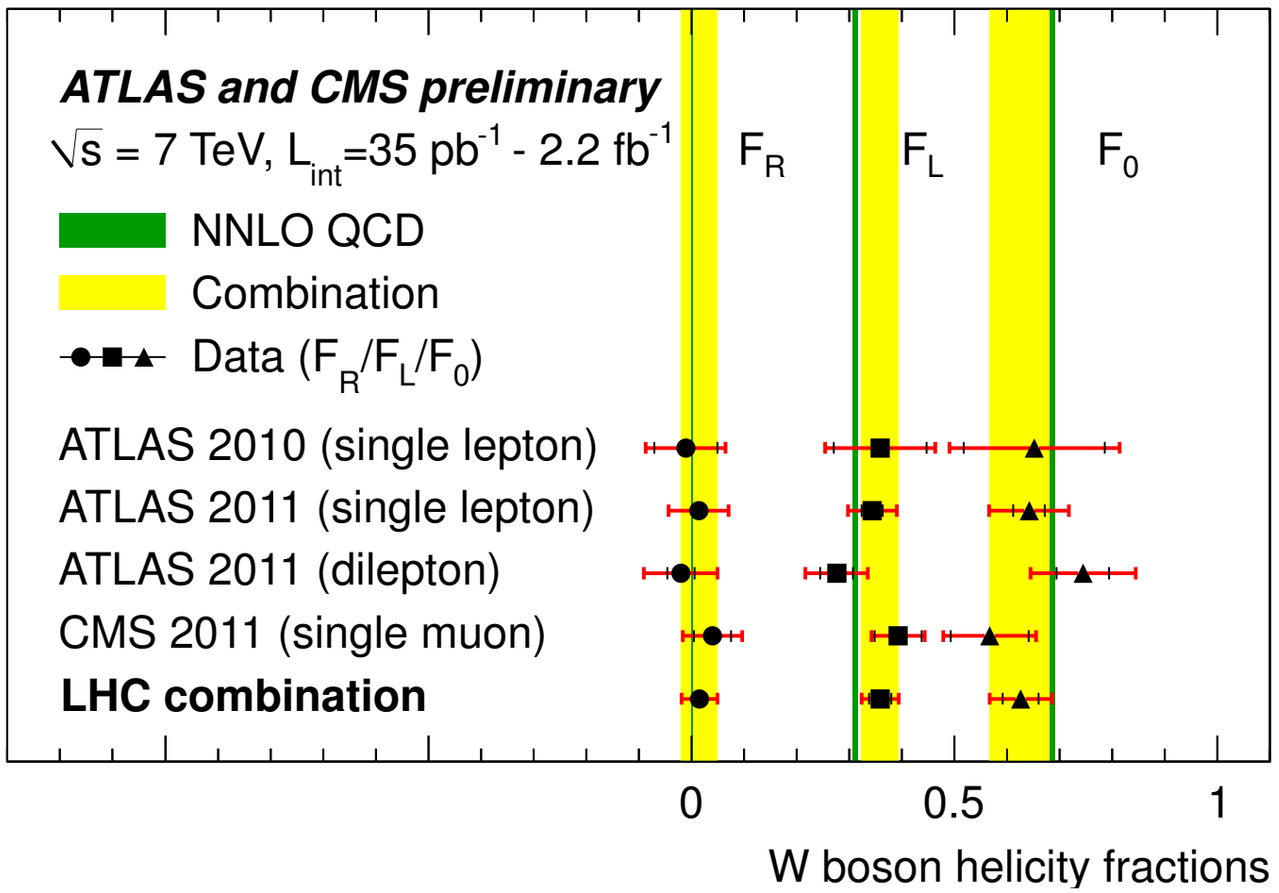
Measurement	F_0	F_L	F_R
ATLAS 2010 (single lepton) [Alj2010]	0.652 ± 0.134 ± 0.092	0.359 ± 0.088 ± 0.056	−0.011 ± 0.060 ± 0.046
ATLAS 2011 (single lepton) [Alj2011]	0.642 ± 0.030 ± 0.071	0.344 ± 0.020 ± 0.042	0.014 ± 0.014 ± 0.055
ATLAS 2011 (dilepton) [Adil2011]	0.744 ± 0.050 ± 0.087	0.276 ± 0.031 ± 0.051	−0.020 ± 0.026 ± 0.065
CMS 2011 (single lepton) [Clj2011]	0.567 ± 0.074 ± 0.048	0.393 ± 0.045 ± 0.024	0.040 ± 0.035 ± 0.043

Category	LHC combination F_0	LHC combination F_L
Detector modeling		
Detector model	0.019	0.011
Jet energy scale	0.020	0.012
Luminosity and pile-up	0.006	0.003
Signal and background modeling		
Monte Carlo	0.012	0.008
Radiation	0.024	0.012
Top-quark mass	0.019	0.012
PDF	0.008	0.004
Background (MC QCD)	0.003	0.001
Background (MC W + jets)	0.007	0.002
Background (MC other)	0.011	0.006
Background (data-driven)	0.013	0.008
Method-specific uncertainties		
Method	0.008	0.005
Total uncertainties		
Total systematic uncertainty	0.048	0.028
Statistical uncertainty	0.034	0.021
Total uncertainty	0.059	0.035



- Uncertainties:
  - statistical ~50% larger than respective largest systematic
  - Jet Energy Scale, Detector Modeling, Radiation, Top Mass





- Combination of F_0, F_R
  - $F_R = 1 - F_0 - F_L$
  - taking into account correlated systematics
- Cobined Results:
  - global correlation $\rho = -0.86$
  - $\chi^2 \sim 3.3$ for 8 measurements

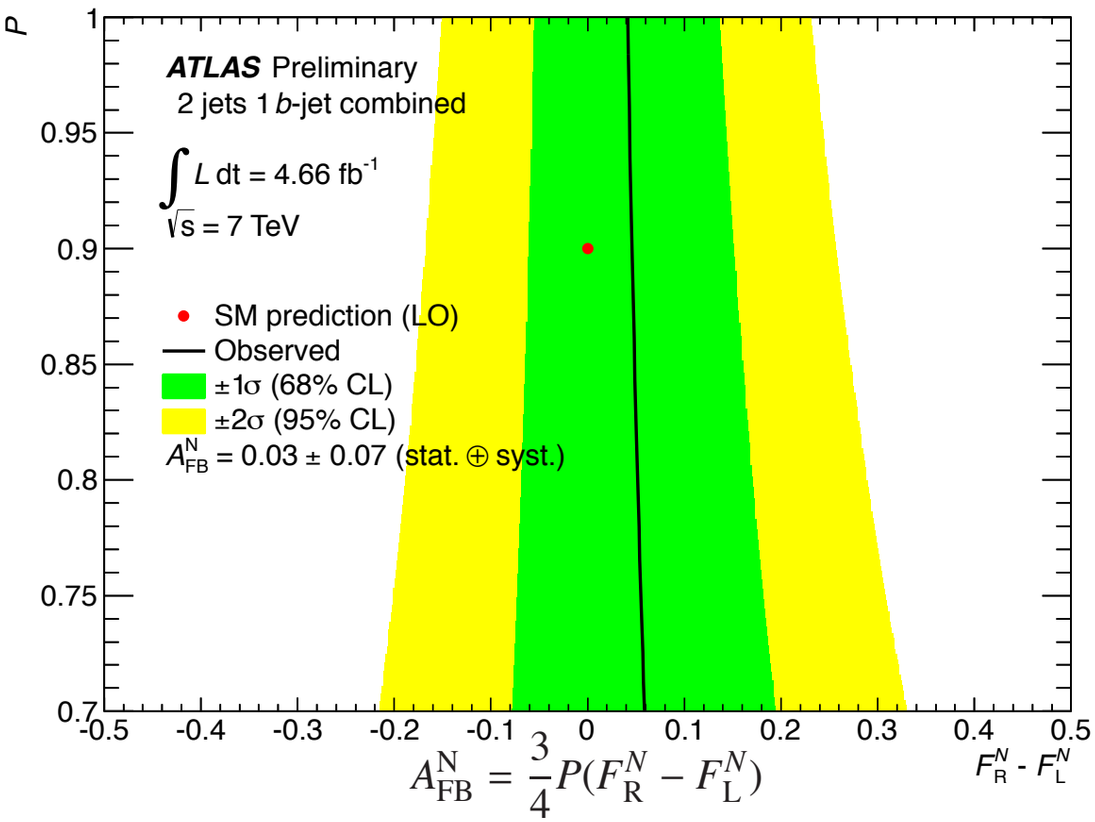
$$F_0 = 0.626 \pm 0.034\ (\text{stat.}) \pm 0.048\ (\text{syst.})$$
$$F_L = 0.359 \pm 0.021\ (\text{stat.}) \pm 0.028\ (\text{syst.})$$

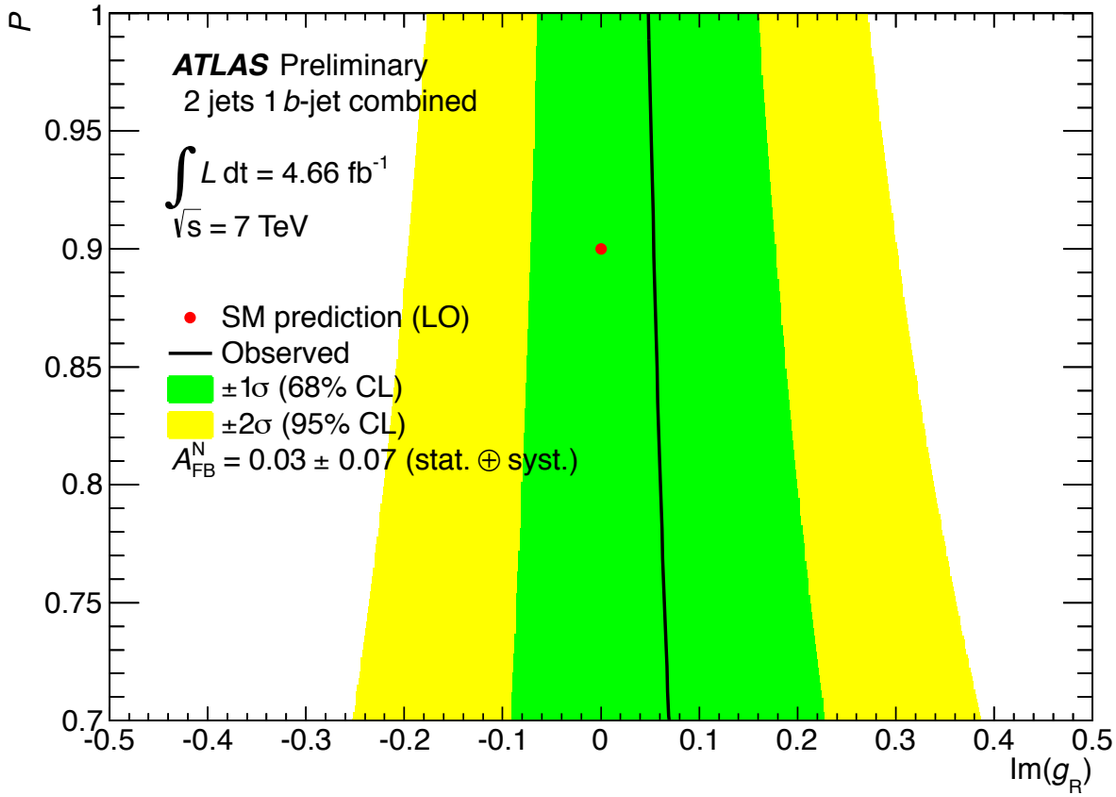
Single Top *CP* Violation 4.66 fb^{-1}, $\sqrt{s}$ = 7 TeV, ATLAS-CONF-2013-032

- Consistent with *CP* invariance in top quark decays (A^N_{FB} = 0).

$$A_{\mathrm{FB}}^{\mathrm{N}} = 0.032 \pm 0.065(\mathrm{stat}) \, ^{+0.029}_{-0.031}(\mathrm{syst})$$

  - [−0.20, 0.30] 95% C.L. on I(g_R)
    - ✦ 0.9 top quark polarization
- Consistent with SM predictions:
  - leading order
  - including one loop E.W. corrections
- First Limit on the I(g_R):
  - prediction: [-7.17 - 1.23*i*] × 10^{-3}
  - *I*(g_R)~0.17 *R*(g_R): Non S.M. contributions can have sizable *CP*-violating component





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

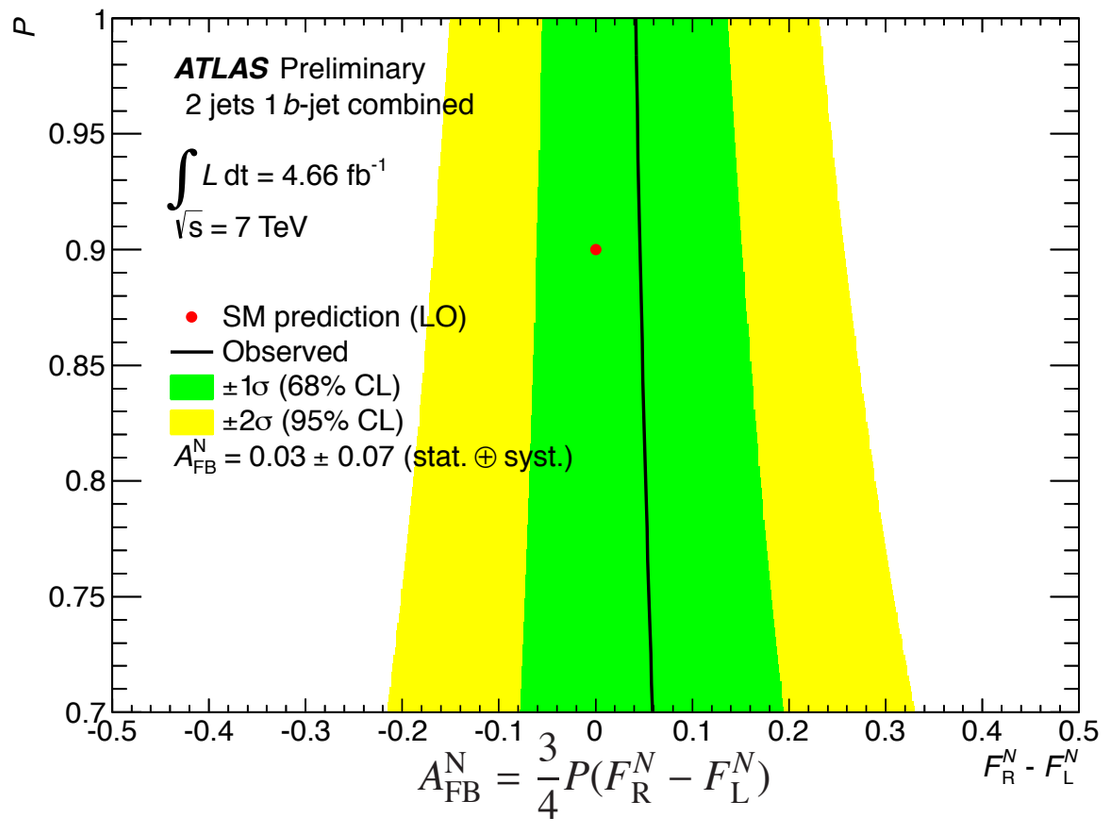
Single Top *CP* Violation 4.66 fb^{-1}, $\sqrt{s}$ = 7 TeV, ATLAS-CONF-2013-032

- Unfolding to parton level of cos θ:

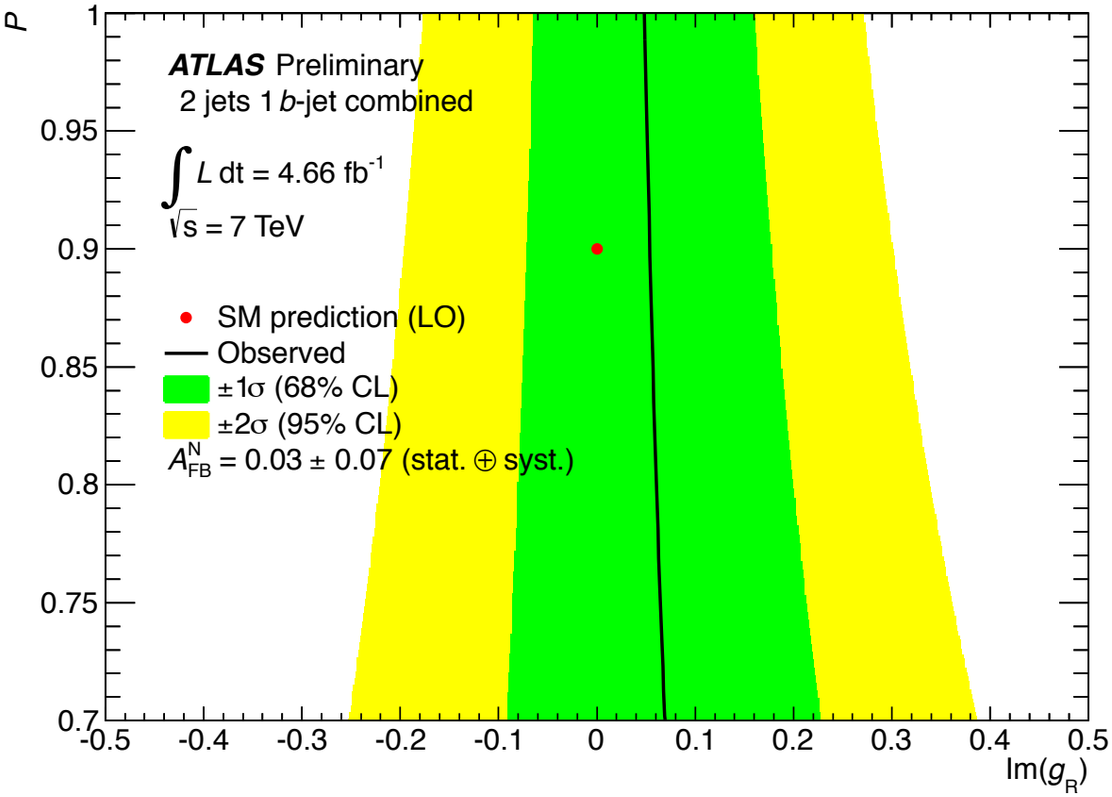
$$N_j^{\text{unfolded}} = \frac{M_{ji}^{-1}(N_i^{\text{data}} - N_i^{\text{bkg}})}{A_j}$$

- Systematics:

Source	$\Delta A_{\text{FB}}^{\text{N}}$
t-channel generator	+0.024 / −0.024
$t\bar{t}$ generator and parton shower	+0.010 / −0.010
Background normalisation	+0.008 / −0.008
Jet energy resolution	+0.007 / −0.007
Jet energy scale	+0.005 / −0.009
Lepton id, reco., trigger and scale	+0.004 / −0.006
PDFs	+0.003 / −0.003
Unfolding	+0.003 / −0.003
$E_{\text{T}}^{\text{miss}}$	+0.002 / −0.004
b-tagging	+0.002 / −0.002
W+jets shape	+0.001 / −0.001
ISR/FSR	+0.001 / −0.001
Jet reconstruction efficiency	+0.001 / −0.001
Luminosity	+0.001 / −0.001
Jet vertex fraction	<0.001 / <0.001
Total systematic	+0.029 / −0.031



$$A_{\text{FB}}^{\text{N}} = \frac{3}{4} P (F_{\text{R}}^N - F_{\text{L}}^N)$$



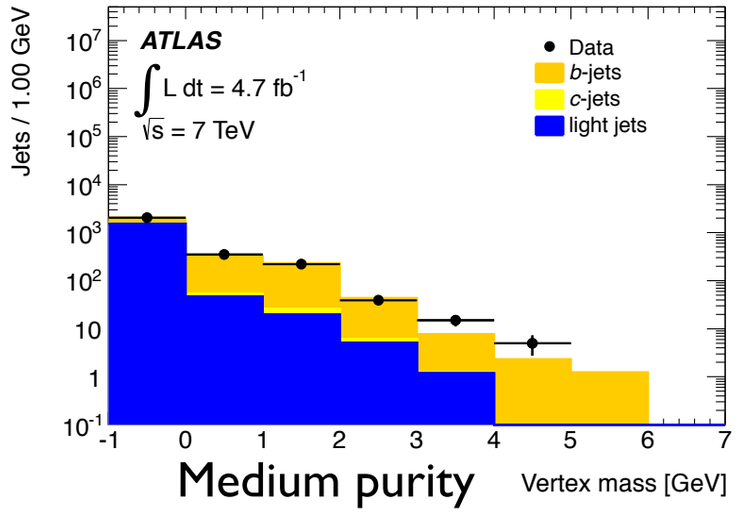
$$A_{\text{FB}}^{\text{N}} = 0.64\, P\, \mathbb{I}(g_{\text{R}})$$

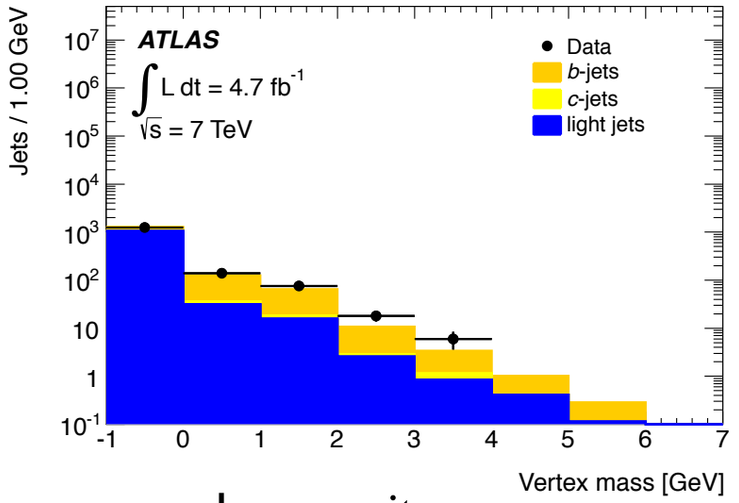
- Search for $t\bar{t}$ associated with heavy-flavor (HF) quarks:

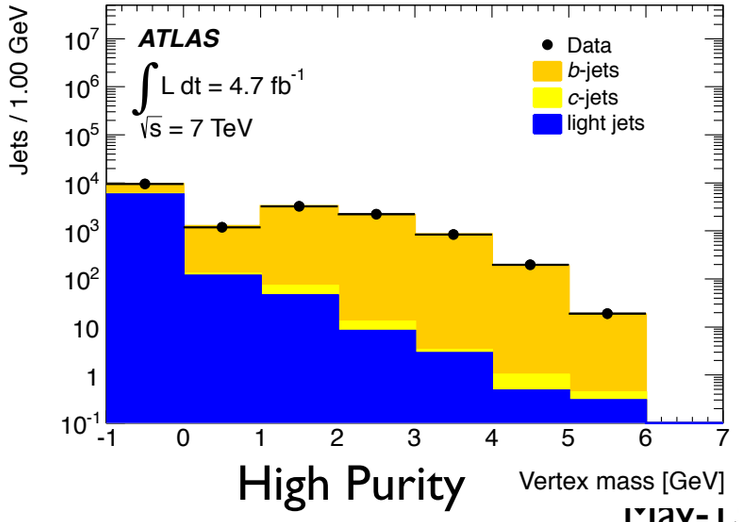
Process	Number of events
$t\bar{t}$	106.7 ± 3.4
Single top	2.2 ± 0.5
Z + jets	0.2 ± 0.1
Fake leptons	$0\ ^{+5}_{-0}$
Total expectation	$109\ ^{+6}_{-3} \pm 35$
Data	106

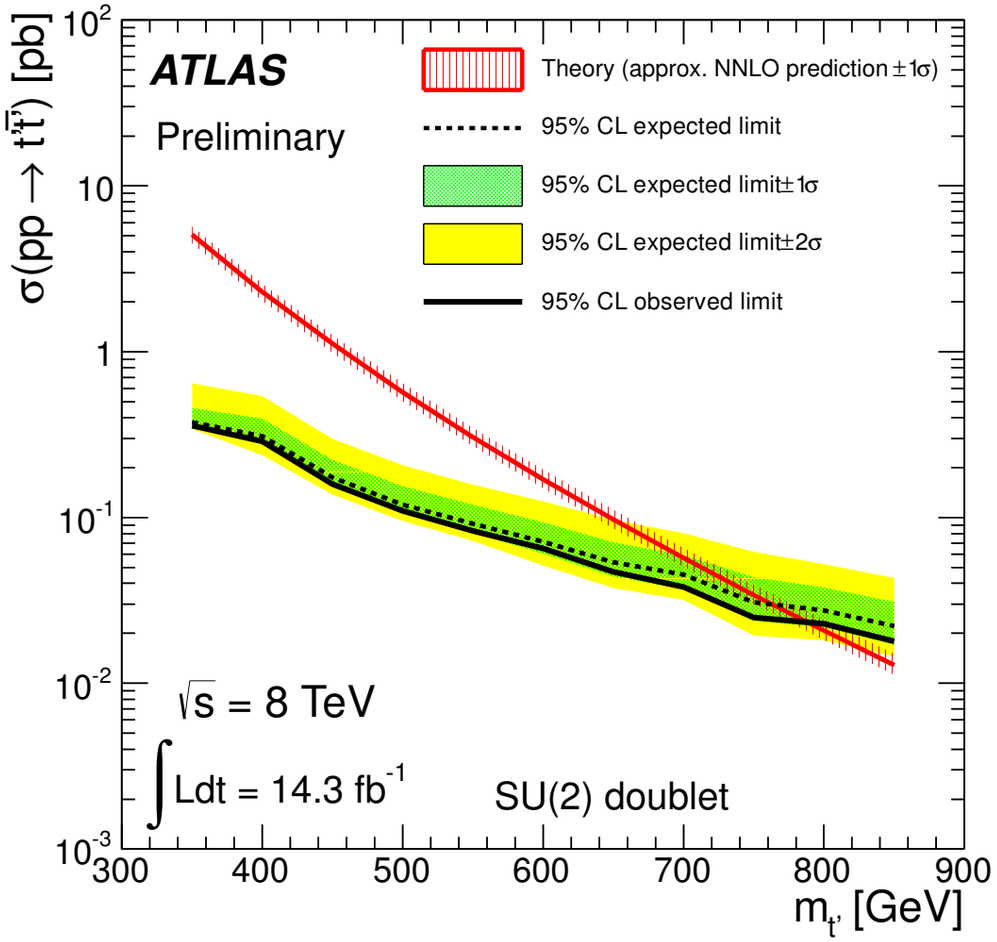
b-purity	b-jet efficiency	c-jet efficiency	light-flavor rejection
Tight	60%	17%	230
Medium	10%	7%	100
Low	5%	6%	75

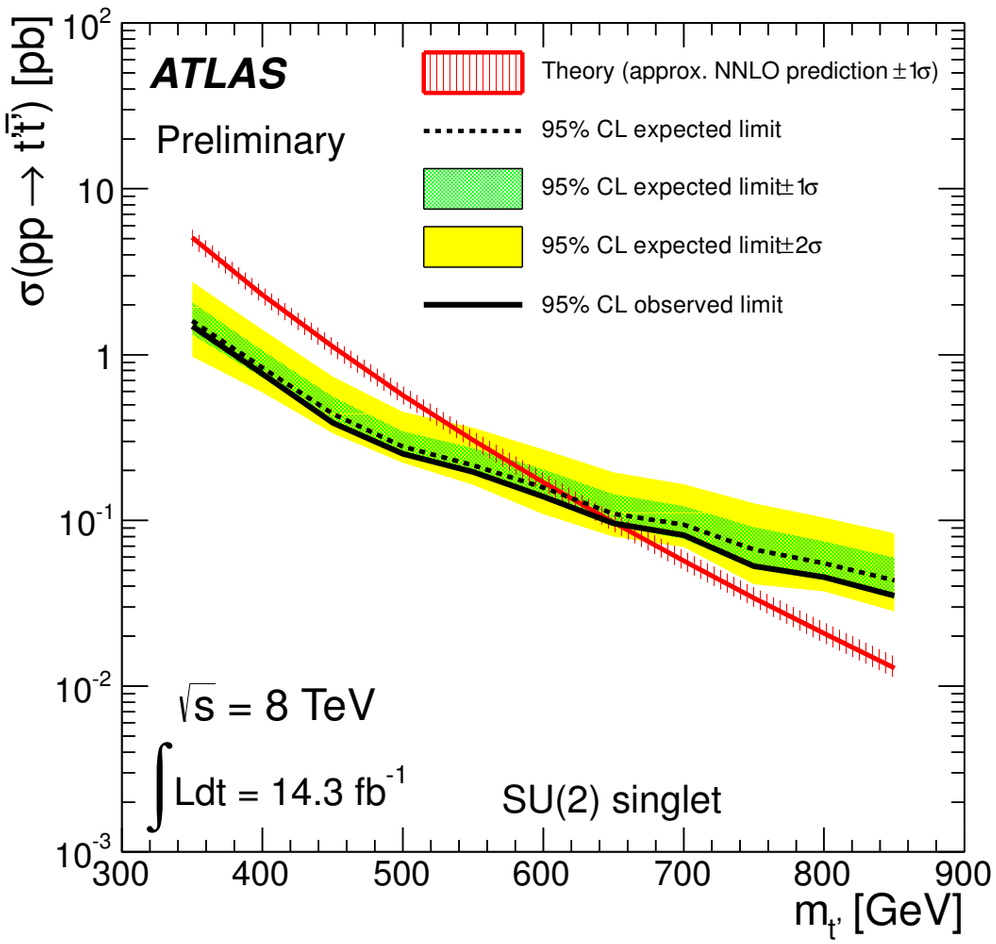
Source	% (full calculation)	% (A x ε_{HF})
Lepton reconstruction	0.2	0.2
Jet reconstruction and calibration	11.2	5.4
E_T^{miss} reconstruction	0.9	0.6
Fake lepton estimate	3.4	0.0
Tagging efficiency for b-jets	3.1	2.4
Tagging efficiency for c-jets	21.2	5.9
Tagging efficiency for light jets	8.4	0.2
Fragmentation modeling	1.2	7.3
Generator variation	4.2	3.4
Initial- and final state radition	2.5	2.2
PDF uncertainties	2.8	1.0
Additional fit uncertainties	6.6	–
Fiducial flavor composition	$^{+69.0}_{-0.0}$	$^{+69.0}_{-0.0}$
Total systematic	$^{+74.2}_{-27.4}$	$^{+69.9}_{-11.9}$







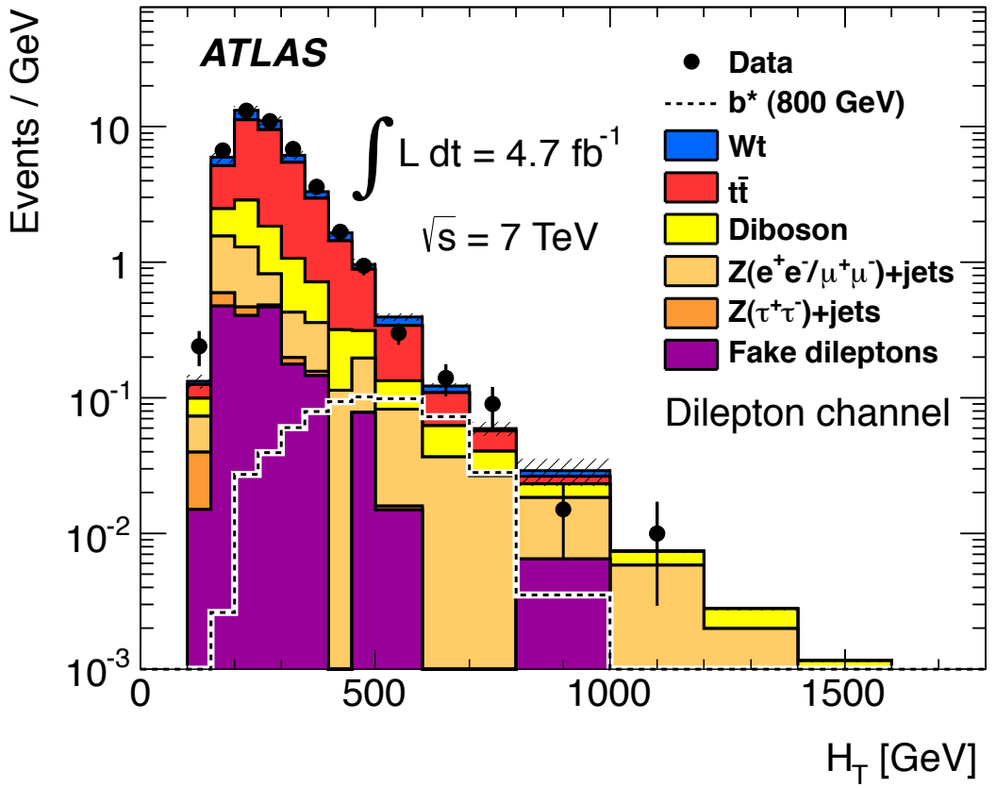


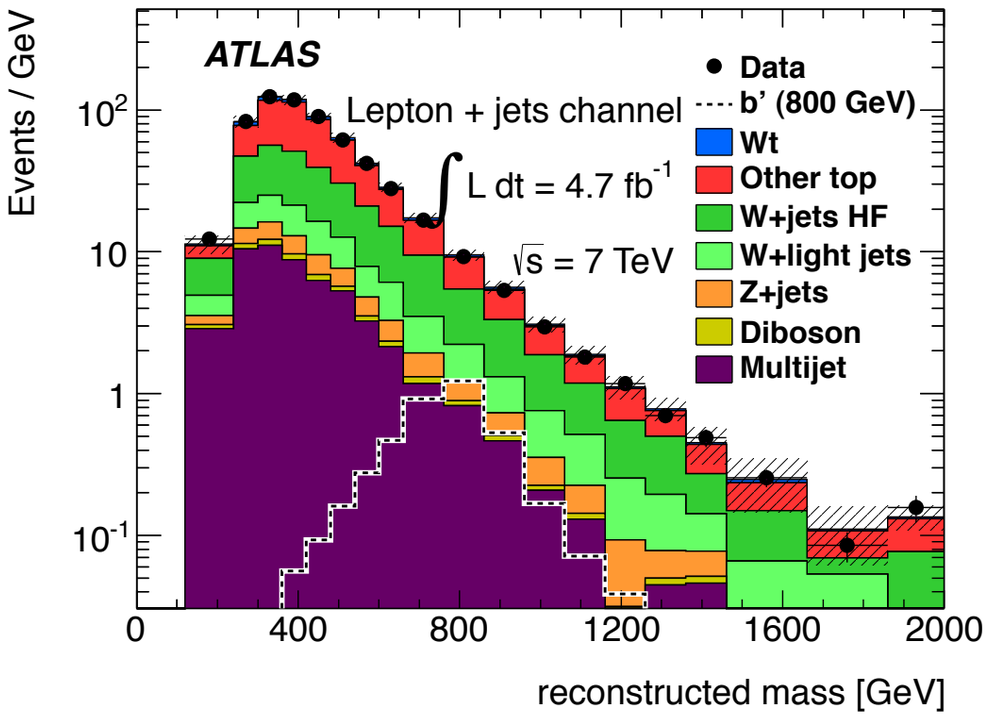


- No observation, 95% C.L. exclusions for the weak isospins:
  - doublet: an observed (expected) $m_{t'} > 790$ (745) GeV
    - ✦ most stringent limit to date
  - singlet: the observed (expected) $m_{t'} > 640$ (615) GeV

b^*-quark production 4.7 fb-1 $\sqrt{s}$ = 7 TeV Phys. Lett. B 721 (2013) 171-189 LC2013

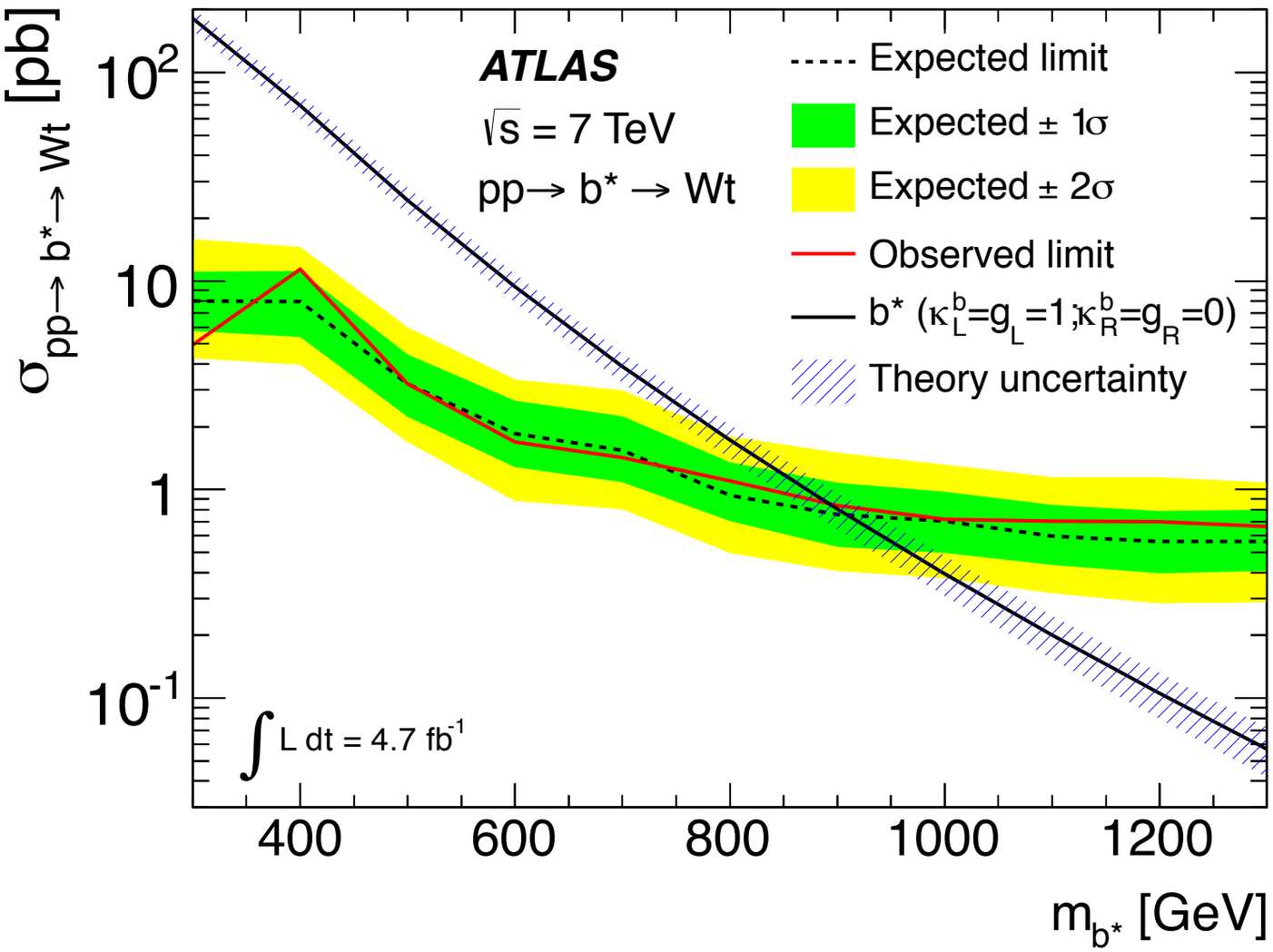
- First search for excited quarks coupling to 3thd gen. fermions
  - $b^* \rightarrow Wt$
  - Randall–Sundrum models (strong interaction)
  - with a heavy gluon partner (ex. composite Higgs models)
- Dilepton channel:
  - two opposite charge lepton, one jet, no b-tag
  - H_T discriminant
- semi-leptonic:
  - one lepton N(b-tag) ≥ 1
  - reconstructed mass
- Absence of deviations from S.M. prediction
  - set limits





b^*-quark production 4.7 fb-1 $\sqrt{s}$ = 7 TeV Phys. Lett. B 721 (2013) 171-189 LC2013

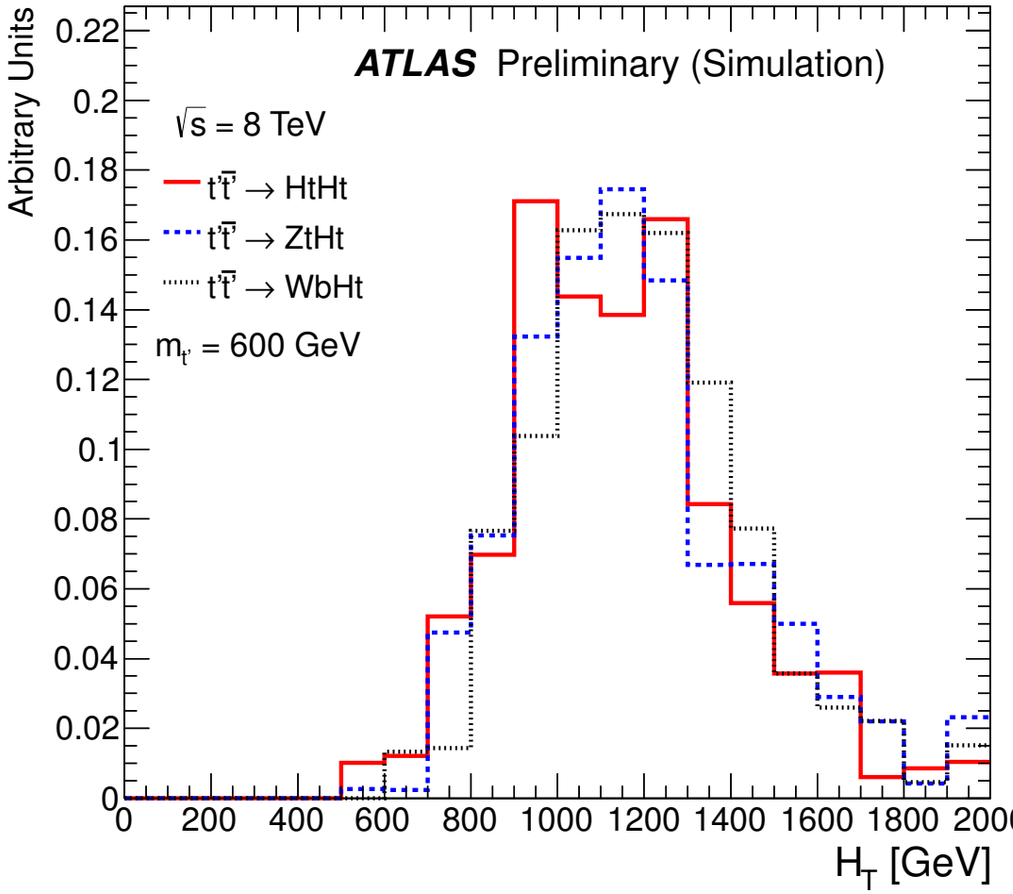
- template likelihood fit
- left-handed models
  - unit strength chromo-magnetic coupling
  - $m_{b^*} < 870$ GeV excluded at 95% C.L.



- right handed models:
  - vector-like b^* couplings
  - $k_L{}^b = g_L = 0$, $k_R{}^b = g_R = 1$ $m_{b^*} < 920$ GeV excluded at 95%
  - $k_L{}^b = g_L = k_R{}^b = g_R = 1$, $m_{b^*} < 920$ GeV excluded at 95%

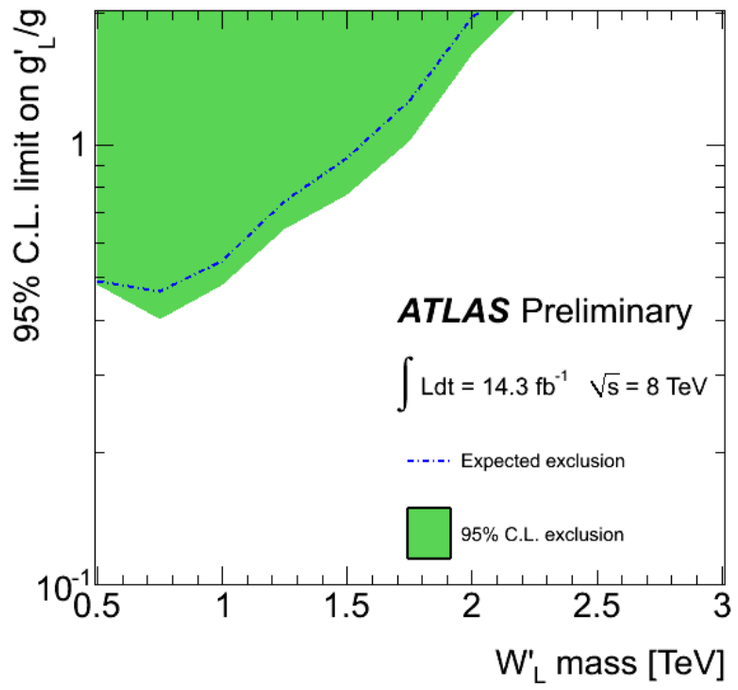
- Systematics:

	≥ 6 jets, 2 b-tags	≥ 6 jets, 3 b-tags	≥ 6 jets, ≥ 4 b-tags
$t\bar{t}$+heavy-flavour jets	1500 ± 900	900 ± 400	170 ± 70
$t\bar{t}$+light-flavour jets	9600 ± 1000	1900 ± 350	75 ± 22
W+jets	250 ± 130	50 ± 30	5 ± 3
Z+jets	50 ± 40	9 ± 6	0.5 ± 0.9
Single top	300 ± 70	75 ± 18	7 ± 3
Diboson	1.7 ± 0.6	0.3 ± 0.1	0.03 ± 0.03
$t\bar{t}V$	70 ± 20	36 ± 12	7 ± 3
$t\bar{t}H$	28 ± 4	31 ± 6	12 ± 3
Multijet	49 ± 23	1.7 ± 0.8	0.15 ± 0.06
Total background	11860 ± 260	2990 ± 210	270 ± 60
Data	11885	2922	318
Doublet			
$t'\bar{t}'(400)$	550 ± 70	1100 ± 100	790 ± 160
$t'\bar{t}'(600)$	4.3 ± 1.2	94 ± 7	79 ± 18
$t'\bar{t}'(800)$	0.12 ± 0.05	10.7 ± 0.8	9.1 ± 2.1
Singlet			
$t'\bar{t}'(400)$	290 ± 30	650 ± 80	330 ± 70
$t'\bar{t}'(600)$	2.3 ± 0.4	61 ± 7	36 ± 9
$t'\bar{t}'(800)$	0.06 ± 0.01	6.9 ± 0.7	4.2 ± 1.1

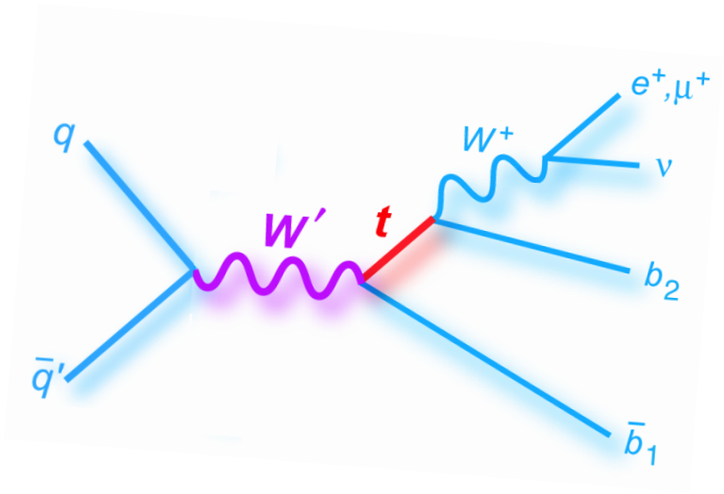


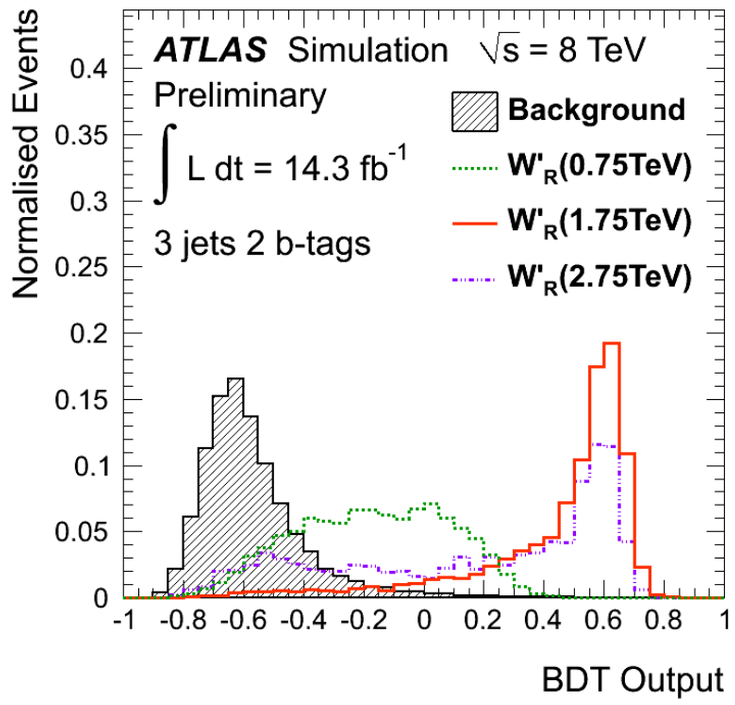
- No deviation observed, 95% C.L. on $m_{W'}$

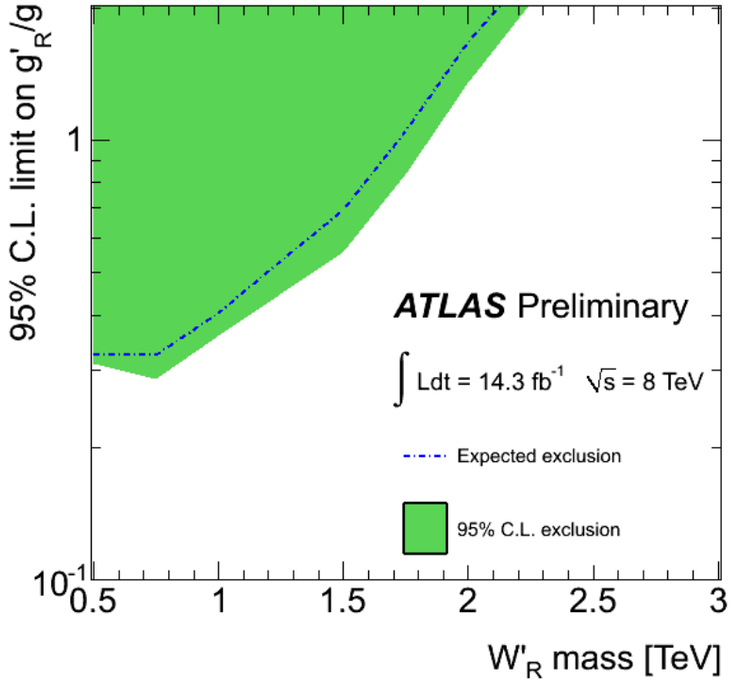
W' mass (TeV)	W'_L Theory	W'_L Obs. limit	W'_R Theory	W'_R Obs. limit
0.5	17	4.0	23	2.2
1.0	1.0	0.24	1.4	0.17
1.5	0.13	0.075	0.17	0.051
2.0	0.022	0.064	0.028	0.056
2.5	0.0044	0.11	0.0054	0.10
3.0	0.0011	0.20	0.0013	0.19



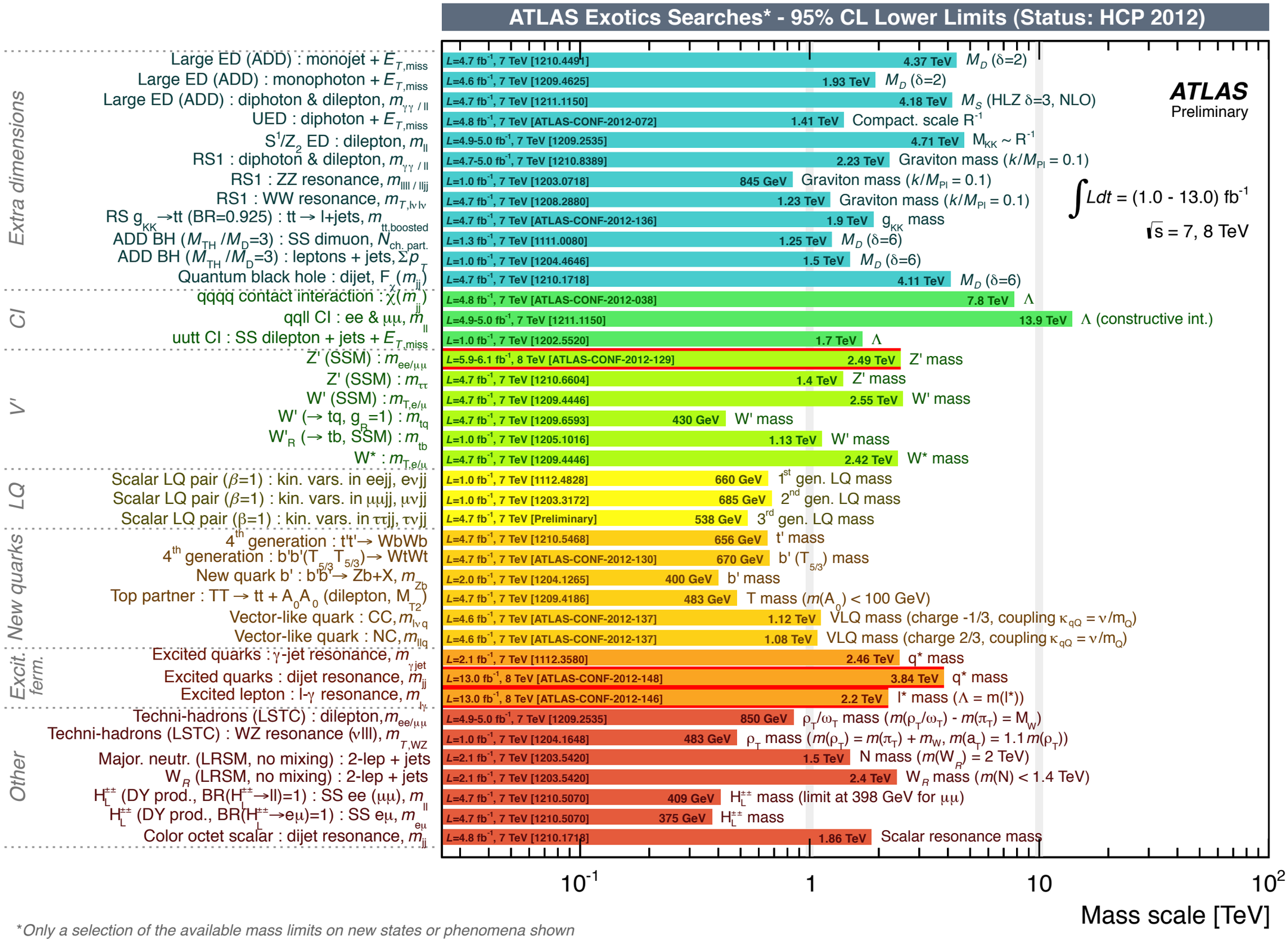
- Expected BDT output for W'R in 3 jet Signal Region



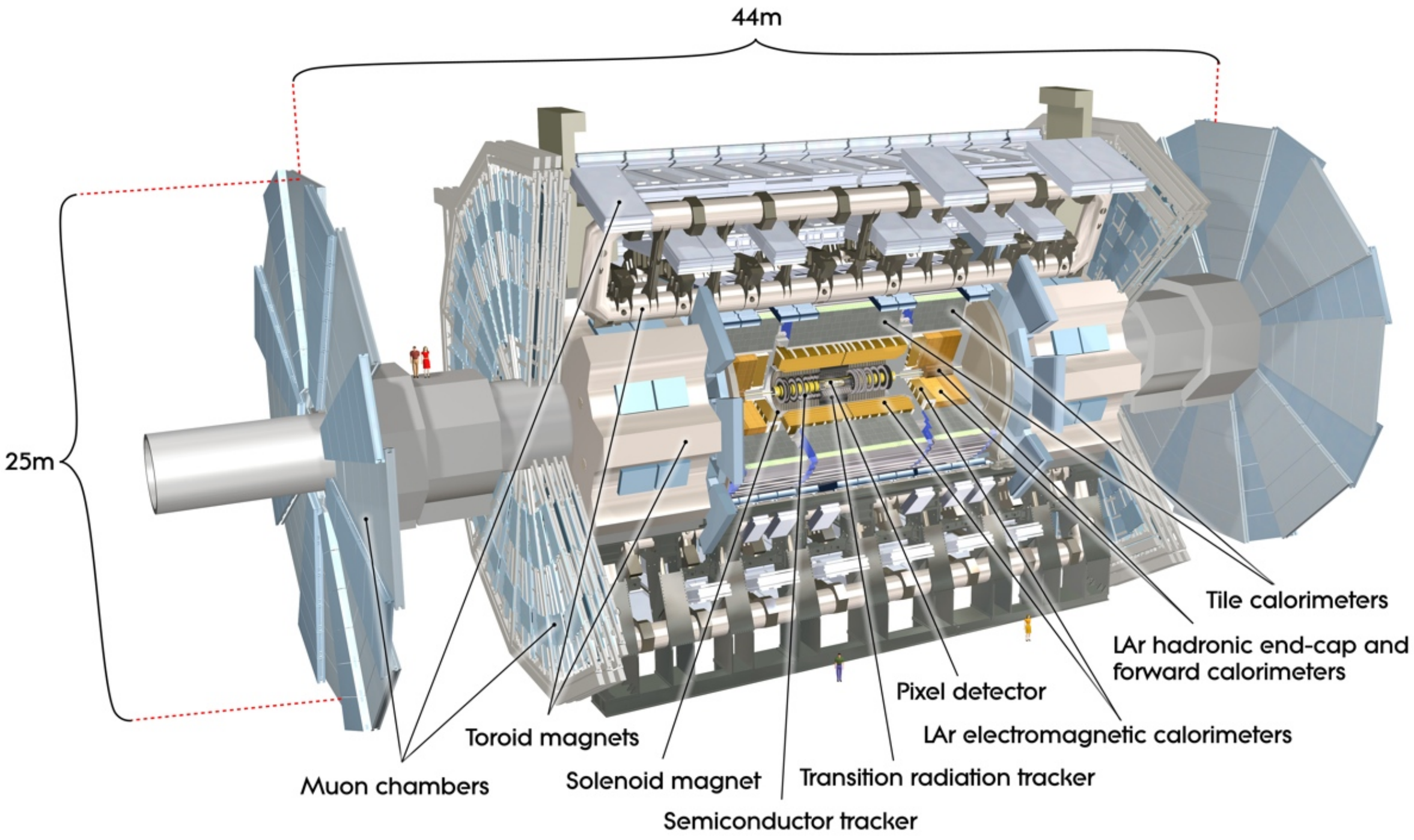




Exotics Summary



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


44m
25m
Muon chambers
Toroid magnets
Solenoid magnet
Semiconductor tracker
Transition radiation tracker
Pixel detector
LAr electromagnetic calorimeters
LAr hadronic end-cap and forward calorimeters
Tile calorimeters