Highlights of top quark properties measurements at ATLAS

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on behalf of the ATLAS collaboration

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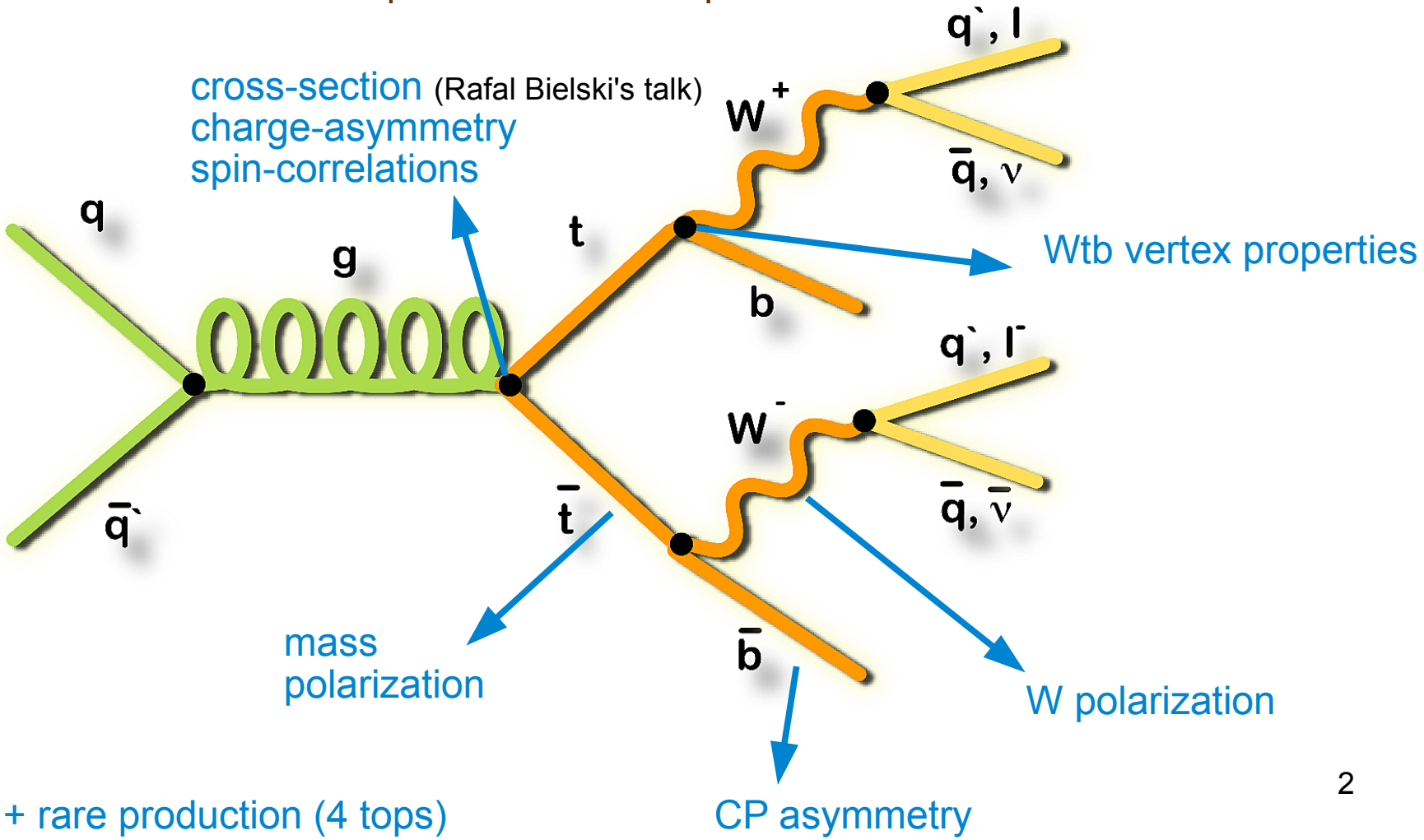
Top physics at LHC

- ATLAS/CMS: ~40 millions of $t\bar{t}$ events produced per experiment
  → era of precise, differential top quark physics
  → searches for rare production and/or phenomena



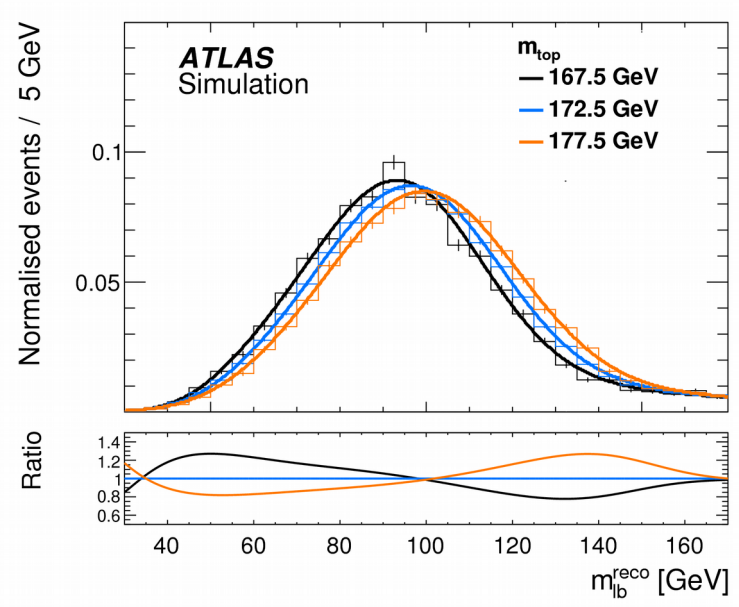
Top quark mass in dilepton channel + combination

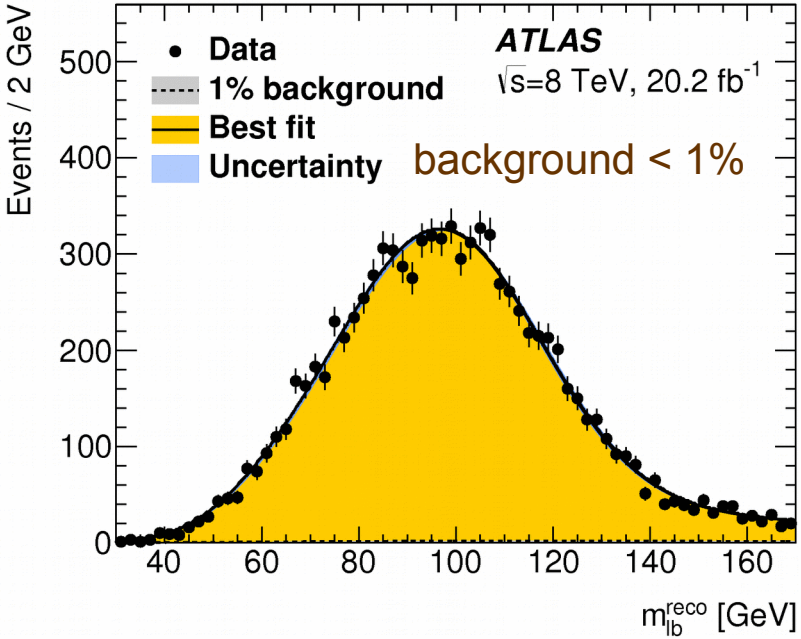
Physics Letters B 761 (2016) 350

- Top mass: fundamental parameter of Standard Model (SM)
- Measured in dilepton channel at $\sqrt{s}$ = 8 TeV
- Template method using as sensitive variable the invariant mass of lepton and b-jet
- Measured value: m_{TOP} = 172.99 ± 0.41 (stat) ± 0.74 (syst) GeV
- Combination together with $\sqrt{s}$ = 7 TeV dilepton and lepton+jets channel:

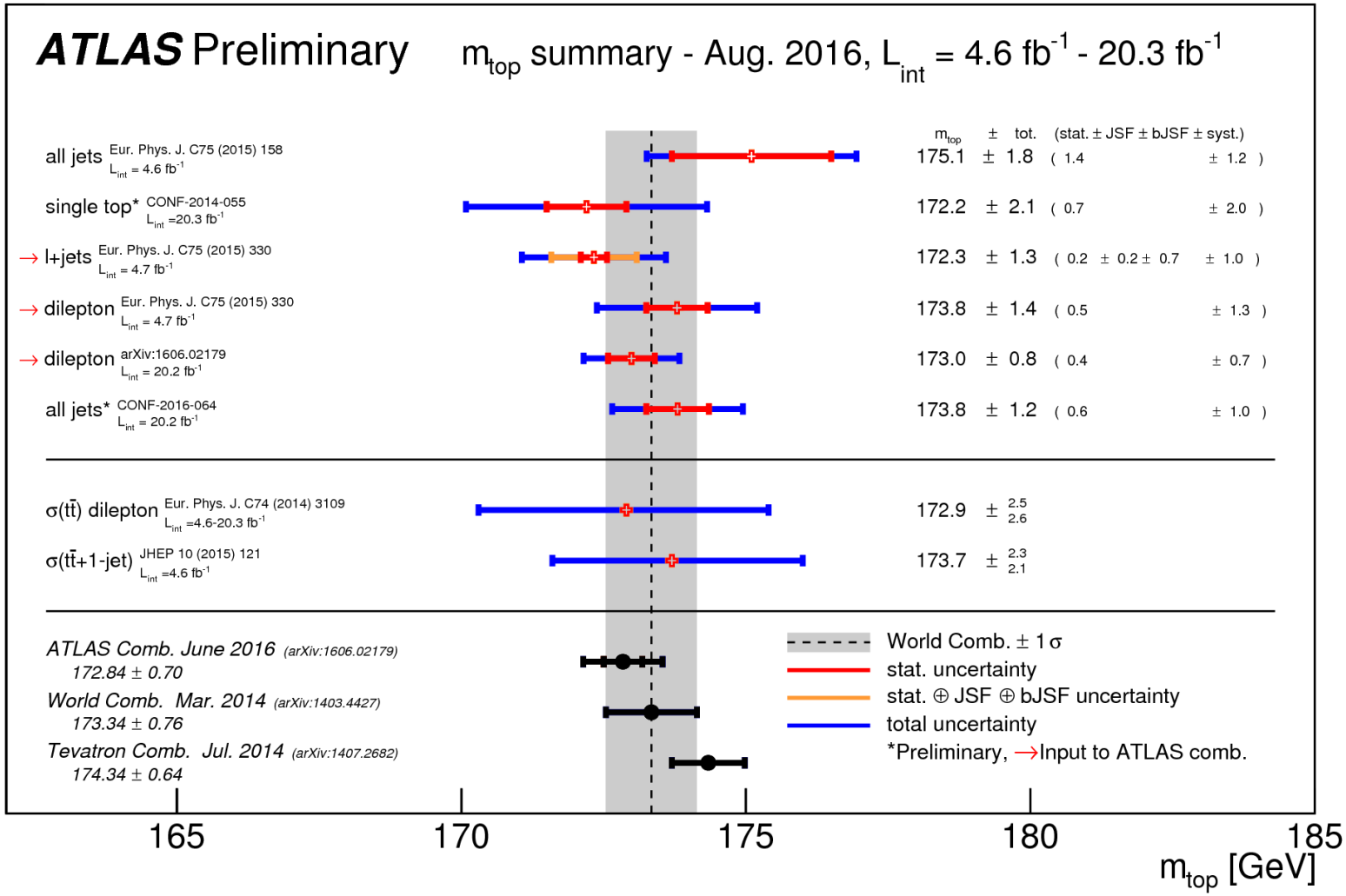
  m_{TOP} = 172.84 ± 0.34 (stat) ± 0.61 (syst) GeV = 172.84 ± 0.70 GeV

  – dominant systematics due to jet energy scale uncertainty (0.41 GeV), relative b-to-light jet energy scale (0.25) and Monte-Carlo (MC) generator hadronization modeling (0.23 GeV)





Top quark mass: ATLAS summary



Charge asymmetry in dilepton channel

Phys. Rev. D 94, 032006

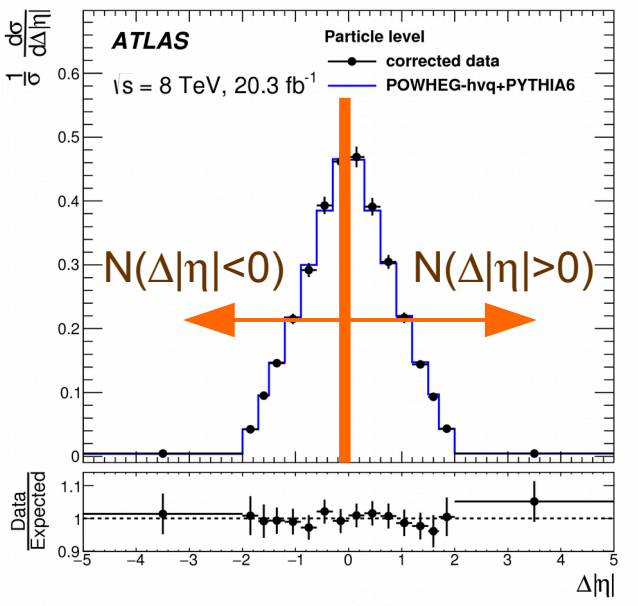
- test top quark production and decay mechanism by measuring both $t\bar{t}$ and leptonic asymmetries:

$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \qquad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

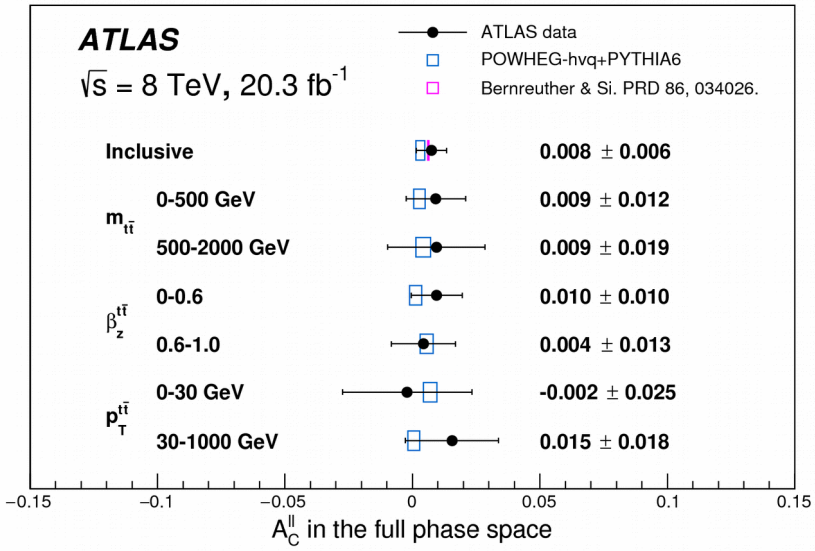
$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)} \qquad \Delta|\eta| = |\eta_{\ell^+}| - |\eta_{\ell^-}|$$

  - Various beyond SM models modify $A_C^{t\bar{t}}$ and A_C^{ll} in different ways

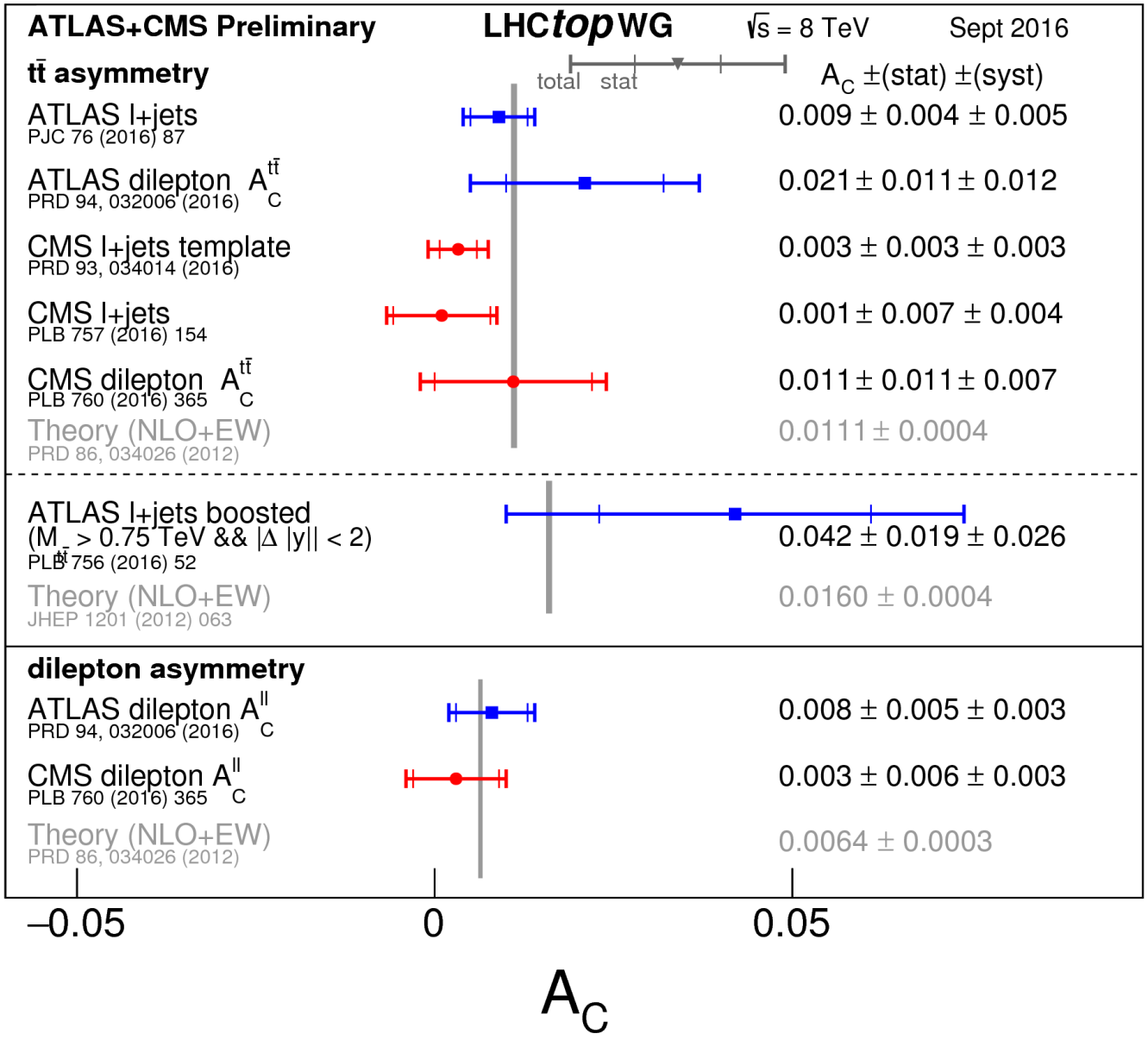
- Inclusive and differential measurements as a function of $m(t\bar{t})$, $\beta_z(t\bar{t})$ and $p_T(t\bar{t})$
- Inclusive measurement: **$A_C^{t\bar{t}} = 0.021 \pm 0.016$, $A_C^{ll} = 0.008 \pm 0.006$**
  SM prediction: $A_C^{t\bar{t}} = 0.011$, $A_C^{ll} = 0.006$



- All results (parton/particle level) consistent with SM



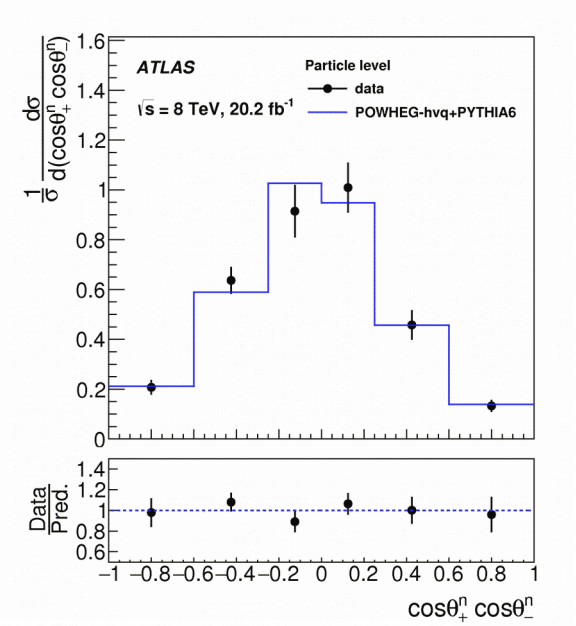
Charge asymmetry LHC summary

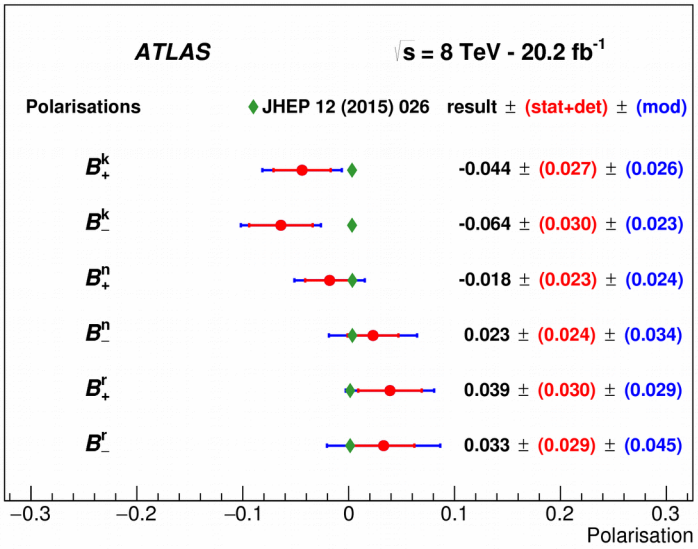


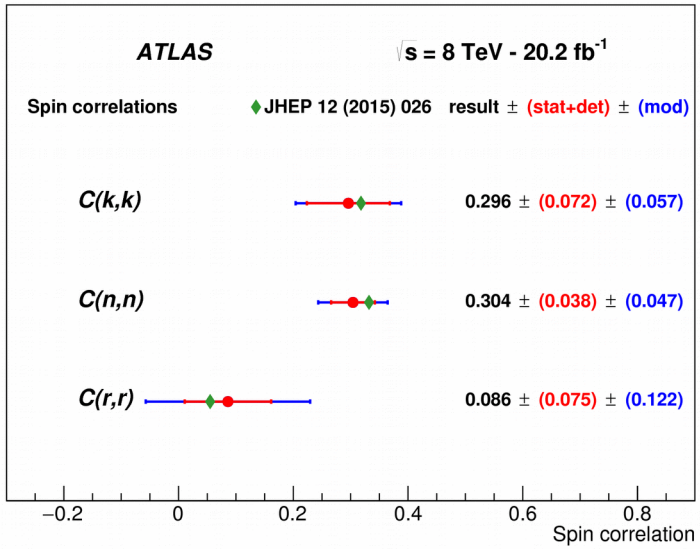
Top quark spin observables

arXiv:1612.07004

- In SM: Top quarks are produced non-polarized in $t\bar{t}$ events, but top – antitop spin correlations are present
- We measure 15 top quark spin observables sensitive to a different coefficient of the $t\bar{t}$ spin density matrix
  - full spin matrix measured for the first time
  - exploring angles between lepton in top quark's rest frame and the spin quantization axis
  - using 3 orthogonal spin quantization axes
- All results consistent with SM predictions
  - spin correlation along transverse axis at 5.1σ from zero







helicity axis

transverse axis

r-axis

W boson polarization in top quark decay

arXiv:1612.02577

- In SM: Wtb vertex determined by V – A structure of weak interactions, general form:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

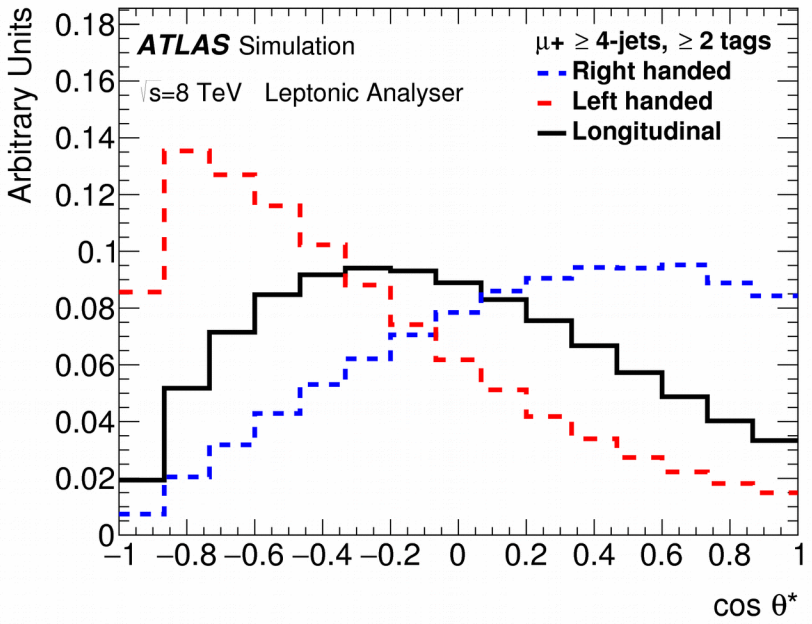
in SM: V_R=0, g_L=0, g_R=0

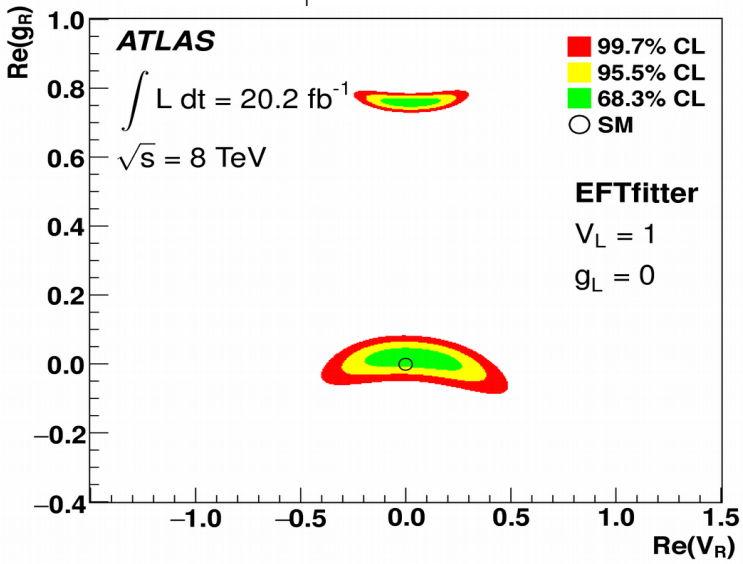
- SM prediction: mostly longitudinal W bosons (F_0~ 69%), ~ no right-handed W bosons(F_R~ 0)
- Template method using angle between lepton and anti-direction of *b*-quark in W rest frame
- W polarization fractions consistent with SM:

F_0 = 0.709 ± 0.019, F_L = 0.299 ± 0.015 and F_R = -0.008 ± 0.014

- Limits placed on anomalous couplings

Coupling	95 % CL interval
V_R	[−0.24, 0.31]
g_L	[−0.14, 0.11]
g_R	[−0.02, 0.06], [0.74, 0.78]





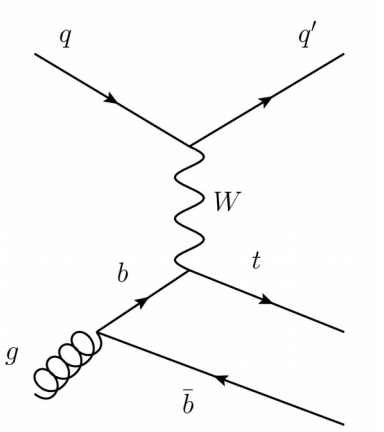
Top and W polarization in single top production

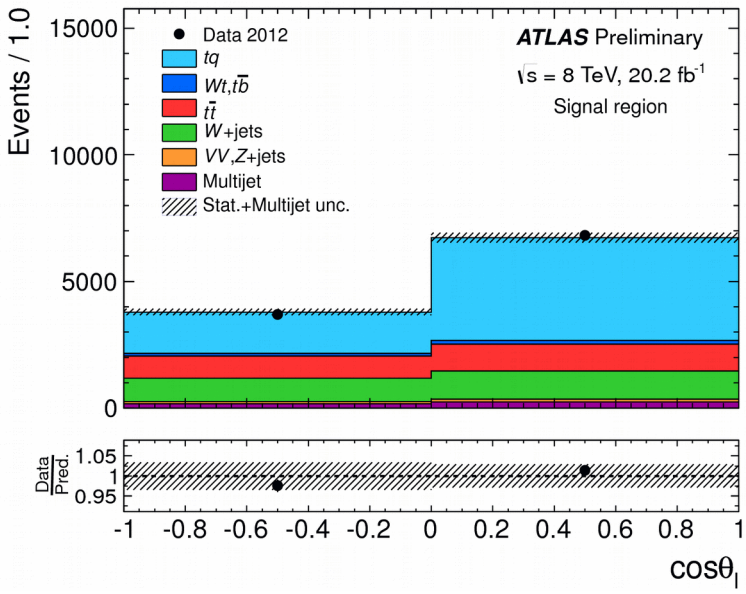
ATLAS-CONF-2016-097

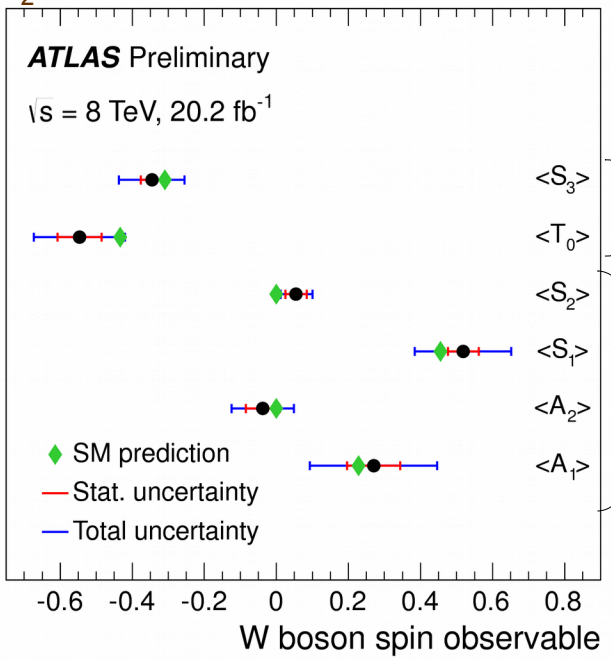
- Single top quark produced by weakly interaction
- Probe Wtb vertex in t-channel single top-quark events
- top-quark and W boson polarisation observables are extracted from asymmetries in angular distributions
- good agreement with the Standard Model predictions
  - top is higly polarised (SM:0.91):

$$\alpha_l * P = 0.96 \pm 0.05(stat) \pm 0.10(syst)$$

- $Im(g_R)$ in range (-0.17, 0.06) at 95% C.L. determined in model-independent measurement from $<S_2>$







Related to W helicity fractions

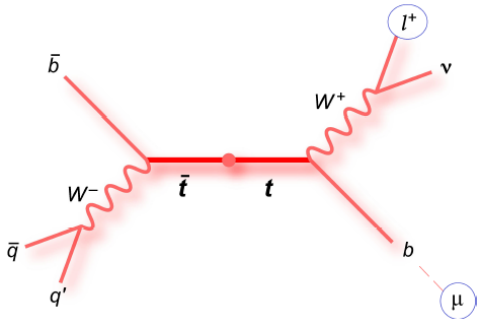
Related to top polarisation

CP asymmetries in b-hadron decays in $t\bar{t}$ events

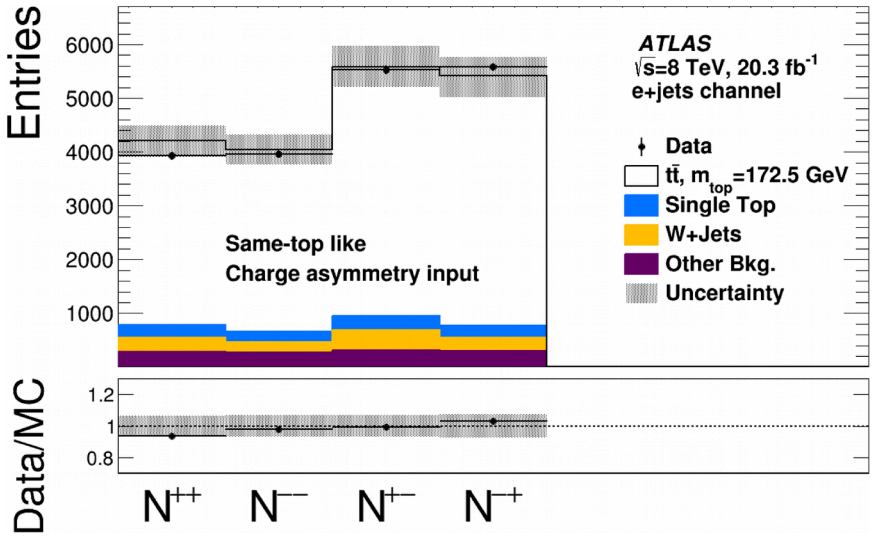
arXiv:1610.07869

- measure CP violation in c/b-quark mixing/decay in $t\bar{t}$ events
- The charge of b-quark determined at production and at decay
- Charge asymmetries based on lepton from W boson and muon from semileptonic b-hadron decay:

$$A^{ss} = \frac{P(b \to \ell^+) - P(\bar{b} \to \ell^-)}{P(b \to \ell^+) + P(\bar{b} \to \ell^-)} \qquad A^{ss} = \frac{\left(\frac{N^{++}}{N^+} - \frac{N^{--}}{N^-}\right)}{\left(\frac{N^{++}}{N^+} + \frac{N^{--}}{N^-}\right)}$$



- Four CP asymmetries (one related to B_q-$\bar{B}_q$ mixing and three to direct CP-violating in b-/c-quark decay) related to measured charge asymmetries
  → all results compatible with zero and consistent with the Standard Model



	Data (10^{-2})		SM prediction (10^{-2})	
A^{ss}	-0.7	± 0.8	$< 10^{-2}$	[19]
A^{os}	0.4	± 0.5	$< 10^{-2}$	[19]
A^{b}_{mix}	-2.5	± 2.8	$< 10^{-3}$	[96] [95]
$A^{b\ell}_{dir}$	0.5	± 0.5	$< 10^{-5}$	[19] [94]
$A^{c\ell}_{dir}$	1.0	± 1.0	$< 10^{-9}$	[19] [94]
A^{bc}_{dir}	-1.0	± 1.1	$< 10^{-7}$	[97]

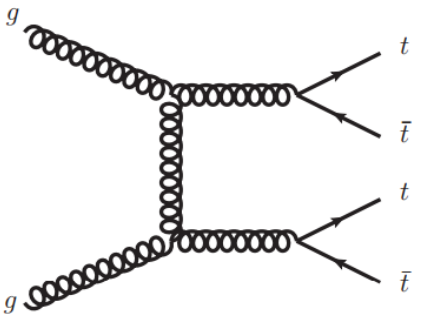
4 top quark production

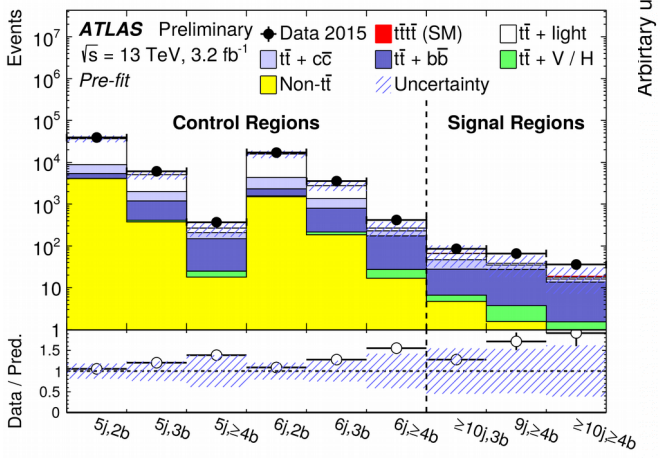
ATLAS-CONF-2015-038

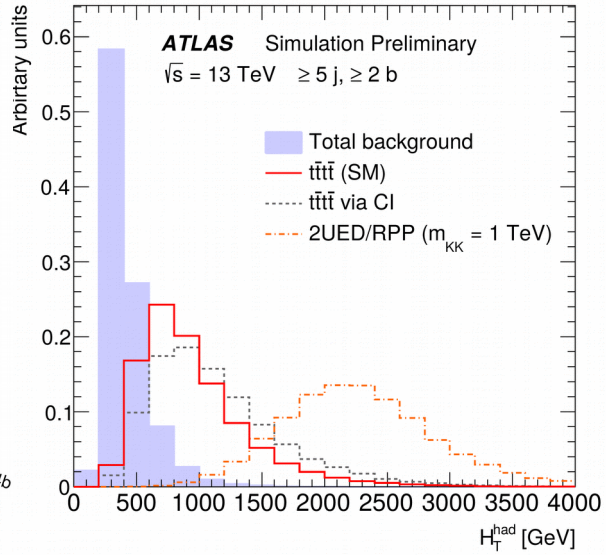
- $t\bar{t}t\bar{t}$ production small in SM
  - enhanced in BSM models, e.g. 4-top contact interaction (CI), universal extra dimensions (UED)
- Using 2015 data at $\sqrt{s}$ = 13 TeV
- Exploring 3 signal and 6 control regions with various jet (<=10) and b-tag (<=4) multiplicities
- Fit to scalar sum of jet transverse momenta
- No excess observed, $\sigma < 21^* \sigma(SM)$ at 95% CL
- CI in EFT:

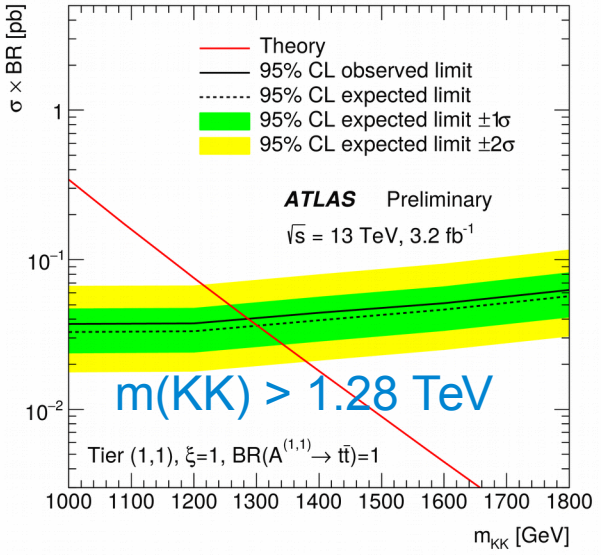
$$\mathcal{L}_{4t} = \frac{|C_{4t}|}{\Lambda^2}(\bar{t}_R\gamma^\mu t_R)(\bar{t}_R\gamma_\mu t_R)$$

→ exclude region $|C_{4t}|/\Lambda^2 > 5.0$ TeV^{-2} at 95% CL









Conclusions

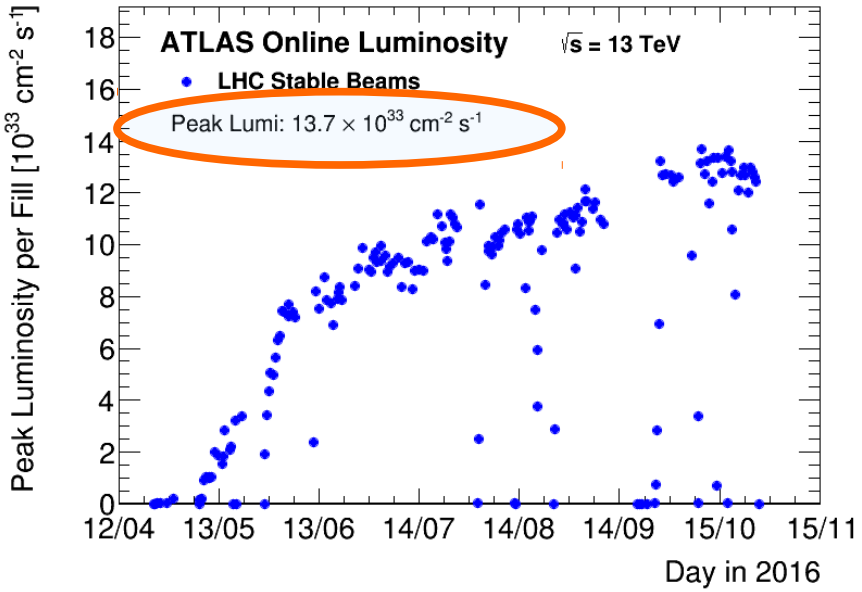
- Most of detailed and precise studies of top quark properties in Run 1 at $\sqrt{s}$ = 8 TeV are finished
  - Top mass measured with precision of 0.70 GeV
  - Charge/lepton asymmetry measured with precision of ~0.5%
  - Top and W boson spin observables measured in both pair and single production
- Up to now, all top quark properties consistent with the Standard Model predictions
- Starting to explore large available statistics in Run 2 at $\sqrt{s}$ = 13 TeV to look for physics beyond SM or to constrain it

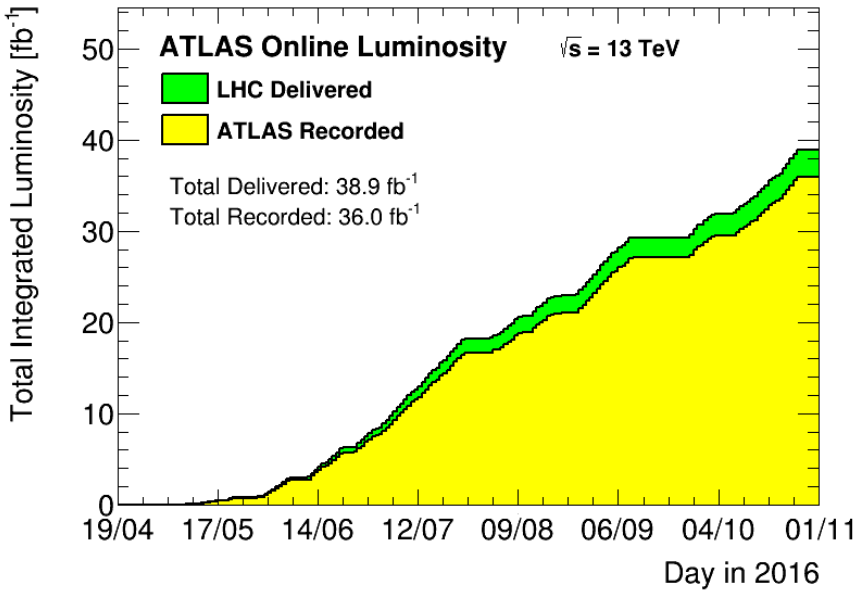
All results available on public web page:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

BACKUP

ATLAS experiment

- LHC Run 2 started in 2015 at new energy frontier $\sqrt{s}$ = 13 TeV
- ATLAS in Run 2:
  - New Pixel Layer “IBL” closest to beamline (at R = 33 mm)
  - Rebuilt Minimum Bias Trigger Scintillators (MBTS) in 2.07 < |η| < 3.86
- Total integrated luminosity (recorded): 3.9 fb^{-1} (2015) + 36 fb^{-1} (2016) = **39.9 fb^{-1}**
- Instantaneous luminosity exceeded the design value (10^{34} $cm^{-2}\,s^{-1}$): **1.37 x 10^{34} $cm^{-2}\,s^{-1}$**

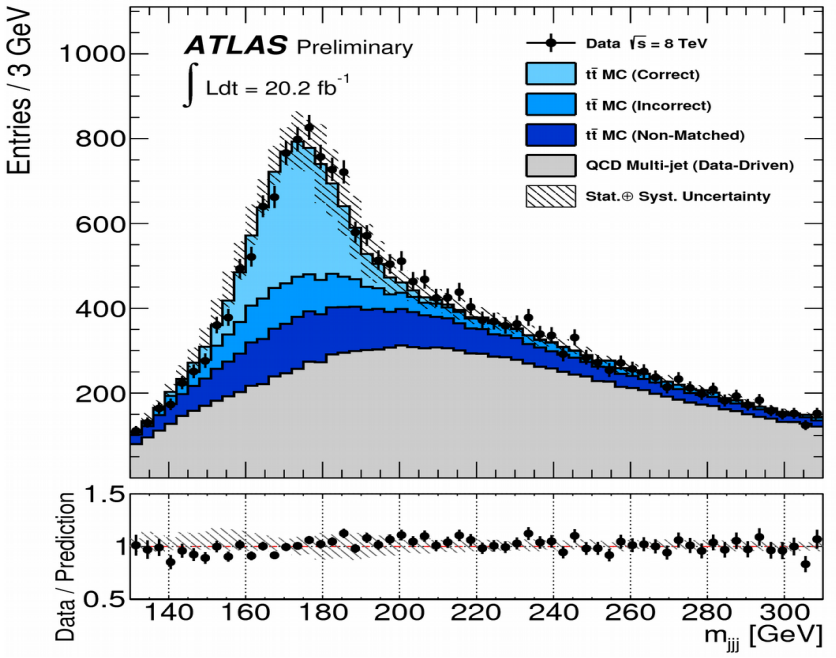


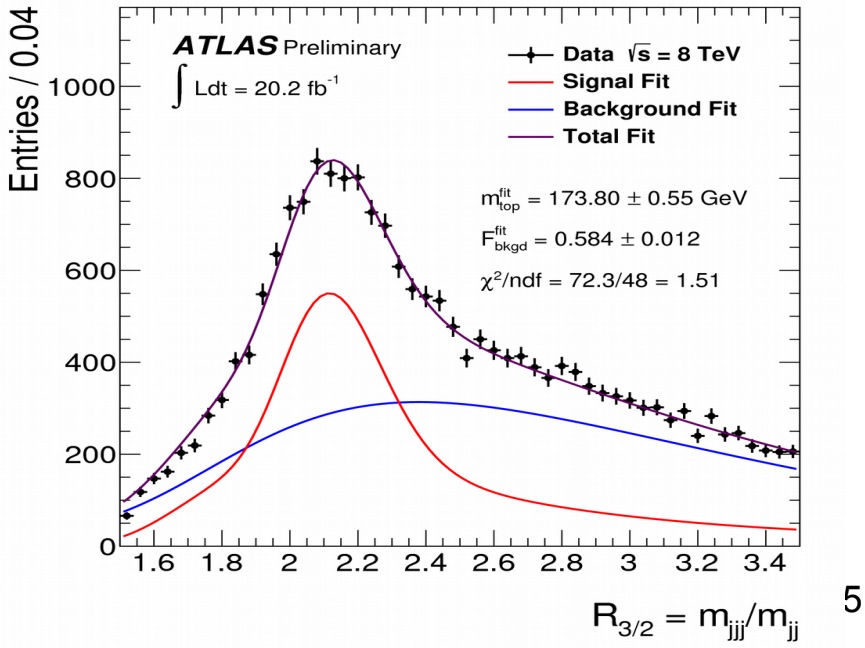


Top quark mass in all-hadronic channel

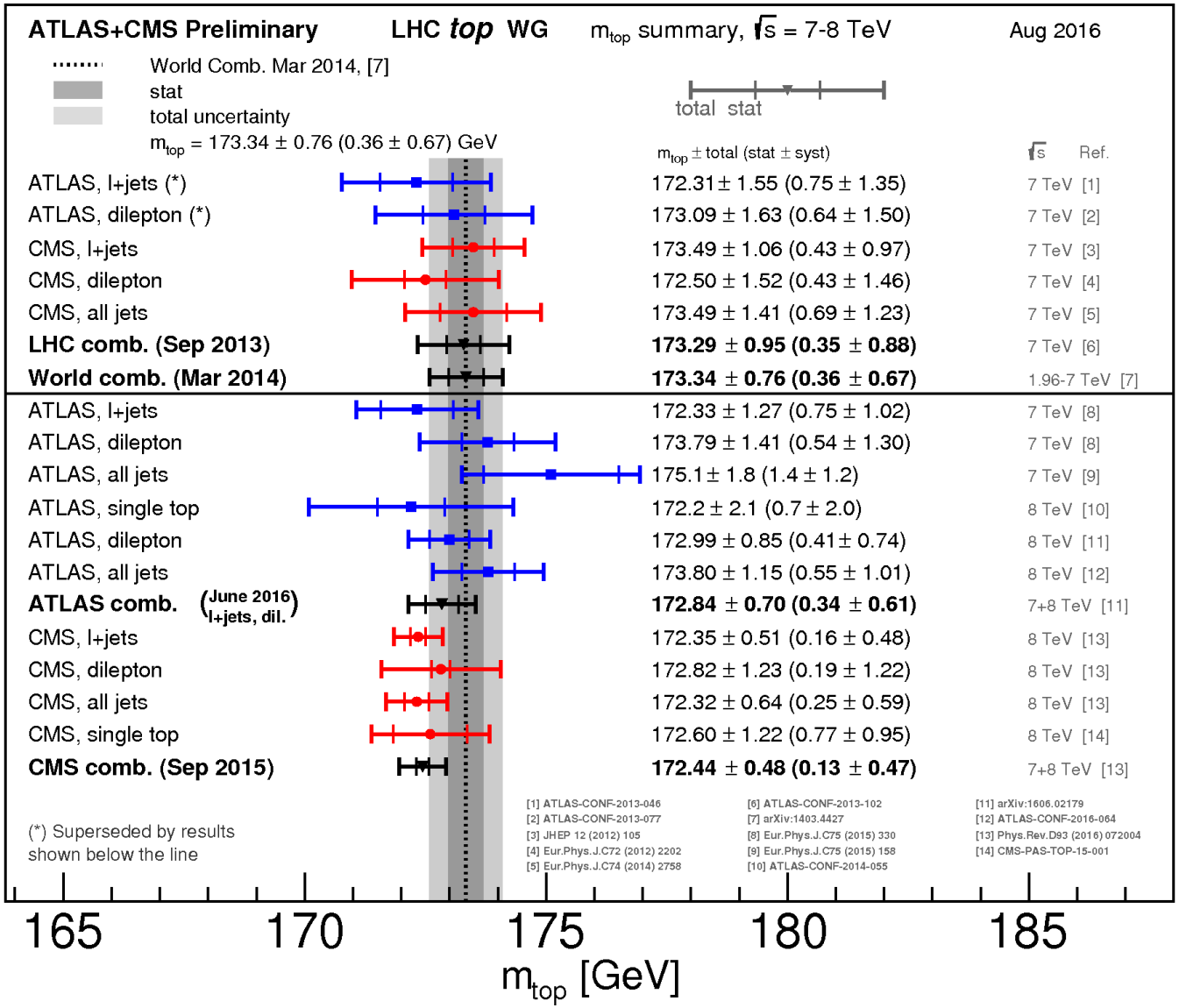
ATLAS-CONF-2016-064

- Measured in all-hadronic (6 jets) channel at $\sqrt{s}$ = 8 TeV
- Template method using ratio of tri-jet to di-jet mass ($R_{3/2}$)
- Measured value: m_{TOP} = 173.80 ± 0.55 (stat.) ± 1.01 (syst.) GeV
- Dominant systematics are due to:
  - jet energy scale uncertainty: 0.60 GeV
  - MC generator hadronization modeling: 0.64 GeV

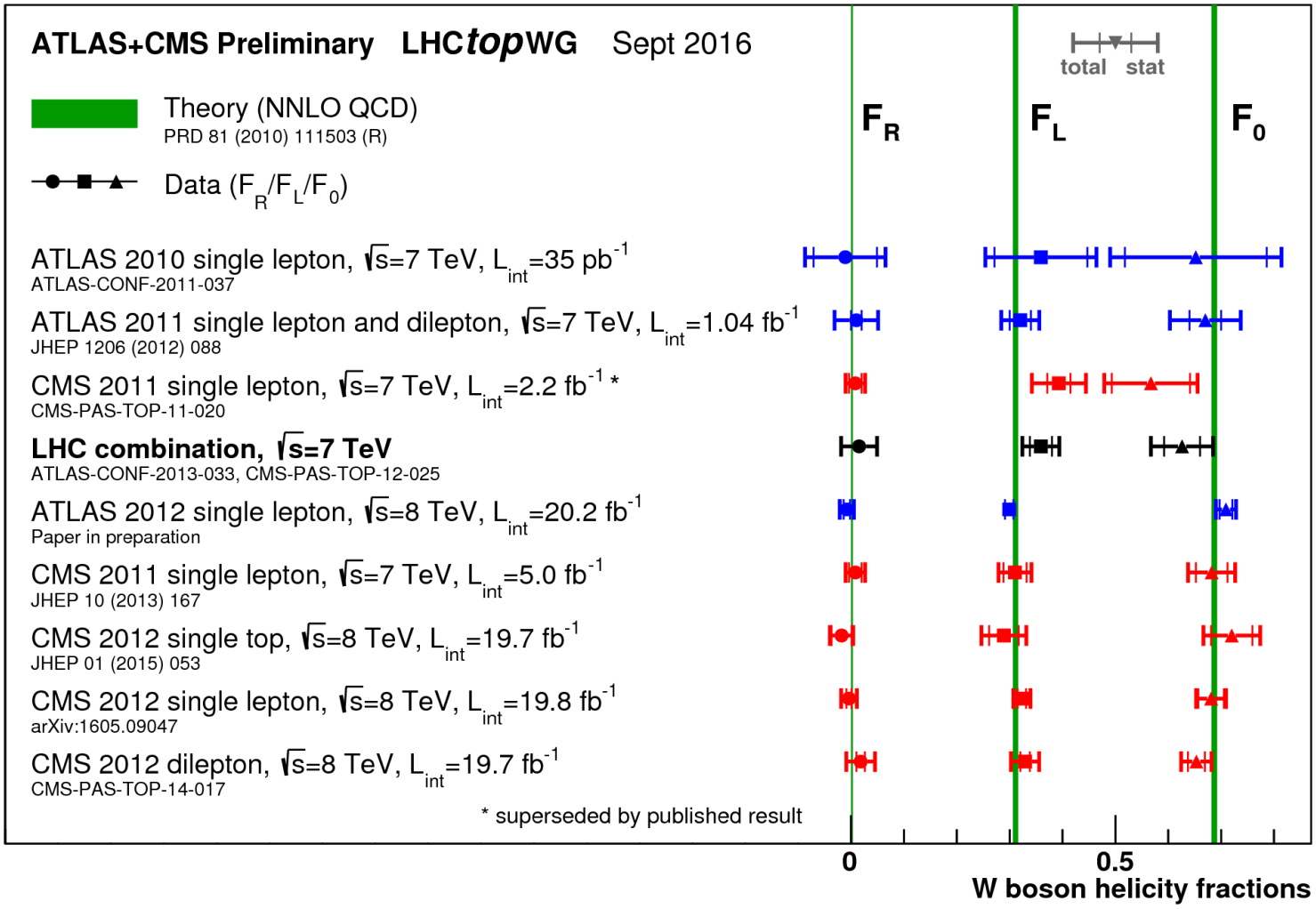




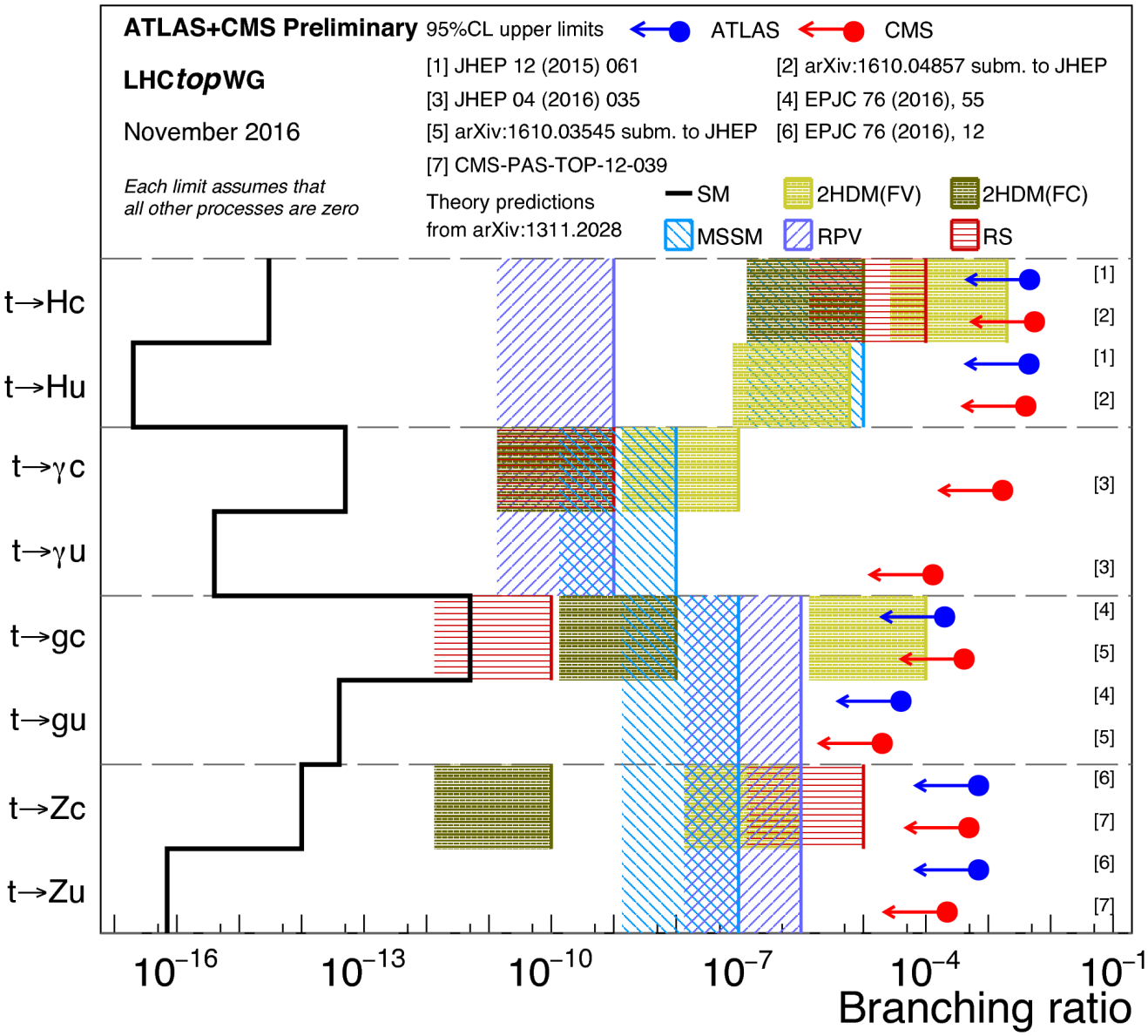
Top quark mass: LHC summary



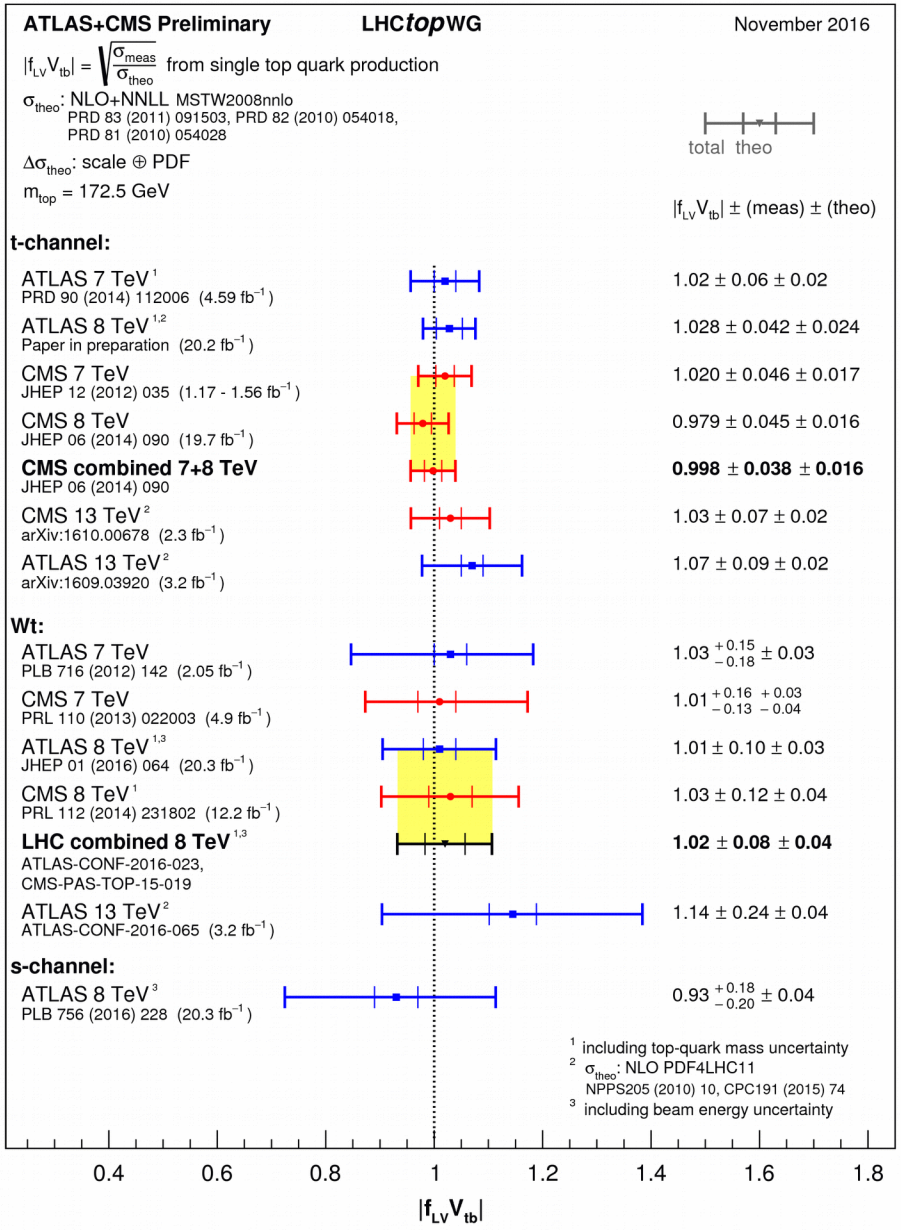
W helicity LHC summary



Top decay: Flavor changing neutral currents



LHC summary plot of $|V_{tb}|$



$t\bar{t}$ + W/Z production

- $t\bar{t}$ + W/Z production can be altered by beyond SM models
  → important check of validity of SM at new energy regime
- Using 2015 data at $\sqrt{s}$ = 13 TeV
- Simultaneous fit of yields in 9 signal and 2 control regions
  - Normalization of diboson background fitted in the control regions
- Measured (expected) significance over the background only hypothesis:

  $t\bar{t}$+Z: 3.9σ (3.4σ), $t\bar{t}$+W: 2.2σ (1.0σ)
- measured cross-sections (statistical uncertainty dominant):

  σ($t\bar{t}$+Z) = 0.9 ± 0.3 pb, σ($t\bar{t}$+W) = 1.5 ± 0.8 pb

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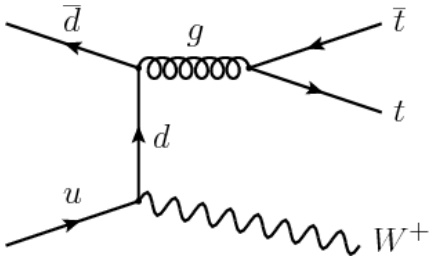

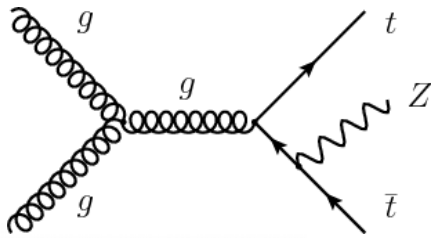

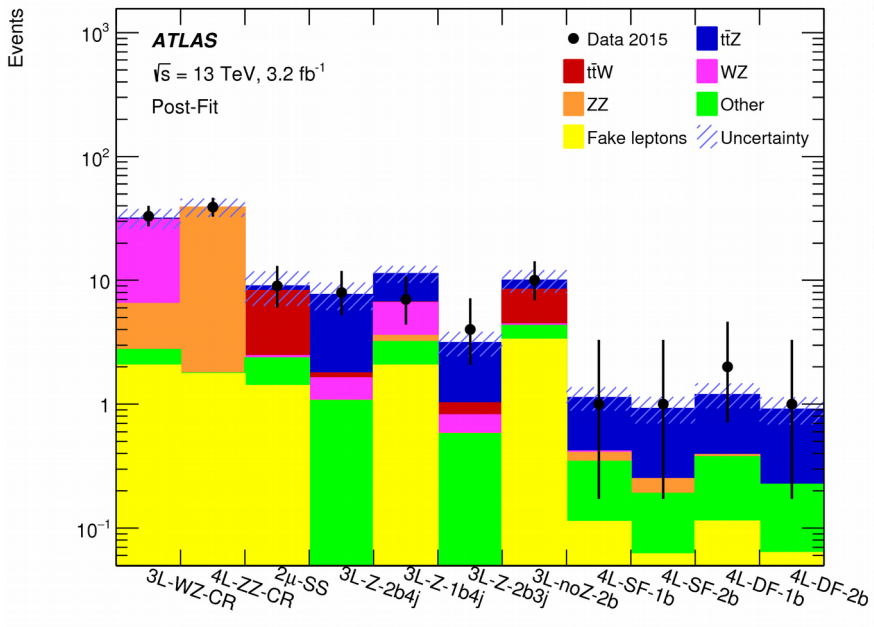

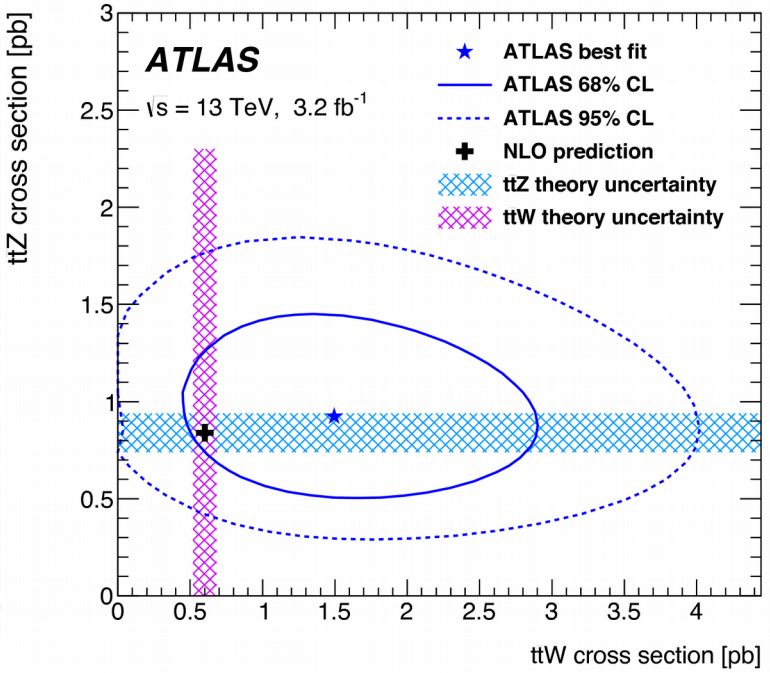

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