Top quark properties at ATLAS

DIS2012 @ Universität Bonn
26-30 March, 2012

Minoru Hirose (Osaka University)
On behalf of the ATLAS Collaboration

Top Quark Physics

- The heaviest particle in the Standard Model (SM)
  - ➡ decays before hadronisation
    - can be a good probe to check the property of “quark”
  - ➡ sensitive to new physics in its production/decay

- LHC is the “top factory”.
  - ➡ ~1million top pairs produced in 2011 ($5fb^{-1}$)
  - ➡ Production cross section has been measured precisely.
  - ➡ It’s time to measure its properties.
    - might give us a clue to catch new physics.

What we measured so far.

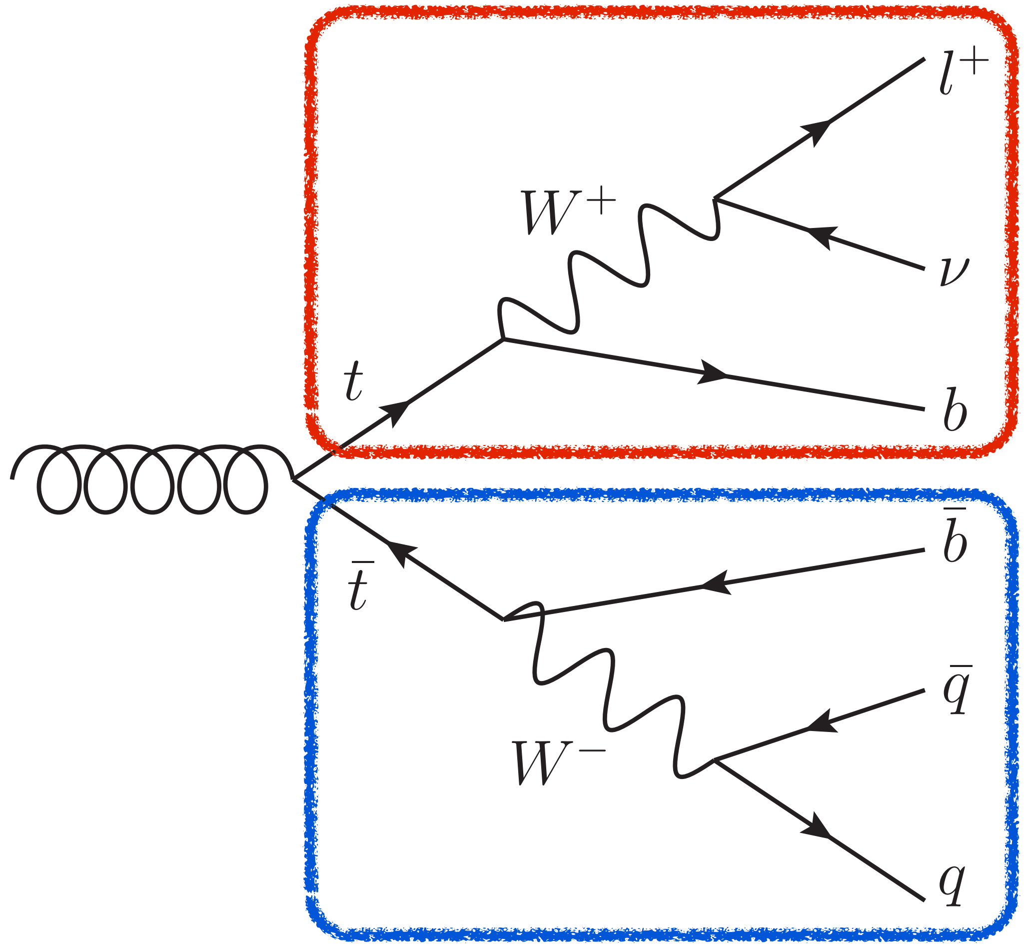
- Covered in this talk...
  - ➡ Top quark charge @ 0.70fb^{-1}
  - ➡ Inclusive $t\bar{t}+\gamma$ cross section @ 1.04fb^{-1}
  - ➡ W boson polarisation in top quark decays @ 0.70fb^{-1}
  - ➡ Spin correlation in the $t\bar{t}$ production @ 2.1fb^{-1} **(New!!)**
  - ➡ Charge asymmetry in the $t\bar{t}$ production @ 1.04fb^{-1} **(New!!)**

- Not covered in this talk...
  - ➡ Inclusive top production cross section (Indico)
  - ➡ Top quark mass (Indico)
  - ➡ "Searches" related to the top quark production/decay (Indico)

Top Quark Pair Signature

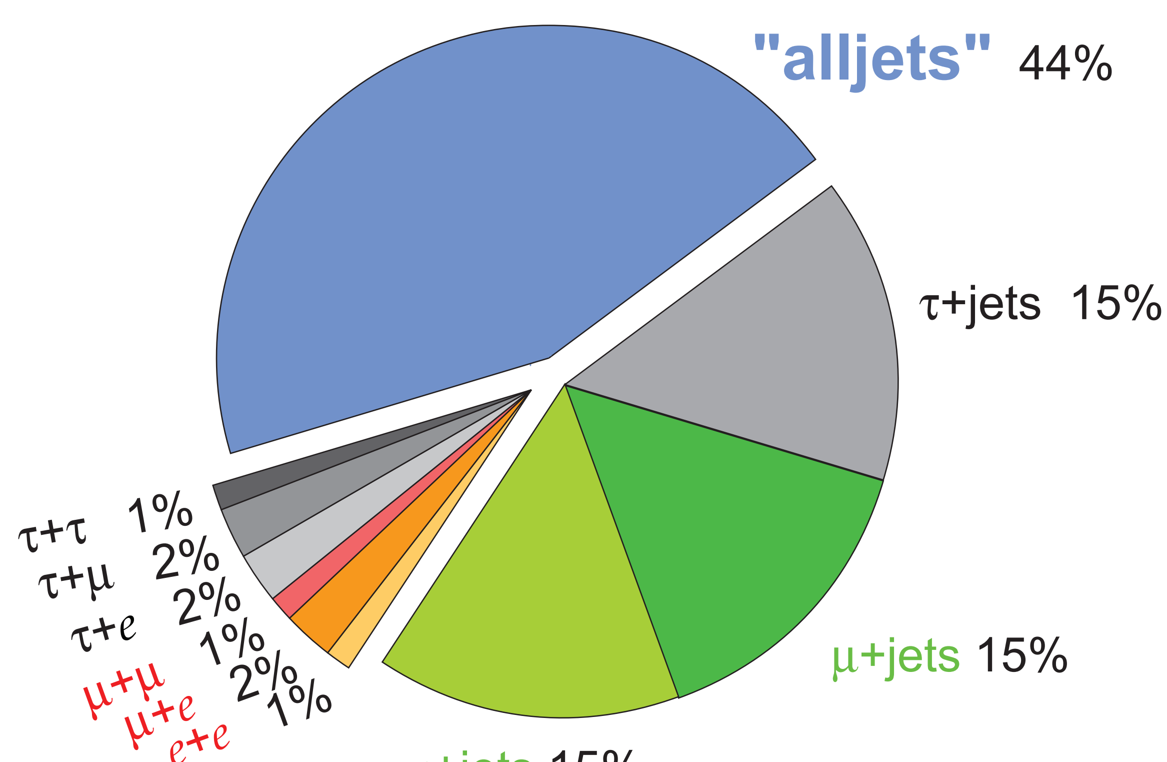
- BR(t→bW) ~ 100%
- Final state of the top pair production
  - ➡ categorised by the number of leptons from W bosons

Lepton, E_T^{miss}, b-jet



Two light-jets, b-jet

Top Pair Branching Fractions



for analyses

The top quark charge

- Motivation
  - ➡ Test for a top-like exotic quark with charge -4/3e
- Signature
  - ➡ lepton+jets final state
- Top quark charge determination

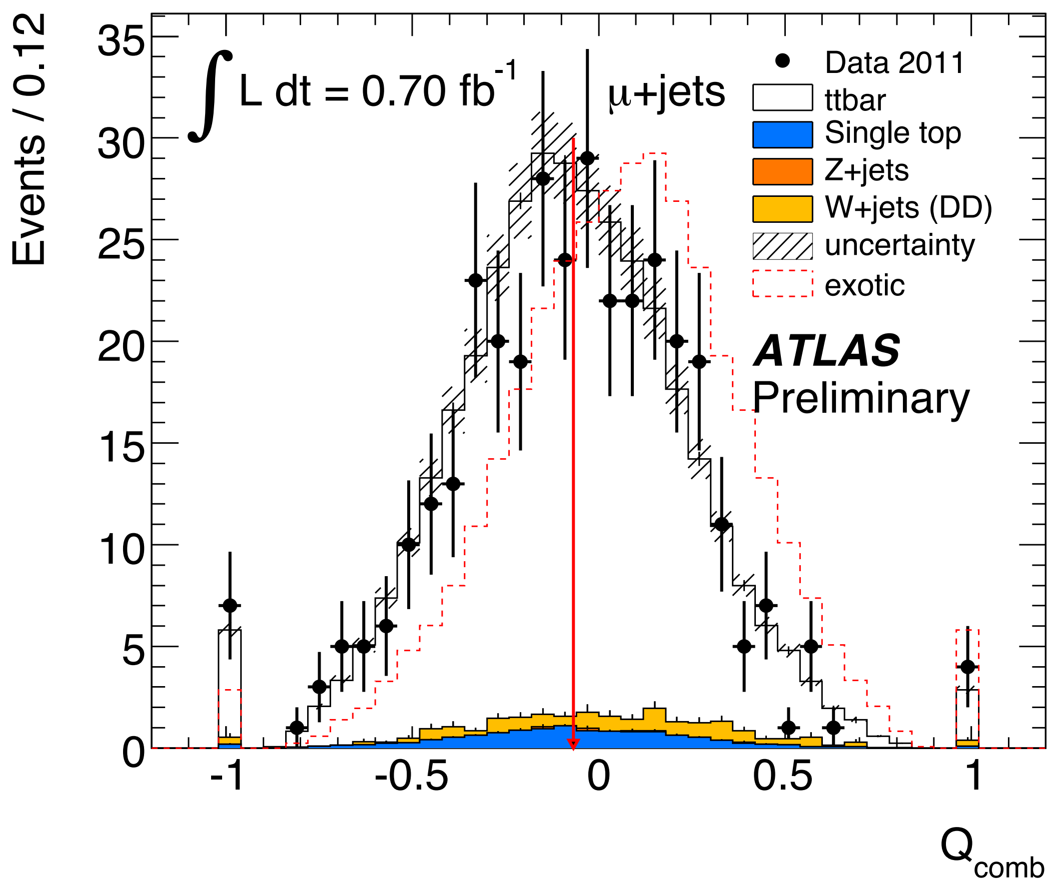
$$t^{(2/3)} \longrightarrow b^{(-1/3)} + \ell^{(+1)} + \nu_\ell$$
$$\widetilde{t}^{(-4/3)} \longrightarrow b^{(-1/3)} + \ell^{(-1)} + \nu_\ell$$

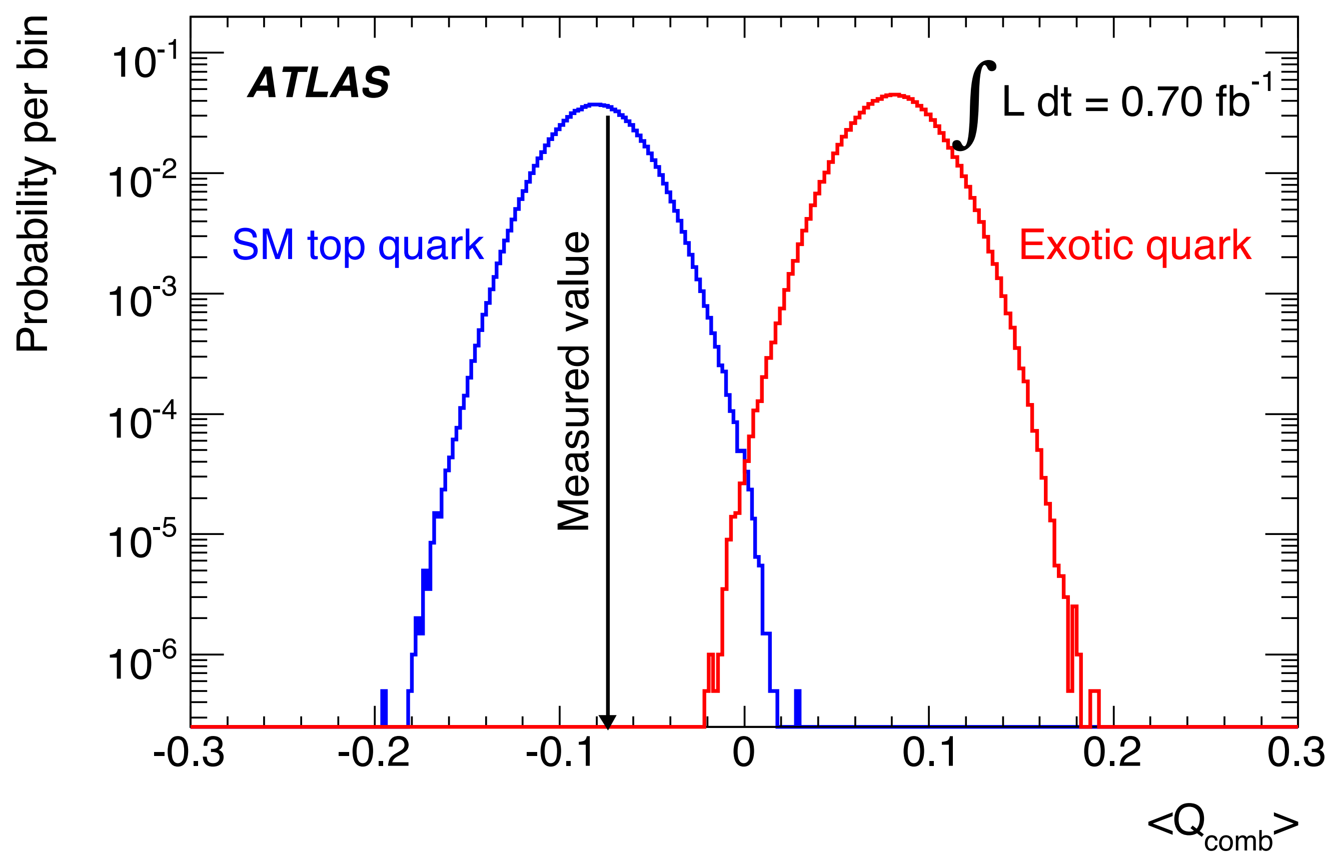
$\Rightarrow$ $Q_{comb} = Q_{bjet} \cdot Q_l$ good discriminant

➡ How to determine the charge of b-jet?

- $Q_{bjet} = \dfrac{\sum_i q_i |\vec{j} \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j} \cdot \vec{p}_i|^\kappa}$ (based on the charge of tracks in b-jet)

The top quark charge





- Data and SM agree well.
- Expected <Q_{comb}> probability distribution for both SM/Exotic scenarios using pseudo-experiments.

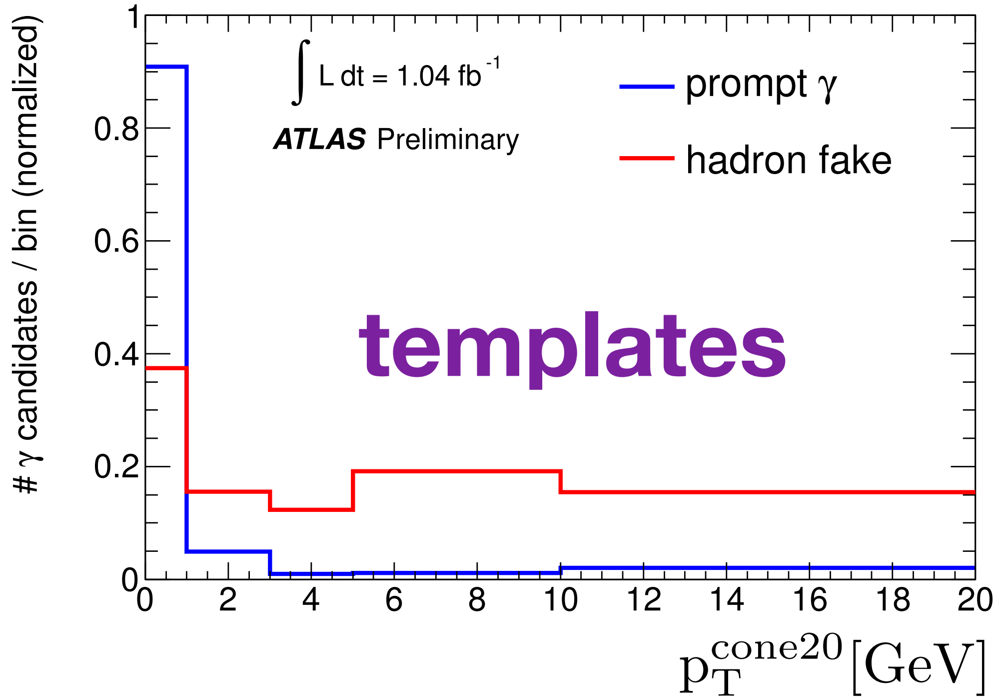
"top-like" quark with -4/3e is excluded at more than 5σ

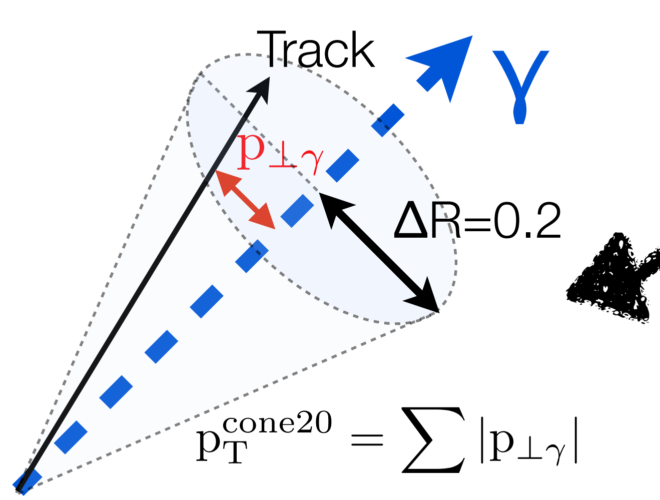
Inclusive $t\bar{t}+\gamma$ cross section

- Motivation
  - ➡ direct access to the electroweak coupling of the quark.
- Signature
  - ➡ “lepton+jets final state” + photon ($P_T \geqq 15$GeV)
- #Candidate events :
  - ➡ 52 (e+jets), 70 (μ+jets)

Background estimation

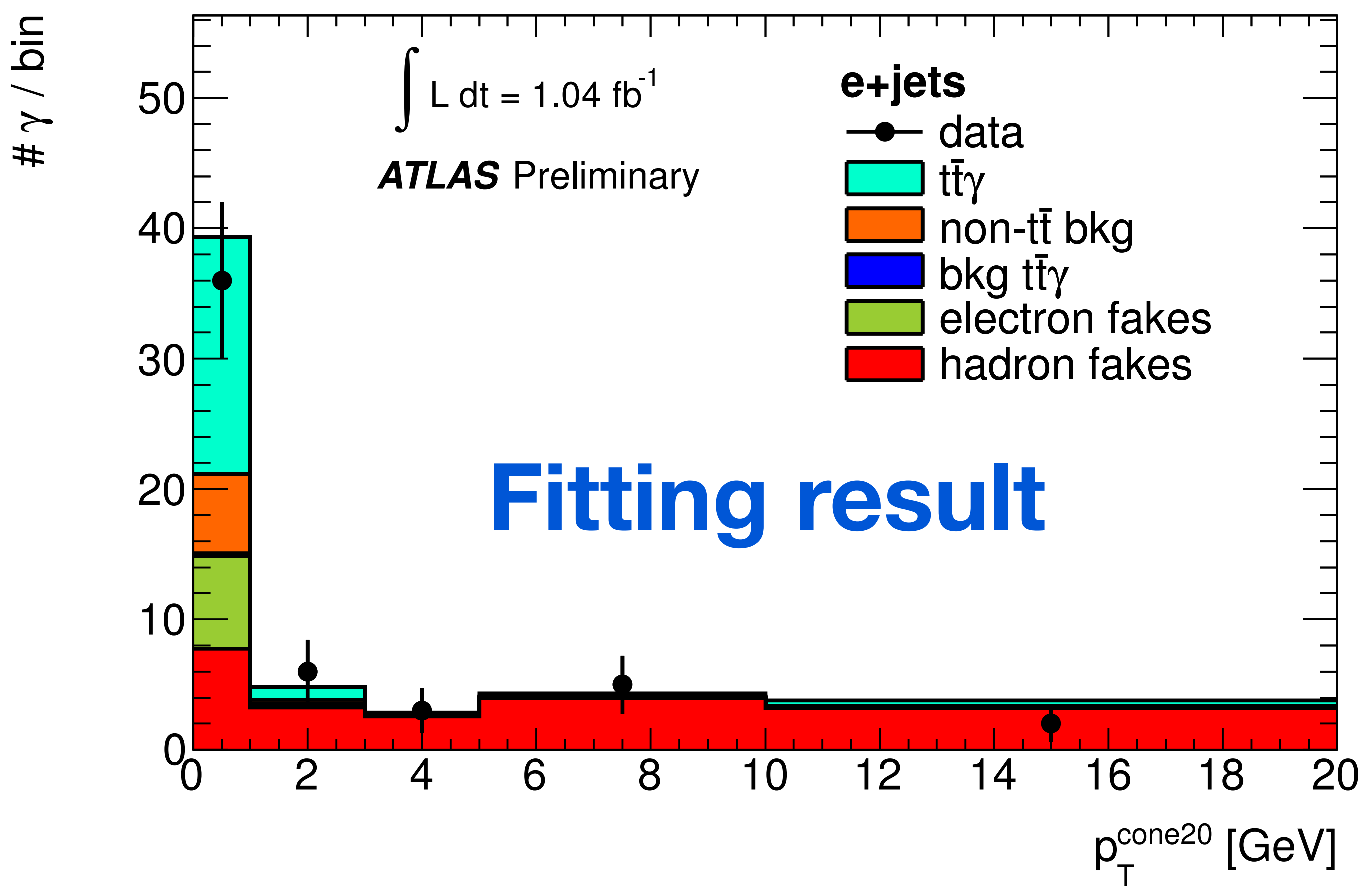
- Photon from hadron fake
  - ✓ Template fitting
- Photon from electron fake
  - ✓ Z→e”γ”





Photon isolation discriminator

Inclusive $t\bar{t}+\gamma$ cross section



$$\sigma_{t\bar{t}\gamma} \cdot \mathrm{BR} = 2.0 \pm 0.5(\mathrm{stat.}) \pm 0.7(\mathrm{syst.}) \pm 0.08(\mathrm{lumi.})[\mathrm{pb}]$$

$$(\text{requirering } \mathrm{P_{T\gamma}} \geq 8\mathrm{GeV} \text{ at generator level})$$

- Consistent with the NLO prediction : 2.1 ± 0.5 [pb]
  - ➡ Main systematic uncertainty : photon identification

ATLAS-CONF-2011-122

W polarisation in the top quark decay

- Motivation
  - ➡Test if there are new physics contributions in V-A coupling

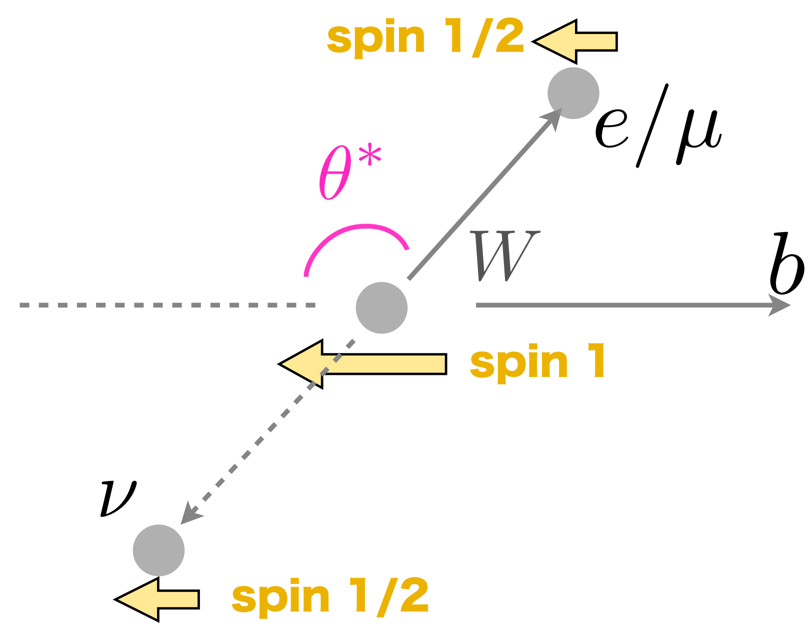
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_{\mathrm{L}}P_L + V_{\mathrm{R}}P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_{\mathrm{L}}P_L + g_{\mathrm{R}}P_R)\,t\,W_{\mu}^{-} + \mathrm{h.c.}$$

SM

New physics

  - ➡Helicity fractions F_0, F_L, F_R (longitudinal, left and right-handed)
    - SM prediction : F_0~0.7, F_L~0.3, F_R~0.0

- Signature
  - ➡Angle θ^* (W boson rest frame)
  - ➡Holding the W boson helicity info.



W boson rest frame

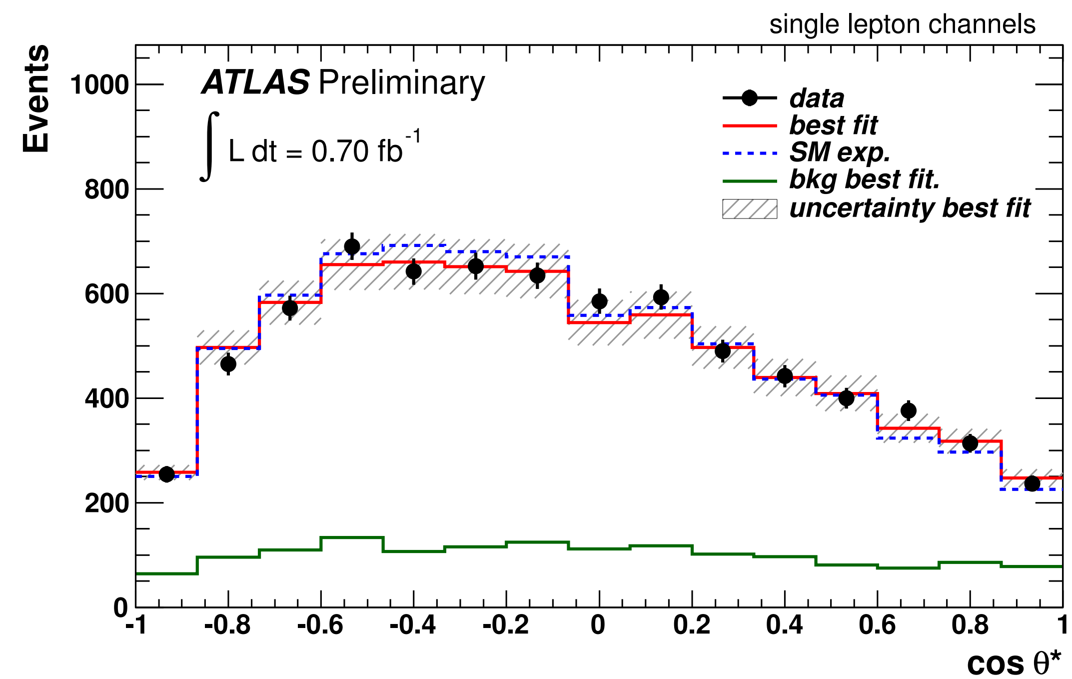
W polarisation in the top quark decay

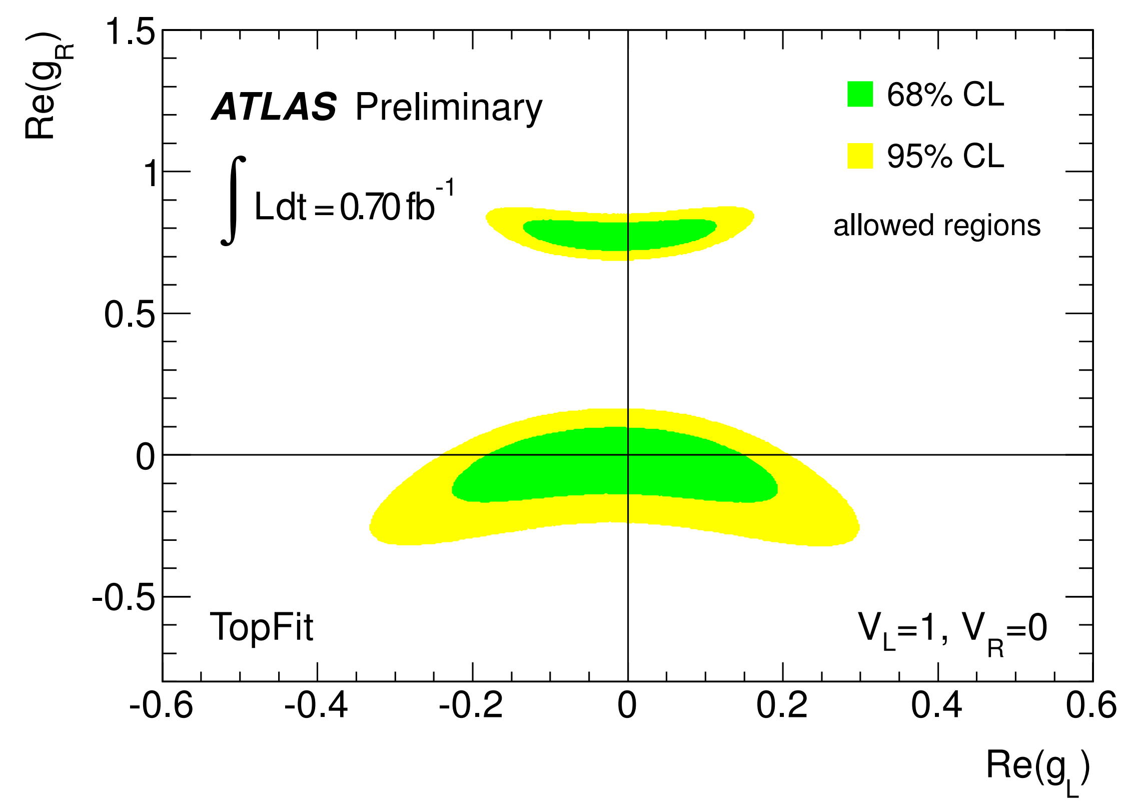
- Extract F_0, F_L by template fitting
  - ➡ $\cos\theta^*$ as templates
- Result (combined single/di-lepton)

$$F_0 = 0.75 \pm 0.08 \text{ (stat.+syst.)}$$
$$F_L = 0.25 \pm 0.08 \text{ (stat.+syst.)}$$
$$(F_R \text{ is fixed to zero.})$$

  - ➡ Main systematics : $t\bar{t}$ modelling
- Consistent with SM
  - ➡ Setting constraints on g_L and g_R.

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





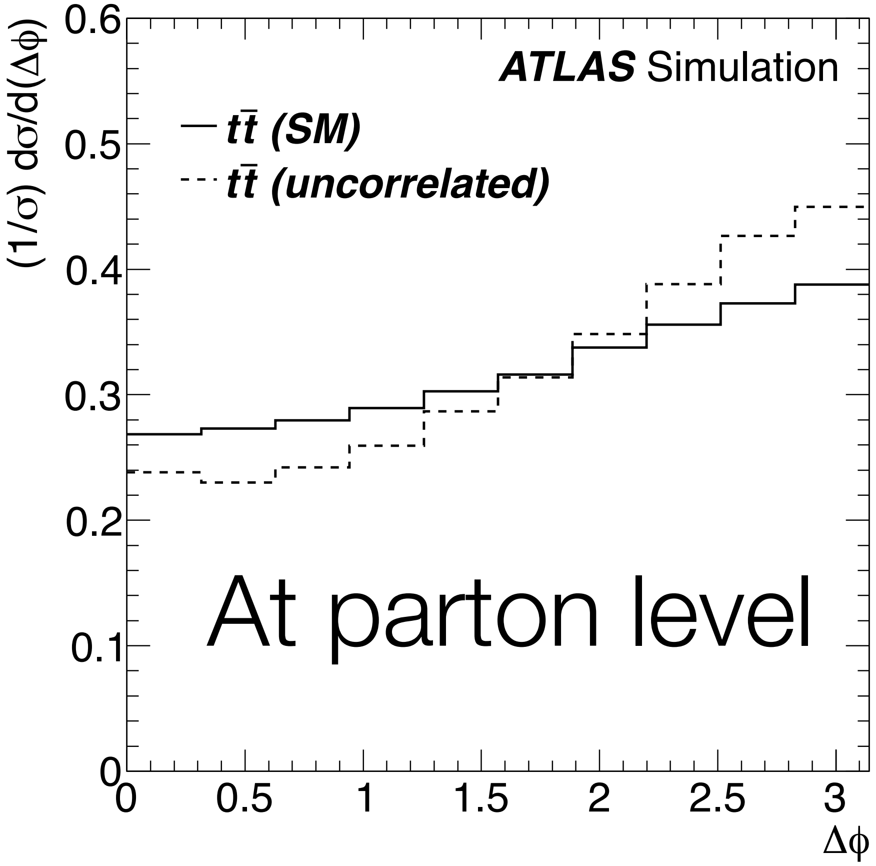
arXiv:1203.4081

Spin correlation in $t\bar{t}$ production

- Motivation
  - ➡We have the access to spins of quark (τ_t is short enough).
  - ➡The strength of the correlation may differ (e.g. H^+ contribution).
- Correlation coefficient

$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}} = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

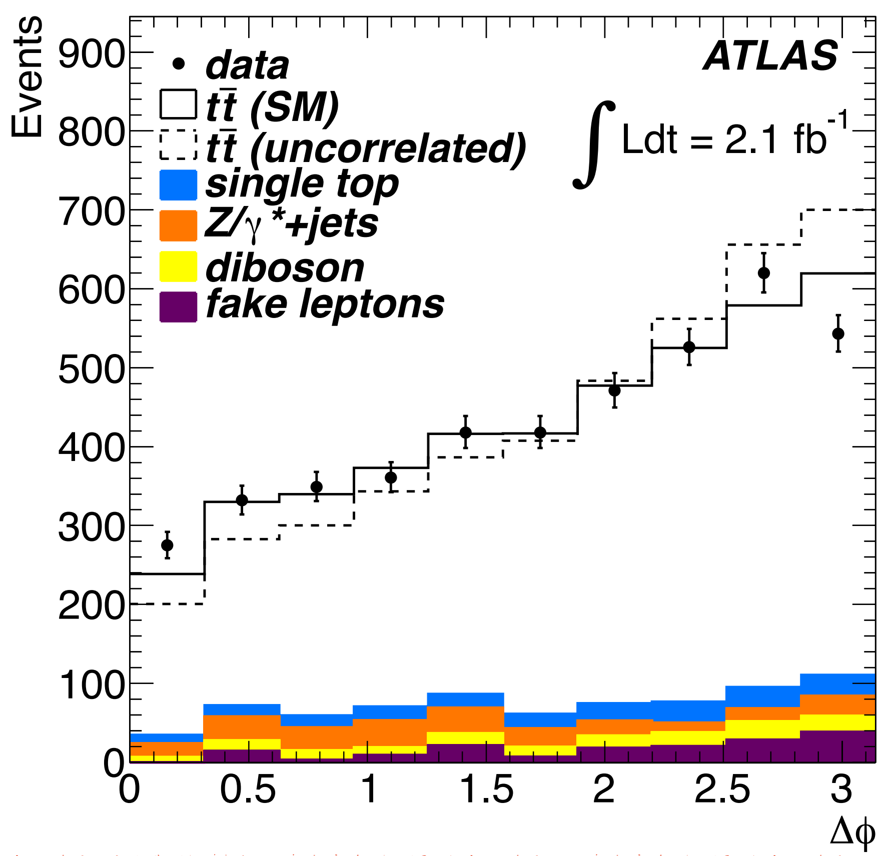
- Signature
  - ➡Dilepton final state
  - ➡Leptons carry the spin information.
    - The distribution of the Δϕ between two leptons in the lab frame is a good discriminator.

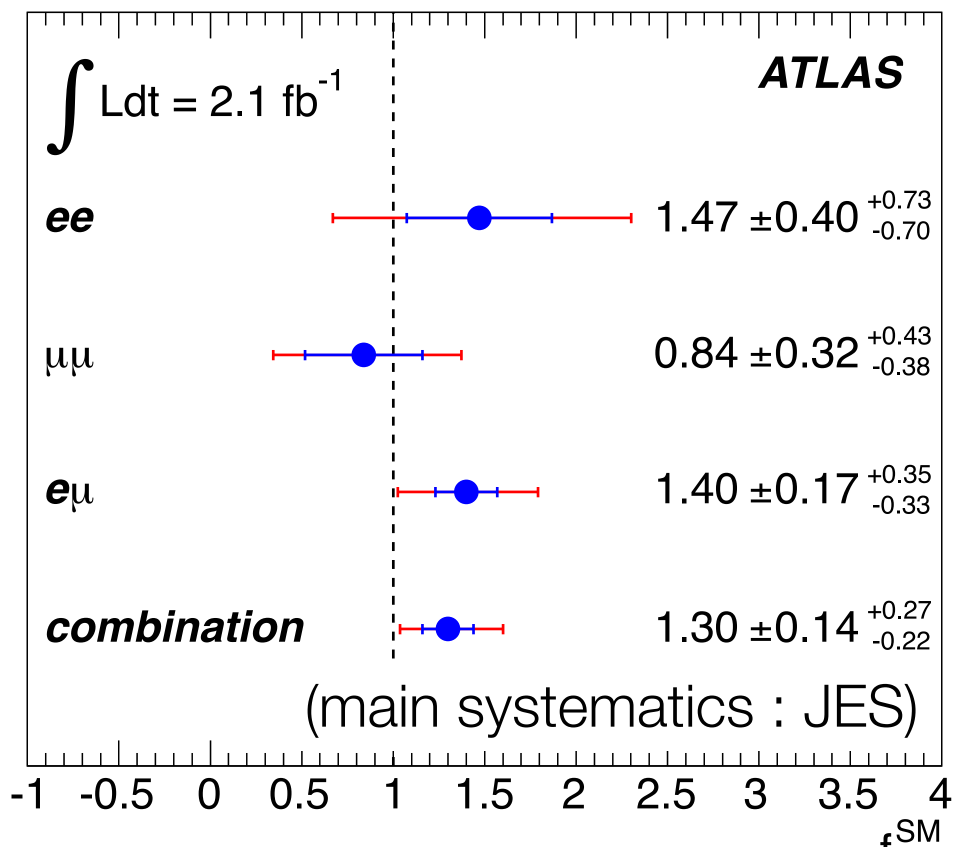


Spin correlation in $t\bar{t}$ production

- Binned likelihood fit for Δϕ distribution to extract f^{SM} and f^{UC}.
  - ➡Constraint with $f^{\mathrm{SM}} + f^{\mathrm{UC}} = 1$
  - ➡Result : $A_{\mathrm{helicity}}^{\mathrm{measured}} = A_{\mathrm{helicity}}^{\mathrm{SM}} \cdot f^{\mathrm{SM}} \; (A_{\mathrm{helicity}}^{\mathrm{SM}} = 0.31)$

$$= 0.40 \pm 0.04(\mathrm{stat.})^{+0.08}_{-0.07}(\mathrm{syst.})$$





"No correlation model" is excluded by 5σ

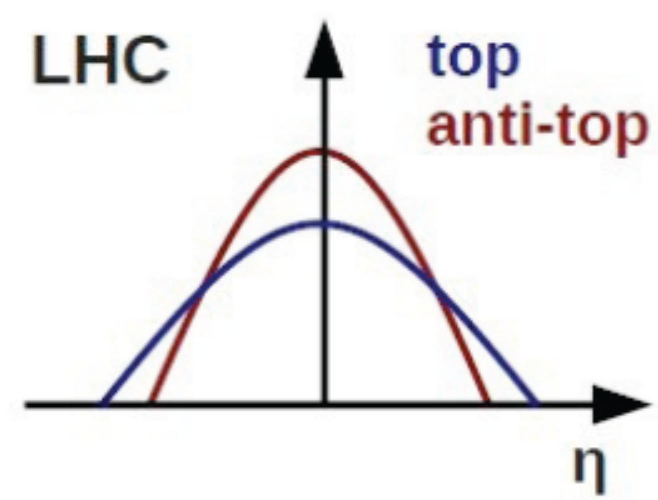
Charge asymmetry in tt̄ production

- Motivation
  - ➡ Indirect search for new heavy particles.
  - ➡ Test the interesting result for A_{FB} at the Tevatron.

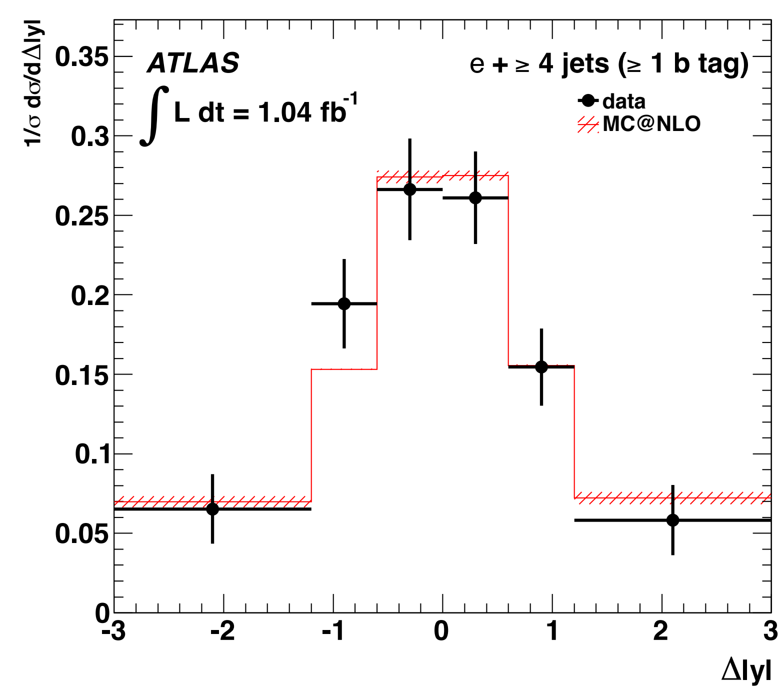
- Define asymmetry parameter A_C

➡ $$A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$

$$\text{where } \Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$



- Obtaining $\Delta|y|$ distribution
  - ➡ Reconstruct a four vector of $t\bar{t}$
    - likelihood based method
  - ➡ Unfolding to correct for acceptance and resolution effects.



Charge asymmetry in $t\bar{t}$ production

- Results : Consistent with SM ($A_C = 0.006 \pm 0.002$)

Inclusive : $A_C = -0.018 \pm 0.028(\text{stat.}) \pm 0.023(\text{syst.})$

Exclusive : $A_C = -0.053 \pm 0.070(\text{stat.}) \pm 0.054(\text{syst.})$ for $m_{t\bar{t}} < 450\text{GeV}$

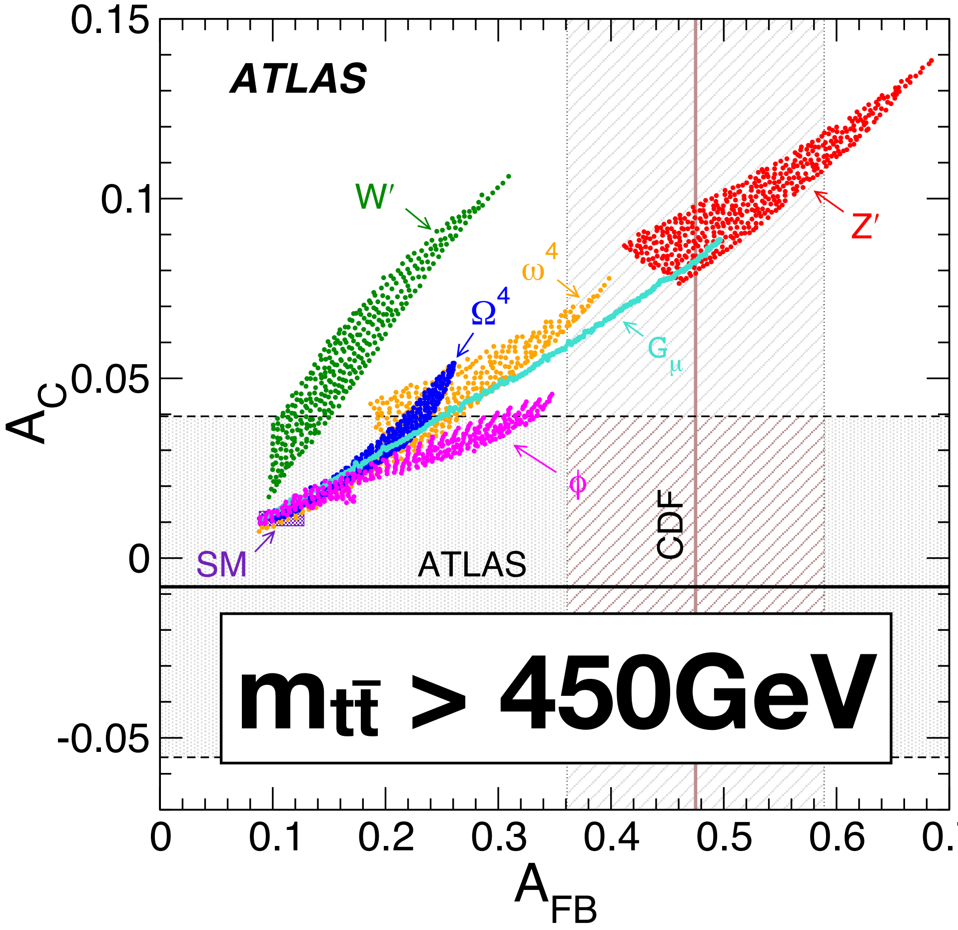
$A_C = -0.008 \pm 0.035(\text{stat.}) \pm 0.032(\text{syst.})$ for $m_{t\bar{t}} > 450\text{GeV}$

➡ Main systematics : $t\bar{t}$ modelling

- Comparing results with some new physics models.

➡ ATLAS disfavours the models that would best fit the CDF result.

➡ We still have a large uncertainty. Measurement will profit from more data.



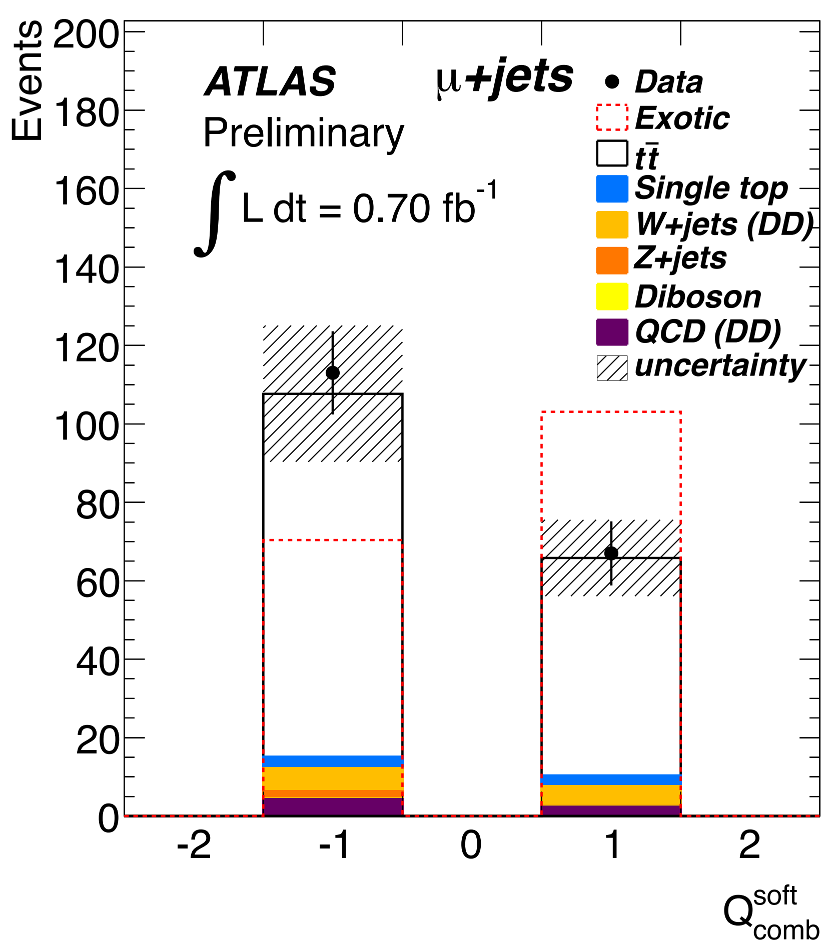
Conclusions

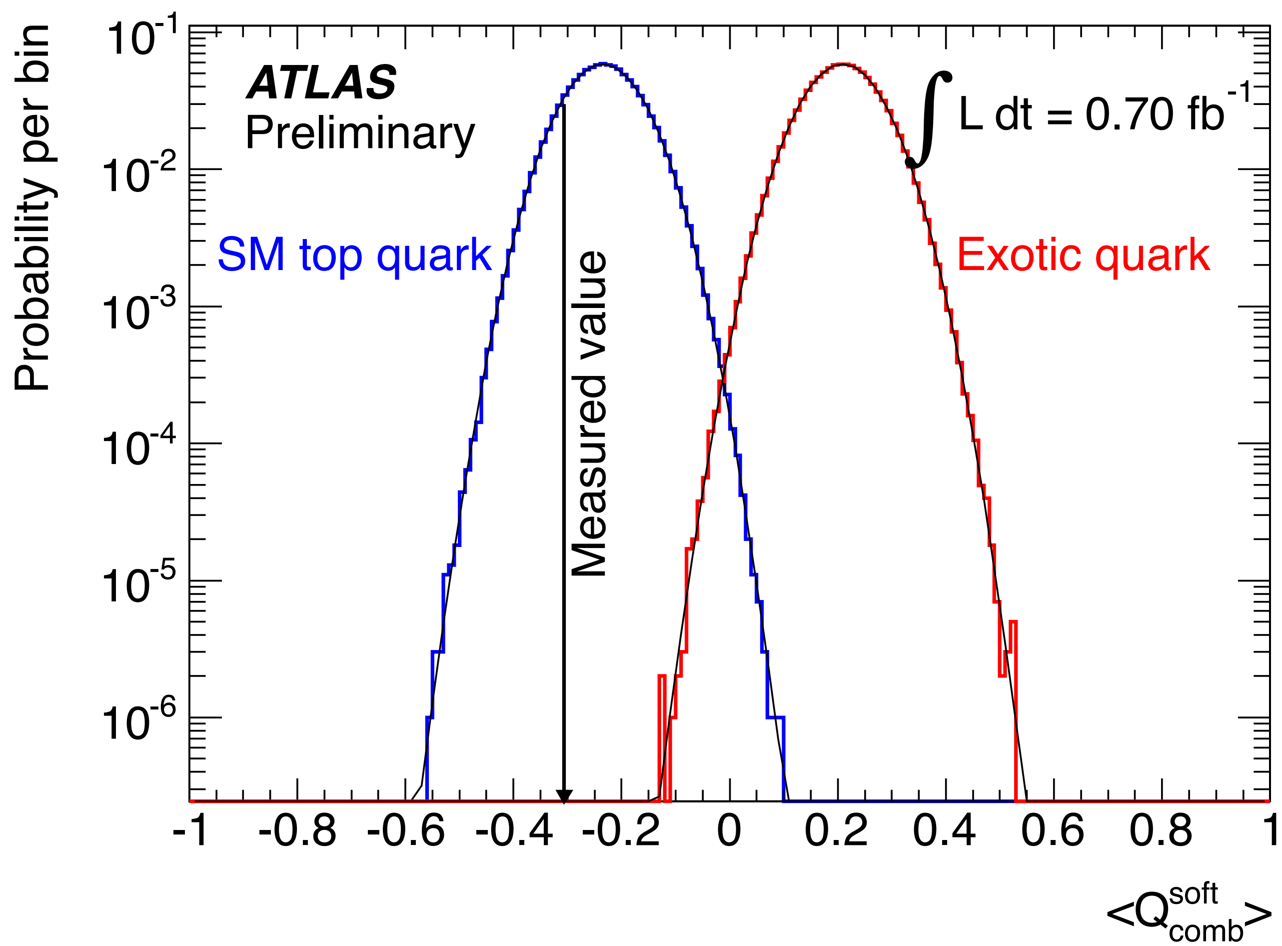
- **Top quark : Important particle for LHC physics**
  - ➡ good probe to check the SM predictions
  - ➡ to understand as a main background for “searches”.
  - ➡ can be used directly to search for BSM physics.
- **Analysis with 2011 datasets**
  - ➡ Property measurements of “the top quark”, “its decay” and “its pair production”.
  - ➡ No evidence of physics beyond the standard model.
- **Outlook**
  - ➡ Measurements with full 2011 dataset are ongoing.
  - ➡ Stay tuned to improve the precision.

backup

The top quark charge

- Other method to determine b-jet charge
  - ➡ utilise the charge of the soft muon inside the b-jet
  - ➡ lepton-bjet pairing : kinematic likelihood for the ttbar events
  - ➡ discriminant : $Q^{\mathrm{soft}}_{\mathrm{comb}} = Q_{\mathrm{soft}\mu} \cdot Q_{\mathrm{lepton}}$



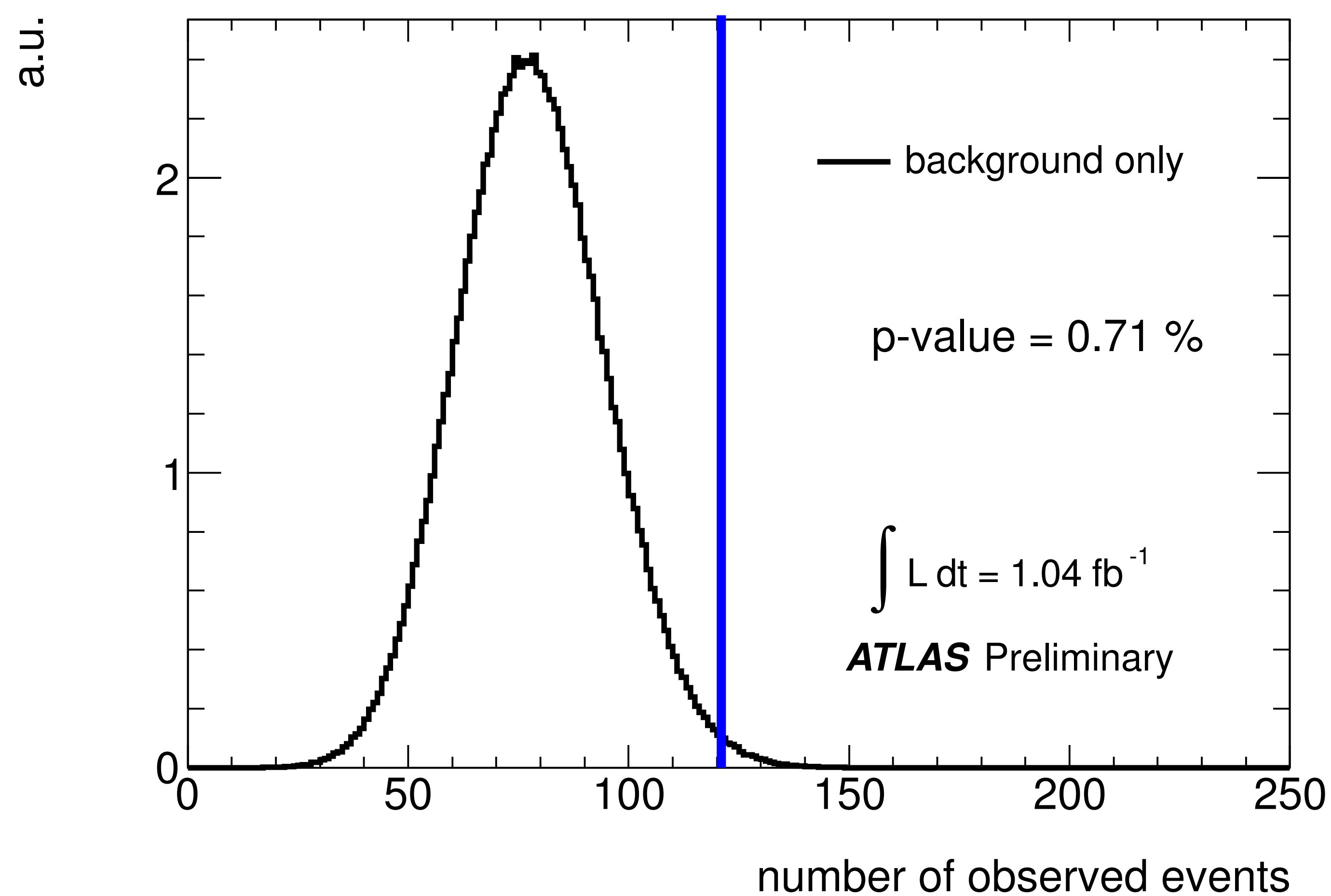


Inclusive $t\bar{t}+\gamma$ cross section

Description	Uncertainty on the cross section [pb]
Modelling	± 0.18
Initial and final state radiation	± 0.31
Electron related	± 0.05
Muon related	± 0.08
Jet energy scale	± 0.24
Jet energy scale (pile-up uncertainty)	± 0.28
b-jet energy scale	± 0.06
Jet reconstruction and resolution	± 0.06
$E_{\mathrm{T}}^{\mathrm{miss}}$ related	± 0.03
b-tagging performance	± 0.18
Treatment of dead region in LAr calorimeter read-out	± 0.05
Luminosity	± 0.08
Photon identification efficiency	± 0.33
Photon energy scale	± 0.02
Photon resolution	± 0.01
$t\bar{t}\gamma$ background yield	± 0.03
non-$t\bar{t}$ background yield	± 0.11
Electron to photon extrapolation	± 0.22
Fraction of converted prompt photons	± 0.03
Fraction of converted hadron fakes	± 0.16
Reweighting of the background templates (p_{T})	± 0.11
Reweighting of the background templates (η)	± 0.06
Pile-up dependence of the signal templates	± 0.01
Pile-up dependence of the background templates	± 0.05
Sum	± 0.7

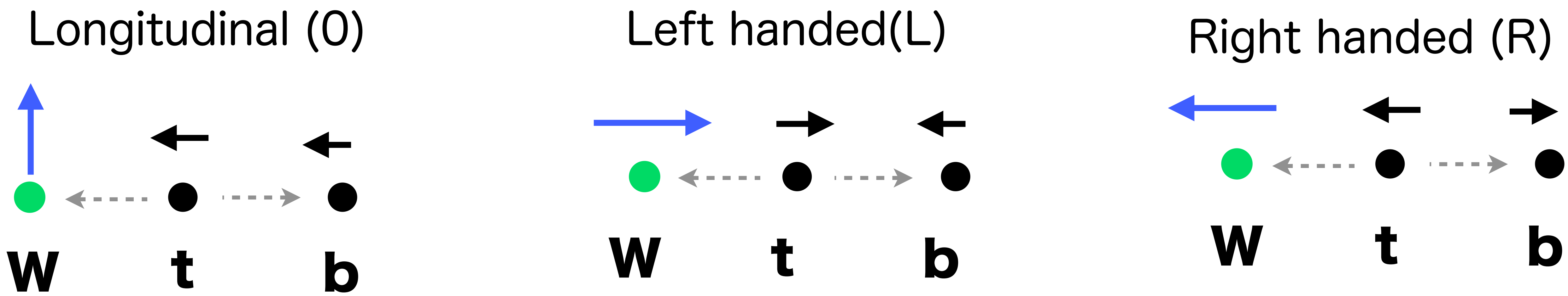
Inclusive $t\bar{t}+\gamma$ cross section

#expected events with BG only assumption.
Blue line : observed events (122).

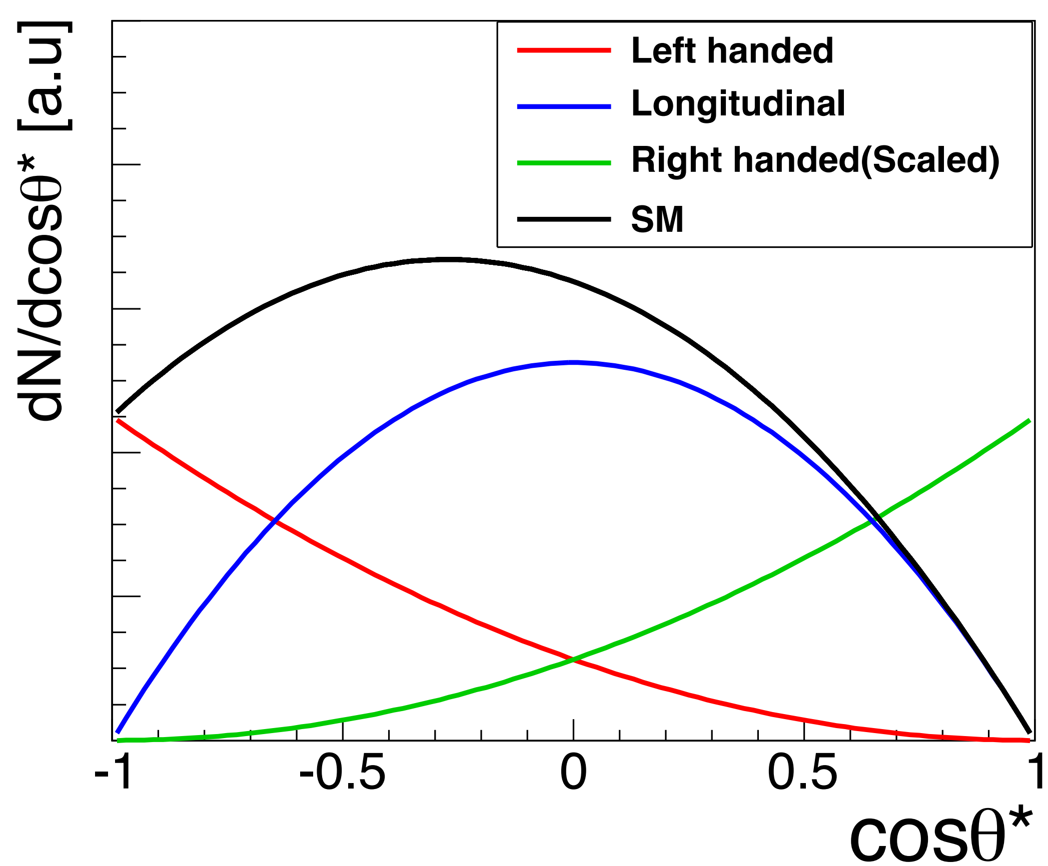


p-value is 0.71 (2.7σ).

W polarisation in the top quark decay



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



W polarisation in the top quark decay

- How to reconstruct top quark in dilepton channel
  - ➡Need to factorise "MEt → two neutrinos".
  - ➡Solve these equations. (6 unknowns, 6 equations)

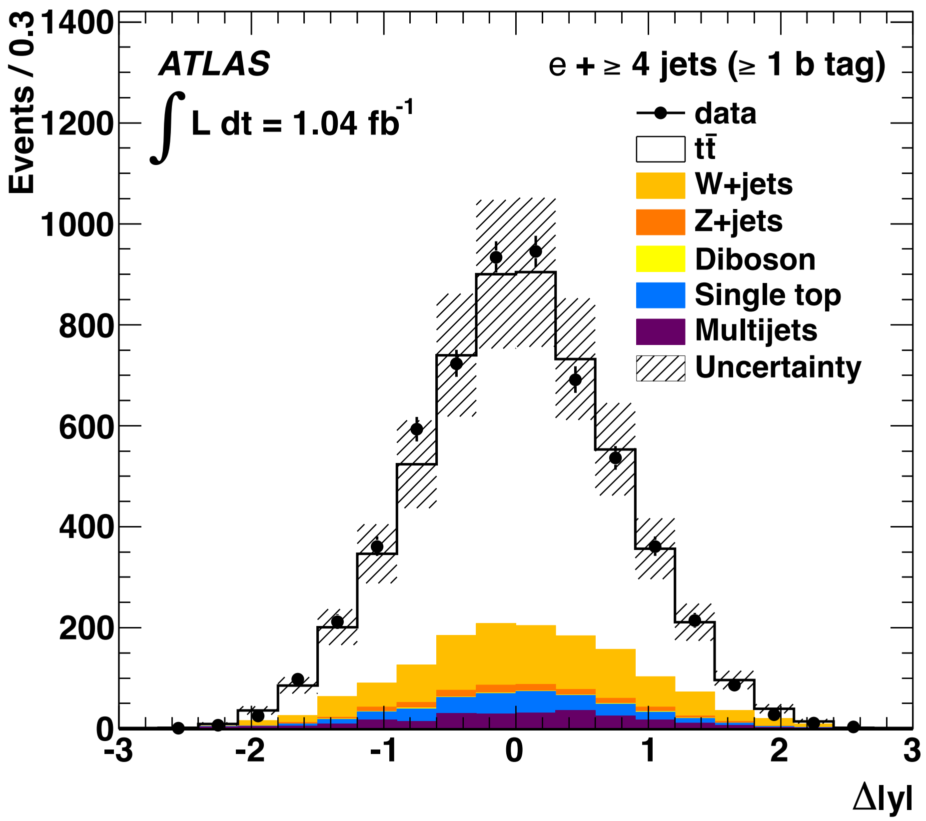
$$
\begin{aligned}
p_x^{\nu_1} + p_x^{\nu_2} &= \not{E}_{\mathrm{x}}, \\
p_y^{\nu_1} + p_y^{\nu_2} &= \not{E}_{\mathrm{y}}, \\
(p_{\ell_1} + p_{v_1})^2 &= m_{\mathrm{W}}^2, \\
(p_{\ell_2} + p_{v_2})^2 &= m_{\mathrm{W}}^2, \\
(p_{W_1} + p_{j_1})^2 &= m_{\mathrm{t}}^2, \\
(p_{W2} + p_{j_2})^2 &= m_{\mathrm{t}}^2.
\end{aligned}
$$

  - ➡lepton-jet pairing
    - utilise sum of invariant masses $m_{l_1 j_1} + m_{l_2 j_2}$.

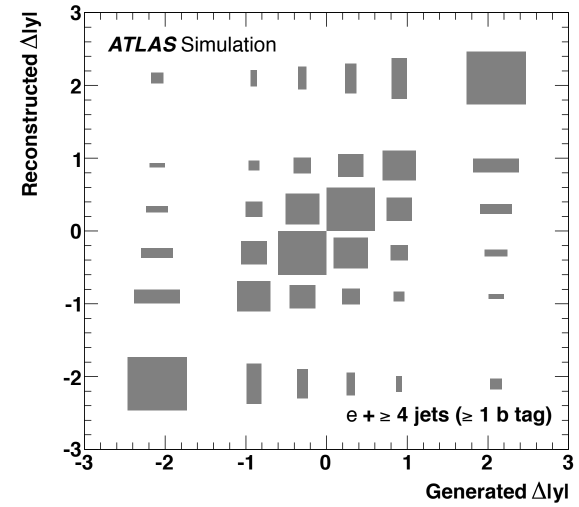
Spin correlation in the tt production

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	$+0.30/-0.26$

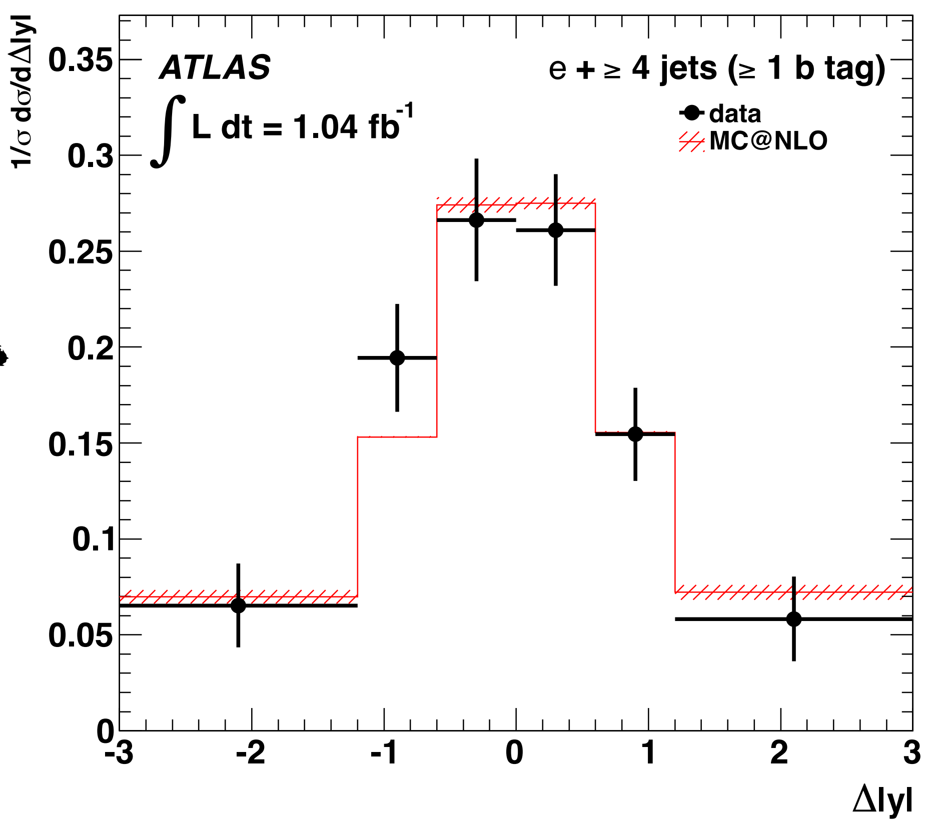
Charge asymmetry in the tt production



response matrix



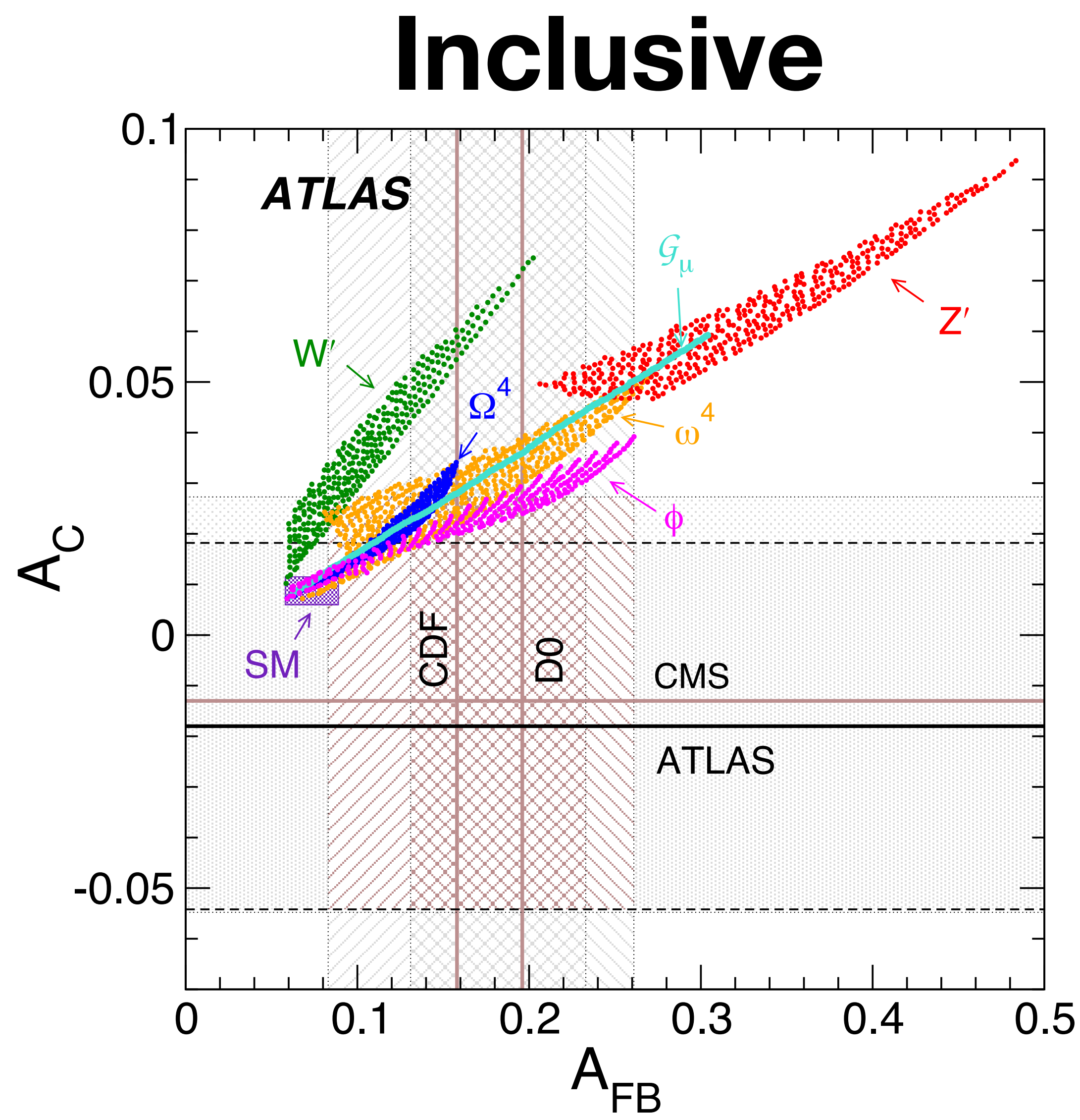
unfolding

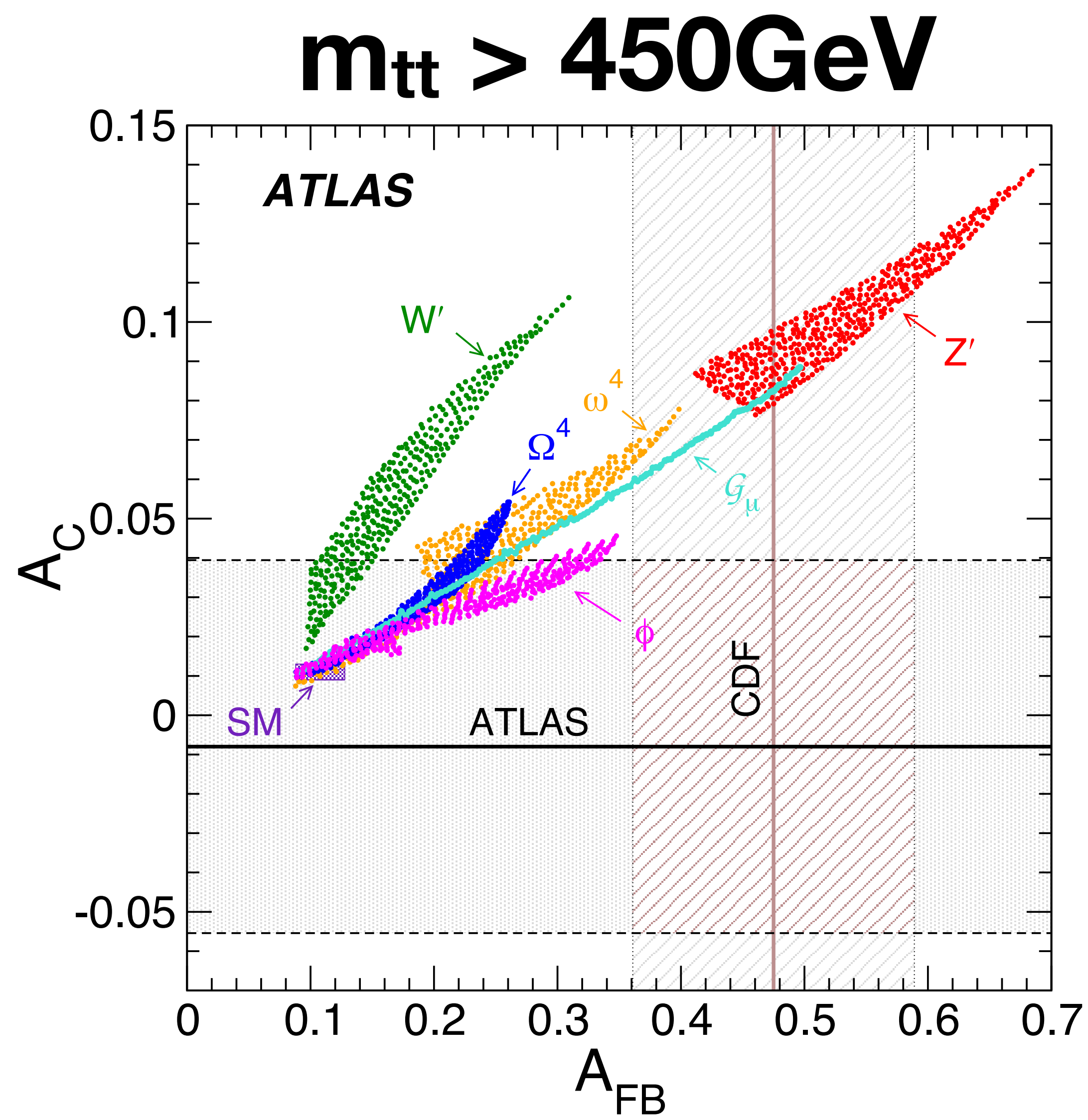


Charge asymmetry in the tt production

Source of systematic uncertainty on A_C	Electron channel	Muon channel
Detector modelling		
Jet energy scale	0.012	0.006
Jet efficiency and resolution	0.001	0.007
Muon efficiency and resolution	<0.001	0.001
Electron efficiency and resolution	0.003	0.001
b-tag scale factors	0.004	0.002
Calorimeter readout	0.001	0.004
Charge mis-ID	<0.001	<0.001
b-tag charge	0.001	0.001
Signal and background modelling		
Parton shower/fragmentation	0.010	0.010
Top mass	0.007	0.007
$t\bar{t}$ modelling	0.011	0.011
ISR and FSR	0.010	0.010
PDF	<0.001	<0.001
W+jets normalization and shape	0.008	0.005
Z+jets normalization and shape	0.005	0.001
Multijet background	0.011	0.001
Single top	<0.001	<0.001
Diboson	<0.001	<0.001
MC Statistics	0.006	0.005
Unfolding convergence	0.001	0.001
Unfolding bias	0.004	<0.001
Luminosity	0.001	0.001
Total systematic uncertainty	0.028	0.023

Charge asymmetry in the tt production





Charge asymmetry in the tt production