Top quark pair charge asymmetry using the ATLAS detector at the LHC

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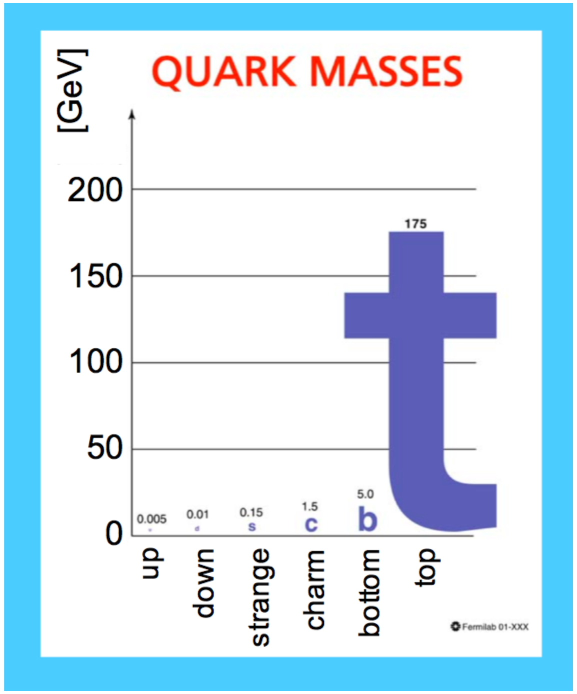
Top quark

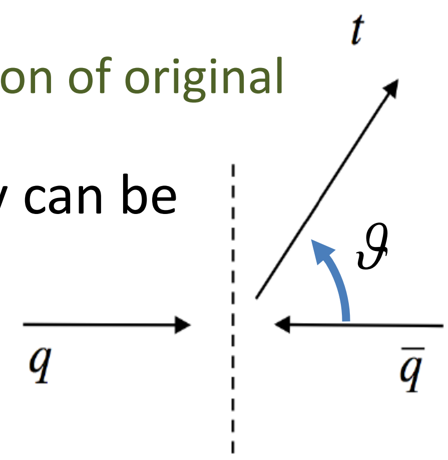
- Top: heaviest quark, mass at the EW scale
  - top production and decays provide important tests of QCD in non-perturbative mode
  - deviation from SM prediction = indication of new physics
- Top quarks are produced in abundance at the LHC
  - a lot of opportunities to study their properties



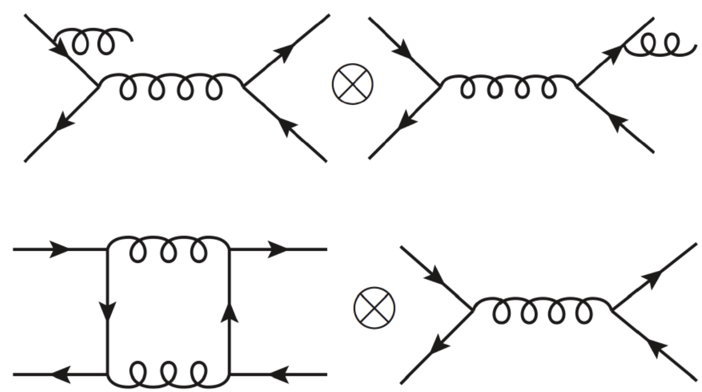
Top quark pair charge asymmetry

- Top-anti top pairs are produced (mainly) through gg→tt (dominant channel at the LHC) and $q\bar{q}\rightarrow t\bar{t}$
  - $gg\rightarrow t\bar{t}$: no asymmetry (no chosen direction)
  - $q\bar{q}\rightarrow t\bar{t}$: tops (anti tops) tend to move along the direction of original quark (anti quark)
- If we know the initial quark direction, the asymmetry can be generally defined as

$$A=\frac{N(\cos\vartheta>0)-N(\cos\vartheta<0)}{N(\cos\vartheta>0)+N(\cos\vartheta<0)}$$

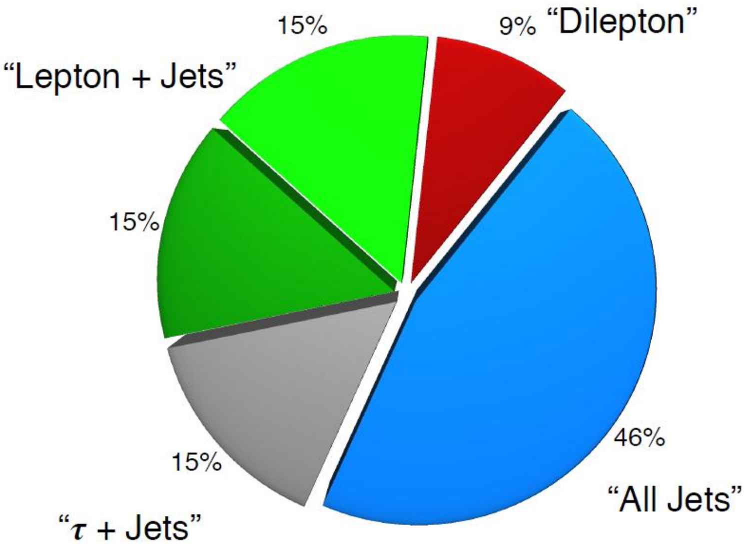


- Charge asymmetry is a small effect
  - not present at LO
  - present at NLO due to (1) interference between ISR and FSR, and (2) interference between Born and box diagrams (+ due to $gq\rightarrow t\bar{t}q$ production)



Charge asymmetry: how to measure

- Top quarks decay in ~100% to bW
  - W→lν: lepton charge = top/anti top
  - W→ud̄/cs̄: can't discriminate between top and anti top
- Useful channels to look at: $t\bar{t}$→dileptons and $t\bar{t}$→l+jets
- How to get top quark direction?
  - reconstruct it from event kinematics: not trivial in dilepton case
  - use the lepton direction: the effect is diluted but lepton asymmetry measurement benefits from precise lepton reconstruction and is sensitive to top polarization effects
- Also, what to do with the initial parton direction?



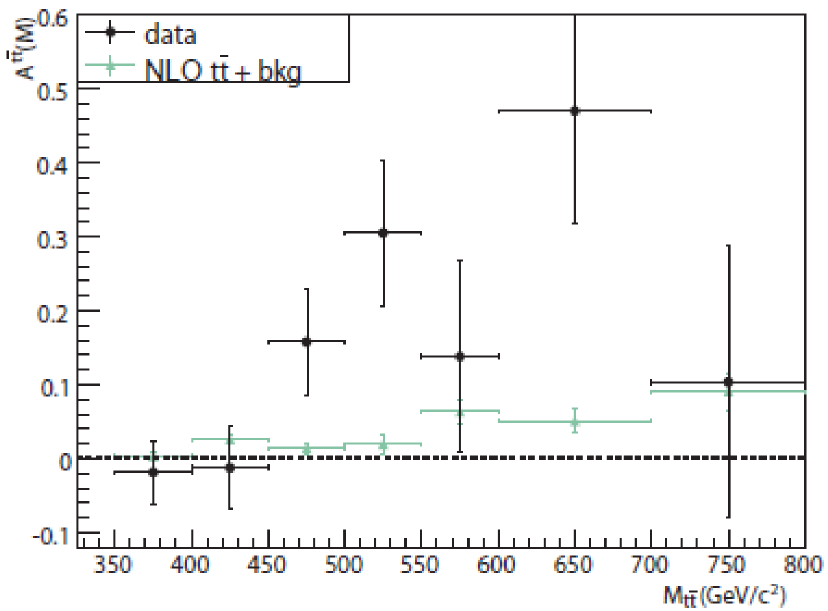
Top charge asymmetry at the Tevatron

- At √s=1.96 TeV, top pairs are mostly produced through $q\bar{q}$ annihilation
- Direction of original (anti)quark is close to direction of (anti)proton beam, can naturally define forward-backward asymmetry A_{FB} as

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y = y(t) - y(\bar{t})$$

- Both CDF and D0 performed the measurement and got results deviating from SM by ~2σ which generated a lot of excitement (later results indicated that the effect is not that pronounced)



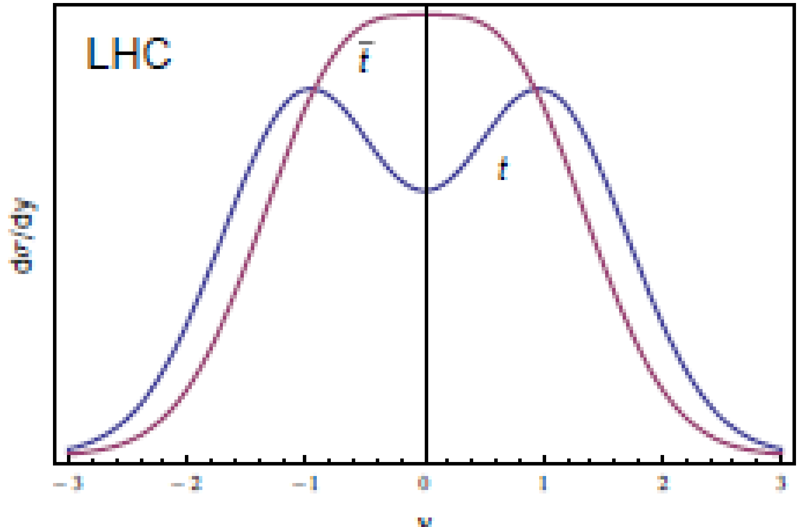
CDF, PRD 83(2011)112003

Top charge asymmetry at the LHC

- Good: top pairs produced in abundance
- Not so good:
  - no initial asymmetry (pp, not pp̄)
  - dominated by gg→tt̄, not qq̄→tt̄
- Still possible to measure asymmetry!
  - initial quarks: valence, larger momentum fractions
  - initial anti quarks: sea, smaller momentum fractions
  - (anti)tops are emitted in the direction of initial (anti)quarks
  - anti tops are more central

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

$$\Delta|y| = |y(t)| - |y(\bar{t})|$$

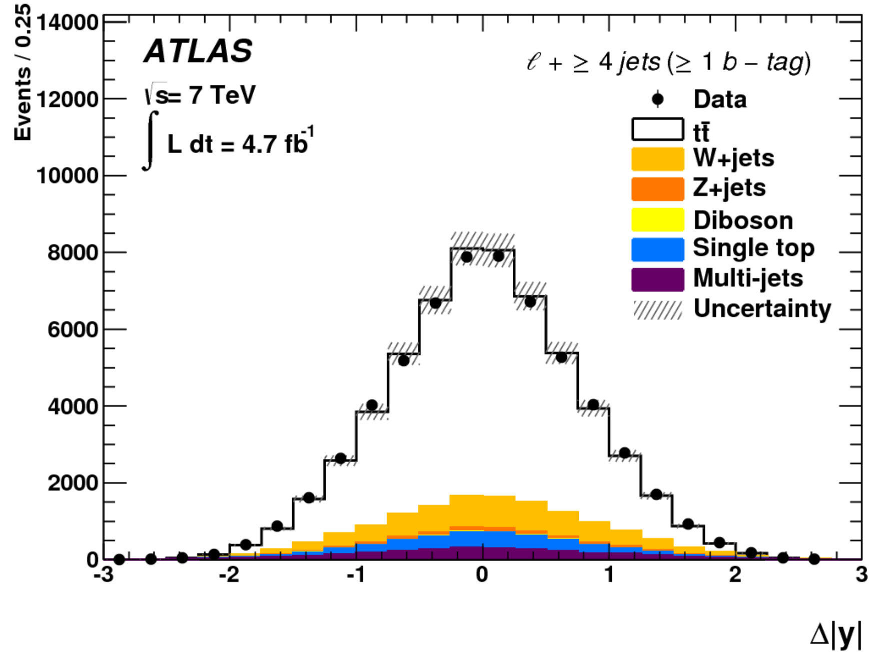


Rodrigo, arXiv 1207:0331

Top charge asymmetry in l+jets

- Data: 4.7 fb^{-1} (7 TeV)
- Selection:
  - one isolated lepton (e, E_T>25 GeV; μ, p_T>20 GeV)
  - ≥4 jets (p_T>25 GeV)
  - ≥1 b-tagged jet (b-tagging efficiency 70%, light jet rejection 150)
- Dominant background: W+jets, data driven estimate

$$N(W^+) > N(W^-)$$



Channel	μ + jets pretag	μ + jets tag	e + jets pretag	e + jets tag
$t\bar{t}$	34900 ± 2200	30100 ± 1900	21400 ± 1300	18500 ± 1100
W+jets	28200 ± 3100	4800 ± 900	13200 ± 1600	2300 ± 900
Multi–jets	5500 ± 1100	1800 ± 400	3800 ± 1900	800 ± 400
Single top	2460 ± 120	1970 ± 100	1530 ± 80	1220 ± 60
Z+jets	3000 ± 1900	480 ± 230	3000 ± 1400	460 ± 220
Diboson	380 ± 180	80 ± 40	230 ± 110	47 ± 22
Total background	40000 ± 4000	9200 ± 1000	21700 ± 2900	4800 ± 1000
Signal + background	74000 ± 4000	39300 ± 2100	43100 ± 3100	23300 ± 1600
Observed	70845	37568	40972	21929

JHEP 1402 107

Top charge asymmetry in l+jets (2)

- Reconstruction: kinematic likelihood method
  - inputs: 4-vectors of jets, lepton, and missing transverse energy (due to escaping neutrino)
  - constraints: top and W masses
  - fraction of correct $\Delta|y|$ sign: 75%
- Unfolding: Fully Bayesian Unfolding
  - estimate parton level distributions from measured spectra
  - used priors: flat ($m(t\bar{t})$, $|y(t\bar{t})|$) and curvature (inclusive, $p_T(t\bar{t})$)
  - reported value and stat. uncertainty of A_C are mean and RMS of posterior probability density distribution

Choudalakis, arXiv 1201:4612

Results in l+jets channel

- Inclusive asymmetry: A_C=0.006±0.010
  - consistent with SM prediction 0.0123±0.0005, computed at NLO with electroweak corrections without m($t\bar{t}$) cut

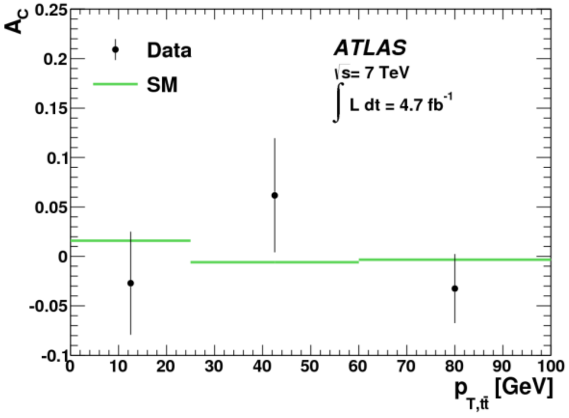
Bernreuther & Si, PRD 86(2012)034026

- Uncertainty is dominated by statistics
  - the largest systematic uncertainties are due to lepton and jet energy scale/resolution (~0.003)

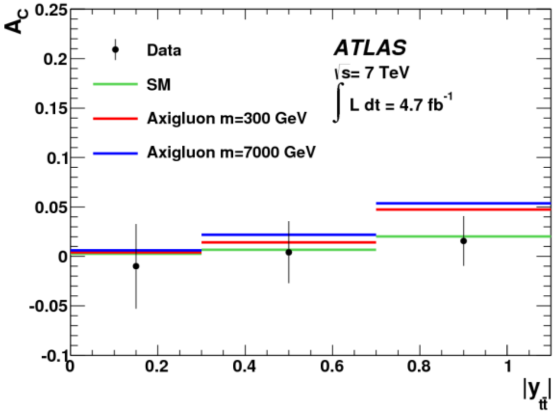
Source of systematic uncertainty	δA_C		
	Inclusive	$m_{t\bar{t}} > 600$ GeV	$\beta_{z,t\bar{t}} > 0.6$
Lepton reconstruction/identification	< 0.001	0.001	< 0.001
Lepton energy scale and resolution	0.003	0.003	0.003
Jet energy scale and resolution	0.003	0.003	0.005
Missing transverse momentum and pile–up modelling	0.002	0.002	0.004
Multi–jets background normalisation	< 0.001	0.001	0.001
b–tagging/mis–tag efficiency	< 0.001	0.001	0.001
Signal modelling	< 0.001	< 0.001	< 0.001
Parton shower/hadronisation	< 0.001	< 0.001	< 0.001
Monte Carlo statistics	0.002	< 0.001	< 0.001
PDF	0.001	< 0.001	< 0.001
W+jets normalisation and shape	0.002	< 0.001	< 0.001
Statistical uncertainty	0.010	0.021	0.017

Results in l+jets channel (2)

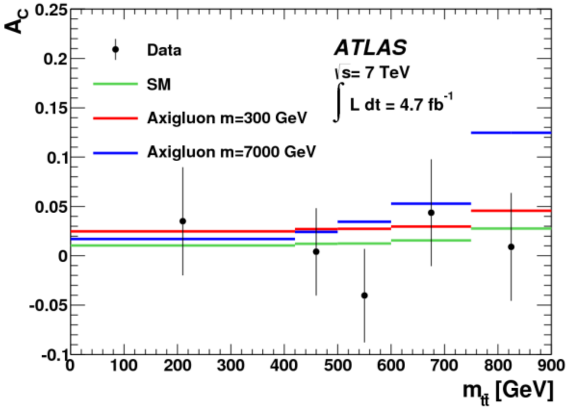
- Differential asymmetries
  - In bins of transverse momentum, rapidity, and invariant mass of $t\bar{t}$
  - all measurements statistically limited, consistent with SM within uncertainties



$p_T(t\bar{t})$



$|y(t\bar{t})|$

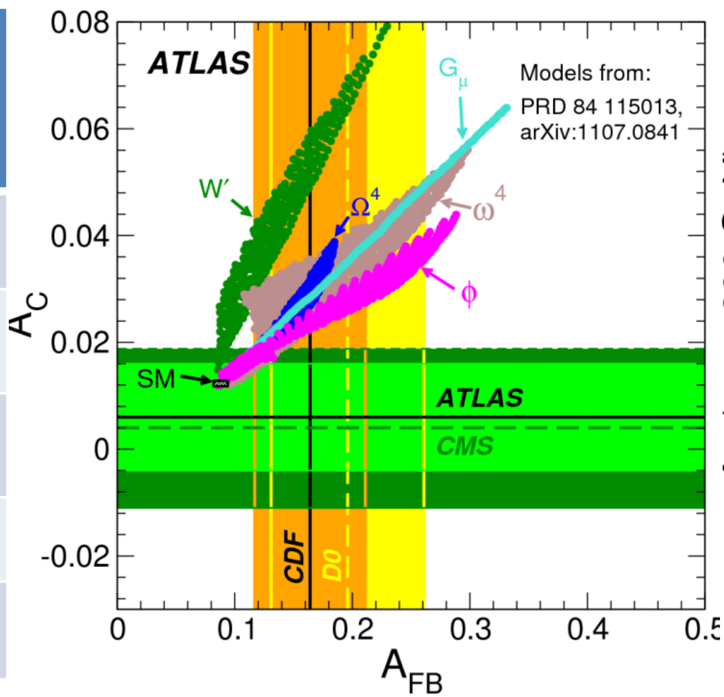


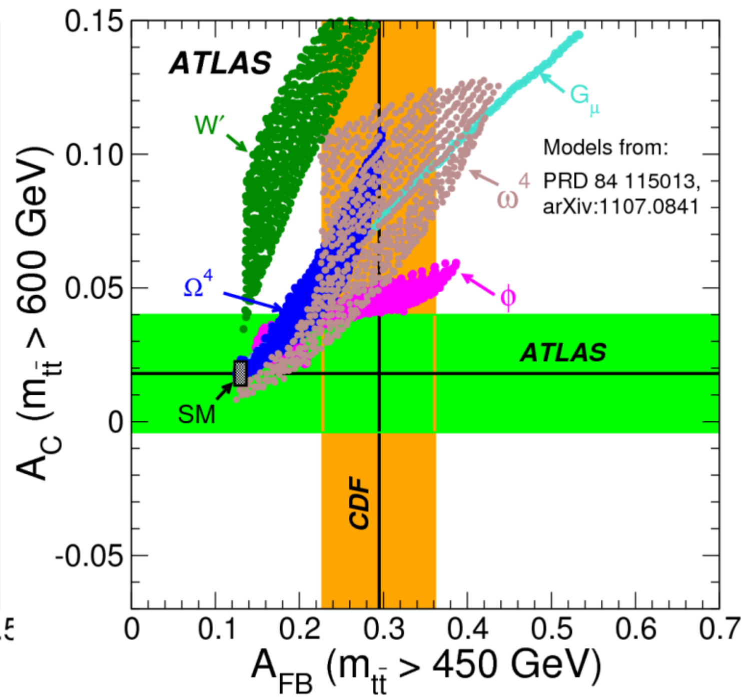
$m(t\bar{t})$

Interpretation

- Compare LHC and Tevatron measurements with SM and BSM predictions

	charge	colour	isospin	channel
W’	1	1	1	t
ω^4	4/3	3	1	u
Ω^4	4/3	6	1	u
G_μ	0	8	1	s
φ	0,1	1	2	t

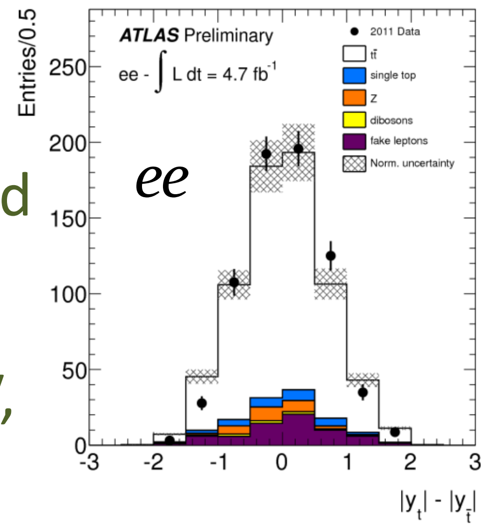


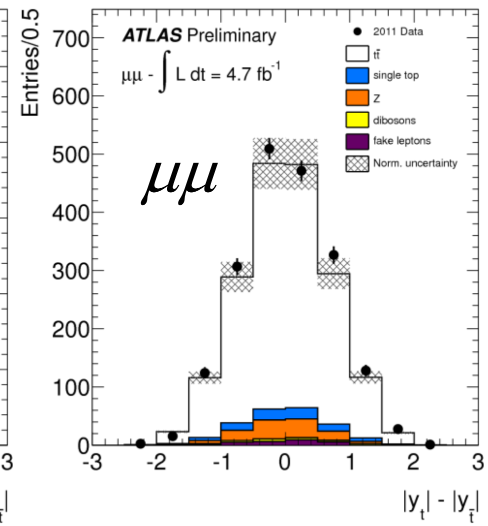


Aguilar-Saavedra & Perez-Victoria, PRD 84(2011)115013, JHEP 1109 097

Top charge asymmetry in dileptons

- Data: 4.7 fb^{-1} (7 TeV)
- Selection:
  - 2 oppositely charged isolated leptons (e, E_T>25 GeV; μ, p_T>20 GeV)
  - ee/μμ: |m(ll)-m(Z)|>10 GeV, MET>60 GeV
  - eμ: H_T>130 GeV
  - ≥2 jets (p_T>25 GeV)

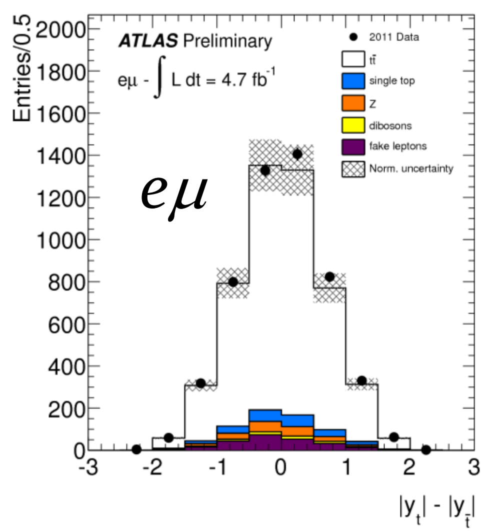




ATLAS-CONF-2012-057

Update in progress

Channel	ee	$e\mu$	$\mu\mu$
$t\bar{t}$	590 ± 60	4400 ± 500	1640 ± 170
$Z \to ee/\mu\mu$	19 ± 7	-	83 ± 29
$Z \to \tau\tau$	19 ± 7	180 ± 60	67 ± 23
Single top	30 ± 2	230 ± 20	82 ± 7
Dibosons	9 ± 1	70 ± 4	23 ± 2
Multijets/W+jets	70 ± 36	250 ± 130	32 ± 17
Total	740 ± 70	5100 ± 500	1930 ± 170
Data	732	5305	2010



Top charge asymmetry in dileptons (2)

- Reconstruction: compute a probability distribution using LO matrix element
  - constraints: t and W vertices (=16), top and W masses (= 4), transverse momentum balance (=2)
  - unknowns: top and W 4-vectors (=16), neutrino momenta (=6)
  - inputs (4-vectors of objects) are varied according to their widths/resolutions and equations solved for each trial point/each jet/lepton permutation
  - the final observable = weighted average over all solutions
- Unfolding: sampling
  - perform MC simulations with various generated asymmetries
  - measured asymmetries for the different truth injected asymmetries are fitted using a straight line

Results in dilepton channel

- Top pair charge asymmetry: $A_C(t\bar{t})=0.057\pm0.024(\text{stat.})\pm0.015(\text{syst.})$
- Lepton pair charge asymmetry: $A_C(ll)=0.023\pm0.012(\text{stat.})\pm0.008(\text{syst.})$
- Consistent with SM

Conclusions

- The top quark charge asymmetry measurements performed by ATLAS experiment have been presented for the single lepton and dilepton channel
- A lepton-based asymmetry measurement in the dilepton channel has also been presented
- All the presented measurements are compatible with the SM predictions