Top quark pair properties

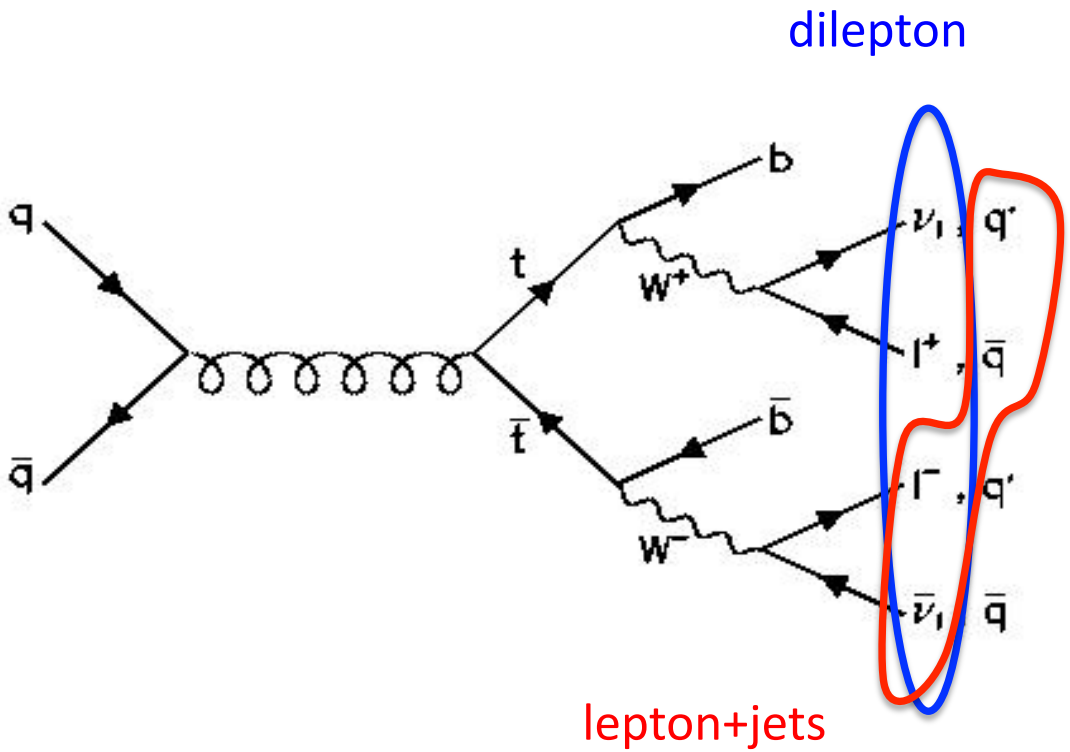
spin correlation, charge asymmetry and complex final states at LHC in ATLAS

F. Rubbo, on behalf of the ATLAS collaboration

Introduction

The top quark
- Heaviest particle, m_{top}~173 GeV
- Decays before hadronization
- Yukawa coupling ~1

Properties
- Test SM predictions
- Search for New Physics



Top pair analyses – common features

Requirements:
- single lepton trigger
- isolated lepton(s)
- missing transverse momentum
- anti-k_t R=0.4 jets
- b-tagging

Backgrounds:
- W/Z+jets (data-driven)
- Fake leptons from multijet (data-driven)
- Single Top, Z+jets, Diboson (MC)

Outline

- Charge asymmetry:
  - lepton+jets — Eur.Phys.J. C72 (2012) 2039
  - dilepton — ATLAS-CONF-2012-057
- Spin correlation:
  - dilepton — Phys. Rev. Lett. 108, 212001 (2012)
- $t\bar{t}\gamma$ cross-section:
  - lepton+jets (+photon) ATLAS-CONF-2011-153
- Search for $t\bar{t}Z$ production:
  - 3 leptons — ATLAS-CONF-2012-126

Charge asymmetry

Charge asymmetry – l+jets

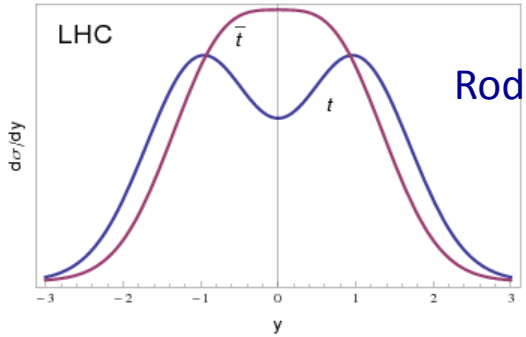
Eur.Phys.J. C72 (2012) 2039

√s = 7 TeV, 1.04 fb^{-1}
single lepton

- Reconstruction: kinematic likelihood fit
- Asymmetry:

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

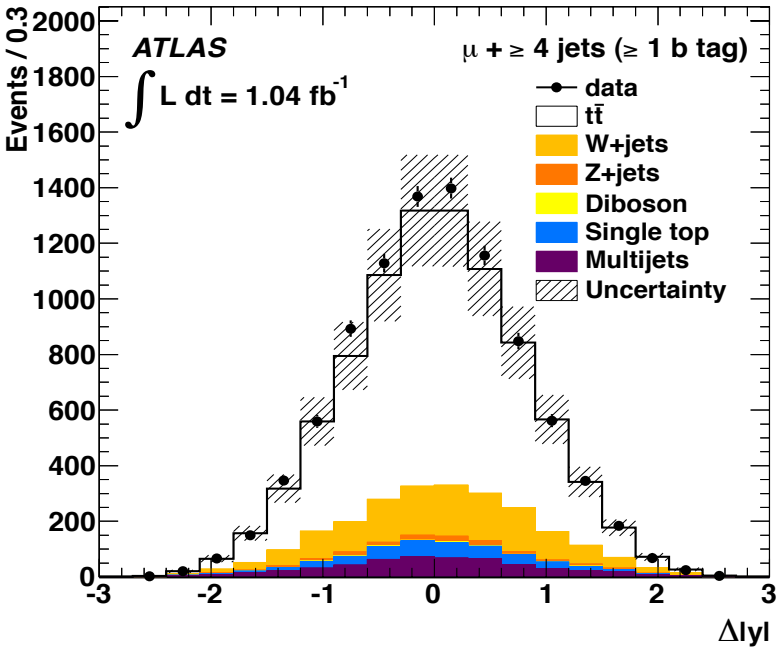
with $\Delta|y| = |y_{top}| - |y_{antitop}|$

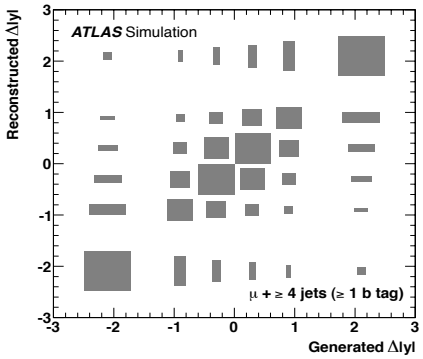


Rodrigo, G., arXiv:1207.0331

- SM prediction : $A_C^{t\bar{t}}$ = 1.15%
  JHEP 1207 (2012) 151

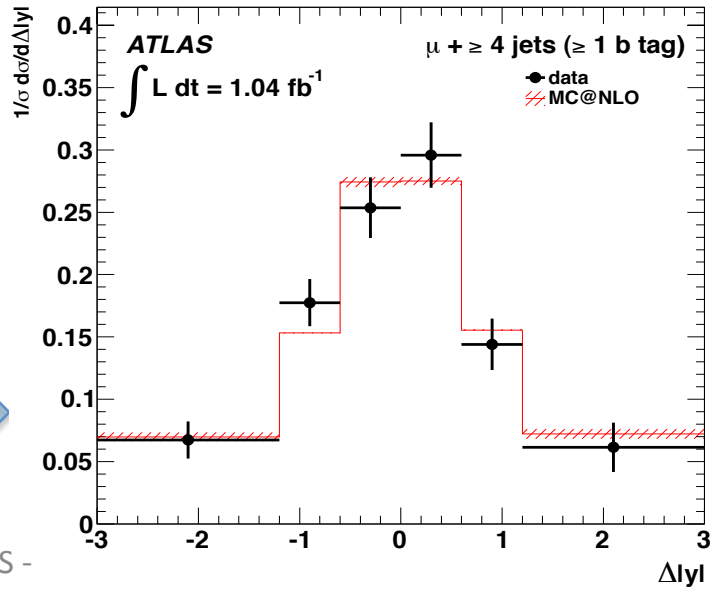
A_C = -0.019 ± 0.028(*stat.*) ± 0.024(*syst.*)





arXiv:1010.0632

Iterative Bayesian Unfolding



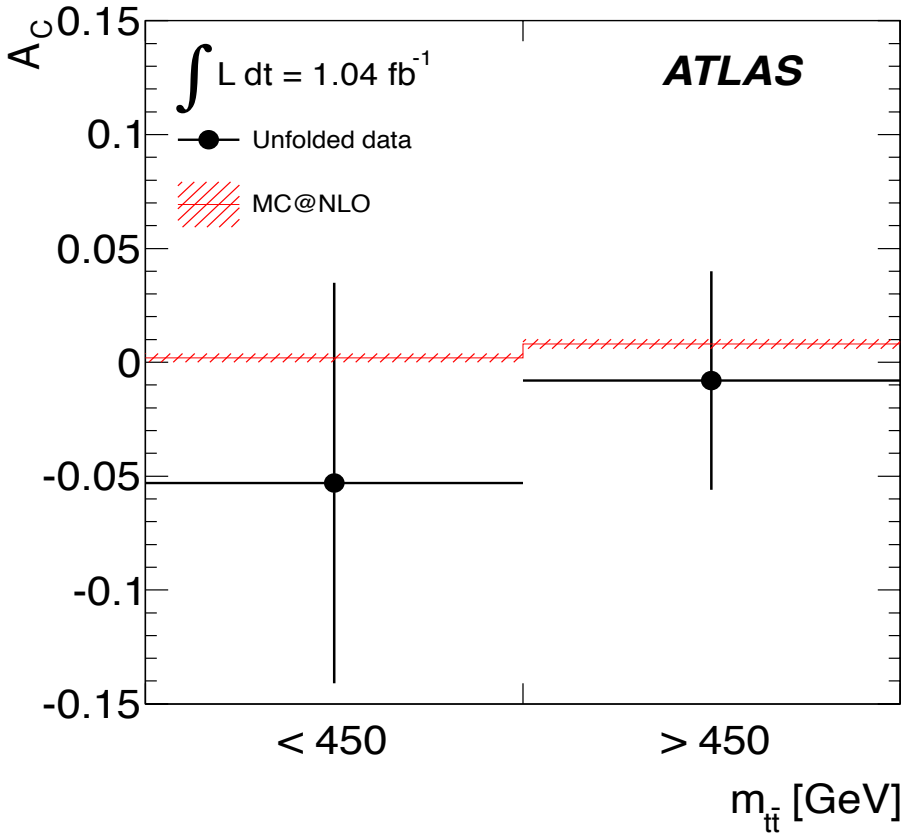
Charge asymmetry vs $m_{t\bar{t}}$

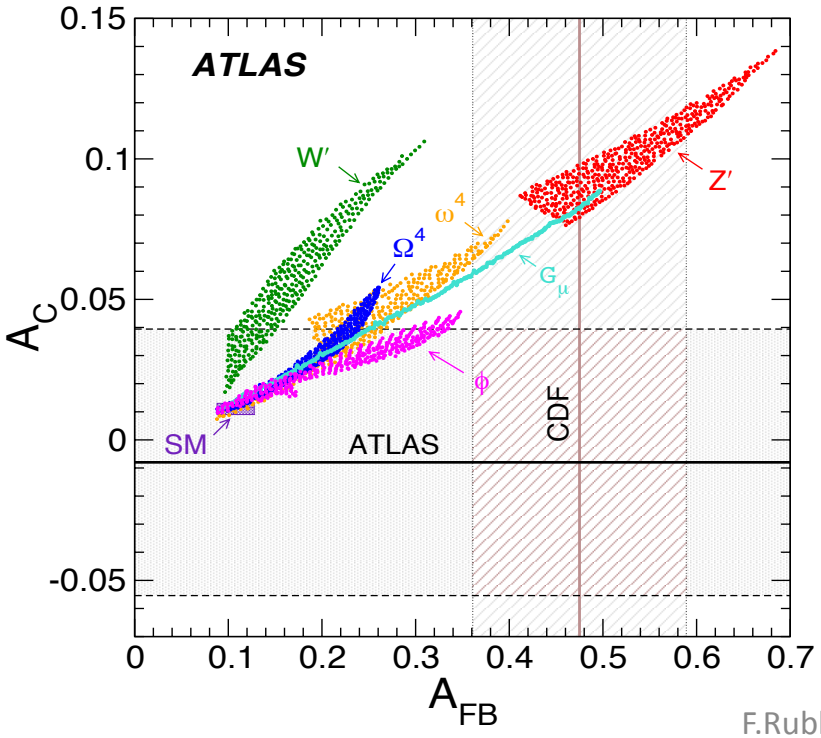
Eur.Phys.J. C72 (2012) 2039

√s = 7 TeV, 1.04 fb^{-1}
single lepton

- A_C vs $m_{t\bar{t}}$: more sensitive to bSM effects
- two bins: below/above $m_{t\bar{t}}$ = 450 GeV
- CDF reports A_{FB} deviations from SM in high $m_{t\bar{t}}$ region (> 450 GeV, 3.1σ) and $m_{t\bar{t}}$ dependence (slope, 2.8σ)

arXiv:1211.1003





- ATLAS measurement compatible with SM
- Some tension with flavor changing Z' models

Charge asymmetry – dilepton

√s = 7 TeV, 4.7 fb^{-1}
di-lepton

Top based asymmetry:

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

(same as for lepton+jets channel)

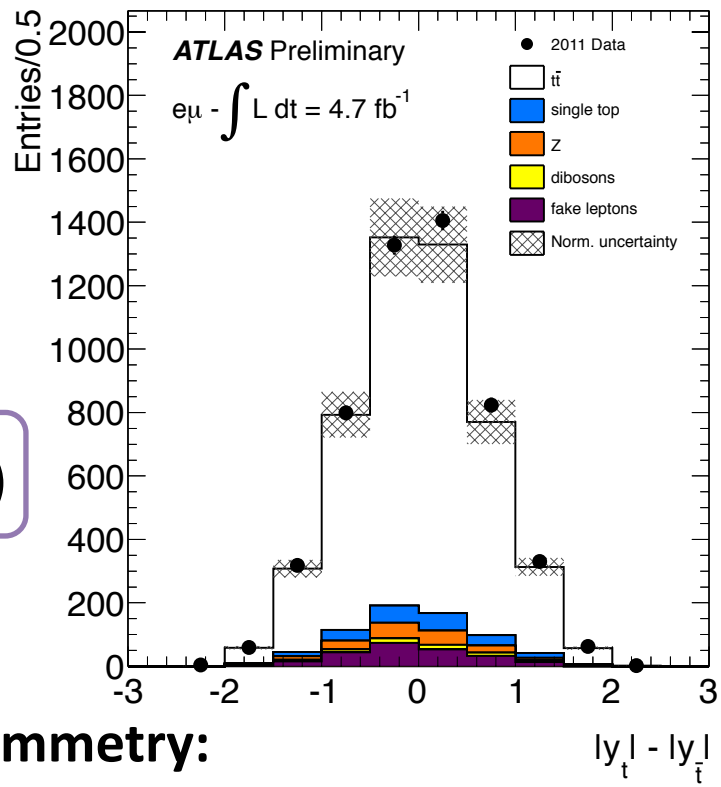
SM: $A_C^{t\bar{t}}$ = 1.15%

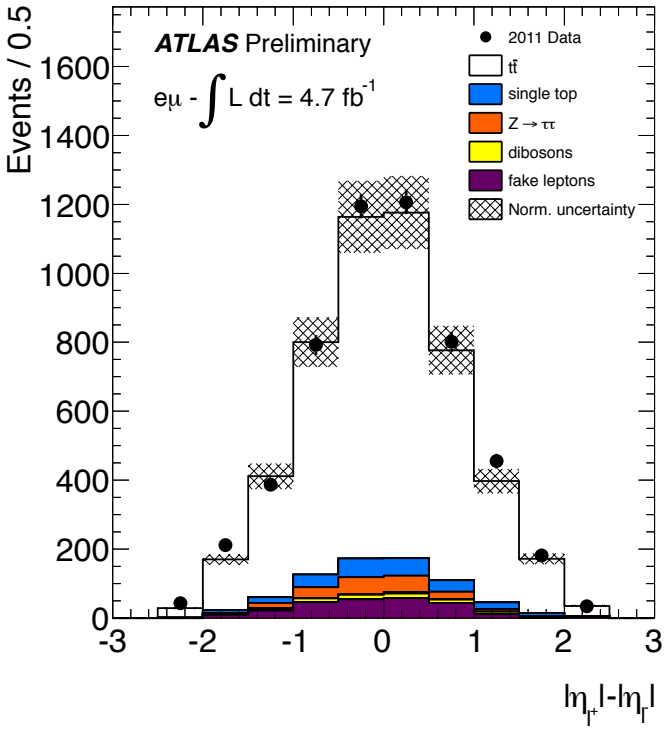
$$A_C^{t\bar{t}} = 0.057 \pm 0.024(stat.) \pm 0.015(syst.)$$

combined:
dilepton (4.7 fb^{-1})
& l+jets (1.04 fb^{-1})

$$A_C^{t\bar{t}} = 0.029 \pm 0.018(stat.) \pm 0.014(syst.)$$

ATLAS-CONF-2012-057





Lepton based asymmetry:

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

- includes top polarization effects.
- does not require full reconstruction.

SM (MC@NLO): $A_C^{\ell\ell}$ = 0.4%

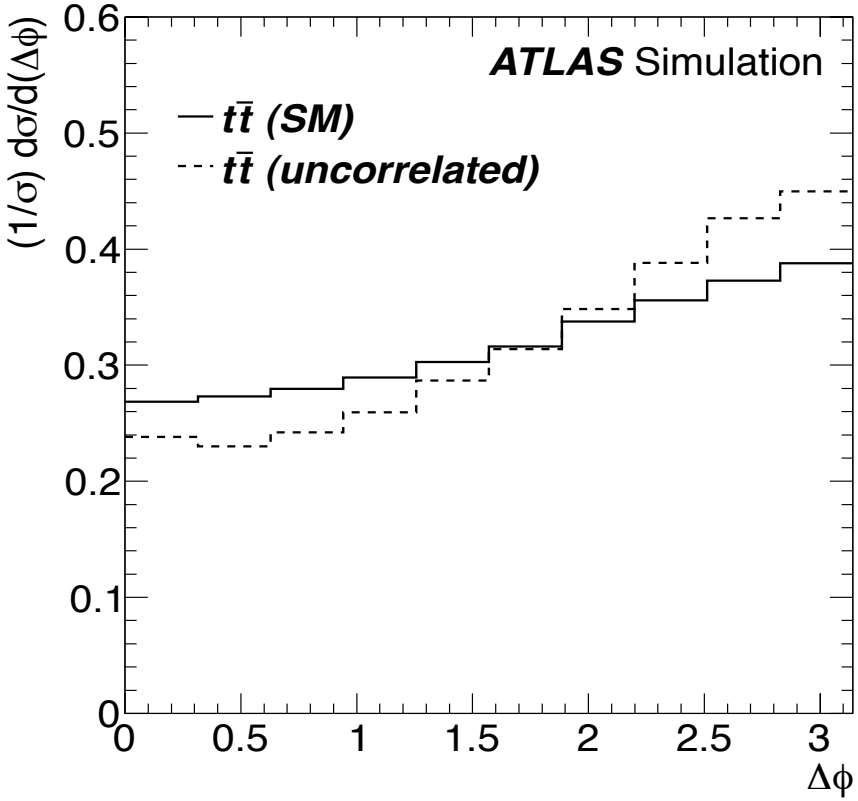
$$A_C^{\ell\ell} = 0.023 \pm 0.012(stat.) \pm 0.008(syst.)$$

Spin correlation

Spin correlation

√s = 7 TeV, 2.1 fb^{-1}
di-lepton

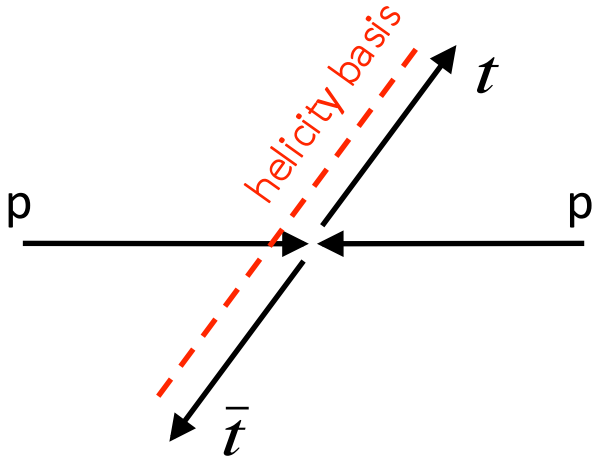
Phys. Rev. Lett. 108, 212001 (2012)



- tops decay before hadronization → spin info in decay products.
- top/antitop spin correlation:

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

- depends on qq/gg fraction.
- opening angle between leptons (Δϕ) carries information about spin correlation.



helicity basis (Phys. Rev. D 81, 074024 (2010)):
- along top/antitop direction in C.M. reference.
- $A^{SM}_{helicity} = 0.31$

maximal basis (arxiv:hep-ph/0412097):
- maximal correlation from gluon fusion.
- $A^{SM}_{maximal} = 0.44$

Spin correlation – fit

Phys. Rev. Lett. 108, 212001 (2012)

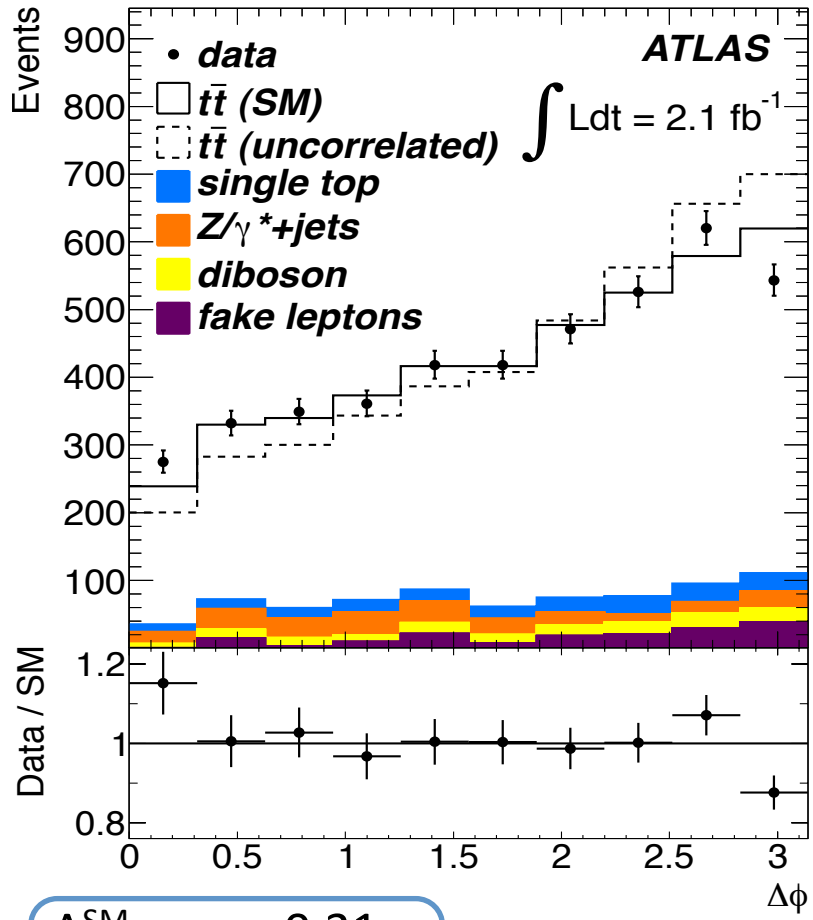
√s = 7 TeV, 2.1 fb^{-1}
di-lepton

- The Δϕ distribution is fit with two signal samples: w/ SM spin correlation (SM, solid line) and w/o spin correlation (UC, dashed line) :

- f_{SM} is the fitted fraction of SM sample
  $N_{meas} = f_{SM} \cdot N_{SM} + (1-f_{SM}) \cdot N_{UC}$

- $A_{basis}^{meas} = A_{basis}^{SM} \cdot f_{SM}$
  - $f_{SM} = 0$ → no correlation
  - $f_{SM} > 1$ → correlation > SM prediction

$$f_{SM} = 1.30 \pm 0.14(stat.)^{+0.27}_{-0.22}(syst.)$$
$$A_{\text{helicity}} = 0.40 \pm 0.04(stat.)^{+0.08}_{-0.07}(syst.)$$
$$A_{\text{maximal}} = 0.57 \pm 0.06(stat.)^{+0.12}_{-0.10}(syst.)$$



$A^{SM}_{\text{helicity}} = 0.31$
$A^{SM}_{\text{maximal}} = 0.44$

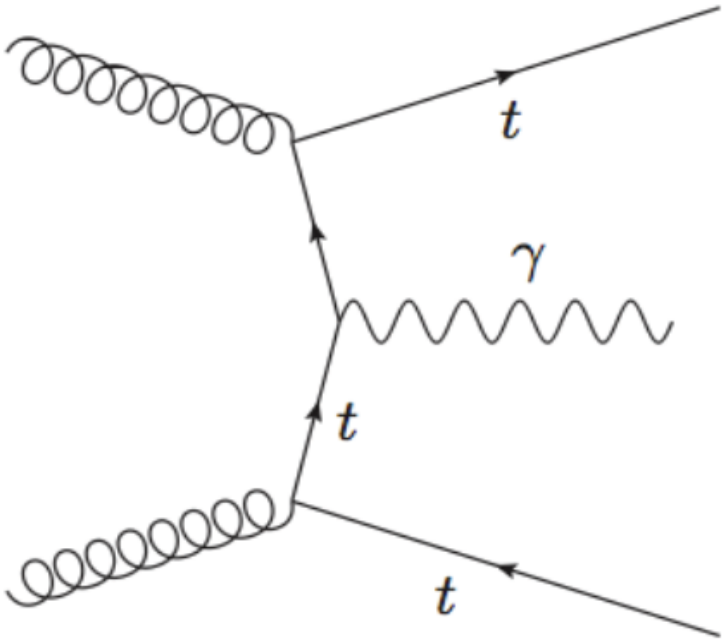
The result (f_{SM}~1) is compatible with SM prediction.

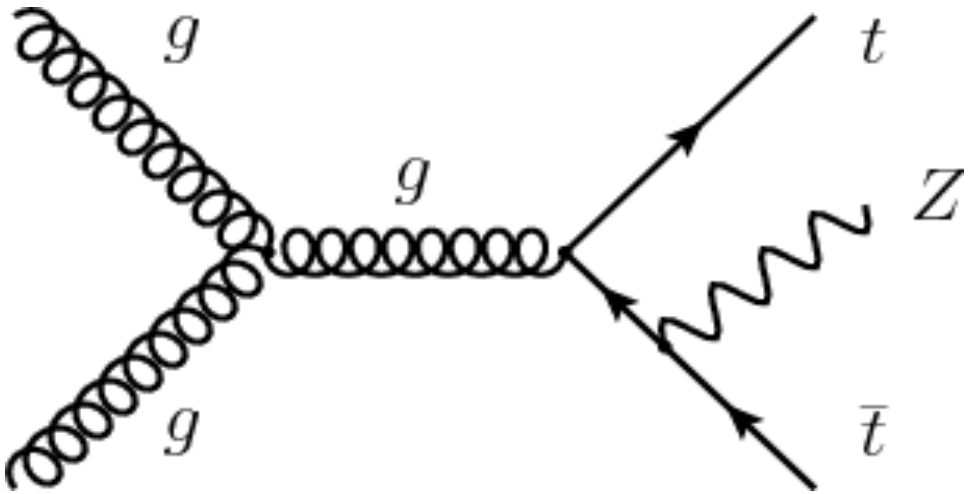
First observation of spin correlation. 5.1σ significance wrt no-correlation hypothesis.

Electroweak couplings

- Studies of top pairs produced in association with vector bosons allow to test the electroweak coupling in the SM.

- Anomalous couplings are symptoms of bSM physics.





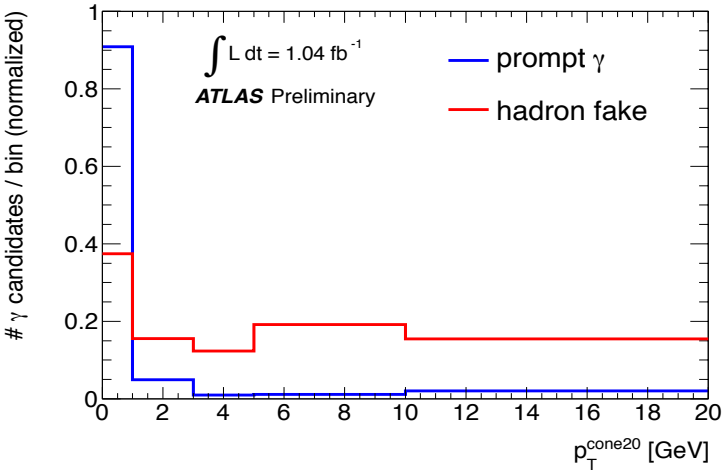
- First step: measurements of inclusive $t\bar{t} + \gamma / Z$ cross-sections.

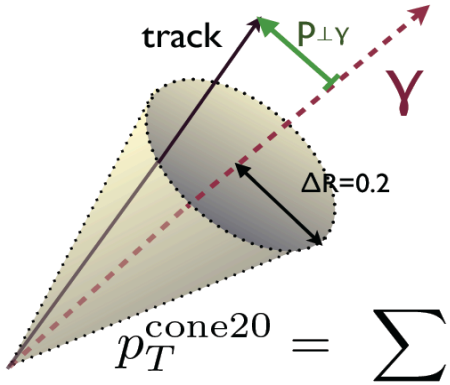
$t\bar{t}\gamma$ cross-section

ATLAS-CONF-2011-153

√s = 7 TeV, 1.04 fb^{-1}
single lepton

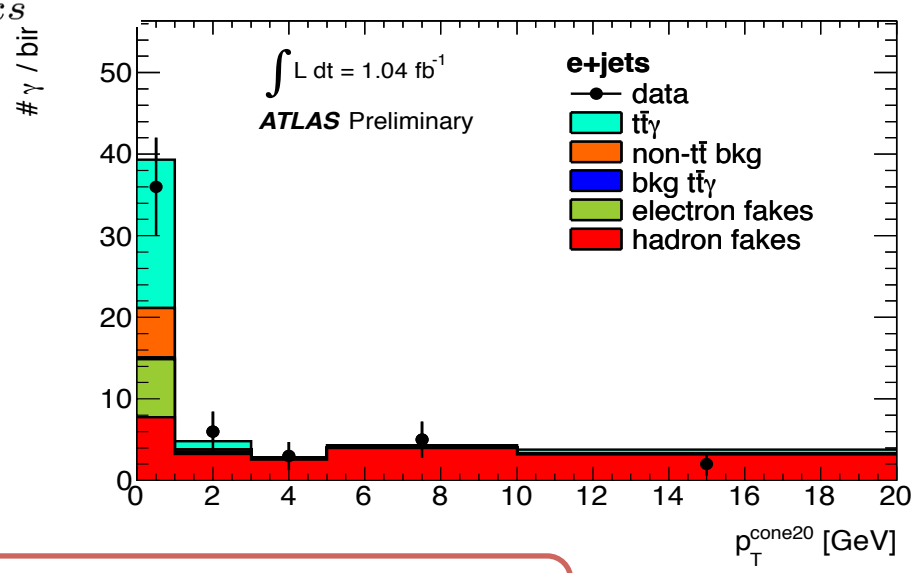
Measurement of $t\bar{t}$ + photon (p_T>8 GeV) cross section:
→ Template fit of photon isolation observable p_T^{cone20}.





$$p_T^{cone20} = \sum_{tracks} |p_T|$$

data-driven background estimation:
- misreconstructed photons from jets or electrons.



- Largest uncertainties: JES, ISR/FSR and photon ID efficiency
- Significance: 2.7σ

SM: $\sigma_{t\bar{t}\gamma} \cdot BR = (2.1 \pm 0.4)\,pb$

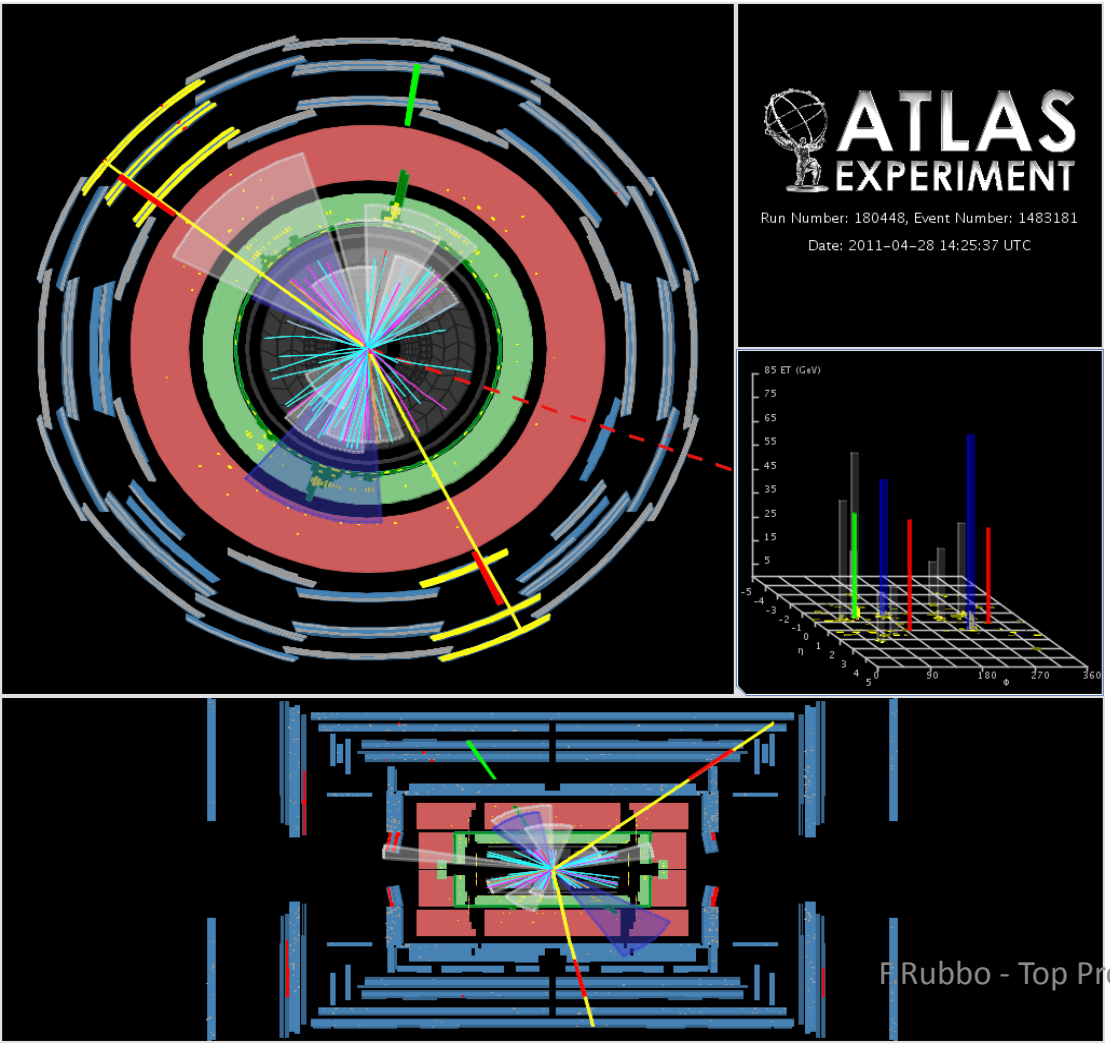
$$\sigma_{t\bar{t}\gamma} \cdot \mathrm{BR} = 2.0 \pm 0.5\,(\mathrm{stat.}) \pm 0.7\,(\mathrm{syst.}) \pm 0.08\,(\mathrm{lumi.})\,\mathrm{pb}$$

Search for $t\bar{t}Z$ production

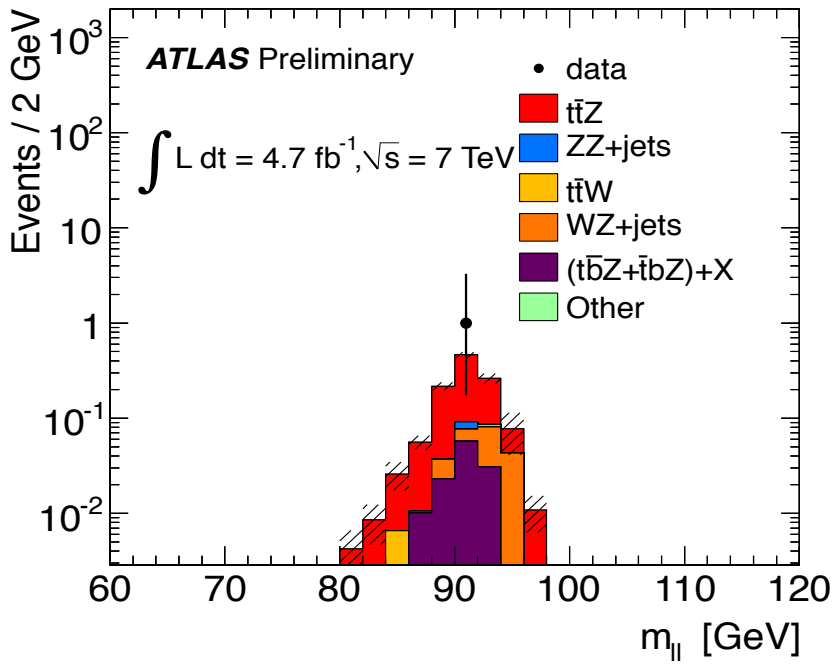
$\sqrt{s}$ = 7 TeV, 4.7 fb^{-1}

Search for $t\bar{t}Z$ events in 3 leptons final state:

- 1 from leptonic W decay
- 2 same-sign, same flavor from Z decay



ATLAS-CONF-2012-126



exp. signal: 0.85 ± 0.04(*stat.*) ± 0.14(*syst.*)
background: 0.28 ± 0.05(*stat.*) ± 0.14(*syst.*)
observed: 1

$\sigma_{t\bar{t}Z} < 0.71$ pb @ 95% C.L.

SM @ NLO: $\sigma_{t\bar{t}Z} = 0.14$ pb

Summary

- The large data samples delivered by LHC allow for precision measurements in the top sector.

- Presented measurements of top pair properties: charge asymmetry, spin correlation, ttγ cross-section and the search for ttZ production.

- All measurements are compatible with SM predictions. Some expected effects are already observed with good sensitivity: 5.1σ spin correlation and 2.7σ $t\bar{t}$ + photon.

- Systematic uncertainties are quickly becoming the main limitation for precise measurements. Large improvements are on the way.

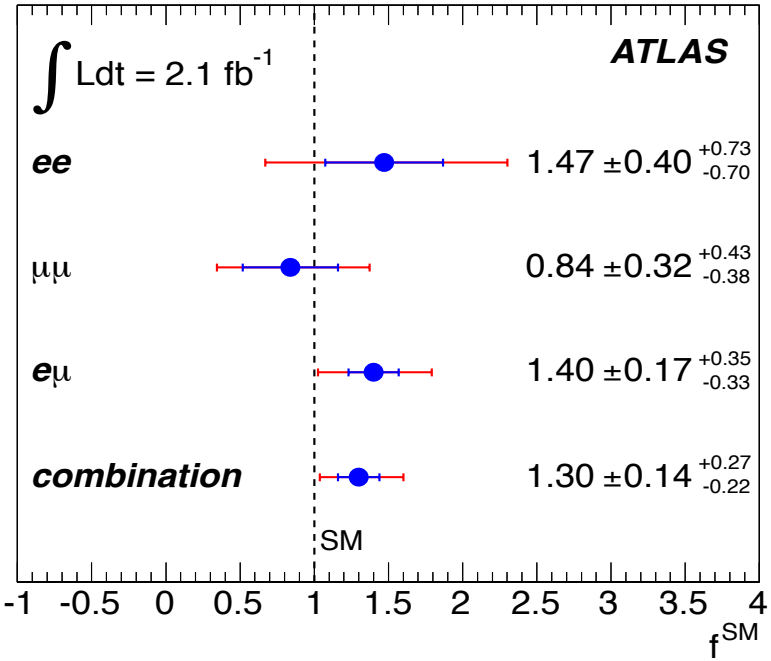
- Cross section and charge asymmetry measurements will benefit from 8 TeV large dataset.

- Updates with full 7 TeV dataset and new measurements at 8 TeV coming soon...

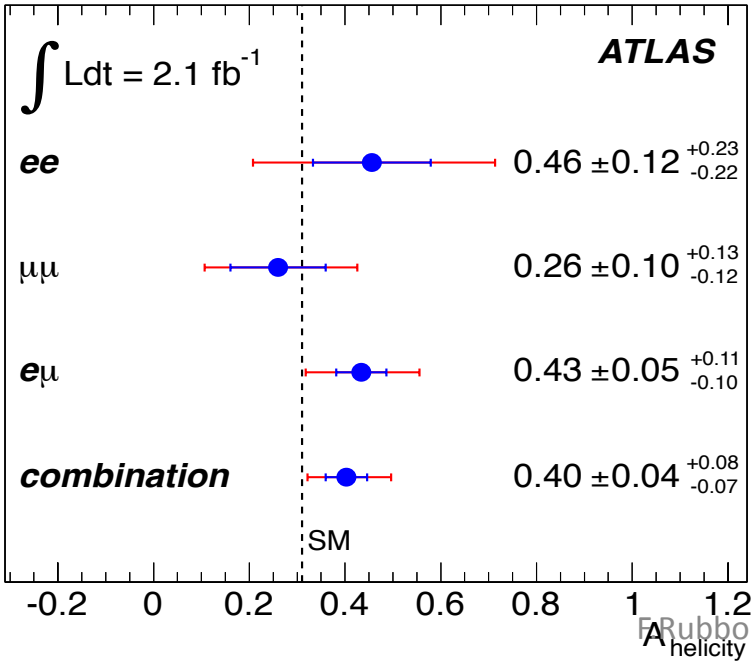
Backup

Spin correlation

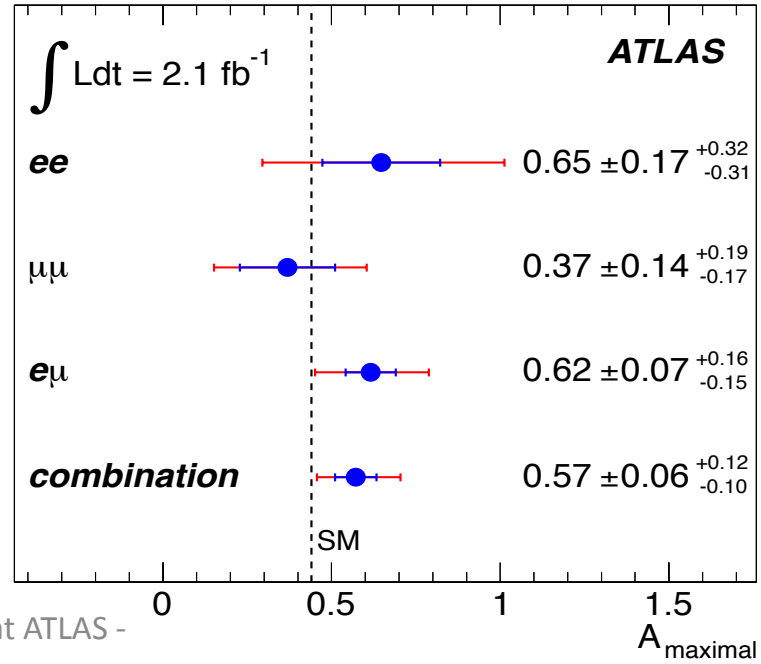
- f_{SM}



- correlation in helicity basis

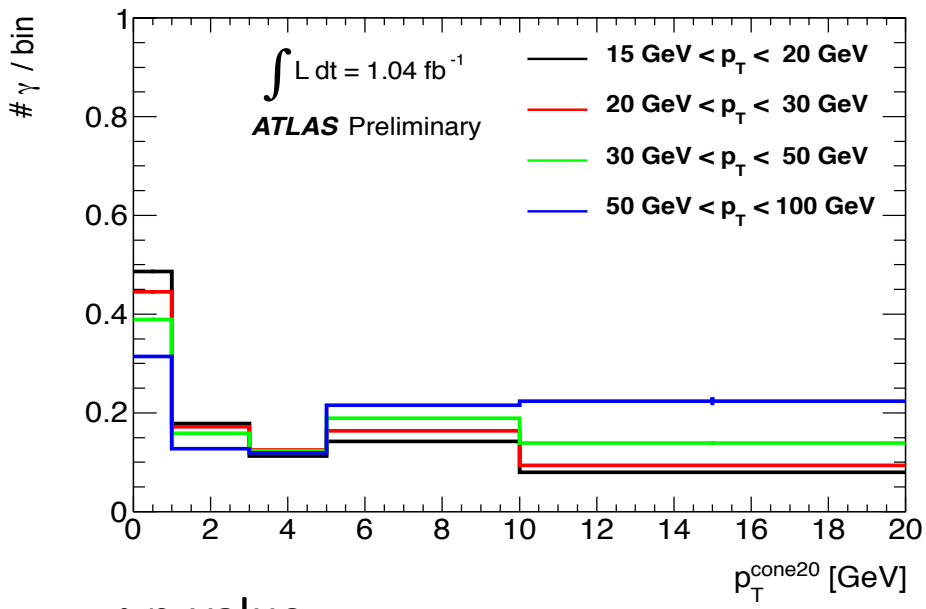


- correlation in maximal basis



$t\bar{t}\gamma$ cross-section

- hadron fakes in different p_T regions



- fit parameters

fit parameter	fit value with statistical uncertainty		
hadron fakes in the e+jets channel	21	± 6	events
hadron fakes in the μ+jets channel	28	± 8	events
electrons faking photons from $t\bar{t}$ in the e+jets channel	7.4	± 1.7	events
electrons faking photons from $t\bar{t}$ in the μ+jets channel	10.9	± 2.2	events
$t\bar{t}\gamma$ background in the e+jets channel	0.2		events
$t\bar{t}\gamma$ background in the μ+jets channel	0.4		events
non-$t\bar{t}$ background in the e+jets channel	6.7		events
non-$t\bar{t}$ background in the μ+jets channel	3.8		events
total number of background events	78	± 14	events
total number of signal events	46	± 12	events
$t\bar{t}\gamma$ signal (before selection and acceptance cuts)	2100	± 500	events

- p-value