Top Quark Mass and Properties at ATLAS

Duc Bao Ta – NIKHEF

on behalf of the ATLAS collaboration

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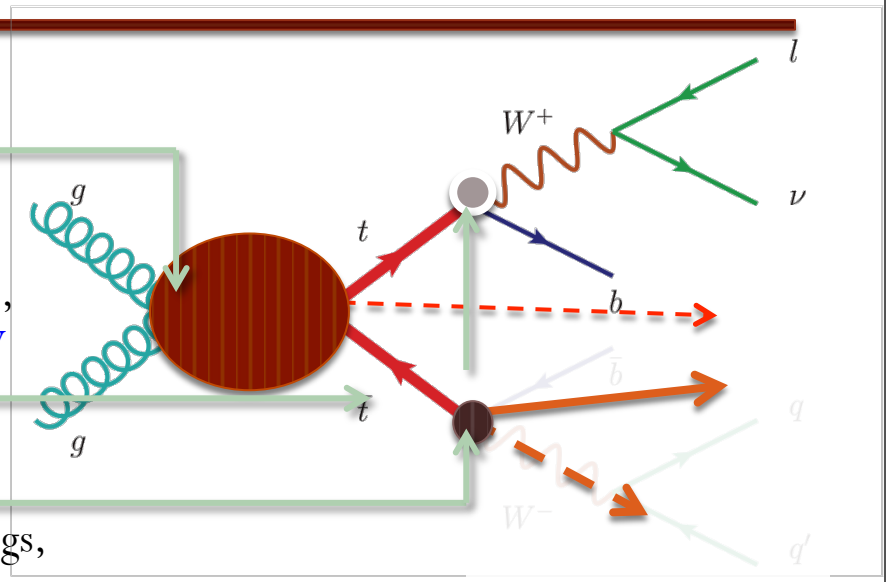
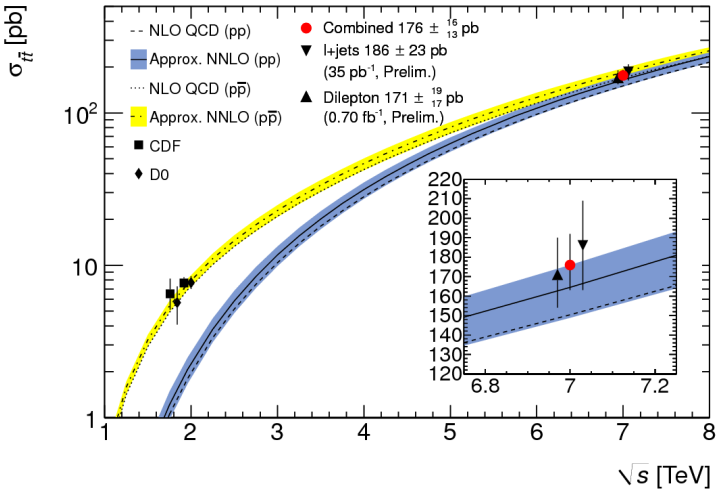
The Top Quark

- Rich phenomenology
  - *Production properties*
    - Cross section, kinematics, resonant production, **anormalous production (T⟶tA^0)**, spin polarization, **charge asymmetry**
  - *Top properties and Decay*
    - **Mass**, width, spin, charge, ***W* polarisation**, branching fractions, anomalous couplings, **rare/**non-SM **decays (FCNC)**

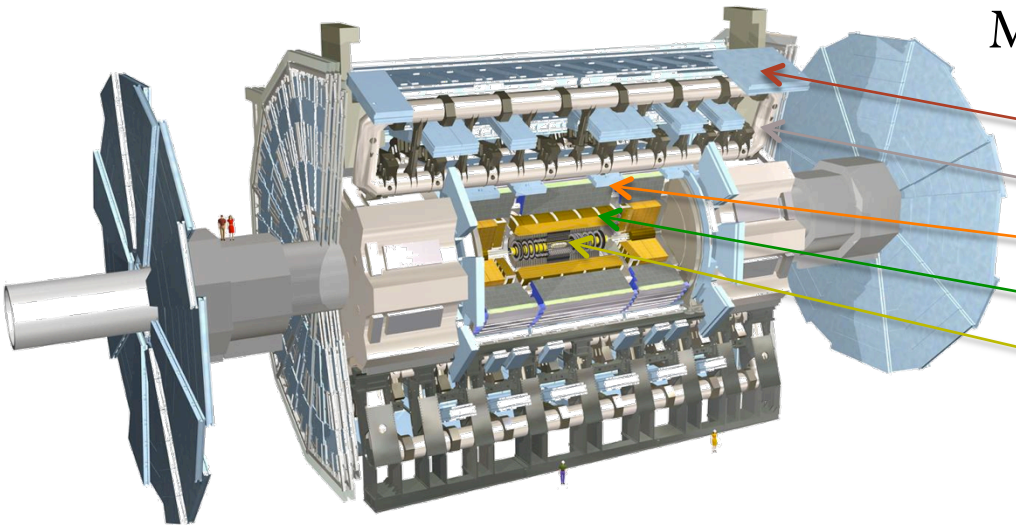




- Large production cross section at the LHC
  - 165pb^{-1}@7 TeV
  - 10 ttbar pairs/min @ 10^{33}cm^{-2}s^{-1}

Cross section: R. Calkins, this session
Resonant production: J. Abdallah, session 4I

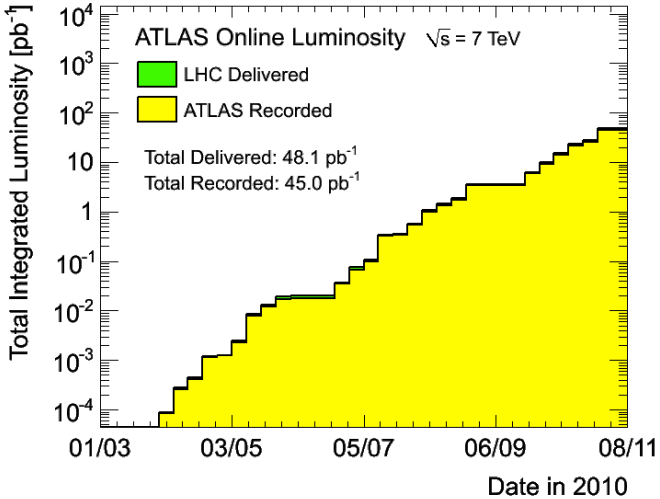
The ATLAS detector



Main detector components

- Muon spectrometer $\Delta p/p<10\%$ up to 1 TeV
- Toroid magnet
- Hadronic calorimeter $\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$
- EM calorimeter $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
- Inner tracker $\sigma/p_T \sim 0.04\% p_T \oplus 1.5\%$
- Solenoid magnet

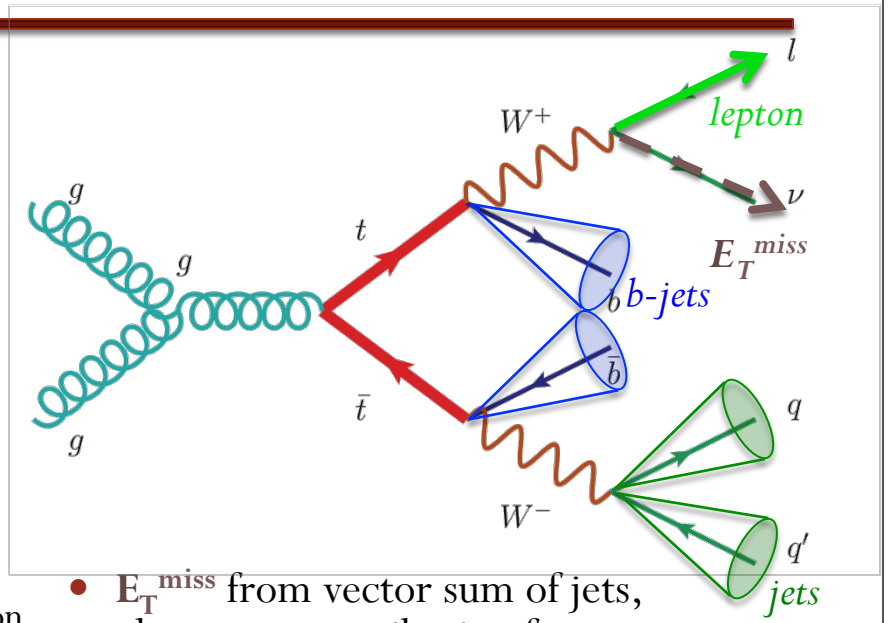
- Analyses presented here with $L=\mathbf{35pb^{-1}}$ 2010 data
- $\Delta L=\mathbf{3.4\%}$ luminosity uncertainty
- Peak luminosity $\mathbf{2.1\ 10^{32}}$ $cm^{-2}s^{-1}$
- max. **4PV** per event on average



General Object and Event Selection

- Analysis mainly in ttbar
  single lepton channel (BR 30%)
  - Trigger on isolated high-p_T lepton at efficiency plateau

- Signature and selection
  - **Exactly one isolated lepton**
    - within tracker acceptance and p_T>20 GeV
    - calorimeter isolation
    - electron 'tight' ID selection
    - muon combined from inner tracker and muon spectrometer, track isolation
  - **At least 4 jets**, anti-kt (R=0.4), from calorimetric clusters
    - within tracker acceptance, p_T>25 GeV
  - **At least one *b*-jets**
    - reconstruct secondary vertex (SV0) @ 50% eff.



- E_T^{miss} from vector sum of jets, electrons, contribution from muons and unassociated calorimeter cells
  - E_t^{miss} >20(35) GeV for muon (electron)
- **Transverse mass M_T** from lepton and neutrino
  - M_T>35 GeV (electron), $M_T+E_t^{miss}$ >60 GeV (muon)

- After selection S/B 3:1-5:1
- Main backgrounds: QCD and W+jets (HF), data driven determination

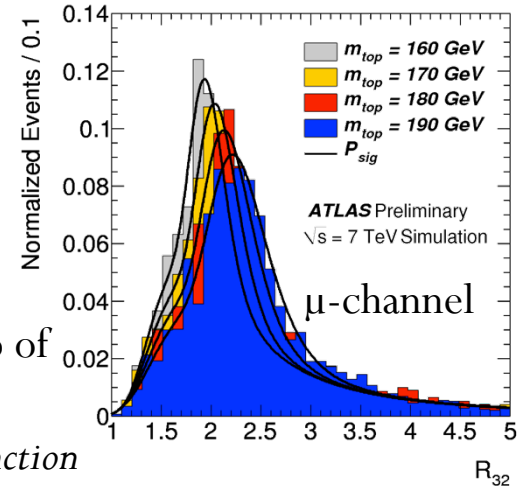
Top mass measurement

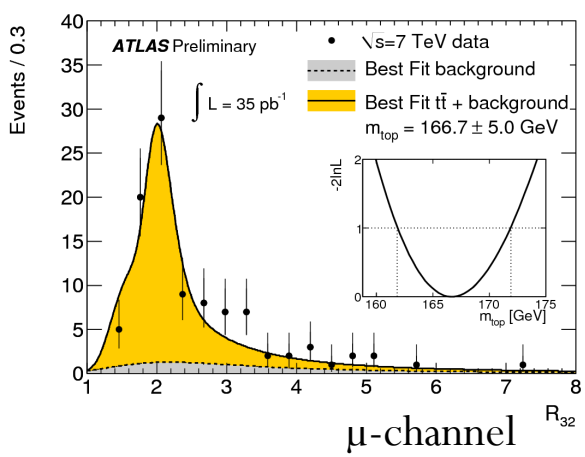
Top mass measurement

- 1-D template fit on top/W mass ratio R_{32}

$$R_{32} = \frac{m_{\text{top}}^{\text{reco}}}{m_W^{\text{reco}}}$$

  - $m_{\text{top}}^{\text{reco}}$ **three jets** with highest vector sum p_T
  - m_W using **the two non *b*-tagged jets** with smallest distance in top rest frame, **select events with 60< m_w<100 GeV**
  - Less sensitive to jet energy scale uncertainties
- m_{top} dependent **signal** templates (ttbar+single top): ratio of *two Gaussians+Landau function*
- **Background** template (MC and data driven): *Landau function*





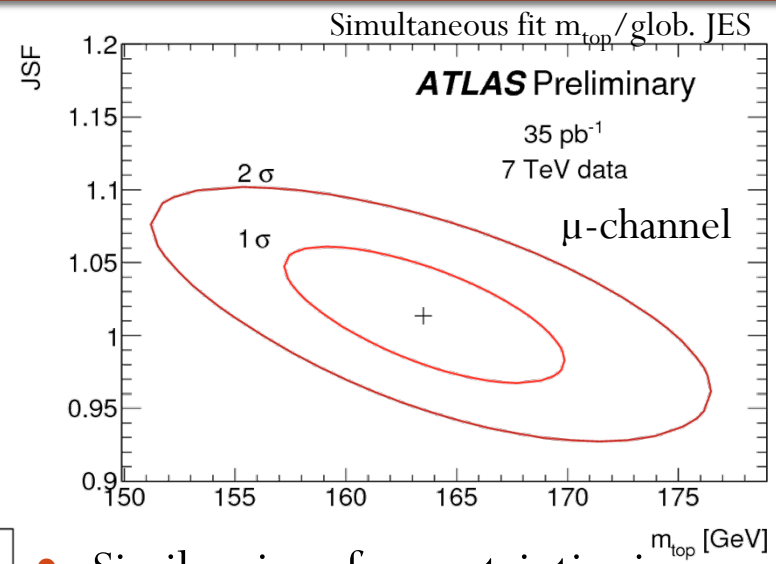
- Unbinned likelihood fit for mass extraction
  - Combined e+μ channel
    m_{top}=169.3±4.0(stat.) ±4.9(syst.) GeV

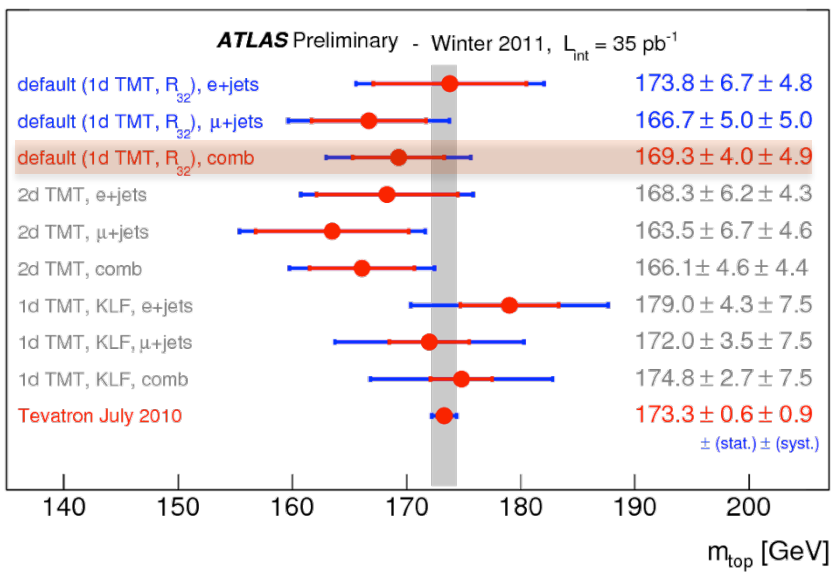
Dominant systematics

Uncertainty [GeV]	e-channel	μ-channel
Statistical	**6.7**	**5.0**
ISR/FSR	2.2	2.6
Jet energy scale	2.3	1.9
b-jet energy scale	2.5	2.5
Total systematic	**4.8**	**5.0**

Top mass measurement

- Cross check analyses
- Template method
  - m_{top} distributions from kinematic fit
- Simultaneous fit to m_{top} and global JES factor
  - reduced JES uncertainty, but increased statistical uncertainty

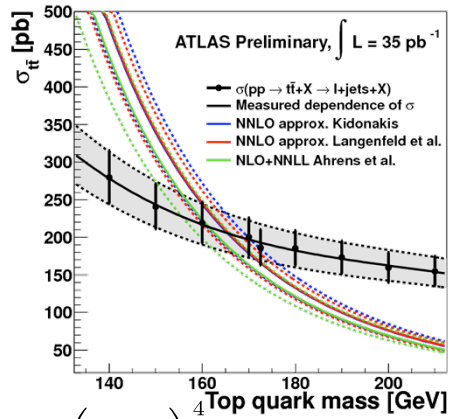




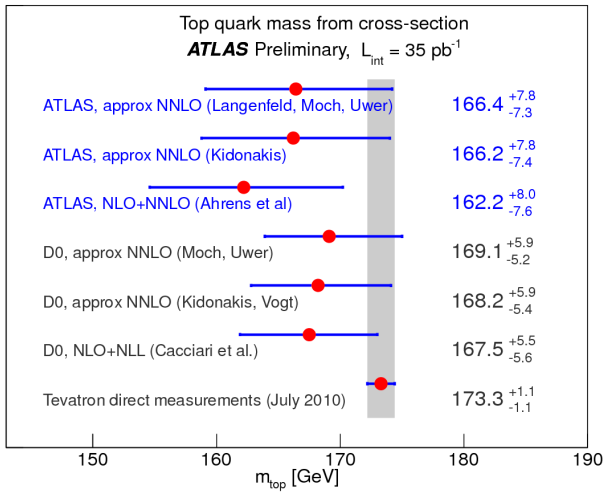
- Similar size of uncertainties in e/μ channel
- Consistent result with all methods and channels
- Smallest uncertainty from 1D template fit:
  - **2.4%(stat.)**
  - **3.7%(syst.)**

Top mass from cross section

- Measure the ***pole mass*** from cross section
  - Unambiguous definition of top mass
  - Test consistency of QCD cross section calculations



$$\sigma_{t\bar{t}} = \left(\frac{1}{m_{\rm top}^{\rm pole}}\right)^4 (a + bx + cx^2 + d^3)\,{\rm pb}$$
$$\text{with } x = m_{\rm top}^{\rm pole} - 170\,{\rm GeV}$$



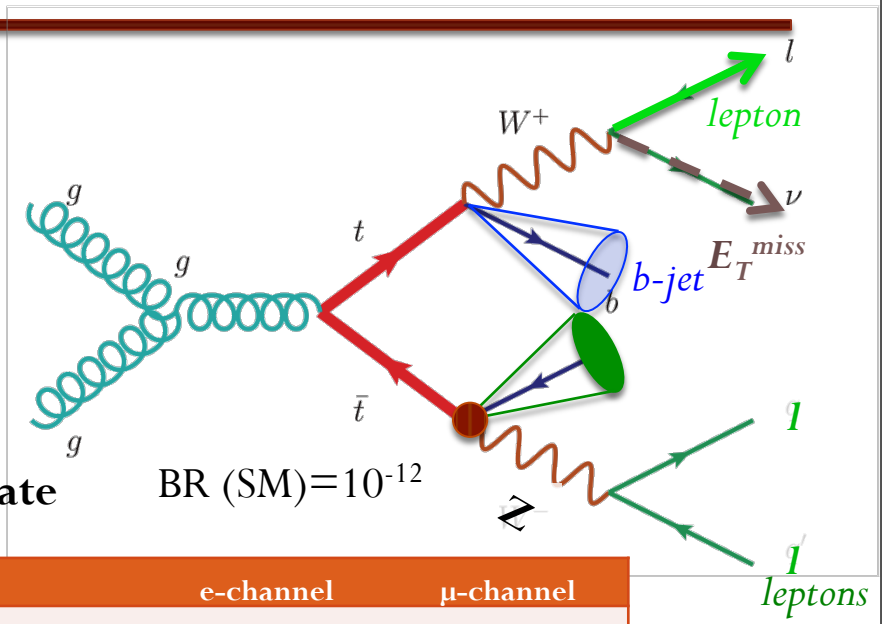
- Using multivariate l+jets b-tag cross section analysis vs. m_{top}
- Three theory calculations
- Uncertainty from
  - cross section (13%) 5GeV
  - scales+PDF 3GeV

- With approx. NNLO Langefeld $\mathbf{m_{top}=166.4^{+7.8}_{-7.3}GeV}$

FCNC, $T \longrightarrow tA^0$, W-helicity,

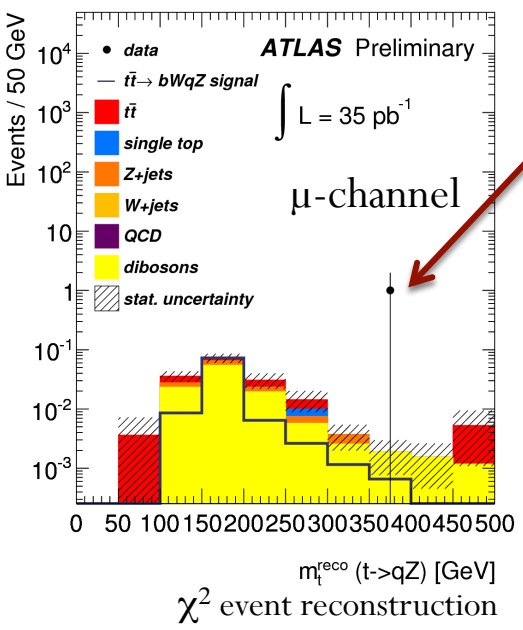
FCNC ttbar

- FCNC vertex t⟶Zq
  - **fully leptonic** to suppress multi-jet background
  - Selection on 3 leptons (p_T>25,20,15GeV), two of them same flavor and OS



BR (SM)=10^{-12}

Only one candidate



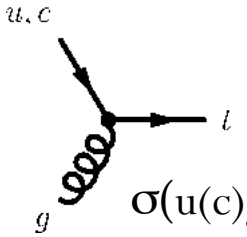
χ^2 event reconstruction

	e-channel	μ-channel
W+jets	0.00±0.08	0.00±0.08
Z+jets	0.10±0.08	0.02±0.01
Dibosons	0.08±0.01	0.11±0.01
ttbar	0.05±0.02	0.04±0.02
Single-top	0.00±0.00	0.00±0.00
Exp. bkg.	**0.23±0.11**	**0.17±0.08**
Data	**0**	**1**
Signal eff. [%]	*8.53±0.09*	*11.96±0.11*

Limits on BR(**t⟶Zq**) (mod. frequentist method) **BR < 17% (obs.)** **BR <12^{+4}_{-3}% (exp.)** @95%CL

FCNC single top

- FCNC vertex gq⟶t
  - Anomalous **single top production**
  - Cross section below *Wt*-channel

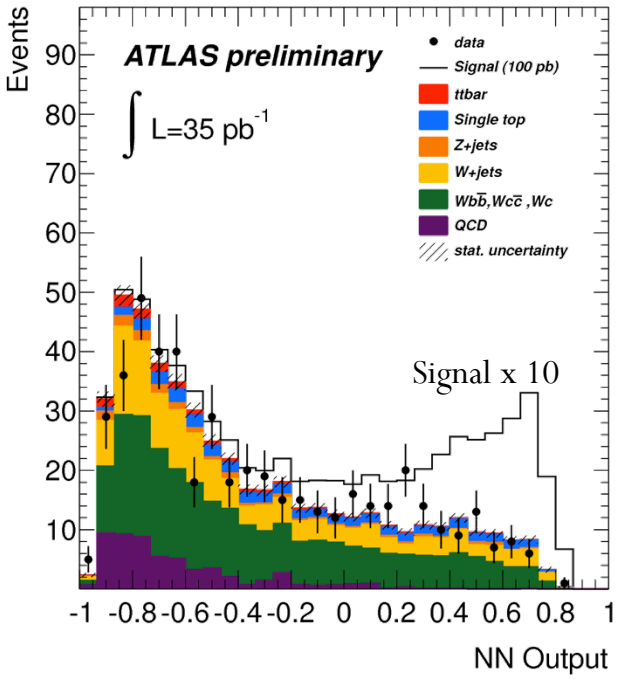


σ(u(c)g⟶t)=10pb

  - Event selection with exactly one *b*-tagged jet
  - Neural network analysis with 13 input variables
  - Limit on σ(u(c)g⟶t)*BR
    - Upper limit from Bayesian posterior:

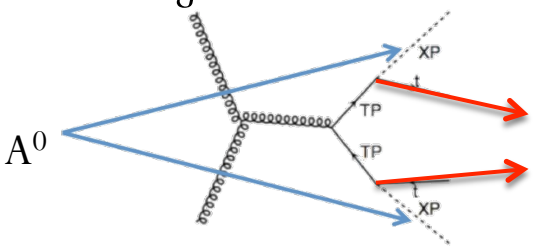
      σ(u(c)g⟶t)*BR<17.3pb (obs.)
      σ(u(c)g⟶t)*BR<$17.4^{+8.2}_{-5.4}$ pb (exp.)

  - Systematics from ISR, JES and W+jets HF fraction



Anomalous E_T^{miss}

- Large E_T^{miss} in lepton+jets events
  - from *exotic top partner T* decay into top quark and *neutral long lived scalar* A^0
  - use $T \longrightarrow tA^0$ as benchmark



Alwall, Feng, Kumar *et al.* (2010)
Berger, Cao (2009)

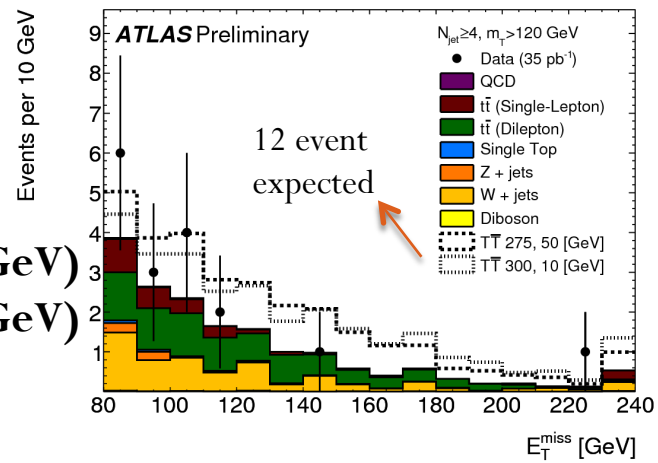
- Event selection:
  - no b-tag required
  - E_t^{miss}>80GeV, transverse mass >120GeV
  - restrictive dilepton veto p_T>15GeV, isolated track, looser electron selection

No disagreement with SM

Exclusion at 95% CL:

m_T<275GeV (m_{A0}<50GeV)

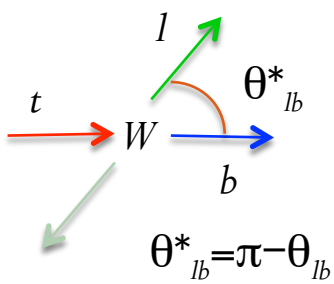
m_T<300GeV (m_{A0}<10GeV)

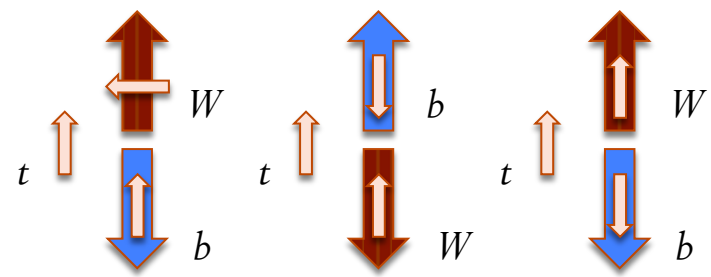


	Yield
single lepton	8.4±1.6
dilepton	7.6±2.0
Z+jets	0.4±0.1
Dibosond	0.2±<0.1
Single-top	0.4±0.1
QCD	0.2±0.6
Total Bkg	**17.2±2.6**
Data	**17**

W helicity in top decays

- W helicity fractions in SM
  - Sensitive variable θ^*_{lb} in W rest frame





longitudial F_0=0.698 | left handed F_L=0.301 | right handed F_L=0.00041

- <u>Asymmetry method</u>
  - χ^2 method reconstruct events
  - Unfold cos θ^*_{lb} distribution to parton level
  - Compute asymmetry A_z at three z values sensitive to the three helicity fractions

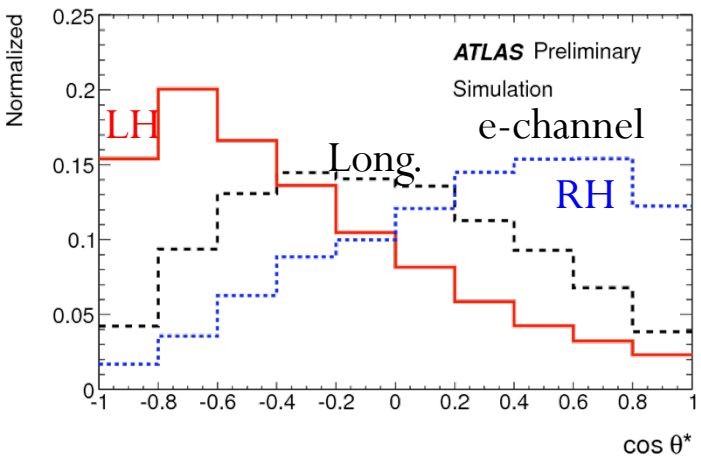
$$A_z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$$

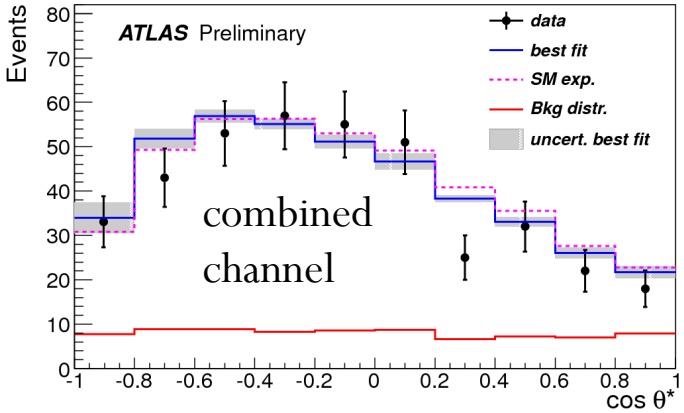
	combined
F_0	0.65±0.15
F_L	0.36±0.10
F_R	-0.01±0.07

W helicity in top decays

- Template method
  - Using kinematic fitter to reconstruct final state
  - Binned likelihood fit to simulated distributions from pure helicity states to data

	combined
F_0	0.59±0.12
F_L	0.41±0.12
F_R	0 fix





- Both compatible result with SM
  - Statistically limited 16%
  - ISR/FSR 7%, JES 5%, background shapes 5%

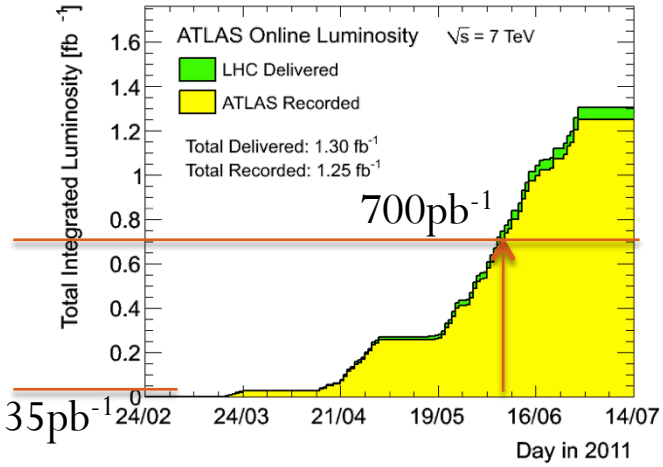
Charge asymmetry

New result with ~700pb^{-1}

Charge asymmetry

New result with 700pb^{-1}

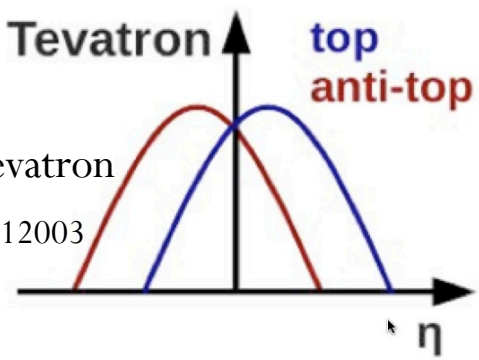
- ΔL=**4.5%** luminosity uncertainty
- Peak luminosity **1.75 10^{33}** cm^{-2}s^{-1}
- max. **10-12PV** per event on average
- Lepton trigger thresholds higher, reconstructed p_T>25GeV

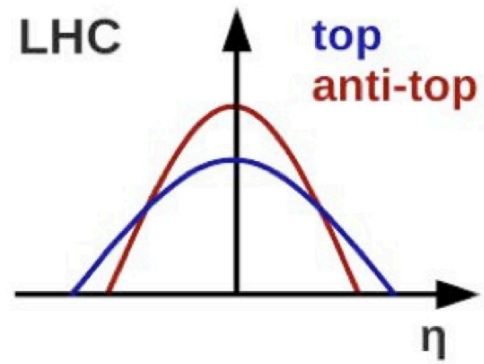


- $|q\bar{q} \to t\bar{t}g + qg \to t\bar{t}q|^2$ not symmetric under C conjugation (Tevatron)
  $gg \to t\bar{t}$ symmetric under C conjugation (LHC)

2-3.4σ excess @ Tevatron

Phys. Rev. D **83** (2011) 112003
D0 6062-CONF (2010)



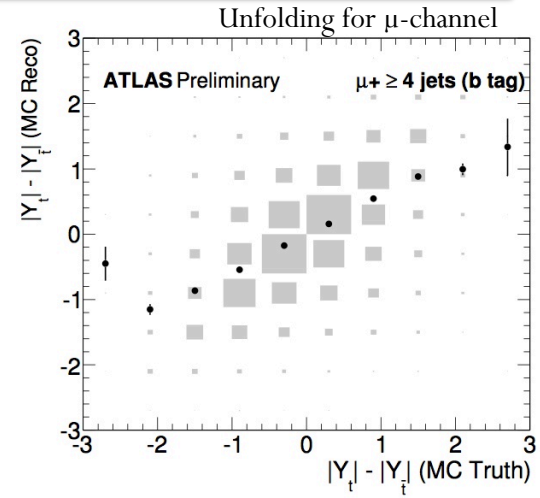


Charge asymmetry

- Modification of **charge asymmetry** in ttbar production due to new physics possible
  - Measure rapidity of top and antitop

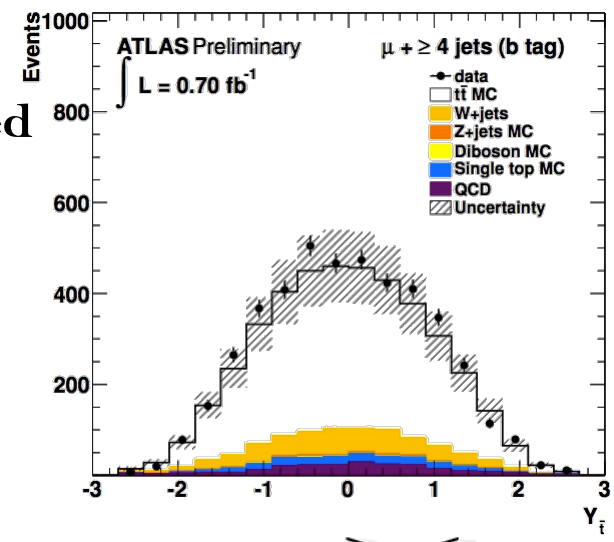
$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)} \quad \Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$

  - Reconstruct final state with kinematic fit
  - Unfold to parton level to enable comparison with theory



A_C=-0.020±0.016(stat.)±0.034(syst.) combined

Theory (MC@NLO) A_C=0.005±0.001(stat.)



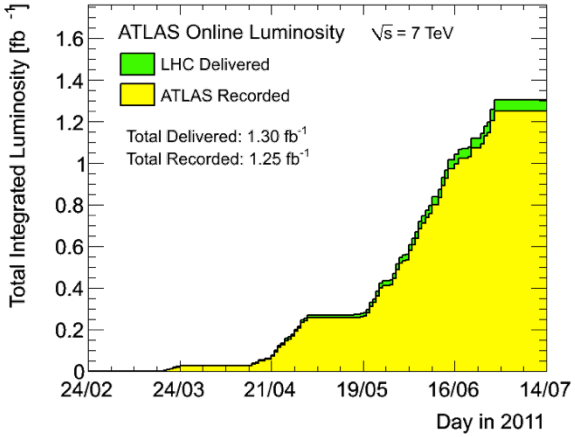
- Largest systematics
  - Theoretical modeling (generator/PS/fragmentation, mass)
  - JES, jet resolution and QCD background uncertainty

Conclusions

Conclusions

- ATLAS measurements of top properties with 35pb^{-1}
  - **Top mass** from template method: m_{top}=169.3GeV±3.7%
  - **W boson helicity** fractions in agreement with SM predictions
  - No evidence for **FCNC** in ttbar and single top
  - No evidence for **excess of events with large E_T^{miss}**
  - **Charge asymmetry** compatible with SM expectation

- Analyses will benefit from 2011 data
  - Already >1fb^{-1} by now (July 2011)
  - Systematic will be reduced with better understanding of detector



- 2011 will open the door for precision top property measurements at the LHC

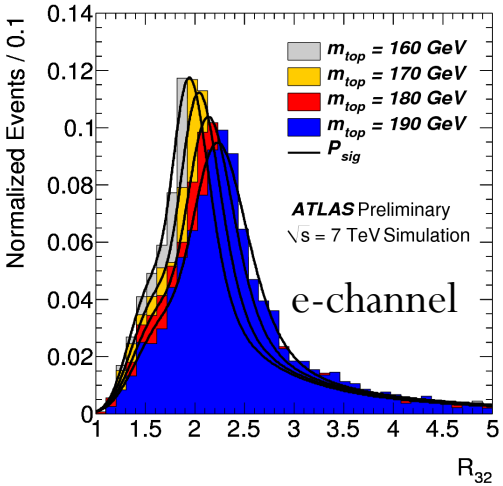
References

- Top Mass: ATLAS-CONF-2011-033
- Top Mass from cross section: ATLAS-CONF-2011-054
- W helicity: ATLAS-CONF-2011-037
- FCNC: ATLAS-CONF-2011-061
- Anomalous E_T^{Miss}: ATLAS-CONF-2011-036
- Charge asymmetry: ATLAS-CONF-2011-106

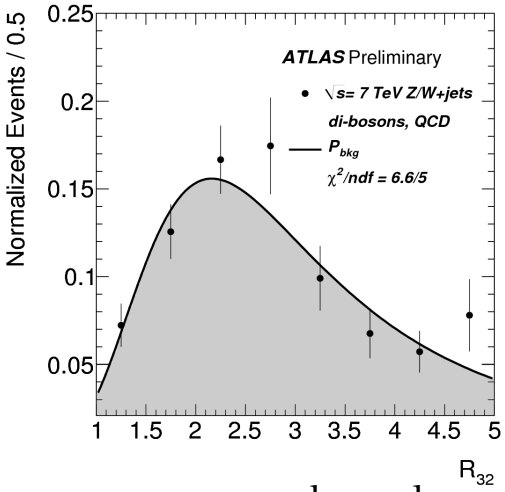
Backup

Top mass measurement

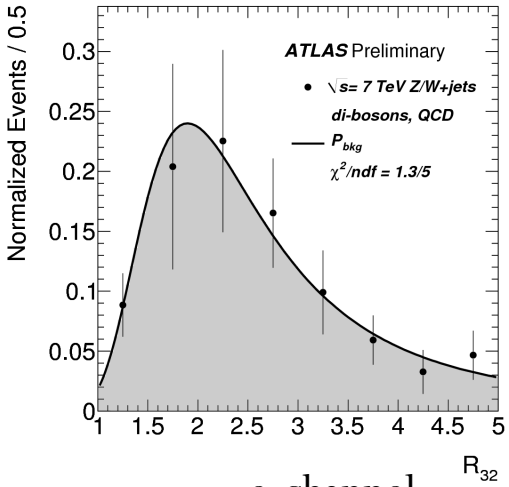
- 1D-template
  electron channel



- 1D-template, background
  muon channel, electron channel



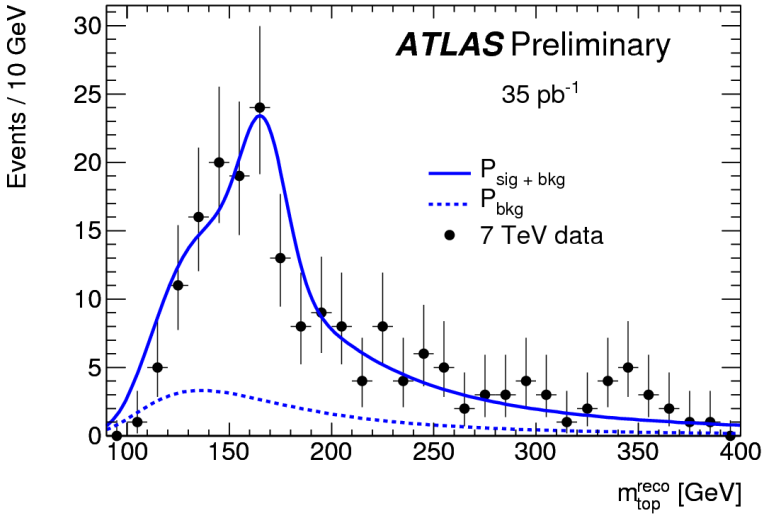
μ-channel



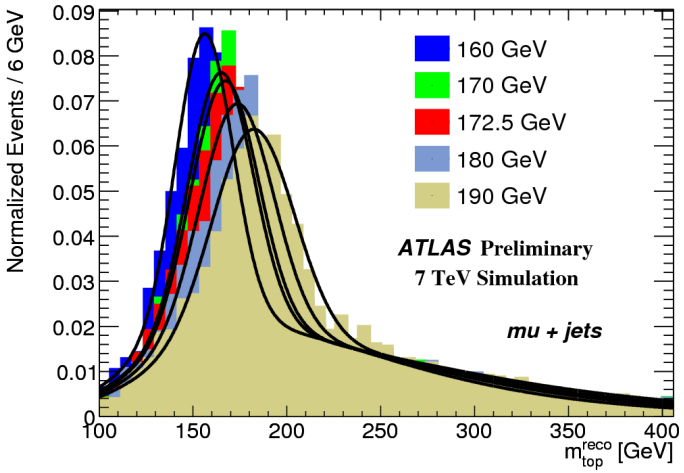
e-channel

Top mass measurement

- Mass distribution 2D-fit muon channel

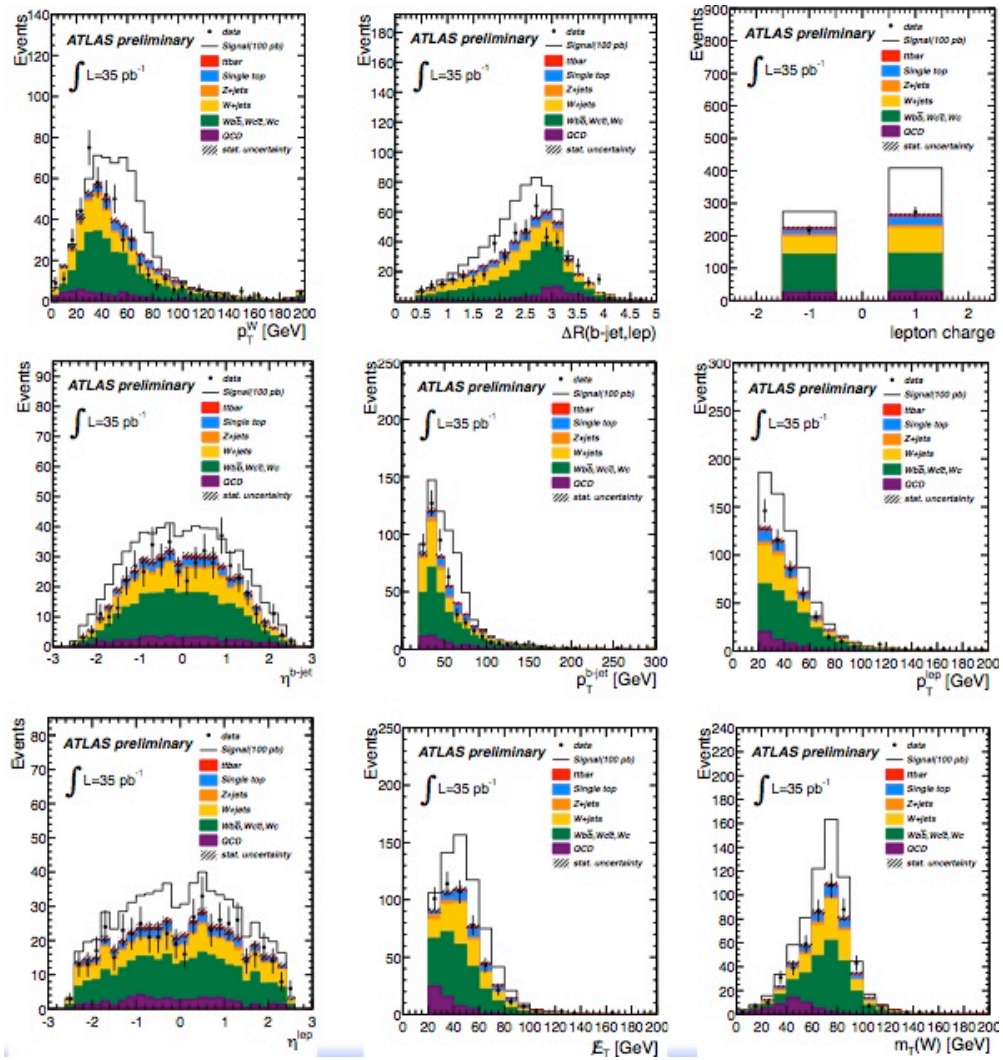


- Templates 1D-kinfit muon channel



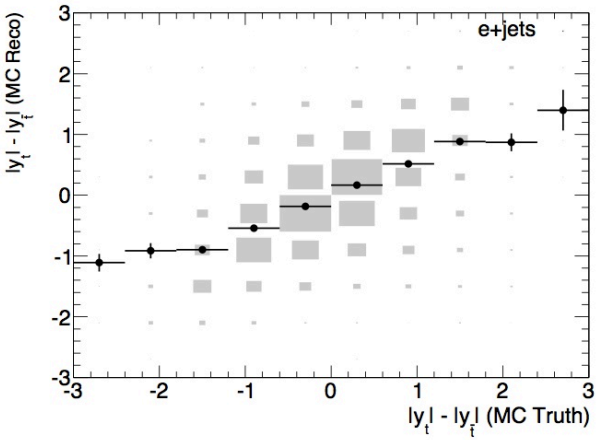
- FCNC NN inputs

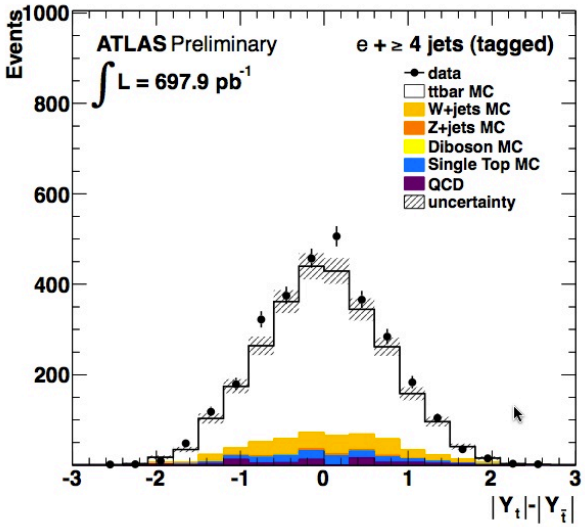
Variable	Significance (σ)
$p_{T,W}$	66
Δ R(ℓ, b)	29
Lepton charge	22
m_t	20
$\Delta\phi(W, b)$	18
η_b	16
W-boson helicity	10
$p_{T,b}$	9.3
$p_{T,t}$	6.9
η_ℓ	6.6
$\not{E}_T$	3.8
m_T^W	4.3
$\Delta\phi(\ell, b)$	4.2



Charge asymmetry

- Electron channel





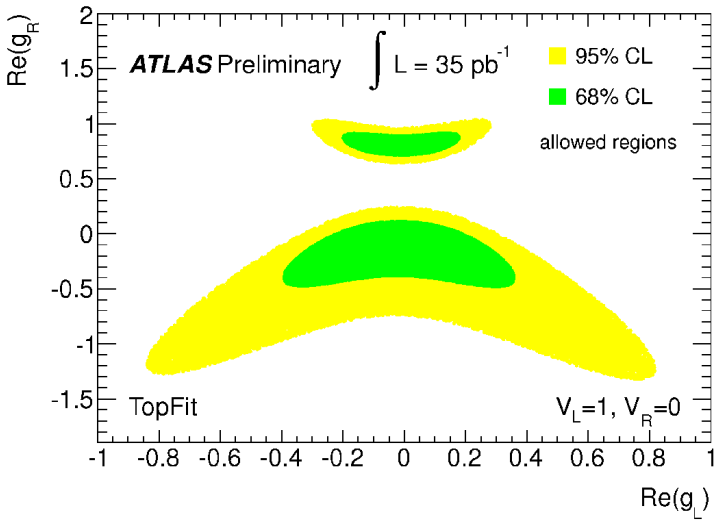
W helicity in top decays

- Setting limits on possible anomalous couplings:

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

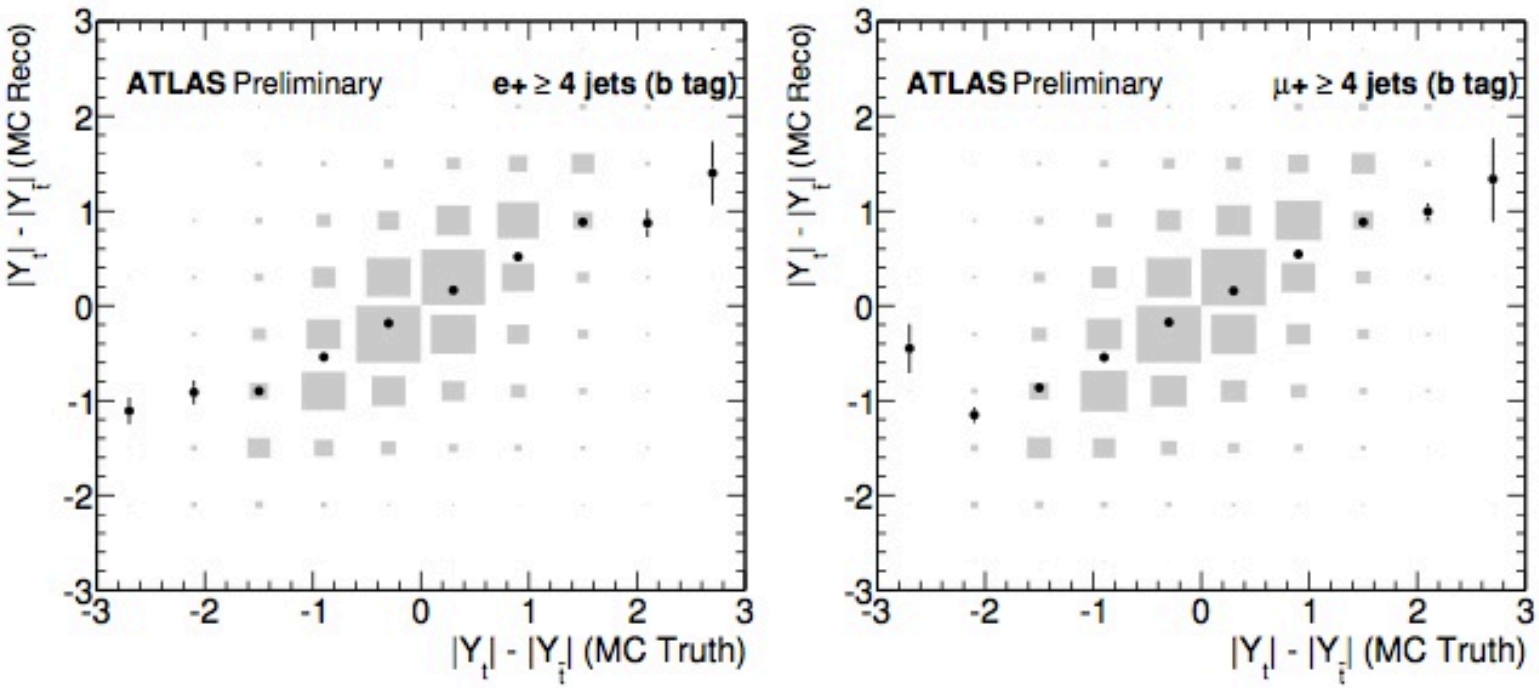
Nucl. Phys. B 840 (2010) 349, Eur. Phys. J. C50 (2007) 519

- From asymmetry method:
  - $-0.44 < V_R < 0.48$
  - $-0.24 < g_L < 0.21$
  - $-0.49 < g_R < 0.15$ @ 95% CL



Charge asymmetry

- Transfer matrix

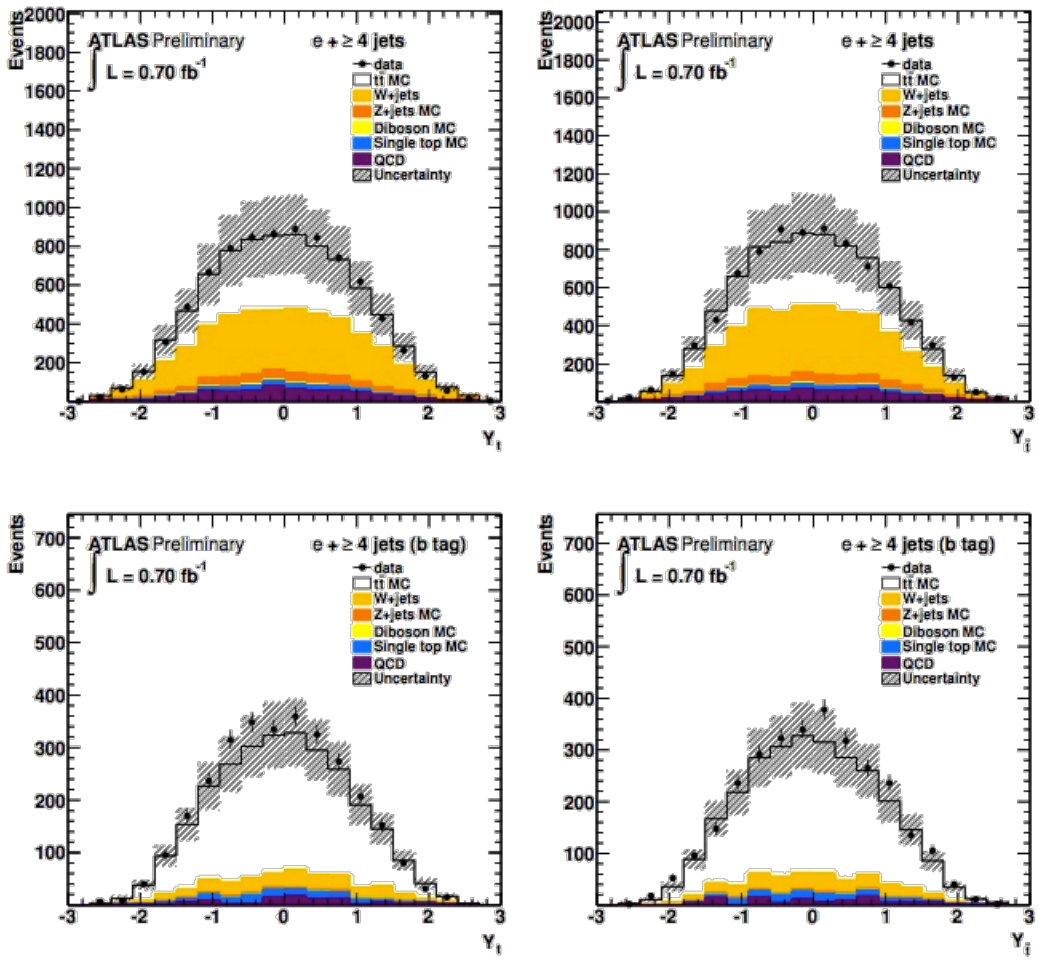


(a) Response Matrix (e+jets)

(b) Response Matrix (μ+jets)

Charge asymmetry

- Rapidity distributions electron (before/after unfolding)



Charge asymmetry

- Rapidity distributions muon (before/after unfolding)