Measurement of the top quark properties at the ATLAS experiment

Nuno Castro
nfcastro@lip.pt

LIP seminar
26/07/2012

Outline

- Introduction
  - Why study the top quark?
  - The ATLAS detector
- Reconstruction of the objects needed for top analyses
- Top quark properties (using $t\bar{t}$ events)
  - Precision measurements
  - New physics in top production or decay?
- Searches for top-like BSM signatures

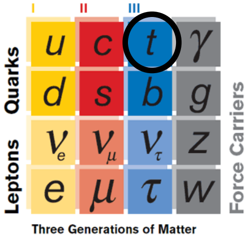
All results available in:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

The top quark

- Top quark completes the 3 family structure of the SM
  - top is the weak-isospin partner of the *b*-quark
  - spin = $1/2$
  - charge = $+2/3\ |e|$

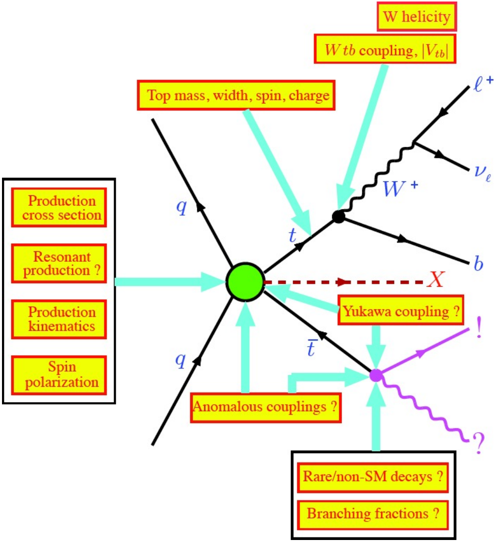


- Top quark is the heaviest known quark ($m_t = 173.2 \pm 0.9$ GeV, CDF+ D0, arXiv:1207.1069)
- Top decays (almost exclusively) through $t \rightarrow bW$
  $BR(t \rightarrow sW) \leq 0.18\%$, $BR(t \rightarrow dW) \leq 0.02\%$
- $\Gamma_t^{SM} = 1.42$ GeV (including m_b, m_W, α_s, EW corrections)
  - Λ_{QCD}^{-1}=(100 MeV)$^{-1}$=10^{-23}s (hadronization time)
  - $\tau_t \ll 10^{-23}$ s
    $\Rightarrow$ top decays before hadronization

Why the Top quark @ LHC ?

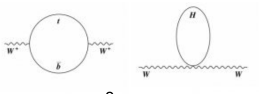
☞ It has a rich phenomenology

- $t\bar{t}$ production
  - $\sigma_{t\bar{t}}$
  - Mass
  - Charge asymmetry
  - Top Charge
  - Rare top decays
  - $t\bar{t}\gamma$ production
  - $t\bar{t}$ resonances
  - W polarization
  - Wtb vertex structure
  - $t\bar{t}$ Spin correlations
- Single top production
  - cross section
  - FCNC
  - polarization

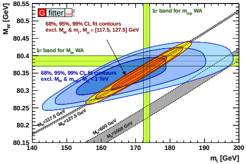


The top quark as a probe for beyond SM physics

- Large mass of the t-quark:
  - $\lambda_t = \sqrt{2} m_t / v \sim 1$ ☞ special role in EWSB?
  - top and W masses constrain the Higgs mass



$\Delta m_W \propto m_t^2$ $\Delta m_W \propto \ln m_H$

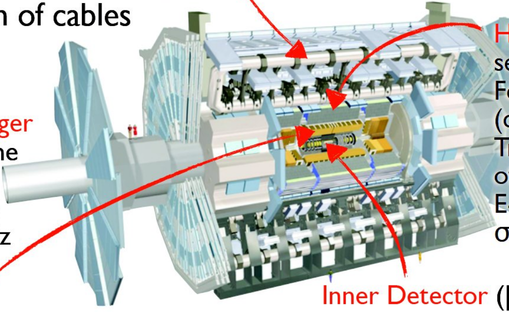


- BSM physics often has consequences in the top sector:
  - $t\bar{t}$ and single top production can be affected by BSM models
  - Wtb vertex: can have a BSM structure
  - rare top decays: BSM models can increase the BR of t-quark decays via FCNC
  - Non-SM Higgs: large coupling to the top
  - Incorporate Gravity using Extra Dimensions: many models predict new states with strong coupling to the top
  - 4th gen. / vector-like quarks: often decay to t-quarks or look like a heavy t
  - ...

The ATLAS detector

Length : ~ 46 m
Diameter : ~ 24 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers; Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV



HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution:
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

3-level trigger reducing the rate from 40 MHz to 200-300 Hz

EM calorimeter ($|\eta|<3.2$):
Pb-LAr Accordion; e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

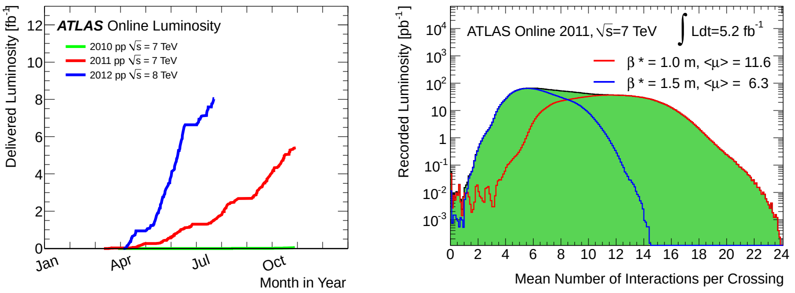
Inner Detector ($|\eta|<2.5$, B=2T): Si Pixels, Si strips, Transition Radiation detector (straws); Precise tracking and vertexing, e/π separation Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\text{GeV}) \oplus 0.015$
i.e. σ/p_T <2% for p_T < 35 GeV

The ATLAS detector

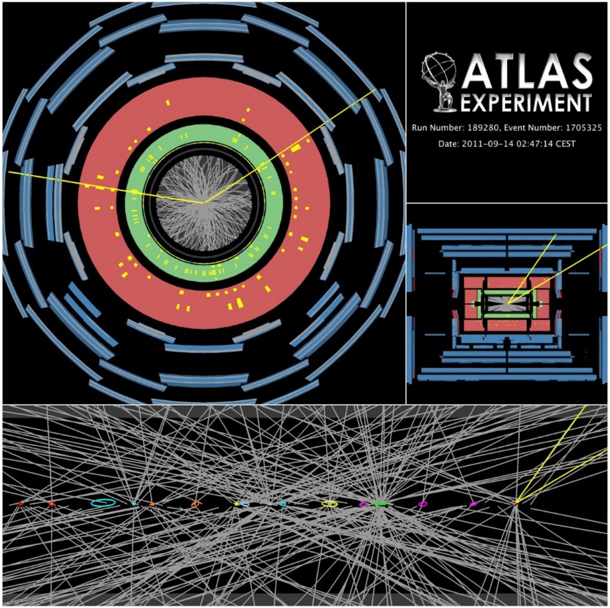
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	99.5%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	99.7%

ATLAS p-p run: March-October 2011										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	96.9	99.2	99.4	98.8	99.4	99.1	99.8	99.3
All good for physics: 89.9%										

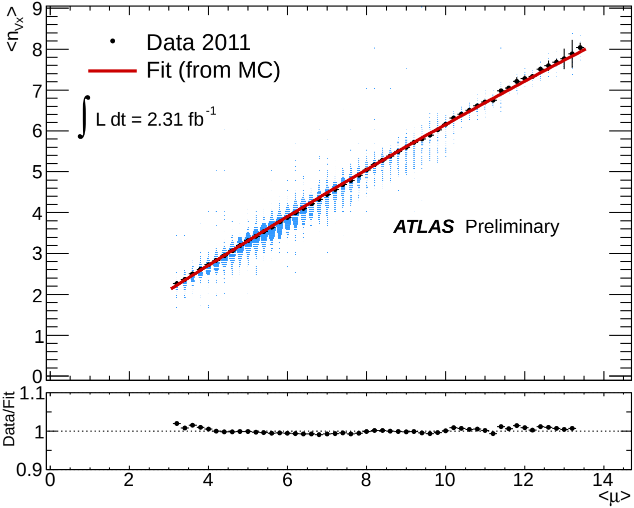
2011 data ($\sqrt{s} = 7$ TeV)



Pileup


ATLAS
EXPERIMENT
Run Number: 189280, Event Number: 1705325
Date: 2011-09-14 02:47:14 CEST

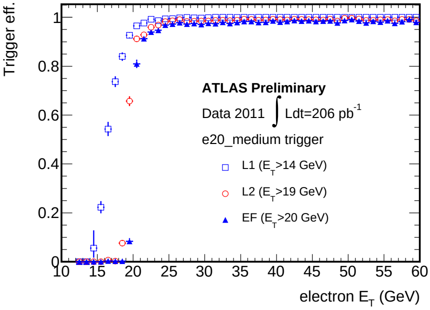
Pileup

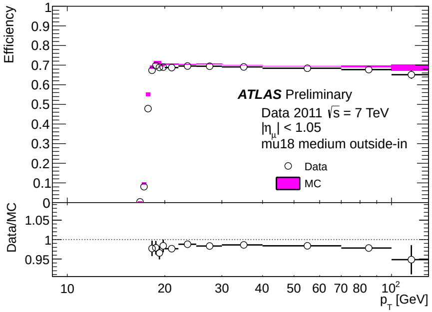


Data 2011
Fit (from MC)
∫ L dt = 2.31 fb^-1
ATLAS Preliminary
<n_Vx>
Data/Fit
<μ>

Triggers for top analyses

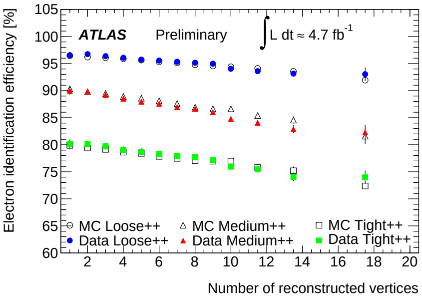
- Single lepton (e, μ) triggers
  - p_{T} thresholds: 20 (22) GeV for e and 18 GeV for μ
  - Eff. measured with tag-and-probe method (in Z events)





Electron reconstruction

- Reco. eff. for offline electrons $\sim$ 95% (tight reco)
- Stable w.r.t. pileup ($\sim$ 1%)
- Measured with data-driven method (tag-and-probe)



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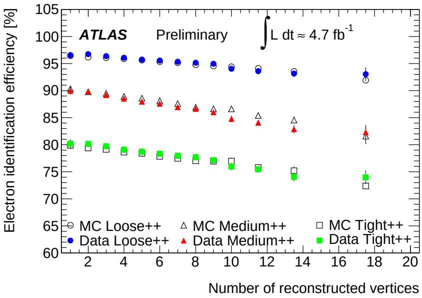
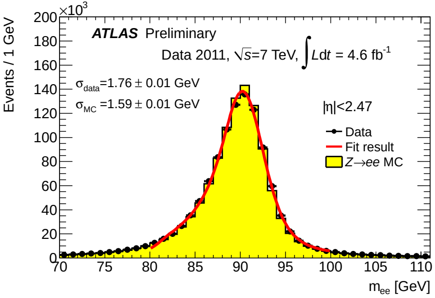
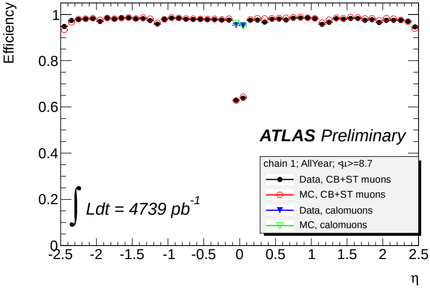




Muon reconstruction

- Reco. eff. for offline electrons $\sim$ 95% (combined muons)
- Stable w.r.t. pileup ($<$ 1%)
- Measured with data-driven method (tag-and-probe)



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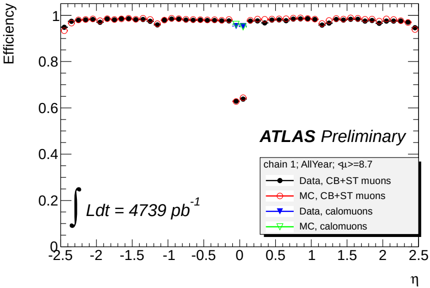
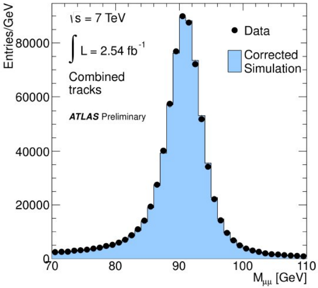
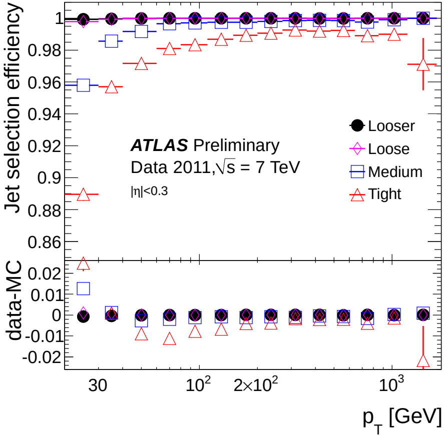




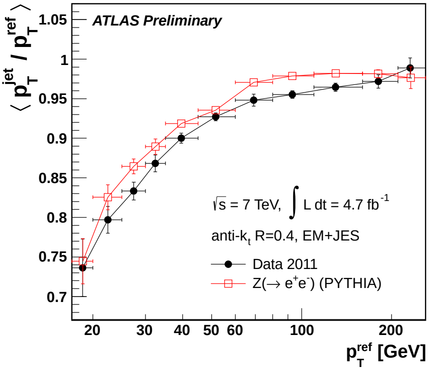
Jets reconstruction

- Di-jet events used to evaluate jet reconstruction efficiency
- Jet "cleaning" allowing to remove:
  - Noise in the calorimeters (average jet quality, f_{EM})
  - Cosmic rays or beam-induced background (f_{EM}, maximum energy fraction in any single calorimeter layer, time w.r.t. beam collision)



Jet Energy Scale (JES)

- Initial calibration of jet energy performed using MC simulation
- *in-situ* p_T balance in di-jet events ☞ $\sim$ 2.5% uncertainty in central calorimeter region for jets w/ $60 < p_T < 800$ GeV (2010 data)
- larger dataset (2011) ☞ additional *in-situ* techniques
  - $Z(\rightarrow ee)$+jet events: Z and jet balance in the transverse plane
  - data/MC comparison



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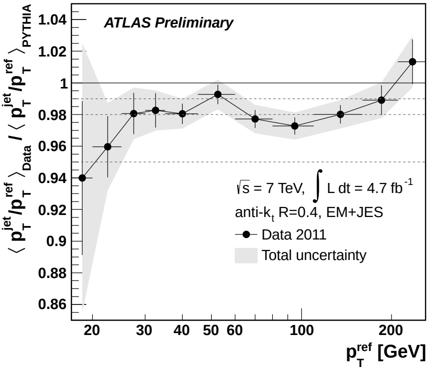

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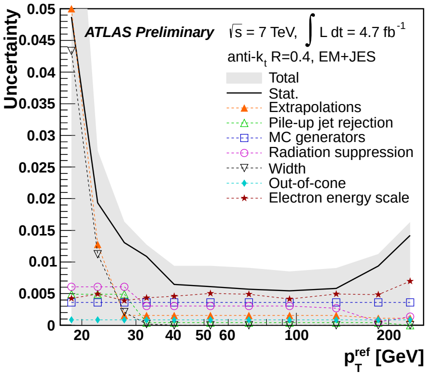
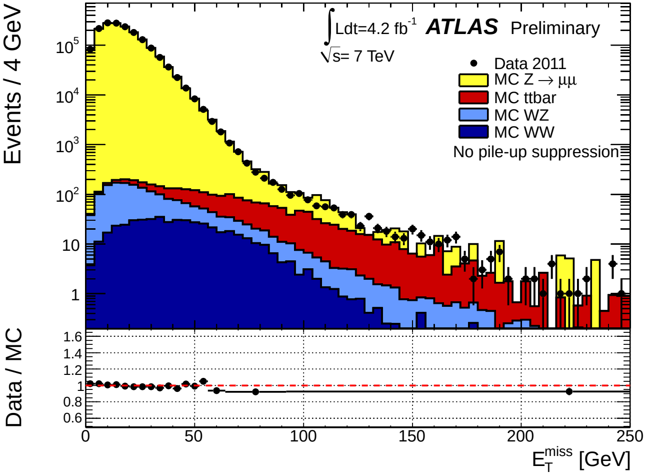


Missing transverse energy reconstruction



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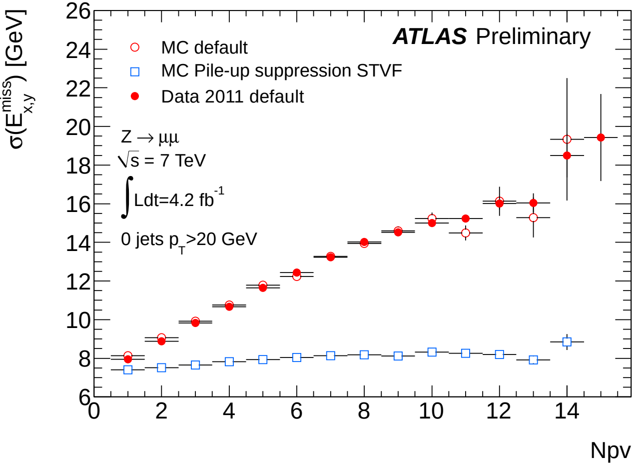
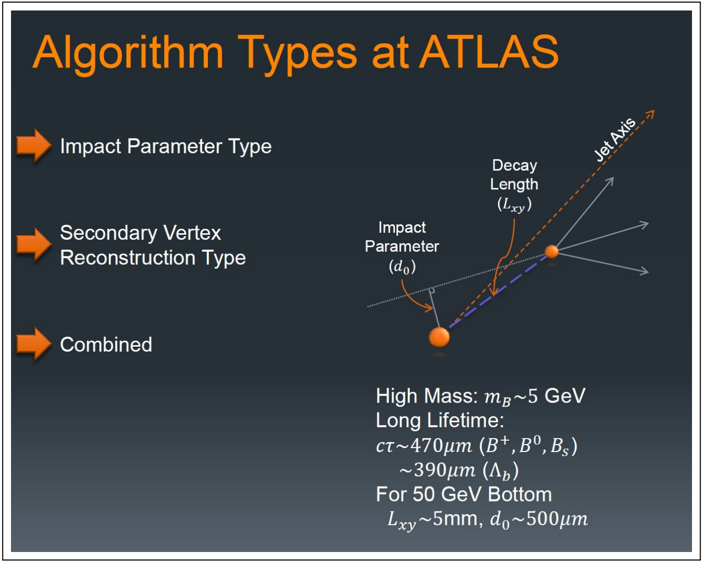
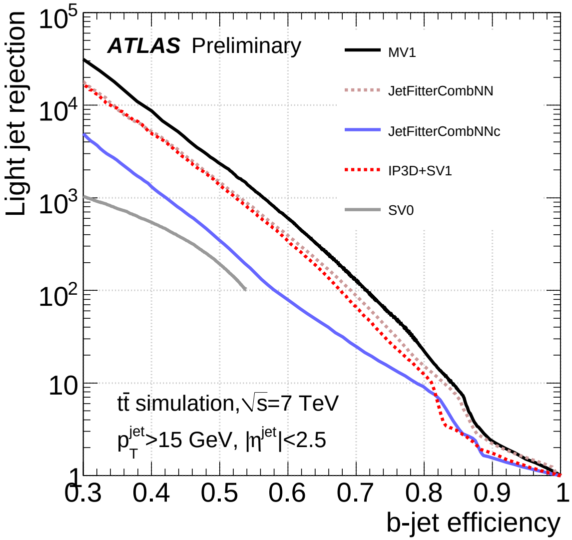


b-tagging



[slide from G. Watts' talk at DPF 2011]

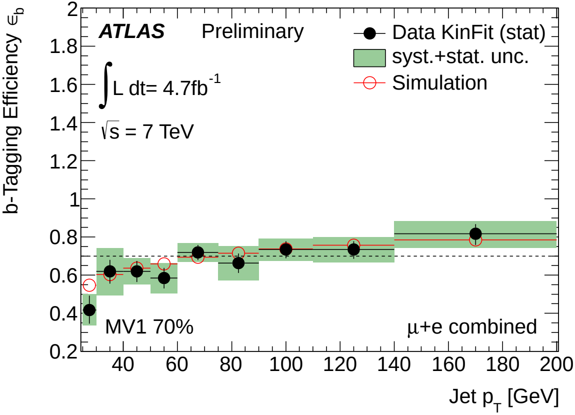
b-tagging



Light jet rejection
ATLAS Preliminary
MV1
JetFitterCombNN
JetFitterCombNNc
IP3D+SV1
SV0
tt̄ simulation, √s=7 TeV
p_T^jet>15 GeV, |η^jet|<2.5
b-jet efficiency

b-tagging efficiency measurement with $t\bar{t}$ events

- Jets' flavour composition in $t\bar{t}$ events allow the measurement of *b*-tagging efficiency (tag & count, kin. selection and kin. fit methods studied)



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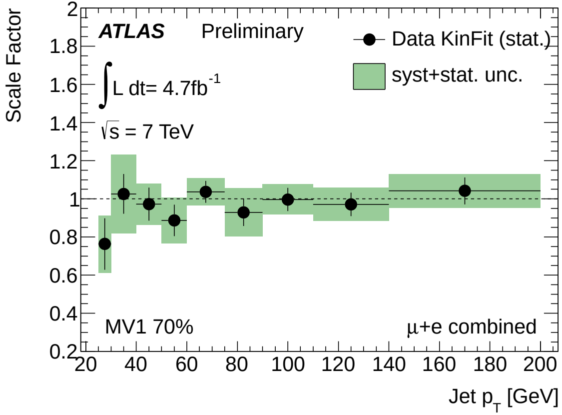
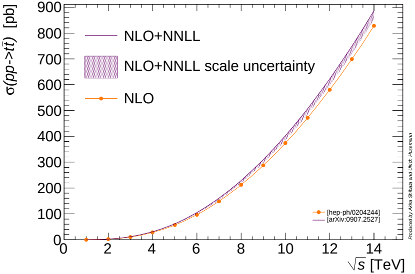
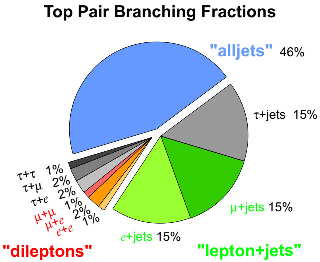
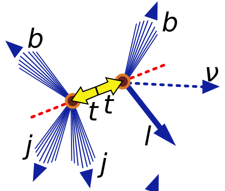


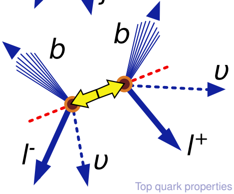
$t\bar{t}$ production at the LHC





- $\sigma(t\bar{t})$ @ 7 TeV $= 167^{+17}_{-18}$ pb (arXiv:1007.1327)
- lepton+jets topology:
  $BR(t\bar{t} \rightarrow bq\bar{q}'\bar{b}\ell\nu;\ \ell = e^{\pm}, \mu^{\pm}, \tau^{\pm}) \sim 44\%$
- dileptonic topology:
  $BR(t\bar{t} \rightarrow b\bar{b}\ell\nu\ell\nu;\ \ell = e^{\pm}, \mu^{\pm}, \tau^{\pm}) \sim 10\%$





Standard $t\bar{t}$ selection

ℓ+jets channel

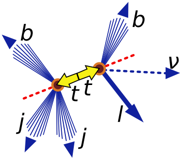
[Phys.Lett. B711 (2012), ATLAS-CONF-2011-121]

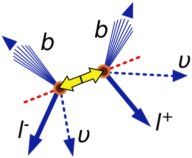
- isolated lepton (e or μ)
- missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$)
- 4 or more jets (anti-k_T, $\Delta R = 0.4$)
- at least 1 b-tagged jet

dilepton channel

[JHEP 1205 (2012) 059]

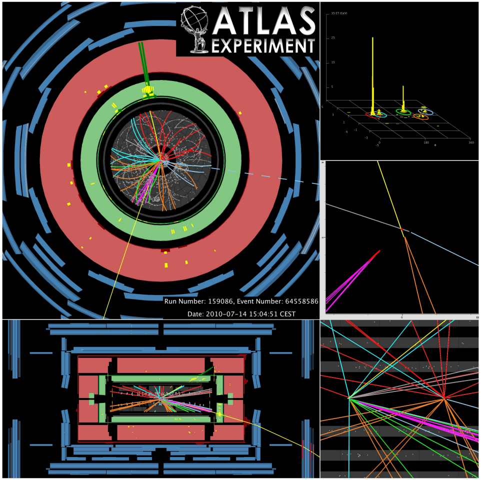
- 2 isolated leptons (ee, $\mu\mu$ or $e\mu$)
- ee, $\mu\mu$: $m_{\ell\ell}$ outside m_Z window
- $e\mu$: large scalar sum of p_T of all hard objects in the event (H_T)
- $E_{\mathrm{T}}^{\mathrm{miss}}$
- 2 or more jets



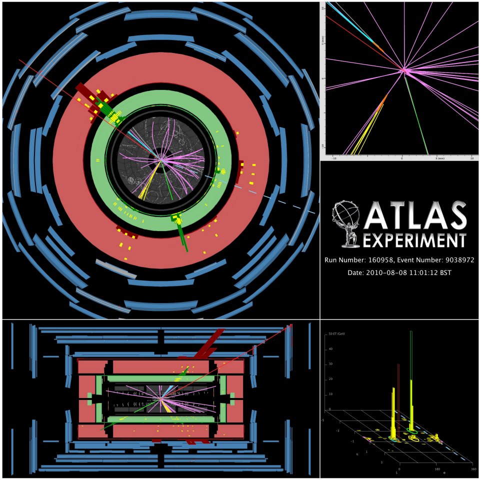


$t\bar{t}$ candidates recorded by ATLAS

single lepton (e+jets w/btag)

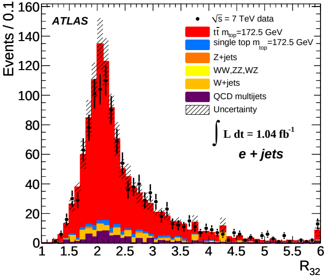


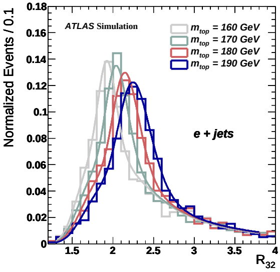
dilepton ($e\mu$+jets w/2 btag)



Measurement of the top quark mass

- single lepton events
- 1D analysis: $R_{32} = \frac{m_t^{\mathrm{reco}}}{m_W^{\mathrm{reco}}}$





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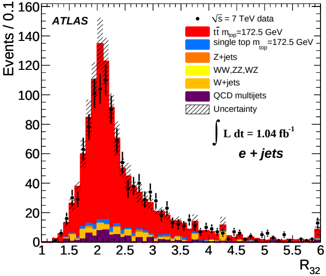
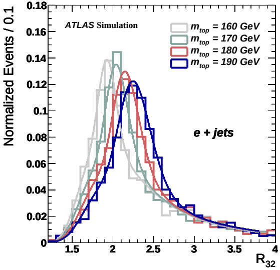
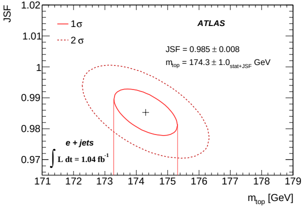
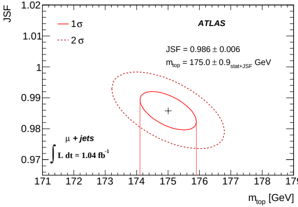




- 2D analysis: fit simultaneously m_t and jet energy scale





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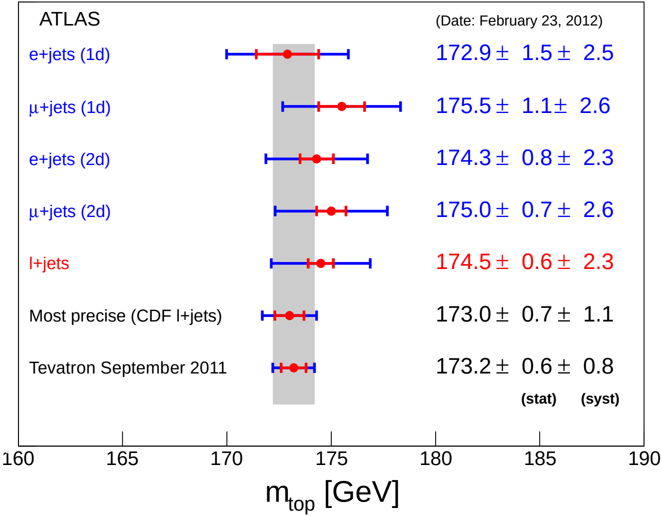

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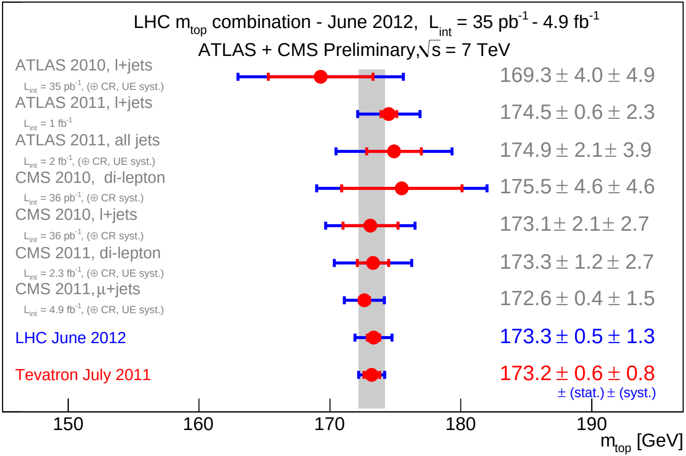
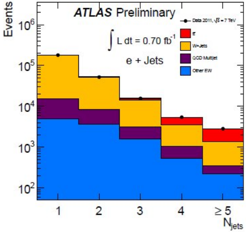
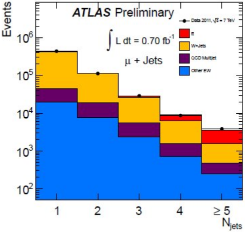
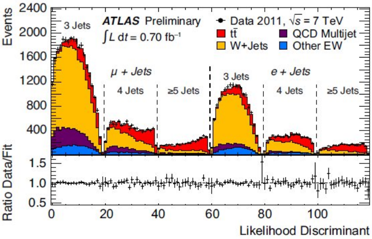


Measurement of $\sigma(t\bar{t})$: single lepton topology

- event selection:
  1 lepton (e or μ); at least 3 jets;
  $E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV (e); $m_{\mathrm{T}}^{W} > 25$ GeV (e); $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV (μ)
- main backgrounds (W+jets and fake leptons) evaluated w/ data-driven methods
- Relevant kinematic variables (η^{ℓ}, p_{T}^{j1}, aplanarity, H_{T}^{3p}) used to build a likelihood

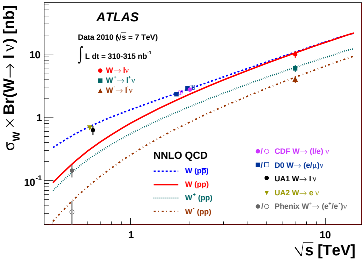






Data-driven evaluation of W+jets normalization

- Shape from Monte Carlo simulation
- Normalization obtained using W charge asymmetry
  - more u than d valence quarks in proton beams
  - more W^+ than W^- produced



  - $N_{W^+} + N_{W^-} = \frac{r_{MC}+1}{r_{MC}-1}(D^+ - D^-)$

    (assuming other back. have charge symmetry)
  - $r_{MC} = 1.56 \pm 0.06$ (electrons), $r_{MC} = 1.65 \pm 0.08$ (muons)
  - Compare $W + 1$ jet and $W + 2$ jet events w/ and wo/ b-tag

    ☞ heavy flavour fraction determination
    solving a system of equations

Data-driven evaluation of multijet events w/ fake leptons

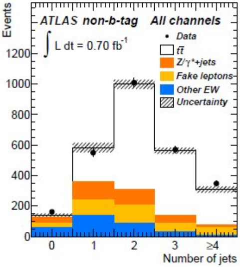
- *Matrix method* used
- *loose* and *tight* lepton selection
  - In single lepton events:

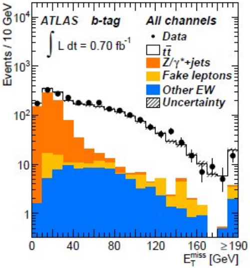
$$\begin{pmatrix} N^{\text{loose}}_{\text{obs.}} \\ N^{\text{tight}}_{\text{obs.}} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ r & f \end{pmatrix} \begin{pmatrix} N^{\text{loose}}_{\text{real}} \\ N^{\text{loose}}_{\text{fake}} \end{pmatrix}$$

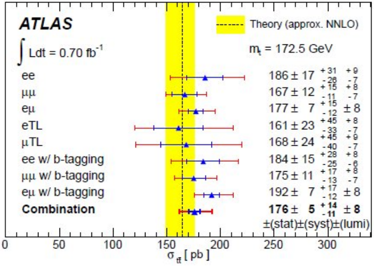
    with r (f) the probability of a real (fake) loose to be tight
  - invert matrix to determine the *true* sample composition
  - same principle for dilepton events
- Measure r and f in data (control samples)
  - $Z \rightarrow \ell^+\ell^-$ events for r
  - multijet events (reversed $E_{\mathrm{T}}^{\mathrm{miss}}$, $m_{\mathrm{T}}(W)$ cuts) for f

Measurement of $\sigma(t\bar{t})$: dilepton topology

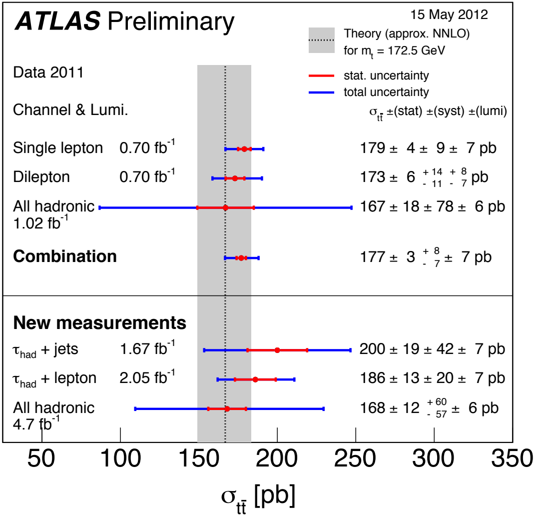
- event selection: 2 OS leptons (e, μ, TL); at least 2 jets; $m_{\ell\ell} - m_Z > 10$ GeV (SF, TL); $H_T > 130$ GeV ($e\mu$); $H_T > 150$ GeV (TL)
- main backgrounds: fake leptons from W+jets, Z+jets
- cross-section measurement for each channel measured with a profile likelihood technique







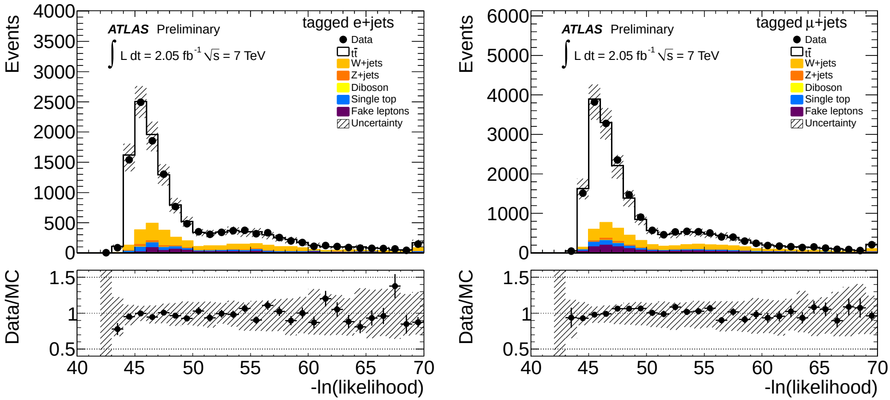
Measurement of $\sigma(t\bar{t})$



- ☞ Dominant systematics: signal modelling, lepton ID, JES
- ☞ Good agreement with SM prediction observed

Measurement of top pair differential cross-sections

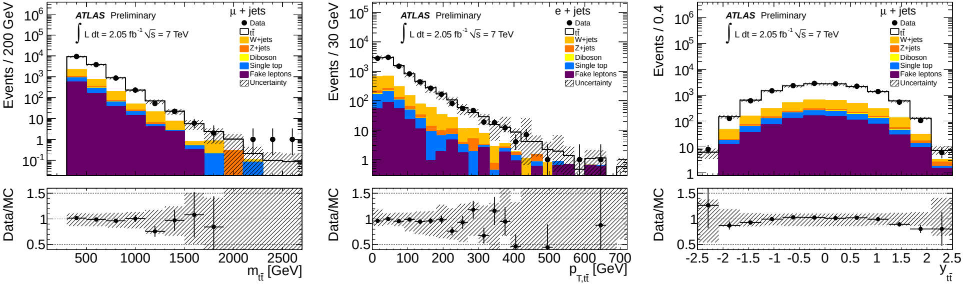
- Single lepton events considered
- $t\bar{t}$ reco. using a likelihood fit of the measured objects



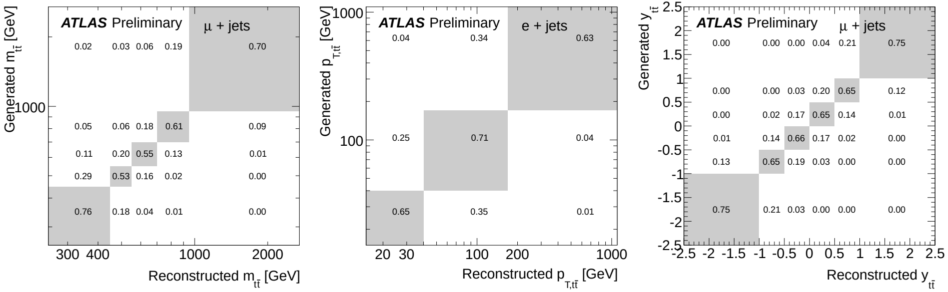
- final selection: -ln(likelihood) $>$ 52

Measurement of top pair differential cross-sections

- Distributions of $m_{t\bar{t}}$, $p_{\mathrm{T},t\bar{t}}$ and $y_{t\bar{t}}$:



- Unfolding:
  1. background subtraction;
  2. response matrix mapping the parton level → reco. migration (obtained from $t\bar{t}$ MC)
  3. Inverted matrix used to unfold the reconstructed differential distributions



- Main systematics: signal modelling, back. evaluation, JES

- Unfolding:
  1. background subtraction;
  2. response matrix mapping the parton level → reco. migration (obtained from $t\bar{t}$ MC)
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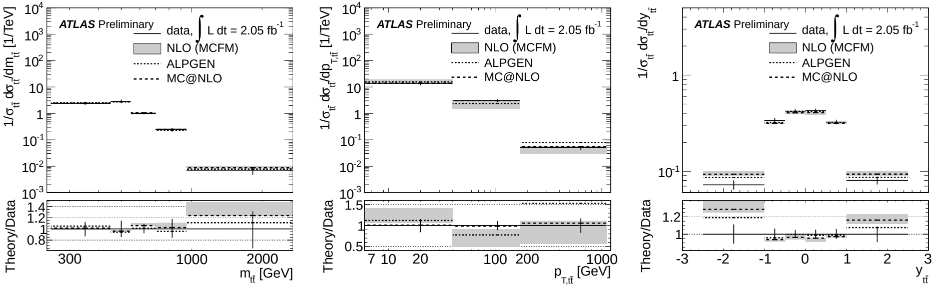
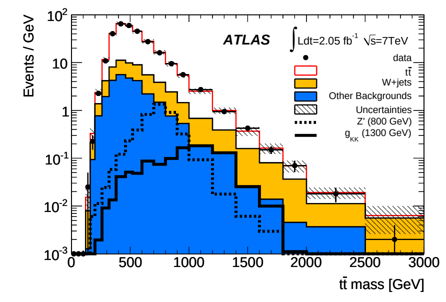


- Main systematics: signal modelling, back. evaluation, JES

Search for $t\bar{t}$ resonances

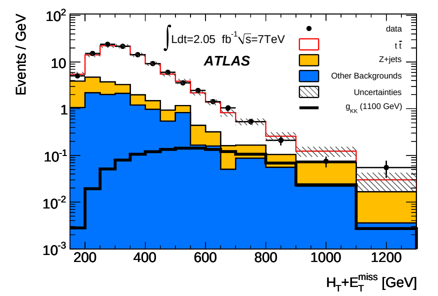
ℓ+jets channel

search for bumps in $m_{t\bar{t}}$



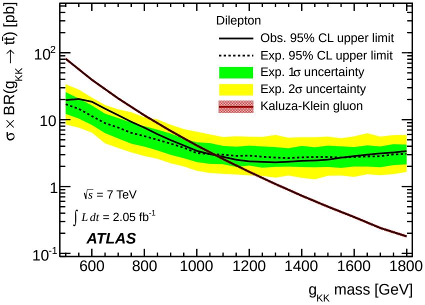
dilepton channel

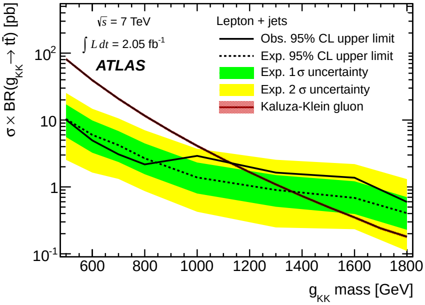
use $H_T + E_{\mathrm{T}}^{\mathrm{miss}}$ variable

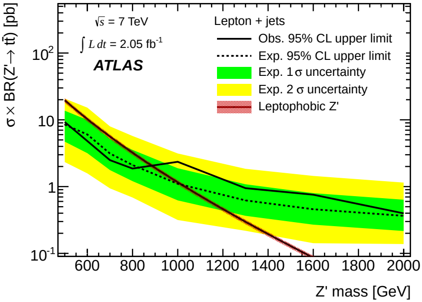


- Data in agreement with the SM expectation in both channels
- 2 benchmark scenarios considered: narrow Z' ($\Gamma/m \sim 1\%$) and broader g_{KK} ($\Gamma/m \sim 15\%$)

Search for $t\bar{t}$ resonances

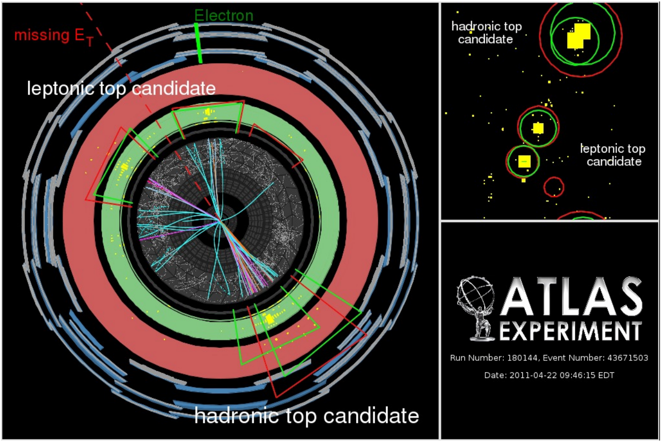






Search for $t\bar{t}$ resonances: boosted jets

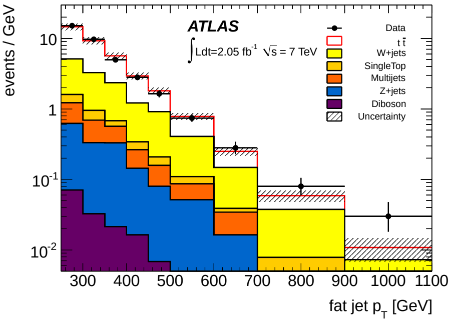
- For higher regions of p_T^t or $m_{t\bar{t}}$ the top decay products are highly boosted and can be reconstructed as only one jet
- Understanding jet substructure in *fat jets* gives access to higher values of $m_{t\bar{t}}$

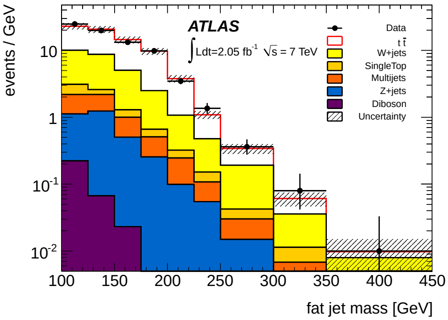


$m_{t\bar{t}} = 2.5$ TeV

Search for $t\bar{t}$ resonances: boosted jets

- Single lepton channel
- fat jet ($R = 1.0$) required to have $p_T > 250$ GeV and $m > 100$ GeV





Search for $t\bar{t}$ resonances: boosted jets

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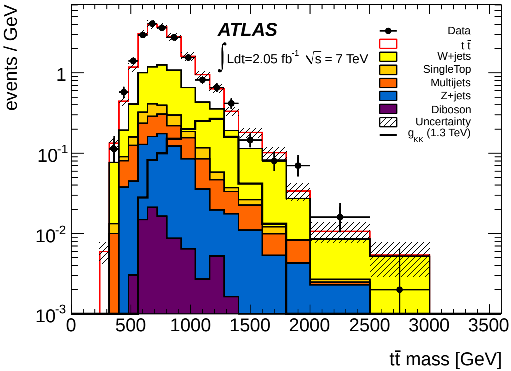
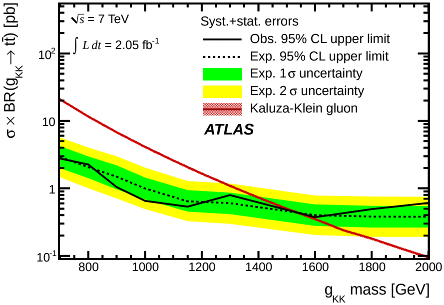
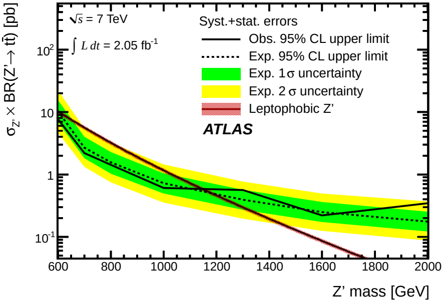


Search for $t\bar{t}$ resonances: boosted jets

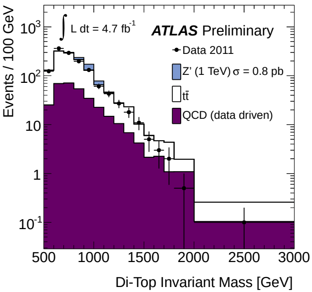
- Single lepton channel
- fat jet ($R = 1.0$) required to have $p_{\mathrm{T}} > 250$ GeV and $m > 100$ GeV

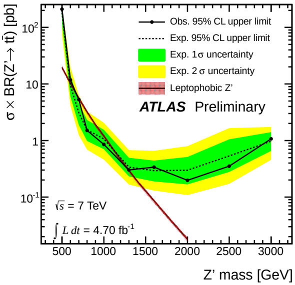


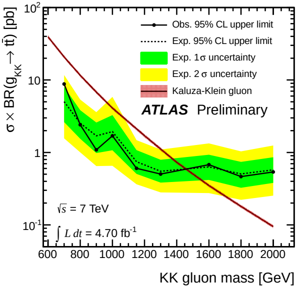


Search for $t\bar{t}$ resonances: boosted jets

- Fully hadronic channel
- at least 2 fat jets ($R = 1.5$) required to have $p_T > 200$ GeV (HEPTopTagger algorithm)

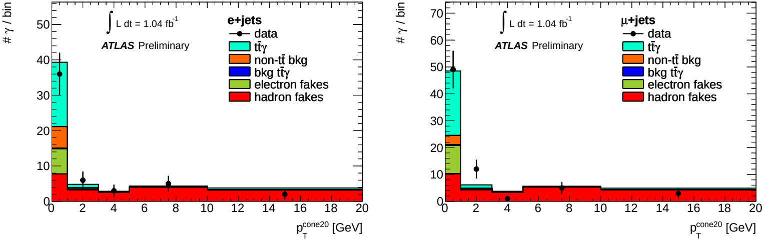






Measurement of inclusive $\sigma(t\bar{t}\gamma)$

- $\sigma(t\bar{t}\gamma)$ ☞ direct measurement of the top quark electromagnetic couplings (and, in particular, its electric charge)
- event selection similar to the one used in the single lepton channel, requiring an additional γ with $E_{\mathrm{T}} > 15$ GeV
- photon isolation used to discriminate prompt photons from fakes



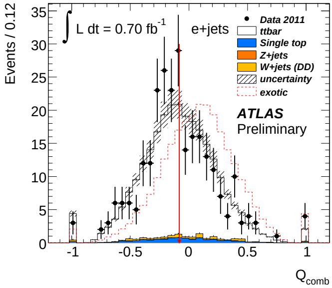
- measurement for $t\bar{t}$ events with leptons:

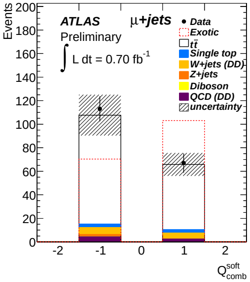
$$\sigma(t\bar{t}\gamma) = 2.0 \pm 0.5\ (\mathrm{stat.}) \pm 0.7\ (\mathrm{syst.}) \pm 0.08\ (\mathrm{lumi.})\ \mathrm{pb}$$

SM expectation: 2.1 ± 0.4 pb

- systematics: ISR/FSR (16%), pile-up (14%), JES (12%)

- single lepton channel
- distinguish $t^{(+2/3)} \longrightarrow b^{(-1/3)}\ W^{(+1)} \longrightarrow b^{(-1/3)}\ \ell^{(+1)}\ \nu_\ell$
  $\tilde{t}^{(-4/3)} \longrightarrow b^{(-1/3)}\ W^{(-1)} \longrightarrow b^{(-1/3)}\ \ell^{(-1)}\ \bar{\nu}_\ell$
- associate ℓ / b-jet ($m_{\ell b}$ / kin. fit)
- measure the charge of the b-jet
  (charge weighting / semileptonic B decays)





- $\tilde{t}^{(-4/3)}$ scenario excluded at more than 5σ

Top quark charge

- single lepton channel
- distinguish $t^{(+2/3)} \to b^{(-1/3)}\ W^{(+1)} \to b^{(-1/3)}\ \ell^{(+1)}\ \nu_\ell$
  $\tilde{t}^{(-4/3)} \to b^{(-1/3)}\ W^{(-1)} \to b^{(-1/3)}\ \ell^{(-1)}\ \bar{\nu}_\ell$
- associate ℓ / b-jet ($m_{\ell b}$ / kin. fit)
- measure the charge of the b-jet
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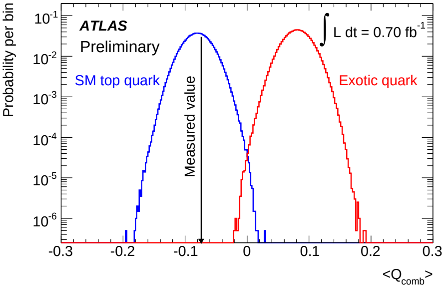
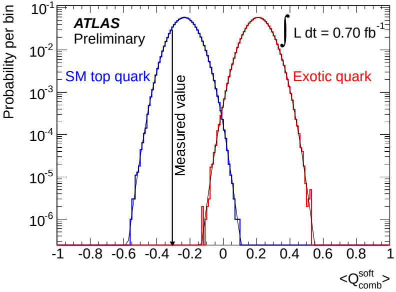




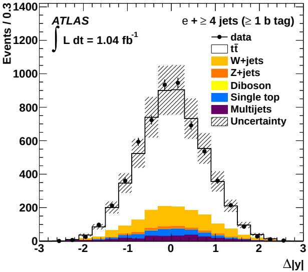
- $\tilde{t}^{(-4/3)}$ scenario excluded at more than 5σ

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

- At LO $t\bar{t}$ production is symmetric under charge conjugation in the SM (small asymmetry expected at NLO)
- Several BSM processes can alter this asymmetry, either with abnormal vector or axial vector couplings or via interference with the SM

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

where $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$



Distributions are unfolded to parton level

$A_C = -0.047 \pm 0.045\ (\text{stat}) \pm 0.028\ (\text{syst})\ (e\text{+jets})$

$A_C = -0.002 \pm 0.036\ (\text{stat}) \pm 0.024\ (\text{syst})\ (\mu\text{+jets})$

$A_C = -0.019 \pm 0.028\ (\text{stat}) \pm 0.024\ (\text{syst})\ (\text{comb})$

single lepton

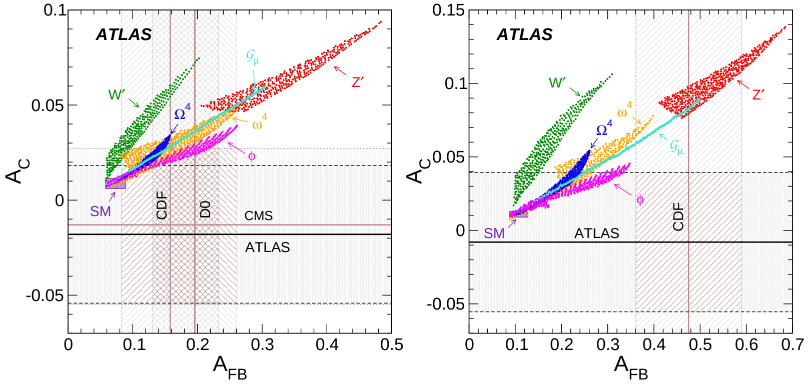
SM expectation (MC@NLO): $A_C = 0.006 \pm 0.002$

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

dilepton events: $A_C = 0.057 \pm 0.024\ (\text{stat}) \pm 0.025\ (\text{syst})$

combination (single lepton+ dilepton):
$A_C = 0.029 \pm 0.018\ (\text{stat}) \pm 0.014\ (\text{syst})$

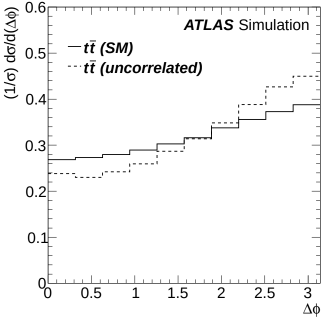
☞contraints on new physics:



$t\bar{t}$ spin correlations

- While t-quark pairs produced at hadron colliders are unpolarized, their spins are correlated
- Different BSM scenarios predict different production and decay dynamics of the top quark, which could be detected by measuring the $t\bar{t}$ spin correlations
- In the dilepton channel $\Delta\phi_{\ell\ell}$ can distinguish the SM expectation from a no-correlation scenario

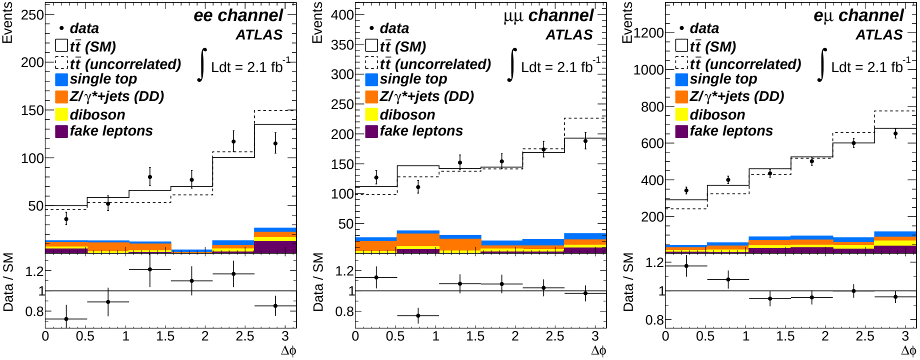
[Phys. Rev D81 (2010) 074024]



$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}}$$

where N_{like} (N_{unlike}) are the number of events where t and $\bar{t}$ spins are aligned (anti-aligned)

$t\bar{t}$ spin correlations

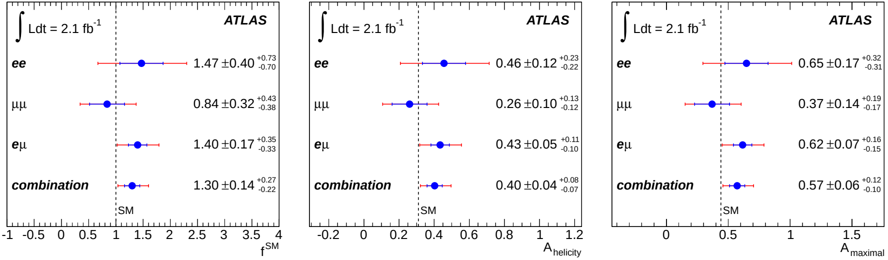


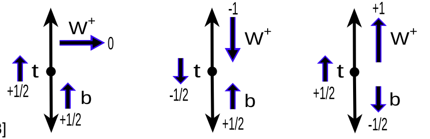
- fit done with 2 templates: SM spin correlation (f^{SM}) and uncorrelated hypothesis (f^{UC})
- $f^{SM} + f^{UC} = 1$

$t\bar{t}$ spin correlations

- Different spin basis can be defined; in the SM: [Phys. Lett. B609 (2005) 271]
  - helicity basis: $A^{SM}_{helicity} = 0.32$
  - maximal basis: $A^{SM}_{maximal} = 0.44$
- Considering A^{SM} in a particular basis, the measured spin correlation coefficient can be obtained:

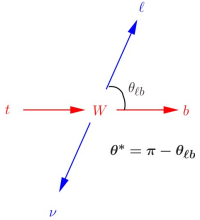
$$A^{measured} = A^{SM} \cdot f^{SM}$$





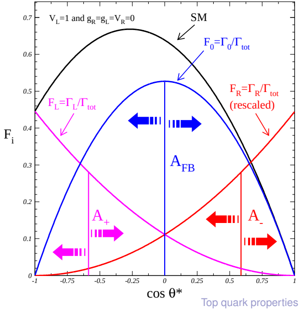
[PRD81 (2010) 111503]

	longitudinal W	left-handed W	right-handed W
SM (NNLO):	$F_0 = 0.687$	$F_L = 0.311$	$F_R = 0.0017$



$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{3}{2}\left[F_0\left(\frac{\sin\theta^*}{\sqrt{2}}\right)^2 + F_L\left(\frac{1-\cos\theta^*}{2}\right)^2 + F_R\left(\frac{1+\cos\theta^*}{2}\right)^2\right]$$

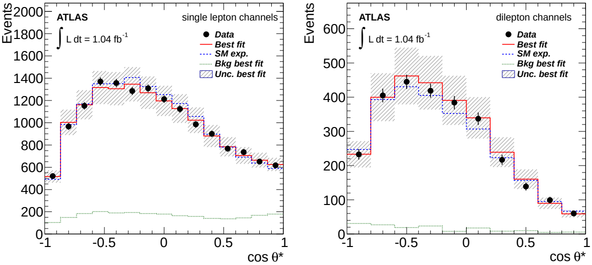
- ☞ fit of the $\cos\theta^*$ using templates
- ☞ evaluation of angular asymmetries
- ☞ Lorentz structure of the *Wtb* vertex can be probed with these observables



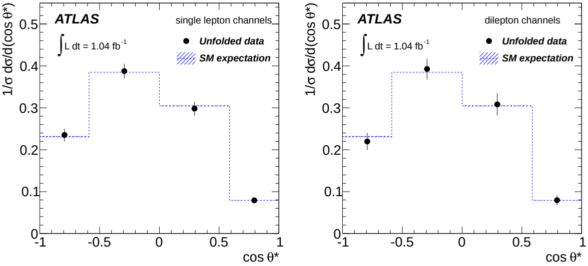
W polarisation in $t \rightarrow bW$ decays

- templates fit

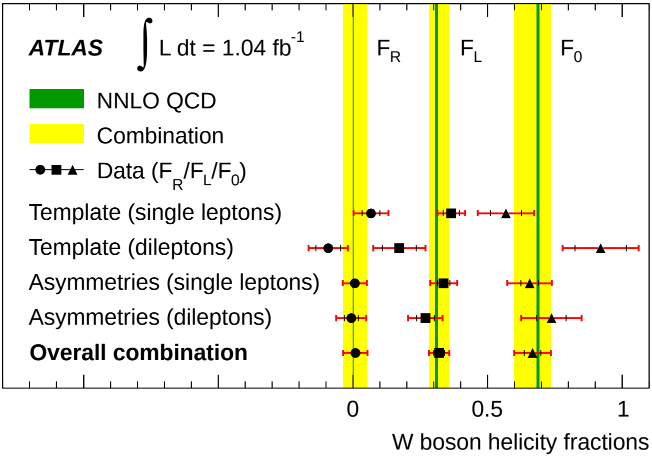
single and dilepton channels



- angular asymmetries



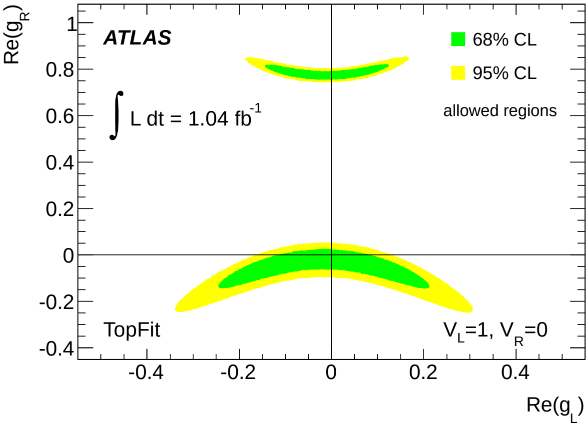
W polarisation in $t \rightarrow bW$ decays



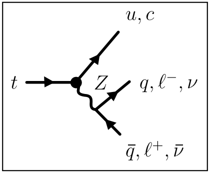
W polarisation in $t \to bW$ decays

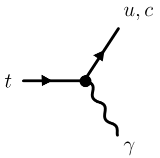
Effective *Wtb* vertex from dim. 6 operators:

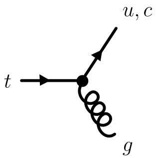
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\;W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\;W_{\mu}^{-}$$



Search for FCNC







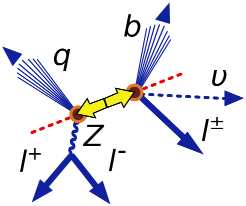
Theoretical predictions for the BR of FCNC top quark decays

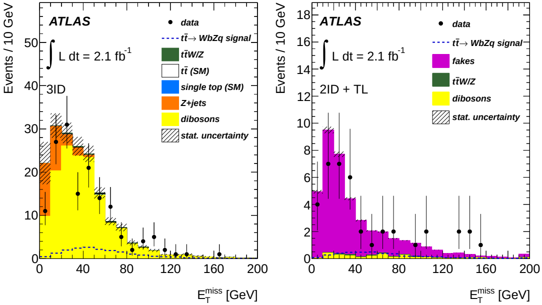
Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	TC2	RS
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	—	—	2×10^{-6}	1×10^{-6}	—	$\sim 10^{-11}$
$\boldsymbol{t \to uZ}$	8×10^{-17}	1.1×10^{-4}	—	—	2×10^{-6}	3×10^{-5}	—	$\sim 10^{-9}$
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	—	—	8×10^{-5}	2×10^{-4}	—	$\sim 10^{-11}$
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}	$\sim 10^{-6}$	$\sim 10^{-9}$
$\boldsymbol{t \to cZ}$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}	$\sim 10^{-4}$	$\sim 10^{-5}$
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}	$\sim 10^{-4}$	$\sim 10^{-9}$

- In the SM flavour changing neutral currents (FCNC) are forbidden at tree level and much smaller than the dominant decay mode ($t \to bW$) at one loop level
- BSM models predict higher BR for top FCNC decays
  ☞ powerful probe for new physics

Search for FCNC $t \to qZ$ decays

- $t\bar{t} \to bWqZ \to b\ell\nu q\ell\ell$ topology





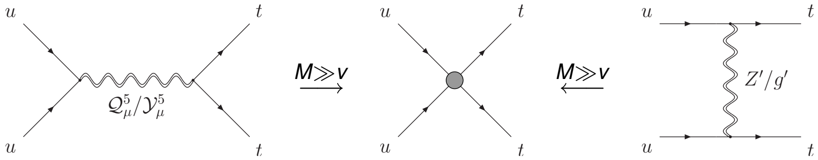
☞ No evidence for signal found

☞ 95% CL limits on $BR(t \to qZ)$:

	observed	(-1σ)	expected	$(+1\sigma)$
3ID + (TL+2ID)	0.73%	0.61%	0.93%	1.4%

Search for same-sign *tt* production

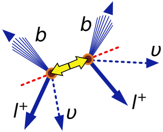
- Production of same-sign top pairs at LHC:

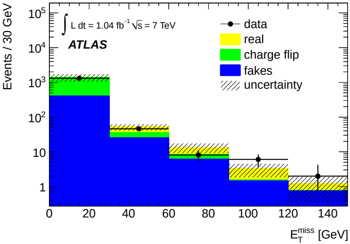


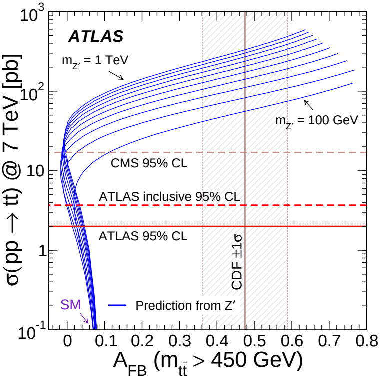
  - *s*-channel: new colour-triplet ($\mathcal{Q}^5_\mu$) or sextet ($\mathcal{Y}^5_\mu$) [$Q = 4/3e$]
  - *t*-channel: new colour singlet (Z') or octet (g') [$Q = 0$]
  - For resonance masses $\gg$ EWSB scale:
    ☞ gauge-invariant effective four-fermion interaction

$$\mathcal{L}_{4F} = \frac{1}{2}\frac{C_{LL}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_L\gamma_\mu t_L) + \frac{1}{2}\frac{C_{RR}}{\Lambda^2}(\bar{u}_R\gamma^\mu t_R)(\bar{u}_R\gamma_\mu t_R)$$
$$-\frac{1}{2}\frac{C_{LR}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_R\gamma_\mu t_R) - \frac{1}{2}\frac{C'_{LR}}{\Lambda^2}(\bar{u}_{La}\gamma^\mu t_{Lb})(\bar{u}_{Rb}\gamma_\mu t_{Ra}) + \text{h.c.}$$

- same-sign dilepton ($\ell^+\ell^+$) topology







Chirality config.	Median expected limit, σ	68% range limit, σ	Observed limit, σ	Observed limit, C
LL	$\sigma < 1.8$ pb	1.1-3.2 pb	$\sigma < 1.7$ pb	$C_{LL}/\Lambda^2 < 0.35$ TeV^{-2}
LR	$\sigma < 1.7$ pb	1.0-3.0 pb	$\sigma < 1.7$ pb	$C_{RL}/\Lambda^2, C'_{LR}/\Lambda^2 < 0.98$ TeV^{-2}
RR	$\sigma < 1.7$ pb	1.0-3.0 pb	$\sigma < 1.7$ pb	$C_{RR}/\Lambda^2 < 0.35$ TeV^{-2}

Summary

- Top quark physics entered the precision measurements era
- Many analysis dominated by systematics
- LHC combinations are needed in the top sector
- The top quark looks quite SM-like (so far)
- LIP team at ATLAS very active in top quark physics
- This is a very active field: stay tuned for news! (2012 dataset is being analysed)

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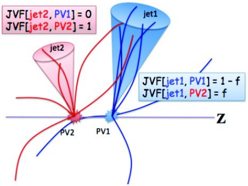
Nuno Castro is supported by FCT (project CERN/FP/116346/2010 and grant SFRH/BPD/63495/2009)

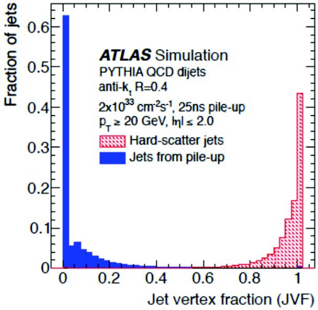
Backup Slides

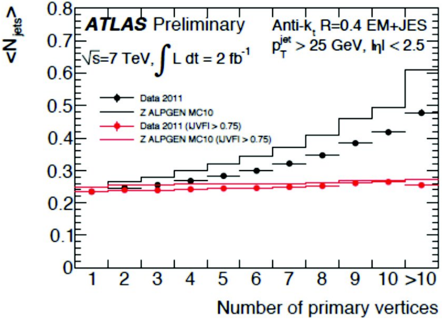
Pileup suppression



Jet Vertex Fraction (JVF)

- Reject fake jets from pile-up fluctuations using jet-vertex association
- Similar technique used to suppress pile-up on missing ET

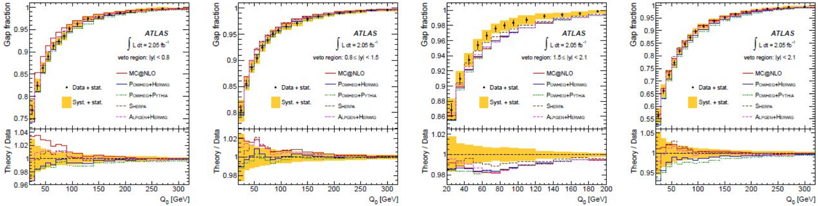




(slide from Ariel Schwartzman's talk at ICHEP'12)

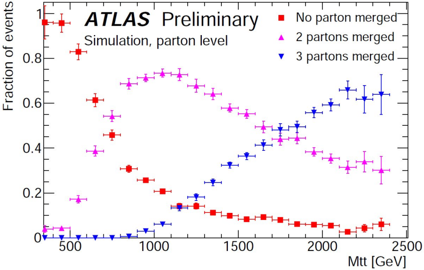
Constraining q/g radiation: central jet veto

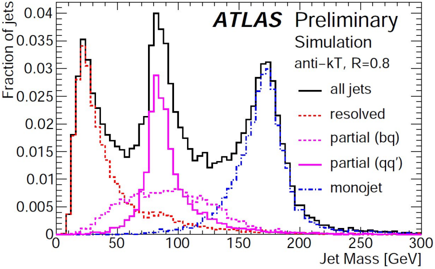
- measurement in dilepton channel of the fraction of events without an additional jet with transverse momentum above a threshold in a central rapidity interval
- comparison to 4 MC generators (MC@NLO, Powheg, Alpgen and Sherpa)



- $|y| < 2.1$: reasonable description of the data
- $1.5 \leq |y| < 2.1$: too much jet activity predicted
- $|y| < 0.8$: MC@NLO produces too little activity
- results constrain ISR uncertainties in other ATLAS measurements
- alternate measurement: veto on events where scalar sum of p_T of additional jets is above threshold in central region (gives similar conclusions)

$t\bar{t}$ resonances: boosted objects



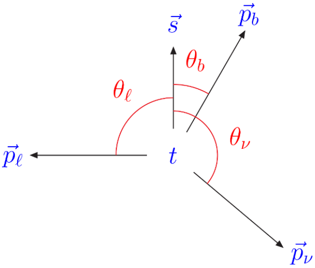


Probing the *Wtb* vertex: spin asymmetries

- polarised top decays

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_X} = \frac{1 + \alpha_X \cos\theta_X}{2}$$

☞ α_X depends on the anomalous couplings



X = top decay product ➡ $\vec{p}_X$ = momentum in t rest frame

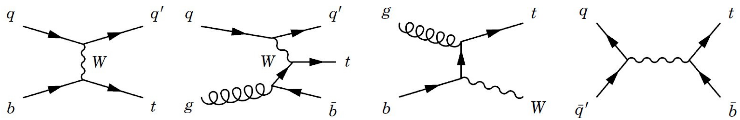
$\vec{p}_j$ = jet momentum in t rest frame

$Q = \cos(\vec{p}_X, \vec{p}_j)$ ➡

$$A_X \equiv \frac{N(Q>0) - N(Q<0)}{N(Q>0) + N(Q<0)} = \frac{1}{2} P \alpha_X \quad [P = 0.95\ (t) \quad P = -0.93\ (\bar{t})]$$

[PLB 476 (2000) 323]

Probing the *Wtb* vertex: single top production cross-section

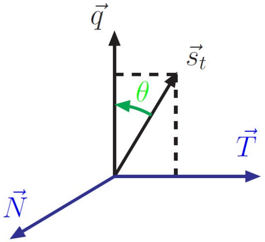


$$\sigma = \sigma_{SM} \left(V_L^2 + \kappa^{V_R} V_R^2 + \kappa^{V_L V_R} V_L V_R + \kappa^{g_L} g_L^2 + \kappa^{g_R} g_R^2 + \kappa^{g_L g_R} g_L g_R + \ldots \right)$$

- the κ factors determine the dependence on anomalous couplings
- the κ factors are, in general, different for t and $\bar{t}$ production
- the measurement of the single top production cross-section allows to obtain a measurement of V_L ($\equiv V_{tb}$) and bounds on anomalous couplings

W polarisation beyond helicity fractions

- New idea to study top decays: [NPB840 (2010) 349]
  ☞ consider transverse and normal directions



$\vec{q}$ ➔ W mom in t rest frame
$\vec{s}_t$ ➔ top spin

$$\vec{N} = \vec{s}_t \times \vec{q}$$
$$\vec{T} = \vec{q} \times \vec{N}$$

meaningful for polarised t decays
(e.g. in single top production)

θ_ℓ^* ➔ angle between ℓ, $\vec{q}$
determine F_+, F_0, F_-

θ_ℓ^T ➔ angle between ℓ, $\vec{T}$
determine F_+^T, F_0^T, F_-^T

θ_ℓ^N ➔ angle between ℓ, $\vec{N}$
determine F_+^N, F_0^N, F_-^N

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^X} = \frac{3}{8}(1+\cos\theta_\ell^X)^2 F_+^X + \frac{3}{8}(1-\cos\theta_\ell^X)^2 F_-^X + \frac{3}{4}\sin^2\theta_\ell^X F_0^X$$

$$A_{FB}^N = \frac{3}{4}\left[F_+^N - F_-^N\right]$$

$$A_{FB}^N \simeq 0.64\, P\, \mathrm{Im}\, g_R$$