Top Quark Physics @ LIP-ATLAS

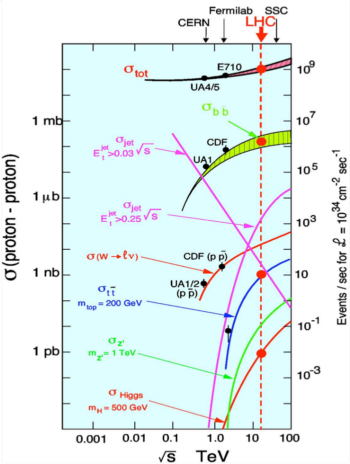
António Onofre

(onofre@lipc.fis.uc.pt)

Workshop on Top Physics at the LHC, Lisboa, March 13^{th} 2009

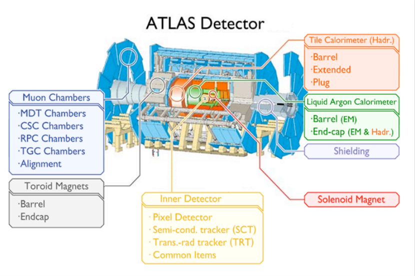
The top quark @ Coimbra:

- Motivation
  Work within ATLAS top properties
  (some expectations shown @ low lum.)
- Current developments
  top quark properties
  (from a small group of people...)
- Conclusions and Questions
  what to expect with data?

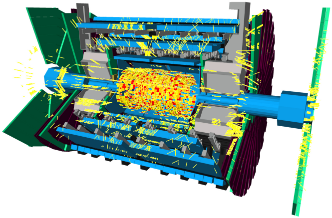


All results from the "Expected Performance of the ATLAS Experiment Detector, trigger and Physics", CERN-OPEN-2008-020

- **Inner Detector (ID)**
  Si pixels and strips +
  transition radiation tracker (TRT)
  $\sigma/p_T \sim 0.05\% \oplus 1\%$
- **Calorimeter**
  Pb-Liquid Ar Electromag.
  $\rightarrow \sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
  Tile Hadronic Calorimeter
  $\rightarrow \sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$
- **Muon Spectrometer**
  Drift tubes, cathode strips (track.)
  RPC, TGC (trigger)
  $\sigma/p_T \sim 2 - 7\%$
- **Magnetic Field**
  Solenoid (ID) $\rightarrow$ 2T
  Toroid (for muons) $\rightarrow$ up to 4T

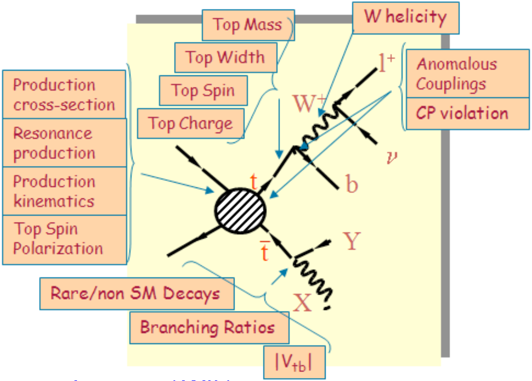


First ATLAS events, 10/09/08



Top quark measurements:

- $\sigma_{t\bar{t}}$
- Mass
- Charge
- Spin correlations
  W polarisation
- Anomalous couplings
- FCNC
- $t\bar{t}$ resonances
- Single top production:
  - spin asymmetries, anomal. coup. (*Wtb*)
  - single top production (FCNC)

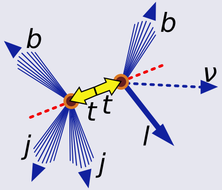


Monte Carlo:

- common full simulation samples were used (signals: MC@NLO, AcerMC and TopRex; fast simulation also used for specific purposes → GRID has been crucial)

Event selection:

- semileptonic $\mathrm{t\bar{t}}$ topology (charge, spin correlations, W polarisation, anomalous couplings and $\mathrm{t\bar{t}}$ resonances)



1 ℓ(e,μ) $p_{\mathrm{T}} > 25$ GeV; $|\eta| < 2.5$

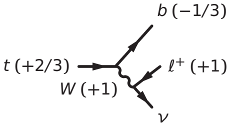
$\geq$ 4 jets (2b), $p_{\mathrm{T}} > 30$ GeV; $|\eta| < 2.5$

$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV

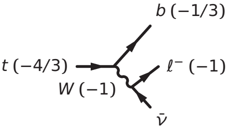
- FCNC processes ($\mathrm{t} \to \mathrm{qX},\ \mathrm{X} = \gamma, \mathrm{g}, \mathrm{Z}$) requires different analysis

Testing a SM prediction:

SM:



Exotic:



CDF: $4/3$ excluded at 87% CL [CDF note 8967]

DØ: $4/3$ excluded at 92% CL [PRL 98, 041801 (2007)]

For top quark charge determination:

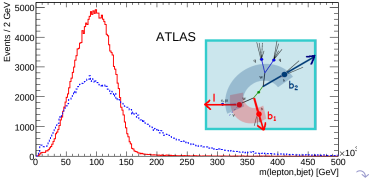
I) Determination of b-jet charge

a) Charge weighting technique

$$Q_{\rm bjet} = \frac{\sum_i q_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}, (\kappa = 0.5)$$

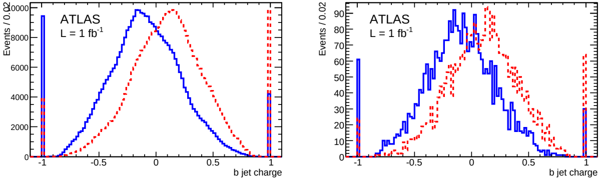
b) Semi-leptonic decay of b quark

II) Correct (l,b) Pairing

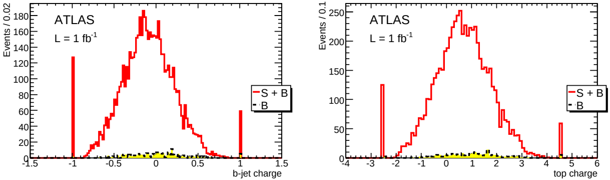


Top quark charge

Charge weighting @ 1fb^{-1}:



estimate for the W+jets background: $S/B = 30:1$



$Q_{\rm comb} = -0.094 \pm 0.004({\rm stat.})$ $\quad (C_{\rm b} = Q_{\rm b}/Q_{\rm comb} = 3.54 \pm 0.16)$

$$Q_{\rm t} = Q_\ell + Q_{\rm b-jet} \times C_{\rm b} = 0.67 \pm 0.06({\rm stat.}) \pm 0.08({\rm sys})$$

ATLAS is likely to distinguish both charge hypotheses with a significance well above 5σ for 1 fb^{-1} of data

Top spin correlations

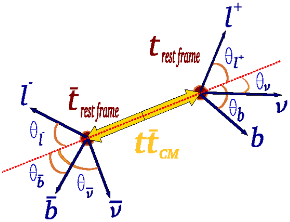
Although produced unpolarised, the t spins are correlated in $t\bar{t}$ events

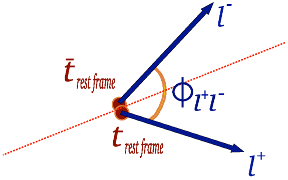
Two spin correl. parameters studied using angular distributions: A and A_D

$$A = \frac{\sigma(t_\uparrow\bar{t}_\uparrow) + \sigma(t_\downarrow\bar{t}_\downarrow) - \sigma(t_\uparrow\bar{t}_\downarrow) - \sigma(t_\downarrow\bar{t}_\uparrow)}{\sigma(t_\uparrow\bar{t}_\uparrow) + \sigma(t_\downarrow\bar{t}_\downarrow) + \sigma(t_\uparrow\bar{t}_\downarrow) + \sigma(t_\downarrow\bar{t}_\uparrow)}$$

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 - A|\alpha_1\alpha_2|\cos\theta_1\cos\theta_2), \qquad \alpha_i = \text{spin analysing power of i}$$

$$\frac{1}{N}\frac{dN}{d\cos\Phi} = \frac{1}{2}(1 - A_D|\alpha_1\alpha_2|\cos\Phi)$$

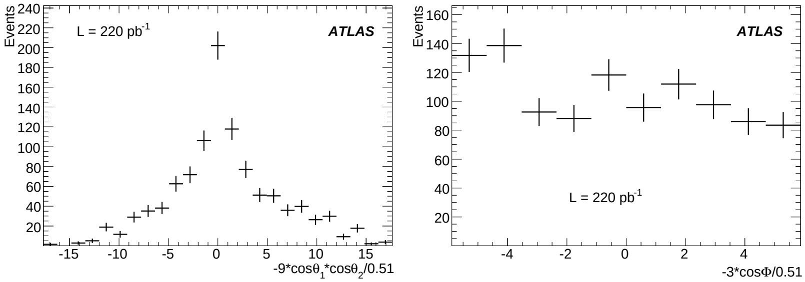




$$A^{SM} = 0.422, \qquad A_D^{SM} = -0.290 \qquad (m_{t\bar{t}} < 550 \text{ GeV})$$

Top spin correlations

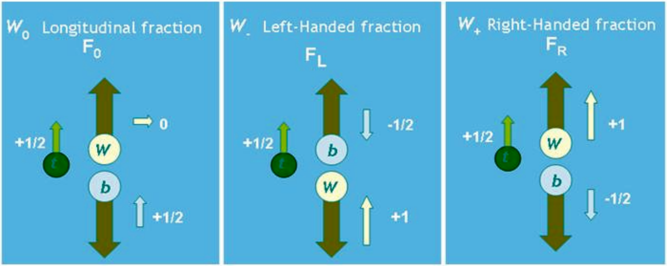
Angular distributions for A and A_D:



$A = 0.67 \pm 0.34$ (stat+sys) $A_D = -0.40 \pm 0.14$ (stat+sys)

with 1fb^{-1} A and A_D can be measured with a precision of 50% and 34%, respectively (can be improved)

Testing a Standard Model prediction: [Phys. Rev. D 45 (1992) 124]



W polarization states with different helicities:

$$F_0^{\rm SM} = 0.695 \quad F_{\rm L}^{\rm SM} = 0.304 \quad F_{\rm R}^{\rm SM} = 0.001, \quad (F_0 + F_{\rm L} + F_{\rm R} = 1)$$

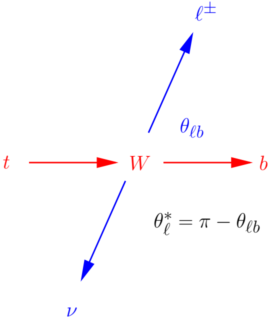
How to measure the W helicity states?

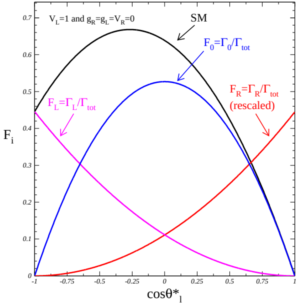
W polarisation

Measuring the W helicity states:

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*_\ell} = \frac{3}{2}\left[F_0\left(\frac{\sin\theta^*_\ell}{\sqrt{2}}\right)^2 + F_\mathrm{L}\left(\frac{1-\cos\theta^*_\ell}{2}\right)^2 + F_\mathrm{R}\left(\frac{1+\cos\theta^*_\ell}{2}\right)^2\right]$$

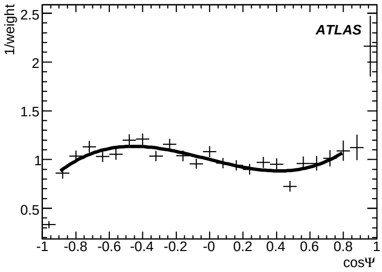
$\theta^*_\ell \rightarrow$ the angle between the ℓ (in W rest frame) and the W (in t rest frame)



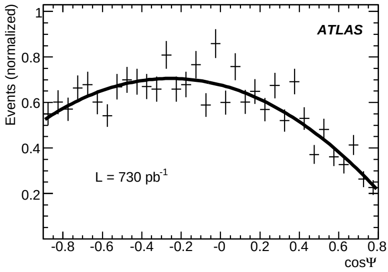


W polarization @ 1fb^{-1}:

Correction function (f_c):



Angular distribution (rec.):



$F_{\mathrm{L}} = 0.29 \pm 0.02 \pm 0.03$ $F_0 = 0.70 \pm 0.04 \pm 0.02$ $F_{\mathrm{R}} = 0.01 \pm 0.02 \pm 0.02$

with 1fb^{-1} F_0, F_{L} and F_{R} can be measured with a precision of 5%, 12% and 0.03, respectively

Anomalous couplings at the Wtb vertex

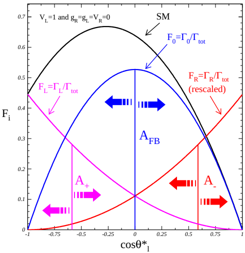
General Wtb vertex

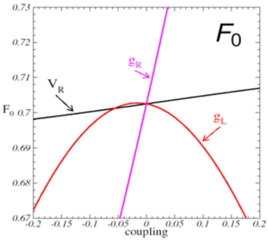
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\, t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)\, t\, W_{\mu}^{-}$$

- Angular distributions of the top decay products (and asymmetries) can be used to probe anomalous couplings:

$$A_t = \frac{N(\cos\theta^*_\ell > t) - N(\cos\theta^*_\ell < t)}{N(\cos\theta^*_\ell > t) + N(\cos\theta^*_\ell < t)}$$

V_R, g_L and g_R change F_R, F_L and F_0 ($\rho_R = F_R/F_0$, $\rho_L = F_L/F_0$)



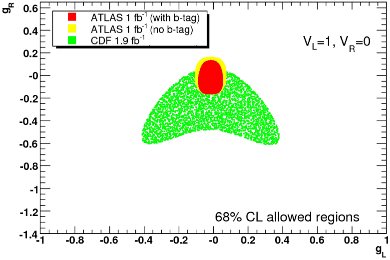


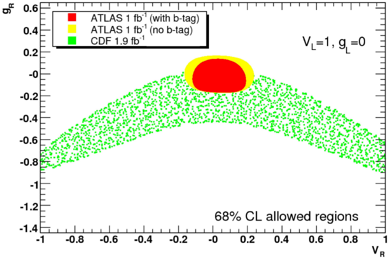
(NLO) A_{FB}=-0.2269, A_+=0.5429, A_-=-0.8402, ρ_L=-0.8402 and ρ_R=-0.8402

Wtb anomalous couplings: expected sensitivity

Anomalous Couplings @ 1fb^{-1}: **(see Nuno's talk)**

$$\left.\begin{matrix}\rho_L\\ \rho_R\\ A_+\\ A_-\end{matrix}\right\} \longrightarrow \text{TopFit} \longrightarrow \left\{\begin{matrix}V_R\\ g_L\\ g_R\end{matrix}\right.$$



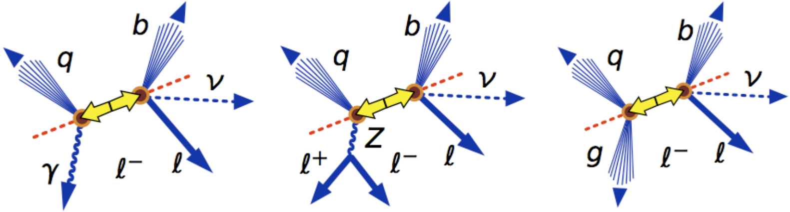


green area: preliminary limits obtained with `TopFit` from the CDF result on the W helicity fractions (Conf. Note 9431)

Rare top quark decays through FCNC

FCNC @ 1fb^{-1}:

different selection cuts applied to the FCNC analyses:



kinematics reconstruction (no b-tag used):

minimize χ^2 by looping on jets (and leptons) and scanning on p_z^{ν}:

$$\chi^2 = \frac{\left(m_t^{FCNC} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m_{\ell_a \nu j} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m_{\ell_a \nu} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m_{\ell_b \ell_c} - m_Z\right)^2}{\sigma_Z^2}$$

$m_t = 175$ GeV
$\sigma_t = 14$ GeV

$m_W = 80.42$ GeV
$\sigma_W = 10$ GeV

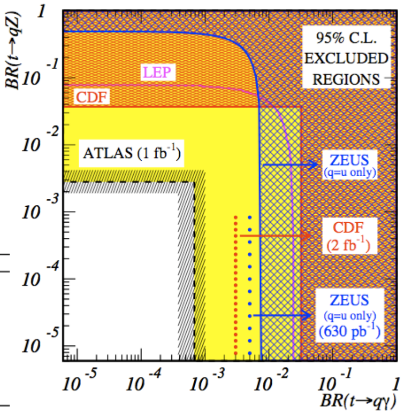
$m_Z = 91.19$ GeV
$\sigma_Z = 3$ GeV

FCNC @ 1fb^{-1}:

(see Filipe's talk)

expected 95% CL limits:

-1σ	expected	$+1\sigma$
$t\bar{t} \to bWq\gamma$:		
3.8×10^{-4}	6.8×10^{-4}	1.0×10^{-3}
$t\bar{t} \to bWqZ$:		
1.9×10^{-3}	2.8×10^{-3}	4.2×10^{-3}
$t\bar{t} \to bWqg$:		
7.2×10^{-3}	1.2×10^{-2}	1.8×10^{-2}



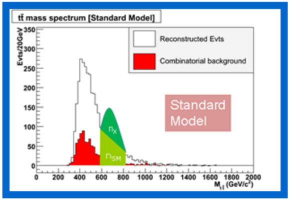
systematic uncertainties:

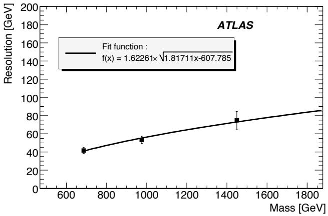
source	$t \to q\gamma$	$t \to qZ$	$t \to qg$
jet energy calibration	2%	5%	4%
luminosity	10%	6%	10%
top mass	6%	12%	5%
backgrounds σ	7%	12%	15%
ISR/FSR	17%	7%	9%
pile-up	22%	0%	13%
generator	4%	14%	4%
χ^2	4%	7%	9%
total	32%	25%	27%

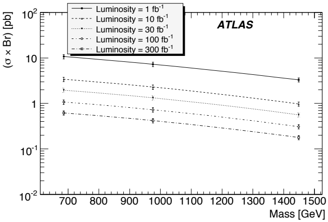
Discovery potential of a narrow $t\bar{t}$ resonance:

1] Define window in $t\bar{t}$ mass distribution

2] Evaluate the number of signal events for discovery: $n_X = 5 \times \sigma_{SM}$





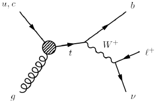


ATLAS will be able to discover a resonance with $m_{t\bar{t}}$=700 GeV (@ 1 fb^{-1}) if $\sigma \times Br \geq 11$ pb

- Study of top quark properties in $t\bar{t}$:
  - Spin and Angular Asymmetries
  - W polarizations (F_R, F_L, F_0, ρ_L and ρ_R)
  - Wtb anomalous couplings (V_R, g_R and g_L)
  - FCNC processes
- Studies in single top (s,t and Wt channels):
  - Spin and Angular Asymmetries (Wtb)
  - Top quark spin
  - Wtb anomalous couplings (exp. comb. with $t\bar{t}$?)
  - FCNC processes
- Tools for $t\bar{t}$ and single top:
  - New MC generator with anomalous couplings Protos **(see Juan's talk)**
  - TopFit **(see Juan's talk)**
  - Single top production through FCNC (Madgraph based MC generator, R.Monteiro)

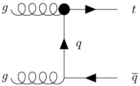
Single top production through FCNC

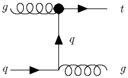
- Direct process + extras [PRD 74 (2006) 014006]:



$$\Gamma(t \to qg) \propto \left(\frac{\kappa_{gq}}{\Lambda}\right)^2$$

$$\sigma(qg \to t) \propto \left(\frac{\kappa_{gq}}{\Lambda}\right)^2$$





  - the $gg \to t\bar{q}$, $gq \to gt$ etc. seem to be also important
  - Other contributions considered (EW sector + interferences)
  - Madgraph based generator under development

- New approach for single top FCNC [Nucl.Phys.B812 (2009) 181]:

  - New generator available (Protos)
  - Simplified number of input parameters

Cross-check between approaches highly desirable

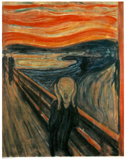
Current Developments

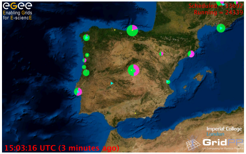
- From a small group of people...

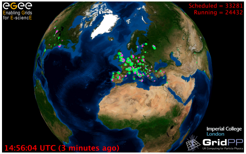
- Theses during 2008:
  - Theory: 1 Phd (R. Monteiro), 1 Msc (M. Won)
  - Experimental: 2 PhD (N.Castro, F.Veloso), 3 Msc (M.Castanheira, P.Martins, M.Fiolhais)
- Newcomers during 2008:
  - Theory: C. Moreira (Msc student)
  - Experimental: S. Santos, I. Ochôa (Msc student) L. Neuhaus (Erasmus), 3 undergraduate
- Visiting:
  - T. Klimkovich (Postdoc), I. Firmo (underg. from RHUL)

Advanced Computing @ Coimbra (resp. M. Oliveira)

...Before.... ...and after 2007







- GRID (TIER2/TIER3):
  - CPU: 160 [fairshare 120(GRID) 40(local)]
  - Disk: 76TB (TIER2); 4.7+3.8+(21)TB (TIER3)
  - Backup: 76x400 GB (robot)
- Milipeia (HPC):
  - CPU: 520
  - Disk: 6TB

Conclusions and Questions

- Conclusions
  - Several studies already performed at 14 TeV
  - Redo the studies at 10 TeV (top mixing exercise)
  - The top quark physics potential is high (not only the physics itself but also in what concerns the preparation for data analysis and development of local groups)
  - $t\bar{t}$ and single top complementar in what concerns top properties
- Questions
  - Should we prepare better for data?
  - Should we prepare common standards for *Wtb* and FCNC studies ?
  - Several problems to solve:
  - .. Problem of the m_b mass in the *Wtb* vertex (BSM)
  - .. Definition of couplings for *Wtb* and FCNC
  - .. Combine $t\bar{t}$ and single top results ?

CMS+ATLAS Combinations in the past (FCNC)

Report of Working Group 1 of the CERN Workshop "Flavour in the era of the LHC", November 2005 - March 2007

Eur.Phys.J. C57 (2008) 183-307