top quark properties: prospects at ATLAS

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contents

- top properties: prospects for 1 fb^{-1} at ATLAS
  - mass → see Jorgen Sjolin and Roger Wolf's talk
  - $t\bar{t}$ resonances → see Florent Chevallier's talk
  - charge
  - $t\bar{t}$ spin correlations
  - W polarisation in top decays
  - anomalous Wtb couplings
  - rare top decays and FCNC
- summary

monte carlo and common selection ③

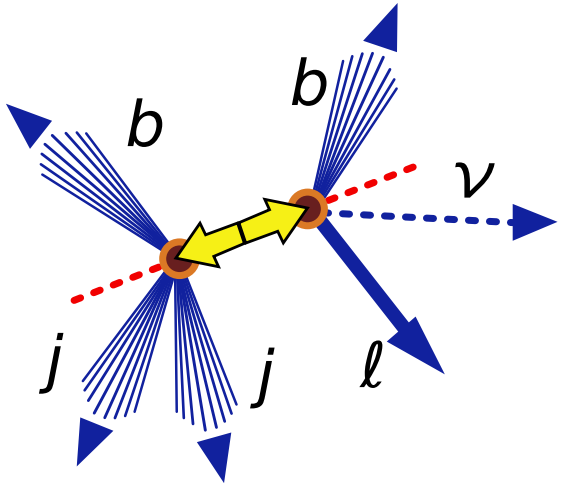
- monte carlo:

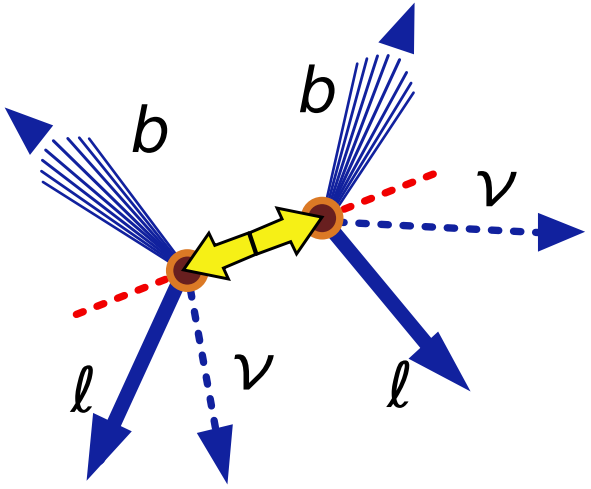
  - common full simulation samples were used

    (signals: MC@NLO, AcerMC and TopReX)

    (fast simulation were also used for specific purposes)

- common event selection (charge, $t\bar{t}$ spin correlations, W polarisation, anomalous Wtb couplings and $t\bar{t}$ resonances):
  - semileptonic topology
  - dileptonic topology

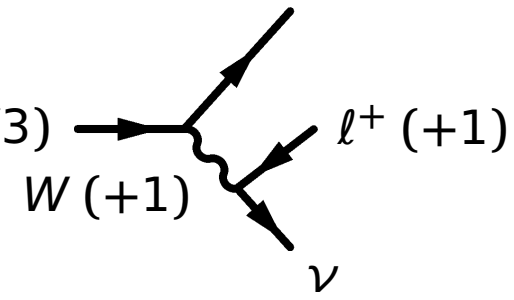




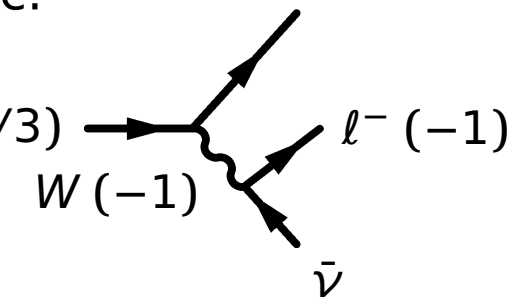
  - FCNC analyses have different selections

charge

SM:



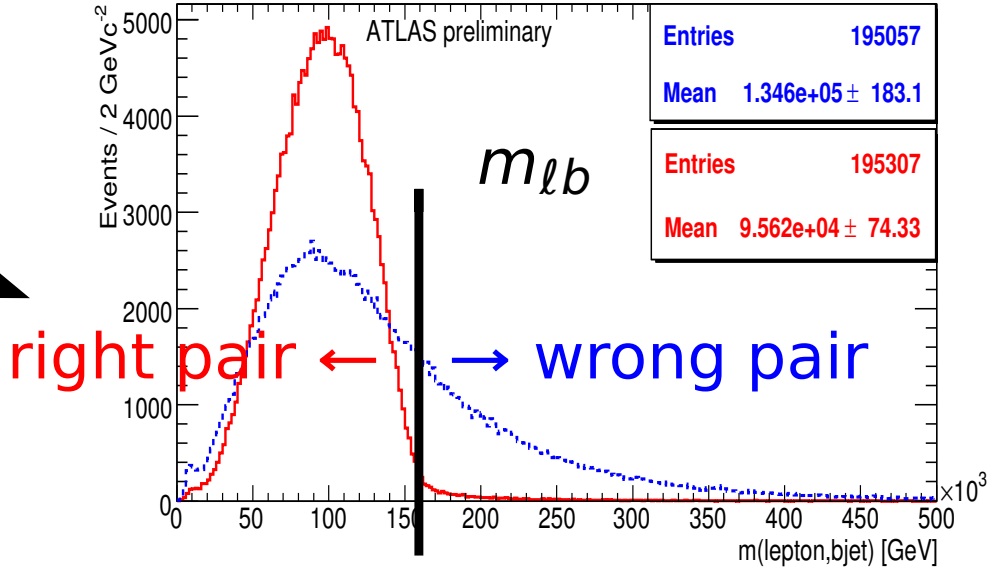
exotic:



CDF: 4/3 excluded at 87% CL [CDF note 8967]
DØ: 4/3 excluded at 92% CL [PRL 98, 041801 (2007)]

need to determine:

1. lepton charge
2. lepton/*b*-jet pair
3. *b* quark charge
   → charge weighting
   → semileptonic *b* decay



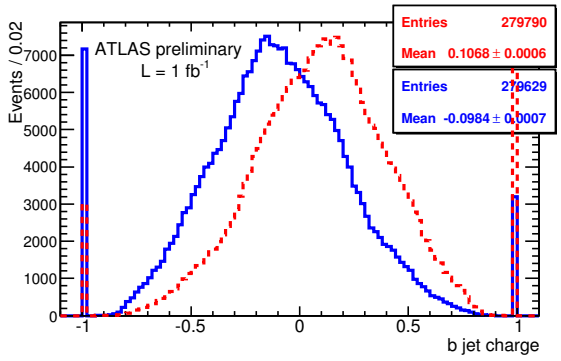
$\varepsilon = 31\%$ $P = 86\%$

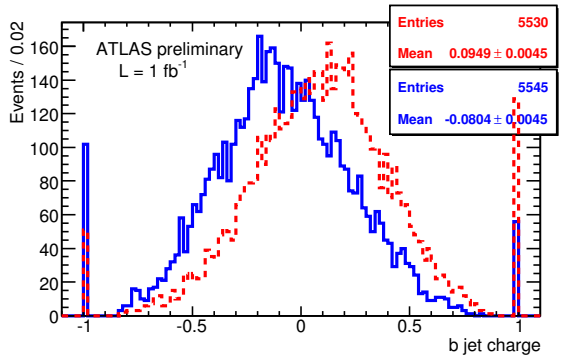
charge

charge weighting:

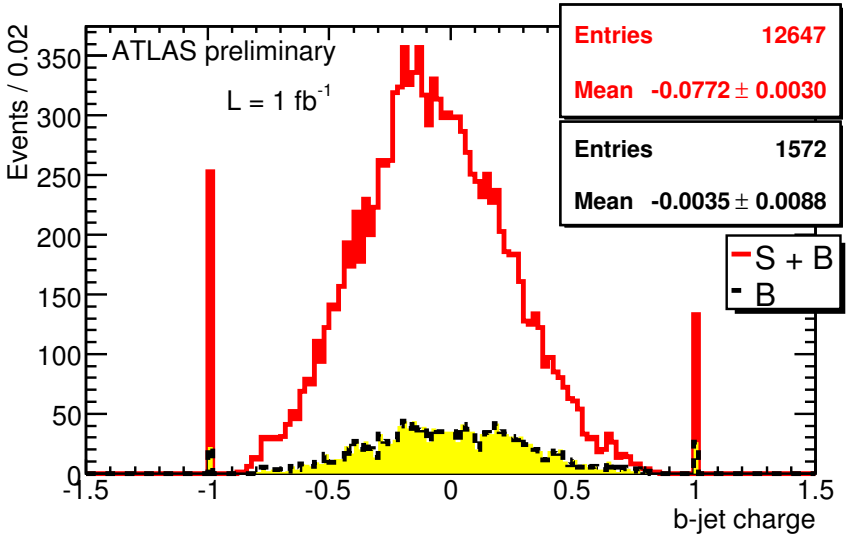
$$Q_{bjet} = \frac{\sum_i q_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}$$

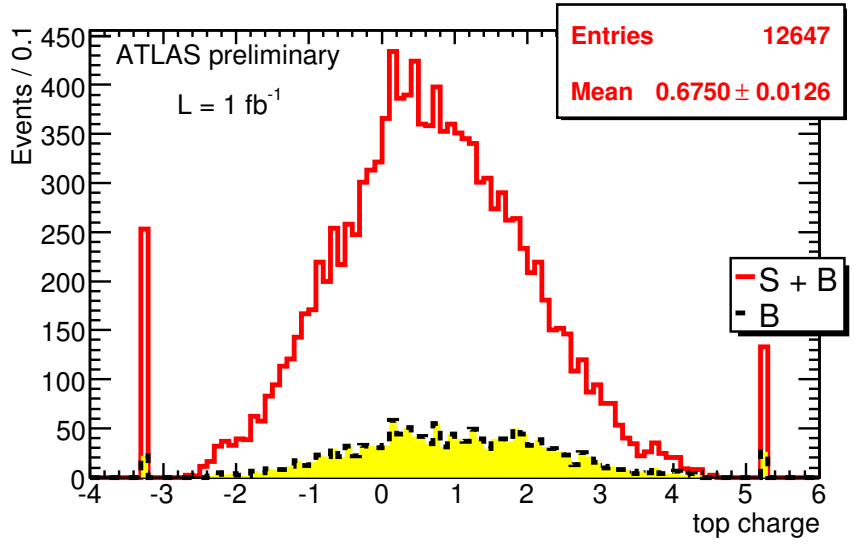
$\kappa = 0.5$





estimate for the W+jets background: $S/B = 7:1$





$Q_{\text{comb}} = -0.077 \pm 0.003(\text{stat.}) \pm 0.003(\text{back.})$

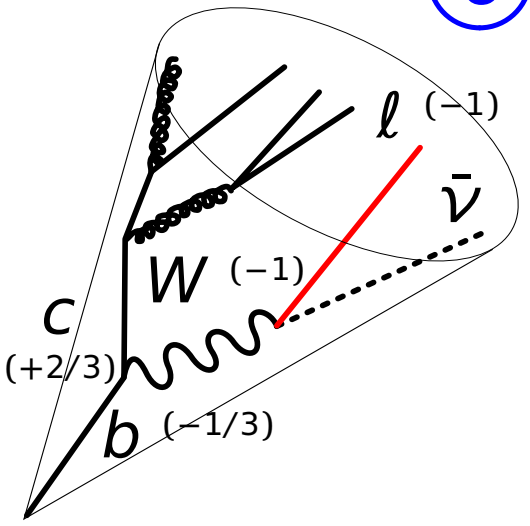
$Q_t = Q_\ell + Q_{b-\text{jet}} \times C_b = 0.67 \pm 0.04(\text{stat.})$ $\quad (C_b = Q_b/Q_{\text{comb}} = 4.33 \pm 0.28)$

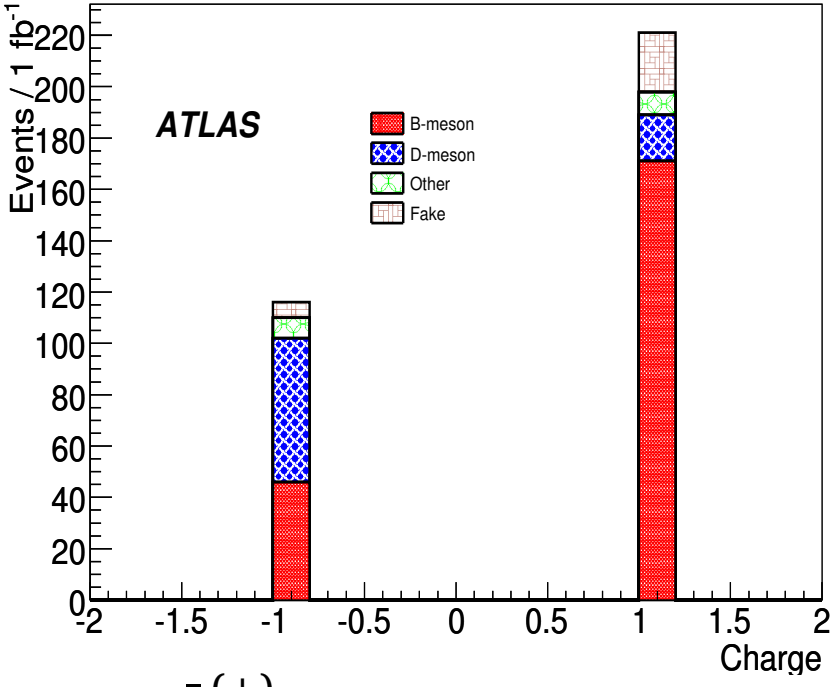
charge

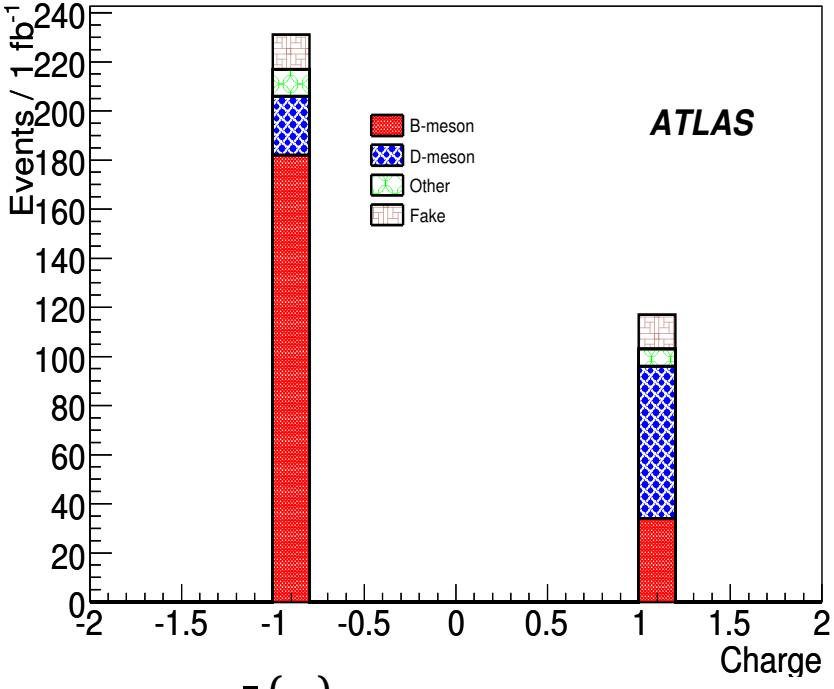
semileptonic b decay:

$$b \to q l^- \bar{\nu},\ \bar{b} \to \bar{q} l^+ \nu,\ (q = u, c)$$

$$\bar{Q}_{nonIs} = \frac{N(l^+) - N(\ell^-)}{N(\ell^+) + N(\ell^-)}$$







$$\bar{Q}^{(+)}_{nonIs} = -0.32 \pm 0.05$$

$$\bar{Q}^{(-)}_{nonIs} = 0.30 \pm 0.05$$

$$\bar{Q}^{(comb)}_{nonIs} = -0.31 \pm 0.04$$

charge

systematic uncertainties on Q_{comb}:

source	weighting	b-decay
jet scale	0.7%	0.3%
b-jet scale	1.9%	6%
Δm_t	1.3%	7%
PDF	0.6%	—
ISR	2.8%	15%
FSR	7.8%	8%
MC modelling	18%	16%
pile-up	11%	1.8%
background	3%	—
total	23%	25%

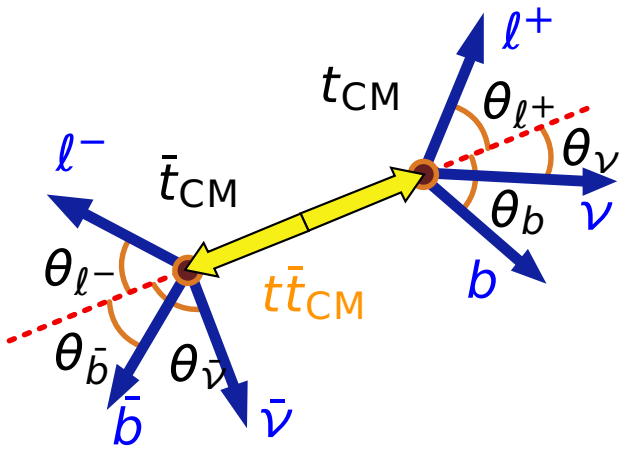
ATLAS will be able to distinguish both charge hypotheses with a significance above 5σ for 1 fb^{-1} of data

$t\bar{t}$ spin correlations

t quarks decay before hadronisation → spin information is conserved

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

$$\frac{1}{N}\frac{\delta^2 N}{\delta \cos\theta_1 \delta \cos\theta_2} = \frac{1}{4}(1 - A|\alpha_1\alpha_2|\cos\theta_1 \cos\theta_2)$$

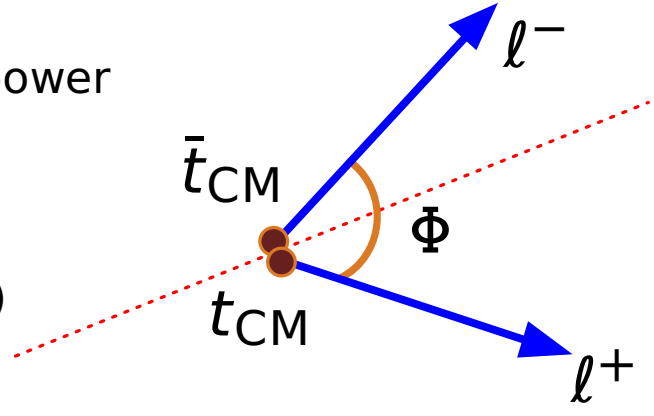


$\cos\theta$ → angle between the t (in $t\bar{t}$ rest frame) and the t decay product (in t rest frame)

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

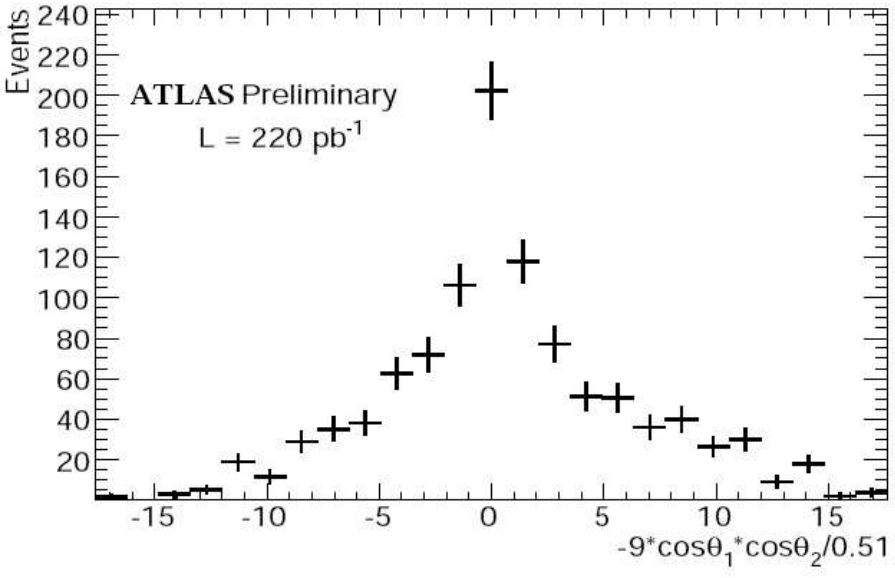
α → spin analysing power

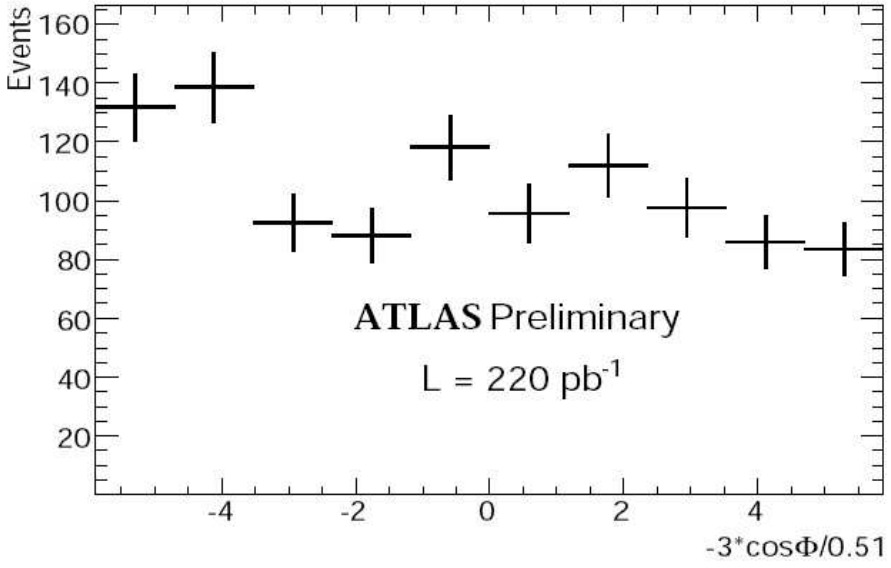
$A^{SM} = 0.422$
$A_D^{SM} = -0.290$
($m_{t\bar{t}} < 550$ GeV)



Φ → angle between the two spin analysers (in the corresponding t rest frame)

$t\bar{t}$ spin correlation





$A = 0.67 \pm 0.34$ (stat+sys)

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

W polarisation

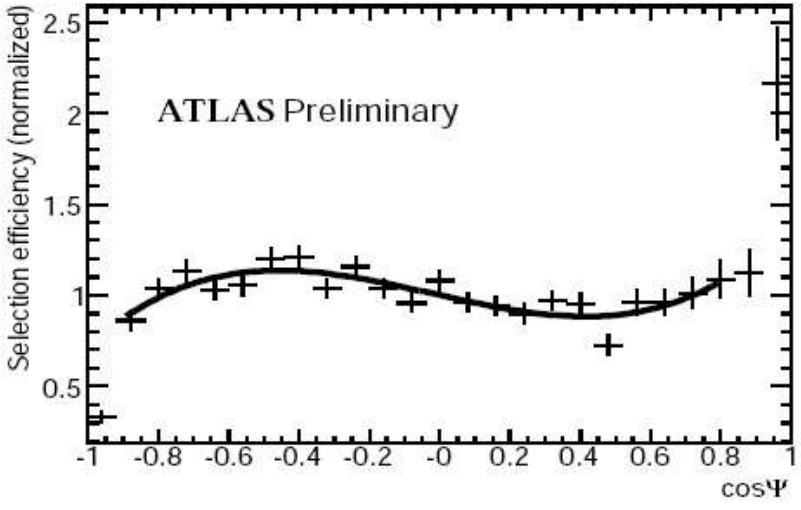
W polarisation: [Phys. Rev. D 45 (1992) 124]

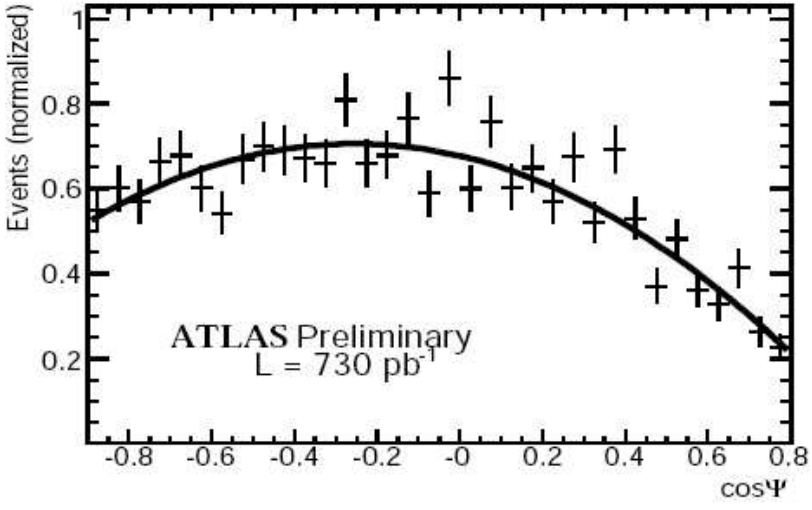
$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\Psi} = \frac{3}{2}\left[F_0\left(\frac{\sin\Psi}{\sqrt{2}}\right)^2 + F_L\left(\frac{1-\cos\Psi}{2}\right)^2 + F_R\left(\frac{1+\cos\Psi}{2}\right)^2\right]$$

W helicity states:

$F_0^{\mathrm{SM}} = 0.695$ $F_L^{\mathrm{SM}} = 0.304$ $F_R^{\mathrm{SM}} = 0.001$ $F_0 + F_L + F_R = 1$

$\Psi \rightarrow$ the angle between the ℓ (in W rest frame) and the W (in t rest frame)





$F_L = 0.29 \pm 0.02 \pm 0.03$ $F_0 = 0.70 \pm 0.04 \pm 0.02$ $F_R = 0.01 \pm 0.02 \pm 0.02$

$t\bar{t}$ spin correlations and W polarisation

systematic uncertainties:

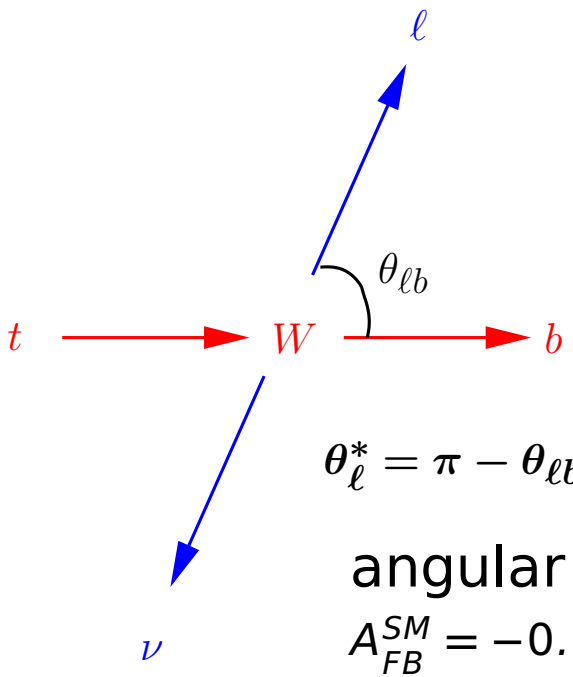
	F_L	F_0	F_R	A	A_D
with fast simulation:					
factorisation	0.000	0.001	0.001	0.029	0.006
structure function	0.003	0.003	0.004	0.033	0.012
ISR	0.001	0.002	0.001	0.002	0.001
FSR	0.009	0.007	0.002	0.023	0.016
b fragmentation	0.001	0.002	0.001	0.031	0.018
hadronization scheme	0.010	0.016	0.006	0.006	0.008
pile-up (2.3 events)	0.005	0.002	0.006	0.001	0.005
input top mass (2 GeV)	0.015	0.011	0.004	0.028	0.013
with full simulation:					
b tagging efficiency (5%)	0.007	0.002	0.005	0.027	0.07
b jet energy scale (5%)	0.02	0.002	0.02	0.07	0.015
light jet energy scale (5%)	—	—	—	0.11	0.017
S/B scale (20%)	0.004	0.002	0.001	0.000	0.004
total	0.03	0.02	0.02	0.15	0.08

anomalous Wtb couplings

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

V_R, g_L, g_R } anomalous couplings

[Phys. Rev. D67 (2003) 014009; Eur. Phys. J. C50 (2007) 519]



fit to $\cos\theta^*_\ell$:

$\rho_{R,L} = F_{R,L}/F_0$

$\rho_R^{SM} = 5.1 \times 10^{-4}$

$\rho_L^{SM} = 0.423$

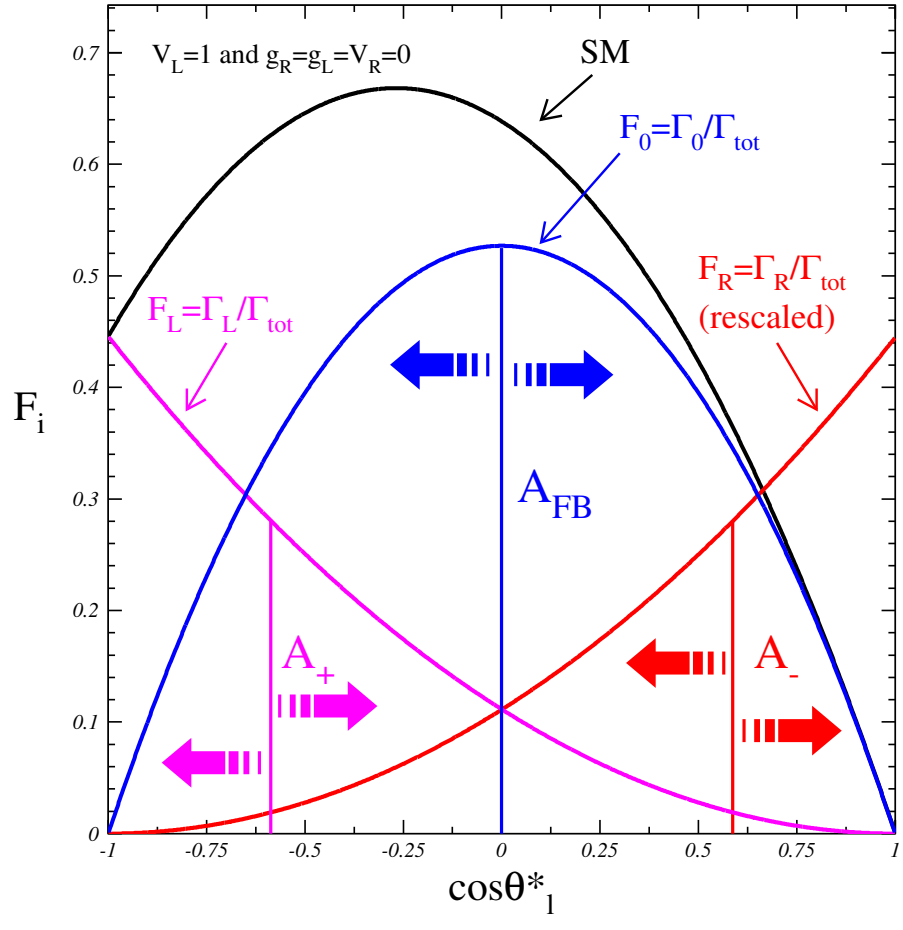
$\theta^*_\ell = \pi - \theta_{\ell b}$

angular asymmetries:

$A_{FB}^{SM} = -0.2225$

$A_+^{SM} = +0.5482$

$A_-^{SM} = -0.8397$



anomalous *Wtb* couplings

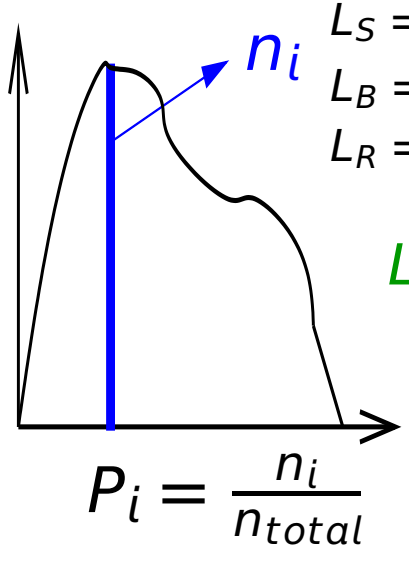
kinematics reconstruction:

minimize χ^2 by looping on jets and scanning on p_z^ν:

$$\chi^2 = \frac{(m_{\ell\nu j_a} - m_t)^2}{\sigma_t^2} + \frac{(m_{j_b j_c j_d} - m_t)^2}{\sigma_t^2} + \frac{(m_{\ell\nu} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_c j_d} - m_W)^2}{\sigma_W^2}$$

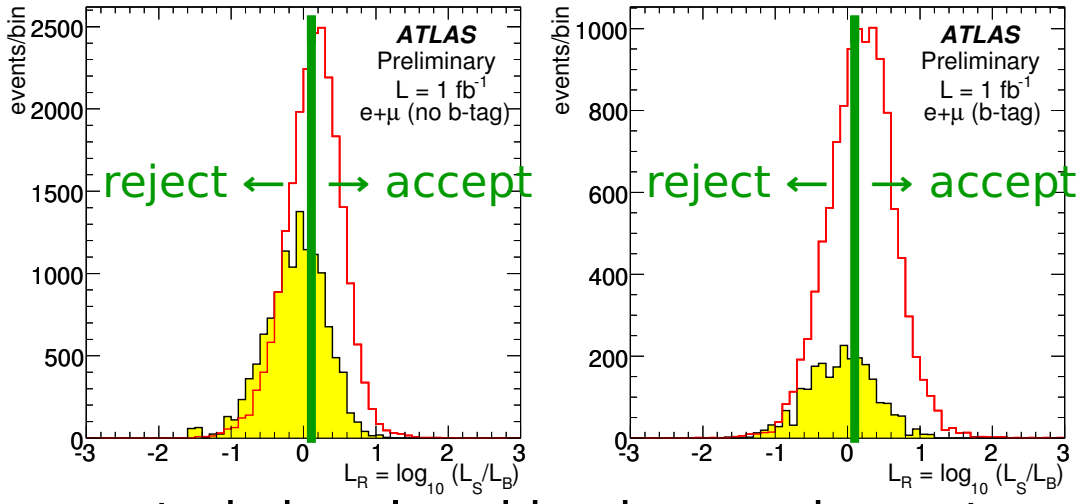
$m_t = 175$ GeV, $\sigma_t = 14$ GeV
$m_W = 80.42$ GeV, $\sigma_W = 10$ GeV

probabilistic analysis:



$$L_S = \Pi_{i=1}^N P_i^{signal}$$
$$L_B = \Pi_{i=1}^N P_i^{back.}$$
$$L_R = \log(L_S/L_B)$$

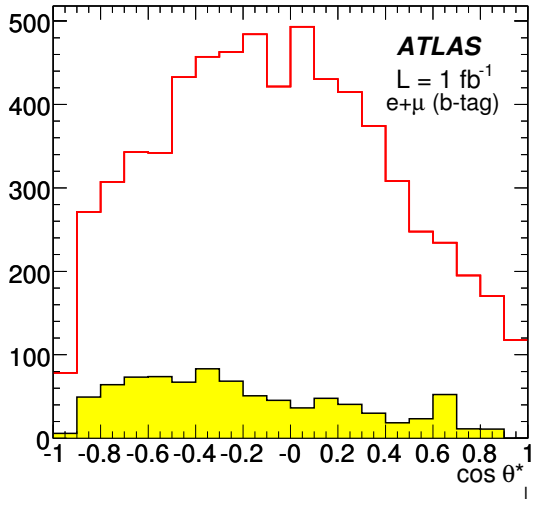
$L_R > 0.1$



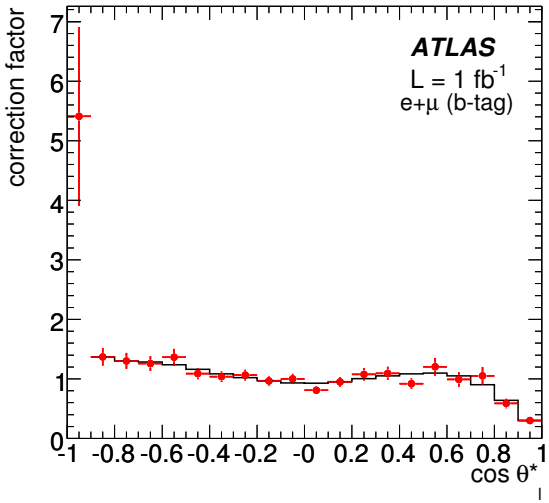
expected signal and background events:

	no b-tag	with b-tag
signal	12627 ± 103	6586 ± 74
background	4011 ± 203	851 ± 94

anomalous *Wtb* couplings



expected values with statistical errors:		
	no *b*-tag	with *b*-tag
ρ_L	0.402 ± 0.050	0.453 ± 0.048
ρ_R	-0.008 ± 0.008	-0.004 ± 0.007
A_{FB}	-0.220 ± 0.025	-0.229 ± 0.026
A_+	0.560 ± 0.024	0.542 ± 0.028
A_-	-0.845 ± 0.012	-0.830 ± 0.014



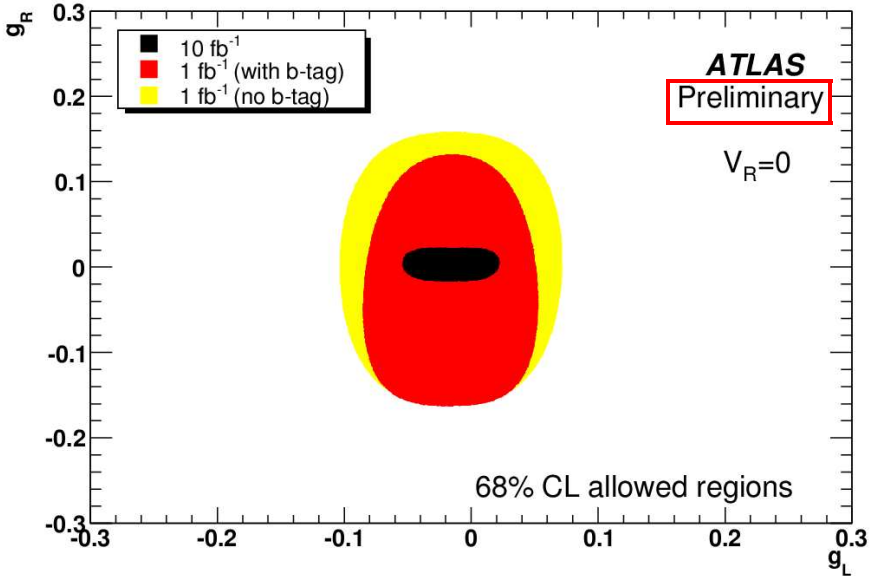
sources of systematic uncertainties (with *b*-tag):

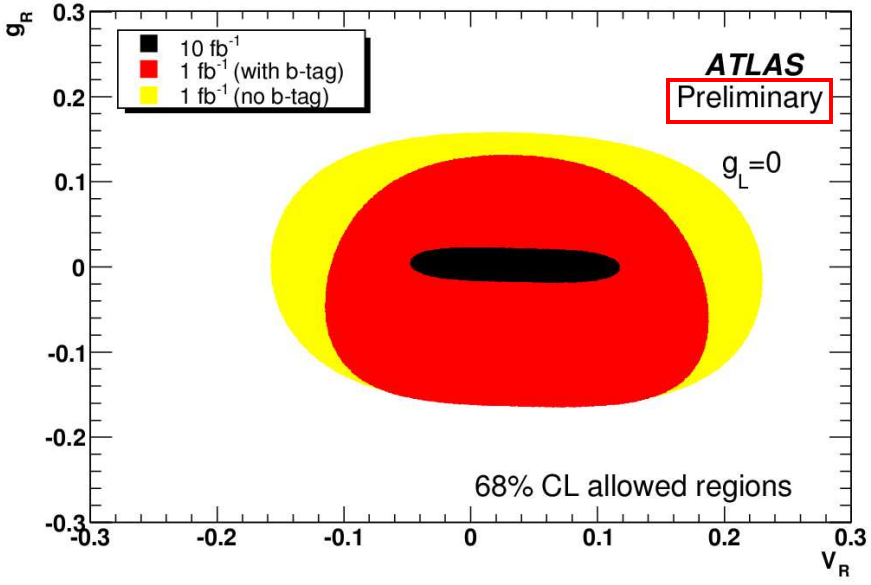
source	ρ_L	ρ_R	A_{FB}	A_+	A_-
jet energy scale	0.038	0.001	0.010	0.004	0.002
luminosity	0.007	0.000	0.006	0.005	0.001
top mass	0.026	0.003	0.013	0.008	0.006
background	0.005	0.000	0.003	0.002	0.004
ISR+FSR	0.052	0.006	0.024	0.028	0.015
MC generator	0.012	0.008	0.009	0.011	0.000
pile-up	0.146	0.006	0.012	0.041	0.022
total	0.163	0.012	0.033	0.052	0.027

anomalous *Wtb* couplings

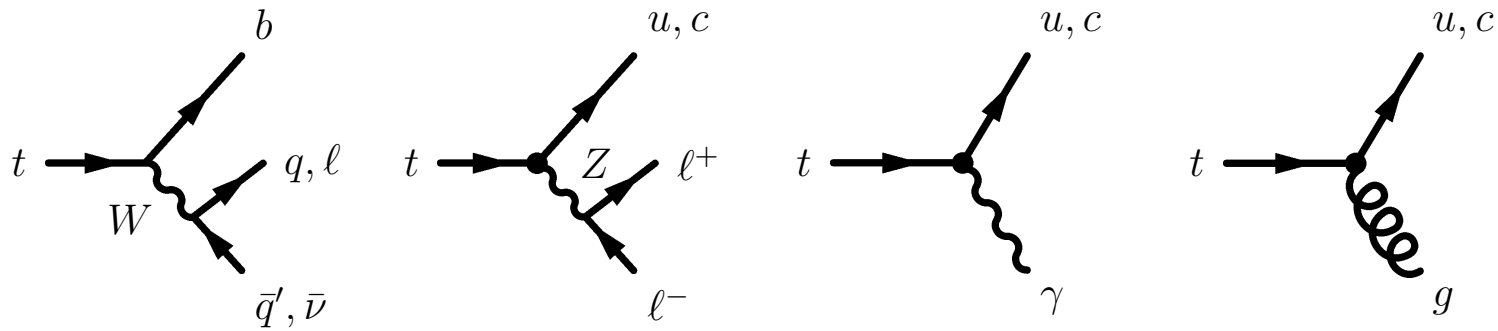
constraints on the anomalous couplings

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





rare top decays and FCNC



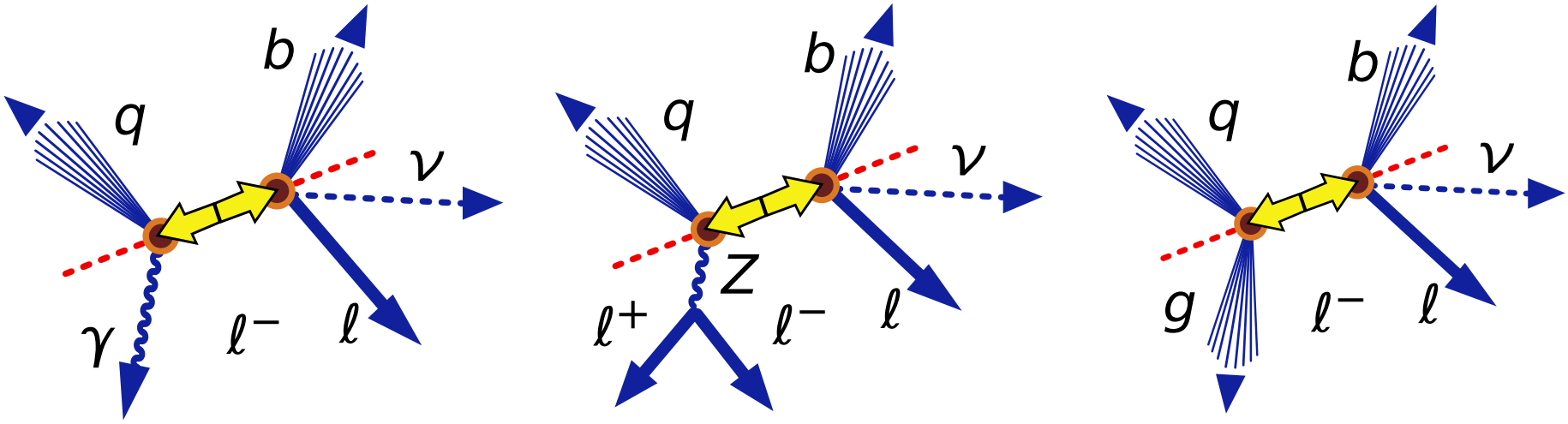
BR($t \to$ FCNC) in several models:

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-5}$	$\sim 10^{-5}$	$\sim 10^{-4}$

[Acta Phys. Polon. B 35 (2004) 2695]

rare top decays and FCNC

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

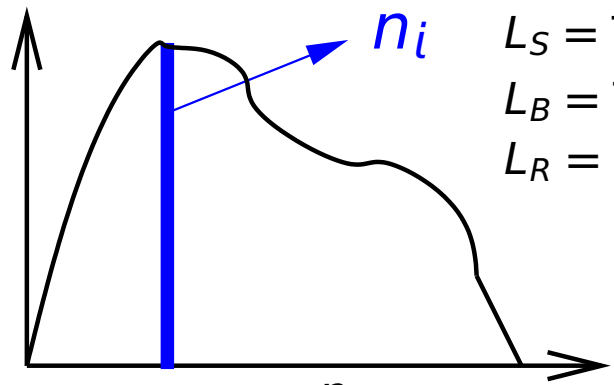
$m_Z = 91.19$ GeV
$\sigma_Z = 3$ GeV

rare top decays and FCNC

after final selection:

$t\bar{t} \to bWq\gamma$:	
total bkg.	650 ± 66
signal %	7.6 ± 0.2
$t\bar{t} \to bWqZ$:	
total bkg.	125 ± 56
signal %	7.6 ± 0.2
$t\bar{t} \to bWqg$:	
total bkg.	19253 ± 359
signal %	2.9 ± 0.1

probabilistic analysis:

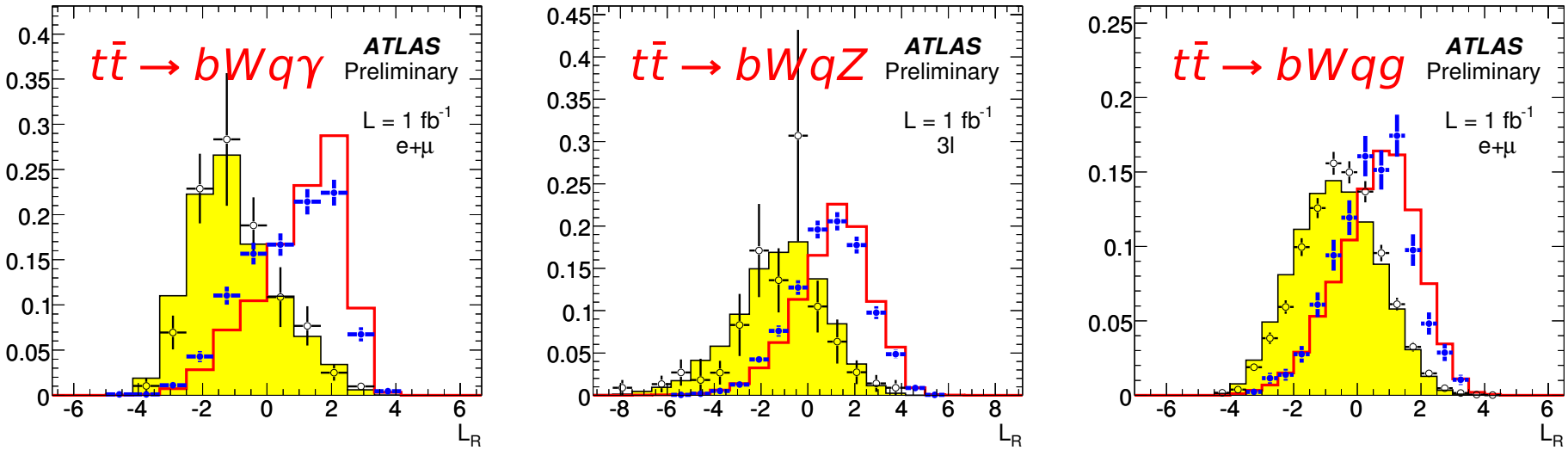


$$L_S = \Pi_{i=1}^{N} P_i^{signal}$$
$$L_B = \Pi_{i=1}^{N} P_i^{back.}$$
$$L_R = \ln(L_S/L_B)$$

no cut on L_R

$$P_i = \frac{n_i}{n_{total}}$$

normalised discriminant variables:



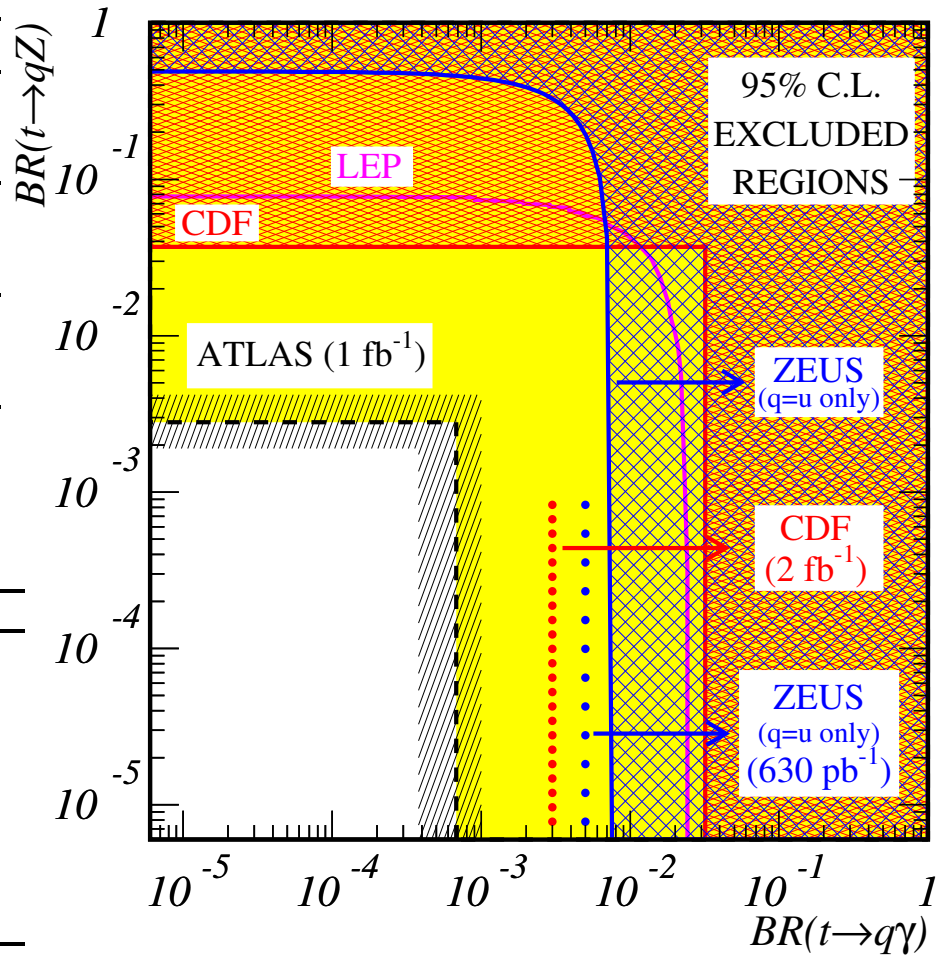
rare top decays and FCNC

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%



summary

expected

precisions

for 1 fb^{-1}

top charge (2/3 versus -4/3)	$\geq 5\sigma$
spin correlations:	
A	50%
A_D	34%
W polarisation:	
F_0	5%
F_L	12%
F_R	0.03
angular asymmetries:	
A_{FB}	18%
A_+	11%
A_-	4%
anomalous couplings:	
V_R	0.15
g_L	0.07
g_R	0.15
top FCNC decays (95% C.L.):	
$Br(t \to q\gamma)$	10^{-3}
$Br(t \to qZ)$	10^{-3}
$Br(t \to qg)$	10^{-2}