Study of ATLAS sensitivity to Wtb anomalous couplings

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Wtb vertex

Most general *Wtb* vertex

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

$V_L \equiv V_{tb} \sim 1$ (within SM)

$V_R, g_R, g_L \Rightarrow$ anomalous couplings

[EPJC50 (2007) 519, NPB804 (2008) 160, NPB812 (2009) 181]

How to probe anomalous couplings in the *Wtb* vertex?

- indirect limits from *B*-physics
- single top production (cross section and spin asymmetries)
- angular distributions of the *t* decays:
  ☞ sensitive to *W* helicity fractions!

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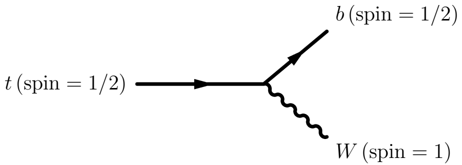
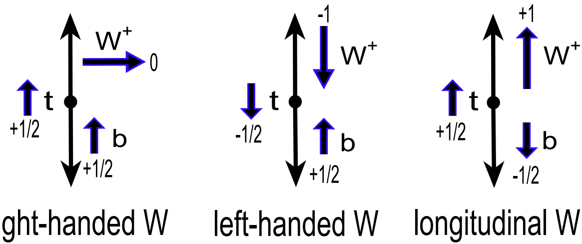
W polarisation in top decays

testing a SM prediction

[PRD 45 (1992) 124]



different W helicity fractions (F_0, F_L, F_R):

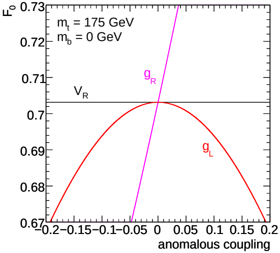


SM (LO): $F_0 = 0.703$ $F_L = 0.297$ $F_R = 0.00036$

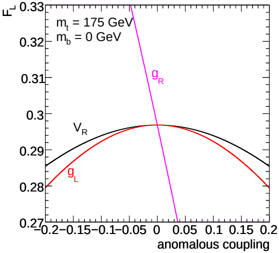
W polarisation and anomalous couplings

anomalous couplings ⇒ deviations in W helicity fractions

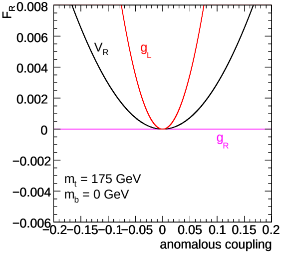
F_0



F_L



F_R



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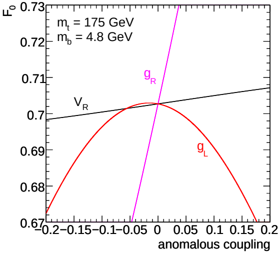
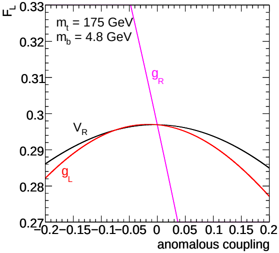
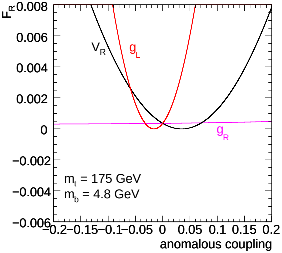


F_L

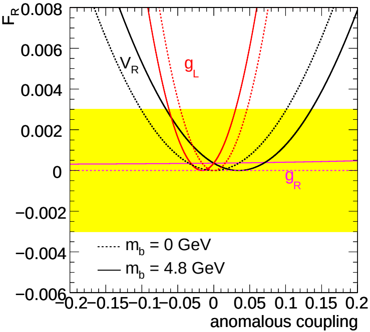


F_R



☞ correct m_b has to be considered!

W polarisation and anomalous couplings



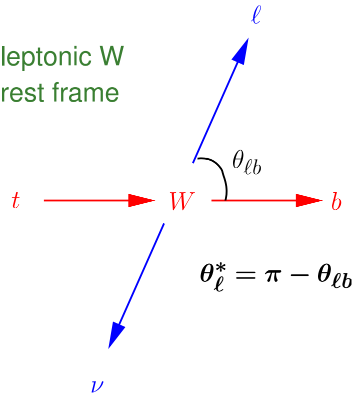
example: $|F_R| < 0.003$ can be converted into a V_R constraint using the intersection method:

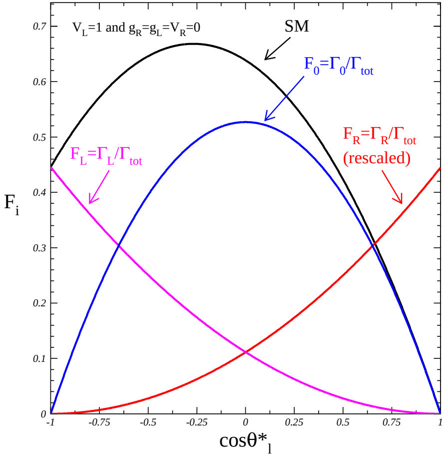
- $-0.101 < V_R < 0.101$ ($m_b = 0.0$ GeV)
- $-0.067 < V_R < 0.136$ ($m_b = 4.8$ GeV)

Measuring the W helicity states

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

leptonic W rest frame





Measuring the W helicity states

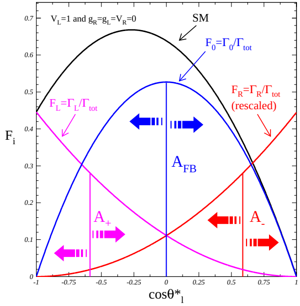
W polarisation can be measured by:

1. Fitting $\cos\theta^*_\ell$ to obtain the W helicity fractions (F_0, F_L, F_R)
2. Fitting $\cos\theta^*_\ell$ to obtain the W helicity ratios:
   - ☞ $\rho_L = F_L/F_0 = 0.438$ (SM, NLO)
   - ☞ $\rho_R = F_R/F_0 = 1.4 \times 10^{-3}$ (SM, NLO)
3. Computing angular asymmetries: $A_t = \frac{N(\cos\theta^*_\ell > t) - N(\cos\theta^*_\ell < t)}{N(\cos\theta^*_\ell > t) + N(\cos\theta^*_\ell < t)}$

   A_{FB}=-0.2269 (SM, NLO)

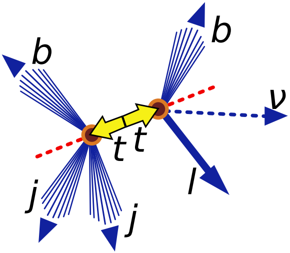
   A_+=0.5429 (SM, NLO)

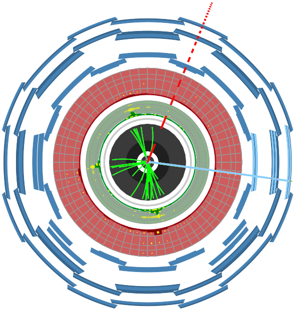
   A_-=-0.8402 (SM, NLO)



Monte Carlo generation

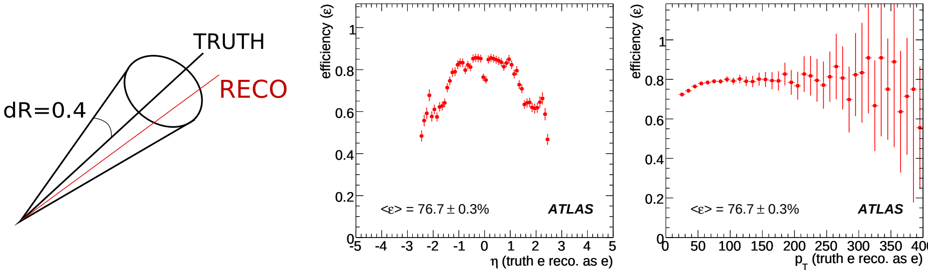
CSC book: CERN-OPEN-2008-020





- $\sqrt{s} = 14$ TeV simulation:
  $t\bar{t}$ signal: MC@NLO (5200), AcerMC (5205)
  background: MC@NLO ($t\bar{t}$), AcerMC (single top),
  Alpgen (W+jets), Pythia (Z+jets),
  Herwig (WW, ZZ, WZ)

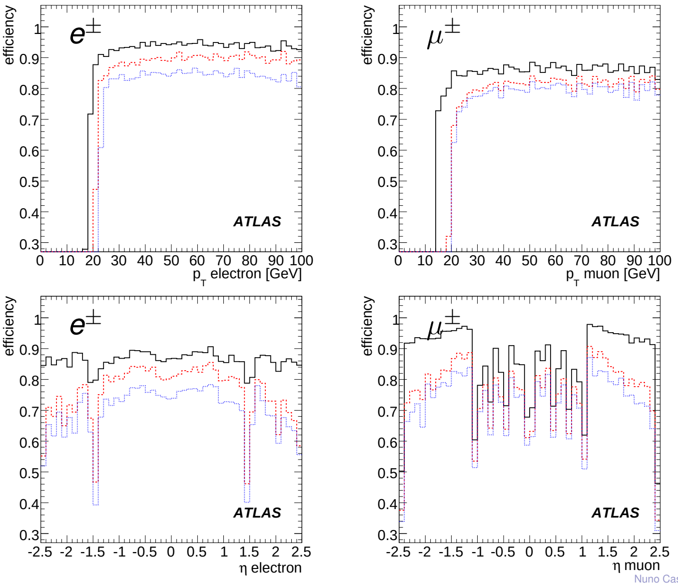
Object reconstruction



	generated				
reconstructed	e	μ	γ	τ	q/g
e	76.7±0.3	<0.1	1.3±0.3	18.4±0.2	1.1±0.1
μ	<0.1	93.9±0.3	0.1±0.1	19.4±0.2	0.1±0.1
γ	5.4±0.1	<0.1	62.0±2.3	1.1±0.1	0.2±0.1
τ	1.5±0.1	<0.1	1.6±0.3	5.8±0.1	0.4±0.1
jet	15.9±0.1	0.6±0.1	34.6±1.6	21.2±0.2	93.0±0.1

Expected trigger performance

— LVL1 trigger - - - LVL2 trigger · · · EF trigger



single lepton trigger:

`e25i`
`mu20i`

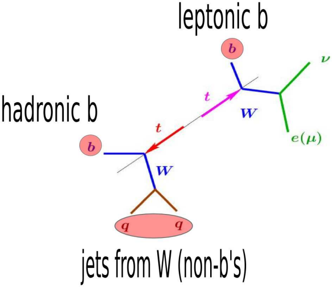
Analysis for L=1 fb^{-1}: event reconstruction

☞ preselection:

$1\ \ell(e,\mu)\ p_T > 25\ (20)$ GeV; $|\eta| < 2.5$

≥ 4 jets (2b), $p_T > 30$ GeV; $|\eta| < 2.5$

$E_T^{\text{miss}} > 20$ GeV



☞ event reconstruction:

$$\chi^2 = \frac{(m_{\ell\nu j_a} - 175)^2}{\sigma_t^2} + \frac{(m_{j_b j_c j_d} - 175)^2}{\sigma_t^2} + \frac{(m_{\ell\nu} - 80.4)^2}{\sigma_W^2} + \frac{(m_{j_c j_d} - 80.4)^2}{\sigma_W^2}$$

- $\sigma_t = 14$ GeV, $\sigma_W = 10$ GeV
- $[j_a, j_b, j_c, j_d] \rightarrow$ combinations of the four highest p_T jets (12 hypotheses)

$\Longrightarrow$ minimization of χ^2:
scan over the jet combinations and a values of neutrino p_Z

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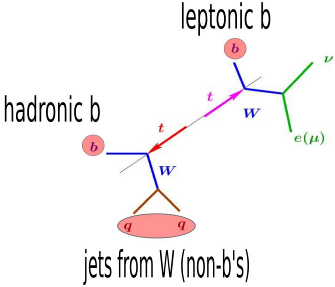

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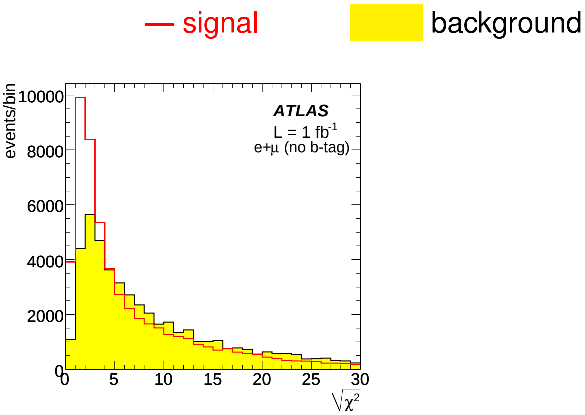

- additional selection requirement: $\sqrt{\chi^2} < 4$
- once a good *b*-tagging performace is achieved, this information can be taken into acount in the jets assignement ($\mathrm{btag_{weight}} > 0$ for "b-jets" candidates)

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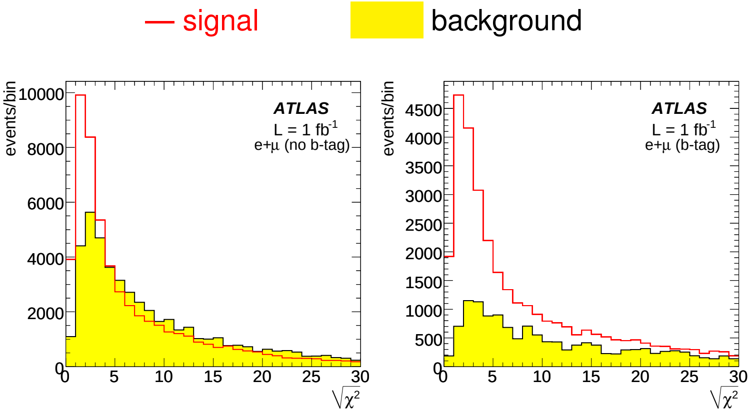

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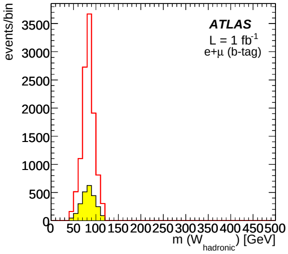
Analysis for L=1 fb^{-1}: event reconstruction

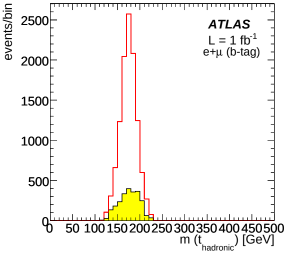
☞ reconstructed invariant masses after the χ^2 cut (analysis with *b*-tagging)

— signal   background

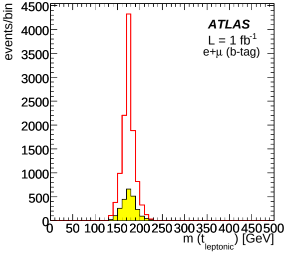
had. *W*



had. *t*



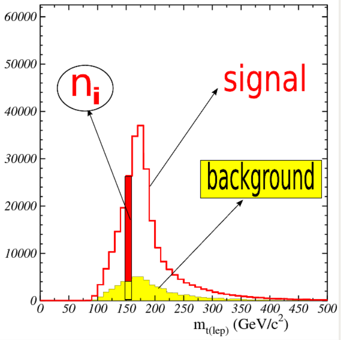
lep. *t*



Probabilistic analysis

- probabilistics analysis (after sequential selection):
  - N probability density functions (based on physical distributions)
  - $P_i = \frac{n_i}{n_{total}}$
  - $L_S = \Pi_{i=1}^{N} P_i^{signal}$
  - $L_B = \Pi_{i=1}^{N} P_i^{background}$
  - discriminant variable:

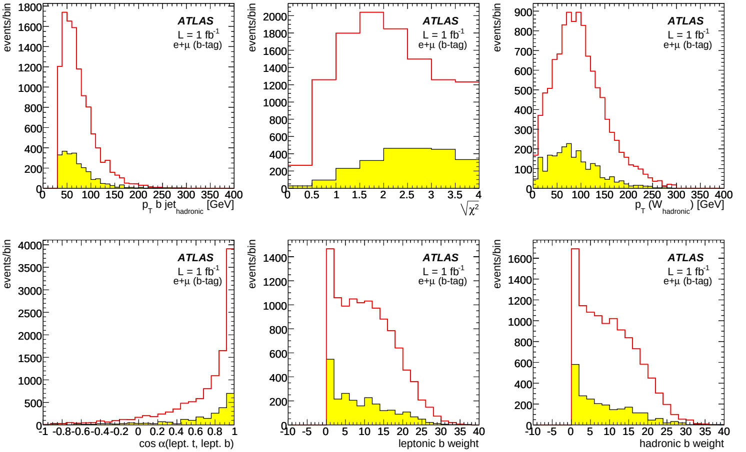
    $L_R = \log_{10}(L_S/L_B)$



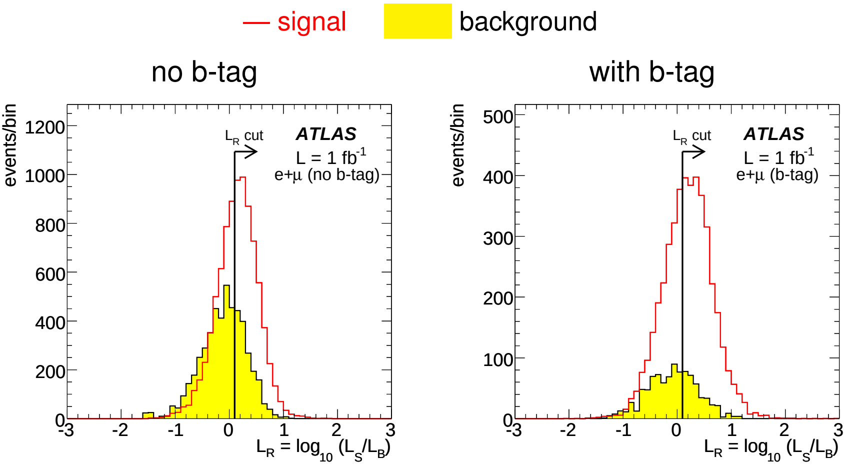
examples of the distributions used to build the p.d.f.s:

(analysis with btag)

— signal   background



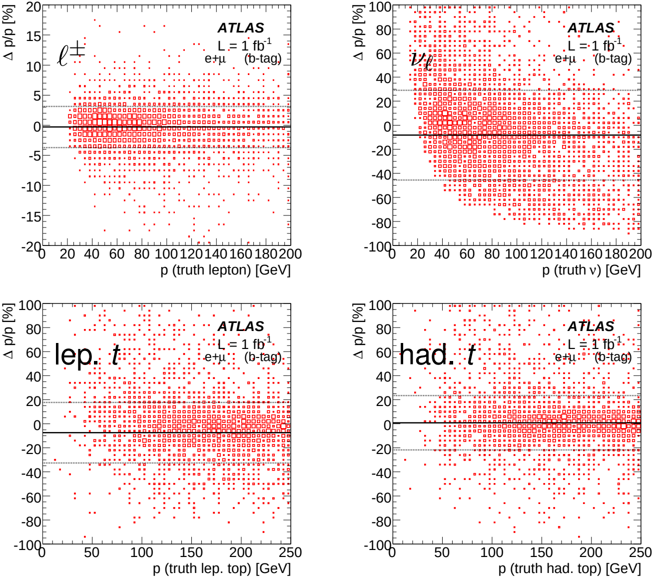
Probabilistic analysis



final selection: $L_R > 0.1$

Reconstruction performance after the probabilistic analysis

(analysis with *b*-tagging)

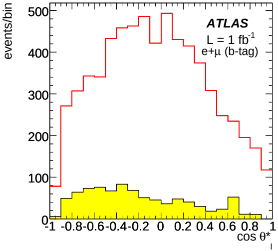


Probabilistic analysis

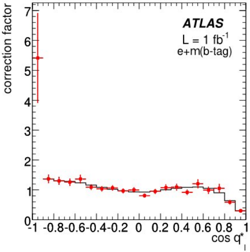
☞ number of expected events for L=1 fb^{-1}
(analysis with b-tagging)

signal	presel.	11200 ± 96
	final sel.	6586 ± 74
W+jets	presel.	181 ± 82
	final sel.	26 ± 73
single t	presel.	359 ± 24
	final sel.	125 ± 14
$t\bar{t}$ (except signal)	presel.	1377 ± 52
	final sel.	613 ± 35
total background	presel.	2385 ± 133
	final sel.	851 ± 94
S/B	presel.	4.7 ± 0.3
	final sel.	7.7 ± 0.9

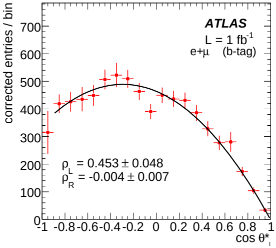
$\cos\theta^*_\ell$ reconstruction



reconstructed



correction function



fake data: $(S_1 + B_1)$

background subtraction: $(S_1 + B_1) - B_2$

correction function: G/S_2

corrected distribution: $[(S_1 + B_1) - B_2] \times G/S_2$

ATLAS sensitivity to the observables ($L=1\ \text{fb}^{-1}$)

considered systematics:

1) JES
2) luminosity
3) top mass
4) background
5) ISR+FSR
6) MC generator
7) pile-up

no btag ($L = 1\ \text{fb}^{-1}$)

ρ_L =	0.402	$\pm$	0.050	(stat)	$\pm$	0.267	(syst.)
ρ_R =	-0.008	$\pm$	0.008	(stat)	$\pm$	0.017	(syst.)
A_{FB} =	-0.220	$\pm$	0.025	(stat)	$\pm$	0.080	(syst.)
A_+ =	0.560	$\pm$	0.024	(stat)	$\pm$	0.074	(syst.)
A_- =	-0.845	$\pm$	0.012	(stat)	$\pm$	0.021	(syst.)

with btag ($L = 1\ \text{fb}^{-1}$)

ρ_L =	0.453	$\pm$	0.048	(stat)	$\pm$	0.163	(syst.)
ρ_R =	-0.004	$\pm$	0.007	(stat)	$\pm$	0.012	(syst.)
A_{FB} =	-0.229	$\pm$	0.026	(stat)	$\pm$	0.033	(syst.)
A_+ =	0.542	$\pm$	0.028	(stat)	$\pm$	0.052	(syst.)
A_- =	-0.830	$\pm$	0.014	(stat)	$\pm$	0.027	(syst.)

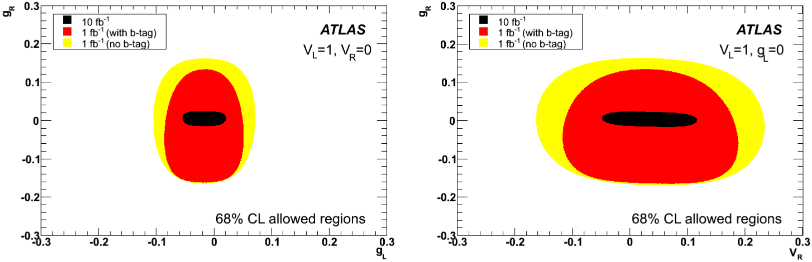
Wtb anomalous couplings: `TopFit`

- evaluation of the expected ATLAS sensitivity to the *Wtb* anomalous couplings:
  - combine the information of the most sensitive observables (taking into account the correlations)
  - evaluate 68% CL allowed regions considering the dependence of these observables with V_R, g_L and g_R

☞ this is the purpose of TopFit

Wtb anomalous couplings: `TopFit`

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



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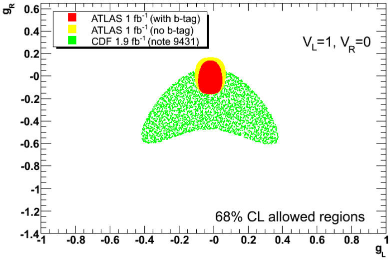

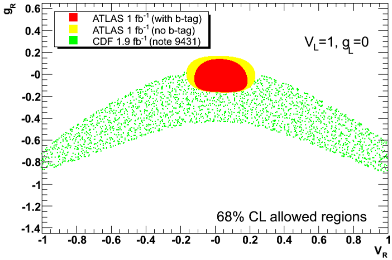

green area: limits obtained with `TopFit` from the CDF result on the W helicity fractions (Conf. Note 9431)

Wtb anomalous couplings: TopFit

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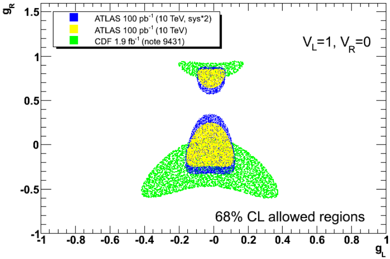
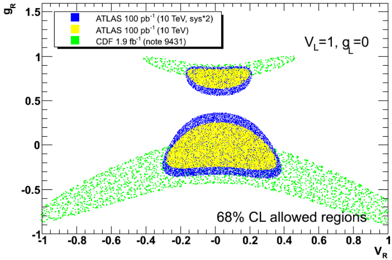
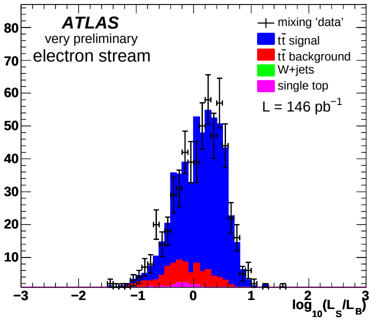


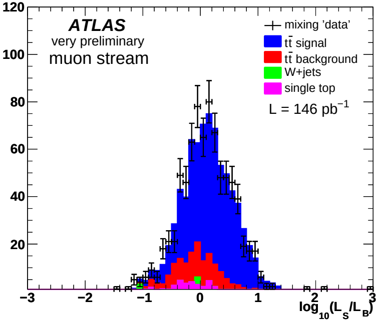


expectation for **L=100 pb**$^{-1}$ @ $\sqrt{s}$ = **10 TeV**:
theoretical extrapolation of the oficial experimental results

Analysis for $\sqrt{s}$=10 TeV

- Starting to analyse the Top Mixing exercise “data”





Wtb anomalous couplings: `Protos` generator

Studying *Wtb* anomalous couplings with `Protos`

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Departamento de Física Teórica y del Cosmos
Universidad de Granada

Top WG meeting, Geneva, 7/11/2008

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

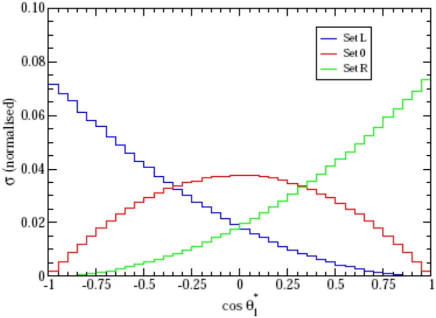
$$q = p_t - p_b = p_W$$

implemented in Protos (PROgram for TOp Simulations)

(JAAS et al. EPJC '07, JAAS NPB '08 and JAAS NPB '09)

Wtb anomalous couplings: `Protos` generator

- `Protos` validation and integration in `Athena` is being done
- *W* polarisation templates ($m_t = 172.5$ GeV):



	V_L	V_R	g_L	g_R
$F_0 = 1$	1.53205	0	-0.01989	0.714647
$F_L = 1$	0.504619	0.001919	0	1.08275
$F_R = 1$	0.001919	0.504619	1.08275	0

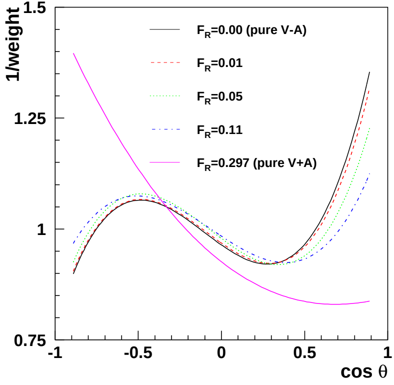
Summary

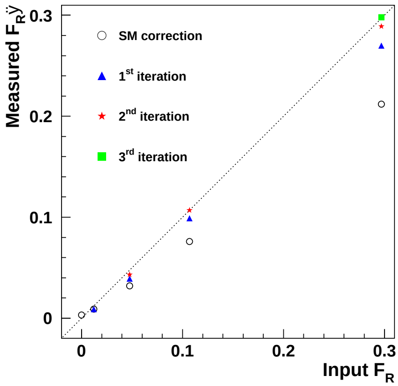
- The LHC data will allow to study the Wtb vertex structure with an unprecedented precision
- Different observables (angular asymmetries and *W* helicity ratios) can be combined to improve sensitivity (`TopFit`)
- `Protos` generator: *Wtb* anomalous couplings in $t\bar{t}$ and single top processes. FCNC processes (production and decay) also available.
- future perspectives:
  - $\sqrt{s} = 10$ TeV analysis
  - data driven methods
  - new observables (single top)
- stay tuned for the LHC data and results!

Backup Slides

New physics: example for $F_R \neq 0$

new corrections functions derived iteratively:





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