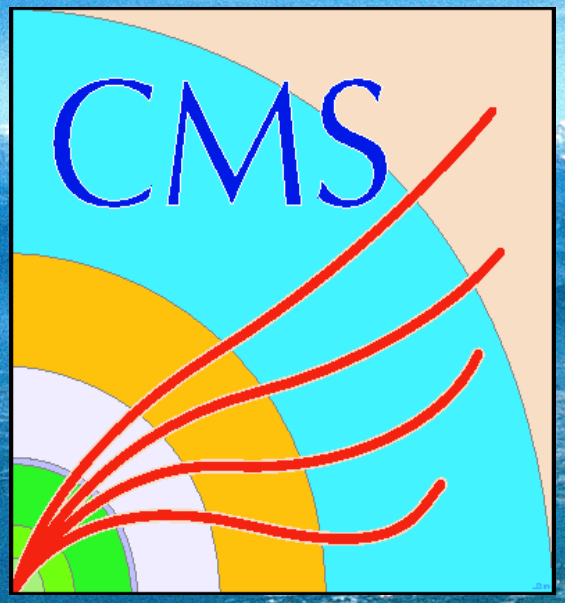

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ATLAS

Challenges in New Physics searches in top-like events at the LHC

On behalf of the ATLAS and CMS collaborations

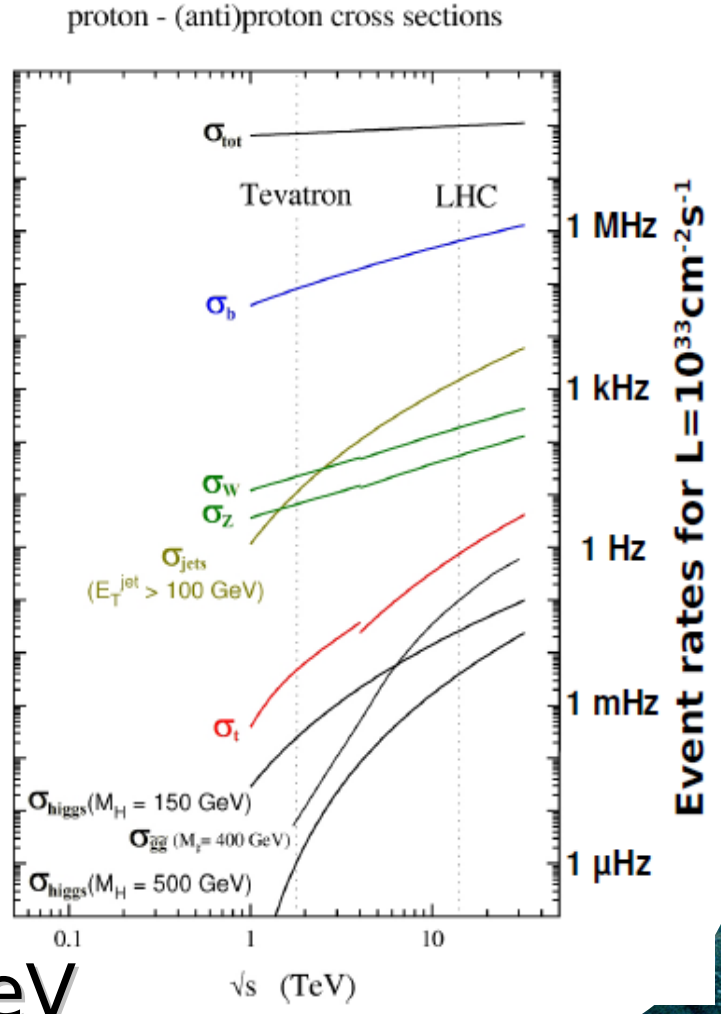
Outline

- 2010-2011 @ LHC
  - Top physics implication of 7 TeV vs 14 TeV
  - Luminosity expected
- BSM top physics to be investigated
  - TTbar resonances
    - Will concentrate on low mass resonances (see Jörgen and Eric's talk for high mass resonances)
  - b' → tW (4 th generation quark)
  - Top charge
  - TTbar spin correlation
  - W polarization in top decays
  - Anomalous Wtb coupling
  - Rare top decays and Flavor Changing Neutral Current (FCNC)

Scaling the Monte Carlo

- Most MC studies have been done assuming
  - 14 TeV or 10 TeV CM energy
- Revision for 2010-2011
  - 7 TeV CM energy
    - 100-200 pb^{-1} in 2010
    - 1 fb^{-1} in 2011

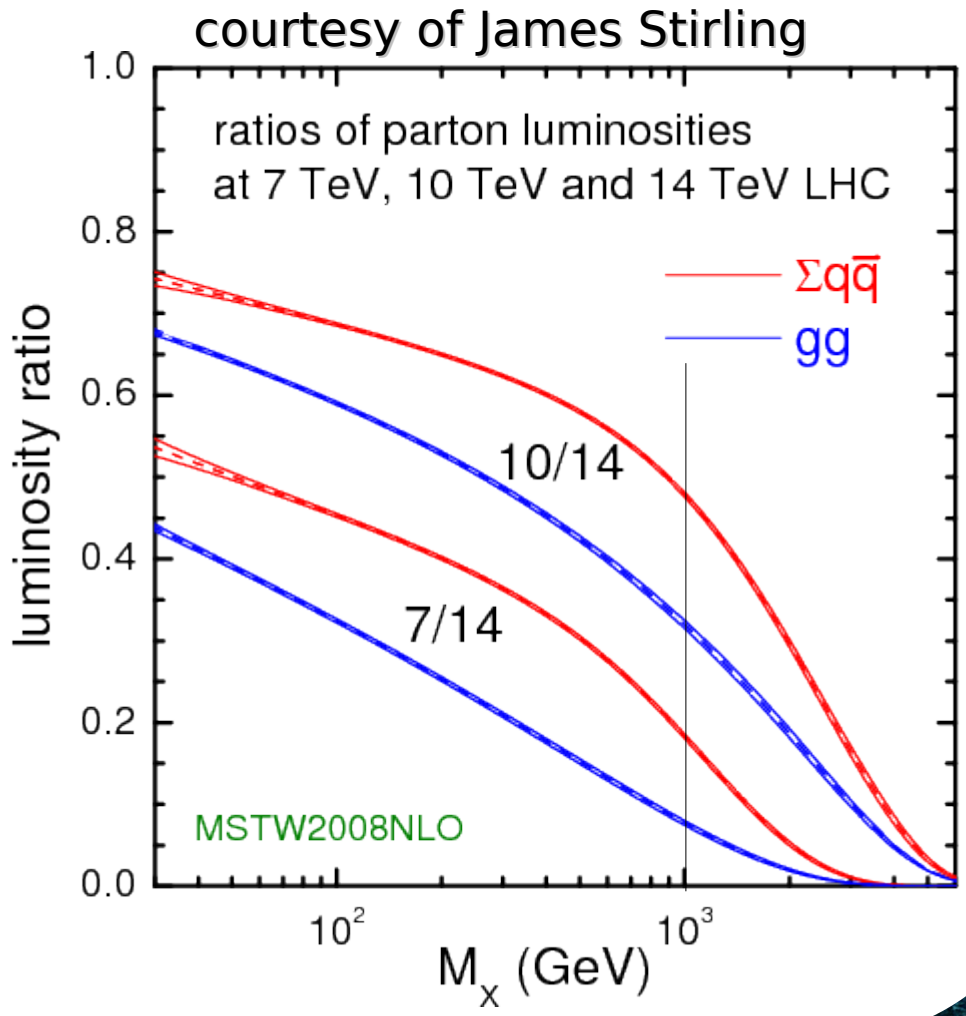
CM energy	TTbar Xsection
14 TeV	883 ± 45 pb
10 TeV	401 ± 25 pb
7 TeV	170 ± 10 pb



Rescale down by ~5 for 14 → 7 TeV

Effect on TTbar resonances

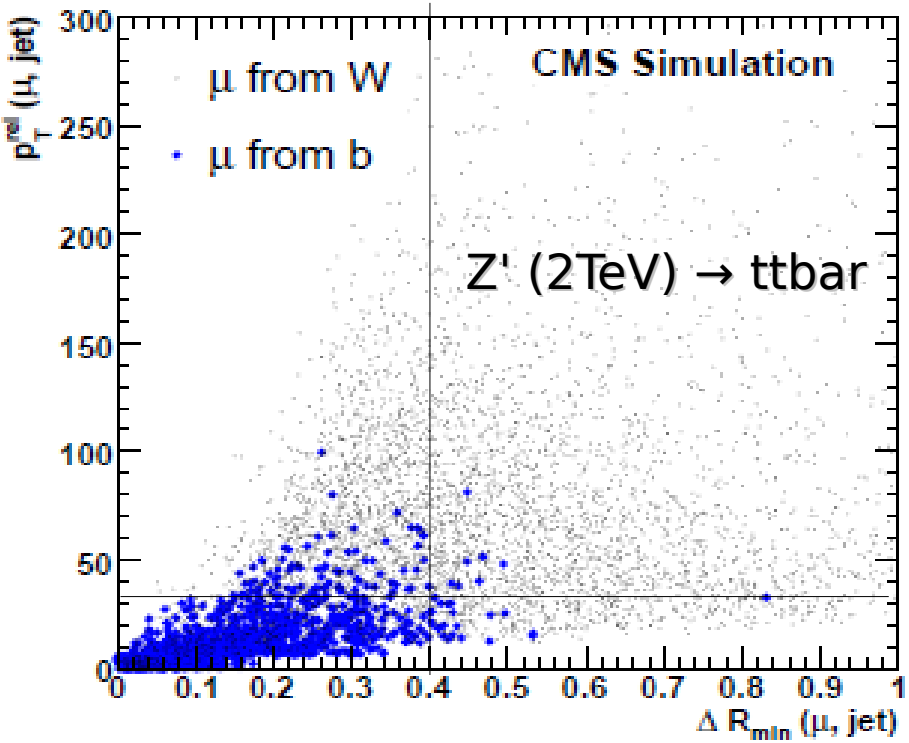
- Assuming a resonance mass of ~ 1 TeV
  - Rescale cross section by a factor of 5-10 (14 TeV → 7 TeV)
  - In the Z' case (only quarks annihilation)
    - Scale down by a factor of 5. Similar to ttbar cross section.



TTbar Resonances

Event Selection

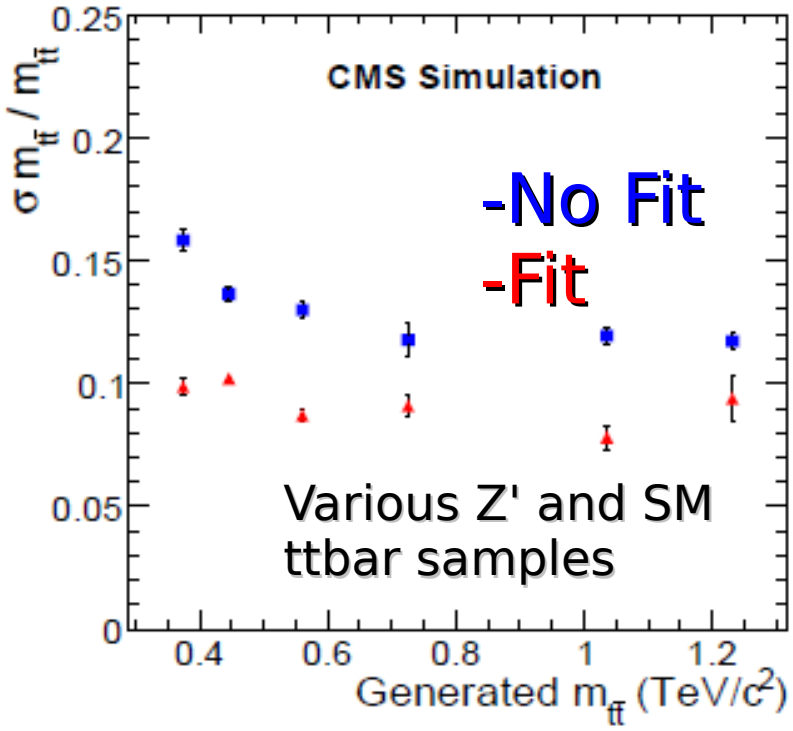
- 1 muon p_T > 35 GeV Isolation optimized to be efficient also for boosted tops.
- 4 jets p_T > 35 GeV



Efficient muon isolation also for boosted tops

Event Reconstruction

- Kinematic fit with top and W mass constraints
- Select the 4 “good jets” in event based on gobal Chi2.
- Fit the 12 quarks->jets combinations and keep the one with lowest Chi2.



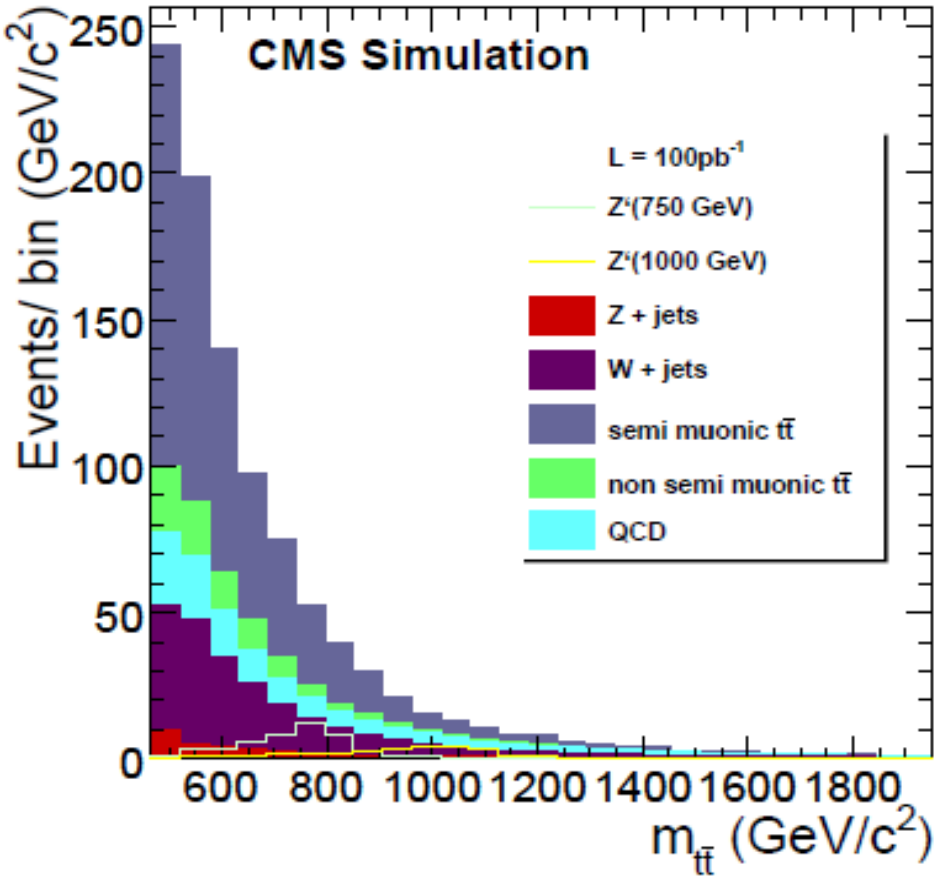
CMS PAS TOP-09-009 (10 TeV)

Kinematic fit improves resolution and linearity

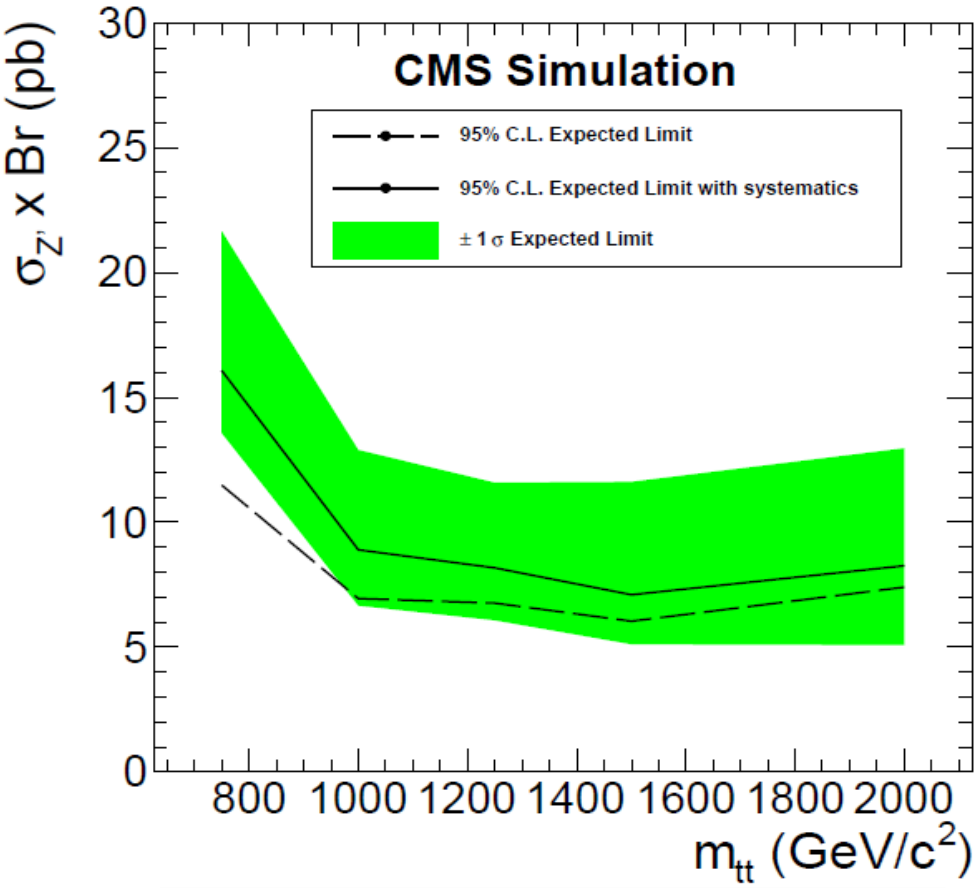
TTbar Resonances

- Invariant mass distribution and expected limits (10 TeV, 100 pb^{-1})

CMS PAS TOP-09-009



Z' normalised to cross section at 95% exclusion



Sensitivity for resonance masses >~ 800 GeV

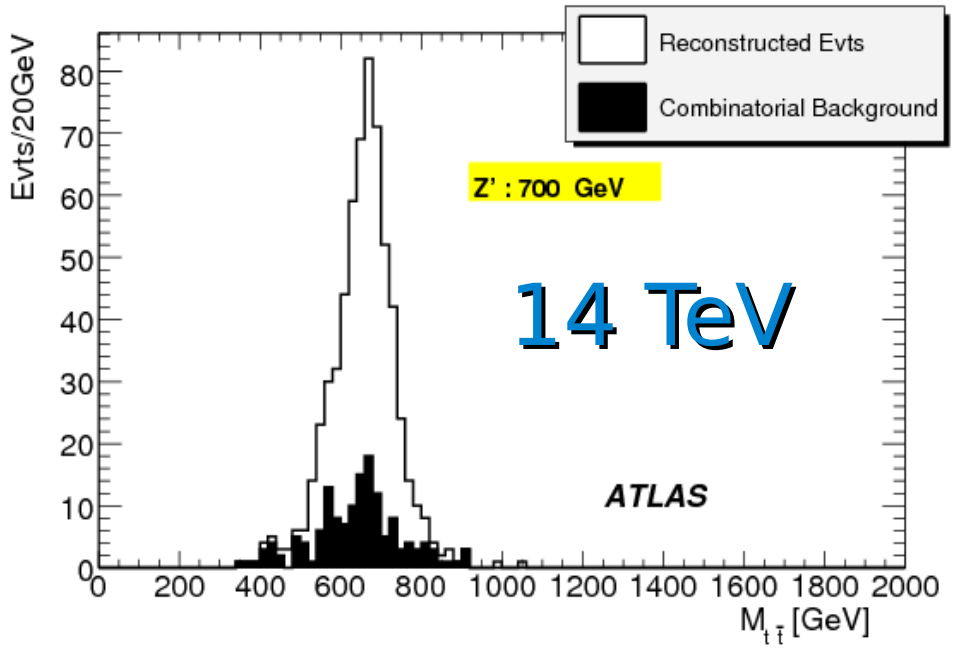
TTbar Resonances

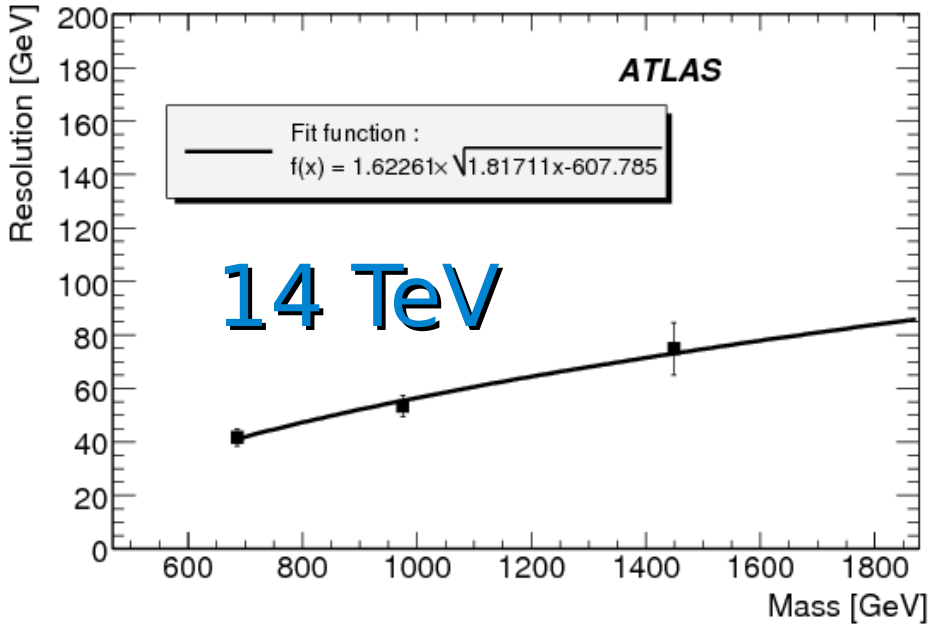
Event Selection

- 1 isolated lepton
- 4 jets p_T > 40 GeV
- 2 b-tagged jets
- MET > 20 GeV

Event Reconstruction

- Hadronic side
  - closest light jets + closest b-jet.
- Leptonic side
  - Pz-neutrino from W mass constraint.
- Window Cuts
  - Hadronic W and both top masses.

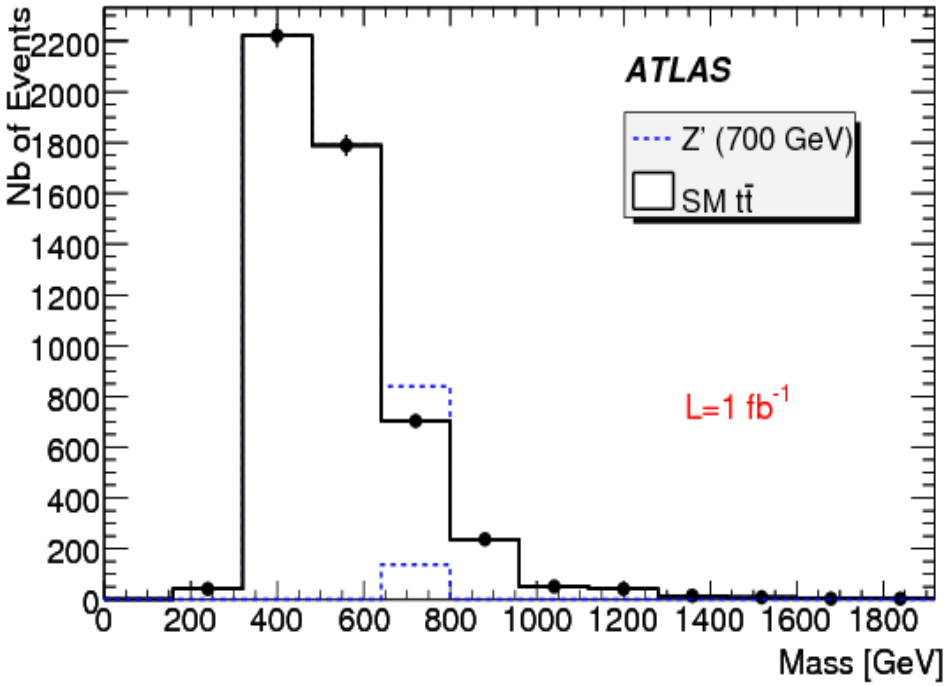


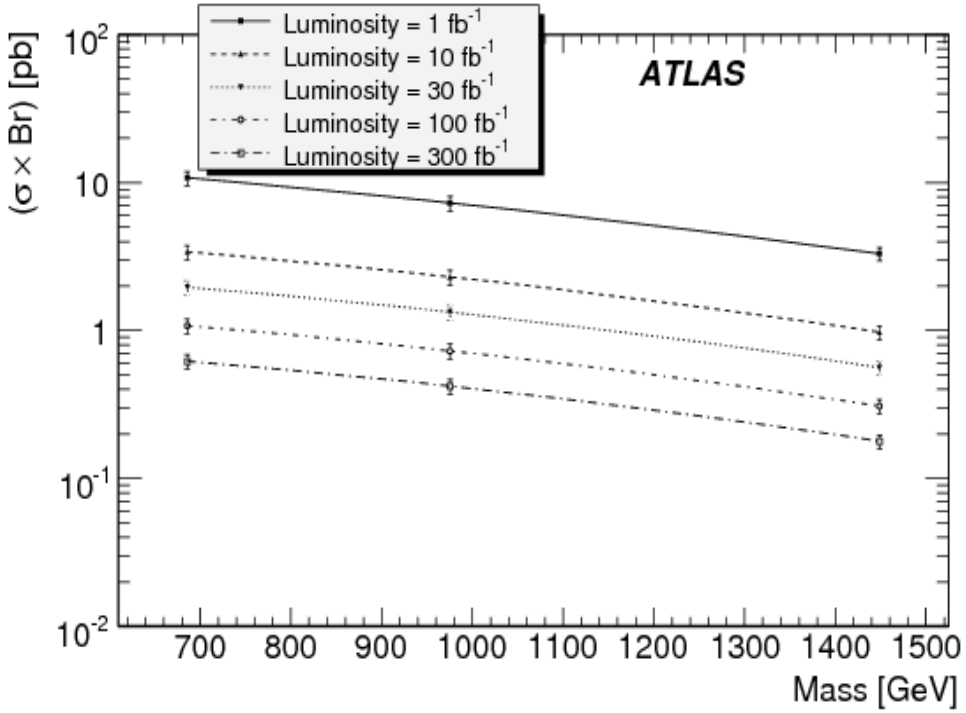


ATLAS: "Expected Performance of the ATLAS Experiment Detector, trigger and Physics", CERN-OPEN-2008-020

TTbar Resonances

- Invariant mass distribution and 5σ discovery potential: 14 TeV and much more luminosity.



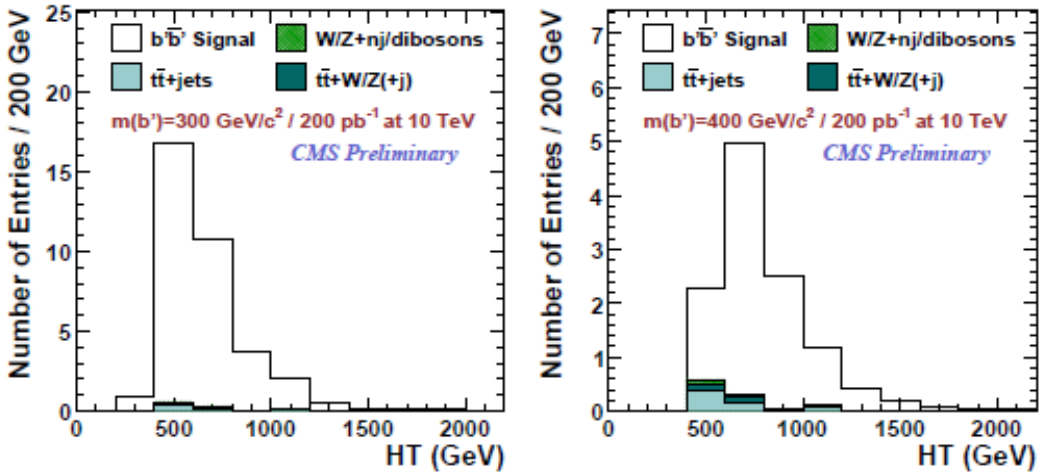


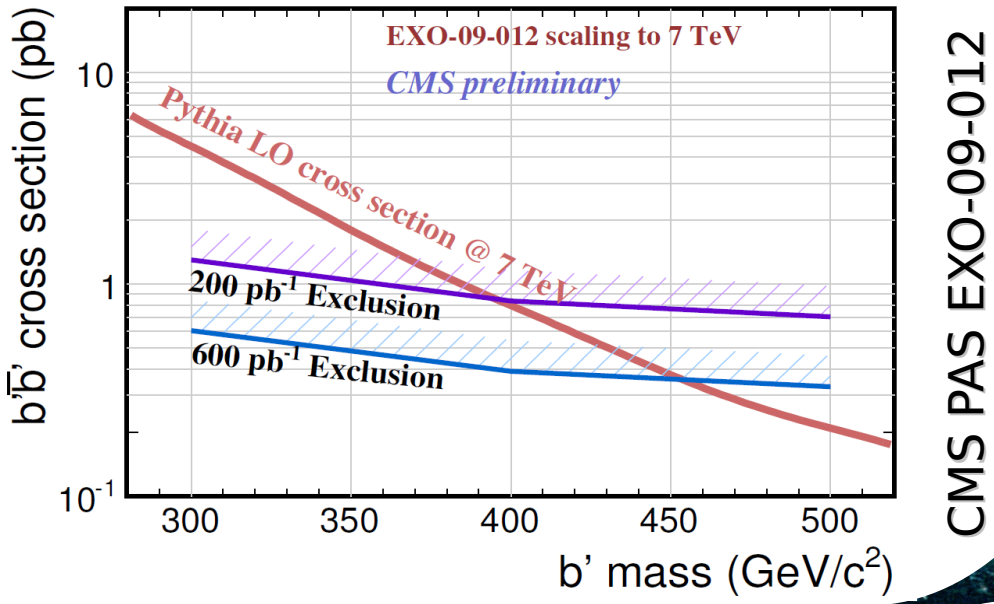
ATLAS: "Expected Performance of the ATLAS Experiment Detector, trigger and Physics", CERN-OPEN-2008-020

b' → top + W

- Topology
  - b'b' → tWtW → WWWWbb
- Selection
  - Same sign dileptons
  - Or three leptons
    - Leading p_T > 35 GeV
  - 4/2 jets p_T > 35 GeV
    - Leading p_T > 85 GeV
- Reconstruction
  - No full reconstruction possible → Use HT
    - Sum the p_T of Jets, leptons and MET.

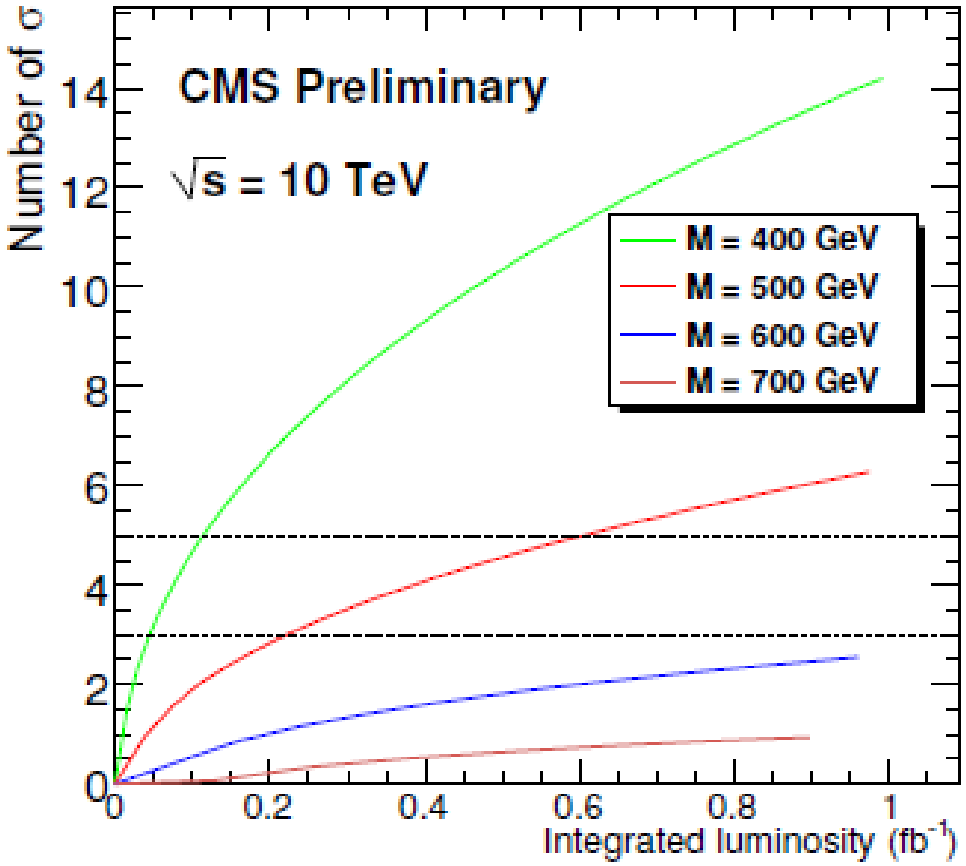
Negligible background

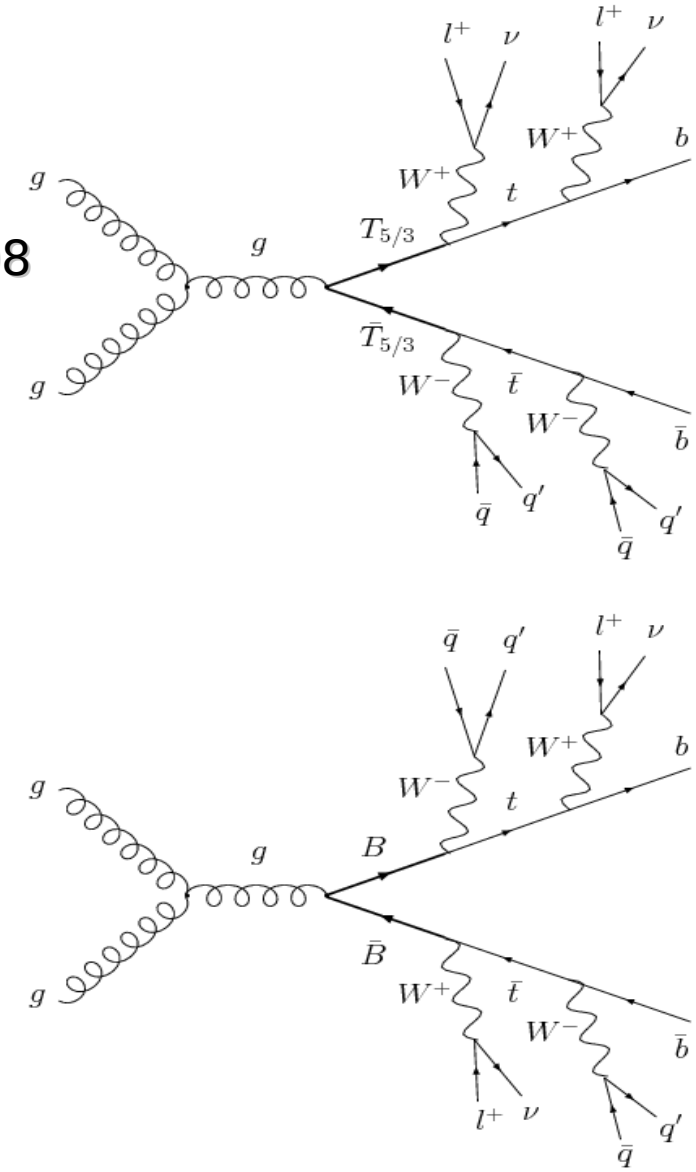




Exotic top partners

- B or $T_{5/3}$ → tW
  - Could be discovered fairly quickly CMS PAS EXO-08-008



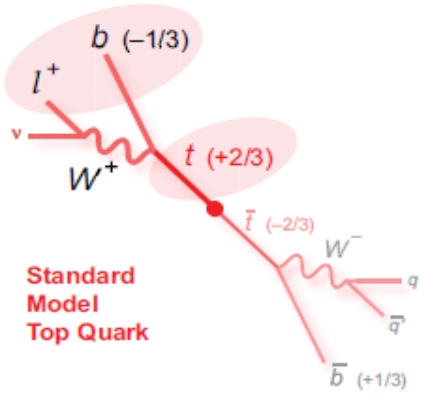


For a study where b'/t' **don't** primarily decay to 3rd generation: ATLAS SN-ATLAS-2008-069

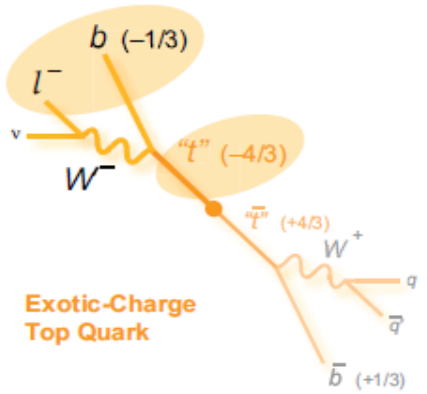
Top quark charge

Testing a SM prediction:

SM:



Exotic:



CDF: Top charge -4/3 excluded at 95% CL [CDF note 9939]
D0: Top charge -4/3 excluded at 92% CL [PRL 98, 031102]

ε = 31%
P = 86%

For top quark charge determination:

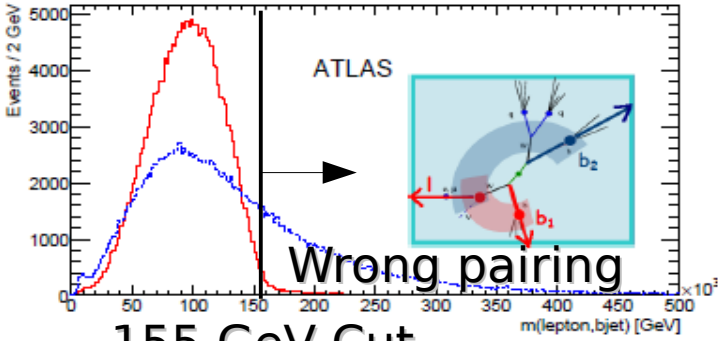
I) Determination of b-jet charge

a) Charge weighting technique

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

b) Semi-leptonic decay of b quark

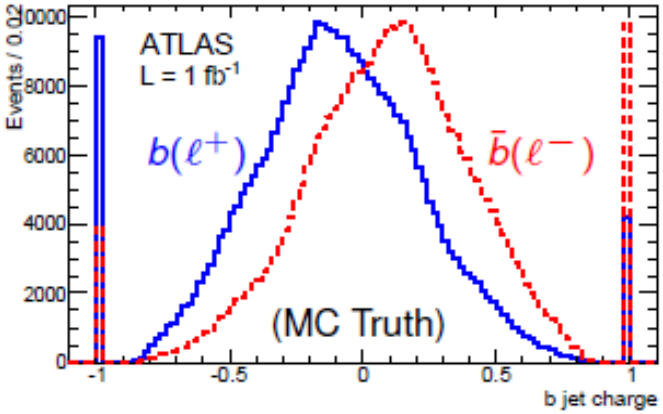
II) Correct (l,b) Pairing

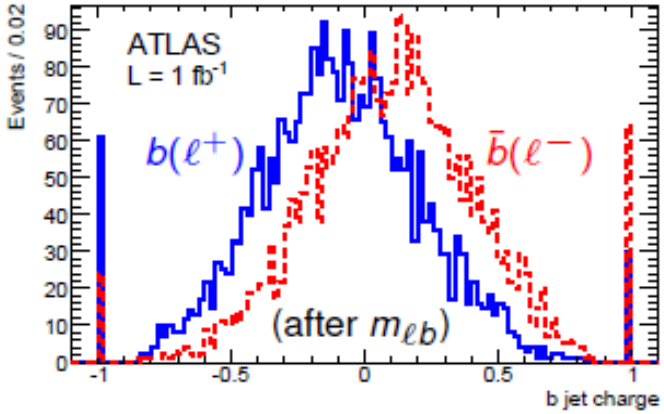


155 GeV Cut

Top quark charge

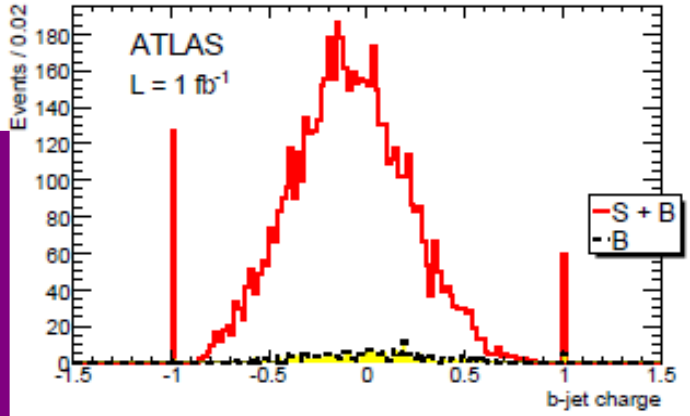
- a) Charge weighting (1 fb^{-1} @ 14 TeV, ATLAS)

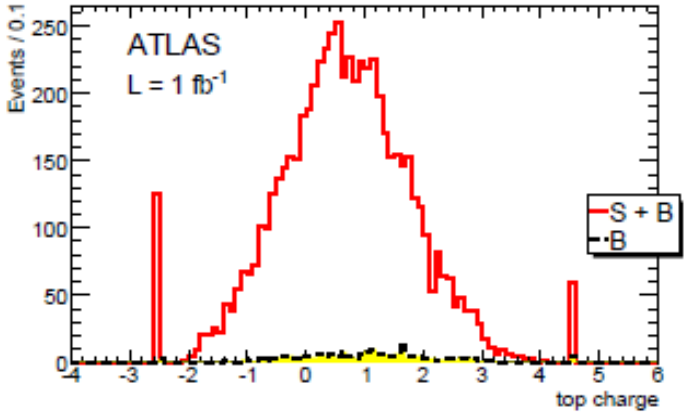




estimate for the W+jets background: S/B=30:1 (after m_W, m_t and $m_{\ell b}$ cuts)

5σ signifi-cance for Q with 100 pb^{-1}





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

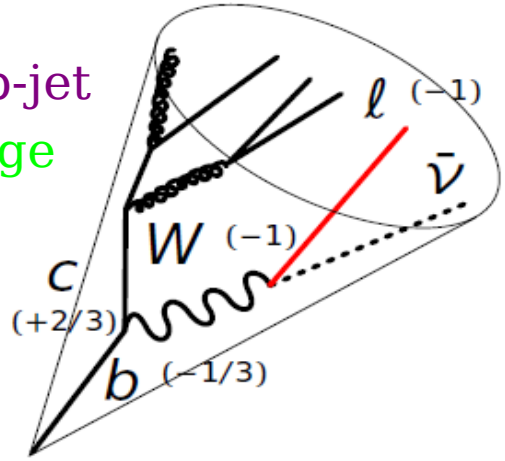
$Q_{\mathrm{t}} = Q_{\ell} + Q_{\mathrm{b-jet}} \times C_{\mathrm{b}} = 0.67 \pm 0.06(\mathrm{stat.}) \pm 0.08(\mathrm{sys})$

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

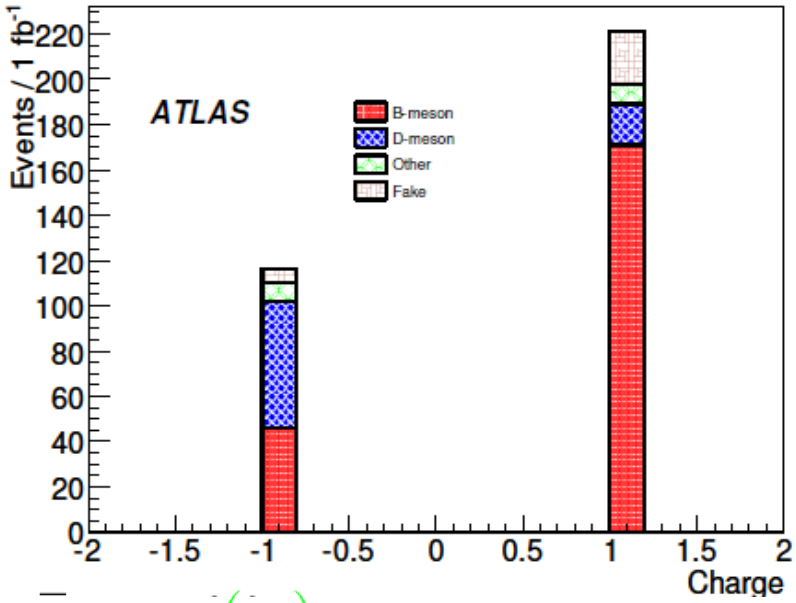
Top quark charge

- b) Semileptonic b-decay
  - Sign of non isolated lepton tells us charge of b-jet
  - Get top charge by adding isolated lepton charge

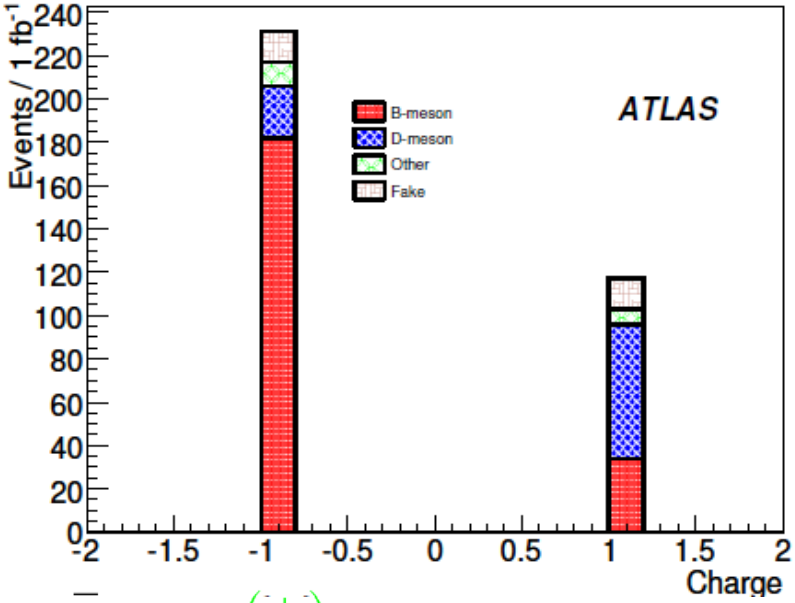
$$b \to q l^- \bar{\nu},\ \bar{b} \to \bar{q} l^+ \nu,\ (q = u, c)$$



To include case where more than one non isolated lepton ⟶ $\bar{Q}_{nonIs} = \dfrac{N(l^+) - N(\ell^-)}{N(\ell^+) + N(\ell^-)}$



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



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

Need 1 fb^{-1} @ 14 TeV for determining Q = +2/3 vs -4/3 (5σ significance)

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

W polarization

Standard model

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

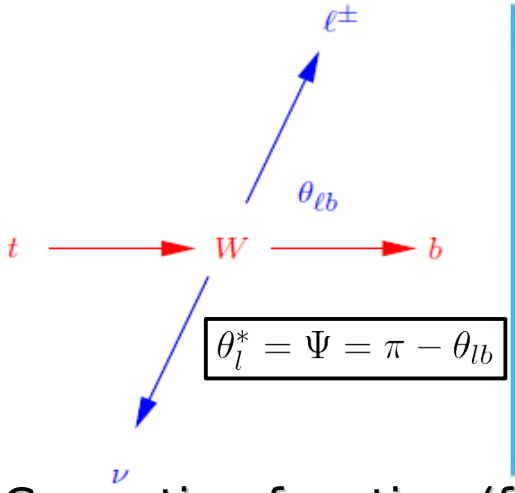
$F_0 = 0.695$

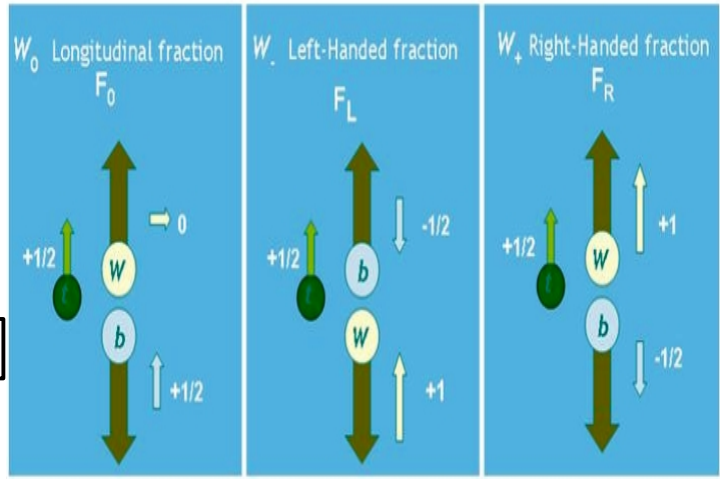
$F_L = 0.304$

$F_R = 0.001$

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

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





Expected precision for ATLAS 14 TeV (L = 1 fb^{-1})

$F_0 \rightarrow$ **5%**: ± 0.04 (stats) ± 0.02 (syst)

$F_L \rightarrow$ **12%**: ± 0.02 (stats) ± 0.03 (syst)

$F_R \rightarrow$ **0.03**: ± 0.02 (stats) ± 0.02 (syst)

CDF (L = 2.7 fb^{-1}) [10004-CONF]

$F_0 = 0.88 \pm 0.11 \pm 0.06 \rightarrow$ **18.0%**

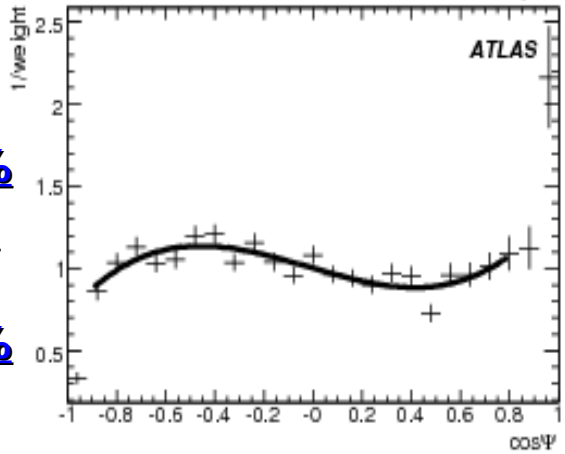
$F_R = -0.15 \pm 0.07 \pm 0.06 \rightarrow$ **0.09**

D0 (L = 2.7 fb^{-1}) [5722-CONF]

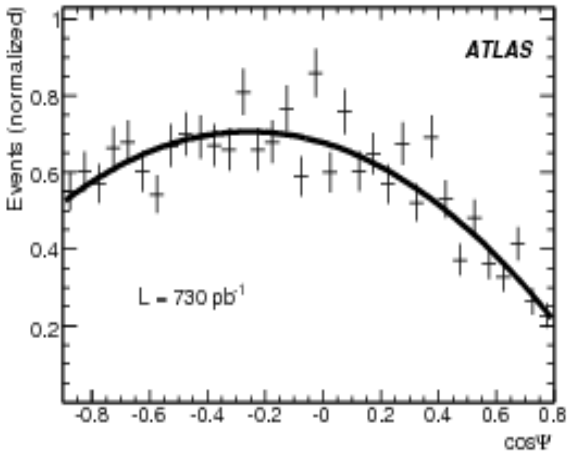
$F_0 = 0.49 \pm 0.11 \pm 0.09 \rightarrow$ **19.5%**

$F_R = 0.11 \pm 0.06 \pm 0.05 \rightarrow$ **0.08**

Correction function (f_c)



Angular distribution (rec.)



The percentages are calculated with respect to SM expected values

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

TTbar spin correlation

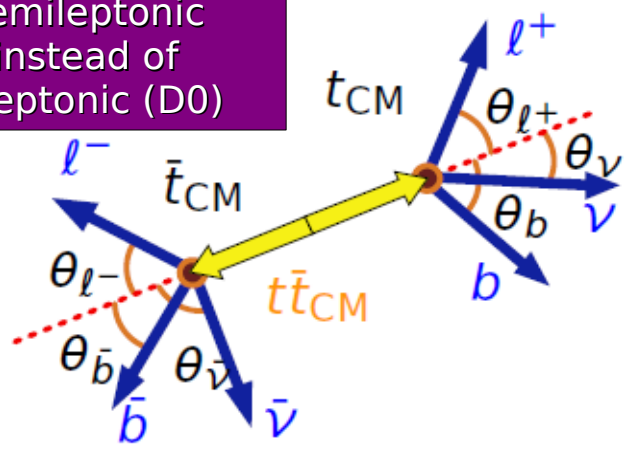
t quarks decay before hadronisation → spin information is conserved

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

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

α_1(lepton) = 1
α_2(least energetic non b-jet) = 0.51

ATLAS used semileptonic instead of dileptonic (D0)

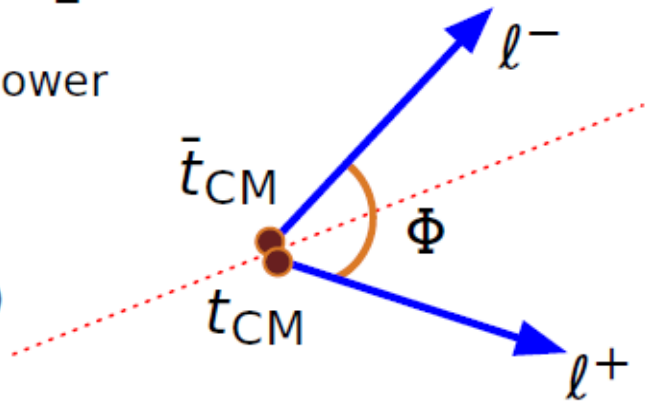


$\cos\theta$ → angle between the t (in $t\bar{t}$ rest frame) and the t decay product (in t rest frame)

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

α → spin analysing power

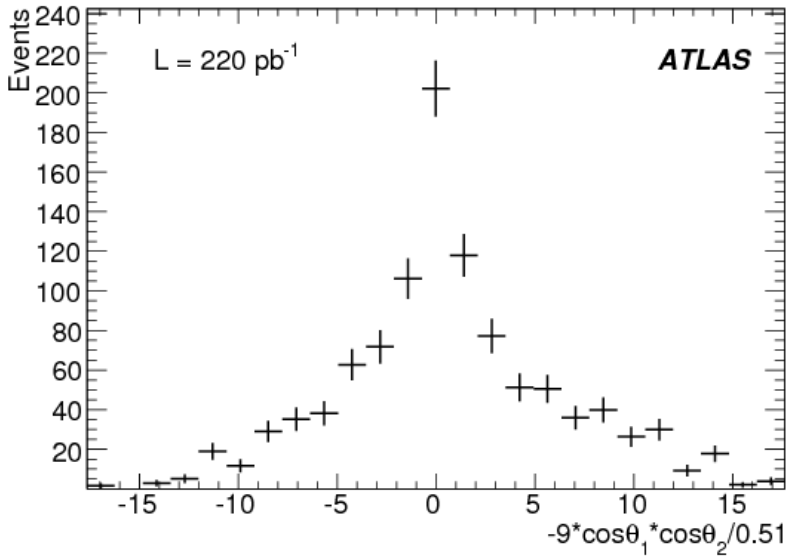
$A^{SM} = 0.422$
$A_D^{SM} = -0.290$
$(m_{t\bar{t}} < 550\ \text{GeV})$

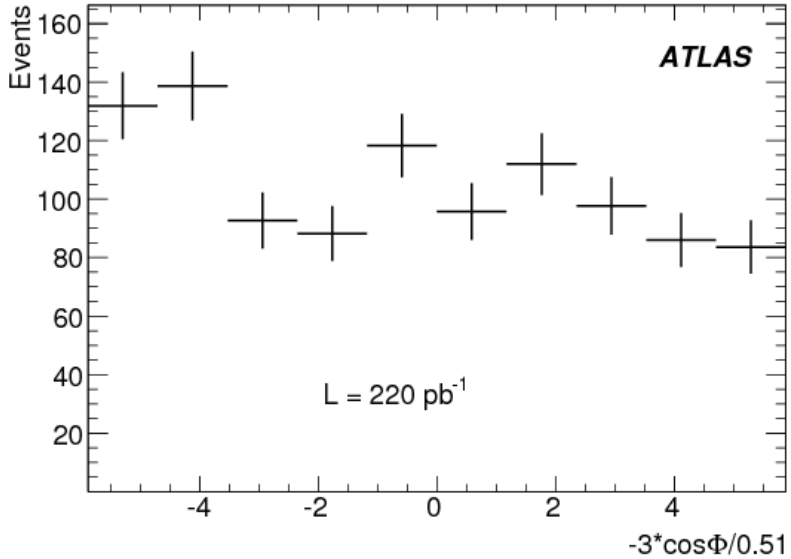


Φ → angle between the two spin analysers (in the corresponding t rest frame)

TTbar spin correlation

- Expected precision, ATLAS 14 TeV @ 1 **fb^{-1}**
  - A → **57%** / [83%]: ± 0.17 (stat) ± 0.18 (syst) ± 0.25 [ATLFAST]
  - A_D → **49%**: ± 0.11 (stat) ± 0.09 (syst)
- Need 10 fb^{-1} @ 14 TeV for 1% to 5% precision
  - Limited principally by b-jet energy scale systematic error.





- CDF @ 4.3 fb^{-1} [CONF, 10048]
  - A = 0.60 ± 0.50 (stat) ± 0.16 (syst) → **124%**
- D0 @ 4.2 fb^{-1} [5950-CONF]
  - A = $-0.17_{-0.53}^{+0.64}$ → **138%**

The percentages are taken with respect to the LHC expect SM values:
A = 0.422, A_D = -0.290

Anomalous Wtb coupling

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

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

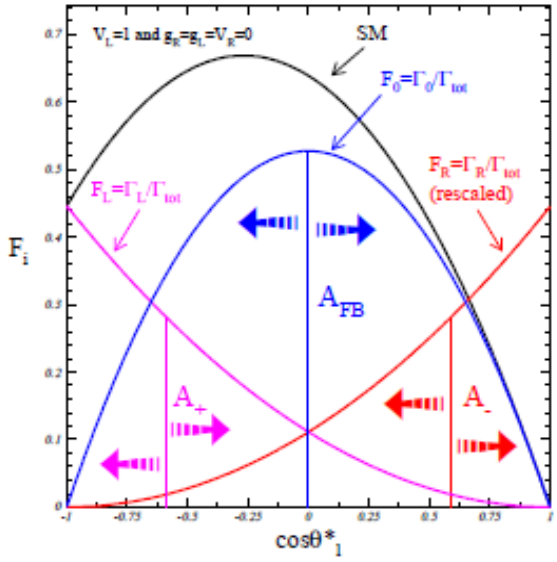
V_R
g_L
g_R

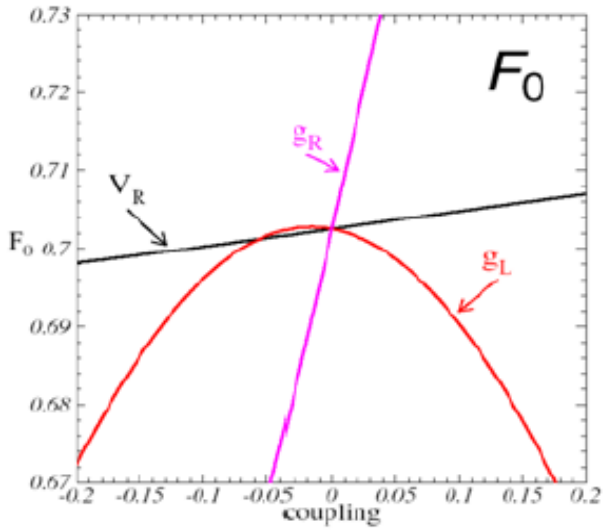
Anomalous coupling

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

With t = 0, ± $(2^{2/3} - 1)$ → $A_{FB}(F_R,F_L)$; $A_-(F_0,F_L)$; $A_+(F_0,F_R)$

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

Anomalous Wtb coupling

- Anomalous Couplings ATLAS 14 TeV @ 1 fb^{-1}

$(A_+, A_-, \rho_L, \rho_R)$

TopFit ↓ [Eur.Phys.J. C50 (2007) 519-533]

(V_R, g_L, g_R)

- D0 limits at 95% CL [5838-CONF]

  $V_R < |0.72|$ (outside the plot)

  $g_L < |0.19|$ and $g_R < |0.20|$

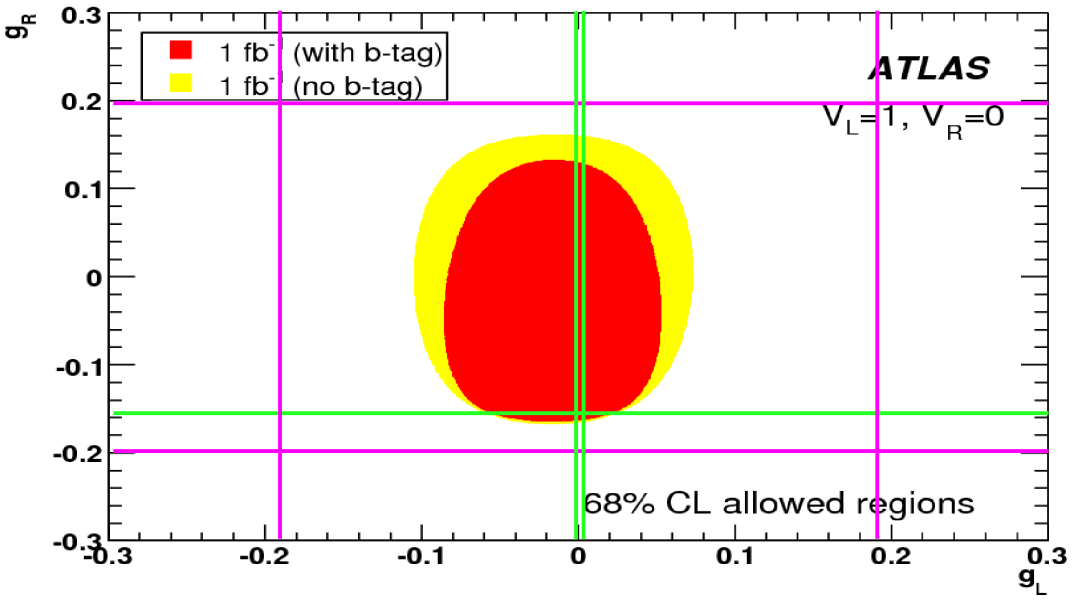
- b → s + gamma limit at 95% CL [hep-ph/arXiv:0802.1413v2]

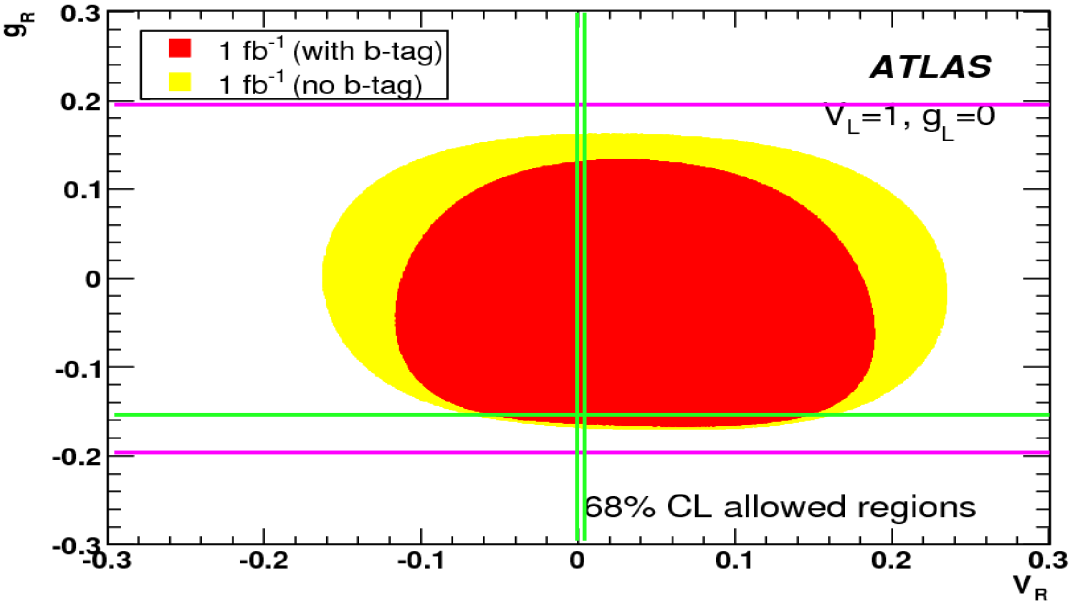
  $-0.0007 < V_R < 0.0025$

  $-0.0015 < g_L < 0.004$

  $-0.15 < g_R < 0.57$ (upper bound outside the plot)

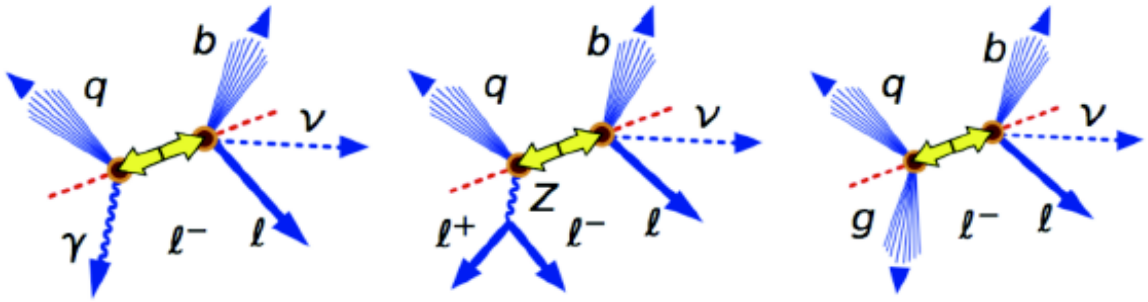
- Will be competive for measurement of g_R





Rare top decays and FCNC

- Several $t\bar{t}$ FCNC Decay Channels Studied @ LHC:



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]

- Full $t\bar{t}$ event reconstruction (without using b-tag):
  - Loop on jets (and leptons for $t \to qZ$)
  - Scan on p_Z^ν
  - Minimize the χ^2:

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

(m_t =175 GeV, σ_t =14 GeV, m_W =80.42 GeV, σ_W =10 GeV, m_Z =91.19 GeV, σ_Z =3 GeV)

Rare top decays and FCNC

ATLAS FCNC (95% CL) @ 1fb^{-1}:

→ Systematic uncertainties:

$\sigma_{sys}(t \to q\gamma) \sim 32\%$

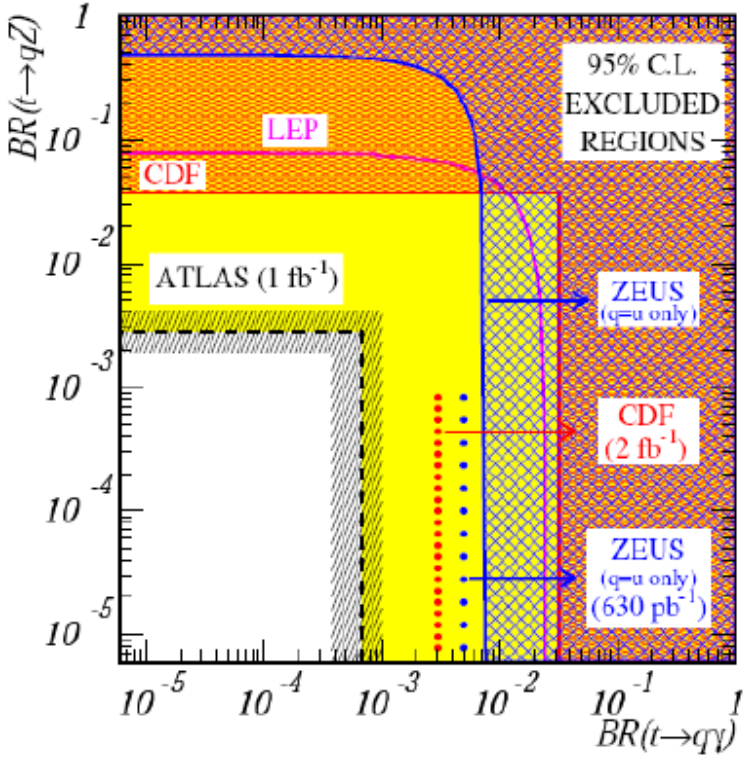
$\sigma_{sys}(t \to qZ) \sim 25\%$

$\sigma_{sys}(t \to qg) \sim 27\%$

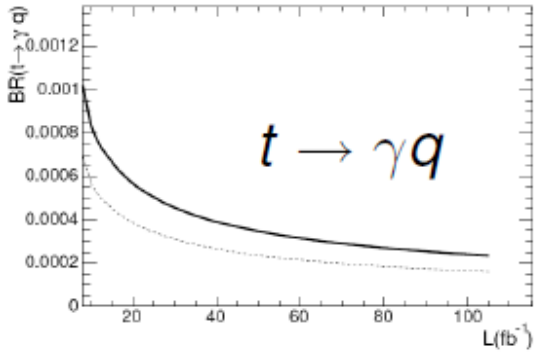
(m_t, ISR/FSR, pile-up, σ_{bck}, Gen.)

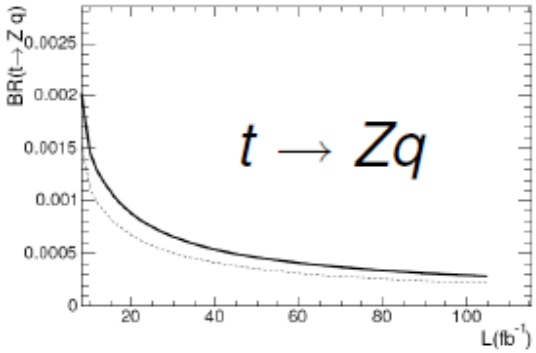
	-1σ	Expected	$+1\sigma$
$t\bar{t} \to$ bWqγ:			
e	4.3×10^{-4}	1.1×10^{-3}	1.9×10^{-3}
μ	4.5×10^{-4}	8.3×10^{-4}	1.3×10^{-3}
ℓ	3.8×10^{-4}	6.8×10^{-4}	1.0×10^{-3}
$t\bar{t} \to$ bWqZ:			
3e	5.5×10^{-3}	9.4×10^{-3}	1.4×10^{-2}
3μ	2.4×10^{-3}	4.2×10^{-3}	6.4×10^{-3}
3ℓ	1.9×10^{-3}	2.8×10^{-3}	4.2×10^{-3}
$t\bar{t} \to$ bWqg:			
e	1.3×10^{-2}	2.1×10^{-2}	3.0×10^{-2}
μ	1.0×10^{-2}	1.7×10^{-2}	2.4×10^{-2}
ℓ	7.2×10^{-3}	1.2×10^{-2}	1.8×10^{-2}

14 TeV



CMS FCNC (5σ) @ 10fb^{-1}:





CMS 5σ sensitivity:

$Br(t \to \gamma q) = 8.4 \times 10^{-4}$

$Br(t \to Zq) = 14.9 \times 10^{-4}$

(CMS: CERN/LHCC 2006-021)

Conclusion

- The revised 7 TeV centre of mass energy for 2010-2011 running has possibilities for discoveries/evidences of new physics.
  - Especially true in the case of TTbar resonances and b' → tW.
  - More top-like MC studies are ongoing at 10 TeV and also 7 TeV.
    - Will help with making quantitative statements.
  - Focus will be moved toward real data as the integrated luminosity increases.
- Moreover, our experience from 2010-2011 should speed up our searches when 14 TeV operation starts.

Backup Slides

Top quark selection

criterion	$\varepsilon(\%)$	criterion	$\varepsilon(\%)$
Semileptonic events	100	Dileptonic events	100
1 isol.lept. (p_T >25/20 GeV)	58.9	2 isol.lept. (p_T >25/20 GeV)	35.5
$\geq$ 4 jets (p_T >30 GeV)	34.2	$\geq$ 2 jets (p_T >30 GeV)	31.8
$\geq$ 2 b-tagged	10.5	= 2 b-tagged	8.3
missing E_T > 20 GeV	8.5	missing E_T > 30 GeV	6.5

Top Charge Systematic

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
Pile-up	–	1.8
Background asymmetry	1	–
S/B ratio	9	–
total	12.5	19.3

W Polarization Systematic

Source of uncertainty	F_L	F_0	F_R	A	A_D
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 quark mass (2 GeV)	0.015	0.011	0.004	0.028	0.013
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
Trigger	-	-	-	0.10	0.03
TOTAL	0.03	0.02	0.02	0.18	0.09

Anomalous Wtb systematic

Without b-tag

Source	ρ_L	ρ_R	A_{FB}	A_+	A_-
Jet energy scale	0.02	0.003	0.004	0.006	0.002
Luminosity	0.02	0.002	0.006	0.005	0.001
Top quark mass	0.02	0.002	0.009	0.006	0.004
Background	0.01	0.002	0.005	0.003	0.002
ISR+FSR	0.13	0.009	0.044	0.046	0.011
MC generator	0.18	0.013	0.039	0.042	0.001
Pile-up	0.14	0.004	0.053	0.039	0.017
Total	0.27	0.017	0.080	0.074	0.021

With b-tag

Source	ρ_L	ρ_R	A_{FB}	A_+	A_-
Jet energy scale	0.04	0.001	0.010	0.004	0.002
Luminosity	0.01	0.000	0.006	0.005	0.001
Top quark mass	0.03	0.003	0.013	0.008	0.006
Background	0.01	0.000	0.003	0.002	0.004
ISR+FSR	0.05	0.006	0.024	0.028	0.015
MC generator	0.01	0.008	0.009	0.011	0.000
Pile-up	0.15	0.006	0.012	0.041	0.022
Total	0.16	0.012	0.033	0.052	0.027

FCNC systematic

	$t \to q\gamma$			$t \to qZ$			$t \to qg$		
Source	e	μ	ℓ	3e	3μ	3ℓ	e	μ	ℓ
Jet energy calibration	1%	2%	2%	3%	2%	5%	4%	4%	4%
Luminosity	9%	8%	10%	3%	2%	6%	10%	8%	10%
Top quark mass	7%	7%	6%	6%	4%	12%	7%	5%	5%
Backgrounds σ	6%	10%	7%	4%	7%	12%	17%	16%	15%
ISR/FSR	21%	18%	17%	6%	29%	7%	3%	7%	9%
Pile-up	37%	21%	22%	30%	14%	0%	8%	10%	13%
Generator	34%	18%	4%	4%	14%	14%	5%	0%	4%
χ^2	5%	0%	4%	2%	5%	7%	3%	7%	9%
Total	56%	36%	32%	32%	36%	25%	24%	24%	27%

Z' systematic

Source of uncertainty	Error (%)	Effect on the discovery potential (%)
Reconstruction efficiency	16.6	8.3
Background contribution	$^{+6.2}_{-4.7}$	3.1
$t\bar{t}$ mass resolution	$\pm 1\sigma_{\text{resolution}}$	2 to 11
Luminosity	5	2.5
Jet energy scale	5	-