Probing top quark anomalous magnetic moment at LHC

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work in progress in collaboration with:

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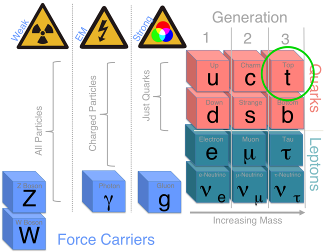
Outline

Top Quark



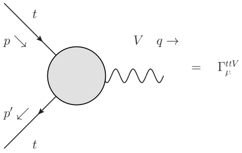
- The heaviest known fundamental particle, discovered at the Tevatron in 1995.
- Top does not produce bound states: $\tau_t \approx 5 \cdot 10^{-25} s < \tau_{\text{had}} \approx 3 \cdot 10^{-24}$.
- Spin correlation of decay products.
- $m_t = 173.5$ GeV, top quark is an excellent probe of the mechanism that breaks the EW gauge symmetry.

Top Quark

- New physics connected with EWSB may thus be found first in top quark precision observables.
- A possible signal of NP are deviations of the $tt\gamma$, ttZ and tbW couplings from the values predicted by the SM.
- Single-top production provides a means of directly measuring $|V_{tb}|$.
  CMS $|V_{tb}| = 1.04 \pm 0.09(\mathrm{exp}) \pm 0.02(\mathrm{th})$ CMS PAS TOP-11-021
  ATLAS $|V_{tb}| = 1.04^{+0.14}_{-0.13}$ CERN-PH-EP-2012-082
- ttZ vector and axial couplings are rather tightly but indirectly constrained by LEP data. Baur & al. PRD 71 (2005) 54013

How can we measure the $tt\gamma$ coupling at LHC?

General $tt\gamma$ Couplings



The most general Lorentz-invariant vertex function describing the interaction of a vector boson V with two on-shell top quarks can be written as:

$$\Gamma_\mu^{ttV} = ie\left\{\gamma_\mu\left[F_{1V}^V(q^2) + \gamma_5 F_{1A}^V(q^2)\right] + \frac{\sigma_{\mu\nu}}{2m_t} q^\nu \left[iF_{2V}^V(q^2) + \gamma_5 F_{2A}^V(q^2)\right]\right\}$$

Taking $V = \gamma$, in the limit $q^2 \to 0$

$$F_{1V}^\gamma(0) = Q_t = \frac{2}{3}, \quad F_{2V}^\gamma(0) = Q_t\frac{g-2}{2}, \quad F_{2A}^\gamma(0) = \frac{2m_t}{e}d_t^\gamma .$$

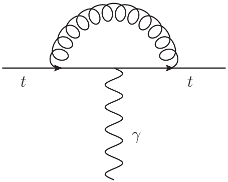
Anomalous Magnetic Moment

The magnetic moment of particle of mass m and charge q:

$$\vec{\mu} = g\frac{q}{2m}\vec{S}.$$

For a spin-1/2 fermion $g = 2$. The g-factor is modified by quantum correction:

$$a_t = \frac{g-2}{2} = \frac{F_{2V}^{\gamma}(0)}{Q_t}$$



$$a_t = \frac{\alpha_s}{2\pi}C_F + \left(\frac{\alpha_s}{2\pi}\right)^2 a_t^{(2l)} + \cdots$$

$Q_t\, a_t^{SM}(\mu = m_t) = 2.00 \cdot 10^{-2}$, T. Gehrmann & al. PRL 95 (2005) 261802

Effective Lagrangian Approach

Effective operators included in the Lagrangian:

$$\mathcal{L}_{\text{eff}} = eA^{\mu}\bar{t}\left[\gamma_{\mu}\left(\Delta F_{1V} + \Delta F_{1A}\gamma_5\right)\right]t + \frac{e}{4m_t}F_{\mu\nu}\bar{t}\left[\sigma^{\mu\nu}\left(\Delta F_{2V} - i\Delta F_{2A}\gamma_5\right)\right]t,$$

where the coefficients $\Delta F_{iV,A}$ parametrize any deviation from the SM tree level values.

- $t\bar{t}\gamma$ and single-top+γ production at LHC as a tool to constrain $\Delta F_{iV,A}$ (in particular a_t).
- Which observable is more suited to unveil any SM deviations?
- What quantitative bounds can be derived on the anomalous $tt\gamma$ couplings?

$t\bar{t}\gamma$ at LHC

Study of the process $pp \to t\bar{t}\gamma$ at LHC@14TeV

U. Baur, A. Juste, L.H. Orr, D. RainWater PLD 71 (2005) 54013

They concentrate on the process $pp \to \gamma\ell\nu_\ell b\bar{b}jj$ with $\ell = e, \mu$. They included minimal detector effects via Gaussian smearing of parton momenta and $\epsilon_b^2 = 40\%$ have been assumed.
Main source of background is $t\bar{t}j$.

Process		LHC
signal		81.7 fb
$t\bar{t}j$	$P_{j\to\gamma} = 1/1600$	45.7 fb

Sensitivity Bounds

Sensitivities achievable at 68.3% CL for anomalous $tt\gamma$ couplings in $pp \to \gamma\ell\nu_\ell b\bar{b}jj$ at the LHC ($\sqrt{s} = 14$ TeV) for an integrated luminosities of 30 fb^{-1}, 300 fb^{-1}, and 3000 fb^{-1}. The limits represent the maximum and minimum values obtained when taking into account the correlations between any possible pair of anomalous couplings.

coupling	30 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
ΔF^{γ}_{1V}	$+0.23$ -0.14	$+0.079$ -0.045	$+0.037$ -0.019
ΔF^{γ}_{1A}	$+0.17$ -0.52	$+0.051$ -0.077	$+0.018$ -0.024
ΔF^{γ}_{2V}	$+0.34$ -0.35	$+0.19$ -0.20	$+0.12$ -0.12
ΔF^{γ}_{2A}	$+0.35$ -0.36	$+0.19$ -0.21	$+0.11$ -0.14

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Single Top+γ

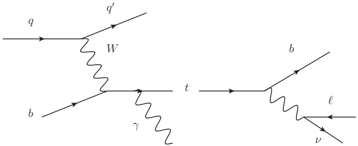
Search for the top $g-2$ in single-top+γ production (t-channel):

$$pp \to bj\ell^+\nu_\ell\gamma$$

with $\ell = e, \mu$.

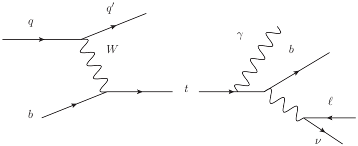
Radiative production:

$$pp \to (t \to b\ell^+\nu_\ell)j\gamma$$



Radiative radiative decay:

$$pp \to (t \to b\ell^+\nu_\ell\gamma)j$$

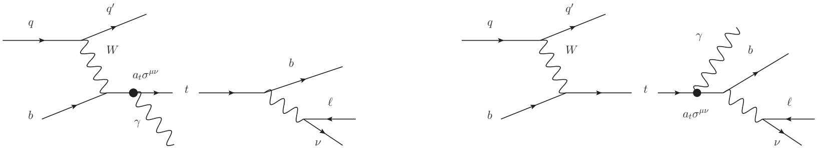


Main source of background $pp \to jj\gamma\,(W \to \ell\nu_\ell)$, one of the two light jet is mistagged as a b-jet.

General Top Interactions in MG5

- Simulation of parton-level events at LHC@14TeV with *MadGraph5*.
- Implementation of the general top anomalous interactions in MadGraph5 via the Mathematica package *FeynRules*.

$$\mathcal{L}_{\text{eff}} \longrightarrow \text{FeynRules} \longrightarrow \text{NewModel.UFO} \longrightarrow \text{MadGraph5}$$



- Optimal cuts
- Study of possible angular correlation induced by the anomalous couplings.

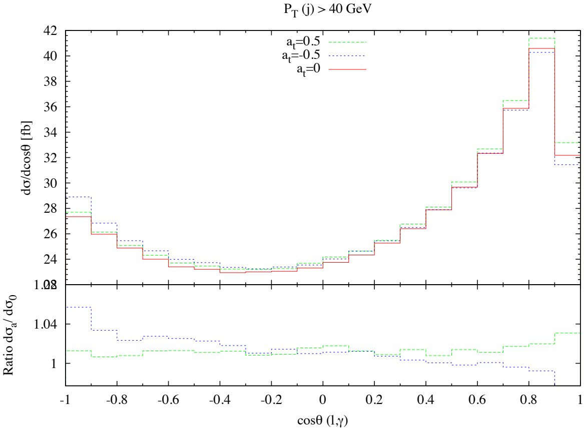
Monte Carlo Simulation

- Signal and backgrounds are generated using MG/ME v.5.1. PDF set CTEQ6L1. Fixed $\mu_R = \mu_F = m_t$.
- Cuts:

$$p_T(j) > 40 \text{ GeV}, \quad p_T(b) > 40 \text{ GeV}, \quad p_T(\gamma) > 30 \text{ GeV}, \quad p_T(\ell) > 20 \text{ GeV}, \quad \not{p}_T > 20 \text{ GeV};$$

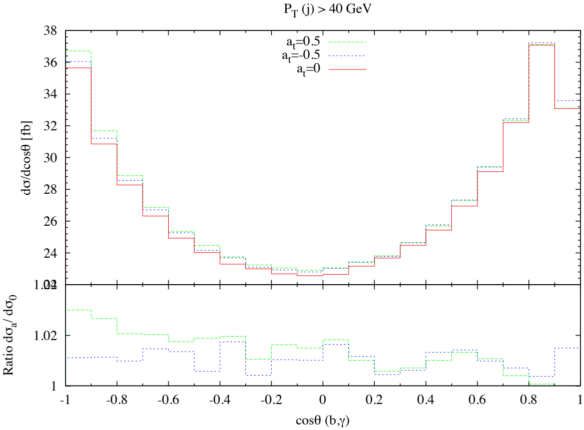
$$|\eta(j)| < 5.0, \quad |\eta(b,\ell,\gamma)| < 2.5, \quad \Delta R_{ab} > 0.4,\ a,b = j,b,\ell,\gamma, \quad m_T(\ell\gamma,\not{p}_T) > 90 \text{ GeV}.$$

Basic Cuts



Process	σ [fb]
$a_t = 0$	60.465
$a_t = 0.5$	61.269
$a_t = -0.5$	60.998
$jj\gamma W$	865
$jj\gamma W \cdot P_{j\to b}$	17.3

Basic Cuts



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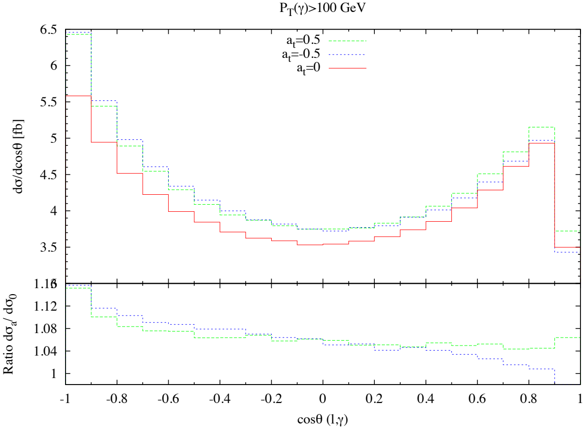
Cuts:

$$p_T(j) > 40 \text{ GeV}, \quad p_T(b) > 40 \text{ GeV}, \quad p_T(\gamma) > 100 \text{ GeV}, \quad p_T(\ell) > 20 \text{ GeV}, \quad \not{p}_T > 20 \text{ GeV};$$

$$|\eta(j)| < 5.0, \quad |\eta(b, \ell, \gamma)| < 2.5,$$

$$\Delta R_{ab} > 0.4, \; a, b = j, b, \ell, \gamma, \quad m_T(\ell\gamma, \not{p}_T) > 90 \text{ GeV}.$$

$p_t(\gamma) > 100$ GeV



Process	σ [fb]
$a_t = 0$	8.13
$a_t = 0.5$	8.68
$a_t = -0.5$	8.64
$jj\gamma W$	168
$jj\gamma W \cdot P_{j\to b}$	3.30

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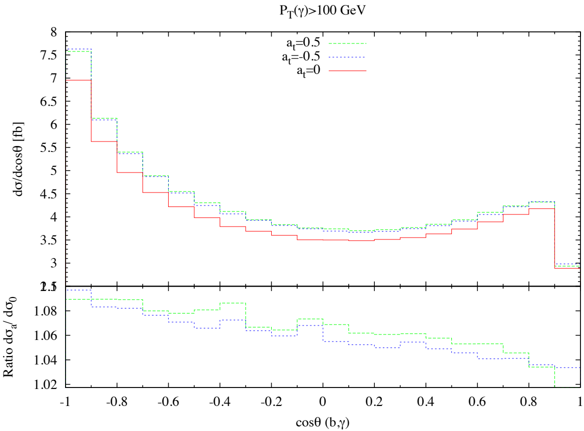

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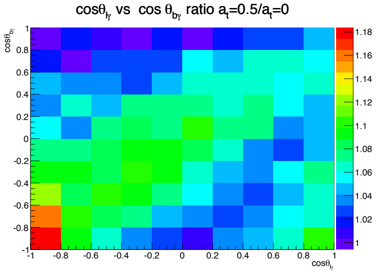
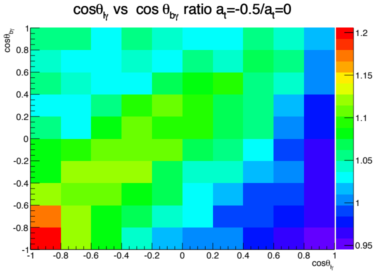




Summary and Outlook

- Search for top quark $g-2$ at LHC.
- Construction of the effective Lagrangian for the top anomalous coupling.
- Bounds from $t\bar{t}\gamma$: $-0.20 \leq \Delta F_{2V}^{\gamma} \leq +0.19$ with 300 fb^{-1} at LHC@14TeV.
- Study of single-top+γ.
- Implementation in MG5 via the Mathematica package FeynRules. MonteCarlo simulation of signal and background at parton level in MG5.
- Optimization of cuts.
- Quantitative bounds on a_t from single-top+γ production.

Thanks!

U. Baur,A. Juste, L.H. Orr, D. RainWater PLD 71 (2005) 54013

The acceptance cuts for $\gamma\ell\nu_\ell b\bar{b}jj$ events at the LHC are

$$\begin{gathered}
\not{p}_T > 20 \ \text{GeV} , \\
p_T(b) > 20 \ \text{GeV} , \qquad |\eta(b)| < 2.5 , \qquad \Delta R(b,b) > 0.4 , \\
p_T(j) > 20 \ \text{GeV} , \qquad |\eta(j)| < 2.5 , \qquad \Delta R(j,j) > 0.4 , \qquad \Delta R(j,b) > 0.4 , \\
p_T(\gamma) > 30 \ \text{GeV} , \qquad |\eta(\gamma)| < 2.5 , \qquad \Delta R(\gamma,j) > 0.4 , \qquad \Delta R(\gamma,b) > 1.0 , \\
p_T(\ell) > 15 \ \text{GeV} , \quad |\eta(\ell)| < 2.5 , \quad \Delta R(\ell,\gamma) > 0.4 , \quad \Delta R(\ell,j) > 0.4 , \quad \Delta R(\ell,b) > 0.4
\end{gathered}$$

$$m(jj\gamma) > 90 \ \text{GeV} \qquad \text{and} \qquad m_T(\ell\gamma;\not{p}_T) > 90 \ \text{GeV},$$

$$m_T^2(\ell\gamma;\not{p}_T) = \left(\sqrt{p_T^2(\ell\gamma) + m^2(\ell\gamma)} + \not{p}_T\right)^2 - \left(\vec{p}_T(\ell\gamma) + \vec{\not{p}}_T\right)^2 ,$$

$$m_T(b_{1,2}\ell;\not{p}_T) < m_t{+}20 \ \text{GeV} \qquad \text{and} \qquad m_t{-}20 \ \text{GeV} < m(b_{2,1}jj) < m_t{+}20 \ \text{GeV},$$

$$m_T(b_{1,2}\ell\gamma;\not{p}_T) < m_t{+}20 \ \text{GeV} \qquad \text{and} \qquad m_t{-}20 \ \text{GeV} < m(b_{2,1}jj) < m_t{+}20 \ \text{GeV},$$

or

$$m_T(b_{1,2}\ell;\not{p}_T) < m_t{+}20 \ \text{GeV} \qquad \text{and} \qquad m_t{-}20 \ \text{GeV} < m(b_{2,1}jj\gamma) < m_t{+}20 \ \text{GeV}.$$

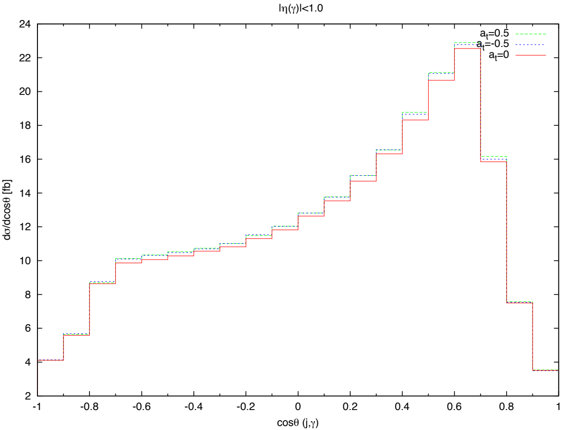
$$\sigma\left(pp \to t\bar{t}\gamma \to \gamma\ell\nu_\ell b\bar{b}jj\right) = 82\text{fb}$$

Cuts:

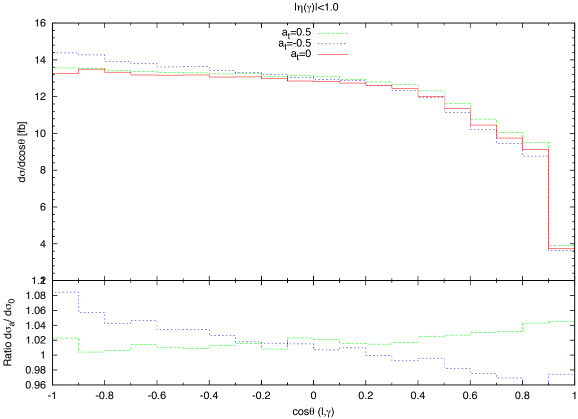
$$p_T(j) > 40 \text{ GeV}, \quad p_T(b) > 40 \text{ GeV}, \quad p_T(\gamma) > 30 \text{ GeV}, \quad p_T(\ell) > 20 \text{ GeV}, \quad \not{p}_T > 20 \text{ GeV};$$

$$|\eta(j)| < 5.0, \quad |\eta(b,\ell)| < 2.5, \quad |\eta(\gamma)| < 1.0,$$

$$\Delta R_{ab} > 0.4, \; a,b = j,b,\ell,\gamma, \quad m_T(\ell\gamma, \not{p}_T) > 90 \text{ GeV}.$$



Process	σ [fb]
$a_t = 0$	11.38
$a_t = 0.5$	11.61
$a_t = -0.5$	11.56
$jj\gamma W$	



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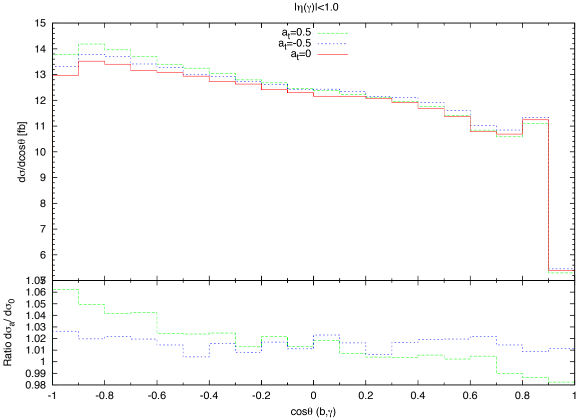

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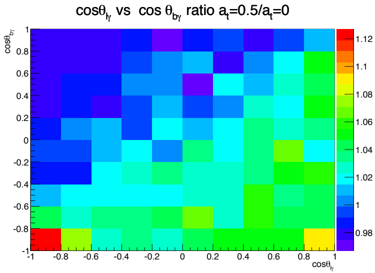
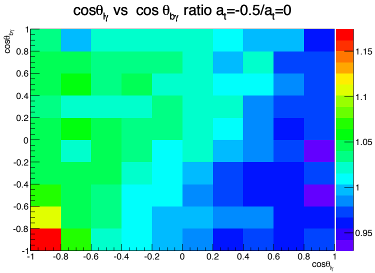

$\cos\theta_{l\gamma}$ vs $\cos\theta_{b\gamma}$ ratio a_t=0.5/a_t=0
$\cos\theta_{b\gamma}$
$\cos\theta_{l\gamma}$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