Top-quark pair spin correlation@LHC (theory)

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Based on discussion with Omura-san and Takeuchi-san

Effective theory approach in top quark production and decay

CP−even operators @ dim=6

operator	process
$O_{\phi q}^{(3)} = i(\phi^+ \tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q)$	top decay, single top
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W_{\mu\nu}^I$ (with real coefficient)	top decay, single top
$O_{qq}^{(1,3)} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$	single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi} G_{\mu\nu}^A$ (with real coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_G = f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$gg \to t\bar{t}$
$O_{\phi G} = \frac{1}{2}(\phi^+ \phi) G_{\mu\nu}^A G^{A\mu\nu}$	$gg \to t\bar{t}$
7 four-quark operators	$q\bar{q} \to t\bar{t}$

CP−even operators @ dim=6

operator	process
$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi} W_{\mu\nu}^I$ (with imaginary coefficient)	top decay, single top
$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi} G_{\mu\nu}^A$ (with imaginary coefficient)	single top, $q\bar{q}, gg \to t\bar{t}$
$O_{\tilde{G}} = f_{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$gg \to t\bar{t}$
$O_{\phi\tilde{G}} = \frac{1}{2}(\phi^+ \phi) \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$gg \to t\bar{t}$

1008.3869

- Various studies of interplay between low-energy (flavor) and high-energy (LHC) physics.
- Interpretation is not obvious in concrete models if anomaly is found.

Top quark decay

Top quark decay ($t \to b\nu e^+$)

$$\frac{1}{\Gamma_t}\frac{d\Gamma_t}{d\cos\theta_f} = \frac{1}{2}(1+\alpha_f\cos\theta_f) \quad (f = e^+, \nu, b)$$

θ_f :angle between top quark spin and fermion f @top rest flame

In SM $\alpha_{e^+}(\simeq \alpha_{\bar{d}}) = 1,\ \alpha_\nu(\simeq \alpha_u) = -0.32,\ \alpha_b = -0.39$

Even if dim=6 operators are included, $\alpha_{e^+}(\alpha_{\bar{d}}) \simeq 1$.

$$\begin{aligned} O_{\phi q}^{(3)} &= i(\phi^+\tau^I D_\mu\phi)(\bar{q}\gamma^\mu\tau^I q) \\ O_{tW} &= (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W_{\mu\nu}^I \end{aligned} \Rightarrow \begin{aligned} L_{eff} &= \frac{C_{\phi q}^{(3)}}{\Lambda^2}\frac{gv^2}{\sqrt{2}}\bar{b}\gamma^\mu P_L t W_\mu^- + h.c. \\ L_{eff} &= -2\frac{C_{tW}}{\Lambda^2}v\bar{b}\sigma^{\mu\nu}P_R t\partial_\nu W_\mu^- + h.c. \end{aligned}$$

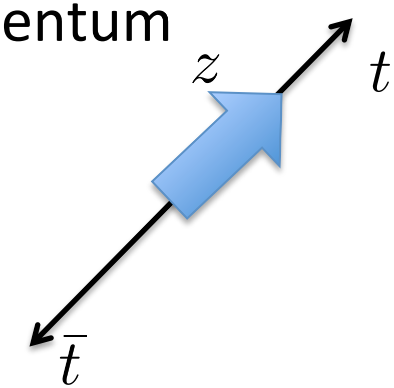
Leptonic modes are a good spin analyzer.

Spin correlation

Normalized diff. ttbar crss section@ttbar rest flame

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+\cos\theta_-} = \frac{1}{4}(1 + b_+\cos\theta_+ + b_-\cos\theta_- + C\cos\theta_+\cos\theta_-)$$

$\theta_\pm$: angle between $l^\pm$ from t(tbar) and t(tbar) momentum



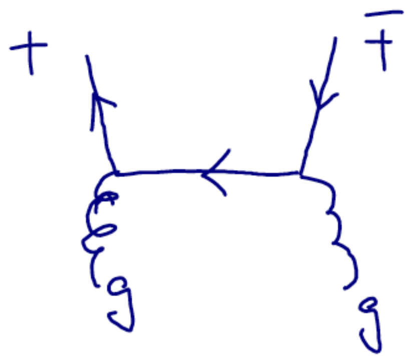
$$C = \frac{1}{\sigma}(\sigma_{RL} + \sigma_{LR} - \sigma_{RR} - \sigma_{LL})$$

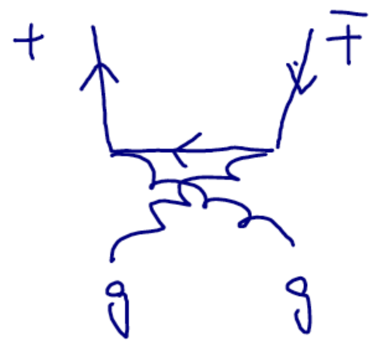
$$b_+ = \frac{1}{\sigma}(\sigma_{RL} - \sigma_{LR} + \sigma_{RR} - \sigma_{LL})$$

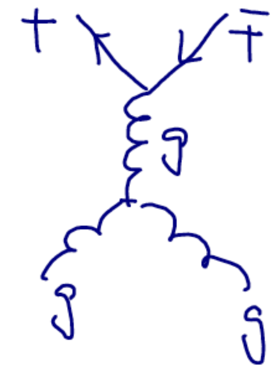
$$b_+ = \frac{1}{\sigma}(\sigma_{RL} - \sigma_{LR} - \sigma_{RR} + \sigma_{LL})$$

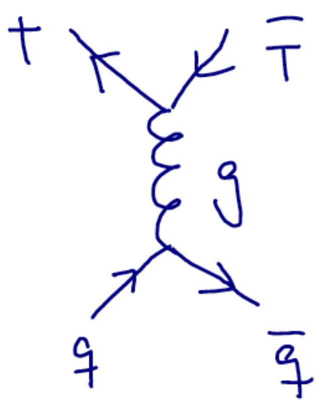
Spin correlation is sensitive to modification to ttbar production.

QCD contribution to ttbar production@LO



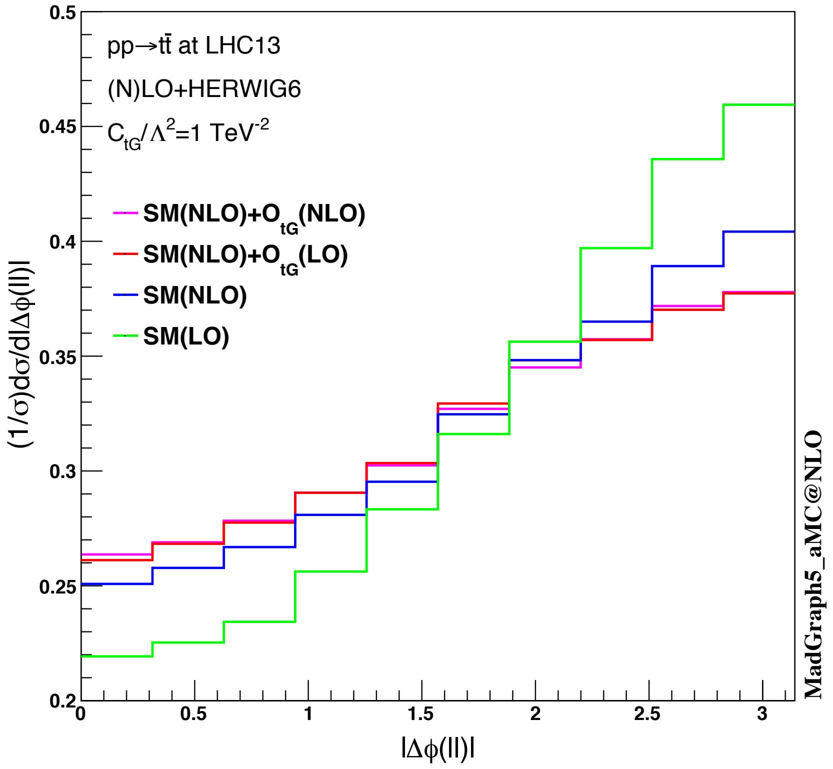






NLO leads to sizable change in SM

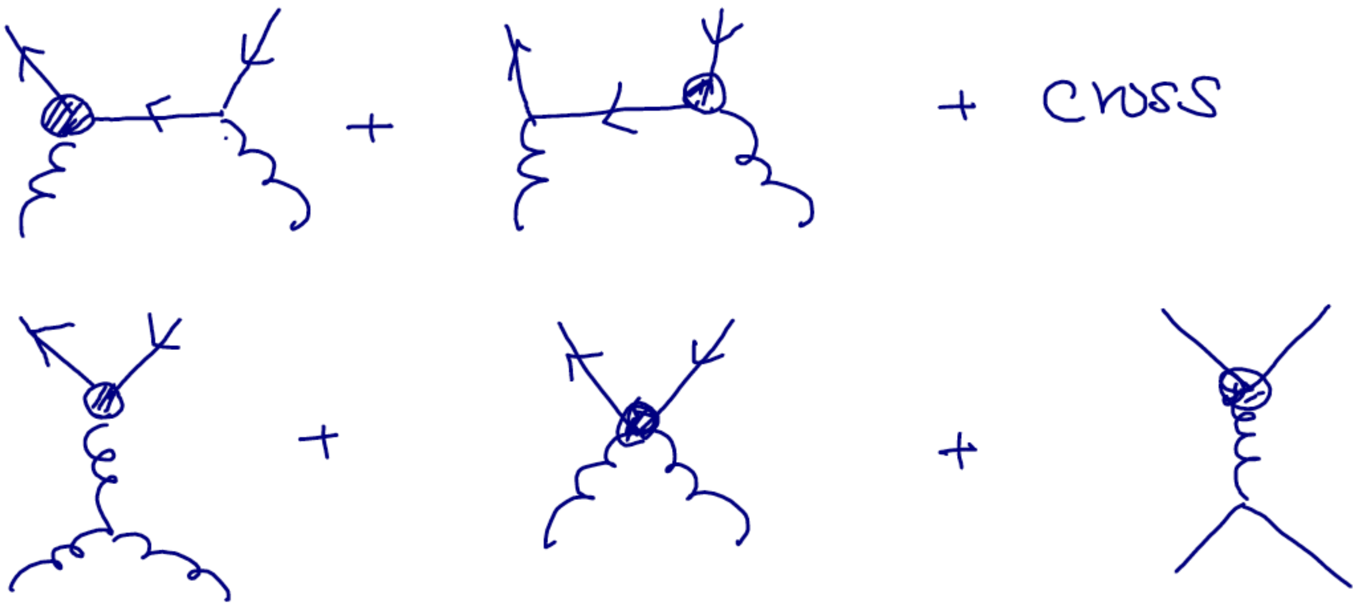
Normalized distribution of distribution of difference in azimuthal angle between muons. Chromomagnetic moment?



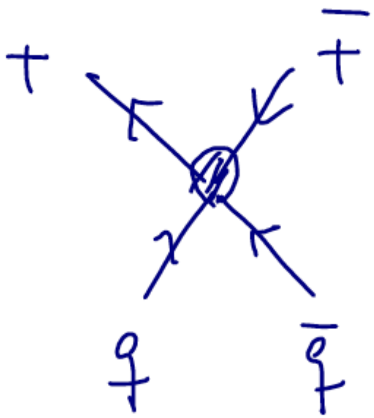
(Franzosi and Zhang, 1503.08841)

Anomalous top coupling: Chromomagnetic moment

$$H_{\rm eff} = \frac{C_{tG}}{\Lambda^2}[f_t(H\bar{Q})\sigma^{\mu\nu}T^A P_R t]G^A_{\mu\nu} \qquad (Q=(t,n))$$



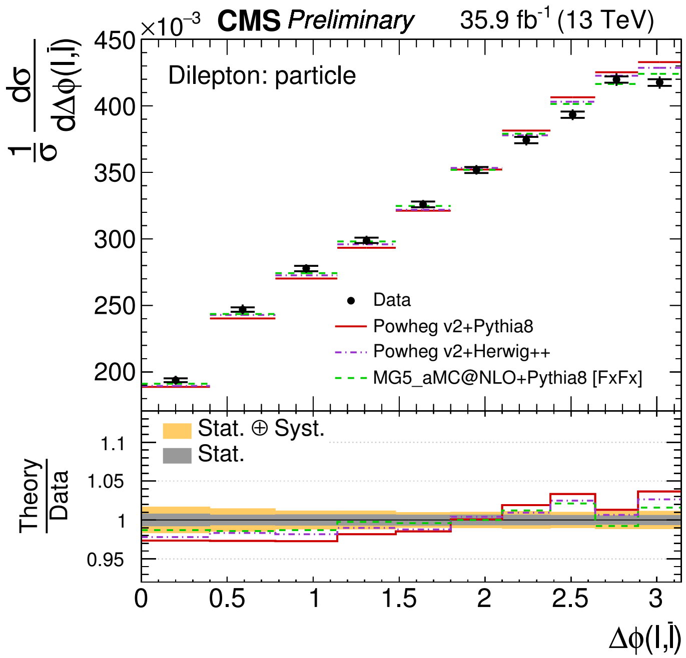
Anomalous top coupling:
Four-Fermi operator



$$H_{\rm eff} = c_{tu}^{(8)} (\bar{t}\gamma^\mu T_A t)(\bar{u}\gamma_\mu T_A u) + \cdots$$

Color–octet S=1 boson ?

Latest results



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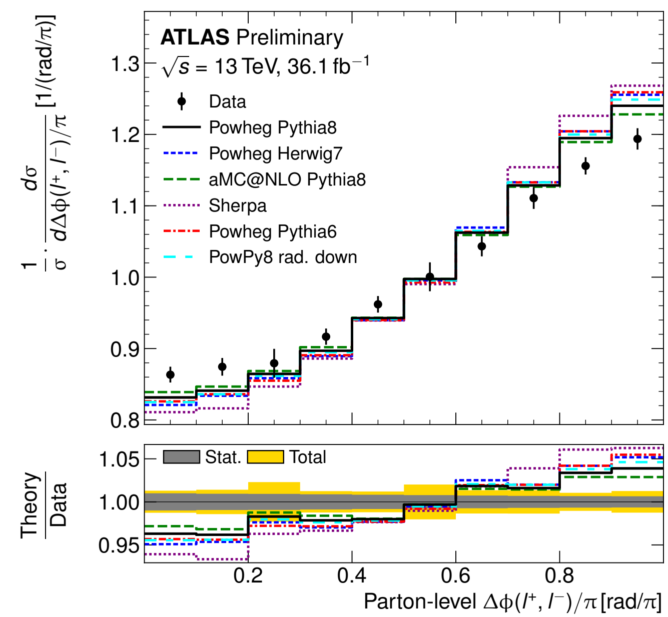

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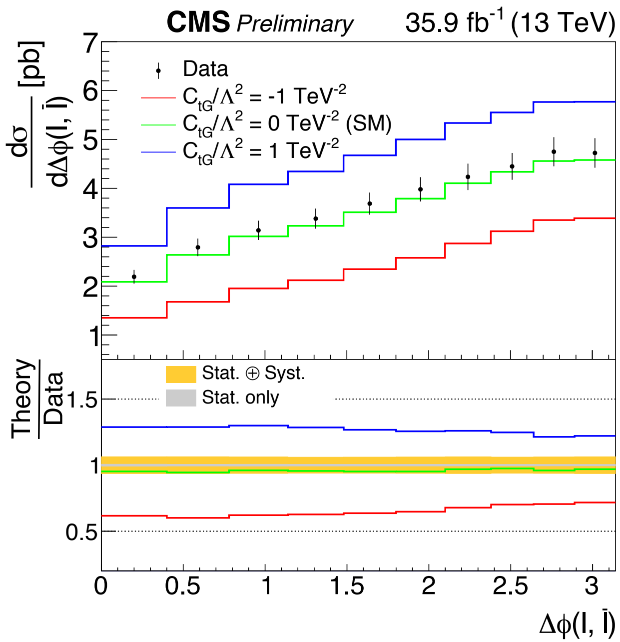
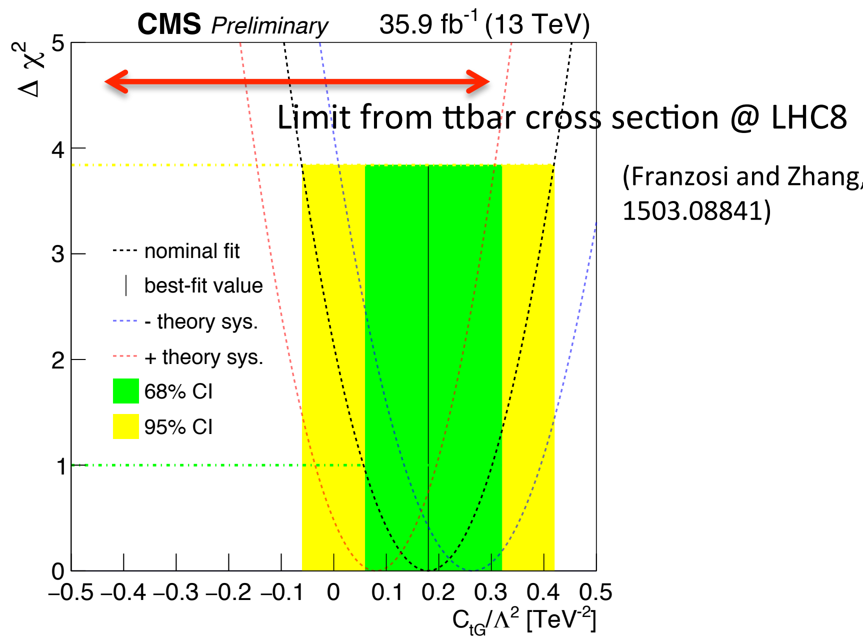
Anomalous top coupling: Chromomagnetic moment





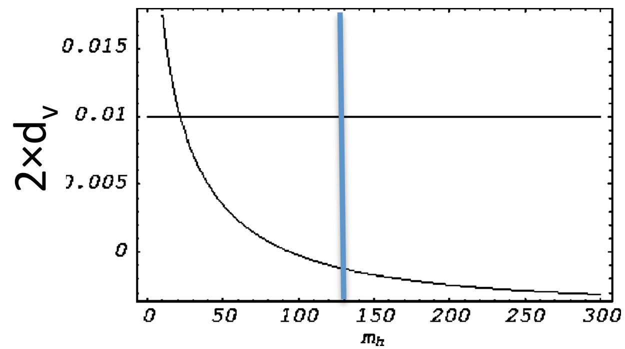
(Franzosi and Zhang, 1503.08841)

$$\mathcal{L} = \frac{g_s}{m_t} d_V \bar{t}\sigma^{\mu\nu} T_A t G^A_{\mu\nu}$$

$$d_V = \frac{C_{tG} m_t^2}{\Lambda^2} = 0.03 \times C_{tG} \left(\frac{\Lambda}{\mathrm{TeV}}\right)^{-2} \sim O(1)\%$$

How to interpret the chromomagnetic moment ?

- The derived chormonagnetic moment is not value at $q^2=0$ and on-shell top.
- Typical values of chormonagnetic moment @$q^2=0$ and on-shell top
  1) $d_v(QCD) = -\alpha_s/(12\pi) = -0.003$
  2) SM (EW+QCD)



Martinez and Rdriguez (0109109)

  3) typical new physics contribution

$$d_V \sim \frac{\alpha_s}{\pi}\frac{m_t^2}{\Lambda^2}$$

How to interpret the chromomagnetic moment ?

New particle masses should be around m_t in order to explain the anomaly, though d_V is not constant and the other contributions, such as box, should be included in the cases. Stop loop?

Exception: Composite top (but elementary Higgs) Pierce and Zhao (1607.01318)