Probing Anomalous Top-Gluon Couplings at Colliders

LCWS10
26th-30th March, 2010
Beijing

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$$\text{SM} \quad : \quad g_s \bar{t} \gamma^\mu T_a t G_\mu^a$$

Higher Dimensional Operators:

$$g_s \frac{1}{\Lambda} \bar{t} \sigma_{\mu\nu} T_a t F_a^{\mu\nu}$$

$\Leftarrow$ dimension-5

$$i g_s \frac{1}{\Lambda} \bar{t} \sigma_{\mu\nu} \gamma_5 T_a t F_a^{\mu\nu}$$

$$i g_s \frac{1}{\Lambda^2} \bar{t} T_a \gamma_\mu D_\nu t F_a^{\mu\nu}$$

$\Leftarrow$ dimension-6

$$g_s \frac{1}{\Lambda^2} \bar{t}_L \sigma_{\mu\nu} T_a t_R \phi^C F_a^{\mu\nu}$$

Buchmuller and Wyler (1986)

Aguilar-Saavedra (2009)

$$\text{SM} \quad : \quad g_s \bar{t} \gamma^{\mu} T_a t G_{\mu}^{a}$$

$$g_s \frac{1}{\Lambda} \bar{t} \sigma_{\mu\nu} T_a t F_a^{\mu\nu} \qquad i g_s \frac{1}{\Lambda} \bar{t} \sigma_{\mu\nu} \gamma_5 T_a t F_a^{\mu\nu}$$

Chromomagnetic Dipole Moment — Chromoelectric Dipole Moment

$$\mathcal{L}_{int} \ni \frac{g_s}{\Lambda} \bar{t} \sigma_{\mu\nu} (\rho + i \rho' \gamma_5) T_a t F_a^{\mu\nu}$$

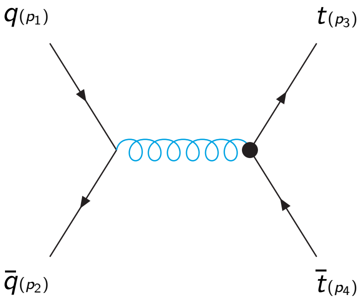
Testing Grounds

$p\bar{p} \longrightarrow t\bar{t}$ Tevatron ($\sqrt{s} = 1.96$ TeV)

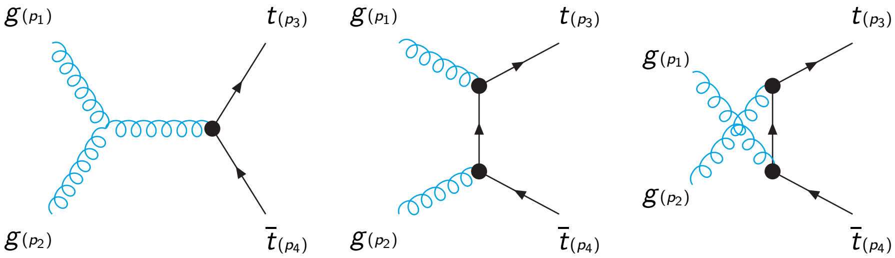
$pp \longrightarrow t\bar{t}$ LHC ($\sqrt{s} = 7, 10, 14$ TeV)

$e^+e^- \longrightarrow t\bar{t}g$ ILC ($\sqrt{s} = 500$ GeV, 1 TeV) ILC-RDR (2007)

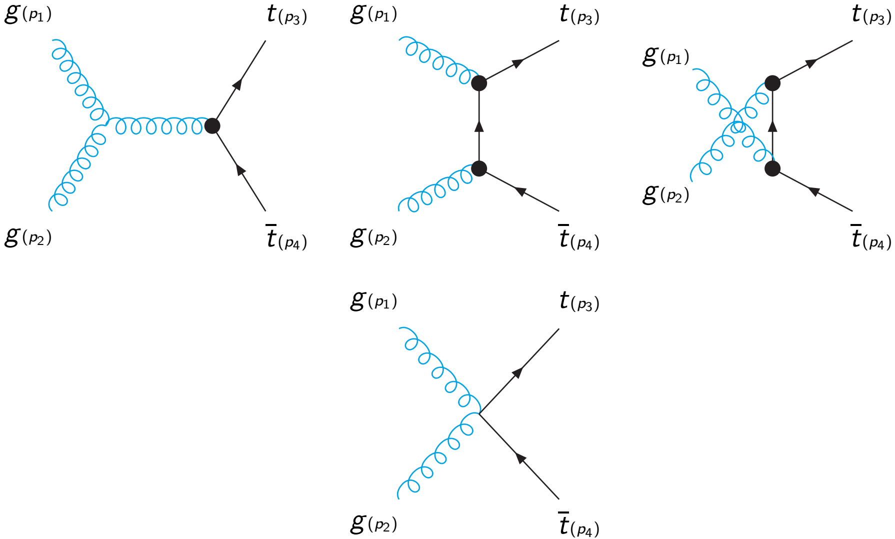
$q\bar{q} \longrightarrow t\bar{t}$



$gg \longrightarrow t\bar{t}$



$gg \longrightarrow t\bar{t}$



$$\sigma_{total} = \sigma_{q\bar{q}} + \sigma_{gg}$$

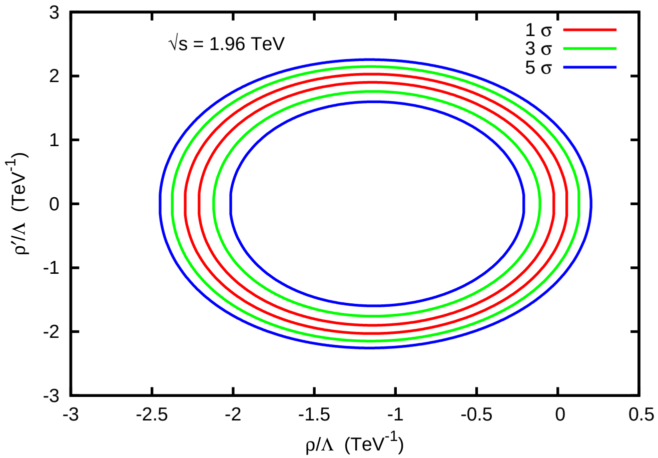
PDF : CTEQ6L1

Q $= m_{top}$

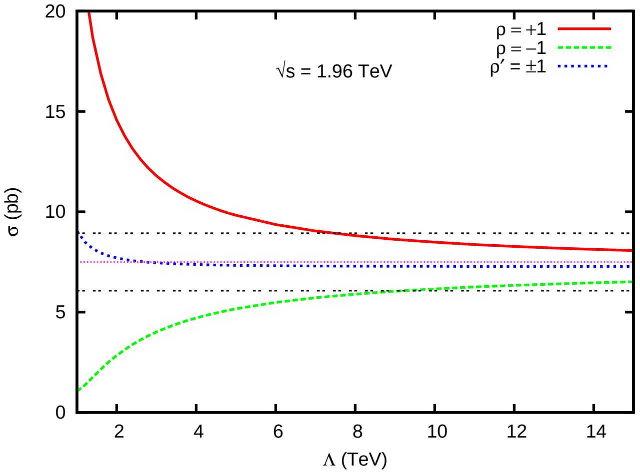
NLO K-Factor : Cacciari et. al. (2008)

Tevatron Limits : Allowed Parameter Range

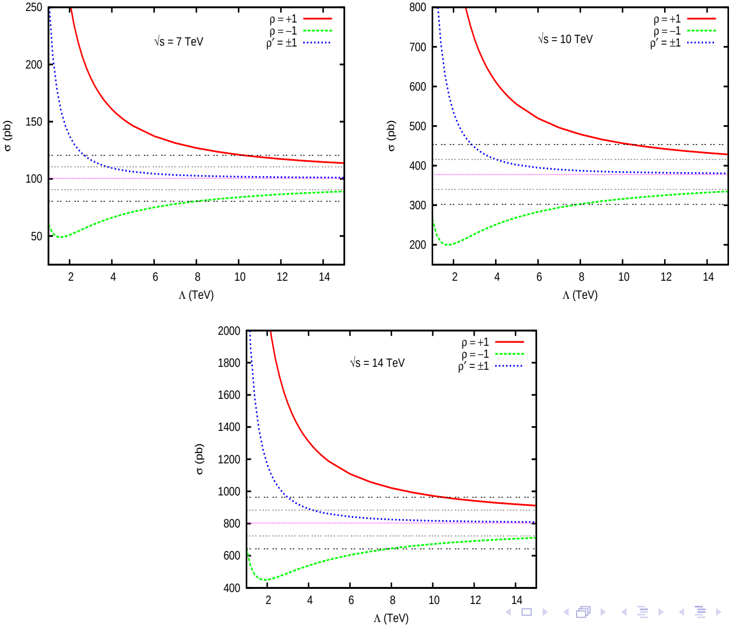
$\sigma_{t\bar{t}}\ (m_t = 172.5\ \text{GeV}) = 7.50 \pm 0.48\ \text{pb}$ CDF 2009 (4.6 fb^{-1})



Tevatron Limits : Total Cross-Section

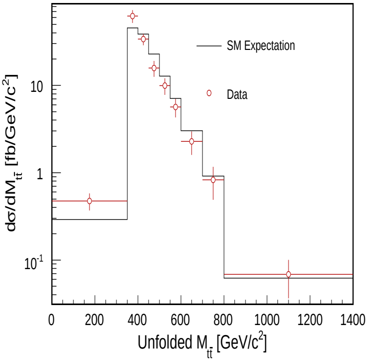


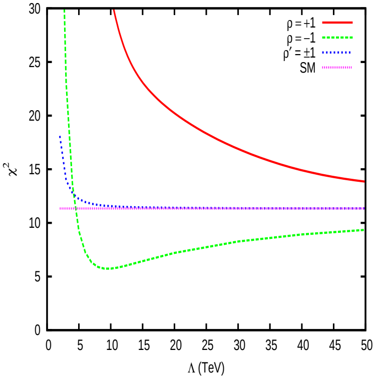
LHC Projections : Total Cross-Sections



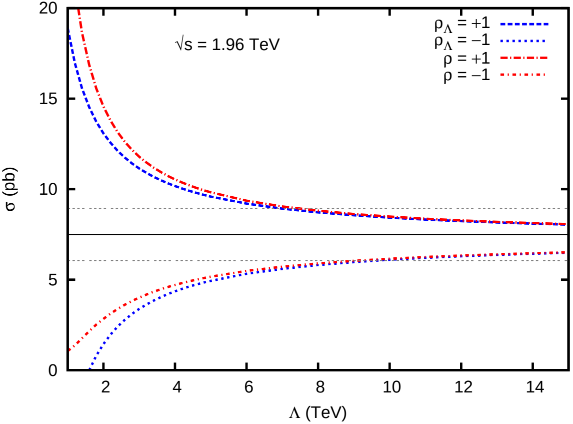
Tevatron Limits : Invariant Mass Distribution

CDF 2009 ($m_{top} = 175$ GeV, 2.7 fb^{-1})





$\mathcal{O}(1/\Lambda)$



	$\sqrt{s} = 7$ TeV		$\sqrt{s} = 10$ TeV		$\sqrt{s} = 14$ TeV	
	Full	Trunc.	Full	Trunc.	Full	Trunc.
$\rho = +1$	10.20	9.20	10.45	9.25	10.50	9.30
$\rho = -1$	8.00	9.20	7.95	9.25	7.85	9.30

Summary of Limits from Hadron Colliders

Rephrasing the results in terms of commonly used notation :

$$\frac{1}{\Lambda}(\rho + i\rho') \longleftrightarrow \frac{1}{2m_t}(\kappa + i\tilde{\kappa})$$

$\rho = +1$: $\Lambda \geq 10$ TeV

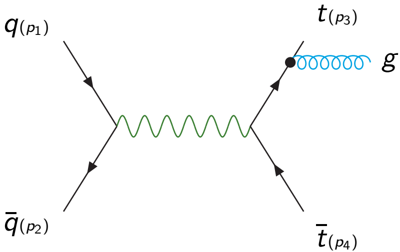
$\rho = -1$: $\Lambda \geq 9$ TeV

$\Rightarrow$ $-0.038 \leq \kappa \leq 0.034$

$\rho' = \pm 1$: $\Lambda \geq 3$ TeV $\Rightarrow$ $|\tilde{\kappa}| \leq 0.12$

Linear Collider Prospects

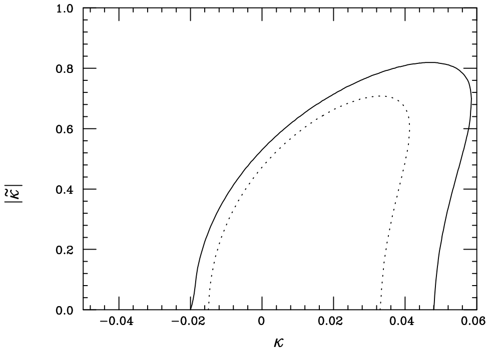
$$e^+e^- \longrightarrow t\bar{t}g$$



T.G. Rizzo, Phys. Rev. D **50**, 4478 (1994); arXiv:hep-ph/9605361

Limits obtained by fitting the energy spectrum of the gluon.

$\sqrt{s} = 500$ GeV ; $\mathcal{L} = 50\ fb^{-1}$(solid), $100\ fb^{-1}$ (dotted) ; $E_g^{min} = 25$ GeV

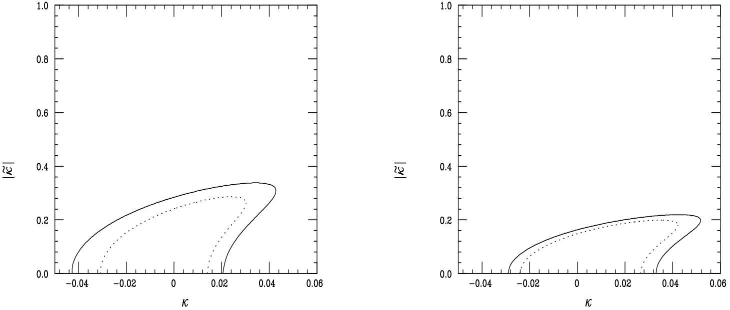


95% CL allowed region

Considering only one of κ and $\tilde{\kappa}$ to be non-zero at a time, from the dotted curve we have :

$$-0.015 \leq \kappa \leq 0.033 \qquad\qquad |\tilde{\kappa}| \leq 0.47$$

$\sqrt{s} = 1$ TeV ; $\mathcal{L} = 100\ fb^{-1}$(solid), $200\ fb^{-1}$ (dotted)



$E_g^{min} = 50$ GeV $E_g^{min} = 25$ GeV

95% CL allowed region

Considering only one of κ and $\tilde{\kappa}$ to be non-zero at a time, from the dotted curve on the right panel we have :

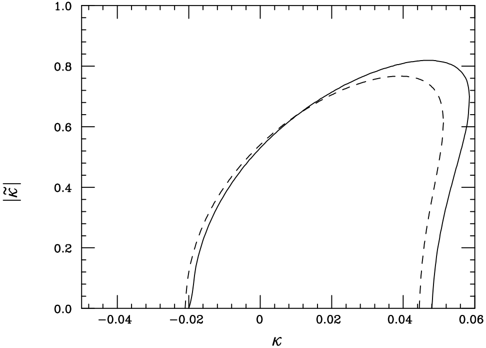
-0.024 $\leq \kappa \leq$ 0.026 $|\tilde{\kappa}| \leq 0.14$

Better sensitivity to κ but not to $\tilde{\kappa}$

Using Polarized Beams

Rizzo (1996)

$\sqrt{s} = 500$ GeV ; $\mathcal{L} = 50\ fb^{-1}$; $E_g^{min} = 25$ GeV



Unpolarized (solid) ; 90% Polarized (dotted)

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http://cdsweb.cern.ch/collection/CMS%20PHYSICS%20ANALYSIS%20SUMMARIES

THE END

EXTRA SLIDES

$$
\begin{aligned}
\left(\frac{2\hat{s}}{\pi\alpha_s^2\beta}\right)\frac{d\hat{\sigma}_{q\bar{q}}}{d\cos\theta} &= \frac{2}{9}\Theta_+ + \frac{8}{9}\frac{m_t^2}{\hat{s}} \\
&+ \frac{32\,\rho\,m_t}{9\,\Lambda} + \frac{8\,\rho^2}{9\,\Lambda^2}\left(\hat{s}\,\Theta_- + 4\,m_t^2\right) + \frac{8\,\rho'^2}{9\,\Lambda^2}\left(\hat{s}\,\Theta_- - 4\,m_t^2\right) \\
\left(\frac{2\hat{s}}{\pi\alpha_s^2\beta}\right)\frac{d\hat{\sigma}_{gg}}{d\cos\theta} &= \frac{2}{3\Theta_-}\left(1 + \frac{4m_t^2}{\hat{s}} + \frac{m_t^4}{\hat{s}^2}\right) - \left(\frac{1}{3} + \frac{3}{16}\Theta_+ + \frac{3\,m_t^2}{2\,\hat{s}} + \frac{16\,m_t^4}{3\,\hat{s}^2}\,\frac{\Theta_+}{\Theta_-^2}\right) \\
&+ \frac{\rho\,m_t}{\Lambda}\left(-3 + \frac{16}{3\Theta_-}\right) + \frac{\rho^2}{\Lambda^2}\left[\frac{7}{3}\hat{s} + m_t^2\left\{-6 + \frac{34}{3\Theta_-}\right\}\right] \\
&+ \frac{\rho'^2}{\Lambda^2}\left[\frac{7}{3}\hat{s} + \frac{2m_t^2}{3\Theta_-}\right] \\
&+ \frac{\rho}{\Lambda}\left(\frac{\rho^2}{\Lambda^2} + \frac{\rho'^2}{\Lambda^2}\right) m_t\left(\frac{28}{3}\hat{s} - \frac{20}{3\Theta_-}m_t^2\right) \\
&+ \frac{4}{3}\left(\frac{\rho^2}{\Lambda^2} + \frac{\rho'^2}{\Lambda^2}\right)^2\left(\hat{s}^2\Theta_- - m_t^2\hat{s} + \frac{4}{\Theta_-}m_t^4\right)
\end{aligned}
$$

Combination of CDF top quark pair production cross section measurements with up to 4.6 fb^{-1} : CDF Public Note 9913

$\sigma_{t\bar{t}}$ (m_t = 172.5 GeV) = 7.50 $\pm$ 0.48 pb

CDF II Detector
Integrated Luminosity : 4.6 fb^{-1}

Combination of :

- lepton+jets channel artificial neural network with a weight of 70%
- lepton+jets channel secondary vertex b-tagging with 18%
- dilepton channel with 18%
- all-hadronic channel with -6%

With :

- statistical uncertainty 0.31 pb
- experimental systematic uncertainty 0.33 pb
- Z boson theoretical cross section uncertainty 0.13 pb
- luminosity uncertainty 0.06 pb

Theoretical Predictions : Tevatron

Using CTEQ6.5

$$\sigma_{t\bar{t}}^{\rm NLO+NLL}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm CTEQ6.5}) = 7.61~^{+0.30(3.9\%)}_{-0.53(6.9\%)}~({\rm scales})~^{+0.53(7\%)}_{-0.36(4.8\%)}~({\rm PDFs})~~{\rm pb}$$

$$\sigma_{t\bar{t}}^{\rm NLO}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm CTEQ6.5}) = 7.35~^{+0.38(5.1\%)}_{-0.80(10.9\%)}~({\rm scales})~^{+0.49(6.6\%)}_{-0.34(4.6\%)}~({\rm PDFs})~~{\rm pb}$$

$$\sigma_{t\bar{t}}^{\rm LO}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm CTEQ6.5}) = 5.92~^{+2.34(39.5\%)}_{-1.54(26.1\%)}~({\rm scales})~^{+0.32(5.5\%)}_{-0.24(4.1\%)}~({\rm PDFs})~~{\rm pb}$$

Using MRST2006nnlo

$$\sigma_{t\bar{t}}^{\rm NLO+NLL}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm MRST2006nnlo}) = 7.93~^{+0.34(4.3\%)}_{-0.56(7.1\%)}~({\rm scales})~^{+0.24(3.1\%)}_{-0.20(2.5\%)}~({\rm PDFs})~~{\rm pb}\,.$$

$$\sigma_{t\bar{t}}^{\rm NLO}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm MRST2006nnlo}) = 7.62~^{+0.45(5.9\%)}_{-0.88(11.6\%)}~({\rm scales})~^{+0.23(3\%)}_{-0.18(2.4\%)}~({\rm PDFs})~~{\rm pb}$$

$$\sigma_{t\bar{t}}^{\rm LO}({\rm Tev}, m_t = 171~{\rm GeV}, {\rm MRST2006nnlo}) = 6.05~^{+2.47(40.8\%)}_{-1.61(26.6\%)}~({\rm scales})~^{+0.16(2.6\%)}_{-0.13(2.1\%)}~({\rm PDFs})~~{\rm pb}\,.$$

Theoretical Prediction : LHC

Using CTEQ6.5

$$\sigma_{t\bar{t}}^{\mathrm{NLO+NLL}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{CTEQ6.5}) = 908\ {}^{+82(9.0\%)}_{-85(9.3\%)}\ (\mathrm{scales})\ {}^{+30(3.3\%)}_{-29(3.2\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

$$\sigma_{t\bar{t}}^{\mathrm{NLO}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{CTEQ6.5}) = 875\ {}^{+102(11.6\%)}_{-100(11.5\%)}\ (\mathrm{scales})\ {}^{+30(3.4\%)}_{-29(3.3\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

$$\sigma_{t\bar{t}}^{\mathrm{LO}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{CTEQ6.5}) = 583\ {}^{+165(28.2\%)}_{-120(20.7\%)}\ (\mathrm{scales})\ {}^{+20(3.4\%)}_{-19(3.3\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

Using MRST2006nnlo

$$\sigma_{t\bar{t}}^{\mathrm{NLO+NLL}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{MRST2006nnlo}) = 961\ {}^{+89(9.2\%)}_{-91(9.4\%)}\ (\mathrm{scales})\ {}^{+11(1.1\%)}_{-12(1.2\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

$$\sigma_{t\bar{t}}^{\mathrm{NLO}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{MRST2006nnlo}) = 927\ {}^{+109(11.7\%)}_{-107(11.5\%)}\ (\mathrm{scales})\ {}^{+11(1.2\%)}_{-12(1.3\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

$$\sigma_{t\bar{t}}^{\mathrm{LO}}(\mathrm{LHC}, m_t = 171\ \mathrm{GeV}, \mathrm{MRST2006nnlo}) = 616\ {}^{+172(27.9\%)}_{-126(20.5\%)}\ (\mathrm{scales})\ {}^{+7.3(1.2\%)}_{-7.8(1.3\%)}\ (\mathrm{PDFs})\ \ \mathrm{pb}$$

K-Factors

Tevatron (1.96 TeV) : 1.13

LHC (14 TeV) : 1.42

LHC (10 TeV) : 1.48

LHC (7 TeV) : 1.0 (not available)

Chi-Square Calculation

$$\chi^2 = \frac{\sigma^{MC} - \sigma^{CDF}}{\Delta\sigma^{CDF}}$$