Top Quark Polarization Observables at Hadron Colliders

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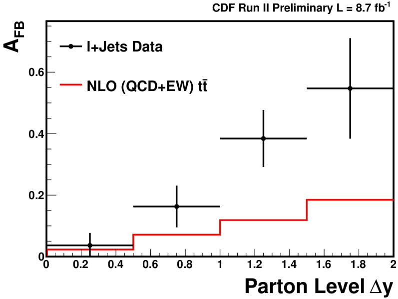
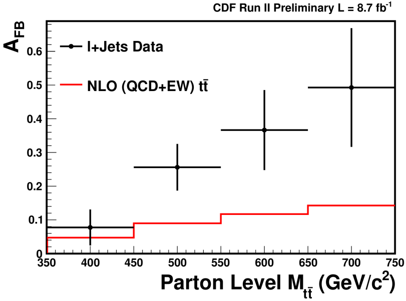
August 13, 2013 @ LHC Physics Monthly Meeting

Recent Results @Tevatron [1]

- **CDF, l+jets:**
  $A_{\rm FB}^{t\bar{t}} = 0.162 \pm 0.042$ $[0.058 \pm 0.009]$
- **CDF, dileptons:**
  $A_{\rm FB}^{t\bar{t}} = 0.42 \pm 0.16$
- **Combined:**
  $A_{\rm FB}^{t\bar{t}} = 0.201 \pm 0.067$ *cf.* $A_{\rm FB}^{t\bar{t}} = 0.196 \pm 0.065$ **@ D0**
- **CDF, l+jets:**
  $A_{\rm FB}^{t\bar{t}}(|\Delta y| < 1.0) = 0.088 \pm 0.042 \pm 0.022$ $[0.043]$
  $A_{\rm FB}^{t\bar{t}}(|\Delta y| \geq 1.0) = 0.433 \pm 0.097 \pm 0.050$ $[0.139]$
- **CDF, l+jets:**
  $A_{\rm FB}^{t\bar{t}}(M_{t\bar{t}} < 450\ {\rm GeV}) = -0.078 \pm 0.048 \pm 0.024$ $[0.047]$
  $A_{\rm FB}^{t\bar{t}}(M_{t\bar{t}} \geq 450\ {\rm GeV}) = 0.296 \pm 0.059 \pm 0.031$ $[0.100]$

[1] The values in the squared bracket are SM predictions.


CDF Run II Preliminary L = 8.7 fb^{-1}
A_{FB}
l+Jets Data
NLO (QCD+EW) $t\bar{t}$
Parton Level Δy


CDF Run II Preliminary L = 8.7 fb^{-1}
A_{FB}
l+Jets Data
NLO (QCD+EW) $t\bar{t}$
Parton Level $M_{t\bar{t}}$ (GeV/c^2)

etc.,etc,.....

Systematic study of New Physics (NP)

With $q = u, d, s, c, b$**,**

- **Spin-1 NP :**

$$\mathcal{L}_{\rm int}^{\rm spin-1} = g_s \sum_{A=L,R} V_{1A}^{\mu} \left[g_{1q}^{A} \, (\bar{q}_A \gamma_\mu q_A) + g_{1t}^{A} \, (\bar{t}_A \gamma_\mu t_A) \right]$$

$$+ \; g_s \sum_{A=L,R} V_{8A}^{a\mu} \left[g_{8q}^{A} \, (\bar{q}_A \gamma_\mu T^a q_A) + g_{8t}^{A} \, (\bar{t}_A \gamma_\mu T^a t_A) \right]$$

$$+ \; g_s \sum_{A=L,R} \left[\tilde{V}_{1A}^{\mu} \, \tilde{g}_{1q}^{A} \, (\bar{t}_A \gamma_\mu q_A) + \tilde{V}_{8A}^{a\mu} \, \tilde{g}_{8q}^{A} \, (\bar{t}_A \gamma_\mu T^a q_A) + {\rm h.c.} \right]$$

- **Spin-0 NP :**

$$
\begin{aligned}
\mathcal{L}_{\rm int}^{\rm spin-0} &= g_s \sum_{A=L,R} S_{1A}\left[\eta_{1q}^{A}\,(\bar{q}\,P_A\,q) + \eta_{1t}^{A}\,(\bar{t}\,P_A\,t)\right] \\
&+ g_s \sum_{A=L,R} S_{8A}^{a}\left[\eta_{8q}^{A}\,(\bar{q}\,T^a P_A\,q) + \eta_{8t}^{A}\,(\bar{t}\,T^a P_A\,t)\right] \\
&+ g_s \sum_{A=L,R} \left[\tilde{S}_{1A}\,\tilde{\eta}_{1q}^{A}\,(\bar{t}\,P_A\,q) + \tilde{S}_{8A}^{a}\,\tilde{\eta}_{8q}^{A}\,(\bar{t}\,T^a P_A\,q) + \text{h.c.}\right] \\
&+ g_s\,\epsilon_{\alpha\beta\gamma}\left[\tilde{\eta}_{3q}\left(q_R^{\alpha}\;t_R^{\beta}\,\tilde{S}_3^{\gamma}\right) + \text{h.c.}\right] \\
&+ g_s\left[\tilde{\eta}_{6q}\left(q_R^{\alpha}\;t_R^{\beta}\,\tilde{S}_6^{\alpha\beta}\right) + \text{h.c.}\right]
\end{aligned}
$$

- **Most generally, the amplitude for the process $q\,\bar{q} \to t\,\bar{t}$ can be cast into the form**

$$
\begin{aligned}
\mathcal{M}(q\bar{q} \to t\bar{t}) \\
= \frac{g_s^2}{\hat{s}} \sum_{A,B=L,R} \Big\{ & C_{S1}^{AB}\, [\overline{v_q(k_2)}\, P_A\, u_q(k_1)]\; [\overline{u_t(p_1)}\, P_B\, v_t(p_2)] \\
& + C_{S8}^{AB}\, [\overline{v_q(k_2)}\, P_A\, T^a\, u_q(k_1)]\; [\overline{u_t(p_1)}\, P_B\, T^a\, v_t(p_2)] \\
& + C_{V1}^{AB}\, [\overline{v_q(k_2)}\, \gamma_\mu\, P_A\, u_q(k_1)]\; [\overline{u_t(p_1)}\, \gamma^\mu\, P_B\, v_t(p_2)] \\
& + C_{V8}^{AB}\, [\overline{v_q(k_2)}\, \gamma_\mu\, P_A\, T^a\, u_q(k_1)]\; [\overline{u_t(p_1)}\, \gamma^\mu\, P_B\, T^a\, v_t(p_2)] \\
& + C_{T1}^{A}\, [\overline{v_q(k_2)}\, \sigma_{\mu\nu}\, P_A\, u_q(k_1)]\; [\overline{u_t(p_1)}\, \sigma^{\mu\nu}\, P_A\, v_t(p_2)] \\
& + C_{T8}^{A}\, [\overline{v_q(k_2)}\, \sigma_{\mu\nu}\, P_A\, T^a\, u_q(k_1)]\; [\overline{u_t(p_1)}\, \sigma^{\mu\nu}\, P_A\, T^a\, v_t(p_2)] \Big\}
\end{aligned}
$$

where $P_A = (1+\alpha\gamma_5)/2$ **with** $\alpha = -\ (+)$ **for** $A = L\ (R)$.

Table: $\tilde{x} \equiv \hat{s}/(\hat{x} - M^2 + iM\Gamma)$ with $x = s, t, u$.

Coef.	SM	V_1^μ	$V_8^{a\mu}$	$\tilde{V}_1^\mu$	$\tilde{V}_8^{a\mu}$
C_{S1}^{LL}					
C_{S1}^{RR}					
C_{S1}^{LR}				$-\frac{2}{N}\tilde{g}_{1q}^L(\tilde{g}_{1q}^R)^*\,\tilde{t}$	$-\left(1-\frac{1}{N^2}\right)\tilde{g}_{8q}^L(\tilde{g}_{8q}^R)^*\,\tilde{t}$
C_{S1}^{RL}				$-\frac{2}{N}\tilde{g}_{1q}^R(\tilde{g}_{1q}^L)^*\,\tilde{t}$	$-\left(1-\frac{1}{N^2}\right)\tilde{g}_{8q}^R(\tilde{g}_{8q}^L)^*\,\tilde{t}$
C_{S8}^{LL}					
C_{S8}^{RR}					
C_{S8}^{LR}				$-4\tilde{g}_{1q}^L(\tilde{g}_{1q}^R)^*\,\tilde{t}$	$\frac{2}{N}\tilde{g}_{8q}^L(\tilde{g}_{8q}^R)^*\,\tilde{t}$
C_{S8}^{RL}				$-4\tilde{g}_{1q}^R(\tilde{g}_{1q}^L)^*\,\tilde{t}$	$\frac{2}{N}\tilde{g}_{8q}^R(\tilde{g}_{8q}^L)^*\,\tilde{t}$
C_{V1}^{LL}		$g_{1q}^L g_{1t}^L\,\tilde{s}$		$\frac{1}{N}\lvert\tilde{g}_{1q}^L\rvert^2\,\tilde{t}$	$\frac{1}{2}\left(1-\frac{1}{N^2}\right)\lvert\tilde{g}_{8q}^L\rvert^2\,\tilde{t}$
C_{V1}^{RR}		$g_{1q}^R g_{1t}^R\,\tilde{s}$		$\frac{1}{N}\lvert\tilde{g}_{1q}^R\rvert^2\,\tilde{t}$	$\frac{1}{2}\left(1-\frac{1}{N^2}\right)\lvert\tilde{g}_{8q}^R\rvert^2\,\tilde{t}$
C_{V1}^{LR}		$g_{1q}^L g_{1t}^R\,\tilde{s}$			
C_{V1}^{RL}		$g_{1q}^R g_{1t}^L\,\tilde{s}$			
C_{V8}^{LL}	1		$g_{8q}^L g_{8t}^L\,\tilde{s}$	$2\lvert\tilde{g}_{1q}^L\rvert^2\,\tilde{t}$	$-\frac{1}{N}\lvert\tilde{g}_{8q}^L\rvert^2\,\tilde{t}$
C_{V8}^{RR}	1		$g_{8q}^R g_{8t}^R\,\tilde{s}$	$2\lvert\tilde{g}_{1q}^R\rvert^2\,\tilde{t}$	$-\frac{1}{N}\lvert\tilde{g}_{8q}^R\rvert^2\,\tilde{t}$
C_{V8}^{LR}	1		$g_{8q}^L g_{8t}^R\,\tilde{s}$		
C_{V8}^{RL}	1		$g_{8q}^R g_{8t}^L\,\tilde{s}$		
C_{T1}^{L}					
C_{T1}^{R}					
C_{T8}^{L}					
C_{T8}^{R}					

Coef.	S_1	S_8^a	$\tilde{S}_1$	$\tilde{S}_8^a$	$\tilde{S}_3^\gamma$	$\tilde{S}_6^{\alpha\beta}$
C_{S1}^{LL}	$-\eta_{1q}^L\eta_{1t}^L\,\tilde{s}$		$\frac{1}{2N}\tilde{\eta}_{1q}^L(\tilde{\eta}_{1q}^R)^*\,\tilde{t}$	$\frac{1}{4}\left(1-\frac{1}{N^2}\right)\tilde{\eta}_{8q}^L(\tilde{\eta}_{8q}^R)^*\,\tilde{t}$		
C_{S1}^{RR}	$-\eta_{1q}^R\eta_{1t}^R\,\tilde{s}$		$\frac{1}{2N}\tilde{\eta}_{1q}^R(\tilde{\eta}_{1q}^L)^*\,\tilde{t}$	$\frac{1}{4}\left(1-\frac{1}{N^2}\right)\tilde{\eta}_{8q}^R(\tilde{\eta}_{8q}^L)^*\,\tilde{t}$		
C_{S1}^{LR}	$-\eta_{1q}^L\eta_{1t}^R\,\tilde{s}$					
C_{S1}^{RL}	$-\eta_{1q}^R\eta_{1t}^L\,\tilde{s}$					
C_{S8}^{LL}		$-\eta_{8q}^L\eta_{8t}^L\,\tilde{s}$	$\tilde{\eta}_{1q}^L(\tilde{\eta}_{1q}^R)^*\,\tilde{t}$	$-\frac{1}{2N}\tilde{\eta}_{8q}^L(\tilde{\eta}_{8q}^R)^*\,\tilde{t}$		
C_{S8}^{RR}		$-\eta_{8q}^R\eta_{8t}^R\,\tilde{s}$	$\tilde{\eta}_{1q}^R(\tilde{\eta}_{1q}^L)^*\,\tilde{t}$	$-\frac{1}{2N}\tilde{\eta}_{8q}^L(\tilde{\eta}_{8q}^R)^*\,\tilde{t}$		
C_{S8}^{LR}		$-\eta_{8q}^L\eta_{8t}^R\,\tilde{s}$				
C_{S8}^{RL}		$-\eta_{8q}^R\eta_{8t}^L\,\tilde{s}$				
C_{V1}^{LL}						
C_{V1}^{RR}					$-\frac{1}{2}\left(1-\frac{1}{N}\right)\lvert\tilde{\eta}_{3q}\rvert^2\,\tilde{u}$	$-\frac{1}{4}\left(1+\frac{1}{N}\right)\lvert\tilde{\eta}_{6q}\rvert^2\,\tilde{u}$
C_{V1}^{LR}			$\frac{1}{2N}\lvert\tilde{\eta}_{1q}^L\rvert^2\,\tilde{t}$	$\frac{1}{4}\left(1-\frac{1}{N^2}\right)\lvert\tilde{\eta}_{8q}^L\rvert^2\,\tilde{t}$		
C_{V1}^{RL}			$\frac{1}{2N}\lvert\tilde{\eta}_{1q}^R\rvert^2\,\tilde{t}$	$\frac{1}{4}\left(1-\frac{1}{N^2}\right)\lvert\tilde{\eta}_{8q}^R\rvert^2\,\tilde{t}$		
C_{V8}^{LL}						
C_{V8}^{RR}					$\lvert\tilde{\eta}_{3q}\rvert^2\,\tilde{u}$	$-\frac{1}{2}\lvert\tilde{\eta}_{6q}\rvert^2\,\tilde{u}$
C_{V8}^{LR}			$\lvert\tilde{\eta}_{1q}^L\rvert^2\,\tilde{t}$	$-\frac{1}{2N}\lvert\tilde{\eta}_{8q}^L\rvert^2\,\tilde{t}$		
C_{V8}^{RL}			$\lvert\tilde{\eta}_{1q}^R\rvert^2\,\tilde{t}$	$-\frac{1}{2N}\lvert\tilde{\eta}_{8q}^R\rvert^2\,\tilde{t}$		
C_{T1}^{L}			$\frac{1}{8N}\tilde{\eta}_{1q}^L(\tilde{\eta}_{1q}^R)^*\,\tilde{t}$	$\frac{1}{16}\left(1-\frac{1}{N^2}\right)\tilde{\eta}_{8q}^L(\tilde{\eta}_{8q}^R)^*\,\tilde{t}$		
C_{T1}^{R}			$\frac{1}{8N}\tilde{\eta}_{1q}^R(\tilde{\eta}_{1q}^L)^*\,\tilde{t}$	$\frac{1}{16}\left(1-\frac{1}{N^2}\right)\tilde{\eta}_{8q}^R(\tilde{\eta}_{8q}^L)^*\,\tilde{t}$		
C_{T8}^{L}			$\frac{1}{4}\tilde{\eta}_{1q}^L(\tilde{\eta}_{1q}^R)^*\,\tilde{t}$	$-\frac{1}{8N}\tilde{\eta}_{8q}^L(\tilde{\eta}_{8q}^R)^*\,\tilde{t}$		
C_{T8}^{R}			$\frac{1}{4}\tilde{\eta}_{1q}^R(\tilde{\eta}_{1q}^L)^*\,\tilde{t}$	$-\frac{1}{8N}\tilde{\eta}_{8q}^R(\tilde{\eta}_{8q}^L)^*\,\tilde{t}$		

- **The amplitude can be decomposed into the colour-singlet and colour-octet parts as**

$$\mathcal{M}(q\bar{q} \to t\bar{t}) = \frac{g_s^2}{\hat{s}} \left[\delta_{ij}\delta_{kl}\, \mathcal{S}(\sigma,\bar{\sigma};\lambda,\bar{\lambda}) + T^a_{ij} T^a_{kl}\, \mathcal{O}(\sigma,\bar{\sigma};\lambda,\bar{\lambda})\right]$$

- **In the $t\bar{t}$ rest frame,**

$$\mathcal{S}(\sigma,\bar{\sigma};\lambda,\bar{\lambda}) = \sum_{A,B=L,R} \left[C^{AB}_{S1}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^S_{AB} + C^{AB}_{V1}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^V_{AB} + C^{A}_{T1}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^T_{A}\right]$$

$$\mathcal{O}(\sigma,\bar{\sigma};\lambda,\bar{\lambda}) = \sum_{A,B=L,R} \left[C^{AB}_{S8}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^S_{AB} + C^{AB}_{V8}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^V_{AB} + C^{A}_{T8}\, \langle\sigma,\bar{\sigma};\lambda,\bar{\lambda}\rangle^T_{A}\right]$$

- **The reduced amplitudes**

$$\langle\sigma,\bar\sigma;\lambda,\bar\lambda\rangle^S_{AB} = -\frac{\hat s}{4}(A+\lambda)(B-\widehat\beta\sigma)\,\delta_{\lambda,\bar\lambda}\,\delta_{\sigma,\bar\sigma}\,,$$

$$\langle\sigma,\bar\sigma;\lambda,\bar\lambda\rangle^V_{AB} = -\frac{m_t\sqrt{\hat s}}{2}(1+A\lambda)\,\sigma\,s_{\widehat\theta}\,\delta_{\lambda,-\bar\lambda}\,\delta_{\sigma,\bar\sigma}$$
$$-\frac{\hat s}{4}\Big[(1+A\lambda)(1+\widehat\beta B\sigma)\,c_{\widehat\theta}+(A+\lambda)(\widehat\beta B+\sigma)\Big]\,\delta_{\lambda,-\bar\lambda}\,\delta_{\sigma,-\bar\sigma}\,,$$

$$\langle\sigma,\bar\sigma;\lambda,\bar\lambda\rangle^T_{A} = \hat s\,(A+\lambda)(\widehat\beta A-\sigma)\,c_{\widehat\theta}\,\delta_{\lambda,\bar\lambda}\,\delta_{\sigma,\bar\sigma} - 2\,i\,m_t\sqrt{\hat s}\,(A+\lambda)\,s_{\widehat\theta}\,\delta_{\lambda,\bar\lambda}\,\delta_{\sigma,-\bar\sigma}\,,$$

with $\widehat\beta = \sqrt{1-4m_t^2/\hat s}$.

- **The squared amplitude**

$$\overline{|\mathcal{M}(q\bar q\to t\bar t)|^2} \equiv \frac{1}{9}\cdot\frac{1}{4}\cdot\frac{g_s^4}{\hat s^2}\sum_{\lambda,\bar\lambda,\sigma,\bar\sigma}\Big[9\,|\mathcal{S}(\sigma,\bar\sigma;\lambda,\bar\lambda)|^2+2\,|\mathcal{O}(\sigma,\bar\sigma;\lambda,\bar\lambda)|^2\Big]$$

using $\sum_{\rm colours}|\delta_{ij}\delta_{kl}|^2=9$, $\sum_{\rm colours}\delta_{ij}T^a_{ij}=0$, $\sum_{\rm colours}|T^a_{ij}T^a_{kl}|^2=2$.

- **The matrix element takes the form**

$$\mathcal{A}(\sigma\bar{\sigma};\lambda\bar{\lambda}) \propto \begin{pmatrix} \langle ++;\lambda\bar{\lambda}\rangle & \langle +-;\lambda\bar{\lambda}\rangle \\ \langle -+;\lambda\bar{\lambda}\rangle & \langle --;\lambda\bar{\lambda}\rangle \end{pmatrix}$$

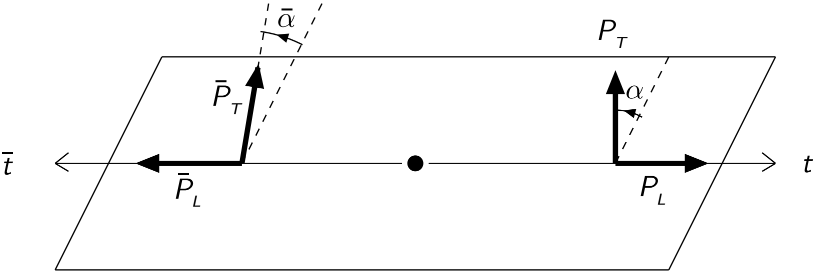
with $\mathcal{A} = \mathcal{S}\,,\mathcal{O}$**.**

- **The top polarization-weighted squared matrix elements are given by**

$$\overline{|\mathcal{M}(q\bar{q}\to t\bar{t})|^2} = \frac{g_s^4}{\hat{s}^2}\sum_{\lambda,\bar{\lambda}}\left\{\sum_{\mathcal{A}=\mathcal{S},\mathcal{O}} f_{\mathcal{A}}\,\mathrm{Tr}\left[\mathcal{A}(\sigma,\bar{\sigma};\lambda,\bar{\lambda})\,\bar{\rho}^T\,\mathcal{A}^\dagger(\sigma,\bar{\sigma};\lambda,\bar{\lambda})\,\rho\right]\right\}$$

with $f_{\mathcal{S}} = 1$ **and** $f_{\mathcal{O}} = 2/9$ **and**

$$\rho = \frac{1}{2}\begin{pmatrix} 1+P_L & P_T e^{-i\alpha} \\ P_T e^{i\alpha} & 1-P_L \end{pmatrix}, \qquad \bar{\rho} = \frac{1}{2}\begin{pmatrix} 1+\bar{P}_L & -\bar{P}_T e^{i\bar{\alpha}} \\ -\bar{P}_T e^{-i\bar{\alpha}} & 1-\bar{P}_L \end{pmatrix}.$$



The $t\bar{t}$ production plane in its rest frame.
The longitudinal-polarization vector $P_L(\bar{P}_L)$ and the transverse-polarization vector $P_T(\bar{P}_T)$ with the azimuthal angle $\alpha(\bar{\alpha})$ of $t\,(\bar{t})$ are shown.

- **The amplitude squared can be spanned as**

$$
\begin{aligned}
\overline{|\mathcal{M}|^2} \;=\; \frac{g_s^4}{\hat{s}^2}\Big\{ & D_0 + D_1(P_L + \bar{P}_L) + D_2(P_L - \bar{P}_L) + D_3 P_L \bar{P}_L \\
& + [D_4 \sin(\alpha - \bar{\alpha}) + D_5 \cos(\alpha - \bar{\alpha}) + D_6 \sin(\alpha + \bar{\alpha}) + D_7 \cos(\alpha + \bar{\alpha})] P_T \bar{P}_T \\
& + D_8(P_T \sin\alpha + \bar{P}_T \sin\bar{\alpha}) + D_9(P_T \sin\alpha - \bar{P}_T \sin\bar{\alpha}) \\
& + D_{10}(P_T \cos\alpha + \bar{P}_T \cos\bar{\alpha}) + D_{11}(P_T \cos\alpha - \bar{P}_T \cos\bar{\alpha}) \\
& + D_{12}(P_L \bar{P}_T \sin\bar{\alpha} + \bar{P}_L P_T \sin\alpha)) + D_{13}(P_L \bar{P}_T \sin\bar{\alpha} - \bar{P}_L P_T \sin\alpha) \\
& + D_{14}(P_L \bar{P}_T \cos\bar{\alpha} + \bar{P}_L P_T \cos\alpha)) + D_{15}(P_L \bar{P}_T \cos\bar{\alpha} - \bar{P}_L P_T \cos\alpha) \Big\}
\end{aligned}
$$

- **The coefficients D_i's are expressed by helicity amplitudes**

$$D_0 = \frac{1}{4}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\left(|\mathcal{A}(++;\lambda\bar{\lambda})|^2 + |\mathcal{A}(--;\lambda\bar{\lambda})|^2 + |\mathcal{A}(+-;\lambda\bar{\lambda})|^2 + |\mathcal{A}(-+;\lambda\bar{\lambda})|^2\right),$$

$$D_1 = \frac{1}{4}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\left(|\mathcal{A}(++;\lambda\bar{\lambda})|^2 - |\mathcal{A}(--;\lambda\bar{\lambda})|^2\right),$$

$$D_2 = \frac{1}{4}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\left(|\mathcal{A}(+-;\lambda\bar{\lambda})|^2 - |\mathcal{A}(-+;\lambda\bar{\lambda})|^2\right),$$

$$D_3 = \frac{1}{4}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\left(|\mathcal{A}(++;\lambda\bar{\lambda})|^2 + |\mathcal{A}(--;\lambda\bar{\lambda})|^2 - |\mathcal{A}(+-;\lambda\bar{\lambda})|^2 - |\mathcal{A}(-+;\lambda\bar{\lambda})|^2\right),$$

$$D_4 = \frac{1}{2}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\,\Im\mathrm{m}[\mathcal{A}(++;\lambda\bar{\lambda})\,\mathcal{A}^*(--;\lambda\bar{\lambda})],$$

$$D_5 = -\frac{1}{2}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\,\Re\mathrm{e}[\mathcal{A}(++;\lambda\bar{\lambda})\,\mathcal{A}^*(--;\lambda\bar{\lambda})],$$

$$D_6 = \frac{1}{2}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\,\Im\mathrm{m}[\mathcal{A}(+-;\lambda\bar{\lambda})\,\mathcal{A}^*(-+;\lambda\bar{\lambda})^*],$$

$$D_7 = -\frac{1}{2}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\,\Re\mathrm{e}[\mathcal{A}(+-;\lambda\bar{\lambda})\,\mathcal{A}^*(-+;\lambda\bar{\lambda})],$$

$$D_8 = \frac{1}{4}\sum_{\lambda,\bar{\lambda},\mathcal{A}} f_{\mathcal{A}}\Big(\Im\mathrm{m}[\mathcal{A}(--;\lambda\bar{\lambda})\,\mathcal{A}^*(+-;\lambda\bar{\lambda})] - \Im\mathrm{m}[\mathcal{A}(++;\lambda\bar{\lambda})\,\mathcal{A}^*(-+;\lambda\bar{\lambda})]$$
$$-\Im\mathrm{m}[\mathcal{A}(++;\lambda\bar{\lambda})\,\mathcal{A}^*(+-;\lambda\bar{\lambda})] + \Im\mathrm{m}[\mathcal{A}(--;\lambda\bar{\lambda})\,\mathcal{A}^*(-+;\lambda\bar{\lambda})]\Big),$$

$$D_9 = \frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$+\Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{10} = \frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$-\Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{11} = \frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$+\Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{12} = -\frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$+\Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{13} = -\frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] + \Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$-\Im\mathrm{m}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Im\mathrm{m}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{14} = -\frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

$$+\Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]\Big),$$

$$D_{15} = -\frac{1}{4}\sum_{\lambda,\bar\lambda,\mathcal{A}} f_{\mathcal{A}} \Big(\Re\mathrm{e}[\mathcal{A}(++;\lambda\bar\lambda)\,\mathcal{A}^*(+-;\lambda\bar\lambda)] - \Re\mathrm{e}[\mathcal{A}(--;\lambda\bar\lambda)\,\mathcal{A}^*(-+;\lambda\bar\lambda)]$$

Table: The CP and $\mathrm{CP\widetilde{T}}$ parities of the polarization coefficients.

Observables	$[\mathrm{CP}, \mathrm{CP\widetilde{T}}]$
D_0	$[+\,,+]$
D_1	$[-\,,-]$
D_2	$[+\,,+]$
D_3	$[+\,,+]$
D_4	$[-\,,+]$
D_5	$[+\,,+]$
D_6	$[+\,,-]$
D_7	$[+\,,+]$
D_8	$[+\,,-]$
D_9	$[-\,,+]$
D_{10}	$[+\,,+]$
D_{11}	$[-\,,-]$
D_{12}	$[-\,,+]$
D_{13}	$[+\,,-]$
D_{14}	$[-\,,-]$
D_{15}	$[+\,,+]$

Example : EFT analysis

- **If the NP particles are heavy enough, we can adopt the veiwpoint of effective Lagragian.**
- **Assuming $SU(2)_L \times U(1)_Y$ and the custodial symmetry $SU(2)_R$ for the light quark sector,**

$$\mathcal{L}_6 = \frac{g_s^2}{\Lambda^2} \sum_{A,B} \Big[C_{1q}^{AB} (\bar{q}_A \gamma_\mu q_A)(\bar{t}_B \gamma^\mu t_B) + C_{8q}^{AB} (\bar{q}_A T^a \gamma_\mu q_A)(\bar{t}_B T^a \gamma^\mu t_B) \Big]$$

where $T^a = \lambda^a/2$, $\{A, B\} = \{L, R\}$, **and** $L, R \equiv (1 \mp \gamma_5)/2$ **with** $q = (u, d)^T, (s, c)^T$.

- **Cross section up to $O(1/\Lambda^2)$ is calculated, keeping only the INTERFERENCE between the SM and NP.**

Amplitude

- **The amplitude for** $q(p_1) + \bar{q}(p_2) \to t(p_3) + \bar{t}(p_4)$

$$\overline{|\mathcal{M}|^2} \simeq \frac{4\,g_s^4}{9\,\hat{s}^2}\left\{2m_t^2\hat{s}\left[1+\frac{\hat{s}}{2\Lambda^2}\left(C_1+C_2\right)\right]s_{\hat{\theta}}^2 + \frac{\hat{s}^2}{2}\left[\left(1+\frac{\hat{s}}{2\Lambda^2}\left(C_1+C_2\right)\right)\left(1+c_{\hat{\theta}}^2\right)+\hat{\beta}_t\left(\frac{\hat{s}}{\Lambda^2}\left(C_1-C_2\right)\right)c_{\hat{\theta}}\right]\right\}$$

where $C_1 \equiv C_{8q}^{LL} + C_{8q}^{RR}$ **and** $C_2 \equiv C_{8q}^{LR} + C_{8q}^{RL}$

- $\hat{s} = (p_1 + p_2)^2$, $\hat{\beta}_t^2 = 1 - 4m_t^2/\hat{s}$, **and** $s_{\hat{\theta}} \equiv \sin\hat{\theta}$ **and** $c_{\hat{\theta}} \equiv \cos\hat{\theta}$, **with** $\hat{\theta}$ **being the polar angle between the incoming quark and the outgoing top quark in the** $t\bar{t}$ **rest frame.**

- **Neglecting the transverse polarization,**

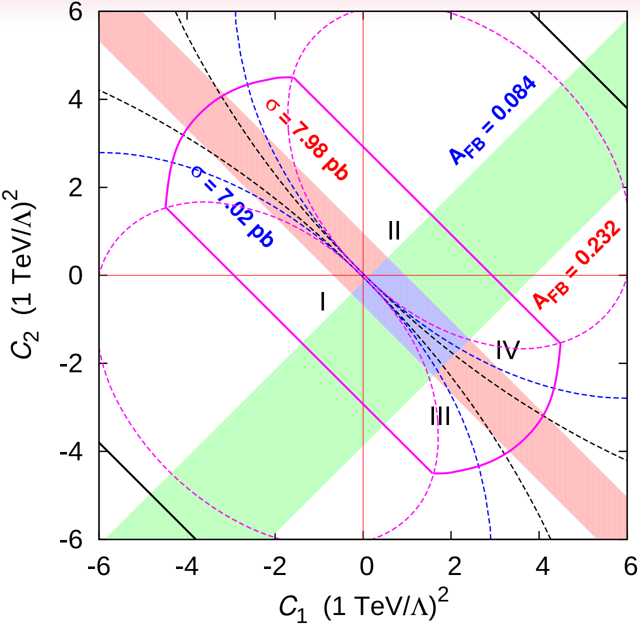
$$\overline{|\mathcal{M}|^2} = \frac{g_s^4}{\hat{s}^2}\left\{\mathcal{D}_0 + \mathcal{D}_1(P_L + \bar{P}_L) + \mathcal{D}_2(P_L - \bar{P}_L) + \mathcal{D}_3 P_L \bar{P}_L\right\}.$$

  The longitudinal polarization of top quark, $P_L \equiv \langle \vec{S}_t \cdot \vec{n}_t \rangle$**.**

  $\vec{n}_t$ **is any unit vector defining the spin quantization axis of the top quark.**

- **If we choose** $\vec{n}_{t\,(\bar{t})} = \vec{p}_{t\,(\bar{t})}/|\vec{p}_{t\,(\bar{t})}|$ **with** $\vec{p}_{t\,(\bar{t})}$ **being the momentum vector of** t **(**$\bar{t}$**),** P_L **(**$\bar{P}_L$**) becomes the usual helicity of (anti)top quark.**

$$\begin{aligned}
\mathcal{D}_0 &= \frac{2}{9}\cdot\frac{1}{4}\sum_{\lambda,\bar{\lambda}}\Big(|\langle ++;\lambda\bar{\lambda}\rangle_{\rm oct}|^2+|\langle --;\lambda\bar{\lambda}\rangle_{\rm oct}|^2 \\
&\qquad +|\langle +-;\lambda\bar{\lambda}\rangle_{\rm oct}|^2+|\langle -+;\lambda\bar{\lambda}\rangle_{\rm oct}|^2\Big),\\
\mathcal{D}_1 &= \frac{2}{9}\cdot\frac{1}{4}\sum_{\lambda,\bar{\lambda}}\Big(|\langle ++;\lambda\bar{\lambda}\rangle_{\rm oct}|^2-|\langle --;\lambda\bar{\lambda}\rangle_{\rm oct}|^2\Big),\\
\mathcal{D}_2 &= \frac{2}{9}\cdot\frac{1}{4}\sum_{\lambda,\bar{\lambda}}\Big(|\langle +-;\lambda\bar{\lambda}\rangle_{\rm oct}|^2-|\langle -+;\lambda\bar{\lambda}\rangle_{\rm oct}|^2\Big),\\
\mathcal{D}_3 &= \frac{2}{9}\cdot\frac{1}{4}\sum_{\lambda,\bar{\lambda}}\Big(|\langle ++;\lambda\bar{\lambda}\rangle_{\rm oct}|^2+|\langle --;\lambda\bar{\lambda}\rangle_{\rm oct}|^2 \\
&\qquad -|\langle +-;\lambda\bar{\lambda}\rangle_{\rm oct}|^2-|\langle -+;\lambda\bar{\lambda}\rangle_{\rm oct}|^2\Big),
\end{aligned}$$



σ = 7.98 pb
σ = 7.02 pb
A_FB = 0.084
A_FB = 0.232
I
II
III
IV
C_1 (1 TeV/Λ)^2
C_2 (1 TeV/Λ)^2

Parity conserving

- $\mathcal{D}_0$ **leads to the** σ_{tt} **and** A_{FB}**.**

- $\mathcal{D}_3$ **leads to the spin-correlation variables,**

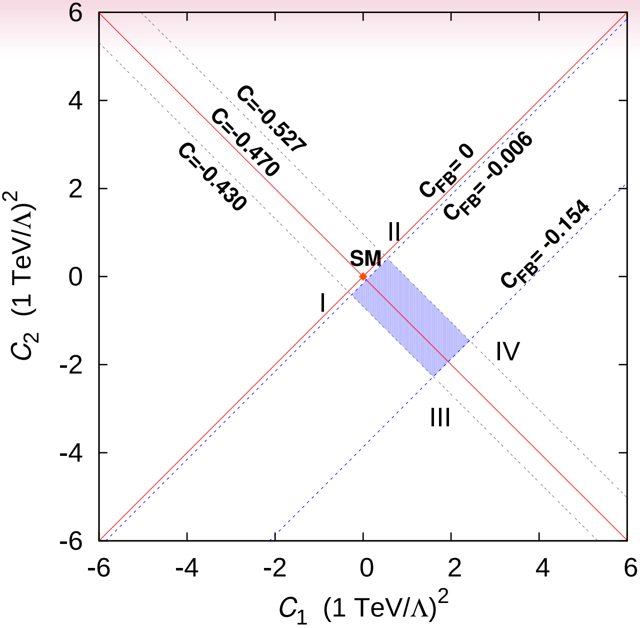
$$C = \frac{\sigma(t_L\bar{t}_L + t_R\bar{t}_R) - \sigma(t_L\bar{t}_R + t_R\bar{t}_L)}{\sigma(t_L\bar{t}_L + t_R\bar{t}_R) + \sigma(t_L\bar{t}_R + t_R\bar{t}_L)}\,.$$

- **It depends only on the** $C_1 + C_2$**, so is NOT related to the** $A_{\rm FB}$**.**

- **If we integrate the** $\mathcal{D}_3$ **for the forward/backward directions separately,** $C_{\rm FB}$ **defined as**

$$C_{FB} \equiv C(\cos\theta \geq 0) - C(\cos\theta \leq 0),$$

where $C(\cos\theta \geq 0(\leq 0))$ **implies the cross sections in the numerator of** C **are obtained for the forward (backward) region:** $\cos\theta \geq 0(\leq 0)$**.**


C=-0.527
C=-0.470
C=-0.430
C_FB= 0
C_FB= -0.006
C_FB= -0.154
SM
I
II
III
IV
C_2 (1 TeV/Λ)^2
C_1 (1 TeV/Λ)^2
6
4
2
0
-2
-4
-6

Parity Violating

- **$\mathcal{D}_1$ is the coefficient of $P_L + \bar{P}_L$, so it is also CP odd.**
- **No such terms in EFT analysis, since the heavy particles are integrated out.**
- **It can arise from the interference between the CP-violating complex couplings together with their decay width etc., if explicit NP form is considered.**

Parity violating, continued

- **$\mathcal{D}_2$ is the coefficient of $P_L - \bar{P}_L$, parity odd but CP-even.**

- **Explicitly,**

$$\mathcal{D}_2 \simeq \frac{\hat{s}}{9\,\Lambda^2}\left[(C_1' + C_2')\hat{\beta}_t(1 + c_{\hat{\theta}}^2) + (C_1' - C_2')(5 - 3\hat{\beta}_t^2)c_{\hat{\theta}}\right]$$

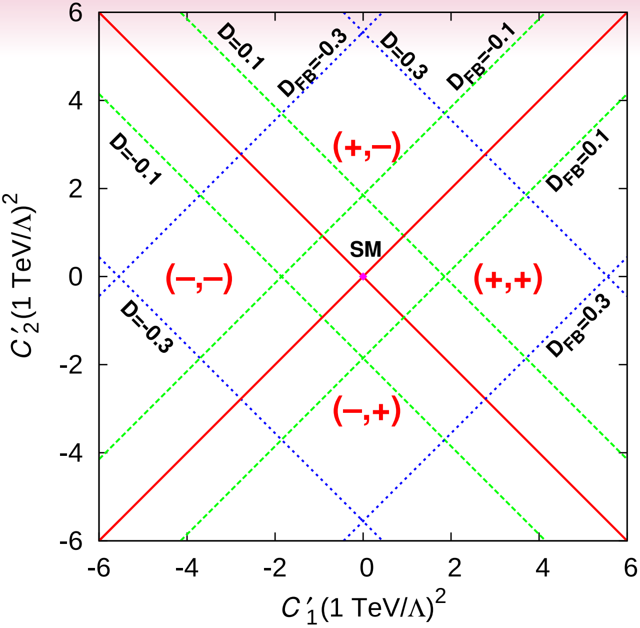
with

$$C_1' \equiv C_{8q}^{RR} - C_{8q}^{LL}\,, \quad C_2' \equiv C_{8q}^{LR} - C_{8q}^{RL}\,.$$

- **As σ_{tt}, A_{FB} and C, C_{FB}, new two polarization observables can be drawn.**

$$D \equiv \frac{\sigma(t_R\bar{t}_L) - \sigma(t_L\bar{t}_R)}{\sigma(t_R\bar{t}_R) + \sigma(t_L\bar{t}_L) + \sigma(t_L\bar{t}_R) + \sigma(t_R\bar{t}_L)}\,,$$

$$D_{\rm FB} \equiv D(\cos\hat{\theta} \geq 0) - D(\cos\hat{\theta} \leq 0)$$



D=0.1
D=0.3
D=-0.1
D=-0.3
D_{FB}=-0.3
D_{FB}=-0.1
D_{FB}=0.1
D_{FB}=0.3
(+,−)
(−,−)
(+,+)
(−,+)
SM
$C'_2(1\ \text{TeV}/\Lambda)^2$
$C'_1(1\ \text{TeV}/\Lambda)^2$
6
4
2
0
-2
-4
-6

Model independent vs. Models

- **We can draw some information on each models from model-independent study.**
- **Integrating out heavy fields, the Wilson coefficients are,**

$$\frac{C_{8q}^{RR}}{\Lambda^2} = -\frac{g_{8q}^R g_{8t}^R}{m_{V_{8R}}^2} - \frac{2|\tilde{g}_{1q}^R|^2}{m_{\tilde{V}_{1R}}^2} + \frac{1}{N_C}\frac{|\tilde{g}_{8q}^R|^2}{m_{\tilde{V}_{8R}}^2},$$

$$\frac{C_{8q}^{LL}}{\Lambda^2} = -\frac{g_{8q}^L g_{8t}^L}{m_{V_{8L}}^2} - \frac{2|\tilde{g}_{1q}^L|^2}{m_{\tilde{V}_{1L}}^2} + \frac{1}{N_C}\frac{|\tilde{g}_{8q}^L|^2}{m_{\tilde{V}_{8L}}^2},$$

$$\frac{C_{8q}^{LR}}{\Lambda^2} = -\frac{g_{8q}^L g_{8t}^R}{m_{V_8}^2} - \frac{|\tilde{\eta}_{1q}^L|^2}{m_{\tilde{S}_{1L}}^2} + \frac{1}{2N_c}\frac{|\tilde{\eta}_{8q}^L|^2}{m_{\tilde{S}_{8L}}^2},$$

$$\frac{C_{8q}^{RL}}{\Lambda^2} = -\frac{g_{8q}^R g_{8t}^L}{m_{V_8}^2} - \frac{|\tilde{\eta}_{1q}^R|^2}{m_{\tilde{S}_{1R}}^2} + \frac{1}{2N_c}\frac{|\tilde{\eta}_{8q}^R|^2}{m_{\tilde{S}_{8R}}^2},$$

- **Another interesting possibility is**
  - **color-triplet S_k^γ with mass m_{S_3} and**
  - **color-sextet $S_{ij}^{\alpha\beta}$ with mass m_{S_6} with the SM quarks .**

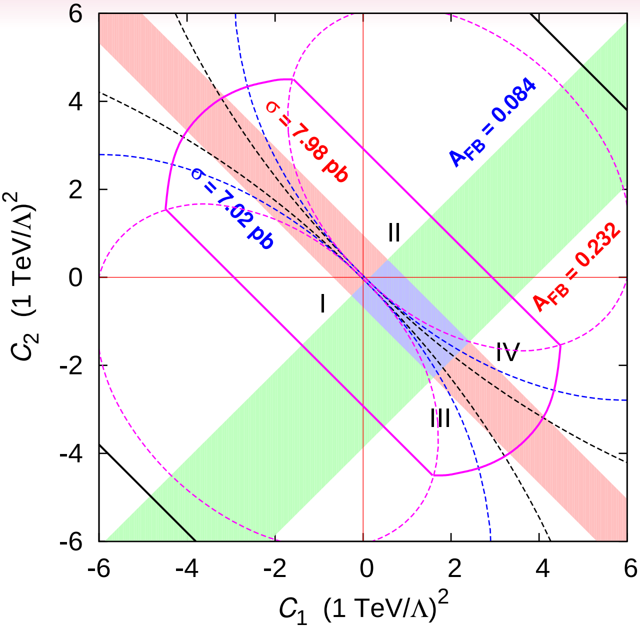
- **With the following interactions**

$$\mathcal{L} = g_s\left[\frac{\eta_3}{2}\epsilon_{\alpha\beta\gamma}\epsilon^{ijk}u_{iR}^{\alpha}u_{jR}^{\beta}S_k^{\gamma} + \eta_6 u_{iR}^{\alpha}u_{jR}^{\beta}S_{ij}^{\alpha\beta} + h.c.\right]$$

the $u-$channel exchange of new scalars can contribute to $u\bar{u} \to t\bar{t}$, resulting in

$$\frac{C_{8u}^{RR}}{\Lambda^2} = -\frac{|\eta_3|^2}{m_{S_3}^2} + \frac{2|\eta_6|^2}{m_{S_6}^2}.$$

Resonance	C^{RR}	C^{LL}	C^{LR}	C^{RL}	$C_1 - C_2$	$C_1' + C_2'$	$C_1' - C_2'$	$A_{\rm FB}$
$\tilde{V}_{1R}$	$-$	**0**	**0**	**0**	$-$	$-$	$-$	$\times$
$\tilde{V}_{1L}$	**0**	$-$	**0**	**0**	$-$	$+$	$+$	$\times$
$\tilde{V}_{8R}$	$+$	**0**	**0**	**0**	$+$	$+$	$+$	$\surd$
$\tilde{V}_{8L}$	**0**	$+$	**0**	**0**	$+$	$-$	$-$	$\surd$
$\tilde{S}_{1R}$	0	0	0	$-$	$+$	$+$	$-$	$\surd$
$\tilde{S}_{1L}$	0	0	$-$	0	$+$	$-$	$+$	$\surd$
$\tilde{S}_{8R}$	0	0	0	$+$	$-$	$-$	$+$	$\times$
$\tilde{S}_{8L}$	0	0	$+$	0	$-$	$+$	$-$	$\times$
S_2^{α}	$-$	0	0	0	$-$	$-$	$-$	$\times$
$S_{13}^{\alpha\beta}$	$+$	0	0	0	$+$	$+$	$+$	$\surd$
V_{8R}	$\pm$	0	0	0	$\pm$	$\pm$	$\pm$	$\surd(+)$ **or** $\times(-)$
V_{8L}	0	$\pm$	0	0	$\pm$	$\mp$	$\mp$	$\surd(+)$ **or** $\times(-)$
V_{8R} , V_{8L}	**indef.**	**indef.**	**indef.**	**indef.**	**indef.**	**indef.**	**indef.**	**indef.**


σ = 7.98 pb
σ = 7.02 pb
A_{FB} = 0.084
A_{FB} = 0.232
I
II
III
IV
C_2 (1 TeV/Λ)^2
C_1 (1 TeV/Λ)^2
6
4
2
0
-2
-4
-6

Simple cases

- **Following four cases are simple :**

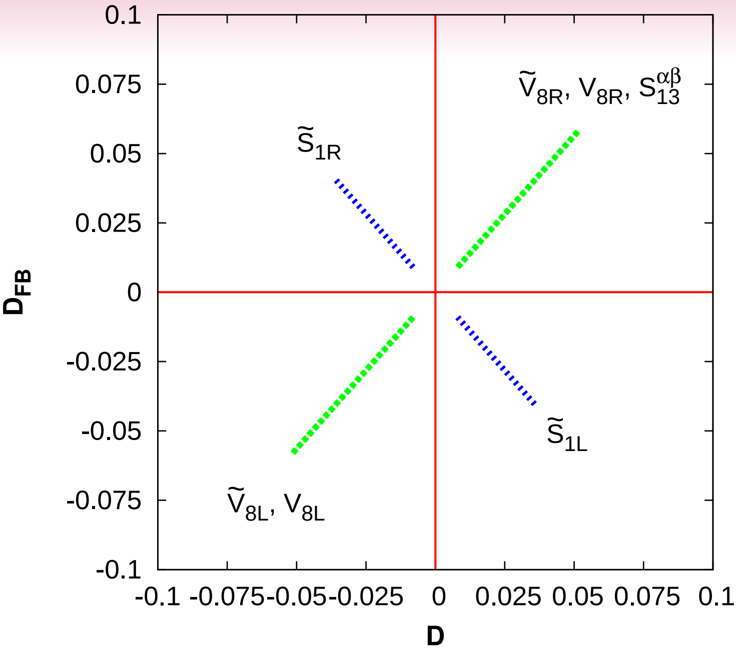
$$V_{8R,8L} \quad : \quad -\frac{g_{8q}^{R,L} g_{8t}^{R,L}}{m_{V_{8R,L}}^2} \simeq 0.649 \pm 0.024, \ ,$$

$$\tilde{V}_{8R,8L} \quad : \quad \frac{1}{N_c}\left(\frac{1\,\mathrm{TeV}}{m_{\tilde{V}_{8R,8L}}}\right)^2 |\tilde{g}_{8q}^{R,L}|^2 \simeq 0.649 \pm 0.024\,,$$

$$\tilde{S}_{1R,1L} \quad : \quad \left(\frac{1\,\mathrm{TeV}}{m_{\tilde{S}_{1R,1L}}}\right)^2 |\tilde{\eta}_{1q}^{R,L}|^2 \simeq 0.799 \pm 0.174\,,$$

$$S_{13}^{\alpha\beta} \quad : \quad 2\left(\frac{1\,\mathrm{TeV}}{m_{S_6}}\right)^2 |\eta_6|^2 \simeq 0.649 \pm 0.024\ .$$

- **New spin-correlation observables D and D_{FB} values are predicted for each case.**



$\tilde{V}_{8R}, V_{8R}, S_{13}^{\alpha\beta}$
$\tilde{S}_{1R}$
$\tilde{S}_{1L}$
$\tilde{V}_{8L}, V_{8L}$
D_{FB}
D
0.1
0.075
0.05
0.025
0
-0.025
-0.05
-0.075
-0.1
-0.1 -0.075 -0.05 -0.025 0 0.025 0.05 0.075 0.1

More general case

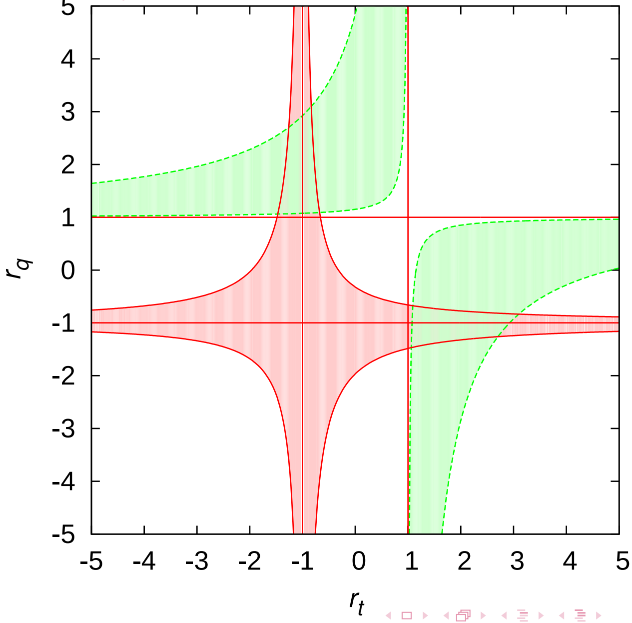
- **In general, V_{8L} and V_{8R} can coexist. In that case the new observables are not so definite compared to the previous cases.**

- **We introduce new parameterizations**

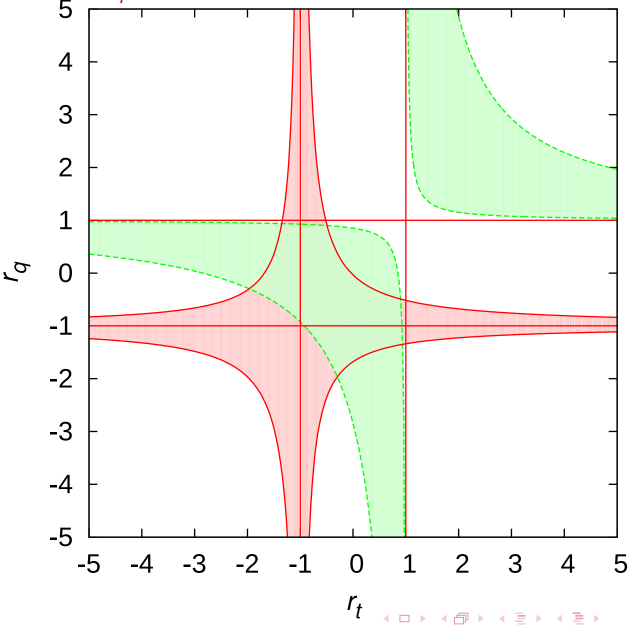
$$
\begin{aligned}
(C_1 + C_2)/\Lambda^2 &= -g_{8q}^L g_{8t}^L (r_q + 1)(r_t + 1)/m_{V8}^2 \\
(C_1 - C_2)/\Lambda^2 &= -g_{8q}^L g_{8t}^L (r_q - 1)(r_t - 1)/m_{V8}^2 \\
(C_1' + C_2')/\Lambda^2 &= -g_{8q}^L g_{8t}^L (r_q + 1)(r_t - 1)/m_{V8}^2 \\
(C_1' - C_2')/\Lambda^2 &= -g_{8q}^L g_{8t}^L (r_q - 1)(r_t + 1)/m_{V8}^2
\end{aligned}
$$

with $r_q \equiv g_{8q}^R / g_{8q}^L$ and $r_t \equiv g_{8t}^R / g_{8t}^L$. Any deviation of r_q (r_t) from 1 characterizes P violation in the light (top) quark sector.

$g^L_{8q} g^L_{8t} \left(1\,\mathrm{TeV}/m_{V8}\right)^2 = +1,$



$g^L_{8q} g^L_{8t} \, (1\,\mathrm{TeV}/m_{V8})^2 = -1,$



Important observations are

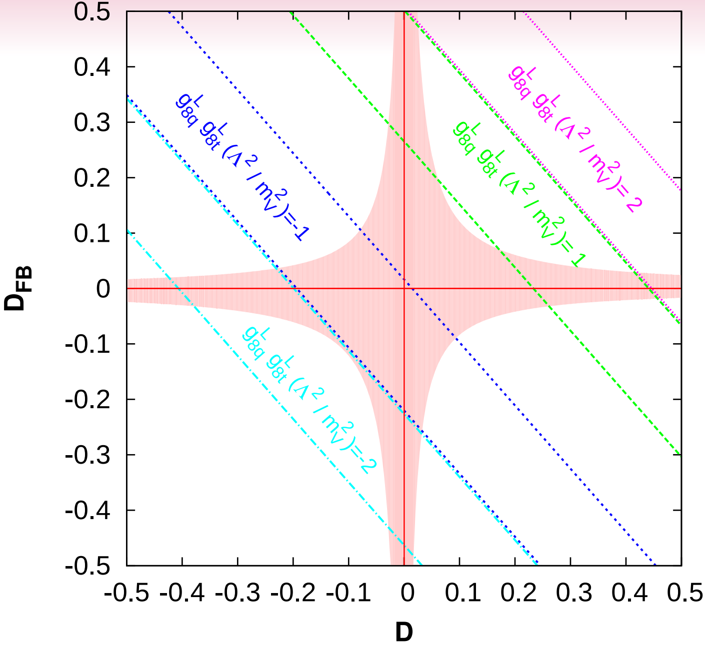
- **By observing the relation** $(C_1 + C_2)(C_1 - C_2) = (C_1' + C_2')(C_1' - C_2')$ **which leads to**

$$\Delta\sigma_{t\bar{t}}\, \Delta A_{\rm FB} \propto D\, D_{\rm FB}\,.$$

Let us note that $\Delta\sigma_{t\bar{t}} \propto (C_1 + C_2)$, $\Delta A_{\rm FB} \propto (C_1 + C_2)$, $D \propto (C_1' + C_2')$, **and** $D_{\rm FB} \propto (C_1' - C_2')$.

- **Furthermore, we observe**

$$g_{8q}^L g_{8t}^L \left(\frac{\Lambda}{m_{V8}}\right)^2$$
$$= \frac{[(C_1' + C_2') - (C_1 + C_2)]\,[(C_1' + C_2') - (C_1 - C_2)]}{4(C_1' + C_2')}$$
$$= \frac{1}{4}\left[(C_1' + C_2') - (C_1 + C_2) - (C_1 - C_2) + (C_1' - C_2')\right],$$



$g_{8q}^L g_{8t}^L (\Lambda^2/m_V^2)=-1$
$g_{8q}^L g_{8t}^L (\Lambda^2/m_V^2)=1$
$g_{8q}^L g_{8t}^L (\Lambda^2/m_V^2)=2$
$g_{8q}^L g_{8t}^L (\Lambda^2/m_V^2)=-2$
D_{FB}
D
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5

Summary and Prospect

- **LHC is a kind of top factory.**
- **NP is highly probable to appear in the top pair production channel.**
- **Polarization observables are very useful for discriminating many forms of the NP models.**
- **Discrete symmetries such as P,CP etc., can be analysed also in this helcity amplitude setup.**
- **Complete and general analysis with FULL theory is in progress, including above 16 observables ($\mathcal{D}_1$ and more) in relation with the Tevatron/LHC signals.**