FORWARD-BACKWARD ASYMMETRY OF TOP QUARK IN UNPARTICLE PHYSICS

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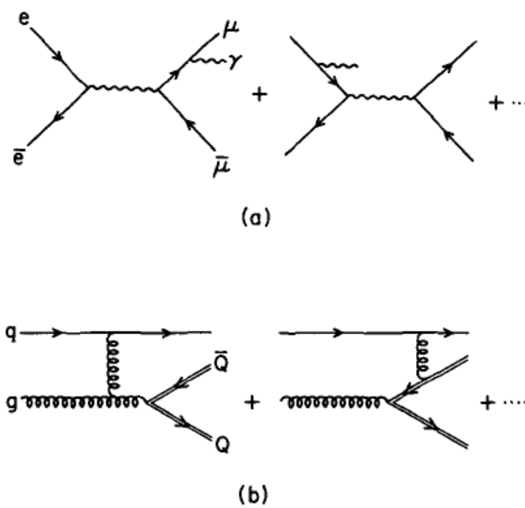
Outline

- Motivation → Observation at Tevatron
- Phenomenon & History over Q-FBA
- Possible Models & Mechanisms
- Our results in Unparticle Physics
- Summary



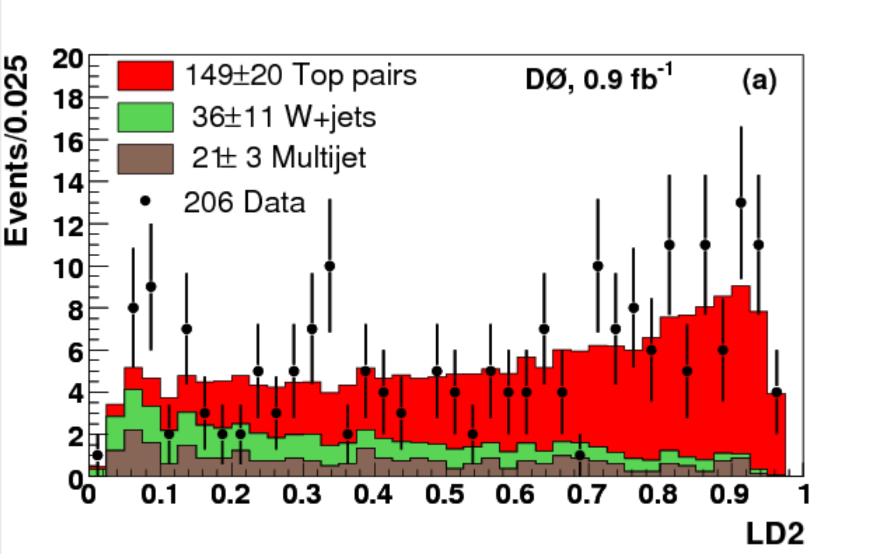
1. Observations at Tevatron

DØ PRL100, 142002 (2008)

- Process: p pbar → t tbar + X;
  the first measurement of the integrated forward-backward (FB) charge asymmetry
- D∅ Observable:

$$A_{FB} = \frac{N_f - N_b}{N_f + N_b}$$

- $N_{f(b)}$: number of events with a p ositive (negative) Δy
  $\Delta y = y_t - y_{tbar}$, y: rapidity



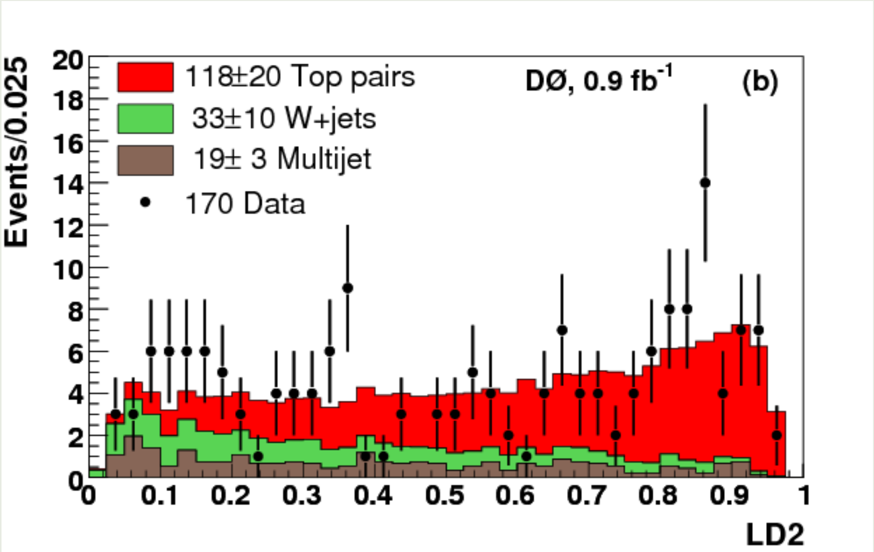


TABLE I. Asymmetry in percent measured on data and as predicted by MC@NLO for different jet multiplicities.

N_{jet}	DØ data	MC@NLO
≥ 4	12± 8(stat)±1(sys)	0.8±0.2(stat)±1.0(acc)
= 4	19± 9(stat)±2(sys)	2.3±0.2(stat)±1.0(acc)
≥ 5	-16^{+15}_{-17}(stat)±3(sys)	-4.9±0.4(stat)±1.0(acc)

Observations at Tevatron

CDF: PRL101, 202001 (2008)

- CDF observable:

$p\bar{p}$ frame:

$$A_{FB}^{p\bar{p}} = \frac{N(-Q_\ell \cos\theta > 0) - N(-Q_\ell \cos\theta < 0)}{N(-Q_\ell \cos\theta > 0) + N(-Q_\ell \cos\theta < 0)}$$

$t\bar{t}$ frame:

$$A_{FB}^{t\bar{t}} = \frac{N(Q_\ell \Delta y > 0) - N(Q_\ell \Delta y < 0)}{N(Q_\ell \Delta y > 0) + N(Q_\ell \Delta y < 0)}$$

$$\Delta y = y_t - y_{\bar{t}} = 2\tanh^{-1}\left(\frac{\cos\theta_{t\bar{t}}}{\sqrt{1 + 4m_t^2/(\hat{s} - 4m_t^2)}}\right)$$

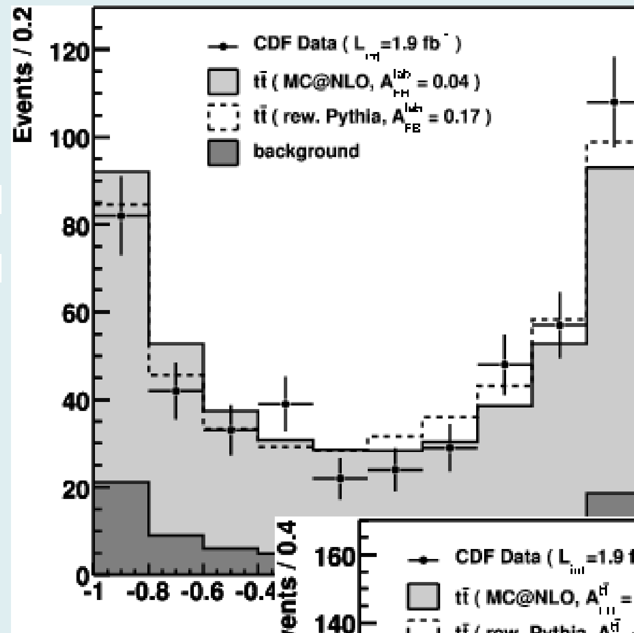
- With 1.9 fb^{-1}

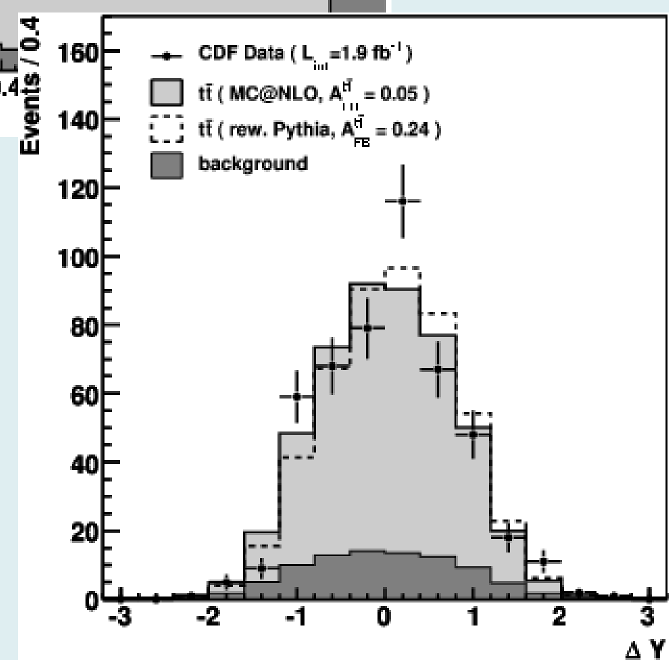
$$A_{FB}^{p\bar{p}} = 0.17 \pm 0.08$$

$$A_{FB}^{t\bar{t}} = 0.24 \pm 0.14$$

- With 3.2 fb^{-1}

$$A_{FB}^{p\bar{p}} = 0.193 \pm 0.065 \pm 0.024$$





2. Phenomenon

Asymmetry

- Integral charge asymmetry

$$A_C = \frac{N_t(p) - N_{\bar{t}}(p)}{N_t(p) + N_{\bar{t}}(p)}$$

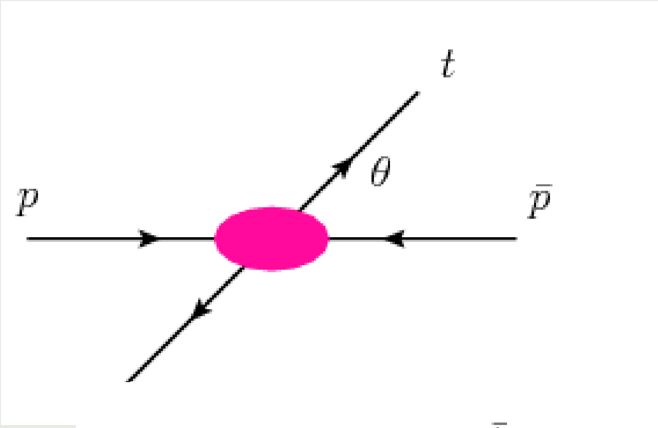
N_i (j): # of particle i observed in the direction of particle j

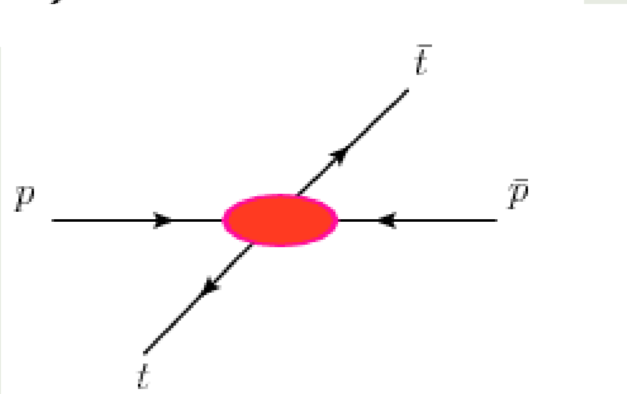
- Forward-backward asymmetry

$$A_{FB} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

- If CP is invariant,

$$N_{\bar{t}}(p) = N_t(\bar{p}) \rightarrow A_C = A_{FB}$$





History over Heavy Quark FBA

1. Brown et al, PRL43(1979)1069; FBA of c-quak production in analogy to QED.

2. [1] F. Halzen, P. Hoyer, C.S. Kim, PLB195(1987)74;
→ FBA of b,t-quark in QCD from (i) radiative corrections to q-qbar annihilation,
(ii) interference between different contributions to qg → t+tbar+q, (and its CP conj.)

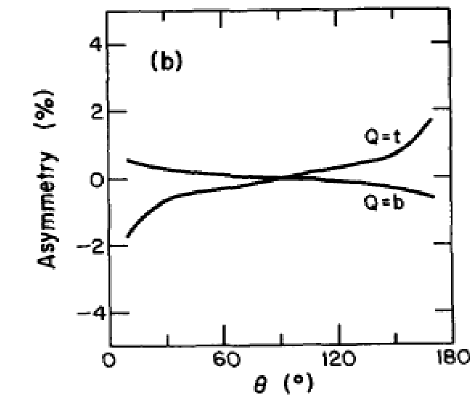


Fig. 4. QCD asymmetries of Q=b and t production in $p\bar{p}\to Q\bar{Q}g(q)$ at (a) $\sqrt{s}=630$ GeV; (b) $\sqrt{s}=1800$ GeV with $|y(Q,\bar{Q}$ and $g(q))|<2.5$, $p_T(\bar{Q}$ or $g(q))>10$ GeV and $[(\Delta\eta)^2+(\Delta\phi)^2]>0.5$ for any jet pair using the DO1 structure function [10].

~~~ no more progress about 10 years

3. [2] J.H. Kuhn, G. Rodrigo, PRL81(1998)49; detailed QCD calculation

3. [3] O. Antunano, J.H. Kuhn, G. Rodrigo, PRD77(2008)014003;
→ FBA of t-quak within the SM = 0.050 +- 0.015

5. D0 and CDF measured FBA ~ 20%
→ Now so many works beyond the SM
~~~

SM prediction

Kuhn& Rodrigo PRD59(99); Antunano etal PRD77(08);

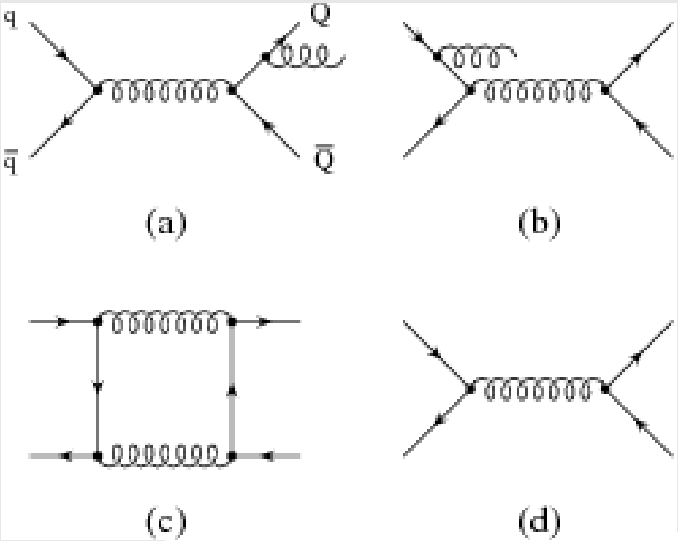
- Leading order (d): charge asymmetry vanishes

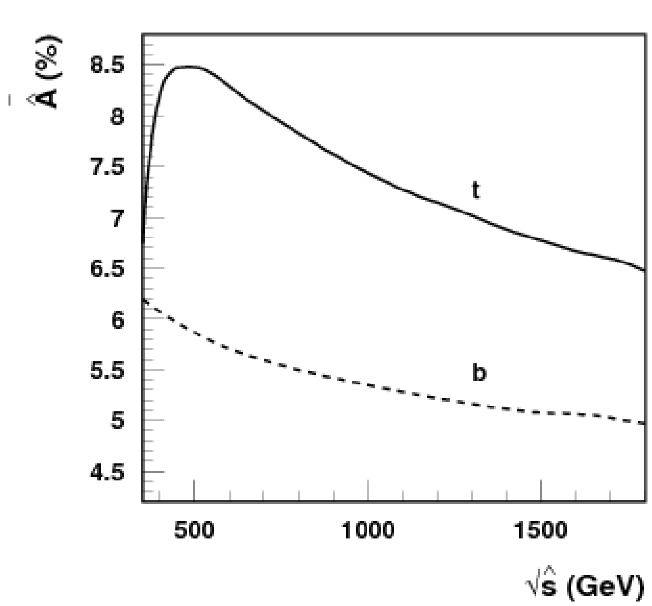
- Next-to-leading order: nonzero A_C will be induced by the interference between (a) and (b) and the interference between (c) and (d)

$$A_C = \frac{N_t(y) - N_{\bar{t}}(y)}{N_t(y) + N_{\bar{t}}(y)} = 0.051(6)$$

- Since the measurements of D∅ and CDF have 2σ deviation from the SM, the observed large FBA strongly indicate the new Physics

$$\left(A_{FB}^{p\bar{p}}\right)_{CDF} = 0.193 \pm 0.065 \pm 0.024$$

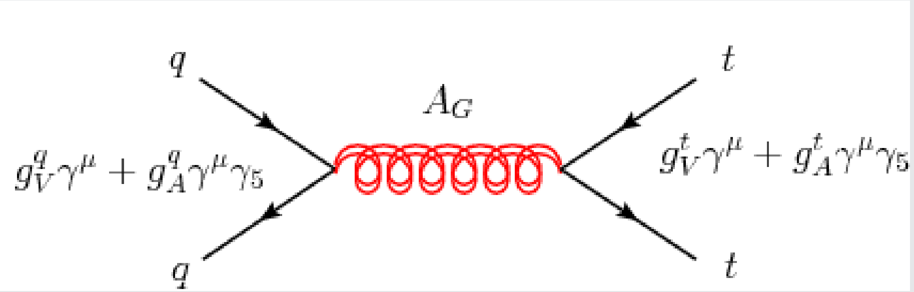




3. Models by s-channel

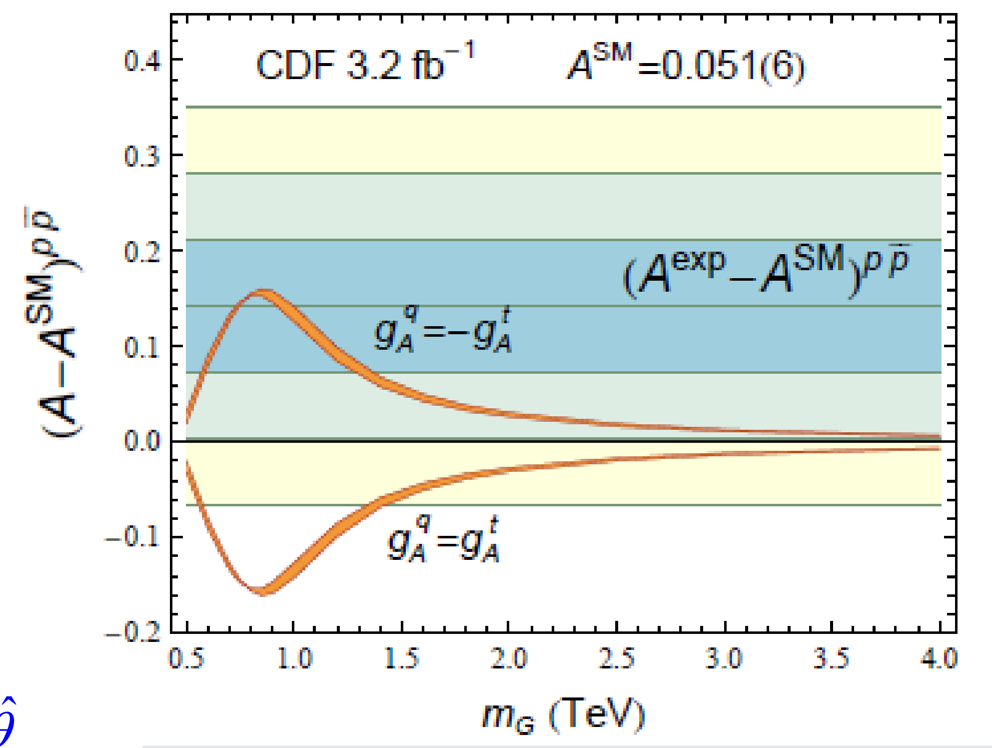
Ferrario & Rodrigo PRD80(09); Frampton etal, arXiv:0911.2955

- Axigluon: Color-octet gauge bosons (A_Gs) that couple to quarks with a nonvanishing axial-vector couplings
- It could be generated by symmetry breaking from $SU(3)_R \times SU(3)_L$ to $SU(3)_C$
- A_G could be as heavy as TeV



$$\frac{d\sigma^{q\bar{q}\to t\bar{t}}}{d\cos\hat{\theta}} = \alpha_S^2 \frac{T_F C_F}{N_C} \frac{\pi\beta}{2\hat{s}} \{1 + c^2 + 4m^2$$
$$+ \frac{2\hat{s}(\hat{s} - m_G^2)}{(\hat{s} - m_G^2)^2 + m_G^2\Gamma_G^2} [g_V^q \, g_V^t \, (1 + c^2 + 4m^2)$$
$$+2\, g_A^q \, g_A^t \, c] + \frac{\hat{s}^2}{(\hat{s} - m_G^2)^2 + m_G^2\Gamma_G^2} [((g_V^q)^2 + (g$$
$$\times ((g_V^t)^2(1 + c^2 + 4m^2) + (g_A^t)^2(1 + c^2 - 4m^2))$$
$$+8\, g_V^q \, g_A^q \, g_V^t \, g_A^t \, c]\} ,$$

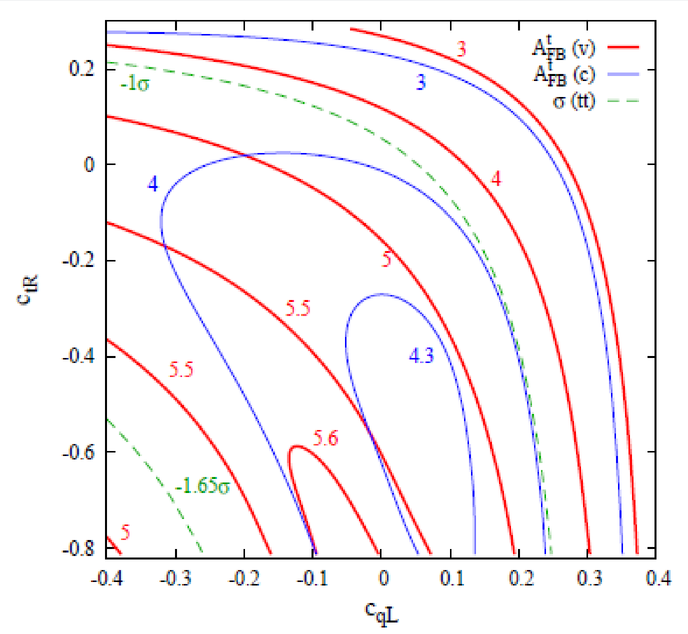
$$c = \beta \cos\hat{\theta}$$



Models by s-channel

Djouadi Moreau, Richard,Singh, arXiv:0906.0604

- KK excitations of gluons in warped extra dimensional models
- The couplings of KK to quarks have the axial-vector component
- $A^t_{FB}|^{RS} \sim$ few %



$$\frac{d\hat{\sigma}}{d\cos\theta_t^*} \propto 2 - \beta_t^2 \sin^2\theta^* + \hat{s}^2|\mathcal{D}|^2 \Big[8 v_q v_t a_q a_t \beta_t \cos\theta^*$$

$$+ (a_q^2 + v_q^2)\left(v_t^2(2 - \beta_t^2 \sin^2\theta^*) + a_t^2\beta_t^2(1+\cos^2\theta^*)\right)\Big]$$

$$+ \hat{4}s\mathrm{Re}(\mathcal{D})\left[v_q v_t \left(1 - \frac{1}{2}\beta_t^2 \sin^2\theta^*\right) + a_q a_t \beta_t \cos\theta^*\right] \quad (6)$$

$$D = \left(\hat{s} - M_{KK}^2 + i\Gamma_{KK} M_{KK}\right)^{-1}$$

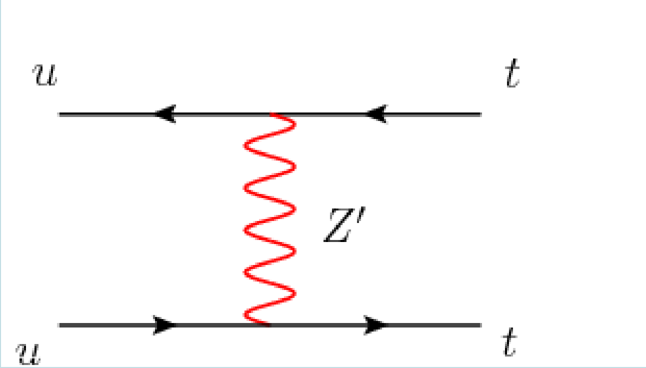
Models by t-channel

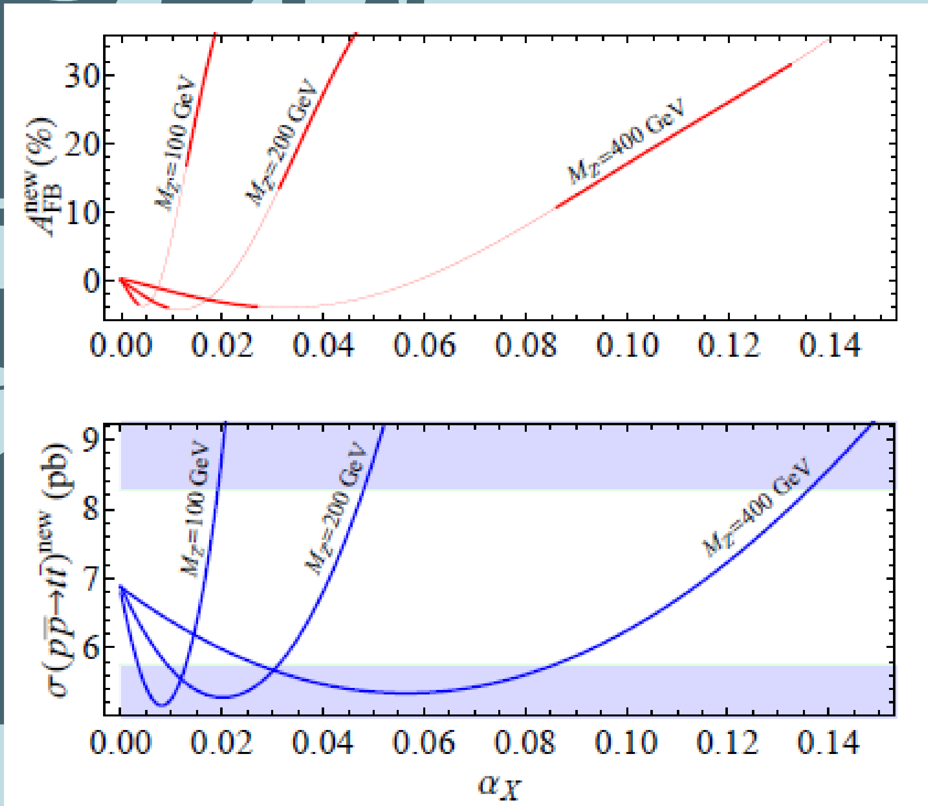
Jung, Murayama, Pierce, Wells, arXiv:0907.4112

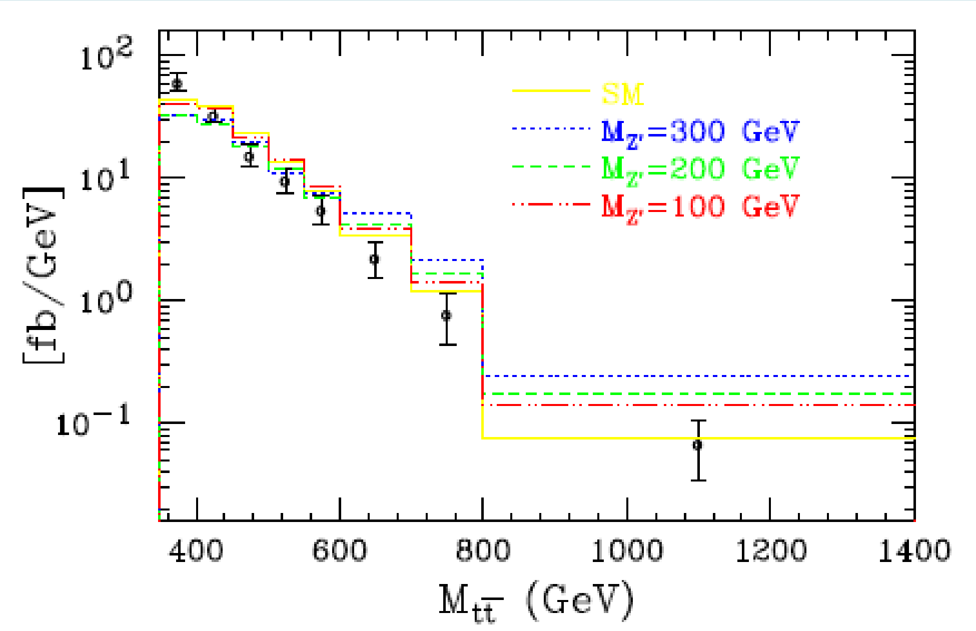
- New Z' gauge boson

$$L_{Z'} \supset g_X \bar{t} \gamma^{\mu} P_R u Z'_{\mu} + h.c.$$

- Nonuniversal Z' model







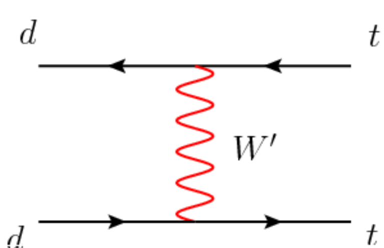
Models by t-channel

Cheung, Keung, Yuan PLB682(09); Barger, Keung, Yu: arXiv:1002.1048

$$\sum |\mathcal{M}|^2 = \frac{9g'^4}{t_{W'}^2}\left[4\left((g_L^4+g_R^4)u_t^2 + 2g_L^2 g_R^2 \hat{s}(\hat{s}-2m_t^2)\right) + \frac{m_t^4}{m_{W'}^4}(g_L^2+g_R^2)^2(t_t^2+4m_{W'}^2\hat{s})\right] \quad (5)$$

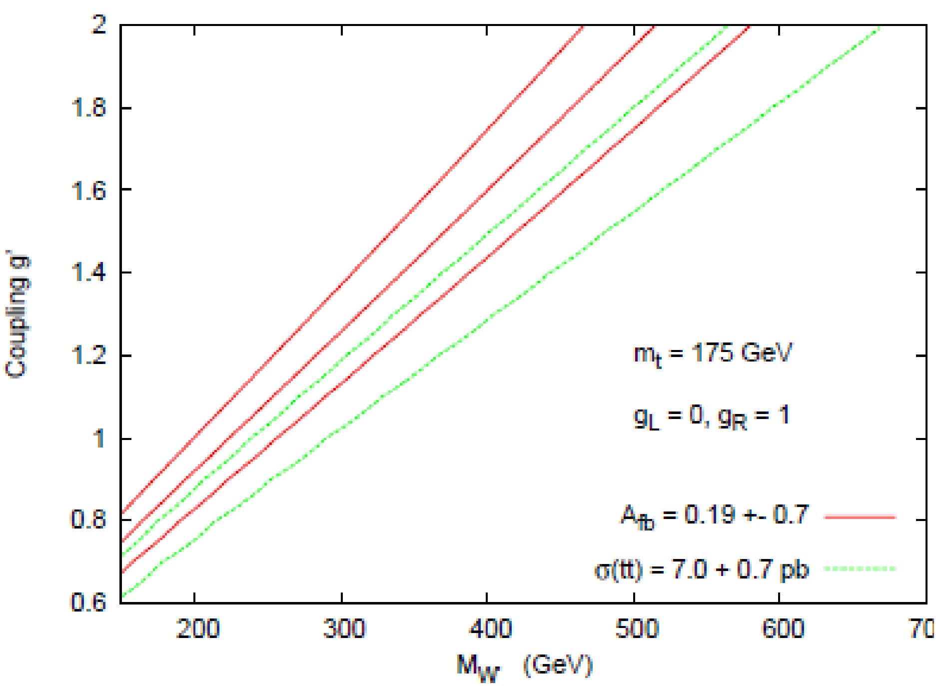
$$+ \frac{16g_s^4}{\hat{s}^2}\left(u_t^2+t_t^2+2\hat{s}m_t^2\right) + \frac{16g'^2g_s^2}{\hat{s}\,t_{W'}}(g_L^2+g_R^2)\left[2u_t^2+2\hat{s}m_t^2+\frac{m_t^2}{m_{W'}^2}(t_t^2+\hat{s}m_t^2)\right],$$

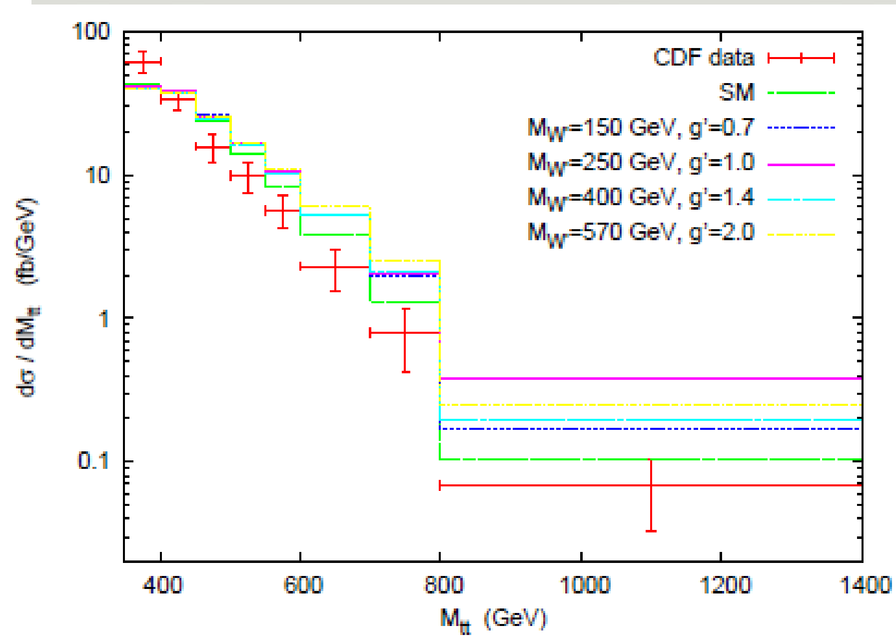
where $\hat{s} = (p_1+p_2)^2$, $t = (p_1-k_1)^2$, $u = (p_1-k_2)^2$ and



$$t = m_t^2 - \frac{\hat{s}}{2}(1-\beta\cos\theta)$$

$$\mathcal{L} = -g'\, W'^{+}_{\mu}\, \bar{t}\gamma^{\mu}\left(g_L P_L + g_R P_R\right) d \; + \; \text{h.c.}$$





Model-independent approach

D.W. Jung, P. Ko, J.S. Lee, S.H. Nam, arXiv:0912.1105

- Effective interactions

New particles	couplings	C_1	C_2	1 σ favor
V_8 (spin-1 FC octet)	$g^{L,R}_{8q,8t}$	indef.	indef.	$\surd$
$\tilde{V}_1$ (spin-1 FV singlet)	$\tilde{g}^{L,R}_{1q}$	$-$	0	$\times$
$\tilde{V}_8$ (spin-1 FV octet)	$\tilde{g}^{L,R}_{8q}$	$+$	0	$\surd$
$\tilde{S}_1$ (spin-0 FV singlet)	$\tilde{\eta}^{L,R}_{1q}$	0	$-$	$\surd$
$\tilde{S}_8$ (spin-0 FV octet)	$\tilde{\eta}^{L,R}_{8q}$	0	$+$	$\times$
S^{α}_2 (spin-0 FV triplet)	η_3	$-$	0	$\times$
$S^{\alpha\beta}_{13}$ (spin-0 FV sextet)	η_6	$+$	0	$\surd$

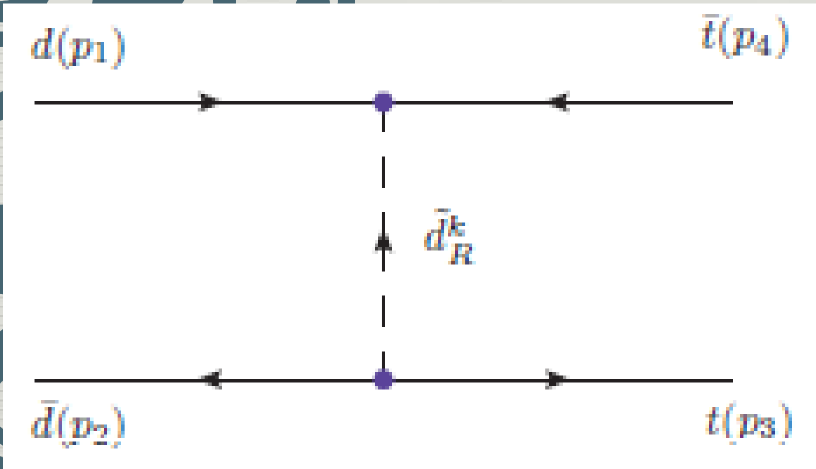
$$\mathcal{L} = g_s\left[\frac{\eta_3}{2}\epsilon_{\alpha\beta\gamma}\epsilon^{ijk}u^{\alpha}_{iR}u^{\beta}_{jR}S^{\gamma}_{k} + \eta_6 u^{\alpha}_{iR}u^{\beta}_{jR}S^{\alpha\beta}_{ij} + h.c.\right]$$

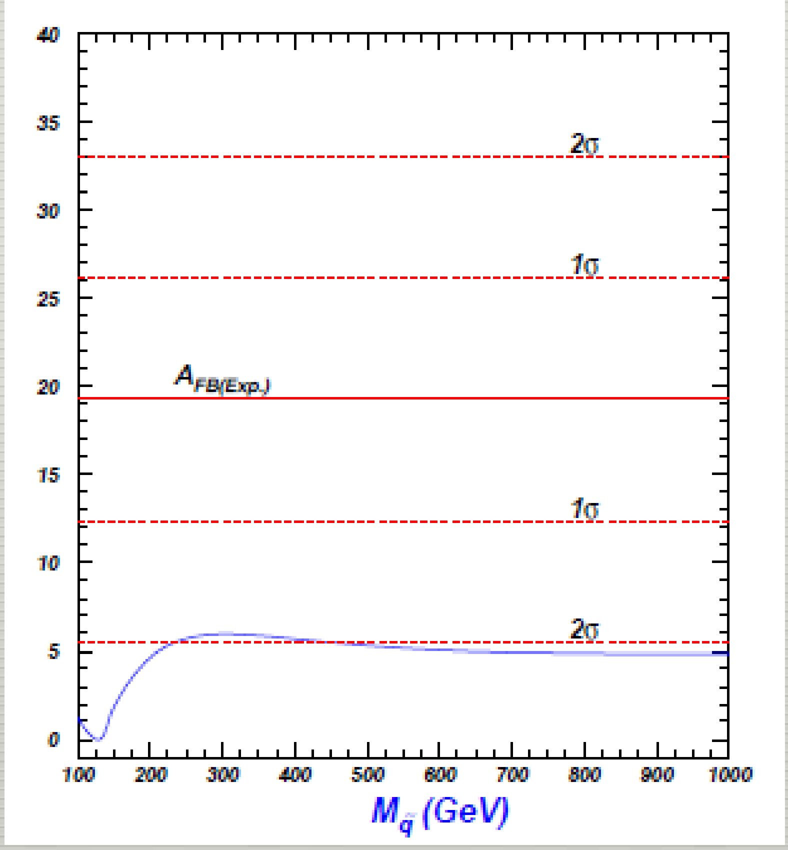
$$\begin{aligned}\mathcal{L}_{\rm int} &= g_s V_8^{a\mu}\sum_A\left[g^A_{8q}(\bar{q}_A\gamma_\mu T^a q_A) + g^A_{8t}(\bar{t}_A\gamma_\mu T^a t_A)\right] \\ &+g_s\left[\tilde{V}_1^{\mu}\sum_A \tilde{g}^A_{1q}(\bar{t}_A\gamma_\mu q_A) + \tilde{V}_8^{a\mu}\sum_A \tilde{g}^A_{8q}(\bar{t}_A\gamma_\mu T^a q_A) + \text{h.c.}\right] \\ &+g_s\left[\tilde{S}_1\sum_A \tilde{\eta}^A_{1q}(\bar{t}Aq) + \tilde{S}^a_8\sum_A \tilde{\eta}^A_{8q}(\bar{t}AT^a q) + \text{h.c.}\right], \qquad (6)\end{aligned}$$

SUSY R-parity violation

by J. Chao, Z. Heng, L. Wu and J.M. Yang, arXiv:0912.1447

$$\mathcal{L} = \lambda'_{ijk} \tilde{l}^i_L \overline{d^k_R} u^j_L - \frac{1}{2}\lambda''_{ijk}[\tilde{d}^{k*}_R \bar{u}^i_R d^{jc}_L + \tilde{d}^{j*}_R \bar{u}^i_R d^{kc}_L] + h.c.,$$





Diquark models

Shu, Tait, Wang :0911.3237, Arhrib, Benbrik,Chen:0911.4875, Dorsner etal :0912.0972

- Diquark is the particle that couples to quarks by $q^{aT}\, C\, q^{b}\, H_{ab}$, where a, b are the color indices

- The possible representations under $SU(3)_C \times SU(2)_L \times U(1)_Y$: $(6, 3)_{1/3}$, $(6,1)_{4/3,1/3,-2/3}$, $(3, 3)_{-1/3}$, $(3,1)_{2/3,-1/3,-4/3}$

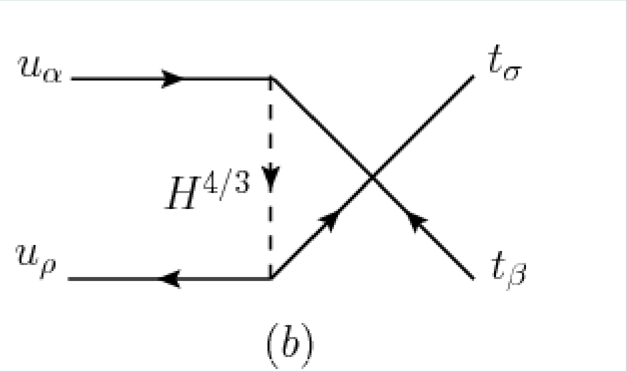
- We would like to pay attention to (3,1,-4/3) and (6,1,4/3)

- The relevant interaction

$$\mathcal{L} = 2 f^{\mathbf{3}}_{ut} \bar{u}_\alpha P_L t^c_\beta \epsilon^{\alpha\beta\gamma} H^\dagger_{\mathbf{3}\gamma} + 2 f^{\mathbf{6}}_{ut} \bar{u}_\alpha P_L t^c_\beta H^{\alpha\beta}_{\mathbf{6}} + h.c.$$

$$f^3_{ij} = - f^3_{ji}, \; f^6_{ij} = f^6_{ji}$$

- The corresponding Feynman diagram



4. Unparticle Physics, s-channel

C.H. Chen, Gorazd Cvetic, C.S Kim, PLB694(2011)393

- A stuff dictated by scale invariance, proposed by Georgi

Phys.Rev.Lett.98:221601,2007
Phys.Lett.B650:275-278,2007

- Here, we considered colored unparticle, in which the effective interactions to quarks are proposed to be

$$L = \frac{1}{\Lambda_U^{d-1}} \bar{q}(\lambda_V^q \gamma_\mu + \lambda_A^q \gamma_\mu \gamma_5) T^a q O_U^{a\mu}$$

$$\lambda_\chi^q / \Lambda_U^{d-1} = g_\chi^q, \chi = V or A$$

Cacciapaglia, Marandella, Terning, JHEP0801:070,2008

- Due to nonintegral scale dimension and no mass scale in the propagator, it will be interesting to see the unparticle effects on the top-quark FBA

The propagator of colored vector unparticle is given by

$$-iC_V \frac{1}{(-p^2 - i\epsilon)^{3-d}} \left[p^2 g_{\mu\nu} - \frac{2(d-2)}{d-1} p_\mu p_\nu \right]$$

with

$$C_V = \frac{A_{d_U}}{2 \sin d_U \pi},$$
$$A_{d_U} = \frac{16\pi^{5/2}}{(2\pi)^{2d_U}} \frac{\Gamma(d_U + 1/2)}{\Gamma(d_U - 1)\Gamma(2d_U)}.$$

Then, the scattering amplitude for $q\bar{q} \to t\bar{t}$ by unparticle exchange in the s-channel is

$$A_{\mathcal{U}} = \bar{q} \left(g_V^q \gamma_\mu + g_A^q \gamma_\mu \gamma_5 \right) T^a q \frac{C_V}{(-p^2 - i\epsilon)^{3-d_{\mathcal{U}}}} \left[p^2 g_{\mu\nu} - \frac{2(d_{\mathcal{U}} - 2)}{d_{\mathcal{U}} - 1} p_\mu p_\nu \right] \times \bar{t} \left(g_V^t \gamma_\nu + g_A^t \gamma_\nu \gamma_5 \right) T^a t$$

Scattering amplitude combined with the SM becomes

$$\begin{aligned} A &= A_{\mathrm{SM}} + A_{\mathcal{U}} \\ &= \frac{g_s^2}{\hat{s}} \bar{q} \gamma_\mu T^a q \bar{t} \gamma^\mu T^a t \\ &+ \frac{\hat{s} C_V}{\hat{s}^{3-d_{\mathcal{U}}}} e^{-i\pi(3-d_{\mathcal{U}})} \bar{q} \left(g_V^q \gamma_\mu + g_A^q \gamma_\mu \gamma_5 \right) T^a q \bar{t} \left(g_V^t \gamma^\mu + g_A^t \gamma^\mu \gamma_5 \right) T^a t \end{aligned}$$

explicitly showing the differential cross section in $t\bar{t}$ invariant mass frame, relevant coordinates of particle momenta as

$$p_{u,\bar{u}} = \frac{\sqrt{\hat{s}}}{2}(1, 0, 0, \pm 1)\,,$$
$$p_{t,\bar{t}} = \frac{\sqrt{\hat{s}}}{2}(1, \pm\beta_t \sin\hat{\theta}, 0, \pm\beta_t \cos\hat{\theta})\,,$$

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

Spin and color averaged amplitude-square is

$$\begin{aligned}
|\bar{A}|^2 &= \frac{1}{2^2}\frac{1}{N_C^2}|A|^2\,,\\
&= \frac{N_C^2 - 1}{16N_C^2}\Bigg\{4(4\pi\alpha_s)^2\left(1 + \beta_t^2\cos^2\hat{\theta} + 4\frac{m_t^2}{\hat{s}}\right)\\
&+ 8(C_V 4\pi\alpha_s)\cos\pi(3 - d_{\mathcal{U}})\frac{\hat{s}^2}{\hat{s}^{3-d_{\mathcal{U}}}}\left[g_V^q g_V^t\left(1 + \beta_t^2\cos^2\hat{\theta} + 4\frac{m_t^2}{\hat{s}}\right) + 2g_A^q g_A^t \beta_t \cos\hat{\theta}\right]\\
&+ 4\hat{s}^2\left(\frac{\hat{s}C_V}{\hat{s}^{3-d_{\mathcal{U}}}}\right)^2\Bigg[(g_V^t)^2\left((g_V^q)^2 + (g_A^q)^2\right)\left(1 + \beta_t^2\cos^2\hat{\theta} + \frac{4m_t^2}{\hat{s}}\right)\\
&+ (g_A^t)^2\left((g_V^q)^2 + (g_A^q)^2\right)\left(1 + \beta_t^2\cos^2\hat{\theta} - \frac{4m_t^2}{\hat{s}}\right) + 8g_V^q g_V^t g_A^q g_A^t \beta_t \cos\hat{\theta}\Bigg]\Bigg\}\,. \qquad (10)
\end{aligned}$$

$$\begin{aligned}
\frac{d\hat{\sigma}^{q\bar{q}\to t\bar{t}}}{d\cos\hat{\theta}} &= \frac{N_C^2 - 1}{128N_C^2\pi\hat{s}}\beta_t\Bigg\{(4\pi\alpha_s)^2\left(1 + \beta_t^2\cos^2\hat{\theta} + 4\frac{m_t^2}{\hat{s}}\right)\\
&+ 2C_V(4\pi\alpha_s)\cos\pi(3 - d_{\mathcal{U}})\frac{\hat{s}^2}{\hat{s}^{3-d_{\mathcal{U}}}}\left[g_V^q g_V^t\left(1 + \beta_t^2\cos^2\hat{\theta} + 4\frac{m_t^2}{\hat{s}}\right) + 2g_A^q g_A^t \beta_t \Box\right]\\
&+ \left(\frac{\hat{s}^2 C_V}{\hat{s}^{3-d_{\mathcal{U}}}}\right)^2\Bigg[(g_V^t)^2\left((g_V^q)^2 + (g_A^q)^2\right)\left(1 + \beta_t^2\cos^2\hat{\theta} + \frac{4m_t^2}{\hat{s}}\right)\\
&+ (g_A^t)^2\left((g_V^q)^2 + (g_A^q)^2\right)\left(1 + \beta_t^2\cos^2\hat{\theta} - \frac{4m_t^2}{\hat{s}}\right) + 8g_V^q g_V^t g_A^q g_A^t \beta_t \Box\Bigg]\Bigg\}\,. \qquad (11)
\end{aligned}$$

3 physical observables are: $\sigma(p\bar{p}\to t\bar{t}) = \int_{-1}^{1} d\cos\theta \, \frac{d\sigma(p\bar{p}\to t\bar{t})}{d\cos\theta}$

$$A_{\rm FB}^{p\bar{p}} = \left(\int_0^1 d\cos\theta \, \frac{d\sigma(p\bar{p}\to t\bar{t})}{d\cos\theta} - \int_0^{-1} d\cos\theta \, \frac{d\sigma(p\bar{p}\to t\bar{t})}{d\cos\theta}\right) / \sigma(p\bar{p}\to t\bar{t})$$

$$\frac{d\sigma(p\bar{p}\to t\bar{t})}{dM_{t\bar{t}}} = 2\,\frac{M_{t\bar{t}}}{s}\int_{M_{t\bar{t}}^2/s}^{1}\frac{dx_1}{x_1}\sum_{i,j} f_i(x_1) f_j(x_2)\int_{-1}^{1} d\cos\theta \frac{\partial\hat{\sigma}^{q_i\bar{q}_j\to t\bar{t}}(\theta, x_1, x_2)}{\partial\cos\theta}\Bigg|_{x_2=M_{t\bar{t}}^2/(s x_1)}$$

3 independent parameters: ($\Lambda_{\mathcal{U}}$, λ and $d_{\mathcal{U}}$)

first we set $\Lambda_{\mathcal{U}} = 1$ TeV

2 remaining dimensionless parameters are

λ from $g = \lambda/\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}$ assuming flavor blind (colored) unparticle

and finally the scale dimension $d_{\mathcal{U}}$ $g_V^t = g_A^t = g_V^q = g_A^q = g$.

➔ i.e. the flavor-blind and chirality-independent couplings

Experimental numerical constraints:

$$\sigma(p\bar{p}\to t\bar{t})^{\rm exp} = 7.50 \pm 0.31\ ({\rm stat})\ \pm 0.34\ ({\rm syst})\ \pm 0.15\ ({\rm th})\ \ {\rm pb}$$
$$= 7.50 \pm 0.48\ {\rm pb}\ .$$

the SM prediction is $\sigma(p\bar{p}\to t\bar{t})^{\rm SM} = 6.73^{+0.71}_{-0.79}$ pb

$$A_{\rm FB}^t \equiv A_{\rm FB}^{p\bar{p}}({\rm exp}) - A_{\rm FB}^{p\bar{p}}({\rm SM}) = 0.143 \pm 0.071$$

M. Cacciari *et al., JHEP* 0809, 127 (2008); N. Kidonakis and R. Vogt, Phys. Rev. D 78, 074005 (2008); S. Moch and P. Uwer, Phys. Rev. D 78, 034003 (2008)

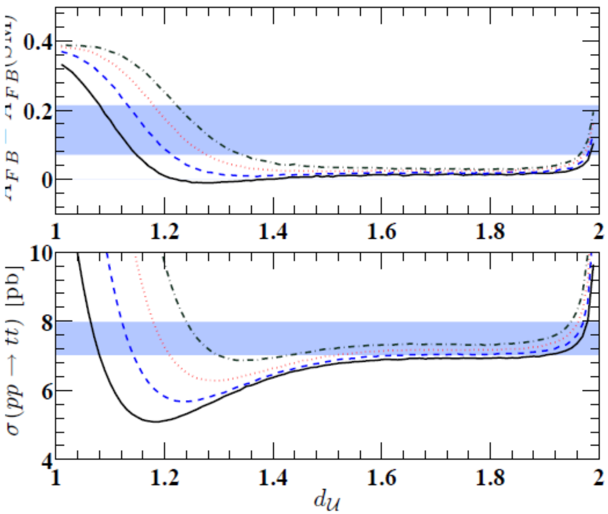
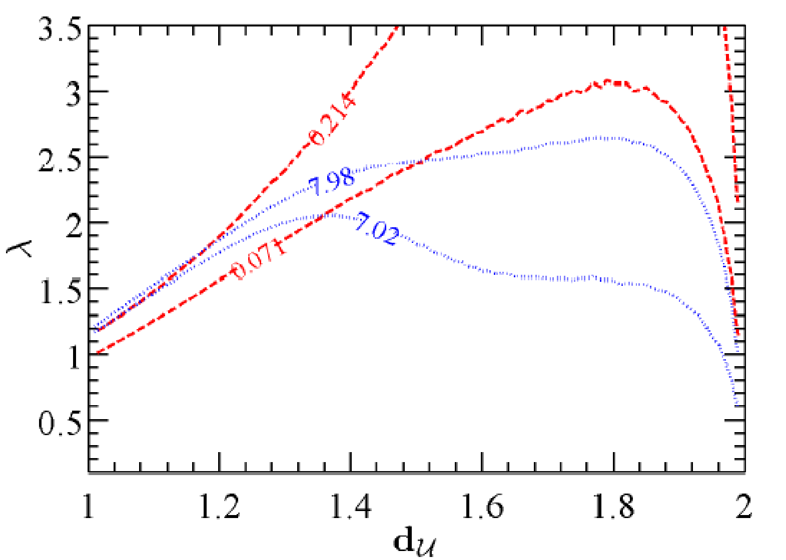


FIG. 1: $t\bar{t}$ production cross section (the lower) and top-quark FBA (the upper figure) as a function of the scale dimension $d_{\mathcal{U}}$, where the solid, dashed, dotted and dash-dotted lines represents λ=1.4, 1.6, 1.8, 2.0, respectively. The band in the plot represents the measured values with 1σ uncertainties.

➔ d_U=1.28+-0.22, lambda=2.05+-0.45



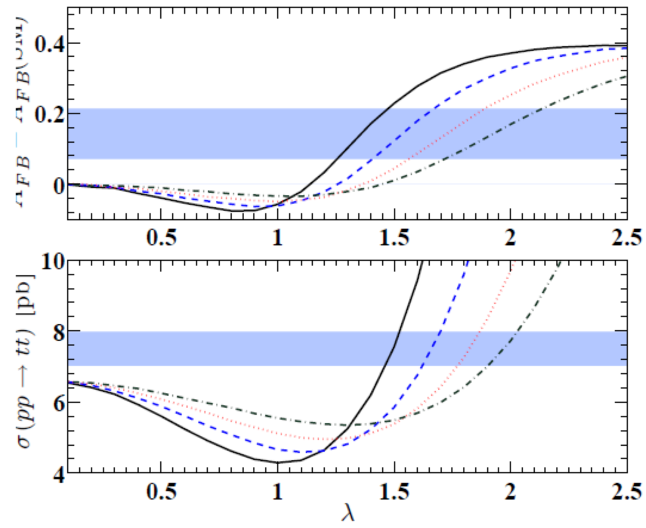


FIG. 2: As Fig. 1, but as a function of the parameter λ. The solid, dashed, dotted and dash-dotted lines represents $d_{\mathcal{U}}$=1.1, 1.15, 1.2, 1.25, respectively.

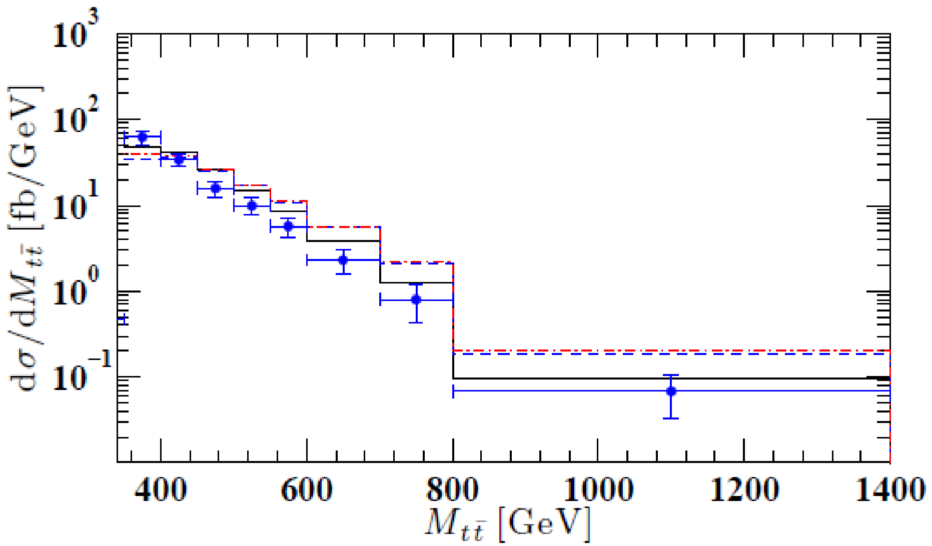


FIG. 4: $d\sigma/dM_{t\bar{t}}$ as a function of invariant mass of top-pair $M_{t\bar{t}}$, where the solid, dash-dotted and dashed lines represent the SM result and colored unparticle with $(\lambda, d_{\mathcal{U}}) = (2.05, 1.28)$ and (1.70, 1.175), respectively. The vertical bars are the data from CDF measurement with an integrated luminosity of 2.5 fb^{-1}, Ref. [32].

Phys.Rev.Lett.102:222003,2009 (CDF).

- (i) The chosen scales of renormalization (μ_R) and factorization (μ_F) for which the usual possible values could be taken between $m_t/2$ and $2m_t$. Here we adopted $\mu_R = \mu_F = m_t$.
- (ii) The $M_{t\bar{t}}$-dependent NLO effects which include the NLO parton distribution fuction (PDF). Here for simplicity we just use a $M_{t\bar{t}}$-independent scale factor value of K=1.36 (*i.e.*, the factor $\sqrt{K} = \sqrt{1.36}$ for the tree-level SM amplitude $A_{\rm SM}$) to fit the $t\bar{t}$ production cross section with LO calculations.

For detailed analysis, cosider Mtt-restricted FBA,

restricted by $M_{t\bar{t}} < M_{t\bar{t}}^{\rm edge}$ (the quantity $A_{\rm FB}^{t,{\rm low}}$) or by $M_{t\bar{t}} > M_{t\bar{t}}^{\rm edge}$ (the quantity $A_{\rm FB}^{t,{\rm high}}$)

$$A_{\rm FB}^{t,{\rm X}} = A_{\rm FB}^{\rm X}({\rm exp}) - A_{\rm FB}^{\rm X}({\rm SM}) \qquad ({\rm X} = {\rm low}, {\rm high})$$

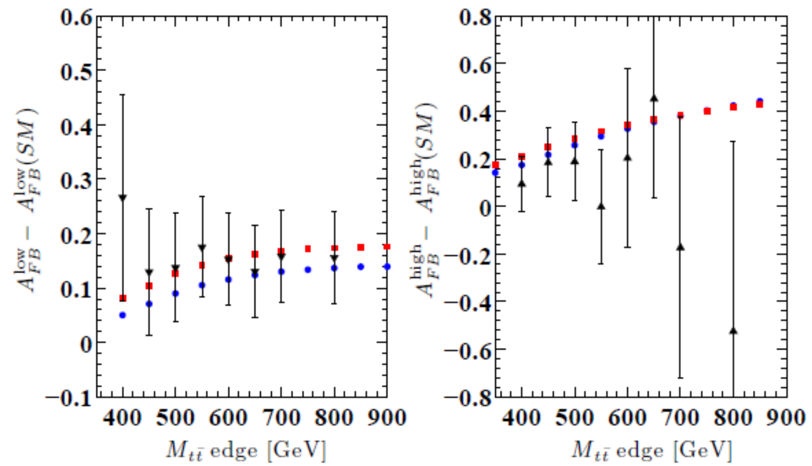


FIG. 5: Restricted forward-backward asymetries $A_{\rm FB}^{t,{\rm low}}$ and $A_{\rm FB}^{t,{\rm high}}$ as functions of the threshold ("edge") $M_{t\bar{t}}$ values, for $(\lambda, d_{\mathcal{U}}) = (2.05, 1.28)$ (circles) and $(1.70, 1.175)$ (squares). Included are also the corresponding CDF measured values [37] (their 8th and 9th figure) subtracted by the SM values [38], as bars with triangles.

This issue remains inconclusive because of: (i) the aforementioned very large experimental uncertainties of $A_{\rm FB}^{\rm high}$ at high $M_{t\bar{t}}^{\rm edge}$; (ii) the severely restricted phase space at high $M_{t\bar{t}}^{\rm edge}$. Namely, our simplified approach of rescaling the tree-level SM (QCD) amplitude by a fixed factor ($\sqrt{K} = \sqrt{1.36}$) for all $M_{t\bar{t}}$ values becomes increasingly unreliable when $M_{t\bar{t}}^{\rm edge}$ increases in $A_{\rm FB}^{t,{\rm high}}$, because the phase space becomes so severely restricted.

5. Summary

- An unexpected large FBA of top-quark is observed by D∅ and CDF: strongly indicate the new physics effects (NLO effects).
- Various possible solutions to the “anomaly” are proposed, like axigluon, KK excitations of gluon, Z’, W’, colored scalars, etc
- We investigated whether colored flavor-conserving unparticle can explain the measured FBA of ttbar production at Tevatron.
- With a natural assumption of quark flavor-blind and chirality-independent unparticle, UP contribution can explain the deviation.

Thank you for your attention