Light colored scalar as a messenger of flavor dynamics in Grand Unified Theories*

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*I.D., Svjetlana Fajfer, Jernej F. Kamenik, Nejc Košnik, *Phys. Rev.* **D** 82:094015, 2010, 1007.2604; *Phys. Rev.* **D** 81:055009, 2010, 0912.0972; *Phys. Lett.* **B** 682:67-73, 2009, 0906.5585.

OUTLINE

- •MOTIVATION
- •COLORED SCALAR – LEPTOQUARK – IN A CLASS OF GRAND UNIFIED THEORIES
  - •UP-QUARK SECTOR
  - •DOWN-QUARK AND CHARGERD LEPTON SECTOR
- •IMPLICATIONS FOR THE GRAND UNIFIED SCENARIOS
- •CONCLUSIONS

MOTIVATION

Leptoquarks[#] are inherent to any theory that treats quarks and leptons on the same footing.

•UNIFICATION THEORIES (PATI-SALAM[#], $\underline{SU(5)}$, $SO(10)$, $E_6 \ldots$)

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LEPTOQUARKS ≡ QUALITATIVELY NEW PHYSICS!

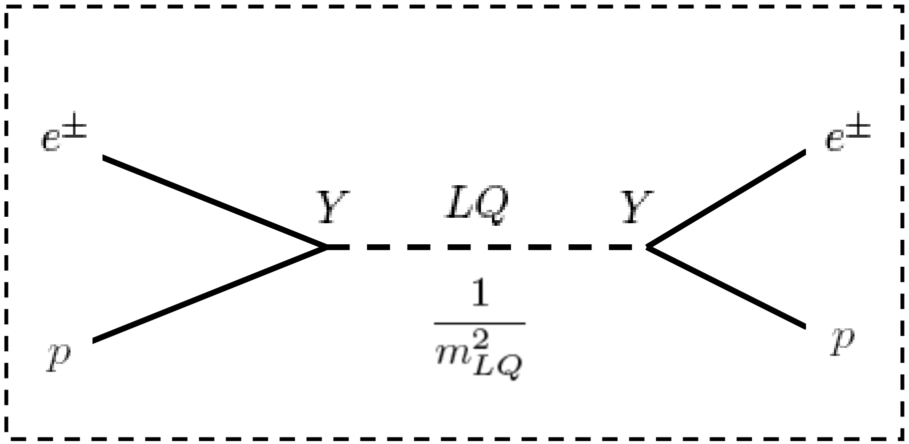
[#]J. C. Pati and A. Salam, *Phys. Rev.* D 10 275-289, 1974.

MOTIVATION

Leptoquarks (*LQ*) can be produced directly in colliders.

SINGLE PRODUCTION (ZEUS, HERA):

$$e^{\pm}p \to e^{\pm}p$$

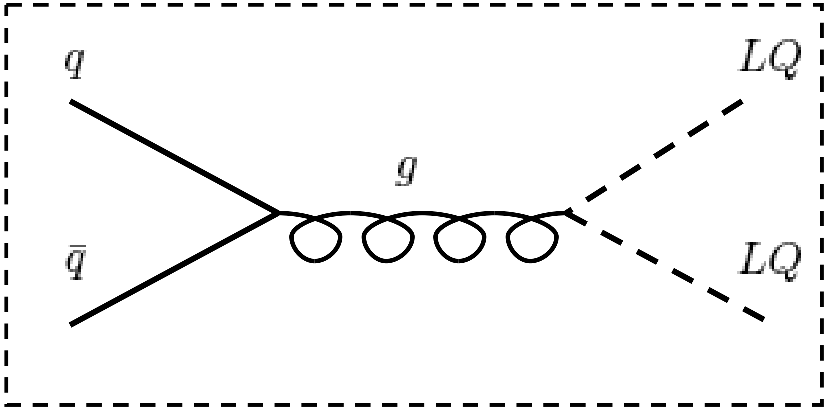


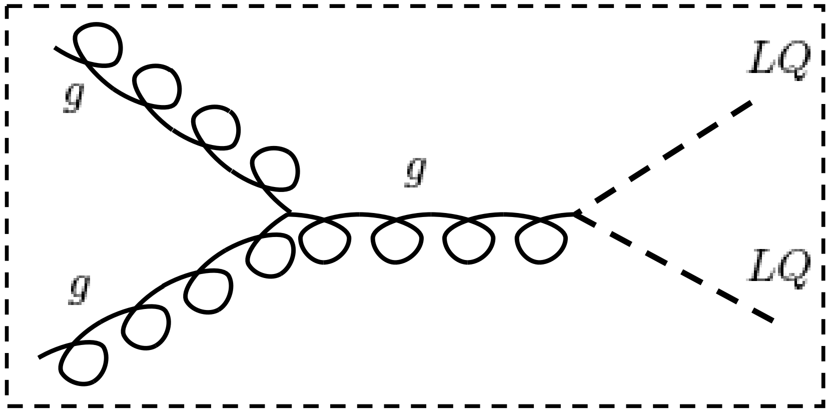
$Y \equiv$ Yukawa coupling(s)

$m_{LQ} \equiv$ Leptoquark mass

MOTIVATION

PAIR PRODUCTION AT HADRON COLLIDERS:





EXPERIMENTAL LIMITS:

	CDF[*]	DØ[‡]
1[st]	$m_{LQ} > 236\,\mathrm{GeV}$	$m_{LQ} > 292\,\mathrm{GeV}$
2[nd]	$m_{LQ} > 226\,\mathrm{GeV}$	$m_{LQ} > 316\,\mathrm{GeV}$

	CMS[#]
2[nd]	$m_{LQ} > 394\,\mathrm{GeV}$

[*]DØ Collaboration, D0 Conference Note 5644-CONF (2008).
[‡]CDF Collaboration, A. Abulencia et al., *Phys. Rev.* D 73 (2006) 051102.
[#]CMS-EXO-10-007, arXiv:1012.4033.

CASE STUDY: AN *SU*(5) SCENARIO[*]

FERMIONS OF THE STANDARD MODEL (SM≡ $SU(3)\times SU(2)\times U(1)$):

$L_a \equiv (\mathbf{1}, \mathbf{2}, -1/2)_a = (\nu_a \quad e_a)^T$	LEPTONS
$e^C_a \equiv (\mathbf{1}, \mathbf{1}, 1)_a$	

$Q_a \equiv (\mathbf{3}, \mathbf{2}, 1/6)_a = (u_a \quad d_a)^T$	
$u^C_a \equiv (\overline{\mathbf{3}}, 1, -2/3)_a$	QUARKS
$d^C_a \equiv (\overline{\mathbf{3}}, 1, 1/3)_a$	

$a = 1, 2, 3$
FAMILY INDEX

[*]H. Georgi and S.L. Glashow (1974).

CASE STUDY: AN *SU*(5) SCENARIO*

FERMIONS OF THE STANDARD MODEL:

LEPTONS

$L_a \equiv (\mathbf{1}, \mathbf{2}, -1/2)_a = (\nu_a \quad e_a)^T$

$e_a^C \equiv (\mathbf{1}, \mathbf{1}, 1)_a$

QUARKS

$Q_a \equiv (\mathbf{3}, \mathbf{2}, 1/6)_a = (u_a \quad d_a)^T$

$u_a^C \equiv (\overline{\mathbf{3}}, 1, -2/3)_a$

$d_a^C \equiv (\overline{\mathbf{3}}, 1, 1/3)_a$

$(\overline{\mathbf{5}}_\alpha)_a$ (L_a and d_a^C)

$a = 1, 2, 3$
FAMILY INDEX

*H. Georgi and S.L. Glashow (1974).

CASE STUDY: AN *SU*(5) SCENARIO*

FERMIONS OF THE STANDARD MODEL:

$$L_a \equiv (\mathbf{1}, \mathbf{2}, -1/2)_a = (\nu_a \quad e_a)^T$$

$$e_a^C \equiv (\mathbf{1}, \mathbf{1}, 1)_a$$

LEPTONS

$$(\mathbf{10}^{\alpha\beta})_a$$

$$Q_a \equiv (\mathbf{3}, \mathbf{2}, 1/6)_a = (u_a \quad d_a)^T$$

$$u_a^C \equiv (\overline{\mathbf{3}}, \mathbf{1}, -2/3)_a$$

QUARKS

$$(\overline{\mathbf{5}}_\alpha)_a$$

$$d_a^C \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)_a$$

$a = 1, 2, 3$
FAMILY INDEX

$\alpha, \beta = 1, 2, 3, 4, 5$
GROUP INDICES

*H. Georgi and S.L. Glashow (1974).

FERMION MASSES

(SCALAR REPRESENTATIONS IN $SU(5)$)

$$\mathbf{10} \times \overline{\mathbf{5}} = \mathbf{5} \oplus \mathbf{45} \ : \ M_E, M_D$$

$$\overline{\mathbf{5}} \times \overline{\mathbf{5}} = \overline{\mathbf{10}} \oplus \overline{\mathbf{15}} \ : \ M_N$$

$$\mathbf{10} \times \mathbf{10} = \overline{\mathbf{5}} \oplus \overline{\mathbf{45}} \oplus \overline{\mathbf{50}} \ : \ M_U$$

5 **10** **15** **45** **50**

FERMION MASSES

(SCALAR REPRESENTATIONS IN $SU(5)$)

$\mathbf{10}\times\overline{\mathbf{5}}=\mathbf{5}\oplus\mathbf{45}\ :\ M_E, M_D$	$\overline{\mathbf{5}}\times\overline{\mathbf{5}}=\overline{\mathbf{10}}\oplus\overline{\mathbf{15}}\ :\ M_N$	$\mathbf{10}\times\mathbf{10}=\overline{\mathbf{5}}\oplus\overline{\mathbf{45}}\oplus\overline{\mathbf{50}}\ :\ M_U$

5 ~~**10**~~ **15** **45** ~~**50**~~

FERMION MASSES

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$\mathbf{5}$ ~~$\mathbf{10}$~~ $\mathbf{15}$ $\mathbf{45}$ ~~$\mathbf{50}$~~

$\mathbf{5}$:

$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{5}^*$

$(\mathbf{10})_i(\mathbf{10})_j\mathbf{5}$

$\mathbf{15}$:

$(\overline{\mathbf{5}})_i(\overline{\mathbf{5}})_j\mathbf{15}$

$\mathbf{45}$:

$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{45}^*$

$(\mathbf{10})_i(\mathbf{10})_j\mathbf{45}$

$i, j = 1, 2, 3$
FAMILY INDEX

FERMION MASSES

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$\mathbf{10} \times \overline{\mathbf{5}} = \mathbf{5} \oplus \mathbf{45} \;:\; M_E, M_D$

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$\mathbf{10} \times \mathbf{10} = \overline{\mathbf{5}} \oplus \overline{\mathbf{45}} \oplus \overline{\mathbf{50}} \;:\; M_U$

$\mathbf{5}$ ~~$\mathbf{10}$~~ $\mathbf{15}$ $\mathbf{45}$ ~~$\mathbf{50}$~~

$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{5}^*$	$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{45}^*$	M_E, M_D
$(\overline{\mathbf{5}})_i(\overline{\mathbf{5}})_j\mathbf{15}$		M_N
$(\mathbf{10})_i(\mathbf{10})_j\mathbf{5}$	$(\mathbf{10})_i(\mathbf{10})_j\mathbf{45}$	M_U

$i = 1, 2, 3$
FAMILY INDEX

$\alpha, \beta = 1, 2, 3, 4, 5$
GROUP INDICES

FERMION MASSES

(SCALAR REPRESENTATIONS IN *SU*(5))

$\mathbf{10}\times\overline{\mathbf{5}}=\mathbf{5}\oplus\mathbf{45}\ :\ M_E, M_D$	$\overline{\mathbf{5}}\times\overline{\mathbf{5}}=\overline{\mathbf{10}}\oplus\overline{\mathbf{15}}\ :\ M_N$	$\mathbf{10}\times\mathbf{10}=\overline{\mathbf{5}}\oplus\overline{\mathbf{45}}\oplus\overline{\mathbf{50}}\ :\ M_U$

$\mathbf{5}$ $\qquad\qquad$ $\mathbf{45}$

$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{5}^*$	$(\mathbf{10})_i(\overline{\mathbf{5}})_j\mathbf{45}^*$	M_E, M_D
$(\overline{\mathbf{5}})_i(\overline{\mathbf{5}})_j\mathbf{15}$		
$(\mathbf{10})_i(\mathbf{10})_j\mathbf{5}$	$(\mathbf{10})_i(\mathbf{10})_j\mathbf{45}$	M_U

LEPTOQUARKS IN *SU*(5)

$$\mathbf{5} = (D, T)$$

$$D = (\mathbf{1}, \mathbf{2}, 1/2)$$

$$T = (\mathbf{3}, \mathbf{1}, -1/3)$$

$$\mathbf{45} = (\Delta_1, \Delta_2, \Delta_3, \Delta_4, \Delta_5, \Delta_6, \Delta_7)$$

$$\Delta_1 = (\mathbf{8}, \mathbf{2}, 1/2)$$

$$\Delta_2 = (\overline{\mathbf{6}}, \mathbf{1}, -1/3)$$

$$\Delta_3 = (\mathbf{3}, \mathbf{3}, -1/3)$$

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- - - ≡ Higgs doublet

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——— ≡ "genuine" leptoquark

LEPTOQUARKS IN *SU*(5)

(*p* DECAY MEDIATING LEPTOQUARK)

$$\mathbf{5} = (D, T)$$

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[dotted box] ≡ *p* decay mediating leptoquark

EXPERIMENTAL RESULTS

(PROTON DECAY)

PROCESS	τ_p (10^{33} years)	
$p \to \pi^0 e^+$	8.2	*
$p \to \pi^0 \mu^+$	6.6	
$p \to K^+ \bar{\nu}$	2.3	@
$p \to K^0 e^+$	1.0	
$p \to K^0 \mu^+$	1.3	
$p \to \eta e^+$	0.313	
$p \to \eta \mu^+$	0.126	
$p \to \pi^+ \bar{\nu}$	0.025	
$\vdots$	$\vdots$	
$p \to \pi^0 e^+$	10.1	¶

*[Super-Kamiokande Collaboration], arXiv:0903.0676.

@[Super-Kamiokande Collaboration], arXiv:hep-ex/0502026.

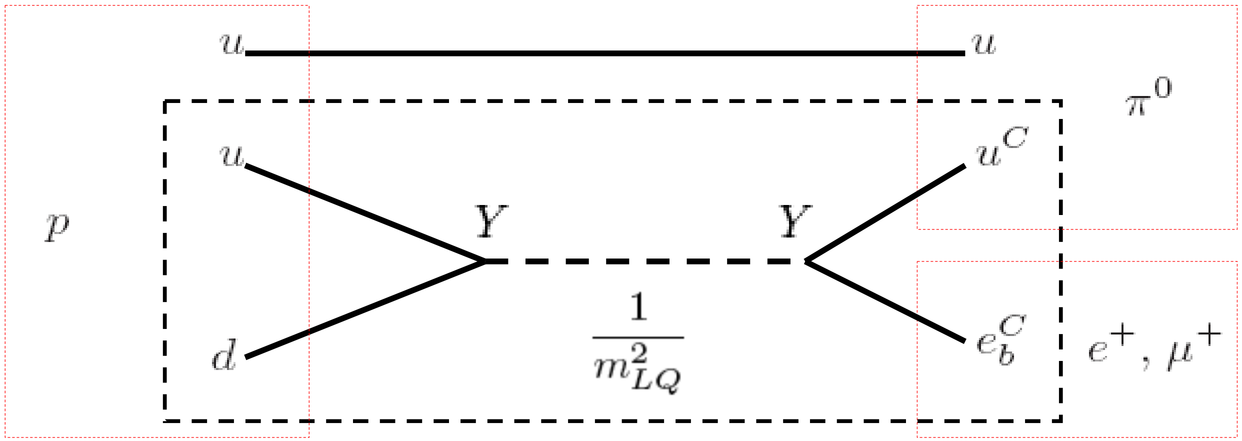
¶ www-sk.icrr.u-tokyo.ac.jp/whatsnew/new-20091125-e.html

d=6 PROTON DECAY OPERATORS

(SCALAR CONTRIBUTIONS*)

PROTON DECAY MEDIATING LEPTOQUARKS SHOULD BE VERY HEAVY!

$$\Gamma_6 \sim \frac{Y^4}{m_{LQ}^4} m_p^5 \quad \Rightarrow \quad m_{LQ} > 10^{12}\,\mathrm{GeV}$$



Y ≡ Yukawa coupling(s) m_{LQ} ≡ Leptoquark mass

*S. Weinberg, *Phys. Rev.* D 22:1694, 1980.

LEPTOQUARKS IN *SU*(5)

(*p* DECAY MEDIATING LEPTOQUARK)

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Δ_6 LEPTOQUARK

SYMMETRY PROPERTIES OF THE COUPLINGS OF Δ_6 TO THE UP-QUARK SECTOR ARE FIXED BY GROUP THEORY!

$$\frac{g_6^{ij}}{2} \epsilon_{abc} u_{i\,a}^{C\,T} C u_{b\,j}^{C} \Delta_{6\,c}$$

$$Y_1^{ij} e_i^{C\,T} C d_{a\,j}^{C} \Delta_{6\,a}^{*}$$

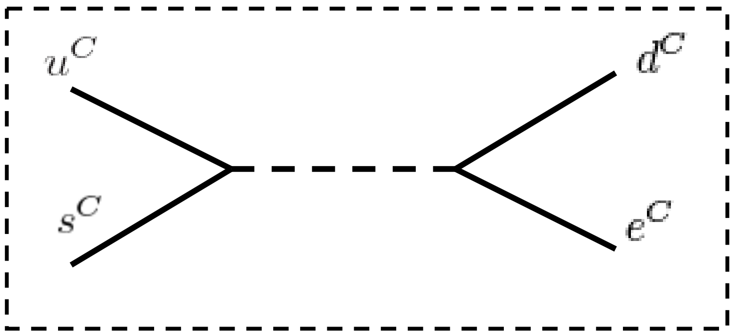
Δ_6 **LEPTOQUARK**

SYMMETRY PROPERTIES OF THE COUPLINGS OF Δ_6 TO THE UP-QUARK SECTOR ARE FIXED BY GROUP THEORY!

$$\frac{g_6^{ij}}{2}\epsilon_{abc}u_{i\,a}^{C\,T}Cu_{b\,j}^{C}\Delta_{6\,c}$$

$$Y_1^{ij}e_i^{C\,T}Cd_{a\,j}^{C}\Delta_{6\,a}^{*}$$

$$g_6^{ij}=-g_6^{ji}$$



WHAT IF Δ_6 IS LIGHT?

Δ_6 LEPTOQUARK

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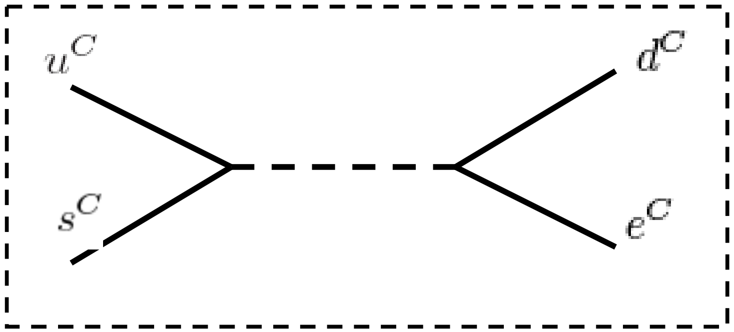
$$\frac{g_6^{ij}}{2}\epsilon_{abc}u_{i\,a}^{C\,T}Cu_{b\,j}^{C}\Delta_{6\,c}$$

$$Y_1^{ij}e_i^{C\,T}Cd_{a\,j}^{C}\Delta_{6\,a}^{*}$$

$$g_6^{ij} = -g_6^{ji}$$

$SU(5)$	$SO(10)$
45	**120**
45	**126**



WHAT IF Δ_6 IS LIGHT?

Δ_6 LEPTOQUARK: UP-QUARK SECTOR

CONSTRAINTS ON g_6^{ij} ORIGINATE FROM
THE UP-QUARK PHENOMENOLOGY!

$m_{\Delta_6} = 400\,\mathrm{GeV}$

$|g_6^{13}| = 1.9$ → $t\,\bar{t}$ FORWARD-BACKWARD (FB) ASYMMETRY AT TEVATRON

$|g_6^{23}| \leq 0.0033$ → $D^0 - \bar{D}^0$ MIXING CONSTRAINTS

$|g_6^{12}| \leq 0.042$ → SINGLE t PRODUCTION CROSS-SECTION AT TEVATRON

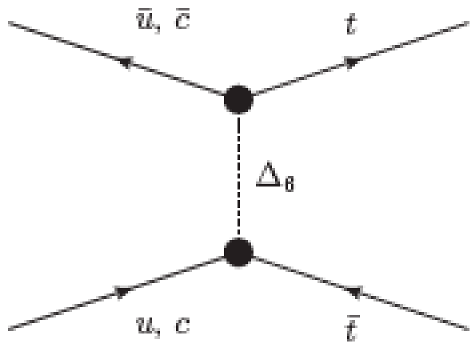
FORWARD-BACKWARD ASYMMETRY

SIMULTANEOUS FIT TO THE INTEGRATED CROSS SECTION $\sigma^{\exp}$ AND A_{FB}

$$A_{FB}^{\exp} - A_{FB}^{SM} = (14.2 \pm 6.9)\%$$

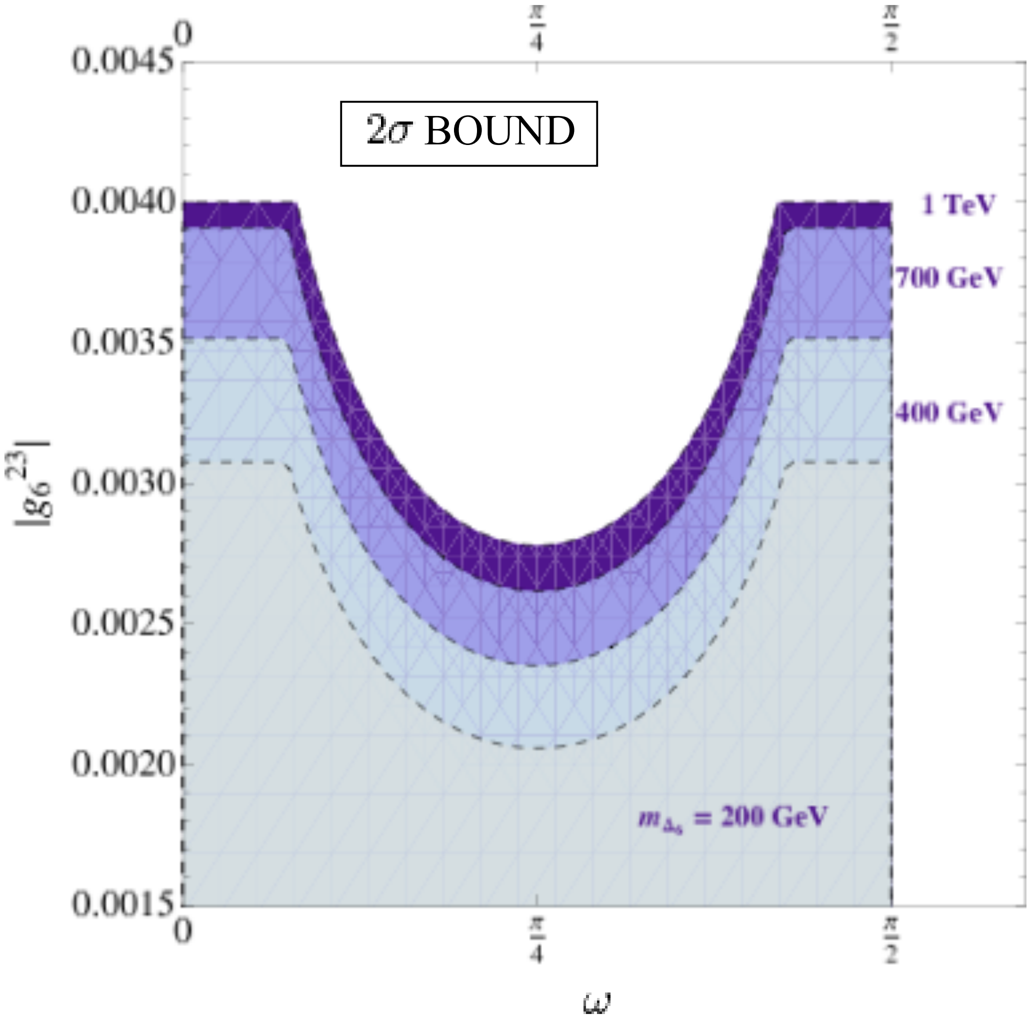
$$\sigma^{\exp} = 7.0 \pm 0.6\,\mathrm{pb}$$

$$|g_6^{13}| = 0.9(2) + 2.5(4)\frac{m_{\Delta_6}}{1\,\mathrm{TeV}}$$



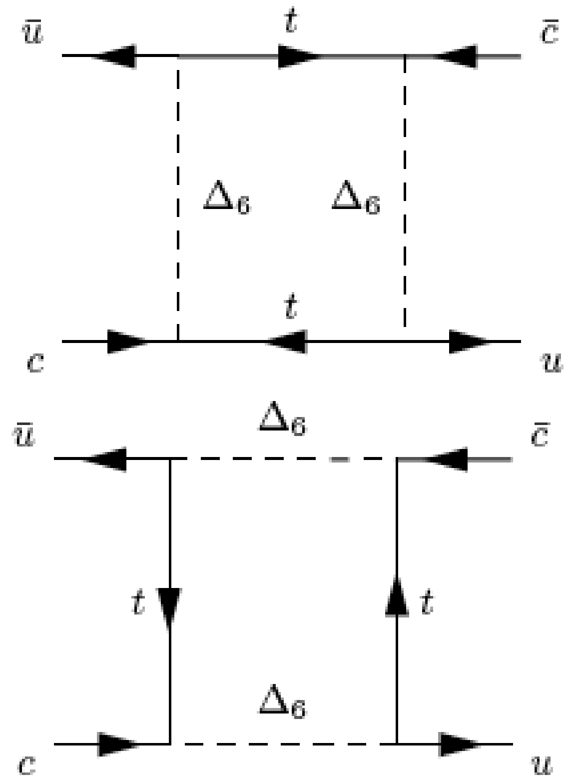
LEADING CONTRIBUTIONS TO $t\,\bar{t}$ PRODUCTION CROSS SECTION AND A_{FB} AT TEVATRON.

$D^0 - \bar{D}^0$ MIXING CONSTRAINTS



$\omega \equiv$ RELATIVE PHASE BETWEEN g_6^{13} AND g_6^{23}

$(g_6^{13} g_6^{23*})^2$ CONTRIBUTIONS TO $|\Delta C| = 2$:



$m_{\Delta_6} = 400\,\mathrm{GeV}$

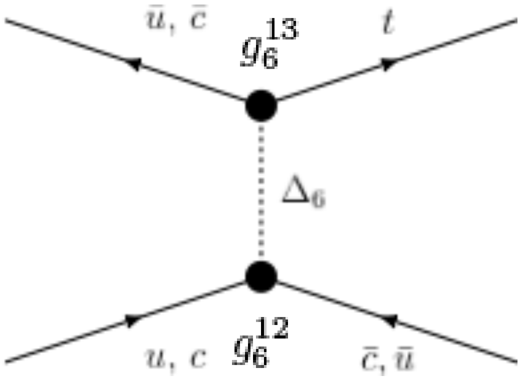
$|g_6^{23}| \leq 0.0033$

SINGLE t PRODUCTION CROSS-SECTION

THE SINGLE t PRODUCTION IS SENSITIVE TO THE PRODUCT $|g_6^{12} g_6^{13*}|$.

TEVATRON RESULT: $\sigma_{1t} = 2.76^{+0.58}_{-0.47}\,\text{pb}$

WE REQUIRE: $\sigma_{1t}^{\Delta_6} \leq 1\,\text{pb}$



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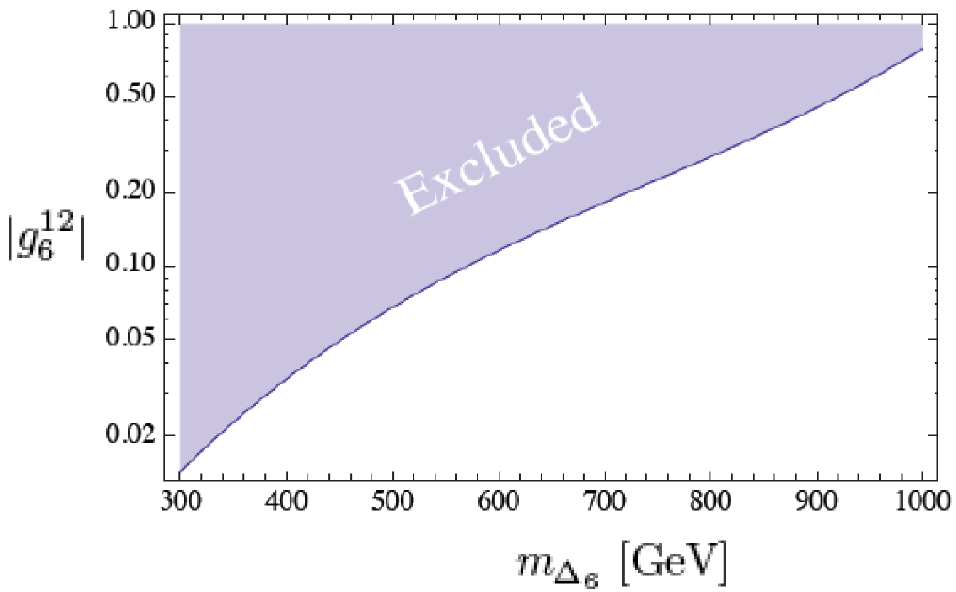


Δ_6 LEPTOQUARK*

$$\frac{g_6^{ij}}{2}\epsilon_{abc}u_{i\,a}^{C\,T}Cu_{b\,j}^{C}\Delta_{6\,c}$$

$$Y_1^{ij}e_i^{C\,T}Cd_{a\,j}^{C}\Delta_{6\,a}^{*}$$

*I.D., Jure Drobnak, Svjetlana Fajfer, Jernej F. Kamenik, Nejc Košnik, work in progress.

Δ_6 LEPTOQUARK: DOWN-QUARK SECTOR

CONSTRAINTS ON Y_1^{ij} ORIGINATE FROM THE PHENOMENOLOGY INVOLVING DOWN-QUARK AND CHARGED LEPTON SECTORS!

Y_1^{ij}

$$\sum_{i=d,s,b} |Y_1^{\mu i}|^2 = (6.45 \pm 2.09) \times \frac{m_{\Delta_6}^2}{(400 \text{ GeV})^2}$$

a_μ^{exp} vs. a_μ^{SM}

$$|Y_1^{ed} Y_1^{\mu d *}|^2 < 1.9(20) \times 10^{-13} \frac{m_{\Delta_6}^4}{(400 \text{ GeV})^4} \quad \text{from Au(Ti)}$$

$\mu - e$ CONVERSION

Δ_6 LEPTOQUARK: DOWN-QUARK SECTOR

CONSTRAINTS ON Y_1^{ij} ORIGINATE FROM THE PHENOMENOLOGY INVOLVING DOWN-QUARK AND CHARGED LEPTON SECTORS!

Y_1^{ij}

$$\begin{pmatrix} Y_1^{ed} & & \\ Y_1^{\mu d} & Y_1^{\mu s} & Y_1^{\mu b} \\ & & \end{pmatrix}$$

$$\sum_{i=d,s,b} |Y_1^{\mu i}|^2 = (6.45 \pm 2.09) \times \frac{m^2_{\Delta_6}}{(400\ \text{GeV})^2}$$

a_μ^{exp} vs. a_μ^{SM}

$$|Y_1^{ed} Y_1^{\mu d *}|^2 < 1.9(20) \times 10^{-13} \frac{m^4_{\Delta_6}}{(400\ \text{GeV})^4} \quad \text{from Au(Ti)}$$

$\mu - e$ CONVERSION

THE DOWN-QUARK SECTOR

decay mode	1.64σ experimental upper bound on $\mathcal{B}$	1σ upper bound in units $(m_{\Delta_6}/400\text{ GeV})^4$
$B_d \to e^- e^+$	8.3×10^{-8}	$\left\lvert Y_1^{eb} Y_1^{ed*} \right\rvert^2 < 4.4$
$B_d \to \mu^- \mu^+$	1.5×10^{-8}	$\left\lvert Y_1^{\mu b} Y_1^{\mu d*} \right\rvert^2 < 1.8 \times 10^{-5}$
$B_d \to \tau^- \tau^+$	4.1×10^{-3}	$\left\lvert Y_1^{\tau b} Y_1^{\tau d*} \right\rvert^2 < 1.3 \times 10^{-2}$
$B_s \to e^- e^+$	2.8×10^{-7}	$\left\lvert Y_1^{eb} Y_1^{es*} \right\rvert^2 < 10.1$
$B_s \to \mu^- \mu^+$	4.7×10^{-8}	$\left\lvert Y_1^{\mu b} Y_1^{\mu s*} \right\rvert^2 < 4.0 \times 10^{-5}$
$B_d \to e^\mp \mu^\pm$	6.4×10^{-8}	$\left\lvert Y_1^{eb} Y_1^{\mu d*} \right\rvert^2 + \left\lvert Y_1^{\mu b} Y_1^{ed*} \right\rvert^2 < 1.6 \times 10^{-4}$
$B_d \to \mu^\mp \tau^\pm$	2.2×10^{-5}	$\left\lvert Y_1^{\mu b} Y_1^{\tau d*} \right\rvert^2 + \left\lvert Y_1^{\tau b} Y_1^{\mu d*} \right\rvert^2 < 2.2 \times 10^{-4}$
$B_d \to \tau^\mp e^\pm$	2.8×10^{-5}	$\left\lvert Y_1^{\tau b} Y_1^{ed*} \right\rvert^2 + \left\lvert Y_1^{eb} Y_1^{\tau d*} \right\rvert^2 < 2.7 \times 10^{-4}$
$B_s \to e^\mp \mu^\pm$	2.0×10^{-7}	$\left\lvert Y_1^{eb} Y_1^{\mu s*} \right\rvert^2 + \left\lvert Y_1^{\mu b} Y_1^{es*} \right\rvert^2 < 3.4 \times 10^{-4}$

decay mode	90 % CL experimental upper bound on $\mathcal{B}$	1σ upper bound in units $(m_{\Delta_6}/400\text{ GeV})^4$
$\tau \to e\pi^0$	8.0×10^{-8}	$\left\lvert Y_1^{ed} Y_1^{\tau d*} \right\rvert^2 < 1.9 \times 10^{-4}$
$\tau \to \mu\pi^0$	1.1×10^{-7}	$\left\lvert Y_1^{\mu d} Y_1^{\tau d*} \right\rvert^2 < 2.7 \times 10^{-4}$
$\tau \to eK_S$	3.3×10^{-8}	$\left\lvert Y_1^{ed} Y_1^{\tau s*} - Y_1^{es} Y_1^{\tau d*} \right\rvert^2 < 9.3 \times 10^{-5}$
$\tau \to \mu K_S$	4.0×10^{-8}	$\left\lvert Y_1^{\mu d} Y_1^{\tau s*} - Y_1^{\mu s} Y_1^{\tau d*} \right\rvert^2 < 1.1 \times 10^{-4}$

THE DOWN-QUARK SECTOR

decay mode	90 % CL experimental upper bound on $\mathcal{B}$	1σ upper bound in units $(m_{\Delta_6}/400\text{ GeV})^4$
$\mu \to e\gamma$	1.2×10^{-11}	$\left\lvert\sum_{i=d,s,b} Y_1^{ei} Y_1^{\mu i*}\right\rvert^2 < 3.8 \times 10^{-7}$
$\tau \to \mu\gamma$	4.4×10^{-8}	$\left\lvert\sum_{i=d,s,b} Y_1^{\mu i} Y_1^{\tau i*}\right\rvert^2 < 4.8 \times 10^{-3}$
$\tau \to e\gamma$	3.3×10^{-8}	$\left\lvert\sum_{i=d,s,b} Y_1^{ei} Y_1^{\tau i*}\right\rvert^2 < 3.6 \times 10^{-3}$

$$\sum_{i=d,s,b} |Y_1^{ei}|^2 < 54 \times \frac{m_{\Delta_6}^2}{(400\text{ GeV})^2}$$

a_e

$$\Re\left[\sum_{\ell} Y_1^{\ell d} Y_1^{\ell s*}\right]^2 < 1.1 \times 10^{-4}\left(\frac{m_{\Delta_6}}{400\text{ GeV}}\right)^2$$

Δm_K

BACK TO GRAND UNIFIED THEORIES

THE UP-QUARK SECTOR

$\mathbf{5}$ | $\mathbf{45}$

$(Y_2')_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{5}$ | $(Y_2)_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{45}$

$$M_U = \left[4(Y_2'^T + Y_2')v_5 - 8(Y_2^T - Y_2)v_{45}\right]/\sqrt{2}$$

VACUUM EXPECTATION VALUES:

$$\langle \mathbf{5} \rangle^5 = \sqrt{2} v_5$$

$$\langle \mathbf{45} \rangle_1^{51} = \langle \mathbf{45} \rangle_2^{52} = \langle \mathbf{45} \rangle_3^{53} = \sqrt{2} v_{45}$$

$\Rightarrow$

$$2|v_5|^2 + 48|v_{45}|^2 = v^2$$

$$v = 246\,\mathrm{GeV}$$

THE UP-QUARK SECTOR

$$4S' = U^\dagger M_U^{diag} + M_U^{diag} U^*$$

$$4A' = U^\dagger M_U^{diag} - M_U^{diag} U^*$$

$$S' (= \sqrt{2} U_R^\dagger (Y_2'^T + Y_2') U_R^* v_5)$$

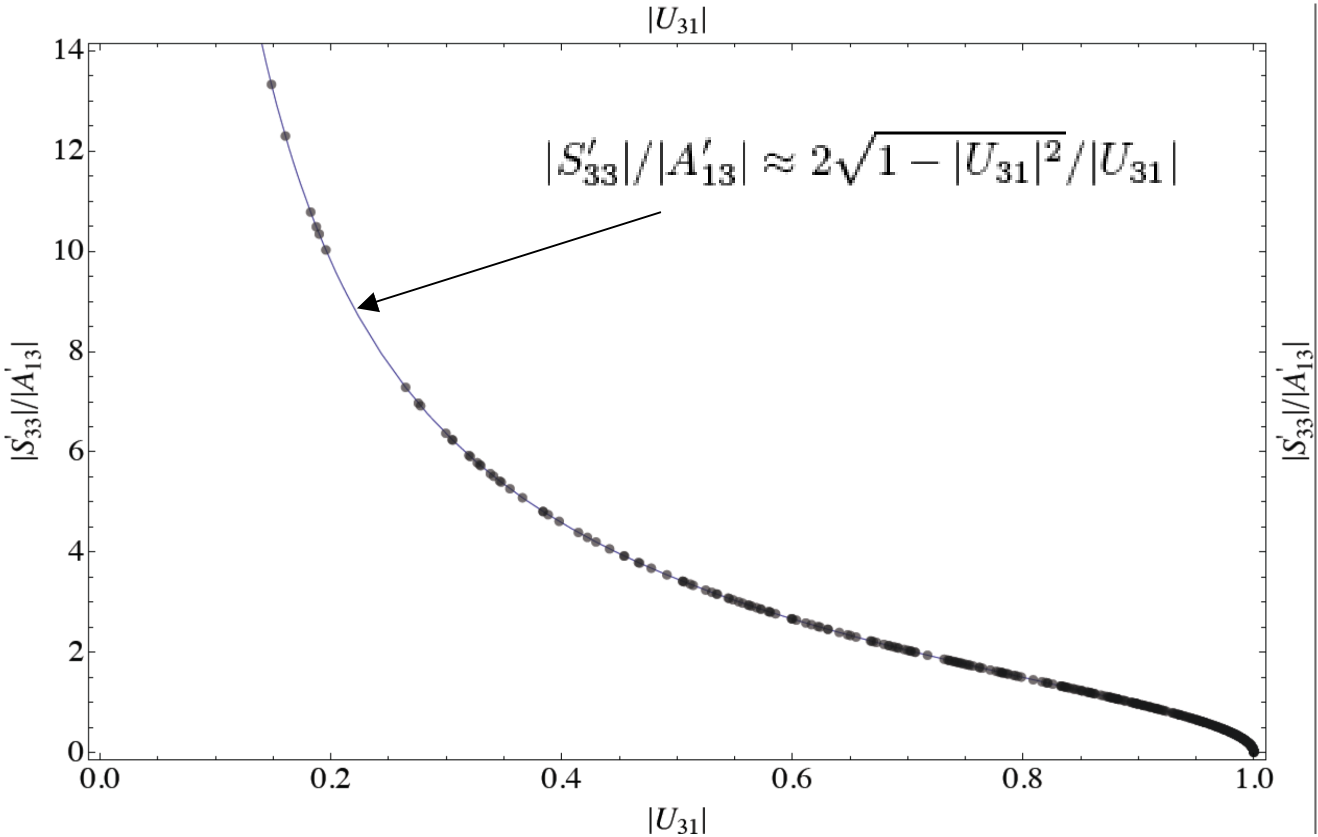
UNIFICATION SCALE RELATION:

$$\boxed{A' = g_6 v_{45}}$$

$$U = \tilde{V}_{CKM} U_R$$

$$|S'_{13}| = |A'_{13}| \qquad |S'_{33}|/|A'_{13}| \approx 2\sqrt{1 - |U_{31}|^2}/|U_{31}|$$

THE UP-QUARK SECTOR



$$|U_{31}| = \frac{4|g_6^{13}|v_{45}}{m_t}$$

EVERY ENTRY OF THE UP-QUARK MASS MATRIX CAN BE DESCRIBED IN TERMS OF ONE PARAMETER $|U_{31}|$.

$|U_{31}|$ OR v_{45} CAN BE CONSTRAINED BY THE DOWN-QUARK AND CHARGED LEPTON SECTOR!

THE DOWN-QUARK SECTOR

$\mathbf{5}$	$\mathbf{45}$
$(Y_1)_{ij}\mathbf{10}_i\bar{\mathbf{5}}_j\mathbf{45}^*$	$(Y_3)_{ij}\mathbf{10}_i\overline{\mathbf{5}}_j\mathbf{5}^*$

$$M_D \;=\; -Y_1 v_{45}^* - \frac{1}{2} Y_3 v_5^*$$

$$M_E \;=\; 3Y_1^T v_{45}^* - \frac{1}{2} Y_3^T v_5^*$$

VACUUM EXPECTATION VALUES:

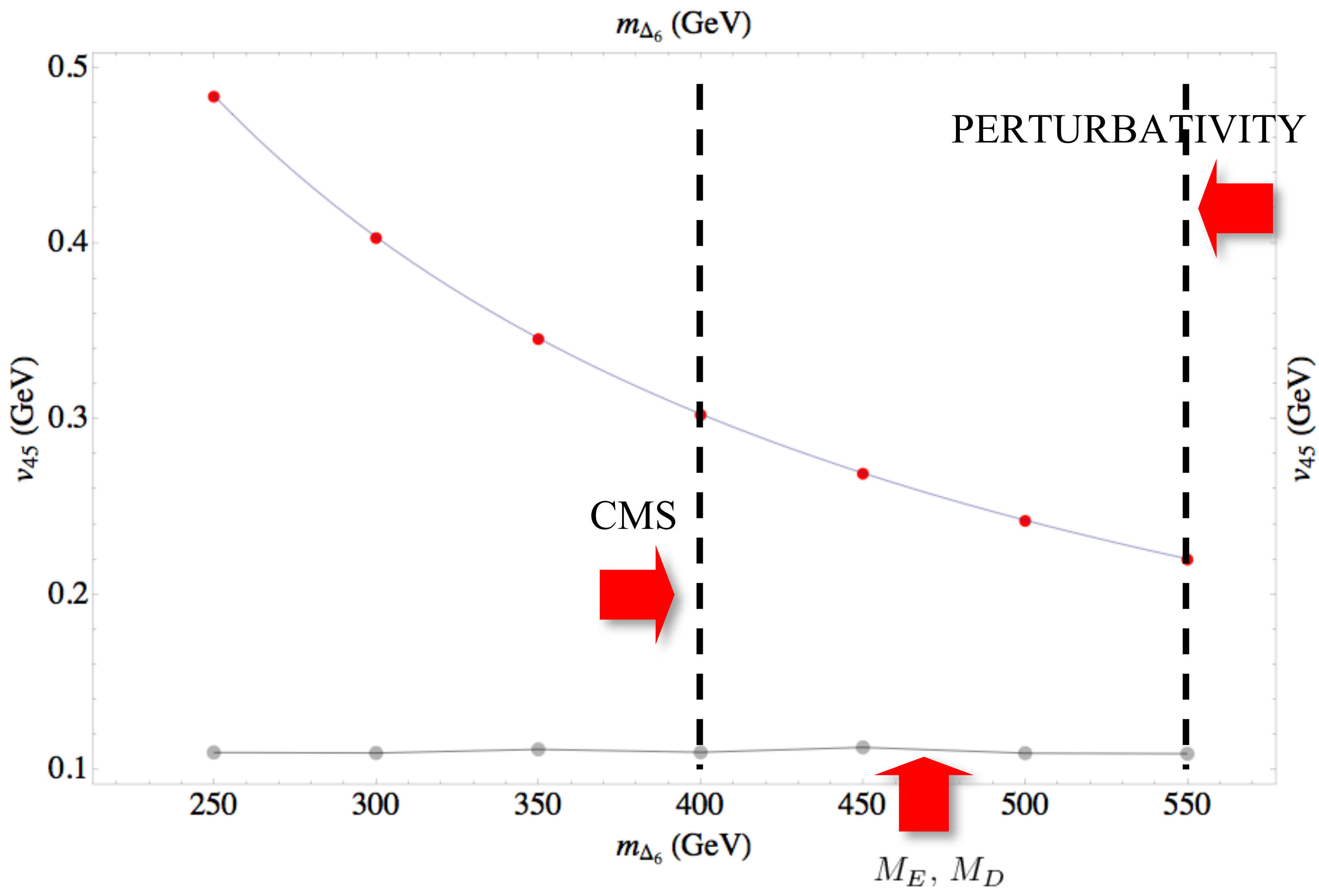
$$\langle \mathbf{5}^5 \rangle = v_5/\sqrt{2}$$

$$\langle \mathbf{45}_1^{15} \rangle = \langle \mathbf{45}_2^{25} \rangle = \langle \mathbf{45}_3^{35} \rangle = v_{45}/\sqrt{2}$$

$$|v_5|^2/2 + 12|v_{45}|^2 = v^2$$

$$v = 246\,\mathrm{GeV}$$

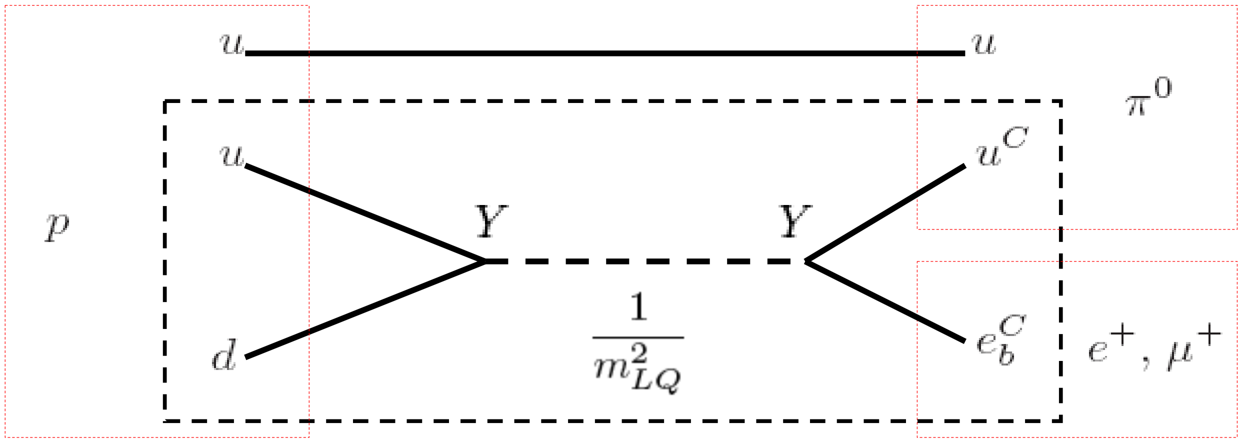
THE DOWN-QUARK SECTOR



d=6 PROTON DECAY OPERATORS

(SCALAR CONTRIBUTIONS*)

PROTON DECAY SIGNATURES CAN BE CALCULATED !



$Y \equiv$ Yukawa coupling(s) $m_{LQ} \equiv$ Leptoquark mass

*S. Weinberg, *Phys. Rev.* D 22:1694, 1980.

CONCLUSIONS

Colored scalars – leptoquarks – appear naturally in theories of (grand) unification.

Genuine leptoquarks, at first sight, look more phenomenologically viable as candidates for New Physics. But…

The Δ_6 scenario offers a possibility to explain FB asymmetry in top pair production at Tevatron, without spoiling the SM prediction for the cross section.

CONCLUSIONS

The Δ_6 scenario offers a possibility to saturate the value of a_μ while being in agreement with all other low-energy constraints.

Δ_6 can help us decipher a pattern of the up-quark, down-quark and charged lepton Yukawa mass matrix if its origin is traced back to the grand unified scenario.

THANK YOU!

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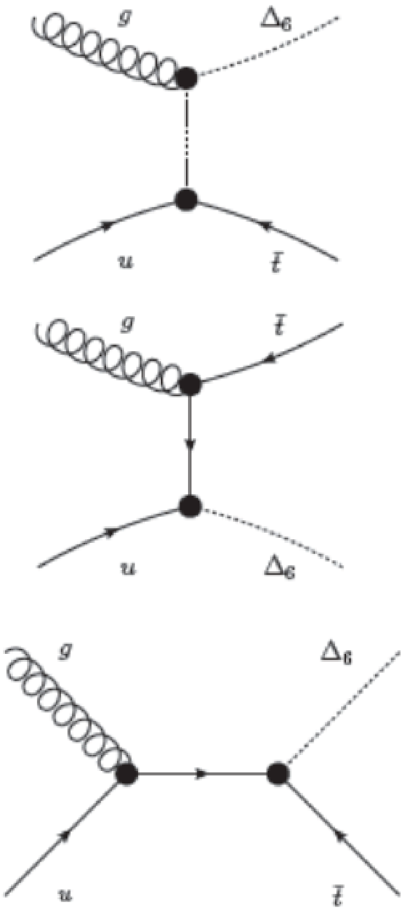
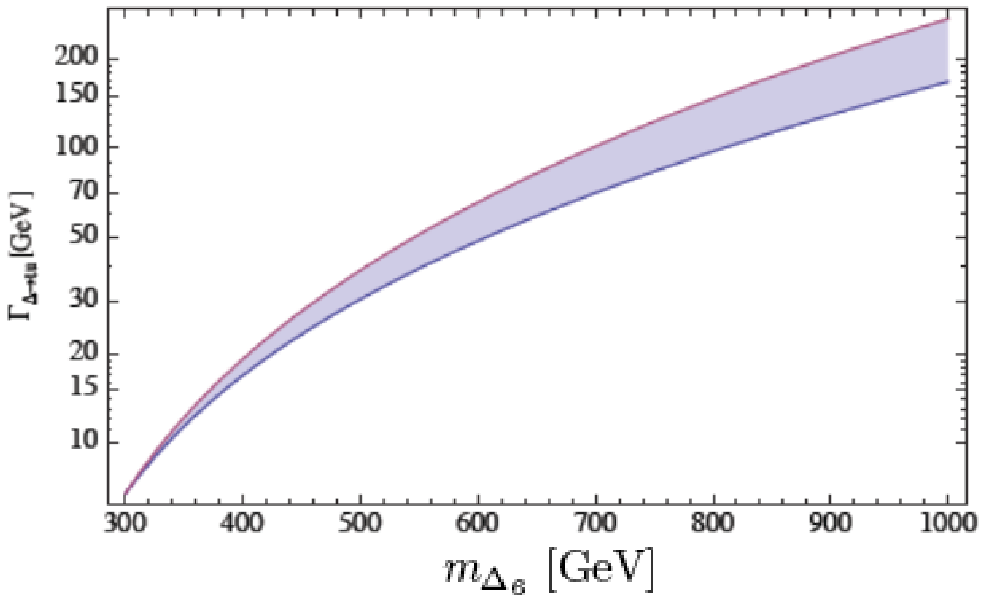
CONCLUSIONS

The best strategy for the experimental search for the Δ_6 state would be to study the spectrum of the $t\bar{t}$ + jet production and search for resonances in the invariant mass of the light jet together with t or t.

SEARCH STRATEGIES AT HADRON COLLIDERS



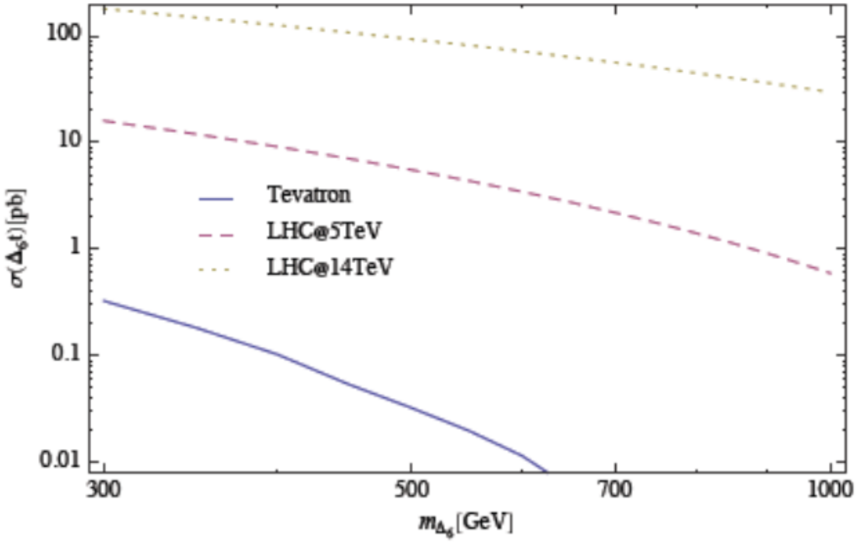


DEPENDENCE OF THE DECAY WIDTH ON Δ_6 MASS

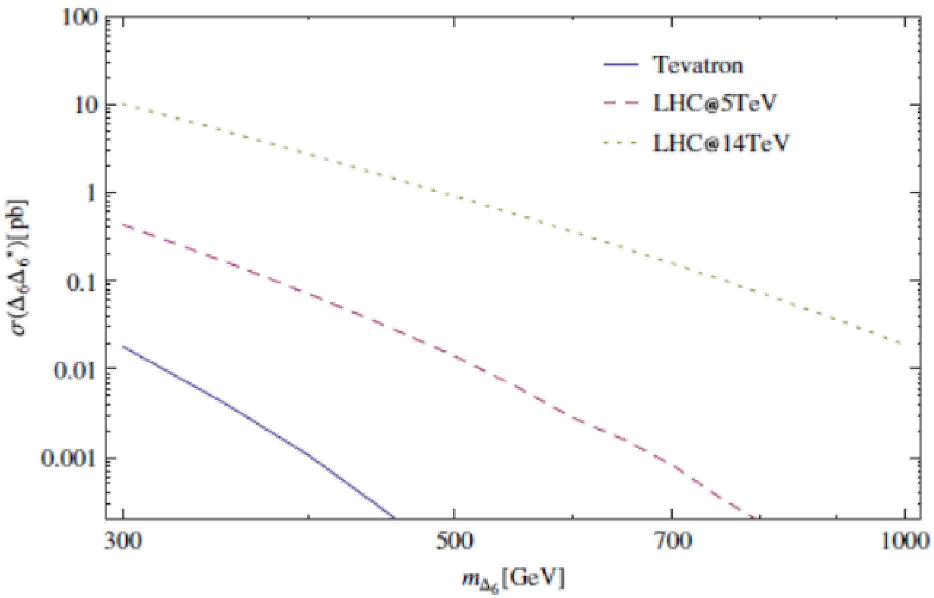
$$\sigma^{\Delta_6}_{t\bar{t}+j} \approx (\sigma_{t\Delta_6^*} + \sigma_{\bar{t}\Delta_6}) \times Br(\Delta_6 \to tu)$$

$$\Gamma(\Delta_6 \to tu) = \frac{|g_6^{13}|^2 (m^2_{\Delta_6} - m_t^2)^2}{16\pi m_t^3}$$

Δ_6 PRODUCTION

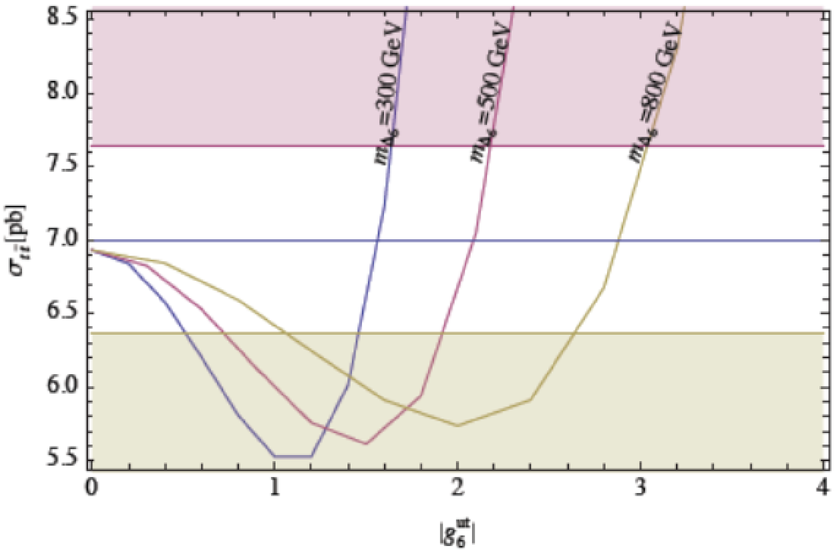


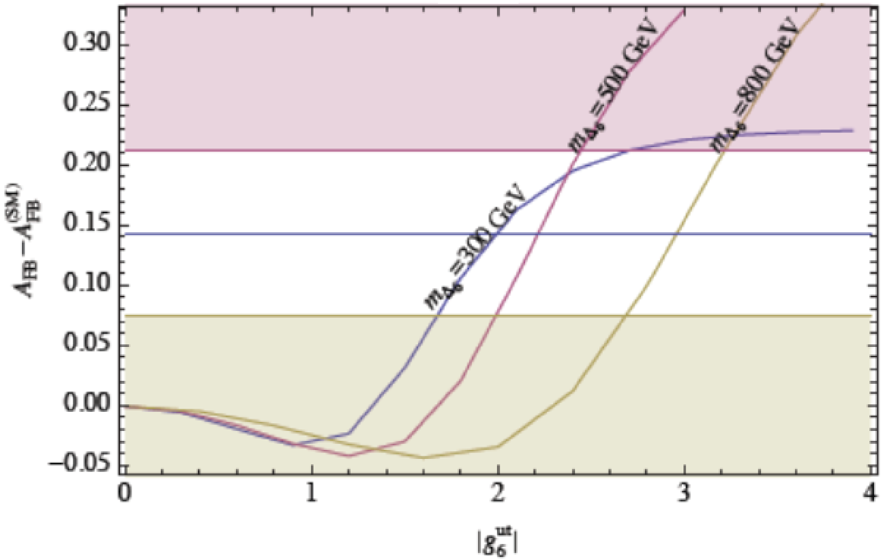
HADRONIC PRODUCTION AT LHC AND TEVATRON



Δ_6 WOULD APPEAR AS A RESONANCE IN THE INVARIANT MASS OF A TOP AND ONE HARD JET.

FORWARD-BACKWARD ASYMMETRY



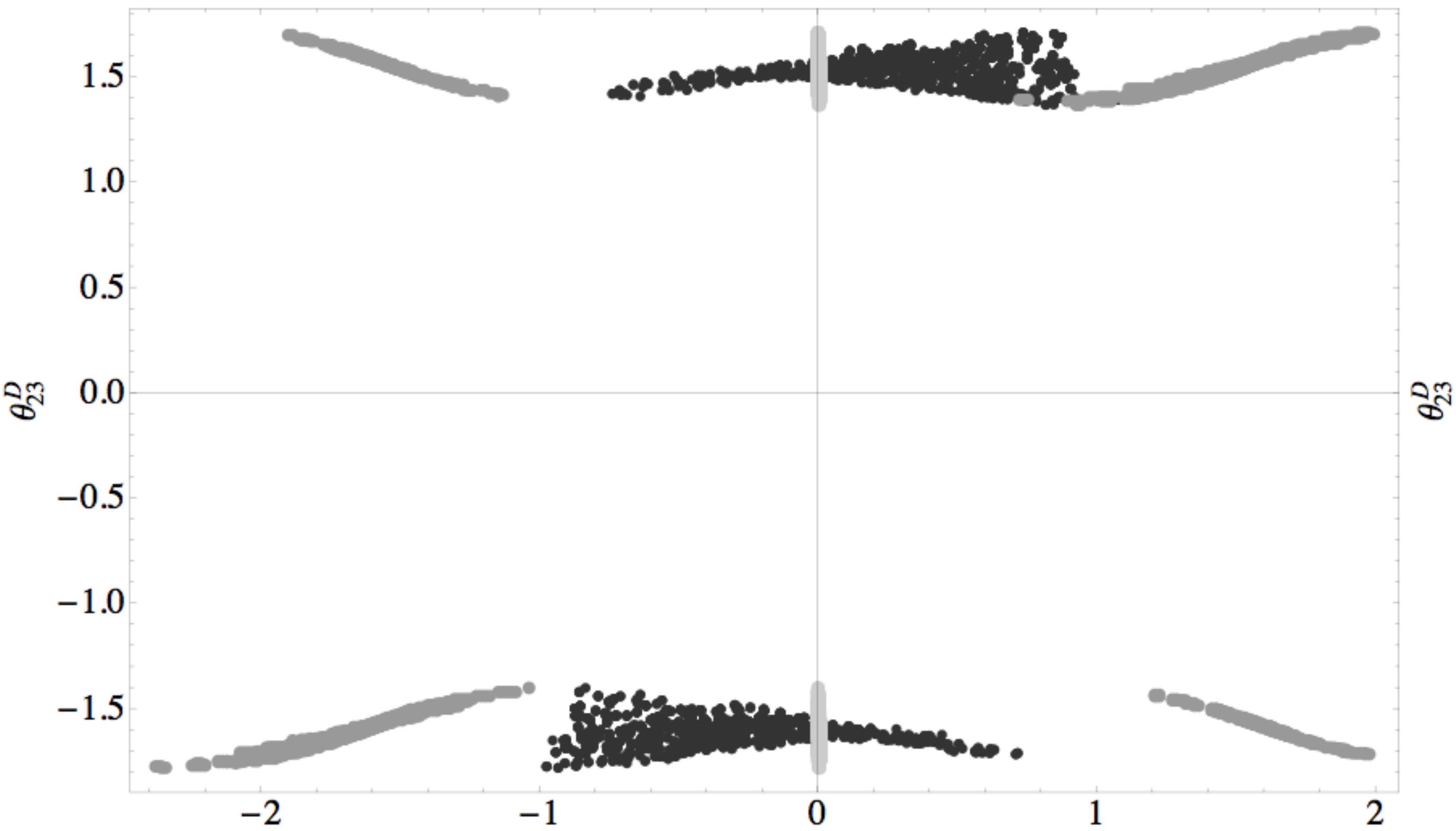


Examples of the $t\bar{t}$ hadronic cross-section and the forward-backward asymmetry at Tevatron including Δ_6. The shaded regions are outside one sigma experimental bound. Our study implies:

$$m_{\Delta_6} \geq 300\,\text{GeV}$$

$$|g_6^{13}| = 0.9(2) + 2.5(4)\frac{m_{\Delta_6}}{1\,\text{TeV}}$$

THE DOWN-QUARK SECTOR



LEPTOQUARKS IN *SU*(5)

(*p* DECAY MEDIATING LEPTOQUARK)

$\mathbf{5} = (D, T)$

$D = (\mathbf{1}, \mathbf{2}, 1/2)$

$T = (\mathbf{3}, \mathbf{1}, -1/3)$

$\mathbf{45} = (\Delta_1, \Delta_2, \Delta_3, \Delta_4, \Delta_5, \Delta_6, \Delta_7)$

$\Delta_1 = (\mathbf{8}, \mathbf{2}, 1/2)$

$\Delta_2 = (\overline{\mathbf{6}}, \mathbf{1}, -1/3)$

$\Delta_3 = (\mathbf{3}, \mathbf{3}, -1/3)$

$\Delta_4 = (\overline{\mathbf{3}}, \mathbf{2}, -7/6)$

$\Delta_5 = (\mathbf{3}, \mathbf{1}, -1/3)$

$\Delta_6 = (\overline{\mathbf{3}}, \mathbf{1}, 4/3)$

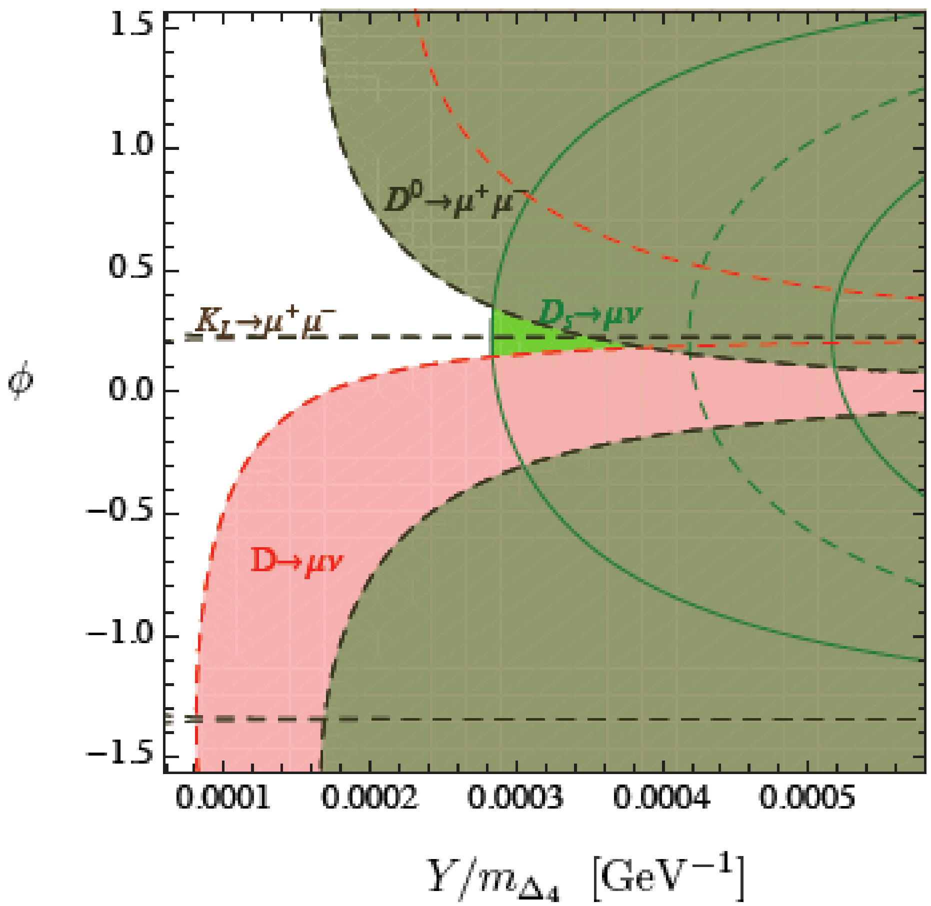
$\Delta_7 = (\mathbf{1}, \mathbf{2}, 1/2)$

- - - ≡ Higgs doublet

——— ≡ "genuine" leptoquark

[dotted box] ≡ *p* decay mediating leptoquark

Δ_4 GENUINE LEPTOQUARK*



STUDY# MOTIVATED BY DISCREPANCIES BETWEEN THE EXPERIMENTAL MEASUREMENTS OF LEPTONIC DECAY MODES OF D_s MESONS AND THE LATTICE RESULTS FOR THE RELEVANT f_{Ds} DECAY CONSTANT.

#B. A. Dobrescu and A. S. Kronfeld, Phys. Rev. Lett. 100, 241802 (2008), 0803.0512.

*I.D., Svjetlana Fajfer, Jernej F. Kamenik, Nejc Košnik, *Phys. Lett.* B 682:67-73, 2009, 0906.5585.
Belle Collaboration (M. Petric et al.), Phys. Rev. D 81:091102, 2010, 1003.2345.