# Top Quark Forward-backward Asymmetry From Family Symmetry

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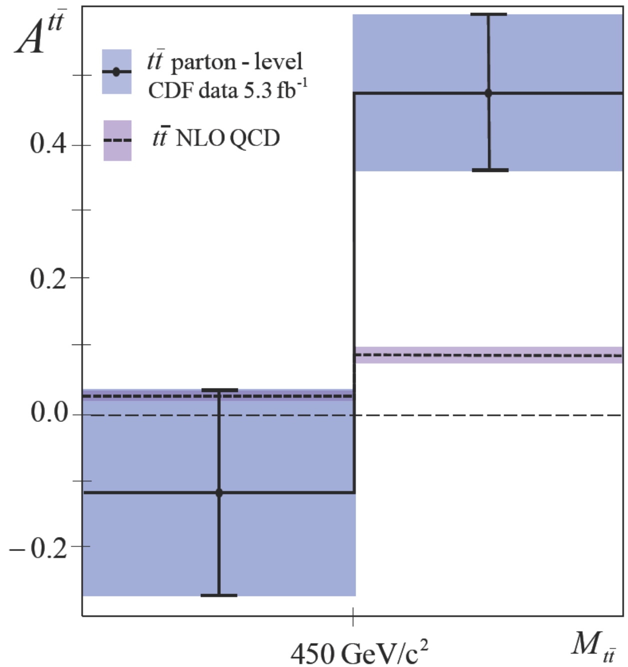
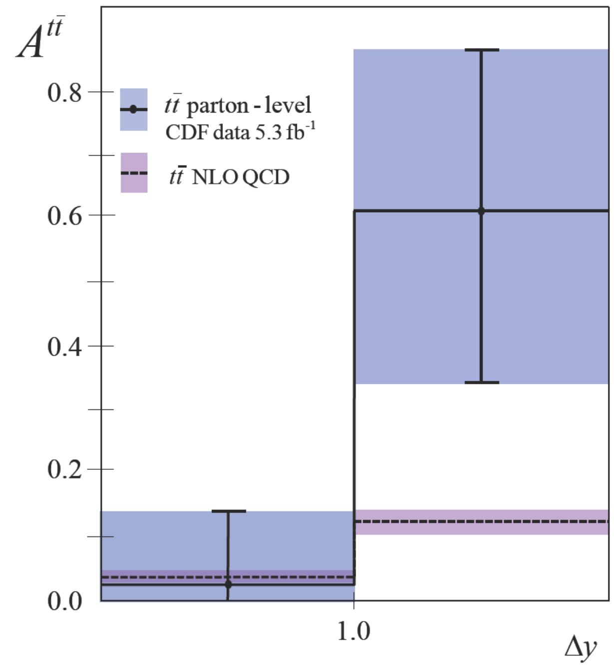
Based on:

“Top quark asymmetry and $Wjj$ excess at CDF from gauged flavor symmetry”

K.S. Babu, M. Frank and S.K. Rai, arXiv:1104.4782 [hep-ph]




$$A_{t\bar{t}}(M_{t\bar{t}} > 450\ \mathrm{GeV})^{\mathrm{CDF}} = 0.475 \pm 0.114$$

$$A_{t\bar{t}}(M_{t\bar{t}} > 450\ \mathrm{GeV})^{\mathrm{SM}} = 0.088 \pm 0.013$$

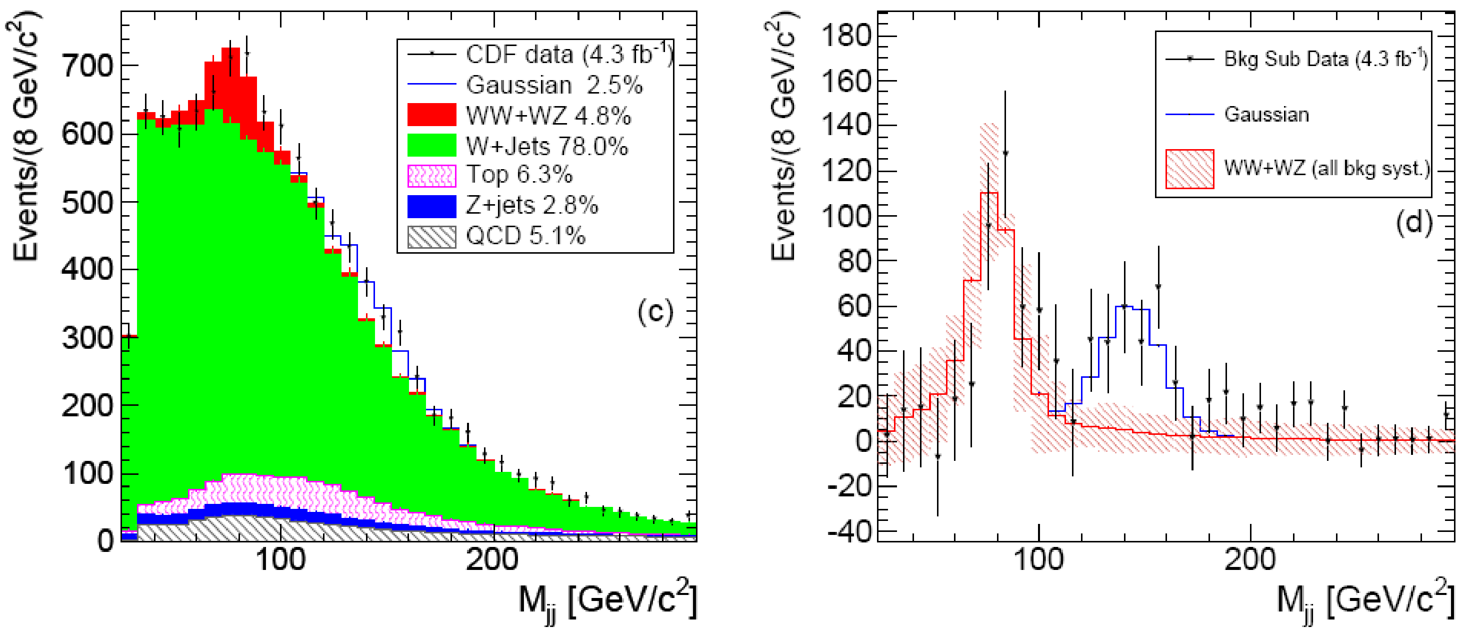
$$A_{t\bar{t}}(|\Delta y| > 1)^{\mathrm{CDF}} = 0.611 \pm 0.256$$

$$A_{t\bar{t}}(|\Delta y| > 1)^{\mathrm{SM}} = 0.123 \pm 0.008$$

$$A_{t\bar{t}} = \frac{N_{\Delta y>0} - N_{\Delta y<0}}{N_{\Delta y>0} + N_{\Delta y<0}}$$

T. Aaltonen *et al.* [CDF Collaboration], arXiv:1101.0034 [hep-ex].

# CDF $Wjj$ excess events




Consistent with a particle of mass $\sim 145$ GeV decaying into jets

No excess in $b$ jets seen

No excess in $Zjj$

No indication of a parent resonance for $Wjj$

Excess $Wjj$ cross section $\sim 4$ pb

T. Aaltonen *et al.* [CDF Collaboration], arXiv:1104.0699 [hep-ex].

# Unified description based on family symmetry

Gauge sector of SM has global $[U(3)]^5$ symmetry:

$$U(3)_Q \times U(3)_{u^c} \times U(3)_{d^c} \times U(3)_L \times U(3)_{e^c}$$

"Gauge principle" :

All anomaly-free symmetries must be gauged

Maximal symmetry that is anomaly-free:

(A) $O(3)_{L\,\{Q,L\}} \times O(3)_{R\,\{u^c,d^c,e^c\}}$

(B) $O(3)_{\{Q,u^c,e^c\}} \times O(3)_{\{L,d^c\}}$

(C) $SU(3)_{\{Q,u^c,d^c\}} \times O(3)_{\{L,e^c\}}$

The 5 $U(1)$ factors are:

$$Y, \quad B-L, \quad B+L, \quad PQ, \quad PQ'$$

With $\nu^c$, global symmetry is $[U(3)]^6$

Maximal anomaly-free subgroups:

$$
\begin{array}{ll}
(A) & SU(3)_{\{Q,u^c,d^c\}} \times SU(3)_{\{L,e^c,\nu^c\}} \times U(1)_{B-L} \\
(B) & SO(3)_{\{Q,L\}} \times SU(3)_{\{u^c,d^c,e^c,\nu^c\}} \times U(1)_{B-L} \\
(C) & SO(3)_{\{Q,u^c,e^c\}} \times SU(3)_{\{L,d^c,\nu^c\}} \times U(1)_{B-L} \\
(D) & SU(3)_{\{Q,u^c,e^c,L,d^c,\nu^c\}} \times U(1)_{B-L} \\
(E) & SO(3)_{\{Q,u^c,e^c\}} \times SO(3)_{\{L,d^c\}} \times SO(3)_{\{\nu^c\}} \\
(F) & SU(3)_{\{Q,u^c,d^c\}} \times SO(3)_{\{L,e^c\}} \times SO(3)_{\{\nu^c\}} \\
(G) & SO(3)_{\{Q,L\}} \times SO(3)_{\{u^c,d^c,e^c\}} \times SO(3)_{\{\nu^c\}}
\end{array}
$$

# $O(3)_L \times O(3)_R$ Family Gauge Symmetry

$Q:(3,1), \quad L:(3,1), \quad u^c:(1,3), \quad d^c:(1,3), \quad e^c:(1,3)$

Higgs doublets: $\Phi^u:(3,3)$, $\Phi^d:(3,3)$

No exotic fermions used

Yukawa couplings of SM promoted to dynamical fields

A single Yukawa coupling in each sector

$\mathcal{L}_{\rm Yuk} = Y_u Q_i u^c_j \Phi^u_{ij} + Y_d Q_i d^c_j \Phi^d_{ij} + Y_\ell L_i e^c_j \Phi^d_{ij} + h.c.$

$i, j = 1-3$ are family indices

$$M^{u,d}_{ij} = Y_{u,d}\langle \Phi^{u,d}_{ij} \rangle$$

For $\left\langle \Phi^u_{33} \right\rangle \equiv v_u \sim v_d \equiv \left\langle \Phi^d_{33} \right\rangle$, $Y_u \simeq 1.4$, with $Y_d, Y_\ell \ll Y_u$

# Suppression of flavor changing neutral currents

$K^0 - \overline{K}^0$ mixing, $D^0 - \overline{D}^0$ mixing, $\mu \to e\gamma$ etc would suggest scale of family symmetry breaking $\Lambda_F > 100$ TeV

CDF anomalies explained by light $(150 - 220$ GeV$)$ scalars

Maximally gauged family symmetry has built-in flavor protection

(i) $\Phi_{ij}^{u,d}$ scalars are near mass eigenstates

(ii) Right-handed fermion mixings are small

Example: $\Phi_{12}^u$ induces operator $|Y_u|^2(\overline{u}_L c_R)(\overline{c}_R u_L)/M^2_{\Phi^u_{12}}$

Does not generate $D^0 - \overline{D}^0$ mixing, even after CKM mixing

$$M_d = \begin{pmatrix} m_d & m_d & m_d \\ 0 & m_s & m_s \\ 0 & 0 & m_b \end{pmatrix} \qquad \Rightarrow V_{ij}^L \sim \frac{m_i}{m_j}, \quad V_{ij}^R \sim \frac{m_i^2}{m_j^2}$$

# Mass degeneacy of scalars

$O(3)_L \times O(3)_R$ symmetry broken above the weak scale by

$(7,1)+(1,7)$ SM singlet scalars $T^{ijk}_{L,R}$

$$\left\langle T^{111}_{L,R} \right\rangle = -\left\langle T^{122}_{L,R} \right\rangle = V_{L,R}$$

$\Rightarrow O(3)_L \times O(3)_R$ breaks to $Q_6 \times Q_6$

$$\Phi^u(3,3) \to (1,1)+(1,2)+(2,1)+(2,2)$$

$$V \supset \kappa^a_{1L} T^{ijk}_L T^{ijk}_L \, \mathrm{Tr}(\Phi^{a\dagger}\Phi^a) + \frac{\kappa^a_{2L}}{4}(\Phi^a\Phi^{a\dagger})^{ij} T^{ikl}_L T^{jkl}_L$$
$$+\kappa^a_{1R} T^{ijk}_R T^{ijk}_R \, \mathrm{Tr}(\Phi^{a\dagger}\Phi^a) + \frac{\kappa^a_{2R}}{4}(\Phi^{a\dagger}\Phi^a)^{ij} T^{ikl}_R T^{jkl}_R$$

$$m^2_{\{\Phi^u_{12},\Phi^u_{13}\}} = \mu^2_u + \kappa^u_{2L} V^2_L; \quad m^2_{\{\Phi^u_{21},\Phi^u_{31}\}} = \mu^2_u + \kappa^u_{2R} V^2_R;$$
$$m^2_{\Phi^u_{11}} = \mu^2_u + \kappa^u_{2L} V^2_L + \kappa^u_{2R} V^2_R; \quad m^2_{\{\Phi^u_{22},\Phi^u_{23},\Phi^u_{32},\Phi^u_{33}\}} = \mu^2_u$$

$\Phi^u_{12}$ explains $Wjj$ data, $\Phi^u_{13}$ explains the top quark asymmetry

# Analysis

$$\mathcal{L} = Y_u[\overline{u}_L c_R \Phi^0_{12} + \overline{d}_L c_R \Phi^-_{12} + \overline{u}_L t_R \Phi^0_{13} + \overline{d}_L t_R \Phi^-_{13}] + h.c.$$

$m_{\Phi^0_{1j}} = 150$ GeV, $m_{\Phi^\pm_{1j}} = 180$ GeV $(j = 2, 3)$

$Y_u = 1.4$

$\Delta T = 0.032$, consistent with prcision EW data

$t \to u\Phi^{0*}_{13}$ allowed, $\Gamma_t = 1.72$ GeV

Consistent with DØ direct measurement

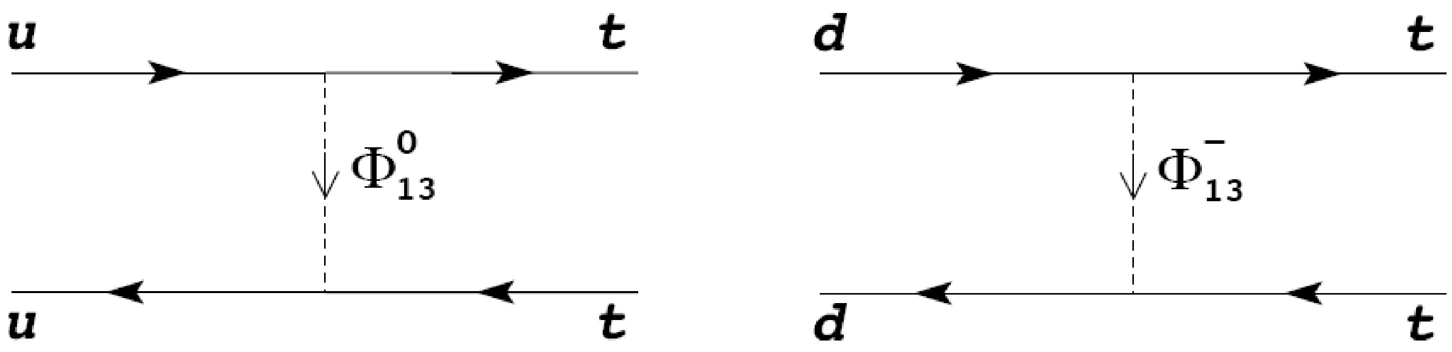
UA2 search for dijet resonance:

$\sigma <$ 90 pb (50 pb) for mass = 150 (180) GeV

$\sigma =$ 70 pb (16 pb) for our choice

Analysis in similar spirit:
A. E. Nelson, T. Okui and T. S. Roy, arXiv:1104.2030 [hep-ph]

# Top quark asymmetry



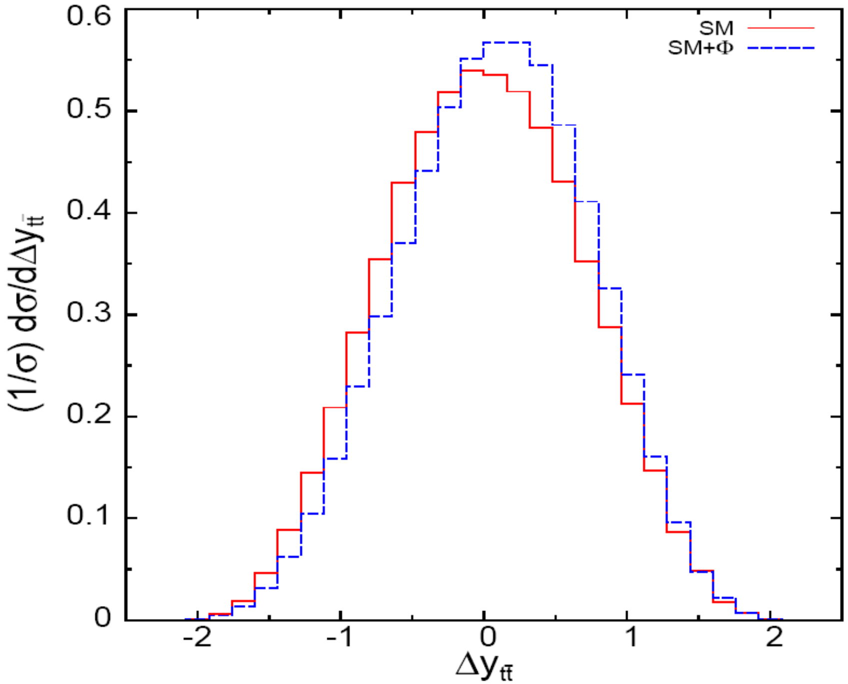

$t$-channel diagrams interfere with SM diagrams

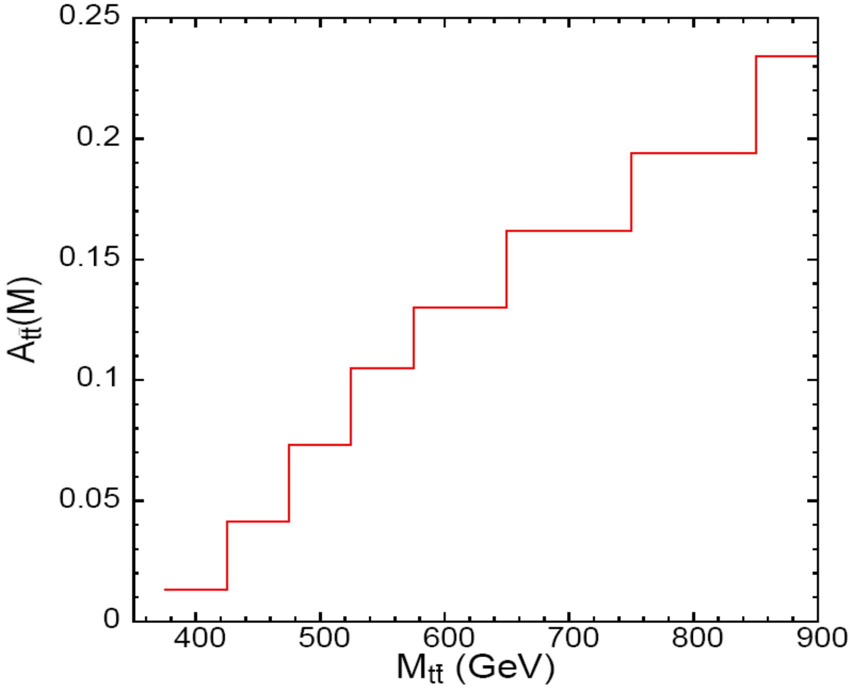
For $Y_u = 1.4$, total cross section changes by $< 5\%$ from SM

$|\eta| < 2.0$ for rapidity coverage for top

Constructed asymmetry parameter:

$$A_{t\bar{t}} = \frac{N_{\Delta y > 0} - N_{\Delta y < 0}}{N_{\Delta y > 0} + N_{\Delta y < 0}}$$




Normalized differential cross section vs $\Delta y$

$A_{t\bar{t}}$ vs $M_{t\bar{t}}$ in $t\bar{t}$ rest frame

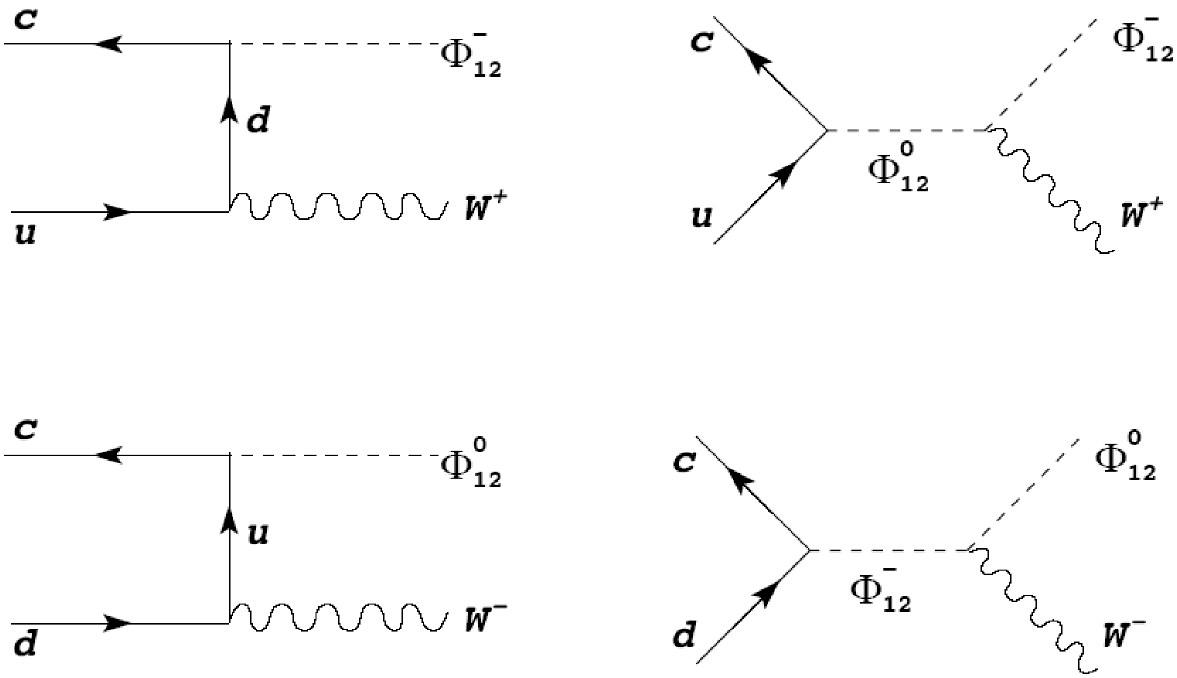
$A_{t\bar{t}} = 0.104$ (new) $+ 0.058 \pm 0.009$ (SM) $\quad A_{t\bar{t}}^{\text{CDF}} = 0.158 \pm 0.075$

(without invariant mass cut)

$A_{t\bar{t}} \simeq 0.156$ (new) $+ 0.088 \pm 0.013$ (SM) $\quad A_{t\bar{t}}^{\text{CDF}} = 0.475 \pm 0.114$

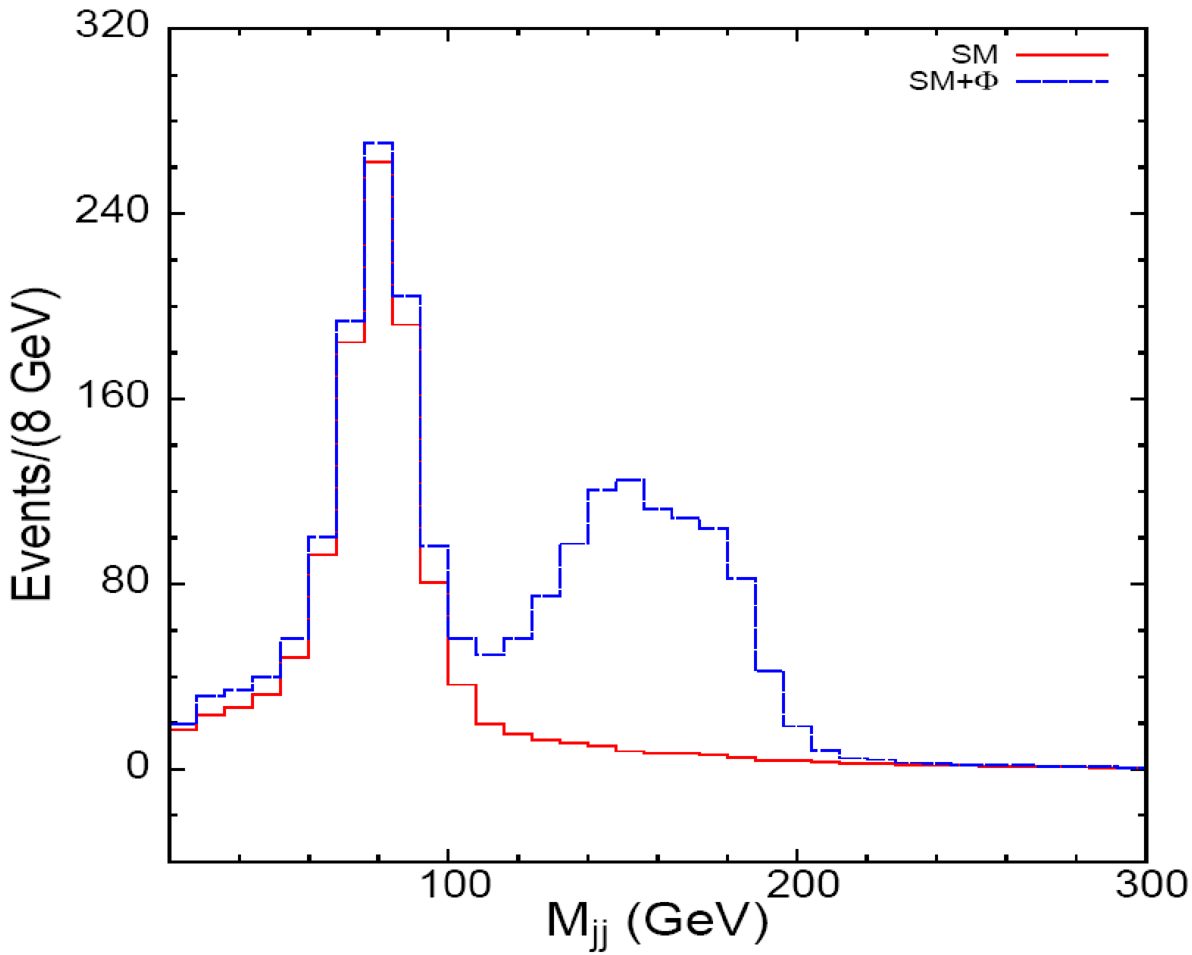
(with $M_{t\bar{t}} > 450$ GeV)

# $Wjj$ excess




Masses and couplings of scalars fixed by top asymmetry analysis

We apply same set of cuts as CDF for this analysis




Events per bin vs dijet invariant mass

Cross section: $\sigma(c\bar{d} \to W^+\Phi_{12}^{0*}) = 765$ fb

$\sigma(u\bar{c} \to W^+\Phi_{12}^{-}) = 919$ fb

plus c.c

With $K = 1.3$, $\sigma^{\text{total}} = 4.38$ pb

# Predictions of the model

Excess cross section for $p\overline{p} \to Zjj$ at Tevatron:

$$\sigma \simeq 0.17 \text{ pb}$$

$$\sigma(p\overline{p} \to \gamma jj) \simeq 2.2 \text{ pb (Tevatron)}$$

Scalar production cross sections at LHC:

$\sigma(Z\Phi^0_{12}) \simeq 2.8\ pb$; $\sigma(Z\Phi^{\mp}_{12}) \simeq 3.3\ pb$; $\sigma(\gamma\Phi^0_{12}) \simeq 23.8\ pb$;
$\sigma(\gamma\Phi^{\mp}_{12}) \simeq 3.3\ pb$; $\sigma(W^{\pm}\Phi^0_{12}) \simeq 73\ pb$; $\sigma(W^{\pm}\Phi^{\mp}_{12}) \simeq 86\ pb$.

Efective operator $|Y_u|^2(\overline{d}_L c_R)(\overline{c}_R d_L)/M^2_{\Phi_{12}}$

$B_d \to J/\Psi K_S$ decay rate hy as much as 10%

# Conclusions

Anomaly–free symmetries may very well be gauged

Gauging $O(3)_L \times O(3)_R$ family symmetry can provide a unified description of CDF top asymmetry and $Wjj$ excess

New processes mediated by scalars of the family symmetry with masses in the $(150 - 200)$ GeV range

Testable at the LHC in $Wjj$ resonant channel