

# Top Quark Forward-backward Asymmetry From Gauged Flavor Symmetry

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**ICHEP 2012**

Melbourne, July 4-11, 2012

Talk based on:

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

K.S. Babu, M. Frank and S.K. Rai,  
Phys. Rev. Lett. **107**, 061802 (2011);

*Top quark forward–backward asymmetry  
from gauged flavor symmetry*

K.S. Babu, J. Julio, M. Frank and  
S.K. Rai (2012).

## Top quark forward-backward asymmetry

Both CDF and D0 have reported significant forward–backward asymmetry in top production

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

CDF:

$$A_{t\bar{t}} = (16.2 \pm 4.1 \pm 2.2)\% \text{ (8.7 fb}^{-1} \text{ data)}$$

$$A_{t\bar{t}}(M_{t\bar{t}} > 450 \text{ GeV}) = (0.296 \pm 0.059 \pm 0.031)\%$$

D0:

$$A_{t\bar{t}} = (19.6 \pm 6.5)\% \text{ (5.4 fb}^{-1} \text{ data)}$$

$$A_{FB}^{\text{SM}} = 0.066 \text{ (0.10)\%}$$

## Gauged family symmetry and top quark asymmetry

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

## $O(3)_L \times O(3)_R$ 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

$$\mathcal{L}_{\text{Yuk}} = Y_u Q_i u_j^c \Phi_{ij}^u + Y_d Q_i d_j^c \Phi_{ij}^d + Y_\ell L_i e_j^c \Phi_{ij}^d + h.c.$$

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

$$M_{ij}^{u,d} = Y_{u,d} \langle \Phi_{ij}^{u,d} \rangle$$

For  $\langle \Phi_{33}^u \rangle \equiv v_u \sim v_d \equiv \langle \Phi_{33}^d \rangle$ ,  $Y_u \simeq 1.4$ , with  $Y_d, Y_\ell \ll Y_u$

## Suppression of flavor changing neutral currents

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

Top asymmetry explained by light ( $\sim 150$  GeV) scalar

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  $|Y_u|^2 (\bar{u}_L c_R)(\bar{c}_R u_L)/M_{\Phi_{12}^u}^2$

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

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

## Mass degeneracy of scalars

$O(3)_L \times O(3)_R$  symmetry broken above the weak scale by  
 $(7, 1) + (1, 7)$  SM singlet scalars  $T_{L,R}^{ijk}$

$$\langle T_{L,R}^{333} \rangle = -\langle T_{L,R}^{322} \rangle = V_{L,R}$$

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

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

$$V \supset \kappa_{1L}^a T_L^{ijk} T_L^{ijk} \text{Tr}(\Phi^{a\dagger} \Phi^a) + \frac{\kappa_{2L}^a}{4} (\Phi^a \Phi^{a\dagger})^{ij} T_L^{ikl} T_L^{jkl}$$

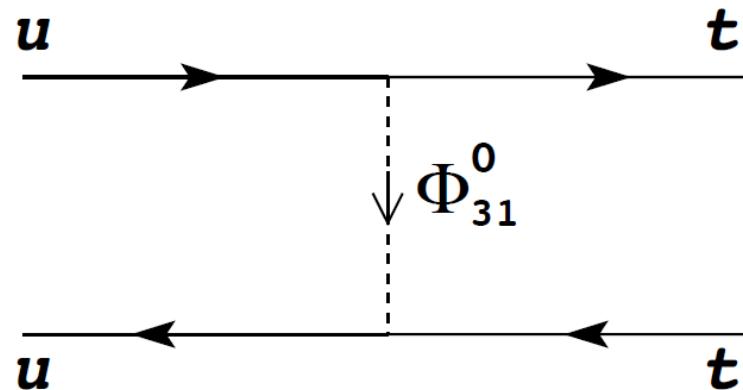
$$+ \kappa_{1R}^a T_R^{ijk} T_R^{ijk} \text{Tr}(\Phi^{a\dagger} \Phi^a) + \frac{\kappa_{2R}^a}{4} (\Phi^{a\dagger} \Phi^a)^{ij} T_R^{ikl} T_R^{jkl}$$

$$m_{\{\Phi_{31}^u, \Phi_{32}^u\}}^2 = \mu_u^2 + \kappa_{2L}^u V_L^2; \quad m_{\{\Phi_{13}^u, \Phi_{23}^u\}}^2 = \mu_u^2 + \kappa_{2R}^u V_R^2;$$

$$m_{\Phi_{33}^u}^2 = \mu_u^2 + \kappa_{2L}^u V_L^2 + \kappa_{2R}^u V_R^2; \quad m_{\{\Phi_{11}^u, \Phi_{12}^u, \Phi_{21}^u, \Phi_{22}^u\}}^2 = \mu_u^2$$

$\Phi_{31}^u$  explains the top quark asymmetry

## Top quark asymmetry



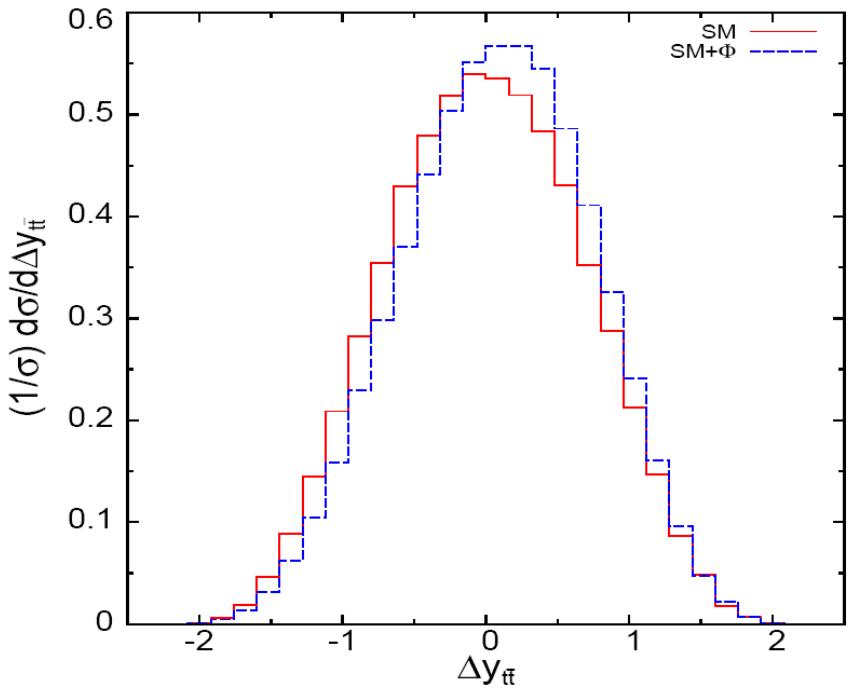
$t$ -channel diagrams interfere with SM diagrams

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

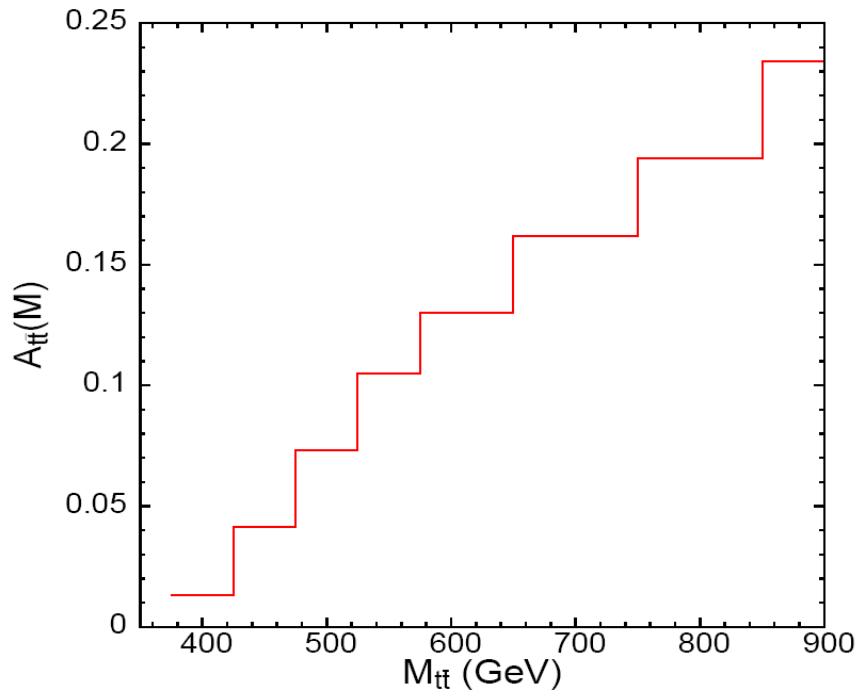
$|\eta| < 2.0$  for rapidity coverage for top

Constructed asymmetry parameter:

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

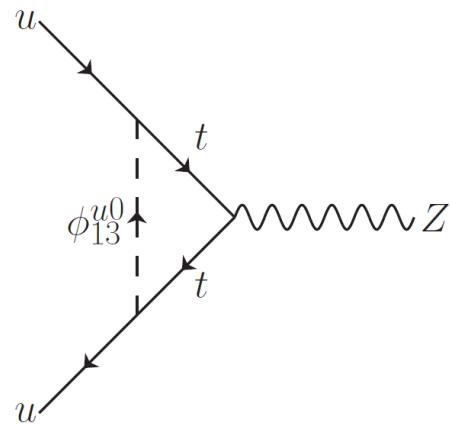


Normalized differential cross section vs  $\Delta y$



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

## Atomic parity violation constraint



Gresham, Ki, Tulin, Zurek (2012)

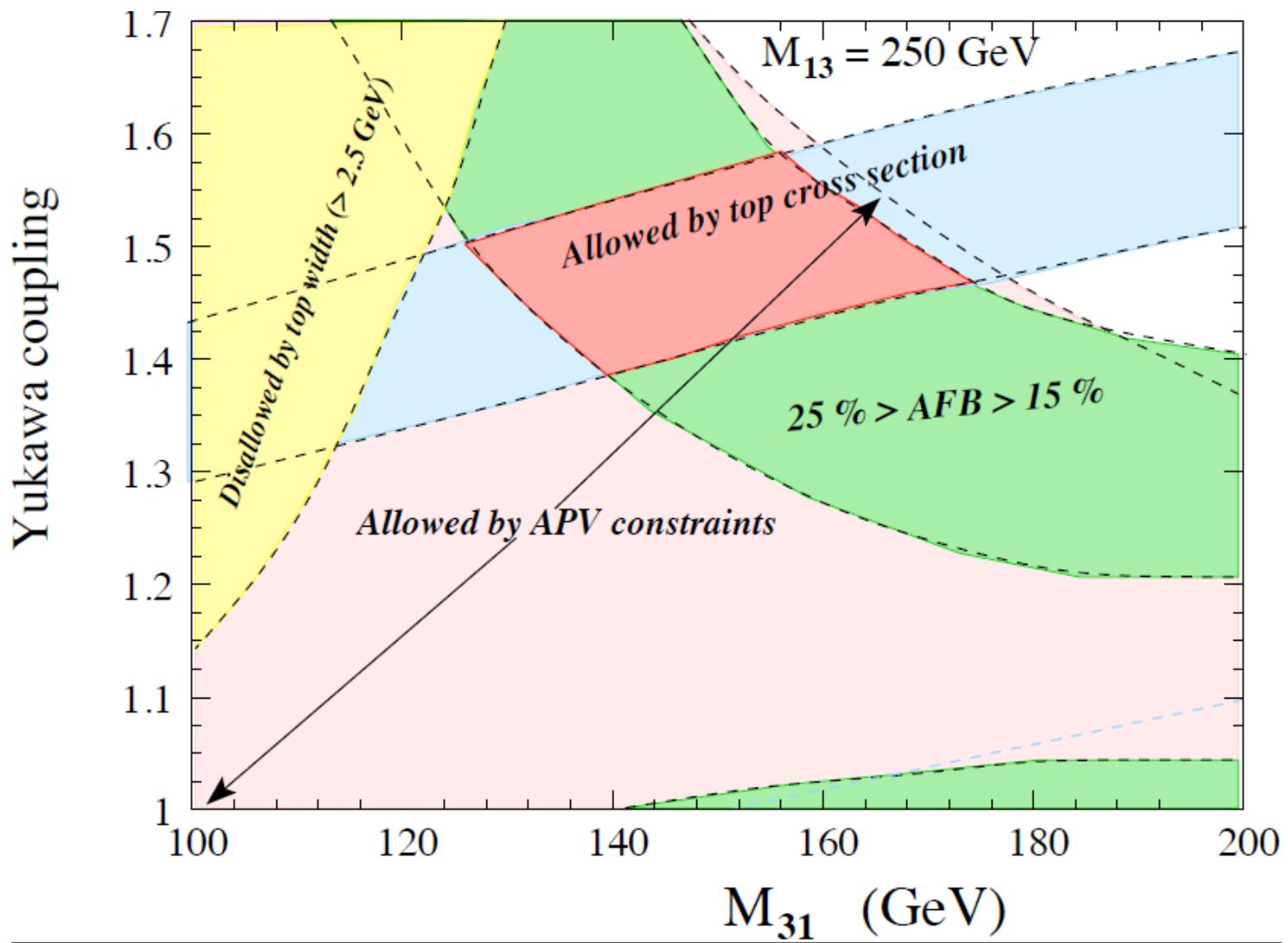
$$\mathcal{L}_{\bar{q}qZ}^{\text{new}} = \frac{g}{\cos \theta_W} (c_L^u \overline{u_L} \gamma^\mu u_L + c_R^u \overline{u_R} \gamma^\mu u_R + c_L^d \overline{d_L} \gamma^\mu d_L) Z_\mu.$$

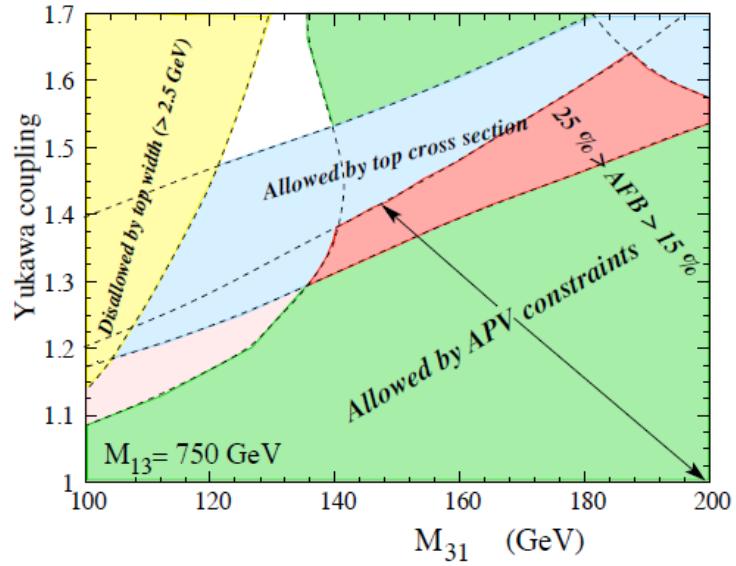
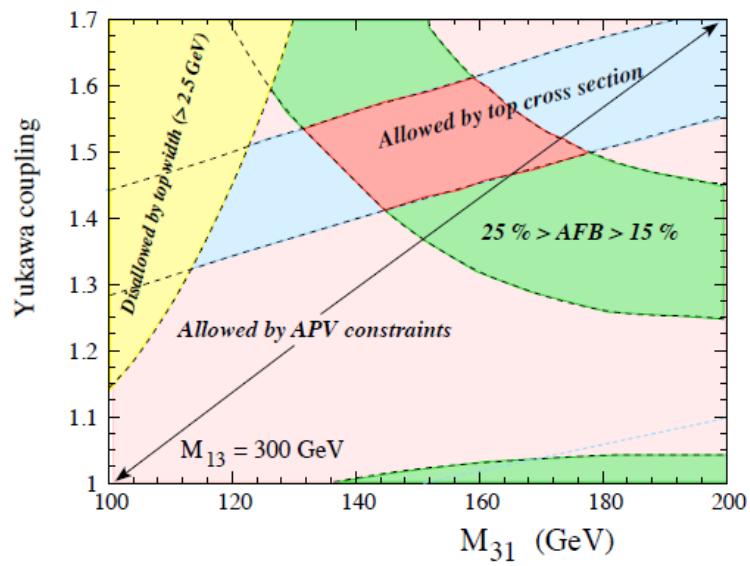
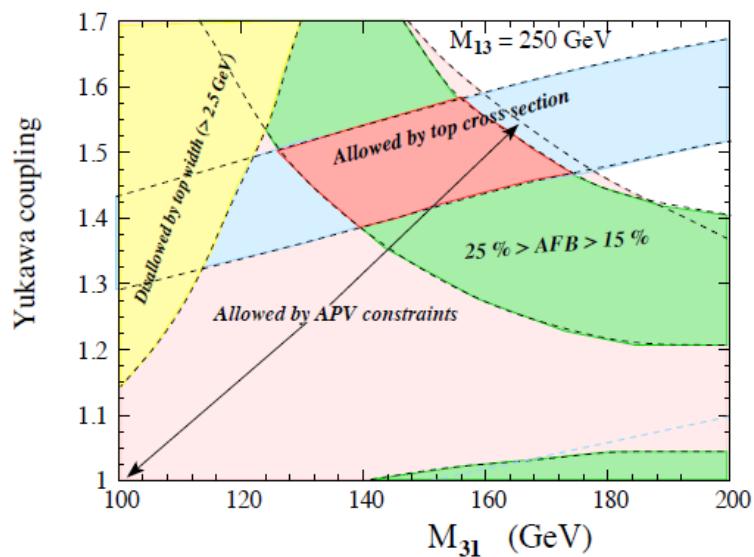
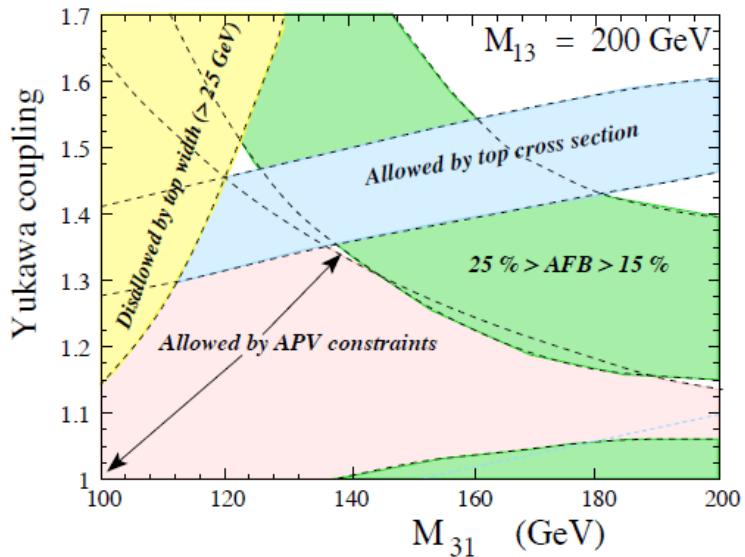
$$c_L^u = \frac{Y_t^2}{32\pi^2} F(m_t^2/m_{\phi_{13}^0}^2); \quad c_R^u = -\frac{Y_t^2}{32\pi^2} F(m_t^2/m_{\phi_{31}^0}^2); \quad c_L^d = \frac{Y_t^2}{32\pi^2} F(m_t^2/m_{\phi_{13}^+}^2)$$

$$F(x) \equiv \frac{x(-1+x-\ln x)}{(1-x)^2}.$$

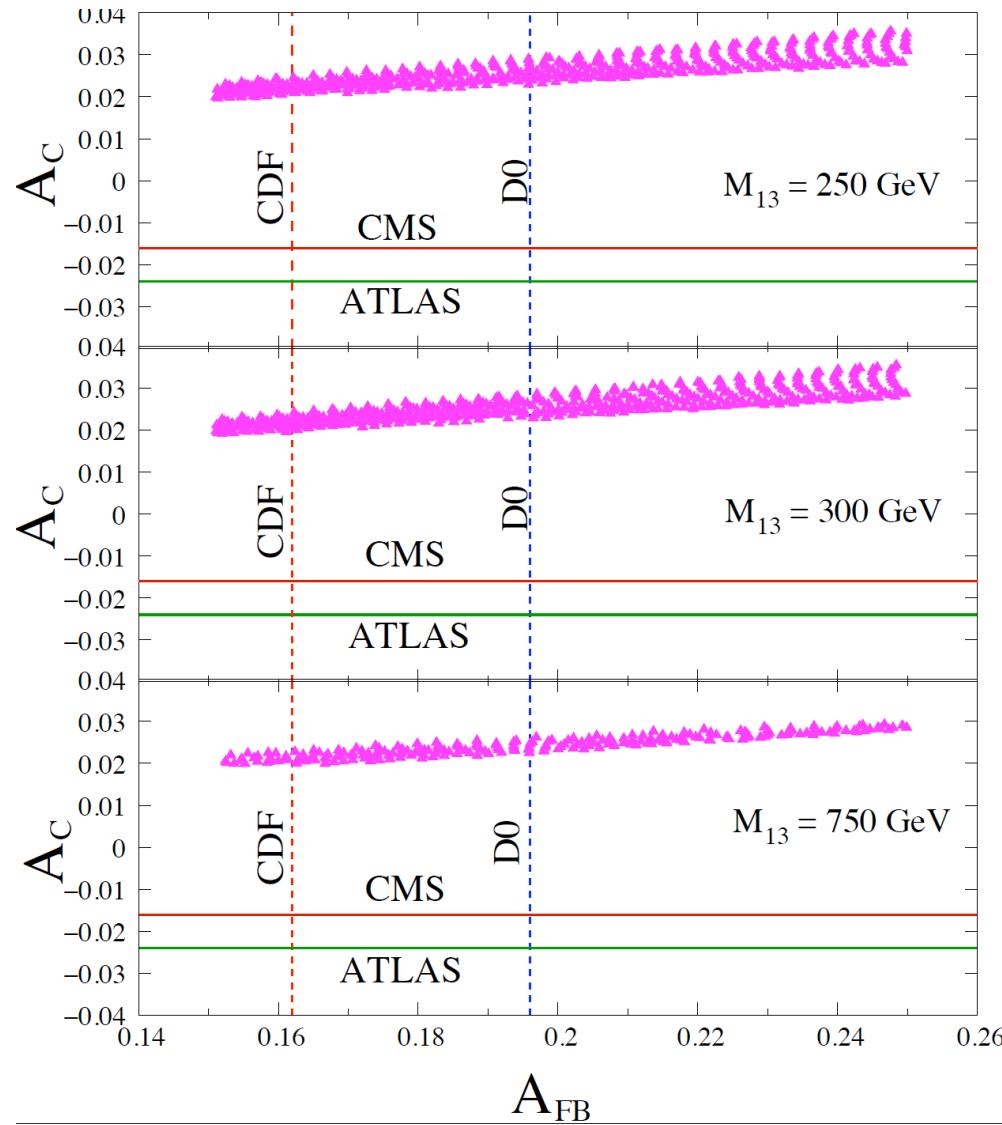
$$Q[Cs] = -73.20(35), \quad Q[Cs]^{\text{SM}} = -73.15(2)$$

## Allowed parameter space

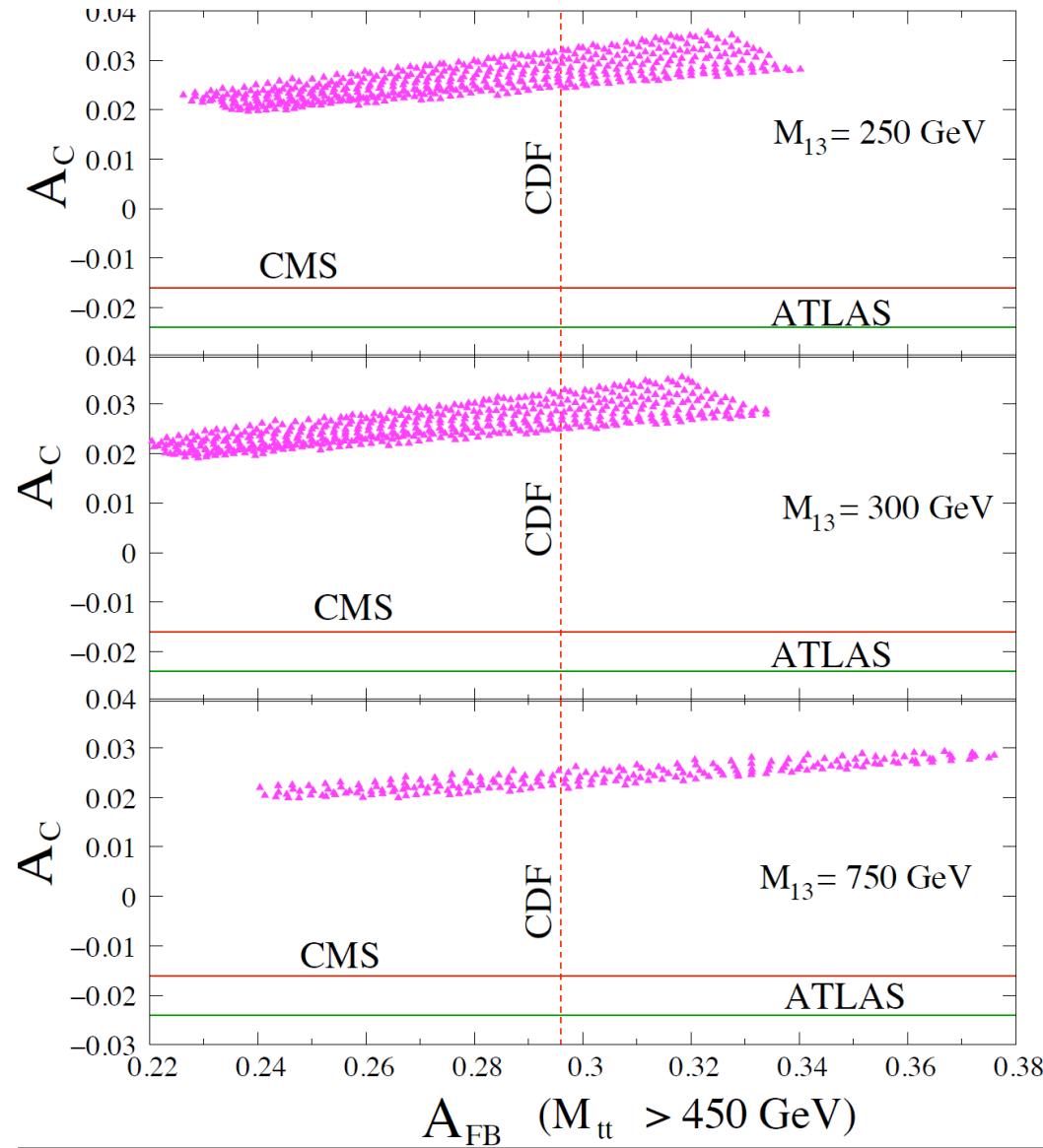




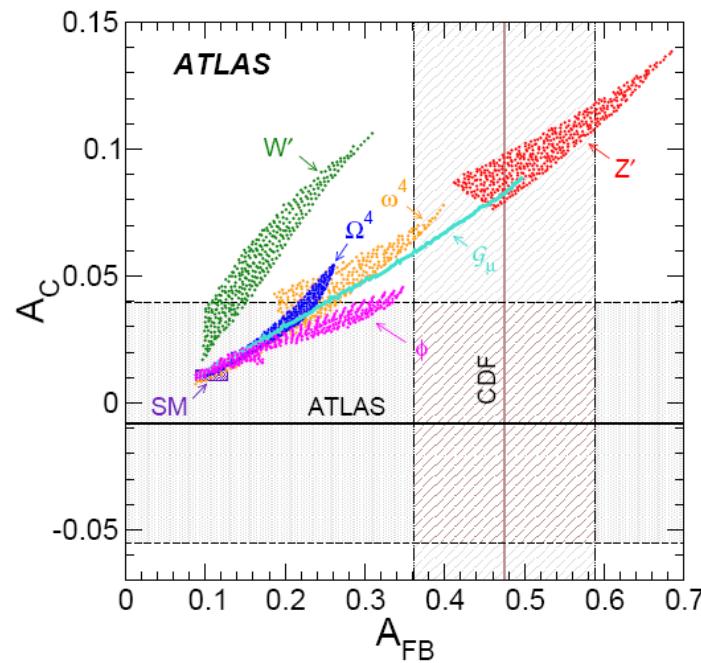
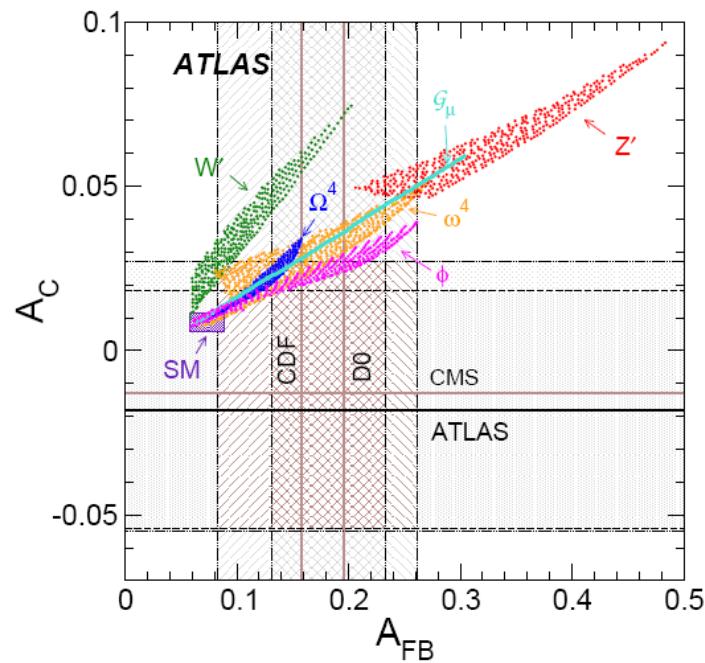
# Charge asymmetry at LHC



## Allowed parameter space



# Model comparison



## Conclusions

Anomaly-free flavor symmetries may be gauged

Gauging  $O(3)_L \times O(3)_R$  family symmetry can provide an understanding of the top forward-backward asymmetry

Small but observable charge asymmetry predicted for LHC