Chiral U(1) flavor models and flavored Higgs doublets: the top FB asymmetry and the Wjj

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Based on arXiv:1108.0350 and 1108.4005
with P. Ko and Chaehyun Yu (KIAS)

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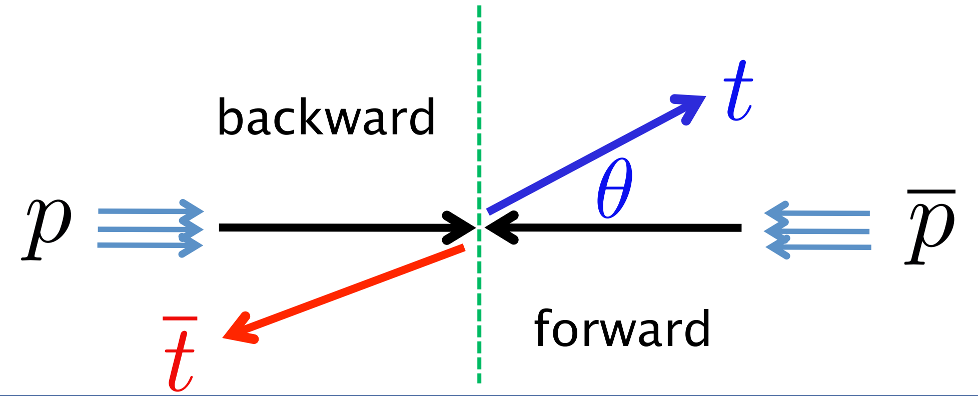
- Motivation

Top forward asymmetry(A_{FB}) at Tevatron



$$A_{FB} = \frac{N(t; \cos\theta > 0) - N(t; \cos\theta < 0)}{N(t; \cos\theta > 0) + N(t; \cos\theta < 0)}$$

$$A^t_{\mathrm{FB}} = \begin{cases} 0.158 \pm 0.074 & \text{(CDF, lepton+jets channel)} \\ 0.42 \pm 0.158 & \text{(CDF, dilepton channel)} \\ 0.19 \pm 0.065 & \text{(D0, lepton+jets channel)} \end{cases}$$

SM prediction

$$A_{\mathrm{FB}} = 0.058 \pm 0.009$$

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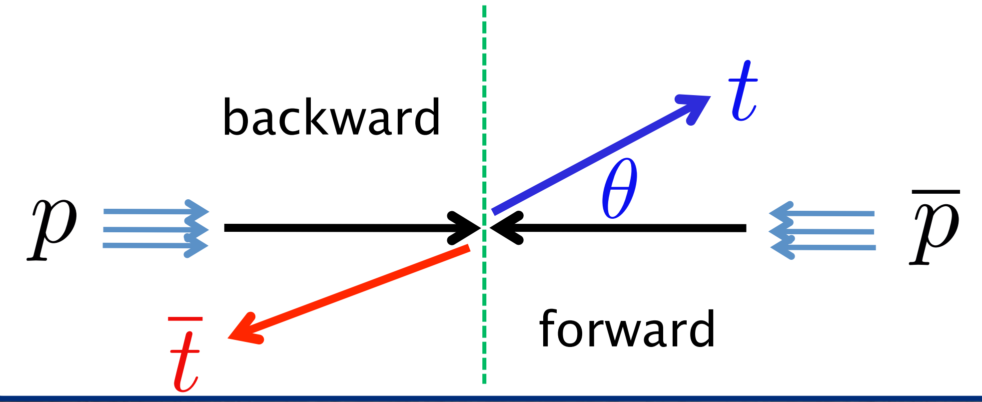

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SM prediction

New particle?

$$A_{\rm FB} = 0.058 \pm 0.009$$

Candidates for A_{FB}

- colored spin-1 (axigluon, coloron, Kaluza-Klein gluon, etc.) exchange in the s-channel
- color triplet or sextet in the u-channel
- light Z' exchange or W' in the t-channel
- color-singlet scalar exchange in the t-channel

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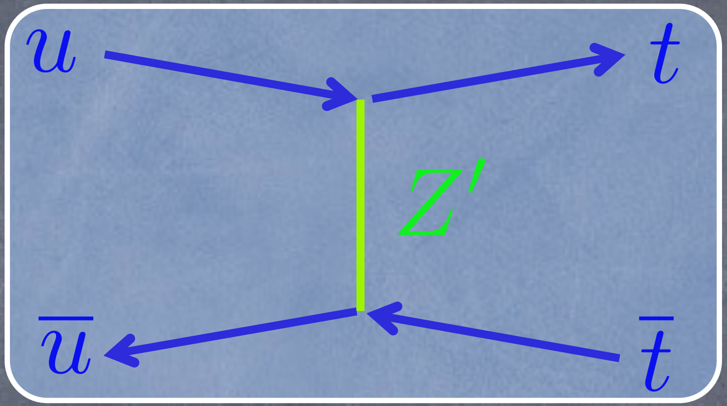
Our models

Z′ for AFB

- Z′ with large (u,t) gauge coupling



Jung, Murayama, Pierce, Wells' model PRD81,015004 (2010)

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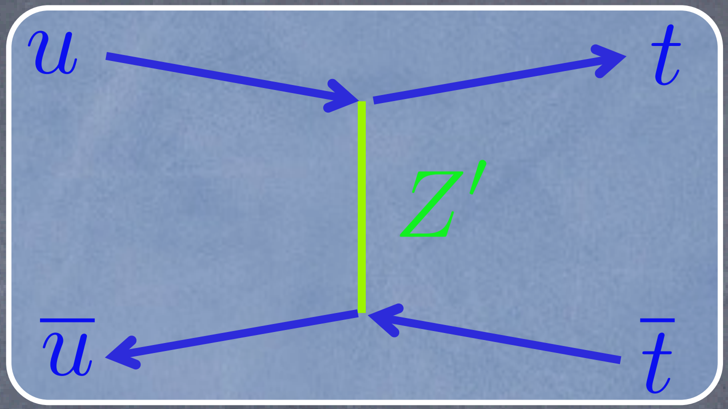

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- How get the Z′? →Gauged U(1)′ Flavor Symmetry

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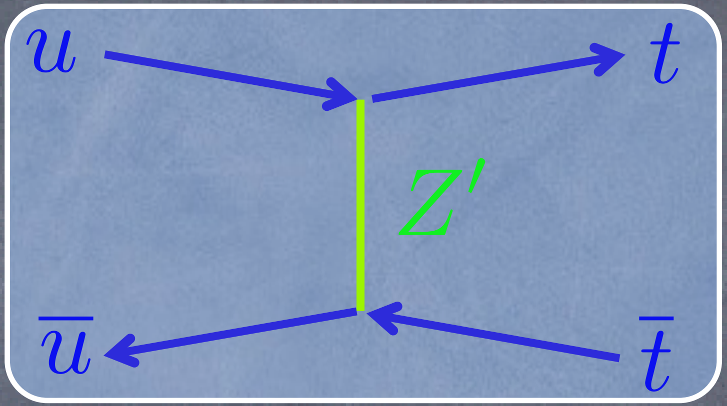

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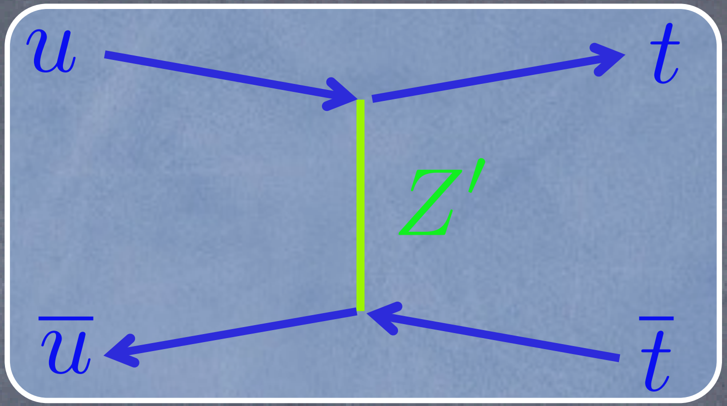

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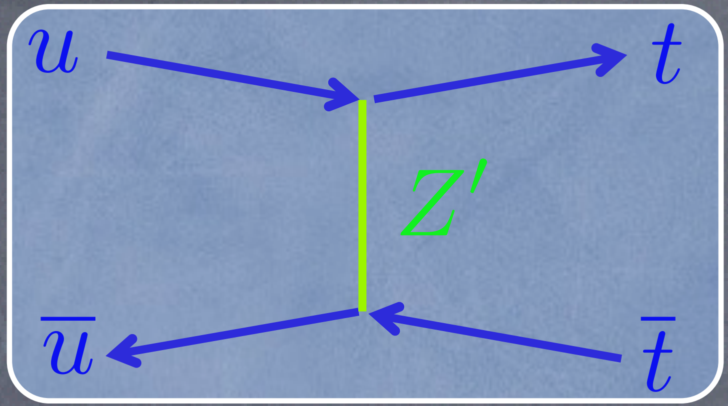
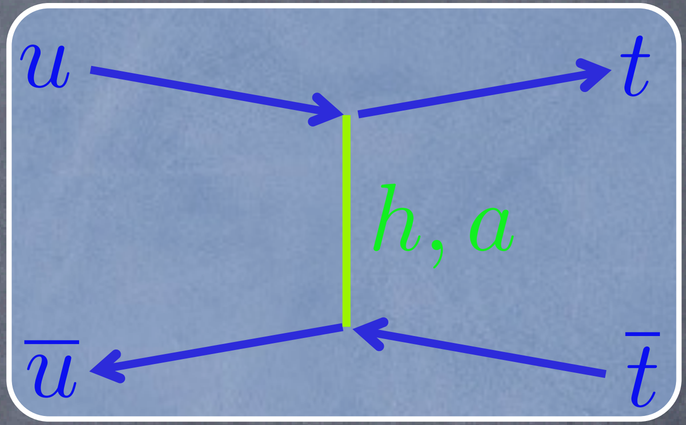
- How get the Z′? →Gauged U(1)′ Flavor Symmetry
- Are Yukawa couplings realistic? →Require extensions !
- Same-sign top at LHC excludes the Z′!

Our models

- Flavor-dependent U(1) charge assignment for the t-channel



- Extra Higgs doublets required for realistic fermion mass matrices



- Z' scenario is revived by Gauge + Yukawa !

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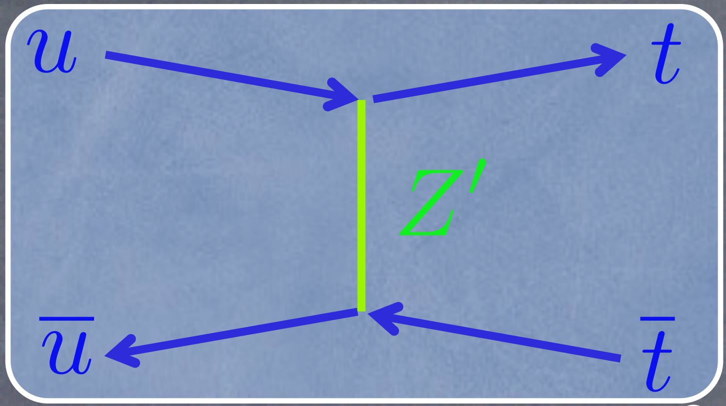

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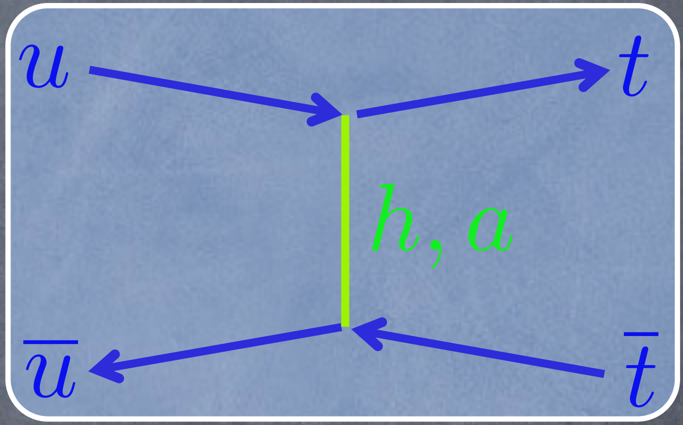

- Z′ scenario is revived by Gauge + Yukawa !
- Wjj signal (CDF reported)
- Anomaly free, adding extra chiral fermion

→CDM candidates

2. Chiral U(1) flavor models

- SM gauge symmetries × U(1)′ models
- Z′ will be light and coupling g′ will be not small
- U(1)′ charges are flavor-dependent and assigned to only quarks, which can avoid LEP bound, Drell-Yang, etc.

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
Q_i	3	2	1/6	q_{Li}
D_{Ri}	3	1	$-1/3$	d_i
U_{Ri}	3	1	2/3	u_i
L_i	1	2	$-1/2$	0
E_{Ri}	1	1	-1	0

gauge couplings in the mass base

Interaction base: $$g' Z'_\mu \left[\, q_i \overline{U^i_L} \gamma^\mu U^i_L + q_i \overline{D^i_L} \gamma^\mu D^i_L + u_i \overline{U^i_R} \gamma^\mu U^i_R + d_i \overline{D^i_R} \gamma^\mu D^i_R \right]$$

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mass base: $$g' Z'^\mu \left[(g^u_L)_{ij} \overline{\hat{U}^i_L} \gamma_\mu \hat{U}^j_L + (g^d_L)_{ij} \overline{\hat{D}^i_L} \gamma_\mu \hat{D}^j_L + (g^u_R)_{ij} \overline{\hat{U}^i_R} \gamma_\mu \hat{U}^j_R + (g^d_R)_{ij} \overline{\hat{D}^i_R} \gamma_\mu \hat{D}^j_R \right].$$

tree-level contributions to FCNC

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tree-level contributions to FCNC

(g^u_L)	(g^d_L)	(g^u_R)	(g^d_R)
$D^0 - \overline{D^0}$	$K^0 - \overline{K^0}$	$D^0 - \overline{D^0}$	$K^0 - \overline{K^0}$
A_{FB}	$B^0 - \overline{B^0}$	A_{FB}	$B^0 - \overline{B^0}$
	$B_s - \overline{B_s}$		$B_s - \overline{B_s}$

CKM matrix requires sizable mixing
(1,2) element ~0.22*(qL1-qL2)

gauge couplings in the mass base

Interaction base: $$g' Z'_\mu \left[q_i \overline{U^i_L} \gamma^\mu U^i_L + q_i \overline{D^i_L} \gamma^\mu D^i_L + u_i \overline{U^i_R} \gamma^\mu U^i_R + d_i \overline{D^i_R} \gamma^\mu D^i_R \right]$$

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tree-level contributions to FCNC

(g^u_L)	(g^d_L)	(g^u_R)	(g^d_R)
$D^0 - \overline{D^0}$	$K^0 - \overline{K^0}$	$D^0 - \overline{D^0}$	$K^0 - \overline{K^0}$
$A_{\rm FB}$	$B^0 - \overline{B^0}$	$A_{\rm FB}$	$B^0 - \overline{B^0}$
	$B_s - \overline{B_s}$		$B_s - \overline{B_s}$

CKM matrix requires sizable mixing
(1,2) element ~0.22*(qL1-qL2)

In order to avoid the strong constraints from FCNC, only right-handed up-type quarks are charged.

Examples

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
Q_i	3	2	1/6	0
D_{Ri}	3	1	$-1/3$	0
U_{Ri}	3	1	2/3	u_i

- We can consider many cases.
- (u1,u2,u3)=(0,0,1) (2HDM)
- (u1,u2,u3)=(-1,0,1) (3HDM)
- Right-handed mixing of up quarks must be controlled,

$$\hat{D}^i_R = (R^u)_{ij} D^j_R \qquad (g^u_R)_{ij} = (R_u)_{ik} u_k (R_u)^\dagger_{kj}$$

depend on Yukawa

small (u,c) for D0
large (u,t) for A_{FB}

Yukawa Couplings

- Flavor-dependent chiral U(1) requires extension of Higgs sector for realistic mass matrices and renormalizability.

$$y^u_{ij}\overline{Q_i}\widetilde{H}U_{Rj}$$

U(1)' charge: $0 \ 0 \ u_j$ → U(1)' symmetry forbids the Yukawa couplings

- Add extra Higgs charged under U(1)'.

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  - (u1,u2,u3)=(0,0,1) → 2 Higgs (2HDM)

$$y^u_{i1}\overline{Q_i}\widetilde{H}U_{R1} + y^u_{i2}\overline{Q_i}\widetilde{H}U_{R2} + y^u_{i3}\overline{Q_i}\widetilde{H_3}U_{R3}$$

U(1)' charge: $0\ 0\ 0$ $\quad$ $0\ 0\ 0$ $\quad$ $0\ -1\ 1$

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U(1)' charge: $0\ 0\ 0$ $\quad 0\ 0\ 0$ $\quad 0\ -1\ 1$

  - (u1,u2,u3)=(-1,0,1) → 3 Higgs (3HDM)

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U(1)' charge: $0\ 1\ -1$ $\quad 0\ 0\ 0$ $\quad 0\ -1\ 1$

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	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
H	1	2	1/2	0
H_3	1	2	1/2	1
Φ	1	1	0	1

3 neutral scalar
+
1 pseudo-scalar
+
1 charged Higgs pair

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Flavor changing through Yukawa interaction

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H	1	2	1/2	0
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Φ	1	1	0	1

4 neutral scalar
+
2 pseudo-scalar
+
2 charged Higgs pair

Flavor changing through Yukawa interaction

Yukawa couplings in the mass base

- (u1,u2,u3)=(0,0,1) → 2 Higgs (2HDM)

$$y^u_{i1}\overline{Q_i}\widetilde{H}U_{R1} + y^u_{i2}\overline{Q_i}\widetilde{H}U_{R2} + y^u_{i3}\overline{Q_i}\widetilde{H_3}U_{R3}$$

$$Y^u_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h - Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^- - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$$

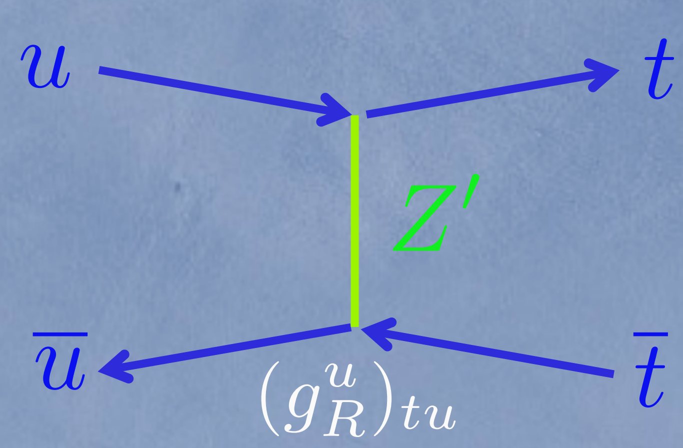
$$\frac{2m^u_i}{v\sin 2\beta}(g^u_R)_{ij}\sin(\alpha-\beta)\cos\alpha_\Phi$$

$$-\frac{2\sqrt{2}m^u_l}{v\sin 2\beta}(g^u_R)_{lj}$$

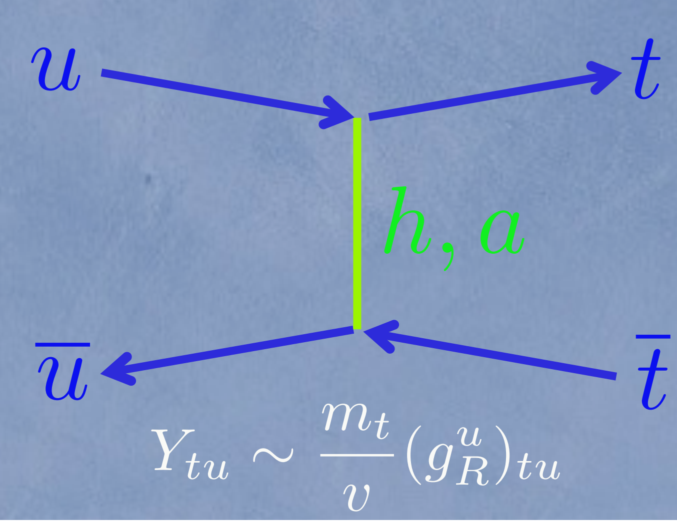
$$-\frac{2m^u_i}{v\sin 2\beta}(g^u_R)_{ij}$$

large (t,u) are possible in the both gauge and Yukawa

$$g' Z'^\mu (g^u_R)_{tu}\overline{t_R}\gamma_\mu u_R$$



$$Y_{tu}h\overline{t_L}u_R$$



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$$Y^u_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h-Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^- - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$$

assumption (gauge coupling)

$$g^u_R=\begin{pmatrix}-\cos 2\theta & 0 & -e^{i(\delta_1-\delta_3)}\sin 2\theta\\ 0 & 0 & 0\\ -e^{-i(\delta_1-\delta_3)}\sin 2\theta & 0 & \cos 2\theta\end{pmatrix},$$

Large

$$(Y^u_{ij})=\begin{pmatrix}\frac{m_u}{v}\left(\frac{O^h_{11}\cos^2\theta}{\cos\beta_1\cos\beta_2}+\frac{O^h_{31}\sin^2\theta}{\sin\beta_2}\right) & 0 & \frac{m_u e^{i(\delta_1-\delta_3)}}{2v}\left(\frac{O^h_{11}\sin 2\theta}{\cos\beta_1\cos\beta_2}-\frac{O^h_{31}\sin 2\theta}{\sin\beta_2}\right)\\ 0 & \frac{m_c}{v}\frac{O^h_{21}}{\sin\beta_1\cos\beta_2} & 0\\ \frac{m_t e^{-i(\delta_1-\delta_3)}}{2v}\left(\frac{O^h_{11}\sin 2\theta}{\cos\beta_1\cos\beta_2}-\frac{O^h_{31}\sin 2\theta}{\sin\beta_2}\right) & 0 & \frac{m_t}{v}\left(\frac{O^h_{11}\sin^2\theta}{\cos\beta_1\cos\beta_2}+\frac{O^h_{31}\cos^2\theta}{\sin\beta_2}\right)\end{pmatrix}$$

Large

$$\left(\frac{(V_{\rm CKM})_{il}Y^{u-}_{lj}}{\sqrt{2}}\right)=(Y^{au}_{ij})=\begin{pmatrix}\frac{m_u\tan\beta_2}{v}\left(\cos^2\theta-\frac{\sin^2\theta}{\tan^2\beta_2}\right) & 0 & \frac{m_u\sin 2\theta e^{i(\delta_1-\delta_3)}}{v\sin 2\beta_2}\\ 0 & \frac{m_c\tan\beta_2}{v} & 0\\ \frac{m_t\sin 2\theta e^{-i(\delta_1-\delta_3)}}{v\sin 2\beta_2} & 0 & \frac{m_t\tan\beta_2}{v}\left(\sin^2\theta-\frac{\cos^2\theta}{\tan^2\beta_2}\right)\end{pmatrix}$$

3. Phenomenology

- A_{FB} in our models:
  - Z′ and neutral scalar light (around top mass.)
  - pseudo scalar and charge Higgs are heavier
  - Yukawa and gauge couplings have large (t,u) elements
- related constraints from collider:
  - $t\bar{t}$ cross section
  - same-sign top
  - dijet search
  - top decay
  - single top

3. Phenomenology

- Top forward-backward asymmetry (A_{FB})

$$A^t_{\rm FB} = \begin{cases} 0.158 \pm 0.074 & \text{(CDF, lepton+jets channel)} \\ 0.42 \pm 0.158 & \text{(CDF, dilepton channel)} \\ 0.19 \pm 0.065 & \text{(D0, lepton+jets channel)} \end{cases}$$

~ 1.32σ
~ 2.7σ
~ 2.2σ

- $m_{t\bar{t}}$

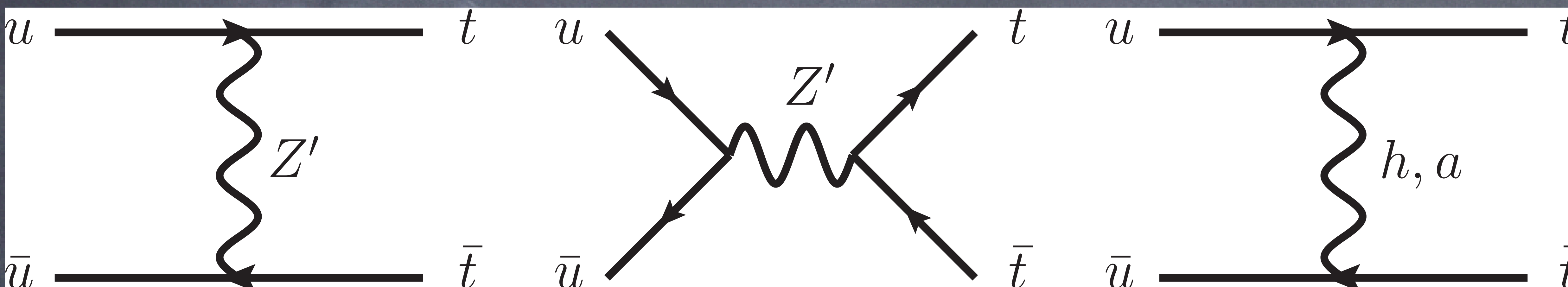
	CDF	SM	
$A^{t\bar{t}}(m_{t\bar{t}} < 450GeV)$	$= -0.116 \pm 0.153$	0.040 ± 0.006	
$A^{t\bar{t}}(m_{t\bar{t}} > 450GeV)$	$= 0.475 \pm 0.114$	0.088 ± 0.013	~ 3.4σ

- $t\bar{t}$ cross section

$$\sigma(t\bar{t}) = (7.5 \pm 0.48)pb$$

$t\bar{t}$ in our models

Z′ exchanging + neutral (pseudo) scalar



mass matrix for up sector

$$\overline{U_{Li}} M^u_{ij} U_{Rj}$$

$$||$$

$$\overline{\hat{U}_{Ln} L_{ni}} M^u_{ij} \underline{R^\dagger_{jk}} \hat{U}_{Rk}$$

$$||$$

$$m^u_k \delta_{nk}$$

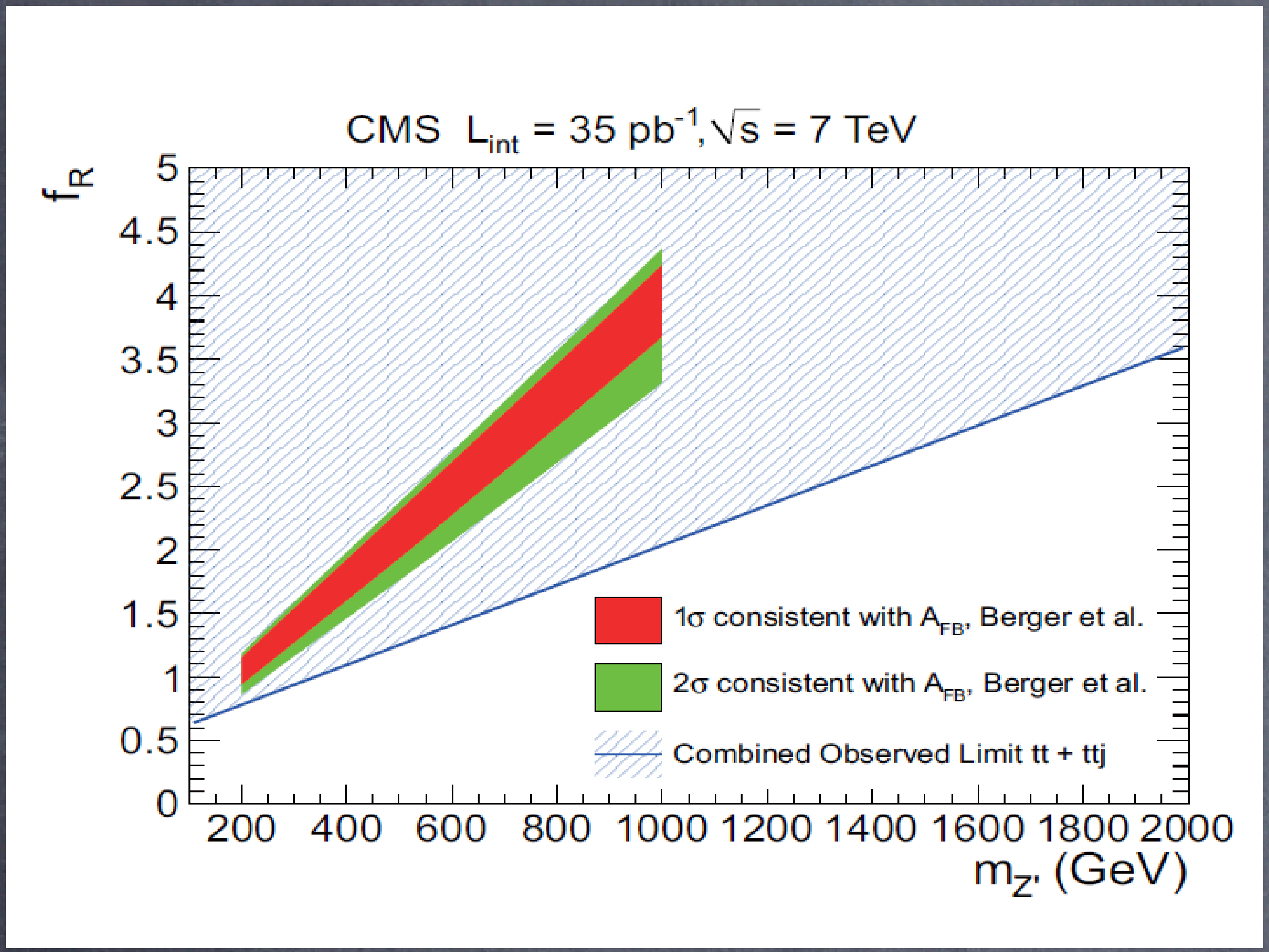
assumption

large (1,3) mixing

Large (t,u) elements in Z′ and (pseudo) scalar.

Small element (d,t) in charged Higgs.

- same-sign top @CMS

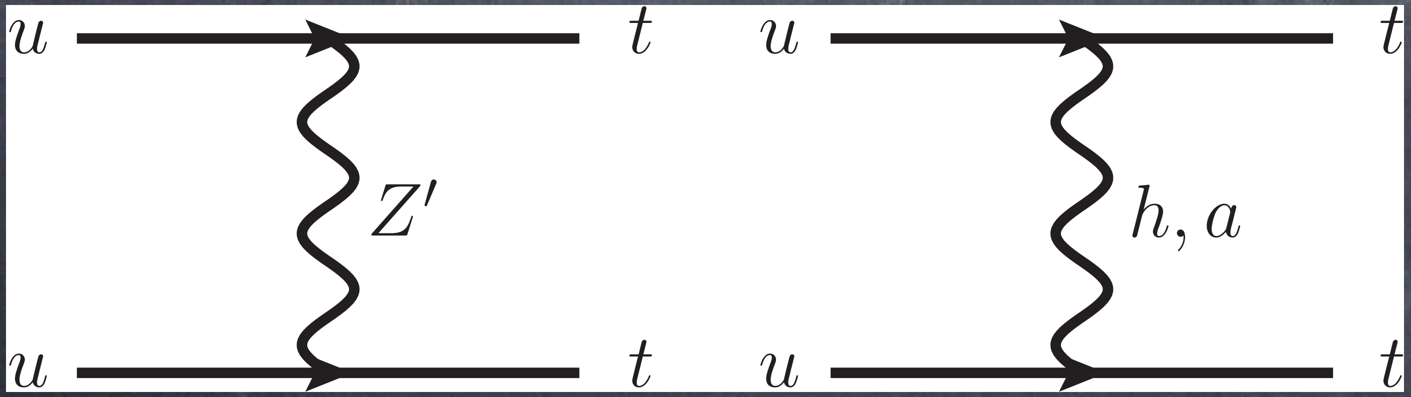


CMS, 1106.2142

The upper bound on the same-sign top

$$\sigma(tt) < 17pb$$

- In our models,

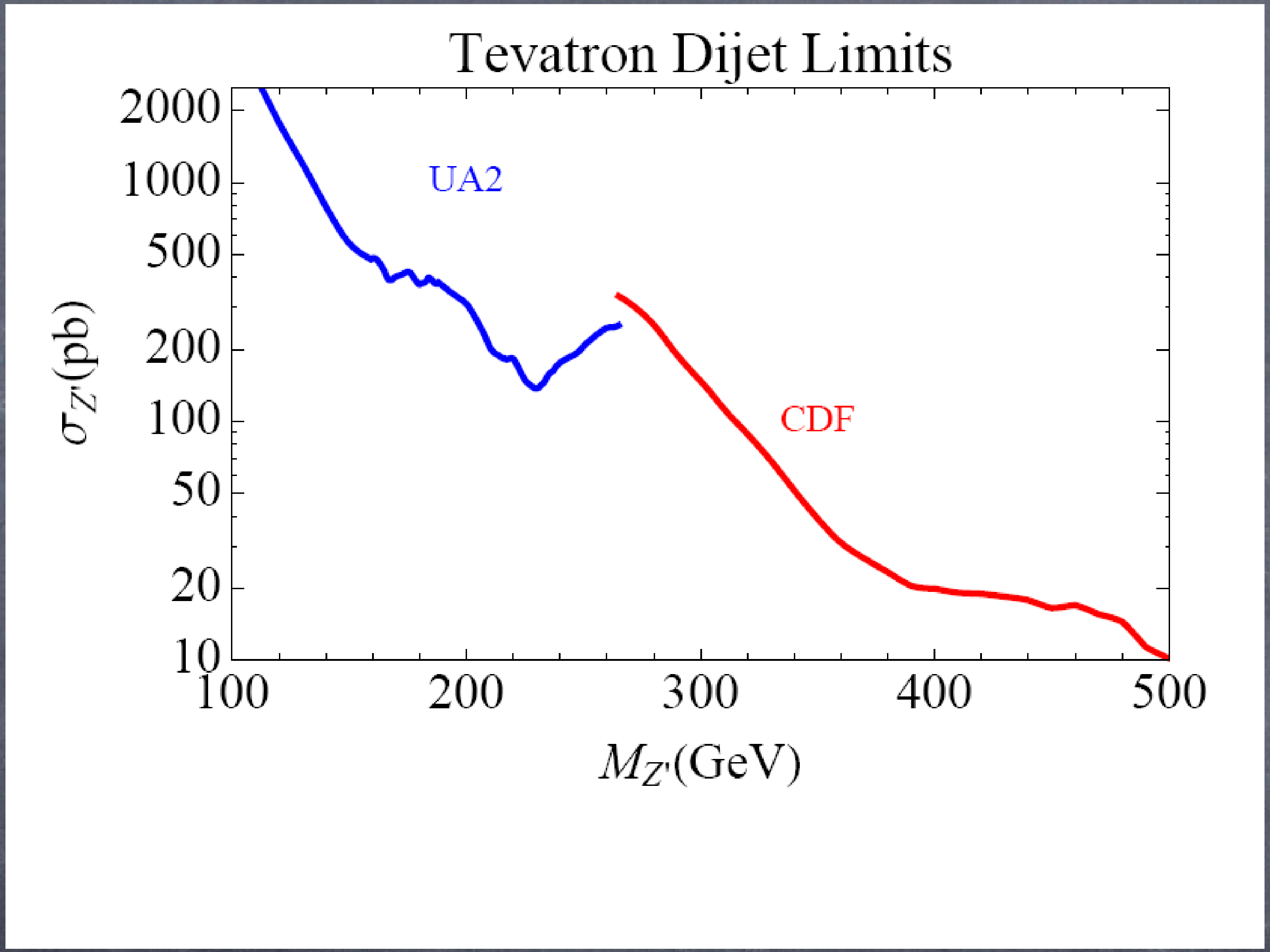


Interference can evade the strong bound!

Dijet bound

Fan, Krohn ,Langacker, Yavin, 1106.1682

an extra resonance couples to the quarks: bound from $p\bar{p} \to jj$



assumption in our models

$$M_{Z'} < 200 GeV$$

Top decay

decay into W+b in SM : Br(t→Wb)~100%.

assume Br(t →Z'u)<5% and $m_h > m_t$.

$m_{Z'}$= 145 or 160 GeV and m_h =180 GeV.

Heavy higgs is excluded by LHC.

From Korytov and Cranmer's talks, EPS-HEP 2011

The bounds are weaker because new decay channels are open.

$$h \to t, \overline{u}$$

$$h \to \Phi \to anything$$

Single top production

D0 D0, 1105.2788

$$\sigma(p\bar{p} \to tbq) = 2.90 \pm 0.59pb$$

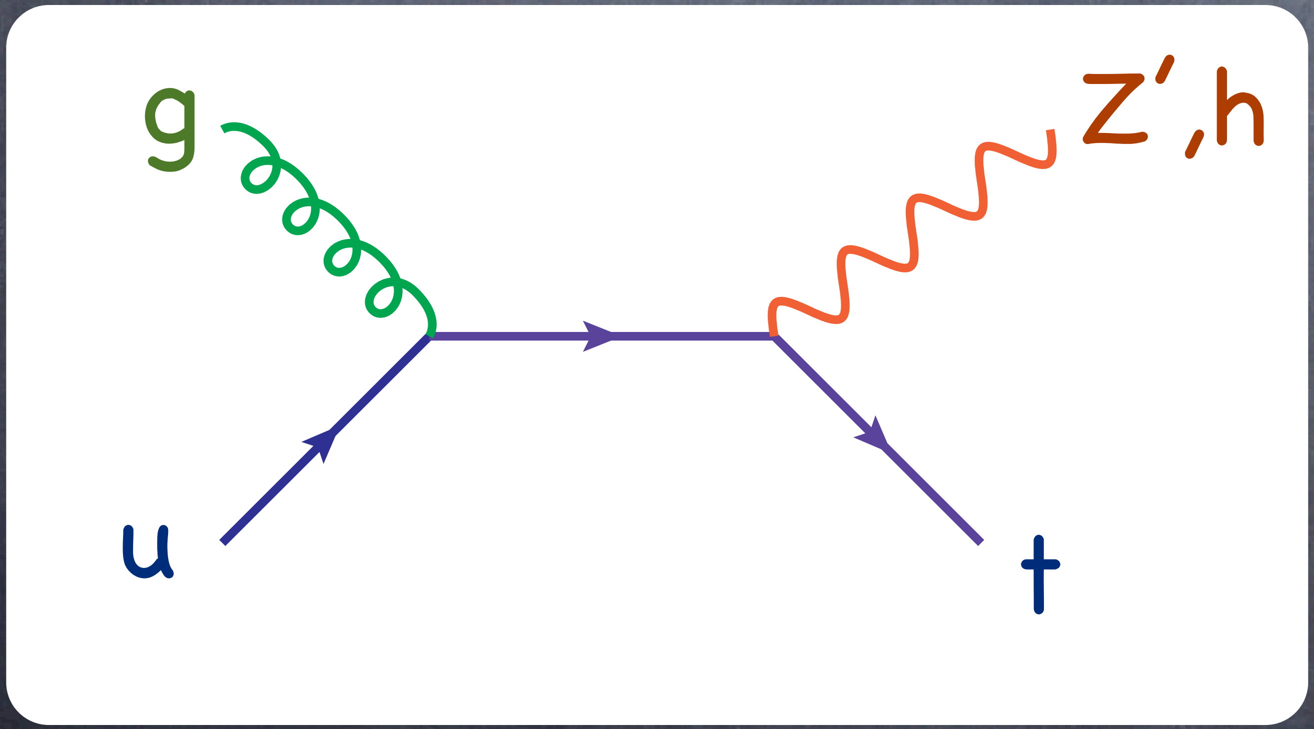
CMS CMS, 1106.3052

$$\sigma(pp \to tbq) = 83.6 \pm 29.8 \pm 3.3pb$$

In the SM,

$$\sigma(p\bar{p} \to tbq)_{SM} = 2.26 \pm 0.12pb$$

$$\sigma(pp \to tbq)_{SM} = 64.3^{+2.1+1.5}_{-0.7-1.7}pb$$

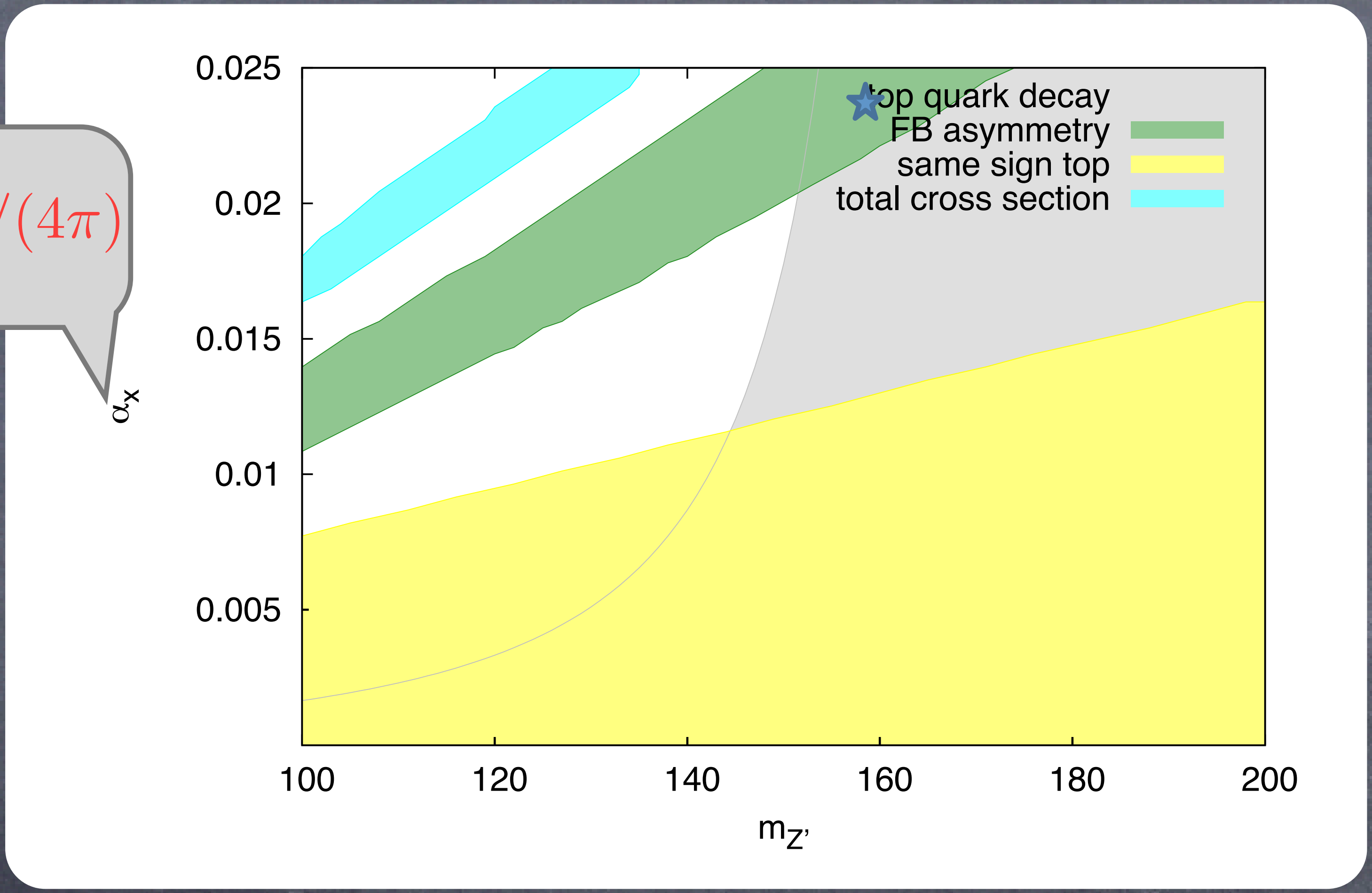


We do not have b in the final state!

Our results

- Z′ dominant case ((t,u) gauge coupling vs Z′ mass)

$$\alpha_x \equiv (g'(g^u_R)_{tu})^2/(4\pi)$$



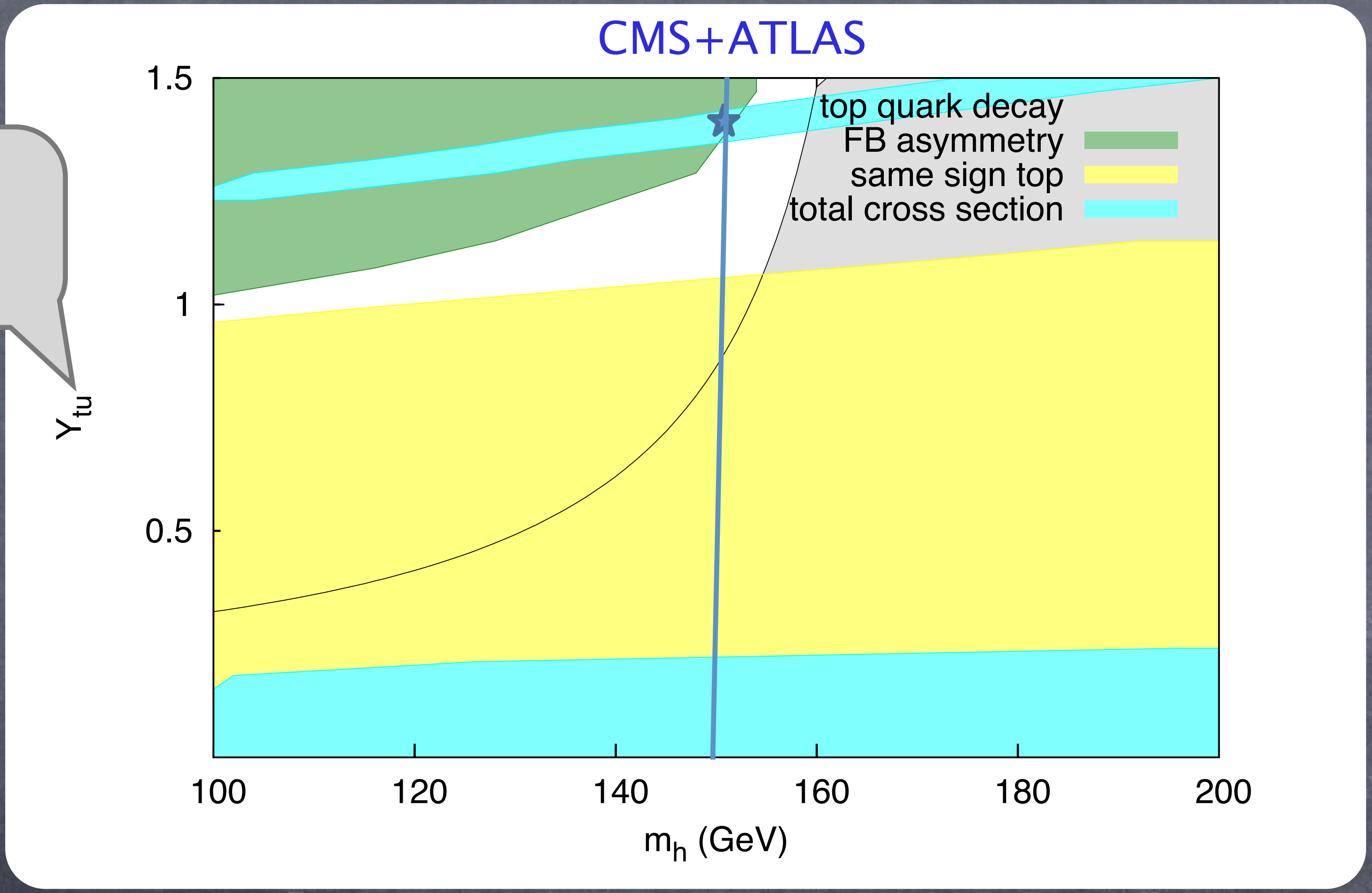
★ = Jung, Murayama, Pierce, Wells' model PRD81,015004 (2010)

Many models are excluded by the same-sign top!

Our results

- lightest scalar (h) dominant case ((t,u) Yukawa vs h mass)

(t,u) element of Yukawa



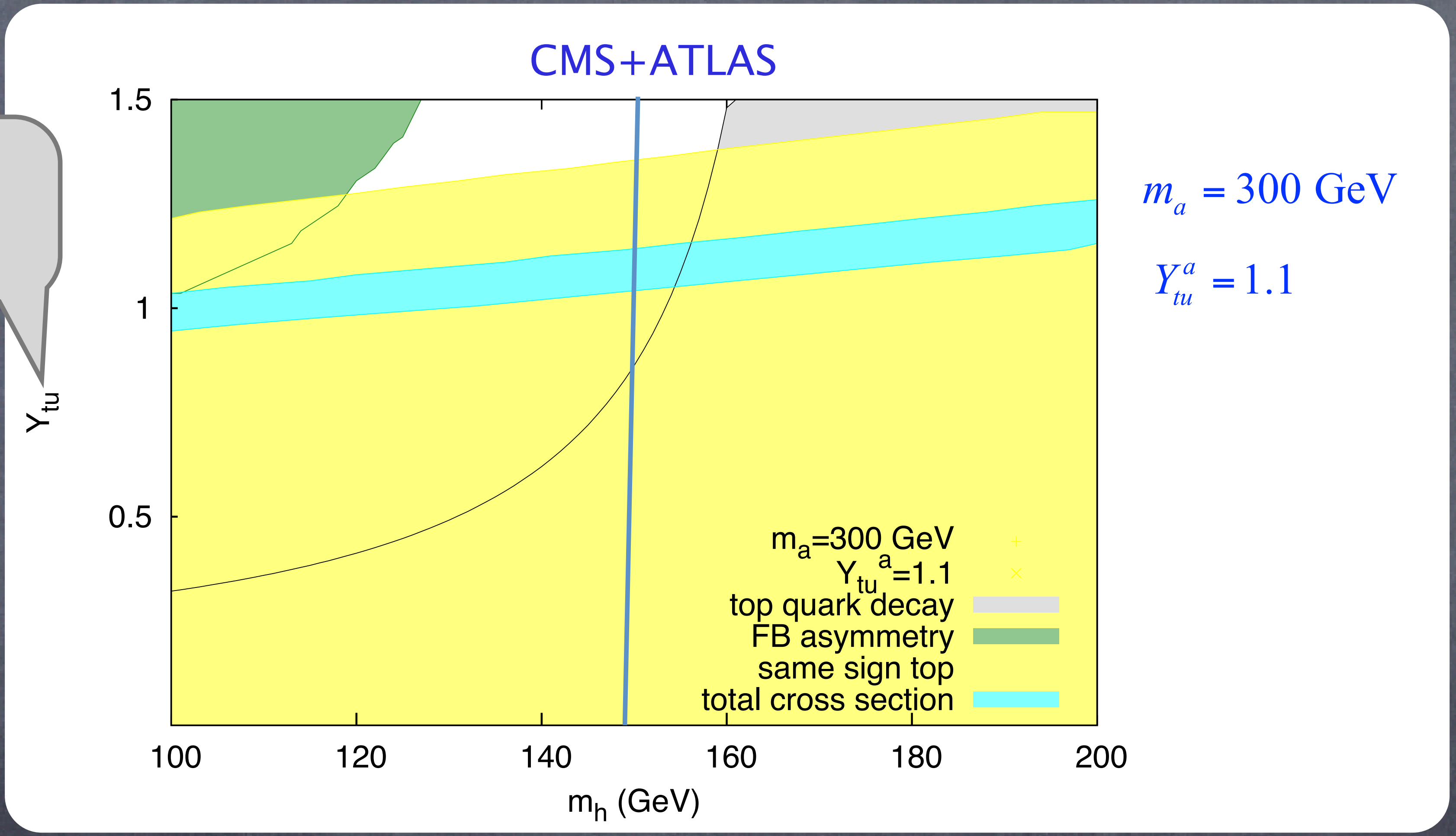
★= Babu, Frank, Rai's model 1104.4782

Many models are excluded by the same-sign top!

Our results

- lightest scalar (h) and pseudo-scalar (a) dominant

(t,u) element of Yukawa

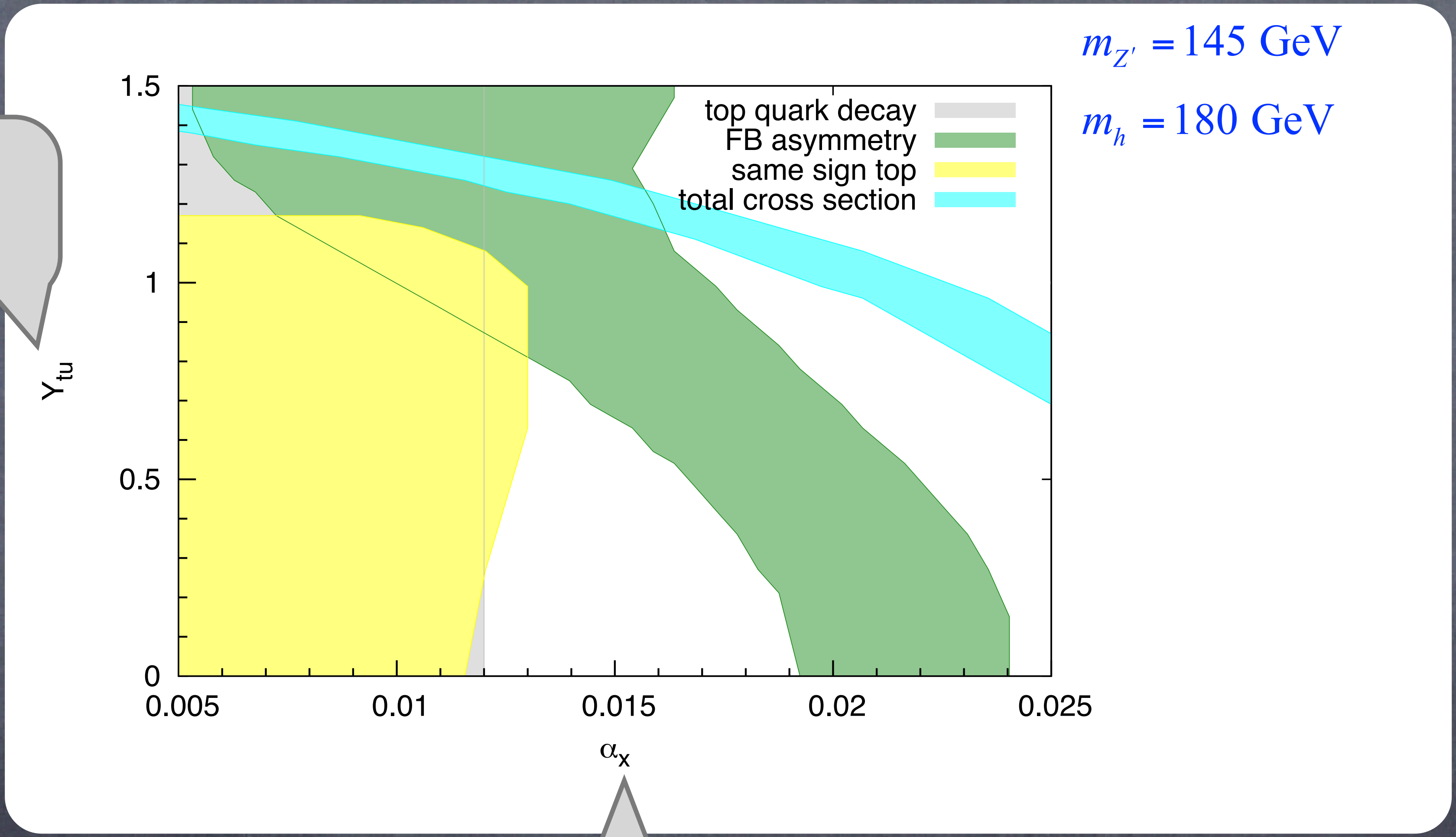


The same-sign top could be relaxed by pseudo-scalar!

Our results

- Z′+h case ((t,u)of gauge vs (t,u) of Yukawa) @mz′=145GeV

(t,u) element of Yukawa



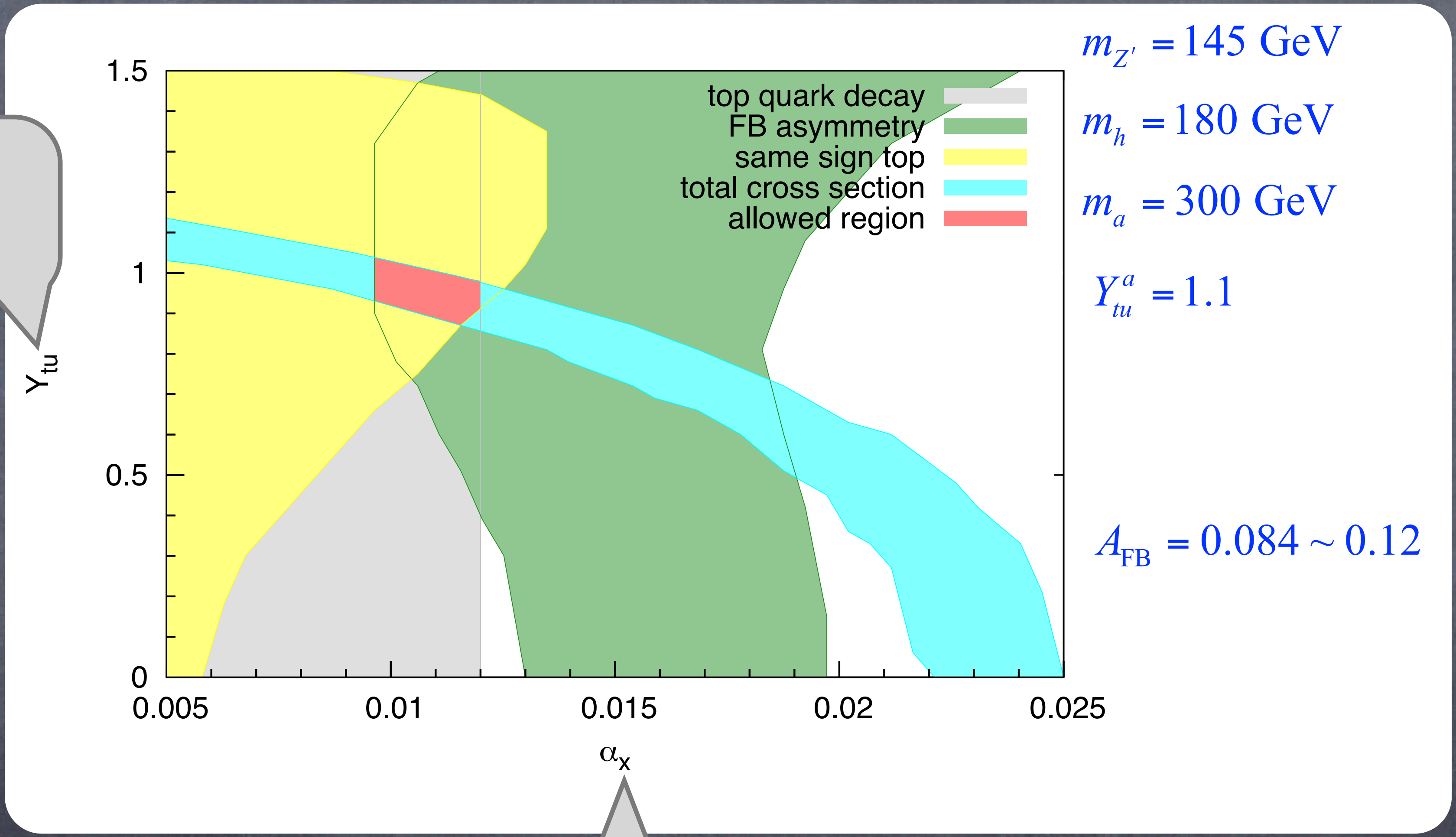
$\alpha_x \equiv (g'(g^u_R)_{tu})^2/(4\pi)$

Interference can relax the strong bound!

Our results

- Z′+h+a case ((t,u)of gauge vs (t,u) of Yukawa) @mz′=145GeV

(t,u) element of Yukawa



$\alpha_x \equiv (g'(g^u_R)_{tu})^2/(4\pi)$

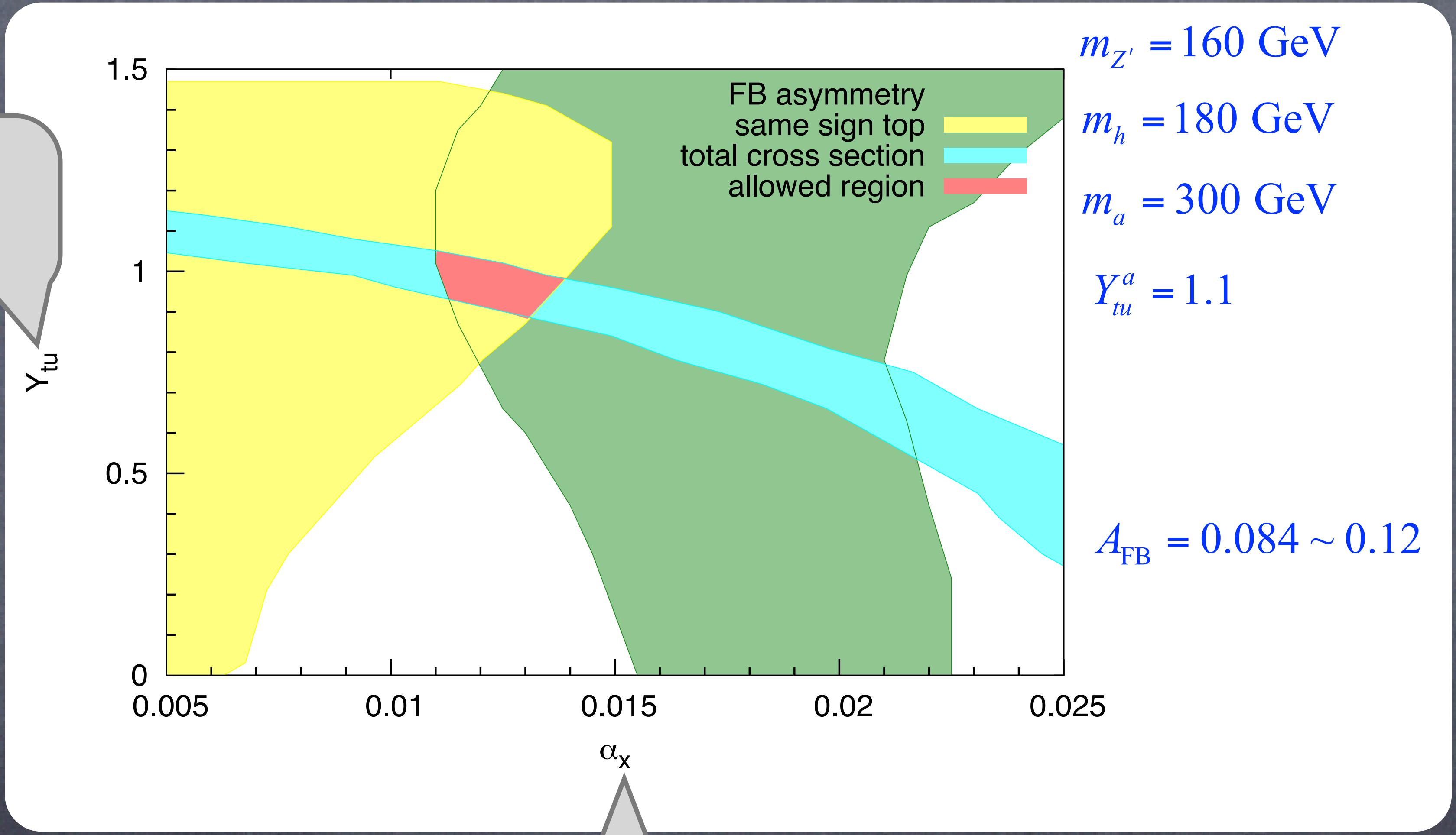
allowed region

$$(Y_{tu},\ \alpha_x) \sim (1,\ 0.01)$$ @mz′=145GeV

Our results

- Z′+h+a case ((t,u)of gauge vs (t,u) of Yukawa) @mz′=160GeV

(t,u) element of Yukawa



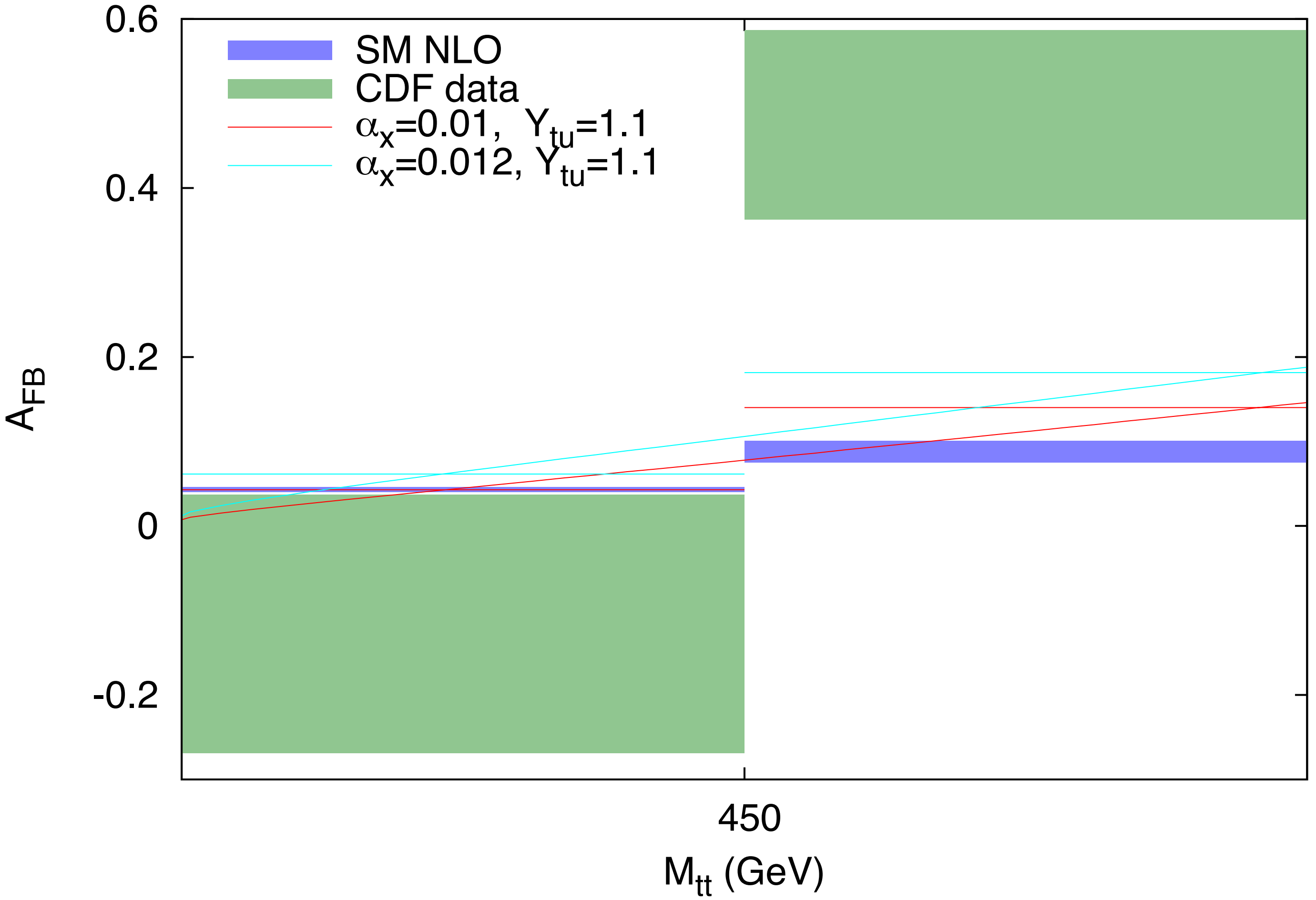
$$\alpha_x \equiv (g'(g^u_R)_{tu})^2/(4\pi)$$

allowed region

$$(Y_{tu},\ \alpha_x) \sim (1,\ 0.012)$$

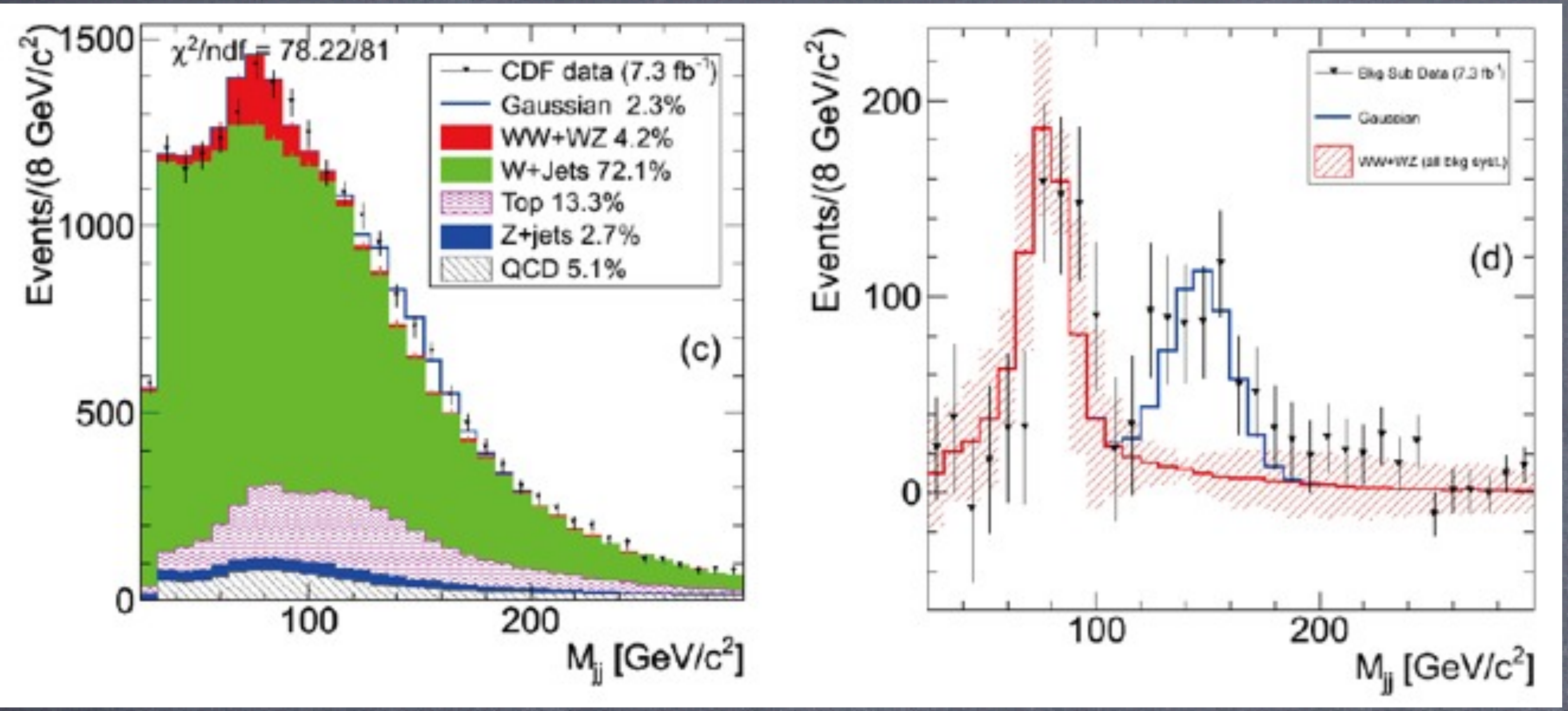
@mz′=160GeV

Mtt dependence of AFB



Wjj signal

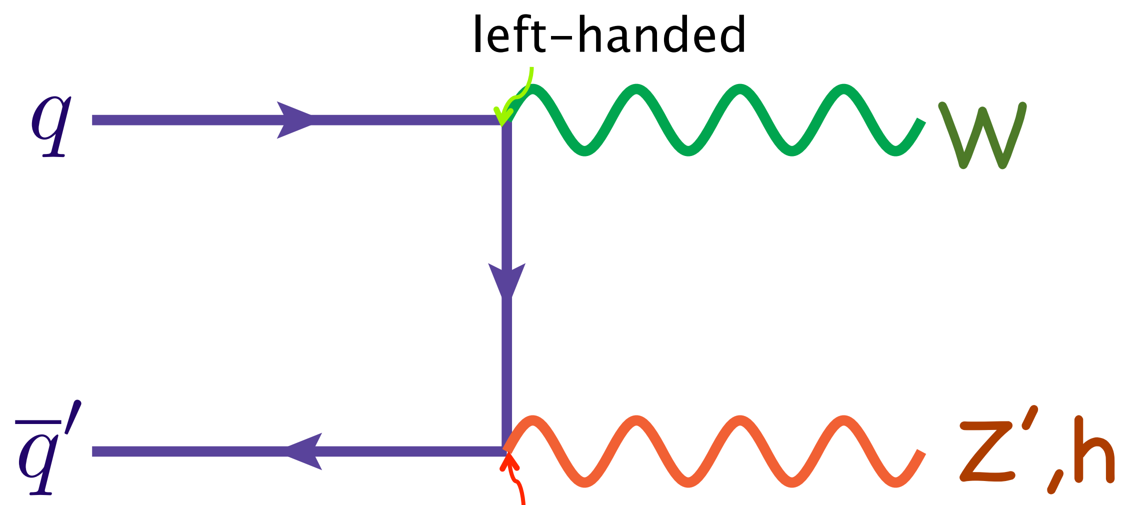
- CDF reported Wjj excess.



- 4.1 sigma deviation with 7.3 fb^{-1}.
- assume an additional Gaussian peak.
- $\sigma(p\bar{p} \to WX) \times Br(X \to jj)$ ~ 4 pb with $m_X \sim 145$ GeV.
- no evidence for anomalous, resonant production of dijets at D0.

Wjj signal

In our U(1)′ Flavor Models,

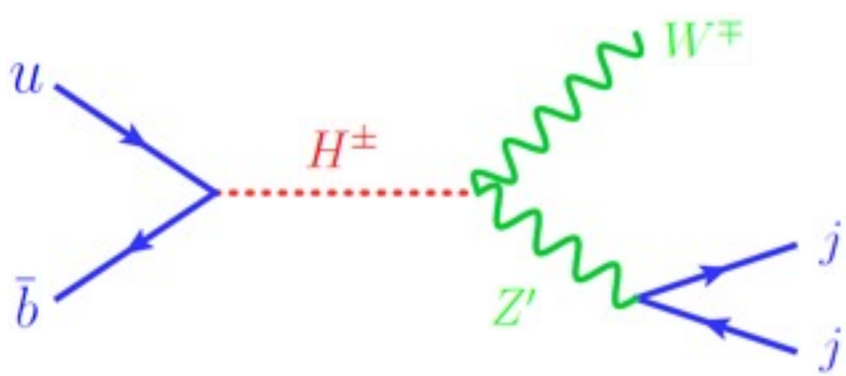


~small

heavy charged higgs could produce Z′ and W

$$\mathcal{L} = -g' m_W \sin 2\beta h^+ W^{-\mu} Z'_\mu + h.c..$$

(2HDM)



$m_{Z'}$ = 145 GeV

m_{h^+} = 270 GeV

$$\sigma(Wjj) \lesssim O(10) pb \times \sin^2 2\beta$$

4. Cold Dark Matters

- Leptophobic U(1) symmetry is usually anomalous
- We have to add extra chiral fields: extra generation (for U(1)' sum=0), two SM vector-like pairs (for $U(1)_Y U(1)'^2$)

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
Q'	3	2	1/6	$-(q_1+q_2+q_3)$
D'_R	3	1	$-1/3$	$-(d_1+d_2+d_3)$
U'_R	3	1	2/3	$-(u_1+u_2+u_3)$
L'	1	2	$-1/2$	0
E'	1	1	-1	0

This set gives

$$U(1)' = SU(3)^2 U(1)' = U(1)_Y^2 U(1)' = 0$$

but

$$U(1)_Y U(1)'^2 \neq 0$$

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	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
l_{L1}	1	2	$-1/2$	Q_L
l_{R1}	1	2	$-1/2$	Q_R
l_{L2}	1	2	$-1/2$	$-Q_L$
l_{R2}	1	2	$-1/2$	$-Q_R$

or

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
q_{L1}	3	1	$-1/3$	Q_L
q_{R1}	3	1	$-1/3$	Q_R
q_{L2}	3	1	$-1/3$	$-Q_L$
q_{R2}	3	1	$-1/3$	$-Q_R$

4. Cold Dark Matters

SU(2) doublet case

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
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l_{R1}	1	2	$-1/2$	Q_R
l_{L2}	1	2	$-1/2$	$-Q_L$
l_{R2}	1	2	$-1/2$	$-Q_R$

or

SU(3) triplet case

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
q_{L1}	3	1	$-1/3$	Q_L
q_{R1}	3	1	$-1/3$	Q_R
q_{L2}	3	1	$-1/3$	$-Q_L$
q_{R2}	3	1	$-1/3$	$-Q_R$

$$l_{Li} = (n_{Li}, l^-_{Li})$$

2 neutral + 2 charged pairs

U(1)' forbids the mixing with SM fileds

↓

stable charged and neutral

↓

radiative correction make charged heavier and neutral becomes CDM

4. Cold Dark Matters

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q_{R2}	3	1	$-1/3$	$-Q_R$

U(1)' forbids the mixing with SM fileds

↓

stable colored particles

↓

adding U(1)' charged scalar, X

$$\lambda_i X^\dagger \overline{D_{Ri}} q_{L1} + \lambda_i X \overline{D_{Ri}} q_{L2}$$

↓

X is CDM

5. Summary and Comments

- Construct complete U(1)′ models where RH up-type quarks are charged.
- require extra Higgs charged under U(1)′ for realistic mass matrices and renormalizability.
- Interference between Z′, h, and a contribute A_{FB} and evade strong bounds from top physics.
- Wjj is achieved by charged Higgs
- require chiral fermions for anomaly free → CDM

5. Summary and Comments

- How about theoretical motivations?

- Our flavor symmetry may be used to explain SM Yukawa textures, such as Froggatt-Nielsen(FN). But we have to consider very specific textures ((t,u) element is large) to avoid FCNC bounds and realize large A_{FB}. It may not be easily compatible with the solution of the hierarchy ......

- Other constraints

- EWPT: Z and Z' mix each other. It will strongly constrain Z' coupling, mass and $\tan\beta$.

- explicit FCNC constraints from $B_d - \overline{B_d}, \; B_s - \overline{B_s}, \; K_0 - \overline{K_0}, \; D_0 - \overline{D_0}$.

- against the Higgs bound from LHC

Thank you