PHENO 2018

Bottom-quark Forward-Backward Asymmetry, Dark Matter and the LHC

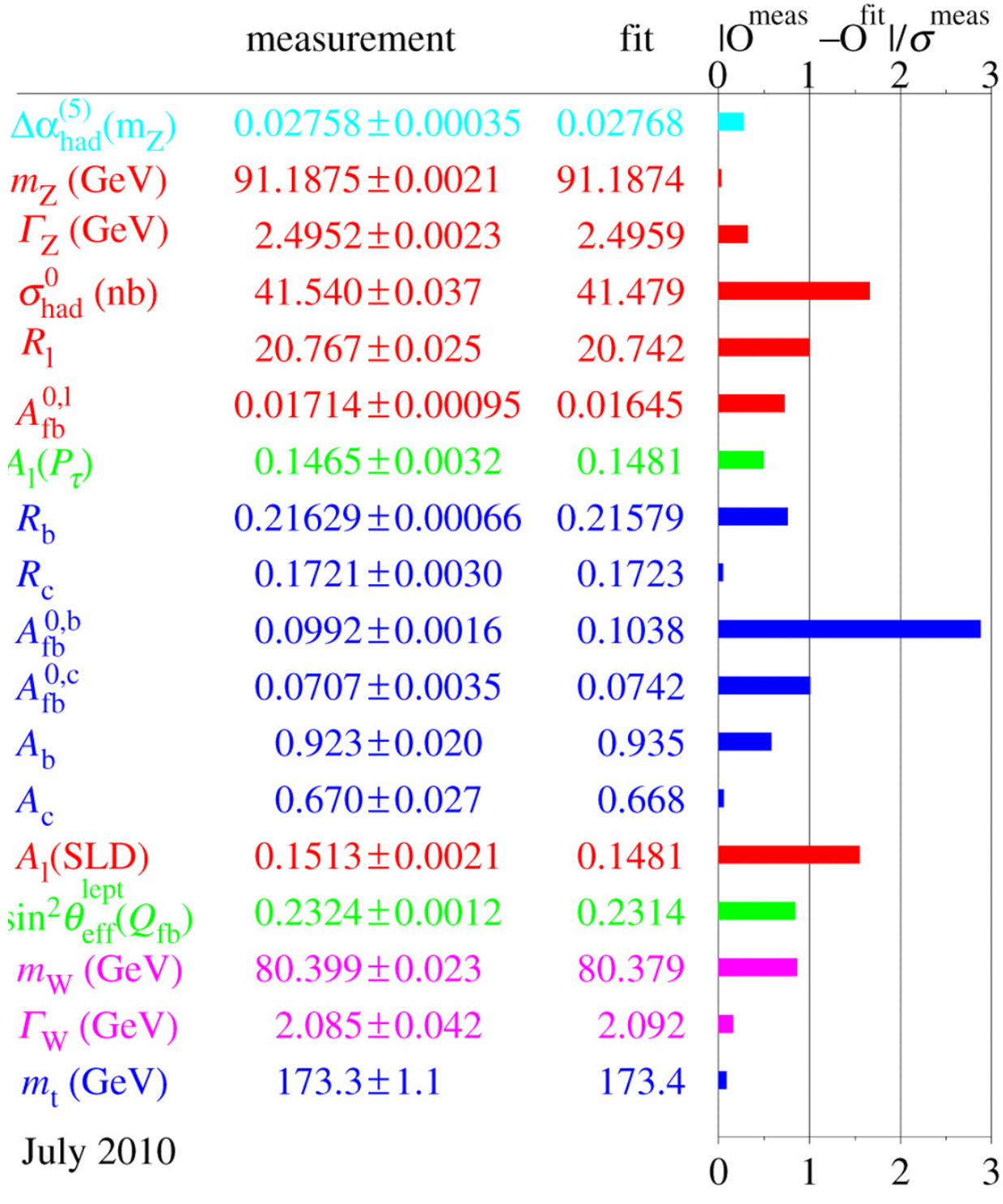
Xiao-Ping Wang

May, 7 @ pheno 2018

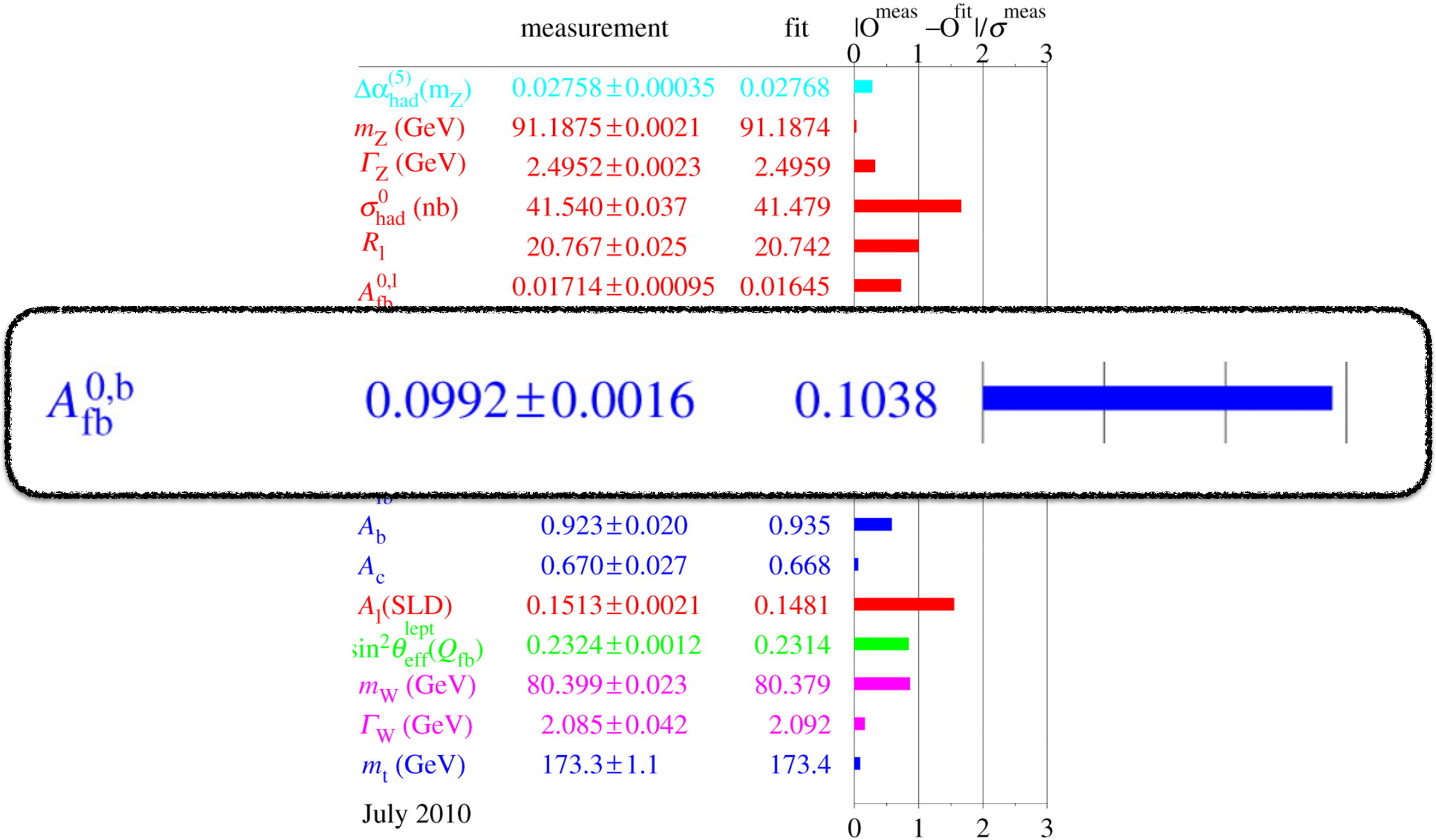
Collaborated with Da Liu, Jia Liu, and Carlos E.M. Wagner

PhysRevD.97.055021 [arXiv: 1712.05802]

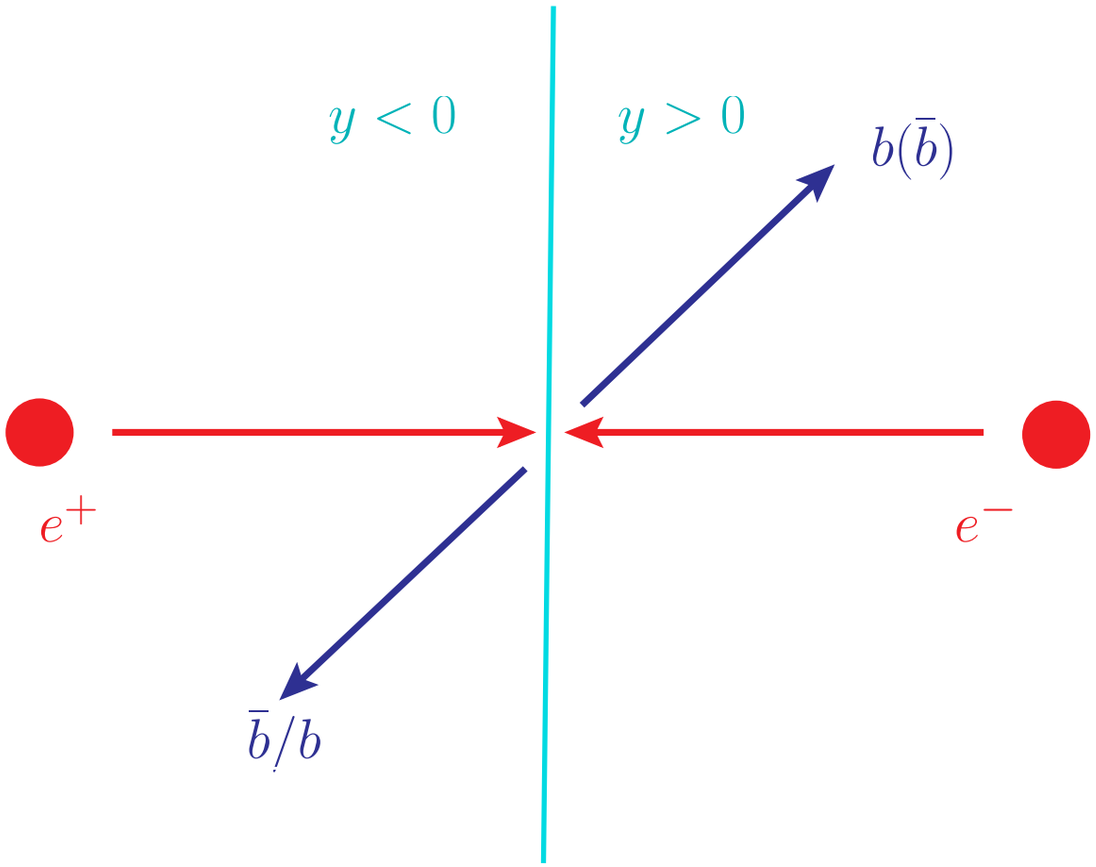
Electro-weak precision measurement



Electro-weak precision measurement



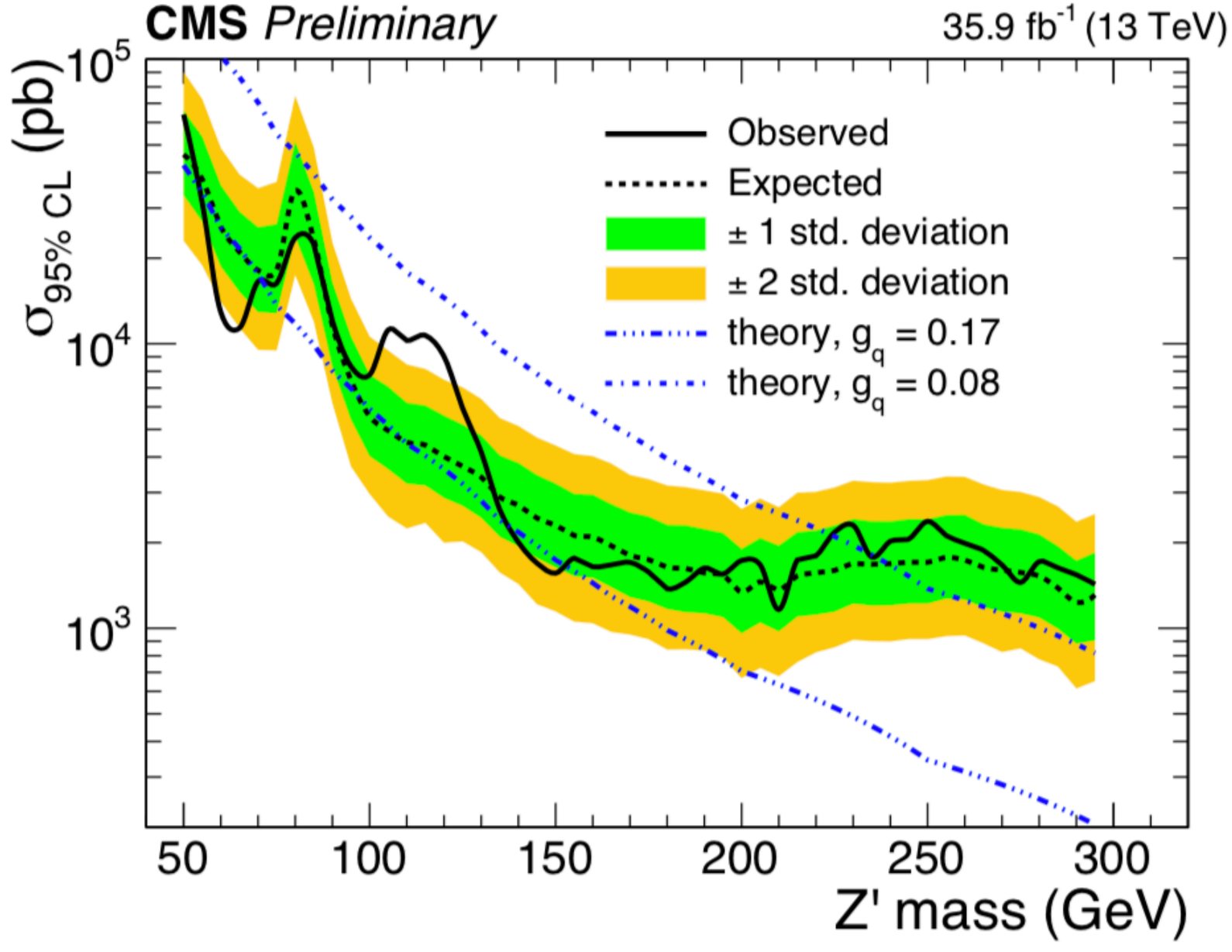
B-quark Forward-Backward Asymmetry



$$A_{FB}^{b} = \frac{\sigma(y>0) - \sigma(y<0)}{\sigma(y>0) + \sigma(y<0)}$$

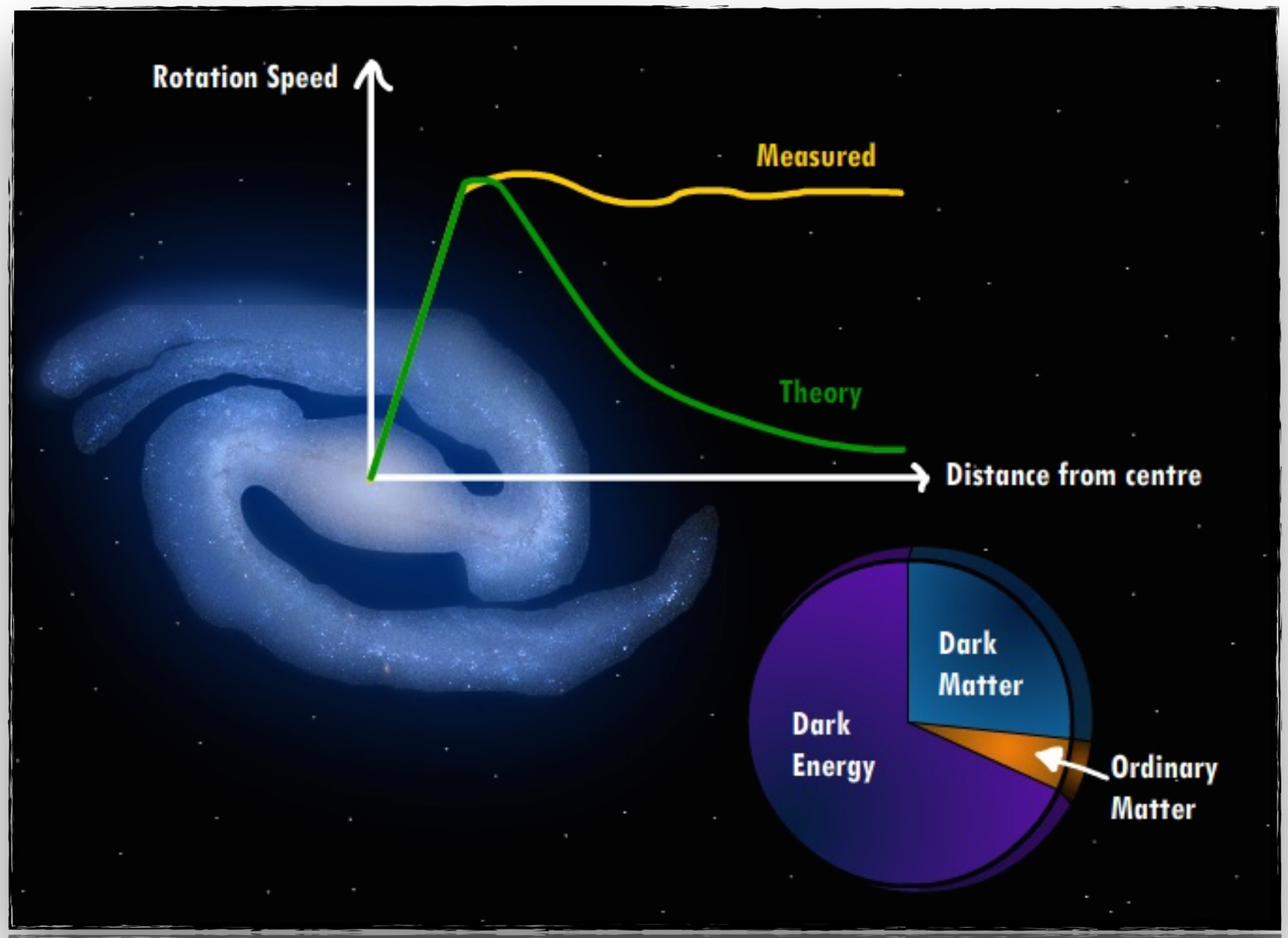
$$A_{FB}^{b} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_b = \frac{3}{4} \times \frac{(g_L^e)^2 - (g_R^e)^2}{(g_L^e)^2 + (g_R^e)^2} \times \frac{(g_L^b)^2 - (g_R^b)^2}{(g_L^b)^2 + (g_R^b)^2}$$

Di-jet search @ LHC



CMS-PAS-EXO-17-001

Dark Matter


Rotation Speed
Measured
Theory
Distance from centre
Dark Matter
Dark Energy
Ordinary Matter

2HDM+S Model

A_μ B_μ K_μ

filed	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_D$
Φ_1	1	2	$\frac{1}{2}$	X
Φ_2	1	2	$\frac{1}{2}$	0
Φ_3	1	1	0	-X
b_R	3	1	$-\frac{1}{3}$	X
c_R	3	1	$\frac{2}{3}$	-X
$\chi_{1,R}$	1	1	-1	X
$\chi_{2,R}$	1	1	0	-X
$\chi_{1,L}$	1	1	-1	0
$\chi_{2,L}$	1	1	0	0
ψ_b	3	1	$-\frac{1}{3}$	0
ψ_c	3	1	$\frac{2}{3}$	0

→ *Higgs Sector*

→ *Fermion Sector*

Gauge Sector

- **Mixing between mass eigenstates**

$$\begin{pmatrix} m_Z^2 & -\frac{2g_D c_\beta^2}{\sqrt{g^2+g'^2}} m_Z^2 \\ -\frac{2g_D c_\beta^2}{\sqrt{g^2+g'^2}} m_Z^2 & m_K^2 + \frac{4g_D^2 c_\beta^2}{g^2+g'^2} m_Z^2 \end{pmatrix} \Rightarrow \begin{pmatrix} Z_\mu \\ K_\mu \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \tilde{Z}_\mu \\ \tilde{K}_\mu \end{pmatrix}$$

$$m_{\tilde{Z}}^2 \approx m_Z^2 - \sin^2\alpha(m_K^2 - m_Z^2) \rightarrow \sim 10^{-3} m_Z^2$$

$$m_{\tilde{K}}^2 \approx m_K^2 + \frac{4g_D^2 c_\beta^2}{g^2+g'^2} m_Z^2 + \sin^2\alpha(m_K^2 - m_Z^2) \rightarrow \sim 0$$

Fermion Sector

- **Source of b mass**

$$\mathcal{L}_q = \sum_q i\bar{q}\not{D}q - m_{b,\psi}\bar{\psi}_b\psi_b - m_{c,\psi}\bar{\psi}_c\psi_c - \left(\bar{Q}^i_L y^{ij}_{2u}\tilde{\Phi}_2 u^j_R + \bar{Q}^i_L y^{ij}_{2d}\Phi_2 d^j_R + h.c.\right)$$

$$- y^i_{2b,\psi}\bar{Q}^i_L\Phi_2\psi_{b,R} - y^i_{2c,\psi}\bar{Q}^i_L\tilde{\Phi}_2\psi_{c,R} - y_{3b,\psi}\bar{\psi}_{b,L}\Phi_3 b_R - y_{3c,\psi}\bar{\psi}_{c,L}\Phi^*_3 c_R + h.c\,,$$

$$M_b = \begin{pmatrix} m_{b,\psi} & \frac{y_{3b,\psi}v_D}{\sqrt{2}} \\ \frac{y_{2b,\psi}v_2}{\sqrt{2}} & 0 \end{pmatrix} \equiv \begin{pmatrix} m_{b,\psi} & m^b_{12} \\ m^b_{21} & 0 \end{pmatrix}$$

If Define: $\begin{pmatrix} \psi_{b,L} \\ b_L \end{pmatrix} = \begin{pmatrix} c_{b,L} & s_{b,L} \\ -s_{b,L} & c_{b,L} \end{pmatrix} \begin{pmatrix} \tilde{\psi}_{b,L} \\ \tilde{b}_L \end{pmatrix}$ $\quad \begin{pmatrix} \psi_{b,R} \\ b_R \end{pmatrix} = \begin{pmatrix} c_{b,R} & s_{b,R} \\ -s_{b,R} & c_{b,R} \end{pmatrix} \begin{pmatrix} \tilde{\psi}_{b,R} \\ \tilde{b}_R \end{pmatrix}$

$$m_{\tilde{b}} \simeq -s_{b,L}s_{b,R}m_{b,\psi}$$

- **The same for c mass**

$$m_{\tilde{c}} \simeq -s_{c,L}s_{c,R}m_{c,\psi}$$

Z Interactions

- **Z interactions**

Z Interactions to SM particle

$$\mathcal{L}^Z_{int} = \tilde{Z}_\mu \left[\bar{\tilde{b}}_L \gamma^\mu \tilde{b}_L \frac{g\cos\alpha}{c_w} \left(\frac{s_w^2}{3} - \frac{1}{2} c_{b,L}^2 \right) + \bar{\tilde{b}}_R \gamma^\mu \tilde{b}_R \left(\frac{g s_w^2}{3 c_w} \cos\alpha - g_D \sin\alpha c_{b,R}^2 \right) \right]$$

$$+ \tilde{Z}_\mu \left[\bar{\tilde{c}}_L \gamma^\mu \tilde{c}_L \frac{g\cos\alpha}{c_w} \left(-\frac{2 s_w^2}{3} + \frac{1}{2} c_{c,L}^2 \right) + \bar{\tilde{c}}_R \gamma^\mu \tilde{c}_R \left(-\frac{2 g s_w^2}{3 c_w} \cos\alpha + g_D \sin\alpha c_{c,R}^2 \right) \right]$$

$$+ \frac{g\cos\alpha s_w^2}{3 c_w} \tilde{Z}_\mu \left\{ \left[c_{b,L}^2 \bar{\tilde{\psi}}_{b,L} \gamma^\mu \tilde{\psi}_{b,L} + (L \leftrightarrow R) \right] - 2 \left[c_{c,L}^2 \bar{\tilde{\psi}}_{c,L} \gamma^\mu \tilde{\psi}_{c,L} + (L \leftrightarrow R) \right] \right\}$$

$$+ \tilde{Z}_\mu \left[\left(\frac{g\cos\alpha \; c_{b,L} s_{b,L}}{2 c_w} \bar{\tilde{\psi}}_{b,L} \gamma^\mu \tilde{b}_L + g_D \sin\alpha \; c_{b,R} s_{b,R} \; \overline{\tilde{\psi}}_{b,R} \gamma^\mu \tilde{b}_R + h.c. \right) - (b \leftrightarrow c) \right]$$

Heavy NP particles' decay

Electroweak Precision Measurement

✤ T parameter

$$\hat{\alpha}(m_Z)T = -\frac{\Delta m_Z^2}{m_Z^2} \sim \sin^2\alpha \frac{m_K^2 - m_Z^2}{m_Z^2} \quad \in [-0.00121, 0.00246]$$

✤ Z pole measurement

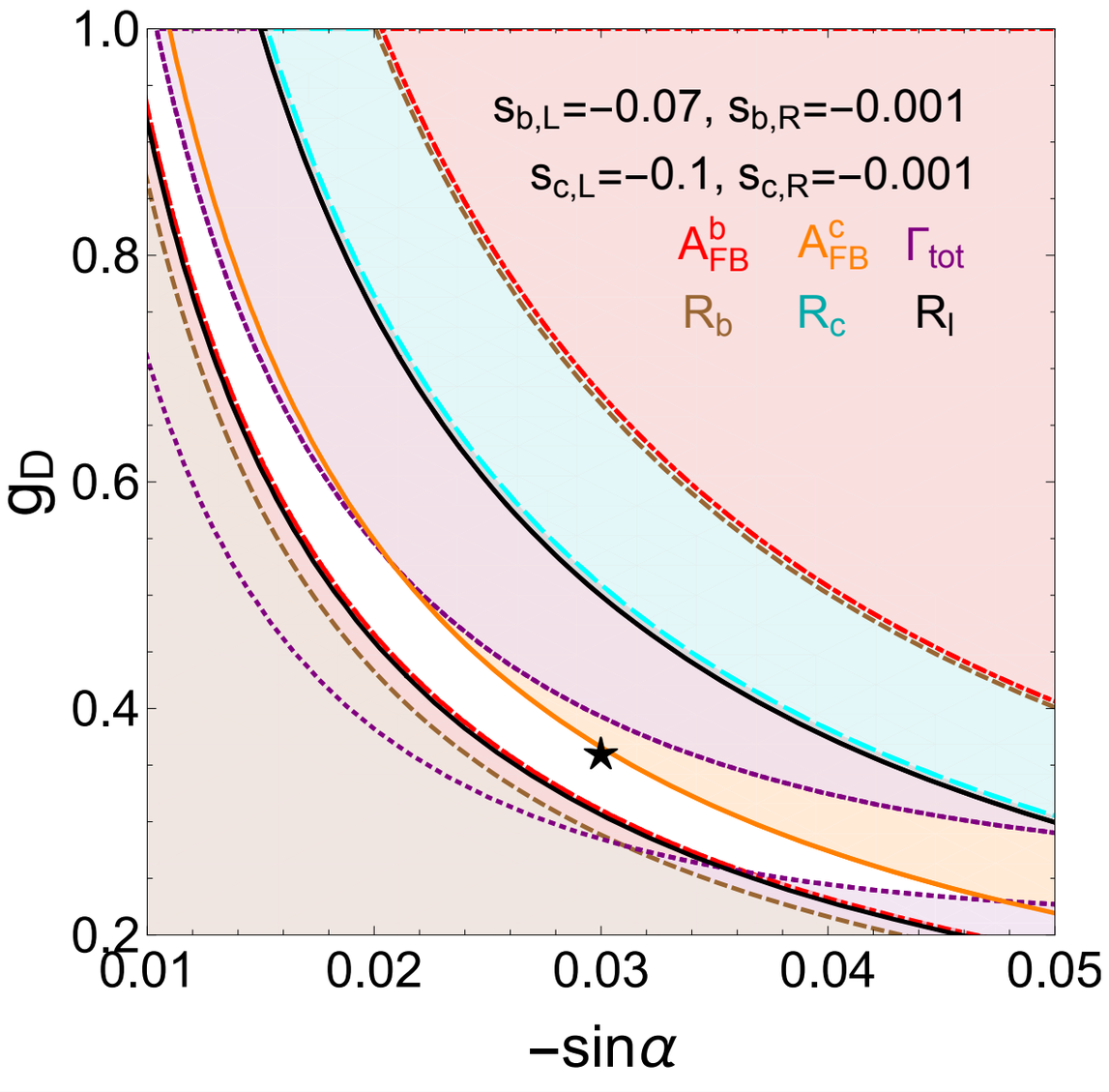
$$R_{b,c} \equiv \frac{\Gamma(\tilde{Z} \to \tilde{b}\bar{\tilde{b}}(\tilde{c}\bar{\tilde{c}}))}{\Gamma(\tilde{Z} \to \text{hadrons})} \simeq \frac{\left(g_L^{(\tilde{b},\tilde{c})}\right)^2 + \left(g_R^{(\tilde{b},\tilde{c})}\right)^2}{\sum_q \left(g_L^q\right)^2 + \left(g_R^q\right)^2}$$

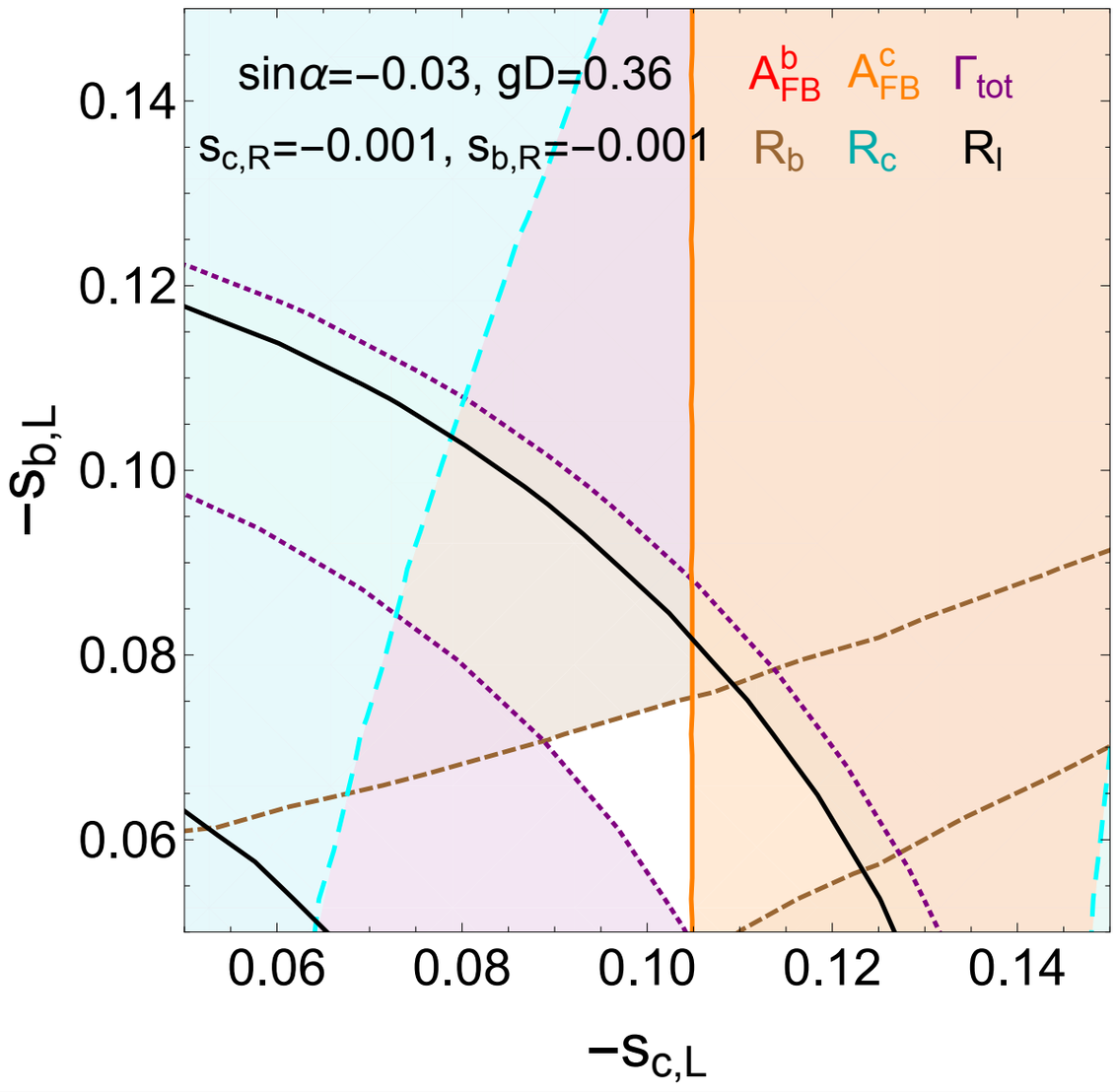
$$A_{FB}^{b,c} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_{b,c} \simeq \frac{3}{4}\mathcal{A}_e \frac{\left(g_L^{(\tilde{b},\tilde{c})}\right)^2 - \left(g_R^{(\tilde{b},\tilde{c})}\right)^2}{\left(g_L^{(\tilde{b},\tilde{c})}\right)^2 + \left(g_R^{(\tilde{b},\tilde{c})}\right)^2}$$

With $\mathcal{A}_f \equiv \frac{\left(g_L^f\right)^2 - \left(g_R^f\right)^2}{\left(g_L^f\right)^2 + \left(g_R^f\right)^2}$

$$R_\ell \equiv \frac{\Gamma_{\text{hadron}}}{\Gamma_{\ell\ell}}$$

Electroweak Precision Measurement





K Interactions

✤ $\tilde{K}$ interactions

Interaction to SM particles

$$\mathcal{L}^K_{int} = \frac{g\sin\alpha}{c_w}\tilde{K}_\mu J^\mu_{Z,q} + \tilde{K}_\mu\left[\bar{\tilde{b}}_L\gamma^\mu b_L\frac{g\sin\alpha}{c_w}\left(\frac{s_w^2}{3}-\frac{1}{2}c^2_{b,L}\right)+\bar{\tilde{b}}_R\gamma^\mu\tilde{b}_R\left(\frac{gs_w^2}{3c_w}\sin\alpha+g_D\cos\alpha c^2_{b,R}\right)\right]$$

$$+\tilde{K}_\mu\left[\bar{\tilde{c}}_L\gamma^\mu c_L\frac{g\sin\alpha}{c_w}\left(-\frac{2s_w^2}{3}+\frac{1}{2}c^2_{c,L}\right)+\bar{\tilde{c}}_R\gamma^\mu\tilde{c}_R\left(-\frac{2gs_w^2}{3c_w}\sin\alpha-g_D\cos\alpha c^2_{c,R}\right)\right]$$

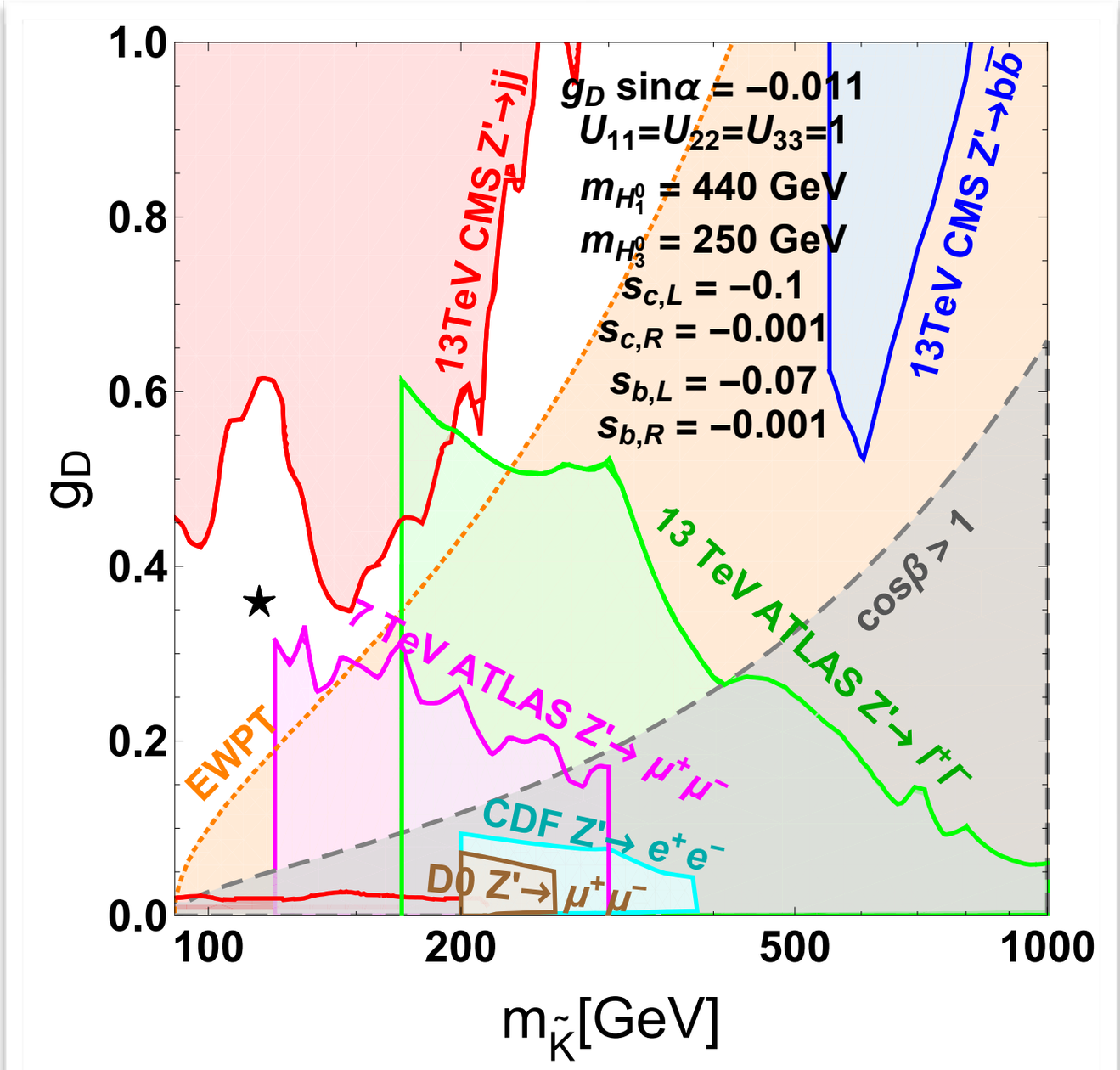
$$+\tilde{K}_\mu\left(\bar{\tilde{\psi}}_{b,L}\gamma^\mu\tilde{b}_L\frac{g}{2c_w}\sin\alpha c_{b,L}s_{b,L}-\bar{\tilde{\psi}}_{b,R}\gamma^\mu\tilde{b}_R g_D\cos\alpha c_{b,R}s_{b,R}\right)$$

$$-\tilde{K}_\mu\left(\bar{\tilde{\psi}}_{c,L}\gamma^\mu\tilde{c}_L\frac{g}{2c_w}\sin\alpha c_{c,L}s_{c,L}-\bar{\tilde{\psi}}_{c,R}\gamma^\mu\tilde{c}_R g_D\cos\alpha c_{c,R}s_{c,R}\right)$$

Heavy particles' decay

$\tilde{K}$ Search @ colliders

- $\tilde{K}$ **Constraint**



Dark Matter Search

✤ Lagrangian for Dirac case

$$\mathcal{L}_{\chi 2} \simeq -g_D \cos\alpha \tilde{K}_\mu \bar{\chi}_{2,R} \gamma^\mu \chi_{2,R} + g_D \sin\alpha \tilde{Z}_\mu \bar{\chi}_{2,R} \gamma^\mu \chi_{2,R}$$
$$+ \frac{m_{\chi 2}}{v_D} \bar{\chi}_2 \chi_2 \left(\frac{v}{v_D} \cos\beta H_1^0 + U_{23} H_2^0 - U_{33} H_3^0 \right) + i \frac{m_{\chi_2} v}{v_D^2} \cos\beta A^0 \bar{\chi}_2 \gamma_5 \chi_2$$

$$(+\frac{1}{2} M_m \bar{\chi}_{2,L} \chi_{2,L}^c)$$

✤ Simplify for Majorana case

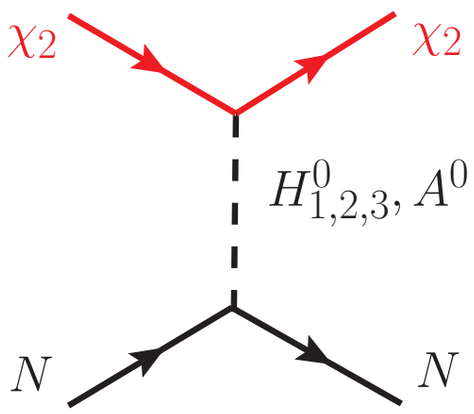
$$\mathcal{L}_{\chi_2'} \simeq \begin{cases} \frac{-g_D}{2} \bar{\chi'}_2 \gamma^\mu \gamma_5 \chi_2' \left(\cos\alpha \tilde{K}_\mu + \sin\alpha \tilde{Z}_\mu \right) - \frac{m_{\chi 2}}{v_D} \bar{\chi'}_2 \chi_2' U_{33} H_3^0 & (M_m \ll m_{\chi 2}) \\ -g_D \bar{\chi'}_2 \gamma^\mu \gamma_5 \chi_2' \left(\cos\alpha \tilde{K}_\mu + \sin\alpha \tilde{Z}_\mu \right) & (M_m \gg m_{\chi 2}) \end{cases}$$

Majorana Dark Matter Search

✣ Annihilation Cross section

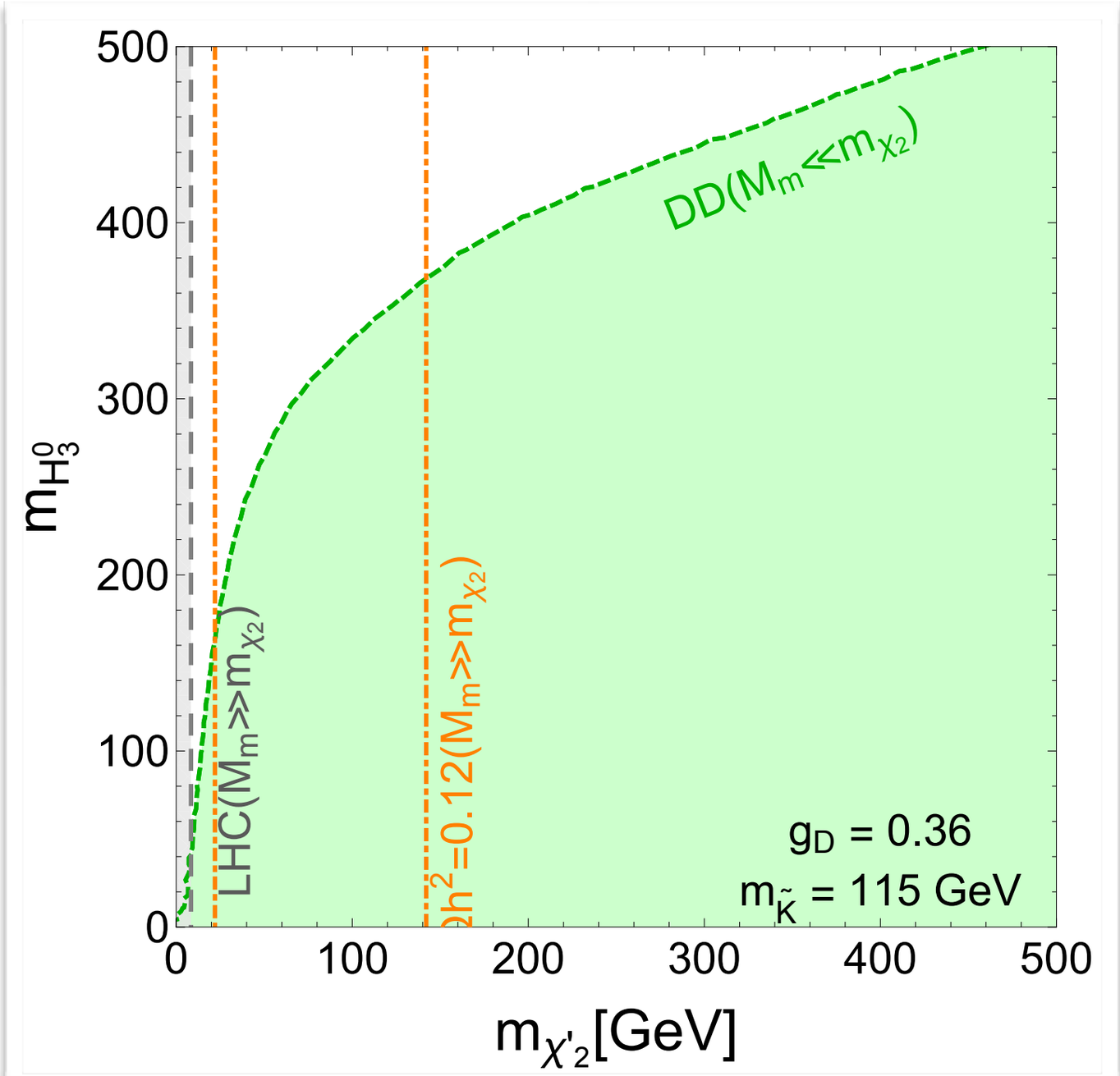
$$(\sigma v)^{q=b,c}_{\chi_2'\bar{\chi}'_2\to\bar{q}q} = \frac{g_D^4 c_{\chi_2}^2 \sqrt{1-\frac{4m_q^2}{s}}}{4\pi\left[(s-m_{\tilde{K}}^2)^2+m_{\tilde{K}}^2\Gamma_{\tilde{K}}^2\right]}\left\{(s-4m_{\tilde{\chi}_2}^2)+m_q^2\left[2m_{\chi_2'}^2\left(\frac{5m_{\tilde{K}}^4-6m_{\tilde{K}}^2 s+3s^2}{sm_{\tilde{K}}^4}\right)-1\right]\right\}$$

✣ Direct Detection



$$\sigma_N^{\mathrm{SI}} = \frac{16\mu_N^2}{729\pi v_D^4}\left(f_{\mathrm{TG}}^{(N)}\frac{m_{\chi_2'}m_N}{m_{H_3^0}^2}\right)^2$$

Majorana Dark Matter Search



Summary

- A_{FB}^{b} **Anomaly**

★ Can be explained via a new U(1) gauge boson.

- **Dark Matter Candidate:**

★ Vector like singlet which can cancel the anomaly can be dark matter candidate.Dark Matter Candidate:

- **CMS di-jet resonance excess:**

★ Can be explained by the U(1) gauge boson with mass 115 GeV.

Any Questions?