Forward-backward asymmetry in the gauge-Higgs unification at the International Linear Collider

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Gauge-Higgs Unification

$$A_M = (A_\mu, A_y)$$

A_y → Higgs boson

The Higgs mass is protected by a gauge symmetry

The Higgs boson obtains finite mass at 1-loop level

Effective potential is written by Wilson line phase

$$\theta_H \equiv g \int_C dy \langle A_y \rangle$$

Hosotani mechanism

Y. Hosotani (1983)
H. Hatanaka, T. Inami, C.S. Lim (1998)

SO(5) × U(1) GHU

On the Randall-Sundrum warped (AdS) spacetime

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

Agashe, Contino, Pomarol (2005)
Contino, Da Rold, Pomarol (2007)
Medina, Shah, Wagner (2007)
Sakamura, Hosotani (2007)
Hosotani, Oda, Ohnuma, Sakamura (2008)
SF, Hatanaka, Hosotani, Orikasa, Shimotani (2013)

SO(5) × U(1) GHU

$$SO(5) \times U(1)_X$$

$$\xrightarrow[\text{B.C.}]{} SO(4) \times U(1)_X$$

$W_R,\ Z_R$

$$\simeq SU(2)_L \times SU(2)_R \times U(1)_X$$

$$\xrightarrow[\text{Brane int.}]{} SU(2)_L \times U(1)_Y$$

$W,\ Z,\ \gamma$

$$\xrightarrow[\text{Hosotani mechanism}]{} U(1)_{\rm EM}$$

Higgs couplings

$$\boxed{\begin{matrix} HWW \\ HZZ \end{matrix}} \simeq \boxed{\begin{matrix} \text{SM} \\ \text{value} \end{matrix}} \times \cos\theta_H$$

$$\begin{matrix} \Gamma(H \to WW) \\ \Gamma(H \to ZZ) \end{matrix} \simeq \boxed{\begin{matrix} \text{SM} \\ \text{value} \end{matrix}} \times \cos^2\theta_H$$

$\sin\theta_H$ corresponds to ξ in MCHMs

Γ(H→γγ) and Γ(H→Zγ) are evaluated in
SF, Hatanaka, Hosotani, Orikasa, Shimotani (2013)
SF, Hatanaka, Hosotani (2015)

Comments on MCHM

Agashe et al, argue

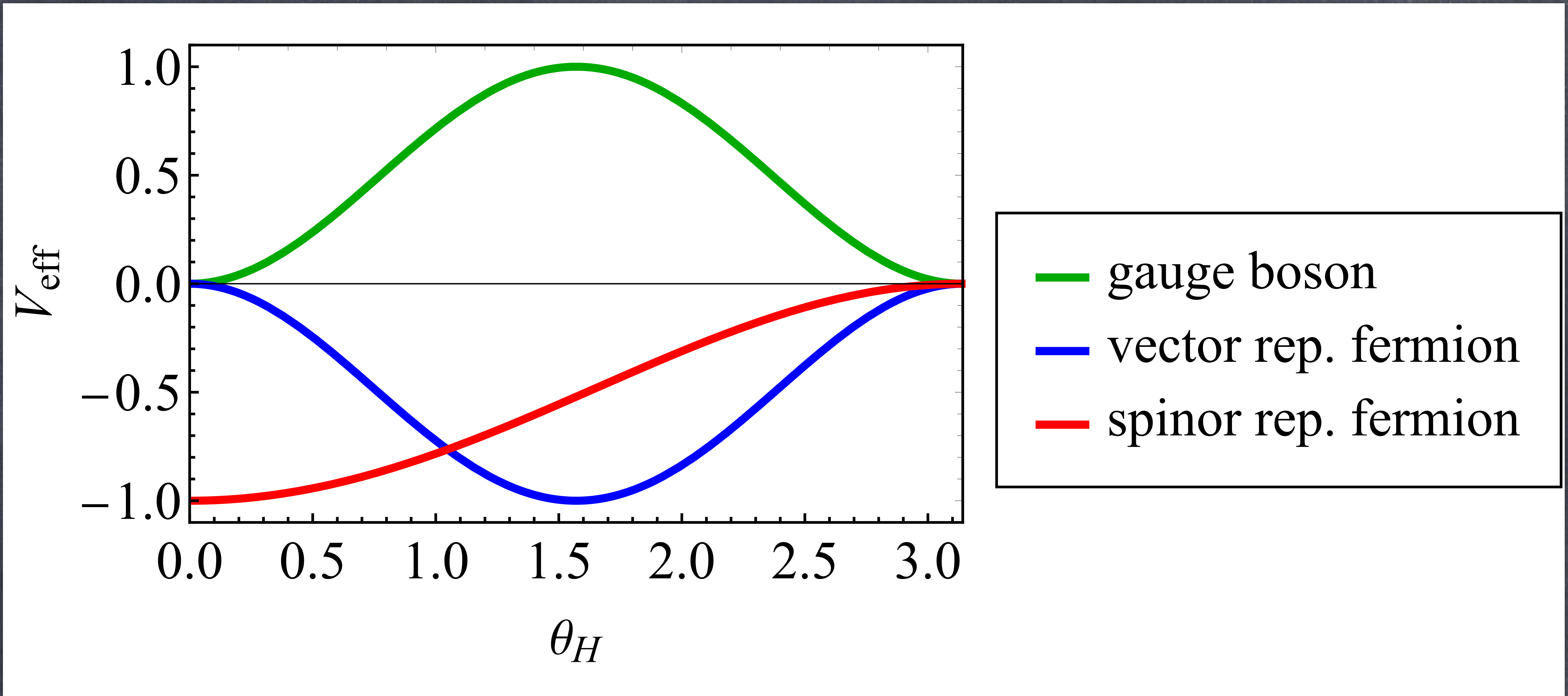
4D CFT	⟷	5D AdS
pNGB		Ay
	holography	

GHU on RS = holographic composite Higgs model

GHU has

- calculable effective potential
- restricted Lagrangian

Effective Potential



Both vector-rep. and spinor-rep. are necessary to obtain $\theta_H \neq 0, \pi/2$

matter content

Two types of the SO(5) × U(1) GHU models

- quarks in **5** and non-SM fermions in **4**
  left-handed quarks in (**2**, **2**)
  right-handed quarks in (**1**, **1**)

SF, Hatanaka, Hosotani, Orikasa, Shimotani (2013)

Today's talk

- quarks in **4** and non-SM fermions in **5**
  left-handed quarks in (**2**, **1**)
  right-handed quarks in (**1**, **2**)

SF, Hatanaka, Hosotani, Orikasa, Yamatsu (2019)

Parameters

- metric: $k,\ e^{kL}$ $\quad m_Z$
- gauge: $g_W^{(5D)},\ g_X^{(5D)}$ $\quad \alpha_{\rm EM},\ \sin^2\theta_W$
- fermion: $c_t,\ r_t$ $\quad m_t,\ m_b$

  c_F $\quad m_H$

  $(c \equiv m^{(5D)}/k)$

▶

One parameter e^{kL} → $\theta_H,\ m_{\rm KK}$ is determined

Parameters

Upper bound by LHC

θ_H	e^{kL}	$\lvert c_t \rvert$	$m_{\rm KK}$ (GeV)
0.10	2.90×10^4	0.16116	8063
0.09	1.70×10^4	0.11646	8721
0.08	1.01×10^4	0.008914	9544

Lower bound from top-mass realisation

small θ_H ⇔ large KK scale

Fermion Localisation

$$\Psi_{L,R}(x,y) = \frac{e^{\frac{3}{2}ky}}{\sqrt{L}} \sum_{n=0}^{\infty} \psi_{L,R}^{(n)}(x) \frac{f_{L,R}^{(n)}(y)}{\sqrt{N^{(n)}}},$$

$$f_{L,R}^{(0)}(y) = e^{(\frac{1}{2} \mp c)ky}$$

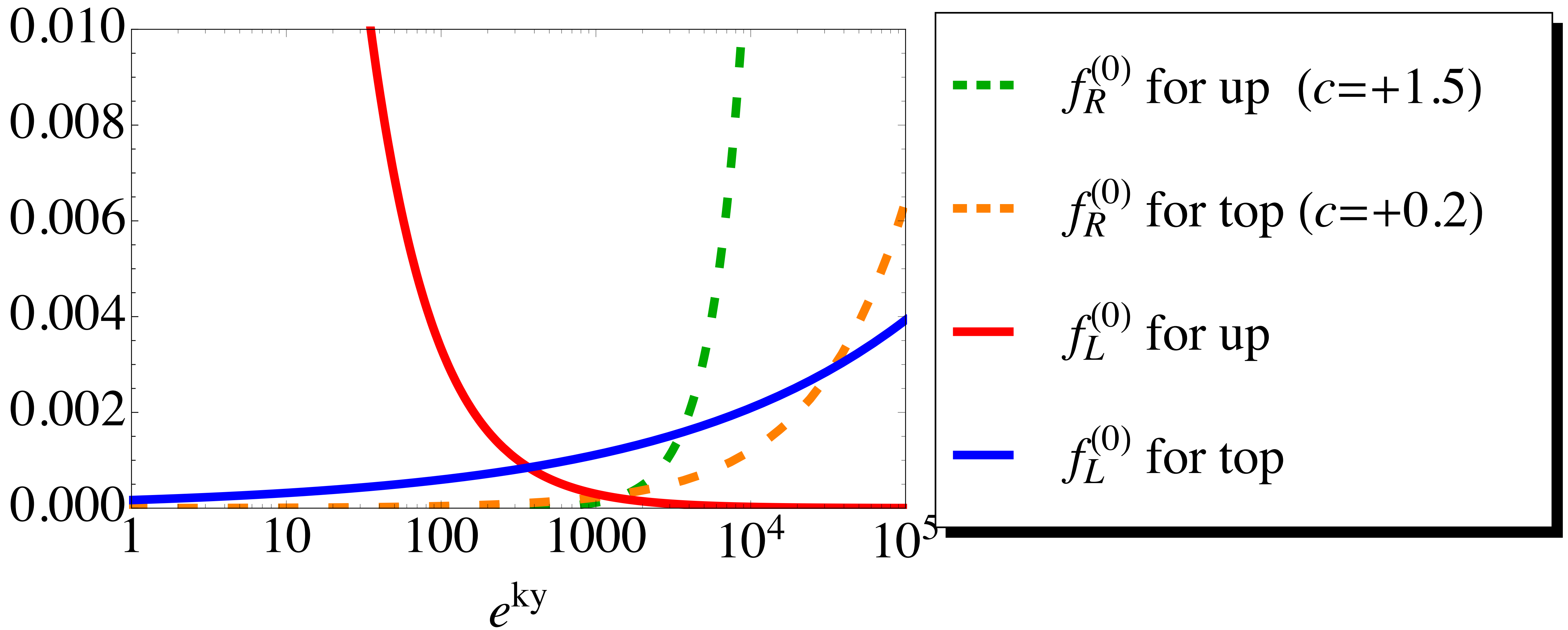
Left-handed : localised toward the UV brane (c>+1/2)
the IR brane (c<+1/2)

Right-handed : localised toward the IR brane (c>−1/2)
the UV brane (c<−1/2)

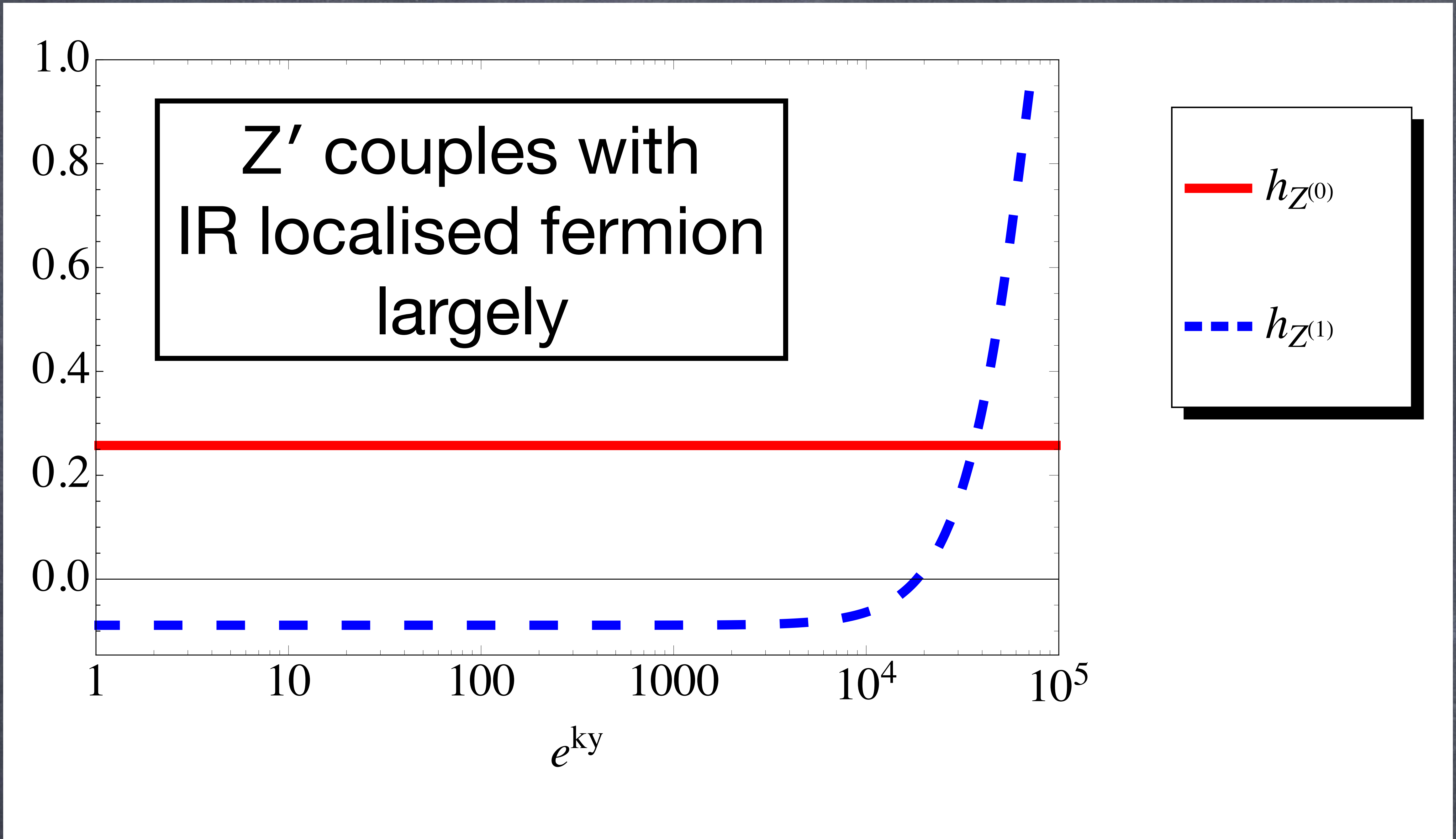
c→−c, the left- and right-handed are reversed

mass is invariant

Fermion Localisation



Gauge Boson Localisation



$Z^{(0)}$: localised toward the IR brane very slightly

$Z^{(1)}$: localised toward the IR brane

Z-couplings

Z-boson couplings in $g_W/\cos\theta_W$ unit

for $\sin^2\theta_W = 0.2312$ and $\theta_H = 0.10$,

	g_{Ze_L}	g_{Ze_R}
SM	-0.2688	$+0.2312$
$c_e > 0$	-0.2688	$+0.2313$
$c_e < 0$	-0.2664	$+0.2338$

For c<0 and $\theta_H = 0.10$, $\sin^2\theta_W = 0.2290$ is required,

so $c_l > 0$ is set.

$Z^{(1)}$-couplings

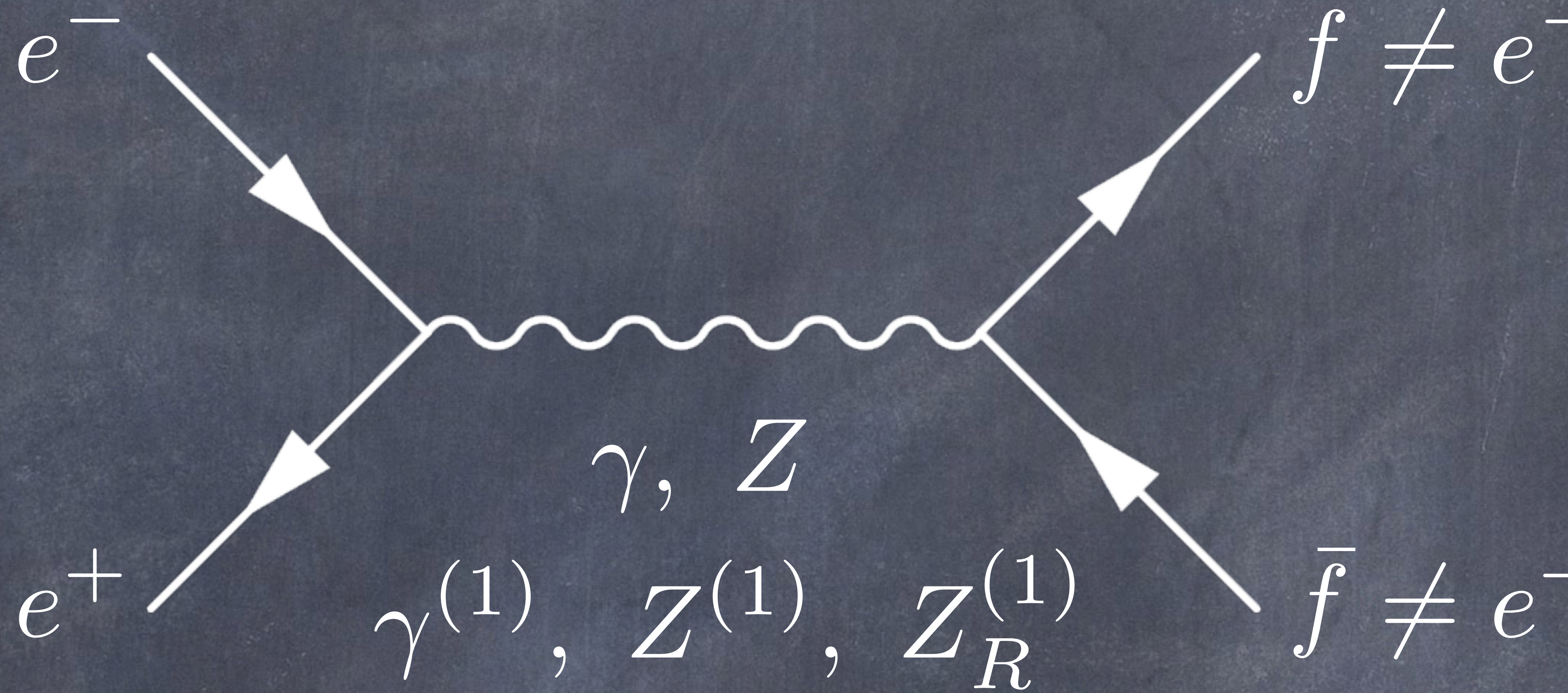
$Z^{(1)}$-boson couplings in $g_W / \cos\theta_W$ unit

for $\sin^2\theta_W = 0.2312$ and $\theta_H = 0.10$,

	$g_{Z^{(1)} e_L}$	$g_{Z^{(1)} e_R}$
$c_e > 0$	$+0.0987$	$+0.9148$
$c_e < 0$	-1.0535	-0.0858

		sign of (c_l, c_q)			
θ_H	$m_{Z^{(1)}}$	$\Gamma_{Z^{(1)}} (+,+)$	$(+,-)$	$(-,+)$	$(-,-)$
0.10	6585	429	1632	959	2162
0.09	7149	463	1674	1014	2225
0.08	7855	534	1705	1112	2283

Processes



Tree level only

Bhabha process: not yet

Polarisation

Ignoring the Higgs exchange,

$$\frac{d\sigma}{d\cos\theta} = \frac{1}{4}\left[(1-P_{e^-})(1+P_{e^+})\frac{d\sigma_{LR}}{d\cos\theta} + (1+P_{e^-})(1-P_{e^+})\frac{d\sigma_{RL}}{d\cos\theta}\right]$$

$$P = +1 : \ \text{right-handed}$$

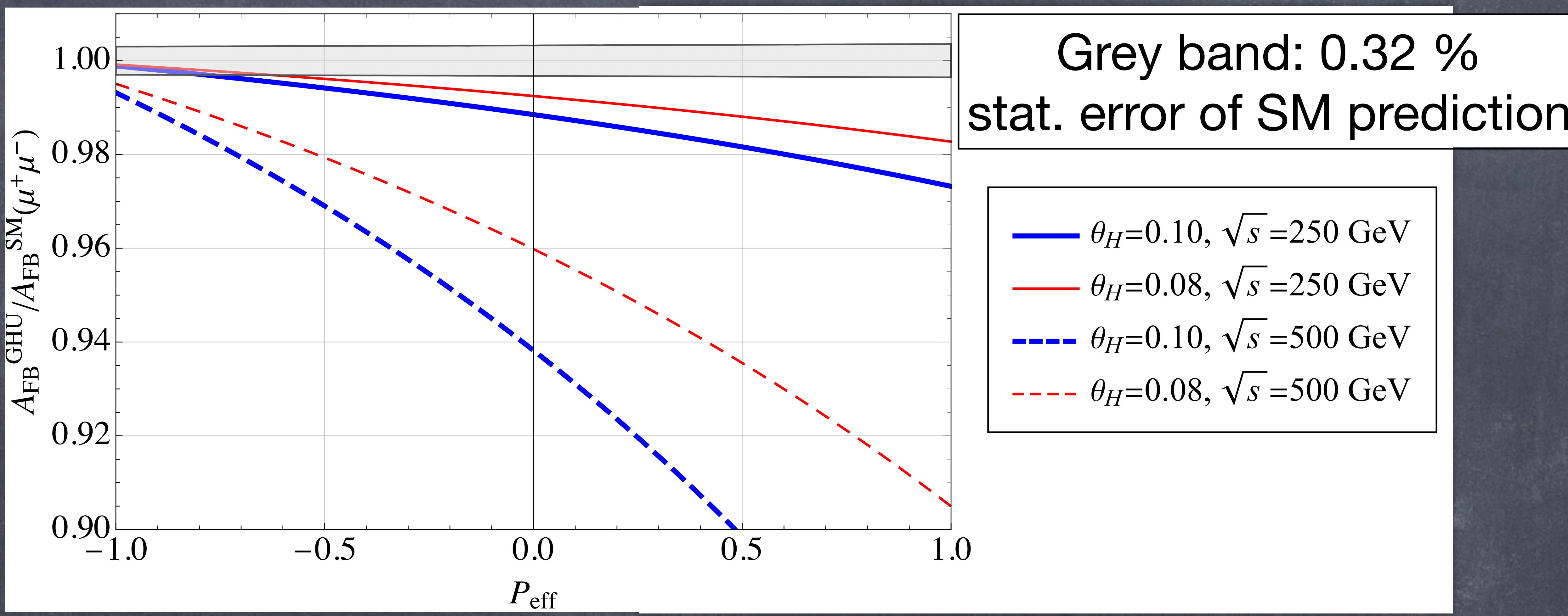
$$P = -1 : \ \text{left-handed}$$

It is rewritten by $P_{\text{eff}} = \dfrac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}}$ as

$$\frac{d\sigma}{d\cos\theta} = \frac{(1-P_{e^+}P_{e^-})}{4}\left[(1-P_{\text{eff}})\frac{d\sigma_{LR}}{d\cos\theta} + (1+P_{\text{eff}})\frac{d\sigma_{RL}}{d\cos\theta}\right]$$

$e^+e^- \to \mu^+\mu^-$

Deviation of AFB from SM ($c_l > 0$)



−1.1 % for P_{eff} = 0, θ_H =0.10, √s =250 GeV

−2.5 % for P_{eff} = 0.887, 〃

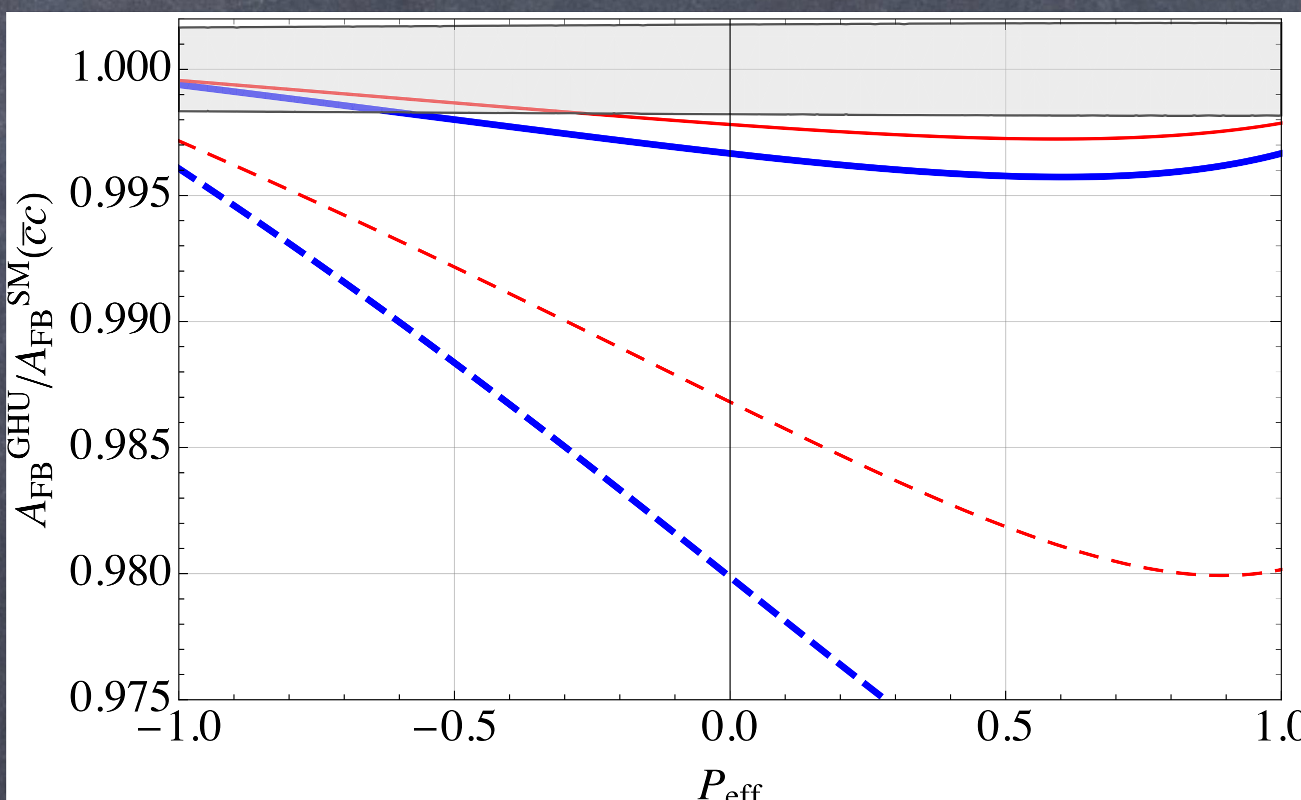
SF, Hatanaka, Hosotani, Orikasa. Phys.Lett. B775 (2017)

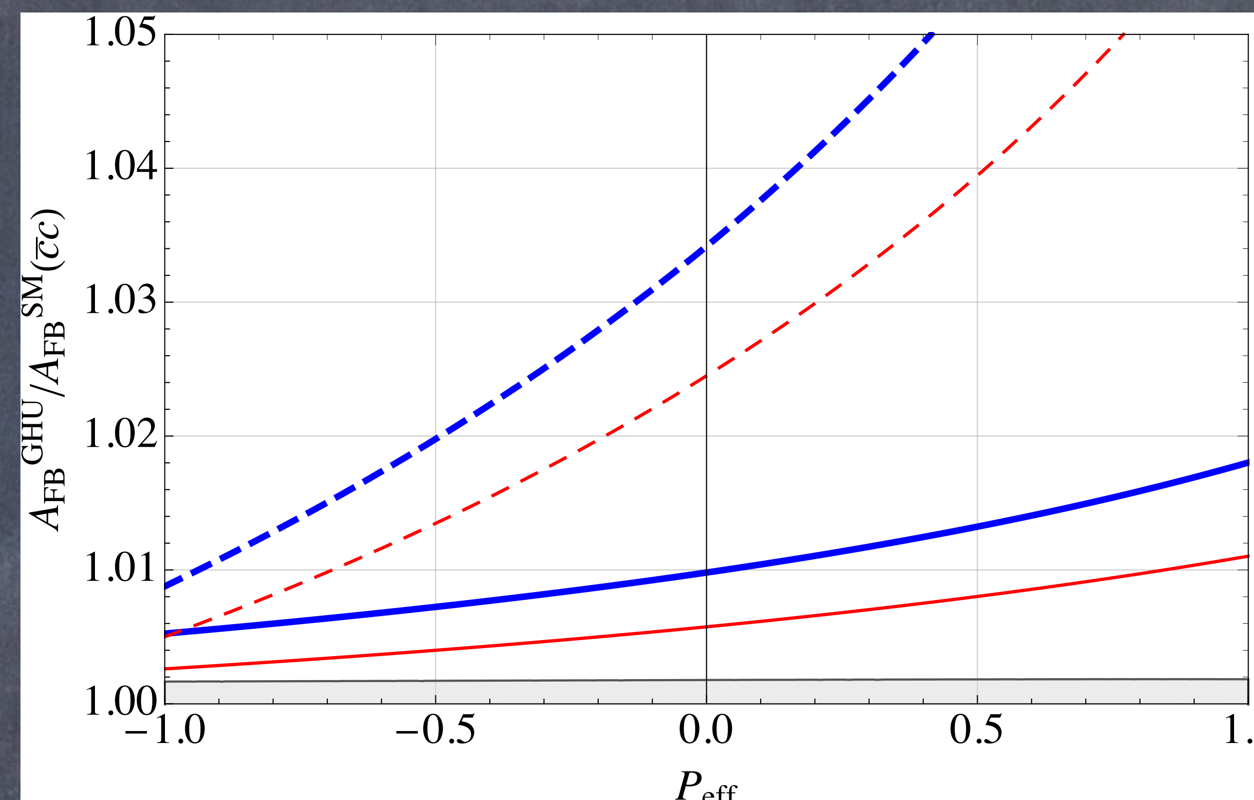
$e^+e^- \to \bar{c}c$

Deviation of AFB from SM

Grey band: 0.17 %
stat. error of SM prediction

$c_c > 0$ | $c_c < 0$





–0.33 % for $P_{\rm eff}$ = 0 | +0.98 % for $P_{\rm eff}$ = 0

–0.38 % for $P_{\rm eff}$ = 0.887 | +1.68 % for $P_{\rm eff}$ = 0.887

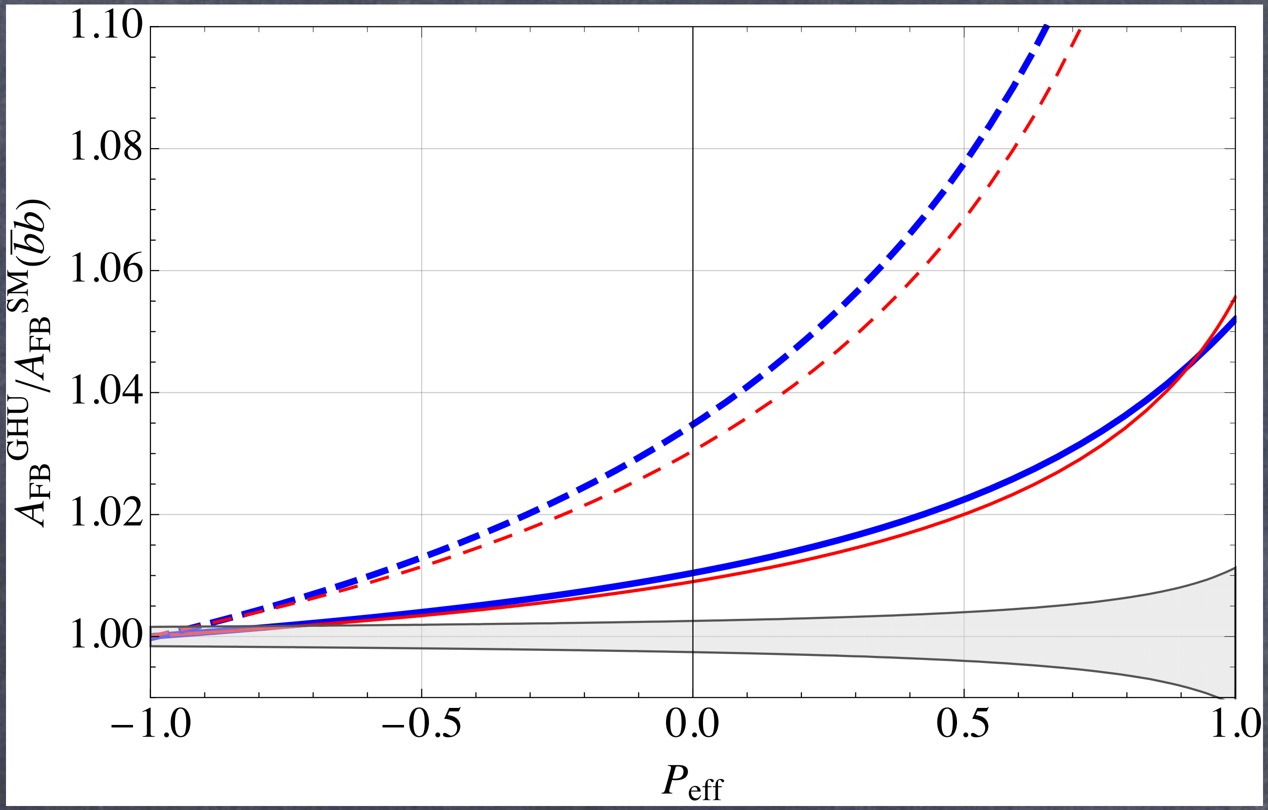
(θ_H =0.10, $\sqrt{s}$ =250 GeV)

$e^+e^- \to \bar{b}b$

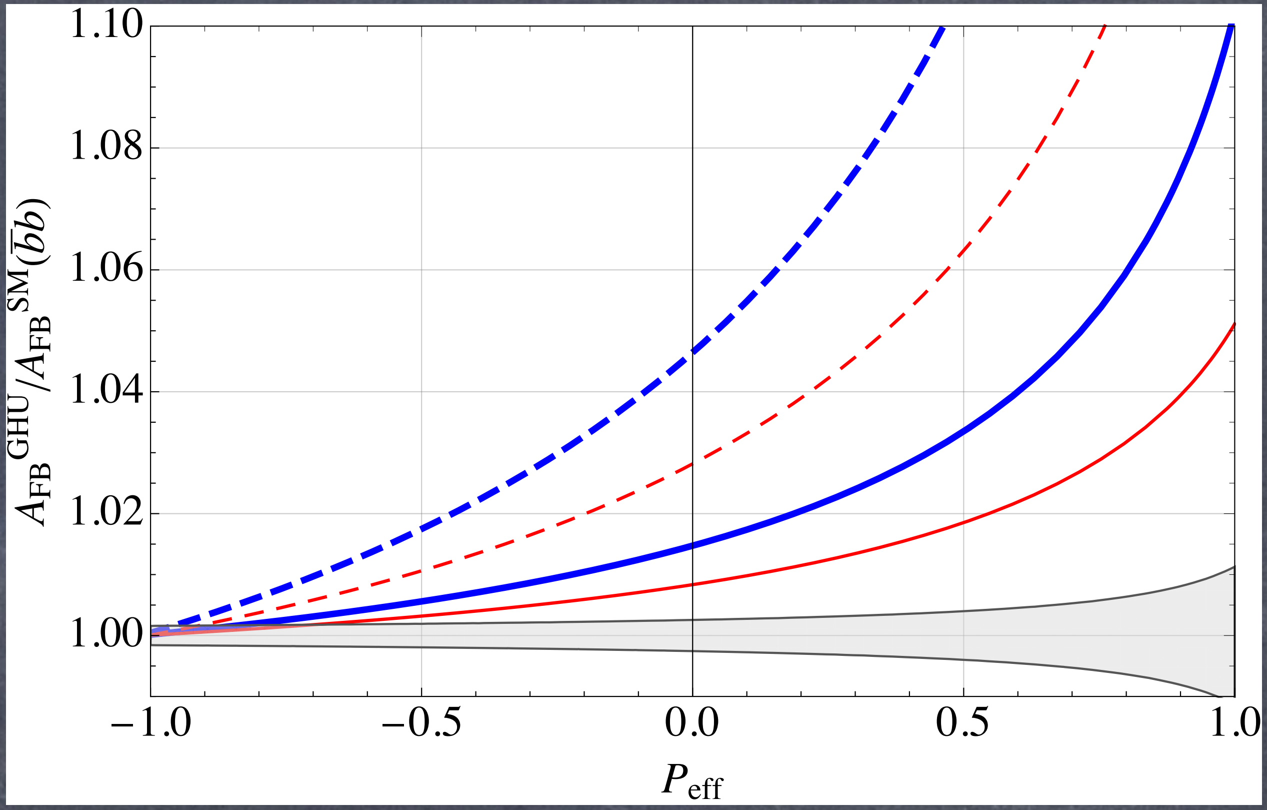
Grey band: 0.11—0.80 %
stat. error of SM prediction

Deviation of AFB from SM

$c_b > 0$



$c_b < 0$



+1.0 % for $P_{\rm eff}$ = 0

+4.2 % for $P_{\rm eff}$ = 0.887

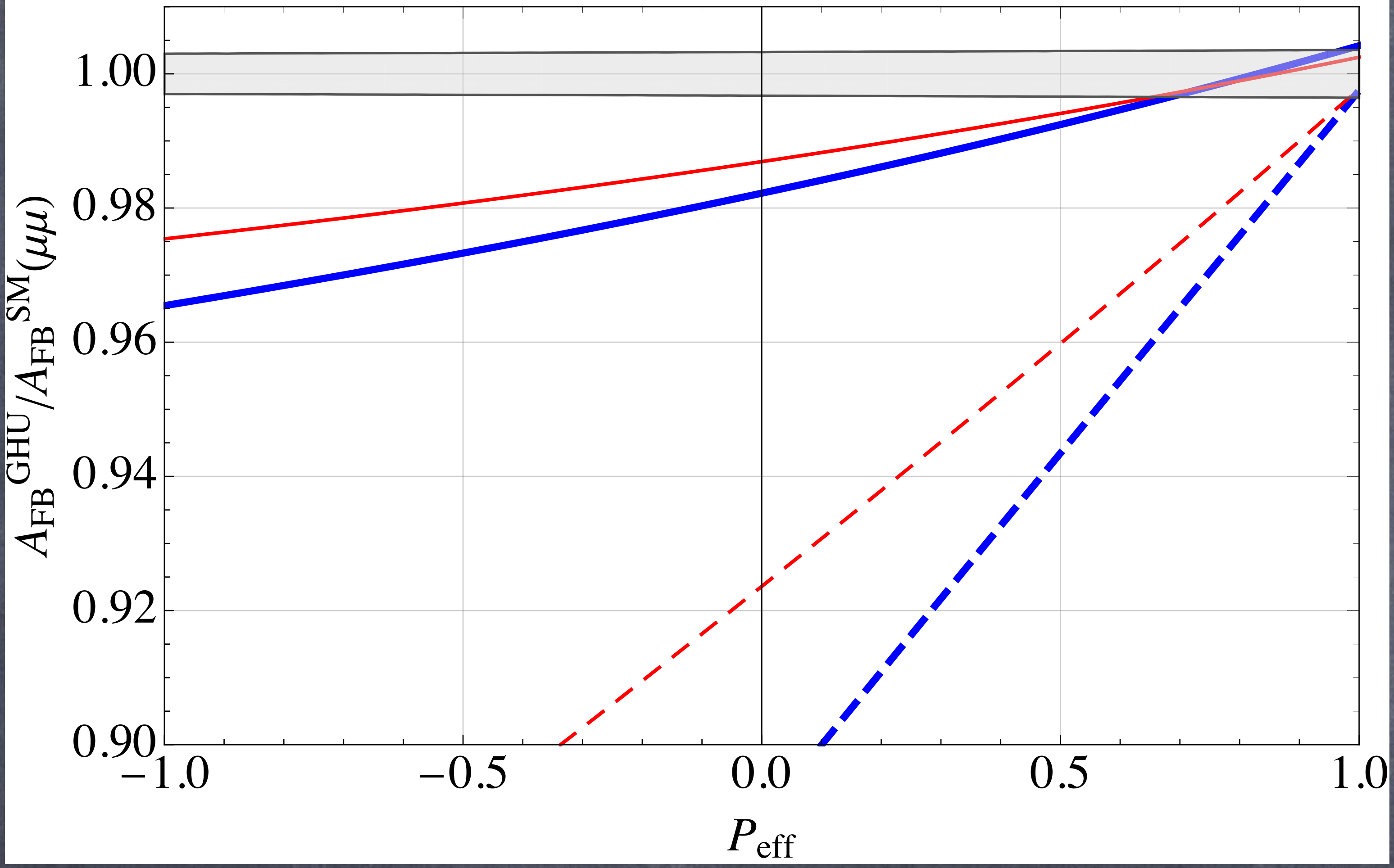
+1.5 % for $P_{\rm eff}$ = 0

+7.3 % for $P_{\rm eff}$ = 0.887

(θ_H =0.10, $\sqrt{s}$ =250 GeV)

$e^+e^- \to \mu^+\mu^-$ (preliminary)

Deviation of AFB from SM ($c_l < 0$)

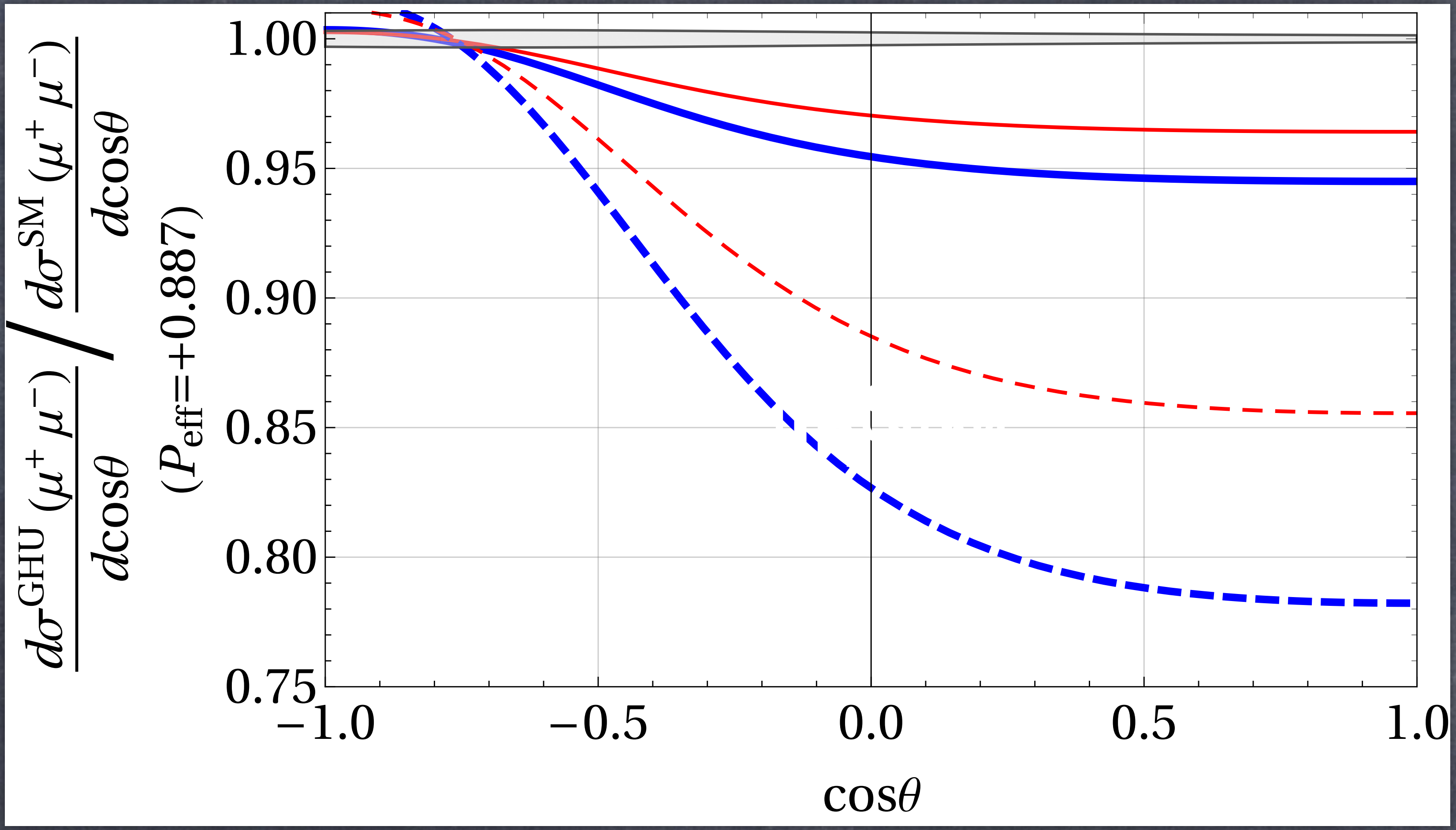


−1.1 % for P_{eff} = 0, θ_H =0.10, $\sqrt{s}$ =250 GeV

−3.9 % for P_{eff} = −0.887, 〃

$e^+e^- \to \mu^+\mu^-$ (preliminary)

Deviation of $d\sigma/d\cos\theta$ from SM ($c_l > 0$)



5.8×10^3 events (0.4 % stat. error) in SM
for $\cos\theta$ = [0.8, 0.9], P_{eff} = 0.887

Summary

- gauge-Higgs unification is a solution to the fine-tuning problem of the Higgs mass
- KK photon, Z, ZR are Z′s
  They have large coupling asymmetries
- 7 TeV Z′ effects are seen by $\sqrt{s}$ =250 GeV