

*Distinct signals of the gauge-Higgs unification
in e^+e^- collider experiments*

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Gauge-Higgs EW unification

Mature and ready for tests.

What are distinct signals of GHU ?

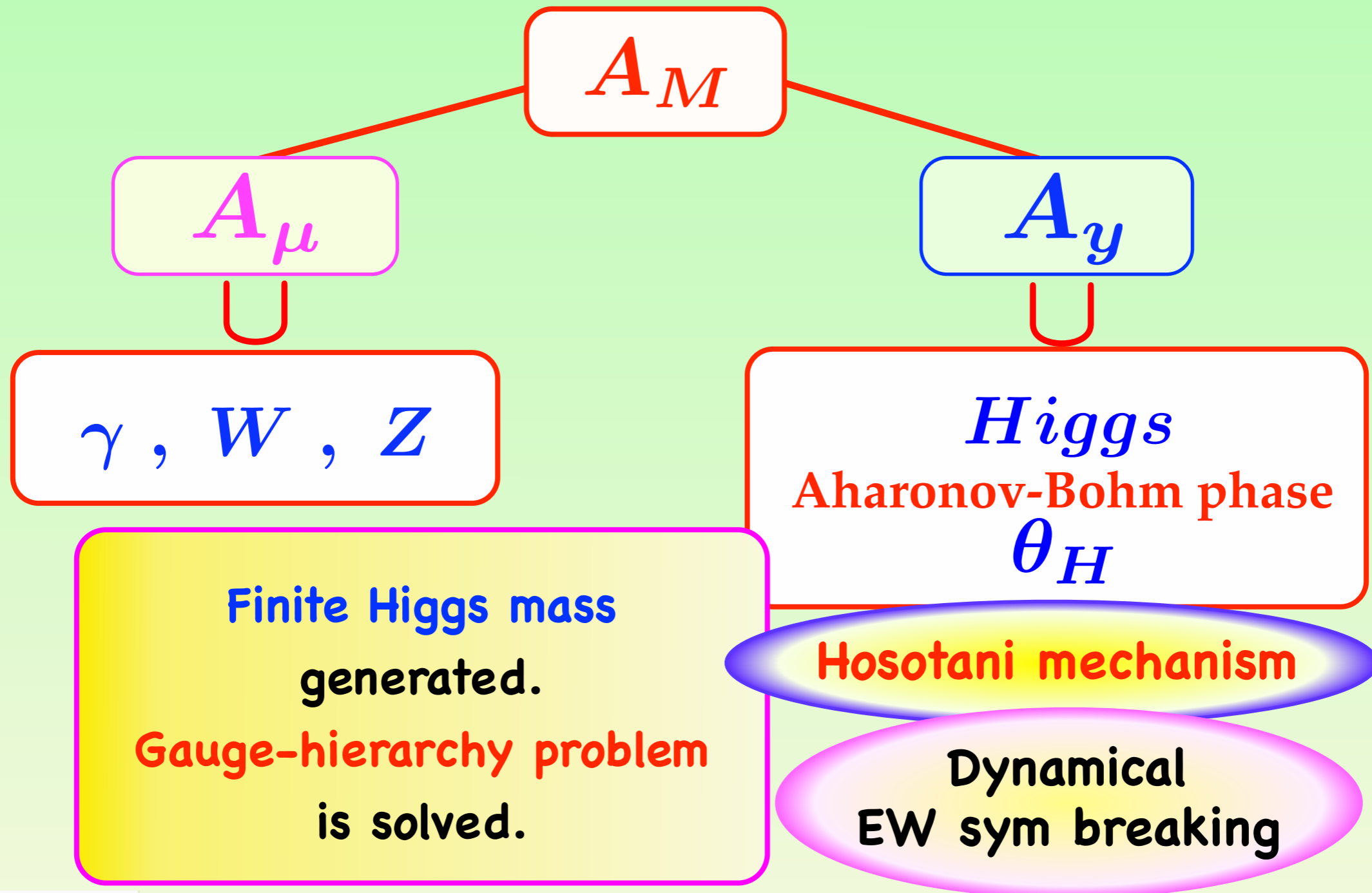
**Theory must make predictions
& must be confirmed by experiments.**

Experiments

in the past (at low energies)

LHC, ILC, ...

Gauge-Higgs unification



SO(5)×U(1) GHU in Randall-Sundrum

Agashe, Contino, Pomarol 2005

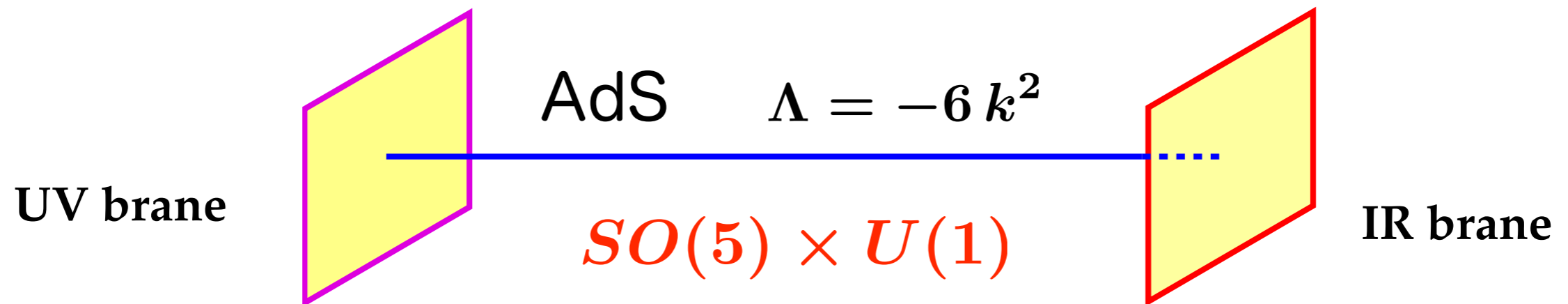
YH, Sakamura 2006

Medina, Shah, Wagner 2007

YH, Oda, Ohnuma, Sakamura 2008

Funatsu, Hatanaka, YH, Orikasa, Shimotani 2013

$$ds^2 = e^{-2k|y|} dx^\mu dx_\mu + dy^2$$



$$\begin{pmatrix} A_\mu \\ A_y \end{pmatrix} (x, y_j - y) = P_j \begin{pmatrix} A_\mu \\ -A_y \end{pmatrix} (x, y_j + y) P_j^\dagger$$

$$(y_0, y_1) = (0, L)$$

4D gauge bosons and Higgs

$$P_0 = P_1 = \begin{pmatrix} -1 & & & & \\ & -1 & & & \\ & & -1 & & \\ & & & -1 & \\ & & & & +1 \end{pmatrix}$$

$$SO(5) \rightarrow SO(4) \simeq SU(2)_L \times SU(2)_R$$

$$A_\mu \sim \begin{pmatrix} \boxed{W \ Z \ \gamma} \\ \phantom{\boxed{W \ Z \ \gamma}} \\ \phantom{\boxed{W \ Z \ \gamma}} \\ \phantom{\boxed{W \ Z \ \gamma}} \end{pmatrix}$$

$$A_y \sim \begin{pmatrix} \boxed{\text{Higgs}} \\ \phantom{\boxed{\text{Higgs}}} \\ \phantom{\boxed{\text{Higgs}}} \\ \phantom{\boxed{\text{Higgs}}} \end{pmatrix}$$

$$e^{i\hat{\theta}_H(x)} \sim P \exp \left\{ ig \int dy A_y \right\}$$

Predictions for LHC/ILC

Nearly the same as SM at low energies

gauge couplings of quarks/leptons ~ SM

	g_{GHU}/g_{SM} ($\theta_H = 0.115$)
W to $\ell\nu$, ud , cs	1.00019
tb	0.9993
WWZ	0.9999998

Higgs couplings to W, Z , quarks/leptons ~ (SM) $\times \cos \theta_H$

$$\cos \theta_H \sim 0.995 \quad \text{for } \theta_H = 0.1$$

What to look at ?

Higgs self-couplings

Deviations from SM

Extra dims → KK excitations

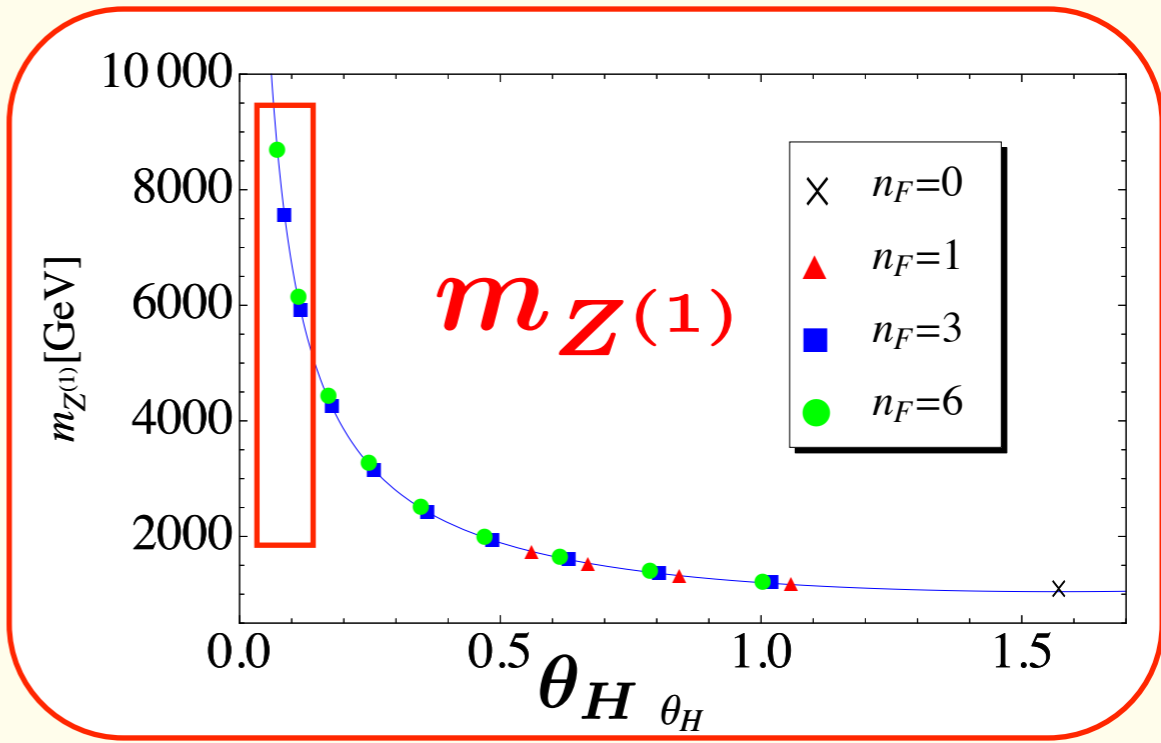
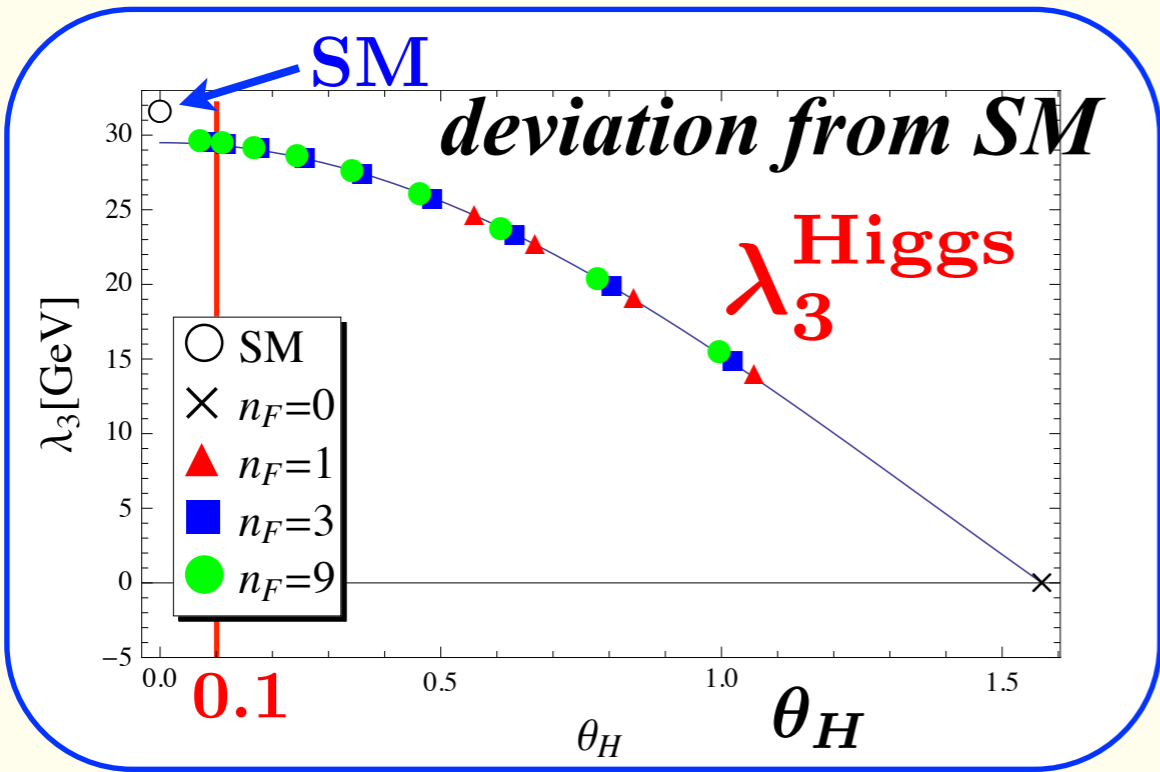
Produce new KK particles

Interference effects due to KK particles

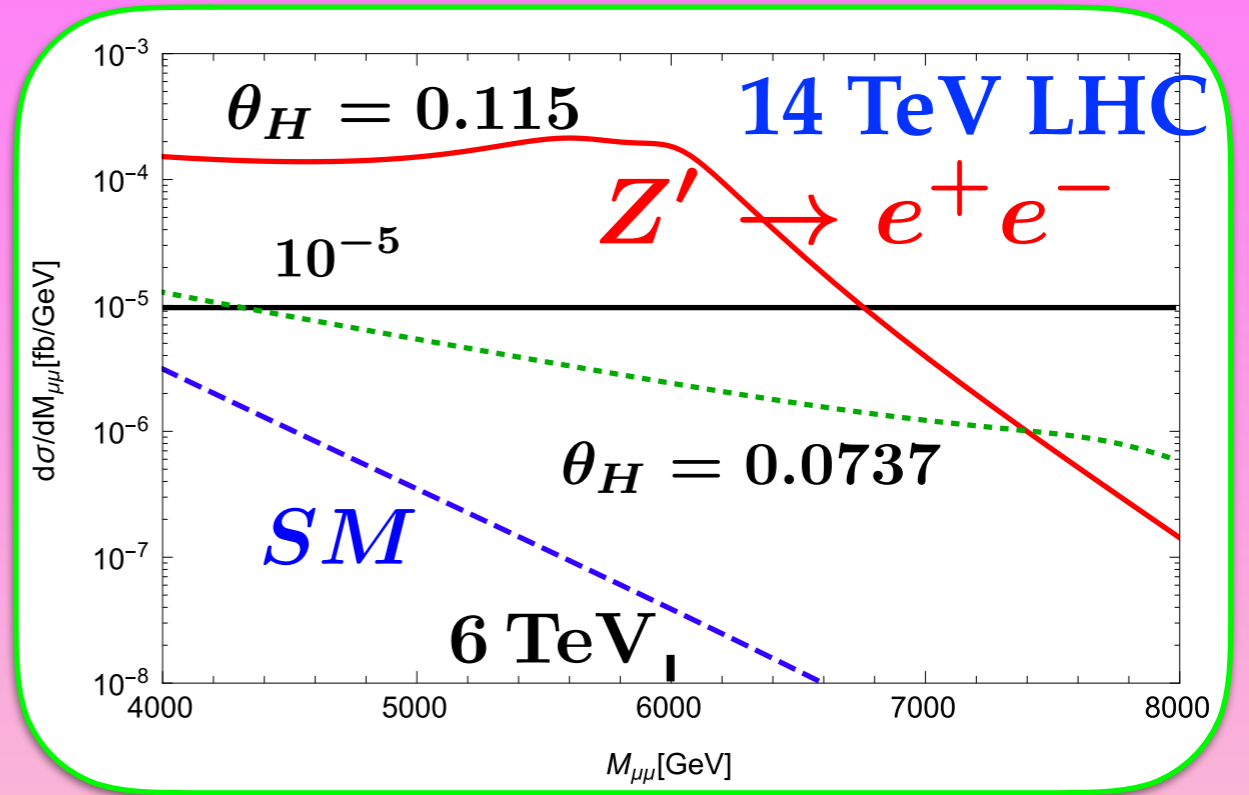
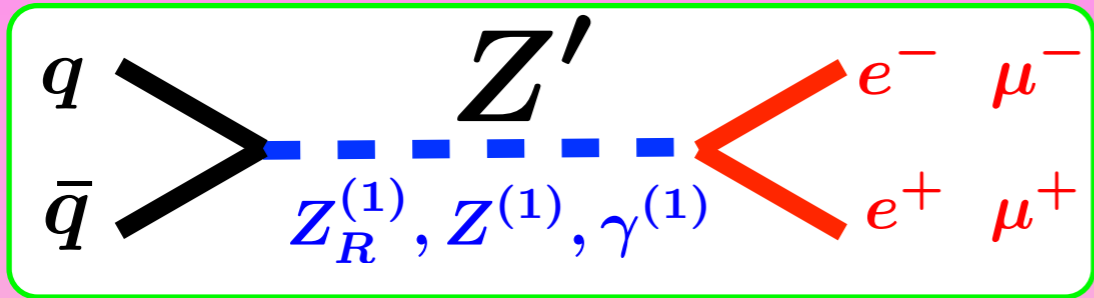
GHU is restrictive.

Universality

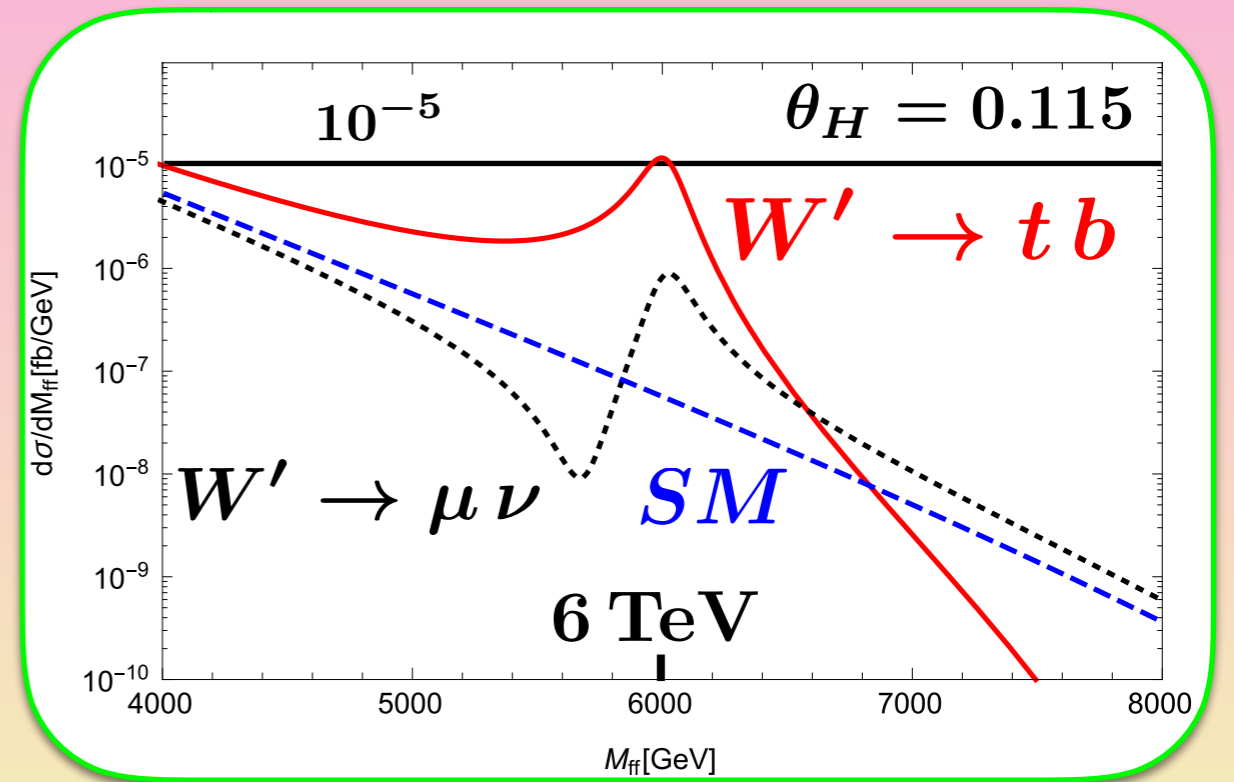
$$m_{KK}(\theta_H), m_{Z^{(1)}}(\theta_H), \lambda_3^H(\theta_H), \lambda_4^H(\theta_H)$$



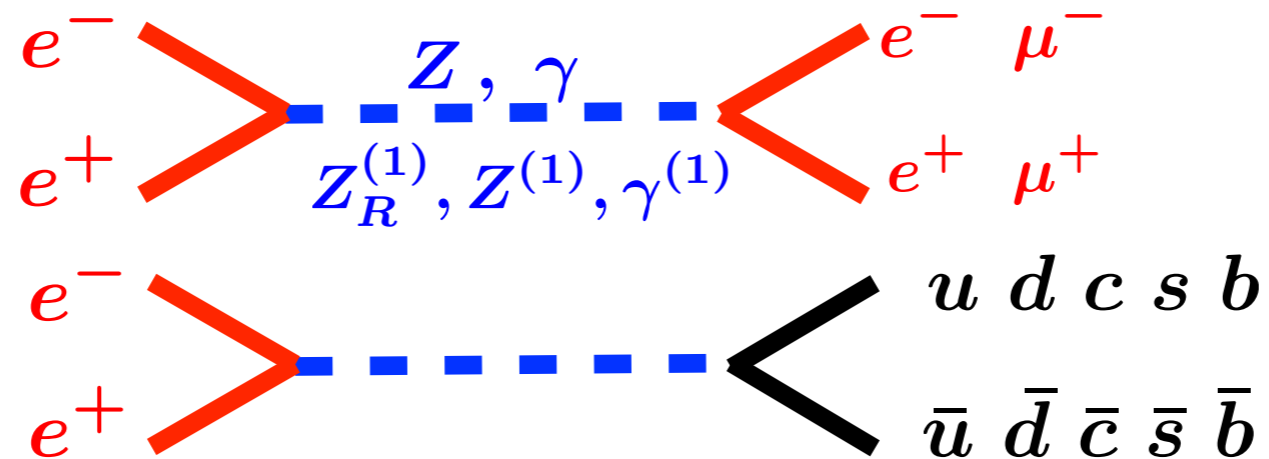
LHC



ATLAS-CONF-2017-027
 (9 April 2017)
 $\sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1}$
 no event for $> 3000 \text{ GeV}$
 ➔ $\theta_H < 0.1$



ILC (e^+e^- linear collider)



Precision measurements at LEP1 & LEP2 (~207GeV)

Energies at 250 GeV, 500 GeV, 1 TeV

Polarized electron/positron beams

In GHU, **right-handed quarks/leptons**
 have **large couplings to Z'** .

Couplings to Z'

Wave functions of f_R, Z' : localized near IR brane **large**
 f_L : localized near UV brane **small**

f	Z		Z'					
	g_{Zf}^L	g_{Zf}^R	$g_{Z^{(1)}f}^L$	$g_{Z^{(1)}f}^R$	$g_{Z_R^{(1)}f}^L$	$g_{Z_R^{(1)}f}^R$	$g_{\gamma^{(1)}f}^L$	$g_{\gamma^{(1)}f}^R$
ν_e	0.5703	0	-0.2225	0	0	0	0	0
ν_μ	0.5703	0	-0.2225	0	0	0	0	0
ν_τ	0.5703	0	-0.2224	0	0	0	0	0
e	-0.3065	0.2638	0.1196	0.9981	0	-1.3762	0.1880	-1.8165
μ	-0.3065	0.2638	0.1196	0.9369	0	-1.3029	0.1880	-1.7051
τ	-0.3065	0.2638	0.1195	0.8847	0	-1.2401	0.1879	-1.6102
u	0.3945	-0.1759	-0.1539	-0.6536	0	0.9034	-0.1253	1.1896
c	0.3945	-0.1759	-0.1539	-0.6041	0	0.8439	-0.1253	1.0994
t	0.3938	-0.1766	0.6888	-0.3431	1.3208	0.5253	0.5616	0.6258
d	-0.4824	0.08795	0.1882	0.3268	0	-0.4517	0.1303	-1.2369
s	-0.4824	0.08794	0.1882	0.3021	0	-0.4220	0.1303	-1.1431
b	-0.4825	0.08794	-0.8470	0.1720	1.3189	-0.2625	-0.5840	-0.6506

in unit of g_w ($\theta_H = 0.115$)

$$e^+ e^- \rightarrow \bar{f} f$$

$$\sigma(\bar{f} f) \quad A_{FB} = \frac{\sigma_{\text{forward}} - \sigma_{\text{backward}}}{\sigma_{\text{forward}} + \sigma_{\text{backward}}}$$

\sqrt{s} , polarization P_{e^\pm}

Interference becomes visible.

$$\sigma(P_{e^-}, P_{e^+}) = (1 - P_{e^-} P_{e^+}) \sigma(P_{\text{eff}}, 0)$$

$$P_{\text{eff}} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-} P_{e^+}}$$

$$= 0.946 \quad \text{for } (P_{e^-}, P_{e^+}) = (0.8, -0.6)$$

LEP2


$$130 \text{ GeV} < \sqrt{s} < 207 \text{ GeV}$$

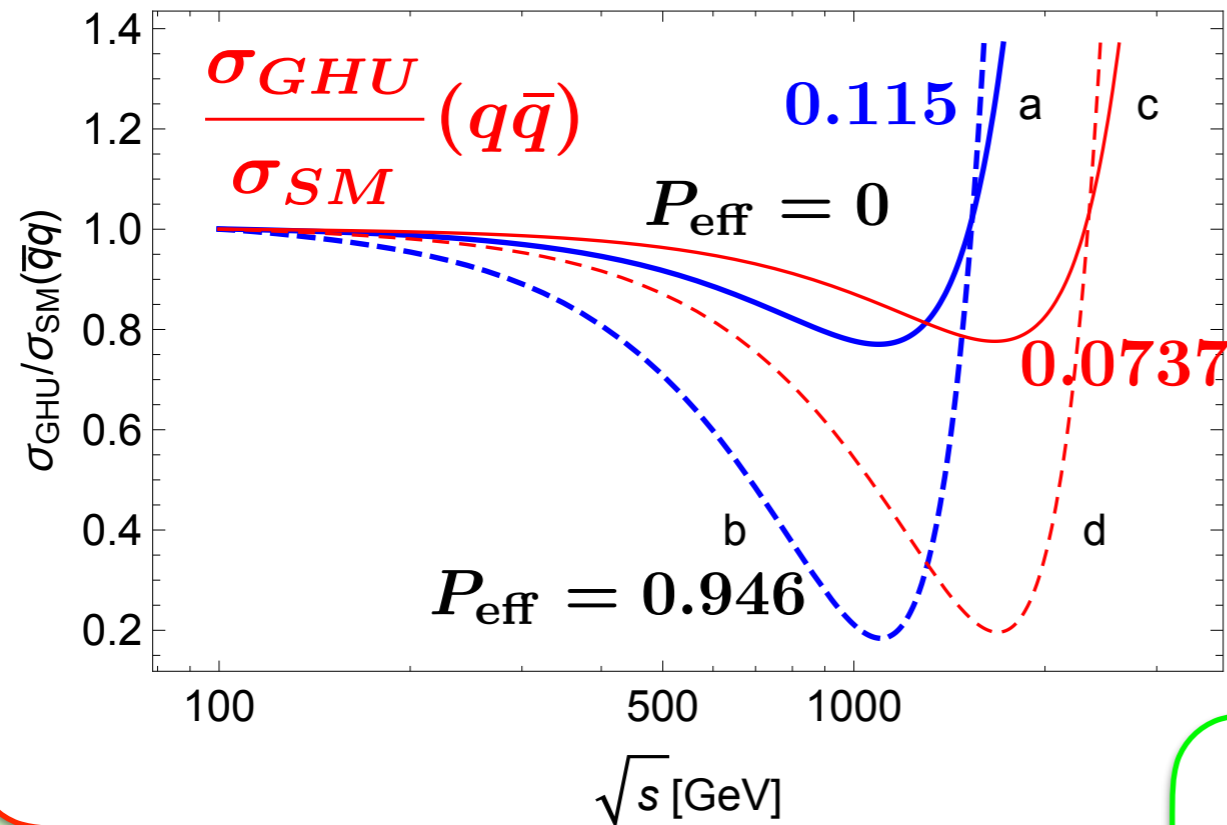
$$\frac{\sigma^{\text{exp}}}{\sigma^{\text{SM}}}(\bar{q}q) = 1.0092 \pm 0.0076$$

$$\theta_H : \quad 0.115 \quad 0.0737$$

$$\frac{\sigma^{\text{GHU}}}{\sigma^{\text{SM}}}(\bar{q}q) \quad 0.9972 \quad 0.9987 \quad \text{at } \sqrt{s} = 130 \text{ GeV}$$

$$0.9868 \quad 0.9944 \quad \text{at } \sqrt{s} = 207 \text{ GeV}$$

 $\theta_H < 0.1$

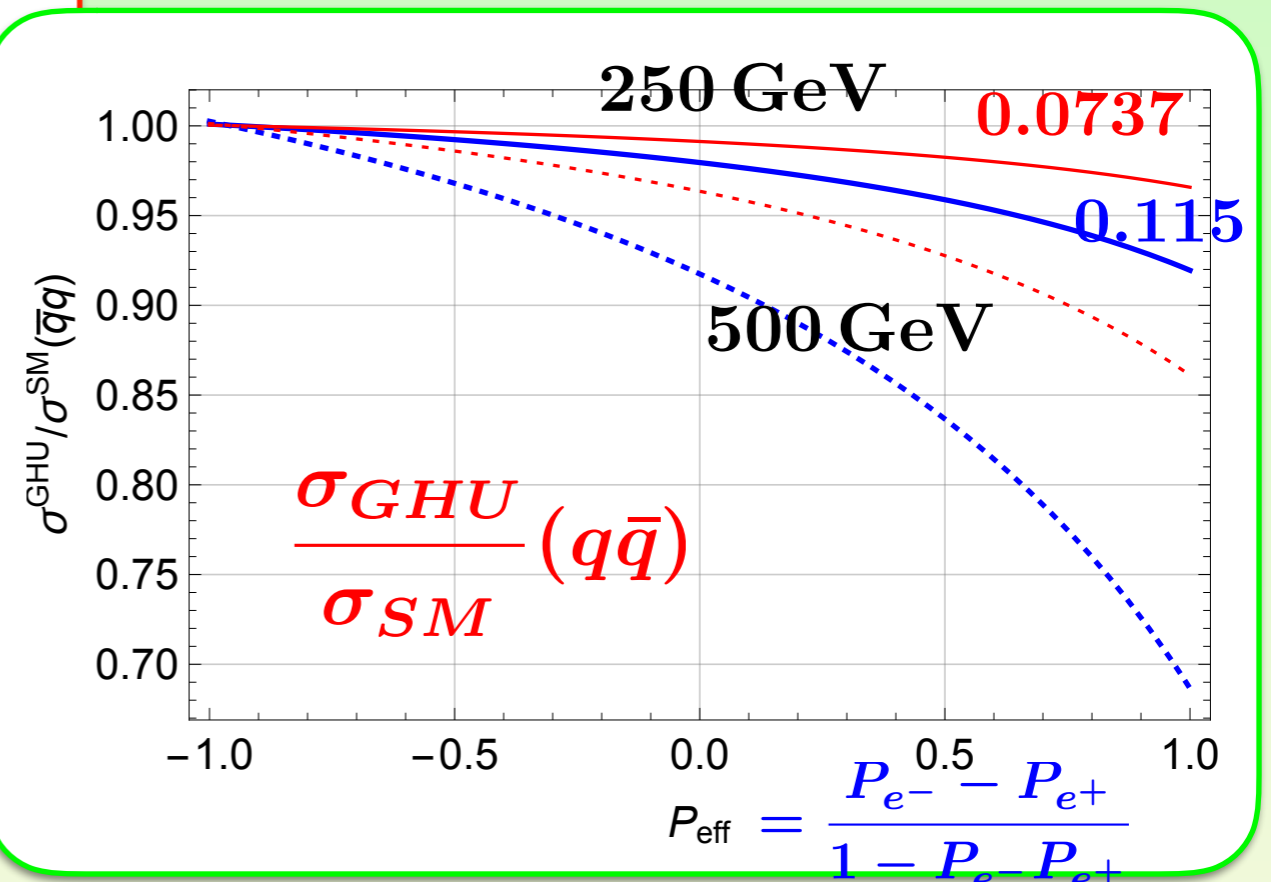


ILC

$$\frac{\sigma^{GHU}}{\sigma^{SM}}(\bar{q}q)$$

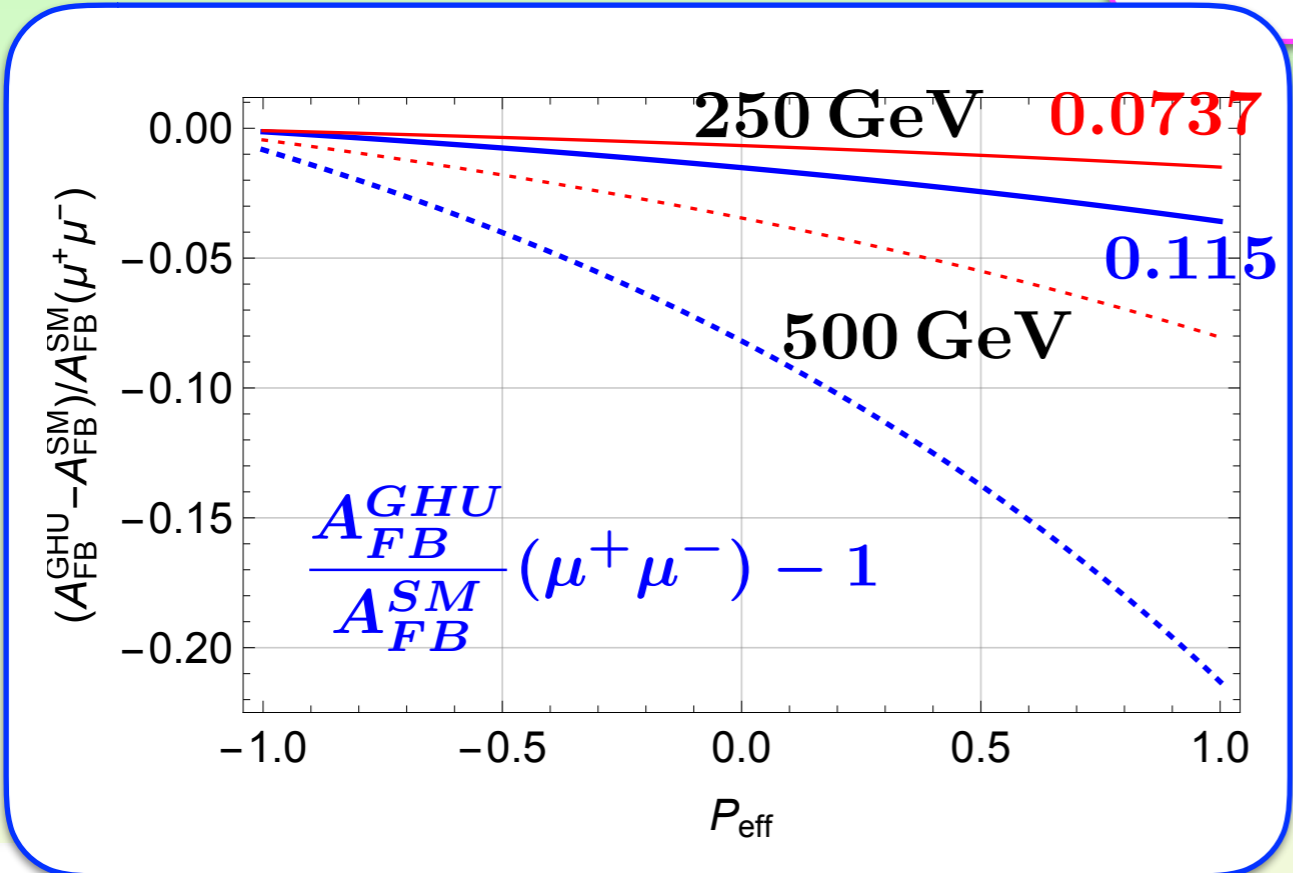
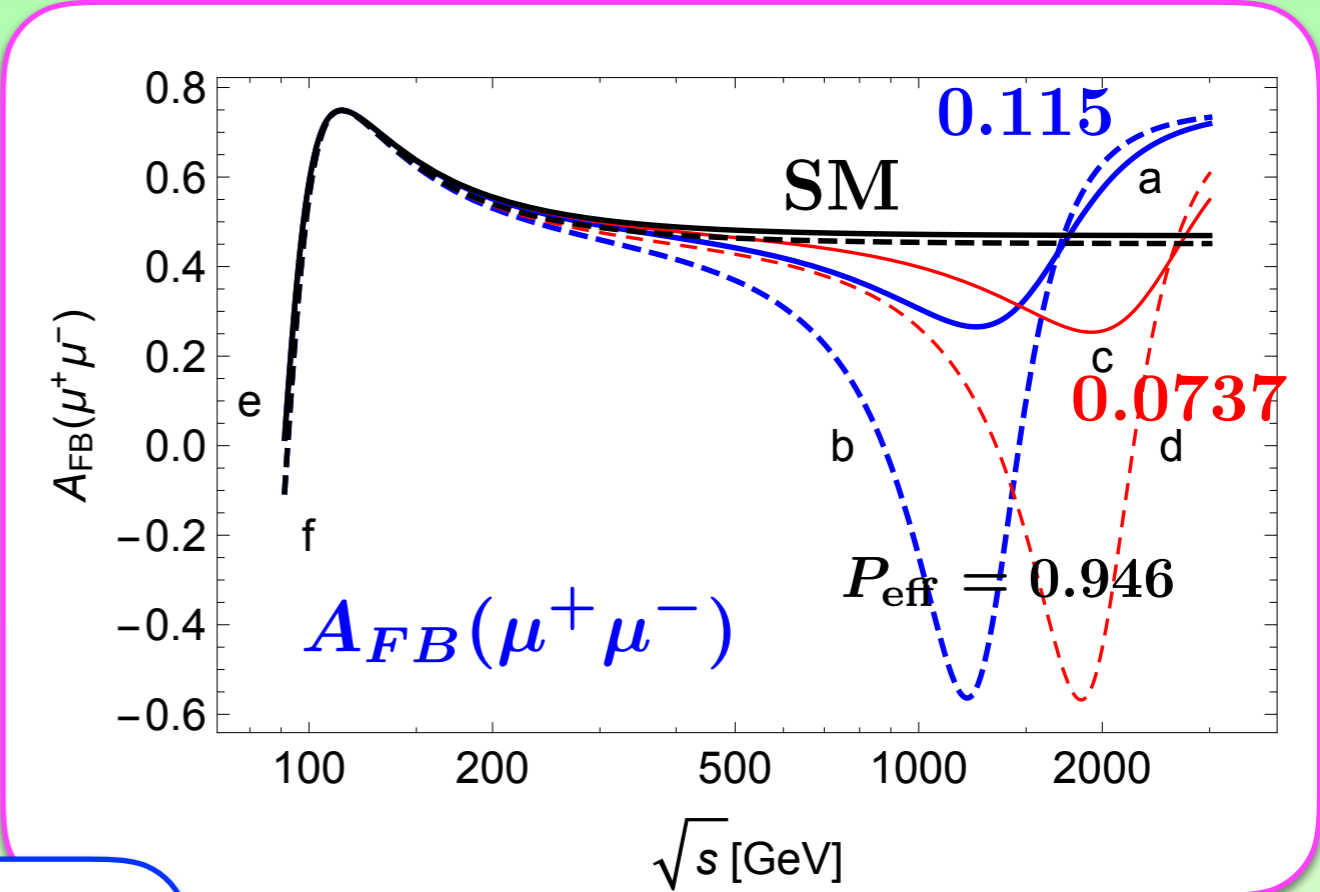
$$q = u, d, s, c, b$$

**Measurable
deviations
even at 250GeV**



ILC

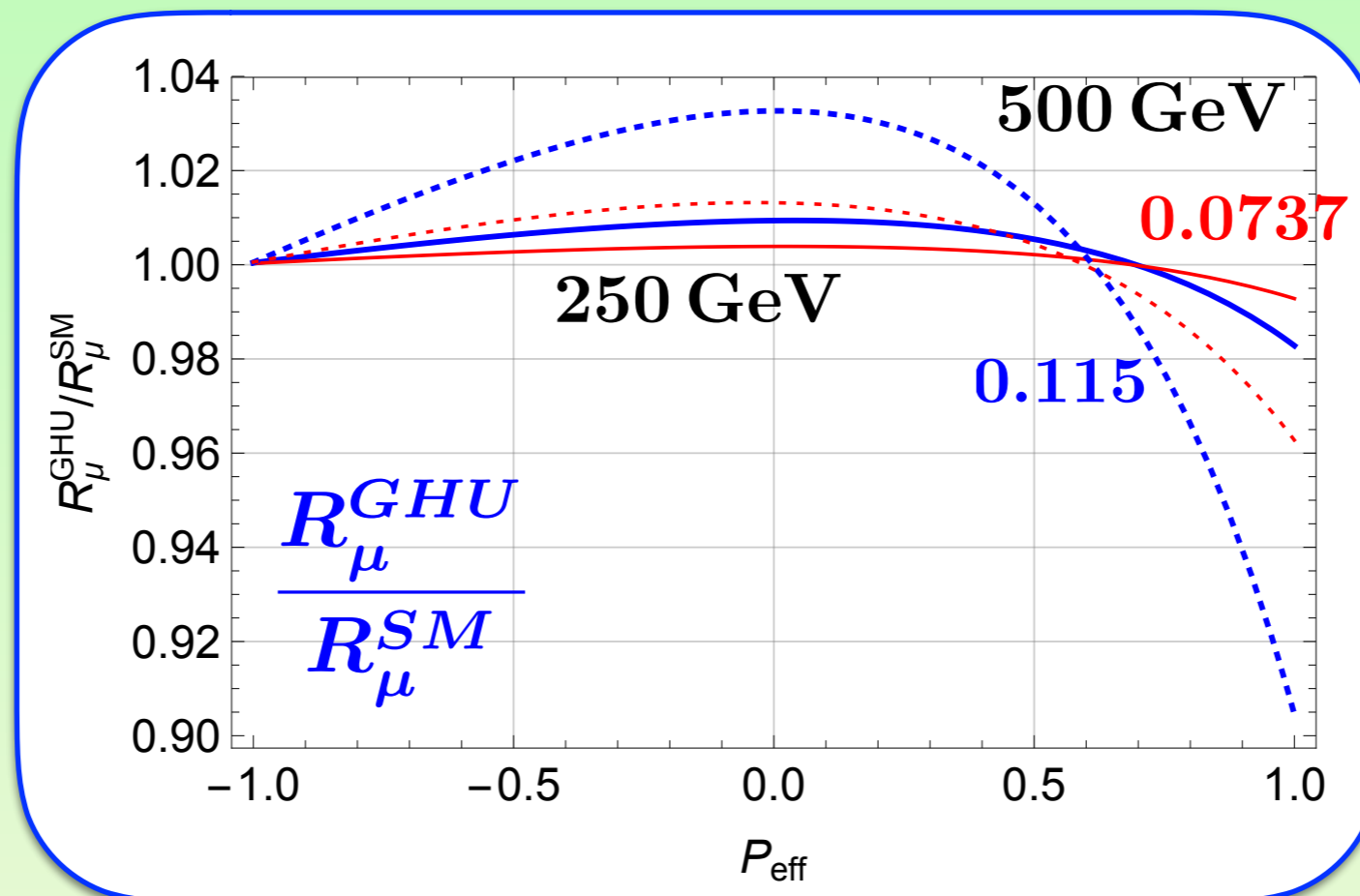
$$A_{FB}(\mu^+\mu^-)$$



Distinct deviations

ILC

$$R_\mu = \frac{\sigma(\bar{q}q)}{\sigma(\mu^+\mu^-)}$$



Distinct deviations

Summary

*Distinct signals of the gauge-Higgs unification
can be seen
in e^+e^- collider experiments*