Gauge-Higgs unification : distinct signals at LHC and ILC

Yutaka Hosotani

Physics
OSAKA UNIVERSITY

Scalars 2017

University of Warsaw, 3 December 2017

Gauge-Higgs unification : distinct signals at LHC and ILC

Yutaka Hosotani

Physics
OSAKA UNIVERSITY

Funatsu, Hatanaka, YH, Orikasa,

LHC : 1612.03378 (PRD) ILC : 1705.05282v3 (PLB)

Scalars 2017

University of Warsaw, 3 December 2017

Gauge-Higgs unification

A_M

A_μ

γ , W , Z

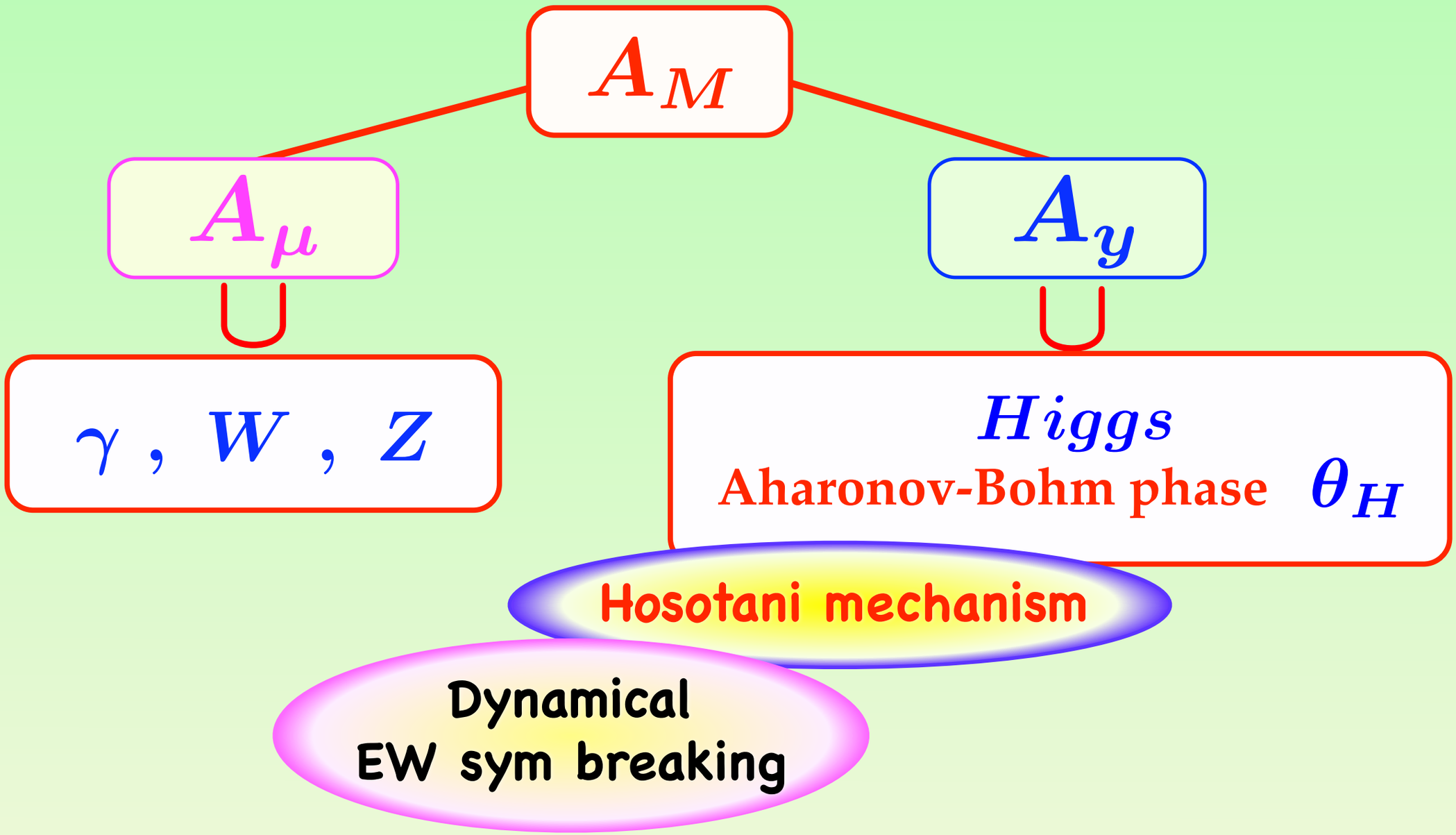
A_y

$Higgs$

Aharonov-Bohm phase θ_H

Physics
OSAKA UNIVERSITY

Gauge-Higgs unification

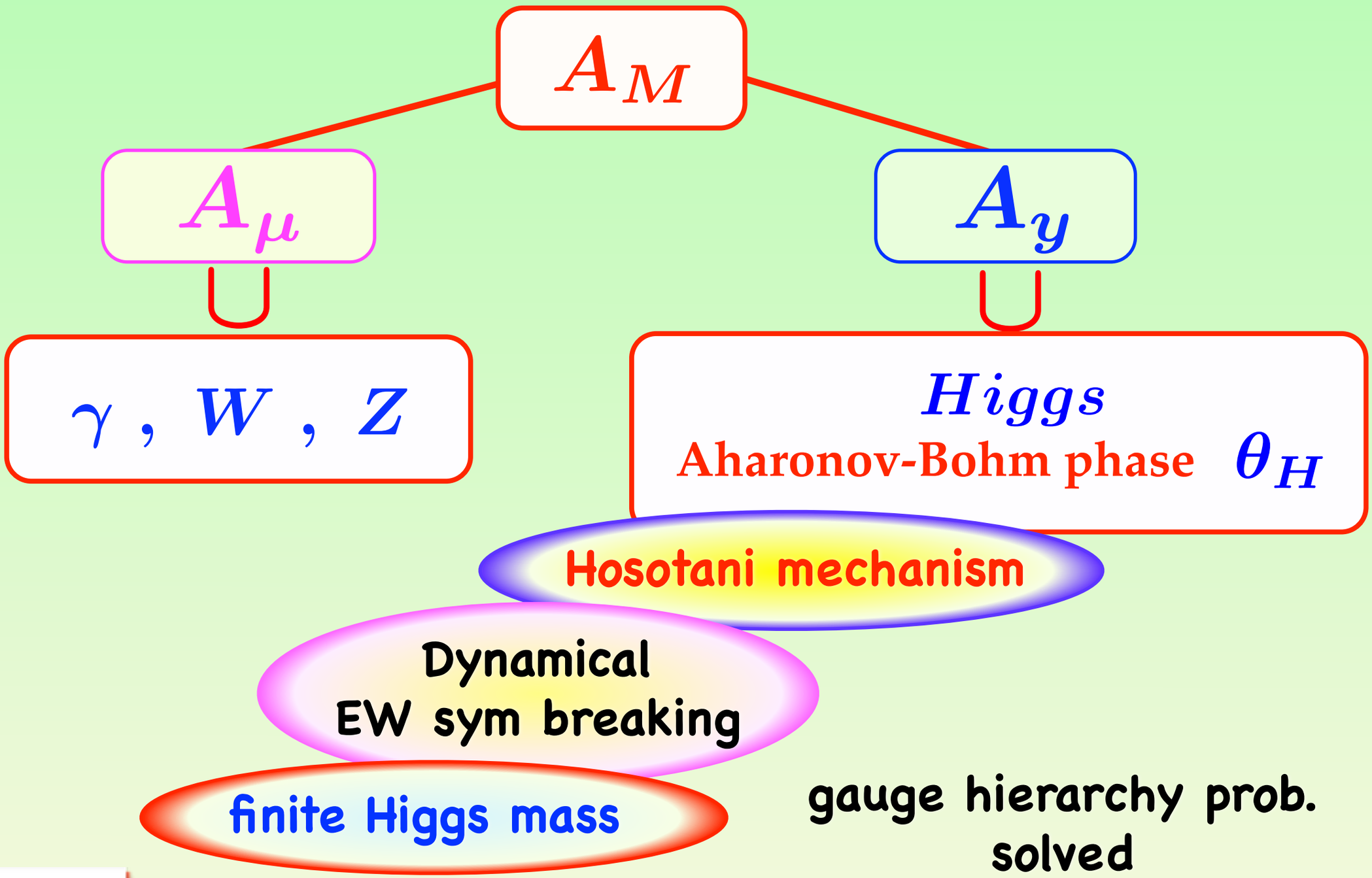


Hosotani mechanism

Dynamical EW sym breaking

Physics OSAKA UNIVERSITY

Gauge-Higgs unification



Hosotani mechanism

Dynamical
EW sym breaking

finite Higgs mass

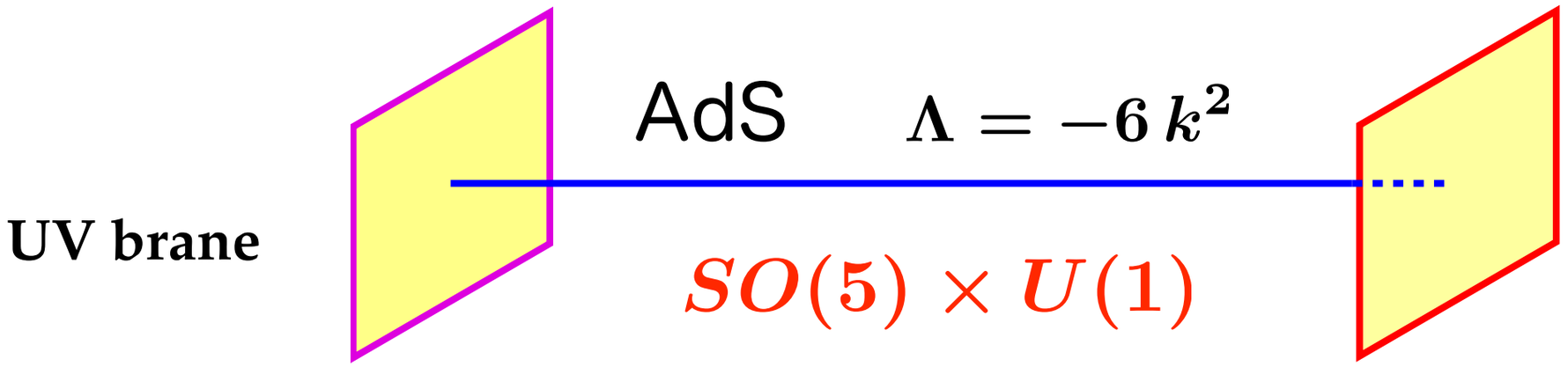
gauge hierarchy prob.
solved

Physics
OSAKA UNIVERSITY

SO(5)xU(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

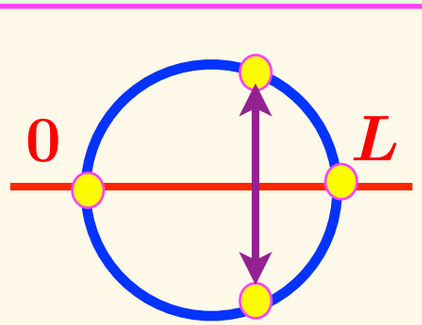
$$ds^2 = e^{-2k|y|} dx^\mu dx_\mu + dy^2$$



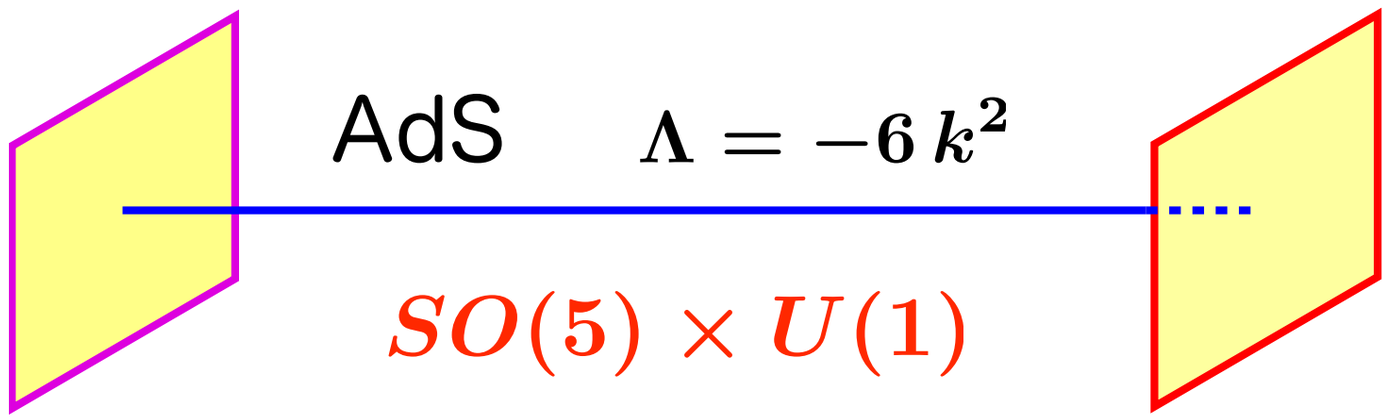
Physics
OSAKA UNIVERSITY

SO(5)xU(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



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



UV brane

IR brane

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

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

Physics
OSAKA UNIVERSITY

4D gauge bosons and Higgs

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

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

4D gauge bosons and Higgs

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

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

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

Physics
OSAKA UNIVERSITY

4D gauge bosons and Higgs

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

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

$$A_\mu \sim \begin{pmatrix} W\ Z\ \gamma & \\ & \end{pmatrix} \qquad A_y \sim \begin{pmatrix} \text{Higgs} & \\ & \end{pmatrix}$$

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

Physics
OSAKA UNIVERSITY

At low energies

Nearly the same as SM

Physics
OSAKA UNIVERSITY

At low energies

Nearly the same as SM

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

At low energies

Nearly the same as SM

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 ~ $(SM) \times \cos\theta_H$

$\cos\theta_H \sim 0.995$ for $\theta_H = 0.1$

Physics
OSAKA UNIVERSITY

At low energies

Nearly the same as SM

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 ~ $(SM) \times \cos\theta_H$

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

Higgs decays:

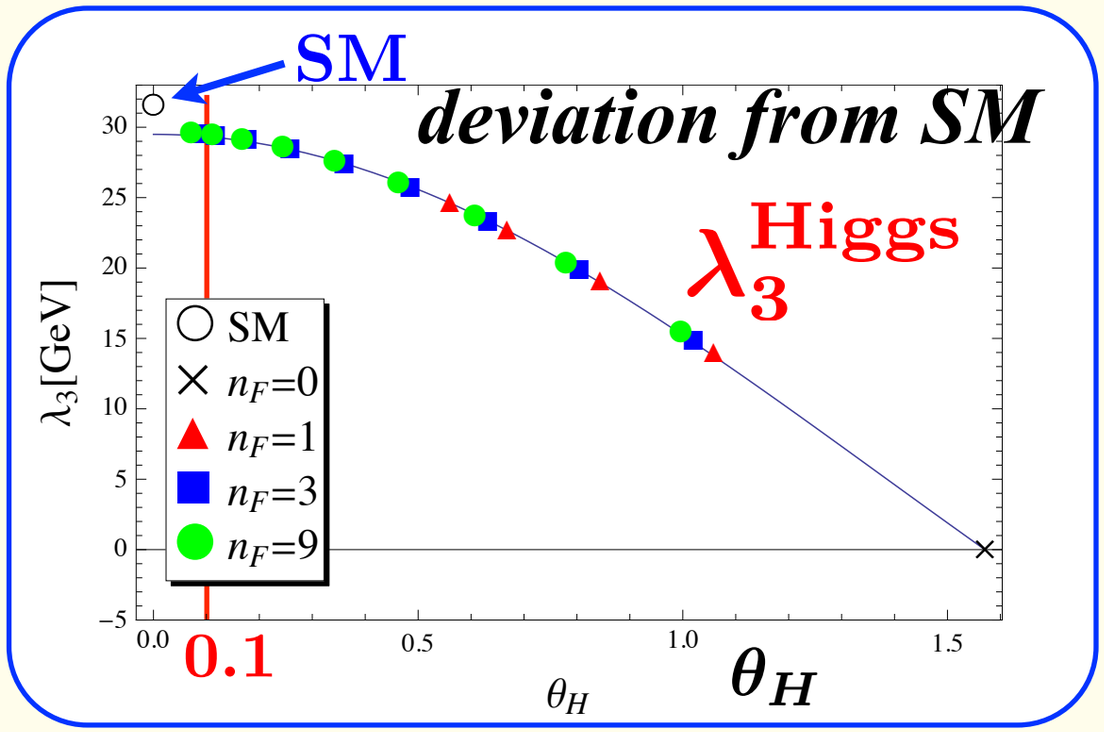
$$\Gamma(H \to \gamma\gamma), \mu(H \to \gamma\gamma) \sim (SM) \times \cos^2\theta_H$$

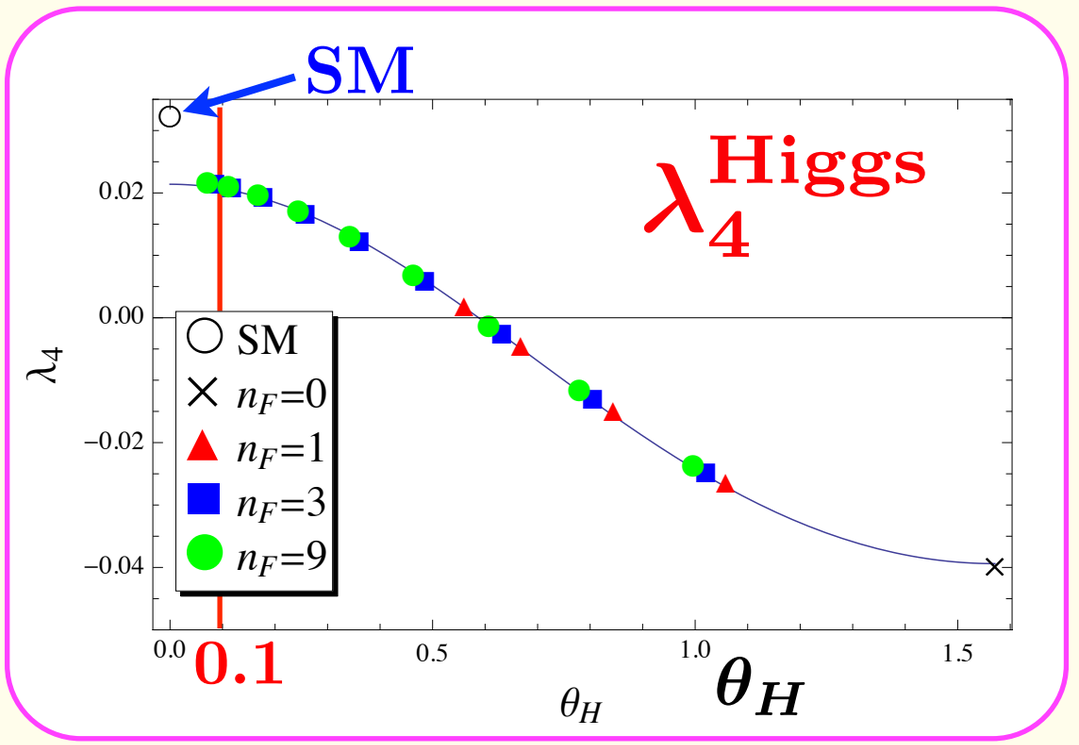
corrections due to KK modes < 0.2%

Branching fractions ~ (SM)

Physics
OSAKA UNIVERSITY

Higgs self-couplings

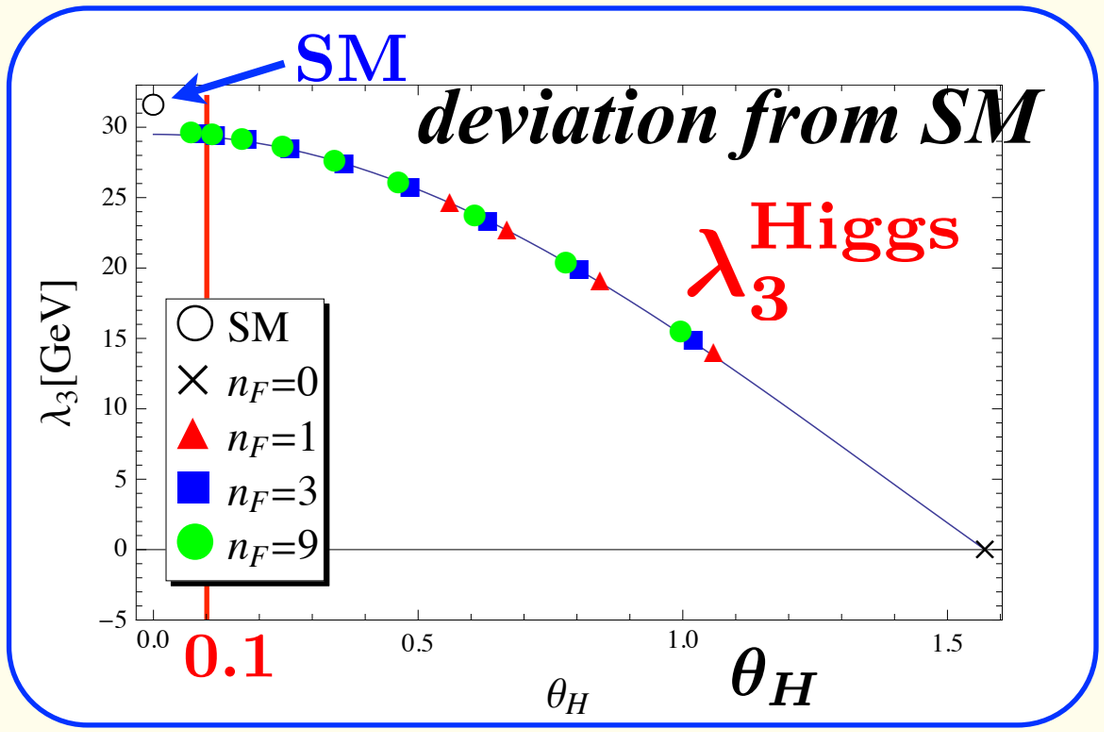


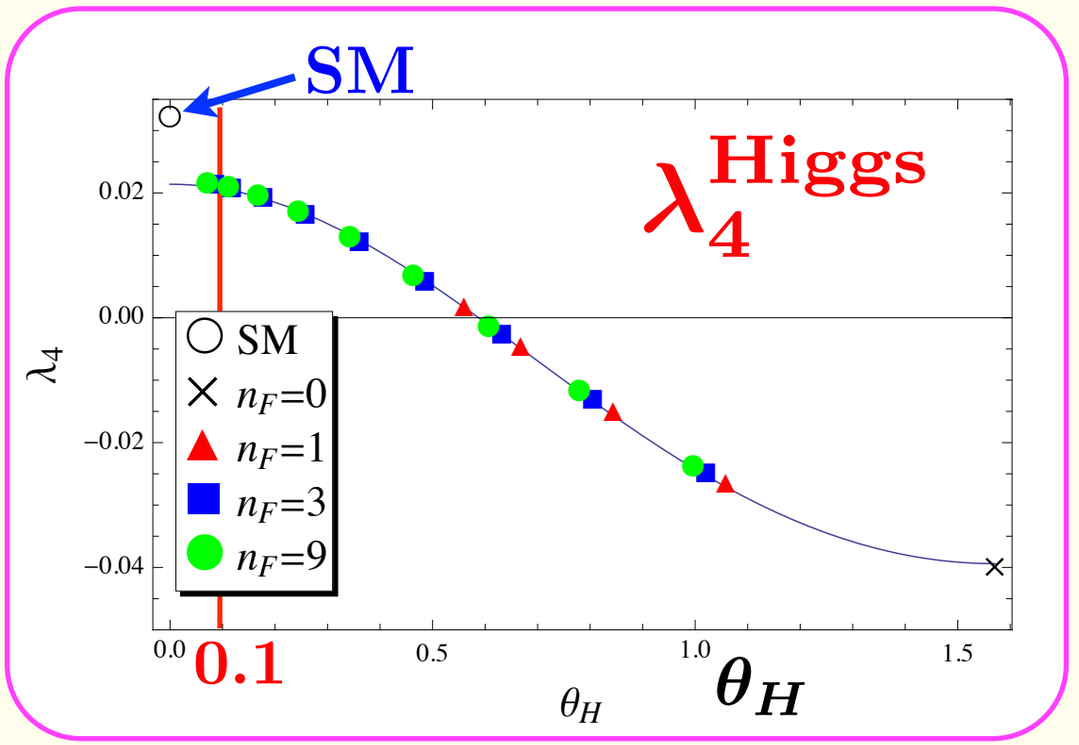


FHHOS 1301.1744, 1404.2748

Physics
OSAKA UNIVERSITY

Higgs self-couplings





FHHOS 1301.1744, 1404.2748

Small deviation for $\theta_H \sim 0.1$

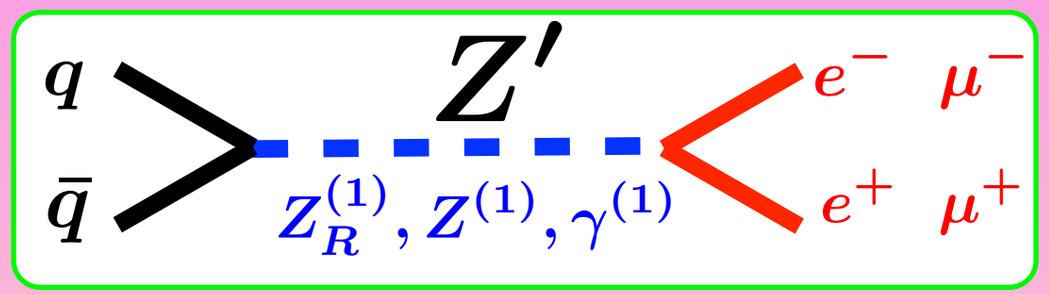
Physics
OSAKA UNIVERSITY

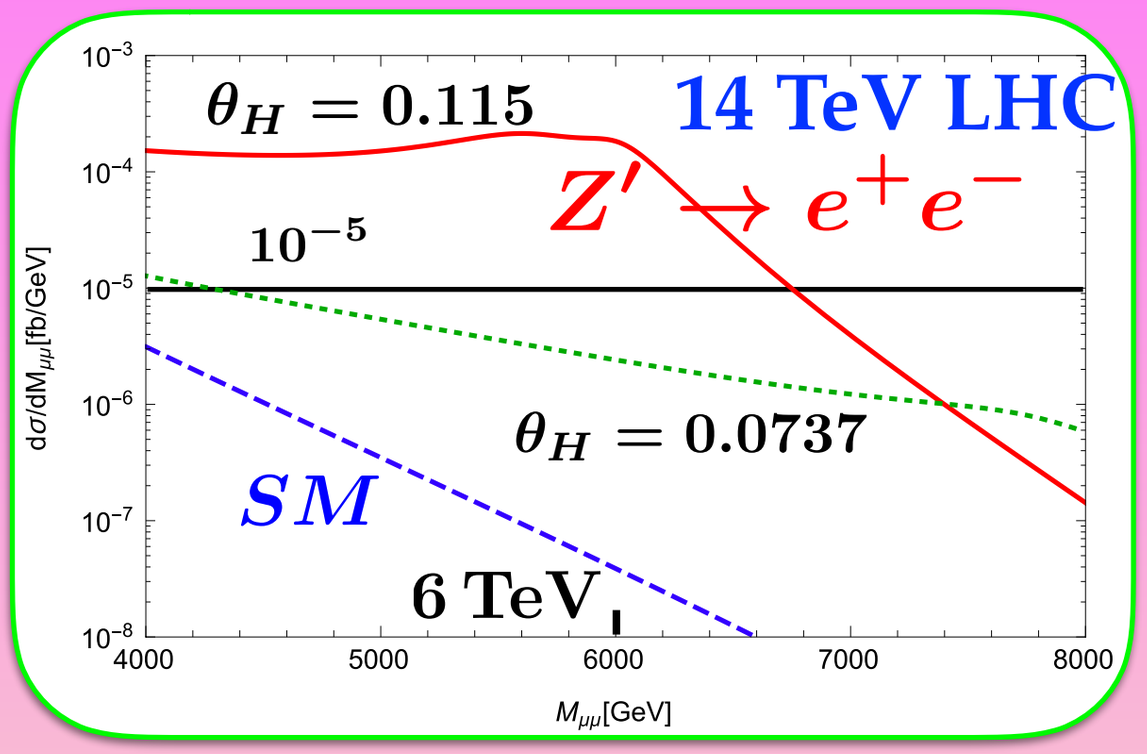
Extra dims ➡ KK excitations

KK gluons, W′, Z′

$n_F = 4$	$\theta_H = 0.115$ $z_L = 10^5$		$\theta_H = 0.0917$ $z_L = 3 \times 10^4$		$\theta_H = 0.0737$ $z_L = 10^4$	
Z'	m (TeV)	Γ (GeV)	m (TeV)	Γ (GeV)	m (TeV)	Γ (GeV)
$Z_R^{(1)}$	5.67	729	6.74	853	7.92	1058
$Z^{(1)}$	6.00	406	7.19	467	8.52	564
$\gamma^{(1)}$	6.01	909	7.20	992	8.52	1068

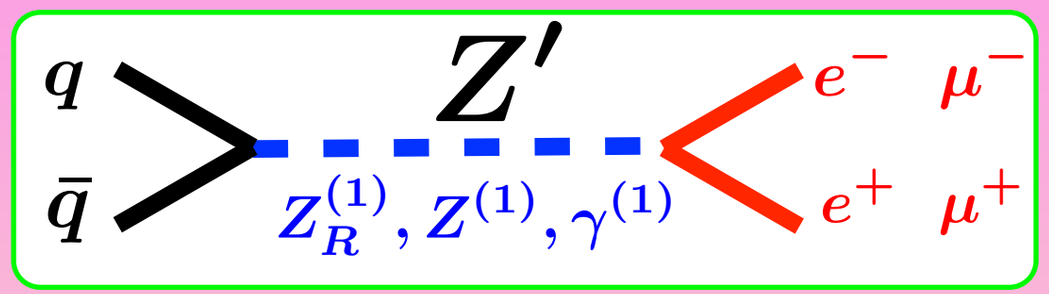
LHC

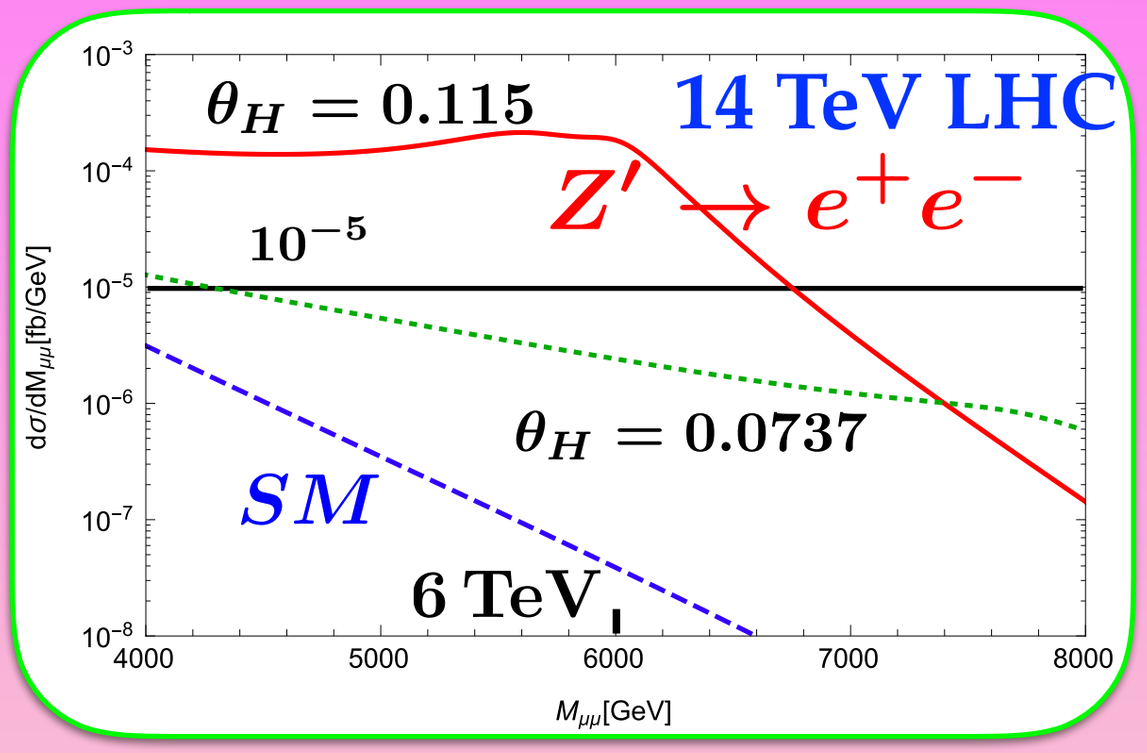


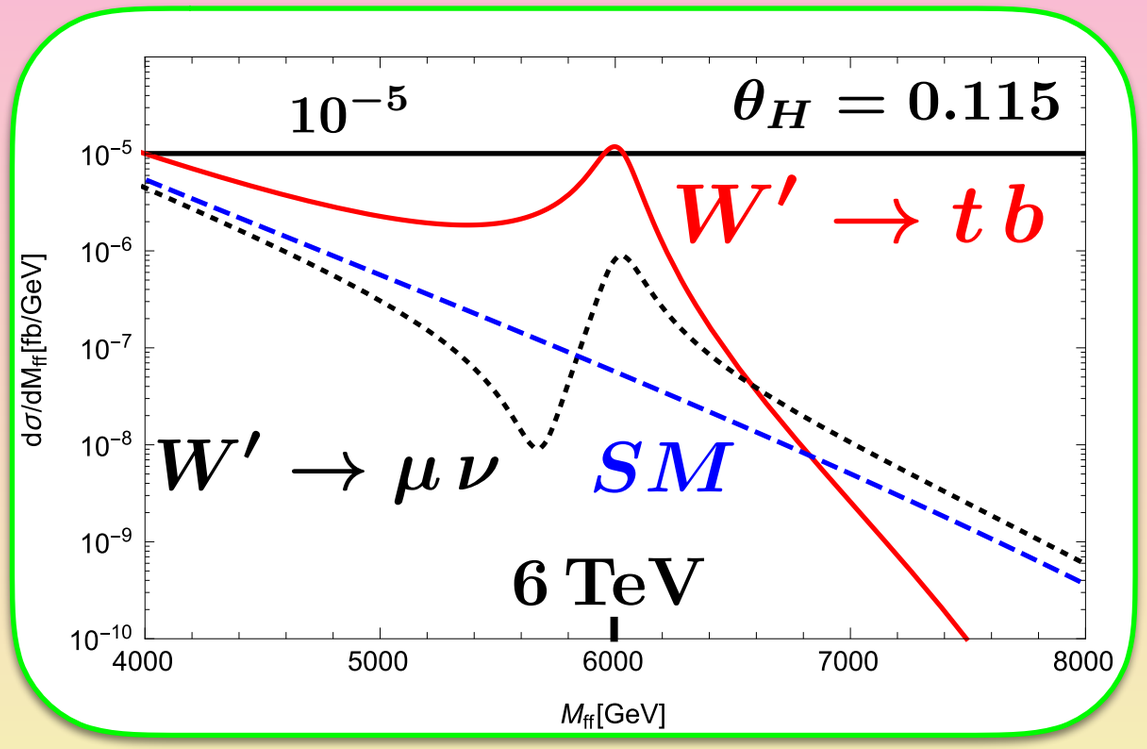


Physics
OSAKA UNIVERSITY

LHC



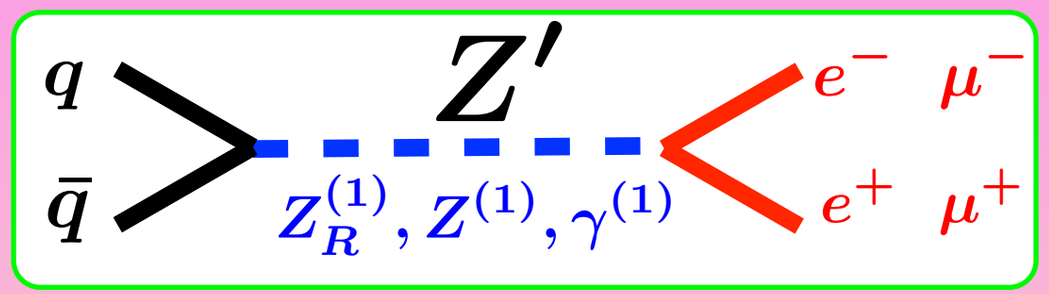


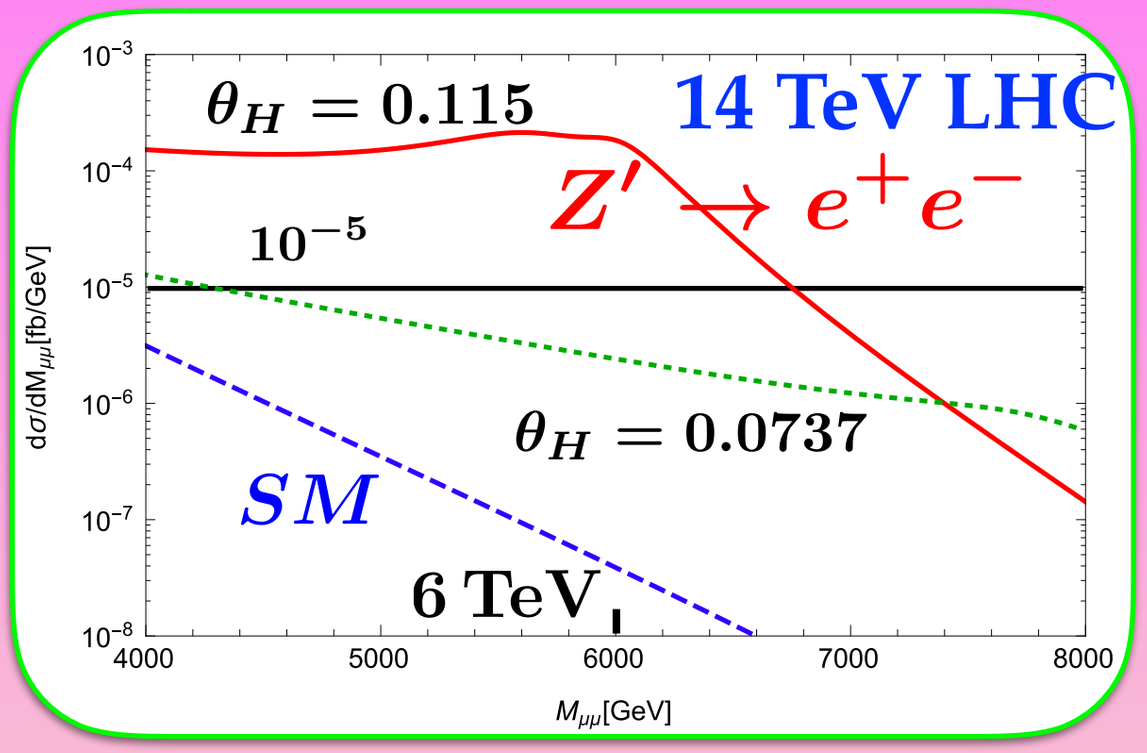


Physics
OSAKA UNIVERSITY

Funatsu, Hatanaka, YH, Orikasa, 1612.03378 (PRD)

LHC

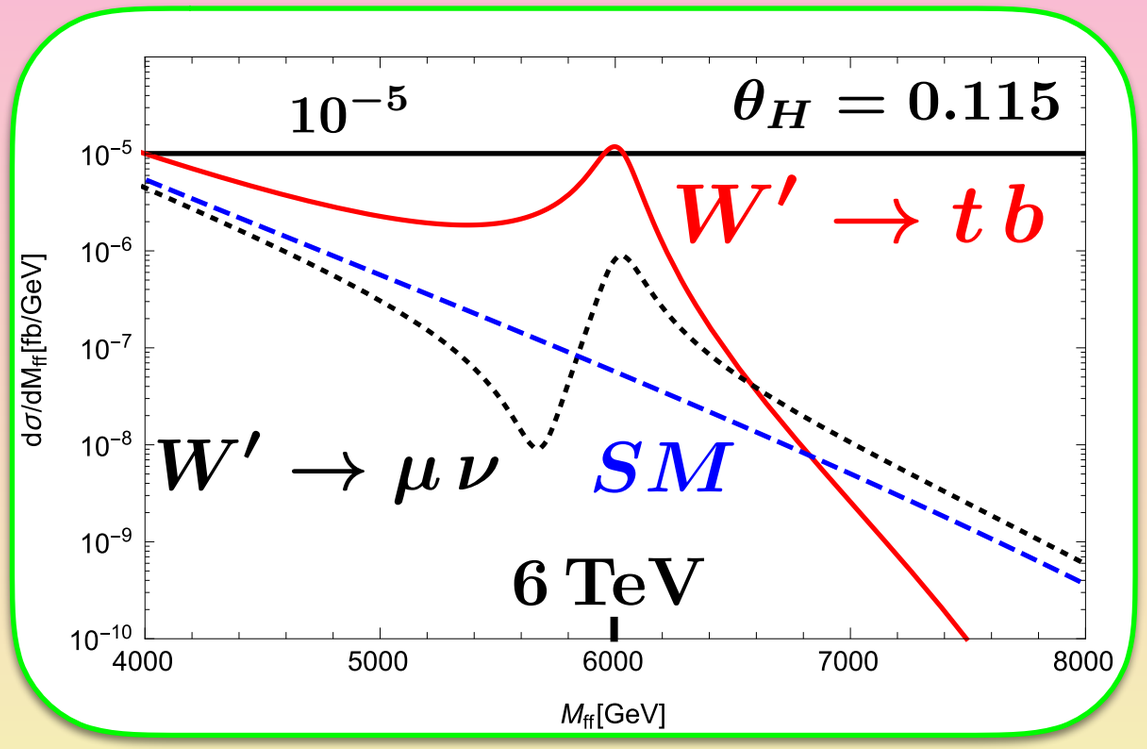




ATLAS-CONF-2017-027
(9 April 2017)
$\sqrt{s} = 13\,\text{TeV}, \quad 36.1\,\text{fb}^{-1}$

no event for > 3000 GeV

$\Rightarrow \quad \theta_H < 0.1$



Physics
OSAKA UNIVERSITY

Funatsu, Hatanaka, YH, Orikasa, 1612.03378 (PRD)

Left-right asymmetry in the couplings to Z′

Left-right asymmetry in the couplings to Z′

Wave functions

Z' : **localized near IR brane**

Left-right asymmetry in the couplings to Z′

Wave functions

Z' : **localized near IR brane**

q_R , ℓ_R **near IR brane**

q_L , ℓ_L **near UV brane**

Physics
OSAKA UNIVERSITY

Left-right asymmetry in the couplings to Z′

Wave functions

Z' : **localized near IR brane**

q_R , ℓ_R **near IR brane**

⇒ **large**

q_L , ℓ_L **near UV brane**

⇒ **small**

Physics
OSAKA UNIVERSITY

Couplings to Z'

	Z		Z'					
f	g^L_{Zf}	g^R_{Zf}	$g^L_{Z^{(1)}f}$	$g^R_{Z^{(1)}f}$	$g^L_{Z^{(1)}_R}$	$g^R_{Z^{(1)}_R f}$	$g^L_{\gamma^{(1)}f}$	$g^R_{\gamma^{(1)}f}$
ν_e	0.5704	0	−0.209	0	0	0	0	0
ν_μ	0.5704	0	−0.209	0	0	0	0	0
ν_τ	0.5704	0	−0.209	0	0	0	0	0
e	−0.3066	0.2639	0.112	1.044	0	−1.438	0.177	−1.869
μ	−0.3066	0.2639	0.112	0.980	0	−1.361	0.177	−1.783
τ	−0.3066	0.2639	0.112	0.973	0	−1.296	0.177	−1.687
u	0.3945	−0.1759	−0.145	−0.684	0	0.944	−0.118	1.243
c	0.3945	−0.1759	−0.148	−0.624	0	0.882	−0.118	1.151
t	0.3937	−0.1759	0.564	−0.425	1.124	0.626	0.461	0.773
d	−0.4824	0.08796	0.177	0.342	0	−0.472	0.059	−0.622
s	−0.4824	0.08796	0.177	0.316	0	−0.441	0.059	−0.575
b	−0.4825	0.08795	−0.696	0.213	1.122	−0.313	−0.230	−0.387

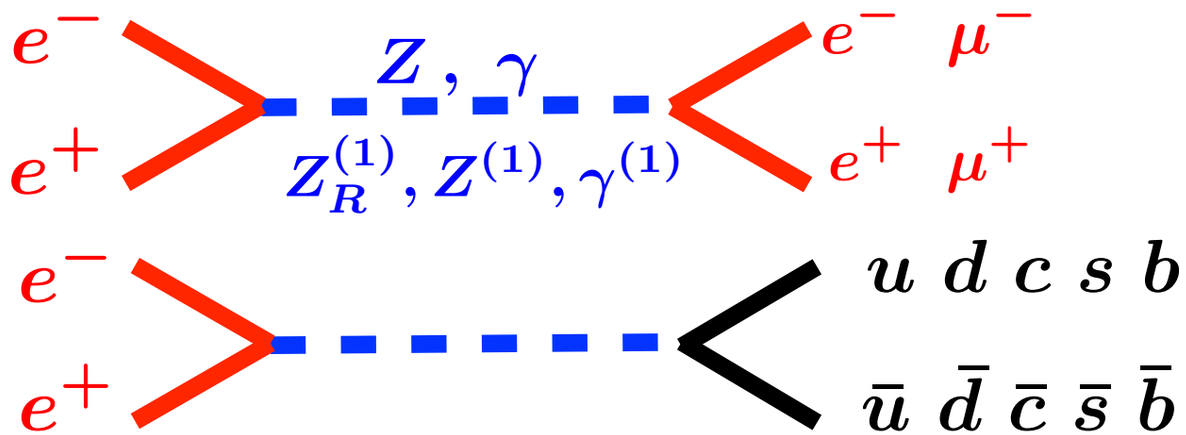
in unit of g_w ($\theta_H = 0.0917$)

Funatsu, Hatanaka, YH, Orikasa, 1705.05282

Physics
OSAKA UNIVERSITY

ILC

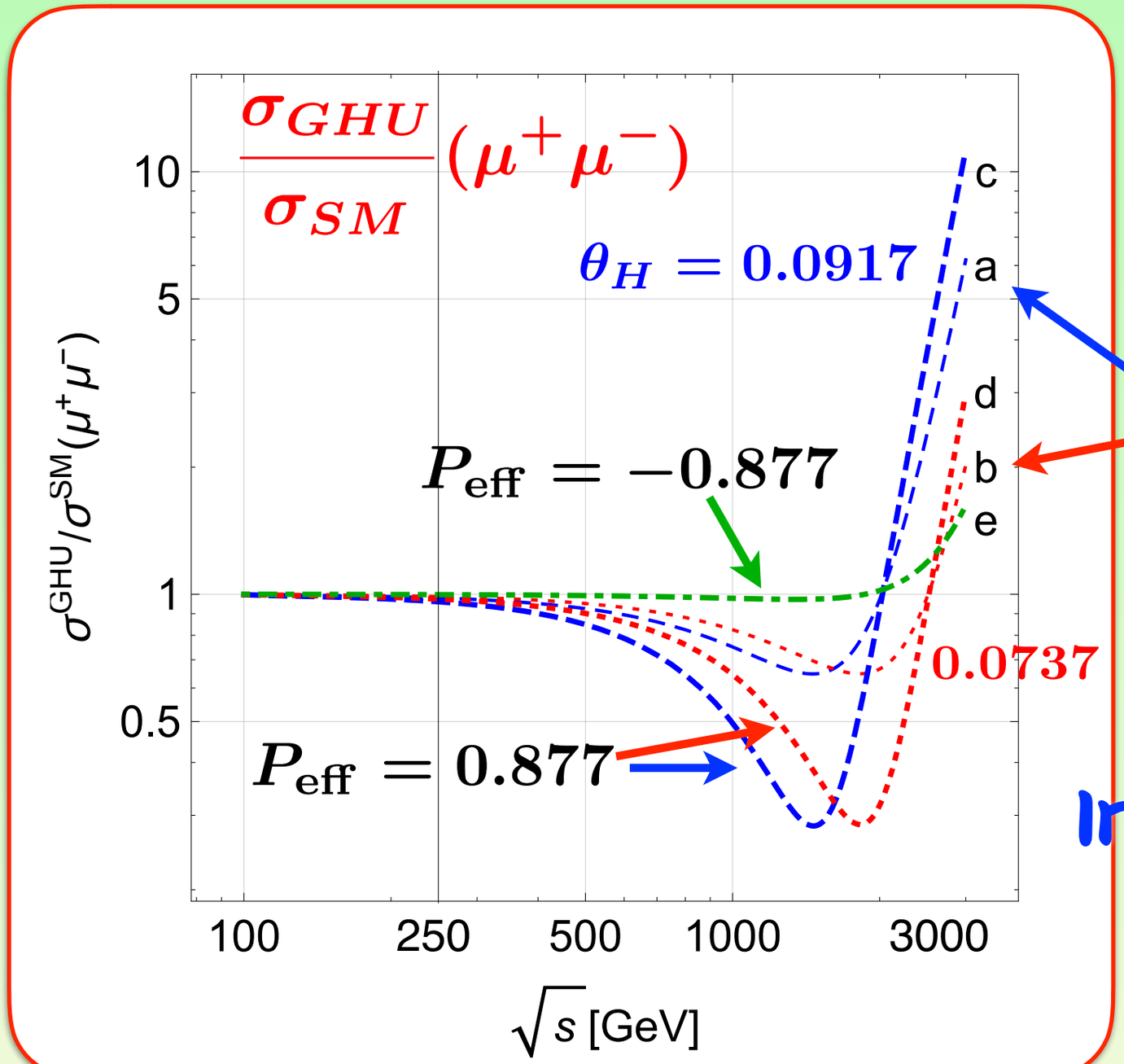
ILC (e^+e^- linear collider)



Energies at 250 GeV, 500 GeV, 1 TeV

Polarized electron/positron beams

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



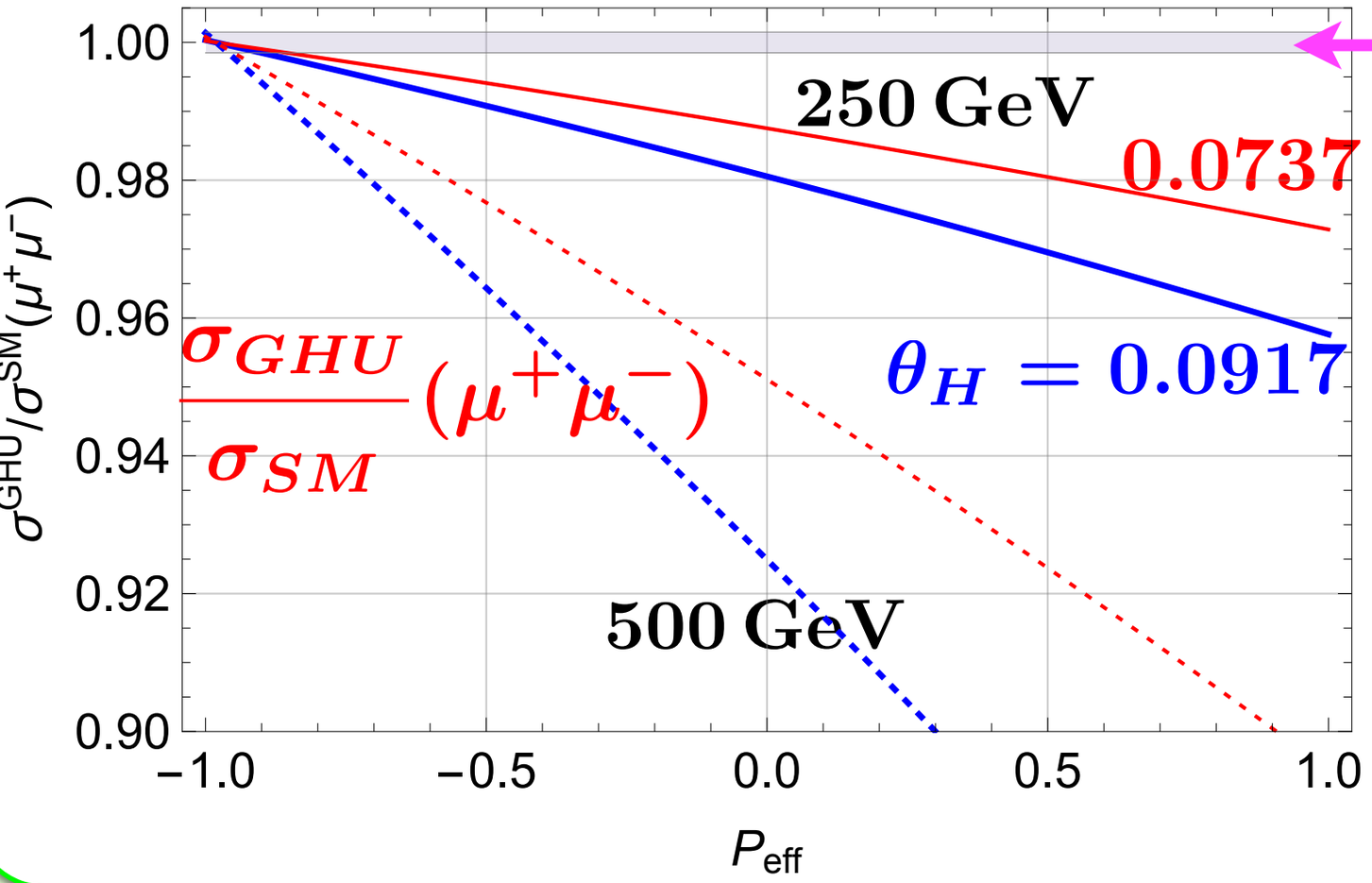
$P_{\rm eff} = 0$

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

Interference among

γ, Z, Z'

Physics
OSAKA UNIVERSITY



statistical uncertainty
$(250\,\mathrm{GeV}, 250\,\mathrm{fb}^{-1})$

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

Interference among γ, Z, Z'

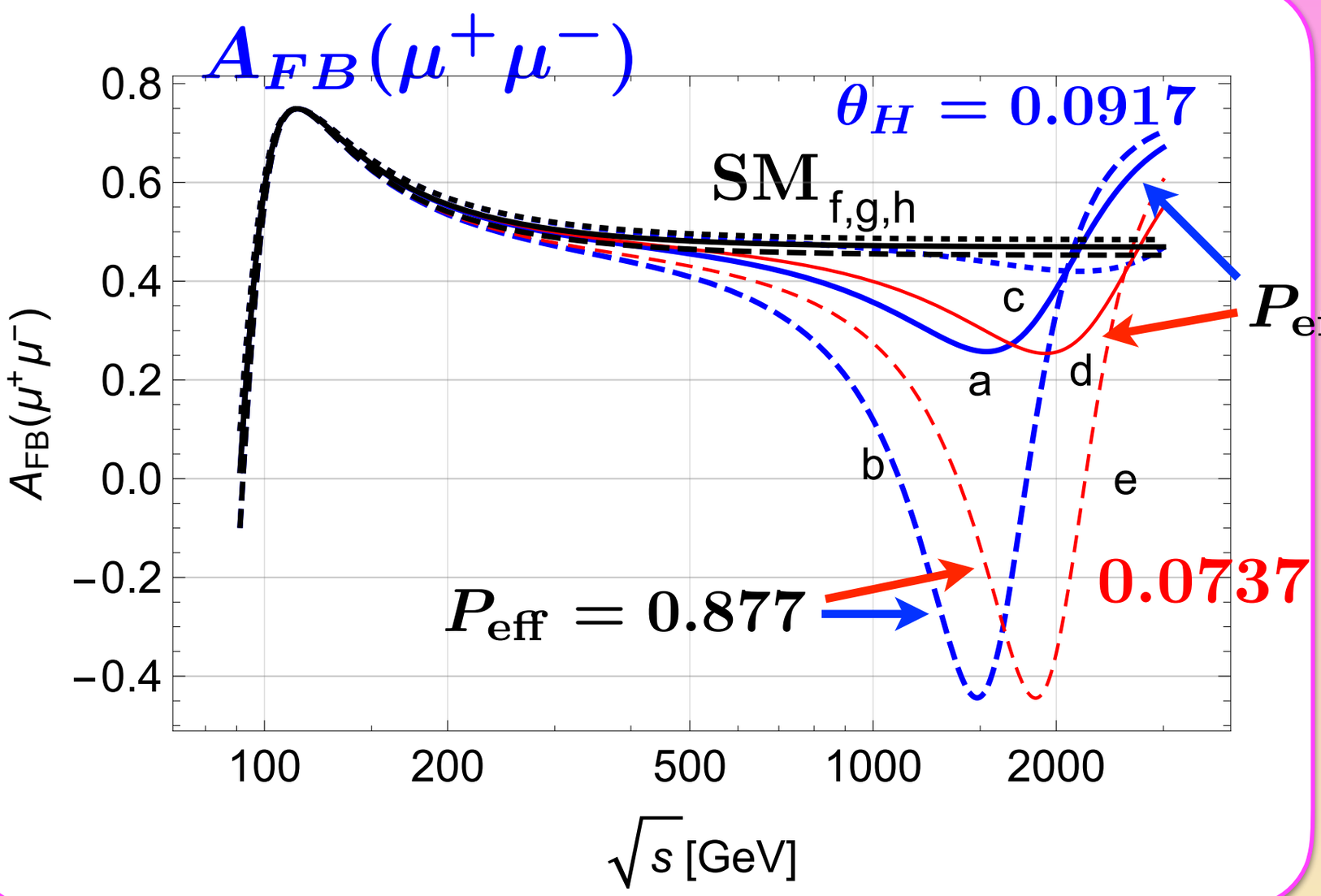
$$4\,\% \text{ at } P_{\rm eff} = 0.877 \quad \text{at } 250\,\mathrm{GeV}$$

Physics
OSAKA UNIVERSITY

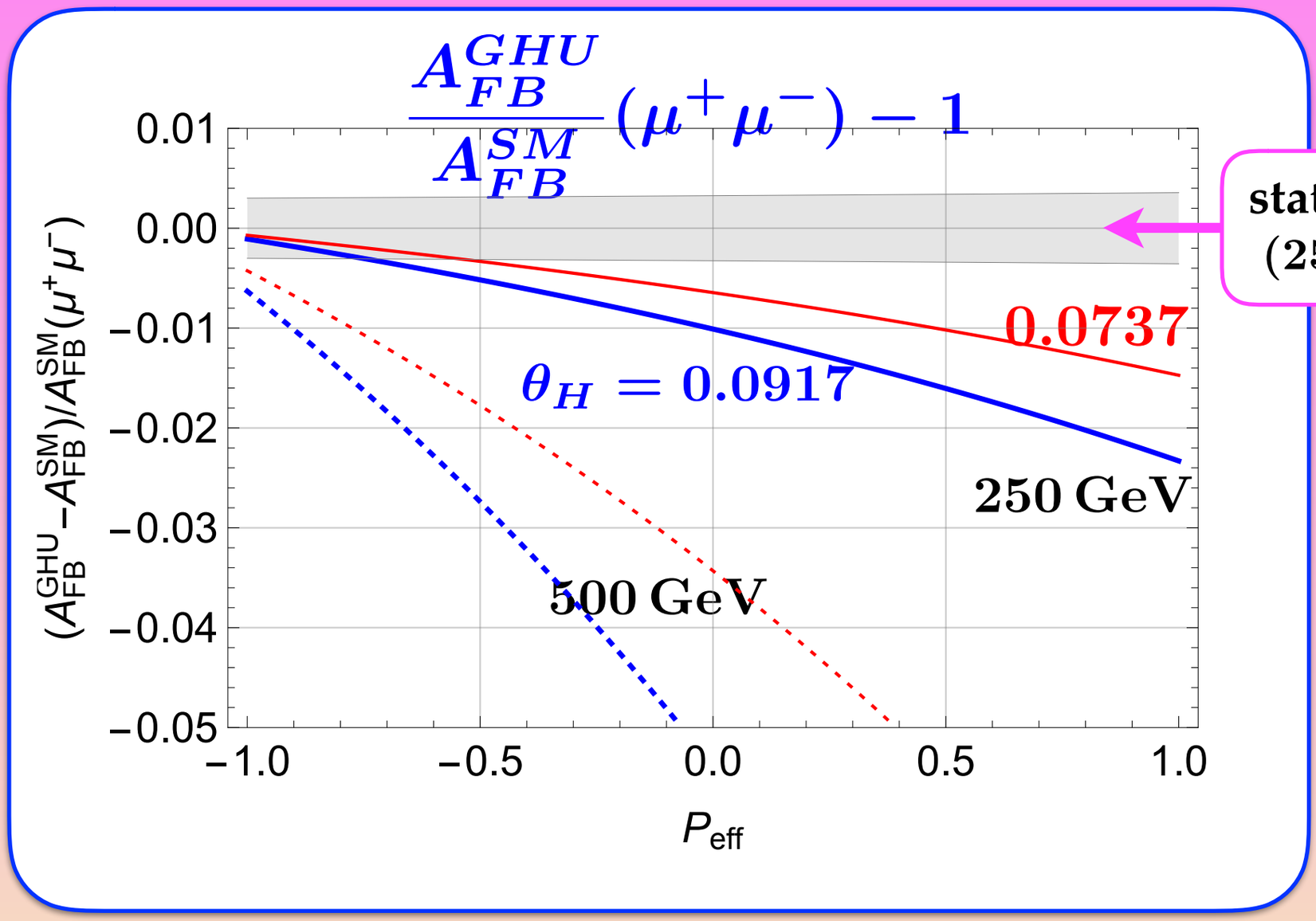
$$A_{FB} = \frac{\sigma_{\mathrm{forward}} - \sigma_{\mathrm{backward}}}{\sigma_{\mathrm{forward}} + \sigma_{\mathrm{backward}}}$$

Physics
OSAKA UNIVERSITY

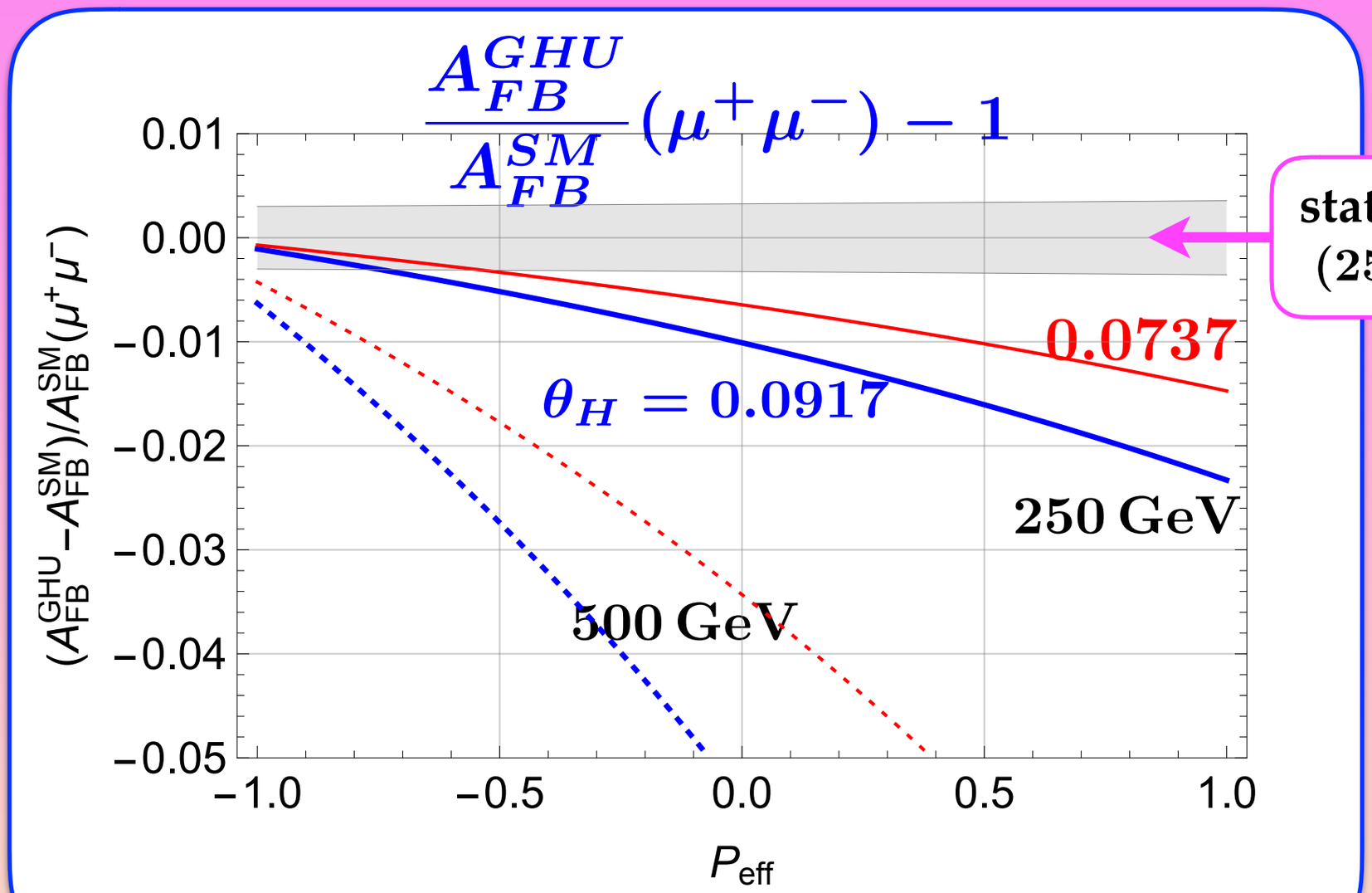
$$A_{FB} = \frac{\sigma_{\text{forward}} - \sigma_{\text{backward}}}{\sigma_{\text{forward}} + \sigma_{\text{backward}}}$$



Physics
OSAKA UNIVERSITY



Physics
OSAKA UNIVERSITY



$250\,\mathrm{GeV},\ 250\,\mathrm{fb}^{-1}$ $\quad P_{\mathrm{eff}} = 0.8$ $\quad 6\,\sigma\,(4\,\sigma)$

Polarization dependence

Left-right asymmetry

$$R_{f,RL} = \frac{\sigma(e^+e^- \to \bar{f}f; P_{e^-} = +\overline{P}, P_{e^+} = 0)}{\sigma(e^+e^- \to \bar{f}f; P_{e^-} = -\overline{P}, P_{e^+} = 0)}$$

Systematic errors reduced.

Physics
OSAKA UNIVERSITY

Left-right asymmetry

$$R_{f,RL} = \frac{\sigma(e^+e^- \to \bar{f}f; P_{e^-} = +\overline{P}, P_{e^+} = 0)}{\sigma(e^+e^- \to \bar{f}f; P_{e^-} = -\overline{P}, P_{e^+} = 0)}$$

Systematic errors reduced.

$250\,\mathrm{GeV},\ \overline{P} = 0.8,\ 250\,\mathrm{fb}^{-1} \times 2$

f	SM		GHU	
	$R_{f,RL}$	$\Delta\sigma$	θ_H 0.0917	0.0737
μ	0.890	0.3%	−3.4 %	−2.2 %
b	0.349	0.3%	−3.1 %	−2.1 %

Physics OSAKA UNIVERSITY

Gauge-Higgs

Composite Higgs

Gauge-Higgs

Composite Higgs

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

	5d gauge theory	Composite picture
Higgs	gauge field AB phase θ_H	**pseudo-NG boson**

Gauge-Higgs

Composite Higgs

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

	5d gauge theory	Composite picture
Higgs	gauge field AB phase θ_H	**pseudo-NG boson**
	θ_H	vacuum misalignment angle $\dfrac{\langle h \rangle}{f_\pi}$

Gauge-Higgs　　Composite Higgs

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

	5d gauge theory	Composite picture
Higgs	gauge field AB phase θ_H	**pseudo-NG boson**
	θ_H	vacuum misalignment angle $\frac{\langle h \rangle}{f_\pi}$
κ_V κ_f	$\cos\theta_H$	$\cos\theta_H$ (MCHM) not fixed

Gauge-Higgs

Composite Higgs

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

	5d gauge theory	Composite picture
Higgs	gauge field AB phase θ_H	**pseudo-NG boson**
	θ_H	vacuum misalignment angle $\frac{\langle h \rangle}{f_\pi}$
κ_V κ_f	$\cos\theta_H$	$\cos\theta_H$ (MCHM) not fixed
Z'	$Z^{(1)}, \gamma^{(1)}, Z_R^{(1)}$ $7 \sim 10\,\mathrm{TeV}$ large widths, $\not{p}$	technirho meson

	Gauge-Higgs	Composite Higgs
	$SO(5) \times U(1)$	
	5d gauge theory	Composite picture
Higgs	gauge field AB phase θ_H	**pseudo-NG boson**
	θ_H	vacuum misalignment angle $\frac{\langle h \rangle}{f_\pi}$
κ_V κ_f	$\cos\theta_H$	$\cos\theta_H$ (MCHM) not fixed
Z'	$Z^{(1)}, \gamma^{(1)}, Z_R^{(1)}$ $7 \sim 10\,\mathrm{TeV}$ large widths, $\not{p}$	technirho meson
constraint	$\theta_H < 0.1$ from Z'	$\epsilon = \sin\theta_H < 0.3$ $(\xi = \theta_H^2 < 0.1)$ from S parameter

Summary

Summary

Gauge-Higgs unification

Summary

Gauge-Higgs unification

Higgs = gauge boson in 5d

Physics
OSAKA UNIVERSITY

Summary

Gauge-Higgs unification

Higgs = gauge boson in 5d

Signals can be seen at LHC/ILC.

Physics
OSAKA UNIVERSITY