Signals of gauge-Higgs unification at 250 GeV ILC

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ALCW 2018, Fukuoka, 29 May 2018

How can we see

new particles (7 - 8 TeV)

at 250 GeV ILC ?

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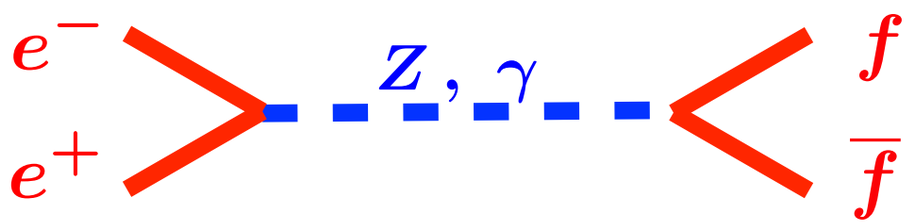
ILC 250 GeV



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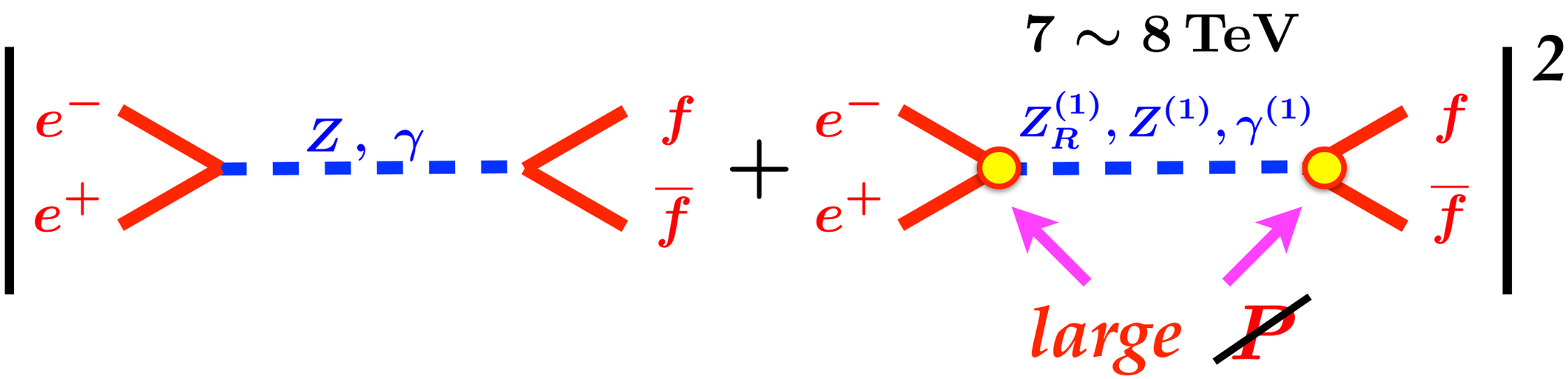

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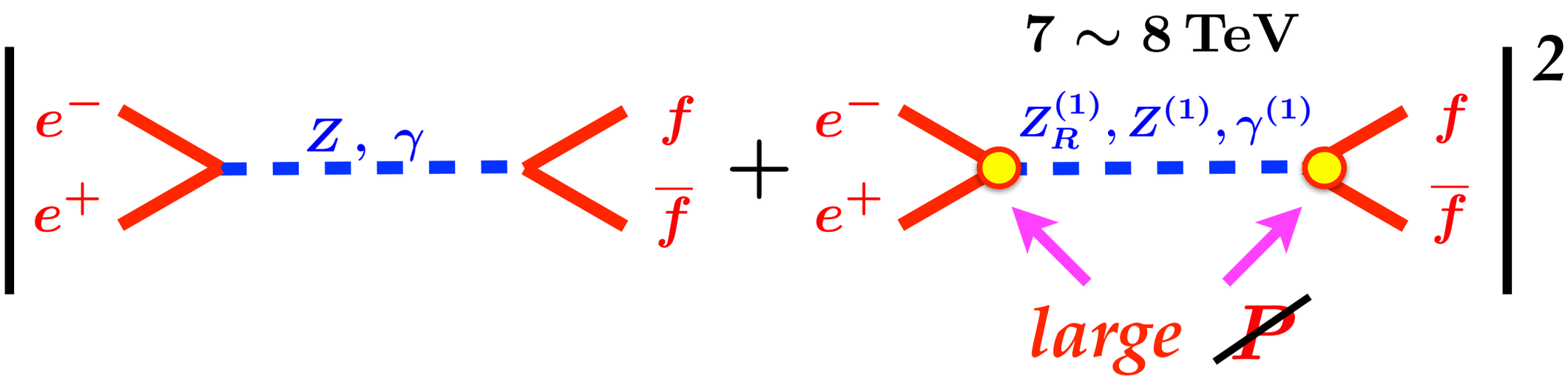

Precision measurements of

interference effects

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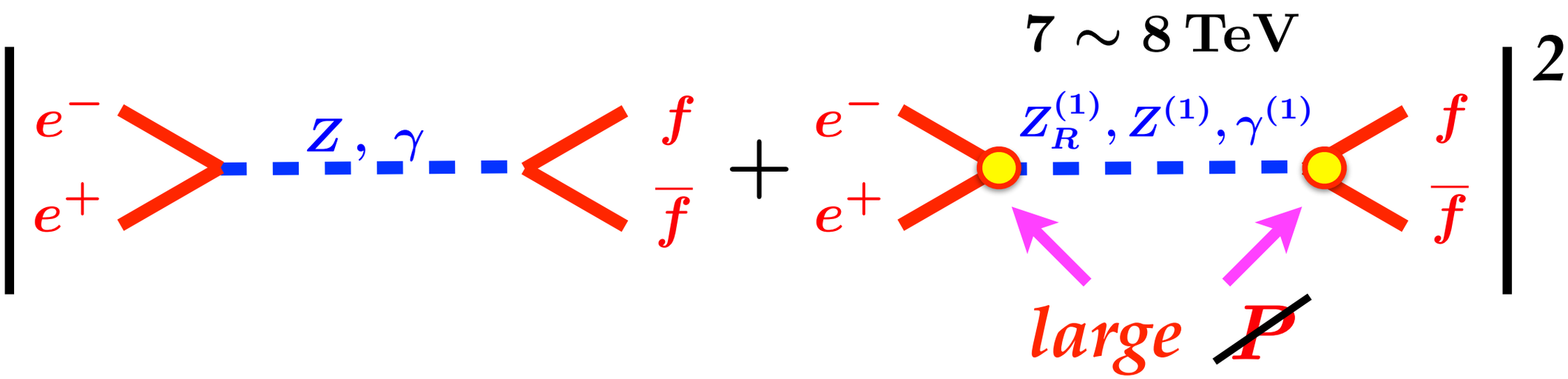

Precision measurements of

interference effects

$250\,\mathrm{fb}^{-1}$ ⇒ $3\sigma \sim 5\sigma$ deviation from SM

polarized e^- large P_{e^-} dep.

Gauge-Higgs unification

A_M

A_μ $\qquad$ A_y

γ , W , Z

$Higgs$

Aharonov-Bohm phase

θ_H

Gauge-Higgs unification

A_M

A_μ $\qquad$ A_y

γ , W , Z

$Higgs$
Aharonov-Bohm phase
θ_H

Hosotani mechanism

Dynamical EW sym breaking

finite m_H generated

gauge hierarchy prob. solved

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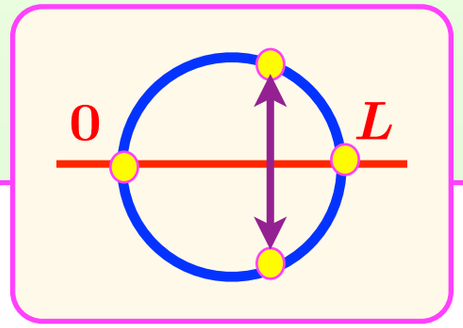
SO(5)xU(1) GHU in Randall-Sundrum

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

AdS $\Lambda = -6\,k^2$

$$P_0 = \begin{pmatrix} -I_4 & \\ & 1 \end{pmatrix}$$

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

$$P_1 = \begin{pmatrix} -I_4 & \\ & 1 \end{pmatrix}$$

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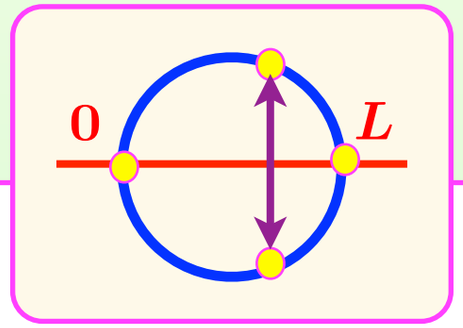

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$$A_\mu \sim \begin{pmatrix} W \;\; Z \;\; \gamma \end{pmatrix} \qquad A_y \sim \begin{pmatrix} Higgs \end{pmatrix}$$

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

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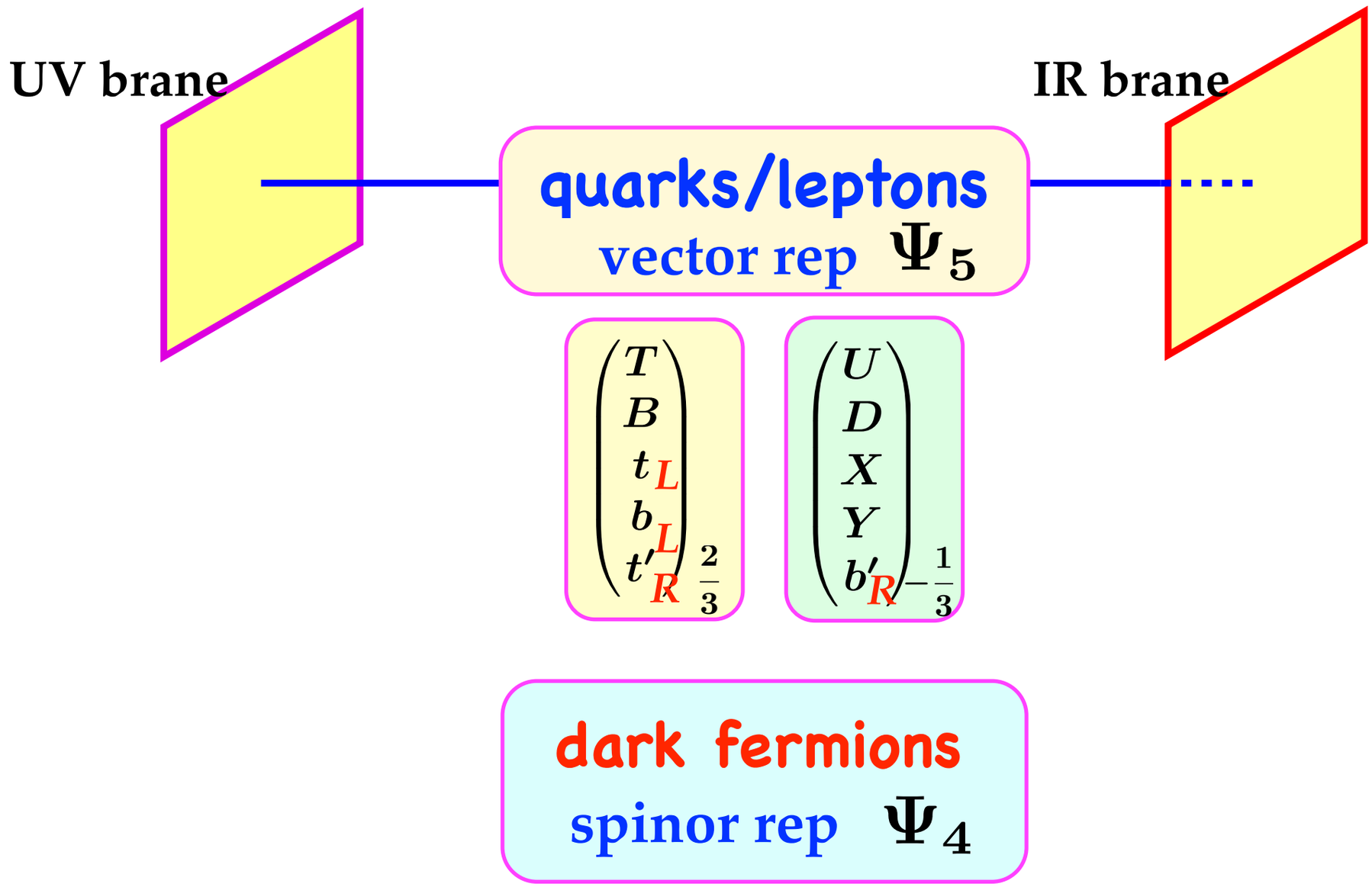
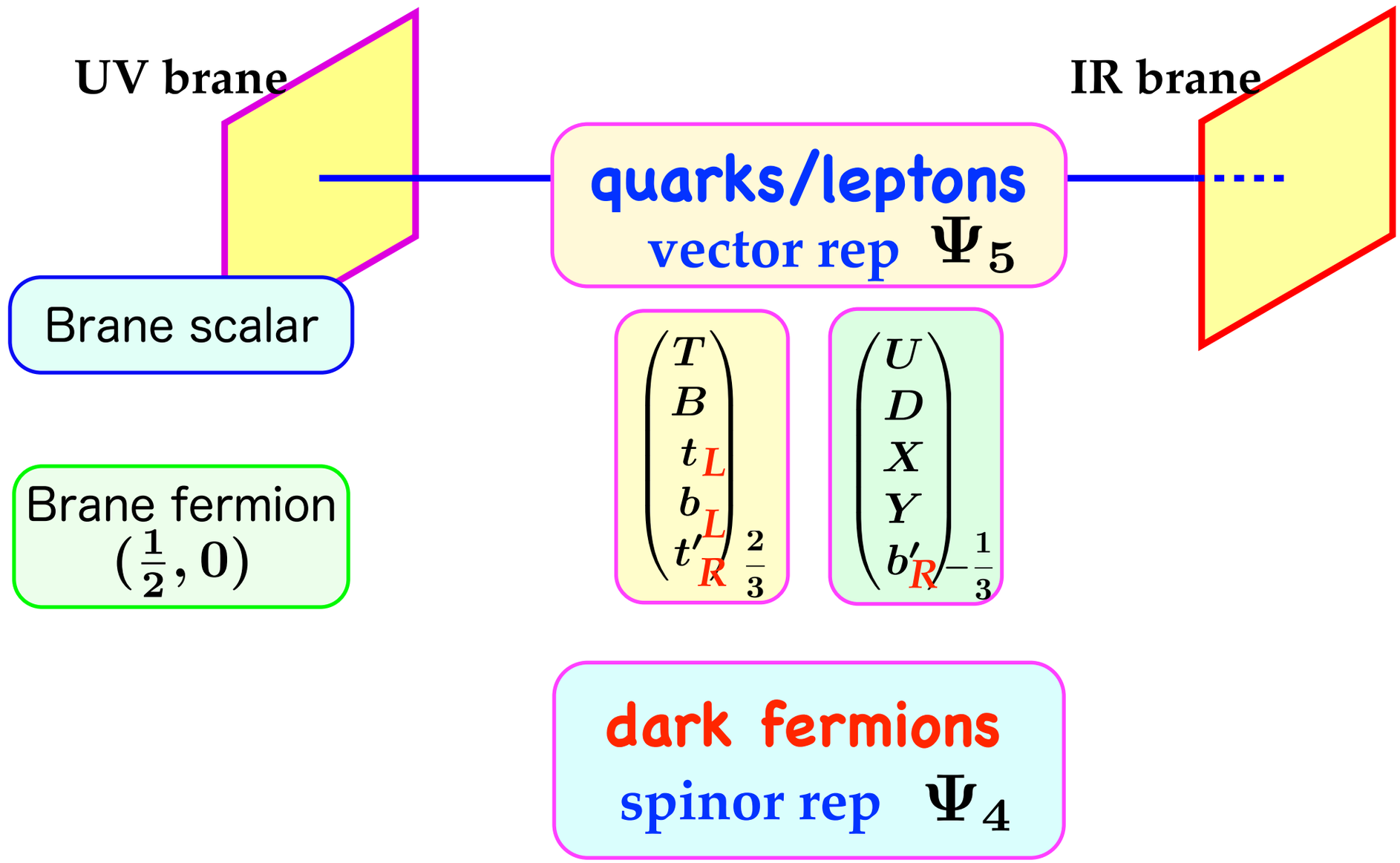
SO(5)xU(1) EW


UV brane
IR brane
quarks/leptons
vector rep Ψ_5
$\begin{pmatrix} T \\ B \\ t_L \\ b_L \\ t'_R \end{pmatrix}_{\frac{2}{3}}$
$\begin{pmatrix} U \\ D \\ X \\ Y \\ b'_R \end{pmatrix}_{-\frac{1}{3}}$
dark fermions
spinor rep Ψ_4

SO(5)xU(1) EW


UV brane
IR brane
quarks/leptons
vector rep Ψ_5
....
Brane scalar
Brane fermion
$(\frac{1}{2}, 0)$
$\begin{pmatrix} T \\ B \\ t_L \\ b_L \\ t'_R \end{pmatrix}_{\frac{2}{3}}$
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dark fermions
spinor rep Ψ_4

At low energies

Nearly the same as SM

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At low energies

Nearly the same as SM

gauge couplings ~ SM

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

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	g_{GHU}/g_{SM} $(\theta_H = 0.115)$
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tb	0.9993
WWZ	0.9999998

Z to $f\bar{f}$

	GHU $(\theta_H = 0.0917)$ left	GHU right	SM left	SM right
$\nu_{e,\mu,\tau}$	0.5001	0	0.5	0
e, μ, τ	−0.2688	0.2314	−0.2688	0.2312
u, c, t	0.3459	−0.1542	0.3458	−0.1541
d, s, b	−0.4230	0.0771	−0.4229	0.0771

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Higgs couplings

to W, Z, quarks/leptons ⇒ $(SM) \times \cos\theta_H$

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

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Higgs decays:

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

Branching fractions ~ (SM)

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Branching fractions ~ (SM)

Nearly the same as in SM

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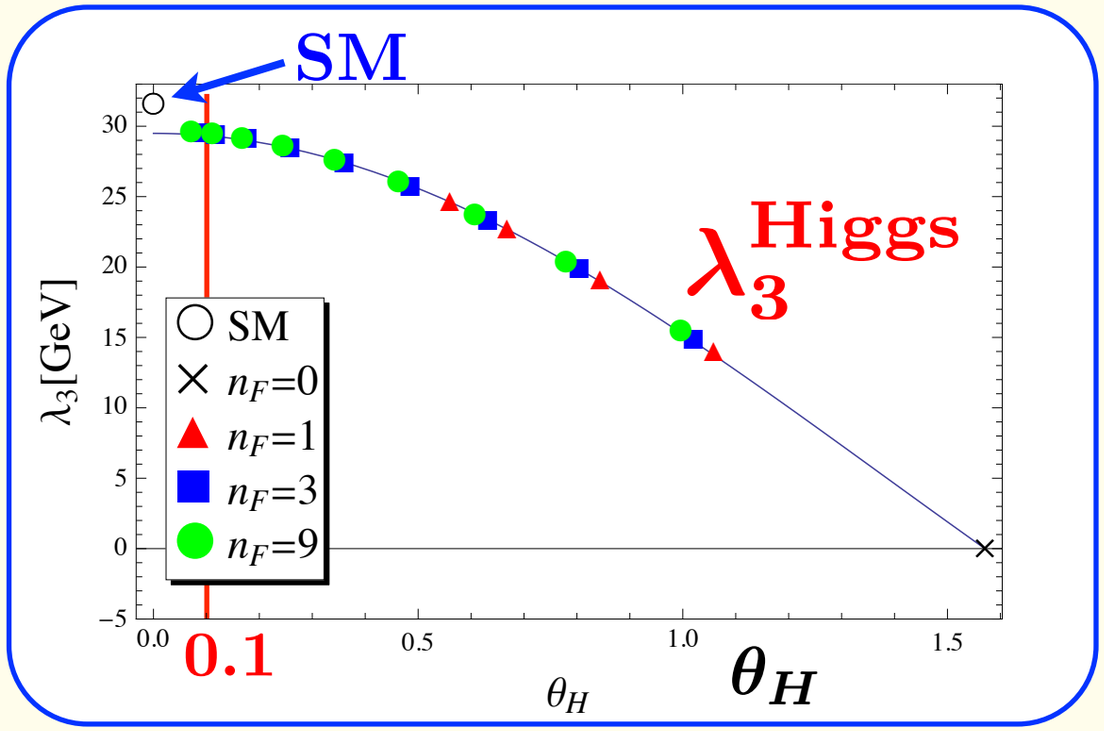
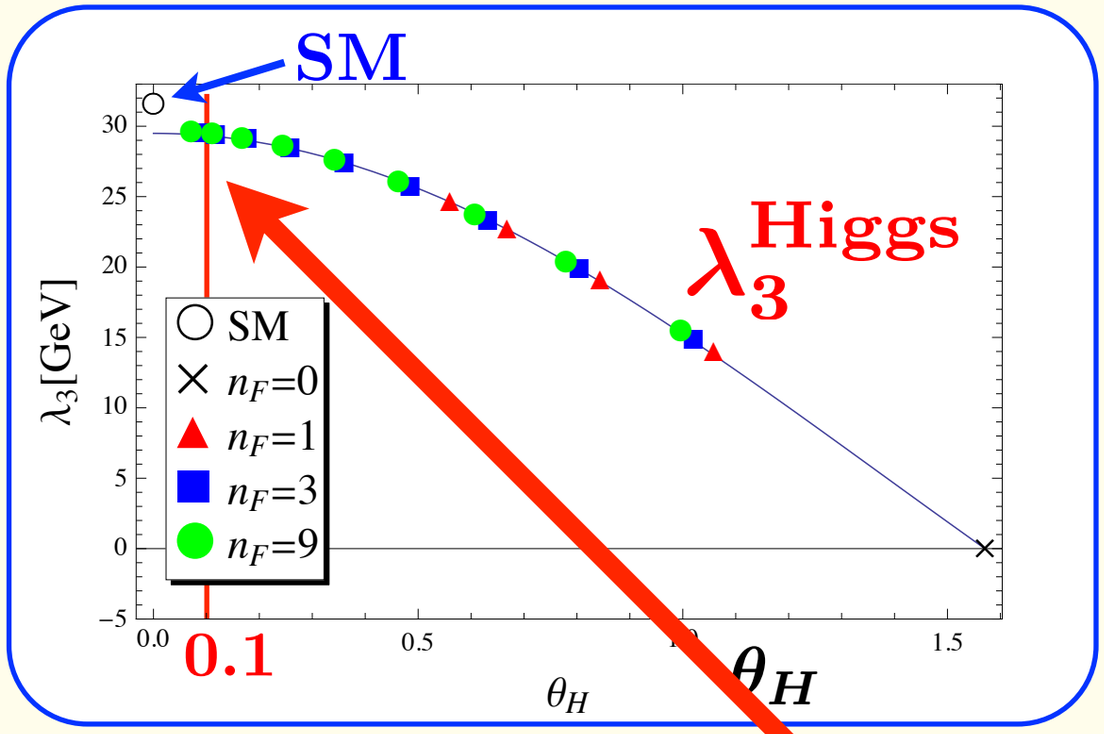
Higgs self-couplings



FHHOS 1301.1744, 1404.2748

Higgs self-couplings



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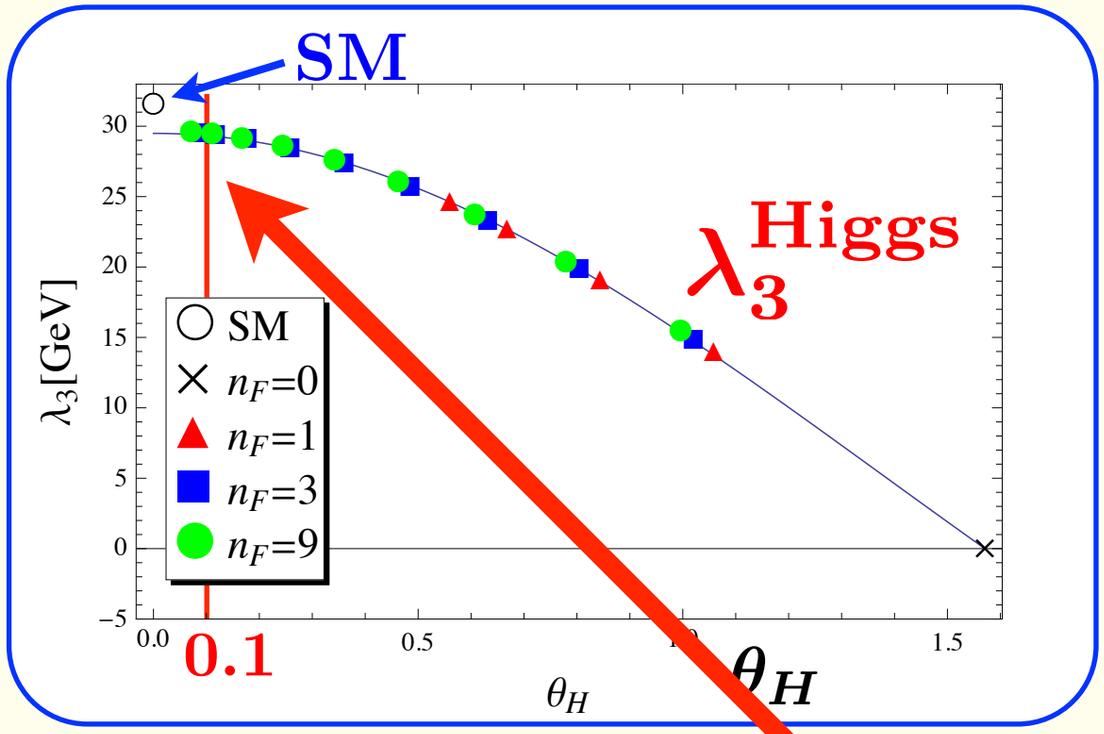
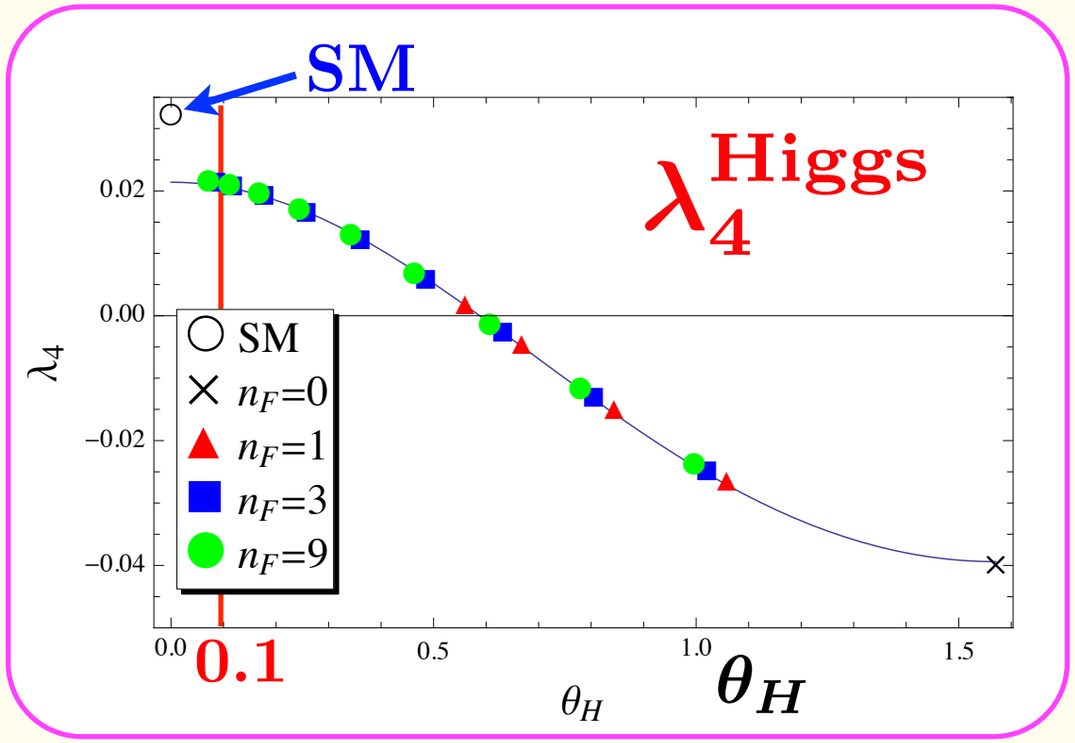
$\lambda_3^{\rm Higgs}$: *Small deviation for* $\theta_H \sim 0.1$

Higgs self-couplings





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Extra dims ➡ KK excitations

KK gluons, W′, Z′, …

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KK gluons, W′, Z′, …

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

Funatsu, Hatanaka, YH, Orikasa,
LHC : 1612.03378 (PRD) ILC : 1705.05282v3 (PLB)

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$\not{P}$ in the Z′ couplings

Wave functions

Z' : **localized near IR brane**

$\not{P}$ in the Z′ couplings

Wave functions

Z'	**: localized near IR brane**
$u_R, d_R, c_R, s_R,\ \ell_R$	**near IR brane**
$u_L, d_L, c_L, s_R,\ \ell_L$	**near UV brane**

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$\not{P}$ in the Z′ couplings

Wave functions

Z'	**: localized near IR brane**
$u_R, d_R, c_R, s_R,\ \ell_R$	**near IR brane**
$u_L, d_L, c_L, s_R,\ \ell_L$	**near UV brane**
$t\ ,\ b$	**: spread with long tails**

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$\not{P}$ in the Z′ couplings

Wave functions

Z' : localized near IR brane

$u_R, d_R, c_R, s_R, \ \ell_R$ near IR brane

⇒ large

$u_L, d_L, c_L, s_R, \ \ell_L$ near UV brane

⇒ small

$t \ , \ b$: spread with long tails

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Couplings to Z′

$$\frac{g_w}{\cos\theta_W} Z'_\mu \{ \hat{g}_L \bar{f}_L \gamma^\mu f_L + \hat{g}_R \bar{f}_R \gamma^\mu f_R \}$$

$\theta_H = 0.0917$

	SM: Z		$Z^{(1)}$		$Z_R^{(1)}$		$\gamma^{(1)}$	
	Left	Right	Left	Right	Left	Right	Left	Right
ν_e			-0.183	0	0	0	0	0
ν_μ	0.5	0	-0.183	0	0	0	0	0
ν_τ			-0.183	0	0	0	0	0
e			0.099	0.916	0	-1.261	0.155	-1.665
μ	-0.2688	0.2312	0.099	0.860	0	-1.193	0.155	-1.563
τ			0.099	0.814	0	-1.136	0.155	-1.479
u			-0.127	-0.600	0	0.828	-0.103	1.090
c	0.3458	-0.1541	-0.130	-0.555	0	0.773	-0.103	1.009
t			0.494	-0.372	0.985	0.549	0.404	0.678
d			0.155	0.300	0	-0.414	0.052	-0.545
s	-0.4229	0.0771	0.155	0.277	0	-0.387	0.052	-0.504
b			-0.610	0.186	0.984	-0.274	-0.202	-0.339

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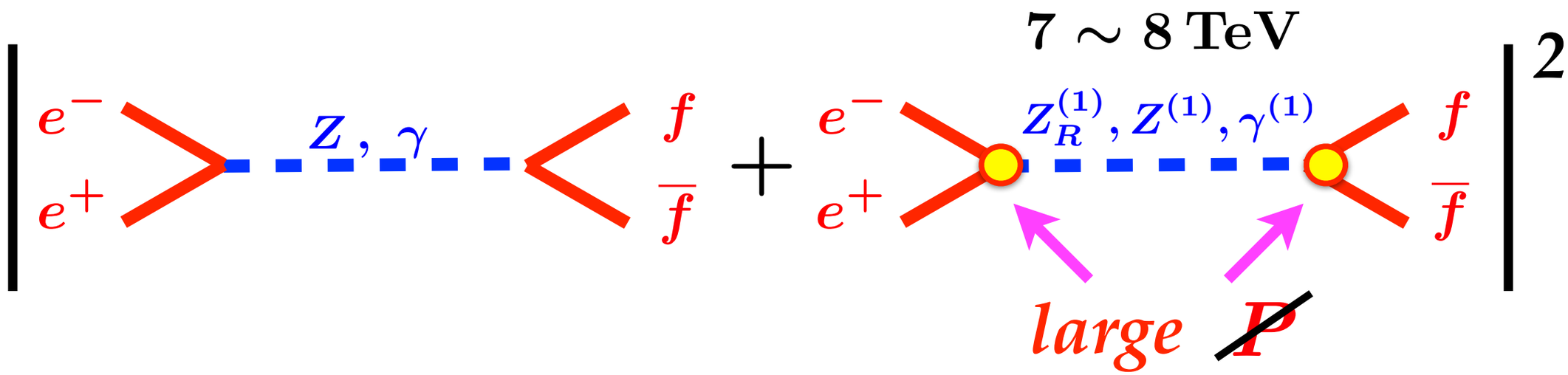
Funatsu, Hatanaka, YH, Orikasa, 1705.05282

ILC



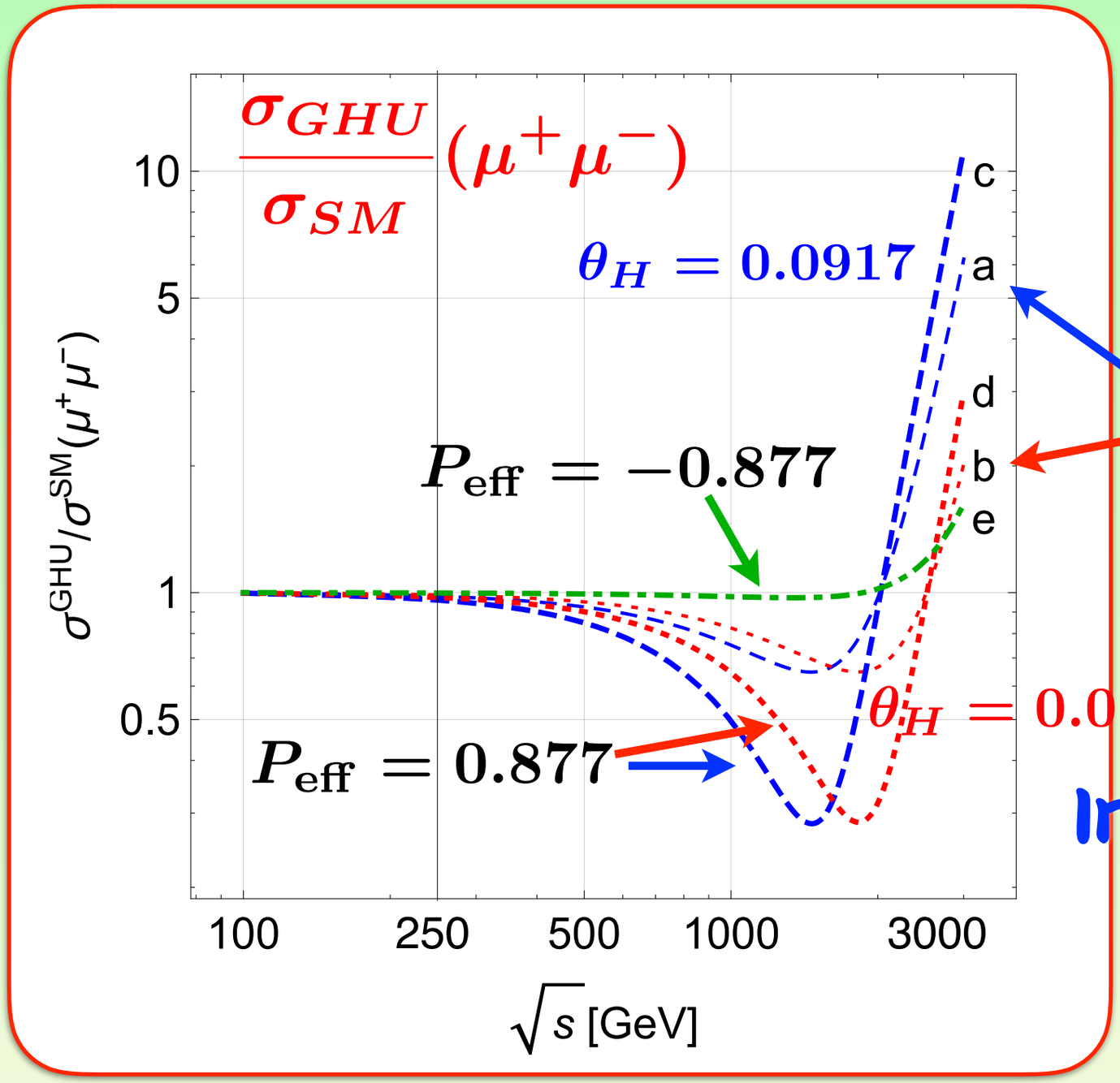
interference effects

Funatsu, Hatanaka, YH, Orikasa, 1705.05282 (PLB 775, Nov 2017)

Bhabha scattering, angular dep

F. Richard, 1804.02846 [hep-ex]

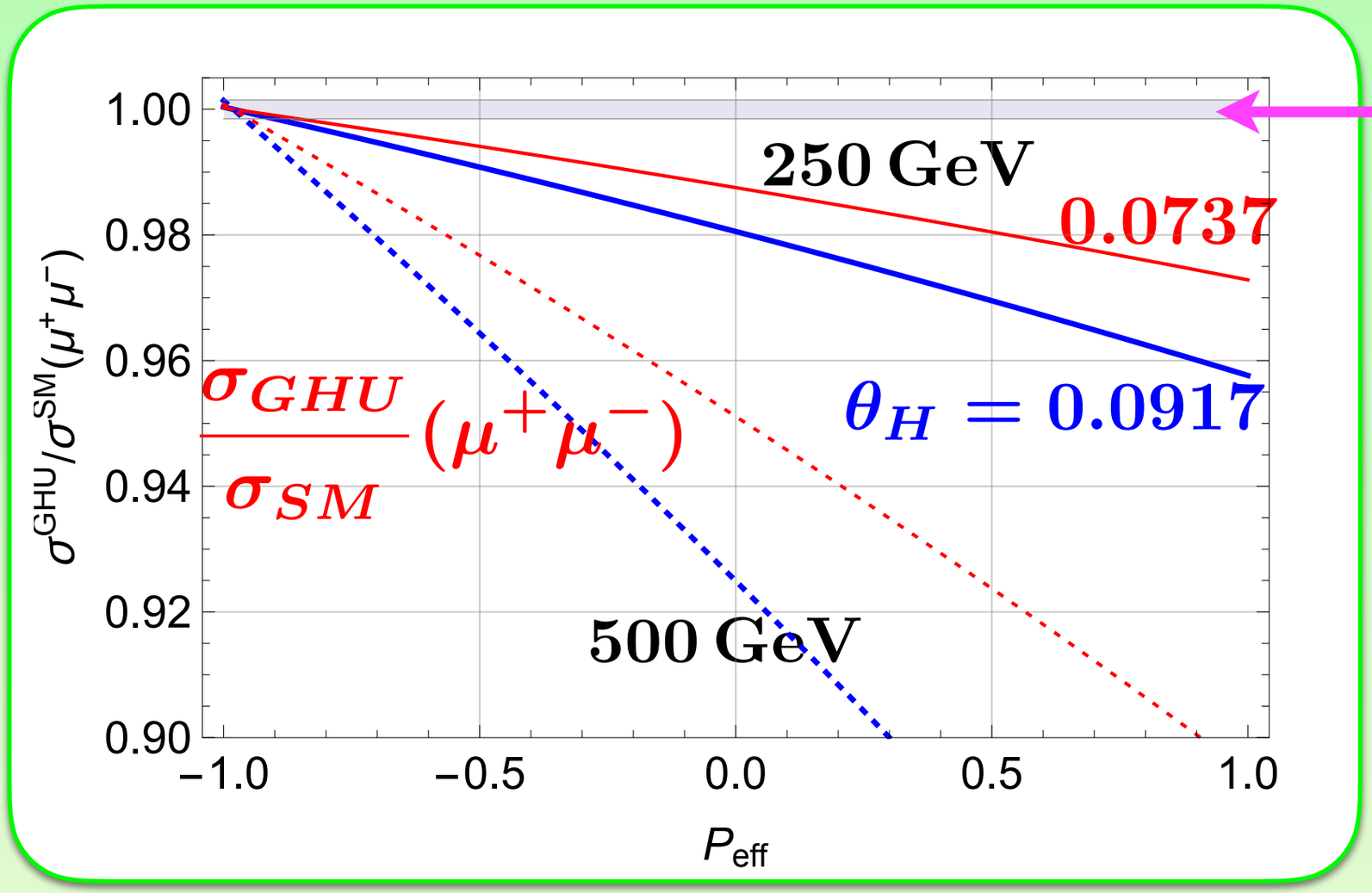
$e^+e^- \to \bar{f}f$



$P_{\rm eff} = 0$

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

Interference among γ, Z, Z'



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'

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

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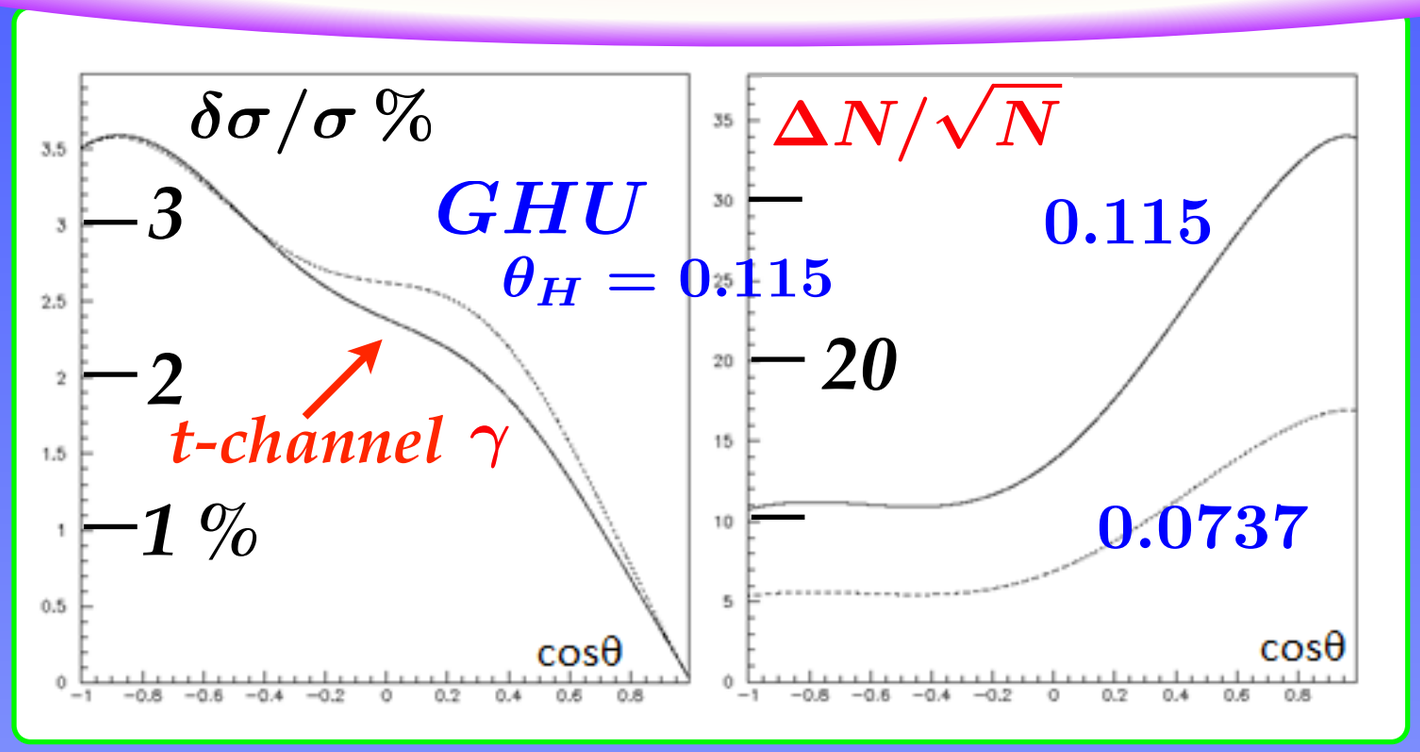
Bhabha scattering $e^+e^- \to e^+e^-$



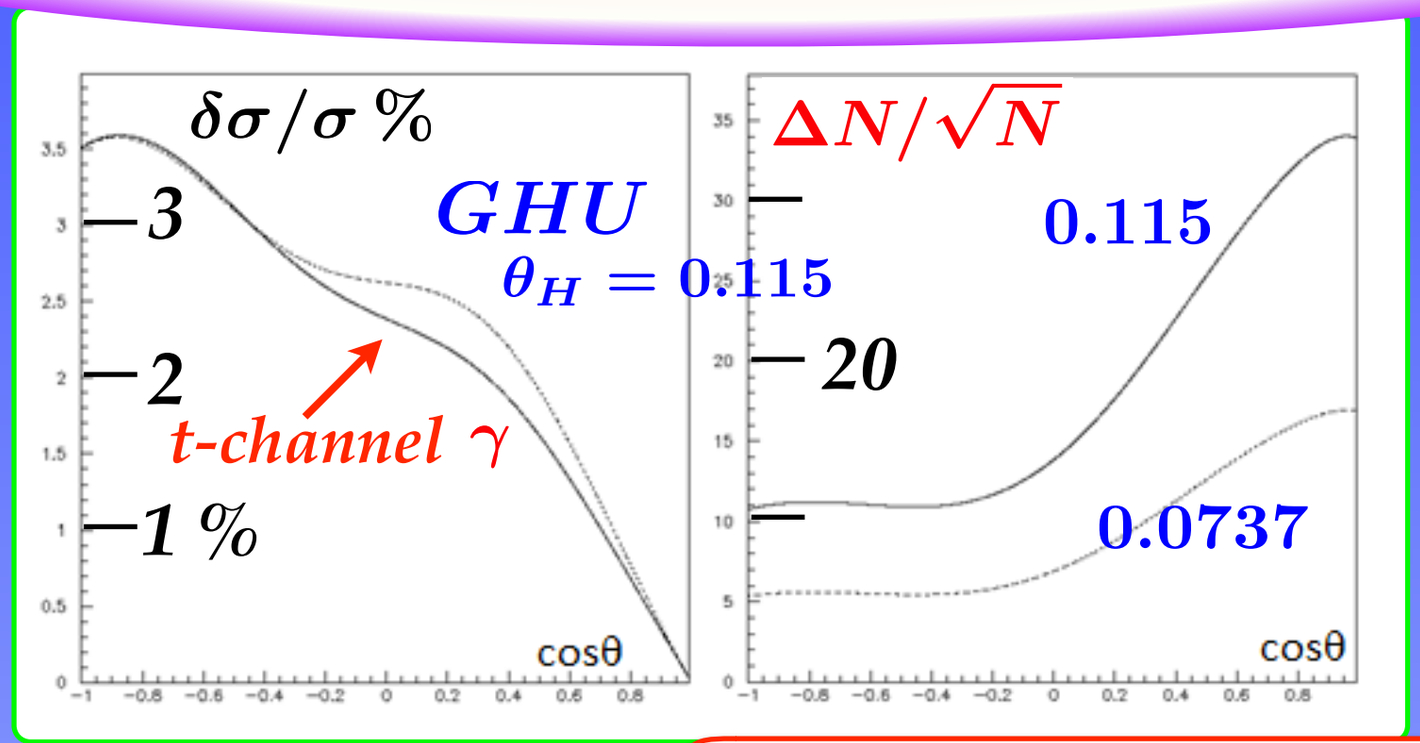
F. Richard, 1804.02846

ILC 250

2000 fb^{-1}

$\cos\theta$ bin width 0.1

Bhabha scattering $e^+e^- \to e^+e^-$



F. Richard, 1804.02846

ILC 250

2000 fb^{-1}

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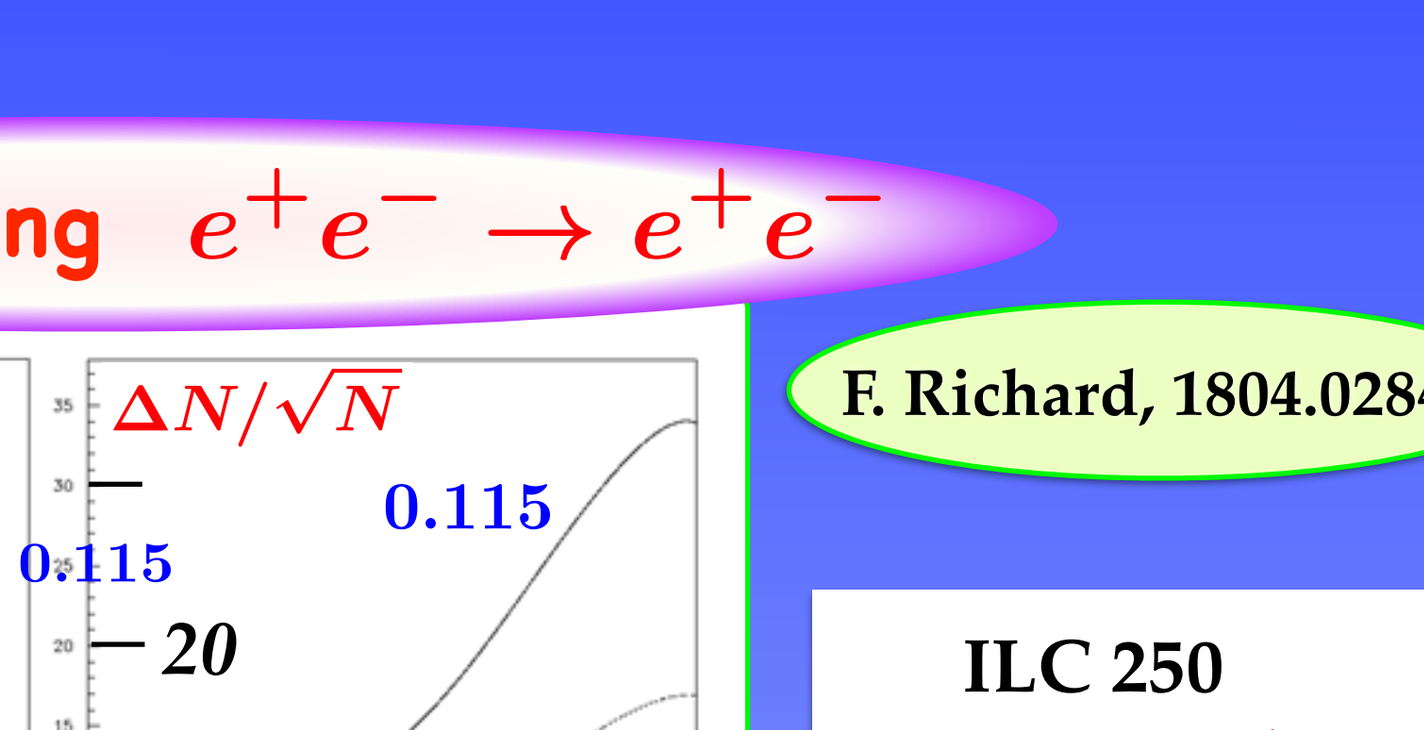
$e^+e^- \to \mu^+\mu^-$



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

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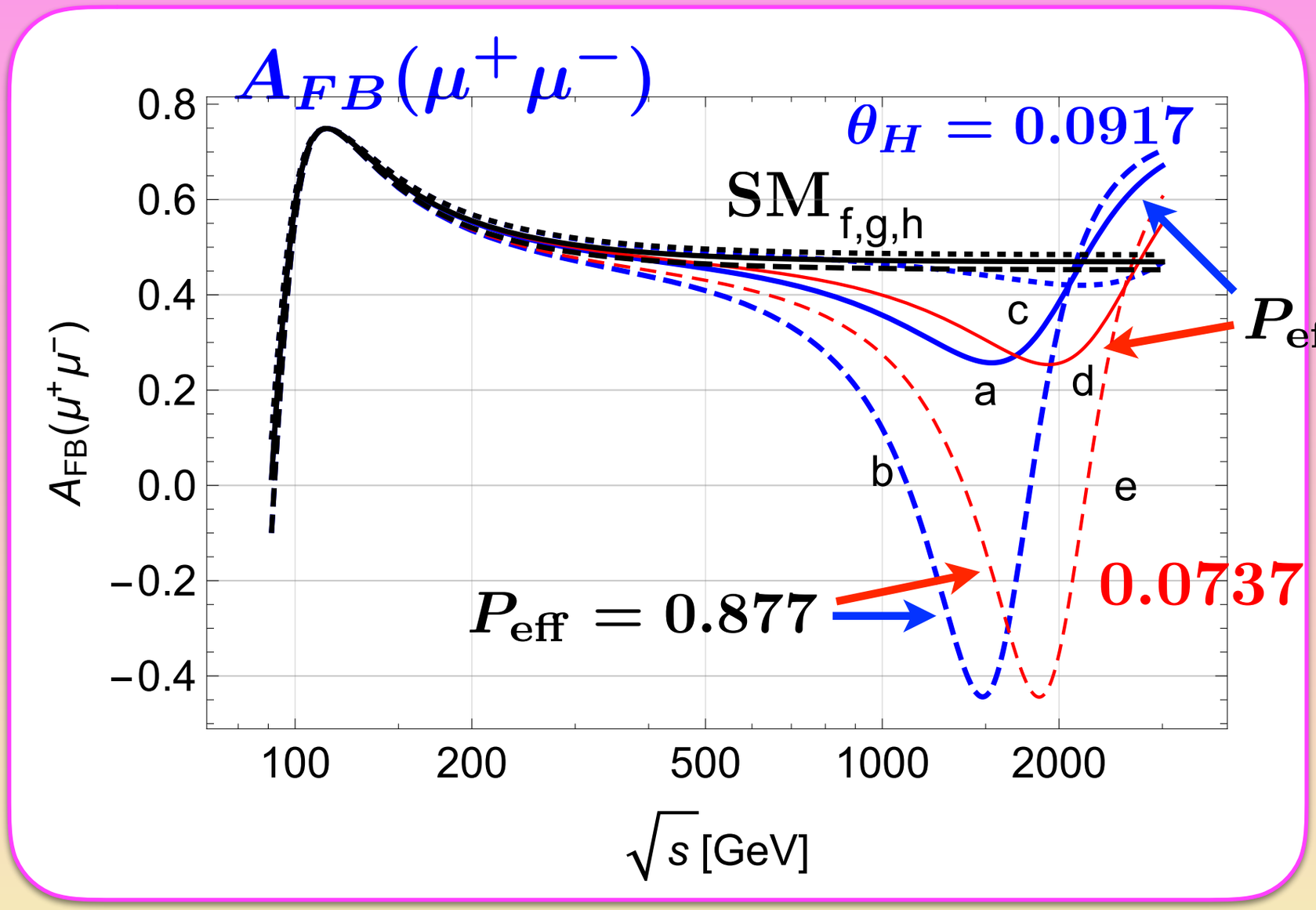

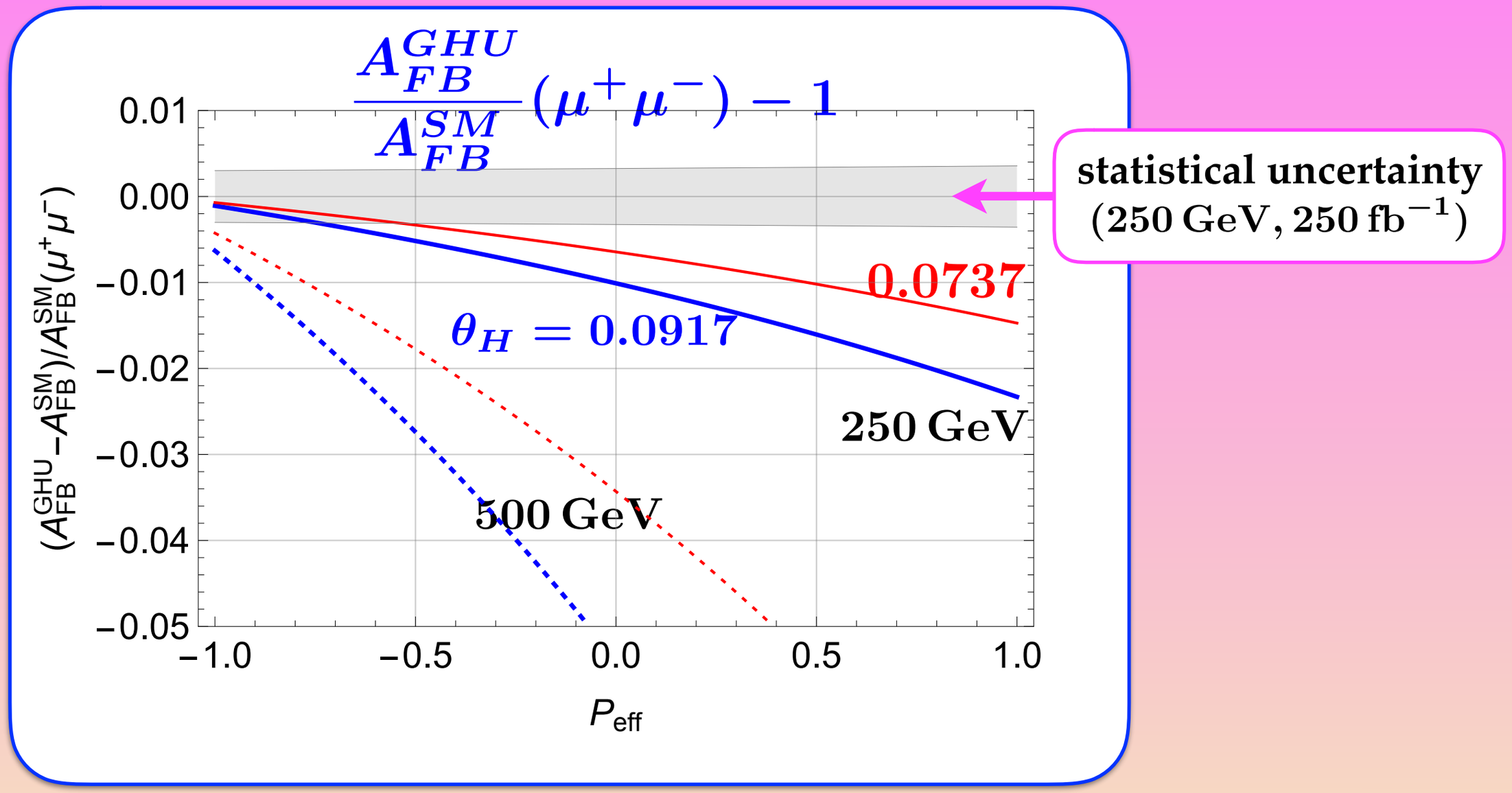

$250\,\mathrm{GeV},\ 250\,\mathrm{fb}^{-1}$ $\quad P_{\mathrm{eff}} = 0.8$ $\quad 6\,\sigma\,(4\,\sigma)$

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.

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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 %

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Summary

Gauge-Higgs unification

Higgs = gauge boson in 5d

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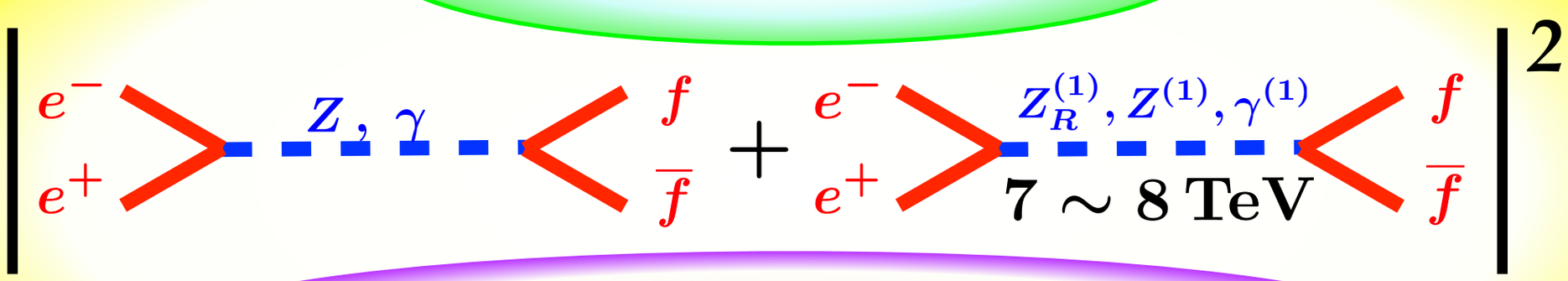
Gauge-Higgs unification

Higgs = gauge boson in 5d

interference



signals of new particles

in the early stage of ILC250

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