Collider signatures of gauge-Higgs unification

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Hosotani, Tanaka, Uekusa, 1103.6076v2

Gauge-Higgs Unification in 5 dimensions

4-dim. components A_μ

extra-dim. component A_y

Hosotani 1983, 1989
Davies, McLachlan 1988, 1989
Hatanaka, Inami, Lim, 1998

Higgs boson as an AB phase in extra dim

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

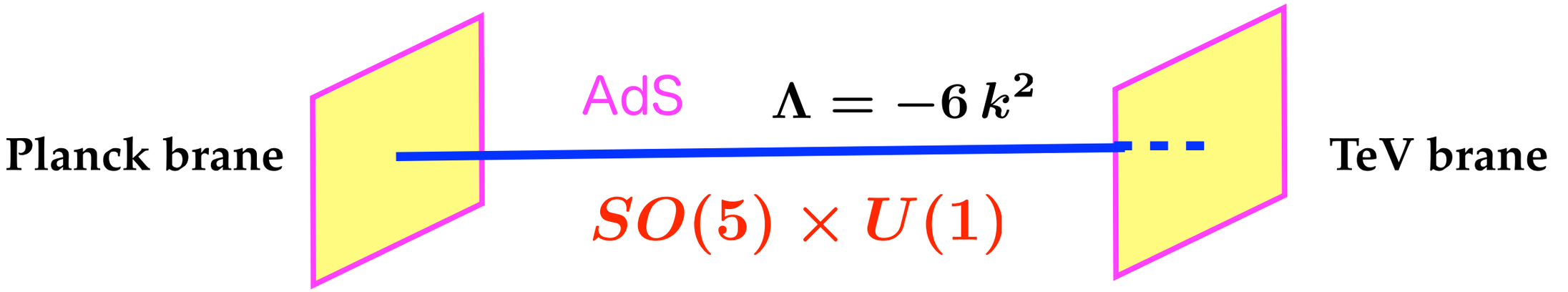
$$\hat{\theta}_H(x) = \theta_H + \frac{H(x)}{f_H}$$

$SO(5) \times U(1)$ in Randall-Sundrum warped space

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

$$0 \le |y| \le L = \pi R$$

Agashe, Contino, Pomarol 2005
Hosotani, Sakamura 2006
Medina, Shah, Wagner 2007



Orbifold BC

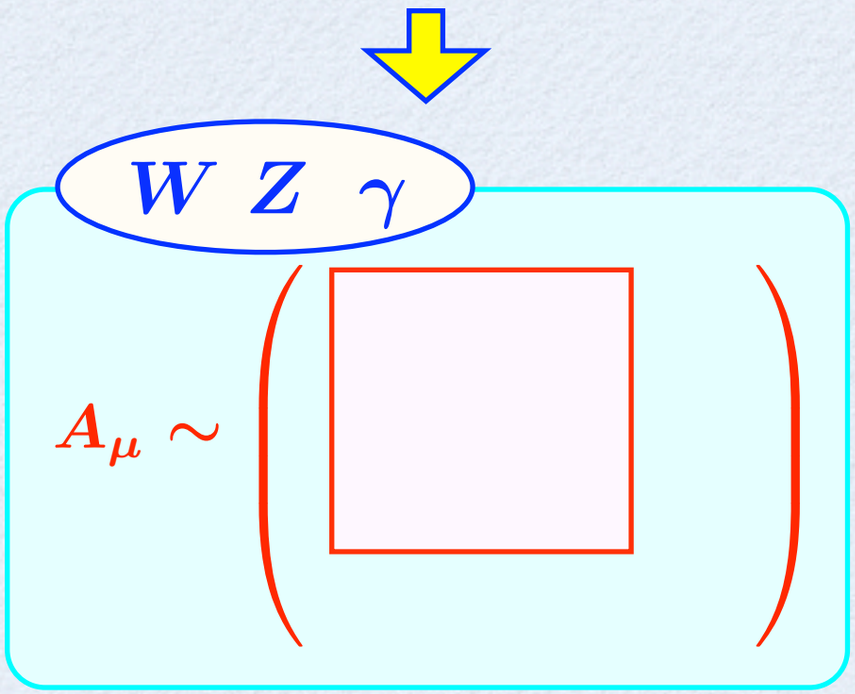
$$\begin{pmatrix} A_\mu \\ A_y \end{pmatrix}(x,-y) = P_0 \begin{pmatrix} A_\mu \\ -A_y \end{pmatrix}(x,y) P_0^\dagger$$

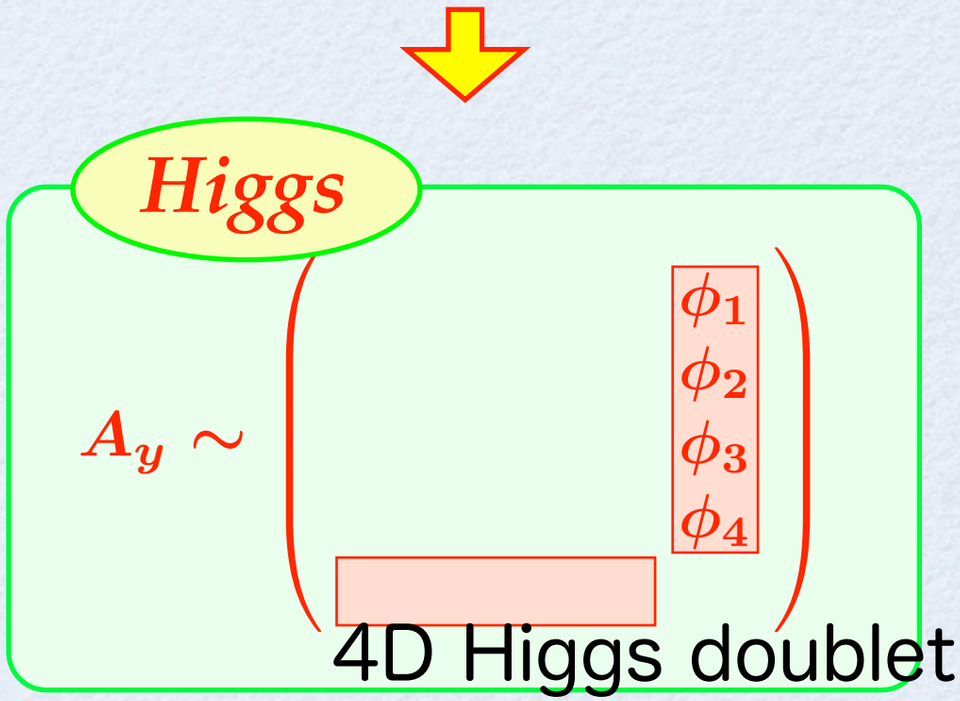
$$\begin{pmatrix} A_\mu \\ A_y \end{pmatrix}(x,\pi R - y) = P_1 \begin{pmatrix} A_\mu \\ -A_y \end{pmatrix}(x,\pi R + y) P_1^\dagger$$

4D gauge bosons and Higgs

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

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





Matter content

YH, Oda, Ohnuma, Sakamura 2008

YH, Noda, Uekusa 2009

Planck brane

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

TeV brane

Quarks

$\begin{pmatrix} \hat{T}_R \\ \hat{B}_R \end{pmatrix}$ $\begin{pmatrix} \hat{U}_R \\ \hat{D}_R \end{pmatrix}$ $\begin{pmatrix} \hat{X}_R \\ \hat{Y}_R \end{pmatrix}$ $(\frac{1}{2}, 0)$

$\begin{pmatrix} T_L \\ B_L \\ t_L \\ b_L \\ t'_R \end{pmatrix}_{\frac{2}{3}}$

$\begin{pmatrix} U_L \\ D_L \\ X_L \\ Y_L \\ b'_R \end{pmatrix}_{-\frac{1}{3}}$

vector rep

$(\frac{1}{2}, \frac{1}{2}) \oplus (0, 0)$

$\Psi(x, -y) = P_0 \gamma^5 \Psi(x, y)$

$\Psi(x, \pi R - y) = P_1 \gamma^5 \Psi(x, \pi R + y)$

Brane scalar

$\hat{\Phi}\ (0, \frac{1}{2})$

$\langle \hat{\Phi} \rangle \neq 0$

Leptons

$\begin{pmatrix} \hat{L}_{2XR} \\ \hat{L}_{2YR} \end{pmatrix}$ $\begin{pmatrix} \hat{L}_{3XR} \\ \hat{L}_{3YR} \end{pmatrix}$ $\begin{pmatrix} \hat{L}_{1XR} \\ \hat{L}_{1YR} \end{pmatrix}$

$\begin{pmatrix} \nu_{\tau L} \\ \tau_L \\ L_{1XL} \\ L_{1YL} \\ \tau'_R \end{pmatrix}_{-1}$

$\begin{pmatrix} L_{2XL} \\ L_{2YL} \\ L_{3XL} \\ L_{3YL} \\ \nu'_{\tau R} \end{pmatrix}_0$

Effective interactions at low energies

AB phase $\hat{\theta}_H = \theta_H + \dfrac{H}{f_H}$ $\qquad f_H = \dfrac{2}{\sqrt{kL}} \dfrac{m_{KK}}{\pi g}$

$$\mathcal{L}_{\rm eff} \sim \; -V_{\rm eff}(\hat{\theta}_H)$$

$$-m_W(\hat{\theta}_H)^2 W_\mu^\dagger W^\mu - \frac{1}{2} m_Z(\hat{\theta}_H)^2 Z_\mu Z^\mu$$

$$-m_f(\hat{\theta}_H)\, \overline{\psi}_f \psi_f$$

$$\theta_H \sim \theta_H + 2\pi$$

Effective interactions at low energies

AB phase $\hat{\theta}_H = \theta_H + \dfrac{H}{f_H}$ $\qquad f_H = \dfrac{2}{\sqrt{kL}} \dfrac{m_{KK}}{\pi g}$

$$\mathcal{L}_{\rm eff} \sim \; -V_{\rm eff}(\hat{\theta}_H)$$

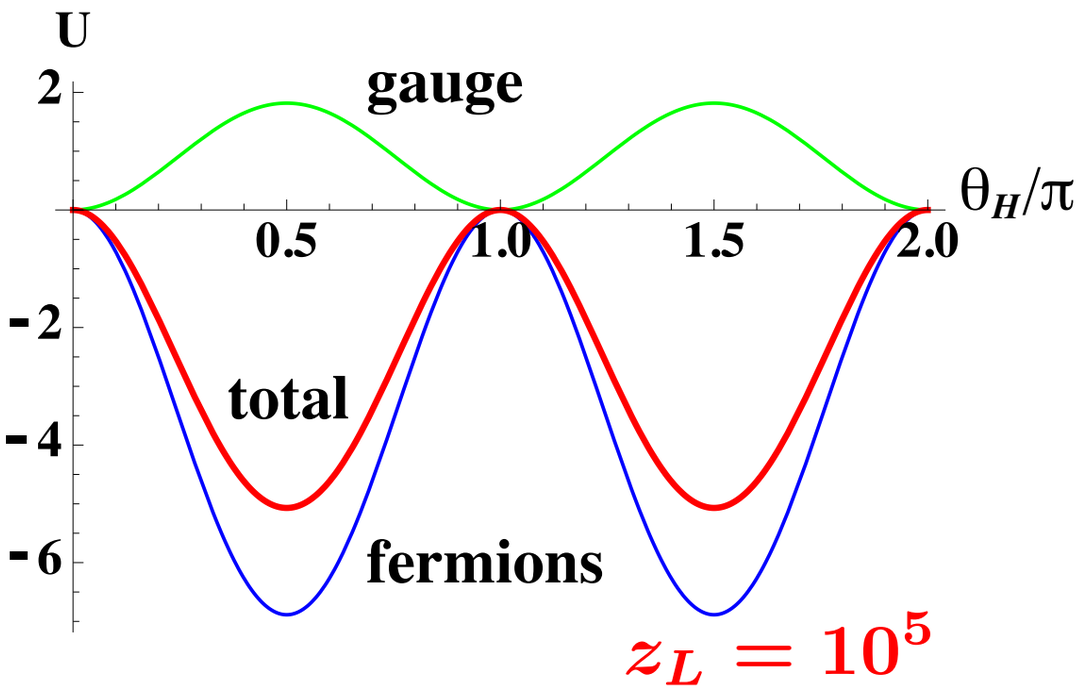
$$-\left(\frac{1}{2} g f_H \sin\hat{\theta}_H\right)^2 \left\{ W_\mu^\dagger W^\mu + \frac{1}{2\cos^2\theta_W} Z_\mu Z^\mu \right\}$$

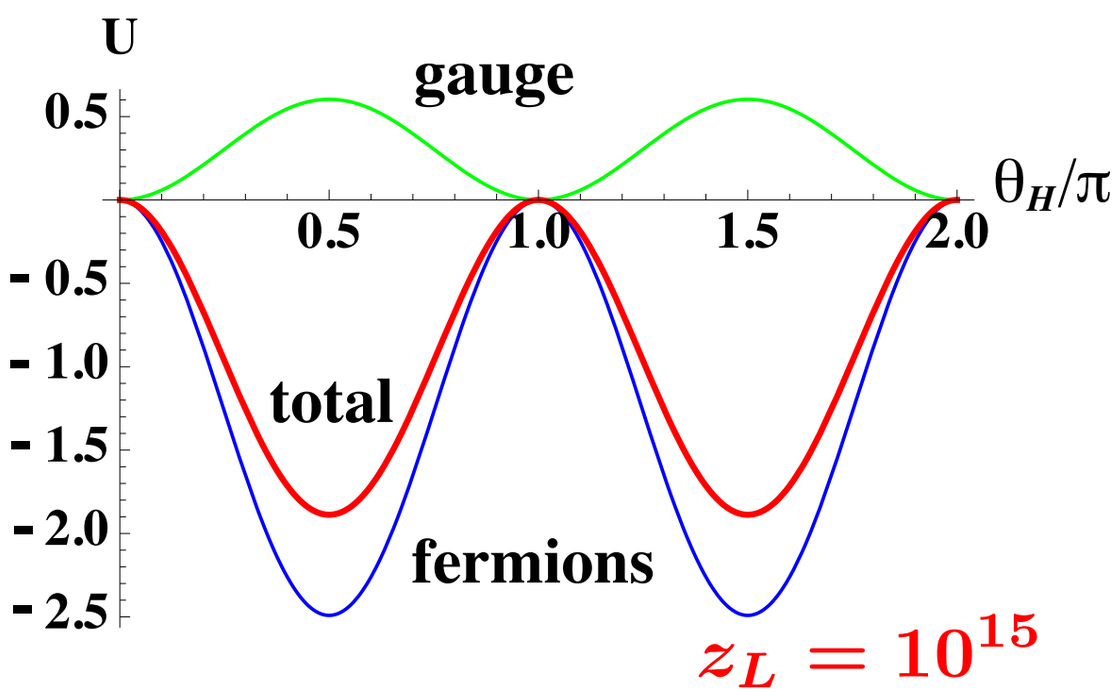
$$-y_f f_H \sin\hat{\theta}_H \, \overline{\psi}_f \psi_f$$

WWH
ZZH
Yukawa

$= SM \times \cos\theta_H$ ⟺ 2HDM, Inert Higgs

$V_{\rm eff}(\theta_H)/m_{\rm KK}^4$





EW symmetry breaking by Hosotani mechanism

$$\theta_H = \frac{\pi}{2}$$

$$m_H = \begin{matrix} 135 \\ 72 \end{matrix} \text{GeV} \quad (z_L = \begin{matrix} 10^{15} \\ 10^5 \end{matrix})$$

H parity

$$SO(5): \quad SO(4) \simeq SU(2)_L \times SU(2)_R \quad SO(5)/SO(4)$$

$$\{ T^\alpha \} = \{ T^{a_L}, T^{a_R}, T^{\hat{a}}, T^{\hat{4}} \}$$

$$P_H: \quad SU(2)_L \leftrightarrow SU(2)_R, \quad T^{\hat{4}} \to -T^{\hat{4}}$$

$\longleftrightarrow$

Agashe, Contino, Da Rold, Pomarol 2006

T parameter $\quad Zb\bar{b}$

$$\theta_H = \frac{\pi}{2}$$

H : $-$

all other SM particles : $+$

Higgs field : the lightest P_H -odd field.

WWH, ZZH, Yukawa = 0

Stable

Collider signatures

◇ $\theta_H = \frac{1}{2}\pi$ ⇨ Absence of single-Higgs production

Higgs pair production

Higgs = missing energy, momentum

$\nu, \bar{\nu}$ background hard to confirm at LHC/ILC

Cheung, Song, 1004.2783, Alves, 1008.0016
YH, Tanaka, Uekusa, 1103.6076

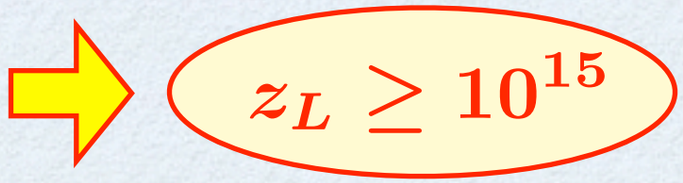
◇ Precision measurements at low energies

◇ KK modes: $Z^{(n)}$, $\gamma^{(n)}$, $t^{(n)}$,

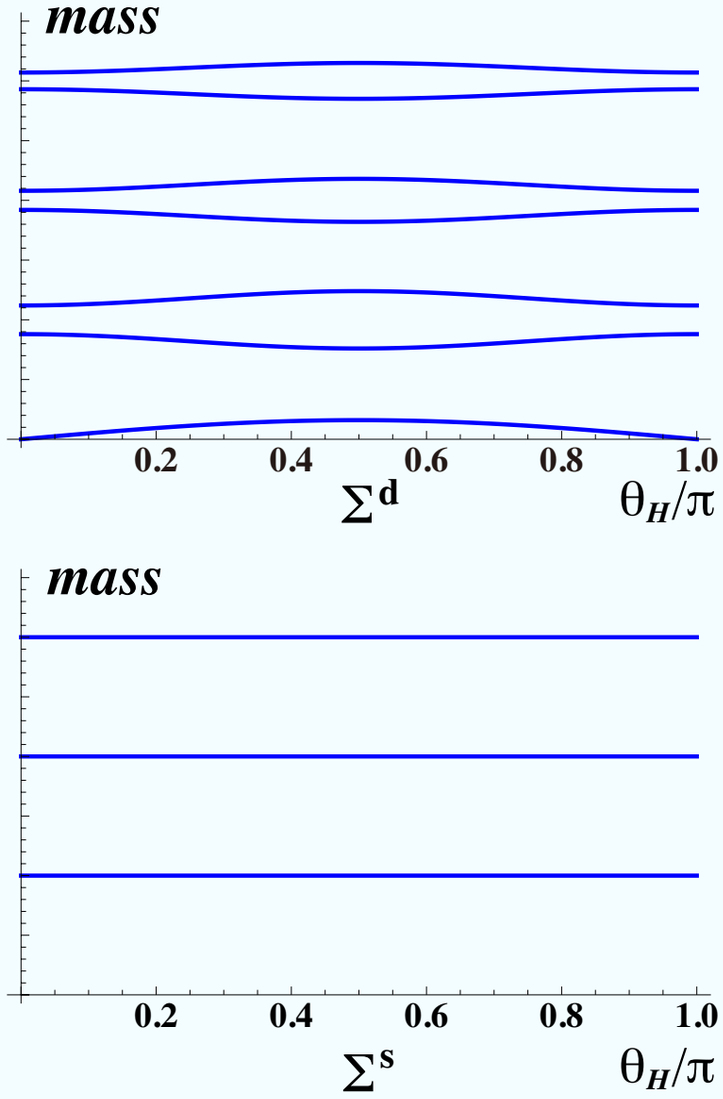
Gauge couplings precision measurements

- ◇ Forward-backward asymmetry in $e^+e^- \to Z \to \ell\bar{\ell}$, $q\bar{q}$
- ◇ Z-decay branching fractions

	No. data	SM	$z_L : 10^{15}$	$z_L : 10^{10}$	$z_L : 10^{5}$
$\sin^2\theta_W$		0.2312	0.2309	0.2303	0.2284
$\chi^2(AFB)$	6	10.8	6.3	6.4	7.1
$\chi^2(Z\ decay)$	8	13.6	16.5	37.7	184.5



1st KK modes



	$z_L : 10^{15}$	$z_L : 10^{5}$
$m_{\rm KK}$	1466	836
$Z^{(1)}$	1130	653
$\gamma^{(1)}, g^{(1)}$	1144	678
$u^{(1)}$	1361	1037
$t^{(1)}$	1121	634

in GeV

KK $Z^{(1)}$ & $\gamma^{(1)}$

$Z^{(1)}$

z_L	10^5	10^{15}
m	653	1130
Γ	104	422

in GeV

$\gamma^{(1)}$

z_L	10^5	10^{15}
m	678	1144
Γ	446	1959

in GeV

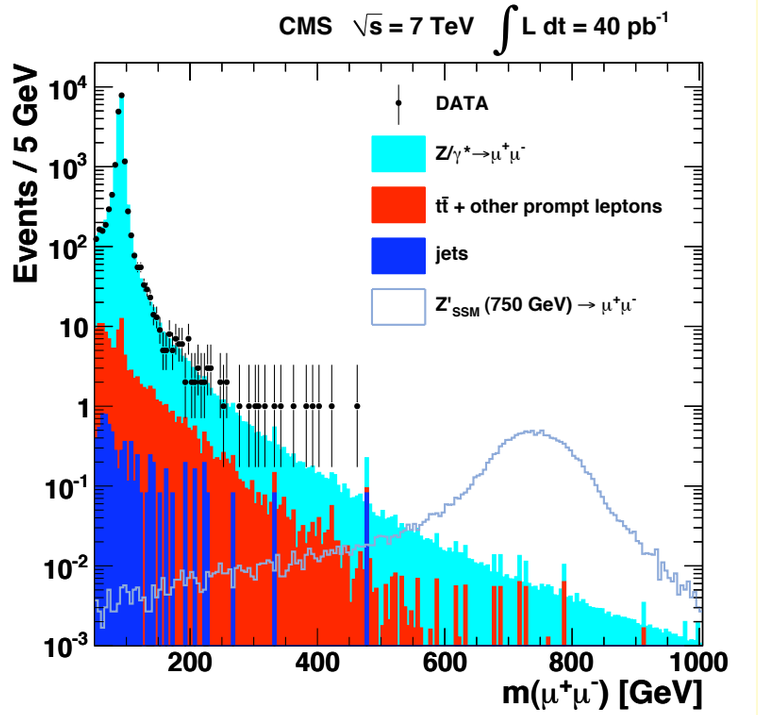
Large widths

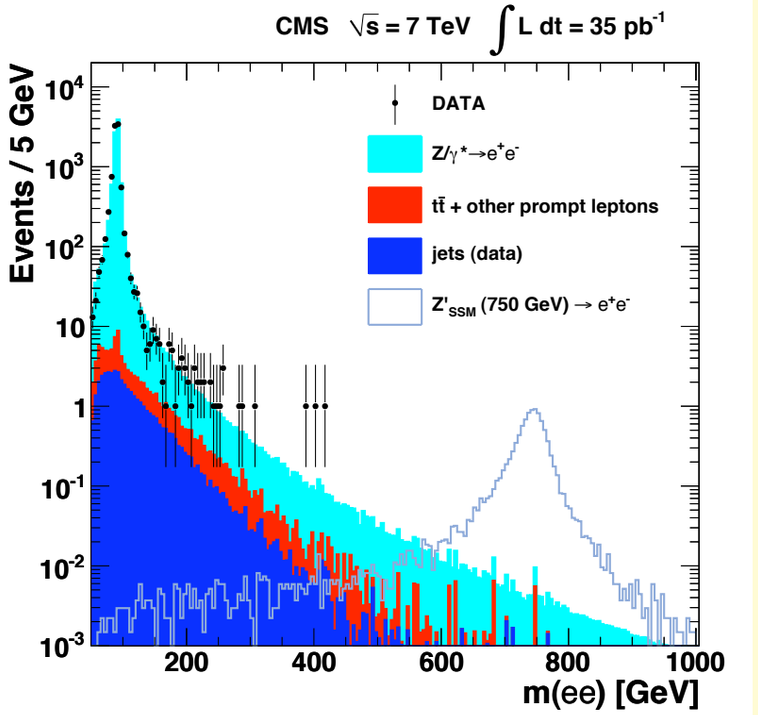
Larger couplings for right-handed quarks and lepton

$\sim \quad \times 10$

Z' search at LHC

CMS 1103.0981

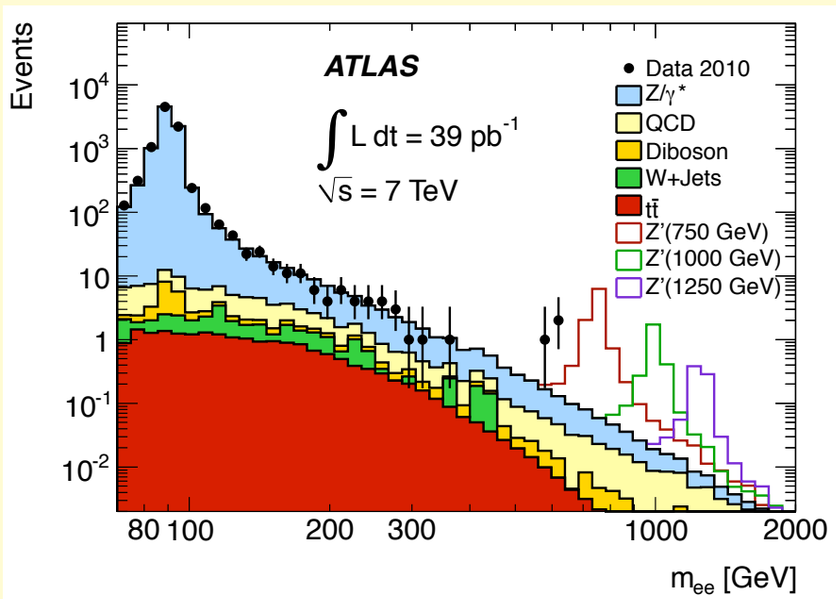


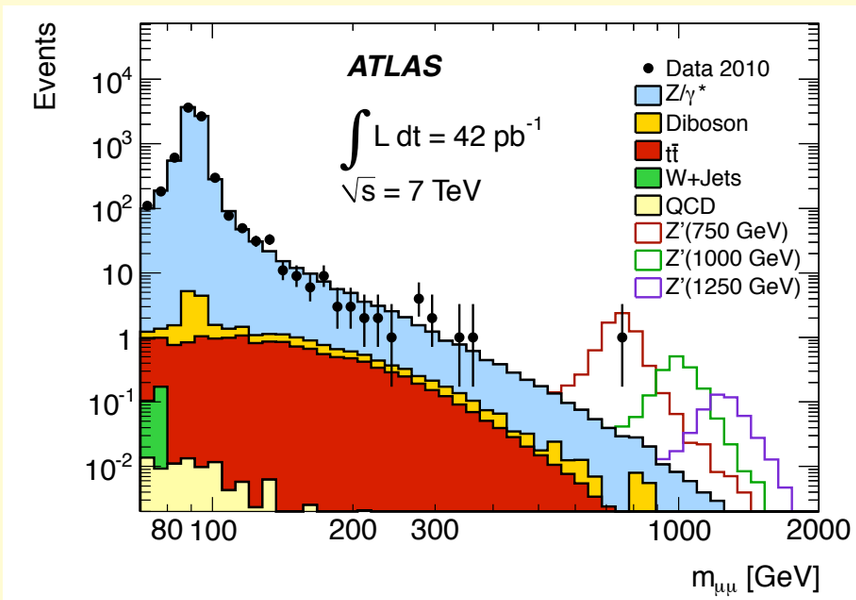


$$Z'_{\rm SSM}: \frac{\Gamma}{M} = 0.03$$

$$M > 1140\,{\rm GeV}$$

ATLAS 1103.6218





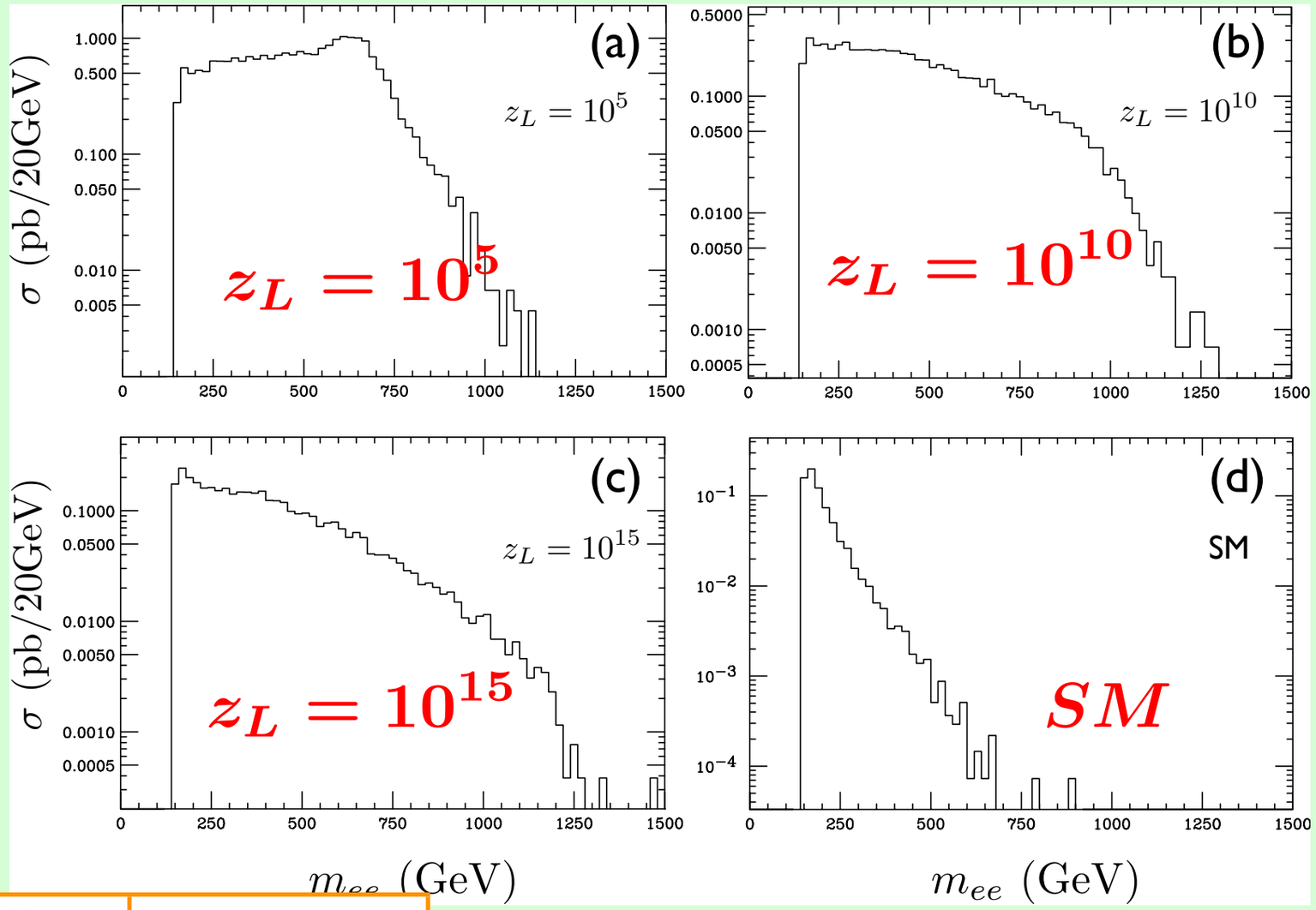
$$M > 1048\,{\rm GeV}$$

Z' Search at Tevatron

$\sqrt{s} = 1.96\,\mathrm{GeV}$

$$p\bar{p} \to Z' \to e^+e^-$$

$$Z^{(1)}, \gamma^{(1)}$$



$Z^{(1)}$

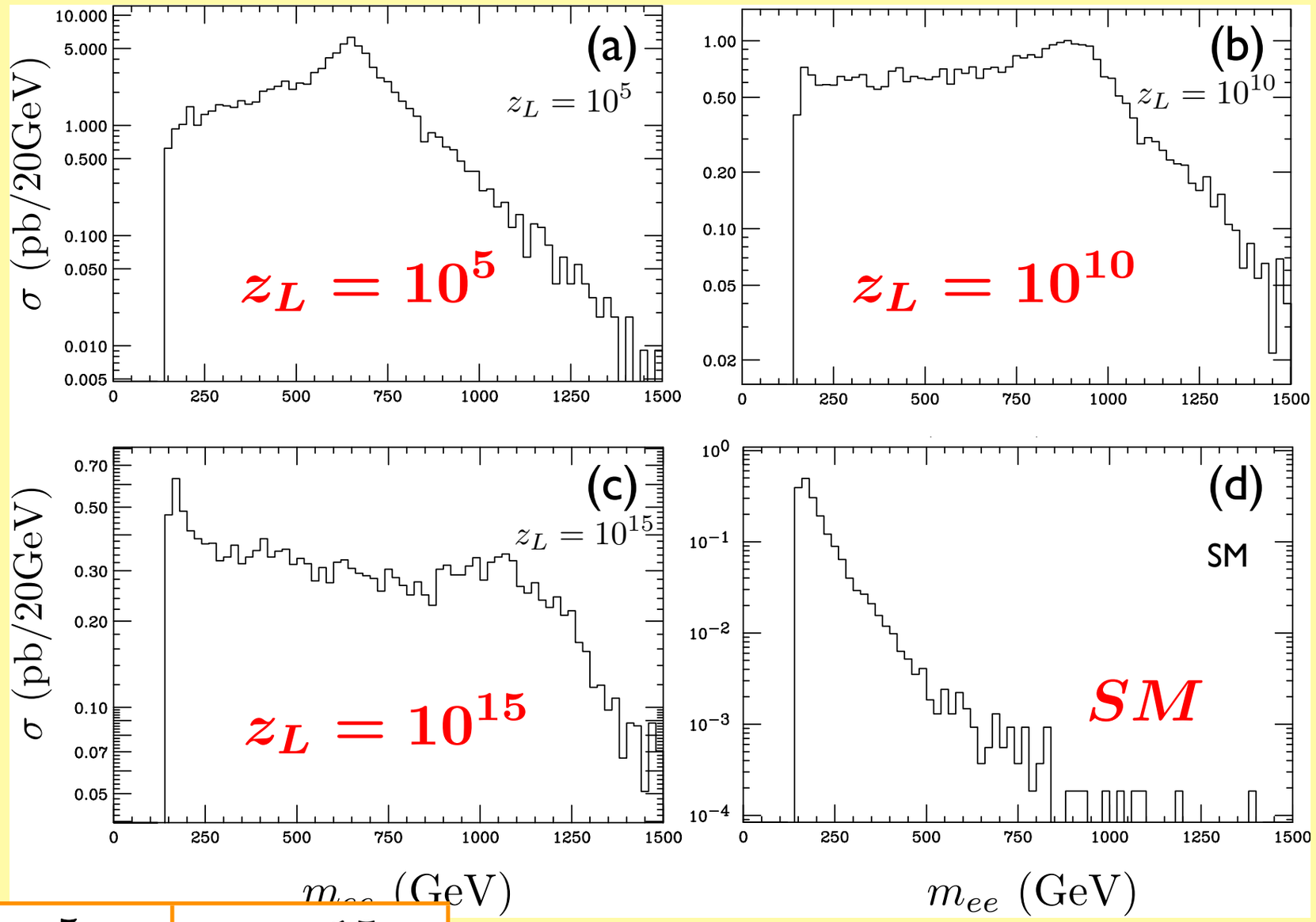
z_L	10^5	10^{15}
m	653	1130
Γ	104	422

in GeV

$$z_L \geq 10^{15}$$

LHC (3.5 + 3.5 TeV)

$$q\bar{q} \to Z^{(1)}, \gamma^{(1)} \to e^+e^-$$



$Z^{(1)}$

z_L	10^5	10^{15}
m	653	1130
Γ	104	422

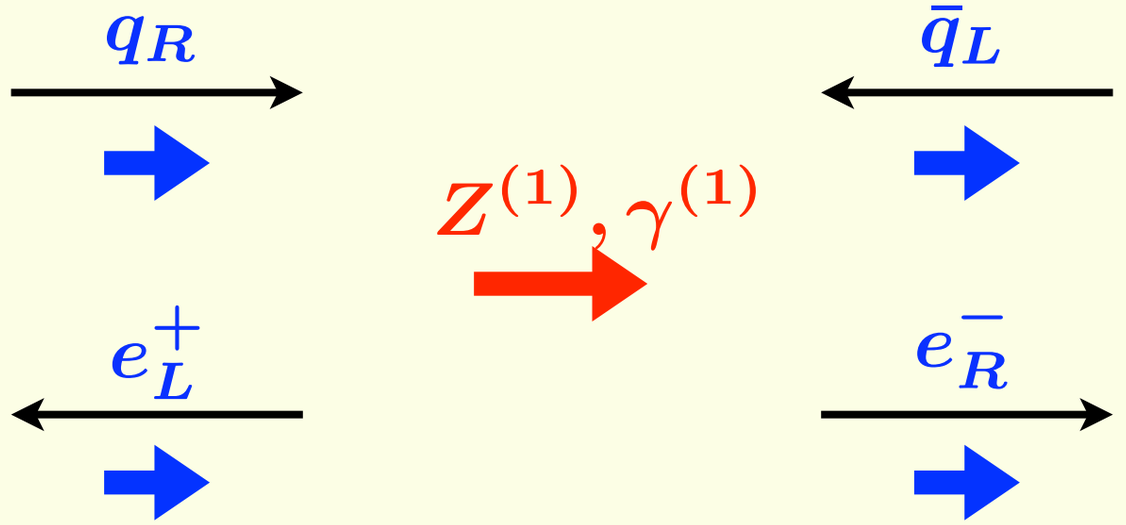
in GeV

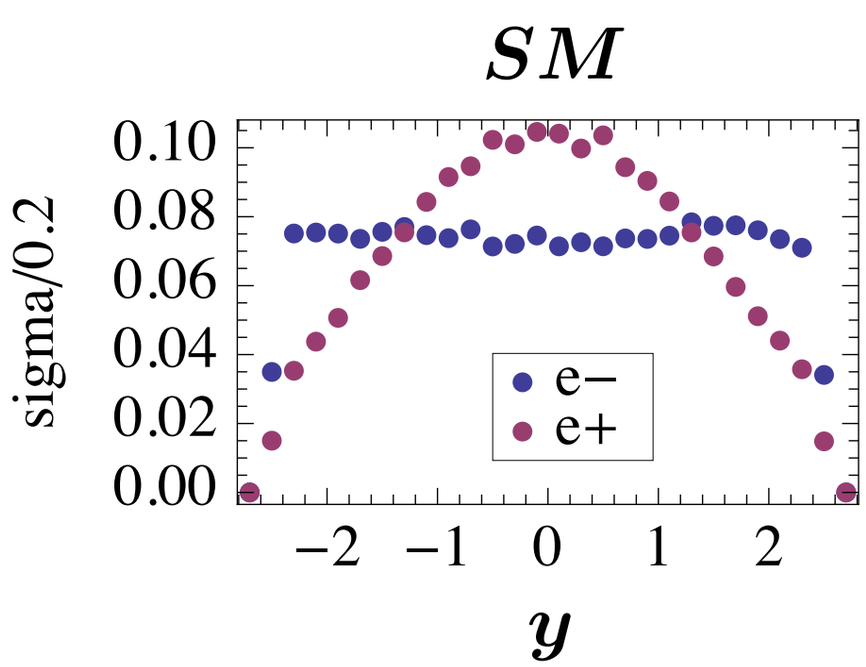
Large BG from $\gamma^{(1)}$

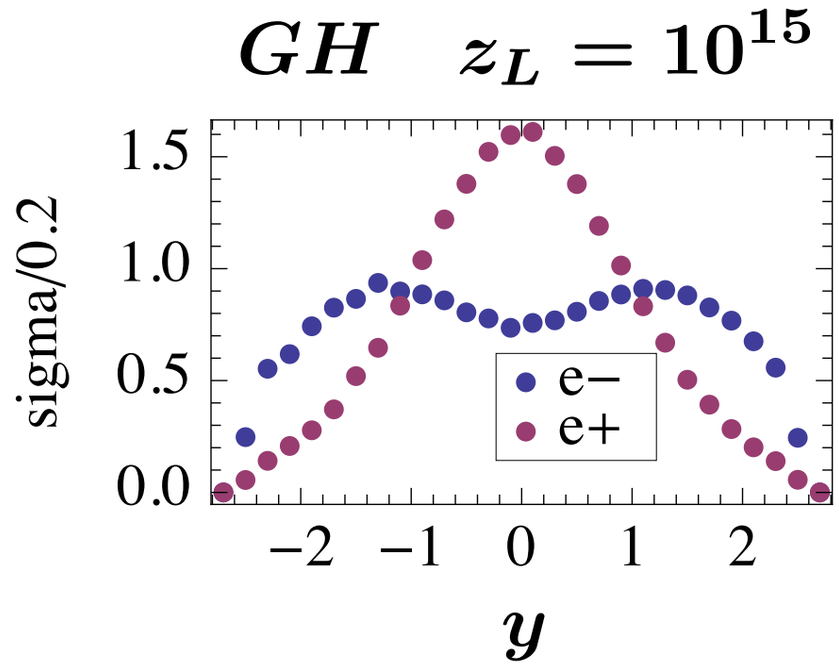
$z_L > 10^{15}$

Asymmetry in rapidity distribution

Much larger couplings for right-handed quarks and leptons







Summary

Gauge-Higgs unification can be tested.

Higgs can naturally become stable.

Higgs = missing energy/momentum

EW precision data A_{FB}, Z decay

$Z^{(1)}$ search (Tevatron/LHC) $\Rightarrow z_L > 10^{15}$

Find $Z^{(1)}$ at LHC.

$\Gamma/m \sim 0.4$

Asymmetry in e^+e^- distribution