

Realistic $SO(5) \times U(1)$ model in RS space

Yutaka Hosotani



**Rencontres de Moriond EW 2012
3 - 10 March 2012**

If the Englert-Brout-Higgs boson is

125 GeV,

but with non-SM couplings,

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as it is stable,

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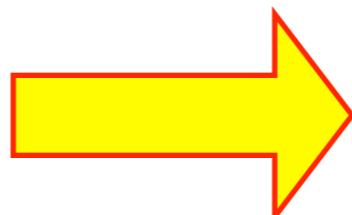
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**gauge-Higgs
unification**

Gauge-Higgs unification

A_M in 5 dim.

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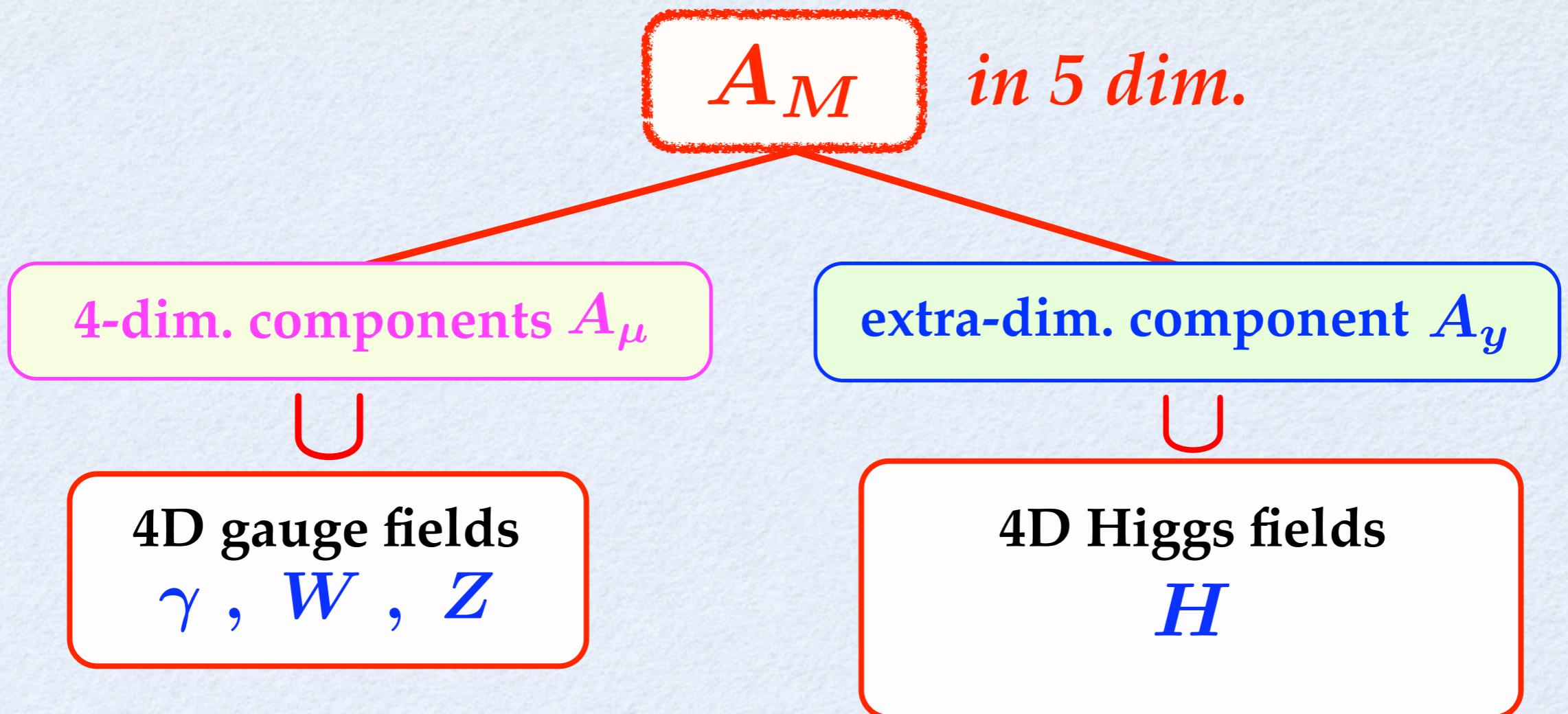
4-dim. components A_μ

U

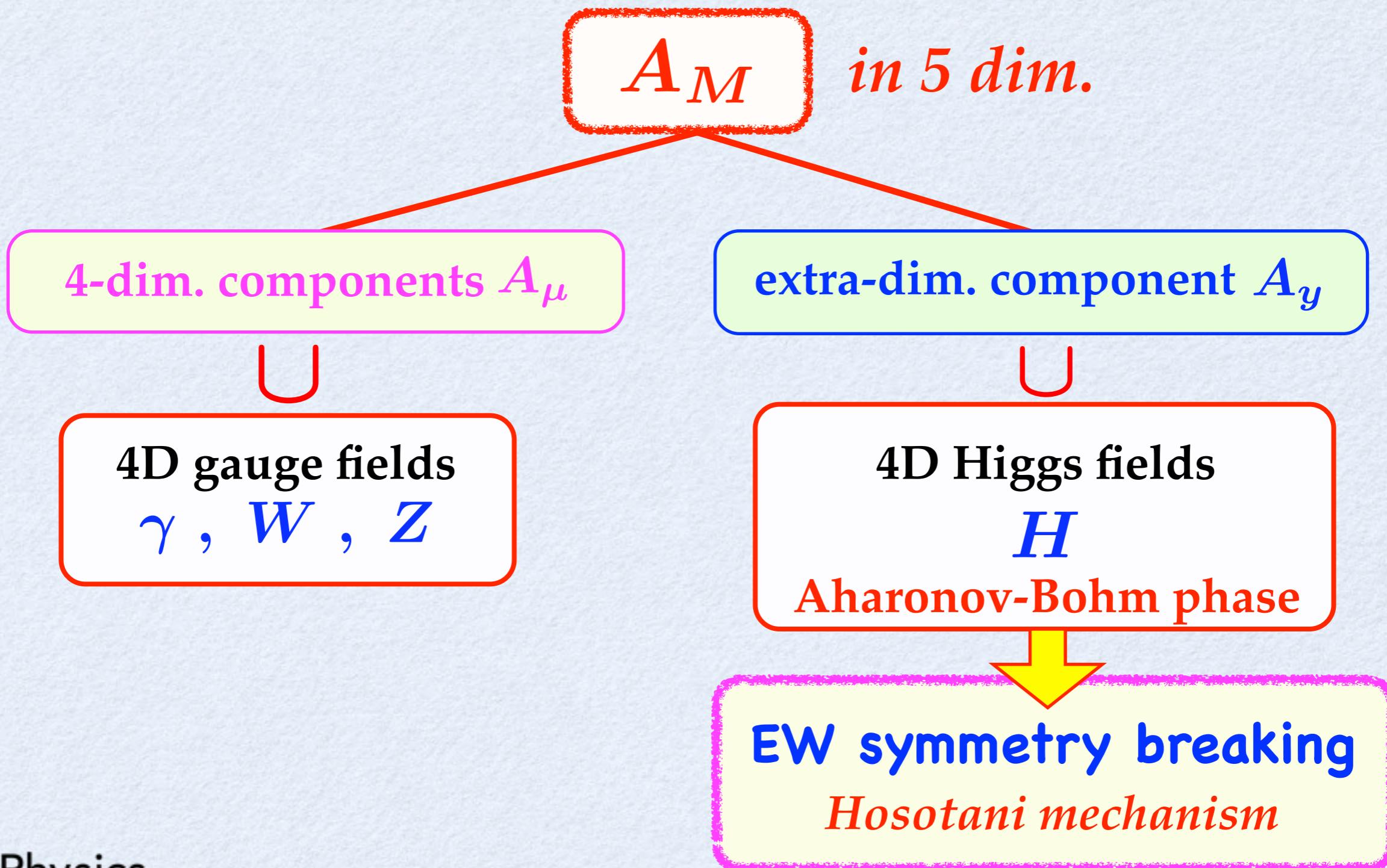
4D gauge fields

γ , W , Z

Gauge-Higgs unification



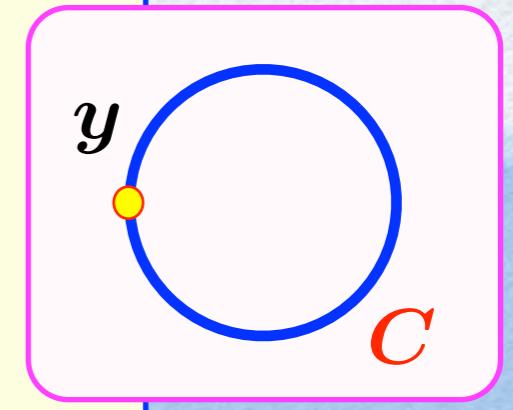
Gauge-Higgs unification



Englert-Brout-Higgs boson as an AB phase in extra dim

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

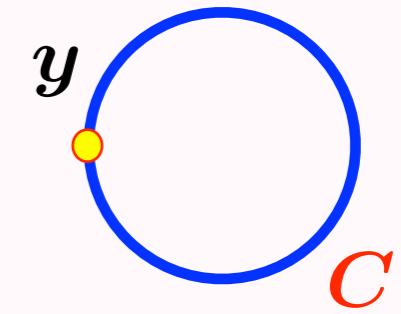
$$\hat{\theta}_H(x) = \theta_H + \frac{H(x)}{f_H}$$



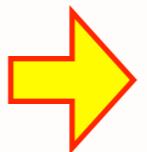
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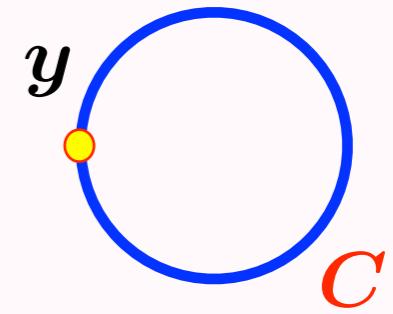


- {
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 - masses for
quarks/leptons/W,Z

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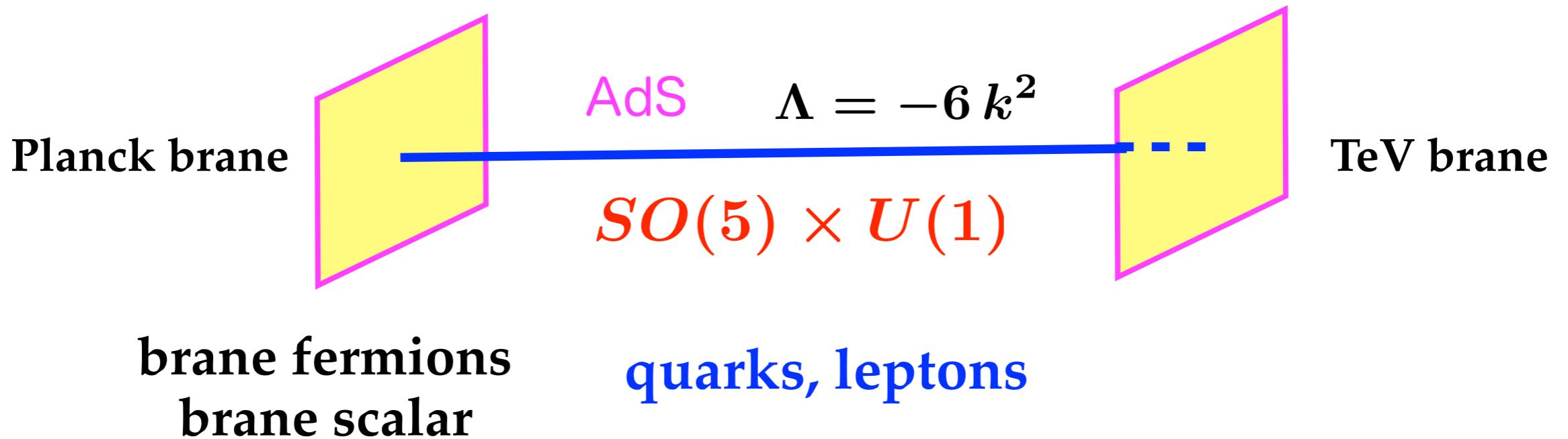
- symmetry breaking
■ masses for
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$$\theta_H \sim \theta_H + 2\pi$$

differs from SM.

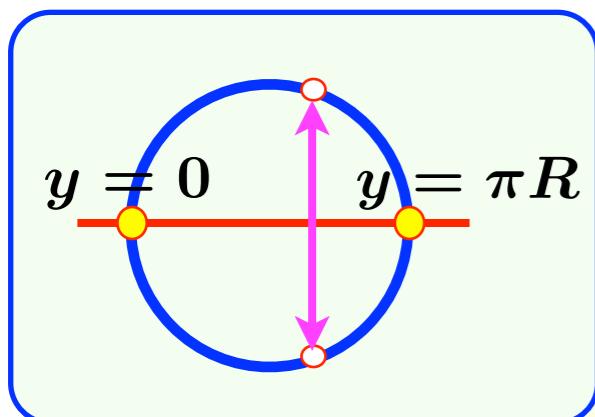
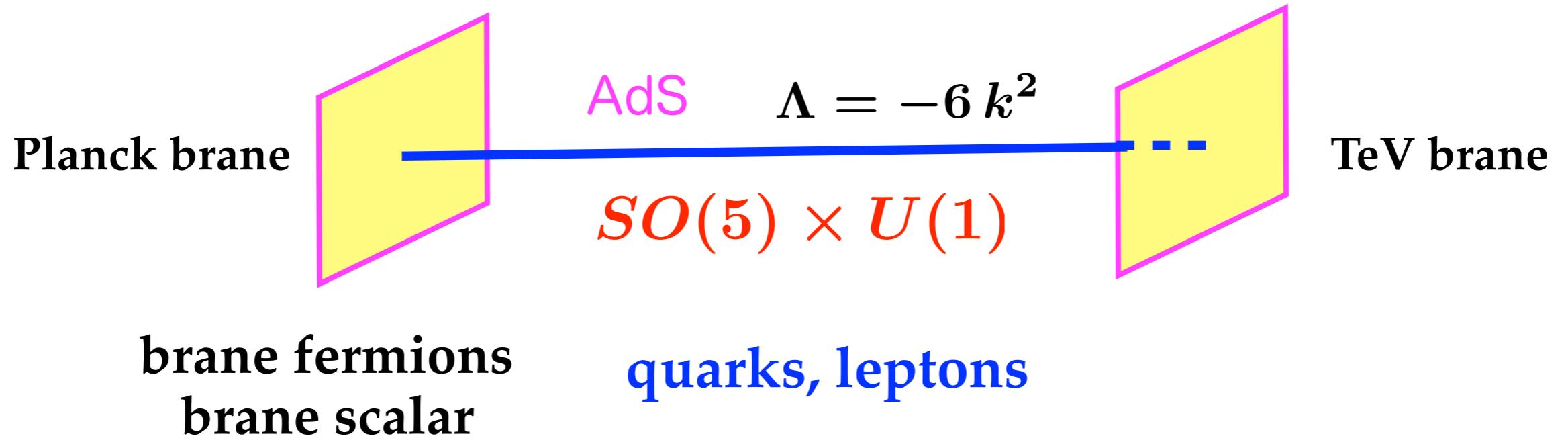
$SO(5) \times U(1)$ in Randall-Sundrum warped space

Agashe, Contino, Pomarol, 2005
YH, Oda, Ohnuma, Sakamura 2008
YH, Noda, Uekusa 2009



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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

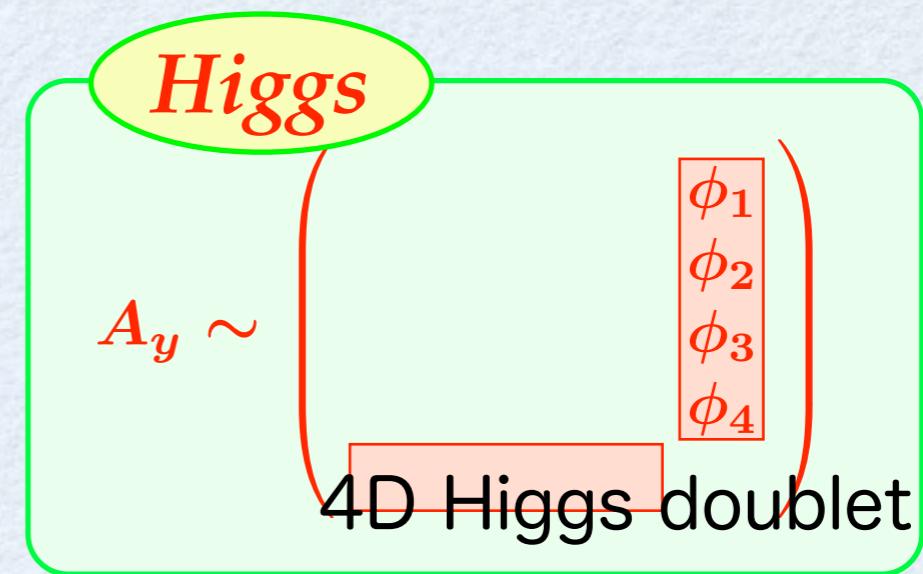
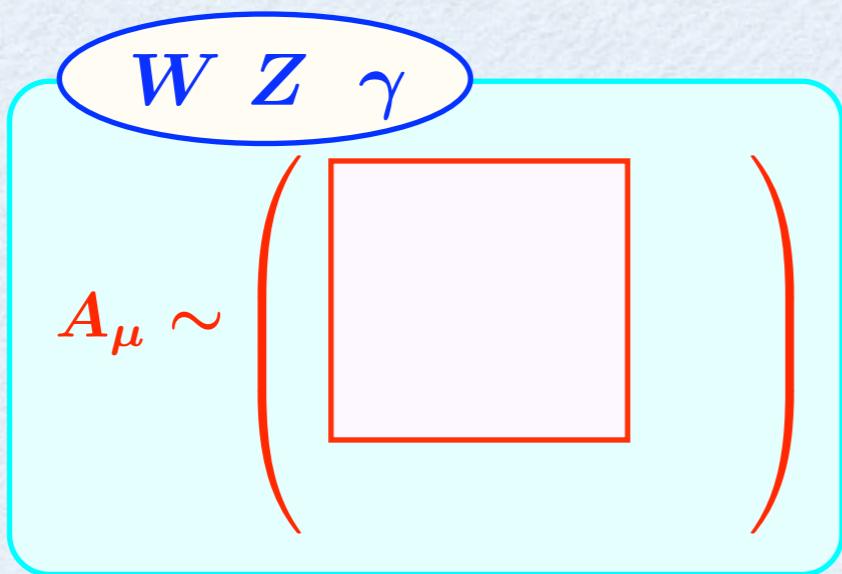
$$P_0 = P_1 = \begin{pmatrix} -1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \\ & & & +1 \end{pmatrix}$$

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

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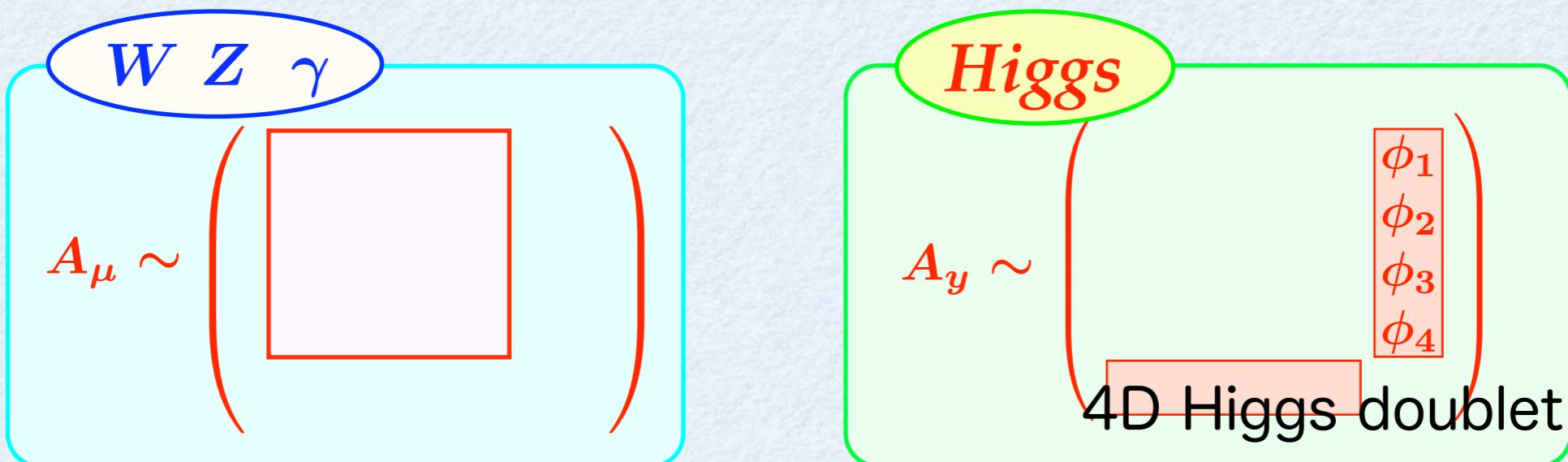
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brane scalar $SO(4) \times U(1) \rightarrow SU(2)'_L \times U(1)'$

$$\theta_H \neq 0 \quad \rightarrow U(1)_{EM}$$

Warped space

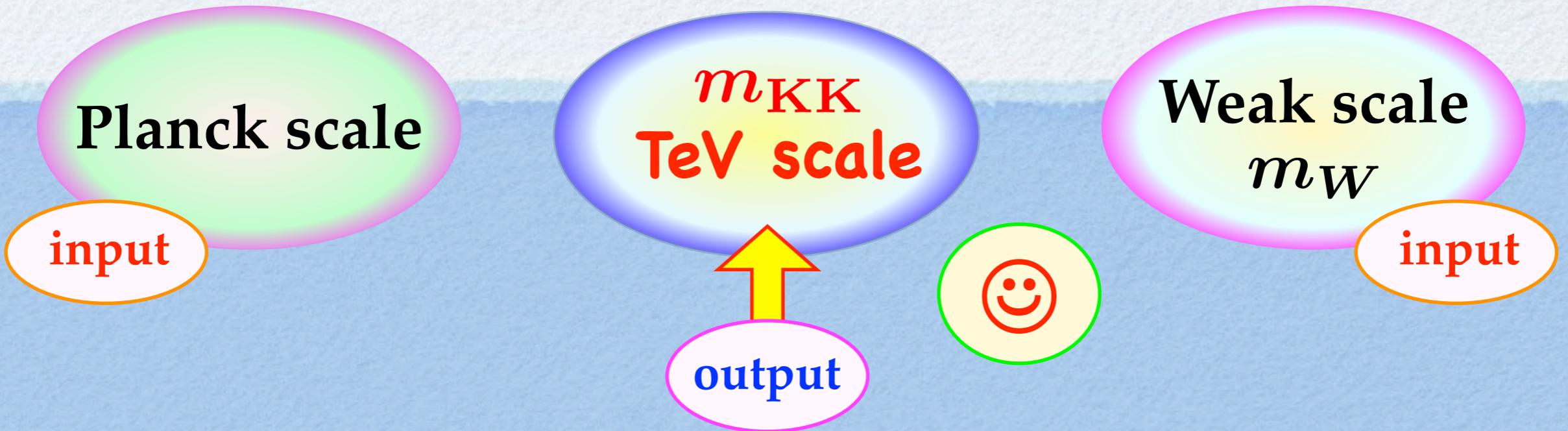
Planck scale

input

Weak scale
 m_W

input

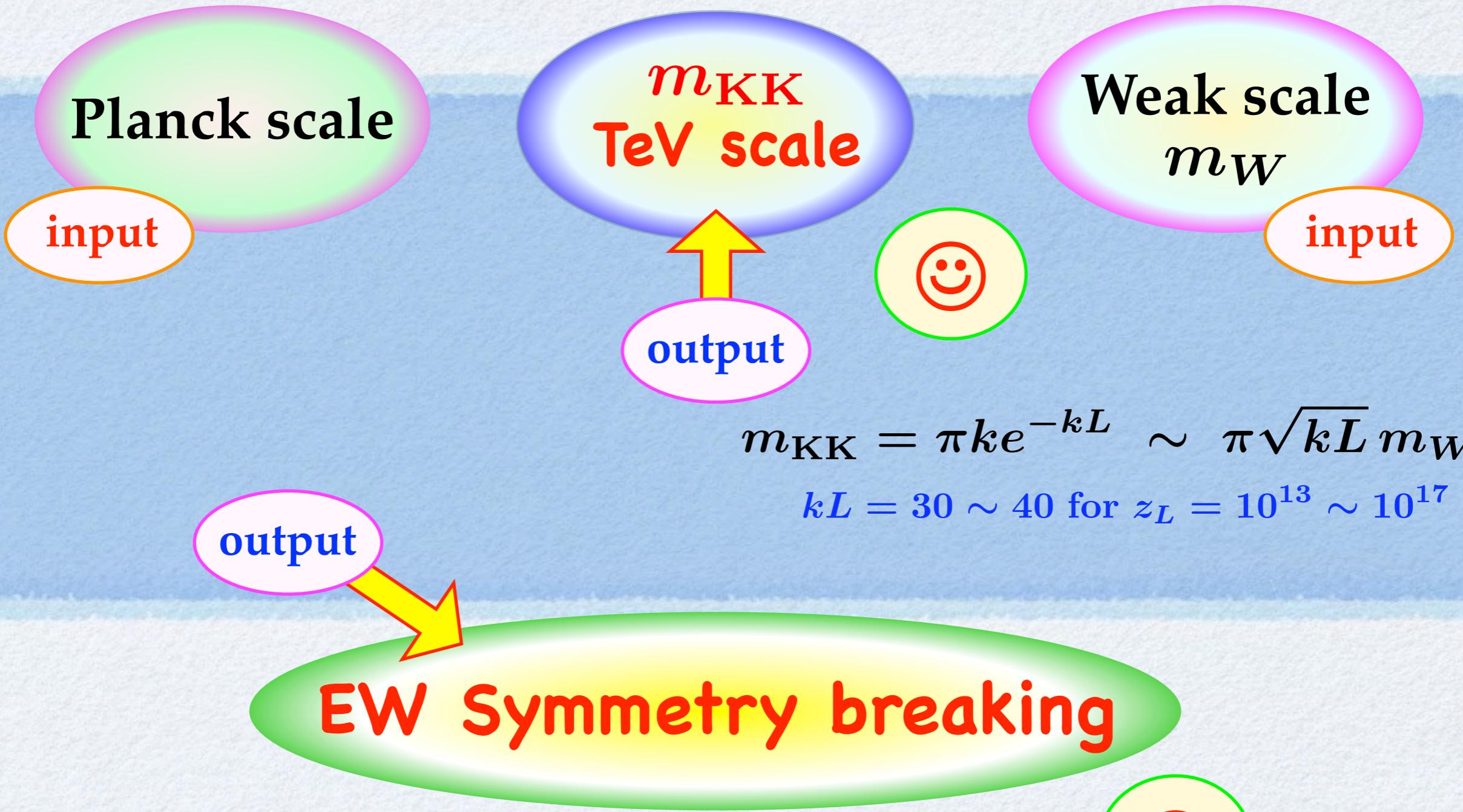
Warped space



$$m_{\text{KK}} = \pi k e^{-kL} \sim \pi \sqrt{kL} m_W$$

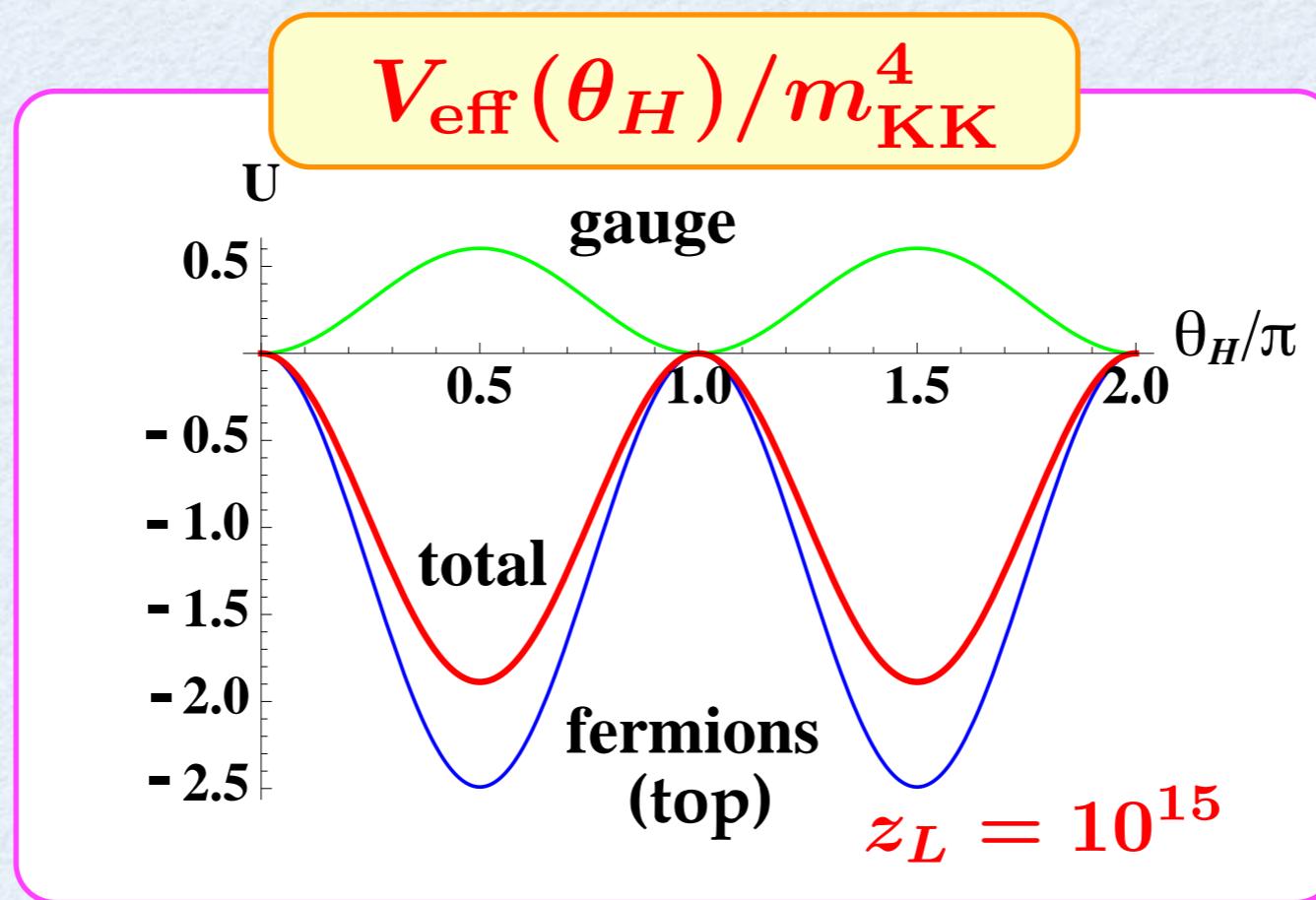
$$kL = 30 \sim 40 \text{ for } z_L = 10^{13} \sim 10^{17}$$

Warped space



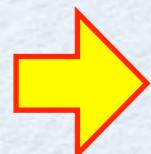
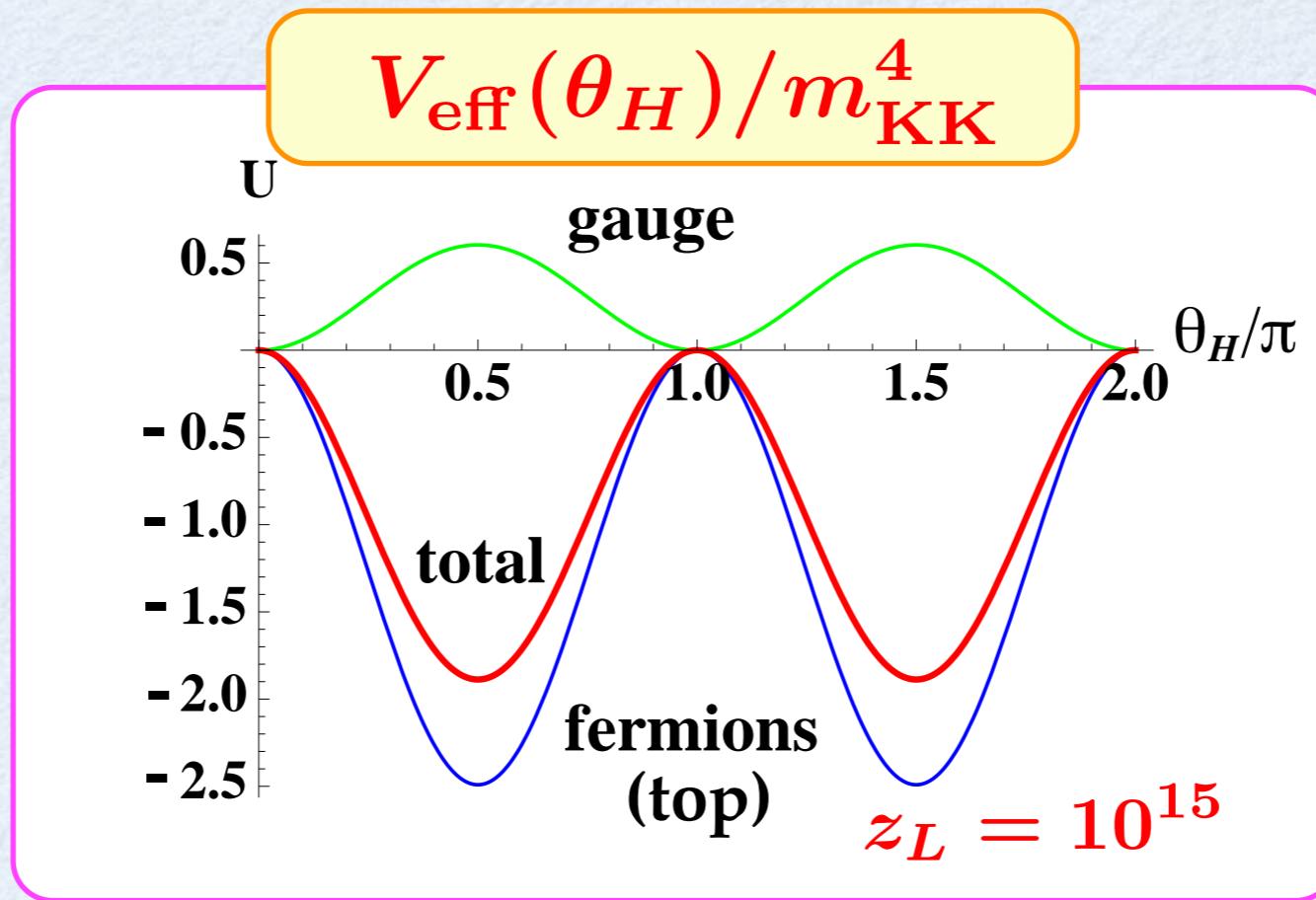
EW Symmetry breaking

Hosotani mechanism



EW Symmetry breaking

Hosotani mechanism



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

$$SU(2)_L' \times U(1)' \rightarrow U(1)_{EM}$$

$$m_H = 135 \text{ GeV } (z_L = 10^{15})$$

Effective interactions

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

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

$$\hat{\theta}_H = \theta_H + \frac{H}{f_H} \quad f_H = \frac{2}{\sqrt{kL}} \frac{m_{KK}}{\pi g}$$

Effective interactions

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

in SM

$$f_H \sin \hat{\theta}_H \rightarrow v + H$$

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WWH
ZZH
Yukawa

= *SM* ×

$\cos \theta_H$

H parity at $\theta_H = \frac{1}{2}\pi$

YH, Ko, Tanaka, 2009

YH, Tanaka, Uekusa, 2010

$$\frac{\pi}{2} + \frac{H}{f_H}$$

$$-\frac{\pi}{2} - \frac{H}{f_H}$$

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$H : -$

all other SM particles : +

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Stable Higgs

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Stable Higgs

$$P_H : \begin{array}{l} SU(2)'_L \leftrightarrow SU(2)'_R \\ T^4 \rightarrow -T^4 \end{array}$$

Agashe, Contino, Da Rold, Pomarol 2006
 T parameter $Z b\bar{b}$

Collider signatures

H parity

No single-Higgs production

Higgs pair production

Collider signatures

H parity

No single-Higgs production

Higgs pair production

Stable Higgs

Higgs = missing energy, momentum

hard to confirm at LHC/ILC

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

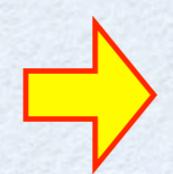
Gauge couplings precision measurements

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

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	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
$\chi^2(Z \text{ decay})$	8	13.6	16.5	37.7	184.5



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

YH, Tanaka, Uekusa, 2011

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

$Z^{(1)}$

z_L	10^5	10^{15}
m	653	1130
Γ	104	422

in GeV

$\gamma^{(1)}$

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Large widths

Strong couplings for right-handed quarks and lepton

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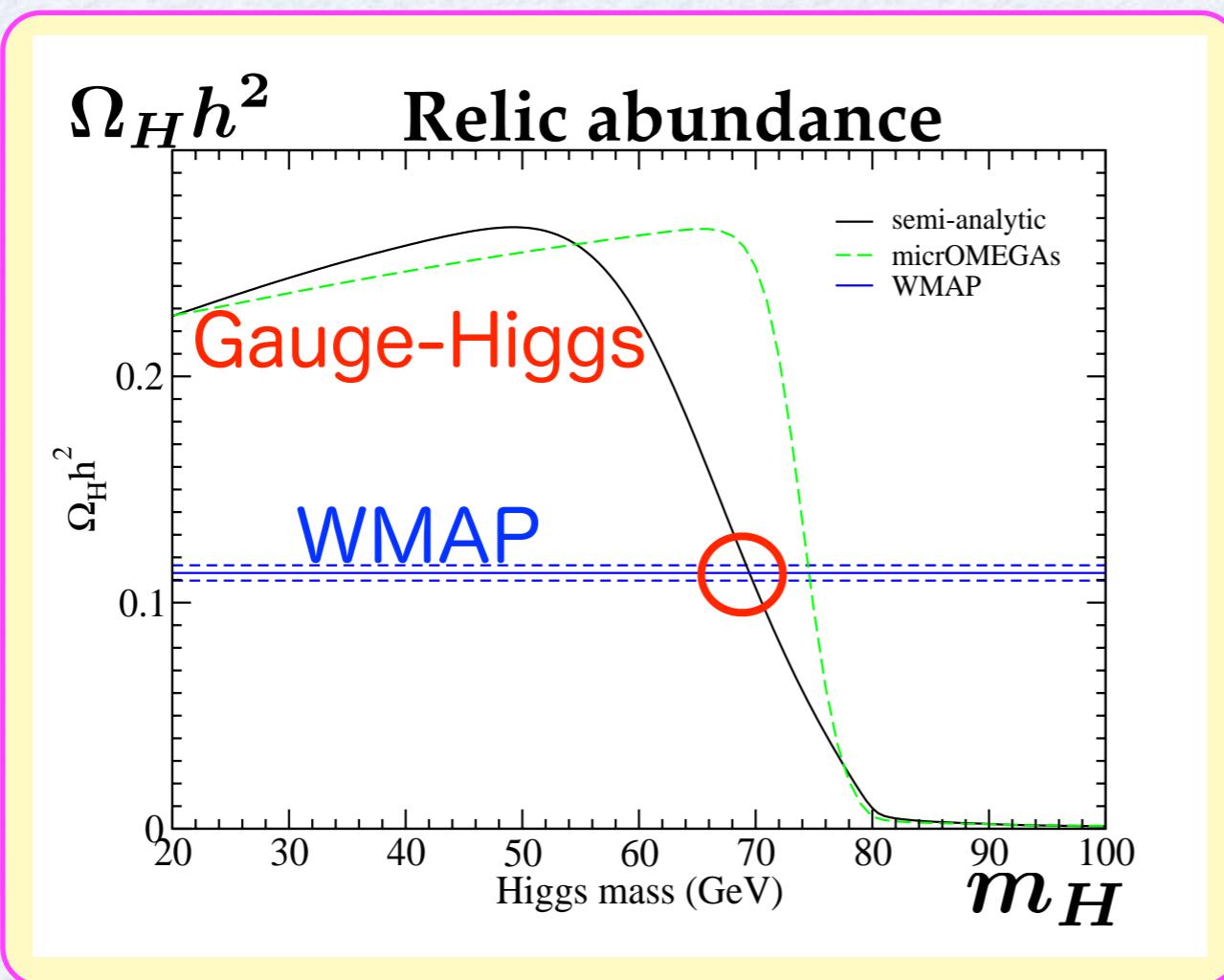
Strong couplings for right-handed quarks and lepton

Not seen at LHC, so far.

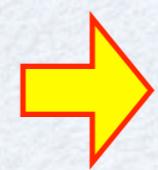


Stable Higgs → Dark Matter

YH, Ko, Tanaka, 2009

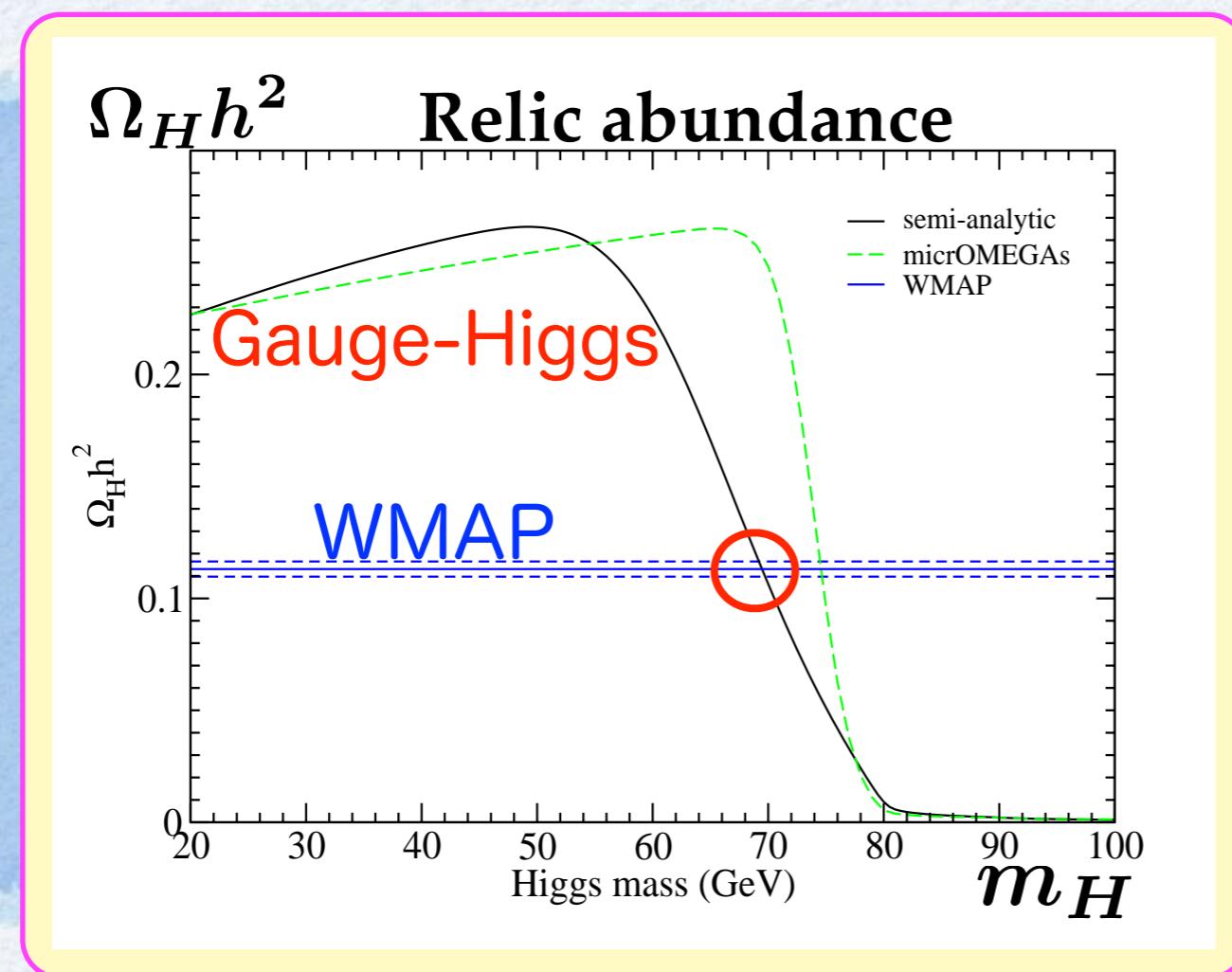


Stable Higgs

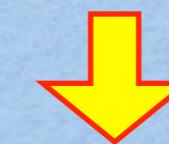


Dark Matter

YH, Ko, Tanaka, 2009



WMAP data



$m_H = 70 \sim 75 \text{ GeV}$

z_L	10^5	10^{10}	10^{15}
m_H	72 GeV	108	135

Collider signatures $\rightarrow z_L > 10^{15} \rightarrow m_H = 135 \text{ GeV}$

Dark matter $\rightarrow m_H = 70 \sim 75 \text{ GeV} \rightarrow z_L \sim 10^5$

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SUSY

exact $\rightarrow m_H = 0$
broken $\rightarrow 70 \sim 75 \text{ GeV}$

Hatanaka, YH, 1111.3756

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$W, Z, Higgs$

$\{ m_n \}$

$\tilde{W}, \tilde{Z}, \tilde{Higgs}$

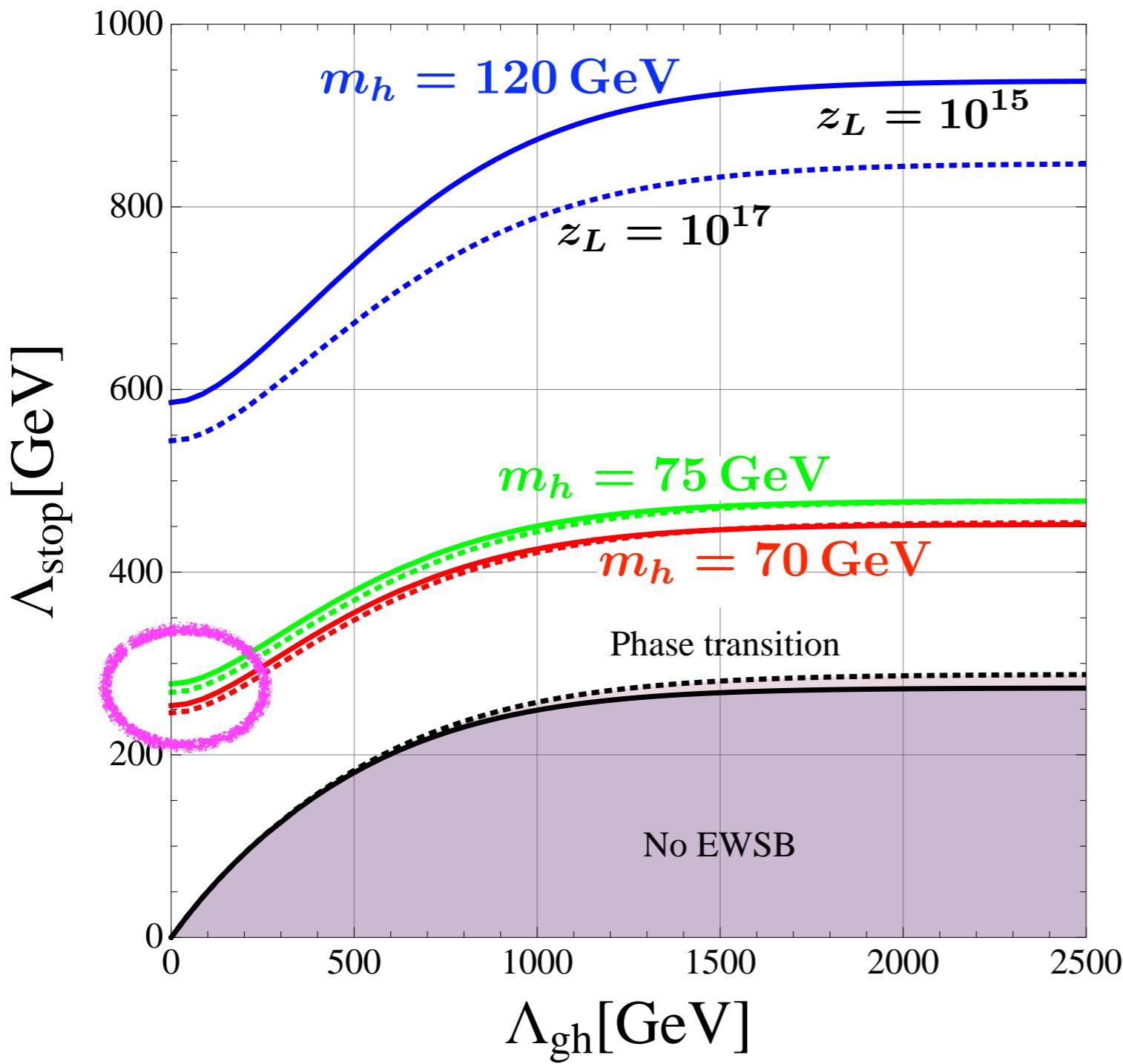
$$\tilde{m}_n = \sqrt{m_n^2 + \Lambda_{\text{gh}}^2}$$

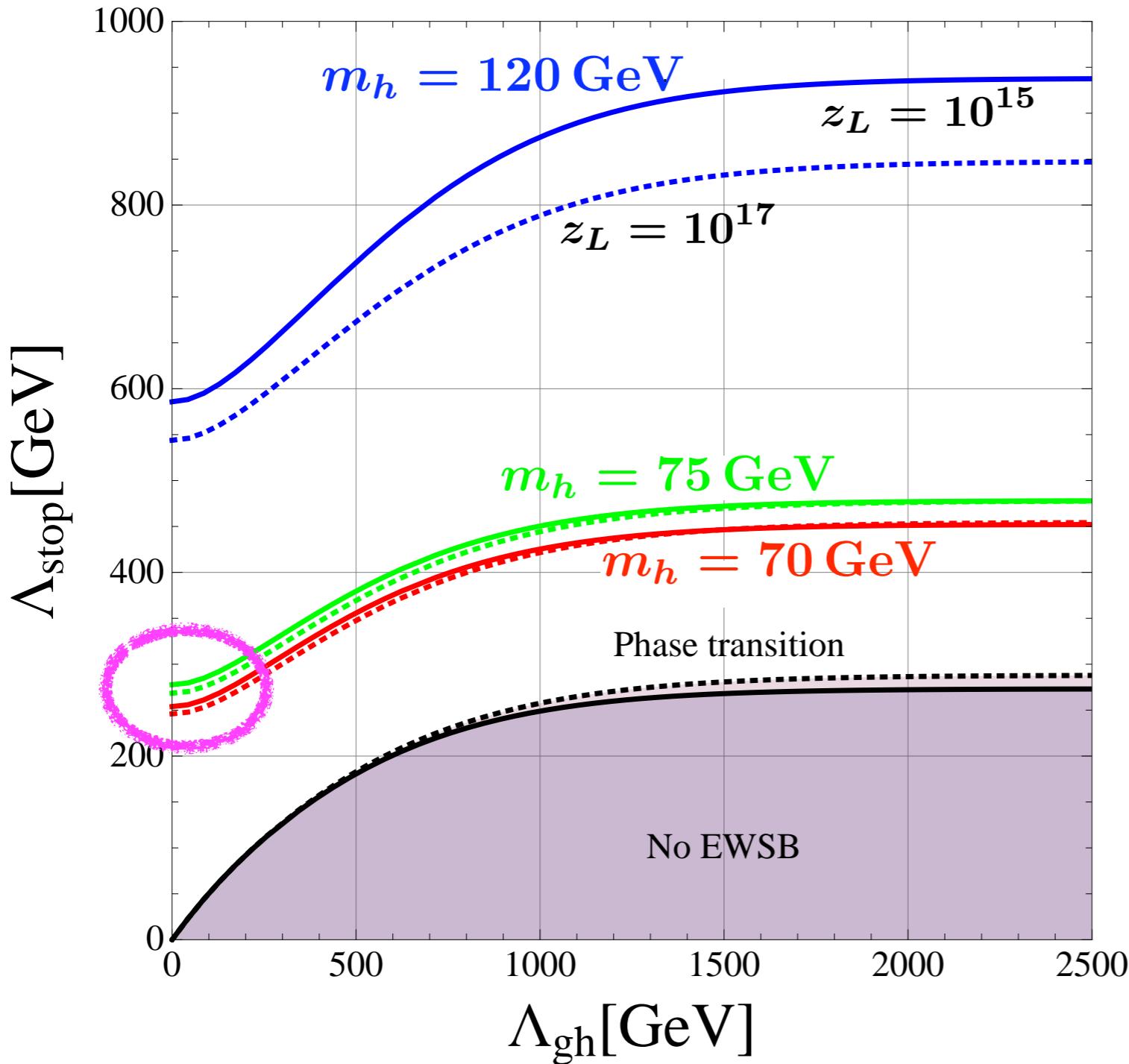
t

$\{ m_n \}$

\tilde{t}

$$\left\{ \tilde{m}_n = \sqrt{m_n^2 + \Lambda_{\text{stop}}^2} \right\}$$





$\Lambda_{\text{stop}} = 250 - 275 \text{ GeV}$
 $\Lambda_{\text{gh}} < 100 \text{ GeV}$


stop
300 - 320 GeV
neutralino < 100 GeV
gluino > 1 TeV

for $m_h = 70 \sim 75 \text{ GeV}$

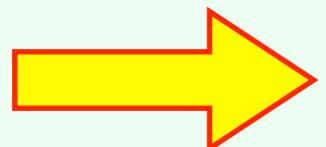
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gauge-Higgs

(extra dimensions).