Gauge-Higgs Unification :

- LHC and Dark Matter -

Yutaka Hosotani (Osaka University)

YH, Ko, Tanaka, 0908.0212 [hep-ph] (PLB)
YH, Noda, Uekusa, 0912.1173 [hep-ph] (PTP)

Planck 2010, , CERN, 2 June 2010

SO(5)xU(1) gauge-Higgs unification in RS

Agashe, Contino, Pomarol 2005
Hosotani, Sakamura 2006
Medina, Shar, Wagner 2007
Hosotani, Oda, Ohmuma, Sakamura 2008
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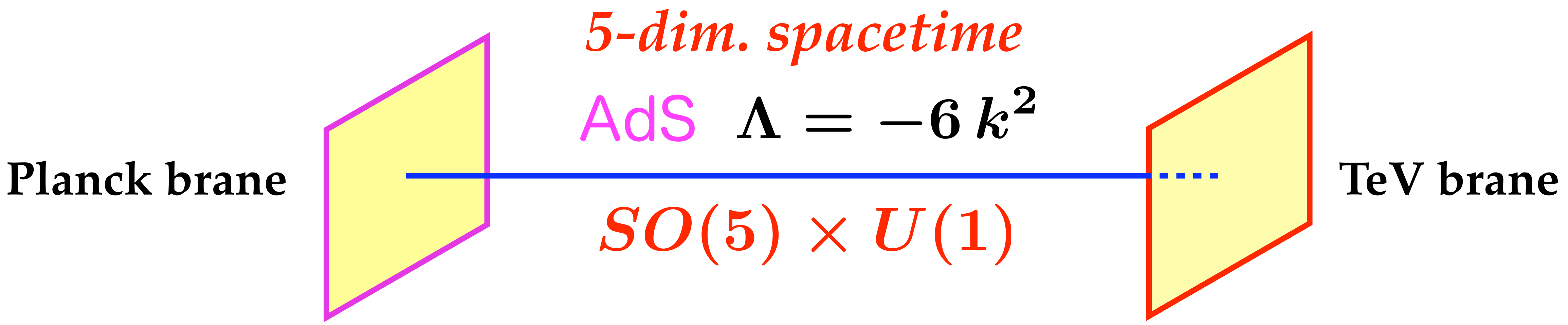

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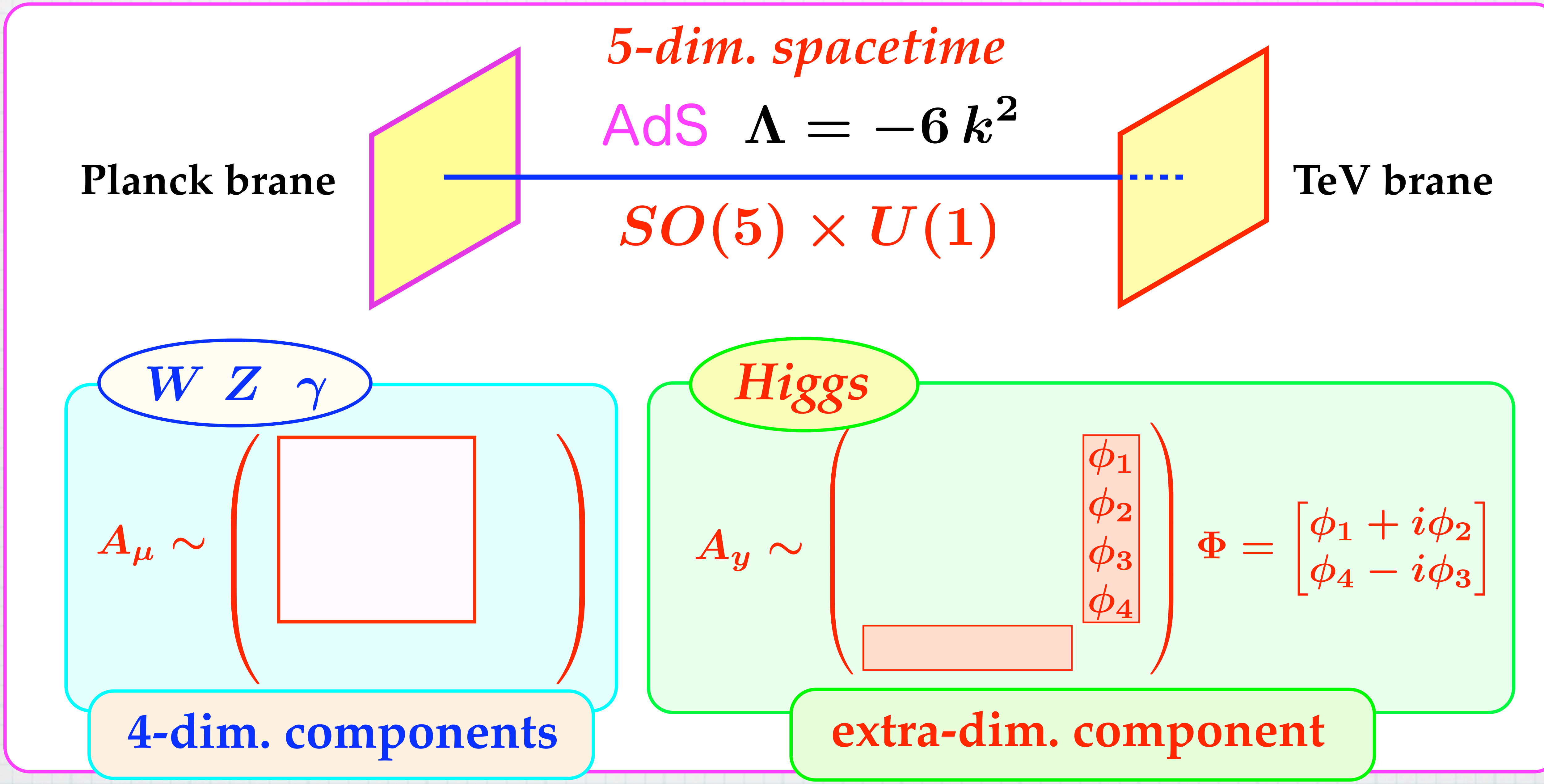
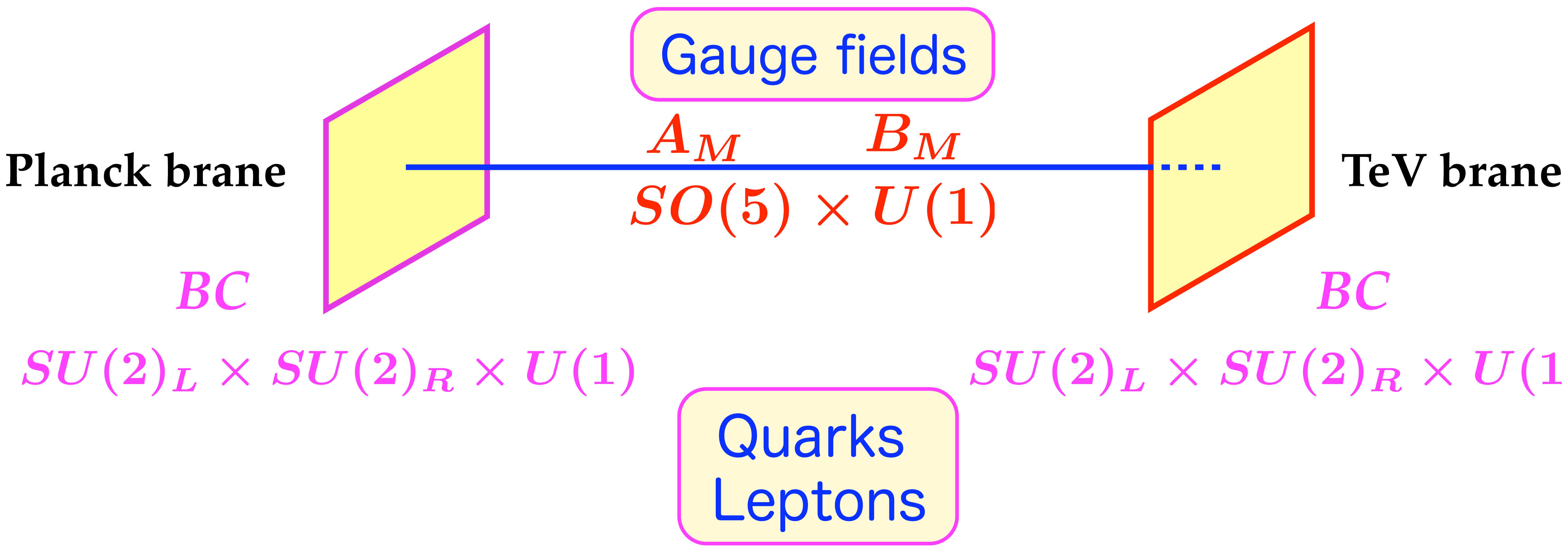


Symmetry breaking



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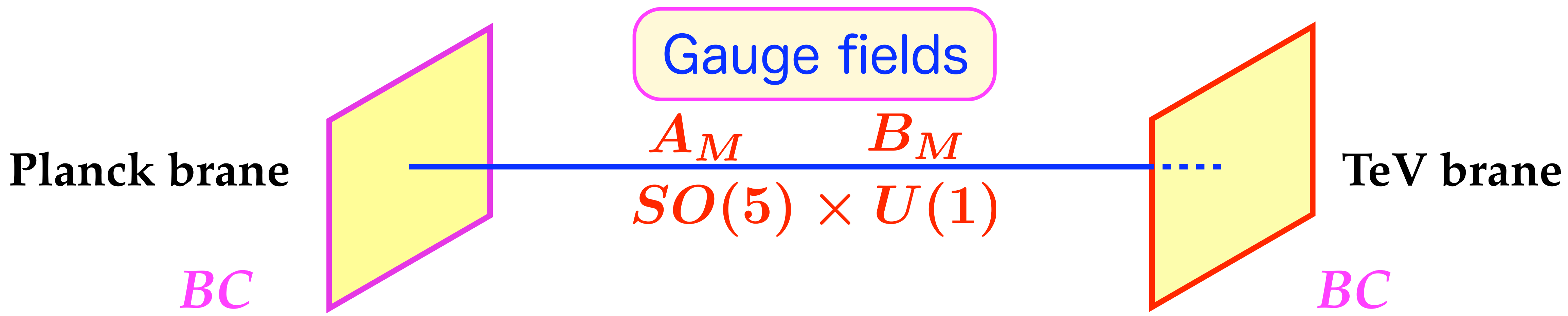


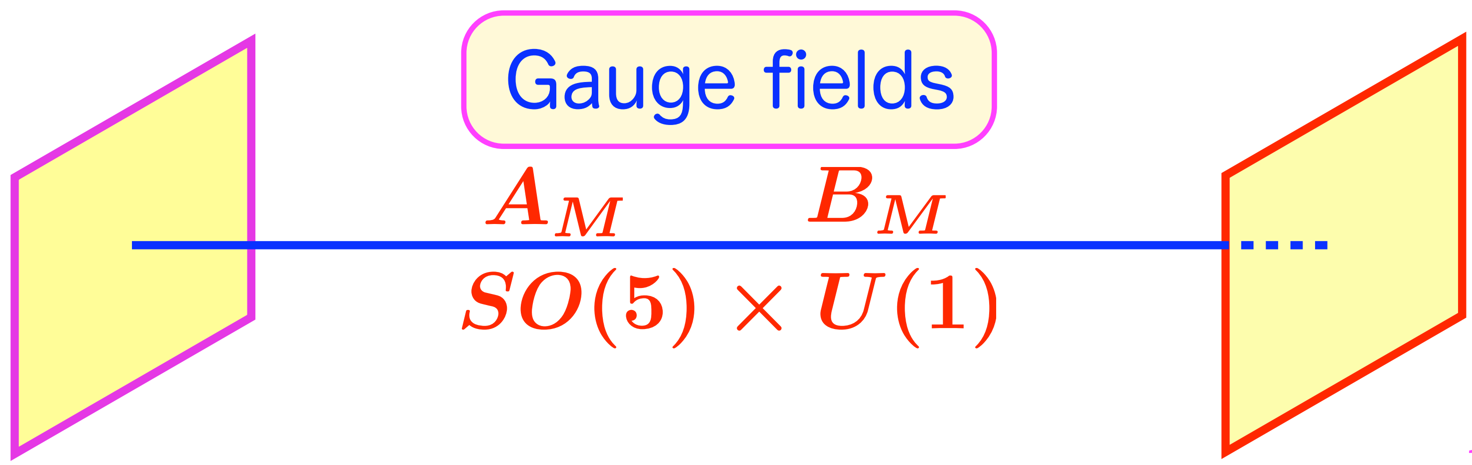
$SU(2)_L \times SU(2)_R \times U(1)$ $SU(2)_L \times SU(2)_R \times U(1)$

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

Quarks
Leptons

$SU(2)_L \times U(1)_Y$

Symmetry breaking



Planck brane | **TeV brane**

BC | *BC*

$SU(2)_L \times SU(2)_R \times U(1)$ | $SU(2)_L \times SU(2)_R \times U(1)$

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

Quarks
Leptons

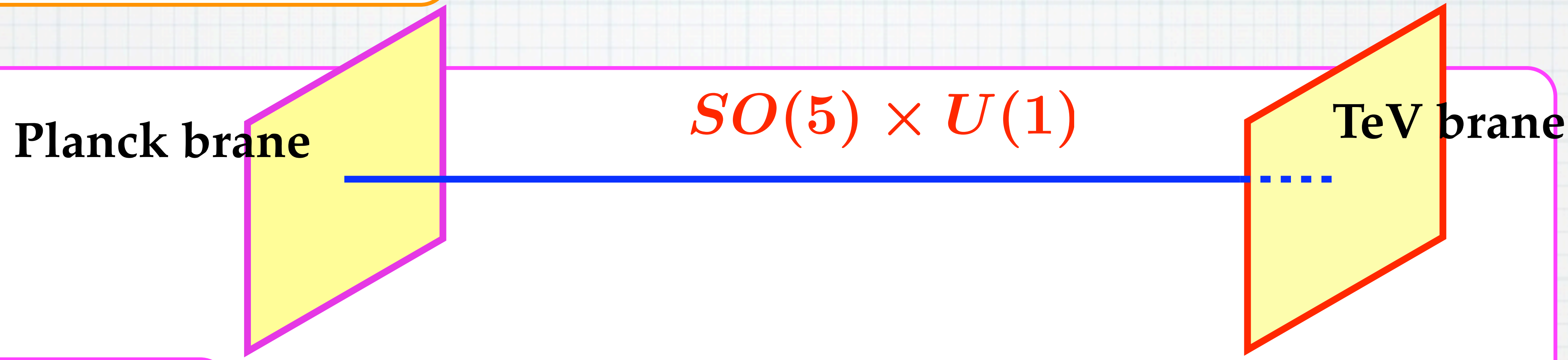
$SU(2)_L \times U(1)_Y$

$\Downarrow$ *top quark multiplet*
Hosotani mechanism

$U(1)_{\rm EM}$

Matter content

YH, Noda, Uekusa 2009
(YH, Oda, Ohnuma, Sakamura 2008)



Quarks

Brane scalar

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

Leptons

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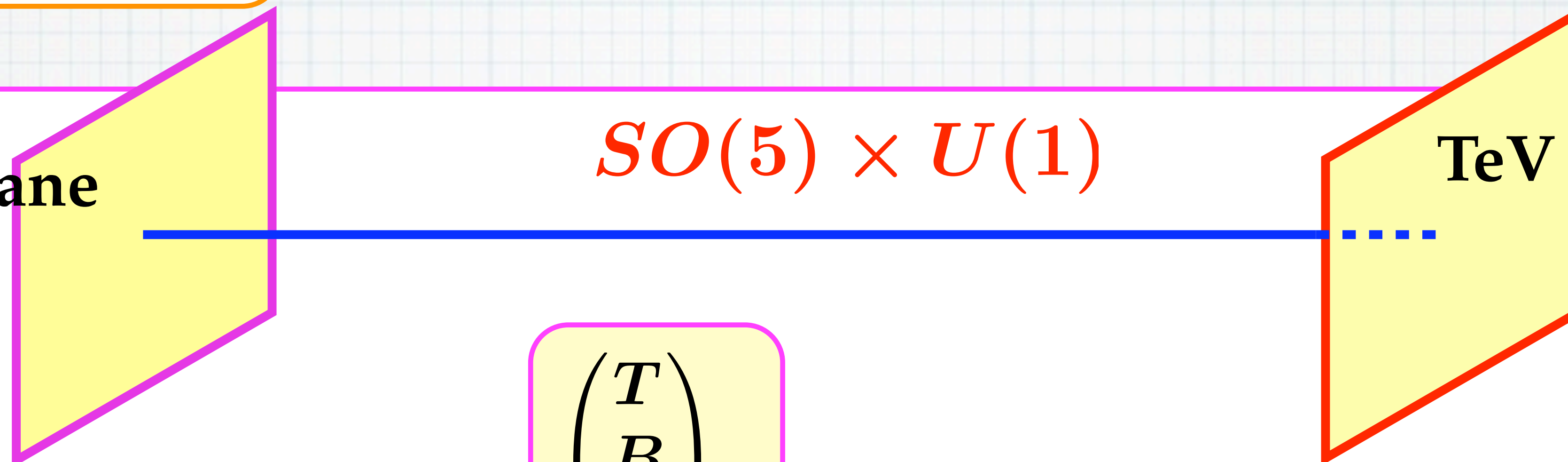

Quarks

$$\begin{pmatrix} T \\ B \\ t \\ b \\ t' \end{pmatrix}_{\frac{2}{3}} \quad \begin{pmatrix} U \\ D \\ X \\ Y \\ b' \end{pmatrix}_{-\frac{1}{3}}$$

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

Brane scalar

$\Phi \quad (0, \tfrac{1}{2})$

Leptons

$$\begin{pmatrix} \nu_\tau \\ \tau \\ L_{1X} \\ L_{1Y} \\ \tau' \end{pmatrix}_{-1}$$

Matter content

YH, Noda, Uekusa 2009
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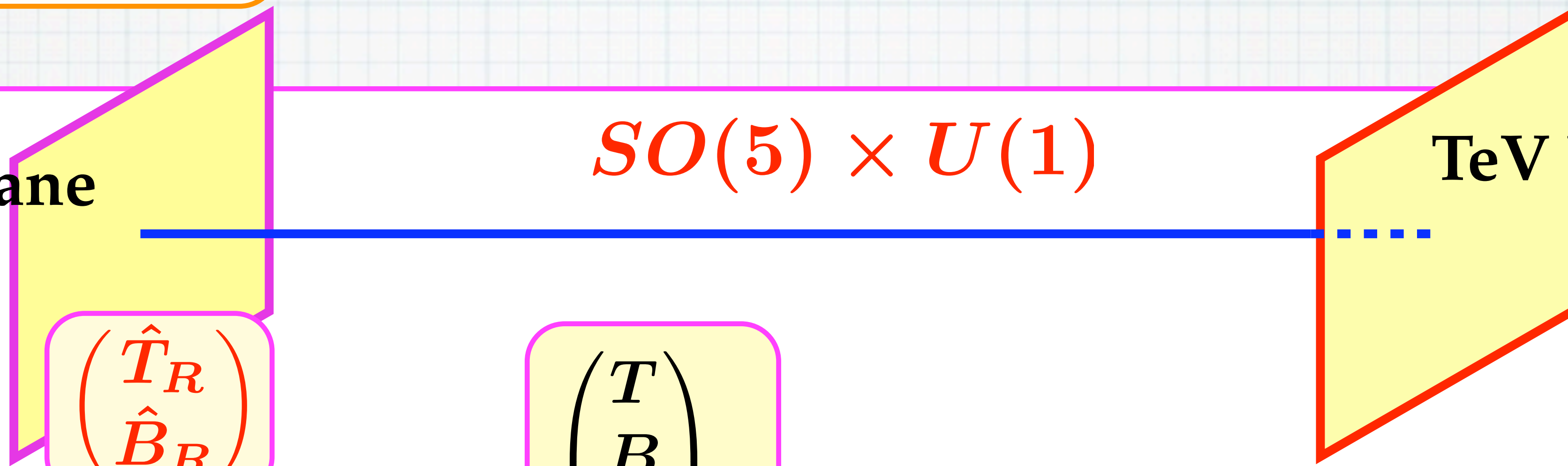


Quarks

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

$$\begin{pmatrix} T \\ B \\ t \\ b \\ t' \end{pmatrix}_{\frac{2}{3}} \quad \begin{pmatrix} U \\ D \\ X \\ Y \\ b' \end{pmatrix}_{-\frac{1}{3}} \qquad (\tfrac{1}{2}, \tfrac{1}{2}) \oplus (0, 0)$$

Brane scalar

$$\Phi \quad (0, \tfrac{1}{2})$$

Leptons

$$\begin{pmatrix} \hat{L}_{1XR} \\ \hat{L}_{1YR} \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \\ L_{1X} \\ L_{1Y} \\ \tau' \end{pmatrix}_{-1}$$

Matter content

YH, Noda, Uekusa 2009

(YH, Oda, Ohnuma, Sakamura 2008)

Planck brane

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

TeV brane

Quarks

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

$\begin{pmatrix} T \\ B \\ t \\ b \\ t' \end{pmatrix}_{\frac{2}{3}}$ $\begin{pmatrix} U \\ D \\ X \\ Y \\ b' \end{pmatrix}_{-\frac{1}{3}}$

Brane scalar

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

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

Leptons

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

$\begin{pmatrix} \nu_\tau \\ \tau \\ L_{1X} \\ L_{1Y} \\ \tau' \end{pmatrix}_{-1}$ $\begin{pmatrix} L_{2X} \\ L_{2Y} \\ L_{3X} \\ L_{3Y} \\ \nu'_\tau \end{pmatrix}_{0}$

SM content at low energies

γ , W , Z

H

$\begin{pmatrix} t_L \\ b_L \end{pmatrix}$ t'_R b'_R $\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$ $\nu'_{\tau R}$ τ'_R

SM content
at low energies

γ , W , Z
H

$\begin{pmatrix} t_L \\ b_L \end{pmatrix}$ t'_R b'_R $\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$ $\nu'_{\tau R}$ τ'_R

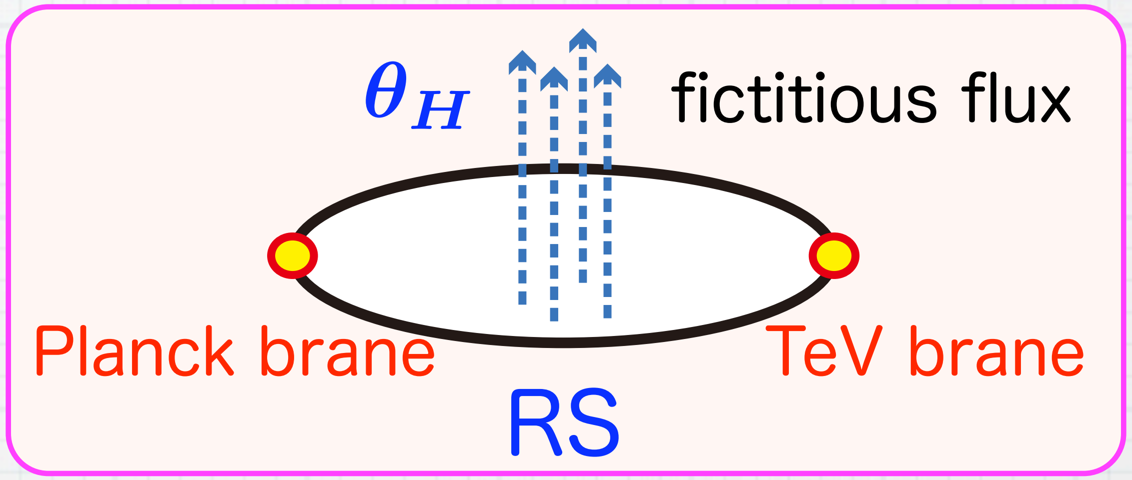
4D anomaly cancellation in
$SU(2)_L \times SU(2)_R \times U(1)$

Higgs field = fluctuations of an AB phase

(gauge field)

$$e^{i\theta_H} \sim P \exp\left\{ ig \int_C dy A_y \right\}$$

(Aharonov-Bohm)



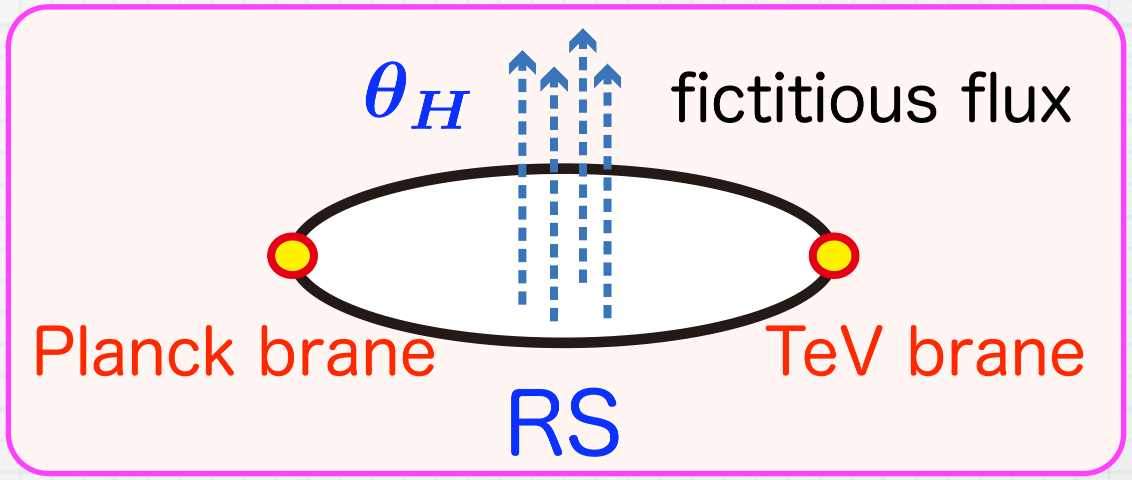
Higgs field = fluctuations of an AB phase

(gauge field)

$$e^{i\theta_H} \sim P\exp\left\{ ig \int_C dy A_y \right\}$$

(Aharonov-Bohm)

$$A_y^{45}(x,y) = h_0(y)\left\{ \theta_H + \frac{H(x)}{f_H} \right\}$$



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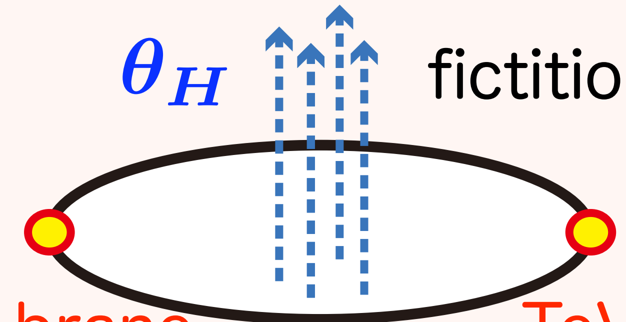

$$\theta_H \sim \theta_H + 2\pi$$

Gauge inv

Effective interactions

Hosotani, Kobayashi 2008

$$\mathcal{L}_{\rm eff} \sim -m_f(H)\,\overline{\psi}_f\psi_f$$

Effective interactions

Hosotani, Kobayashi 2008

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Gauge-Higgs | **SM**

$$m_f(H) \sim y_f f_H \sin\left(\theta_H + \frac{H}{f_H}\right) \qquad\qquad y_f(v + H)$$

Effective interactions

Hosotani, Kobayashi 2008

$$\mathcal{L}_{\rm eff} \sim -m_f(H)\, \overline{\psi}_f \psi_f$$

Gauge-Higgs

$$m_f(H) \sim y_f f_H \sin\left(\theta_H + \frac{H}{f_H}\right)$$

periodic
nonlinear

Gauge inv

SM

$$y_f(v+H)$$

linear

Effective interactions

Hosotani, Kobayashi 2008

$$\mathcal{L}_{\rm eff} \sim -m_f(H)\,\overline{\psi}_f \psi_f$$

Gauge-Higgs

$$m_f(H) \sim y_f f_H \sin\left(\theta_H + \frac{H}{f_H}\right)$$

periodic
nonlinear

Gauge inv

SM

$$y_f(v + H)$$

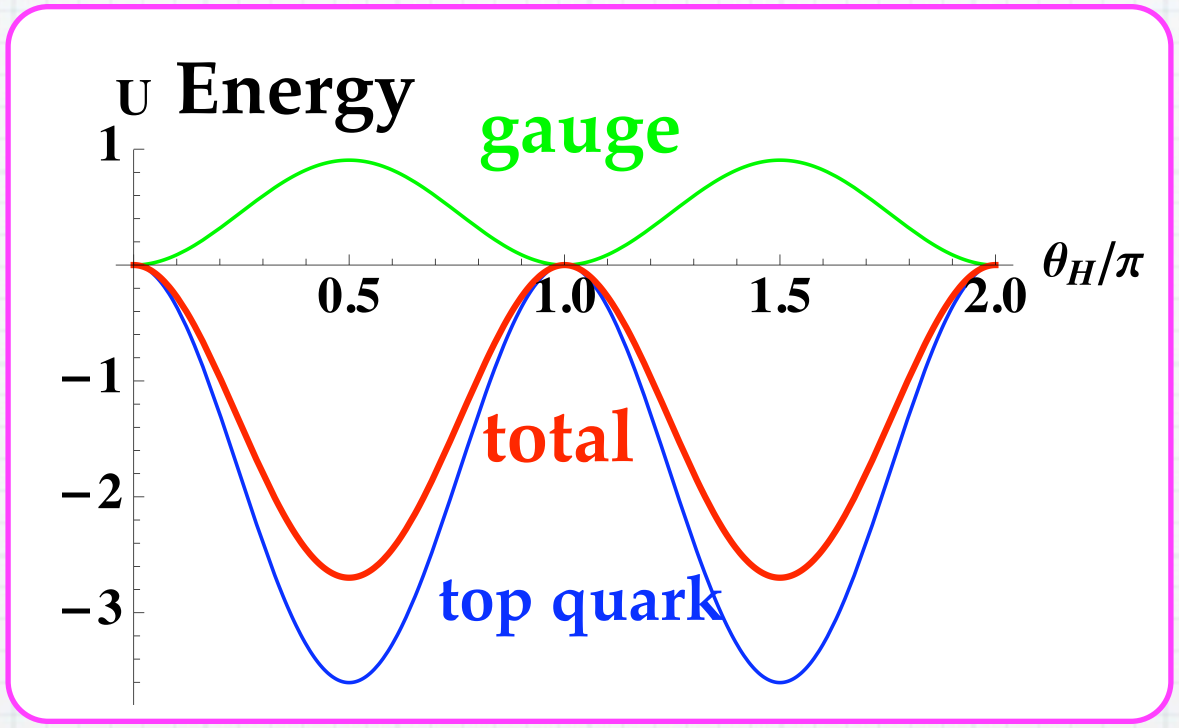
linear

WWH
ZZH
Yukawa

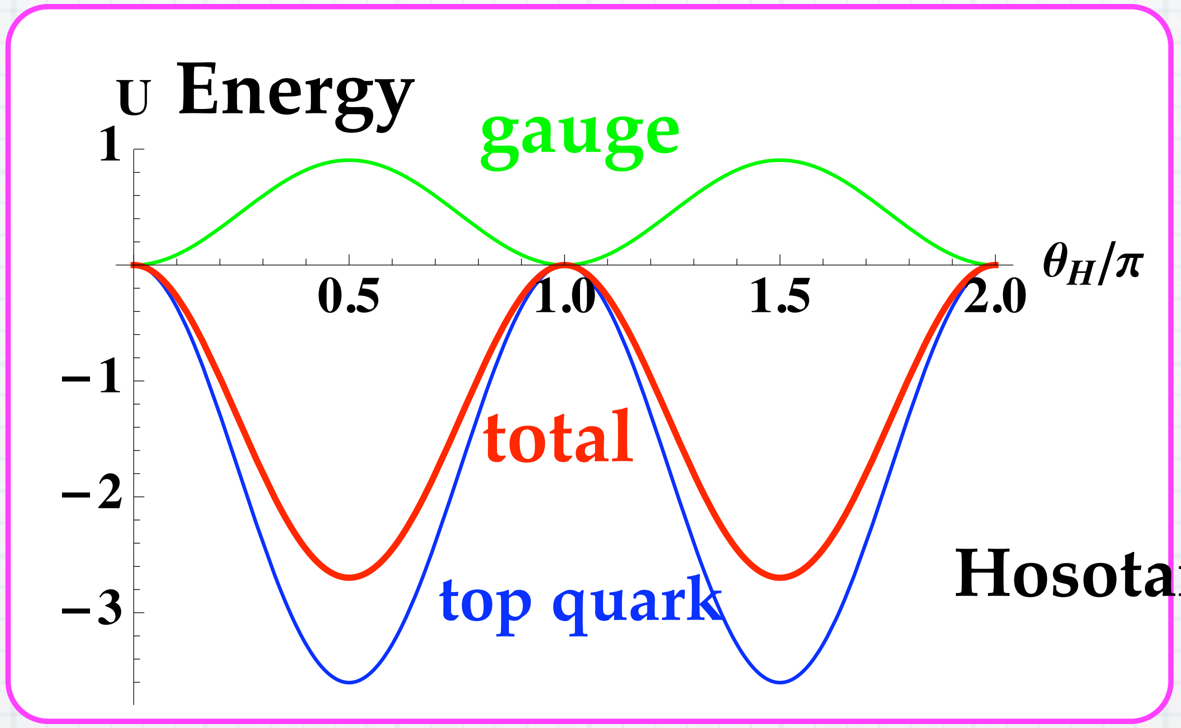
= *SM* × $\cos\theta_H$

large deviation

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



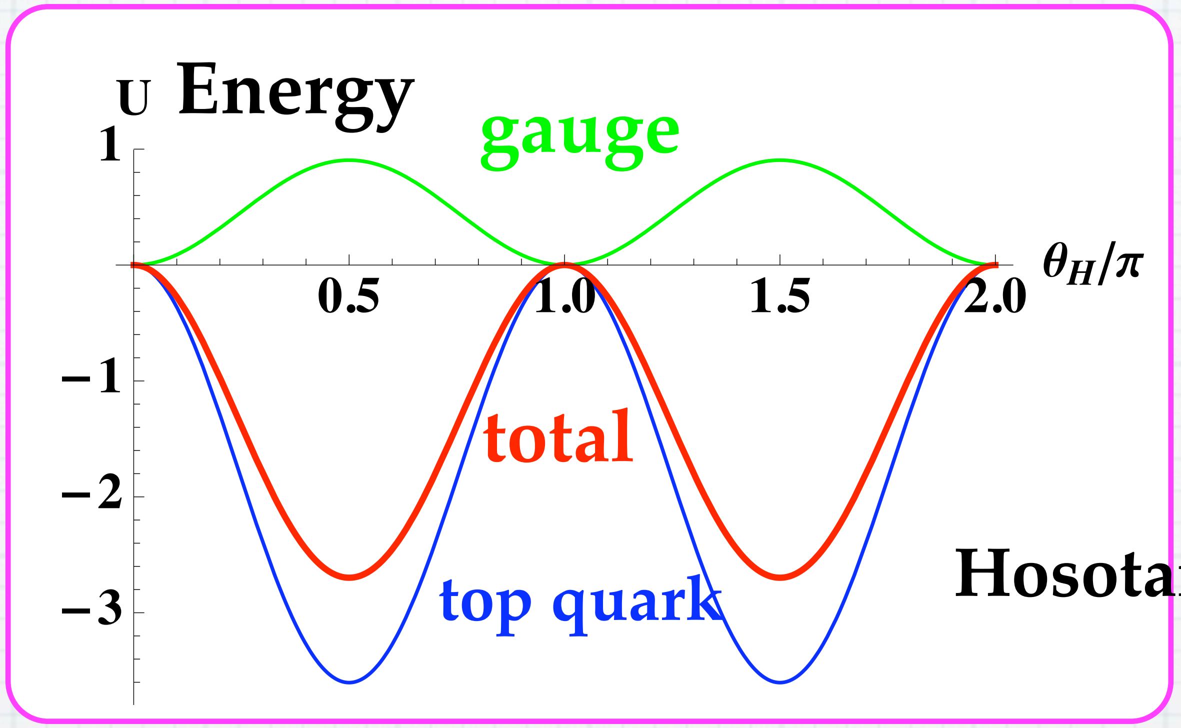
Dynamics choose $\theta_H = \dfrac{\pi}{2}$



Hosotani mechanism 1983

⇨ EW symmetry breaking

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



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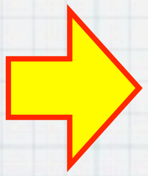
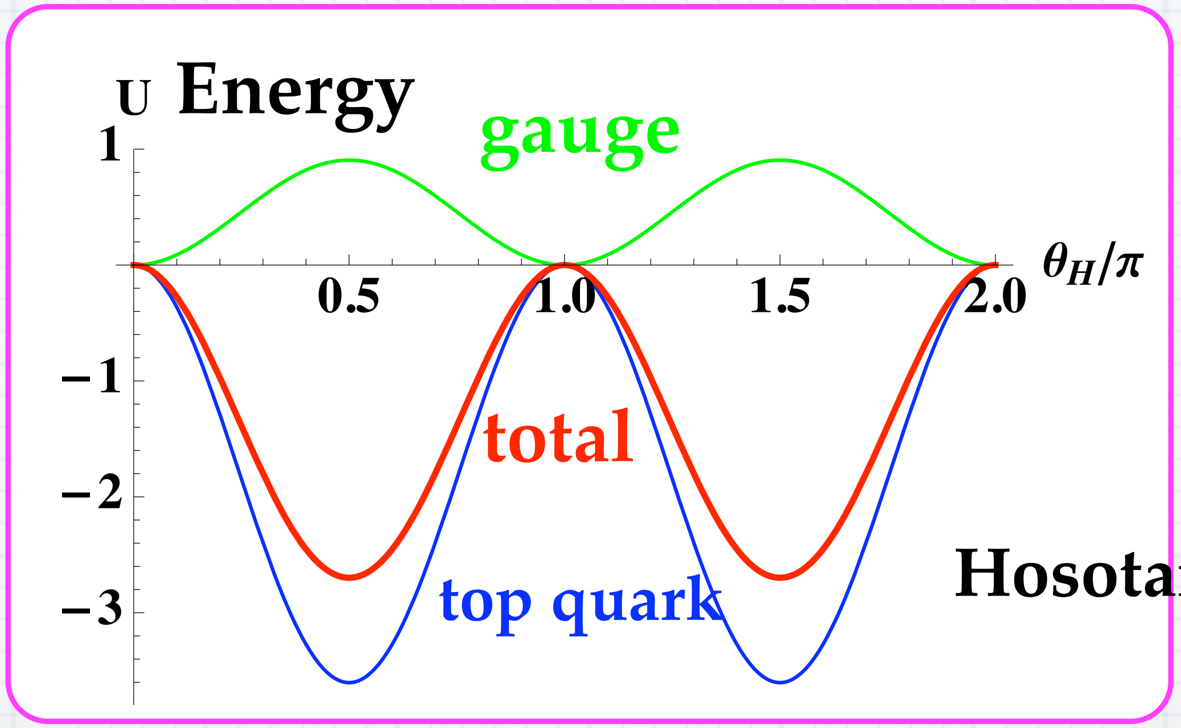


EW symmetry breaking

$$m_H : 55\,\text{GeV} \sim 140\,\text{GeV}$$

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



Hosotani mechanism 1983

⇒ EW symmetry breaking

$$m_H : 55\,\mathrm{GeV} \sim 140\,\mathrm{GeV}$$

$\cos\theta_H = 0$ ⇒ WWH, ZZH, Yukawa = 0

LEP2 bound is evaded.

In the SO(5) x U(1) gauge-Higgs unification

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

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

H-parity

$$H : -$$

$$\text{all other SM particles} : +$$

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

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⇨ Higgs bosons become absolutely stable.

WWH, ZZH, Yukawa = 0

Higgs bosons become stable and become the Dark Matter.

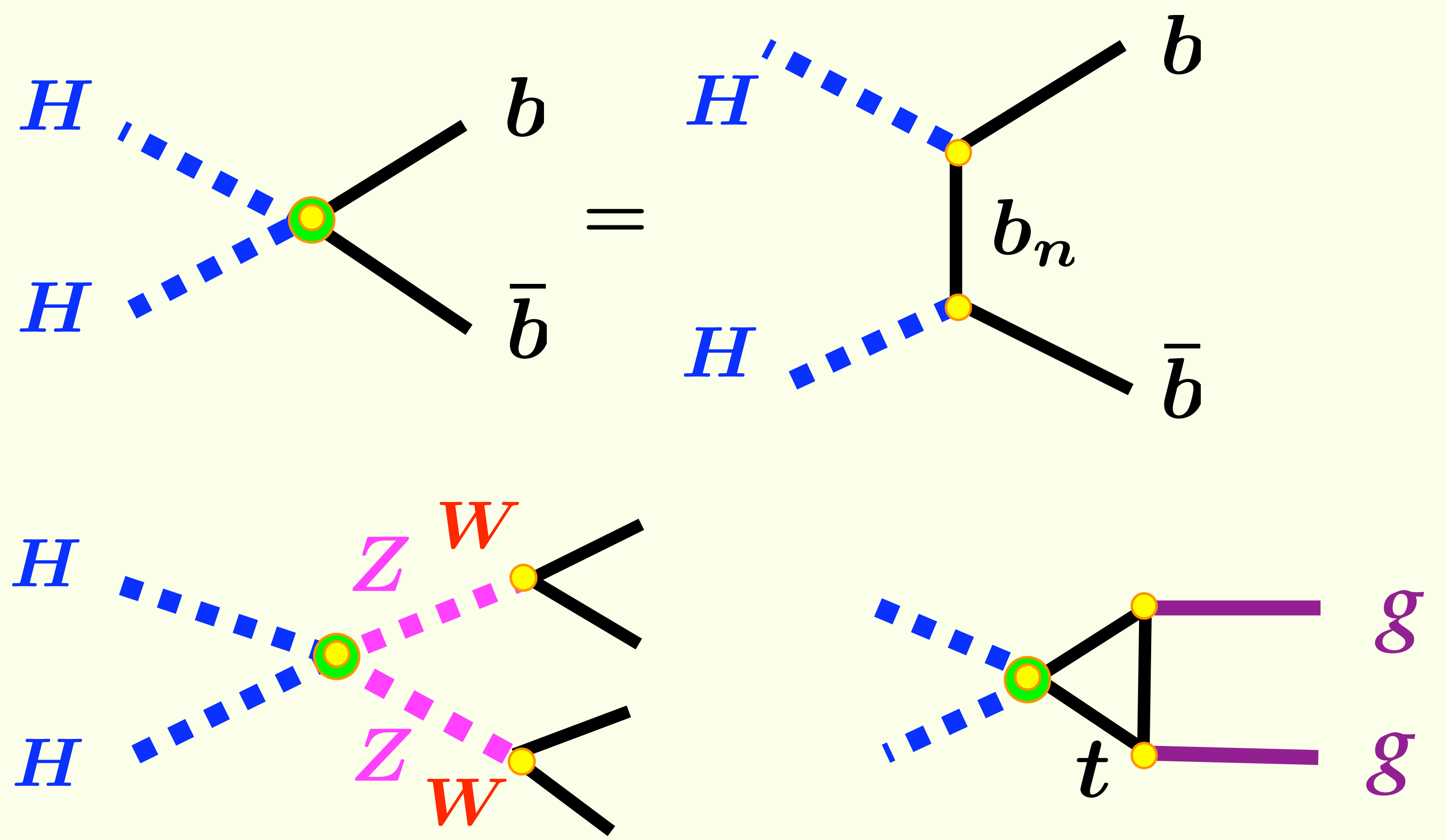
Higgs bosons become stable and become the Dark Matter.

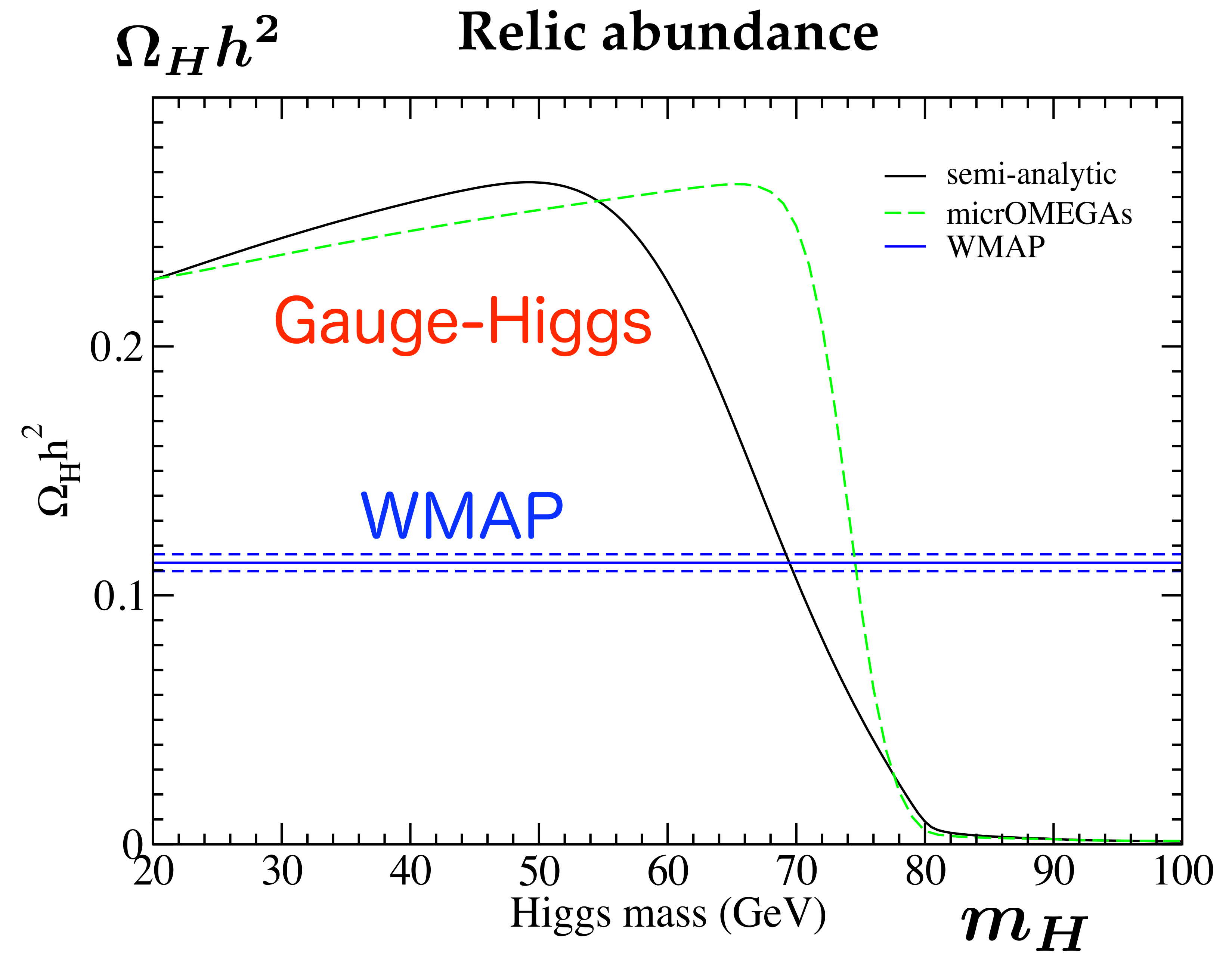
WMAP data
fixes
the Higgs mass.

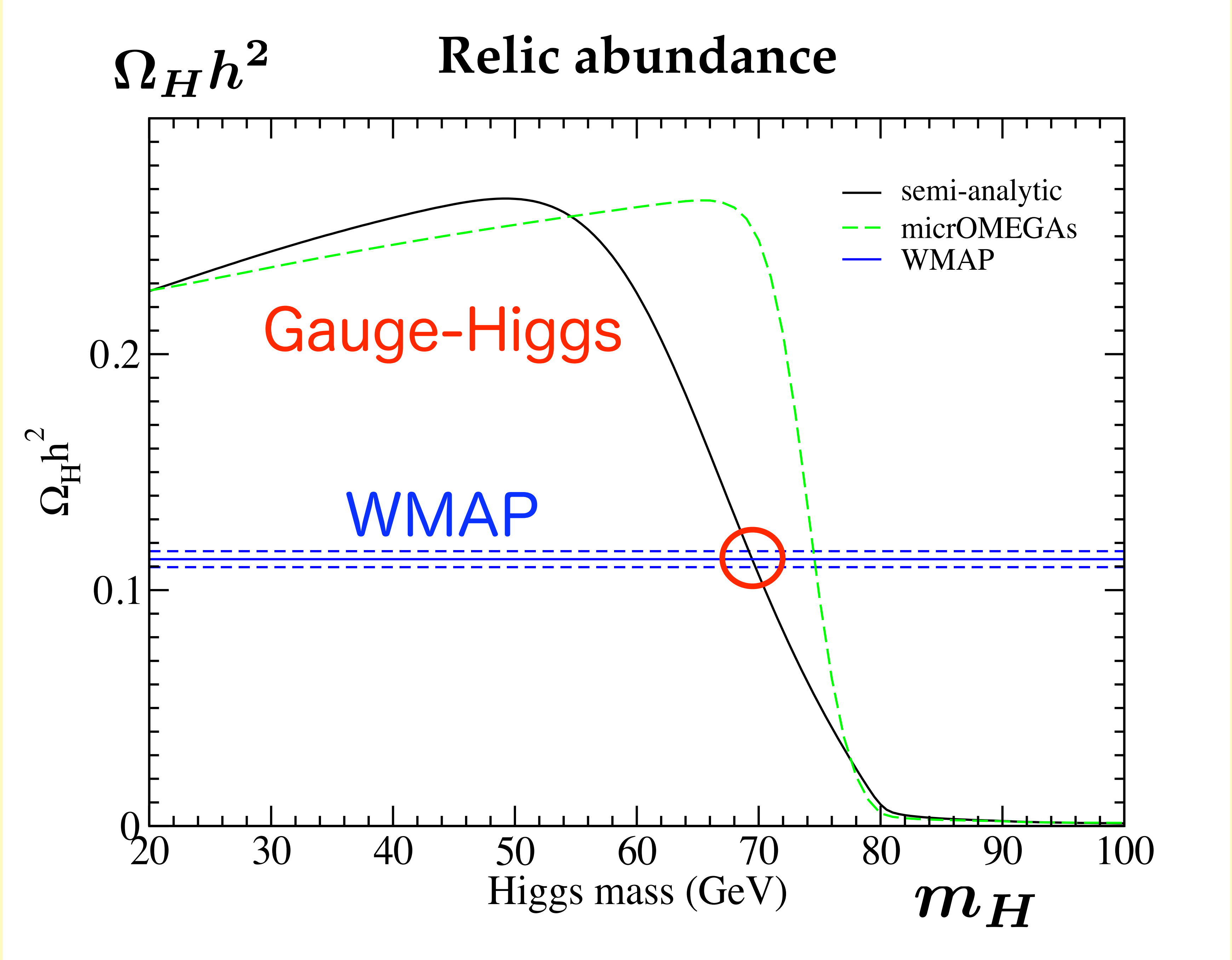
Hosotani, Ko, Tanaka
0908.0212 [hep-ph]

Higgs = Dark Matter

Annihilation




$\Omega_H h^2$
Relic abundance
semi-analytic
micrOMEGAs
WMAP
Gauge-Higgs
WMAP
0.2
0.1
0
$\Omega_H h^2$
20
30
40
50
60
70
80
90
100
Higgs mass (GeV)
m_H



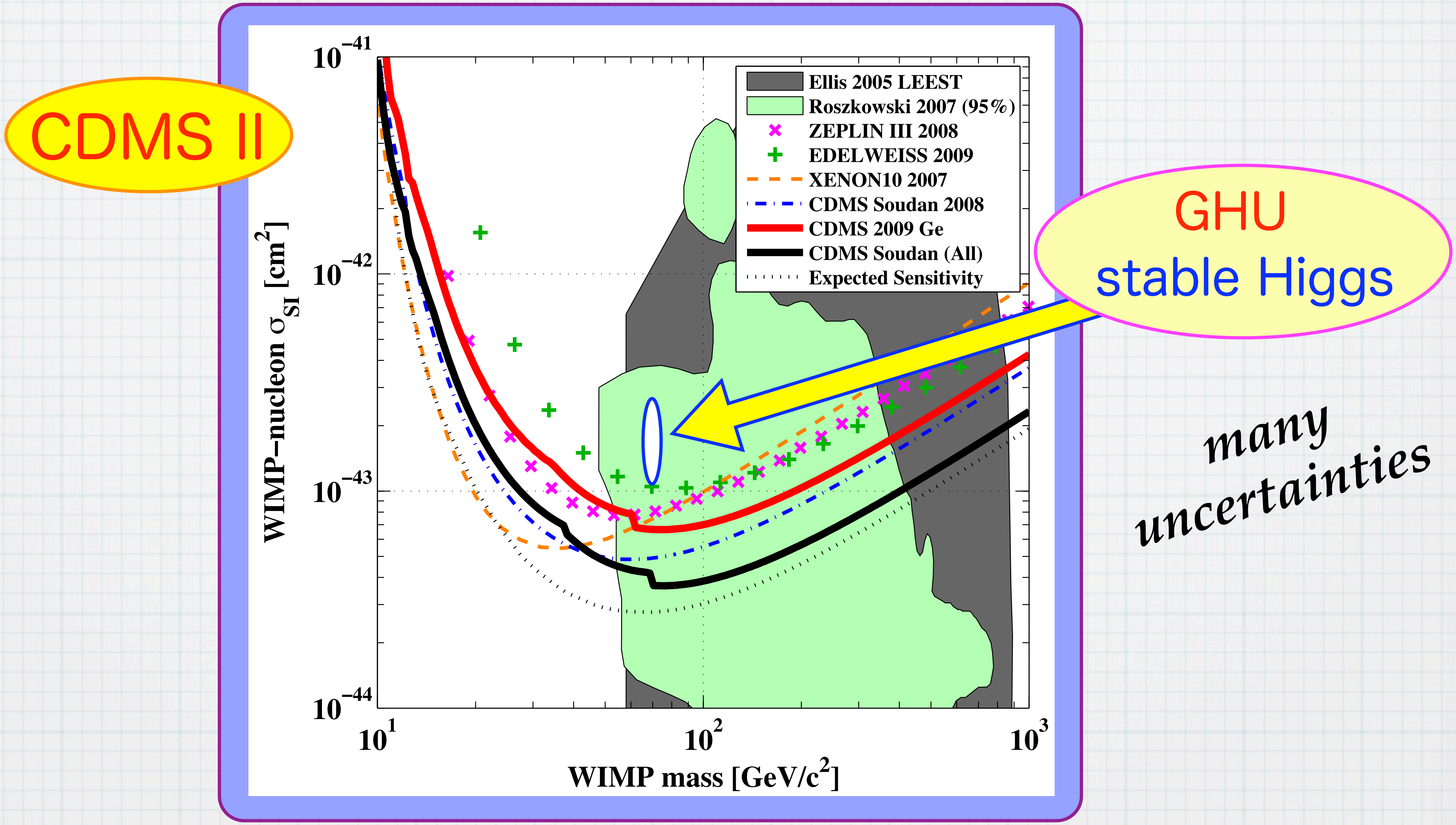
WMAP data ⇨ $m_H \sim 70\,\mathrm{GeV}$

$T_f \sim 3\,\mathrm{GeV}$

$HH \to b\bar{b}$ 34%

$\to WW$ 61%

Direct detection rate

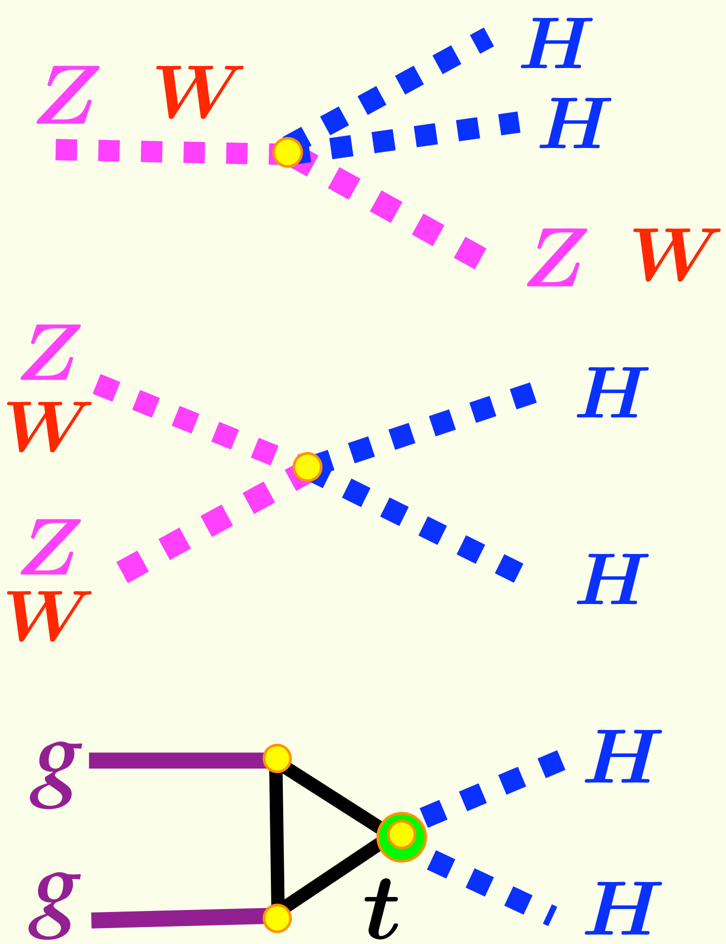


arXiv:0912.3592 [astro-ph.CO] 18 Dec 2009

Two events in the signal region

How to see the Higgs bosons at LHC/ILC

Production:



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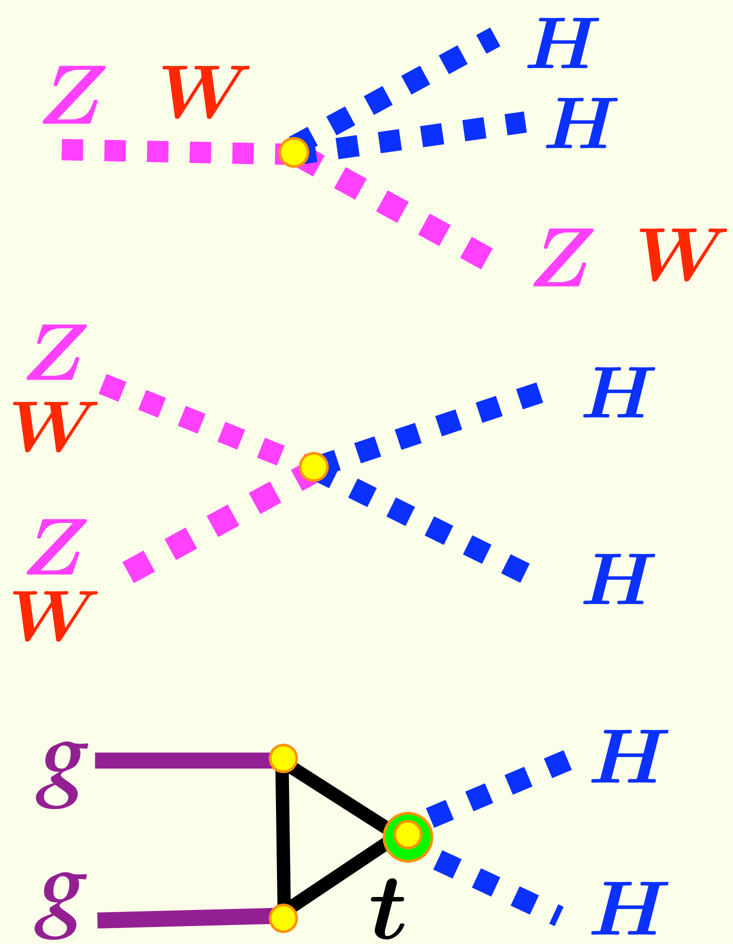

Stable Higgs boson

=

missing energy,

missing momentum

K. Cheung, J. Song arXiv:1004.2783

hard at LHC, possible at ILC

Summary

In the Gauge-Higgs unification

Higgs bosons = gauge bosons

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In the Gauge-Higgs unification

Higgs bosons = gauge bosons

Higgs naturally become stable.

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Dark Matter＝Higgs $m_H \sim 70\,\mathbf{GeV}$

Summary

In the Gauge-Higgs unification

Higgs bosons = gauge bosons

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Dark Matter＝Higgs $m_H \sim 70\,\mathrm{GeV}$

Collider signatures:

Higgs, gauge couplings, KK modes

We might see extra dimensions !