14TeV LHC signals and dark matter in the SO(5)xU(1) gauge-Higgs unification

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TeV-scale physics after the discovery of the Higgs particle
TWCU,Tokyo, 26 March 2014

Funatsu, Hatanaka, YH, Orikasa, Shimotani,

(1) "Novel universality and Higgs decay $H \to \gamma\gamma, gg$ in the $SO(5) \times U(1)$ gauge-Higgs unification"
1301.1744 [PLB 722 (2013) 94]

(2) "LHC signals of the $SO(5) \times U(1)$ gauge-Higgs unification"
to appear soon. OU-HET 806, KIAS-P14007

(3) "Dark matter in the $SO(5) \times U(1)$ gauge-Higgs unification"
to appear soon. OU-HET 807, KIAS-P14008

125.5 GeV Higgs boson was found.

Higgs decay: $H \to \gamma\gamma\ ,\ gg, ZZ, \cdots$

Branching fractions: consistent with SM

No new particles found.

Case 1: Supports SM.

Case 2: No new physics up to "GUT" or "Planck" ?

Case 3: Indicates new physics at 14 TeV LHC ?

Gauge-Higgs unification is in Case 3.

Gauge-Higgs unification

gauge theroy A_M *in 5 dim.*

4-dim. components A_μ

extra-dim. component A_y

4D gauge fields

γ , W , Z

4D Higgs fields

H

Aharonov-Bohm phase

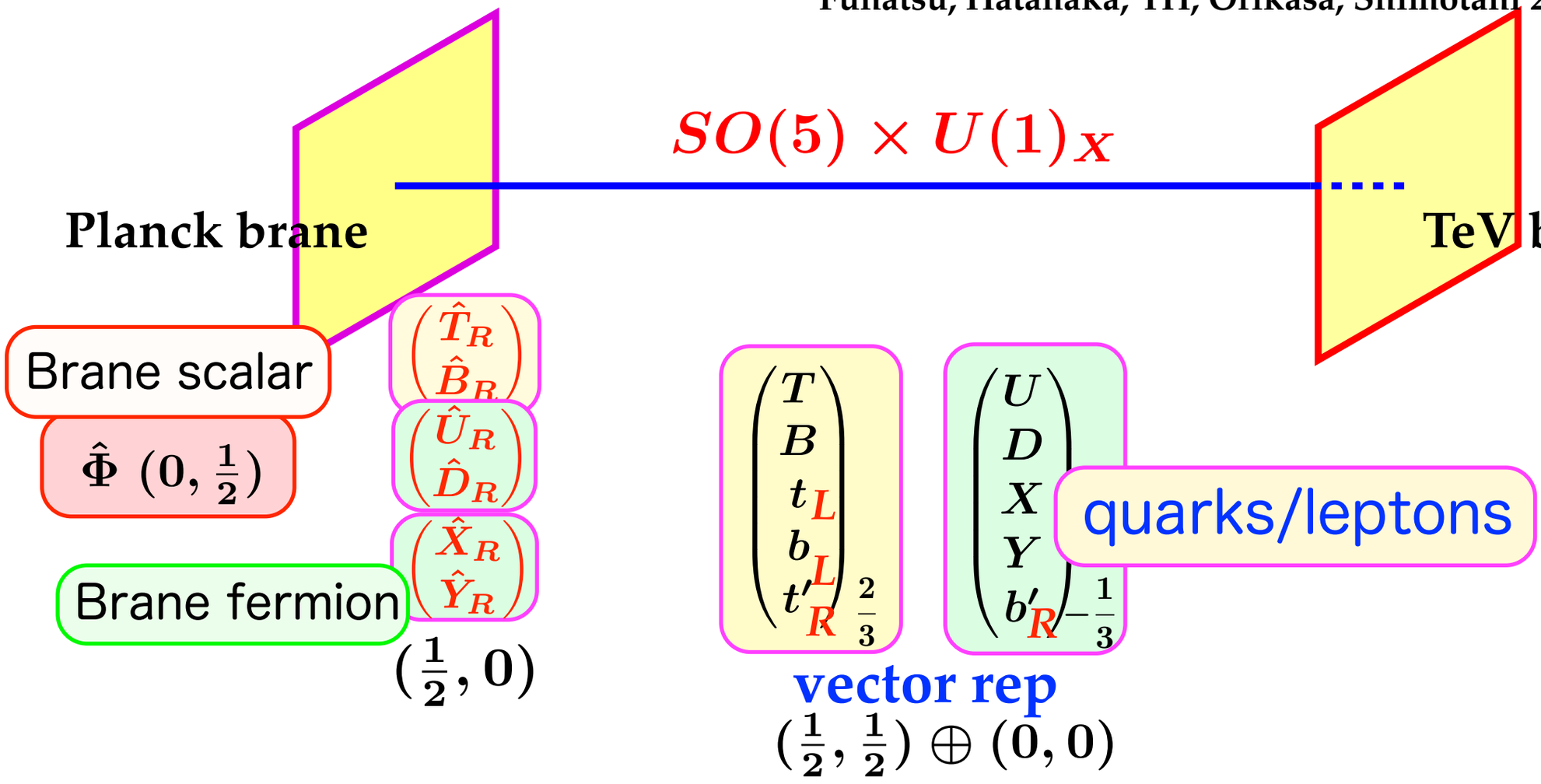
θ_H

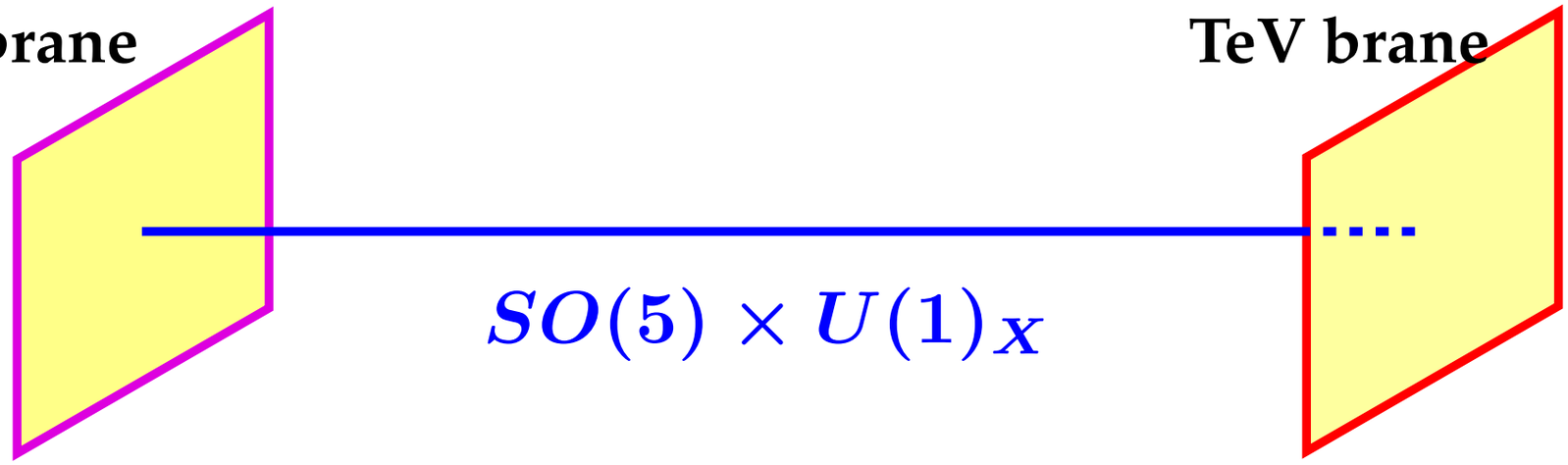
Hosotani mechanism

EW symmetry breaking

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

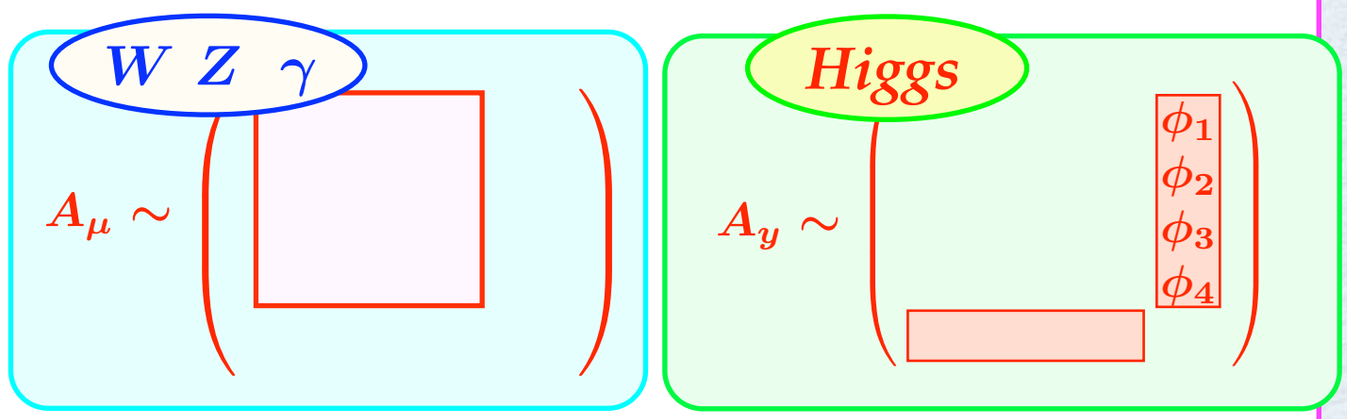
Agashe, Contino, Pomarol, 2005
YH, Oda, Ohnuma, Sakamura 2008
YH, Noda, Uekusa 2009
Funatsu, Hatanaka, YH, Orikasa, Shimotani 2013, 2014





$\xrightarrow{B.C.}$ $SO(4) \times U(1)_X$

$\xrightarrow[\langle \hat{\Phi} \rangle]{}$ $SU(2)_L \times U(1)_Y$



Higgs boson as an AB phase in extra dim

$$e^{i\hat{\theta}_H(x)} \sim P \exp\left\{ ig \int_C dy A_y \right\} \qquad \hat{\theta}_H(x) = \theta_H + \frac{H(x)}{f_H}$$

Hosotani mechanism

$\xrightarrow[\theta_H \neq 0]{}$ $U(1)_{EM}$

Input - Output

parameters

$$k,\ z_L = e^{kL},\ g_A,\ g_B$$

$$c_t,\ \tilde{\mu}/\mu_2$$

$$c_F,\ n_F$$

input

$$m_Z,\ g_w,\ \sin^2\theta_W$$

$$m_t,\ m_b$$

$$m_H$$

$$V_{\rm eff}$$

$$\theta_H \ :\ \frac{dV_{\rm eff}}{d\theta_H} = 0$$

$$m_H^2 = \frac{1}{f_H^2}\frac{d^2V_{\rm eff}}{d\theta_H^2}\bigg|_{\rm min}$$

$$\theta_H(z_L, n_F)$$

gauge couplings

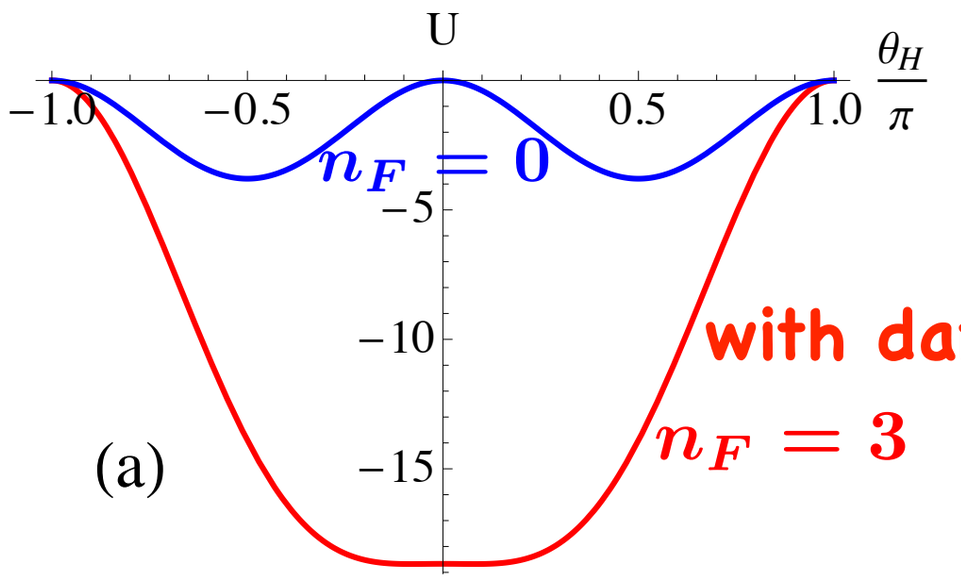
Higgs couplings

KK spectrum

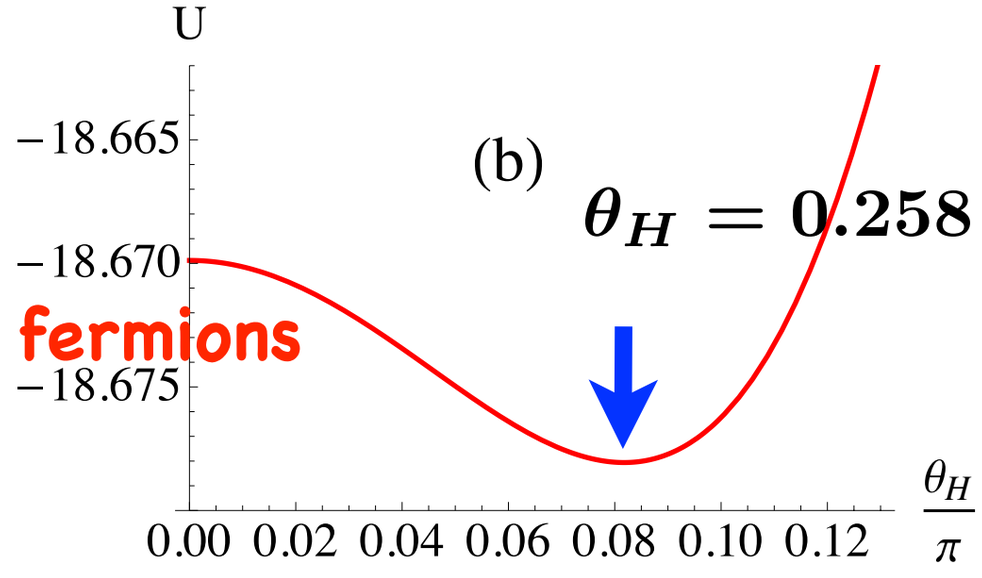
$$V_{\rm eff}(\theta_H) = \left(\frac{m_{\rm KK}}{2\pi}\right)^4 U$$

$$z_L = 10^7 \ , \quad n_F = 3$$

$$c_t = 0.330 \ , \ c_F = 0.353$$



with dark fermions



Dynamical EW symmetry breaking

Finite Higgs boson mass generated.

gauge hierarchy prob : solved

No Higgs boson instability prob.

Universality

2 parameters (z_L, n_F) ⇒ $\theta_H, m_{\rm KK}, m_{Z^{(1)}}, \lambda_3, \lambda_4, \cdots$

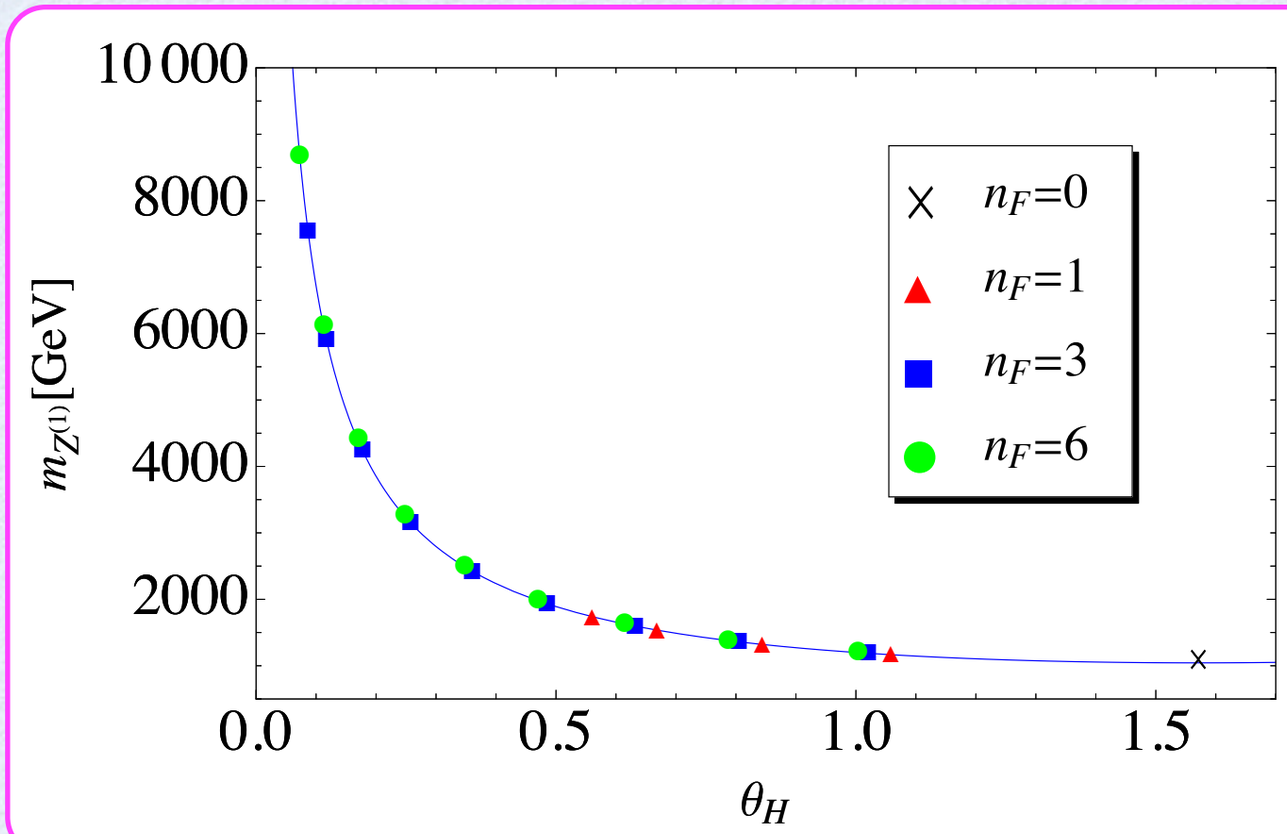
dark fermions

In general, one expects $m_{Z^{(1)}} = m_{Z^{(1)}}(\theta_H; n_F)$ *etc.*

We discovered

$$m_{Z^{(1)}} = m_{Z^{(1)}}(\theta_H)$$

$$\sim \frac{1044\,\mathrm{GeV}}{(\sin\theta_H)^{0.808}}$$



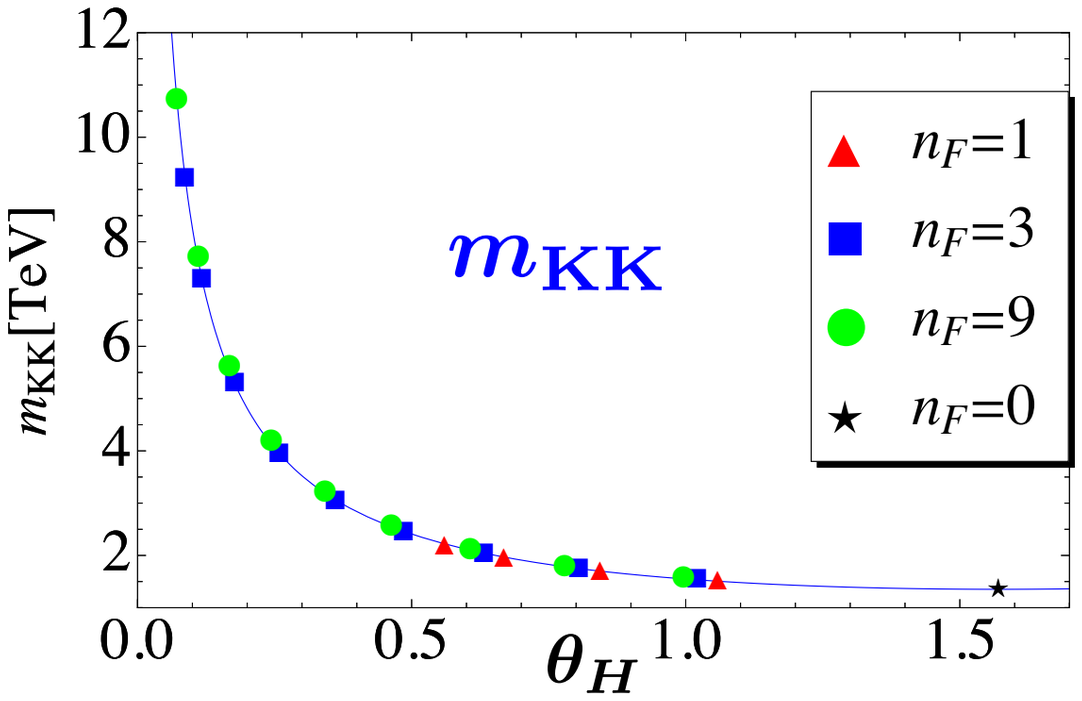
Universality

$$m_{\mathrm{KK}} \sim \frac{1352\,\mathrm{GeV}}{(\sin\theta_H)^{0.786}}$$

$$m_{Z_R^{(1)}} \sim \frac{1038\,\mathrm{GeV}}{(\sin\theta_H)^{0.784}}$$

$$m_{Z^{(1)}} \sim \frac{1044\,\mathrm{GeV}}{(\sin\theta_H)^{0.808}}$$

$$m_{\gamma^{(1)}} \sim \frac{1056\,\mathrm{GeV}}{(\sin\theta_H)^{0.804}}$$



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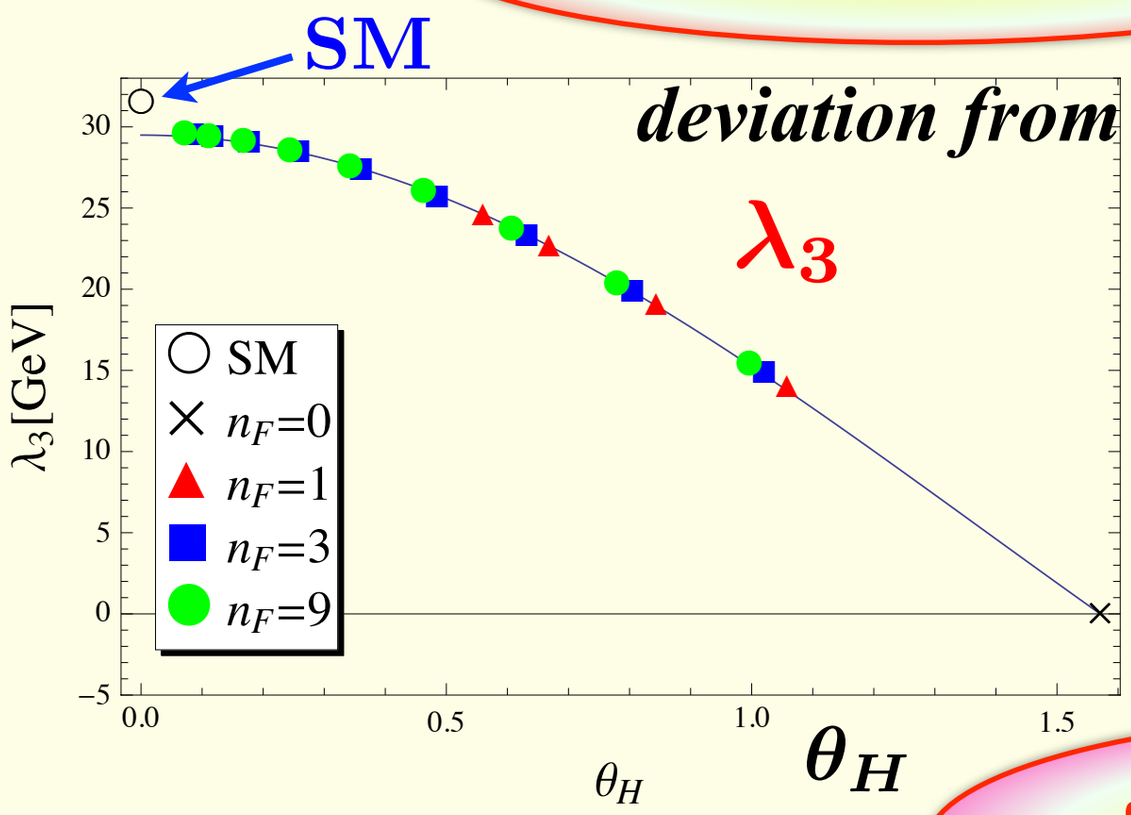
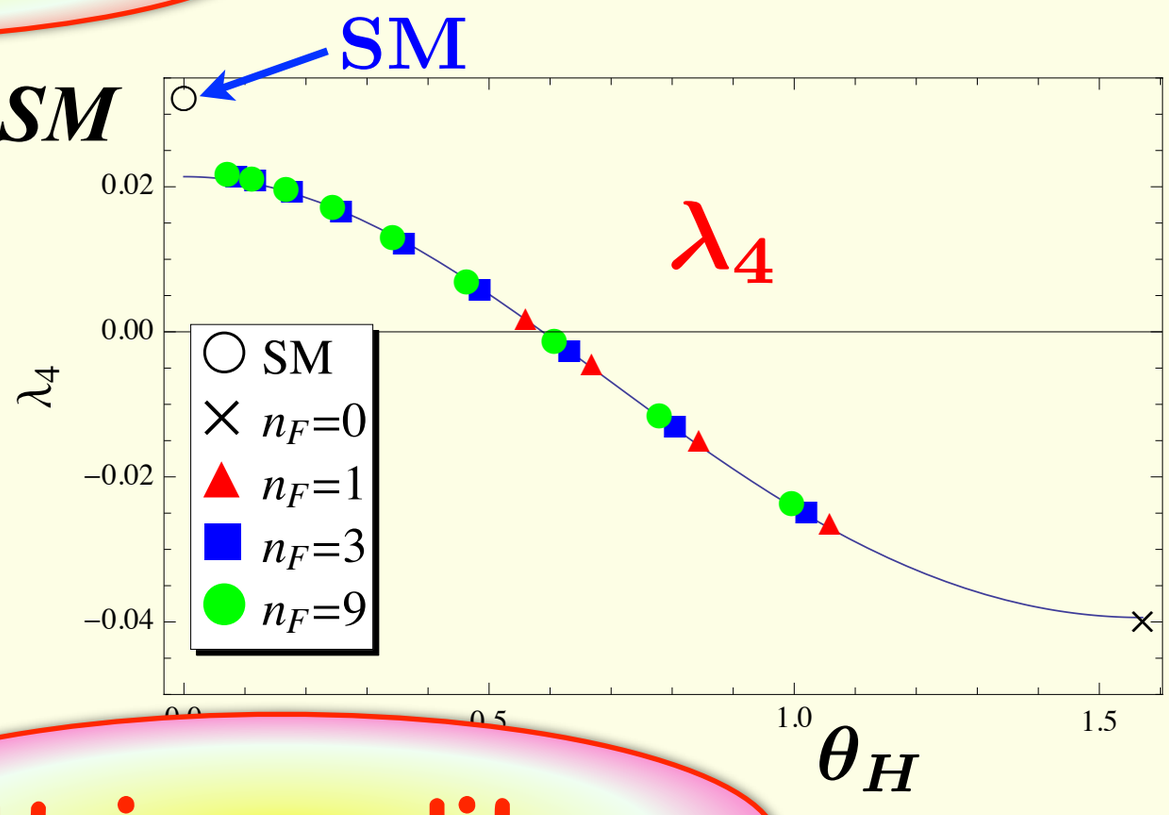
gauge couplings of SM particles : close to SM

Higgs-WW, -ZZ, -qq, -ll : SM x $\cos\theta_H$

Higgs self-couplings





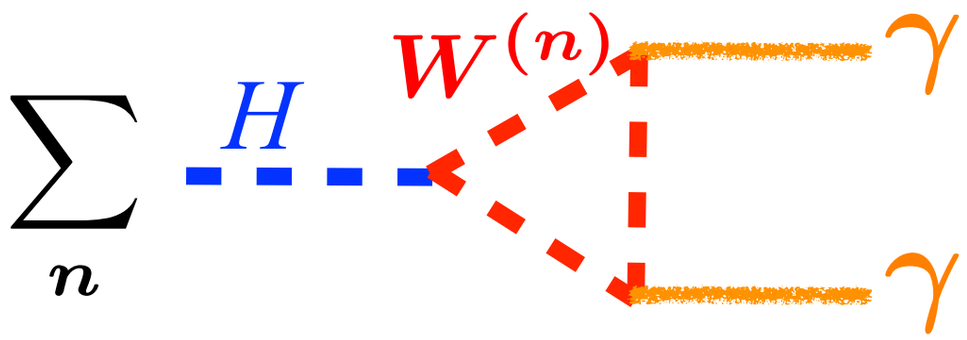
Universality

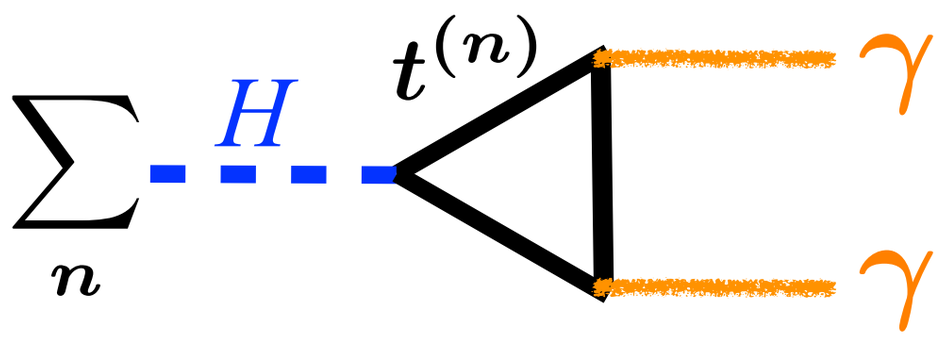
Higgs boson: Production and decay rates

$$\left(\begin{array}{c} WWH \\ ZZH \\ Yukawa \end{array}\right) = SM \times \cos\theta_H$$

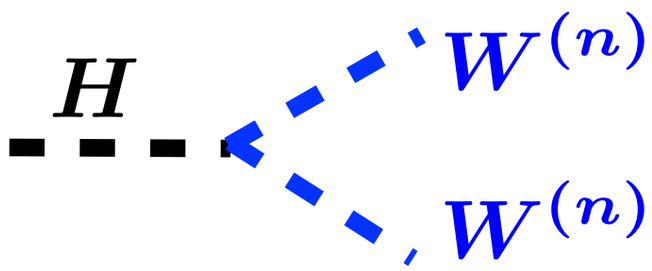
Suppression at tree level

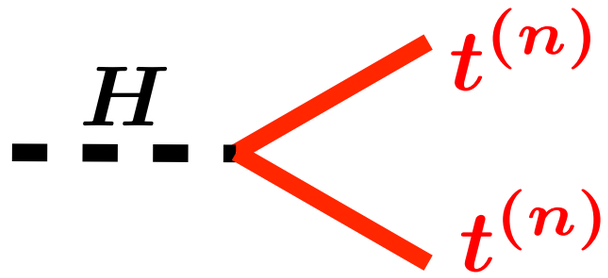
$$gg \to H \ , \quad H \to \gamma\gamma \ , \ gg$$





Enhanced or not ?





$$I_{W^{(n)}} = \frac{g_{HW^{(n)}W^{(n)}}}{g_w m_{W^{(n)}} \cos\theta_H}$$

$$I_{t^{(n)}} = \frac{y_{t^{(n)}}}{y_t^{\rm SM} \cos\theta_H}$$

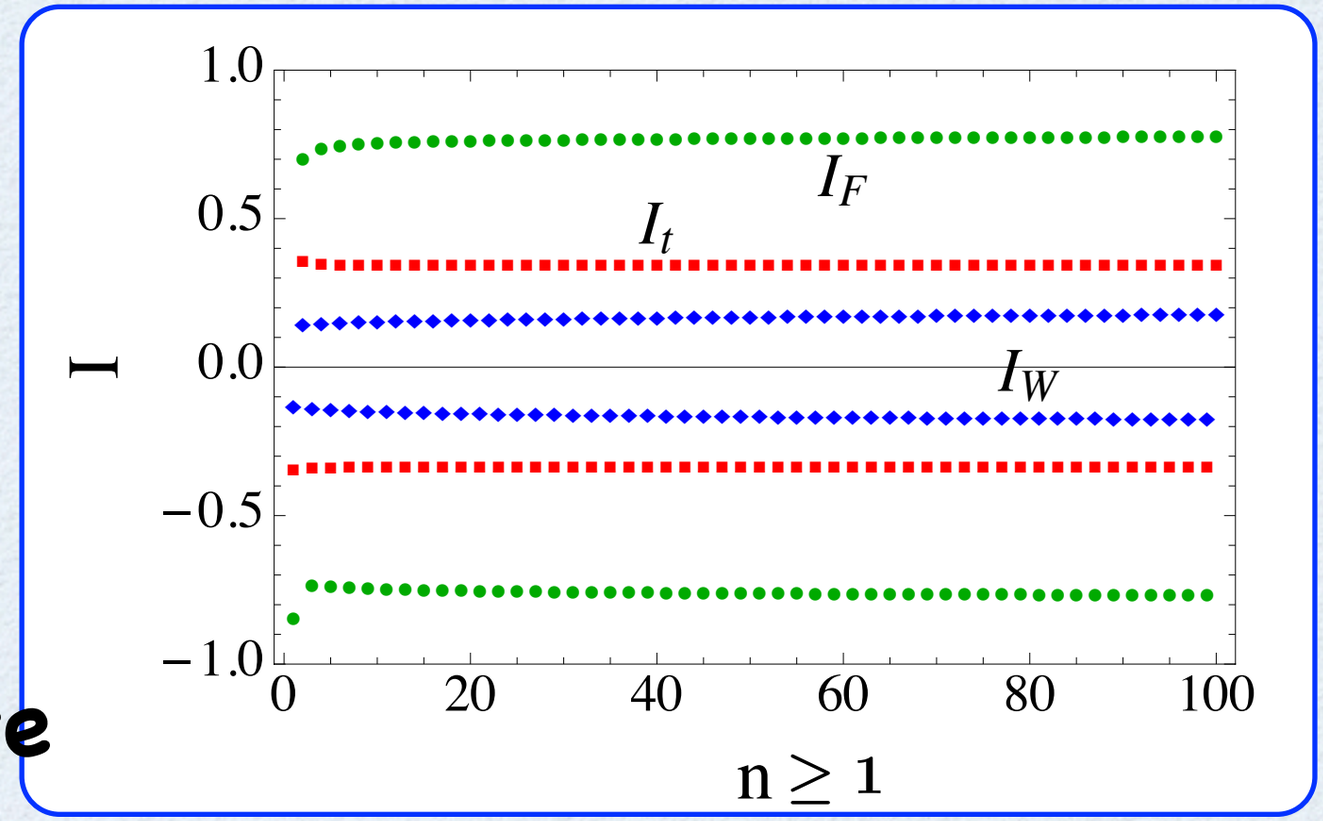
Sign alternates.

$n = 1, 2, 3, \ldots$

destructive interference

Maru, Okada, 2008

Falkowski, 2008



in sharp contrast to UED

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$H \to \gamma\gamma$

$$\Gamma(H \to \gamma\gamma) = \frac{\alpha^2 g_w^2}{1024\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{F}_{\rm total} \right|^2$$

$$\mathcal{F}_{\rm total} = \mathcal{F}_W + \frac{4}{3}\mathcal{F}_t + \frac{1}{2} n_F \mathcal{F}_F$$

θ_H	0.117
$\mathcal{F}_{W^{(0)}}$	8.330
$\mathcal{F}_W / \mathcal{F}_{W^{(0)}}$	0.9996
$\mathcal{F}_{t^{(0)}}$	-1.372
$\mathcal{F}_t / \mathcal{F}_{t^{(0)}}$	0.998
$\mathcal{F}_F / \mathcal{F}_{t^{(0)}}$	-0.0034
$\mathcal{F}_{\rm total}$	6.508
$\mathcal{F}_{\rm total} / (\mathcal{F}_{W^{(0)}} + \mathcal{F}_{t^{(0)}})$	1.001

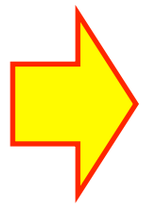
All decay rates $\Gamma(H \to b\bar{b}, c\bar{c}, \cdots, WW, ZZ, \gamma\gamma, gg)$

$$\sim \Gamma^{\rm SM} \times \cos^2\theta_H$$

Branching fraction $B(H \to j) \sim B^{\rm SM}(H \to j)$

$$\sigma^{\rm prod}(H) \cdot B(H \to \gamma\gamma) \sim ({\rm SM}) \times \cos^2\theta_H$$

S parameter
Tree unitarity
Z′ search



$\theta_H < 0.2$

Low energy physics : close to SM

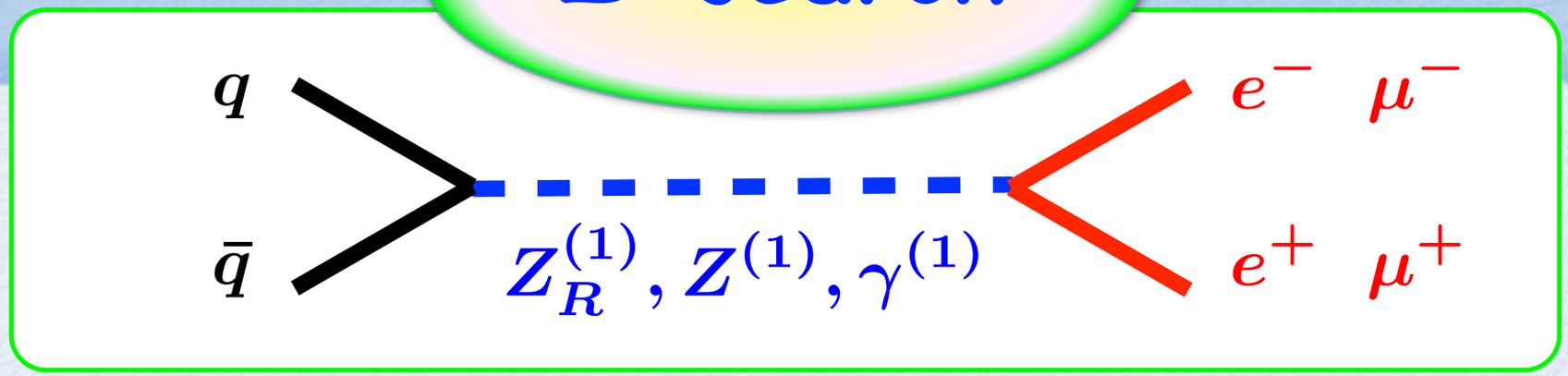
Need to see other signals at higher energies.

Higgs self-couplings λ_3, λ_4

Z′

Dark matter

Z′ search



$\theta_H = 0.114$

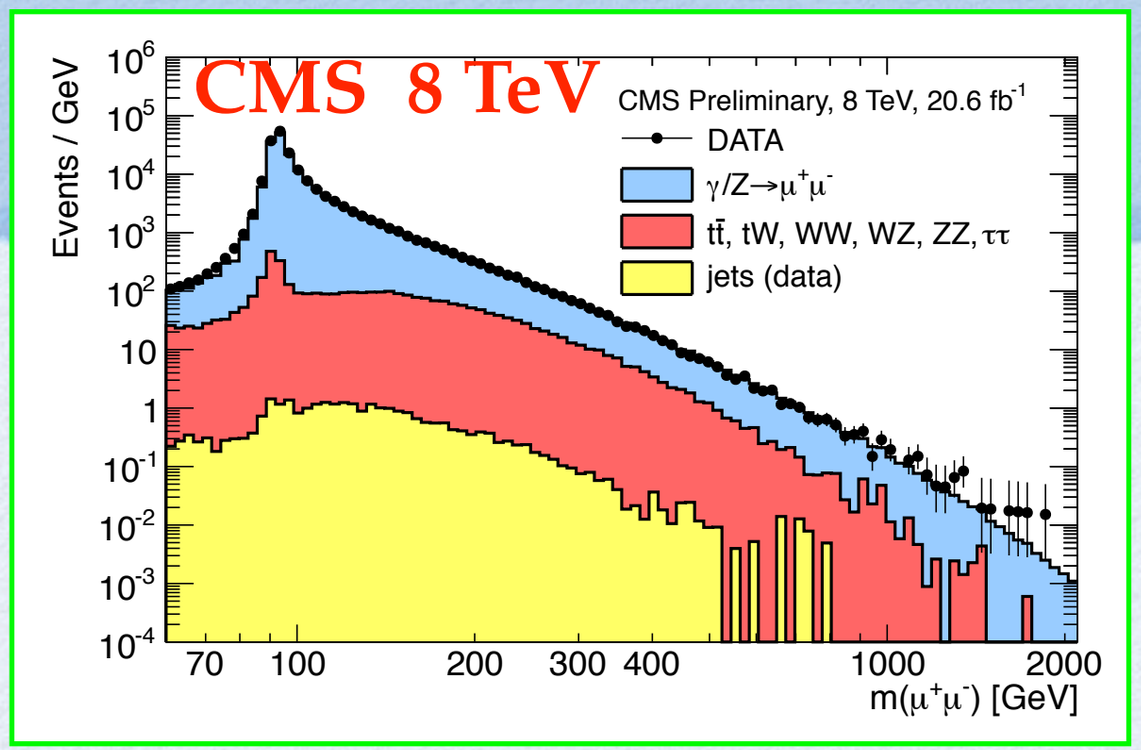
Z'	$m\,(\mathrm{TeV})$	$\Gamma\,(\mathrm{GeV})$
$Z_R^{(1)}$	5.73	482
$Z^{(1)}$	6.07	342
$\gamma^{(1)}$	6.08	886

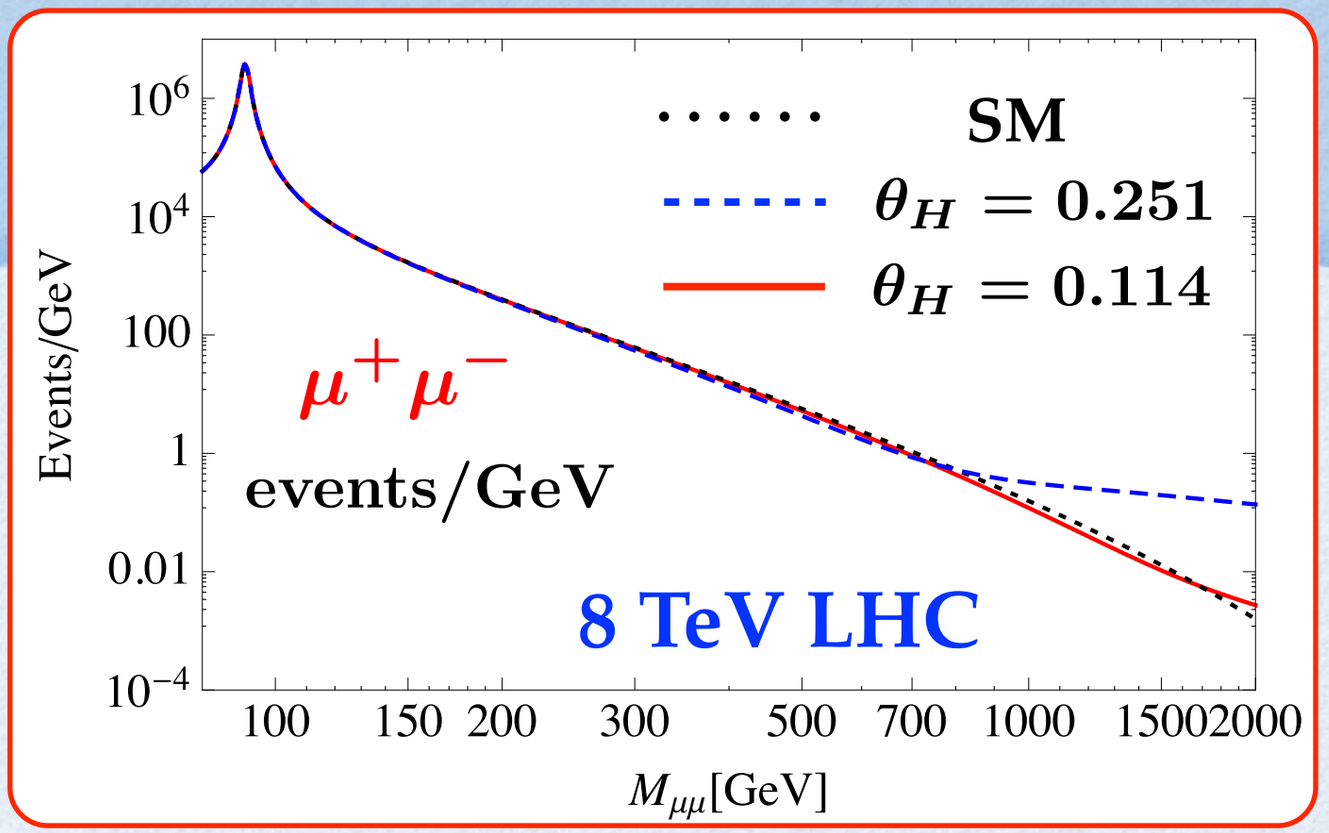
$\theta_H = 0.073$

Z'	$m\,(\mathrm{TeV})$	$\Gamma\,(\mathrm{GeV})$
$Z_R^{(1)}$	8.00	553
$Z^{(1)}$	8.61	494
$\gamma^{(1)}$	8.61	1040

Large widths

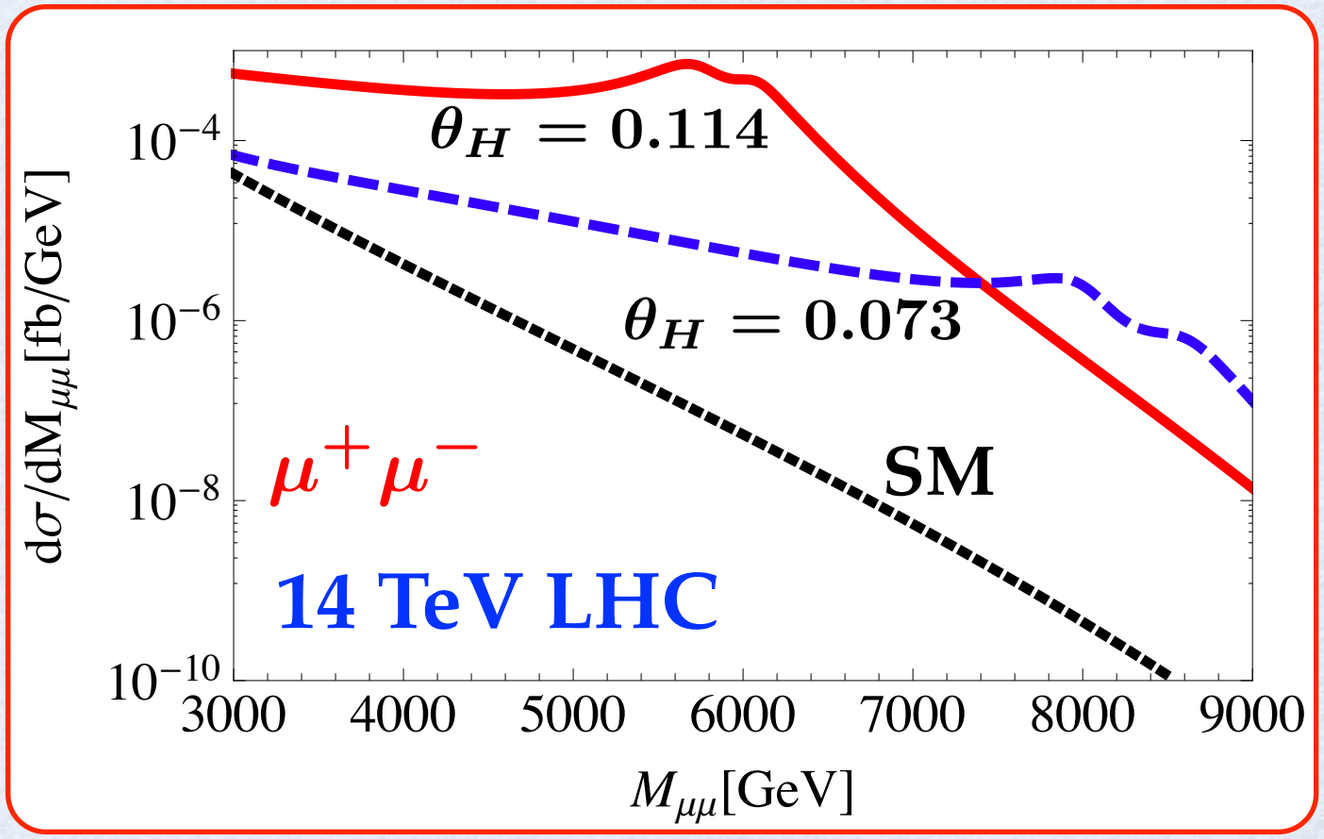
large couplings for right handed quarks/leptons





Z′ search

clear signals



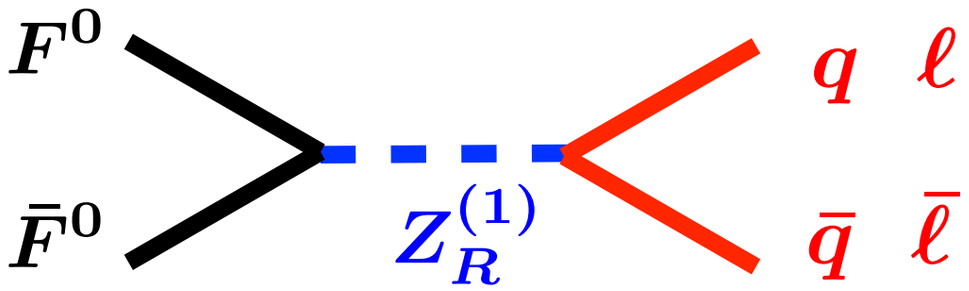
Dark fermion becomes Dark matter

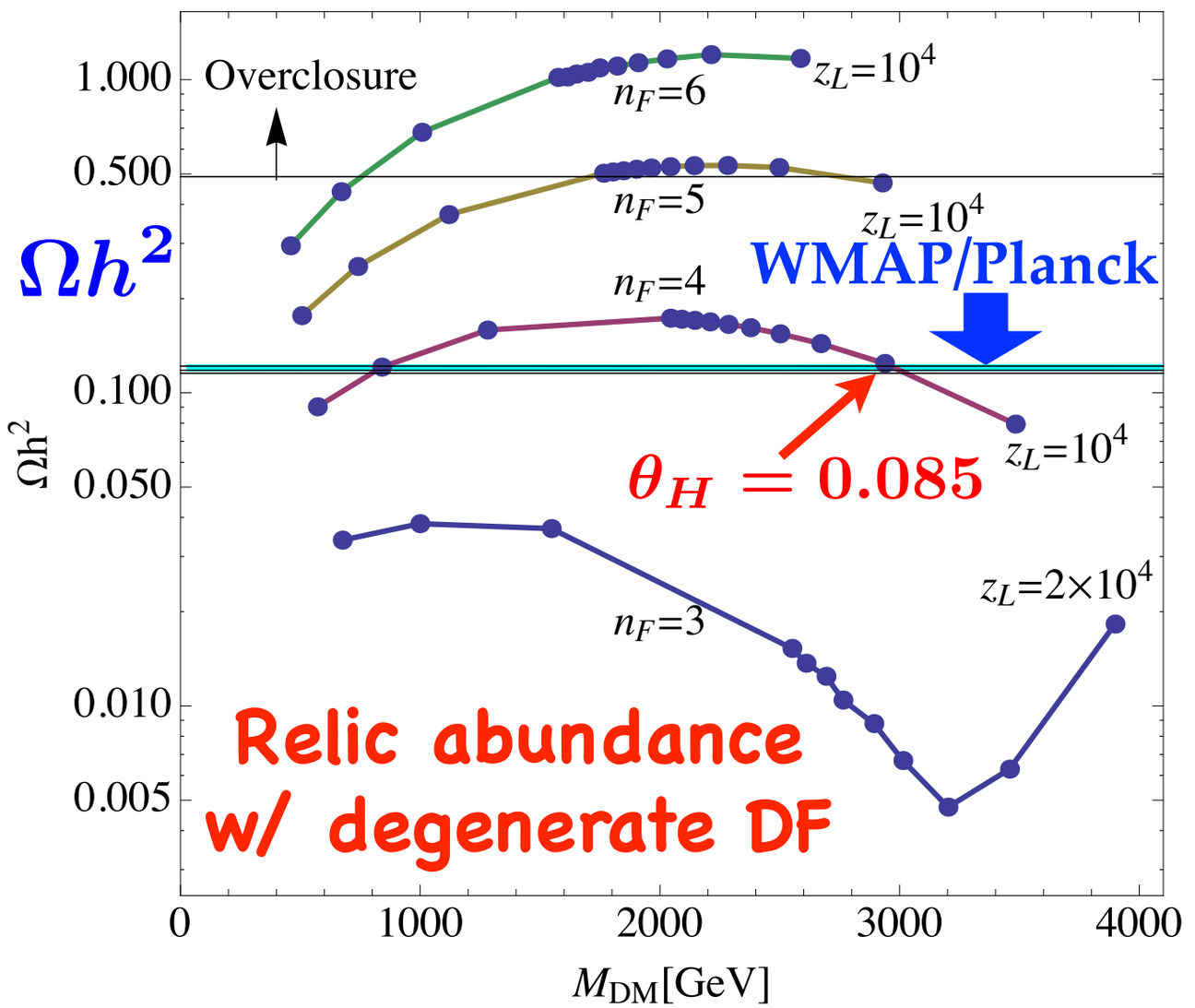
SO(5) spinor (F^+, F^0)

Necessary for having unstable Higgs

F^0 stable ⟶ DM

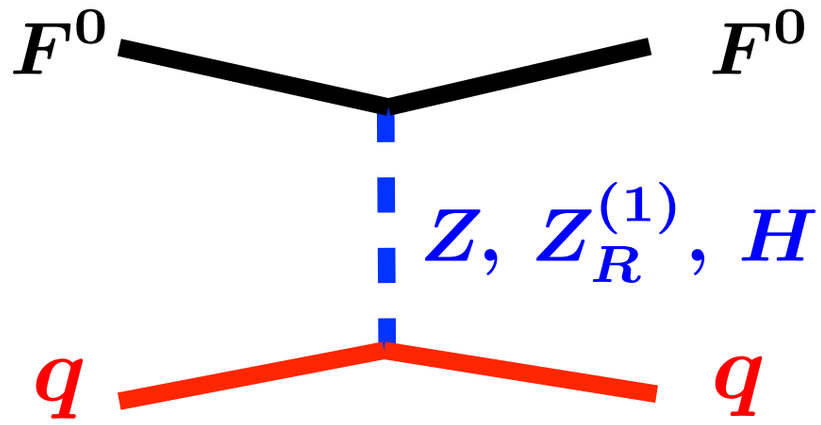
Dominant annihilation





Direct detection of DM

Dominant scattering



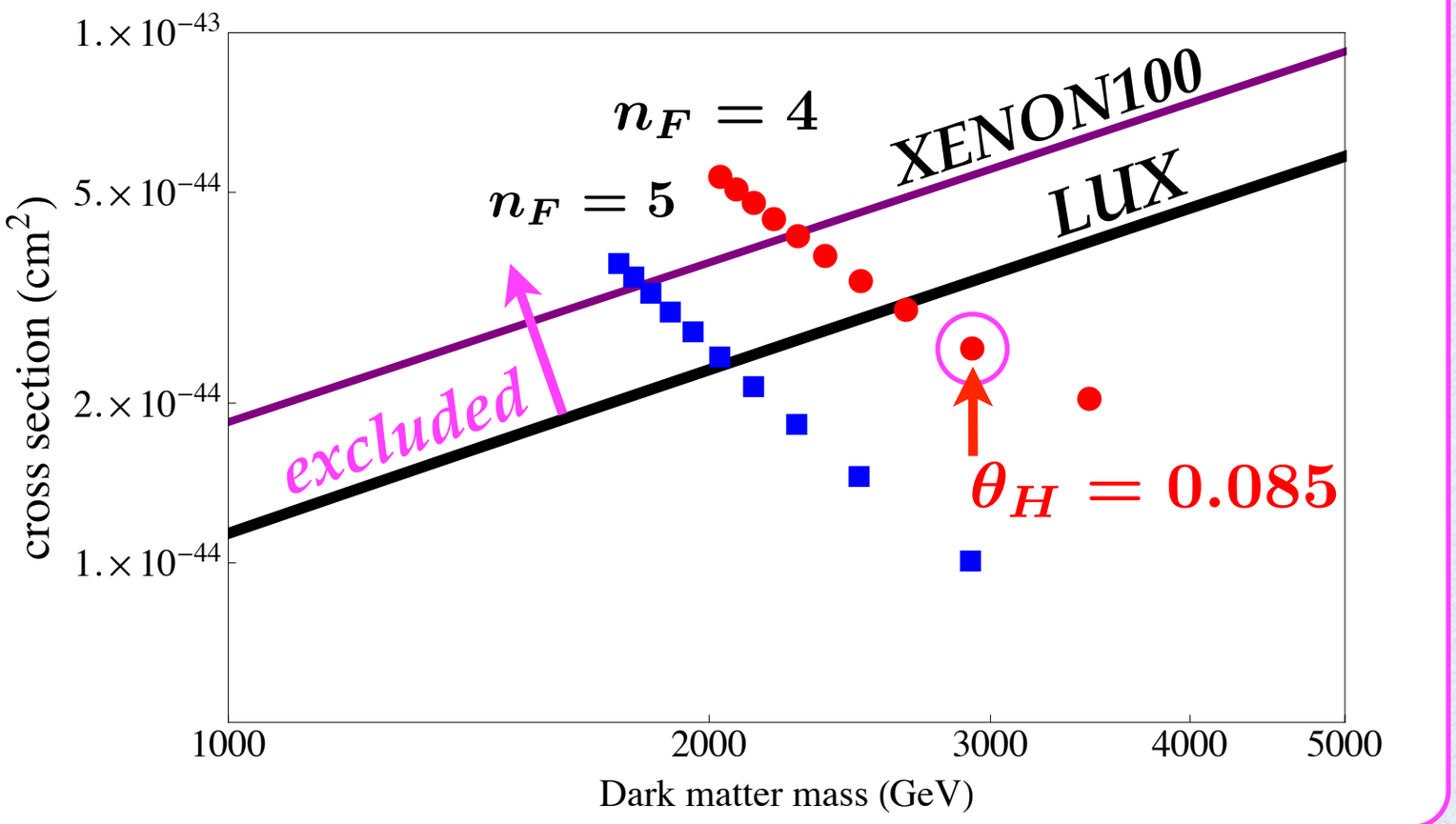
Consistent

$n_F = 4$

$z_L = 2 \times 10^4$

$\theta_H = 0.085$

$m_F = 2.92\,\mathrm{TeV}$



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Summary: SO(5)xU(1) gauge-Higgs unification

Higgs boson = gauge field, fluctuation mode of θ_H

Close to SM at low energies. Consistent with 8 TeV LHC.

Gauge hierarchy problem solved.

No Higgs instability problem.

Universality in $\theta_H, m_{\rm KK}, m_{Z^{(1)}}, m_{\gamma^{(1)}}, \lambda_3, \lambda_4, \cdots$

Z' $[Z_R^{(1)}, Z^{(1)}, \gamma^{(1)}]$ signals in 4 to 9 TeV at 14 TeV LHC.

Dark fermions → Dark Matter $m_F \sim 3\,\mathrm{TeV}$

Promising !