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

Yutaka Hosotani

Physics
OSAKA UNIVERSITY

Funatsu, Hatanaka, YH, Orikasa, Shimotani,

"LHC signals of the $SO(5) \times U(1)$ gauge-Higgs unification" 1404.2748
[PRD89 (2014) 095019]

"Dark matter in the $SO(5) \times U(1)$ gauge-Higgs unification" 1407.3574

SUSY 2014, Manchester, England, 24 July 2014

Gauge-Higgs unification

gauge theroy A_M *in 5 dim.*

Gauge-Higgs unification

gauge theroy A_M *in 5 dim.*

4-dim. components A_μ

∪

4D gauge fields

γ , W , Z

extra-dim. component A_y

∪

4D Higgs fields

H

Gauge-Higgs unification

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Aharonov-Bohm phase

θ_H

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Aharonov-Bohm phase

θ_H

Hosotani mechanism

EW symmetry breaking

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

Agashe, Contino, Pomarol, 2005
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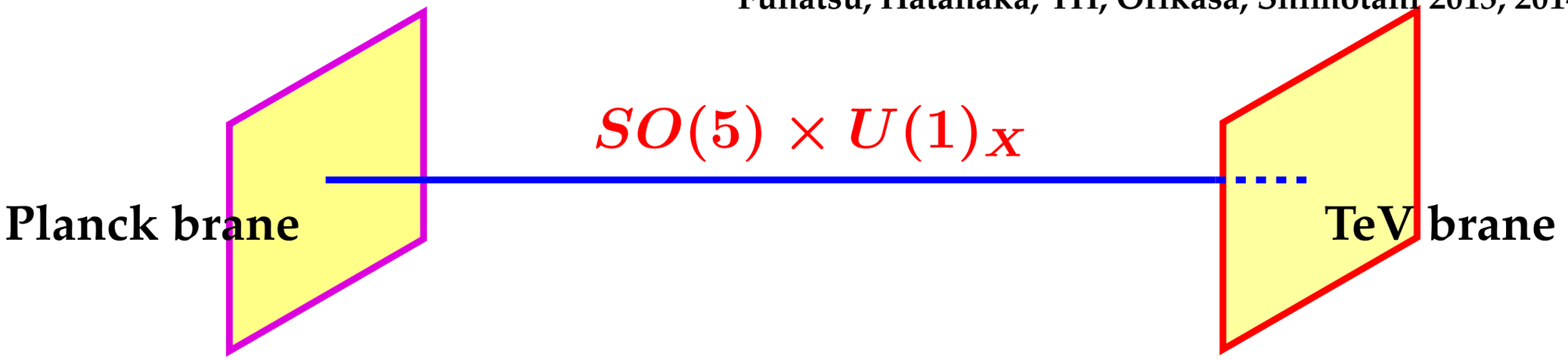

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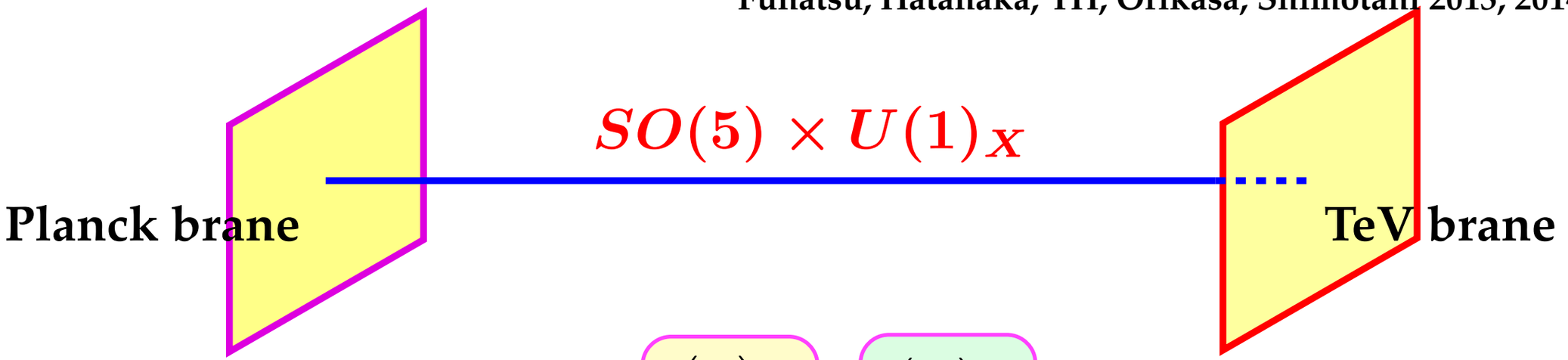

vector rep

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

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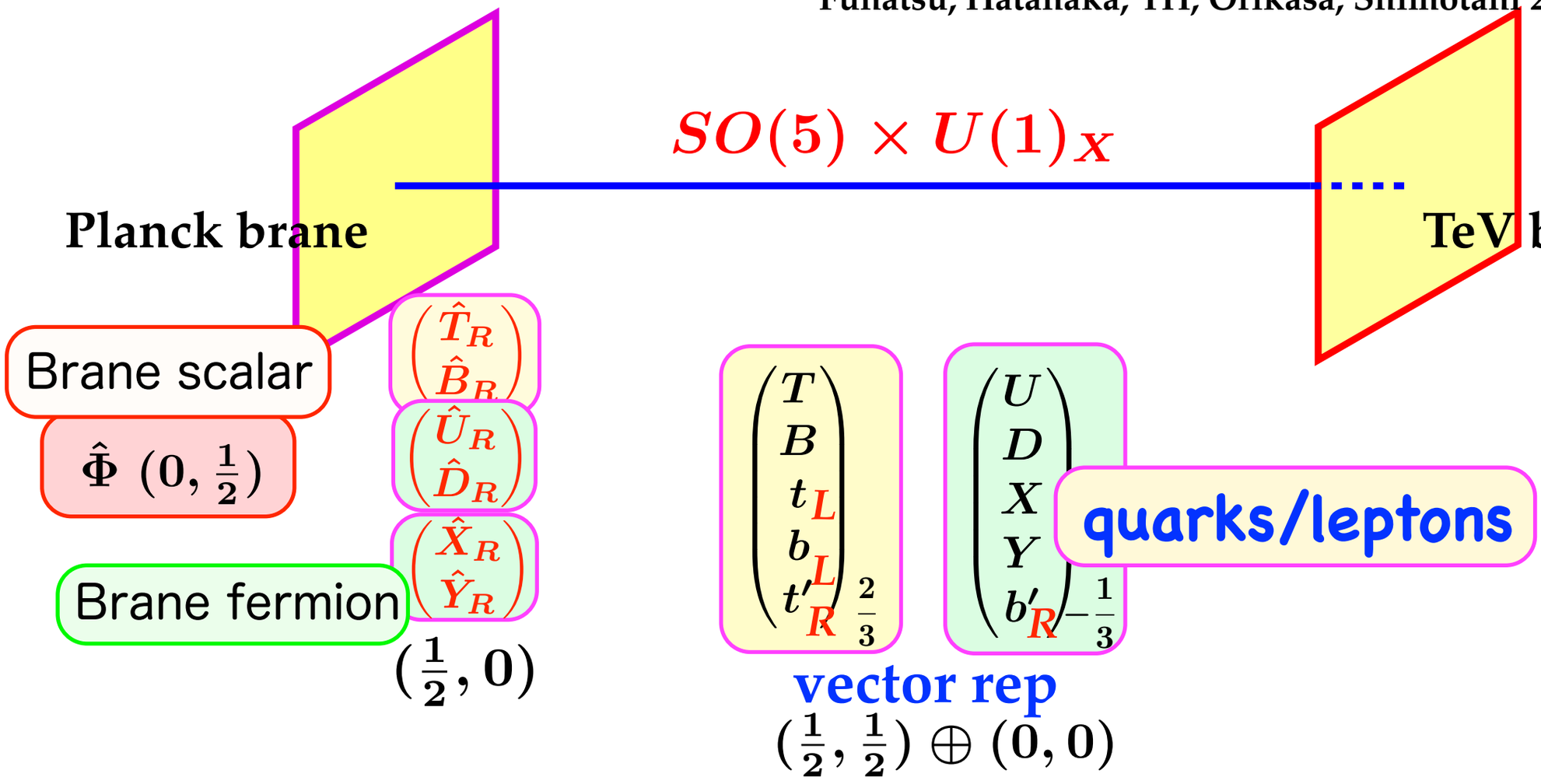

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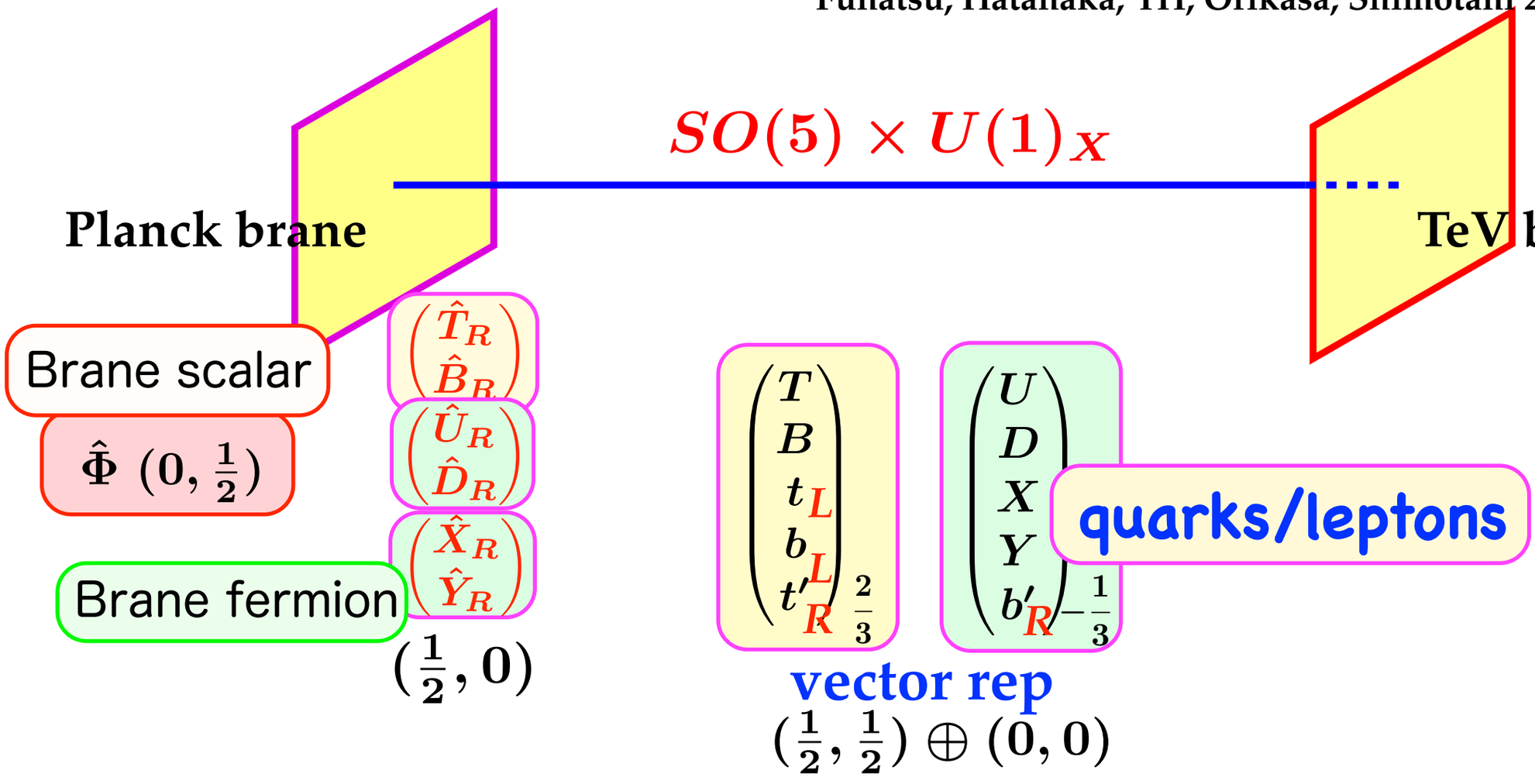
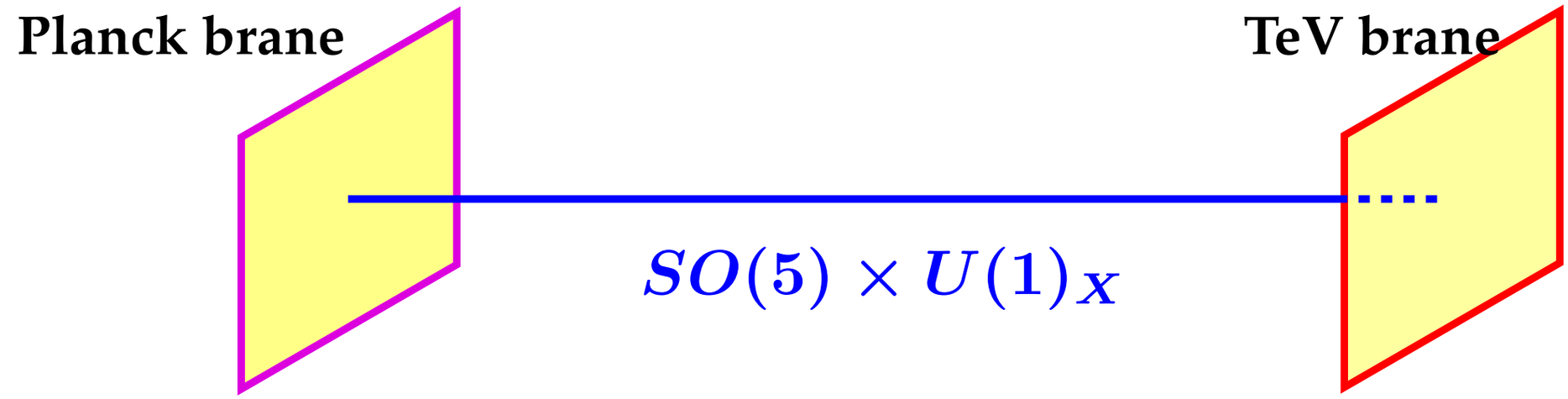
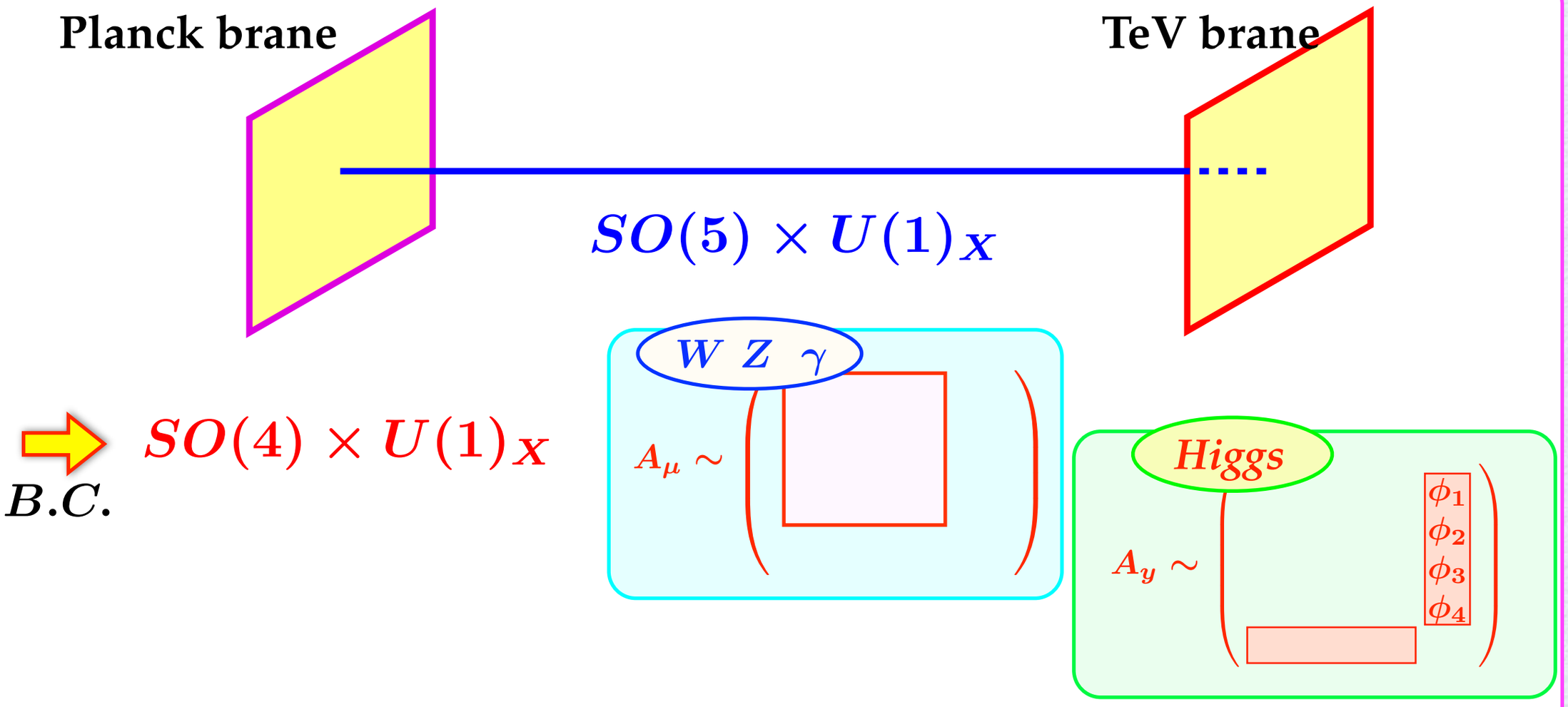
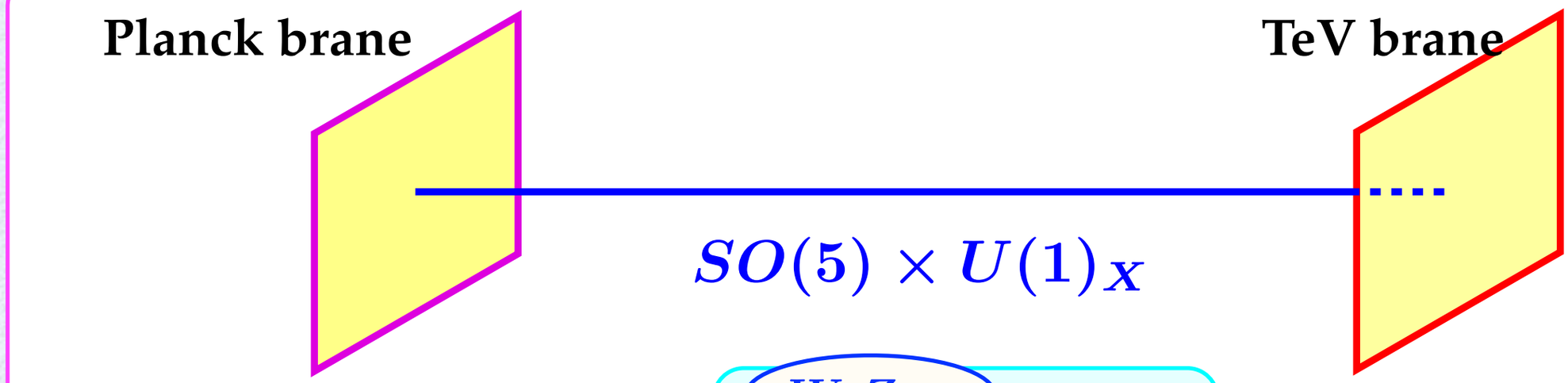



Planck brane
TeV brane
$SO(5) \times U(1)_X$


Planck brane
TeV brane
$SO(5) \times U(1)_X$
$SO(4) \times U(1)_X$
B.C.
W Z γ
$A_\mu \sim$
Higgs
$A_y \sim$
ϕ_1
ϕ_2
ϕ_3
ϕ_4

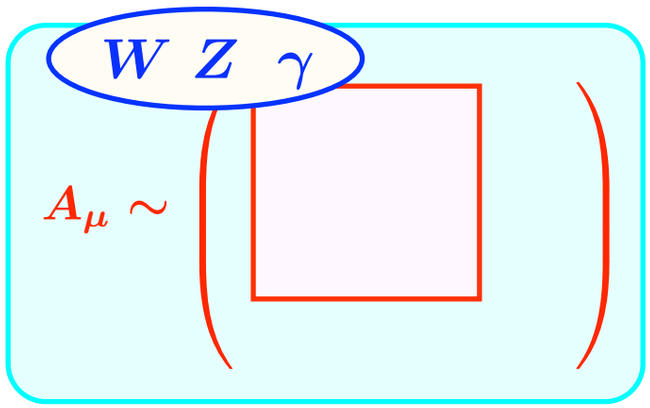


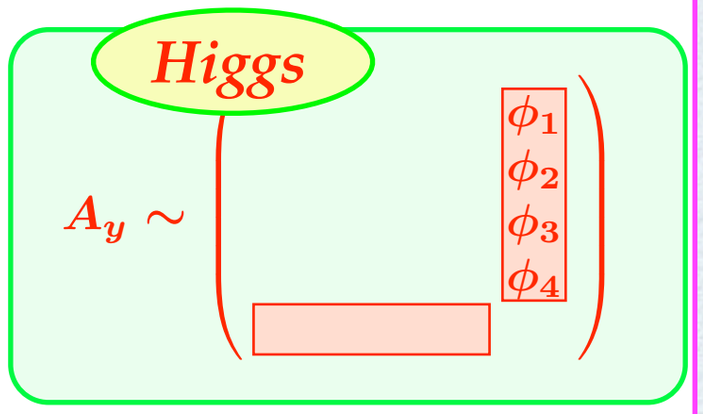
$\Rightarrow$ $SO(4) \times U(1)_X$

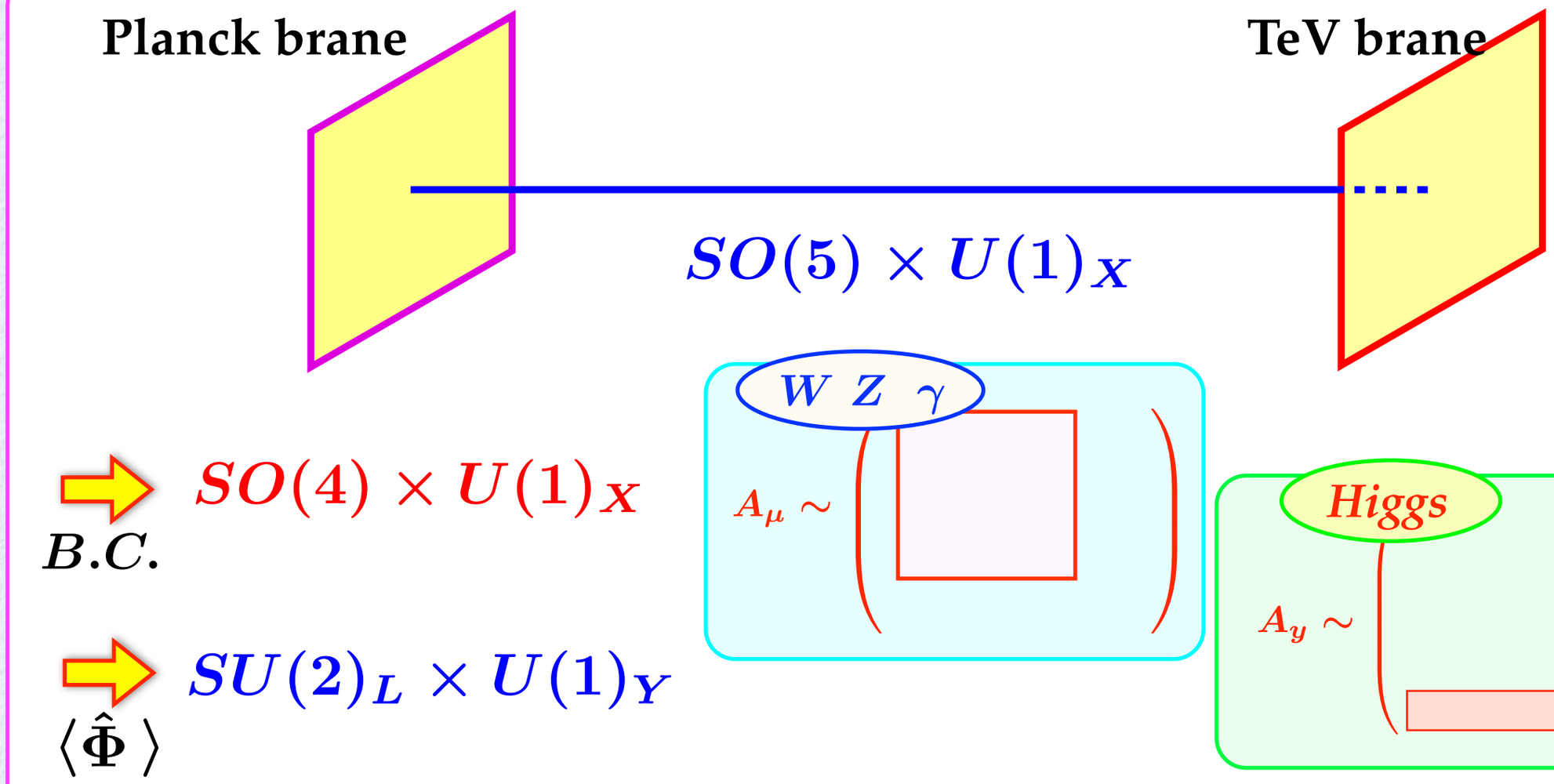
B.C.

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

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

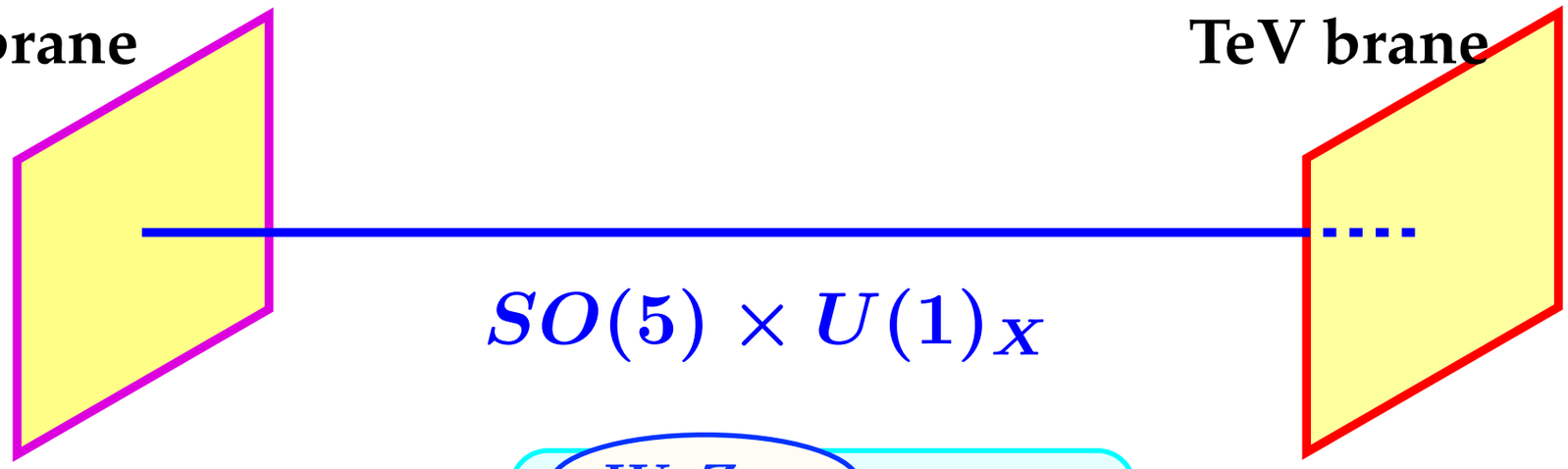




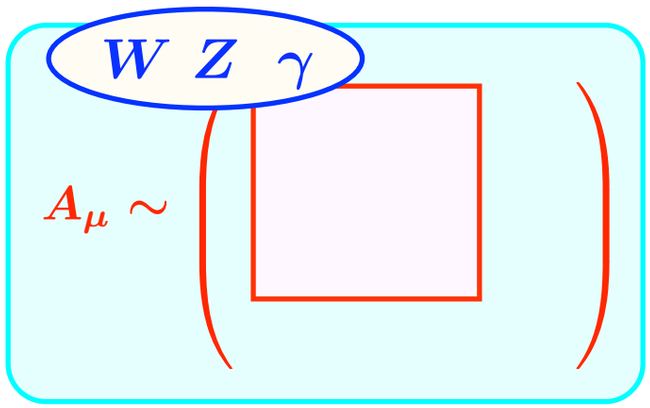


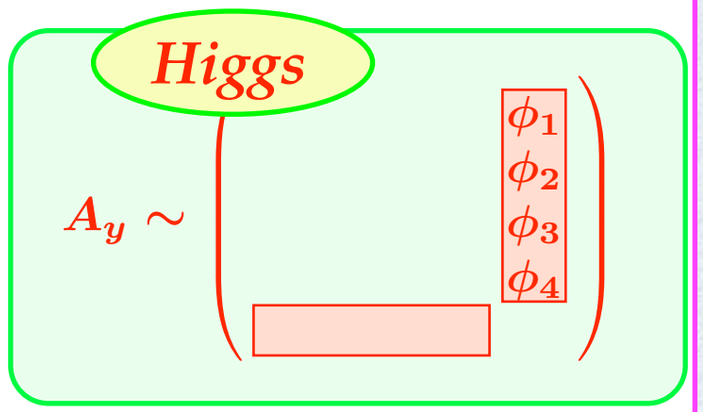
Higgs boson as an AB phase in extra dim

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



$\Rightarrow$ $SO(4) \times U(1)_X$ *B.C.*





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

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

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

$\theta_H \neq 0$

Predictions

input

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

$$m_t,\ m_b$$

$$m_H$$

model parameters

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

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

$$c_F,\ n_F$$

Predictions

input

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

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$$\theta_H \ :\ \frac{dV_{\rm eff}}{d\theta_H} = 0 \qquad m_H^2 = \frac{1}{f_H^2}\frac{d^2V_{\rm eff}}{d\theta_H^2}\bigg|_{\rm min}$$

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$$\theta_H(z_L, n_F)$$

gauge couplings

Higgs couplings

KK spectrum

Predictions

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$$m_t,\ m_b$$

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model parameters

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$\theta_H(z_L, n_F)$

gauge couplings
Higgs couplings
KK spectrum

Z′ bosons
Dark matter

$\theta_H\ ,\ n_F$

Physics
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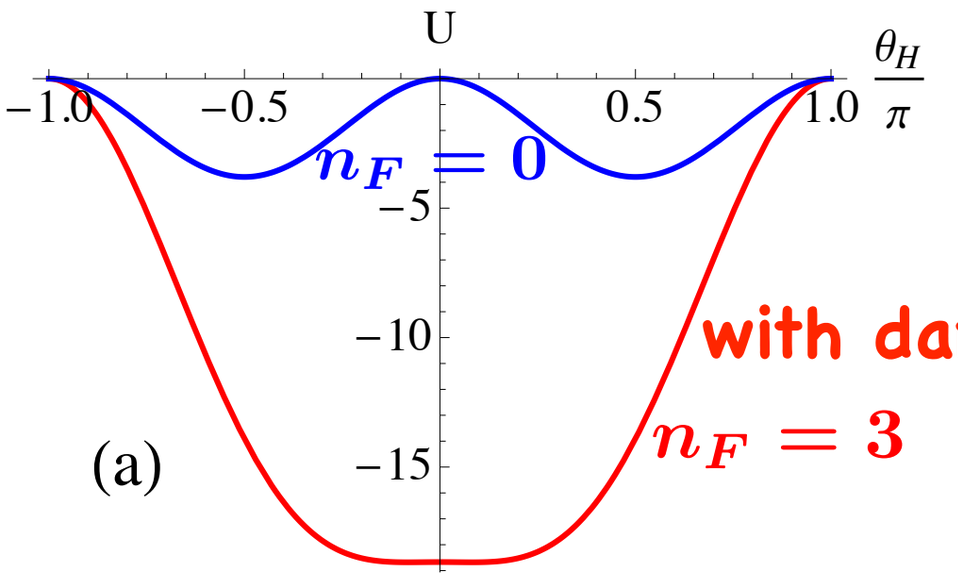
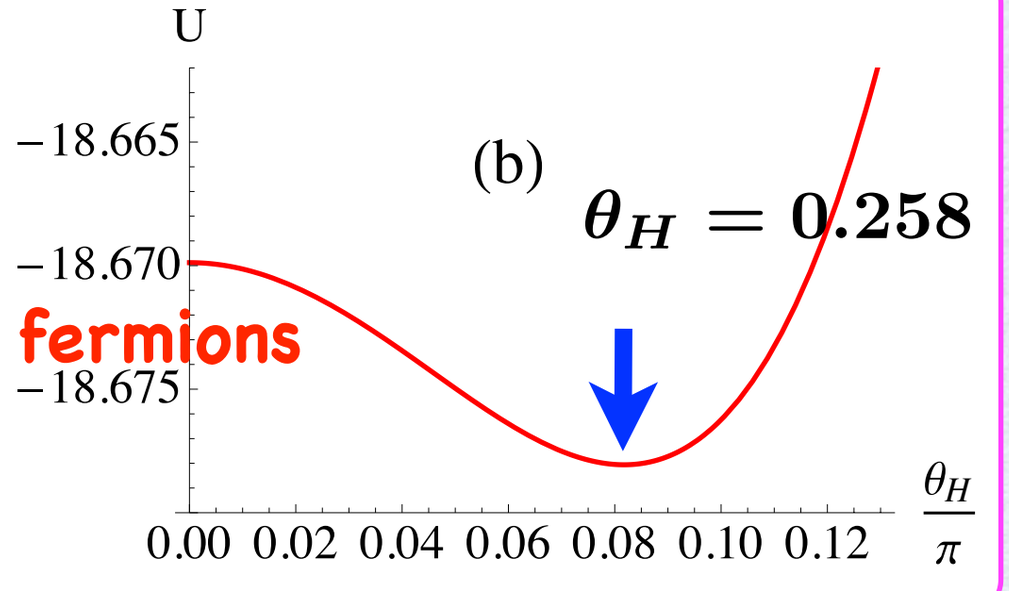
$$V_{\rm eff}(\theta_H) = \left(\frac{m_{\rm KK}}{2\pi}\right)^4 U \qquad z_L = 10^7\,, \quad n_F = 3$$





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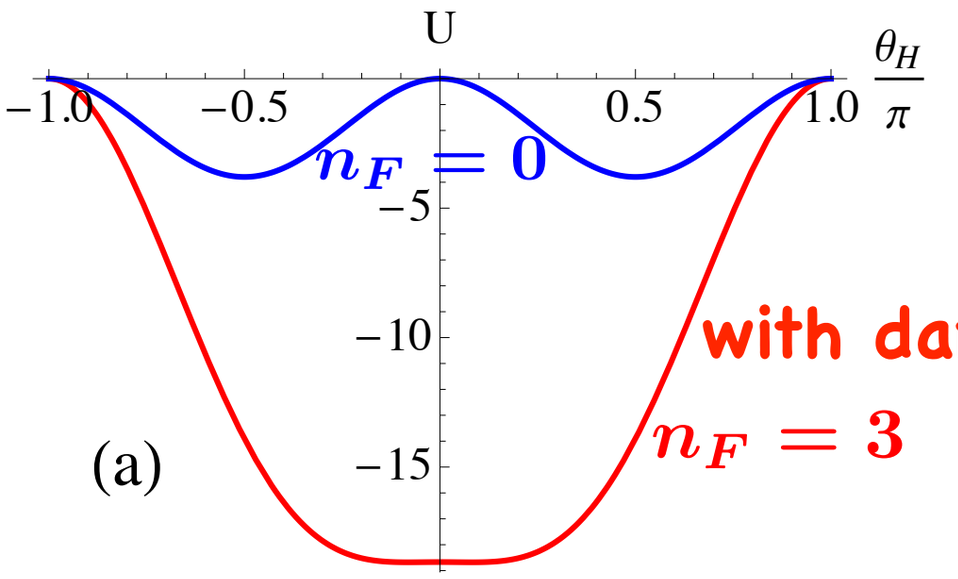

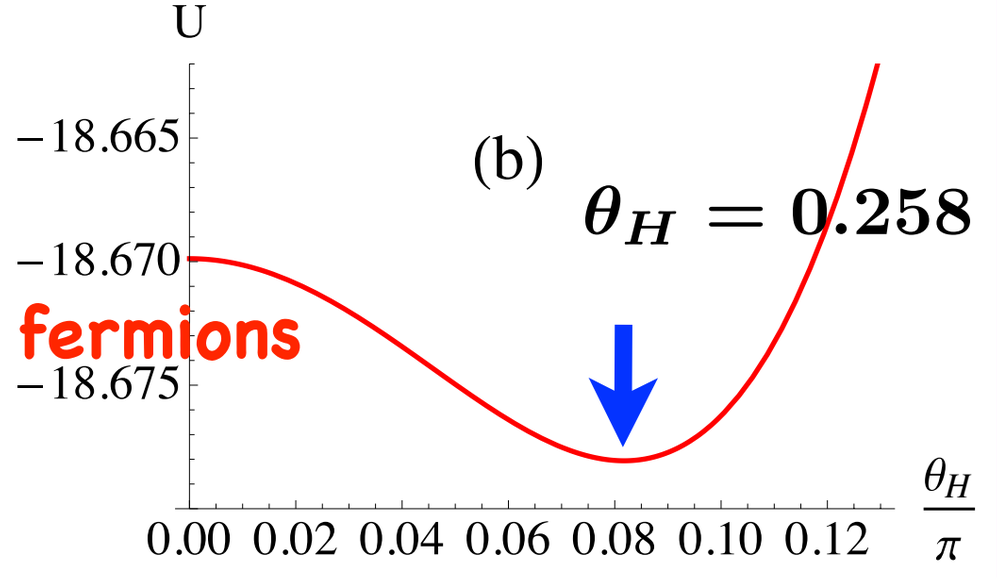

Dynamical EW symmetry breaking

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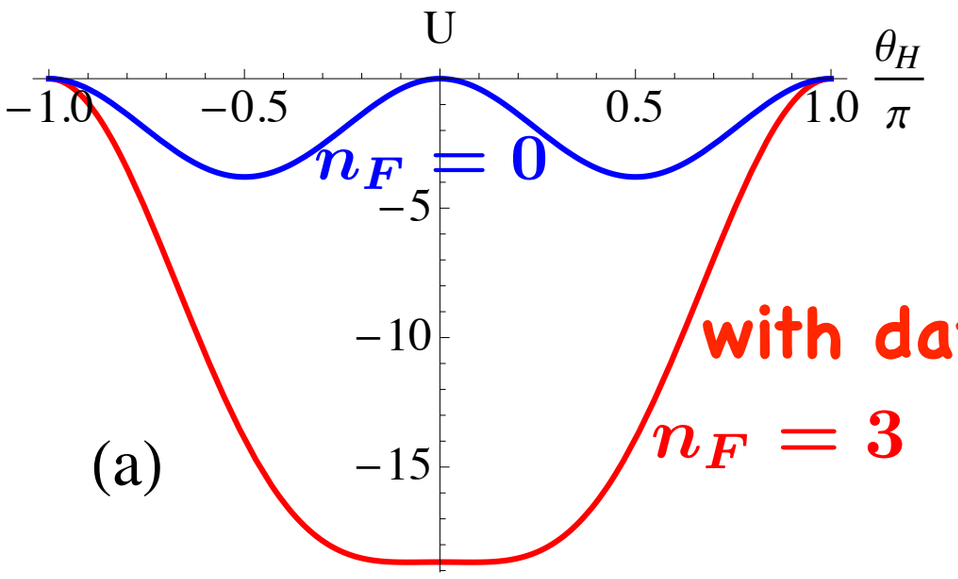

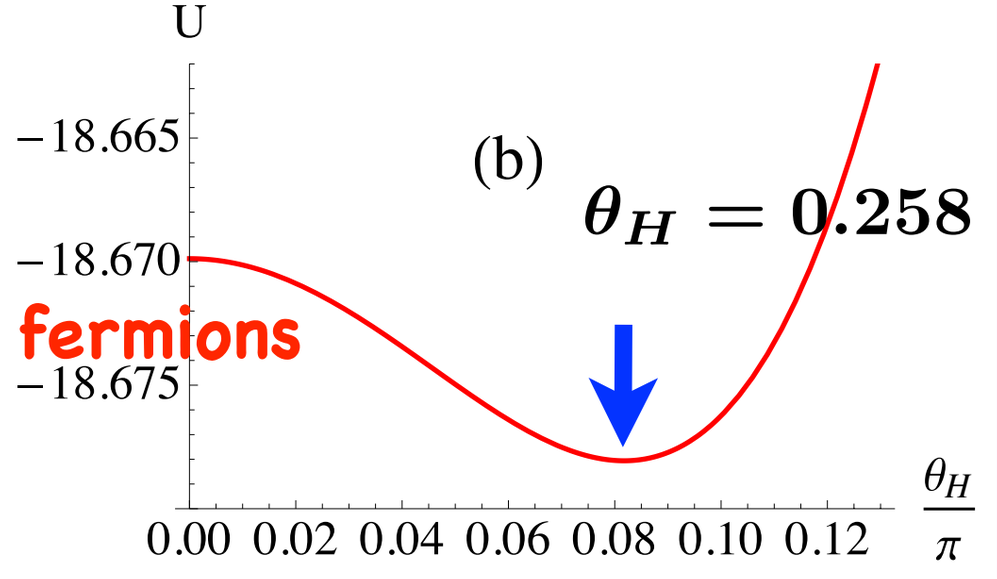

Dynamical EW symmetry breaking

Finite Higgs boson mass generated.

Gauge hierarchy prob : solved

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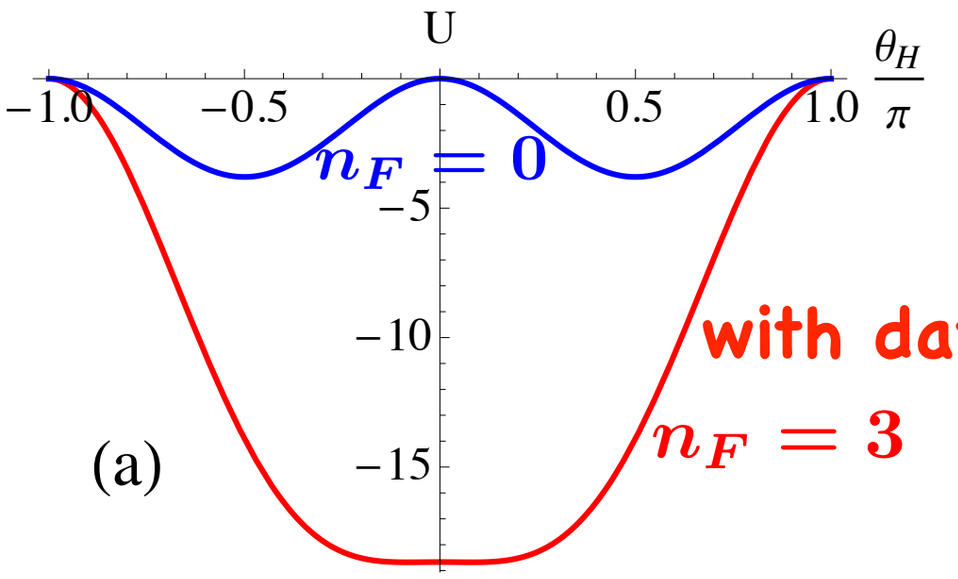

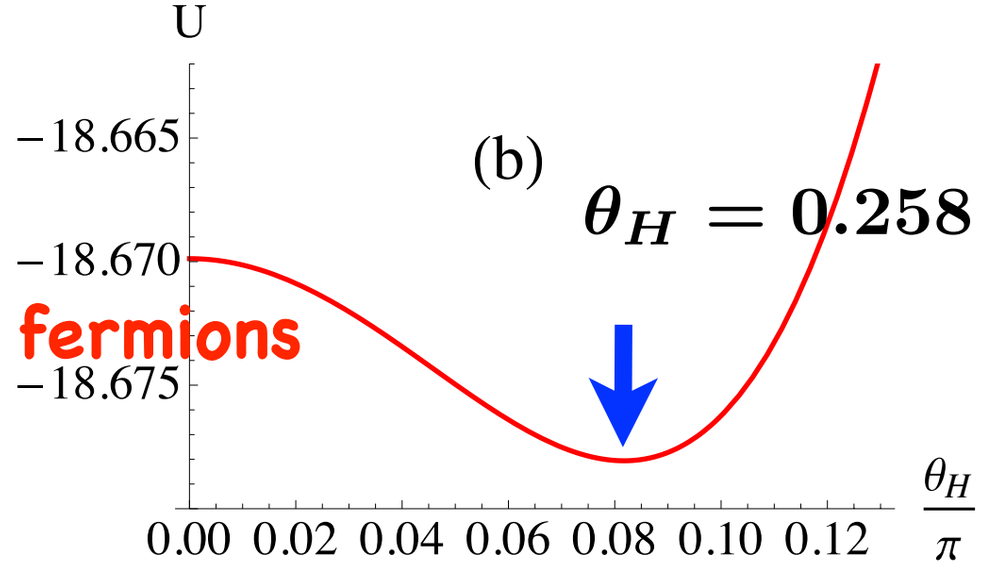

with dark fermions

Dynamical EW symmetry breaking

Finite Higgs boson mass generated.

Gauge hierarchy prob : solved

No Higgs boson instability prob.

Universality

We discovered

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

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

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

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

independent of "dark fermions" n_F

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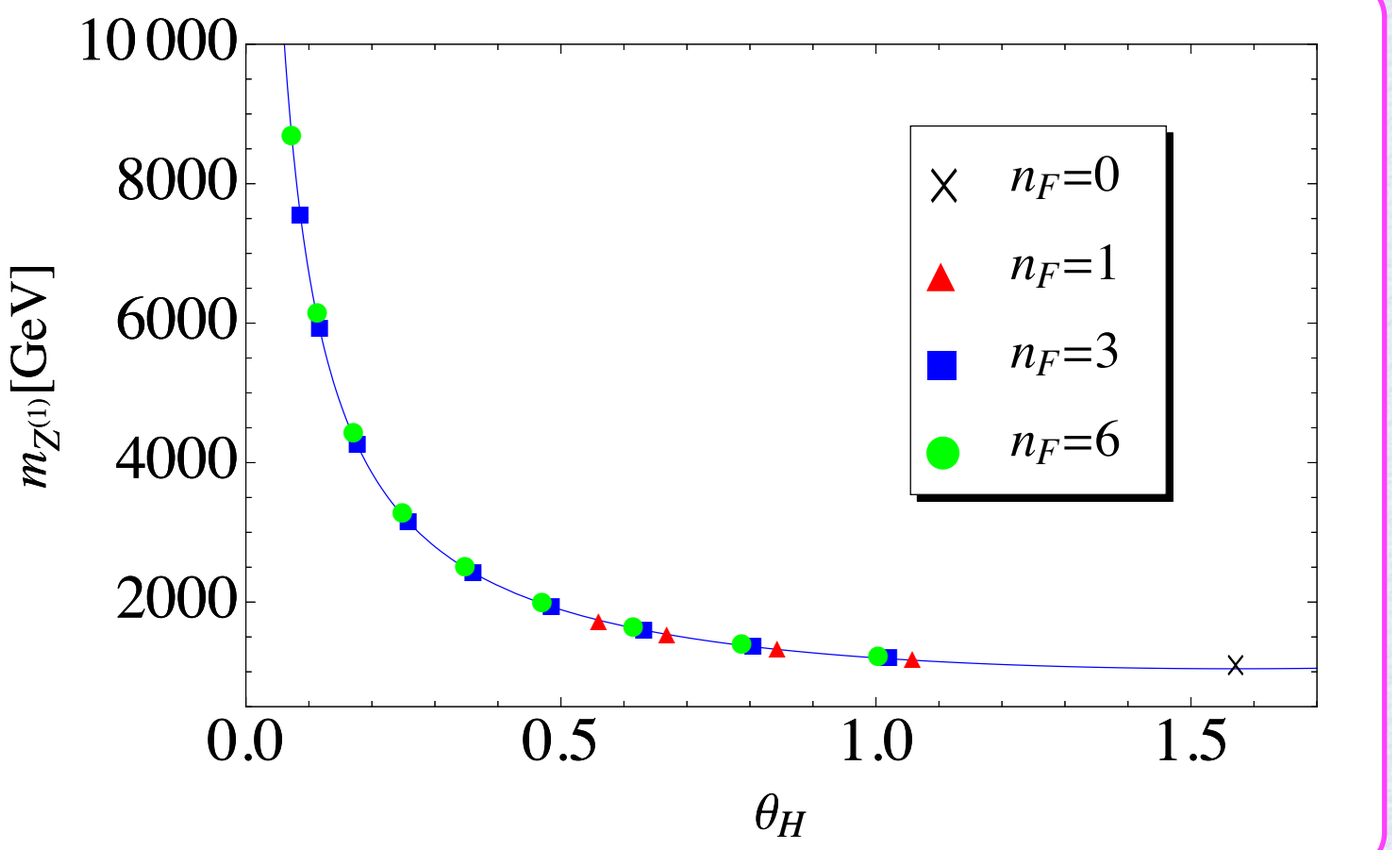

gauge couplings of SM particles : close to SM

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

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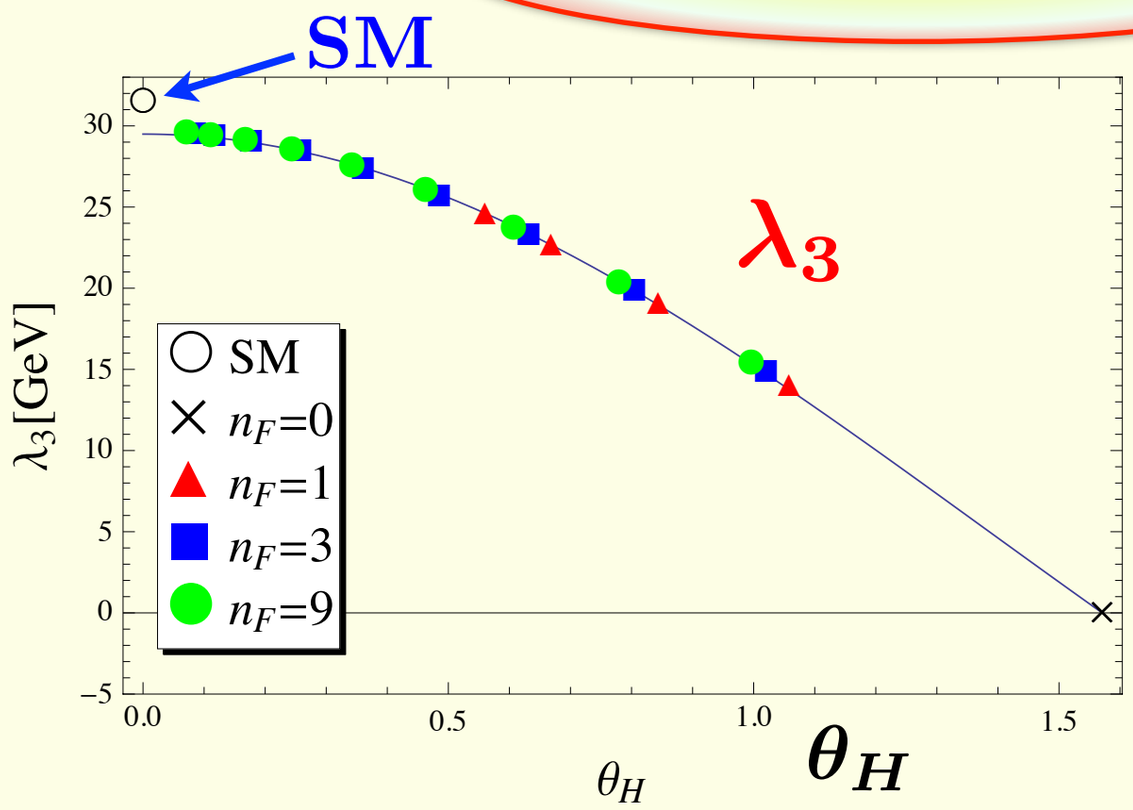
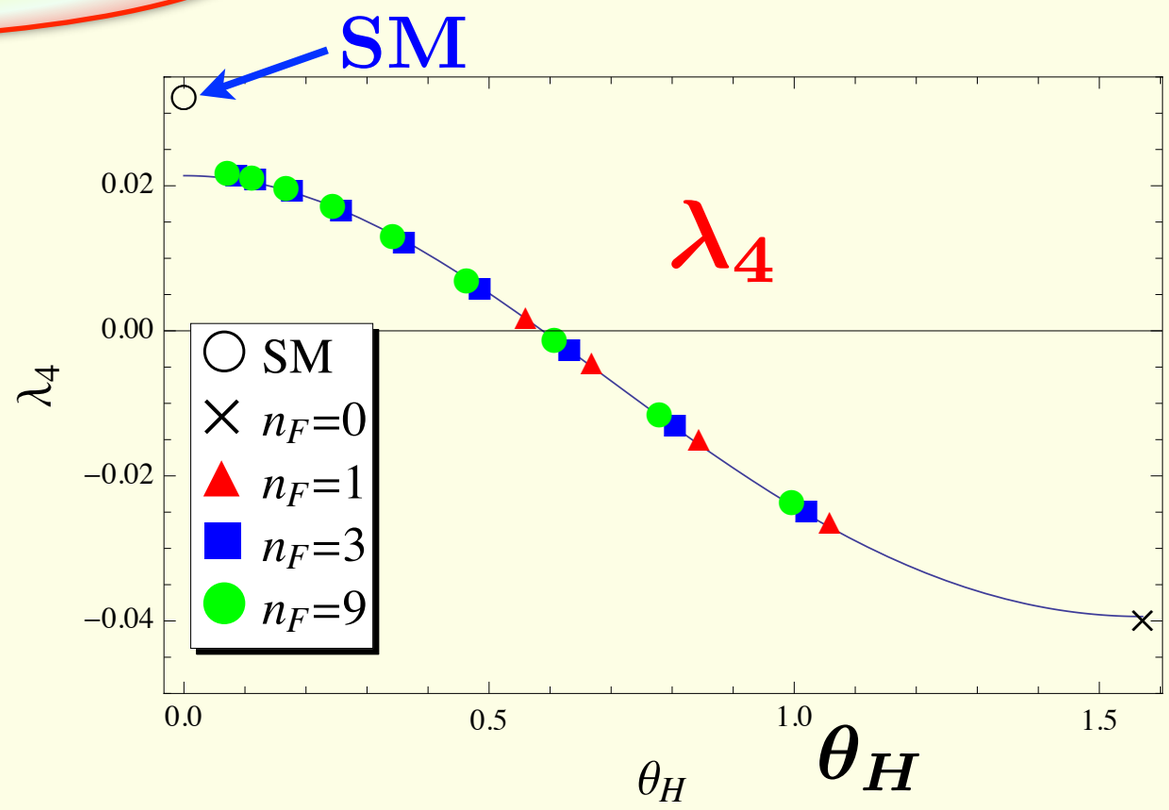
Higgs self-couplings





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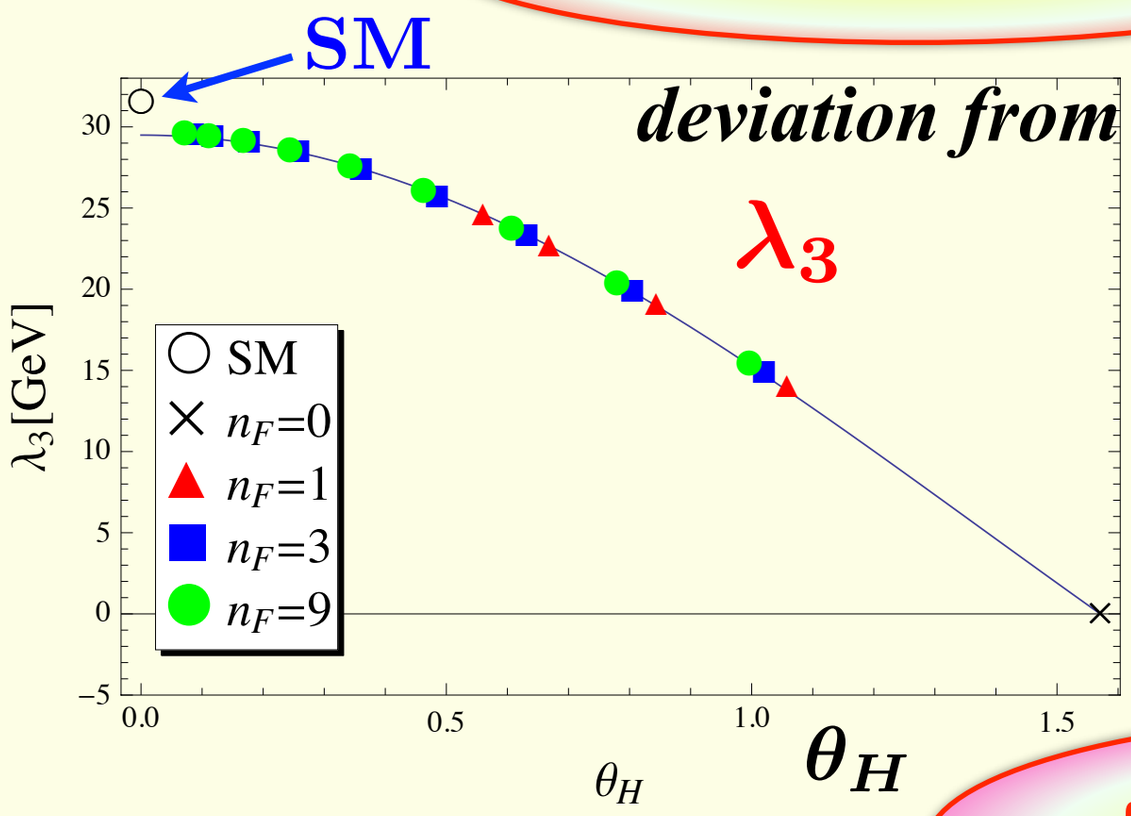
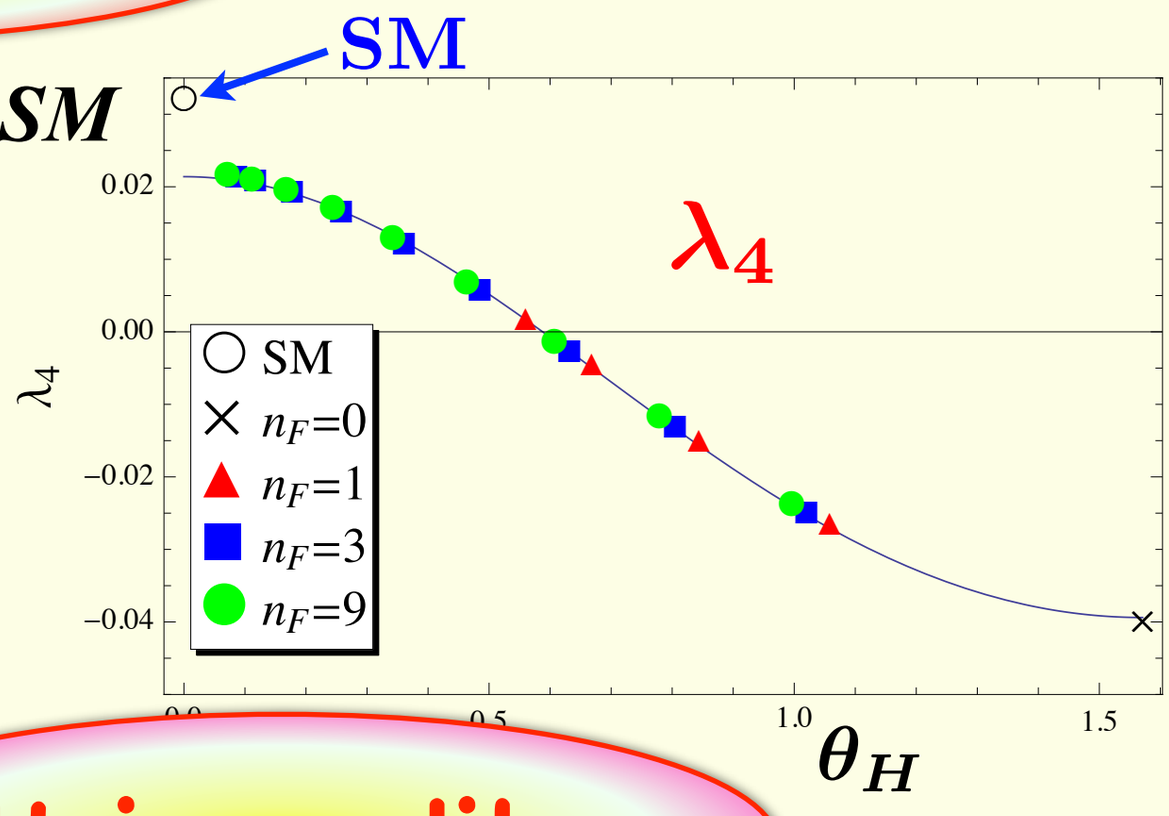




Universality

Low energy physics : close to SM

Low energy physics : close to SM

Need to see other signals at higher energies.

Low energy physics : close to SM

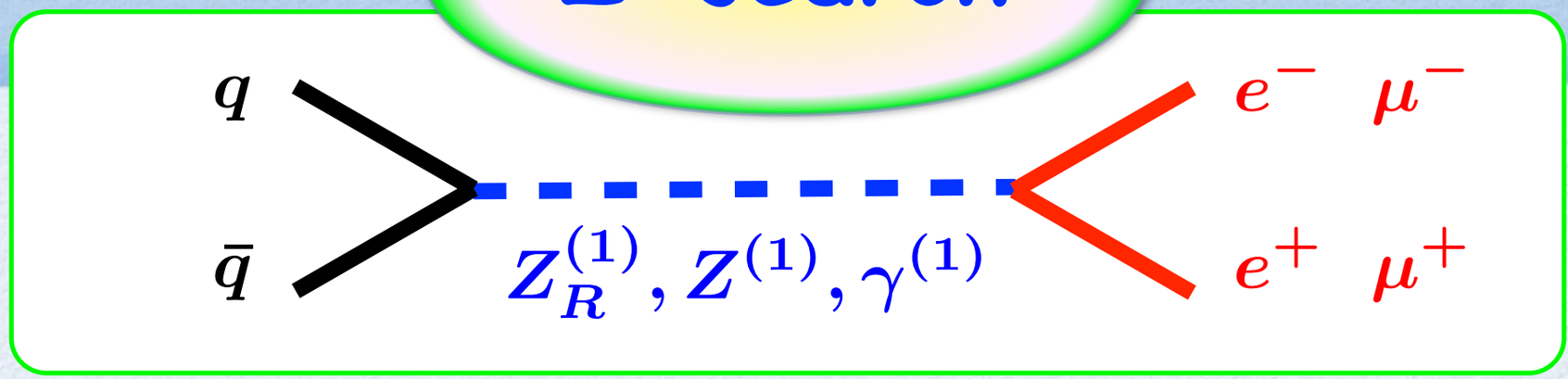
Need to see other signals at higher energies.

Higgs self-couplings λ_3, λ_4

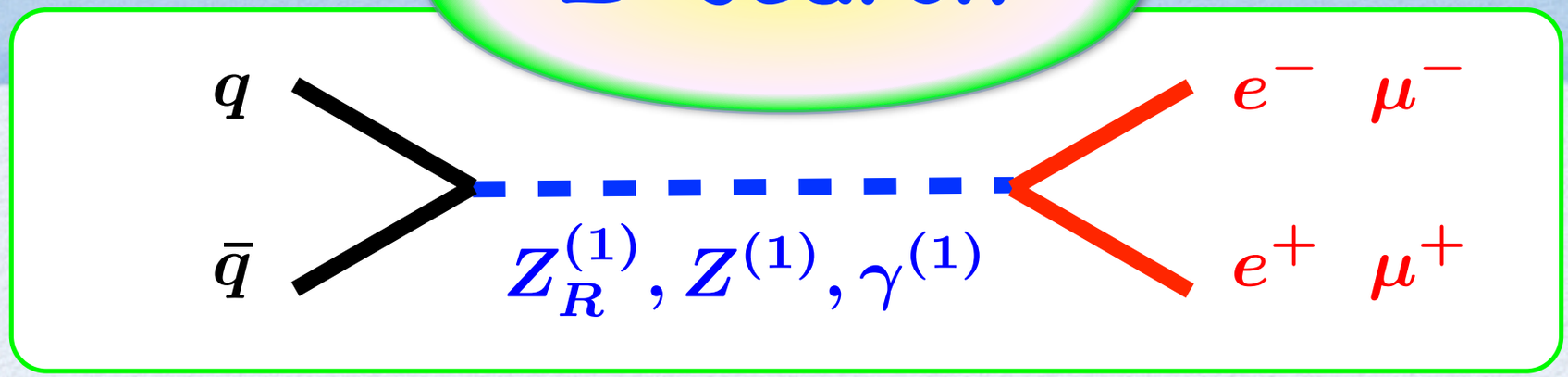
Z′

Dark matter

Z′ search



Z′ search



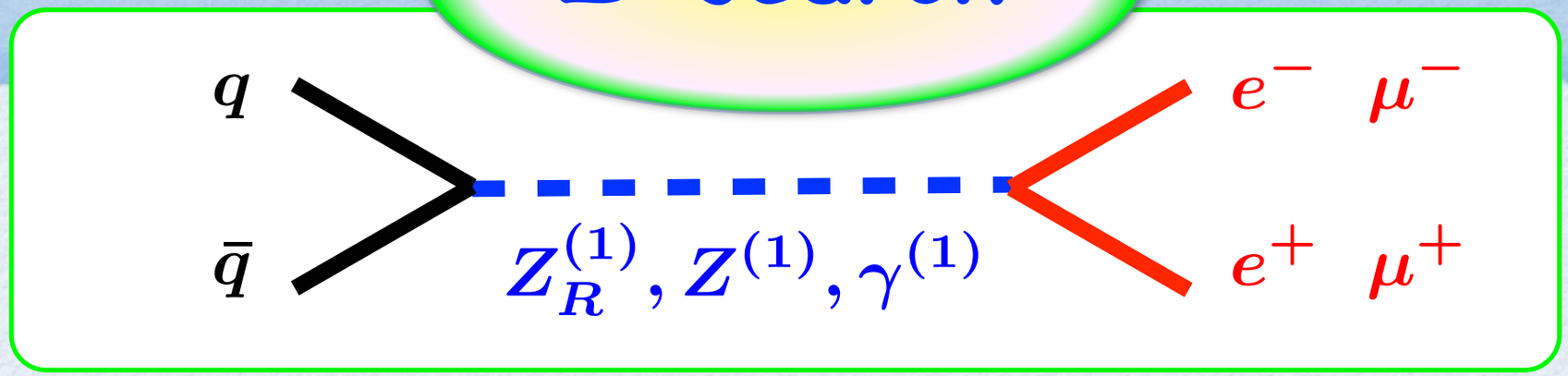
$\theta_H = 0.114$

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

Z′ search



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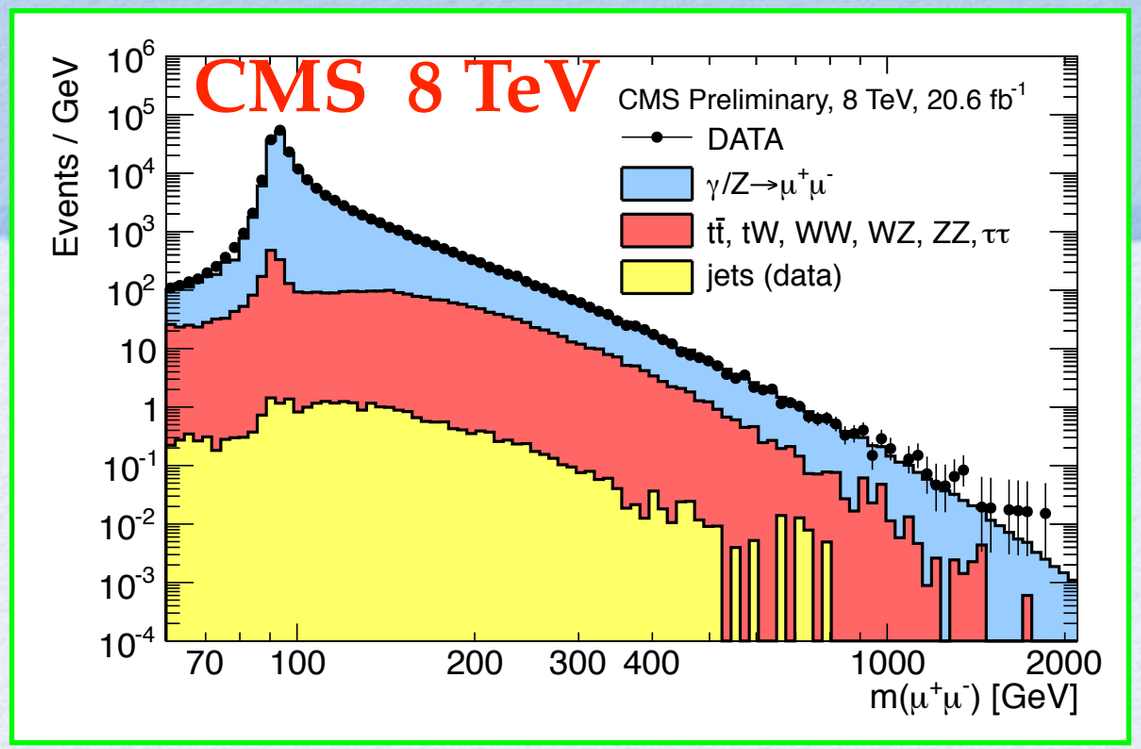
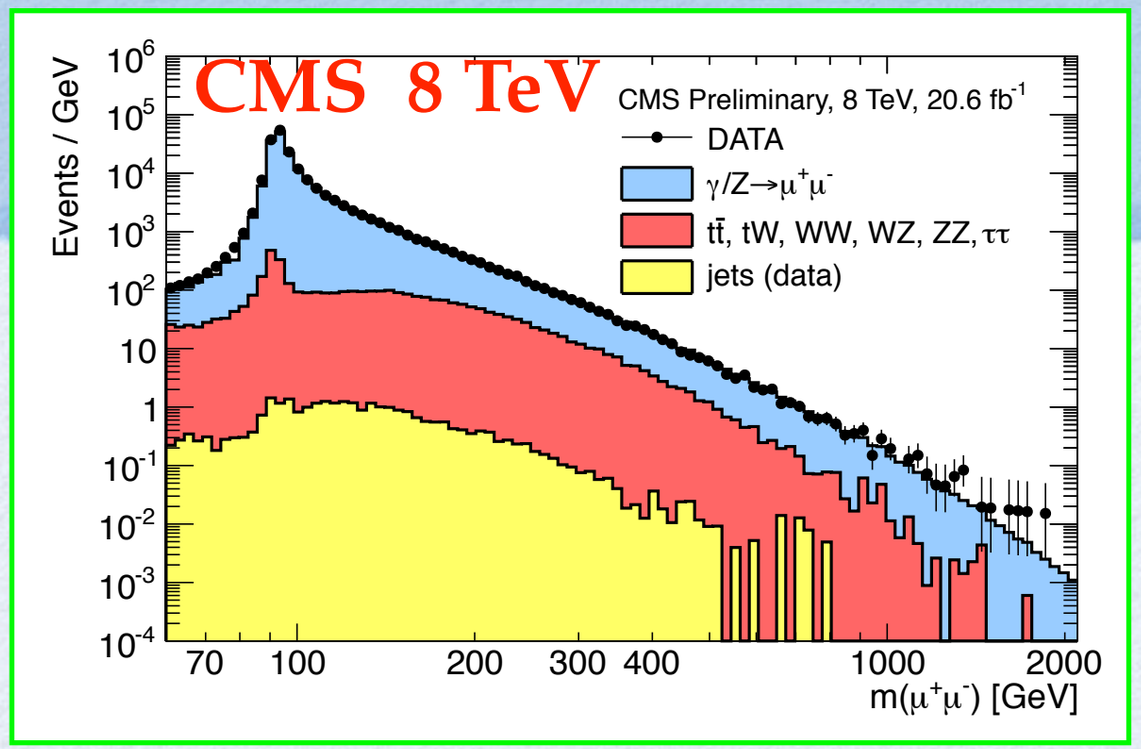
Large widths

large couplings for right handed quarks/leptons


CMS 8 TeV
CMS Preliminary, 8 TeV, 20.6 fb-1
DATA
γ/Z→μ+μ-
tt̄, tW, WW, WZ, ZZ, ττ
jets (data)
Events / GeV
m(μ+μ-) [GeV]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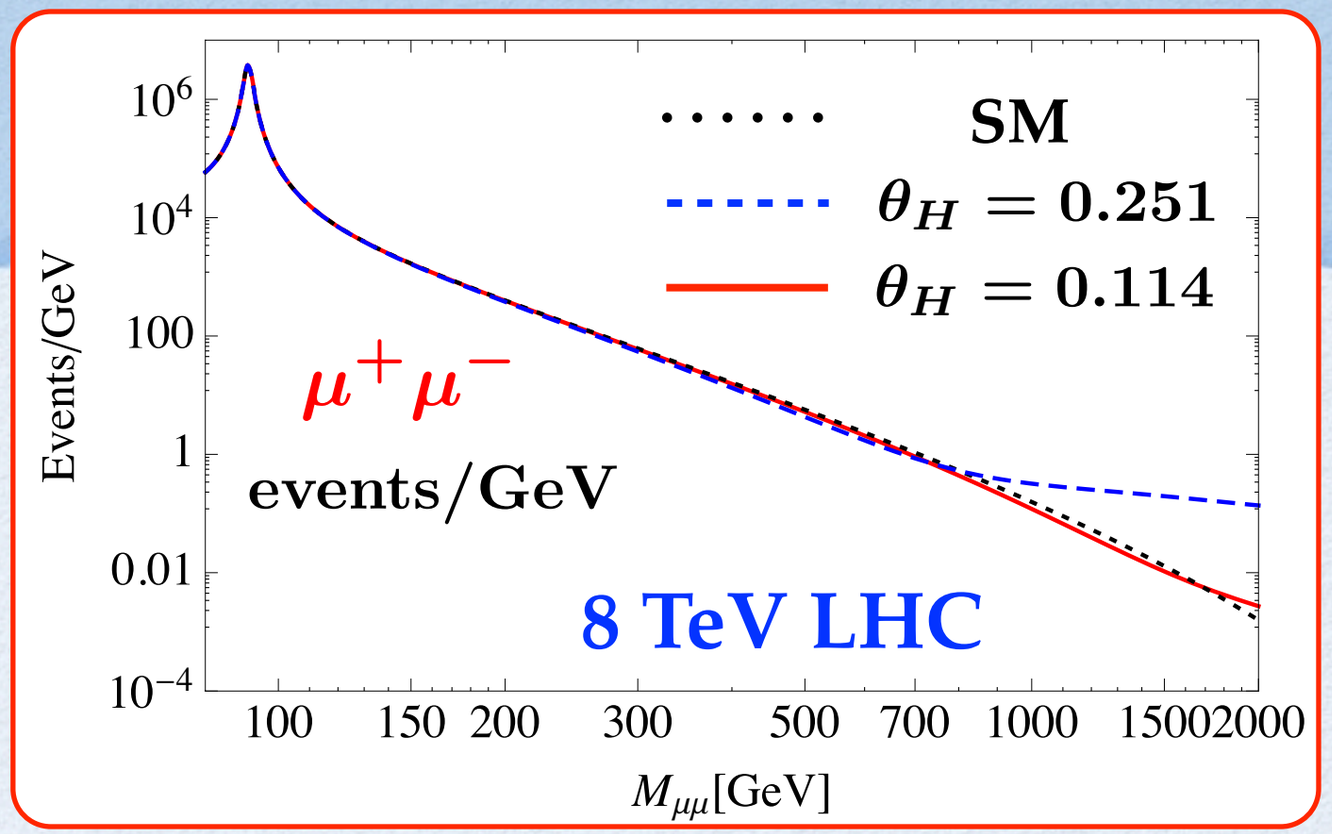
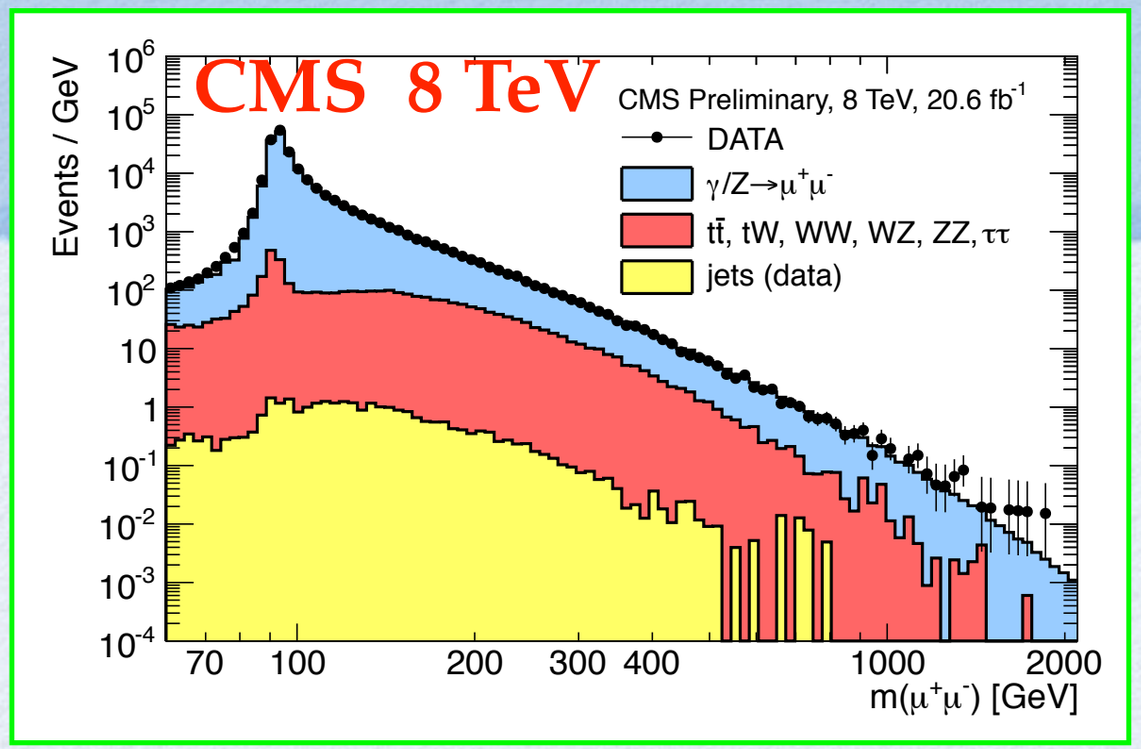

SM
$\theta_H = 0.251$
$\theta_H = 0.114$
$\mu^+\mu^-$
events/GeV
8 TeV LHC
Events/GeV
$M_{\mu\mu}$[GeV]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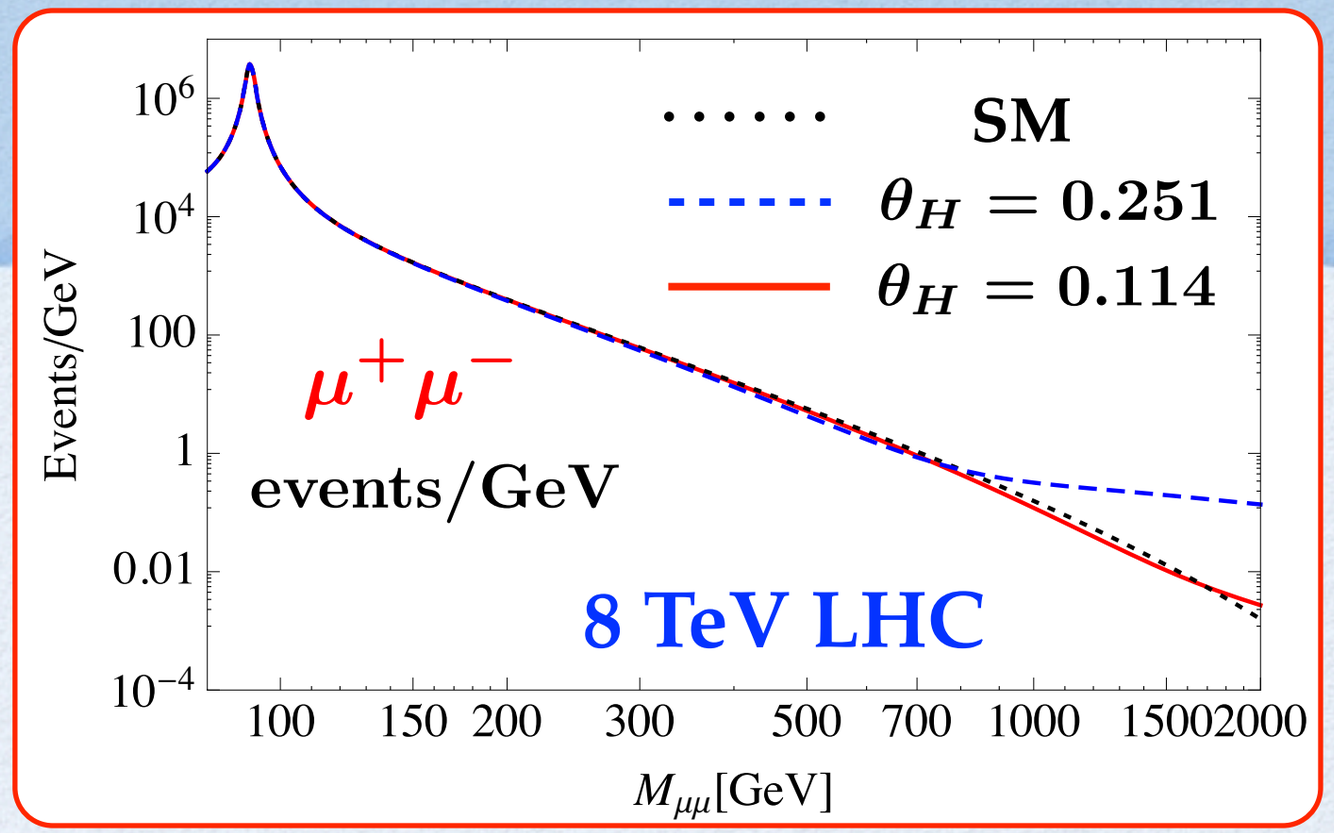
tt̄, tW, WW, WZ, ZZ, ττ
jets (data)
Events / GeV
m(μ+μ-) [GeV]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events/GeV
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Events/GeV
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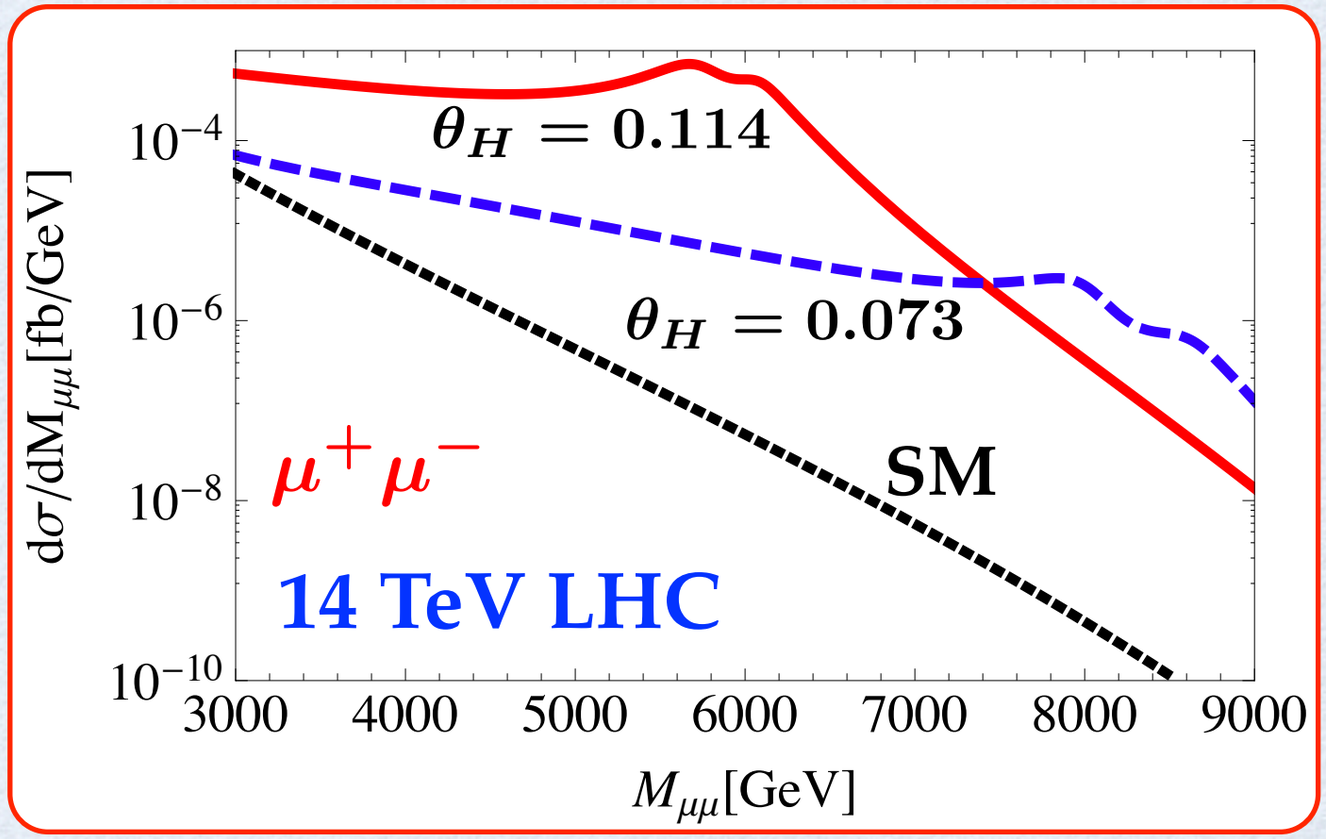
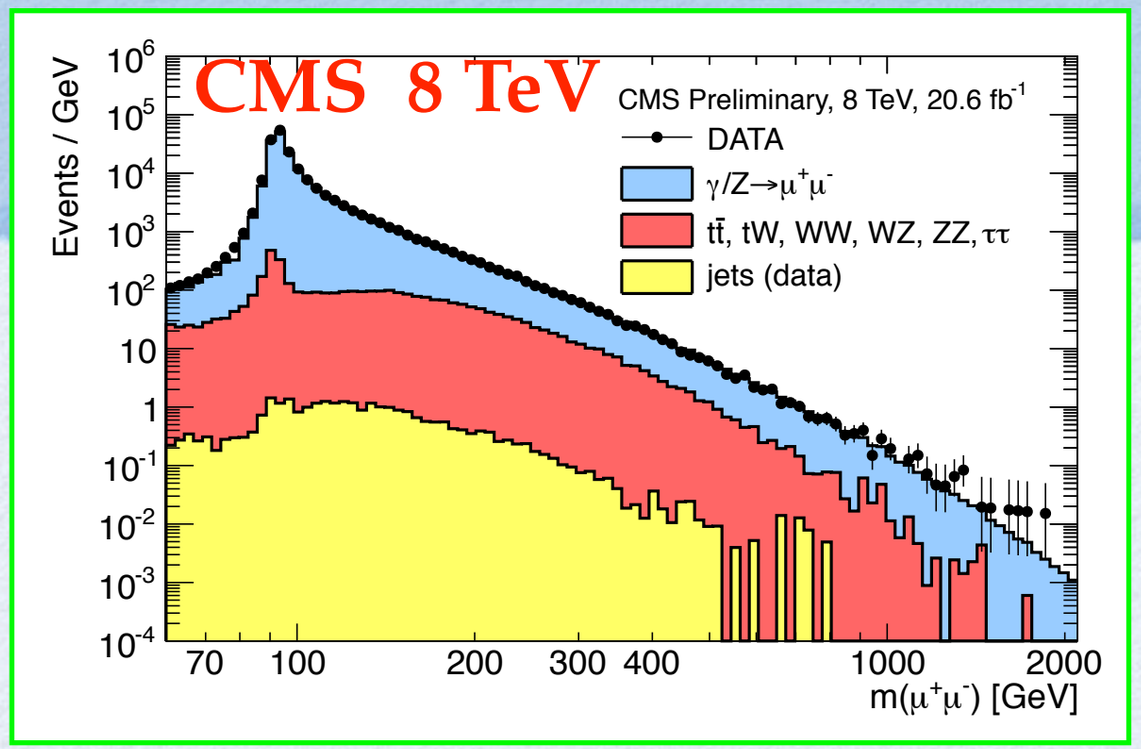
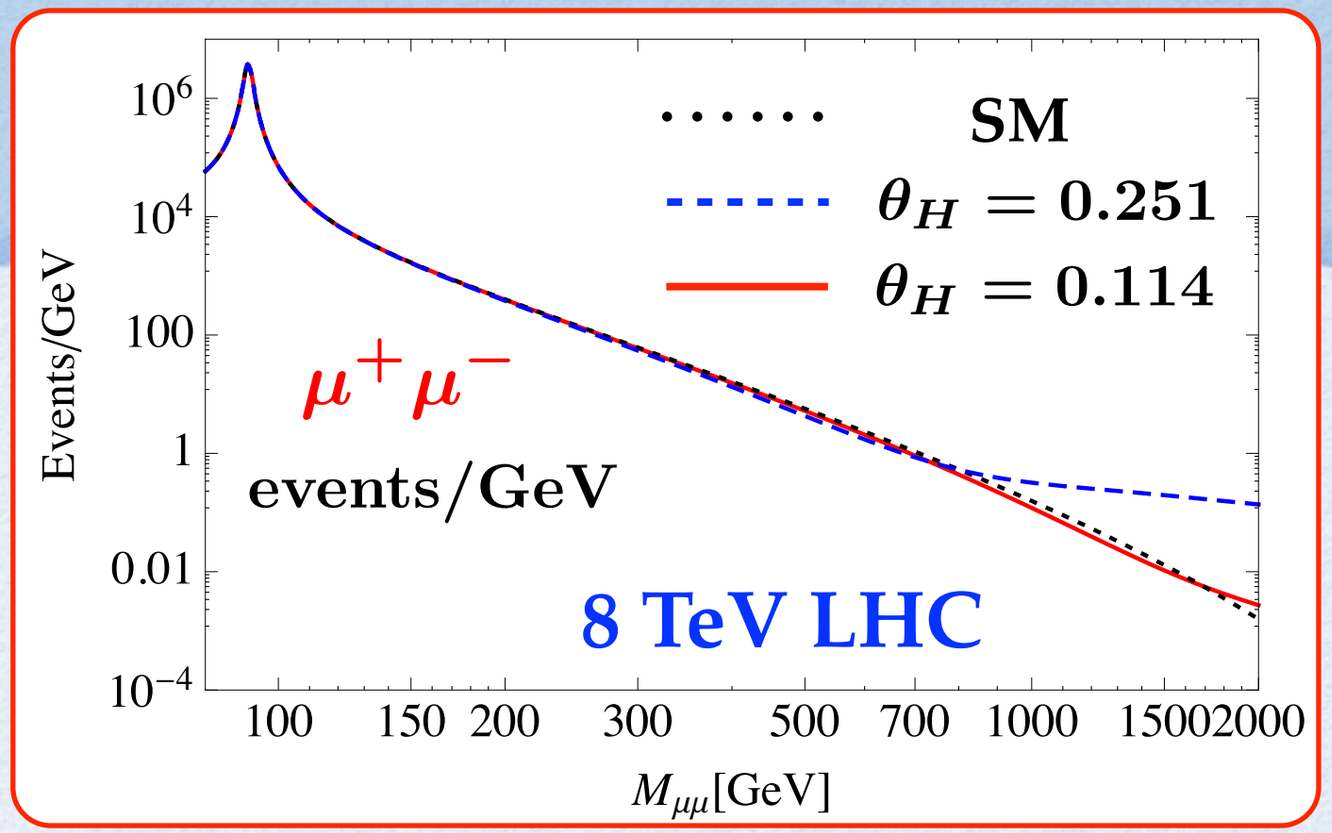
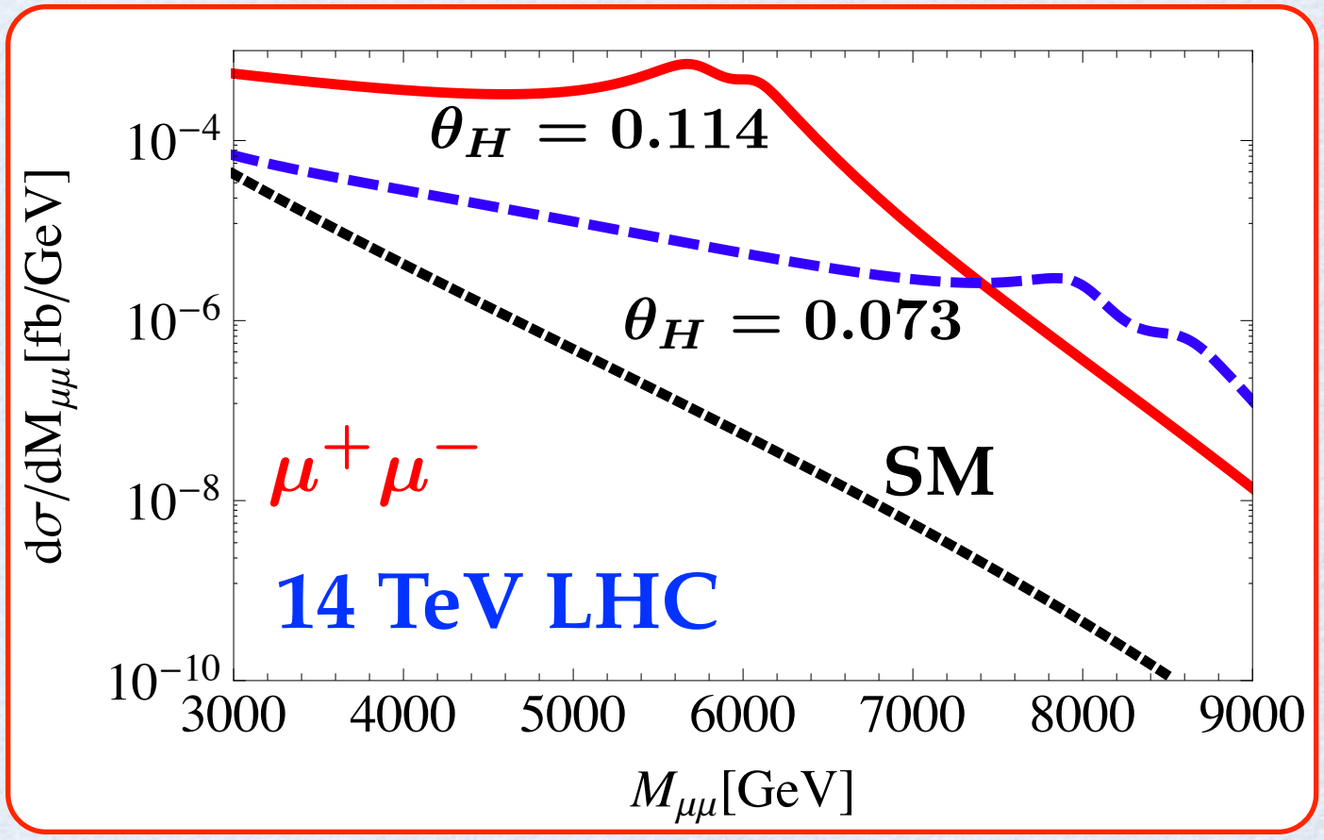

$\theta_H = 0.114$
$\theta_H = 0.073$
SM
$\mu^+\mu^-$
14 TeV LHC
$d\sigma/dM_{\mu\mu}$[fb/GeV]
$M_{\mu\mu}$[GeV]





Z′ search

clear signals



Dark fermion **becomes** **Dark matter**

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

Necessary for having the observed unstable Higgs

F^0 stable ⟶ DM

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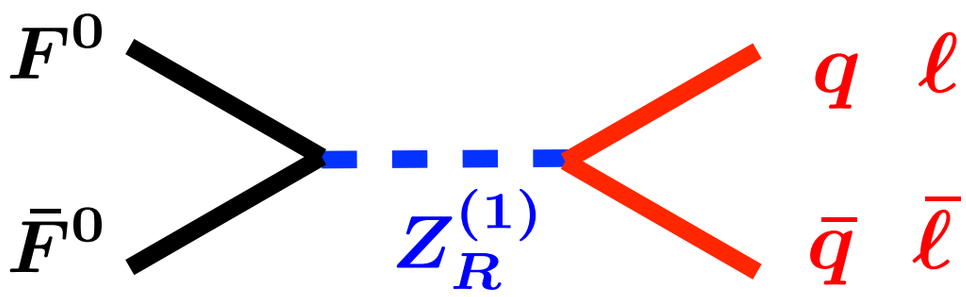
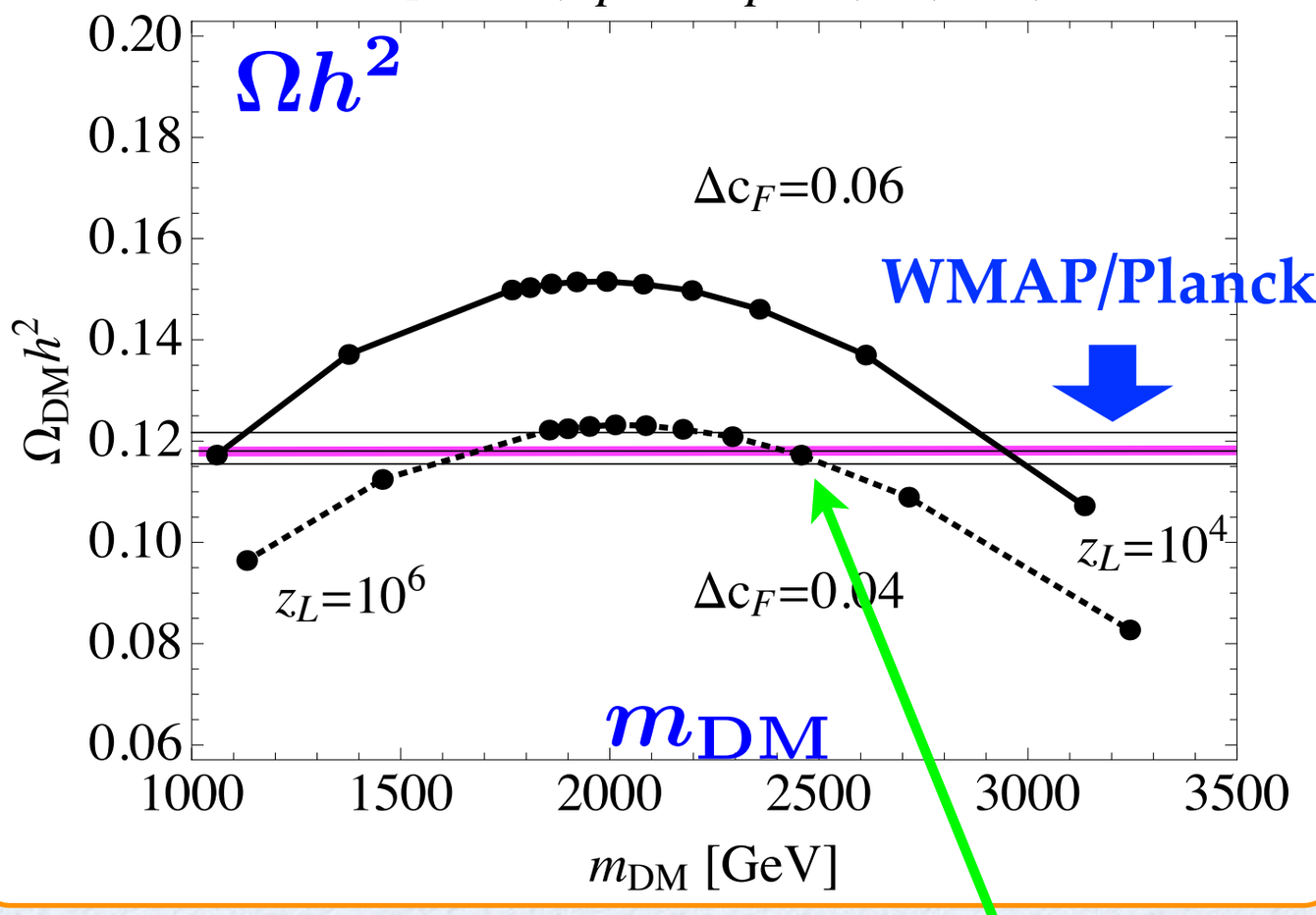
Dominant annihilation



Relic abundance

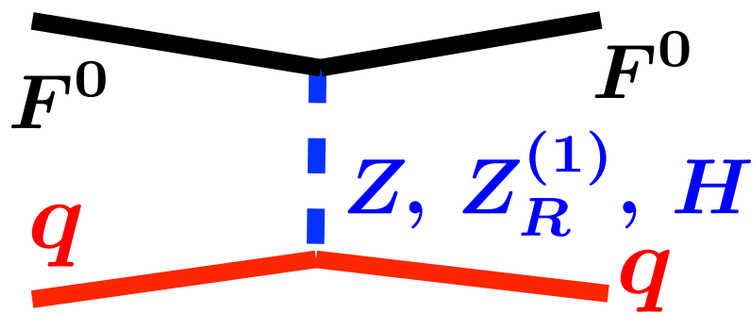


$$(m_{\rm light}, m_{\rm heavy}) = (2.46, 2.72)\ {\rm TeV}$$

1 light and 3 heavy dark fermions

Direct detection of DM

Dominant scattering



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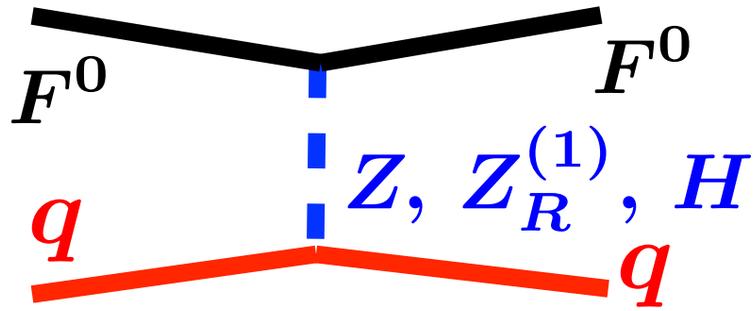

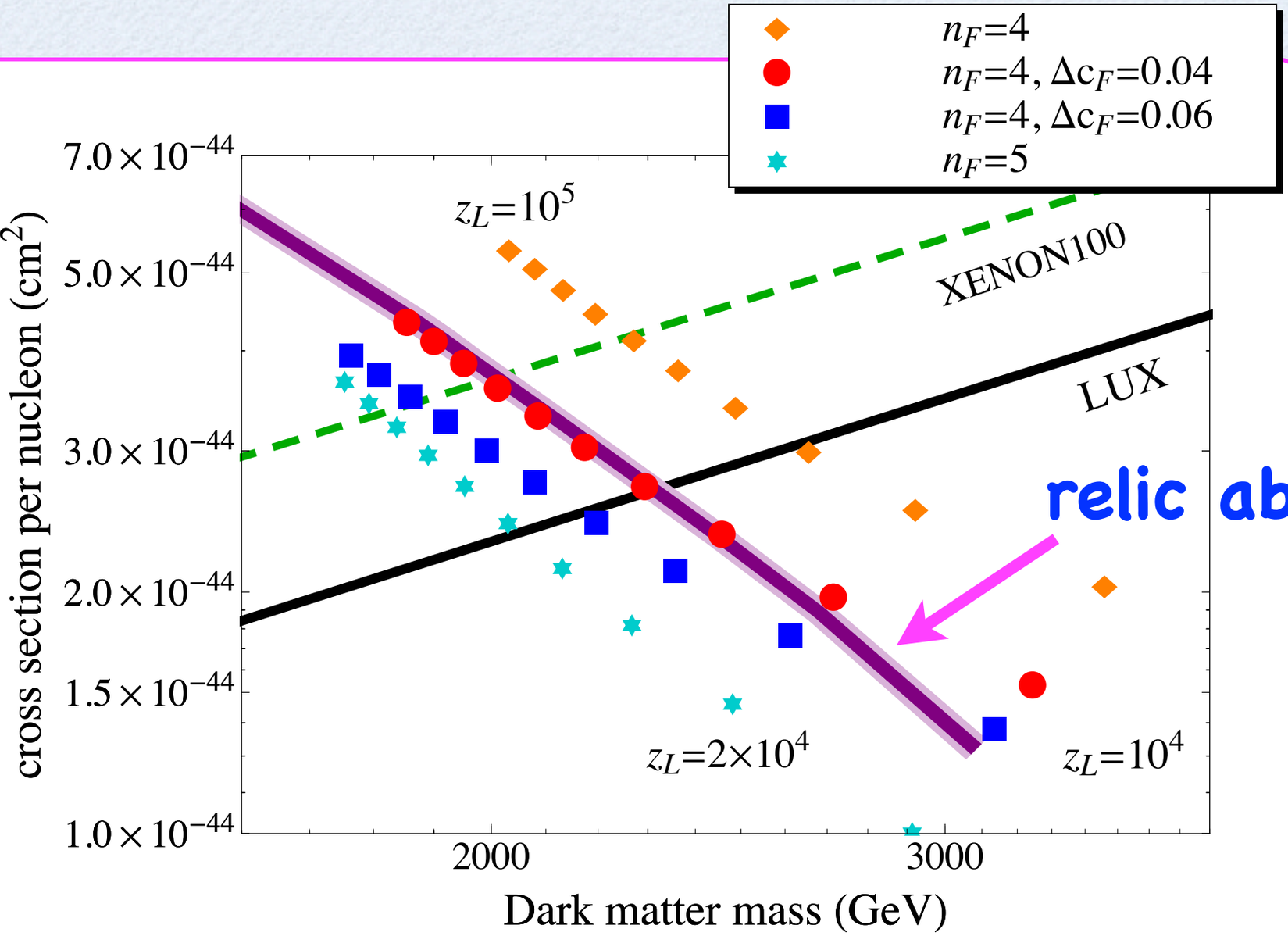

relic abundance : OK

$$(n_F^{\text{light}}, n_F^{\text{heavy}}) = (1, 3)$$

Dark matter

relic abundance (WMAP, Planck)
direct detection (LUX)

$$(n_F^{\rm light}, n_F^{\rm heavy}) = (1, 3)$$

$$m_{\rm DM} = 2.3\,{\rm TeV} \sim 3.1\,{\rm TeV}$$

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$$m_{Z'} = 6.5\,{\rm TeV} \sim 8\,{\rm TeV}$$

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Promising !