Constraints on radion in a warped extra dimension model from Higgs boson searches at the LHC

お茶の水女子大学　素粒子論研究室

大野 慶子

共同研究者：曹 基哲 (お茶大) , 野村大輔 (東北大)

arXiv:1305.4431 [hep-ph].

お茶の水女子大学
Ochanomizu University

@神戸大学セミナー

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0 : Today's talk

I : Introduction

Short review of Randall-Sundrum model

II : Production and Decay of radion

III : Constraints on m_Φ and Λ_Φ from search for Higgs boson at the LHC

(IV : Discrimination of heavy Higgs search and heavy radion search at LHC)

V : Conclusion

原子より小さい、物質の”最小”構成単位＝素粒子

素粒子の振る舞いを説明する枠組み＝標準模型(Standard Model)

http://www.u-tokyo.ac.jp/ja/todai-research/feature-stories/atlas2012/

＊標準模型の完成：

ヒッグス粒子の発見(2012年7月)

→ 陽子 – 陽子衝突 (LHC@CERN)


2012年(平成24年)7月5日(木曜日)

東京新聞

万物に質量与えた「神の粒子」

ヒッグス粒子 ほぼ確認

国際チーム 99.9999%

宇宙の始まり

ヒッグス粒子が働くと…

大型ハドロン衝突型加速器(LHC)

年内断定へ追加実験

＊標準模型の完成：

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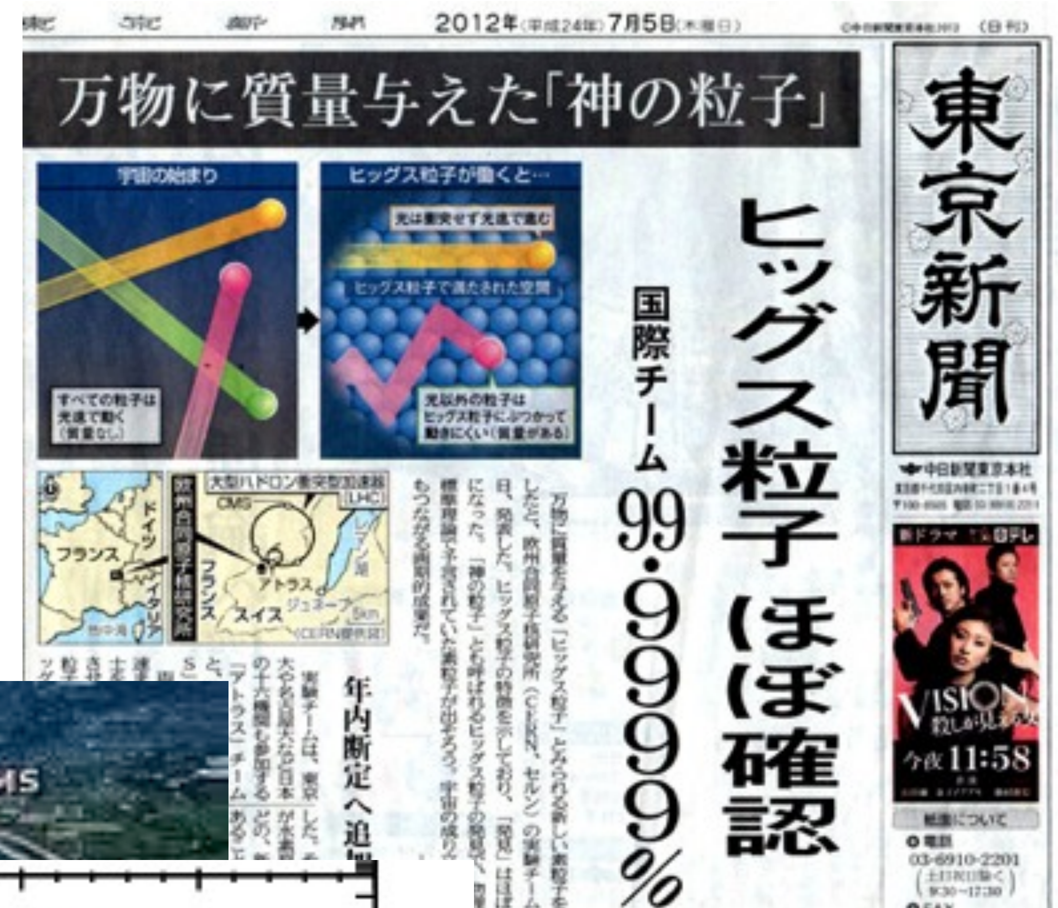
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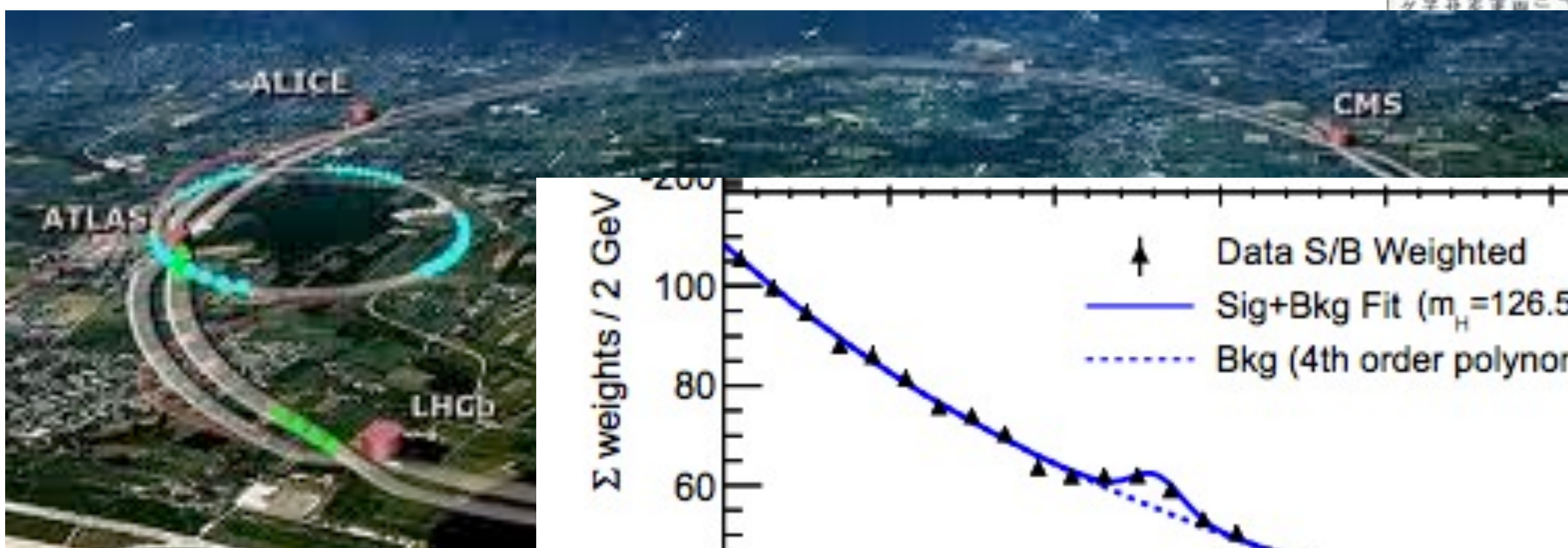
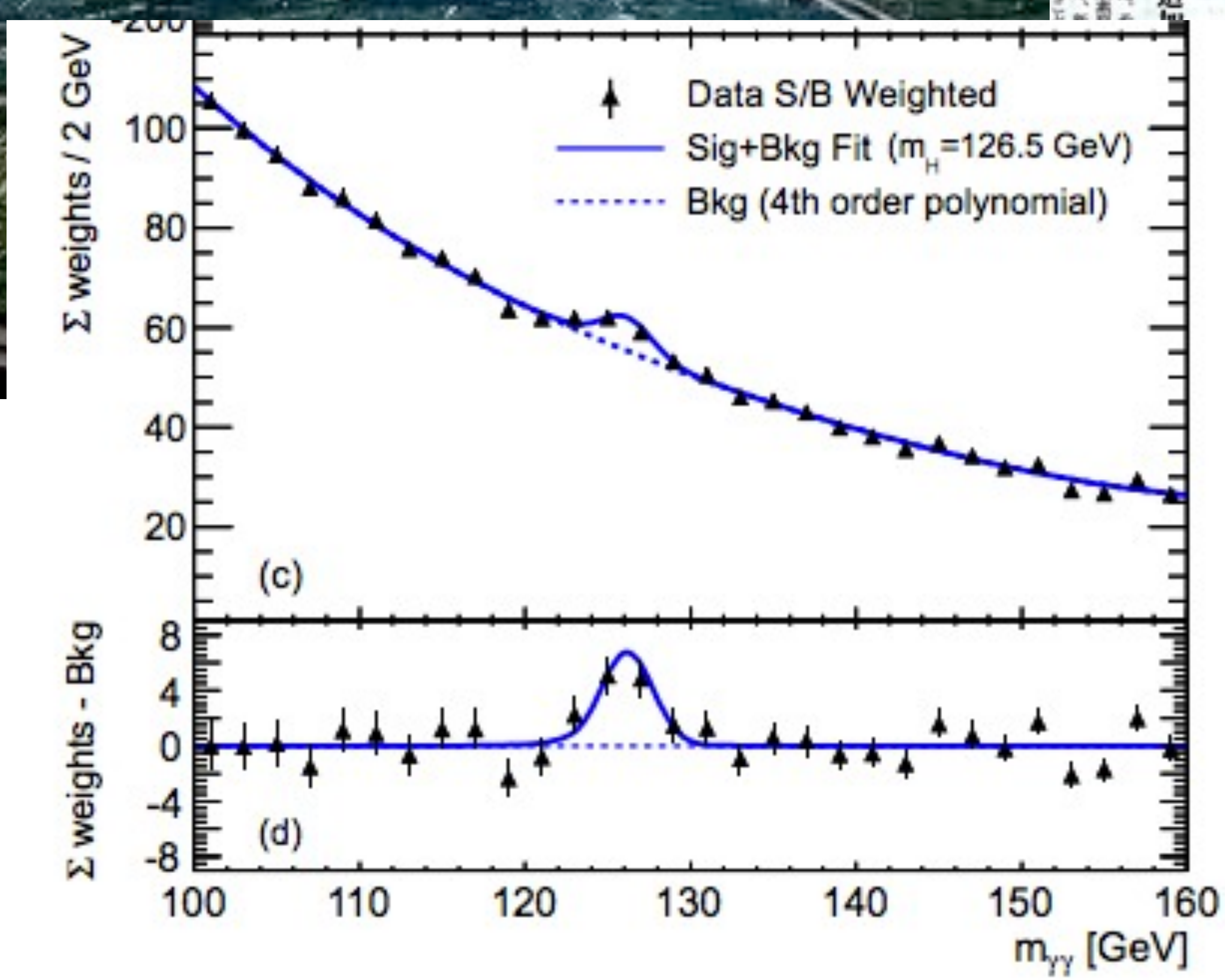




Phys. Lett. **B716**, 1(2012)

Ⅰ：Introduction

Short review of Randall-Sundrum model

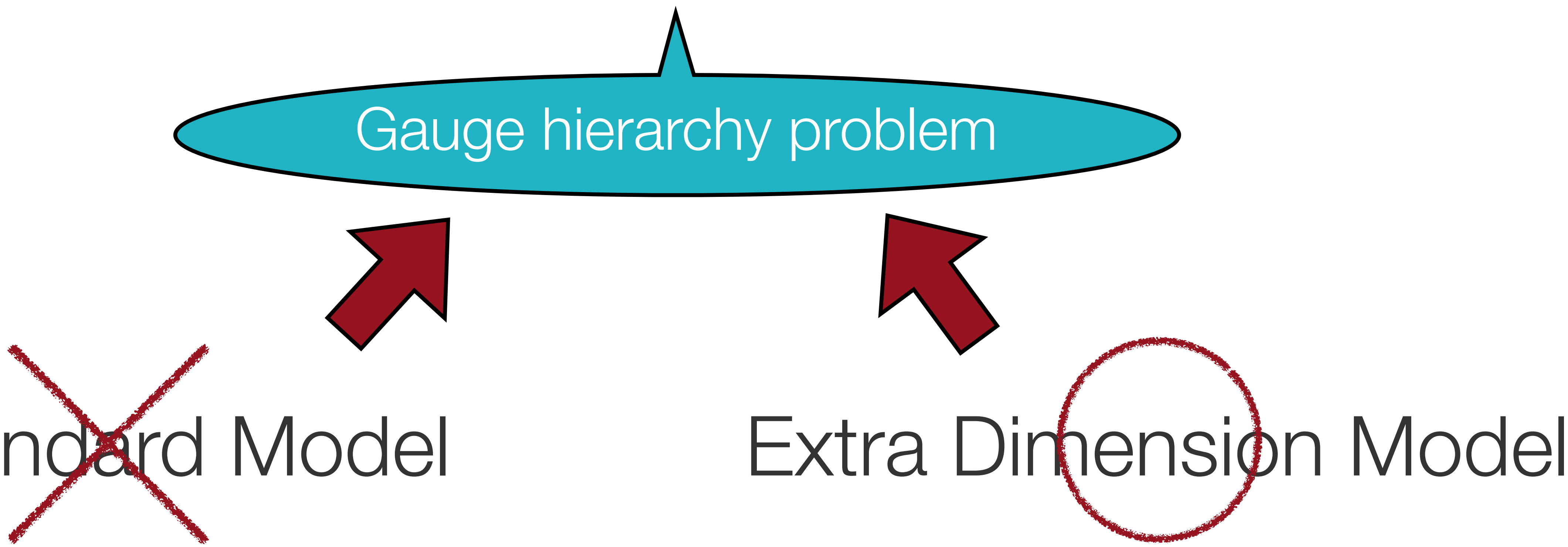
Gauge hierarchy problem:

Standard Model (SM) can explain behavior of particle physics in electroweak scale M_{EW} .

On the other hand, the planck scale M_{pl} which is characterized by Newton constant G_N exists in our world.

$$M_{EW} \sim 10^2 \text{ GeV} \longleftrightarrow M_{pl} \sim 10^{19} \text{ GeV}$$

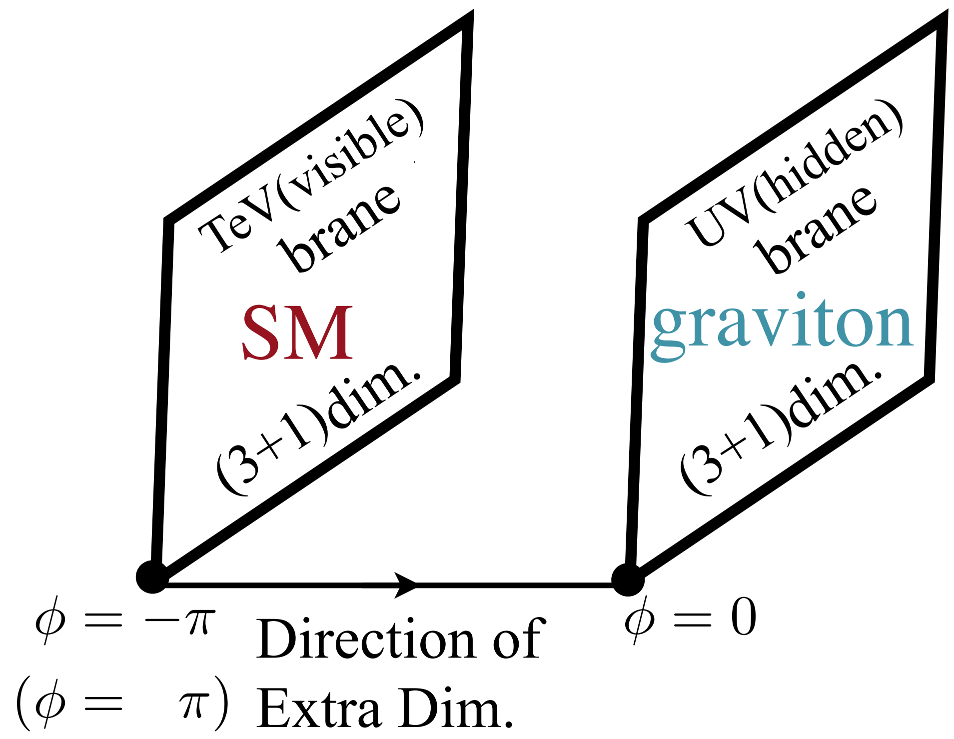
$$10^{17} \text{ GeV}$$



Randall-Sundrum model solves the gauge hierarchy problem.

Randall-Sundrum metric is

$$ds^2 = e^{-2kr_c\phi}\eta_{\mu\nu}dx^\mu dx^\nu + r_c^2 d\phi^2,$$



To solve the hierarchy problem,
we must select $kr_c = 10 \sim 12$

L.Randall, R.Sundrum (1999)

$$M_{pl}^2 = M^3 r_c \int_{-\pi}^{\pi} d\phi e^{-2kr_c|\phi|} = \frac{M^3}{k}[1 - e^{-2kr_c\pi}]$$

hierarchy relation

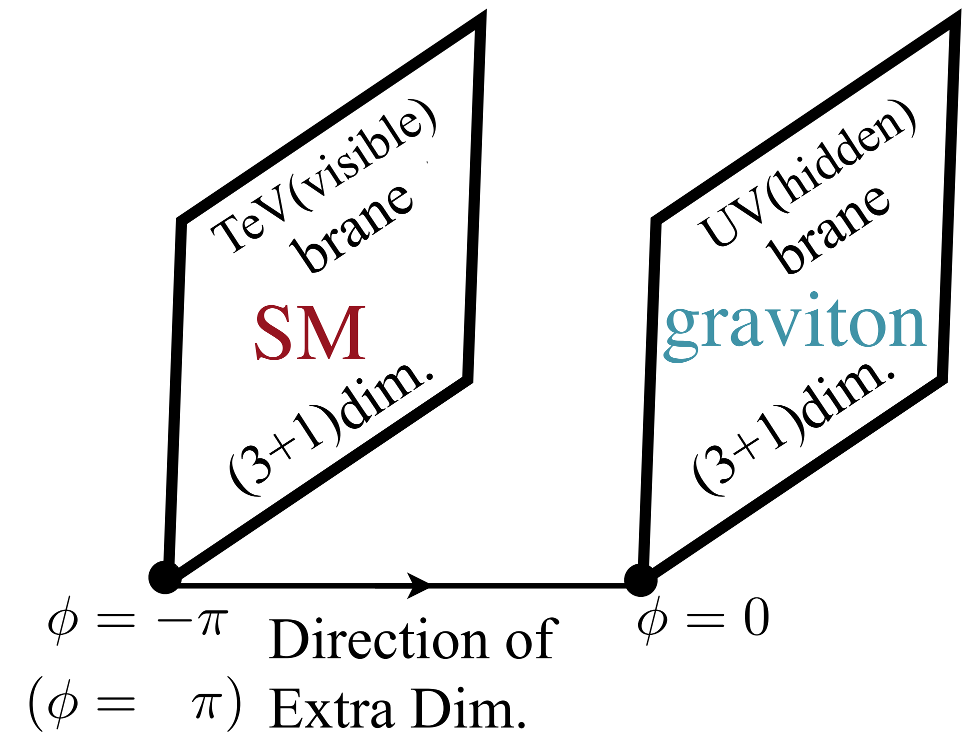
visible (TeV) ブレーン

→ The metric fluctuation is so called **radion**.

Why kr_c = 10~12 ?

→ ex) Goldberger-Wise Mechanism

To stabilize the distance between hidden brane and visible brane, we introduce a scalar field.



Radion Φ is a canonically normalized 4D scalar field after integrating out the extra dimension.

W. D. Goldberger, M. B. Wise
Phys.Rev.Lett. **83** , 4922-4925 (1999)

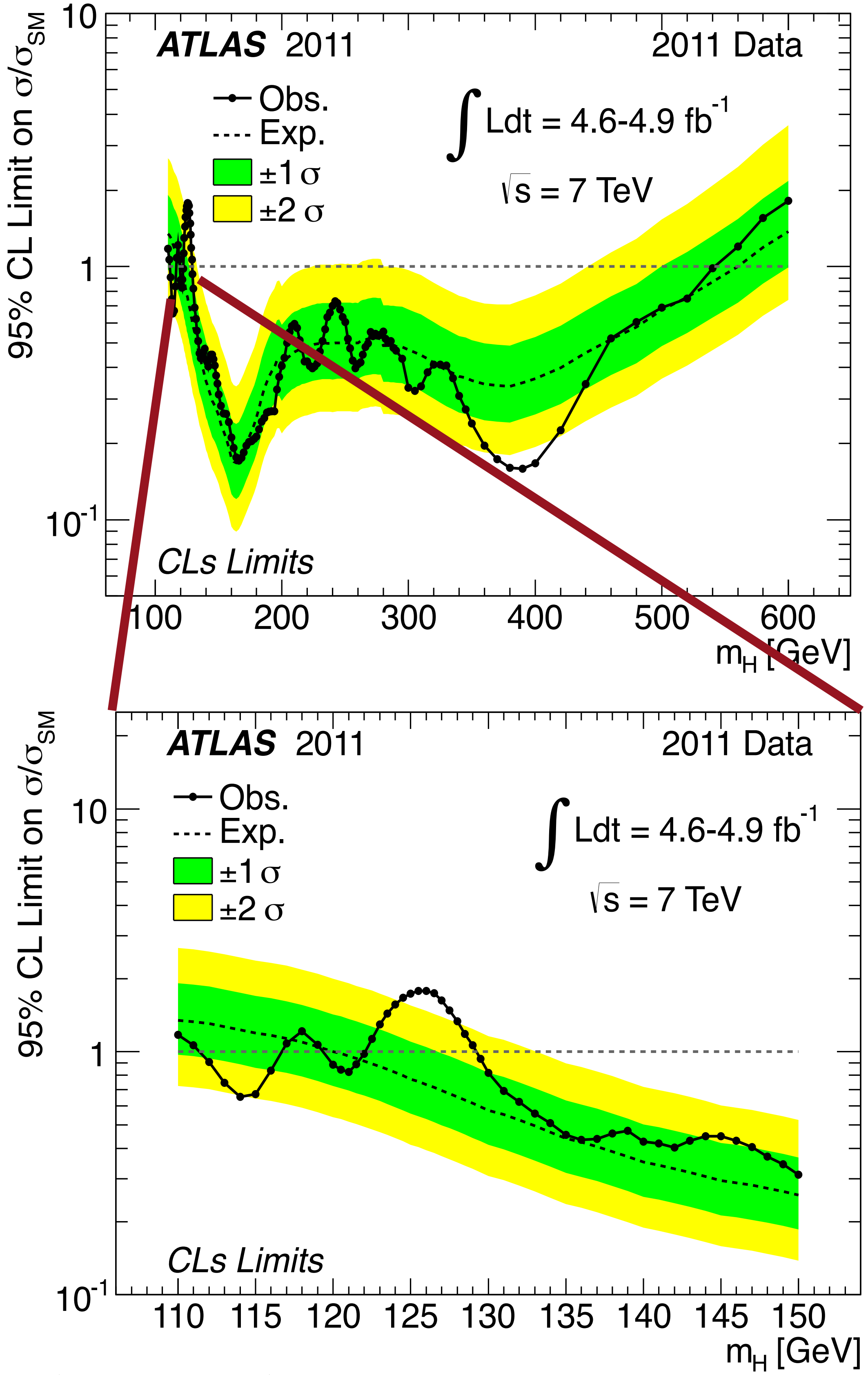
Radion Φ：Metric fluctuation (G_{55}), Scalar particle (spin=0)

① Production & decay are very similar to Higgs

② Radion mass $\mathbf{m_\Phi}$ is O(TeV) and it is lighter than 1st KK graviton

③ Strength of coupling to the SM fields is proportional to $1/\Lambda_\Phi$ (∼1/TeV)

Motivation:



arXiv:1209.0590v1 [hep-ex]
for the ATLAS Collaboration

SM Higgs was found at low mass region.

→ Then we focused heavy radion search.

(no radion-Higgs mixing)

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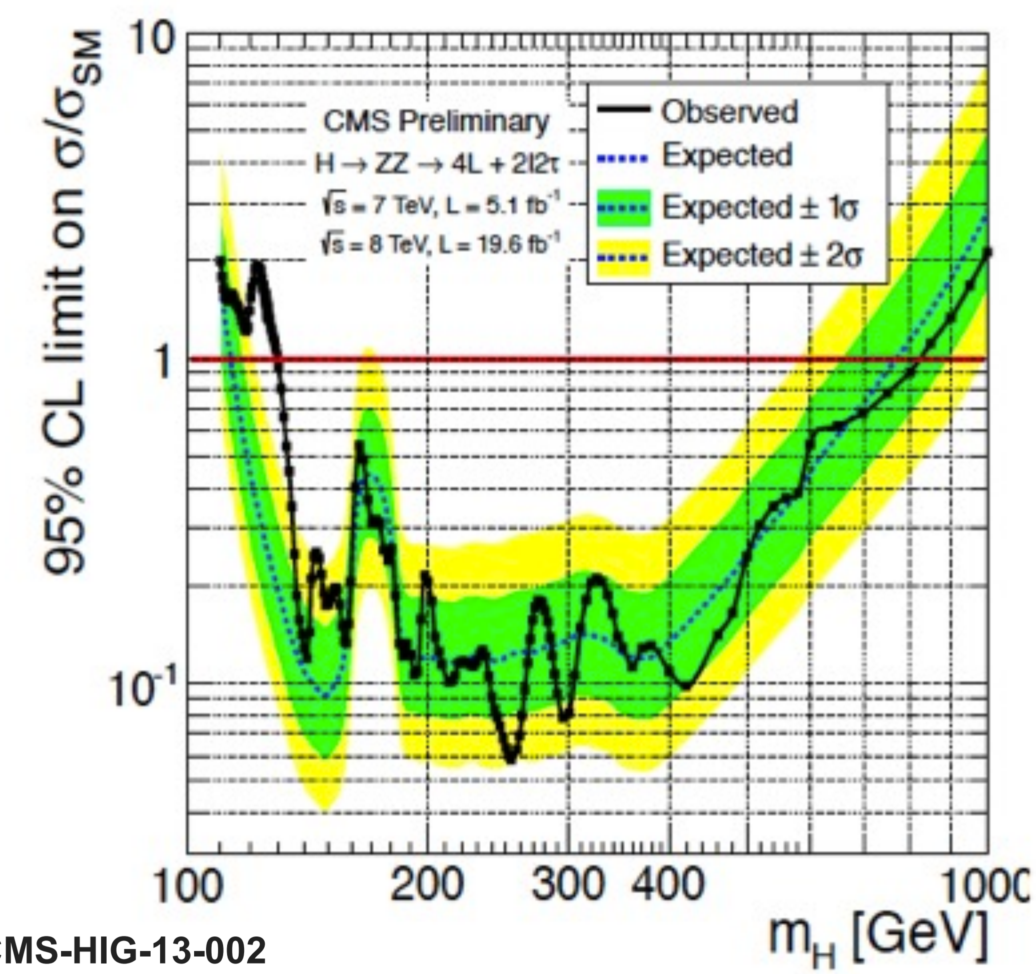


CMS-HIG-13-002

I) Production & decay of radion are very similar to SM Higgs.

II) We know the ratio of σ/σ_{SM} from SM Higgs search.

It might be an indirect constraint on an extra (SM Higgs like) scalar.

→ we study allowed region of m_Φ and Λ_Φ.

II：Production and Decay of radion

Interaction of radion to SM fields (in detail)

For fermion, W, Z, SM Higgs：

$$\mathcal{L}_{\rm int} = \frac{\phi}{\Lambda_\phi} T^\mu_\mu({\rm SM}) ,$$

Free parameter

$$\left(T^\mu_\mu({\rm SM}) = \sum_f m_f \bar{f} f - 2m_W^2 W^+_\mu W^{-\mu} - m_Z^2 Z_\mu Z^\mu + (2m_H^2 H^2 - \partial_\mu H \partial^\mu H) + \cdots \right),$$

For gluon, photon：

$$T^\mu_\mu({\rm SM})^{\rm anom} = \sum_a \frac{\beta_a(g_a)}{2g_a} F^a_{\mu\nu} F^{a\mu\nu} .$$

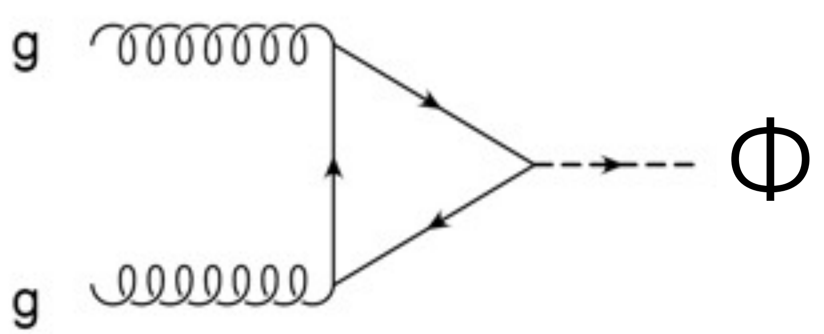
$$\left(\beta_{\rm QCD}/2g_s = -(\alpha_s/8\pi) b_{\rm QCD} \right)$$

$$\left(b_{\rm QCD} = 7 \quad (for \quad n_f = 6) \right)$$

C. Csáki, M. Graesser, L. Randall, J. Terning, PR**D62** , 045015 (2000)

Production(main)：

gluon fusion (top + bottom loops)



$$\sigma(s) = \int_{m_\phi^2/s}^1 \frac{dx}{x} g(x) g\left(\frac{m_\phi^2}{sx}\right) \frac{\alpha_s^2}{256\pi\Lambda_\phi^2} \frac{m_\phi^2}{s} |b_{\rm QCD} + x_t(1 + (1 - x_t) f(x_t)|^2$$

K.Cheung, PR**D63** , 056007 (2001)

Radion decay:

$$\Gamma(\phi \to gg) = \frac{\alpha_s^2 m_\phi^3}{32\pi^3 \Lambda_\phi^2} \left| b_{\rm QCD} + x_t(1+(1-x_t)f(x_t)) \right|^2$$

$$\Gamma(\phi \to \gamma\gamma) = \frac{\alpha_{\rm em}^2 m_\phi^3}{256\pi^3 \Lambda_\phi^2} \left| b_2 + b_Y - (2 + 3x_W + 3x_W \times (2 - x_W) f(x_W)) + \frac{8}{3} x_t (1 + (1 - x_t) f(x_t)) \right|^2$$

$$\Gamma(\phi \to f\bar{f}) = \frac{N_c m_f^2 m_\phi}{8\pi \Lambda_\phi^2} (1 - x_f)^{3/2}$$

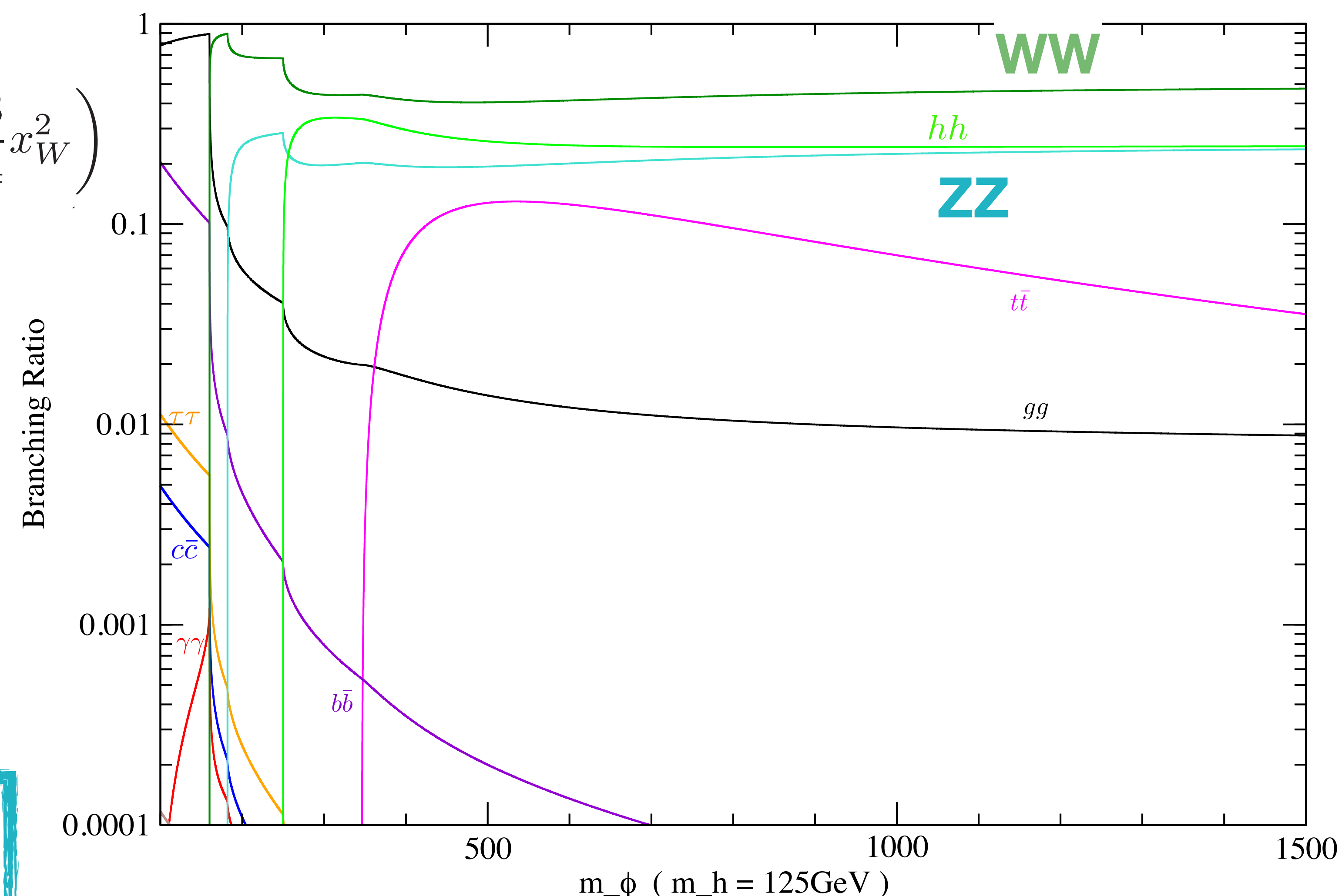
$$\Gamma(\phi \to W^+W^-) = \frac{m_\phi^3}{16\pi \Lambda_\phi^2} \sqrt{1 - x_W} \left(1 - x_W + \frac{3}{4} x_W^2 \right)$$

$$\Gamma(\phi \to ZZ) = \frac{m_\phi^3}{32\pi \Lambda_\phi^2} \sqrt{1 - x_Z} \left(1 - x_Z + \frac{3}{4} x_Z^2 \right)$$

$$\Gamma(\phi \to HH) = \frac{m_\phi^3}{32\pi \Lambda_\phi^2} \sqrt{1 - x_H} \left(1 + \frac{x_H}{2} \right)^2$$

$x_i = 4m_i^2/m_\phi^2$ $(i = f, W, Z, H)$ and $N_c = 3\,(1)$

K.Cheung, PR**D63** 056007 (2001)



→ Free parameters :

Λ_Φ, m_Φ

III: Constraints on m_Φ and Λ_Φ from search for Higgs boson at the LHC

high mass region→WW, ZZ modes

Experimental bound from LHC

Radion interaction to SM fields is very similar to SM Higgs.

We know the ratio of σ/σ_{SM} from SM Higgs search.

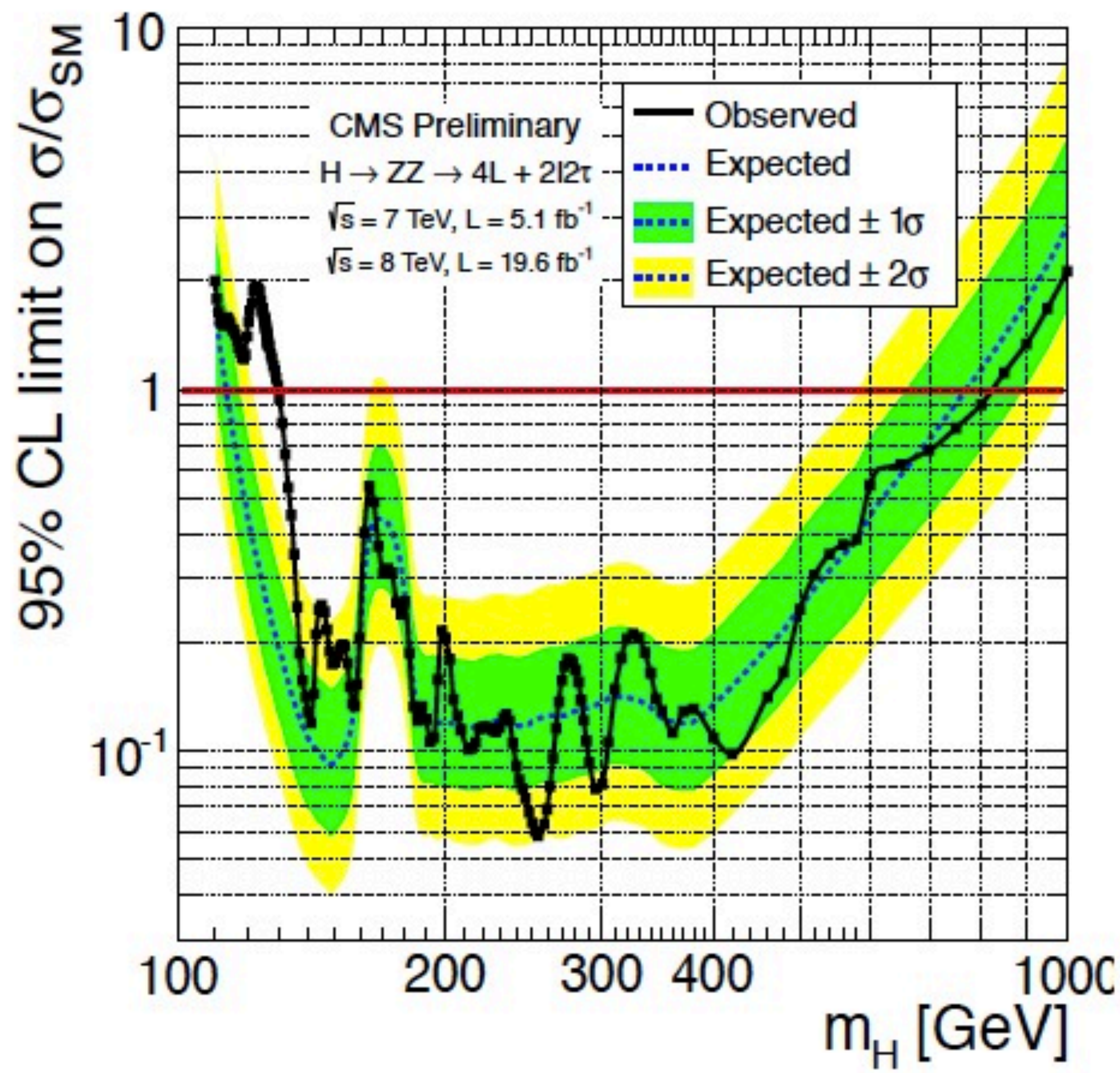
→ It might be an indirect constraint on an extra (SM Higgs like) scalar.

In other words, we calculated ...

$$\left[\int \mathcal{L}_{7\mathrm{TeV}} dt \cdot \sigma(pp \to \phi X; 7\mathrm{TeV}) + \int \mathcal{L}_{8\mathrm{TeV}} dt \cdot \sigma(pp \to \phi X; 8\mathrm{TeV})\right] \mathrm{Br}(\phi \to ZZ)$$

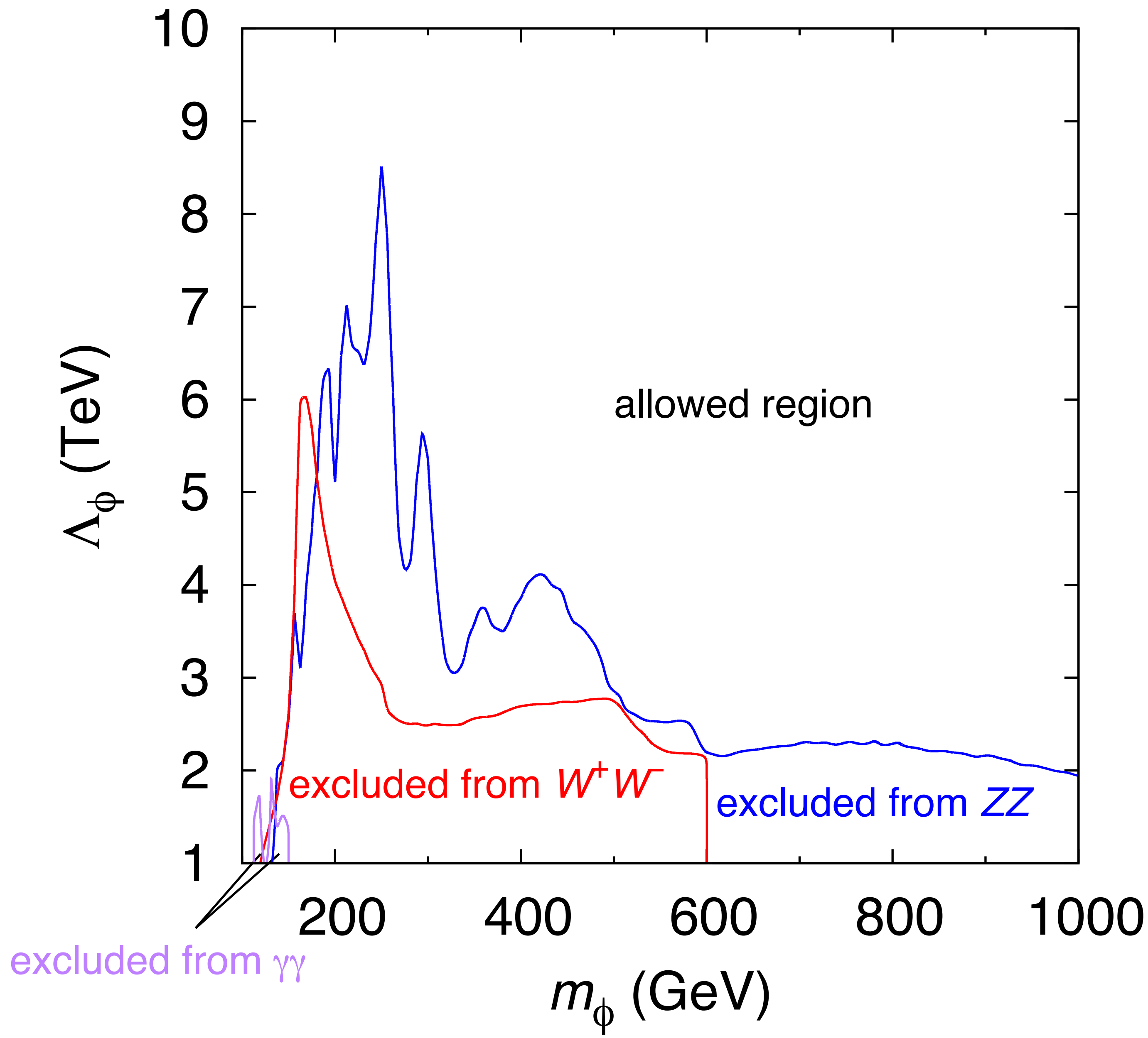
$$\leq$$

$$f(m_h) \left[\int \mathcal{L}_{7\mathrm{TeV}} dt \cdot \sigma(pp \to hX; 7\mathrm{TeV}) + \int \mathcal{L}_{8\mathrm{TeV}} dt \cdot \sigma(pp \to hX; 8\mathrm{TeV})\right] \times \mathrm{Br}(h \to ZZ)\Big|_{m_h = m_\phi}$$



→ We study allowed region of ΛΦ and mΦ.

We analyzed h → ZZ / WW / γγ decay modes

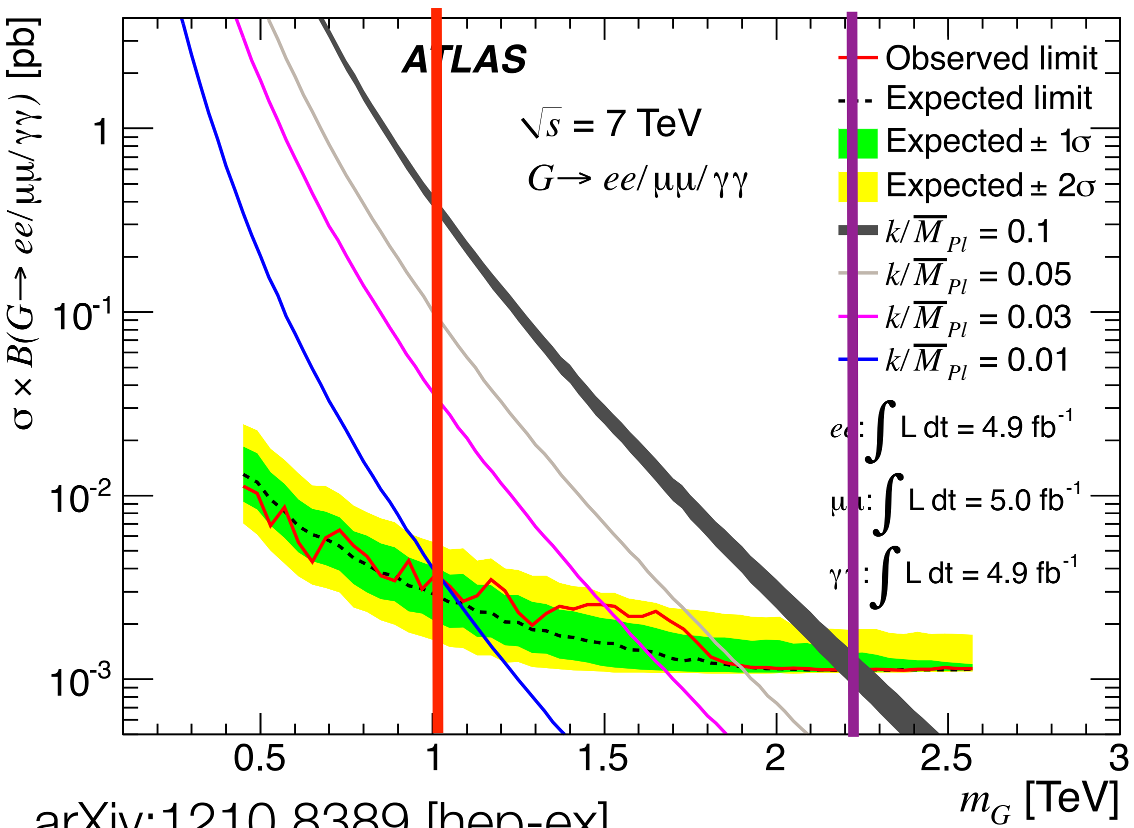


→ The bounds are *not* depend on the stabilization mechanism .

On the other hand ...

Constraints on Λ_Φ from search for 1st KK graviton at the LHC

Constraints of ΛΦ



arXiv:1210.8389 [hep-ex]
for the ATLAS experiments

1st KK Graviton mass is

$$m_{G_1} = x_1 \frac{k}{M_{pl}} \Lambda_G \qquad (x_1 = 3.83)$$

free parameter

Relation between ΛG and ΛΦ is

$$\Lambda_\phi = \sqrt{6}\Lambda_G$$

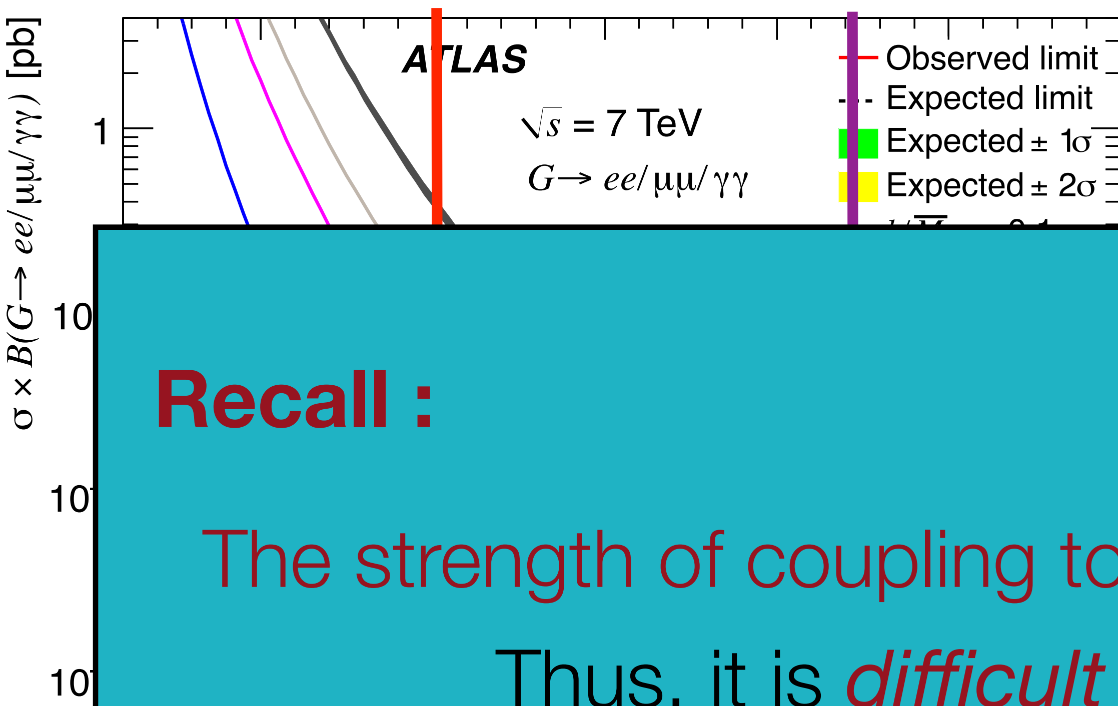
Thus the relation between ΛΦ and mG1 is

$$\therefore \quad \Lambda_\phi = \frac{\sqrt{6}}{x_1}\frac{M_{pl}}{k} m_{G_1}$$

k/Mpl=	0.1	0.01
mG1	2.23TeV	1.03TeV

k/Mpl=	0.1	0.01
ΛΦ	14.3TeV	65.8TeV

Constraints of ΛΦ



1st KK Graviton mass is

$$m_{G_1} = x_1 \frac{k}{M_{pl}} \Lambda_G \quad (x_1 = 3.83)$$

arX
for

Recall :

The strength of coupling to the SM fields is proportional to **1/ΛΦ.**

Thus, it is *difficult to discover light radion*.

→ Then we focus heavy radion search at LHC.

k/Mpl=	0.1	0.01
mG1	2.23TeV	1.03TeV

→

k/Mpl=	0.1	0.01
ΛΦ	14.3TeV	65.8TeV

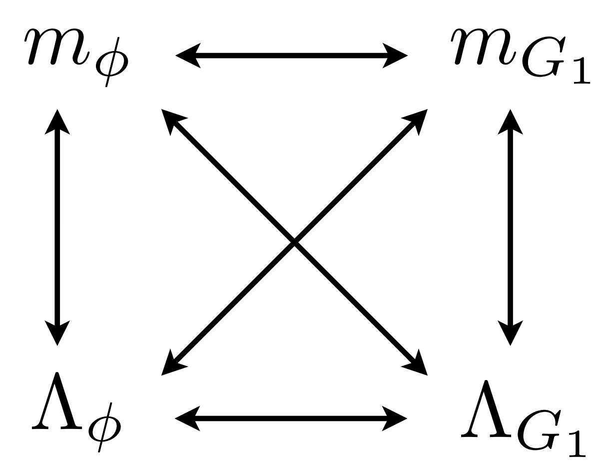
Considering the correlation between mΦ and k/Mpl

1st KK Graviton mass is

$$m_{G_1} = x_1 k e^{-kr_c}, \quad (x_1 = 3.83)$$

$$(\Lambda_G = M_{pl} e^{-k\pi r_c})$$

G.D. Kribs (2006)



Relation between ΛG and ΛΦ is

$$\Lambda_\phi = \sqrt{6}\Lambda_G$$

C. Csáki, J. Hubisz, S. J. Lee (2007)

In GWM, Relation between mΦ and mG1/ΛΦ is

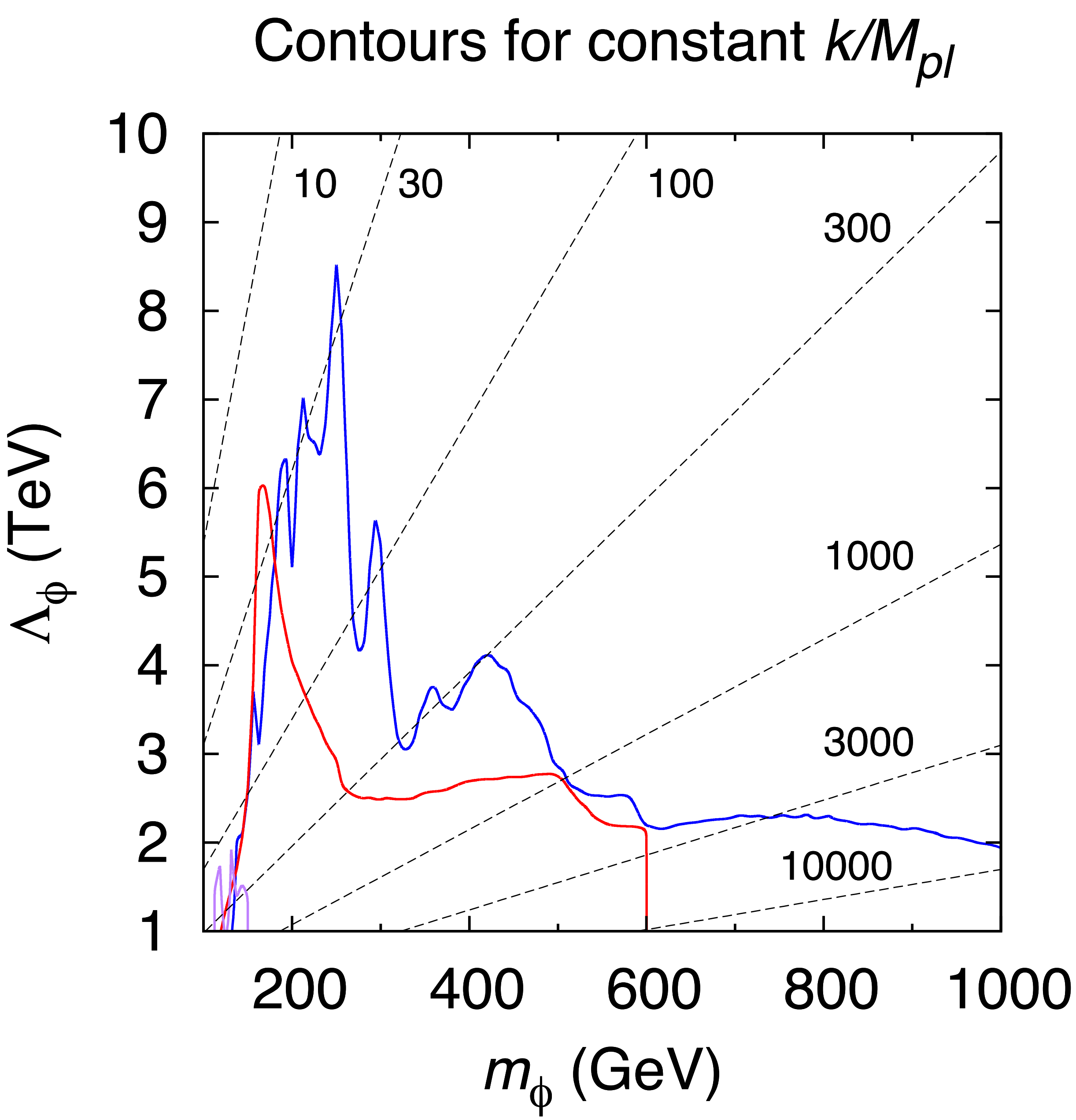
$$m_\phi = \sqrt{\frac{1}{3}\frac{k}{Mpl}}\,\epsilon\Lambda_G \quad , \quad \epsilon \sim 1/40$$

W. D. Goldberger, M. B. Wise (1999)

$$m_\phi = \sqrt{\frac{M_{pl}}{3k}\frac{\epsilon}{x_1}}\,m_{G_1}$$

$$m_\phi = \sqrt{\frac{k}{18M_{pl}}}\,\epsilon\Lambda_\phi$$

Results:



ex: natural $k/M_{pl} = 1, 0.1, 0.01$

unnatural $k/M_{pl} = 10, 0.00001...$

V：Conclusion (and Future Works...)

∗ We study production and decay of the radion in Randall-Sundrum (RS) model at the LHC taking account of the recent SM Higgs search by the ATLAS and CMS experiments.

∗ A certain class of new physics predicts extra neutral scalars, e.g., MSSM/THDM...

∗ Discrimination of radion to heavier Higgs in MSSM is studied (in a decoupling scenario in MSSM Higgs sector)

∗ From analysis, we found useful modes to discriminate two models (RS,MSSM) .

- Φ → WW/ZZ (no H/A → WW/ZZ)
- Number of events (pp→Φ→WW/ZZ) ∼ 1000 (WW @8TeV, $\mathcal{L}$ =100 $[fb]^{-1}$, ΛΦ=5TeV)

∼ 500 (ZZ @8TeV, $\mathcal{L}$=100 $[fb]^{-1}$, ΛΦ=5TeV)

(for mΦ=1TeV)

∗ Our future works:

estimation of backgrounds, p_T cut ,...