Low scale supergravity mediation in brane world scenario and hidden sector phenomenology

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Hideo Itoh (KEK)
in collaboration with
Nobuchika Okada (KEK) and Toshifumi Yamashita (SISSA)

1.Introduction

Standard Model → We have fine-tuning prob.

SM vacuum is not stable under quantum corrections
since Higgs self energy is UV sensitive: $\Delta m_h^2 \sim \Lambda^2$

Supersymmetry → A possibility to solve above prob.

New physics without quadratic div. in quantum corrections

Minimal Supersymmetric SM (MSSM)

Minimal supersymmetric extension of the Standard Model

But…

Sparticles have not been observed yet

SUSY must be broken at low energy

↓ MSSM

We introduce soft breaking terms to break SUSY by hand

SUSY should be spontaneously broken

What is the origin of SUSY breaking?

Basic scenario

SUSY is broken by hidden sector

Simplest hidden sector model

Polonyi model: $W = m^2 X + \text{const.} \rightarrow F_X = m^2 \neq 0$

X : super field of hidden sector
F_X: F-term of hidden sector

SUSY breaking is caused by F-term of hidden sector

Next we consider SUSY breaking mediation

Image of SUSY breaking mediation

Hidden sector → Mediated by gravity, gauge, anomaly, gaugino… → MSSM sector

$F_X \neq 0$ (SUSY)

gravity
gauge
anomaly
gaugino… at Λ which is a mediation scale

SUSY breaking effect is mediated at mediation scale Λ

Ex.)

- gravity mediation (mSUGRA)

$$\Lambda = M_{\mathrm{Pl}} = 10^{18}\mathrm{GeV}$$

- gauge mediation

$$\Lambda = M_{\mathrm{Messenger}} \geq 100\mathrm{TeV}$$

Sparticle mass

Sfermion mass: $\widetilde{m}$

Gaugino mass: $M_{1/2}$

$$\left.\begin{array}{l}\widetilde{m}\\ M_{1/2}\end{array}\right\} \sim \frac{F_X}{\Lambda}$$

Our work

We propose a new scenario of the low scale SUGRA mediation

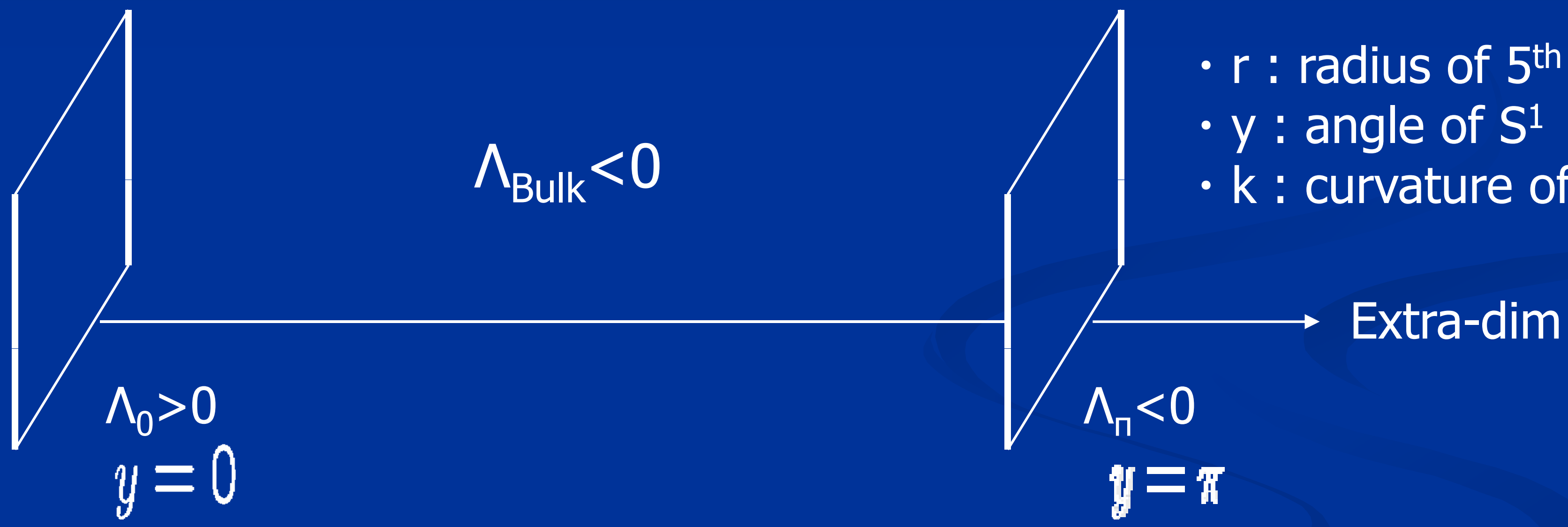
- Brane world scenario in warped extra dimensions
- Mediation scale becomes low: $\Lambda \sim 1$–10TeV
- Interesting collider phenomena as will be shown

2.New low scale SUSY breaking model

Brane setup in warped extra dimensions (Randall-Sundrum setup)

We conpactified 5th dim. as S^1/Z_2 orbifolding

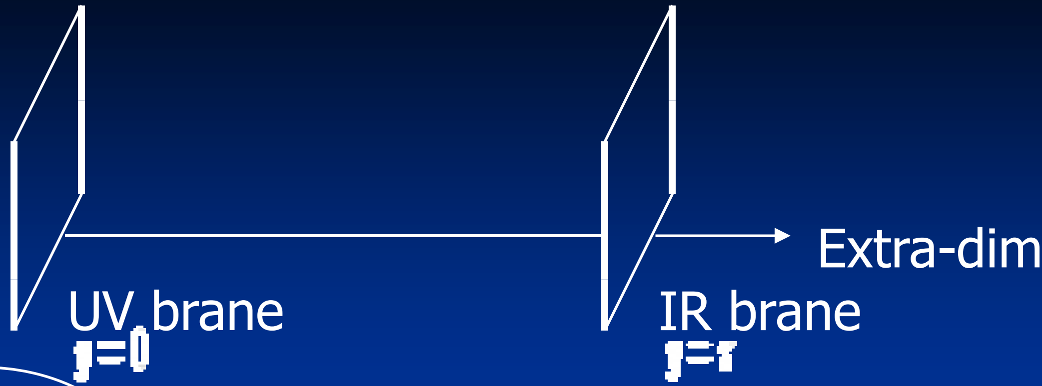
- r : radius of 5th dim.
- y : angle of S^1
- k : curvature of bulk



Solution of Einstein eq.

$$ds^2 = e^{-2kr|y|}\eta_{\mu\nu}dx^\mu dx^\nu + r^2 dy^2$$

On the IR brane



$$ds^2 = e^{-2kr|y|}\eta_{\mu\nu}dx^\mu dx^\nu + r^2 dy^2$$

$$\omega \equiv e^{-kr\pi}$$ ← Warp factor

In effective 4-dim. theory

Cutoff on the IR brane (Λ_{IR}) is effectively "warped down"

$$\Lambda_{IR} = \omega M_{Pl}$$

Our new field setup on branes

Both of the hidden and visible sectors on the same IR brane

In this setup, SUSY breaking mediation is the same as mSUGRA on the IR brane.

Sparticle masses on this set up

Generate from higher dimensional operators

$$\int d^4\theta \frac{X^\dagger X}{M_{Pl}^2} Q_i^\dagger Q_j \rightarrow \int d^4\theta \frac{X^\dagger X}{\Lambda_{IR}^2} Q_i^\dagger Q_j \Rightarrow \tilde{m}^2 = \frac{|F_X|^2}{\Lambda_{IR}^2}$$

$$\int d^2\theta \frac{X}{M_{Pl}} \mathrm{Tr}[\mathcal{W}^\alpha \mathcal{W}_\alpha] \rightarrow \int d^2\theta \frac{X}{\Lambda_{IR}} \mathrm{Tr}[\mathcal{W}^\alpha \mathcal{W}_\alpha] \Rightarrow M_{1/2} = \frac{F_X}{\Lambda_{IR}}$$

4D mSUGRA case

Suppressed by effective mass scale $\Lambda_{IR} = \omega M_{Pl}$ not by 4D Planck scale!

Warp factor is a free parameter of our model

$\rightarrow \Lambda_{IR}$ is a free parameter!

Interaction between hidden and visible sectors

If $\Lambda_{IR} << M_{Pl}$ → Contact int. between hidden and visible sectors become strong!

$$\int d^2\theta \frac{X}{\Lambda_{IR}} \mathrm{Tr}[\mathcal{W}^\alpha \mathcal{W}_\alpha] \to \frac{\mathrm{Re}(X)}{\Lambda_{IR}} F^{\mu\nu} F_{\mu\nu} + \cdots$$

$$\int d^4\theta \frac{X^\dagger + X}{\Lambda_{IR}} Q^\dagger Q \to 2\frac{\mathrm{Re}(X)}{\Lambda_{IR}} \overline{\psi}_q \sigma^\mu \partial_\mu \psi_q + \cdots$$

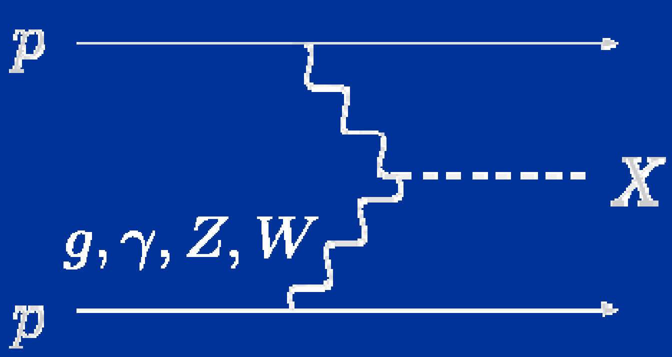
In the following, we investigate hidden sector pheno.

3.Hidden sector phenomenology

If Λ_{IR} is order TeV scale → Can produce hidden sector at collider experiments

If the hidden sector scalar X is light enough (M_X < 1TeV), it can be produced at LHC and ILC!

LHC

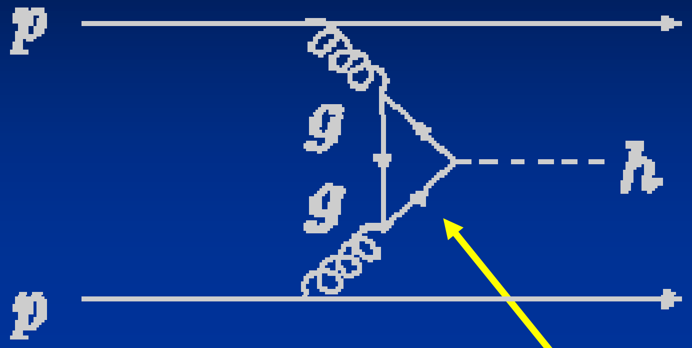


ILC

Production processes are similar to Higgs productions

At LHC

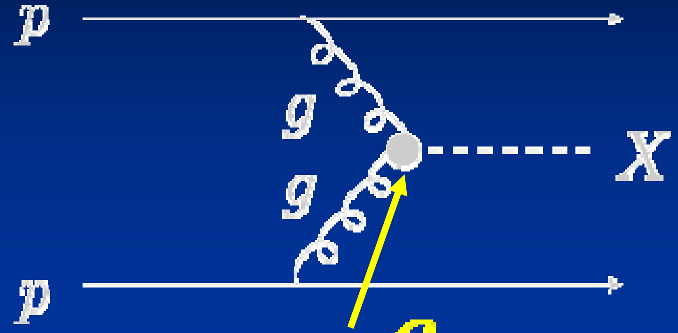
- Higgs production



$$\mathcal{L}_{eff} \sim \frac{\alpha_s}{16\pi v} h G^a_{\mu\nu} G^{a\mu\nu}$$

$$\frac{\alpha_s}{16\pi v}$$

- X-production



$$\frac{c}{4\Lambda_{IR}}$$

- $m_X \sim m_h \sim 120\mathrm{GeV}$
- $\Lambda_{IR} \sim 10\mathrm{TeV}$

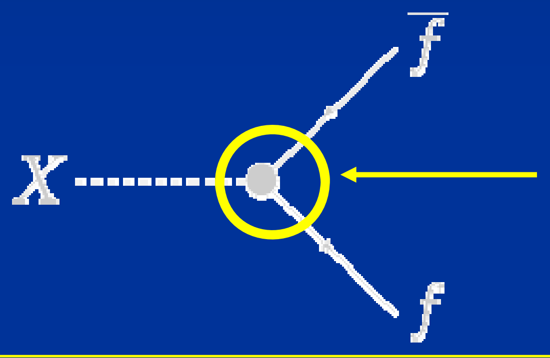
$$\sigma_X \sim \sigma_h$$

But, the decay processes are quite different as will be discussed in the following

Decay processes

X to SM fermion pair coupling

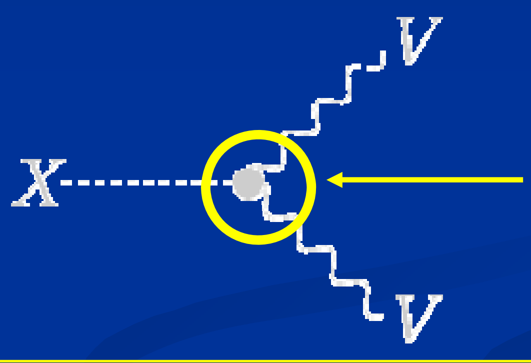
$$\int d^4\theta\, c\, \frac{X + X^\dagger}{\Lambda_{\mathrm{IR}}} Q^\dagger Q \to c\, \frac{\mathrm{Re}(X)}{\Lambda_{\mathrm{IR}}} \mathcal{L}_{\mathrm{kin}}$$



$$\sim \frac{m_f}{\Lambda_{\mathrm{IR}}}$$

X to gauge boson pair coupling

$$\mathcal{L}_{\mathrm{int}} \supset -\frac{1}{4}\frac{\mathrm{Re}(X)}{\Lambda_{\mathrm{IR}}}\left(c_3 \mathrm{Tr}[G^{\mu\nu}G_{\mu\nu}] + c_2 \mathrm{Tr}[F^{\mu\nu}F_{\mu\nu}] + c_1 B^{\mu\nu}B_{\mu\nu}\right)$$



$$\sim \frac{m_X}{\Lambda_{\mathrm{IR}}}$$

Partial decay width into light fermion pairs is very much suppressed

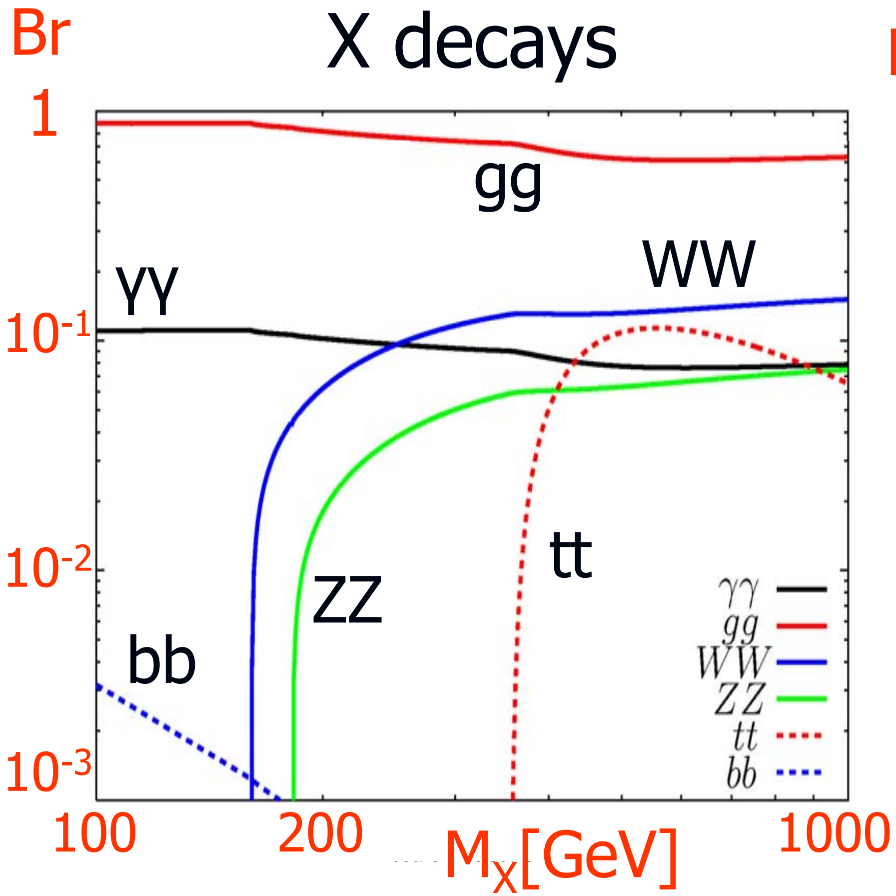
$$\Gamma(X \to f\bar{f}) \propto \left(\frac{m_f}{\Lambda_{\mathrm{IR}}}\right)^2 m_X \leftrightarrow \Gamma(X \to VV) \propto \left(\frac{m_X}{\Lambda_{\mathrm{IR}}}\right)^2 m_X$$

This feature is quite different in comparison with Higgs case.

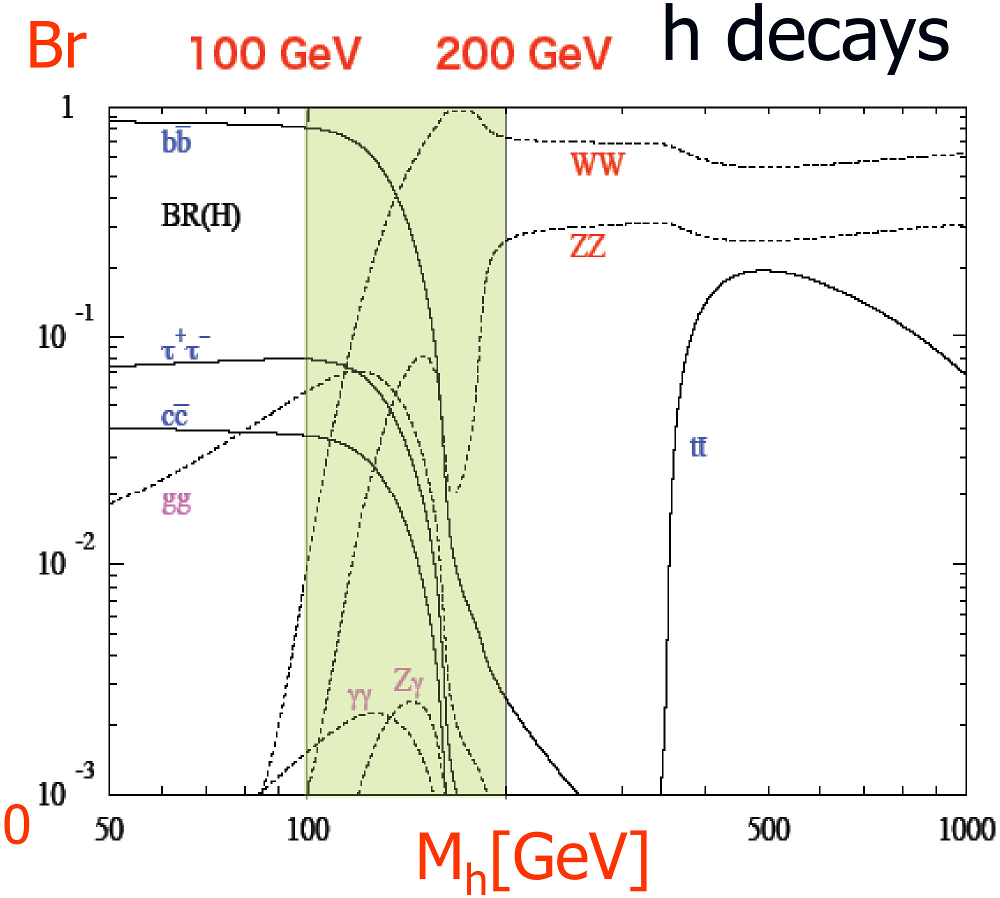
$$\Gamma(h \to b\bar{b}) \gg \Gamma(h \to \gamma\gamma) \leftrightarrow \Gamma(X \to b\bar{b}) \ll \Gamma(X \to \gamma\gamma)$$

(c, c_1, c_2 and c_3 are order one parameters)

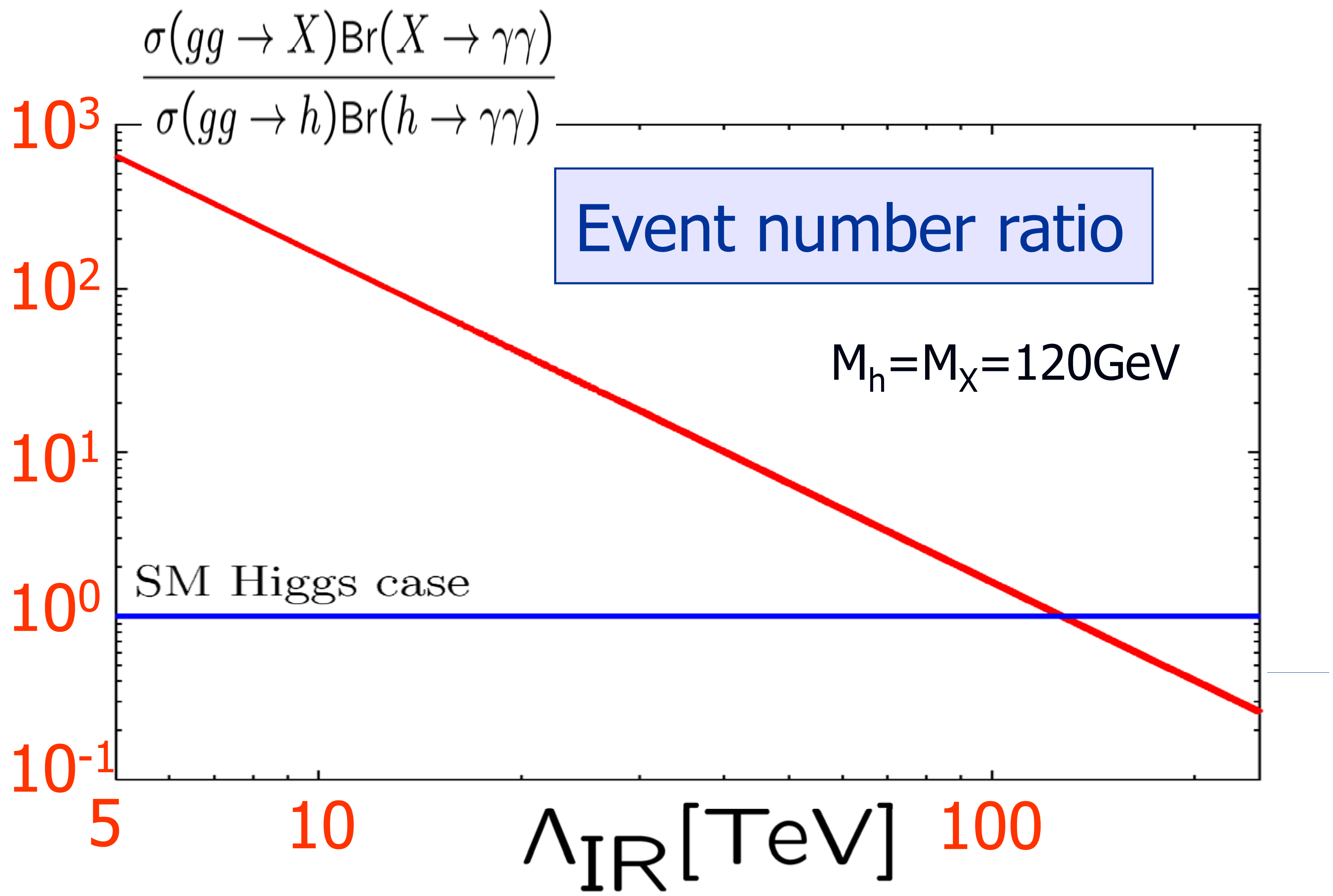
Branching ratio



Assumed: $c_1 = c_2 = c_3 = 1$



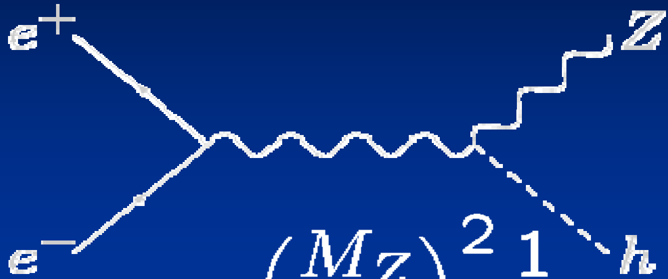
Br($X \to \gamma\gamma$) is large.



Event number ratio is very much enhanced up to $\Lambda_{IR} \sim 100$TeV.
So we may probe hidden sector to use this signal at LHC.

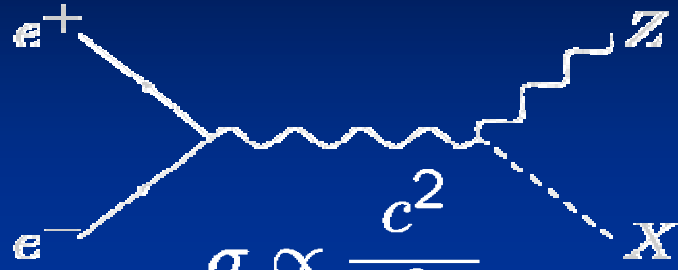
At ILC

Higgs production

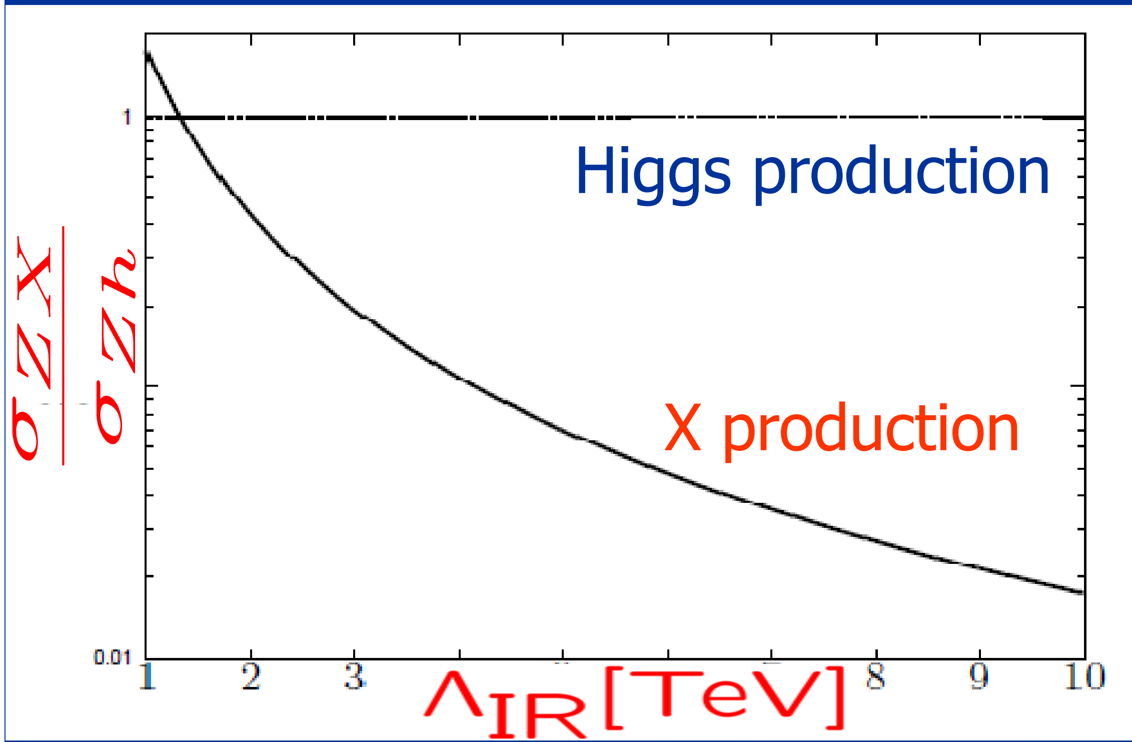


$$\sigma \propto \left(\frac{M_Z}{v}\right)^2 \frac{1}{s}$$

X production



$$\sigma \propto \frac{c^2}{\Lambda_{IR}^2}$$



$$\Lambda_{IR} \sim 1.3\text{TeV}$$
$$\downarrow$$
$$\sigma(e^+e^- \to ZX) \sim \sigma(e^+e^- \to Zh)$$

Angular distribution is quite different as you will see next.

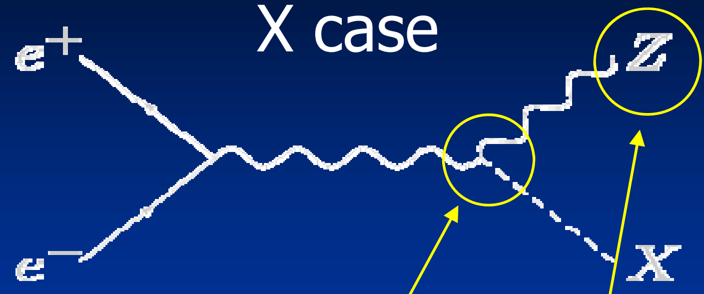
Angular distribution

Higgs case

$$2\frac{M_Z^2}{v} h Z_\mu Z^\mu$$

Longitudinal mode dominates

X case

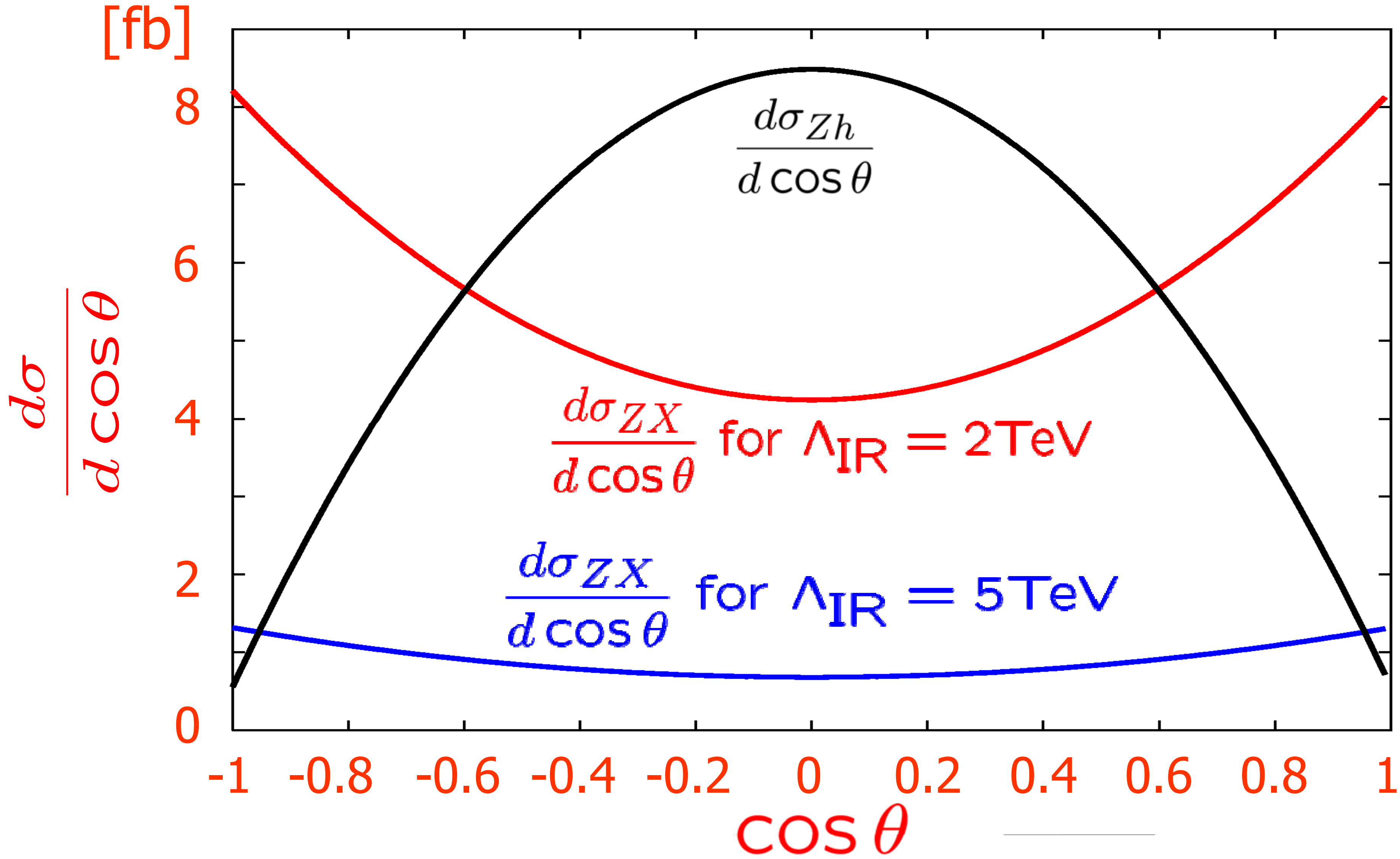


$$\frac{1}{\Lambda_{IR}} X F_{\mu\nu} F^{\mu\nu}$$

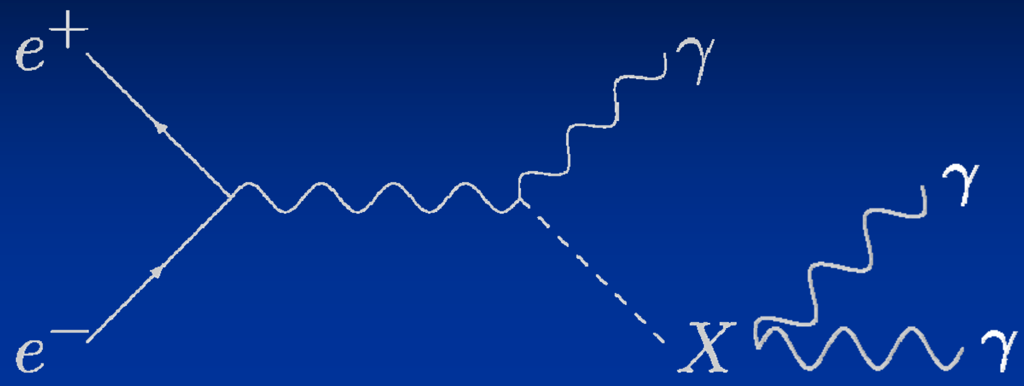
Transverse mode dominates

$$\frac{d\sigma_{Zh}}{d\cos\theta} \propto (1-\cos^2\theta) \leftrightarrow \frac{d\sigma_{ZX}}{d\cos\theta} \propto (1+\cos^2\theta)$$

Angular distribution



Other interesting process



$$\sigma(e^+e^- \to \gamma X) = c_g \frac{\alpha_{em}}{48}\left(1 - \frac{M_X^2}{s}\right)^3 \frac{1}{\Lambda_{IR}}$$

If $c_g = 1$, $M_X = 120[\mathrm{GeV}]$, $\Lambda_{IR} = 1[\mathrm{TeV}]$, $\alpha_{em} = \frac{1}{129}$, and $\sqrt{s} = 500[\mathrm{GeV}]$

$$\sigma(e^+e^- \to \gamma X) = 52.5[\mathrm{fb}]$$

$X \to \gamma\gamma$: $\mathrm{Br} \sim 0.1$

No SM background!

We are doing simulation studies
H. Itoh, K. Fujii, N. Okada & T. Yoshioka,
work in progress

4.Summary

We have proposed a new setup
of the mSUGRA in warped extra dimensions.

- Visible and hidden sectors on the same IR brane
- Cutoff scale can be low

Cutoff scale is low

→ Enhanced contact interactions between hidden and visible fields

The hidden sector field may be produced at LHC or ILC!

Production processes are similar to Higgs

Cutoff scale ~ TeV

Production cross sections become comparable with Higgs case

<u>But</u>

Decay processes are quite different

Br($X \to \gamma\gamma$) is enhanced event number very much in comparison with $h \to \gamma\gamma$.
This signal is large and clean at LHC!!

We may detect hidden sector at LHC and ILC!

Back up slide

Another interesting feature

In our model

$$\mathcal{L}_{\rm int} \supset -\frac{1}{4}\frac{{\rm Re}(X)}{\Lambda_{\rm IR}}\left(c_3 {\rm Tr}[G^{\mu\nu}G_{\mu\nu}] + c_2 {\rm Tr}[F^{\mu\nu}F_{\mu\nu}] + c_1 B^{\mu\nu}B_{\mu\nu}\right)$$

induce

relation

Gaugino masses

$$M_i = c_i \frac{F_{X_1}}{\Lambda_{\rm IR}}$$

$c1 = c2 = c3 = 1$

$$M_1 = M_2 = M_3$$

Decay width of X to VV

$$\Gamma(X\to gg) = \frac{c_3^2}{8\pi}\frac{m_X^3}{\Lambda_{\rm IR}^2}$$

$$\Gamma(X\to \gamma\gamma) = \frac{c_1\cos^2\theta_W + c_2\sin^2\theta_W}{64\pi}\frac{m_X^3}{\Lambda_{\rm IR}^2}$$

$$\Gamma(X\to ZZ) \simeq \frac{c_1\sin^2\theta_W + c_2\cos^2\theta_W}{64\pi}\frac{m_X^3}{\Lambda_{\rm IR}^2}$$

$$\Gamma(X\to W^+W^-) \simeq \frac{c_2^2}{32\pi}\frac{m_X^3}{\Lambda_{\rm IR}^2}$$

$$X \to gg, \gamma\gamma, ZZ, W^+W^- = 8:1:1:2$$

4. $\Lambda_{IR} \sim$ 10TeV is natural

$\Lambda_{\rm IR} \sim 10\,{\rm TeV} \to \sigma_X \sim \sigma_h$ at LHC

⇒ We may probe the hidden sector.

In the RS brane setup, it is natural that $\Lambda_{IR} \sim$ 10TeV.

$$k \times r \sim 10 \quad \to \quad \omega = e^{-kr\pi} \sim 10^{-14}$$

(Suppose mild hierarchy)

$$\Lambda_{\rm IR} = \omega M_{\rm Pl}$$

Every original mass scale is warped down on the IR brane.

Ex.) $\sqrt{F_X} \sim 0.1 M_{\rm Pl} \to 0.1 \omega M_{\rm Pl} = 0.1 \Lambda_{\rm IR} \sim 1\,{\rm TeV}$

$\mu \sim 0.1 M_{\rm Pl} \to 1\,{\rm TeV}$

<u>From a view point of naturalness,</u>

<u>everything looks like going well…</u>

• Backup slide

Gravitino mass

4D effective theory → should reproduce 4D gravity correctly

$$m_{3/2} \simeq \frac{F_X}{M_{Pl}} \simeq \tilde{m} \times \left(\frac{\Lambda_{IR}}{M_{Pl}}\right)$$

Gravitino becomes LSP by warping down