

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

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# 1. Introduction

Standard Model  $\longrightarrow$  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  $\longrightarrow$  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

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

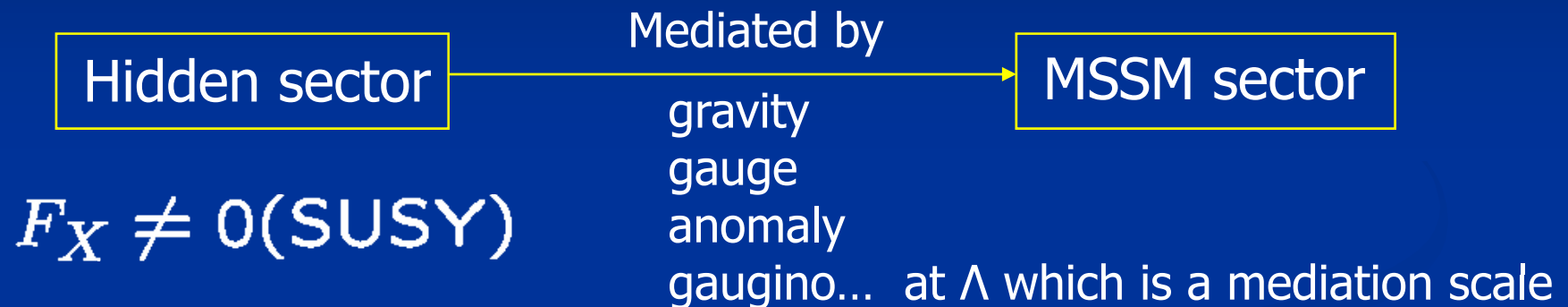
$X$  : super field of hidden sector

$F_X$  : 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



SUSY breaking effect is mediated at mediation scale  $\Lambda$

Ex.) • gravity mediation (mSUGRA)

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

• gauge mediation

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

## Sparticle mass

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

## Our work

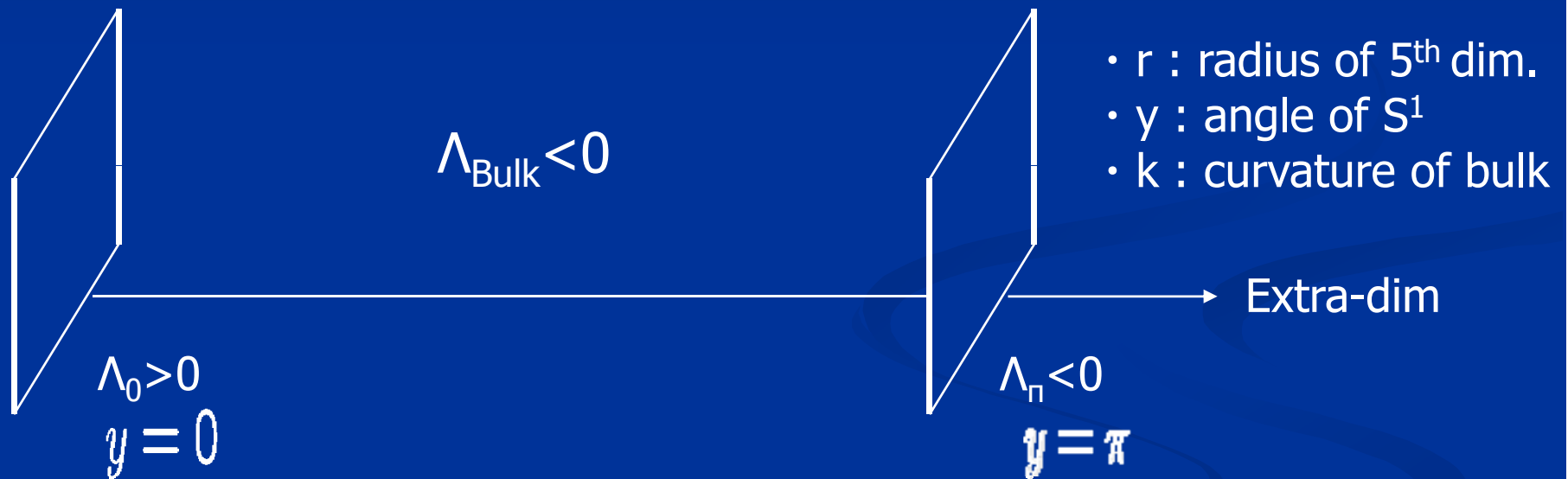
We propose a new scenario of the low scale SUGRA mediation

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

## 2. New low scale SUSY breaking model

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

We compactified 5<sup>th</sup> dim. as  $S^1/Z_2$  orbifolding



Solution of Einstein eq.

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

On the IR brane



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

$$\omega \equiv e^{-kr\pi} \quad \leftarrow \text{Warp factor}$$

In effective 4-dim. theory

Cutoff on the IR brane ( $\Lambda_{\text{IR}}$ ) is effectively "warped down"

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



## 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

$$\int d^4\theta \frac{X^\dagger X}{M_{\text{Pl}}^2} Q_i^\dagger Q_j \rightarrow \int d^4\theta \frac{X^\dagger X}{\Lambda_{\text{IR}}^2} Q_i^\dagger Q_j \Rightarrow \tilde{m}^2 = \frac{|F_X|^2}{\Lambda_{\text{IR}}^2}$$
$$\int d^2\theta \frac{X}{M_{\text{Pl}}} \text{Tr}[W^\alpha W_\alpha] \rightarrow \int d^2\theta \frac{X}{\Lambda_{\text{IR}}} \text{Tr}[W^\alpha W_\alpha] \Rightarrow M_{1/2} = \frac{F_X}{\Lambda_{\text{IR}}}$$

4D mSUGRA case

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

Warp factor is a free parameter of our model  
 $\rightarrow \Lambda_{\text{IR}}$  is a free parameter!

## Interaction between hidden and visible sectors

If  $\Lambda_{\text{IR}} \ll M_{\text{Pl}}$

Contact int. between hidden and visible sectors become strong!

$$\int d^2\theta \frac{X}{\Lambda_{\text{IR}}} \text{Tr}[\mathcal{W}^\alpha \mathcal{W}_\alpha] \rightarrow \frac{\text{Re}(X)}{\Lambda_{\text{IR}}} F^{\mu\nu} F_{\mu\nu} + \dots$$
$$\int d^4\theta \frac{X^\dagger + X}{\Lambda_{\text{IR}}} Q^\dagger Q \rightarrow 2 \frac{\text{Re}(X)}{\Lambda_{\text{IR}}} \bar{\psi}_q \sigma^\mu \partial_\mu \psi_q + \dots$$

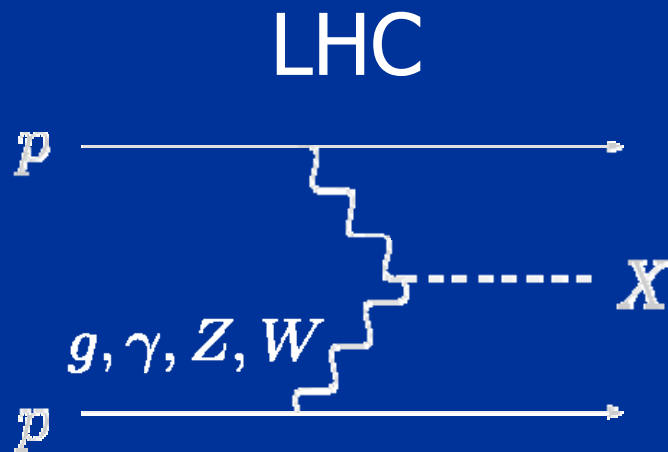
In the following, we investigate hidden sector pheno.

### 3. Hidden sector phenomenology

If  $\Lambda_{\text{IR}}$  is order TeV scale

Can produce hidden sector at collider experiments

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



Production processes are similar to Higgs productions

# At LHC

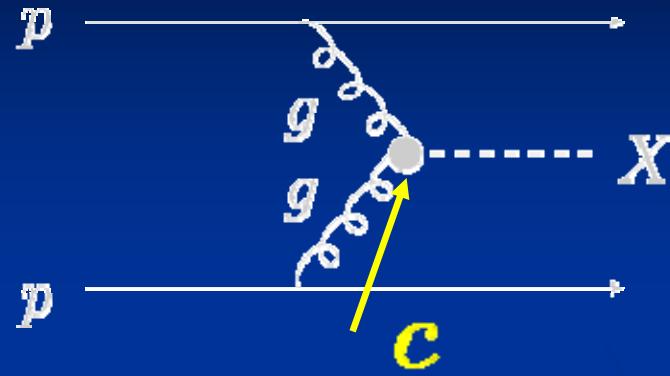
## • Higgs production



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

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

## • X-production



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

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

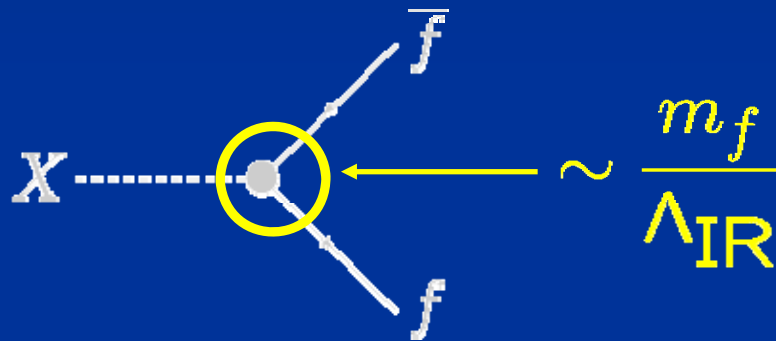
$$\sigma_X \sim \sigma_h$$

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

# Decay processes

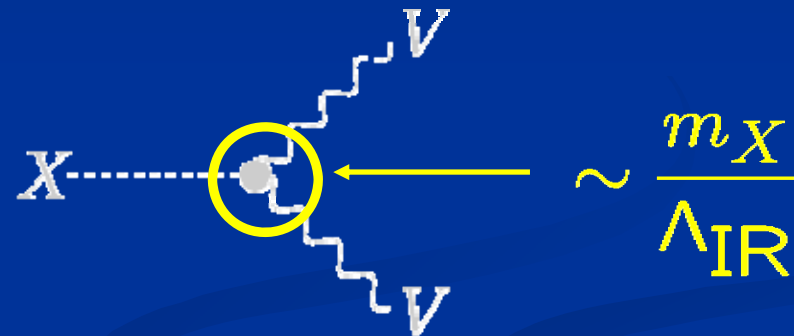
X to SM fermion pair coupling

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



X to gauge boson pair coupling

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



Partial decay width into light fermion pairs is very much suppressed

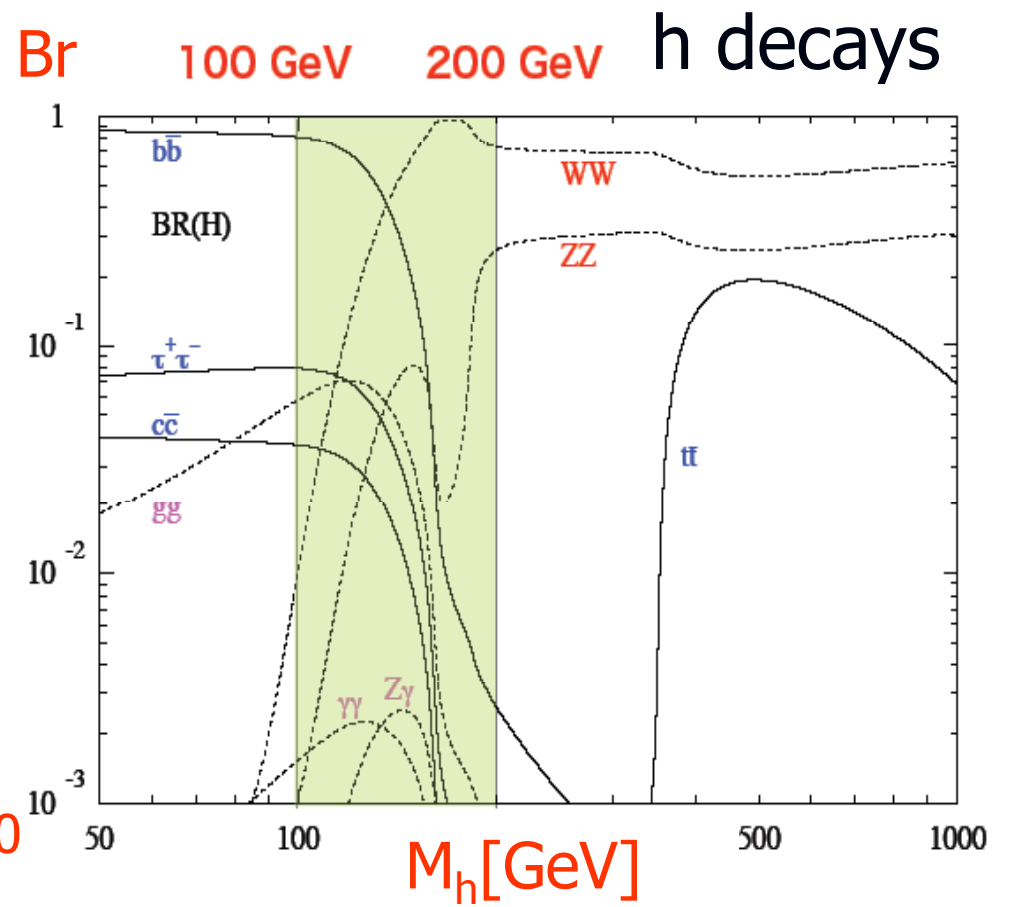
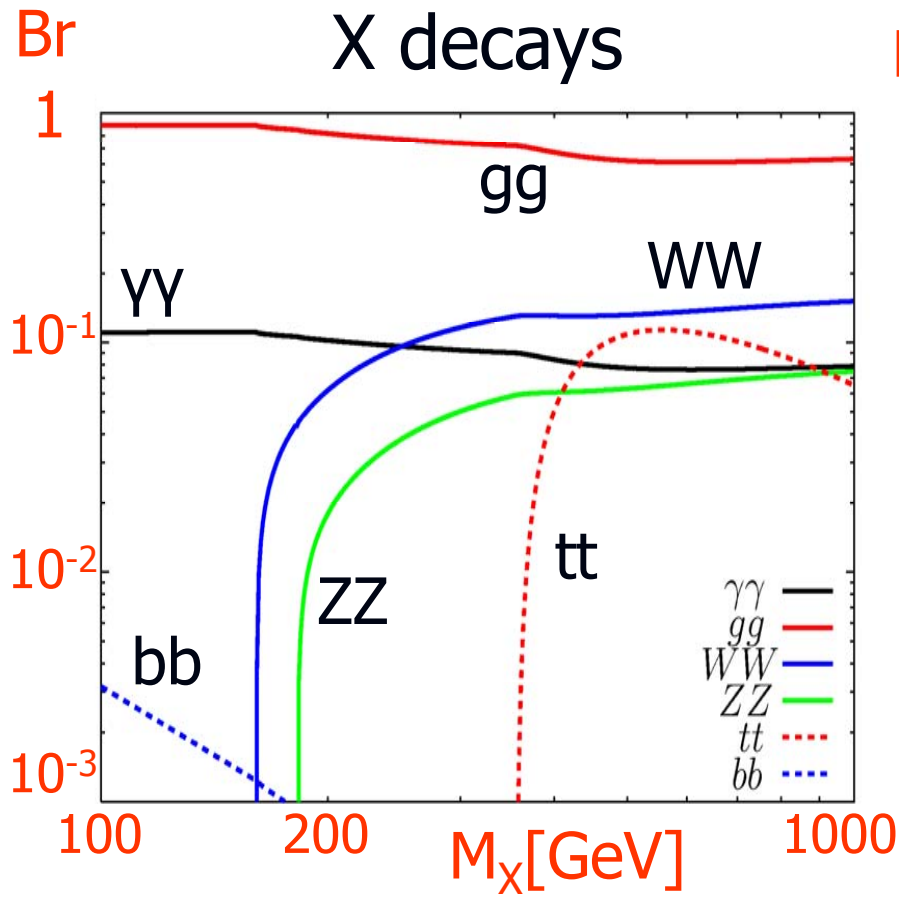
$$\Gamma(X \rightarrow f\bar{f}) \propto \left(\frac{m_f}{\Lambda_{\text{IR}}}\right)^2 m_X \leftrightarrow \Gamma(X \rightarrow VV) \propto \left(\frac{m_X}{\Lambda_{\text{IR}}}\right)^2 m_X$$

This feature is quite different in comparison with Higgs case.

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

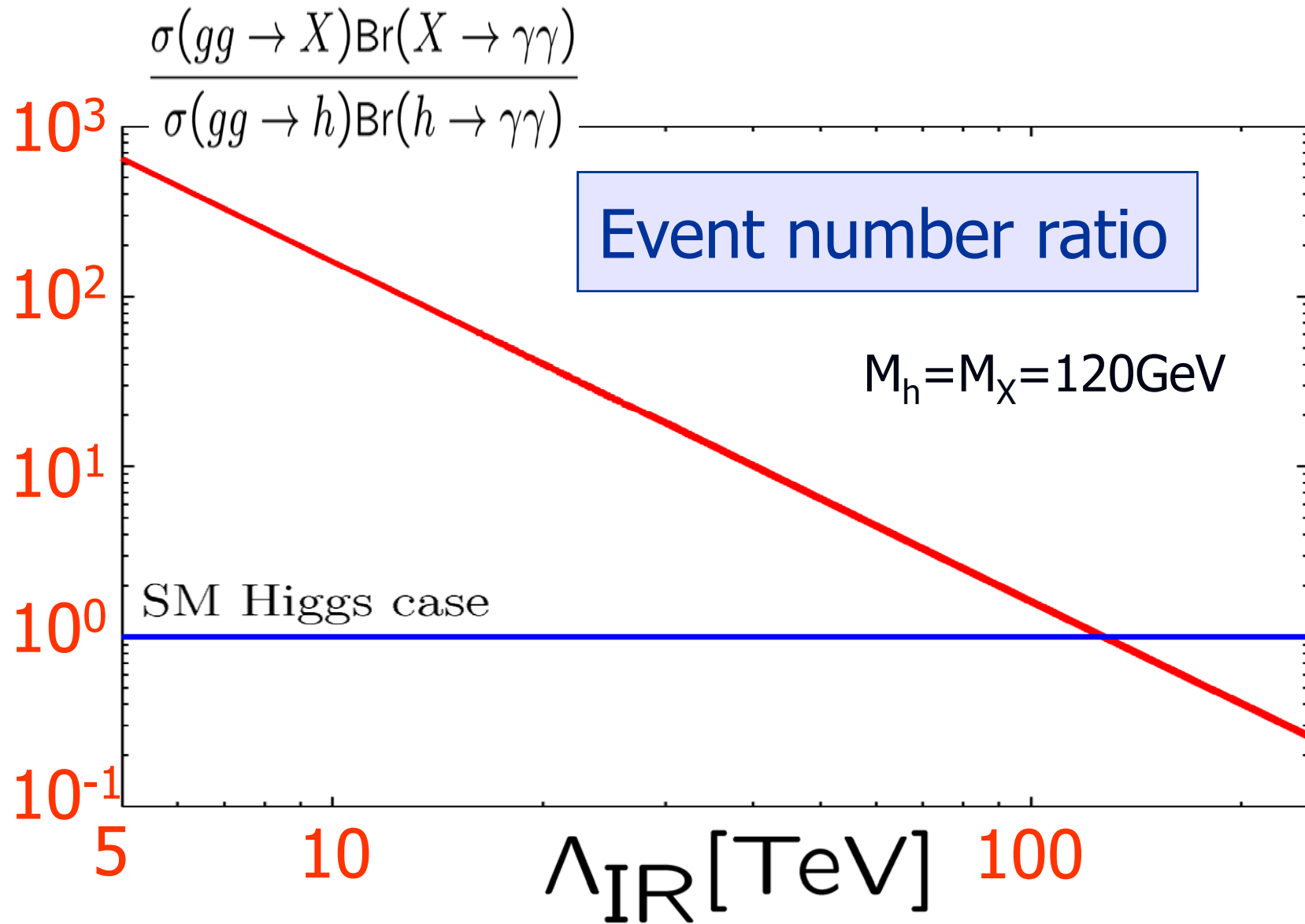
(c, c<sub>1</sub>, c<sub>2</sub> and c<sub>3</sub> are order one parameters)

Branching ratio



Assumed:  $c_1 = c_2 = c_3 = 1$

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

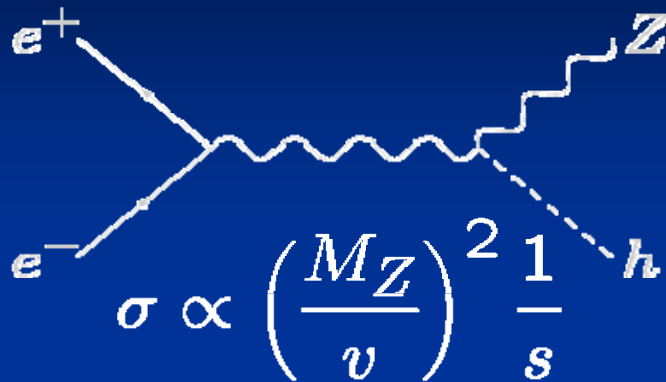


Event number ratio is very much enhanced up to  $\Lambda_{\text{IR}} \sim 100\text{TeV}$ .  
 So we may probe hidden sector to use this signal at LHC.

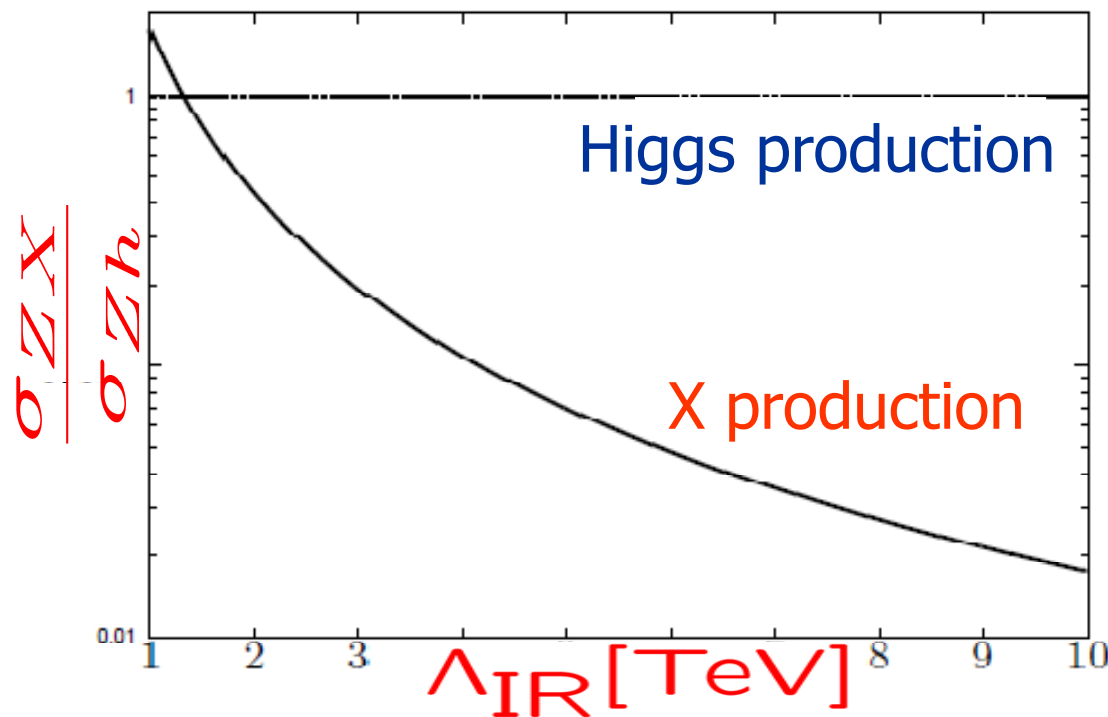
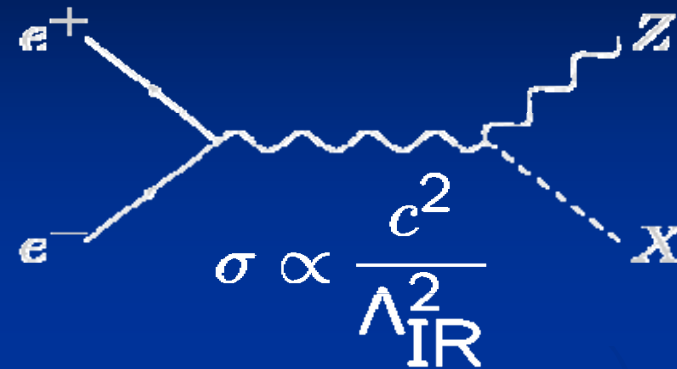


# At ILC

Higgs production



X production



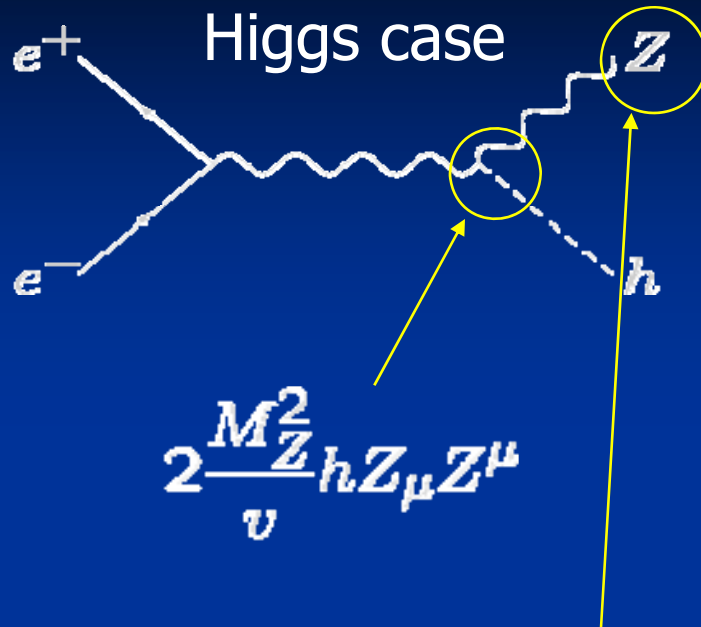
$$\Lambda_{IR} \sim 1.3 \text{ TeV}$$



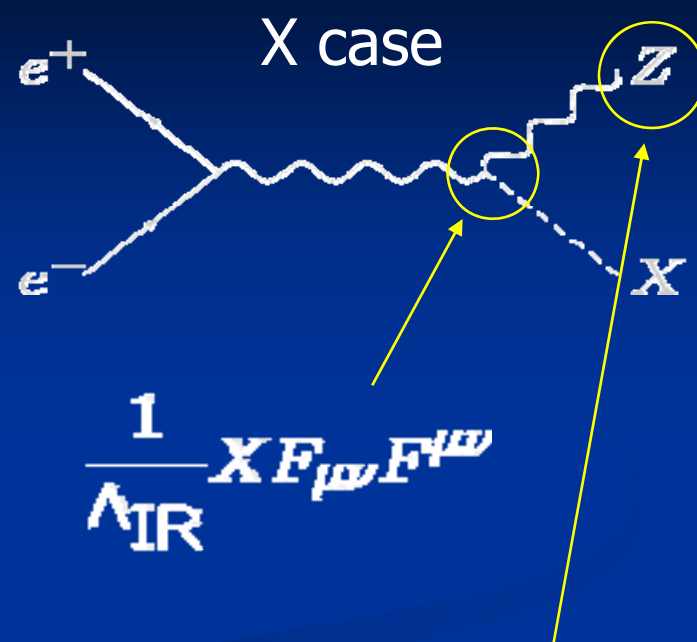
$$\sigma(e^+e^- \rightarrow ZX) \sim \sigma(e^+e^- \rightarrow Zh)$$

Angular distribution is quite different as you will see next.

# Angular distribution



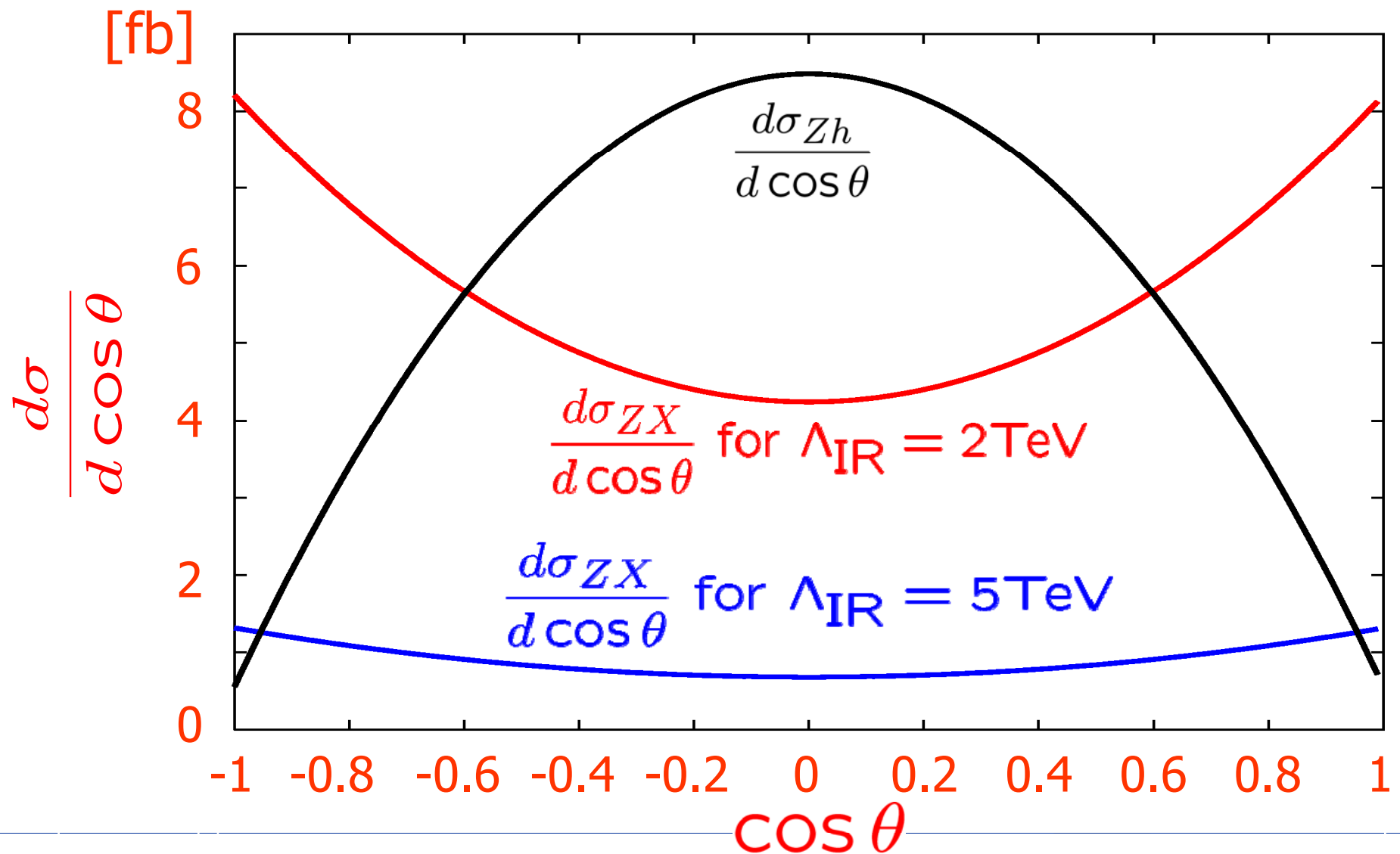
Longitudinal mode  
dominates



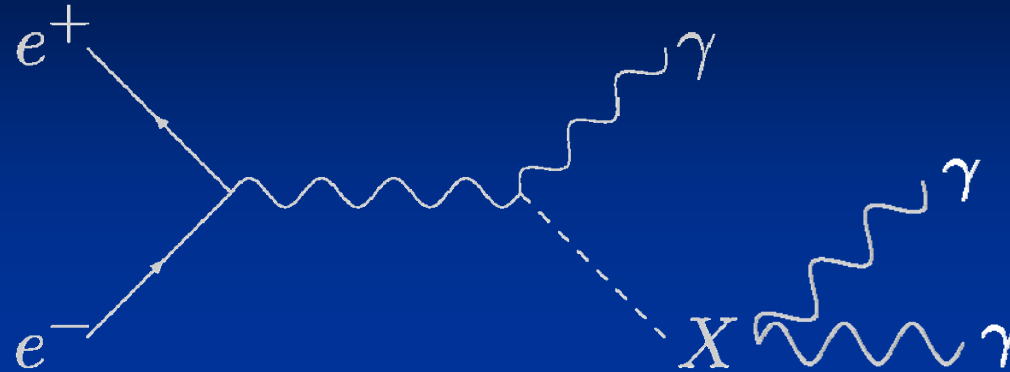
Transverse mode  
dominates

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

# Angular distribution



## Other interesting process



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

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

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

$$\gamma\gamma : \text{Br} \sim 0.1$$

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

**No SM background!**

## 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  $\sim$  TeV

Production cross sections become comparable with Higgs case

But

Decay processes are quite different

$\text{Br}(X \rightarrow \gamma\gamma)$  is enhanced event number very much in comparison with  $h \rightarrow \gamma\gamma$ .

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

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

induce

Gaugino masses

relation

Decay width of X to VV

$$M_i = \frac{c_i F_X}{\Lambda_{\text{IR}}}$$

$$M_1 = M_2 = M_3$$

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

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

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

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

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



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

$$\Lambda_{\text{IR}} \sim 10\text{TeV} \rightarrow \sigma_X \sim \sigma_h \text{ at LHC}$$

↳ We may probe the hidden sector.

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

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

(Suppose mild hierarchy)

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

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

$$\text{Ex.) } \sqrt{F_X} \sim 0.1 M_{\text{Pl}} \rightarrow 0.1 \omega M_{\text{Pl}} = 0.1 \Lambda_{\text{IR}} \sim 1\text{TeV}$$
$$\mu \sim 0.1 M_{\text{Pl}} \rightarrow 1\text{TeV}$$

From a view point of naturalness,  
everything looks like going well...

# • 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