Low scale gravity mediation in warped extra dimensions and collider phenomenology on sector hidden sector

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hep-ph/0603xxx, in preparation

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1. Introduction

Fine-tuning (naturalness) problem in the Standard Model

Serious problem: SM vacuum is not stable under quantum corrections

because Higgs self energy is UV sen $\Delta m_h^2 \sim \Lambda_{new}^2$

In order to solve this problem → Supersymmetry (SUSY)

New Physics without quadratic divergence in quantum corrections

But… sparticles have not been observed yet

→ SUSY should be broken at low energy

Basic model for phenomenology → MSSM with soft SUSY breaking terms

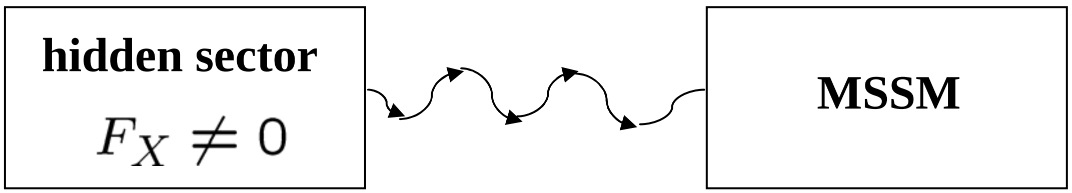
Important issues: Origin of SUSY breaking?

Origin of SUSY breaking mediation to MSSM sector?

1. SUSY breaking in hidden sector

Singet chiral superfield: $X = \theta^2 F_X \neq 0$

2. Some mechanism for SUSY breaking mediation



gravity, gauge,…

Effective interaction for SUSY braking mediation

Gaugino masses: $\int d^2\theta c \frac{X}{\Lambda} tr[\mathcal{W}^\alpha \mathcal{W}_\alpha] \to M_{1/2} = c \frac{F_X}{\Lambda}$

Sfermion masses: $\int d^4\theta \, c_0 \frac{X^\dagger X}{\Lambda^2} Q_i^\dagger Q_i \to \tilde{m}_0^2 = c_0 \frac{|F_X|^2}{\Lambda^2}$

Λ : **SUSY breaking mediation scale**

Ex) Gravity mediaiton (mSUGRA): $\Lambda \to M_P$

Gauge mediation: $\Lambda \to M_{messenger}$ $(> 100\text{TeV})$

What if $\Lambda \sim 1 - 10\text{TeV}$?

← **SUSY breaking mediation @ very low scale**

1. **Is there any model?**
2. **New phenomenology @ future colliders?**

Plan of this Talk

1. **Introduction**
2. **New SUSY breaking mediation scenario @ low scale**

   ``Low scale gravity mediation in warped extra-dimension''

   $\Lambda = 1 - 10\text{TeV}$ **is possible without any fine-tuning**
3. **Collider phenomenology on hidden sector fields**

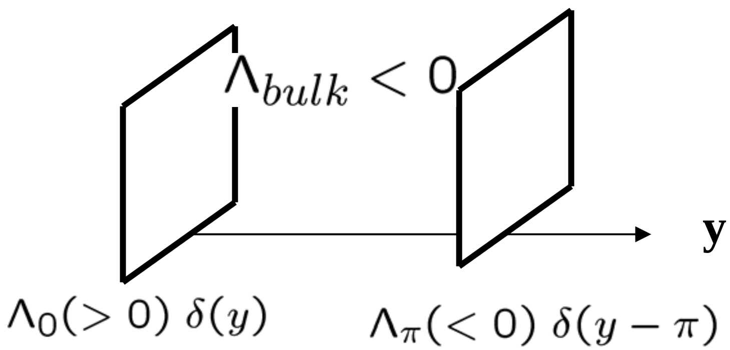
   low Λ → **strong interaction among hidden & MSSM sector fields**
4. **Summary**

2. Model ``low scale gravity mediation in warped extra-dimensions''

Warped Extra Dimension Scenario (Randall-Sundrum type scenario)

Randall & Sundrum, PRL 83, 3370 (1999)

5-dim. theory compactified on orbifold S^1/Z_2



slice of AdS_5

$$S_G = -\frac{1}{2}\int d^4x \int_0^\pi dy \sqrt{-g}\left(M_5^3 R_5 + \Lambda\right)$$

$$S_{\substack{UV\\IR}} = \int d^4x \sqrt{-g_{\substack{UV\\IR}}}\left(\mathcal{L}_{\substack{UV\\IR}} - \Lambda_{\substack{UV\\IR}}\right)$$

Solution of Einstein Eqs.

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

Flat 4D theory

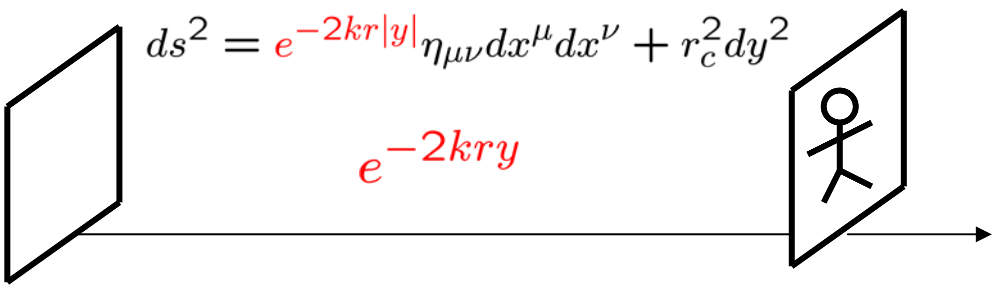
Appropriate tuning of cosmological constants in the bulk and on the branes

$$\Lambda_{bulk} = -24 M_5^3 k$$

$$\Lambda_0 = -\Lambda_\pi = 24 M_5^3 k$$

Warping down of the scale $M \to M\omega$

→ mass parameter on IR brane is always accompanied by the warp factor $\omega = e^{-kr\pi}$



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

$$e^{-2kry}$$

- r : radius of 5[th] dim.
- y : angle of S^1

UV brane $y = 0$ **IR brane** $y = \pi$

M_P → ``warping down'' → $\Lambda_{IR} = M_P\omega$

Effective cutoff (gravity) scale on IR brane

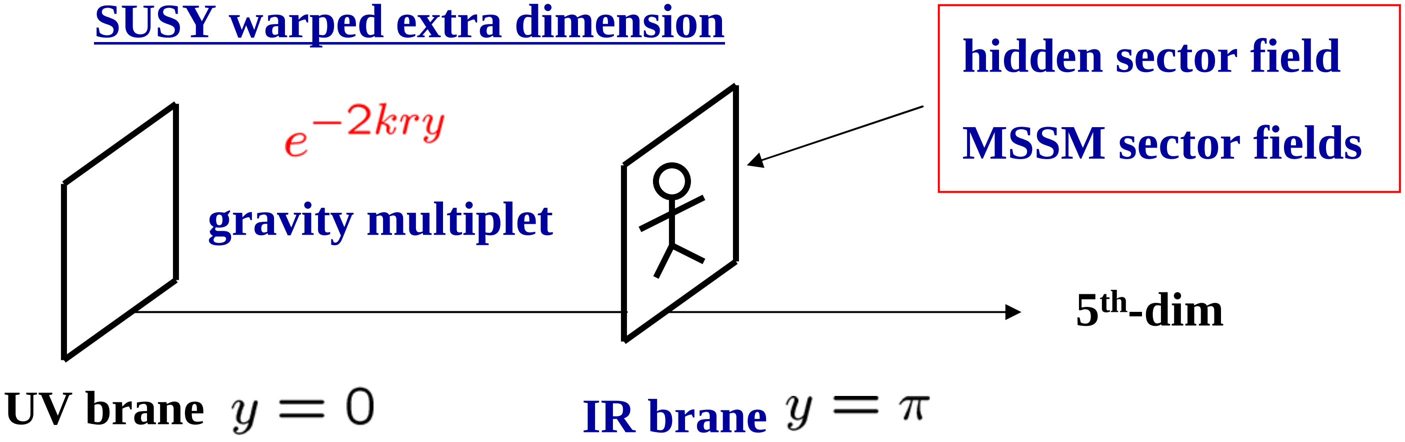
We need just a mild hierarchy

$$\left.\begin{array}{l} k \sim M_p \\ \frac{1}{r} \sim 0.1 M_P \end{array}\right\} \rightarrow \omega = e^{-kr\pi} \sim 10^{-15} - 10^{-14}$$

Λ_{IR} can be 1-10 TeV!

Low scale gravity mediation

Setup **SUSY warped extra dimension**



Gravity mediation (mSUGRA) on IR brane

Usual 4D mSUGRA

$$\int d^2\theta \frac{X}{M_P} tr[\mathcal{W}^\alpha \mathcal{W}_\alpha] \qquad\longrightarrow\qquad \int d^2\theta \frac{X}{\Lambda_{IR}} tr[\mathcal{W}^\alpha \mathcal{W}_\alpha] \to M_{1/2} = \frac{F_X}{\Lambda_{IR}}$$

$$\int d^4\theta \frac{X^\dagger X}{M_P^2} Q^\dagger Q \qquad\longrightarrow\qquad \int d^4\theta \frac{X^\dagger X}{\Lambda_{IR}^2} Q^\dagger Q \to \tilde{m}^2 = \frac{|F_X|^2}{\Lambda_{IR}^2}$$

Suppressed by effective cutoff scale Λ_{IR} not by 4D Planck scale!

Consequence in low scale mSUGRA mediation

Scale down of $\Lambda_{IR} \ll M_P$ due to the warp factor

(we take $\Lambda_{IR} \sim 1 - 10\text{TeV}$)

→ Strong contact interactions among hidden and visible sector fields

The same Lagrangians which provide soft terms

lead to

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

$$\int d^4\theta \frac{X^\dagger X}{\Lambda_{IR}^2} Q^\dagger Q \rightarrow \frac{\langle X^\dagger \rangle}{\Lambda_{IR}} \frac{X}{\Lambda_{IR}} \frac{i}{2} \bar{\psi}_q \sigma^\mu \partial_\mu \psi_q + \cdots$$

3. Collider phenomenology on hidden sector field

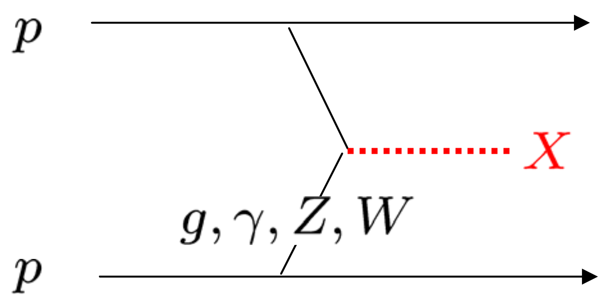
Itoh, N.O. & Yamashita, in preparation

$$-\frac{1}{4}\int d^2\theta \left(1 + c_i \frac{X}{\Lambda_{IR}}\right) \mathcal{W}_i^{\alpha}\mathcal{W}_{\alpha i} \to \quad \mathcal{L}_{int} \supset -\frac{c_i}{4}\frac{Re(X)}{\Lambda_{IR}} tr\left[\mathcal{F}_i^{\mu\nu}\mathcal{F}_{\mu\nu\, i}\right]$$

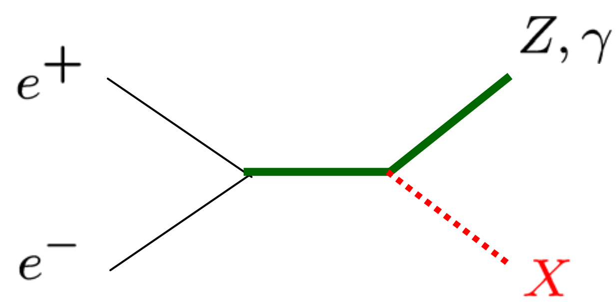
$$\int d^4\theta \left(1 + c_0 \frac{X + X^{\dagger}}{\Lambda_{IR}}\right) Q_i^{\dagger} Q_i \to \mathcal{L}_{int} \supset 2c_0 \frac{Re(X)}{\Lambda_{IR}} \mathcal{L}_{kin}^{fermion}$$

If the hidden sector scalar X is light enough → produce at LHC and ILC!

LHC



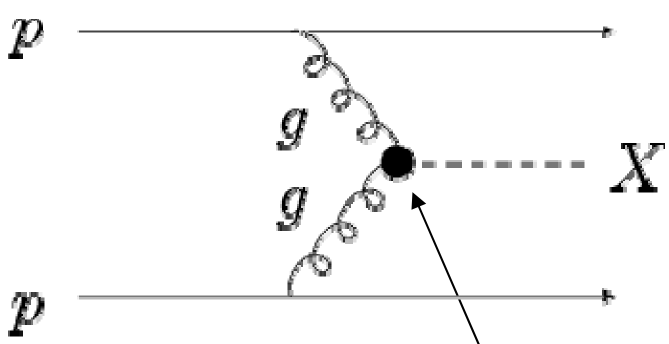
ILC



Production processes are similar to Higgs production

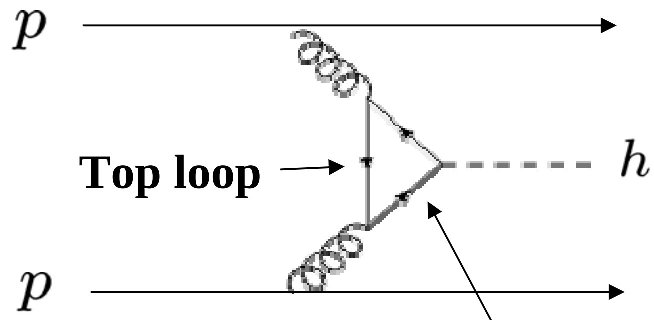
X-production @ LHC via gluon fusion

X particle behaves like Higgs boson



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

Higgs production via gluon fusion



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

$$\mathcal{L}_{eff} = -\frac{c}{4\Lambda_{IR}} X\, G^a_{\mu\nu} G^{a\mu\nu}$$

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

Suppose $m_X \sim m_h,\ c \sim 1$

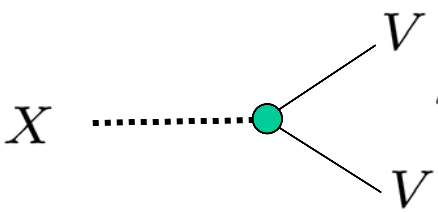
$$\Lambda_{IR} \sim 10\text{TeV} \to \sigma_X \sim \sigma_h$$

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

X decay

Couplings to gauge bosons

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



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

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

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

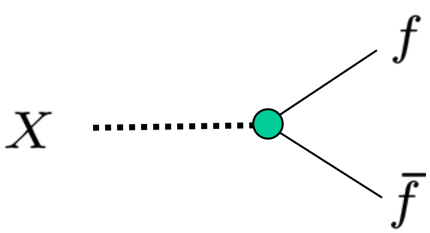
$$\Gamma(X \to ZZ) \simeq \frac{(c_1 \sin^2\theta_w + c_2 \cos^2\theta_w)^2}{64\pi}\frac{m_X^3}{\Lambda_{IR}^2}$$

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

$$\Gamma(X \to \gamma Z) \simeq \frac{(\sin\theta_w \cos\theta_w (c_1 - c_2))^2}{64\pi}\frac{m_X^3}{\Lambda_{IR}^2}$$

Coupling to fermions

$$\mathcal{L}_{int} \supset 2c_0 \frac{Re(X)}{\Lambda_{IR}}\mathcal{L}_{kin}^{fermion}$$



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

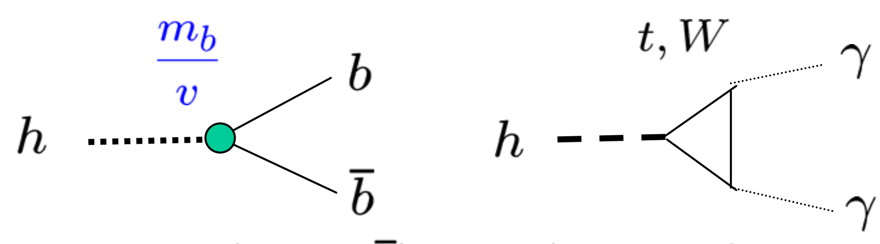
$$\Gamma(X \to f\bar{f}) = \frac{c_0^2}{4\pi}\left(\frac{m_X m_f^2}{\Lambda_{IR}^2}\right)$$

For X decay

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

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

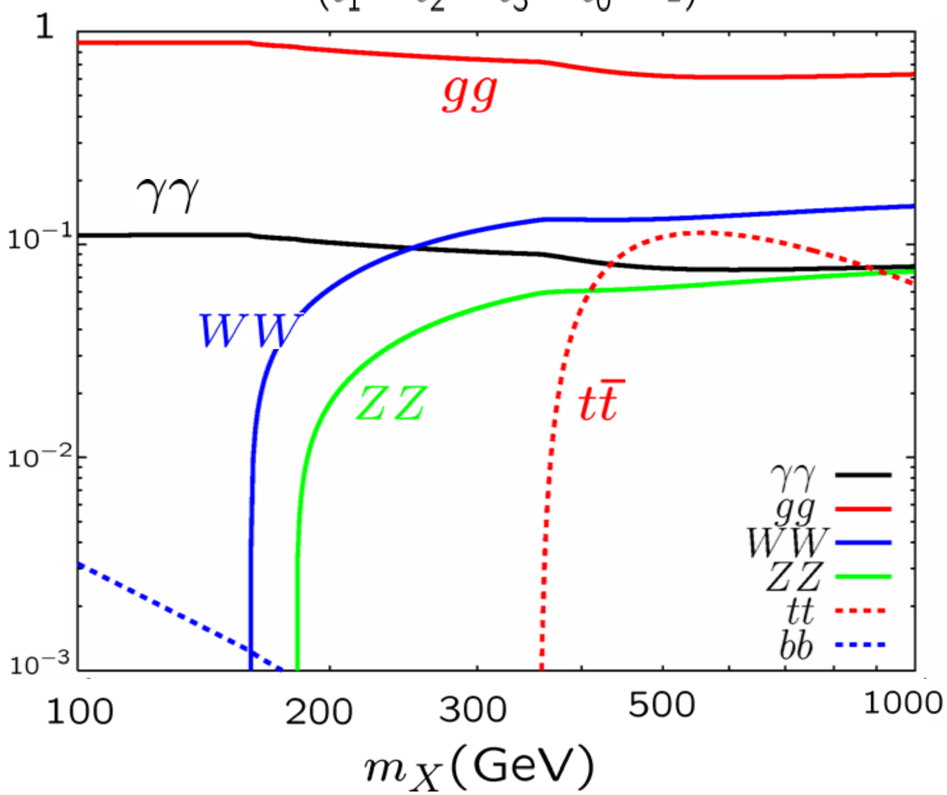
For Higgs decay



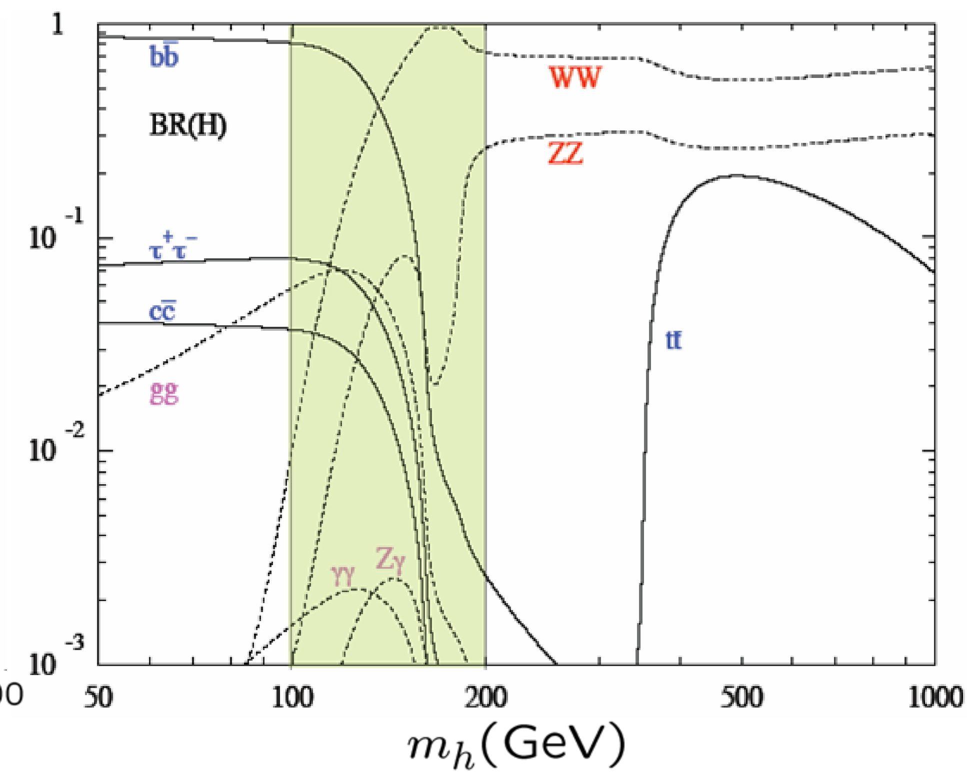
$$\Gamma(h \to b\bar{b}) \gg \Gamma(h \to \gamma\gamma)$$

Branching ratio

X boson $(c_1 = c_2 = c_3 = c_0 = 1)$



Higgs boson

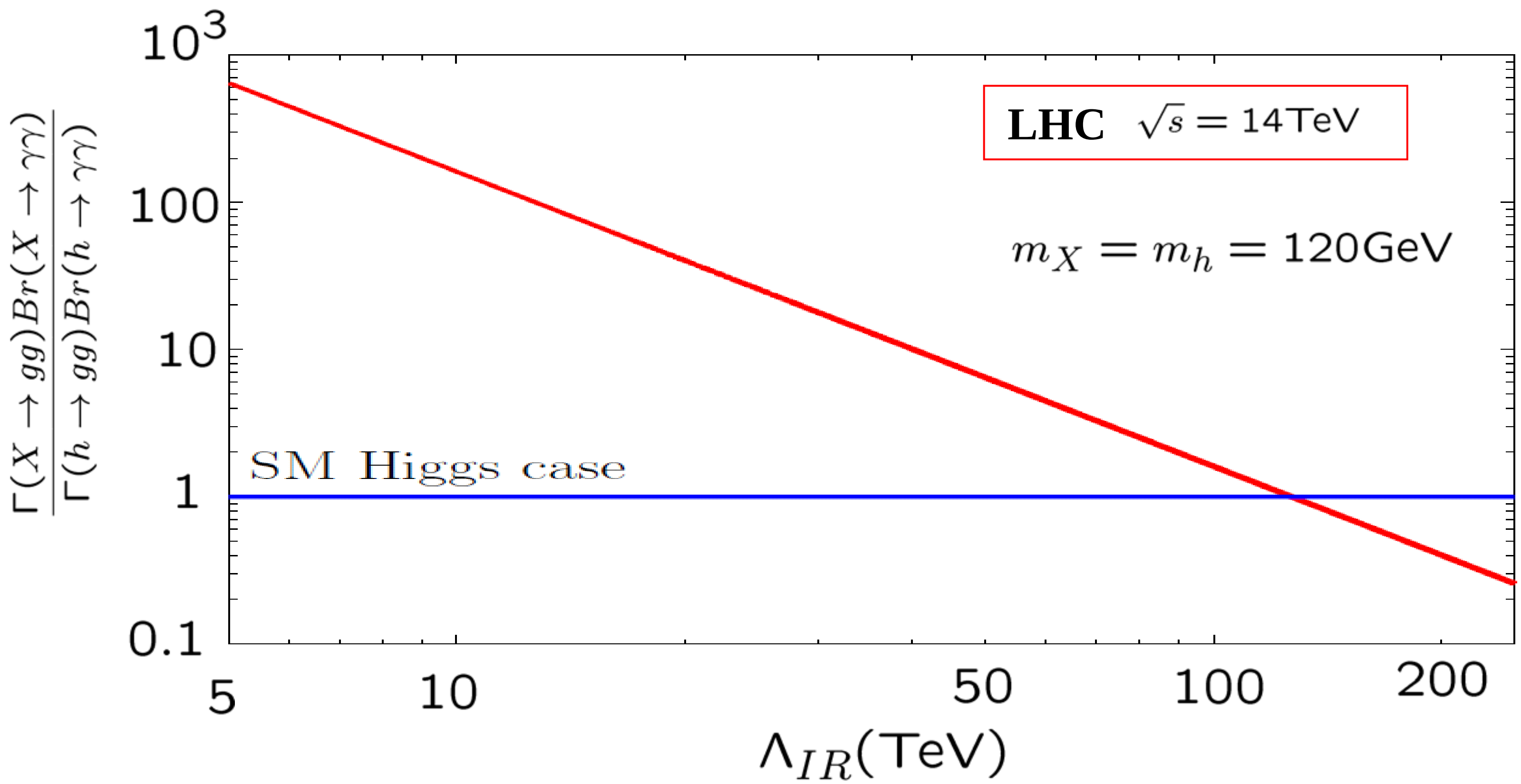


$\Lambda_{IR} = \mathcal{O}(10\text{TeV}) \rightarrow \sigma(gg \rightarrow X) \simeq \sigma(gg \rightarrow h)$

But, $Br(X \rightarrow \gamma\gamma) \simeq 100 \times Br(h \rightarrow \gamma\gamma)$

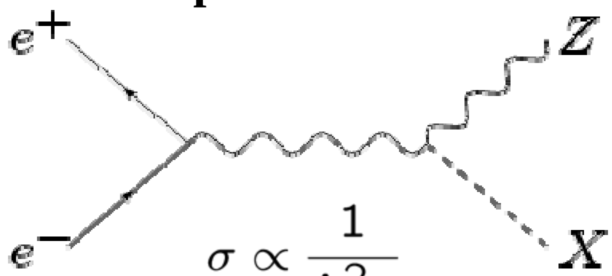
For light X boson, we can expect very clean signature of the process $gg \rightarrow X \rightarrow \gamma\gamma$ **for** $\Lambda_{IR} = \mathcal{O}(10\text{TeV})$

Event number ratio



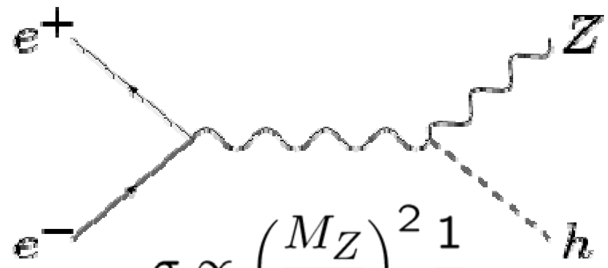
X-production @ ILC (associate production)

X production



$$\sigma \propto \frac{1}{\Lambda_{IR}^2}$$

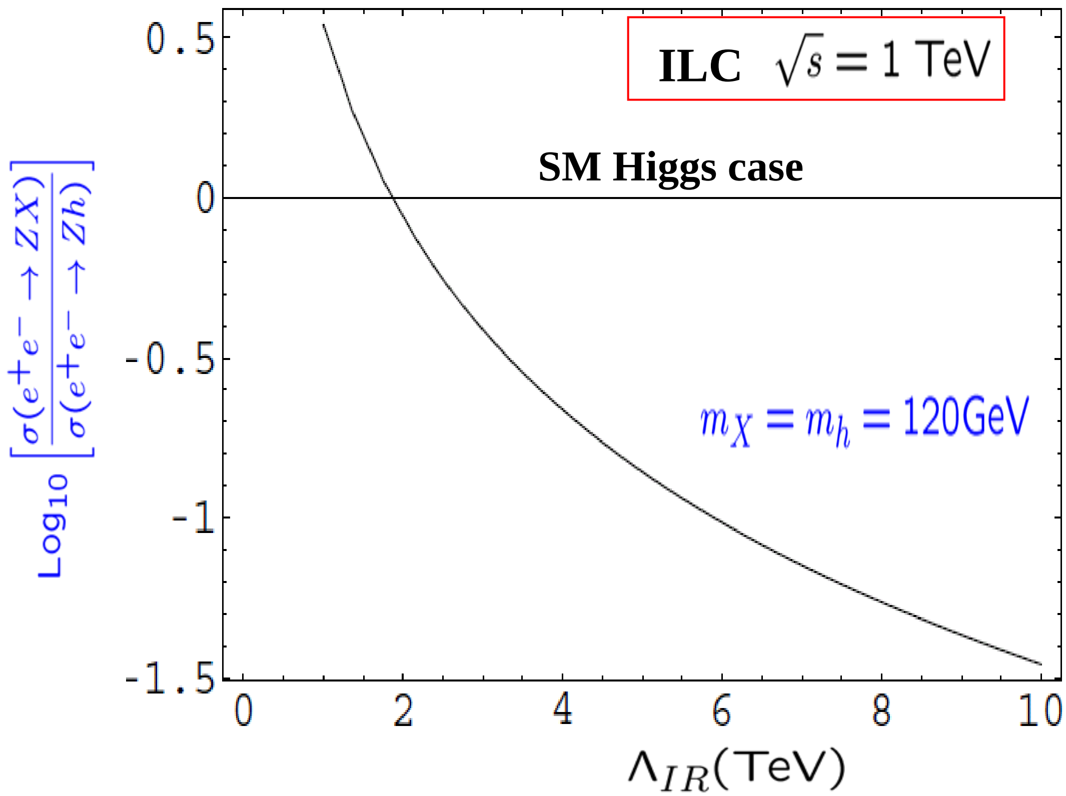
Higgs production



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

@ 1 TeV ILC $(\sqrt{s} \gg m_h, m_X)$

$$\frac{\sigma(e^+e^- \to ZX)}{\sigma(e^+e^- \to Zh)} \sim \left(\frac{1.85\text{TeV}}{\Lambda_{IR}}\right)^2$$



Angular distribution is different!

For X boson production

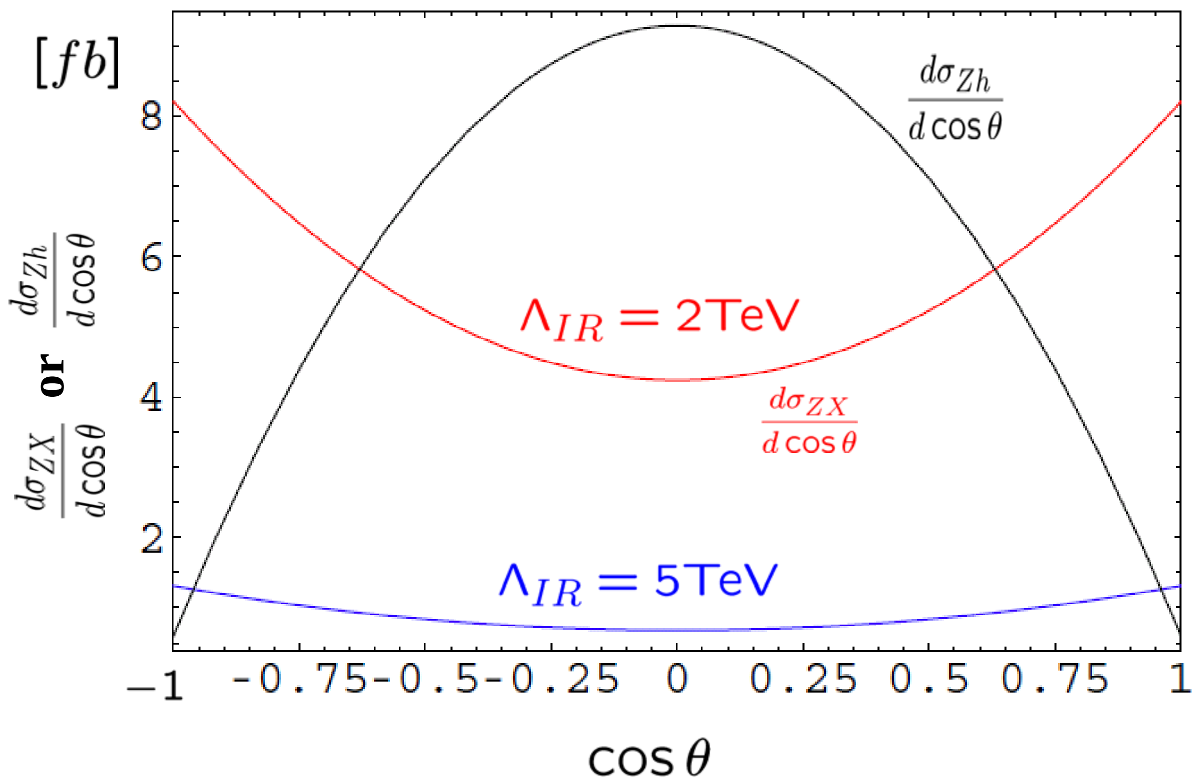
$$\mathcal{L}_{int} \sim X F^{\mu\nu} F_{\mu\nu}$$

$$\frac{d\sigma_{ZX}}{d\cos\theta} \sim (1 + \cos^2\theta)$$

For Higgs boson production

$$\mathcal{L}_{int} \sim h Z^{\mu} Z_{\mu}$$

$$\frac{d\sigma_{Zh}}{d\cos\theta} \sim (1 - \cos^2\theta)$$



ILC $\sqrt{s} = 1$ TeV

$m_X = m_h = 120\text{GeV}$

One more interesting feature

$$-\frac{1}{4}\int d^2\theta \left(1 + c_i \frac{X}{\Lambda_{IR}}\right) \mathcal{W}_i^\alpha \mathcal{W}_{\alpha i}$$

$$M_i = \frac{1}{2} c_i \frac{F_X}{\Lambda_{IR}}$$

Originate from the same L

$$\mathcal{L}_{int} \supset -\frac{c_i}{4} \frac{Re(X)}{\Lambda_{IR}} tr\left[\mathcal{F}_i^{\mu\nu} \mathcal{F}_{\mu\nu\ i}\right]$$

$$M_1(\Lambda_{IR}) : M_2(\Lambda_{IR}) : M_3(\Lambda_{IR})$$
$$= c_1 : c_2 : c_3$$

RGEs from Λ_{IR} to m_Z

$$M_1(M_Z) M_2(M_Z) : M_3(M_Z)$$
$$= \frac{\alpha_1(M_Z)}{\alpha_1(\Lambda_{IR})} c_1 : \frac{\alpha_2(M_Z)}{\alpha_2(\Lambda_{IR})} c_2 : \frac{\alpha_3(M_Z)}{\alpha_3(\Lambda_{IR})} c_3$$

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

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$$\Gamma(X \to \gamma Z) \simeq \frac{(\sin\theta_w \cos\theta_w (c_1 - c_2))^2}{64\pi} \frac{m_X^3}{\Lambda_{IR}^2}$$

gaugino mass spectrum ↔ **Partial decay width of X to two gauge bosons**

One to one correspondence

Measurements of M_i and Γ_i → check SUSY breaking mediation mechanism

4. Summary

We have proposed ``low scale gravity mediation scenario''
in warped extra dimensions

SUSY breaking mediation in the same manner as in mSUGRA,
but, with low scale $\Lambda_{IR} \sim 1 - 10\text{TeV}$

Strong contact interactions between hidden and MSSM sector fields

Collider phenomenology on hidden sector fields

→ **hidden sector field production @ LHC and ILC**

We can expect clean signature of $gg \to X \to \gamma\gamma$ **@LHC**

Hidden sector is no more hidden!