New Physics Working Report - I

Nobuchika Okada (KEK)

1. New physics subgroup's calendar

2003/4/25: LC Physics Study Group Kickoff meeting

New physics subgroup was formed

Conveners: K. Fujii & N. Okada

In order to expand the activity

for New Physics Study at a linear collider

New Physics = SUSY, Extra-dimension, ….

SUSY has been studied very well

Little detailed study on Extra-dim. Phys.

5/30: 1st New Physics Subgroup Meeting

concentrate on Physics of Extra-dimensions

prepare a handbook

Review talk on Physics of Extra-dimensions

7/30: 2nd New Physics Subgroup Meeting

Report on preparation of handbook
Two Review Talks on:

Little Higgs Model by M. Hashimoto

SUSY Dark matter by T. Nihei

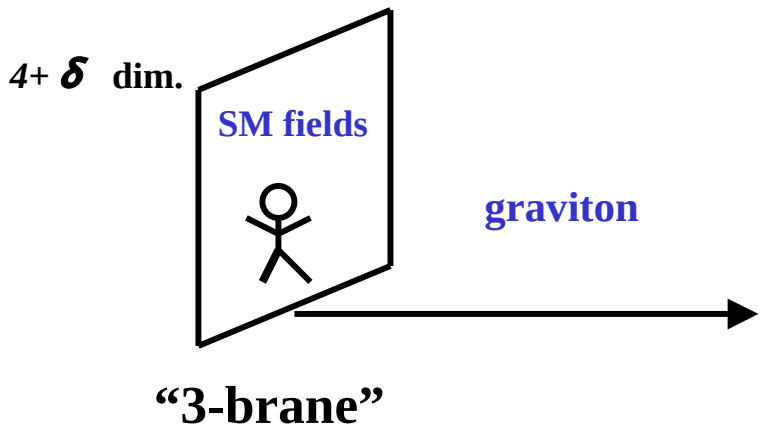
New Physics Subgroup home page

http://www-jlc.kek.jp/subg/physics/subg/newphysics/

Minutes & Slides of review talks

2. Physics of Extra-dimensions

Phenomenological Models



We are confined on "3-brane"
Graviton lives in the bulk

Beyond the standard model → **Brane World Scenario**
4+ δ dimension

New property
"geometry"

Typical Scenario: Large (flat) Extra Dimension (Arkani-Hamed-Dimopoulos-Dvali, '98)
Warped (small) Extra Dimension (Randall-Sundrum, '99)

Large Extra Dimension Scenario

Alternative solution to hierarchy problem

without SUSY, TC, etc.

$M_W \sim 10^2 \mathrm{GeV} \ll M_4 \sim 10^{19} \mathrm{GeV}$ **If** $M_W \sim M_{4+n} \Rightarrow$ **O.K.**

Low scale gravity model

$$S_{4+\delta} = M_{4+\delta}^{2+\delta} \int d^4x d^\delta y \sqrt{-g_{4+\delta}} R_{4+\delta}$$
$$= M_P^2 \int d^4x \sqrt{-g_4} R_4$$

$M_P^2 = M_{4+\delta}^{2+\delta} V_\delta$ **V_δ: volume of δ extra-dim.**

$V_\delta = (2\pi r)^\delta$ (compactified on T^δ)

For $M_{4+\delta} \sim 1\mathrm{TeV}$

δ	r	
1	10^{13} cm	excluded
2	10^{-1} mm	allowed
3	10^{-6} mm	allowed

← **r < 218 μm**

Hoyle et al., PRL 86 (2001) 1418

Phenomenology

- M4+δ～O（1TeV）
- many graviton Kaluza-Klein modes

$$G_{\mu\nu}(x^\mu, y^1, y^2, .., y^n) = \sum_n g_{\mu\nu}^{(\vec{n})}(x^\mu)\ \chi^{(\vec{n})}(\vec{y})$$

$$\chi^{(n)} \propto e^{i\frac{\vec{n}\cdot\vec{y}}{r}}\ ,\quad \left(m_{KK}^{(\vec{n})}\right)^2 = \frac{|\vec{n}|^2}{r^2}$$

If 6 dim. ➔ $\frac{1}{r} \sim 10^{-4}\mathrm{eV}$

Phenomenology of Extra-dimension Scenario

= Phenomenology of graviton Kaluza-Klein modes

Preparation of Handbook

comprehensive guide for studies

Construction of effective action in 4D

1. 4D Lagrangian

4+ δ dim. Graviton → 4D graviton in 4D

KK gravitons

KK gravi-scalars

KK gravi-vectors

2. Feynman rules

4D reduction of 4+ δ dim. Einstein's Eqs.

KK graviton

$$(\Box + \hat{n}) G^{(n)}_{\mu\nu} = \frac{1}{\bar{M}_P}\left[-T_{\mu\nu} + \frac{1}{3}\left(\frac{\partial_\mu \partial_\nu}{\hat{n}^2}\right) T^\lambda_\lambda\right]$$

KK gravi-scalar

$$(\Box + \hat{n}) H^{(n)} = \frac{\sqrt{\frac{3(\delta-1)}{\delta+2}}}{\bar{M}_P} T^\mu_\mu$$

Vector

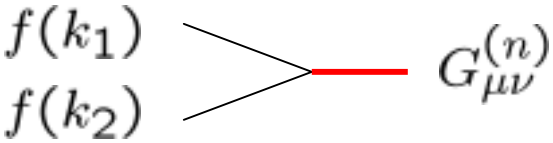
$$(\Box + \hat{n}) V^{(n)}_{\mu j} = 0$$

Scalar

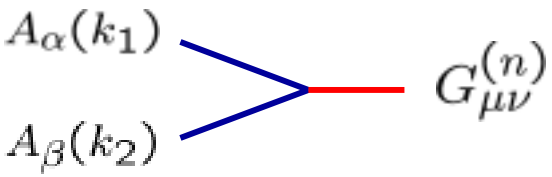
$$(\Box + \hat{n}) S^{(n)}_{ij} = 0$$

Feynman rules

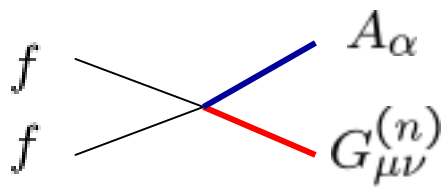
ex) QED + KK graviton



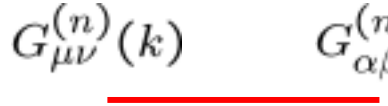
$$-\frac{i}{4\bar{M}_P}[(k_1+k_2)_\mu\gamma_\nu+(\nu\leftrightarrow\mu)]$$



$$\begin{aligned}-\frac{1}{\bar{M}_P}\ [\ & \frac{1}{2}\eta_{\mu\nu}(k_{1\beta}k_{2\alpha}-(k_1k_2)\eta_{\alpha\beta})+\eta_{\alpha\beta}k_{1\mu}k_{2\nu}\\ & +\ \eta_{\mu\alpha}(\eta_{\nu\beta}(k_1k_2)-k_{1\beta}k_{2\nu})-\eta_{\mu\beta}k_{1\nu}k_{2\alpha}\\ & +\ (\mu\leftrightarrow\nu)]\end{aligned}$$



$$-\frac{ieQ}{2\bar{M}_P}[\gamma_\mu\eta_{\nu\alpha}+(\mu\leftrightarrow\nu)]$$



$$\frac{iP_{\mu\nu\alpha\beta}}{k^2-m^2}$$

$$\begin{aligned}P_{\mu\nu\alpha\beta}\ =\ & \frac{1}{2}(\eta_{\mu\alpha}\eta_{\nu\beta}+\eta_{\mu\beta}\eta_{\nu\alpha}-\eta_{\mu\nu}\eta_{\alpha\beta})\\ & -\ \frac{1}{2m^2}(\eta_{\mu\alpha}k_\nu k_\beta+\eta_{\nu\beta}k_\mu k_\alpha+\eta_{\mu\beta}k_\nu k_\alpha+\eta_{\nu\alpha}k_\mu k_\beta)\\ & +\ \frac{1}{6}\left(\eta_{\mu\nu}+\frac{2}{m^2}k_\mu k_\nu\right)\left(\eta_{\alpha\beta}+\frac{2}{m^2}k_\alpha k_\beta\right)\end{aligned}$$

Detection of Extra-dimension @ LC

→ **detection of KK graviton**

direct → KK graviton emission

indirect →KK graviton mediated process

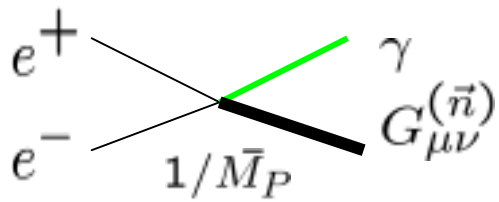
First detection of spin 2 particle !

KK graviton emission

Emitted KK graviton → non-interacting & stable particle

→ missing energy event

Example: $e^+e^- \to \gamma + \text{nothing}$

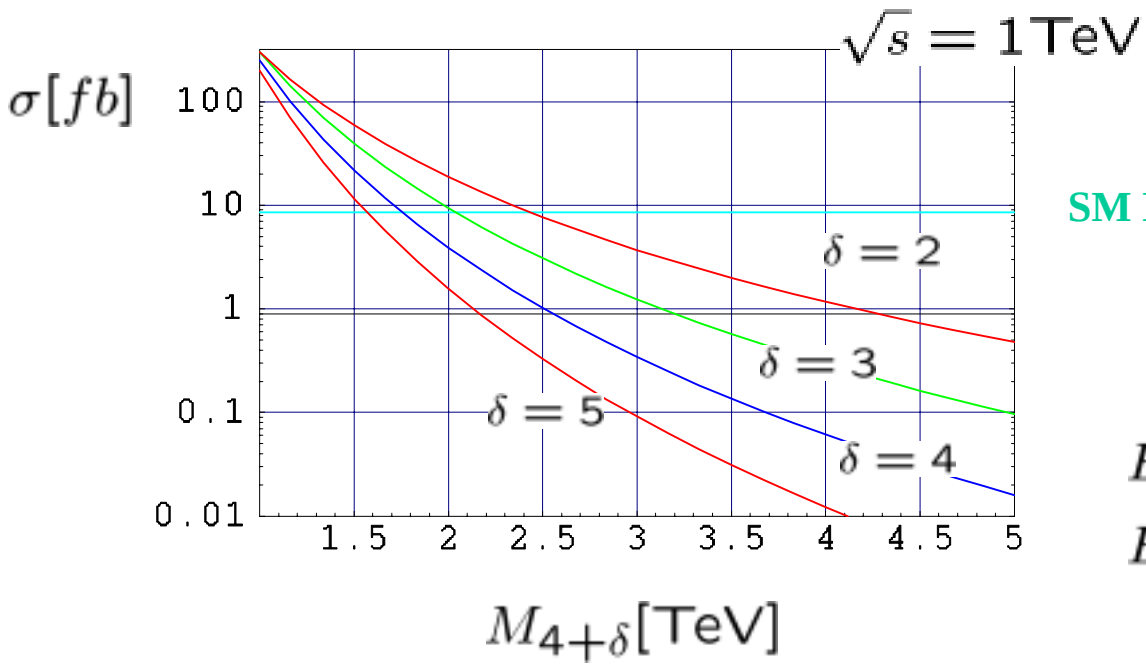


SM background: $e^+e^- \to \gamma\bar{\nu}\nu$

Each process is suppressed by $1/\bar{M}_P{}^2$

But ✕ **# of KK modes** $\Longrightarrow \dfrac{1}{M^2_{4+\delta}}$

Result $e^+e^- \to \gamma + E_{\text{missing}}$



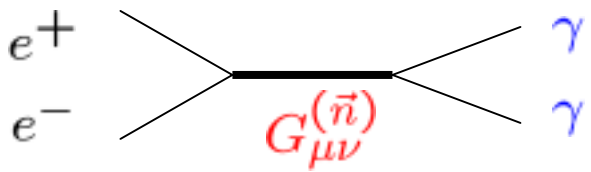
SM Bkgd

$E_\gamma < 450\text{GeV}$

$E_{T,\gamma} > 300\text{GeV}$

$$\sigma \propto \left(\frac{\sqrt{s}}{M_{4+\delta}}\right)^{\delta+2}$$

Virtual KK graviton mediated process



$$\sum_{\vec{n}} \frac{1}{s - \left(m_{KK}^{(\vec{n})}\right)^2} \to \infty \quad (\text{for } \delta \geq 2)$$

Need regularization

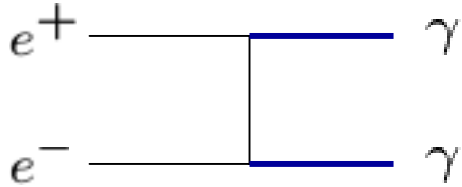
Naïve: Cut Off by $m_{KK}^{MAX} = \Lambda \sim M_{4+\delta}$

$$\mathcal{L}_{int} = \frac{2\pi\,\lambda}{\Lambda^4} T_{\mu\nu} T^{\mu\nu} \; ; \qquad \lambda = \pm 1$$

Result I

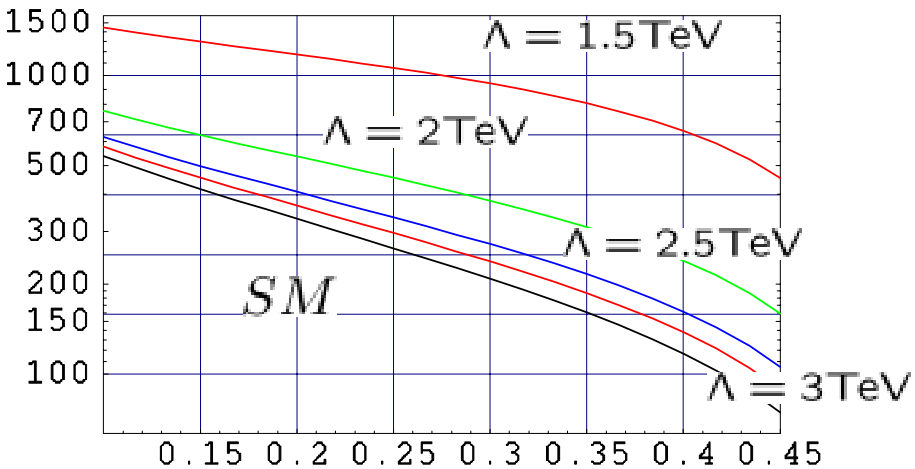
$e^+e^- \to \gamma + \gamma$

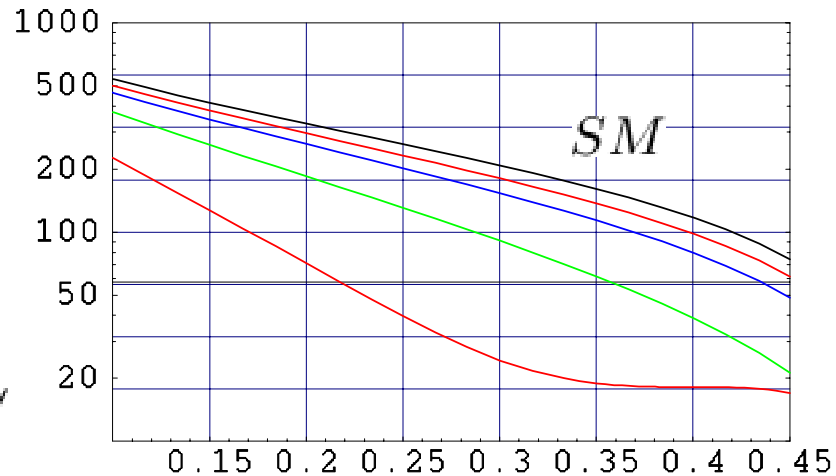
SM bkgd



+ cross

σ[fb] $\lambda = +1$ $\lambda = -1$ $\sqrt{s} = 1\,\text{TeV}$





$E_{T,\gamma}^{min}$[TeV]

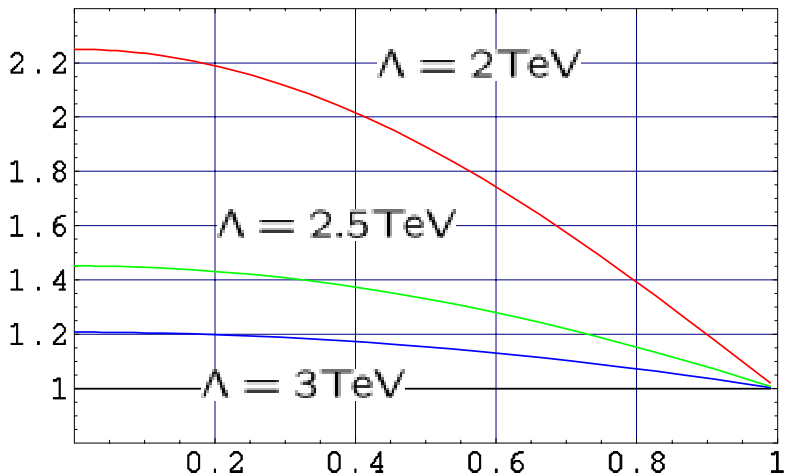
Result II $e^+e^- \to \gamma + \gamma$

Angular distribution ← spin 2 particle exchange

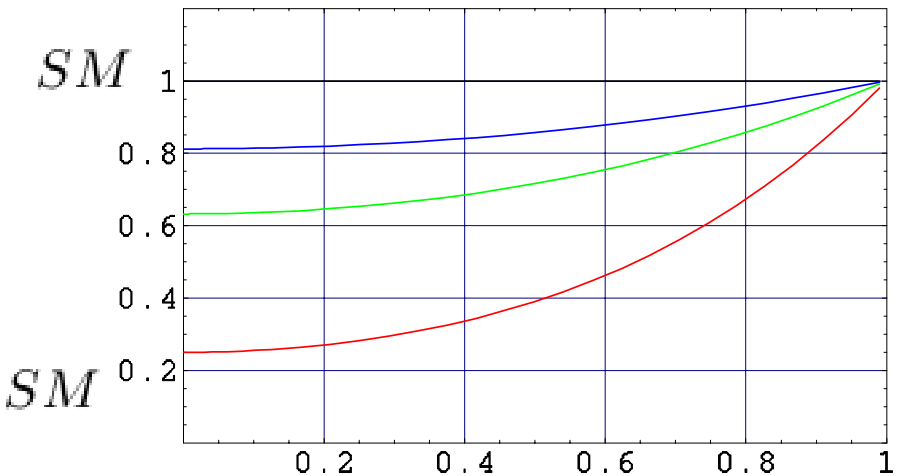
$$\frac{d\sigma}{d\cos\theta} \Big/ \frac{d\sigma}{d\cos\theta}\Big|_{SM}$$

$\sqrt{s} = 1\,\mathrm{TeV}$

$\lambda = +1$



$\lambda = -1$



3. Future plan

We are calculating other processes

$$e^+ + e^- \to \quad f + \overline{f} \qquad \text{with polarization}$$
$$W + W \ , Z + Z$$

Options $e + \gamma \to X, Y, ...$

$\gamma + \gamma \to X, Y, ...$

- **Calculations are mostly straightforward**

  but very complicated and tedious

- **Some calculation tools are very useful**

  FeynCalc: http://www.feyncalc.org/

Two Problems

No enough Time & Manpower

6th ACFA Workshop, TIFR, Mumbai, India

15-17 December 2003

Need people whom we work with !!