Report on New Physics Subgroup Activities

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Joint Subgroup Meeting

Jan. 19 (Wed), 2005

Collider signal of large extra dimensions

Large extra-dimension (ADD) scenario (Arkani-Hamed-Dimopoulos-Dvali, '98)

Phenomenology of extra-dimension scenario

= Phenomenology of graviton Kaluza-Klein modes

Detection of Extra-dimension @ future colliders

→ detection of KK graviton

- **direct → KK graviton emission processes**
- **indirect → KK graviton mediated processes**

First detection of spin 2 particle !

$$G_{MN}^{(\vec{n})} \begin{cases} \textbf{KK graviton:} & G_{\mu\nu}^{(\vec{n})} \\ \textbf{KK gravi-scalar:} & S^{(\vec{n})} \\ \left.\begin{array}{l}\textbf{KK vectors} \\ \textbf{KK scalars}\end{array}\right\} & \textbf{do not couple to SM fields} \end{cases}$$

$$\boxed{\mathcal{L}_{int} = -\frac{1}{\bar{M}_P} \sum_{\vec{n}} \left(G_{\mu\nu}^{(\vec{n})} T^{\mu\nu}} + \cancel{S^{(\vec{n})} T_\mu^\mu} \right)$$

Reduced Planck mass

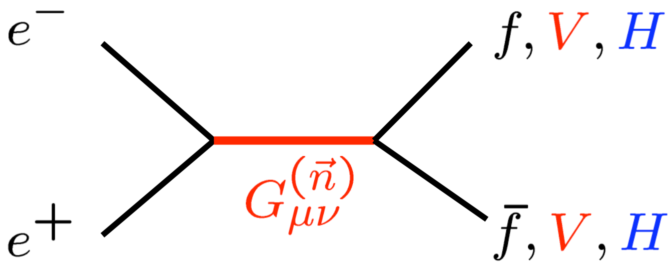
$$\bar{M}_P = \frac{M_4}{\sqrt{8\pi}}$$

$T_\mu^\mu \propto m$ **: negligible at high energies**

Characteristic features: infinite tower of KK gravitons

universal couplings

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 $m_{KK}^{MAX} \sim M_D$

$$\boxed{\frac{4\pi\lambda}{{M_S}^4}} = -\frac{8\pi}{M_P^2} \sum_{\vec{n}} \frac{1}{s - \left(m_{KK}^{(\vec{n})}\right)^2}; \qquad \lambda = \pm 1$$

$$\boxed{\mathcal{M} = \frac{4\pi\lambda}{M_S^4} T_{\mu\nu}(p_1, p_2) T^{\mu\nu}(p_3, p_4)}$$

Important points:

I: <u>total cross section</u>

← new physics evidence

deviation from the SM ↗ collider energy ↗

LC < LHC

II: <u>angular dependence of cross section</u>

← effects due to spin 2 particle exchange

precise measurements of angular dependence

LC > LHC

Example: $\boxed{e^+e^- \to HH \text{ process}}$

N. Delerue, K. Fujii & N. Okada
PRD 70, 091701 (2004)

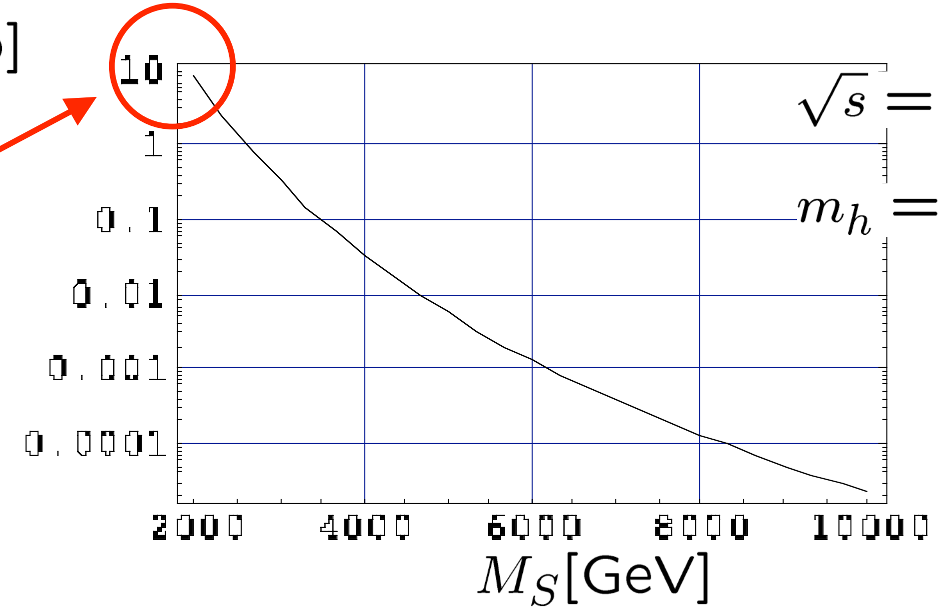
KK graviton exchange is dominant

SM background free → very interesting

if this cross section is large enough

$$\sigma(e^+e^- \to hh) = \frac{\pi}{480 M_S^8}\sqrt{1 - 4\frac{m_h^2}{s}}\left(s^3 - 8m_h^2 s^2 + 16 m_h^4 s\right)$$

σ[fb]



$\sqrt{s} = 1$ TeV

$m_h = 120$GeV

Comparable to

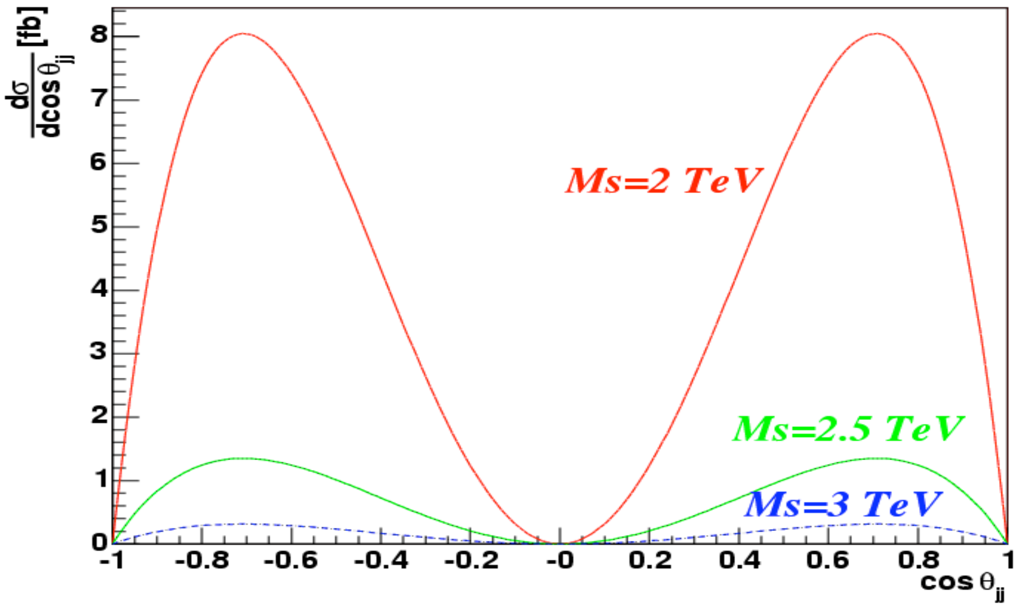
$\sigma(e^+e^- \to ZH)$

Angular dependence of cross section

$$\frac{d\sigma(e^+e^- \to hh)}{d\cos\theta}[\mathrm{fb}]$$

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

$$m_h = 120\mathrm{GeV}$$



$$\sum |\mathcal{M}|^2 = \frac{1}{2}\left(\frac{4\pi\lambda}{M_S^4}\right)^2 (t-u)^2(tu - m_h^4) \propto \sin^2\theta\cos^2\theta$$

Qualitative understanding of angular dependence

Initial state helicity: ± 1

$$T^{\mu\nu}(p_1, p_2) \;=\; \frac{1}{4}\bar{v}(p_2)\left[(p_1 - p_2)^\mu \gamma^\nu + (p_1 - p_2)^\nu \gamma^\mu\right] u(p_1)$$

→ $e^-_L e^+_R$ **or** $e^-_R e^+_L$

Final state helicity: ***0***

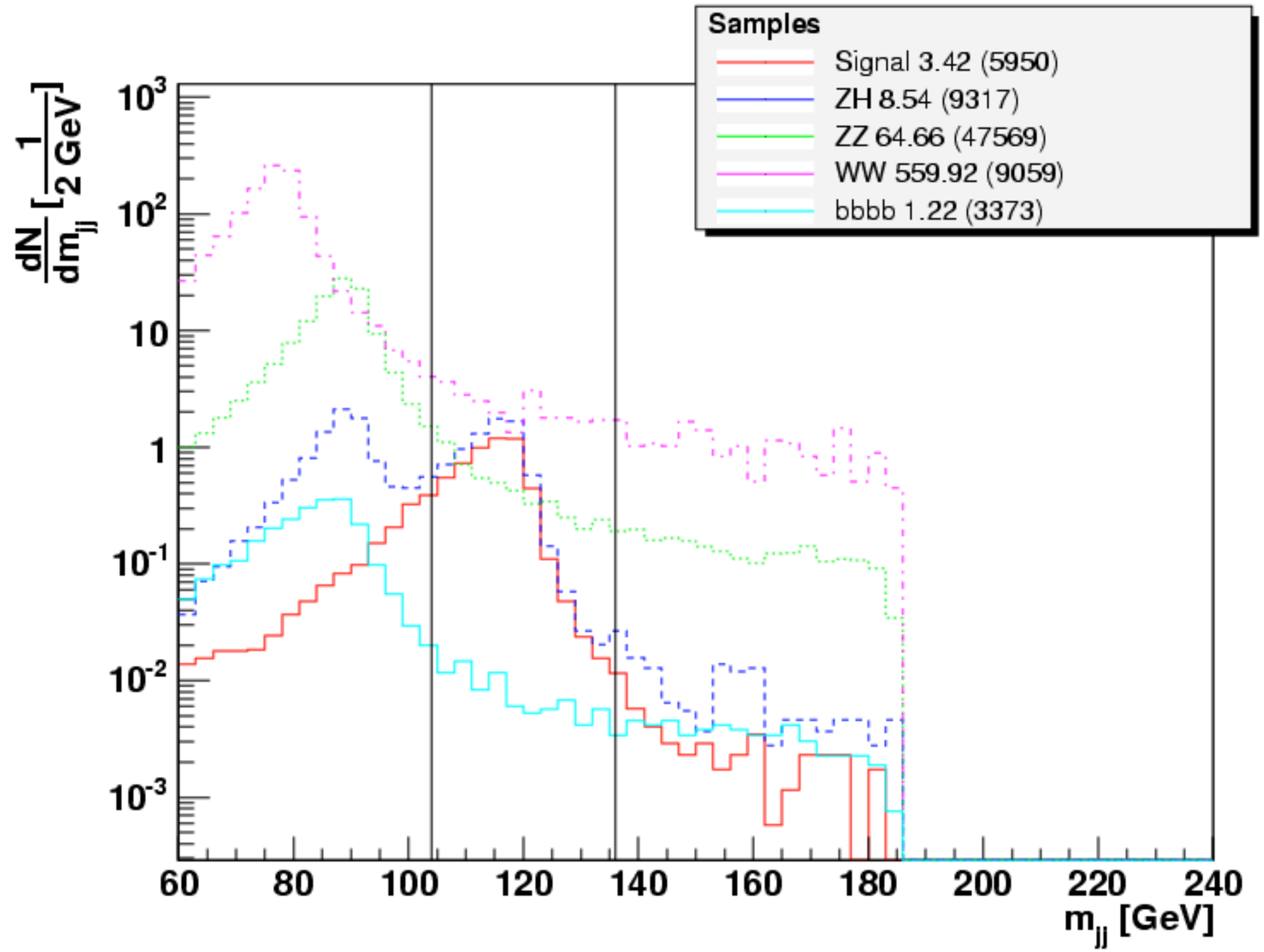
Orbital angular momentum is needed

to make up spin 2 of intermediate KK gravitons

$$\mathcal{M} \sim Y^{m=\pm 1}_{l=2} \propto \sin\theta \cos\theta$$

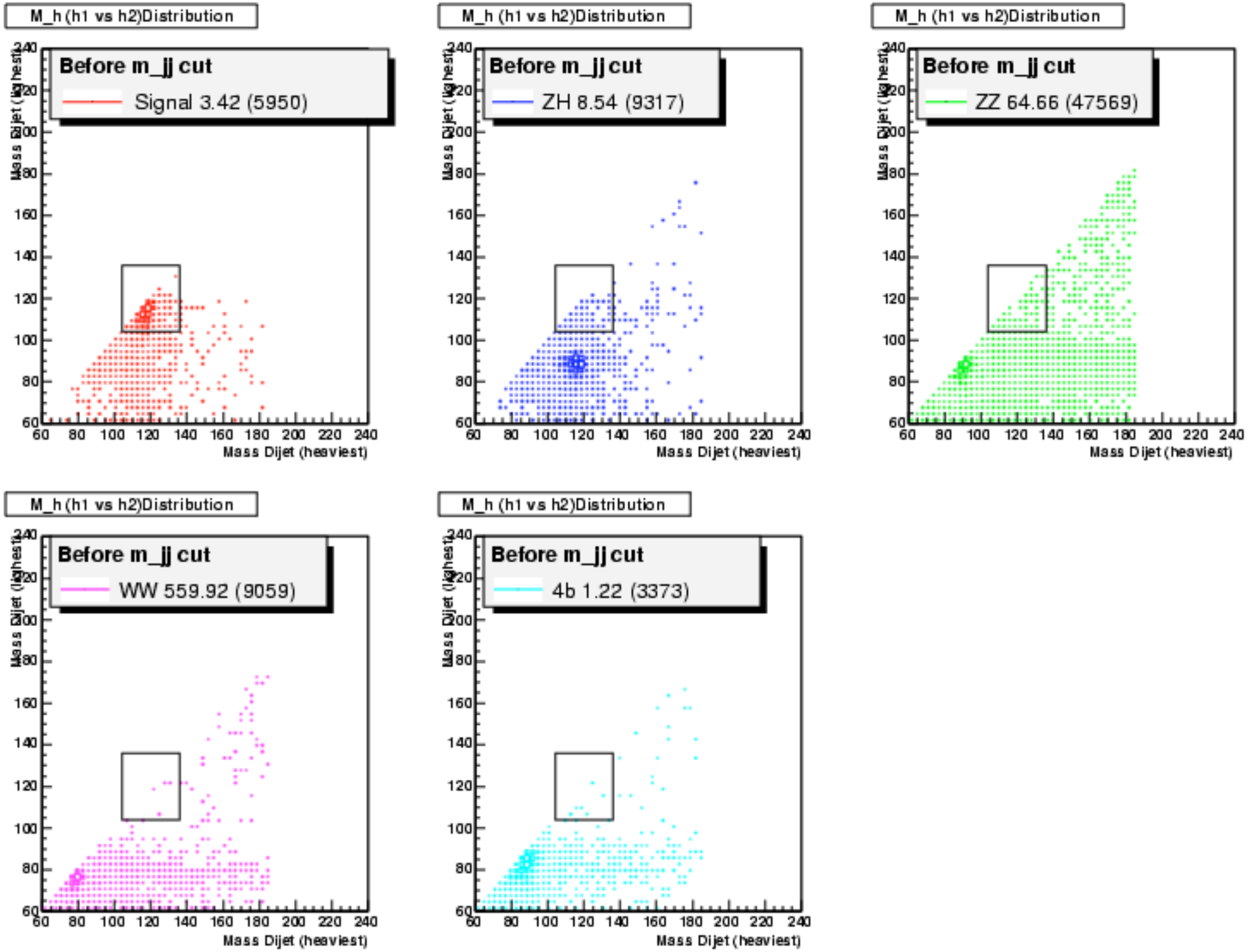
Angular distribution reflects the spin 2 nature of KK gravitons

Invariant mass distributions $\sqrt{s} = 1\text{TeV}$ $M_S = 2\text{TeV}$



$m_H = 120$ GeV

Invariant mass distributions



Number of remaining evens per $1\,fb^{-1}$

$$\sqrt{s} = 1\ \text{TeV},\ M_S = 2\text{TeV},\ m_h = 120\text{GeV}$$

Selection criteria	Signal	ZZ	ZH	WW
No cut	5.772	206.666	18.395	3833.3
$N_{\text{tracks}} > 25$	5.674	164.330	18.202	2427.1
$E_{\text{vis}} > 600$ GeV	5.471	90.8559	11.287	1203.8
$P_t \leq 50$ GeV	3.662	79.9122	8.9160	939.61
$N_{\text{jets}} \geq 4$	3.481	69.682	8.6308	644.89
$\lvert m_{jj} - m_H \rvert \leq 16$ GeV	2.234	0.136	0.174	0.319
b-tagging	1.313	0.006	0.038	0.0

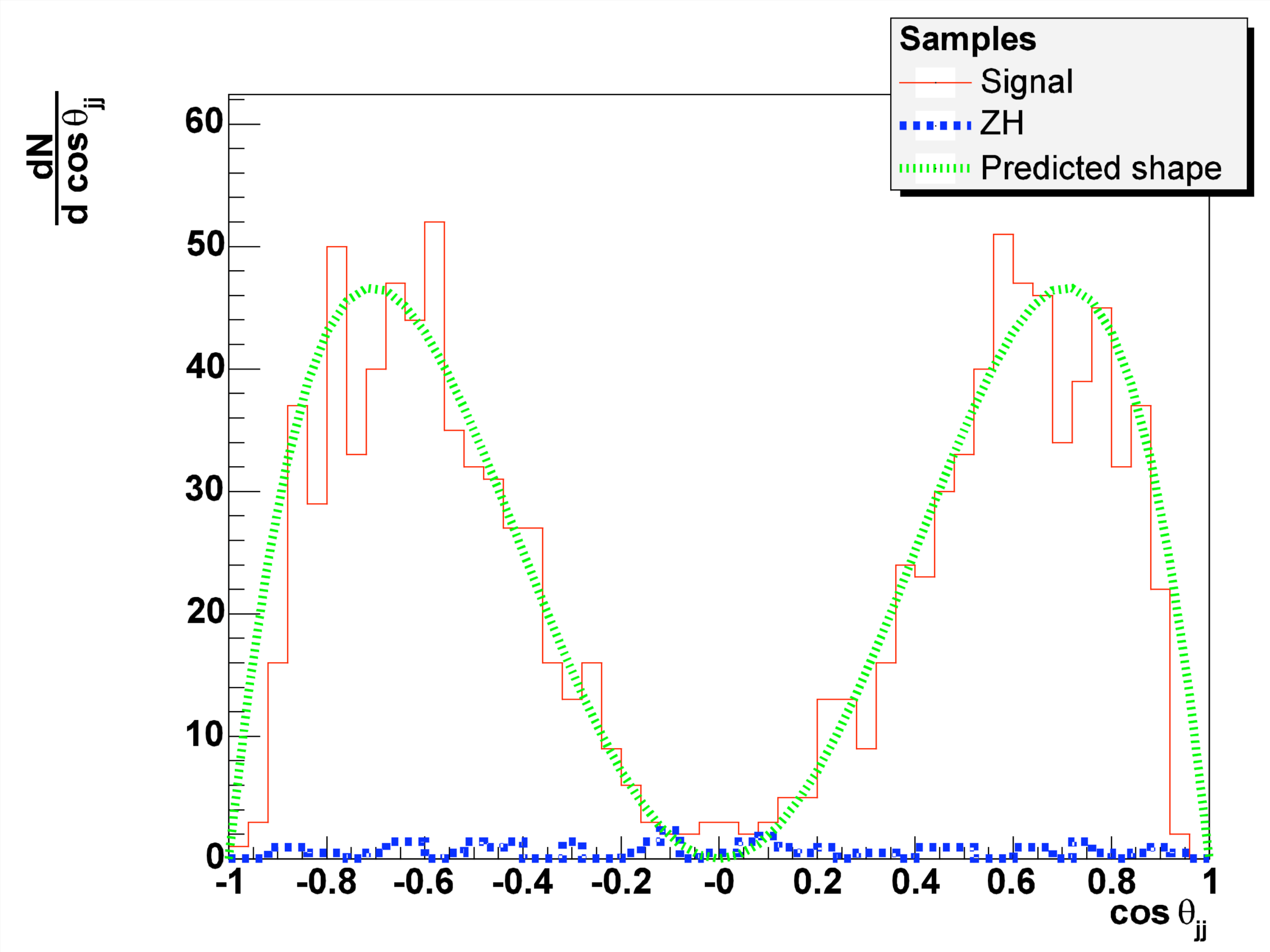
700 Higgs Pair events @ 1TeV LC

integrated luminosity fb^{-1}

500

Essentially No SM backgrounds!

Reconstruction of Angular Distribution (after selection)

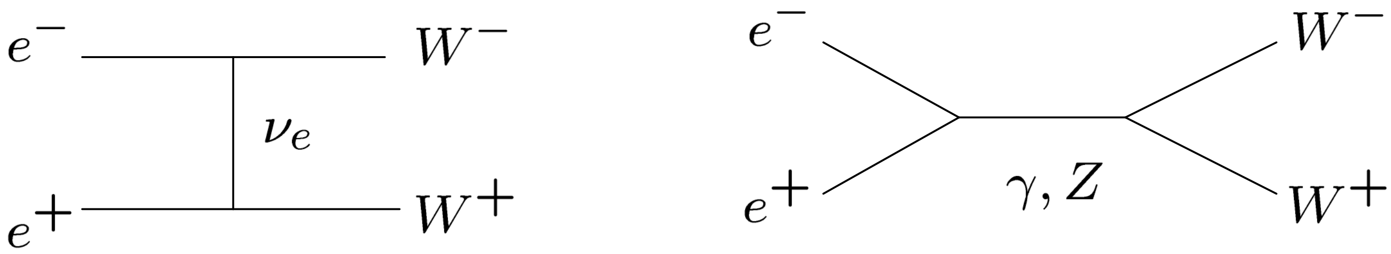


integrated luminosity 500 fb^{-1}

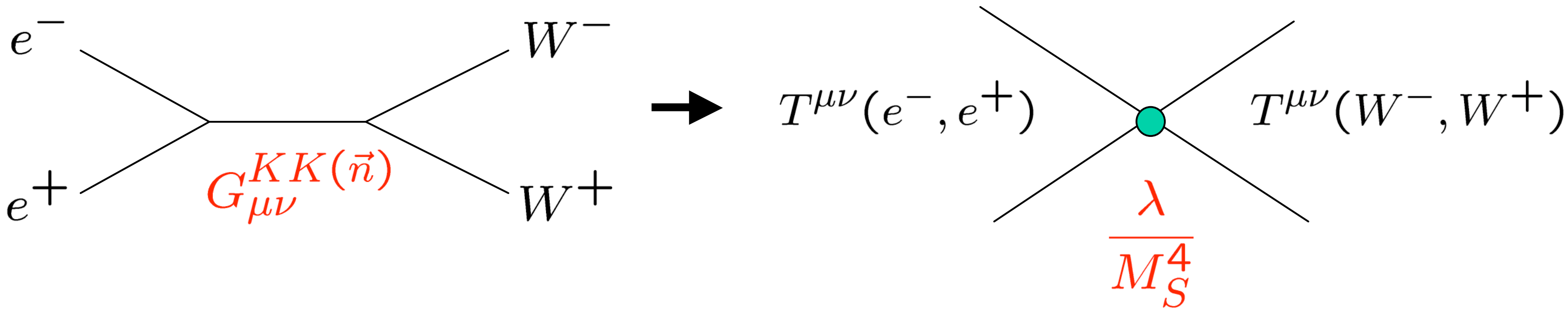
Next example: $e^+e^- \to W^+W^-,\ ZZ$

$e^+e^- \to W^+W^-$ process

SM background



KK graviton contribution



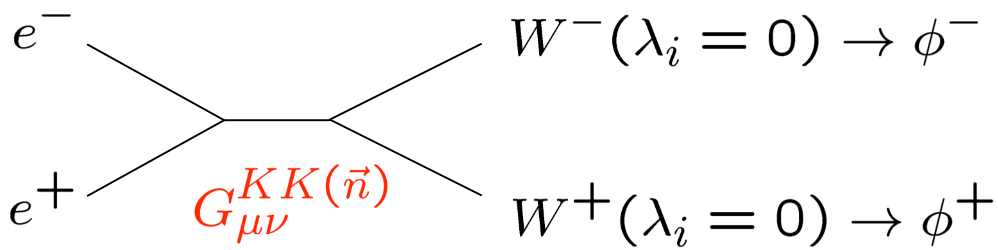
<u>Helicity amplitude</u> for KK graviton mediated processes

$$e^-(\pm)\, e^+(\pm) \to W^-(\pm)\, W^+(\pm)$$

$$\begin{aligned}
\mathcal{M}_G(-,+;\pm,\pm) &= \left(\frac{4\pi\lambda}{M_S^4}\right) \times \left(\frac{s^2}{4}\right) (\beta^2 - 1) \sin\theta \cos\theta \\
\mathcal{M}_G(-,+;,\pm,\mp) &= \left(\frac{4\pi\lambda}{M_S^4}\right) \times \left(-\frac{s^2}{4}\right) (\cos\theta \mp 1) \sin\theta \\
\mathcal{M}_G(-,+;\pm,0) &= \mathcal{M}^G(-,+;0,\mp) \\
&= \left(\frac{4\pi\lambda}{M_S^4}\right) \times \left(-\frac{s^2}{4}\right) \sqrt{\frac{1-\beta^2}{2}}(1 \mp \cos\theta)(1 \pm 2\cos\theta) \\
\mathcal{M}_G(-,+;0,0) &= \left(\frac{4\pi\lambda}{M_S^4}\right) \times \left(\frac{s^2}{4}\right) (2 - \beta^2) \sin\theta \cos\theta \\
\mathcal{M}_G(+,-;\lambda_3,\lambda_4) &= \mathcal{M}_G(-,+;-\lambda_3,-\lambda_4)
\end{aligned}$$

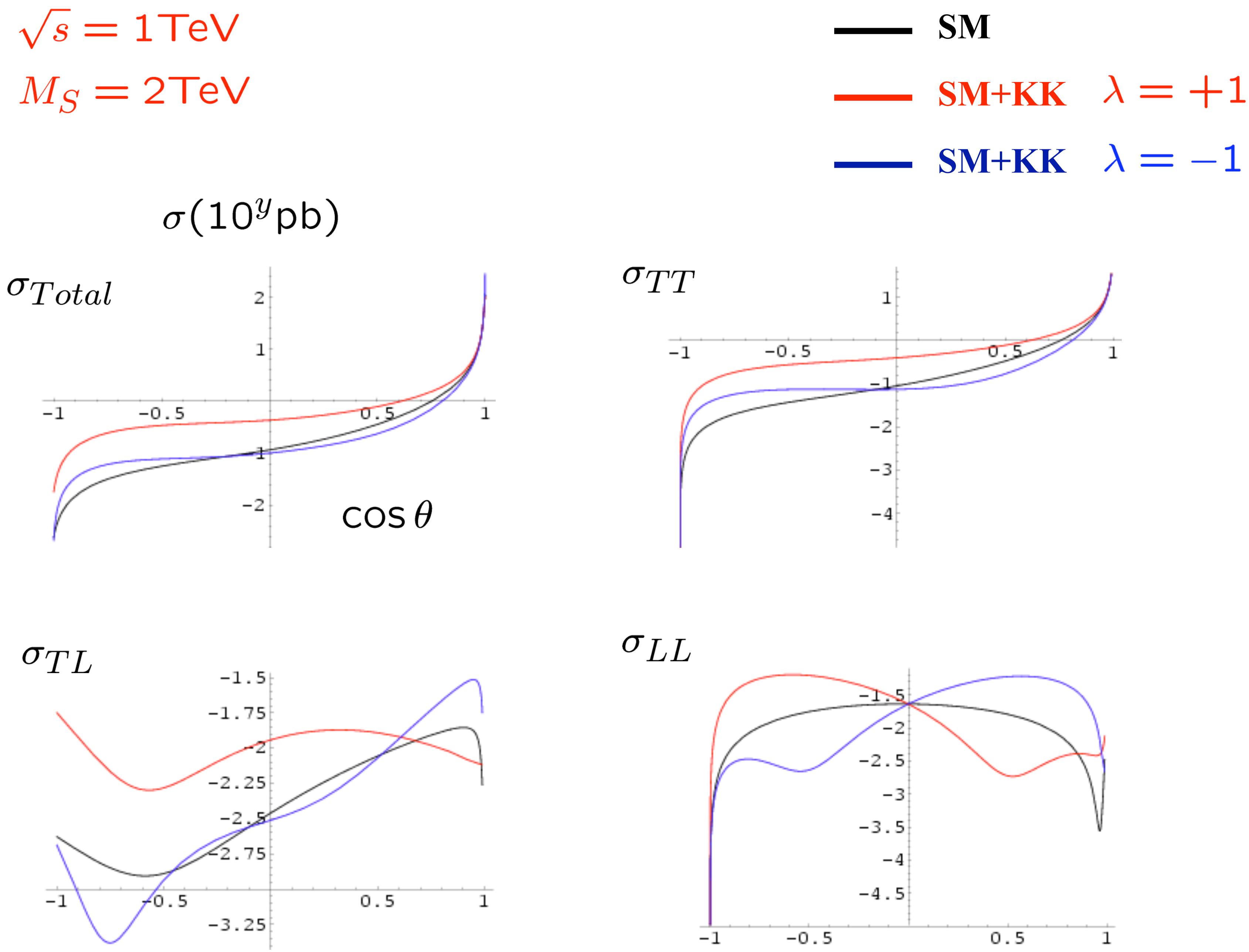
Spin 2 nature of KK gravitons

$$\mathcal{M}_G(\mp,\pm;0,0) = \left(\frac{4\pi\lambda}{M_S^4}\right) \times \left(\frac{s^2}{4}\right)(2-\beta^2)\sin\theta\cos\theta$$



Helicity amplitude for SM processes

$$
\begin{aligned}
\mathcal{M}_{SM}(-,+;\pm,\pm) &= \frac{e^2}{4s_w^2}\sin\theta\left[\frac{s}{t}(\cos\theta-\beta)-4\beta\left(s_w^2-\left(-\frac{1}{2}+s_w^2\right)\frac{s}{s-M_Z^2}\right)\right] \\
\mathcal{M}_{SM}(-,+;\pm,\mp) &= \frac{e^2}{4s_w^2}\frac{s}{t}\sin\theta(\cos\theta\mp 1) \\
\mathcal{M}_{SM}(-,+;\pm,0) &= \mathcal{M}_{SM}(-,+;0,\mp) \\
&= \frac{e^2}{8s_w^2}\sqrt{\frac{2}{1-\beta^2}}(\cos\theta\mp 1) \\
&\times \left[\frac{s}{t}\left(2\beta-2\cos\theta\mp(1-\beta^2)\right)+8\beta\left(s_w^2-\left(-\frac{1}{2}+s_w^2\right)\frac{s}{s-M_Z^2}\right)\right] \\
\mathcal{M}_{SM}(-,+;0,0) &= \frac{e^2}{4s_w^2}\frac{1}{1-\beta^2}\sin\theta \\
&\times \left[\frac{s}{t}(3\beta-\beta^3-2\cos\theta)+4\beta(3-\beta^2)\left(s_w^2-\left(-\frac{1}{2}+s_w^2\right)\frac{s}{s-M_Z^2}\right)\right] \\
\mathcal{M}_{SM}(+,-;\pm,\pm) &= -e^2\beta\sin\theta\left(1-\frac{s}{s-M_Z^2}\right) \\
\mathcal{M}_{SM}(+,-;\pm,\mp) &= 0 \\
\mathcal{M}_{SM}(+,-;\pm,0) &= \mathcal{M}_{SM}(+,-;0,\mp) \\
&= e^2\sqrt{\frac{2\beta^2}{1-\beta^2}}(\cos\theta\pm 1)\left(1-\frac{s}{s-M_Z^2}\right)
\end{aligned}
$$



$\sqrt{s} = 1\text{TeV}$
$M_S = 2\text{TeV}$
SM
SM+KK $\lambda = +1$
SM+KK $\lambda = -1$
$\sigma(10^y\text{pb})$
σ_{Total}
$\cos\theta$
σ_{TT}
σ_{TL}
σ_{LL}

100% polarized e^-_R

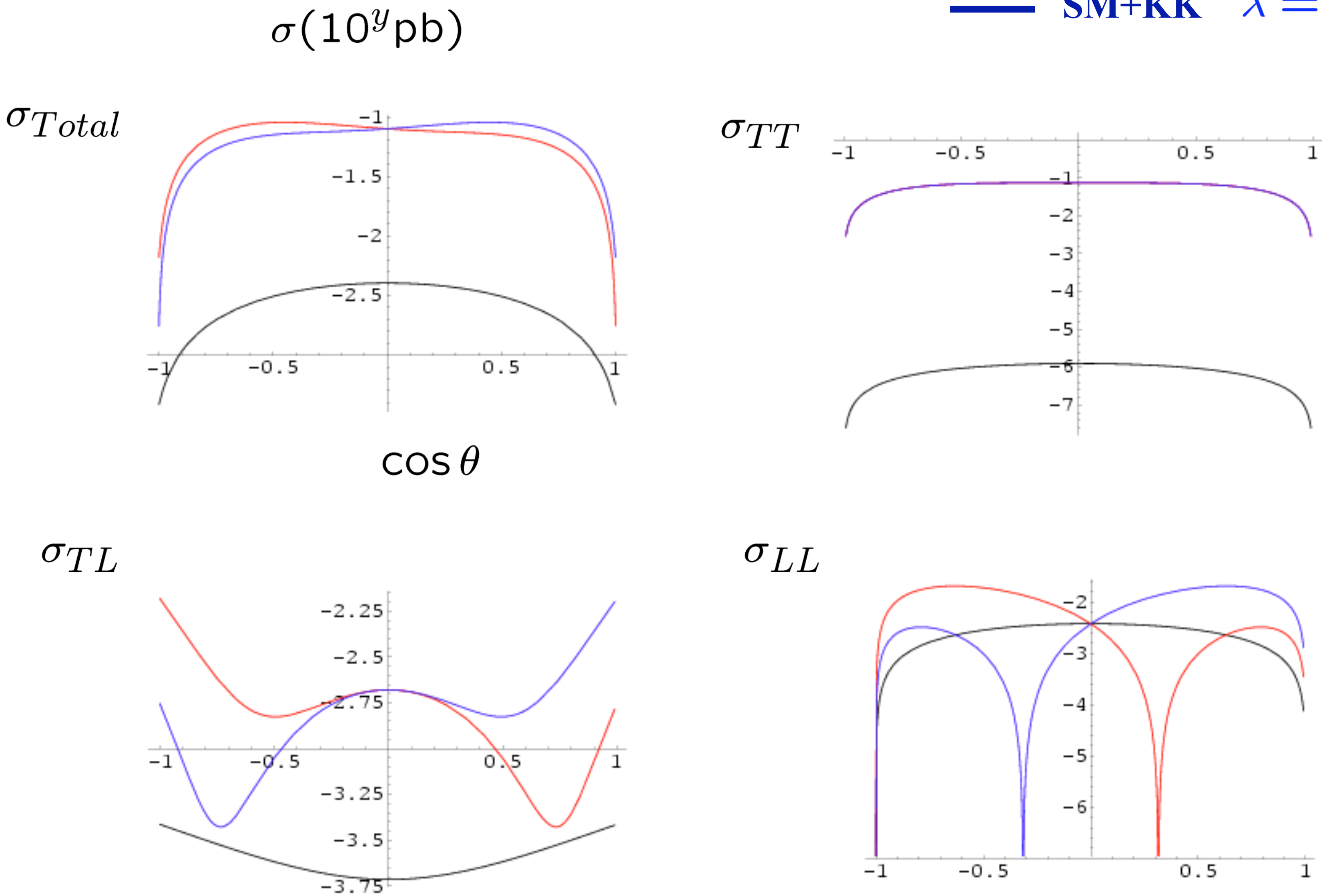
$\sqrt{s} = 1\text{TeV}$

$M_S = 2\text{TeV}$

SM

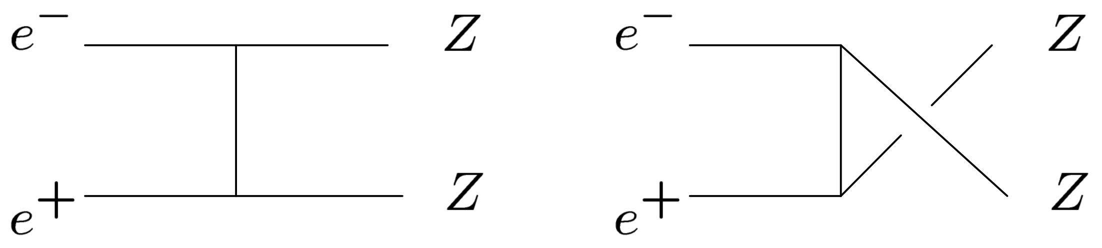
SM+KK $\lambda = +1$

SM+KK $\lambda = -1$

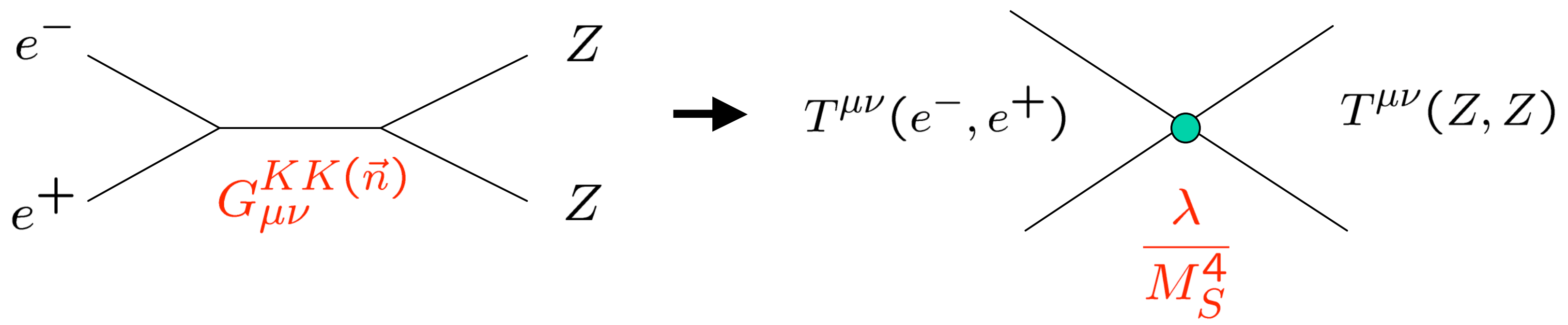


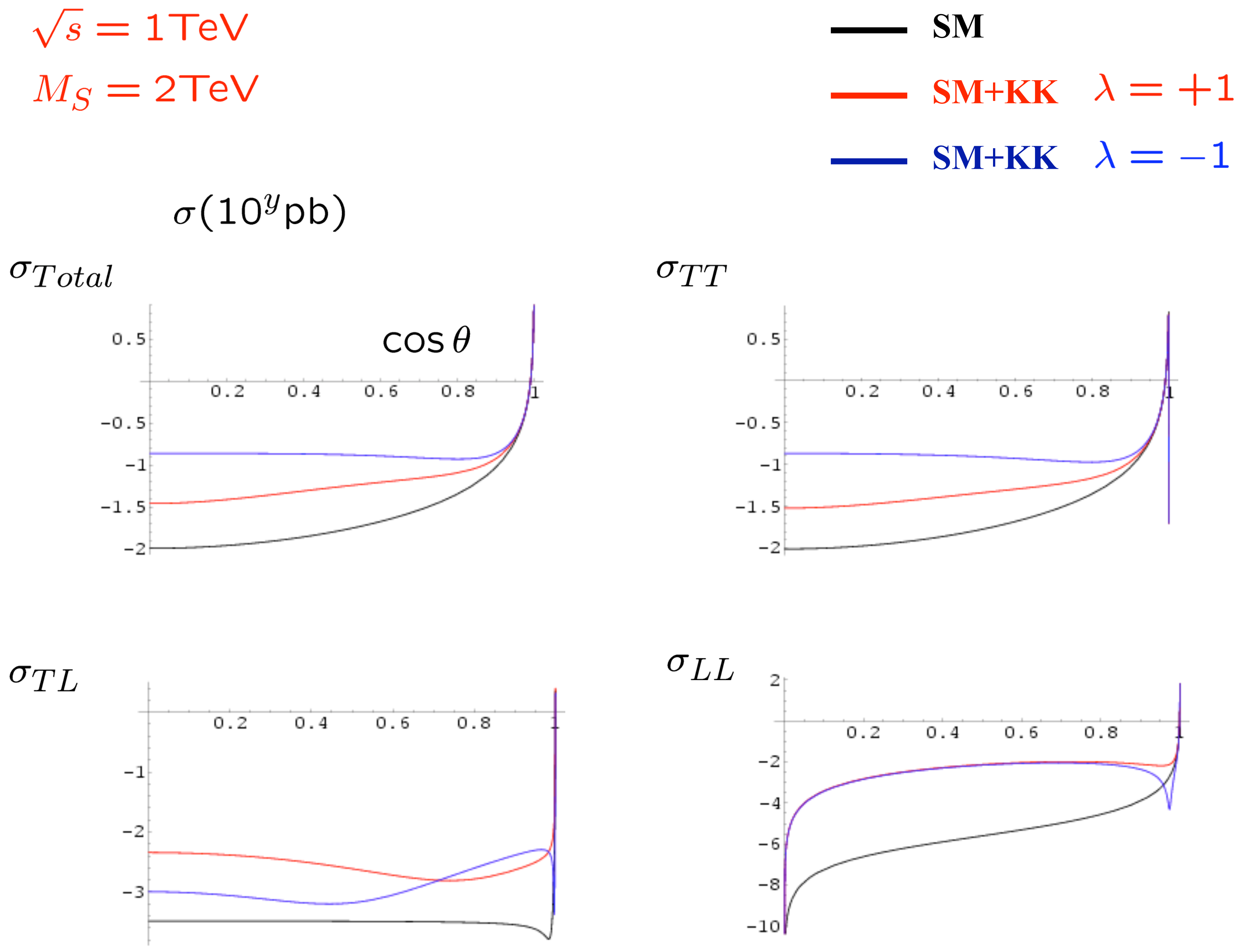
$e^+e^- \to ZZ$ process

SM background



KK graviton contribution





$\sqrt{s} = 1\text{TeV}$
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SM
SM+KK $\lambda = +1$
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$\sigma(10^y\text{pb})$
σ_{Total}
$\cos\theta$
σ_{TT}
σ_{TL}
σ_{LL}

Plan

Realistic Monte Carlo simulations

Is it possible to distinguish final states with different helicity ?

Collider energy should be high as possible

Ms should be low as possible

$$\begin{cases} \sigma_{SM-KK} \propto \dfrac{1}{M_S^4} \\ \sigma_{KK} \propto \dfrac{1}{M_S^8} \end{cases}$$