Little Higgs model effects in $\gamma\gamma \rightarrow \gamma\gamma$ [a]

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[a] prepared using TEXPower `http://texpower.sourceforge.net`

Introduction

The process

$$\gamma(p_1,\lambda_1)\gamma(p_2,\lambda_2) \to \gamma(p_3,\lambda_3)\gamma(p_3,\lambda_3)$$

can be represented by "sixteen" possible helicity amplitudes $F_{\lambda_1\lambda_2\lambda_3\lambda_4}$ where p_i and λ_i represents respective momenta and helicities.

$$\hat{s} = (p_1+p_2)^2,\ \hat{t} = (p_1-p_3)^2,\ \hat{u} = (p_1-p_4)^2$$

All of the helicity amplitudes are not independent. Bose statistics demands

$$F_{\lambda_1\lambda_2\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) = F_{\lambda_2\lambda_1\lambda_4\lambda_3}(\hat{s},\hat{t},\hat{u})$$
$$F_{\lambda_1\lambda_2\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) = F_{\lambda_2\lambda_1\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u})$$

Crossing symmetry implies

$$\begin{aligned} F_{\lambda_1\lambda_2\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) &= F_{-\lambda_4\lambda_2\lambda_3-\lambda_1}(\hat{t},\hat{s},\hat{u}) \\ &= F_{\lambda_1-\lambda_3-\lambda_2\lambda_4}(\hat{t},\hat{s},\hat{u}) \\ F_{\lambda_1\lambda_2\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) &= F_{-\lambda_3\lambda_2-\lambda_1\lambda_4}(\hat{u},\hat{t},\hat{s}) \\ &= F_{\lambda_1-\lambda_4\lambda_3-\lambda_2}(\hat{u},\hat{t},\hat{s}) \end{aligned}$$

Parity and time-invariance gives

$$\begin{aligned} F_{\lambda_1\lambda_2\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) &= F_{-\lambda_1-\lambda_2-\lambda_3-\lambda_4}(\hat{s},\hat{t},\hat{u}) \\ F_{\lambda_3\lambda_4\lambda_1\lambda_2}(\hat{s},\hat{t},\hat{u}) &= F_{\lambda_2\lambda_1\lambda_3\lambda_4}(\hat{s},\hat{t},\hat{u}) \end{aligned}$$

16 possible helicity amplitudes can be expressed in terms of just three amplitudes

$$\boxed{F_{++++}(\hat{s},\hat{t},\hat{u}),\, F_{+++-}(\hat{s},\hat{t},\hat{u}),\, F_{++--}(\hat{s},\hat{t},\hat{u})}$$

$\gamma\gamma \rightarrow \gamma\gamma$ cross section can be written as : [a]

$$\frac{d\sigma}{d\tau dcos\theta^*} = \frac{d\bar{L}_{\gamma\gamma}}{d\tau}\left\{\frac{d\bar{\sigma}_0}{dcos\theta^*} + \langle\xi_2\xi_2'\rangle\frac{d\bar{\sigma}_{22}}{dcos\theta^*} + [\langle\xi_3\rangle cos2\phi + \langle\xi_3'\rangle cos2\phi']\right.$$
$$\times\frac{d\bar{\sigma}_3}{dcos\theta^*} + \langle\xi_3\xi_3'\rangle[\frac{d\bar{\sigma}_{33}}{dcos\theta^*}cos2(\phi+\phi') + \frac{d\bar{\sigma}_{33}'}{dcos\theta^*}cos2(\phi-\phi')]$$
$$\left.+[\langle\xi_2\xi_3'\rangle sin2\phi' - \langle\xi_3\xi_2'\rangle sin2\phi']\frac{d\bar{\sigma}_{23}}{dcos\theta^*}\right\}$$

$d\bar{L}_{\gamma\gamma}$ describes photon-photon luminosity in $\gamma\gamma$ mode and $\tau = s_{\gamma\gamma}/s_{ee}$.

ξ_2, ξ_2', ξ_3 and ξ_3' are the stokes parameters.

[a] Gounaris et.al. Phys. Lett B 452, 76 (1999)

$$\frac{d\bar{\sigma}_0}{dcos\theta^*} = \left(\frac{1}{128\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4}[|F_{++\lambda_3\lambda_4}|^2 + |F_{+-\lambda_3\lambda_4}|^2]$$

$$\frac{d\bar{\sigma}_{22}}{dcos\theta^*} = \left(\frac{1}{128\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4}[|F_{++\lambda_3\lambda_4}|^2 - |F_{+-\lambda_3\lambda_4}|^2]$$

$$\frac{d\bar{\sigma}_3}{dcos\theta^*} = \left(\frac{-1}{64\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4} Re[F_{++\lambda_3\lambda_4}F^*_{-+\lambda_3\lambda_4}]$$

$$\frac{d\bar{\sigma}_{33}}{dcos\theta^*} = \left(\frac{1}{128\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4} Re[F_{+-\lambda_3\lambda_4}F^*_{-+\lambda_3\lambda_4}]$$

$$\frac{d\bar{\sigma}'_{33}}{dcos\theta^*} = \left(\frac{1}{128\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4} Re[F_{++\lambda_3\lambda_4}F^*_{--\lambda_3\lambda_4}]$$

$$\frac{d\bar{\sigma}_{23}}{dcos\theta^*} = \left(\frac{1}{64\pi\hat{s}}\right)\sum_{\lambda_3\lambda_4} Im[F_{++\lambda_3\lambda_4}F^*_{+-\lambda_3\lambda_4}]$$

Little Higgs models

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Basic Idea

Higgs field is the pseudo-Goldstone boson of a global symmetry which is broken at some higher scale.

Quadratic divergences in Higgs mass are cancelled at one loop level with new particles.

Higgs particle acquire mass at radiatively at electroweak scale

Particle content of Little Higgs models (apart from SM):

- Higgs bosons $(\Phi, \Phi^+, \Phi^{++})$
- Heavy Gauge bosons (W_H, Z_H, A_H)
- Vector like top quark (T)

Standard Model results

- Jikia & Tkabladze, Phys. Lett B 323, 453 (1994)
- Gounaris et.al. Phys. Lett B 452, 76 (1999)

Characterstics in SM:

- helicity amplitudes are determined in SM by 1-loop diagrams involving charged fermions and $W^{\pm}$ bosons.
- For $\sqrt{s_{\gamma\gamma}} \geq 250$ GeV the amplitudes are dominated by W contribution over fermionic contributions.
- Dominant amplitudes are purely imaginary at such energies.

W loop contribution to helicity amplitudes can be written as :

$$\frac{F^{W}_{++++}(\hat{s},\hat{t},\hat{u})}{\alpha^2} = 12 - 12\left(1+\frac{2\hat{u}}{\hat{s}}\right)B_0(\hat{u}) - 12\left(1+\frac{2\hat{t}}{\hat{s}}\right)B_0(\hat{t}) + \frac{24m_W^2\hat{t}\hat{u}}{\hat{s}}D_0(\hat{u},\hat{t}) + 16\left(1-\frac{3m_W^2}{2\hat{s}}-\frac{3\hat{t}\hat{u}}{4\hat{s}^2}\right)[2\hat{t}C_0(\hat{t}) + 2\hat{u}C_0(\hat{u}) - \hat{t}\hat{u}D_0(\hat{t},\hat{u})] + 8(\hat{s}-m_W^2)(\hat{s}-3m_W^2) \times[D_0(\hat{s},\hat{t}) + D_0(\hat{s},\hat{u}) + D_0(\hat{t},\hat{u})] \ ,$$

$$\frac{F^{W}_{+++-}(\hat{s},\hat{t},\hat{u})}{\alpha^2} = -12 + 24m_W^4[D_0(\hat{s},\hat{t}) + D_0(\hat{s},\hat{u}) + D_0(\hat{t},\hat{u})] + 12m_W^2\hat{s}\hat{t}\hat{u}\left[\frac{D_0(\hat{s},\hat{t})}{\hat{u}^2} + \frac{D_0(\hat{s},\hat{u})}{\hat{t}^2} + \frac{D_0(\hat{t},\hat{u})}{\hat{s}^2}\right] - 24m_W^2\left(\frac{1}{\hat{s}}+\frac{1}{\hat{t}}+\frac{1}{\hat{u}}\right)[\hat{t}C_0(\hat{t}) + \hat{u}C_0(\hat{u}) + \hat{s}C_0(\hat{s})] \ ,$$

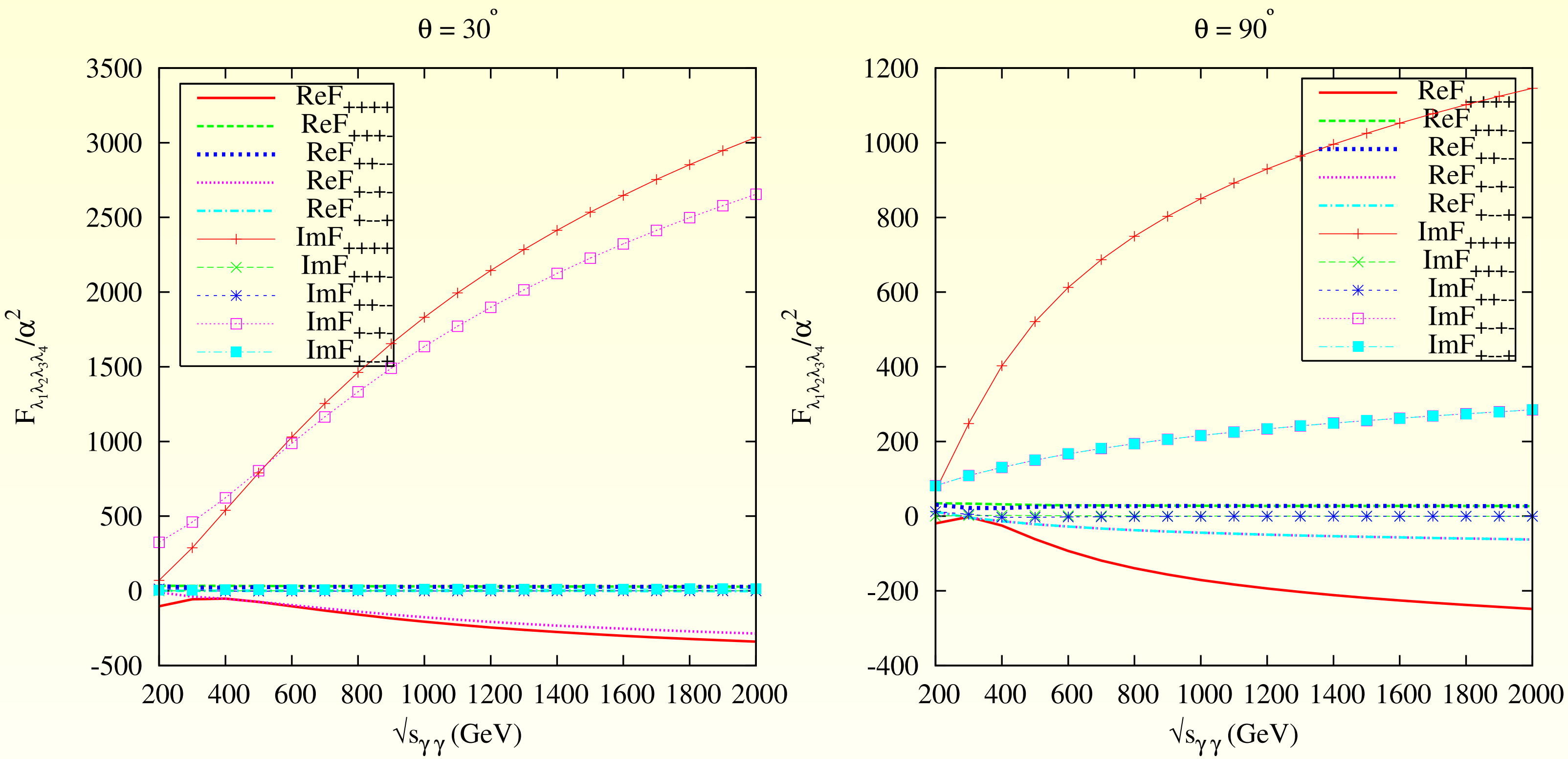
$$\frac{F^W_{++--}(\hat{s},\hat{t},\hat{u})}{\alpha^2} = -12 + 24 m_W^4 [D_0(\hat{s},\hat{t}) + D_0(\hat{s},\hat{u}) + D_0(\hat{t},\hat{u})] \ .$$

Contribution of fermion of charge Q_f and mass m_f to the helicity amplitudes are :

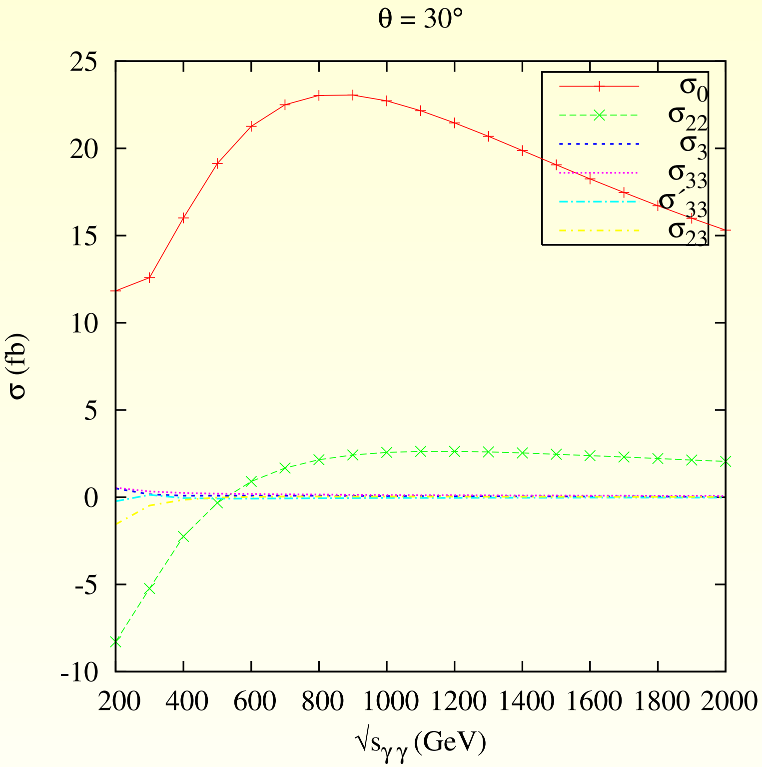
$$\begin{aligned}
\frac{F^f_{++++}(\hat{s},\hat{t},\hat{u})}{\alpha^2 Q_f^4} &= -8 + 8\left(1 + \frac{2\hat{u}}{\hat{s}}\right) B_0(\hat{u}) + 8\left(1 + \frac{2\hat{t}}{\hat{s}}\right) B_0(\hat{t}) \\
&\quad -8\left(\frac{\hat{t}^2 + \hat{u}^2}{\hat{s}^2} - \frac{4m_f^2}{\hat{s}}\right)[\hat{t}C_0(\hat{t}) + \hat{u}C_0(\hat{u})] \\
&\quad +8m_f^2(\hat{s} - 2m_f^2)[D_0(\hat{s},\hat{t}) + D_0(\hat{s},\hat{u})] \\
&\quad -4\left[4m_f^4 - (2\hat{s}m_f^2 + \hat{t}\hat{u})\frac{\hat{t}^2 + \hat{u}^2}{\hat{s}^2} + \frac{4m_f^2\hat{t}\hat{u}}{\hat{s}}\right] D_0(\hat{t},\hat{u}) \ , \\
F^f_{+++-}(\hat{s},\hat{t},\hat{u}) &= -\frac{2}{3} Q_f^4 \left\{F^W_{+++-}(\hat{s},\hat{t},\hat{u}) \ ; \ m_W \to m_f\right\} \ ,
\end{aligned}$$

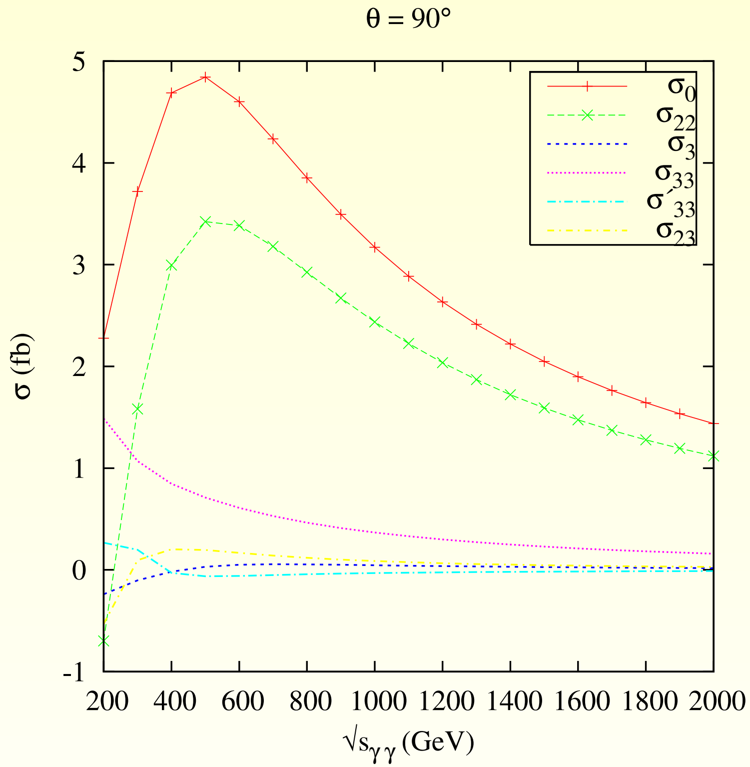
$$F^{f}_{++--}(\hat{s},\hat{t},\hat{u}) \;=\; -\,\frac{2}{3}Q_f^4\left\{F^{W}_{++--}(\hat{s},\hat{t},\hat{u})\;;\;m_W \longrightarrow m_f\right\}\;.$$

Helicity amplitudes in SM



Crossections in SM





Little Higgs model results

Motivation :

For scalars exchange diagrams in $\gamma\gamma \to \gamma\gamma$ the helicity amplitudes in general are

$$\boxed{F_{\lambda_1\lambda_2\lambda_3\lambda_4} \propto Q_s^4}$$

where Q_s is the charge of scalar particle.

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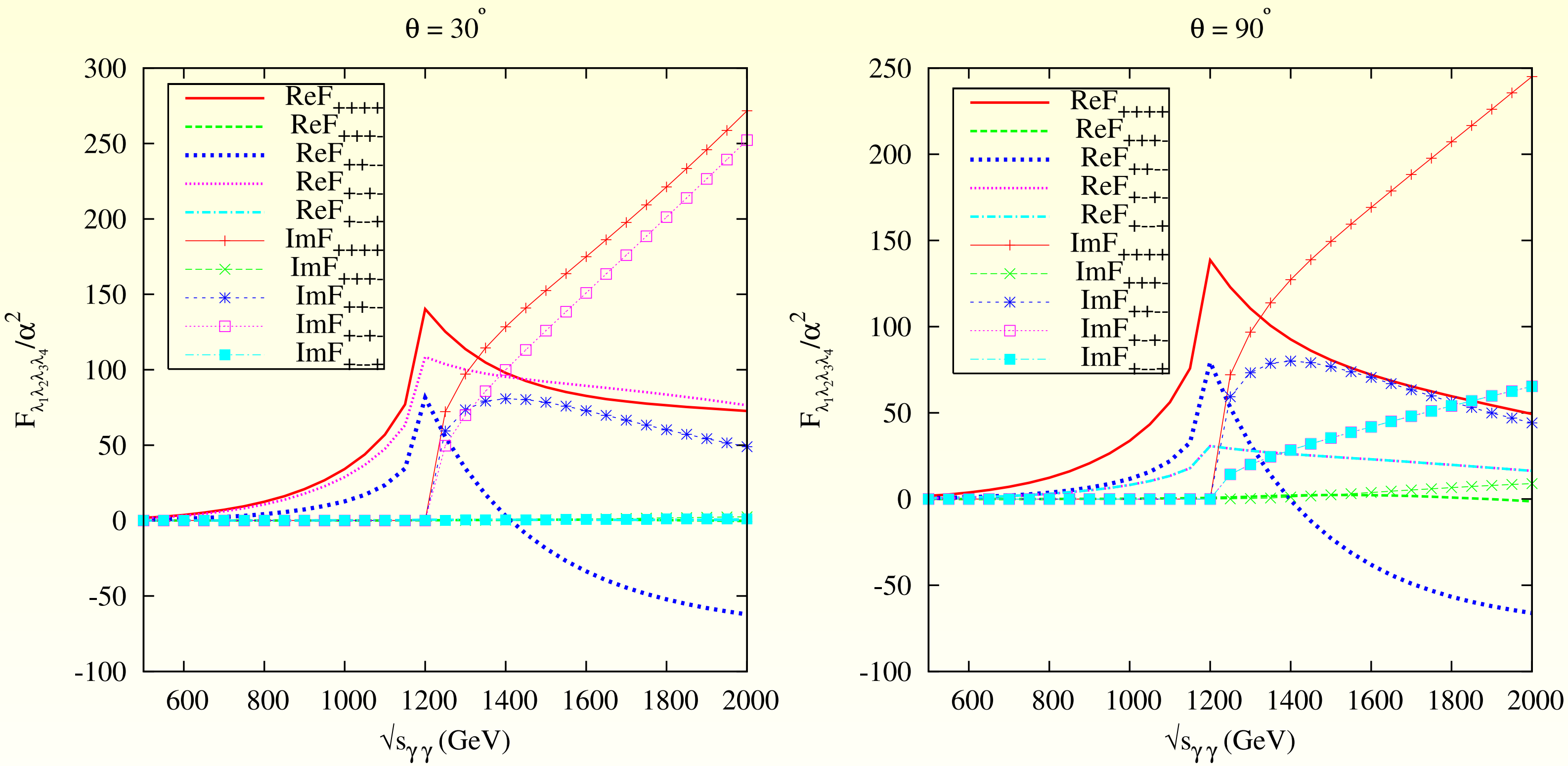
- We have doubly charged scalars (Φ^{--}) in LH models hence we could have a additional factor of **16** in amplitude and hence a factor of **256** in crossection.
- $\gamma\gamma \to \gamma\gamma$ proceeds through loops (in SM and LH) where intermediate particles are pair produced hence its interesting to study LH models with T-parity (precision and cosmological constraints on LH particle masses is much weaker [a]).

[a] M. Asano et.al. hep-ph/0602157, J. Hubisz et.al. hep-ph/0506042

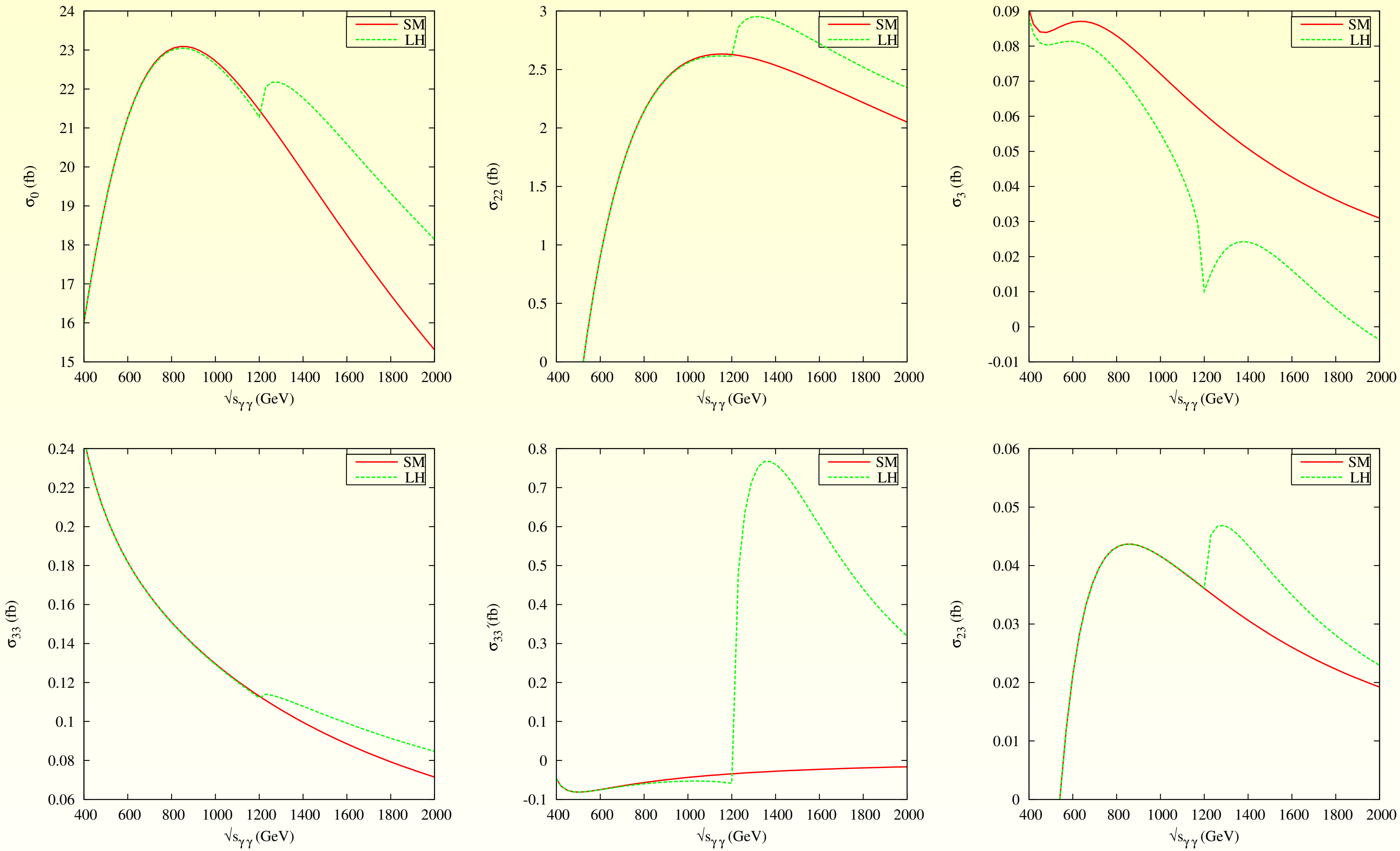
Contribution of scalar of mass m_s and charge Q_s to helicity amplitudes can be written as :

$$
\begin{aligned}
\frac{F^s_{++++}(\hat{s},\hat{t},\hat{u})}{\alpha^2 Q_s^4} &= 4 - 4\left(1+\frac{2\hat{u}}{\hat{s}}\right)B_0(\hat{u}) - 4\left(1+\frac{2\hat{t}}{\hat{s}}\right)B_0(\hat{t}) + \\
&\frac{8m_s^2\hat{t}\hat{u}}{\hat{s}}D_0(\hat{t},\hat{u}) - \frac{8m_s^2}{\hat{s}}\left(1+\frac{\hat{u}\hat{t}}{2m_s^2\hat{s}}\right)[2\hat{t}C_0(\hat{t}) \\
&+2\hat{u}C_0(\hat{u}) - \hat{t}\hat{u}D_0(\hat{t},\hat{u})] + 8m_s^4[D_0(\hat{s},\hat{t}) \\
&+D_0(\hat{s},\hat{u}) + D_0(\hat{t},\hat{u})] \;, \\
F^s_{+++-}(\hat{s},\hat{t},\hat{u}) &= \frac{1}{3}Q_s^4\left\{F^W_{+++-}(\hat{s},\hat{t},\hat{u}) \;;\; m_W \to m_s\right\} \;, \\
F^s_{++--}(\hat{s},\hat{t},\hat{u}) &= \frac{1}{3}Q_s^4\left\{F^W_{++--}(\hat{s},\hat{t},\hat{u}) \;;\; m_W \to m_s\right\} \;.
\end{aligned}
$$

Helicity amplitudes in LH (all heavy particles are assumed to be degenerate with mass 600 GeV)



Cross sections in LH ($\theta = 30$)



Conclusions

We can get substantial deviations in crossections due to LH effects which could be interesting in LH models with T-parity where constraints on LH particle masses is comparitively weak.

(Work under progress)

Crossections ($m_{W_H} = 450, m_\Phi = 500, m_T = 500$ and $\theta = 90$)