Spin identification of the RS graviton using diphoton signals

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Outline

1. Motivation

2. Center-Edge method

3. NLO QCD corrections

4. Numerical results

5. conclusions

Motivation

- Heavy new particles are predicted in many BSM physics scenarios $viz.$ Supersymmetry, Extra dimension models and Z' models.
- They can be seen as resonances in the invariant mass distribution of dilepton or diphoton like channels.
- Discovery reach: The upper limit on the resonance mass range where a signal can be detected above SM background at a given confidence level.
- Identification reach: The upper limit on the mass of the resonance where the underlying model could identified as a source of peak, excluding other competing models for all values of their parameters.
- Identification will be easy if the total number of signal events are different for different models.
- The problem lies when two models give identical number of signal events, for some parameter values.

New resonances

- Spin-0: Scalar resonances (S). e.g. sneutrinos in SUSY
- Spin-1: Heavy neutral gauge bosons e.g. Z' bosons in models like E_6, LR, ALR, SSM etc.
- Spin-2: Graviton (G) modes in warped extra dimension (RS) model.

Decays to a pair of leptons

- $q\,\bar{q} \;\rightarrow\; S \;\rightarrow\; l^+\,l^-$
- $q\,\bar{q} \;\rightarrow\; Z' \;\rightarrow\; l^+\,l^-$
- $q\,\bar{q} \;\rightarrow\; G \;\rightarrow\; l^+\,l^-$ and $g\,g \;\rightarrow\; G \;\rightarrow\; l^+\,l^-$

Decays to a pair of photons

- $q\,\bar{q} \;\rightarrow\; S \;\rightarrow\; \gamma\,\gamma$
- $q\,\bar{q} \;\rightarrow\; Z' \;\rightarrow\; \gamma\,\gamma$ (Not possible)
- $q\,\bar{q} \;\rightarrow\; G \;\rightarrow\; \gamma\,\gamma$ and $g\,g \;\rightarrow\; G \;\rightarrow\; \gamma\,\gamma$

New resonances

- A resonance in diphoton invariant mass distribution clearly excludes a class of models that predict Z' bosons (Yang's theorem).
- There is no known model in which $S \to \gamma\gamma$ (at least at LO).
- However, theoretically such an interaction is always possible.

$$c_1 \frac{g^2}{\Lambda} F^{\mu\nu} \, F_{\mu\nu} \, S + c_f \, \frac{m_f}{\Lambda} \, f \, \bar{f} \, S$$

R. Barbieri and R. Torre arXiv:1008:5302.

- Assuming scalar resonances is an optimistic approach, but not having them is somewhat a conservative one.
- Spin determination is very crucial in identifying the resonance and hence the underlying model.
- The spin information is contained in the angular structure of the matrix elements.

Angular distributions

- For $S \to \gamma\gamma$, the angular distribution is $\frac{d\sigma}{dz} = constanat$.
- For $G \to \gamma\gamma$, the angular distributions are

$$\begin{aligned} \frac{d\sigma}{dz}(q\bar{q} \to \gamma\gamma) &\sim \frac{t^2+u^2}{stu}|tu\ D(s)|^2 \\ \frac{d\sigma}{dz}(gg \to \gamma\gamma) &\sim \frac{t^4+u^4}{s}|D(s)|^2 \end{aligned}$$

where

$$\mathcal{D}(s) = \frac{1}{\Lambda_\pi^2}\sum_{n=1}^{\infty}\frac{1}{s-m_n^2+im_n\Gamma_n}$$

- Angular integration gives better statistics but the spin information is lost.
- A suitable observable is Center-Edge asymmetry A_{CE} which involves integration but still has the information of the angle.

Center-Edge asymmetry

- The whole angular region can be split into two regions.
- central region: $-z^* < z < z^*$
- edge regions: $-1 < z < -z^*$ and $z^* < z < 1$.

- Construct the Center-Edge cross section as given by:

$$\sigma_{CE} = \left[\int_{-z^*}^{z^*} - \left(\int_{-1}^{-z^*} + \int_{z^*}^{1}\right)\right] \frac{d\sigma}{dz}\, dz$$

- Compute the Center-Edge asymmetry defined as: $A_{CE} = \frac{\sigma_{CE}}{\sigma}$
- Look for the deviations of the measured A_{CE} from that of the scalar resonance:

$$\Delta A_{CE} = A_{CE} - A_{CE}^S \quad \text{for some} \quad z^* = 0.5.$$

- $|\Delta A_{CE}| = k\ .\delta A_{CE}$.
- $k^2 = 3.84$ is the 95% confidence limit for the identification of the graviton.

RS MODEL

This model is proposed by Randall and Sundrum.

1. There is only one very small extra dimension with orbifold symmetry.
2. The gravity only can propagate the $extra\ dimension$ while the SM fields are confined to the $brane$.
3. The metric in the RS model is given by

$$ds^2 = e^{-2kr_c|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu + r_c^2 d\phi^2$$

4. There are two branes on the extra dimension, namely $SM\ brane$ and the $Planck\ brane$ at $\phi = \pi$ and $\phi = 0$ respectively.
5. Any fundamental mass parameter M_0 in higher dimensions will correspond to a physical mass $m_p \simeq e^{-kr_c\pi}M_0$ on the brane.
6. For $kr_c \sim 12$, one can generate $\Lambda = e^{-kr_c\pi}M_{Pl}$, where $\Lambda \sim \mathcal{O}$(TeV).

Phy. Rev. Lett.83 (1999) 3370

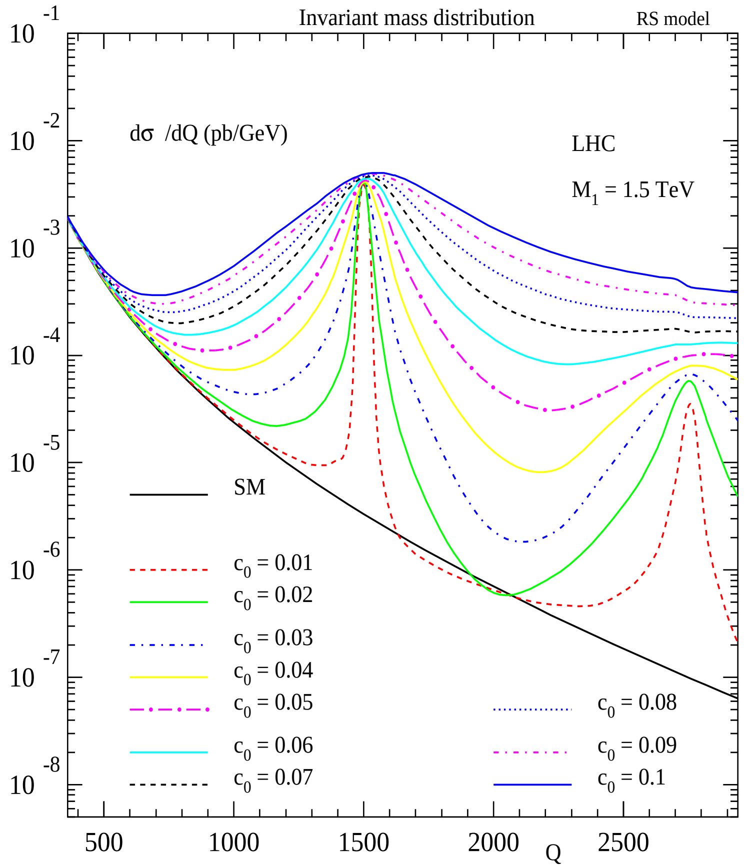
L.Randall and R.Sundrum

Invariant mass distribution

The RS modes are given by

$$m_n = x_n k \exp(-\pi k r_c) \equiv x_n m_0; \quad \text{and} \quad c_0 = \frac{k}{\bar{M}_{Pl}}, \quad k \sim M_{Pl}$$

where $x_1 = 3.8317$ and $x_n = 7.0156 + (n-2)\pi$ for $n > 2$.



Need for NLO QCD corrections

- For quantitative estimation of the higher order QCD corrections.
- To reduce the factorization scale uncertainties.
- Q_T distributions possible at NLO.
- Quantum corrections are more pronounced in the BSM case than in the SM, due to the presence of additional vertices in the BSM case e.g. the four point interactions in the RS model.
- In our case, we have used *two cut-off phase space slicing method* to compute NLO QCD corrections.

Phys.Rev.D65:094032,2002

B.W.Harris and J.F.Owens

cuts

Primary cuts

- Rapidity cut on the individual photons : $|y^{\gamma_{1,2}}| \leq 2.5$
- Transverse momentum cuts on the photons : $|p_T^{\gamma}| \geq 40$ GeV (hard) , 25 GeV (soft)

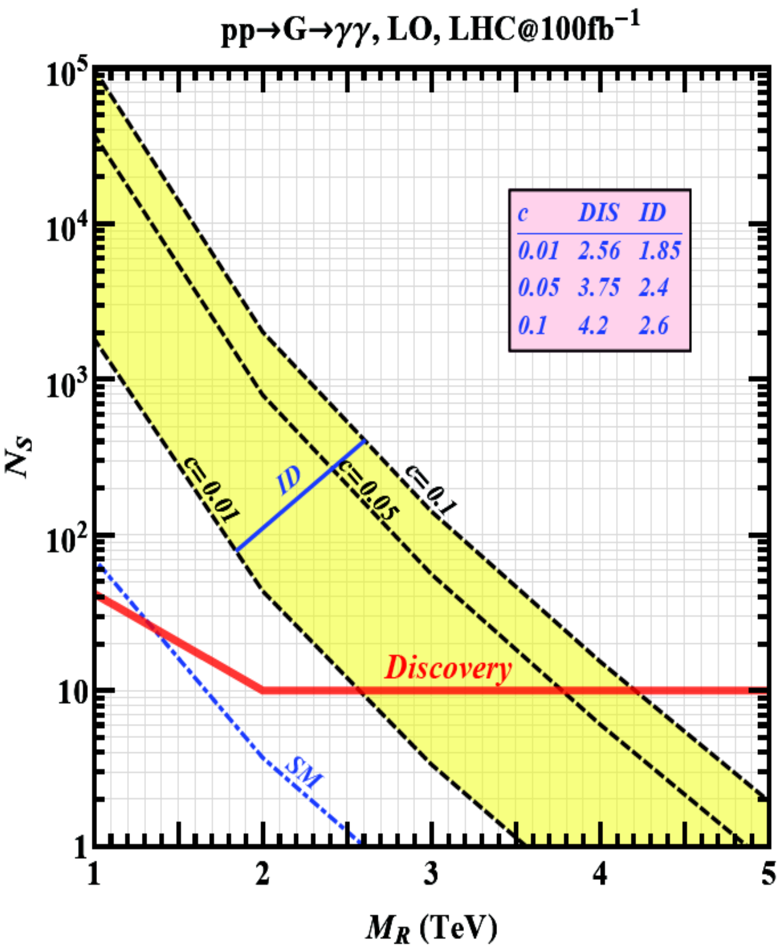
Isolation cuts

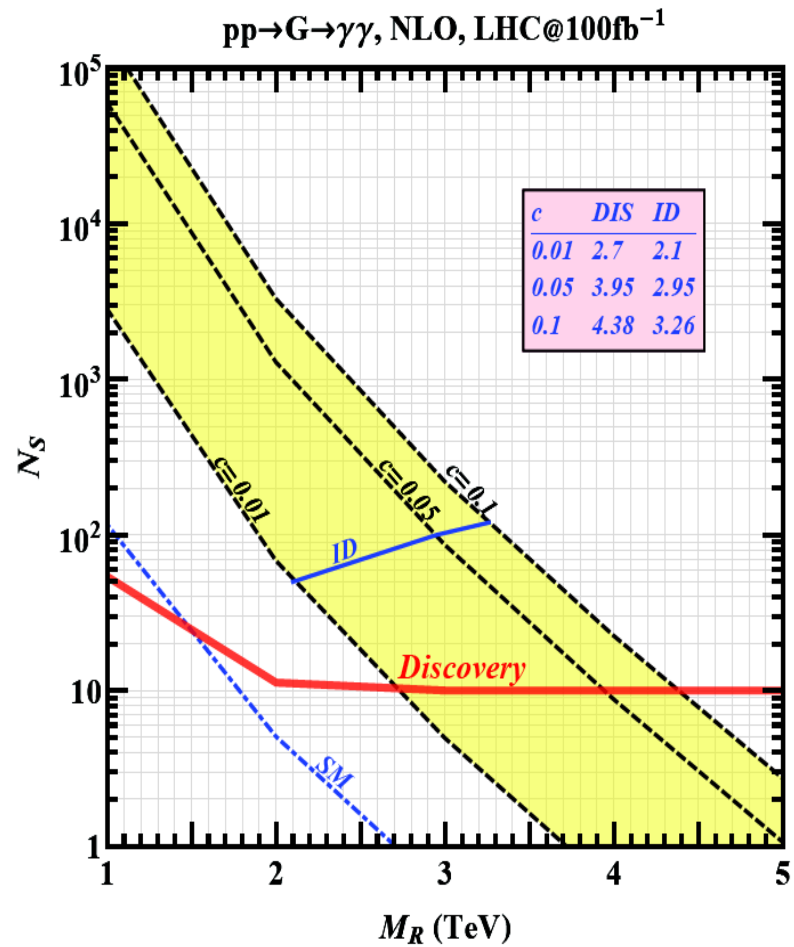
- The radius of the cone around each of the photons in the rapidity-azimuthal angular plane is given by

$$\Delta r(p_\gamma, p_j) = \sqrt{(y_\gamma - y_j)^2 + (\phi_\gamma - \phi_j)^2}$$

- $\Delta R = 0.4, E^{iso} = 15$ GeV
- Discard the event with $\Delta r(p_{\gamma_1} p_{\gamma_2}) \leq \Delta R$.
- Discard the event if $\Delta r(p_\gamma, p_{jet}) \leq \Delta R$ and $E_T^{jet} \geq 15$ GeV .
- Discard the event if $\Delta r(p_\gamma, p_{jet}) \leq \Delta R$ and $\chi\left[\Delta r(p_\gamma, p_{jet})\right] \leq E_T^{jet} \leq E^{iso}$. (smooth cone isolation algorithm).

Discovery and identification reaches (14 TeV)





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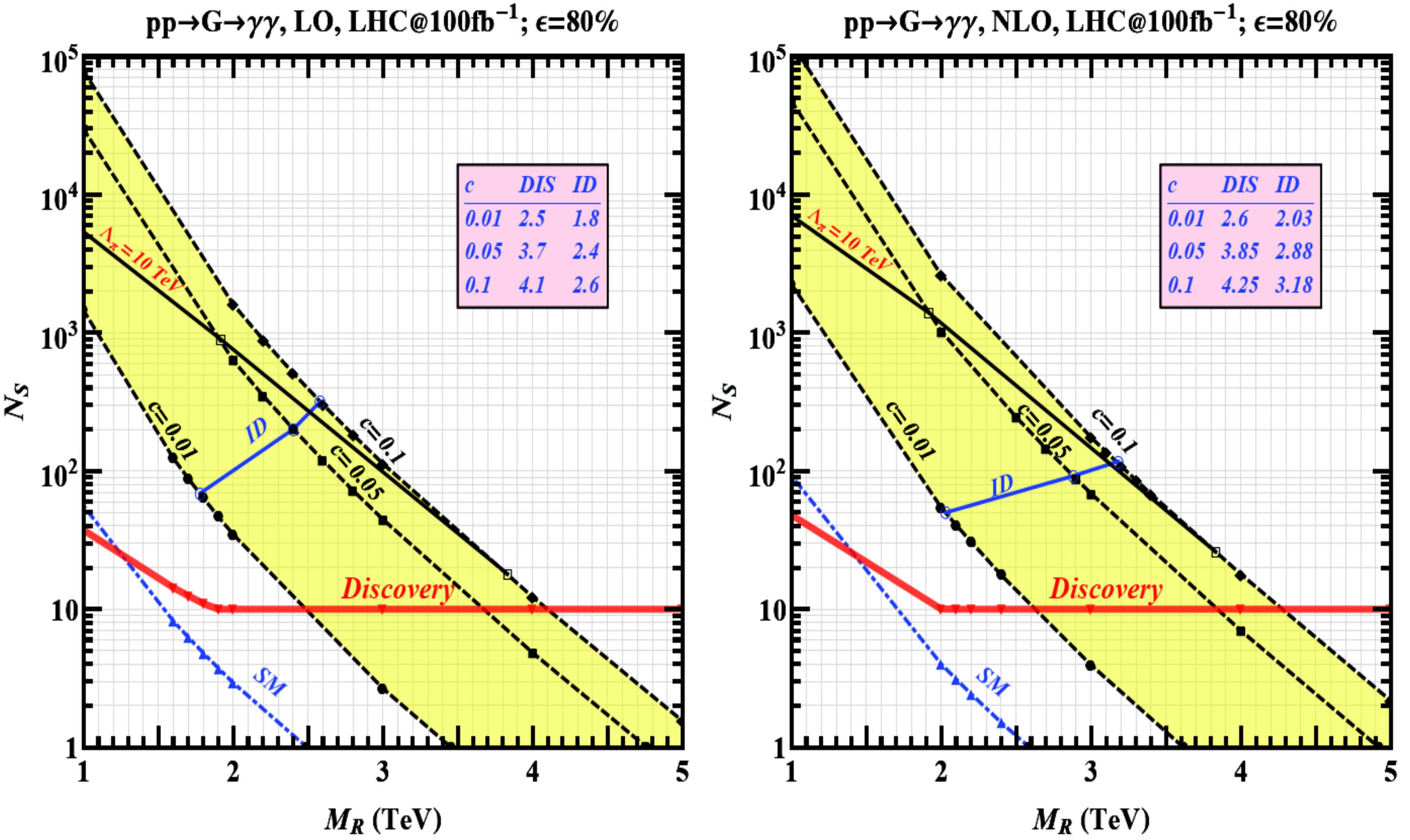
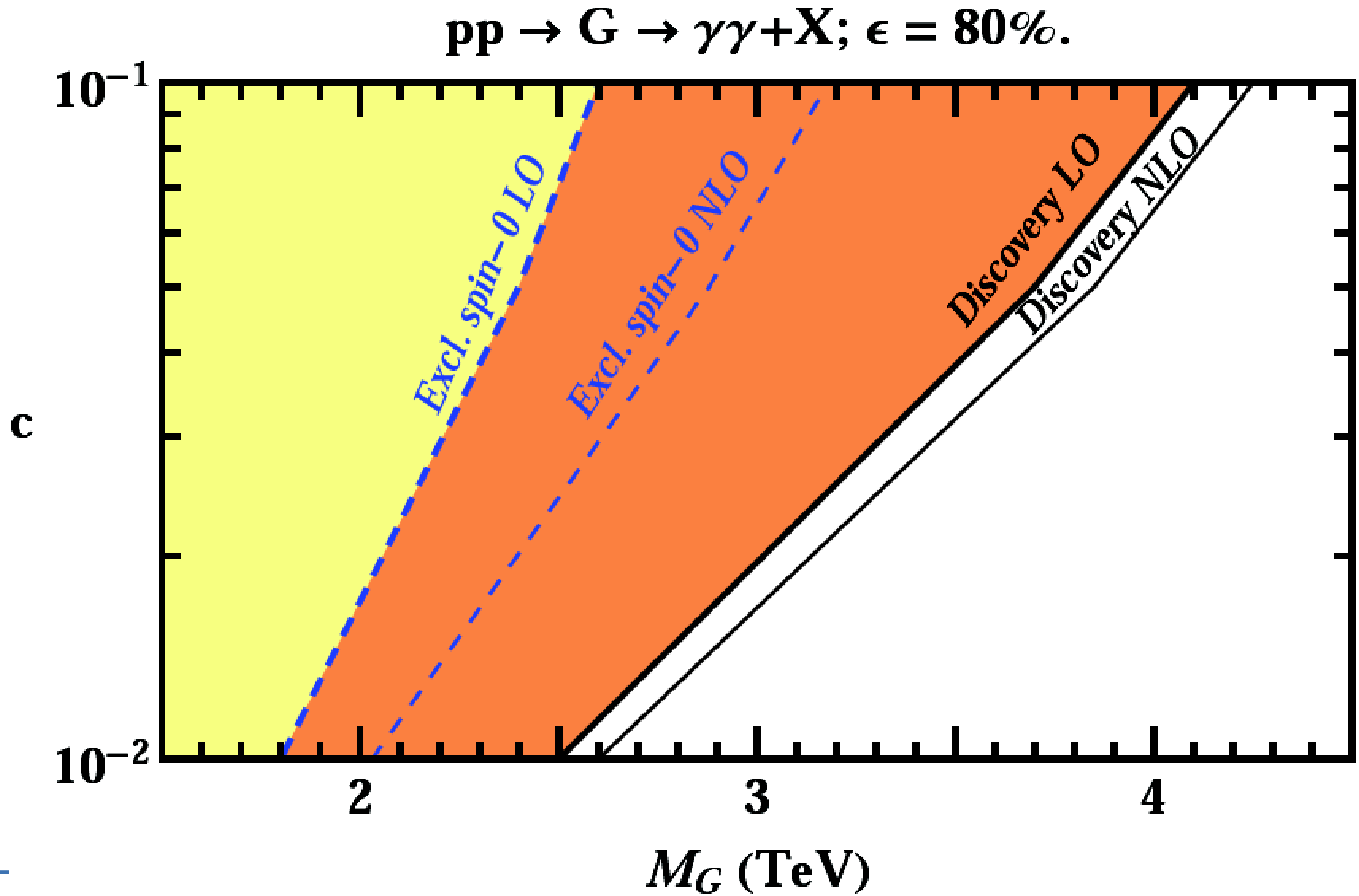
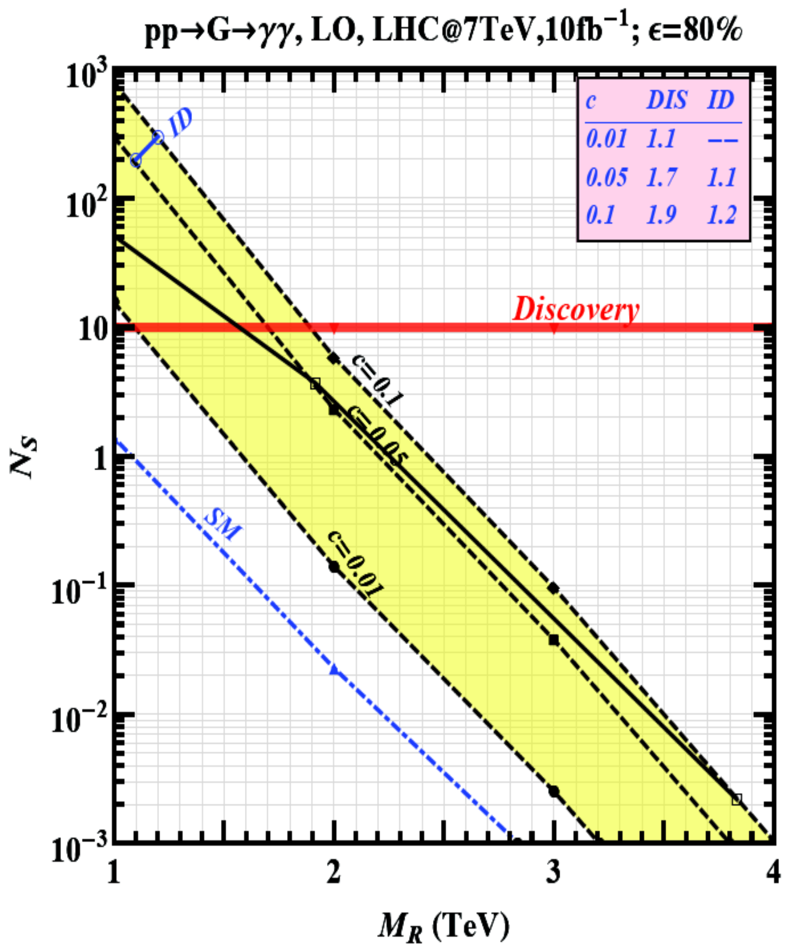
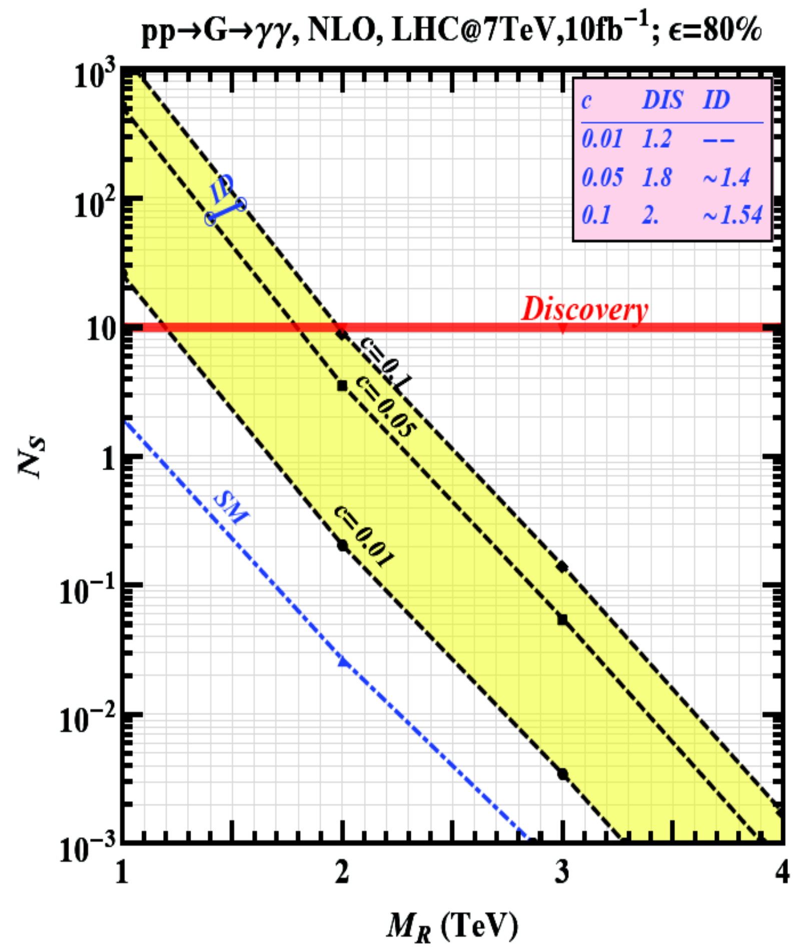


RS parameter space (14 TeV)

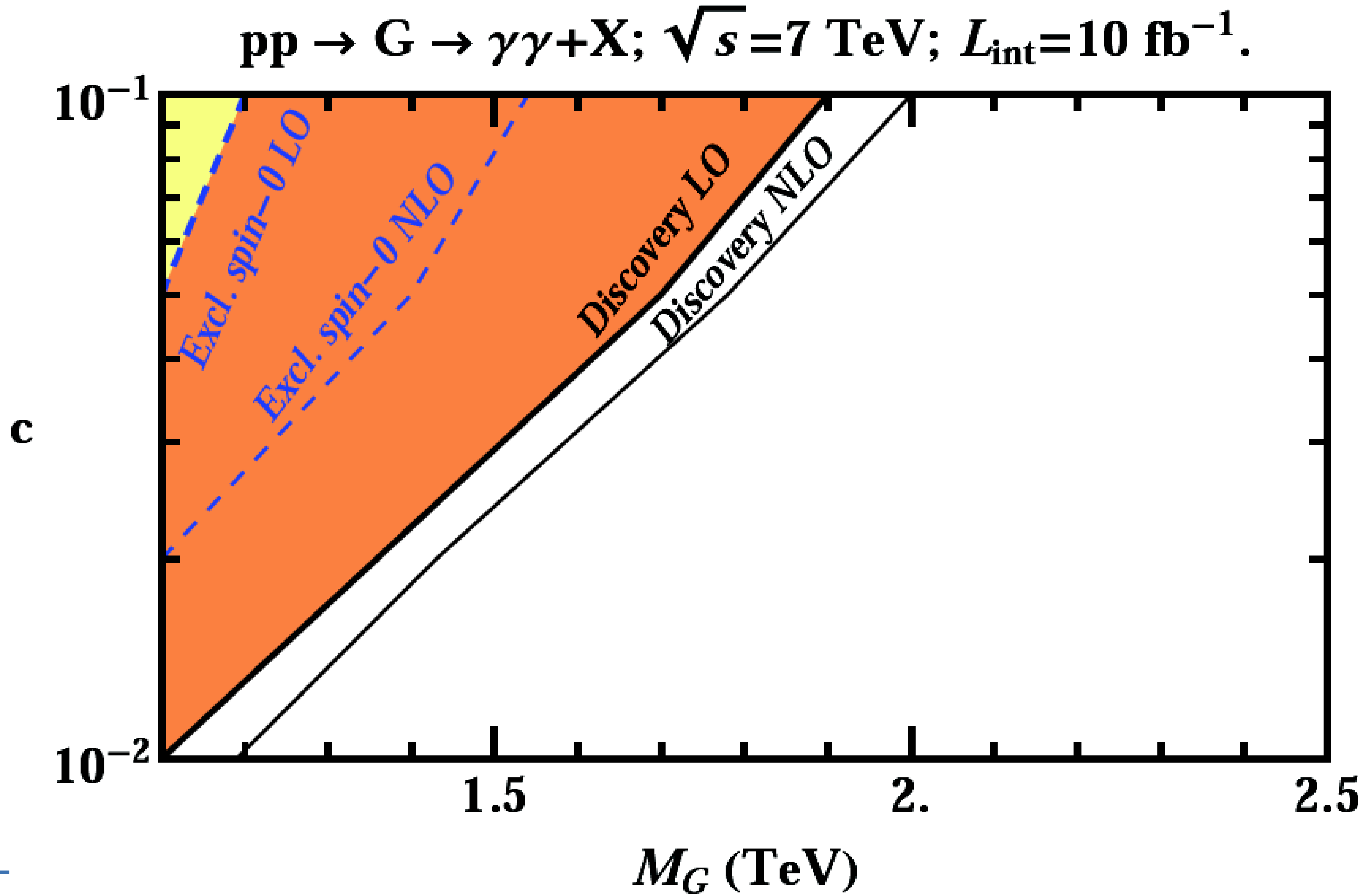


Discovery and identification reaches (7TeV)





RS parameter space (7TeV)



Conclusions

1. Center-Edge asymmetry is a robust method for the spin identification of heavy resonances at the LHC.
2. It has been studied very well in distinguishing varios new physics models.
3. Spin-1 resonances do not couple to photons and hence a class of new physics models can be excluded using diphoton signals.
4. We have presented the discovery and identification reaches of the RS graviton at the LHC for 7 TeV as well as 14 TeV.
5. NLO QCD corrections are computed using phase space slicing method.
6. QCD corrections are found to have enhanced both the discovery and the identification reaches of the RS graviton.