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Search for graviton resonances in the di-photon channel in the experiment ATLAS at LHC

S. M. Mazza
Università statale di Milano and INFN Sezione di Milano - Milano, Italy

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Summary. — In this article a search for a Randall-Sundrum graviton (RS) decaying to two photons is presented. The $3.2\,\mathrm{fb}^{-1}$ of analyzed data were recorded with the ATLAS detector. An excess of events is observed with a local significance of 3.6 σ and 1.8 σ of global significance, in a region around the invariant mass of 750 GeV.

An analysis optimized for the search for spin-2 Randall-Sundrum graviton resonance is presented. The $3.2\,\mathrm{fb}^{-1}$ of analyzed data were recorded with the ATLAS detector [1], which is a multipurpose detector with a forward-backward symmetric cylindrical geometry. A RS graviton would manifest itself in this channel as a resonance which width is proportional to the coupling (that is proportional to $k/\overline{M}_{\mathrm{Pl}}$) with the Standard Model [2]. The background was estimated with a combination of data driven techniques and MC simulation. A first result of this analysis was published with 7 TeV and 8 TeV data [3,4]. The di-photon channel was already crucial in the discovery of the Higgs boson, and it still seems to be holding surprises.

1. – Photon reconstruction and identification

The photon reconstruction is seeded from clusters of energy deposits in the electromagnetic calorimeter; tracks are used to distinguish among electrons, converted photons and unconverted photons. The efficiency is about 96.5% averaged over the transverse energy E_{T} and η ranges expected from photons from a graviton decay.

The energies of the clusters are calibrated, to account for energy losses upstream of the calorimeter and for energy leakage outside of the cluster. The identification of photons is based on shower shapes measured in the electromagnetic calorimeter.

2. – Selection of two photons events

The selection of di-photon events in the analysis proceeds as follows. Only photon candidates with $|\eta| < 2.37$ are considered. An initial loose identification is derived using only the information from the hadronic calorimeter and the lateral shower shape in the second layer of the electromagnetic calorimeter. The efficiency of the photon identification increases with E_T, from 85% at 50 GeV to 95% at 200 GeV.

To further reject the background from jets misidentified as photons, the photon candidates are required to be isolated using both calorimeter and tracking detector informations. The selection requirement on isolation depends on the E_T of the photon. Furthermore the transverse energy of each photon is required to satisfy $E_T > 55$ GeV.

With this selection, 5066 events with two photons satisfying the requirements described above and a di-photon invariant mass $m_{\gamma\gamma} > 200$ GeV are selected in the data.

3. – Signal modelling

The invariant mass distribution of the di-photon pair for the signal is expected to peak near the assumed mass of the new particle, with an additional spread given by the experimental resolution. The signal mass distribution for any value of the mass and $k/\overline{M}_{\mathrm{Pl}}$ is obtained by a convolution of the intrinsic detector resolution, modelled by a Double Sided Crystal Ball (DSCB) function, with the predicted distribution of the mass line-shape at generator level. The parameters of the DSCB function are determined from RS graviton signal samples of various masses with $k/\overline{M}_{\mathrm{Pl}} = 0.01$, which is negligible compared to the detector resolution.

4. – Background estimates

The background is separated into the di-photon irreducible component and the reducible contributions from photon+jet and dijet events. To normalize properly each component, the composition of the data sample in the invariant mass interval from 200 GeV to 500 GeV is determined following a data-driven procedure that exploits the shape of the isolation variable distribution. This method is called isolation template fit (section "background estimate" of [3]). The normalized distribution of the total background shape can then be estimated over the full mass range, summing the different background components with their relative normalizations obtained in the 200–500 GeV range.

The Diphox MC NLO computation is used to reweight fully simulated di-photon events generated with Sherpa MC as a function of the di-photon invariant mass. Diphox has uncertainties on the PDF from variations of the 22 eigenvectors that are provided with the CTEQ6.6M PDF (from ±2% at a mass of 200 GeV up to ±35% at a mass of 3500 GeV), on the choice of the PDF set from a comparison with the MSTW2008NLO PDF set (up to ±5%), on the photon isolation applied at the parton level (±10%), and on the factorization, renormalization and fragmentation scales used in Diphox (±5%).

To predict the shape of the photon+jet and dijet backgrounds, control samples where one or two of the photons fail the tight identification criteria but fulfill looser selections are used. The shape of the invariant mass distribution in these control samples is fitted with a function of the form

$$f(x) = p_0 \times x^{p_1 + p_2 \log(x)} \times \left(1 - \frac{1}{1 + e^{(x-p_3)/p_4}}\right), \tag{1}$$

where $x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$ and p_i are free parameters. The uncertainty on the shape of this background is estimated by varying the identification criteria used to select the photons in the control sample.

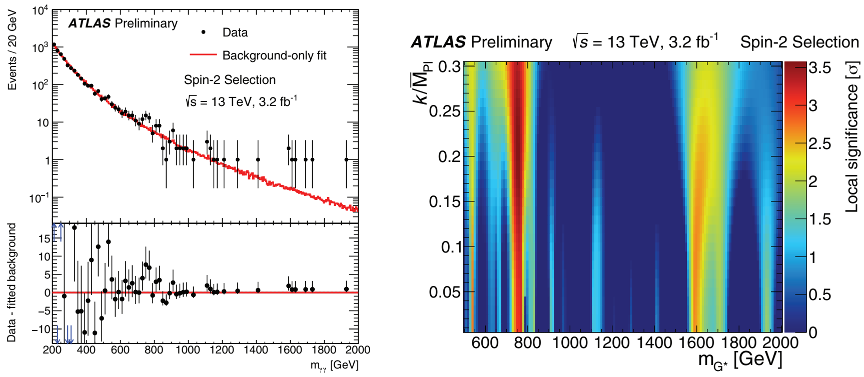

Fig. 1. – Left: Distribution of the di-photon invariant mass for the graviton selection, with superimposed the best background-only fit. There is no overflow entry at high mass. Right: Compatibility, in terms of local significance σ, with the background-only hypothesis as a function of the assumed signal mass and $k/\overline{M}_{\rm Pl}$ for the spin-2 resonance search.

Four independent sources of systematic uncertainties are considered, each of them with an impact varying with the invariant mass but fully correlated across the full mass range. These sources are the shape of the reducible background, the relative normalization of the reducible and irreducible backgrounds, the impact of the parton-level isolation requirement in DIPHOX and the effect of the uncertainties on the scales and PDF in the DIPHOX computation. In addition, MC statistical uncertainties, which range from $\pm 5\%$ to $\pm 10\%$ in a 5 GeV mass interval, are also considered, uncorrelated between bins.

5. – Conclusion

An analysis optimized for the search for spin-2 Randall-Sundrum graviton resonances was performed. Over most of the di-photon mass range, the data are consistent with the background-only hypothesis and 95% CL, limits are derived on the cross section for the production of a RS graviton as a function of its mass and $k/\overline{M}_{\rm Pl}$. The largest deviation from the background-only hypothesis is observed in a broad region near a di-photon invariant mass of 750 GeV and a $k/\overline{M}_{\rm Pl} = 0.2$ (as seen in fig. 1), corresponding to a width of about 50 GeV. The local significance found is of 3.6 standard deviations. The global significances is estimated to be 1.8 standard deviations.

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