Sensitivity Measurement for the Spin of the Resonance Observed in the $\gamma\gamma$ Channel

Sinan Kefeli

Summer Student at DESY, in the ATLAS Group

Home University: Bogazici University

sinan.kefeli@boun.edu.tr

Supervised by:

Nicolas Berger (LAPP)

Sergei Gleyzer (DESY)

Kerstin Tackmann (DESY)

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Abstract

Contents

1 Introduction

A new particle with mass $\approx$ 125 GeV has been discovered at the LHC, which has similarities with the Higgs Boson H (Figure 1) [2]. It is essential to measure the spin of the particle for its identification. The Standard Model Higgs is predicted to have spin 0.

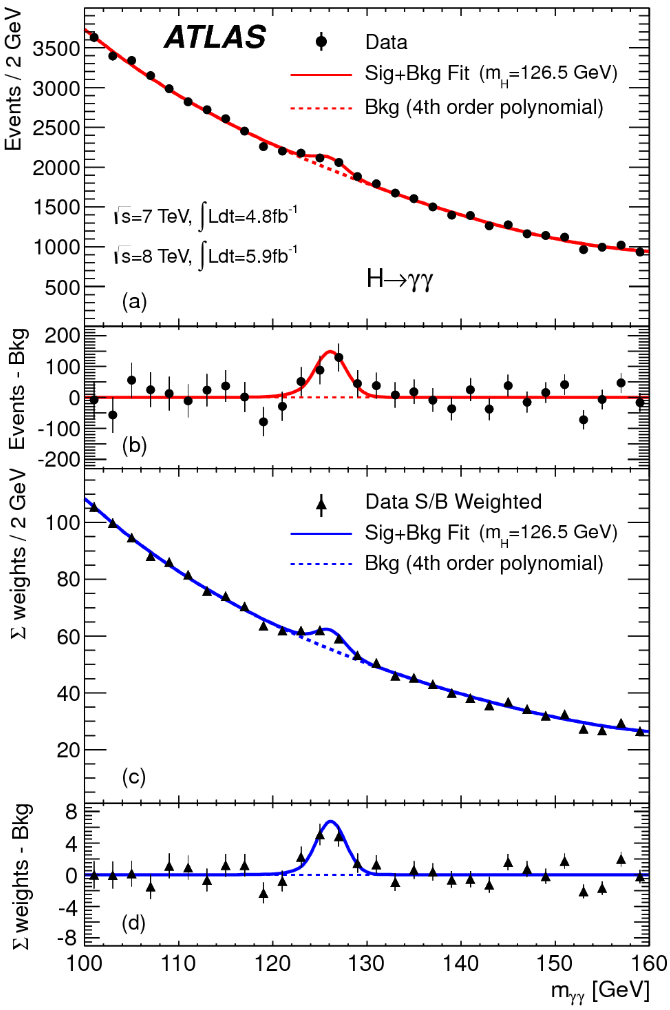


Figure 1: Resonance observed in the $\gamma\gamma$ channel

The analysis is done in the $\gamma\gamma$ channel, where the excess observed cannot have spin 1. The only possibilities are spin 0 or spin 2. Pseudo-experiments are generated for signal spin 0 and spin 2 cases. A likelihood test is applied to differentiate alternative spins.

2 Theory

2.1 Angular Variable $\cos\theta^*$

A spin test can be achieved by looking at the distributions of the angular variable $\cos\theta^*$, defined to be the angle between the leading photon and the beam direction in the lab frame, measured in the Higgs rest frame (Figure 2). This variable can be used to differentiate alternative spins. A spin 0 particle would have a flat distribution.

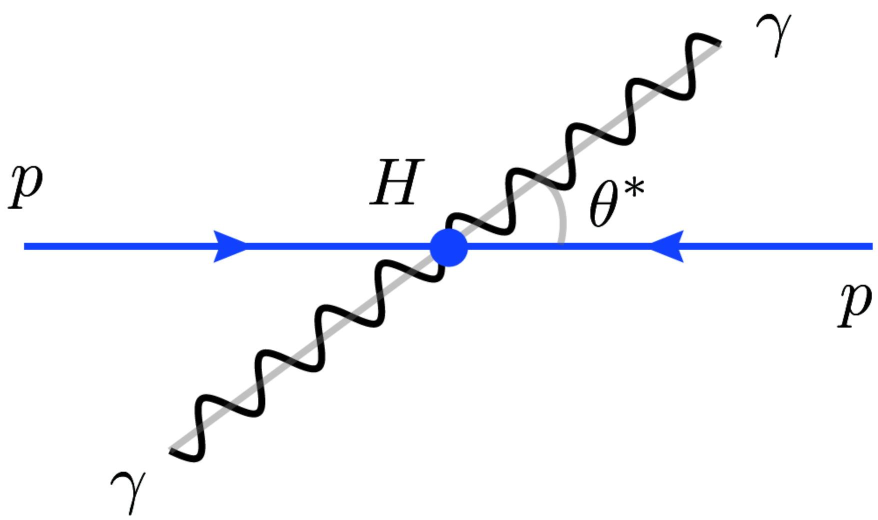


Figure 2: Angular Variable $\cos\theta^*$

2.2 Spin 2 Model

The angular distribution of the $\gamma\gamma$ pair from a spin 2 particle is unique and different from the spin 0. The total $\gamma\gamma$ cross section $d\sigma/d\Omega$ is given by (Figure 3)[1]:

$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4} + \frac{3}{2}\cos^2\theta + \frac{1}{4}\cos^4\theta$$

2.3 Likelihood Ratio Test

In this analysis there are two observables: $m_{\gamma\gamma}$ and $\cos\theta^*$. These are assumed to be uncorrelated

- Background PDF $= p_b(m_{\gamma\gamma}, \cos\theta^*) = a_b(m_{\gamma\gamma})b_b(\cos\theta^*)$, obtained from sidebands

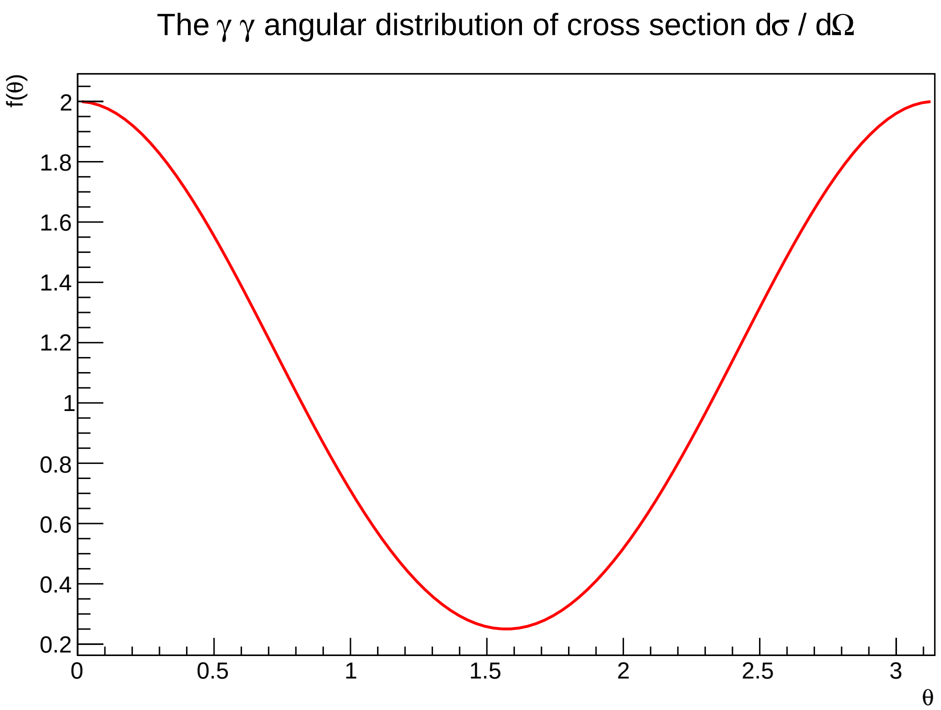


Figure 3: $\gamma\gamma$ cross section $d\sigma/d\Omega$

- Signal PDF $= p_s(m_{\gamma\gamma}, \cos\theta^*; m_H) = f_s(m_{\gamma\gamma}; m_H) g_s(\cos\theta^*)$
  There are two models to be tested: spin 0 and spin 2 (same $f_s(m_{\gamma\gamma}; m_H)$, different $g_s(\cos\theta^*)$)
  - Spin 0 $\rightarrow f_s(m_{\gamma\gamma}; m_H) g_0(\cos\theta^*)$
  - Spin 2 $\rightarrow f_s(m_{\gamma\gamma}; m_H) g_2(\cos\theta^*)$

Likelihood is a measure of agreement between data and a possible model used to describe the data

$$-L_0 = (n_A + n_b) - \sum \ln\left[n_s f_s(m_{\gamma\gamma}; m_H) g_s(\cos\theta^*) + n_b p_b(m_{\gamma\gamma}, \cos\theta^*)\right]$$

For our purposes we consider the log likelihood ratio:

$$\lambda = -2\ln\frac{L(\text{data,spin0})}{L(\text{data,spin2})} = -2\sum \ln\left[\frac{n_s f_s(m_{\gamma\gamma}; m_H) g_0(\cos\theta^*) + n_b p_b(m_{\gamma\gamma}, \cos\theta^*)}{n_s f_s(m_{\gamma\gamma}; m_H) g_2(\cos\theta^*) + n_b p_b(m_{\gamma\gamma}, \cos\theta^*)}\right]$$

Negative values of λ would favor spin 0 model in this analysis.

3 Monte Carlo

Process	Contribution
gg Fusion	88.5%
tt Fusion	0.5%
Vector Boson Fusion	7.5%
WH	2.7%
ZZH	0.5%

Table 1: Processes and their Contributions

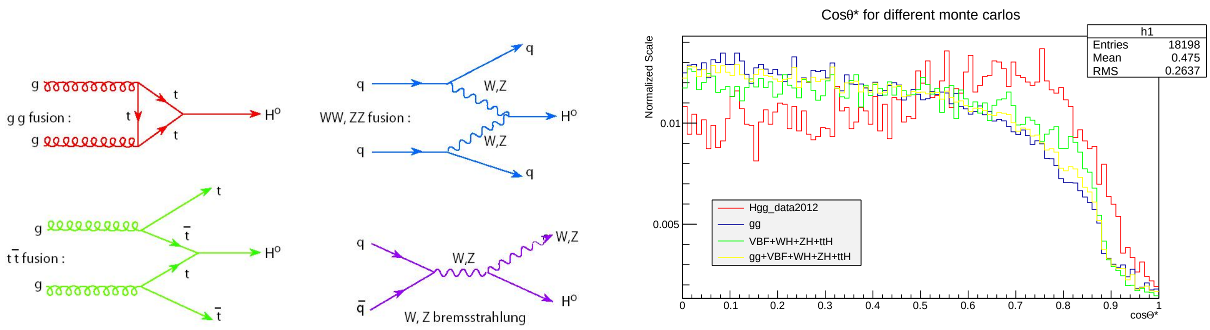


Figure 4: Processes and their Contributions

Only gg fusion is considered in this analysis, because it is the most dominant one (Table1, Figure 4). Background is taken from ATLAS 2012 data, sidebands region of 124 GeV $< m_{\gamma\gamma} <$ 128 GeV. The overall mass region of the analysis is 100 GeV $< m_{\gamma\gamma} <$ 160 GeV.

4 Applying Spin-2 Reweighting

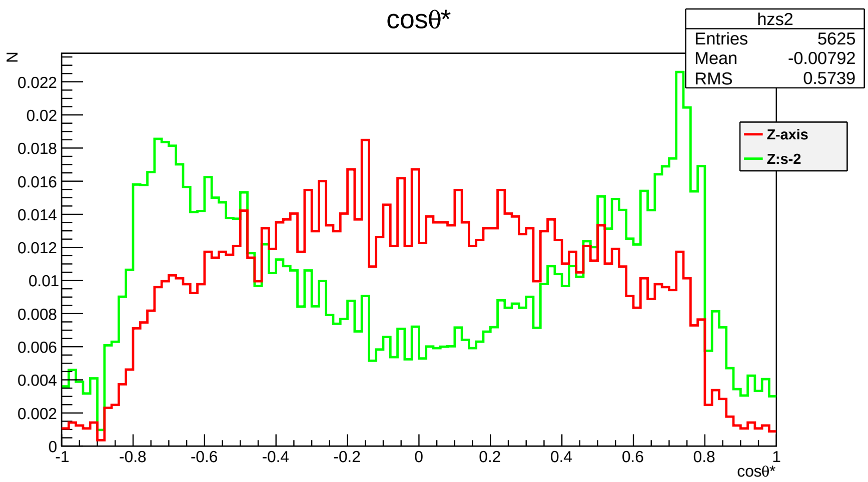


Figure 5: $\cos\theta^*$ distributions for signal spin 0 and spin 2

$$\text{weight: } \frac{d\sigma}{d\Omega} \propto \frac{1}{4} + \frac{3}{2}\cos^2\theta + \frac{1}{4}\cos^4\theta$$

Signal spin 0 is simulated for $m_H = 125$ GeV monte carlo. Signal spin-2 is produced by applying reweighting, both distributions are normalized (Figure 5).

Spin-0 $\cos\theta^*$ is supposed to be flat in Figure 5, but there is a decrease in the value.This is due to analysis cuts. The cuts for the photons are:

$$E_{T_1} = 40 \text{ GeV} \qquad E_{T_2} = 30 \text{ GeV}$$

which can be seen in Figure 6.

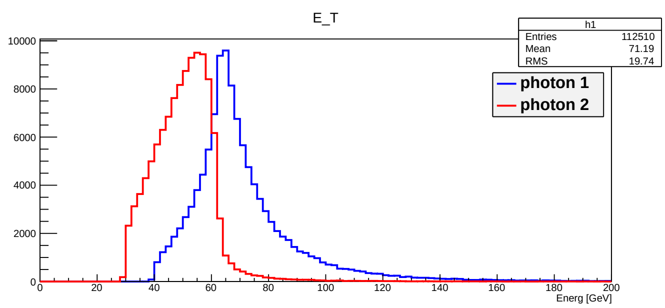


Figure 6: E_T

5 Parametrization

5.1 Parametrization of the Background

4^{th} degree Bernstein polynomial is used to parametrize the background $\cos\theta^*$. Fits are unbinned. The background is taken from sidebands of the data, excluding the region

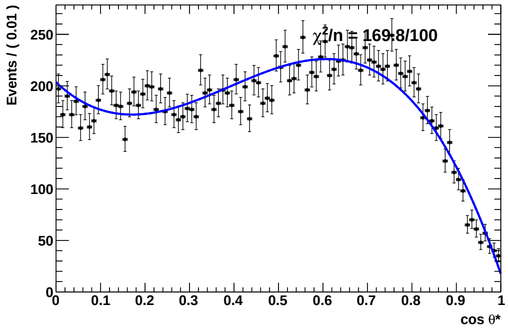


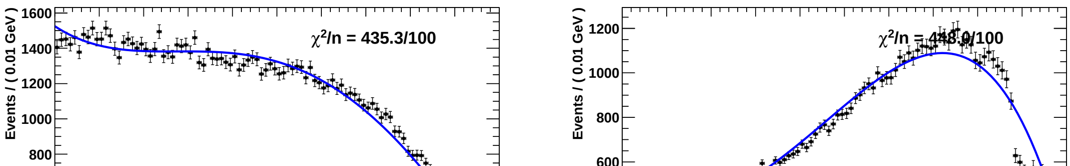
Figure 7: 4^{th} degree Bernstein polynomial for the background $\cos\theta^*$
$\chi^2/\text{dof} = 169.8/100$

$124\text{GeV} < m_{\gamma\gamma} < 128\text{GeV}$

5.2 Parametrization of the Signal

Using 4^{th} degree Bernstein polynomial for the spin-0 and spin-2 signals $\cos\theta^*$

spin 0 spin 2



$\chi^2/\text{dof} = 435.3/100$ $\chi^2/\text{dof} = 448.0/100$

Figure 8: 4^{th} degree RooBernstein polynomial for the signal $\cos\theta^*$

The fits are not so good, they can be improved for better results.

6 Toys and Separation

Pseudo experiments (toys) with spin 0 and spin 2 are generated for various luminosities. A plot is shown for 1000 toys with 30 fb^{-1} (Figure 9).

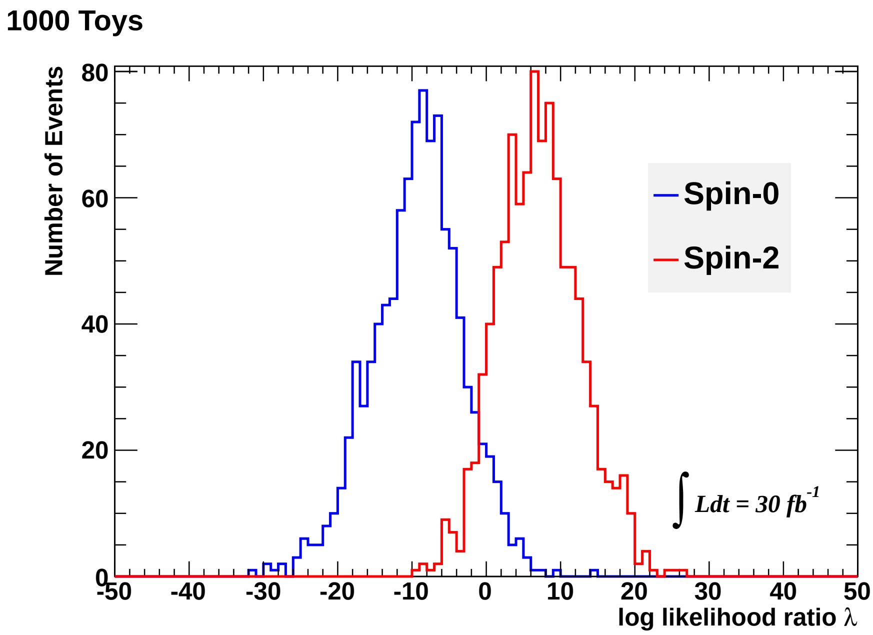


Figure 9: Histogram of $\lambda = -2\log\frac{L(\text{data,spin0})}{L(\text{data,spin2})}$

There are two methods for quantifying separation:

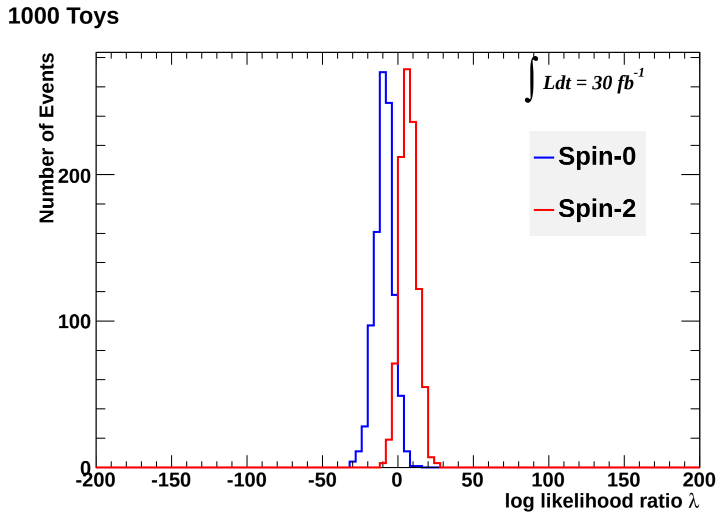
- 95% CL exclusion
  First, find λ_0 that corresponds to 95% of a model. Find fraction of the other model with λ beyond λ_0. The fraction corresponds to exclusion probability 95% CL. This is the probability to get such an exclusion if the hypotesis is the real one. If the particle is spin-A, then I would have x% chance to exclude spin-B at 95%.

- Median exclusion First, find λ_0 that corresponds to the median of a model. Find the fraction of the other model with λ beyond λ_0. Fraction corresponds to minimum probability of exclusion that can be reached in 50% of the cases.

7 Results

The results are shown in Figure 10

30 fb^{-1}



300 fb^{-1}

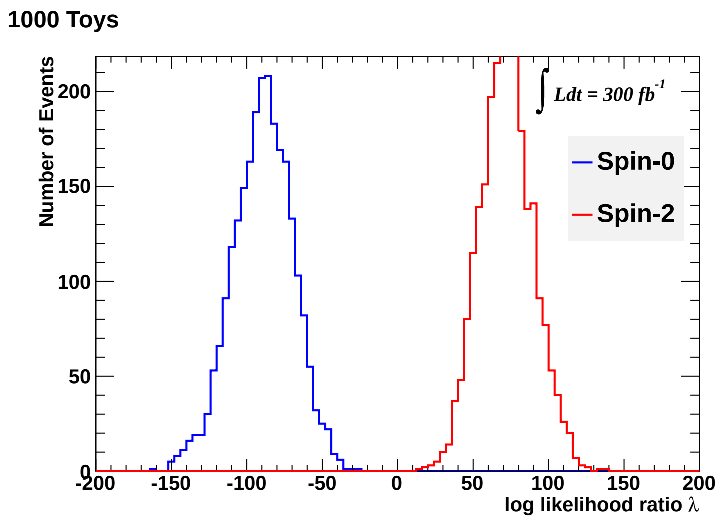


Figure 10: Histogram of $\lambda = -2 \log \frac{L(\text{data,spin0})}{L(\text{data,spin2})}$ for 30 fb^{-1} (top) and 300 fb^{-1} (bottom)

Qualitatively it can be seen the separation gets bigger with increasing luminosity.

p-values and the corresponding standard deviations are:

Lumi (fb^{-1})	# of Toys	$p_{\%95}$	$p_{\%95}$	p_{Median}	p_{Median}
		spin-0	spin-2	spin-0	spin-2
30	1,000	0.11	0.093	0.001	0.004
300	1,000	-	-	-	-

Lumi (fb^{-1})	# of Toys	$\sigma_{\%95}$	$\sigma_{\%95}$	σ_{Median}	σ_{Median}
		spin-0	spin-2	spin-0	spin-2
30	1,000	1.60	1.68	3.29	2.88
300	1,000	-	-	-	-

Separation in terms of σ for 300 fb^{-1} cannot be calculated due to low statistics. More toys are needed.

8 Summary

In this analysis, the sensitivity of separation between spin 0 and spin 2 is studied using the angular variable $\cos\theta^*$. Background is taken from data sidebands Spin 0 signal is generated with 125 GeV gg fusion monte carlo Spin 2 signal is generated using reweighting on Spin 0 $\cos\theta^*$ Likelihood test is used to study exclusions for different luminosities for spin-0 and spin 2. Results depend on parametrization. No correlation between $m_{\gamma\gamma}$ and $\cos\theta^*$ is assumed. This analysis shows that spin 0 and spin 2 have some separation for 30 fb^{-1}

9 Outlook

The Results can be improved, with better fits and more toys. Other angular variables can be analyzed. The correlation of $m_{\gamma\gamma}$ and $\cos\theta^*$ can be investigated.

References

[1] "Does the Higgs have Spin Zero?" *John Ellis, Dae Sung Hwang*

[2] "Search for the Standard Model Higgs boson in the diphoton decay channel with 4.9 fb-1 of pp collisions at sqrt(s)=7 TeV with ATLAS." *ATLAS Collaboration*