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

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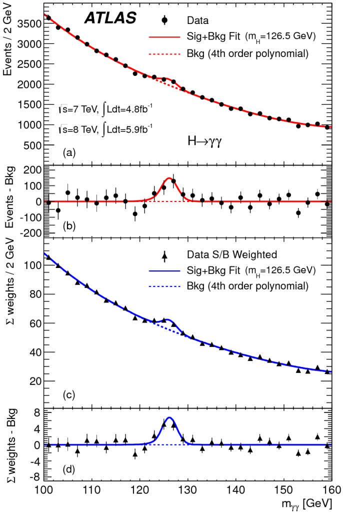
Motivation and Aims

- Measuring the spin of the recently discovered particle at $m \approx 125$ GeV essential for its identification - Is it Higgs (SM: spin-0) ?
- A spin test is achieved by looking at the distributions of angular variable $\cos\theta^*$ (next slide)
- Spin-1 is disfavored in diphoton channel (`arXiv:1202.6660`). Resonance can only be spin-0 or spin-2 in this channel.
- What is the sensitivity to separate spin-0 and spin-2?



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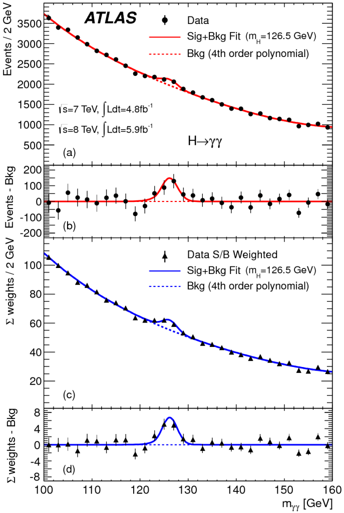

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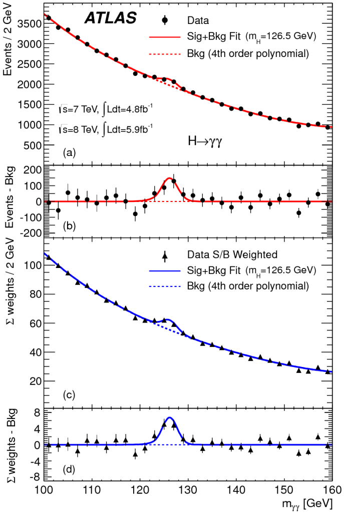

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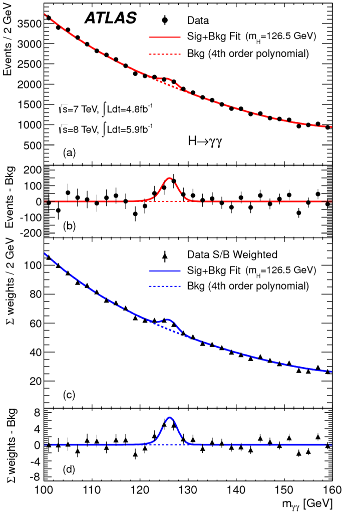
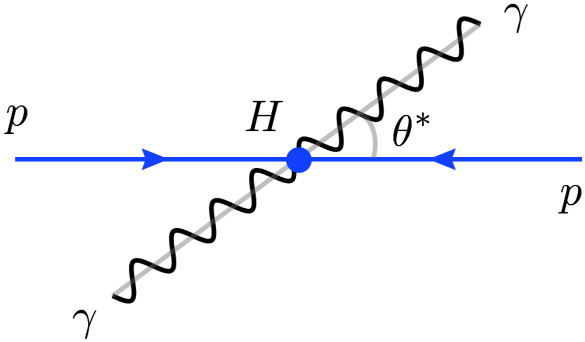


$\cos\theta^*$

The variable $\cos\theta^*$ is defined as the angle between the leading photon and the beam direction in the lab frame, measured in the Higgs rest frame.

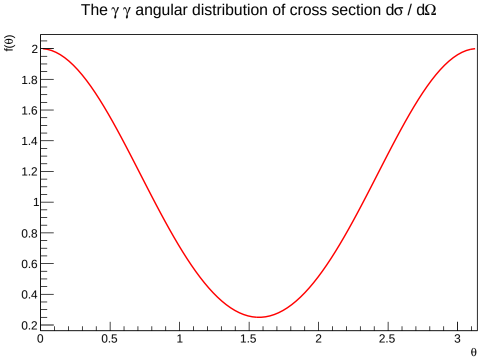
$\cos\theta^*$ can be used to differentiate alternative spins



Spin-2 Modeling

$\cos\theta^*$ distribution for spin-0 is flat.

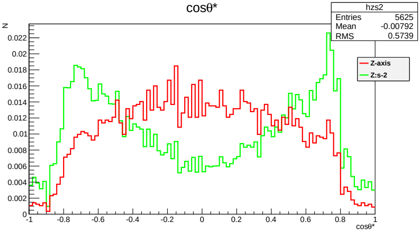
Our spin-2 model is based on a reweighting scheme.



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

`arXiv:abs/1202.6660` John Ellis, Dae Sung Hwang

Applying Spin-2 Weight



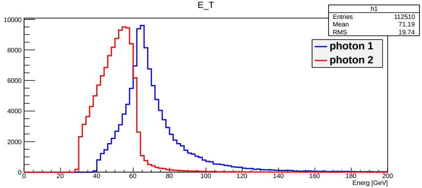
- Spin-0 $\cos\theta^*$ is supposed to be flat
- Decrease in $\cos\theta^*$ due to analysis cuts

The cuts for photons are:

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

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

- Spin-0 simulated for $m_H = 125$ GeV MC
- Spin-2 produced by applying weight
- Both distributions normalized.



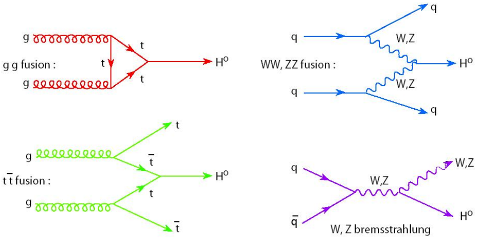
Monte Carlo and Data

Data

- ATLAS 2012 data

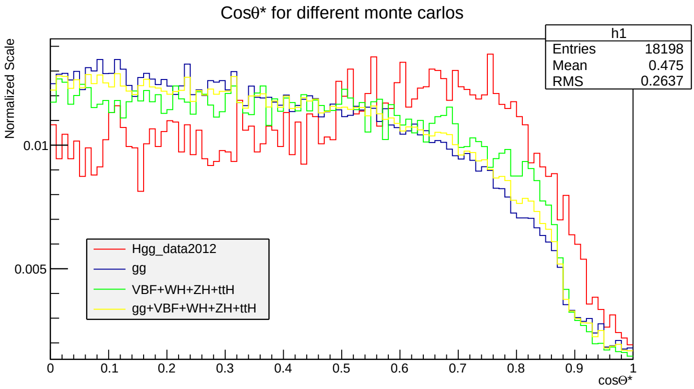
Monte Carlo, $m_H = 125$ GeV

- (88.5%) ggH125 - PowHeg + Pythia
- (0.5%) ttH125 - Pythia
- (7.5%) VBFH125 - PowHeg + Pythia
- (2.7%) WH125 - Pythia
- (0.5%) ZZH125 - Pythia



Monte Carlo and Data

- Only gg fusion considered because most dominant process.
- Overal mass region of analysis: $100\,\text{GeV} < m_{\gamma\gamma} < 160\,\text{GeV}$
- Background taken from ATLAS 2012 data sidebands, mass range: $m_{\gamma\gamma} < 124$ GeV and $128\,\text{GeV} < m_{\gamma\gamma}$



Likelihood Ratio Test

In this analysis there are two observables: $m_{\gamma\gamma}$ and $\cos\theta^*$, and 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
- 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

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:

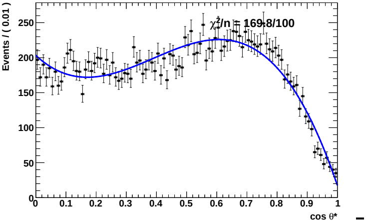
$\lambda = -2 \ln \frac{L(\text{data,spin0})}{L(\text{data,spin2})} = -2 \sum \ln \left[\frac{n_s f_s(m_{\gamma\gamma}; m_H) g_0(\cos\theta^*) + n_b p_b(m_{\gamma\gamma}, \cos\theta^*)}{n_s f_s(m_{\gamma\gamma}; m_H) g_2(\cos\theta^*) + n_b p_b(m_{\gamma\gamma}, \cos\theta^*)} \right]$

Negative values of λ would favor spin-0 model

Parametrization of Background

4^{th} degree Bernstein polynomial for the background $\cos\theta^*$.
Fits are unbinned.

Figure: 4^{th} degree Bernstein polynomial for the background $\cos\theta^*$



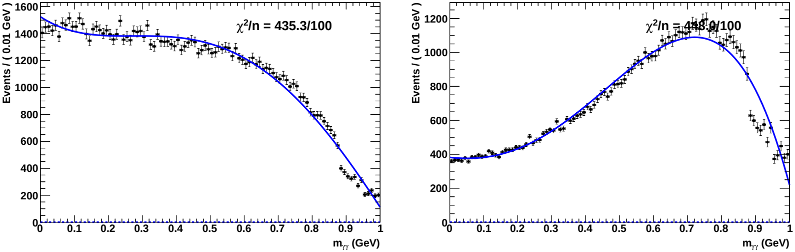
$$\chi^2/\text{dof} = 169.8/100$$

The background is taken from sidebands of the data, excluding the region $124\text{GeV} < m_{\gamma\gamma} < 128\text{GeV}$

Parametrization of Signal

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

It can be seen that fits are not so good and can be improved if there is enough time.

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}

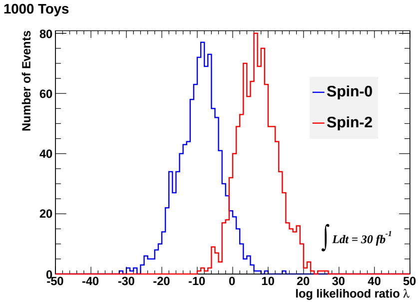


Figure: Histogram of $\lambda = -2 \log \frac{L(\text{data,spin0})}{L(\text{data,spin2})}$

We consider two methods for quantifying separation: 95% CL exclusion and Median Exclusion

95% CL exclusion:

- Find λ_0 corresponding to 95% of model
- Find fraction of other model with λ beyond λ_0
- Fraction corresponds to exclusion probability 95% CL

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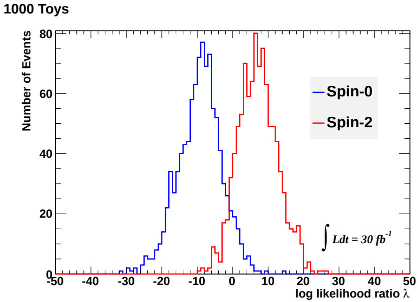

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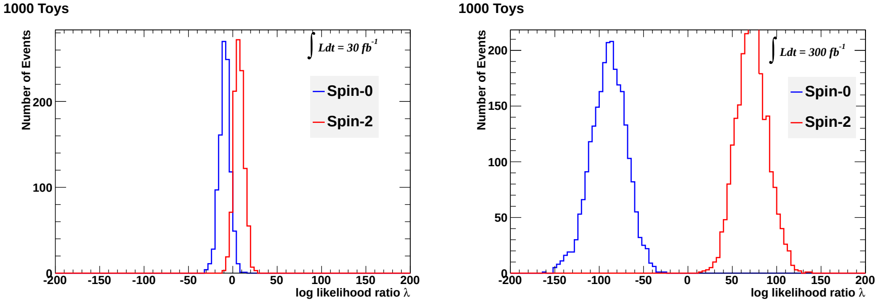
Median exclusion:

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

Results

Results are plotted and given in table(next slide).



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

Results

p-values and the corresponding standard deviations are given

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	-	-	-	-

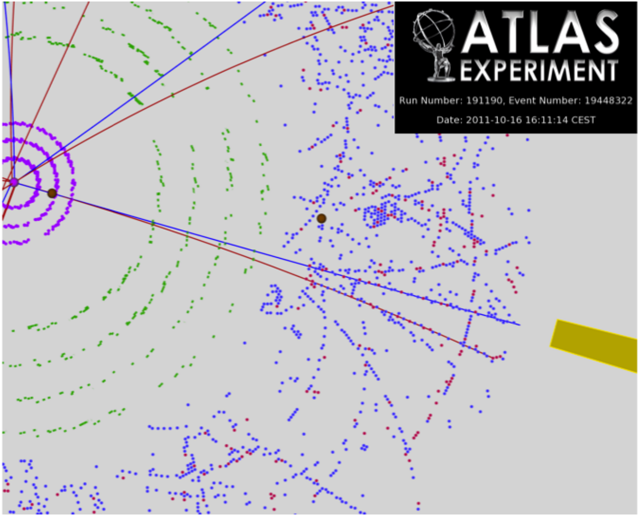
Separation in terms of σ for 300 fb^{-1} cannot be calculated.
Needs more toys.

Summary

- Study of sensitivity using $\cos\theta^*$ for discriminating between spin-0 and spin-2
  - Background taken from data sidebands
  - Spin-0 generated 125 GeV gg fusion
  - Spin-2 generated using weight 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 $\cos\theta^*$ assumed.
- Shown that spin 0 and spin 2 have some separation for 30 fb^{-1}

Outlook

- Results can be improved
  - Better fits
  - More toys
- Other angular variables can be analyzed
- The correlation of $m_{\gamma\gamma}$ and $\cos\theta^*$ can be investigated



These are exciting times for particle physics!
Thank you for listening