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CP of a Light Higgs in tth($h \rightarrow \gamma\gamma$)

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Introduction

Once the Higgs has been observed it will be important to important to study its properties in order to verify if it is the verify if it is the Higgs of the SM or if there is some new some new physics involved.

This study aims to investigate the ATLAS potential to study potential to study the CP quantum numbers of a light Higgs light Higgs boson.

SM Higgs is spin 0 and CP-even

This may not be the case in models with extended Higgs extended Higgs sectors:

- **general 2HDM**
- **MSSM with complex phases**

MSSM predicts 3 neutral Higgs particles. h, H (CP-even) A (CP-even) A (CP-odd)
Presence of complex phases causes mixing and the mass the mass eigenstates (h_1, h_2, h_3) then have mixed CP
CP

Carena, Ellis, Mrenna, Pilaftsis, Wagner. Nucl.Phys. B659 (2003) 145-178 - hep-

- hep-ph/0211467

Light Higgs CP

Using ideas from Gunion, He (*PRL 76, 24, 4468 (1996)*)

Interaction Lagrangian

$$\mathcal{L} \equiv \bar{t}(c + id\gamma_5)th$$

c is the CP-even coupling and d is the CP-odd coupling

SM has c = 1 and d = 0

$$|\mathcal{M}|^2 \propto M_{Q^2}(c^2 - d^2)$$

Can try to examine this coupling structure in the associated tth production production channel

CP sensitive variables

$$a_1 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{|(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})|}$$

$$a_2 = \frac{p_t^x p_{\bar{t}}^x}{|p_t^x p_{\bar{t}}^x|}$$

$$b_1 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{p_t^T p_{\bar{t}}^T}$$

$$b_2 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

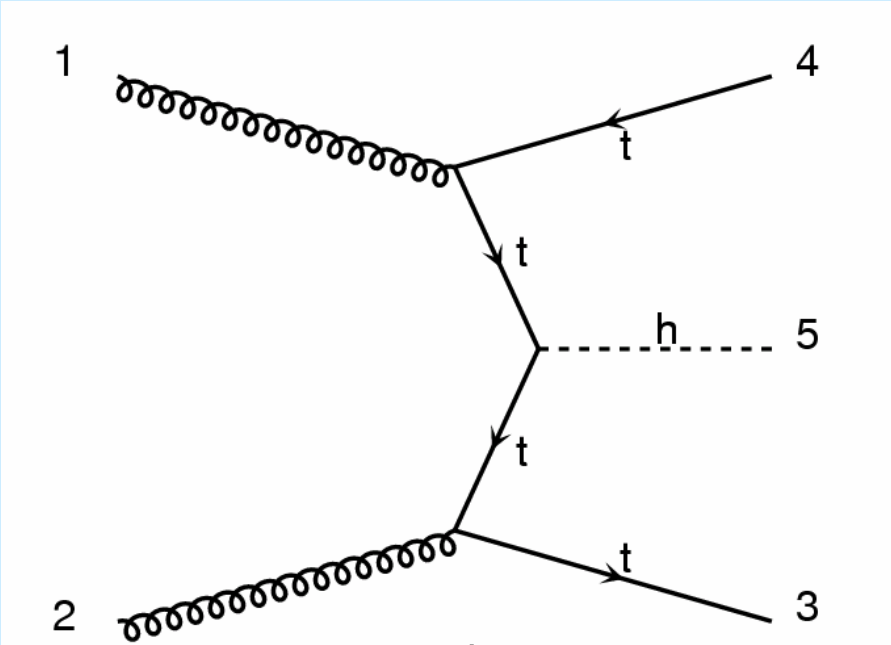
$$b_3 = \frac{p_t^x p_{\bar{t}}^x}{p_t^T p_{\bar{t}}^T}$$

$$b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

CP information is contained in the momenta of the top-quarks. Need to quarks. Need to fully reconstruct the 3-momenta of both tops to use tops to use these variables.

Parton Level Study

Parton Level



Use HERWIG to generate the pure CP-even and pure CP-odd, tth and ttA ttA channels

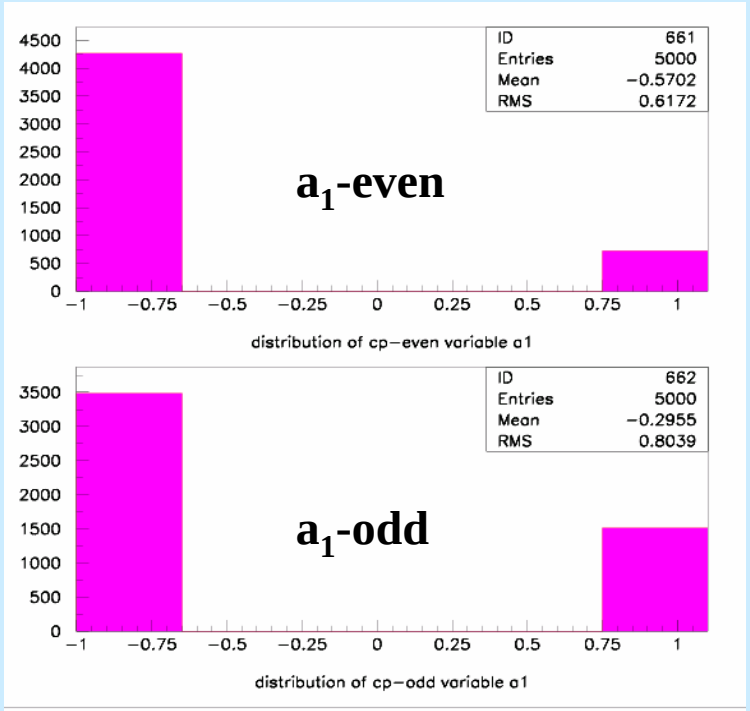
IPROC =3816

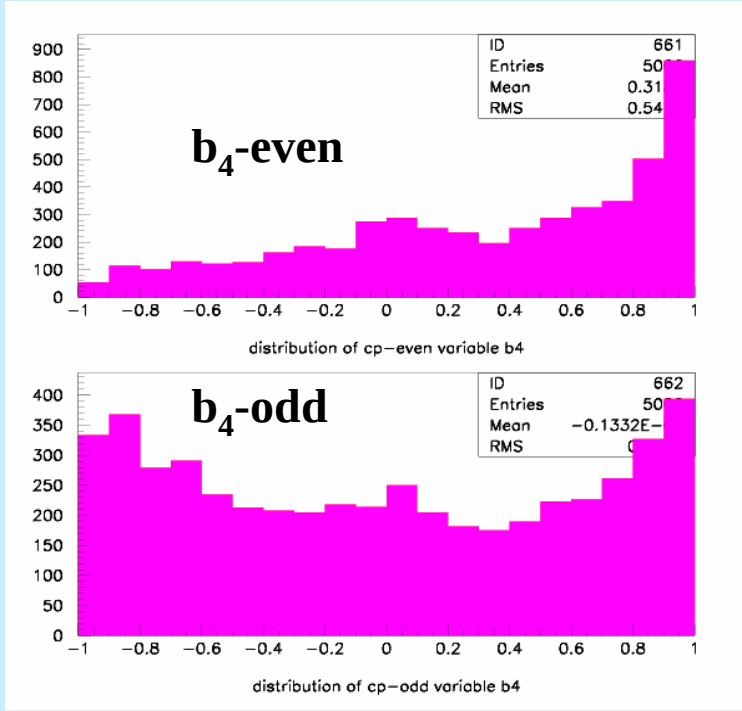
IPROC =3836

Calculate the CP sensitive variables

Obtain the form of the the variables

Example distribution of the variables





Generate sample data for a Higgs mass of 110GeV

Gunion and He used 130 signal events and 20 background events background events in their paper.

Here we look at 100 signal events only.

Create a mixed CP state by combining the CP-even and CP-odd and CP-odd samples in different proportions

Maximum Likelihood

Use the method of maximum likelihood to try and determine the determine the mixing parameter α.

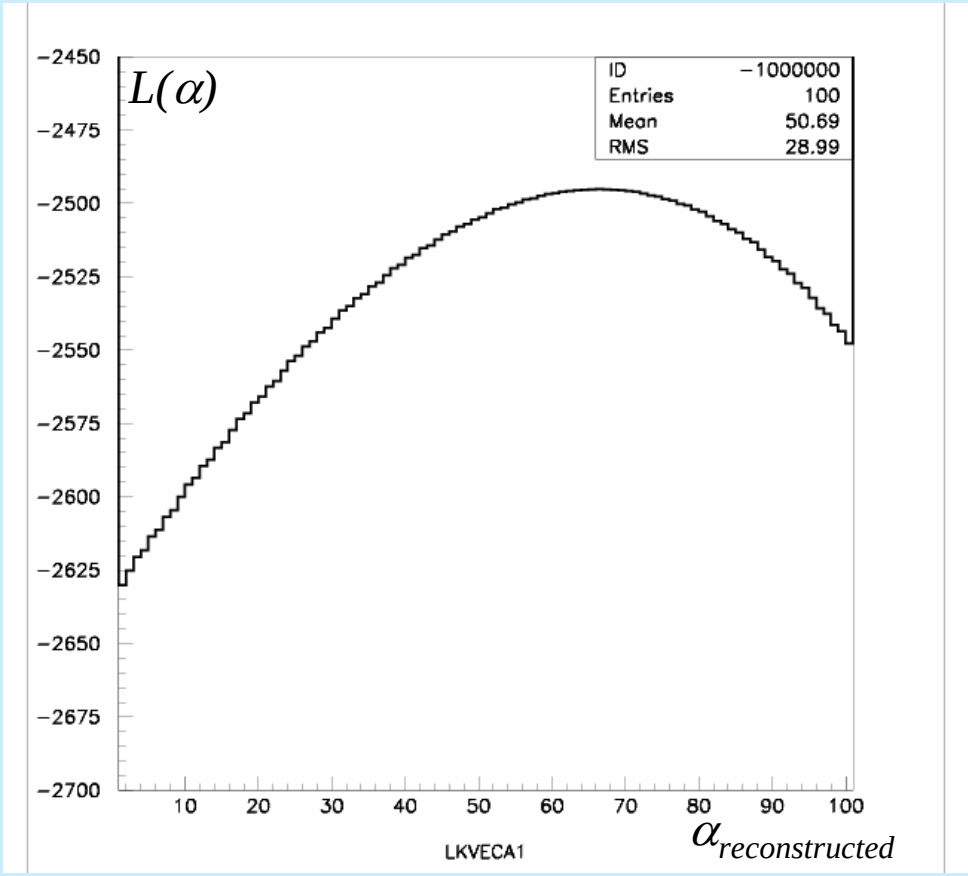
$$\mathcal{L}(\alpha) = \prod_{events} f(x;\alpha)_{mix}$$

$$f(x;\alpha)_{mix} = \alpha f(x)_{\mathrm{CP-even}} + (1-\alpha) f(x)_{\mathrm{CP-odd}}$$

Where *f(x)* are the PDF's for the test statistic, which in our case are our case are just the individual variables (e.g. PDF for a_1, a_2, …) a_1, a_2, …)

Example Likelihood distribution

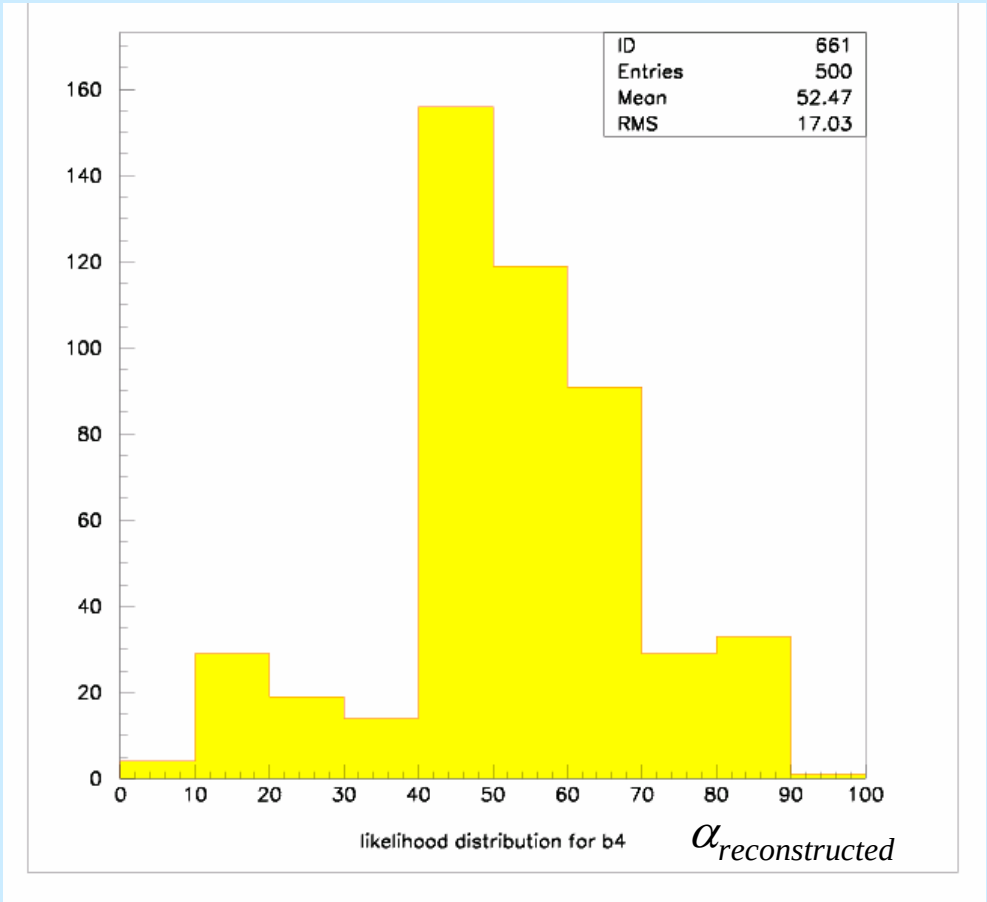
Distribution of the likelihood function for function for a_1 for α_{true} α_{true} = 50%. Here the the maximum is at around 65%



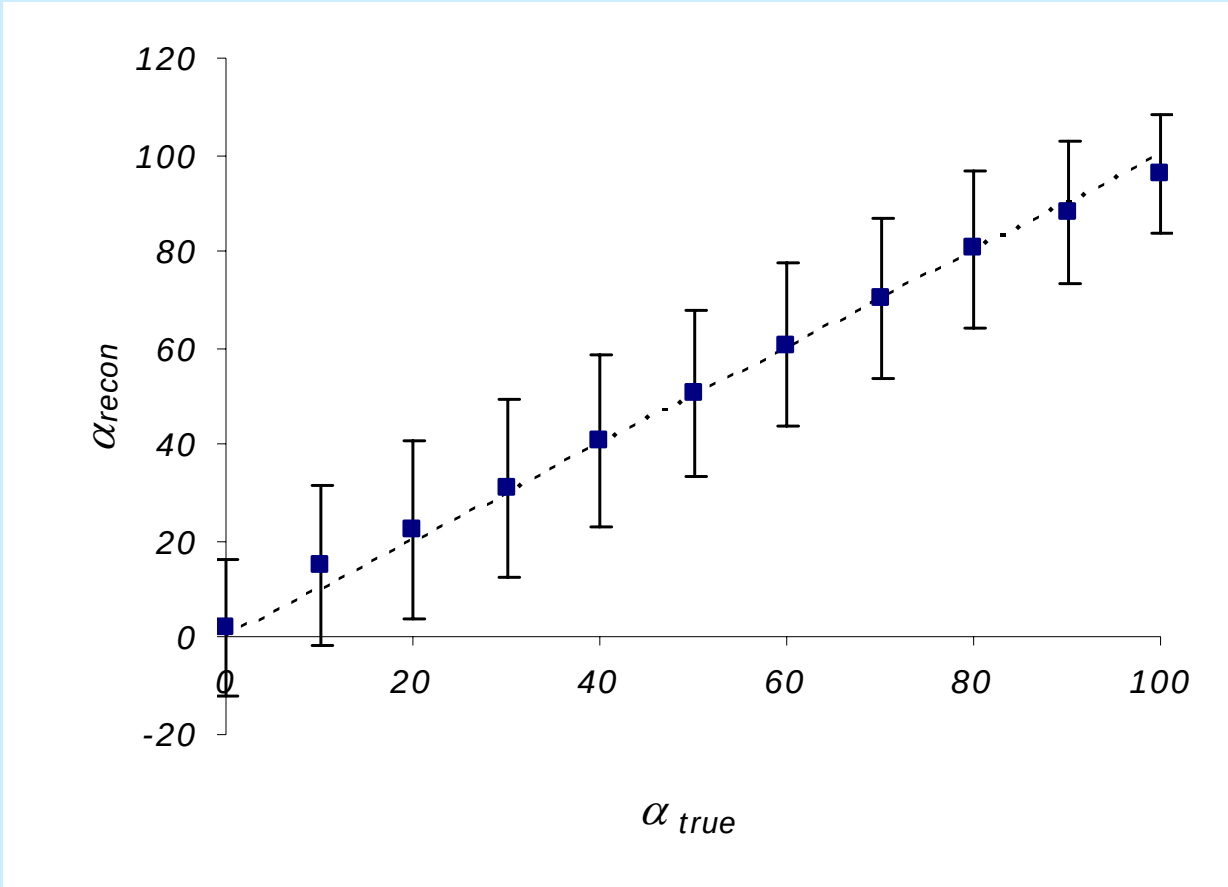
Errors

The uncertainty in using this method is given by the distribution of distribution of $\alpha_{reconstructed}$ for independent data samples

Distribution of maximum maximum likelihood using using b_4 as the test statistic statistic for α_{true} = 50%



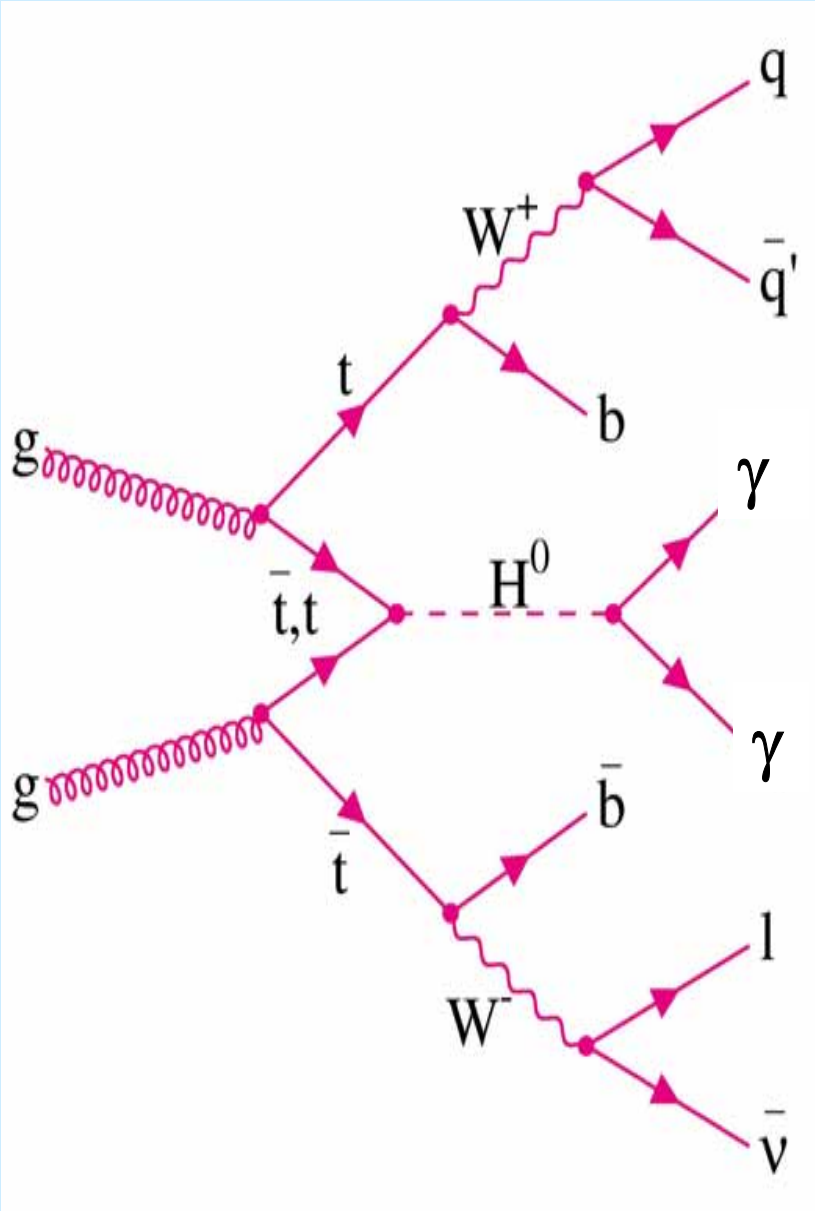
Results



Dashed line is $\alpha_{true} = \alpha_{recon}$

- **Means of the distributions are unbiased**
- **width of around 15-20%**

Detector Level Study



Selection Procedure

- ≥ 2 light jets
- 2 bjets
- 2 photons (pT ≥ 25 GeV)
- 1 electron or muon (pT ≥ 25 GeV)

Top Reconstruction

Reconstruct a top for all bjj and blν combinations.

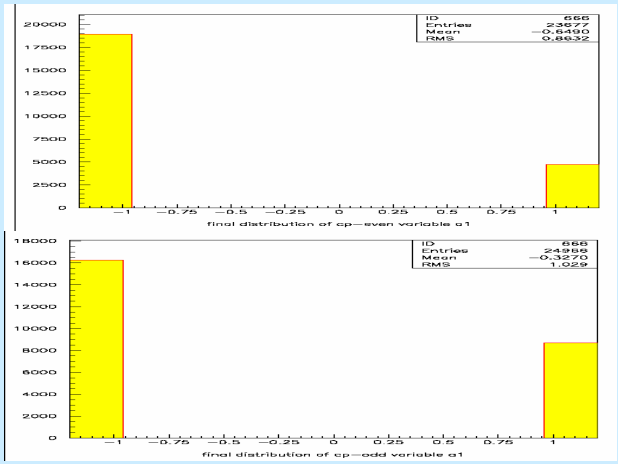
4-vectors of the two tops are found by selecting the combination which minimizes the χ^2

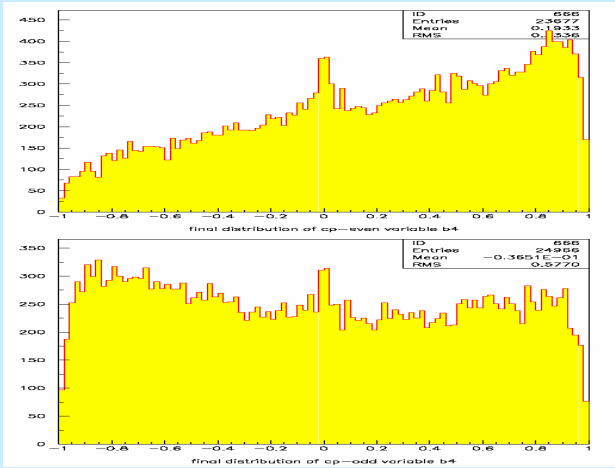
$$\chi^2 = \frac{(m_t - m_{bjj})^2}{\sigma^2_{bjj}} + \frac{(m_W - m_{jj})^2}{\sigma^2_{jj}} + \frac{(m_t - m_{bl\nu})^2}{\sigma^2_{bl\nu}}$$

m_t = 175 GeV, m_w = 80 GeV, σ from TDR

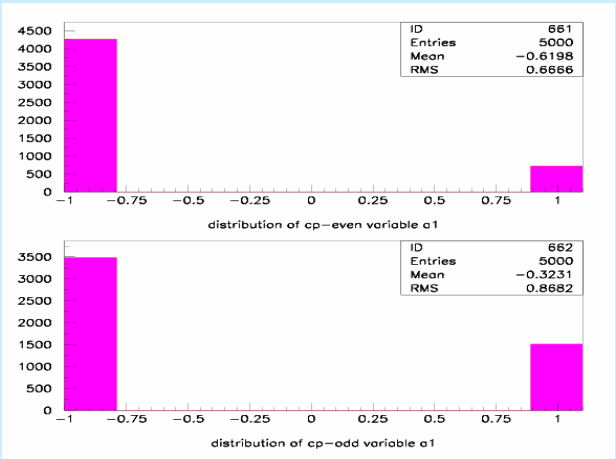
The selected tops are then used to determine the values of the CP sensitive variables

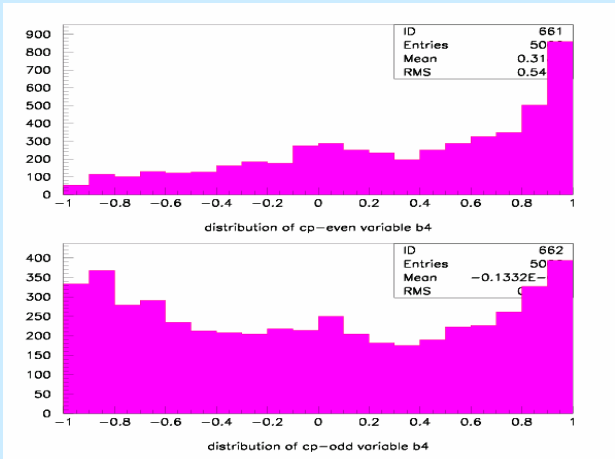
CP sensitive variables: a_1 , b_4





ATLFAST LEVEL





PARTON LEVEL

Can do a similar ML analysis.

CP can still be extracted but the widths of the distributions of $\alpha_{reconstructed}$ increase from around 15% to 25%

Still need to include backgrounds

However these are very low in this channel and so it is hoped that they will not be too bad

Backgrounds

Main backgrounds in this channel are $tt\gamma\gamma$, $tj\gamma$, $ttjj$, $bb\gamma\gamma$, $W\gamma\gamma$ + n jets, $Z\gamma\gamma$ + n jets, mW + nZ + jets …

Simulate using ME generator MADGRAPH and interfacing with HERWIG and ATLFAST

Problems:

Need to generate large number of MC events for some of these backgrounds as they have a large cross-section. Eg. $tth(\gamma\gamma) \sim 1fb^{-1}$, $tt\gamma\gamma \sim 5fb^{-1}$ $bb\gamma\gamma \sim 200fb^{-1}$

May need to do this 100s of times to obtain errors on the distributions

Conclusions and Future Plans

- **Finish background study**

- **Redo the tth analysis. TDR is now quite old and now have new event generators. Could substantially change the analysis required.**

- **Other Decay channels**

- **Improved test statistic with greater sensitivity to CP – how best to combine the variables?**

- **Full simulation – DC2 has tth(h→bb), h→γγ**