Higgs CP phase measurement in $H \to \tau^- \tau^+ \to \rho^- \nu_\tau \rho^+ \nu_\tau \to \pi^- \pi^0 \nu_\tau \pi^+ \pi^0 \nu_\tau$

Andres Rios

Event selection

The events are required to have:

- Two taus with $p_T > 20$ GeV
- Two neutral and two charged pions
- Two extra jets/leptons
- $M_H > 120$ GeV
- Higgs $p_T < 55$ GeV

First I just used gen-level information, including the generated Z. This is why I also require the generated taus. Also the last two cuts are applied with the reconstructed information, and then I scaled down the results of gen level.

Theta variable

Defined as $$\Theta = \mathrm{sgn}\left[\vec{v}_{\tau^+}\cdot(\vec{E}_-\times\vec{E}_+)\right]\,\mathrm{Arccos}\left[\frac{\vec{E}_+\cdot\vec{E}_-}{\left|\vec{E}_+\right|\,\left|\vec{E}_-\right|}\right]$$

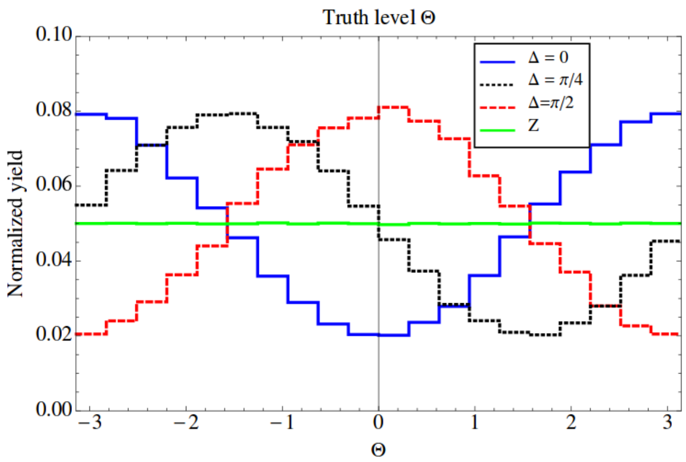
where $$\vec{E}_\pm = \frac{m_h}{2}\left[(y_\pm - r)\,\vec{p}_{\pi^\pm}\big|_0 - (y_\pm + r)\,\vec{p}_{\pi^0\pm}\big|_0\right]^\perp$$

$$y_\pm \equiv \frac{2q_\pm\cdot p_{\tau^\pm}}{m_\tau^2+m_\rho^2} = \frac{q_\pm\cdot p_{\tau^\pm}}{p_{\rho^\pm}\cdot p_{\tau^\pm}} \qquad r \equiv \frac{m_\rho^2-4m_\pi^2}{m_\tau^2+m_\rho^2} \approx 0.14 \qquad q_\pm \equiv p_{\pi^\pm} - p_{\pi^0\pm}$$

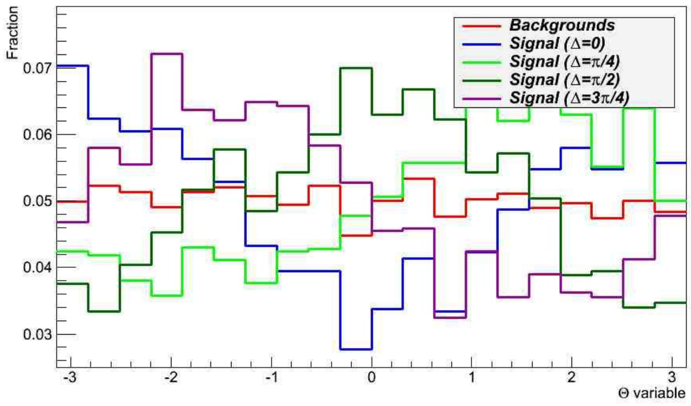
This is the main variable we are interested in.

Theta distribution

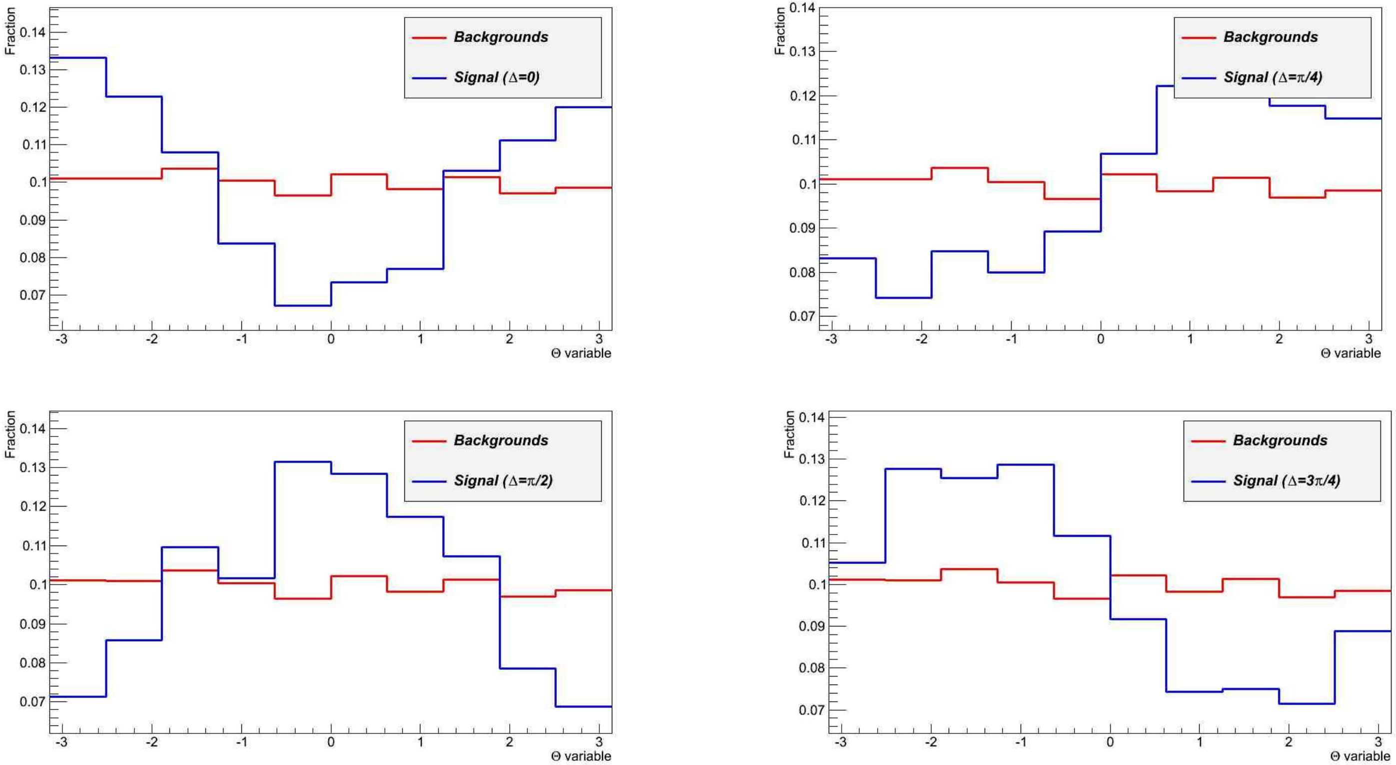
Paper



What I have



Theta distributions



Event yields (1 ab^{-1})

These are the yields with the event selection described above. Recall that this is using gen-level information, and some cuts were applied at reco level and then I scaled down the gen level results.

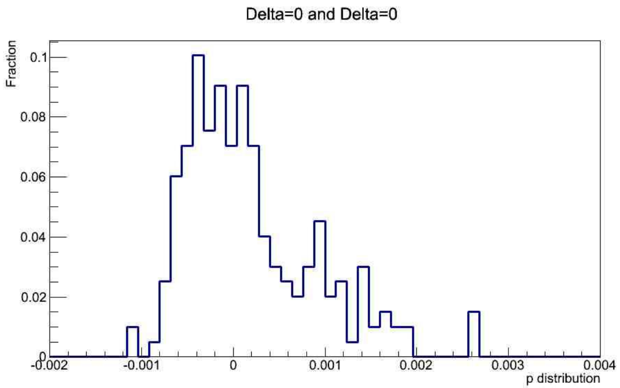
	Signal (all Δ)	dy	WW	ZZ	ZZee
After all cuts	~180	11.8	10.8	102.0	93.71

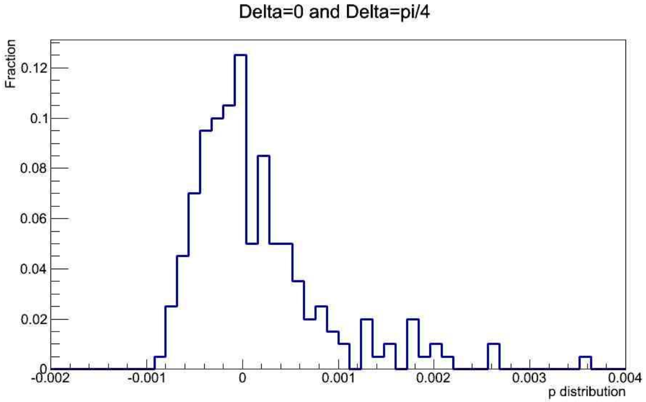
Using Williams' method with the theta variabele

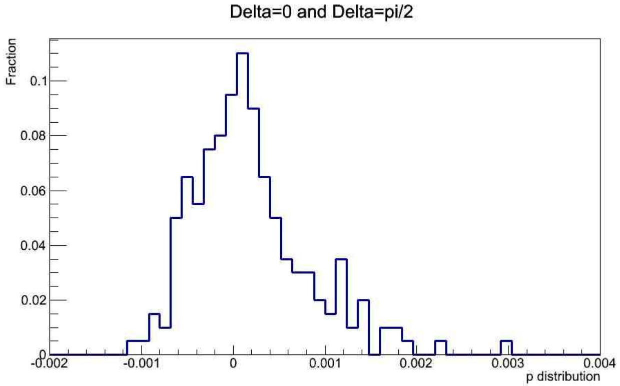
	SM and SM	SM and Δ=π/4	SM and Δ=π/2	SM and Δ=3π/4
T	-0.00467183	0.0035214	0.00592432	0.00475984
p	1	0.005	0	0

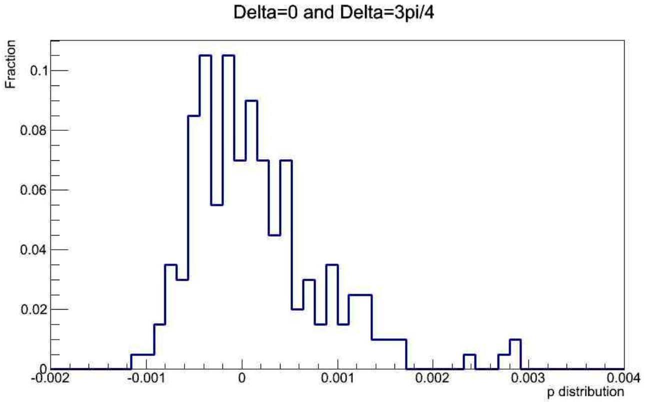
I only used ¼ of the samples due to the long time it takes to run. The results are expected to be better when using the full samples.

P distributions



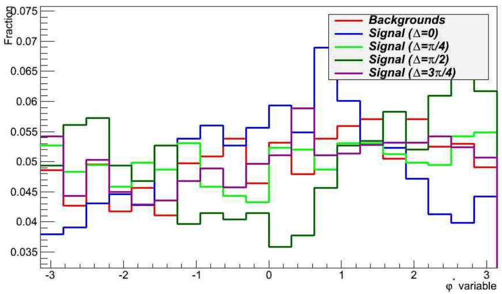


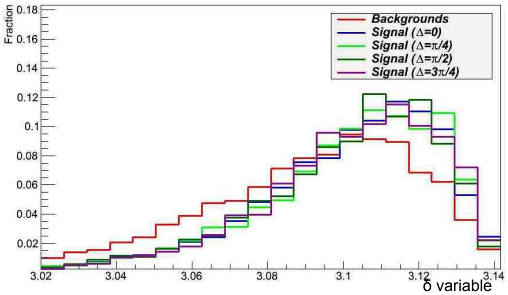




Alternative variables

There are a few alternative variables used in other papers before the theta variable was proposed. The main two are the phi-star variable (the acoplanarity angle) and the delta variable (the acolinearity angle). The distributions are the following.





As you can see, the delta variable doesn't offer much discrimination between the different CP phases, only the peaks are supposed to be slightly shifted. On the other hand, the phi-star variable offers good discrimination between the CP-odd and CP-even cases, but it is not very good for the other cases. Therefore, the theta variable is indeed the best option, but we can probably still use these variables with Williams' method.

Using reconstructed info

It turned out to be problematic to use reconstructed information due to the momentum of the Z not being entirely correct. This results in imaginary solutions when computing the momenta of the two neutrinos. I found that it is a very good approximation to simply use the absolute value of the quantity inside the square root, for signal events. However, for background events this is not a good approximation and the theta variable is strongly deformed. There is no reason for this to be the case, so I will have to check if I am selecting the right taus in background events.

The following are the results using the reconstructed information.

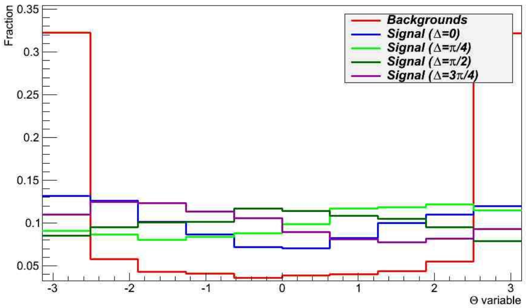
Event selection

The events are required to have:

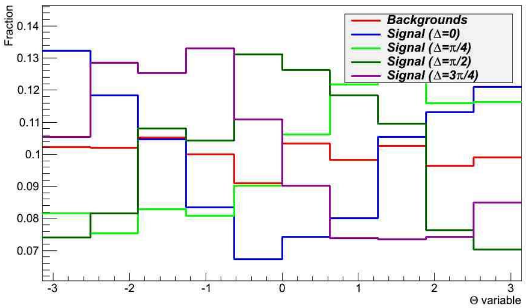
- Two neutral and two charged pions
- Two extra jets/leptons
- dR(jets/leptons) > 2.0
- dR(rhos) > 2.25
- $M_H > 120$ GeV
- Higgs $p_T < 55$ GeV
- $M_V > -20$ GeV
- $M_T > -10$ GeV
- Taus $p_T > 20$ GeV

Theta variable

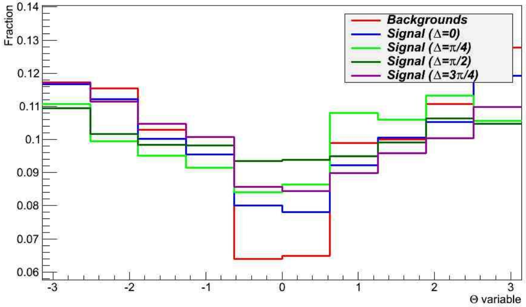
The reason of all the previous cuts is that the distribution of the theta variable gets very deformed, and has decreased amplitude. The following is the distribution without the strong cuts.



gen Z, reco τ



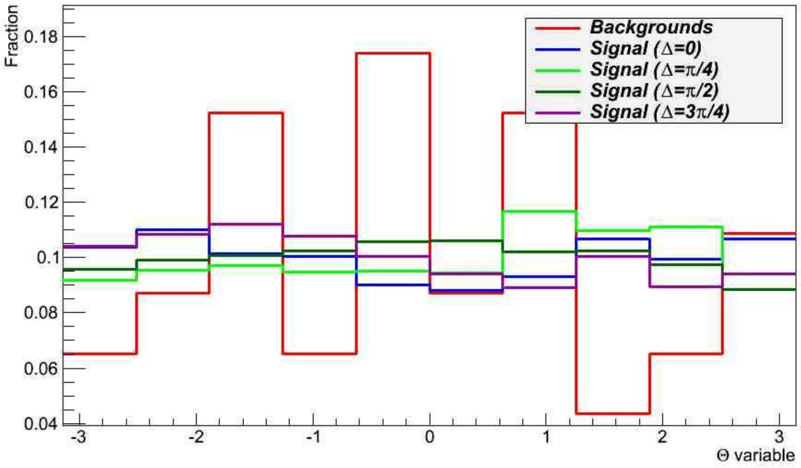
reco Z, gen τ



reco Z, reco τ

Theta variable

After applying the strong cuts, almost all the backgrounds are eliminated. The distribution of the background is still very deformed due to the low statistics. However, Williams' method can now easily distinguish between the different phases.



Event yields (1 ab^{-1})

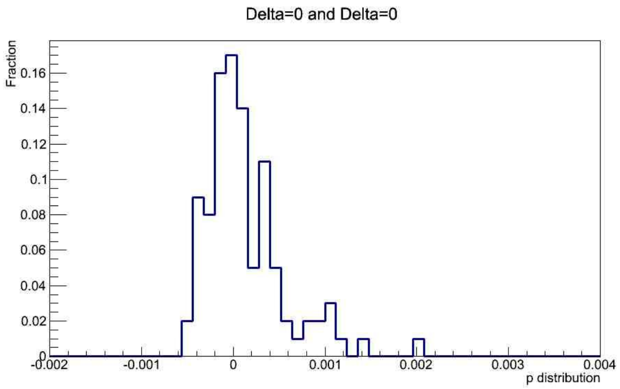
	Signal (all Δ)	dy	WW	ZZ	ZZee
After all cuts	~140	1.4	0	1.7	0

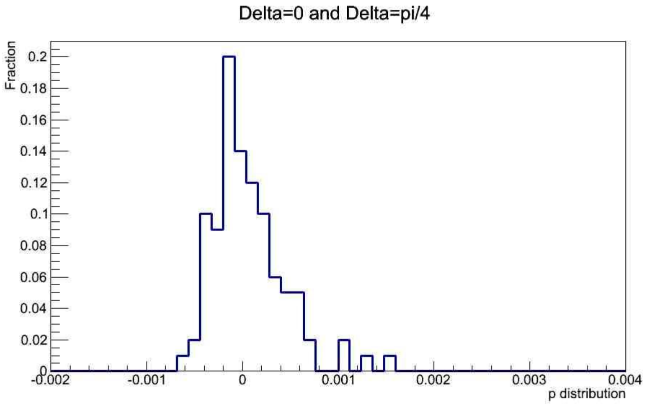
Using Williams' method with the theta variable

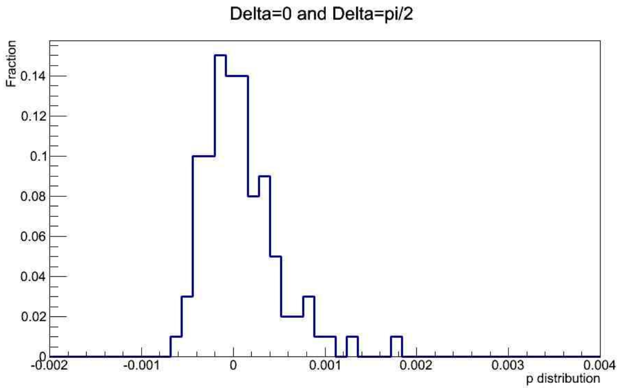
	SM and SM	SM and Δ=π/4	SM and Δ=π/2	SM and Δ=3π/4
T	-0.00287177	0.00183605	0.00182245	0.00114574
p	1	0	0	0.03

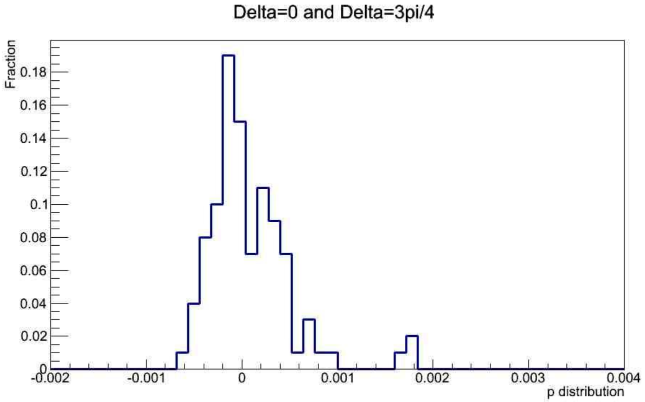
Here I used the full samples.

P distributions









Determining mixture of CP-odd and CP-even

I tried to use Williams' method to determine the mixture of CP-even and CP-odd events in some dataset. For this I made three datasets.

D1: CP-even + Backgrounds **D2**: ½ CP-even + ½ CP-odd + Backgrounds **D3**: ¼ CP-even + ¾ CP-odd + Backgrounds

Then I used Williams method comparing D1 with the other two. These are the results.

	D1 and D2	D1 and D3
T	-0.000158259	0.00115737
p	0.73	0.02

So this method seems to be able to determine if there is a mixture, but it is not good to determine the exact amount. I will have to find another method for this.