

# 1 Madgraph5 lhe file analysis

I generated  $pp > e + e - a$  process using MadGraph5 MC generator. This should produce two electrons and a photon in final state. Possible Standard Model Scenarios are (tree level - LO): ISR - photon radiated from initial quark and FSR - photon radiated from lepton. This can happen with Z production ( $Z\gamma$  production) or without (DY process, with only FSR case).

Due to the fact that my distribution of  $\cos\theta_\ell$  ?? has some "acceptance effects" at the edges of the distribution, I decided to look into the *lhe* file and see what actually gets generated. Here are the results.

Resultant file contains 3 types of events:

Event Type 1:

pdgId	Status	Mother1	Mother2	Px	Py	Pz	E	M
2	-1	0	0	0.00	0.00	0.82E+03	0.82E+03	0.0
-2	-1	0	0	0.00	0.00	-0.24E+01	0.24E+01	0.00
23	2	1	2	0.71E-14	-0.11E-12	0.82E+03	0.82E+03	80.00
-11	1	3	3	0.23E+01	-0.38E+02	0.59E+03	0.59E+03	0.00
11	1	3	3	-0.65E+01	0.31E+02	0.17E+03	0.17E+03	0.00
22	1	3	3	0.42E+01	0.65E+01	0.53E+02	0.54E+02	0.00

So, we have 6 particles. First two are incoming quarks that only have Pz component. Then we have Z boson which has  $Mother1 = 1$  and  $Mother2 = 2$ , so it comes from quarks. Then we have two electrons that has  $Mother1 = Mother2 = 3$ , hence it comes from Z boson. Then we have a photon that has Z boson as its mother particle. I do not quite understand this, but closest I can associate this with is FSR production of  $Z\gamma$ . It should be mentioned that no anomalous production was allowed during generation.

Event Type 2:

pdgId	Status	Mother1	Mother2	Px	Py	Pz	E	M
-2	-1	0	0	0.00E+00	0.00E+00	0.41E+02	0.41E+02	0.00
2	-1	0	0	0.00E+00	0.00E+00	-0.38E+03	0.38E+03	0.00
-11	1	1	2	-0.48E+02	0.72E+02	-0.39E+02	0.95E+02	0.00
11	1	1	2	0.45E+02	-0.72E+02	-0.30E+03	0.31E+03	0.00
22	1	1	2	0.23E+01	0.38E-01	0.77E+01	0.81E+01	0.00

In this case, there are 5 particles. Two quarks, two electrons with these quarks as parents and a photon with quarks as parents. I do not understand this case either, but closest I can associate it with is DY production.

Event 3:

pdgId	Status	Mother1	Mother2	Px	Py	Pz	E	M
-2	-1	0	0	0.00E+00	0.00E+00	0.24E+01	0.24E+01	0.00
2	-1	0	0	0.00E+00	0.00E+00	-0.90E+03	0.90E+03	0.00
23	2	1	2	-0.10E+01	-0.18E+01	-0.84E+03	0.85E+03	91.00
-11	1	3	3	0.28E+02	-0.30E+02	-0.59E+03	0.59E+03	0.00
11	1	3	3	-0.29E+02	0.29E+02	-0.25E+03	0.25E+03	0.00
22	1	1	2	0.10E+01	0.18E+01	-0.50E+02	0.50E+02	0.00

Here we again have 6 particles. Two quarks, Z boson, two electrons and a photon that shows quarks as its parents. So this would be a normal  $Z\gamma$  production process, one that here is called ISR.

If my understanding is right I can look into each process separately. I removed all the DY events, so I am left with the events where we actually have leptons coming from Z.

Here are the plots for each case separately and together:

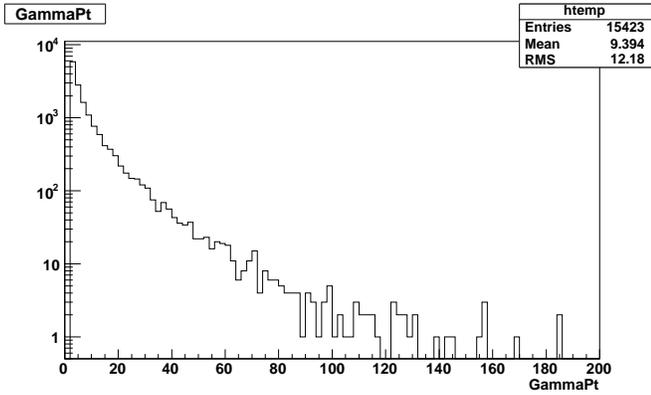


Figure 1: Photon  $P_t$

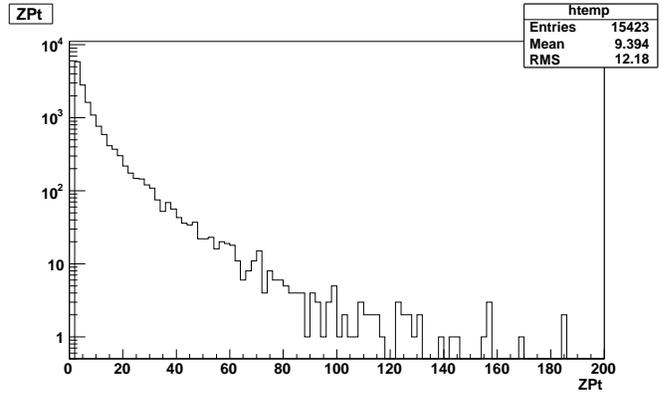


Figure 2: Z boson  $P_t$

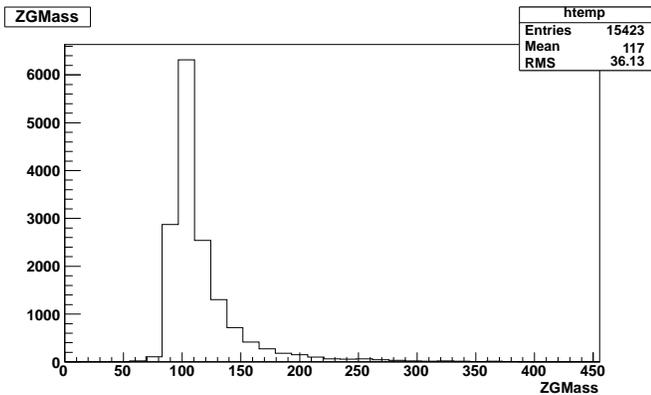


Figure 3:  $Z\gamma$  Invariant Mass

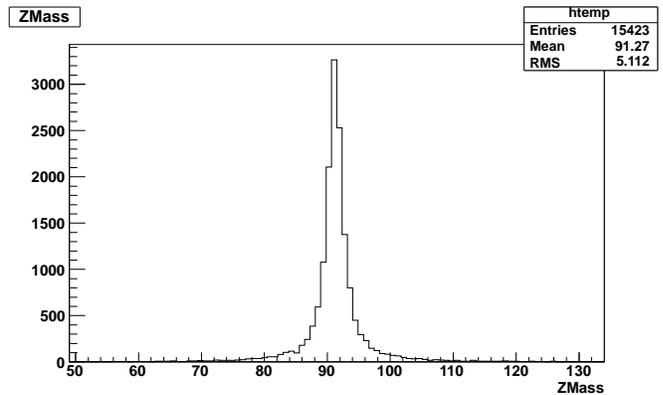


Figure 4: Z Invariant Mass

## 1.1 ISR

Plots in this section require the Event to be type 3 (from my list above).

We see that transverse momentum of Z and a photon are exactly the same. So my assumption that type 3 is a proper ISR event seems to be right and Madgraph seems to generate the leading order process where incoming quarks system is at rest and so is the  $Z\gamma$  system.

We see the Z peak as it is supposed to be and  $Z\gamma$  invariant mass with no obvious problems.

On the figure 5 we see that ISR generation has some intrinsic cut on  $M_{Z\gamma} - M_Z$  and I am not sure how correct this is. On the right had side 6 once again we see that  $Z\gamma$  system was generated at rest.

## 1.2 FSR

## 1.3 ISR+FSR

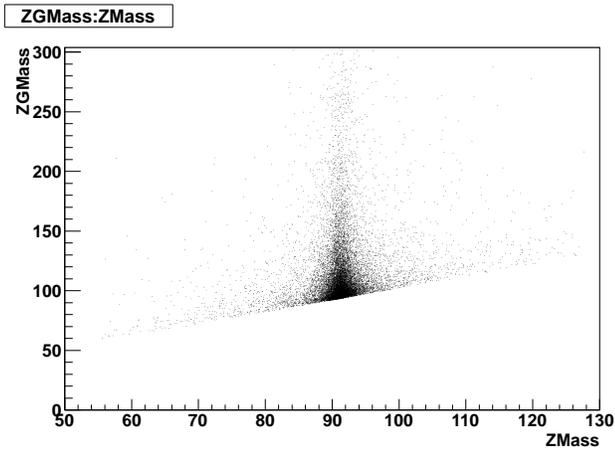


Figure 5:  $M_Z$  vs.  $M_{Z\gamma}$  Scattered Plot

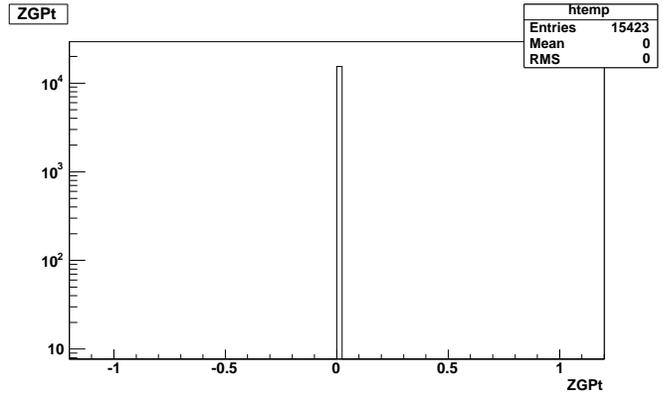


Figure 6:  $Z\gamma P_t$

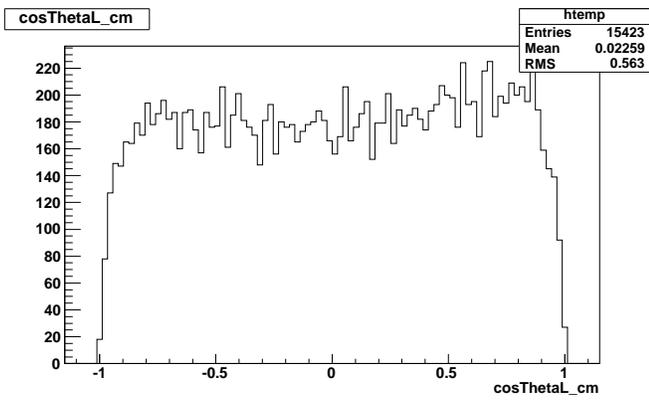


Figure 7:  $\cos\theta_\ell$

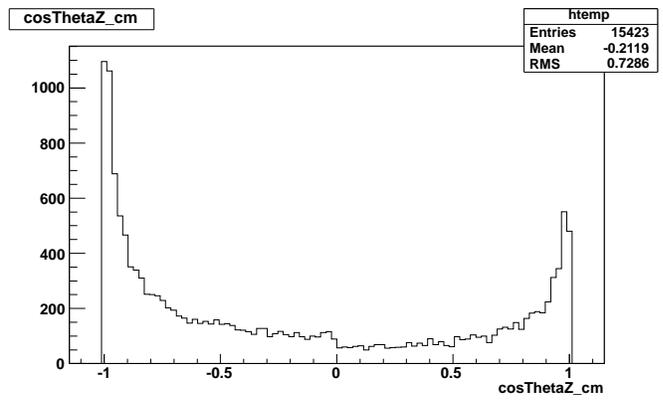


Figure 8:  $\cos\theta_Z$

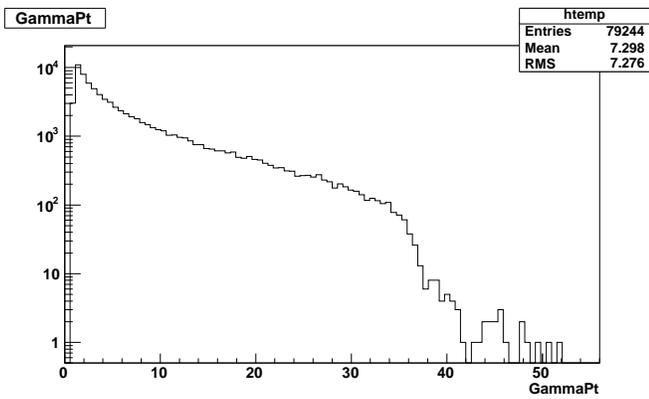


Figure 9: Photon  $P_t$

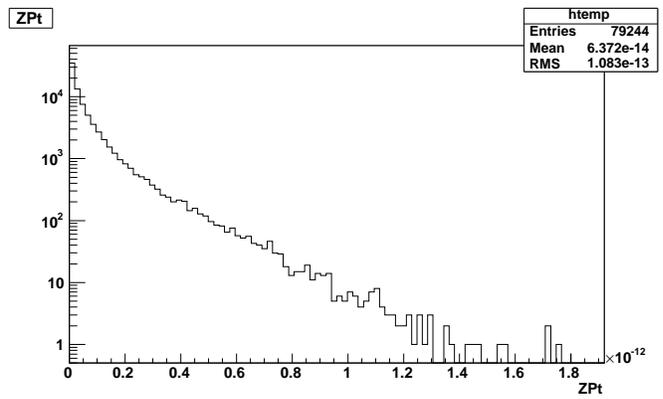


Figure 10: Z boson  $P_t$

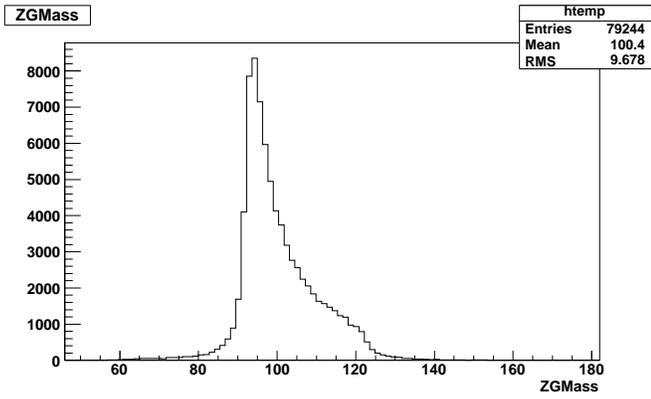


Figure 11:  $Z\gamma$  Invariant Mass

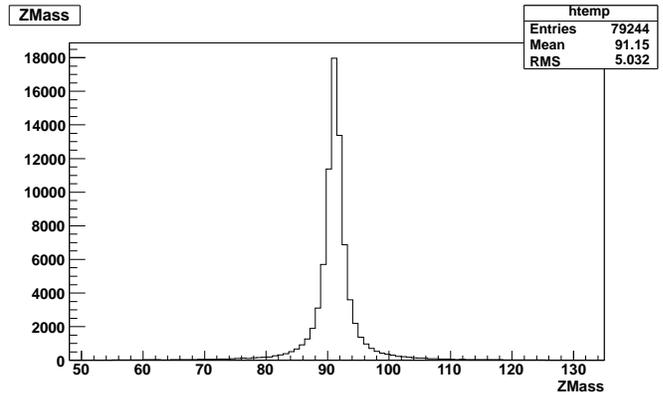


Figure 12: Z Invariant Mass

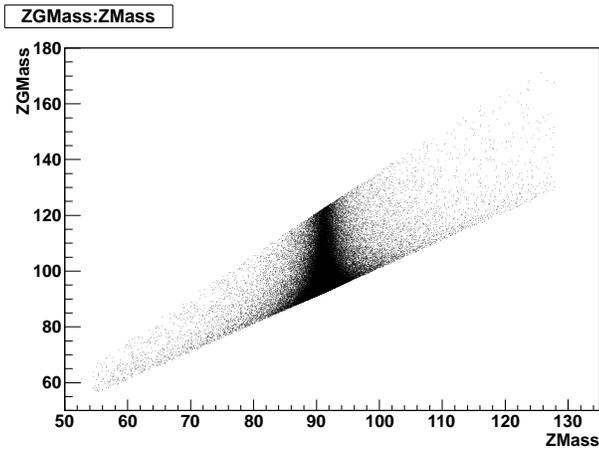


Figure 13:  $M_Z$  vs.  $M_{Z\gamma}$  Scattered Plot

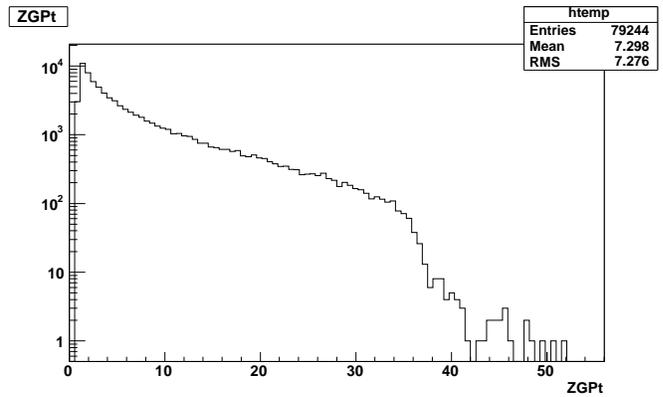


Figure 14:  $Z\gamma P_t$

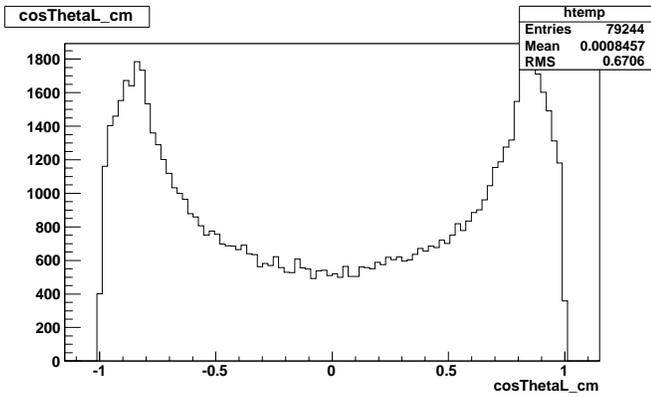


Figure 15:  $\cos\theta_\ell$

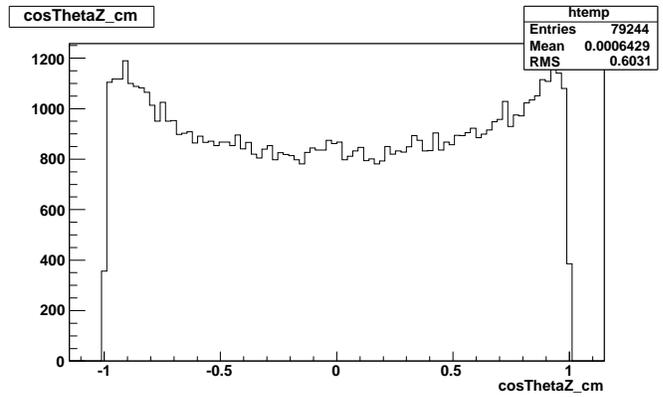


Figure 16:  $\cos\theta_Z$

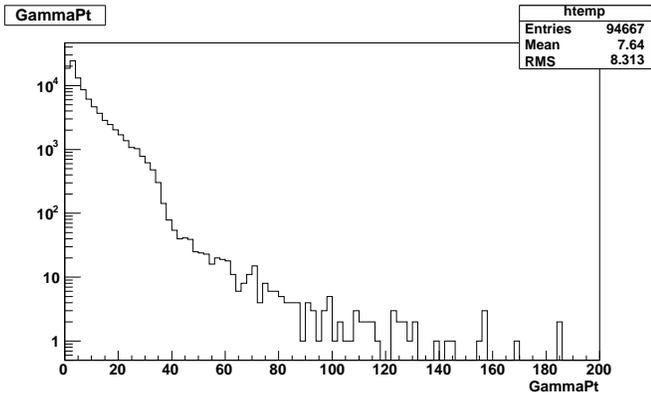


Figure 17: Photon  $P_t$

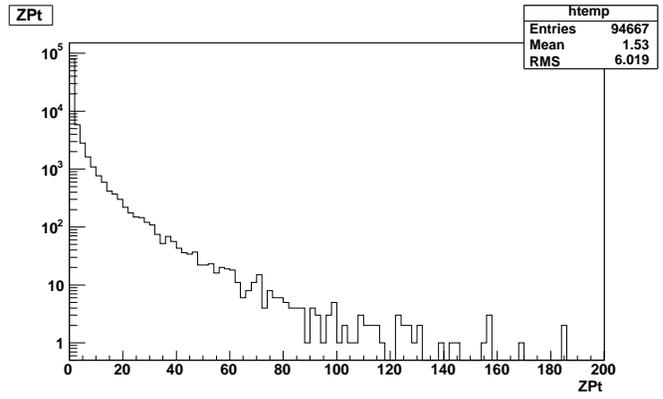


Figure 18: Z boson  $P_t$

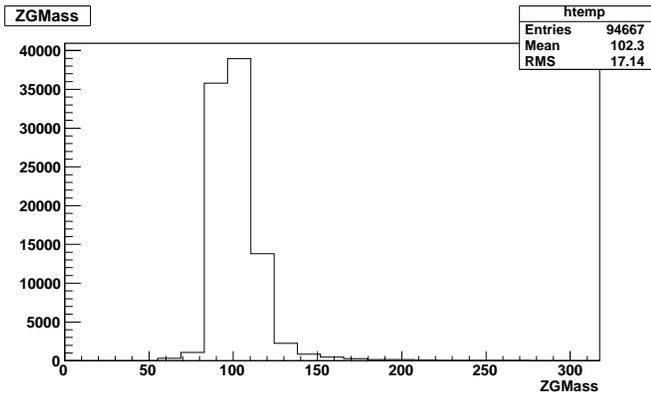


Figure 19:  $Z\gamma$  Invariant Mass

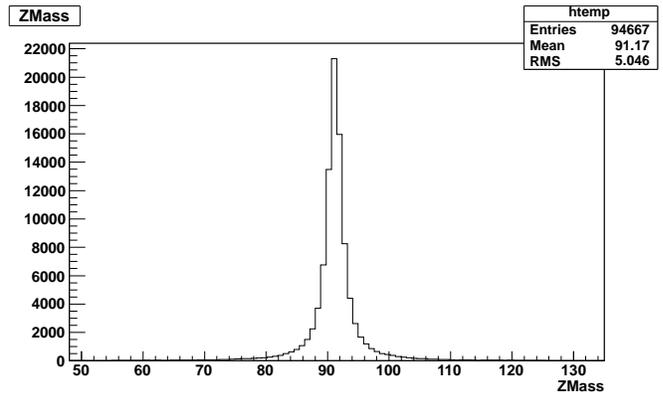


Figure 20: Z Invariant Mass

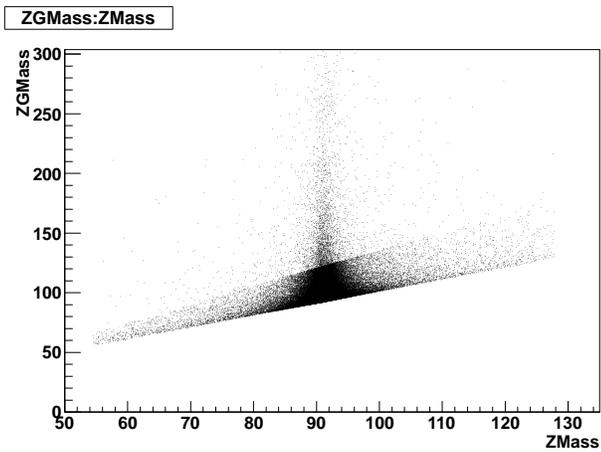


Figure 21:  $M_Z$  vs.  $M_{Z\gamma}$  Scattered Plot

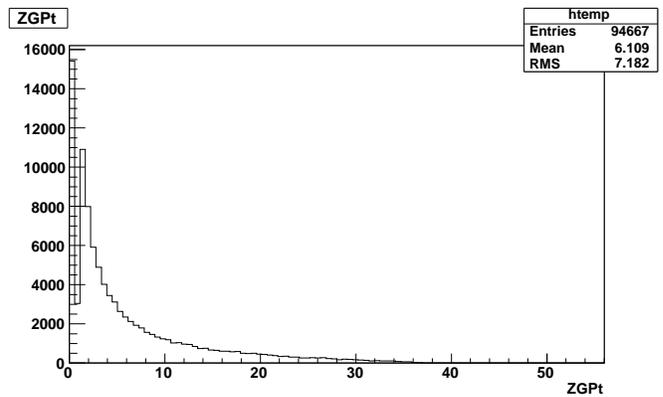


Figure 22:  $Z\gamma P_t$

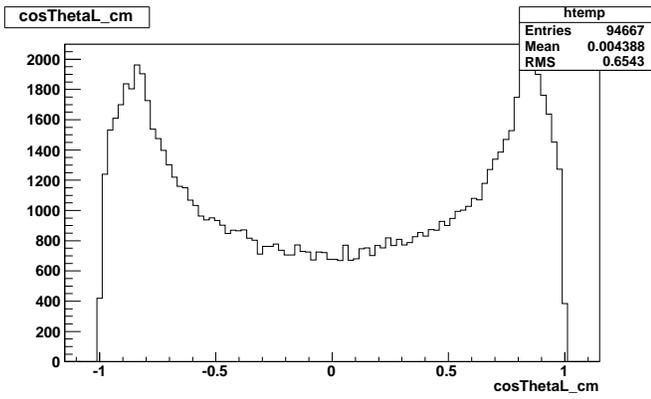


Figure 23:  $\cos\theta_\ell$

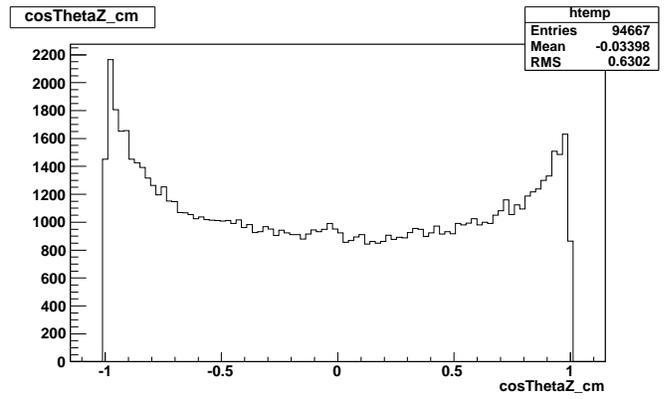


Figure 24:  $\cos\theta_Z$