

# Results from the Geant4 Milagro Monte Carlo simulation

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v1.0

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## Abstract

This memo presents results from the latest Milagro simulation and analysis software. Comparisons between MC hadrons and data were made both for specific trigger types separately and for all the trigger types simultaneously. A comparison between MC hadrons vs MC gammas was also made. The muon peak, the trigger and crab rates were compared between MC and data. Lastly, the quality factors for X2 and A4 cuts were calculated. In general the MC agrees with data if the latest calibration v.601 is used.

## Contents

<b>1</b>	<b>Introduction</b>	<b>2</b>
1.1	Things to consider when comparing data and MC . . . . .	2
<b>2</b>	<b>Comparing data vs hadrons</b>	<b>4</b>
2.1	Using only the high multiplicity trigger (trigger #1) . . . . .	4
2.2	Using the low multiplicity trigger (#3) . . . . .	11
2.3	Using all the triggers . . . . .	17
2.4	Trigger rates . . . . .	23
2.5	Crab rate . . . . .	24
2.6	Quality factor . . . . .	25
2.6.1	Using VMETrigger . . . . .	25
2.6.2	Using single 50 PMT multiplicity trigger . . . . .	26
2.7	The muon peak . . . . .	26
<b>3</b>	<b>Comparing hadrons vs gammas</b>	<b>29</b>
<b>4</b>	<b>Discussion</b>	<b>37</b>
<b>5</b>	<b>APPENDIX</b>	<b>40</b>
5.1	Variability of the Milagro data . . . . .	40
5.2	Version history . . . . .	41

# 1 Introduction

The versions of g4sim and milinda used in the following analyses were 2.0 and 1.1 respectively. The progress in the MC and analysis software doesn't stop. For that reason, this memo will be updated each time new results, worth of mentioning, are available. There will be a version history in the appendix and the latest version of the document will be available from the g4sim web page<sup>1</sup>.

## 1.1 Things to consider when comparing data and MC

There are some factors that need to be taken into account when comparing data and MC. These are:

- **Dead and uncalibrated PMTs**

Using Aws' code, found in *milinda/tools/DataAnalysis/PMTs*, the dead and not calibrated PMTs from a data run can be found. Two files are created (DeadPMTs.txt & Dontfits.txt) containing a list of the relevant PMTs. Using milinda's command line arguments (-e and -d) these files can be taken into account when analysing MC data.

- **Trigger settings**

The correct VME trigger configuration must be used when analysing MC data. Milinda's default trigger configuration file (*milinda/config\_milagro/VMETrig.txt*) uses the following format:

```
pretrigger_threshold
trig1_min_#PMT_threshold trig1_risetime_cut trig1_skip_factor
trig2_min_#PMT_threshold trig2_risetime_cut trig2_skip_factor
trig3_min_#PMT_threshold trig3_risetime_cut trig3_skip_factor
trig4_min_#PMT_threshold trig4_risetime_cut trig4_skip_factor
```

Milinda's command line argument "-t" can be used to select a custom trigger configuration file.

The trigger configuration used for each data run is saved in the status files that can be found on sparky or in UMD (*at /data/scratch01/asmith/Status/\* .dbs*). The relevant information is saved at the last field of each line. The format of that field is

```
| pretrigger_threshold 5x(PMT threshold) 5x(risetime cuts) 5x(skip factors) 0
```

Take note that the PMT\_thresholds are not the actual minimum number of AS PMTs hit but the voltage thresholds (in units of 5mV) of the analog sum for each trigger. Since each AS PMT hit contributes about 6.25mV<sup>2</sup> to the analog sum, this voltage threshold can be converted to number of PMTs by multiplying with 5/6.25. Milinda's trigger simulation code (*files code/SimulateVMETrigger.c or code/SimulateVMETrigger2.c*) uses this ratio to perform the conversion. A lot of discussion has been made regarding if this ratio is correct. The amplitude of the 6.25mV square wave pulse produced for each hit PMT can either drift with time or not be the same for each PMT. Also, there can be an unknown time-varying DC offset in the analog sum. For that reason, it is strongly recommended to fine tune the pmt threshold values, in your custom trigger configuration file, so that the thresholds of the ncaltop histograms, for each trigger, are the same for MC and data. From my experience, almost correct PMT\_thresholds for milinda can be found by multiplying the status file PMT\_thresholds with 0.9/0.8<sup>3</sup>.

- **Simulated detector configuration**

Care must be taken to compare real and MC data produced with similar experimental conditions. Parameters such as type of baffles, air under the cover and water properties can be configured in the MC. The time of year and the log entries should be examined in order to determine the actual experimental conditions. In general, data taken in the winter under freezing conditions shouldn't be used for comparing data and MC since ice under cover is

<sup>1</sup><http://ummgrb.umd.edu/vlasisva/g4sim>

<sup>2</sup>in milinda it is 6.25mV, in Erik Blaufuss' "VME Trigger card manual" it is 6mV

<sup>3</sup>In other words the actual ratio is ~ 0.9 instead of 0.8

not currently simulated (and won't be in the future). September or October runs with alot of water over the cover are good candidates for comparison with MC data produced with no air under the cover. On the other hand, long dry periods or periods right after a repair correspond to runs taken with some or alot of air under the cover. Care must be taken not to use special runs for comparisons, such as runs taken with curtains.

- **Proper mixing of protons and helium**

Data from protons and helium are similar but not identical. For energies over 30GeV, the helium flux is about 35% of the total hadron flux[1]. For that reason, the weight of the helium events must be multiplied with a factor equal to

$$Weight_{mix} = \frac{0.35}{0.65} \cdot \frac{P_{thrown\ showers}}{He_{thrown\ showers}}$$

- **Using the correct spectral indices**

Proton and helium MC data is produced using a 2.75 spectral index. The correct spectral indices for helium and protons are 2.68 and 2.76 respectively[1]. The weight of each particle must be multiplied by a factor equal to [2]

$$Weight_{Energy} = \frac{spectrum_{real} - 1}{spectrum_{MC} - 1} \left( \frac{energy}{energy_{min,MC}} \right)^{spectrum_{MC} - spectrum_{real}}$$

## 2 Comparing data vs hadrons

In this chapter, the results from a comparison of v2.0 hadrons with data run 6662 are shown. The MC files analysed can be found in the UMD folders

`/data/links/G4MCData/sets/20/proton/scattering_0.99_AbsL30m_ScatL50m/` and  
`/data/links/G4MCData/sets/20/proton/scattering_0.99_AbsL30m_ScatL50m/`.

The main features of the MC configuration used for creating these files are no air under cover, water absorption length 50m, water scattering length 30m and Mie scattering asymmetry factor<sup>4</sup> 0.99. The data run was taken at 10/22/2005, a period without considerable air or ice under the cover and with most of the curtains removed.

The dead and non-calibrated PMT files used correspond this data run. The thresholds for each trigger were adjusted so that the `ncalTOP`<sup>5</sup> curves from MC and data start from the same number of PMTs. The relevant files (`DeadPMTs.txt`, `Dontfits.txt` and `VMETrig.txt`) and the analysis code can be found under `milinda/code/mctest/analysis`.

The trigger simulation and especially the risetime calculation in `milinda` is not perfect. For that reason, it is useful to make separate comparisons of data and MC using each of the different triggers each time. There were three types of comparisons; one using only the high multiplicity/no risetime cut trigger (#1), one using the low multiplicity/low risetime cut trigger(#3) and one using all the triggers simultaneously. For the first two tests, only events that triggered (among others) the selected trigger were analysed. The cut made was an inclusive bitwise-and cut (`VMEWord&triggerbit`), a cut that would accept events independently of the state of the other triggers. On the contrary, an exclusive `VMEword==triggerbit` cut, would keep events with only the selected trigger on; this was not the case in this analysis. No other cuts were made on the data (`nfit`, `delAngle` etc). In the plots black is MC and red is data.

### 2.1 Using only the high multiplicity trigger (trigger #1)

Only events that triggered the high multiplicity trigger (trigger #1) were analysed. This trigger corresponds to at least 88 AS PMTs hit without any risetime cut.

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<sup>4</sup>Average cosine of the Mie scattering angle distribution. More info about this in my fore coming MC memo.

<sup>5</sup>number of calibrated PMTs hit per event in the AS layer

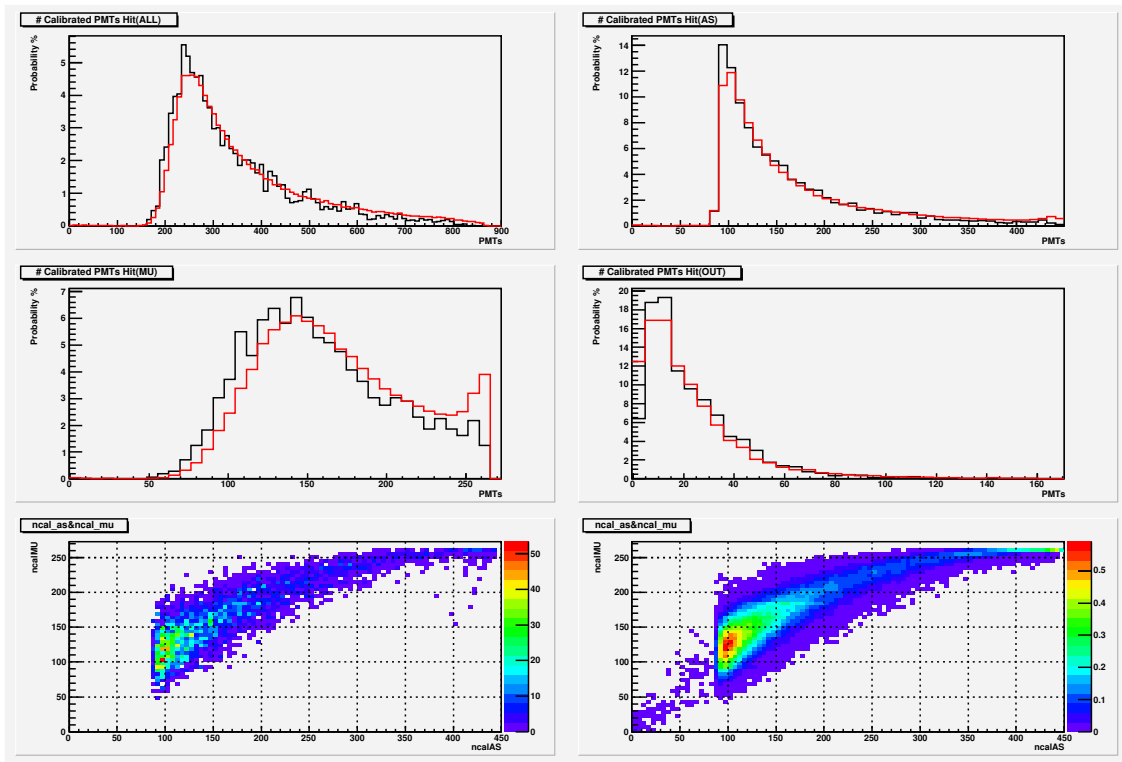


Figure 1: Number of calibrated PMTs hit. Bottom left plot is for MC and bottom right is for data.

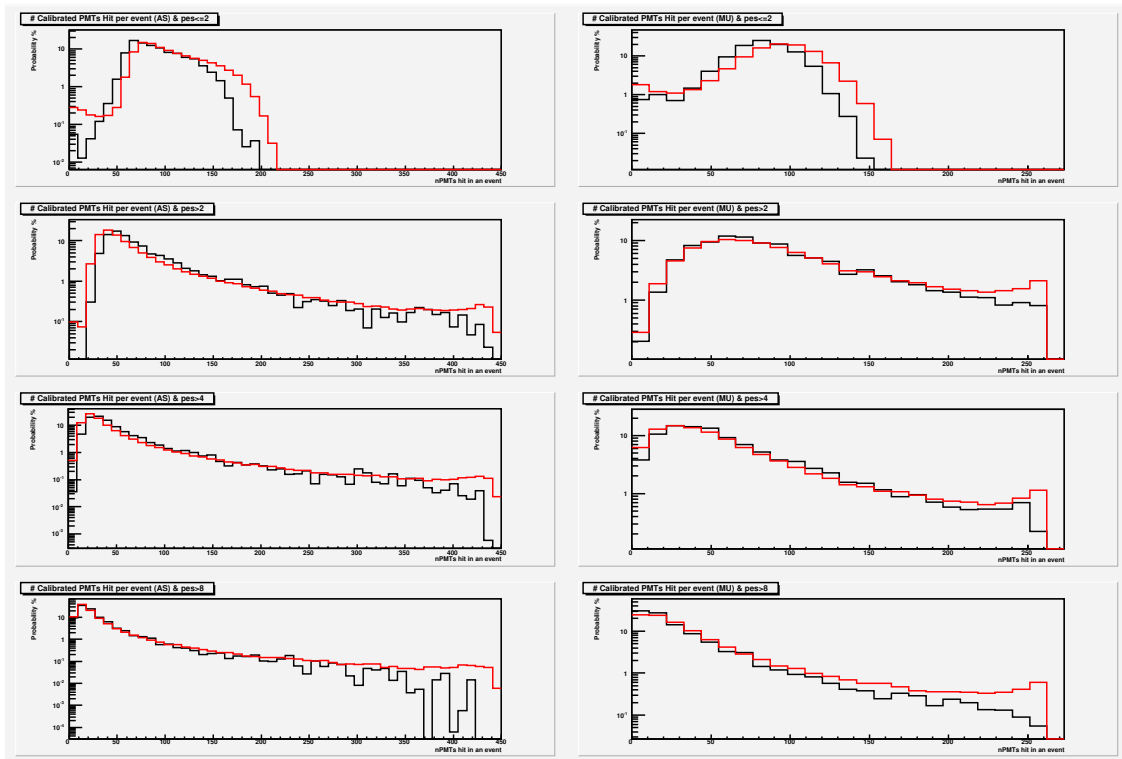


Figure 2: Number of calibrated PMTs hit for each PE multiplicity

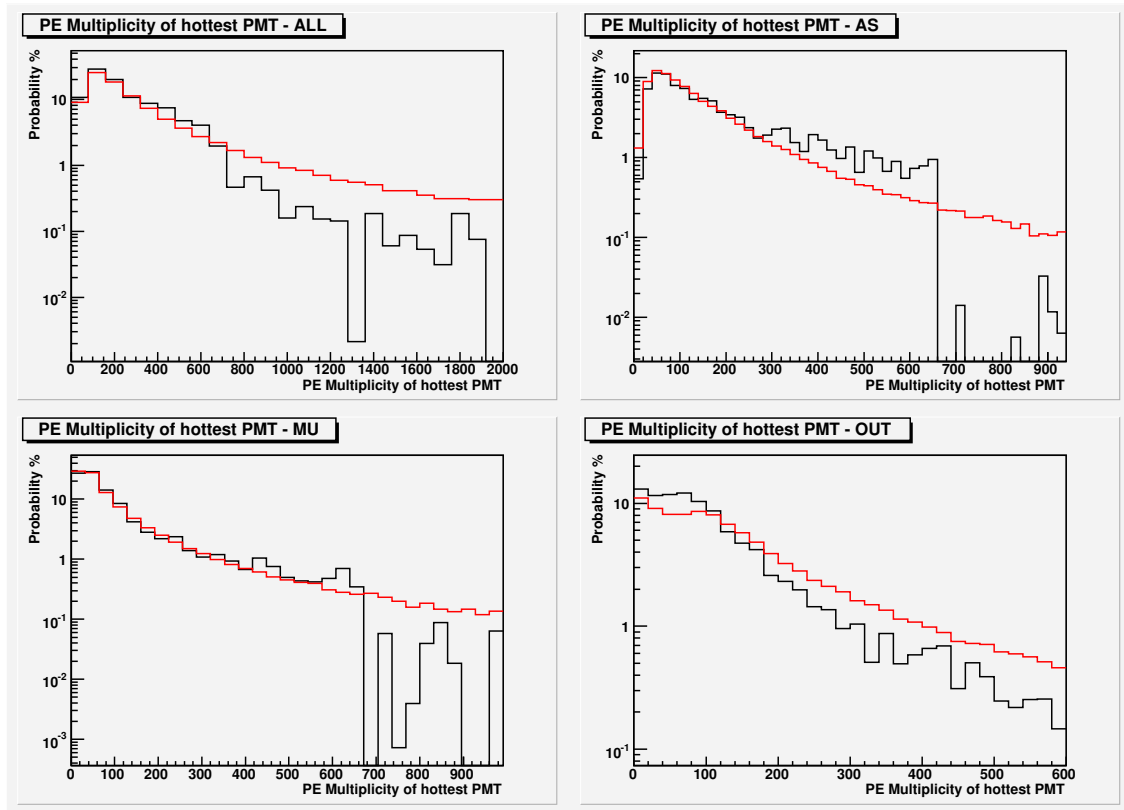


Figure 3: Multiplicity of the hottest PMT (mxpe)

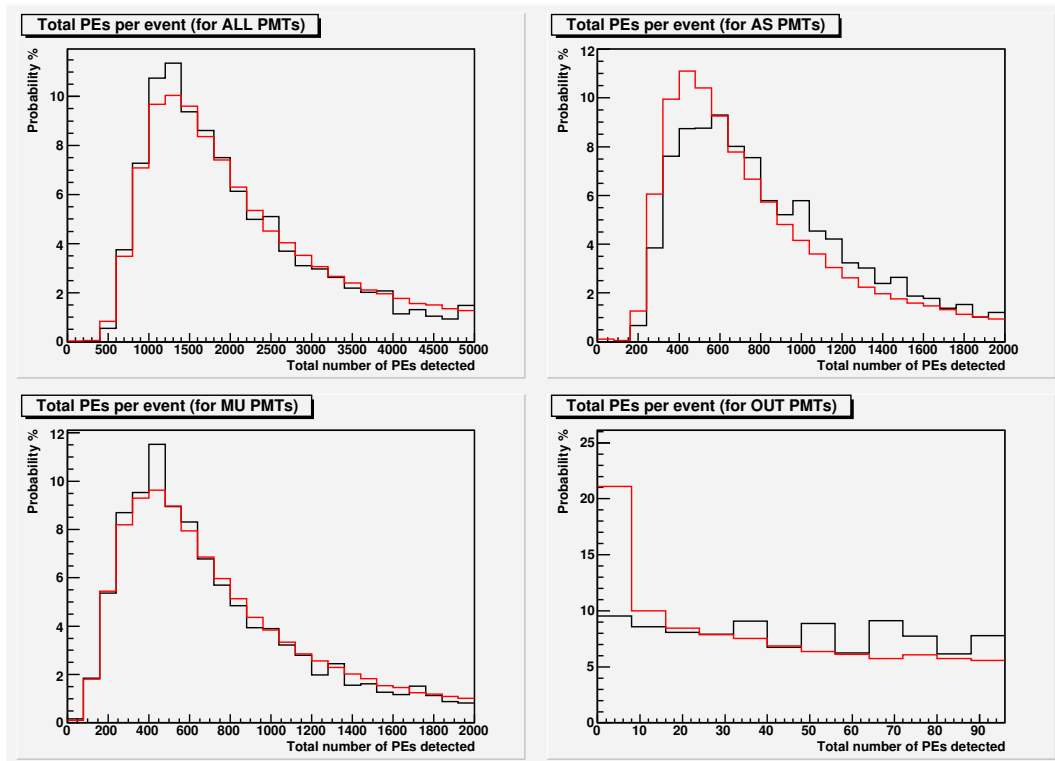


Figure 4: Total PE per event

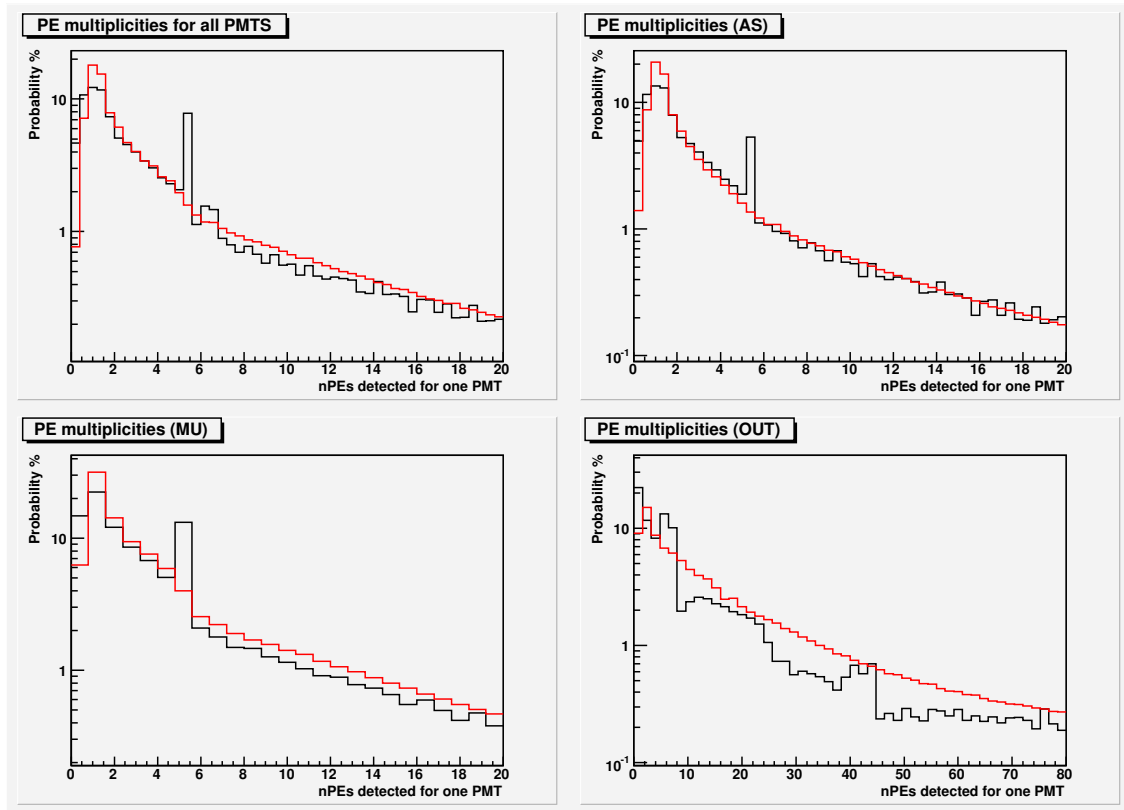


Figure 5: Number of PEs per PMT hit

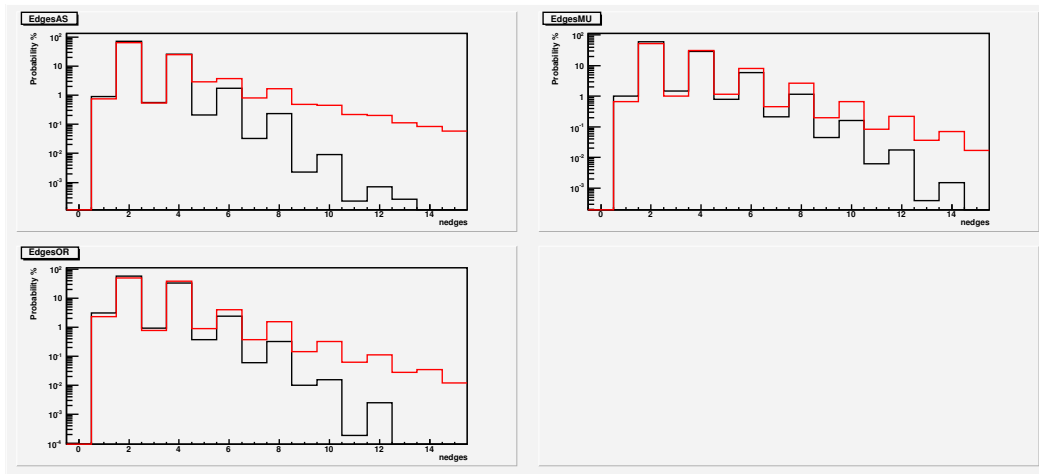


Figure 6: Number of edges per PMT hit

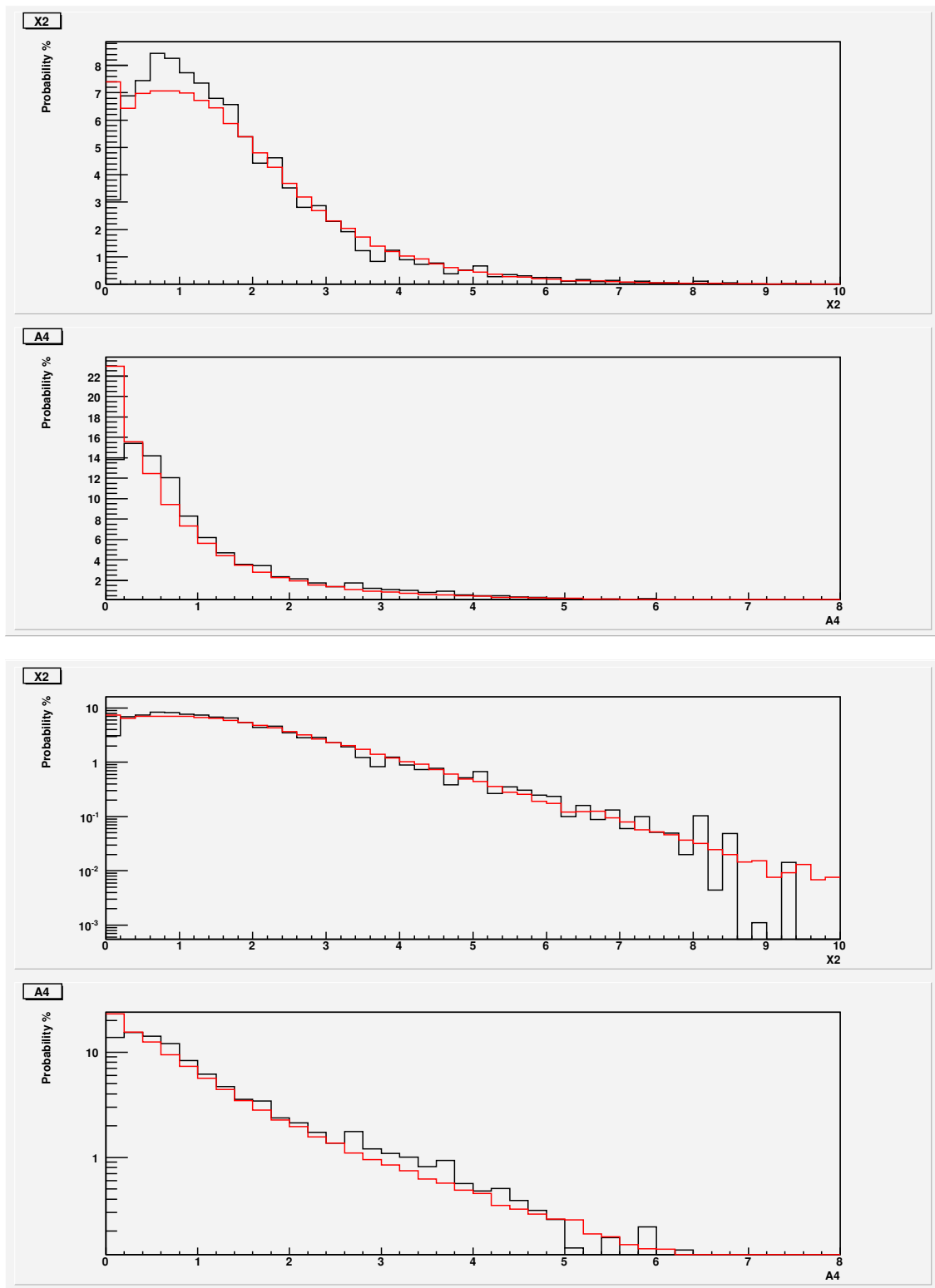


Figure 7: X2 and A4



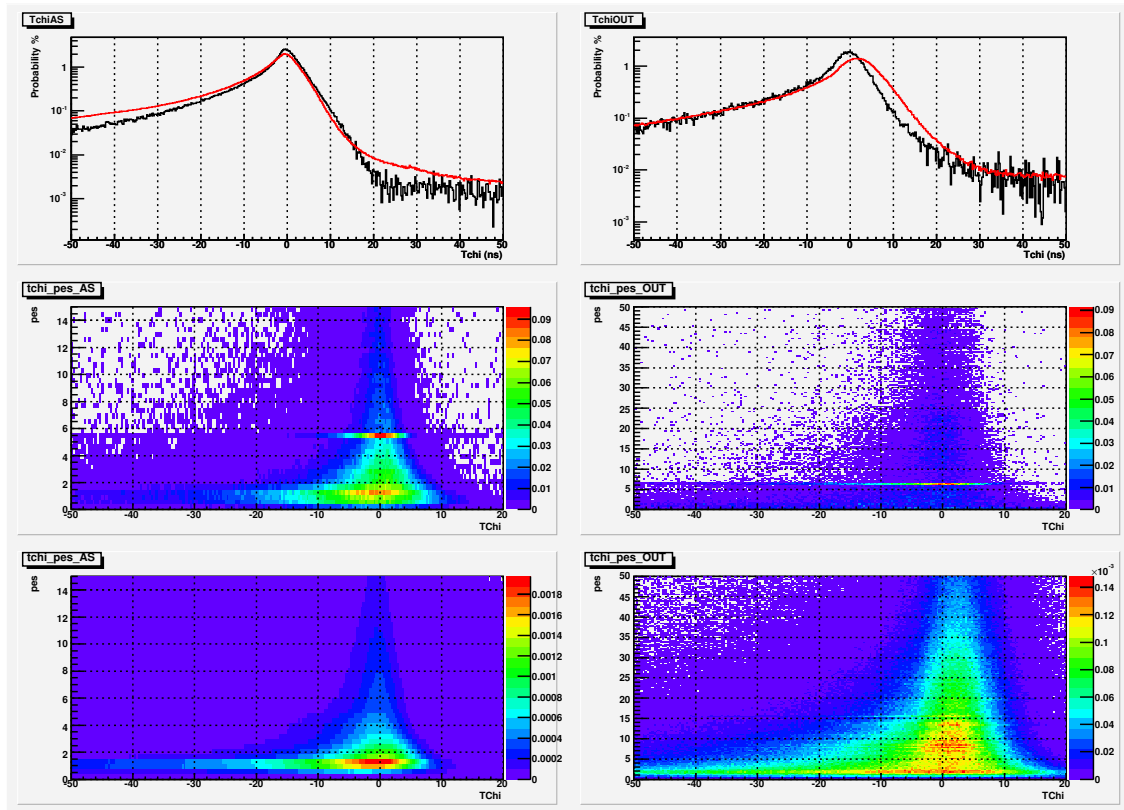


Figure 8: tchi and tchi vs PEs. Left 2D plots are for MC and right are for data.

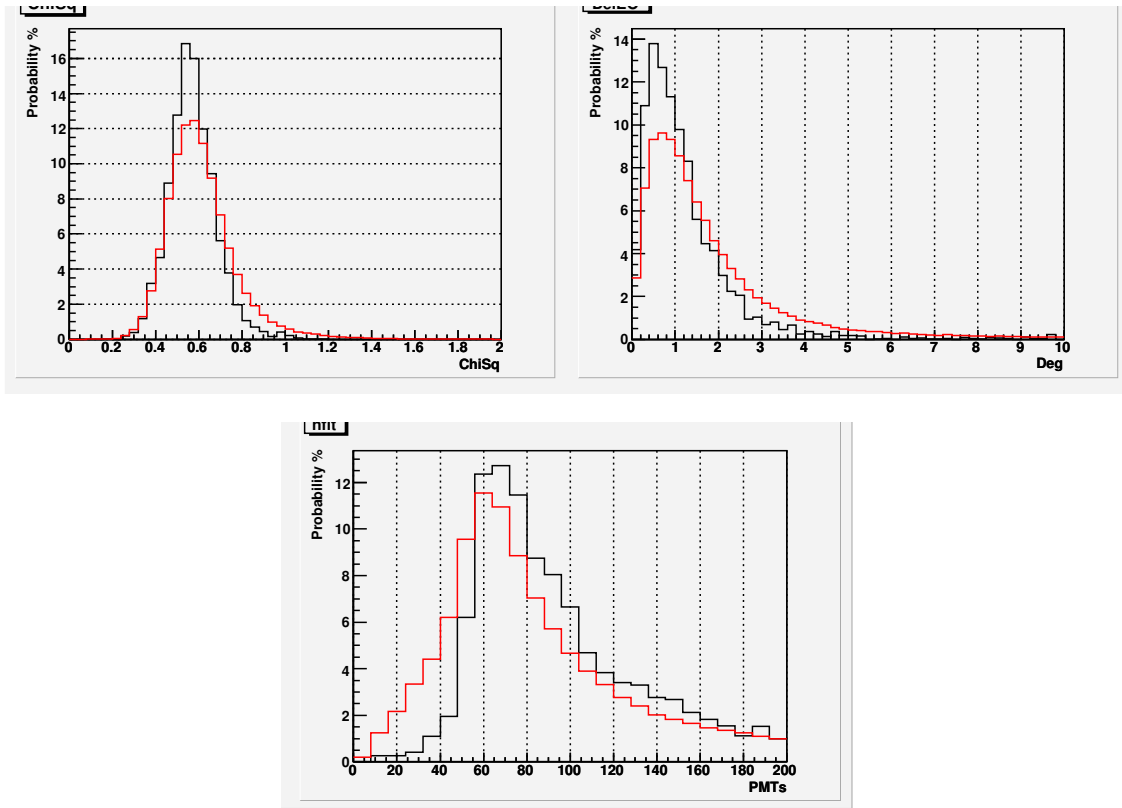


Figure 9: Chisq, delEO and nfit

## 2.2 Using the low multiplicity trigger (#3)

Only events that triggered the low multiplicity/low risetime cut (trigger #3) were analysed. This trigger corresponds to at least 24 AS PMTs hit in a window of 50 nsec.

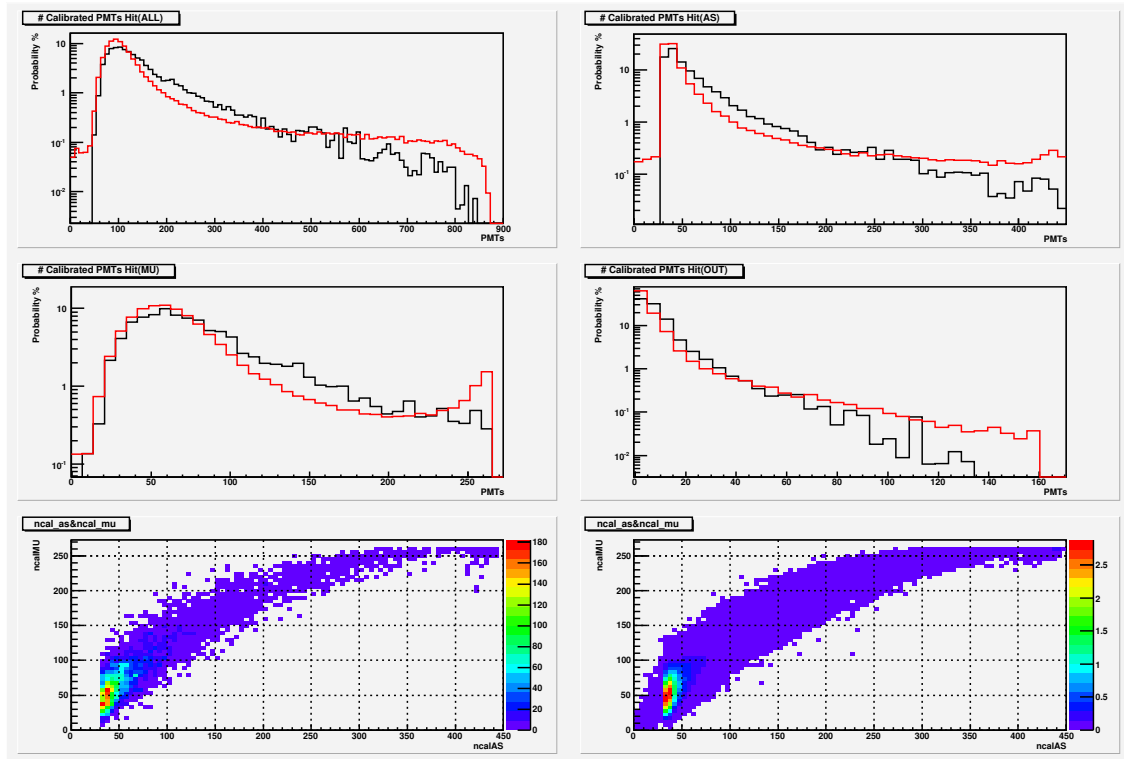


Figure 10: Number of calibrated PMTs hit. Bottom left plot is for MC and bottom right is for data.

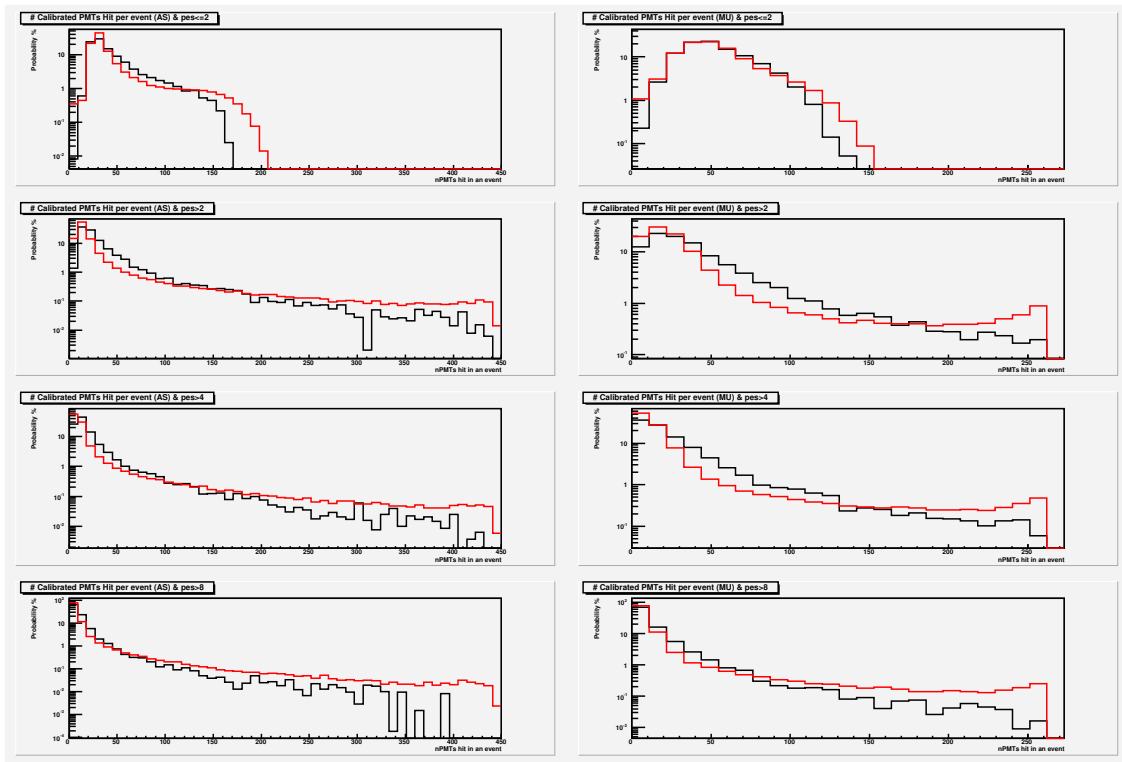


Figure 11: Number of calibrated PMTs hit for each PE multiplicity

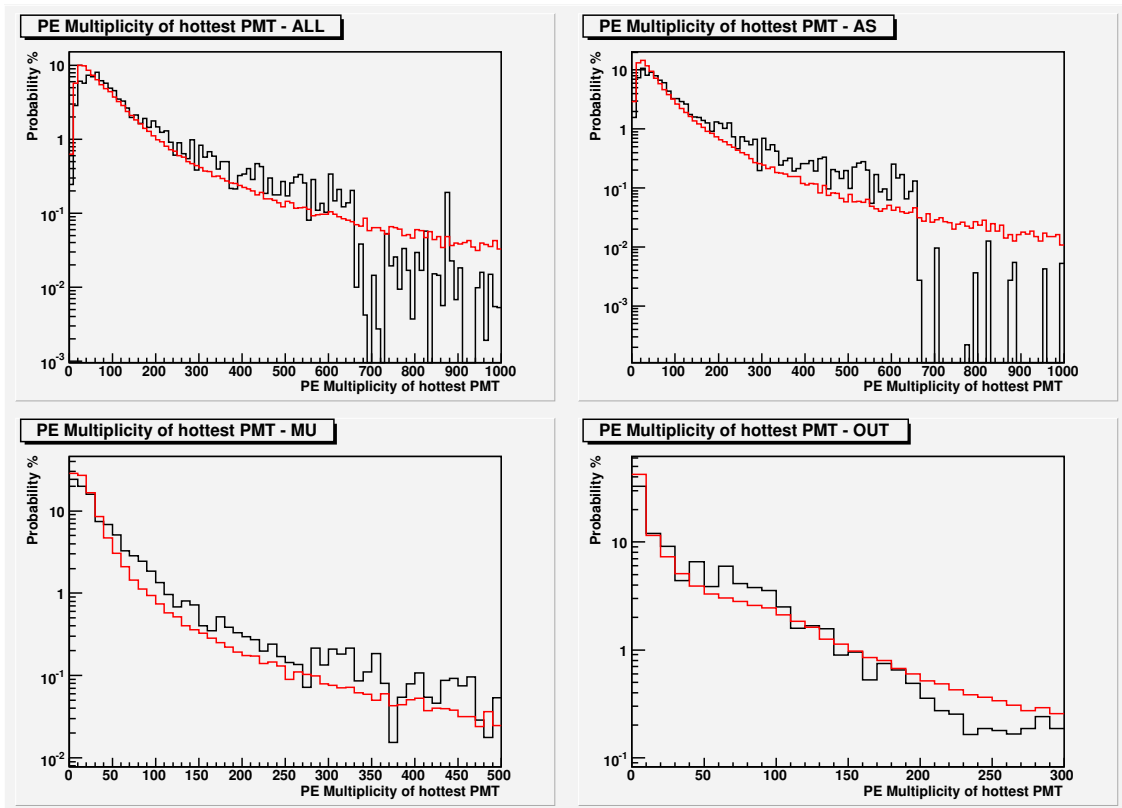


Figure 12: PE Multiplicity of the hottest PMT (mxPE)

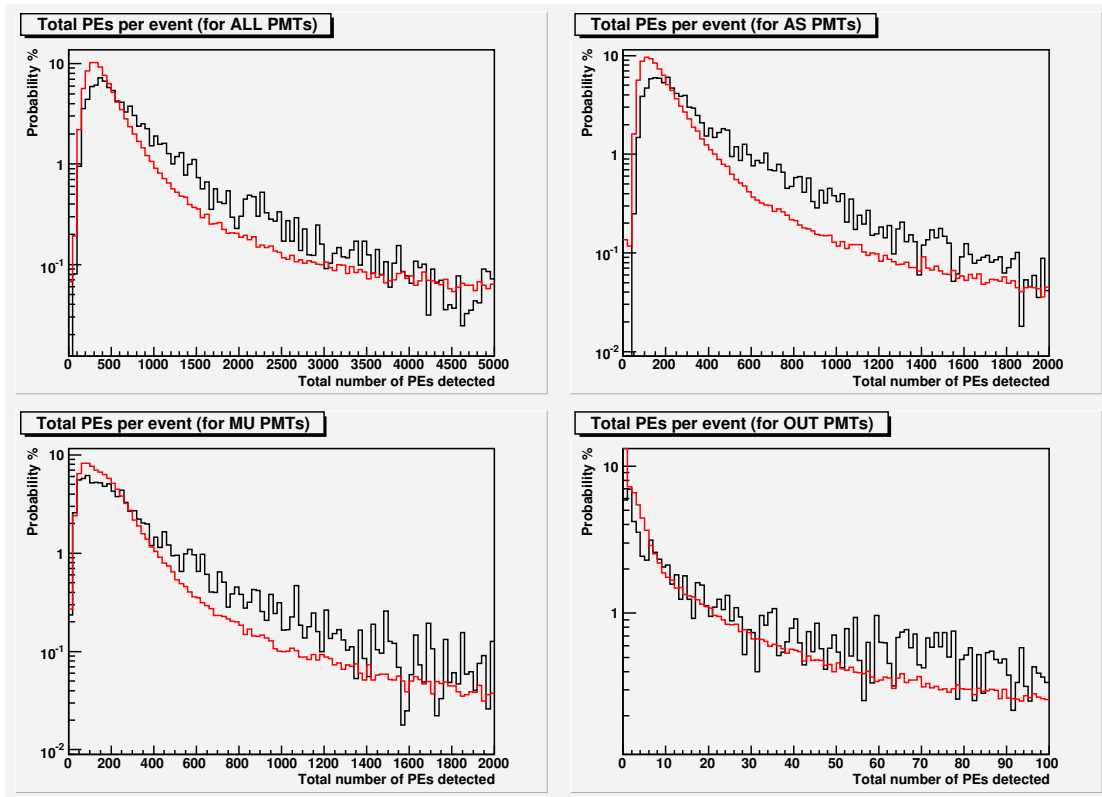


Figure 13: Total PEs per event

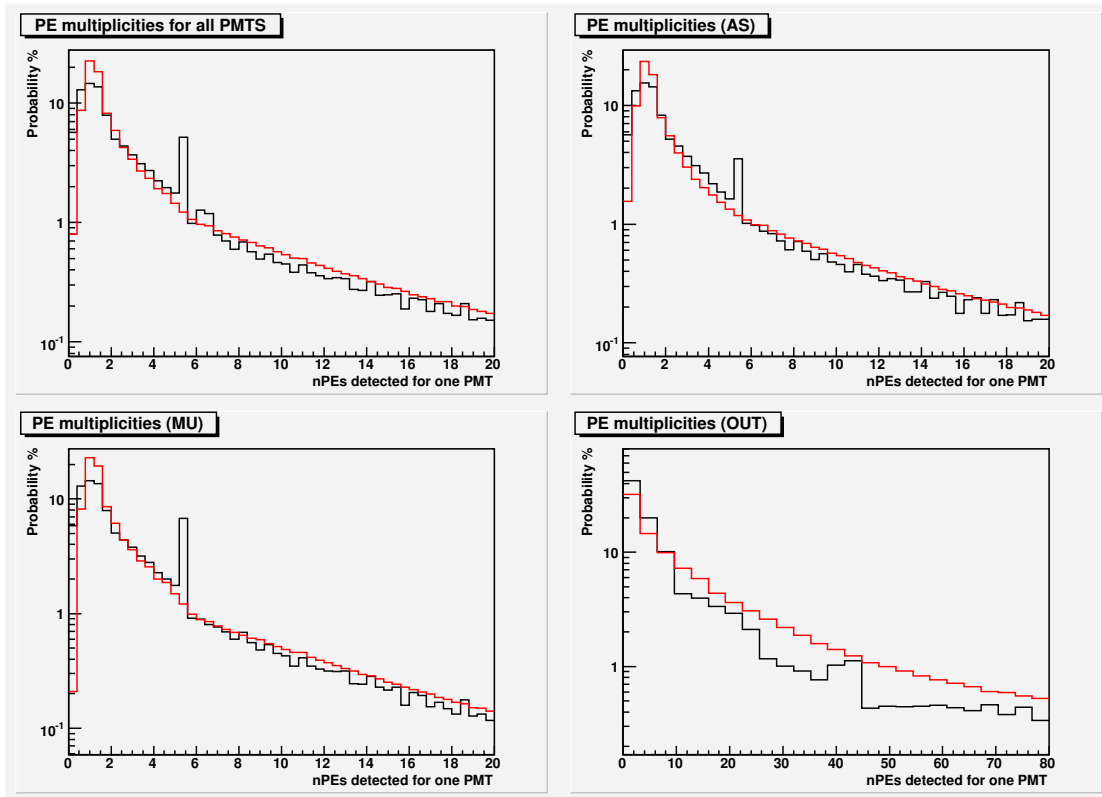


Figure 14: Number of PEs per PMT hit

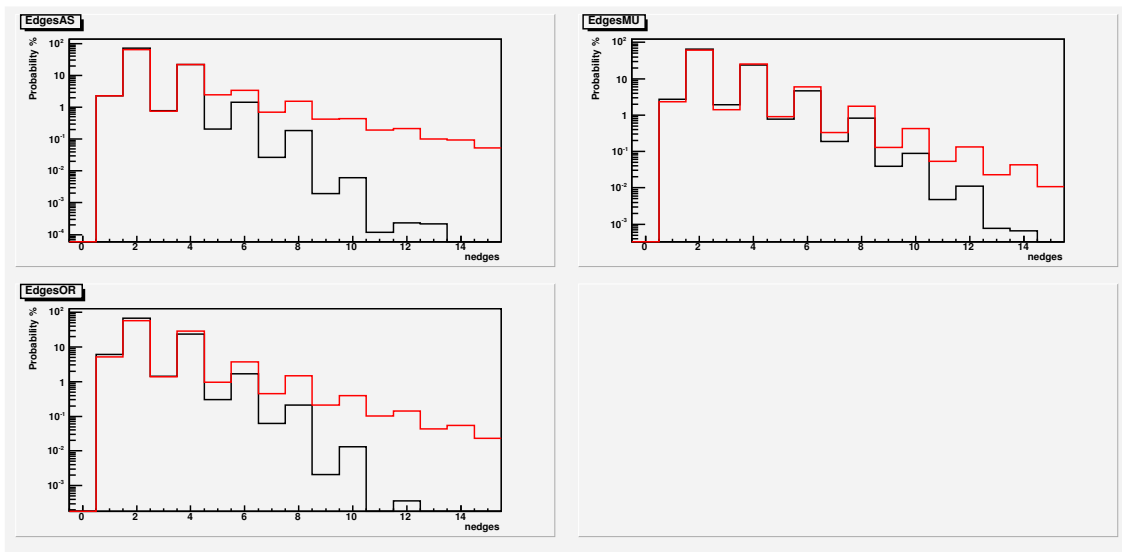


Figure 15: Number of edges per PMT hit

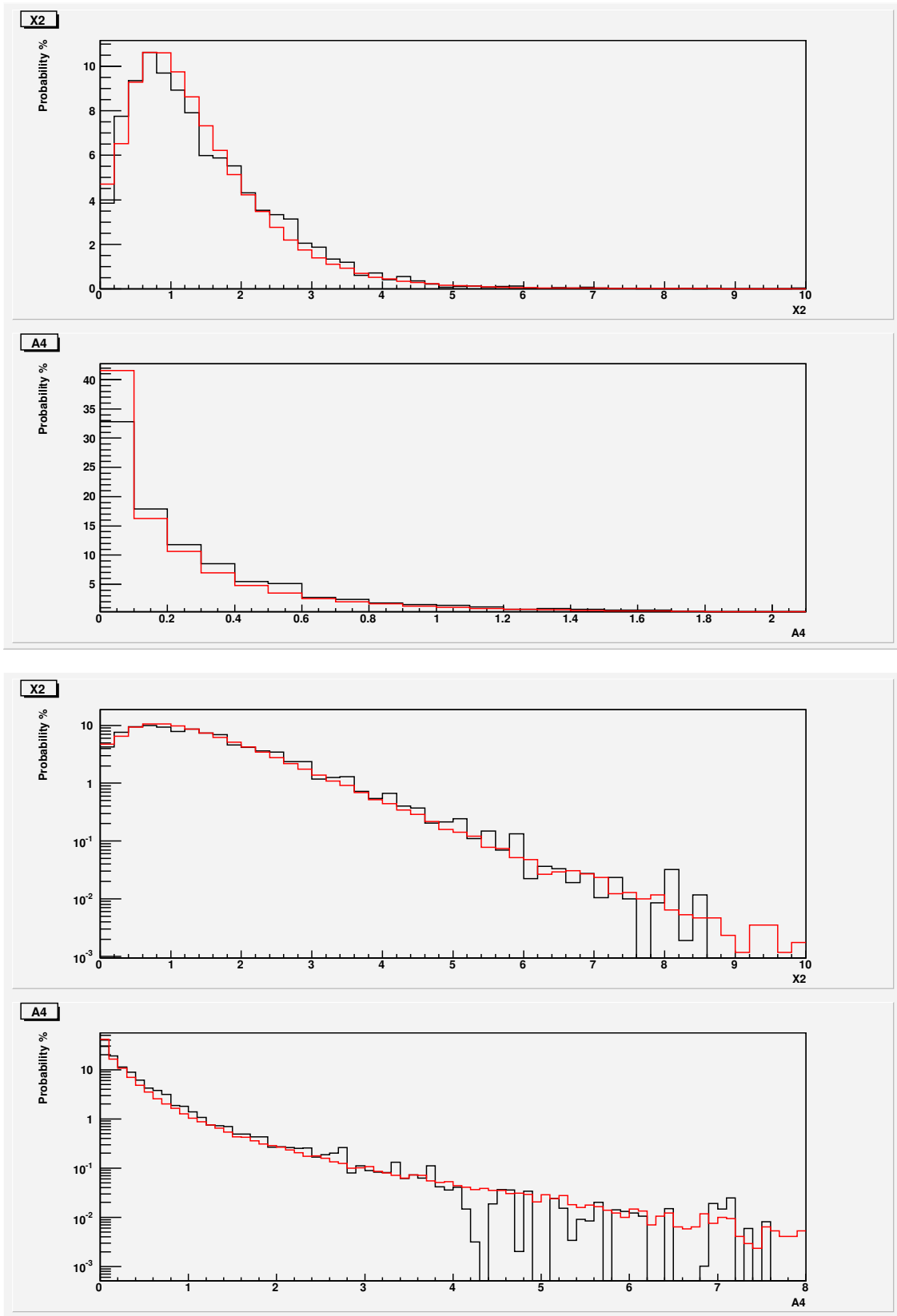


Figure 16: X2 and A4

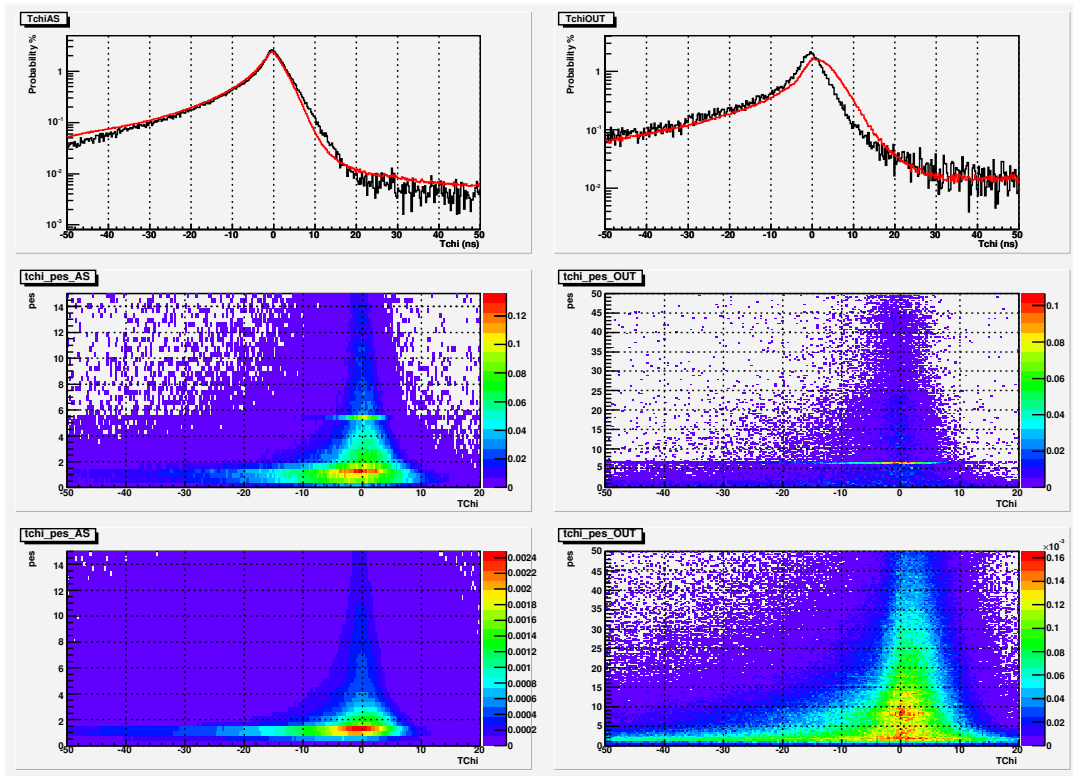


Figure 17: tchi and tchi vs PEs. Left 2D plots are for MC and right are for data.

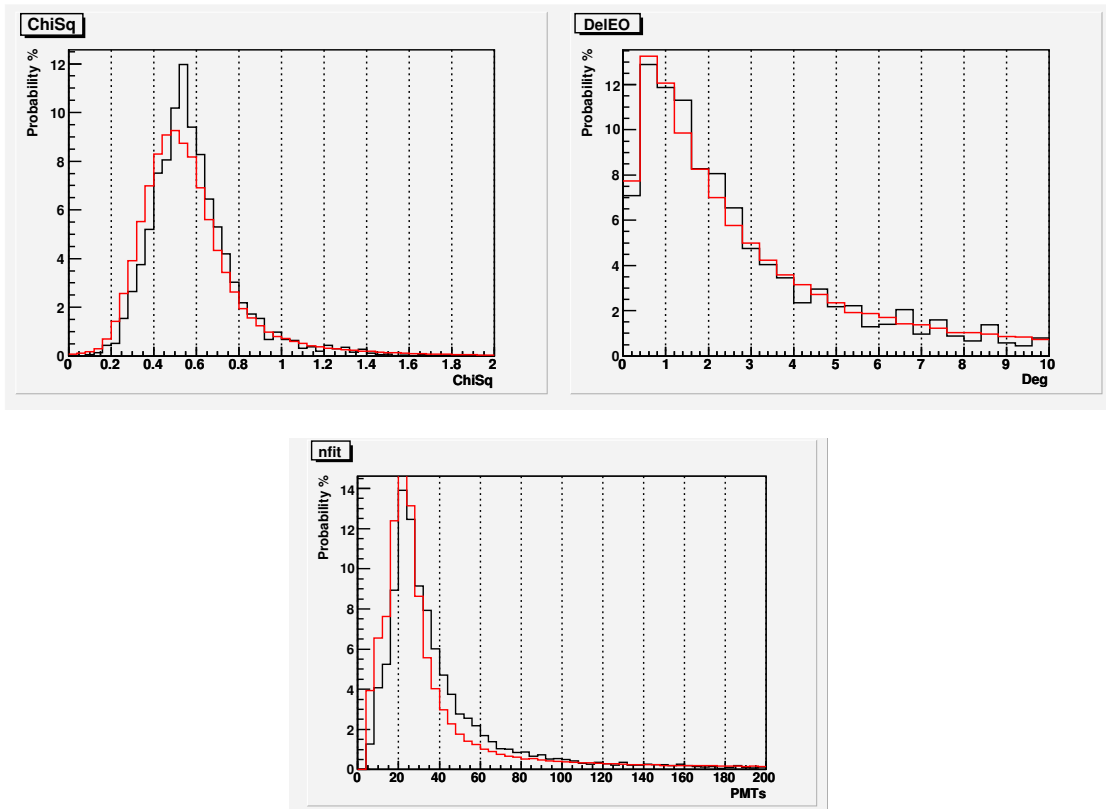


Figure 18: Chisq, delEO and nfit



## 2.3 Using all the triggers

All triggered events were analysed.

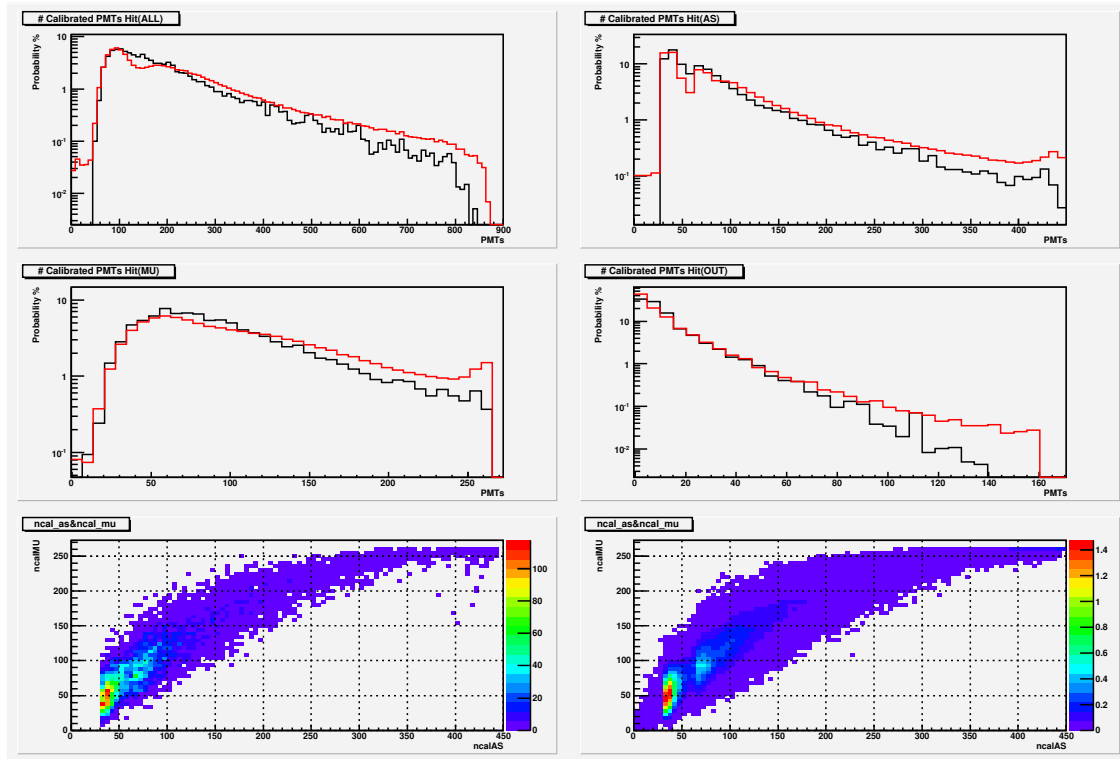


Figure 19: Number of calibrated PMTs hit. Bottom left plot is for MC and bottom right is for data.

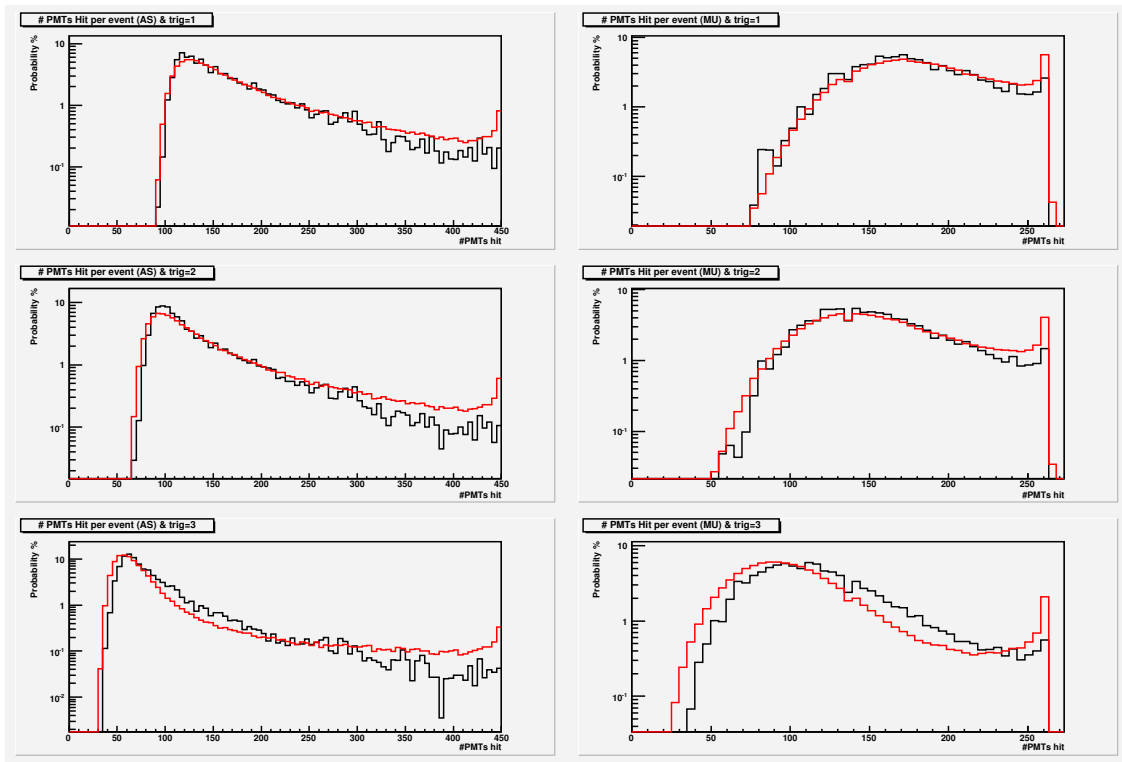


Figure 20: Number of PMTs hit per different trigger

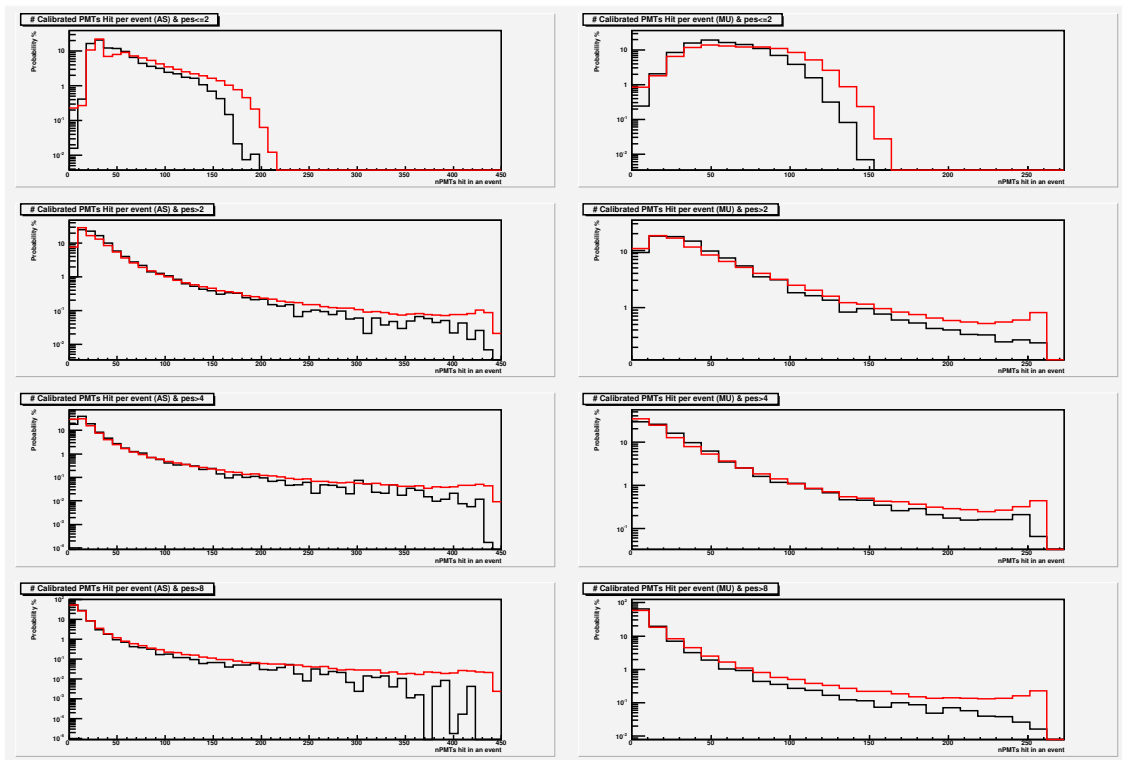


Figure 21: Number of calibrated PMTs hit for each PE multiplicity

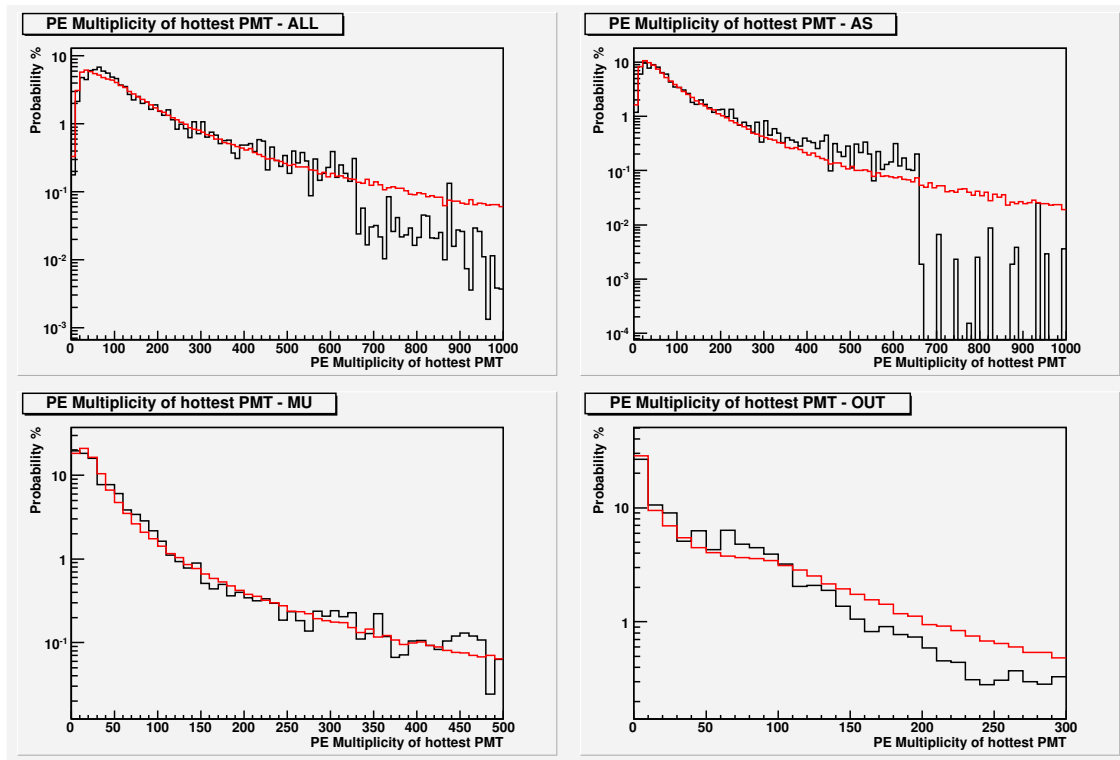


Figure 22: Multiplicity of the hottest PMT

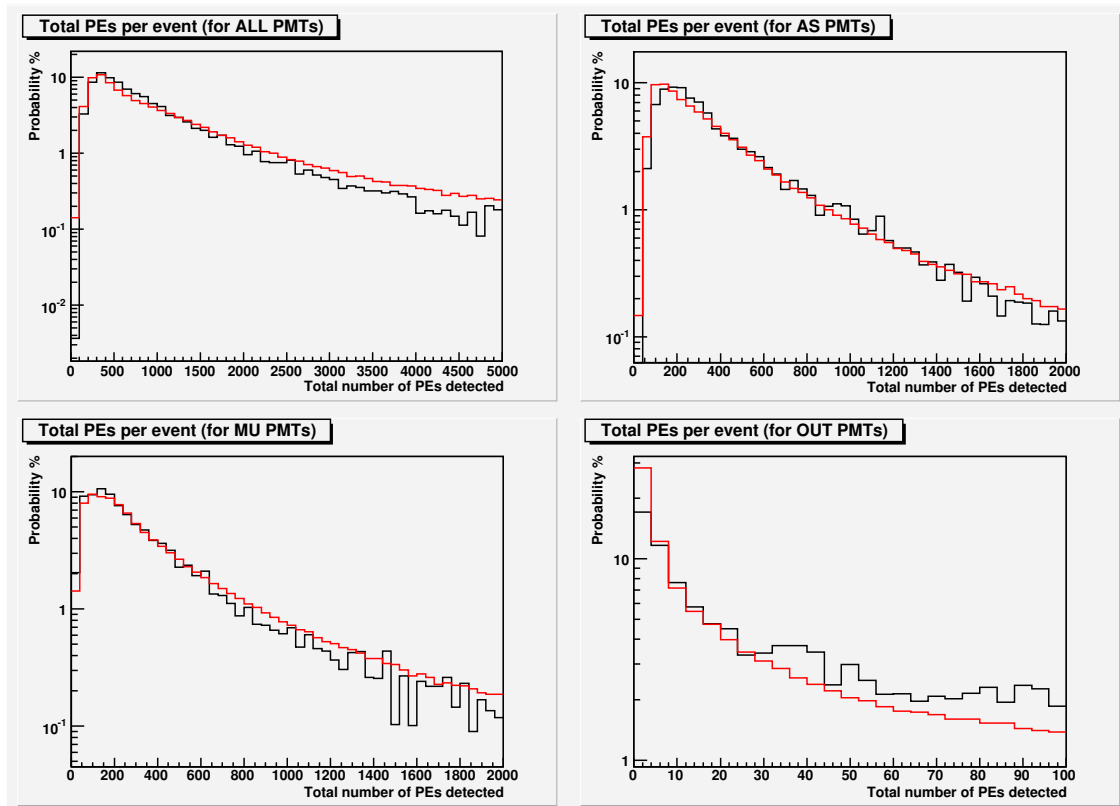


Figure 23: Total PEs per event

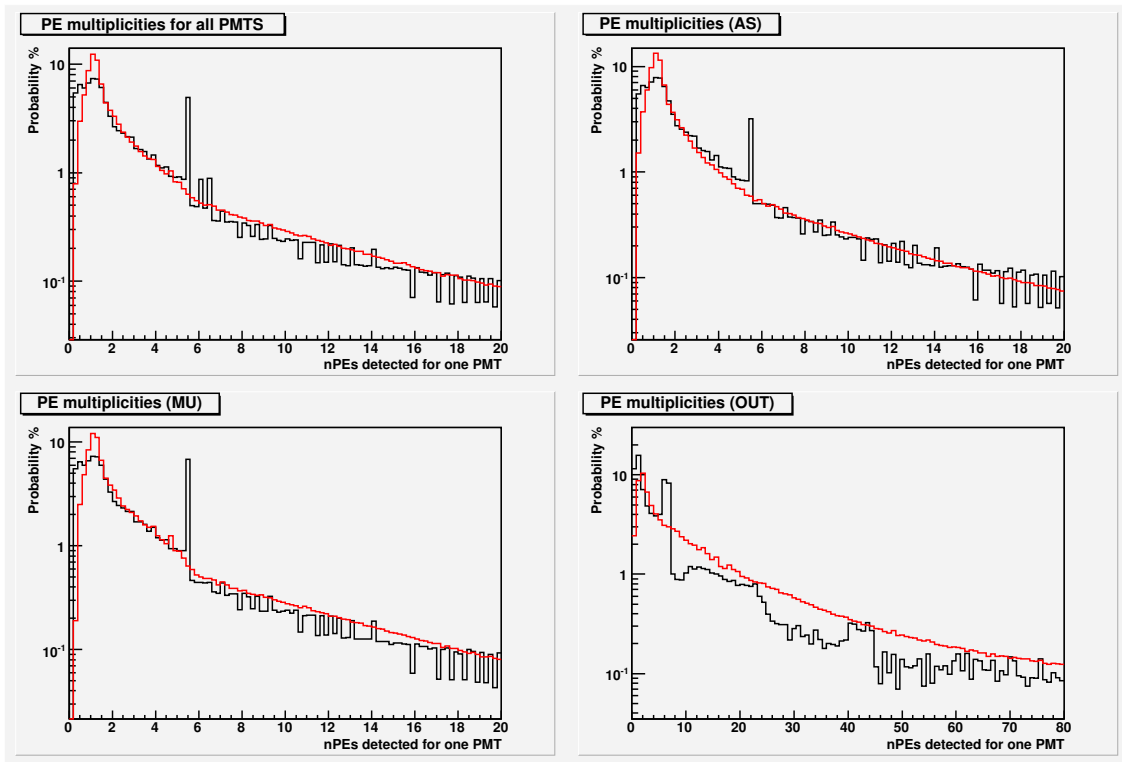


Figure 24: Number of PEs per PMT hit

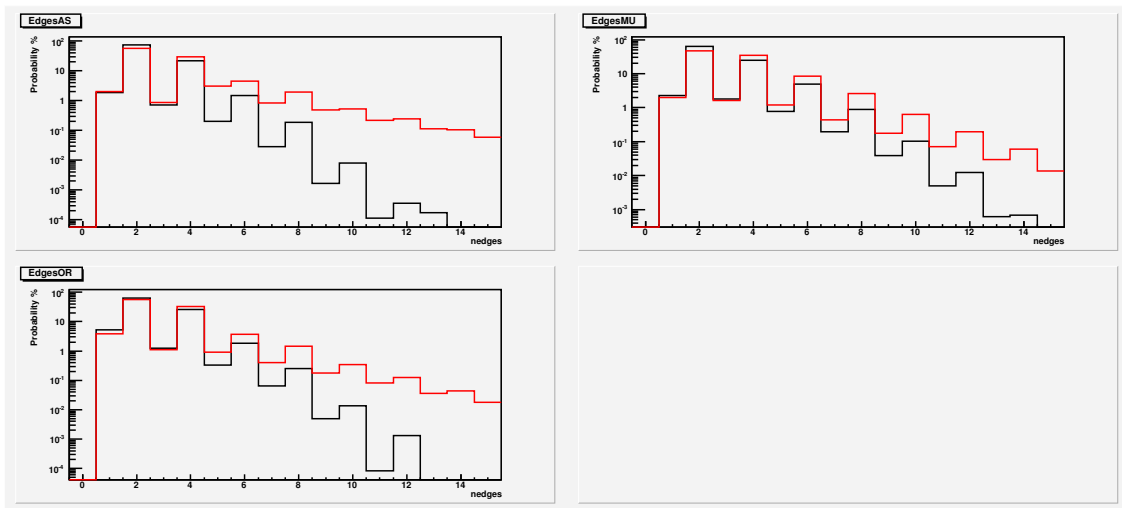


Figure 25: Number of edges per PMT hit

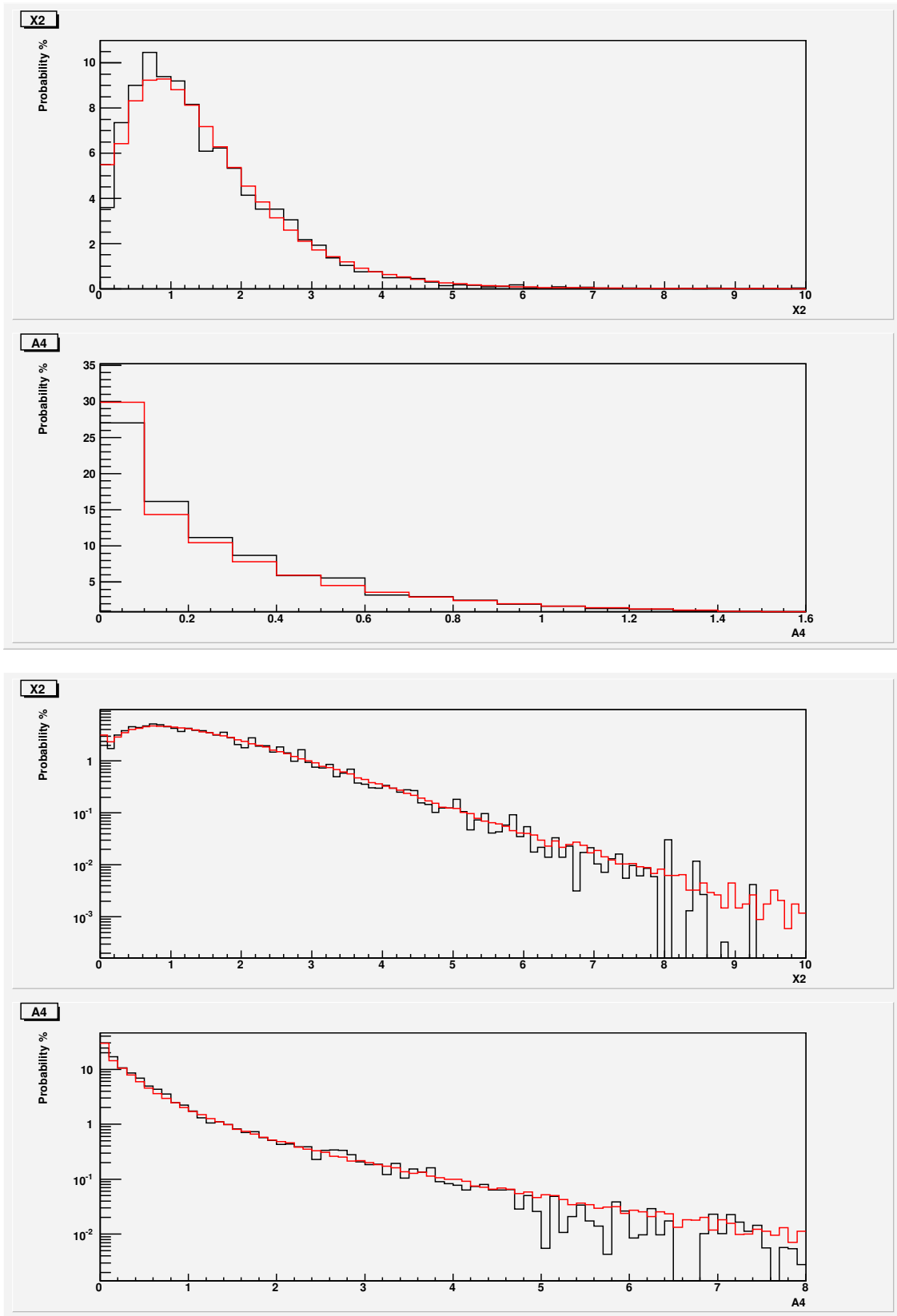


Figure 26: X2 and A4

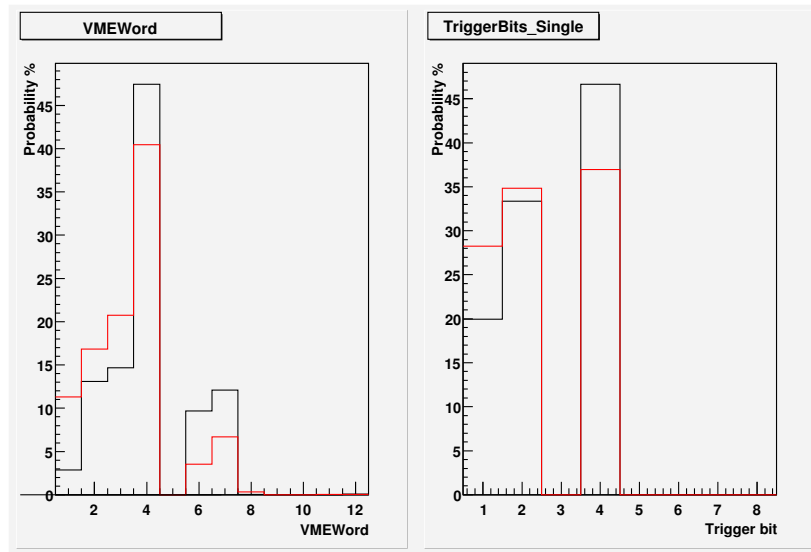


Figure 27: VMEWord per event and frequency of appearance of each different bit

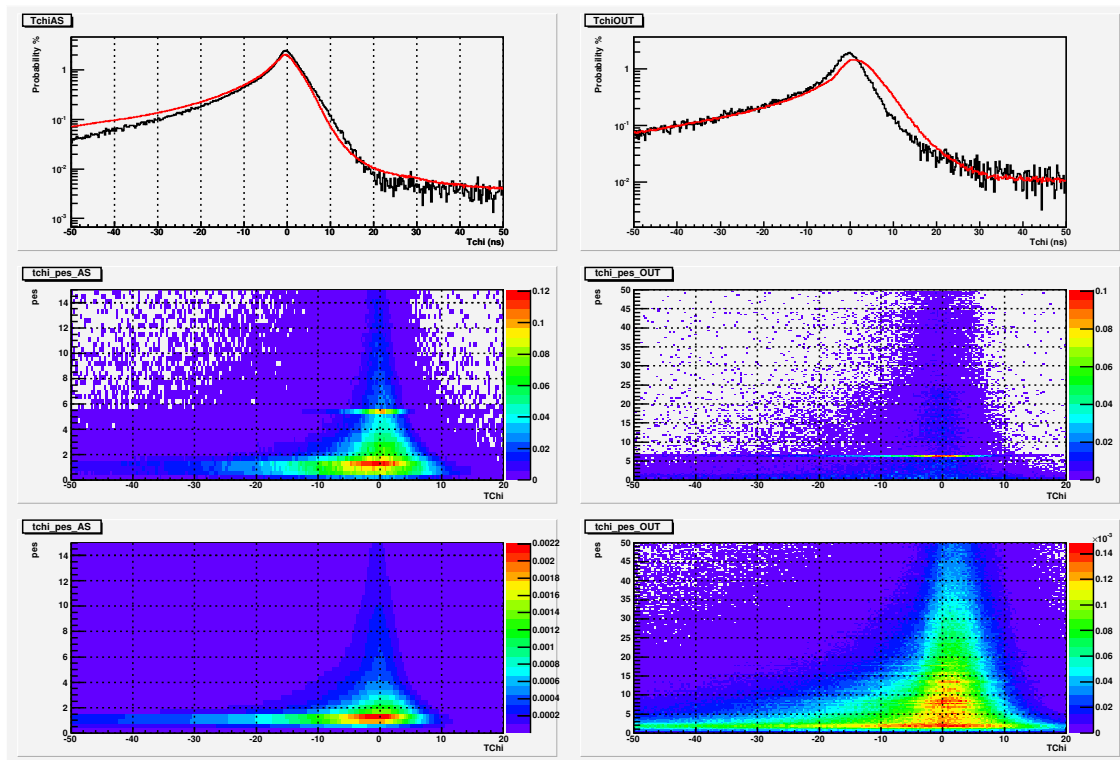


Figure 28: tchi and tchi vs PEs. Left 2D plots are for MC and right are for data.

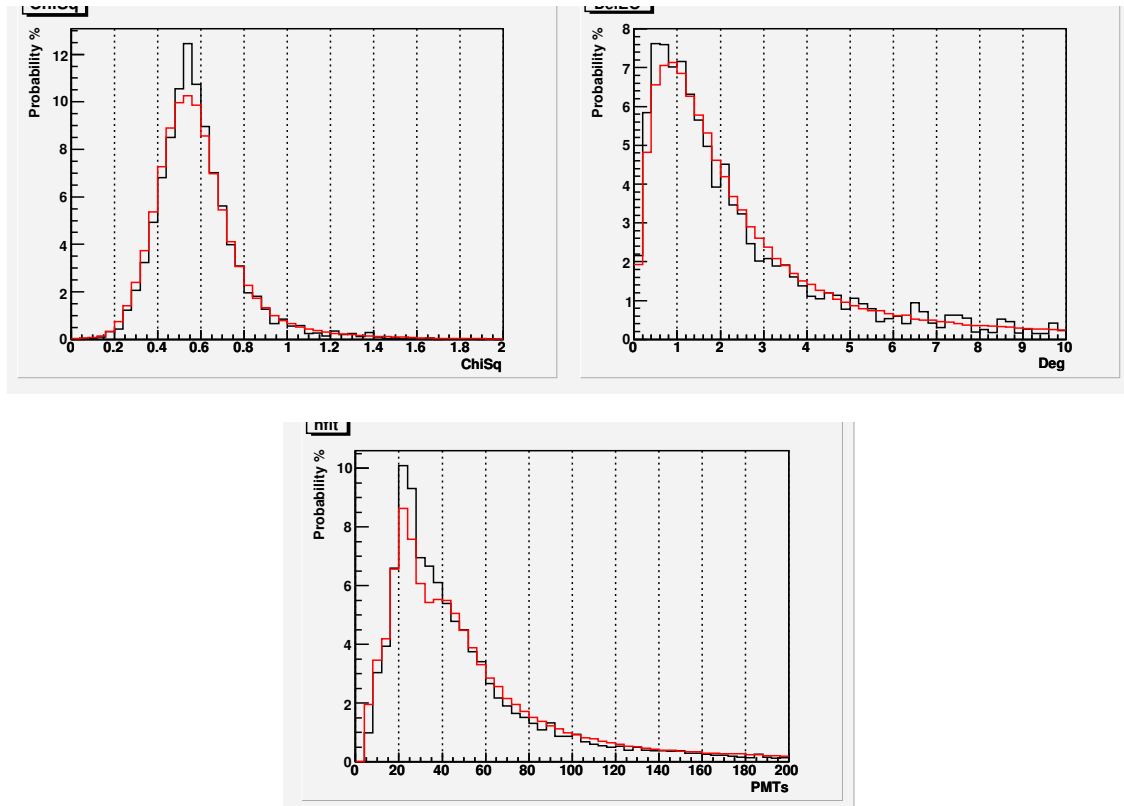


Figure 29: Chisq, delEO and nfit

## 2.4 Trigger rates

The MC trigger rates can be calculated using the code found under milinda/examples/mctest/TriggerRate. The trigger rates show the frequency a specific trigger bit was present in the VMEword (check is VMEword&bit). The MC files, data run, DeadPMTs, Dontfits and VMETrig configuration used were the same used for the previous analyses. The results are shown in Table 1. The trigger rates for data are shown in figure 30. The 6662 run used was taken at 10/22/2005 or 335 days into the year.

It is important to note that the MC trigger rates include the effects from a non perfect trigger simulation and that the data trigger rates include any effects from the curtains, from DC offsets in the analog sum and from a different #PMTs/analog-sum-amplitude ratio (and from a broken VME trigger card).

Trigger	Rate (Hz)			Data run 6662
	Helium	Proton	Total	
Any	279	742	<b>1021</b>	~1750
#1 (1)	87	203	<b>318</b>	~620
#2 (2)	140	347	<b>487</b>	~800
#3 (4)	187	528	<b>715</b>	~850

Table 1: Trigger rates

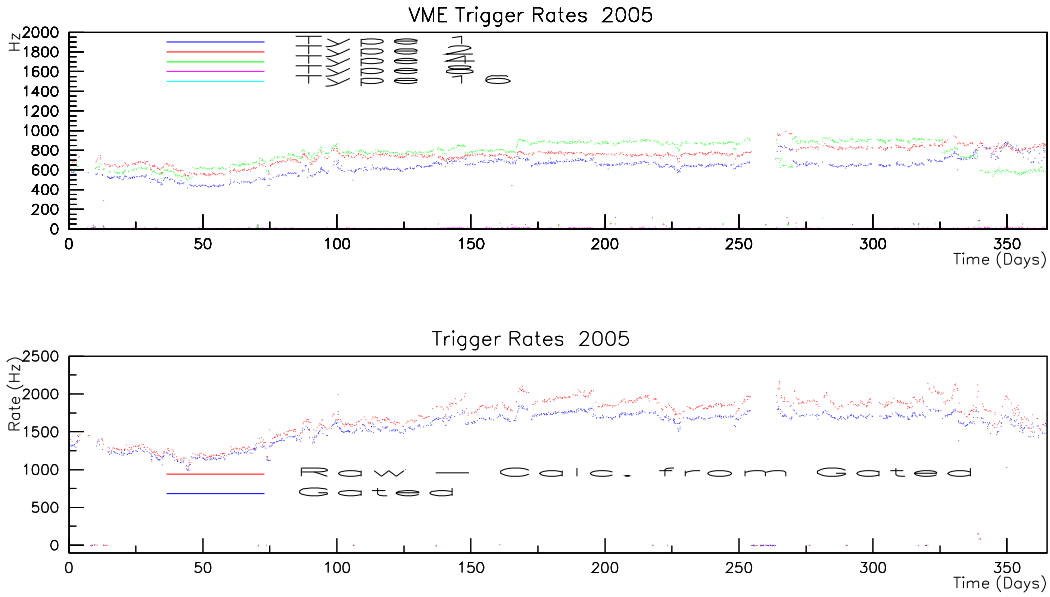


Figure 30: Trigger rates from 2005 data

## 2.5 Crab rate

Milinda's sensi code was used to find the number of gamma events per day from the crab. The configuration used was the following:

Binsize: 1.2

CXLevel: 0

Spectrum: HegraCrab

TriggerType: Multiplicity

Risetime (ntop, risetime) = (75, 10000) , (52, 87.5) , (23, 50) , (23, 10000). This is the default configuration.

Data: v2.0 gamma files produced with materials\_AbsL50m\_ScatL30m.dat geometry file

The results are shown in table 2.

Trigger type	min X2	min nfit	Rate (gamma events/day)	Error
Multiplicity (60PMTs)	2.50	20	13.98	1.66
Multiplicity (60PMTs)	4.00	100	5.16	1.16
Multiplicity (60PMTs)	5.50	175	1.27	0.56
Multiplicity (50PMTs)	2.50	20	15.67	1.73
Multiplicity (50PMTs)	4.00	100	5.16	1.16
Multiplicity (50PMTs)	5.50	175	1.27	0.56
Risetime	2.50	20	21.02	2.50
Risetime	4.00	100	5.16	1.16
Risetime	5.50	175	1.27	0.56

Table 2: Crab rates



## 2.6 Quality factor

The effects of different X2 and A4 cuts on MC and data were calculated. The quality factors were also calculated. Two different analyses were performed using different trigger and cuts. The results from the second analysis are meant to be compared with the ones from the 2003 Crab paper.

### 2.6.1 Using VMETrigger

The angle fitter in the analysis used both OR and AS layers. The equivalent of the usual  $n_{\text{fit}} \geq 20$  cut (using just the AS layer for angle fitting) was used. The VMETrigger configuration, DeadPMTs and Dontfits used are the same as above (from run 6662). The only cut applied was an  $n_{\text{fit}} \geq 35$  cut.

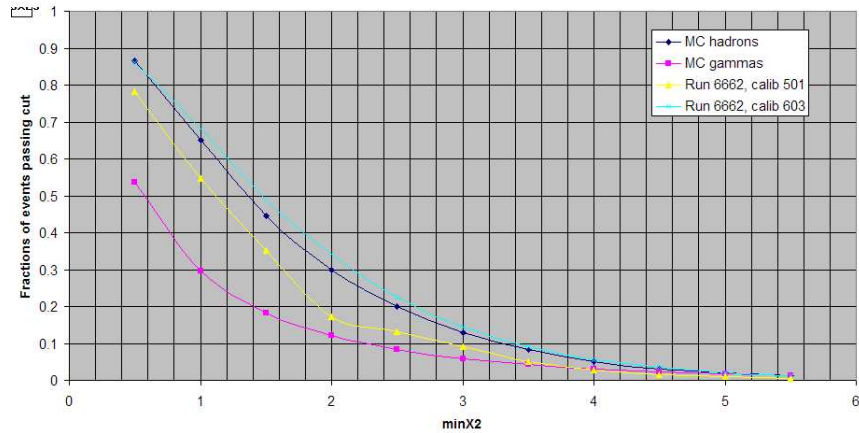


Figure 31: Fraction of events passing an X2 cut

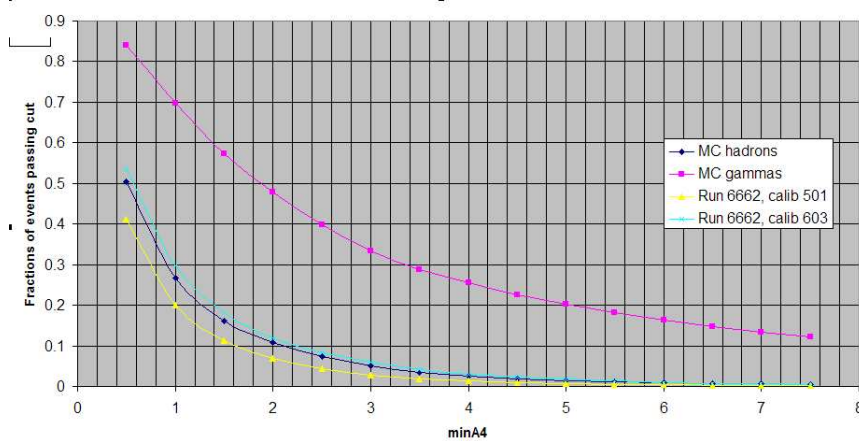


Figure 32: Fraction of events passing an A4 cut

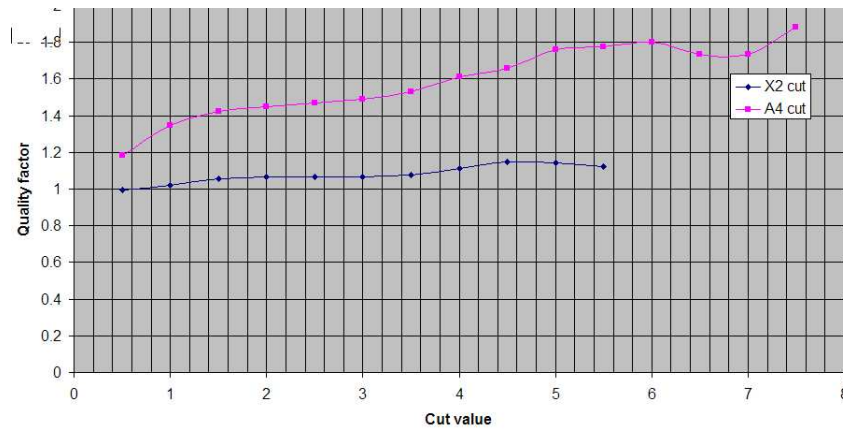


Figure 33: Quality factor

It is worth noting that the MC results are considerably closer to data analysed with v603 calibrations. Data analysed with different calibration versions are considerably different. The fact that the quality factor for X2 is that low is alarming and needs further consideration. Because of low statistics no harder X2 and A4 cuts were analysed.

### 2.6.2 Using single 50 PMT multiplicity trigger

The results of this analysis are meant to be compared with the Crab paper results. The MC hadron events were generated up to  $\theta=70^\circ$ . MC gammas go up to  $\theta=45^\circ$ . In the Crab paper, protons with zenith angles only up to  $45^\circ$  were analysed. The DeadPMTs and Dontfits used are the same as above (from run 6662). The angle fitter uses just the AS layer. The core fitters used are the default ones for milinda and not the ones available at the time before the Crab paper. The trigger used was a single 50PMT multiplicity trigger with no rise time cut. The cuts used are the ones used in the Crab paper ( $n_{\text{fit}} > 20$ ,  $n_{\text{caltop}} > 60$  and  $\text{delAngle} < 1.2^\circ$  (just for gammas) ).

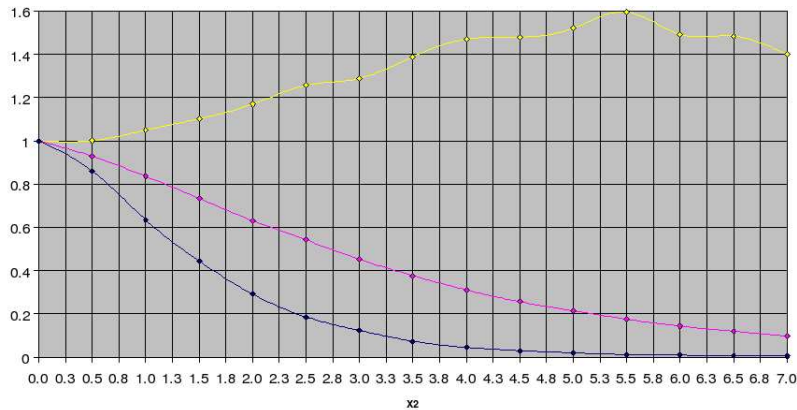


Figure 34: Fractions of events passing cut (blue MC hadrons, purple MC gammas) and Quality factor (yellow)

For reference, the number quoted from the Crab paper are  $\sim 50\%$  of gammas and  $\sim 10\%$  of protons pass an  $X2 > 2.5$  cut, giving a quality factor of  $Q \sim 1.6$ . From the latest MC, the corresponding numbers are  $\sim 55\%$  and  $19\%$ .

## 2.7 The muon peak

The number of pes at the muon layer produced by a muon is another factor that can be used for validating the Milagro MC. This number depends mainly on the efficiency of the PMTs and the

reflectivity of the baffles. Since the light from muons detected from the bottom layer PMTs is considered to be produced locally (near the PMTs), this number doesn't depend strongly on the water properties.

At the total number of PEs in the MU layer plot, the muon contribution appears as a wide peak near 100pes. In triggered data analysis, the muon peak is hidden under the contribution from all the other shower particles. To find the muon peak, untriggered data must be analysed. For that reason, when analysing real data, the window of the edge finder is offset by 1000 counts after the trigger. At that time, only particles from weak non-triggering showers are in the pond so the muon contribution can be easily seen. For MC data, non-triggering showers can be analysed for the the muon peak to be shown.

Because the muon peak is wide, the  $\log_{10}$  of the total pes is plotted instead. The peak is fitted with a gaussian and the muon peak is found from the centroid of the fit. A plot showing the muon peak from data run 6662 using calibrations v603 and from proton MC can be found in figure 35.

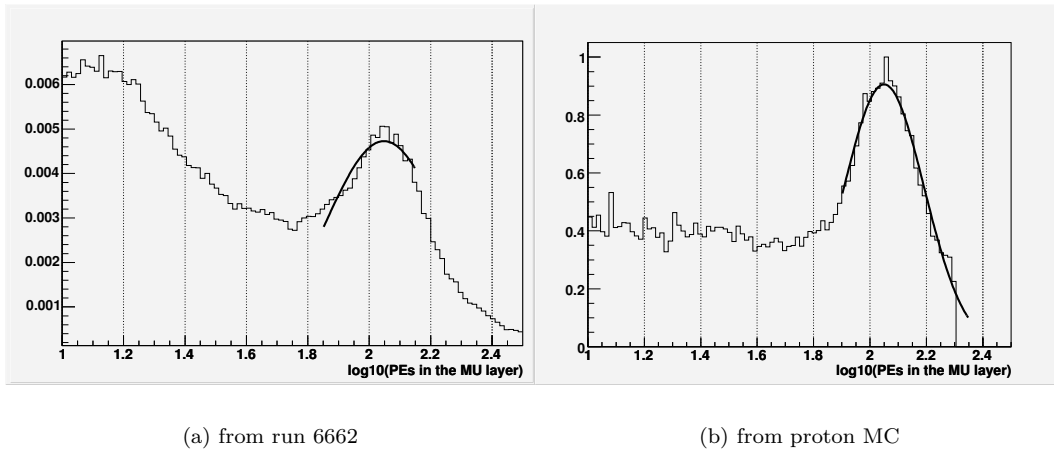


Figure 35: The muon peak

The muon peak in data is fairly constant in time. Considering the large variability of the water quality in the last three years, it can be said that the muon peak is not strongly dependent on the water absorption. A plot of the muon peak pes versus modified julian date from data is shown in figure 36. It is evident that the muon peak is strongly dependent on the calibration used.

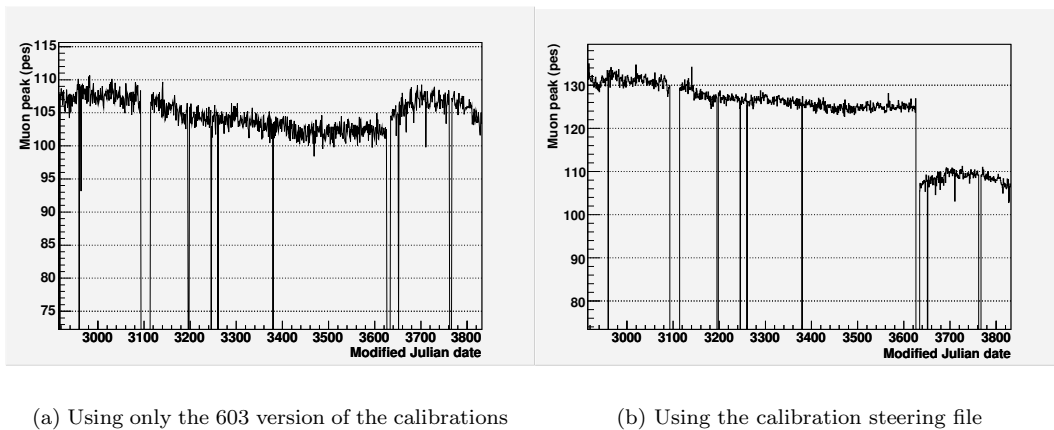


Figure 36: Location of the data muon peak data versus time

The location of the muon peak in data, as shown in figure 35 is at  $\sim 107$ pes. Its location from

v2.0 protons is at  $\sim 110$ pes. The corresponding number from G3 v3.2 protons is 232pes.

### 3 Comparing hadrons vs gammas

The hadron data used in the previous analyses and gammas produced using the materials\_AbsL50m\_ScatL30m.dat geometry file were compared. The DeadPMTs, Dontfits and trigger configuration used were the same as the ones used above. The gamma events were reweighted in order for their spectral index to be -2.59 (Hegra Crab spectrum). In the plots below black is hadrons and red is gamma.

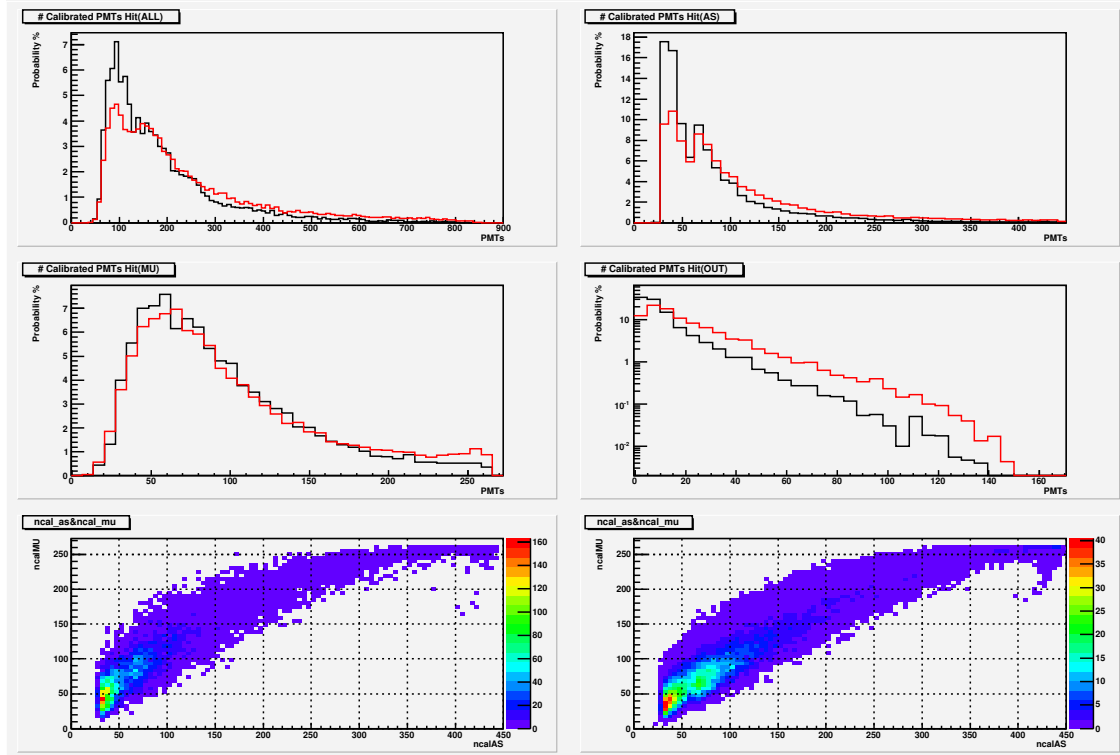


Figure 37: Number of calibrated PMTs

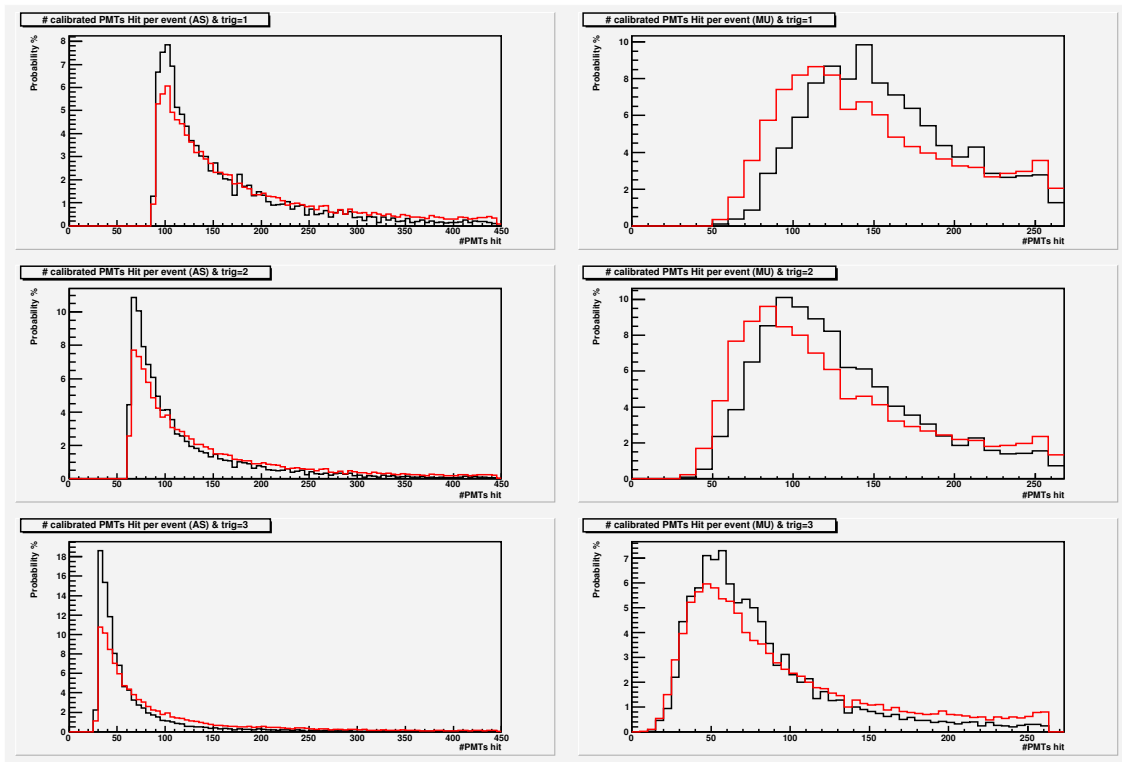


Figure 38: Number of PMTs hit per different trigger

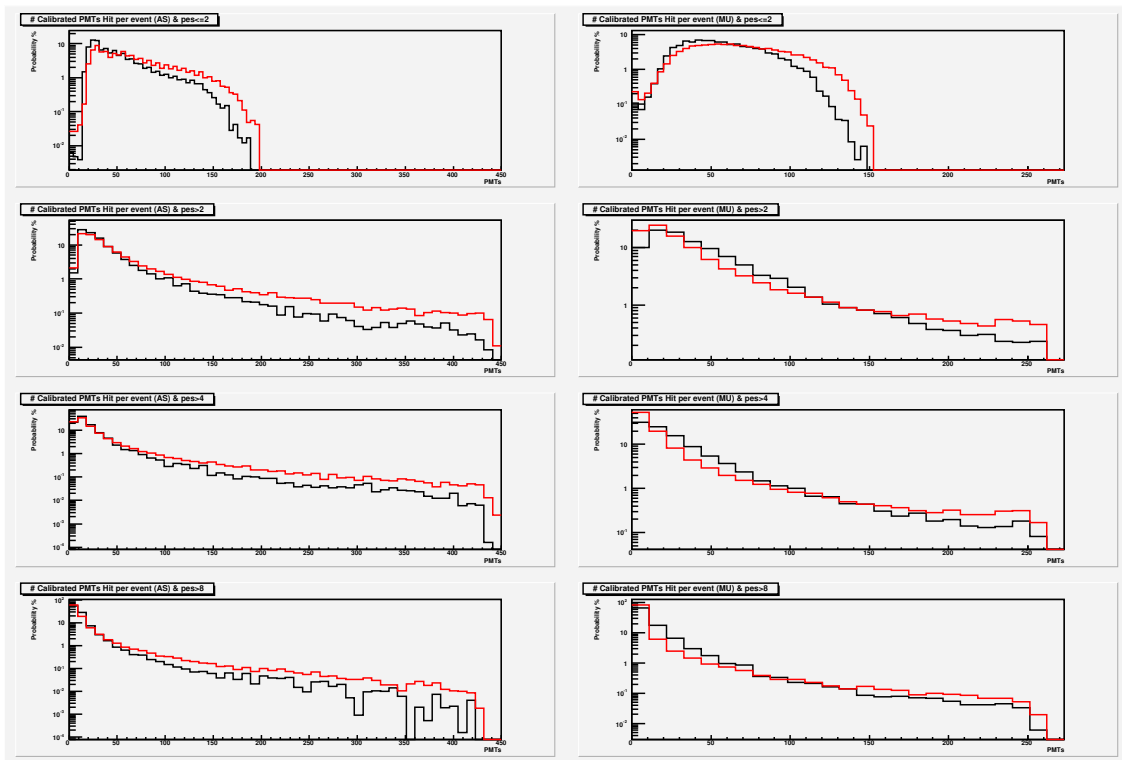


Figure 39: Number of calibrated PMTs hit for each PE multiplicity

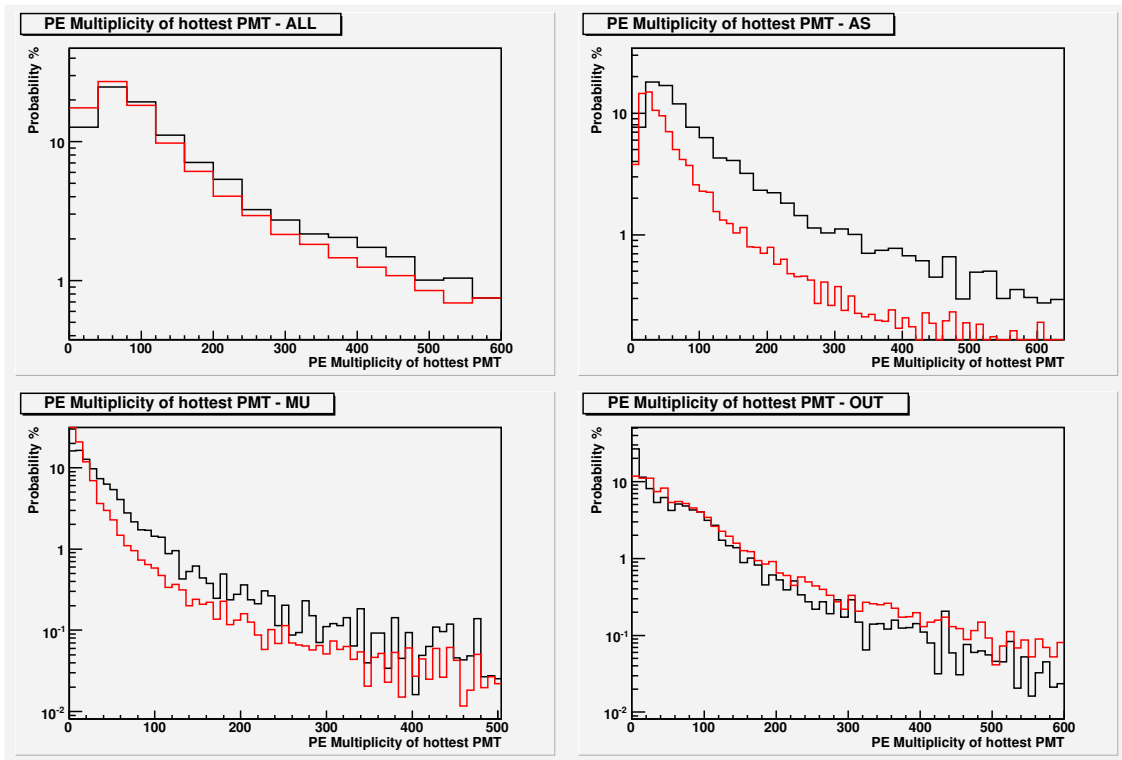


Figure 40: Multiplicity of the hottest PMT

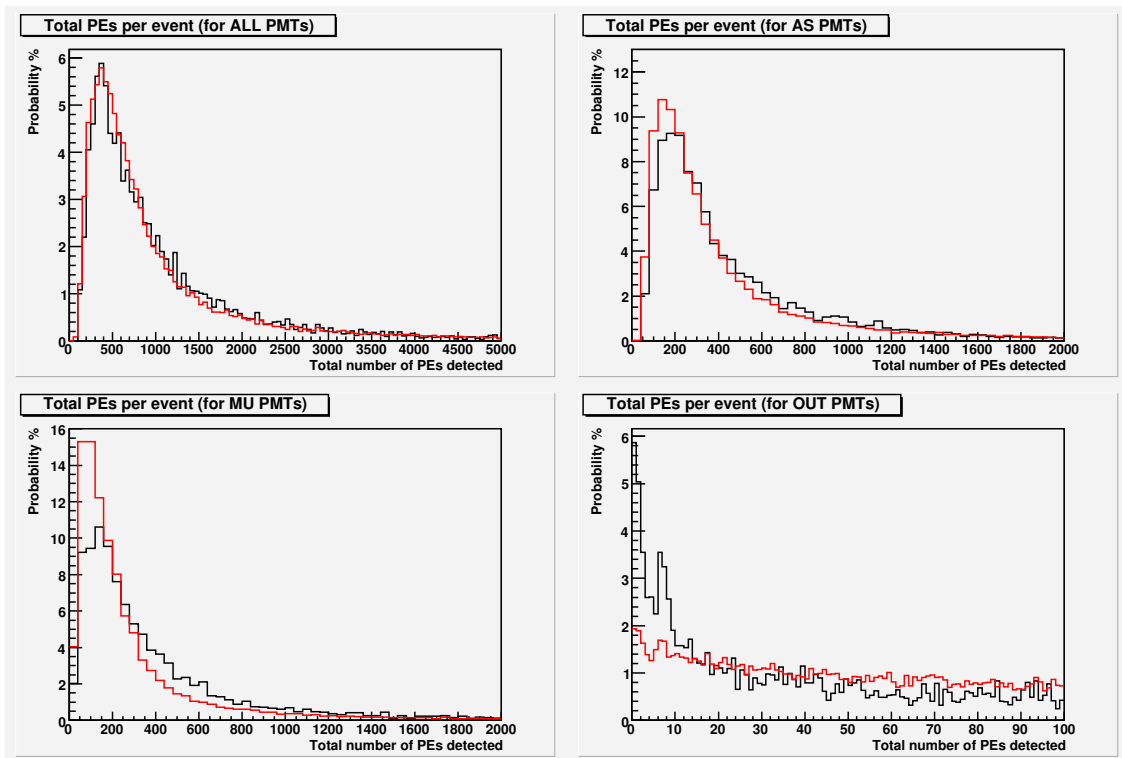


Figure 41: Total PEs per event

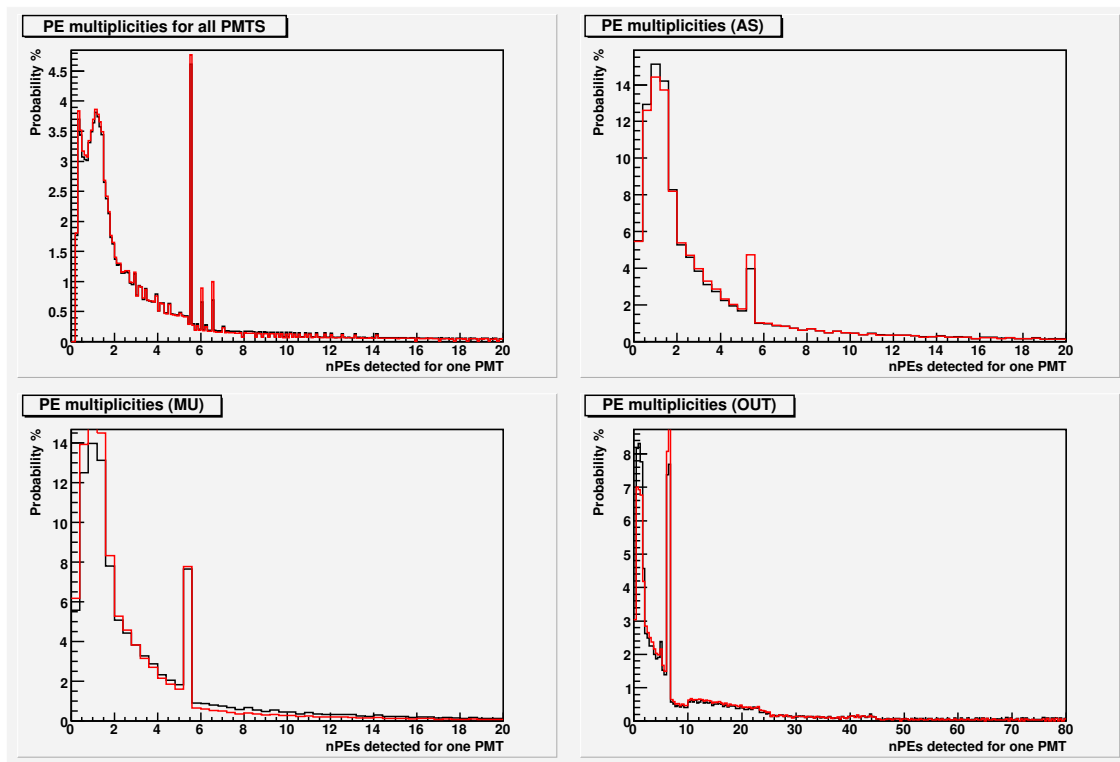


Figure 42: Number of PEs per PMT hit



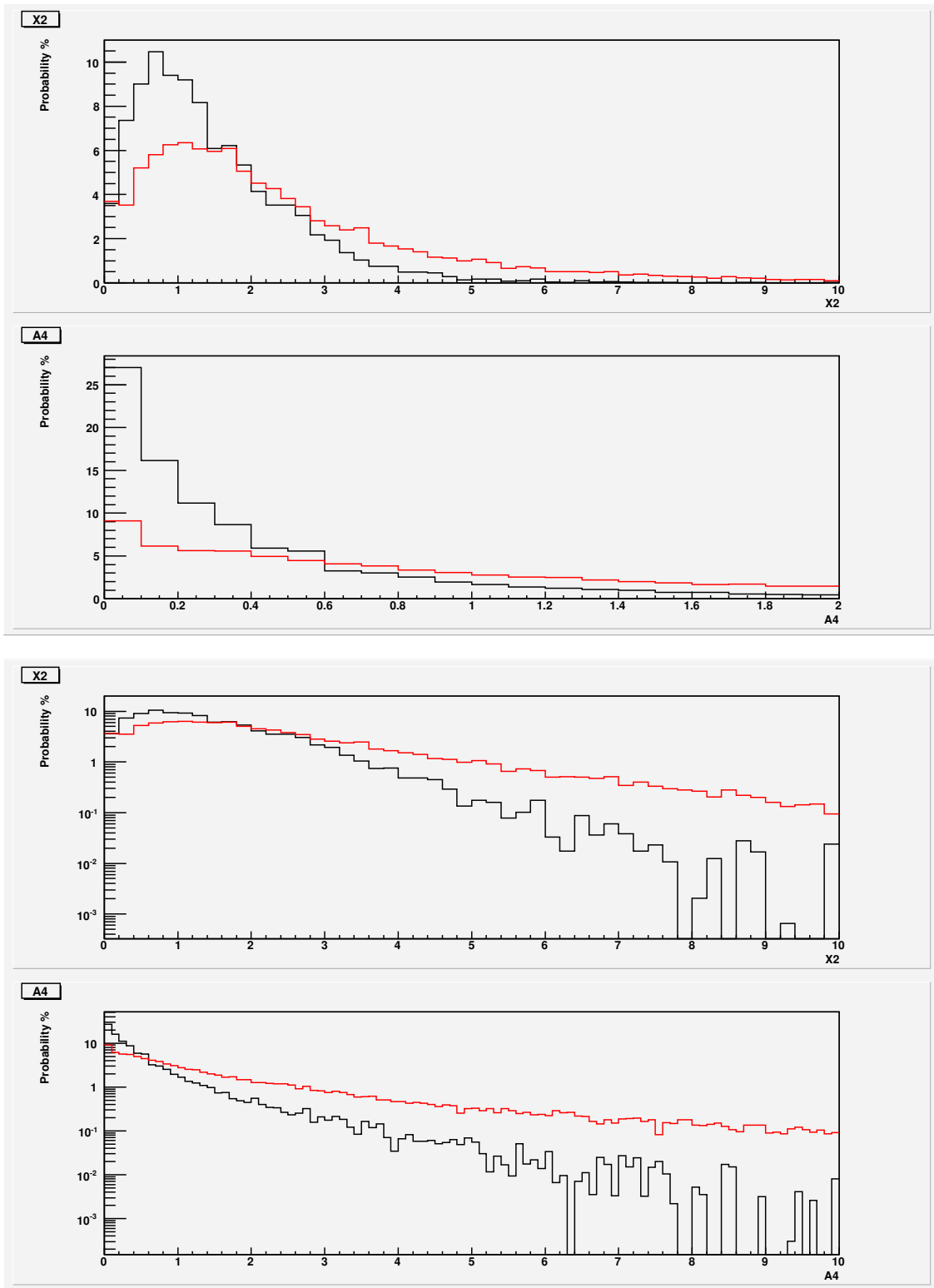


Figure 43: X2 and A4

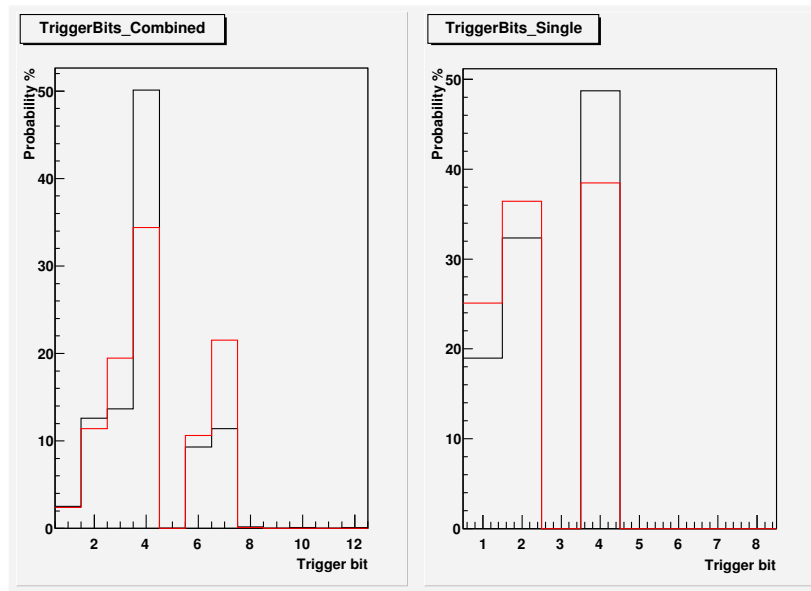


Figure 44: VMEWord per event and frequency of appearance of each different bit

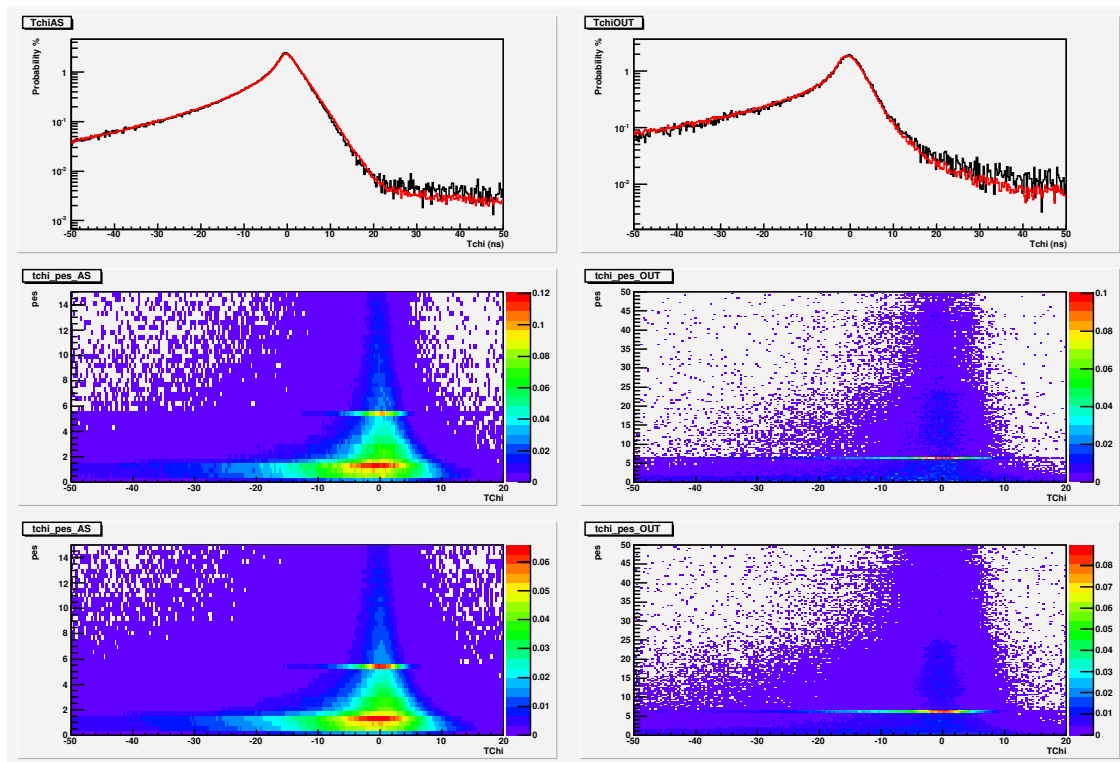


Figure 45: tchi and tchi vs PEs. Left 2D plots are for MC and right are for data.

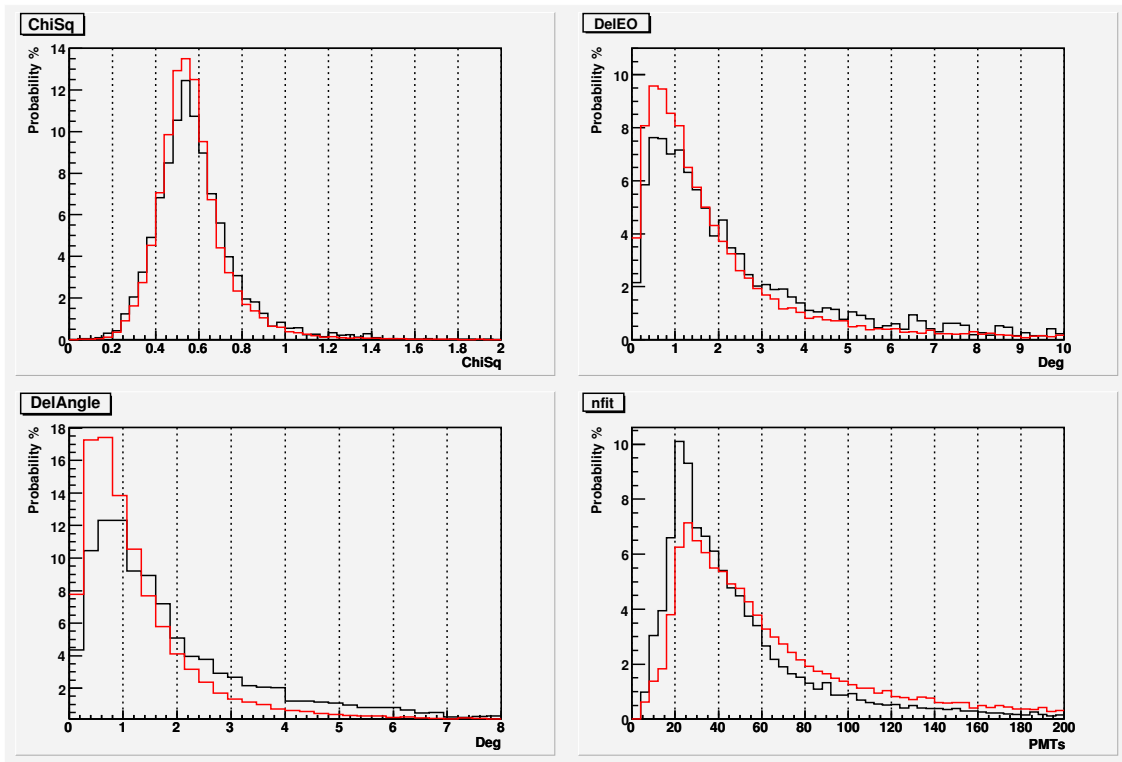


Figure 46: Chisq, delAngle, delEO and nfit

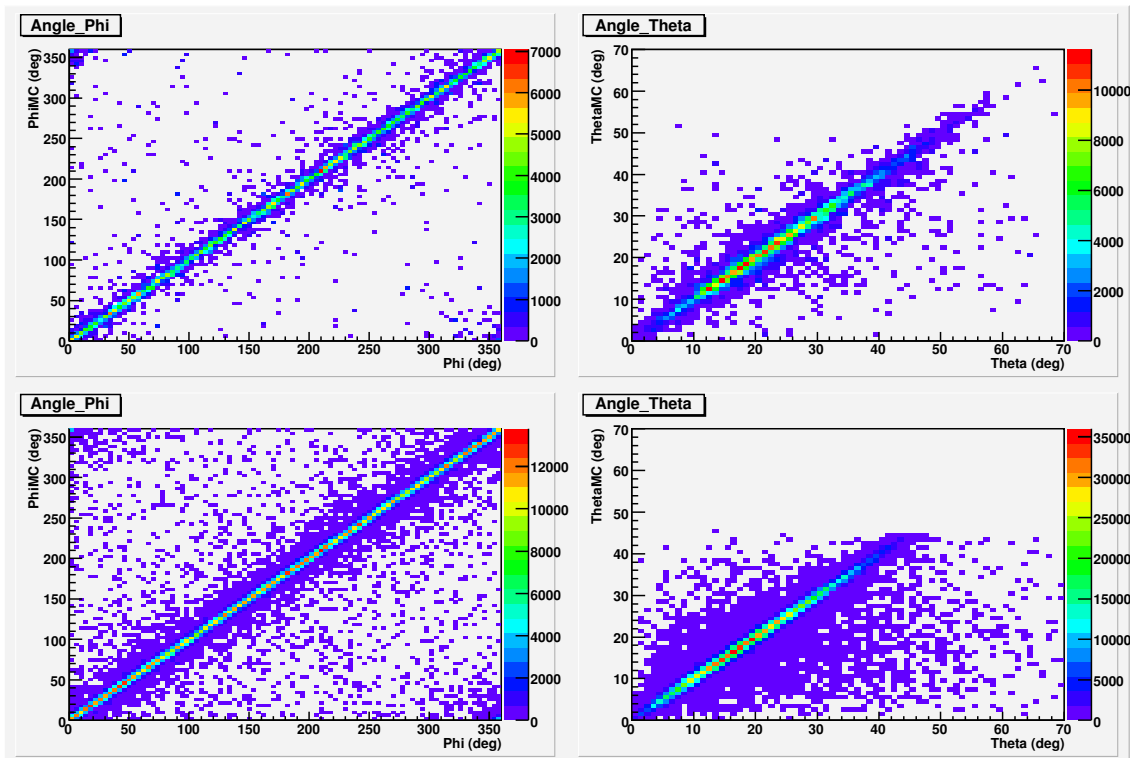


Figure 47: Angle fitter results. Top plots are for hadrons and bottom for gammas.

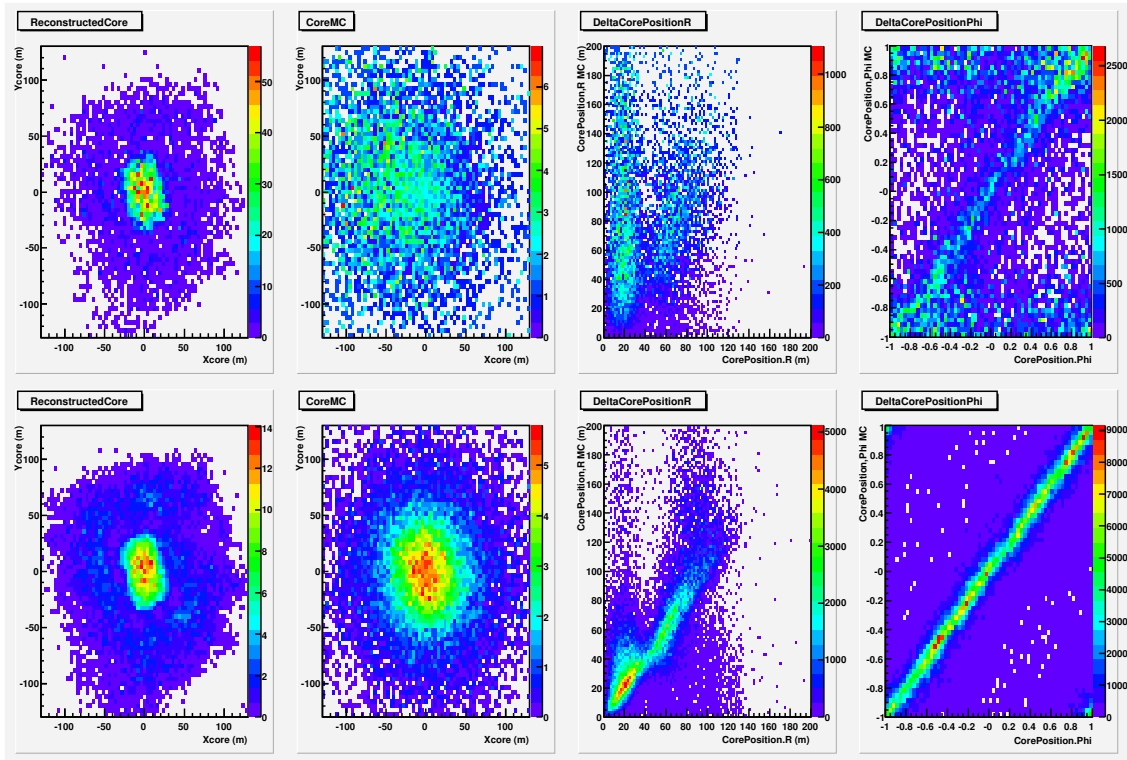


Figure 48: Core fitter results. Top plots are for hadrons and bottom for gammas.

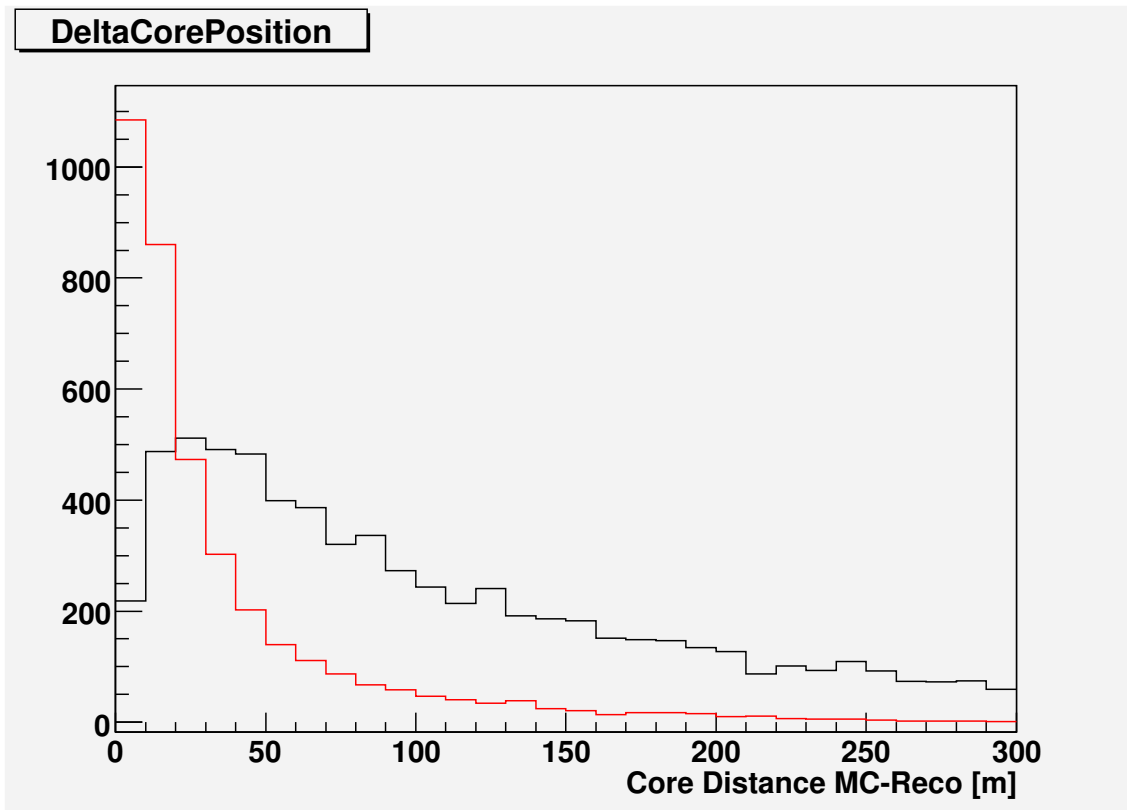


Figure 49: DeltaCore

## 4 Discussion

From the above, one can say that the MC agrees reasonably well with data analysed with the latest calibration v603. There are some differences when analysing data with different calibration versions. The main difference is at the number of PEs for high PE multiplicities. The mxPE and totalPE distributions are considerably different. The differences in the mxPE affect the X2 distribution and as a result the quality factors of an X2 cut. In the following plots the main differences caused by using the different calibration versions are shown. Both curves correspond to data run 6662, with the v501 calibration being in black and the v603 calibration in red.

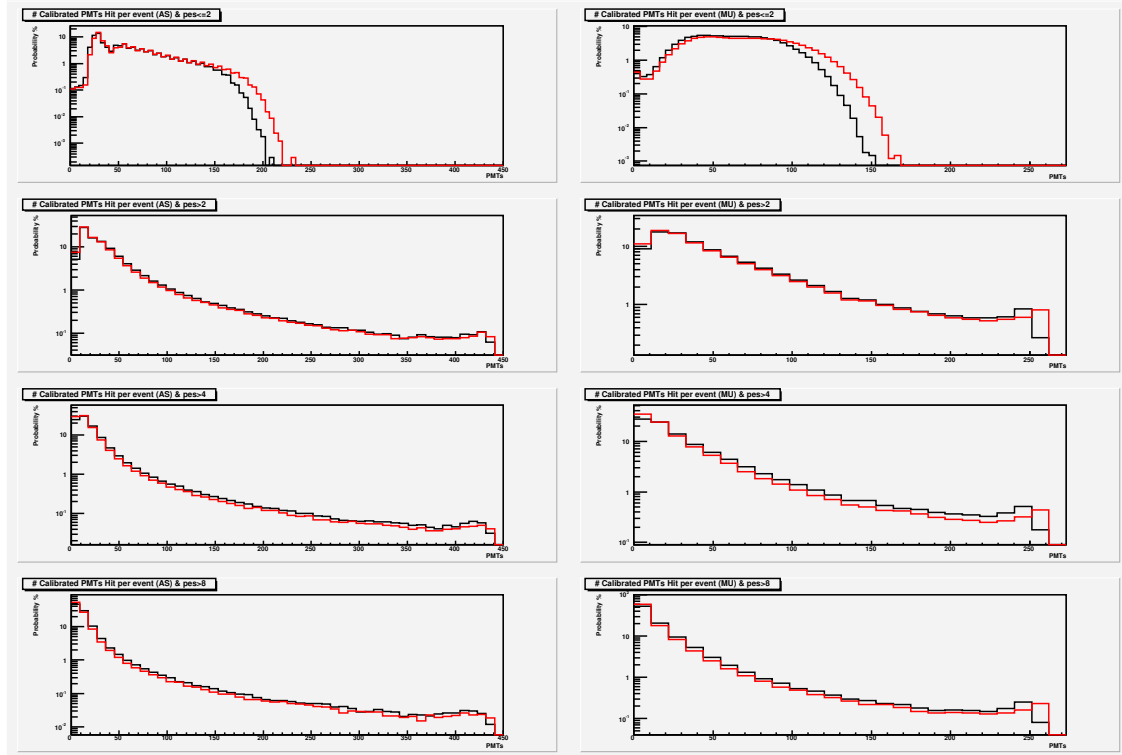


Figure 50: Number of calibrated PMTs hit vs PE multiplicity

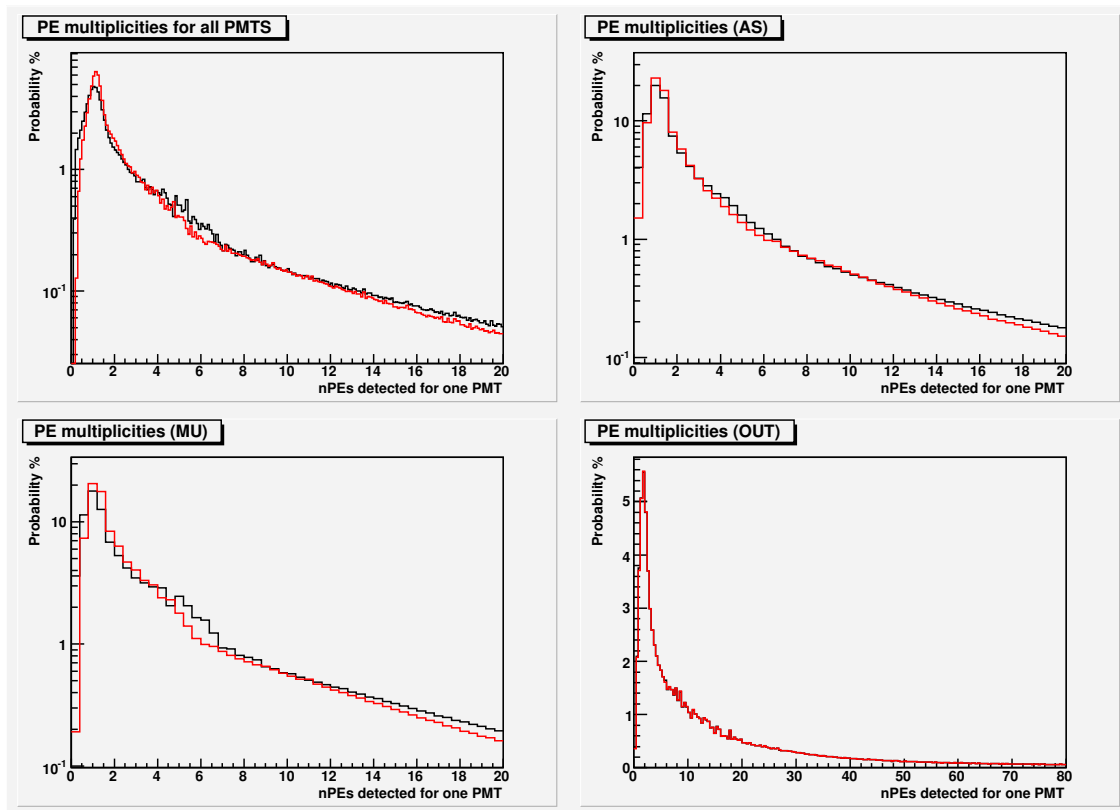


Figure 51: Number of PEs per PMT hit

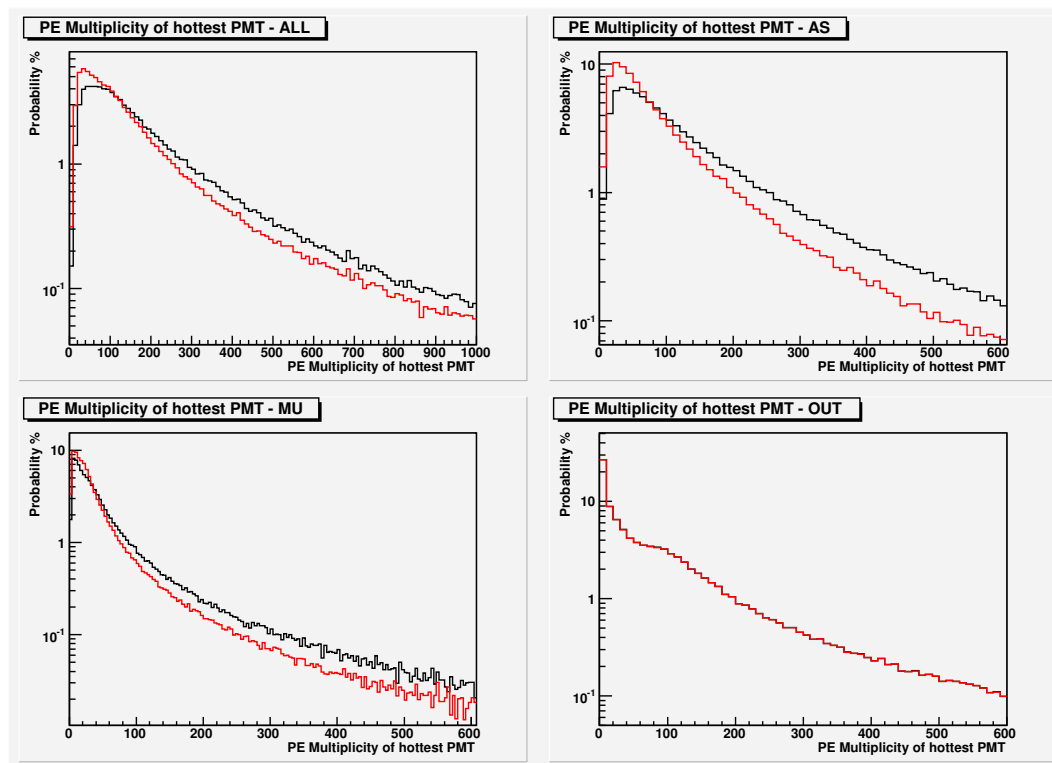


Figure 52: Number of PEs for the hottest PMT (mxPE)

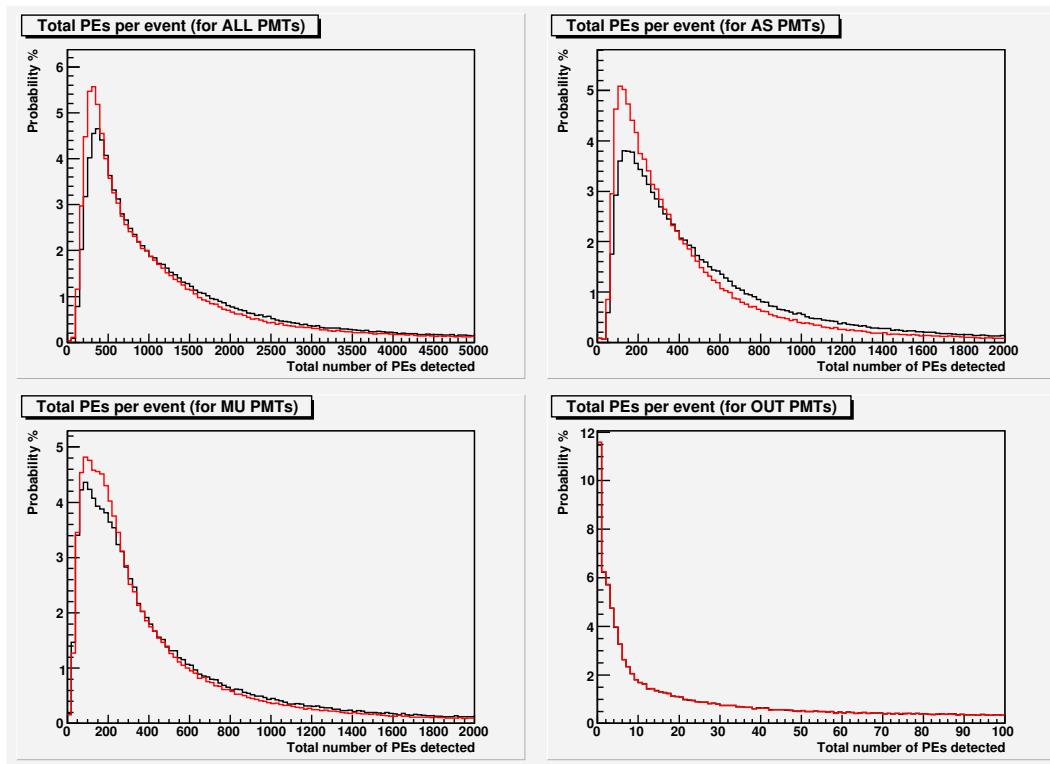


Figure 53: Total number of PEs for each PMT per event

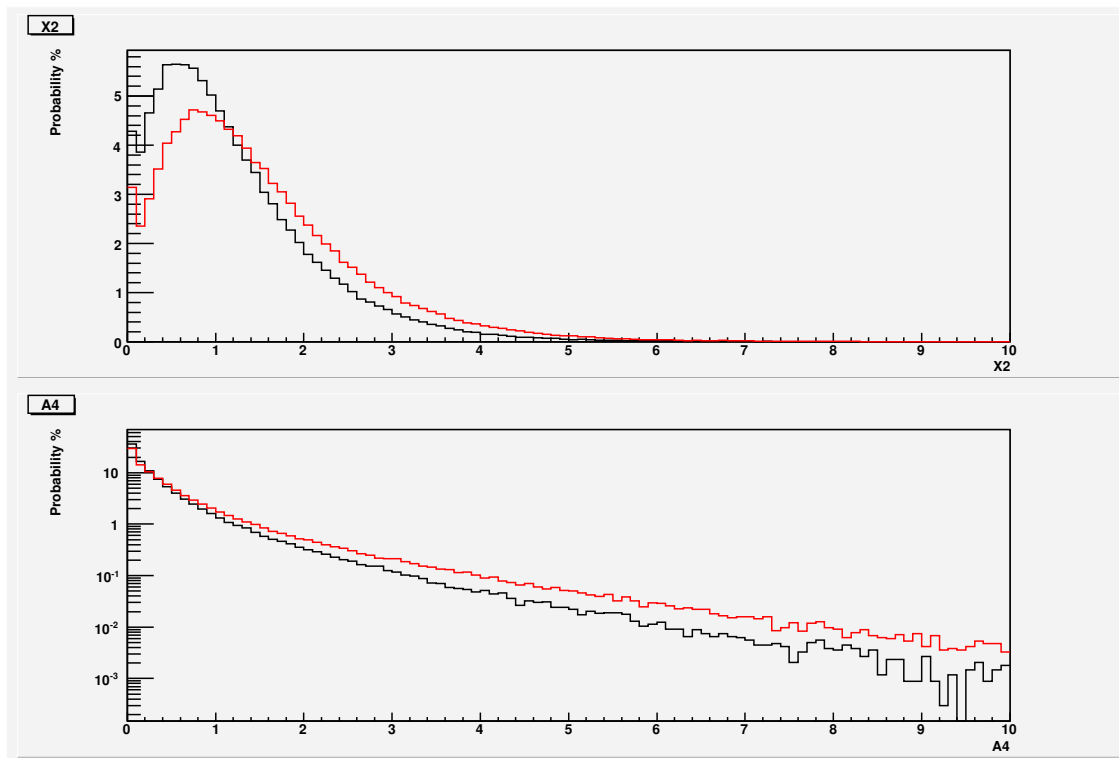


Figure 54: X2 and A4

The arguments supporting the latest calibration is that it is expected to be more accurate in

the region of high PE multiplicity hits (since we are using the new more intense laser) and that it agrees with the MC. The argument against it is that the quality factors with v603 are lower than when using the v501 (because X2 is greater with v603); the results quoted at the crab paper, show that the quality factor of the X2 cut is considerably higher than the one from v603.

There are still some other parts that don't agree as much, such as the number of PMTs hit in the MU layer or the late tail of the tchi distributions. Probably, the factors causing these differences are the reflections from the water and from the pond surfaces. The Mie scattering angular distribution used had an average cosine of 0.99, which corresponds to very forward scattering. Less forward scattering or a shorter scattering length would increase the hits at the muon layer and the late hits in the AS layer. The white pipes at the bottom of pond or the reflections from them are not simulated in the MC. Also, there was no air under the cover in the MC configuration used. In the real experiment, there is almost always some air trapped under the cover. The reflectivity of the water-air interface is higher than the one from the air-polypropylene interface, since in the first total internal reflection can occur. There was a cutoff in the MC mxpe curves at about 600pes. This was probably caused by a cutoff applied in milinda's calibration code inserted there because the the old calibrations (with the old laser) didn't have data up to these pe multiplicities.

## 5 APPENDIX

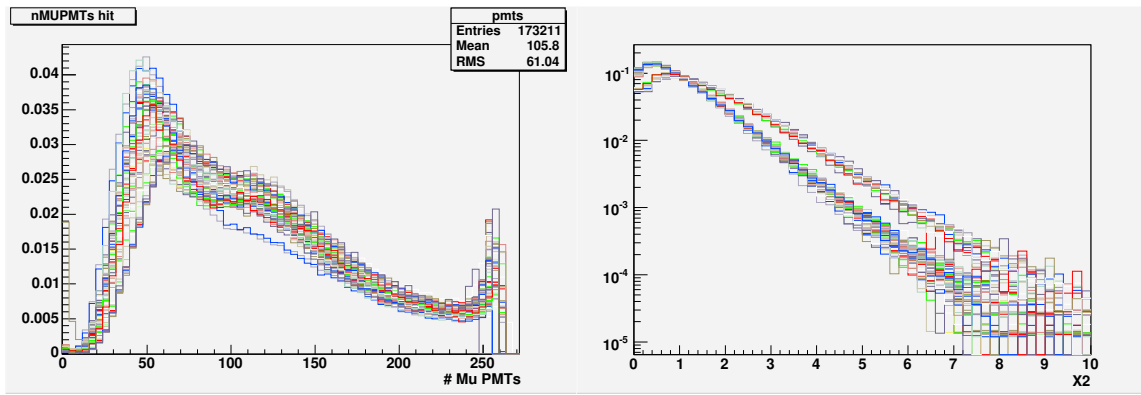
### 5.1 Variability of the Milagro data

There are many time-varying experimental conditions that affect the data properties. Some of these are the:

- Calibrations
- Water properties: scattering and absorption lengths, type of scattering (scattering angle distribution)
- Reflectivity from the cover due to formation of ice or accumulation of air
- Baffle deterioration (melting of the old aluminum baffles)
- Changes in the the electronics: DC offsets in the analog sum in the trigger card, different VME trigger configuration

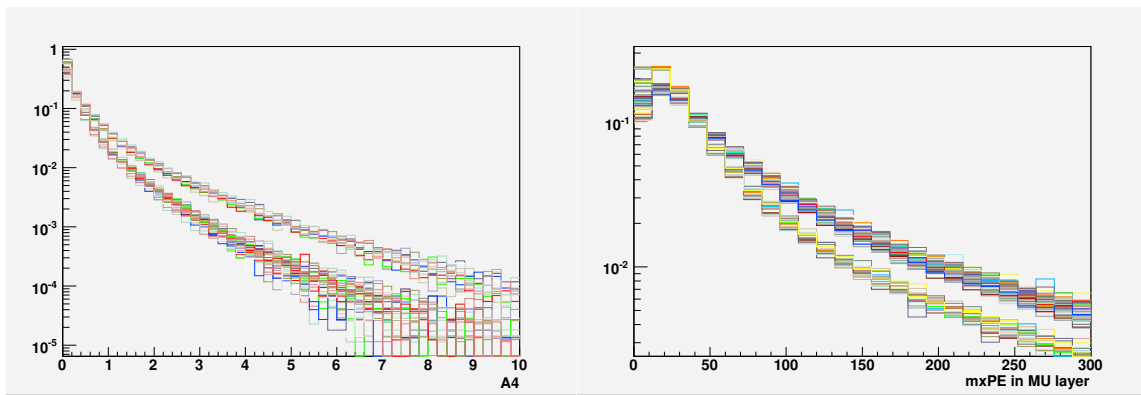
In figure 55 plots of various quantities are shown for runs 5163 through 6883 and every 20 runs. This runs correspond to data taken from 10/2003 to 4/2006. Each curve is produced from analysing data contained in the first four subruns of a run using the calibration version corresponding to each era.





(a) Number of calibrated MU PMTs hit

(b) X2



(c) A4

(d) Muon mxPE

Figure 55: Variability of data. Plots from runs 5163 to 6883 every 15 runs

## 5.2 Version history

- Version 1.0, 4/14/2006  
First version  
g4sim v2.0, milinda v1.1

## References

- [1] Robert Ellsworth, “Fitting Proton and Helium Spectra from BESS-TeV Data”
- [2] Robert Ellsworth, “Calculation of the trigger rate from MC data”