Plane by plane muon alignment study of SM1

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These are the results of a study done on using Nicolai Tobien's alignment package: *Alignment* to do a muon alignment of SM1. First, a quick overview of *Alignment.* Second, results of a muon alignment based on 72 hours of live time are presented. Finally, an estimate is given for the number of muons needed to do a module by module alignment of SM1.

Overview of *Alignment*:
Alignment was written by Nicolai Tobien to make a plane by plane alignment of the MINOS far detector (FD). *Alignment* uses muon tracks and fits them to straight lines to calculate misalignments in the FD. *Alignment* does separate alignments for the U and V views and was designed to be used on both real data and MC, however, this study involves only real far detector data.

There are two separate parts to *Alignment*, track reconstruction and actual alignment using the reconstructed tracks. For track reconstruction, a special private version of *Bubblespeak* is used. PlotMuonCluseterModule is modified in such a way that it outputs a text file that contains track information (plane number, z position, transverse position, event number, hit count, adc count and plane view) for a total of 7 numbers. An important cut is applied at this stage of analysis, which sets the number of events that go on to next stage. In order for Bubblespeak to write out an event to the text file, the event must pass a QC cut. The cut is set by a parameter fMaxChiSq (which is a non-normalized χ^2/dof), which in the base release is set to 3. However, the rate of events passing this cut was a much lower rate than what would be expected (~1/4 Hz) for the rate of muons . By changing this cut to 50 it was possible to greatly increase the data ~ 15 times more data. A systematic study to determine the proper value of fMaxChiSq was never carried out. However, there is some understanding (now) of the effect of choosing fMaxChiSq = 50, as it turns out a better value could have been chosen (about 800). An even better approach would be to use a more advanced technique to improve the QC cut.

After the tracks are reconstructed and written out to the text file, the process moves to the actual alignment code. The code that actually aligns the detector consists of two parts: a root script and several special classes. The algorithm that is used to obtain the alignment is simple:

1) Fit tracks to a straight line by leaving out one hit plane and calculate the residual for that point.
2) Repeat this for all planes in the track.
3) Calculate residuals and sum over all tracks and sum over all planes
4) Iterate through process: Move each plane by mean residual
5) Iterate through until condition is met (20 iterations in this study)

The root script reads in the text file and runs the alignment algorithm. The code stops after 20 iterations, although the alignment does not change very much after the first iteration (see Results and plot 1 & plot 2 in back). The code outputs several plots and the “aligned” detector position.

Alignment is not compliant with the MINOS software framework. Besides using a private version of *Bubblespeak*, *Alignment* uses it own private version of the geometry, which is hardwired into the special classes which themselves are not part of the framework. This effectively means two things, *Alignment* cannot be brought into the framework without significant work and any comparison made by *Alignment* to a framework compliant study is valuable cross check. Independent of how valuable this cross check might be, the non-compliance of *Alignment* makes maintaining *Alignment* a challenge too great to attempt. B. Viren has begun work on a new compliant version of the alignment software.

Results of the plane by plane muon alignment with *Alignment*:
Alignment has not been used for an actual alignment. Rather, it has been used for a study on what is needed for an alignment. The data used for this study was a total of 72 hours long. It includes plane trigger runs over the range of Run 5963 to Run 6109 (Not necessarily every run in that range). Some of these runs were 3 hours in length, while other were 6 hours in length. All of these runs were made with 248 planes in SM1 prior to turning on the magnetic field. The cuts that were applied:

Track finding stage:
FMaxChiSq ≤ 50

Alignment Stage:
Minimum Track length per view = 7 planes
Maximum Track Length per view = 124 (entire detector)
Maximum Track Number = 100,000

The single most important result of *Alignment* is the study of the distribution of all track residuals. The plots of U and V residual distributions (see plot 1 and plot 2 in back) show how well the detector can be aligned. Each of these plots show six histograms. The six histograms show how the distributions change by iteration, starting at the first iteration and ending at iteration 20. Each plots has ‘count of tracks’ on the y-axis versus residual (cm) on the x-axis. For iteration 1 and iteration 20, a gaussian has been fitted to the distribution. The RMS value shown for each plot is based off data truncated at +/- 10 cm. The width of the residual distribution is what sets the alignment precision (see below). For the alignment survey the following results are found:

View	Iter_1_sigma	Iter_20_sigma	Iter_1_RMS	Iter_20_RMS
U	17.1 mm	16.8 mm	16.0 mm	15.9 mm
V	17.1 mm	17.0 mm	16.1 mm	16.0 mm

These results can be compared with the ideal case. In the ideal case:

Sigma ~ (Strip width standard deviation) ~ (Strip Width)/SQRT(12) ~ 11.5 mm

These results are about 1.5 times wider than the idea case. However, U and V seem consistent with each other. This can also be compared with an analysis using different geometry and different track reconstruction software by R. Lee (Spatial Alignment In the Far Detector-MINOS Collaboration Meeting, July 2002) in which the residual distribution was found to 15.8 mm for all tracks and 15.1 mm after cuts were applied.

Although *Alignment* will not be used *for the final* alignment it did provide *an* alignment. The alignment produced by *Alignment* (see plot 3 in back) can be studied. There are several features which stand out in these plots, the ends of the detector and plane 52.

The ends of the detectors look different than the rest of the detector. As it turns out this is an important realization. By examining a histogram of number of tracks per plane as a function of plane (see plot 4 in back), it will become obvious something is wrong. These distributions are peaked at the ends of the detector and this is not what is expected. The explanation for this comes from looking at the non-normalized χ^2 distribution (see plot 5 in back). This plots the χ^2 versus the number of plane in an event (the fact that the number of planes on occasion is >> 248 is because sometimes multiple lines are fit to an event). This plot was based off a 3 hour run, not the entire data set. The cut was set at non-normalized $\chi^2 = 50$ for this study.

When $\chi^2 < \sim 800$ there appears to be a definite correlation between QC and event length. This it would appear has biased the sample towards shorter events and biased the ends of the detector. This means that χ^2 is not track length independent. Since χ^2 is not normalized this results is not too surprising. The track quality of these short tracks in the end of detector should also be relatively poorer than the tracks in the middle of the detector. The implication is that this analysis missed many good events. This should bode well for the final analysis.

Whether, this explains the fact that the aligned positions at the ends of the detector (~25 planes) have very little spread (plane to neighboring plane difference) is unknown. It could be that the small spread is caused by the increased statistics or it could be caused by the excess of short (poorer quality) tracks in the end of the detector causing a systematic error. Also, Plane 247 does not have an aligned position in this analysis. This is unusual, as planes 246 and 248 both have aligned positions. The cause of this is not completely known, although it appears to be an IO problem with the script.

Plane 52 appears to be ~ 15 mm out of alignment with its nearest neighbors. This is observed in both this analysis and in R. Lee's study (Spatial Alignment In the Far Detector-MINOS Collaboration Meeting, July 2002). Although, the sign is different (consequence of different geometry definitions) the magnitude of the difference easily stands out to the unaided eye. The two studies agree with each other to about 1.5 mm on magnitude of the difference (15 vs. 13.5 mm), which is consistent with the statistics.

Implication of the plane by plane muon alignment for the module by module alignment:

An estimate of the number of muons needed to align SM1 module by module can be calculated from the results on the plane by plane alignment. Since the detector consists of eight modules per plane, a first estimate is that each module has about ~ 1/8 of the tracks in the entire plane. Using this approximation, there are two results from the plane by plane alignment which are significant: minimum number of tracks that hit any plane and the sigma (or RMS) of the track distribution. The accuracy to which any module location is know is then given by:

Alignment precision ~ ((sigma_tracks)/SQRT(track_number))

Where sigma_tracks is the sigma obtained by a fit to a gaussian of the center of the track residual distribution and track_number is 1/8 the number of tracks which passed through the plane.

For purposes of this calculation it will be assumed that 2mm alignment per module is the goal of the module by module alignment. Since the alignment is done separately for U views and V views the requirement for both is slightly different. The view which will need the most muons, will set the requirement for the entire detector. From the previous section sigma_tracks = 17.0 mm will be chosen. Given the 2mm requirement this suggests that each module needs ~ $(17/2)^2$ or about 75 tracks. Plane 143 is the plane with the fewest tracks in the data set. Plane 143 had only 142 tracks that pass all the cuts. Thus the number of tracks that went each module per day was about 6 in this analysis. This suggests that about 12.5 days of data is needed to align the detector module by module to a 2mm precision.

Conclusion:

The conclusion that it will take 12.5 days to do a module by module alignment of SM1 in the far detector, should be thought of as an upper limit. At a minimum two parts of the analysis can be improved. By properly using a proper track fitting QC cut, the number of events should increase and the time needed to complete the alignment reduced accordingly. Also, by using a different track fitter and the "framework" geometry, the residual distribution can be improved.

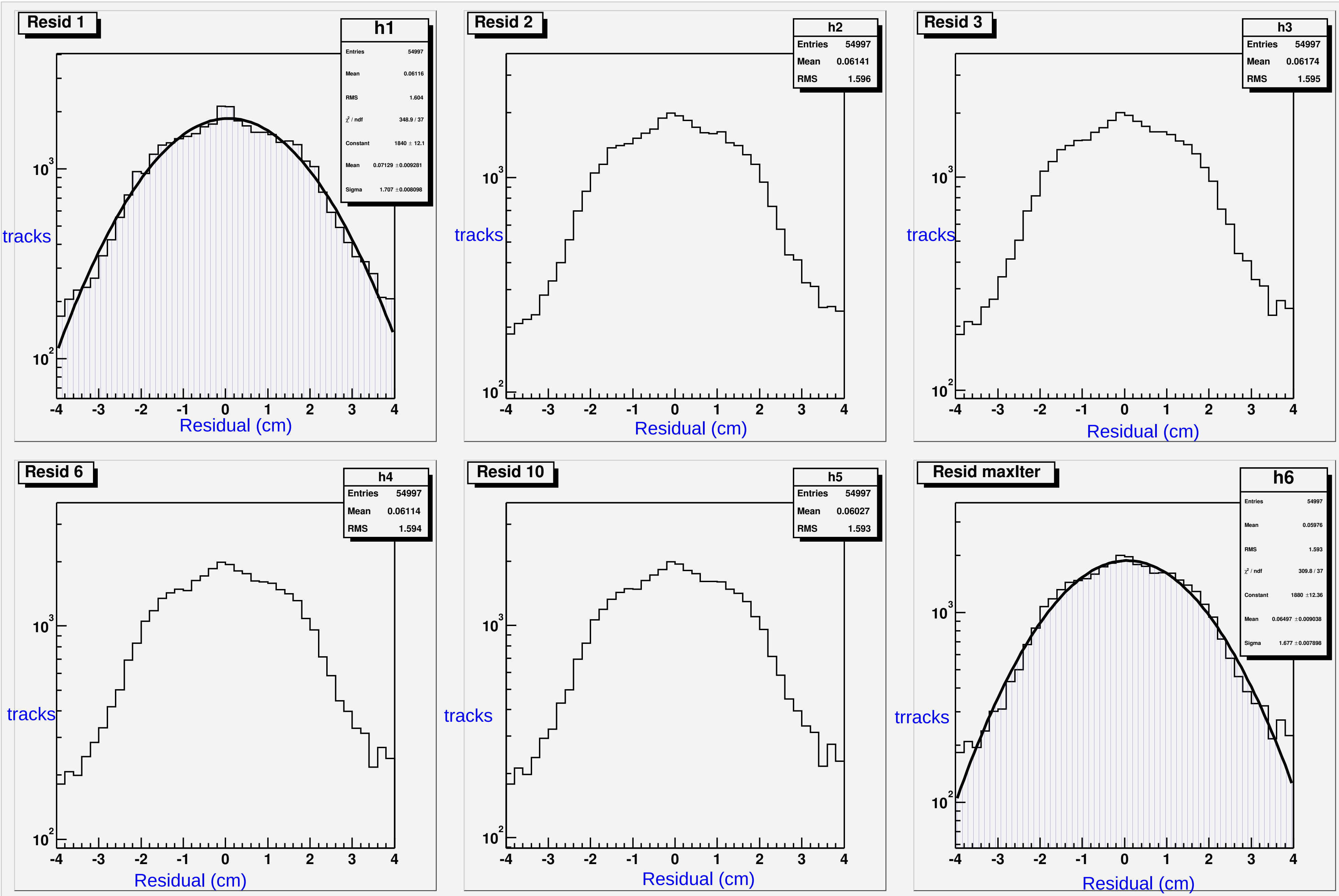
A time estimate for module by module alignment with improved statistics can be made with an improved estimate of the true number of muons in the study. It is clear from the data, the rate of muons in this study is low. A better estimate, even if it is a rough estimate is valuable. One way to estimate this improvement is to simply compare the number of events that pass fMaxChiSq = 50 with the number of that pass fMaxChiSq = 800. This was done for the χ^2 sample that plot 5 is based on. If a 14 plane requirement is applied (compared with a 7 plane per view requirement for the actual analysis), the results imply that only ~ 10% of valid data was used. This means the alignment should take:

~ 12.5 days/SQRT(10) ~ 4 days

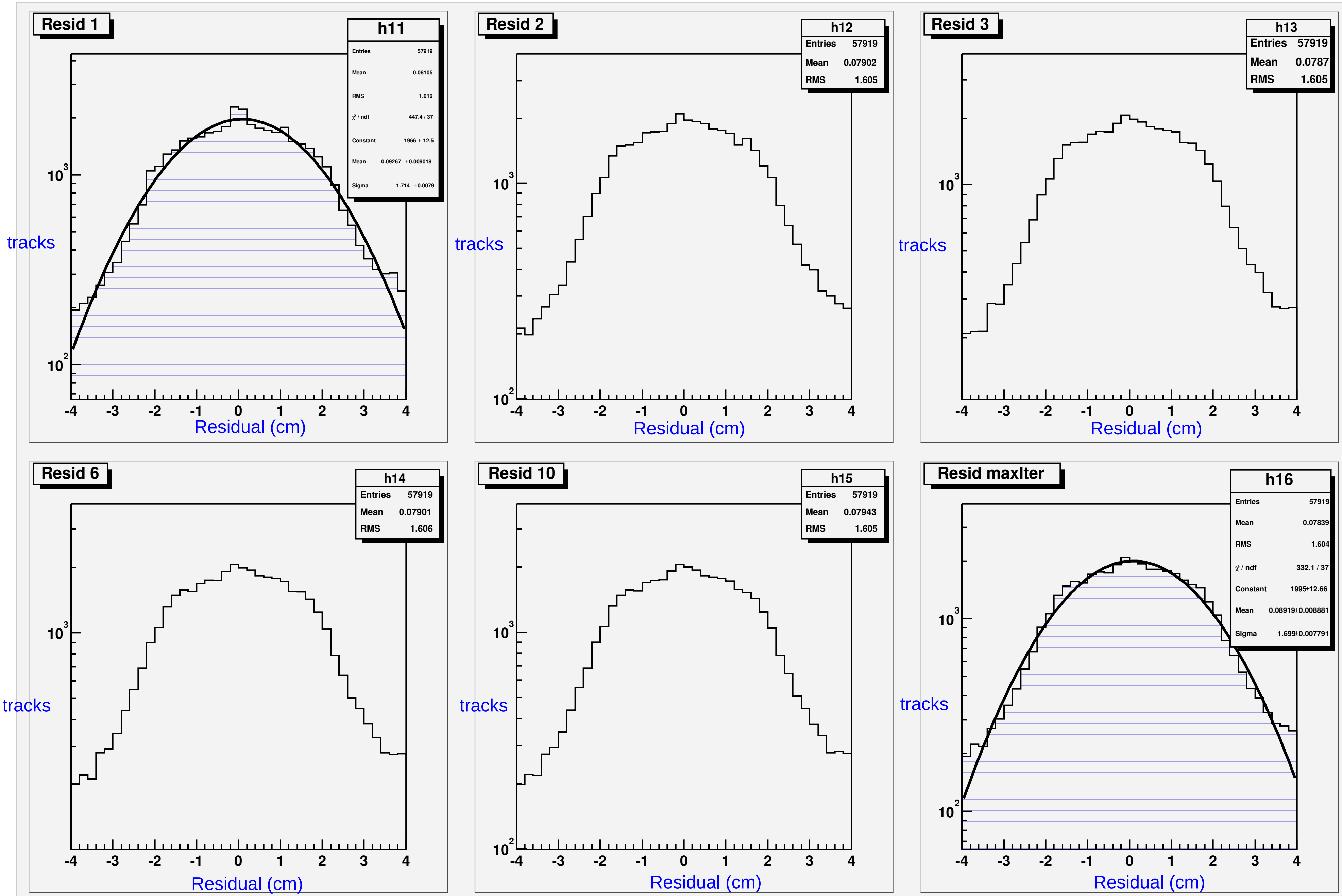
However, this is based on the assumptions that the data quality is similar to the data that was used for the study alignment presented above. This may or may not be true, so some caution should be used with this estimate.

I would like to offer thanks to many MINOS collaborators for there discussions and work with me on this study but in particular I would like to thank N.Tobien, D.Boehnlein, R.Lee, B.Viren, J. Urheim and J. Nelson.

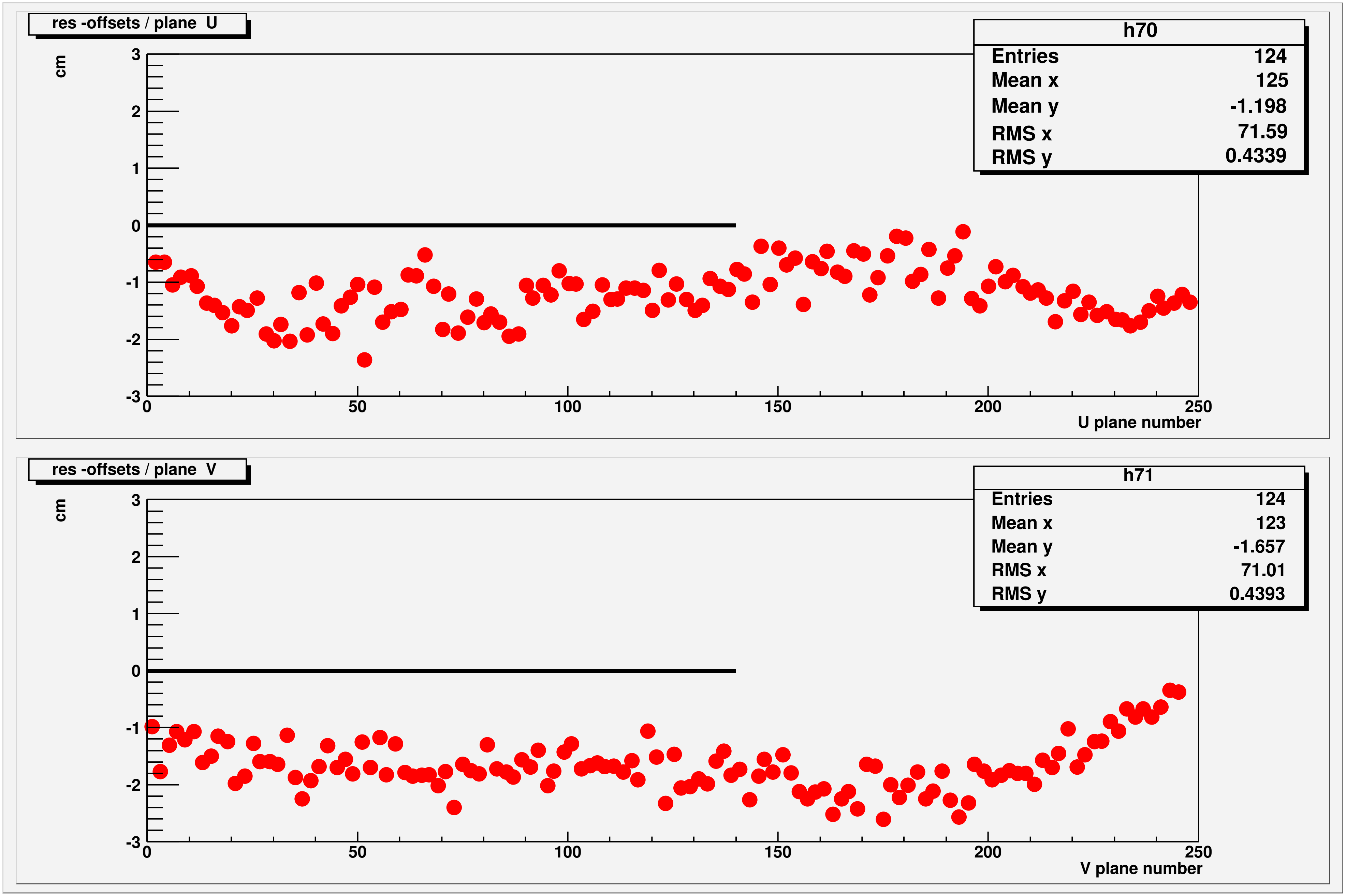
PLOT 1- Residual Distribution U



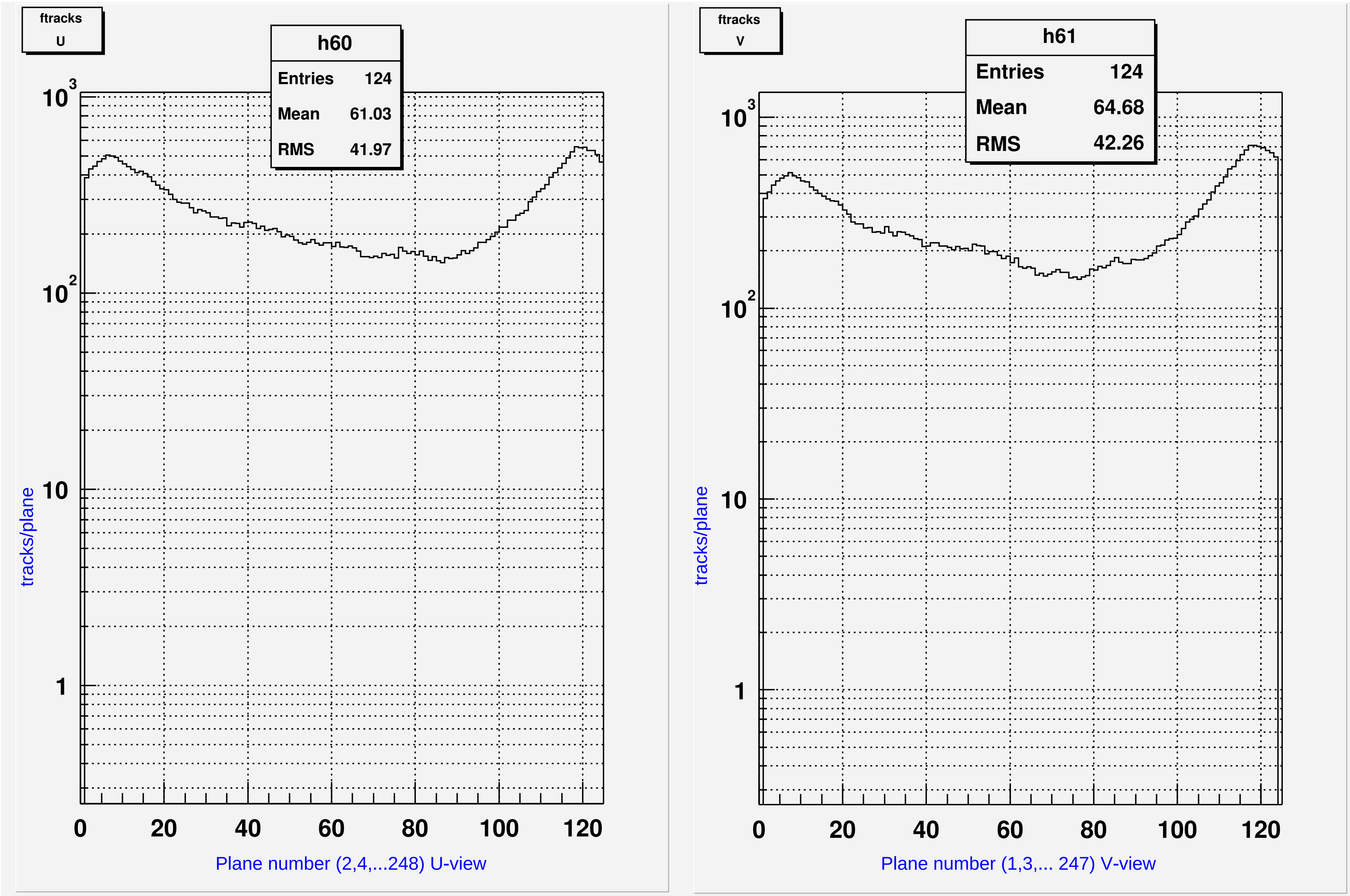
Plot 2-Residual Distribution V

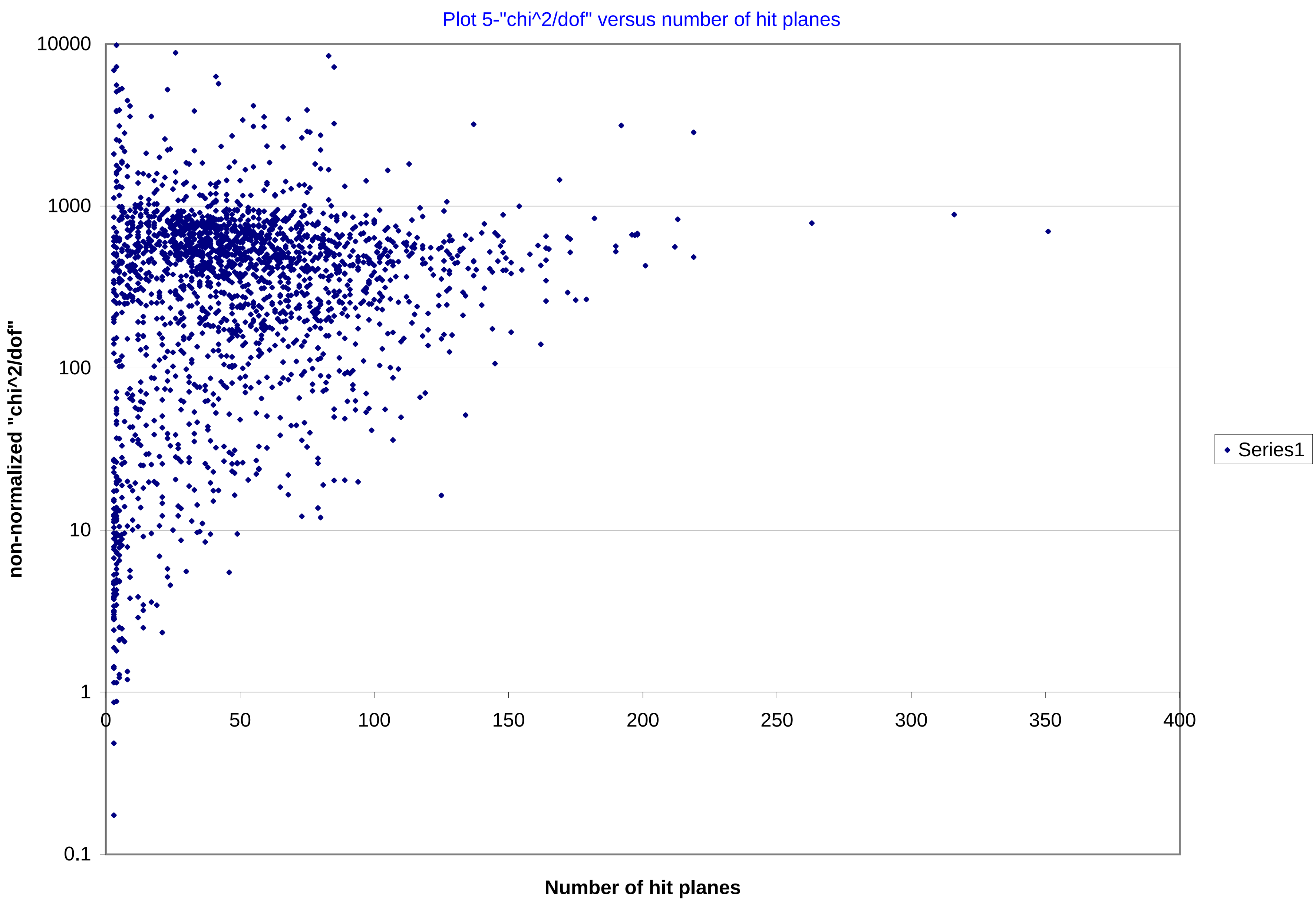


Plot 3 - Alignment offsets



Plot 4-Track Distribution





Plot 5-"chi^2/dof" versus number of hit planes
10000
1000
100
10
1
0.1
non-normalized "chi^2/dof"
0
50
100
150
200
250
300
350
400
Number of hit planes
Series1