Beam Quality Study

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Abstract

Beam parameters at the face of crystal part of HyCal detector were studied. The goal of this study was to determine the beam position and entrance angles at the calorimeter as well as its spatial and angular divergence. This note is divided into two parts. The first describes the method used in the analysis of beam stability as well as its results and the other presents the results of the beam divergence study. This study however needs further work. The beam position from 2C21A BPM needs to be incorporated in the position fits.

1 Beam Stability

1.1 Method Description

The approach adopted in this study relied on double arm Compton scattering data and Hall B BPM readout to determine the position of the γ-Profiler with respect to HyCal. This procedure is detailed below.

- Initially, double-arm Compton scattering data (runs 4868, 4871, 4873, 4875, 4877 on Beryllium and runs 4943, 4944, 4945, 4946, 4965, 4966, 4967, 4970, 4971, 4973 on Carbon) were used to find the intersection points for the lines connecting both clusters. These values were used to bring the calorimeter to (0,0) position in transverse directions, x and y.

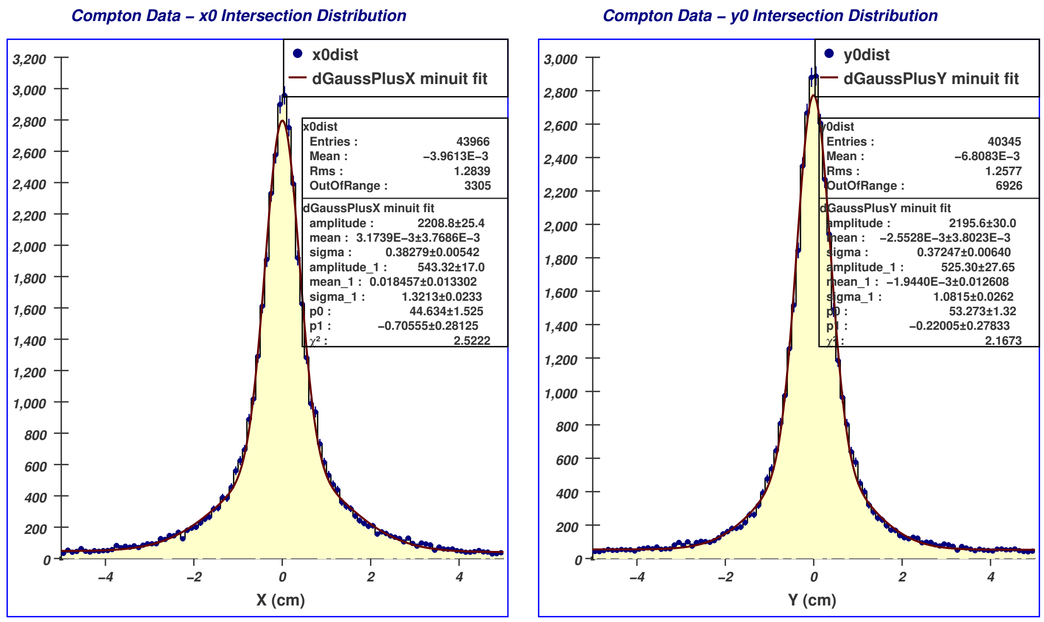


Figure 1: Distributions of intersection points for lines connecting coordinates of two clusters.

A typical intersection point distributions are shown in Figure 1 for run 4965 taken on a Carbon target.

- This information was then combined with Hall B 2C24A BPM readouts that were fed into the data stream as a part of EPICS events during the experiment. For each run distributions of BPM x and y values were fitted to a Gaussian to determine the mean value. Typical fits, for run 4944, are shown in Figure 2.

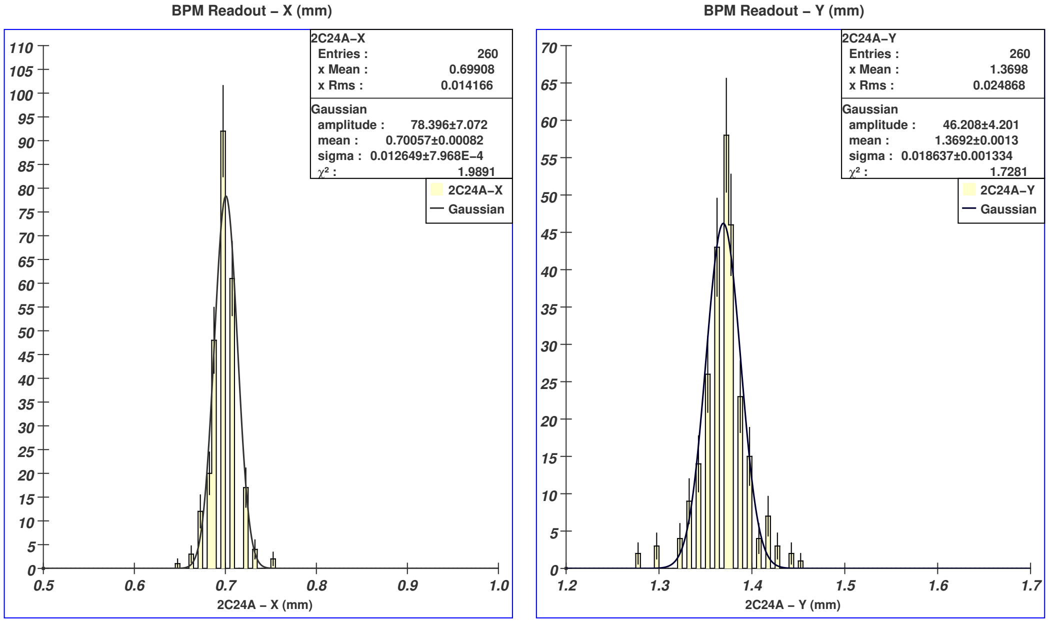


Figure 2: Gaussian fits to 2C24A BPM readouts.

- Assuming that there are no magnetic field induced deflections of the electron beam past 2C24A BPM, parametric equations for a straight line,

$$x_\gamma = x_{BPM} + (x_{HyCal} - x_{BPM}) * t \tag{1}$$
$$y_\gamma = y_{BPM} + (y_{HyCal} - y_{BPM}) * t \tag{2}$$
$$z_\gamma = z_{BPM} + (z_{HyCal} - z_{BPM}) * t \tag{3}$$

were employed to project the beam trajectory to the face of γ-Profiler x scintillators. Its intersection with the xy-plane yielded the position of the beam at that detector. Figure 3 shows all the information pertaining to that part of the analysis.

- These calculated values were then compared to the γ-Profiler scaler readouts that was also part of the EPICS information during the data taking. Before this was possible however, the response of this detector was fitted to a triple Gaussian distribution in order to get the mean position of the beam. This was done on an EPICS-event-by-EPICS-event basis. Typical fits to γ-Profiler light output are shown in Figure 4. The distributions shown pertain to the run 4943.

- The weighted average for those position differences in x and y directions were then taken as offsets that needed to be subtracted from the γ-Profiler measured x and y values. In Figure 5 the differences are plotted as a function of run number. Distributions in Figure 6 test this alignment for one of the π^0 runs, namely run 5018.

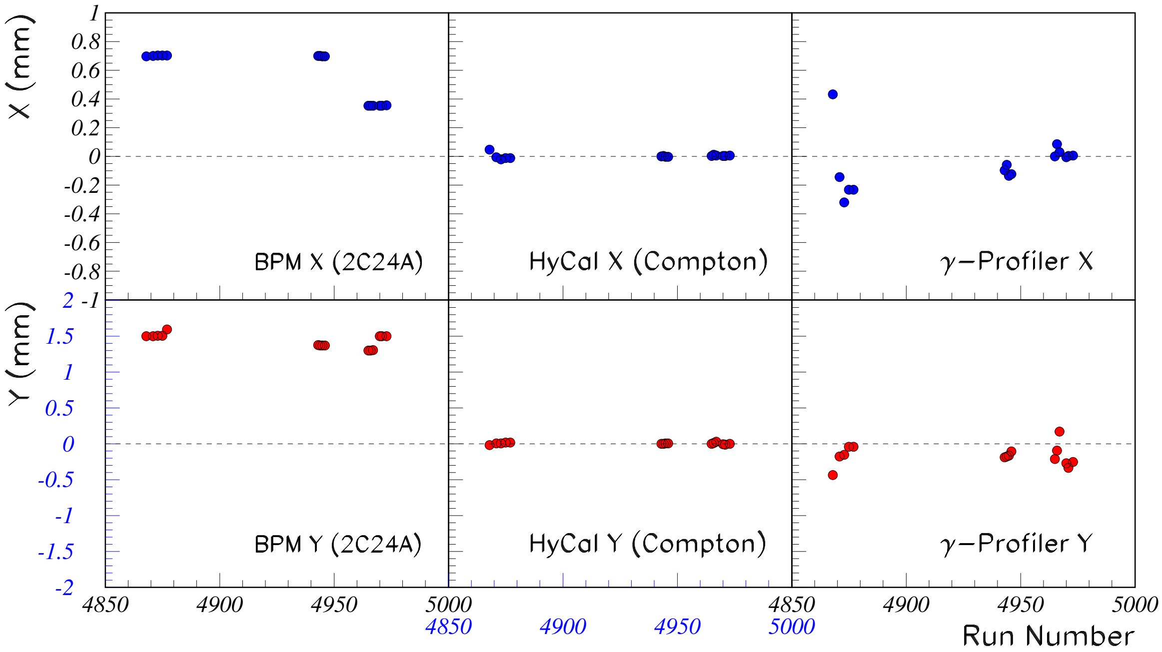


Figure 3: Information needed to determine offsets of the γ-Profiler.

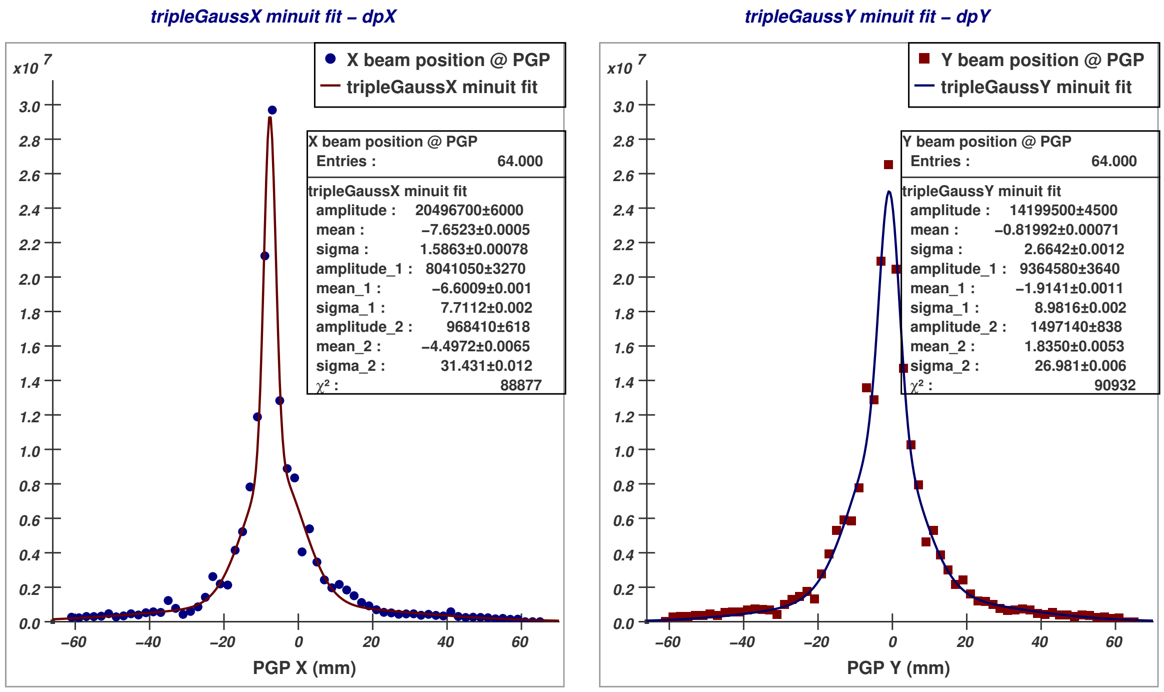


Figure 4: Triple Gaussian fit to γ-Profiler light output turned out to be very stable parametrization of that signal through the entire running period.

1.2 Results

As one of the results of the above described procedure the relative locations of had to be determined. The location of 2C24A beam position monitor and γ-Profiler were read off the

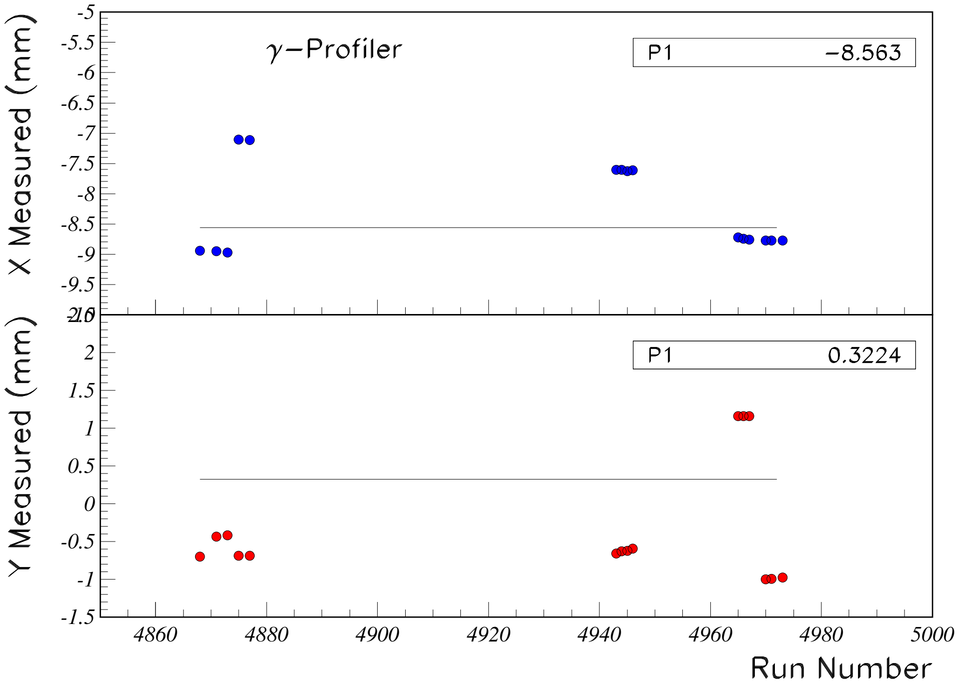


Figure 5: The results of γ-Profiler offset determination

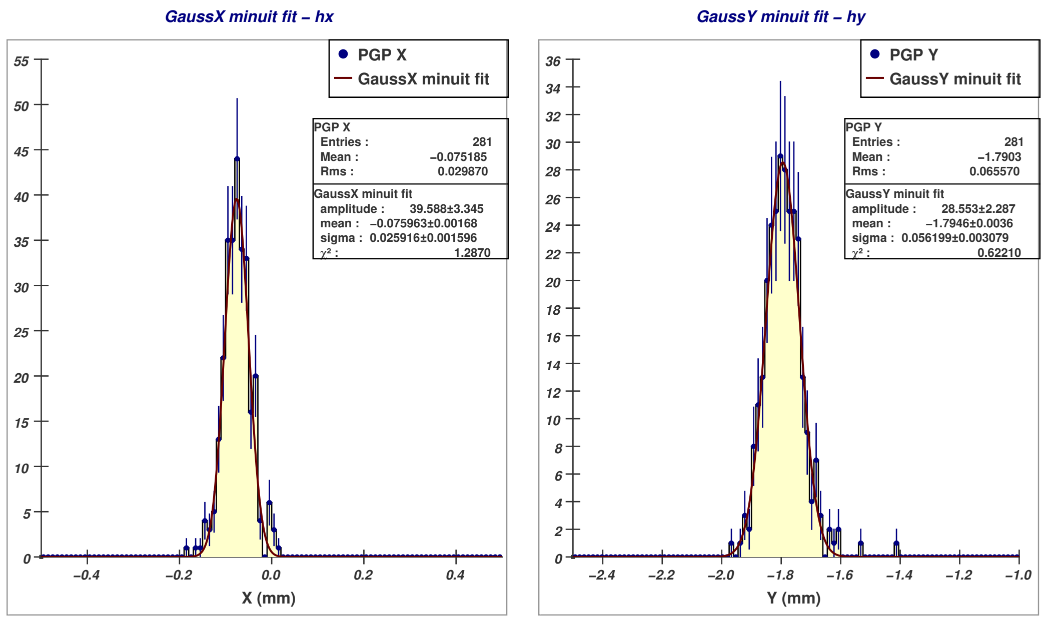


Figure 6: The result of application of the found offsets to the γ-Profiler positions.

design drawing 28405-E-0034 and related drawings. The z location of the crystal part of HyCal came from survey data. The coordinates of these beam line devices were collected in a table below,

In a similar manner as above, the beam position and entrance angles at the face of crystal part of the calorimeter were determined using BPM and γ-Profiler information. The analysis

device	x (cm)	y (cm)	z (cm)
γ-Profiler	-0.8563	0.0322	980.30
HyCAL	0.0	0.0	731.89
Target	-0.063	0.07	0.0
HARP 2H00	0.0	0.012	-65.73
BPM 2C24A	0.0	0.0	-1049.99

was done for only a handful of runs shown in a table below.

4979	4980	4981	4982	4984	4985	4987	4988	4989	4998
4999	5001	5002	5003	5004	5012	5013	5016	5018	5030
5032	5033	5034	5035	5037	5039	5041	5042	5043	5044
5047	5050	5051	5054	5055	5056	5057	5058	5059	
4977	4983	4986	5000	5005	5006	5007	5014	5015	5017
5024	5025	5036	5038	5040	5053				

Table 1: π^0 **runs used in the study**. First 4 rows are high quality data, while the quality of two bottom ones is a little worse.

Inspection of the results shows that the average x position at HyCal was quite stable, but y distribution showed two well defined peaks. Therefore, the results are presented as two separate sets, runs before run 5024 and runs after this run. The run 5024 belongs to the latter.

Figures 7 and 8 show the distributions of beam position in transverse directions at HyCal detector. While x coordinate seems to be well centered, ~ -0.01mm with the width of $\sim$ 0.025mm, for both sets, y coordinate is off-centered by ~ -1.4mm, with the width of ~ 0.1mm, for the first set and ~ -1.2mm, with the width of ~ 0.03mm, for the other. It is worth mentioning that beam position as reported by 2C24A monitor has not changed between the both sets.

Similarly, the distributions of directional cosines were divided into two sets and Figures 9 and 10 demonstrate the results. Again, in the y direction two distinct average values are observed. In the course of the analysis directional cosines of the beam trajectory relative to HyCal were determined. In Figure 9 the right panel shows the distribution of θ_z, an angle between the beam and z-direction. The other two angles are primed to distinguish their different definition. These are the angles that beam makes with its projection on the perpendicular plane. For both $\cos(\theta_x)$ and $\cos(\theta_y)$ the angles are close to 90^o therefore one can write $\cos(\theta_\alpha) = \cos(\pi/2 - \theta'_\alpha) = \sin(\theta'_\alpha)$ where $\alpha = x$ or y and $\theta_\alpha + \theta'_\alpha = \pi/2$.

The widths of the θ'_y and θ_z distributions for runs prior to run 5024 are comparable with the angular resolutions of the experiment while the angular distributions widths after run 5024, inclusively, tend to be within experimental resolutions.

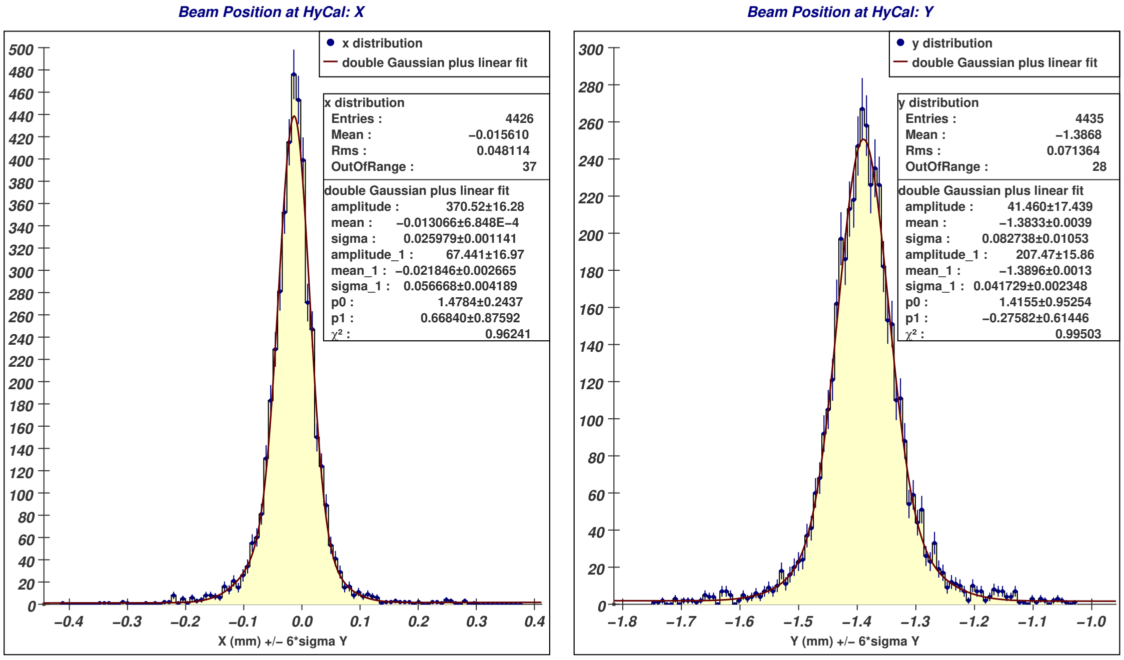


Figure 7: Beam position results for runs before run 5024.

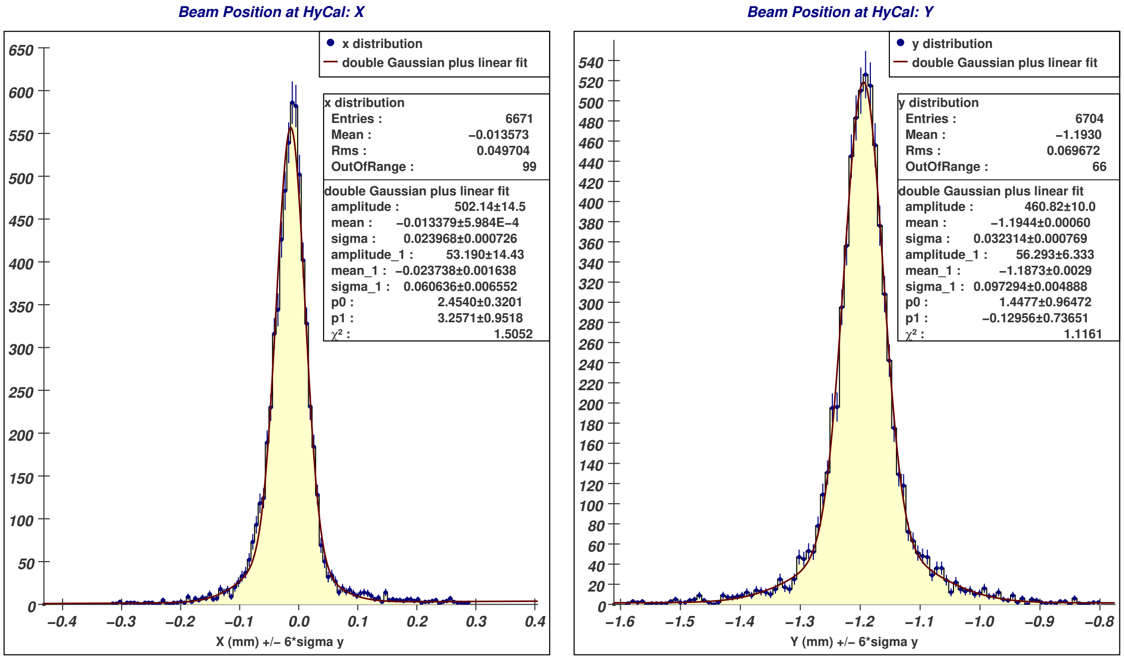


Figure 8: Beam position results for runs after run 5024, which is included in this set.

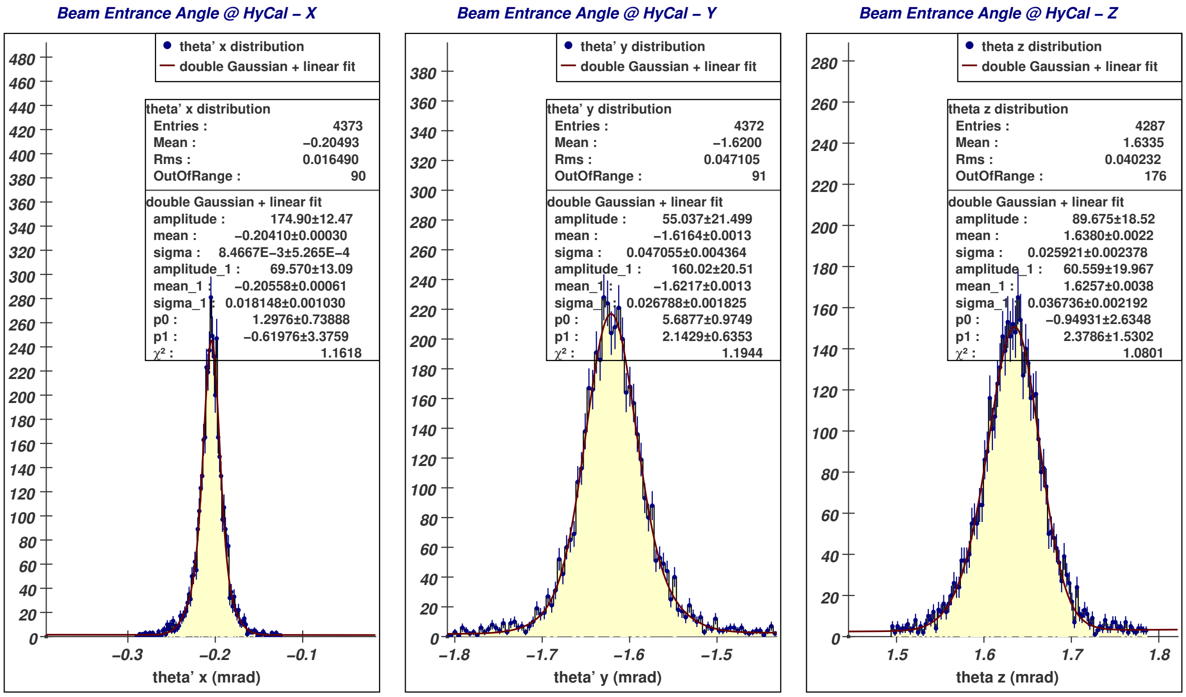


Figure 9: Beam angular stability results for runs before run 5024. See text for angle definitions.

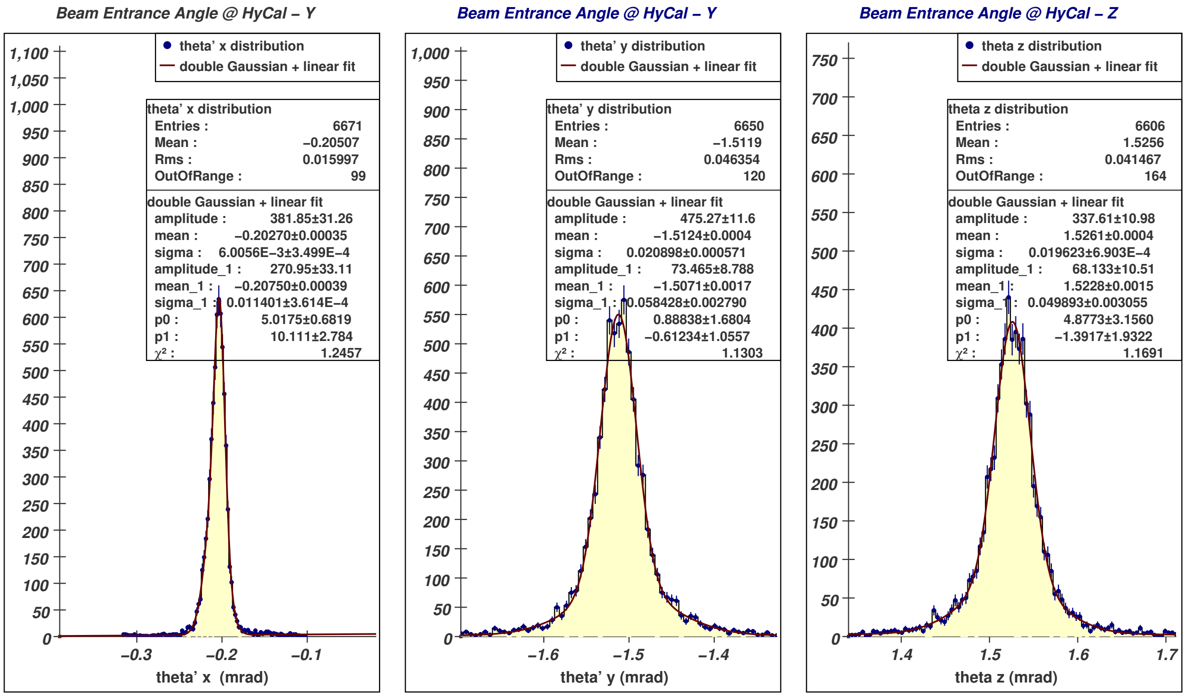
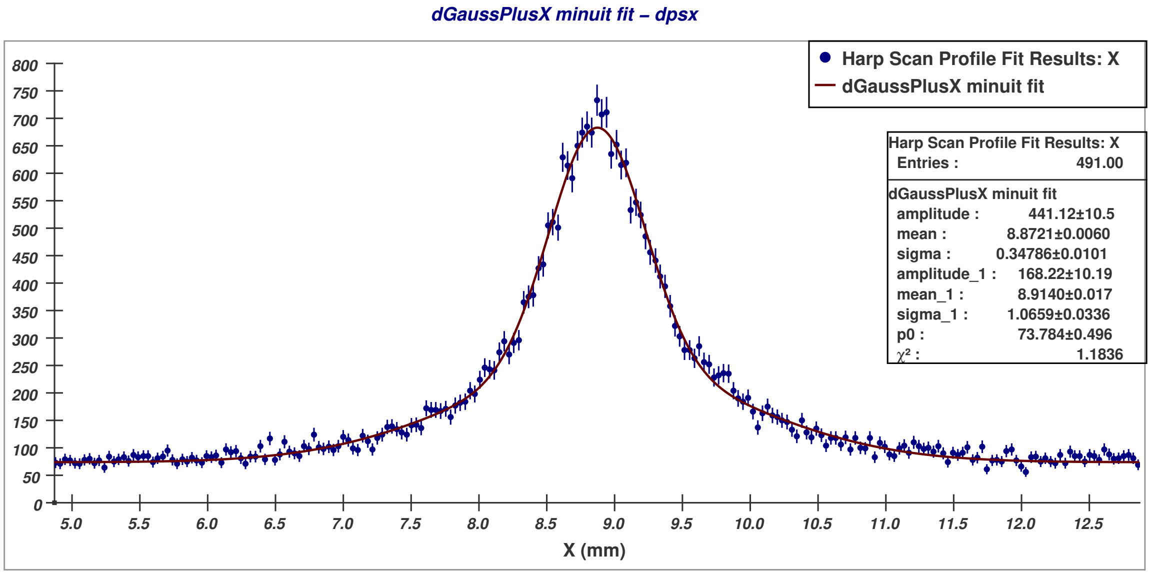


Figure 10: Beam position results for runs after run 5024.

2 Beam Divergence

2.1 Photon Harp Scans

Photon harp scans that were taken during the running of the experiment serve to define the photon beam profile. This profile is then used in the Monte Carlo simulation of the experiment.



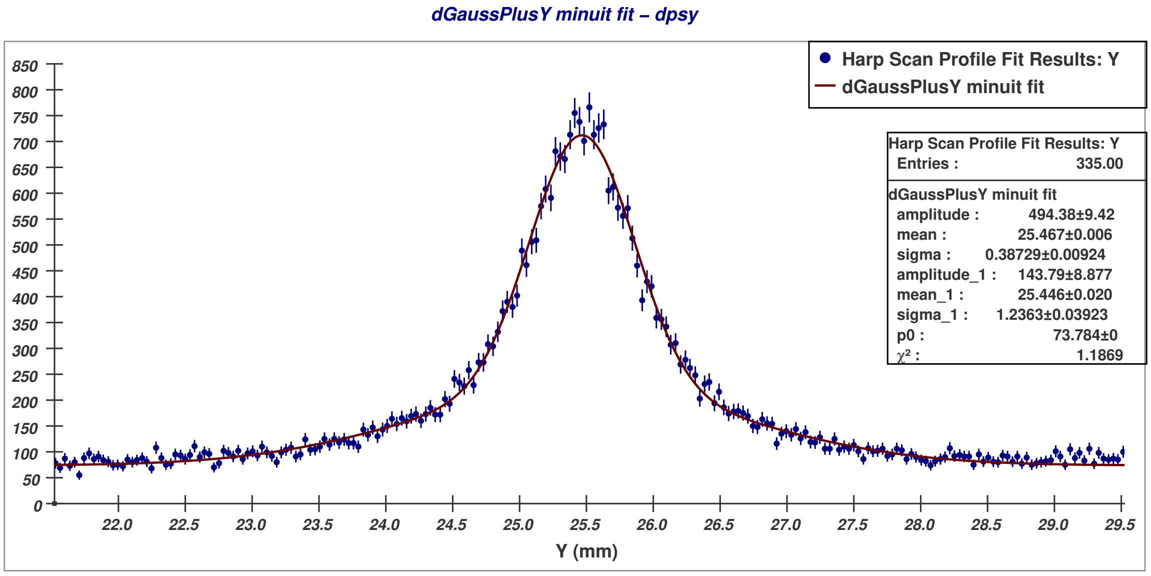


Figure 11: Fits to photon harp scan data.

Figure 11 displays two typical fits to the harp data, while Figure 12 proves that assumed functional form for the beam profile is quite stable across the running period. Data used for the fits were taken with high statistic PMT.

Run	Radiator	$A_1 \pm \delta A_1$	$x_1 \pm \delta x_1$ (mm)	$\sigma_1 \pm \delta\sigma_1$ (mm)	$A_2 \pm \delta A_2$	$x_2 \pm \delta x_2$ (mm)	$\sigma_2 \pm \delta\sigma_2$ (mm)	$p_0 \pm \delta p_0$
5136	B	248.8 ± 9.0	10.47 ± 0.0108	0.40 ± 0.0183	70.9 ± 8.6	10.43 ± 0.0344	1.23 ± 0.075	16.7 ± 0.3
5105	C	310.2 ± 7.7	10.48 ± 0.0095	0.47 ± 0.0142	50.8 ± 6.3	10.38 ± 0.0492	1.49 ± 0.100	18.3 ± 0.4
5105	C	5094.5 ± 43.1	10.47 ± 0.0025	0.45 ± 0.0045	1277.3 ± 44.0	10.49 ± 0.0087	1.25 ± 0.019	345.8 ± 1.6
5082	B	367.6 ± 7.8	10.65 ± 0.0089	0.50 ± 0.0133	57.9 ± 6.1	10.61 ± 0.0489	1.64 ± 0.097	22.2 ± 0.4
5024	B	249.4 ± 8.4	10.73 ± 0.0111	0.46 ± 0.0196	54.8 ± 8.3	10.68 ± 0.0482	1.40 ± 0.107	15.6 ± 0.3
4968	B	550.3 ± 10.5	10.71 ± 0.0065	0.40 ± 0.0097	128.2 ± 7.6	10.72 ± 0.0207	1.30 ± 0.035	6.6 ± 0.2
4962	B	543.3 ± 12.2	10.67 ± 0.0071	0.39 ± 0.0127	177.0 ± 11.5	10.75 ± 0.0171	1.18 ± 0.032	8.8 ± 0.2
4949	B	503.0 ± 9.0	10.66 ± 0.0070	0.46 ± 0.0113	89.3 ± 7.2	10.72 ± 0.0272	1.52 ± 0.058	5.6 ± 0.2
4941	B	573.8 ± 7.0	11.35 ± 0.0047	0.46 ± 0.0077	113.6 ± 5.5	11.36 ± 0.0168	1.46 ± 0.032	6.9 ± 0.1
4893	B	341.1 ± 8.4	10.93 ± 0.0067	0.40 ± 0.0134	103.2 ± 9.2	10.92 ± 0.0193	1.15 ± 0.046	21.5 ± 0.2
4892	B	1657.1 ± 17.4	10.68 ± 0.0030	0.41 ± 0.0050	499.6 ± 16.6	10.69 ± 0.0093	1.16 ± 0.018	112.0 ± 0.8
4880	B	692.0 ± 7.7	11.63 ± 0.0042	0.45 ± 0.0064	141.4 ± 5.5	11.65 ± 0.0148	1.46 ± 0.026	7.9 ± 0.1
4870	B	1105.6 ± 8.6	10.71 ± 0.0044	0.58 ± 0.0039	44.3 ± 2.0	10.97 ± 0.1806	2.45 ± 0.132	485.7 ± 1.6
4847	D	285.1 ± 4.4	15.71 ± 0.0076	0.52 ± 0.0101	34.7 ± 2.1	16.79 ± 0.4943	3.02 ± 0.435	34.2 ± 0.4
4717	A	1019.6 ± 12.8	10.83 ± 0.0039	0.44 ± 0.0067	265.7 ± 12.4	10.83 ± 0.0137	1.27 ± 0.028	78.8 ± 0.5
4645	A	927.7 ± 12.8	10.77 ± 0.0042	0.43 ± 0.0069	245.5 ± 12.3	10.76 ± 0.0149	1.25 ± 0.030	88.3 ± 0.5
4577	A	1014.9 ± 12.6	10.81 ± 0.0040	0.46 ± 0.0071	233.7 ± 12.5	10.82 ± 0.0163	1.37 ± 0.037	97.9 ± 0.6
4576	A	1063.8 ± 13.9	10.88 ± 0.0038	0.42 ± 0.0066	280.1 ± 13.8	10.89 ± 0.0133	1.23 ± 0.030	97.5 ± 0.6
4535	A	1014.9 ± 12.3	10.81 ± 0.0037	0.42 ± 0.0065	219.9 ± 11.8	10.86 ± 0.0167	1.30 ± 0.036	92.2 ± 0.6
4479	B	290.2 ± 7.2	10.83 ± 0.0072	0.41 ± 0.0127	79.2 ± 7.1	10.78 ± 0.0253	1.22 ± 0.055	26.7 ± 0.3
4437	B	504.6 ± 9.2	10.98 ± 0.0054	0.41 ± 0.0099	122.3 ± 8.9	11.02 ± 0.0239	1.33 ± 0.056	67.4 ± 0.5
4434	B	441.1 ± 10.5	8.87 ± 0.0060	0.34 ± 0.0101	168.2 ± 10.1	8.91 ± 0.0170	1.06 ± 0.033	73.7 ± 0.4
4307	B	403.0 ± 10.5	13.84 ± 0.0066	0.38 ± 0.0121	148.3 ± 10.8	13.84 ± 0.0195	1.12 ± 0.041	71.2 ± 0.5
4289	D	460.0 ± 10.1	13.85 ± 0.0063	0.41 ± 0.0106	135.9 ± 10.0	13.82 ± 0.0226	1.22 ± 0.045	81.6 ± 0.5
3605	B	215.4 ± 5.3	15.19 ± 0.0076	0.40 ± 0.0141	58.0 ± 4.9	15.17 ± 0.0236	1.29 ± 0.053	4.0 ± 0.1

Table 2: Fit parameters for the x coordinate. Magnitudes, A_1, A_2, p_0, are in counts.

Run	Radiator	$A_1 \pm \delta A_1$	$x_1 \pm \delta x_1$ (mm)	$\sigma_1 \pm \delta\sigma_1$ (mm)	$A_2 \pm \delta A_2$	$x_2 \pm \delta x_2$ (mm)	$\sigma_2 \pm \delta\sigma_2$ (mm)	$p_0 \pm \delta p_0$
5136	B	265.8 ± 9.4	25.43 ± 0.0102	0.37 ± 0.0163	83.4 ± 8.7	25.51 ± 0.0300	1.18 ± 0.0586	16.7
5105	C	293.5 ± 9.7	25.42 ± 0.0102	0.42 ± 0.0173	80.8 ± 9.6	25.38 ± 0.0323	1.20 ± 0.0613	18.3
5105	C	5174.0 ± 40.5	25.40 ± 0.0024	0.40 ± 0.0041	1480.5 ± 39.1	25.39 ± 0.0074	1.21 ± 0.0145	345.8
5082	B	365.2 ± 10.1	25.43 ± 0.0089	0.41 ± 0.0141	103.5 ± 9.0	25.42 ± 0.0281	1.25 ± 0.0509	22.2
5024	B	251.3 ± 8.0	25.54 ± 0.0106	0.40 ± 0.0163	70.7 ± 6.9	25.58 ± 0.0344	1.30 ± 0.0612	15.6
4968	B	559.1 ± 10.4	25.53 ± 0.0067	0.44 ± 0.0111	128.4 ± 8.7	25.56 ± 0.0214	1.35 ± 0.0387	6.6
4962	B	593.5 ± 11.3	24.51 ± 0.0063	0.38 ± 0.0092	161.1 ± 7.9	24.55 ± 0.0183	1.28 ± 0.0281	8.8
4949	B	483.6 ± 9.8	25.71 ± 0.0072	0.43 ± 0.0119	119.7 ± 8.0	25.69 ± 0.0219	1.35 ± 0.0383	5.6
4941	B	573.8 ± 7.3	25.61 ± 0.0046	0.42 ± 0.0071	133.5 ± 5.4	25.62 ± 0.0147	1.38 ± 0.0245	6.9
4893	B	285.2 ± 7.7	25.19 ± 0.0075	0.40 ± 0.0154	93.6 ± 8.6	24.99 ± 0.0284	1.14 ± 0.0441	21.5
4892	B	1771.4 ± 16.1	25.37 ± 0.0029	0.42 ± 0.0049	456.1 ± 15.6	25.37 ± 0.0098	1.24 ± 0.0190	112.0
4880	B	724.9 ± 7.9	25.32 ± 0.0041	0.45 ± 0.0068	145.4 ± 6.1	25.36 ± 0.0146	1.46 ± 0.0269	7.9
4870	B	983.1 ± 16.7	25.29 ± 0.0050	0.41 ± 0.0083	274.1 ± 16.5	25.43 ± 0.0245	1.27 ± 0.0414	485.7
4847	D	293.3 ± 5.9	26.48 ± 0.0070	0.46 ± 0.0143	48.1 ± 6.1	26.40 ± 0.0467	1.72 ± 0.1443	34.2
4717	A	1034.6 ± 12.5	25.55 ± 0.0040	0.47 ± 0.0068	256.7 ± 12.3	25.55 ± 0.0144	1.33 ± 0.0281	78.8
4645	A	758.3 ± 16.4	25.52 ± 0.0050	0.40 ± 0.0088	308.7 ± 17.2	25.53 ± 0.0117	1.01 ± 0.0223	88.3
4577	A	1000.7 ± 13.7	25.59 ± 0.0040	0.41 ± 0.0069	297.6 ± 13.7	25.60 ± 0.0128	1.21 ± 0.0255	97.9
4576	A	1012.5 ± 14.7	25.68 ± 0.0041	0.41 ± 0.0071	306.6 ± 15.1	25.73 ± 0.0125	1.15 ± 0.0248	97.5
4535	A	991.8 ± 13.3	25.55 ± 0.0040	0.43 ± 0.0071	258.6 ± 13.6	25.57 ± 0.0143	1.24 ± 0.0295	92.2
4479	B	295.5 ± 6.7	25.51 ± 0.0071	0.40 ± 0.0114	80.9 ± 6.2	25.50 ± 0.0249	1.22 ± 0.0445	26.7
4437	B	434.4 ± 10.2	25.41 ± 0.0061	0.34 ± 0.0101	177.1 ± 9.9	25.41 ± 0.0157	1.04 ± 0.0282	67.4
4434	B	494.3 ± 9.4	25.46 ± 0.0056	0.38 ± 0.0092	143.7 ± 8.8	25.44 ± 0.0205	1.23 ± 0.0392	73.7
4307	B	400.5 ± 11.1	25.39 ± 0.0072	0.42 ± 0.0135	133.1 ± 12.0	25.40 ± 0.0224	1.17 ± 0.0470	71.2
4289	D	409.1 ± 11.1	25.39 ± 0.0068	0.34 ± 0.0106	199.7 ± 10.9	25.42 ± 0.0151	0.98 ± 0.0244	81.6
3605	B	226.6 ± 5.0	24.13 ± 0.0075	0.41 ± 0.0134	57.4 ± 4.5	24.15 ± 0.0232	1.32 ± 0.0471	4.0

Table 3: Fit parameters for the y coordinate. Magnitudes, A_1, A_2, p_0, are in counts.

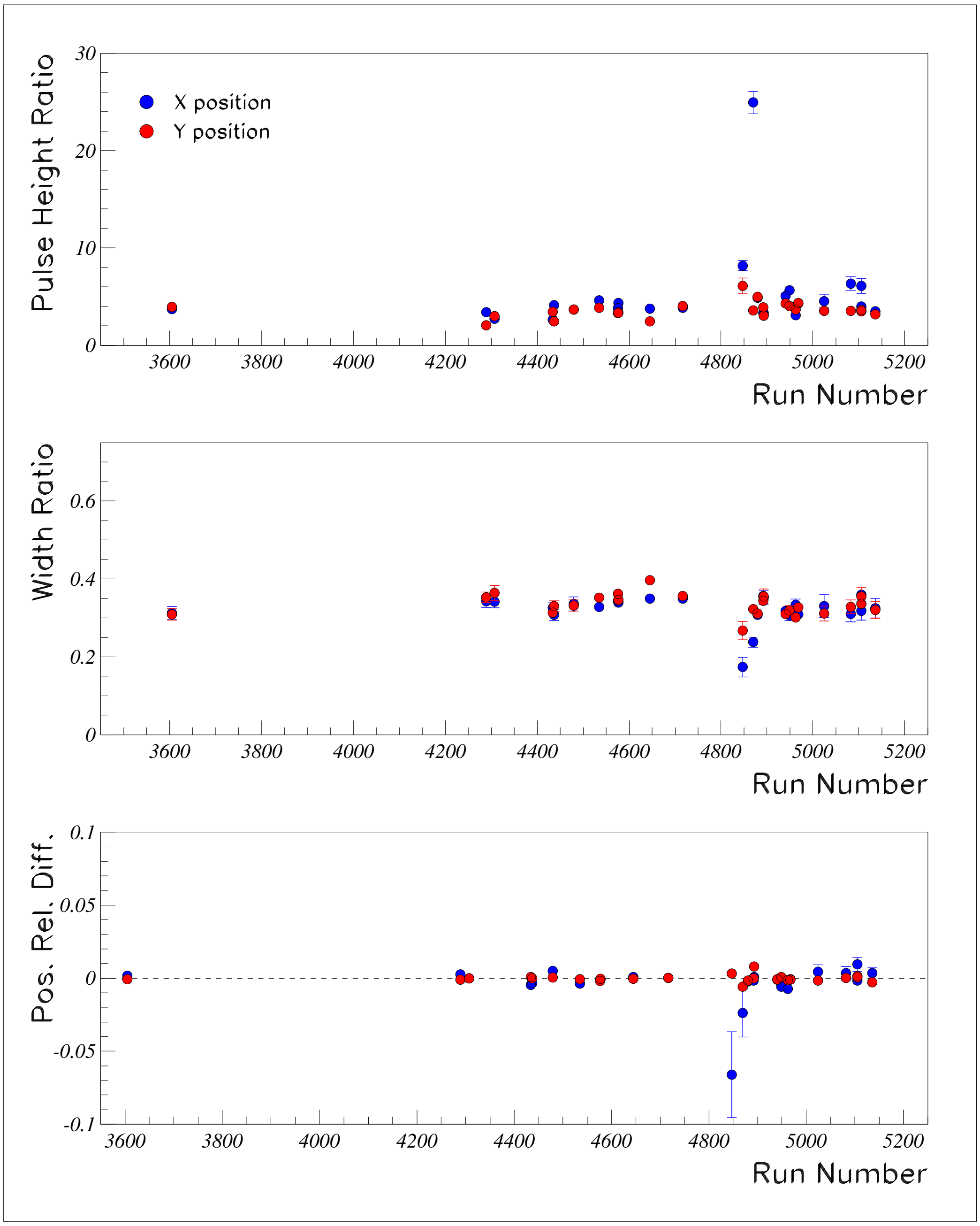


Figure 12: Beam profile parametrization stability.