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Calibration of LHC BGI monitor with orbital bump

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Summary

The goal of this study was to find the absolute calibration of the LHC Beam Gas Interaction monitors (BGIs). This calibration will be used during the 2011 run, but also to correct the data registered in 2010 run, with old calibration. The calibration run has been performed on the 5th of December 2010, using orbital bumps. The beam position has been measured with Beam Position Monitors. Because the closest BPMs are many meters from the BGI location, the beam position has been interpolated. Two-dimensional beam images were registered in order to correct for the tilt of the cameras. A set of issues which still have to be understood has been identified for further study.

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Contents

1 Introduction

The calibration run took place during the night from December 5th to 6th from 23:45 till 00:40 of local time using the lead ion beam. This was "end of fill" study, and the beam was in **ADJUST** mode. Beam energy was 3.5 ZTeV. The intensities of beams were:

- beam 1: $8.6 \cdot 10^{11}$ charges,
- beam 2: $7.9 \cdot 10^{11}$ charges.

The intensities have not changed significantly during the calibration process. The orbital bumps of ± 3.5 mm in steps of 0.5 mm were created in the position of the BGI monitors for each beam and for each plane. Because of high intensity and large cross section for rest gas ionisation with ions, the additional gas was not injected. The pressures registered by vacuum gauges were:

- beam 1, logged variable: VGI.659.5L4.B.PR $(7 - 9) \cdot 10^{-11}$ mbar,
- beam 2, logged variable: VGI.661.5R4.R.PR $(1.2 - 2.2) \cdot 10^{-10}$ mbar.

The High Voltage (HV) settings are summarized in Table 1. The EGPin and EGPout voltages are configured for normal data taking. For unknown reason the monitors measuring the vertical beam size need smaller voltages (on MCPout and Phosphor screen) to obtain clean signals. The BGI magnets were switched on to their nominal current of 50 A per magnet (100 A per circuit of 2 magnets).

HV [V]	BGI.B1V	BGI.B2V	BGI.B1H	BGI.B2H
EGPin	-1585	-1592	-1574	-1601
EGPout	-1680	-1701	-1688	-1694
Cgrid	-1989	-1968	-1966	-1979
MCPin	1951	1973	1955	1999
MCPout	2705	2746	2834	2891
Ph	5072	5007	5548	5466

Table 1: *Values of HV used diring the scan on the four BGI monitors, as registered in Logging DB.*

The 2D images of the BGI cameras were registered for every step (one per step of the orbital bump, data available only in expert acquisition mode). One-dimensional projections used to calculate the beam size have been saved in Logging DB with 1 Hz rate.

2 Methodology

The method used to calibrate the BGI consists of the following steps:

- reading BPMs signal and interpolating the beam position to the location of the BGI,
- comparing the interpolated beam position with the one read by the BGI camera,
- correcting the obtained result for the camera tilt (discussed separately in Section 7).

The BPM resolution is of the order of micrometers, which is much better than the BGI resolution. The error of the measurement of beam position with BPMs is estimated here as an RMS of the distribution of the set of the consecutive measurements (disposable every second).

In case of BGI the distribution of the signal is first rebinned (2 neighbouring bins are grouped) in order to avoid the saw-like pattern due to the signal transmission protocol. Then the distribution is fitted with gaussian. The mean of the fit is used as beam position determination, with error of the mean as the measurement error.

At the end of the calibration procedure it is expected to obtain, for every BGI, a value of the size of the BGI pixel.

3 B1V calibration

In Table 2 the set of data used for the BGI B1V (dcum = 9934.8652 m) calibration is presented. The BPM measurement is based on linear interpolation between BPMYA.5L4.B1 (dcum=9861.7432 m) and BPMWA.B5L4.B1 (9964.0292 m).

In Figure 1 the calibration curve is shown. A small effect similar which bends points with negative beam position slightly up from the curve and points with positive beam position slightly below the curve is not explained yet.

4 B2V calibration

In Table 3 the set of data used for the BGI B2V (dcum = 10059.2972 m) calibration is presented. The BPM measurement is based on linear interpolation between BPMYA.5R4.B2 (dcum = 10132.4192 m) and BPMWA.B5R4.B2 (dcum = 10029.8482 m).

The Figure 2 illustrates the measurements of the two BPMs used for calibration during the calibration bump setting. The Figure 3 shows the calibration curve.

timestamp (UTC)		No of	BPM [μm]		BGI [pixel]	
start	end	measurements	value	error	value	error
22:45:00	22:49:20	260	-291.8	14.4	152.62	0.01
22:49:30	22:52:21	171	199.9	14.6	157.23	0.01
22:52:30	22:53:10	40	699.5	15.1	162.06	0.01
22:53:30	22:54:01	31	1195.5	15.5	166.49	0.01
22:54:10	22:54:30	20	1692.8	12.9	170.772	0.004
22:54:40	22:55:30	50	2184.7	14.5	174.688	0.004
22:55:39	22:56:51	72	2670.5	16.7	177.893	0.003
22:56:59	22:58:20	81	3160.5	14.5	181.650	0.003
22:59:15	22:59:50	35	-280.2	13.9	152.816	0.008
23:00:00	23:00:30	30	-775.5	13.7	147.869	0.006
23:00:39	23:01:04	25	-1265.3	13.4	143.649	0.005
23:01:10	23:01:55	45	-1754.8	15.6	139.602	0.004
23:02:10	23:02:35	25	-2238.1	10.7	135.068	0.004
23:02:50	23:03:10	20	-2736.8	15.2	131.060	0.003
23:03:20	23:04:05	45	-3227.0	12.1	127.225	0.003
23:04:15	23:04:40	25	-3737.2	11.9	123.302	0.003
23:05:30	23:06:00	30	-303.1	13.4	152.865	0.008

Table 2: *Data used for B1V calibration. The (UTC) date is 2010-12-05.*

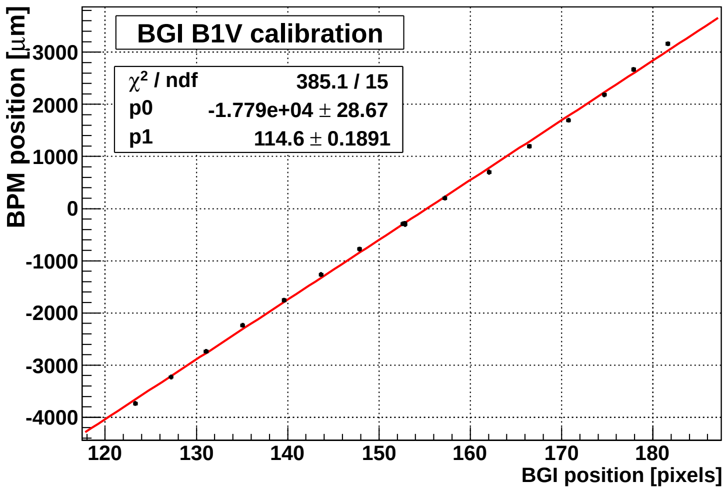

Figure 1: *The calibration of BGI B1V. The calibration coefficient obtained from a linear fit is* 0.1146 ± 0.0002 mm/pixel. *A small hysteresis of the measured points around a straight line is not yet explained.*

5 B1H calibration

In Table 4 the set of data used for the BGI B1H (dcum = 9933.0652 m) calibration is presented. The BPM measurement is based on linear interpolation between

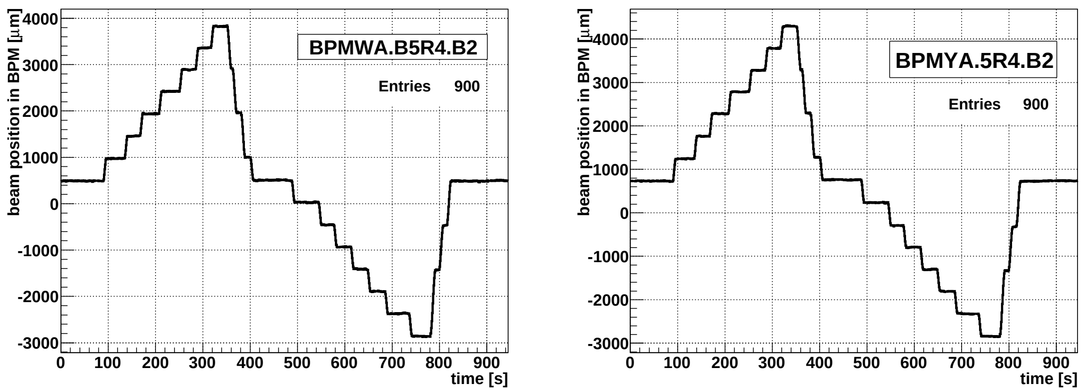

Figure 2: *The beam position in the two neighbouring BPMs during the calibration run.*

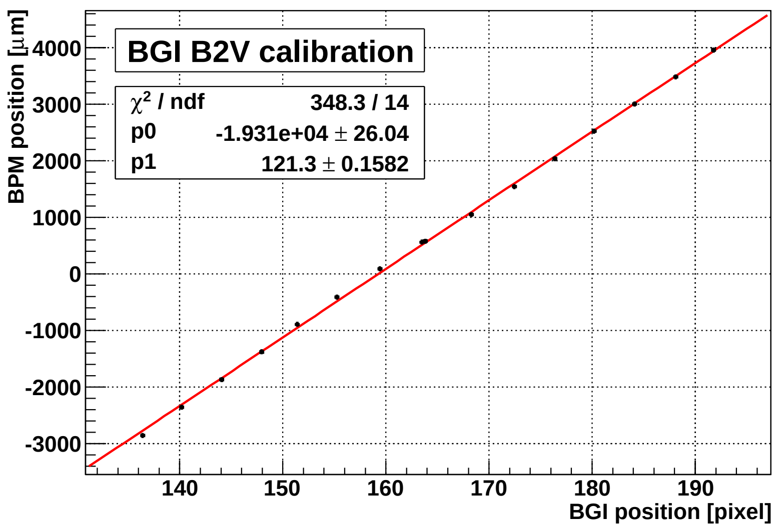

Figure 3: *The calibration of BGI B2V. The calibration coefficient obtained from a linear fit is* 0.1213 ± 0.0002 mm/pixel.

BPMYA.5L4.B1 (dcum = 9861.7432 m) and BPMWA.B5L4.B1 (dcum = 9964.0292 m).

6 B2H calibration

In Table 5 the set of data used for the BGI B2H (dcum = 10061.0972 m) calibration is presented. The BPM measurement is based on linear interpolation between BPMYA.5R4.B2 (dcum = 10029.8482 m) and BPMWA.B5R4.B2 (dcum = 10132.4192 m). Here the bump size has not been increased up to 3.5 mm because of appearance of beam losses, therefore the set of data points is shorter.

timestamp (UTC)		No of	BPM [μm]		BGI [pixel]	
start	end	measurements	value	error	value	error
23:06:00	23:07:10	70	561.3	9.2	163.493	0.009
23:07:33	23:08:05	32	1052.9	9.2	168.299	0.009
23:08:15	23:08:40	25	1546.3	10.4	172.451	0.009
23:08:45	23:09:10	25	2037.8	11.1	176.385	0.008
23:09:25	23:09:55	30	2527.1	9.9	180.188	0.008
23:10:05	23:10:30	25	3003.9	11.4	184.128	0.008
23:10:40	23:11:00	20	3482.9	9.6	188.101	0.007
23:11:07	23:11:35	28	3961.0	11.7	191.782	0.007
23:12:30	23:13:40	70	580.4	11.0	163.815	0.010
23:13:50	23:14:35	45	88.9	10.9	159.414	0.009
23:14:45	23:15:10	25	-409.3	9.3	155.249	0.009
23:15:15	23:15:40	25	-892.8	8.7	151.395	0.008
23:15:50	23:16:15	25	-1379.0	12.2	147.947	0.008
23:16:25	23:16:50	25	-1867.5	10.7	144.066	0.007
23:17:00	23:17:40	40	-2356.3	11.6	140.190	0.006
23:17:50	23:18:22	32	-2855.2	10.1	136.398	0.006

Table 3: *Data used for B2V calibration. The date is 2010-12-05.*

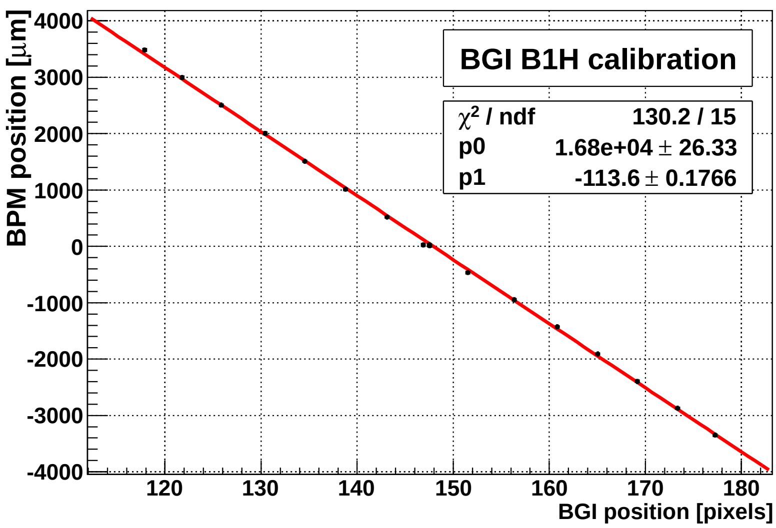

Figure 4: *The calibration of BGI B1H monitor. The calibration factor obtained from linear fit is* 0.1136 ± 0.0002 mm/pixel.

7 The tilt of the cameras

The BGI cameras are not perfectly aligned along the beam. This means that the fit to a projected image (as in the current electronics), overestimates the actual beam

timestamp (UTC)		No of	BPM [μm]		BGI [pixel]	
start	end	measurements	value	error	value	error
23:30:50	23:32:10	80	30.3	14.3	147.500	0.023
23:32:40	23:33:00	20	520.9	11.6	143.102	0.021
23:33:10	23:33:30	20	1015.2	12.9	138.798	0.020
23:33:40	23:33:55	15	1512.2	8.5	134.551	0.018
23:34:05	23:34:32	27	2005.4	15.7	130.430	0.016
23:34:40	23:35:05	25	2505.4	12.7	125.839	0.013
23:35:10	23:35:35	25	2996.8	14.8	121.766	0.011
23:35:45	23:36:05	20	3484.7	13.7	117.865	0.009
23:36:45	23:37:25	40	24.8	14.8	146.898	0.022
23:37:35	23:38:10	35	-465.1	13.3	151.533	0.021
23:38:20	23:38:50	30	-947.6	15.3	156.343	0.020
23:39:00	23:39:20	20	-1425.1	11.9	160.827	0.018
23:39:30	23:39:50	20	-1911.0	10.1	165.055	0.016
23:40:00	23:40:25	25	-2394.1	15.3	169.162	0.014
23:40:35	23:40:55	20	-2872.0	10.7	173.349	0.011
23:41:05	23:41:30	25	-3347.6	13.7	177.261	0.009
23:42:05	23:42:45	40	11.5	14.2	147.561	0.024

Table 4: *Data used for B1H calibration. The date is 2010-12-05.*

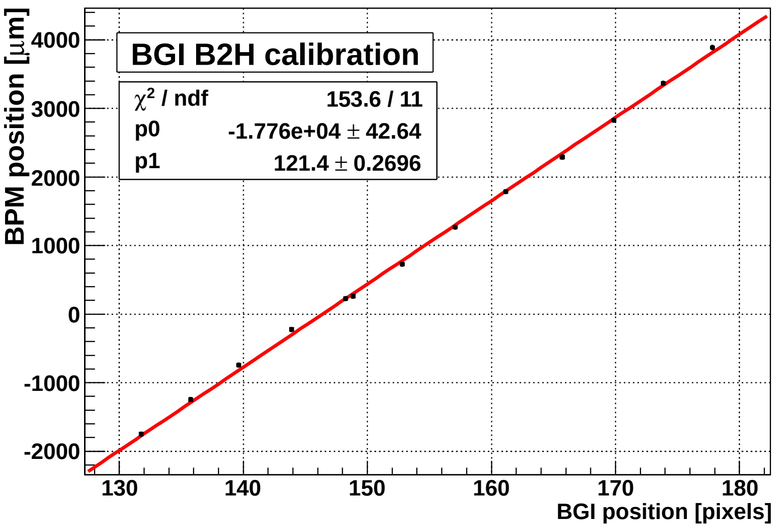

Figure 5: *The calibration of BGI B2H. The calibration factor obtained from linear fit is found to be* 0.1214 ± 0.0003 mm/pixel.

size. The mean value of the fitted gaussian as a function of the position along the beam is shown on the left plot of Figure 6. Every point on this plot has been obtained

timestamp (UTC)		No of	BPM [μm]		BGI [pixel]	
start	end	measurements	value	error	value	error
23:20:00	23:21:15	75	222.5	14.7	148.309	0.033
23:21:23	23:21:56	33	728.2	13.4	152.908	0.031
23:22:05	23:22:30	25	1250.5	14.5	157.118	0.026
23:22:35	23:23:10	35	1772.6	14.2	161.182	0.021
23:23:20	23:23:42	22	2288.5	15.2	165.774	0.016
23:23:50	23:24:10	20	2821.2	13.1	169.917	0.012
23:24:20	23:24:50	30	3353.7	13.5	173.883	0.010
23:25:00	23:25:30	30	3884.8	10.2	177.865	0.008
23:26:10	23:26:51	41	250.8	17.4	148.876	0.033
23:27:00	23:27:40	40	-233.9	15.8	143.973	0.029
23:27:50	23:28:16	26	-747.1	13.4	139.701	0.023
23:28:25	23:29:00	35	-1255.2	16.5	135.807	0.018
23:29:10	23:29:35	25	-1756.3	17.9	131.831	0.014

Table 5: *Data used for B2H calibration. The date is 2010-12-05.*

by fitting to a slice of image with arbitrary thickness of 9 pixels. Only the points with $\chi^2 < 5000$ are shown.

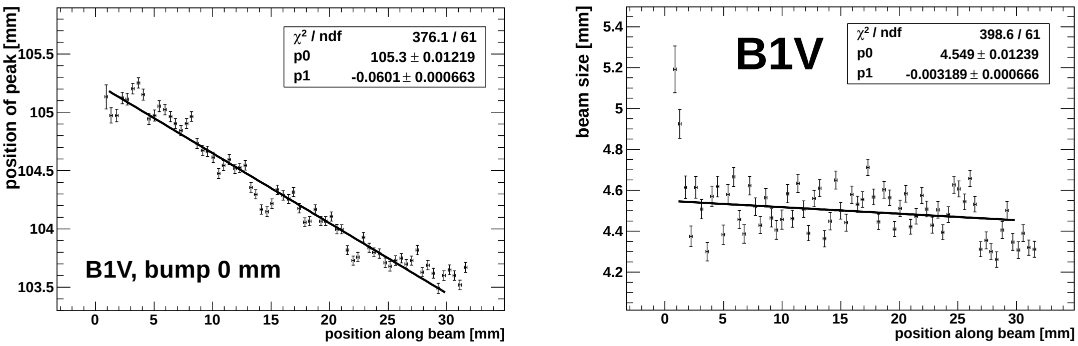

Figure 6: *Left plot: the tilt of the BGI B1V camera, corresponding to 3.4 degrees. Right plot: the beam size measured along the beam using slices of BGI camera image.*

The effect seems to be large, but plotting the distribution of beam sigma along the beam and comparing it to the beam size calculated from a global projection reveals rather small effect. It is shown on the right plot of Figure 6 that the σ of the gaussian fitted to the slices of the image (partial) depends weakly on the position along the beam.

In Table 6 the procedure of obtaining the final calibration factor is summarized. The "rough calibration" column is without the tilt correction. The tilt is calculated from plots similar to the left one in Figure 6.

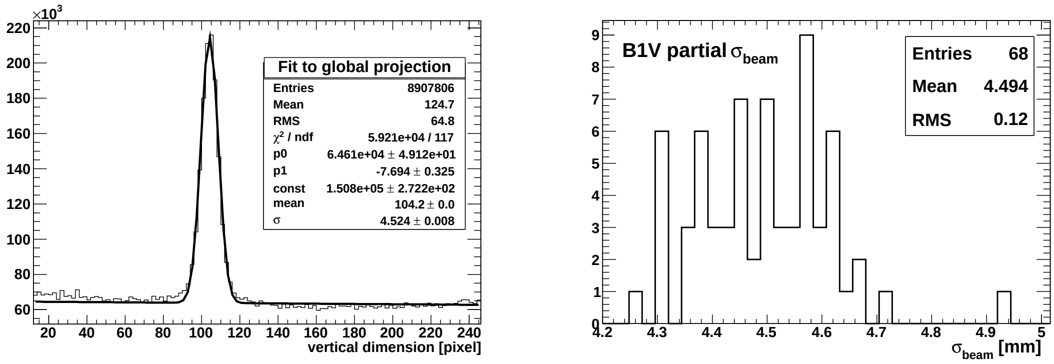

Figure 7: *The distribution of beam width along the beam (left plot) and total projection.*

The correction due to the tilt is calculated as the ration of the mean value of the σ_{beam} calculated on slices (eg. right plot of Figure 7) to σ_{beam} of the global fit (eg. left plot of Figure 7). The error of this correction is dominated by the RMS of the partial σ_{beam} distribution and in most cases the correction factor is consistent with 1 (for instance the error on the correction factor for B1V monitor is 0.028).

In case of B1H monitor the mean value of the partial σ_{beam} is larger than the global fit, what needs further investigations. In the meantime it has been decided to keep the angular correction equal to 1, as tilt should not decrease the measured σ_{beam}.

monitor	rough calibration [mm/pixel]	tilt	correction	final calibration [mm/pixel]
B1V	0.1146	3.4°	0.993	0.1138
B2V	0.1213	8.3°	0.952	0.1155
B1H	0.1136	4.5°	1.000	0.1136
B2H	0.1214	3.9°	0.996	0.1209

Table 6: *The calibration factors, camera tilt and corrected calibration factors.*

8 Correction to data logged in 2010

The beam size data logged in 2010 and stored in the Logging DB used a calibration factor of 0.0816 mm/pixel. This first estimation was based on the wrong technical drawing (SPSBI_PMV0105) which suggests that the distance between the cathode wires, which are visible during EGP calibration [1], is 3.1 mm. The estimation based on orbital bump is relies on high accuracy of the BPMs and estimates the camera calibration in the plane where the beam is.

The correction algorithm to 2010 data should therefore be simply multiplication of last year data by current correction and dividing by 0.0816. The correction values are presented in Table 7.

monitor	B1V	B2V	B1H	B2H
correction	1.395	1.415	1.392	1.482

Table 7: *The correction factors to 2010 data.*

9 Conclusions

The calibration of the image size of the LHC BGI monitors has been performed using the orbital bump technique. An attempt to correct for the tilt of the BGI cameras with respect to the local beam trajectory has been made. New calibration factors, to be used in the beginning of the 2011 run, are presented.

A number of issues has been detected. Cameras present quite large tilt, up to 8 °. But the final impact of the tilt on the measured value of the beam size is small, in the worst case reaches only 5%. The inverse effect of tilt on B1H camera remains to be explained. The larger than other calibration for B2H monitor also needs further investigations. The calibration curves feature small deviation from linearity (called sometimes "hysteresis"), of unknown origin.

In the future the calibration should be repeated. The choice of the proton beam is suggested because of its smaller emittance. Before the calibration with the orbital bump, a calibration of the MCP uniformity should be performed, as aging of the MCP has been observed already at the end of 2010 run.

References

[1] H. Refsum, " Design, Simulation and Testing of a 2D Electron Source Based Calibrating System for a Proton Beam Ionisation Profile Monitor", CERN thesis 2004.