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BGI results of BI MD June 24th, 2012

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Summary

This note describes the results of analysis of LHC BGI data collected during BI MD on June 24th, 2012. The BGI measurements were devoted to testing new fitting procedure, however some typical measurements, like camera tilt and image scale calibration with orbital bump have been taken as well. At the end of the MD a cross-calibration with BSRT during emittance blowup with ADT has been performed.

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1 Introduction

On June 24, 2012 a second Beam Instrumentation (BI) Machine Development (MD) period of 2012 took place. About one hour of the MD period was devoted to BGI [1] study. Because of problems with detectors on beam 1 (broken MCP on B1V and very weak signal on B1H), only measurements with beam 2 have been made. The instrumental conditions are summarized in Table 1.

	BGI.B2V	BGI.B2H
HV EGPin [V]	-1800	-1800
HV EGPout [V]	-1900	-1900
HV Cgrid [V]	-2000	-2000
HV MCPin [V]	2000	2000
HV MCPout [V]	2600	2750
HV Phosphor [V]	5000	5150
camera gain	930	930
camera gate	max	max
BTV offset	-201	-370
window origin [pixel]	57x7	90x15
window size [pixel]	285x285	285x285

Table 1: *Values of HV, camera gain and gate and parameters of the BTV card used during the MD on the two BGI monitors.*

The gas injection was established at the level of $5.2 \cdot 10^{-9}$ mbar. The beam intensity was the full machine, i.e. 1368 bunches, grouped in 3 trains of 72 bunches and 8 trains of 144 bunches (check!). The EGP calibration was zeroed, so no corrections to 2D images (neither 1D profiles) have been done. That is because it was estimated that this correction will have a small effect on the final result. During the MD an orbital bump in the BGI location was done with maximum safe amplitude of ± 1 mm.

The data acquisition was manual (2-dimensional images stored in *comma seprated value* - csv - files) and automatic (1-dimensional profiles in Logging Database). The data collected by the BSRT in DC mode were saved in ASCII files and further used for cross-calibration of the two instruments.

A particularly interesting part of the MD was a blowup of the whole beam with ADT. Such operation has been done for the first time. The ADT dumping (in our case exciting) window was set to a whole train of 144 bunches. After exciting one train the window was shifted to excite the next one. The most interesting was the vertical blowup during the period from 15:58 till 16:15 (end of MD time for BGI).

2 Tilt of the cameras

The tilt of the BGI cameras with respect to the beam is calculated from 2D images. The image is cut into slices 20 pixels each. The choice of 20 pixels is rather arbitrary. The slice is projected to obtain a 1D profile. This profile is fitted with gaussian function. The position of the peak (gaussian mean) is ploted as a function of position along the beam. Fit to this dependence gives the tilt of the cameras.

2.1 Beam 2 vertical

In Figures 1-5 the 2D images and calculated from them camera tilts are shown for B2V monitor and for 5 bump amplitudes together with graphs showing the beam position along the camera sensor. The image quality at the edge is often poor (low signal) therefore the fit to determine the tilt is done omitting the edge region.

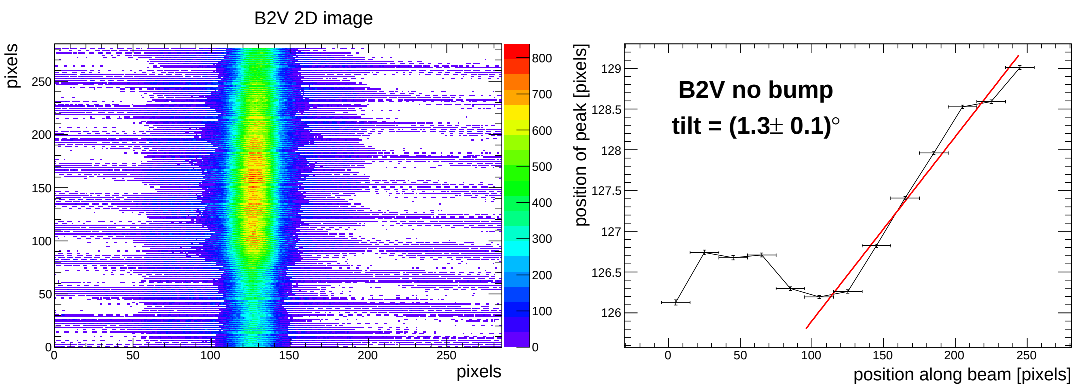

Figure 1: *Beam image of B2V BGI (left plot) and measurement of the camera tilt (right plot) for zero bump.*

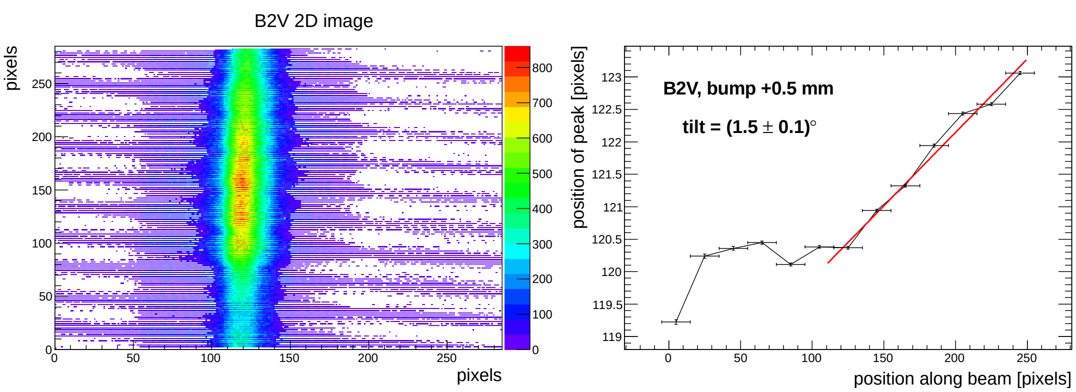

Figure 2: *Beam image of B2V BGI (left plot) and measurement of the camera tilt (right plot) for bump +0.5 mm.*

The resulting tilt is, for most cases 1.3 degrees, except the two positive bumps, where it deviates to 1.1 and 1.5 degrees.

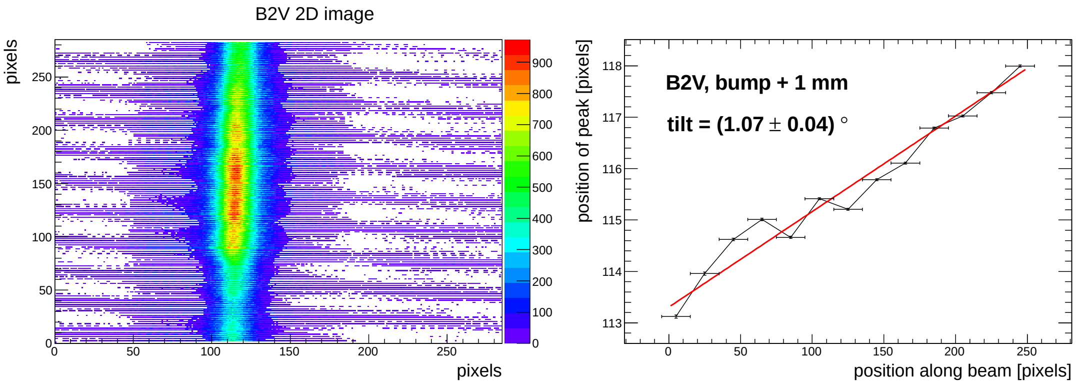

Figure 3: *Beam image of B2V BGI (left plot) and measurement of the camera tilt (right plot) for bump +1.0 mm.*

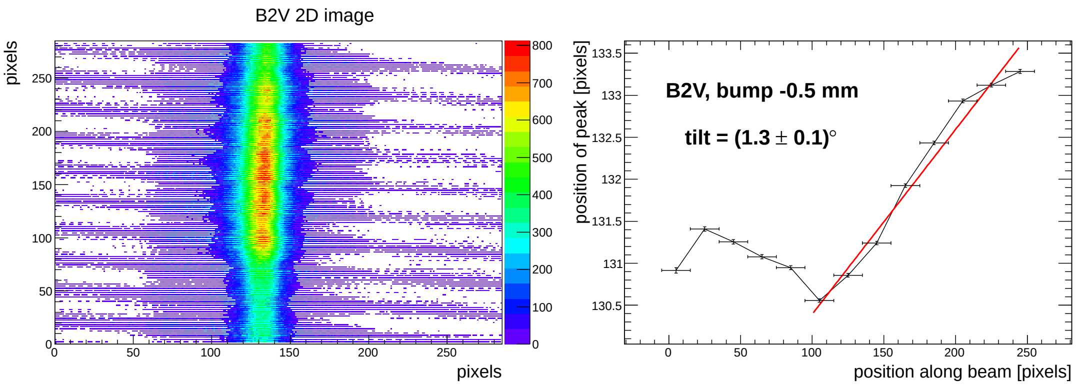

Figure 4: *Beam image of B2V BGI (left plot) and measurement of the camera tilt (right plot) for bump -0.5 mm.*

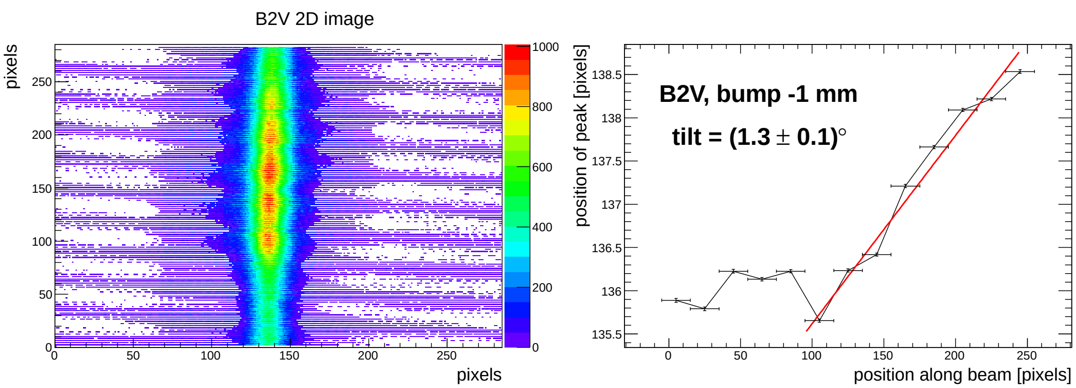

Figure 5: *Beam image of B2V BGI (left plot) and measurement of the camera tilt (right plot) for bump -1.0 mm.*

2.2 Beam 2 horizontal

In Figures 6-10 the 2D images and calculated from them camera tilts are shown for B2H monitor and for 5 bump amplitudes. Note the different orientation of the camera with respect to the beam. As for B2V monitor, the image quality at the edge is often poor (low signal) therefore the fit is done omitting the edge region.

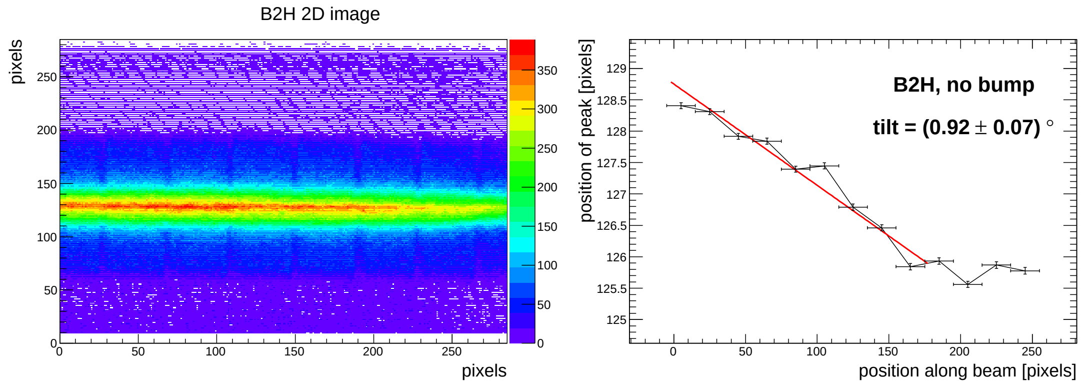

Figure 6: *Beam image of B2H BGI (left plot) and measurement of the camera tilt (right plot) for zero bump.*

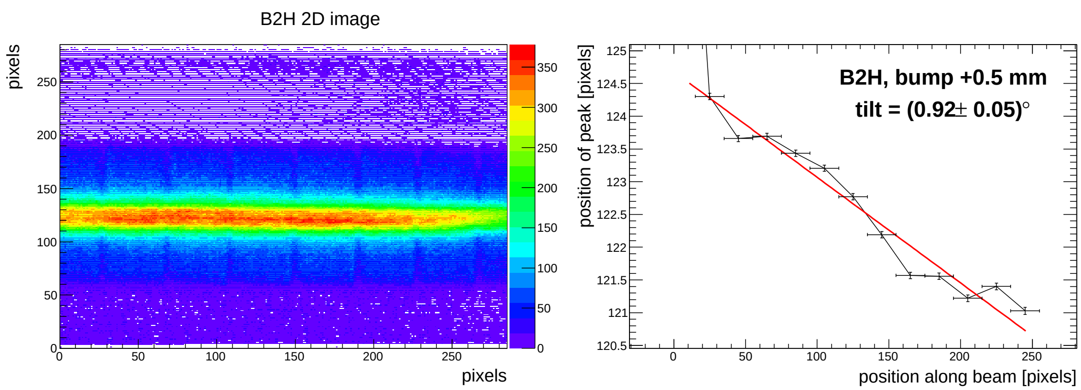

Figure 7: *Beam image of B2H BGI (left plot) and measurement of the camera tilt (right plot) for bump +0.5 mm.*

The resulting tilt is $(1.0 \pm 0.1)^{\circ}$, so less than in case of vertical monitor.

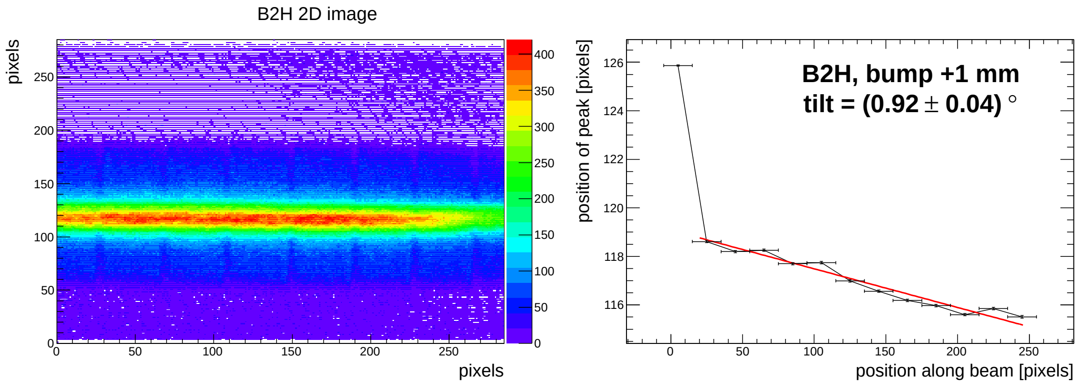

Figure 8: *Beam image of B2H BGI (left plot) and measurement of the camera tilt (right plot) for bump +1.0 mm.*

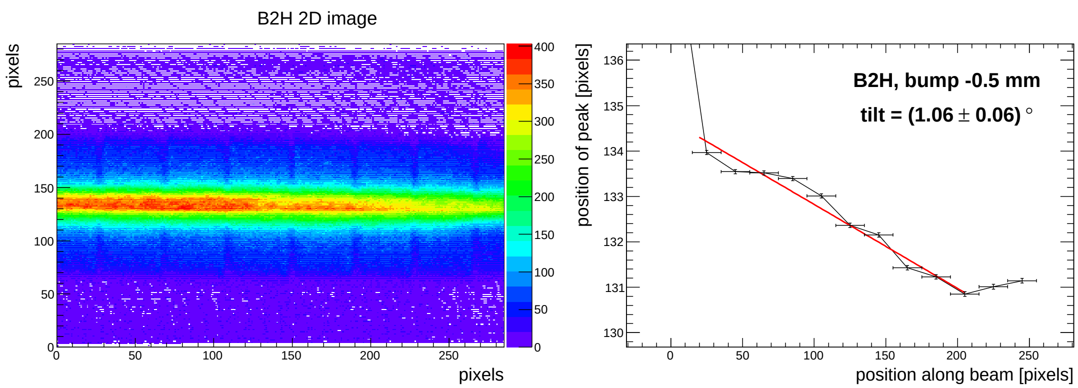

Figure 9: *Beam image of B2H BGI (left plot) and measurement of the camera tilt (right plot) for bump -0.5 mm.*

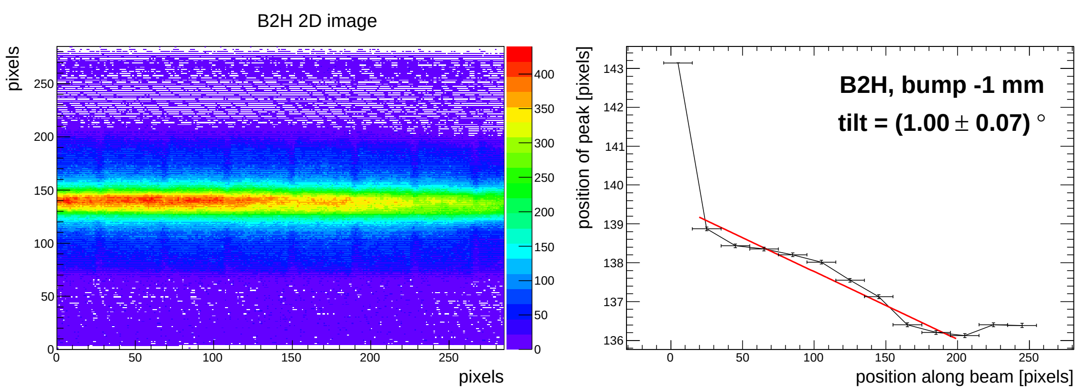

Figure 10: *Beam image of B2H BGI (left plot) and measurement of the camera tilt (right plot) for bump -1.0 mm.*

3 Pixel size calibration with orbital bump

The pixel size calibration has been performed before [2], using ion beam and larger orbital bumps. It gave larger values than the present calibration. This might be due to better implementation of BGI position in the bump control software or due to smaller physical size of the proton beam.

In Figure 11 the calibration curves are shown for vertical and horizontal BGIs. They both give the same result, within error, i.e. about 97 μm/pixel. The tilt of the cameras was not taken into account in this calibration, so effectively the value could be slightly smaller.

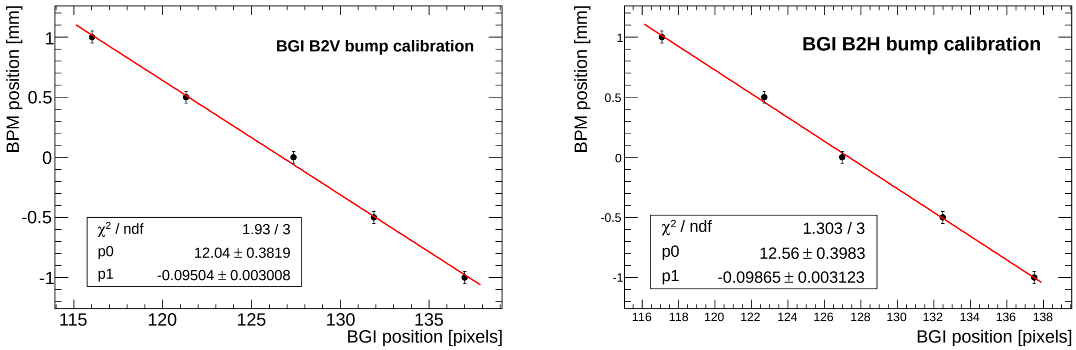

Figure 11: *Pixel size calibration of B2V (left plot) and B2H (right plot) monitors with orbital bump.*

4 Beam size evolution during ADT blowup

The beam size evolution during the blowup of the beam with ADT is shown on the left plot of Figure 12. The beam size is estimated using the new fitting procedure, which takes into account only the beam core. The various stages of blowup are clearly visible. On the right plot the evolution of the beam vertical normalized emittance ($\gamma\epsilon$) is shown. It assumes $\beta_{\rm ver} = 216.12$ m.

A comparison with BSRT blowup data is shown in Figure 13. The assumed optical functions are:

- $\beta_{\rm BSRT} = 394.57$ m,
- $\beta_{\rm BGI} = 217.19$ m.

Left plot shows normalized emittance evolution assuming that the BGI pixel calibration is 0.095 mm/pixel and no correction is added in quadrature. Right plot uses old calibration obtained by comparing BGI and BSRT at injection and at the flat top (so for small beams). The pixel calibration is 0.1356 mm/pixel and the correction in quadrature is 0.074 mm.

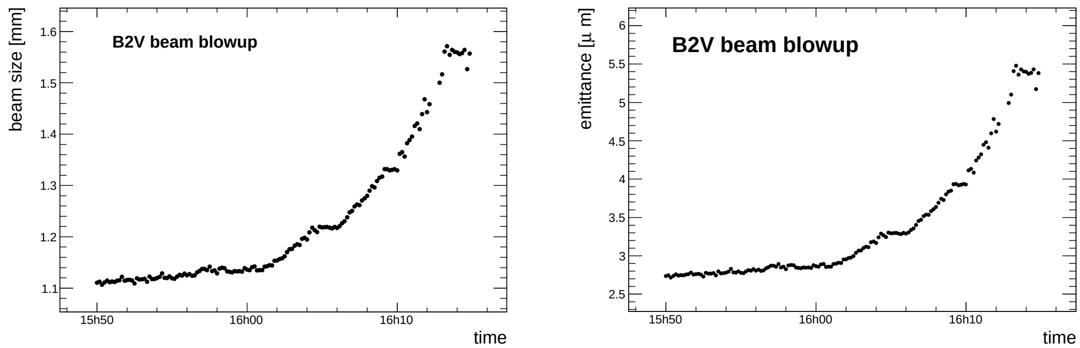

Figure 12: *Evolution of vertical beam size (left plot) and normalized emittance (right plot) during the exercise with ADT blowup of the beam.*

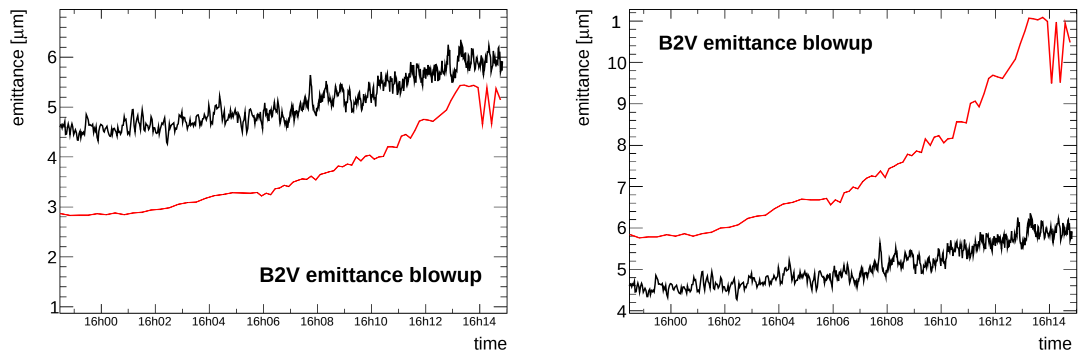

Figure 13: *Comparison of BSRT and BGI measurements of normalized emittance.*

Clearly, none of the proposed calibrations makes the BGI and BSRT data consistent. Therefore a cross-calibration procedure proposed by [3] was used. It assumes that:

- BSRT gives correct beam size $\sigma_{BSRT} = \sigma_{beam}$,
- BGI beam size is affected by smearing function is quadrature, what is expressed by Equation 1.

$$\sigma^2_{beam}[mm^2] = (c \cdot \sigma_{BGI})^2 - \sigma^2_{corr} \tag{1}$$

- Emittance measured with BGI and BSRT are the same:

$$\frac{(c \cdot \sigma_{BGI})^2 - \sigma^2_{corr}}{\beta_{BGI}} = \frac{\sigma^2_{BSRT}}{\beta_{BSRT}} \tag{2}$$

Therefor, the dependence between σ^2_{BGI} and σ^2_{BSRT} is expected to be linear. The parameters of the linear dependency are:

$$p_1 = \frac{\beta_{BGI}}{c^2 \cdot \beta BSRT} \quad (3)$$

$$p_0 = \frac{\sigma_{corr}}{c^2} \quad (4)$$

The σ^2_{BGI} versus σ^2_{BSRT} plotted on left plot of Figure 14. On this plot every point is obtained by averaging 12 consecutive BSRT measurements and 3 BGI measurements. Errors are just RMS calculated from each subset of measurements. The values of c and σ_{corr} are:

$$c^2 = \frac{\beta_{BGI}}{p_1 \beta_{BSRT}} = 5.3703 \cdot 10^{-3} \quad (5)$$

$$\sigma^2_{corr} = \frac{p_0 \beta_{BGI}}{p_1 \beta_{BSRT}} = -1.3028 \quad (6)$$

The value of c obtained this way is surprisingly smaller than obtained with bump calibration. From the fit $c = 0.0733 \frac{mm}{pixel}$ while with the bump the number is $0.097 \frac{mm}{pixel}$. But the value of σ^2_{corr} is negative, what suggests that there is an effect which leads to compactification of the beam image, not smearing. These effect must be furter investigated. It must be stressed that the beam shape due to the blowup is not as gaussian as without it, therefore the quality of the BGI fit is low.

On the right plot of Figure 14 the BSRT and BGI emittance comparison using the newly obtained calibrations is shown. A good agreement is visible as expected.

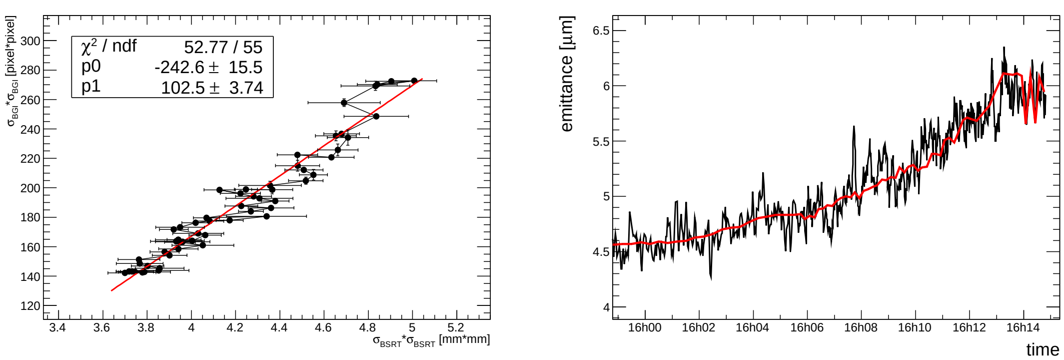

Figure 14: *Cross-calibration with BSRT based on ADT blowup data.*

5 Conclusions

The calibration of the image size of the beam 2 LHC BGI monitors has been performed using the orbital bump technique. The calibration factors have been found identical within error (between 95 and 98 micrometers per pixel).

The tilt of the cameras was measured. It was found to be independent of bump size (as expected) and of about 1 degree for B2H camera and 1.3 degree for B2V camera.

The beam size evolution during the blow of the beam emittance with ADT is presented. The beam is blown from width of about $\sigma = 1.1$ mm to $\sigma = 1.5$ mm, what corresponds to emittance increase from 2.7 to 5.5 μm. Comparison with BSRT measurements done in DC mode are done. Agreement is found only after performing a recalibration procedure (on the same data!).

References

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

[2] M. Sapinski, " Calibration of LHC BGI monitor with orbital bump", EDMS 1130606

[3] F. Roncarolo, priv comm.