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ASACUSA Beam Line Commissioning

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Summary

In order to obtain the challenging beam characteristics for the ASACUSA beam line experiments, a stepwise line re-commissioning is taking place. This experimental work has the aim to characterize the beam along the line upstream the RFQD to improve the transmission and the matching to the RFQ.

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1. Beam line simulation with Trace3D

The transport line previously simulated with MADX was converted into Trace3D for an easier interface and matching capabilities. Figure 1 shows the complexity of the layout: 32 m long, five bending magnets, eleven quadrupoles and only one profile monitor, located before the last doublet. This monitor, at the present stage, is configured to have an active area of 10x10 cm2 and a resolution of 3.2 mm (32 channels each side). More than six Multi Wire Proportional Chambers are scattered along the line and they are used just for the beam steering in daily operation as their resolution is not high enough to provide useful information about the beam profiles. Two circular scintillating scrapers are placed in front of the RFQ to define the input parameters trimming the beam out of the acceptance: reducing the beam visible on the plates helps finding the requested Twiss parameters.

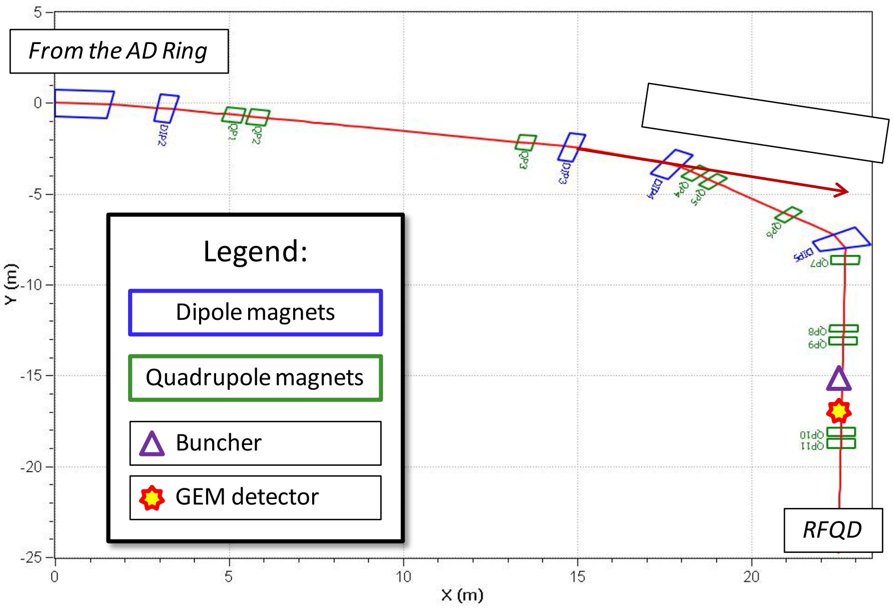

Figure 1: Sketch of the transport line to the RFQD.

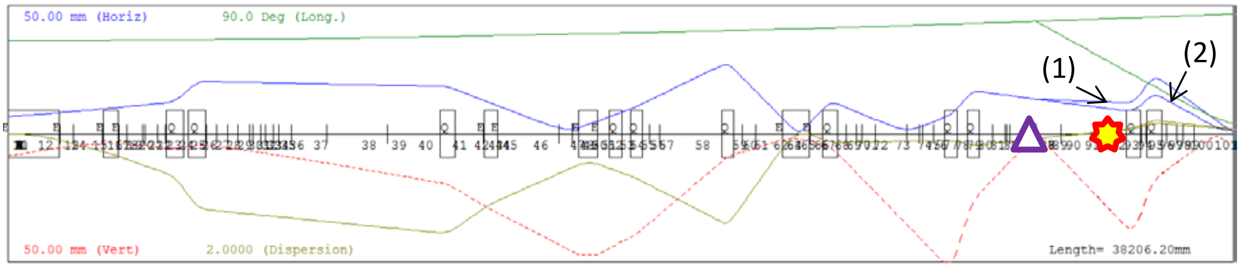

Figure 1: Trace3D simulation from the AD to the RFQ, with the buncher on (1) and off (2). The transverse emittance used is 1 mm mrad normalized total.

The beam dynamics of the line reported in Figure 2 shows that:

- The vertical envelope in nominal conditions is close to the beam pipe in three points. A slight mismatch and/or beam misalignment will cause severe beam current reduction.
- The horizontal plane is not focused at the buncher position. While the vertical Twiss parameters at the line output are independent of the operational status of the buncher, the horizontal plane is defocused while the buncher is on, as it is shown in Figure 3.
- The Dispersion function is maintained small along the line but it is not zero at the RFQ entrance. This may affect the RFQD transmission.

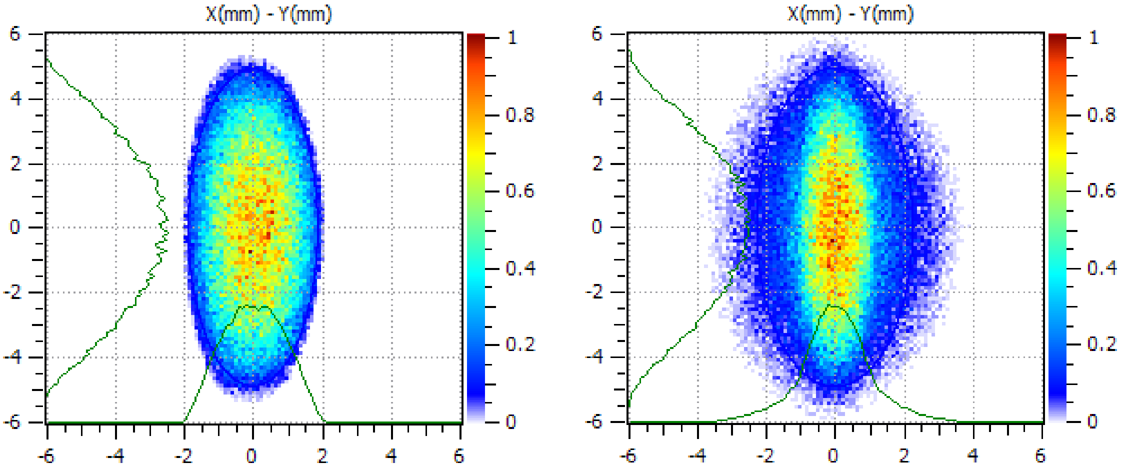

Figure 2: Beam cross section at the RFQ input with the buncher off (left) and on (right).

Before defining a new optics (see the Appendix for details) to correct the aforementioned problems, this line has to be experimentally validated. It must be proven in particular that it is able to provide the right Twiss parameters at the RFQD input at the right transverse emittance.

The GEM detector is therefore used as monitor for the reconstruction of the emittance before the second last doublet of the line: once the transverse emittance is characterized at this position, the four remaining quadrupoles will be sufficient to provide the requested matching.

2. Study for emittance reconstruction via the 3 gradients method

The three gradients method provides a straightforward solution for the problem of emittance reconstruction if:

1. The line between the active element, which is going to be varied, and the monitor is very simple (avoiding non-linearity) in order to use the matrix formalism.

2. No space charge routine is applied, as the transport matrix must be kept independent of the beam dimensions.

3. No beam is lost along the line. The variation of the rms parameter depends only on the active element effect.

4. The range of the variation of the active element is such that the effect on the beam profile is symmetric with respect to a minimum. This ensures a precise Twiss parameters calculation.

5. The monitor resolution must be high enough to have an accurate value for the minimum width. This will be reflected on the calculation of the emittance value.

Given the nominal optics of the line between the last doublet of the line and the GEM detector, the points 1-2 are clearly satisfied. Moreover, varying the current of the magnet DE1-QN40 from 20 A to 30 A one can obtain the RMS sizes of Figure 5 (point 4 ok), with the additional benefit that one can reach the minimum of both planes for almost the same quadrupole value.

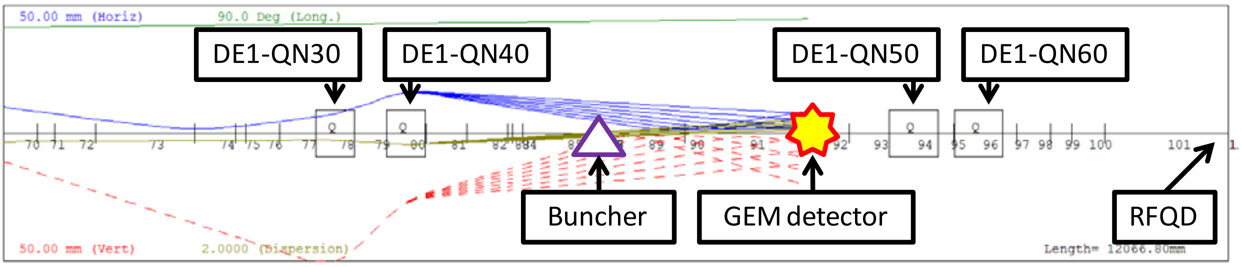

Figure 3: Sketch of the line in front of the RFQD. The beam envelopes (x in blue and y in red) are plotted for different values of DE1-QN40 current (from 20 to 30 A) and 1 mm mrad total normalized emittance.

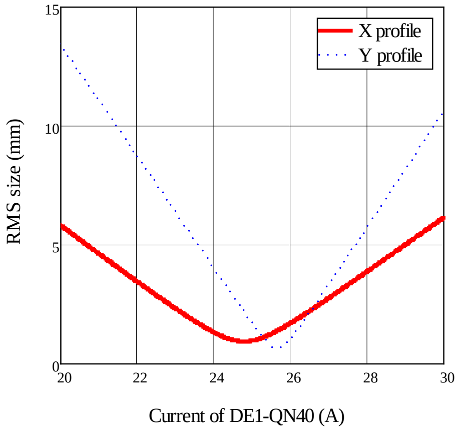

Figure 4: Transverse RMS sizes at the GEM detector as function of DE1-QN40 current for 1 mm mrad total normalized emittance.

Concerning the beam transmission along the line (point 3), the distribution will be only very marginally cut by the buncher restricted bore (15 mm), as shown in the Figure 4.

For point 5, the GEM detector resolution is 3.2 mm for the standard configuration of 32 channels ±50 mm and it can be enhanced to 1.6 mm ±25 mm. To study whether it is high enough, it is necessary to run a multiparticle code like Travel and to simulate the response of the detector to the beam for the given resolution, as shown in Figure 6.

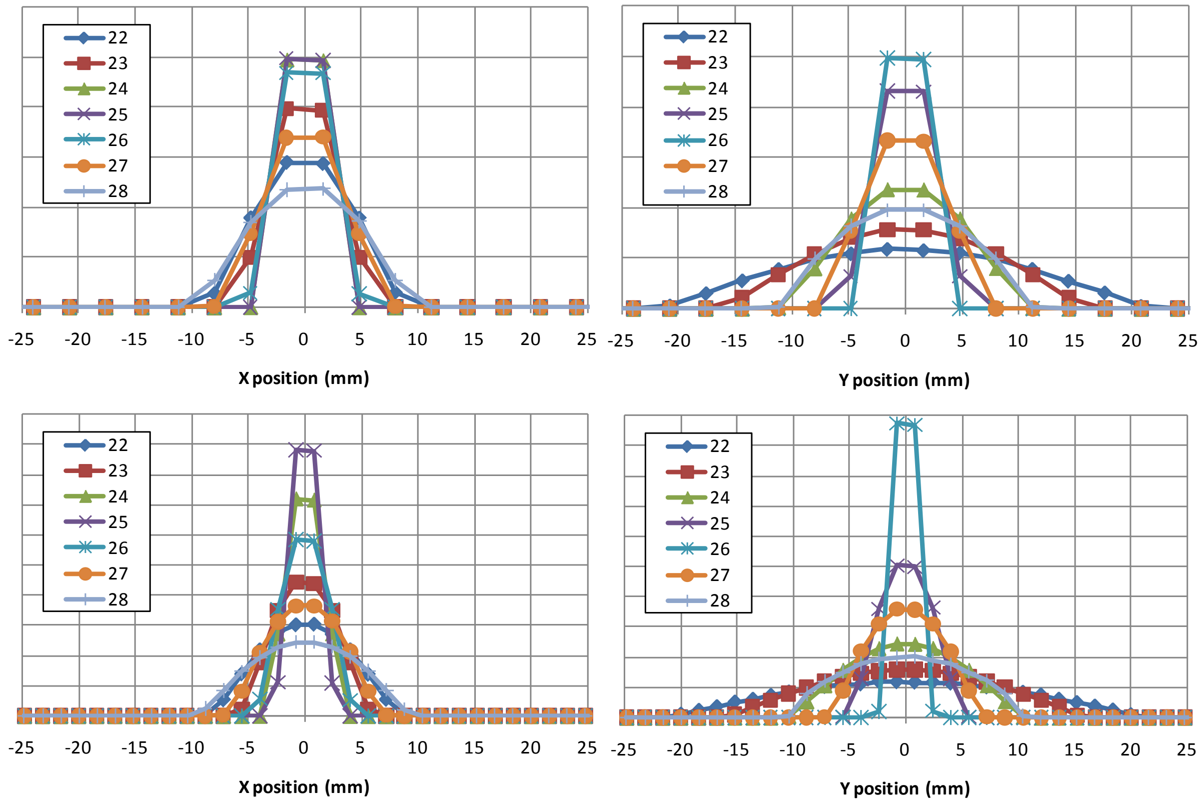

Figure 5: Beam profiles at the GEM detector at function of the current of DE1-QN40. The top graphs are obtained with 3.2 mm resolution, whereas the bottom ones with 1.6 mm.

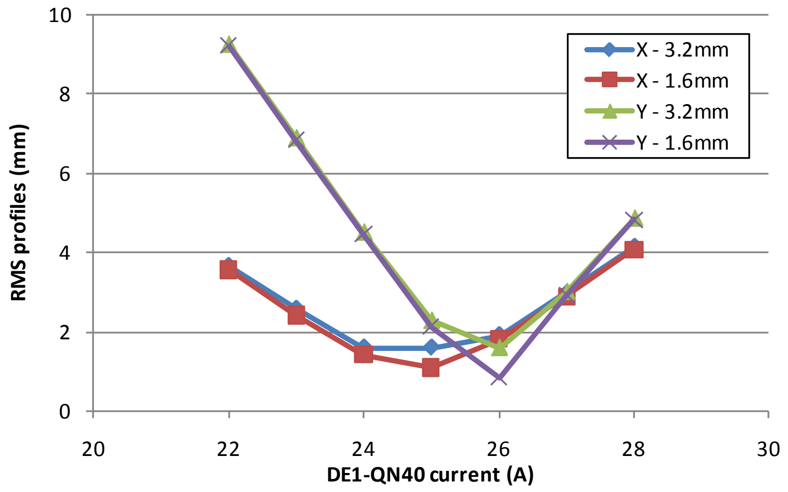

Figure 6: RMS size of the profiles as function of the current of DE1-QN40 for the given resolution.

From these plots it is possible to calculate the RMS size of the profiles, as shown in Figure 7. The resolution of 3.2 mm seems to be enough for the vertical plane, whereas for the horizontal one almost all the values are smaller than 3.2 mm. Consequently, the RMS of the minimum can be calculated correctly only for the higher resolution.

In order to find the corresponding values for the emittance at the reference point, the RMS data are fitted as shown below.

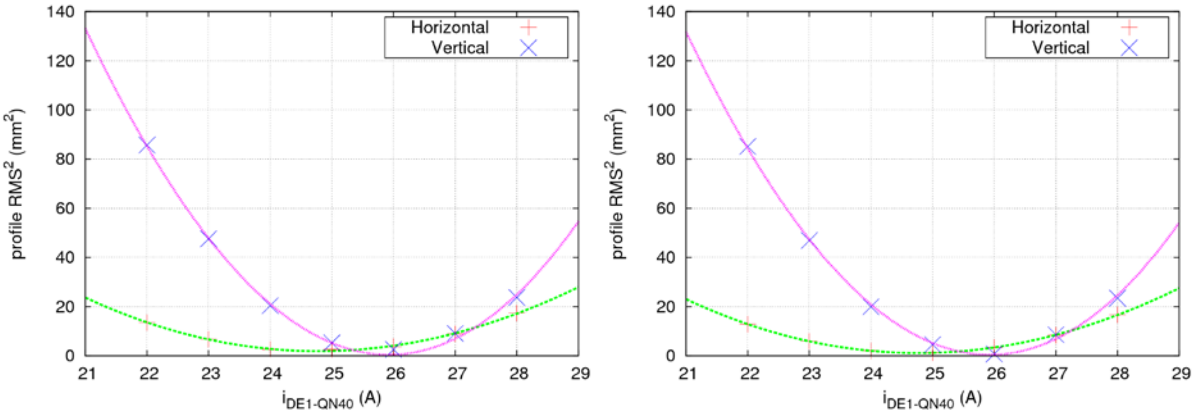

Figure 7: Fit of the RMS sizes for 3.2 mm (left) and 1.6 mm (right) resolution.

From the fit it possible to find the parameters reported in Table 1. As mentioned already, with the resolution of 3.2 mm is difficult to obtain values for the horizontal plane close to the theoretical ones. For 1.6 mm the difference is within the error.

Table 1: Emittance parameters for the different resolutions

Parameters	**Horizontal**			**Vertical**		
	theoretical	*3.2 mm*	*1.6 mm*	*theoretical*	*3.2 mm*	*1.6 mm*
α	-21.4	-15.3 ± 1.5	-20.0 ± 1.1	140.6	141.0 ± 9.1	140.8 ± 7.0
β (mm/mrad)	22.4	16.0 ± 1.6	21.0 ± 1.2	118.2	118.2 ± 7.6	118.0 ± 5.8
ε RMS (mm mrad)	1.89	2.68 ± 0.21	2.06 ± 0.10	1.85	1.75 ± 0.16	1.74 ± 0.12

3. Measurement of the profiles

For the nominal optics it is possible to obtain reliable parameters, at least for the vertical plane, with the three gradients method. Therefore the beam profiles are measured experimentally for the same range of currents of DE1-QN40. The results are reported in Figure 9. For comparison in Figure 10 the RMS values of the measured profiles are plotted with the simulated ones for the nominal emittance and for higher values: even if the current is reduced due to the losses all along the line upstream and at the buncher, the simulated profiles are sensitive to the quadrupole current, differently from what is experimentally measured. The profiles are symmetrical, they keep the same RMS value and the same integral over 100% quadrupole current variation.

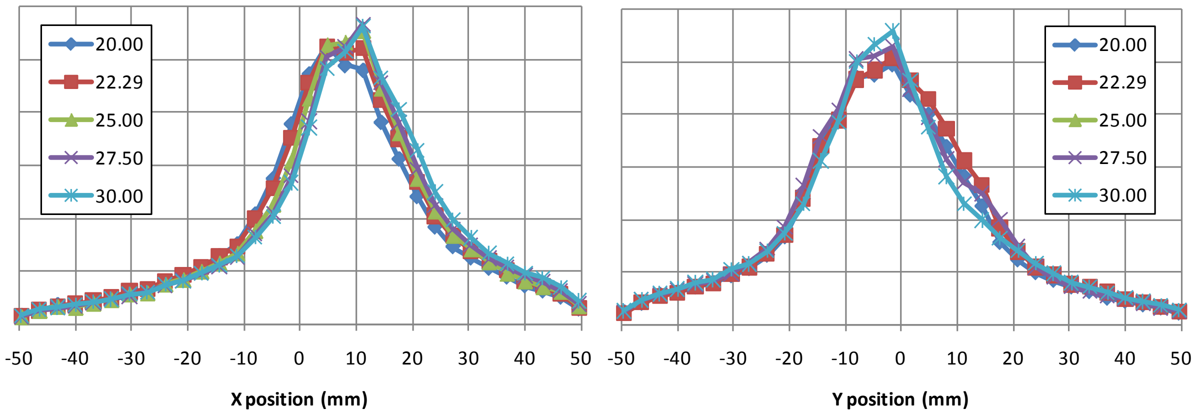

Figure 8: Measured profiles as function of the current of DE1-QN40 with 3.2 mm resolution.

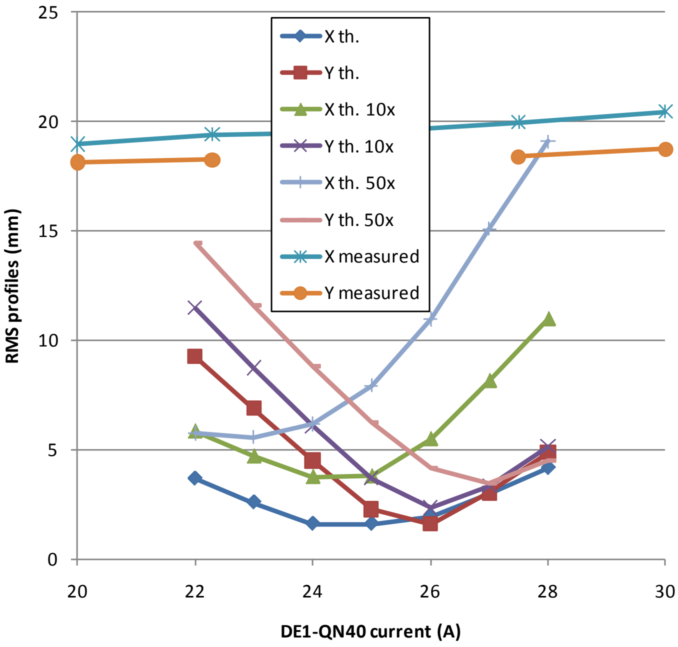

Figure 9: RMS values of the measured profiles in comparison with the simulated one, for 1, 10 and 50 mm mrad normalized total emittance.

The analysis is extended with the beam response to the DE1-QN30 current variation (Figure 11), showing the same behaviour as before. Neither the horizontal nor the vertical profiles change significantly and they keep the same integral.

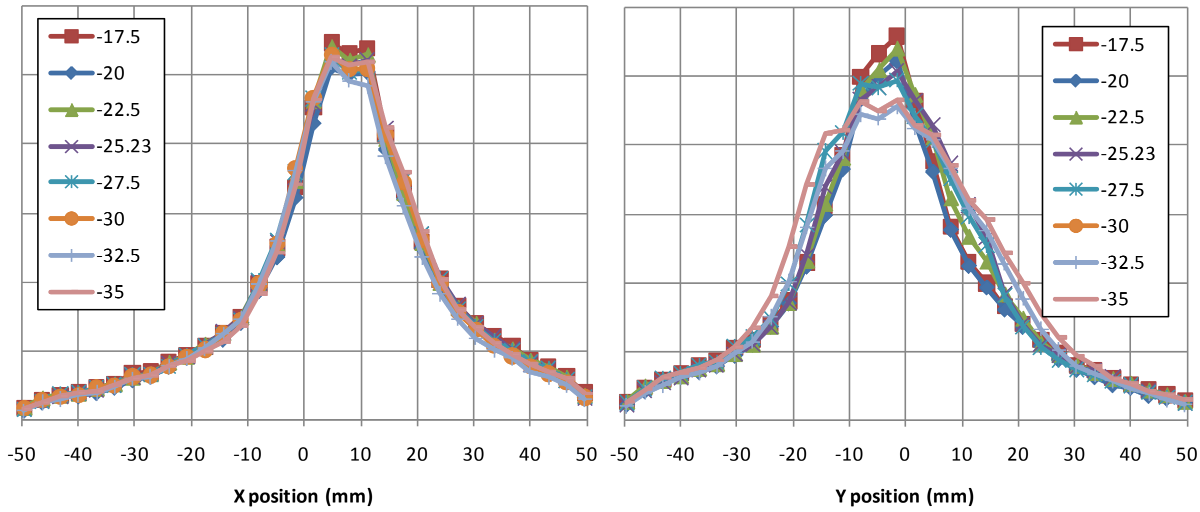

Figure 10: Measured profiles as function of the current of DE1-QN30 with 3.2 mm resolution.

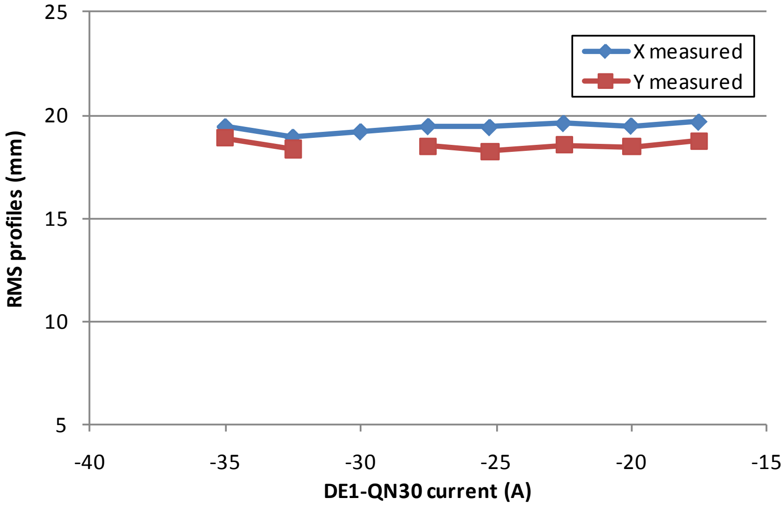

Figure 11: RMS values of the measured profiles.

4. Conclusions after the first measurement campaign

The beam profiles at the GEM detector are insensitive to the setting of the DE1-QN30/40 doublet. A series of tentative explanations of what cannot be the reason is listed hereafter:

- The GEM detector was used successfully to centre the beam, excluding the possibility that the detector signal is not reliable. A simulation of the line was performed with an emittance 10-50 times the nominal and even in this extreme case a variation of the profile at the GEM detectors should be seen.

- The beam cannot be off center and badly cut by the buncher, since the integral of the measured profiles is constant. The quadrupoles would act as steerers if the beam is misaligned, moving the beam center and therefore changing the measured current.

- The buncher cannot be too badly aligned, otherwise the profiles would not be highly symmetrical and the evidence of a cut would be there.

This brings to the conclusion that the beam is highly mismatched when it arrives at the doublet. In particular it may be focused at the doublet in such a way that the doublet has a very low effect. Together with the reduced aperture of the buncher and an emittance bigger than the nominal, it may cancel completely the evidence of focusing at the GEM detector. A way to verify experimentally could be:

- Changing the beam size at the doublet (tuning the quadrupoles upstream) and verify that the doublet has an effect on the beam.

- Removing temporarily the buncher that represents the bottleneck of the line. Move the GEM detector in DE1-MWPC45, the diagnostics box just before the buncher. Since it would be closer to the doublet, the emittance reconstruction method would be less sensitive to the quadrupole variation though. Anyway this would not be the ideal final placement (for routine operation), since the information on the buncher on/off effect would be missing.

- Adding a new the GEM detector either in the DE1-MWPC27 diagnostics box and repeating a quadrupole scan using DE1-QN20 or in DE0-MWPC42 using DE0-QN40. This configuration would allow the reconstruction of the horizontal emittance but will not be favorable for the vertical one.

5. Appendix: the new beam optics

To avoid beam scrapping along the line, especially in the vertical plane inside the bending magnets for higher emittances out of AD, a new optics is proposed which uses all the quadrupoles in the line, some of them with the opposite polarity than the nominal one (see Table 2). The other advantage of the new line is that by going through a waist in the buncher cavity, the beam optics after the buncher is fairly insensitive to the buncher settings providing an easier way to match the beam to the RFQD in the transverse planes. The Dispersion is matched before the last straight line to the RFQ. The gradients of the magnets in the new settings are within the limits.

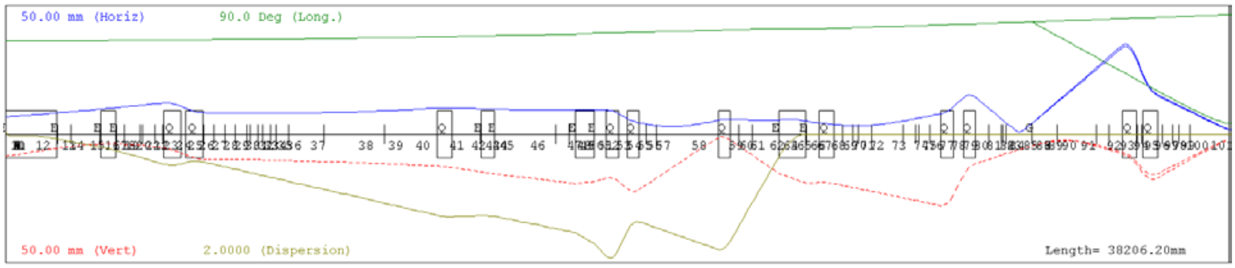

Figure 12: Trace3D simulation from the AD to the RFQ, with the buncher on and off. The transverse emittance used is 1 mm mrad normalized total.

Table 2: Comparison between the quadrupole setting of the present and new optics

Quadrupole	**Current (A)**	
	present	*new*
DE.QF07020	-25.98	-20.28
DE.QDE7030	20.56	20.53
DE0.QN10	0.82	-0.34
DE0.QN20	0.00	-19.38
DE0.QN30	-2.49	20.41
DE0.QN40	16.66	-14.22
DE1.QN20	5.13	-0.56
DE1.QN30	-24.98	23.57
DE1.QN40	22.91	-35.34
DE1.QN50	-4.21	-4.10
DE1.QN60	4.04	4.40