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EXTERNAL MAGNETIC FIELD INFLUENCE ON THE LINAC 3 BUNCH LENGTH AND VELOCITY DETECTOR

O. Dubois & C. Riviere

Introduction

A Bunch Length and Velocity Detector (BLVD) developed by the Russian Institute for Nuclear Research is used in the LINAC 3 filter line. The Pb^{27+} beam impinges on a target (a tungsten wire) and causes secondary electron emission. Afterwards, the electrons are focused and accelerated to 10keV by an electrostatic field before passing through a set of deflector plates. The electrons can then be detected using an electron multiplier behind a slit. Because of the low rigidity of the electron beam, their trajectory is very sensitive to external magnetic fields. This trajectory is corrected by a permanent magnet to make sure the electrons reach the recording system. Time of flight measurements require the movement of the BLVD along the beam. If the external field is not constant, the perturbation of the trajectory depends on the position of the BLVD. Moreover, the magnetic field might not be constant in time. Some experiments have been carried out to assess this magnetic effect and its consequences on the bunch shape and velocity measurements. The influence of different possible sources of magnetic field have been tested (PS magnets, quadrupoles in the filter line and the steerer following the detector). After new measurements, more reliable values of energy have been found.

1. Influence of PS magnet cycles

During the period of experiments, B cycles were strong magnet cycles whereas D cycles were rather weak, as the magnetic rigidity of the beam transported during the last type of cycle was lower. After two sets of 100 bunch shape measurements, one during B cycles and the other one during D cycles, the average value (denoted $\overline{X}$ for any variable X) and the standard deviation ($\sigma(X)$) of bunch centre and bunch width measurements have been derived:

Table 1: comparison of the bunch shape during B and D magnet cycles

Magnet cycles	$\overline{\varphi}$	$\sigma(\varphi)$	$\overline{\Delta\varphi}$	$\sigma(\Delta\varphi)$
B	226.91°	0.27°	1.48° or 41ps	0.021° or 0.6ps
D	226.93°	0.26°	1.46° or 40ps	0.018° or 0.5ps

One can see that the bunch centre distributions (figure 1) are very similar (almost identical averages and standard deviations). Even if the bunch width distributions (figure 2) are slightly shifted, the average bunch width difference is small enough (0.02° or 0.55ps) to be neglected. These results suggest that there is little influence of the PS cycles on the bunch center, and therefore on the energy measurements. Restriction of measurements to only D like PS cycles can be suppressed. As a consequence, maximum random errors (twice the standard deviation) can now be given for the bunch shape measurements, independent of the PS cycles:

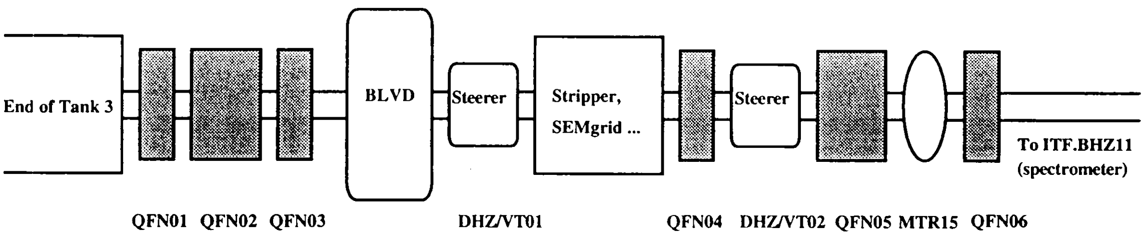
Table 2: Maximum random error for bunch shape measurements

	Maximum random error
φ	±0.54° or ±15ps
$\Delta\varphi$	±0.042° or ±1.2ps

The maximum random error does not take into account the systematic error, which one has to add to this value to find the total error interval of one measurement. Performing several measurements reduces the random error. For instance, a series of ten measurements reduces the bunch centre random error to 0.17° (5ps). Those results confirm the very good quality of the bunch shape detector and the good reproducibility of the bunch shape measurements, as mentioned by Bylinsky *et al.* in [2].

2. Filter line quadrupoles influence

There are two sets of three quadrupoles in the LINAC 3 filter line (see drawing 1). The first one (ITF.QFN01,02,03) is a triplet. It is between the output of tank 3 and the detector itself. The second set (ITF.QFN04,05,06) is between the stripper and the spectrometer magnet (ITF.BHZ11). The first set is DC, the second is pulsed.



Drawing 1: Elements of the LINAC 3 filter line (ITF) around the BLVD

2.1 Influence of the second set of pulsed quadrupoles (ITF.QFN04,05,06)

Since this set is after the BLVD (drawing 1), changing the current in the quadrupoles does not affect the lead ion beam where the detector stands. QFN04, the nearest quadrupole, is the most in a position to affect the secondary electron beam. Exploring the whole range for current in QFN04 (from 30A to 300A) showed no influence either on the bunch center or on the bunch width, for any BLVD position.

2.2 Influence of the (DC) first triplet (ITF.QFN01,02,03)

This triplet focuses the beam onto the stripper. Since the distance between the last quadrupole and the detector is only a few centimetres, it is possible to record the bunch even with currents in the triplet far from the nominal settings, or even when the triplet is off. However, the beam shape is strongly distorted transversally and longitudinally by triplet changes (figure 3). It is difficult to distinguish between the direct effects on the bunch shape and the perturbing effect of the magnetic field generated by the triplet on the secondary electrons trajectory.

After measuring the energy five times, switching the triplet off, and then on again, it has not been possible to show any change. Then, the bunch center and width versus the current in QFN01 and QFN03 have been recorded for two positions of the BLVD: upstream, i.e. as close as possible to the triplet, and downstream (37.25mm further). The intensity of the electron beam is proportional to the density and the size of the lead ion beam and therefore depends on the current in the quadrupoles. The bunch is too distorted and the BLVD's signal too small between 0 and 100A to rely on the results in this range (figure 4). On the contrary, the signal is almost maximum above 100A. As shown in figures 5 and 6, from 100A to 200A, the bunch center is shifted by 4.5°(120ps) and the width increases from 1.5° (40ps) to 3° (80ps). The same change is observed for all the positions of the detector, which explains why it had not been seen it during the previous energy measurements. This leads to suspect that this is not a magnetic perturbation but an effect of the quadrupoles on the lead ion beam.

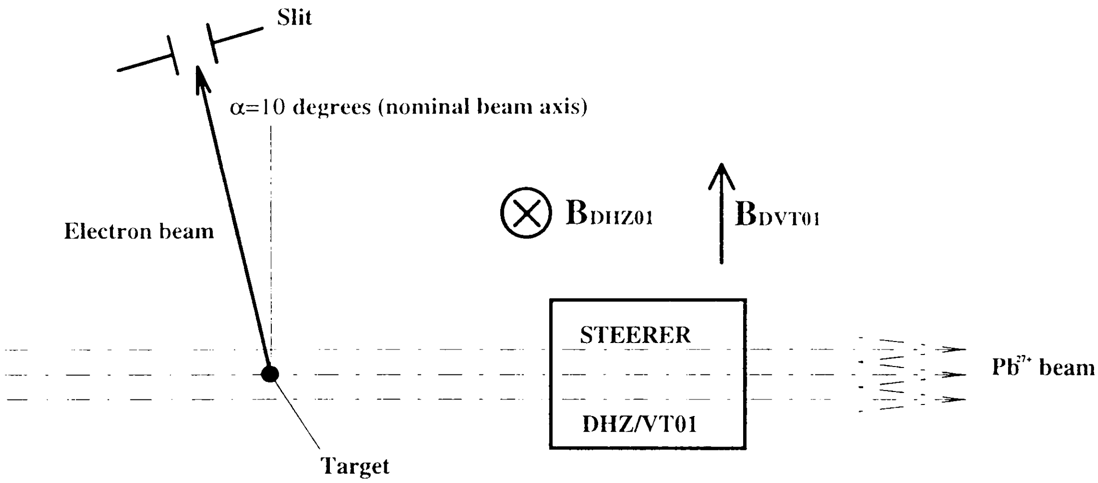
3. Steerer (ITF.DHZ/VT01) influence

A beam steerer is located immediately after the BLVD (drawing 1). The two pairs of windings generate a field perturbing the motion of the electron beam ([1]). As shown in figure 7, the bunch center, as given by the detector, linearly changes with the current in the horizontal and the vertical magnets. The coefficient $k=\partial\varphi/\partial I$, where φ is the bunch center and I the current in DVT01 or DHZ01, decreases with the distance between the target and the steerer.

Table 3: Influence of the steerer(ITF.DHZ/VT01) on the bunch center

Position of the BLVD	k_{DHZ01}	k_{DVT01}
+ 0 mm (upstream)	0.73	0.08
+10 mm	0.92	0.13
+20 mm	1.34	0.22
+30 mm	1.44	-

The horizontal steerer creates a mainly vertical field, perpendicular to the electron beam. Therefore, it changes the horizontal motion of the electrons (see schematic drawing shown below). The small vertical component of the field created by the vertical steerer is an order of magnitude less influent. However, the main component of this field, the horizontal one, changes the vertical trajectory of the electrons to the point that for certain values of I_{DVT01} a good proportion of the electrons do not reach the slit, as shown in figure 8. Since the maximum intensity is reached for $I_{DVT01} \approx 3A$, the electron beam is not perfectly vertically steered in nominal operations but the part of electrons lost is negligible (a few percents). For the +30mm position of the detector, this effect was so big that not enough reliable data have been recorded to derive the bunch centre as a function of I_{DVT01}.



Drawing 2: Top view of the magnetic fields created by the steerer and perturbing the electron beam

4. New energy measurements

It has been discovered that, whereas different origins were possible, the non homogeneous magnetic field of the steerer had the main influence on the secondary electrons trajectory. Then new energy measurements have been performed, switching DHZ/VT01 off.

4.1 New values

Since the influence of the steerer has been discovered, a total of 36 energy measurements have been performed over several days. The average energy found (see figure 9) was 4.213 MeV/u, which is almost equal to the design value (4.207 MeV/u). The distribution of those measurements is still quite wide (σ=55keV/u) but more than 60% of the values are in the range [4.175, 4.250].

4.2 Comparison between spectrometer and detector

As described by R. Scrivens in [3], an adjustment of the phase and amplitude of tank 3 allows the mean energy of the beam to be varied without significant change in the energy spread. However, and these points differ from the experiment carried out in [3], the plungers have been left to their nominal positions and the phase of tank 2 has not been adapted. To measure the energy with the spectrometer, one can use two configurations of the quadrupoles QFN04,05,06: the DØF one, where QFN04 defocuses in the horizontal plane, QDN05 is off and QFN06 focuses in the horizontal plane, and the FDF one (see TRACE runs in figure 11). Using both the DØF and the FDF spectrometer optics, a comparison of the energy changes given by the SEMgrid ITF.MSG1 (figure 10) and the BLVD gave the following results:

Table 4: Energy comparison between BLVD and spectrometer line (DØF optics)

DØF optics	Phase of T3	Amp. of T3	ΔE_{MSG10} (keV/u)	ΔE_{BLVD} (keV/u)
Reference	306°	2160	0	0
Highest energy	312°	2260	+32	+22
Lowest energy	300°	2020	-66	-47

Table 5: Energy comparison between BLVD and spectrometer line (FDF optics)

FDF optics	Phase of T3	Amp. of T3	ΔE_{MSG10} (keV/u)	ΔE_{BLVD} (keV/u)
Reference	306°	2110	0	0
Highest energy	315°	2270	+56	+75
Lowest energy	300°	2030	-42	-20

Even though the changes are somewhat different, they always have the same sign. Taking into account the small range of variation of energy (about 100keV/u) and the fact that only a small number of energy measurements has been done each time, the results agree very well.

Conclusion

This campaign of tests, after the series of improvements described in [4], led to keep only one prevailing source of magnetic influence: the steerer ITF.DVT/HZ01. Switching it off caused no problem to LINAC 3 operations and the following series of energy measurements gave an average value very close to the nominal energy (4.213 against 4.207 MeV/u). More experiments will be carried out in 1996 to reduce the dispersion of energy measurements in order to cut down the time necessary to have a very precise value. While some care and experience is required to use this delicate and sensitive tool, the BLVD turns out to be a very useful and precise detector that would deserve being integrated into the LINAC 3 control system for a more daily use.

References

[1] Bylinsky Y., Feschenko A., Liiou A., Men'shov A., Ostroumov P., Kugler H., Soby L., Williams D., *"Design and Performance Characteristics of the Bunch Length and Velocity Detector"*, 1994.

[2] Bylinsky Y., Feschenko A., Liiou A., Men'shov A., Ostroumov P. N., *"Bunch Length and Velocity Detector and its Application in the CERN Heavy Ion LINAC"*.

[3] Scrivens R., *"MD on LINAC 3 in Week 39", PS-HI Note 95-21(Techn.).*

[4] O. Dubois, A. Feschenko, C. Riviere, *"BLVD improvements", PS-HI Note 95-25(Tech).*

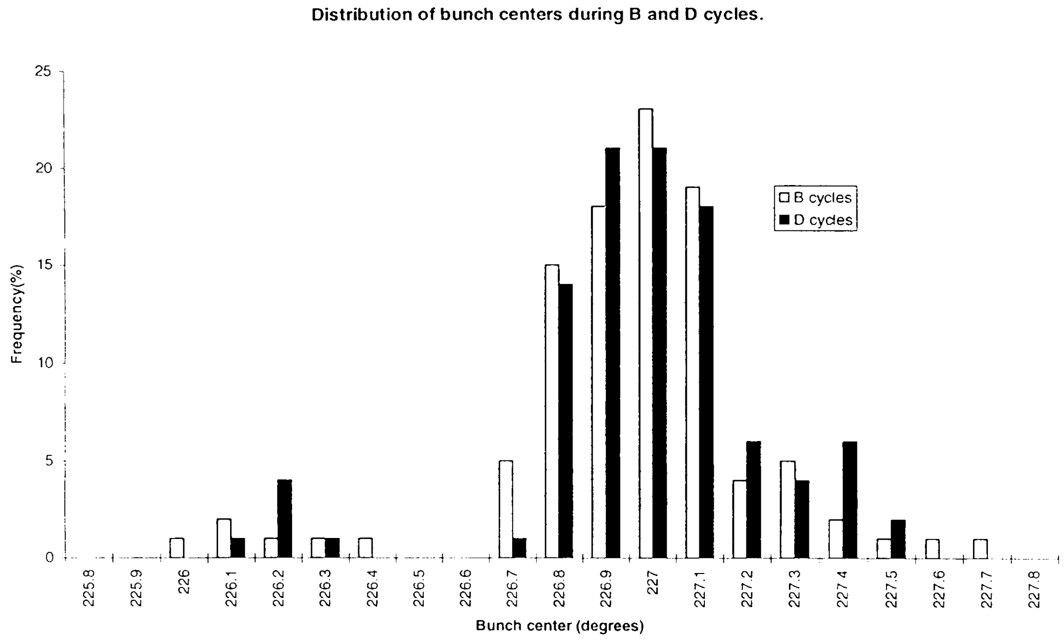


Fig. 1: Distribution of bunch center during B and D PS-magnets cycles.

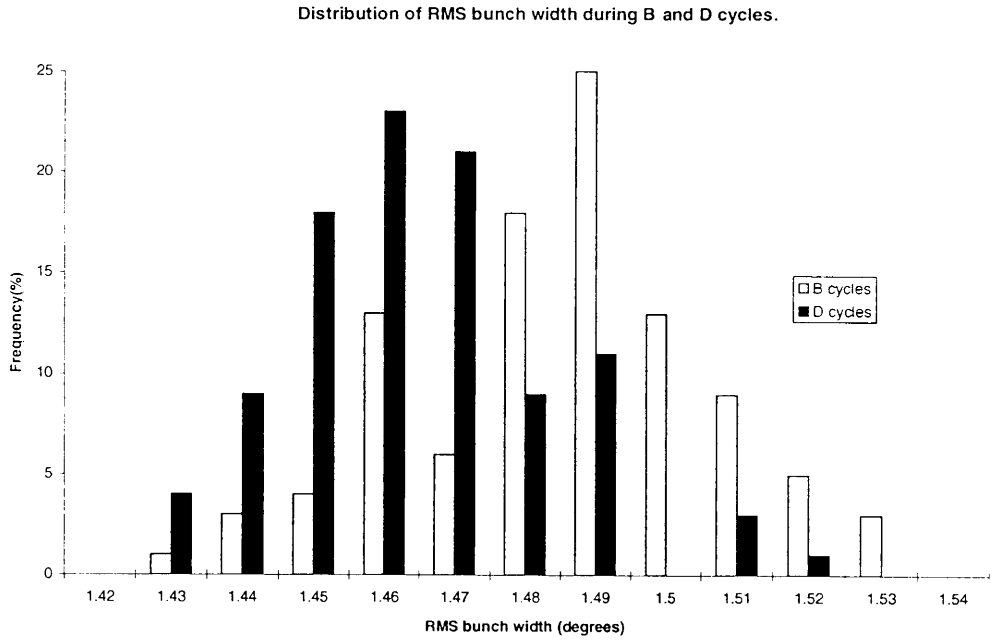


Fig. 2: Distribution of bunch width during B and D PS-magnets cycles.

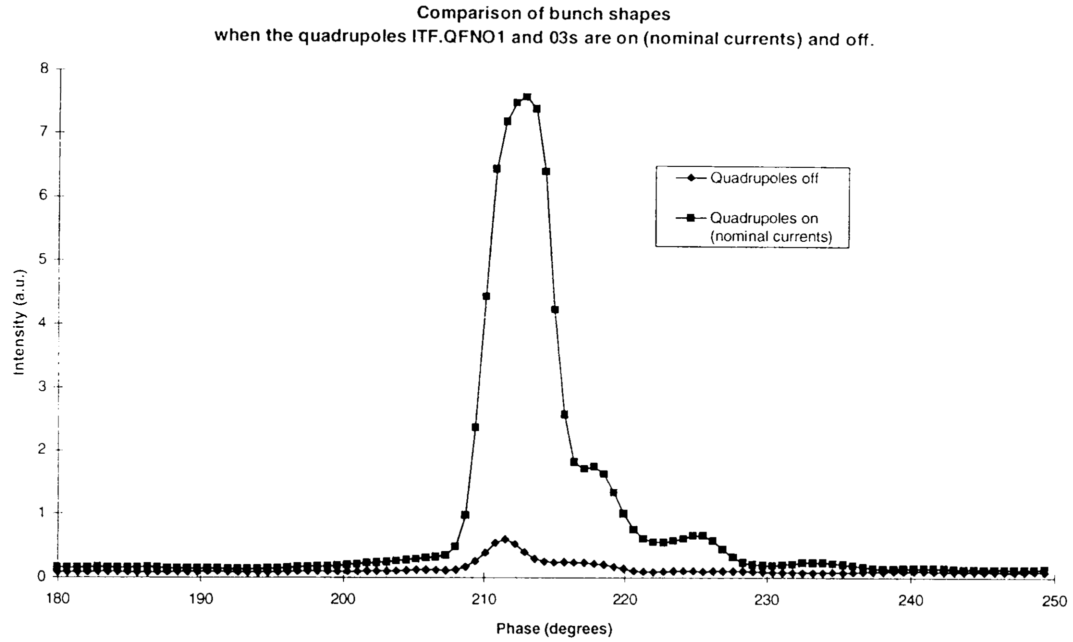


Fig. 3: Effect of switching off the quadrupoles QFN01 and 03s on the bunch shape.

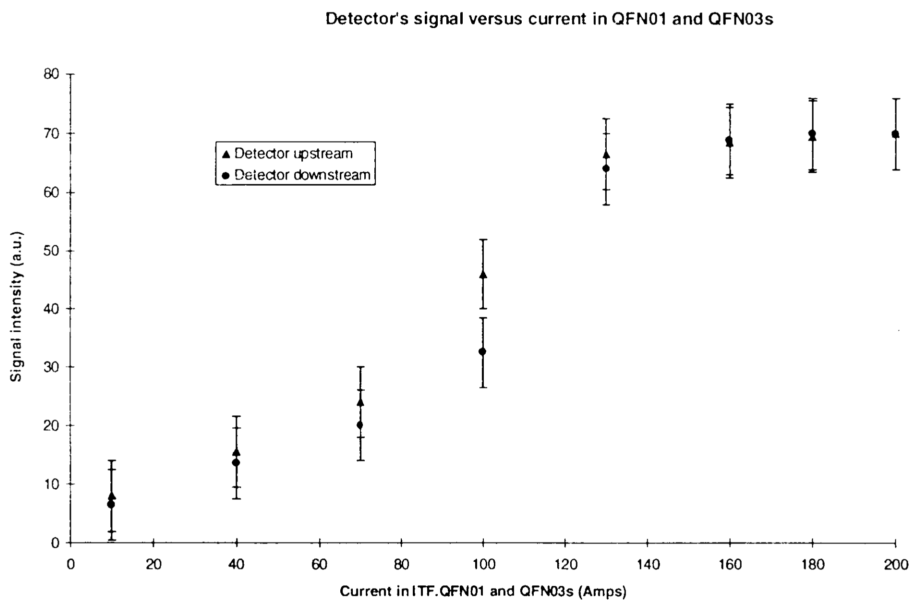


Fig. 4: Intensity of the secondary electrons beam versus current in QFN01 and 03s.

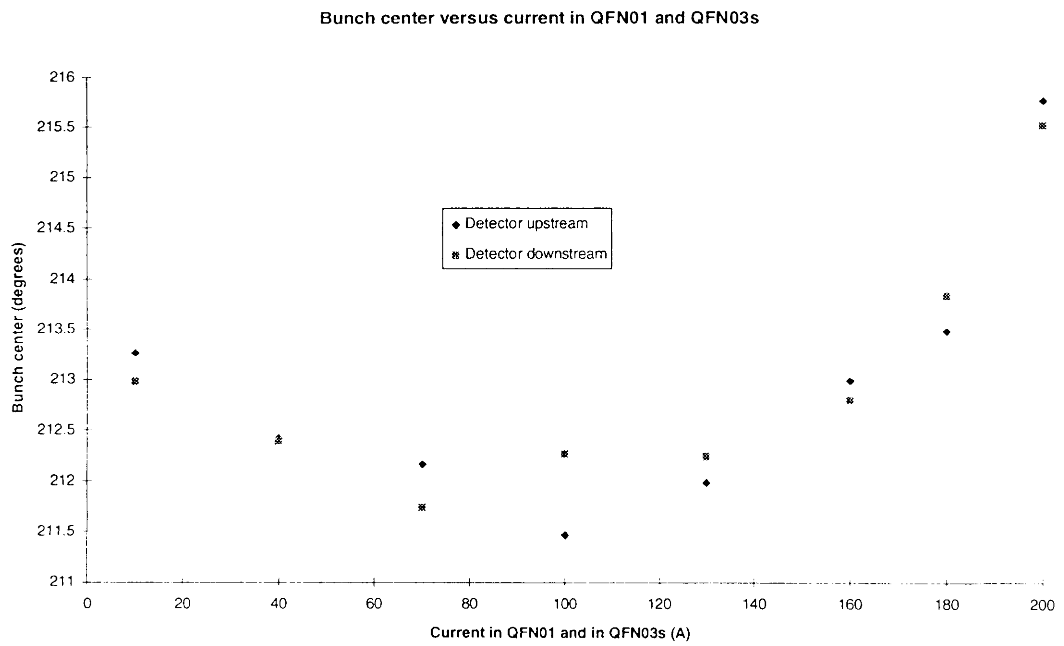


Fig. 5: Bunch center versus current in quadrupoles QFN01 and QFN03s.

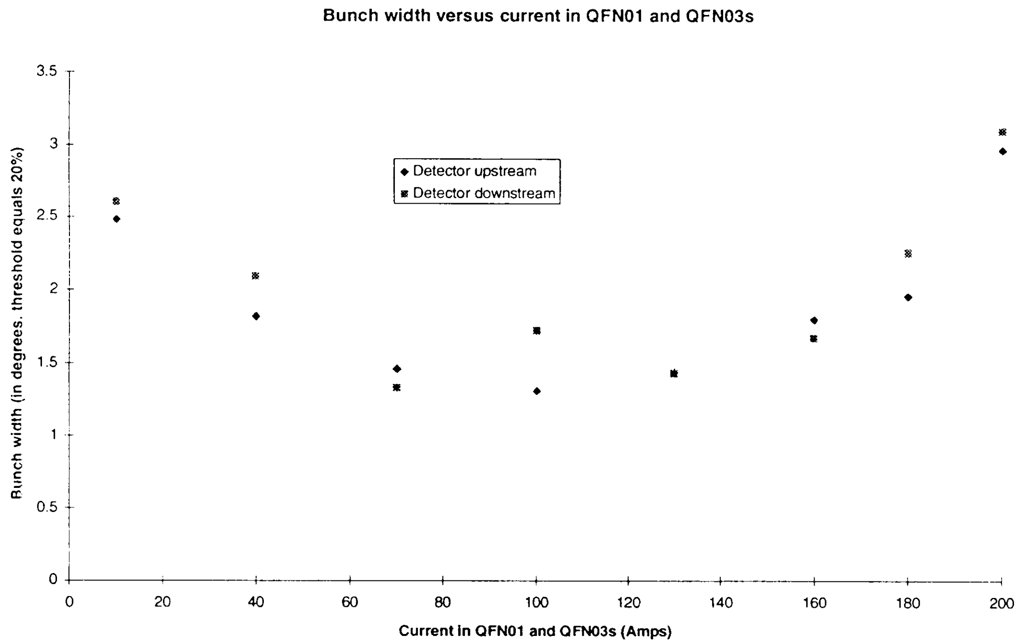
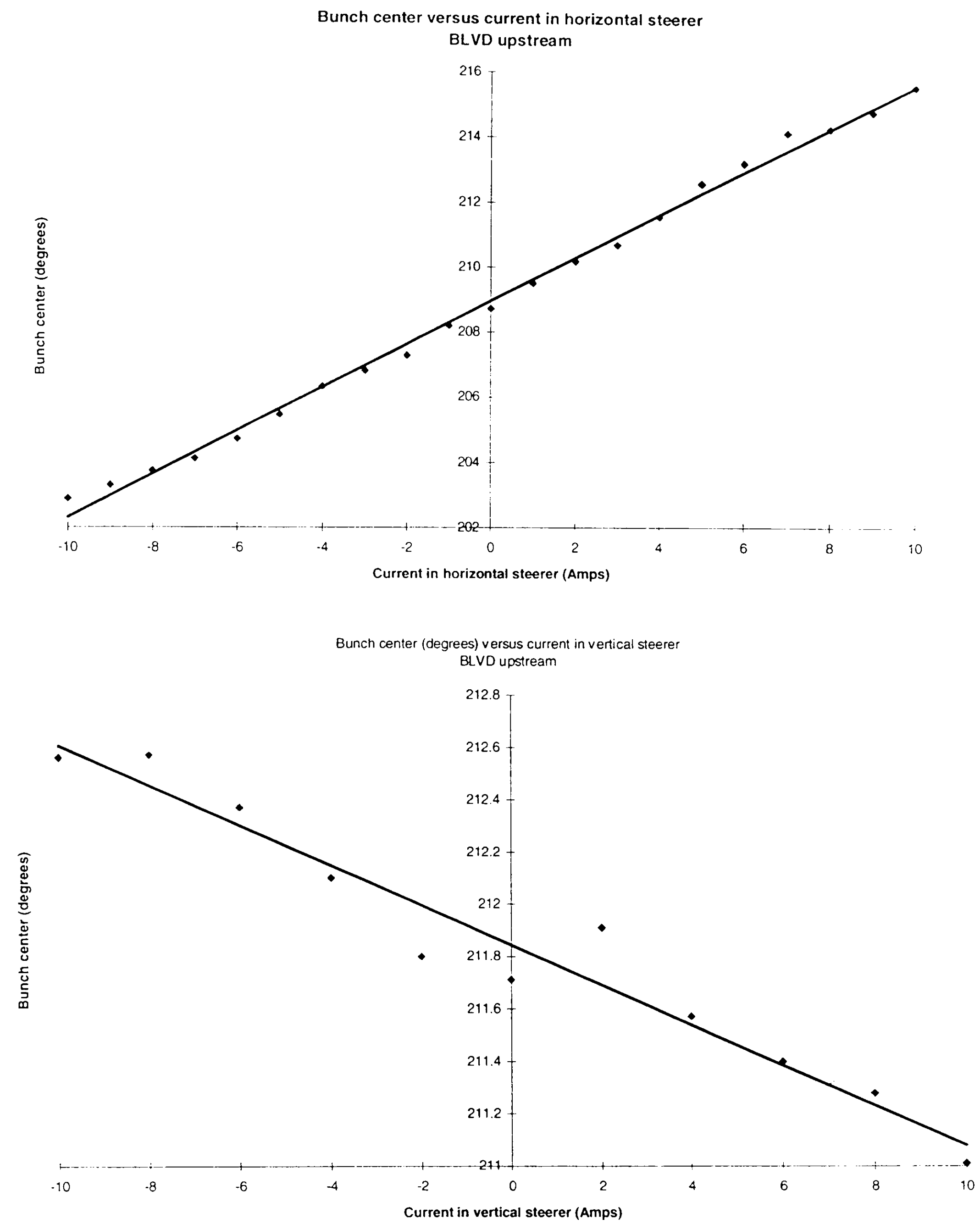


Fig. 6: RMS Bunch width versus current in quadrupoles QFN01 and QFN03s.



<u>Fig. 7:</u> Bunch center versus current in horizontal and vertical steerers (DVT/HZ01).

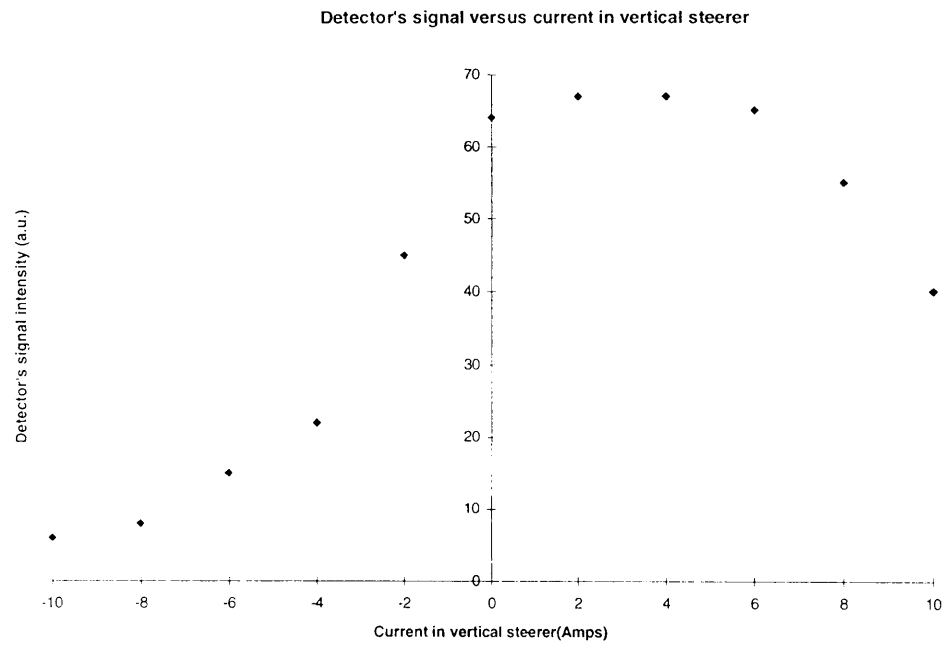


Fig. 8: Vertical steerer influence on the amount of electrons reaching the secondary electron multiplier.

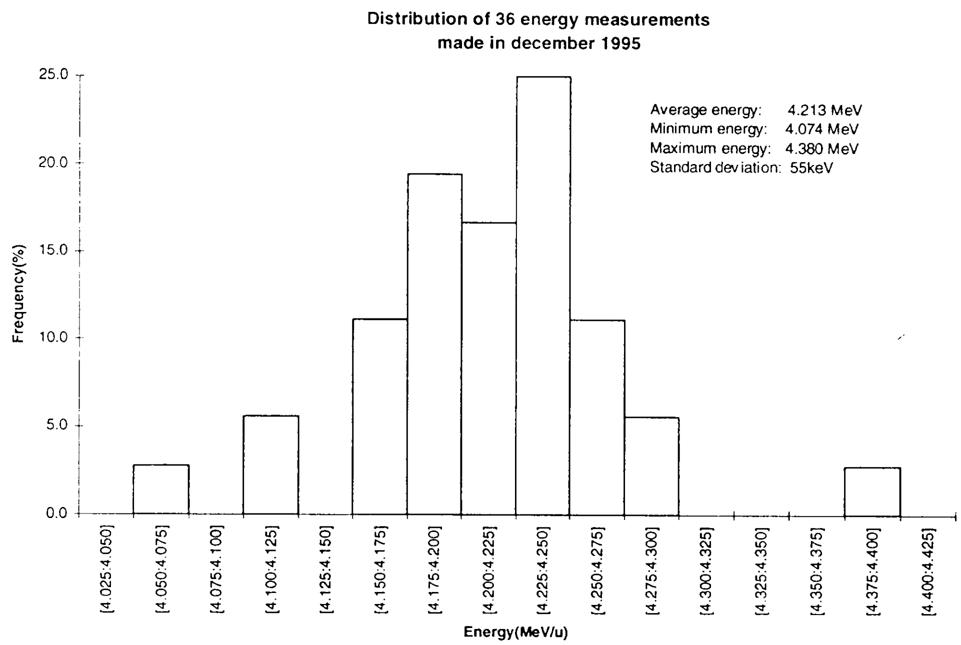
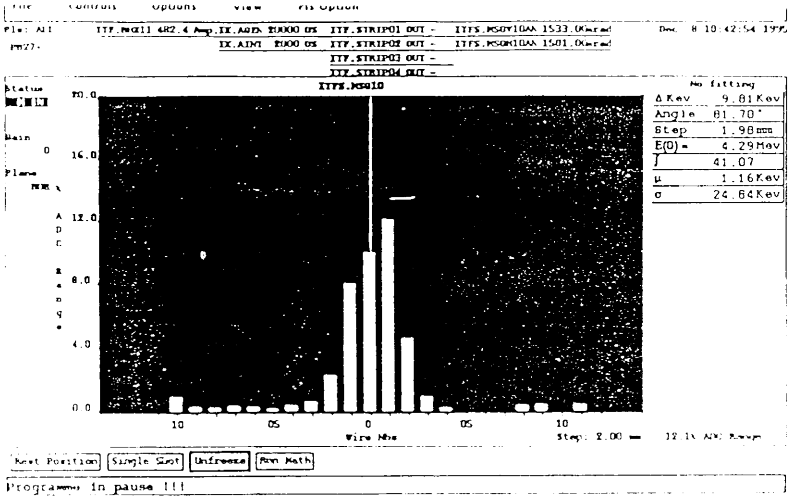
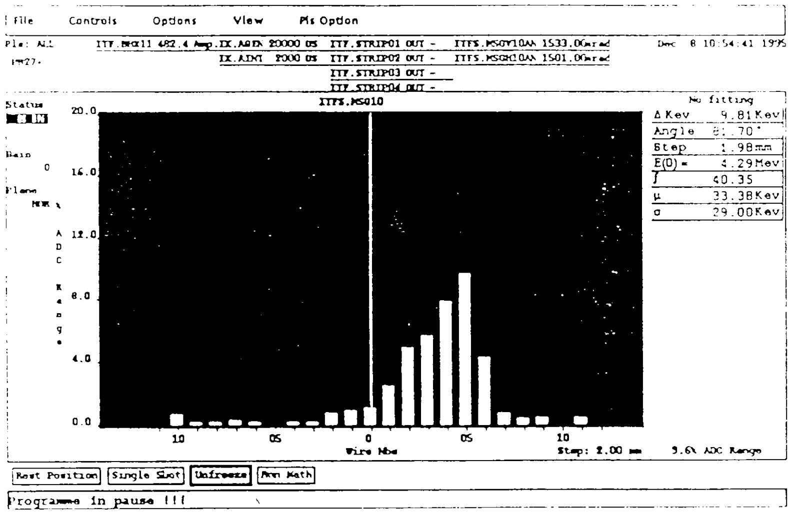


Fig. 9: Ditribution of the energy measurements made while the steerer was off.

a. ΔE_{BLVD}= 0 keV/u.



b. ΔE_{BLVD}= +22 keV/u.



c. ΔE_{BLVD}= -47 keV/u.

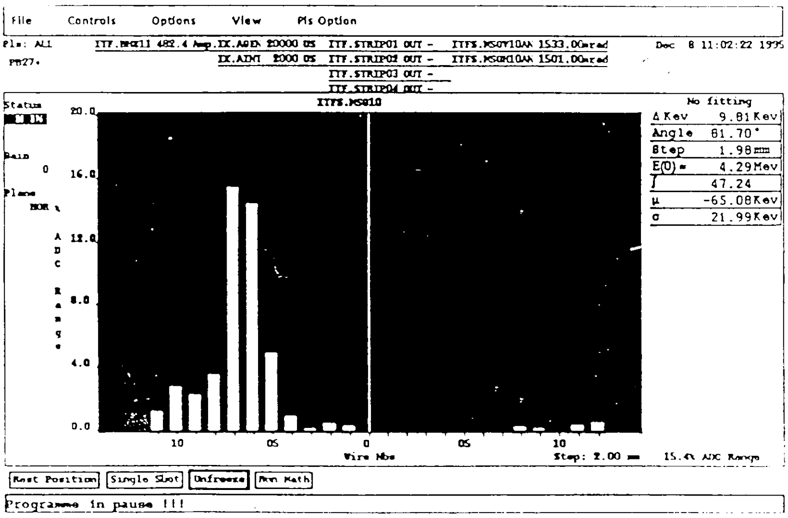
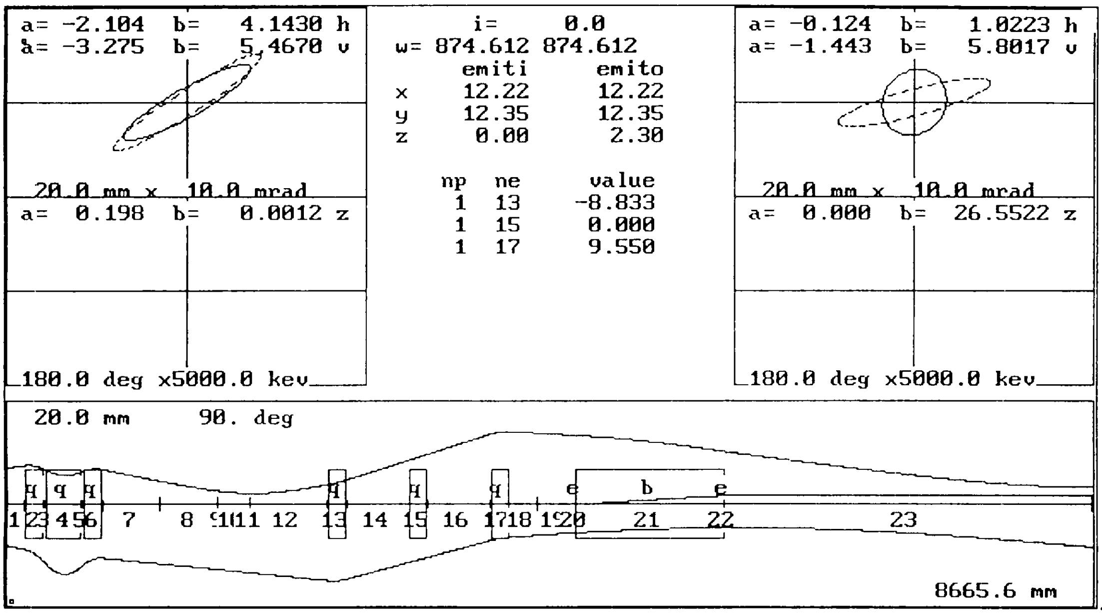


Fig. 10: Three energy measurements for Pb^{27+} beam measured in the ITF spectrometer (DØF spectrometer optics), compared to BLVD measurements.

a. DØF configuration.



b. FDF configuration.

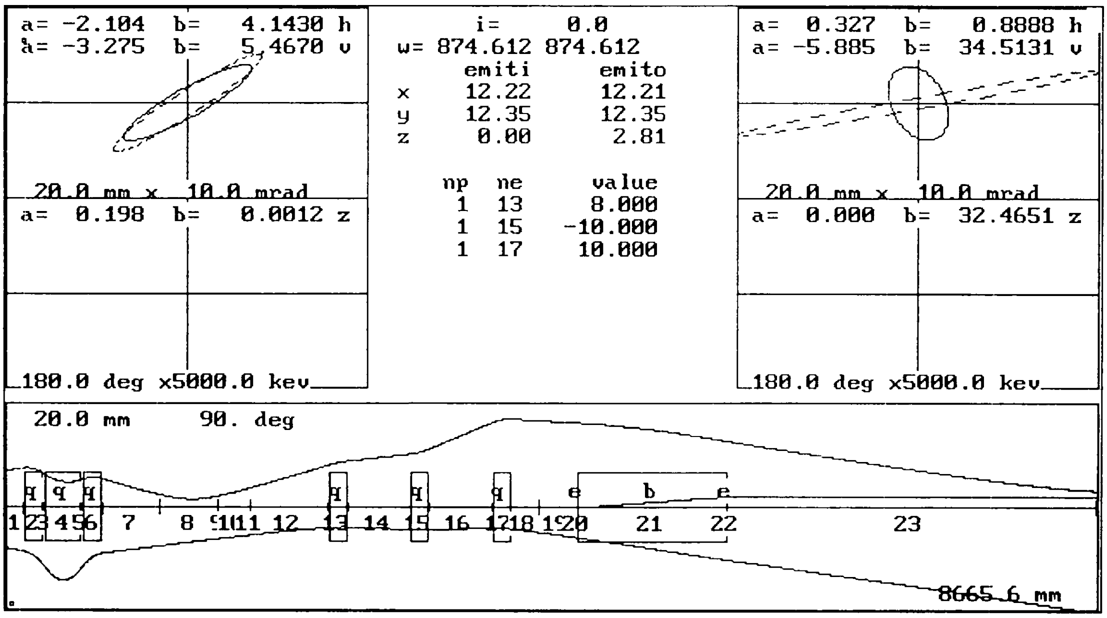


__Fig. 11:__ Trace runs with (a) DØF and (b) FDF configuration of the quadrupoles. They show that it is possible to focus the beam horizontaly on the semgrid (at the end of drift tube number 23) without defocusing it too much in the vertical plane with DØF and FDF optics. In the latest case, it is not necessary to change the polarity of ITF.QFN04 to use the spectrometer line.