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SIMULATIONS OF THE BEAM DIAGNOSTICS LINE FOR THE SPL 3 MeV CHOPPER LINE

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ABSTRACT

The IPHI beam diagnostic line will be placed after the SPL 3 MeV chopper line and will be used for measurements of the beam parameters and for setting up the line elements. The diagnostics line is equipped with sufficient beam instrumentation to measure the beam energy and energy spread, to set up the RF phase and the effective voltage of the 3 MeV chopper line bunchers and for other measurements.

Some simulations of the future measurements are presented. The procedure of setting up the RF phase and the effective voltage in the bunchers is described and the necessary formulae for calculating the beam energy and the energy spread are presented.

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INTRODUCTON

The IPHI beam diagnostic line will be placed after the SPL 3 MeV chopper line to perform measurements of the beam parameters and to check the settings of the line elements. The layout of the diagnostic line is sketched in Fig.1. It has two sections: a straight one and a bent one. The straight section consists of five quadrupoles and a dump at the end, whereas the bent section has first three quadrupoles common with the straight section, following by a spectrometer magnet with two quadrupoles downstream. Beam diagnostics devices are indicated in Fig.1.
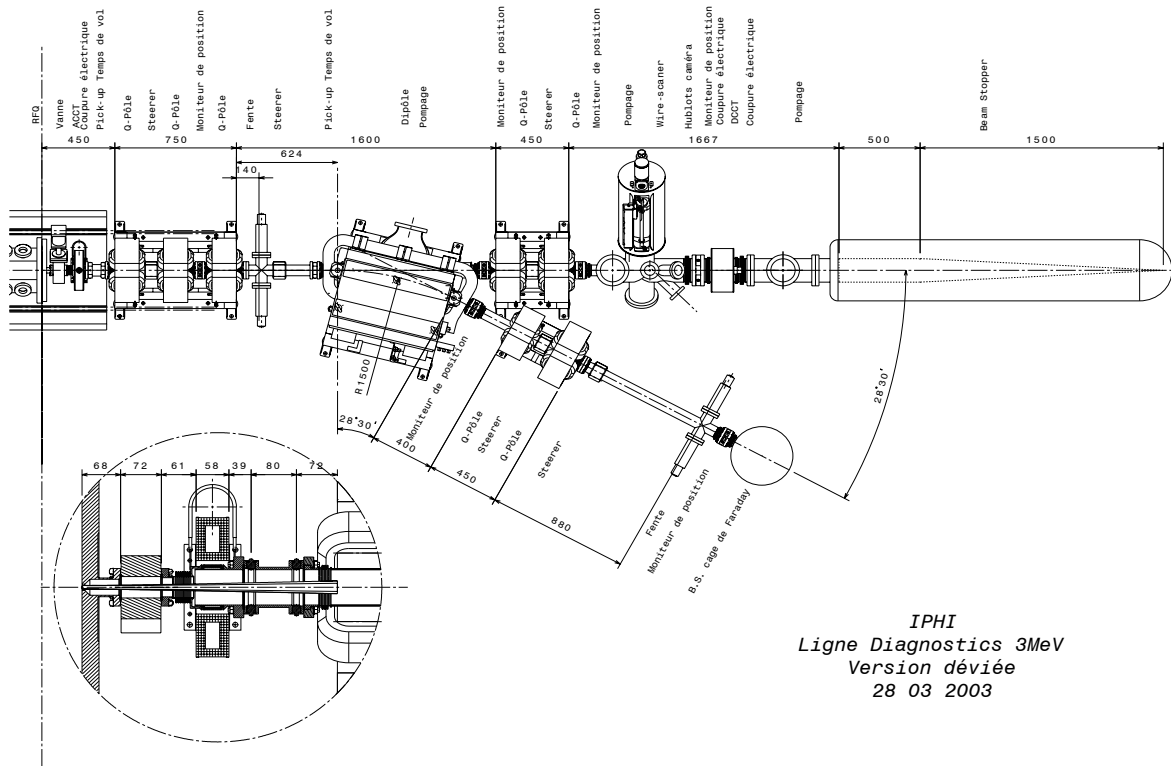

Fig.1 Layout of the IPHI diagnostics line

The diagnostic line is equipped with six Beam Position Monitors (BPM) and a Wire Scanner. A slit is used to define a narrow beam at the entrance to the spectrometer magnet. The BPMs have a resolution of about 0.1 mm and the Wire Scanner has a resolution of better than 0.05 mm. The spectrometer magnet has a central trajectory curvature radius of 1500 mm and bending angle of 0.5 rad.

In the following sections some simulations of the future measurements are discussed. The chopper line input beam parameters are summarized in Table 1.

Table 1. Chopper line input beam parameters

Energy	3.016 MeV
Current	40 mA
Norm. RMS emittances x/y	0.2647 / 0.2641 π mm.mrad
Long. RMS emittance	120.5 π deg.keV at 352 MHz
Twiss parameters	X: $\alpha = 0.7711$, $\beta = 0.1823$ mm/π mrad Y: $\alpha = -1.5602$, $\beta = 0.3766$ mm/π mrad Z: $\alpha = 0.3439$, $\beta = 0.47856$ deg/π keV

1. SIMULATIONS OF MEASUREMENTS IN THE STRAIGHT SECTION

In the straight section of the diagnostic line one could envisage the beam emittance measurements using the following methods: either by measuring the transverse beam dimensions with a fixed screen and varying the quadrupole settings or by measuring the beam profiles at different places along the line with a fixed optics. Since only one Wire Scanner is available in the line, the first method could be applied. The beam size in x and y is measured as a function of the gradient of the quadrupole preceding the screen. Knowing the transfer matrix between the position where we want to measure the emittance and the screen, one can calculate the beam emittance from three measurements of the beam size corresponding to three different settings of the quadrupole. This method is well described in [1].

However, this method is not valid when nonlinear effects such as space-charge are present. In our case the beam current is 40 mA and this method underestimates the emittance by 50%. In our condition a similar method can be used for the emittance estimate. Presented in Fig.2 is the transverse beam size as a function of the 4th quadrupole gradient for emittances different from the nominal (expected) one.
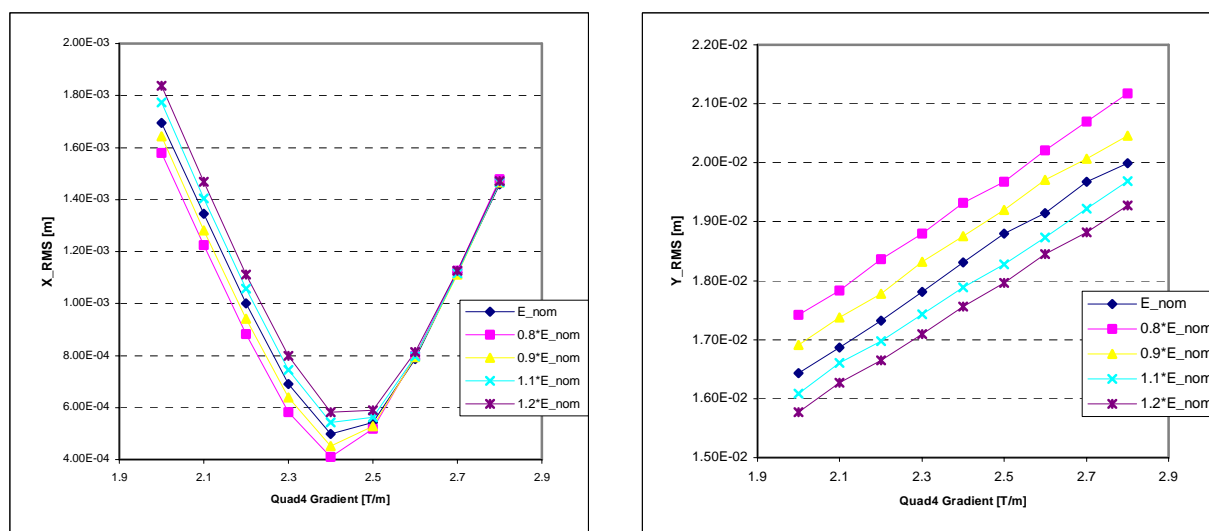

Fig.2. Transverse beam size at the Wire Scanner location
as a function of the 4th quadrupole gradient

From the plots one can see that the horizontal beam size is a parabolic function of the gradient and it has a well pronounced minimum, while the vertical one is a linear function. The minimum is very easy to identify with a quadrupole scan and the relative position of the minimum does not depend on the quadrupole calibration. From the plots for the x size one can see that the curves for emittances smaller than the nominal are shifted down w.r.t. the curve for the nominal one and the curves for emittances bigger than the nominal one are shifted up and they all have the minimum at the same value of the quadrupole gradient. Under these conditions we can estimate the emittance by comparing the minimum with the value of Fig.2. The resolution of the Wire Scanner (0.05 mm) allows us to estimate the emittance with a precision of 10%. A similar situation is obtained for the vertical plane by reversing the polarities of the quadrupoles. The result is presented in Fig.3.
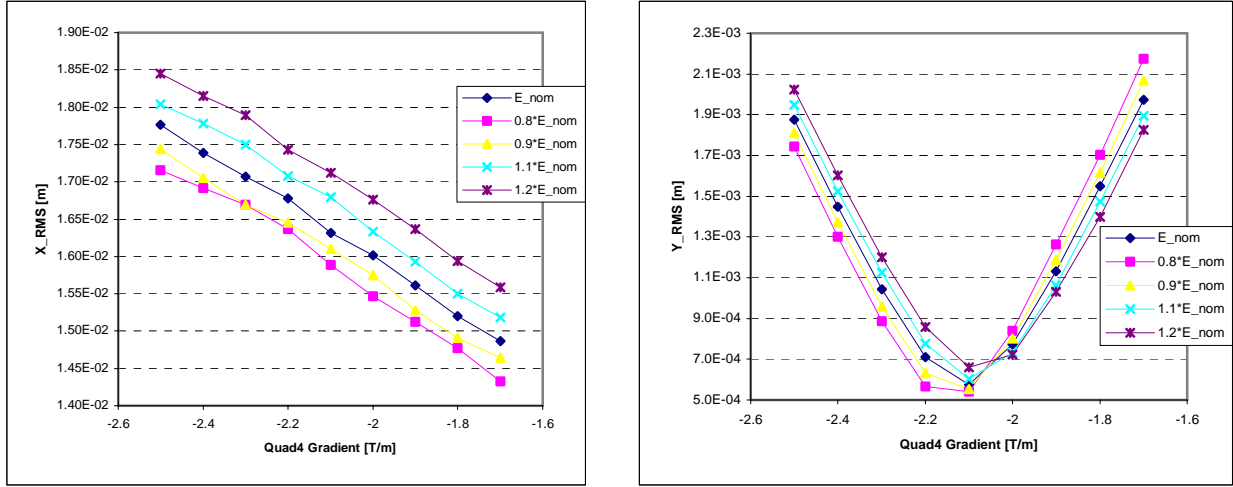

Fig.3. Transverse beam size at the Wire Scanner location as a function of
the 4th quadrupole gradient (reversed)

A shift of the minimum on the horizontal axis, i.e. a shift in the quadrupole gradient, would mean a wrong quadrupole calibration.

2. SIMULATIONS OF MEASUREMENTS IN THE BENT SECTION

Several measurements can be done using the spectrometer magnet in the bent section of the measurement line. The spectrometer has a bending angle of 28.5 deg and a radius of curvature of the central trajectory of 1.5 m. First of all one should set the correct RF phase and voltage in all three buncher cavities in the chopper line with the help of the spectrometer. The nominal effective voltage in Buncher 1, 2 and 3 is 145 kV, 70 kV and 130 kV respectively and the RF phase is –90 deg for all three buncher cavities. The procedure for setting the RF phase is the following. First, the RF phase and the maximum effective voltage in Buncher 1 are set to an arbitrary value (more or less close to the nominal values), Buncher 2 and 3 are off. The spectrometer field is set for the nominal beam energy and is obtained from the expression

$$B[T] = \frac{1}{300Z\rho}\sqrt{W^2 + 2WE_0} \qquad (1)$$

where ρ is the curvature radius of the central trajectory in m, Z is the charge state, W is the beam energy in MeV and E_0 is the rest mass of the particle (H^-) in MeV. The beam profile is obtained from the BPM. Independently from the voltage applied to Buncher 1, there should be no energy gain in the buncher if the RF phase is correctly set to the nominal –90 deg and thus the beam profile is in the centre of the BPM. As at this stage there is an uncertainty in the initial value of both the RF phase and the voltage, one cannot obtain the value of either directly from the energy calculation. Thus, the only way to ensure that the RF phase is correctly set is to change its value until the beam is centered in the BPM. After the beam profile is centered in the BPM there is still an uncertainty about whether the obtained RF phase is set to –90 deg or 90 deg, which can be easily derived from the direction of the beam movement from the central position in the BPM. Scanning the RF phase over the full range and calculating the energy one would obtain the beam energy as a function of the buncher phase as shown in Fig.4.
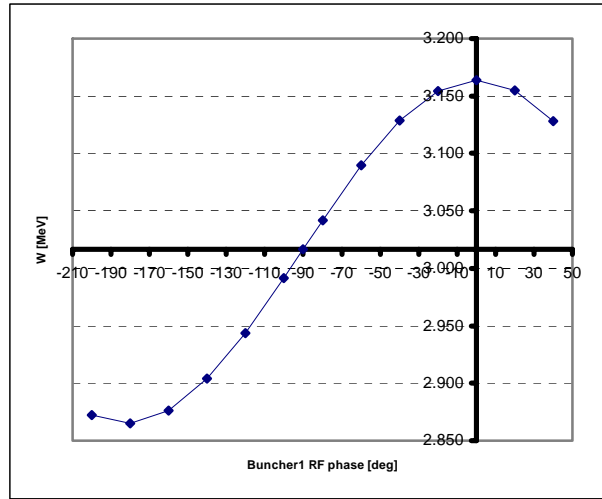

Fig.4. Mean energy vs. RF phase in Buncher 1

Once the correct RF phase has been obtained, the effective voltage can be set. To set the maximum effective voltage one needs to set the RF phase to 0 deg, i.e. 90 deg up from the nominal (-90 deg). In that case we will have

$$W = W_0 + V_{max} \cos \varphi = W_0 + V_{max} \qquad (2)$$

That means, knowing the energy of the beam we can obtain the value of the effective voltage in the buncher cavity. If the voltage is set correctly to its nominal value and the spectrometer field corresponds to the energy $W = W_0 + \Delta W_{max}^{nom}$, where ΔW_{max}^{nom} is the maximum energy gain for the nominal effective voltage, then we would see the beam profile in the centre of the BPM. Otherwise it will be shifted from the central position (see Fig.5).
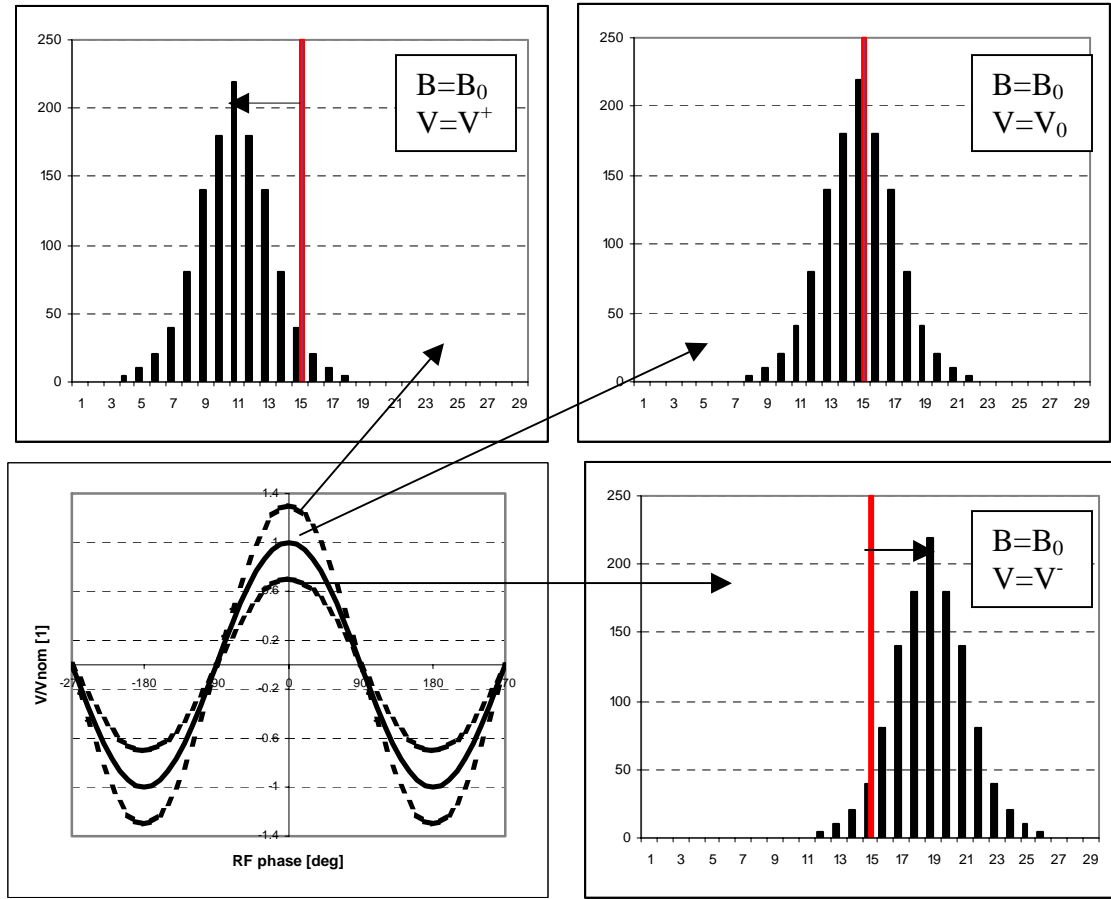
Fig.5. Beam profile on the BPM corresponding to
the voltages different from the nominal one

Thus, according to Fig.5 if the beam profile is shifted to the right (left) from the central position in the BPM one should increase (decrease) the voltage to center the beam and thus, to obtain the nominal value for the effective voltage. The energy (or the voltage) can be calculated from the expression:

$$W = \left(\frac{2\Delta x}{\alpha L} + 1 \right) W_0 \qquad (3)$$

where Δx is the beam displacement from the central position in the BPM, $\alpha = 0.5 rad$ is the bending angle of the spectrometer magnet, $L = 2345 mm$ is the distance between the center of the magnet and BPM and W_0 is the nominal energy. The spectrometer field required to bring the shifted beam profile to the center in the BPM can be calculated from (1) or the opposite, the beam energy (or the voltage) can be calculated also from the magnet field, applied to re-center the beam profile. The energy and the maximum effective voltage at 0 deg RF phase are linear functions of the magnet field required to re-center the beam (see Fig.6).
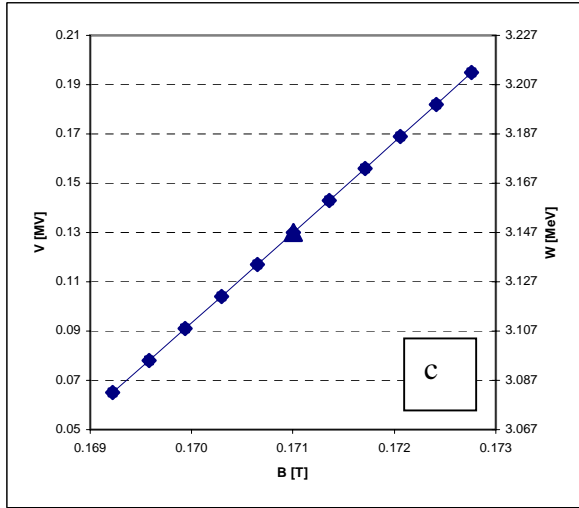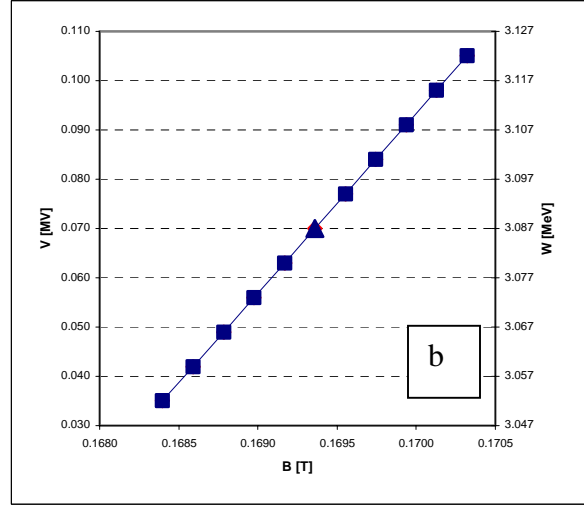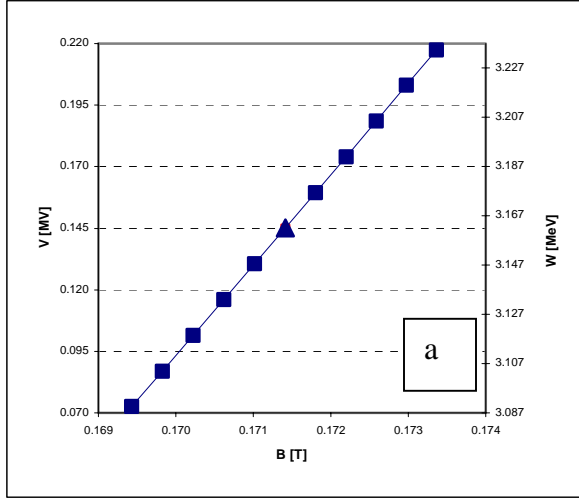
Fig.6. Mean beam energy and maximum effective voltage in the bunchers vs. magnetic field in the spectrometer: a) for Buncher 1, b) for Buncher 2 and c) for Buncher 3

The procedure described above is applied to Buncher 2 and then to Buncher 3.

Another measurement that can be done using the spectrometer magnet is the energy spread measurements for the nominal beam. The energy spread is calculated from the expression:

$$\frac{\Delta W}{W_0} = \frac{2\Delta x}{\alpha L}. \qquad (4)$$

The meaning of the parameters is the same as in (3), except $2\Delta x$, which is the beam full width in this case. For this measurement the spectrometer field should be set for the nominal beam energy and the quadrupoles after the spectrometer magnet should be off. The first slit in the line is used to select a narrow sample of the beam to go through the magnet in order to make the beam size resulted from the betatron motion much smaller than the beam size resulted from the energy spread. The beam profile is built up by means of the second slit, the BPM and the Faraday Cup placed at the end of the bent section. The slit is moved across the beam and the intensity of the beam passing through the slit in different positions is measured in the Faraday Cup. Then, the beam profile is build up from the intensities in each position. Then Δx is measured and the

energy spread is calculated from the expression (4). As an example, the simulation gives $\Delta x = 13mm$ and $\Delta W / W = 2.02\%$, while calculating the energy spread by (4) using the value of the beam size from the simulation we obtain $\Delta W / W = 2.22\%$ that is ~10% difference.

CONCLUSIONS

The IPHI 3 MeV beam diagnostics line provides sufficient beam instrumentation for setting up RF phase and effective voltage of the bunchers and for measurements of the energy and the energy spread of the beam. Simulations of the future measurements have shown a good agreement with presented formulae and methods for the measurements campaign. With the available means one can give a good estimate for the beam emittance.

REFERENCES

[1] K. Hanke, Measurement of Picosecond Electron Bunches in a Linear Accelerator, DESY - TESLA 97-19.