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Study of a spectrometer line for the Linac4 diagnostics movable bench

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Abstract

A movable diagnostics bench is currently being designed as part of the Linac4 commissioning plan to characterize the H-beam at the exit of each DTL tank. A spectrometer line has been proposed for installation on the bench to allow performing measurements of the beam energy spread with a slit/dipole/monitor technique. A layout for this diagnostics line is here proposed together with the results of beam dynamics studies to evaluate the resolution achievable and the measurement reach.

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1. Introduction

A movable diagnostics bench is currently being designed as part of the Linac4 commissioning plan.
The bench will be positioned directly after each of the DTL tanks (which will be commissioned one by one) and will be used to characterise the beam through a full suite of instrumentation devices: beam profile measurements, pick-ups, beam current transformers etc.
A spectrometer line has been proposed for installation on the movable bench to allow energy spread measurements of the beam coming out of the DTL tanks (using a slit/dipole/monitor technique), and possibly also complement other devices in the characterisation process of the RF tanks.
Beam dynamics studies have been carried out to specify a potential layout and assess the precision level that could be achieved in the measurements.

2. Layout

Space restrictions in the Linac4 machine tunnel put some constraints on the geometry of the line (see Fig.1). In particular, given the planned tunnel half-width of approximately 220cm and allowing 80cm at the end of the spectrometer line for the beam monitor, dump and any free space required, the spectrometer magnification factor, expressed by

$$\Delta x = k \cdot \frac{\Delta W}{W}, k = \frac{L\alpha}{2}$$

is limited to values near unity (k~1) for angles in the 40 to 60deg range. In other words, the dispersion locally generated at the spectrometer magnet converts the relative energy spread at the slit (downstream of the DTL tank) into transverse beam size spread at the monitor according to a 1:1 ratio.

An angle α=45deg was assumed in the layout and a distance L=2.3m between the center of the dipole and the beam monitor.

Starting from the beam energy spread values at the end of each tank, as obtained from end-to-end simulations, the resolution that could be achieved with such a scheme from a purely geometrical point of view (i.e. without tracking or including space charge effects) is given in Table 1.

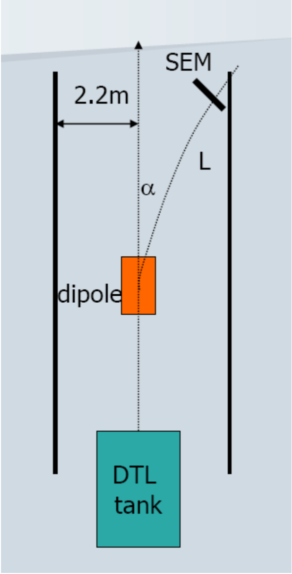

Figure 1 Sketch of possible implementation of a spectrometer line.

Table 1 Geometrical resolution of the spectrometer line. Beam size and energy spread are 2.2σ values.

	W[MeV]	90% ΔW[keV]	90% Δx [mm]	Res. [keV/mm]
Tank1	12.2	83	6	14
Tank2	31.8	150	4.3	35
Tank3	50	165	3	55

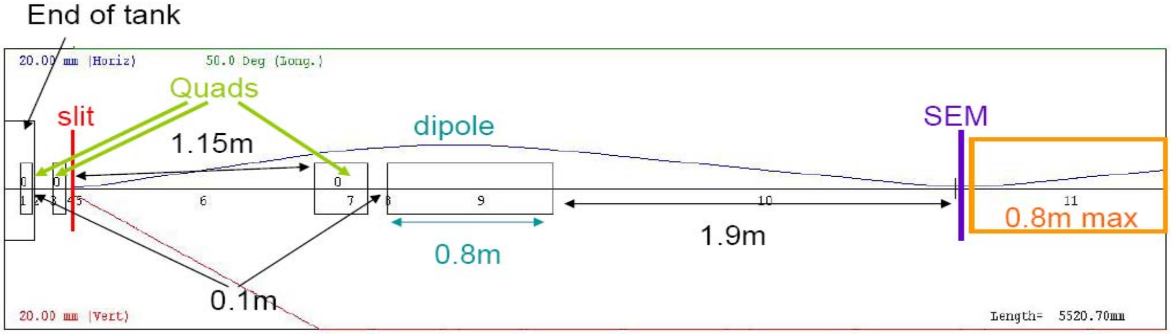

Figure 2 Proposed layout.

Figure 2 shows the proposed layout for a spectrometer line. Two quadrupole magnets are placed immediately after the end of the DTL tanks to produce a parallel beam at the slit. It might be possible to use for this function the intertank electromagnetic quadrupoles that provide beam matching between DTL tanks, if they can be powered to up to twice their nominal gradient. The slit itself needs to be positioned as close as possible to the beginning of the line (<10cm from the upstream quadrupole) to avoid an energy spread blowup due to space charge effects which could impair the measurements at low energy (simulations show a 75% increase in energy spread over 1m at 12MeV). A 0.2mm opening cuts off about 97% of the beam, thus killing any residual space charge downstream of the slit. Future energy deposition studies will have to assess the thickness required for the slit and the cooling needs for an approximate 160W power dissipation (63mA current at 50MeV and commissioning duty cycle of 0.005% as foreseen). Any finite thickness may further reduce beam transmission by acting as a divergence cut. Studies will also need to assess whether the slit activation is compatible with full hands-on operation of the line. Finally, a third quadrupole is placed after the slit for optical enhancement (to decrease the distance to the image point), followed by a 0.8m long bending magnet with 45 deg deflection angle, ρ=1m bending radius and a magnetic B field varying between 0.5 and 1T.

An inventory of the magnets needed for this diagnostics line and their specifications (for use up to 50MeV) is given in Table 3. To be added to the required equipment list are also a slit, a harp beam monitor, a beam dump and a NMR probe for magnetic field calibration.

The results of end-to-end beam dynamics simulations with the PATH code and 2D space charge modeling for the three separate DTL tank cases are summarized in Table 2.

Table 2 Results of beam simulations of the spectrometer line. From left to right: average tank output energy, 2.2σ beam energy spread at the tank output, 2.2σ beam size at the monitor (for zero and full current cases) and energy resolution.

	W [MeV]	ΔW [keV]	ΔW/W [%]	Δx [mm] I=0mA	Δx [mm] I=65mA	resol. [keV/mm]
DTL Tank 1	12.2	83	0.7	7.2	7.7	11
DTL Tank 2	31.8	150	0.5	3.8	4.0	37.5
DTL Tank 3	50.0	165	0.3	2.6	2.7	61

As shown by the last two columns, the performance of the scheme is rather satisfactory, though a 0.5mm sampling monitor resolution might be required to achieve a better measurement sensitivity. By comparing the beam size values at the monitor for the cases with initial zero and full current, one can see that space charge effects are negligible, and that the beam dimensions are mostly dominated by the dispersive term, as should be the case for this kind of measurement. An aperture radius of 10mm before the slit and 50mm after the slit has been assumed in the simulations: this limits beam losses between the dipole and the beam monitor downstream to approximately 0.35W for a 0.005% commissioning duty cycle at 12MeV. No significant losses have been observed at higher energies. Smaller aperture requirements would involve revisiting the layout of the line, since losses in that case would exceed or come very close to the 1W/m limit established by radioprotection.

The energy resolution per mm achieved in this study is comparable to the precision that is required for characterizing RF field and phase of the DTL tanks at 1%-1deg level RF tolerance. Error studies show that for this kind of precision one would need to resolve energy deviations of the order of -13/12 keV, -10/21 keV and -69/50 keV min/max for DTL Tank1, Tank2 and Tank3 respectively. The spectrometer diagnostics could therefore also be used to complement TOF measurements when determining the RF set points.

Table 3 Equipment specifications.

Magnets	Length [mm]	Gradient [T/m] or B field [T]	Aperture radius[mm]
Quad1	56	~60	10
Quad2	60	17 to 30	10
Quad3	250	0.9 to 2	50
Dipole	800	0.5 to 1	50

3. Conclusions

In conclusion, a layout has been proposed for a spectrometer line to be installed on the movable diagnostics bench for Linac4 commissioning. Beam dynamics simulations results show that the achievable measurements sensitivity is satisfying for the given beam characteristics.

However, some caveats remain on the suitability of such a beam diagnostics solution. Apart from cost considerations, the practicality of such an important and heavy installation for a temporary, movable bench is at present being evaluated, and has prompted a research into possible alternative solutions for comparison.