TRASCO-RFQ AS INJECTOR FOR THE SPES-1 PROJECT

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Abstract

The funded first phase of SPES foresees the realization at LNL of a facility able, on one hand, to accelerate a 10 mA protons beam up to 20 MeV for nuclear studies and, on the other hand, to accelerate a 30 mA protons beam up to 5 MeV for BNCT and preliminary ADS studies. In this two-way facility, the TRASCO RFQ will operate in two different current regimes. Moreover a specific MEBT has to be designed able to match the beam to the following superconducting linac and to deliver a beam with the correct characteristics to the neutron production target for the BNCT studies.

INTRODUCTION

The first phase of SPES facility (see Fig. 1) will produce a CW proton beam at 20 MeV 10 mA for nuclear studies and at 5 MeV 30 mA for BNCT (Boron Neutron Capture Therapy) studies [1]. The accelerator chain comprises the proton source TRIPS developed at LNS, a low energy beam transport (LEBT) [2] and the 352 MHz TRASCO RFQ [3], which can handle a beam up to 50 mA of current and 5 MeV of energy. After the RFQ a MEBT is necessary to inject the beam to the following superconducting linac [4] and to switch the line when the BNCT facility is operated.

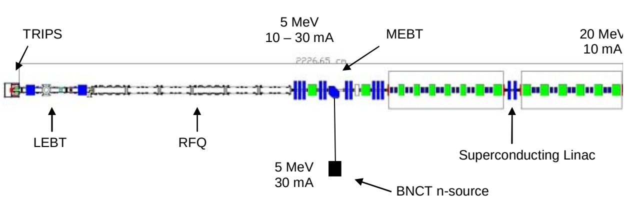


Figure 1: The SPES-1 project.

MEBT DESIGN

The MEBT lattice matches the 10 mA beam from the RFQ through 5 normal-conducting magnetic doublets and 2 longitudinal focusing 3-gap buncher into the first period of the superconducting linac and, at the same time, it should bend the 30 mA beam out of the linac direction for the BNCT studies. As shown in Fig. 2, the line to the BNCT target starts almost from the centre of the MEBT with a 90° degree bend (200 mm radius), for which a free length of 600 mm has been left: this choice is made in order to have a very short MEBT ensuring a high beam quality to the linac and, at the same time, to restrict the interferences between the BNCT facility and the RFQ-linac building.

The lattice of the BNCT line doesn't include any longitudinal focusing system because the BNCT target [5] requires a well defined transverse distribution and prefers a non bunched beam. Differently from the linac case, for which the requirements are on the 6 Twiss parameters, the focusing condition for the BNCT target is described by the transverse spot dimensions and by the condition of a very small dispersion to reduce error on beam position. These requirements are obtained with a simple combination of 4 normal-conducting doublets before the 4.5 m long drift to the collimator of the target (the drift is necessary for the radiation shielding walls and for the remote handling of the neutron converter).

Table 1: MEBT characteristics (line to BNCT from the dipole to the last doublet).

Line to		**Linac** (10 mA)		**BNCT** (30 mA)	
Total length (m)		3.15		5.9	
No. Doublets		5		4	
Length (mm)		100-70-100		150-100-150	
Bore radius (mm)		20		50	
Max env. (mm)		7.5		20	
Max gradient (T/m)		25		10	
		In	*Out*	*In*	*Out*
$\varepsilon_{n,RMS}$	x (mm.mrad)	0.204	0.208	0.217	0.709
	y (mm.mrad)	0.201	0.204	0.212	0.215
$^*\Delta E/E$	z (deg.MeV)	0.253	0.240	*0.83%	*1.9%

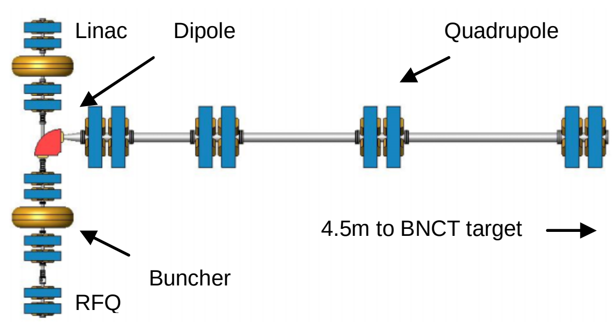


Figure 2: MEBT and BNCT line overview.

THE LINE TO THE LINAC

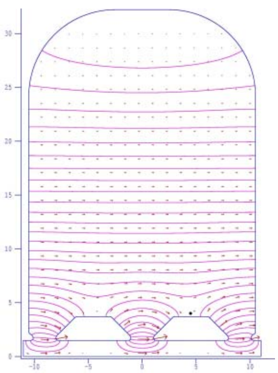
The choice of having 2 current regimes and the need for a dedicated line to the BNCT facility forces the shared part of the lattice to be flexible: this requirement is obtained with the use of normal conducting doublets (see Tab. 1) with independent power supply for each magnet.

The MEBT can be ideally divided in 2 parts, before and after the dipole, where the second one is specific designed to match the beam into the linac. More in details:

- the first doublet, also required in order to place the RFQ vacuum valve and some diagnostics in the following drift, should reduce the RMS differences between the two types of beam (10 mA and 30 mA) at the RFQ out;

- the second doublet let the beam to have a waist at the first buncher (where the bore radius is 15 mm instead of the 20 mm of the MEBT pipe);
- the third doublet should help the beam to be controlled in the long middle drift (10 mA) and to be injected in the right way in the dipole (30 mA);
- the last two doublets should keep the envelope small inside the second buncher and are used to find the match to the first period of the linac.

Table 2: Cavity characteristics.



Inner length	220 mm
Inner radius	322 mm
Bore	15 mm
Mode	TM_{010}
Frequency	352 MHz
E_0	1 MV/m
E_{max} / E_0	7.76
TTF	0.715
Power loss	6.1 kW
Q	36000
Z_S	39.7 MΩ/m

The 2 bunchers are used to find the longitudinal focusing condition with a quite low longitudinal electric field (E_0TL<0.16 MV) and a preliminary study on the cavity design with Poisson Superfish (see Tab. 2) shows that a solution may be a normal-conducting 352 MHz 3-gap cavity that operates at the synchronous phase of -90 degree. The use of only 2 longitudinal focusing elements is not a problem for the matching capability because of the long drift in between, but is a constraint to the total length of the line if we want to limit the phase envelope in the linear zone.

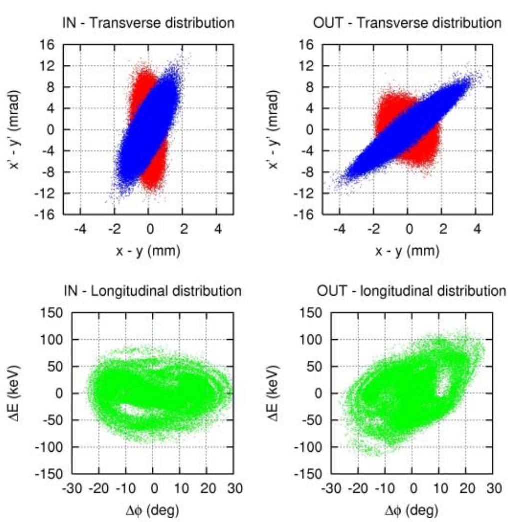


Figure 3: 10 mA in and output phase space distributions, x-x' plane in blue and y-y' in red.

First step of the simulation work of the line was performed with Trace 3-D [6] and Parmila [7] using a uniform distribution with the RMS parameter of the RFQ output (obtained accelerating a 4D waterbag with 100k macroparticles trough the RFQ). Afterwards we transported directly the RFQ out distribution (see Fig. 4) through the line and we monitored envelopes, emittances and halo. After a deeper optimization we obtained:

- a bore over RMS ratio greater than 9 inside the buncher and greater than 10 elsewhere (as shown in Fig. 3, the RMS envelope is less then 2 mm);
- the transverse RMS emittances growth contained in 2% of the entrance value;
- a redistribution of the longitudinal plane that reduces the RMS emittance of 5.5%.
- negligible transverse beam halo increase.

A preliminary error study shows no beam losses up to 0.5 mm of uniformly random off axis displacement of the line magnets.

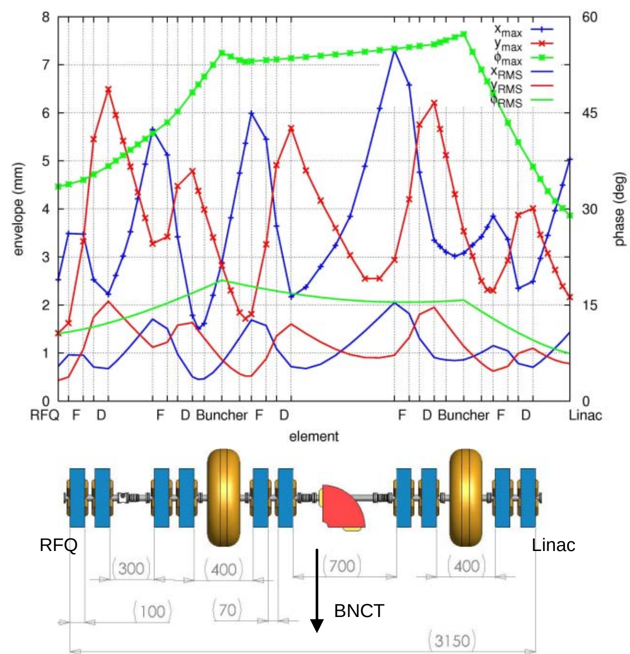


Figure 4: The beam envelopes (RMS and max) and some line specifications in mm.

THE LINE TO THE BNCT TARGET

The beam full current beam to BNCT has to reach the high power (150 kW) Be target for neutron production under development at the Efremov Institute [5]. Due to the limitation on the power density on the target, the beam has to arrive with a large spot and a well determined distribution. Since the transverse envelopes in the shared part is less the 10 mm and we need a half width spot on target of about 60 mm, the line to BNCT has to have a waist and a large magnification. Therefore we chose a bore radius of 50 mm for the line before the final drift (where the envelopes reach 20 mm) and of 100 mm for the last part where there are no more magnets (see Fig. 5).

Concerning the longitudinal phase space, the target accepts a debunched beam with the given energy spread.

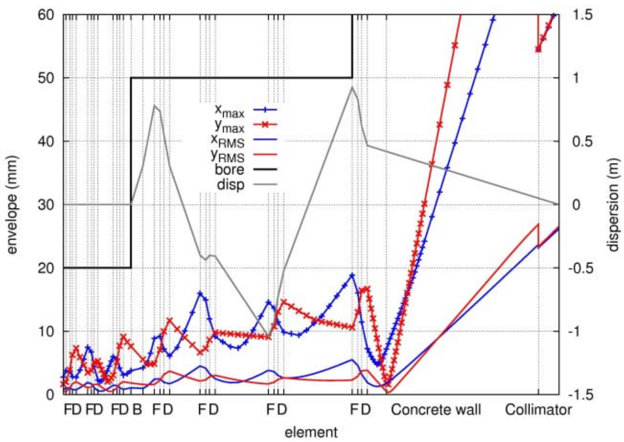


Figure 5: The envelopes and the dispersion function for the line to BNCT.

To avoid that the energy distribution of the beam contributes to the horizontal profile at the target, the energy dispersion is annulled on the target. As shown in Fig. 5, we get a very low dispersion angle (-92 mrad) and a small dispersion envelope, ensuring that even for out of nominal energy beam the probability of undesired beam loss along the pipe due to dispersion is very low.

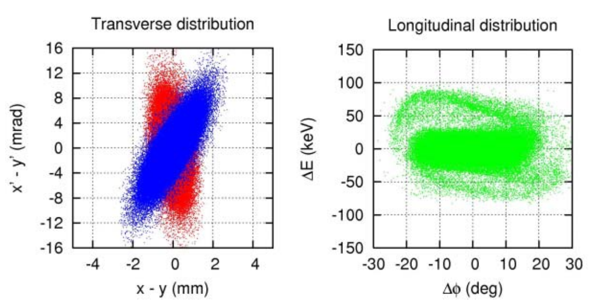


Figure 6: 30 mA RFQ output phase space distributions, x-x' plane in blue and y-y' in red.

Simulating the line with the RFQ output distribution (see Fig. 6) as input, we optimized the choice of the last two quadrupoles strength and the squared target collimator width (100.9 mm) in order to have a beam spot with axial symmetry, with a maximum width of 62 mm and a RMS radius of 26.5 mm. The resulting beam loss on the cooled collimator is evaluated in 8 kW and the losses in the meter before (already in the shielded zone) are contained in 0.5 kW.

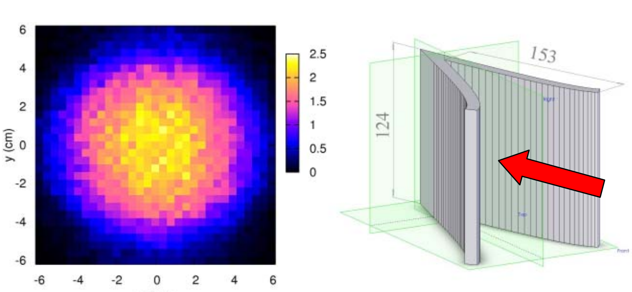


Figure 7: At left density power distribution (kW/cm^2) at the target on a plane perpendicular to the line, at right Beryllium converter profile (units are in mm).

As shown in Fig. 7, the maximum of the density power distribution on a plane perpendicular to the line reaches 2.5 kW/cm^2: that is the reason of the Beryllium converter profile. This design is optimized in order to keep the maximum density power of this beam below 700 Watt/cm^2 and depending on a technical choice for the orientation of the cooling channels could be used whether horizontal or vertical (see Fig. 8).

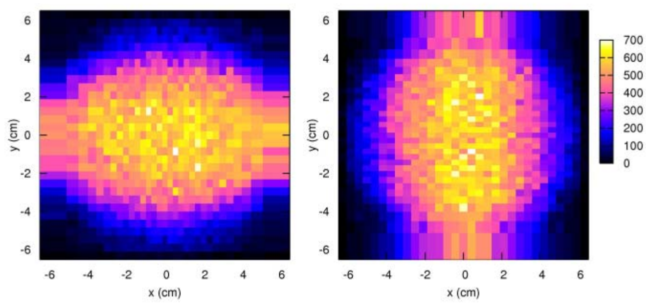


Figure 8: Density power distribution (Watt/cm^2) on the Beryllium converter surface: left with vertical and right with horizontal cooling channels.

A preliminary error study shows furthermore that we are working in a stable region in terms of the maximum of the density power distribution on the converter when we vary the last doublet strength up to 0.5%.

CONCLUSIONS

The MEBT structure can find the match requirements of the SPES-1 actual linac and it is able to work well with 5 mA of beam current as well, without degrading the quality of the beam in terms of emittance and halo.

The line to BNCT is able to reach the required target parameters with low losses, but may be modified following the technological improvements of the target and after a deeper study on halo growth (responsible of the last meter beam losses).

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