Design of a new beamline for electrons, positrons and photons at the HRRL lab

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1 Introduction

The HRRL is an S-band electron linac providing pulsed beams with energies between 3 MeV and 16 MeV. The maximum repetition rate is 1.2 kHz, the maximum peak current is 80 mA, and the minimum pulse length is 25 ns. The HRRL laboratory is located in the basement of the Physical Science Building. This lab consists of a shielded accelerator cell and an experimental area. Currently, a 3-m beamline with a 90-degree bend delivers electron and photon beams to the experimental area.

This project has two main goals: (a) to improve the quality of electron and photon beams in the HRRL lab; (b) to build a positron source for the IAC which could serve as a prototype for the CEBAF machine at Jefferson Lab [1].

For this project, we envision moving the HRRL machine and building a 5-m beamline with two 45-degree bends (Fig. 1). Specifically, we want to achieve the following:

- measure the properties of the e^- beam;
- provide a test stand for positron production targets;
- provide space for testing positron collection systems;
- measure the properties of the outcoming e^+ beam;
- improve delivery of electron beams to the experimental area;
- deliver photon beams produced in a secondary target downstream of the second bend.

The electron beam properties include intensity, position, profile, and momentum distribution. The intensity will be measured with a current transformer at the exit port of the HRRL, cross-calibrated with a Faraday cup downstream of the 0-degree port of the first bend. The beam profile can be inferred from the image on a fluorescent screen placed upstream of the production target. For the momentum distribution, we need to provide slits in a dispersive region after the first bend and a Faraday cup downstream of the 0-degree port of the second bend.

For positron production, we would like to study tungsten foils of various thicknesses, approximately between 0.1 mm and 2 mm. Enough space (about 50 cm) should also be provided to test high-power targets: rotating radiation-cooled metal disks and, possibly in the future, liquid metal targets.

Positrons are produced with a wide spread in momentum and divergence. The efficiency of the collection system is critical to achieve reasonable intensities. A collection system based on quadrupole triplets has been proposed and needs to be tested. Alternatively, we should provide enough space (about 50 cm) for a DC solenoid or an adiabatic matching device.

The intensity, position, profile, and momentum distribution of the positron beam can be measured with a microchannel plate placed downstream of the 0-degree port of the second bend. The same slits in the high-dispersion region can be used for both electrons and positrons. An emittance filter should also be installed to estimate the phase-space distribution of the positron beam. The background level from scattered photons needs to be measured to ensure the positron beam is detectable.

2 Beamline design

The beamline optics is subject to several constraints. First of all, the geometry of the HRRL cell, including the position of the beam hole in the wall, limits the total length of the beamline to about 5 m.

The design is based on the following optical elements, which are available at the IAC:

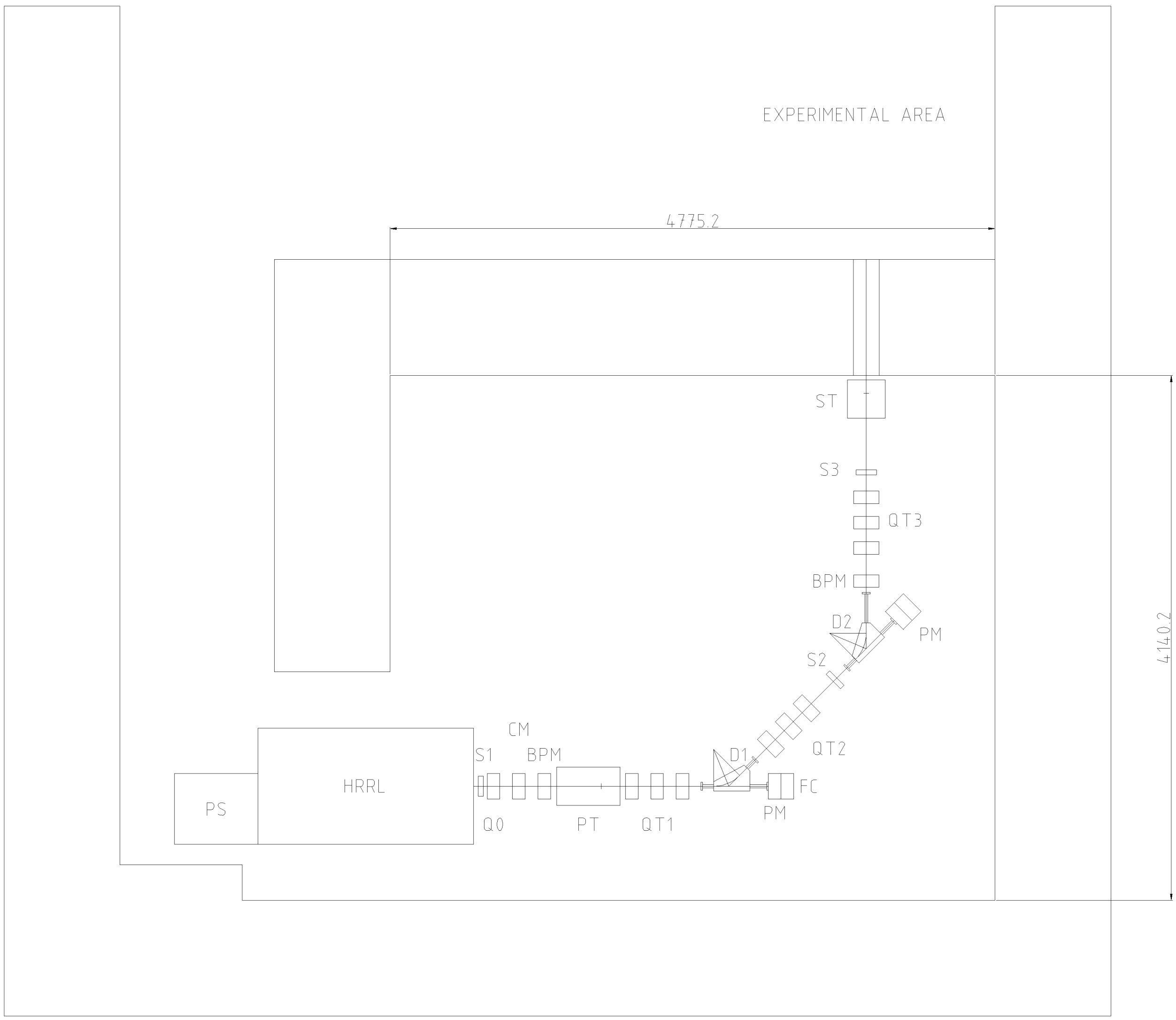

Figure 1: Floor plan of the proposed beamline: HRRL power supplies (PS); linac with stand (HRRL); collection quadrupole or doublet (Q0); positron production target (PT); 45-degree dipoles (D1 and D2); quadrupole triplets (QT1, QT2, and QT3); correction steerers (S1, S2, and S3); current monitor (CM); beam-position monitors (BPM); profile monitors (PM); Faraday cups (FC); secondary target (ST). Dimensions are in mm.

- orange ‘kiwi’ dipoles: pole gap 1 in; 45° bend; radius of curvature $\rho = 290$ mm;

- Tesla Type 1 Quadrupoles: pole gap 1 in; physical length 100 mm; maximum gradient 19 T/m;

- Tesla Type 2 Quadrupoles: pole gap 2 in; physical length 150 mm; maximum gradient 9 T/m.

Some dispersion is needed in the beamline for two reasons: to measure the momentum distribution of electrons and positrons; and to have the capability to mimick a given momentum aperture with slits (for injection into CEBAF, $\delta_{\max} = (\Delta p/p)_{\max} = \pm 2\%$). We also require a dispersion-free region ($D = 0$, $D' = 0$) downstream of the last steerer and in the secondary target. This is useful for reducing correlations between energy and position in electron, positron, and photon beams sent to the experiments. These dispersion requirements can be met by a double-bend achromat, which, in this case, includes two 45-degree bends.

For the electron beam, we assume a typical 10-MeV linac emittance of 1 μm and a focus with a 3σ beam size of 3 mm at the positron production target. This implies amplitude functions equal to $\beta = (3\text{ mm})^2/(1\ \mu\text{m}) = 9$ m at the target in both planes. Of course, these assumptions need to be tested experimentally. We also require a focus of same size at the secondary target.

The properties of the positron source are simulated with a GEANT4 Monte Carlo assuming a 10-MeV electron beam on a 0.5-mm tungsten target [2]. The momentum distribution of positrons peaks at 1.7 MeV and it is relatively flat within ±0.2 MeV. We choose 1.7 MeV as the design momentum for the beamline.

The spatial distribution of the outcoming positron beam is only slightly wider than that of electrons. For this design, we assume a focus (i.e., no correlation between positions and momenta) with 3σ beam size of 4 mm.

For calculating transverse admittances, we assume the beamline elements, including the vacuum pipe, have a half aperture of at least 12 mm. We need a beamline admittance (which will be completely filled by the positrons) larger than the CEBAF admittance, 1 μm. We choose to aim at an admittance $A = 10\ \mu$m, which can then be restricted with slits to mimick the CEBAF admittance.

In practice, to take both transverse and longitudinal constraints into account, we require the maximum beam size in both planes to be everywhere smaller than the half aperture a of the beamline:

$$\sqrt{\beta A + (D\delta_{\max})^2} < a.$$

Element		Location (m)	Field strength
QT1	Q1	0.200	+0.185 T/m
	Q2	0.400	−0.171 T/m
	Q3	0.600	+0.007 T/m
D1		1.001	19.5 mT
QT2	Q4	1.415	+0.170 T/m
	Q5	1.615	−0.258 T/m
	Q6	1.815	+0.226 T/m
D2		2.524	19.5 mT
QT3	Q7	3.261	−0.082 T/m
	Q8	3.461	−0.047 T/m
	Q9	3.661	+0.122 T/m

Table 1: Magnet settings for positrons at 1.7 MeV/c. Locations refer to the center of the element with respect to the positron production target, along the beamline.

The positions of the correction steerers S2 and S3 need to be chosen so that the phase advance between the two is approximately 90°.

The beamline optics was designed using the MAD-X program. Optics for the positron beamline is shown in Figs. 2 (amplitude functions and horizontal dispersion) and 3 (phase advances). Beam profiles are shown in Fig. 4. The magnet settings can be found in Table 1.

Some diagnostic components will need to be acquired. A possible set of choices is shown in Table 2.

References

[1] International Workshop on Positrons at Jefferson Lab (JPOS09), Newport News, Virginia, 25–27 March 2009, <http://conferences.jlab.org/JPOS09>.

[2] S. Golge et al., Simulation of a CW Positron Source for CEBAF, Proceedings of PAC07, p. 3133, <http://www.jacow.org>; J. Dumas, Design of a High Intensity Positron Source, Internship Report, LPSC Grenoble, June 2007; M. Stancari, private communication.

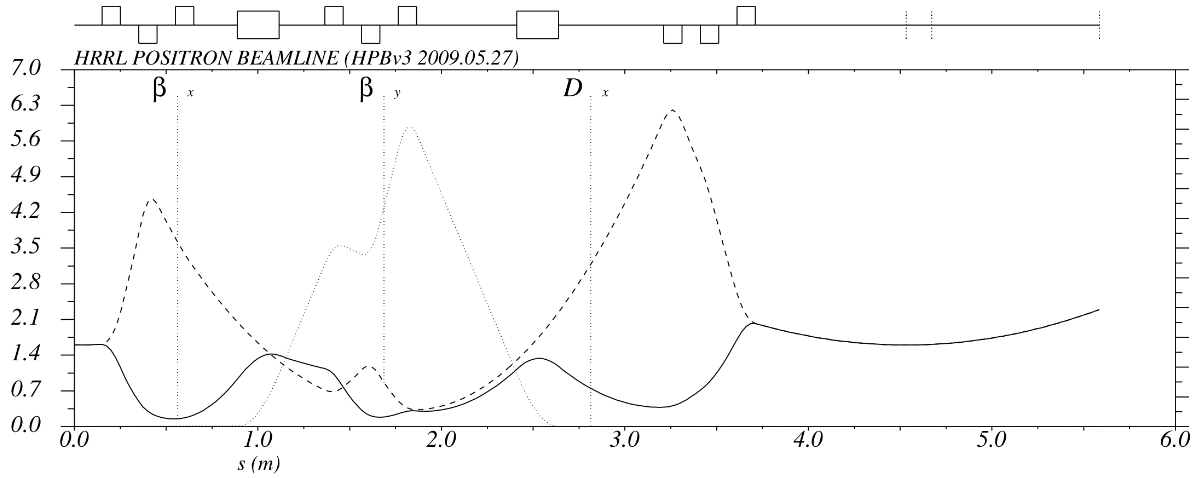

Figure 2: Amplitude functions (left axis; horizontal: solid line; vertical: dashed line) and horizontal dispersion (right axis; dotted line) in m.

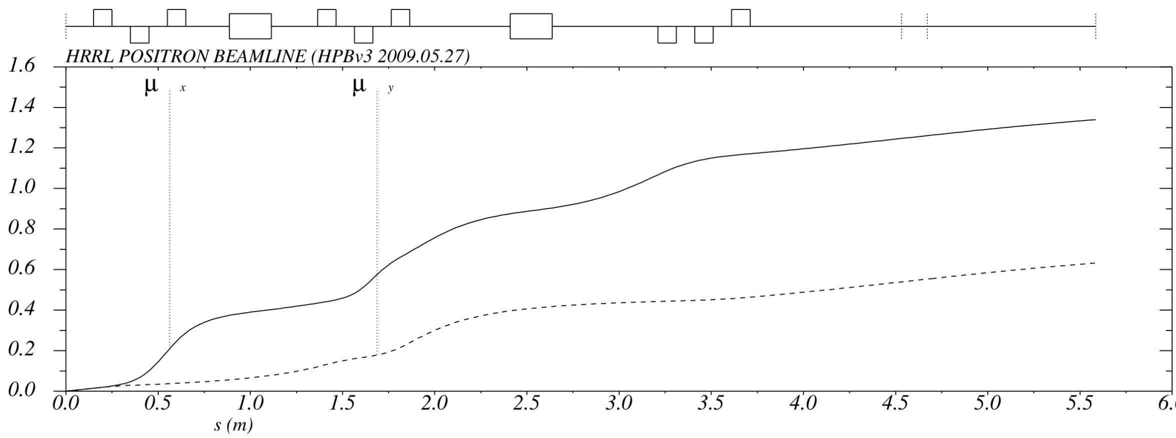

Figure 3: Phase advances in $\mathrm{rad}/(2\pi)$ (horizontal: solid line; vertical: dashed line).

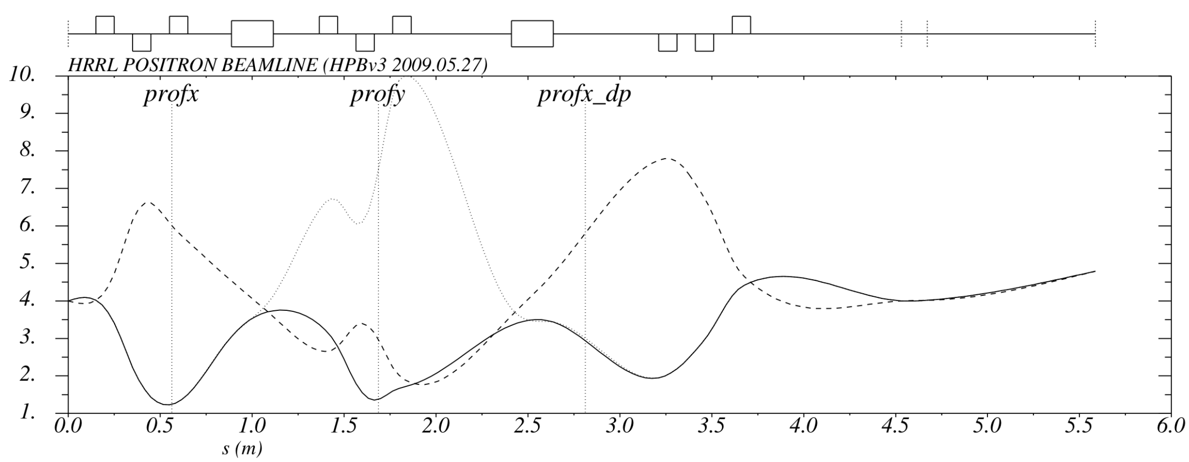

Figure 4: Beam profiles in mm for $\varepsilon_x = \varepsilon_y = 10\ \mu$m. Horizontal profiles are shown for both design momentum (solid line) and for a momentum spread $\Delta p/p = 2\%$ (dotted line).

Component	Model	Features	Approx. unit price
Fast current transformer	Bergoz FCT-028	inner diam. 28-mm	$2,000
Faraday cup	Radiabeam FARC-02-300		$1,295
Emittance slits	Radiabeam EMTS-##-###	custom	
Integrated transverse diagnostics	Radiabeam IBIS-02-VAC-OPT	YAG:Ce	
Beam position monitors	Bergoz	S-band	$10,000 (w/readout)
X-Y Steerers	Radiabeam STM-02-340-110	length 30 mm	$1,250
Microchannel plates	Hamamatsu		$3,000 (w/ pow. supply)

Table 2: Diagnostic components.