

# DEFLECTING CAVITY FOR BEAM DIAGNOSTICS IN ERL INJECTOR\*

S. Belomestnykh<sup>#</sup>, V. Shemelin, K. Smolenski, V. Veshcherevich,  
Laboratory for Elementary-Particle Physics, Cornell University, Ithaca, NY 14853, U.S.A.

## Abstract

A 1300 MHz deflecting cavity will be used for beam slice emittance measurements, and to study the temporal response of negative electron affinity photocathodes in the ERL injector currently under construction at Cornell University. A single-cell TM110-mode cavity was designed to deflect the beam vertically. The paper describes the cavity shape optimization procedure, its mechanical design and performance at low RF power.

## INTRODUCTION

An injector for the Energy Recovery Linac (ERL), where a high average current beam will be accelerated to energy of several MeV, is being constructed at Cornell University [1] and a suite of sophisticated methods to measure low-emittance beam parameters is under development. Some of the proposed techniques use a deflecting cavity. These include: photoemission response time measurement and temporal profile of the initial electron distribution after the gun, bunch temporal profile determination at 5 to 15 MeV, and reconstruction of an unprojected (temporal slices) emittance both after the gun and after the injector.

ERL deflecting cavity will be used for experiments at different energies from 500 keV ( $\beta = 0.914$ ) after the gun to 15 MeV after the injector. A deflecting angle of 12 mrad is required at all energies. At low energy the cavity will operate in CW mode with the available RF power of 200 W from a TWT amplifier. At high energies, after the injector, it will operate in pulsed mode from a high-power klystron transmitter with the pulse length of 18  $\mu$ s and repetition rate of 1 kHz. As the latter case is more challenging, the deflector was optimized for  $\beta = 1$ .

## CAVITY SHAPE CONSIDERATIONS

The amplitude of transverse deflecting voltage acting on a beam of charge  $e$  particles passing through the deflecting cavity on axis is

$$V_{\perp} = \frac{\Delta p_{\perp}}{ec} = \left| c \int_{-\infty}^{\infty} B_{\perp}(z) \cdot e^{ikz/\beta} dz - i \frac{1}{\beta} \int_{-\infty}^{\infty} E_{\perp}(z) \cdot e^{ikz/\beta} dz \right|,$$

where  $\Delta p_{\perp}$  is change of particle transverse momentum after passing through the cavity,  $B_{\perp}(z)$  and  $E_{\perp}(z)$  are the transverse components ( $B_x$  and  $E_y$  in our case) of the magnetic and electric fields on the cavity axis,  $z$  is the coordinate along the axis,  $k = \omega/c$  is the wave number,  $c$  is the speed of light,  $\omega$  is the circular frequency of the RF field. Then the transverse shunt impedance is

$$Z_{\perp} = \frac{V_{\perp}^2}{2P} = \frac{V_{\perp}^2 Q}{2\omega U},$$

here  $P$  is the power dissipated in the cavity walls,  $Q$  is the quality factor of the operating mode, and  $U$  is the stored energy. For the simplest case of a TM110 mode in a  $\lambda/2$ -long pill-box cavity, one calculates  $Z_{\perp} = 1.12$  MOhm. The transverse impedance drops with the addition of beam pipes, e.g., adding 1 $\frac{3}{8}$  inches ID beam pipes reduces the impedance to  $Z_{\perp} = 1.08$  MOhm.

While multi-cell deflectors are used at higher beam energies (see [2], for example), available space limited our choice to a single-cell cavity. A relatively low beam energy and use of an optimized cavity shape allowed us to design such a cavity with a TM110-like mode. In our design we utilized an approach similar to one of the CEBAF RF deflector [3], where four round rods are used to concentrate electromagnetic field near the axis. In our case the relative beam pipe opening is six times larger than that of the CEBAF deflector, so simple rods become less effective. We have used protrusions of a more elaborate shape to reach our design goals. Figure 1 illustrates difference between the CEBAF and Cornell ERL deflecting cavity shapes. The protrusions make the cavity azimuthally asymmetric thus splitting resonant frequencies of two usually degenerative TM110 modes far apart. The cavity was designed to deflect the beam vertically.

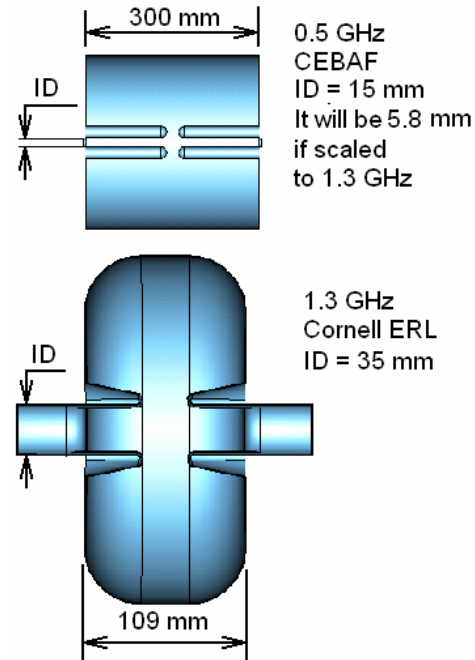


Figure 1: Comparison of the CEBAF and Cornell ERL deflecting cavity shapes.

\* Work is supported by the NSF grant PHY 0131508

<sup>#</sup> sab@lepp.cornell.edu

The shape optimization procedure consisted in varying the cavity dimensions to maximize  $Z_{\perp}$ . The conical shape of the protrusions and a proper radius of the cavity shell (Fig. 2) help to increase the  $Q$  factor. The cavity length is 5.5% shorter than the half wavelength to compensate for fields propagating into the beam pipe. Table 1 summarizes results of Microwave Studio® [4] calculations for the deflecting cavity equipped with auxiliary components.

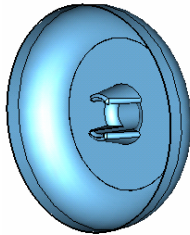


Figure 2: Optimized shape of the ERL deflecting cavity.

Table 1: Calculated parameters of the deflecting cavity.

Resonance frequency, $f$	1300 MHz
Quality factor, $Q$	14,050
Transverse shunt impedance, $Z_{\perp}$	5.27 MOhm
Peak surface electric field at 200 W	2.82 MV/m
Max. dissipated power density at 200 W	5.80 W/cm <sup>2</sup>

Most of our efforts were spent on finding optimal dimensions of the protrusions. The following constraints were observed: the maximum surface electric field was limited to 3 MV/m and the maximum dissipated power density was sought to be less than 10 W/cm<sup>2</sup> for the total dissipated power of 200 W. In spite of a relatively big beam pipe diameter, we have obtained the transverse impedance of 5.3 MOhm.

Distributions of RF current density and surface electric field in the most strained area are shown in Figure 3. For the power of 200 W the maximal electric field is 2.8 MV/m, and the maximal power density is 5.8 W/cm<sup>2</sup>. The  $Q$  factor was assumed to be 11,500 or 20% below its ideal value. Increasing the rounding radius of the beam pipe iris ( $R = 10$  mm), as compared to that of the protrusion edges ( $R = 3.5$  mm), lowers current density in this critical region.

The lowest parasitic modes were also calculated. Resonant frequencies of some modes are presented in Table 2. More details about cavity shape optimization can be found elsewhere [5].

## CAVITY DESIGN

The body of deflecting cavity (Fig. 4) is made of three main OFHC copper parts: a central piece and two side plates. The central piece houses a 40 mm ID port for a tuner at the cavity top and a pumping port at the cavity bottom. To better distribute RF currents near the pumping port, the port is divided by a partition. Two side plates accommodate conical protrusions and 35 mm ID beam pipes. The protrusions have channels for water

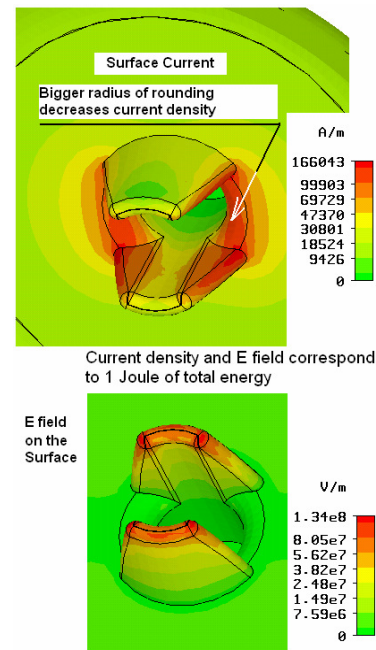


Figure 3: RF current density and surface electric field near the protrusions.

Table 2: Resonant frequencies of several modes.

Frequency [MHz]	Mode
797.4	TM010, fundamental
1300	TM110, operating mode
1550	TE101, dipole, beam pipe region
1677	TM110, orthogonal polarization
1678	Dipole mode strongly interacting with the tuner

cooling. One of the side plates also has a 16 mm port for a field probe and a 22.2 mm port for an input coupler. At first step the stainless steel ports are brazed to the individual copper pieces, and then the three sub assemblies are brazed together (at a lower temperature). Finally, Conflat™ flanges are welded to all ports.

Positions of the coupler and the RF probe are chosen so that the ratio between electric and magnetic RF fields is equal to the impedance of free space. In this case the antenna coupling change does not disturb the cavity frequency. The input coupler is of a coaxial antenna type with a disk ceramic window interfaced to a 1/8" coaxial line.

The tuner is of a plunger type, similar to that designed for the buncher cavity [6]. The tuner should compensate for thermal shift of the cavity frequency and fabrication errors. The total stroke of  $\pm 10$  mm from the initial position ( $-3.5$  mm) will secure the total tuning range of more than 2 MHz, see Figure 6. After the cavity was fabricated and assembled, its tuning range was checked with a network analyzer and is 1299.1 MHz to 1301.7 MHz. The corresponding range of  $Q$  factor is 9,450 to 10,050.

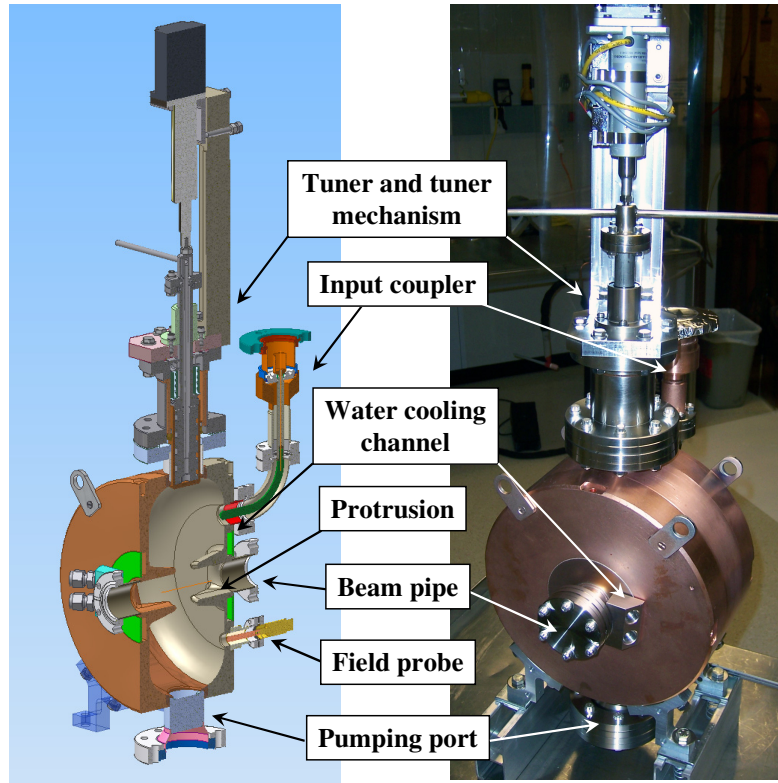


Figure 4: Cornell ERL injector deflecting cavity

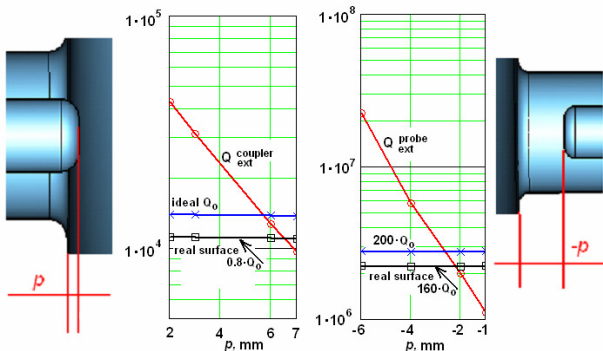


Figure 5: External  $Q$  versus position of the input power coupler (left) and the RF probe (right).

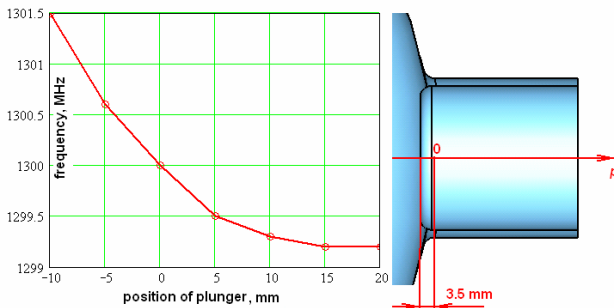


Figure 6: Resonant frequency tuning.

## CONCLUSIONS

We have designed a 1300 MHz deflecting cavity to be used for beam diagnostics in the Cornell ERL injector. Introduction of conical protrusions allowed us to concentrate electromagnetic fields on the cavity axis and thus increase its transverse shunt impedance to approximately five times that of the pill-box cavity impedance. The cavity was manufactured and its parameters measured at low RF power level are in line with calculations.

## REFERENCES

- [1] I. Bazarov and C. Sinclair, "High Brightness, High Current Injector Design for the Cornell ERL Prototype," *Proc. of PAC'03*, pp.2062-2064.
- [2] D. Alesini et al., "RF deflector design and measurements for the longitudinal and transverse phase space characterization at SPARC", *Nucl. Instr. & Meth., A* **568** (2006) 488.
- [3] A. Krycuk et al., "Construction of the CEBAF RF Separator," *Proc. of PAC'93*, pp.939-940.
- [4] CST GmbH, Darmstadt, Germany.
- [5] V. Shemelin and S. Belomestnykh, "RF Design of the Deflecting Cavity for Beam Diagnostics in ERL Injector," Cornell LEPP Report *ERL 07-2*, <http://www.lns.cornell.edu/public/ERL/2007/>
- [6] V. Veshcherevich and S. Belomestnykh, "Buncher Cavity for ERL," *Proc. of PAC'03*, pp.1198-1200.