MEASUREMENT OF THE EQUILIBRIUM EMITTANCE OF AN ELECTRON-COOLED 45 MeV PROTON BEAM

Mark Ball, Dave Caussyn, Scott Curtis, Mike Ellison, Tim Ellison, Jeff Frey, Brett Hamilton, Jeff Hudson, Bill Lozowski, Chris Merton, Tom Rinckel, and Bill Jones
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

Pete Dittner
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

An upper limit for the equilibrium emittance of an electron-cooled 45 MeV proton beam was determined by measuring the profile of the neutral hydrogen beam emerging from the cooling region using a 2-dimensional position-sensitive microchannel plate detector borrowed from Oak Ridge National Laboratory. The detector was placed 8.6 m downstream from the center of the electron cooling region; since this distance is much greater than the beta functions in the cooling region ($\approx$ 3m), the neutral beam size is nearly a direct measurement of the proton beam angular divergence in the cooling region. A 6 μm thick Kapton foil was placed 0.42 m upstream of the detector to isolate the cooling region vacuum system (operating at 2×10^{-10} Torr) from the detector ($\approx 2 \times 10^{-7}$ Torr). The electron current was 0.723 A, and the unbunched proton beam current $75 \pm 25 \mu$A.

The measured horizontal and vertical proton beam rms divergence in the cooling region is shown in Fig. 1 as a function of the horizontal angular misalignment between the electron beam trajectory and the proton beam closed orbit. Note that there is an

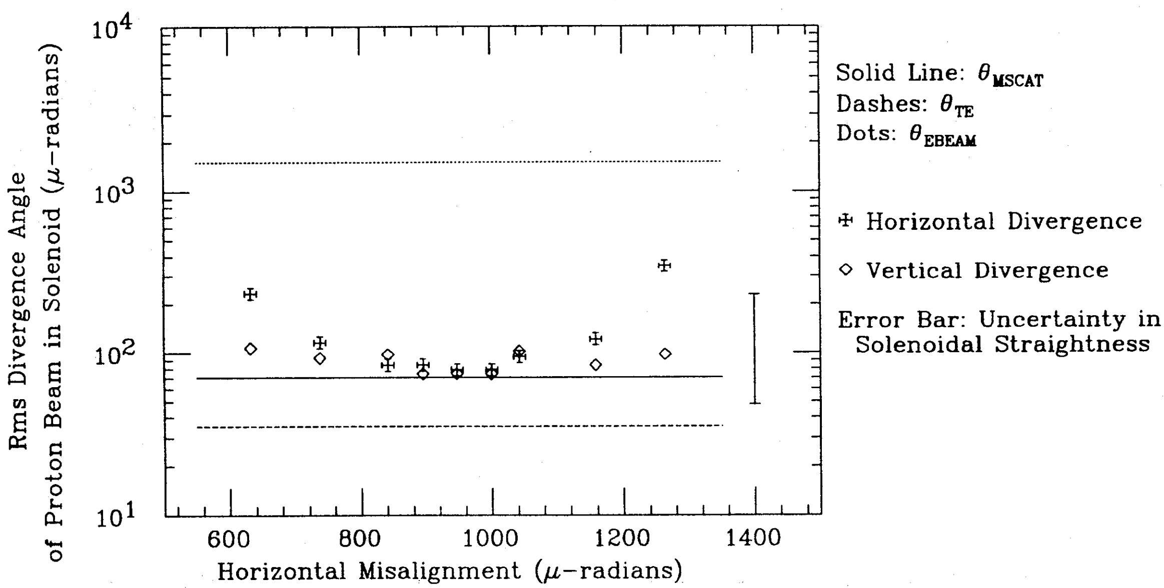

Figure 1. Measured horizontal and vertical angular divergences in the cooling region as a function of the angular misalignment between the proton beam closed orbit and electron beam trajectory. Note that there is an offset of about 1,000 μrad on the x-scale. (See text for further explanation).

arbitrary offset added to the x-scale; aligned beams with no angular misalignment correspond to about 1,000 μrad. The horizontal dotted line towards the top of the figure shows the electron beam rms angular divergence in one plane due to the cathode temperature, $(kT/mc^2)^{1/2}/\beta\gamma$, where k is the Boltzmann constant, T is the cathode temperature (1350 °K), m is the electron mass, $\beta = v/c = 0.3$, and $\gamma = E/mc^2 = 1.05$. The Kapton foil thickness was measured using a precision balance and found to be 1.20 mg/cm^2. The solid line in Fig. 1 shows what the measured (apparent) proton beam divergence would be for a zero-emittance beam due to multiple scattering in the foil, as calculated using the program MSCAT. It is obvious that the data for aligned beams is consistent with a zero-emittance beam and multiple scattering in the Kapton foil. The dashed line towards the bottom of Fig. 1 corresponds to the expected rms angular divergence for a proton beam with the same temperature as the electron beam, $(kT/Mc^2)^{1/2}/\beta\gamma$.

We can conclude that the equilibrium proton beam temperature is $\ll 4kT = 0.5$ eV, and the rms emittance is $\ll 0.02\pi\mu$m. The nonmagnetized theories of electron cooling predict an equilibrium proton beam temperature of $kT/2 \approx 0.06$ eV, and the magnetized theories predict temperatures up to 2 orders of magnitude smaller. In the future we plan on installing a profile monitor with much better resolution.

As the beams are misaligned, we find that the proton beam rms divergence increases; the rms divergence is approximately equal to the angular misalignment between the proton and electron beams. This effect is schematically shown in Fig. 2B. We did not observe a double-peaked profile for misaligned beams indicative of a ring-shaped phase space distribution as shown in Fig. 2C.

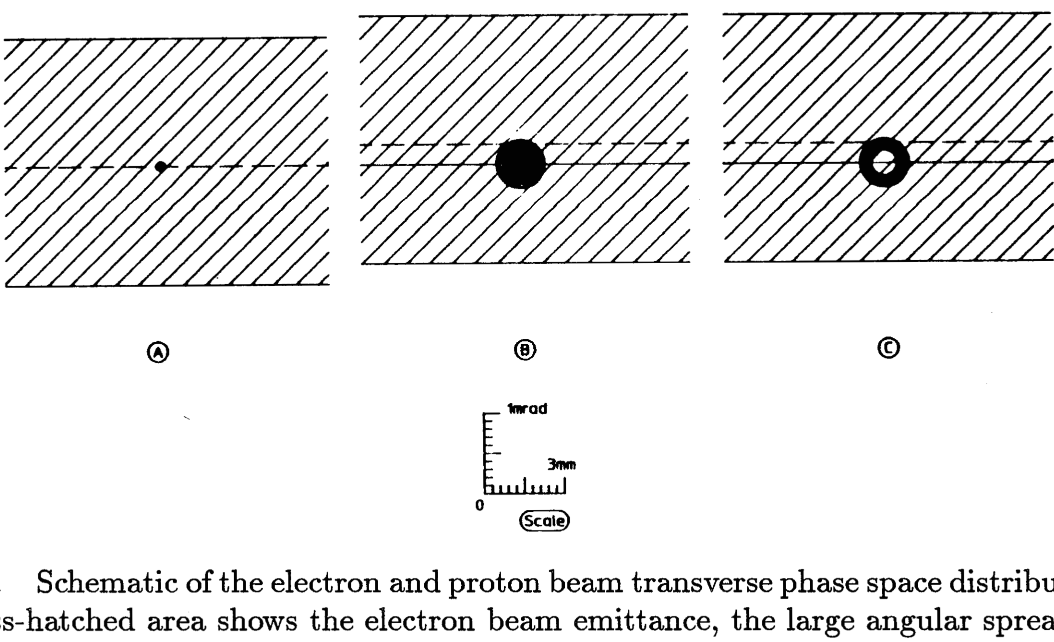

Figure 2. Schematic of the electron and proton beam transverse phase space distributions. The cross-hatched area shows the electron beam emittance, the large angular spread due to the cathode temperature; the dark area shows the cooled proton beam phase space distribution. In Fig. 2A, the proton beam closed orbit is coincident with the average electron beam trajectory (dashed line); in Fig. 2B, the angle of the electron beam trajectory has been shifted with respect to the proton beam closed orbit (solid line). Figure 2C shows the phase space "ring" which may be expected to occur, but was not observed.