Limitations of a Residual Gas Ionization Beam Profile Monitor for the SSC Collider

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Abstract

A residual gas ionization beam profile monitor for the Superconducting Super Collider is considered in detail using the Monte Carlo simulation code. It is shown that a good spatial resolution could be obtained using a combination of strong electrical and magnetic fields.

A system of beam profile monitors that can control the beam emittance is a very important factor in the commissioning and reliable operation of the Superconducting Super Collider (SSC). The Conceptual Design of the SSC[1] proposes flying-wire scanners and synchrotron-radiation light monitors for this purpose. Both methods have their own shortcomings, and some alternatives would be desirable. A residual gas ionization monitor to measure the collider beam profile is discussed below.

The characteristic parameters for the warm section and cold section of the collider are shown in Table 1.

Calculations indicate that the statistics are high enough to expect good spatial resolution for a residual gas ionization monitor. However, systematic effects could smear the resolution for the SSC beam. Electrons produced with velocity close to zero are affected by beam charge, and so the space information could be essentially lost. One can expect a better performance of such a monitor if strong external electrical and magnetic fields are applied.

A diagram of the residual gas ionization monitor using a dipole magnetic field is presented in Figure 1. Two compensating magnets are used to compensate for the influence of the magnetic field on beam dynamics. Electrons are accelerated up to the energy of about 30 KeV and are detected either by silicon microstrip detectors or by microchannel electron multipliers with a multicathode readout. A similar detection system was proposed in Reference 4. One can achieve some magnification of the beam profile image using shaped magnetic and electrical fields.

Investigation of electron collection from the residual gas has been carried out using a computer simulation code, ZBEAM,[5] which traces electrons and ions under the influence of applied electrical and magnetic fields. A two-dimensional Gaussian distribution with $\sigma_x = \sigma_y = 50\ \mu$m was used to describe a bunched beam; the bunch length was taken to equal 10 cm, and protons were uniformly distributed in the *Z*-direction. The number of protons in the bunch was 10^{10}. External electrical and magnetic fields directed along the *Y*-axis (perpendicular to the beam direction) were applied. Ion-electron pairs are produced in space according to the proton density in a bunch. The energy spectrum of electrons was produced according to a $1/E^2$ dependence, beginning from $E_e = 3$ eV[3]. It was assumed that 90% of electrons will produce a good image of the beam, *i.e.*, we neglect 10% of all electrons with recoil energy of more than 30 eV. The velocity vectors of the electrons were distributed isotropically in space. Finally, electrons were "collected" at the $Y = 2$ cm plane.

Table 1.
Parameters for Warm and Cold Sections of Collider.

Warm Section	
Pressure (nitrogen)	10^{-9} Torr (1.65×10^{-15} g/cm^3)[1]
Ionization losses of MIP in nitrogen	1.82 MeV/g/cm^2[2]
Average energy loss of MIP to produce one primary electron-ion pair in nitrogen	196 eV[3]
Beam intensity	75 mA (0.45×10^{18} p/s)
Number of ionization electrons	0.7×10^7/cm-s
Cold Section	
Hydrogen density	3×10^8 H_2/cm^3 (1.0×10^{-15} g/cm^3)[1]
Ionization losses of MIP in hydrogen	4.12 MeV/g/cm^2[2]
Average energy loss of MIP to produce one primary electron-ion pair in hydrogen	65 eV[3]
Beam intensity	75 mA (0.45×10^{18} p/s)
Number of ionization electrons	2.8×10^7/cm-s

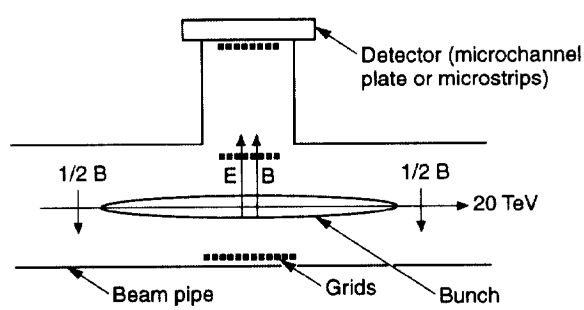

Figure 1. Residual Gas Ionization Beam Profile Monitor for the SSC.

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Figure 2 illustrates the distribution of electrons arriving at the detector plane of the residual gas ionization monitor for a uniform magnetic field of 2 T and external constant electrical field of 10 kV/cm. Simulation data were taken at an X-coordinate of 50 μm. An rms spread of about 5 μm was obtained, and this satisfies the requirements for the SSC emittance monitors. Figure 3 shows the rms spread vs. X-coordinate, and Figure 4 presents possible systematical deviations of the measured X-coordinates from the true ones vs. the X-position. No significant dependence effects were found for the rms spread or the deviation.

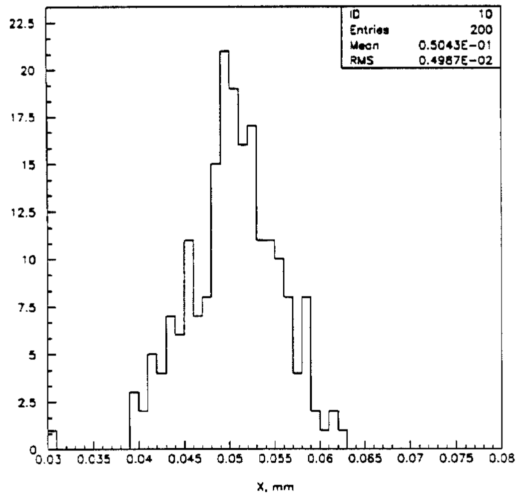

Figure 2. Distribution of the Coordinates of Electrons Arriving at Plane $Y = 2$ cm (the same we expect at the plane of the detector). Initial X-coordinate is 50 μm. Two hundred events are simulated, and Y and Z positions of ion-pair production are randomized, as are initial energies of electrons and their directions. The resolution of approximately 5 μm is achieved.

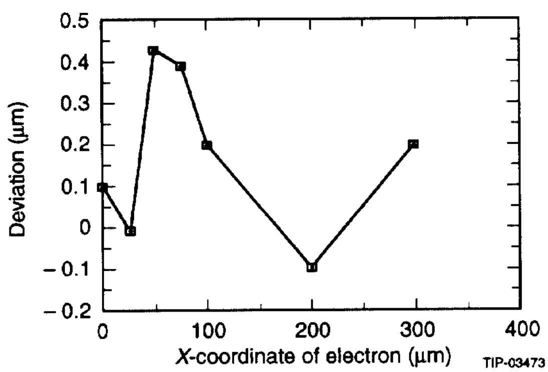

Figure 3. Space Resolution of the Device vs. Position of an Ionization Electron.

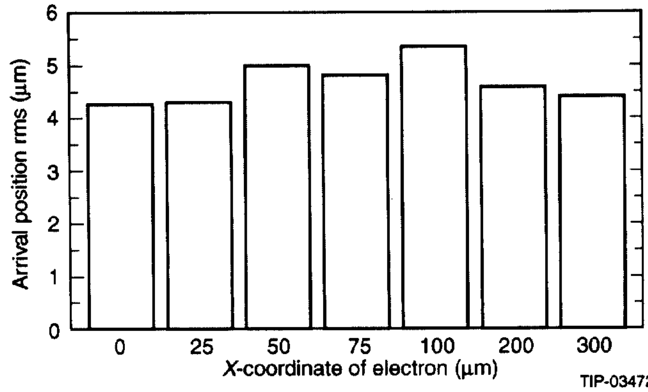

Figure 4. Deviation of the Average Positions of the Arriving Electrons for Different Starting Positions. Statistical accuracy is about 0.3 μm.

Some electron trajectories produced by the tracing code ZBEAM are presented in Figures 5–8.

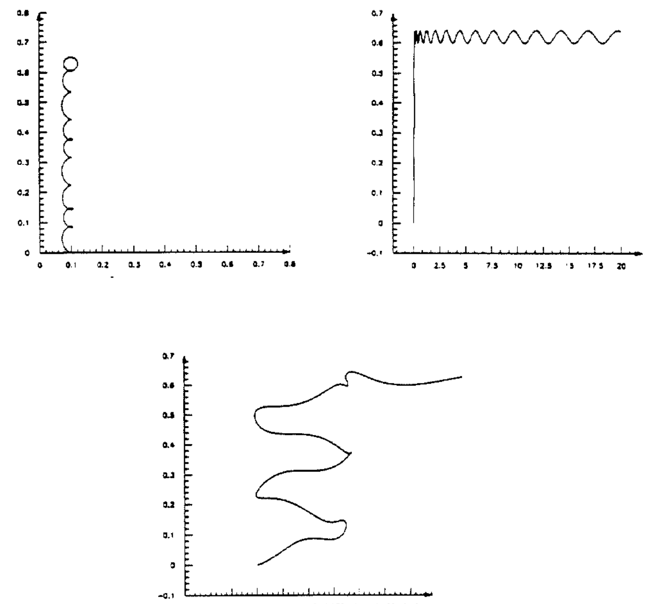

Figure 5. Motion of Zero Velocity Electron Near the 20-TeV Proton Beam in case of $E = 10$ kV, $B = 1$ T. Initial X-position of the electron is 100 μm. (a) in the X-Z plane; (b) in the Y-Z plane; (c) in the Y-Z plane, extended scale. Coordinates are in millimeters. In (c) one can see a kind of oscillation of the electron around some equilibrium position defined by the sum of the beam electrical field and the external electrical field applied. A bunch-occupied time is 0.3 ns, and full electron travel time is 0.8 ns.

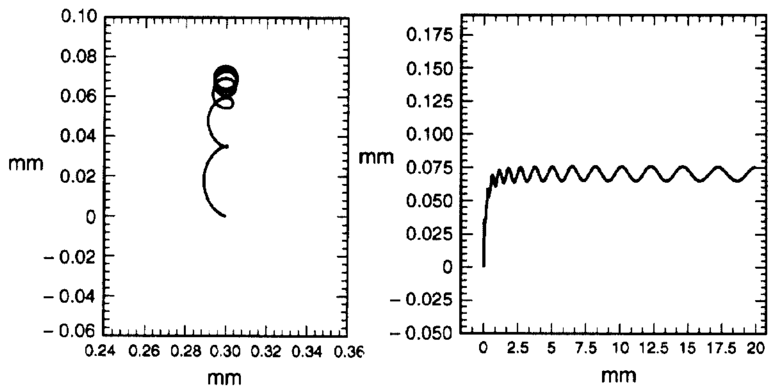

Figure 6. The same as in Figure 5, except the initial electron position is 300 μm. There are no oscillations.

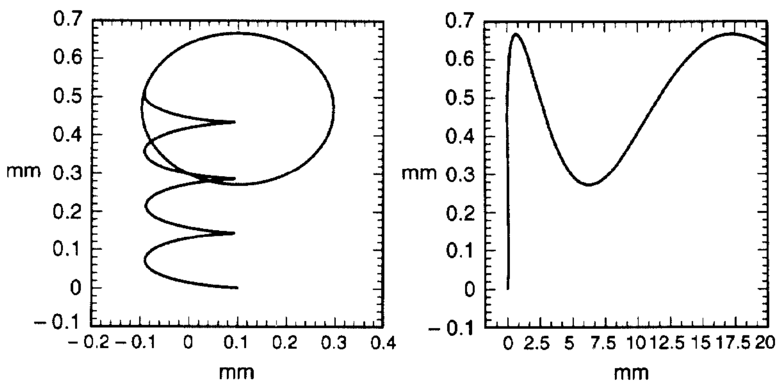

Figure 7. The same as in Figure 5, except $B = 0.1$ T.

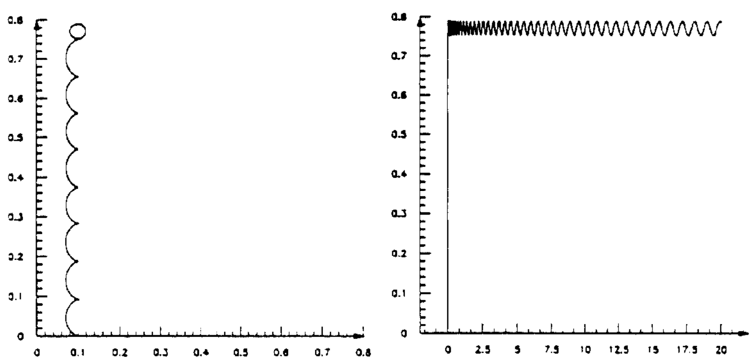

Figure 8. The same as in Figure 5, except $E = 1$ kV/cm.

Results of the analysis presented here demonstrate that even for the strict SSC requirements, construction of a residual gas ionization beam profile monitor with good space resolution looks feasible with the use of a strong magnetic field. In practice, a much lower magnetic field could be used with no significant degradation of the results. For example, in the utility region, where the rms beam size is about 150 μm, a monitor resolution of 20 μm is quite adequate, because it is added to the measured beam size in quadrature. Therefore, a 0.5-T magnetic field could be used, which is technically more attractive.

For the immediate future, a more detailed study of the electron drift process should be carried out, a corresponding read-out system should be constructed, and a prototype of the residual gas ionization beam profile monitor should be built and tested.

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