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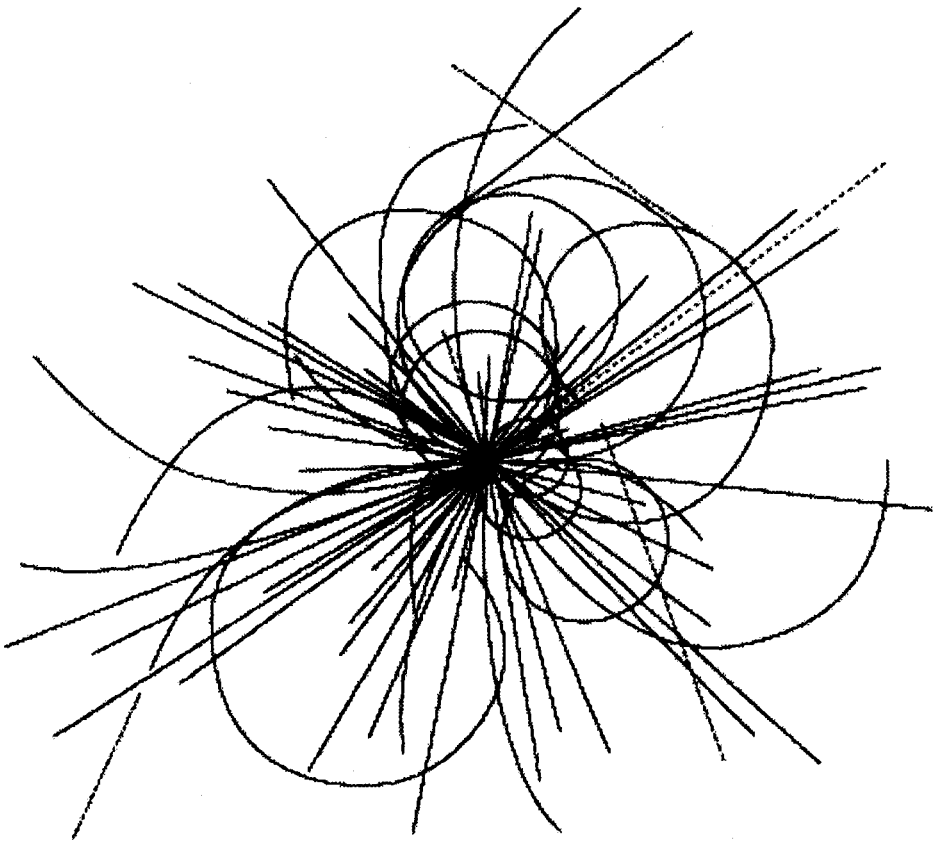

Superconducting Super Collider Laboratory

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ZBEAM, Charge Tracing Code for the SSC Environment

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ZBEAM, Charge Tracing Code for the SSC Environment

E. Tsyganov and A. Zinchenko

Abstract

A full Monte Carlo computer code describing behavior of electrons and ions in the vicinity of any space charges, electrical fields, and magnetic fields is described. Parameters of the code are optimized for the Superconducting Super Collider environment. Some results of calculations with a neutral beam profile monitor, a residual gas beam profile monitor, and an electron beam emittance monitor are presented to illustrate the method.

1.0 INTRODUCTION

Transport codes to trace particles in high-energy accelerators have been well established for many years. However, some miscellaneous processes accompanying acceleration of particles—such as motion of the residual gas ions and electrons in the field of a beam space charge under the influence of external electrical and magnetic fields—usually have not been treated accurately. Nonperturbing beam diagnostics using low-energy electron beams as a probe also require special computer codes to understand the results.[1] Here we describe a computer code developed for simulations of processes in beam profile monitors for the Superconducting Super Collider (SSC).[2-4]

2.0 GENERAL APPROACH

The motion of charges in the laboratory frame in some external electrical and magnetic fields and in the presence of some additional moving electrical charges can be described by the equation

$$m\frac{d^2\vec{r}}{dt^2} = q(\vec{E} + (\vec{v}_p \times \vec{B}) + \sum_{i=1}^{n}\vec{E}_i + \sum_{i=1}^{n}(\vec{v}_p \times \vec{B}_i)). \tag{1}$$

Here m is the particle mass, q its electrical charge, $\vec{v}_p$ its velocity, $\vec{E}$ and $\vec{B}$ external electrical and magnetic fields, $\vec{E}_i$ an electrical field created by the electrical charges near the particle (bunch charge), and $\vec{B}_i$ a magnetic field associated with a moving charge. In a simulation code a bunch could be presented as a "cloud" of moving electrical charges with a total charge equal to the bunch charge.

We found, however, that the practical limit due to a limited speed of computation restricts us to use more than 10^6 separate charge sources in the trajectory code. This amount of charges still does not allow us to perform precise trajectory calculations due to the large fluctuations of a "charge density" in such a bunch. This is especially emphasized by the circumstance that the longitudinal size of a bunch at the SSC is much larger than its transverse sizes. The design length of the bunch in the Collider is of the order of 10 cm, while its transverse sizes are about 100 μm. We decided to represent the bunch by the set of the "wire" charges. As it happens, it is quite possible to reach a satisfactory solution to the problem with a number of "wire" charges of the order of 10^4. Therefore, we neglect the longitudinal component of the electrical force of the bunch charge. Our code, although truly three-dimensional, uses a "two-dimensional" bunch representation. The Z-variation of the bunch charge density is described with the corresponding time variation of the "wire" charge (and current) density. Lorentz shrinking of the electrical field of an individual proton does not really change the time integral of the bunch field in the case of the dense bunch.[5]

The X- and Y-distributions of the bunch charge are varied separately according to the desired shape—Gaussian, uniform density, *etc.* The electromagnetic field created by each "wire" is calculated as a field of infinitely long wire with a charge (and a current) density variable in the Z-direction:

$$\vec{E}_i = \frac{q_i(Z)\vec{u}_r}{2\pi\varepsilon_0 r} \tag{2}$$

$$\vec{B}_i = \frac{1}{c^2}\left(\vec{v}_b \times \vec{E}_i\right) . \tag{3}$$

In its turn, $Z = Z(t) = ct$, where c is the speed of light, and $\vec{v}_b$ is a bunch velocity.

Additional input parameters are ion (or electron) velocity and magnitudes of the external electrical and magnetic fields. In the cases of the electron or the neutral probe beam, a relative synchronization of the beam and the proton bunch is required.

Tracking a particle in ZBEAM code is achieved by integrating the equation of motion over successive small time steps. Tracking stops when the particle reaches a detector or leaves the region of interaction.

ZBEAM code is available at the SSCVX1 computer.

3.0 SOME RESULTS OF THE CALCULATIONS

First, the code was used to estimate a divergence of Ar^+ and Cs^+ ions appearing after the interaction of a 10-KeV neutral beam with the Collider beam. A neutral beam profile monitor was proposed[6] to measure the beam profiles in the SSC accelerators with a real nondestructive technique, as presented in Figure 1.

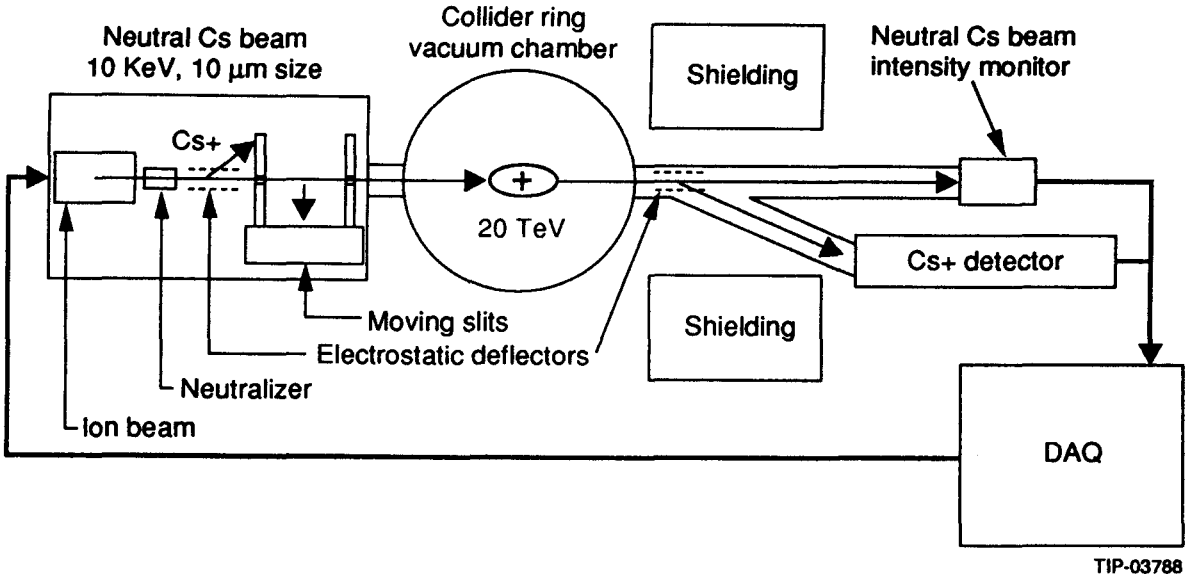

Figure 1. Schematic View of the Neutral Beam Emittance Monitor for the SSC, Proposed by A. Maschke.[6] A 10-KeV Cs or Ar neutral beam with a dimension of approximately 10 μm strikes the collider beam. Having been ionized, a fraction of the beam is detected, giving the profile measurement.

After being ionized, Cs^+ or Ar^+ will be scattered by the bunch space charge, and the detection efficiency may drop. This effect was studied by the ZBEAM code. Results of the calculations are presented in Figure 2, where ion-scattering angles are plotted versus the impact parameter of the neutral beam. For comparison, results obtained by the numerical calculations of motion equations are also presented.[2] There is satisfactory agreement between these two methods. A bunch uniform in the Z-direction with the length of 10 cm and Gaussian in the X- and Y-directions with sigma equal to 100 μm was used for the calculations, and the total charge of the bunch was equal to the charge of 10^{10} protons. Ionization is assumed to take place in the median plane of the 20-TeV beam at the front edge of the bunch, and the multibunch structure of the beam was taken into account. Ion trajectories were traced to $Y = 2$ cm, where the further scattering by the proton beam is negligible. Data show that the typical scattering angles are rather small, and ions could be detected with high efficiency.

The performance of a residual gas beam profile monitor for the SSC was also considered using the ZBEAM code; results are described elsewhere.[3] In this case some detailed calculations by pure analytical methods are not feasible, and the Monte Carlo simulation is the only reasonable approach. Figure 3 presents an example of the trajectory of the residual gas ionization electron of zero initial velocity traveling to the detector under the influence of a bunch space charge and external electrical and magnetic fields. Parameters of the device were optimized, and the spatial resolution of this type of beam profile monitor was demonstrated.

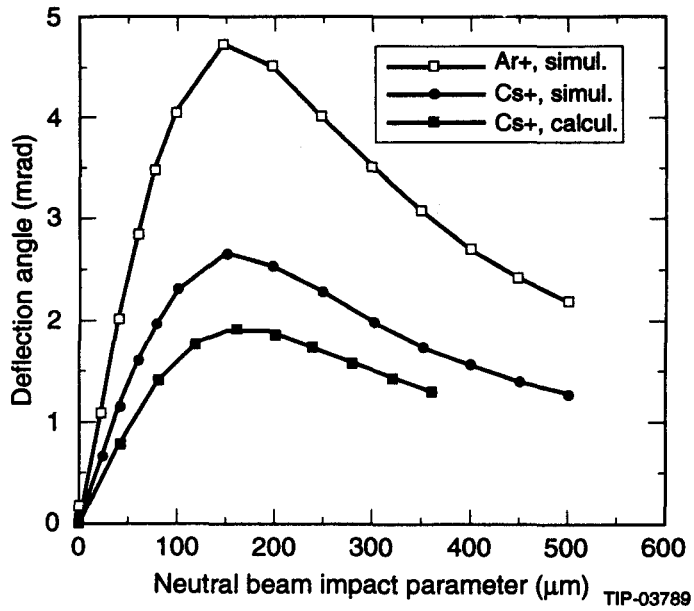

Figure 2. Scattering Angles of 10-KeV Cs^+ and Ar^+ Ions Produced in the Bunch by its Space Charge vs. Impact Parameter of the Neutral Beam.

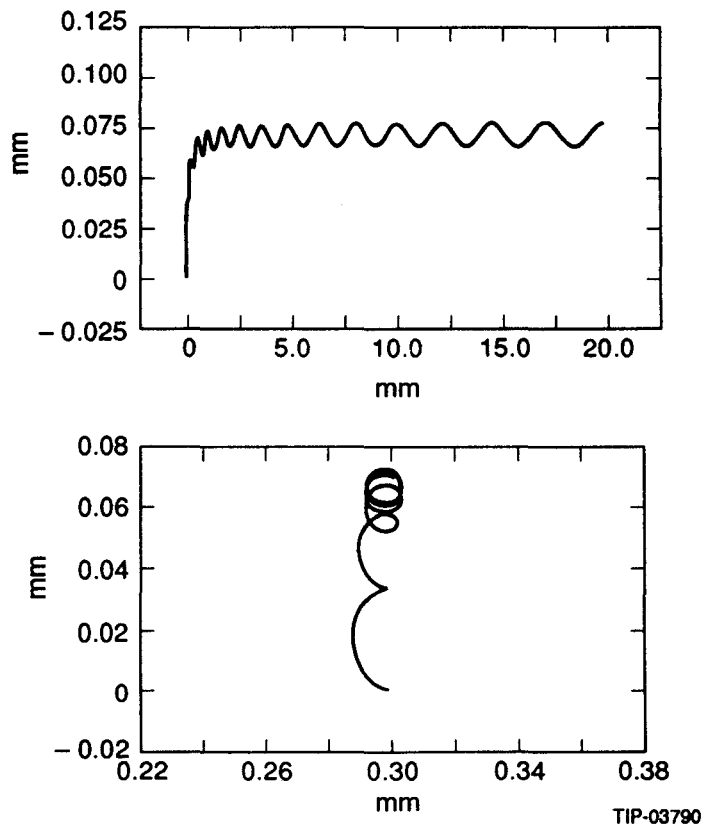

Figure 3. Trajectory of the Residual Gas Ionization Electron With Zero Initial Velocity in the Presence of an External Electrical Field, a Magnetic Field, and a Bunch Space Charge. The electron is released at 300 μm off the beam center. Magnitude of the magnetic field is 2 T, and the electrical field is 10 KV/cm.

Detailed calculations of the low-energy electron beam scattering off the proton bunches were performed in Reference 4. Again, scattering angles of the 10-KeV electrons were obtained by tracing down the electron trajectories through the space charge of the proton bunch. Fortunately, for the small scattering angles there is a straightforward interpretation of the results, leading to the deduction of the beam profile data from the scattering angle vs. impact parameter curve just by differentiation of it. Therefore, this method of beam profile measurements is very similar to the "flying wire" technique, having a much higher intrinsic speed and being more flexible. Some of the results of the calculations with the electron beam probe are presented in Figure 4.

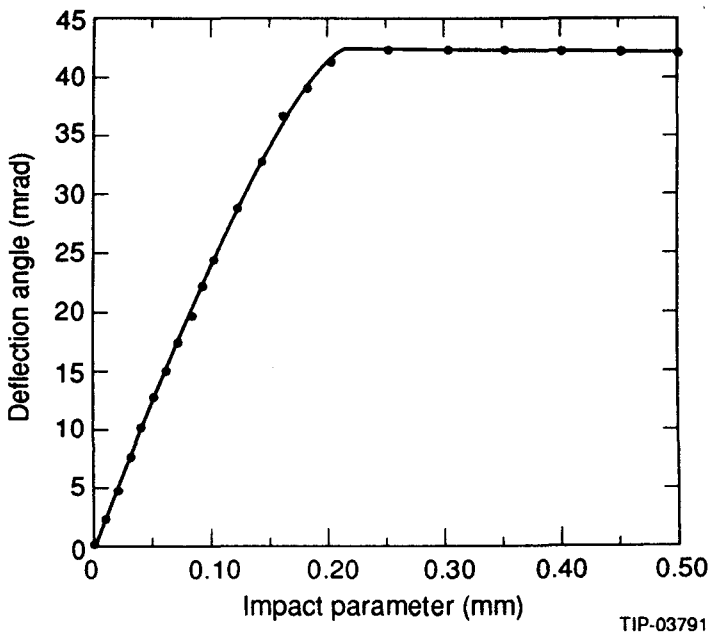

Figure 4. Scattering Angle of the 10-KeV Electrons vs. Impact Parameter Relative to the Center of a 20-TeV Proton Bunch. The bunch has a cylindrical shape with the radius of 200 μm (which corresponds to an rms radius of 100 μm) and a length of 10 cm. The solid curve is the best fit for such a shape.

ACKNOWLEDGMENTS

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