THE ION SOURCE AND INJECTION SYSTEM (ISIS) FOR THE TRIUMF CENTRAL REGION MODEL (CRM)

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ABSTRACT

The central region model was built primarily for checking the beam dynamical properties of the first five turns in the TRIUMF 500 MeV cyclotron. It also serves as an ideal model for a high intensity H^- ion source and injection system. The H^- ions are produced in an "Ehlers-type" source (from Cyclotron Corporation), accelerated to 300 keV by a low gradient acceleration tube and axially injected into the central region model by a spiral inflector. The 22 m long beam transport system between source and central region consists of three 90 deg electrical bends (non dispersive), about 50 electrostatic quadrupoles, a buncher and a chopper. A pulser for changing the macroscopic duty cycle and a 1:5 selector which suppresses 4 out of 5 beam bunches are to be installed later. Beam measurements and calculations have shown that space-charge effects play an important role for currents above 100 μA.

1. INTRODUCTION

A polarized and two unpolarized H^- sources will be installed for feeding the TRIUMF 500 MeV cyclotron. These sources have to be placed outside the cyclotron vault, which gives TRIUMF the somewhat dubious world record for the longest low energy proton beamline (40 m). The first unpolarized source and the polarized source are in construction; the second unpolarized high intensity source is not yet budgeted. The source and beamline for the central region model (CRM) are operating. The CRM itself (including the spiral inflector) is covered in a separate paper by E.W. Blackmore.

2. ION SOURCE

The 12 keV H^- ion source has been bought from Cyclotron Corporation in Berkeley. It is essentially the hooded arc hot cathode cyclotron source developed by Ehlers.[1] The specifications are 2 mA within emittances of 64π mm mrad in both directions. The source is located in a 2.8 kG C-magnet and floats at -12 kV above terminal voltage. The puller has terminal voltage. The arc chamber anode-block is made from copper and is water cooled. The diameter of the collimating hole adjacent to the filament was changed at TRIUMF from the Cyclotron Corporation value of 2.5 mm to 1.6 mm, which

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resulted in more stable arc conditions but less beam output (1 mA). The source slit is 1 × 10 mm and the puller slit 3 × 15 mm. Filament and cathode are made of tantalum and have the same potential. Typical values for a 1 mA beam are: arc voltage = 240 V, arc current = 2.2 A, filament current = 380 A, electron current drain = 13 mA.

3. TERMINAL, ACCELERATION TUBE, PUMPS AND CONTROL

The Cockcroft-Walton unit is regulated to $\pm 10^{-4}$ in the range 288 ± 12 kV and can deliver up to 10 mA. The electrical power for the terminal is provided by a 480 V/480 V, 3-phase, oilfilled isolation transformer of 50 kVA. The 90 cm acceleration tube is from Radiation Dynamics. The 36 re-entrant electrodes have an aperture of 7.5 cm. To cope with the high gasload of up to 30 cc/min, well trapped oil diffusion pumps have been chosen. A 10 in. pump is connected to the ion source chamber and a 6 in. pump to a box between source and acceleration tube. The pressure in these regions with beam on is 2×10^{-5} and 3×10^{-6} Torr, respectively. The cooling for source, pumps, etc. is provided by a 7.5 t refrigerator system with the freon compressor at ground potential and the expansion valve plus heat exchanger in the terminal. The primary circuit uses Freon 22 which crosses the 300 kV potential through polyethylene pipes. The secondary system uses water.

The ion source and the associated equipment in the terminal are manually controlled by push- or rotary-rods crossing the 300 kV potential. The safety interlocks are hardwired. An input/output link with 16 parallel channels connected to a CAMAC crate in the terminal has been tested and found to have problems due to electronic crosstalk. The transmission across the 300 kV protential was no problem. An improved version using serial data transmission will be implemented.

4. ION SOURCE OPTICS

The 1.3 m long distance between source and acceleration tube leaves room for emittance defining slits, optical lenses, Faraday cup, viewing quartz, etc. On the other hand, this long drift space creates space-charge problems at 12 keV. Fig. 2 shows the beam envelope for 0 and 0.3 mA currents using the generalized Kapchinsky-Vladimirsky equations.[2] These equations were modified to include also acceleration through the acceleration tube with realistic fringe fields. One clearly sees the strong focusing action of the tube entrance. Fig. 3 shows a comparison of space-charge calculations with an emittance measurement at 300 keV for a 0.5 mA beam. The best agreement was obtained for a current parameter of 0.3 mA in the calculations. This might be interpreted as a partial neutralization of the beam from positive residual ions in the beamline. Since the pressure, and hence the neutralization, decreases strongly from source to acceleration tube, this fixed current parameter of 0.3 mA gives only an averaged picture of the neutralization effect. More emittance measurements at different current and pressure values have to be done before clear conclusions can be made.

5. BEAMLINE

To speed up the commissioning of the central region model we decided to build the beamline in three stages. The first stage operated from April to June 1972 and delivered a 10 μA DC beam into the CRM. The alignment of this line was done rather quickly, which resulted in an overall transmission of only 60%. In the second stage, which is presently commissioned, a chopper, buncher and rotating wheel are incorporated to give small microscopic and macroscopic duty cycles. The final version of the CRM beamline will include also a 1:5 selector and an electrical pulser (described in section 5.3).

The 15 cm diam beam pipe is made out of stainless steel. Several 20 cm cubic diagnostic boxes are placed at strategic locations along the beamline. They contain vibrating wire scanners[3] which display the beam profile on a screen. Several sublimation pumps keep the vacuum down to about 4×10^{-7} Torr average, at which pressure the beam loss due to gas-stripping is a few per cent, provided the residual gas molecules have cross-sections about the same as nitrogen.

5.1 Periodic Sections. About 50 electrostatic quadrupoles, 10 cm long with 5 cm aperture, are distributed along the 22 m long beamline. For the long drift sections a periodic arrangement with 30 cm spacing between adjacent quadrupoles was selected.

5.2 Electrostatic Bends. To have a big operating flexibility all bends are made dispersionless, with a combination of 45 deg electrodes and quadrupoles. The electrode voltages are ±30 kV, the electrode spacing is 3.8 cm and the radius of curvature, 38 cm. The energy band transmitted through a 90 deg bend is ±3 keV.

5.3 Pulsing Elements. The beamlines for the CRM and for TRIUMF will have a variety of pulsing elements. A schematic picture of all components in the CRM beamline can be seen in Fig. 1 (the CRM beamline obviously seen by the "time structure specialist").

Chopper: The chopper consists of a pair of 8 cm long deflection plates which are connected in the push-pull mode to two 11.5 MHz resonators. The chopper sweeps the beam symmetrically past a narrow slit. This produces a pulsed beam with the cyclotron RF of 23 MHz. The length $\Delta\tau$ of short beam pulses is given roughly by the formula

$$\Delta\tau = \frac{\tau}{\pi} \frac{w}{y_{max}} \qquad (1)$$

where τ = RF period = 44 nsec
w = slit width = 1.5 - 2.5 mm
y_{max} = maximum deflection of beam at the slit produced by the chopper = 2 cm for a chopper voltage of ±4 kV.

The pulse length can thus be varied with the chopper voltage or the slit width. The "upsweep" and "downsweep" pulses are both transmitted with only a small increase in emittance. This has been achieved by choosing short chopper plates, a narrow slit and a long drift space between chopper and slit. Fig. 4 shows the beam envelopes in the symmetric chopper section with a double waist at the slit. This section can be fitted modularly into any part of the periodic beamline.

Buncher: Bunching of the DC beam is achieved with a conventional two-gap sinusoidal buncher operating at 23 MHz. The spiral inflector in the centre of the cyclotron is dispersive and transforms an energy spread of the incoming beam into a vertical betatron oscillation. The tolerance for the energy spread is ±0.2% (±600 eV), which puts a limit on the buncher voltage and therefore also on the amount of bunching which can be obtained.

1:5 Selector: This device transmits only every fifth micropulse through a narrow slit. Since the cyclotron operates on the fifth harmonic, only one spike will thus rotate in the cyclotron. The pulses in the external beam will then be separated by 220 nsec which gives "clean" time-of-flight experiments. Like the chopper the 1:5 selector consists of two deflection plates. One plate is biased whereas the other one is connected to a 4.6 MHz resonator with the same amplitude as the bias voltage. The beam only gets transmitted when the voltages on the two plates are equal.

Electric Pulser: In front of the 1:5 selector are two other deflection plates connected to a bias voltage and a pulsed voltage from a pulse generator. The generator can give rectangular pulses up to 2.2 kV in amplitude, with the pulse length varying between 50 nsec and 10 msec. The macroscopic duty cycle of the beam can be varied between 0 and 1.5% and is limited by the power dissipation of the pulse generator. (With both pulse generator and bias voltage off the duty cycle is, of course, 100% whereas the 1:5 selector alone gives 20%.) Apart from delivering short bursts of beam to experimenters the pulser with its low duty cycle is very useful for beam diagnostics. The phase probes need a peak current of at least 10 μA for a good signal-to-noise ratio, while the cyclotron should be commissioned with an average current less than 100 nA.

Mechanical Pulser: The electrical pulser will probably not be incorporated into the CRM beamline before 1973. In the meantime a mechanical pulser was built as a substitute. A 3 mm thin 25 cm diam carbon wheel with an opening for the beam on its periphery rotates with 30 rev/sec and intercepts the beam for 95% of the time. This 5% macroscopic duty cycle is very helpful for studying space-charge effects at high peak currents and low average beam power.

5.4 Space-Charge Effects. At the low energy level of 300 keV space-charge effects get noticeable already around instantaneous currents of 100 μA. If one allows a 50% filling of the apertures with beam and limits the quadrupole voltages to 3 kV, one gets a transverse space-charge limit of 10 mA. In the longitudinal direction the space-charge repulsion for a pulsed beam is much more serious: for an average current of 100 μA with 2 nsec long pulses (16 deg RF phase width) it takes only 4 m drift space to double the pulse length and create an energy spread of ±0.6%. Therefore, the chopper slit should be placed as close to the cyclotron centre as possible (about 3 m in the main cyclotron, 8 m in the CRM). Furthermore, one has to rely on internal phase slits to produce very short intense pulses. The computer program BUNCH of Los Alamos[4] was used to calculate the bunching factor and the energy spread induced by a sinusoidal buncher (see Figs. 5 and 6). The electric space-charge fields were calculated with a Monte Carlo technique involving 2000 particles in a bunch. The transversal beam size was kept approximately constant with focusing lenses. One sees clearly that the optimum bunching factor, the minimum induced energy spread and the location of this minimum are very strongly current dependent. Provision for shifting the buncher along the beamline in modular units is foreseen for the TRIUMF beamline.

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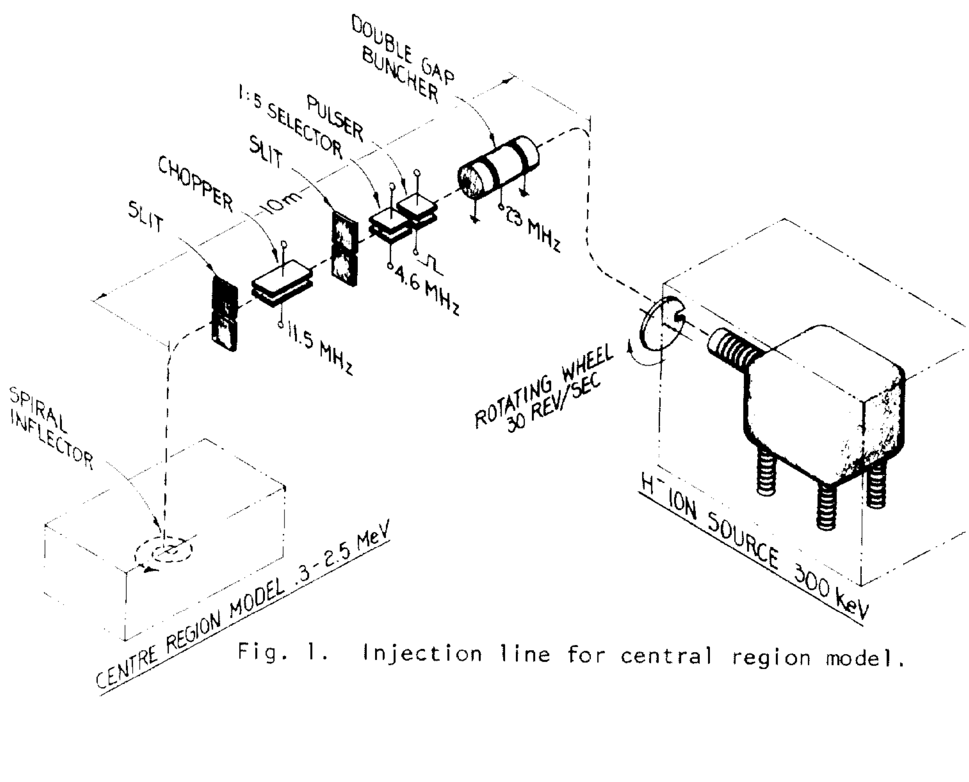


Fig. 1. Injection line for central region model.

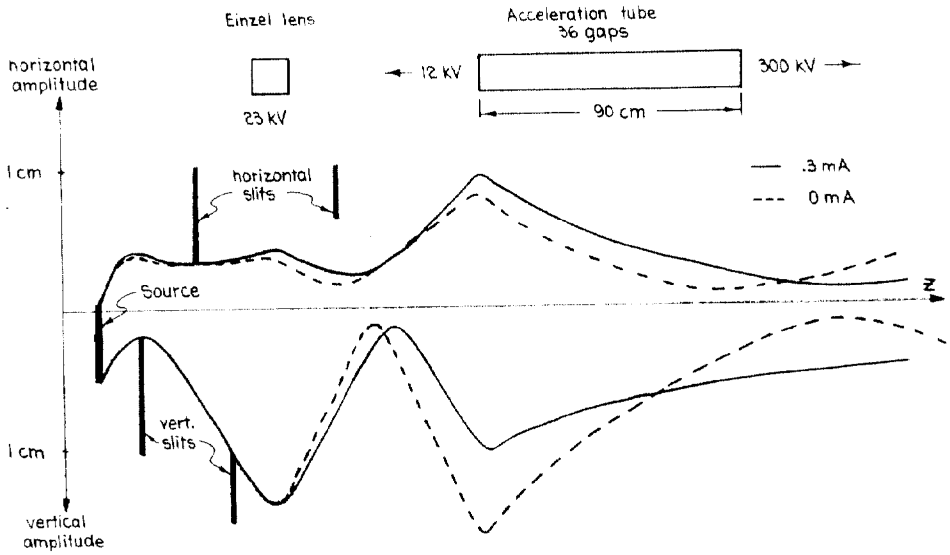


Fig. 2 Beam envelopes from source to acceleration tube

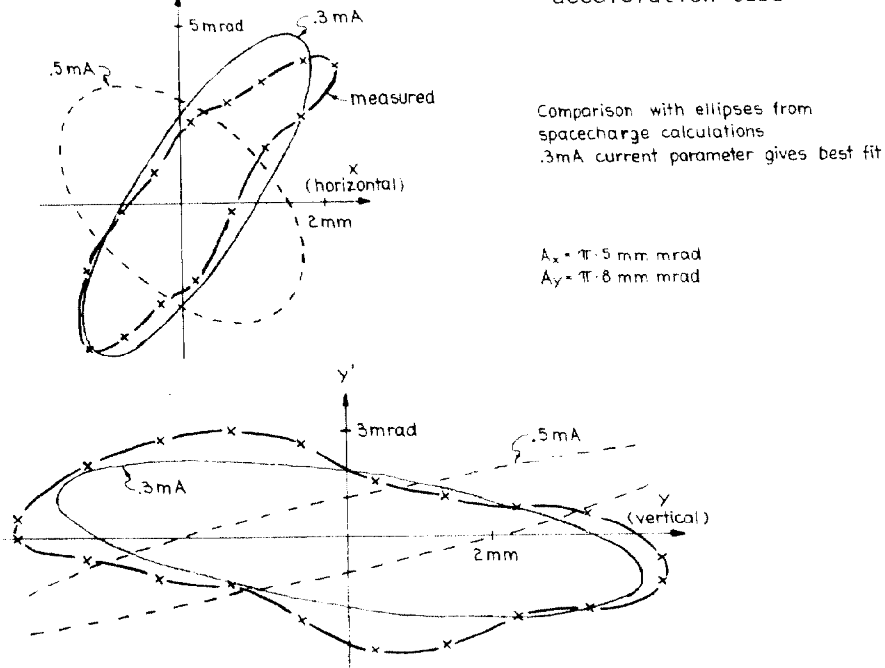


Fig. 3. Emittance measurements at 300 keV 0.5 mA H^- beam.

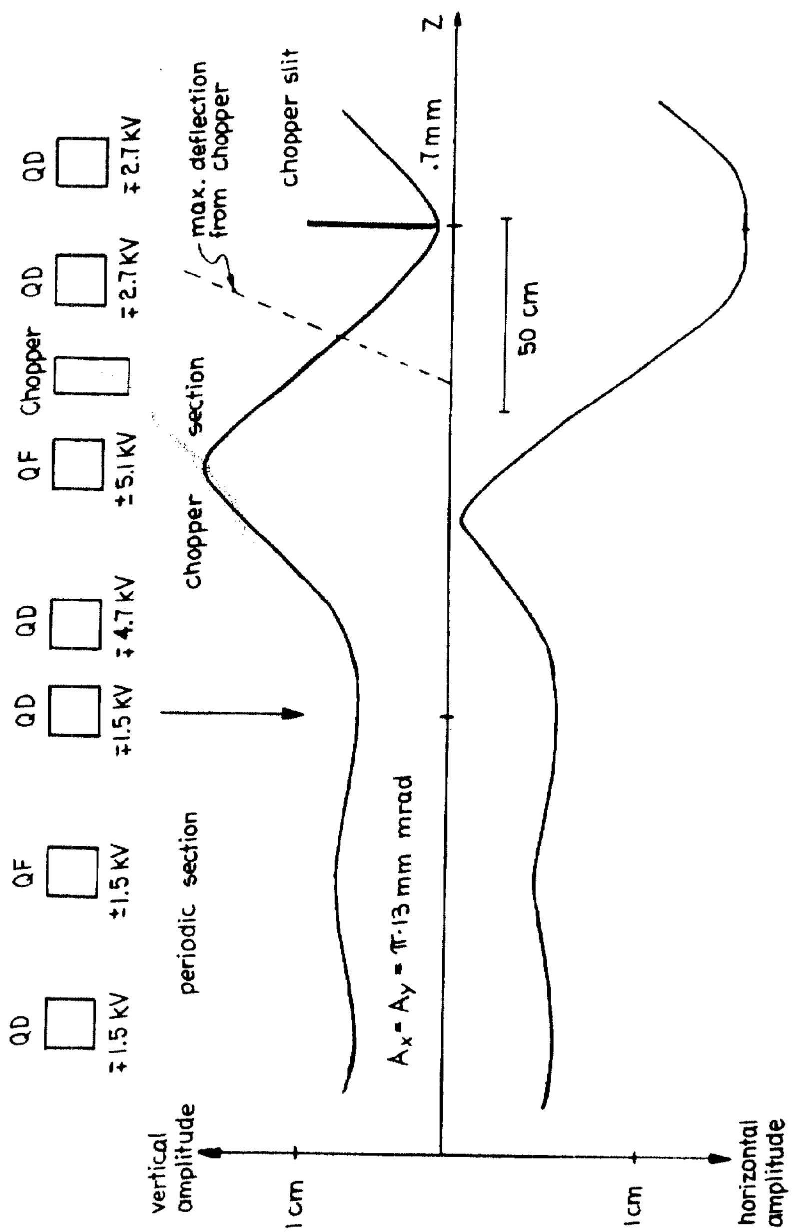


Fig. 4. Beam envelopes of 300 keV H^- beam in chopper section for 1 nsec pulses.

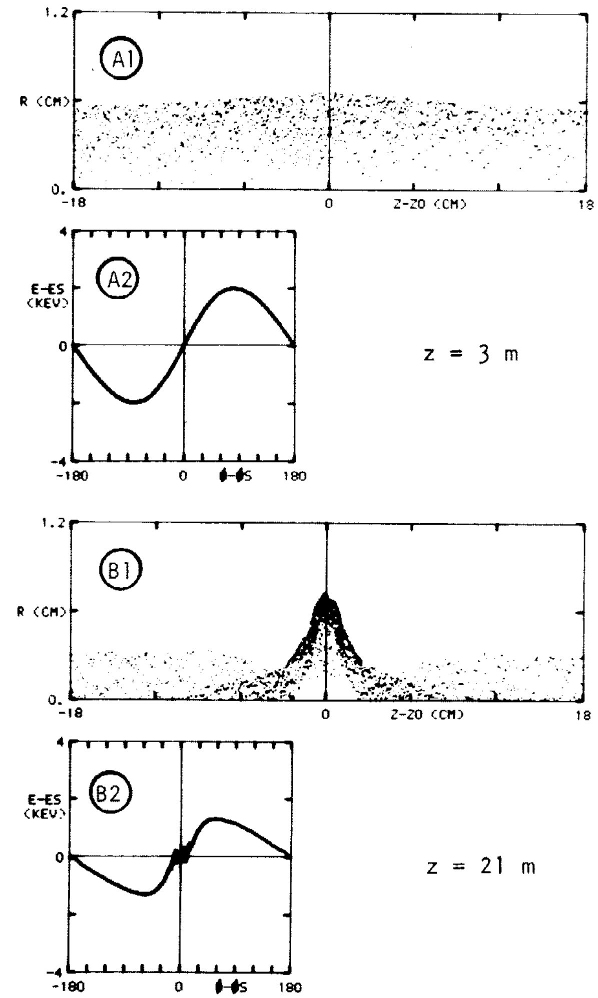
Fig. 5. Bunching on the 300 keV injection line.

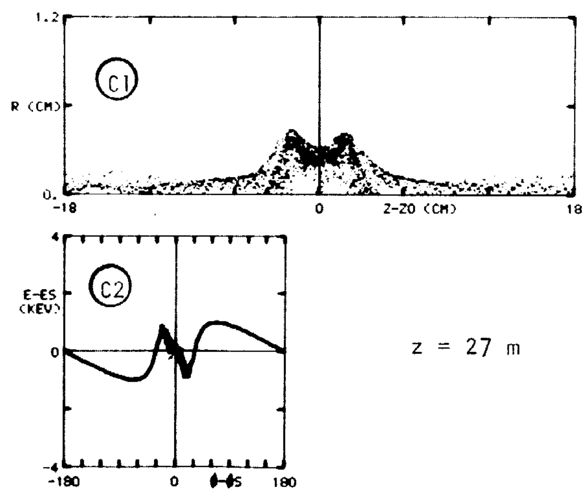
I = 0.5 mA
Peak voltage of buncher (at z = 0 m) = 2 kV

Results of computer run BUNCH[4] at various distances z along the beamline:

A1, B1, C1: radial and longitudinal distribution of 2000 particles in 36 cm long bunch.

A2, B2, C2: energy spread versus phase; the transversal beam size is kept approximately constant with focusing lenses.





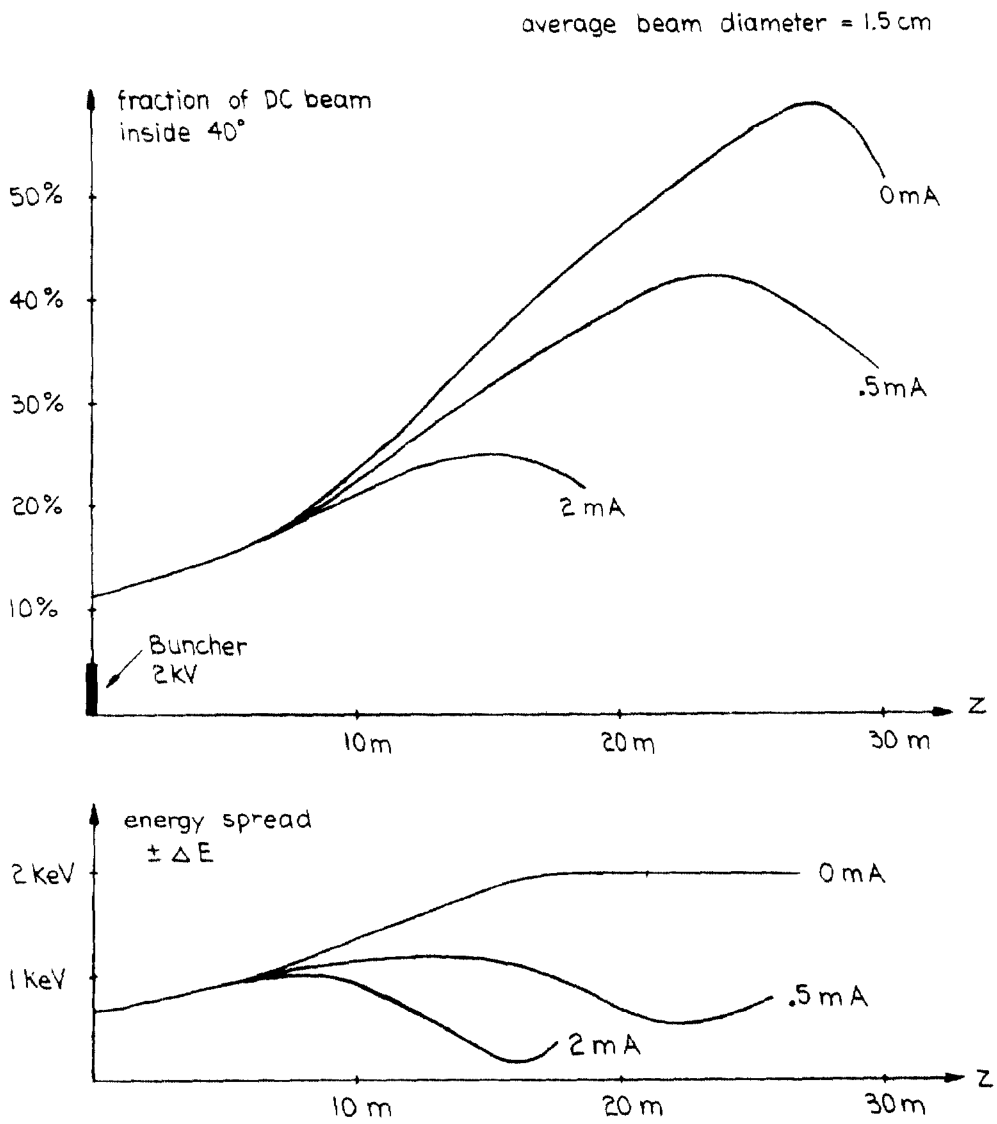


Fig. 6. TRIUMF 300 keV injection line - effect of space charge on munching and energy spread.

DISCUSSION

REGENSTREIF: We have heard some arguments against the use of einzel lenses this afternoon, first its flexibility and then its special properties. I saw you have one at the 24 kV level. What is the justification?

JOHO: Our einzel lens is not in a magnetic field; therefore we don't have this electron trapping as in an axial injection system. We could use a doublet or a triplet instead of an einzel lens, but this requires more high voltage power supplies. For the TRIUMF ion source we will use extra quadrupoles beside the einzel lens to give a more flexible matching between ion source and accelerator tube.

MARTIN: Is there any possibility of using a double-gap buncher to advantage? Or are there space charge difficulties?

JOHO: In principle we could, but we are a bit restricted in the amount of bunching we can have, due to the induced energy spread. If we bunch stronger, with higher voltages or with a double-gap buncher like at Los Alamos, then we run into trouble because the dispersive spiral inflector can tolerate an energy spread of only ±0.2%, which is really very low. You can see from Fig. 6 that space charge effects reduce the bunching efficiency but help to make the energy spread smaller, too.