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EMITTANCE OF THE PONI-1 CESIUM GUN

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Abstract

The emittance of the cesium gun on PONI-1 was measured using a standard BNL emittance head. The measurement showed a larger emittance than expected from calculations. A quadrupole focusing system was designed and tested. The limitation to focusing factor for the quadrupole was due primarily to saturation in the quadrupole magnet poles. Implications for use on PONI-1 are discussed.

Introduction

One of the ways to produce polarized H^- for acceleration in the Linac and AGS is to have the atomic hydrogen beam charge exchange with a co-linear beam of fast cesium atoms. Several polarized ion sources have been constructed with colliding beam ionizers: DC sources at Wisconsin[1] and Washington[2], and a pulsed source at BNL[3].

The H^- current produced by a colliding beam ionizer is dependent upon the neutral cesium current density and atomic beam density via

$$I_{H-} = J_{Cs}\ (nV)\sigma$$

where J_{Cs} is the Cs^o current density, n is the density of the H^o target atoms, V is the interaction volume and σ is the charge exchange cross section. The interaction volume is defined as the volume that is common to both beams, and will be a function of both the cesium beam emittance and the atomic hydrogen beam emittance.

Figure 1[4] shows a schematic of PONI-1. The cesium gun is located at the bottom of the drawing. The ionization column (IC) is located towards the center of the source. The cesium beam is created by extracting Cs^+ from a hot, porous tungsten button at approximately 40 kV. The extracted beam is transported to a cesium vapor cell where the fast cesium ions are converted into fast cesium atoms. The atoms then drift through the H^- extraction system into the IC. Further details concerning beam formation can be obtained from Reference 3.

It is clear that the beam size limitations are the apertures of the neutralizer and the collimator in the electrostatic bend. The long drift length from the neutralizer to the end of the IC limits the divergence of the atomic cesium beam. The atomic hydrogen beam entering the IC has been assumed to be essentially a parallel beam. Figure 2 shows the acceptance of the neutralizer/ionizer beam line at the entrance to the neutralizer. From the diagram, the geometric acceptance of the neutralizer/ionizer system is approximately 290 mm-mrad. It should be noted that small angle scattering in the neutralizer vapor has not been included in this diagram: the effect of scattering would be to reduce the acceptance even further and would be dependent upon the neutralizer vapor pressure. The cesium beam from the gun must be matched to this acceptance diagram to provide optimum Cs^o current in the IC.

Gun Emittance Measurements

Description of Measurements

The cesium gun was removed from PONI-1 and mounted on a test stand equipped with a set of standard LEBT emittance heads. The emittance heads had a 0.1 mm high entrance slit. The detector foil stack was comprised of 30 foils spanning roughly 4.2 mm transverse to the beam axis, and was located approximately 77.5 mm behind the entrance slit. Table 1 gives the relevant parameters for the vertical and horizontal emittance heads. The distance from the exit of the gun's vacuum housing to the entrance of the emittance heads was 218 mm. A biased Faraday cup was located after the emittance heads to provide the current measuring capability needed to observe the condition of the source during start-up. The system was evacuated with two Sargent-Welch turbomolecular pumps to an operating pressure of $3x10^{-6}$ Torr. The source current was 15 mA for these measurements. Figure 3 is a sketch showing a typical current pulse and the sample trigger required by the emittance electronics. The sample timing of each measurement was set so that the sample-and-hold circuit was triggered immediately after the peak current was obtained. The gun was operated at the AGS period of 2.80 seconds. Source and electronics timing was obtained from the AGS timing system.

Two sets of measurements were made in this condition. First, the extraction voltage was varied between 25 and 43 kV with the emitter position in its nominal zero setting. The second set of measurements had the extraction voltage fixed at 40 kV and the extraction gap length was changed.

Results

Figure 4a shows the measured emittance of the gun at an extraction voltage of 39 kV and the emitter at its nominal zero position. The points included 85% of the beam current. The break in the middle is due to one of the channels in the electronics not functioning. Integrating the area in the diagram yields a geometric emittance of 490 mm-mrad. This is almost twice that of the acceptance of the system. The ellipse that is drawn over the data is a fit to the data at 85% beam fraction. The emittance as a function of the beam fraction is shown in Figure 4b. Roughly 40% of the beam will be outside the acceptance of the neutralizer/ionizer system.

The entrance of the neutralizer is located 110 mm from the exit flange of the Cs gun. The orientation of the emittance relative to the acceptance diagram, which was transported to a distance of 219 mm from the exit flange, is shown in Figure 5. The acceptance is largely filled by the beam, although the extreme edges will not be filled. It is also interesting to note that the orientation of the ellipse representing the data shows that the beam is divergent while a proper match to the acceptance would require a convergent beam entering the neutralizer. This mismatch is seen to eliminate the current that is carried in the large "wings" that extend outward.

Figure 6a shows the Twiss parameter α, obtained from the fits to the data at a 75% beam fraction, as a function of extraction voltage. At all extraction potentials α is negative indicating that the beam is diverging. The position of the previous beam waist can be obtained from

$$\ell = \frac{\alpha}{\gamma}$$

and is plotted in Figure 6b. The distance from the exit flange to the emitter is 8.2 cm. Since the distance to the upstream waist is on the order of 75 cm, the beam is diverging as soon as it is emitted. A better estimate of the waist position can be obtained at a beam fraction of 25% beam where the aberrations are not visible and the data is better represented by an ellipse. For a 35 KeV, 11.5 mA cesium beam the value of α is -14.9 and is γ 20.96, yielding a distance to the upstream waist of 71 cm.

A Quadrupole Focused Cesium Beam

Calculations

The emittance data collected from the previous measurement provided a starting point for designing a magnetic quadrupole focused beamline. The emittance for 39 kV extraction and the emitter in its nominal zero position were chosen as input for a MAD calculation of the beam line. The initial Twiss parameters for the cesium beam at the gun exit flange were obtained by taking the fitted ellipse parameters from LEBT_EMIT and projecting them back to the flange. The values used were

$$\alpha = -1.001$$
$$\beta = .9495$$

The extracted beam is assumed to be axially symmetric.

A quadrupole triplet was located 425 mm from the exit of the gun. The triplet consisted of three quadrupoles each with a bore of 100 mm. The two outermost quadrupoles were 100 mm in length and had their gradients coupled. The inner quadrupole was 200 mm long and its gradient was independent of the outer quadrupoles. The gap between magnets was set at 100 mm.

Figure 7a shows the final design of the beam line and Figure 7b shows the result of the MAD calculation. The marker in Figure 7b indicates the anticipated location of the collimator in the electrostatic bend of PONI-1. The emittance head in Figure 7a is located at approximately the position of the neutralizer entrance. The quadrupole strengths were varied to produce a waist at the marker and a reasonable match to the acceptance of the neutralizer. The final field gradients needed to produce a focused beam in the collimator and match into the acceptance of the system are: the outer quadrupoles set at 5.82 T/m and the inner quadrupole set at 5.96 T/m.

Table 2 is a complete listing of the input file for MAD. The quadrupole strengths listed produce the beta function shown in Figure 7b. Beta in the center of the quadrupole reaches a maximum of approximately 6.8; using the acceptance of the neutralizer as a guide for evaluating ϵ, the physical size of the beam in the center of the quadrupole is roughly 2 inches in diameter. At the collimator, the beam is once again reasonably round and remains so until it reaches the end of the IC. This means that the interaction volume can be approximated by a cylinder whose diameter is that of the atomic beam. The beta function is seen to double between 2.4 m and 2.8 m; therefore Cs^o current density will decrease by a factor of 2 during passage through that region. One would then expect that the current density in the IC will change substantially from one end to the other.

Teststand Operation

A test stand was constructed to test quadrupole focusing using a beam from the cesium gun. The beamline was assembled as close to Figure 7a as possible. In addition to the quadrupoles, two sets of magnetic steerers were added to the beamline: one before the quadrupoles and a second after the quadrupoles.

The quadrupoles used for the test were the 4"x 4" quads from LEBT-2A line. The calculations listed in Table 2 show that a poletip field of 3 kG is required for this experiment. A set of water cooled booster coils were wrapped around the main coils to provide some additional magnetomotive force to achieve higher poletip fields and some cooling. The booster coils were powered up to 50 A DC. The main coils were pulsed up to 20 A with a duty cycle of 50 percent. These limits were set by the power supplies. Figure 8 shows measurements of the poletip field for two conditions: no boosting field and the booster coils carrying 50 A. Both curves show that the magnet is starting to saturate at poletip fields of 2 kG. Since 3 kG is required for operation at an extraction potential of 39 kV, the quadrupoles will be under-powered and not be able to focus the beam. The fields available will limit the energy of the beams that can be focused on the teststand to 17.3 keV.

The cesium gun was operated at an extraction voltage of 29 kV. A pulse was extracted and detected by a biassed Faraday cup located 2 m from the gun. The Faraday cup current passed through a 10 kΩ resistor with the resulting voltage pulse measured by a LeCroy 9400A digital oscilloscope. Figure 9a shows the detected pulse when the quadrupoles are turned off. The bottom trace of Figure 9b is the cesium current pulse when the quadrupoles are turned on. The top trace in 9b is the extraction voltage monitor provided by the source electronics. The current pulse shows a 75% increase in peak current during the flattop of the extraction voltage pulse. As the extraction voltage decreases, a second peak appears that is due to the focusing of the quadrupoles. The energy of this second peak is estimated to be 18 keV, which would agree with the energy limit set by saturation in the magnets. The ratio of currents at 18 keV for magnets on to magnets off is eleven.

Table 3 lists the ratio of currents measured in the Faraday cup as a function of magnet current. The ratio of quadrupole currents remained fixed throughout the measurements. The data show that the ratio is increasing as the field grows but does not pass through a maximum. The addition of 50 A of boosting current yielded an additional 50% more current.

Conclusions

The 85% emittance of 15 mA, 39 keV beam produced by the PONI-1 cesium gun was measured to be 490 mm-mrad, and 40% of this beam will be lost due to a mismatch with the acceptance of the neutralizer/ ionizer system. A quadrupole focused beam has been tested; however, limitations in the available magnets have prevented a test at the energy required for source operation. Additional tests with a quadrupole triplet capable of producing field gradients of greater than 6 T/m should be performed.

References

1. D. Hennies, R.S. Raymond, L.W. Anderson, W. Haeberli, and H.F Glavish, Phys. Rev. Lett. 19 (1978) 1234.

2. T.A. Trainor, et al., Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys. (Osaka, 1985), Suppl. J. Phys. Soc. Jpn. 55, (1986) 435.

3. J.G. Alessi, Vacuum 34 (1984) 7.

4. J.G. Alessi, A. Kponou, and Th. Sluyters, Helv. Phys. Acta 59 (1986) 563.

Table 1

Emittance Head Parameters

	Vertical	Horizontal
Slit opening [mm]:	.1	.1
Foil Separation [mm]:	.142	.138
Slit/Detector Distance [mm]:	83.31	77.47
Maximum angle [mrad]:	25.6	26.7
Bias Voltage [V]:	+200	+200

Table 2

```
! Magnetic optics for the PONI-1 cesium gun transport line.  Want to match
!       into the acceptance of the neutralizer and the ionizer.
!
!                               C.R. Meitzler
!
!
! Quadrupole field strengths
!
PARAMETER, DBDR1=5.8210        !Magnetic field gradient in T/m
PARAMETER, DBDR2=5.9624        !Magnetic field gradient in T/m
!
! Common parameters and constants
!
PARAMETER, QHS=1.
PARAMETER, QVS=-1.
PARAMETER, I2M=.0254                            !Inches to metres
PARAMETER, CHARGE=1.                            !Charge state;
PARAMETER, MOMENTUM=98.302                      !MOMENTUM of Part.; [MeV/c]
PARAMETER, RIGID=.0033356*MOMENTUM/CHARGE       !RIGIDITY OF BEAM
PARAMETER, D2R=PI/180.                          !Conversion between degrees
                                                !   and radians
!
! Beamline component specifications
!
M1:     MARKER                                  !
M2:     MARKER                                  !
M3:     MARKER                                  !
ME:     MARKER                                  !
MD:     MARKER                                  !
MS1:    MARKER                                  !
MS2:    MARKER                                  !
D1_8:   DRIFT, L=.4/8.                          !
Q1_4:   QUAD, L=.150/4., K1=QVS*DBDR1/RIGID     !
D2_4:   DRIFT, L=.05/4.                         !
Q2_4: QUAD, L=.250/8., K1=QHS*DBDR2/RIGID       !
D3_4:   DRIFT, L=.05/4.                         !
Q3_4:   QUAD, L=.150/4., K1=QVS*DBDR1/RIGID     !
D4_10: DRIFT, L=1.0/10.                         ! Drift to entrance of VAT valve
!
! Drift tubes
!
D1:     LINE=(8*D1_8)
D2:     LINE=(4*D2_4)
D3:     LINE=(4*D3_4)
D4:     LINE=(10*D4_10)
!
! Quadrupoles
!
Q1:     LINE=(4*Q1_4)
Q2:     LINE=(8*Q2_4)
```

```
:     LINE=(4*Q3_4)
!
! Beamline component stack-up
!
GUN:    LINE=(D1,Q1,D2,Q2,D3,Q3,D4,ME,D4)
!
!  Calculate the Twiss parameters along the beamline
!
USE, GUN
PRINT, GUN
TWISS, TAPE, ALFX=-1.001, BETX=.9495, ALFY=-1.001, BETY=.9495
```

<u>Table 3</u>

Quadrupole focusing parameters for 29 keV extraction.

Q1[A]	2[A]	Boost[A]	I_{on}/I_{off}
15.07	16.29	0	2.9
16.96	18.32	0	4.2
18.84	20.36	0	6.0
18.84	20.36	50	9.0

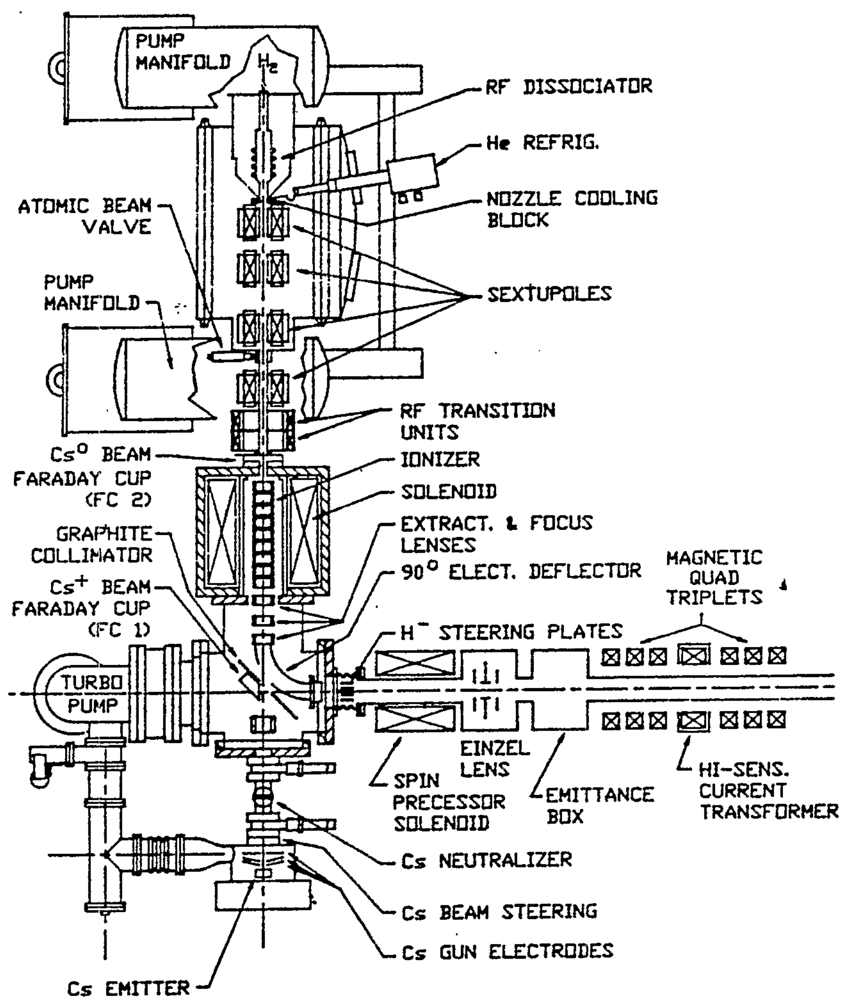

Fig. 1 Schematic drawing of the PONI-1 polarized ion source.

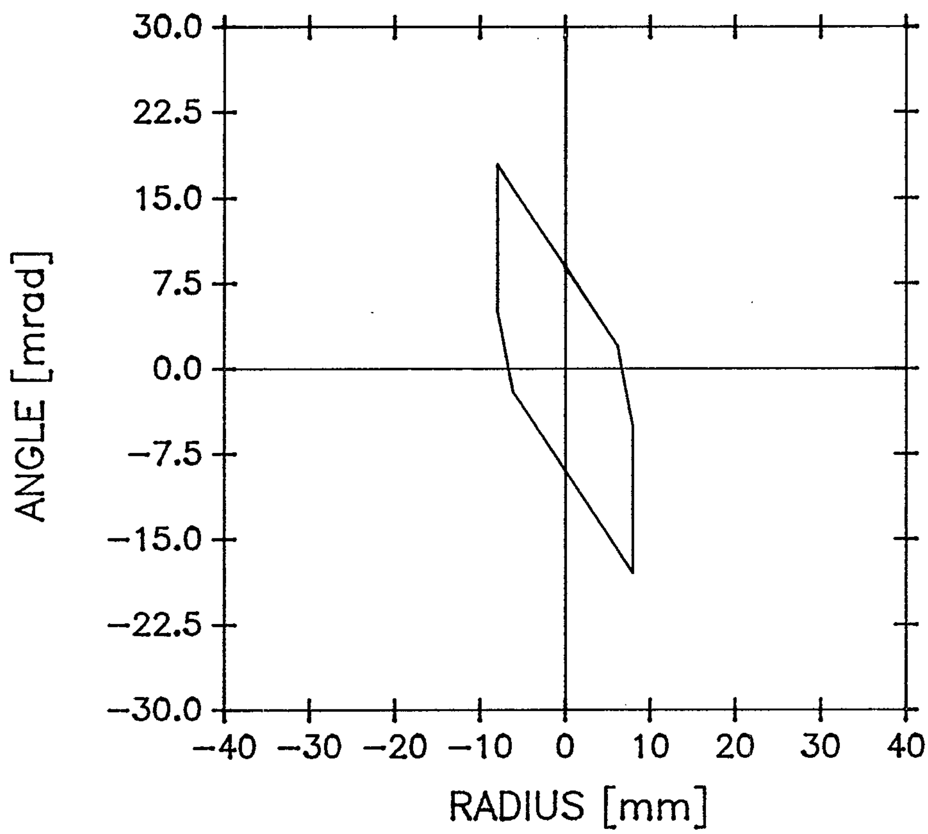

Fig. 2 Acceptance of neutralizer/ionizer assembly at the entrance to the neutralizer.

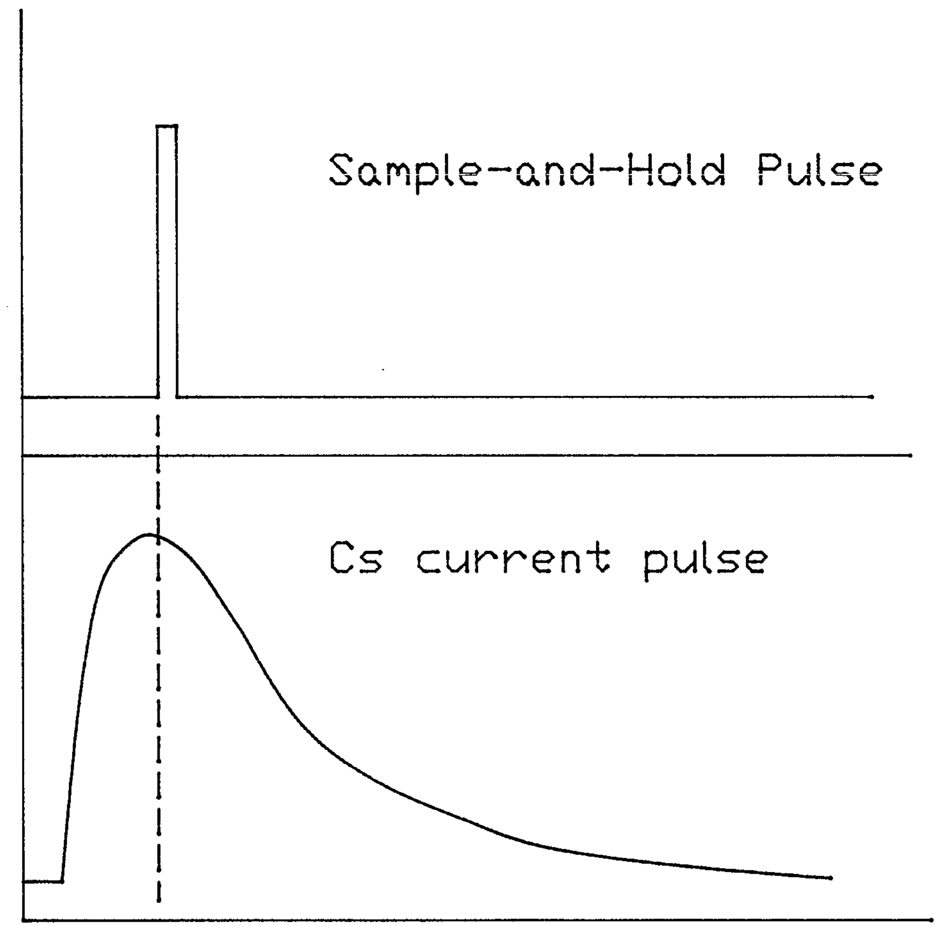

Fig. 3 Timing of the sample and hold circuit in the emittance head electronics.

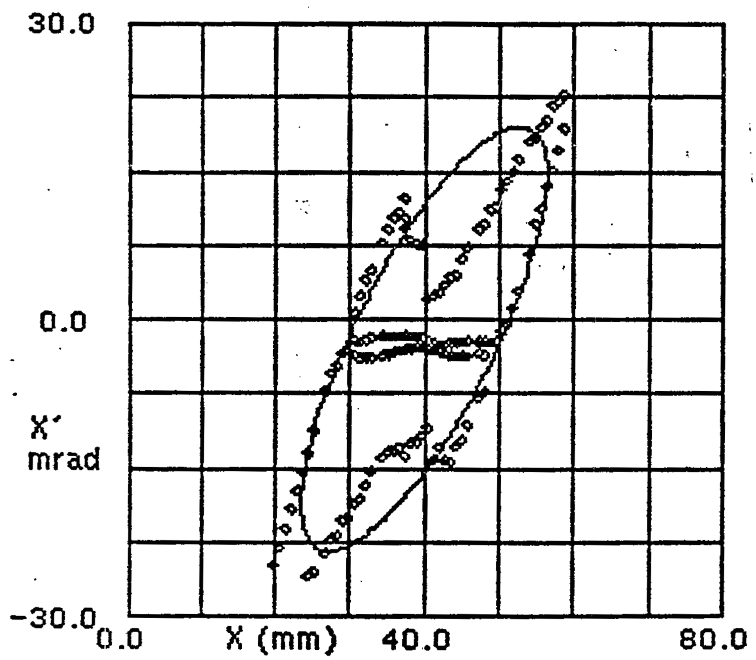

Fig. 4a Measured emittance of a 39 KeV Cs^+ beam emitted by the Cs gun.

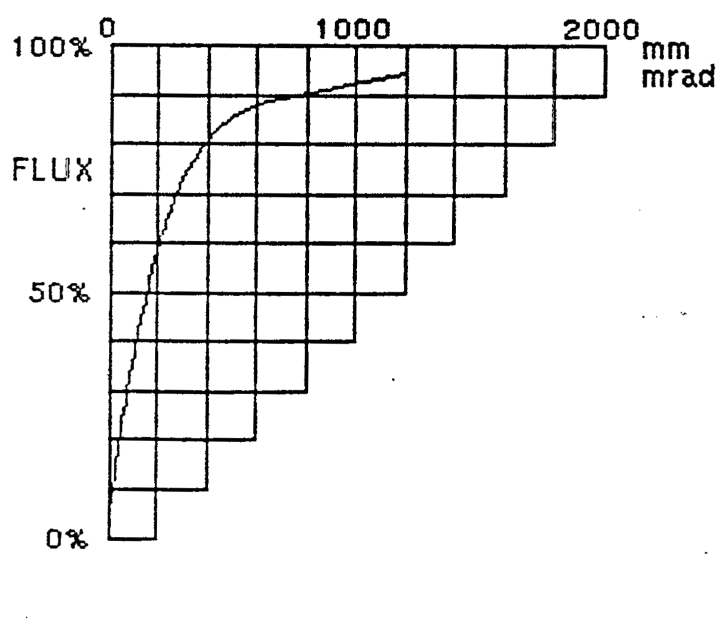

Fig. 4b Emittance as a function of beam fraction for the measurement shown in Fig. 4a.

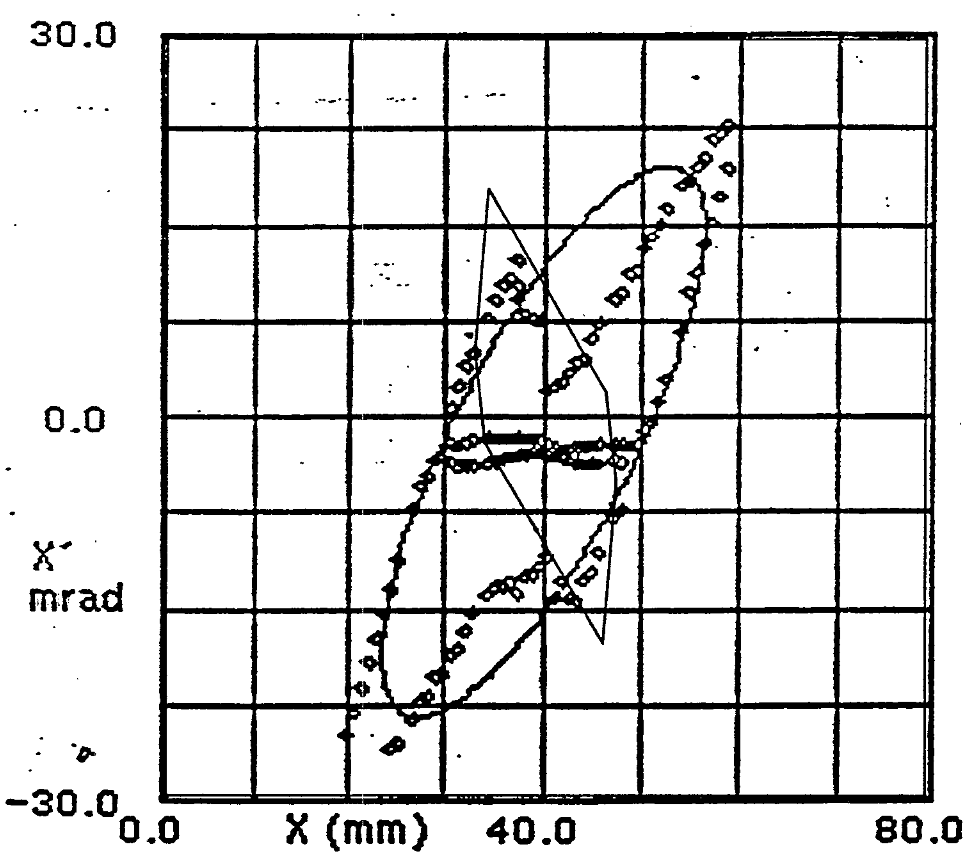

Fig. 5 The 39 keV emittance overlaying the acceptance of the neutralizer/ionizer. The acceptance has been transferred to the location of the emittance head.

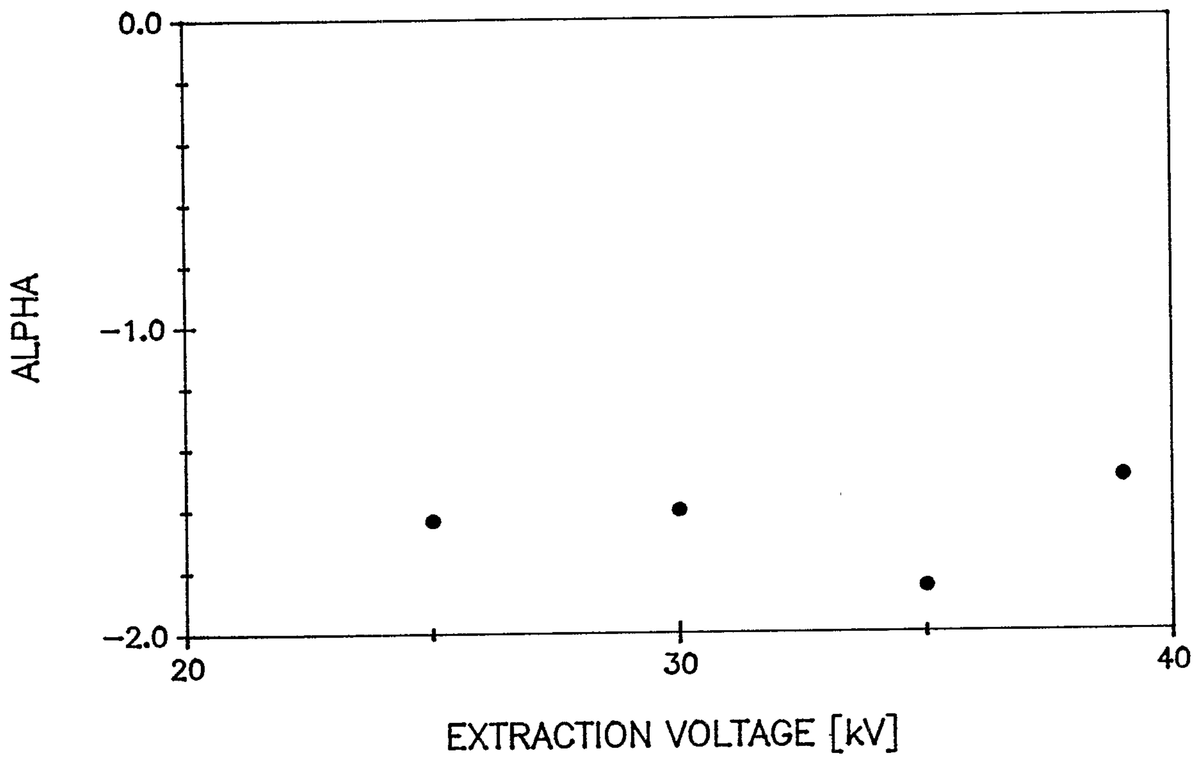

Fig. 6a α as a function of extraction voltage.

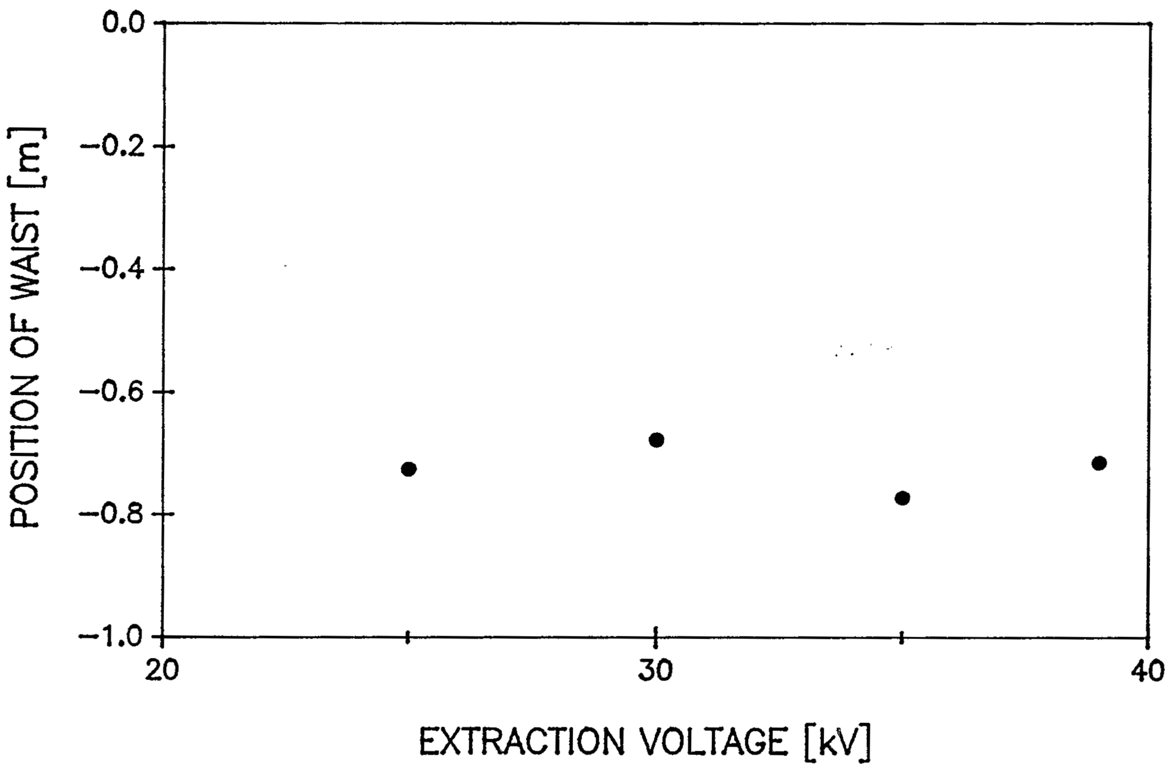

Fig. 6b Estimated position of upstream waist relative to the emittance head.

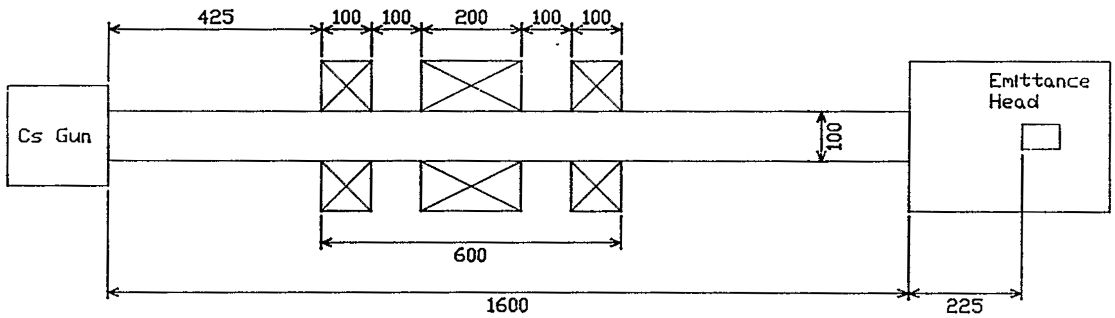

Fig. 7a Schematic of the quadrupole focusing system proposed for PONI-1.

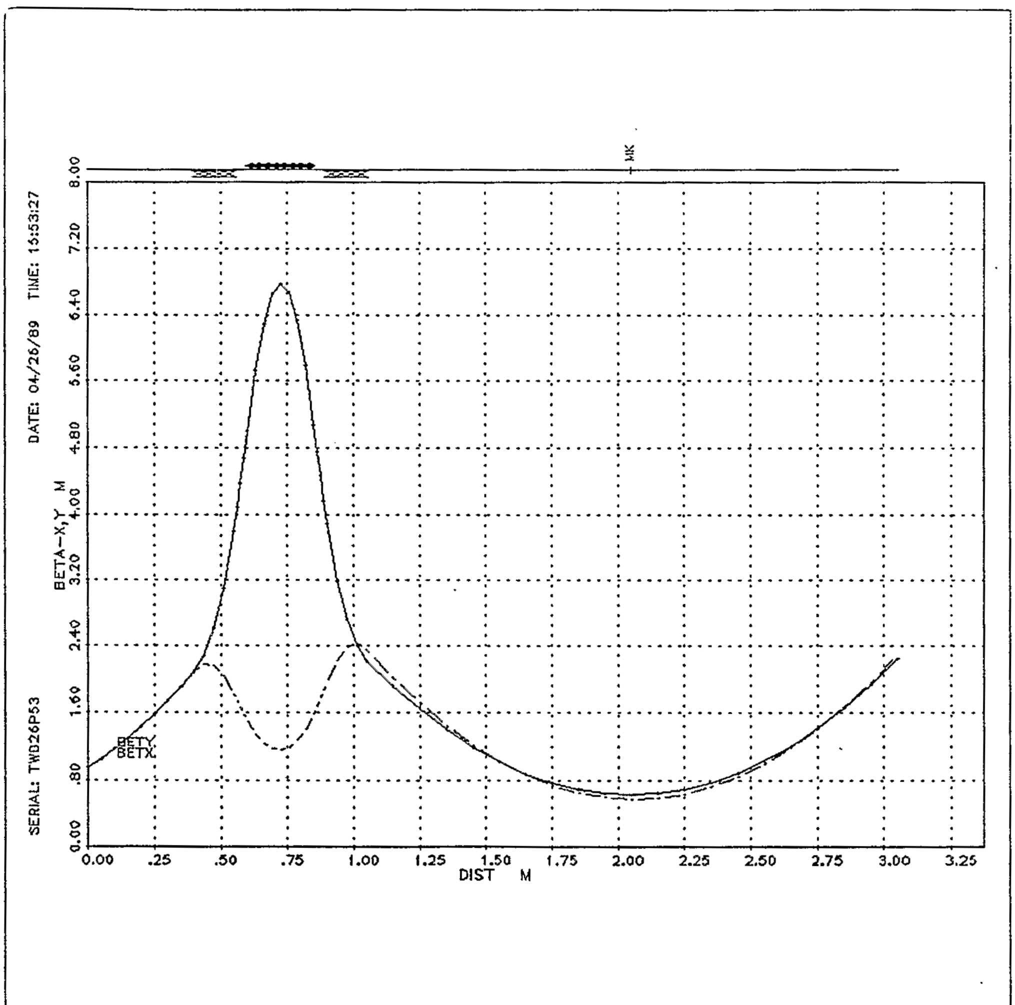

Fig. 7b Calculated β function for the channel.

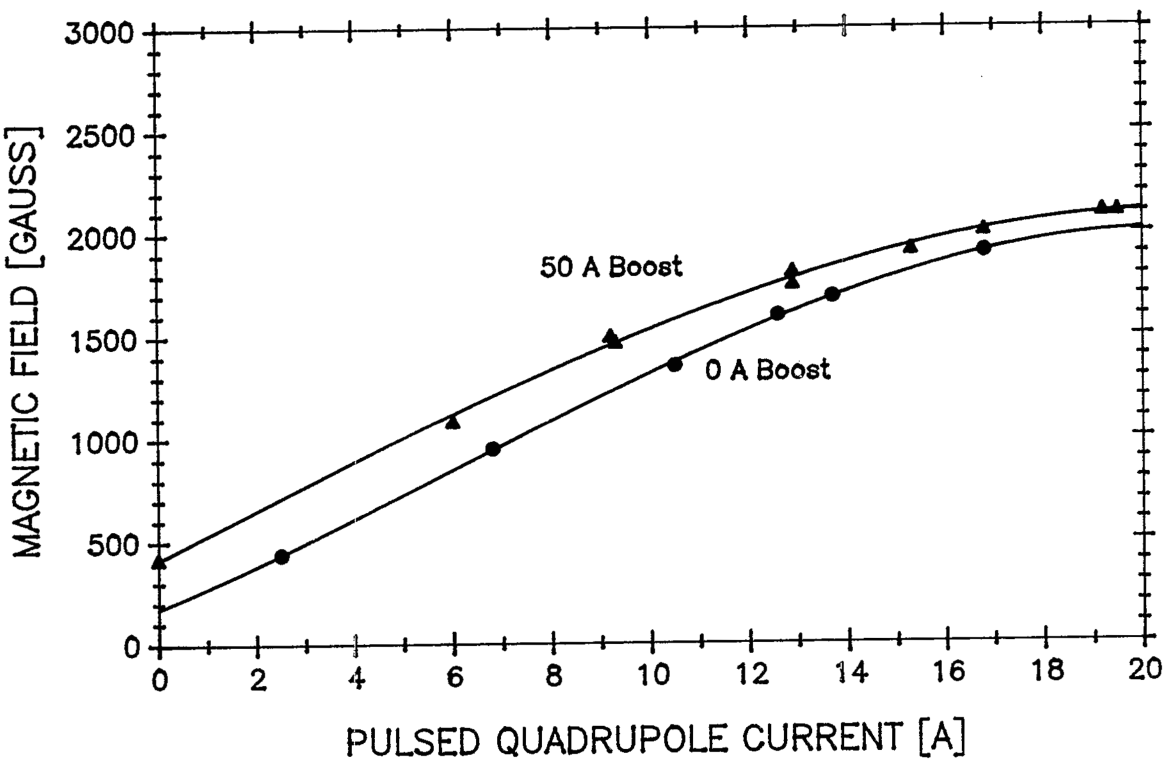

Fig. 8 Calibration of the quadrupole poletip field as a function of current.

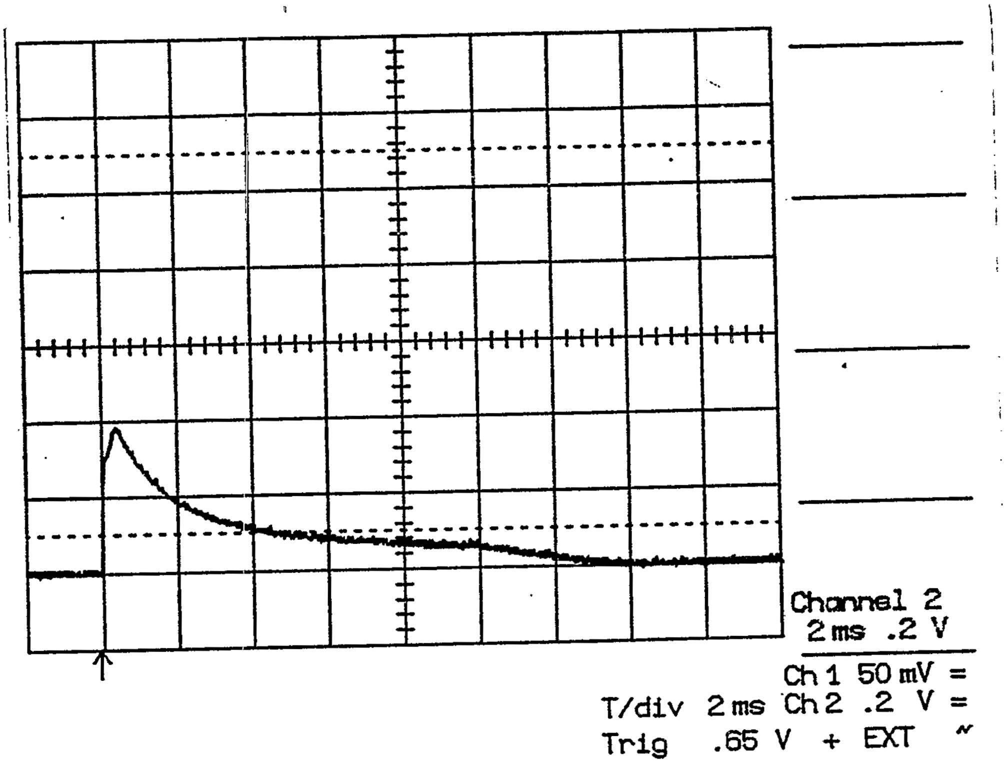

Fig. 9a Cs^+ current measured in a Faraday cup 2 m from the gun with the quadrupoles off.

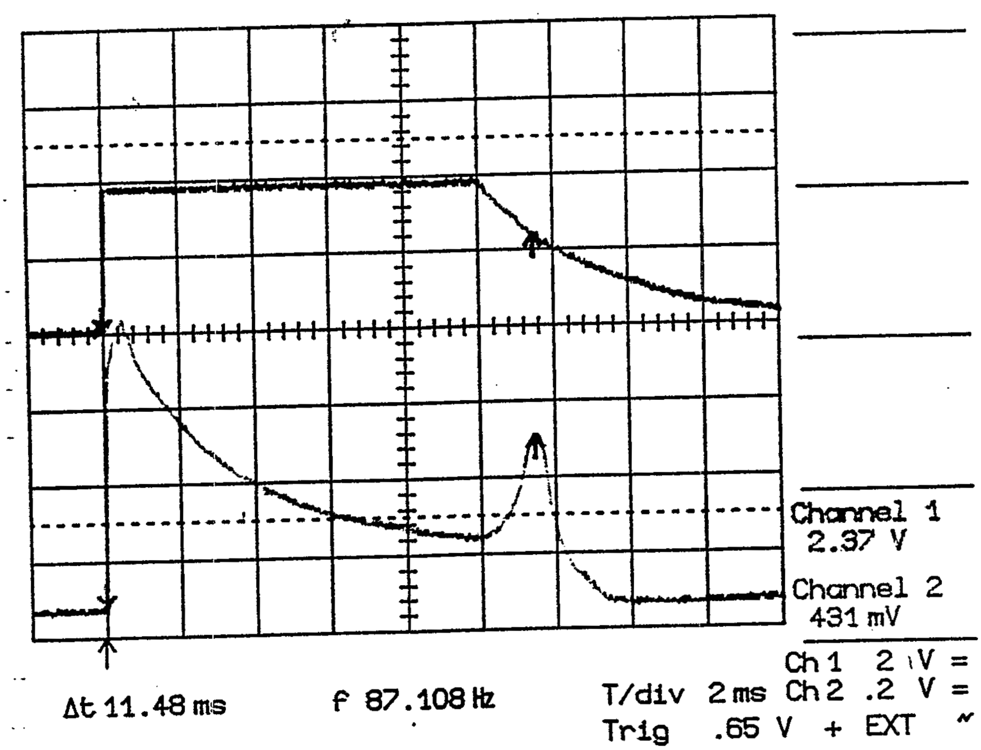

Fig. 9b Cs^+ current measured in a Faraday cup 2 m from the gun with the quadrupoles on.