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Spin Note

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1 Introduction

The RHIC polarized H^- ion source, so called BOPPIS (Brookhaven Optical Pumped Polarized Ion Source), is being developed at TRIUMF. This report describes ion optics calculations for BOPPIS.

A simple schematic of BOPPIS is shown by Fig.1. Polarized H^- ion beam is produced by following method[1]: H^+ ions extracted from the ECR cavity enter the rubidium cell and capture polarized electrons from optically pumped rubidium vapor in a 2.5T magnetic field. As a result, they become hydrogen atoms having a polarized electron. Then, the hydrogen atoms pass through a Sona region where the polarization is transfered from electron spin to nuclear spin. The nuclear spin polarized hydrogen atoms capture an unpolarized electron from the sodium vapor in the sodium jet ionizer cell and become nuclear spin polarized H^- ions. The required beam parameter value of BOPPIS are shown by Table. 1.

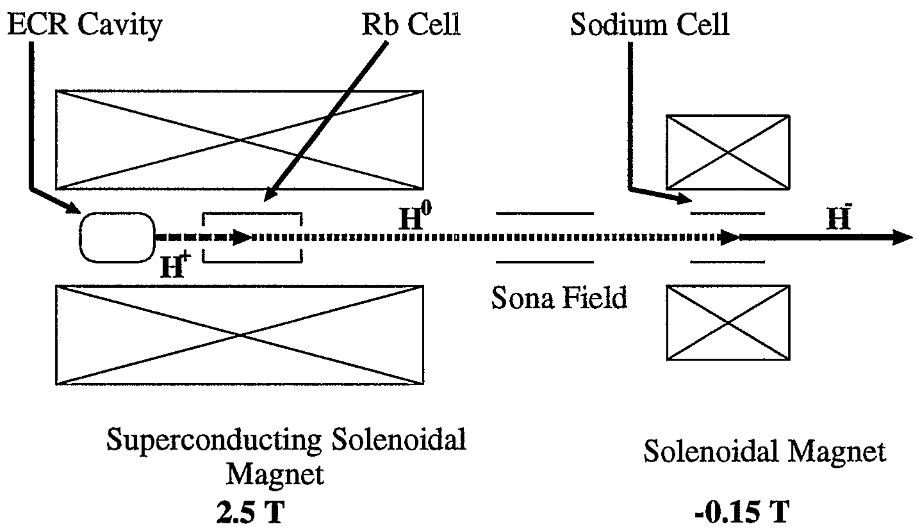


Figure 1: Schematic of BOPPIS.

Current (mA)	0.5~1.5
Pulse duration (μs)	100~300
Charge/pulse (mA·μs)	≥150
Polarization (%)	≥80
Normalized emittance (mm mrad)	≤2π
Repetition rate (Hz)	7.5

Table. 1 The requirements for BOPPIS.

The H^- ion beam extracted from the sodium jet ionizer cell is influenced by the fringing field of the solenoidal magnet surrounding Na. On the other hand, the incident beam is not affected by the fringing field, because of the beam is in a neutral charge state. Moreover, since multiple charge exchange processes between the beam and the sodium vapor occur, the beam emittance cannot be conserved. In spite of its importance, it is impossible to calculate the ion optics of the Na cell in a simple way. Therefore, we carried out a detailed ion optics calculation in this region.

Our operation is mainly 3 points on follows:

1. To estimate the H^- yield ($H^0 \rightarrow H^-$) at the exit of the sodium jet ionizer cell.
2. To investigate now the beam profile (x,y) and the beam emittance (x,x') are affected by the fringe field at the exit of the sodium jet ionizer cell.
3. To learn how to optimize BOPPIS. The optimization of beam line components is very important because the beam emittance at the exit of the BOPPIS dominates the direction later beam line design will take.

2 Calculational Method

We assume the following initial conditions for performing the ion optics calculation. H^0 atoms (number = 5000) originate 10 cm upstream of the sodium jet ionizer cell (20cm $\times$ ϕ 2.0 cm). The incident H^0 beam emittance ($\pm$ 10mm: circle)$\times$($\pm$ 1mrad) , the almost parallel beam, is assumed and looks like the parallel beam. The H^0 atoms enter the sodium jet ionizer cell. We calculate the beam emittance and the beam profile 30 cm downstream of the sodium jet ionizer cell. We include the contribution of the sodium vapor density distribution. As boundary conditions, we assume that the total sodium vapor thickness is 10^{15} atoms/cm^2. And, we assume a Gaussian distribution for the sodium vapor density distribution and operate the sigma (σ) of the Gaussian distribution as a parameter.

We assume $H^0 \rightarrow H^-$ and $H^- \rightarrow H^0$ as charge exchange processes between hydrogen and

Na atoms, with cross sections of about 0.03×10^{-14} cm^2 and 0.30×10^{-14} cm^2, respectively. At the present beam energy (3.5 keV), other charge exchange cross sections are some orders smaller than the cross sections of the above processes and are negligible for this calculation.

The calculation program using a combination of the Runge Kutta method and the Monte Carlo method. The former is used for the particle tracking. When we calculate the particle tracking, components (r,z,B_r,B_z) are precisely calculated by the magnetic field calculation program [OPERA2D] are used as the space mesh of the Runge Kutta calculation. Monte Carlo method is done for the charge exchange. Further details about the calculation of the charge exchange by means of the Monte Carlo method has already been published [2].

3 Results

First, we show the beam trajectory along the solenoid axis. Figure 2(i)-2(iii) show the calculated results of the beam trajectory as a function of Z (along the solenoid axis), the solenoidal magnetic field distribution and the sodium vapor density distribution. Z=0 is the center of the sodium vapor cell (length = 20.0 cm). Figure 2(i), 2(ii), and 2(iii) have the difference of the sodium vapor density distribution, and those are Gaussian (σ=1.0cm), Gaussian (σ=5.0cm), and the uniform distribution in the sodium vapor cell, respectively. In Figures (a), thick and thin solid line are the magnetic field distribution and the sodium vapor density distribution, respectively. Figures (b) and (c) are H^0 and H^- trajectory of the transverse X projection, respectively, where the number of 100 particles is traced. It is clearly seen that H^- ion diverge from Z axis at the fringing field of the solenoidal magnetic field. On the other hand, many of H^0 atoms pass straight through the sodium jet ionizer cell.

The point of charge exchange of $H^0 \rightarrow H^-$ or $H^- \rightarrow H^0$ is plotted in figures (d).

In the previous paragraph, we saw that H^- ions are diverging by the fringing field of the solenoidal magnetic field. As the next step, it is informative to see the beam at the final point (30 cm point toward downstream of the sodium jet ionizer cell). The beam profile (x,y) and the beam emittance (x,x') are shown by figure 3. Figure 3(i), 3(ii), and 3(iii) are results of Gaussian (σ=1.0cm), Gaussian (σ=5.0cm), and the uniform distribution in the sodium vapor cell, respectively. The beam profile (x,y) and the beam emittance (x,x') are shown by the figures 3(a)-(b) and 3(c)-(d), respectively. The figures on left (a) and (c) are for H^0 and those on the right (b) and (d) are for H^-. It seems that the beams of H^0 and H^- are clearly separated. From comparison of (ii) and (iii), it is possible to understand that some H^0 atoms of the far point from the center of figures is due to the charge exchange at the fringing field. In figures (ii) and (iii), the shape of the beam profile and emittance is diffused due to the multiple charge exchange [2]. In this case, a number of diffused H^0 are less than 10% of particles (about 4500) of the center region. The beam radius and the normalized beam emittance for the H^- ion are about 13 mm and 2.4 π mm mrad, respectively. We regard the normalized beam emittance as an 100% area of an ellipse on the phase space coordinate.

The charge exchange rate ($H^0 \rightarrow H^-$) for (i), (ii), and (iii) is 9.12, 8.42, and 9.26 %, respectively. We found that the dependence on the shape of the sodium vapor distribution is relative small.

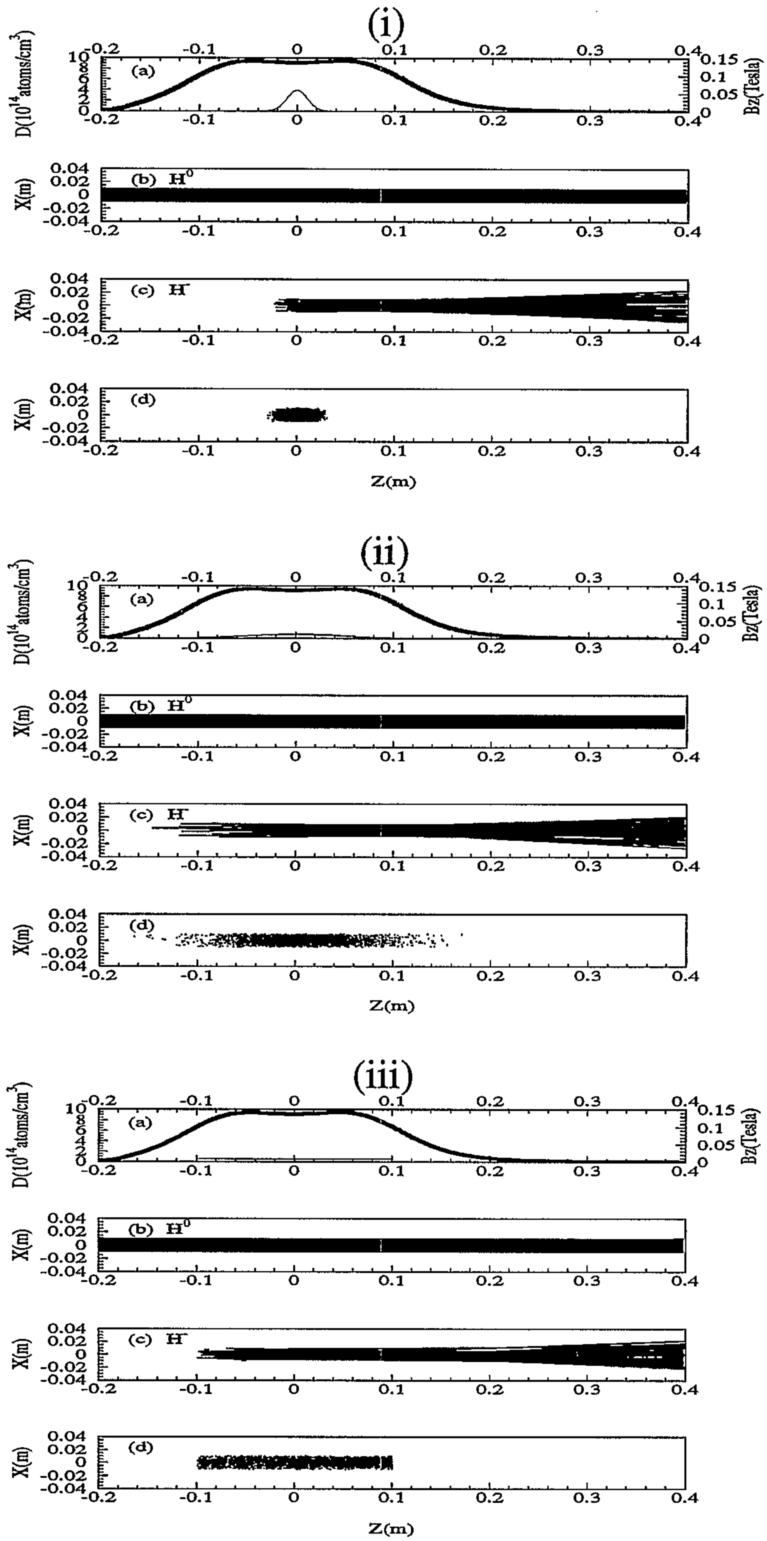
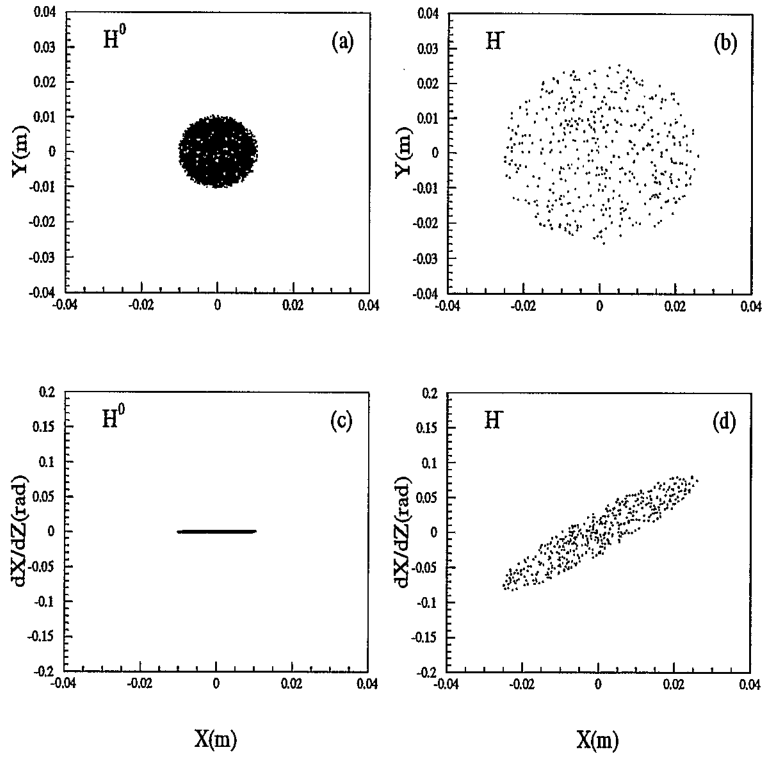
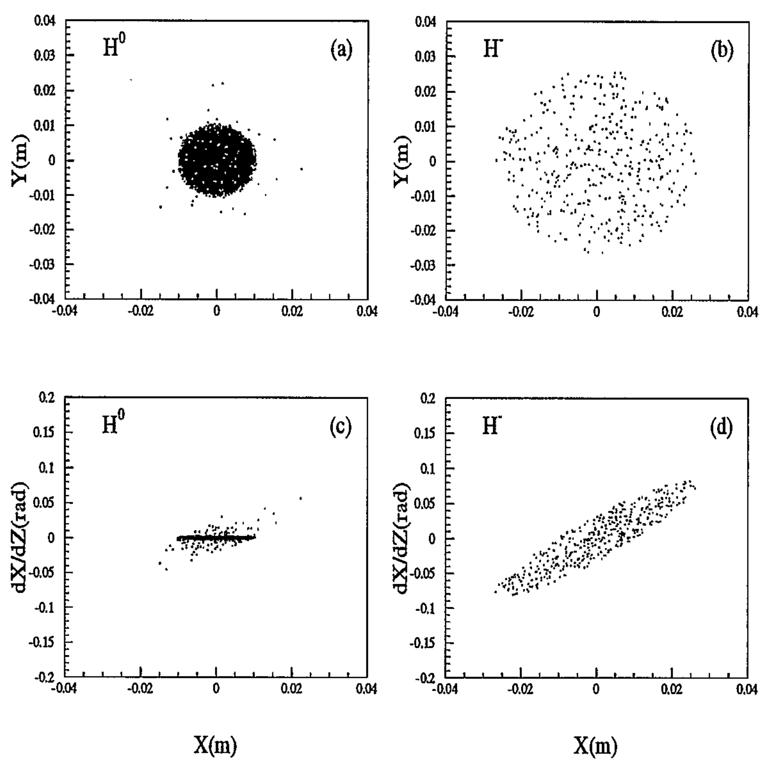


Figure 2: The beam trajectory, the solenoidal magnetic field distribution and the sodium vapor density distribution.

(i)


H0
(a)
Y(m)
H-
(b)
Y(m)
H0
(c)
dX/dZ(rad)
H-
(d)
dX/dZ(rad)
X(m)
X(m)

(ii)


H0
(a)
Y(m)
H-
(b)
Y(m)
H0
(c)
dX/dZ(rad)
H-
(d)
dX/dZ(rad)
X(m)
X(m)

(iii)

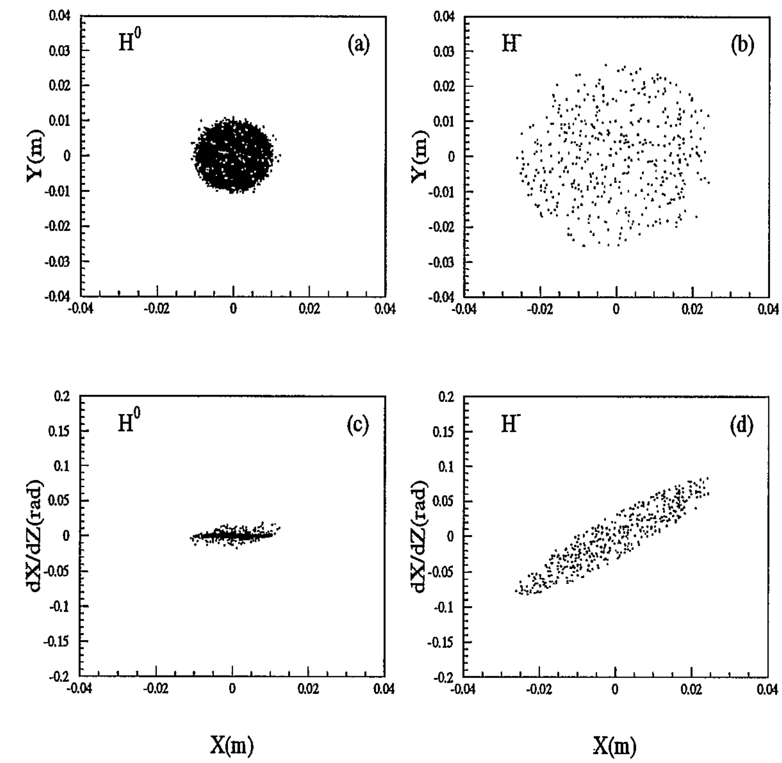


Figure 3: The beam profile (x,y) and the beam emittance (x,x').

4 Conclusion and Future Prospects

The results of the previous section are summarized in Table. 2. As a future prospect, it is raised to extend the calculation to the whole BOPPIS beam transport. With the extension of the calculation, we will be able to design an accelaratting column and an electrostatic magnet injecting the beam into the high energy beam line.

H^- yield[$H^0 \rightarrow H^-$] (%)	8.4~9.2
Beam Radius (mm)	13
Normalized Beam Emittance (mm mrad)	2.4π

Table. 2 The results of the ion optics calculation for BOPPIS. We regard the normalized beam emittance as an 100% area of an ellipse on the phase space coordinate.

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