Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

# OPTICALLY-PUMPED POLARIZED H$^-$ ION SOURCES FOR RHIC AND HERA COLLIDERS

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*Abstract*

The TRIUMF OPPIS (Optically Pumped Polarized Ion Source) provides high quality polarized H$^-$ ion beam for studies of hadronic structure via the parity-violating weak interaction. High-current polarized H$^-$ ion source development is now underway at TRIUMF for the new generation of polarization facilities at RHIC and HERA. The required $2\times10^{32}$ /s cm$^2$ luminosity in RHIC can be obtained with a 0.5 mA injected H$^-$ ion beam intensity. Such an intensity was already produced in dc operation of the TRIUMF OPPIS, and a similar KEK OPPIS is being upgraded at TRIUMF for future installation at RHIC. Much higher 10-20 mA polarized H$^-$ ion beam intensity is necessary for the proposed polarized proton-electron collider at HERA (DESY). The feasibility of such pulsed current has been proven earlier and the first results of polarization measurements are presented here.

## 1 INTRODUCTION

The OPPIS technique for polarized H$^-$ ion beam production was developed in the early 80's at KEK (Japan), INR Moscow (Russia), LAMPF (USA) and TRIUMF (Canada). This technique is based on spin-transfer collisions between a proton or atomic hydrogen beam of a few keV beam energy and optically-pumped alkali metal vapors [1,2]. The modern technology involved -- a super-conducting solenoid, a 28 GHz microwave generator and high power tunable solid state lasers -- is essential for this development. Achievement of 0.55 mA dc H$^-$ ion current with 85% polarization and 1.0 mA current with 75% polarization (limited by the available dc laser power) was reported at PAC95 [3] and in excess of 20 mA pulsed H$^-$ ion current was obtained in experiments with the atomic hydrogen injector [4]. At present, OPPIS development is continuing only at TRIUMF where the OPPIS is heavily used for parity violation studies in pp collisions at 220 MeV. The source operation is very reliable and spin-correlated current, position and beam energy modulations are very small, meeting the stringent requirements of the parity experiment [5].

## 2 OPPIS FOR RHIC

The polarization facility at RHIC will provide 70% polarized proton-proton collisions at energies up to sqrt(S)=500 GeV with luminosity of $2\times10^{32}$ /cm$^2$ s [6]. This luminosity will be obtained with 57 bunches of polarized proton beam having $2\times10^{11}$ particles/bunch in each ring. The polarized source must produce in excess of 0.5 mA H$^-$ ion current during a 300 μs pulse, or current×duration ≥150 mA μs, within a normalized emittance of less than 2 π mm mrad. This current corresponds to $9\times10^{11}$ particles/pulse. Assuming 50% beam losses in the LEBT, RFQ, LINAC, and injection to the AGS Booster, that gives $4.5\times10^{11}$ polarized protons per booster bunch and finally $2\times10^{11}$ particles for the RHIC bunch. The polarization preservation during acceleration is described in a talk by T.Roser at this conference.

The first ECR-type OPPIS was constucted at KEK [7]. Polarized beam is not presently required at KEK , and the KEK OPPIS is on loan to BNL to produce polarized H$^-$ ion beam for RHIC. The source is now being upgraded at TRIUMF to meet the RHIC requirements. Table I. compares the RHIC requirements and the KEK OPPIS parameters with what has been obtained at TRIUMF.

*Table I.*

| | KEK | TRIUMF | RHIC |
|---|---|---|---|
| Peak current I (mA) | 0.1 | 0.5-1.0 | 0.5-1.5 |
| Pulse duration t (μs) | 100 | dc | 100-300 |
| Charge/pulse (mA μs) | 10 | 150 (in 300 μs) | ≥150 |
| Polarization (%) | 75 | 75-85 | ≥80 |
| Normalized emittance (mm mrad) | 2 π | 2 π | ≤2 π |
| Repetition rate (Hz) | 25 | dc | 7.5 |

### 2.1 ECR primary proton source upgrade

A 28 GHZ ECR source is used at TRIUMF vs. 18 GHz at KEK. In the KEK OPPIS the protons are produced in a 6.4 kG field and extracted at a 27 kG field which is necessary to obtain high polarization. With the 28 GHz frequency at TRIUMF the resonance field is 10 kG. It is believed this gives a factor of 2-3 current gain, other

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conditions being similar, for the TRIUMF OPPIS. In dc operation, the extraction grids are hot which prevents Rb deposition and provides practically spark-free operation (sparking was a serious problem in the pulsed KEK source operation). After modification to 28 GHz dc operation, a 0.6 mA $H^-$ ion current was obtained with a 120 hole extraction system (and 1.0 mA with 199 holes) within the specified emittance. The same extraction system produced twice as much current in the TRIUMF OPPIS. The difference is partly due to the longer distance between the ECR source and the ionizer (the KEK OPPIS superconducting solenoid has a room temperature yoke and the TRIUMF OPPIS has a cold yoke). In addition the large hole in the KEK solenoid yoke disturbs the magnetic field symmetry and might be responsible for a transverse field component which missteers the proton beam. The displacement was observed by direct measurements of the atomic H beam profile, produced after proton beam neutralization in a Rb cell. The biggest problem was the degradation of the source performance, within 12 hrs, to 50% or less of the initial current obtained with the fresh grids and cavity assembly. After systematic tests the explanation has been found in the ECR gas composition. With the fresh source assembly there is water vapor contamination to the hydrogen in the discharge tube. Water desorbs from the boron-nitride cups which isolate the plasma from the copper cavity walls. As the cavity dries out by discharge and cryopumping, the ECR current goes through a maximum (in a few hours) and then drops after about 12 hrs. of operation. A controlled water vapor supply was set up , comprising a water reservoir at O° C , needle valves and bypass pumping by an oil-free diaphragm pump. Optimal ECR operation is quite sensitive to the hydrogen:water ratio. When properly tuned, the $H^-$ ion current recovered to its best value and remained stable for hundreds of hours of operation. Another remarkable feature was very quiet ECR operation. Similar behaviour was previously observed in ECR sources of multiply-charged ions. It was speculated that an oxygen admixture helps to activate the wall surface for better electron emission to the ECR plasma. We also observed current recovery with an oxygen admixture to the hydrogen supply.

## *2.2 Sodium-jet ionizer cell*

The polarized $H^-$ ion beam emittance is completely determined by the ionizer cell aperture diameter and ionizer magnetic field. A field of 1.5 kG is necessary to reduce polarization losses during ionization to below 2.5%. Therefore, the specification for beam emittance of 2.0 $\pi$ mm mrad gives the limit for the sodium cell aperture diameter of 2.0 cm. The sodium vapor flow and corresponding sodium consumption, deposition and, more important, penetration into the low field region is proportional to the cube of the cell diameter in an oven-type cell. The laser beam diameter and corresponding diameter of the proton beam and extraction system is limited by the ionizer cell because the laser beam must pass through the ionizer cell. The neutral atomic beam enters the ionizer, and $H^-$ ions produced in the cell can be accelerated to 35 keV energy (which is required for injection to the RFQ) by ionizer biasing to -31.0 kV. A large cell aperture is essential for this purpose because the neutral beam collimated to 2.0 cm in diameter before the cell must not touch the biased cell parts, otherwise secondary emission will cause sparking. A new jet-type ionizer cell with transverse sodium flow was developed to allow large apertures (see Fig.1). Sodium- and lithium-jet cells with apertures up to 20×10 $cm^2$ were originally developed by D'yachkov [8]. In our case the aperture diameter is 20 mm. The reservoir is loaded with 100-150 g of sodium and heated to 480° C. At this temperature the sodium vapor pressure is about 5 torr and the vapor density is about $10^{17}$ atoms/$cm^3$. The vapor is delivered through a hot transport tube to the nozzle assembly, which produces a horizontal vapor jet having an effective thickness of about $5\times10^{15}$ atoms/$cm^2$, sufficient for $H^-$ ion yield saturation. A nozzle slit 0.2 cm wide and 2.0 cm tall was used in initial tests ( a Laval nozzle with an expanding cone is prepared for the next test). The transport tube and nozzle temperatures are maintained at 485° C.

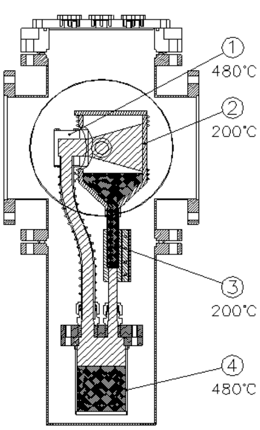


Figure 1: Sodium jet ionizer cell: 1-nozzle; 2-collector; 3-return line; 4-sodium reservoir.

The sodium vapor condenses at the collector walls, which are air-cooled to about 200° C. At this temperature the sodium vapor density is $2\times10^{12}$ atoms/$cm^3$ and the sodium viscosity is low. Liquid sodium flows down the return tube and back to the reservoir. The return tube temperature is kept at about 200-250° C by an attached cooling line. The backstream vapor flow through the return tube is negligible due to the low conductance at 200° C. Sodium in the jet-cell circulates along the path reservoir-nozzle-collector-return line-reservoir and the system provides continual, stable operation for hundreds of hours with 100-150 g of sodium. Without the circulation the cell works for only 3 hours, measured in a test with the collector water-cooled to 29° C. The frozen sodium in the collector had a volcano shape perfectly confined within the 10 cm collector length. The sodium flow outside the cell was much less than with an oven-type cell. The whole ionizer assembly including the solenoid magnet is attached to the rest of the OPPIS by 5.0 cm thick Delrin isolation flanges, and is ready for the biasing tests.

## 3 PULSED OPPIS FOR POLARIZED HERA COLLIDER

Polarization of a 820 GeV proton beam in HERA, in addition to the existing longitudinally polarized electron beam, would signficantly expand the kinematic range for proton spin-structure studies and will allow measurements of the gluon contribution to the proton spin, provided that the luminosity of the polarized beam is the same as the unpolarized beam [9]. The bunch intensity should be $1.0\times10^{11}$ protons/bunch, i.e. half that in RHIC , but the capture time to the DESY III booster ring is only 33 μs at the 50 MeV linac energy. This pulse is split into 10 bunches which eventually become HERA bunches. Therefore, the peak polarized $H^-$ ion current out of the source must be almost 100 times higher than for RHIC. At least 20 mA current in a 50 μs pulse within 2.0 π mm mrad is required from the polarized HERA injector. A pulsed $H^-$ current in excess of 20 mA was demonstrated in experiments with an atomic hydrogen injector in an INR-type OPPIS . At present, the atomic H injector is installed at the extended TRIUMF OPPIS test-bench. The ECR proton source is replaced with a pulsed He ionizer cell, and a new 45 cm long Rb cell has been installed. The proton polarization is measured by a low energy Lamb-shift type polarimeter, which was tested and calibrated with the well known dc polarized beam from the TRIUMF OPPIS. The source operates at a 1 Hz repetition rate and about 100 μs pulse duration. The optical pumping is produced by the pulsed Ti:sapphire laser as described above.

The TRIUMF OPPIS superconducting solenoid is designed for ECR source application. While the total length is 105 cm, the flat section of 24.5 kG produced by the main coil is only 30 cm long. The fields of the other two coils are limited, and to produce a more or less flat field 60 cm long, only 10.0 kG is achievable. The low field in the optically-pumped Rb cell causes about 40% polarization losses due to the spin-orbital interaction in the hydrogen excited states. The ideal magnet would produce a 25-30 kG field with a flat top 80 cm long.

Preliminary results of polarization measurements are shown in Fig.2. Results can be compared with polarization calculations by T. Sakae for spin exchange plus charge-exchange polarization with the He-ionizer cell [2]. The cell thickness is limited by radiation trapping to about $2.5\times10^{14}$ atoms/cm$^2$ in a 10 kG field and can be at least doubled in a higher 25 kG field and 60 cm long cell.

The use of Cs vapor instead of Rb, or a Cs-Rb mixture with the pumping of both is also promising due to the expected large spin-exchange cross-section and higher radiation trapping limit of Cs vapor. The expected charge-exchange polarization with the He-ionizer is reduced significantly in the 10 kG field. The experimental results are to be compared with the dashed curve in Fig.2, which is reduced by a factor 0.65 compared to the solid line calculated neglecting depolarization. This neglect is valid for a magnetic field in the Rb cell higher than 25 kG. The polarized $H^-$ ion current is reduced to 6.0 mA with the He ionizer in operation because of nonhomogeneity of the magnetic field in the cell.

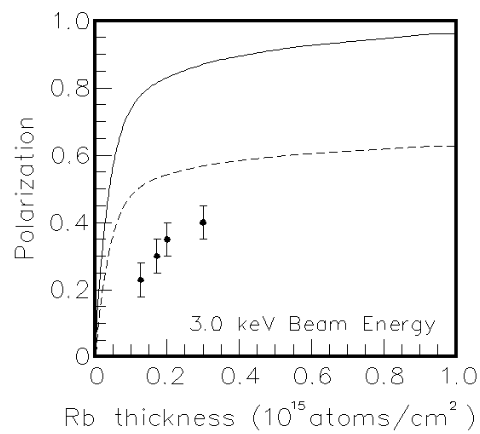


Figure 2: Solid line – expected polarization in the high 25 kG field; Dashed line – polarization for 10 kG field.

## 4 ACKNOWLEDGEMENTS

The work on OPPIS development for RHIC is funded by DOE. The pulsed OPPIS development has been partly funded by DESY through the Spin Collaboration (spokesperson A.Krisch) and by INR, Moscow.

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