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DEVELOPMENT OF SPIN ROTATOR AND AN ABSOLUTE POLARIMETER FOR POLARIZED He-3 AT BNL*

D. Raparia#, G. Atoian, S. Ikeda, R. Lambliase, M. Okamura, A. Poblaguev, J. Ritter, S. Trabocchi, A. Zelenski, Brookhaven National Laboratory, PO Box 5000, Upton, NY 11974
R. G. Milner and M. Musgrave, Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract

EBIS preinjector will provide longitudinally polarized $^3He^2$ ions with about 80% polarization and 5×10^{11} particles per bunch at 6 MeV, which must be rotated to vertical direction before ions are injected into the Booster. The $^3He^2$ longitudinal polarization is first rotated to the transverse direction by the 21.5° bending magnet. Then a solenoid, spin-rotator, rotates the spin to the vertical direction. The spin-rotator will be a pulsed solenoid with a reversible field to enable spin flips. The vertically polarized beam will be returned back to the straight HEBT line by the system of three dipole magnets after the spin rotator solenoid. The polarimeter can be installed in the straight beam line section after the second dipole magnet. To measure transverse (vertical) polarization of the ^3He beam at 5-6 MeV, the spin correlated asymmetry of ^3He scattering on a ^4He gas target (~5 Torr) will be measured with left/right symmetric strip detectors.

INTODUCTION

A Polarized ^3He ion beam in RHIC would enable new, unique high-energy QCD studies of nucleon structure with existing polarized proton beams. We have previously developed a concept for a polarized ^3He ion source based on the existing Electron Beam Ionization Source (EBIS) at Brookhaven National Laboratory (BNL) [1]. Polarized ^3He atoms are polarized via the technique of metastability exchange optical pumping (MEOP) [1] in a glass cell at a pressure of 1 mbar and directed into the EBIS vacuum system. An intense 10 Amp electron beam in extended EBIS completely ionizes the polarized atoms, which are then electrostatically confined in extended EBIS. By pulsing high voltage electrodes $^3He^2$ ion can be extracted. Extracted ion longitudinally polarized will be accelerated by an RFQ and IH-Linac to 6 MeV/u. The design goal for the EBIS preinjector is 5×10^{11} $_3He^2$ per pulse at 80 % polarization.

HELIUM-3 SPIN ROTATION

The longitudinally polarized $^3He^2$ beam will be produced in the EBIS. Polarization must be rotated to vertical direction for polarization measurements and further beam transport and acceleration in the Booster, AGS and RHIC. The spin-rotator will enable vertically polarized beam injection to AGS and RHIC. The $^3He^2$ polarization alignment to the transverse vertical direction can be done in the HEBT line after the EBIS Linac at 6.0 MeV beam energy. Polarization charge particle momentum (**p**) and spin (**s**) in the magnetic field are govern by the Thomas-BMT equations [2]

$$\frac{d}{dt}\vec{p} = -\frac{q}{m\gamma}\{ \quad \vec{B}_\perp \quad \} \times \vec{p}\,,$$
$$\frac{d}{dt}\vec{s} = -\frac{q}{m\gamma}\{(G\gamma+1)\vec{B}_\perp + (1+G)\vec{B}_\parallel\} \times \vec{s}\,.$$

Where m, q are the mass and charge of the particle, γ is the relativistic factor, $B_\parallel$ is magnetic field in the beam direction, $B_\perp$ is the magnetic field in transverse plane and G = -4.18 for the ^3He. Initially ^3He polarization is parallel to the beam line, polarization direction will be rotate by a 21.5 º ($G\gamma\theta$ = -90º -> θ = 21.5º) pulse dipole to horizontal direction. Finally, polarization direction changes to vertical by a switchable pulse solenoid.

The layout for the spin direction alignment system is shown in Figure 1.

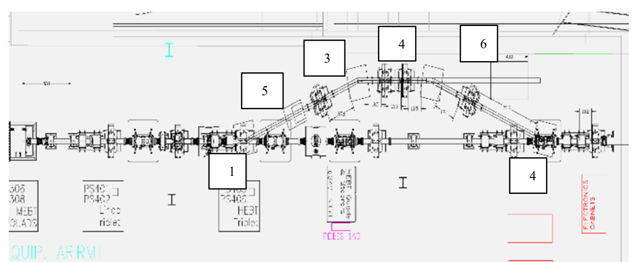

Figure 1: Layout of the spin rotator chicane. Key: Pulsed dipole 1, 4, DC dipole 2, 3, Solenoid 5, Polarimeter 6.

Figure 2 to show the beam optics for the $^3He^2$ with 5 mA and 2 π mm mrad (TRACE3D) for the spin rotation chicane.

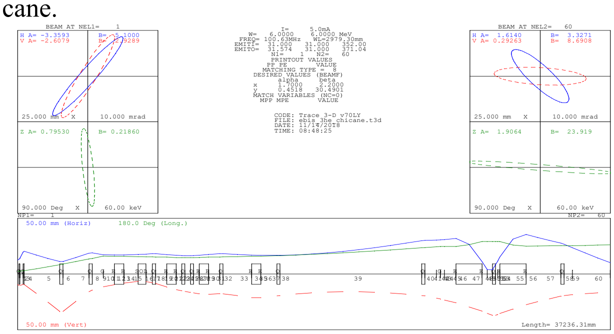

Figure 2: Beam optics for 3He2 with 5 mA and 2 π mm mrad. Beam envelop shown are: Blue - horizontal, Red - vertical, Green - longitudinal. Trace3D output.

The spin rotation chicane will have 4 DC quadrupoles, 2 pulse dipole, 2 DC dipole, 1 switchable pulse solenoid,

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# raparia@bnl.gov

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4 steering magnet, 1 buncher, 1 profile monitor and 1 current monitor. The DC quadrupoles will be the same as used in the existing EBIS To Booster (ETB) line and its power supplies will similar to supplies used now for ETB line (KEPCO BOP 50-20GL). Two dipoles on the existing ETB line should be pulse with rise and fall time less than a second and flat top duration 2.4 second. Two dipoles in the chicane can be DC. The dipole design is complete and is shown in Figure 3, and Table 1 shows the main parameter for the pulse dipoles.

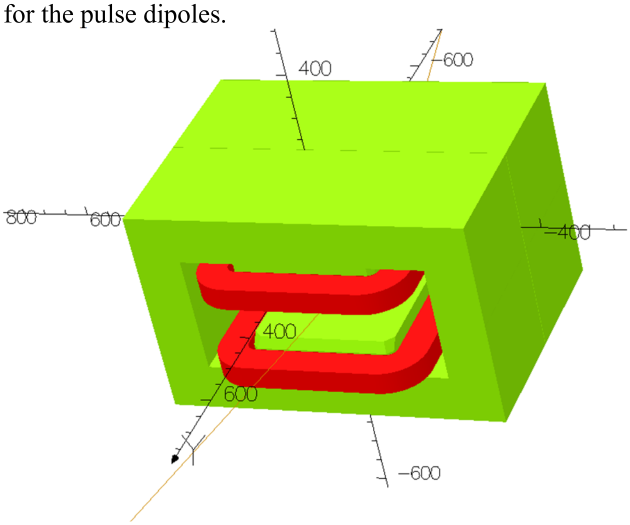

Figure 3: Pulse dipole, (254×520×716 mm), for the spin rotator chicane. All four dipole have same mechanical design.

Table 1: Dipole Parameters

Parameters	Value
B	1.90 kG
Radius of curvature	1.60 m
Bend angle	21.5°
B·dL	0.155 T-m
Effective length	0.60 m
Gap	110 mm
Pole width	300 mm
Weight	1 ton
Total current	2×84 kA
Stored energy	3890 J

The total number of turns will be 48 per coil. There will be three pancake consisting 2×8 turns, conductor size will 6.6×6.6mm with 4 mm diameter cooling channel. Estimated pressure-drop across per pancake will be about 30 psi, and temperature rise per pancake 11.7° C, resistance of the coil will be 0.12 Ω and inductance will be 30 mH.

The spin flip solenoid has to rotate spin by 90° and flip spin direction every other pulse (3-6 sec). $d\emptyset = -(1+G)\frac{qB}{p}dl = \frac{\pi}{2}$; It requires integrated magnetic field strength (B.dl) of about 0.15 T-m. The spin solenoid should operate with rise and fall time of 1 sec and flattop 2.4 sec. The spin solenoid and its power supply will be same as the existing solenoid in the EBIS low energy transport line. This solenoid specification are: B = 1.2 T, length = 230 mm, B·dL = 0.27 T-m, resistance = 22 mΩ, inductance = 1.49 mH.

Buncher cavity will be quarter-wave resonator and its specifications are following: Frequency 100.625 MHz, energy 2 MeV/u, dimension 200×720×255 mm, drift tube diameter 80 mm, effective voltage 40 kV, Quality factor, Q, 10300, shunt impedance 17 MΩ/m, power 500 Watts. Figure 4 depicts Computer Simulation Technology (CST) buncher model. The ratio of integrated E_y to E_z is less than 5×10^{-4}.

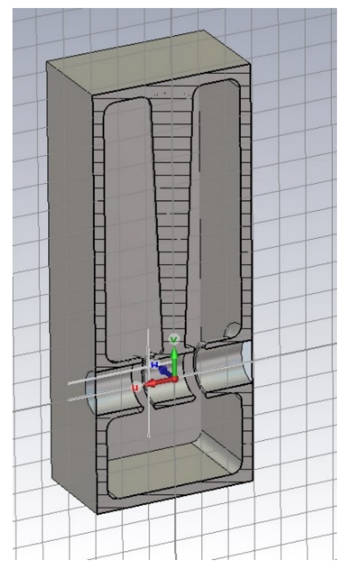

Figure 4: CST computer model, the ratio of integrated Ey to Ez is less than 5×10^{-4}.

The physics design of the spin chicane is completed, dipoles is being fabricated, buncher has been ordered, power supply for solenoid is under construction. The space for the spin chicane is very narrow, to see the interference with other existing equipment a 3D model was developed. The 3-D layout of the chicane is shown in Figure 5.

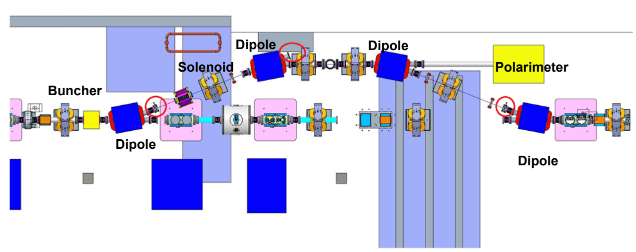

Figure 5: 3-D layout of the spin chicane.

ABSOLUTE POLARIMETER

To determine beam polarization, spin correlated asymmetry (a) of ^{3}He scattering on the gas ^{4}He target will be measured (see Figure 6). This scheme has been successfully used at BNL [3] (p-carbon and jet polarimeter). The analysing power for ^{3}He-^{4}He elastic scattering at 5.3 MeV beam energy and 53.6° angle is closed to 100% [4,5]

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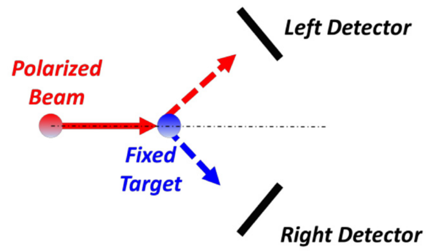

Figure 6: Measuring correlated asymmetry.

Asymmetry a given by

$$a = A_N P = \frac{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} - \sqrt{N_R^{\downarrow} N_L^{\uparrow}}}{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} + \sqrt{N_R^{\downarrow} N_L^{\uparrow}}}$$

Where P is the beam polarization, a is correlated asymmetry and A_N is the analysing power. Analysing power is a function of beam energy and scattering angle. Figure 7 shows the polarimeter layout. Right chamber will have ^{4}He gat at 5 Torr and separated by 1 µm thick Al window with high vacuum, and two Si detector at 10 cm from the target at angle $\theta_{lab} = \pm 40.75°$. This configuration will have energy resolution batter than 2% and time resolution less than 0.2 ns and angular resolution about 1.2°. The expected energy loss of the beam in the 1µm Al window will be about 200 keV. The recoil energy range of pair ^{3}He and ^{4}He is about 2-4 MeV and energy loss at 5 Torr will inconsiderable (less than 25 keV). The estimated systematic error will be less 0.5%.

The ^{3}He beam will be at 1 Hz and 20 us bunch length, and the estimated event rate will be 100 event per bunch.

Data AcQuisition (DAQ) system will have 32 channels with capability of 160 Hz/channel, a VME 64x crate, an Acromag XVME-650 single board computer, and two wave digitizer SIS3316-14. The data flow rate will be about 0.3 MB/sec, 30 GB/day.

The testing of prototype polarimeter using alpha source is completed, final design of polarimeter is completed, all parts for polarimeter are ordered.

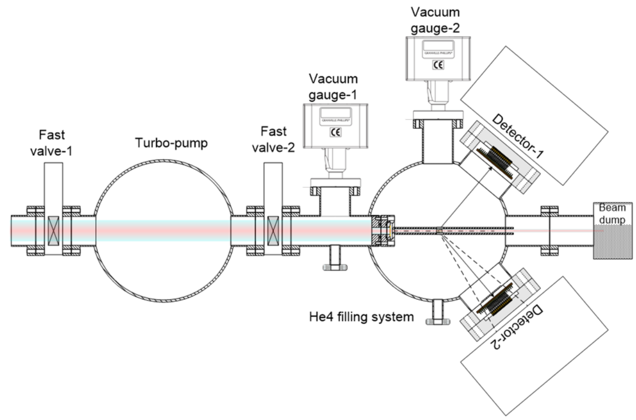

Figure 7: Layout of polarimeter. Right chamber will have 4He gat at 5 Torr and separated by 1 µm thick Al window with high vacuum, and two Si detector at 10 cm from the target at angle $\theta_{lab} = \pm 40.75°$.

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