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Precision absolute polarimeter development for the $^3He^{++}$ ion beam at 5.0-6.0 MeV energy

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We propose to make precision measurements of the absolute $^3He^{++}$ polarization at beam energies 5.0-6.0 MeV after the EBIS LINAC. The analyzing power A_N for the elastic scattering of polarized ^3He with unpolarized ^4He target with selected kinematic angles is expected to reach the value 100% in this energy range. The main effort of this work is the development of the precision absolute polarimeter for the measurements of the $^3He^{++}$ beam polarization produced in the EBIS as a reference for the further polarization measurements along the accelerator chain. The polarimeter vacuum system is integrated in the spin-rotator transport line. The $^3He^{++}$ ion beam will enter the scattering chamber through the thin window to minimize beam energy losses. The scattering chamber is filled with ^4He gas at about 5 torr pressure. The silicon strip detectors will be used for energy and TOF measurements of the scattered ^3He and recoil ^4He nuclei (in coincidence) for the identification of the scattering kinematics. The status of the polarimeter development: vacuum system, scattering chamber, thin window, Si-strip detectors with end-off electronics and WFD- based DAQ will be presented.

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1. Introduction

A concept for a polarized ^{3}He ion source based on the existing Electron Beam Ion Source (EBIS) at Brookhaven National Laboratory (BNL) [1-4] was discussed in these Proceedings [5]. For the beam energies 5-6 MeV, there is a unique opportunity for precise measurements of the absolute ^{3}He polarization since the analyzing power can be close to 100% for some scattering angles [8].

We suggest a standard configuration with spin-flip beam and left/right symmetric Si strip detectors (~12 channels in each side) as shown in Fig. 1.

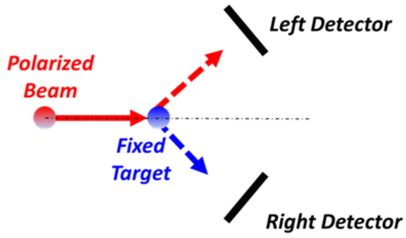

Figure 1. A schematic plan view of the left/right symmetric polarimeter to measure polarization of the vertically polarized beam.

This schema has been successfully used in BNL (p-carbon polarimeters in AGS and RHIC; hydrogen jet polarimeter in RHIC) for many years. The spin correlated asymmetry

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

can be derived from the number of the detected scattered (or recoiled) particles $N_{LR}^{\uparrow\downarrow}$ in the left/right (L/R) detectors depending on the beam spin up/down (↑↓).

1.1 Analizing power

For elastic scattering of polarized ^{3}He$^{\uparrow}$ beam by ^{4}He target, the analyzing power is, generally, a function A_N(E$_{beam}$, θ_{CM}) of the beam kinetic energy E$_{beam}$ and the center of mass scattering angle θ_{CM}. The experimental and theoretical study of this process at low energies has a more than 50 years history [6-11]. It was shown in Ref. [8] that the analyzing power A_N can reach 100% in some points (E$_{beam}$, θ_{CM}) and the method to find these points was provided.

One such maximum [9,11], $A_N = +1$ at E$_{beam}$ ≈5.4 MeV, θ_{CM} ≈ 79° (Fig. 2), can be employed for precision measurement of the polarization of the 6 MeV ^{3}He beam emitted from the EBIS LINAC. However, the exact position of the maximum is not accurately known and, thus, the analyzing power for the 6 MeV beam may be uncertain. The issue can be overcome with a beam energy scan covering the following beam energies, 5< E$_{beam}$ <6 MeV, and scattering angles, 70°< θ_{CM} <100°, (yellow area in Fig. 2) .

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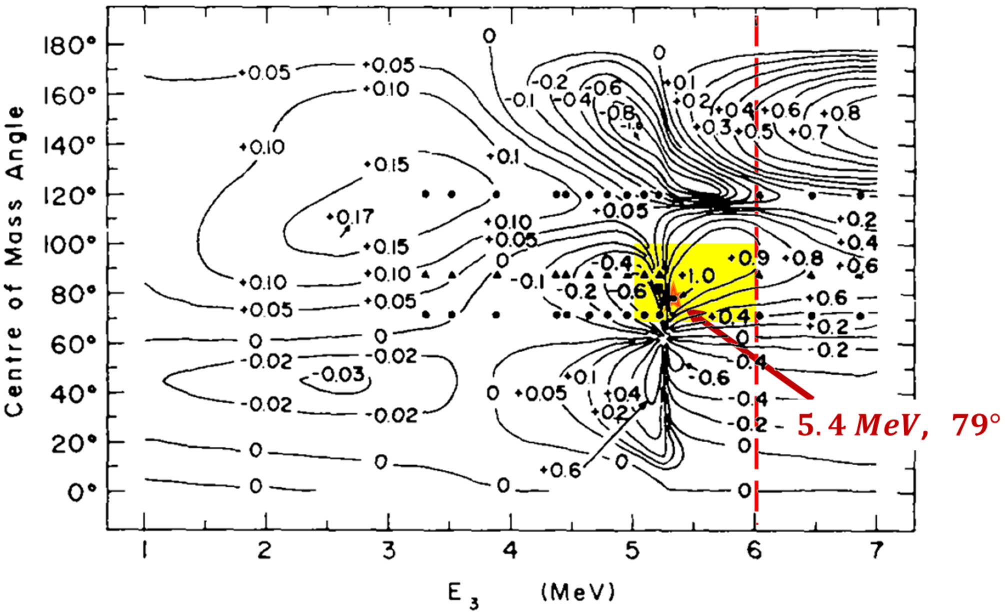

Figure 2. The analyzing power in ^{3}He-^{4}He elastic scattering versus ^{3}He beam energy and the center of mass the scattering angle. The expected location, E_{beam} ≈5.4 MeV, $\theta_{CM}\approx 79°$, of the absolute maximum A_N=+1 is shown by the red star marker. The area proposed for experimental calibration of measured analyzing power at E_{beam} =6 MeV (dashed red line) is shown by the yellow color.

1.2 Kinematics

The kinetic energies T and angles θ_{Lab} of the scattered ^{3}He and recoil ^{4}He (in the laboratory system) derived from E_{beam} and θ_{CM} are shown in Fig. 3. The kinematics allows us to concurrently detect both ^{3}He and ^{4}He in the same detectors, which is very helpful for background suppression. For covering all necessary angels θ_{CM}, the detector must cover the laboratory angles 40°< θ_{Lab} <60°, which corresponds to the center of the mass scattering angles 70°< θ_{CM} <100° (Fig.3a). The angle range of scattered ^{3}He is 40°< θ_{Lab} <58° (red area on Fig.3a) and for recoil ^{4}He is 40°< θ_{Lab} <55° ° (blue area on Fig.3a). The dependence on the beam energy is negligible in the considered beam energy range.

The detecting energy range of scattered ^{3}He is ~2-4MeV (red area on Fig.3b) and recoil ^{4}He is ~1.5-3.5MeV (blue area on Fig.3b). The above conditions for simultaneous detection of ^{3}He and ^{4}He are consistent with the requirements for the beam energy scan (5-6 MeV).

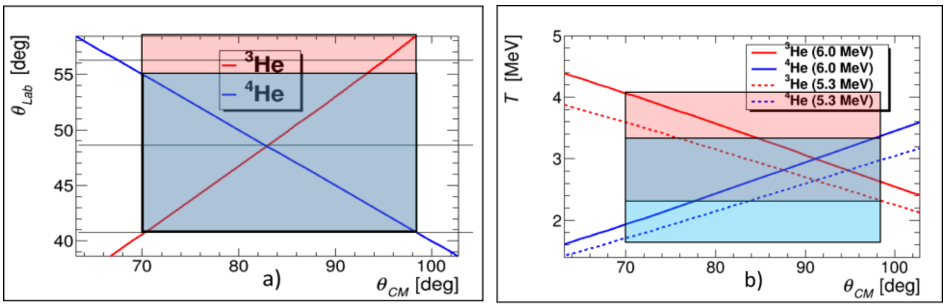

Figure 3. Kinematics of elastic ^{3}He-^{4}He scattering. (a) The laboratory system scattering ^{3}He (red line) and recoil ^{4}He(blue line) angles versus the center of the mass scattering angle θ_{CM}; (b) The scattered and recoil kinetic energies versus corresponding the center of the mass angle.

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1.3 The 6 MeV ^{3}He polarimeter design

The requirements to the geometry (Fig.1) and measured energy range can be satisfied by the next design and developed polarimeter (Fifure 5).

The polarized ^{3}He beam has entered the scattering chamber through a very thin window (~1.8 um of aluminum foil) to minimize beam energy losses (~0.25 MeV).

The scattering chamber is filled with 5 Torr ^{4}He gas. The effective size of the target (~5 mm high and 10mm long) is constrained by the collimators. Two Si detectors are in the chamber at $\theta_{Lab}\sim 50°$, 12 cm from the "center of the target". The expected displacement $\sim$0.2 mm of the scattered/recoil particles in the detector due to multiple scattering is small compared to the Si strip width.

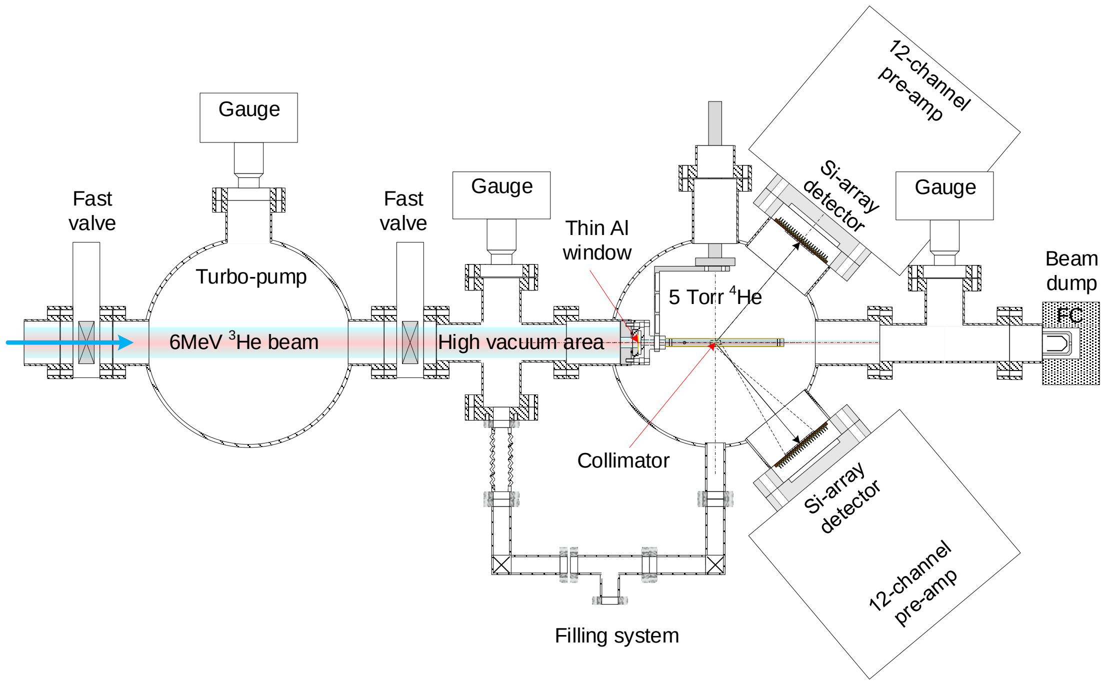


Figure 5. A plan view of the low energy ^{3}He polarimeter. The thin Al-foil (~2um) separated high vacuum area from 5 Torr chamber. The effective target is part of the ^{4}He gas. The scattered/recoil particles detecting by the Si-array.

For evaluation of the polarimeter performance, we choose to consider the available Hamamatsu Si-photodiode array S4114-35Q (Figure 4).

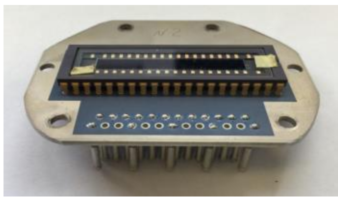
a)  b) 

Figure 4. a) Hamamatsu Si photodiode array S4114-35Q [12]. b) Assemble of Si-array on the ceramic board

Centered at θ_{Lab} ~50° with a distance of 12 cm from the ^{3}He-^{4}He scattering point, this detector can cover the center of mass angles 40°< θ_{Lab} <60° (69°< θ_{CM} <100°). The 30 μm depletion

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region of the choosen detector is sufficient enough to stop 5.5 MeV ^{3}He and 5.8 MeV ^{4}He. The detected particles energy range is ~ 2.5-3.5 MeV for ^{3}He and ~ 2.0-3.1 MeV for ^{4}He. Based on our experience with the H-jet polarimeter, the expected energy resolution is σ_E ~ 20 keV and time resolution is $\sigma_t \lesssim 0.2$ ns. The Si strip structure (35 strips by 0.9mm width and 4mm high) potentially provides a measurement of the scattering/recoil angle at a laboratory system to a resolution of about σ_θ ~ 0.2°. However, taking into account the effective size of the target (~1 cm), the effective angular resolution is about σ_θ ~ 1.2°, which corresponds to the effective σ_E $(geom)$ ~ 0.1 MeV. For readout, several Si strips can be combined into one readout channel. The detector can be equipped with a standard 12-channel preamplifier (one channel combined 3 stips) and shaper from the pC and H-jet polarimeters in RHIC. Figure 6a shows a waveform of signal-rise time ~20 ns and full signal width ~130 ns. The results of a preliminary test study of the S4114-35Q array are shown in Figure 6.

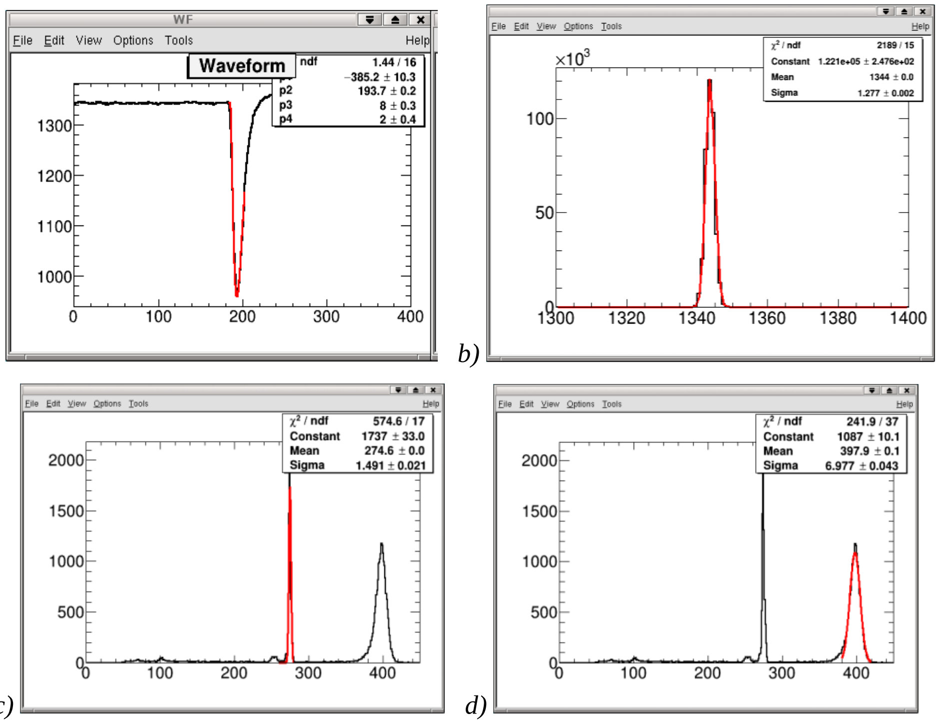

Fig.6 a) a waveform of signal after preamplifier and shaper(1ch~ 4ns); b) a spectrum of pedestal (1ch ~ 14.5 keV); c) a spectrum of alpha sources- ^{148}Gd ~3.184MeV (1ch ~ 14.5 keV); d) a spectrum of alpha sources- ^{241}Am ~5.486MeV and ~10um Al-foil.

For energy calibration, we plan to employ ^{148}Gd (3.183 MeV) and ^{241}Am (5.486 MeV) α-sources, and both the dead-layer and gain can be determined. This method was proven in the calibration of the RHIC polarimeters.

For Data Acquisition we are considering using VME 250 MHz 14-bit waveform digitizers (SIS3316-250-14). These WFDs will allow us to record the full (20 us/ 5000 samples) bunch signal in every readout channel which is essential for monitoring the possible rate dependent systematic errors. The expected data rate per readout channel does not seem to be a problem.

1.4 Systematic Errors

The proposed design allows us to strongly suppress systematic errors. For that, we can use many constraints implied on measured energy E, angle (the strip number) θ, and time of flight t for scattered ^{3}He and recoil ^{4}He:

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- $E_{3\mathrm{He}} + E_{4\mathrm{He}} = E_{beam}$ (σ_E ~ 20 keV);
- $\Delta E = E_{He3} - E_{He4} > 0.7$ MeV;
- Left − right counsidence ($\sigma_t \lesssim 0.2$ ns);
- $t_{He} = \frac{L(\theta)}{c}\sqrt{\frac{M_{He}}{2E_{He}}}$ (separately for ^{3}He and ^{4}He, $L(\theta)$is the distance to the Si strip).

Apparently, these equations can help to strongly suppress background events and to separate ^{3}He and ^{4}He signals.

We do not expect any noticeable systematic errors caused by the beam spin independent backgrounds (such as neutrons and gammas from other beam lines).

Taking into account (i) the smearing ~0.1 MeV of the $E(\theta_{Lab})$ dependencies due to the target size and (ii) expected energy resolution $\sigma_E \sim 20\ k$eV we have to conclude that statistical equivalent of the ^{3}He - ^{4}He separation power is more than 5 standard deviations. In addition, signal time measurements can be also used for separation of the ^{3}He and ^{4}He signals.

For precise absolute polarization measurement, we must scan the beam energy. The systematic error of determination of the analyzing power is dominated by the stability of the beam polarization during the scan.

We use two absolute polarimeters for the RHIC Spin Program: 200 MeV proton-Carbon polarimeter at LINAC and Hydrogen Jet Target Polarimeter (HJET) for 100-255 GeV proton beams at RHIC. In both polarimeters, the systematic error of polarization measurement does not exceed 0.6%. The preliminary consideration of the low energy ^{3}He polarimeter does not indicate any reasons why systematic error in this polarimeter should be larger. Thus, based on our experience with 200 MeV LINAC polarimeter and HJET, we can make a conservative estimate for the systematic error of the ^{3}He beam polarization measurement as:

$(\sigma_P/P)_{\mathrm{syst}} \lesssim 0.5\%$.

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