PRECISION, ABSOLUTE PROTON POLARISATION MEASUREMENTS AT 200MEV BEAM

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Abstract

A new polarimeter for absolute proton beam polarization measurements at 200MeV to accuracy better than ±0.5% has been developed as a part of the RHIC polarized source upgrade. The polarimeter is based on the elastic proton-carbon scattering at 16.2° angle, where the analyzing power is close to 100% and was measured with high accuracy. The elastically and in-elastically scattered protons are clearly identified by the difference in the propagation through variable copper absorber and energy deposition of the protons in the detectors. The 16.2° elastic scattering polarimeter was used for calibration of a high rate inclusive 12° polarimeter for the on-line polarization tuning and monitoring. This technique can be used for accurate polarization measurements in energy range of at least 160-250 MeV.

POLARIZATION MESUREMENTS TECHNIQUE

The polarized beam for RHIC spin physics experimental program is produced in the optically pumped polarized H^- ion source (OPPIS) and then accelerated in linear accelerator (Linac) to 200MeV beam energy for strip-injection to Booster and further acceleration to 24.3GeV in AGS for injection in RHIC [1].

Precision, absolute polarization measurements in the wide energy range from a few keV (in the source) to 250GeV (top RHIC energy) are required for accelerator tuning to minimize depolarization and finally for experimental data normalization. Therefore, the polarimeter is an essential component of the polarized collider facility. A complete set of polarimeters includes: Lamb-shift polarimeter at the source energy, a 200 MeV polarimeter after the Linac, and polarimeters in AGS and RHIC based on proton-Carbon scattering in Coulomb-Nuclear Interference region [2]. A polarized hydrogen jet polarimeter was used for the absolute polarization measurements in RHIC [3].

A 200 MeV polarimeter is based on proton-Carbon inclusive scattering at 12° angle and was calibrated to ±5% absolute accuracy in calibration experiment by comparison with proton-Deuteron elastic scattering. This polarimeter is used for the source development polarization tuning and optimization. The ongoing program of the polarized source upgrade to 10mA H^- intensity and 85% polarization [4] requires more accurate absolute polarization measurements at very high peak intensity.

The precision absolute measurements at injection to Booster and AGS are also essential for depolarization studies in Booster and AGS.

The 200MeV inclusive polarimeter was upgraded and calibrated in 2009 Run to absolute accuracy better than ±0.5% by using the proton-Carbon elastic scattering measurements in additional 16.2° arms. The analyzing power A_y for proton-Carbon elastic scattering at 200 MeV has been precisely measured in experiments at IUCF. "These measurements are based on basic constrains imposed polarization observables for reaction with spin structure: **½ +0 → ½+ 0** (proton+ Carbon) and represent some of the most accurately known spin observables at intermediate energies" [5]. The results are presented in Fig.1. The analyzing power for elastic scattering is: A_y= 99.35±0.1% at 16.2° scattering angle. Since the A_y is reaching maximum at this angle, the systematic error contribution to A_y due to the energy measurement accuracy ~1.0MeV and scattering angle accuracy of a 0.1° does not exceed ~0.1%.

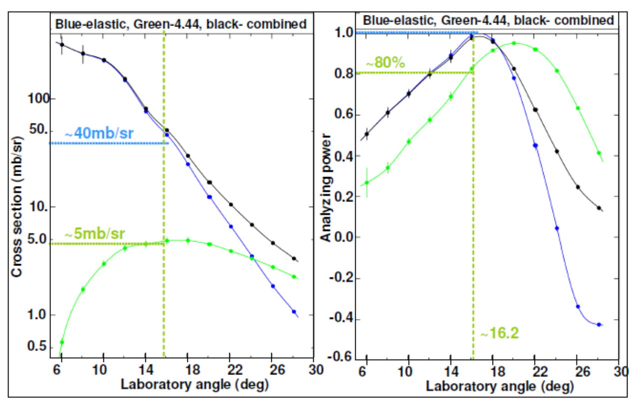

Figure 1a, b: Measurements of **a-** the cross section and **b-** analyzing power for proton scattering from ^{12}C at 200 MeV. The blue (green) curves correspond to protons exiting from the ground (4.44-MeV) state. The black curve represents the sum of the two data sets [7].

The elastic scattering was selected by using the copper absorber with the variable thickness. Without separation the A_y for inclusive scattering at 16.2° angle is diluted by inelastic processes to about 52% [6]. The well known first exited state in Carbon is at 4.44-MeV energy. The cross section and analyzing power for the ground and 4.44-MeV states in ^{12}C has been reported by Meyer et al. [7]. The cross-sections for the elastic scattering state and the 4.44-MeV state excitation are shown in Fig.1a. At16.2°, contamination of the analyzing power amounts to 2.2%, if all of the 4.44-MeV state is not suppressed. At this angle the energy of elastically scattered protons is 198.0MeV, excitation of the 4.44-MeV state reduce this energy to ~193.6MeV.

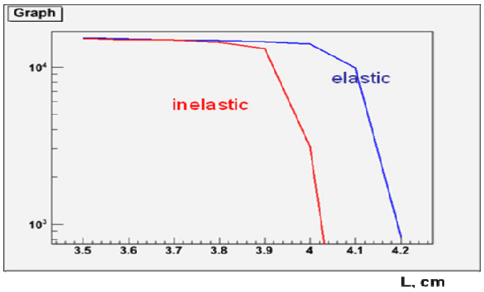

Figure 2: The number of elastically (198.0MeV) and in-elastically (193.6MeV) scattered protons detected after Cu absorber (vs. the absorber thickness).

EXPERIMENTAL SETUP

The AGS cycle for polarized beam operation is about 4 seconds. The OPPIS operates at 1Hz repetition rate and additional source pulses are directed to a 200 MeV p-Carbon polarimeter by a pulsed bending magnet in the high-energy beam transport line (for polarization measurements and continuous monitoring). The polarimeter layout after upgrade is shown in Fig.3. Five carbon strip targets of different sizes are attached to the target ladder, which situated inside the square vacuum chamber with thin Mylar vacuum windows. A new quadruple focusing and steering magnets were installed in the beam line for better control of the beam size and position at the target. A beam diagnostic system includes Secondary Emission Monitors and multi-wire beam profile monitor in the front of polarimeter chamber. Using these tools background signals in the detectors (from beam halo scattering on the Al target ladder and upstream beam transport pipes) were reduced to below 0.3% level even in inclusive 12° arms. In 16.2° arms an additional suppression at elastic events selection reduces background to below 0.05% level.

A new detector telescope arms were installed at 16.2°. The telescope includes three scintillator detectors, with fast photomultipliers. The first scintillator (Sc1) of a 6.4×6.4 mm^2 is situated at a distance 220cm from the Carbon target. It is accurately aligned at 16.2° angle on the common for all detectors flat table. A high polarized peak current (typically ~ 200 µA) produced a high peak event rate (~ 0.1-0.2MHz in the 16.2° and ~1-3MHz in 12° polarimeter) in this small solid angle with thin Carbon strip targets (strip width ~1-4 mm, thickness 60-100µm). The second (Sc2) and third (Sc3) scintillator the 16.2° polarimeter are 10×10 and 15×15 mm^2 with 10mm thickness. A variable copper absorber is situated in between first and second detector. The absorber consists of three Cu blocks of a 12.7mm thickness and two variable step shaped copper ladders. The first ladder is made with 10 steps by 1.0mm, the second with 10 steps by 0.1mm (see Fig.4). This layout allowed the measurement in the absorber thickness range from zero to 49 mm by step 0.1mm (total absorption length for 198.4 MeV protons is about 43mm).

With the thickness of the copper absorber chosen to be 41.5 mm thick, the elastic protons passed through the absorber and absorbed into the second scintillator, depositing 20-30MeV of energy. The energy thresholds for the second and third detectors were set at ~10MeV, which further suppress the background. For the same configuration, inelastic protons from the formation of the 4.44-MeV state had a range in the copper absorber of 40.4 mm and came to a stop before entering the third detector.

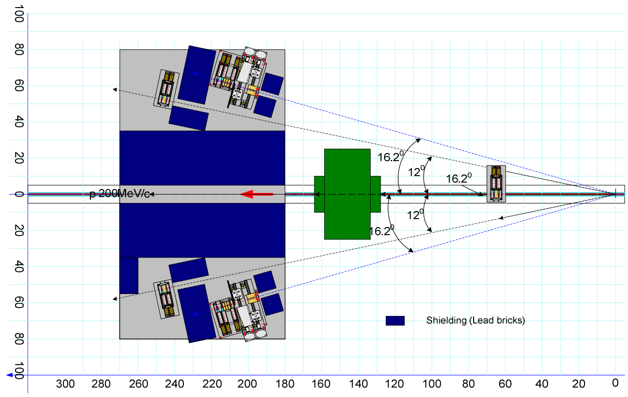

Figure 3: A 200 MeV polarimeter layout. The inclusive 12° polarimeter and elastic 16.2° polarimeter are installed and aligned at the common table. The distance from carbon target to the elastic scattering detectors is 220cm; the distance to 12° detectors is 250cm.

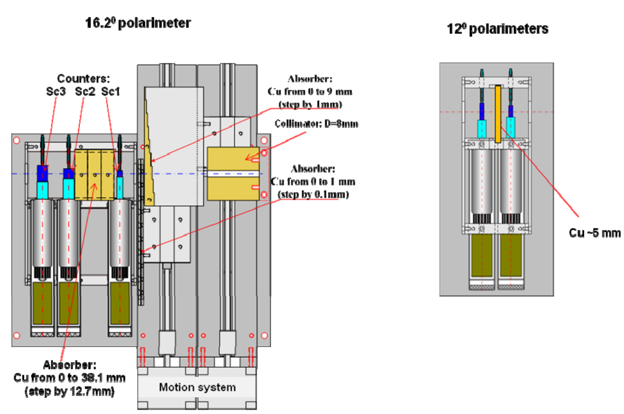

Figure 4: Detector telescope and absorbers layout. The absorber in between Sc1 and Sc2 detectors consists of three removable 12.7mm copper blocks. All scintillator (Sc1, Sc2, and Sc3), absorber and collimator are mutually aligned on common base plate.

EXPERIMENTAL RESULTS

Beam energy calibration The energy of the proton beam out of the Linac can be varied by the RF-cavity phase tune. The energy measurements and calibration to at least ±0.5MeV accuracy were done by using the magnetic spectrometer and cross-checked at injection to Booster. The results of the measurements a counting rate of coincidence Sc1^Sc2 in 16.2° polarimeter at different beam energies are presented in Fig.5. At the absorber thickness 41.5 mm the suppression factor for 194.0 MeV scattered beam energy (which corresponds to a 4.4-MeV state excitation) is about 30 times in agreement with GEANT simulations. These measurements directly confirm the feasibility of elastic scattering separation by the absorber of properly fine tuned thickness. At 41.5 mm absorber thickness, the elastically scattered protons of "correct" 198.0 MeV beam energy are completely stopped in the second detector (Sc2), therefore the rate in the third telescope detector (Sc3) is very low. The Linac beam energy can drift in time about ±2MeV. The ratio (S1^S3)/ (S1^S2) is used for the beam energy monitoring and tuning to improve polarization measurement accuracy.

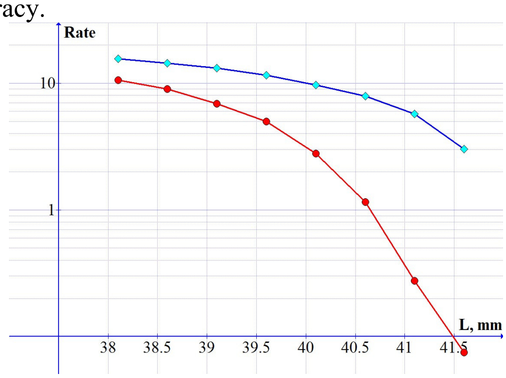

Figure 5: Rate of coincidence S2^S1 after absorber vs. the absorber thickness at different primary beam energies (blue- 200 MeV, red-195.6 MeV). The suppression factor of about 30 at absorber thickness 41.5 mm is in agreement with GEANT simulations.

A_y vs. copper absorber thickness The measurements of A_y vs. absorber thickness are presented in Fig.6. Since at 41.5mm absorber thickness the analyzing power is completely determined by elastic scattering (as demonstrated above) the A_y should be saturated at 99.35% value, as precisely measured in experiments at IUCF [5]. Then the beam polarization of about 80-82% was calculated back from experimentally measured asymmetries. The analyzing power for inclusive 12° polarimeter was also calculated and then beam polarization measured by 12° polarimeter was used for 16.2° analyzing power measurements vs. absorber thickness (see Fig.6). At zero thickness the A_y (16.2°) = 52% in agreement with old calibrations [6].

Systematic errors As mentioned above the small cross-section and additional strong suppression of inelastic (4.4-MeV state) by absorber reduce the elastic A_y dilution by inelastic component admixture to less than 0.1%. The beam energy and multiple scattering angle errors are minimal for the analyzing power measurements near maximum value and do not exceed 0.1%. The size of scintillator and alignment (±5mm) error are for the analyzing power measurements less than 0.1%. The estimate of the extrapolation error for 200 MeV beam energy and 16.2° angle and absorber more than 40.1mm of Cu was estimated at about 0.2%.

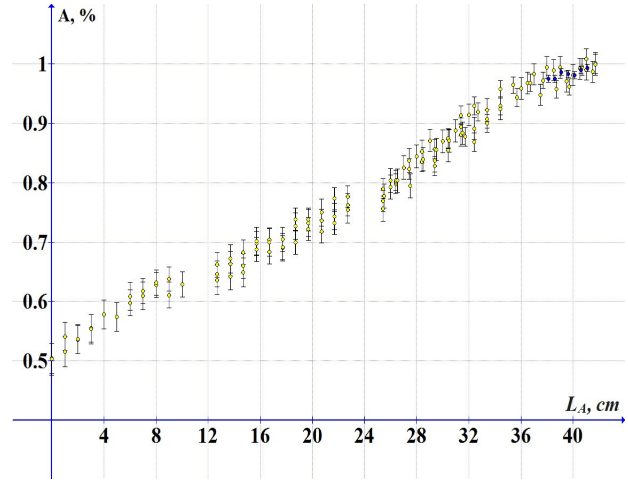

Figure 6: A_y (16.2°) measurement vs. copper absorber thickness. The scale is normalized for A_y saturation at 0.9935 value extrapolated from precision measurements [5].

SUMMARY

A new polarimeter for absolute proton beam polarization measurements at 200 MeV to accuracy better than ±0.5% has been developed as a part of the RHIC polarized source upgrade. The polarimeter is based on the elastic proton-carbon scattering at 16.2° angle, where the analyzing power is large 99.35% and was measured with high accuracy. The elastically and in-elastically scattered protons are clearly identified by the difference in the propagation through variable copper absorber and energy deposition of the stopped protons in the detectors. The rate difference in the subsequent detectors of telescope arms was used for the beam energy monitoring and tuning to improve polarization measurement accuracy. The 16.2° elastic scattering polarimeter was used for calibration of a high rate inclusive 12° polarimeter, which was used for the on-line polarization tuning and monitoring.

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