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Precision, Absolute Proton Polarization Measurement at 200 MeV

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Abstract.

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

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1. Introduction

RHIC spin program are required a precise absolute polarization measurement and control in wide energy range [1]. A complete set of polarimeters consists of:

- Lamb-shift polarimeter at the source energy (~25keV);
- 200MeV polarimeter after linac;
- AGS pC "CNI" polarimeter at the AGS ring for 24GeV proton beam;
- RHIC absolute h-jet polarimeter at energy region 24÷250GeV in the RHIC;
- And RHIC pC "CNI" polarimeter for polarization measures at energy region 24÷250GeV based on pC scattering in coulomb-nuclear interference region [2] (Fig.1)

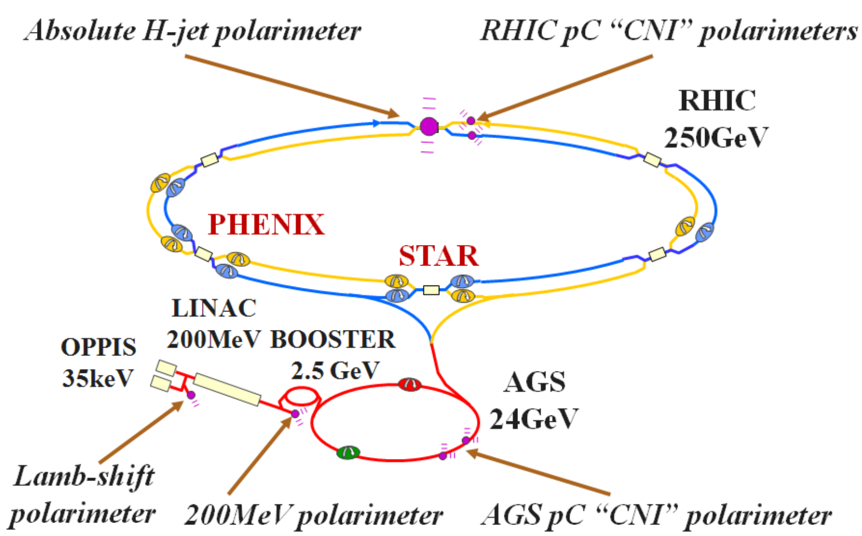


Figure 1: Polarization facilities at RHIC

The ongoing program of the polarized source upgrade to higher intensity (~10mA) and polarization (~ 85%) requires a new 200MeV polarimeter [3].

The 200MeV polarimeter is the most important tool for optimizing parameters for all elements of the OPPIS source for best performance, permanent control of source polarization during run and essential for depolarization studies in Booster and AGS. The polarization depends on many factors. A fast and precise measure of the polarization allows better customize the elements of the source.

The polarimeter is based on the elastic pC scattering at 16.2° angle, where the analyzing power is close to 100% (99.35%). The cross section and the analyzing power A_y for pC elastic and in-elastic scattering at 200 MeV has been precisely measured in experiments at IUCF [4-6]. The analyzing power for elastic pC scattering at 16.2° is A_y= 99.35±0.1%. The first excited state in Carbon is 4.44MeV energy. The cross-sections for the elastic scattering state and the first excited state are shown in Fig.2. Without separation elastic scattered protons analyzing power A_y will depends of thickness absorber between target and detector. The elastic scattering proton was selected by using the copper absorber with the variable thickness.

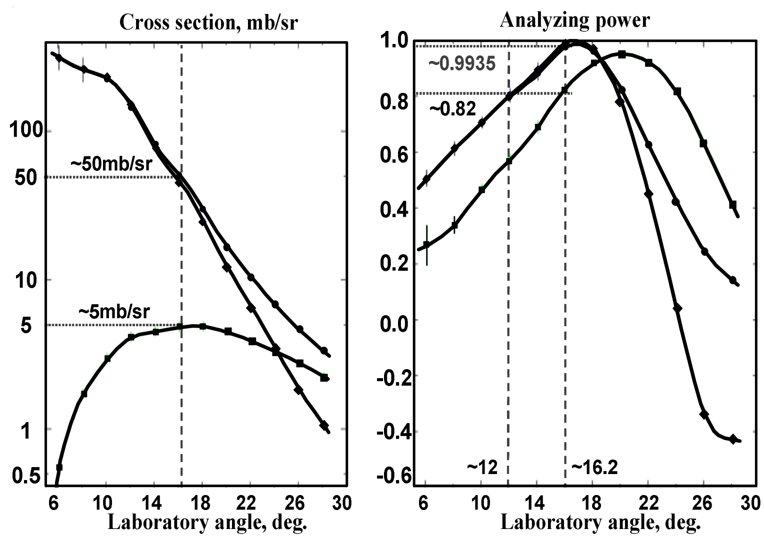


Figure 2: The cross section and analyzing power for pC scattering at 200MeV- *The rhombus curves correspond to protons exiting from the ground state of carbon. The square curve corresponds to protons exiting from the first excited state (-4.44MeV). The circle curve represents the sum of the two data sets.*

The elastically and in-elastically scattered protons are clearly identified by the difference in the propagation through the variable copper absorber and energy deposition of the stopped protons in the detectors (Fig.3).

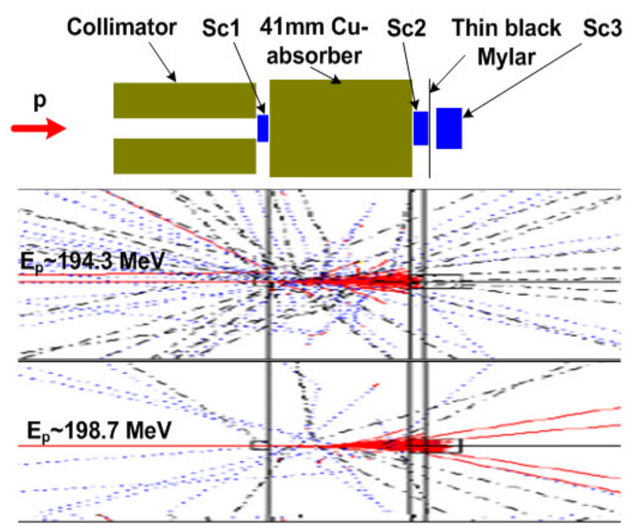
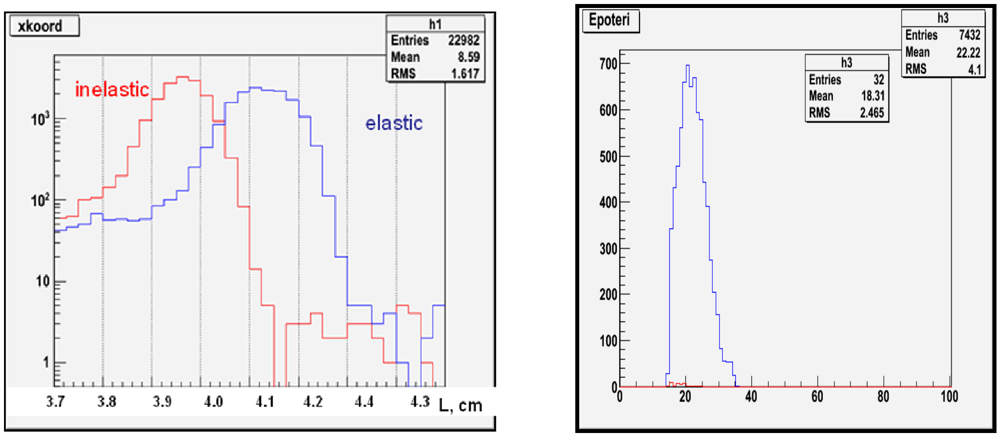


Figure 3: The GEANT simulation of penetration a protons thru 41mm Cu-absorber with energy 198.7MeV and 194.3MeV

At this angle the energy of elastically scattered protons is 198.7MeV and proton scattered from first excited state of carbon is 194.3MeV. GEANT calculation has shown the possibility of suppression of an inelastic scattering proton from a carbon by an absorber (Fig.4).



a b

Figure 4: The number rotons (red- with energy 198.7MeV and blue- with 194.3MeV): a) stopped in the slice of Cu-absorber b) energy deposited in the scintillator after an absorber

A sharp edge in the Fig.4a promises a good separation of the inelastic scattered proton from elastic. At the thickness of copper equal 41mm the ratio of number in-elastic (energy 194.3MeV - prototype of in-elastic protons) to the elastic protons (energy 198.7MeV - prototype of elastic protons) with energy threshold ~10MeV is less than 0.5% Fig.4b.

2. Experimental setup

The AGS cycle for the polarized beam operation is about 4 seconds. The OPPIS operates at 1Hz repetition rate and additional source pulses are directed to a 200MeV pC 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.5.

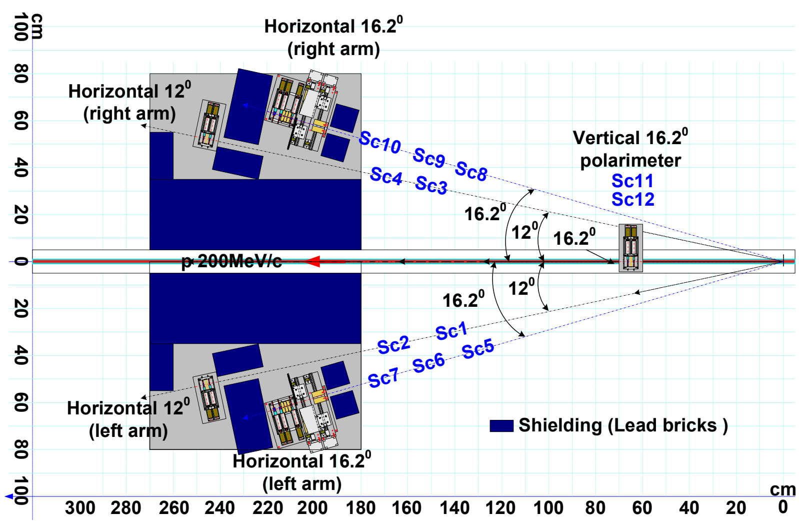
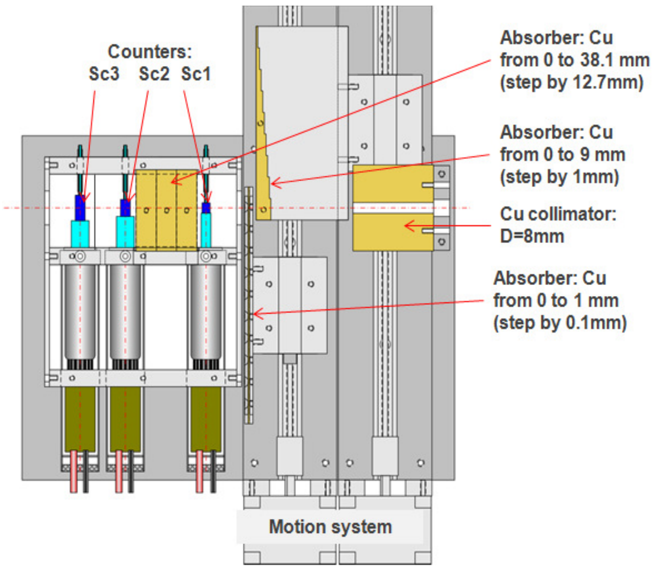


Figure 5: The 200MeV pC polarimeter setup

The 200MeV polarimeter consists of three polarimeters:

- the 16.2° horizontal polarimeter with remote changeable Cu-absorber for absolute polarization measurements at intense beam and monitor the energy of the beam;
- the 12° horizontal polarimeter for fast polarization measurement;
- and vertical 16.2° polarimeter to control the direction of polarization (Fig.5).



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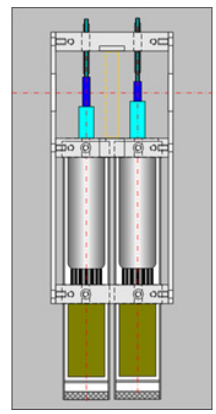

b

Figure 6: Counting modules of polarimeter a) the 16.2° horizontal polarimeter and b) the 12° horizontal polarimeter and the 16.2° vertical polarimeter

The counting modules of the 16.2° horizontal polarimeter consist of three scintillate counters and a changeable thickness absorber (Fig.6a). The first scintillator (Sc1) of a 6.4×6.4x6 mm^3 is situated at a distance 220cm from the Carbon target. The second (Sc2) and third (Sc3) scintillator of the 16.2° polarimeter are 10×10 and 15×15 mm^2 with 6mm thickness. Thickness of scintillator is equivalent to the 0.25 mm of copper. They are accurately aligned at a 16.2° angle on the common for all modules on a flat table. The absorber consists of three Cu blocks of a 12.7mm thickness and two variable step shaped copper ladders. A variable copper absorber is situated before first counter and the copper blocks in between the first and second detector. The first ladder of variable absorber is made with 10 steps by 1.0mm, the second with 10 steps by 0.1mm and the remotely moveable.

The counting modules of the 12° horizontal and vertical 16.2° polarimeters consist of two scintillator counters and fixed absorber with thickness 6 mm (Fig.6b). These polarimeters were calibrated by 16.2° horizontal polarimeter.

Fast Hamamatsu photomultiplier tube R1450 with fast scintillator BC-404 (decay time ~1.8nsec) gave the output pulse less than 15nsec (rise time ~2.4nsec). A coincidence signal is formed in the vicinity of the detector in the beam line by fast discriminators. Time resolution without amplitude correction is less than 0.5nsec.

The thickness of the copper absorber chosen in the 16.2° horizontal polarimeter is 40.5 mm thick. The elastic protons passed through the absorber and absorbed into the second and third scintillator, depositing 5-30MeV of energy. The energy thresholds for the first counter were set ~1MeV and for second and third detectors were set at ~5MeV, which further suppress the background. For the same configuration, most of the inelastic protons from the formation of the 4.44-MeV state had a range in the copper absorber of 40.5 mm and came to a stop before entering the second counter.

Table 1: Rate of counters from different targets at typical beam current ~200mkA

	Target#1	Target#2	Target#3	Target#4	Targe#5
Size, mm	2x0.1	2x0.1	2x0.06	D~ 0.3	4x0.1
Rate of Horiz. 12^0 L_{abs}=6mm	~400	~400	~220	~200	~800
Rate of Horiz. 16.2^0 L_{abs}=40.1mm	~30	~30	~18	~15	~60
Rate of Vert. 16.2^0 L_{abs}=5mm	~1600	~1600	~1100	~900	~2500

Five carbon targets (Table 1) of different sizes are attached to the target ladder, which is situated inside the vacuum chamber with thin Mylar vacuum windows. The distance from carbon target to the horizontal 16.2° detectors is 220cm; the distance to 12° detectors is 250cm and the distance to the vertical 16.2° detector is 80cm.

3. Experimental results

3.1 A_y vs. copper absorber thickness

The measurements of A_y vs. absorber thickness are presented in Fig.8. Since for absorber at 40.5mm 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 [4,5]. A_y dropped by 2% at thickness of an absorber about 39 mm. This can be explained by adding in account in-elastically scattered protons exiting from the first excited state of carbon. At zero thickness of absorber analyzing power A_y at 16.2° is 52%. This is in agreement with the old calibrations [8].

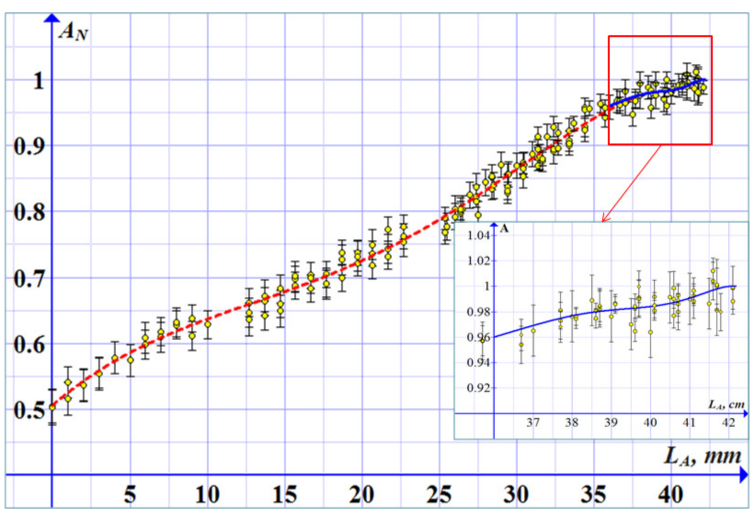

Figure 8: A_y (16.2°) measurement vs. copper absorber thickness.

3.2 Beam energy monitoring

The ratio of the coincidence Sc1xSc2 and Sc1xSc3 in the 16.2° polarimeter at the thickness of absorber close to the value when almost all protons are stopped at the Sc2 strongly depend on the energy of the proton. The calibration curve of this ratio was done by using the magnetic spectrometer and cross-checked at injection to the Booster with accuracy better than 0.2 MeV. The results of the measurements of this ratio at the chosen thickness of absorber (40.5mm) at different beam energies are presented in Fig.8.

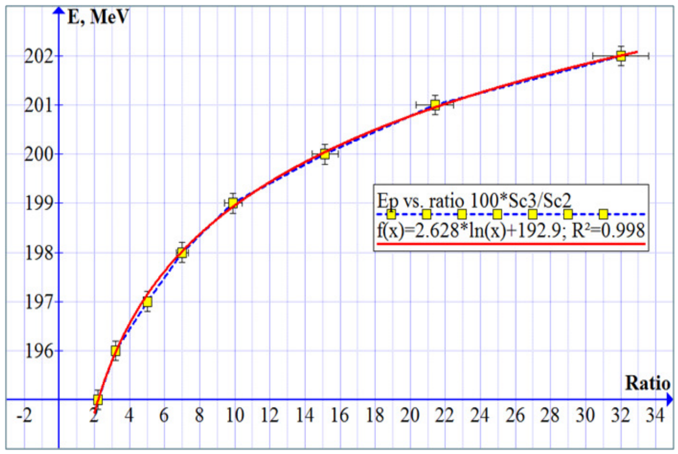

Figure 7: Calibration curve for defined a beam energy

Calibration curve is:

$F(x) = 2.628\times\ln(x) + 192.9$,

were $x= 100\times(Sc3*Sc1/Sc2*Sc1)$.

The Linac beam energy can drift in time about ±2MeV. The calibration curve is used for the beam energy monitoring and tuning to improve polarization measurement accuracy (Fig.9).

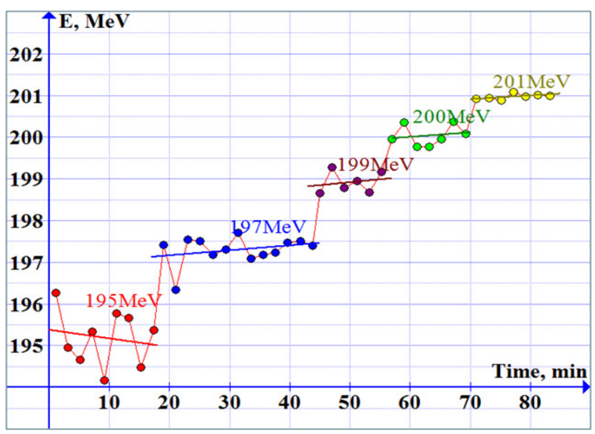

Figure 8: Time chart of energy monitoring at different energy of the beam by the 16.2° polarimeter

The ratio N(Sc1*Sc2)/N(Sc1*Sc3) is a simple and stabile monitor of beam energy with accuracy better than 0.5 MeV per tens of pulses.

3.3 Systematic errors

The systematic error of the A_y by:

- alignment of detectors (±5mm);
- variation of the beam energy (200±1.0 MeV) [6,7];
- size of the scintillator (Sc1~6.4x6.4mm) and
- multiple scattering in target, vacuum wall and air [9]

is about ±0.2 % (Fig.7).

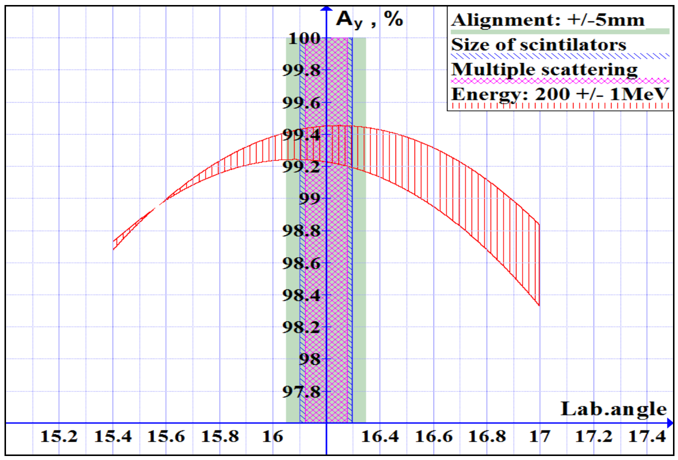

Figure 9: Systematic error an analyzing power

Additional error is systematic error from an accidental coincidence by:

- beam halo (depends on the adjustment of the LINAC) and
- the rate of the detector

is less than ±0.3%.

4. Summary

A polarimeter for absolute proton beam polarization measures at 200 MeV – to an accuracy better than ±0.5%. It has been developed as a part of the RHIC polarized source upgrade.
The 200MeV polarimeter consists of three polarimeters:

1. the 16.2° horizontal polarimeter with remote changeable Cu-absorber for absolute polarization measurement at intense beam and monitor energy of the beam;
2. the 12° horizontal polarimeter for fast polarization measurement and
3. vertical 16.2° polarimeter for control direction of polarization.

The 16.2° horizontal polarimeter is based on the elastic pC scattering at 16.2° angle, where the analyzing power was measured with high accuracy and close to 100% (99.35%). 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 polarization. All three detectors gave the total information about polarization of 200MeV proton source in the outside of LINAC.subsequent detectors was used for the beam energy monitoring and tuning to improve polarization measurement accuracy. The 16.2° elastic scattering polarimeter was used for calibration two others polarimeters, measured polarization and beam energy. The horizontal 12° polarimeter was used for the on-line polarization tuning and monitoring and the vertical 16.2° polarimeter- for monitoring of the direction of

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