PROCEEDINGS OF SCIENCE

HJET performance in RHIC Run 22

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In Run 22, the polarized proton beams were resumed at RHIC after four years of heavy ion beam operation. Here we compare HJET performance in the 255 GeV proton Runs 17 and 22. It was found that the analyzing power calibration obtained in Run 17 can be used in Run 22 for absolute proton beam polarization measurements. Spin asymmetries measured in Runs 17 and 22 were found to be well consistent within the evaluated systematic uncertainty of $\sigma^{\mathrm{syst}} a/a \lesssim 0.5\%$.

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1. Introduction

In the Relativistic Heavy Ion Collider (RHIC) Spin Program [1], the Polarized Atomic Hydrogen Gas Jet Target [2] (HJET) is employed to measure absolute transverse (vertical) polarization of the proton beams. In RHIC Run 17 (255 GeV beam energy), a typical result for the measured polarization was $P_{\text{beam}} = (\sim 56 \pm 2.0_{\text{stat}} \pm 0.3_{\text{syst}})\%$ [3]. Also, in these measurements, single $A_{\text{N}}(t)$ and double $A_{\text{NN}}(t)$ spin-flip elastic pp Coulomb-nuclear interference analyzing powers were precisely determined [4] for the 100 GeV (Run 15) and 255 GeV (Run 17) beam energies.

The primary goal of the HJET operation during heavy ion RHIC Runs 18-21 was a systematic error study in HJET measurements and experimental evaluation of $p^{\uparrow}$A analyzing powers in the forward elastic scattering [5]. In Runs 19 – 21, HJET was also used as a luminescent beam profile monitor for the LEREC [6] development and operation. Several problems in HJET detectors, electronics, and DAQ operation were identified.

After a four-year break for the heavy ion program, polarized proton beams (255 GeV) were resumed at RHIC. In preparation for polarized Run 22, the major vacuum system upgrades were implemented in collaboration with the Collider-Accelerator Department vacuum group. Noise in detector pre-amplifiers, observed in previous years, was eliminated with all pre-amplifiers board replacements and signal cables refurbishment.

In this note, we advocate that spin-correlated asymmetry measurements in Runs 17 and 22 are consistent within $\sim 0.3\%$ (relative) accuracy limited by statistical uncertainties, which allowed us to interpret online obtained values of the beam polarization as final ones.

2. HJET recoil spectrometer

At HJET, to determine the vertical polarization of the proton beam, recoil protons from the beam scattering off the vertically polarized hydrogen jet target are counted [3] in the left–right symmetric Si strip detectors (see Fig. 1). For each recoil proton, time of flight, kinetic energy T_R, and z-coordinate (discriminated by the Si strip width) in the detector are measured, which allows us to isolate elastic pp events. Since, for a given T_R, the background rate is nearly the same in all Si strips (in a detector), the background events can be thoroughly subtracted from the elastic data.

Due to concurrent measurement of both, beam and jet, spin asymmetries

$$\langle a_{\text{N}}^{\text{beam}}(T_R)\rangle = \langle A_{\text{N}}(T_R)\rangle\, P_{\text{beam}}, \qquad \langle a_{\text{N}}^{\text{jet}}(T_R)\rangle = \langle A_{\text{N}}(T_R)\rangle\, P_{\text{jet}}, \tag{1}$$

the average analyzing power is the same in both cases and, consequently, the beam polarization can be experimentally related, $P_{\text{beam}} = P_{\text{jet}}\,\langle a_N^{\text{beam}}\rangle/\langle a_N^{\text{jet}}\rangle$, to the jet one, $P_{\text{jet}} = 0.957 \pm 0.001$ accurately monitored [2] by a Breit-Rabi polarimeter. In Run 17 (255 GeV) data analysis [3], systematic uncertainty in the HJET proton beam polarization measurements was evaluated as

$$\sigma_P^{\text{syst}}/P \lesssim 0.5\%, \tag{2}$$

which strongly improves the original requirement of the Spin Program.

In the Run 17 data analysis, two main sets of event selection cuts [3] were used. The first one (Cuts I) accepts as many elastic events as reasonably possible to minimize the statistical uncertainty

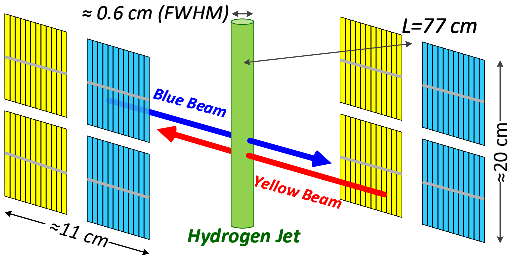

Figure 1: A schematic view of the HJET recoil spectrometer. Polarization of both RHIC beams, *blue* and *yellow*, are measured continuously and concurrently during RHIC stores.

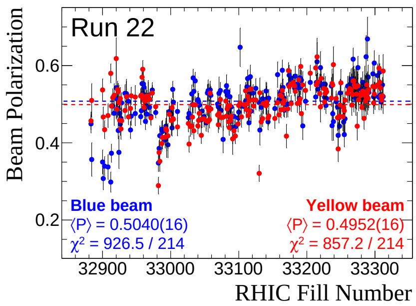

Figure 2: Online measurements of the *blue* and *yellow* proton beam polarization in RHIC Run 22. The shown numbers are the results of the zero-degree polynomial fit (dashed lines).

in the measurements. The second set (Cuts II) minimizes uncontrollable systematic corrections. Comparing values of the beam polarization found with Cuts I and II, effective (*calibrated*) analyzing powers

$$\left(A_\text{N}^\text{cal}\right)_{blue} = 3.749 \pm 0.013_\text{stat} \pm 0.014_\text{syst}, \qquad \left(A_\text{N}^\text{cal}\right)_{yellow} = 3.739 \pm 0.012_\text{stat} \pm 0.014_\text{syst} \tag{3}$$

for *blue* and *yellow* beams were calculated. Using the RHIC Run averaged *calibrated* A_N^cal allows us to minimize statistical uncertainties in a single RHIC store polarization measurement,

$$P_\text{beam} = \langle a_\text{N}^\text{beam} \rangle_\text{Cuts I} \,/\, A_\text{N}^\text{cal}, \tag{4}$$

while the systematic error is kept as small as possible. The stability of the spin asymmetry measurements during several months of a RHIC Run required to implement this method will be discussed below.

3. Online data analysis in Run 22

Since the recoil proton spectrometer was not modified between RHIC Runs 17 and 22, for online determination of the beam polarization in Run 22 we have used event selection Cuts I and *calibrated* analyzing powers given by central values in Eq. (3). The measured store averaged absolute polarization of RHIC *blue* and *yellow* beams in Run 22 Fills are depicted in Fig. 2.

To verify that effective analyzing powers found in Run 17 can be used in Run 22 measurements, we can compare (see Fig. 3) the values of A_N measured in these two RHIC Runs. One can see that all four Run averaged analyzing powers are in reasonable agreement within relative statistical uncertainties of about 0.2%.

It should be noted that for *blue* beam, the χ^2/ndf ratio is noticeably larger than 1. However, according to Ref. [3], this does not affect the interpretation of the results of the beam polarization measurements. If the excess of χ^2 can be attributed to an instability of the systematic corrections, then the effect can be approximated by about a 20% (relative) increase in the statistical uncertainty.

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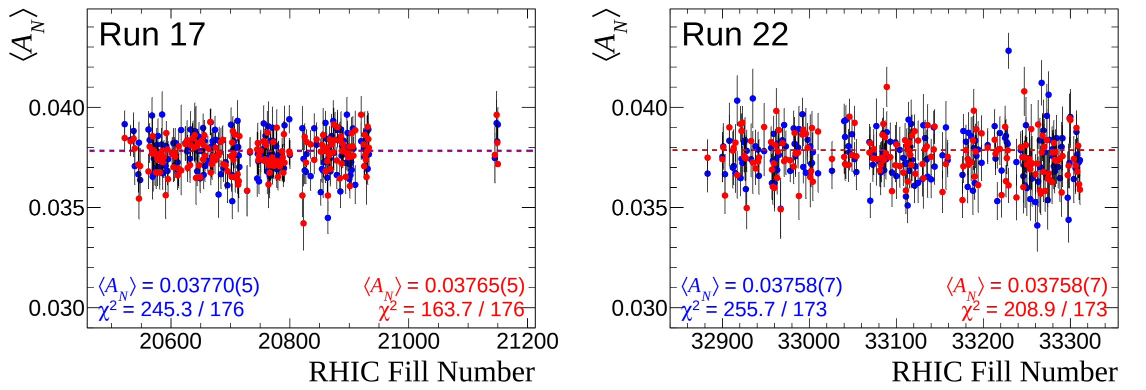

Figure 3: The measured effective analyzing power $A_{\rm N} = \langle a_{\rm N}^{\rm beam} \rangle_{\rm Cuts\,I}/P_{\rm jet}$ in Runs 17 and 22.

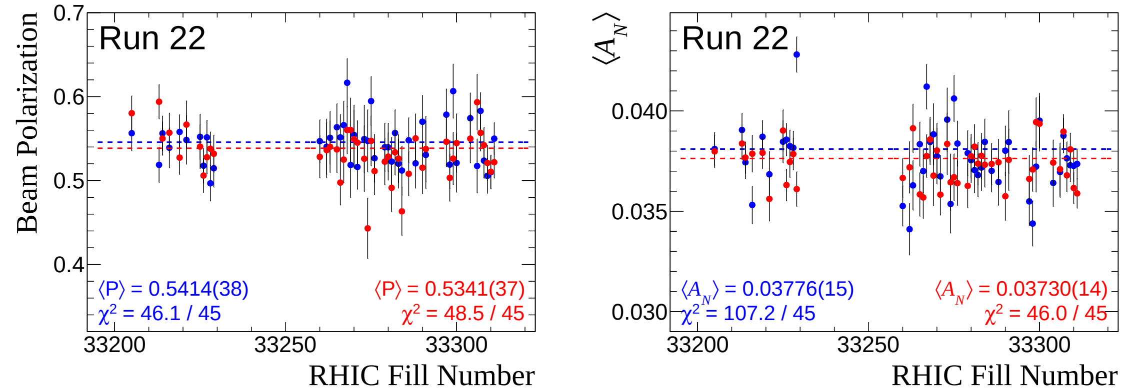

Figure 4: Measured beam polarization and analyzing power for the Run 22 steady polarization stores.

To compare the stability of the measurements of the jet $a_{\rm N}^{\rm jet}$ and beam $a_{\rm N}^{\rm beam}$ asymmetries, we selected RHIC Fills, 33205 – 33229 and 33260 - 33312 with approximately steady beam polarization (see Fig. 4). For the beam polarization, $\chi^2/\text{ndf} \approx 1$, while for the *blue* beam analyzing power $\chi^2/\text{ndf} = 2.4 \pm 0.2$. Even if Fill 33229 with an anomalously large value of $A_{\rm N}$ is excluded from the fit, then $\chi^2/\text{ndf} = 73.6/44$, which corresponds to a 3.2 standard deviation discrepancy.

Thus, the results shown in Fig. 4 suggest that increased χ^2 in the $A_{\rm N}$ fit is not directly relevant to the beam polarization measurements. For example, such a situation can be caused by fluctuations of the systematic uncertainties due to *molecular hydrogen* [3] background or due to *Weak Field Transition correlated noise* [3].

It must be pointed out that, since relative statistical uncertainties for $P_{\rm beam}$ $(a_{\rm N}^{b})$ are about factor 2 larger than for $A_{\rm N}$ $(a_{\rm N}^{j})$, the conclusion should not be considered unambiguous. Nonetheless,

– a similar effect was also observed in Run 17;
– in the beam polarization measurements, there is no evidence of systematic error fluctuations.

The measured values of single $A_{\rm N}$ and double $A_{\rm NN}$ analyzing powers must be Run year and RHIC ring independent. Although these values found in Run 17 are systematically lower than those in Run 22 (see Table 1), the discrepancy cannot yet be interpreted as statistically significant.

Table 1: Comparison of the average values of the beam polarization $P_{\text{beam}} = a_{\text{N}}^{\text{beam}}/A_{\text{N}}^{\text{cal}}$, single $A_{\text{N}} = a_{\text{N}}^{\text{jet}}/P_{\text{jet}}$ and double $A_{\text{NN}} = a_{\text{NN}}/P_{\text{jet}}P_{\text{beam}}$ spin analyzing powers, and the asymmetry b_{NN} in RHIC Runs 17 and 22. Since asymmetry b_{NN}, defined in Ref. [3], is expected to be identical to 0, it may be used to search for systematic errors in the measurements.

	Run 22		**Run 17**		
	Blue beam	*Yellow* beam	*Blue* beam	*Yellow* beam	χ^2/ndf
$\langle P_{\text{beam}}\rangle$ [%]	50.0 ± 0.18	49.5 ± 0.18	55.3 ± 0.15	56.1 ± 0.14	
$\langle A_{\text{N}}\rangle$ [%]	3.757 ± 0.007	3.757 ± 0.007	3.769 ± 0.006	3.765 ± 0.006	2.6 / 3
$\langle A_{\text{NN}}\rangle$ [%]	0.050 ± 0.015	0.063 ± 0.015	0.076 ± 0.009	0.073 ± 0.009	2.5 / 3
$\langle b_{\text{NN}}\rangle$ [%]	-0.003 ± 0.007	-0.003 ± 0.007	-0.003 ± 0.006	0.000 ± 0.005	0.8 / 4

Table 2: The ratio of single spin asymmetries a_{N} determined with and without background subtraction.

	Jet asymmetry $a_{\text{N}}^{\text{jet}}$		Beam asymmetry $a_{\text{N}}^{\text{beam}}$	
	Blue beam	*Yellow* beam	*Blue* beam	*Yellow* beam
Run 22	1.156	1.155	1.125	1.117
Run 17	1.067	1.068	1.049	1.044

To evaluate elastic data contamination by background events, one can consider the ratio of the single spin asymmetries determined with and without background subtraction (see Table 2). Since the *molecular hydrogen* background does not affect the beam asymmetry measurement, we can easily evaluate this background fraction as ~ 2% (Run 17) and ~ 3.5% (Run 22). For the *pA scattering* [3] background fraction, we find ~4.5% (Run 17) and ~12% (Run 22). It should be noted that the fractions are given for recoil proton energies range $0.6 < T_R < 10.6$ MeV. Increasing the lower limit for T_R leads to fast dilution of the background fraction.

4. Summary

For online determination of the RHIC 255 GeV proton beam polarization in Run 22, we have used *calibrated*, i.e. including systematic corrections, analyzing power determined in the offline analysis [3] of the Run 17 data. Since the measured analyzing powers in Runs 17 and 22 appeared to be the same within ~0.2% statistical uncertainty, we can conclude that Run 17 evaluation of the systematic uncertainties (2) is also valid for Run 22 online measurements.

Although the background fraction in the elastic data in Run 22 is about factor 2.3 (or by about 9% in absolute units) larger than in Run 17, the measured analyzing power was not altered. This result may be interpreted as proof that the background subtraction method works sufficiently well. The uncertainty in the evaluation of the background fraction does not exceed 3–4% of the background rate.

If a small difference between Runs 17 and 22 values of A_N in Fig. 3 will be attributed to a possible inaccuracy of the background subtraction, then one should conclude that the corresponding systematic error in Run 17 measurements was $\delta P/P \approx 0.2\%$. Since this value does not exceed the estimated systematic uncertainty [3] due to the background subtraction, it does not require revisiting the systematic error analysis for Run 17. Although the expected systematic error of about 0.4% for Run 22 is already comparable with the estimate in Eq. (2), it is still negligible for the beam polarization measurement accuracy required by the RHIC experiments.

Thus, we found that HJET provides a stable and accurate determination of the proton beam absolute polarization at RHIC energies. The precision of the online measurements in Run 22 fully satisfies the requirements for absolute calibration of the proton beam polarization at RHIC.

For further Run 22 data analysis, we consider independent evaluation of the *calibrated* analyzing power for these measurements, as well as determination of the hadronic spin-flip amplitude parameter r_5 [4, 7].

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