Polarimetry with inclusive charged pions at U-70 accelerator of IHEP

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Abstract. A feasibility of the proton beam polarimetry based on exploiting the observed large single-spin asymmetry A_N in inclusive charged pion production is evaluated for the SPASCHARM experiment at IHEP, Protvino, Russia. It is shown that, for a few hours of beam exposition time, the beam polarization could be measured at the statistical errors of ∼3-5%. The inclusive pion polarimetry at SPASCHARM does not require construction of a special polarimeter. The polarimetry will be carried out entirely by the main SPASCHARM spectrometer simultaneously with physics data taking.

1. Introduction

The new experimental program SPASCHARM [1] for the 70 GeV proton synchrotron U-70 is currently under development at the Institute for High Energy Physics (IHEP), Protvino, Russia. The main physics motivation for the SPASCHARM experiment is the systematic study of spin phenomena for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons. The experiment will be carried out in two stages. At the first stage, the measurements of single-spin asymmetries will be performed, using unpolarized meson and proton beams interacting with the transversely polarized protons of a "frozen" target. At the second stage, polarized proton and antiproton beams in the energy range of ∼10-45 GeV will be available along with the polarized target at the new beam channel 24A. The SPASCHARM physics program, experimental setup and characteristics of polarized beams have been presented in details elsewhere [1–3].

The SPASCHARM polarized proton and antiproton beams will be formed by the method similar to the one already used in two experiments: E581/704 at Fermilab [4] and FODS at IHEP [5]. The parity-violating decays of Λ-hyperons, $\Lambda \to p\pi^-$ and $\overline{\Lambda} \to \overline{p}\pi^+$, serve as a source of a tertiary (anti)proton beam. A transversely polarized beam is produced by selecting a portion of these Λ-decays. Such a selection is based on strong correlations of decay (anti)proton's transverse polarization and its emission angle in Λ-decay. The selection is done either by tagging each beam trajectory with tracking detectors [4], or using a collimation [5].

The beam tagging method is very robust and reliable because it fully relies on the well known characteristics of Λ-decays and the spin-$\frac{1}{2}$ evolution in magnetic field. The beam absolute polarization is calculated at a quite descent accuracy from a beam-line computer simulations. The authors of the E704 analysis [6] estimated their beam polarization $P = 0.45 \pm 0.03$, with $\Delta P/P \simeq \pm 6.7\%$. The respective values at FODS experiment were [7, 8]: $P = 0.39 \pm 0.02$, $\Delta P/P \simeq \pm 5.1\%$. Still, the complexity of a beam channel geometry, of a magnetic field configuration, a potential presence of errors in sophisticated on-line tagging algorithms, uncertainties in Λ-spectra, etc. make it highly desirable the verification and confirmation of tagging results with independent beam polarization measurements as well as continuous polarization monitoring for various instabilities. One option for the proposed SPASCHARM beam polarimeter is based on using the known analyzing power A_N in elastic pp-scattering. It is presented in details in Refs. [3, 9]. Here we discuss the feasibility of a complementary approach based on exploiting the experimentally observed large analyzing power A_N in inclusive charged pion production.

2. Experimental data on analyzing power A_N in inclusive pion production

For the last decades, the measurements of spin asymmetries in inclusive processes at high energies have been in the focus of a number of experiments across a wide energy range, $\sqrt{s}$ from ∼5 to 200 GeV. To the surprise of early pQCD predictions, the asymmetry A_N in pion production in forward direction at $x_F \gtrsim 0.4 - 0.6$ and moderate $p_T \sim 0.5 - 1$ GeV/c had been found large, for charged pions at the level of up to ∼40%, and its large value persists in the entire explored energy range. This is illustrated by the compilation [10] of some experimental data shown in figure 1.

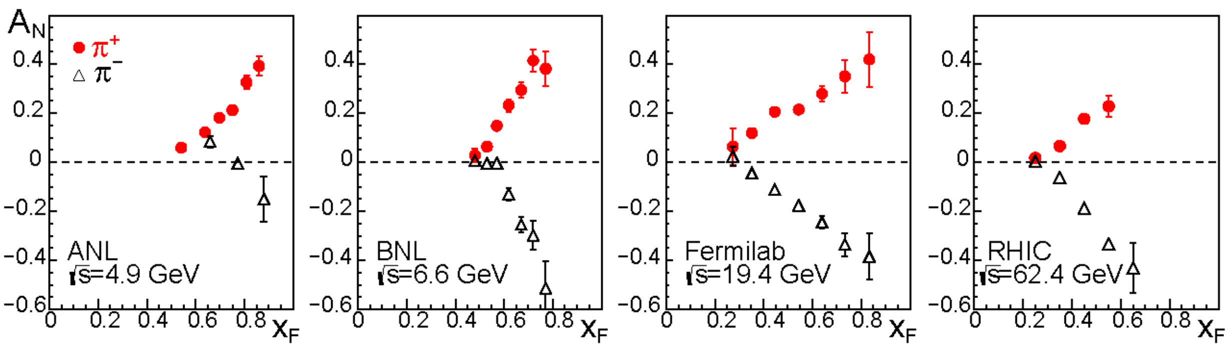

Figure 1. The asymmetry A_N in forward $\pi^{\pm}$ production as measured in polarized proton-proton collisions across a range of center-of-mass energies. From left to right, the data are from Refs. [11], [12], [13] and [14].

The similar A_N behavior has been revealed also in $p^{\uparrow}p \to \pi^0 X$ processes[1]. But A_N's absolute values for inclusive $\pi^{\pm}$ appeared to be more than twice as large as for π^0. Moreover, more data and of the better accuracy are currently available on charged pions in the energy range of interest for SPASCHARM. It was also found that the asymmetry A_N in $p^{\uparrow}A \to \pi^{\pm}X$ processes with a carbon target stays remarkably close to the one in $p^{\uparrow}p \to \pi^{\pm}X$ reaction [12], and at least up to copper, it is virtually independent of a target material [7].

3. Experimental setup for polarimetry and measurement time estimates

The measurements of single-spin asymmetries, including A_N in inclusive production of light mesons, is important part of the SPASCHARM program [1]. Therefore the main SPASCHARM

[1] See, for example, the relevant sections in RHIC Spin Collaboration write-ups [15] and references therein.

spectrometer will perfectly do the job for inclusive pion polarimetry, and no any additional detectors are required. The detailed descriptions of the SPASCHARM setup can be found elsewhere [1]. It is the wide aperture spectrometer for charged and neutral particles with good identification, covering 2π in azimuth, p_T up to 2.5 GeV/c, $0 < x_F < 1$ for the beam momenta in the range of ∼10-45 GeV/c. Its key properties are briefly listed below:

Tracking: Wide aperture spectrometer magnet; 5 thin-wall drift tube stations; $\Delta p/p \simeq 0.4\%$ at 10 GeV/c; Acceptance: 2π in azimuth and up to 250 mrad vertically and 350 mrad horizontally in polar angle θ.

Particle ID: 2 multi-channel Cherenkov counters ($\pi^{\pm}$ ID 3-23 GeV; $K^{\pm}$ ID 11-23 GeV; proton ID > 11 GeV).

Electromagnetic calorimeter: Fine-segmented Lead-Scintillator 'shashlyk'-type, cell size 55×55 mm^2, total area ∼2×3 m^2, energy resolution $\sigma_E/E \simeq 1.3\% \oplus 2.8\%/\sqrt{E}$ (E in Gev).

Hadron calorimeter: Compensated Lead-Scintillator sandwich, ∼7 interaction lengths, $\sigma_E/E \simeq 60\%/\sqrt{E}$, ($E$ in Gev).

Table 1. Event rate and time estimates for the beam polarization measurements, using the reaction $p^{\uparrow}p \to \pi^+X$ with a 20 cm long liquid hydrogen target. See text for more details. Only statistical errors for A_N from Ref. [12] are shown. The scale error of 14.5% is not included.

Parameter name for $p^{\uparrow}p \to \pi^+X$	$0.55 < x_F < 0.6$ $< p_T >= 0.7$ GeV/c	$0.6 < x_F < 0.65$ $< p_T >= 0.7$ GeV/c	$0.65 < x_F < 0.7$ $< p_T >= 0.8$ GeV/c
Analyzing power A_N, %	15.7 ± 1.5	23.7 ± 2.0	29.1 ± 2.9
Required N_{events}	$\sim 5.5 \times 10^4$	$\sim 2.5 \times 10^4$	$\sim 1.6 \times 10^4$
Cross section σ, μb	∼15	∼7	∼4
N_{events}/spill	∼12.7	∼6.0	∼3.4
Measurement time	∼10.8 hours	∼10.4 hours	∼11.8 hours

Table 2. Same as table 1 but for the reaction $p^{\uparrow}C \to \pi^+X$ with a 4 cm thick graphite target. Only statistical errors for A_N from Ref. [12] are shown. The scale error of 25% is not included.

Parameter name for $p^{\uparrow}C \to \pi^+X$	$0.55 < x_F < 0.6$ $< p_T >= 0.7$ GeV/c	$0.6 < x_F < 0.65$ $< p_T >= 0.7$ GeV/c	$0.65 < x_F < 0.7$ $< p_T >= 0.8$ GeV/c
Analyzing power A_N, %	12.5 ± 1.1	22.8 ± 1.5	30.2 ± 2.4
Required N_{events}	$\sim 8.7 \times 10^4$	$\sim 2.6 \times 10^4$	$\sim 1.5 \times 10^4$
Cross section σ, μb	∼110	∼50	∼30
N_{events}/spill	∼48	∼22	∼13
Measurement time	∼4.5 hours	∼3 hours	∼3 hours

The estimates for event rates and beam exposition times which are necessary for measuring the polarization of a 22 GeV/c proton beam at the statistical errors $\Delta P \simeq 4\%$ ($\Delta P/P \simeq 10\%$ for an expected $P \simeq 40\%$) are presented in tables 1 and 2. In these estimates, an intensity of a polarized proton beam has been assumed at 10^6 protons/spill with the spill repetition frequency of 0.11 Hz. The measured A_N values for inclusive π^+ production in $p^{\uparrow}p$ (table 1) and $p^{\uparrow}C$

(table 2) collisions are from Ref. [12]. The cross sections σ have been estimated, using the measurements [12] normalized with the data from Ref. [16]. The results are presented for three kinematic bins, and the statistical error of 4% is required to be achieved for each bin of the size $\Delta x_F \times \Delta p_T$=0.05×0.1 GeV/c. These errors will be further reduced by the simultaneous spin asymmetry measurements with negative pions although the production cross sections for inclusive π^--mesons in pp and pA collisions are noticeably lower than for π^+ [12].

4. Conclusion

A feasibility of the proton beam polarimetry based on exploiting the observed large single-spin asymmetry A_N in inclusive charged pion production is evaluated for the SPASCHARM experiment at U-70 accelerator of IHEP. It is shown that, for a few hours of beam exposition time, the beam polarization could be measured at the statistical errors of ∼3-5%. The measurements could be performed as with cryogenic hydrogen targets as well as with much more easier to handle solid nuclear, for example, graphite target.

The accuracy of the currently available experimental A_N data in inclusive production of charged pions is good enough for utilizing them for verification and confirmation of the beam-tagging operation and for continuous monitoring the time stability of beam polarization. The A_N accuracy for inclusive pions will undoubtedly be improved by the SPASCHARM experiment on the course of its physics program realization which is, however, beyond the scope of this paper.

It is important to underline that the inclusive charged pion polarimetry at SPASCHARM does not require construction of a special polarimeter. The polarimetry will be carried out entirely by the main SPASCHARM spectrometer simultaneously with physics data taking.

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