Single-spin asymmetry measurement of inclusive charged pions production in the SPASCHARM experiment

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Introduction

Experimental studies at various accelerators have shown the presence of significant spin effects in exclusive and inclusive processes. For example, the transverse polarization in the inclusive production of Λ-hyperons was discovered in 1976 in the interaction of unpolarized 300 GeV protons with a fixed beryllium target [1]. Contrary to expectations, the polarization turned out to be significant.

A number of phenomenological models have been developed that explain individual details of polarization data [2–7].

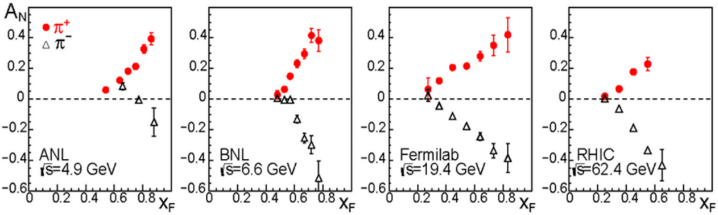
Introduction

In particular, the transverse single-spin asymmetry A_N in the formation of hadrons is of interest:

$$A_N(\phi) = \frac{D}{\langle P \rangle} \cdot \frac{N^{\uparrow}(\phi) - N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + N^{\downarrow}(\phi)},$$

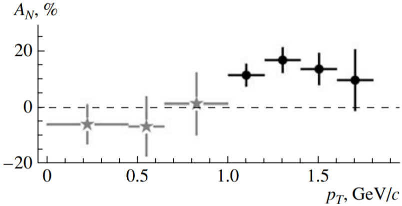
where D – target dilution factor (ratio of the number of interactions on all target nuclei to the number of interactions on hydrogen nuclei), $\langle P \rangle$ – average target polarization, $N^{\uparrow}$ and $N^{\downarrow}$ – observed hadron yields, normalized to the number of beam particles, for target polarization "up" ($\uparrow$) and "down" ($\downarrow$), respectively, ϕ – azimuthal angle of emission of secondary particles in the laboratory frame.

Introduction



Theoretical models within QCD predict a decrease in single-spin asymmetry with increasing transverse momentum of secondary particles [8], but experiments at various accelerators have shown that single-spin asymmetry in the inclusive formation of charged pions is almost independent of energy [9].

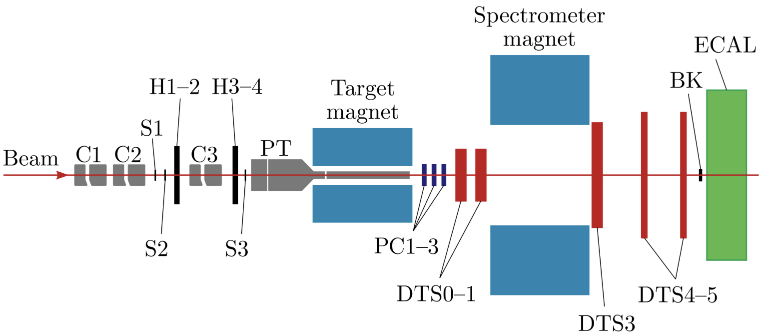
Introduction



Also, non-zero asymmetries in the region of fragmentation of the unpolarized beam were observed in inclusive production of π^0 ($\pi^- d^\uparrow \to \pi^0 X$) at the PROZA facility (Protvino) with a beam energy of 40 GeV [10].

Conducting research on asymmetries is one of the tasks of the SPASCHARM experiment at the U-70 accelerator.

SPASCHARM experiment at the U-70 accelerator



Beam tracks by hodoscopes H1-4, identification by threshold Cherenkov counters C1-3. Target magnet ($\sim$ 0.4 T·m), in the center is a cryostat with a polarized target (PT). Tracking system: PC1-3 - proportional chambers, DTS0-5 - drift tube stations, spectrometer magnet with $\int Bdl \sim 0.7$ T·m. There is a lead-glass electromagnetic calorimeter (ECAL).

Physical session 2018

In the first physical session of the SPASCHARM facility, a beam of negative particles (π^-($\approx$ 98.0 %), K^-($\approx$ 1.5 %) and $\bar{p}$ ($\approx$ 0.3 %)) was extracted from the internal target of the U-70 accelerator with a momentum of 26.5 GeV/c and interacted with a polarized pentanol ($C_5H_{12}O$) target (20 cm). Trigger for interaction in target - $S1 \cdot S2 \cdot S3 \cdot \overline{BK}$.
Four measurement cycles were carried out with the direction of proton polarization in the target up and down. The average polarization of the target protons was about 65%.
Also data on carbon target was collected. Total trigger number about 500 million.

Monte Carlo simulation

The change in the polarization sign of protons in the target occurs once every two days, so the stability of the facility is important. When the efficiency of the tracking system changes over time, a "false" asymmetry may appear.
The selected measurement cycles were divided into parts of ~ 5 hours. Then, for each such set of measurements, events were generated using the Monte Carlo method, a total of 17 sets of 100 million events.

Monte Carlo simulation

For this purpose, the experimental parameters of each set of measurements were included to the SpascharmRoot software package.
PYTHIA 8.212 (minimum bias), GEANT 3.2111 were used.

The statistics for each set were divided:

- 36 intervals by ϕ (in increments of 10°);
- 4 intervals by p_T (0.00 - 0.15 - 0.25 - 0.50 - 1.50 GeV/c);
- 4 intervals by x_F (0.00 - 0.25 - 0.50 - 0.75 - 1.00).

As a result, for each set of measurements, the efficiency of charged track reconstruction $\epsilon(\phi, p_T, x_F)$ was obtained.

Event selection

- One track in beam hodoscopes.
- Beam particle type determination (π^-, K^-, $\bar{p}$).
- One or more tracks in the spectrometer.
- Presence of a primary vertex, distance between the beam track and secondary tracks < 0.5 cm.
- Distance from primary vertex to target axis < 1.5 cm.
- The coordinate of the primary vertex is within -25 - $+25$ cm from the origin (polarized target center).

Asymmetry calculation

- $A_N^{raw}(\phi) = \frac{N_{UP}(\phi) - N_{DN}(\phi)}{N_{UP}(\phi) + N_{DN}(\phi)}$ - "raw" asymmetry,
  $N(\phi) = \frac{\sum_i \frac{n_i(\phi)}{\epsilon_i(\phi)} M_i}{\sum_i M_i}$ (weighted average), where i - number of measurement set for target polarization UP or DN, $n(\phi)$ – observed hadron yield ($\pi^{\pm}$), $\epsilon(\phi)$ - efficiency of charged track reconstruction, M - number of beam particles.
- $\delta A_N^{raw}(\phi) =$
  $\frac{2}{(N_{UP}(\phi) + N_{DN}(\phi))^2} \sqrt{N_{UP}^2(\phi) \delta N_{DN}^2(\phi) + N_{DN}^2(\phi) \delta N_{UP}^2(\phi)}$ - statistical error of $A_N^{raw}(\phi)$.
- $A_N(\phi) = \frac{D}{\langle P \rangle} \cdot A_N^{raw}(\phi) = 10.3 \cdot A_N^{raw}(\phi)$.
- Approximating $A_N(cos(\phi))$ by a function $A_N \cdot cos(\phi) + C$, the desired values A_N were extracted.

Single-spin asymmetry of inclusive production of charged pions

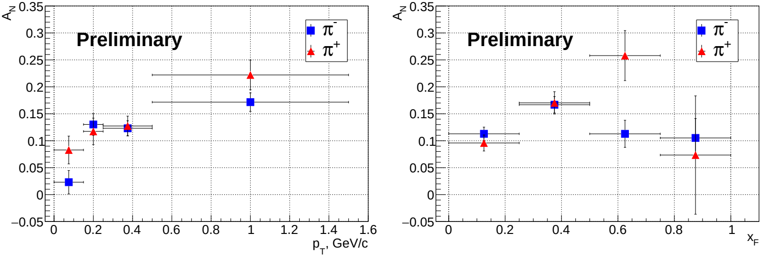
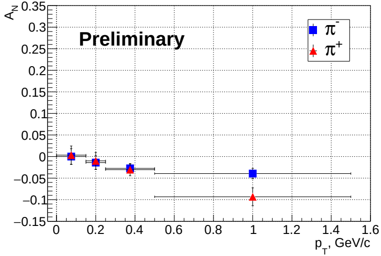


Figure: Graphs of $A_N(p_T)$ (left) and $A_N(x_F)$ (right) for $\pi^{\pm}$-mesons ($\pi^- p^{\uparrow} \to \pi^{\pm} X$) in session 2018.

Average value $\langle A_N(p_T) \rangle$ for π^--mesons – (12.1 ± 0.9) %, for π^+-mesons – (13.3 ± 1.2) %, $\langle A_N(x_F) \rangle$ for π^- – (12.9 ± 0.9) %, for π^+ – (12.9 ± 1.1) %.

Estimation of the systematic error

To estimate the systematic error, asymmetries of all "carbon"/"carbon" measurement sets were obtained.



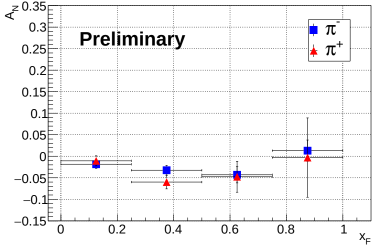


Figure: Graphs of $A_N(p_T)$ (left) and $A_N(x_F)$ (right) for $\pi^{\pm}$-mesons ($\pi^- p^{\uparrow} \to \pi^{\pm} X$) for the carbon target in session 2018.

$\langle A_N(p_T)\rangle$ for π^- – (-2.5 ± 0.6) %, for π^+ – (-3.2 ± 0.9) %,
$\langle A_N(x_F)\rangle$ for π^- – (-2.4 ± 0.6) %, for π^+ – (-2.9 ± 0.9) %.

Summary

The first results on the single-spin asymmetry of inclusive charged pions production in the pion beam fragmentation region with a momentum of 26.5 GeV/c were obtained at the SPASCHARM facility at the U-70 accelerator complex.

The obtained data indicate a small asymmetry in the region $p_T < 0.5$ GeV/c and a large value (~ 20 %) in the region $0.5 < p_T < 1.5$ GeV/c. $A_N(p_T)$ for $\pi^{\pm}$-mesons has the same positive sign.

"Asymmetry" on carbon $\sim 2 - 3$ %, further it is planned to study false asymmetries on data with one polarization sign (UP/UP and DN/DN).

References

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Graphs of $A_N(cos(\phi))$

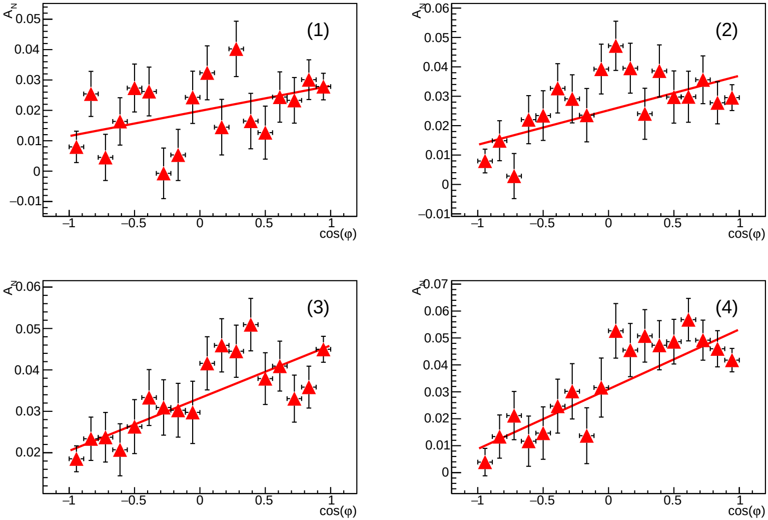

Figure: Graphs of $A_N(cos(\phi))$ for π^+-mesons:
(1) - $0.00 < p_T < 0.15$ GeV/c, (2) - $0.15 < p_T < 0.25$ GeV/c,
(3) - $0.25 < p_T < 0.50$ GeV/c, (4) - $0.50 < p_T < 1.50$ GeV/c.

Graphs of $A_N(cos(\phi))$

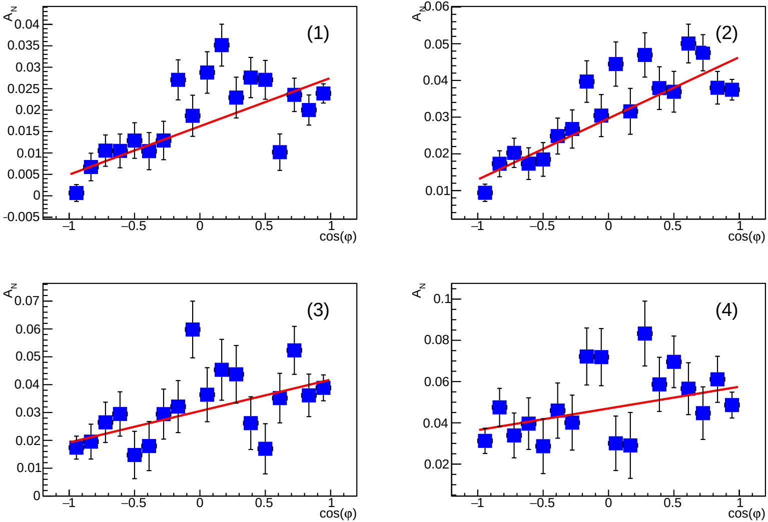

Figure: Graphs of $A_N(cos(\phi))$ for π^--mesons:
(1) - $0.00 < x_F < 0.25$, (2) - $0.25 < x_F < 0.50$,
(3) - $0.50 < x_F < 0.75$, (4) - $0.75 < x_F < 1.00$.

Graphs of $A_N(cos(\phi))$ without taking into account $\epsilon(\phi)$

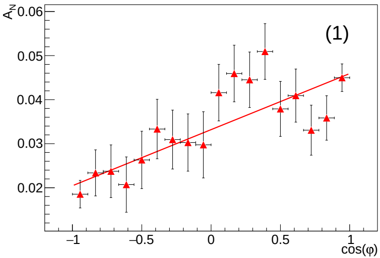

Figure: Distribution example $A_N(cos(\phi))$ taking into account $\epsilon(\phi)$ (left) and without (right).