Proposal of the complete experiment for elastic pp and p(bar)p scattering at SPASCHARM program at U70 accelerator

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Abstract. Newly developing SPASCHARM (SPin Asymmetry in CHARMonia) experiment at U70 accelerator will give the unique possibility to measure spin effects with the use of polarized proton and antiproton beams and polarized target. We suggest to carry out the measurements of the pp and p(bar)p elastic scattering spin observables at 16 GeV/c (direct reconstruction of elastic pp and p(bar)p elastic scattering amplitudes at SPASCHARM experiment). To date the direct reconstruction of amplitudes for pp elastic scattering was performed up to 6 GeV/c only, meanwhile there is no available data for p(bar)p elastics scattering. New measurements at SPASCHARM will significantly extend the energy range of the spin studies and will give unique possibility to compare elastic pp and p(bar5)p scattering

Introduction

A significant base for conducting spin phenomena research in the fixed target experiment SPASCHARM (SPin ASymmetry in CHARMonia) [1] is being created at the largest accelerator in Russia, the U-70 in the National Research Center Kurchatov Institute (NRC KI) - IHEP, Protvino (hereinafter IHEP).. The project is aimed at studying the spin structure of the nucleon and the spin dependence of the strong interaction of antimatter and matter with matter at energies up to 50 GeV. The core of the SPASCHARM program relies, first of all, on the study of interactions of high energy polarized protons and antiprotons selected and transported to the experiment through the beam-line 24A, second on the use of polarized target. SPASCHARM experiment also requires polarimetry [2] to verify beam polarization, which will help to study spin effects in elastic processes, since the detectors in both cases are similar. The proposal to measure polarization effects in elastic reactions at SPASCHARM experiments was published earlier [3]. Here we suggest to carry out complete experiment for elastic pp and p(bar)p scattering (direct reconstruction of pp and p(bar)p elastic scattering amplitudes at SPASCHARM experiment). To date the direct reconstruction of amplitudes for pp elastic scattering was performed up to 6 GeV/c [4] only, meanwhile there is no available data for p(bar)p elastics scattering. Complete set of the existing experimental data in elastic scattering is presented in the overview [5]. New measurements at SPASCHARM will significantly extend the energy range of the spin studies and will give unique possibility to compare elastic pp and p(bar)p scattering.

1. Direct reconstruction of the scattering amplitudes

Assuming parity conservation, time reversal and isospin invariance, the scattering matrix is written in terms of 5 complex amplitudes *a, b, c, d* and *e* [6]. SPASCHARM experiment will allow to perform a direct reconstruction of the scattering amplitudes (DRSA) [4],[7] by the measuring of 11 spin observables, namely: σ, P, A_{NN}, A_{LL}, A_{SL}, D_{NN}, K_{NN}, K_{SS}, K_{LS}, N_{LLN}, and N_{SLN}. The differential cross section σ is the only absolute quantity given in *(mb/sr)*. The spin-dependent observables, multiplied by the differential cross section, are bilinear combinations of the real and imaginary parts of the amplitudes. The bilinear terms are invariant with respect to the introduction of an arbitrary phase common to all amplitudes.

The measurement of the differential cross section σ, spin correlation A_{NN} and two polarization transfer coefficients D_{NN} and K_{NN} related to the vertical polarization of the particles allows to reconstruct the modules of the *b*, *c* and *d* amplitudes as[1]:

$|b|^2 = \sigma\,(1 - A_{NN} + D_{NN} - K_{NN})\,/2,$
$|c|^2 = \sigma\,(1 - A_{NN} - D_{NN} + K_{NN})\,/2,$
$|d|^2 = \sigma\,(1 + A_{NN} - D_{NN} - K_{NN})\,/2.$

One can obtain also the sum of the squared amplitudes *a* and *e* as:

$|a|^2 + |e|^2 = \sigma\,(1 + A_{NN} + D_{NN} + K_{NN})\,/2$

Other 7 observables: analysing power P, two spin correlations A_{LL} and A_{SL}, two polarization transfers K_{SS} and K_{LS}, and two three-spin observables N_{LLN}, and N_{SLN} are used to reconstruct real and imaginary parts of the scattering amplitudes.

In order to measure all possible spin observables one needs a polarized proton target, a polarized proton (or antiproton) beam, and "analyzers" of the polarization of the recoil proton and the scattered proton (or antiproton). While there are standard techniques to polarize a proton target, a high-intensity polarized antiproton beam does not exist yet.

The polarizations of the incident and target particles in the laboratory system are oriented along the basis unit vectors **k** – along the particle momentum, **n** – normal to the production plane, **s = n x k** (Figure 1).

The observables of the first type (A_{NN} and D_{NN}) will be measured with a transverse polarized beam and target.

The observables of the second type (A_{SL}, A_{LL}, N_{LLN} and N_{SLN}) will be deduced from the measurements with the longitudinally polarized target and the beam polarization oriented in three different (**n**, **s** and **k)** directions.

The observables of the third type (K_{SL}, K_{SS}, K_{NN}, and P) not require polarized target and will be measured for three different beam polarizations (**n**, **s** and **k** directions).

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[1] $\sigma = (|a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2)\,/2,$
$\sigma A_{NN} = (|a|^2 - |b|^2 - |c|^2 + |d|^2 + |e|^2)\,/2,$
$\sigma D_{NN} = (|a|^2 + |b|^2 - |c|^2 - |d|^2 + |e|^2)\,/2,$
$\sigma K_{NN} = (|a|^2 - |b|^2 + |c|^2 - |d|^2 + |e|^2)\,/2$ [5],[6]

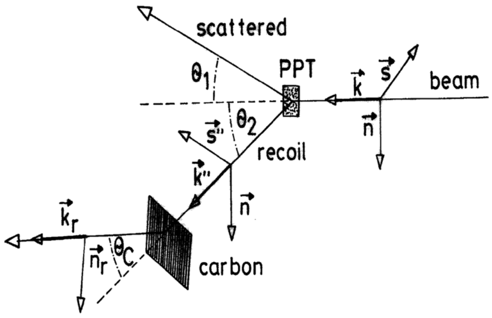

Figure 1. The unit vectors n, s, and k for the beam and target laboratory frame, and n, s ", and k" for the recoil particle frame.

2. Experimental possibilities

Measurements of single- and double-spin effects are required for direct reconstruction of the amplitudes as shown above. SPASCHARM experiment will use polarized beams as well as polarized targets to study single-spin asymmetries (inclusive and exclusive, including elastic, of the light hadrons in the beam fragmentation region with polarized beam or target) and double-spin asymmetries A_{NN} and A_{LL}.

The polarized proton and antiproton beams will be produced due to parity-violating decays of Λ – and Λ(bar) – hyperons. Special study was carried out to optimize beam characteristics [8]. The beam-line allows to obtain polarized proton (antiproton) beam with known vertical polarization about 40-45%. Tagging system allows to measure vertical polarization of each particle with accuracy better than 5% [2]. All three directions of beam polarization (vertical, horizontal and longitudinal) are required to measure all observables mentioned above[2].

Spin flipper (or Siberian snake) will rotate spin of protons or antiprotons, which come from Λ-meson decay with the energy up to 40 GeV. In this case, two superconducting helical magnets with opposite helicities and magnetic field 4.5 T will be used. Additional dipole correctors are required to correct beam trajectory inside spin flipper. The solution was proposed by BINP (Yu.M. Shatunov) group [9].

The intensity of polarized protons (antiprotons) as a function of the beam momentum is shown in Figure 2 for the maximum transmittable $\Delta p/p$ along with the background from $K^0_S \to \pi^+\pi^-$ decays. The intensity of the proton beam is quite above the requirements, while the intensity and background for antiprotons depends significantly on energy.

Apparently, for the antiprotons the background from $\Lambda \to p\pi^-$ at low momenta is very high, but fortunately, it has a sharp cut off at ∼15 GeV/c due to specific properties of Λ-decay kinematics. It follows that the lowest π^-/p ratio of only ∼3 is reached at about 16 GeV/c, where the intensity of antiproton beam would be $\sim 4 \times 10^5$ particles per accelerator cycle. The spatial distributions of the 16 GeV/c antiproton beam at the experiment target for the maximum transmittable $\Delta p/p$ are close to those for 15 GeV/c proton beam.

[2] The polarized target may have only vertical and longitudinal polarization

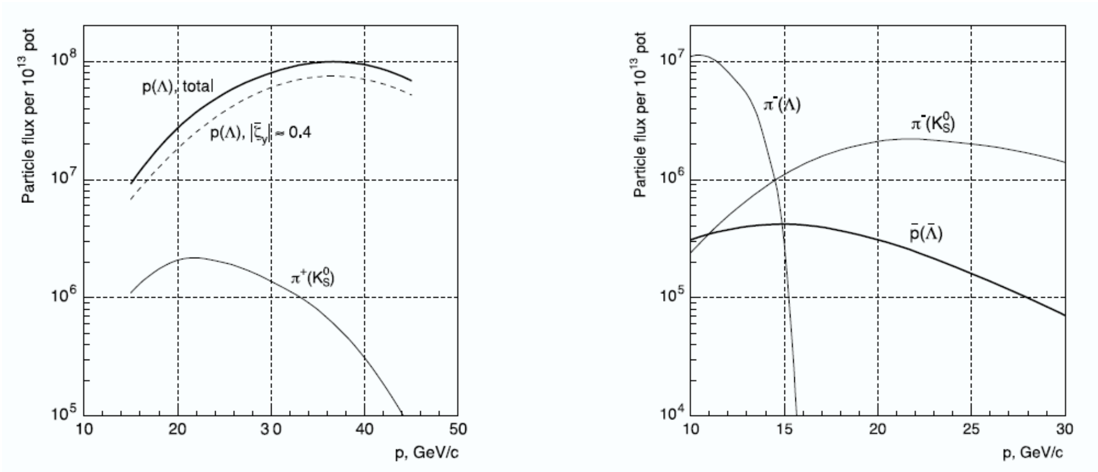

Figure 2. The proton (left) and antiproton (right) beam intensity at the experiment target as a function of the beam momentum for the maximum transmittable $\Delta p/p0$, along with the background from $K^0{}_s$ decays (the dashed line shows the summary intensity of two samples with the opposite average polarization ±40%) [8].

The high pion background to antiprotons from $\Lambda \rightarrow p\pi^-$ decays might make it not feasible operating antiproton beam at momenta below 16 GeV/c. This fact motivated us to choose the following kinematic region: beam momentum p_b=16 Gev/c and $|t| < 0.3$ (GeV/c)^2. The background to antiprotons from $K_s{}^0 \rightarrow \pi^+\pi^-$ decays is expected to be suppressed by the beam Cherenkov counters.

We will use the conservative intensity $I=4\cdot10^6$ for the polarized proton beam, while the intensity of the polarized antiproton is 10 times less[3].

The configuration of the experimental set-up SPASCHARM for elastic scattering measurements is presented in Figure 3. This configuration allows to measure all observables except the measurement of the polarization of recoil particle is required. Special carbon polarimeter for these measurements should be designed and will replace one of the recoil detectors.

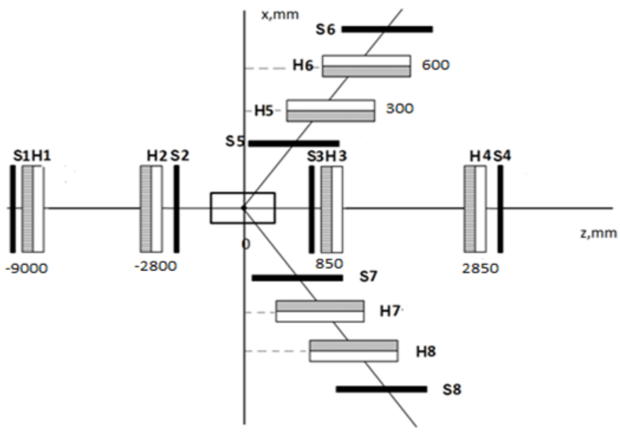

Figure 3 Design of the experimental setup (the description is presented in [3]).

[3] The intensity of the polarized antiproton beam may be increased twice [8], but it requires additional study

3. Estimation of required time

Numerical calculations for the number of elastic scattering events has been done for the following conditions:

- the polarized protons beam momentum p_b=16 Gev/c,
- intensity I=$4\cdot10^6$ per 10 sec cycle,
- average beam polarization P_B= (45±3) %,
- the luminosity L=$0.65\cdot10^{28}$ $cm^{-2}s^{-1}$,
- selected transferred momenta |t|= 0.3 $(GeV/c)^2$ and interval Δt=±0.1$(GeV/c)^2$.

An event rate is defined as n=L Δt dσ/dt $\Delta\varphi/\varphi$, where dσ/dt =8 mb/$(GeV/c)^2$ [10] and $\Delta\varphi/\varphi$=0.1. Finally, at the assumptions above, the counting rate n=1.047 s^{-1}. The expected value of A_{NN} is 5,25 %.

Four days are required to measure this parameter with a precision $\Delta A_{NN}/A_{NN}$ = 0.10. A_N and P will be measured with the accuracy 10% in two days for the same value of |t| = 0.3 $(GeV/c)^2$, and the beam running time will be 2 days. Better precision will be achieved for smaller |t| values. The required time to measure N_{LLN}, N_{SLN} is under calculation.

Conclusion

The complete set of 11 observables (σ, P, A_{NN}, A_{LL}, A_{SL}, D_{NN}, K_{NN}, K_{SS}, K_{LS}, N_{LLN}, N_{SLN}) is sufficient for direct reconstruction of elastic scattering amplitudes at SPASCHARM experiment with the use of polarized proton and antiprotons beam these amplitudes for pp and p(bar)p reactions will be compared for the first time.

The most of the suggested measurements can be carried out using SPASCHARM setup configuration designed for elastic polarimetry measurement. The estimated run time to measure spin correlation parameter A_{NN}, analyzing power A_N and proton beam polarization P is less than 6 days.

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