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THE MEASUREMENTS OF SPIN CORRELATION IN THE REACTION dp → *pd* (PROPOSAL)

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Recent measurements of the polarization observables in the reaction *dp* → *pd* at Dubna and Saclay are reviewed. It is shown that new polarization observables need to be measured. Effects due to the polarization of the interacting particles are considered. It is shown that a previously unobserved polarization characteristic, namely the spin correlation due to the transverse polarization of beam and target particles is sensitive to possible *P*-wave components in the deuteron. We propose to carry out the measurements of this spin-correlation observable in Dubna. It will be an important step in the completion of a program to obtain all independent polarization observables in backward elastic scattering.

The investigation has been performed at the Laboratory of High Energies, JINR.

Измерения спиновой корреляции в dp → pd реакции (проект)

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Дан обзор недавних измерений поляризационных характеристик реакции *dp* → *pd* в Дубне и Сакле. Показана необходимость измерения новых поляризационных характеристик этой реакции. В этой связи рассмотрены эффекты, связанные с поляризацией обеих начальных частиц. Показано, что не измерявшаяся ранее поляризационная характеристика, а именно спиновая корреляция при поперечной векторной поляризации обеих начальных частиц, чувствительна к возможному существованию *P*-волновых компонент в дейтроне. Рассмотрена возможность проведения таких измерений в Дубне. Это будет важный шаг в выполнении программы полного эксперимента для реакции упругого *dp*-рассеяния назад.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

The *dp* backward elastic scattering (BES) is one of the classic reactions to obtain infromation about the deuteron structure. The matter is in the framework of the Impulse Approximation (IA), there is one-to-one connection between the only kinematical parameter of this reaction, s, and the argument of the deuteron wave function (DWF) in the momen-

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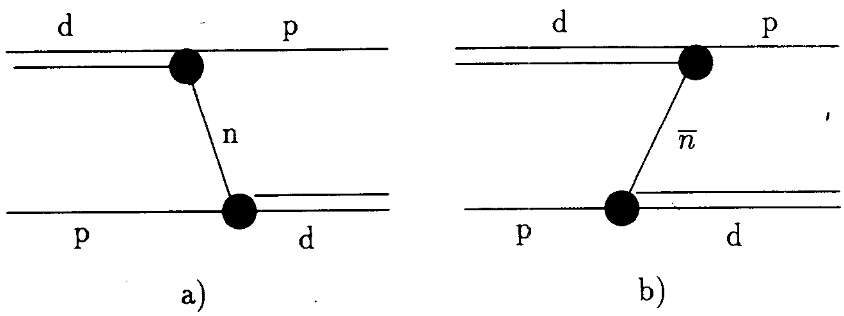

Fig.1. The IA diagrams for the $p\ (d,\ p)\ d$ reaction: a) exchange by the neutron; b) exchange by the antineutron

tum space, when the deuteron is implied as two-nucleon system. That is a serious advantage of this reaction (and of the deuteron electrodisintegration also) in comparison with *ed* elastic scattering, where observables are connected with argument of the DWF through integral.

The differential cross section and the tensor analysing power T_{20} were measured in the GeV range at SATURNE II a long time ago (see Ref.[1] and Refs. therein, and [2], respectively).

Usually this reaction is considered as the one-neutron-exchange (ONE) process (Fig.1*a*), which is a particular case of the IA.

Of course, one does not expect that such a simple approach is valid at large internal momenta, when the 6-q rather than the two-nucleon picture of the deuteron structure is relevant. Therefore investigation of this reaction up to the maximal energy available is of central importance to the study of the deuteron structure at small distances.

2. Status of Investigations of BES

The momentum densities extracted from electro-disintegration data [3] and from the *dp* backward scattering [1] using an approach [4] (Fig.2) demonstrate a good agreement with one another, in spite of a substantial discrepancy with the IA predictions using standard DWF. This agreement between electron and proton data constitutes a solid foundation, indicating that BES *pd* is a reliable source of information about the deuteron structure. Therefore the study of polarization observables of this reaction seems to be very attractive because of much more counting rate in comparison with the investigation of the same problem using electron probe.

The polarization observables of BES T_{20} and the deuteron to proton polarization transfer coefficient κ_0 have simple expressions in the IA approach when written in terms of the DWF components $u(k)$ (S-wave) and $w(k)$ (D-wave) [5,6,8]; for T_{20} the relation is:

$$T_{20} = \frac{1}{\sqrt{2}} \frac{\sqrt{8}uw - w^2}{u^2 + w^2} = -\sqrt{2}\frac{x^2 - 1}{x^2 + 2}, \qquad (1)$$

where $x = 1 + b(k)/a(k)$, $a(k) = u(k) + w(k)/\sqrt{2}$ and $b(k) = -3w(k)/\sqrt{2}$, k is internal momentum of nucleons in the deuteron.

For the polarization transfer coefficient it is:

$$\kappa_0 = \frac{u^2 - w^2 - uw/\sqrt{2}}{u^2 + w^2} = \frac{3x}{x^2 + 2}\ . \tag{2}$$

It was shown in [7] that one can eliminate u and w and obtain a connection between κ_0 and T_{20} which does not depend upon the particular DWF:

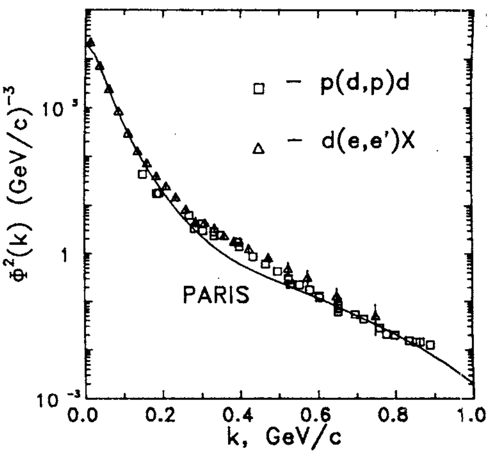

Fig.2. The momentum distributions of nucleons extracted from the *dp* backward scattering [1] and electrodisintegration data [3]

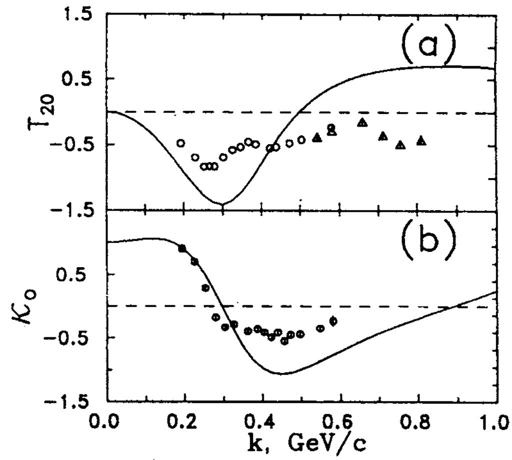

Fig.3. a) T_{20} data [9,10] versus Infinite Momentum Frame variable k; b) κ_0 data [10] versus k

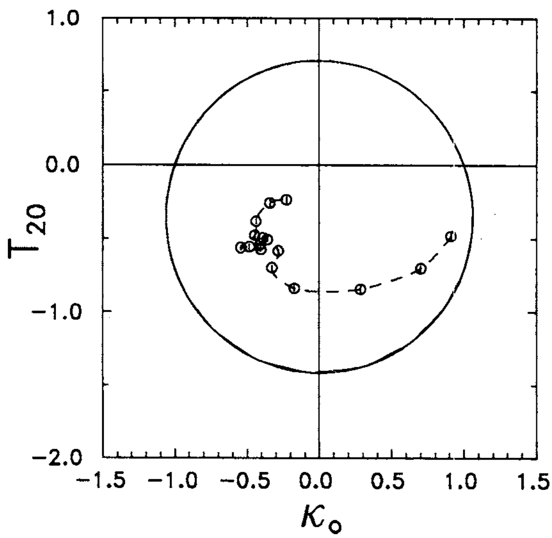

Fig.4. Correlation between T_{20} and κ_0 in backward elastic scattering

$$\kappa_0^2 + \left(T_{20} + \frac{1}{2\sqrt{2}} \right)^2 = \frac{9}{8}. \tag{3}$$

The Virginia-Dubna-Saclay collaboration was conceived in 1991 to measure the polarization observables T_{20} and κ_0 in the $dp \to pd$ reaction and the data were obtained in Saclay in 1992—93 [10]. The measurement of the tensor analysing power T_{20} was continued to larger energies in Dubna [9]. The combined T_{20} data are shown in Fig.3*a*, and the Saclay data for κ_0 are presented in Fig.3*b*.

The principal contradiction of the data [10] with the circle (3) in a ($T_{20} - \kappa_0$) correlation plot (Fig.4) demonstrates that at least one of two main assumptions (namely that the ONE diagram dominates, and the DWF contains *S*- and *D*-wave only) is not correct [10]. In Ref. [7] it is shown that similar correlation and deviation from the IA circle (3) takes place for the *p* (*d*, *p*) *X* reaction. To say more let us try to consider the *dp* backward elastic scattering in a model independent approach.

3. General Analysis of BES

In general, *dp* elastic scattering can be described by 12 complex amplitudes. That means one needs to measure at least 23 polarization observables [12] to reconstruct all amplitudes. Due to *P*-invariance of strong interaction and total helicity conservation BES (as well as 0° scattering) can be described by only four independent complex amplitudes for the following transition $\lambda_d, \lambda_p \to \lambda_d', \lambda_p'$,

$$\begin{aligned} F_{0+ \to 0+} &= g_2(s), \\ F_{++ \to ++} &= g_1(s) + g_4(s), \\ F_{-+ \to -+} &= g_1(s) - g_4(s), \\ F_{0+ \to +-} &= -\sqrt{2} g_3(s), \end{aligned}$$

where $F_{\lambda_d, \lambda_p \to \lambda_d', \lambda_p'}$ are helicity and $g_1 - g_4$ are the so-called scalar amplitudes, which are complex in the general case. Therefore only 7 polarization observables must be measured to reconstruct all of them.

The general spin structure of this reaction can be written in the following form [5]

$$\mathcal{M} = \chi_2^\dagger F \chi_1, \qquad F = A + i\boldsymbol{\sigma}\cdot\mathbf{B},$$

$$A = g_1(s)\,[\mathbf{U}_1\mathbf{U}_2^* - (\mathbf{n}\mathbf{U}_1)\,(\mathbf{n}\mathbf{U}_2^*)] + g_2(s)\,(\mathbf{n}\mathbf{U}_1)\,(\mathbf{n}\mathbf{U}_2^*),$$

$$\mathbf{B} = g_3(s)\,[\mathbf{U}_1 \times \mathbf{U}_2^* - \mathbf{n}\,(\mathbf{n}\mathbf{U}_1 \times \mathbf{U}_2^*)] + g_4(s)\,\mathbf{n}\,(\mathbf{n}\mathbf{U}_1 \times \mathbf{U}_2^*), \tag{4}$$

where $\mathbf{U}_1$ ($\mathbf{U}_2$) is the initial (final) deuteron spin vector, χ_1 (χ_2) is the two-component spinor of the initial (final) proton, $\boldsymbol{\sigma}$ are the Pauli matrices, s is the Mandelstam's variable (squared total energy). The parametrization (4) is valid for any mechanism of the discussed reaction.

For any form of the Impulse Approximation (ONE + exchange of any number of nucleon resonances with arbitrary spin and space parity) the scalar amplitudes remain real functions of s. On the other hand, such additional mechanisms to the IA, as those described in Ref.[13] lead unavoidably to complex amplitudes for this reaction.

Any polarization observable can be calculated in terms of these scalar amplitudes. In particular, the observables mentioned above can be expressed via the following combinations of them:

$$T_{20} = -\sqrt{2}\,\frac{-|g_1|^2 + |g_2|^2 + |g_3|^2 - |g_4|^2}{D^2}, \tag{5}$$

$$\kappa_0 = \frac{3\mathrm{Re}\,[g_3\cdot(g_1 + g_2 + g_4)^*]}{D^2},$$

$$D^2 = 2\,|g_1|^2 + |g_2|^2 + 4\,|g_3|^2 + 2\,|g_4|^2. \tag{6}$$

In the IA approach, when the deuteron is considered to contain two nucleons in S- and D-states, only two real independent amplitudes are sufficient to describe the $dp \to pd$ process. In this case we have [5]

$$\begin{aligned} g_4 &= g_1, & g_3^2 &= g_1\cdot g_2, \\ g_1 &= a^2, & g_2 &= a^2\cdot x^2, \\ D &= (2g_1 + g_2) = a^2\,(x^2 + 2), \end{aligned} \tag{7}$$

where a and x are defined in (1).

But as is shown in the previous section, this approach breaks down at smaller s than one expects a 6-q description of the deuteron to come into the picture.

A number of more complicated deuteron models and more complicated reaction mechanisms could pretend to explain the revealed effects. In terms of general approach, the next natural step must be an attempt to describe this process by four but sitll real amplitudes. This approach can be justified in generalized version of the IA with the deuteron as superposition with additional P-states (Fig.1*b*). Such components are inevitable when a relativistic description of the deuteron [14] is used: they also emerge in models based on quark counting [15], when the 6-q states are projected on two-nucleon systems such as NN^*. In this case the process is described by the same diagram as in Fig.1*a*, with neutron replaced by an N^*.

If the assumption about reality of amplitudes is valid, only 3 independent polarization observables must be measured to reconstruct all of them.

4. What to Measure

New polarization observables can be obtained using a polarized proton target. The simplest polarization observable in this case is the asymmetry of the cross section due to mutual spin orientation of initial protons and deuterons. Here we mention the expressions for transversal spin correlation effect in general case

$$A_t = \frac{2\mathrm{Re}\,[g_3\,(g_1 + g_2 - g_4)^*]}{D^2} \tag{8}$$

and (using simplification (7)) in the ONE approach:

$$A_t = \frac{2}{9}\,\frac{u^4 - 2w^4 + 3u^2w^2 - uw\,(5u^2 - 2w^2)/\sqrt{2}}{(u^2 + w^2)^2} = \frac{2x^3}{(x^2 + 2)^2}\,. \tag{9}$$

The case with additional *P*-waves is considered in detail in Ref. [5]. As is seen from Fig.5, the new observable is very sensitive to the contribution of possible *P*-states in the deuteron.

The combined analysis of new observable, A_t, together with those measured earlier, will allow one to reconstruct all amplitudes of the $dp \to pd$ process if they are purely real.

We mention for reference that another polarization observable, polarization transfer from the deuteron to the deuteron, is proposed to be measured by a Virginia-Japan-Saclay-Dubna collaboration at KEK (spokesman is C.F.Perdrisat). The general expression for this observable is

$$K_{y,0}^{y',0} = \frac{2\mathrm{Re}\,(g_1 g_2 + |g_3|^2)}{D^2}\,. \tag{10}$$

One can see that it is a new independent polarization observable. In the ONE approach we have

$$K_{y,0}^{y',0} = \frac{2}{3}\left(\frac{u^2 - w^2 - uw/\sqrt{2}}{u^2 + w^2}\right)^2 = \frac{4x^2}{(x^2 + 2)^2}\,. \tag{11}$$

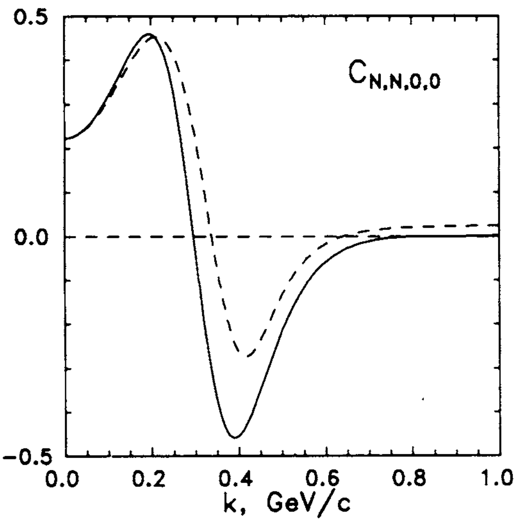

Fig.5. Spin correlation parameter $C_{N,N,0,0}$ calculated for standard DWF [11] (solid line) and for DWF with additional *P*-wave components [14] (dashed line)

Comparing latter expression with (2) it is easy to see that in the ONE approach there is simple relation between expressions for polarization transfer coefficients to the proton and to the deuteron:

$$K_{y,0}^{y',0} = \frac{4}{9}\,\kappa_0^2\,. \tag{12}$$

As is mentioned above, only additional to IA mechanisms of the reaction generate non-zero imaginary parts in the amplitudes describing this process. All of the polarization observables mentioned above contain combinations of the amplitudes such as $|g_i|^2$ and/or $\mathrm{Re}\,(g_i\,g_k^*)$. Assuming that the imaginary parts remain small, then they play a role in second order only. In this case any essential deviation from predictions can be interpreted as a non-adequateness of the deuteron model rather than of the reaction mechanism.

To be more sensitive to imaginary parts of the amplitudes it is necessary to measure polarization observables containing the Im $(g_i \cdot g_k^*)$ contributions. Needed combinations appear for only *T-odd* combinations of the particle polarization vectors and the unit vector along the beam direction (all observables, mentioned above, are *T-even*).

Here we followed to denotations accepted in Ref. [5]. More accepted denotation for observable suggested to be measured is $C_{N,N,0,0} = A_t$.

5. How to Measure

We are planning to measure spin correlation parameter $C_{N,N,0,0}$ using the Synchrophasotron (Nuclotron) polarized deuteron beam and the Moveable Polarized Target which now is installed at Dubna.

There are two possible ways to select events for BES. Having 180° scattering in the CM system, in Lab system both the final deuteron and the proton go in the forward direction. So, we can select either fast protons or slow deuterons. Our group have an experience in measuring T_{20} in BES selecting protons. Even having momentum resolution as good as $\Delta p/p \simeq 0.2\%$ we had the very hard situation to separate elastic events from the

$$d + p \to p + (n + p)$$

reaction with a small excitation of the $(n + p)$ system comparing with the deuteron mass (Fig.6).

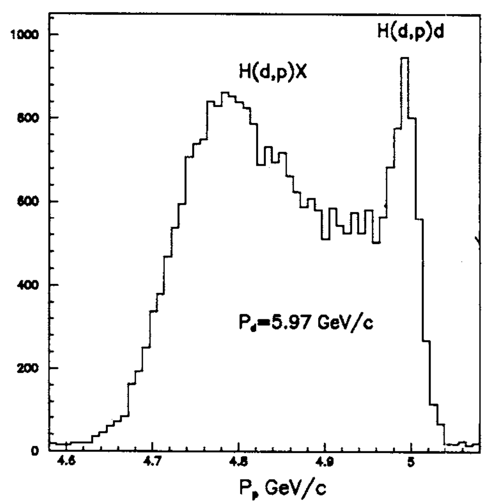

Fig.6. The momentum distributions of protons in Lab system

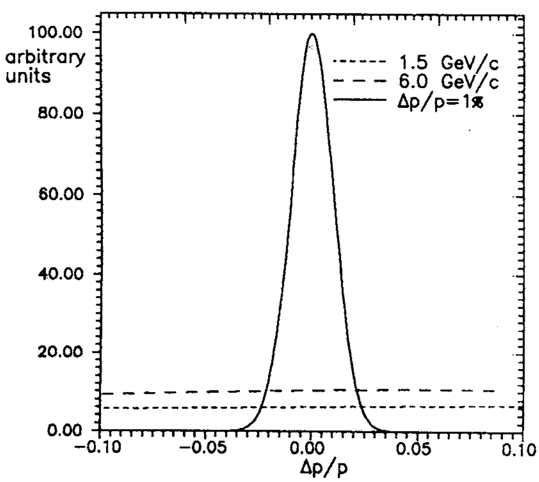

Fig.7. Contributions of quasi-elastic process on nucleon of the target at the primary beam momentum of 1.5 and 6.0 GeV/c

In case of the MPT the situation will be worse, because the target material contains only $\simeq$ 15% of hydrogen: the backward quasi-elastic scattering on the other nuclei in the target will increase the background under the elastic peak considerably.

Selecting of slow deuterons (which we are choosing). gives us the following advantages:

- no problem to distinguish the deuteron from $(n + p)$ system;
- momentum resolution $\simeq$ 1% is sufficient to have a good suppression of quasi-elastic events (see Fig.7);
- no problem to distinguish BES from $d + p \to p + d + \pi$ reaction: in latter case the deuteron momentum will be larger (depending on the primary beam energy) as much as 5%—15% (because of opposite directions of the secondary deuteron momentum in the CM and Lab systems, it increases in the Lab while decreasing in the CM).

Unfortunately, we will have disadvantages also. The unfavourable Jacobian (depending on energy 10—30 times worse than in case of selecting of protons) necessitates a large acceptance spectrometer not very far from the target. As a consequence, the space separation between the secondary zero angle deuterons and the primary beam using dipoles is more difficult.

The suggested scheme of the experiment is shown in Fig.8. The last chambers have 1.4×1 m^2 and are situated at the distance of 10 m from the target. The solid angle is 10^{-2} rad. That is 25 times larger than the solid angle for protons during our measurements of T_{20} [9] and it almost compensates for the unfavourable Jacobian. So, we can evaluate beam time necessary for this experiment from our experience with measurements of T_{20} at Dubna.

The first stage of separation of the primary and secondary beams will take place in the holding magnet of the MPT. The SP-57 dipole will be used for second stage of separation and the SP-40 dipole will be used both as separating and analysing magnet.

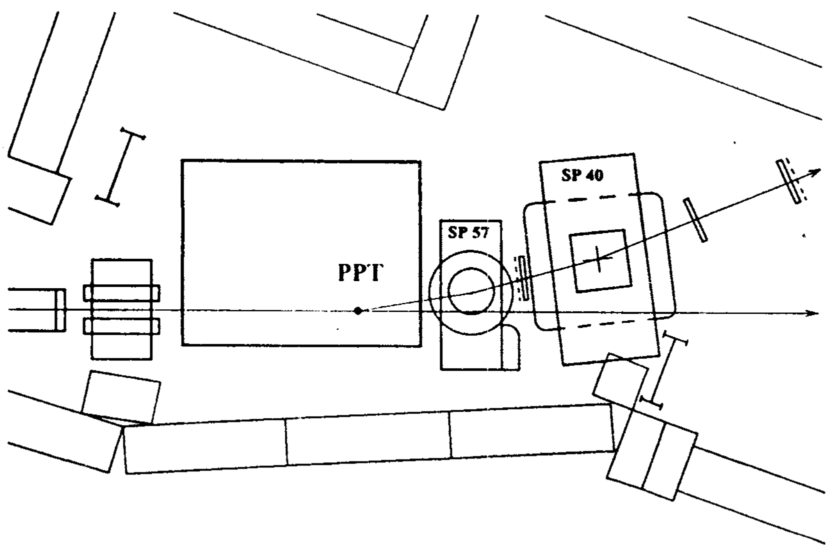

Fig.8. Layout of the spectrometer. PPT — polarized proton target; SP-57, SP-40 — dipoles; boxes — blocks of proportional chambers; dashed lines — TOF hodoscopes

The distance of about 3 m between proportional chambers downstream and one chamber 0.3×0.3 m^2 upstream the SP-40 dipole will allow reconstruction of the deuteron momentum with an accuracy of 1% (we assume $\simeq$ 100 mrad bending angle and the accuracy of track detection with proportional chambers of 0.5 mm).

We intend to investigate BES in the region of primary beam of 2.0—6.5 GeV/c. This corresponds to internal momenta of 0.33—0.85 GeV/c will be covered. The secondary deuterons will have momenta of 0.55—1.1 GeV/c. One can see that the ratio between momenta of primary and secondary beams changes from $\simeq$ 3 at lowest energy up to $\simeq$ 6 at highest one. The main task will be to adjust the currents in the dipoles in such a way as to bring the primary beam into a rather narrow gap between the pole and the yoke of the SP-40 dipole. The trajectory of the secondary deuteron beam will change depending on the energy of the primary beam. So, the system of proportional chambers must be moveable in a direction transversal to the beam.

The deuterons of interest will be accompanied by huge background, mostly pions and protons of the same momenta; therefore we need to have a high resolution time of flight (TOF) system. Besides, we expect high flux (especially through the first chamber) of forward elastically scattered deuterons and of protons of half of the primary beam momentum. There will be no problem to distinguish such events from the desired ones, but too high flux of other particles will require the following measures:

- instead of simple TOF counters overlapping proportional chambers we need to install two hodoscopes. In this case we will have rough position of tracks due to the hodoscopes which will prompt us to choose relevant tracks in proportional chambers where we expect as a rule many tracks situation;
- unambiguous identification of the good track in the first and last blocks of proportional chambers (thanks to hodoscopes) and condition of straight line in the y-plane will help us find the relevant tracks in the first chamber block downstream of the magnet.

6. Conclusion

The analysis of polarization observables such as T_{20} and polarization transfer coefficient both in the *p* (*d*, *p*) *d* and *A* (*d*, *p*) *X* (zero angle) reactions obtained at Saclay and Dubna shows deviation from the IA based on a DWF with *S*–*D*-components only. New independent polarization characteristics must be measured to check whether we are dealing with more complex reaction mechanisms or with more than two-component DWF.

We suggest here to measure new polarization observable for the backward elastic *dp* scattering, namely, the spin correlation parameter, when both initial deuteron and proton have the transversal (parallel or antiparallel) polarization. Such an observable of this reaction has never been measured. Firstly this observable was considered in Ref. [5] where it is shown that this observable is most sensitive to any deviations of the deuteron structure from the commonly accepted picture, in particular, respectively possible existing of *P*-wave. Such measurements are an important step in the realization of the complete experiment for this reaction.

The internal momentum region of 0.33—0.85 GeV/c will be covered, when changing the primary beam momentum from 2.0 up to 6.5 GeV/c. We intend to measure 10 points inside pointed out region with the error bars about ± 0.03. The beam times request is about 15 days (for data taking only).

A total of about 300,000$ is needed to assemble a spectrometer for this experiment; this spectrometer can also be used for other experiments using polarized target in the future [16,17].

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