Exclusive Deuteron Break-up Study With Polarized Protons and Deuterons at COSY (Proposal #20)

- First measurements with unpolarized beam and target -

ANKE collaboration

Spokesman: V.I.Komarov (komarov@nusun.jinr.ru)
Local contact: S.Dymov (s.dymov@fz-juelich.de)

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Contents

1. Introduction

The present report is an update and extension of the COSY-proposal #20, "Exclusive Deuteron Break-up Study With Polarized Protons and Deuterons at COSY", it presents new ideas for measurements of the deuteron breakup at ANKE and is a beam-time request in order to carry out the final unavoidable detector tests as well as first measurements with both unpolarized deuteron cluster-jet target and proton beam.

The original proposal [1] has been graded "A" by the COSY-PAC in March '92. In the meantime, ANKE has been installed and commissioned at the target position TPA and first measurements on subthreshold K^+-production and nucleon-nucleon FSI interaction have been carried out. In August '99 a cluster-jet target has been installed and successfully put into operation. Most of the detectors, needed to carry out the measurements described here, have already passed first tests at ANKE under beam conditions.

The ANKE setup allows to measure simultaneously two channels of the deuteron break-up: the first with a proton pair emitted in forward direction, the second with one proton in forward and the other one in backward direction. As shown in Sect. 2 where we present a compilation of the physics underlying this proposal, the measurement of two forward protons from the reaction

$$p + d \to (pp)(0^\circ) \ + n(180^\circ)$$

allows to study the low energy excitation region ($E_{pp} < 5$ MeV) of the two outgoing protons. We show that even the measurement of spin averaged cross sections can supply valuable information of the short range NN interaction responsible for the break-up process. The complementary case of forward-backward emission of the two protons,

$$p + d \to (pn)(0^\circ) \ + p(180^\circ)$$

has been considered in detail in the original proposal. Accordingly not only the spin averaged cross sections will be measured but in a later step also the vector and tensor analyzing powers in a wide range of relative energy of the two forward emitted nucleons, $E_{NN} = 0 \ldots 600$ MeV.

The requested beam time basically consists of two parts: first, during two weeks of beam time with a break in between in the first half of 2000 when we want to do final tests and tuning of the detection systems. Special emphasis has to be put on beam development with the goal to reduce the flux of background particles in the forward counters. Second, another week of beam time for the second half of 2000 for first unpolarized measurements is requested. At a later stage, depending on the results of these first measurements, we will apply for additional beam time, in particular, using polarized targets and beams. It should be noted that we already applied for test beam time in the PAC meeting April '99. It was decided to shift this beam time until a revised proposal is presented.

2. Scientific justification

2.1 Goals of the study.

2.1.1. Main problems the experiment concerns.

There still exists the old but urgent problem of the high-momentum structure of nuclei or, in other words, their short-range structure. The main properties of this structure will be determined by a future fundamental theory of strong interactions in the nonperturbative region. At present the problem consists in clear experimental observation of this structure and determination to which limiting values of the intrinsic momenta of nucleons in nuclei the traditional description of nuclei in terms of nucleons is valid. The nuclear structure in the nucleon overlap region at short relative distances $R_{NN} < 0.5\,fm$ can be studied in processes with large transferred momenta $Q > 1\,GeV/c$. It is expected that there is a transition region at these distances from meson-nucleon to quark-gluon degrees of freedom of nucleus. One of the signals of this region at high-momentum transfers can be a failure of the conventional picture based on the phenomenological NN-interaction potential fitted to the NN- phase shifts. In this respect the problem of the nuclear high-momentum structure is closely related to the a problem of the potential approach to the nucleon-nucleon interaction at short distances. There are other interesting aspects of this problem, i.e. relativistic description of composite systems, excited baryons in nuclei etc.

Obviously, study of the high-momentum structure of nuclei can be realized only in the framework of definite and well established mechanisms of the probing processes. Unfortunately, the higher internal momentum of the constituent nucleon inside a nucleus under investigation, the less determined and studied the corresponding mechanisms. Therefore, the problem arises to separate the effects of the nucleus structure at short distances from the "non-short-range-structure" effects caused by specific interaction mechanisms.

The deuteron, being the simplest nuclear system plays a special role in studying these problems. In spite of its fragile structure the deuteron became the main subject of the short-distance NN physics both in experiment and theory. The COSY experiment no. 20 [1], suggested for the interval of initial kinetic energy of the proton beam $T_p = 0.5 - 2.5\,GeV$, deals with the study of the proton-deuteron interactions at relative nucleon momentum inside the deuteron in the range $q = 0.3 - 0.6\,GeV/c$. Here the spectator mechanism, formulated within the relativistic hamiltonian dynamics, serves as a first approach. Therefore, the experiment [1] definitly concerns the above referred significant problems.

2.1.2. Present status of the problem.

There is a large number of experiments performed on ed- and pd-interactions in the so called cumulative kinematical region, i. e. in the region forbidden for the collision of an incident particle with a free nucleon at rest. Recent TJNAF data on ed- and γd-interaction cross section demonstrate in some cases an intriguing dimensional scaling behaviour of some observables at transferred momenta $Q^2 > 2\,(GeV/c)^2$ [2,3]. These properties are correlated formally with the well known quark counting rules [4,5]. However, according to perturbative QCD calculations [6,7], they are expected to be valid only at higher transferred momenta $Q^2 > 100\,(GeV/c)^2$. Therefore, further experimental investigations are necessary. Electron-nucleus collisions provide the clearest test for nucleus structure beyond the region of meson exchange currents. However, they are probing only the quark content of the nucleus, but not the gluon field. In this respect, the hadron-nucleus interactions in the same kinematical region can provide independent information.

The main part of experiments performed in pd-interactions after 1992 was done in inclusive [8] and semiinclusive kinematics [9]. These data only allow an ambiguous theoretical interpretation. A preliminary indication of the presence of a preexisting NN^* component, related to a six-quark component of the deuteron wave function, was obtained recently in an analysis [10] of inclusive break-up data for the reactions $dp \to p(0^o)X$ and $d^{12}C \to p(0^o)X$ [8]. In the cumulative π -meson production reaction $\vec{d}^{12}C \to \pi^+(0^o)X$ the measured tensor analyzing power T_{20}, found to be close to zero [11], can be explained by the presence of a $\Delta\Delta$-component in the deuteron [12]. However, in this six-quark model an unreasonable large radius of the nucleon inside the deuteron is used being almost 1.5 times larger than the free nucleon radius. Moreover, this model fails to explain the observed polarization effects in backward elastic pd-scattering [13] at initial energies $T_p > 0.4\,GeV$. Besides, one should note that mechanisms with intermediate pions may play an important role in these reactions [14]. New measurements of T_{20} in backward elastic dp-scattering [15] and the deuteron break-up reaction without pion production [9] were performed recently up to an initial proton laboratory kinetic energy $T_p = 2.46\,GeV$. The remarkable feature of backward elastic and inelastic pd-scattering both in inclusive and semiinclusive kinematic is a strong contradiction between the measured values of the T_{20} and the impulse approximation (IA) whereas the spin averaged cross section can be explained qualitatively in the framework of IA with realistic NN-interaction potentials. One of the possible reasons for this contradiction may be inadequacy of the impulse approximation for the description of processes at high momentum transfers. Another, less possible explanation is that the deuteron high-momentum structure is drastically different from the convential picture. It means that a more extensive investigation should be performed to determine the interaction mechanisms. The exclusive study of the break-up reaction is a promising way for such an investigation.

An exclusive study of the break-up reaction has been done at $1\,GeV$ [16]. In the framework of impulse approximation the momentum distribution of the nucleon in the deuteron was determined up to q = 0.5 GeV/c from the measured spin averaged cross sections. A large systematical deviation from the impulse approximation with realistic NN-potentials was observed at $q >$ 0.3 GeV/c. A reasonable description of the data has been achieved when double scattering and Δ-excitation were added to the one-nucleon exchange diagram. The deuteron break-up in the exclusive reaction $\vec{d} + p \to \vec{p} + p + n$ was investigated at SATURNE at an energy $T_d = 2\,GeV$ [17,18]. A remarkable deviation from the pole diagram of the impulse approximation was observed even in the kinematics of quasi-free pN-scattering, i. e. at low momenta of the spectator nucleon. Besides the

IA, rescattering and Δ- excitation effects were taken into account in the same way as in Ref.[16]. A reasonable account of the measured polarization observables was obtained in the region of quasi-free pN-kinematics, but outside this region the agreement with data was not satisfactory. In spite of some progress in the Refs. [16,17,18] a definite information about the high-momentum structure of the deuteron at $q > 0.3$ GeV/c was not obtained. In fact, in the kinematics used in these experiments there are several effects which mask the deuteron structure in the nucleon overlap region. (i) First, at low spectator momenta $q_s = 0 - 0.2$ GeV/c only medium and large distances between nucleons inside the deuteron can be investigated. On the other hand, with increasing q_s the role of off-shell effects in NN-scattering increases rapidly in many partial waves simultaneously. It makes the theoretical interpretation of the data rather difficult. (ii) Second, both the double scattering and the Δ-isobar excitation allow for emitting the fast nucleon in the final state without using the high-momentum component of the deuteron wave function [13,19]. A theoretical treatment of this contribution is rather nontrivial especially with respect to spin observables. As was shown in Ref. [13], it is very important to control the Δ contribution to the pd-interaction by means of independent experimental data on other basic reactions like $pp \to pn\pi^+$ in the corresponding kinematical region. In particular, it is not easy to perform such kind of control in view of the break-up data at $T_p = 1\,GeV$ [16,18]. Moreover, the spin observables in the elementary reaction $pp \to pn\pi^+$ in the Δ region were not explained in the theory of coupled $NN - \pi NN$ channels [20]. The same problem also shows up in the backward elastic pd scattering [21].

To summarize, one has to conclude that the question of the deuteron short-range structure and determination of mechanisms of high-momentum transfer in pd-interaction still attract significant experimental and theoretical efforts. It has been rather clearly demonstrated during the last years that the impulse approximation alone can not be used to extract a reliable information on the short-range structure of the deuteron due to presence of some screening effects. Therefore, special efforts should be done to separate the effects of short-range structure.

2.2 Why the suggested experiment is unique

2.2.1. A new approach to the study of the break-up process.

Screening effects arising both in the break-up and $pd \to dp$ processes can be minimized by means of using special experimental conditions of the deuteron break-up in the $pd \to pnp$ reaction. We suggest here to measure the deuteron break-up in the kinematic of quasi-elastic backward pd-scattering with the isotriplet NN-pair at low relative energy ($E_{NN} = 0 - 5\,MeV$) in the final state instead of the deuteron:

$$p + d \to (pp)(0^o) + n(180^o). \qquad (1)$$

According to theoretical estimations [22,23,24], reaction (1) provides an essentially new situation for the relative contribution of the different mechanisms in comparison with the backward elastic pd-scattering. This reaction was not investigated experimentally anywhere previously. In addition, as a first step towards the polarization experiment [1], we will measure the cross section of the reaction

$$p + d \to p(0^o) + n + p(180^o) \tag{2}$$

at low energy E_{pn} of the forward pn-pair ($E_{pn} = 0 - 5\,MeV$). In this reaction we have two different final states of the forward pn-pair: the triplet $(pn)_t$ and singlet $(np)_s$. The amplitude with the triplet pair $A(p + d \to (pn)_t + p)$ with a high accuracy is related to the amplitude of backward elastic scattering $A(pd \to dp)$ by

$$A(p + d \to (pn)_t + p) = f(k)A(p + d \to d + p), \tag{3}$$

where $k = \sqrt{E_{pn}m}$ is the relative momentum of the final pn-pair (E_{pn} is the relative energy, m is the nucleon mass) and the function $f(k)$ is defined in Refs. [25,26]. As it is shown in the next section, the amplitude for the singlet final NN-pair is the most interesting object of the deuteron break-up with respect to the problems under discussion. However, there is only a very poor experimental information available about the squared amplitude for singlet pair formation $|A(p + d \to (pn)_s + p)|^2$ obtained in indirect experiments [9,26]. Neglecting the Coulomb interaction in the final pp-pair at $E_{pp} > 1\,MeV$ one can express the amplitude of the reaction (1) through the singlet amplitude of (2) by the following isotopic relation

$$A(p + d \to (pn)_s + p) = \frac{1}{\sqrt{2}}A(p + d \to (pp)_s + n). \tag{4}$$

The relations (3,4) can be used as an independent way to obtain experimental information about the singlet pair production in reaction (2) in addition to the direct measurement of reaction (1). Therefore, the simultaneous measurement of both channels (1) and (2) of the deuteron break-up, proposed here, allows to check the compatibility of the data and adequacy of the used theoretical analysis. Up to now the process (2) was investigated experimentally only in the semiinclusive kinematics of the dp-collision in the interval of incident deuteron momenta $p_d = 3.5 - 6.5\,GeV/c$ which corresponds to the laboratory kinetic energy of incident proton $T_p = 1.046 - 2.46\,GeV$ [9]. The reaction $\vec{d}p \to pnp$ was also investigated in Ref.[27] for the two values of kinetic energy of the incident deuteron $T_d = 0.4\,GeV$ and $1.6\,GeV$. They correspond to $T_p = 0.2\,GeV$ GeV and $0.8\,GeV$, respectively in the reaction (2). According to the analysis of Ref. [26], the spin-singlet state provides about 30% of the strength in the reaction $\vec{d}p \to pnp$ at $T_d = 1.6\,GeV$ [27]. However we cannot use here the experimental data from Refs. [9,27], because the energy resolution was not high enough and there was a problem in semiinclusive experiments how to separate the elastic channel from the inelastic one at low excitation energies of the final pn-pair.

2.2.2 Unique experimental conditions

The kinematical conditions of the exclusive deuteron break-up study experiments [16,17,18] have been chosen in accordance with the quasielastic nucleon-nucleon scattering. The kinematics of the COSY experiment no. 20 is chosen completely different from the free NN-scattering. It is done in collinear kinematics with backward emission of a fast nucleon which is completely forbidden for the free NN-scattering for the nucleon at rest. This means that the initial proton provides high-momentum transfer to both nucleons of the deuteron. It also means that such a high momentum transfer process involves both nucleons of the deuteron target. There are two possibilities for such a transfer: first, multiple-interaction processes (double scattering, Δ-exchange etc.) and second, the one-nucleon exchange process (Fig. 1.a) by the nucleon strongly removed from the mass shell in the deuteron which means that a nucleon is at a short distance to its partner inside the deuteron. This last configuration can be separated if the kinematics of quasi-elastic pd-backward scattering in the reaction with formation of singlet NN- pair is used as it was shown in Refs. [22,23,24]. At large values of the relative energy E_{NN} the multiple-interaction processes are expected to be dominating and therefore can be investigated too, but mainly with aim to study the mechanisms of high-momentum transfers.

To our knowledge, the chosen kinematical conditions can be realized at present only at the ANKE facility. The other significant advantage of this experiment at COSY is the possibility to study the break-up in a wide range of incident energy from 0.5 GeV up to 2.5 GeV. It provides an opportunity to compare the data at different energies where contributions of different mechanisms change drastically (see Refs.[13,21]).

2.3 The relation to theory

A theoretical analysis of the process (1) was performed first in Ref. [22]. Recently new results were obtained in Refs. [23,24] especially devoted to the COSY experiment no. 20. The cross section of the reactions (1) and (2) can be written in the following form for the particular case of transversal polarization of beam and target

$$d\sigma_{pol} = d\sigma_0 \left(1 + p_y^p A_y^p + \frac{3}{2} P_y^d A_y^d + \frac{1}{2} P_{yy} A_y^d + \frac{3}{2} p_y^p P_y^d C_{yy} + \frac{1}{2} p_y^p P_{yy} C_{yyy}\right). \qquad (5)$$

We choose the coordinate system using the following set of orthogonal basis vectors $OX \uparrow\uparrow \mathbf{l} = \frac{1}{2}(\mathbf{k}_i + \mathbf{k}_f)$, $OY \uparrow\uparrow \mathbf{n} = [\mathbf{k}_i \times \mathbf{k}_f]$, $OZ \uparrow\uparrow \mathbf{m} = [\mathbf{l} \times \mathbf{n}]$, where $\mathbf{k}_i\,(\mathbf{k}_f)$ is the initial (final backward going) nucleon momentum in the p+d center-of-mass frame. At low E_{NN}, $k_i^2 \sim k_f^2$ and the directions of $\mathbf{m}$ and $\mathbf{k}_i - \mathbf{k}_f$ essentialy coincide. In Eq. (7) $d\sigma_0$ is the cross section with unpolarized beam and target, $\mathbf{p^p} = (p_x^p, p_y^p, p_z^p) = (0, p_y^p, 0)$ is the polarization vector of the initial proton in case of transversal polarization; $\mathbf{P^d} = (P_x^d, P_y^d, P_z^d) = (0, P_y^d, 0)$ and P_{yy}, P_{xx}, P_{zz} are the vector and tensor polarizations of the deuteron. Furthermore A_y^p, A_y^d are the vector analyzing powers of the proton and deuteron, A_{yy} is the tensor analyzing power of the deuteron, and C_{yy}, C_{yyy} are the spin-correlation parameters.

The $ONE{+}\Delta{+}SS$ model of the backward elastic pd-scattering (see Fig.1), developed in Ref.[19] and improved later in Ref.[28] with respect to the $\Delta-$ contribution, was used in Refs. [22,24] to analyze the reactions (1),(2). As it is known, in the backward elastic pd- scattering at initial energies $T_p = 0.5 - 1.5\,GeV$ the $\Delta-$mechanism gives the dominant contribution (see Fig.3) and allows to explain qualitatively the energy dependence of the cross section at $\theta_{c.m.} = 180^o$. However, there is a problem in the explanation of the tensor analyzing power T_{20} in the process $pd \to dp$ in the framework of the $ONE + \Delta + SS$ mechanisms [13]. A negative sign of the T_{20} was reproduced in Ref. [21] under some approximation for the two-loop integrals of the Δ-mechanism but the dip structure of T_{20} observed experimentally could not be explained. Uncertainties, arising from the off-shell behaviour of the $NN \rightleftharpoons \Delta N$ amplitudes, increase essentially in the $pd \to dp$ process [28]. Therefore it is of interest to find a way to suppress the $\Delta-$ contribution.

Let us discuss here qualitatively what variations of the relative contributions of the ONE, Δ and SS mechanisms are expected when coming from the elastic process $pd \to dp$ to the quasi-elastic reaction (4) with formation of the singlet pair $pd \to p(np)_s$. For this aim we define the following ratio of the amplitudes [24]

$$R \equiv \frac{|A(p+d \to p+(np)_s)|}{|f(k)A(pd \to dp)|} = \frac{|A(p+d \to p+(np)_s)|}{|A(p+d \to p+(np)_t)|}, \tag{6}$$

where relation (5) was used. There are two suppression factors for the Δ-mechanism in the reaction (1) [24]. First, assuming that the spatial parts of the singlet and triplet np-pairs at $E_{pn} = 0 - 5$ MeV are the same, one obtains from the ratio (8) the isotopic factor R^I which equals $\frac{1}{3}$ for the Δ-amplitude of the reaction (1) in Fig. 1.d,e and equals 1 for the ONE-amplitude in Fig. 1.a. As shown in [24] the same isotopic suppression factor 1/3 occurs for a broader class of diagrams including any isovector mesons in the intermediate state (Fig.2). For isosinglet mesons in the diagram of Fig.2 the isotopic factor equals 1. However, these mesons are not so important in the reactions under discussion as the isotriplet mesons. On the other hand, for the processes $p + d \to p + (pn)_t$ and $pd \to dp$ the corresponding isotopic factors equal 1 within the same diagrams with meson-nucleon rescattering. Second, there is an additional suppression factor $R^X \approx \frac{1}{2} \div \frac{1}{3}$ [24] for the Δ-mechanism arising from the difference between the spatial parts of the scattering wave functions in the singlet ^1S_o and triplet $^3S_1$ state. Approximately the same value of the spatial factor arises for the mechanism with excitation of heavier resonances N^* in the double pN-scattering instead of a Δ- excitation [24]. Therefore, the total suppression factor $R^2 = (R^I \times R^X)^2$ for the Δ mechanism in the cross section of the reaction (1) is about $\sim \frac{1}{6^2} - \frac{1}{9^2}$ with respect to the ONE mechanism.

As shown in Refs. [13,19,28], the SS mechanism is not important for the $pd \to dp$ cross section both in the Δ- region and at $T_p > 1\,GeV$ (see Fig.3). Due to mixing of the isotopic spins in the NN-scattering we are unable to extract the isotopic factor from (8). However, it was shown numerically in [24], that there are no spatial suppression factors for the SS mechanism. For this reason the SS amplitude is taken into account here.

As it follows from the above consideration, the $\Delta-$mechanism is drastically suppressed in reaction (1). The ONE mechanism dominates in the cross section of the reaction (1) in the model $ONE + \Delta + SS$ both in the Δ-interval 0.5-1.0 GeV and at $T_p > 1$ GeV (Fig.4) [22,24]. The maximal contribution of the mechanisms of double pN-scattering with excitation of heavier nucleon resonances N^* is expected at energies > 1 GeV. One may hope that these mechanisms are also not important in the reaction (1) both due to the spatial suppression factors $R^X \approx \frac{1}{2} \div \frac{1}{3}$ and the isotopic spin factor $R^I = \frac{1}{3}$ for those

N^*-isobars which are excited mainly by the isovector mesons (see Fig.2).

The influence of the SS mechanism is not negligible only in the region where the contribution by the ONE mechanism is minimal ($T_p = 0.5 - 0.8\,GeV$). The role of the SS mechanism is most important for the tensor analyzing power (Fig.5) and the spin-spin correlation parameter C_{yy} (Fig.6) at $T_p = 0.4 - 0.7\,GeV$. However in the spin averaged cross section the SS and Δ mechanisms do not fill the remarkably deep minimum caused by the ONE mechanism (Fig.7).

We note that the tensor analyzing power for the SS mechanism calculated in the framework of the spinless approximation for the pN-scattering in the region $T_p < 0.5\,GeV$ of the deuteron break-up process is very close to the T_{20} from the elastic electron scattering (Fig.8) and its behaviour is in a qualitative agreement with preliminary experimental data from TJNAF obtained recently in the interval of transferred momenta $Q = 0 - 1.36\,GeV/c$. This region of Q corresponds to the interval of initial energy $T_p = 0 - 0.5\,GeV$ in backward (quasi) elastic pd- scattering. The big bump in the T_{20} for the reaction (1) at $T_p \sim 0.6\,GeV$ (see Fig. 5), calculated in the framework of the potential model of the NN-interaction, corresponds to recent (preliminary) TJNAF data on T_{20} at the upper limit of the transferred momentum $Q = 1.3$ GeV/c [31]. There is a complete dominance of the ONE mechanism at $T_p > 0.9\,\mathrm{GeV}$ both in the spin averaged cross section (Fig.4) and in the spin observables T_{20}, C_{yy}, A_y^p , A_y^d (Figs. 5,6,9,10).

The dominance of the ONE mechanism implies that the following important properties of the process (1) with unpolarized beam and target can be tested in the proposed experiments:

(i) It allows to measure the combination of $(u(q)^2 + w(q)^2) \times |t(q', k)|^2$ at large $q, q' \sim$ 0.5GeV/c, where $u(q)$ and $w(q)$ are the S- and D-components of the deuteron wave function in momentum space. Furthemore $t(q', k)$ is the half-off-shell amplitude of pp-scattering in the $^1S_0$ state, where the momentum k is related to the relative energy of the NN-pair in the final state ($E_{NN} = k^2/m$, m is the nucleon mass). According to the calculations performed in Refs. [22,23] with the RSC and Paris potentials for the deuteron, the differential cross section for the reaction (1) is approximately a constant when the initial energy becomes larger than 1 GeV (see Fig.4). On the contrary, according to the Regge model or the quark counting rules one would expect a power decrease of the cross section [4,5]. Future polarization measurements will allow to separate the factor $|t(q', k)|^2$ from the deuteron structure $u(q)^2 + w(q)^2$.

(ii) The value $t(q', k)$ is related to the off-shell behaviour of the NN-interaction potential in the $^1S_0$ state. There is a full analogy with the deuteron vertex $d \to p + n$ which is related to the off-shell behaviour of the $^3\mathrm{S}_1 - ^3\mathrm{D}_1$ state. In particular, the amplitude $t(q', k)$ has a node at $q' \approx 0.4$ GeV/c similarly to the node of the S component of the deuteron wave function $u(q)$. Both of these nodes originate from the repulsive core in the NN-interaction potential. The node of $u(q)$ was observed only indirectly by means of very complicated measurements of the tensor analyzing power T_{20} in elastic electron-deuteron scattering and extraction of the charge formfactor of the deuteron $F_C(q)$ (see Ref.[32] and references therein). The node in the $t(q', k)$ was not yet observed experimentally. As can be seen from Fig.4, this node can manifest itself as a dip in the cross section of the reaction (1) with unpolarized beam and target. Therefore, the experiment suggested here may provide valuable information about NN-interaction in the $^1S_0$ state even in the first phase using unpolarized beam and target.

(iii) In the next step, using the polarized beam and target, one can separate the S- and D-wave components of the deuteron by measuring the tensor analyzing power T_{20}. A clear signal for dominance of the ONE mechanism will be the change of the sign of T_{20} at some incident energy in the interval $T_p = 1 - 1.5\,GeV$ (Fig.5). A nontrivial structure is expected in the vector analyzing power of the deuteron in the region of initial energies $0.4 - 0.7\,GeV$(Fig.10). The spin-spin correlation parameter calculated for the case of vector polarization of the deuteron is shown in Fig.6.

The properties (i-iii) being studied in the foreseen experiments allow us to clarify the main question discussed in the beginning: up to which values of the relative nucleon momenta q does the deuteron show the properties of a system consisting of two nucleons with frozen internal degrees of freedom which interact by means of a conventional NN-potential defined from the the NN-phase shift data?

2.4 Other physical aspects of the experiment justification

The quasielastic backward pd-scattering processes (1) and (2) contribute only by a small part to the deuteron break-up reaction at collinear geometry with backward emission of a fast nucleon. The other part of the break-up, corresponding to large values of E_{NN}, dominates the cross section and can be taken during the measurement of the processes (1) and (2) without any additional beam-time. Triggering of the data acquisition by a coincidence of the forward and backward protons provides the measurements of the E_{NN} distribution from zero to $0.6\,GeV$. There are several points to motivate such a measurement.

The first one consists in checking predictions given by the Bethe-Salpeter equation approach [33,34]. The unpolarized cross sections, tensor analyzing power and polarization transfer have been calculated especially for the kinematical conditions at ANKE implying large values of E_{NN}.

The second one arises from the phenomenon of cumulative particle production. It is well known that such production processes bear some very specific properties. One of them is an exponential form of the energy spectra of the backward emitted fast particles (protons, deuterons etc). A lot of existing experimental data give a slope parameter of the spectra close to 150 MeV with almost no dependence on the initial energy, the type of the projectiles and the mass number of the nuclear target. In spite of such a general and intriguing character of this phenomenon, no convincing and commonly accepted interpretation exists up to now. One of the early suggested explanation treats it as a manifestation of high and local excitation of the nuclear matter. This idea of excitation of few-nucleon systems (clusters) is used in the Rossendorf Collision Model

(ROC-model) [35,36]. In this semiphenomenological approach the excitation spectra of the few-nucleon systems are treated as an inherent property practically independent of type and energy of projectile. The free parameters determining these spectra are deduced by fitting some cumulative data. Such fitting performed for inclusive experimental data allowed to describe a very wide range of other inclusive experiments [35,36]. Therefore, it is of significant interest to get the exclusive data for the simplest nuclear target to clarify the level of accuracy which can be achieved by the model under such well determined conditions.

To investigate the origin of the cumulative excitation of few-nucleon systems in a microscopic approach one can use a set of Feynman graphs describing the main mechanisms of high momentum transfer to the deuteron. The model developed in Refs.[16,18,37,38] can be exploited for this aim. Some numerical results for spin averaged cross section, tensor and vector analyzing power have been obtained in Ref. [37] especially for the conditions of COSY experiment no. 20.

Since the Δ-exchange mechanism should be dominant in the $0.6 - 0.8\,GeV$ energy region, its clear manifestation is expected to be observed in form of a prominent peak in the momentum spectrum of the backward protons. Some direct indication of this effect has been already observed in the bubble chamber data on the deuteron break-up at proton energy of $1\,GeV$ [39]. A broad bump at proton momenta around $0.3\,GeV/c$ was seen in the cross sections for events taken in the $130^o - 180^o$ angular interval. A much more pronounced manifestation of the virtual Δ- exchange in the deuteron is expected in the present experiment. It can be used for direct study of the off-shell behaviour of the $NN \rightleftharpoons \Delta N$ amplitude.

3. Experimental setup: design, performance, status

The layout of the experimental setup is shown in Fig.11. The Fig. 12 presents details of the Forward (FD) (b) and Backward (BD) (a) detector systems, which are the essential parts for the present experiments. Their design, performance, and status are described in the sections 3.1 and 3.2. Section 3.3 gives some data about the target to be used for later count-rate estimates and section 3.4 concerns the data-acquisition and analysis software.

3.1 The Forward Detector system.

The boundary conditions for its design and operation are:

- Momentum and angular resolution for the forward emitted ejectiles of $< 1\%$ and around 1 mrad, respectively.
- High ejectile flux produced from the target region in the forward direction.
- Limited space as well between D2 and D3 (about 150 cm) as between the PSD and the COSY beam tube (varying between 30 and 60 cm only).

- High background level due to the proximity to the beam tube.

The resulting requests of

- good resolution of the counters ($< 1ns$) and as good as possible for the MWPC ($< 50ns$),
- horizontal and vertical space resolution of about 5 cm for the hodoscope counters and of about 1 mm for the MWPC,
- measurement of energy losses and Cherenkov radiation for background suppression and ejectile discrimination,
- minimum detector material in order to keep the multiple Coulomb scattering and the sensitivity to neutral particles low

have guided the development of the components of the forward detector system. They are discussed in the following in the standard right-handed coordinate system, the positive Z axis of which is the beam direction whereas the positive X axis is directed to the outer side of the ring and the positive Y axis points up perpendicular to the ring plane. Azimutal angles, projected to the XZ plane, are given positive (negative) for X being positive (negative), i.e. for ejectiles being emitted to the left (right) hemisphere relative to the beam direction.

3.1.1 The Forward Multiwire Proportional Chambers.

Each of the 3 chambers contains 4 planes as is shown in Fig.13: the vertical X-resolving wires, the U strips (rotated by $+18^o$ from the vertical (Y) direction), the Y-resolving wires, and the V strips (rotated by -18^o from the horizontal (X) direction). The sensitive areas, starting from the left hand side in Fig.11, are: 32 (horizontal) x 26 (vertical), 42 x 32, and 58 x 35 cm^2. From the 3 chambers in total 2304 signals from wires and 1536 from strips have to be read out. In the chamber construction the space saving design described in Ref. [40] is used. To provide the necessary stability against the high electromechanical forces, caused by the high ratio of wire length to wire spacing (1 mm), the wires are supported by dielectric foils to which they are pressed and kept in place by the strong attractive force between the wires and strips [41] as is depicted in Fig. 13. With use of 80% CF_4 and 20% i-C_4H_{10} gas mixture, the chambers provide short signals of about 20 ns length and time jitter of about 6 ns (FWHM, see Fig. 14). These data of Fig. 14 demonstrate efficiencies close to 100% even if the strobe signal length is reduced to 30 ns. The small time jitter even may allow to use the MWPC for special trigger purposes.

First measurements with 2 chambers installed at ANKE were performed in the June 1999 beam time with use of the RAL boards also used at the SD MWPC's. The obtained hit distributions gave satisfactory results on the forward ejectile flux along the strips and wires. In order to reduce the chamber operation voltages to avoid fast aging, in the recent September beam time RAL boards with lower threshold were used. The obtained results show that careful detailed studies of the individual RAL boards are necessary. These studies are being performed. After the necessary modification and tests the 2 completed chambers will be installed at ANKE in the shut-down period before the end of 1999.

3.1.2 The Forward Scintillation Counter Hodoscope.

Its horizontal structure and dimensions can be taken from Fig.12.b. The scintillators are viewed by PM tubes at the upper and lower ends. The subsequent electronics consist of constant fraction discriminators and meantimers developed in IKP and a special trigger unit developed at JINR. The counters have been tested at the laboratory and in ANKE beam times. As typical values satisfactory 30% amplitude and 350 to 500 ps time resolution (FWHM) were measured. The measured time differences between the upper and lower PMT signals yield position resolutions along the vertical direction 3.5 to 6 cm. As examples Fig. 15 shows 2 energy spectra. The lower one, taken with triggering by the pion signal from one of the side telescopes, shows a distinct peak. According to kinematics and energy loss it is attributed to deuterons from the reaction $pp \to d\pi^+$. Triggering by the hodoscope itself (upper part) yields additional strong low energy distributions which are interpreted as due to protons from the hydrogen-cluster target or scattered by the magnet.

3.1.3 The Forward Cherenkov Counter Hodoscope.

By their implementation particle identification can be improved as is necessary. Total internal reflection in rectangular radiator bars, inclined towards the ejectile directions, is used. The hodoscope layout is shown in Fig. 16. Its particle separation properties have been demonstrated by Monte Carlo simulation calculations [42] and a test measurement [43] at the ITEP accelerator using 1.5 GeV/c beam containing protons and pions.

The hodoscope counters were tested in the June 1999 beam time with 1 GeV beam energy. For the corresponding forward ejectiles they show performance close to that expected from the simulations and thus are ready for the experiments [44,45] for which they are essential. Fine tuning of the high voltage and of the inclination angle have to be done for the ejectile momenta on the individual counters under the conditions of each experiment.

3.1.4 Momentum acceptance and resolution of the Forward Detector.

The angular-momentum acceptance of the FD is shown in Fig.17. Its presents the momentum P_{ejec} of the ejectile against the projection Θ_{xz} of the polar angle Θ on to the medium plane XZ of ANKE. It is seen that the acceptance region (shaded area) is centered around $\Theta_{xz} = 0°$ and extends from about $-10°$ to $+10°$. The solid angle Ω as a function of P_{ejec} reaches its maximum of about $38\,msr$ for $\Theta_{xy} = 0°$. The curves in Fig.17 show the kinematical locus for protons and deuterons from several processes of interest.

The label $pd \to (pp)n$ denotes the deuteron break-up $p + d \to (pp)_f + n_b$ with backward emission of the neutron n_b and forward emission of proton pair $(pp)_f$ with zero relative momentum. It is seen that the protons from such a process come into the FD acceptance region at the polar angle close to zero. The same conclusion takes place evidently for the process $p+d \to (pn)_f + p_b$ with backward emission of the proton p_b and forward emission of the proton-neutron pair $(pn)_f$ with zero relative momentum.

Fig.18 (lower part) demonstrates the expected momentum resolution of the FD. It is $(0.5 - 0.6)\%$ for the proton momentum p in the $(0.8 - 2.2)\,GeV/c$ range. The accuracy of the angle Θ_{xz} determination (upper left) in the same range is $(1 - 3.4)\,mrad$ and $(0.25 - 0.5)\,mrad$ for Θ_{yz} (upper right). The procedure of the calculation is described in Ref.[46].

3.2 The Backward Detector system.

The expected conditions of the BD operation are relatively favourable: the ejectile flux produced in the backward direction is rather low, and the deflection angle of charged particle trajectories in the D1 is sufficiently large to use it as an analyzing magnet for charged backward going particles in the $(200 - 600)\,MeV/c$ momentum range (see Figs. 11 and 12.a.) That has determined the concept of the BD: drift chambers triggered by a scintillation counter hodoscope.

3.2.1 The Backward Drift Chambers.

Each of the 3 chambers contains two independent modules: one to measure the X coordinate of tracks and the other for the Y coordinate. Each module contains two sensitive planes placed inside a common gas volume. The drift cells of these planes are shifted relative to each other by half the drift cell length of $2\,cm$ to get rid of the left-right ambiguity.

The required sensitive area of $240 \times 480\,mm^2$ size is covered by 11 cells in the X plane and 5 cells in the Y plane. That gives a total number $[(11 + 5) * 2] * 3 = 96$ of drift channels.

The chambers were tested in the laboratory with a collimated $^{90}Sr\,\beta$ –source. The drift velocity and space resolution measurements have been carried out with use of the shadow method. The time difference between the signals from a scintillator and one of the anode wires allows to deduce the drift velocity, the space resolution and the chamber efficiency. For absolute calibration the measured drift time difference to one anode wire can be used, which results from shifting the collimator from one field-forming wire to the next. The dips in the measured time distributions result as shadows by the field-forming wires (see Fig. 19). The space resolution is determined as $\sigma = 75\,\mu m$. The obtained performance completely meets the requirements of operation at ANKE.

The chambers will be mounted at the ANKE position in the Christmas shut-down time.

3.2.2 The Backward Scintillation Counter Hodoscope.

Its layout can be seen from Fig.12.a (left). There are 8 counters in each of two planes. The scintillator strips are viewed by PMTs from the both sides. The hodoscope was tested with cosmics and under beam conditions. The counters reveal proper performances: $25\% - 28\%$ FWHM in the amplitude distributions and $350\,ps$ (FWHM) time resolution for minimum ionizing particles. That provides separation of backward pions and protons already by the counters (see Fig.20). The time difference of the signals from the pairs of the PMTs on each scintillator yields the vertical hit coordinate in the hodoscope (see Fig.21).

3.2.3 BD Momentum acceptance and resolution.

Angular-momentum acceptance (in the form used before for the FD) is shown in Fig.22. The lines denote kinematical locus for protons from the $pd \to dp$ process and pions from the $pd \to {}^3H\pi^+$ reaction. It is seen that the high-momentum part of the backward proton spectrum from the deuteron break-up is accepted by the BD system. High-momentum pions from the $pd-$interaction can be also recorded. The angular acceptance $\Theta_{xz} = 180^{+4.0}_{-5.0}$ degree is provided at a solid angle acceptance of $20 - 25\,msr$.

The simulation of the momentum resolution gives σ_p/p in the range of $(0.3 - 0.6)\%$ and the RMS of the azimutal angle in the range $(3 - 8)\,mrad$.

3.3. The Target.

For the experiments with unpolarized deuterons the deuterium cluster target, developed by Universität Münster, will be used. It is similar to the target used in the COSY-11 experiments [47]. The target will yield a cluster beam 15 mm wide in COSY-beam direction and 6 mm wide perpendicular to it. With a target density up to 10^{14} atoms $/cm^2$ will provide luminosities up to $10^{30}cm^{-2} \cdot s^{-1}$. The count rates estimated below are based on this number. The target was installed at ANKE in August 99 and tested in the September run.

3.4 The data acquisition and data handling software

The data acquision software for the experiment is based on the common DAQ software of ANKE. The part of it concerning the hodoscopes and forward multiwire proportional chambers was already tested during the beam runs.

The data handling software is based on the code system developed for processing and data analysis of the side detector data. It has been used in the momentum calibration of the side detector using the data from the $pp \to d\pi^+$ reaction. The developed system allowed to get a systematic uncertainty $\Delta p_\pi/p_\pi < 4 \cdot 10^{-3}$ in the momentum range of interest. The corresponding missing mass uncertainty obtained was $< 0.3\,MeV$. A similar procedure will be used for data handling of the processes under consideration. Some more details concerning that can be found in Ref. [48].

4. Procedure of the measurements.

4.1 Observables to be measured.

In accordance with the physical justification given in Sec.2 we intend to measure:

a. The absolute value of the differential cross section $d\sigma/dp_1 d\Omega_1 d\Omega_2$ of the process (1)

$$p + d \to (p_1 + p_2)_{forward} + n_{backward}$$

at small relative energies E_{pp} of the proton pair in the range $E_{pp} = (0-5)\,MeV$, in the collinear geometry and at several values of the incident energy T_p in the range $(0.6 - 2.0)\,GeV$.

The immediate aim of the measurement is:

- to compare the absolute value of the cross sections with the theoretical predictions [22,23,24,28];
- to establish the existence of a minimum in the T_p-dependence of the cross section expected by the theory near $T_p = 0.75\,GeV$. Observation of such minimum would be a direct evidence of the node in the momentum dependence of the half-off-shell amplitude of the *pp*-scattering predicted by the potential approach of the interaction;
- to establish the existence of a plateau in the energy dependence of the cross section expected by the theory in the $(1.2 - 2.0)\,GeV$ range.

b. The absolute value of the differential cross section $d\sigma/dp_1 d\Omega_1 d\Omega_2$ of the process (2)

$$p + d \to (p_1 + n)_{forward} + p_{2backward}$$

at small relative energies E_{np} of the forward *np*-pair in the range $E_{np} = (0-5)\,MeV$, in the collinear geometry and at several values of the incident energy T_p in the range $(0.6 - 2.0)\,GeV$.

The aim of the measurement is to check consistency of the cross section values obtained for these processes **a** and **b** and the known values of the backward elastic *pd*-scattering, predicted by the theory [19–22].

It is of interest to perform the measurements at least for two values of T_p, for example at $0.6\,GeV$ and $1.0\,GeV$, where the contribution of different mechanisms changes essentially.

c. The absolute value of the differential cross section $d\sigma/d\Omega_1 dp_2 d\Omega_2$ of the process **b** in the collinear geometry, in the range of the backward proton momentum $p_2 > 250\,MeV/c$ at the energies $T_p = 0.5\,GeV$, $0.7\,GeV$, $1\,GeV$, $1.5\,GeV$, $2\,GeV$.

The aim of the measurement is:

– to compare the data with predictions of the theory [37,38] and to determine the accuracy of the approach based on taking into account the three main mechanisms — ONE, Δ-isobar excitation and rescattering;

– to get a direct information for adjusting the parameters of the semiphenomenologic ROC-model [35,36];

– to search for a broad peak in the p_2-spectrum caused by the Δ virtual rescattering mechanism. At energies of dominance of this mechanism ($T_p = 0.6 - 0.8\,GeV$) one expects to observe its clear manifestation. The T_p-dependence of the spectra is of interest since the contribution of the Δ-mechanism changes drastically in the $(0.6 - 1.5)\,GeV$ energy interval. The analysis of data may give a direct information on the off-shell behaviour of the $\Delta N \rightarrow NN$ amplitude.

4.2 Luminosity monitoring and calibrations.

For all reactions on the Hydrogen Target, the pp elastic scattering will be used as a luminosity monitor. On a deuterium target the quasi-elastic pp scattering can be used for the same purpose.

In all cases only one of the two scattered protons is within the acceptance of the Forward Detectors. The second proton will depending on the beam energy be identified in an angular region from 80 to 90 degree. Horizontal angle and energy of this proton are measured by two layers of silicon-strip detectors 300μ and 5000μ thick. The proton is identified by a dE/E measurement. Its horizontal angle with respect to the target is fixed by the two layers.

The reactions $p + p \rightarrow d + \pi^+$ and $p + d \rightarrow {}^3H + \pi^+$ will be used also for calibrations.

4.3 Count rate.

The cross sections of the process (1) are calculated in the framework of the theory [23,24] (see Fig.7). The corresponding energy dependence of the count rates is given in Fig.23 under the assumption of 100% detector efficiency. Since changes of the D2 magnetic field and its position seem necessary at $T_p = 1.20\,GeV$ and $1.75\,GeV$, the acceptance changes at these energies. This causes the jumps in the energy dependence of the count rate. A similar procedure simulated the count rate of the process (2) at small relative energies E_{np} of the forward np-pair (see Fig.24). For the wide range of larger E_{np}, a different theoretical approach [37,38] can be used. However, the simulation requires the use of the threefold differential cross sections in a wide energy range, which are not available at present. Therefore, we used for this aim the event-generator based on the ROC-model [35,36]. We could verify the applicability of the model for describing the deuteron break-up under conditions of interest by comparing the results of the calculations with existing experimental data at $1\,GeV$. These data have been obtained with the hydrogen bubble chamber (HBC) exposed to a $3.3\,GeV/c$ deuteron beam [49]. The 4π-geometry conditions and the reliable separation of all main channels of the pd-interaction in these studies provide a proper event-generator for the GEANT simulation in the same form as the ROC-model does. We observed a good agreement between the results of the ROC-model and HBC experimental data [50]. An example of such comparison can be seen in Fig.25. This agreement enables us to use the ROC-model for simulation of the break-up process and the accompanying background processes at $2.5\,GeV$ energy [51]. At $1\,GeV$ we used for the event-generator the HBC data immediately [50]. The expected count rates at $1\,GeV$ are presented in the following table:

	Counting rates (s^{-1}) for 100% detector efficiency					
$pd \to \cdots$	BD		FD		BD	$*\ FD$
ppn(dir)	(p)	8	(p)	$0.93 \cdot 10^3$	$(p*p)$	1.2
ppn(cex)	(p)	12	(p)	—		—
pd	(p)	0.4	(p)	$1.70 \cdot 10^3$		—
	(d)	–	(c)	2		—
$ppn\pi^\circ$	(p)	1.8	(p)	$0.61 \cdot 10^3$	$(p*p)$	0.05
$pnn\pi^+$	(π^+)	10	(p)	$0.66 \cdot 10^3$	$(\pi^+ * p)$	0.4
	(p)	0.3	(π^+)	$0.10 \cdot 10^3$	$(p * \pi^+)$	$\ll 1$
total		32.5		$4.0 \cdot 10^3$		1.65

For $2.5\,GeV$ energy the total FD-count rate is calculated as $6.5 \cdot 10^3\,s^{-1}$ and the coincidence $BD * FD$ count rate as about $0.4\,s^{-1}$[51].

These values should be considered only as an estimation of the expected rates, appropriate for planning the experiments.

4.4 Triggering.

The trigger for study the process (2) will be realized by coincidence of the signals from FD and BD.

Triggering of the process (1) will be done by recording two protons in the FD. We intend to use as a trigger on double-energy-loss event in the hodoscope in a single counter or in two different counters. A special trigger unit, under development at JINR, will be used to select such event.

4.5 Identification of the process.

Main criterion for the process identification is the missing-mass criterion. Measurement of the three-momentum of two protons allows to determine the missing-mass which is the neutron mass for the envisaged processes.The missing-mass spectrum expected in the framework of the ROC-model for measurement of forward and backward protons is shown in Fig.26 [51,52]. The peak at the neutron mass position should be clearly visible and separated from the background. The RMS of the missing mass distribution for two forward protons is expected equal to $11\,MeV$.

For the events in the peak region the relative kinetic energy E_{NN} of the NN-pair can be found, since kinematics of each event is completely determined. For the process (1), the energy E_{pp} can be expressed at its small values as:

$$E_{pp} = m\beta^2 x^2 + (m/4)(\beta^2/(1-\beta^2))\vartheta_{pp}{}^2,$$

where β is an average velocity of the both protons and ϑ_{pp} is the angle between the in emission directions of the protons. Furthermore $x = a/p$ is a measure of the proton momentum difference: $p_1 = p\,(1+x)\,,\;\; p_2 = p\,(1-x)$. Then under assumption of independence of the x and ϑ error one gets:

$$\sigma_x(E_{pp}) = \frac{\sqrt{2}\,\beta^2\,x\sigma(p)}{p} \sim \sqrt{E}_{pp}\ , \quad and$$

$$\sigma_\vartheta(E_{pp}) = \frac{m}{\sqrt{2}}\,\frac{\beta^2}{1-\beta^2}\,\vartheta\,\sigma(\alpha) \sim \sqrt{E}_{pp}\ ,$$

where $\sigma(p)/p$ is the relative error in the momentum measurement and $\sigma(\alpha)$ is the error of the proton ejection angle measurement. The expected values already have been given in Fig. 18.

More accurate calculations, taking into account the correlation between p and ϑ, were done by Monte-Carlo calculations with use of the GEANT code to simulate the process and to reconstruct the three-momentum of tracks. The results calculated for 5 values of E_{pp}, are given in Fig. 27 together with the curve calculated from $\sigma(E_{pp}) = (\sigma_x^2 + \sigma_\vartheta^2)^{1/2}$ $\sim \sqrt{E_{pp}}$. This curve has lies slightly higher. However, the fit to the 5 calculated points confirms the $\sqrt{E_{pp}}$ dependence and shows that the analytic approximation can be used for further estimates. The data of Fig. 27 confirm the possibility to achieve the needed accuracy in the E_{pp} measurement.

4.6 Background.

The accidental background count rate is expected as insignificant because of the low count rate and the high time resolution. In the case of the process (1) one gets

$$n_{cc} = \Delta t \cdot (n_f)^2 = 10^{-9}s \cdot (6.5 \cdot 10^3 s^{-1})^2 = 0.04\,s^{-1},$$

which is less than the expected rate of the effect (see Fig.23). After use of the missing-mass criterion this background should be negligible.

The only physical process producing the nucleon pairs in collinear geometry and small relative momenta at energy close to $1\,GeV$ with comparable intensity is the pion production

$$p + d \rightarrow (p+p) + N + \pi \quad , \quad p + p \rightarrow (p+p) + \pi.$$

However, as it was discussed above, this background can be separated by the missing-mass criterion.

5. Beam time request.

In summary, we apply for the following beam time:

1. **One week** in February 2000.
   Beam energy: 0.5, 2.0 GeV.
   Intensity: $> 5 \cdot 10^9$ protons in the ring.
   Target: cluster target (hydrogen and deuterium).
   Goals of this beam time are:

   — T_p=0.5 GeV, ANKE magnet D2 deflection angle $\alpha = 10.6^o$ and B=0.86 Tesla, hydrogen cluster target

   — rough tuning of the FD, BD and Luminosity Monitors (LM)

   — with use of known SD efficiency for $pp \to \pi + X$ beam and target optimization to achieve luminosity $> 5 \cdot 10^{29} cm^{-1} \cdot s^{-1}$ and target **ON/OFF** count rate 10, (to allow this: on-line presentation of FD, SD, BD, LM count rates and spectra, of FD trajectories to fix origin of background events)

   — fine tuning of FD, BD, FD$*$LM ($pp \to pp$).
   Total time needed: 3 days.

   — T_p=2.0 GeV, ANKE magnet D2 deflection angle $\alpha = 7.4^o$ and B=1.57 Tesla (as for ω production [45]),
   hydrogen (deuterium) cluster target

   — beam optimization as above

   — fine tuning FD Cherenkov's (inclination angles, HV)

   — fine tuning FD$*$LM and coincidences of FD and Spectator detector (FD$*$SpecD [45])

   — optimization of proton-deuteron discrimination by the FD Cherenkov's

   — test measurement with deuterium cluster target and FD$*$LM.
   Total time needed: 4 days.

2. **One week** in April–June 2000 for tuning of the complete setup (FD and BD, after analysis of the data from the February beam-time)).
   Beam energy: 0.5 GeV, 1.0 GeV.
   Intensity: $5 \cdot 10^{10}$ protons in the ring (not less than 10^{10}).
   Target: H_2 and D_2 cluster target.
   Goals of this beam time are:

— Tuning of the time delays to provide $FD{*}BD$ coincidences and a proper timing for the DAQ system.

— Tuning of the double energy-loss trigger unit for the identification of events where two protons hit a single scintillator of the FD.

— Adjustment of the high-voltage, thresholds and delays for the BD drift chambers (6 modules, 96 TDC channels). Collection of data sets with a sufficient number of tracks to obtain the drift characteristics of the chamber cells.

— Study of conditions for recording the calibration processes, data taking for preliminary calibrations including absolute calibration of the luminosity monitors.

— First data taking for count rate estimates in the following production beam time. The data will also be used for the development of data-analysis software to reconstruct the full kinematics of the recorded events.

3. **One week** in the second half of the 2000 for data taking (after analysis of the first beam time).
Target: D_2 cluster target.
Schedule for the measurements:
Two days are foreseen for final tuning and calibration procedures, 1 day of beam development for 5 beam energies, 20 hours to check of the setup (4 hours for each energy) and about 3 days for collecting statistics shown in the following table:

T_0, GeV	$\varepsilon * n, \mathrm{s}^{-1}$	t_{stat}, h	N
0.5	0.075	15	$4 \cdot 10^3$
0.7	0.010	30	$1 \cdot 10^3$
1.0	0.075	15	$4 \cdot 10^3$
1.5	0.160	7	$4 \cdot 10^3$
2.0	0.115	10	$4 \cdot 10^3$

Here n denotes the rate of particles hitting the forward counters (see Fig. 23), ε - the total detection efficiency ($\varepsilon = 0.5$), t_{stat} - the time for taking statistics and N - the total number of recorded events (two protons in the forward counters).

Simultaneously, to the measurement of two-proton forward events, backward-forward coincidences will be recorded with ~ 5 times higher rates due to the higher cross sections.

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