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F.Lehar*

CURRENT EXPERIMENTS USING POLARIZED BEAMS OF THE **JINR LHE** ACCELERATOR COMPLEX

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*DAPNIA, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France

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The present review is devoted to the spin-dependent experiments carried out or prepared at the JINR LHE Synchrocyclotron. The acceleration of polarized deuterons, and experiments using the internal targets, the beam axtraction and the polarimetry are briefly described. Then, representative experiments using either the extracted deuteron beam or secondary beams of polarized nucleons produced by polarized deuterons are treated.

Three current experiments: «DELTA-SIGMA», «DELTA» and «*pp*-SINGLET», require the polarized nucleon beams in conjunction with the Dubna polarized proton target. Already available $\Delta\sigma_L(np)$ results from the first experiment show unexpected energy dependence. Experiment «DELTA» should investigate the nucleon strangeness. The aim of the third experiment is to study a possible resonant behavior of the spin-singlet *pp* scattering amplitude.

For all other Dubna experiments unpolarized nucleon or nuclei targets are used. The polarized deuteron beam allows determining spin-dependent observable necessary for understanding the deuteron structure, as well as the nucleon substructure. One part of investigations concerns deuteron break-up reactions and deuteron proton backward elastic scattering. A considerable amount of data was obtained in this domain. Another part is dedicated to the measurements of the same spin-dependent observable in a «cumulative» region. Interesting results were obtained for proton or pion productions in inclusive and semi-inclusive measurements. In the field of inelastic deuteron reactions, the analyzing power measurements were performed in the region covering Roper resonances. Many existing models are in disagreement with observed momentum dependences of different results.

Finally, the proton-carbon analyzing power measurements extended the momentum region of rescattering observables. Some inclusive Dubna results are compared to exclusive Saclay data, and to lepton-deuteron measurements. Most of the JINR LHE experiments are carried out within the framework of a large international collaboration.

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This review is dedicated to the memory of Academician A.M.Baldin, who often declared that Spin Physics is even more important than the Nuclotron.

INTRODUCTION

The spin dependent experiments performed or accepted at the JINR LHE Synchrophasotron-Nuclotron Accelerator Complex are reviewed. Vector and/or tensor polarized deuteron beams, with vertical quantization axis are often directly used. This axis remains practically fixed, since the deuteron magnetic momentum is small. Break-up of vector polarized deutrons produces vertically polarized neutrons and protons. Due to a large anomalous momentum of nucleons, its polarization direction along any base space vector may be obtained by rotation or precession of nucleon spins in magnetic fields.

I recall that the responsible person for the SPIN PHYSICS PROGRAM in LHE (Program Number 0941) was Academician A.M. Baldin up to April 2001.

Most of LHE experiments use unpolarized LH_2, CH_2 or nuclei targets in conjunction with the extracted polarized beams. Several important JINR results (V.A.Nikitin et al.) were obtained using internal targets. In some investigations the extracted polarized beam and the polarized proton target (PPT) are needed. The polarized deuteron target (PDT) in Dubna could be used in near future. It is also possible to construct internal polarized targets. In addition to a polarized jet or a cell target a polarizable thin foil, even scintillating, was developped at PSI (S.Mango et al., E.Bunyatova, Yu.Kisselev). This kind of target was never used in an experiment, but may be interesting for particle physics, as well as for heavy-ion accelerators.

1. POLARIZED BEAM AND POLARIMETRY

The Nuclotron beam is still unpolarized and the development of the beam polarization is foreseen. Only the Synchrophasotron provides polarized deuteron beams now. Vector and tensor polarized deuterons from the ion source POLARIS (Anischenko et al., 1983) are accelerated in the linear accelerator, reach 10 MeV, and then are injected into the main ring. The responsible person is Yu.K.Pilipenko, which was a leader of the polarized deuteron beam construction.

To measure the deuteron beam polarization before injection, semiconductor detector systems were installed behind the linac. Deuterons hit a gaseous ^4He target and the left-right asymmetry in the reaction $d + {}^4He \to d + {}^4He$

was measured ($\theta_{lab}(d) = 126°$, $\theta_{lab}(^4He) = 15°$) to determine the vector polarization. From the asymmetry in the stripping reaction $d + ^3He \to p + ^4He$ the tensor polarization can be determined. This polarimeter was dismounted, but probably will be needed for the Nuclotron development.

A recoil particle polarimeter installed inside the Synchrophasotron ring also existed. It was used to determine the vector polarization from the measured left-right proton asymmetry in the elastic *dp* scattering. A thin polyethylene target foil was inserted in the internal beam. Such a polarimeter may again be useful for Nuclotron.

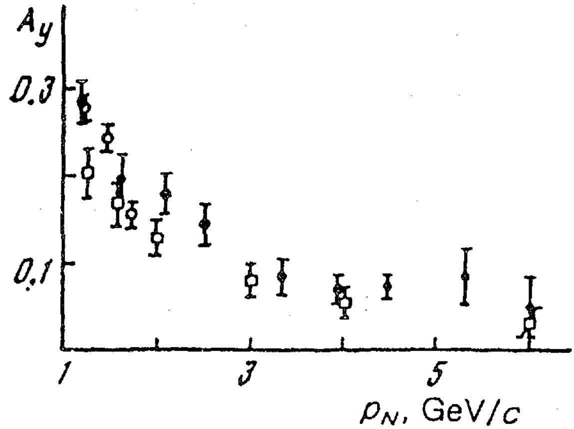

Fig. 1a. Vector analyzing power of elastic $d \uparrow p$ scattering as a function of momentum (per nucleon) of the beam: • - Avdeichikov et al. 1989, o - Alberi et al. 1982, open squares - calculation using equation (1.1).

Several experiments were performed at this polarimeter. As an example (Avdeischikov et al., 1989), the vector analyzing power for the elastic *dp* and *dd* scattering in the momentum interval from 2.38 to 10 GeV/c and for the inelastic reaction $d + C \to p + X$ at 2.38 GeV/c was measured. For elastic processes the $-t$ interval was from 0.005 to 0.054 (GeV/c)^2. In the inelastic interactions protons were recorded at the laboratory angles 75° and 120° in the energy interval 40-300 MeV. Figure 1a shows A_y at $-t = 0.025$ (GeV/c)^2 as a function of deuteron momentum per nucleon. The momentum dependence can be described in generalized Glauber-Sitnenko model by the approximate formula (Alberi et al., (1982))

$$A_y^{dp}(t,s) = 1/3(A_{oono}^{pp}(t,s) + A_{oono}^{np}(t,s)) \ . \qquad (1.1)$$

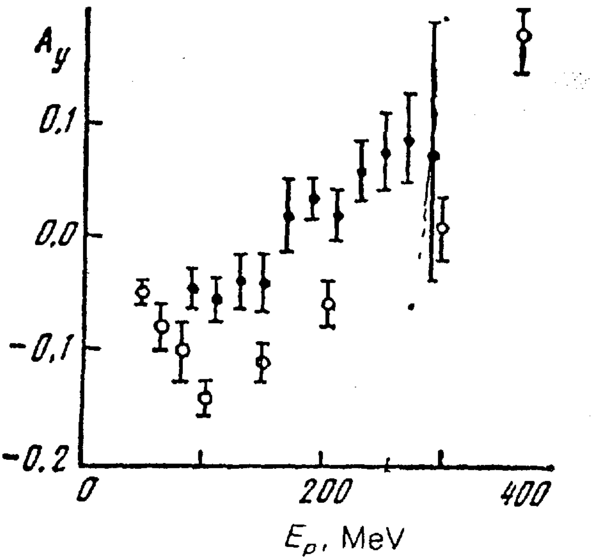

Fig. 1b. Analyzing power as a function of the kinetic energy of the detected protons at angle 75° for $d\uparrow C \rightarrow pX$ (• – Avdeichhikov et al., 1989) and $p\uparrow C \rightarrow pX$ (∘ – Brody et al., 1981).

Equation (1.1) is satisfied within errors and gives an indirect confirmation of the P_d preservation during the acceleration (see below).

Figure 1b shows A_y for $d + C \rightarrow p + X$ at 2.38 GeV/c and at 75° as a function of the detected proton energy. The Dubna data are compared with the analyzing power data from $p+C \rightarrow p+X$ at 1.49 GeV/c. No quantitative models for an explanation of the difference exist. A qualitative conclusion can be drawn that at low energy of secondary protons the role of rescattering of nucleons in $d + C$ reaction is important.

Note that one of the first experiments using the extracted vector polarized deuteron beam in Dubna was the measurement $dp \rightarrow ppn$ break-up reaction at 3.34 GeV/c in the liquid hydrogen bubble chamber (Glagolev et al., 1988). The pp and np elastic scattering analyzing powers, measured at the ANL-ZGS and at Saturne II were used in order to deduce the beam polarization.

The slow extraction of the beam into different beam lines gave the possibility to perform fast detectors. The average intensity of the existing polarized beams turns around 3×10^9 deuterons/burst. The polarization value is checked by two kinds of polarimeters. Any of them measure asymmetries and need a knowledge of corresponding analyzing powers.

In the first one, the *dp* elastic scattering asymmetry is measured by the two-arms magnetic spectometer ALPHA at the deuteron kinetic energy of 1.6 GeV (Ableev et al. 1991). At this energy, the vector and tensor *dp* analyzing power angular distributions are well known from the Saturne II data and are applied to the measured asymmetries. The scattering angle is fixed close to the maximal values of the analyzing powers, respectively.

The second method consists of the asymmetry measurement in the quasi-elastic *pp* scattering, considering the deuteron as a weakly bound proton and neutron. This method, applied at the 1.6 GeV deuteron energy, uses $A_{oono}(pp)$ data, accurately measured at LAMPF and at Saturne II. This polarimeter was constructed by the Gatchina group and the responsible person was A.N.Prokofiev (refs. Azhgirey et al., 1996, 1998).

The results of both methods are in excellent agreement. The second method provides a continuous check of a possible $P(d)$ fluctuation within the data acquisition period. On the other hand, such a polarimeter checks the vector polarization only and is used in experiments with polarized nucleons.

Here the question arises again about the absence of depolarizing resonances in the deuteron acceleration procedure over the entire Synchrophasotron energy region. Only in this case $P(d)$ is independent on energy and it is sufficient to determine it at one energy only. Theory fixed the first depolarizing resonance at 11.4 GeV deuteron energy, i.e. above the Synchrophasotron upper limit. It may occur close to the highest planned Nuclotron energy. Per analogy with proton accelerators, it is expected to be narrow. The beam depolarization, due to other possible instrumental sources, may be measured by the so called "deceleration method". It consists in two asymmetry measurements at the same low momentum (e.g. 3 GeV/c). The first measurement is carried out, when the deuteron beam is extracted, reaching 3 GeV/c. Then the beam is accelerated up to 9 GeV/c, then decelerated down to 3 GeV/c and extracted. The difference of the two asymmetries reveals a possible beam depolarization (Ableev et al., 1991).

At the Synchrophasotron, the ratio of the vector polarization values, obtained with these two beams, turned out to be constant within 4 %. One concludes that no appreciable depolarizing effects exist up to 9 GeV/c. It will be necessary to provide the same test for Nuclotron.

The deceleration method was developped at Saturne II (1985) for accelerated polarized protons, but it was too expensive to construct a slow extraction for the decelerated beam. During the deceleration, protons were extracted within few μsec only and the measurements were time-consuming. Moreover, the experiment with protons must be repeated for any maximal energy used, since many depolarizing resonances occur.

The machine experts in Dubna constructed the slow extraction during the deceleration very succesfully and the JINR results are accurate (Ableev et al., 1991). Figure 1c compares the vector and tensor analyzing power data (A_y and A_{yy} $-t$ dependence) at 3 GeV/c measured in Dubna and at Saturne II. The data are in excellent agreement.

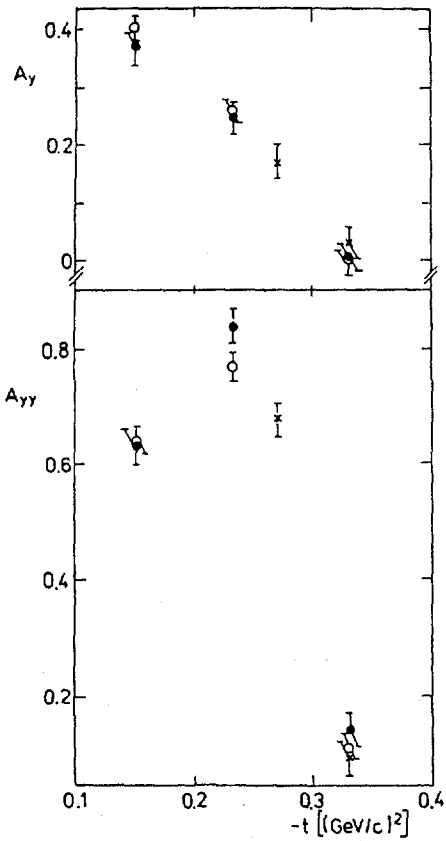

Fig. 1c. Tensor analyzing power A_y and A_{yy} vs four-momentum transfer. The Dubna data (crosses) are compared with the ones of Saclay.

The deceleration method is to be considered as a powerful polarimetry tool. In principle the method is also relative, but it considerably reduces a systematic error. Today, this method is often used at other accelerators (e.g. at COSY).

The polarimeter POMME, constructed in Saclay, has been installed in LHE. The responsible person for the polarimeter reconstruction in LHE is N.M. Piskunov. The measurement of the analyzing powers for the reaction $p + CH_2$ at $P(p) = 3 - 6$ GeV/c started.

2. EXPERIMENTS USING POLARIZED BEAM AND TARGET

In this section the three experiments using polarized beams of nucleons in conjunction with the polarized proton target (PPT) are treated. A large Argonne-Saclay PPT, 20 cm long and 3 cm in diameter, was transported into Dubna and reconstructed in the LNP during 1994 by Russian, Ukrainian and French experts as a "movable polarized target" (MPT) (Refs. Bazhanov et al., 1996, 1998). It was installed in the Synchrophasotron beam line and used in the first experiment in March 1995. During 1996 and 1997 a new polarizing solenoid for the PPT was constructed in LHE (Anischenko et al., 1998). Only the target polarization in the longitudinal direction could be obtained. The MPT is to be completed by the vertical superconducting holding coils, constructed in Kharkov and tested recently in Dubna. The MPT may work using hydrogenous as well as deuterated polarizable compounds, including ^6LiD. It is operated by the international "polarized target group" from several laboratories, under the responsibility of Yu.A.Usov.

Note that the PPT can be considered as one of the "basic facilites" in this institute, and the JINR cheef-ingeneer I.Meshkov should take this fact into account. From his periodical reports the members of the JINR Scientific Council will soon understand, how this operationnel powerful tool remains unexploited. I would like to stress that a major part of LHE experiments, enumerated in Sections 3 and 5, using unpolarized proton or deuteron targets, could be carried out with the MPT. In this case, existing results will appear as by-products of possible experiments.

2a. Experiment "DELTA SIGMA"

The measurements were carried out within the nucleon-nucleon experimental program which started in 1995. The aim of the program is to extend studies of *np* spin-dependent interactions above 1.1 GeV. The responsible person for this experiment is V.I.Sharov.

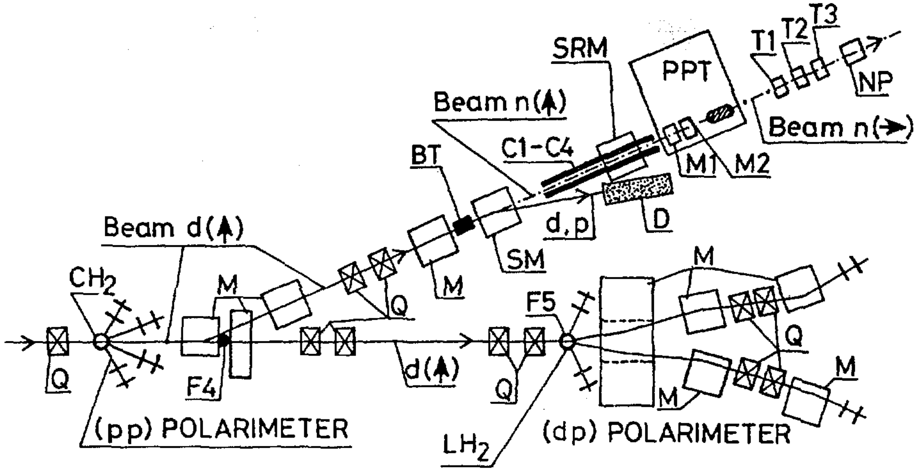

Fig. 2a. The experimental "DELTA SIGMA" set-up.

The nucleon-nucleon (NN) total cross section differences $\Delta\sigma_L$ and $\Delta\sigma_T$ together with the spin-average total cross section σ_{0tot} are measured in pure inclusive transmission experiments. They are linearly related with three non-vanishing imaginary parts of the NN forward scattering amplitudes via optical theorems. They check predictions of available dynamic models and provide an important contribution to databases of phenomenological analyses. From the measured data it is possible to deduce the $\Delta\sigma_{L,T}$ nucleon-nucleon isosinglet ($I = 0$) parts using the existing pp (isotriplet $I = 1$) results.

The general expression of the total cross section for a polarized nucleon beam transmitted through a PPT, with arbitrary directions of beam and target polarizations, $\vec{P}_B$ and $\vec{P}_T$, respectively, was first deduced by Bilenky and Ryndin (1963) and independently by Phillips (1963). Taking into account fundamental conservation laws, it is written in the form :

$$\sigma_{tot} = \sigma_{0tot} + \sigma_{1tot}(\vec{P}_B, \vec{P}_T) + \sigma_{2tot}(\vec{P}_B, \vec{k})(\vec{P}_T, \vec{k}), \tag{2.1}$$

where $\vec{k}$ is a unit vector in the direction of the beam momentum. The term σ_{0tot} is the total cross section for unpolarized particles, σ_{1tot}, σ_{2tot} are the spin-dependent contributions. They are related to the measurable observables $\Delta\sigma_T$ and $\Delta\sigma_L$ by :

$$-\Delta\sigma_T = 2\sigma_{1tot}, \tag{2.2}$$

$$-\Delta\sigma_L = 2(\sigma_{1tot} + \sigma_{2tot}), \tag{2.3}$$

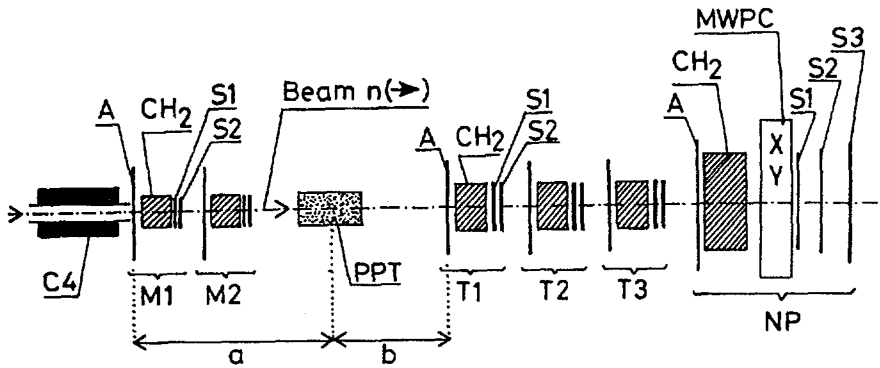

Fig. 2b. The set of dedicated neutron detectors. A - veto counters, S - coincidence counters.

called "total cross section differences". The negative signs for $\Delta\sigma_T$ and $\Delta\sigma_L$ in equations (2.2) and (2.3) correspond to the usual, although unjustified, convention in the literature. The total cross section differences are measured with either parallel or antiparallel beam and target polarization directions. Polarization vectors are transversally oriented with respect to the beam direction for $\Delta\sigma_T$ measurements and longitudinally oriented for $\Delta\sigma_L$ experiments.

Only $\Delta\sigma_L$ measurements were performed in Dubna. The free polarized neutron beam for this experiment was produced by break-up of accelerated polarized deuterons. The maximal neutron beam energy is 3.7 GeV. The $\vec{P}_B$ direction at the Synchrophasotron could be reversed every cycle of the accelerator, the $\vec{P}_T$ direction is reversed ones per few hours.

The experimental set-up is shown in Fig. 2a. The neutron beam was collimated and its vertical polarization was rotated in the longitudinal direction by magnetic field. A set of dedicated neutron detectors (Fig. 2b) with corresponding electronics and data acquisition system were performed. At the beginning of 1995, the first three $\Delta\sigma_L(np)$ data points were successfully measured at the central energies 1.19, 2.49 and 3.65 GeV (Adiasevich et al., 1996) They were completed in 1997 by new measurements at 1.59, 1.79 and 2.20 GeV (Sharov et al., 2000). The measured data are shown in Fig. 3, where they are compared with the existing free-neutron data from other laboratories.

For the first time $\Delta\sigma_L(pn)$ results from 0.51 to 5.1 GeV were deduced in 1981 from the $\Delta\sigma_L(pd)$ and $\Delta\sigma_L(pp)$ measurement at the ANL-ZGS. Taking a simple difference between *pd* and *pp* results, corrected only for Coulomb-nuclear rescattering and deuteron break-up, yields data in qualitative agreement with the free *np* results. Correction for Glauber-type rescattering including 3-body final state interactions provides a disagreement. For these reasons, the ANL-ZGS *pn* results were omitted in many existing databases.

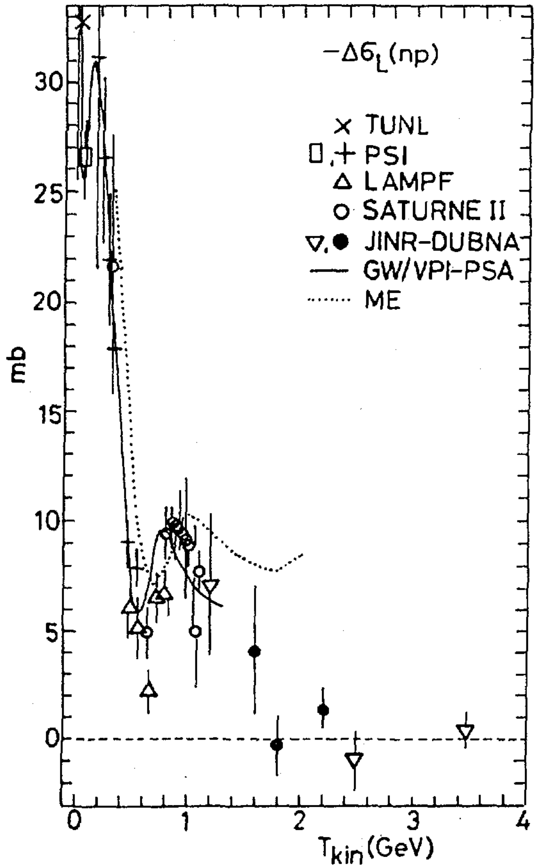

Fig. 3. Comparison of the data from different laboratories. Note that the LAMPF data were obtained within several years.

Using free polarized neutrons at SATURNE II, $\Delta\sigma_L(np)$ results were obtained at 10 energies in the interval from 0.31 to 1.10 GeV. The Saclay results were soon followed by PSI measurements at 7 energy bins from 0.180 to 0.537 GeV, using a continuous neutron energy spectrum. $\Delta\sigma_L(np)$ has also been measured at five energies between 0.484 and 0.788 GeV at LAMPF. A quasi-

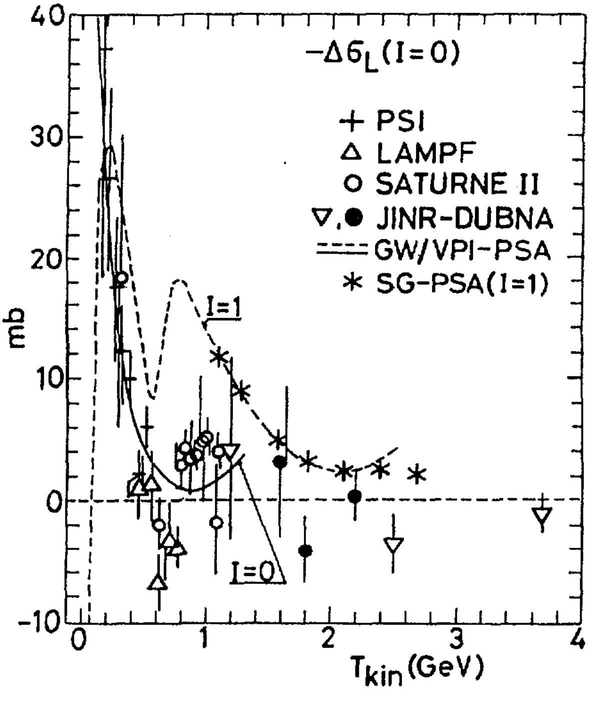

Fig. 4. Values of the $I = 0$ part of $\Delta\sigma_L$.

monoenergetic polarized neutron beam was produced in $pd \to n + X$ scattering of longitudinally polarized protons. Large neutron counter hodoscopes have to be used due to the small neutron beam intensity. To be complete, at low energies, $\Delta\sigma_L(np)$ at 66 MeV was measured at the PSI injector, between 4.98 and 19.7 MeV in TUNL and at 16.2 MeV in Prague (in collaboration with JINR Dubna).

All the JINR results smoothly connect with the existing data. The $-\Delta\sigma_L(np)$ energy dependence shows a fast unexpected decrease to zero between 1.1 and 2.0 GeV. The data are compared with the meson-exchange model prediction and with the Arndt's phase shift analysis (PSA) fit. One can see a disagreement with the model prediction at high energy. Values of the $I = 0$ part of $\Delta\sigma_L$ are presented in Fig. 4, where the fast decrease is also well pronounced.

The new "perpendicular" superconducting holding coils provide the possibility to determine the $-\Delta\sigma_T(np)$ energy dependence. The set-up for this measurement is similar as for $-\Delta\sigma_L(np)$. These data are needed to determine separately the imaginary parts of the two spin-dependent forward scattering amplitudes and to study their possible energy dependent structure.

The experiment was recently completed by an apparatus, allowing the measurement of the spin correlation parameters A_{ookk} and A_{oonn} in np elastic scattering at 180°. They can be measured simultaneously with the $\Delta\sigma_L$ and $\Delta\sigma_T$ experiments, respectively. These two observables, together with the known np elastic differential cross section, allow to determine the real parts of the three non-vanishing scattering amplitudes for np and $I = 0$ scattering in the forward direction. The short test-run, using the unpolarized beam and target provided encouraging results (V.Sharov, L.Strunov et al., 2000).

2b. Experiment "DELTA"

The aim of this experiment using the new DELTA set-up is a search for the spin dependent phenomena of π^0 and η−meson production in NN collisions with a polarized nucleon beam and PPT at energies up to 2.5 GeV. The responsible person is V.A.Krasnov.

Table 1. Properties of π^0- and η−meson

	π^0	η
J^{PC}	0^{-+}	0^{-+}
(I, I_3)	(1,0)	(0,0)
Quark w.f.	$(u\bar{u} - d\bar{d})\sqrt{2}$	$(u\bar{u} + d\bar{d} - 2s\bar{s})\sqrt{6}$
Mass	134.9 MeV	548.8 MeV
Mean life	0.83×10^{-16} sec	0.75×10^{-18} sec
2γ decay fraction	98.8 %	39 %

Properties of π^0 and η mesons are given in table 1. Both mesons are members of the pseudoscalar meson nonet and their spins, parity and G-parity are identical. A major difference is in their isospin and quark wave function, since η also contains a $s\bar{s}$ pair, reflecting its relative large mass. An attractive feature of the η−meson is a selective excitation of the $N^*(1535)$ S_{11} resonance in ηN interaction close to the production threshold.

The reaction $NN \rightarrow NN\pi$ is the dominant inelastic process in NN interactions in the energy region under discussion. Since the pion can rescatter on the nucleon before its emission, it could be used to study the off-shell properties of πN interactions. Furthermore, the reactions $NN \rightarrow NN\pi$ check meson production models for such heavier mesons as σ and ω (see model calculation in Fig. 5). The role of different pion production mechanisms can be investigated in inelastic reaction with polarized nucleons, including $np \rightarrow d\pi^0$.

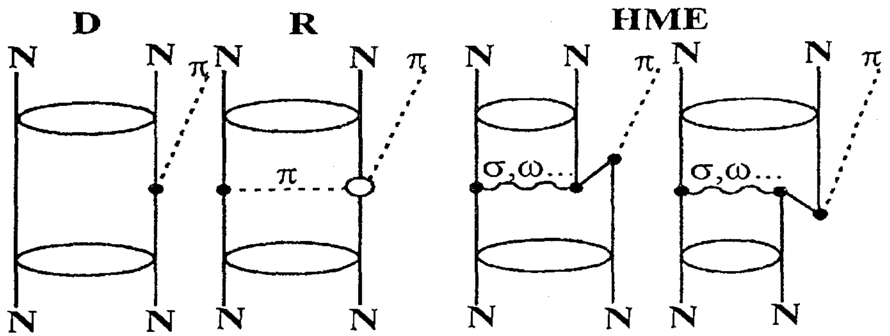

Fig. 5. Pion production mechanisms included in the model: (D) direct pion emission, (R) pion rescattering and (HME) heavy meson exchange.

No experimental data for $\eta-$meson production with polarized nucleons are available yet. Existing data concern mainly the total cross section energy dependence for neutral meson production. Neverheless, these experiment are interesting, since:

- • A high momentum transfer ($\sim$ 1 GeV) to the nucleon takes place in these processes.
- • An unexpected strong energy dependence of $\eta-$meson production was observed near the threshold.
- • The question of nucleon strangeness rises (Ellis et al., 1995).

A possible existence of hidden strangeness in the nucleon has recently become one of the most controversial problems in nuclear and hadron physics. A significant role of strange sea quarks in nucleon structure was suggested by the polarized deep-inelastic lepton-proton scattering experiments (EMC, NMC, SMC, SLAC) and e.g. by Ellis, Gabathuler and Karliner, 1989). Measurements of some two-spin observables in pp and np collisions may be very sensitive to the hidden strangeness content of nucleons (Rekalo, Arvieux, Tomasi-Gustafsson, Schematic View of DELTA Detector Positions

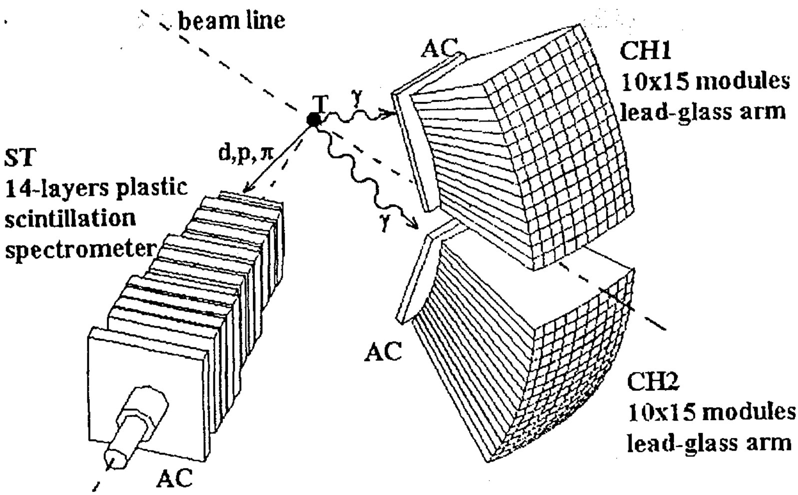

Fig. 6. A schematic view of the DELTA detector positions. T- polarized proton target PPT; CH1,CH2 - two arms of the Cherenkov lead glass spectrometer for two gammas after neutral meson decay measurements, ST - 14-layer fiber-optics scintillation telescope for multi-ΔE measurements of charged particles; AC - anticoincidence detectors.

1997, and Sapozhnikov). The determination of a relative spin-singlet and spin-triplet amplitude contributions may result in a model independent theoretical analysis of the problem.

To study π^0 and η production, the DELTA lead-glass Čerenkov spectrometer has been designed to determine the energies and outgoing angles of $\gamma-$quanta from meson decay in the target (Fig. 6). The spectometer is completely assembled. It consists of two blocks, each of them containing 150 lead-glass prisms and of a 14 layer scintillation telescope (opto-fiber plates) for multi$-\Delta$E measurements of charged particles. The detectors may be adjusted or rotated in the vertical and horizontal planes by remote computer control.

At least a part of the DELTA experiment may run simultaneously with the measurement of $-\Delta\sigma_T(np)$ (Section 2a).

2c. Experiment "pp SINGLET"

This experiment uses extracted vector polarized deuterons, considered as

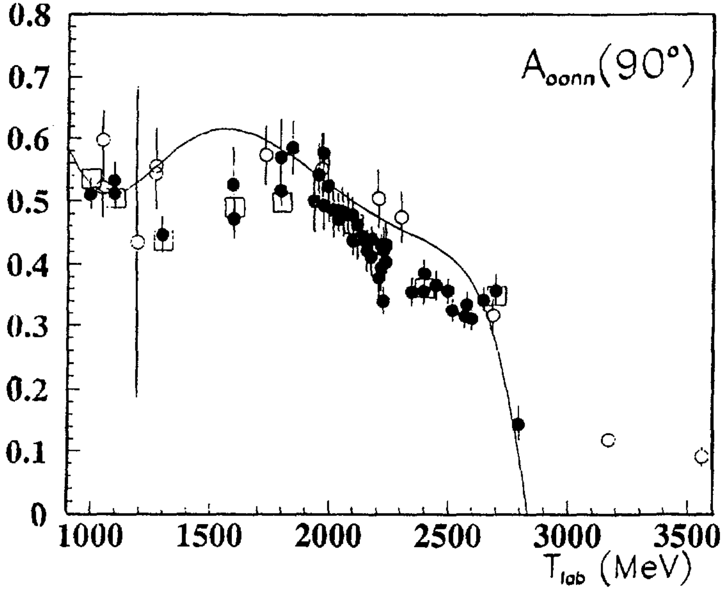

Fig. 7. The distribution of $A_{oonn}(90°)$: • - Saturne II data, ○ - other data - Arndt et al. PSA (WI00), open squares - Saclay - Geneva PSA.

a beam of weakly bound protons and neutrons. The beam and target polarizations are oriented vertically and vertical holding coils for MPT are needed. The aim of the experiment is the measurement of the energy dependence of the spin correlation parameter A_{oonn} in quasi-elastic pp scattering at angles close to $\theta_{CM} = 90°$. The proton kinetic energy values will cover an interval of a few hundreds MeV around 2.8 GeV. The person responsible for the experiment is E.A.Strokovsky.

This experiment was triggered off by a surprising behaviour of the $A_{oonn}(90°)$ energy dependence, observed around 2.8 GeV at Saturne II, close to the energy limit of the accelerator. Accurate measurements between 2.35 and 2.70 GeV in small energy steps show roughly constant values of $A_{oonn}(90°) \sim 0.35$. When increasing the beam energy to 2.8 GeV, the $A_{oonn}(90°)$ value dropped down by factor 3 within a small energy interval. From the existing ANL-ZGS data, measured at several higher energies, it follows that $A_{oonn}(90°)$ remain on the level of 0.1 up to $\sim$ 7 GeV. This is shown in Fig. 7, where, in addition, the predictions of the PSA are plotted.

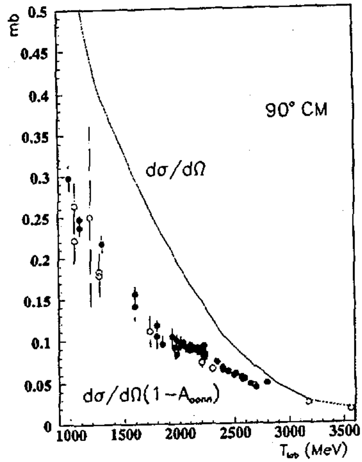

Fig. 8. The spin-singlet amplitude reconstruction: • - Saturne II data, ○ - other data.

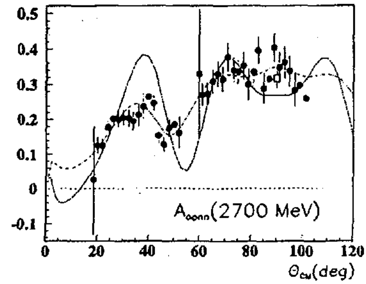

Fig. 9. The angular dependences of A_{oonn} at 2.7 GeV: • - Saturne II data, dashed curve - PSA Saclay-Geneva, solid curve - PSA Arndt et al.

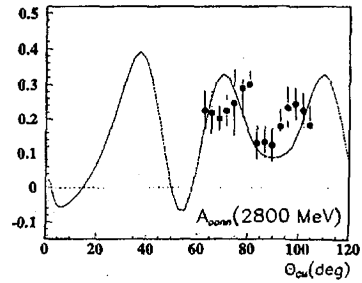

Fig. 10. The angular dependences of A_{oonn} at 2.8 GeV: • - Saturne II data, solid curve - PSA Arndt et al.

Moreover, the simple relation at $\theta_{CM} = 90°$

$$\frac{d\sigma}{d\Omega}(1 - A_{oonn}) = |A_S|^2 \qquad (2.4)$$

gives the pure spin-singlet scattering amplitude $|A_S|^2$. The direct amplitude reconstruction of this function for all measured data is shown in Fig. 8. One observes a clear narrow local maximum at 2.8 GeV. It is worth checking its position and width in a dedicated counter experiment, since one of the possible explanations of this anomaly is a spin-singlet resonance behaviour.

The importance of the measurement is supported by the fact that the angular dependences of A_{oonn} at 2.7 and at 2.8 GeV are totally different. This is demonstrated by Figs. 9 and 10.

3. INVESTIGATION OF DEUTERON STRUCTURE

In this and following sections the experiments using deuteron polarized beams and unpolarized targets are treated.

It is well known that nucleons have an internal structure, that they can be excited to a resonance and that they are extended objects. This means that the standard "nucleonic" picture of nuclei is not self-consistent and contains internal contradictions. To avoid these contradictions, one must take into account the compositeness of the nucleons and their quark structure when the relative momenta are high enough, i.e. the relative distances are short.

Applying the Pauli principle on the level of the nucleon quark structure, in any consistent description of the nuclear structure at short distances the compositeness of nucleons is to be taken into account. This was stressed e.g. by A.P.Kobushkin (1998). A large amount of spin-dependent data, which are very sensitive to the non-standard content of nuclei, provide strong arguments that the composite nature of nucleons can not be ignored starting from relative momenta of $\sim$ 200-300 MeV/c. Such data come from deuteron break-up experiments and from backward elastic dp scattering. The experiments were done mostly in Dubna and in Saclay. Most of the authors are the same and the number of relevant papers is considerable. The JINR experiments were performed at ALPHA and ANOMALON arrays, recently at the SPHERE installation as well.

3a. Deuteron Break-up in Collinear Kinematics

The key feature of these experiments was collinear kinematics, i.e. spectra of proton-fragments were studied at 0° (in the direction of the incident beam). The proton momentum region was from $p_d/2$ (the most probable proton momentum) up to the maximal possible which corresponds to the limit of the backward elastic dp scattering. In this kinematics the shape of the spectra is determined mostly by the wave function of the studied nuclei. Strong disagreement between the data on inclusive differential cross sections and theoretical models of the reaction mechanism, which make use of standard nucleon-proton wave functions (WF) of the probed nuclei, was observed in all experiments. It is demonstrated in Fig. 11a, where the "empirical momentum density" (EMD) distribution of protons in the deuteron, extracted from the inclusive cross sections of $d + p \to p + X$ is shown. It is plotted together with similar data from

$e + d \to e' + X$ reaction. An excellent agreement of the hadronic and electromagnetic probes clearly demostrates that the type of probes is irrelevant.

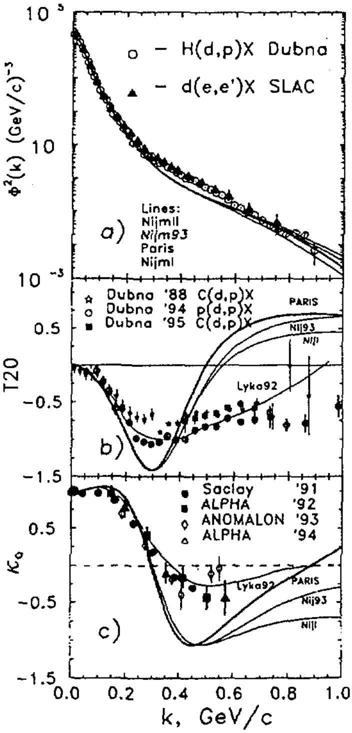

Fig. 11 a,b,c. World data for deuteron breakup on protons and carbon nuclei. The EMD, denoted here as Φ^2, is defined in the text. Lines are calculated in the quasi-impulse approximation with different models for the *deuteron wave function (DWF) (labels "PARIS", "Nij93", "NijI"; for the* Paris and Nijmegen DWFs and in the model where rescattering effects and final state interactions are taken into account ("Lyka92").

The EMD is related to the invariant cross section $E_p\, d^3\sigma/d\vec{p}$:

$$E_p \frac{d^3\sigma}{d\vec{p}} \sim \Phi^2(k) \cdot \frac{1}{4(1-\alpha)} \sqrt{\frac{m_p^2 + p_\perp^2}{\alpha(1-\alpha)}} \cdot F(N,d) \cdot \frac{E_p}{d\vec{p}} \, , \qquad (3.1)$$

$$\alpha = \frac{p_{||} + E_p}{p_d + E_d} \; ; \; k_\perp = p_\perp \; ; \; k = \sqrt{\frac{m_p^2 + p_\perp^2}{4\alpha(1-\alpha)} - m_p^2} \qquad (3.2)$$

Here $d\vec{p} = dp_x dp_y dp_z$, Φ is the EMD, k is the Light Cone Dynamics (LCD) variable, p is the momentum of the proton-fragment, with the perpendicular ($p_\perp$) and the longitudinal ($p_{||}$) components relative to the initial beam momentum direction, m_p is proton mass, E_p, and E_d are the total energies of the detected proton and the initial deuteron, respectively. The factor F is the so called kinematical "flux factor", which garantees that outside the kinematic limits the cross sections are zero. It can be written as the ratio of the kinematic "triangle functions" $\sqrt{\lambda(a,b,c)}$, where a is the mass of the target nucleus squared M_{targ}^2, b is either the averaged nucleon mass squared (m_N^2), or the corresponding quantity for the deuteron ($4m_N^2$). Finally, c is the total energy squared, s_N or s_d in the CM systems "N+target nucleus" or "d+target nucleus".

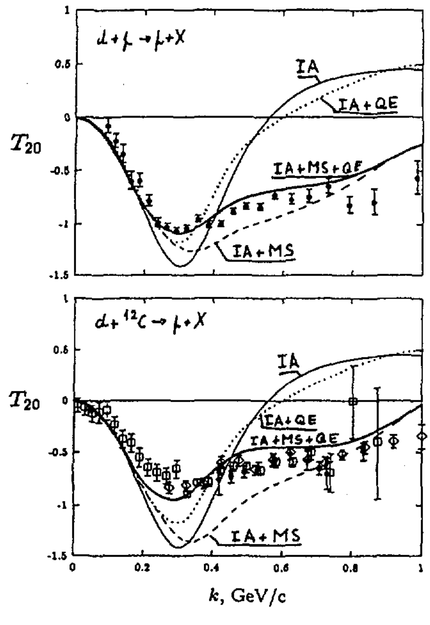

Fig. 11d. Tenzor analyzing power, T_{20}, for the 0° inclusive $^1H(d,p)$ (upper panel) and $^{12}C(d,p)$ (down panel) breakup at $p_d = 9.1$ GeV/c plotted versus the relativistic internal momentum in the deuteron k (see text for definition). IA-impulse approximation, MS-multiple scattering, QE-quark exchange.

In the experiments with polarized deuteron beams new observables were measured in the same kinematics, namely, the tensor analyzing power (T_{20} or A_{yy}) and the coefficient of the polarization transfer (κ_0) from the vertically polarized deuterons to the proton-fragments. The measurements were done in the entire available interval of the polarized deuteron momenta, from few GeV/c up to 9 GeV/c. This made it possible to probe the deuteron structure up to the relative momenta of the nucleon constituents close to 1 GeV/c (relative inter-nucleon distances as small as $\sim 0.2 - 0.3$ fm.) Summary of these data is presented in Figs. 11b,c.

The relevant references are:

- Ableev et al. 1983 ($d\sigma/d\Omega$), 1988, 1990. 1992, 1994, 1996,
- Cheung et al., 1992 (κ_0),
- Nomofilov et al., 1994 (κ_0, T_{20} at ANOMALON),
- T.Aono et al., 1995,
- Azhgirey et al., 1996 (κ_0), 1997,
- Dzikowski et al., 1992 (κ_0),
- Kuehn et al., 1994 (κ_0 at ALPHA),
- Perdrisat et al., 1987,
- Punjabi et al., 1989.

The predictions before 1998 are plotted. A strong discrepancy between models and data is obvious, only one more or less successful approach uses the Pauli principle on the constituent quark level. (Former predictions were given e.g. by Braun and Tokarev, 1991).

A systematic analysis of the observables carried out by A.P.Kobushkin (2000) (see reference therein) shows, that impulse approximation (IA), multiple scattering (MS) and contribution of quark exchange (QE) are important to explain the existing data. An example concerning T_{20} data description is given in Fig. 11d.

3b. Deuteron-Proton Backward Elastic Scattering

Since this reaction involves large $-t$ values, it may be a good probe for very short distances in the deuteron and it contains information about the short

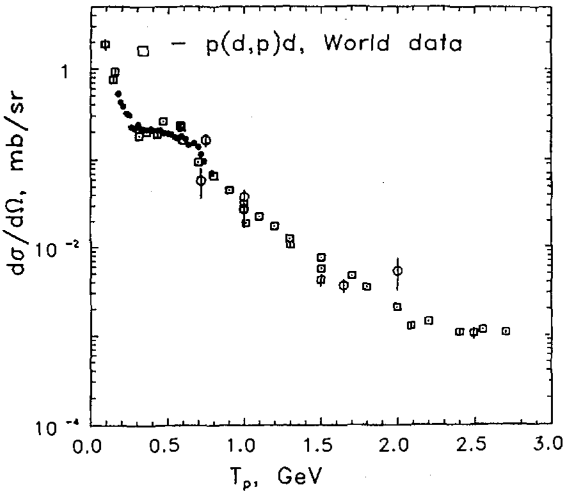

Fig. 12. The differential cross sections for $p(d,p)d$ elastic scattering, plotted versus initial kinetic energy per nucleon, T_p.

range regime of the 3-nucleon system. The available data for the differential cross section are shown in Fig. 12. No quantitative description of the energy dependence exists so far above 1 GeV.

The Empirical Momentum Density of protons in the deuteron can be related with the differential cross section as follows:

$$\frac{d\sigma}{d\Omega} = \frac{3\pi^2}{64s} \cdot \frac{\epsilon^2}{(1-\alpha)^2} \cdot (4\epsilon^2 - m_d^2) \cdot \Phi^4(k) \; ; \; 4\epsilon^2 = \frac{m_p^2 + k_\perp^2}{\alpha(1-\alpha)} \tag{3.3}$$

$$k_\perp = p \cdot \sin(\pi - \theta_{CM}) \; ; \; \alpha = \frac{E_p + p \cdot \sin(\pi - \theta_{CM})}{E_d + p} \tag{3.4}$$

where p is the CM momentum of the pd system. The EMD extracted from the data in Fig. 12 is shown in Fig. 13a.

The world spin-dependent data for T_{20} and κ_0 are summarized in Figs. 13b,c. The relevant references are:

- Arvieux et al, 1983, 1984,
- Punjabi et al., 1995 (κ_0),
- Azghirey et al., 1997, 1998,
- Alkhazov et al., 2000 - exclusive data from SPES4-π setup.

Data for T_{20} were measured in Saclay and Dubna, using detection of recoil protons only. One Saclay point was obtained from kinematically redundant experiment at SPES4-π setup, where both scattered deuteron and proton were detected in coincidence and their momenta were measured. Recently the data were analyzed and are shown in Fig. 13d.

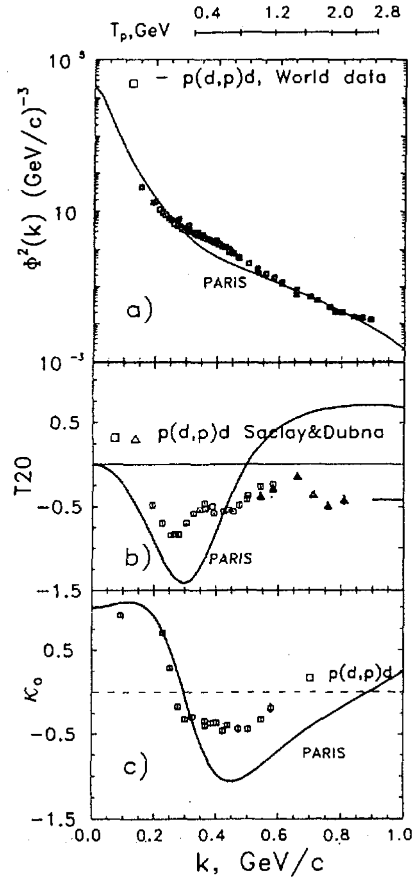

Fig. 13a,b,c. The summary of the date for backward elastic $p(d,p)d$. The EMD is extracted from the data presented in Fig. 12. Line: One-Nucleon-Exchange (ONE) predictions with Paris DWF. The upper scale illustrates the correspondence between T_p and k.

Comparing Figs. 11a,b,c with Figs. 13a,b,c, one can conclude that the EMDs, extracted from $(d,p)X$ break-up and $p(d,p)d$ elastic scattering coincide unexpectedly well, whereas the spin-dependent observables have rather different k-dependence. But, surprisingly, when T_{20} and κ_0 data from these reactions are plotted on the same $T_{20} - \kappa_0$ plot (Kuehn, Perdrisat, Strokovsky, 1995), the corresponding trajectories coincide very well. They are far away from the circle

$$(T_{20} + \frac{1}{2\sqrt{2}})^2 + \kappa_0^2 = \frac{9}{8} . \qquad (3.5)$$

Equation (3.5) is valid strictly for "one nucleon exchange" (ONE) and Impulse Approximation for the $(d,p)X$ and $p(d,p)d$ reactions, if the DWF contains only two orbital momentum states: S and D. If there are more orbital states, e.g. P-waves coming from $N-N^*$ content of the deuteron with negative parity baryonic resonance N^*, the circle will be destroyed. The behaviour of T_{20} as a function of κ_0 is shown in Fig. 14 and remains unexplained.

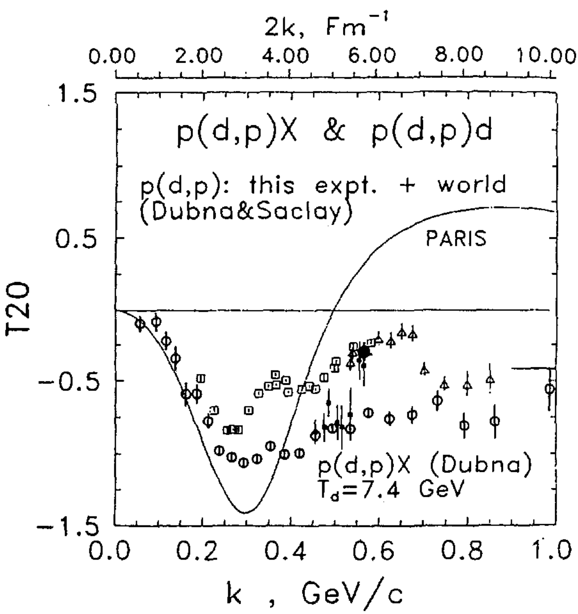

Fig. 13d. Comparison of the break-up results and the backward *dp* elastic scattering data. The black dot is from the Saclay exclusive experiment.

Intriguing are two structures in the spin observables energy dependence. One at $k \sim 0.35$ GeV/c was first observed at Saclay (Arvieux et al., 1983, 1984, Punjabi et al., 1995), the second one in Dubna (Azhgirey et al., 1997, 1998).

Please note that it will be hardly possible to extend the electron-deuteron scattering data to high k in order to search for similarities between hadronic and leptonic probes.

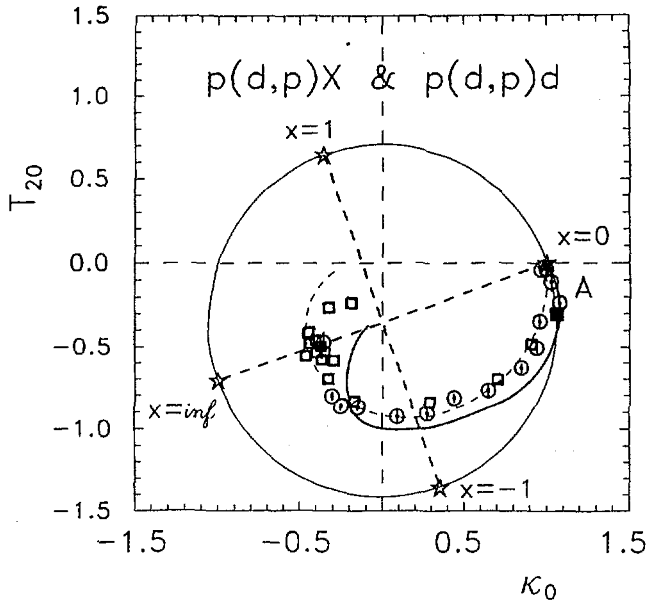

Fig. 14. $T_{20} - \varkappa_0$ plot of existing data. The circle is given by eguation (3.5).

3c. Deuteron Break-up in Non-Collinear Kinematics

The data on A_{yy} in the deuteron inclusive break-up reactions of 9 GeV/c deuterons on hydrogen and carbon nuclei were measured in non-collinear kinematics as well. Some relevant references are:

- Afanasiev et al., 1998,
- Ladygin et al., 1999, 2000,
- Azhgirey et al., 1999.

In these experiments protons were emitted at $\theta_{lab} = 85, 130$ and 160 mr and their transverse momenta up to 900 MeV/c were measured. The SPHERE set-up was used. In figure 15 the data obtained at $\theta_{lab} = 85$ mr are compared to the data measured at $\theta = 0°$ and to different model predictions. The data indicate a significant dependence of A_{yy} on the transverse momenta, what contradicts to the calculations using standard DWFs.

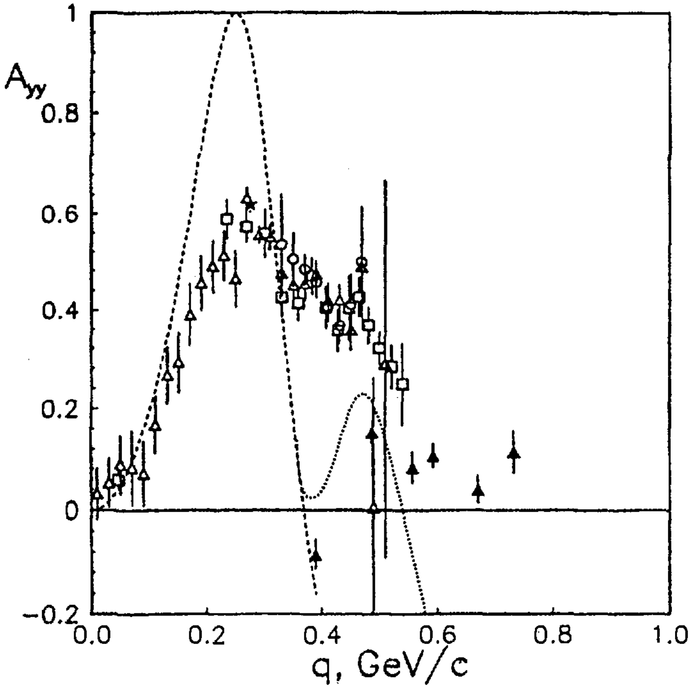

Fig. 15. A_{yy} data at $\theta_{lab} = 85$ mrad (filled triangles) compared with the data obtained at 0° on carbon target, q is the proton momentum in the rest frame of the deuteron. The dashed and dotted lines are the results of calculations using Paris DWF for 0 and 85 mr proton emission angles, respectively.

4. SPIN-DEPENDENT OBSERVABLES IN CUMULATIVE REGION

The study of cumulative particle production (CPP) has been carried out in Dubna and at other accelerators from the beginning of the 70^{th}:

- Alanakyan et al., 1977,
- Stavinski 1979,
- Nikoforov et al., 1980,

- Anderson et al. 1983,
- Moeler et al, 1983,
- Baldin 1985,
- Boyarinov et al., 1989, 1991,
- Gavristhuk et al., 1991,
- Braun and Tokarev, 1991,
- Belyaev et al., 1993.

As usual, by cumulative particles (Baldin 1985) are meant the particles, produced in the fragmentation region of one of the colliding particles beyond the kinematic limit of free nucleon-nucleon collisions. The study of cumulative reactions gives information about a high momentum component in fragmenting nuclei. Such an internal momentum corresponds to small internucleonic distances (~ 0.1 fm) at which a manifestation of non-nucleon degrees of freedom in nuclei could be expected;

- Burov et al., 1976,
- Lukyanov, Titov 1979,
- Baldin 1983,
- Efremov et al., 1994.

In deep inelastic scattering of the leptons this internal momentum corresponds to $x_{Bjorken} \geq 1$, where the cross sections are too small. From this point of view the hadronic probes are preferable.

4a. Analyzing Power for Cumulative Proton Production

The first JINR "spin-dependent cumulative" experiment (Beznogikh et al., 1991) measures the analyzing power in reactions involving emission of fast protons in the interaction of vector polarized deuterons with carbon nuclei. The inclusive reaction $d + C \to p + X$ was studied at energies 0.6, 0.8, 1.0 and 2.1 GeV/nucleon. A correlation of the two outgoing protons in the reaction $d + C \to p + p(d) + X$ was investigated at 0.8 GeV/nucleon.

Inclusive measurements of A_y^p were carried out in the internal beam of polarized deuterons, intersecting a thin polyethylene target. The fast protons

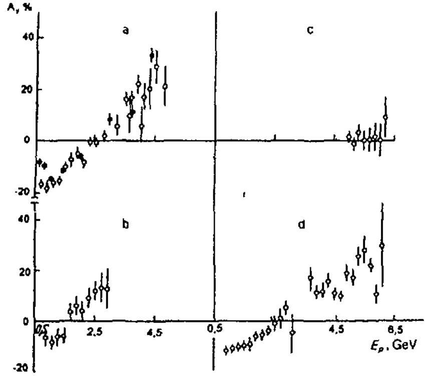

Fig. 16a. Analyzing power of the $d \uparrow C$ reaction as a function of E_p for $\theta_{lab} = 75°$: (a) $E_d = 0.8$ GeV/nucleon; (b) 0.6; (c) 2.1; (d) 1.0 GeV/nucleon.

were detected by telescopes of scintillation detectors at several angles. The detectors could identify protons, deuterons and pions. The results at $\theta_{lab} = 75°$ are shown in Fig. 16a.

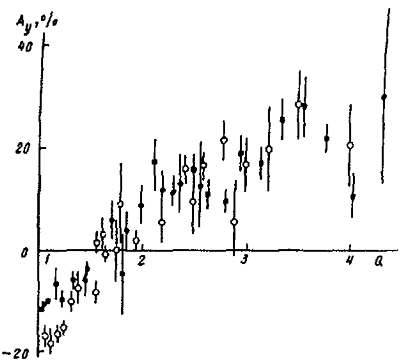

Fig. 16b. Analyzing power of the $d \uparrow C$ reaction as a function of the "cumulative number": (•) 0.6 GeV/nucleon; (∘) 0.8; black squares - 1.0; open squares - 2.1 GeV/nucleon.

Figure 16b shows values of $A_y^p(75°)$ as a function of the variable $Q = M_{eff}/m_p$. Here M_{eff} is the mass of the target (at rest), at which the incident proton would have to be scattered elastically in order to be detected with the given momentum. Q is called a "cumulative number" in certain papers. It can be considered as a number of the target nucleons simultaneously interacting with the incident deuteron. We see that the data for all deuteron energies conform well to a common curve. This agreement may be evidence that scattering by heavy clusters is contributing substantially in this kinematic range.

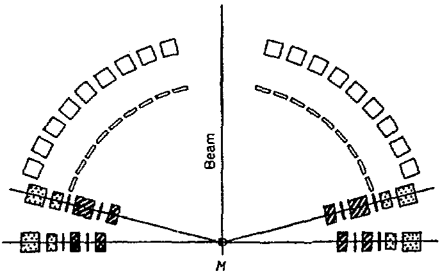

Fig. 17a. Set-up for the correlation experiment. Open rectangles - plastic scintillators; hatched rectangles - moderators; dotted rectangles - $NaI(Tl)$ crystals.

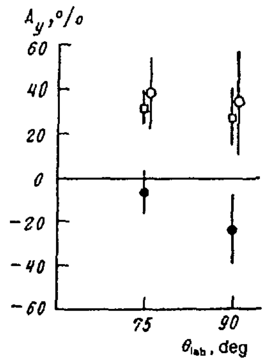

Fig. 17b. Analyzing power of the reaction $d \uparrow C \to p(p,d) + X$ for angles of 75° and 90°, and for various angles of the particles emitted forward. Symbols: the open squares - data for a "cumulative" proton in coincidence with a slow proton (the kinetic energy is from 0.04 to 0.22 GeV); $\circ$ - in coincidence with a slow deuteron (the kinetic energy is from 0.05 to 0.25 GeV); $\bullet$ - in coincidence with a fast proton (with energy above 0.22 GeV).

In the "correlation" experiment coincidences were detected between fast protons emitted at $\theta_{lab} = 75°$, or at 90° and particles in the forward hemisphere. A reaction in which the "cumulative proton" is accompanied by fast forward proton is usually linked with the mechanism of single pp scattering. For a cumulative proton, the analyzing power is negative. Coincidences with slower protons and deuterons , which are linked with scattering by clusters, give a positive analyzing power. Its value is larger than A_y^p for inclusive measurements (Fig. 17a,b).

4b. Tensor Analyzing Power for Cumulative Pion Production

The experiments measuring the tensor analyzig power T_{20} for cumulative pion production will be treated together (Afanasiev et al. 1997, 1998):

- • Study of the reaction $d + C \rightarrow \pi^-(0°) + X$ at six incident polarized deuteron momenta (P_d = 6.2, 6.6, 7.0, 7.4, 8.6, 9 GeV/c) and the same reaction with positive outgoing pions at 7.4 and 9 GeV/c. The pion momentum was fixed to 3.0 GeV/c at all energies.
- • Reaction $d + A \rightarrow \pi^-(0°) + X$ at P_d = 9 GeV/c using H, Be and C targets. The pion momenta from 3.5 to 5.3 GeV/c were measured.

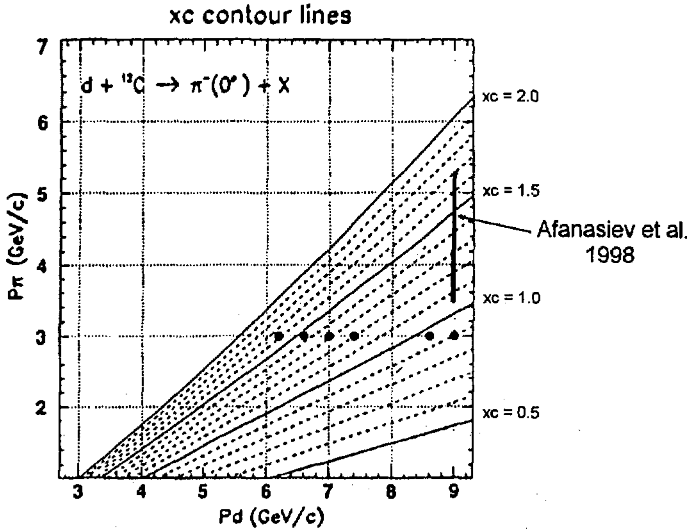

Fig. 18. x_C for the reaction $d+{}^{12}C \rightarrow \pi^- + X$ as a function of the momenta of the deuteron and the pion. The closed circles and the line indicate the measured momentum combination.

The cumulative variable x_C ("cumulative number") for the cumulative pion production in the reaction $A + B \to \pi + X$ can be written as:

$$x_C = \frac{p_B p_\pi - m_\pi^2/2}{p_A p_\pi - m_N^2 - p_A p_\pi} \ . \tag{4.1}$$

where p_A, p_B are the four-momenta per nucleon for projectile and target nuclei, respectively, p_π is the four-momentum of the produced pion, m_N and m_π are the nucleon and pion masses.

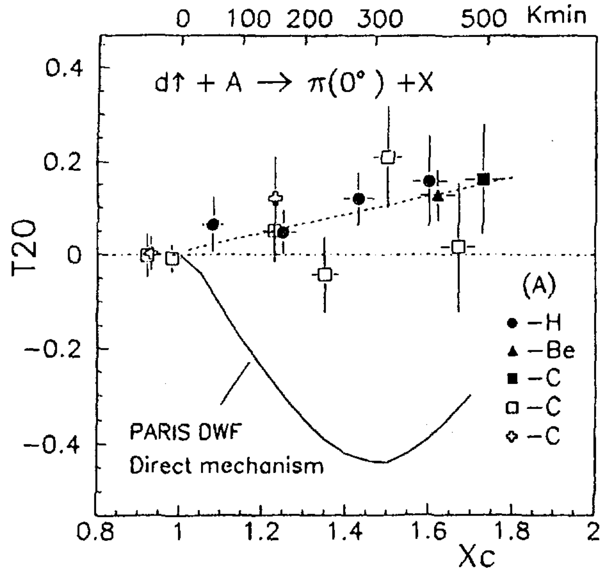

Fig. 19a. T_{20} vs x_C and k_{min} (MeV/c) for the reaction $d + C \to \pi^-(0°) + X$ at the fragmentation of 9 GeV deuterons on the hydrogen, beryllium and carbon targets. The dashed line is a linear fit of the data ($\chi^2/DF = 0.5$). The solid curve is the calculation based on the Paris DWF.

x_C range is up to the mass number of the fragmenting nucleus. When the hadron with $x_C > 1$ is produced, it is considered as a cumulative hadron. The backward elastic scattering $dp \to pd$ is a special case of cumulative reactions, when $x_C = 2$. Figure 18 shows x_C for the $d + C \to \pi^-(0°) + X$ reaction as a function of the deuteron and pion momenta. The black dots indicate the momentum combination in the first experiment, the vertical line is the x_C region of the second one.

T_{20} in pion production was found to be independent of the target mass. The results from both experiments are plotted in Fig. 19a. One can see that the sign is positive over the whole cumulative region and opposite to that obtained by the calculations, assuming the direct mechanism and the effect of Fermi motion (standard DWFs). Note that the results in the non-cumulative region agree well with existing data. Figure 19b shows the vector analyzing power as a function of the outgoing pion momentum. The angles of emitted pions are around 90° (Averichev et al., 1997, see Section 5) .

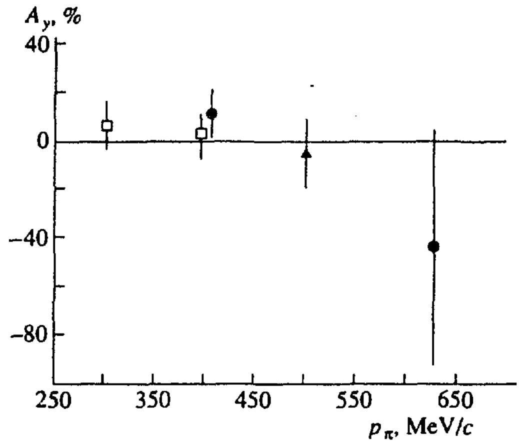

Fig. 19b. A_y versus the pion momentum for $d\uparrow + H \to \pi^{\pm} + X$ reactions at $p_d = 8.9$ GeV/c: (•) - $\pi^+(90°)$, black triangle - $\pi^+(78°)$, open squares - $\pi^-(90°)$.

5. ANALYZING POWERS IN INELASTIC DEUTERON REACTIONS

Inelastic (d, d') scattering on protons and nuclei at various energies offer a possibility to investigate spin-dependent effects in reactions with excitations of baryonic resonances ($\Delta(1232), N^*(1440)$, etc.) Such information in the Δ, Roper and overlapping region, where interference between these resonances might be essential, can help to understand the properties and underlying mechanism of the reactions studied. It is particularly important for the theory of charge exchange reactions at intermediate energies. The theory is unable at present to provide a quantitative description of these reactions with nuclei.

Spin dependent experiments measuring T_{20} (or A_{yy}) in (d, d') scattering at the laboratory angles of 0° and $\sim 5°$ on H and C in the P_d interval from 4 to

9 GeV were performed in 1994 to 1997. The results are usually presented as functions of the 4-momentum transfer squared $-t$ $(\mathrm{GeV/c})^2$ and an approximately universal behaviour of $T_{20}(t)$ (the scaling) was observed: (Azhgirey et al., 1995, 1998 and Afanasiev et al., 1997, 1998, Fig. 20a).

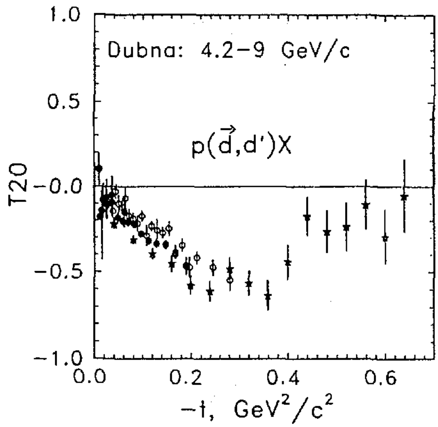

Fig. 20a. $T_{20}(t)$ for $p(\vec{d}, d')X$. Open circles: 4.2-4.5 GeV/c; full circles: 5.53 GeV/c; stars: 9 GeV/c.

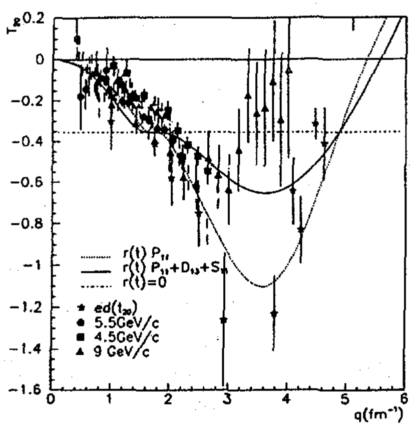

Fig. 20b. Comparison of (d, d') and ed scattering.

The $T_{20}(t)$ data in (d, d') scattering could be compared with the $t_{20}(t)$ results in (e, d) elastic scattering (Fig. 20b). In the case of the ω exchange in collinear kinematics $t_{20}(t) \sim T_{20}(t)$. The two quantities are related to the deuteron electromagnetic form-factors and to the ratio of the longitudinal over transverse isoscalar form-factors of the N^* excitation. It turns out that in the kinematical region under discussion this ratio is non-zero only for $N^*(1440)$ Roper resonance (ref. E.Tomasi-Gustafsson et al., RPC 1999).

Note that a measurement of (d, d') represents few hours, whereas the time needed for $ed \to ed$ measurement is two or three orders longer.

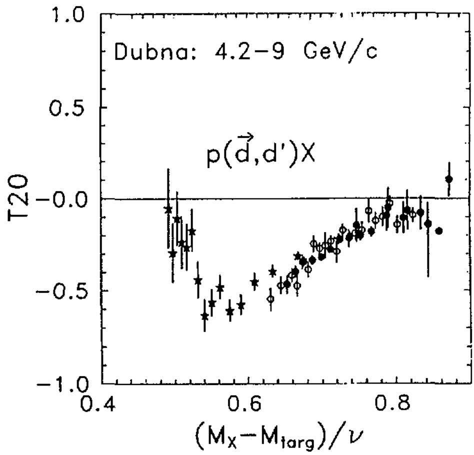

Fig. 21. Data from the Fig. 20b plotted versus $\Re$.

A new dimensionless variable with better scaling properties has been proposed by Korovin, Malinina and Strokovsky:

$$\Re = \frac{M_x - M_{targ}}{\nu} \ , \ \nu = \frac{1}{M_{targ}} P_t(P_d - P_{d'}) = m_d u_t (u_d - u_{d'}) \ , \qquad (5.1)$$

where P_d, $P_{d'}$ and P_t are 4-momenta of the projectile, the outgoing deuteron and the target, respectively, u_d, $u_{d'}$ and u_t are their 4-velocities, M_x is the missing mass (final state) and M_{targ} is the target mass (final state). $\Re$ may be interpreted as the ratio of the excitation energy to the full transfered energy, therefore it measures a "degree of inelasticity" of the scattering ($\Re = 0$ is the special case for elastic scattering). Figure 21 shows the $T_{20}(\Re)$ results from Fig. 20a.

Figure 22 shows the tensor analyzing power A_{yy} in (d, d') inelastic scattering at 80 mrad on Be at 4.5 GeV/c (SPHERE collaboration, Ladygin, Azhgirey, Afanasiev et al., 2000) compared with the data on Hydrogen at 4.5, 5.5 and 9

GeV/c (at 0°) from the papers of Azhgirey et al., 1995, 1998. They are plotted together with the predictions of Paris (1981) and Bonn (1987) potentials. A complete disagreement is obvious. Other preliminary results were published by almost the same authors in 2001.

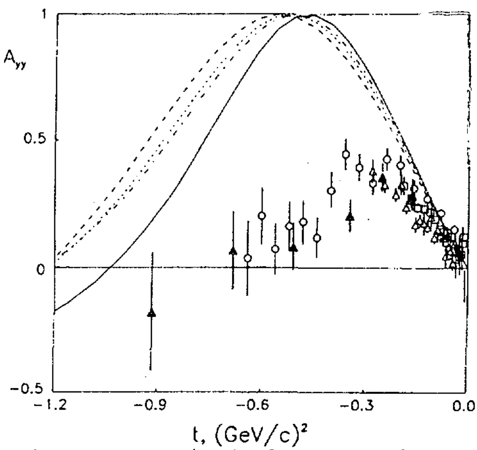

Fig. 22. Tensor analyzing power A_{yy} in deuteron inelastic scattering on beryllium for 4.5 GeV/c at an angle of 80 mr (full triangles) and on hydrogen for 4.5, 5.5 GeV/c and 9 GeV/c at a zero angle plotted as a function of the 4-momentum. The solid, dashed, dotted and dash-dotted lines are predictions using DWFs for Paris and Bonn potentials.

More recent results from the SPHERE collaboration (Ladygin 2001) were obtained in the vicinity of the lowlying baryons (1440), (1535) and (1650) at P_d of 4.5 and 9.0 GeV/c in the new kinematic region. Results for A_{yy} confirm the previous data. The non-zero value of A_y demonstrates that the spin dependent part of the elementary processes $NN \to NN^*$ play a significant role.

The JINR inclusive inelastic A_{yy} and A_y data may be compared with the exclusive results obtained at Saturne II, using the SPES4-π setup (Malinina et al., 2001). The reactions:

- • $d + p \to d + n + \pi^+$,
- • $d + p \to d + p + \pi^0$ and
- • $d + p \to d + N + \pi\pi$

have been measured at 3.73 GeV/c deuteron beam momentum. Figure 23 shows $A_{yy}(-t)$ and the authors conclude that the exclusive data are systematically larger than those inclusive ones, which were taken a nearby beam momentum. In figure 23: squares: 9 GeV/c, circles: 5.5 GeV/c, diamonds: 4.5 GeV/c.

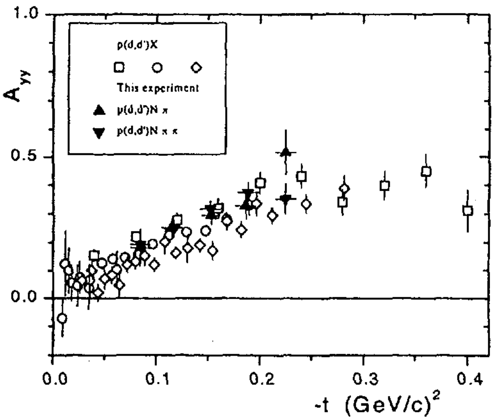

Fig. 23. Comparison of the tensor analyzing power data with the exclusive results (black symbols).

The pion asymmetry was measured in the inclusive $d + A \rightarrow \pi^{\pm} + X$ processes at incident beam momenta from 3 to 9 GeV/c (Averichev et al., 1997). Pion emission angles were close to 90° in the laboratory frame. The vector analyzing power was determined using proton and carbon targets. Large vector analyzing power values and the π^+ and π^- asymmetries of opposite signs were observed with the hydrogen target at deuteron beam momenta from 3.5 to 6.5 GeV/c and at relatively low pion momenta in the range 300-350 MeV/c. The absolute value of A_y decreases with increasing beam and pion momenta. Evidence for nonzero values of the vector analyzing power was obtained with the carbon target. For this experiment the magnetic spectrometer DISC was used.

6. PROTON-NUCLEUS ANALYZING POWER

The analyzing power in $p - C$ scattering, when only one charged particle is observed in a large detector, was determined. This experiment represents a special case of polarimetry, The results are often used for the second scattering, in which the polarization of particles, outgoing from an arbitrary reaction, is measured. Similar measurements were performed at TRIUMF, PSI, LAMPF and Saturne II. The Dubna experiment (the responsible person was L.I.Sarycheva) uses polarized protons produced in the polarized deuteron break-up reaction on Be target. An accepted angular region is usually

$3° \leq \theta_{lab} \leq 25°$, where the analyzing power is large enough and the differential cross section value is not negligible. The results extended the available data region to high energy (Anoshina et al., 1997).

A_y was recently determined in an inclusive experiment at the SPHERE set-up (A.A.Yershov et al., 2001). The vector analyzing power for quasielastic and inelastic scattering of polarized protons and deuterons on the C and CH_2 targets was measured. The energy of incident polarized deuterons was 3.6 GeV, that of polarized protons was either the same, or 2.51 GeV. The polarized proton beam was obtained as described above.

7. CONCLUSION

The Spin Physics has been a traditional experimental and theoretical field of fundamental research in JINR. Experiments started with the foundation of the Institute at the Synchrocyclotron of the Laboratory of Nuclear Problems. The Laboratory of High Energies staff extended the energy region of the spin-dependent experiments by the development of the polarized deuteron beams at the Synchrophasotron. The laboratory continued with the construction of a high level machine - the Nuclotron. Due to common efforts, this kind of attractive experimental physics survived the very difficult period following the decision to remove the Synchophasotron from the JINR budget. The fact that experimental Spin Physics remains attractive was confirmed by the fruitfull international cooperations after 1989, either in Dubna, or at other accelerators, by the existence of the young new generation and the number of theses on the relevant subjects. The large amount of scientific papers and contributions to international conferences in the field reflects a considerable number of original experiments in Dubna, providing new data recognized all over the world. The instrumental and accelerator achievements obtained acknowledgements in foreign laboratories. We can hope, that the Nuclotron, constructed with minimal funds, will soon become fully operational.

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