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Yu.K.Pilipenko, P.A.Rukoyatkin, L.S.Zolin

POLARIZED BEAMS AT THE 10 GeV MACHINE OF JINR (DUBNA)

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Пилипенко Ю.К., Рукояткин П.А., Золин Л.С. E9-97-314
Поляризованные пучки на 10 ГэВ ускорителе ОИЯИ (Дубна)

Исследования по спиновой физике были начаты в Лаборатории высоких энергий ОИЯИ в начале 1980-х гг., когда поляризованные дейтроны были ускорены на дубненском ускорителе на 10 ГэВ (синхрофазотроне). Источник поляризованных дейтронов ПОЛЯРИС производит поляризованные дейтроны как в векторной, так и в тензорной модах. Система медленного вывода позволяет снабжать экспериментальные установки в основном экспериментальном зале пучками поляризованных дейтронов с импульсами до 9 ГэВ/с с интенсивностью до $5 \cdot 10^9$ в цикл. Первые эксперименты были ориентированы на изучение инклюзивных и бинарных реакций с поляризованными дейтронами. В 1995 г. была установлена поляризованная протонная мишень и создан квазимонохроматичный пучок поляризованных дейтронов для изучения поведения разности $\vec{n}\vec{p}$-сечений в интервале энергий 1,2÷3,65 ГэВ. В настоящее время основное кольцо нового сверхпроводящего ускорителя (нуклотрона) смонтировано и успешно испытано. После ввода в действие нового инжектора и системы вывода исследования по спиновой физике с использованием поляризованных дейтронных и нейтронных пучков будут продолжены на этом новом ускорителе. Использование на нуклотроне газовой поляризованной мишени с накопительной ячейкой даст возможность расширить программу исследований по спиновой физике в ЛВЭ.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1997

Pilipenko Yu.K., Rukoyatkin P.A., Zolin L.S. E9-97-314
Polarized Beams at the 10 GeV Machine of JINR (Dubna)

The spin physics program of the Laboratory of High Energies, JINR was started in early 1980s when polarized deuterons were accelerated at the Dubna 10 GeV machine (Synchrophasotron). The source of polarized deuterons POLARIS provides deuterons in both vector and tensor polarization modes. The slow extraction system allows one to provide experimental setups in the main experimental hall with polarized deuteron beams of up to 9 GeV/c momenta at an intensity of up to $5 \cdot 10^9$ per spill. The first spin experiments were oriented to study inclusive and binary reactions with polarized deuterons. In 1995, the polarized proton target was installed and a quasi-monochromatic polarized neutron beam was prepared to study the behaviour of $\vec{n}\vec{p}$ cross section differences over an energy range of 1.2 ÷ 3.65 GeV. At present, the main ring of the new superconducting accelerator (Nuclotron) is mounted and successfully tested. After new injection and extraction systems have been constructed, the spin physics studies with polarized deuteron and neutron beams will be continued at this new machine. The use of a gas polarized target with a storage cell at the Nuclotron can give an additional chance to enlarge the LHE spin physics program.

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

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Introduction. The investigation of the nuclear structure at short distances is the main subject of research at the Laboratory of High Energies, JINR (Dubna). Beams of relativistic nuclei ($E > 1 GeV/nucleon$) are an effective tool to study the nuclear structure at $r < 0.5 fm$ where quark-gluon degrees of freedom in nuclei should manifest themselves. In the QCD scale the phenomena of relativistic nuclear physics should refer to the domain of long distances QCD, which problems wait their decisions. Numerous experimental data have been obtained at the LHE and other laboratories in studies of the cumulative effect – fragmentation of nuclei into hadrons in the kinematic region forbidden for free NN–interactions [1],[2]. Many nucleon and quark models proposed to explain the mechanism of cumulative hadron production, cannot describe specific features of reactions of this kind requiring the kinematic participation of a few correlated nucleons in the nucleus. As in the study of the inner nucleon structure, the short range nuclear structure cannot be successfully studied without taking into consideration spin degrees of freedom in nuclei. The deuteron as the simplest nucleus with the well-defined spin structure (excluding the one of deuteron core, to be careful) is the most convenient object for this kind of investigations.

The first spin experiments at the LHE have been carried out to study inclusive and binary reactions with vector and tensor polarized deuterons [3]. Some of these experimental data obtained with magnetic spectrometers ALPHA [4] and ANOMALON [5] are shown in Fig.1. After installing the Saclay-ANL proton polarized target in 1995 , the LHE spin program is supplemented with spin correlation experiments [6].

LHE accelerators and beams. At the present time, two accelerators operate in the LHE: a) Synchrophasotron was put into operation in 1957 as a 10 GeV proton synchrotron and modified later for the acceleration of ions up to ^{32}S, b) the Nuclotron, a 6 $GeV/nucleon$ superconducting accelerator of nuclei, which is in the commissioning stage and is operating for physics only with an internal target at present. A schematic view of the LHE accelerator facility and a layout of the beam lines into the main experimental hall are shown in Figs.2,3. Main parameters of the accelerators and beam characteristics [7] for light nuclei are listed in Tables 1,2.

Main beam line VP-1 transports particles from crossover F3, the final point of slow extraction line MV-1, through experimental hall 205 to the beam dump (Fig.3). Seven side beam lines 1V-7V provide ten physics setups with primary beams over a momentum range of 2÷9 GeV/c. Some experiments at the ALPHA and ANOMALON setups were performed at the target location in F3. This allowed

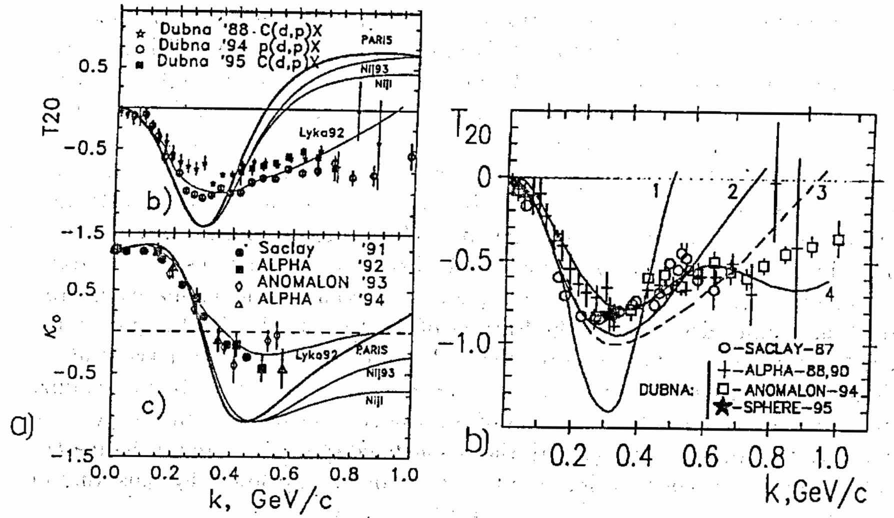

Fig.1. *Tensor analyzing power* (T_{20}) *and polarization transfer* (κ_o) *for deuteron breakup and dp backward elastic scattering, measured on polarized deuteron beams with momenta from 3.5 to 9 GeV/c (k is the internal momentum of the proton in the deuteron)*

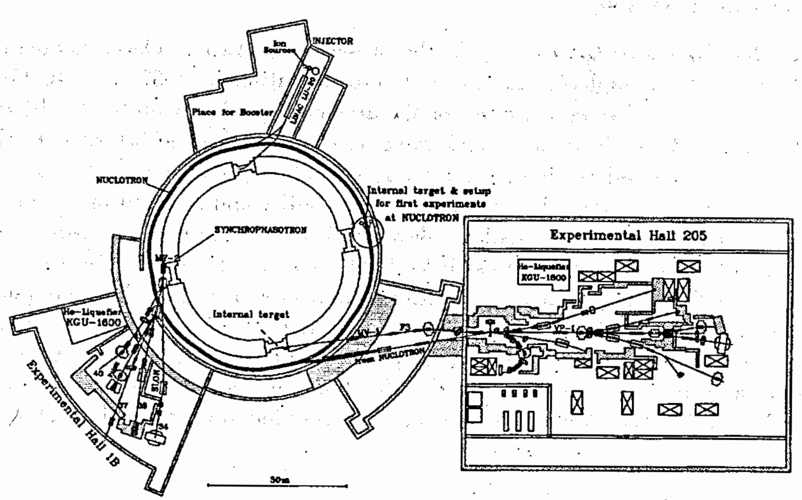

Fig.2. *Laboratory of High Energies accelerator facility*

the use of long (up to $70m$) flight bases for particle identification. For experiments with a low yield of registered particles (the deuteron fragmentation into cumulative mesons, for example), the target is located in crossover F5 and secondary particle beam line 4V with a large angular acceptance ($\Delta\Omega = 6 \cdot 10^{-5} sr$ at $\Delta p/p = \pm 2\%$) can be used. Three liquid hydrogen targets 100 to $1000mm$ in length are available for deuteron beam experiments.

Table 1. Main parameters of the LHE accelerators, Synchrophasotron (SPH) and Nuclotron

Parameters		Units	SPH	Nuclotron
Energy (max)		A GeV	4	6
Repetition rate		p.p.s.	0.12	0.5 - 1
Extraction time (max)		s	0.5	10
Vacuum		Torr	$10^{-6} - (10^{-7})$	$10^{-6} - (10^{-7})$
Magnetic field (max)		T	1.1	2.1
Circumference		m	208	252
Extracted beam emittance	ϵ_{hor}	mm mr	35π	2.5π
	ϵ_{ver}		40π	2.0π

Table 2. Light nuclei beam intensities (particles per cycle)

Beam	*SPH* (now)	*Nuclotron* (plan)	*Nuclotron + Booster* (plan)
p	$4 \cdot 10^{12}$	$1 \cdot 10^{11}$	$1 \cdot 10^{13}$
d	$1 \cdot 10^{12}$	$5 \cdot 10^{10}$	$1 \cdot 10^{13}$
$\vec{d}$	$5 \cdot 10^{9}$	$3 \cdot 10^{8}$	$1 \cdot 10^{11}$
^3He	$2 \cdot 10^{10}$		
^4He	$5 \cdot 10^{10}$	$5 \cdot 10^{9}$	$2 \cdot 10^{12}$
^7Li	$2 \cdot 10^{9}$	$2 \cdot 10^{10}$	$5 \cdot 10^{12}$
^{12}C	$1 \cdot 10^{9}$	$7 \cdot 10^{9}$	$2 \cdot 10^{12}$

Deuteron beam polarimetry. The $200\mu A$ cryogenic ion source POLARIS is used to produce polarized deuteron beams at the 10 GeV accelerator [9]. POLARIS operates either in the vector (HFS transitions $3-6$ at p_z^+ and $1-4$ at p_z^-) or in the tensor (HFS transitions $2-6$ at p_{zz}^+ and $3-5$ at p_{zz}^-) polarization modes. The sign of polarization can be changed pulse by pulse. To measure the beam polarization after acceleration in the 5 $MeV/nucleon$ linac, two types of low energy polarimeters with semiconductor detectors were used. The vector polarization was measured via the measurement of the left-right asymmetry by detecting α-particles at the elastic scattering of 10 MeV deuterons on ^4He, $\vec{d} + ^4He \rightarrow d(126°) + ^4He(15°)$. The tensor polarization can be determined by detecting stripping protons in the reaction $\vec{d} + ^3He \rightarrow p(0°) + ^4He$ on a ^3He gas target.

To measure the deuteron polarization at the slow extraction beam line VP-1, the two-arm magnetic spectrometer ALPHA is used as a high energy polarimeter (Fig.4) [10]. The deuteron polarization components ($p_z^{\pm}, p_{zz}^{\pm}$) are measured by detecting the deuteron elastic scattering on a hydrogen target. The vector A_y and the tensor A_{yy}

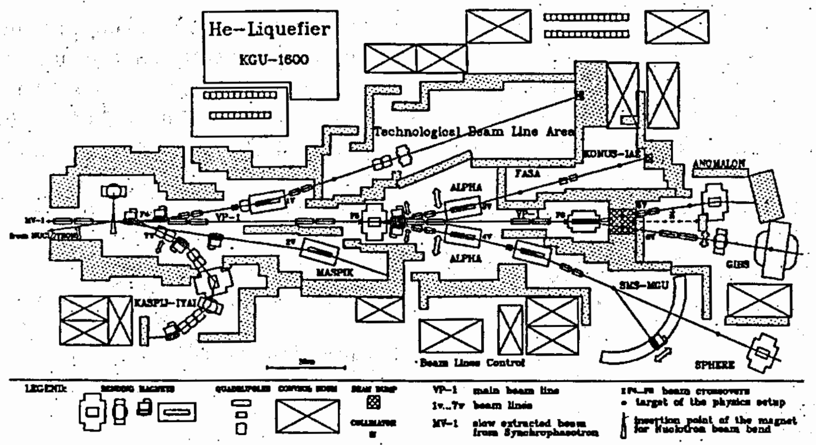

Fig.3. *Layout of beam lines in the main experimental hall*

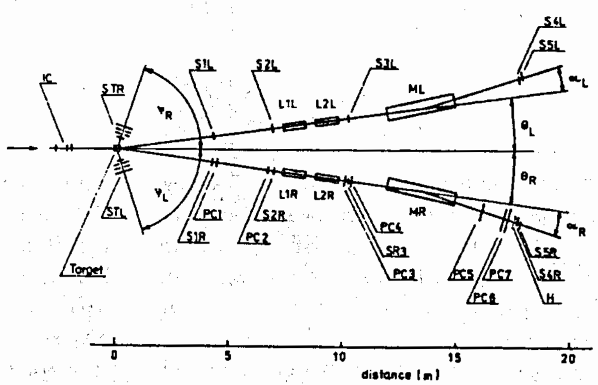

Fig.4. *High-energy polarimeter ALPHA. IC – beam monitors; S (ST) – scintillation counter (telescope); PC – multiwire proportional chamber; H – scint. counter hodoscope; L1,L2 – quadrupole lenses; ML,MR – dipoles*

analyzing power for this reaction at p_d=3 GeV/c are known to a high precision [11]. The polarimeter arm angles are fixed at 7.5° as the value of A_y shows no t-dependence in the vicinity of the four momentum transfer $-t = 0.15(GeV/c)^2$. To estimate depolarization effects at deuteron acceleration over 3 GeV/c, the comparison of the vector polarization p_z was made at deuteron extraction on reaching a momentum of 3 GeV/c and for deuterons accelerated up to 9 GeV/c , then decelerated down to 3 GeV/c and extracted. The values of p_z in these two measurements turn out to be coincident within the limits of 4%. The ALPHA polarimeter provides a high absolute precision ($\Delta p_z(syst.) \simeq 2\%$) in measuring of the deuteron polarization at a registration point of 3 GeV/c. However, it is necessary to readjust repeatedly the extraction system for 3 GeV/c using this polarimetry method in long time runs at other beam momenta.

For experiments with a tensor polarized deuteron beam a more convenient method was tested to check periodically the beam polarization. It is based on the measurement of the tensor analyzing power T_{20} in the reaction $\vec{d} + A \rightarrow p(0°) + X$. The T_{20} has an extreme value of $\simeq -1$ when the ratio of the proton to the deuteron momentum $p_p/p_d = 2/3$ (it corresponds to the internal momentum of proton in the deuteron k=0.3 GeV/c)(Fig.1b). The value of $T_{20}(k = 0.3)$ does not show any energy dependence in the region from 3 to 9 GeV/c and there are no theoretical reasons for its appearance at higher energies. For rather a high proton yield at 0° ($\frac{d\sigma}{dp d\Omega} \simeq 100 mbGeV^{-1}sr^{-1}c$ at p_d=9,p_p=6 GeV/c) increasing as p_p^2 with increasing energy , the breakup reaction can be recommended as an effective express method of tensor polarization monitoring of a high energy deuteron beam. In comparison with other known polarimetry reactions which analyzing power drops with increasing energy, this method has no limitation at high energies. As an example, the measurement result of $T_{20}(\vec{d} \rightarrow p)$ in a long time run for studying the tensor polarized deuteron fragmentation into cumulative pions ($\vec{d} \rightarrow \pi$), is shown in Fig.1b (the point denoted by a star). In the second run at the SPHERE spectrometer, similar measurements were repeated 24 times during the five-day run and confirmed a long time stability of the POLARIS operation. Typical values of vector and tensor deuteron beam polarizations are $p_z^{\pm} = \pm 0.5$ and $p_{zz}^{\pm} = \pm 0.7$.

Relativistic polarized neutron beams. The most convenient way to generate high energy polarized neutron beams with well-defined characteristics is the breakup of relativistic deuterons. The deuteron breakup cross section is a significant part of the total dA cross section which slowly changes in the GeV region. The properties of neutron beams produced in this way improve with increasing beam energy in accordance with the decrease of the ratio of the average internal nucleon momentum in the deuteron to the neutron momentum in the laboratory frame k_{int}^{rms}/p_n. At high energies, the angular spread (σ_θ) and yield (Y) at a zero angle behave as $\sigma_\theta \sim 1/p_n$, $Y \sim p_n^2$. However, the nonmonochromaticity of stripping neutron beam remains at any energies ($dp_n/p_n \rightarrow const \simeq k_{int}^{rms}/m_n \simeq 0.05$ at

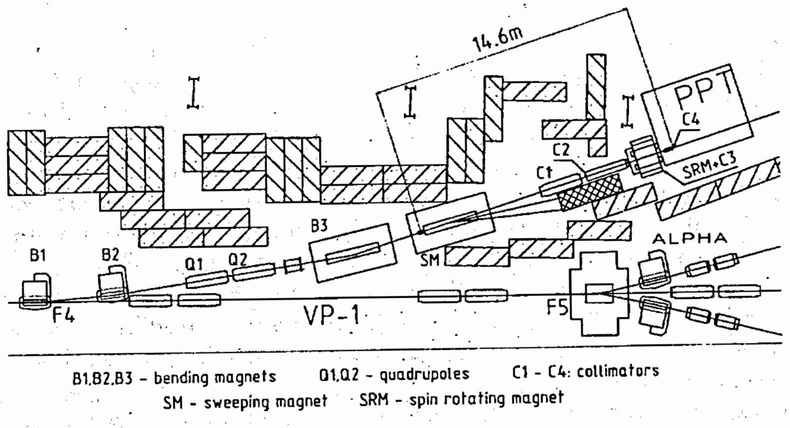

Fig.5. Neutron beam line for the experiments with PPT [6]

$E \to \infty$). The polarization of nucleons (P_N) produced in the vector polarized deuteron fragmentation is characterized by the coefficient of polarization transfer $k_\circ = P_N/P_d$, studied in a series of experiments (Fig.1a). It is shown that $k_\circ \simeq 1$ for the predominant part of stripping protons. So, one can assume that neutron beams, formed at 0°, have $P_n = P_d$, i.e. they inherit the polarization of primary deuterons. The neutrons beams at the Dubna 10 GeV accelerator operate on the basis of a slowly extracted deuteron beam. Two neutron beam channels, situated in the main experimental hall (Fig.3), were mounted [8]. The first channel assembled at the end of the central VP-1 line was used for methodical purposes. Neutron fluxes at different neutron momenta obtained with a 20cm CH-target at the outlet of the 2.5m long iron collimator ($\phi 30mm$), are shown in Table 3.

Table 3.

P_n,GeV/c	1.13	1.5	1.77	2.25	4.5
$I_n/I_d(10^9)$,ppc	$7.6 \cdot 10^3$ /0.1	$3.5 \cdot 10^4$ /0.3	$7.7 \cdot 10^4$ /0.5	$1.6 \cdot 10^5$ /0.8	$1.0 \cdot 10^6$ /1.0

The neutron beam line for the experiments with the polarized proton target (PPT) is shown in Fig.5 [8]. The polarized neutron beam was formed by the collimator composed of four stages: C1,C2 ($\phi 4cm$, $\phi 3cm$,iron) and C3,C4 ($\phi 2.8cm$, brass) 6m in total length. The collimator determined a solid angle $\Delta\Omega$ of $3\mu sr$, an angular divergence of $1.2mrad$ and a beam spot in the PPT that fitted into a $\phi 3cm$ circle. The PPT neutron beam line is equipped with the spin rotator magnet of a $2.7T \times m$ maximum field integral to turn neutron spins from the vertical direction to the longitudinal one. During the runs, the neutron space distribution was continuously monitored by a MWPC placed 0.5m downstream the PPT (Fig.6). In the first data taking runs performed at 1.92, 3.31 and 4.50 GeV/c

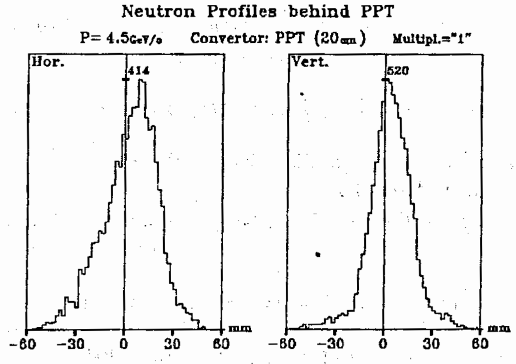

Fig.6. Neutron space distributions on the PPT beam line ($p_n = 4.5GeV/c$)

neutron beam momenta, the intensities averaged over each run were $2.7 \cdot 10^4, 2.0 \cdot 10^5$ and $4.7 \cdot 10^5 \vec{n}/cycle$ at deuteron intensities of $5.3 \cdot 10^8$, $6.1 \cdot 10^8$, and $6.4 \cdot 10^8 \vec{d}/spill$ (a composed $Be, 17cm + C, 6cm$ target for deuteron stripping was used). The charge contamination was negligible [12].

Future progress of spin physics in LHE is connected with putting into operation the new injector of the Nuclotron. It will increase to a great extent the intensity of polarized deuteron beams (see Table 2). This will open the way for probing the deuteron spin structure at high internal momenta unavailable up to now. A small internal beam emittance of the Nuclotron gives an opportunity to use a polarized gas internal target with a storage cell. At a luminosity of $L \geq 1 \cdot 10^{29} cm^{-2}s^{-1}$ and taking into account a low density of the gas target, it makes possible studying, for instance, the Pomeron spin structure by means of the measurement of asymmetry A_{pp} in $\vec{p}\vec{p}$ elastic scattering in the region of Coulomb-nuclear interference ($-t \simeq 10^{-3}GeV^2/c^2$) [13]. A_{pp} can be measured with an uncertainty of $\delta A_{pp} = 1\%$ at $L \simeq 1 \cdot 10^{29}cm^{-2}s^{-1}$, which corresponds to the target density $\rho_t = 10^{13} atoms/cm^2$, the internal beam intensity $I = 10^{10}p$ and $T_N = 0.8\mu s$ (the time of one turn in the Nuclotron). The internal gas target has well-known advantages of thin internal targets: a low density allowing the registration of low energy recoils, small beam losses and the possibility to be used (in the time sharing regime) simultaneously with running external beam experiments.

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