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Recent results from polarization experiments at the LHE-JINR Accelerator.

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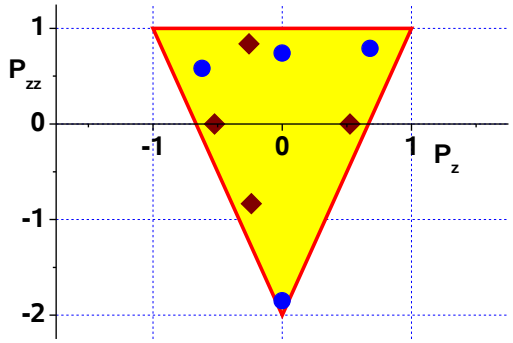


V.P.Ladygin et al.

VI-th International Conference on Perspectives in Hadronic Physics, 12-16 May 2008, Triest

Content of the talk

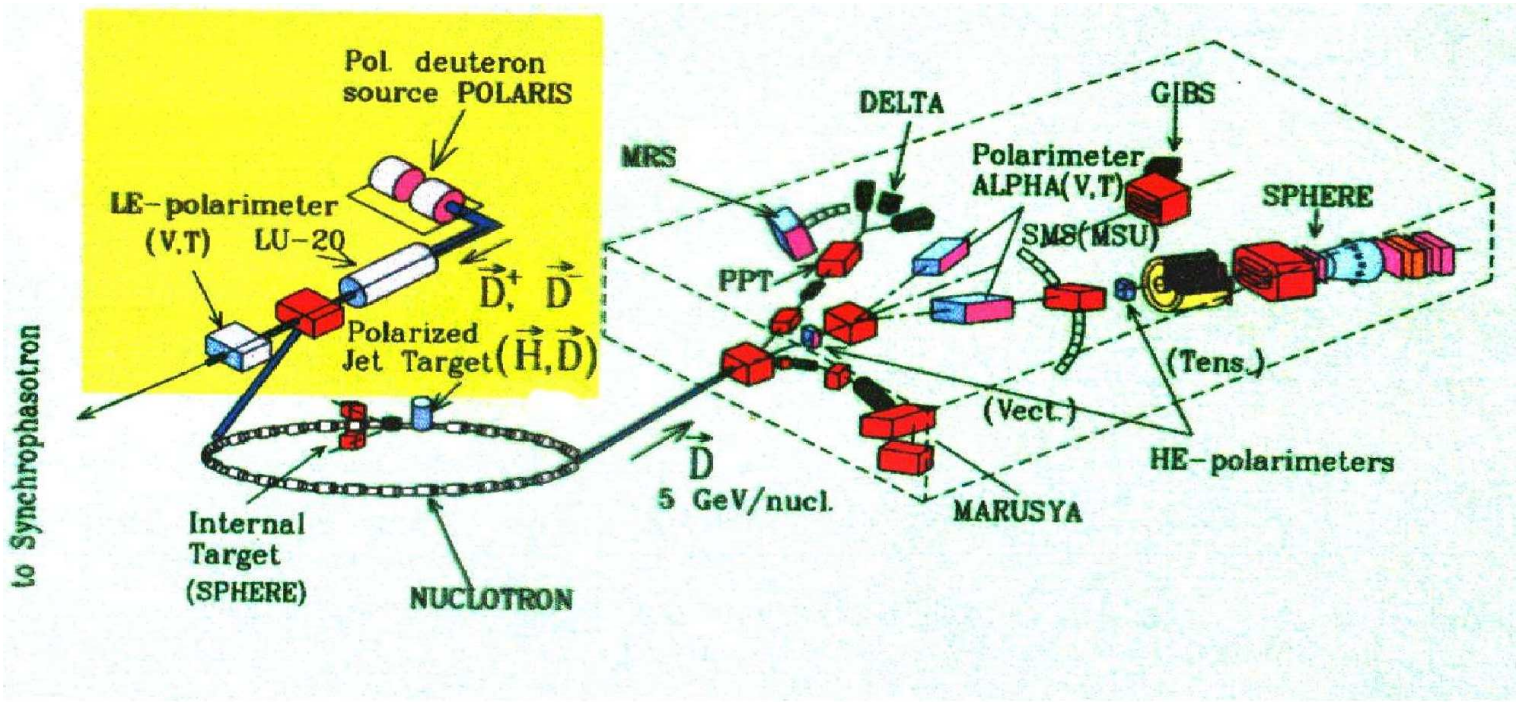
- Introduction
- Review of the current status of spin physics at LHE
- Future plans for Nuclotron-M
- Spin physics at NICA at $\sqrt{s_{NN}} = 4 \div 12$ GeV/c
- Conclusions

Motivation to study spin effects in a GeV-range

The main goal of the polarization program at **Nuclotron** is to investigate the spin effects in the region of transition regime from nucleon-meson degrees of freedom to the fundamental one: quarks and gluons.

- **Non-perturbative QCD region**
- **Importance of the effective degrees of freedom**
  ($\Delta\Delta$, NN^*, N^*N^* configurations - hidden color)
- **Threshold effects in meson-production**
- **Relativistic effects**
- **Medium effects for the polarization observables**
  (χ-symmetry restoration)

Synchrophasotron-Nuclotron Accelerator Complex



- PIS on 360 kV terminal
- 10 MeV/A LINAC
- Tensor and vector LEPs
- Nuclotron Ring: 6 GeV/A
- ITS polarimeter
- Extraction beam line
- HE polarimeters
- Experimental setups

Relativistic effects

- The principal feature of the relativistic quantum mechanics is the impossibility to separate the relative motion of the constituents and motion of the composite system as a whole. This leads to the dependence of the **relativistic** wave function not only on the relative momenta of the nucleons $\vec{\mathbf{q}}$ inside the composite system, but also on the total momentum $\vec{\mathbf{p}}$ of this system

$$\mathbf{\Psi = \Psi(\vec{q}, \vec{p})}$$

- Therefore, **relativistic** wave function is the function of the relative momentum $\vec{\mathbf{q}}$ in each new reference system.

- However, it is enough to know wave function in the infinite momentum frame, $\vec{\mathbf{p}} \to \inf$, where the structure of the wave function simplifies. Namely, the dependence on $|\vec{\mathbf{p}}|$ disappears, only the dependence on the direction of the vector $\vec{\mathbf{n}} = \vec{\mathbf{p}}/|\vec{\mathbf{p}}|$

$$\mathbf{\Psi = \Psi(\vec{q}, \vec{n})}$$

Deuteron wave function on the light cone

Relativistic deuteron wave function on light cone (**V.A.Karmanov, J.Carbonell et al.**) is defined by **6** invariant functions $\mathbf{f_1}, ..., \mathbf{f_6}$ (instead of **2** in the non-relativistic case), each of them depends on 2 scalar variables $\mathbf{k}$ and $z = cos(\widehat{\mathbf{kn}})$:

$$\psi(\mathbf{k},\,\mathbf{n}) \;=\; \frac{1}{\sqrt{2}}\sigma f_1 + \frac{1}{2}\left[\frac{3}{k^2}\mathbf{k}(\mathbf{k}\cdot\sigma) - \sigma\right] f_2 + \frac{1}{2}\left[3\mathbf{n}(\mathbf{n}\cdot\sigma) - \sigma\right] f_3 + \frac{1}{2k}[3\mathbf{k}(\mathbf{n}\cdot\sigma)$$
$$+\; 3\mathbf{n}(\mathbf{k}\cdot\sigma) - 2\sigma(\mathbf{k}\cdot\mathbf{n})]f_4 + \sqrt{\frac{3}{2}}\frac{i}{k}[\mathbf{k}\times\mathbf{n}]f_5 + \frac{\sqrt{3}}{2k}[[\mathbf{k}\times\mathbf{n}]\times\sigma]f_6,$$

$$k \;=\; \sqrt{\frac{m_p^2 + \mathbf{k}_T^2}{4x(1-x)} - m_p^2}, \qquad (\mathbf{n}\cdot\mathbf{k}) = (\frac{1}{2} - x)\cdot\sqrt{\frac{m_p^2 + \mathbf{p}_T^2}{x(1-x)}},$$
$$x \;=\; \frac{E_p + p_{pl}}{E_d + p_d} \quad (x \approx x_F),$$

where $\mathbf{E_d}$ and $\mathbf{p_d}$ are the energy and momentum of the initial deuteron, respectively, $\mathbf{p_{pl}}$ is the longitudinal momentum of the proton, $\mathbf{m_p}$ and $\mathbf{E_p}$ are the mass and energy of the proton, respectively.

Short internucleonic distances

- When the distances between the nucleons are comparable with the size of the nucleon, the nucleon-nucleon interaction is **non-local**.
- Fundamental degrees of freedom in the frame of QCD are the quarks and gluons. These degrees begin to play a role at the internucleonic distances comparable with the size of the nucleon.

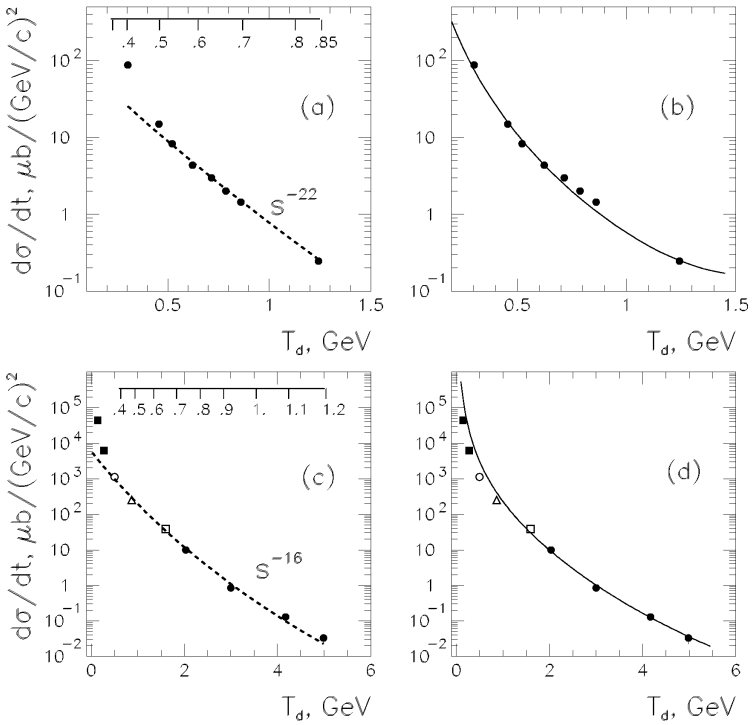
  ($\Delta\Delta$, N^*N, N^*N^*, $6q$ components in the deuteron)
- At high energies $\mathbf{s}$ and large transverse momenta $\mathbf{p_T}$ the constituent counting rules (**CCR**) are working. For the binary reactions:

$$\frac{d\sigma}{dt}(AB \to CD) \sim \frac{F(t/s)}{s^{n_{part}-2}}$$

$$n_{part} = n_A + n_B + n_C + n_D$$

(**Matveev, Muradian, Tavkhelidzhe, Brodsky, Farrar** et al.)

Quark degrees of freedom



Yu.N.Uzikov

- For the reaction $\mathbf{dp \to pd}$

  $\mathbf{n_A + n_B + n_C + n_D - 2 = 16}$

- For the reaction $\mathbf{dd \to {}^3He n}$

  $\mathbf{n_A + n_B + n_C + n_D - 2 = 22}$

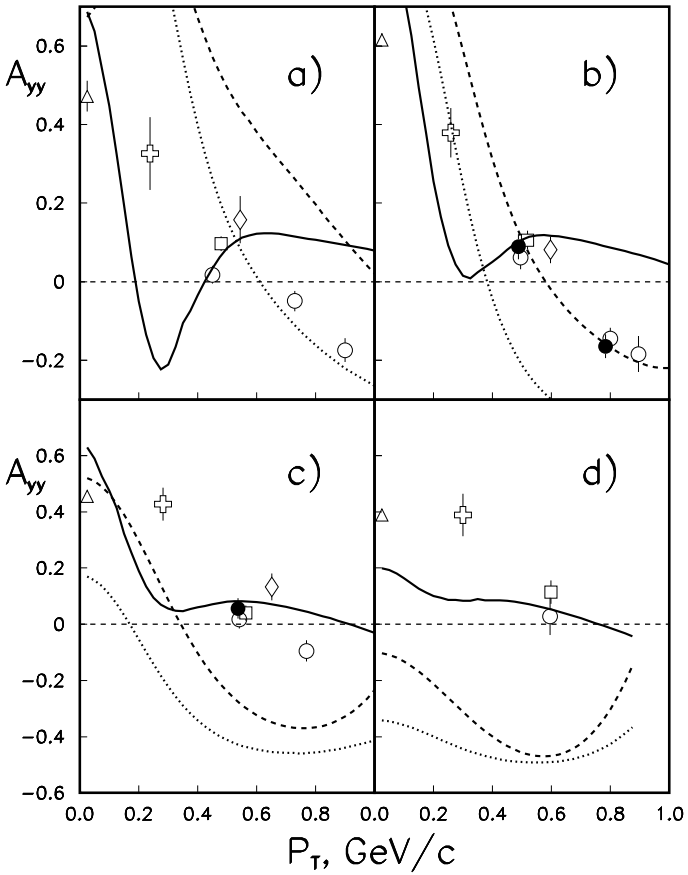
- The regime corresponding to **CCR** occurs already at $T_d \sim$500 MeV.

Three nucleon forces manifestation

- During last several years a new generation of **NN** potentials are built (Nijmegen, CD-Bonn, AV-18 etc.). These potentials reproduced the **NN** scattering data up to 350 MeV with very good accuracy.
- But these potentials cannot reproduce triton binding energy (underbinding is 0.8 MeV for CD-Bonn), deuteron-proton scattering and breakup data.
- Incorporation of the 3 nucleon forces (**3NF**), when interaction depends on the quantum numbers of the all three nucleons, allows to reproduce triton binding energy and unpolarized deuteron-proton scattering and breakup data.
- However, the **3NF** cannot reproduce polarization data intensively accumulated during last decade.

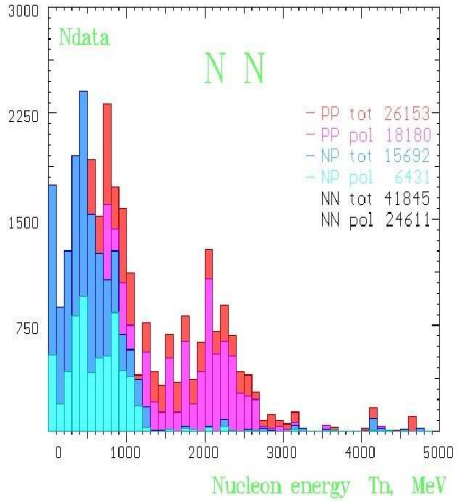
Energy dependence of 3NF spin structure via dp elastic scattering measurements

Tensor analyzing power A_{yy} for the reaction $A(d,p)X$ versus p_T



- The strong variation of A_{yy} obtained at the fixed values of $x \sim 0.62$, 0.67, 0.72, 0.78 versus p_T.
- The value of A_{yy} is positive at small p_T and changes the sign at $p_T \sim$600–650 MeV/c.
- The deviation of the data on the calculations with the use both standard and covariant DWFs is observed.

NP versus PP data

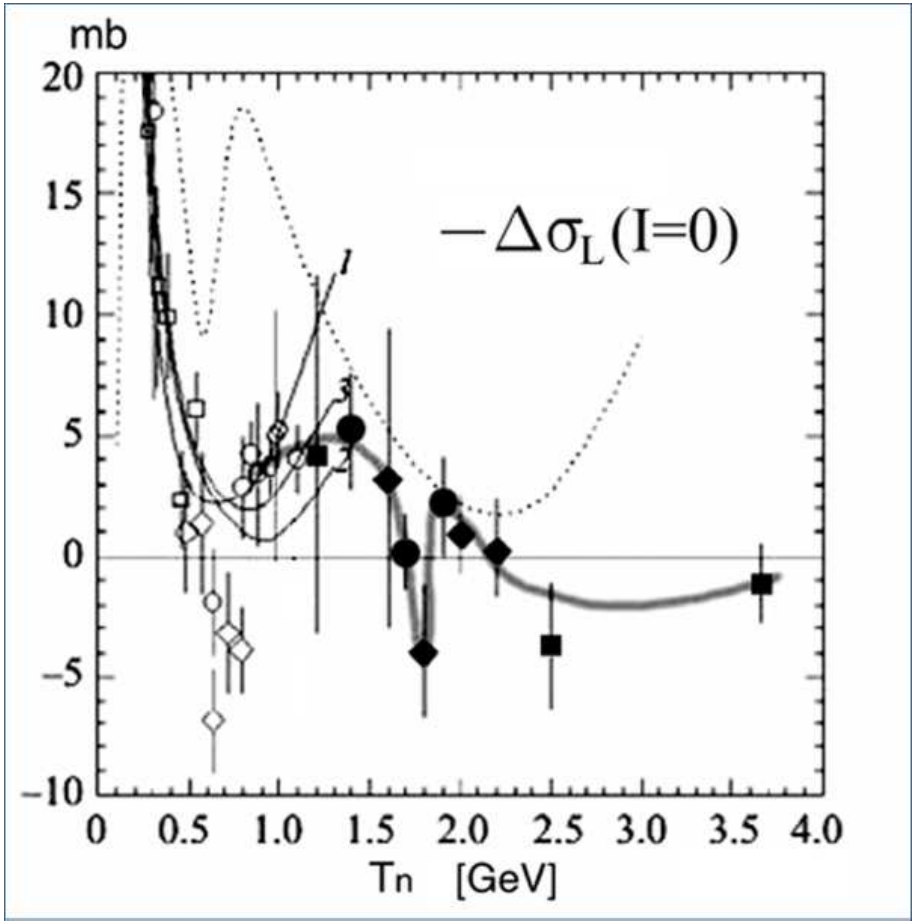


Red - are the **PP** data

Blue - are the **NP** data (practically absent at $\mathbf{T_n \geq 1.1}$ GeV)

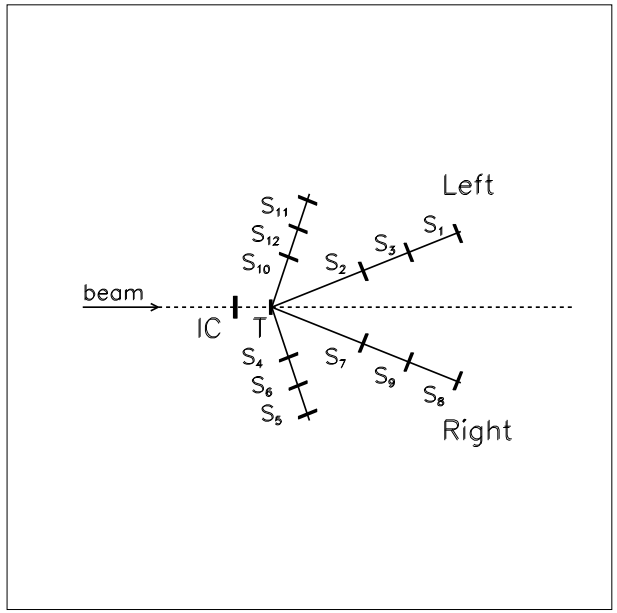
The unique neutron channel with the energies 0.55-3.7 GeV equipped by the polarized proton, liquid and nuclear targets. Neutrons are obtained from deuteron breakup ($\Delta p/p \sim 3\%$).

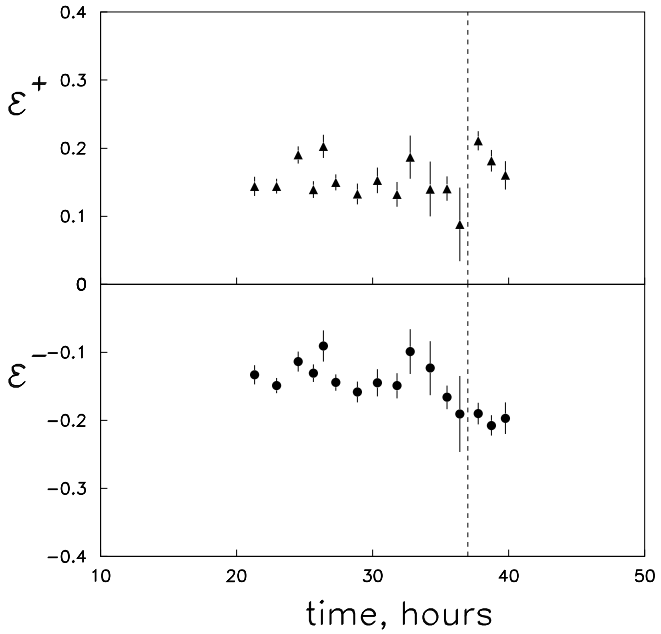
Results on $\Delta\sigma_L$ in np elastic forward scattering



- The measurements of the **np** and **pp** elastic scattering allow to extract the amplitudes with $\mathbf{I = 0}$
- The significant variation of $\mathbf{\Delta\sigma_L(I = 0)}$ versus energy:
- Structure at $\mathbf{T_n \sim 0.5–1.0}$ **GeV**
- Structure at $\mathbf{T_n \sim 1.7}$ **GeV** ???

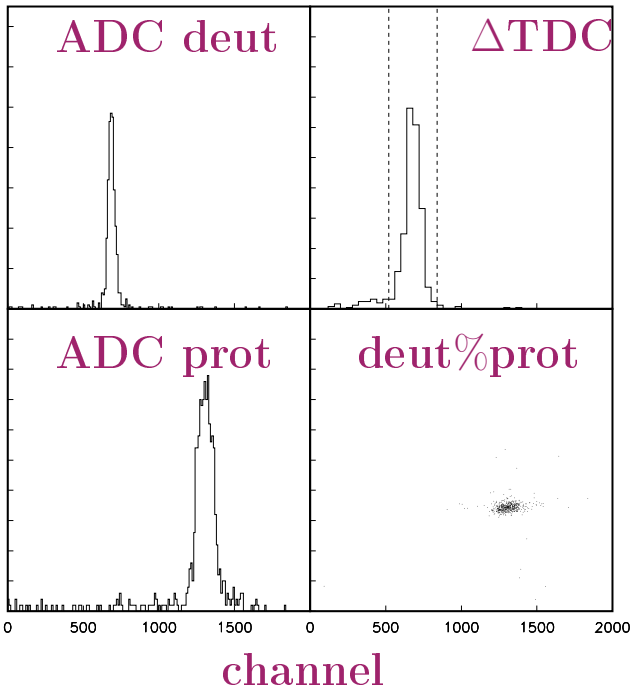
Vector polarization of the deuteron beam at Nuclotron





- Vector polarimeter is based on the left-right asymmetry measurement in quasi-elastic pp scattering (5% of systematics).
- Measurements of the deuteron beam vector polarization have been performed at **3.5** and **5.0 GeV/c**.
- There is no depolarization at Nuclotron.

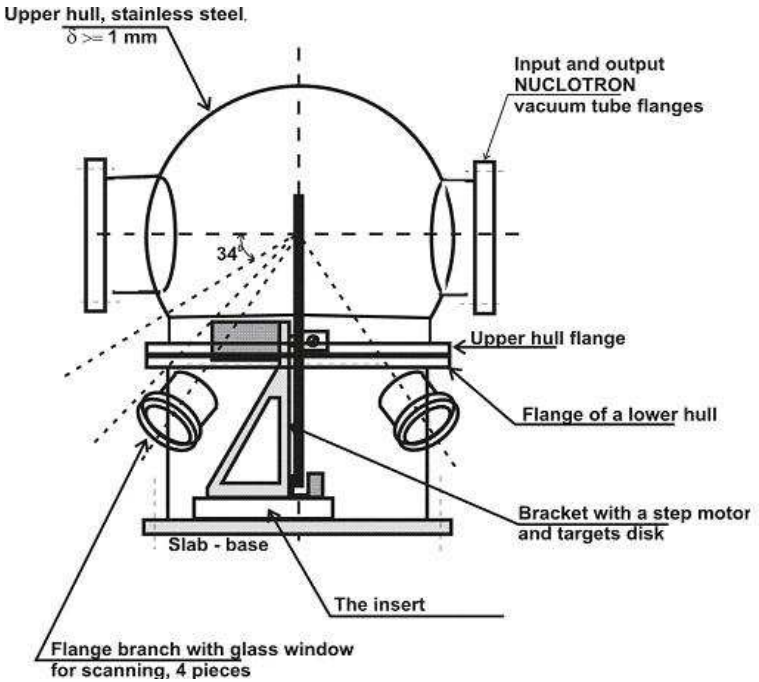
Vector and tensor polarizations measurements at 270 MeV



	Pol.	Mode 2-6	Mode 3-5
ITS	T	0.557± 0.026	-0.555± 0.022
ITS	V	0.215± 0.012	0.221± 0.015
LEP	T	0.69±0.13	-0.67± 0.16

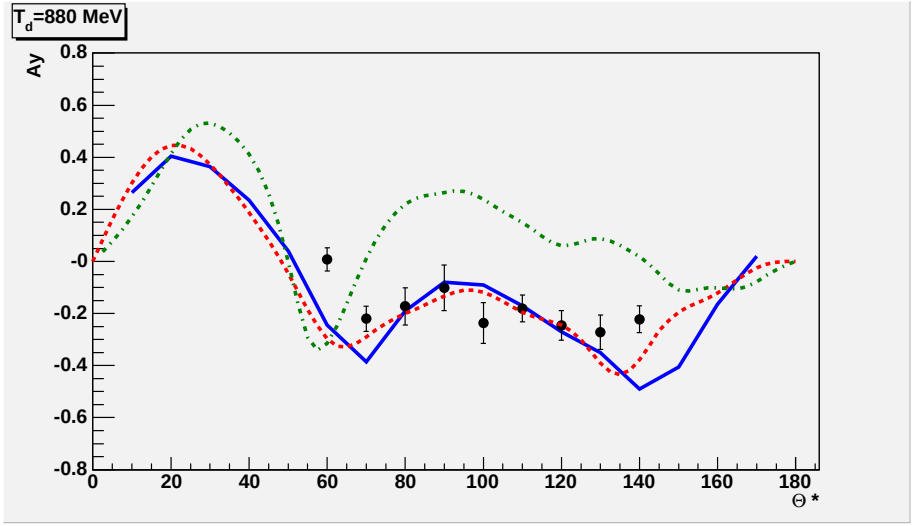
- Polarimeter is based on the asymmetry measurement in dp elastic scattering. (2% of systematics).
- Measurements of the deuteron beam vector and tensor polarization have been performed at 270 MeV (RIKEN data).

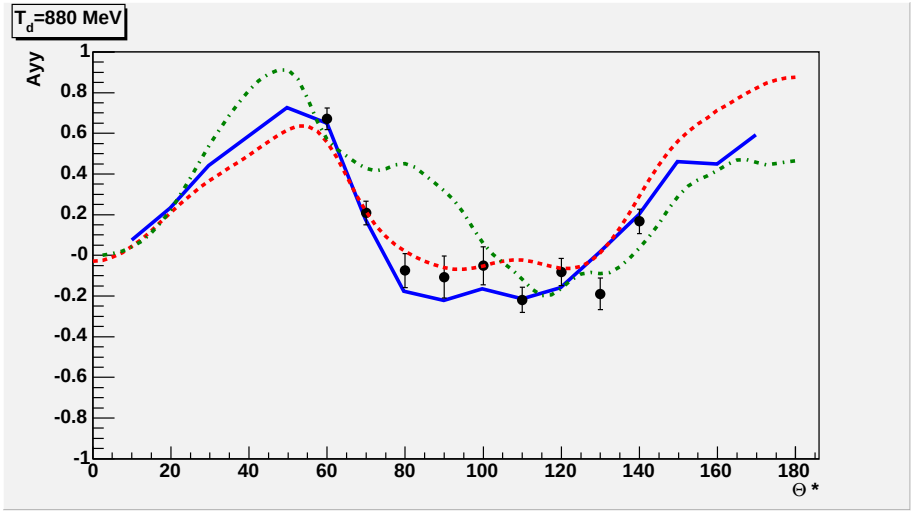
Joint CNS-JINR experiment at Internal Target Station at Nuclotron (LNS-PHe3-projects)



New Internal Target Station is very well suited for the measurements of the dp- elastic scattering observables at large angles in the cms.

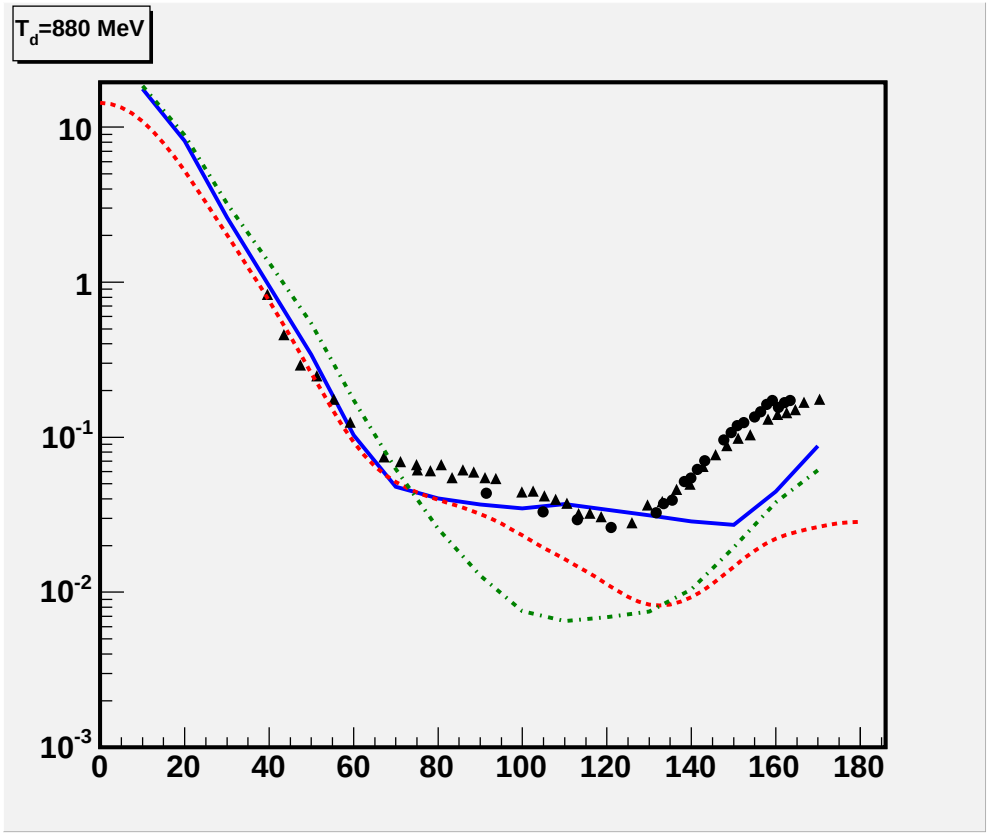
A_y and A_{yy} in dp- elastic scattering at 880 MeV





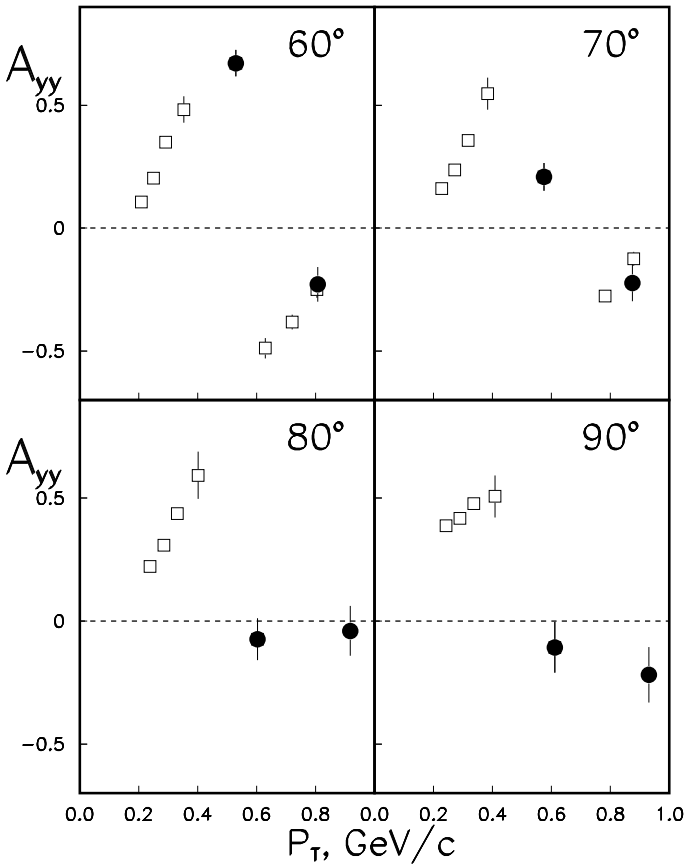
- Solid lines are the multiple scattering model calculations using CD-Bonn DWF (N.B.Ladygina, arXiv:0705.3149v1 [nucl-th]);
- Dashed lines are the Faddeev calculations using CD-Bonn potential (H.Witala, private communication);
- Dott-dashed lines are the optical-potential calculations using Dibaryon DWF (M.Shikhalev, to be submitted in Yad.Fiz.)

Cross section in dp- elastic scattering at 880 MeV



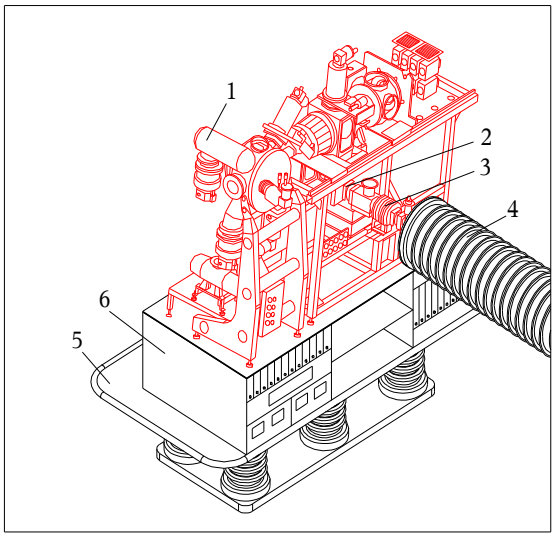
- The results of the multiple scattering model are in agreement with the cross section data in the range $\mathbf{30-130^\circ}$.
- Faddeev calculations (without usual **3NF**) fails to reproduce the data at the angles larger than $\mathbf{90^\circ}$
- Double scattering dominates over single scattering at the angles larger than $\mathbf{70^\circ}$
- The deviation of the data on the calculations at backward angles are related with the $\mathbf{s-type}$ of **FM 3NF**.

Energy dependence of A_{yy} in dp- elastic scattering



- The strong variation of $\mathbf{A_{yy}}$ obtained at the fixed values of the cms angles **60°**, **70°**, **80°** and **90°** versus $\mathbf{p_T}$.
- The values of $\mathbf{A_{yy}}$ are positive at small $\mathbf{p_T}$ and changes the sign at $\mathbf{p_T}$~600–650 MeV/c as in the case of deuteron breakup reaction.
- Negative asymptotic of $\mathbf{A_{yy}}$ at large $\mathbf{p_T}$?

New Polarized Deuteron Source for LHE



- New source will provide up to 10^{10} ppp and higher values of polarization than **POLARIS**.
- Part of the **IUCF** source can be used for the construction.
- **350 k$** and **2** years are required to put into operation new source.
- First operation is planned in **2010 y**. (**see talk of V.D.Kekelidze at June-2007 JINR PAC-meeting**)

Figure of merit increasing by a factor $\sim 10^3$

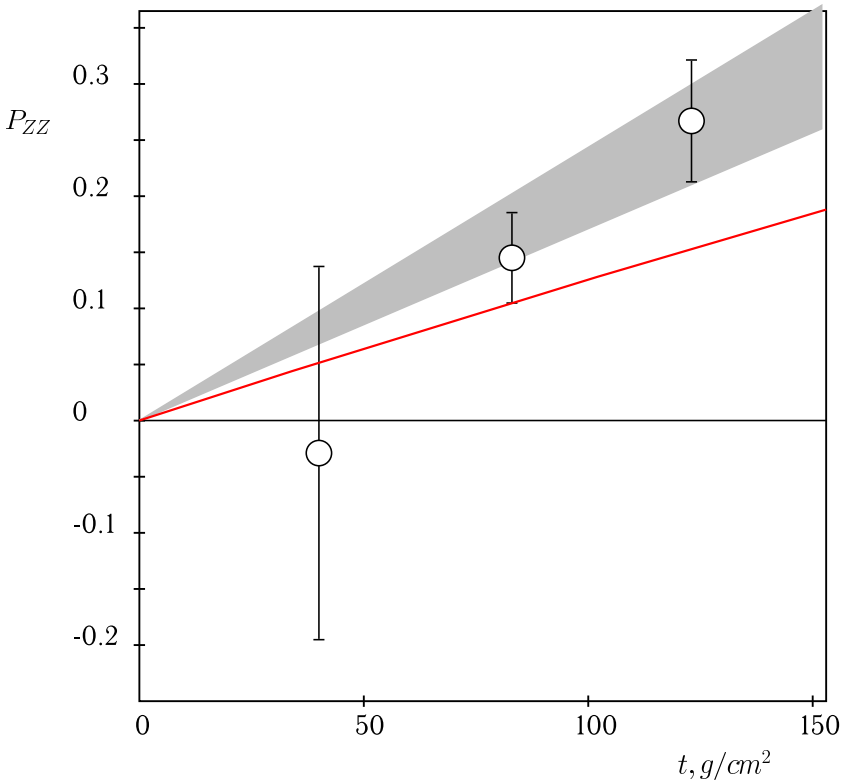
Polarization studies at Nuclotron (Fixed Target)

Experiments with NEW PIS and upgraded PPT at Nuclotron:

- Spin structure of NN and 3N forces
  (relativity and transition to non-nucleonic degrees of freedom)
- Polarization effects in meson production (spin crisis).
- Medium effects for polarization observables
  (χ-symmetry restoration)
- Development of polarization techniques
  (beam and focal plane polarimetry)

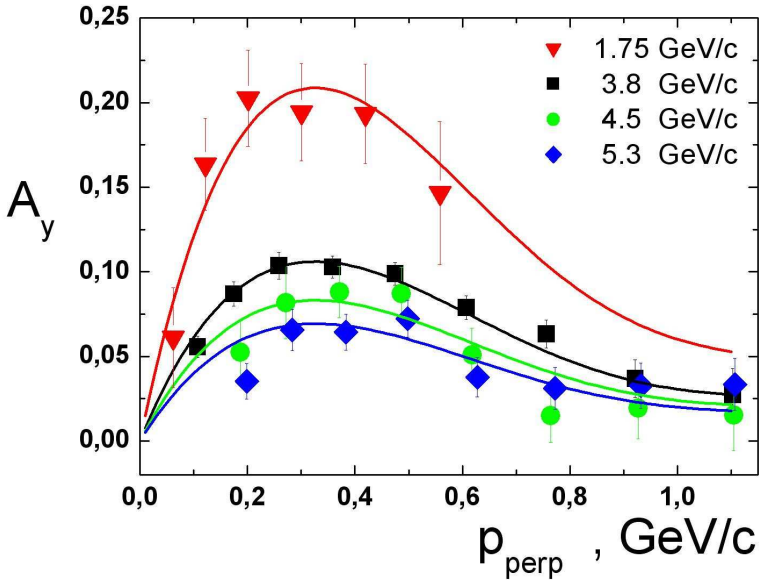
In 2008-2009 experiments with POLARIS and unpolarized beams

Tensor polarizability of the deuteron passing through the matter (TPD-project)



- The strong variation of tensor asymmetry versus the target length is observed for unpolarized deuterons with the momentum **5.5 GeV**.
- The effect of the deuteron spin rotation and oscillations in the matter is predicted by **V.Baryshevsky**. Another explanation of such effect is the Glauber multiple scattering.
- The experiment is planned for continuation in 2008.

Measurement of the inclisive $\vec{p}CH_2$ analyzing power at high energies for JLAB-12



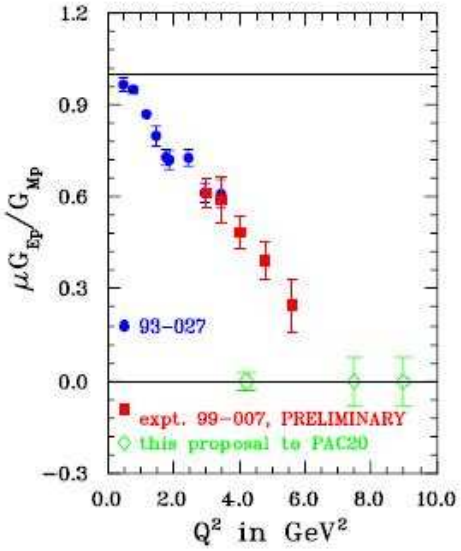
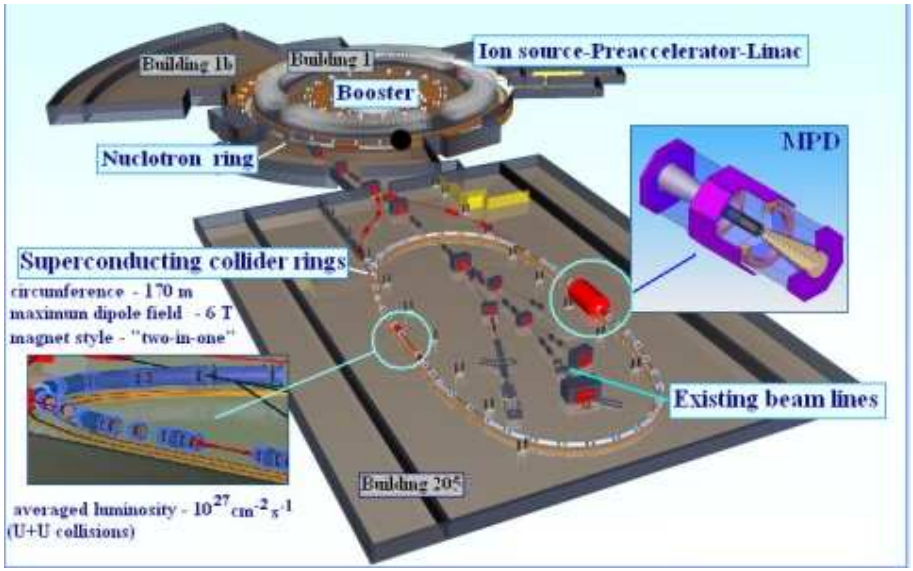


Figure 16: The $\mu_p G_{Ep}/G_{Mp}$ results of experiments 93-027, 99-007 (PRELIMINARY) and proposed 00-111.

The main goal of the project is to obtain the analyzing power for $pCH_2 \rightarrow pX$ reaction at large momenta for G_{Ep}/G_{Mp} experiment at JLAB-12. Also these data are necessary to develop the proton focal-plane polarimetry at hadronic facilities.

Spin-NICA activity

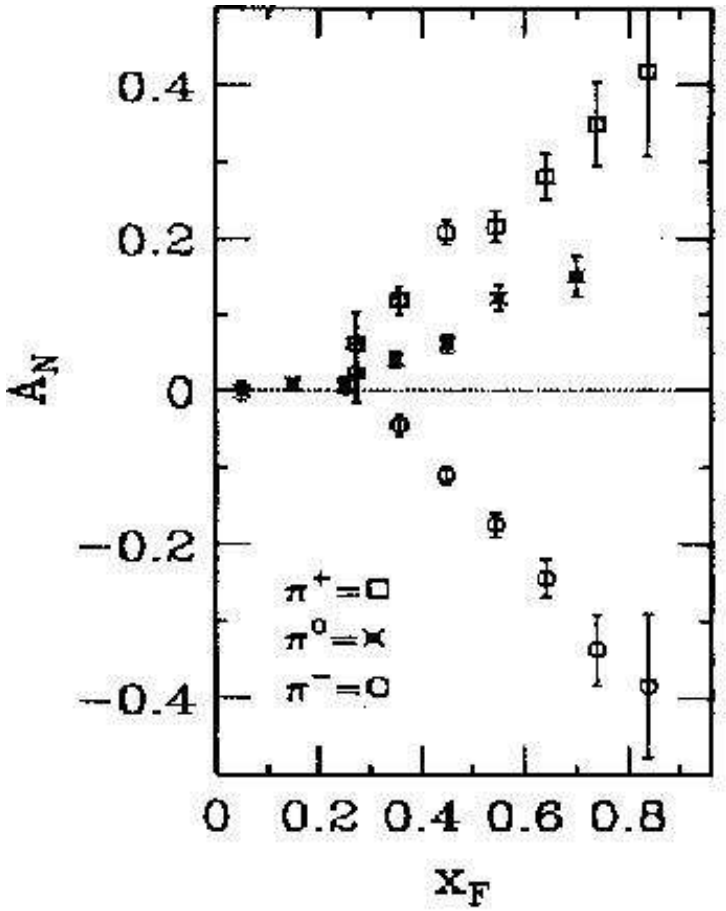


- Spin content of nucleon.
- Nuclear and color transparency in spin observables.
- Polarization effects in hyperon production
- Single and double spin asymmetries in meson production
- Deuteron short-range spin structure (A_{yy} measurements)

New facility is planned to work at $\sqrt{s_{NN}} = 4 \div 12$ GeV for deuterons and up to $\sqrt{s_{NN}} = 27$ GeV for protons.

Serious advantage is the availability of polarized deuterons (neutrons).

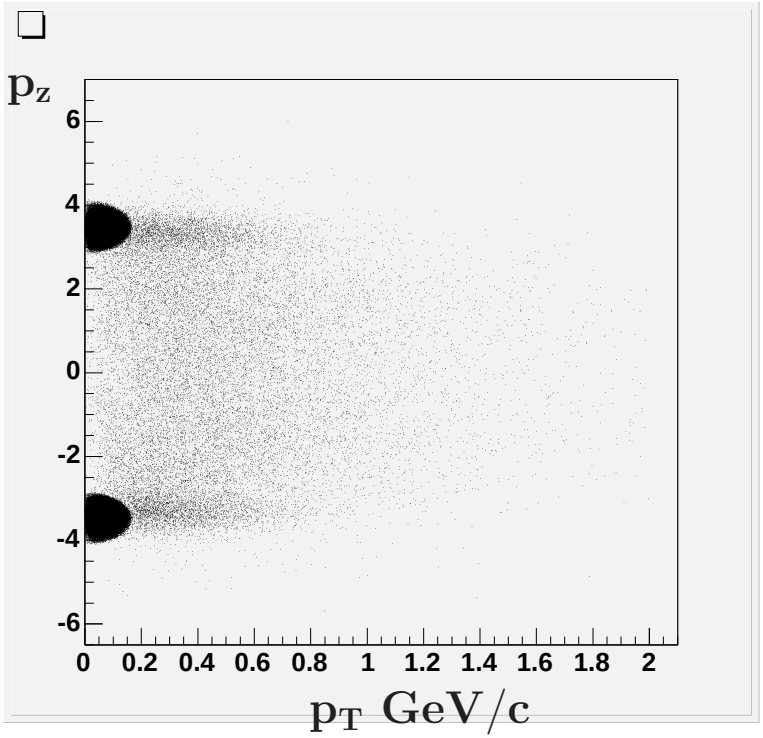
Spin physics at NICA from $\vec{d}\vec{d}$ collisions

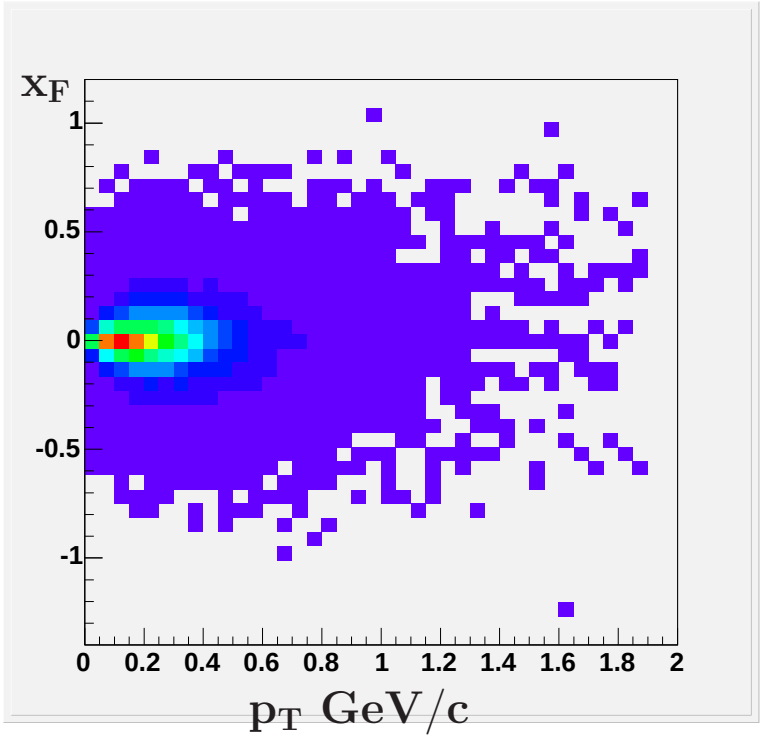


- The perturbative regime in SSA for meson production occurs already at T_N =22 GeV ($\sqrt{s_{NN}} \sim 7$ GeV).
- Single and double spin asymmetries for charged mesons in polarized neutron-proton collisions can be measured using polarized deuteron. Neutrons are produced from deuteron breakup with the proton spectator identification.
- The same motivation for P_N, A_N and D_{NN} for Λ^0 and Ξ^- production.

MPD can be used for V^0 particles detection.

SSA in π production in $\vec{d}\vec{d}$ collisions





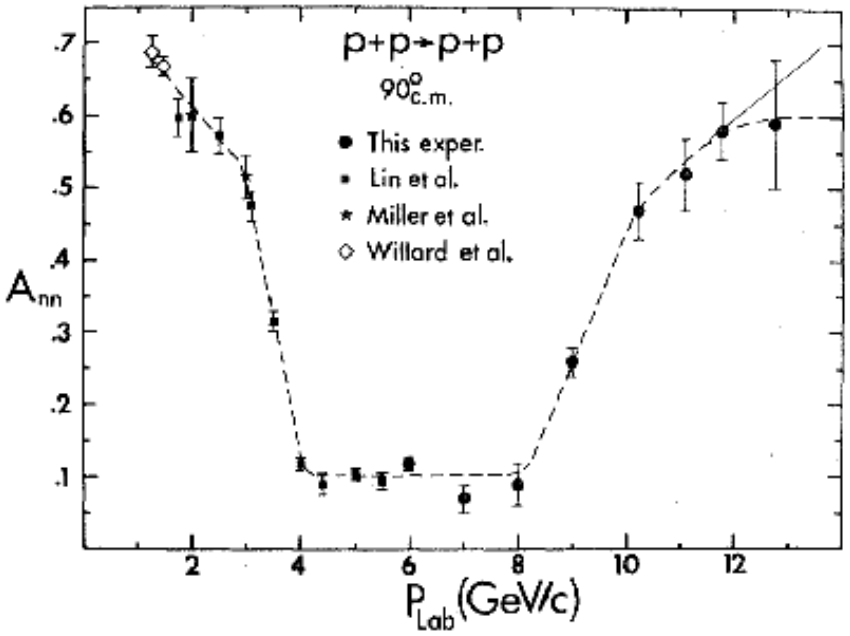
At $\sqrt{s_{NN}} \geq 7$ GeV different SSA sign is expected for the neutron and proton spectators.

Other physics at NICA with polarized deuterons

- A_{NN} puzzle in NN elastic scattering.
- Deuteron and ^{3}He(^{3}H) spin structure from $\vec{d}d \to pX$ and $\vec{d}d \to {}^3$Hen(^{3}Hp) reactions (L.Azhgirey, V.Ladygin et al.).
- Nuclear& color transparency in $\vec{d}A$ collisions.
  Short range 2N and 3N correlations in nuclei.
- Sivers effect in Drell-Yan process (having opposite sign to SIDIS) can be studied in SSA (A.Efremov et al.)
- Transversity A_{TT} measurement: h_1 in DY-process.
- Tensor structure of the deuteron in $\vec{p}\vec{d}$ DY-process. Total number of structure functions is 108 (S.Kumano et al.).

These studies can be complimentary to U-70, J-PARC and FAIR spin programs.

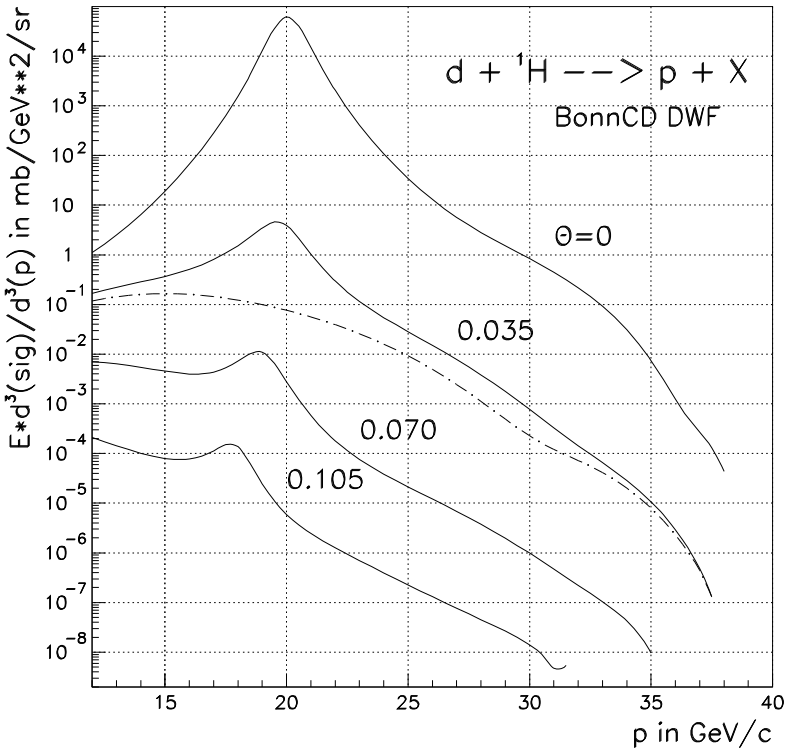
Color and nuclear transparency

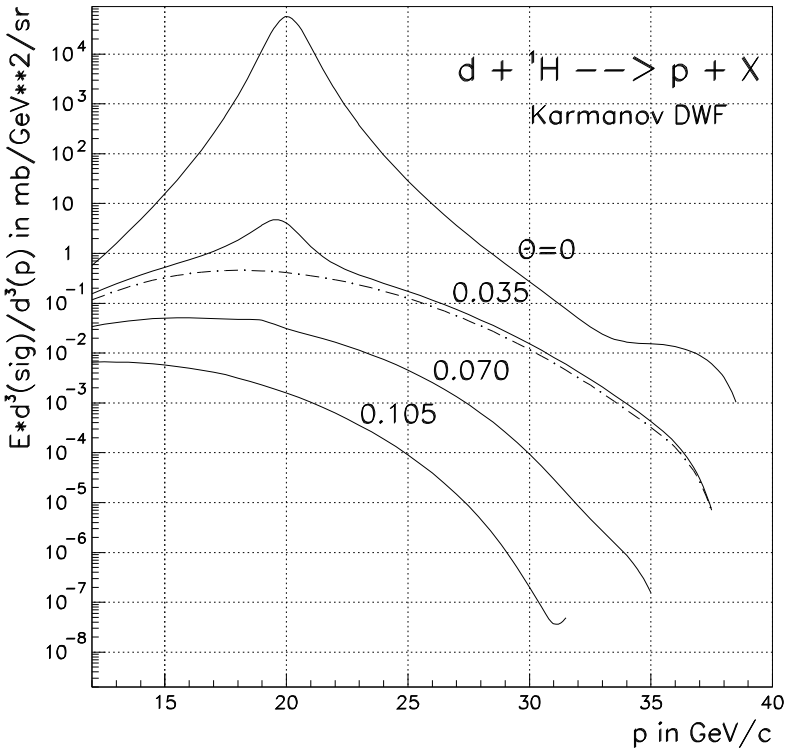


- A_{NN} puzzle in pp elastic scattering in some models are closely related with the problem color and nuclear transparency (S.Brodsky et al.).
- At NICA one can measure A_{NN} for the both pp and np channels.
- Additional measurements of D_{NN} at 90° will allow to separate 2 spin-singlet amplitudes. This can be done at NICA.

The data from Nuclotron are necessary to develop focal plane polarimetry for NICA.

The ^{1}H(d, p)X reaction cross section at 40 GeV/c





- The deuteron internal structure can be probed up to $\mathbf{p_T}\sim$ 2–3 GeV/c.
- $\mathbf{x}$ and $\mathbf{p_T}$ dependences given by two models are very different.
- Hidden color in deuteron: $\mathbf{N(d, p\pi)X}$ vs $\mathbf{N(d, p)X}$.
- NICA will provide the opportunity to measure $\mathbf{A_{yy}}$ and $\mathbf{K^y_y}$.

Conclusions

- The current spin program at Nuclotron brings new insight on the spin effects in the region of non-perturbative QCD where the transition from nucleon-meson degrees of freedom to the quark-gluon ones occurs.
- The putting into operation new PIS and upgrade of the existing PPT will significantly increase the potentialities of Nuclotron as a spin facility in a GeV range. This development is also the key point for NICA.
- First stage of spin studies at NICA can be done using $\vec{d}\vec{d}$ collisions at $\sqrt{s_{NN}} = 4 \div 12$ GeV.

Thank you for attention