FEW-BODY STUDIES AT NUCLOTRON-JINR





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Outline

- Introduction
- Recent results on the cross section energy scan of dp-elastic scattering at intermediate and high energies
- Preliminary results on **dp** nonmesonic breakup
- Plans for Nuclotron
- Conclusion

Collaboration: Bulgaria-JINR-Japan-Romania-Russia-Slovakia

Talk is based on the results of Yu.Gurchin, S.Piyadin, A.Terekhin.

Motivation

- Modern NN potentials (CD-Bonn, AV-18, Njimegen etc.) accurately reproduce the NN data set up to about 350 MeV. However they fail in the description of the binding energy and data on unpolarized dp-elastic scattering and breakup reactions.
- Incorporation of three nucleon forces (3NF), when interaction depends on the quantum numbers of the all three nucleon, allows to reproduce the binding energy of the three-nucleon bound systems and the data on unpolarized dp- interaction.
- Polarization data for the reaction with participation of three and more nucleons aren't described even with the 3NF inclusion.
- The cross section data for dp- elastic scattering are reproduced well up to 150 MeV taking into account 3NF. Manifestation of three-nucleon forces effect in the cross-section of dp-elastic scattering at this energy: up to 30% in the vicinity of Sagara discrepancy.

Cross section in dp- elastic scattering at intermediate energies



The differential cross section in elastic Nd scattering at the energy of 135 (left figure) and 250 (right figure) MeV/u.

K. Sekiguchi et al., Phys. Rev. Lett. 95, 162301 (2005)

K. Hatanaka et al., Phys. Rev. C 66, 044002 (2002)

The study of hadronic reactions induced by deuterons at Nuclotron will allow to study the structure of 2N and 3N forces.

Analyzing powers in dp- elastic scattering at 880 MeV



Dashed lines are the multiple scattering model calculations using CD -Bonn DWF (N.B.Ladygina, Phys.Atom.Nucl.71 (2008), 2039) Solid 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, Phys.Atom.Nucl.72 (2009), 588)
Published in P.K.Kurilkin et al., Phys.Lett.B715 (2012) 61-65

A_y and A_{yy} in dp- elastic scattering at 2000 MeV



Open squares are the data obtained at Nuclotron JINR. Open circles are the Synchrophasotron data (V.V.Glagolev, Eur. Phys. J. A48 (2012) 182)

Solid symbols are the data obtained by ANL group (Haji-Saied et al., Phys.Rev.C.36 (1987) 2010). Dashed and solid lines are the relativistic multiple scattering model calculations using CD-Bonn DWF taking into account single scattering and single+double scattering, respectively.

Energy dependence of the dp-elastic scattering analyzing powers at fixed scattering angles in the c.m.s.



- Full symbols are the data obtained at JINR
- Open symbols are the data obtained at RIKEN, Saclay and ANL.
- The study of the energy dependence of the analyzing powers in dp- elastic scattering at large p_T is one of the tools to study cold dense matter



The purpose of the **DSS** experimental program is to obtain the information about **2NF** and **3NF** (including their spin – dependent parts) from two processes:

1.dp-elastic scattering at the energies between 300 - 2000 MeV;

2.dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

Experiments at Internal Target Station at Nuclotron (DSS-proect)



Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.

Scheme of the LE- dp- experiment

 M_{1-6}





Vertical

plane

P and D - proton and deuteron detectors (dp-elastic scattering)

PP-L and PP-R –proton detectors (pp-quasi elastic scattering)

M₁₋₆ - monitor counters.

Yu.V.Gurchin

The **dp**- elastic scattering investigation at Nuclotron



- Commissioning experiment with the upgraded setup has been performed in March 2011 at the energies of 500 and 880 MeV.
- Systematic studies of dp- elastic scattering cross section at ITS at Nuclotron at 400-1000 MeV. New data on cross section at 600, 700, 800, 880 and 1000 MeV in 2011-2012.

Cross section in *dp*- elastic scattering at 880 MeV



World data:

N.E.Booth et al., Phys.Rev.D4 (1971) 1261 J.C.Alder et al., Phys.Rev.C6 (1972) 2010

- The results of the multiple scattering model are in agreement with the cross section data in the range 30 - 130°.
- Double scattering dominates over single scattering at the angles larger than 70°.
- Deviation of the data on the calculations at backward angles are related with the s-type of the FM 3NF.
- Is the deviation on the data from the calculations around 90° manifestation of 3N short range forces?

Relativistic multiple scattering model calculation: N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

Red circles are the preliminary LHEP-JINR results: DSS-project at Nuclotron.



Scheme of the HE-dp experiment





 $P = 20x60x20 \text{ mm}^3$ $D = 10x40x24 \text{ mm}^3$ $PP = 50x50x20 \text{ mm}^3$ **March 2013**



 $P = 20x60x20 \text{ mm}^3$ $D = 50x50x20 \text{ mm}^3$ $PP = \phi 100 x 200 mm^3$ December 2012

HE dp-experiment data analysis



Differential cross section at 2000 MeV



dp-elastic differential cross section



Blue triangles – data at 792.7 MeV/n (Culmez E. Phys.Rev.C, V43, №5, 1991)
Green triangles – data from 800 MeV/n (Winkelmann E. Plays.Rev.C, V21, №6, 1980)

Experimental system for dp-breakup.





S.Piyadin



Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deutron energy 300 MeV.



Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deutron energy 400 MeV.

The deuteron energy of 500 MeV. netu $\Theta_1 = 24.7^\circ, \Theta_8 = 53.3^\circ,$ $\Theta_2 = 24.7^\circ, \Theta_4 = 33.3^\circ,$ $\Theta_1 = 24.7^\circ, \Theta_3 = 33.3^\circ,$ $\phi_{18} = 135.4^{\circ}$ $\varphi_{24} = 46.5^{\circ}$ $\phi_{12} = 44.6^{\circ}$ EdotIII/MoV EdetVIII/MeV EdetIV(MeV 80 100 120 140 160 180 110 120 130 140 150 160 170 180 60 80 100 120 140 160 180 EdetIII(MeV) EdetI(MeV) EdetI(MeV)

Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deutron energy 500 MeV.

New Polarized Deuteron Source for LHEP



 New source will provide up to 2*10¹⁰ ppp and higher values of polarization than POLARIS.

Part of the **IUCF** source is used for the construction. The putting into operation of new PIS is planned in 2014.

Large variety of the spin modes. **DSS** project will use the spin modes with the following ideal values of (p_z, p_{zz}) : (0,0), (0,-2), (2/3,0) and (-1/3,+1)

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



Physics for the BM@N spectrometer with inner tracker: -The measurements of the (sub)threshold cascade hyperons production in order to obtain the information on the nuclear matter EOS.

Physics for the first stage of the BM@N spectrometer:
-In-medium effects for vector mesons decaying in hadron modes
-Flows, polarizations, azhimuthal correlations and vorticity.
-Femtoscopy for different hadrons (and photons)
-NN, NA, dA interactions as the reference for AA collisions
(including spin observables!)



Conclusion

- The data on the analyzing powers A_y, A_{yy} and A_{xx} in dp- elastic scattering have been measured at ITS at the Nuclotron at the energies of 880 and 2000 MeV.
- The data on the energy dependence of the **dp** elastic scattering cross section have been accumulated at 400-2000 MeV. The data analysis is in progress.
- The data on **dp** nonmesonic breakup have been obtained at 300, 400 and 500 MeV for different kinematic configurations.
- Future studies of the deuteron-induced reactions like dp→pd, dpbreakup, dd → ³Hp(³Hen) and d³He → p⁴He at Nuclotron are related with new PIS developed at LHEP-JINR. These new experimental data and further development in theoretical approaches will be important for adequate description of the short-range light nuclei spin structure.
- New project "Baryonic Matter at Nuclotron" will allow to measure spin and polarization effects in a GeV region with extracted beams.

New ideas are welcome!

Thank you for the attention!!!

dd \rightarrow ³Hen(³Hp) reactions at Nuclotron energies



The relativistic multiple scattering model can be successfully used to describe the $dd \rightarrow {}^{3}Hen({}^{3}Hp)$ reactions in a GeV region at the Nuclotron. The calculations require a large amount of CPUs. The results will be published in Few Body Systems (talk N.B.Ladygina).

Quark degrees of freedom

• At high energy **s** and large transverse momenta **p**_t the constituent counting roles (CCR) predict the following behavior of the differential cross section for the binary reactions:

$$\frac{d\sigma}{dt}(ab \rightarrow cd) = \frac{f(t/s)}{s^{n-2}} \qquad ; \qquad n = N_a + N_b + N_c + N_d$$

(Matveev, Muradyan, Tavkhelidze, Brodsky, Farrar et al.)



Yu. N. Uzikov (JETP Lett, 81, pp. 303-306, 2005) For the reaction dd \rightarrow ³Hen $N_A + N_B + N_C + N_D - 2 = 22$ For the reaction dp \rightarrow dp $N_A + N_B + N_C + N_D - 2 = 16$

$$N_{A} + N_{B} + N_{C} + N_{D} - 2 = 16$$

The regime corresponds to CCR can occur already at $T_{\rm d} \sim 500~MeV$

CNS-JINR setup to study **dp**- elastic scattering



- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH₂ target (C for background estimation)
- Polarization measurement at 270 MeV
- Analyzing powers measurement at 880 and 2000 MeV
- The data were taken for three spin modes of PIS: unpolarized, "2-6" and "3-5" $(p_z, p_{zz}) = (0,0), (1/3,1) \text{ and } (1/3,-1)$

Measurement of the deuteron beam polarization at ITS using CNS detection system at 270 MeV



A schematic view of the polarimeter setup installed downstream the ITS spherical chamber.



Tensor p_{yy} and vector p_y polarization of the beam for "2-6" and "3-5" spin modes of PIS POLARIS as a function of the deuteron scattering angle in the c.m.s.

- Main deuteron beam polarimeter at Nuclotron-M.
- dp- elastic scattering at large scattering angles in the center of mass system.
- The detectors cover the angular range 60-140° in the c.m.s. (P.K. Kurilkin et al., Nucl. Instr. and Meth. A 642 (2011) 45)

Deuteron beam polarimetry at the ITS at Nuclotron-M

Measurement of the beam polarization is an important element in different physical experiments.

dp elastic scattering at large angles(Θ_{cm} >60°) – the deuteron beam polarimetry at RIKEN (E_d ~100MeV).

The advantages of the use of the dp- elastic scattering at large angles(Θ_{cm} >60°) at the 270 – 2000 MeV energy range:

- Analyzing powers of this reaction have large values.
- The kinematical coincidence measurement of the deuteron and proton with plastic scintillation counters sufficient for event identification.

Talk of Pavel Kurilkin at this Conference

Subtraction of carbon contribution





The quality of the carbon contribution subtraction for dd->³Hp at 200 MeV at several scattering angles in c.m.s.

The quality of the carbon contribution subtraction for dd->³Hen at 270 MeV at several scattering angles in c.m.s.

R308 experiment at RIKEN

- Investigation of the ³H, ³He and deuteron spin structure at short distances at the energies 140, 200, 270 MeV.
- Polarization observables comparison from mirror channels: ³Hp and ³Hen.



RIKEN Accelerator Research Facility. SMART spectrometer.

Polarization observables from the dd \rightarrow ³Hen(³Hp) reactions (Japan-JINR)



The solid curve is the result of the ONE calculations using CD-Bonn ³He and deuteron wave functions. The dotted curve is the result of the ONE calculations using ³He and deuteron wave functions derived from Paris potential. The ³He wave function were taken from the work (V.Baru Eur.Phys.J.A16:437-446,2003).