Measurements of the total cross section difference $\Delta\sigma_T$ (np) and spin-correlation parameter A_{oonn}(np) using high intensity polarized deuteron beams from the Nuclotron-M.

Delta-Sigma-T experiment

Extending of the investigation of elastic np spin - dependent observables for the GeV energy range at the JINR Nuclotron-M Facility

Outline

- Recent understanding of the NN interactions. Urgency of the data obtaining for np spin observables in the GeV region.
- Aims of the Delta-Sigma-T experiment.
- Use of the expected results
- Why this project is proposed just now?
- Results obtained and coming research program
- Readiness of the Delta-Sigma experimental set-up
- High intensity polarized deuteron beam at the Nuclotron-M

- Summary

Outline

- Recent understanding of the NN interactions. Urgency of the data obtaining for np spin observables in the GeV region.
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Recent understanding of the NN interactions

Why a problem of the data obtaining for elastic np scattering spin observables in the GeV region and above is discussed today?

We quote the points of view on this question of the two well known physicists of today: theorist and experimentalist.

Recent understanding of the NN interactions

"The theory of the nucleon-nucleon (NN) interaction in the range of about 1-10 GeV is one of the most pressing open questions of modern nuclear / particle physics.

Below that energy range, chiral effective field theory applies as well as meson theory.

At very high energies (~ 100 GeV) perturbative QCD can be used.

But it is the "intermediate" region of a few GeV where theory has big problems. Meaningful theoretical work cannot be done unless we have also data in that critical region. The data for np are very scarce, too few to even pin down a reasonable phenomenology.

For our understanding of the fundamental NN interaction on a broad scale, it is vital to have data for np spin observables in the GeV region.
These data will be useful for the entire international nuclear/particle physics Community ".

Ruprecht Machleidt

Professor of Physics

One of the authors of the Bonn NN potential.

Recent understanding of the NN interactions

Indeed the elastic NN spin observables data base (in particular np data) is poor for energy region of interest.

Full phenomenological description (energy dependent phase shift analysis) of NN interactions are possible now only up to 3 GeV for pp and 1.3 GeV for np collisions.

There is no dynamical theory (meson exchange, nonperturbative QCD) which can describe measured NN spin dependent observables over energy region above 1 GeV.

Prof. A.D. KRISCH. Invited talk at DSPIN-09
1-5 September 2009, JINR-Dubna

SUMMARY

"For the past 30 years QCD-based calculations have continued to disagree with the ZGS 2-spin & AGS 1-spin elastic data and the ZGS, AGS, Fermilab & RHIC inclusive data.
*** These large spin effects do not go to zero at high-energy or high-$P_\perp$ as was predicted.**
*** No QCD-based model can explain all the large spin effects.**

BASIC PRINCIPLE OF SCIENCE:

If a theory does not agree with reproducible experimental data,
then the theory must be modified.

These precise spin experiments provide experimental guidance for the required modification of the theory of Strong Interactions.
Elastic dσ/dt, Ann and An experiments at higher energy and $P_\perp$ could provide more guidance,
just as the RHIC inclusive An experiments confirmed the similar Fermilab experiments. (E-704 Yokosawa et al.).

Elastic scattering is especially important, because it is the:
Only exclusive process that is large enough to be measured at TeV energy.
This is because proton-proton elastic scattering is dominated by the diffraction due to the millions of inelastic channels competing for the $\sigma_{TOT} \leq 100$ milibarns at TeV energies.
Many people may have forgotten this simple but important geometrical point.
See: *R. Serber, PRL **10**, 357 (1963); ADK, PRL **11**, 217 (1963); PR **135**, B1456 (1964); PRL **19**, 1149 (1967)"*

Recent understanding of the NN interactions

We emphasize the following.
"BASIC PRINCIPLE OF SCIENCE: If a theory does not agree with reproducible experimental data, then the theory must be modified.

The precise existing and those to be obtained experimental data on spin dependent NN observables provide experimental guidance for the required modification of the strong interactions theory.

It is imperative to obtain new precise and detailed elastic NN spin data over the energy region of interest is obvious now.

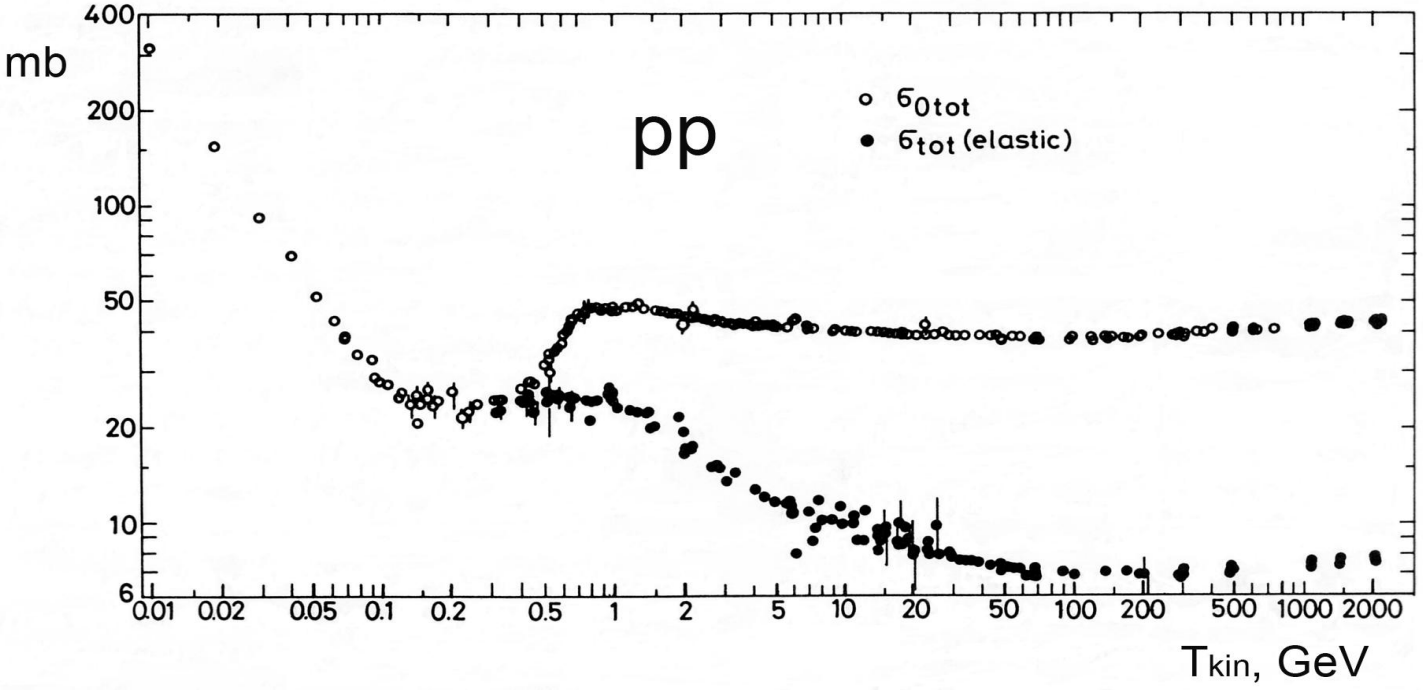
Recent understanding of the NN interactions

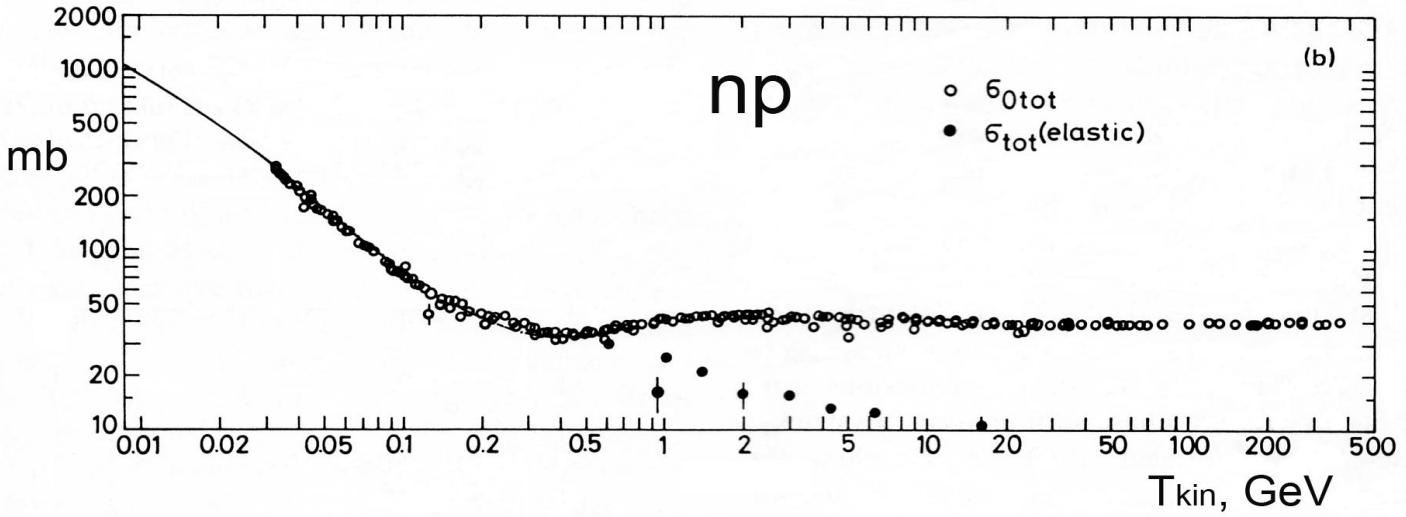
Why the elastic NN scattering spin-dependent observables are most suitable for experimental investigation and attempts of dynamical description of the strong interactions?

1. The inelasticies do not complicate the attempts of dynamical models creation.

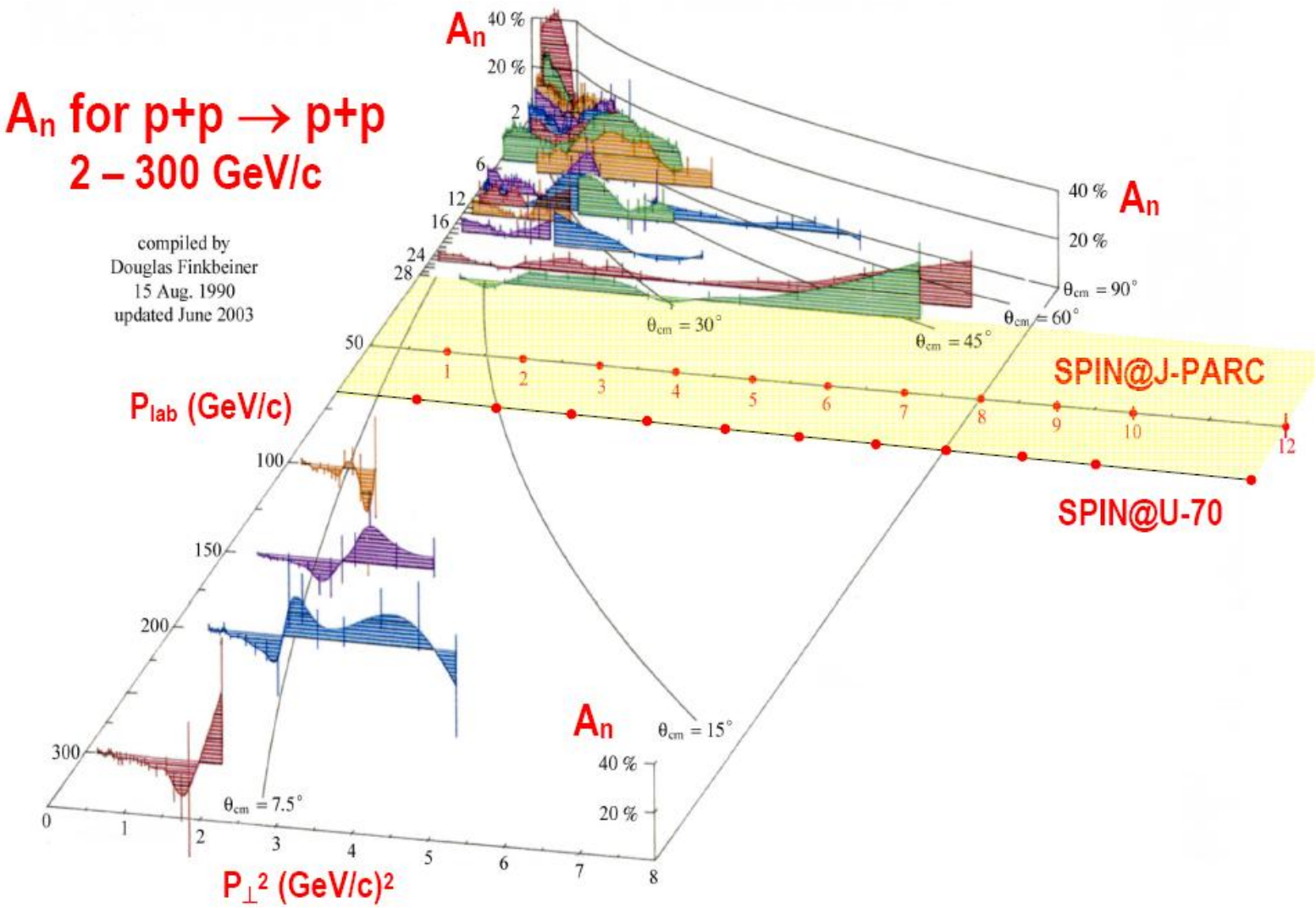
2. The corresponding formal description of the NN interaction (S matrix theory) exists.

3. Total elastic NN cross sections are large enough over the energy region up to ~ TeV





4. Spin effects are large enough over a wide energy region



Recent understanding of the NN interactions

5. Experimental data for the elastic NN spin dependent observables contain complete information about NN interaction properties:

- pp data for the isovector part,
- np data for the isoscalar part and
- spin-dependent results for the spin characteristics.

Many particle physicists are aware of the problem and support continuation measurements of spin dependent np observables over the Dubna accelerators energy region 1 – 4 GeV.

Outline

- Recent understanding of the NN interactions. Urgency of the data obtaining for np spin observables in the GeV region.
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- Use of the expected results
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Aim of the Delta-Sigma-T experiment

The main aim of the project “Delta-Sigma-T experiment” is accumulation of a complete set of detail and precise experimental results for the elastic np scattering spin-dependent observables over a new high energy region of free polarized neutron beams 1.2 – 4 GeV provided at present only at the JINR VBLHEP accelerator Nuclotron-M .

Aim of the Delta-Sigma-T experiment

The Delta-Sigma research program foresees the measurements of energy dependences of total cross section differences $\Delta\sigma_{L,T}(np)$ and spin correlation parameters $A_{00kk}(np)$ and $A_{00nn}(np)$ at $\theta_{CM} = \pi$ for the longitudinal (**L** - along the incident nucleon momentum **k**) and transverse (**T** – along the perpendicular **n** to the **k**) beam and target polarization directions, respectively.

The $\Delta\sigma_T(np)$, $\Delta\sigma_L(np)$, $A_{oonn}(np)$ and $A_{ookk}(np)$ data obtained under the Delta-Sigma-T program, together with the obtained early $\Delta\sigma_L(np)$ and R_{dp} results, will form a complete set of the spin-dependent observables for the forward (backward) elastic np scattering at the neutron beam energy range of 1 ~ 4 GeV.

Such set of the np observables data will be obtained for the first time over this energy region.

Use of the expected results

Obtained data set

- can be used to check the predictions of dynamical models for NN interaction;
- can be used to extend the NN phase shift analysis to higher energies;
- will allow to obtain by direct reconstruction the values of all imaginary and real parts of spin-dependent forward np-scattering amplitudes.

Values of σ_{0tot}, $\Delta\sigma_T$ and $\Delta\sigma_L$ are connected with the imaginary parts of three invariant forward scattering amplitudes **a + b**, **c** and **d** via three optical theorems:

$$\sigma_{0tot} = (2\pi/K)\ \mathrm{Im}\ [a(0) + b(0)], \qquad (3)$$

$$-\Delta\sigma_T = (4\pi/K)\ \mathrm{Im}\ [c(0) + d(0)], \qquad (4)$$

$$-\Delta\sigma_L = (4\pi/K)\ \mathrm{Im}\ [c(0) - d(0)]. \qquad (5)$$

From measured $\Delta\sigma_{L,T}$ **(np)** values one can unambiguously extract imaginary parts of invariant forward scattering amplitudes **c** and **d** using Eq. (4, 5).

Using the known imaginary parts of the forward amplitudes transformed into the backward direction, the np differential cross section $d\sigma/d\Omega\ (\pi)$ and the two spin correlation parameters $A_{ookk}(np)$ and $A_{oonn}(np)$ at $\theta_{CM} = \pi$ are sufficient to obtain the real parts of all the three amplitudes from Eqs. (9) − (12).

But in contrast to the optical theorems at $\theta_{CM} = 0$, the scattering amplitudes in the backward direction are related to the np scattering observables by bilinear equations. Each of them may have, in principle, an independent ambiguity in the sign.

The total ambiguity is then eight-fold at most and any independent experiment decreases it by a factor of two.

To reduce the total ambiguity in the scattering amplitude determination, the Delta-Sigma collaboration performed the measurements of the ratio

$R_{dp} = d\sigma/d\Omega\ (nd \rightarrow p(nn)) / d\sigma/d\Omega\ (np \rightarrow pn)$.

for the charge exchange processes on the deuterium and hydrogen targets.

Why this project is proposed namely today?

1. New high intensity source of polarized deuterons (SPD) will be put in operation at the Nuclotron-M in the near future .

The intensity of polarized deuteron beam produced by SPD will be more then 10 times higher than the intensity from POLARIS .

Therefore measurements of polarized observables can be carried out with the statistical errors 3 times less. This will provide a new qualitative level of polarization experiment at the JINR LHEP.

Event rate comparison for the collider and "fix" target experiments

Planned luminosity in the spin experiments at the collider is estimated by a value of $L=1\times10^{30}$ sm^{-2} s^{-1} for the polarized pp colliding beams. That is 1 count per second will be for the events with total cross section of $\sigma_{tot} \sim 10^{-30}$ sm^{-2} (1 μb).

In the "fix" target experiments with polarized proton target ($n_H \sim 10^{24}$ sm^{-2}) and at the polarized proton beam intensity of $I \sim 10^{10}$ p/cycle, 1 count per second will be for the events with total cross section of

$\sigma_{tot} \sim 10^{-34}$ sm^{-2} (100 pb).

That's why a necessity of the "fix" target spin experiments is obvious.

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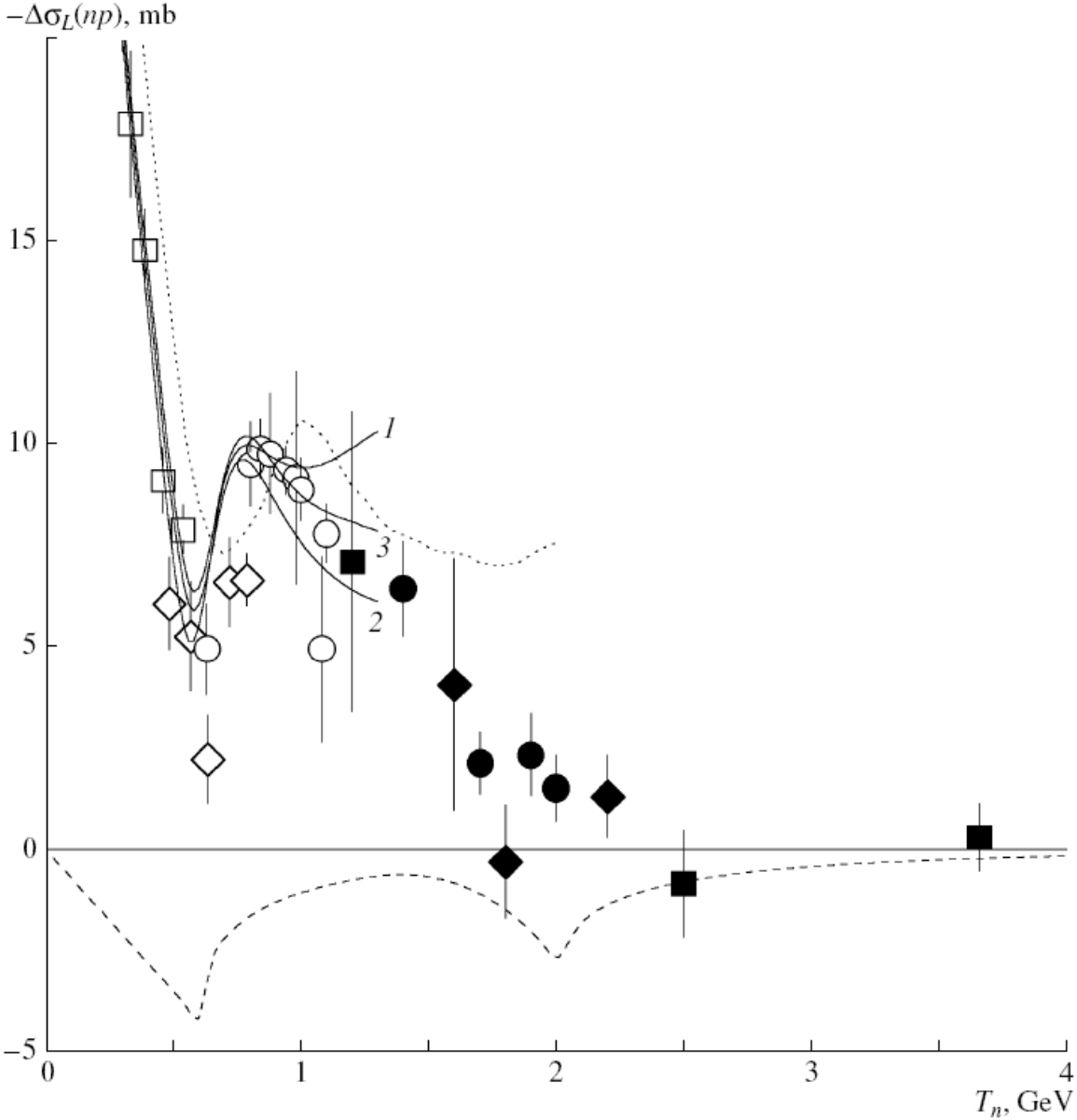
Energy dependence of the $-\Delta\sigma_L$ (np) observable



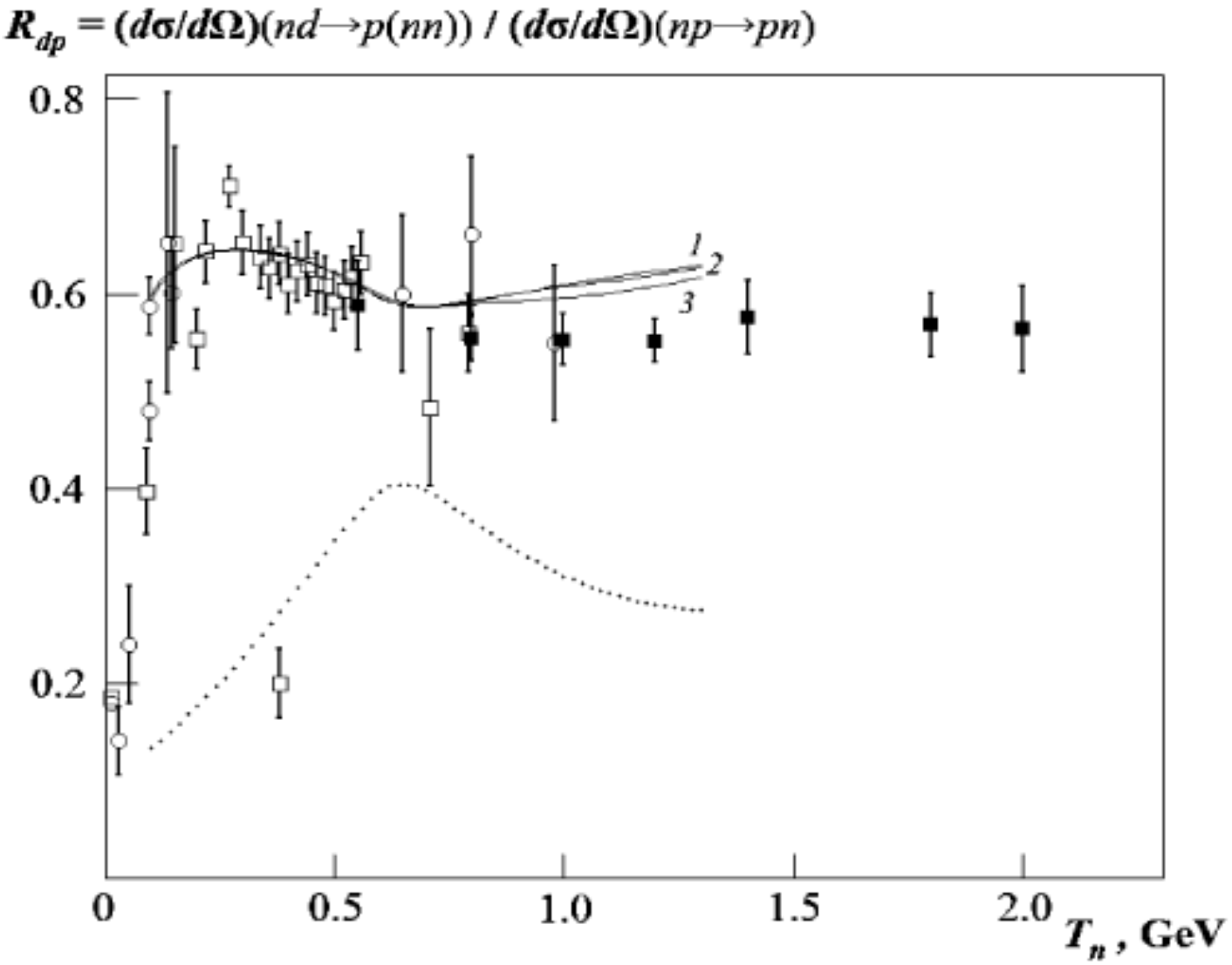
Measurements of the $-\Delta\sigma_L$ **(np)** energy dependence were in the main completed.

Results were published in proceedings of intern. workshops (>12 contributions) and scientific journals (6 regular papers):

References on $-\Delta\sigma_L$ (np) results

1. B.P.Adiasevich, V.G.Antonenko, S.A.Averichev, L.S.Azhgirey et al. **Zeitschrift fur Physik C71 (1996) 65.**
2. V.I.Sharov, S.A.Zaporozhets, B.P.Adiasevich, V.G.Antonenko et al. **JINR Rapid Communications 3[77]-96 (1996) 13.**
3. V.I.Sharov, S.A.Zaporozhets, B.P.Adiasevich, N.G.Anischenko et al. **JINR Rapid Communications 4[96]-99 (1999) 5.**
4. V.I.Sharov, S.A.Zaporozhets, B.P.Adiasevich, N.G.Anischenko et al. **European Physical Journal C13 (2000) 255.**
5. V.I.Sharov, N.G.Anischenko, V.G.Antonenko, S.A.Averichev et al. **European Physical Journal C37 (2004) 79-90.**
6. V.I.Sharov, N.G.Anischenko, V.G.Antonenko, S.A.Averichev et al. **Yadernaya Fizika v.68, №11 (2005) 1858-1873.**
   Physics of Atomic Nuclei v.68, №11 (2005) 1796-1811.

Energy dependence of the R_{dp} observable



Eur. Phys. J. A **39**, 267–280 (2009) DOI: 10.1140/epja/i2008-10719-x

Measurements of the ratio R_{dp} of the quasi-elastic nd $\rightarrow$ p(nn) to the elastic np $\rightarrow$ pn charge-exchange process yields at zero proton emission angle over the 0.55–2.0 GeV neutron beam energy region

V.I. Sharov, A.A. Morozov, R.A. Shindin, V.G. Antonenko, S.B. Borzakov, Yu.T. Borzunov, E.V. Chernykh, V.F. Chumakov, S.A. Dolgii, M. Finger, M. Finger jr., L.B. Golovanov, D.K. Guriev, A. Janata, A.D. Kirillov, A.D. Kovalenko, V.A. Krasnov, N.A. Kuzmin, A.K. Kurilkin, P.K. Kurilkin, A.N. Livanov, V.M. Lutsenko, P.K. Maniakov, E.A. Matyushevsky, G.P. Nikolaevsky, A.A. Nomofilov, Tz. Panteleev, S.M. Piyadin, I.L. Pisarev, Yu.P. Polunin, A.N. Prokofiev, V.Yu. Prytkov, P.A. Rukoyatkin, M. Slunevcka, V. Slunevckov'a, A.Yu. Starikov, L.N. Strunov, T.A. Vasiliev, E.I. Vorobiev, I.P. Yudin, I.V. Zaitsev, A.A. Zhdanov and V.N. Zhmyrov

ЯДЕРНАЯ ФИЗИКА, 2009, том 72, №6, с. 1051–1064
ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

THE RATIO *Rdp* OF THE QUASI-ELASTIC *nd*→*p*(*nn*) TO THE ELASTIC *np*→*pn* CHARGE-EXCHANGE-PROCESS YIELDS AT THE PROTON EMITTING ANGLE $\theta_{p,\mathrm{lab}} = 0^\circ$ OVER 0.55–2.0-GeV NEUTRON BEAM ENERGY REGION. EXPERIMENTAL RESULTS

V. I. Sharov1)*, A. A. Morozov1), R.A.Shindin1), V.G.Antonenko2), S. B. Borzakov3), Yu. T. Borzunov1), E. V. Chernykh1), V. F. Chumakov1), S.A.Dolgii1), M. Finger4), 5), M.Finger, Jr.4), L. B. Golovanov1), D. K. Guriev1), A. Janata4), A. D. Kirillov1), A. D. Kovalenko1), V.A.Krasnov1), N. A. Kuzmin6), A. K. Kurilkin1), P. K. Kurilkin1), A.N.Livanov1), V.M.Lutsenko6), P.K.Maniakov1), E. A. Matyushevsky1), G. P. Nikolaevsky1), A. A. Nomofilov1), Tz. Panteleev3), 7), S. M. Piyadin1), I. L. Pisarev4), Yu. P. Polunin 2), A. N. Prokofiev8), V.Yu.Prytkov1), P.A.Rukoyatkin1), M. Slunecˇ ka4), 5), V.Slunecˇ kova. 4), A.Yu.Starikov1), L.N.Strunov1), T. A. Vasiliev1), E. I. Vorobiev1), I.P.Yudin6), I.V.Zaitsev1), A. A. Zhdanov8), V.N.Zhmyrov4)

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Physics of Atomic Nuclei, 2009, Vol. 72, No. 6, pp. 1007–1020.
ELEMENTARY PARTICLES AND FIELDS
Experiment

ЯДЕРНАЯ ФИЗИКА, 2009, том 72,№6, с. 1065–1069
ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

THE RATIO *Rdp* OF THE QUASI-ELASTIC *nd*→*p*(*nn*) TO THE ELASTIC *np*→*pn* CHARGE-EXCHANGE-PROCESS YIELDS AT THE PROTON EMITTING ANGLE $\theta_{p,\mathrm{lab}} = 0^\circ$ OVER 0.55–2.0-GeV NEUTRON-BEAM ENERGY REGION. COMPARISON OF THE RESULTS WITH THE MODEL-DEPENDENT CALCULATIONS

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Joint Institute for Nuclear Research, Dubna, Russia
Received May 20, 2008; in final form, October 4, 2008

Physics of Atomic Nuclei, 2009, Vol. 72, No. 6, pp. 1021–1025.
ELEMENTARY PARTICLES AND FIELDS
Experiment

THE COMING RESEARCH PROGRAM

The coming research program under the Delta-Sigma-T experiment project is following:

Using adequate T-polarized neutron beam and T-polarized proton target to perform

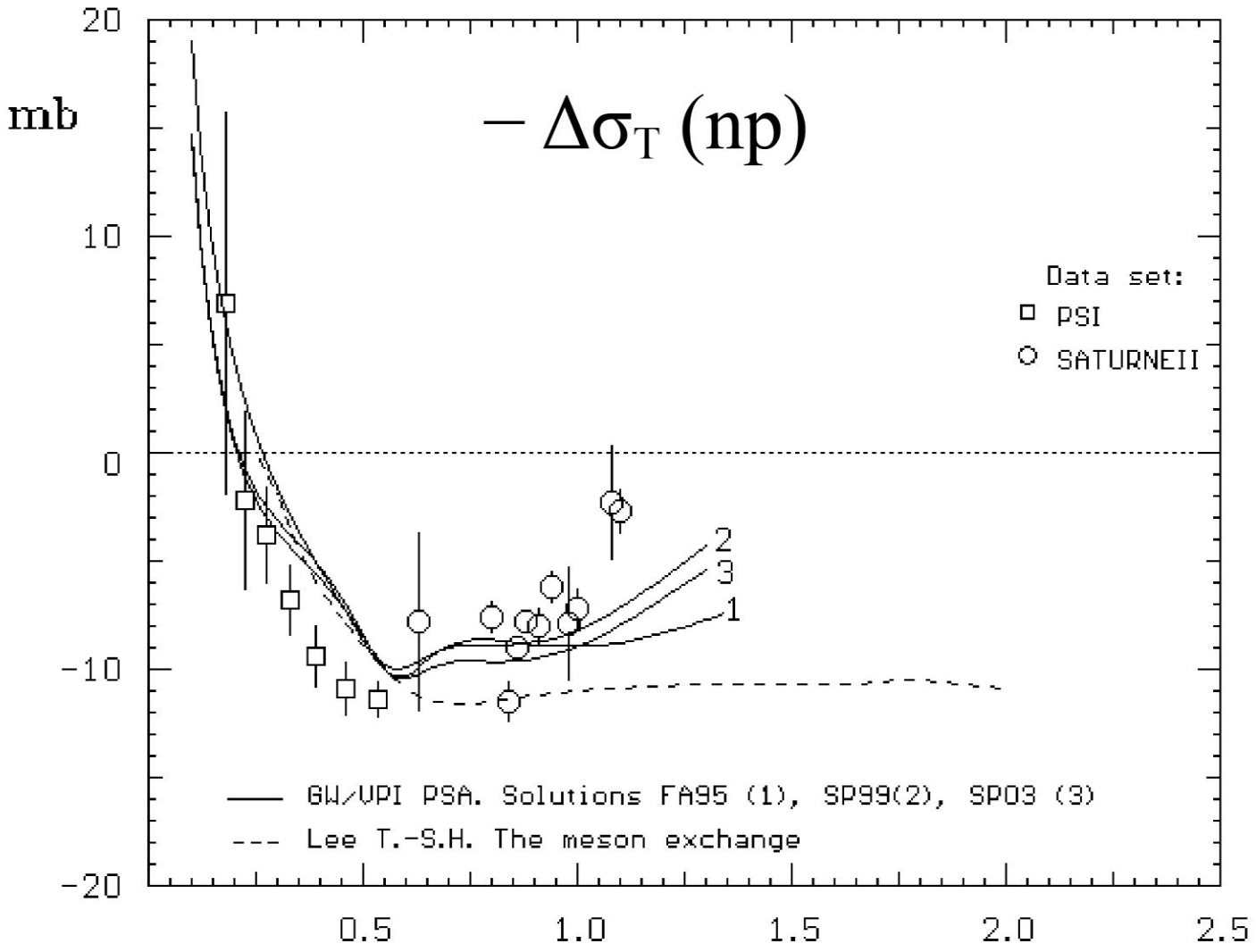
- the measurements of the **$\Delta\sigma_T$ (np)** at the same energy points (**1.2 – 3.7 GeV**) as for **$\Delta\sigma_L$ (np)** with energy steps of **100–200 MeV** and expected statistical errors **≤ 0.5 mb**;
- the measurements of the energy dependence of spin-correlation parameter **A_{00nn} (np)** at the same energy points as for **$\Delta\sigma_T$ (np)** with expected statistical errors **0.02–0.05**.

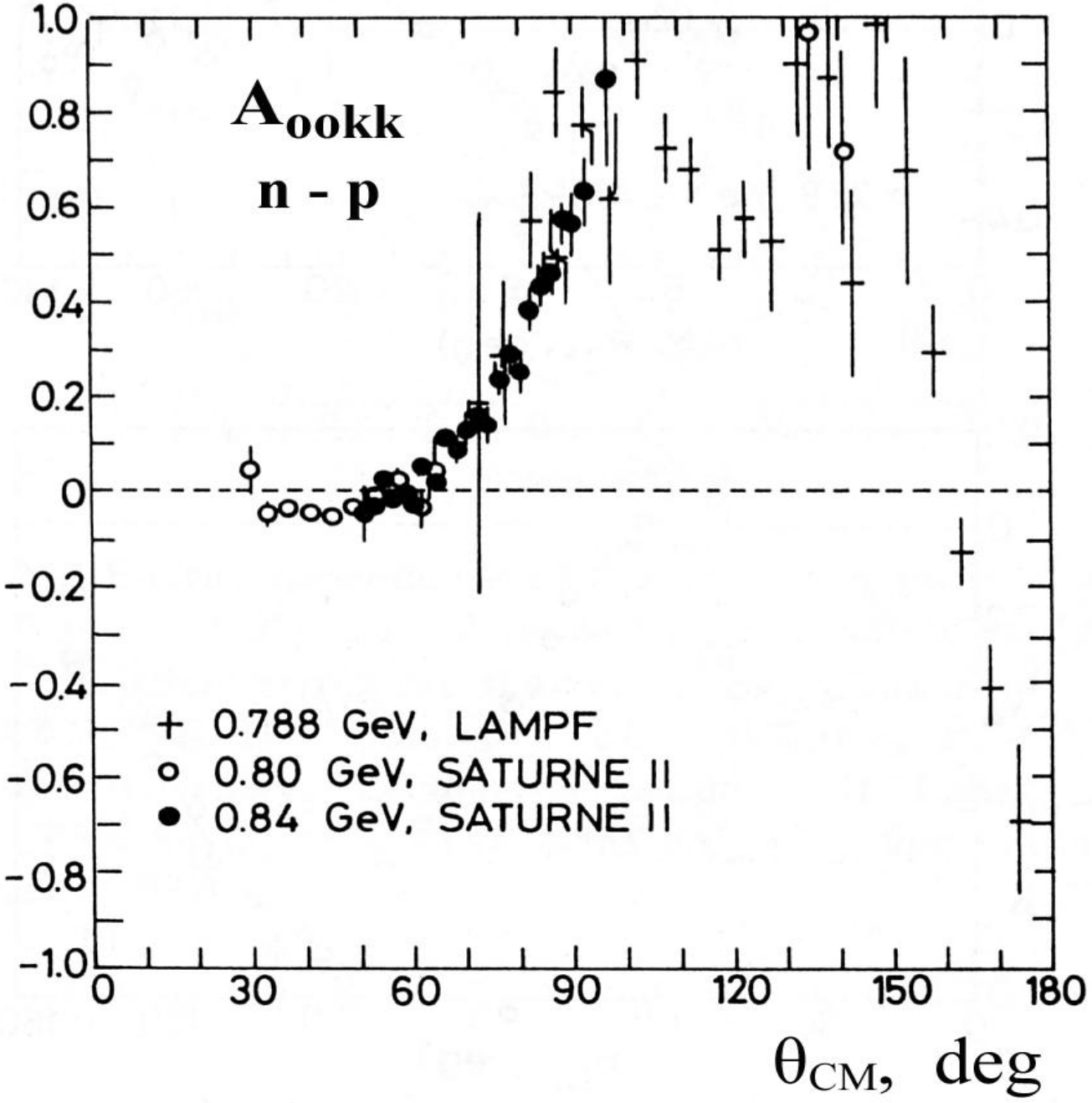
These measurements can be performed simultaneously with and independently of the **$\Delta\sigma_T$ (np)** ones.

FURTHER MEASUREMENTS WANTED

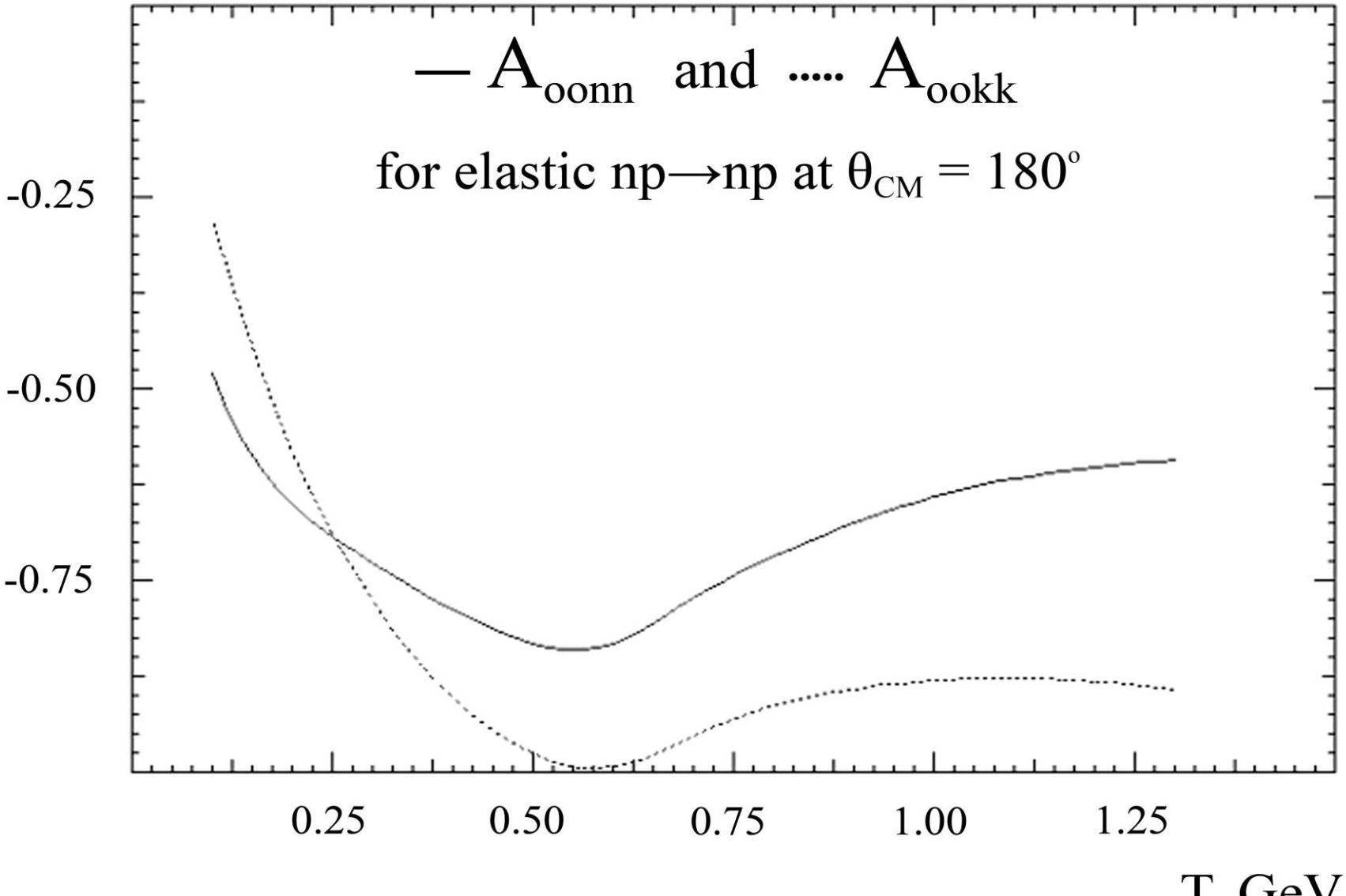
- Using suitable L-polarized neutron beam and L-polarized proton target to perform
  - the more precise and detailed measurements of the **$\Delta\sigma_L$ (np)** near **T_n=1.8 GeV** at 2–3 energy points with energy steps of **100 MeV** and expected statistical errors less than **0.5 mb**;
  - the measurements of the energy dependence of spin-correlation parameter **A_{00kk} (np)** at the same energy points as for **$\Delta\sigma_L$ (np)** with expected statistical errors **0.02–0.05**. These measurements can be performed independently of the **$\Delta\sigma_L$ (np)** ones.
- Using a high intensity unpolarized deuteron beam for preparing free neutron beam and liquid hydrogen and deuterium targets to continue the measurements of ratio **Rdp=dσ/dΩ(nd) / dσ/dΩ(np)** for elastic charge exchange process **np→pn** at **0°** angle with **5%** statistical errors at the energies more then 2.0 GeV.

Energy dependence of the $-\Delta\sigma_T$ (np) observable




A_{ookk}
n - p
+ 0.788 GeV, LAMPF
o 0.80 GeV, SATURNE II
● 0.84 GeV, SATURNE II
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
0
30
60
90
120
150
180
θ_{CM}, deg

Phenomenological energy dependences of spin correlation parameters $A_{ookk}(np)$ and $A_{oonn}(np)$



Participants of the Delta-Sigma project

V.G.Antonenko[1], N. S. Borisov[2], S.B.Borzakov[3], Yu.T.Borzunov[4], L.B.Golovanov[4], D.K. Guriev[4], S.A.Dolgii[4], I.V.Zaitsev[4], A.D.Kovalenko[4], N.I.Kochelev[5], V.A.Krasnov[4], E.A. Kuraev[5], N.A.Kuzmin[4], A.N.Livanov[4], P.K.Maniakov[4], E.A.Matyushevsky[4], A.A.Morozov[4], G.P.Nikolaevsky[4], A.A.Nomofilov[4], Tz.Panteleev[3,6], A.N.Prokofiev[7], P.A.Rukoyatkin[4], V.I.Sharov[4], R.A.Shindin[4], M.Slunechka[2,8], V.Slunechkova[2], A.Yu.Starikov[4], L.N.Strunov[4], V.V.Fimushkin[4], M.Finger[2,8], M.Finger Jr.[2], E.V.Chernykh[4], V.F.Chumakov[4], I.P.Yudin[4], A.Janata[2].

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(results of preliminary discussions)

Outline

- Recent understanding of the NN interactions. Urgency of the data obtaining for np spin observables in the GeV region.
- Aims of the Delta-Sigma-T experiment.
- Use of the expected results
- Why this project is proposed namely today?

Results obtained and coming research program

- Readiness of the Delta-Sigma experimental set-up
- High intensity polarized deuteron beam at the Nuclotron-M

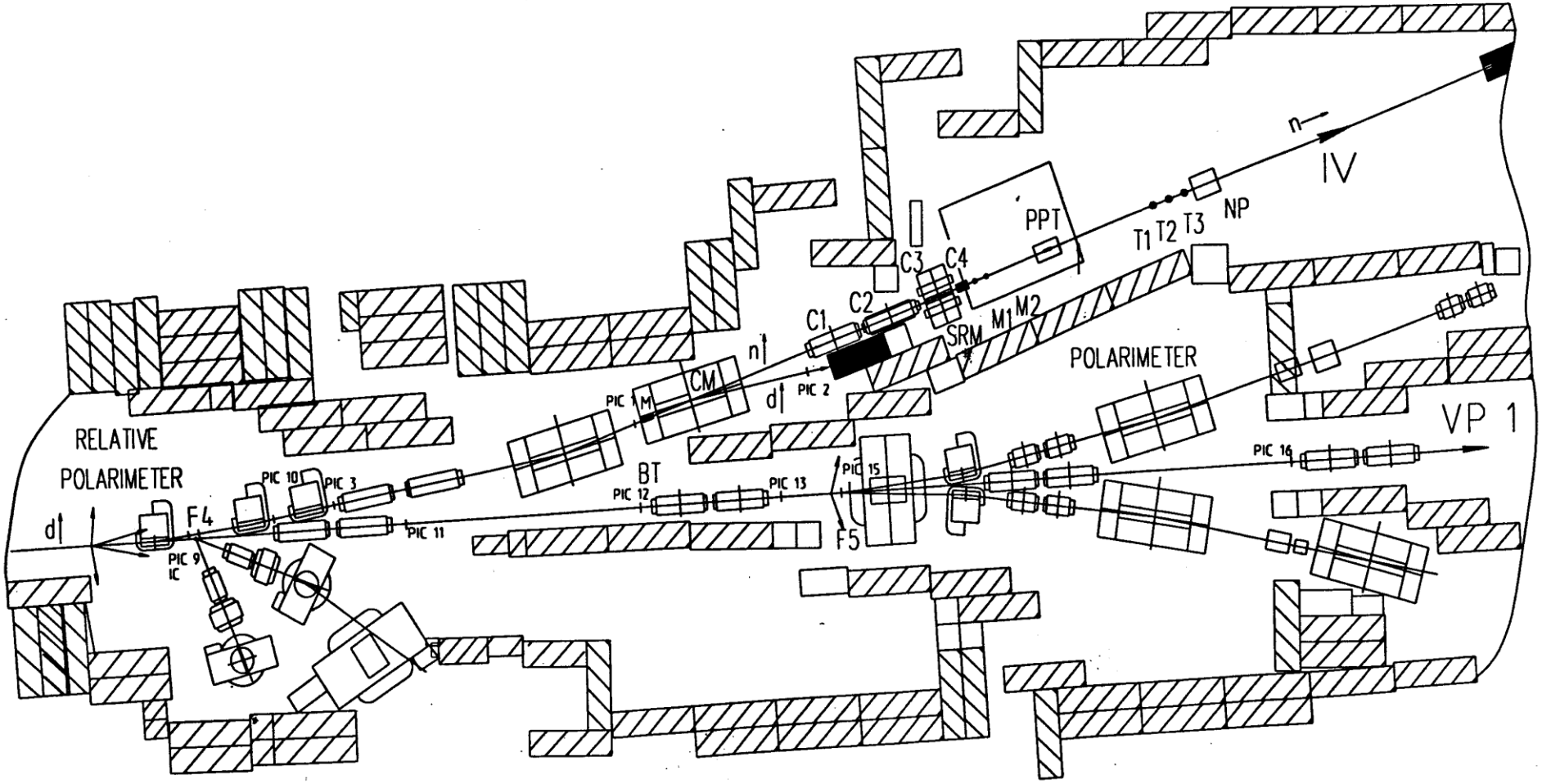
- Summary

Readiness of the Delta-Sigma experimental set-up

The participants of the of the **$\Delta\sigma_L$ (np)** measurements have obtained wide experience in carrying out transmission measurements and are ready now to measure the **$\Delta\sigma_T$** (np) spin dependent observable.

The detectors for transmission measurement, electronics and data acquisition system are also ready.

(today's status)



DELTA-SIGMA Setup at the Polarized Neutron Beams of the JINR VBLHE

VP 1 **– beam line of polarized deuterons;** ***1V*** **– beam line of polarized neutrons;**
BT **– beryllium neutron production target;** ***IC*** **– ionization chamber;**
PIC 1-3, 9-16 **– multiwire proportional/ionization chambers;** ***CM*** **– sweeping magnet;**
C1-C4 **– set of neutron beam collimators;** ***SRM*** **– neutron spin rotating magnet;**
PPT **– polarized proton target;** ***NP*** **– neutron profilometer**

Magnetic spectrometer of the Delta-Sigma set-up

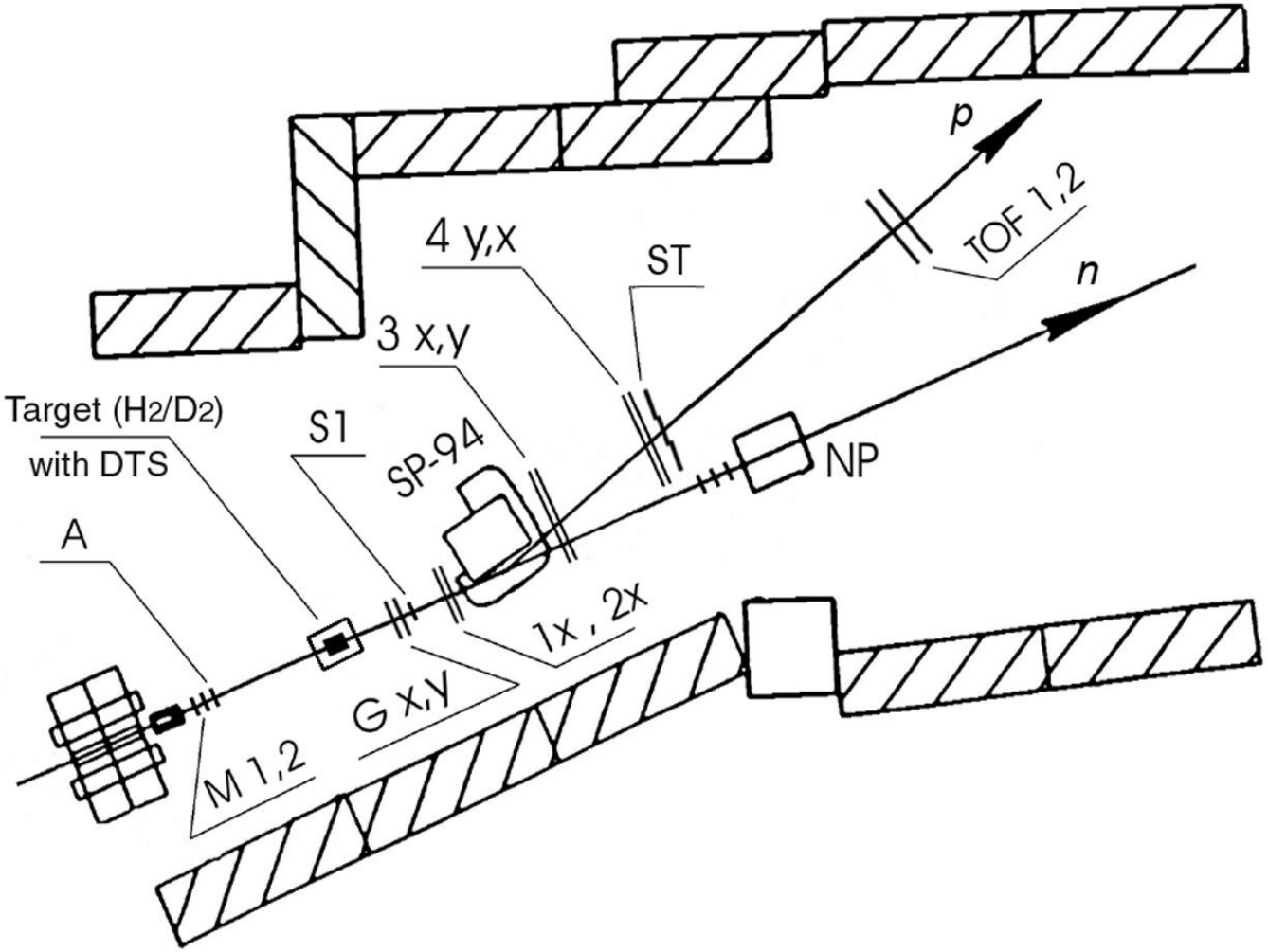
The testing of the spectrometer elements and carrying out the $\mathbf{R}_{dp}$ measurements were a powerful test for the future measurements of the spin correlation parameters $\mathbf{A}_{ookk}(np)$ and $\mathbf{A}_{oonn}(np)$.

These measurements will be made using the same approved method and the existing spectrometer.

We have obtained wide experience in carrying out the charge-exchange measurements.

Some upgrading of the track detectors (PC) is needed.

(today's status)



Magnetic spectrometer for detection of protons from np → pn elastic charge exchange at zero Lab. angle: SP-94 is analyzing dipole, Gx, y, 1x, 2x, 3x, y, 4x, y are two sets of multiwire proportional chambers, H2/D2 are the liquid H2 or D2 targets, S1, TOF1,2 and A, ST are time-of-flight and trigger counters

Readiness of the Dubna Polarized Proton Target

The equipment (superconducting coils) needed for the providing of T mode of target polarization has been prepared and complex tests of coils together with systems MPT were begun. But since a middle of 2007 the financing of the MPT modernization works was completely stopped.

Works on modernization of Saclay-Argonne-JINR polarized proton target (setup PPT) will be foreseen by the new JINR theme 02-1-1097-2010/12 "Study of Polarization Phenomena and Spin Effects at the JINR Nuclotron-M Facility".

For the modernization of the PPT equipment and purchase of spare parts 25 - 30 k$ is required . It seems reasonable to perform the PPT modernization and its current operation under a new technical project in frame of the future JINR theme 02-1-1097-2010/12

High intensity polarized deuteron beam at the Nuclotron-M

A creation of new Source of Polarized Deuteron ions is foreseeing now for the Nuclotron-M accelerator under the JINR theme 02-0-1065-2007/2009. The proposed project of source assumes the development of a universal high-intensity source of polarized deuterons (protons) using a charge-exchange plasma ionizer.

The output current of the source under design will be up to 10 mA for ↑ D+(↑ H+) and polarization will be up to 90% of the maximal vector (±1) and tensor (+1,−2) polarization.

The project is based on the equipment which was supplied within the framework of an agreement between JINR and IUCF (Bloomington, USA).

The SPD putting into operation is planned at the near future.

Estimation of the count rate in transmission measurements using the new SPD

If intensity of the polarized deuteron beam will be 2×10^{10} d/cycle then:
at the neutron beam energy $T_n = 1.2$ GeV
during 8 hours there
will be accumulated a statistics that provides the $-\Delta\sigma_T$ (np) statistical error of ≈ 0.1 mb.

The count rate which will be accessible with new source of polarized deuteron ions at the Nuclotron-M estimated above, allows obtaining the $-\Delta\sigma_T$ values with very high precision (< 0.5 mb).

Summary

- Importance and necessity of the data obtaining for the np spin observables in the GeV region were shown.
- Aims of the Delta-Sigma-T experiment and use of the expected results were presented.
- Readiness of the Delta-Sigma experimental set-up and other needed equipment were discussed.

Thank you for attention!

We invite to take part in Delta-sigma experiment all those who are interested in continuation of spin dependent NN observables research in the neutron beam Gev energy area, and are ready to take part in carrying out these observables energy dependences measurements using the Nuclotron-M accelerator intense polarized neutron beam and the polarized proton target.