SPIN PHYSICS AT JINR: now and future

A.P. Nagaytsev, JINR , Dubna

1. JINR in spin studies.
2. Spin physics facilities at JINR.
3. Spin physics at Nuclotron.
4. Spin physics at NICA.
5. Conclusions.

JINR in Spin Studies.

Started in early 50-th from:

- experiments at Laboratory of Nuclear Problems with polarized beams and targets at Synchrocyclotron,
- pioneering Development of super-frozen polarized targets,
- experiments at Serpukhov 70 GeV proton Synchrotron,
- experiments at Synchrophasotron with movable polarized target and other fixed target experiments.

Continued with JINR participation in Nucleon Spin structure experiments:

SMC, COMPASS-I, COMPASS-II (SPS CERN),
HERMES (DESY),
STAR (BNL),
JLAB;
IHEP, Protvino.

Accompanied by theoretical developments (Lapidus, Ryndin, Kopeliovich, Efremov, Teryaev, Sidorov, Goloskokov…) and *Organization* of biannual International Spin Workshops DSPIN (1981-2011).

S.B. Nurushev DEBUT OF SPIN PHYSICS AT DUBNA, IHEP Preprint 97-75, 1997 (Protvino);
Invited talk at 7th Workshop on High-Energy Spin Physics (SPIN 97),
Dubna, Russia, 7-12 Jul 1997.

JINR in Spin Studies. Polarized Targers.

Pioneering development of frozen targets required a super low temperature of order of milli-Kelvins.

Achieved at Dubna in 1965 by the group of B. Neganov using a dilution of He^3 in He^4 (dilution refrigerator) - ~20 mK.

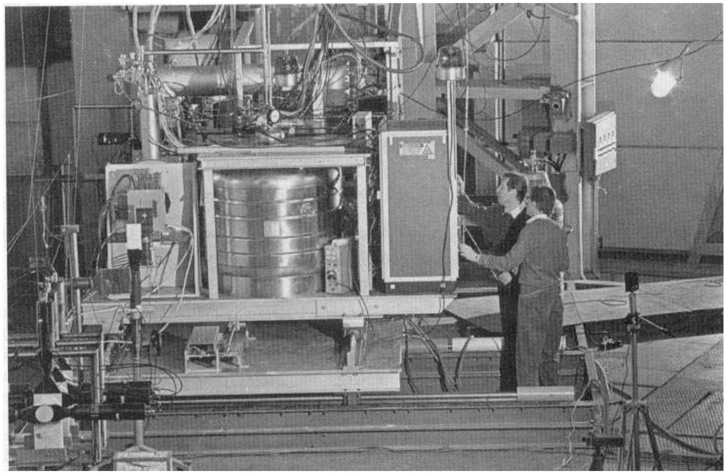
Published in:

B. Neganov, N. Borisov and M. Liburg, Sov.Phys. JETP23 (1966)959

The first frozen polarized target in the experiments at the Synchrocyclotron

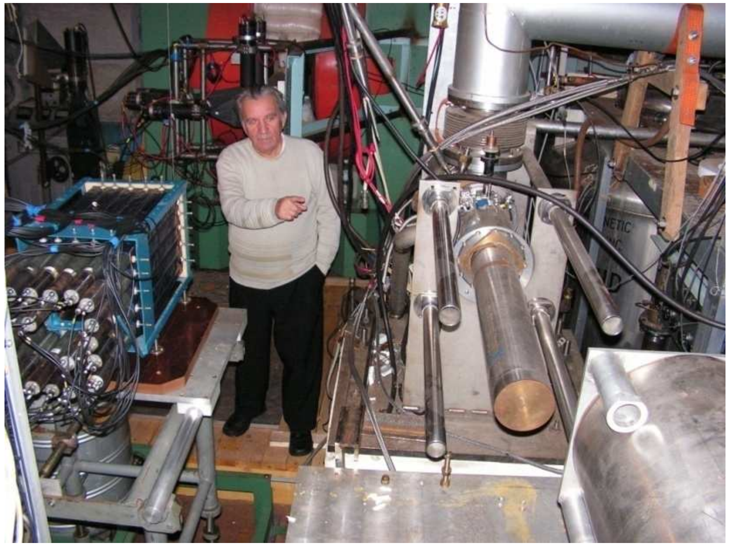
Yu.A. Usov, NIM A 526 (2004) 153-156).

JINR in Spin Studies. Polarized Targers.



Movable Polarized Proton Target at the Synchrophasotron

- -200 mm length and 30 mm diameter – 9 10^{23} atoms/cm^2
- - Refrigerator temperature $\leq$ 50 mK
- -Solenoid magnetic field 2.5 T
- -Proton (L,T) polarization, $\geq$ 80 %.



JINR-Saclay-ANL

Nucl. Instr. & Meth. A372 (1996) 349-351

Spin physics facilities at JINR.

NOW

JINR ***developing the new accelerator facility*** **"NICA Complex"**

for HEP @ JINR providing

intensive beams of relativistic ions from p to Au,

polarized protons and deuterons

with max energy up to

$\sqrt{S_{NN}}$= 11 GeV (Au^{79+}) and =26 GeV (p) .

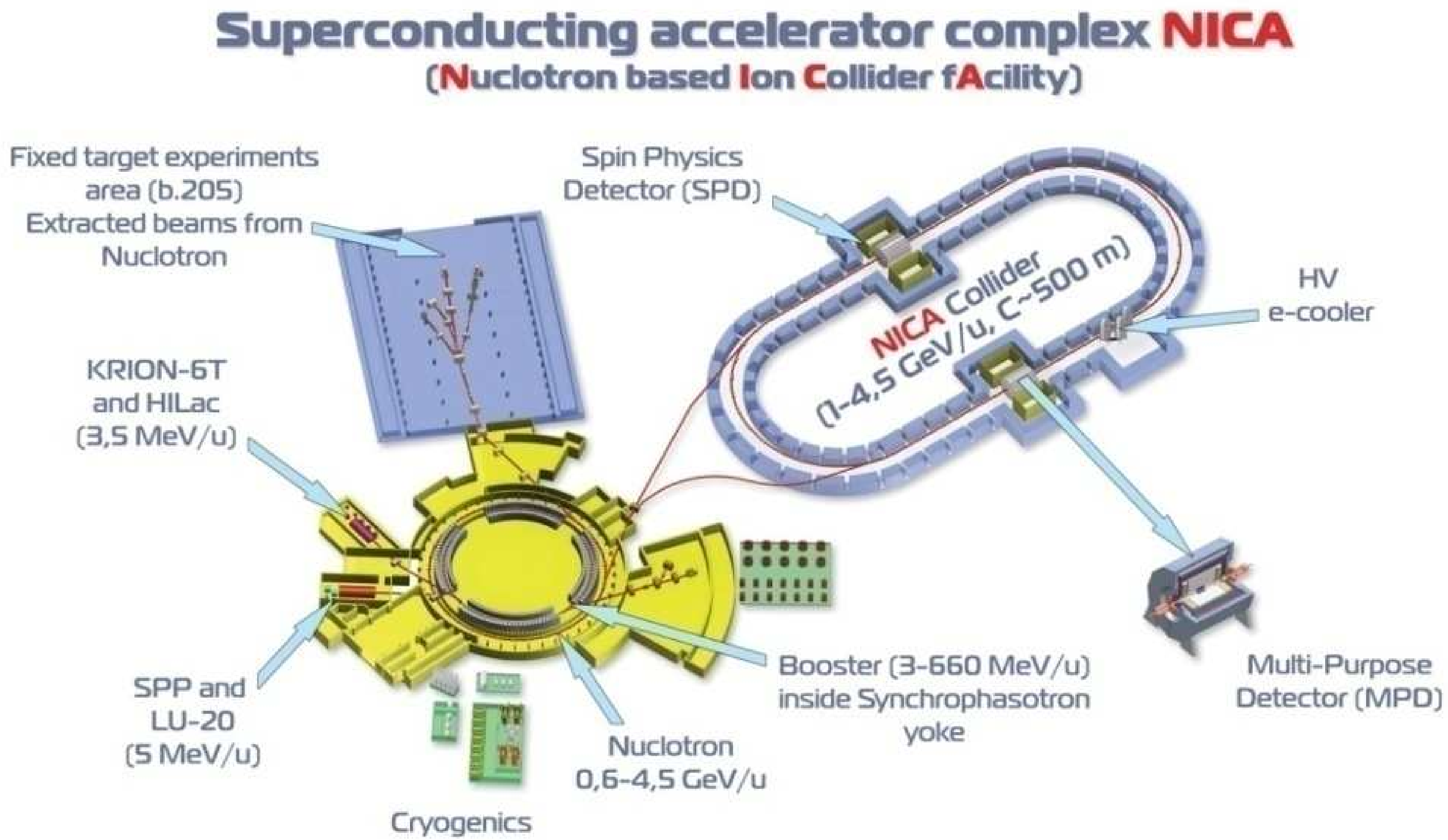
Main targets of "NICA Complex":

-study of hot and dense baryonic matter,

- study of nucleon spin structure and

- polarization phenomena in heavy ion collisions.

Spin physics facilities at JINR.



Spin physics facilities at JINR.

Machine aspects: **(see talk A. Kovalenko)**

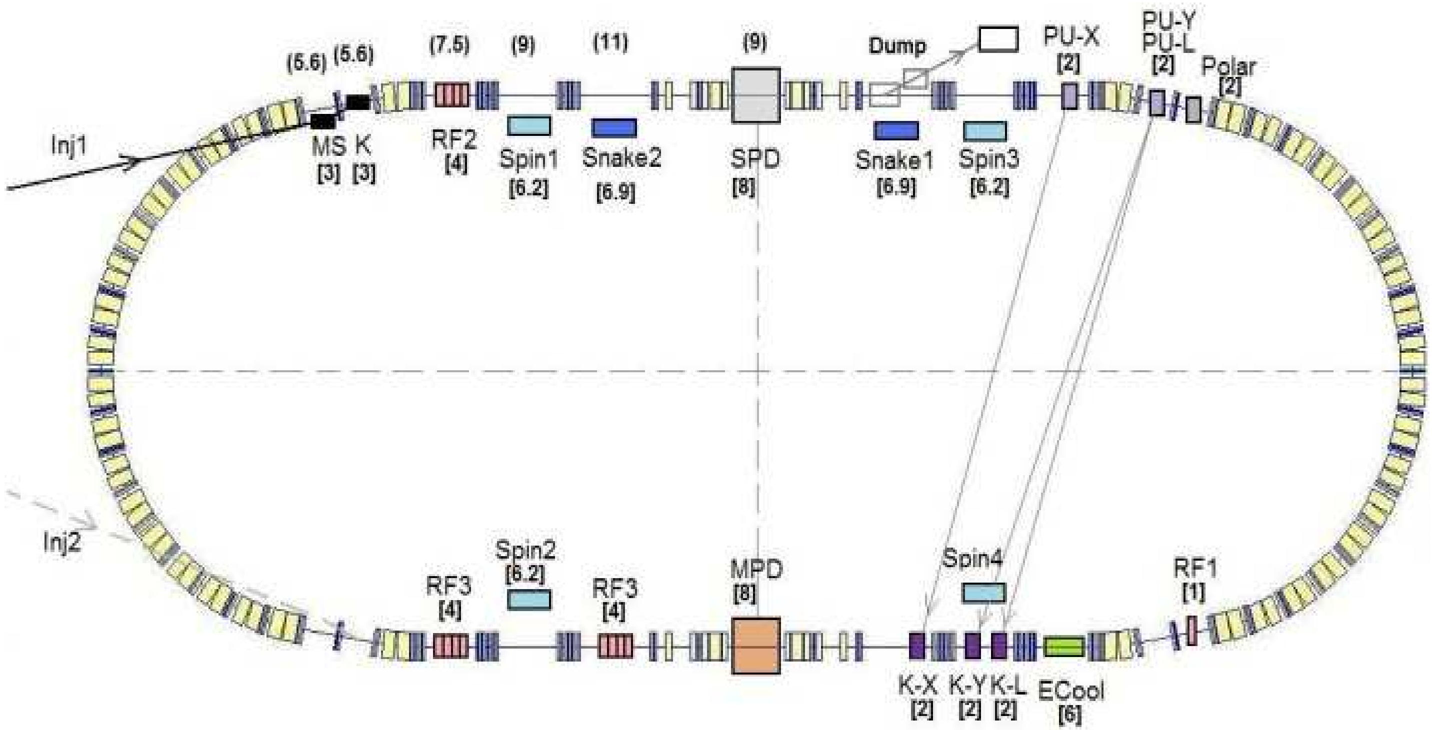
Source(s) of polarized p & d,

Acceleration, extraction (injection) & control of polarized beams,

Technique of the polarized beam manipulations @ NICA MPD &SPD:

- transversal-longitudinal polarization rotators,
- relative beam polarization monitors,
- absolute beam polarization measurements,
- luminosity monitors.

Scheme of NICA for proton polarized beam.
For both (deuteron and proton) beams
- talk A.Kovalenko



Spin physics facilities at JINR.

Parameters of polarized proton beams

Energy, GeV	5	12
Proton number per bunch	6E10	1.5E10
Rms relative momentum spread	10E-3	10E-3
Rms bunch length, m	1.7	0.8
Rms (unnormalized) emittance, $\pi \cdot$mm$\cdot$mrad	0.24	0.027
Beta-function in the IP, m	0.5	0.5
Lasslet tune shift	0.0074	0.0033
Beam-beam parameter	0.005	0.005
Number of bunches	10	10
Luminosity, $cm^{-2} \cdot s^{-1}$	1.1E30	1.1E30

I.Meshkov, Yu.Filatov, Polarized Beams in NICA, SPIN2010, Sep 27-Oct 02, 2010, Juelich

Spin physics at Nuclotron.

The main topics are:

1. POLARIZED BEAM AND POLARIMETRY.

2. EXPERIMENTS WITH POLARIZED NUCLEONS AND MPPT.

3. INVESTIGATION OF DEUTERON SPIN STRUCTURE.
   Deuteron Break-Up in Collinear and Noncollinear Kinematics.

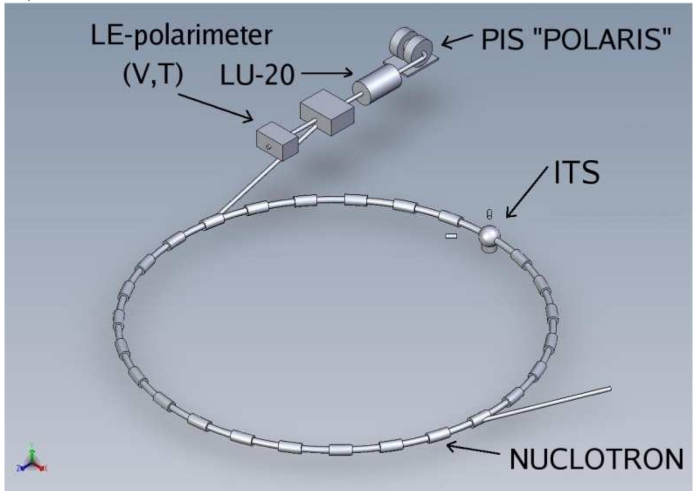
4. SPIN-DEPENDENT OBSERVABLES IN CUMULATIVE REGION.
   Analyzing Power for Cumulative Proton Production

5. PROTON-NUCLEUS ANALYZING POWER.

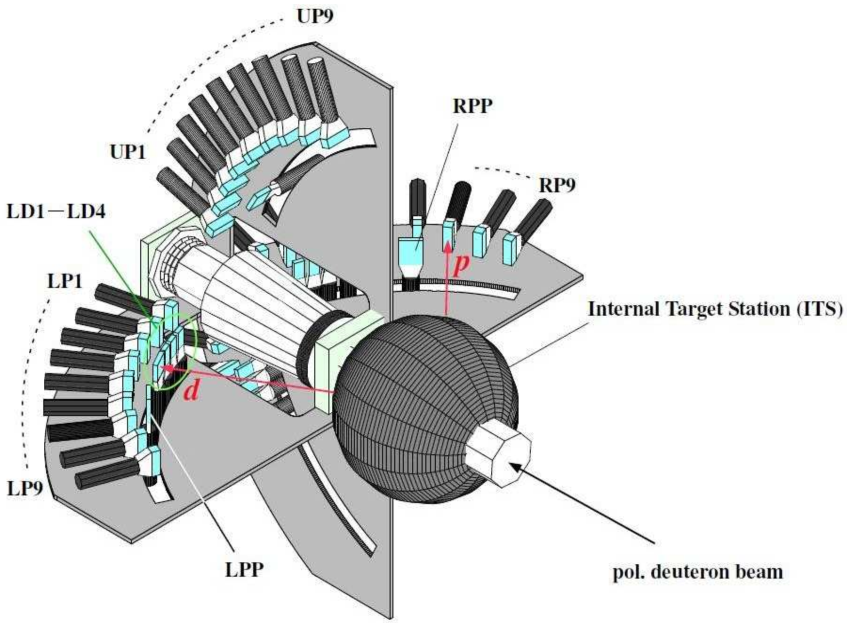
6. ANALYZING POWERS IN INELASTIC DEUTERON REACTIONS.

F. Lehar, Phys.Part.Nucl. 36 (2005) 501-528, Fiz.Elem.Chast.Atom.Yadra 36 (2005) 955-1002, JINR-E1-2001-238 and references therein

Spin physics at Nuclotron. DSS.



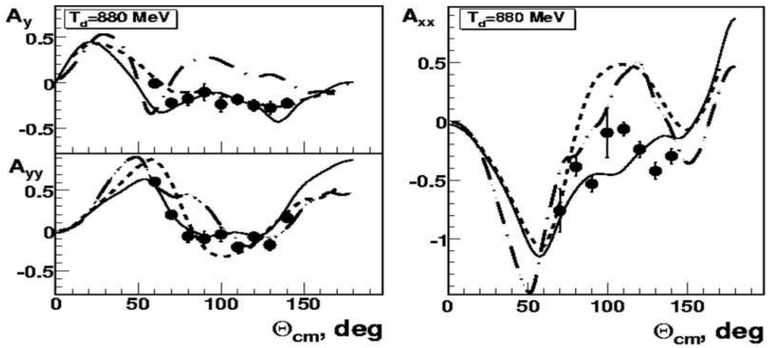
- PIS POLARIS on 360 kV terminal
- 5 MeV/A (20 MeV protons) LINAC LU20
- Tensor and vector LEPs based on the $d^3He \rightarrow p(0^\circ)^4He$ and $d^4He \rightarrow d^4He$ reactions, respectively
- Nuclotron Ring: 6 GeV/A deuterons.



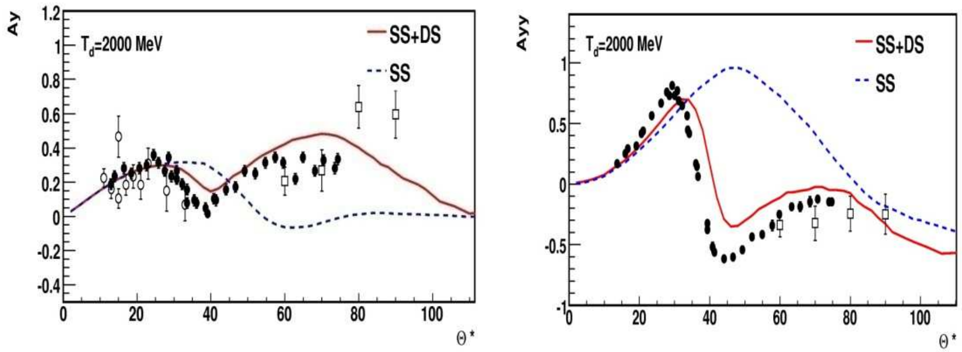
- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Polarization measurement at 270 MeV
- Analyzing powers measurement at 880 and 2000 MeV

Spin physics at Nuclotron. DSS.

Analyzing powers in dp- elastic scattering at 880 MeV



A_y and A_{yy} in dp- elastic scattering at 2000 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 Dibarion DWF (M.Shikhalev, Phys.Atom.Nucl.72 (2009), 588)

Published in P.K.Kurilkin et al., Phys.Lett.B715 (2012) 61-65

- Open symbols are the data obtained at JINR.
- 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.

Spin physics at Nuclotron. ALPOM.

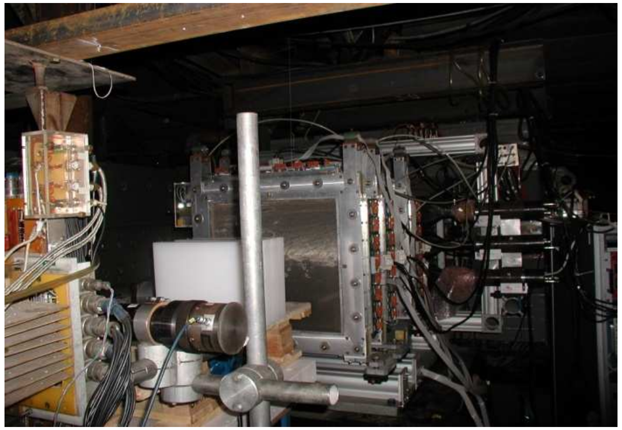
Analyzing powers for reaction p + CH2 for proton momenta up to ~7 GeV/c

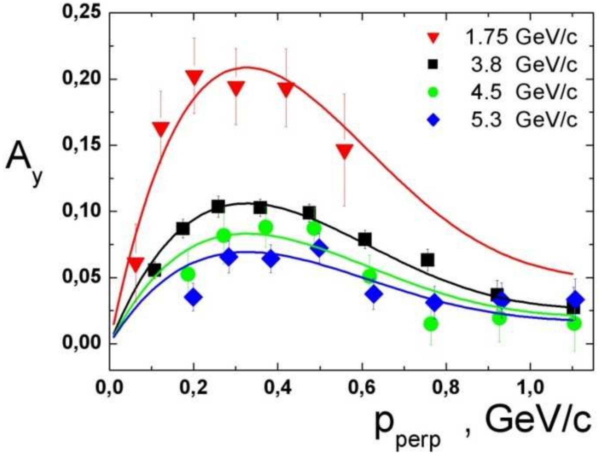
Calibration of polarimeter for JLAB $\mu_p G_{Ep}/G_{Mp}$ experiment

JINR-TJNAF collaboration - College of William and Mary - Norfolk State Univ. – DAPNIA Saclay, Rutger Univ. and P.J. Safarik Univ.

The GEp collaboration at Jefferson Lab is preparing to measure the ratio of the electric and magnetic form factors of the proton G_E/G_M, by the recoil proton polarization method.

This experiment requires a knowledge of the polarization of the recoil proton of momentum up to ~7 GeV/c.





Spin physics at Nuclotron.

Study of Polarization Phenomena and Spin Effects at the JINR Nuclotron-M Facility. SPRINT project.

1.Methodical support of the experiments at polarized beams of the Nuclotron-M and NICA facilities, including development of polarimetery systems.

2.Measurement of analyzing power for the reaction $p + CH_2$ (ALPOM-2).

3.Measurement of tensor analyzing power and spin correlation in *d p* reaction in the deuteron core area with the use of polarized ^3He target and polarized deuteron beam of the Nuclotron-M.

4.Works on modernization of Saclay-Argonne-JINR polarized proton target (setup PPT). The measurements of set of the *np* spin observables, the total *np* cross section differences. Determination of the forward scattering *NN* amplitudes over this energy region.

5.Study of charge-exchange processes in *dp*-interactions at the setup STRELA.

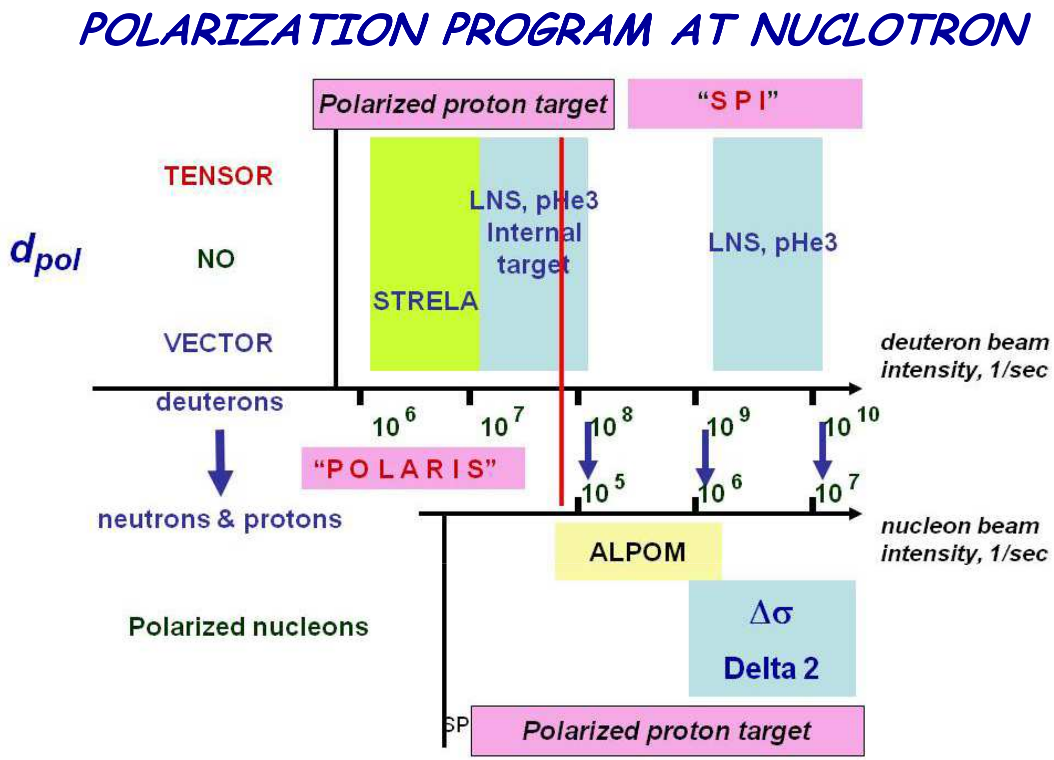
6.Development of theoretical models.Theoretical analysis of experimental data obtained at Nuclotron-M.

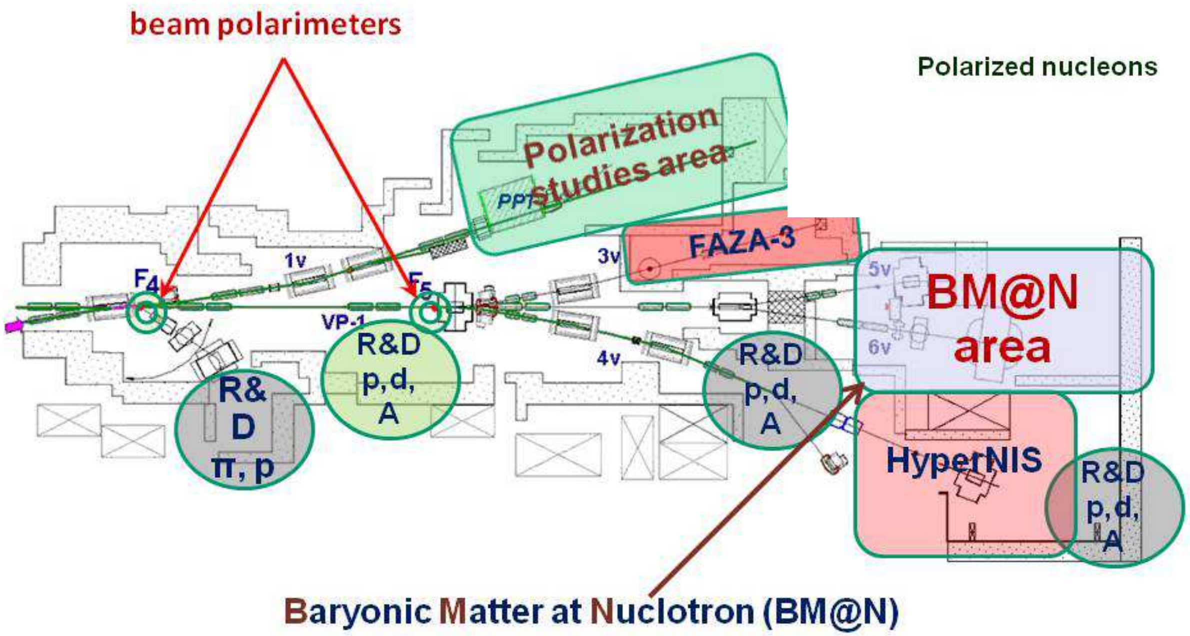
7.The study of the properties of strongly interacting matter utilizing polarization phenomena in hadron-nucleon and lepton-nucleon interactions.

8.Study of highly excited nuclear matter and collective effects in nuclear media.

Spin physics at Nuclotron.

Research zones for fixed target experiments with extracted beams.





Spin physics at Nuclotron.

The main topics spin physics program at Nuclotron :

- investigate pp, pd, dd, p^{3}He, d^{3}He, ^{3}He^{3}He collisions with polarized beams;
- strong polarization effects in NN interactions at p_{lab} > 6 GeV in the region of limiting large p_T ;
- problems of P and T parity violation in NN interactions;
- cumulative (subthreshold) processes;
- quark counting rules violation and determine the region of their applicability (including at interaction of lightest nuclei);
- study of resonance behavior of color transparency at p_{lab} ~ 9.5 GeV/c (p_T ~ 2 GeV/c).

Details will be given in talk by Dr S.Shimansky, S8, September 21

Spin Physics at NICA.

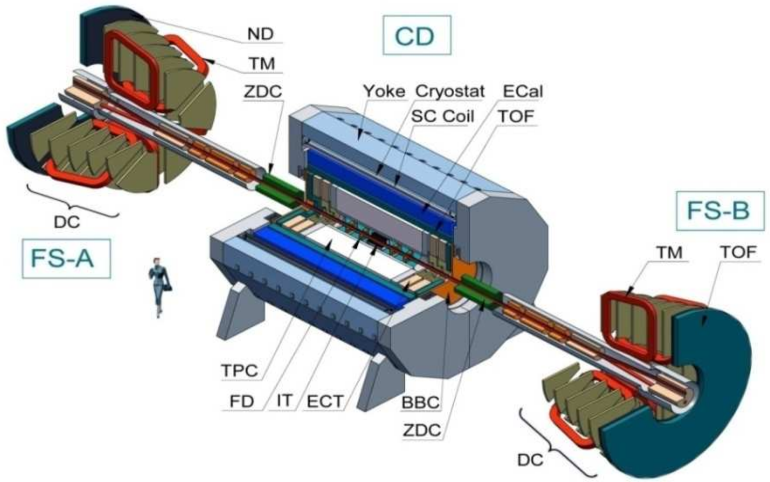
The following subjects are under consideration for both detectors:

- Polarization effects in heavy ion collisions using spin dependent observables in multi-particle production reactions.

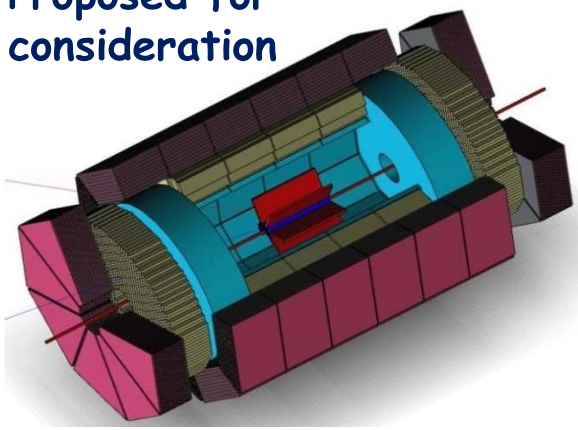
- Nucleon spin structure via DY and J/Ψ production processes and others.

Spin Physics at NICA.

Polarization effects in heavy and light ions collisions with MPD and SPD



Proposed for consideration



The following polarization observables at NICA can be studied with MPD &SPD:

- DY studies;
- Λ Polarization as a probe of isotropic matter formation;
- Correlations of Λ polarization with charge separation as a complementary signal for CP-violation in dense matter ,
- Transverse handedness as a probe for collective orbital momentum of the matter,
- Tensor polarization of dileptons as a complementary probe of matter formation, dilepton production mechanisms and collective orbital momentum.

PROPOSED MEASUREMENTS at SPD/NICA

The following subjects are under considerations:

- ► Polarization effects in multiparticle production by heavy ions
- ► DY & J/Ψ production processes in proton (deuteron) collisions. Studies of various spin-dependent PDFs/TMDs in nucleons.
- ► Elastic reactions ("Krisch effect")
- ► Spin effects in one and two hadron production processes
- ► Spin effects in inclusive high-p_T reactions
- ► Spectroscopy of quarkonia with any available decay modes

Spin Physics at NICA.DY.

Extraction of unknown (poor known) parton distribution functions (PDFs):

$$p(D)p(D) \to \gamma^* X \to l^+ l^- X$$

Boer-Mulders PDF

$$p^{\uparrow}(D^{\uparrow})p(D) \to \gamma^* X \to l^+ l^- X$$

Sivers PDFs
(Efremov,… PLB 612 (2005), PRD 73(2006));

$$p^{\uparrow}(D^{\uparrow})p^{\uparrow}(D^{\uparrow}) \to \gamma^* X \to l^+ l^- X$$

Transversity PDF (Anselmino, Efremov, …)

$$p^{\uparrow}(D^{\uparrow})p(D) \to \gamma^* X \to l^+ l^- X$$

$$p(D)p(D) \to \gamma^* X \to l^+ l^- X$$

Transversity and first moment of Boer-Mulders PFDs
(Sissakian, Shevchenko, Nagaytsev , Ivanov, PRD 72(2005), EPJ C46 ,2006 C59, 2009)

$$p^{\rightarrow}(D^{\rightarrow})p^{\leftarrow}(D^{\leftarrow}) \to \gamma^* X \to l^+ l^- X$$

Longitudinally polarized sea and strange PDFs and tenzor deuteron structure
(Teryaev, …)

The same PDFs from J/ψ production processes ($\sqrt{s} \leq 10 GeV$).

Spin Physics at NICA.DY.

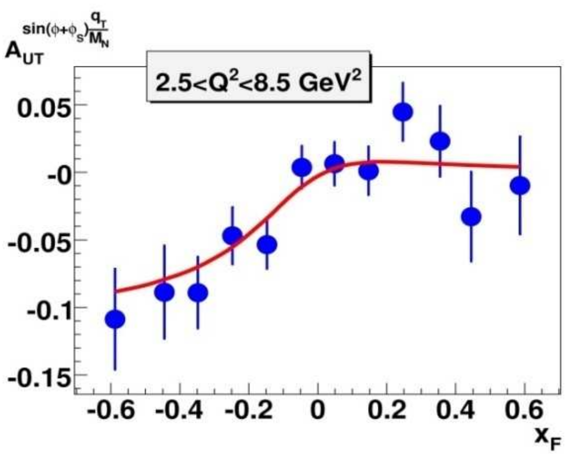
	σ_{DY}, total, nb	L, cm $^{-2}$s^{-1}	Events
PAX, $\sqrt{s}$=14.6 GeV	2	10^{30}	~10000
NICA, $\sqrt{s}$=20 GeV	1	10^{30}	~5000
NICA, $\sqrt{s}$=26 GeV	1.3	10^{30}	~7000

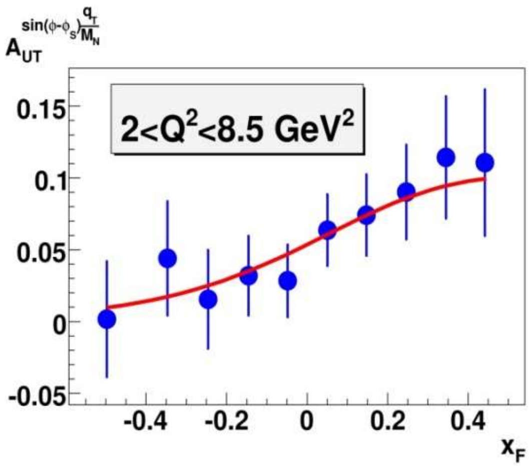
Estimations were done for 1 month of data taking.
For 3 years of data taking: we expect to take ~100K DY events.

The estimations on SSA asymmetries.

Transversity and Boer-Mulders PDFs (left).

Access to Sivers PDFs (right)





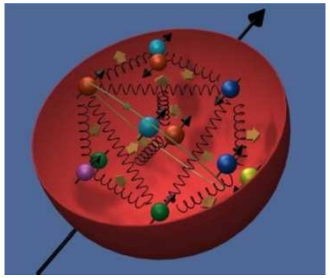
Efremov et al., PLB 612(2005), PRD 73(2006)

A.N. Sissakian, O.Yu. Shevchenko, A.P. Nagaytsev, O.N. Ivanov, Phys.Part.Nucl.41:64-100,2010

Spin Physics at NICA.

Experiment	Status	Remarks
RHIC	Running	Detector upgrade for DY (collider)
PANDA	Plan > 2016	Unpolarized fixed target
PAX	Plan > 2016	Preparation in progress
COMPASS	Plan > 2014	Fixed target, valence PDFs
J-PARC	Plan > 2013 ?	s~ 60-100 GeV^2, unpolarized proton beam
SPASCHARM	Plan >2013	s ~ 140 GeV^2 , unpolarized proton beam
NICA	Plan 2017	s ~ 670 GeV^2 for polarized ,unpolarized p, d beams, (collider)

Collaborators are welcomed !



"... le spin est certainement un des éléments les plus essentiels, *peut-être même le plus essentiel*, de l'existence des particules."
Louis de Broglie

Thank you for attention!