The SPD project
at the Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna

Polarization data has often been the graveyard for fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

J.D. Bjorken, 1987

Roumen Tsenov (LHEP), for the SPD project team
Main targets of the NICA project:
- **study of hot and dense baryonic matter**
- **investigation of nucleon spin structure, polarization phenomena**

<table>
<thead>
<tr>
<th>Main Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ring circumference, m</strong></td>
<td>503.04</td>
</tr>
<tr>
<td><strong>Heavy ions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Energy range for Au\textsuperscript{79}+</strong>: $\sqrt{S_{NN}}$, GeV</td>
<td>4 - 11</td>
</tr>
<tr>
<td><strong>r.m.s. $\Delta p/p$, \times 10^{-3}$</strong></td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Luminosity for Au\textsuperscript{79}+, cm\textsuperscript{-2} s\textsuperscript{-1}</strong></td>
<td>$1 \times 10^{27}$</td>
</tr>
<tr>
<td><strong>Polarized particles</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Max. $\sqrt{S}$ for polarized $p$, Gev</strong></td>
<td>27</td>
</tr>
<tr>
<td><strong>Luminosity for $p$, cm\textsuperscript{-2} s\textsuperscript{-1}</strong></td>
<td>$1 \times 10^{32}$</td>
</tr>
</tbody>
</table>
The NICA complex

existing facilities

PS & LU-20 (5MeV/u)

Booster (600 MeV/u)

NUCLOTRON 0.6-4.5 GeV/u

KRION-6T+ HILac (3MeV/u)

hall for fixed target experiments

to be constructed

BM@N

SPD

SPD hall

MPD hall

Collider

MPD
Polarized beams

NICA Collider Luminosity in pp Collisions

- \( L_{\text{peak}} \approx 1.8 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \)

- Particle number per bunch in \( 10^{11} \) units
- Maximum proton number in each ring \( \approx 2 \cdot 10^{13} \)

Proton energy \( E \) in GeV

- Luminosity \( L(E) \) in \( 10^{30} \) units

- Bunch crossing each 80 ns;
- Crossing rate 12.5 MHz.

- Circumference: - 503 m,
- Number of intersection points (IP): - 2,
- Beta function \( \beta_{\text{min}} \) in the IP: - 0.35 m,
- Number of protons per bunch: \( \sim 1 \cdot 10^{12} \),
- Number of bunches: - 22,
- RMS bunch length: - 0.5 m,
- Incoherent tune shift, \( \Delta_{\text{Lasslett}} \): - 0.027,
- Beam-beam parameter, \( \xi \): - 0.067,
- Beam emittance \( \varepsilon_{\text{rms}}, \pi \text{ mm mrad} \): - 0.15 (normalized at 12.5 GeV).
Physics tasks

- Nucleon spin structure studies
  - Drell-Yan pair production;
  - Direct photons;
  - Nucleon PDFs by J/ψ production;

- Spin-dependent effects in elastic pp, pd and dd scattering;
- Spin effects in exclusive hadron production;
- Spin effects in production of hadrons with high $p_T$;
- etc….
Spin dependent PDFs

Transversity Momentum Distributions: TMD $(x, k_T)$ probe the transverse parton momentum dependence.

Generalized Parton Distributions: GPD $(x, b_T)$: probe the transverse parton distance dependence.
3 PDFs are needed to describe nucleon structure in collinear approximation.

8 PDFs are needed if we want to take into account intrinsic transverse momentum $k_T$ of quarks.
Drell-Yan pairs

$\sigma_{tot} \sim 9 \, nb$

Dimuon spectrum from NA51 ($\sqrt{s} = 29.1 \, GeV$)

12 Sept. 2018
Asymmetries in DY pair production

\[ Q^2 = 4 \text{ GeV}^2 \]

\[ Q^2 = 15 \text{ GeV}^2 \]

\[ s = 400 \text{ GeV}^2 \]

Sivers

Boer-Mulders

J.C. Collins et al., PRD73
(2006)014021
The gluon Compton scattering gives access to the gluon content of proton:

Transverse beam polarization: access to the Sivers function for gluons

\[
\sigma^\uparrow - \sigma^\downarrow = \sum_i \int_{x_{\text{min}}}^1 dx_a \int d^2k_{Ta}d^2k_{Tb} x_a x_b x_a - \frac{p_T}{\sqrt{s}} e^y \left[ q_i(x_a, k_{Ta}) \Delta_N G(x_b, k_{Tb}) \right. \\
\left. \times \frac{d\hat{\sigma}}{dt}(q_i G \to q_i \gamma) + G(x_a, k_{Ta}) \Delta_N q_i(x_b, k_{Tb}) \frac{d\hat{\sigma}}{dt}(G q_i \to q_i \gamma) \right]
\]

Longitudinal beam polarization: access to gluon polarization \(\Delta g/g\)

\[
A_{LL} \approx \left( \frac{\Delta g(x_1)}{g(x_1)} \right) \left[ \frac{\sum_q e_q^2 \left[ \Delta q(x_2) + \Delta \bar{q}(x_2) \right]}{\sum_q e_q^2 \left[ q(x_2) + \bar{q}(x_2) \right]} \right] + (1 \leftrightarrow 2)
\]
Expected asymmetries


Charmonia production

Gluon fusion

Charmonia production is sensitive to gluon distributions of colliding hadrons.

![Diagrams of gluon fusion and quark annihilation]

NRQCD                CEM

**NRQCD cross section at NLO**

MRST2002

![Graphs showing NRQCD cross section]
Asymmetries in high $p_T$ hadron production

- Diquark properties;
- Confinement laws;
- Nature of the huge spin effects;
- Deuteron spin structure;
- Properties of the bare NA- and NK-interactions;
- Nature and properties of the cold super dense baryonic matter (CsDBM) (pA and AA);
- Dilepton production puzzle in np-interaction.
On spin crisis

TMDs

GPDs

SPIN PHYSICS WITH HIGH $p_T$

DIRECT PHOTONS ($\Delta G$)
SIDIS WITH $\pi^0$ ($L_g, L_q$ PDFs)
EXCLUSIVE DY ($\Delta G$)
DY (PDFs)
SIDIS $J/\psi$ (PDFs)
EXCLUSIVE $J/\psi$ (PDFs)
EXCLUSIVE $\pi^0$ (PDFs)
EXCLUSIVE $\rho$, $\omega$ (PDFs)
SIDIS $\pi^+$, $\pi^-$
ELASTIC, QUASIELASTIC
Minimum biased events

PYTHIA 6, $\sqrt{s_{\text{pp}}} = 26$ GeV; 4 MHz event rate
- Average charged particles' multiplicity $\sim 14$
- Average neutral particles' multiplicity $\sim 23$

from A. Guskov

12 Sept. 2018
Requirements for the SPD

- close to $4\pi$ geometrical acceptance;
- high-precision ($\sim 50 \, \mu m$) and fast vertex detector;
- high-precision ($\sim 100 \, \mu m$) and fast tracker,
- good particle ID capabilities;
- efficient muon range system,
- good electromagnetic calorimeter,
- low material budget over the track paths,
- trigger and DAQ system able to cope with event rates at luminosity of $10^{32} \, (cm.s)^{-1}$,
- modularity and easy access to the detector elements, that makes possible further reconfiguration and upgrade of the facility.
General view
Dimensions
Hybrid magnetic system

½ model symmetry

\[ B^{(z)}(x, y, 0) = 0. \]

\[ J_T = 40 \frac{A}{mm^2}, \]

\[ J_B^{(1,2)} = n80 \frac{A}{mm^2}, \]

\[ S = 200 \times 20 mm^2, \]

\[ I_T = J_T \cdot S = 160 kA, \]

\[ I_B^{(1,2)} = J_B^{(1,2)} \cdot S = n820 kA. \]
Silicon Vertex Detector

- Silicon vertex detector around the beam pipe;
- Several layers of double sided silicon strips or MAPS;
- Optimized number of layers w.r.t. material budget;
- Goal: few tens of µm resolution for the vertex reconstruction → detection of particles with open charm and rejection of (π⁻)⁻.

From A. Zinchenko, MPD ITS with MAPS → open charm registration
Central tracker: straw tubes

- Minimum material on the particle tracks ($X_0 \sim 0.1$);
- Time ($\sim 100$ ns) and spatial resolution ($\sim 100$ μm);
- Expected particle rates (DAQ rates) $\sim$ MHz;
- Technology developed also in JINR, production workshops available
Photon energy range 0.1 - 10 GeV;
Due to space limitations the total length of the ECAL module should be less than 50 cm;
Required energy resolution $<10.0%/\sqrt{E}$ (GeV) and energy threshold below 100 MeV.
The version of ECal modules developed at JINR for the COMPASS-II experiment at CERN could be a good candidate ("shashlik" design);
Crystal variant is being considered, too.

Avalanche multichannel photodetectors

Surface mount type    Custom made
It should provide good (>95%) muon identification for momenta above 1 GeV.
Combination of responses from the ECal and RS could give additional lever for rejecting of pions and protons in a wide energy range.
The RS also provides additional coordinate measurement.

Our design will follow closely the design of the PANDA experiment range system (at FAIR, GSI) being developed now at the DLNP of JINR.
The SPD DAQ may be developed *a la* FPGA-based DAQ of the COMPASS experiment;

- Event rate ~3.0 MHz (at \( L=10^{32} \text{ cm}^{-2}\text{s}^{-1}, \sqrt{s}=27 \text{ GeV} \));

- Rough preliminary estimation of the total data flux from the detectors (Si tracker + straw tracker + RPC + ECal + range system): 10-20 GBytes/s (no detailed simulation results available yet);

- Triggered or trigger-less DAQ: to be decided.
Systems that have not been thought out yet...

- TOF system for particle ID (multigap glass RPCs, Micromegas, Aerogel Cherenkov?);
- Beam-beam counters (BBC) and T0 counter;
- "Zero degree" system (fine grained hadron calorimeter?)
- System for a local polarimetry;
- Front-end electronics;
Project status and roadmap
• **Letter of Intent** presented at the JINR PAC in summer 2014, where:
  • the physics program of the experiment was developed;
  • requirements to NICA polarized beams were formulated;
  • desired detector characteristics and sketch of the facility were given;
• A few presentations at international conferences about the physics potential and program of the SPD were given;
• Several workshops on spin physics at NICA were organized:
  • NICA-SPIN-2013, Дубна, 17-19.03.2013
  • SPIN-Praha-2013, 7-13.07.2013
  • NICA-SPIN-2014, Praha, 11-16.02.2014
  • SPIN-Praha-2015, 26-31.07.2015
  • DSPIN2013, DSPIN2015, DSPIN2017

In 2017 a new stage of the project started: *From LoI to CDR (Conceptual Design Report)*
Status

- Simplified detector sketch and simulations of basic physics processes (Oct. 2017- end of 2018) **ONGOING**;
- Development of a simplified design of the detector and costing **ONGOING**;
- Negotiations for an international collaboration and sharing of responsibilities for the design and construction of the facility **ONGOING**:
  - INFN section of Turin and University of Turin;
  - Charles University, Prague;
  - Technical University, Prague
  - Tomsk State University;
  - Tomsk Polytechnic University;
  - Institute of Applied Physics of the Belarus Academy of Sciences;
  - Gomel State Technical University, Belarus;
  - Institute for High Energy Physics, Protvino;
  - Institute of Nuclear Physics of the Moscow State University;
  - Institute for Nuclear Research, Troitsk;
  - Lebedev Physics Institute, Moscow;
  - Institute for Theoretical and Experimental Physics, Moscow;
  - St. Petersburg Nuclear Physics Institute, Gatchina;
  - St. Petersburg State University;
  - St. Petersburg Polytechnic University
  - ...

Protocols for joint research within the SPD project signed.

Bilateral agreements on NICA exist.
Roadmap

- Writing up of a formal JINR project for the SPD design (i.e. for preparation of the Conceptual and Technical Design Reports) and submission of the project to the PAC for Particle Physics:
  - status report presented at the PAC meeting in Jan. 2018;
  - submission of the application to the PAC in Nov. 2018 for their meeting in Jan. 2019;
- Setting up of the collaboration and election of its management bodies (2019);
Roadmap (cont’d)

- Preparation of the Conceptual Design Report (2019);
- Preparation of the Technical Design Report, including prototyping – first stage (2020 – 2022), second stage (2023);
- Construction of the detector (2022-2025);
- First measurements – 2025…
You are welcome to join the SPD/NICA project!

Web site: spd.jinr.ru.
Contact person: Roumen Tsenov (tsenov@jinr.ru)
SPD/NICA will provide a unique opportunity not available at other facilities to study all of the PDFs in one experiment and obtain comprehensive information on the nucleon spin structure at high statistical level with minimal systematic uncertainties.