Concept of the Spin Physics Detector

Vladimir Ladygin,
for the SPD working group
NICA (Nuclotron based Ion Colider fAcility) is the flagship project in high energy physics of the Joint Institute for Nuclear Research.

Main targets of the NICA project:
- **study of hot and dense baryonic matter**
- **investigation of nucleon spin structure, polarization phenomena**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring circumference, m</td>
<td>503.04</td>
</tr>
<tr>
<td><strong>heavy ions</strong></td>
<td></td>
</tr>
<tr>
<td>energy range for Au(^{79+}): (\sqrt{S_{NN}}), GeV</td>
<td>4 - 11</td>
</tr>
<tr>
<td>r.m.s. (\Delta p/p), 10(^{-3})</td>
<td>1.6</td>
</tr>
<tr>
<td>Luminosity for Au(^{79+}), cm(^{-2}) s(^{-1})</td>
<td>(1 \times 10^{27})</td>
</tr>
<tr>
<td><strong>polarized particles</strong></td>
<td></td>
</tr>
<tr>
<td>max. (\sqrt{S}) for polarized p, GeV</td>
<td>27</td>
</tr>
<tr>
<td>Luminosity for p, cm(^{-2}) s(^{-1})</td>
<td>(1 \times 10^{32})</td>
</tr>
</tbody>
</table>
Structural and Operation Regimes

**Nuclotron (45 Tm)**
- Injection bunch: $\sim 2 \times 10^9$ ions
- Acceleration up to $1 - 4.5$ GeV/u

**Booster (25 Tm)**
- Storage of $(2 \div 4) \times 10^9$ ions
- Acceleration up to 600 MeV/u

**Stripping (80%)**
$^{197}\text{Au}^{31+} \Rightarrow ^{197}\text{Au}^{79+}$

**Linac LU-20**
- Ion sources

**Linac HILac**

**Fixed Target Area**

**Two SC collider rings**

---

**KRION**
- Ion sources
Nuclotron (45 Tm)

- injection bunch: ~ $2 \times 10^9$ ions
- acceleration up to 1 - 4.5 GeV/u

Booster (25 Tm)

- storage of $(2 \div 4) \times 10^9$ ions
- acceleration up to 600 MeV/u

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Ion sources

KRION

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Structure and Operation Regimes
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Linac LU-20

Linac HILac

KRION Ion sources

Fixed Target Area

IP1

IP2 Two SC collider rings ~ 2 x 22 injection cycles 22 bunches per ring
The NICA complex

existing facilities

NUCLOTRON 0.6-4.5 GeV/u

PS & LU-20 (5MeV/u)

Booster (600 MeV/u)

existing facilities

to be constructed

BM@N

MPD hall

SPD hall

Collider

SPD

MPD
Civil construction, bld. 17

April 2019

MPD Hall

SPD Hall

08-29-2019 Thu 10:31:45

http://nucloweb.jinr.ru/nucloserv/205corp.htm
Collisions of polarized particles

Long tradition at the Synchrophasotron and Nuclotron

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
Polarized beams

A bunch crossing each 80 ns; crossing rate 12.5 MHz.

- 503 m, - 2, - 0.35 m, - $\sim 1 \cdot 10^{12}$, - 22, - 0.5 m, - 0.027, - 0.067, - 0.15 (no

Polarized beams

- $p^+p^+$ at $\sqrt{s_{pp}} = 12 - 27$ GeV, $L_{av} \approx 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- $d^+d^+$ at $\sqrt{s_{NN}} = 4 - 13$ GeV
- longitudinal and transverse polarization at SPD and MPD
Physics tasks

Talk of A. Guskov

- Nucleon spin structure studies
- Spin-dependent effects in elastic pp, pd and dd scattering;
- Spin effects in exclusive hadron production;
- Spin effects in production of hadrons with high $p_T$ in interaction of vector and tensor (d) polarized beams;
- Multiquark states and correlations
Minimum biased events

PYTHIA 6, $\sqrt{s}_{pp} = 26$ GeV; 4 MHz event rate

- Average charged particle multiplicity $\approx 7.8$
- Average neutral particle multiplicity $\approx 6.5$
- close to $4\pi$ geometrical acceptance;
- high-precision (~50 µm) and fast vertex detector;
- high-precision (~100 µm) 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)$^{-1}$. 
General view

- Length: 9.2 m;
- Diameter: 6.8 m;
- Mass: 1800 t;
- Consists of barrel and 2 endcups

Hybrid magnetic system is one of possible solutions (presented at JINR PAC in January 2019)
Hybrid magnetic system

½ model symmetry

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

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

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

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

\[ I_T = J_T \cdot S = 160 \text{kA}, \]

\[ I_{B,F} = J_{B,F} \cdot S = n820 \text{kA}. \]

Backward coils

Toroid coils

Forward coils

1. NbTi/Cu 33/33/33%

2. Stainless steel tube

3. Insulation epoxy layer, 0.3 mm

4. Copper shield

5. Multilayer thermal shield

6. Outer cover, 1mm stainless steel

\[ Z = 1600 \text{mm} \]

\[ Z = 2800 \text{mm} \]
Vertex detector (Inner tracker)

- Silicon vertex detector around the beam pipe;
- Several layers of double sided silicon strips and MAPS;
- Optimized number of layers w.r.t. material budget;
- Goal: few tens of µm resolution for the vertex reconstruction.

Charged particle creates electron/hole pairs, which migrates to electrodes creating signal in the nearest strips.
- Six particles from the vertex
- Vertex detector with 5 layers
- Silicon resolution: 50 mkm (blue) and 25 mkm (red)
Central tracker

- 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.
Momentum resolution

Hybrid magnetic system

Vertex Det.: 5 silicon layers of 300 μm thickness each;

Barrel TS: 8 straw-tube layers, two planes of 1 cm thickness in each

Pseudo-solenoidal or $3 \leftrightarrow 3$
Electromagnetic calorimeter

- 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;
- Design ("shashlik") similar of that for KOPIO Ecal
- We consider option of the projective geometry

About 6500 modules

Shashlik
- 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.
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.

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**PID pictures of Muon System**

*(single point equals one hit wire – 1x1 cm²; beam momentum – 5 GeV/c)*

- *muonic sample* -> ‘straight’ line
- *hadronic sample* -> shower

35 mm – gaps for MDT detectors

19 x30 mm / Fe

End Cap

Barrel, 8 modules
The SPD DAQ may be developed \textit{a la} upgraded DAQ of the COMPASS experiment;

- Event rate 4.0 MHz (at $L=10^{32}$ cm$^{-2}$s$^{-1}$, $\sqrt{s}=27$ GeV);
- Rough preliminary estimation of the total data flux from the detectors (Si tracker + straw tracker + PID + ECal + Range system): 10-20 GBytes/s (no detailed simulation results available yet);
- Triggered or trigger-less DAQ: to be decided.
Software and computing

ROOT- and Geant4-based software SPDRoot
Start of the SPD project

- **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, Dubna, 17-19.03.2013
  - SPIN-Praha-2013, 7-13.07.2013
  - 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)**
Roadmap

- JINR project for the SPD design (Jan. 2019);
  Conceptual and technical design of the Spin Physics Detector (SPD) at the NICA collider
- Setting up of the collaboration, MoU (2020);
- Preparation of the Conceptual Design Report (2019-2020);

Construction of the detector would take at least three years (2022-2025) and first measurements could be expected as early as close to the end of 2025…
Collaborating institutions – 25 so far

✓ National Science Laboratory, Armenia
✓ Institute of Applied Physics of the Belarus Academy of Sciences;
  • Gomel State Technical University, Belarus;
  • Institute for Nuclear Problems of BSU – Minsk;
  • Chilean cluster of universities, Chile
  • Tsinghua University, Tsinghua, China
  • Instituto Superior de Tecnologías y Ciencias Aplicadas (INsTEC), Havana University;
✓ Charles University, Prague;
✓ Technical University, Prague
• INFN section of Turin and University of Turin;
• CEA, Saclay, France;
✓ Warsaw University of Technology;
✓ Tomsk State University;
• Tomsk Polytechnic University;
✓ Lebedev Physics Institute of the RAS, Moscow;
✓ Institute for High Energy Physics, Protvino;
✓ Institute of Nuclear Physics of the Moscow State University;
• Institute for Nuclear Research of the RAS, Troitisk;
✓ Institute for Theoretical and Experimental Physics, Moscow;
• St. Petersburg Nuclear Physics Institute, Gatchina;
• St. Petersburg State University;
• St. Petersburg Polytechnic University;
✓ Samara National Research University;
✓ Belgorod National Research University;
• Kharkov National University, Kiev, Ukraine

Protocols for joint research within the SPD project signed.
✓ EoI letters received

Bilateral agreements on NICA exist.

List is permanently growing
**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.
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You are welcome to join the SPD/NICA project!

Web site: spd.jinr.ru.
**SPD advantages:**
- measurements with pp, pd and dd beams,
- possibility to perform energy scan with small steps,
- measurements via muon and electron-positron pairs,
- operations with non-polarized, transverse and longitudinally polarized beams and their combinations,
- possibility to extract all first order PDFs in one experiment.

<table>
<thead>
<tr>
<th>HOME INSTITUTE, EXPERIMENT</th>
<th>RHIC, STAR</th>
<th>RHIC, fsPHENIX</th>
<th>NICA, SPD</th>
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<tbody>
<tr>
<td>Beams</td>
<td>pp, pA, pHe³</td>
<td>pp pA, pHe³</td>
<td>pp,pd, dd, pHe³, dHe³</td>
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<tr>
<td>Polarization</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6-0.8</td>
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<tr>
<td>Luminosity, cm⁻¹ s⁻¹</td>
<td>5·10³²</td>
<td>(0.8-6)·10³²</td>
<td>10³²</td>
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<td>√s , GeV</td>
<td>160,200, 500</td>
<td>160,200, 500</td>
<td>10-26</td>
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<td>X₁, range</td>
<td>0.3-1.0</td>
<td>0.3-1.0</td>
<td>0.1-0.8</td>
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<td>Q_T, GeV</td>
<td>1-10</td>
<td>1-10</td>
<td>0.5-6</td>
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<tr>
<td>Lepton pairs</td>
<td>μ+μ⁻</td>
<td>μ+μ⁻</td>
<td>μ+μ⁻, e+e⁻</td>
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<tr>
<td>Start of data taking</td>
<td>&gt;2020</td>
<td>&gt;2021</td>
<td>2025</td>
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<td>Measurements</td>
<td></td>
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<td>Transversity</td>
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<td>yes</td>
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<td>Boer-Mulders</td>
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<td>Worm-Gear</td>
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<td>Flavour separation</td>
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<td>Exclusive DY</td>
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<tr>
<td>Deuteron quadrupole structure</td>
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<td>yes</td>
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</table>
JINR participation:
112 authors, 37.7 FTE

- Laboratory of High-Energy Physics
  - authors: 74
  - FTE: 24.4

- Laboratory of Nuclear Problems
  - authors: 30
  - FTE: 11.3

- Laboratory of Theoretical Physics
  - authors: 6
  - FTE: 2

- Directorate (1), Laboratory of Information Technologies (1)
- System for particle ID (multigap glass RPCs, Micromegas, Aerogel Cherenkov);
- "Zero degree" system (fine grained hadron calorimeter);
- Front-end electronics of the different subsystems;

Systems that have not been thought out yet...
### Beam test facility

The image shows a layout of a beam test facility with various components labeled such as HMC, MARUSYA, and Technical area.

Below is a table summarizing particle content ratios for different momenta (P, MeV/c):

<table>
<thead>
<tr>
<th>P, MeV/c</th>
<th>d</th>
<th>p,n</th>
<th>π±</th>
<th>K+</th>
<th>K−</th>
<th>μ±</th>
<th>e±</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>$10^3$</td>
<td>$10^5$</td>
<td>$10^5$</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^3$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>800</td>
<td>$10^3$</td>
<td>$10^4$</td>
<td>$10^4$</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^3$</td>
<td>$10^3$</td>
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<tr>
<td>1500</td>
<td>$10^2$</td>
<td>$10^4$</td>
<td>$10^4$</td>
<td>$10^3$</td>
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<td>2000</td>
<td>$10^4$</td>
<td>$10^5$</td>
<td>$10^4$</td>
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<tr>
<td>7000</td>
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<td>$10^6$</td>
<td>$10^3$</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^3$</td>
<td>$10^3$</td>
</tr>
</tbody>
</table>