MPD and BM@N detectors at NICA
Prospects for the Polarization Effects Measurements

D.Peshekhonov JINR
From Synchrophasotron to heavy ion collider

1957
Synchrophasotron

10 GeV proton synchrotron

V. Veksler – author of the phase stability principle

1993
Nuclotron

Superconducting accelerator of heavy ions

A. Baldin

2019
NICA

Superconducting collider of heavy ions

Investigation of
- nuclear matter at extreme densities
- nucleon spin structure and polarized phenomena

For this purpose it is necessary:

to develop the accelerator complex at JINR, which will allow obtaining of intense beams from p to Au and polarized protons and deuterons with the maximum energy up to $\sqrt{S_{NN}} = 11$ GeV (Au$^{79+}$) and $=26$ GeV (p)

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Collider basic parameters: \( \sqrt{s_{NN}} = 4-11 \) GeV; *beams*: from \( p \) to \( Au \); \( L \sim 10^{27} \text{ cm}^{-2} \text{ c}^{-1} (Au), \sim 10^{32} \text{ cm}^{-2} \text{ c}^{-1} (p) \)
Civil Construction of NICA Complex

The whole Complex is split into several Objects:

- **MPD Hall**  
- **SPD Hall**  
  Jan. 2020 (?)
- **West semi-ring**  
  end of 2017
- **East semi-ring**  
  end of 2018
- **Beam extraction**  
  affect Nuclotron operation
- **Reconstruction of building #1**

The schedule of object constructions should be coordinated with:

- **Nuclotron operation plans**
- **MPD magnet fabrication schedule**
- **Equipment installation plans**
MultiPurpose Detector (MPD)
MultiPurpose Detector (MPD)

9 m length, 6 m in diameter

Magnet: \(0.66\, T\)

superconducting solenoid

Tracking: \(TPC,\ IT,\ ECT\)

ParticleID: \(TOF,\ ECAL,\ TPC\)

T0, Triggering: \(FFD\)

Centrality, Event plane: \(ZDC\)

MPD potential advantages:

- Hermetic & homogenous acceptance (\(2\pi\) in azimuth), low material budget
- Good tracking performance and powerful PID (nuclei, hadrons, e, \(\gamma\))
- High event rate capability and reliable event separation

Stage 1: \(TPC,\ barrel\ (TOF,\ ECAL),\ ZDC,\ FFD\)

Stage 2: \(Endcaps\ (tracker,\ TOF,\ ECAL) + IT\)

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MPD status

1. Magnet – survey for producers
2. Integration – project preparation
3. TOF, ECAL, ZDC – TDR preparation
4. FFD – fabrication stage
5. TPC
   • assembly area preparations
   • fabrication of basic elements
   • readout chambers – production + R&D (alternative)
   • FEE (ALTRO-based Front-End card prototype
     - preproduction stage
The weight of the magnet (~980 t) and the whole detector (~1200 t) led to rather tough technical requirements for the basement surface and stability.
B=0.66 T; level ~ $10^{-4}$ of magnetic field homogeneity

The 5 Packages:

1. Yoke + Poles, support structure
2. Cryostat vacuum system
3. Correction coils
4. Cryogenic System
5. Control System

Field simulation
ASG Superconducting (Genova, Italy) -> CMS Solenoid

Three meetings at CERN with the CMS magnet team;

Two visits to ASG (Genova);
  • Production drawing preparation & adaptation - few months
  • Production ~ 2 years

TOSHIBA (Japan) -> ATLAS Solenoid

Letter exchange with TOSHIBA
Consultancy with ATLAS representatives

Contracts for Magnet Packages:

✓ selection of producers by November 2014
✓ contract preparation January 2015
## Schedule for MPD Magnet fabrication and put in operation

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
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<td>Technical Project development &amp; follow-up</td>
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<td>Choice of producer for the Cold Mass &amp; Cryostat (CMC)</td>
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<td>Contract preparation for the CMC</td>
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<td>Technical Project for Magnet-Detector Interface</td>
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<td>The CMC + Control Dua production</td>
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<tr>
<td>Choice of producer for the Yoke &amp; Supp. Structure (SS)</td>
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<td>The Yoke and SS production</td>
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<td>The Trim Coils (TC) production</td>
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<td>The SS &amp; 1/2 Yoke delivery &amp; installation in the MPD Hall</td>
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<td>The CMC delivery and mounting on the 1/2 Yoke</td>
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<td>The TC delivery &amp; mounting (integration with the Yoke)</td>
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<td>Delivery &amp; assembly of the complete Yoke &amp; mechanics</td>
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<td>Cryogenic Equipment (CE) production</td>
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<td>The CE delivery and installation</td>
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<td>PS and Engineering Infrastructure (EI) fabrication</td>
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<tr>
<td>Integration, tests &amp; commissioning of the CE, PS &amp; EI</td>
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<td>Magnet tests</td>
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<tr>
<td>The field measurement</td>
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<tr>
<td>The overall commissioning</td>
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</table>

*the MPD Hall Is available*
The barrel of the TOF consist of 12 supermodules (two modules connected together)

- Active area of TOF barrel: ~56 m²
- Number of channels: 13824

Number of gaps: 2 stacks by 6 gaps
Width of gap: 220 mkm
Sensitive area: 300*600 mm²
Inner/outer glass: 550 mkm
Number of strips: 48 strips by 5 mm width
Gas: \( \text{C}_2\text{H}_2\text{F}_4, \text{i-C}_4\text{H}_{10}, \text{SF}_6 \) (90%/5%/5%)
Radiation length: 2.09 g/cm²

A full scale prototype of mRPC
FFD goals:
1. Precise start signal for the TOF detector with $\sigma \leq 50$ ps
2. Pseudo-Vertex signal selecting collision in center of MPD

Concept of FFD is based on registration of high-energy photons from neutral pion decays

FFD Design
The high-energy photons are registered by their conversion to electrons inside a lead plate (1.5–2 $X_0$). The Cherenkov light, produced by the electrons in quartz radiator, is detected by MCP-PMT XP85012/A1-Q (Photonis).
Results of beam tests on the Nuclotron

Cooperation with Hefei & Tsinghua Universities

Time resolution and efficiency of full scale prototype of the mRPCs.

$\sigma_{FFD} = \sqrt{\frac{54}{2}} = 38 \text{ ps}$

$\sigma_{PRPC} = \sqrt{\frac{89}{2}} = 63 \text{ ps}$

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Physics requirements:
The overall acceptance on $|\eta| \sim 1.2$
The momentum resolution $\sim 3\%$ in $p_t$ interval from 0.1 to 1 GeV/c
Two-track resolution $\sim 1$ cm.
Charged particle multiplicity $\sim 1000$ in a central collisions
Hadron and lepton identification by dE/dx measurements with resolution better than 8%

Sketch of TPC MPD

TPC Prototype
TPC - fabrication stage

Cylinder C2, preparation for vacuum tests

Ø27 cm, l=3.4 m

Prototype assembly

Cylinder C3 manufactured

Ø140 cm, L=3.4 m
4 mm thickness
0.1 mm precision

FEC-64 prototype
(ALTERA FPGA, ALTRO, PASA chips)
ECAL tests with $e$:
- performance study of two ECAL modules with different WLS-fibers
- Tests of the ECAL read-out electronics (amplifiers and ADCs)
- Energy scan ($E_e = 1 - 6$ GeV)

Analysis of the recorded data indicates good performance

Preparation for tests with electron beams at DESY (December'13)

cosmic ray test

ECAL response to 4 GeV electrons
MPD with polarized beams
TMD parton distributions

- 8 intrinsic-transverse-momentum dependent PDFs at leading twist
- Azimuthal asymmetries with different angular modulations in the hadron and spin azimuthal angles, $\Phi_h$ and $\Phi_s$
- Vanish upon integration over $k_T$ except $f_1$, $g_1$, and $h_1$
Physics motivations

2.1. Nucleon spin structure studies using the Drell-Yan mechanism.
2.2. New nucleon PDFs and $J/\Psi$ production mechanisms.
2.3. Direct photons.

2.4. Spin-dependent high-$p_T$ reactions.
2.5. Spin-dependent effects in elastic $pp$ and $dd$ scattering.
2.6. Spin-dependent reactions in heavy ion collisions.

2.7. Future experiments on nucleon structure in the world.
Extraction of poor known or unknown PDFs with colliding proton and deuteron unpolarized, longitudinally & transversely polarized beams and asimmetries measuring

\[ H_a(P_a, S_a) + H_b(P_b, S_b) \rightarrow l^- (l, \lambda) + l^+(l', \lambda') + X , \]
Asymmetries: \(A_{LU}, A_{UL}, A_{TU}, A_{UT}, A_{LL}, A_{TL}, A_{LT}, A_{TT}\)

\[
A_{LU} \equiv \frac{\sigma_{00}^0}{\sigma_{00}^{\text{int}}} = \frac{1}{2\pi} (1 + D \cos 2\phi A_{UU}^{\cos 2\phi})
\]

\[
A_{UL} \equiv \frac{\sigma_{00}^{\text{int}} - \sigma_{10}^{\text{int}}}{\sigma_{00}^{\text{int}} + \sigma_{10}^{\text{int}}} = \frac{|S_{al}|}{|S_{bl}|} \frac{D \sin 2\phi A_{LU}^{\sin 2\phi}}{2\pi}
\]

\[
A_{TT} \equiv \frac{\sigma_{00}^{\text{int}} - \sigma_{00}^{\text{int}}}{\sigma_{00}^{\text{int}} + \sigma_{00}^{\text{int}}} = \frac{|S_{bl}|}{|S_{al}|} \frac{D \sin 2\phi A_{UL}^{\sin 2\phi}}{2\pi}
\]

\[
A_{TU} \equiv \frac{\sigma_{\uparrow 0} - \sigma_{\downarrow 0}}{\sigma_{\uparrow 0} + \sigma_{\downarrow 0}} = \frac{|S_{al}|}{|S_{bl}|} \frac{A_{TU}^{\sin(3\phi - \phi_s)} \sin(\phi - \phi_s) + D \left(A_{TU}^{\sin(3\phi - \phi_s)} \sin(3\phi - \phi_s) + A_{TU}^{\sin(\phi + \phi_s)} \sin(\phi + \phi_s)\right)}{2\pi}
\]

\[
A_{UT} \equiv \frac{\sigma_{\uparrow 0} - \sigma_{\downarrow 0}}{\sigma_{\uparrow 0} + \sigma_{\downarrow 0}} = \frac{|S_{bl}|}{|S_{al}|} \frac{A_{UT}^{\sin(\phi - \phi_s)} \sin(\phi - \phi_s) + D \left(A_{UT}^{\sin(3\phi - \phi_s)} \sin(3\phi - \phi_s) + A_{UT}^{\sin(\phi + \phi_s)} \sin(\phi + \phi_s)\right)}{2\pi}
\]

\[
A_{LL} \equiv \frac{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} - \sigma_{\uparrow \uparrow} - \sigma_{\downarrow \downarrow}}{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} + \sigma_{\uparrow \uparrow} + \sigma_{\downarrow \downarrow}} = \frac{|S_{al}S_{bl}|}{2\pi} \left(A_{LL}^{1} + DA_{LL}^{\cos 2\phi} \cos 2\phi\right)
\]

\[
A_{TL} \equiv \frac{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} + \sigma_{\uparrow \uparrow} - \sigma_{\downarrow \downarrow}}{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} + \sigma_{\uparrow \uparrow} + \sigma_{\downarrow \downarrow}} = \frac{|S_{al}S_{bl}|}{2\pi} \left[A_{TL}^{\cos(\phi - \phi_s)} \cos(\phi - \phi_s) + D \left(A_{TL}^{\cos(3\phi - \phi_s)} \cos(3\phi - \phi_s) + A_{TL}^{\cos(\phi + \phi_s)} \cos(\phi + \phi_s)\right)\right]
\]

\[
A_{LT} \equiv \frac{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} - \sigma_{\uparrow \uparrow} - \sigma_{\downarrow \downarrow}}{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} + \sigma_{\uparrow \uparrow} + \sigma_{\downarrow \downarrow}} = \frac{|S_{al}S_{bl}|}{2\pi} \left[A_{LT}^{\cos(\phi - \phi_s)} \cos(\phi - \phi_s) + D \left(A_{LT}^{\cos(3\phi - \phi_s)} \cos(3\phi - \phi_s) + A_{LT}^{\cos(\phi + \phi_s)} \cos(\phi + \phi_s)\right)\right]
\]

\[
A_{TT} \equiv \frac{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} - \sigma_{\uparrow \uparrow} - \sigma_{\downarrow \downarrow}}{\sigma_{\uparrow \downarrow} + \sigma_{\downarrow \uparrow} + \sigma_{\uparrow \uparrow} + \sigma_{\downarrow \downarrow}} = \frac{|S_{al}S_{bl}|}{2\pi} \left[A_{TT}^{\cos(2\phi - \phi_s)} \cos(2\phi - \phi_s) + D \left(A_{TT}^{\cos(2\phi - \phi_s)} \cos(2\phi - \phi_s) + A_{TT}^{\cos(\phi + \phi_s)} \cos(\phi + \phi_s)\right)\right]
\]
Estimations of DY total cross sections and numbers of events

<table>
<thead>
<tr>
<th>lower cut on $Q$, GeV</th>
<th>2.0</th>
<th>3.1</th>
<th>3.5</th>
<th>4.0</th>
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<tbody>
<tr>
<td>$\sqrt{s} = 20$ GeV ($L \simeq 0.5 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$)</td>
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<tr>
<td>$\sigma_{DY}$ total, nb</td>
<td>0.86</td>
<td>0.13</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>$N$ events for a month, $10^3$</td>
<td>120</td>
<td>18</td>
<td>9.7</td>
<td>4.6</td>
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<tr>
<td>$\sqrt{s} = 22$ GeV ($L \simeq 0.7 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$)</td>
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<tr>
<td>$\sigma_{DY}$ total, nb</td>
<td>1.01</td>
<td>0.16</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>$N$ events for a month, $10^3$</td>
<td>200</td>
<td>33</td>
<td>18</td>
<td>9.0</td>
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<tr>
<td>$\sqrt{s} = 24$ GeV ($L \simeq 1.0 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$)</td>
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<tr>
<td>$\sigma_{DY}$ total, nb</td>
<td>1.15</td>
<td>0.20</td>
<td>0.12</td>
<td>0.06</td>
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<td>$N$ events for a month, $10^3$</td>
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<td>52</td>
<td>30</td>
<td>15</td>
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<td>$\sqrt{s} = 26$ GeV ($L \simeq 1.2 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$)</td>
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<tr>
<td>$\sigma_{DY}$ total, nb</td>
<td>1.30</td>
<td>0.24</td>
<td>0.14</td>
<td>0.07</td>
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<tr>
<td>$N$ events for a month, $10^3$</td>
<td>415</td>
<td>77</td>
<td>45</td>
<td>24</td>
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</tbody>
</table>

Possible DY statistics for NICA – p. 4
Direct photons

Direct photon productions in the non-polarized and polarized $pp$ ($pd$) reactions provide information on the gluon distributions in nucleons.

Vertex $H$ corresponds to $q + qbar \rightarrow \gamma + g$ or $g + q \rightarrow \gamma + q$ hard processes.

the polarized gluon distribution (Sivers gluon function) can be extracted from measurement of the transverse single spin asymmetry

$$A_N = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}.$$ . It is of order few %.

Via double spin asymmetry $A_{LL}$ one can measure a gluon polarization in the nucleon:

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \cdot \left[ \frac{\sum_q e_q^2 [\Delta q(x_2) + \Delta \bar{q}(x_2)]}{\sum_q e_q^2 [q(x_2) + \bar{q}(x_2)]} \right] \cdot \hat{a}_{LL}(gq \rightarrow \gamma q) + (1 \leftrightarrow 2),$$

$$2.5 < p_T < 3.1 \text{ GeV}/c$$

25
Direct photons at MPD

\[ \sigma^+ - \sigma^- = \sum_i \int_{x_{\text{min}}}^{1} dx_a \int d^2 k_Ta \int d^2 k_Tb \frac{x_ax_b}{x_a - (p_T/\sqrt{s}) \ c_y} \left[ q_i(x_a, k_{Ta}) \Delta_N G(x_b, k_{Tb}) \right] \]

\[ \times \frac{d \hat{\sigma}}{d t} (q_i G \rightarrow q_i \gamma) + G(x_a, k_{Ta}) \Delta_N q_i(x_b, k_{Tb}) \frac{d \hat{\sigma}}{d t} (Gq_i \rightarrow q_i \gamma) \]

\[ \sigma, \mu \text{bn} \]

- NICA
- RHIC

Material, %X0 / cm

Distance from (0,0,0), cm
### Estimations of direct photon production rates

<table>
<thead>
<tr>
<th></th>
<th>$\sqrt{s}=24$ GeV</th>
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<th>$\sqrt{s}=26$ GeV</th>
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<tr>
<td></td>
<td>$L = 1.0 \times 10^{32}$, cm$^{-1}$s$^{-1}$</td>
<td>$L = 1.2 \times 10^{32}$, cm$^{-1}$s$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{tot}$, nbarn</td>
<td>$\sigma_{P_T&gt;4}$ GeV/c, nbarn</td>
<td>Events/year, $10^6$</td>
<td>Events/year, $10^6$</td>
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<tr>
<td>All processes</td>
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<tr>
<td>$qq \rightarrow q\gamma$</td>
<td>1290</td>
<td>42</td>
<td>1440</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow g\gamma$</td>
<td>1080</td>
<td>33</td>
<td>1220</td>
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<tr>
<td></td>
<td>210</td>
<td>9</td>
<td>240</td>
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</tbody>
</table>
BM@N advantage: large aperture magnet (~1 m gap between poles)

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and “far” detectors with coordinate detectors

- Central tracker (GEM) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (DCH, Straw) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions and form trigger
- Detectors to form T0, L1 centrality trigger and beam monitors
- Electromagnetic calorimeter for γ,e+e-
1. The comprehensive program of the spin nucleon structure and other spin dependent reactions study can be realized at NICA using the polarized proton, deuteron and heavy ion beams and MPD detector.

2. Some spin dependent reactions can be studied with BM@N setup if polarized target will be added.
Thank you
Straw wheels & Fast Forward Calorimeter

Straw: end-cup tracker
good spatial resolution & low material budget

FFD:
Trigger start-up, fast response (<40 psec)
Assembly & Integration

Project preparation

D. Peshekhonov
Superconducting accelerator complex NICA
(Nuclotron based Ion Collider fAcity)

Fixed target experiments
area (b.205)

Extracted beams from
Nuclotron

KMION-6T
and HILac
(3,5 MeV/u)

SPP and
LU-20
(5 MeV/u)

Cryogenics

Spin Physics
Detector (SPD)

Nuclotron
0,6-4,5 GeV/u

Booster (3-660 MeV/u)
inside Synchrophasotron
yoke

NICA Collider
(1-4,5 GeV/u, C~500 m)

HV
e-cooler

MultiPurpose
Detector- MPD

Detector (MPD)

D.Peshekhonov

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Требования к ТРС

✓ Высокая эффективность регистрации треков в интервале псевдобыстрот $|\eta| \sim 1.2$;

✓ Двухтрековое разрешение $\sim 1$ см для разделения треков частиц;

✓ Для идентификации адронов и лептонов разрешение по $dE/dx$ должно быть лучше 8%;

✓ Разрешение по импульсу заряженных частиц лучше 3% при поперечном импульсе до 1 ГэВ/с

➢ Множественность вторичных частиц $\sim 1000$,

➢ Частота столкновений 5 кГц.
Assembly & Integration

Project preparation

Solenoid + ECal + TOF

Solenoid + ECal + TOF + TPC
Drell-Yan with registration of electron pairs

Extraction of poor known or unknown PDFs with proton and deuteron unpolarized, longitudinally/transversely polarized beams With help of double and single asymmetries measurements

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

\[ p(D)p(D) \rightarrow \gamma^* X \rightarrow l^+ l^- X \]  
Boer-Mulders PDF

\[ p^{\uparrow}(D^{\uparrow})p(D) \rightarrow \gamma^* X \rightarrow l^+ l^- X \]  
Sivers PDFs (Efremov, ... PLB 612 (2005), PRD 73(2006));

\[ p^{\uparrow}(D^{\uparrow})p^{\uparrow}(D^{\uparrow}) \rightarrow \gamma^* X \rightarrow l^+ l^- X \]  
Transversity PDF (Anselmino, Efremov, ...)

\[ p^{\uparrow}(D^{\uparrow})p(D) \rightarrow \gamma^* X \rightarrow l^+ l^- X \]  
Transversity and first moment of Boer-Mulders PFDs  
(Sissakian, Shevchenko, Nagaytsev , Ivanov, PRD 72(2005), EPJ C46 ,2006 C59, 2009)

\[ p^{\rightarrow}(D^{\rightarrow})p^{\leftarrow}(D^{\leftarrow}) \rightarrow \gamma^* X \rightarrow l^+ l^- X \]  
Longitudinally polarized sea and strange PDFs and tenczor deuteron structure (Teryaev, ...)

D. Peshekhonov

SPIN2014 China
## Unpolarized beams

<table>
<thead>
<tr>
<th>Process</th>
<th>Beams</th>
<th>Energy, GeV</th>
<th>L</th>
<th>To measure</th>
<th>Expected results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DY- J/ψ</td>
<td>pp</td>
<td>12x12</td>
<td>$10^{32}$</td>
<td>Asymmetry</td>
<td>Duality test</td>
</tr>
<tr>
<td>DY via e+e-</td>
<td>pp</td>
<td>12x12</td>
<td>$10^{32}$</td>
<td>Asymmetry</td>
<td>Boer-Mulders PDF</td>
</tr>
<tr>
<td>J/ψ via e+e-</td>
<td>pp</td>
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<td>$10^{32}$</td>
<td>Cross sections</td>
<td>Model tests</td>
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</table>

## Longitudinally polarized beams

<table>
<thead>
<tr>
<th>Process</th>
<th>Beams</th>
<th>Energy, GeV</th>
<th>L</th>
<th>To measure</th>
<th>Expected results</th>
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<tbody>
<tr>
<td>Direct Photons</td>
<td>pp, dd</td>
<td>12x12, 6x6</td>
<td>$10^{32}, 10^{31}$</td>
<td>Asymmetry</td>
<td>$\Delta G/G$</td>
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<tr>
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<td>pp, dd</td>
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<td>$10^{32}, 10^{31}$</td>
<td>Asymmetry</td>
<td>Sea and strange PDFs, tensor deuteron structure</td>
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<tr>
<td>DY+ hadron</td>
<td>pp</td>
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<td>$10^{32}$</td>
<td>Asymmetry</td>
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<tr>
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<td>pp, dd</td>
<td>12x12, 6x6</td>
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<td>Asymmetry</td>
<td>Model tests</td>
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## Transversally polarized beams

<table>
<thead>
<tr>
<th>Process</th>
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<th>Expected results</th>
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<tbody>
<tr>
<td>DY- J/ψ</td>
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<td>Duality test</td>
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<td>Asymmetries, cross section ratios</td>
<td>Transversity, Sivers, Pretzelority PDFs, sign(DY-SIDIS), EMC effect test</td>
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<td>Gluon Sivers PDF</td>
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