Multi Purpose Detector to study heavy-ion collisions at NICA collider

V.V. Kekelidze,
Joint Institute for Nuclear Research, Dubna

V. K. Kekelidze, QM-2018, Venezia
basic facility

Nuclotron ring (c=251.5 m)

May 13-19, V. Kekelidze, QM-2018, Venezia
NICA
accelerator complex
Nuclotron (45 Tm)

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

*Injection bunch*

~ $2 \times 10^9$ ions

*Acceleration up to*

$1 - 4.5 \text{ GeV/u}$
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

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

Linac HILac
Linac LU-20
KRION
ion sources

Fixed Target Area

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Structure 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 HILac**

**Linac LU-20**

**Fixed Target Area**

**KRION**

**Two SC collider rings**
- $\sim 2 \times 22$ injection cycles
- 22 bunches per ring

**IP-1**

**IP-2**

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**Injection Complex**

**SPI**

*commissioning in 2016*

**KRYON:** *commissioning in 2018*

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**HILAC:** “BEVATECH OHG”

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<table>
<thead>
<tr>
<th>Source</th>
<th>Kryon-6T</th>
<th>SPI</th>
<th>Douplasmatron</th>
</tr>
</thead>
<tbody>
<tr>
<td>ions</td>
<td>Au$^{31+}$</td>
<td>H, D↑</td>
<td>H$^+$, D$^+$</td>
</tr>
<tr>
<td>N/cycle</td>
<td>$\sim2.5 \times 10^9$</td>
<td>$\sim5 \times 10^{11}$</td>
<td>$\sim5 \times 10^{12}$</td>
</tr>
<tr>
<td>rep, Hz</td>
<td>10</td>
<td>0.2</td>
<td>1.0</td>
</tr>
</tbody>
</table>

- **E injection, keV/amu**: 17
- **E extraction, MeV/amu**: 3.24 (A/Z=6)
- **input current, mA**: up to 10

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*commissioning in 2016*
**Booster – commissioning in 2018**

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion types</td>
<td>A/Z $\leq$ 3</td>
</tr>
<tr>
<td>injection energy, MeV/u</td>
<td>3.2</td>
</tr>
<tr>
<td>maximum energy, MeV/u</td>
<td>600</td>
</tr>
<tr>
<td>magnetic rigidity, T m</td>
<td>1.6 – 25.0</td>
</tr>
<tr>
<td>circumference, m</td>
<td>210.96</td>
</tr>
<tr>
<td>vacuum, Torr</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>intensity, Au ions/pulse</td>
<td>$1.5 \times 10^9$</td>
</tr>
<tr>
<td>RF range, MHz</td>
<td>0.5 -2.53</td>
</tr>
</tbody>
</table>

RF stations (2) are tested

Electron Cooling System

tunnel for Booster
Collider structure

45 T*m, 11.0 GeV/u for Au^{79+}

Au(+79) ion mode

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### Collider parameters

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference, m</td>
<td>503.04</td>
</tr>
<tr>
<td>structure</td>
<td>FODO, 12 sectors</td>
</tr>
<tr>
<td>bunch number</td>
<td>22</td>
</tr>
<tr>
<td>bunch length, m</td>
<td>0.6</td>
</tr>
<tr>
<td>( \beta ) –function at IP, m</td>
<td>0.35</td>
</tr>
<tr>
<td>ring acceptance, ( p ) mm mrad</td>
<td>40</td>
</tr>
<tr>
<td>( E ) in the c.m.s. for ( _{197}A^{79+} ), GeV/u</td>
<td>( 4.0 ) ( 8.0 ) ( 11.0 )</td>
</tr>
<tr>
<td>ion number in bunch</td>
<td>( 2.0 \times 10^8 ) ( 2.4 \times 10^9 ) ( 2.3 \times 10^9 )</td>
</tr>
<tr>
<td>momentum spread, ( Dp/p )</td>
<td>( 0.55 \times 10^{-3} ) ( 1.15 \times 10^{-3} ) ( 1.5 \times 10^{-3} )</td>
</tr>
<tr>
<td>beam emittance, ( p ) mm mrad</td>
<td>( 1.1/0.95 ) ( 1.1/0.85 ) ( 1.1/0.75 )</td>
</tr>
<tr>
<td>luminosity, ( cm^{-2} s^{-1} )</td>
<td>( 0.6 \times 10^{25} ) ( 1.0 \times 10^{27} ) ( 1.0 \times 10^{27} )</td>
</tr>
<tr>
<td>time life of luminosity, s</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>1800</td>
</tr>
</tbody>
</table>
SC Magnets for NICA & SIS-100/FAIR workshop at VBLHEP (bld. 217) was put in operation (full configuration) in Nov. 2016

> 80% of the Booster magnets are fabricated & tested
Civil Construction bld.17

> 5000 piles are already pressed in
> 20k m³ concrete works are done
metal constructions - in progress

readiness for equipment installation in the MPD Hall - 2018
NICA heavy ion collisions program in 2021-2023
Physics objectives

Comprehensive study of:

- **bulk properties, EOS**
  - particle yields & spectra, ratios, femtoscopy, flow

- **in-medium modification of hadron properties**
  - onset of low-mass dilepton enhancement

- **deconfinement (chiral) phase transition**
  - strangeness production
  - Chiral Magnetic (Vortical) effect, $\Lambda$ polarization

- **search for QCD Critical Point**
  - event-by-event fluctuations & correlations

- **Y-N interactions in dense nuclear matter**
  - hypernuclei

  in the region of max net baryon density
Exploring high-density baryonic matter: maximum freeze-out density

Present and future HI experiments

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Interaction rate [Hz]

Collision energy $\sqrt{S_{NN}}$ [GeV]

2023: SIS-100 FAIR

NICA/BM@N II

HADES

STAR F.T.

STAR BES II

NICA/MPD

energy region of max. baryonic density

NA-61/SHINE

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QCD matter at the NICA energies:

- maximum in the net baryon density – density frontier;
- maximum in $K^+/\pi^+$ ratio;
- maximum in $\Lambda/\pi$ ratio;
- maximum yield if hypernuclei
- transition from a Baryon dominated system to a Meson dominated one;
- maximum of the $\Lambda$ polarization;
- 1-st order transition & mixed phase creation;
- Critical EndPoint?
Physics targets for the exploration of first order phase transitions in the region of the QCD phase diagram accessible to NICA & FAIR and possible observable effects of a “mixed phase indicated in the release of the “NICA White Paper” as a Topical Issue of the EPJ A (July 2016).
MPD detector for Heavy-Ion Collisions

Tracking: up to $|h|<1.8$ (TPC)
PID: had., $e, \gamma$ (TOF, TPC, ECAL)
Reaction: centrality & plane determination (FHCal)

Stage 1 (2020):
TPC, TOF, ECAL, ZDC, FFD

Status: technical design – completed; production / preparation for production

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MPD detector for Heavy-Ion Collisions @

**Stage 1 (2020):**
- TPC, TOF, ECAL, ZDC, FFD

**Stage 2 (2023):**
- ITS + EndCap (tracker, TOF, ECAL)

**Tracking:** up to $|h|<1.8$ (TPC)

**PID:** had., e, $\gamma$ (TOF, TPC, ECAL)

**Reaction:** centrality & plane determination (FHCal)

**Status:** technical design – completed; production / preparation for production

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Magnet production: at ASG (Genova) & Vitkovice HM

- yoke control assembly at HM Vitkovice - June 2018
- coils & cryostat delivery to Dubna - May 2019

B₀ = 0.5 T, ~ 900 t
### Time Projection Chamber (TPC) – basic tracker

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>340 см</td>
</tr>
<tr>
<td>Out Radii</td>
<td>140 см</td>
</tr>
<tr>
<td>In Radii</td>
<td>27 см</td>
</tr>
<tr>
<td>Gas</td>
<td>90% Ar + 10% CH₄</td>
</tr>
<tr>
<td>Drift Velocity</td>
<td>5.45 см / mcs;</td>
</tr>
<tr>
<td>Velocity Time</td>
<td>&lt; 30 mcs;</td>
</tr>
<tr>
<td>N R-O Chamb.</td>
<td>12 + 12</td>
</tr>
<tr>
<td>N pads / chan.</td>
<td>95232</td>
</tr>
<tr>
<td>Max Event Rate</td>
<td>&lt; 7 kGz (L = 10²⁷)</td>
</tr>
</tbody>
</table>

**FEC64SAM - dual SAMPA card**

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Time of Flight (TOF) system

28 modules
280 MPRC's
13 440 ch.

efficiency and time resolution

Efficiency, %

Time resolution, ps

High Voltage, kV
Fast Forward Detector – (FFD)

FFD_E

\[ 2.3^\circ < |\theta| < 7.5^\circ \]

FFD_W

\[ 2.7 < |\eta| < 3.9 \]

L = 14.0 cm

time resolution < 50 ps

array of 20 modules
Planacon MCP-PMTs

80 +20 channels

Au + Au, \( \sqrt{s_{NN}} = 5 \text{ GeV} \)

15 mm quartz radiator
10 mm lead converter

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FHCAL: determination of reaction plane and centrality

2 x 45 modules (15 x 15 cm$^2$ each) located left and right at ~3.2 m from the IP

light collection
WLS-fibers & SiPM

acceptance: 2.2<$|\eta|<$ 4.8

\[ \sigma(E)/(E) = 53%/\sqrt{E\text{(GeV)}} +10\% \]

transverse granularity allows to measure:
- the reaction plane with accuracy $\sim 20^0-30^0$
- the centrality with accuracy below 10%.

Au+Au @$\sqrt{S_{NN}}$ = 11 A GeV, UrQMD, GEANT3, 2M events
Electromagnetic calorimeter: ECAL

- Pb+Sc “Shashlyk”
- read-out: WLS fibers + MAPD
- $L \sim 35$ cm ($\sim 14 X_0$)
- Segmentation (4x4 cm$^2$),
- $\sigma(E)$ better than 5% @ 1 GeV;
- time resolution $\sim 500$ ps

Barrel ECAL $\sim 43\,000$ modules
MPD I stage

feasibility study
Stage 1: 2021-2023
energy and system size scan from 4 to 11 GeV in steps of 1-2 GeV

limitation by the accelerator:
- lower luminosity
- extra reduction by 40% because of a larger beam diamond

Detector limitation
- **TPC** tracking: $|\eta|<1.8$ (N points$>10$)
- **TOF** coverage: $|\eta|<1.2$
- **PID**: combined $|\eta|<1.2$, $0.1<pT<4$ GeV/c,
  limited in $1.2 < |\eta| < 1.8$ (only dE/dx)
- **ECAL** coverage: $|\eta|<1.2$
- **FHCAL** coverage: $2.2<|\eta|<4.8$
- **FFD** inside the TPC inner pipe
Strange and multi-strange baryons

Stage’1 (TPC+TOF): Au+Au @ 11 GeV, UrQMD

large phase-space

<table>
<thead>
<tr>
<th>particle</th>
<th>$\Lambda$</th>
<th>anti-$\Lambda$</th>
<th>$\Xi^-$</th>
<th>anti-$\Xi^+$</th>
<th>$\Omega^-$</th>
<th>anti-$\Omega^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>yield in 10 weeks</td>
<td>$3 \cdot 10^8$</td>
<td>$3.5 \cdot 10^6$</td>
<td>$1.5 \cdot 10^6$</td>
<td>$8.0 \cdot 10^4$</td>
<td>$7 \cdot 10^4$</td>
<td>$1.5 \cdot 10^4$</td>
</tr>
</tbody>
</table>

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Prospects for study of dileptons

- **Event generator:** *UrQMD+Pluto (for the cocktail) central Au+Au @ 8 GeV*
- **PID:** \(dE/dx\) (from TPC) + TOF (\(s \sim 100\) ps) + ECAL

\[ \sigma_\omega \approx 14\text{ MeV/c}^2 \]

hadron suppression up to \(10^{-5}\)

- **PID**
  - electrons
  - pions
  - protons
  - kaons
  - electron selection

\[ \frac{dN}{d\eta} \]

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Flow performance

**Au+Au@11 A GeV; GEANT3; UrQMD (LAQGSM), 4M events**

\[ v_n = \frac{\{\cos[n(\phi - \Psi_{EP,1})]\}}{R_n(\Psi_{EP,1})} \]

- flow harmonics \((v_1 / v_2)\)
- flow coefficients \(R_n(\Psi_{EP,1})\) – resolution correction factor
- \(\phi\) – azimuthal angle of produced particle
- \(\Psi_{EP,1}\) – event plane angle

**Event plane resolution**

**Flow performance event plane resolution**

**Flow harmonics**

**good reproducibility**

**Event plane:** FHCal

**Centrality:** TPC

**PID:** TOF+TPC

**May 13-19, 2018**

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Hyper nuclei

Stage 2: central Au+Au @ 5 AGeV; DCM-QGSM

<table>
<thead>
<tr>
<th>Hyper nucleus</th>
<th>Yield in 10 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3\Lambda$He</td>
<td>$9 \cdot 10^5$</td>
</tr>
<tr>
<td>$^4\Lambda$He</td>
<td>$1 \cdot 10^5$</td>
</tr>
</tbody>
</table>

A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stocker

$^3\Lambda$He $\rightarrow$ $^3$He + $\pi^-$

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$^4\Lambda$He $\rightarrow$ $^3$He + $p$ + $\pi^-$

S/B = 4.3
S/$\sqrt{S+B} = 13.0$
Eff. = 0.4%

Peak 115.3
Mean 3.926
Sigma 0.0023

S/B = 8.4
S/B = 2.9
Eff. = 0.8%

Peak 61.07
Mean 2.992
Sigma 0.0019
Prospects to search for CEP

trajectories calculated by a 3-fluid hydrodynamics (Toneev & Ivanov)

abnormal fluctuations are expected for trajectory in the vicinity of the CEP

MPD provides a uniform midrapidity phase-space coverage necessary to search for the CEP via EvE fluctuations

Au+Au; net-protons

4 A GeV

11 A GeV

May 13-19, V.Kekelidze, QM-2018, Venezia
kick-off meeting on formation of the MPD and BM@N Collaborations

carried out in Dubna on 11-13 April, 2018

https://indico.jinr.ru/conferenceDisplay.py?ovw=True&confId=385
Concluding remarks

- NICA complex has a potential for competitive research in the field of baryon rich matter
- The construction of both accelerator complex & MPD is progressing close to the schedule
- Welcome to join the MPD collaboration
Thank you!