Veksler-Baldin
Laboratory of High Energy Physics
of JINR

E.A.Strokovsky

VBLHEP, JINR, Dubna

Dubna, 08.09.2014
Laboratory for High Energies: appearance

V.I. Veksler with D.I. Blokhintsev, F. Joliot-Curie

A.M. Baldin
Phase stability principle (V.I. Veksler; 1945 - E.M. McMillan)

1949-1950
Physics grounds of the Synchrophasotron, prototyped in Lebedev Physics Inst. of AS USSR; construction of the Synchrophasotron started.

1953
Electrophysics Lab. of AS USSR with the Synchrophasotron as a future basic facility

1956, March 26
Laboratory for High Energy of Joint Institute for Nuclear Research

1957, April
Synchrophasotron was put into operation.

Research program was developed and performed under leadership of V.I. Veksler, M.A. Markov, I.V. Chuvilo, A.M. Baldin

1970
Acceleration of deuterons in Synchrophasotron; later on – relativistic nuclei.

1981
Acceleration of polarized deuterons

1993
Nuclotron was put into operation;
In mid 90’ – Movable Polarized Proton Target in LHE.

Synchrophasotron operated almost 50 years
Group of postgraduated students (magisters) arrived to the EPhLAS (1955)

Photos are taken from A.A.Kusnetsov, PEPAN Lett. v.1 N6 (123) 2004
Early days of LHE JINR

Photos are taken from A.A. Kusnetsov, PEPAN Lett. v.1 N6 (123) 2004

Photo 2. V.I. Veksler (left) and Van Ganchan discuss a scientific program of the Department in the V

Van Ganchan

Photo 15. The group discovered antisuigma–minus–hyperon, upper row, from left to right: A.A. Kuznetsov, M.I. Solov’ev, A.V. Nikitin, E.N. Kladnitskaya, N.M. Varyasov (USSR); lower row, from left to right: V.I. Veksler (USSR), Din Datsao (People’s Republic of China), Kim Khi In (Democratic People’s Republic of Korea), Nguyen Din Ty (People’s Republic of Vietnam), and A. Mikhul (Socialist Republic of Romania). The antisuigma–minus–hyperon is seen in the picture in front of the microscope.
Selected examples
(personal view)
Method of internal jet targets: who, when and where...
1.5. ИЗМЕРЕНИЕ ПАРАМЕТРА НАКЛОНА ДИФРАКЦИОННОГО КОНУСА В ИНТЕРВАЛЕ ЭНЕРГИИ 10—70 Гэв
Data on elastic pp scattering in the region of the Coulomb-nuclear interference.

$\alpha$ is the ratio of real to imaginary part of the amplitude of the "forward" elastic scattering (i.e. at the scattering angle $= 0$).

The analogy with optics: $\alpha$ is an analog of ratio of the refractive index to the absorption index.
Cryogenic supersonic hydrogen jet target: from LHE JINR to IHEP

Photos are taken from
A.A.Kusnetsov, PEPAN Lett. v.1 N6 (123) 2004

Photo 24. V.A. Nikitin and A.A. Kukushkin at the facility for leading-in the internal target at the IHEP accelerator.

Photo 26. V.V. Smelyanskii, an engineer from the Cryogenic Department, prepares the gas-hydrogen jet target for the experiment at the IHEP accelerator.

Dubna, 08.09.2014
Cryogenic supersonic hydrogen jet target: from LHE JINR to FNAL
The first JINR-FNAL (Soviet-American) collaborative experiment

Dubna, 08.09.2014
Now this technology is in use worldwide.

Few recent examples: CELSIUS, COSY, PANDA@FAIR, …

Gas jet targets, cluster targets, pellet targets, …
Kinematics, Monte-Carlo methods in particle physics; the \((K\pi)\) method of hypernuclei production; Interference of identical particles (now known as HBT correlations): base for femtoscopy.

Photos are taken from A.A.Kusnetsov, PEPAN Lett. v.1 N6 (123) 2004
For reaction \( a + b \rightarrow c + d \)

Mandelstam variables are:

- \( s = (\mathbf{P}_a + \mathbf{P}_b)^2 = (\mathbf{P}_c + \mathbf{P}_d)^2 \) total energy in c.m.
- \( t = (\mathbf{P}_a - \mathbf{P}_c)^2 \) 4-momentum transfer from \( a \) to \( c \) squared
- \( u = (\mathbf{P}_a - \mathbf{P}_d)^2 = (\mathbf{P}_b - \mathbf{P}_c)^2 \) 4-momentum transfer from \( a \) to \( d \) squared

\[
\begin{align*}
    s + t + u &= m_a^2 + m_b^2 + m_c^2 + m_d^2 \\

t &= (E_a^* - E_c^*)^2 - (\mathbf{p}_a^* - \mathbf{p}_c^*)^2 = -2 (|\mathbf{p}^*|^2) \cos \vartheta^* - 2 (|\mathbf{p}^*|^2) (1 - \cos \vartheta^*) = -4 (|\mathbf{p}^*| \sin \vartheta^*/2)^2 \sim - (|\mathbf{p}_a^*| \cdot \vartheta^*)^2 \sim -(p_{\perp})^2
\end{align*}
\]

Diffraction of elementary particles and relativistic nuclei. Partons …
The empirical momentum density (EMD) is independent on:
- the probe
- the initial $T_{\text{kin}}$
  (1.5 to 7.4 GeV)
- the target
- The same for $\kappa_0$; $T_20$ has 25% sensitivity to the type of target
- $T_20$ tends to be a negative constant

The EMD is the same as in $(d,p)X$ at 0°
- $T_20$ has a new structure
- $\kappa_0$ and $T_20$ differs from $(d,p)X$ at 0°
- the same track at the $\kappa_0 - T_20$ plot as for $(d,p)X$ at 0°
Polarization, observables

\[ P_z = S_z ; \quad P_{zz} = 3S_z^2 - 2 ; \quad \eta = \frac{q^2}{4M_d^2} ; \quad E_p \frac{d^3\sigma}{dp^2} \sim u^2 + w^2 \]

\[ T_{20} = \frac{w}{\sqrt{2}} \cdot \frac{2\sqrt{2}u - w}{u^2 + w^2} \quad \Rightarrow \quad Q_d = \frac{1}{20} \int_0^\infty r^2 dr \cdot w(2\sqrt{2}u - w) \]

\[ \frac{P_z^{prot}}{P_z^d} = \frac{1}{1 - \rho_2 T_{20}/2} \cdot \kappa_0 \quad \Rightarrow \quad \kappa_0 = \frac{u^2 - w^2 - uw/\sqrt{2}}{u^2 + w^2} \]

Electromagnetic formfactors

\[ C_E = \int_0^\infty j_0(qr/2) \left[u^2 + w^2\right] dr \Rightarrow F_{ch}(q^2) = 2f_{ch}(q^2) \cdot C_E(q^2) \rightarrow 1 \]

\[ C_Q = \frac{3}{4\eta} \int_0^\infty j_2(qr/2)w(2\sqrt{2}u - w)dr \Rightarrow F_Q(q^2) = 2f_{ch}(q^2) \cdot C_Q(q^2) \rightarrow M_d^2 \cdot Q_d \]

\[ C_L = \frac{3}{2} \int_0^\infty \left[j_0(qr/2) + j_2(qr/2)\right] w^2 dr \leftarrow Convection \text{ contribution} \]

\[ C_S = \frac{1}{2} \int_0^\infty \left[2 \left(u^2 - w^2/2\right) j_0(qr/2) + j_2(qr/2) \left(\sqrt{2}uw + w^2\right)\right] dr \]

\[ F_m(q^2) = \frac{M_d}{m_N} \left[2f_m(q^2) \cdot C_S(q^2) + f_{ch}(q^2) \cdot C_L(q^2)\right] \rightarrow \mu_d \]

\[ C_S \rightarrow 1 - \frac{3}{2}P_D ; \quad C_L \rightarrow \frac{3}{2}P_D \]
Deuteron structure at short distances: summary of the data

$p(d,p)X$ and $p(d,p)d$

$T_d = 7.4 \text{ GeV (Dubna)}$

- $M_{eff} = M_d \Rightarrow$ elastic backward scattering
- $2M_N < M_{eff} < 2M_N + m_\pi \Rightarrow$ ”cold” breakup
- $M_{eff} > 2M_N + m_\pi \Rightarrow$ ”hot” breakup
Cumulative and other inelastic processes
Polarization effects in cumulative particle production.


\[ d^\uparrow + A \rightarrow \pi (\Theta) + X \]

Paris DWF
direct mechanism

CQM

preliminary
(180 mrad)

\[ A_{yy} \]

\[ \begin{array}{cccc}
\Theta = 0 & 0 & 0.1 & 0.3 & 0.5 \\
3.0 & 3.5 & 4.0 & 4.5 & 5.0 & 5.3
\end{array} \]

\[ X_C = \frac{P_{\text{targ}P_\pi - m_N^2/2}}{(P_{\text{targ}P_{\text{beam}}} - m_N^2 - (P_{\text{beam}P_\pi})} \]

Fig.3. \( A_{yy}(R) \) for \( p(d, d')X \) and \( ^{12}\text{C}(d, d')X \) inelastic scattering; data are taken from Refs. 2, 3. Open-circles: 4.2–4.5 GeV/c; full circles: 5.53 GeV/c; stars: 9 GeV/c; full squares: 9 GeV/c at 85 mrad scattering angle, carbon target [3]
Synchrophasotron magnet and the dipole magnet of Nuclotron
Laboratory for High Energy Physics (current)
Scientific cooperation of LHEP

- ALICE
- ATLAS
- CMS
- NA61
- NA62
- COMPASS-II
- NICA

Termalization
- NICA
- STAR
- NICA

LHEP
- HADES, CBM, PANDA
- SIS100/SIS300, NICA

Dubna, 08.09.2014
ongoing projects
(accelerators, experiments)

at home:

*Nuclotron-NICA, MPD, BM@N,*
*HyperNIS, ALPOM-2, DSS, FAZA-3, E&TM*

CERN:

*ALICE, CMS, ATLAS, NA62, COMPASS-II, NA61*

GSI/FAIR:

*HADES, CBM, PANDA*

BNL:

*STAR*

Accelerators, R&D:

*ILC, FEL,*
*IREN (FLNP)*

Activities: *SPD, NA48/2, NA49, Termalization, Becquerel, Marusya,…*
Selected examples
(personal view)
JINR CMS 2013 Physics Results

JINR CMS group concentrated on 8 TeV data analysis within few selected topics

Discovery of Higgs boson

search for Higgs bosons in multi muon channel

→ ZZ → 4l

SM Tests

studies of SM in new energy scale:
mcross-sections of Drell-Yan muon pairs, and forward-backward asymmetry

Di-muons

New Physics beyond SM

search for microscopic Black holes in multi particle production

$M_{BH} > 4.7 \text{ – } 6.3 \text{ TeV}$

Multi-jets

Search for new gauge boson resonance states and RS-graviton in di-muon channel

$M_{ZSM} > 2950 \text{ GeV}$

$M_{RS} > 2390 \text{ GeV}$

Dubna, 08.09.2014
ATLAS activities at VBLHEP (in 2013)

Ongoing analysis of associative WH/ZH production

F. Ahmadov
Invariant mass of two b-jets

95%CL upper limit for VH cross section

From Run-1 data (~30/fb):
- No confident excess of events over the Standard Model background
- The upper limit is 1.4 times higher than those expected from the SM

A. Cheplakov, V. Kukhtin
Neutron irradiation of diamond sensors
(in collaboration with TRIUMF)

N. Javadov
Relative non-linearity

Jet energy resolution

MC simulation for the di-jet events including effects of the preamplifier’s degradation due to irradiation (~10^{14} n/cm^2) showed:
- significant deterioration of the signal;
- necessity of exchange the HEC cold electronics

F. Ahmadov, N. Javadov, A. Cheplakov, V. Kukhtin

Dubna, 08.09.2014
JINR-ALICE group results:

Femtoscopic analysis for pairs of identical charged kaons for (p-p, p-Pb, Pb-Pb) collisions led to measurements of invariant source radius ($R_{inv}$) versus transverse mass/momentum ($m_T/k_T$).

- for Pb-Pb it is seen an approximate $m_T$-scaling predicted by the Hydrodynamic model;
- the same radius dependence on the $k_T/m_T$ and event centrality is seen in p-Pb and Pb-Pb events (collective expansion of the source);
- the same effect is observed for p-p events at higher $N_{ch}$;
- the radii in the p-Pb events are much lower than in Pb-Pb ones (more close to the p-p events).

This result contradicts to some theoretical prediction and is under study.
Goals of NA48, NA48/1

- Direct CP violation in
  \[ \Delta \text{Re}(\varepsilon'/\varepsilon) \approx 2 \cdot 10^{-4} \quad (\text{statistics limited by } K_L \rightarrow \pi^0 \pi^0) \]

- K_{L/S} rare decays
  - \( K_{L/S} \rightarrow \pi^0 \gamma \gamma \)
  - \( K_{L/S} \rightarrow \gamma \gamma \)
  - \( K_S \rightarrow \pi^0 e^+ e^- \)
  - \( K_{L/S} \rightarrow \pi^+ \pi^- e^+ e^- \)
  - …

- Precise measurements of \( \Xi^0, K_L \) and \( \eta \) - masses, \( \tau_S \)

- Dalitz plots & CPV in
  - \( K_L \rightarrow \pi^0 \pi^0 \pi^0 \quad … \)

- Hyperons
  - \( \Xi^0 \rightarrow \Lambda \gamma \)
  - \( \Xi^0 \rightarrow \Sigma^0 \gamma \)

Dubna, 08.09.2014
NA48 detector

- **Magnetic spectrometer (4 DCHs):**
  - redundancy $\Rightarrow$ high efficiency;
  - $\Delta p/p = 1.0\% \pm 0.044\% \cdot p$ [GeV/c]

- **Hodoscope**
  - fast trigger;
  - precise time measurement.

- **Liquid Krypton EM calorimeter (LKr)**
  - see next slide
5.33 x 10^6

K_L → π^0 π^0 decays

Re(ε'/ε) = (14.7 ± 2.2) x 10^{-4}
Conclusions

• Preliminary NA48/2 2003 result on CP-violating charge asymmetry in $K^\pm \rightarrow \pi^\pm \pi^0\pi^0$:

$$A_g = (1.7 \pm 1.7_{\text{stat.}} \pm 1.2_{\text{trig.(stat.)}} \pm 1.3_{\text{syst.}} \pm 0.2_{\text{ext.}}) \times 10^{-4}$$

$$= (1.7 \pm 2.4) \times 10^{-4}$$

• This result has almost 10 times better precision than the previous measurements;

• The error is dominated by statistics;

• The systematic uncertainties are conservative for the preliminary result.

• The result is consistent with the predictions of the Standard Model.
the decay is sensitive to CPV & New Physics

more than 2 500 $K^+ \rightarrow \pi^+ \pi^0 e^+ e^-$ - decays are observed

preliminary: $\text{Br}(\pi^+ \pi^0 e^+ e^-) = (4.22 \pm 0.09_{\text{stat.}} \pm 0.07_{\text{syst.}} \pm 0.13_{\text{ext.}}) \times 10^{-6}$

$\text{Br}(\pi^+ \pi^0 e^+ e^-)_{IB} = (3.96 \pm 0.09_{\text{stat.}} \pm 0.07_{\text{syst.}} \pm 0.13_{\text{ext.}}) \times 10^{-6}$

major background sources:
- $K^+ \rightarrow \pi^+ \pi^0 D \rightarrow \pi^\pm e^+ e^- \gamma \quad (+ \gamma \text{ acc})$
- $K^+ \rightarrow \pi^\pm \pi^0 \pi^0 D \rightarrow \pi^\pm \pi^0 e^+ e^- \gamma \quad (\gamma \text{ lost})$

the normalization channel for the $\text{Br}$ evaluation: $K^+ \rightarrow \pi^+ \pi^0 D \rightarrow \pi^\pm e^+ e^- \gamma$

prediction with internal $\gamma$ conversion

4.18x10^{-6} - IB only

no isospin correction

[Cappiello, Cata, D’Ambrosio, Gao, EPJ C72 (2012) 1872]
New strategic course of the JINR in relativistic heavy ions & particle physics is based on:
- development of the home accelerator facility **NICA**
  providing relativistic heavy ions & polarized beams
- scientific programs at home & external accelerators including
  a study of various phases of strongly interacting matter,
  urgent topics of particle physics and spin physics

Relativistic Heavy Ion Physics is a **high priority task** in many scientific centers (BNL, CERN, GSI) since last few decades

**Theoretical motivation of relativistic heavy ion studies at JINR is developed in the works of:**

A.Sissakian, A.Sorin, V.Toneev, G.Zinoviev etc.

**From particles to hadronic/QCD matter → the present trend**
Relativistic Ion Facilities from Synchrophasotron and AGS to NICA and FAIR

Over the last 30 years a lot of efforts have been made to provide the conditions for searching for new states of strongly interacting matter under extreme conditions.

**Synchrophasotron:** $E_{\text{lab}} \sim 4.2 \text{ AGeV}$ ($\sqrt{s_{NN}} = 3 \text{ GeV}$)
1971 - 1999, pioneer experiments in the field of relativistic nuclear physics.

**AGS:** $E_{\text{lab}} \sim 11 \text{ AGeV}$ ($\sqrt{s_{NN}} = 5 \text{ GeV}$)

**SPS:** $E_{\text{lab}} \sim 158 \text{ AGeV}$ ($\sqrt{s_{NN}} = 18 \text{ GeV}$)
1986 - up to now, study of compressed baryonic matter.

**RHIC:** $\sqrt{s_{NN}} = 200 \text{ GeV}$ ($E_{\text{lab}} \sim 80000 \text{ AGeV}$)
1996 - up to now,

**LHC:** $\sqrt{s_{NN}} = 5520 \text{ AGeV}$ ($E_{\text{lab}} \sim 6.1 \times 10^7 \text{ AGeV}$)
2008 - planned

**SIS 300 (FAIR):** $E_{\text{lab}} \sim 34 \text{ AGeV}$
($\sqrt{s_{NN}} = 8.5 \text{ GeV}$),
full performance will be reached in 2015, study of compressed baryonic matter.

**NICA:** $\sqrt{s_{NN}} = 9 \text{ GeV}$ ($E_{\text{lab}} \sim 40 \text{ AGeV}$),
full performance will be reached in 2013, search for the mixed phase of strongly interacting matter.

Dubna, 08.09.2014
In experimental study of the strongly interacting matter:

- Formation (creation)
- Evolution (for example, from hot and dense to cold and sparse matter where particles can appear)
- Condensing and/or hadronization

The general feature: unavoidable problems of non-perturbative nature.

In different types of reactions one meets with different aspects of those stages.

Modification of particle properties in medium (structure functions might be different in the cold and hot matter, dense and sparse; particle spectra; widths of resonances),

Hadronization of quarks (fragmentation functions) occurs also in a different environment, etc.
New aspect: strong external electromagnetic field

**Comparison of magnetic fields**

<table>
<thead>
<tr>
<th>Magnetic Field Type</th>
<th>Magnetic Field Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Earth's magnetic field</td>
<td>0.6 Gauss</td>
</tr>
<tr>
<td>A common, hand-held magnet</td>
<td>100 Gauss</td>
</tr>
<tr>
<td>The strongest steady magnetic fields achieved so far in the laboratory</td>
<td>$4.5 \times 10^5$ Gauss</td>
</tr>
<tr>
<td>The strongest man-made fields ever achieved, if only briefly</td>
<td>$10^7$ Gauss</td>
</tr>
<tr>
<td>Typical surface, polar magnetic fields of radio pulsars</td>
<td>$10^{13}$ Gauss</td>
</tr>
<tr>
<td>Surface field of Magnetars</td>
<td>$10^{15}$ Gauss</td>
</tr>
</tbody>
</table>

http://solomon.as.utexas.edu/~duncan/magnetar.html

Heavy ion collisions: the strongest magnetic field ever achieved in the laboratory

Off central Gold-Gold Collisions at 100 GeV per nucleon

$$eB(\tau=0.2 \text{ fm}) = 10^3 \sim 10^4 \text{ MeV}^2 \sim 10^{17} \text{ Gauss}$$

from D.Kharzeev (Nov. 5-6, 2008, in Dubna, “NIC-A round table” 3)
Probing of different regions of the phase diagram for hot and dense hadronic matter:

- Phase transitions
  - Baryonic to hadronic and QCD (quark-gluon) matter
  - Critical endpoint (exists or not); mixed phase
  - Liquid-to-fog (at the condensing-hadronization stage 3)
- Exotic nuclei (hypernuclei; stabilizing role of strangeness
  • implemented into nuclear matter)

**Spin and polarization phenomena**
- Nucleon structure, phenomenology of the nucleon-nucleon interactions
- Few nucleon systems at short distances (probe of sub-nucleonic aspects; multinucleon forces etc.)

**Flavour physics**, i.e.
*Fundamental symmetries* and mechanisms of their violation
*Particle structure* (constituents, quark content) in empty space and in the strongly interacting medium, exotics
*Particle properties in medium* (cold and normal/sparse; hot and dense)
The main strategic direction is to start in the coming 5÷7 years experimental study of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions.

Instrumental basis:

NICA with polarized beams
Multipurpose detectors at NICA: MPD, SPD, MPDL
Nuclotron-M with extracted polarized beams and MPPT
External facilities at CERN (SPS, LHC), FAIR, RHIC
Phase diagram (after 2009)
High baryonic densities

Hadronic freeze-out

Maximal baryonic densities on freeze-out curve! ⇒ High densities on interaction stage!? 

J. Randrup, J. Cleymans, 2006
Why a search for the mixed phase is so important

The beam energy of the NICA is particularly interesting; it is considerably lower than the region covered by the Large Hadron Collider (LHC) in Geneva but it sits right on top of the region where the baryon density at the freeze-out is expected to be the highest. In this energy range the system occupies a maximal space-time volume in the mixed quark-hadron phase (the phase of coexistence of hadron and quark-gluon matter similar to the water-vapor coexistence-phase). The net baryon density at LHC energies will be lower because of a phenomenon called nuclear transparency: at very high energies nuclei fly "through" each other, produce a very large number of mesons and, therefore, reach very high energy densities but due to a large number of mesons achieve fairly low baryon densities. The energy region of NICA will allow analyzing the highest baryonic density under laboratory conditions.

Water-steam transition (first-order phase transition with the latent heat) ends a critical point (second order). No difference between steam and water above the critical point.

According to modern theoretical models, quark-hadron phase transitions manifest a structure similar to water, with a crossover above the critical point ($\mu_B$ is baryon chemical potential related to the baryon density, $T$ is temperature).

Freeze-out (cease of particle interactions in the system) estimated for different colliding energies (J. Randrup and J. Cleymans, 2006). Freeze-out baryon density is maximal at collider energy $\sqrt{s_{NN}} = (4+4)$ GeV. The blue colored numbers stand for energy in the laboratory system, the red ones - in the system of centre of mass.

Phase trajectories in the phase diagram calculated within the 3-fluid hydrodynamic model for central Au+Au collisions at different energies (Yu. Ivanov, V.N. Russkikh, V.D. Toneev, 2005; A.N. Sissakian, A.S. Sonin, M.K. Suleymanov, V.D. Toneev, G.M. Zinovjev, 2005, 2006). Freeze-out curve is shown by dots, the shaded region is a mixed phase for baryon and strange conserved charges. For $E_{lab} = 30$ GeV ($\sqrt{s_{NN}} = 8$ GeV) the trajectory goes near the critical end-point. Points with numbers indicate the time of the system evolution ($1$ fm/c $\sim 3.3 \times 10^{-24}$ sec).
Subject: phase transitions in hot nuclear matter (expansion and evolution from hot to cold)

The first goal: measurement of the mean emission time for thermal multifragmentation.

Data: FAZA for p+Au collisions.

Assumed nuclear phase diagram. Baryon density is given in units of the normal one.

Line: zero rigidity of the nuclear matter

mean time of thermalization
mean time to climb on the barrier top
dispersion of $t_3$ determines the mean emission time
mean time of the multineck rupture
NICA complex at JINR Dubna

based on the existing heavy ion accelerator Nuclotron - the superconductive synchrotron with max. energy of 6 GeV/u for deuterons

(\textit{In red: installations under preparation, in blue: existing ones})

**NICA Storage Rings**

Spin physics with nuclear and **polarized** proton targets at **polarized** beams

**MPD (MultiPurpose Detector)**

for study of dense and hot baryon matter (QCD phase diagram exploration)

Spin physics with the **SPD detector**

**Nuclotron+booster**

**Heavy ion source**

**Polarized ion source**

Areas for experiments at extracted beams

**BM@N spectrometer**

**Baryonic Matter @ Nuclotron**, to study (multi) strange matter in heavy ion collisions beams of \( T=2A - 6A\) GeV
**NICA parameters:**

- **Energy range:** $\sqrt{s_{NN}} = 4-11 \text{ GeV}$
- **Beams:** from $p$ to $Au$
- **Luminosity:** $L \sim 10^{27} \text{ (Au)}, 10^{32} \text{ (p)}$
- **Detectors:** MPD (ions), SPD (spin physics)
Basis of the JINR “spin physics” program (polarization studies of few nucleon systems and NN interaction):
Source of Polarized Deuterons (CIPIOS based) for Nuclotron/NICA complex

must be in operation in 2015

It will provide $\sim 10^{10}$ per pulse polarized deuterons from Nuclotron

1. SPD assembly
2. Extraction block
3. Spin-precessor
4. Pre-accelerator tube
5. High voltage terminal
6. Supply rack

Dubna, 08.09.2014
Fields of Research

Dubna, 08.09.2014
The physics program (high energy heavy ion Physics):

1. The equation-of-state of nuclear matter at high densities. Search for the mixed phase.

2. In-medium properties of hadrons.


4. The first order deconfinement and/or chiral symmetry restoration phase transitions.

5. The QCD critical endpoint.
Physics at the Nuclotron/NICA facility

1. High energy heavy ion (or relativistic nuclear) physics
2. Spin physics (polarization studies of nucleon structure, NN interactions, few nucleon system and nuclear structures)
3. Flavour physics (physics of strange quarks, exotic hadrons, violation of basic symmetries)

Renewal of the instrumental basis: nuclear collider over the Nuclotron

- Beam infrastructure for “fixed target” experiments will be kept;
- Nuclear collider (instrumented) will be built; $\sqrt{s} \approx (5-10)$ GeV per nucleon; luminosity $\sim 10^{27}$ cm$^{-2}$s$^{-1}$ (U+U)
The MPD experiment is proposed to study in-medium properties of hadrons, & search for phase transition, mixed phase & critical end-point in collisions of heavy ion (over atomic mass range A = 1-238) by scanning of the energy region $\sqrt{s_{NN}} = 3-9$ GeV. A program of corresponding R&D's is foreseen including ones in the framework of the experiments carried out at Nuclotron.
Relativistic Heavy Ion Physics at Nuclotron & at higher energies

**FAZA at Nuclotron**
S. Avdeev, V. Karnaukhov
effects of phase transition in thermal multifragmentation

**HADES & CBM**
A. Malakhov, Yu. Zanevsky, Yu. Murin
at SIS 18, 100/300 GSI

**NA49 -> NA61**
G. Melkumov
at SPS CERN

**STAR**
R. Lednicky, Yu. Panebratcev
at RHIC BNL

**ALICE**
A. Vodopianov
at LHC CERN

Dubna, 08.09.2014
Spin Physics

**Source of Polarized Deuterons (CIPIOS based)** for Nuclotron-M / NICA complex will provide \(~ 10^{10}\) d↑/pulse from Nuclotron-M

**MPPT** (movable p↑⊥ target) for f.t. experiments

Spin physics of **few nucleon system A.Kovalenko**

- pp elastic scattering (analyzing powers & correlation coefficients)
- meson production in pp near the threshold
- pd (3-nucleon forces, analyzing powers & correlation coefficients)

**Nucleon Spin structure**

» **COMPASS** (SPS CERN), **HERMES** (Desy)

» **SPD** at **NICA** (pp, pd -polarized, \(\sqrt{S} = 20\) GeV) LoI in preparation

Dubna, 08.09.2014
### Particle Physics

**Physics at LHC CERN**  
*(CM tests, Higgs, SUSY, ...)*

- **CMS**  
  A.Zarubin, A.Golutvin

- **ATLAS**  
  V.Kukhtin, V.Peshekhonov

**Flavor Physics**

- **NA48-NA62 (SPS CERN)**  
  V.Kekelidze, Yu.Potrebenikov
  *Precise check of the CM & CPV in Kaon very rare decays*

- **NIS-GIBS (Nuclotron)**  
  E.Strokovsky, Yu.Lukstins
  *check of the OZI rule*
  *search for multiquark states (pentaquarks)*
  *exotic nuclei (hyper nuclei)*
Accelarator Projects

- **LUE-200** for *IREN*, (finished)  
  A. Sumbaev

- **LHC damping system** *(CERN)* (finished)  
  V. Zhabitsky

- **SIS-100** (for *GSI*) fast cycling magnets R&D, production  
  A. Kovalenko

Dubna, 08.09.2014
beam test facility

Experimental zone in bld.205
Lab scientists give lectures in
- Moscow State University
- Moscow Physical and Technical Institute
- Moscow Institute of Energy
- Dubna University
- JINR Educational Center
- Moscow Institute of Radio technique, Electronics & Automatization

Regular international schools for young scientists

- ~ 25 students & PhD students are working at the Lab
- 6 young scientists are scholars of the Veksler research grant,
  2 - are scholars of the Markov research grants
Scientific cooperation of LHEP

Terمالization
NICA

ALICE
ATLAS
CMS
NA61
NA62
COMPASS-II
NICA

H1
HERMES
XFEL
NICA

HADES, CBM, PANDA
SIS100/SIS300, NICA

Dubna, 08.09.2014
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)

1949-1960
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)

1961-1970
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)

1971-1980
Accelerators for particle and nuclear physics in Europe and Asia
(intermediate and high energies)

1981-1990
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)

1991-2000
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)

2001-2010
Accelerators for particle and nuclear physics in Europe and Asia (intermediate and high energies)
Europe (intermediate and high energies)

1949-1960
Europe (intermediate and high energies)

1961-1970
Europe (intermediate and high energies)

1971-1980
Europe (intermediate and high energies)

1981-1990
Europe (intermediate and high energies)

1991-2000
Europe (intermediate and high energies)

2001-2010
Europe (intermediate and high energies)

2011-...
Thank you!