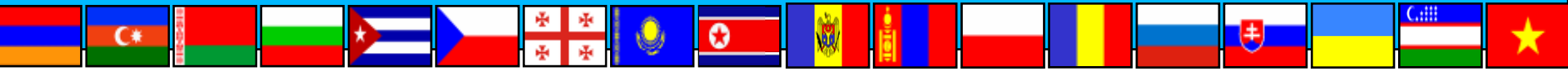


Joint Institute for Nuclear Research, Dubna

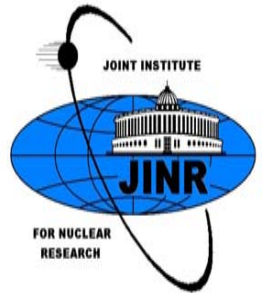


Nuclotron-based Ion Collider Facility (NICA) at JINR: New Prospect for Heavy Ion Collisions and Spin Physics

G.V. Trubnikov
(for the NICA team)



**New Opportunities in the Physics Landscape at CERN
CERN, May 11 - 13, 2009**



I. Status of the NICA project at JINR

II. Heavy ion physics at NICA

III. Spin physics at NICA

IV. Concluding remarks



JINR Basic Facility

Nuclotron:

Superconducting

Proton

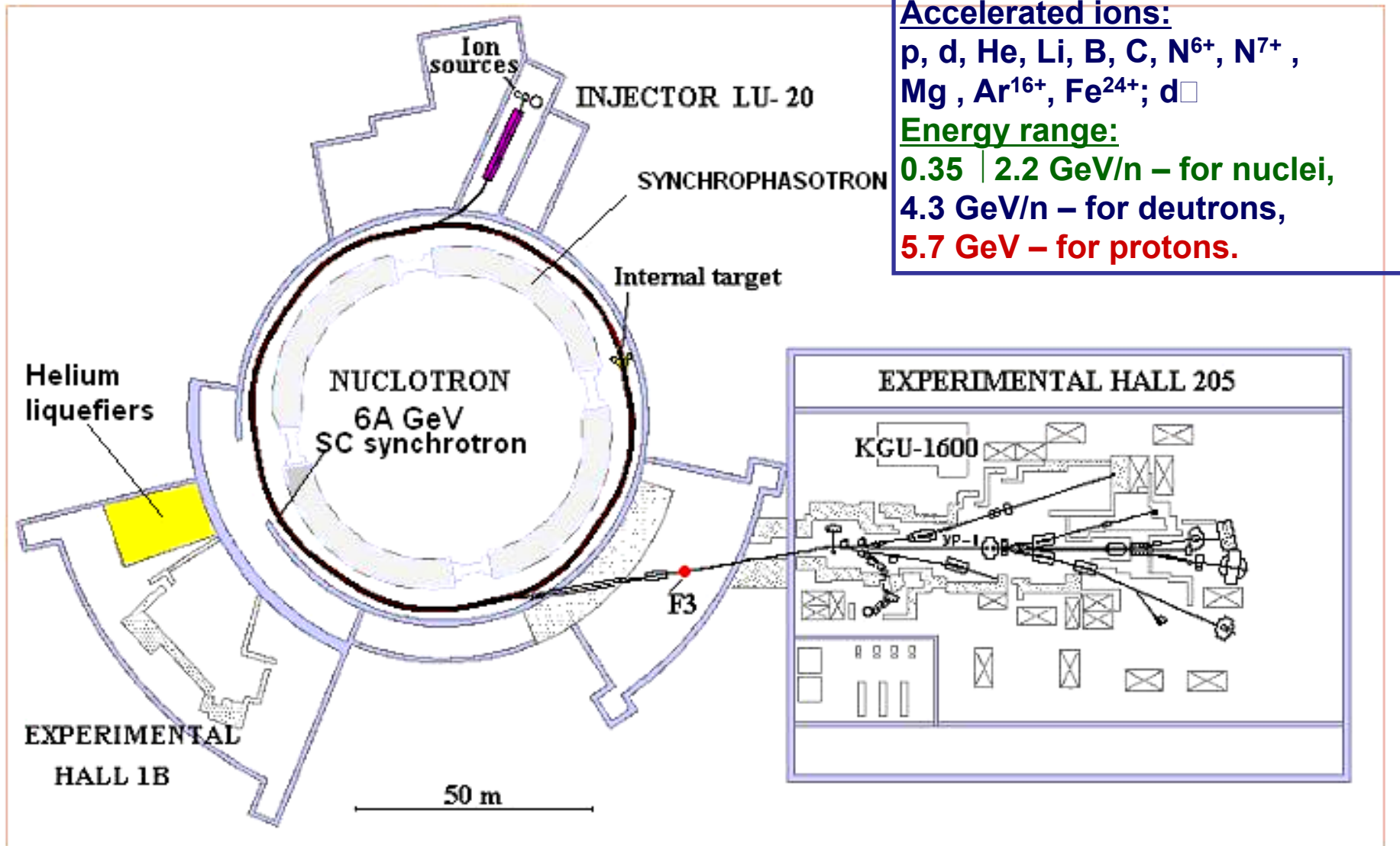
Synchrotron (since 1993)



Alexander M. Baldin



Nuclotron provides now performance of experiments on accelerated proton and ion beams (up to Fe^{24+} , $A=56$) with energies up to 5,7 and 2,2 GeV/n correspondingly (project parameters for ions 6 GeV/n with $Z/A = 0,5$)



Accelerated ions:
 p, d, He, Li, B, C, N^{6+} , N^{7+} ,
 Mg, Ar^{16+} , Fe^{24+} ; d□
Energy range:
 0.35 | 2.2 GeV/n – for nuclei,
 4.3 GeV/n – for deuterons,
 5.7 GeV – for protons.

Status of the NICA project at JINR

The main goal of the NICA project is an experimental study of hot and dense nuclear matter and spin physics

These goals are proposed to be reached by:

- **development of the Nuclotron as a basis for generation of intense beams over atomic mass range from protons to gold and light polarized ions;**



- **design and construction of heavy ion collider with maximum collision energy of $\sqrt{s_{NN}} = 9$ GeV/n and average luminosity 10^{27} cm⁻² s⁻¹ (for Au⁷⁹⁺), and polarized proton beams with energy $\sqrt{s} \sim 25$ GeV and average luminosity $> 10^{31}$ cm⁻² s⁻¹**
- **design and construction of the MultiPurpose Detector (MPD)**

Project of the Nuclotron-based Ion Collider fAcility (NICA) and MultiPurpose Detector (MPD) at JINR



Scientific case:

1. Study of excited nuclear matter in NN, pN and pp interactions and search for the mixed phase of strongly interacting matter in energy range of $\sqrt{s} = 4 \div 11$ GeV/u
i.e. $^{197}\text{Au} \times ^{197}\text{Au}$ in the kinetic energy range of $1 \div 4.5$ GeV/u
at average luminosity (at 3.5 GeV/u)

$$L_{\text{average}} = 1 \oplus 10^{27} \text{ cm}^{-2} \oplus \text{s}^{-1}$$

2. Study of spin physics in $p \square p \square$ and $d \square d \square$ collisions in the energy range of $\sqrt{s} = 10 \div 27$ GeV/u (pp) and $4 \div 13$ GeV/u (dd)

$$L_{\text{average}} \sim 1 \oplus 10^{30 \div 32} \text{ cm}^{-2} \oplus \text{s}^{-1}$$

NICA Project leaders: A.Sissakian, A.Sorin

Accelerator group leaders: I.Meshkov, A.Kovalenko, G.Trubnikov

JINR: N. Agapov, V. Alexandrov, A. Alfeev, O. Brovko, A. Butenko, E.D.Donets, E.E.Donets, A. Eliseev, I.Issinsky, V.Fimushkin, A.Fateev, F.Govorov, G. Khodzhbagiyan, V. Karpinsky, V. Kobets, O.Kozlov, A. Kuznetsov, V. Mikhaylov, V.Monchinsky, A. Sidorin, G. Sidorov, A.Sidorov, V. Shevtsov, A.V. Smirnov, B. Vasilishin, V.Volkov, V. Zhabitsky, S.Yakovenko,

IHEP: O. Belyaev, Yu. Budanov, S.Ivanov, A. Maltsev, I. Zvonarev

INR RAS: L. Kravchuck

Budker INP: V.Arbuzov, Yu.Biryuchevsky, S.Krutikhin, G.Kurkin, B.Persov, V.M. Petrov, A.M.Pilan

INP(Bulgaria) D.Dinev, A.Angelov, V.Angelov, I.Geshkov, I.Stamenov

Physics group: V.Kekelidze (MPD), A.Nagaitsev (SPD)

JINR: Kh.U.Abraamyan, S.V.Afanasiev, N.Anfimov, D.Arkipkin, V.A.Babkin, S.N.Basylev, D.Blaschke,I.V.Boguslavski, V.V.Borisov, V.V.Chalyshev, S.P.Chernenko, V.F.Chepurnov, V.F.Chepurnov, G.A.Cheremukhina, I.E.Chirikov-Zorin, K.Davkov, V.Davkov, D.Drnojan, E.Egorov, O.V.Fateev, Yu.I.Fedotov, V.M.Golovatyuk, N.Grigalashvili, Yu.A. Gornushkin, A.V.Guskov, A.Yu.Isupov, V.N.Jejer, G.D.Kekelidze, V.Kizka, A.G.Litvinenko, S.P.Lobastov, V.M.Lysan, J.Lukstins, V.M.Lucenko, N.Krahotin, Yu.T.Kiryushin, Z.V.Krumshtein, D.T.Madigozhin, A.I.Malakhov,V.V.Mialkovski, I.I.Migulina, N.A.Molokanova, Yu.A.Murin, G.J.Musulmanbekov, V.A.Nikitin, A.G.Olchevski, V.F.Peresedov, D.V.Peshekhonov, V.D.Peshekhonov, I.A.Polenkevich, Yu.K.Potrebenikov, V.S.Pronskikh, S.V.Razin, O.V.Rogachevskiy, A.B.Sadovsky, I.Savin, Z.Sadygov, A.A.Savenkov, B.G.Shchinov, A.V.Shabunov,I.V.Slepnev, V.M.Slepnev, O.V.Teryaev, V.D.Toneev,I.A.Tyapkin, N.M.Vladimirova, S.V.Volgin, Yu.V.Zanevsky, A.I.Zinchenko, V.N.Zrjuev, R.Ya.Zulkarneev, Yu.R.Zulkarneeva

INR: V.A.Matveev, M.B.Golubeva, F.F.Guber, A.P.Ivashkin, L.V.Kravchuck, A.B.Kurepin, T.L. Karavicheva, A.I. Maevskaya, A.I.Reshetin

Lomonosov MSU: E.E.Boos, I.P.Lokhtin, L.V.Malinina, M.M.Merkin, L.I.Sarycheva, A.M.Snigirev, A.G.Voronin

St.Petersburg SU: S.Igolkin, G.Feofilov, V.Zherebchevskiy, V.Lazarev

Bogolyubov ITP, NAS, Ukraine: G.M.Zinovjev, K.A.Bugaev

IAP, AS, Moldova: K.K.Gudima, M.I.Baznat

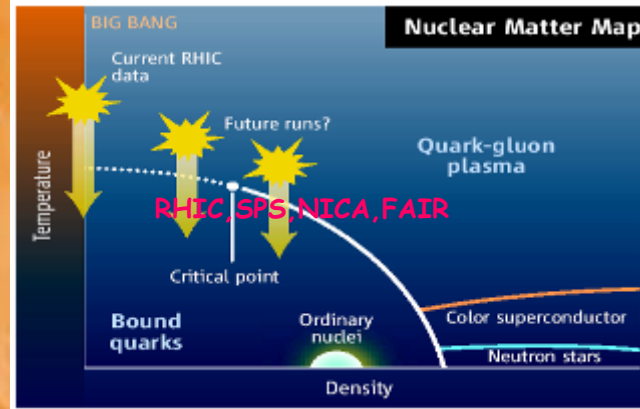
Institute for Scintillation Materials, Kharkov, Ukraine: B.V.Grinyov

State Enterprise STRIAC, Kharkov, Ukraine: V.N.Borshchov, O.M.Listratenko, M.A.Protsenko, I.T.Tymchuk

Particle Physics Center of Belarusian State University: N.M.Shumeiko, F.Zazulia

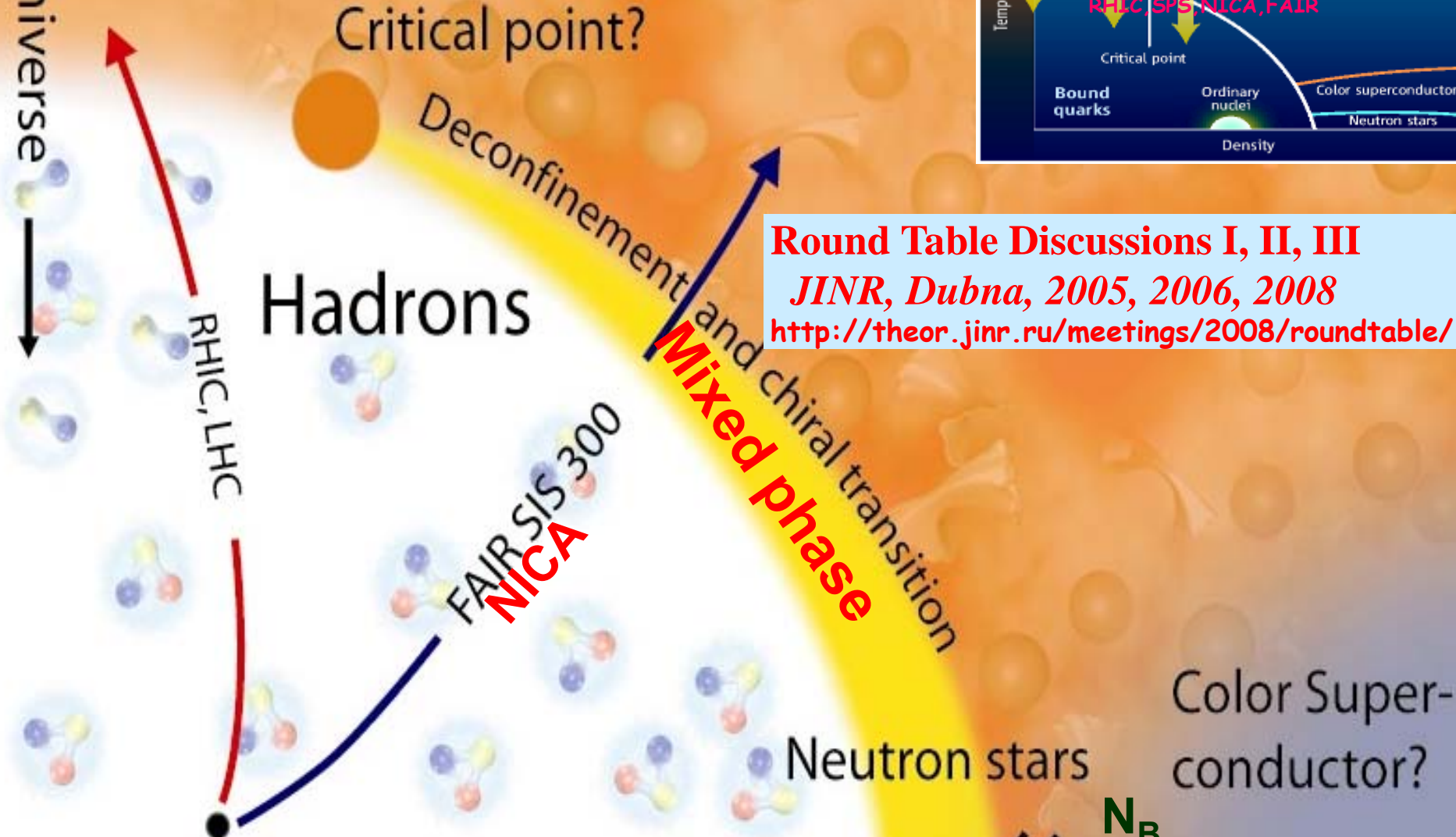
Heavy ion physics at NICA

14 APRIL 2006 VOL 312 SCIENCE www.sciencemag.org



Quarks and Gluons

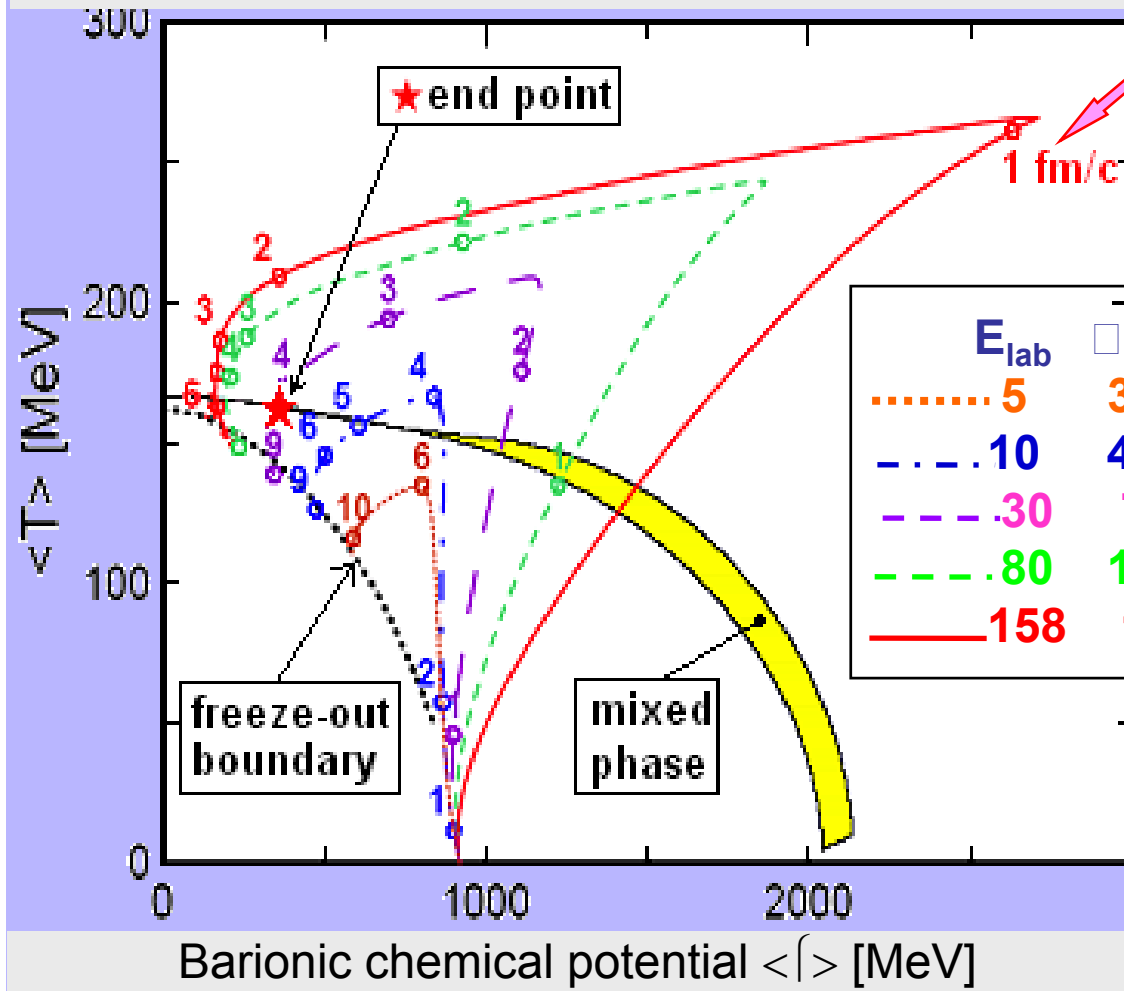
Early universe
↓



Round Table Discussions I, II, III
JINR, Dubna, 2005, 2006, 2008
<http://theor.jinr.ru/meetings/2008/roundtable/>



Search for the mixed phase of strongly interacting matter



1 fm/c $\sim 3 \cdot 10^{-24}$ s

1 fm/c

The NICA Physics Program

Study of in-medium properties of hadrons and nuclear matter **equation of state**, including a search for possible signs of deconfinement and chiral symmetry restoration **phase transitions** and **QCD critical endpoint**

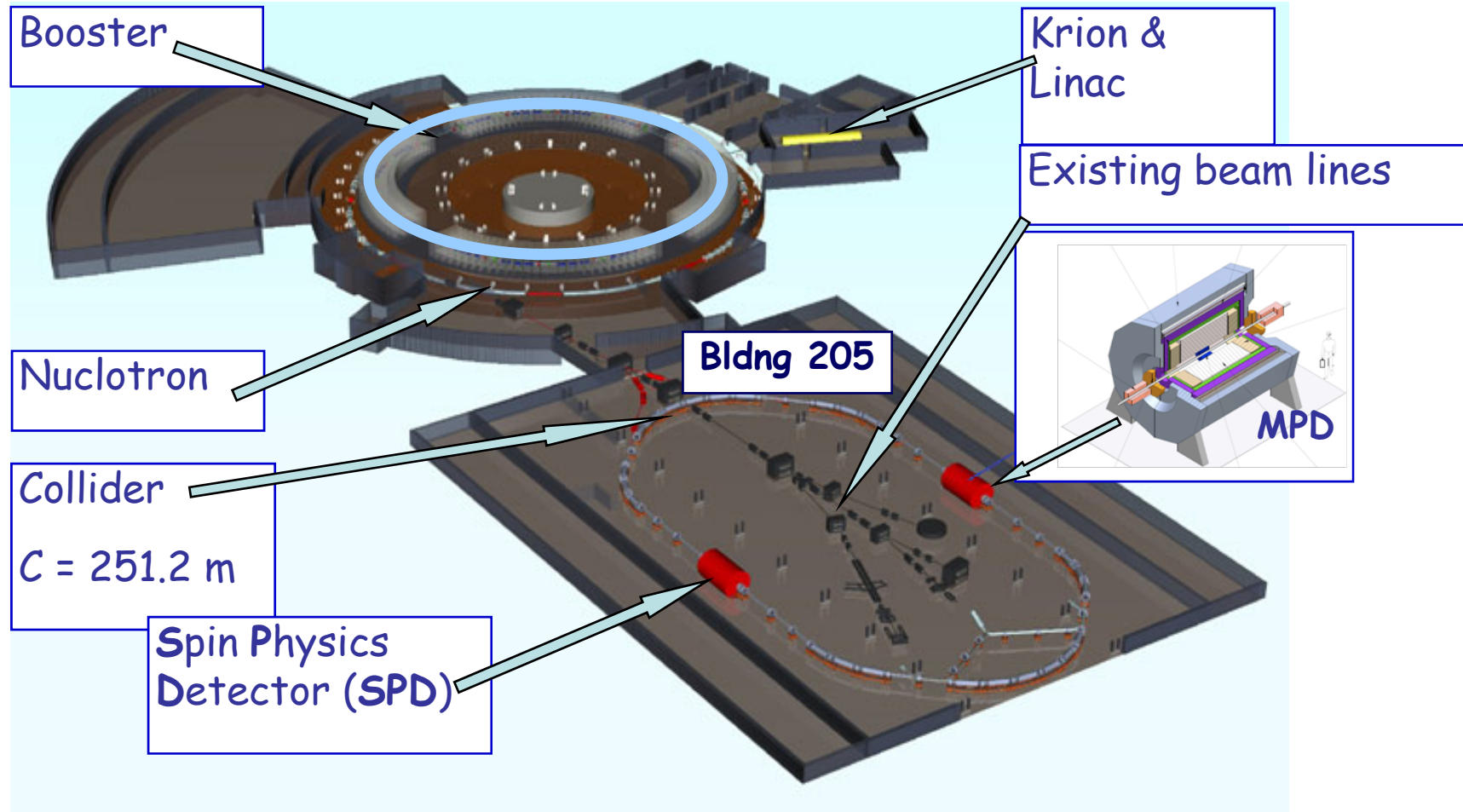
Experimental observables:

Scanning in beam energy and centrality of **excitation functions** for

- ♣ Multiplicity and global characteristics of identified hadrons including **(multi)strange** particles
 - ♣ Fluctuations in multiplicity and transverse momenta
 - ♣ Directed and elliptic flows for various identified hadrons
 - ♣ Particle correlations
 - ♣ Dileptons and photons



NICA Layout



Injector: 2×10^9 ions/pulse of $^{197}\text{Au}^{32+}$
at energy of 6 MeV/u



Booster (25 Tm)

2(3) single-turn injections,
storage of 3.2×10^9 ,
acceleration up to 100 MeV/u,
electron cooling,
acceleration
up to 640 MeV/u

Collider (45 Tm)

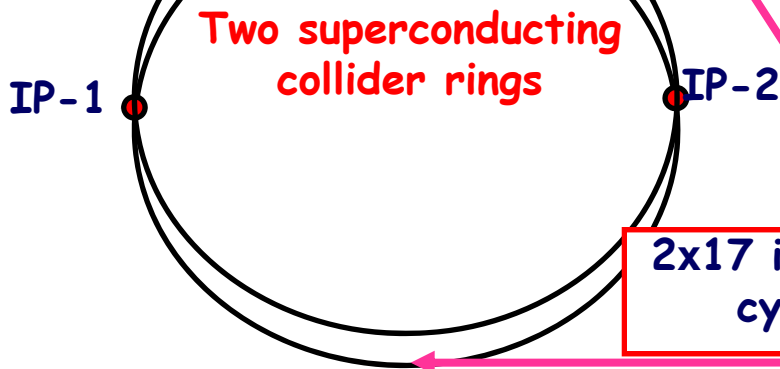
Storage of
17 bunches · $1 \oplus 10^9$ ions per ring
at 1÷4.5 GeV/u,
electron and/or stochastic cooling

Stripping (80%) $^{197}\text{Au}^{32+} \rightarrow ^{197}\text{Au}^{79+}$



Nuclotron (45 Tm)

injection of one bunch
of 1.1×10^9 ions,
acceleration up to
1÷4.5 GeV/u max.

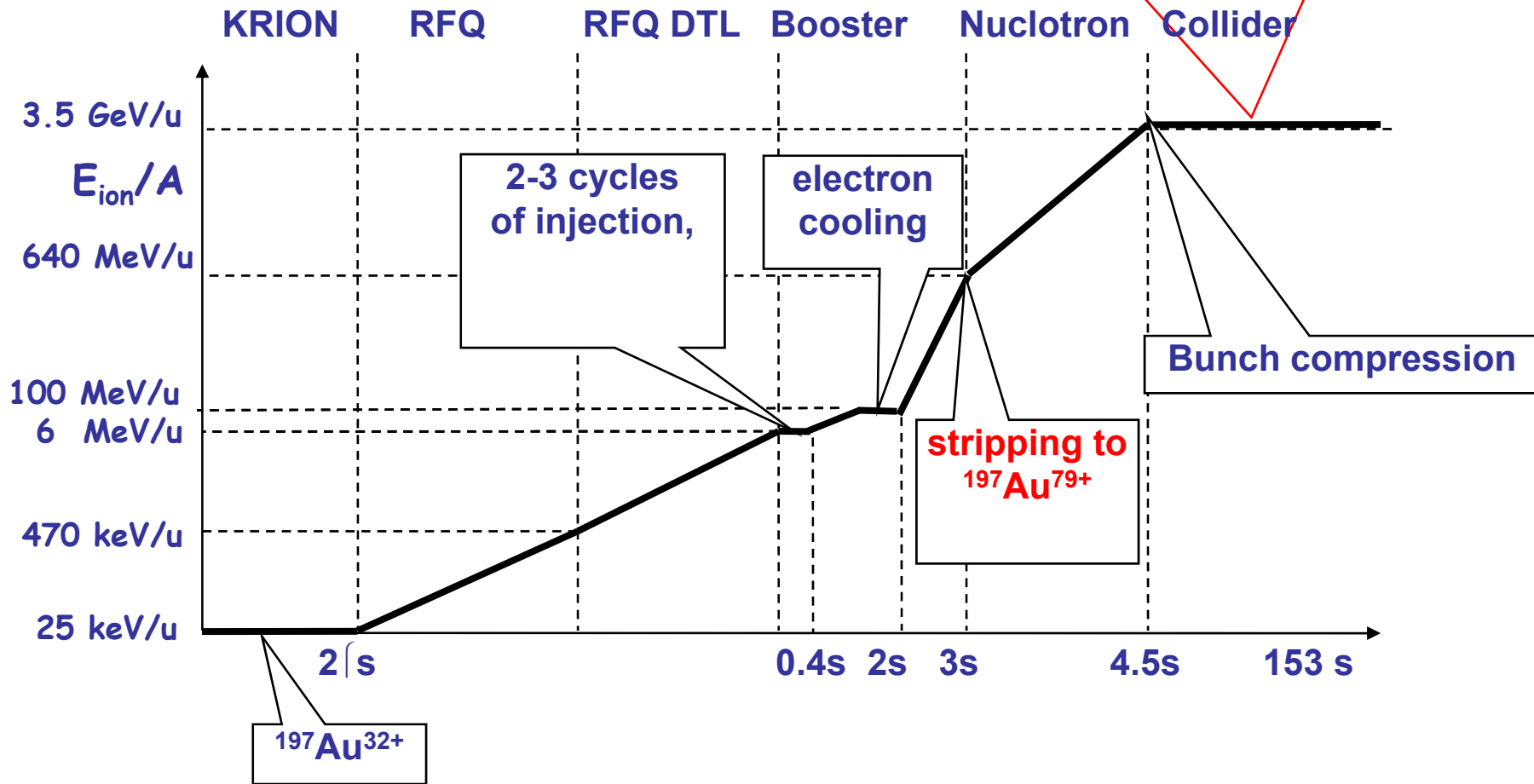


2x17 injection
cycles

Bunch compression ("overturn" in phase space)

34 injection cycles of $1 \oplus 10^9$ ions $^{197}\text{Au}^{79+}$ per cycle
 $1.7 \oplus 10^{10}$ ions/ring @ $L \approx 1 \cdot 10^{27} \text{ cm}^{-2} \cdot \text{s}^{-1}$

Time Table of The Storage Process





Vladimir I.
Veksler



Dismounting is in progress presently

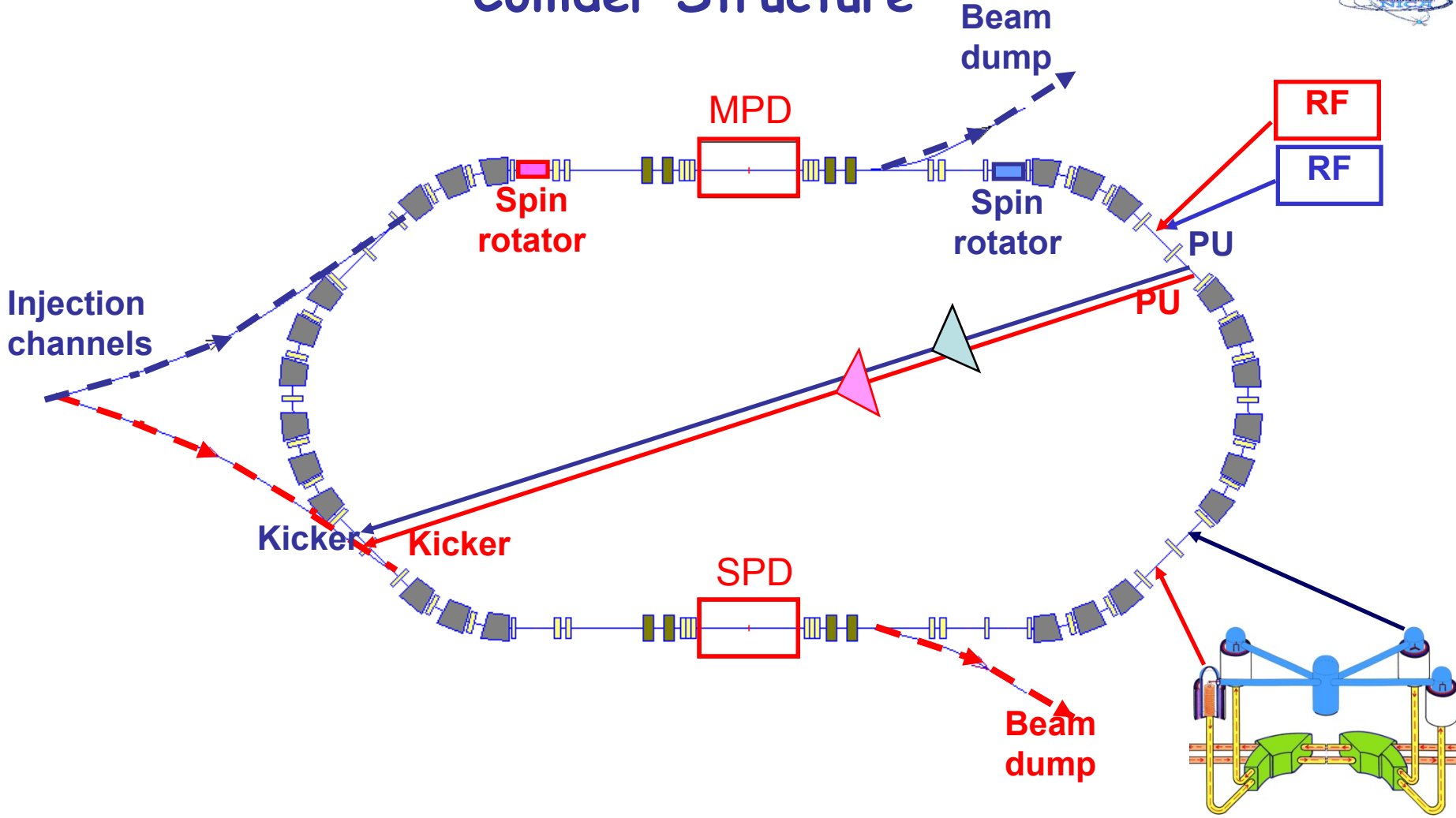


Collider General Parameters

| | |
|--|-----------------|
| Ring circumference, [m] | 251.5 |
| B_{max} ($^{197}\text{Au}^{79+}$), [T \oplus m] | 45.0 |
| Ion kinetic energy, [GeV/amu] | 1.0 \div 4.58 |
| Dipole field (max), [T] | 4.5 |
| Long straight sections number / length, [m] | 2 x 48.0 |
| Short straight sections number / length, [m] | 4 x 7.2 |
| Vacuum, [pTorr] | 100 \div 10 |
| RF harmonics amplitude, [kV] | 70 150 |



Collider Structure



Collider beam parameters and luminosity

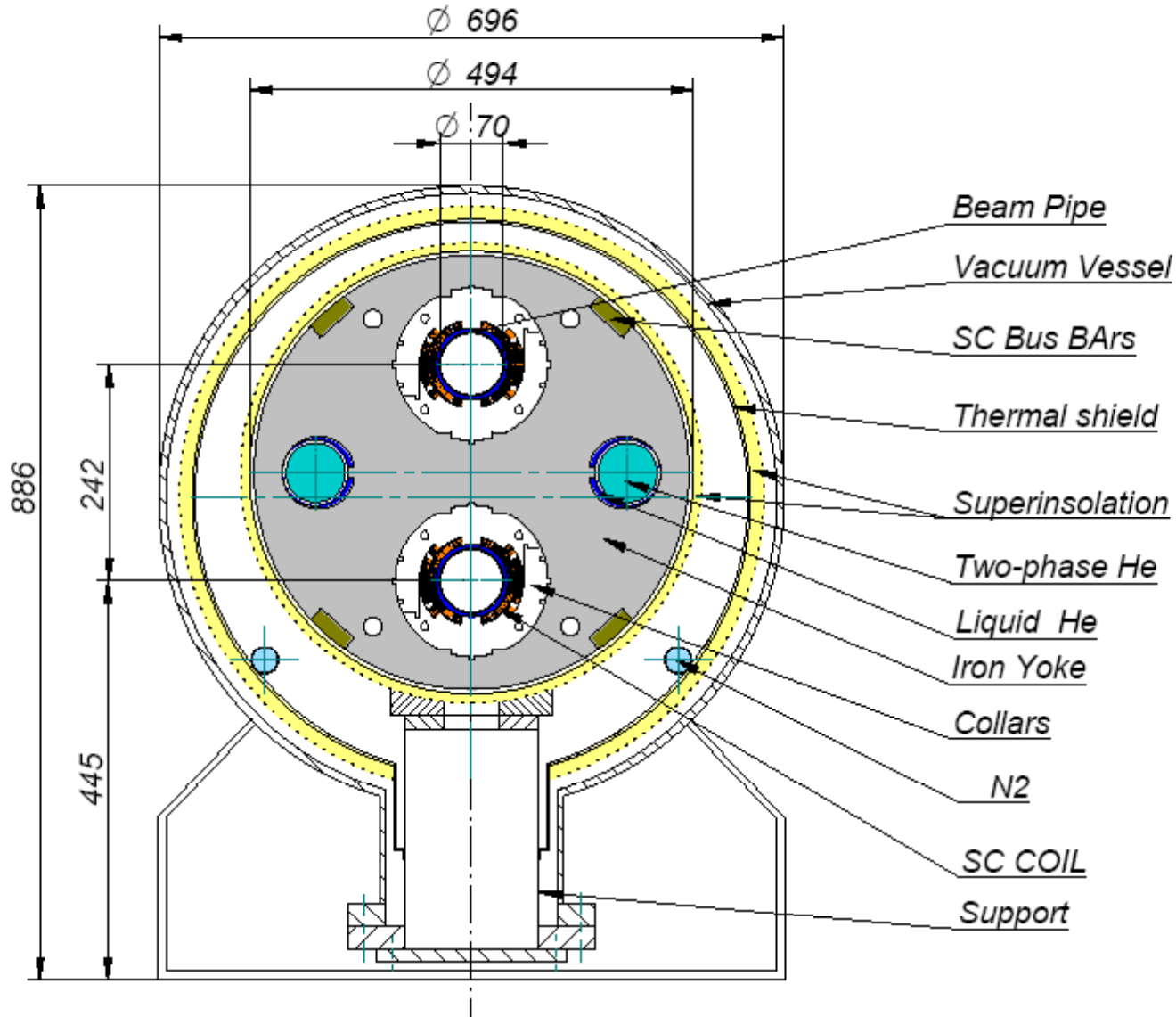


| | | |
|---|------------------|----------------|
| Energy, GeV/u | 1.0 | 4.6 |
| Ion number per bunch | 1E+09 | 1E+09 |
| Number of bunches per ring | 17 | 17 |
| Rms unnorm. beam emittance, $\mu\text{m mrad}$ | 3.8 | 0.3 |
| Rms momentum spread | 1E-03 | 1E-03 |
| Rms bunch length, m | 0.3 | 0.3 |
| Luminosity per one IP, $\text{cm}^{-2} \cdot \text{s}^{-1}$ | 0.75·E+26 | 1.3E+27 |
| Incoherent tune shift $\otimes Q_{SC}$ | 0.05 | 0.05 |
| Beam-beam parameter \lfloor (per 1 IP) | 0.002 | 0.001 |
| Luminosity "life time" limited by IBS, s | 1700 | 100 |

"Twin magnets" for NICA collider rings



"Twin" dipoles (4.5 T)





Polarized proton beams in NICA

| | | | |
|---|-------------------|-------------------|-------------------|
| Energy, GeV/u | 5.0 | 12.6 | |
| Rms bunch length, m | 0.3 | 0.3 | |
| RF harmonics / amplitude, kV | 102 / 100 | 102 / 100 | |
| Beta function in IP, m | 0.5 | 0.5 | |
| Ion number per bunch | $3 \cdot 10^9$ | $1 \cdot 10^{10}$ | $3 \cdot 10^{10}$ |
| Rms unnormalized beam emittance, $\mu\text{m mrad}$ | 0.023 | 0.01 | |
| Rms momentum spread | $1 \cdot 10^{-3}$ | | |
| Luminosity per one IP, $\text{cm}^{-2} \cdot \text{s}^{-1}$ | 1.5E+30 | 3.6E+30 | 3.2E+31 |
| Number of bunches | 17 | | |
| Incoherent tune shift $\otimes Q_{SC}$ | 0.14 | 0.027 | 0.082 |
| Beam-beam parameter \lfloor | 0.008 | 0.008 | 0.025 |

Spin Physics at NICA

EMC, 1987 $\Delta\Sigma = 0.12 \pm 0.17$

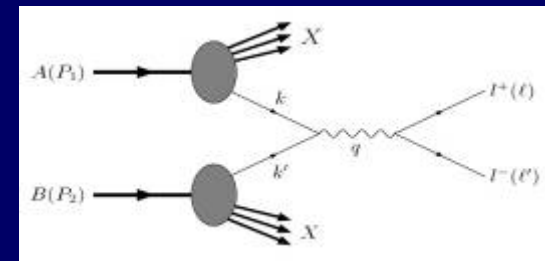


Polarization data has often been the graveyard for fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

J.D. Bjorken, 1987

Preliminary topics:

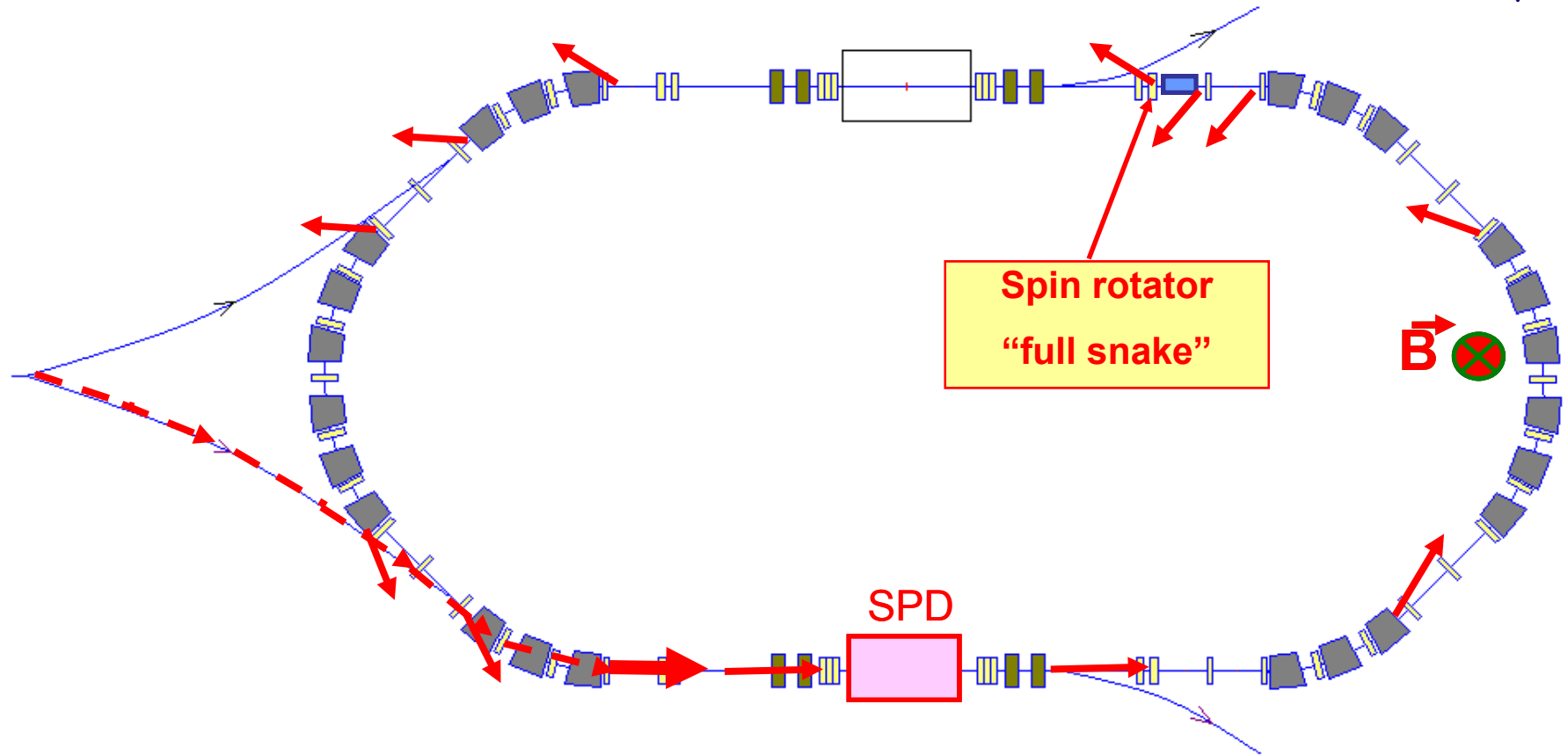
- *Drell-Yan processes with L&T polarized p & D beams: extraction of unknown (poor known) PDF*
- *PDFs from J/ψ production processes*
- *Spin effects in baryon, meson and photon productions*
- *Spin effects in various exclusive reactions*
- *Diffraction processes*
- *Cross sections, helicity amplitudes & double spin asymmetries (Krisch effect) in elastic reactions*
- *Spectroscopy of quarkoniums with any available decay modes*
- *Polarimetry*



Longitudinally polarized beams in NICA

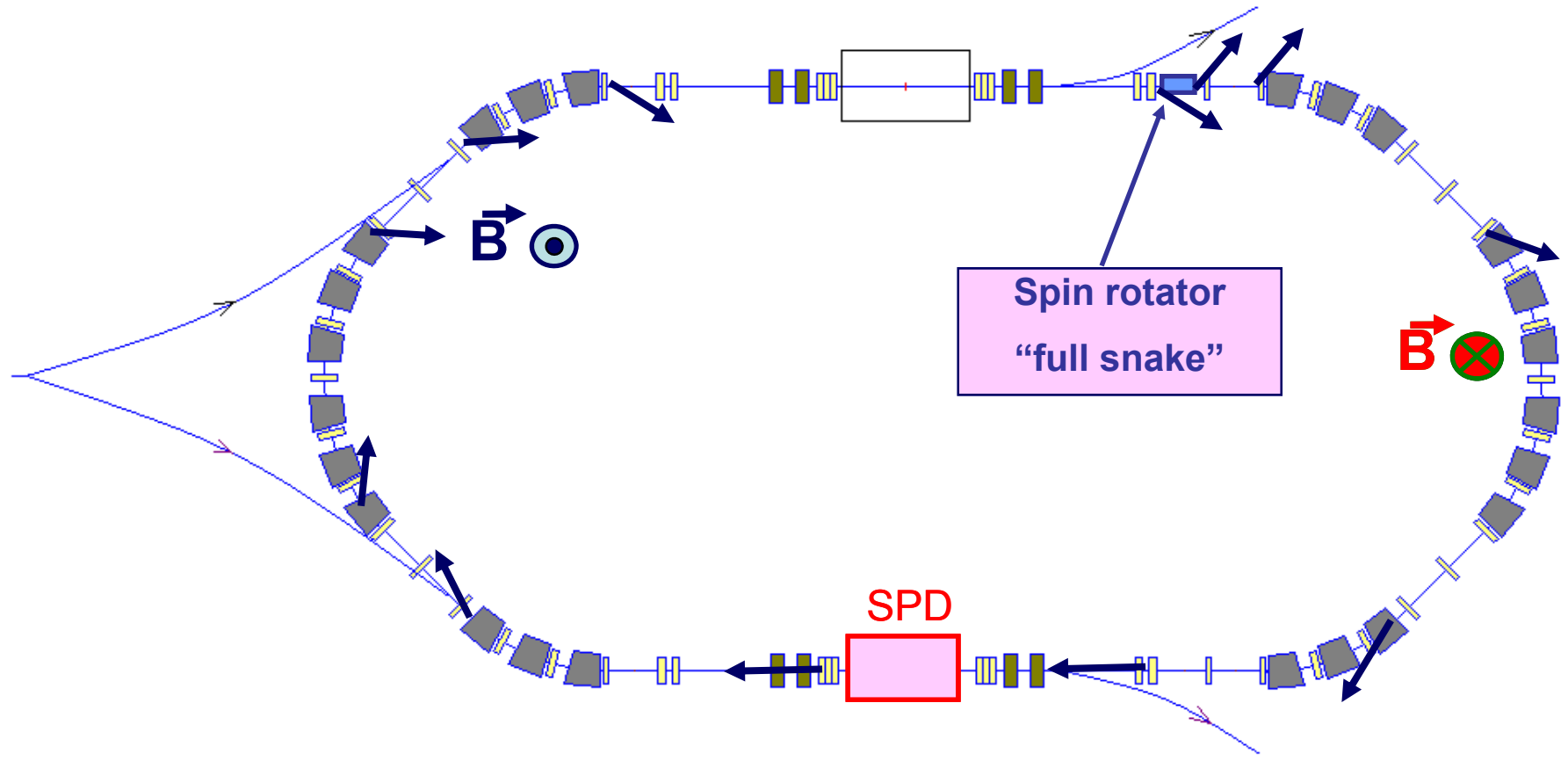


Yu.Filatov, 2009



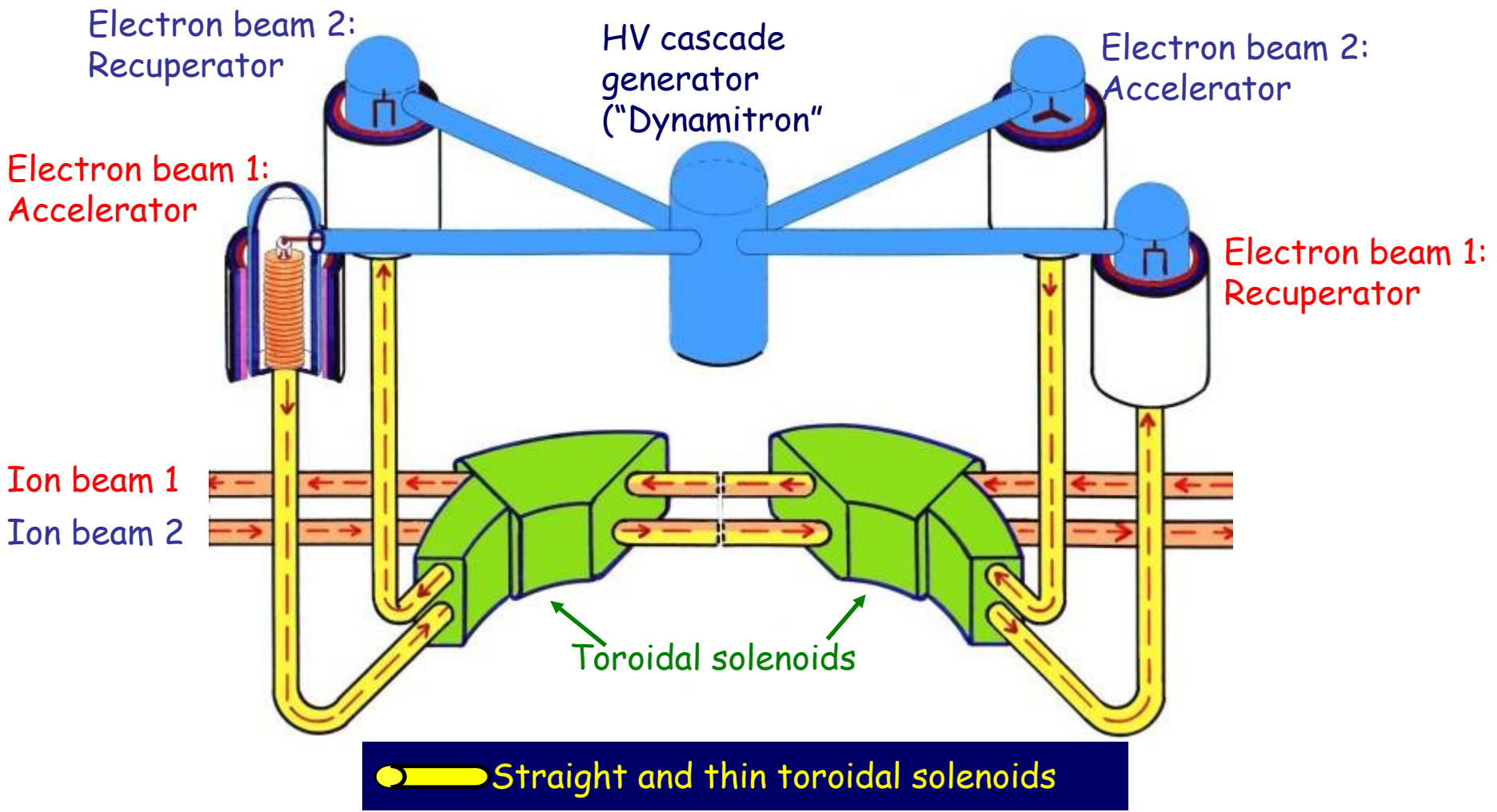


Longitudinally polarized beams in NICA (Contnd)



2.5 MeV x 0.5 (1.0?) A
SC solenoid 0.2 ÷ 1.0 T

The electron cooler for NICA collider





The Basic Conditions for the Project Development

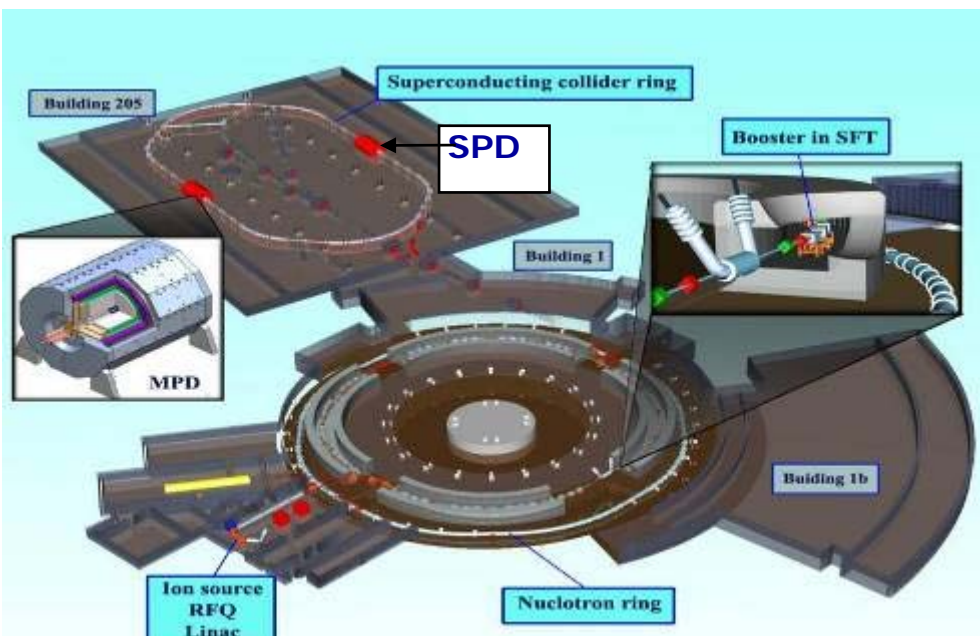
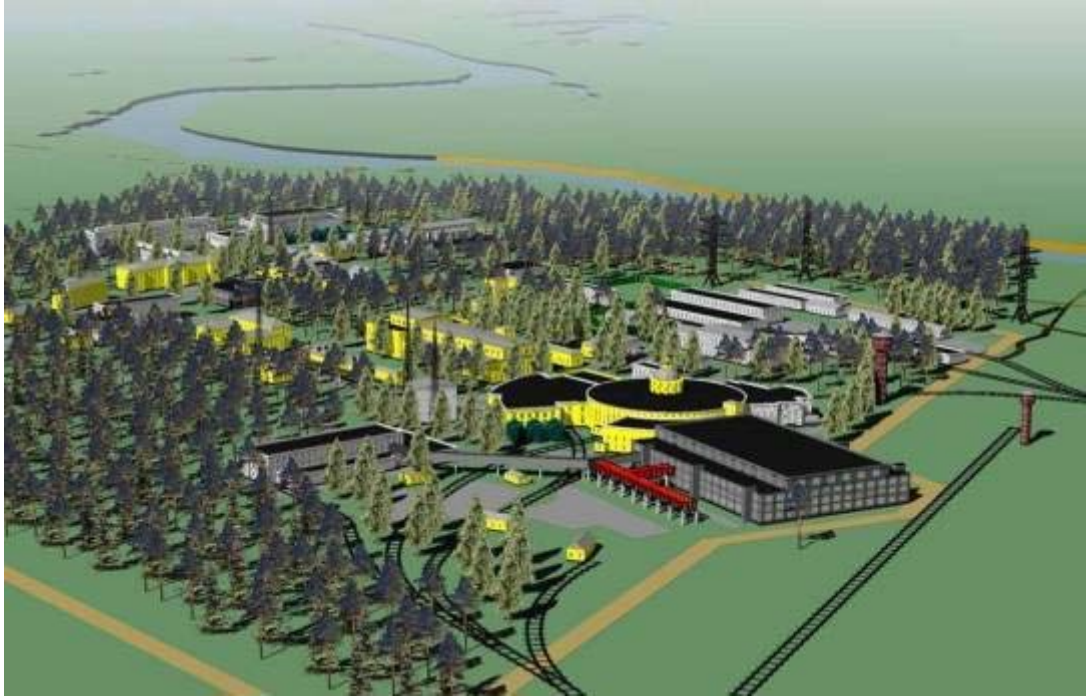
Minimum of R & D

Application of existing experience

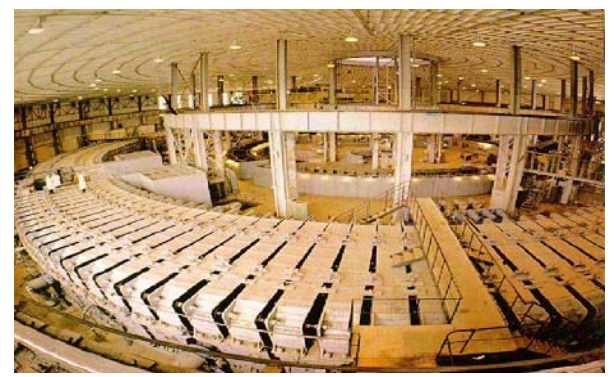
Co-operation with experienced research centers

Cost: as low as possible

Realization time: 6 – 7 years



NICA general layout



The NICA Project Milestones



- **Stage 1: years 2007 – 2009**
 - Upgrade and Development of the Nuclotron
- Preparation of Technical Design Report of the NICA and MPD
 - Start prototyping of the MPD and NICA elements

- **Stage 2: years 2008 – 2013**
Design and Construction of NICA and MPD

- **Stage 3: years 2010 – 2013**
 - Assembling

- **Stage 4: year 2014 - 2015**
 - Commissioning

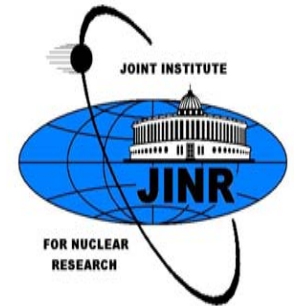
Concluding remarks

Round Table Discussion I

Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron

July 7 - 9, 2005

<http://theor.jinr.ru/meetings/2005/roundtable/>



Round Table Discussion II

Searching for the mixed phase of strongly interacting matter at the JINR Nuclotron: Nuclotron facility development

JINR, Dubna, October 6 - 7, 2006

<http://theor.jinr.ru/meetings/2006/roundtable/>

Round Table Discussion III

Searching for the mixed phase of strongly interacting QCD matter at the NICA: Physics at NICA

JINR (Dubna), November 5 - 6, 2008

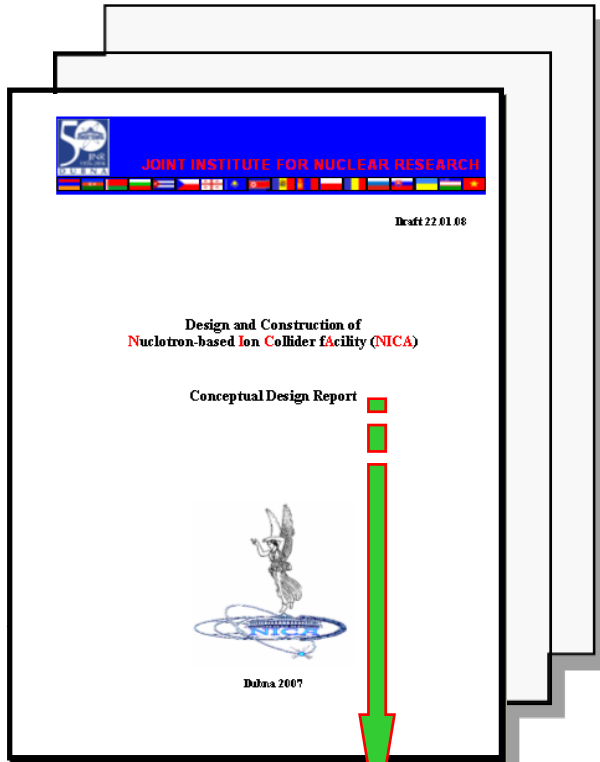
<http://theor.jinr.ru/meetings/2008/roundtable/>



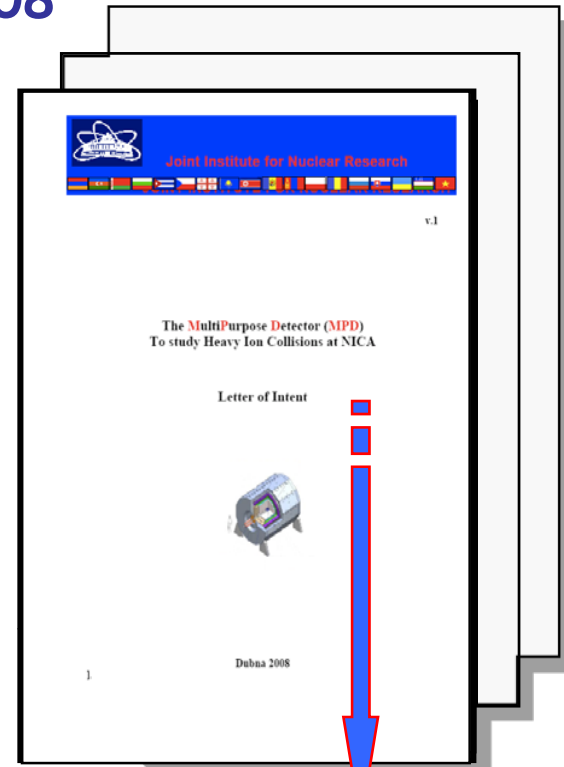


NICA/ MPD Concept

January 2008



Technical Design Report
in progress,
to be completed May 2009



Conceptual Design Report
in progress,
to be completed 2009

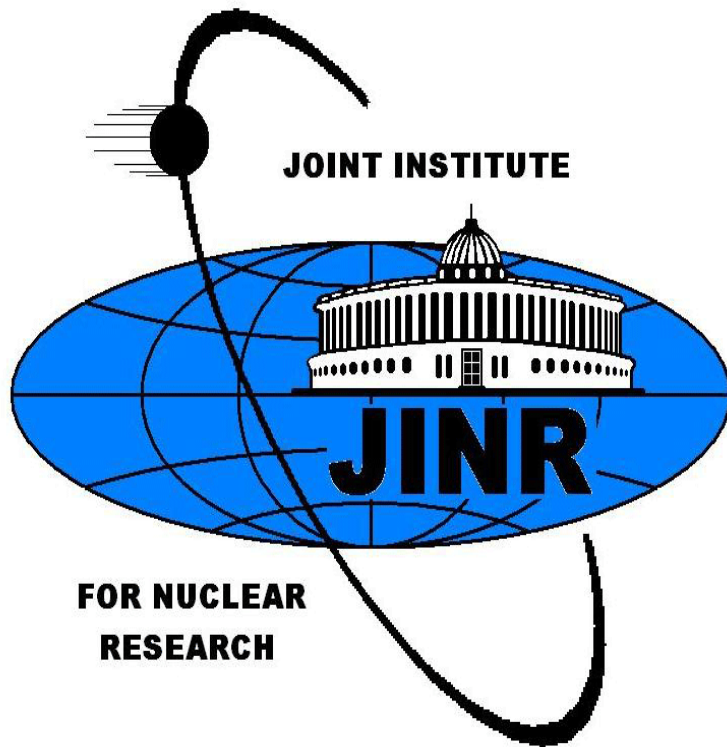
International Coordinating Committee meeting on the NICA Project



Visit of D.A.Medvedev to JINR 18.04.08



Welcome to the collaboration!



Round table-IV in September 2009 at Dubna

Thank you for your attention !

R.Aymar and J.Ellis at the JINR Nuclotron and Magnet test facility



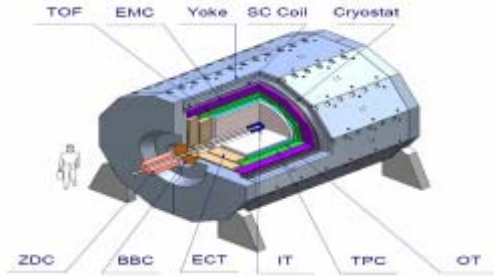
**J.Engellen(left) at the JINR Magnet test facility.
A.Sissakian (center), A.Kovalenko (right)**



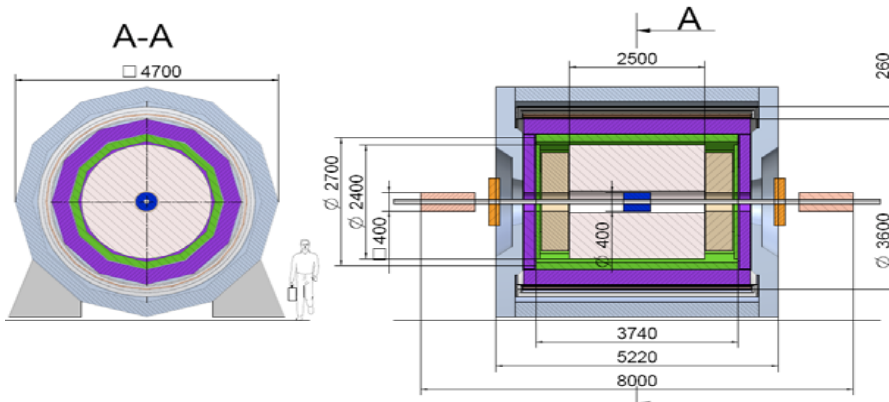
**J.Engellen(left) at the JINR Nuclotron.
A.Sissakian (right), A.Kovalenko (center)**

MPD conceptual design

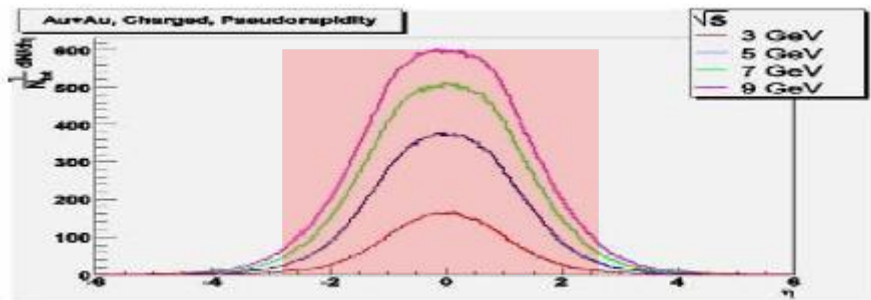
1



MPD basic geometry



Acceptances for MPD



Inner Tracker (IT) silicon strip detector / micromegas for tracking close to the interaction region.

Barrel Tracker (BT) - TPC + Straw (for tagging) for tracking & precise momentum measurement in the region $-1 < | \eta | < 1$

End Cap Tracker (ECT) - Straw (radial) for tracking & p-measurement at $| \eta | > 1$

Time of Flight (TOF) - RPC (+ start/stop sys.) to measure Time of Flight for charged particle identification.

Electromagnetic Calorimeter (EMC) for p^0 reconstruction & electron/positron identification.

Beam-Beam Counters (BBC) to define centrality (& interaction point).

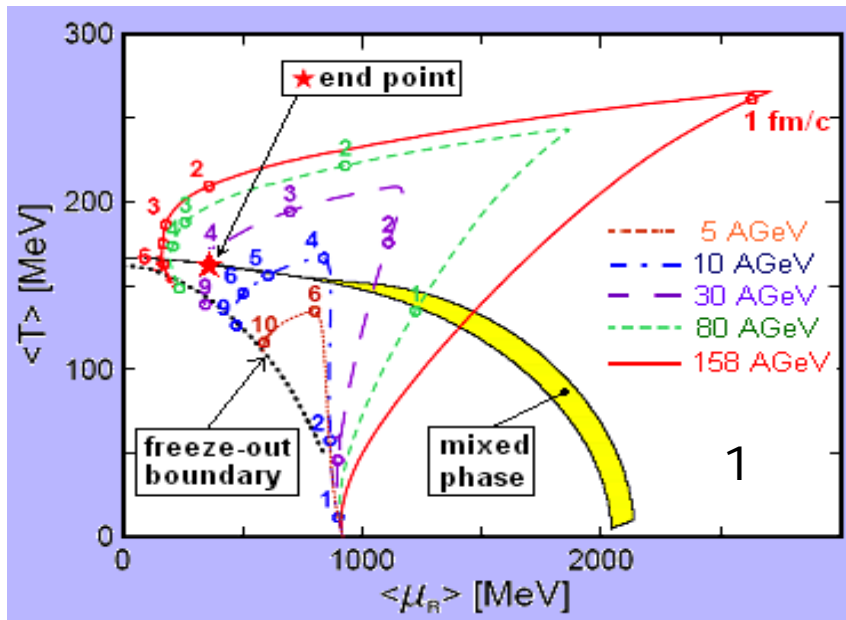
Zero Degree Calorimeter (ZDC) for centrality definition.

2

3

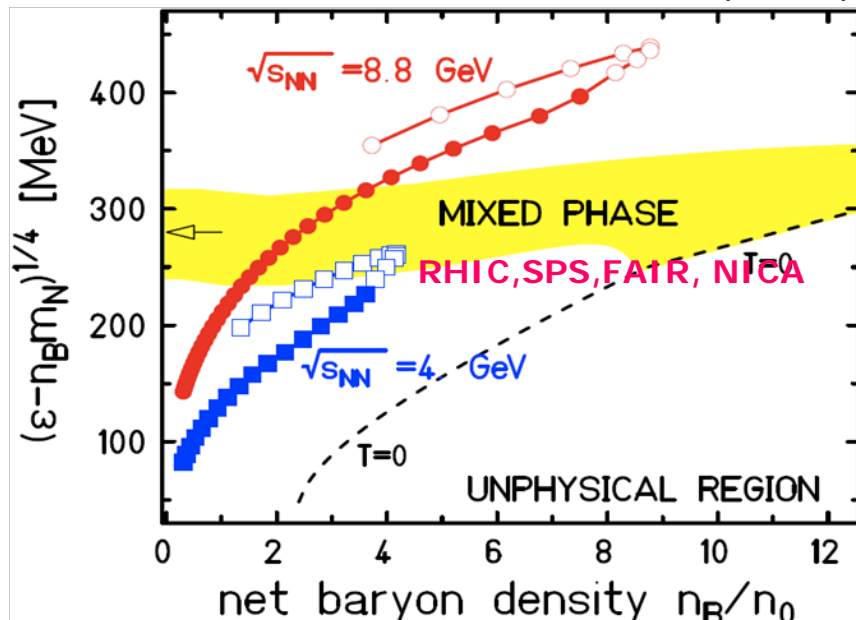
Phase Diagram

Yu.Ivanov, V.Russkikh, V.Toneev, 2005

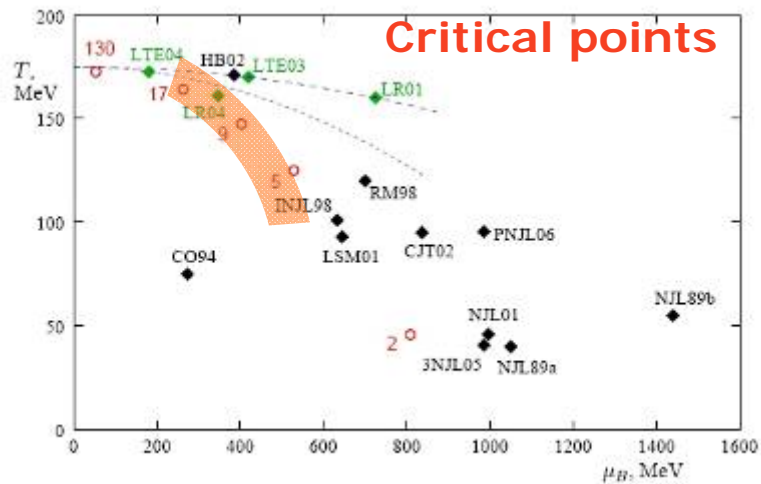


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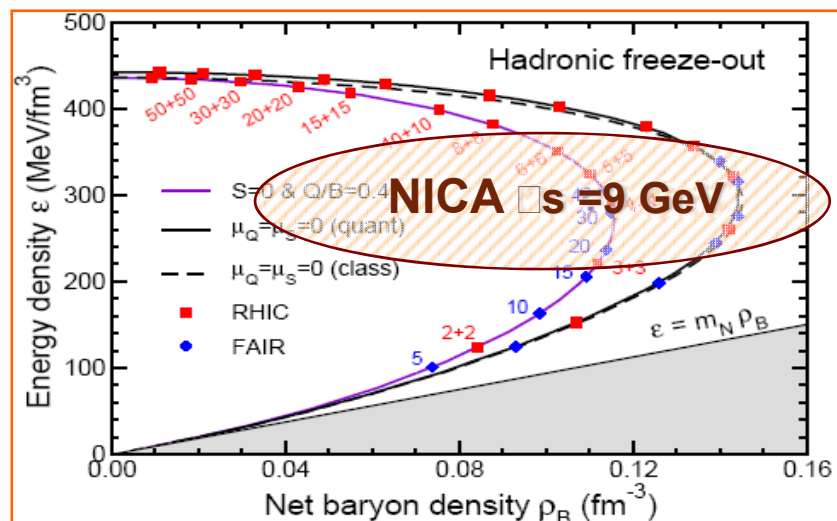
MPD Letter of Intend (2007)



2



3



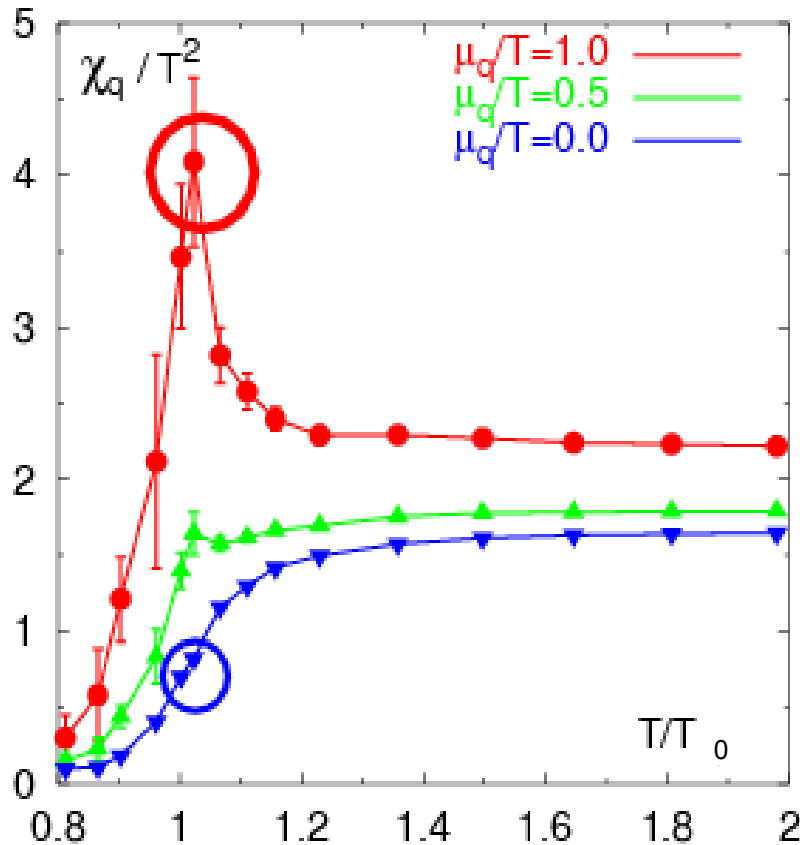
4

M.Stephanov, 2006

J.Randrup, J.Cleymans, 2006

Fluctuations

Lattice QCD predictions: Fluctuations of the quark number density (susceptibility) at $\mu_B > 0$ (C.Allton et al., 2003)



$$\frac{\chi_q}{T^2} = \left[\frac{\partial^2}{\partial (\mu_q / T)^2} \frac{P}{T^4} \right]_{T_{fixed}}$$

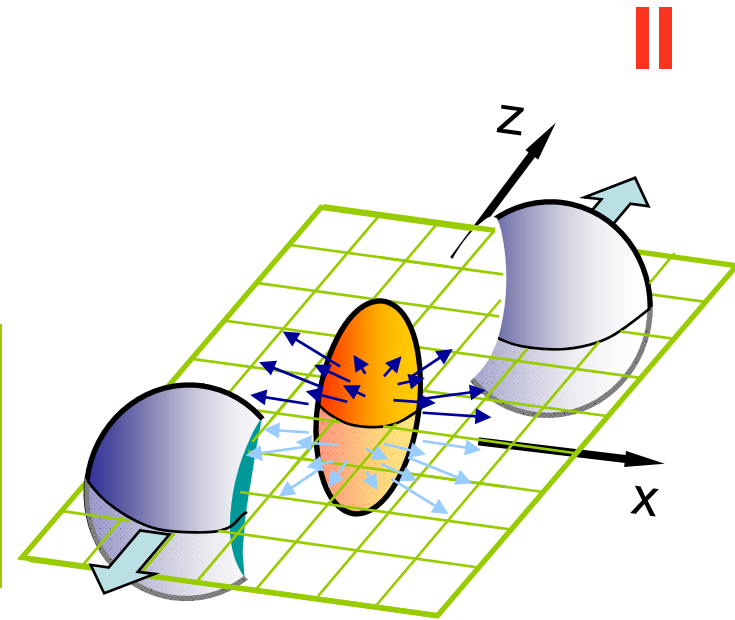
← χ_q (quark number density fluctuations) will diverge at the critical end point

Experimental observation:

- Baryon number fluctuations
- Charge number fluctuations

Collective flows

Interactions between constituents lead to a pressure gradients => spatial asymmetry is converted in asymmetry in momentum space => collective flows



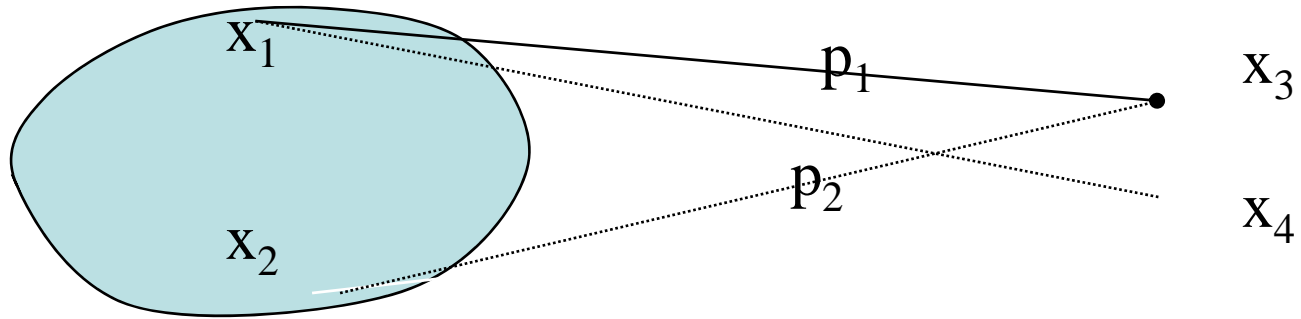
Non-central collisions

$$\frac{dN}{dy_T dp_T d\varphi} = \frac{dN}{dy_T dp_T} \frac{1}{2\delta} (1 + 2v_1 \cos(\varphi) + 2v_2 \cos(2\varphi) + \dots)$$

directed
flow

elliptic
flow

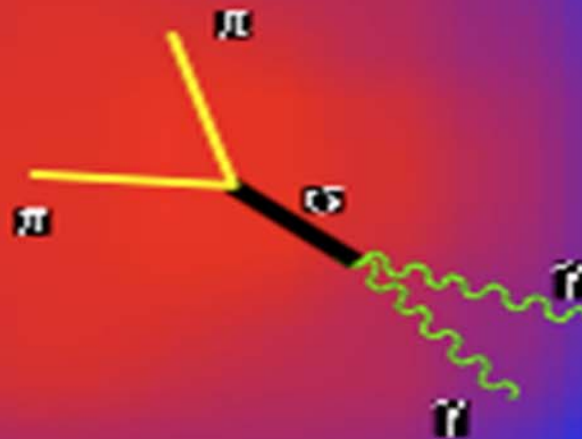
Correlation femtoscopy of identical particles



$$q = p_1 - p_2, \quad \otimes x = x_1 - x_2$$

$$C_2 = 1 + (-1)^S \langle \cos q \Delta x \rangle \rightarrow 1 + \lambda \exp(-R_{long}^2 q_{long}^2 - R_{side}^2 q_{side}^2 - R_{out}^2 q_{out}^2 - 2R_{out}^2 q_{out} q_{long})$$

Signals of chiral symmetry restoration



Round Table Discussions I, *JINR, Dubna, 2005*
<http://theor.jinr.ru/meetings/2005/roundtable/>

MPD Collaboration

- Joint Institute for Nuclear Research
- Institute for Nuclear Research Russian Academy of Science
- Bogolyubov Institute of Theoretical Physics, NASUk
- Skobeltsyn Institute of Nuclear Physics of Lomonosov MSU, RF
- Institute of Applied Physics, Academy of Science Moldova
- *Open for extension ...*

A consortium involving GSI, JINR & other centers for IT module development & production is created.

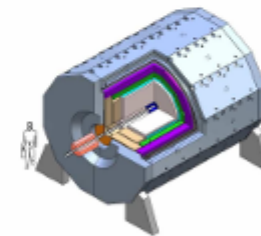
Signed MoU with GSI in July 2008



Version 1

The **M**ulti**P**urpose **D**etector (**MPD**)
to study Heavy Ion Collisions at NICA

Letter of Intent



Dubna, 2008

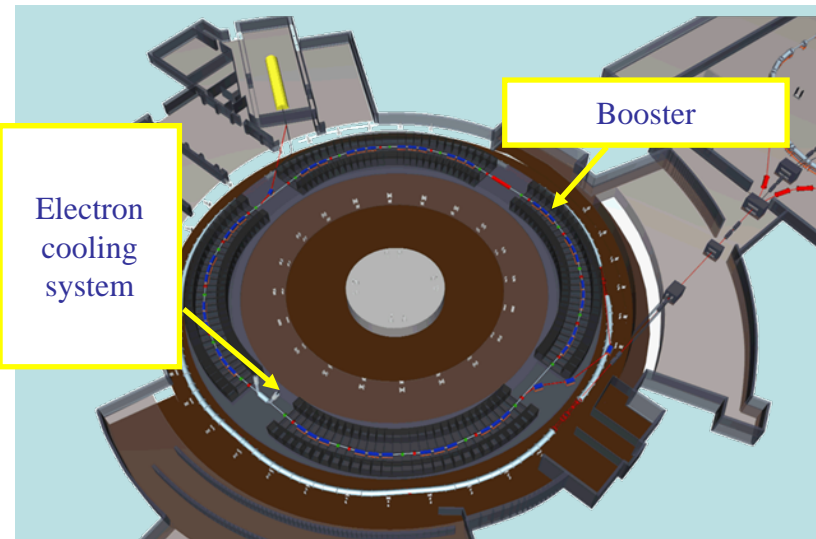
<http://nica.jinr.ru>

Experiments on Drell-Yan measurements



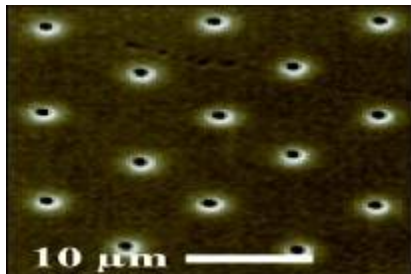
| Experiment | Status | Remarks |
|------------|-------------|--|
| E615 | Finished | Only unpolarized DY |
| NA10 | Finished | Only unpolarized DY |
| E886 | Running | Only unpolarized DY |
| RHIC | Running | Detector upgrade for DY measurements (collider) |
| PAX | Plan > 2016 | Problem with \bar{p} polarization (collider) |
| COMPASS | Plan > 2010 | Only valence PDFs |
| J-PARC | Plan > 2011 | low s (60-100 GeV ²), only unpolarized proton beam |
| SPASCHARM | Plan? | $s \sim 140$ GeV ² for unpolarized proton beam |
| NICA | Plan 2015 | $s \sim 670$ GeV ² for polarized proton beams, high luminosity (collider) |

IV. Applied research at NICA

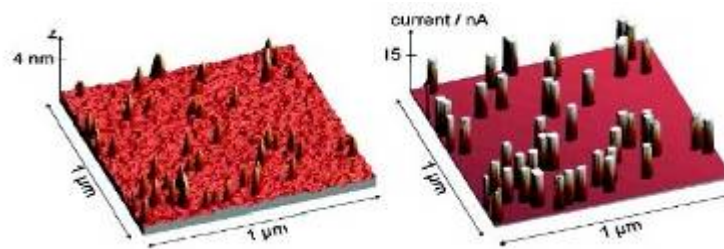


Design and parameters of booster, including wide accessible energy range, possibility of the electron cooling, allow to form dense and sharp ion beams. System of slow extraction provides slow, prolonged in time ion extraction to the target with space scanning of ions on the target surface and guaranty **high controllability** of experimental conditions.

Ion-track technologies:



Ion tracks in a polymer matrix (GSI, Darmstadt)



Production of nanowires, filters, nanotransistors, ...

Topography and current of a diamond-like carbon (DLC) film. The 50 nm thick DLC film was irradiated with 1 GeV Uranium ions.