Joint Institute for Nuclear Research
International Intergovernmental Organization

Megascience Project NICA

V. Kekelidze, A. Kovalenko, R. Lednicky, V. Matveev,
I. Meshkov, A. Sorin, G. Trubnikov
(for the NICA collaboration)

NICA

JINR Day in France
Centre de Russie pour la Science et la Culture
Paris, 15 February 2018


NICA

Synchrophasotron ; SC synchrotron- **Nuclotron (1993)** *h*

based on superconducting fast cycling magnets developed at LHE JINR

NICA (Nuclotron-based Ion Colider fAcility)

Main targets:

http://nica.jinr.ru/

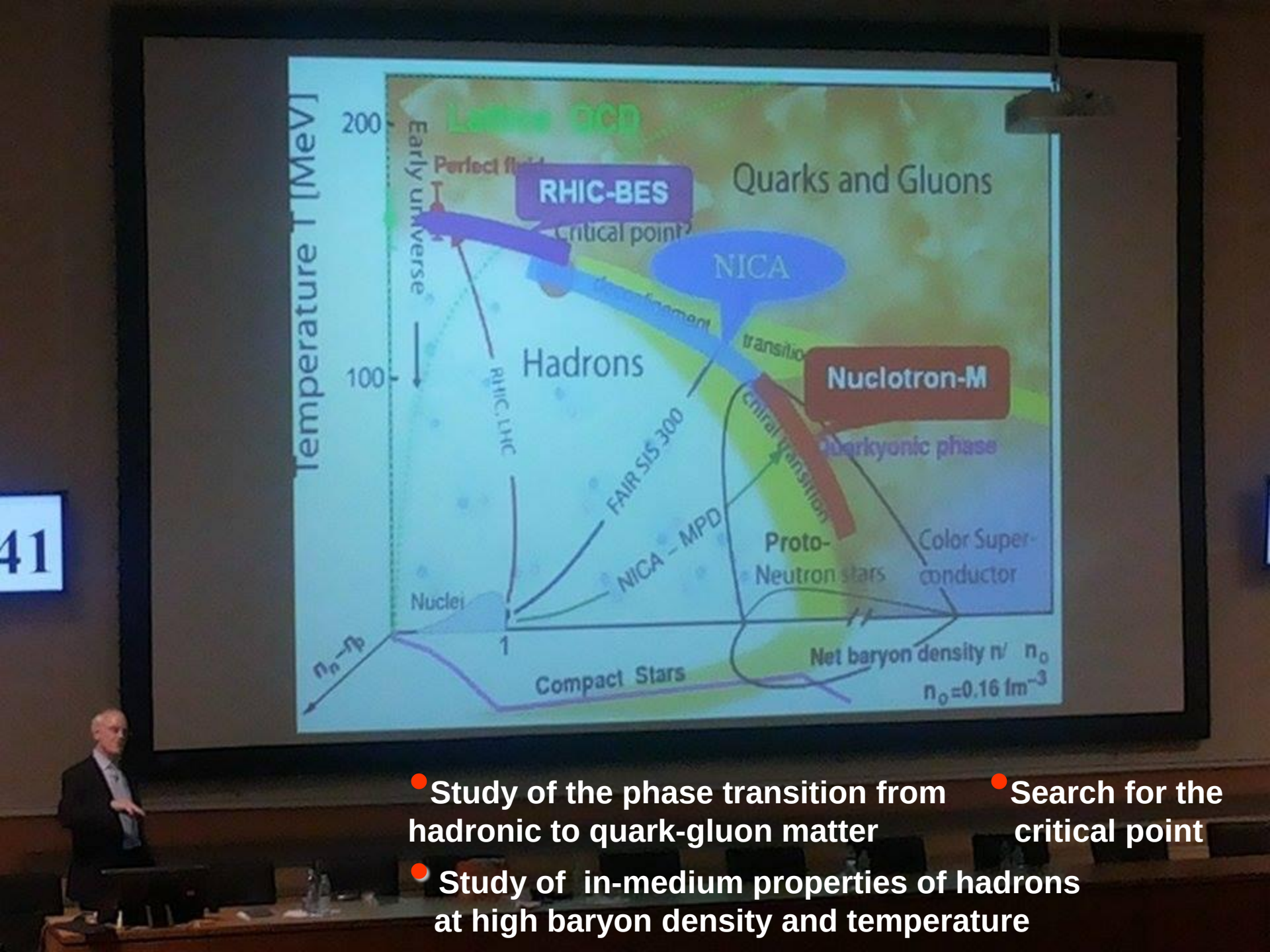
- *study of hot and dense baryonic matter*
  at the energy range of max baryonic density
- *investigation of nucleon spin structure, polarization phenomena*

Construction of Collider of relativistic ions from p to Au,
polarized protons and deuterons

with max energy up to $\sqrt{S_{NN}}$= 11 GeV (Au^{79+}) and =27 GeV (p)

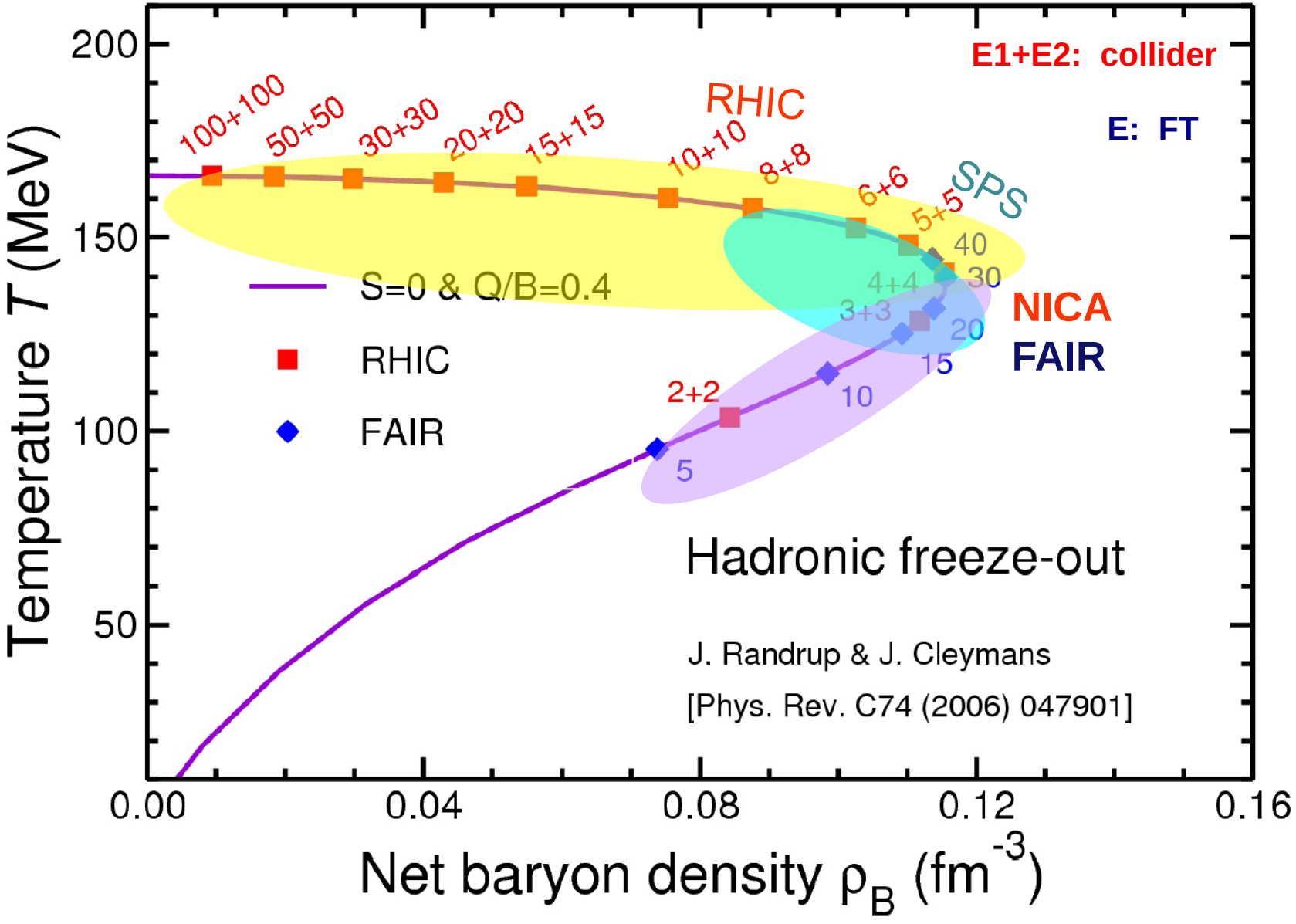
$\sqrt{S_{NN}}$ = 11 GeV (Au^{79+} , L ~ 10^{27} cm^{-2} c^{-1})

$\sqrt{S}$ =27 GeV (p, L ~ 10^{32} cm^{-2} c^{-1})



- Study of the phase transition from hadronic to quark-gluon matter
- Search for the critical point
- Study of in-medium properties of hadrons at high baryon density and temperature

Freeze-out conditions



"Hilbert Problems" of Dense Matter Physics:

- Which phases?
- Which degrees of freedom?
- Nature of the (spin) nucleon?
- How hadronization proceeds?
- ...

Challenging questions:

- Character of phase transitions (if any)?
- Signals for 1st order phase transition?
- Critical Point?
- When does the perfect fluid turn on?
- Duality of dynamical and thermal descriptions?
- Global polarization in HIC?
- …

Dense QCD Matter Physics

- **Nuclear equation-of-state, new forms of matter at high densities?**
  What are the properties and the degrees of freedom of QCD matter at neutron star core densities?

- **Hadrons in dense matter:**
  What are the in-medium properties of hadrons?
  Is chiral symmetry restored at very high baryon densities?

- **Production of single and double hypernuclei**
  How far can we extend the third (strange) dimension of the nuclear chart?

- **Strange matter:**
  Does strange matter exist in the form of heavy multi-strange objects?

«The only source of knowledge is experience»
A. Einstein

heavy ion collisions

particle physics: *most of discoveries in last decades have been obtained in researches guided by the **Standard Model***

heavy ion collisions: *is a **data driven** physics*

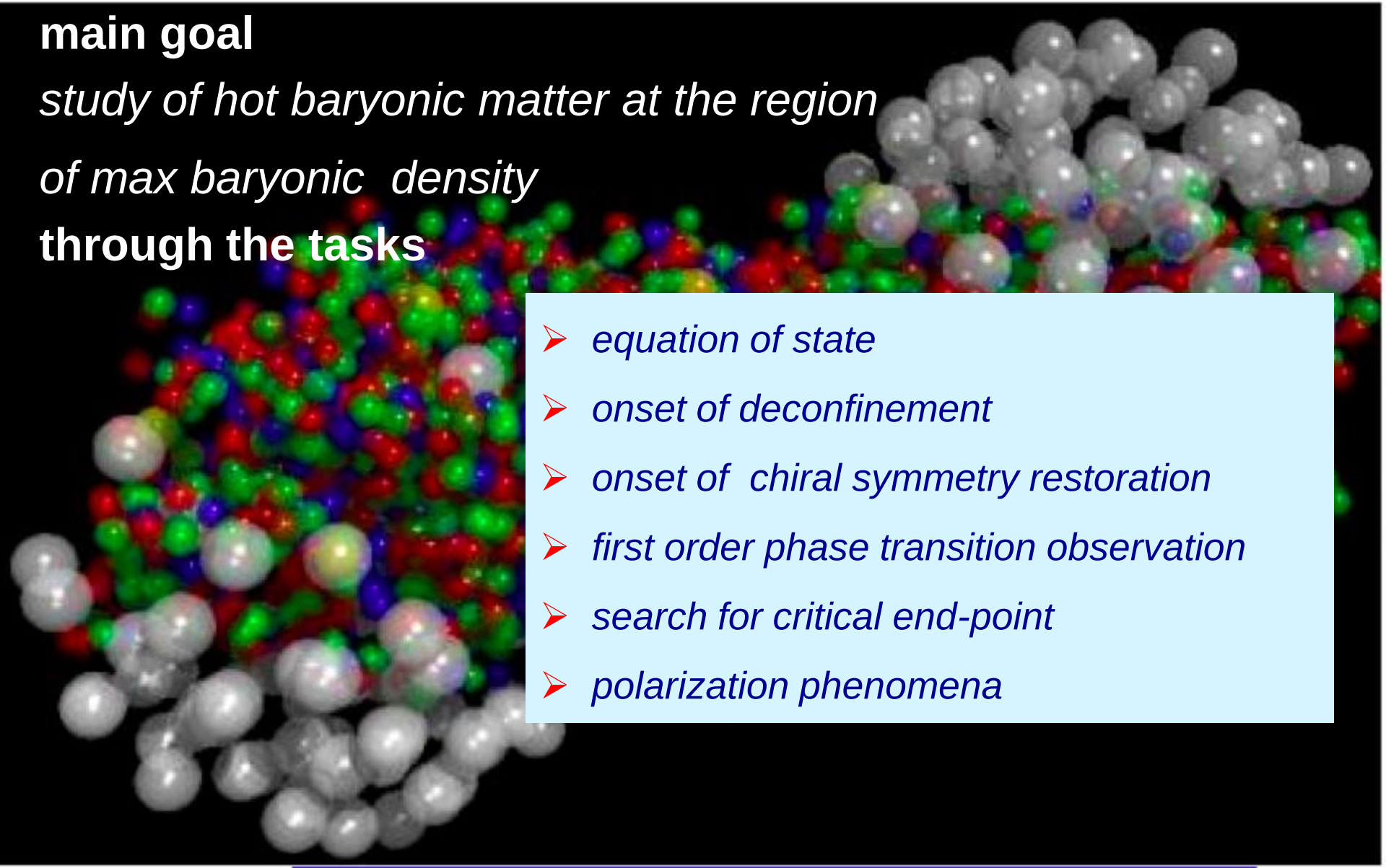
new data in less explored region of QCD phase diagram at **high baryon density**

are highly required for both:

- *observation / discovery new phenomena;*
- *development of theoretical models*

“Science can only ascertain what is, but not what should be, and outside of its domain value…”

A. Einstein



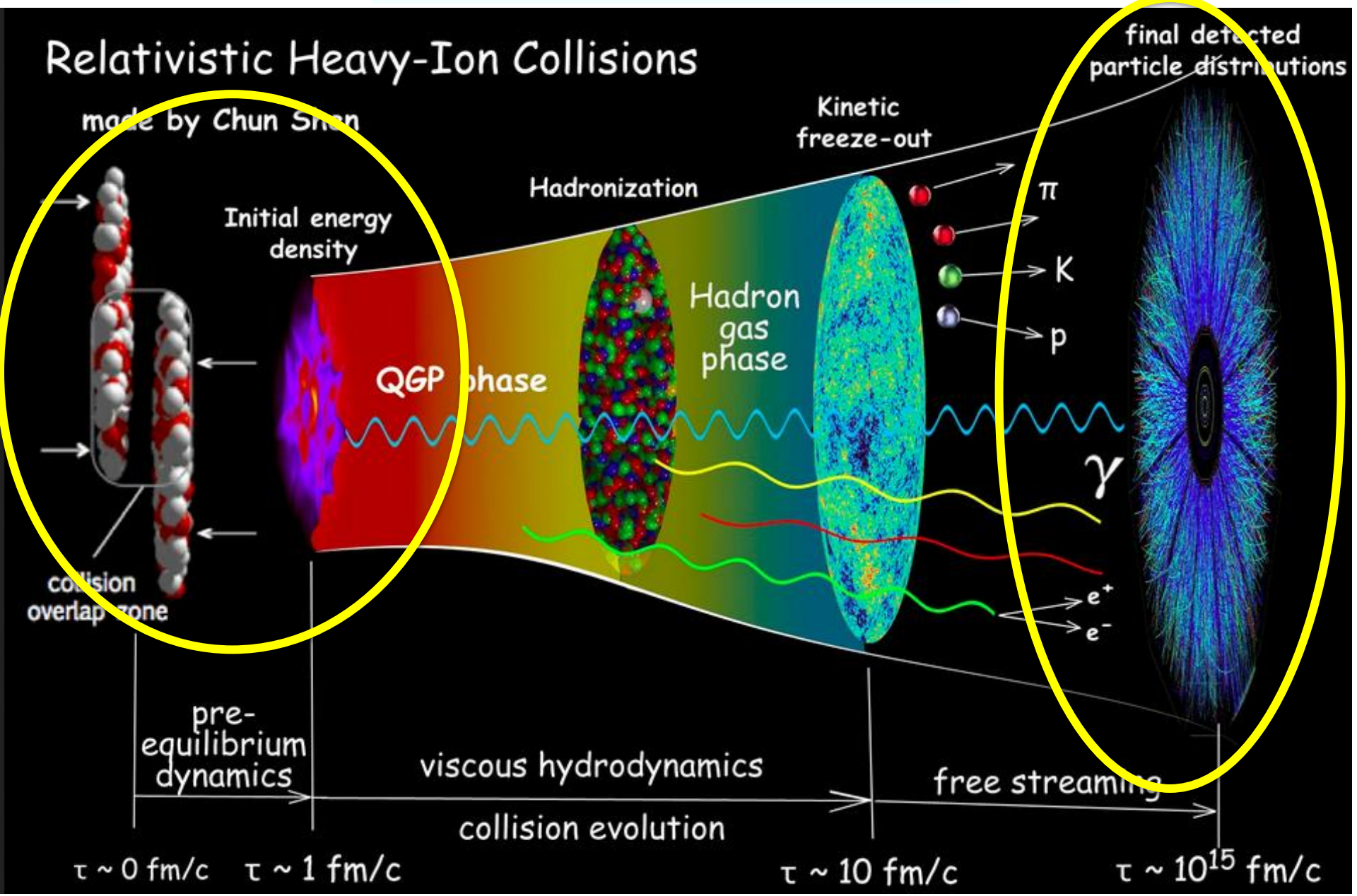
main goal

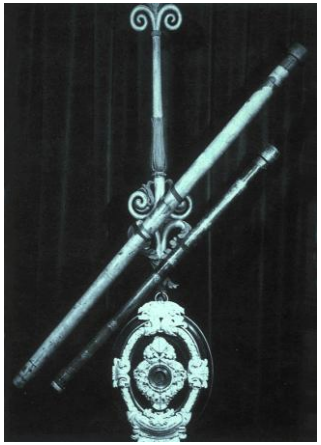
study of hot baryonic matter at the region of max baryonic density

through the tasks

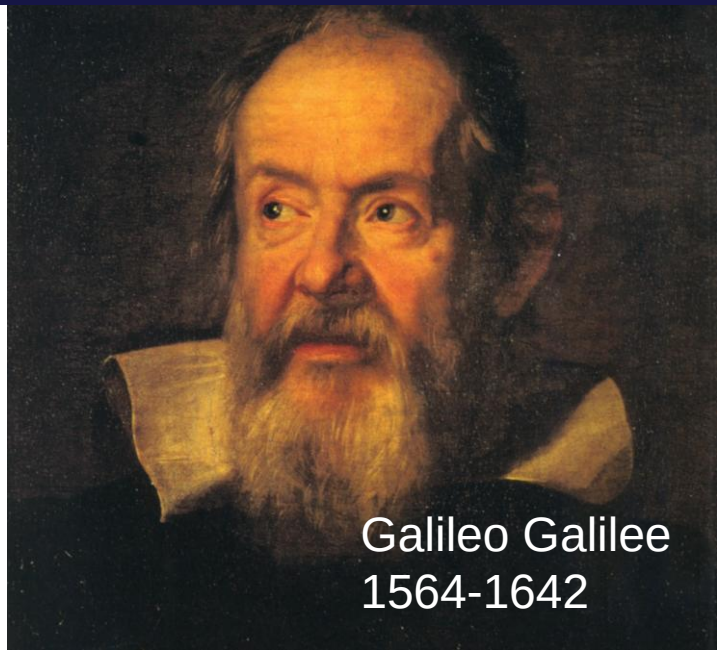
- *equation of state*
- *onset of deconfinement*
- *onset of chiral symmetry restoration*
- *first order phase transition observation*
- *search for critical end-point*
- *polarization phenomena*

Evolution of RHI collision





“Measure what is measureable and make measureable what is not so.”



Observables:

- *particle yields*
- *strangeness production*
- *dileptons, vector mesons*
- *collective phenomena (flows), hydrodynamics*
- *vorticity - polarization*

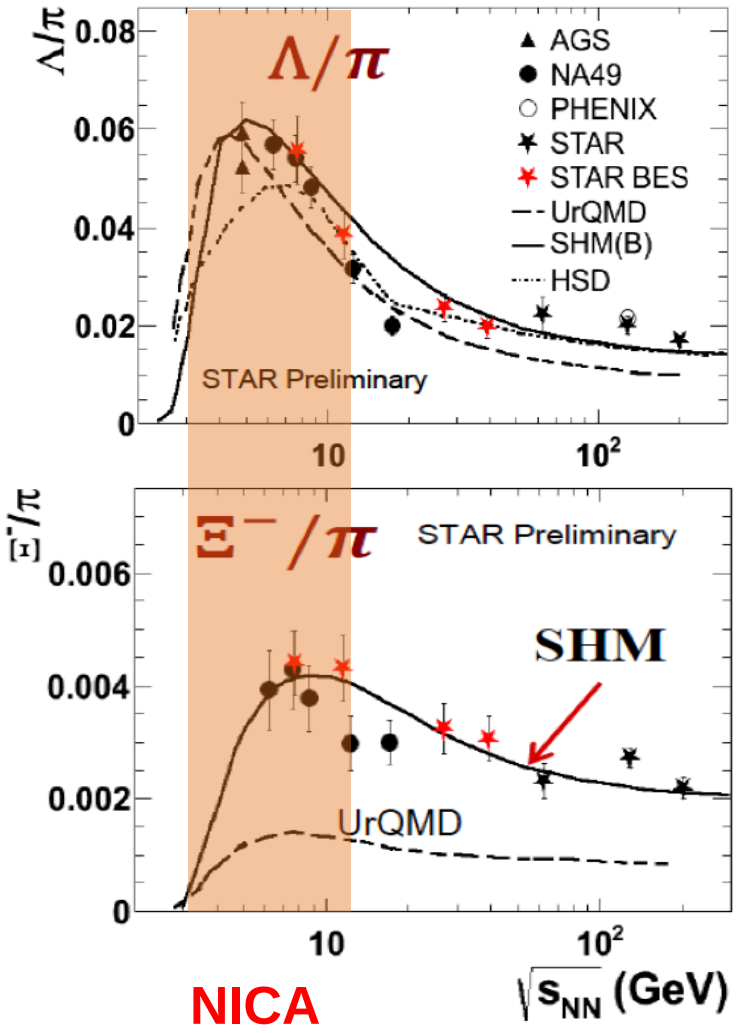
Particle production

- **Thermal / Statistical models:**
  the system is described by a grand canonical ensemble (**T, V, μ**)
  of non interacting fermions and bosons (*hadron gas*)
  in *thermal and chemical equilibrium* (***no dynamics***)

- **Hydrodynamical models:**
  conservation laws + equation of state; assumption of local
  thermal and chemical equilibrium (***simplified dynamics***)

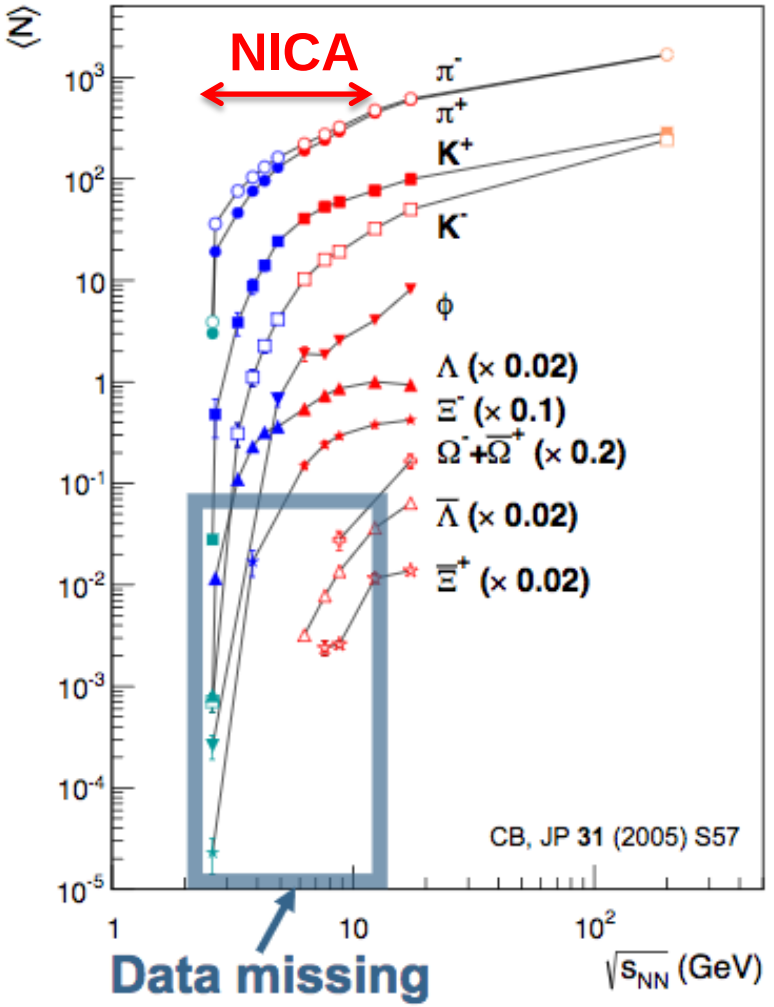
- **Transport models:**
  based on transport theory of relativistic quantum many-body systems off-shell Kadanoff-Baym equations for the Green-functions in phase-space representation;
  actual solutions: Monte Carlo simulations with a large number of test-particles (***full dynamics***)

Strange baryon to pion ratios



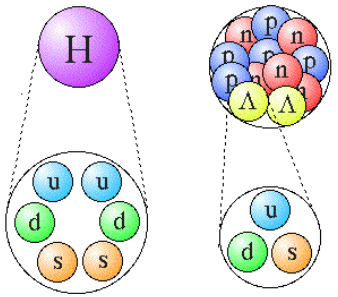
D. Tlusty, SQM-2017

Total yields



C. Blume, SQM-2017

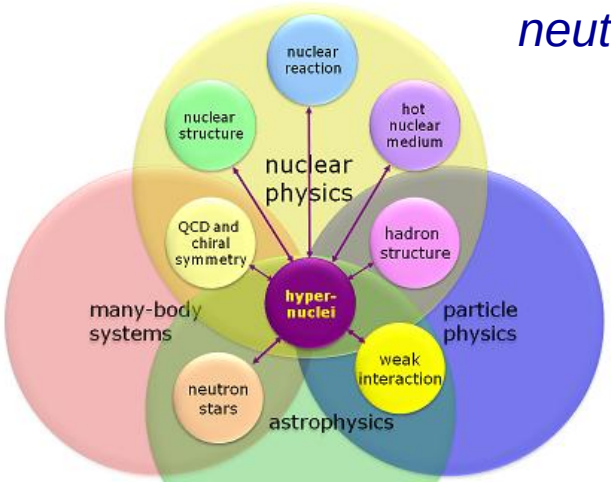
Hypernuclei

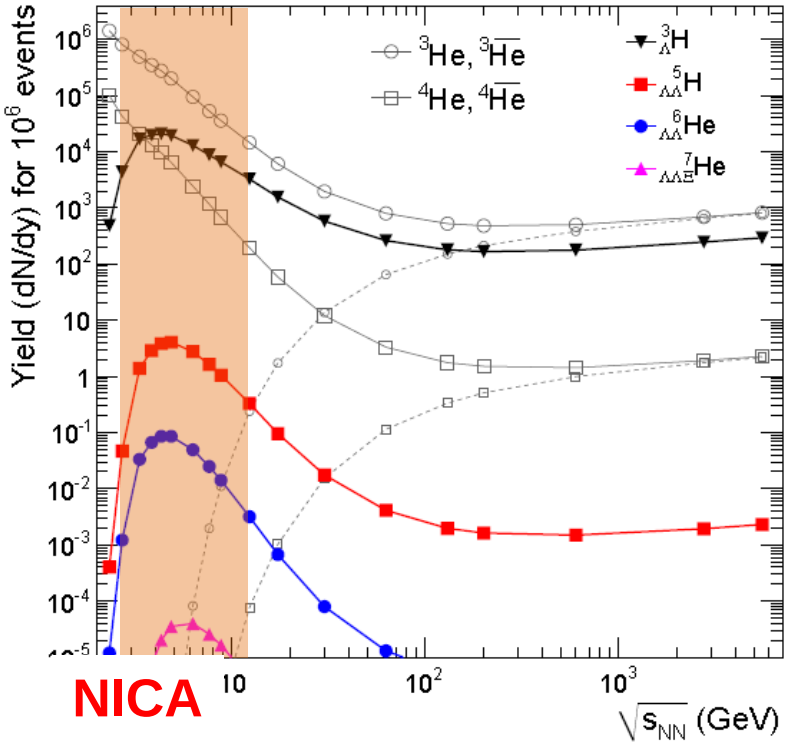


Hypernuclei provides unique opportunity to study the strange particle-nucleus interaction in a many-body environment.

*production enhanced at high baryon densities (**NICA**)*

On the astrophysical scale the appearance of hyperons in the dense core of a neutron star has been a subject of extensive studies since the early days of neutron star research

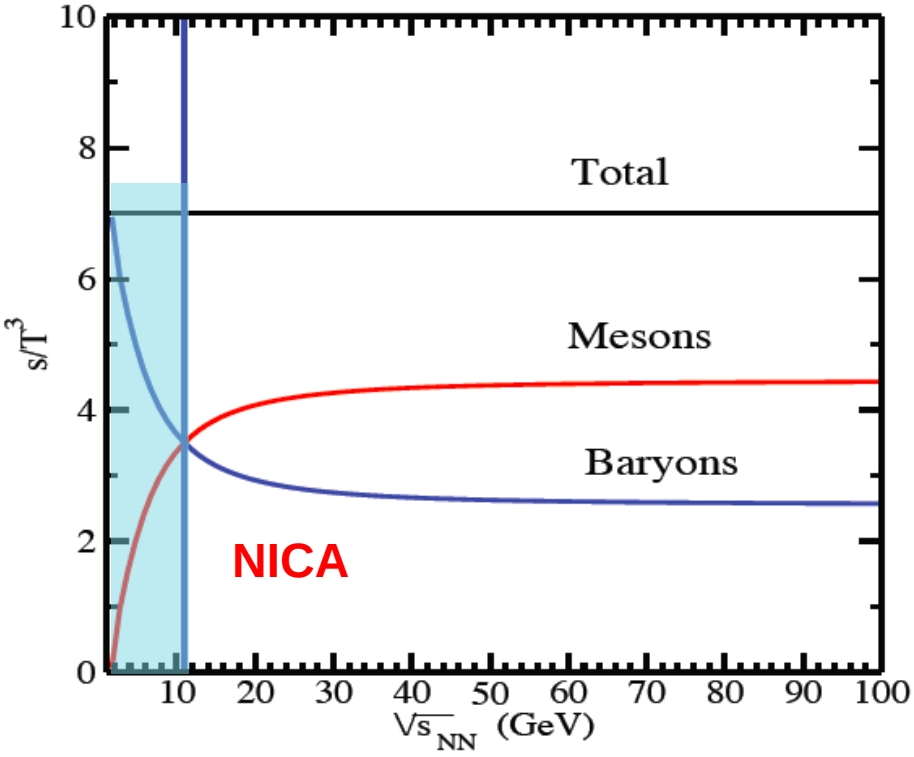




A. Andronic et al., Phys. Lett. B697 (2011) 203

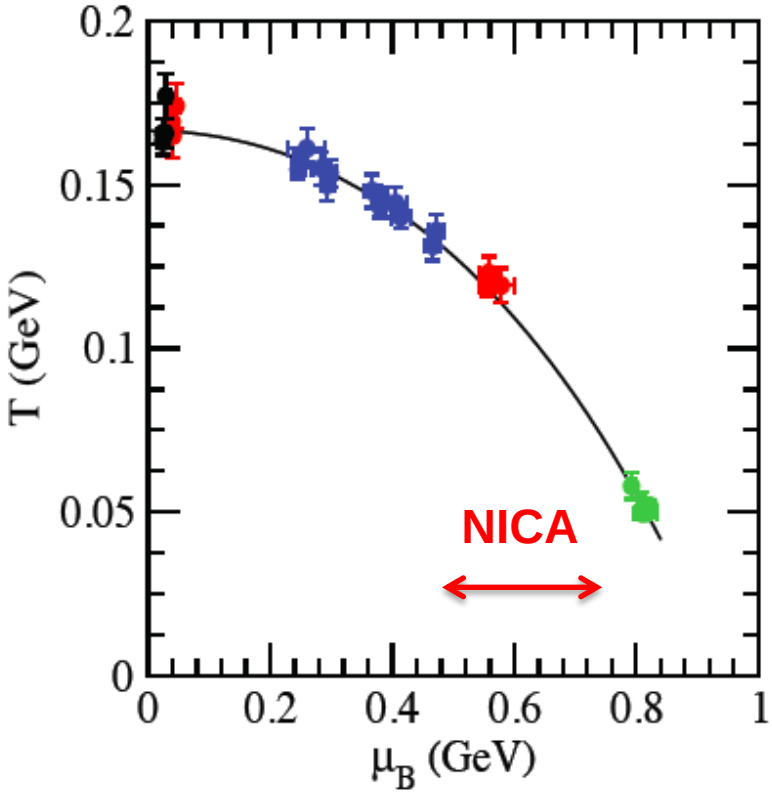
NICA energy region

a transition from a baryon-dominated to a meson-dominated media



H. Oeschler et al.
Physics Letters B615 (2005) 50-54.

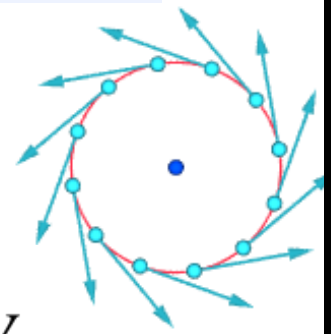
less studied region



J. Cleymans, SQM-2017.

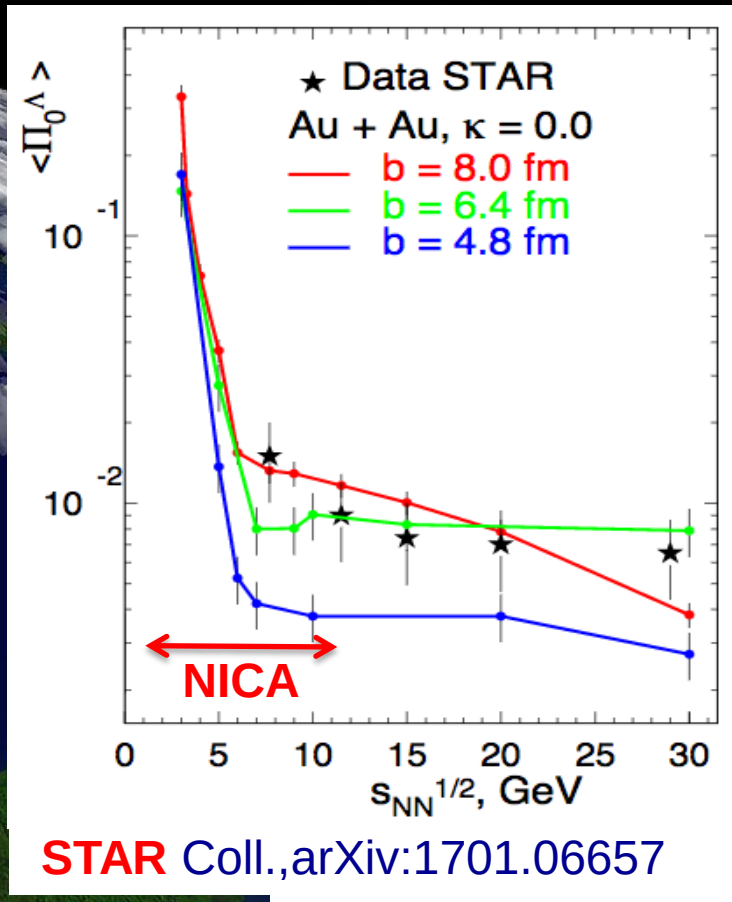
Vorticity, Λ polarization

$$\vec{J} = \frac{1}{\pi^2}\mu_5\mu\vec{\omega} \qquad \vec{\omega} = \frac{1}{2}\vec{\nabla}\times\vec{v}$$



$$J_A^{\mu} \sim \mu^2\left(1-\frac{2\mu n}{3(\varepsilon+P)}\right)\varepsilon^{\mu\nu\lambda\rho}V_\nu\partial_\lambda V_\rho$$

Λ polarization due to *anomalously induced axial current*

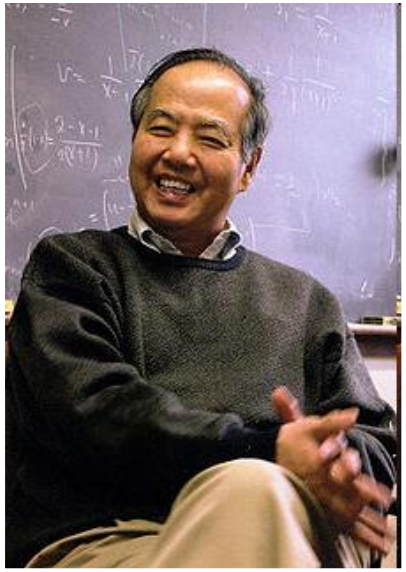


STAR Coll.,arXiv:1701.06657

O. Rogachevsky, A. Sorin, O. Teryaev, Phys. Rev. C 82, 054910, 2010;
M.Baznat, et. al, arXiv:1701.00923

QCD matter at the NICA energies:

- *maximum in the net baryon density – **density frontier**;*
- *maximum in K^+/π^+ ratio;*
- *maximum in Λ/π ratio;*
- *maximum yield if hypernuclei*
- *transition from a Baryon dominated system to a Meson dominated one;*
- *maximum of the Λ polarization;*
- *1-st order transition & mixed phase creation;*
- *Critical Endpoint ?*

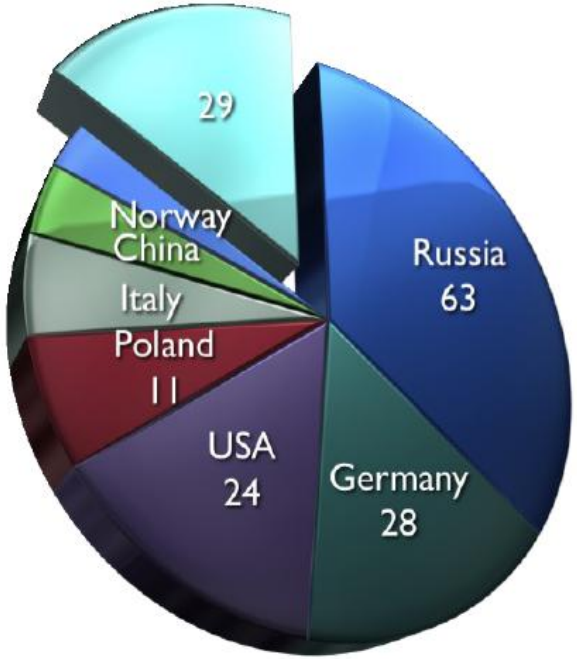


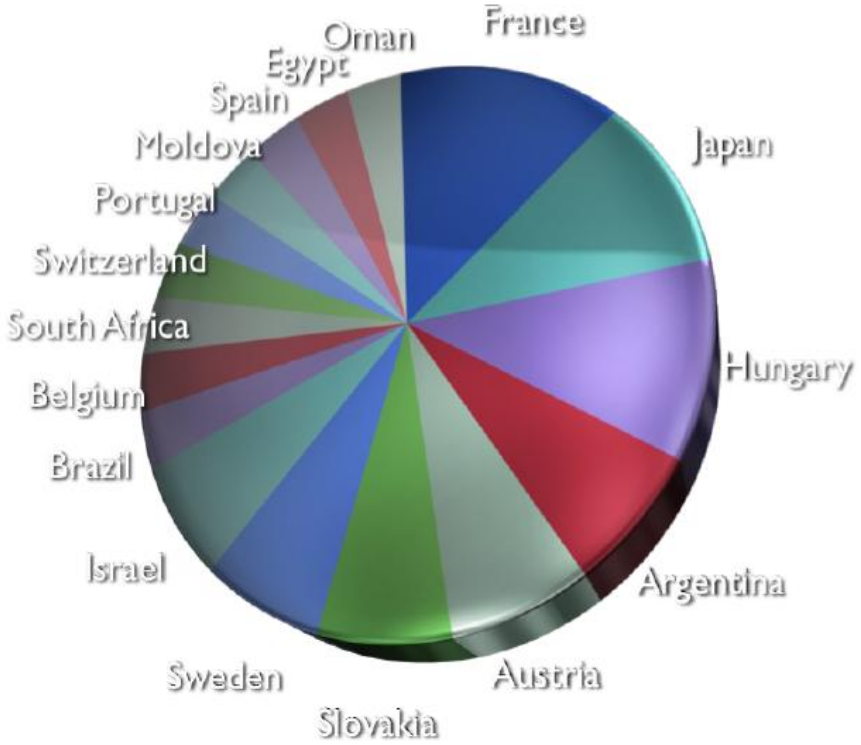
NICA White Paper– International Effort

I am very much looking forward to the completion and future success of the NICA heavy ion collider.

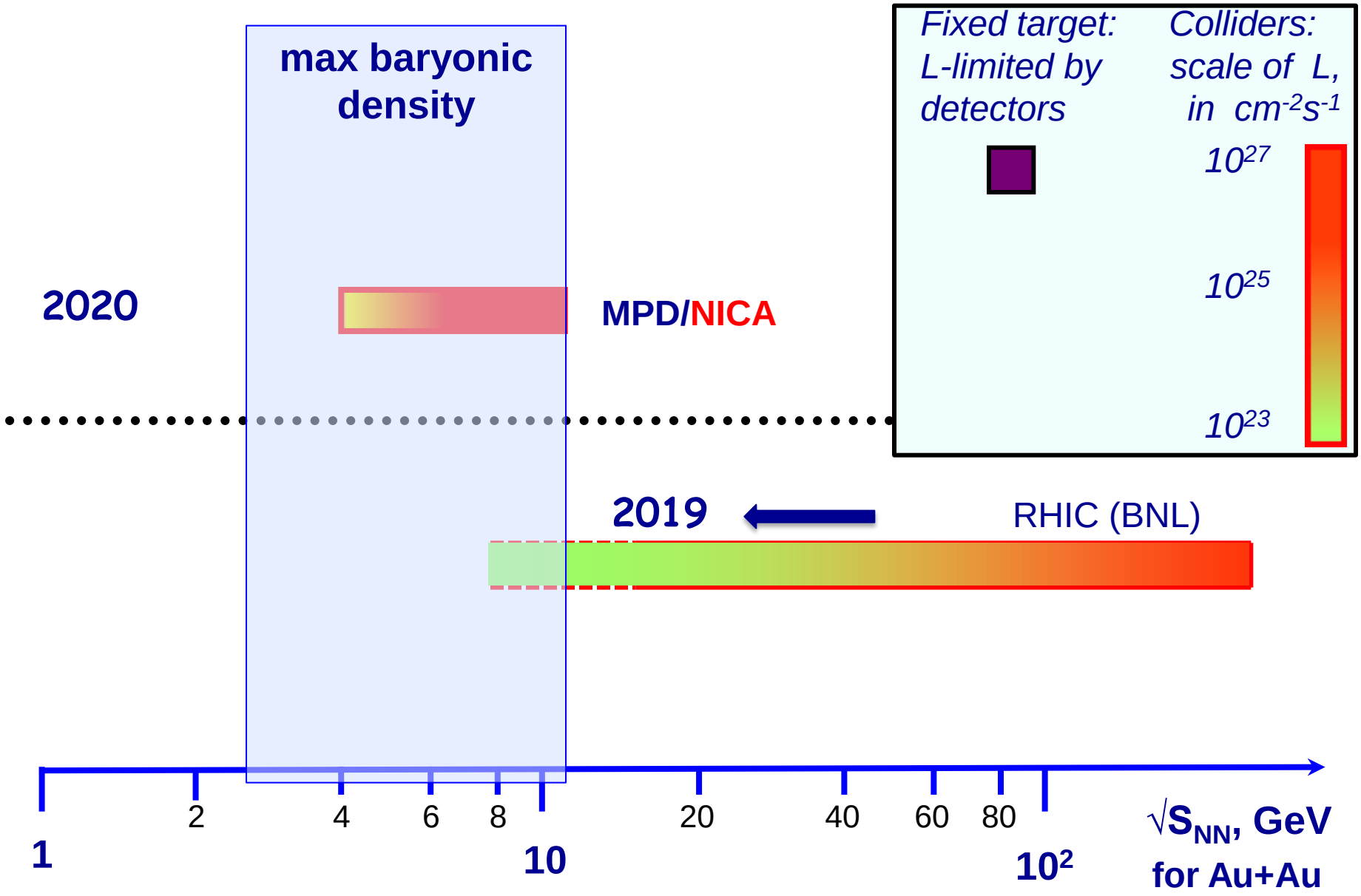
T.D. Lee

111 *contributions:* **188** *authors from* **24** *countries*

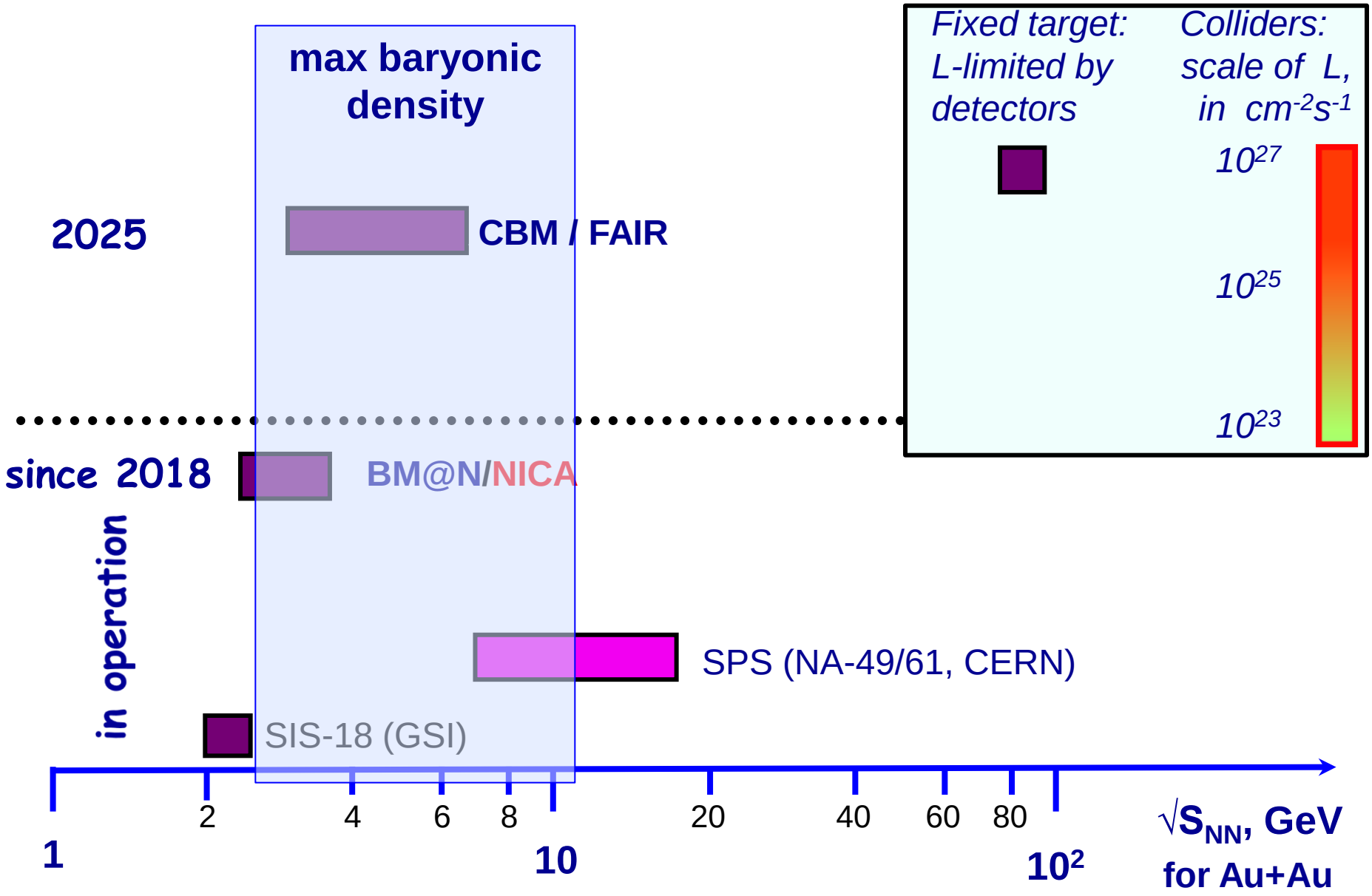




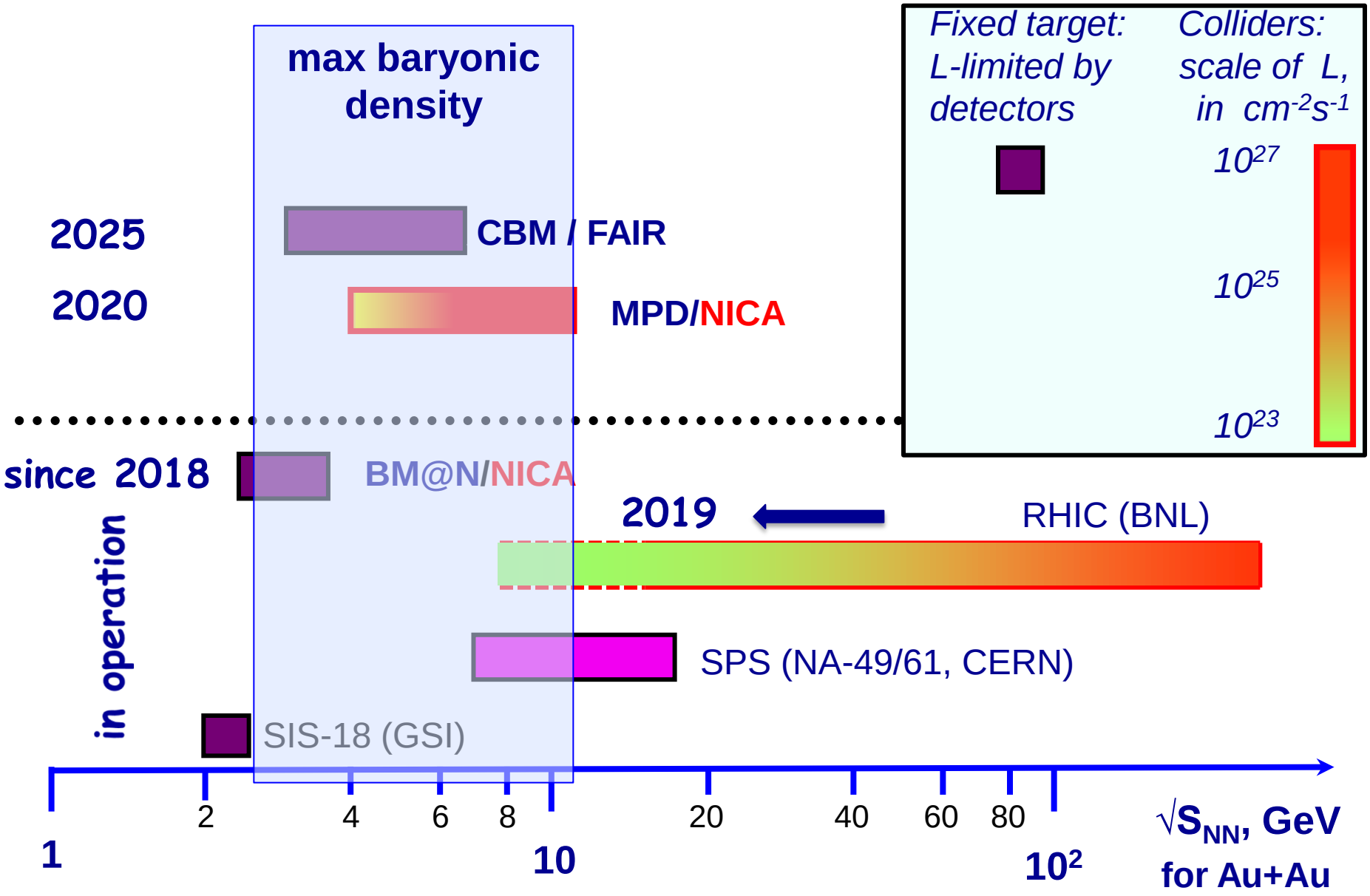
HI collider experiments



Present and future HI f.t. experiments



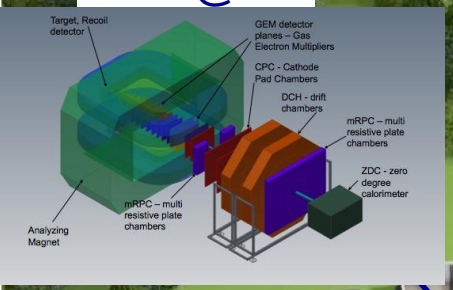
Present and future HI experiments



The NICA basic facility

NICA

BM@N



SPD (Detector)

MPD (Detector)

E-cooling

BM@N (Detector) Extracted beam

Collider ring (c=503 m)

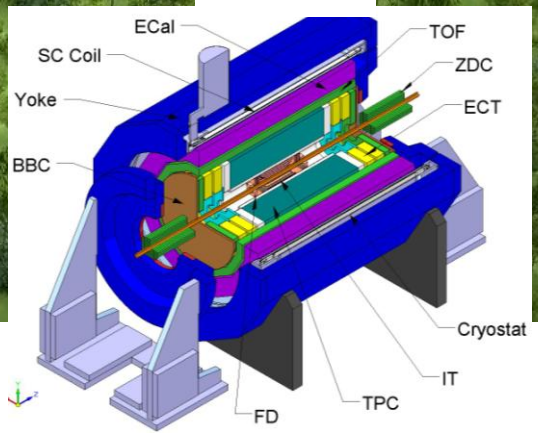
Injection Complex

Nuclotron

Booster

Nuclotron ring (c=251,5 m)

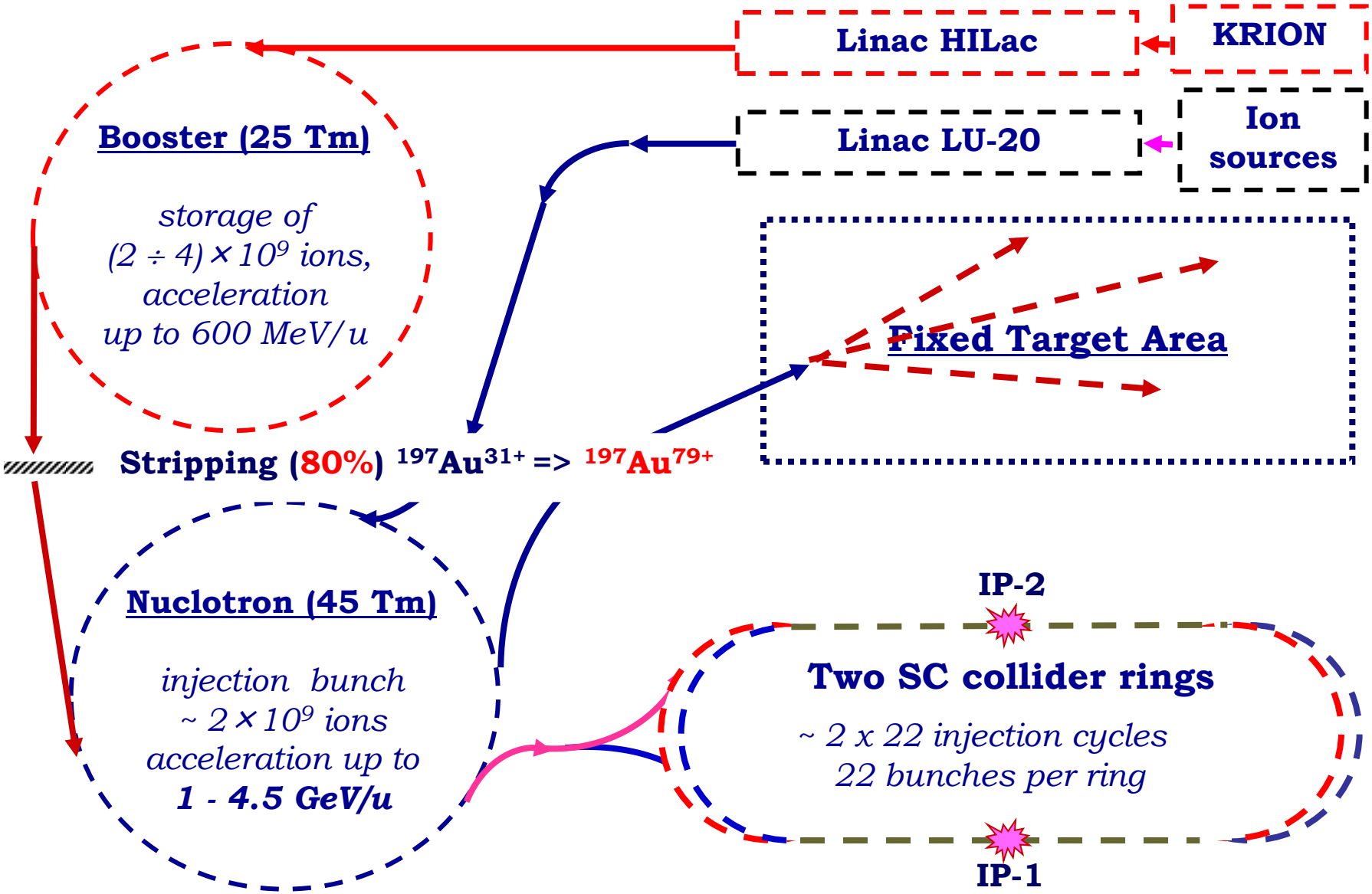
MPD



"Looking ahead is better than dreaming about the past."

Voltaire

Structure and Operation Regimes



Structure and Operation Regimes

Linac HILac

KRION

Ion sources

Booster (25 Tm)

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

Stripping (80%) $^{197}Au^{31+}$

Nuclotron (45 Tm)

injection bunch
~ 2×10^9 ions
acceleration up to
1 - 4.5 GeV/u

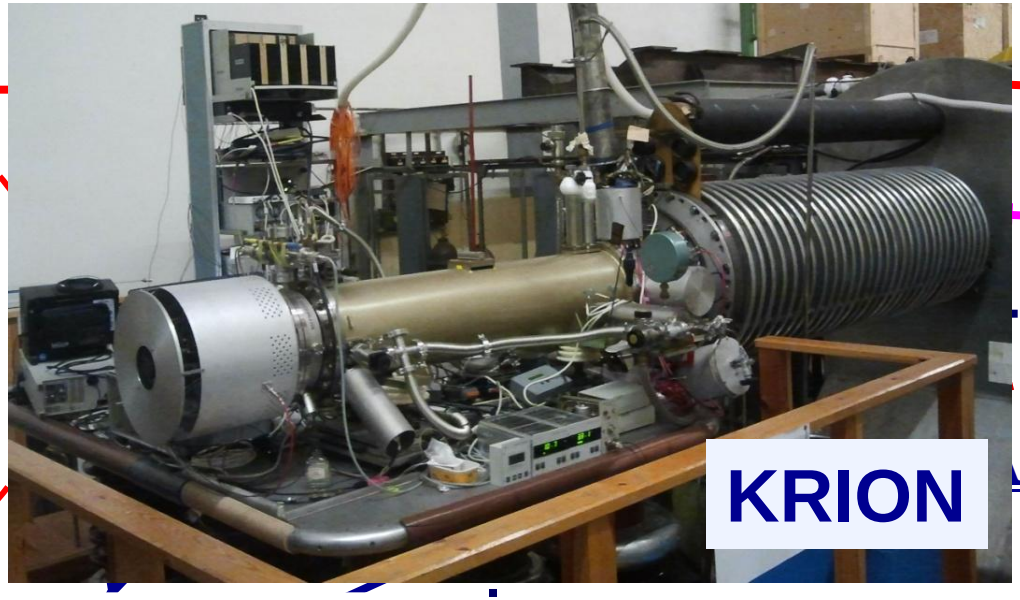
IP-2

Two SC collider rings

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

Structure and Operation Regimes



KRION

Ion sources

Booster (25 Tm)

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

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$

Nuclotron (45 Tm)

injection bunch
~ 2×10^9 ions
acceleration up to
1 - 4.5 GeV/u

IP-2

Two SC collider rings

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

Structure and Operation Regimes

commissioning: May '16

Linac HILac ← **KRION**

Linac LU-20 ← **Ion sources**

Fixed Target Area

Stripping (80%) $^{197}Au^{31+}$ => $^{197}Au^{79+}$

Nuclotron (45 Tm)

injection bunch
~ 2 × 10⁹ ions
acceleration up to
1 - 4.5 GeV/u

IP-2

Two SC collider rings

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

Structure and Operation Regimes

Linac HILac ← **KRION**

Booster (25 Tm)

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

commissioning: Oct. '16

Stripping (80%) $^{197}Au^{31+}$

Nuclotron (45 Tm)

injection bunch
~ 2×10^9 ions
acceleration up to
1 - 4.5 GeV/u

IP-2

Two SC collider rings

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

Structure and Operation Regimes

Booster (25 Tm)

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

Stripping (80%)

Nuclotron (45 T

injection bunci
~ 2×10^9 ions
acceleration up to
1 - 4.5 GeV/u

Commissioning starts in 2018

~ 2 x 22 injection cycles
22 bunches per ring

IP-1

The technological line for assembly, tests and certification of SC magnets for NICA and FAIR was officially put in operation on November 28, 2016

SC magnets fabrication and certification
NICA и SIS-100/FAIR

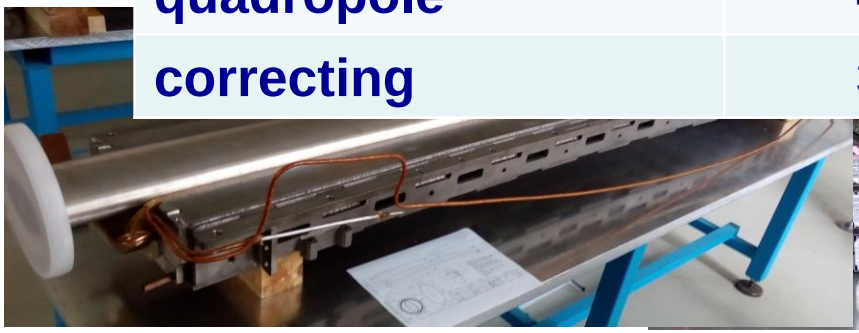
SC Magnets for NICA & SIS-100/FAIR workshop at VBLHEP

(bld. 217) was put in operation (full configuration) ***in Nov. 2016***

Serial tests of Booster magnets have started

Booster magnet production status (15.01.2018)

type	тperequired	produced		tested
		yokes	*coiles*	
dipole	**40**	**40**	**42**	**33**
quadropole	**48**	**48**	**48**	**6**
correcting	**32**	**32**	**2**	**2**



Infrastructure

NICA “corner stone” ceremony, JINR, March 25, 2016

NICA Civil Construction

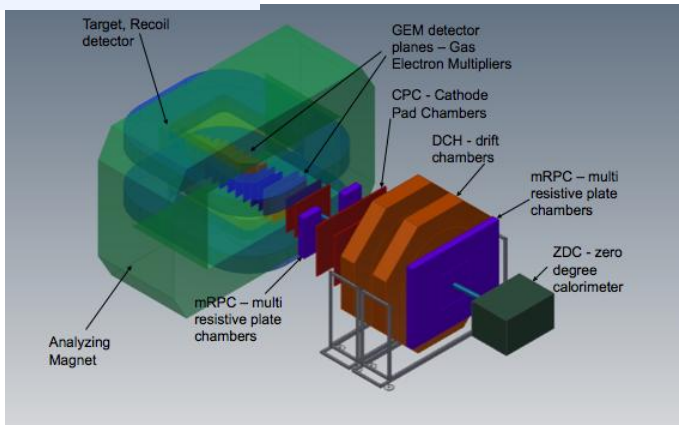
Contract signed with DO ARENA for «Center NICA» design works

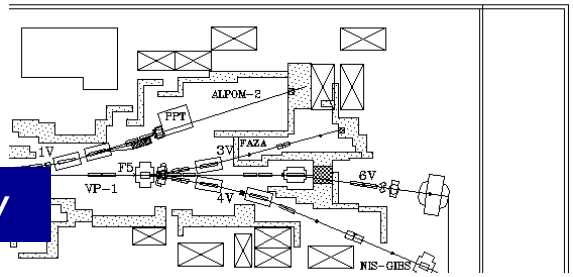
Experiment
Baryonic Matter at Nuclotron
(BM@N)

Baryonic Matter at Nuclotron (BM@N)

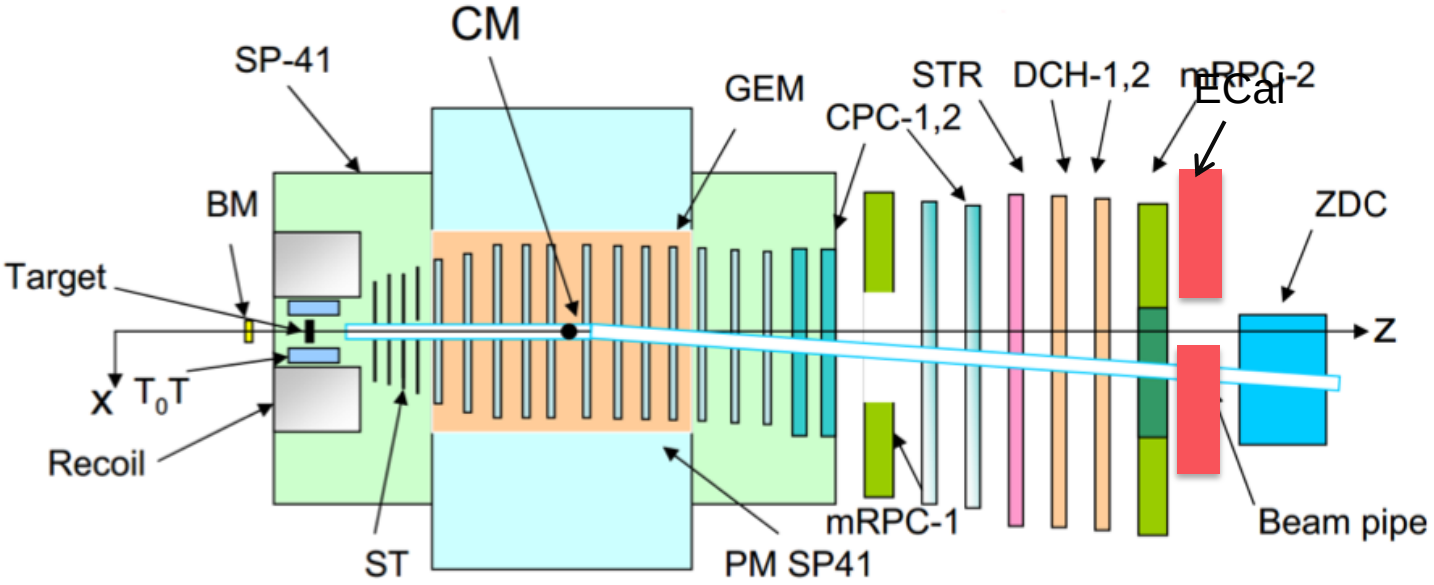
BM@N сотрудничество:

Russia: *INR, MEPhi, SINP, MSU,*
IHEP, S-Ptr Radium Inst.
Bulgaria: *Plovdiv University;*
China: *Tsinghua University, Beijin;*
Poland: *Warsaw Tech.Uni.*
Israel: *Tel Aviv Uni.,*
Germany: *Frankfurt Uni.; GSI*
USA*: MIT, FIU, ODU, PSU*
France: *CEA*

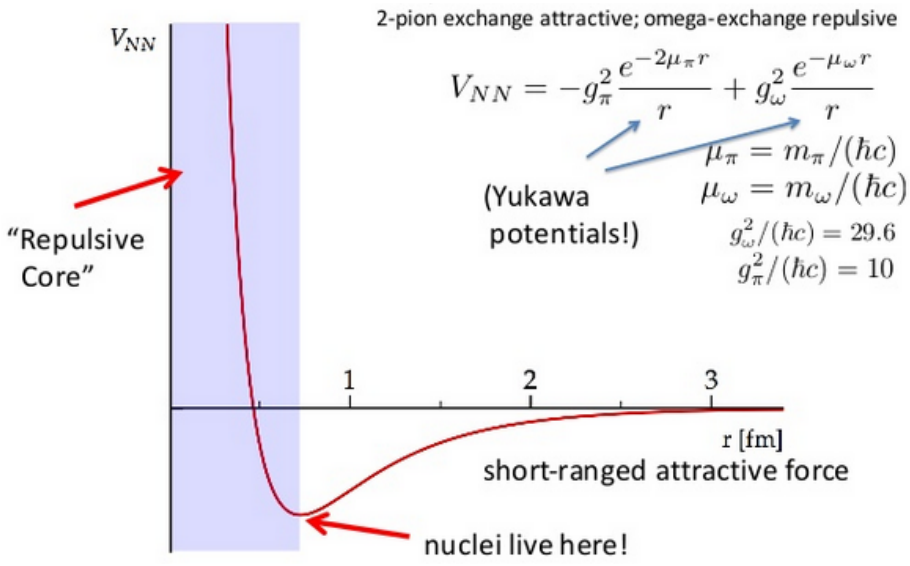




BM@N *schematic view*



Addition to the BM@N physics program: "Probing Short-Range Correlations"



BM@N collaboration +

***Israel**: Tel Aviv University*

***Germany**: TUD and GSI*

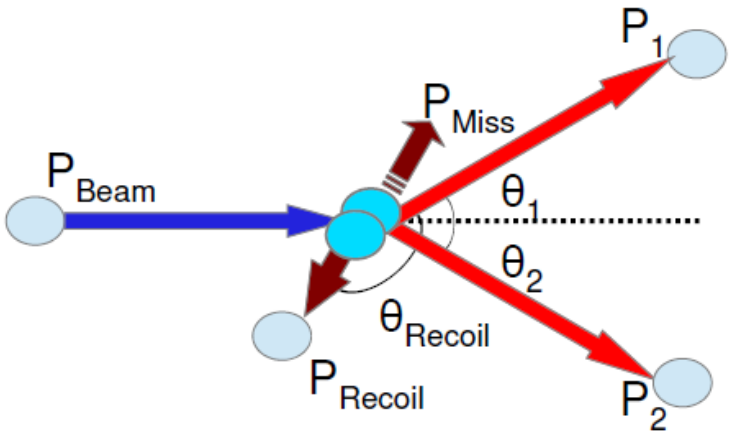
***USA**: FIU, MIT, ODU, PSU*

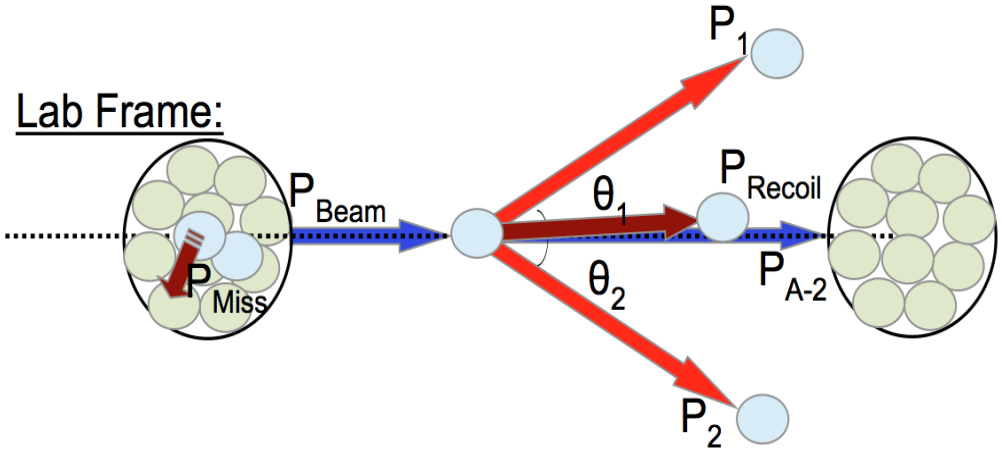
***France**: CEA*

$^{12}C + p \rightarrow 2p + {}^{11}_{5}B$ QE

$^{12}C + p \rightarrow 2p + {}^{10}_{5}B + n$ np SRC

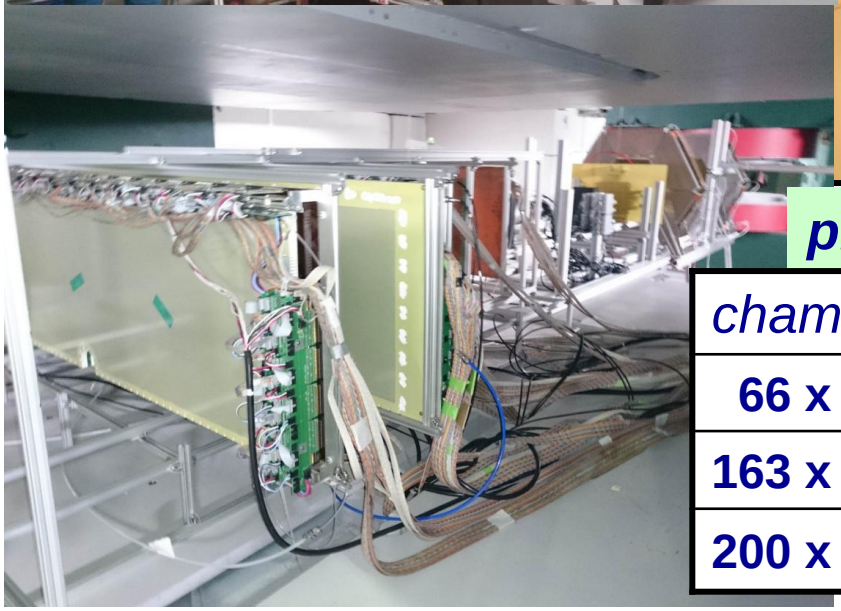
$^{12}C + p \rightarrow 2p + {}^{10}_{4}Be + p$ pp SRC





GEM detectors for BM@N central tracker

GEM production at CERN PH-DT MRT workshop for BM@N

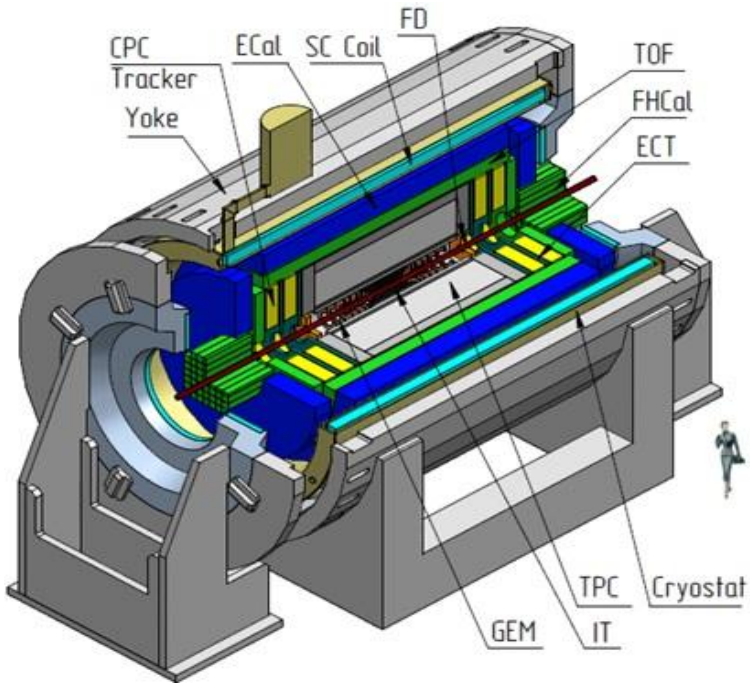


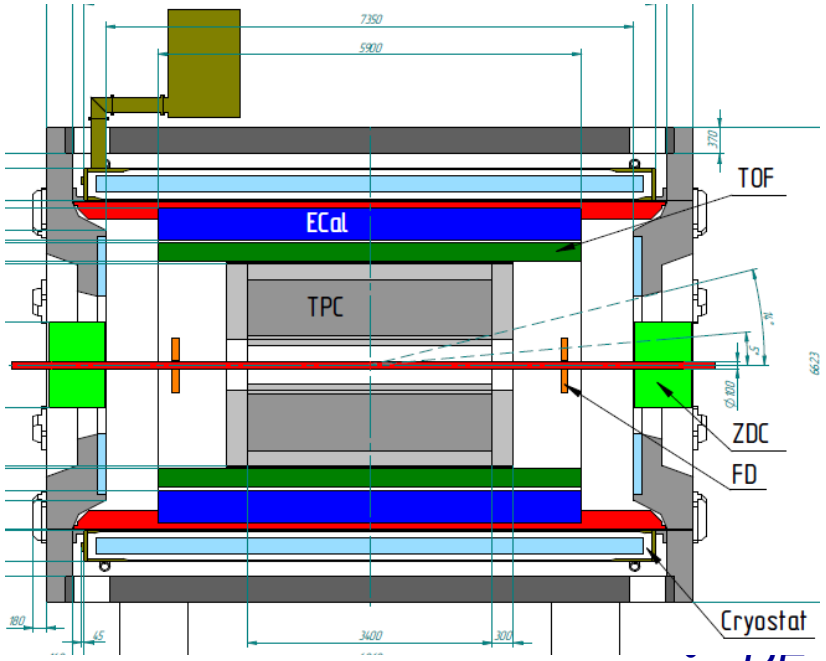
plan of production of triple GEM's

chamber size	**2015-16**	**2017**	**2018**	**2019**
66 x 41 cm²	**5**			
163 x 45 cm²	**2**	**6**	**6**	
200 x 45 cm²			***design***	**6**

Experiment
Multi Purpose Detector
(MPD)

Multi Purpose Detector @ NICA





Establishing meeting of MPD collaboration:
April 11-13, 2018

MPD Collabo

- *JINR, Dubr*
- *Tsinghua University, Beijing, China;*
- *GSI, Germany*
- *MEPhI, Moscow, Russia*
- *INR, RAS, F*
- *PPC BSU, M*
- *WUT, Warsa*

Status:
TDR – completed / close to completion;
preparation for / start of mass production

expression of interest:

- *CERN;*
- *DF, US, Mexico;*
- *A; Mexico;*
- *N, Mexico;*
- *a, Mexico;*
- *FCF-MB UAP, Puebla, Mexico;*
- *PI Az.AS. Baku, Azerbaijan;*
- *oscow, Russia;*
- *rsburg, Russia;*
- *C, Hefei, China;*
- *SS, HU, Huzhou, Republic of South Africa.*

Basic configuration milestones

- ***2018*** *– start of* ***BM@N*** *experiment*
- ***2018*** *– start of* ***Booster*** *commissioning*
- ***2018*** *–* ***MPD*** *hall completion*
- ***2019*** *– completion of civil constructions (****b. 17)***
- ***2019*** *–* ***MPD*** *magnet commissioning*
- ***2019*** *– start of* ***MPD*** *detectors assembly*
- ***2019*** *– start of* ***Collider*** **assembly**
- ***2020*** *– start of* ***Collider*** *commissioning*
- ***2020*** *– start of* ***MPD*** *commissioning*
- ***2020*** *– completion of* ***«Center NICA»*** *construction*
- ***2020 –*** *start of assembly of* ***Computer center*** *elements*

XXIII A.M. Baldin International Seminar

Relativistic Nuclear Physics & Quantum Chromodynamics

Dubna, 19 – 24 September, 2016

“All genuine education comes about through experience.”
John Dewey

Students from Warsaw University of Technology in BVLHEP to practice at the NICA facility

July- September, 2017

potential participants of the NICA project

NICA Days in Warsaw

On 6 – 10 November, the second conference "NICA Days in Warsaw" organized by the Warsaw University of Technology and the Joint Institute for Nuclear Research was held

- **The agreement on establishment of the Consortium of Polish research institutes interested in the NICA project was signed.**
- **The exhibition of NICA/JINR was presented.**

NICA/JINR at the XIX World Festival of Youth and Students

Sochi, 15 – 22 October 2017

International team of JINR young scientists

JINR participated actively in the exposition "Megascience: Russia in the World – Russia for the World", where the Joint Institute for Nuclear Research presented its megascience flagship project – the accelerator complex NICA.

The NICA megaproject was represented by an international JINR team, including young scientists from Poland, Bulgaria, and Russia.

In addition to the NICA project, JINR also presented its educational programmes and opportunities for undergraduate and postgraduate students.

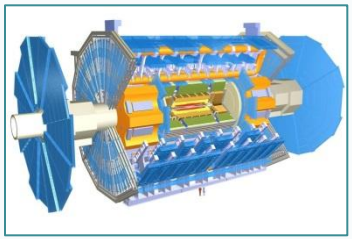
The JINR exposition was of great interest not only to young participants of the Festival who interested in science, but also to distinguished guests who have already done a significant contribution to science. So the JINR exposition was visited by George Fitzgerald Smoot, an American astrophysicist and cosmologist who won the Nobel prize in physics in 2006.

The JINR exposition was also visited by Minister of Education of Cuba Jose Ramon Saborido, Chairman of the State Duma Committee on Education Vyacheslav Nikonov, Deputy Minister of education and science of the Russian Federation Pavel Zenkovich, Deputy and Deputy Head of the Information and Public Relations Office of the Kursk NPP Alexander Prytkov.


JINR team at the exposition

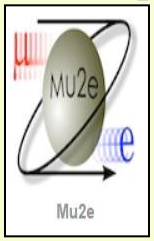
High Energy Physics Frontiers:
CERN, FNAL, DOE, NASA, JINR,…

Energy Frontier

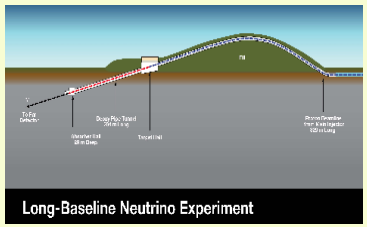


experiments at CERN

Intensity Frontier



FNAL (Mu2e)



FNAL (LBNE)

SLAC (BaBar)

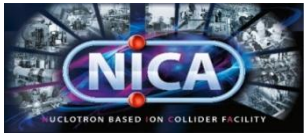
Cosmic Frontier

Supernova Cosmology

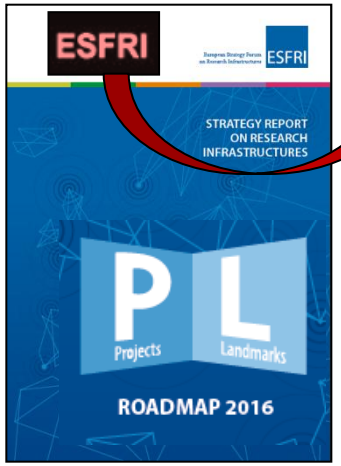
Dark Energy Spectr. Instum.

DOE, NASA, …

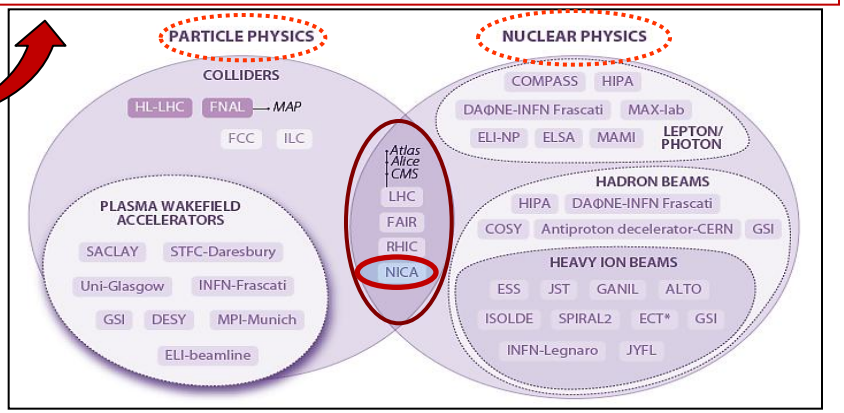
JINR → HIGH DENSITY BARYONIC MATTER FRONTIER

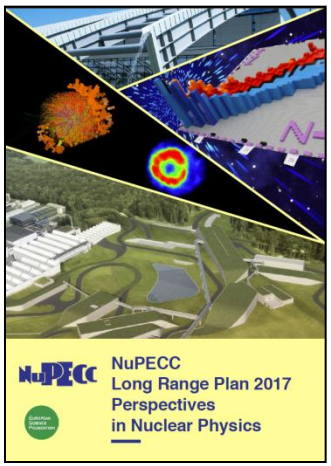


NICA is included in the ESFRI ROADMAP-2016 and in the NuPECC Long Range Plan 2017 - Perspectives in Nuclear Physics



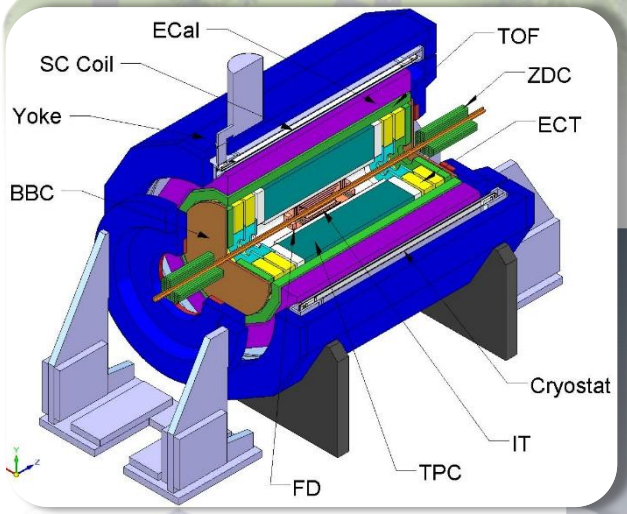
Main Research Infrastructures in Particle and Nuclear Physics





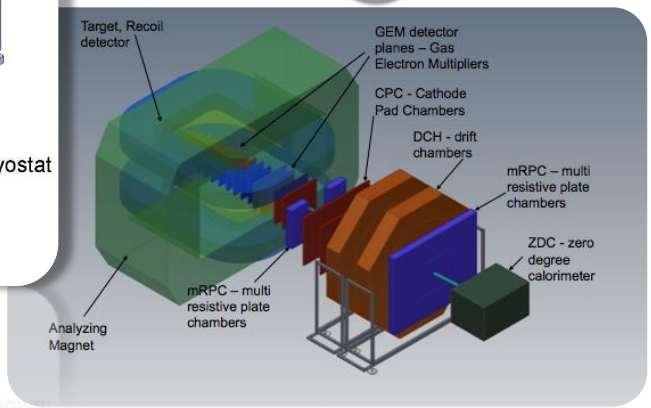
Status of the NICA complex realization

Nuclotron & channels	40%
Injection complex	49%
Booster	64%
Collider	18%
MPD	35%
BM@N	60%
SPD	2%
Infrastructure	39%
Innovation area	1%
IT & computing	25%



MPD

BM@N



NICA Center

Announcement of the kick-off meeting on formation of the MPD and BM@N Collaborations

11-13 April, 2018

Detailed information about the meeting can be found at:

https://indico.jinr.ru/conferenceDisplay.py?confId=385

Those who might be interested in participating in the NICA project could join the meeting.

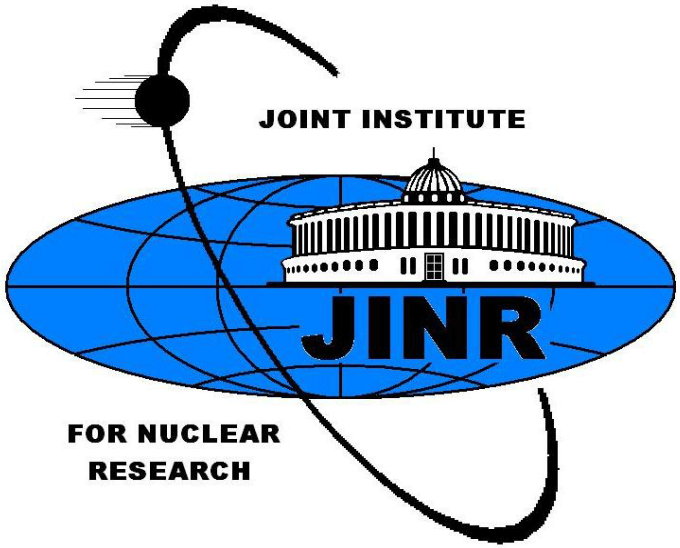
The registration is now open.

- drafts of **MoU** and **By-low** are under consideration and edition;
- must satisfy to framework of **Provision on collaboration** adopted at **JINR**;
- will be approved by the **Institutional Board** of the Collaborations.

Concluding remarks

- **Density frontier** is less explored area of the QCD phase diagram and its study could *lead to interesting discoveries*
- **NICA** complex has a potential for competitive research *in the field of baryon rich matter*
- The construction of accelerator complex and both detectors **BM@N** & **MPD** *is going close to the schedule*
- **NICA** got a recognition as a part of European research infrastructure
- **NICA** is open for new participants

Welcome to join NICA!



Thank you for attention!