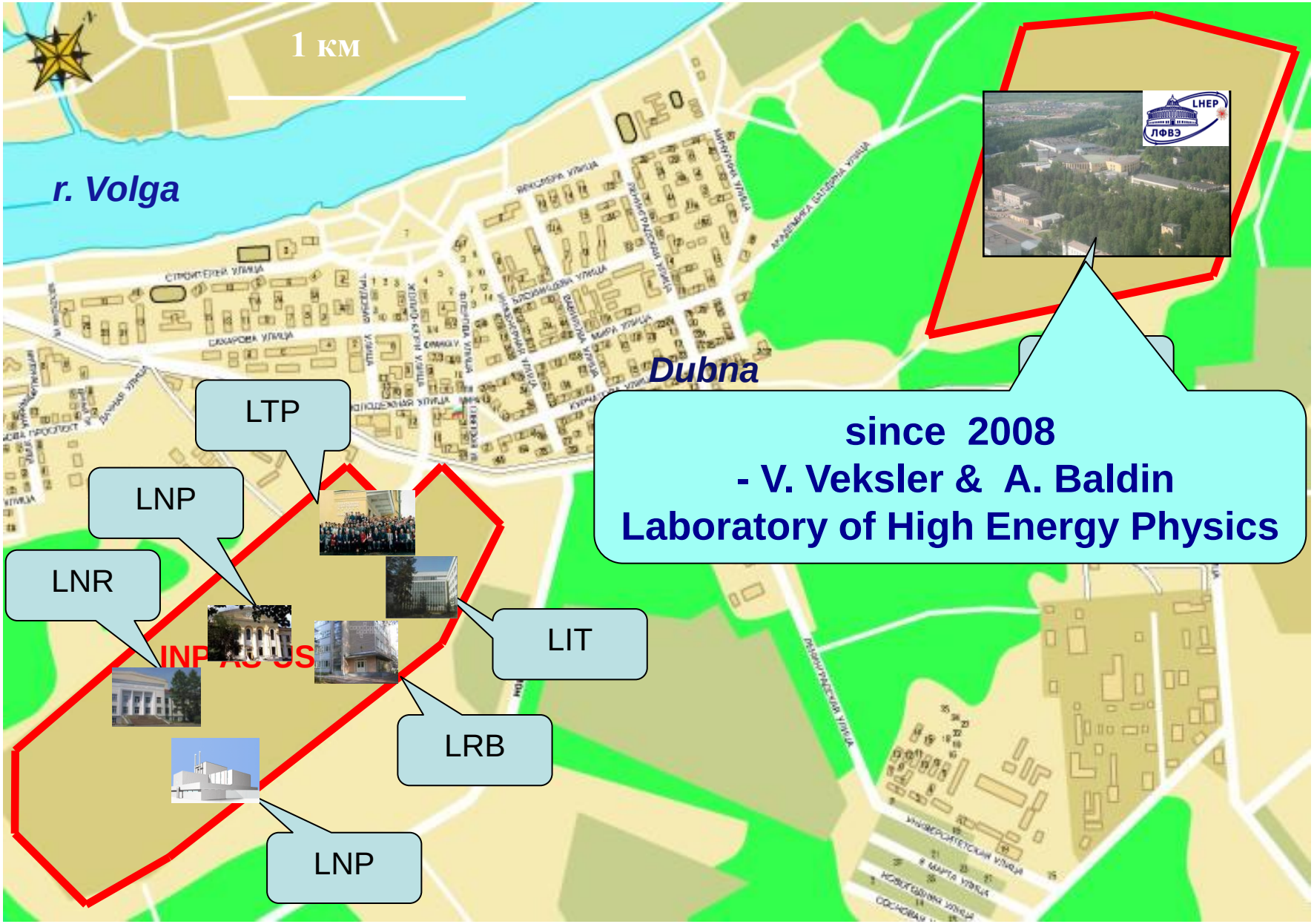
Challenges of NICA project at JINR

V. Kekelidze

Joint Institute for Nuclear Research (JINR) – International Intergovernmental Organization established through the Convention of March 26, 1956 by 11 founding States and registered with the United Nations on 1 February 1957

Governed by the
Committee of Plenipotentiary
*representing governments of **18** countries*

Structure of Joint Institute for Nuclear Research



HISTORY

1949-1950 *accelerator physics program developement;*
1953 *Electrophysical Laboratory of the USSR AS is founded*;
1957 *Synchrophastron is put in operation.*

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

A. Sołtan and H.Niewodniczanski

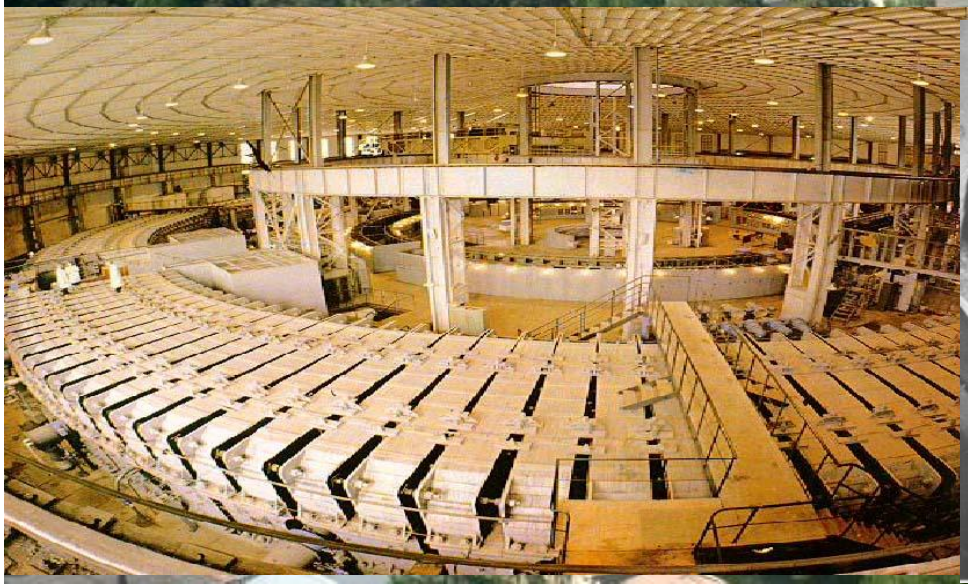
Polish scientists - founders of JINR:
Andrzej Sołtan, Leopold Infeld, Henryk Niewodniczanski, Marian Danysz, Andrzej Hrynkiewicz

M. Danysz and J. Cockcroft

1957 - Synchrophasotron – *10* GeV proton synchrotron

– the world leader in energy

pioneering research in RNP since ’70-th



V. Veksler – discovery of *Phase Stability Principle (1944)*

1993: Nuclotron - *the first SC accelerator of heavy ions based on Dubna type SC magnets developed in LHE*

ring of 251,5 m

A. Baldin
– *pioneer of RNP research*

NICA (Nuclotron based Ion Colider fAcility

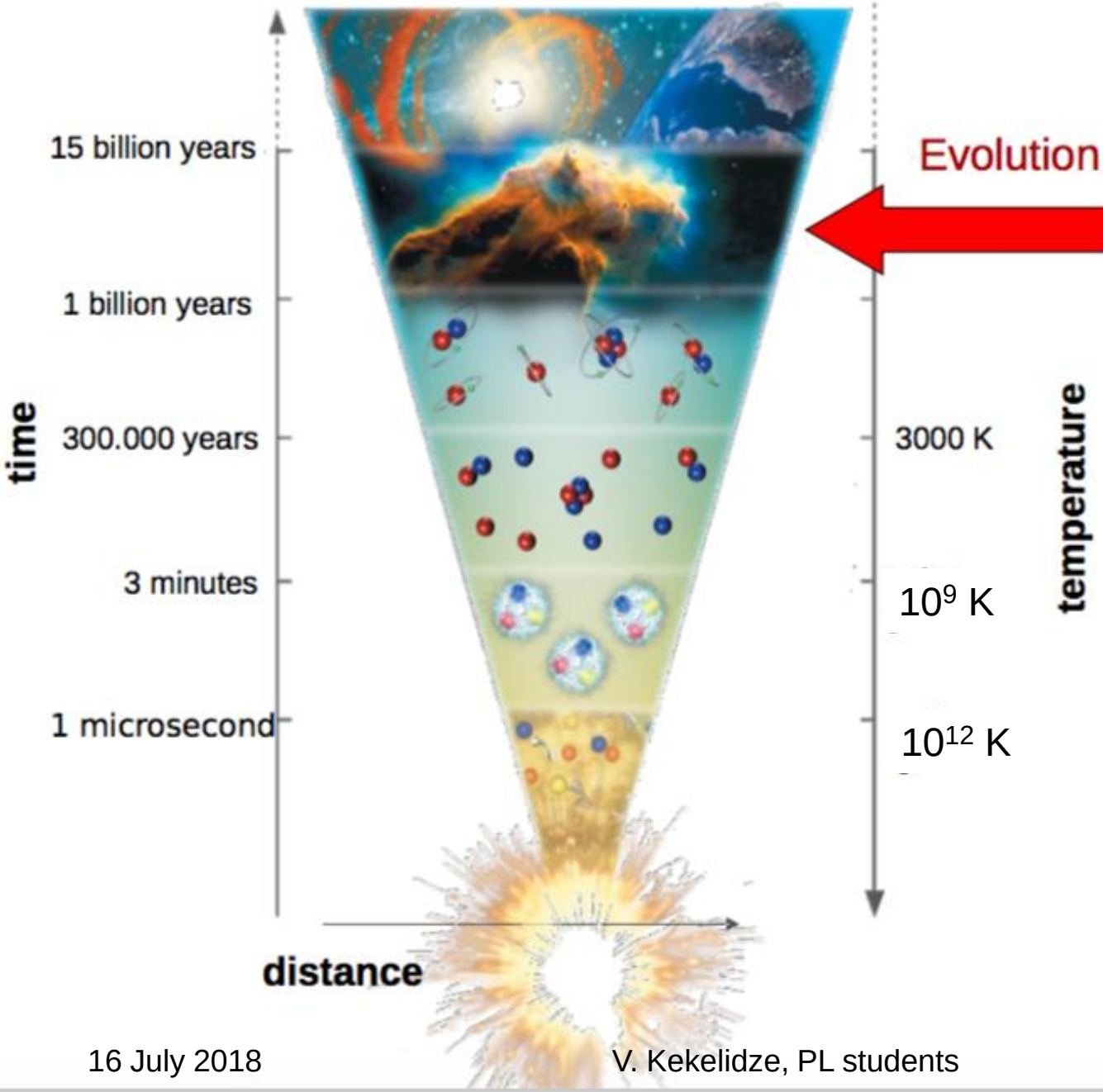
Main targets:

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

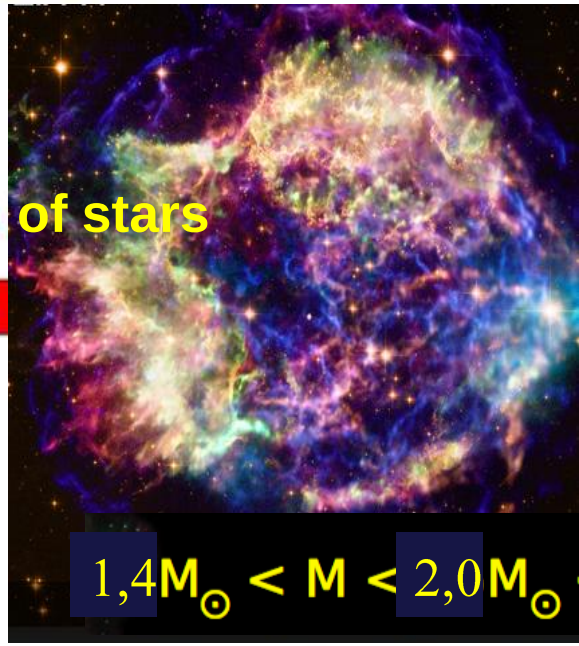
- *development of accelerator facility for HEP @ JINR*
- *construction of Collider of relativistic ions from **p** to **Au**,*
  polarized protons and deuterons

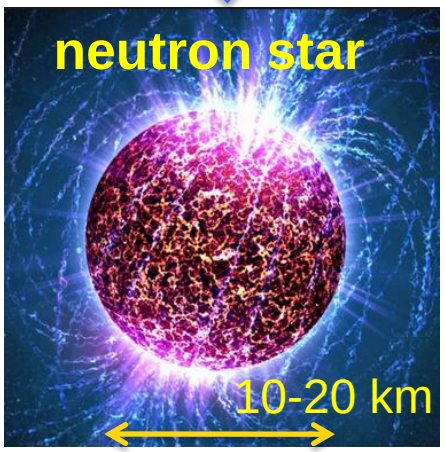
with max energy up to $\sqrt{S_{NN}}$ = **11** *GeV* (Au^{79+}) *and* = **27** *GeV (p)*

The evolution of matter in the universe



Evolution of stars





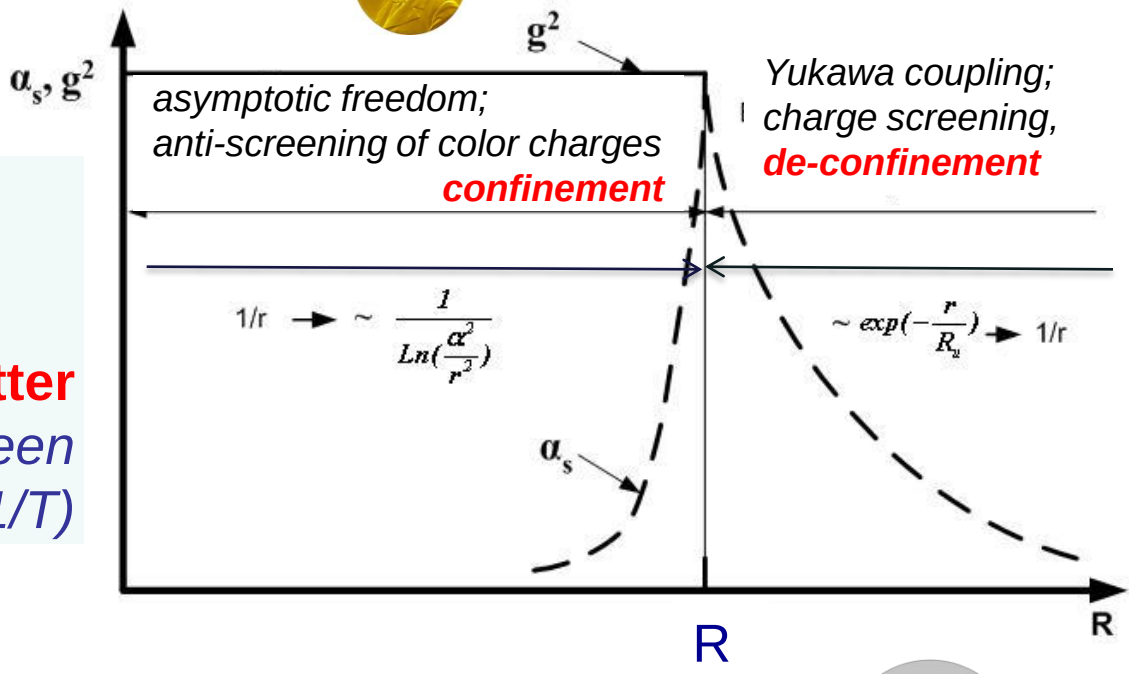
Asymptotic freedom of quarks

The regime of "asymptotic freedom" is reached in hard processes at sufficiently high energies,

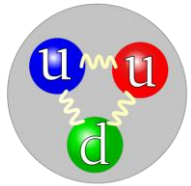
however, this regime could be available already at rather low energies in **super dense nuclear matter** *(the distance between particles ~ 1/T)*

D.J.Gross, H.D.Politzer, F.Wilczek

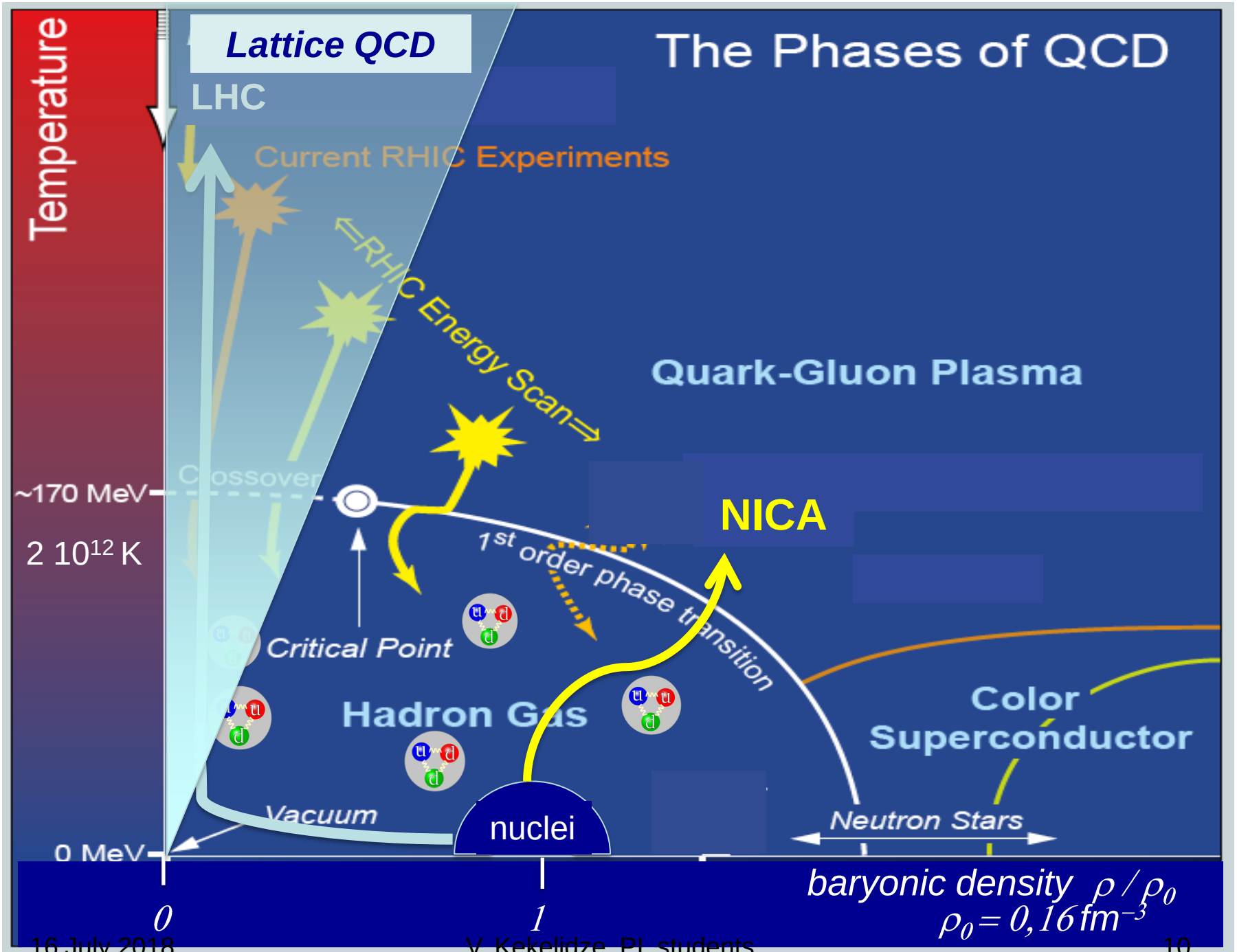
Nobel Prize in 2004 г.



typical size $R_0 \sim 1$ fm $= 10^{-13}$ cm



The super dense nuclear matter could be obtained in heavy ion collisions


The Phases of QCD
Lattice QCD
LHC
Temperature
Current RHIC Experiments
⇐RHIC Energy Scan⇒
Quark-Gluon Plasma
Crossover
~170 MeV
2 10^12 K
NICA
1st order phase transition
Critical Point
Hadron Gas
Color Superconductor
Vacuum
nuclei
Neutron Stars
0 MeV
0
1
baryonic density ρ / ρ0
ρ0 = 0,16 fm−3

«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

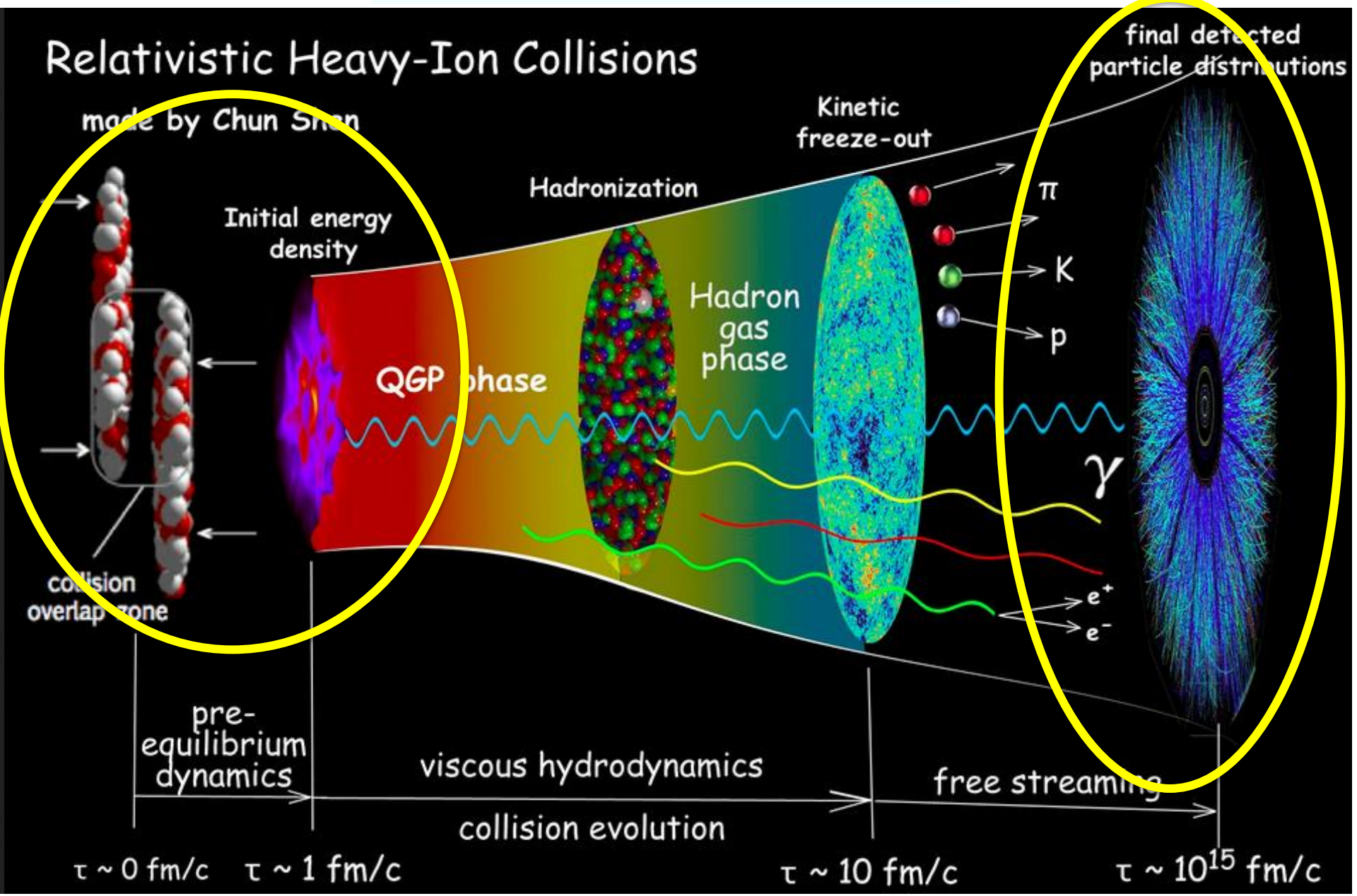
main goal

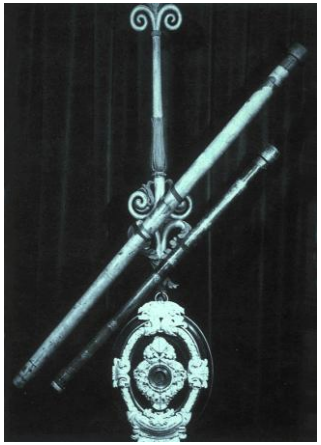
study of hot baryonic matter at the region of max baryonic density

through the tasks

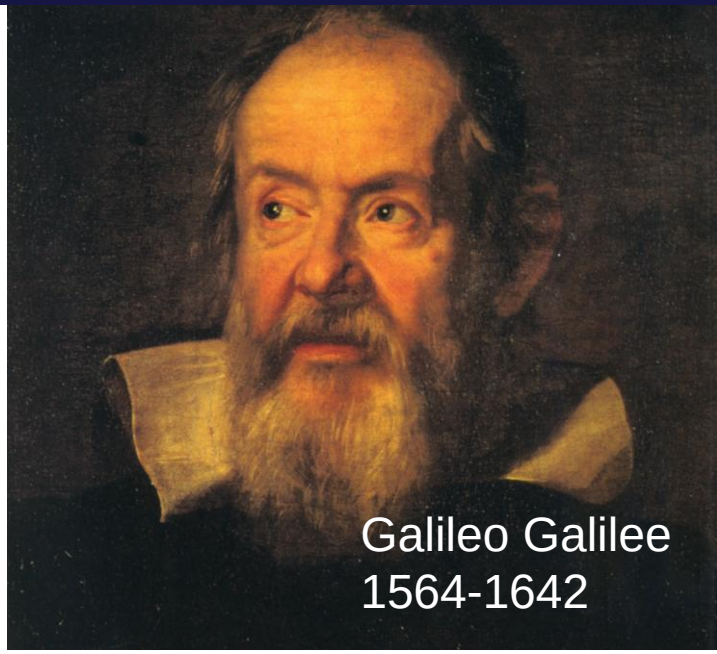
- *equation of state*
- *onset of deconfinement*
- *onset of chiral symmetry restoration*
- *first order phase transition observation*
- *search for critical end-point*
- *polarization phenomena*

Evolution of RHI collision





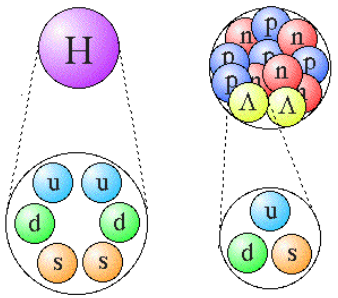
“Measure what is measureable and make measureable what is not so.”



Observables:

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

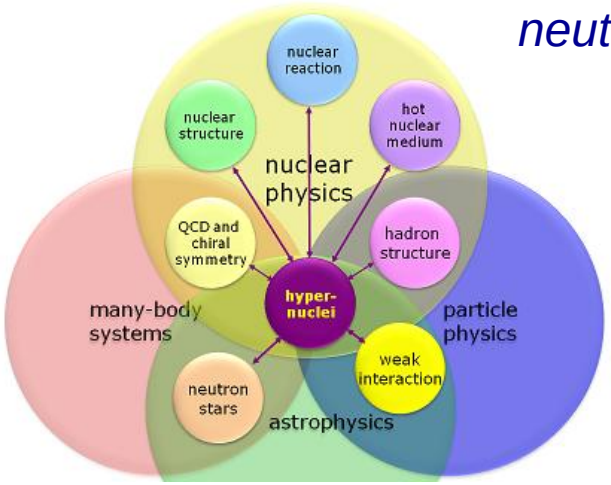
Hypernuclei

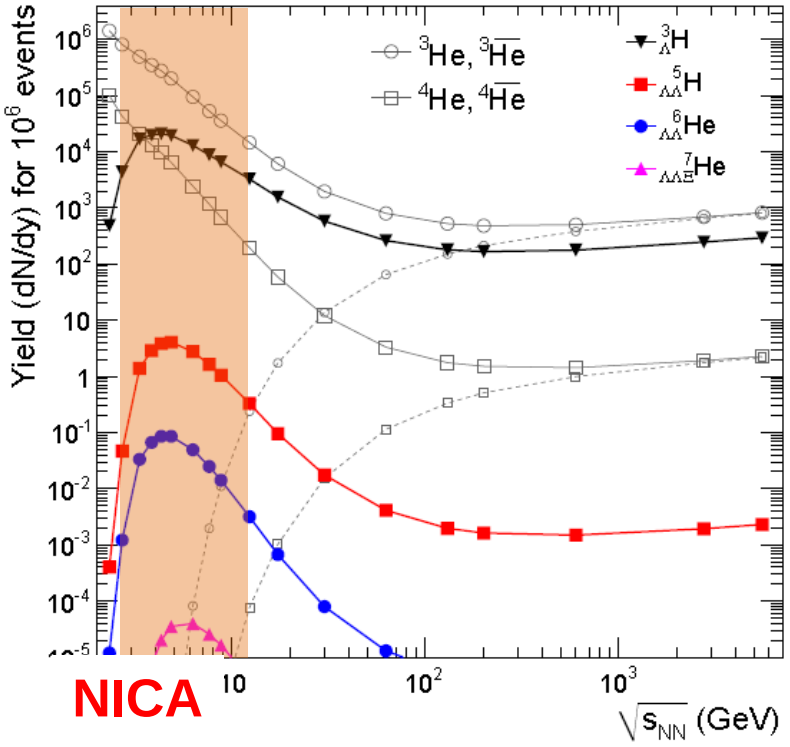


Hypernuclei provides unique opportunity to study the strange particle-nucleus interaction in a many-body environment.

*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

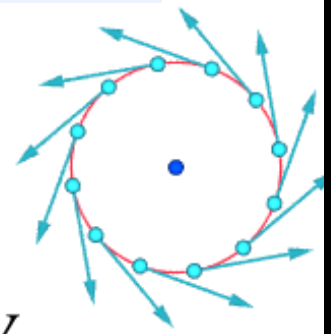




A. Andronic et al., Phys. Lett. B697 (2011) 203

Vorticity, Λ polarization

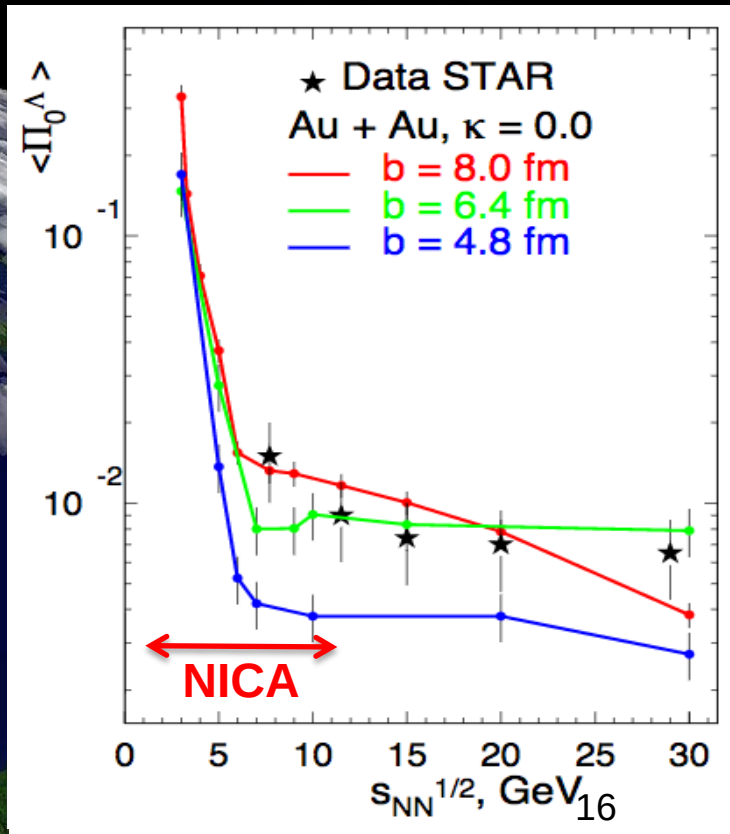
$$\vec{J} = \frac{1}{\pi^2}\mu_5\mu\vec{\omega} \qquad \vec{\omega} = \frac{1}{2}\vec{\nabla}\times\vec{v}$$



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

Λ polarization due to *anomalously induced axial current*

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

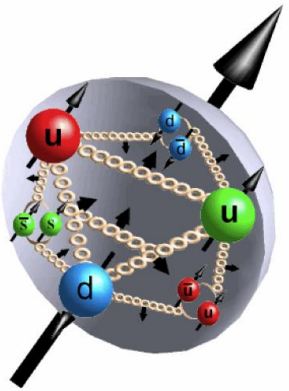


STAR Coll.,arXiv:1701.06657

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 ?*

Spin Physics Detector (SPD)



study of nucleon spin structure

to confirm

the sum rule: $$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g.$$

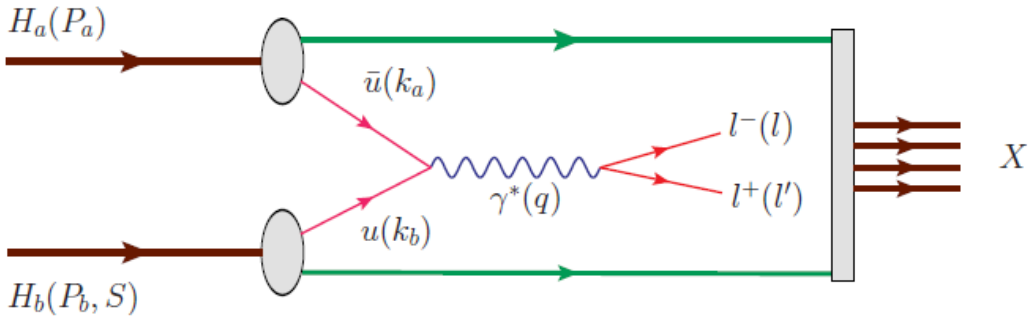
NICA collider will provide collisions of protons and deuterons with all combinations of polarization – *transversal and longitudinal*

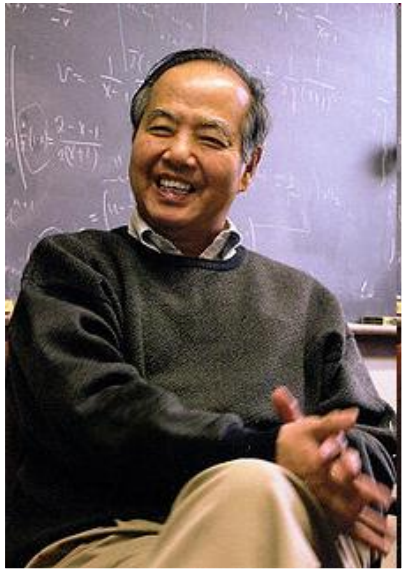
*It will allow to measure all **8** intrinsic-transverse-momentum dependent **PDF**s (at leading twist)* ***in one experiment***

Matveev-Muradyan-Tavkhelidze-Drell-Yan mechanism and **SIDIS** processes **–** *are good tools for these measurements*

Direct photons production

(*gluon polarization***)**



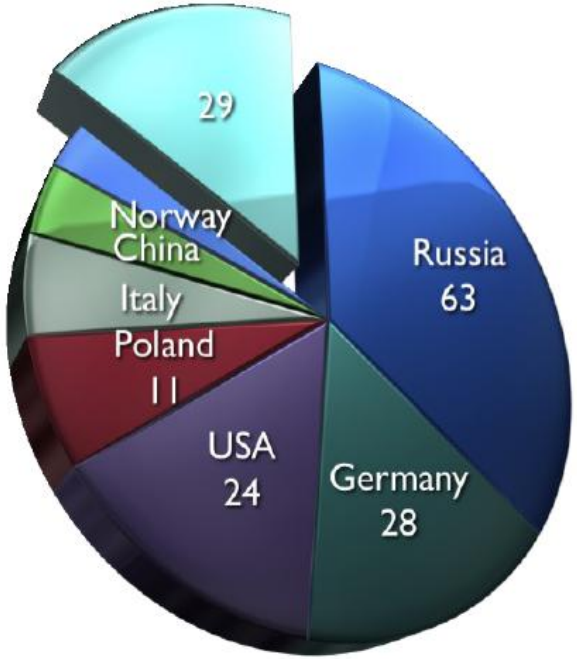


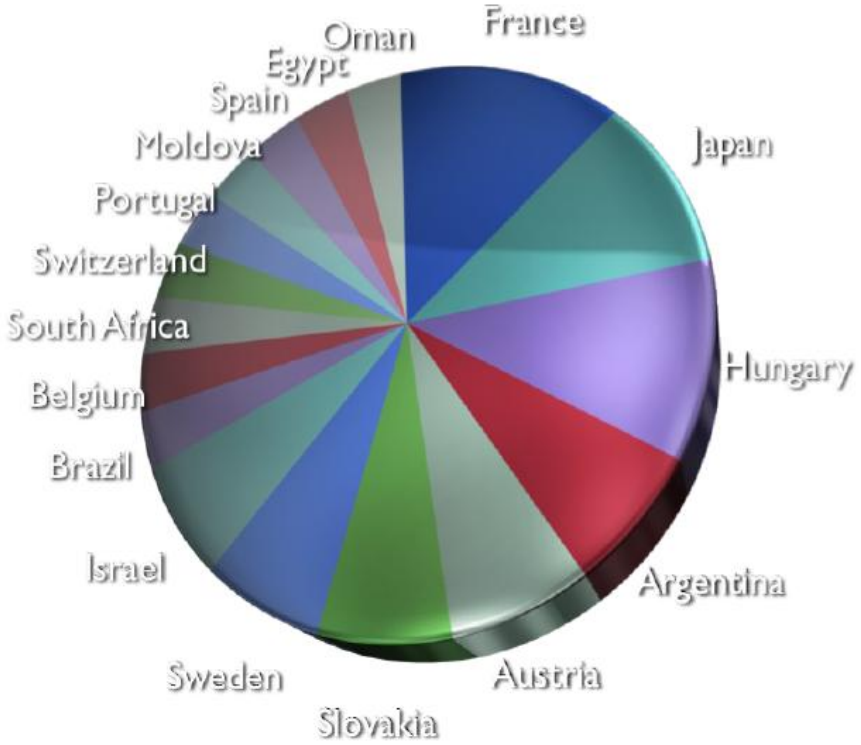
NICA White Paper– International Effort

*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*





charged particle collisions :

electrons, protons (hydrogen nucleus), heavy ions (nuclei)

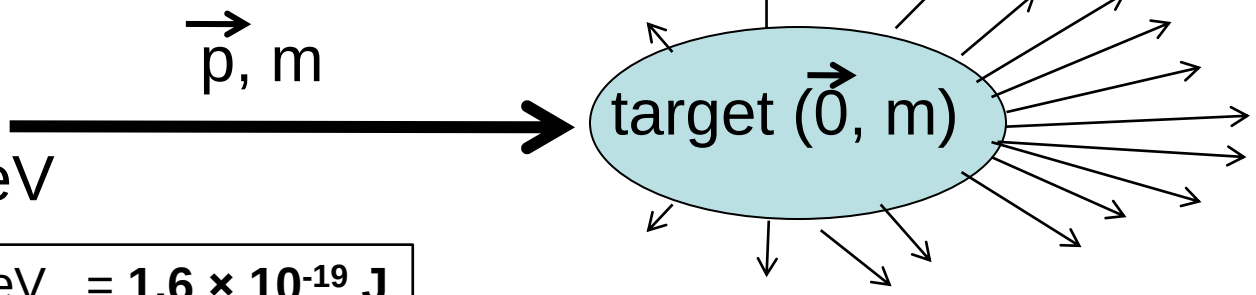
Expriments:

Advantage:
- *high rate of interactions*
- *easy upgradable*

✓ **with fixed target**

p = **10** GeV

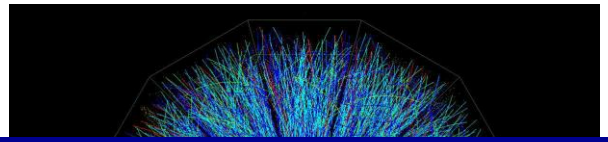
$\sqrt{S_{NN}} \approx$ **4,5** GeV



1eV = **1.6×10^{-19} J**

1GeV=10^9 eV ≈ m

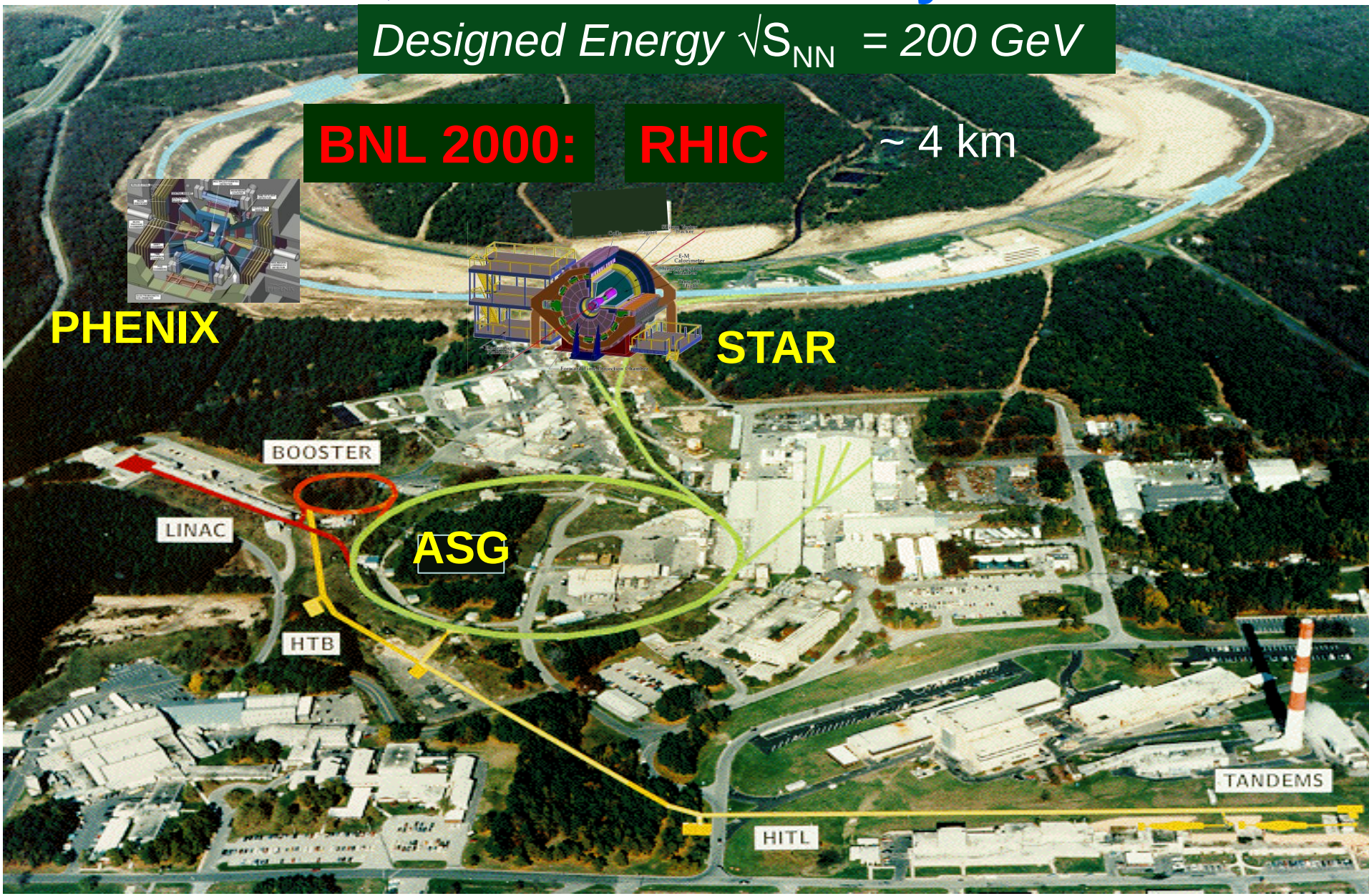
✓ **at collider**



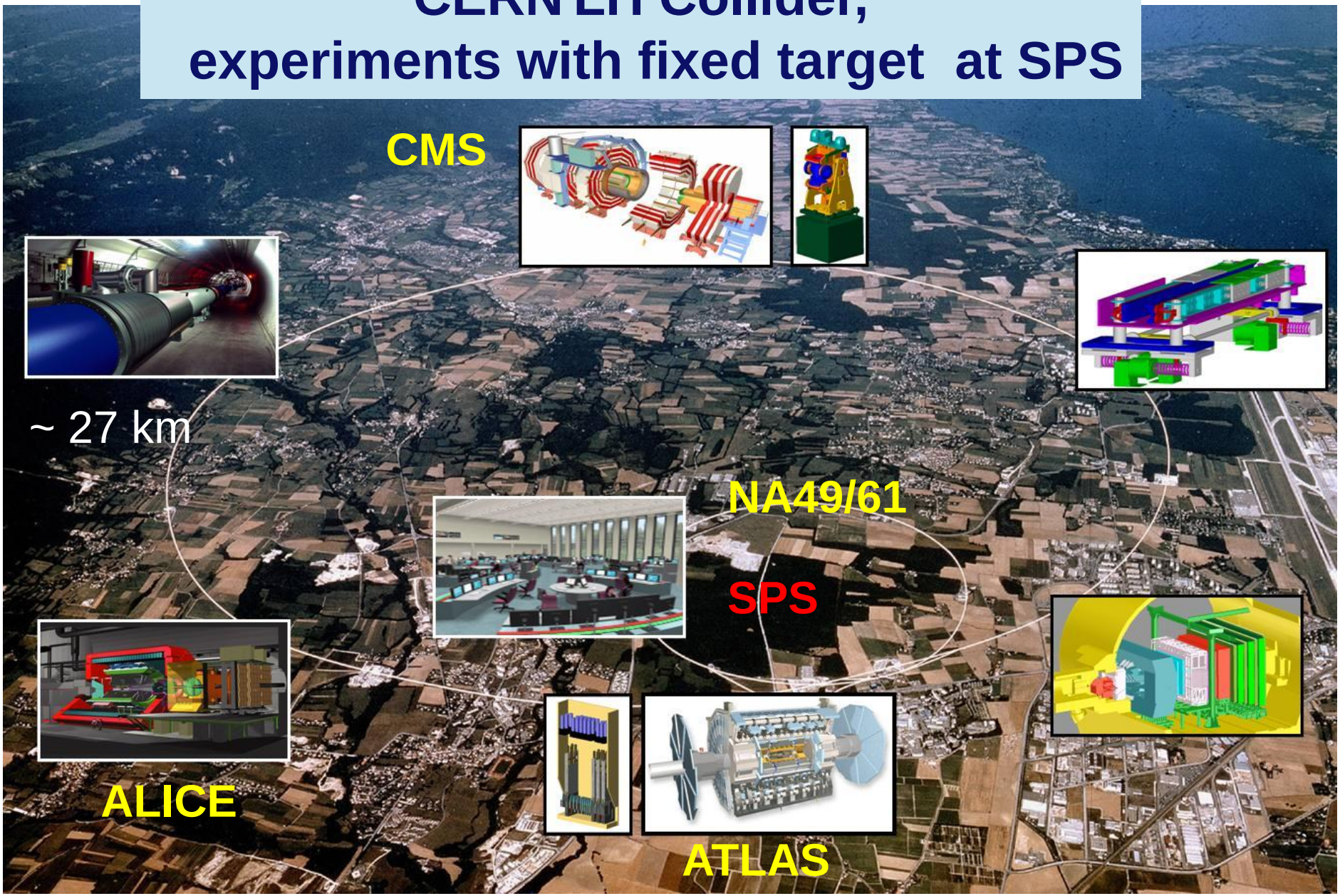
$\sqrt{S_{NN}} \approx 2p =$ **20** GeV

Advantage:
- *coverage of max. phase space*
- *minimum biased acceptance*
- *free of target parasitic effects*
- *….*

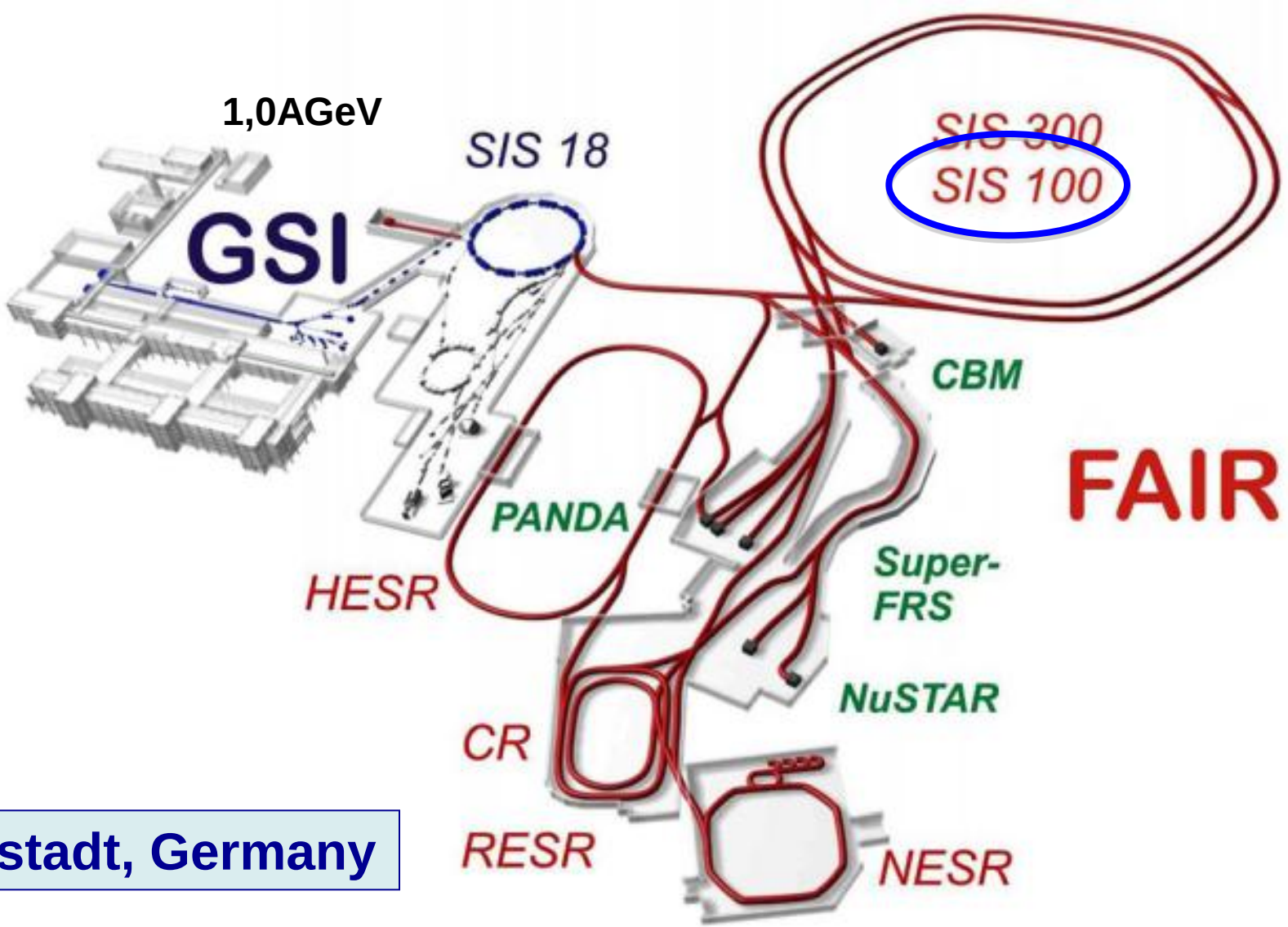
BNL: ASG, Relativistic Heavy Ion Collider



CERN LH Collider, experiments with fixed target at SPS



*Complex **FAIR:** experiments with fixed target*

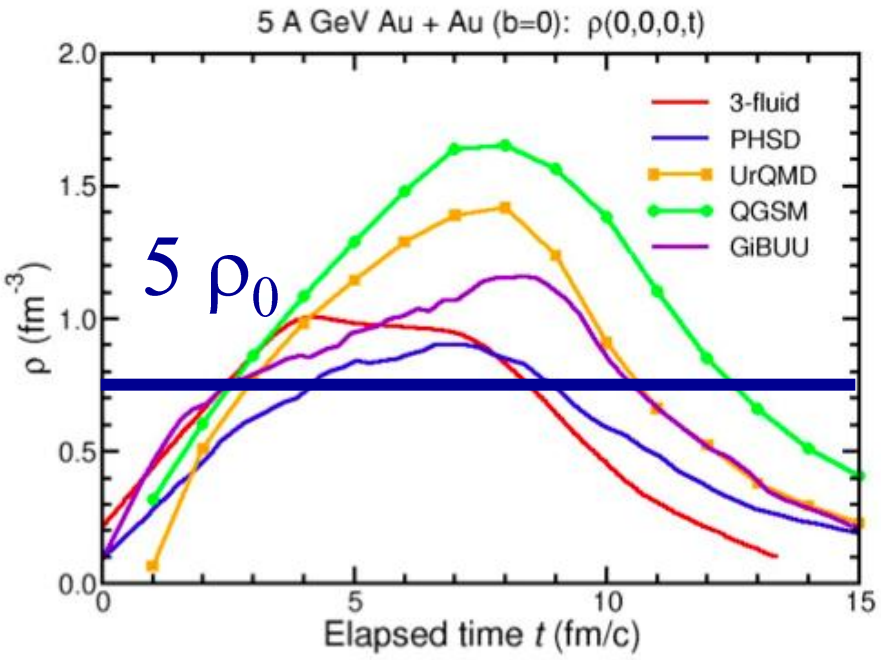


Darmstadt, Germany

Net Baryonic density to be reached in Au + Au collisions

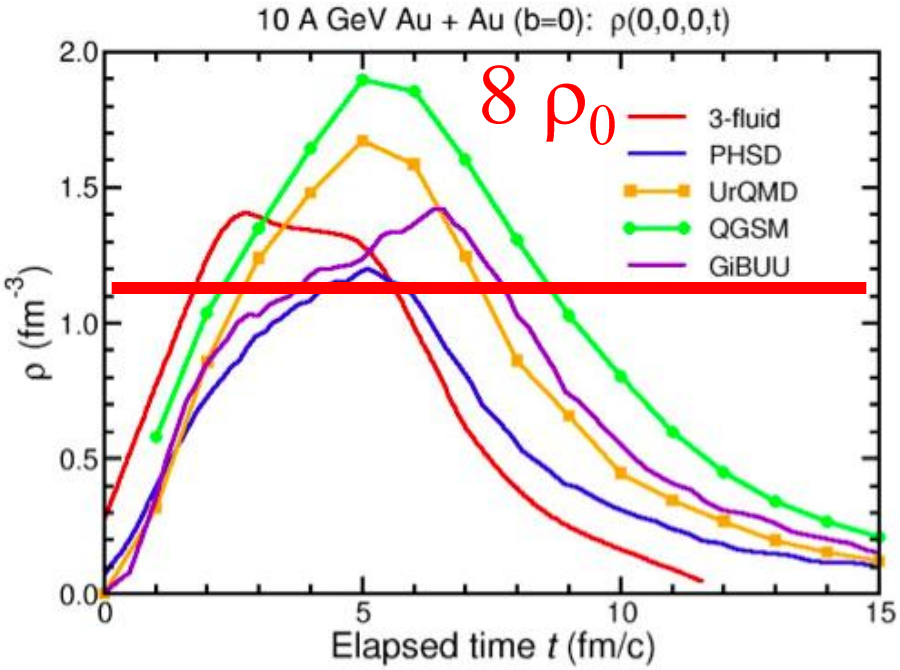
FAIR SIS-100

5 A GeV



NICA

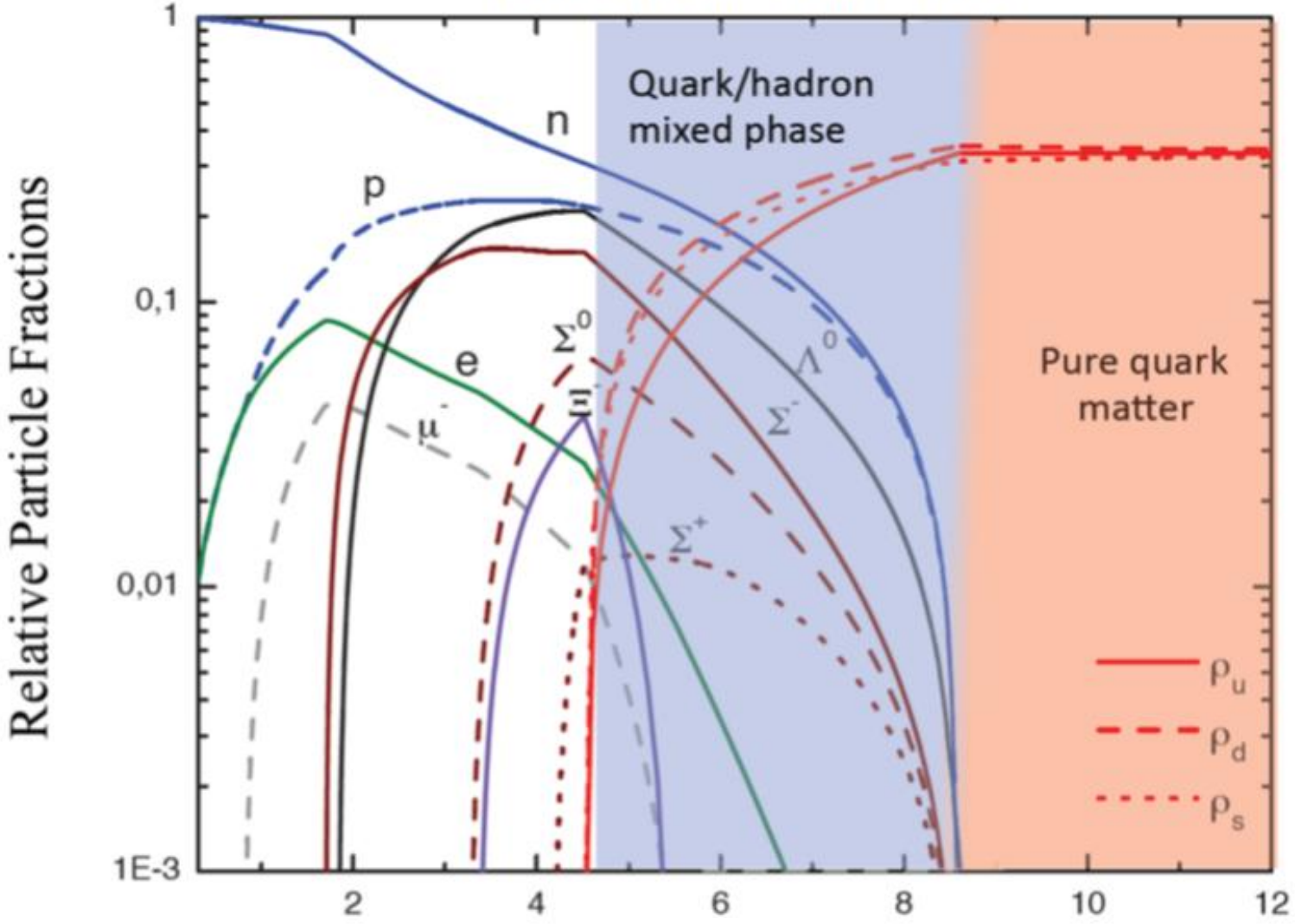
10 A GeV



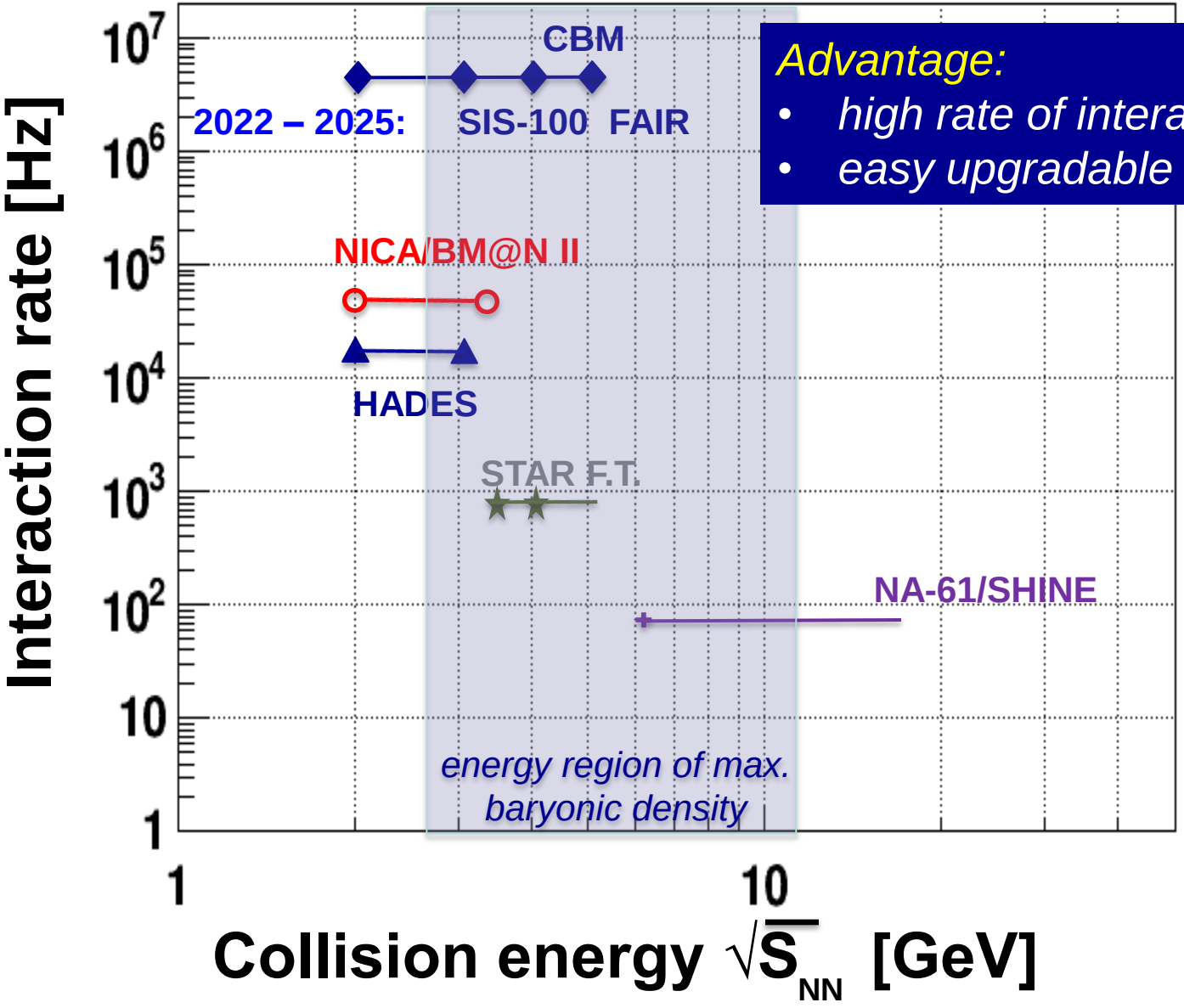
I.C. Arsene at al., Phys. Rev. C75 (2007) 24902.

Quark matter in massive neutron stars?

M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, arXiv:1308.1657
Phys. Rev. C 89, 015806, 2014



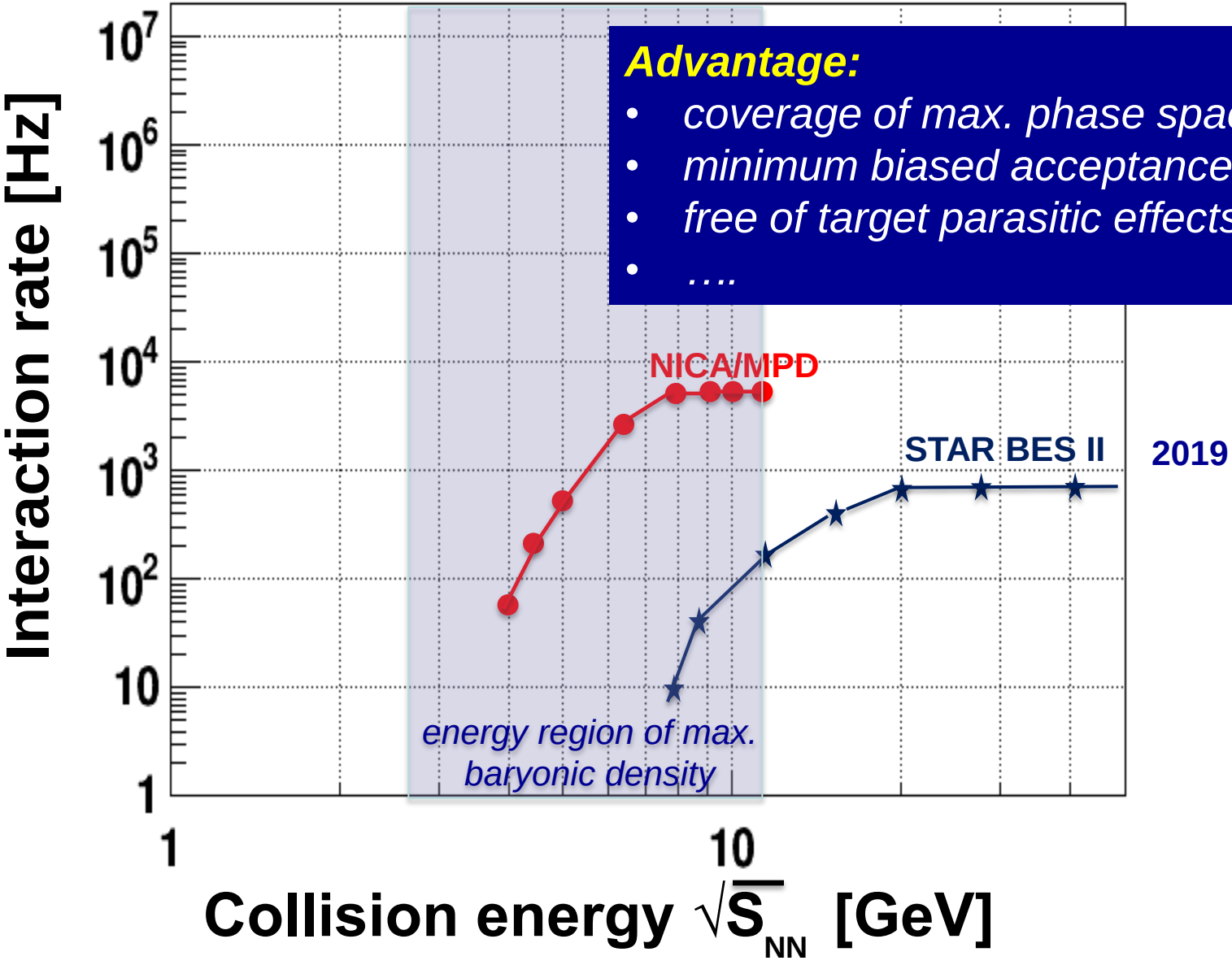
Present and future HI F.T. experiments



Advantage:

- *high rate of interactions*
- *easy upgradable*

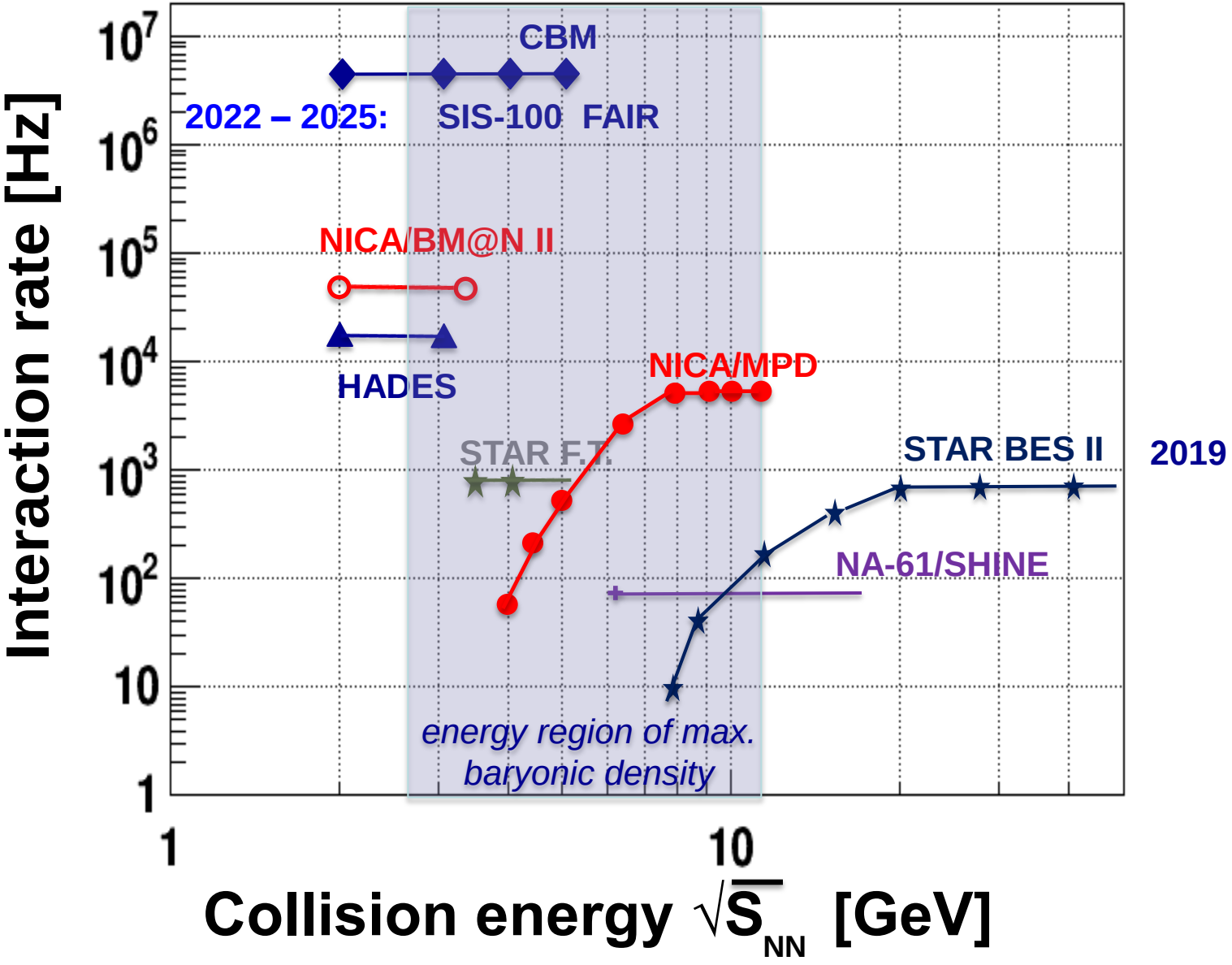
Present and future HI collider experiments



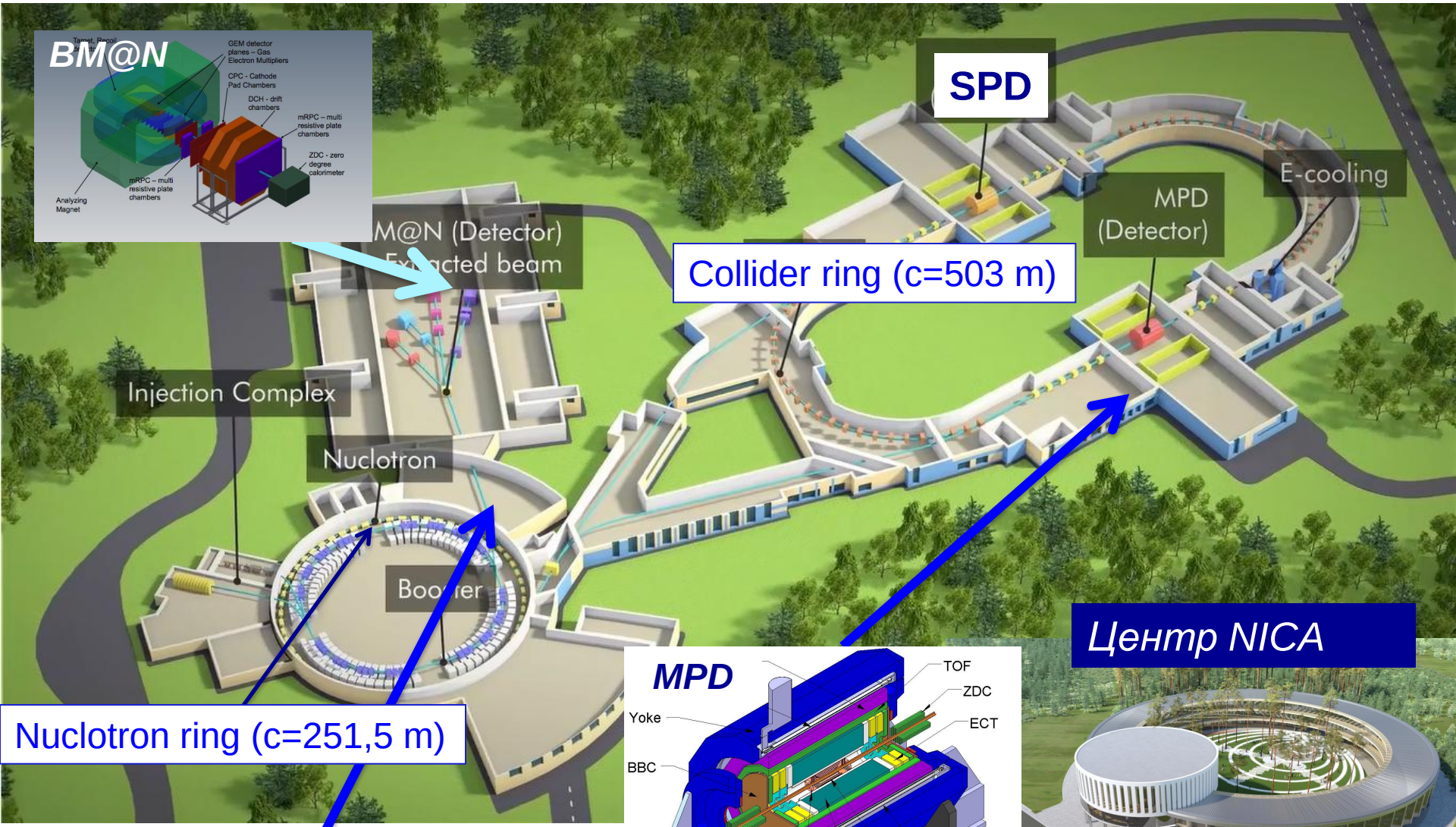
Advantage:

- *coverage of max. phase space*
- *minimum biased acceptance*
- *free of target parasitic effects*
- *….*

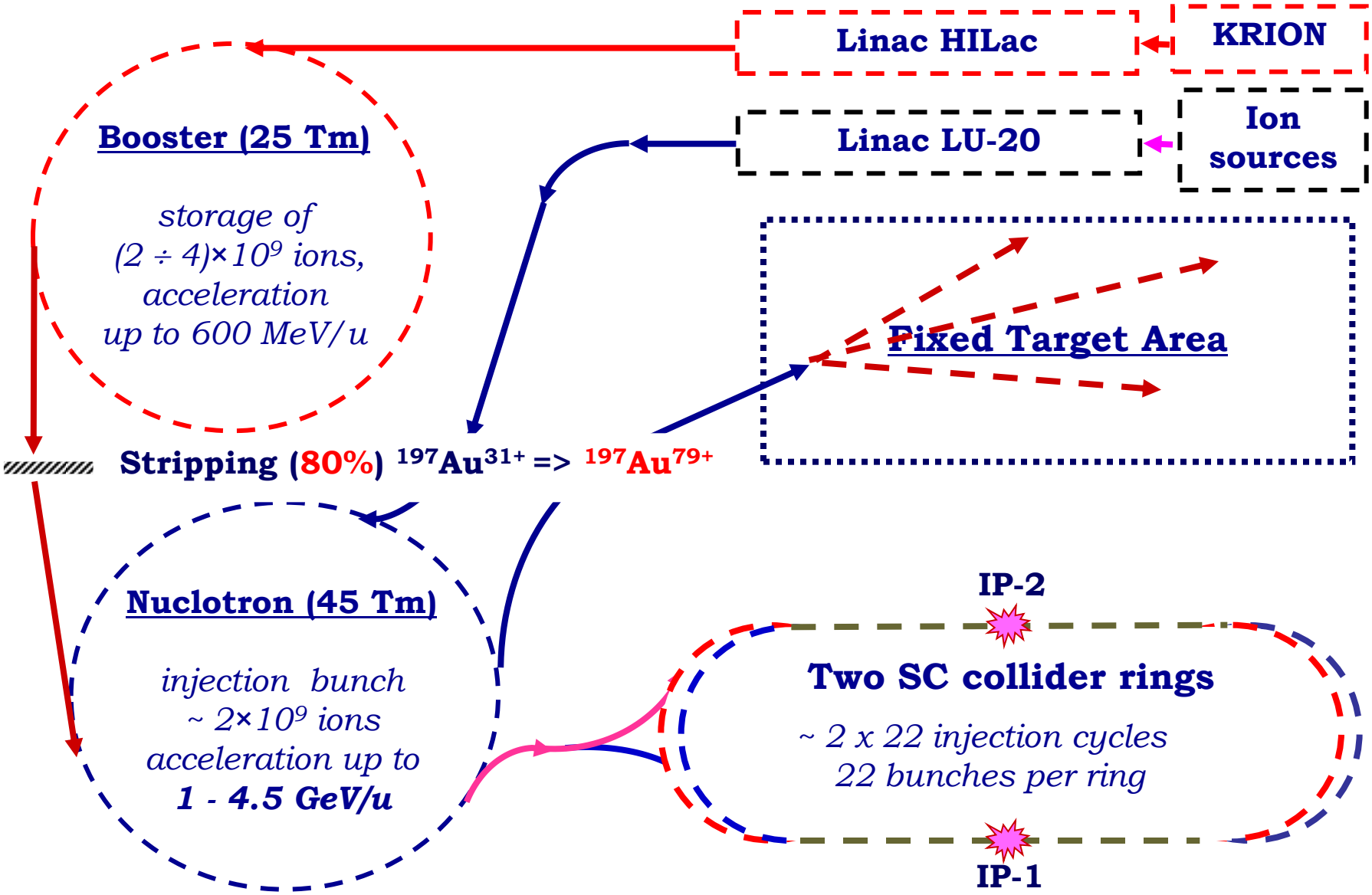
Present and future HI experiments



basic facility



Structure and Operation Regimes



Structure and Operation Regimes

Linac HILac

KRION

Ion sources

Booster (25 T

storage of
(2 ÷ 4)×10⁹ io
acceleration
up to 600 MeV

rea

Stripping (8

Nuclotron (

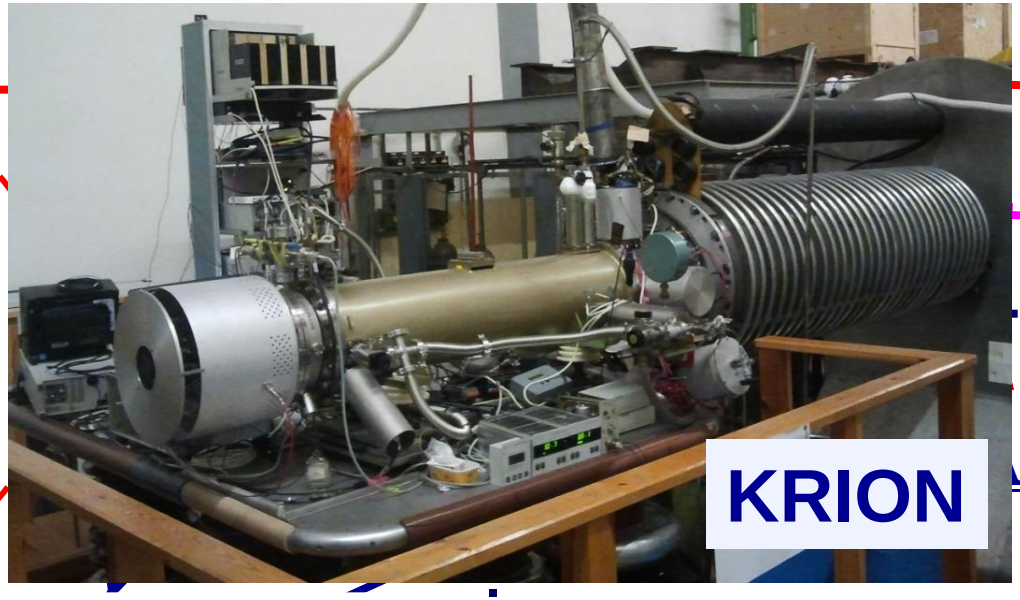
injection b
~ 2×10⁹ i
acceleration up to
1 - 4.5 GeV/u

gs

22 bunches per ring

IP-1

Structure and Operation Regimes



KRION

Ion sources

Booster (25 Tm)

storage of
$(2 \div 4)\times10^9$ 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

Structure and Operation Regimes

Structure and Operation Regimes

Li So Yon (South Korean Cosmonaut)
LHEP JINR, Dubna, 7 Sep., 2011

Booster (25 Tm)

storage of
$(2 \div 4)\times10^9$ ions,
acceleration
up to 600 MeV/u

Stripping (80%)

Nuclotron (45 T

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

Commissioning start in 2018

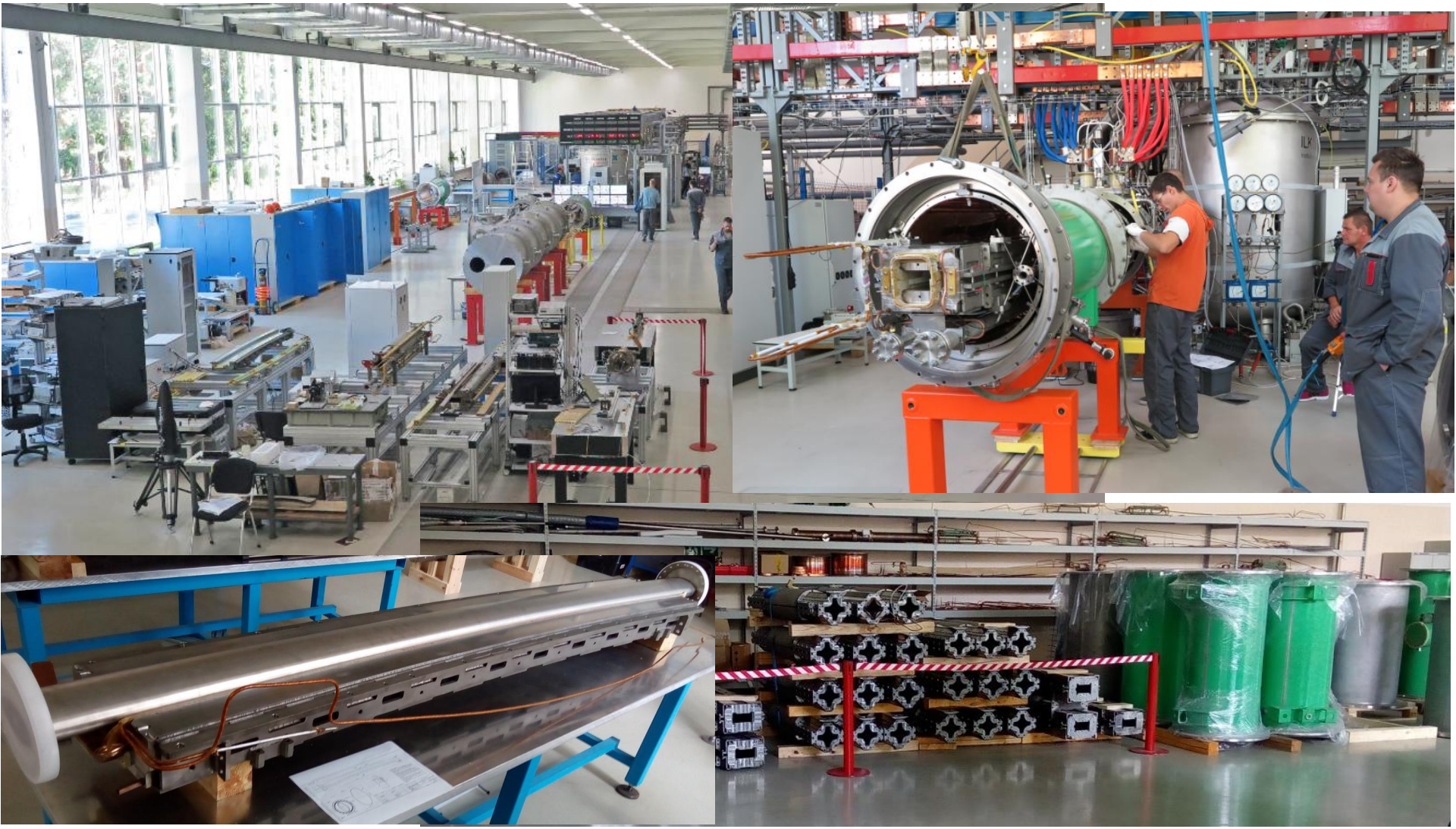
~ 2 x 22 injection cycles
22 bunches per ring

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

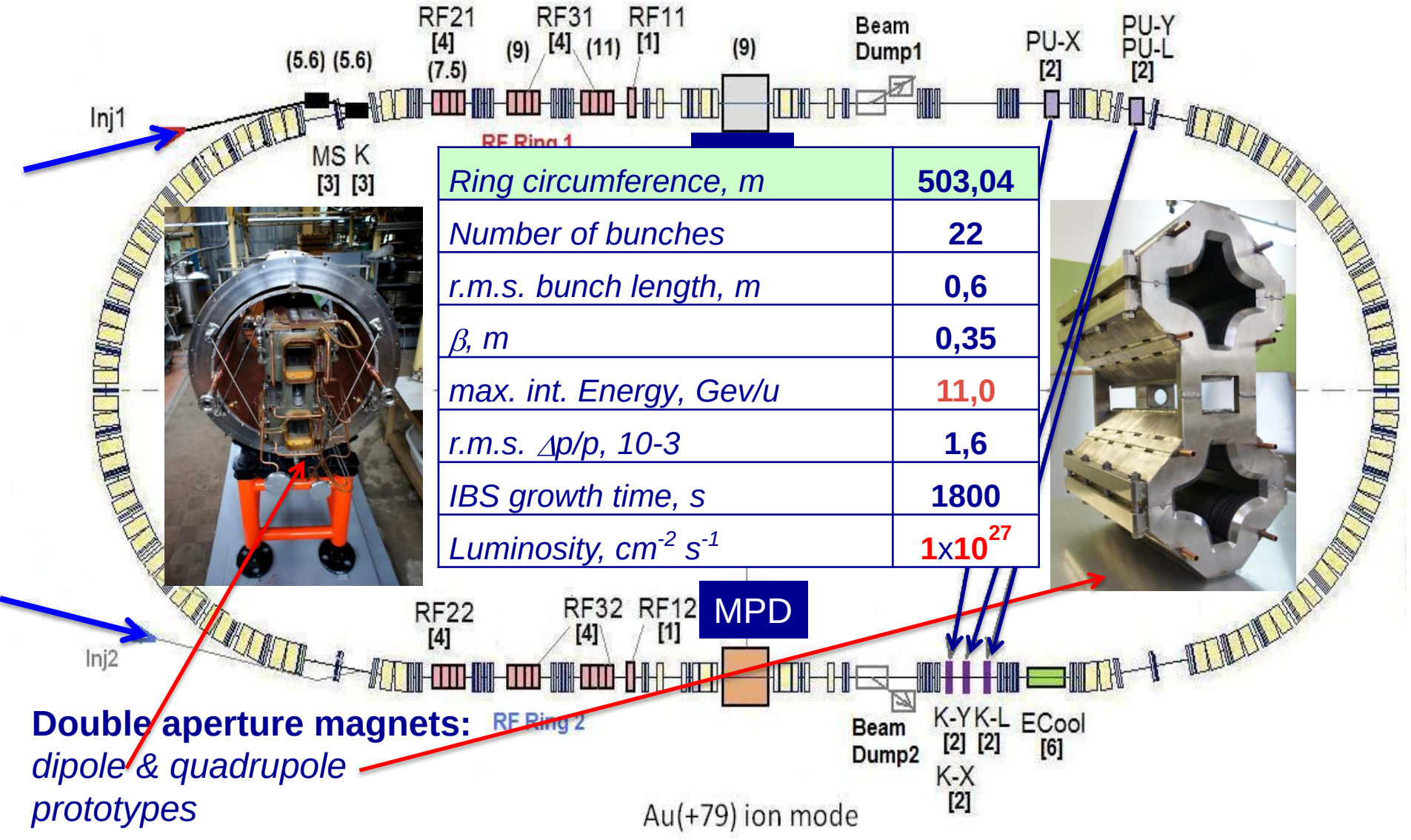
The technological line for assembly, tests and certification of SC magnets for NICA and FAIR

> 90% of the Booster magnets are produced & tested



The Collider

45 T*m, *4.5 GeV/u for* ***Au^{79+}***



Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. $\Delta p/p$, 10-3	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**1×10^{27}**

Double aperture magnets: *dipole & quadrupole prototypes*

Infrastructure

Cryogenics at NICA

completion in 2017

500 kg/h nitrogen re-condenser RA-0.5

recondenser RA-05
- *designed*

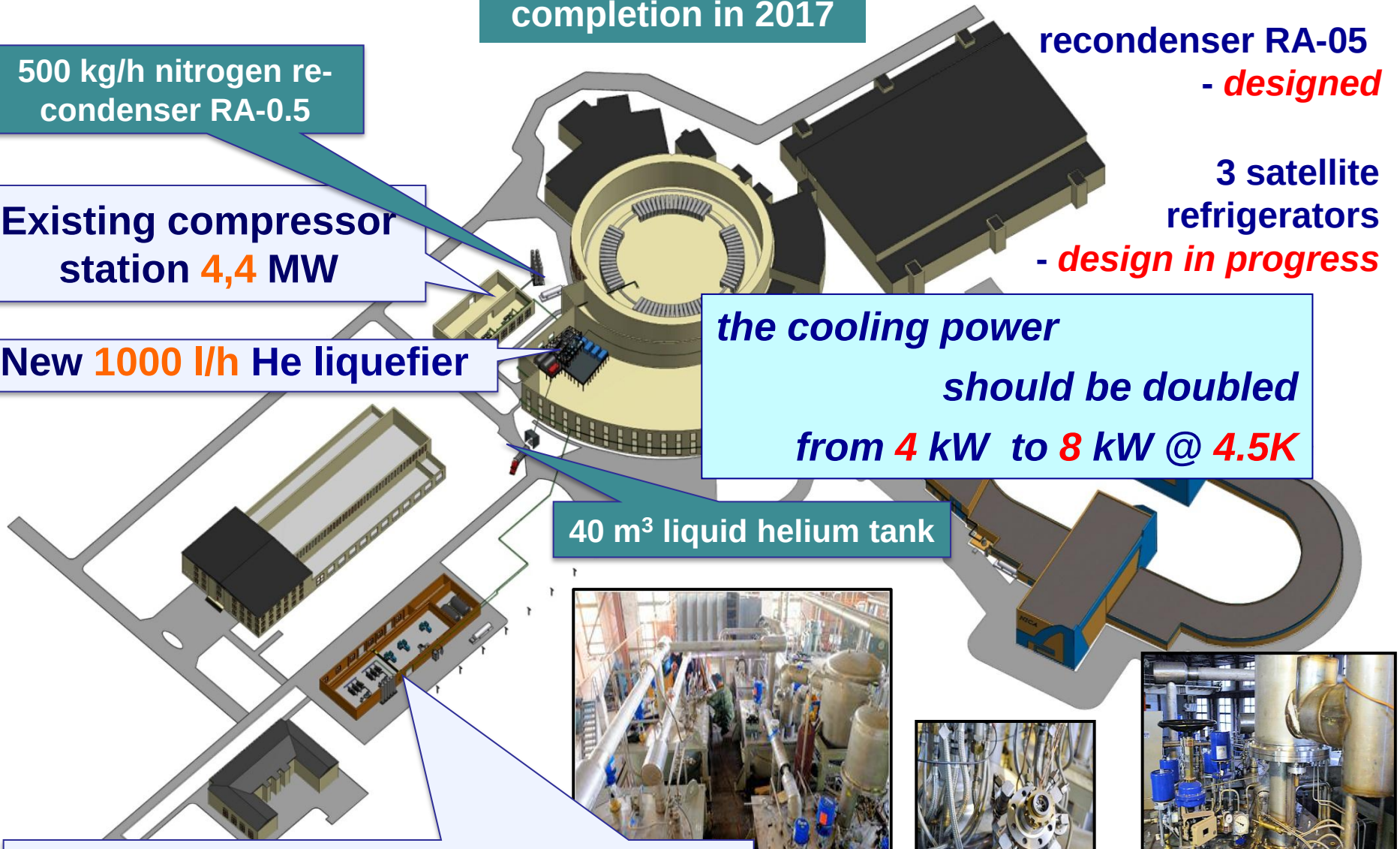
Existing compressor station 4,4 MW

3 satellite refrigerators
- *design in progress*

New 1000 l/h He liquefier

the cooling power should be doubled from 4 kW to 8 kW @ 4.5K

40 m^3 liquid helium tank



New compressor station 9,6 MW

procedure for laying the first stone in the construction of the complex

Civil Construction, bld.17

June 2018

readiness for equipment installation in the MPD Hall - 2019

Civil Construction, bld.17

June 2018

readiness for equipment installation in the MPD Hall - 2019

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

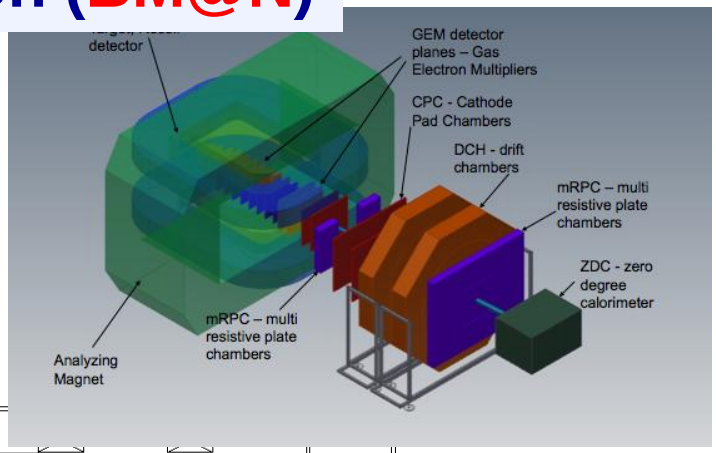
Experiment
Baryonic Matter at Nuclotron
(BM@N)

Baryonic Matter at Nuclotron (BM@N)

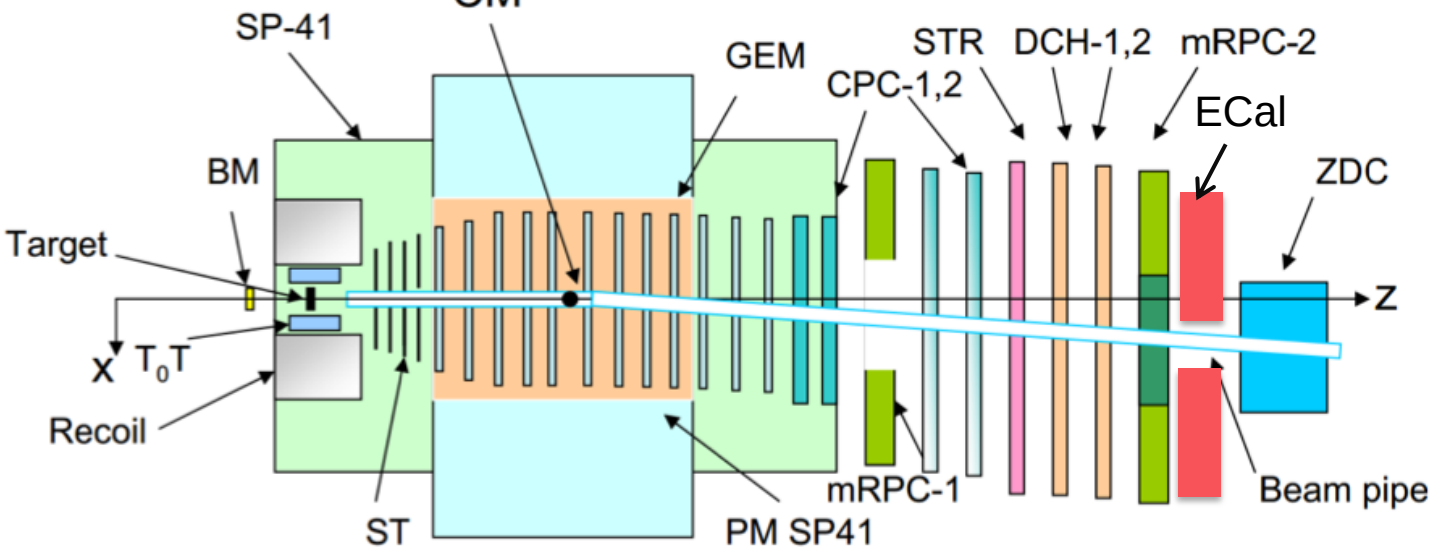
The first run: ***March 22 – April 3, 2018*:**

- *targets:* ***C, Al, Cu, Sn, Pb;***

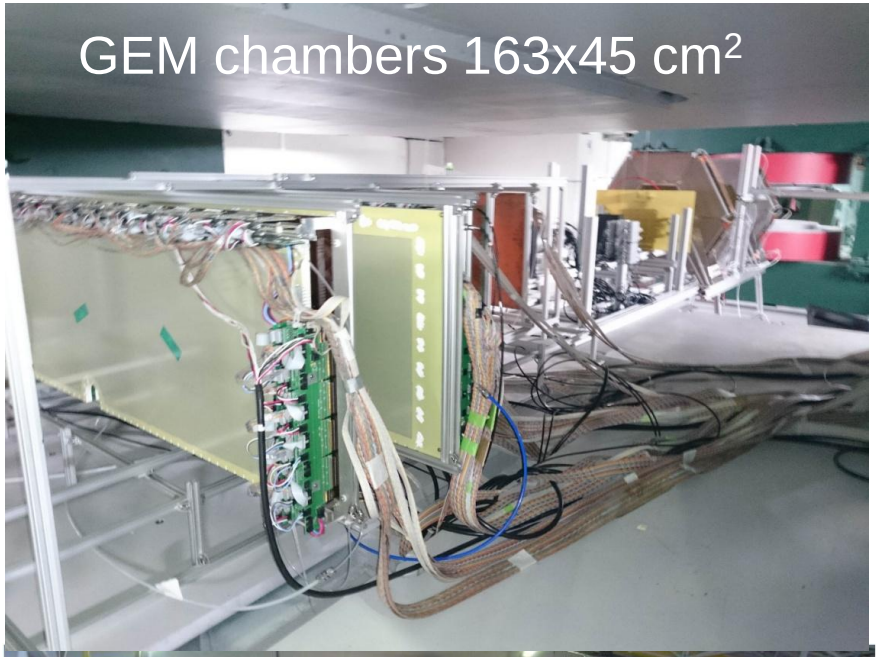
- *beams:* $^{12}C^{6+}$ ***4,0 AGeV***
  $^{40}Ar^{16+}$ ***3,2 AGeV***
  $^{84}Kr^{26+}$ ***2,3 AGeV***



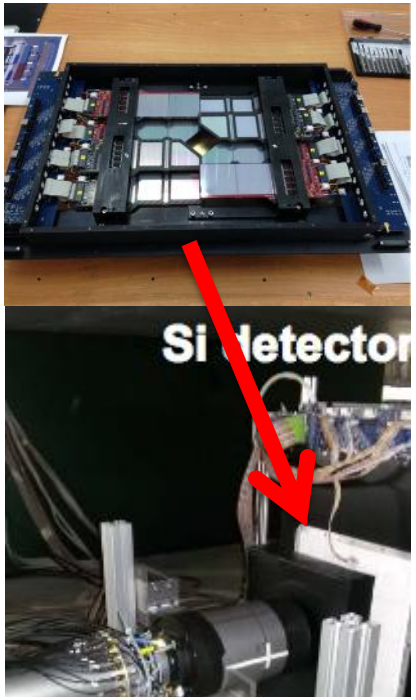
BM@N *schematic view*



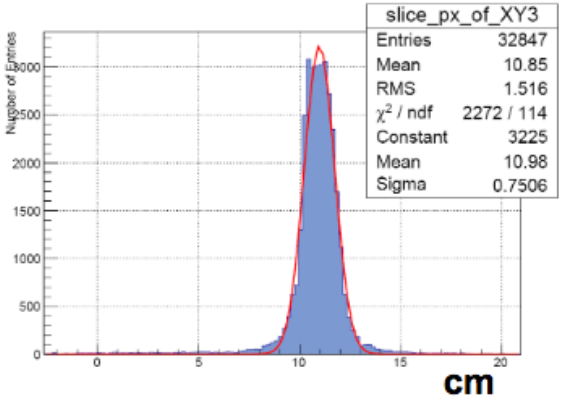
Deuteron / Carbon beam at BM@N

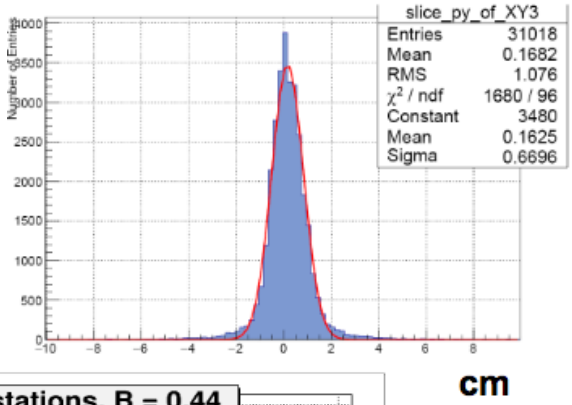


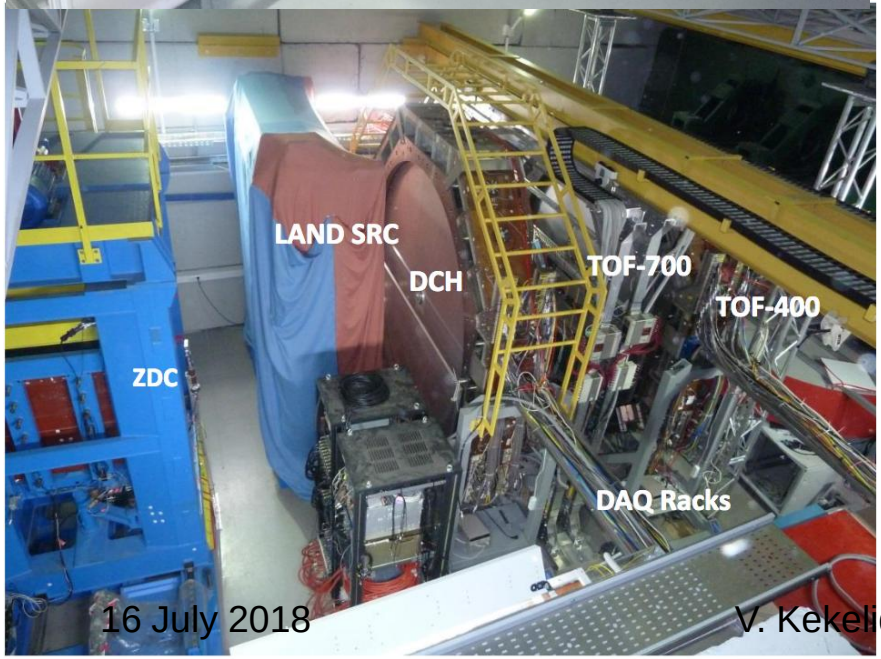
Si detector

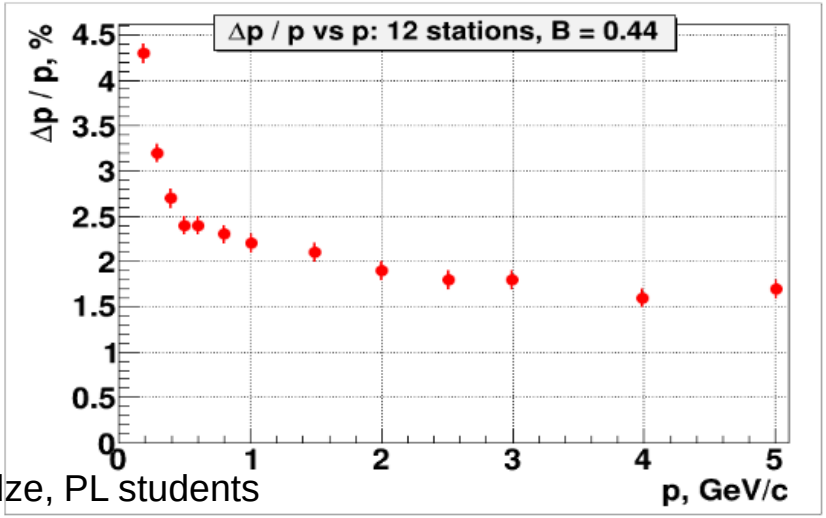


X, Y profiles of deuteron beam in 1st GEM

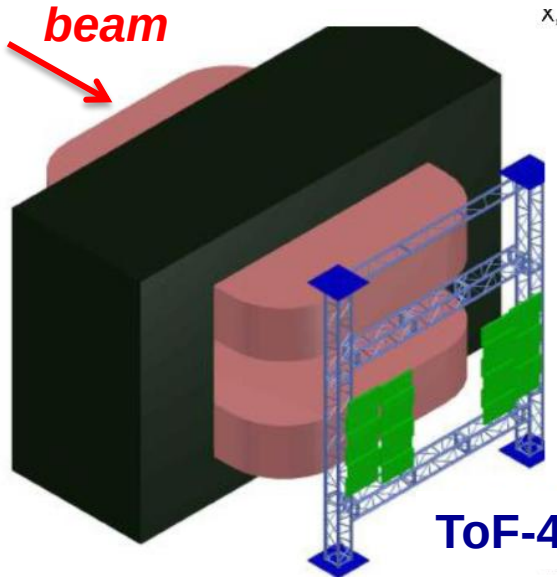


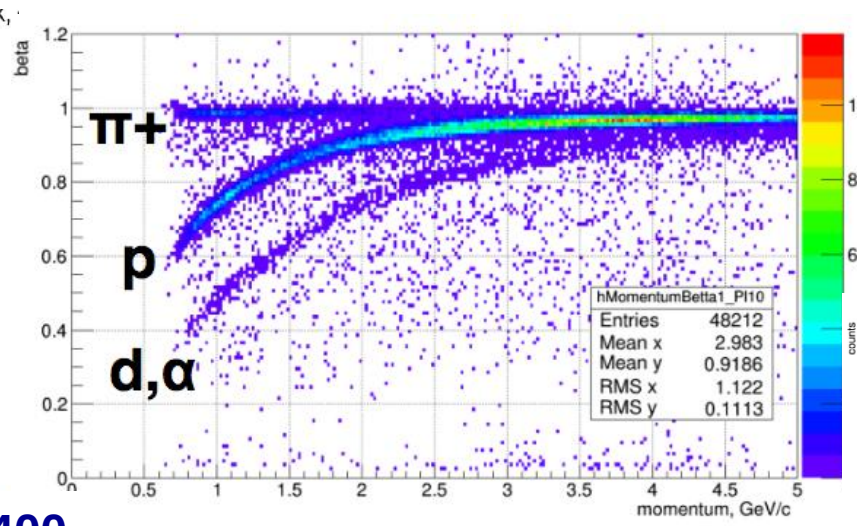




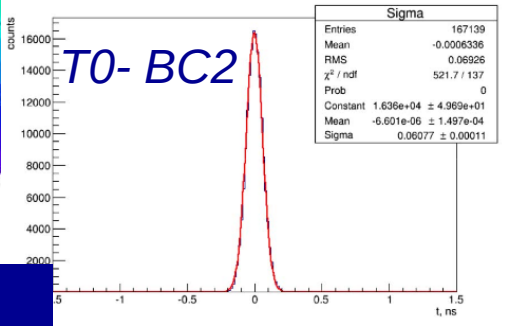


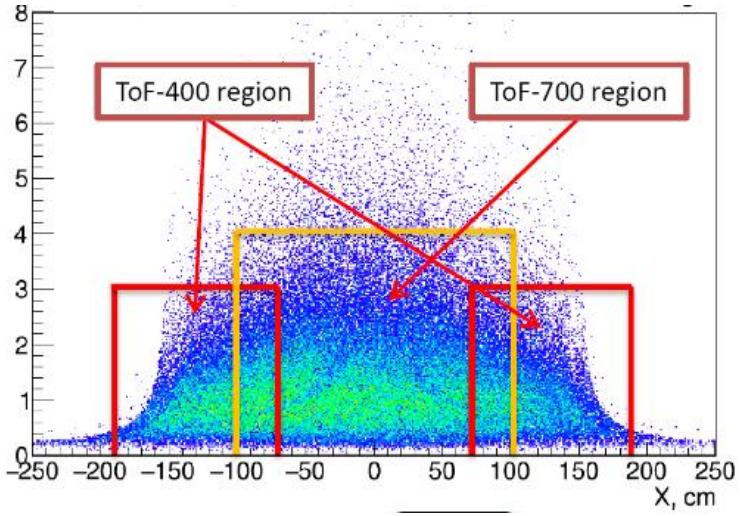
Deuteron / Carbon beam at BM@N





time resolution:
- *T0 ~43 ps*
- *ToF-700 ~65 ps*
- *ToF-400 ~53 ps*





beam: **E_{kin}= 3.5, 4.0, 4.5 AGeV**

BM@N plans

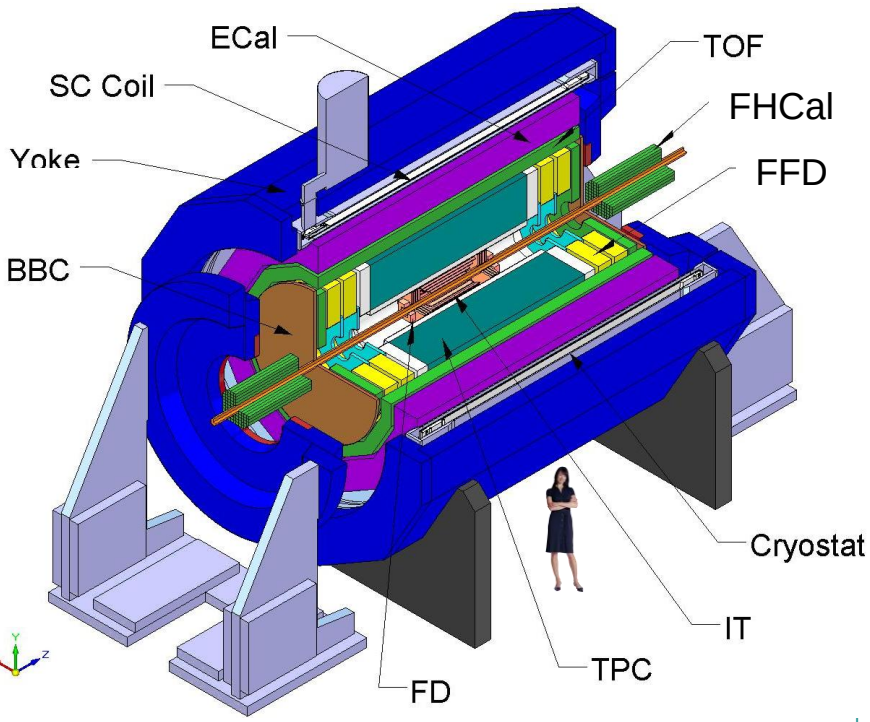
year	2018	2019	2020 +
beam	**C, Ar/Kr**	**Au**	**Au, p**
intensity, Hz	**0,5M**	**1M**	**10M**
trig. rate, Hz	**10k**	**20k**	**50k**
central tracker	**10 GEM half pl.**	**8 GEM full pl.**	**12 GEM or 8+2Si**
status	**stage 0**	**stage 1**	**stage 2**

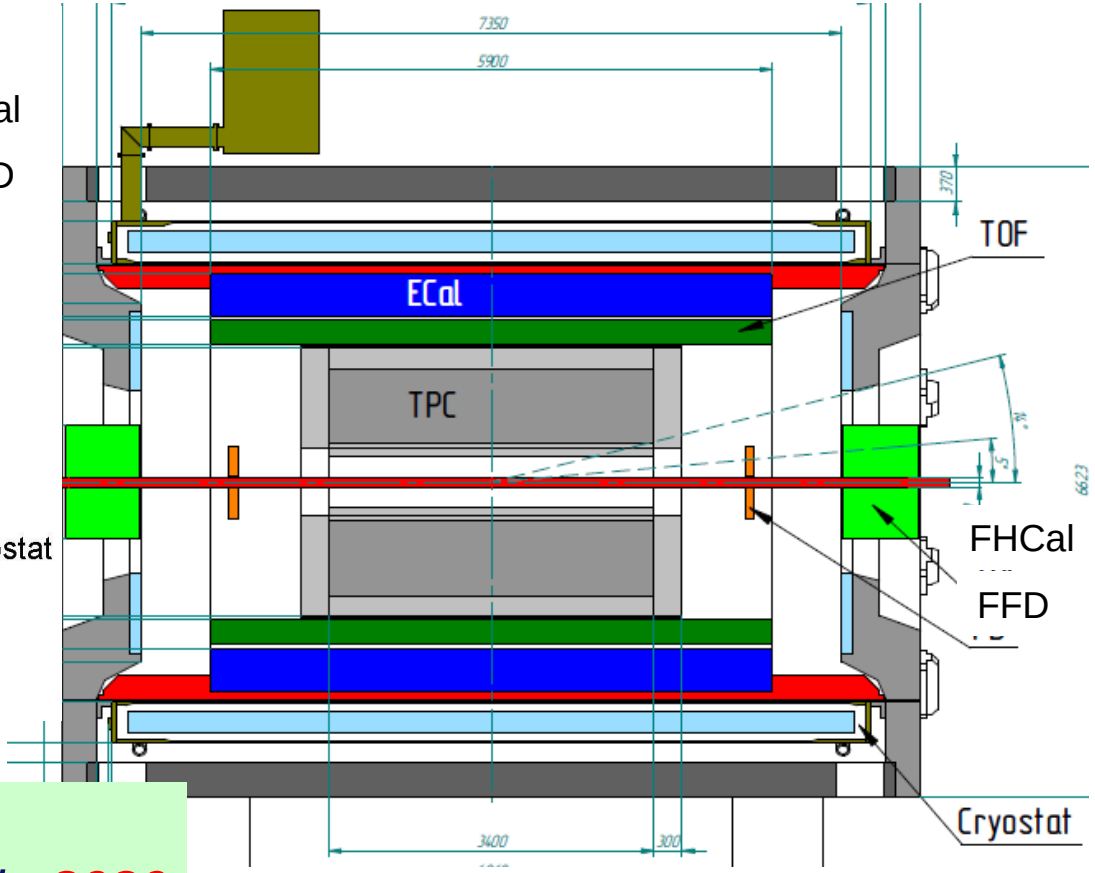
Experiment
Multi Purpose Detector
(MPD)

Multi-Purpose Detector (MPD)

tracking: *up to |h|<1.8* (**TPC**)
PID: *had., e, γ* (**TOF**, **TPC**, **ECAL**)
Reaction: *centrality & plane determination* (**FHCal**)

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





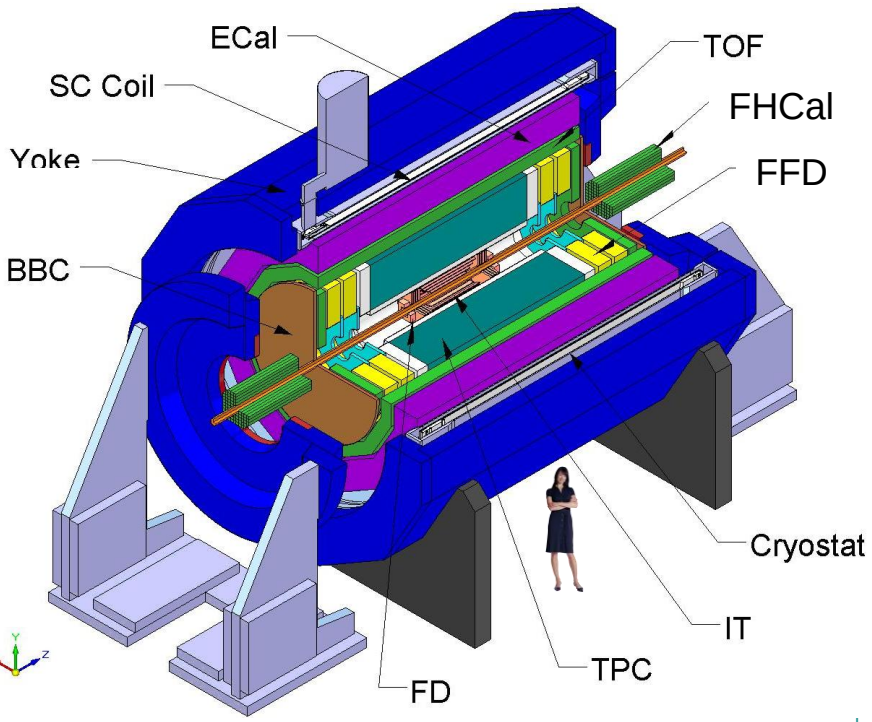
Plan: *overall commissioning starts in* ***2020***

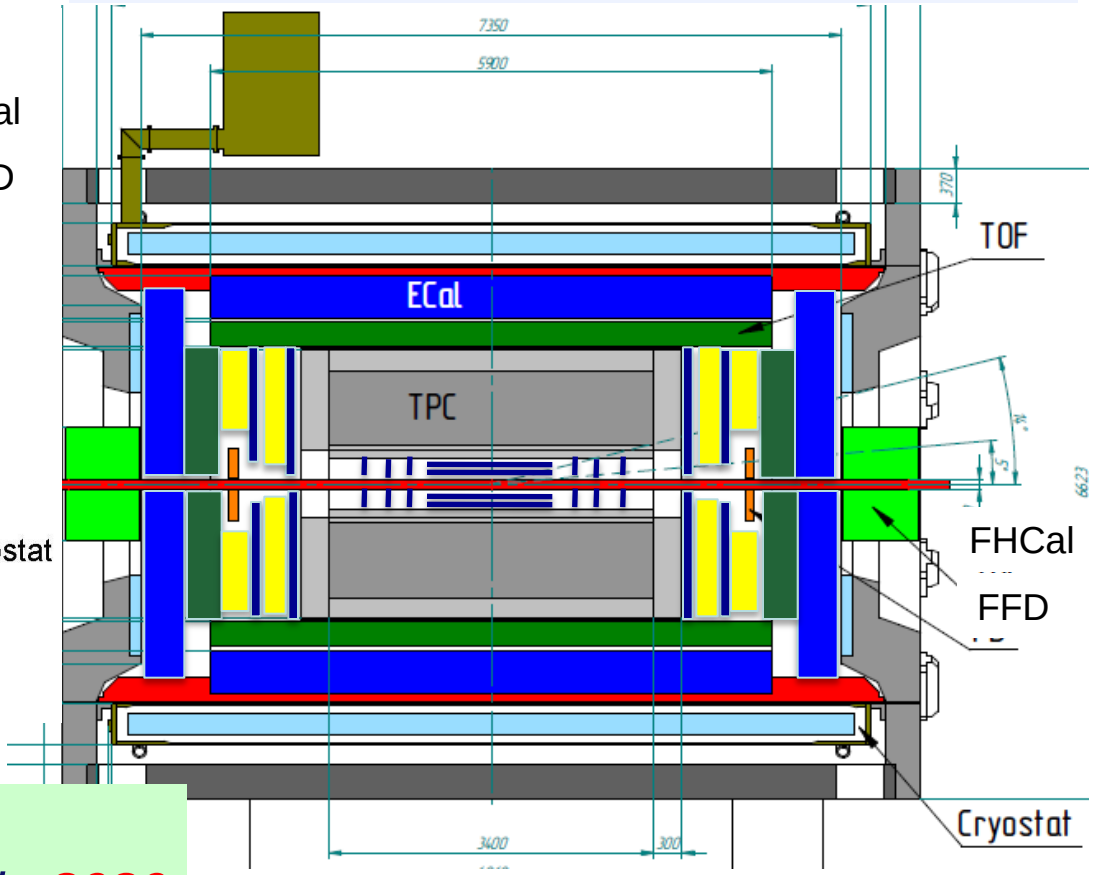
Multi-Purpose Detector (MPD)

tracking: *up to |h|<1.8* (**TPC**)
PID: *had., e, γ* (**TOF**, **TPC**, **ECAL**)
Reaction: *centrality & plane determination* (**FHCal**)

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

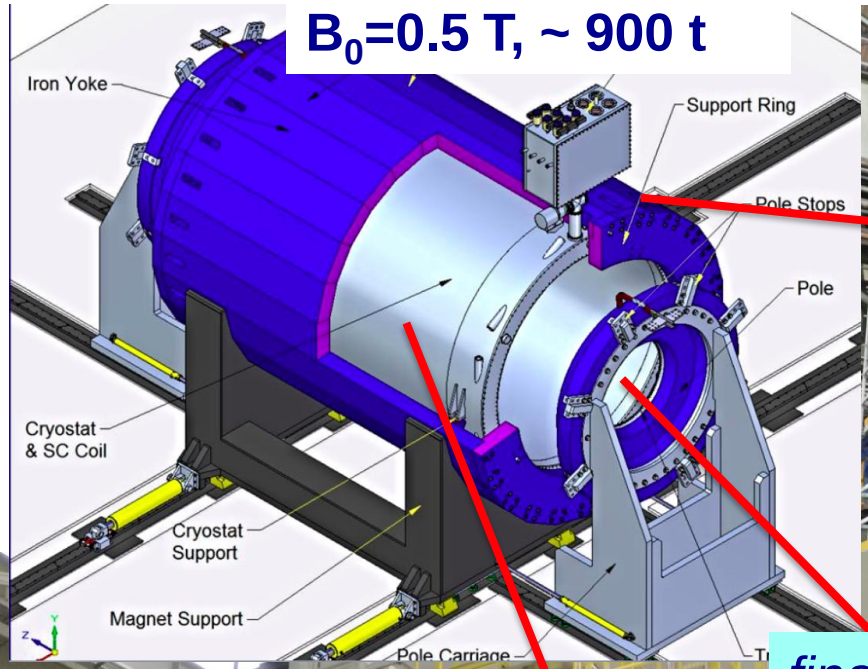
Stage 2 (2023):
ITS + EndCap (tracker, TOF, ECAL)





Plan: *overall commissioning starts in* ***2020***

Magnet production: *ASG (Genova) & Vitkovice HM*

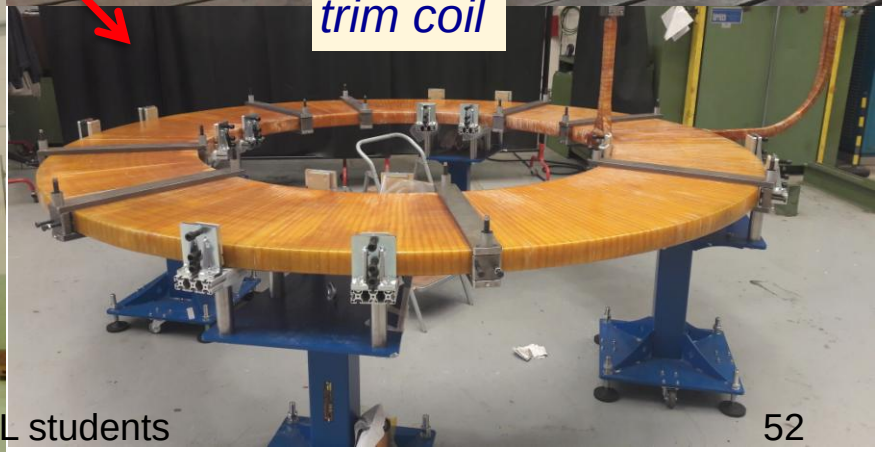


yoke control assembly at HM Vitkovice

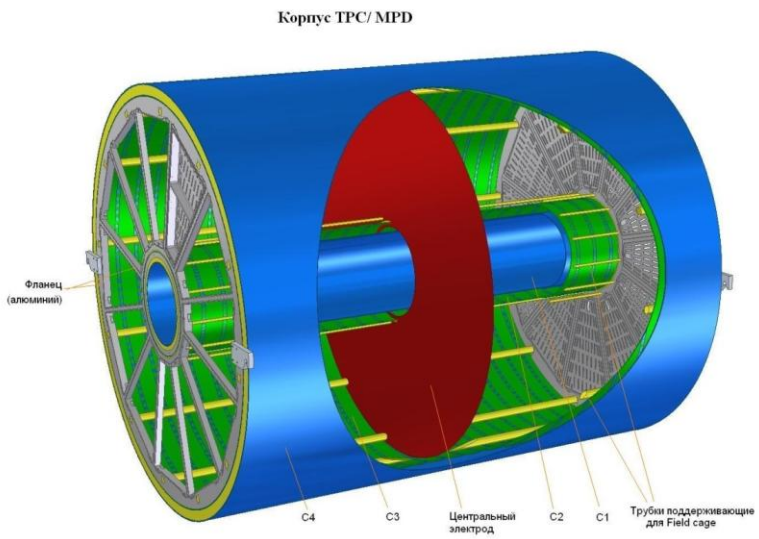
*final assembly in the MPD hall - **June 2019***

machine is winding a SC solenoid

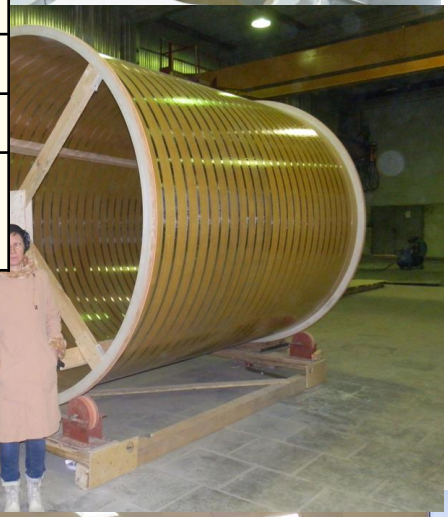
trim coil

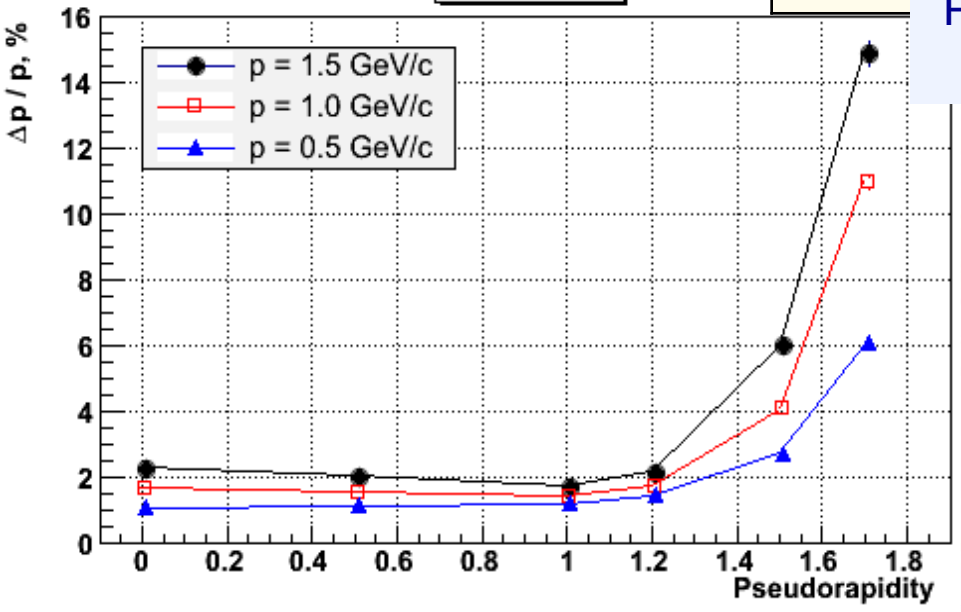


Time Projection Chamber (TPC) – basic tracker



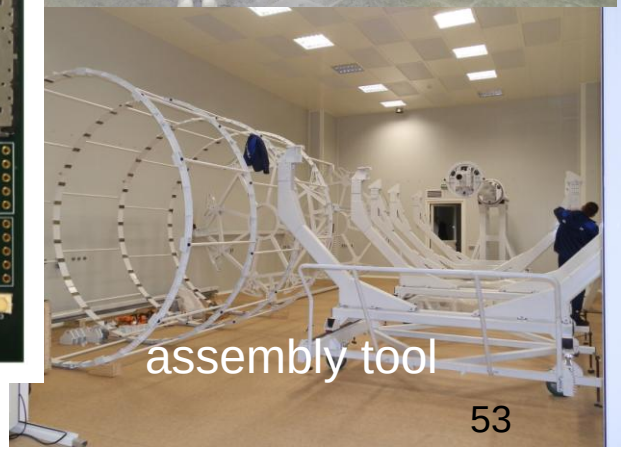
length	*340 см*
out Radii	*140 см*
in Radii	*27 см*
gas	*90% Ar+10% CH_4*
drift velocity	*5.45 см / mcs;*
velocity time	*< 30 mcs;*
N R-O Chamb.	*12 + 12*
N pads / chan.	*95232*
max event rate	*< 7 kGz (L= 10^{27}*



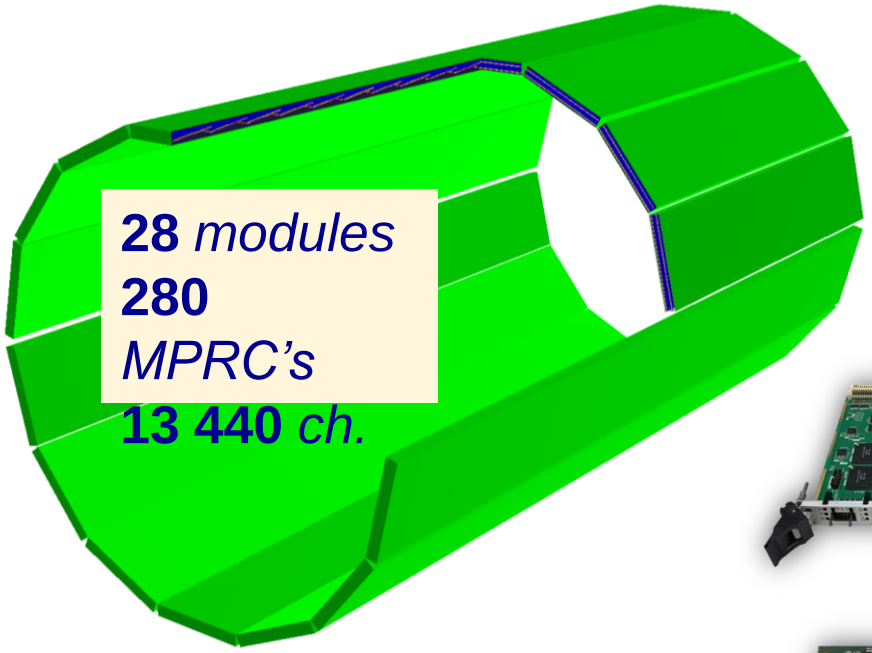


FEC64SAM - d*ual SAMPA card*

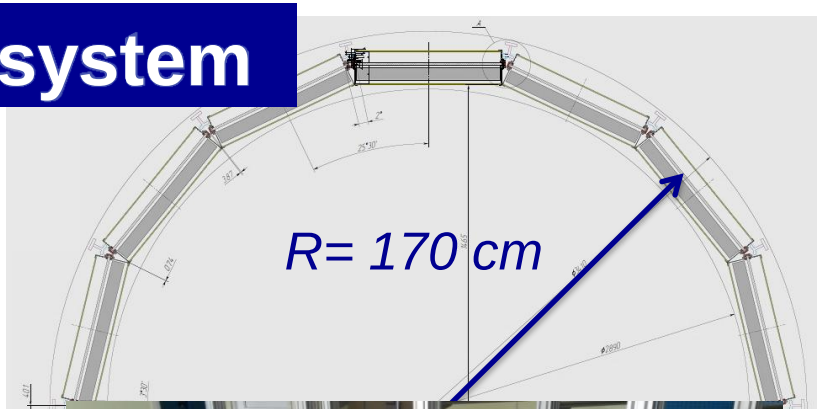
TPC/MPD Front-end card

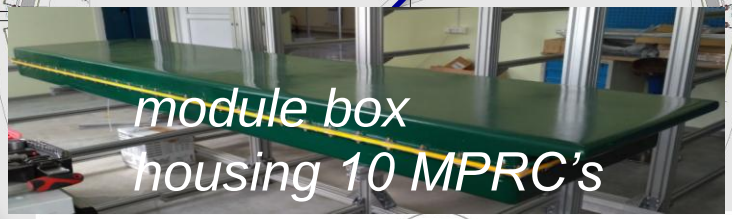


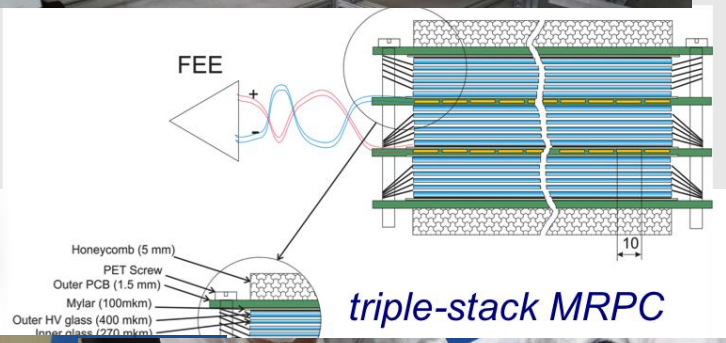
Time of Flight (TOF) system



28 *modules*
280
MPRC's
13 440 *ch.*

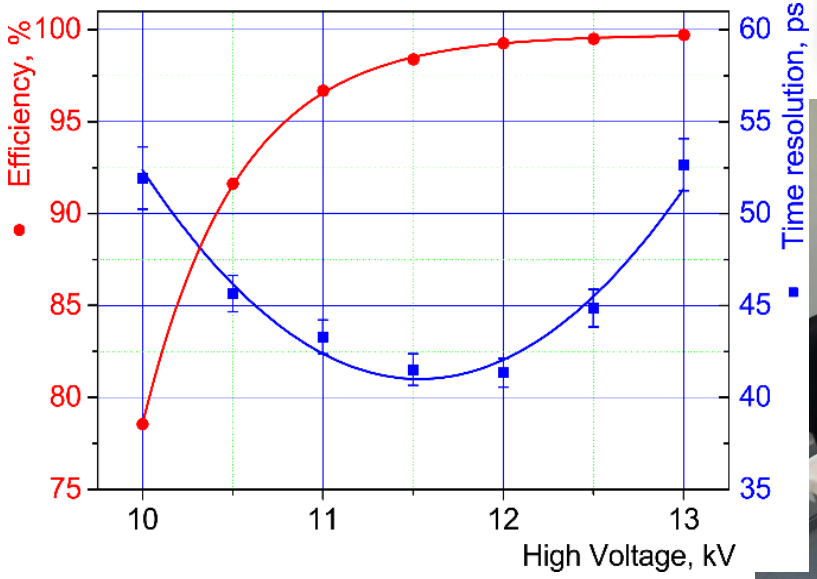


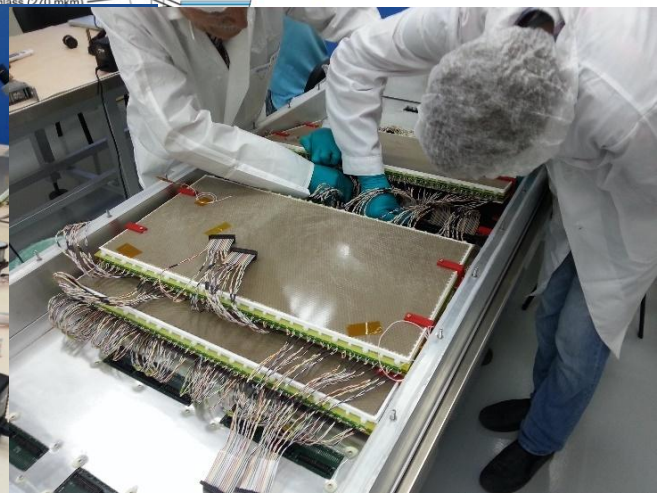




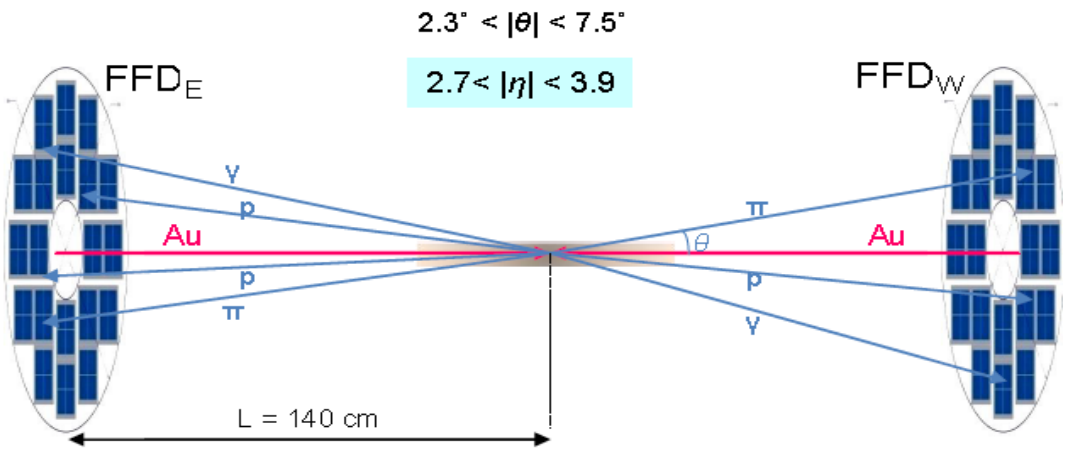
triple-stack MRPC

efficiency and time resolution

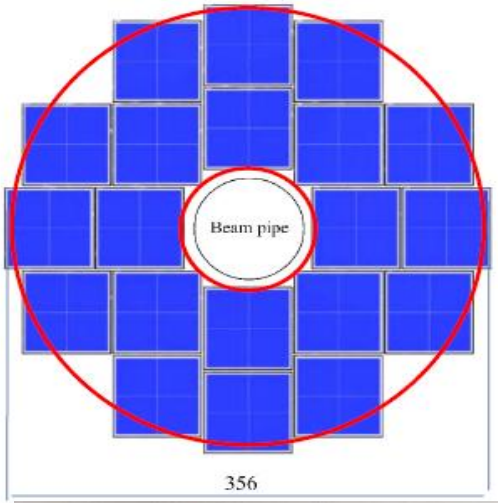




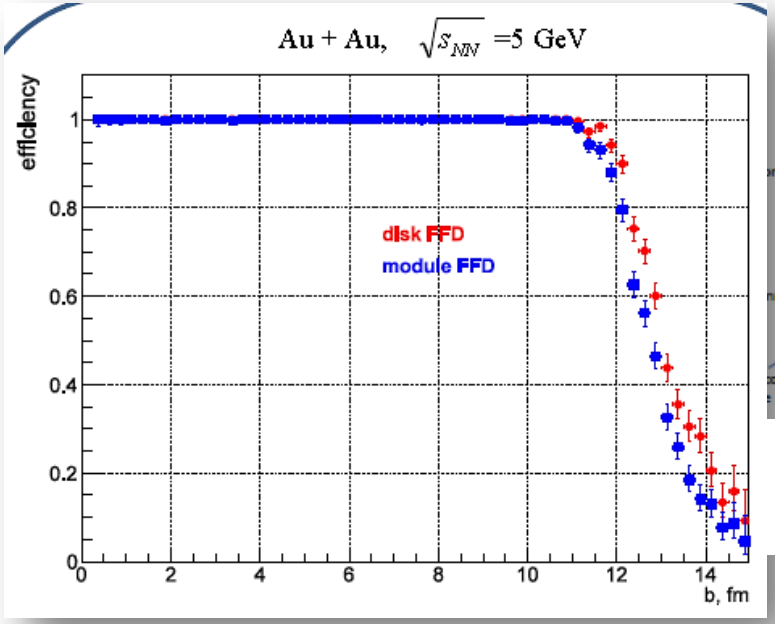
Fast Forward Detector – (FFD)

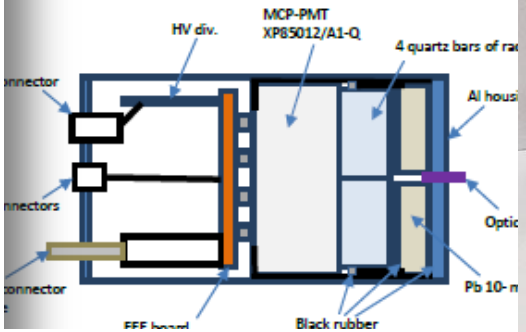


array of 20 modules
Planacon MCP-PMTs
80 +20 channels

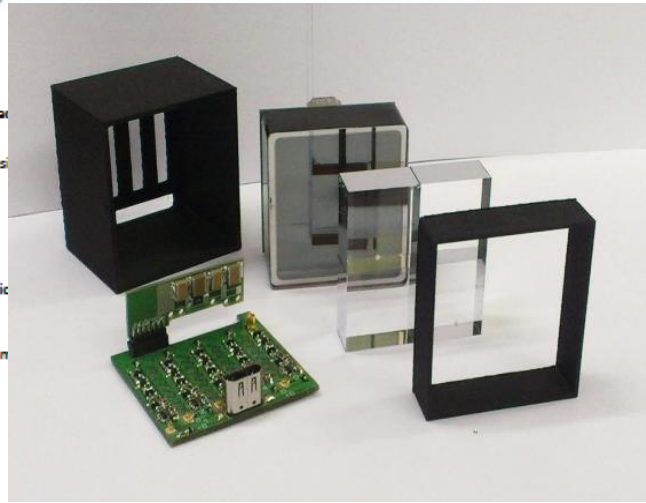


time resolution < 50 ps

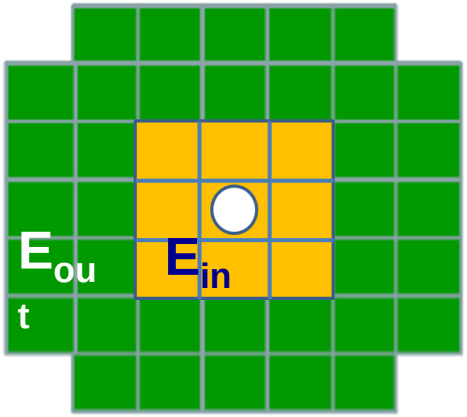


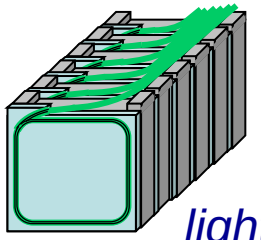


15 mm quartz radiator
10 mm lead converter



FHCAL: determination of reaction plane and centrality





light collection
WLS-fibers & SiPM

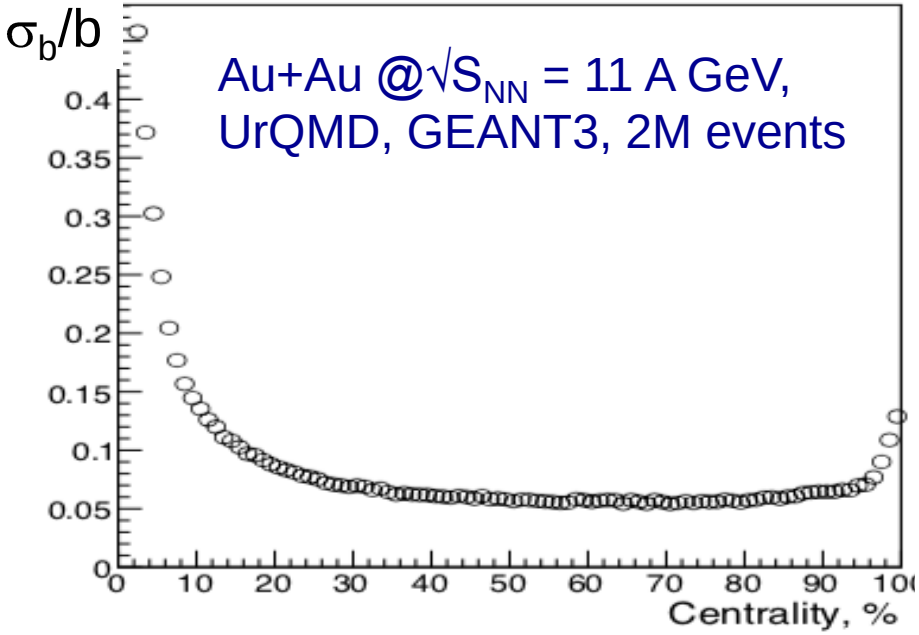
2 x **45** modules (15 x 15 cm^2 each)
located left and right at ~3.2 m from the **IP**)

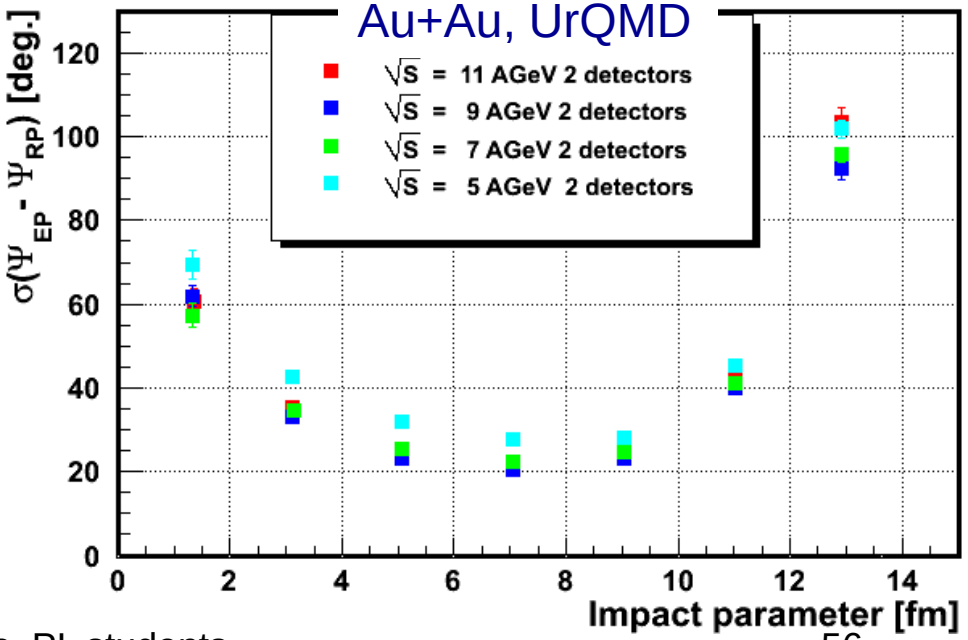
acceptance: $2.2<|\eta|<4.8$

$\sigma(E)/(E) = 53\%/\sqrt{E(GeV)} + 10\%$

transverse granularity allows to measure:

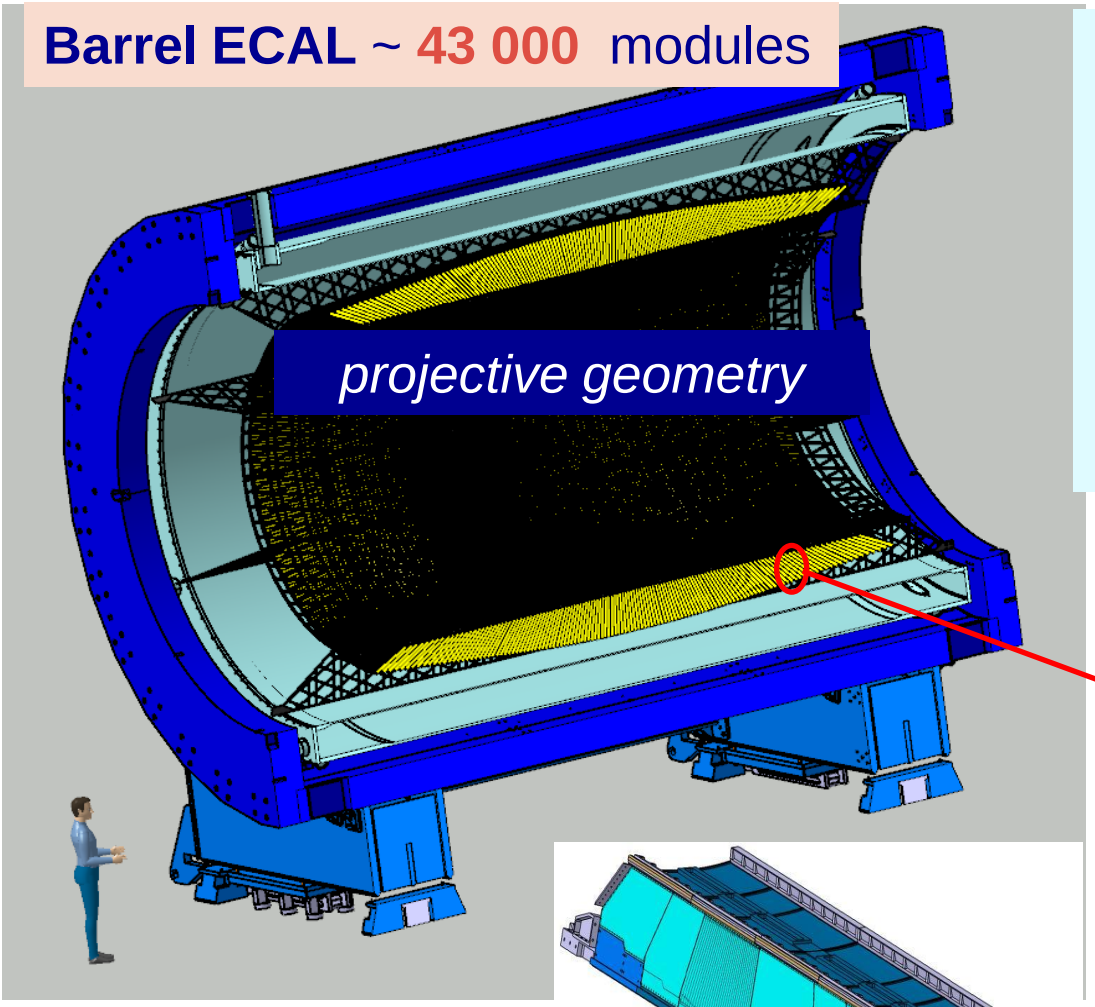
- *the reaction plane with accuracy* **~ 20^0-30^0**
- *the centrality with accuracy below* **10%.**



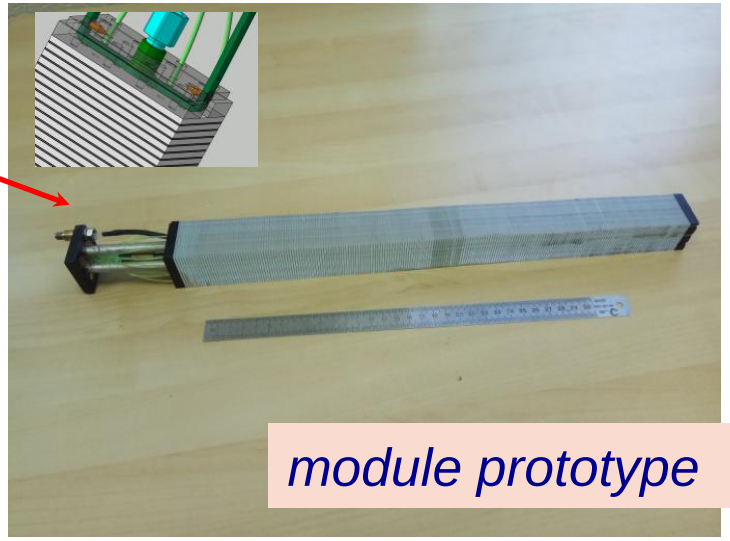


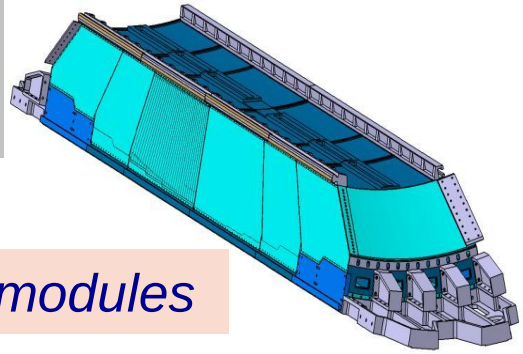
Electromagnetic calorimeter: ECAL

Barrel ECAL ~ **43 000** modules



- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2),*
- *σ(E) better than 5% @ 1 GeV;*
- *time resolution ~500 ps*





block of modules

Inner Tracking System

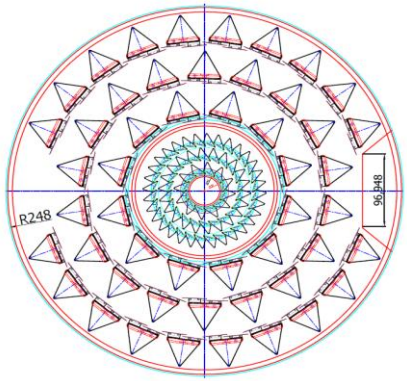
*cooperation with **CBM/FAIR**, **ALICE/CERN**:*

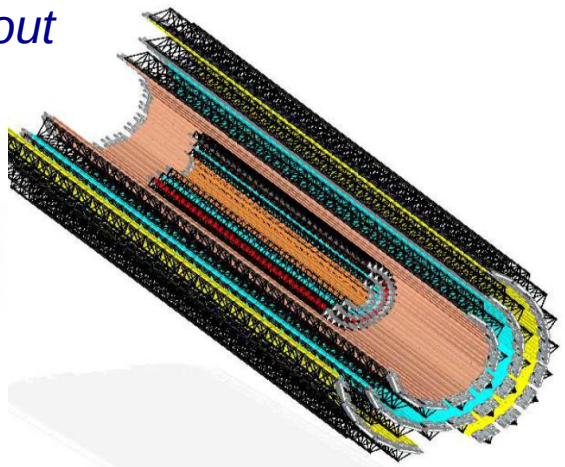
- *manufacturing the **ITS** carbon fiber space frames for **NICA** (BM@N & MPD)& **FAIR;***
- *construction of **ALICE type** (MAPS) **ITS***

*workshop for detector assembly & test was put in operation in **2015***

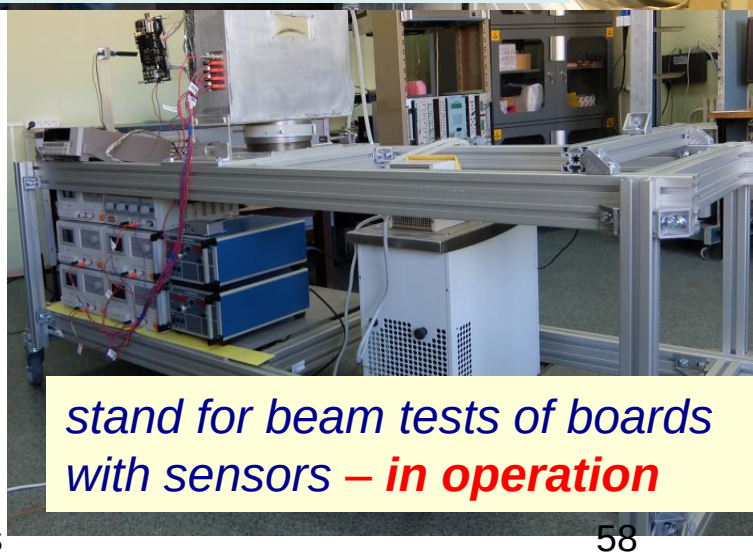
D. Gross in the workshop

***ITS MPD** layout*





# layer	R0 mm	Active l, mm	N of staves	N of chips / layer	active area, cm2	number of pixel cells,
1	24,4	542,4	12	216	889,9	113 246 208
2	42,0	542,4	22	396	1 087,7	207 618 048
3	60,0	542,4	32	576	1 582,1	301 989 888
4	107,	1477,5	12	2 352	4 845,1	1 233 125 376
5	156,5	1477,5	18	3 528	7 267,7	1 849 688 064
6	206,5	1477,5	24	3 920	9 690,2	2 055 209 960
Total:				10 988	25 362,7	**5 760 877 544**



*stand for beam tests of boards with sensors – **in operation***

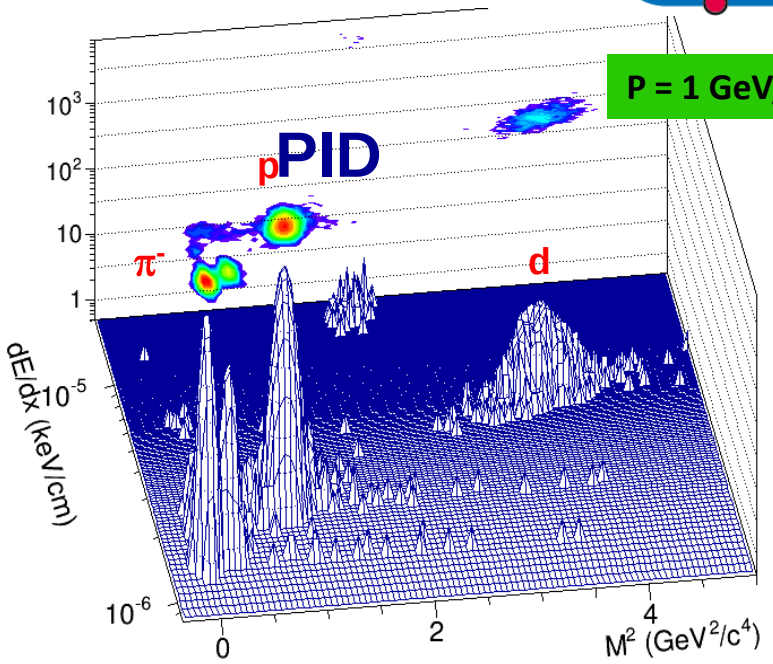
Hypernuclei @ MPD

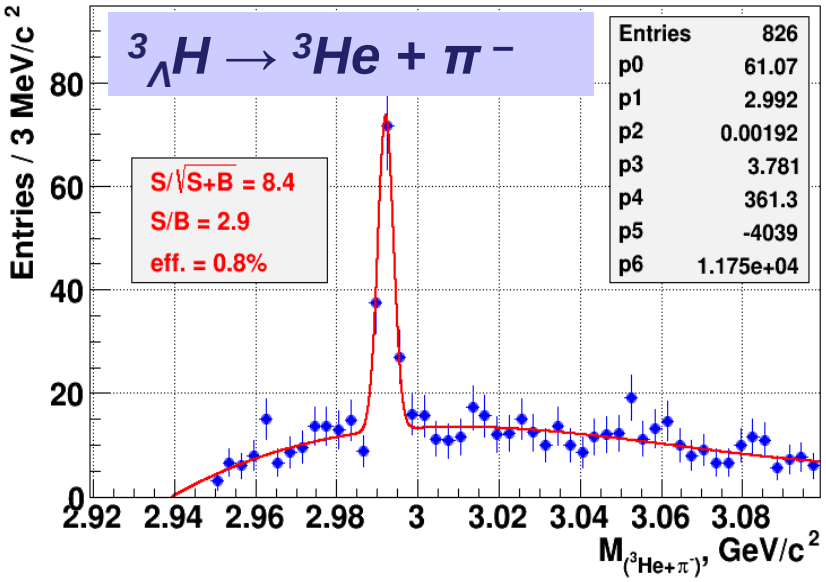
Hypertritons

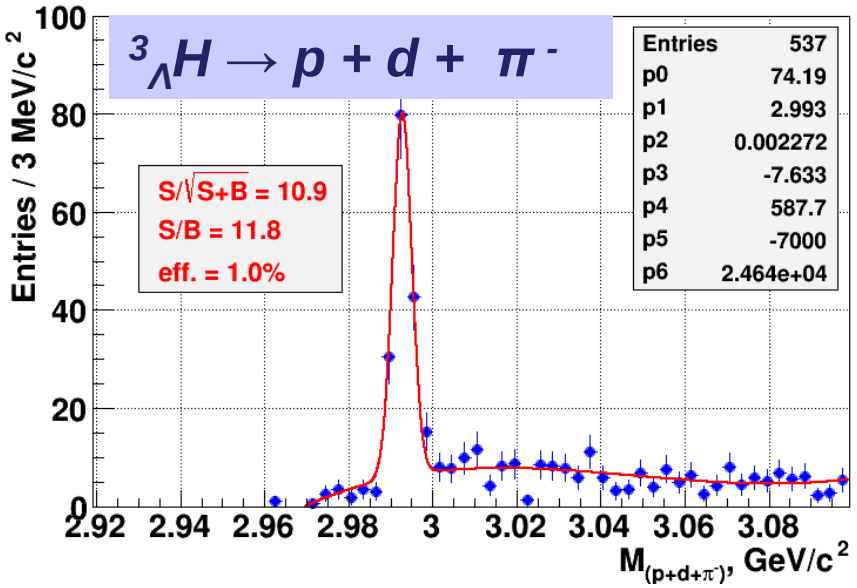
central Au+Au @ 5A GeV

(DCM-QGSM

~ 10^6 $^3_\Lambda H$ *are expected in 10 weeks*







Basic configuration milestones

- ***2018*** *– start of* ***BM@N*** *experimen*
- ***2018*** *– start of* ***Booster*** *commissioning*
- ***2019*** *–* ***MPD*** *hall completion*
- ***2020*** *– 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*

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

The second meeting will take place on 29-31 October, 2018

The organizations which have joined the collaborations:

Baku State University, National Nuclear Research Center, ***Azerbaijan****;*
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chili****;*
Tsinghua University, Beijing, ***China****;*
USTC, Hefei, ***China****;*
Huizhou University, Huizhou, ***China****;*
Shandong University, Shandong, ***China****;*
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China****;*
Central China Normal University, ***China****;*
IHEP, Beijing, ***China****;*
University of South China, ***China****;*
Palacky University, Olomouc, ***Czech Republic****;*
NPI CAS, Rez, ***Czech Republic****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
Tubingen University, Tubingen, ***Germany****;*
Tel Aviv University, Tel Aviv, ***Israel****;*
IPT, Almaty, ***Kazakhstan****;*
UNAM, Mexico City, ***Mexico****;*
Institute of Applied Physics, Chisinev, ***Moldova****;*
WUT, Warsaw, ***Poland****;*
NCN, Otwock – Swierk, ***Poland****;*
UW, Wroclaw, ***Poland****;*
Jan Kochanowski University, Kielce, ***Poland****;*
INR RAS, Moscow, ***Russia****;*
MEPhI, Moscow, ***Russia****;*
PNPI, Gatchina, ***Russia****;*
INPMSU, Moscow, ***Russia****;*
SPSU - Dept. of NP, St. Petersburg, ***Russia****;*
SPSU – Dept. of HEP, St. Petersburg, ***Russia****;*
KI NRS, Moscow, ***Russia****;*
MIT, Cambridge, ***USA****;*

XXIII A.M. Baldin International Seminar, *Relativistic Nuclear Physics & QCD; Dubna, 19–24 September, 2016*

NICA days in Warsaw

International scientific & engineering conference, 6–10 Nov. 2017, Warsaw

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***
- **We invite new students, PHD students, scientists and engineers to join the NICA project**

INTERNATIONAL INTERGOVERNMENTAL ORGANIZATION

Welcome to the Veksler & Baldin Laboratory of High Energy Physics

Welcome to join NICA project