Prospects for the dense baryonic matter research at NICA

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QUARK MATTER 2015
Sep.27 – Oct.3, 2015 Kobe, Japan

NICA (Nuclotron based Ion Colider fAcility) – the flagship project in HEP of Joint Institute for Nuclear Research (JINR)

Main targets of the NICA project:

- ***study of hot and dense baryonic matter***
- *investigation of nucleon spin structure, polarization phenomena*

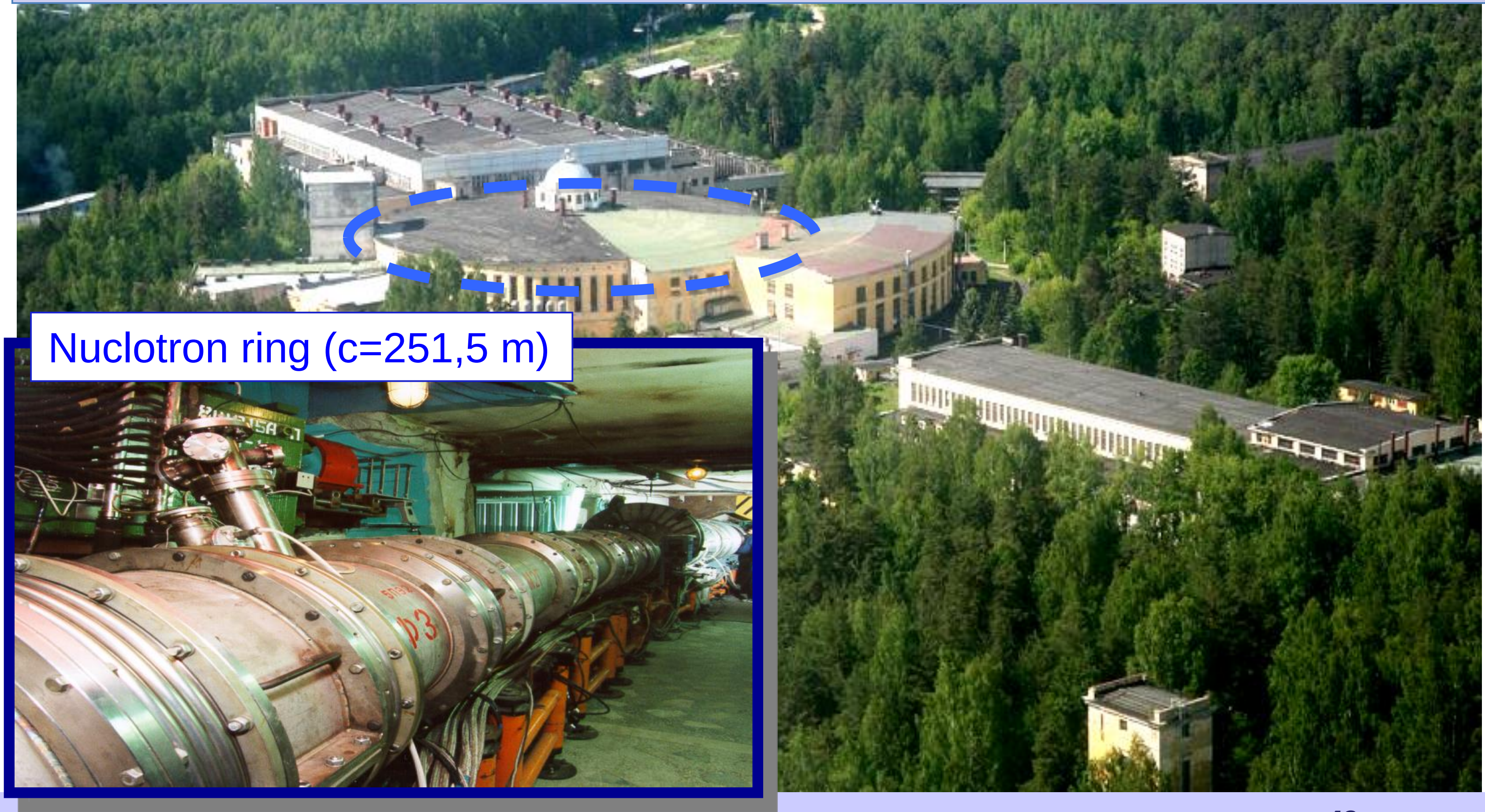
- *development of accelerator facility for HEP @ JINR providing intensive beams of relativistic ions from p to Au*

polarized protons and deuterons with max energy up to

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

Synchrotron **Nuclotron** is in operation since **1993**

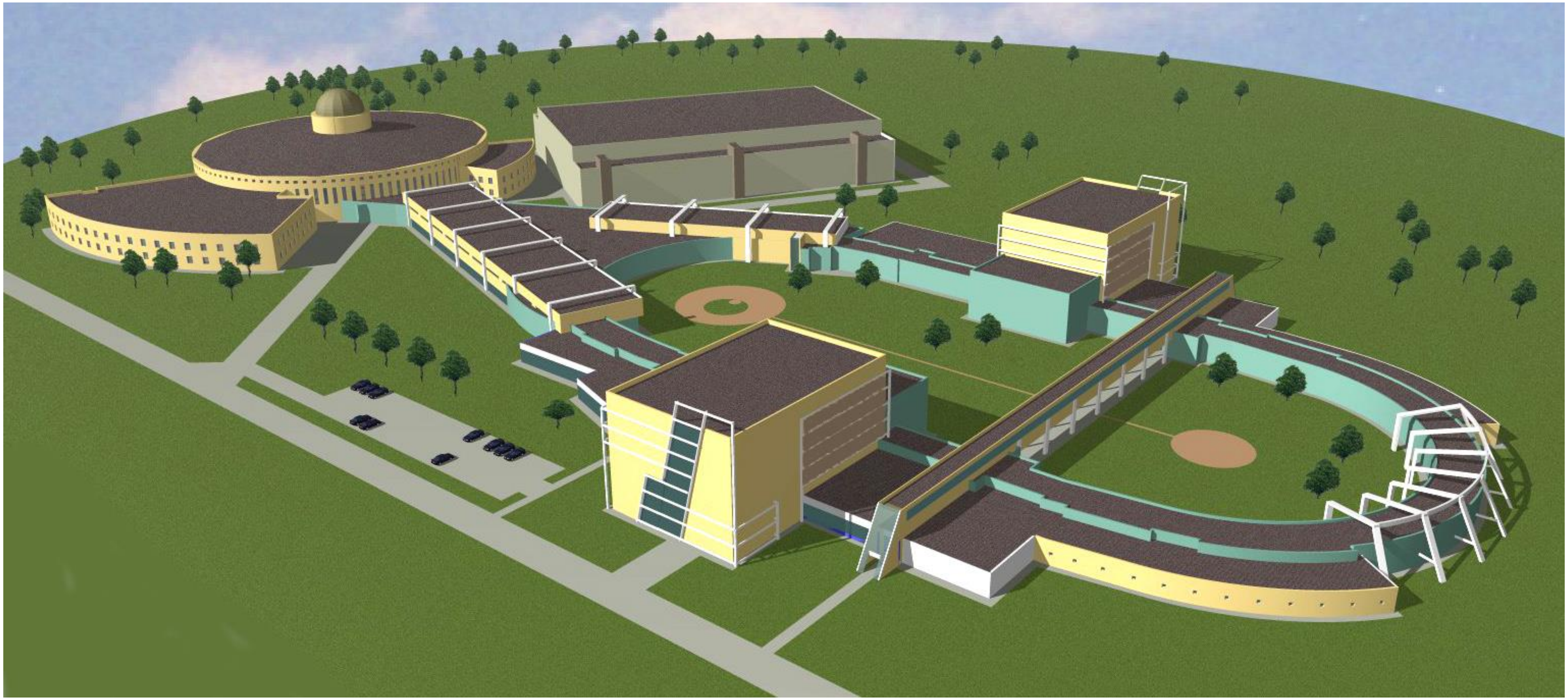
it is based on the superconducting fast cycling magnets developed in Dubna



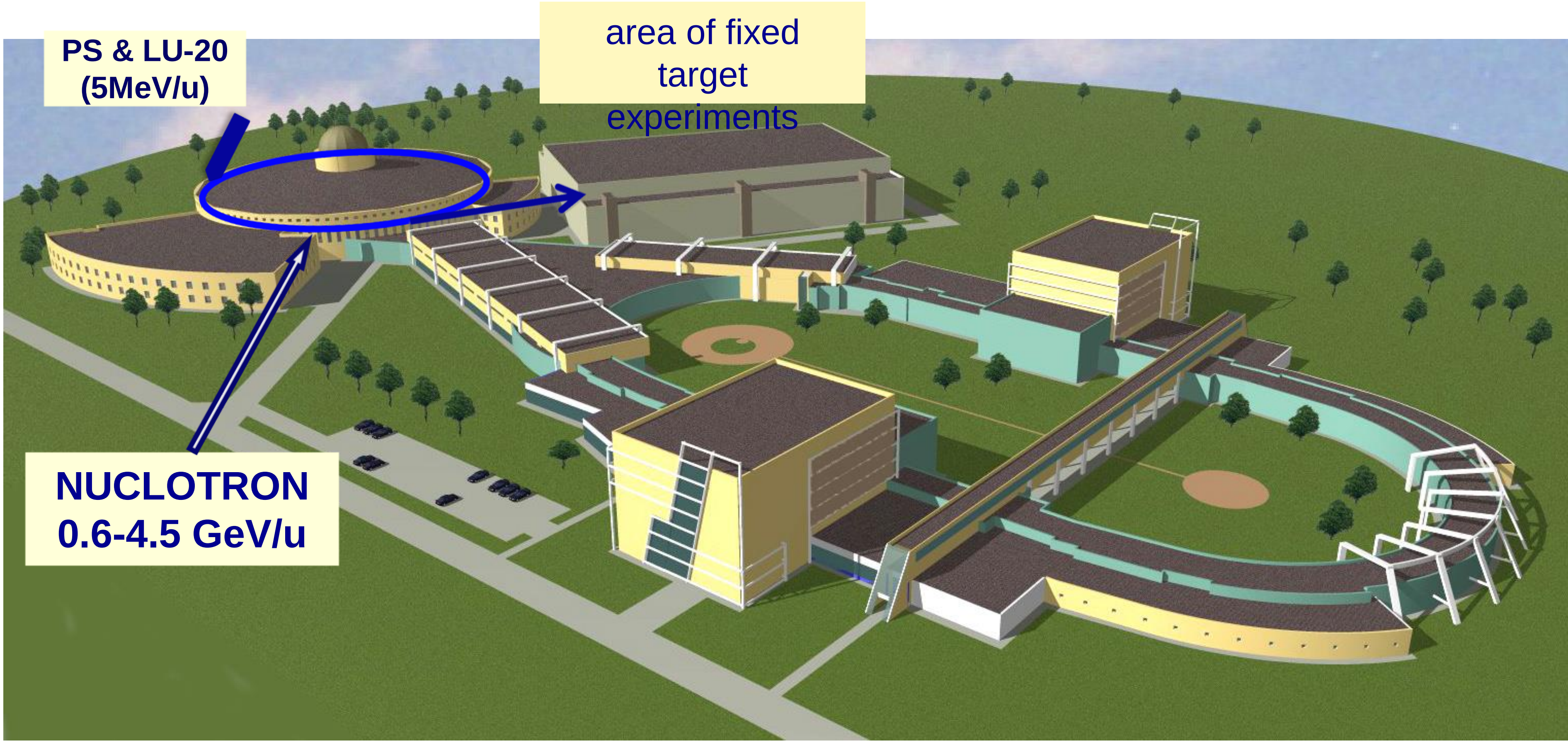
Nuclotron ring (c=251,5 m)

Nuclotron provides accelerated proton and ion beams (up to *Xe^{42+}*, *A=124*) with energies up to 6 AGeV (Z/A = 1/2)

NICA complex



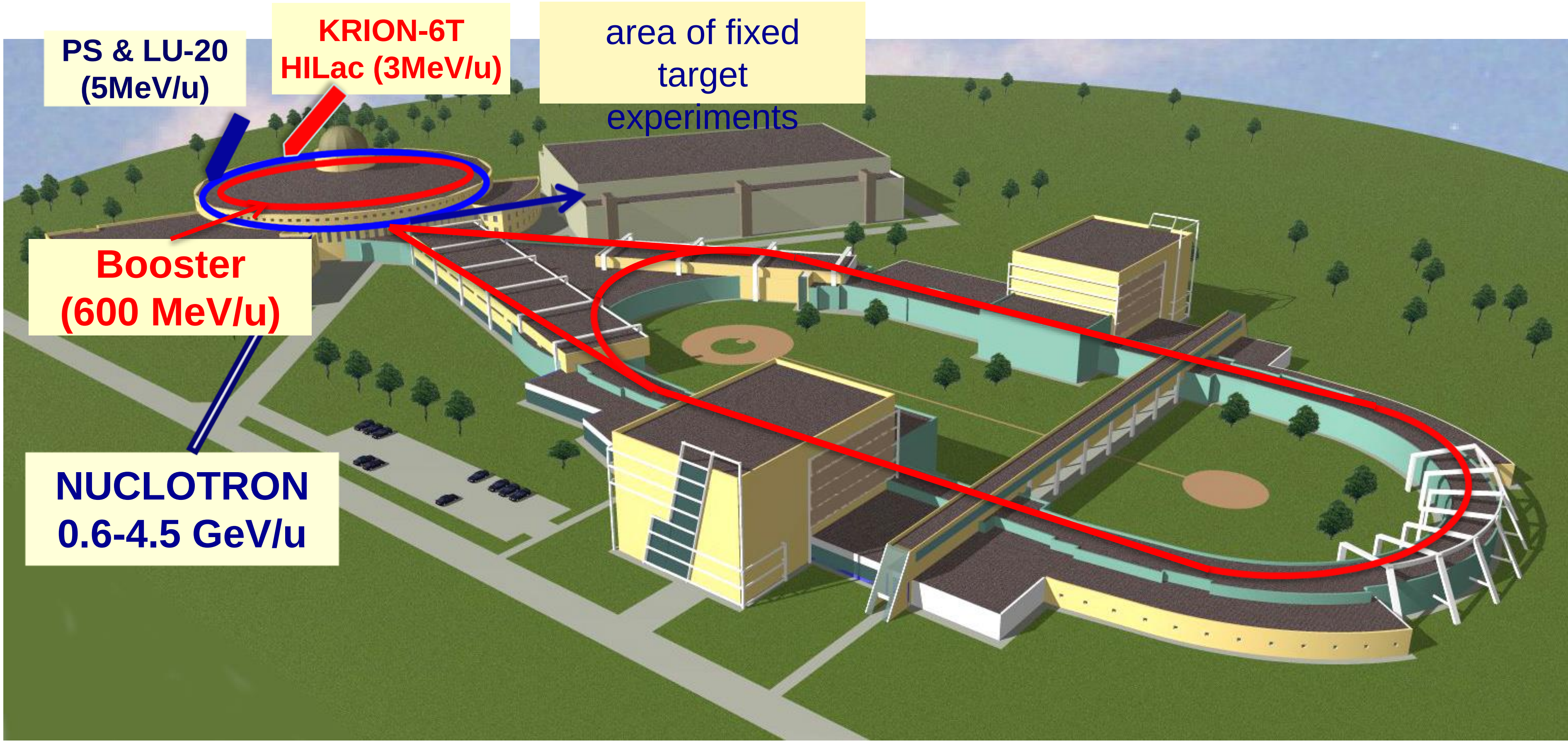
NICA complex existing facility



NICA complex

existing facility

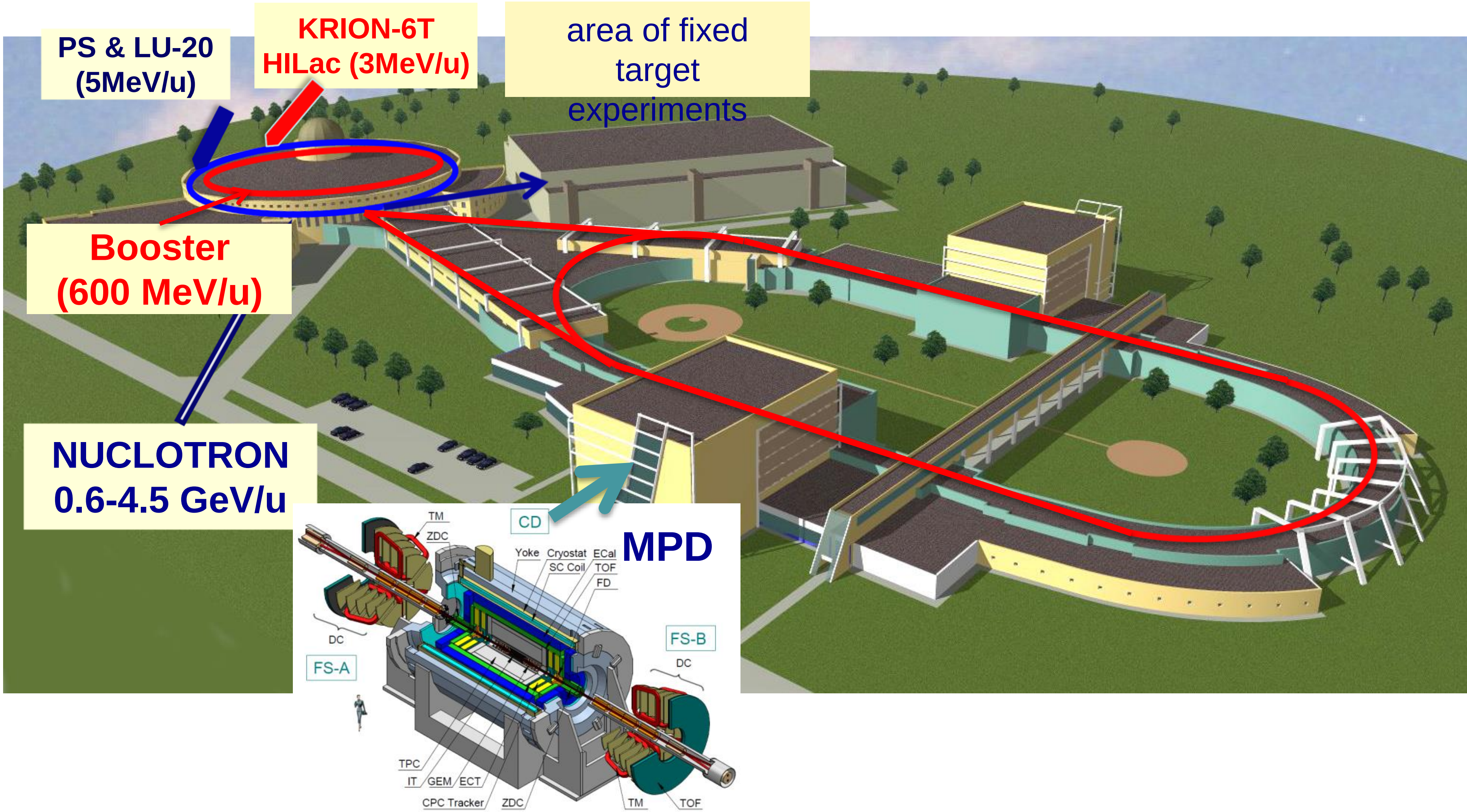
to be constructed



NICA complex

existing facility

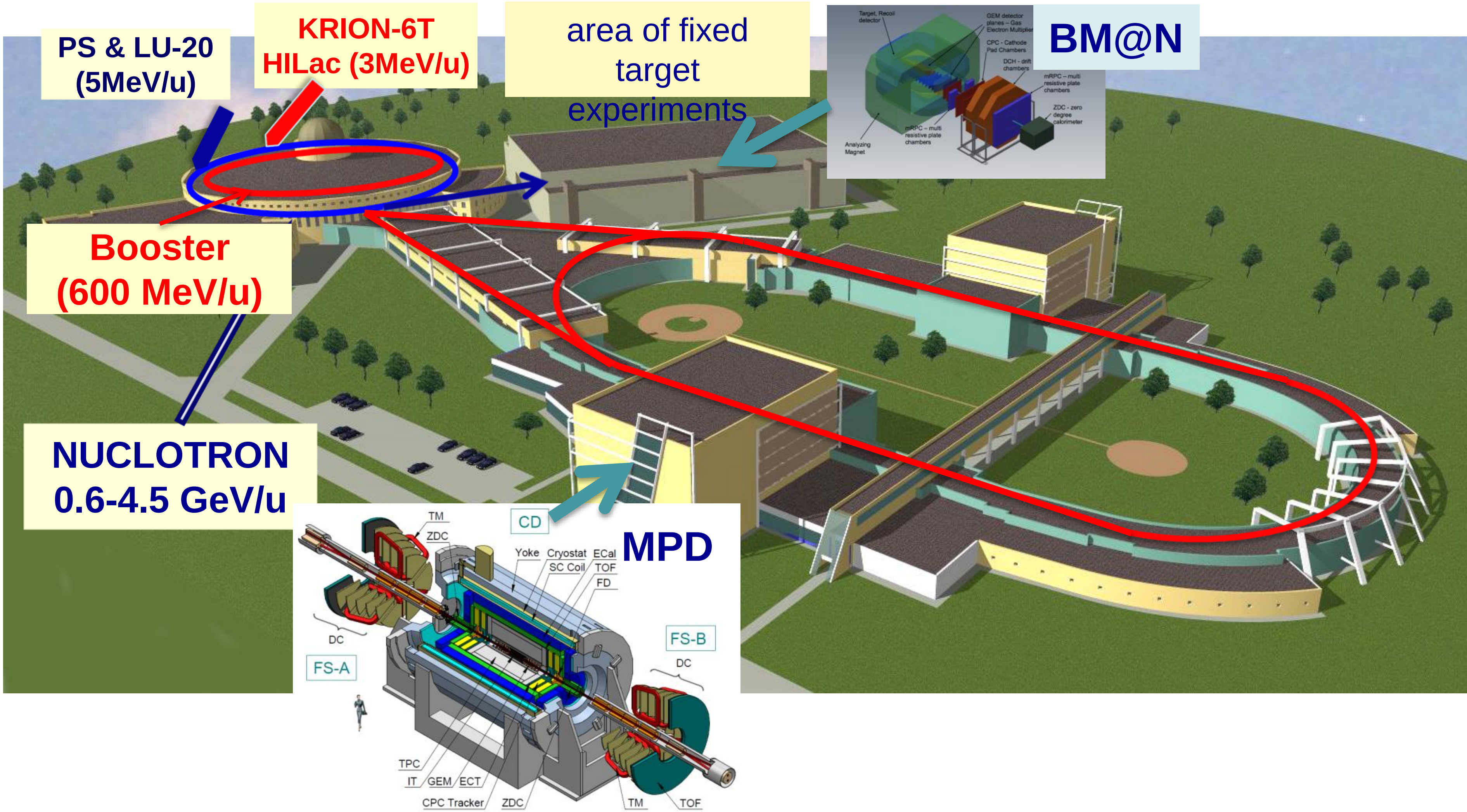
to be constructed



NICA complex

existing facility

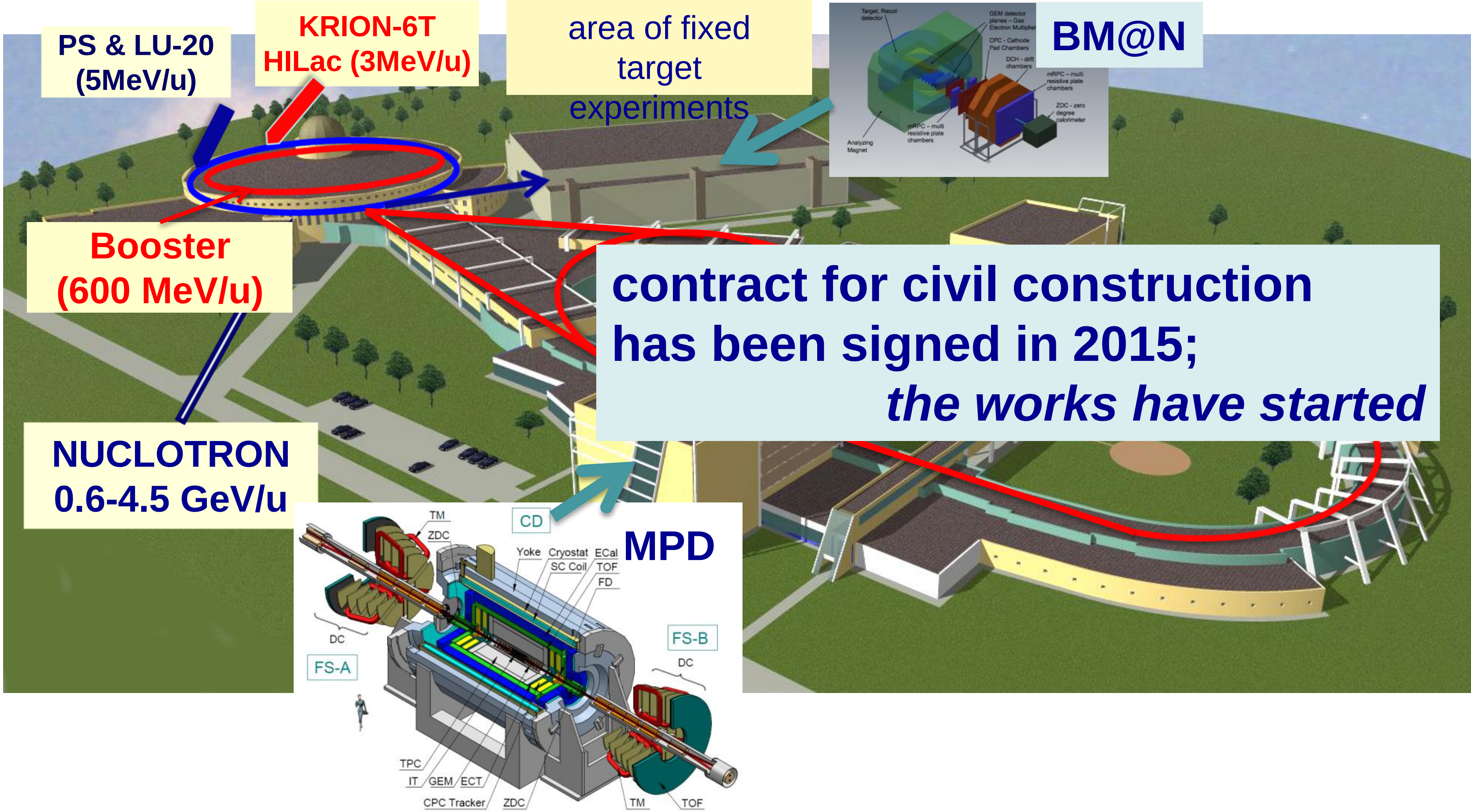
to be constructed



NICA complex

existing facility

to be constructed



PS & LU-20 (5MeV/u)

KRION-6T HILac (3MeV/u)

area of fixed target experiments

Booster (600 MeV/u)

NUCLOTRON 0.6-4.5 GeV/u

BM@N

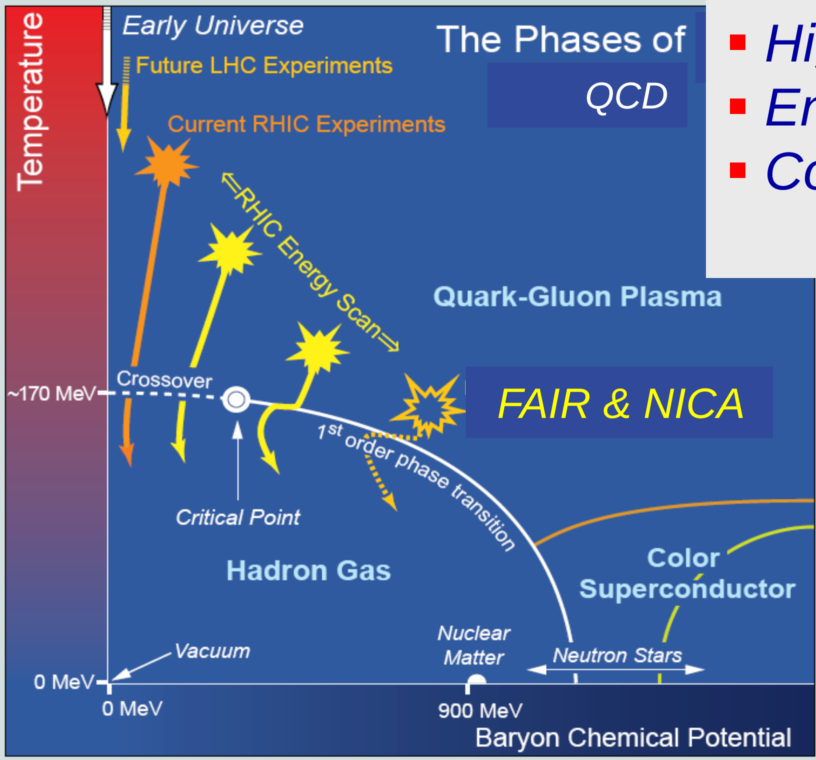
contract for civil construction has been signed in 2015;
the works have started

NICA collider major parameters

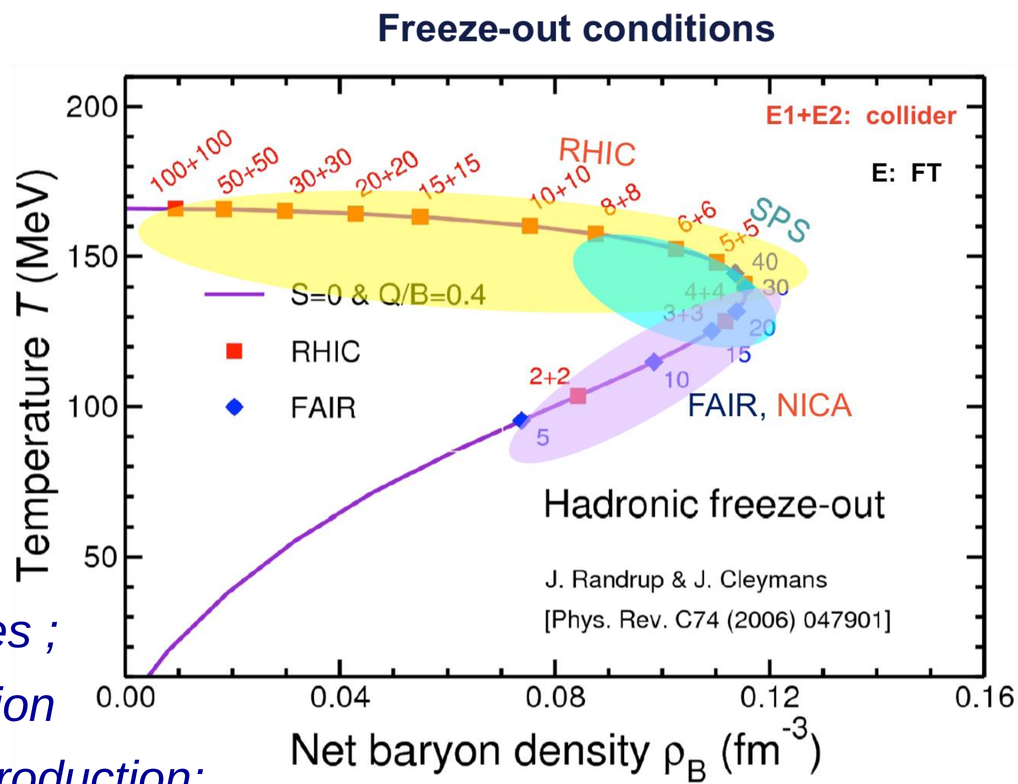
Ring circumference, m	**503.04**
heavy ions	
β, m	**0.35**
*energy range for **Au^{79+}**: $\sqrt{S_{NN}}$, GeV*	**4 - 11**
r.m.s. $\Delta p/p$, 10^{-3}	**1.6**
*peak Luminosity for **Au^{79+}**, cm^{-2} s^{-1}*	**1×10^{27}**
polarized particles	
*max. energy for polarized **p**, Gev*	**27**
*peak Luminosity for **p**, cm^{-2} s^{-1}*	**1×10^{32}**

Physics objectives

QCD matter at NICA

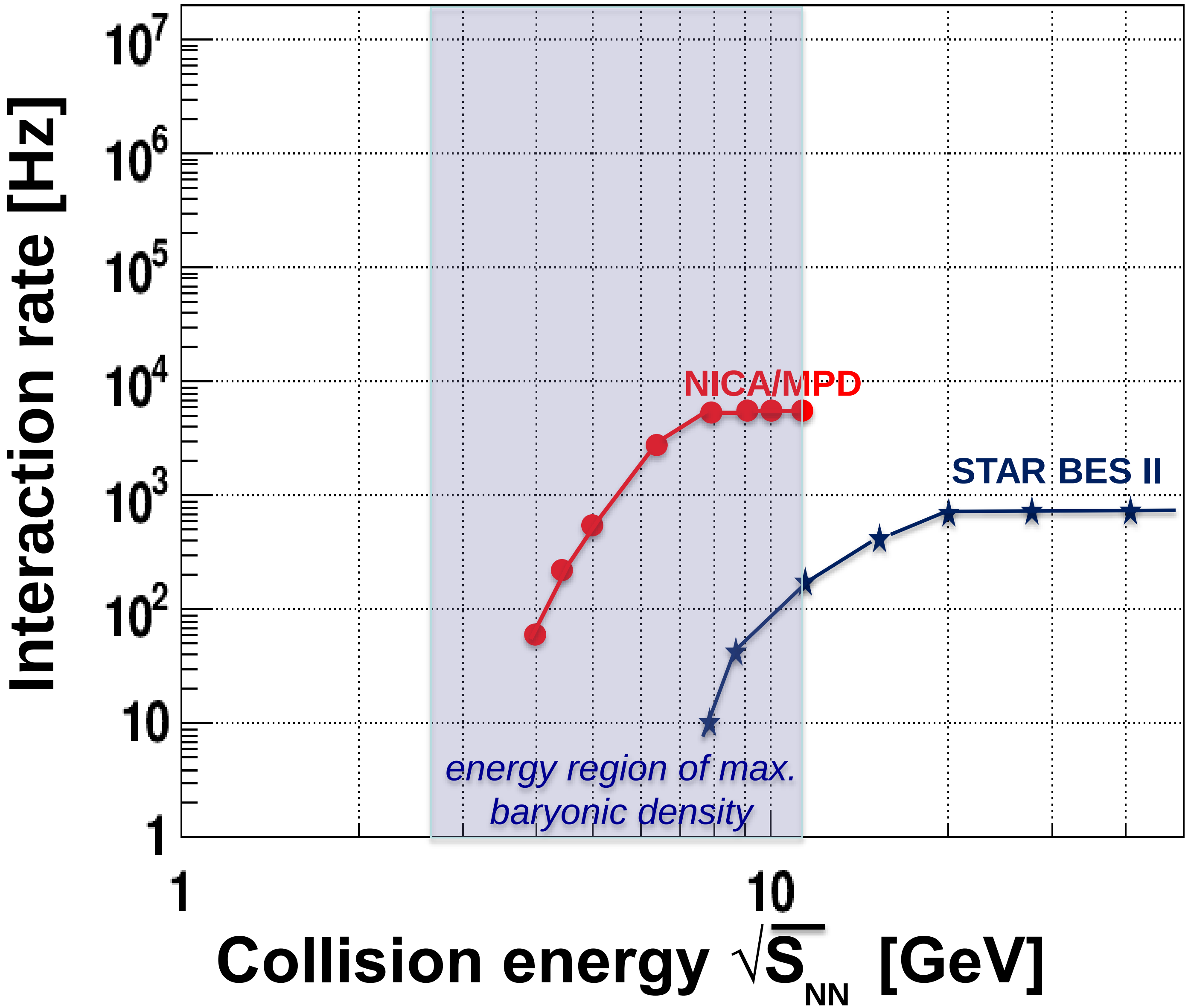


- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*

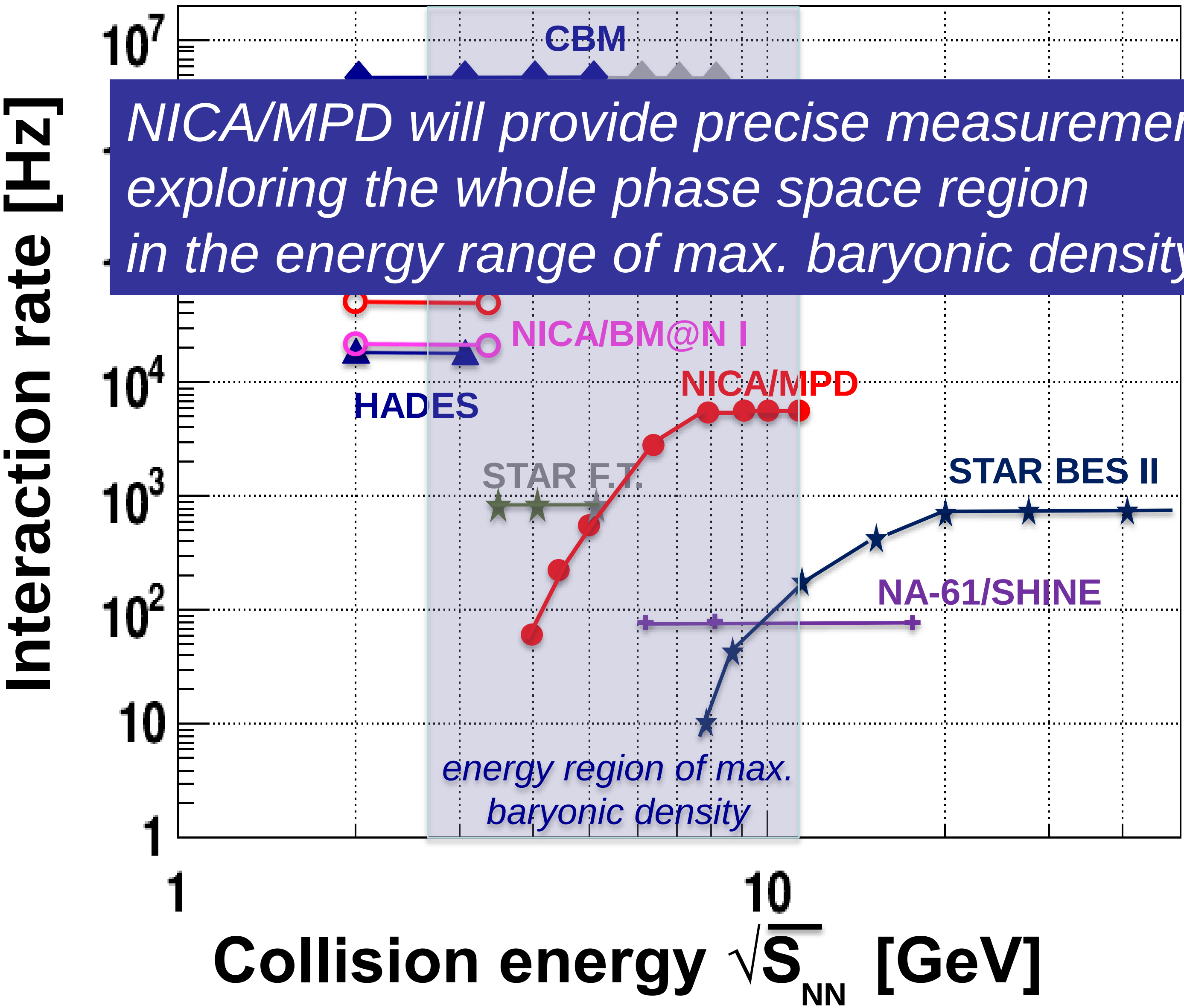


- *Bulk properties, EOS - particle yields & spectra, ratios, femtoscopy, flow;*
- *In-Medium modification of H properties ;*
- *Deconfinement (chiral), phase transition at high ρ_B - enhanced strangeness production;*
- *QCD Critical Point - event-by-event fluctuations & correlations;*
- *Strangeness in nuclear matter - hypernuclei*

Present and future HI collider experiments

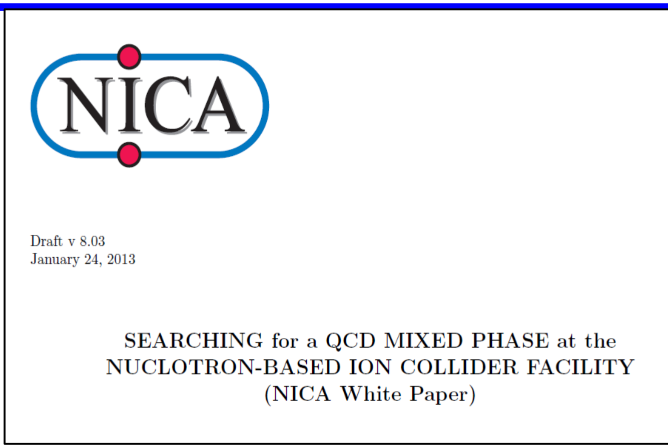


Present and future HI experiments/machines



NICA/MPD will provide precise measurements exploring the whole phase space region in the energy range of max. baryonic density

NICA White Paper – International Effort


NICA

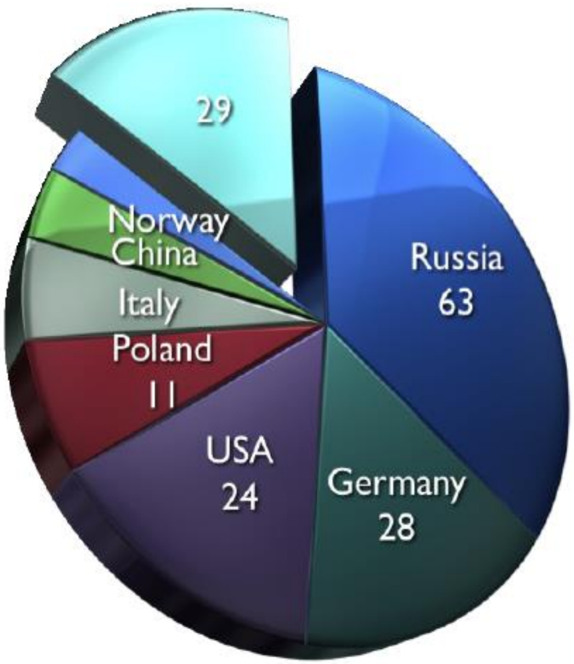
Draft v 8.03
January 24, 2013

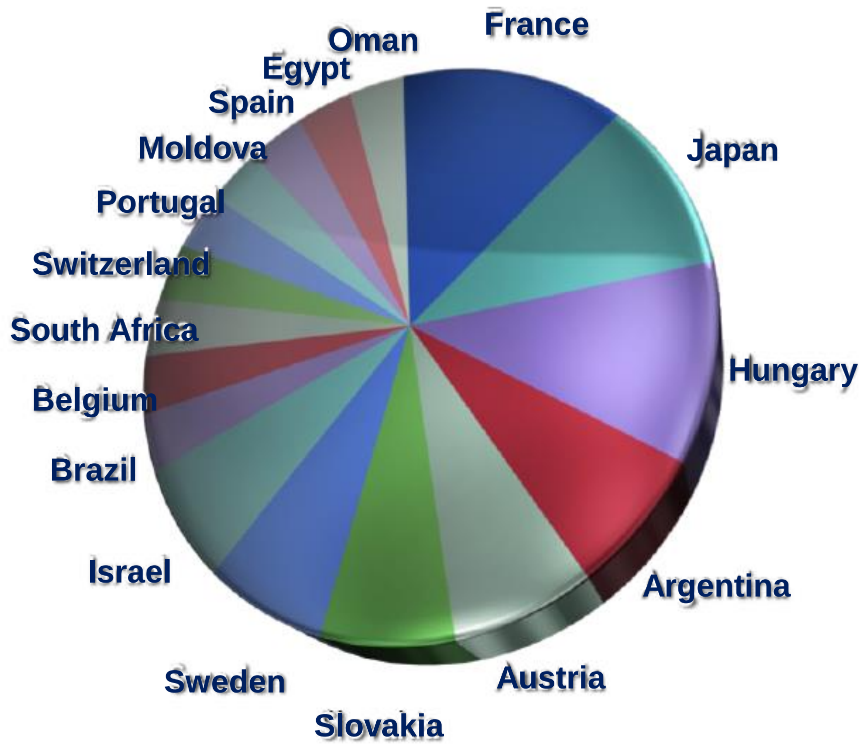
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

Statistics of White Paper Contributions

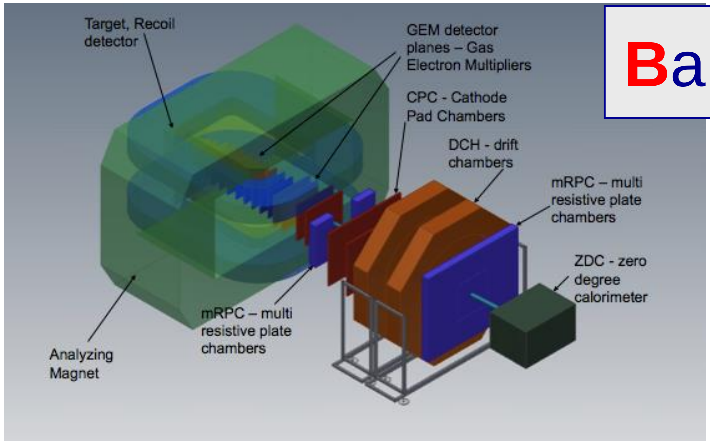
111 *contributions:*
188 *authors from* **70** *centers in* **24** *countries*

Indicates wide international interest
to the physics at MPD & BM@N





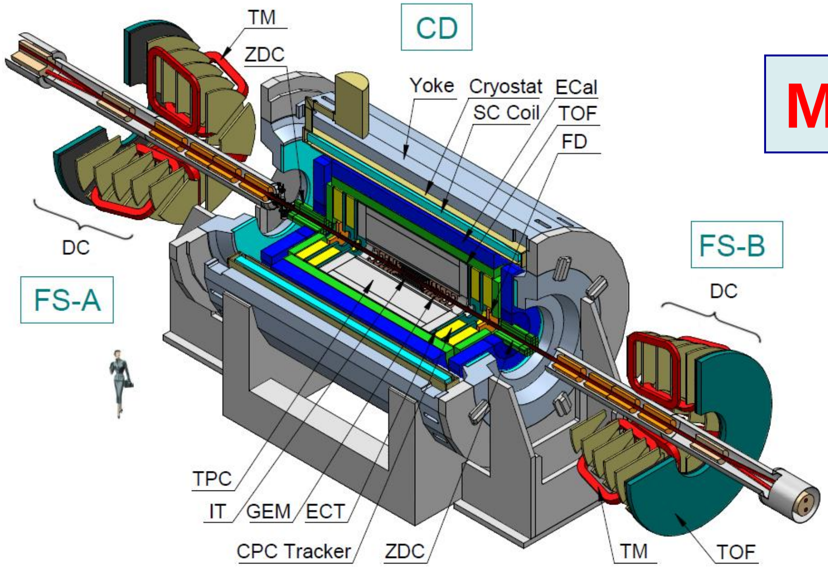
3 detectors



Baryonic Matter at Nuclotron (BM@N)

the fixed target experiment at the Nuclotron

Stage I 2017



MultiPurpose Detector (MPD)

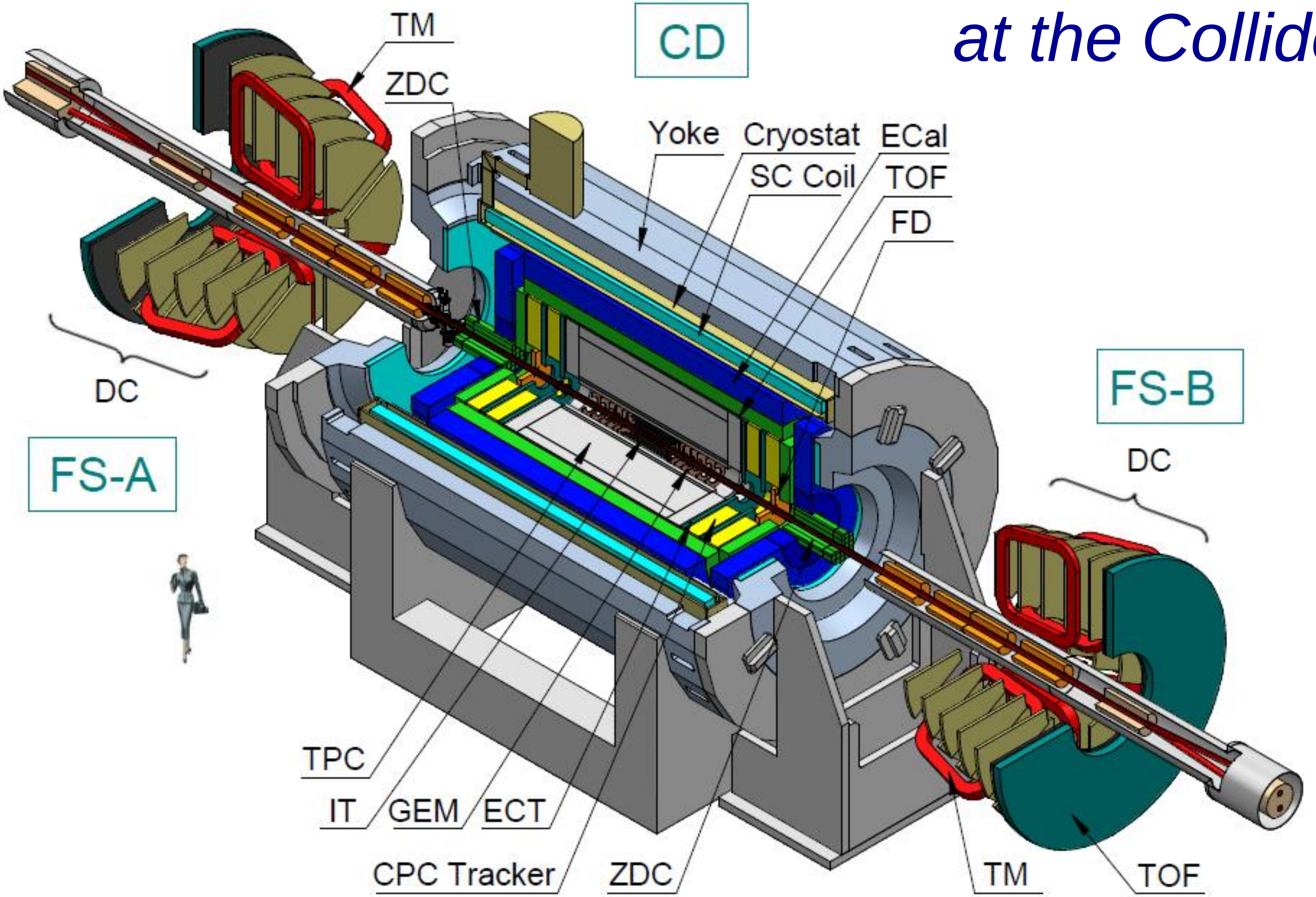
at the Collider

Stage I 2019

SPD (Spin Physics Detector) *at the Collider*

project is under preparation

Experiments at NICA: **MultiPurpose Detector (MPD)** *at the Collider*

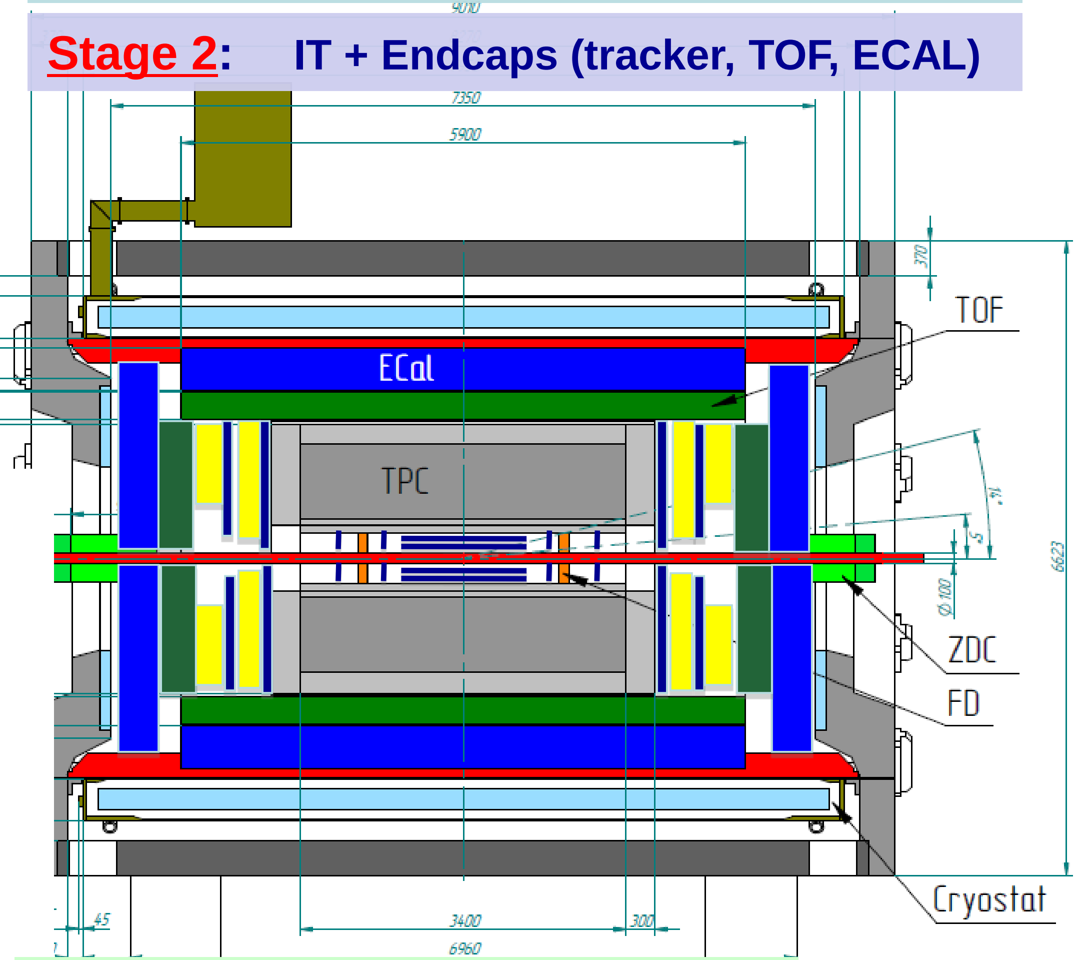


MPD detector for Heavy-Ion Collisions @ NICA

Tracking: up to $|\eta|<2$ (TPC)
PID: hadrons, e, γ (TOF, TPC, ECAL)
Event characterization:
centrality & event plane (ZDC)

Stage 1: TPC, TOF, ECAL, ZDC, FD

Stage 2: IT + Endcaps (tracker, TOF, ECAL)

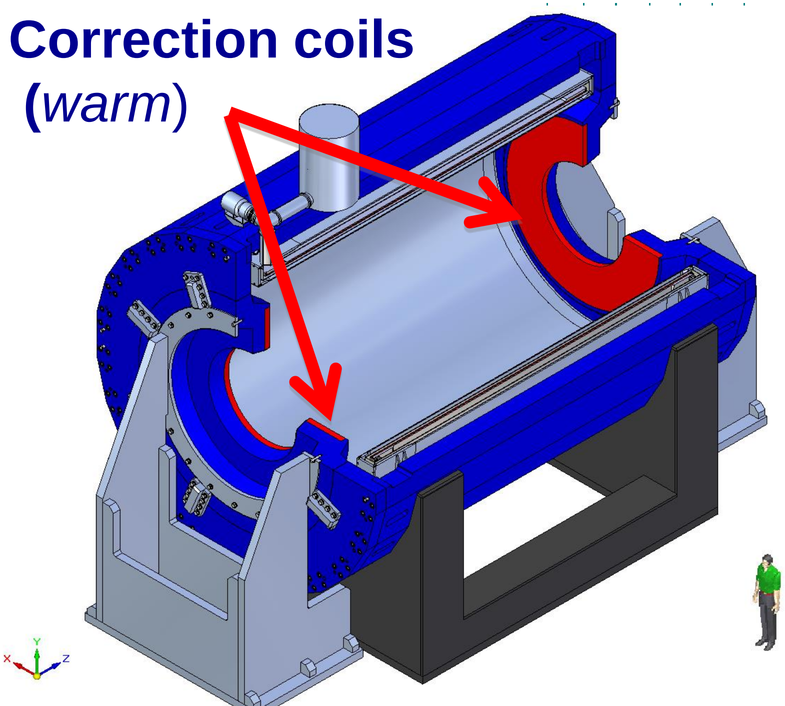


Superconducting solenoid:

high level (~ 3×10^{-4}) of magnetic field homogeneity

B_0=0.66 T

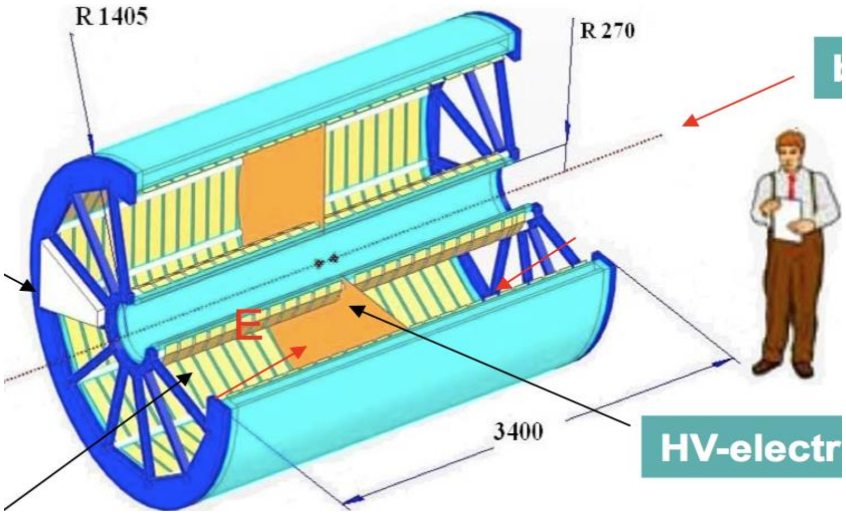
Correction coils (*warm*)



Magnet status:
technical design – completed;
Contracts under preparation

TPC- *technical project, preparation for fabrication*

Dia. =3000 mm, L = 3400 mm, FEE = 120 000 ch, $\delta p/p < 2\%$



FEC-64 prototype (ALTERA FPGA, ALTRO, PASA chips)

Cylinder C3 manufactured in Dec. 2013

R140 cm, L=3.4 m
4 mm thickness
0,1 mm precision

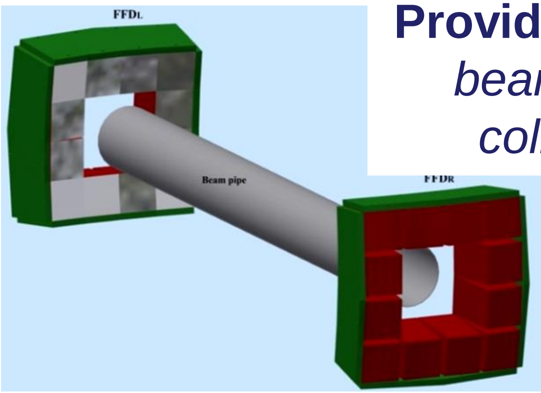
Cylinder C2, preparation for vacuum tests

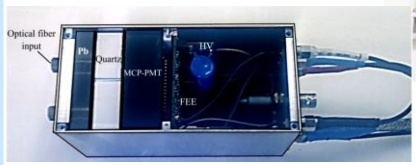
∅54 cm, l=3.4 m

Time of Flight system (TOF)

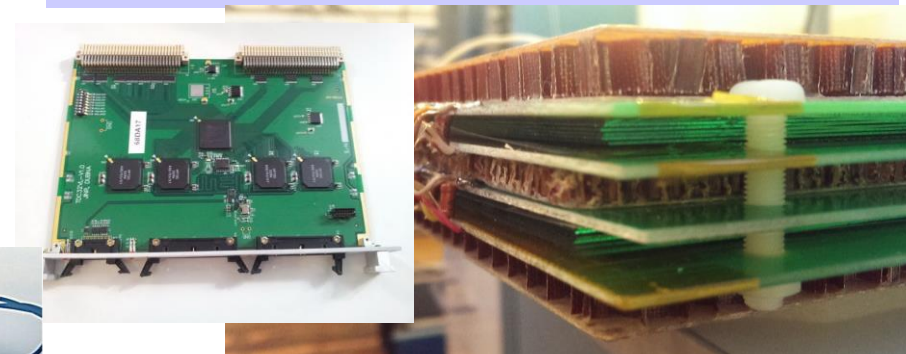
Fast Forward Detector (FFD):
production stage

Provides: *T0 for TOF, beam adjustment & collision L0-trigger*



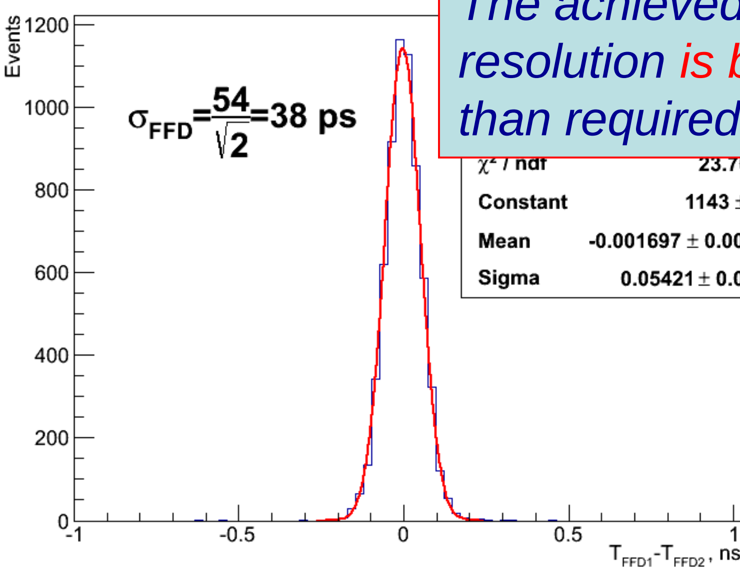


mRPC – TDR has been prepared,
ready for mass production

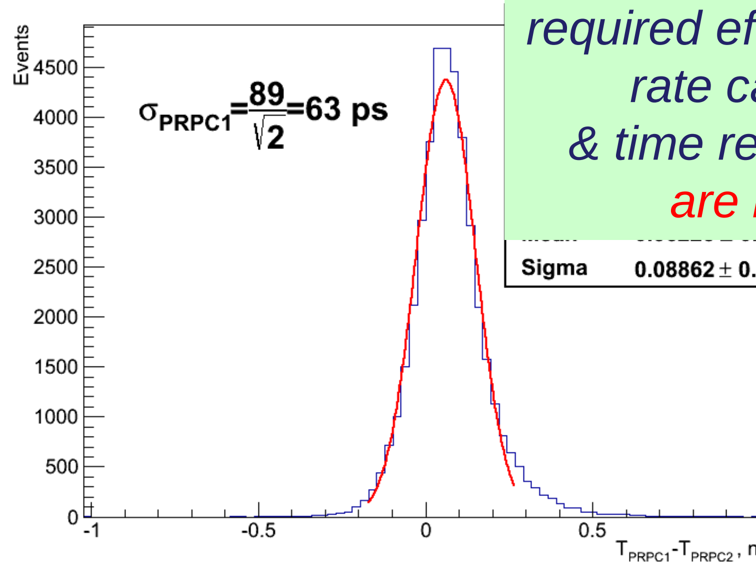


Zhu Weipinga, Wang Yi, Feng Shengqin, Wang Jingbo, Huang Xinjie, Shi Li, V. Babkin, V. Golovatyuk, M. Rumiantcev, G. Eppley, T. Nussbaum, ***NIM A 735, 277–282, 2014***

The achieved time resolution *is better* *than required*



required efficiency, rate capability & time resolution *are reached*

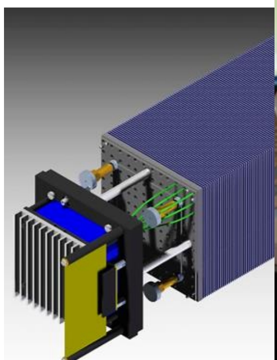


Calorimetry

ECAL – *TDR - in preparation*

L ~35 cm (~ 14 X_0), Pb+Scint. (4x4 cm^2)
read-out: WLS fibers + MAPD

Energy resolution **2.5% / √E**

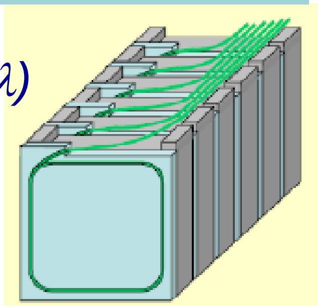


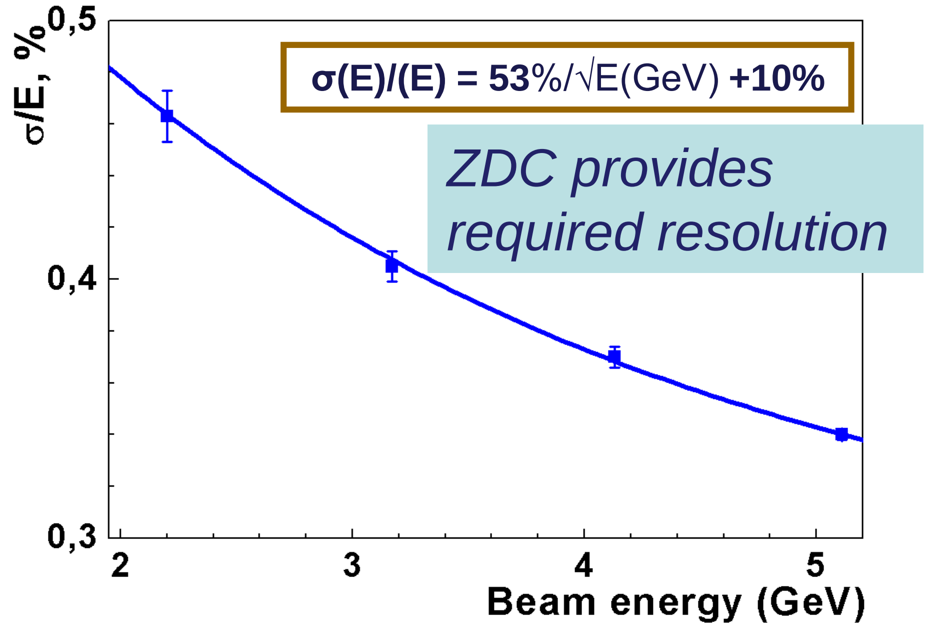
Preparation for tests with electron beams at DESY (December'13)

Zero Degree Calorimeter (ZDC): TDR stage

ZDC coverage: 3.2<|η|< 4.8

Pb-scintillator sampling (5λ)
Read-out: fibers + AvalanchePD





ZDC provides required resolution

MPD *(I-stage)* detector status

1. **Magnet** – *survey for producers*
2. **Integration** – *project in preparation*
3. **ECAL** – *TDR in preparation*
4. **ZDC** – *TDR close to completion*
5. **TOF** – *TDR close to completion*
6. **FFD** – *TDR close to completion*
7. **TPC** – *TDR close to completion:*
   - *assembly area preparations*
   - *fabrication of basic elements*
   - *readout chambers – production + R&D (alternative)*
   - *ALTRO-based Front-End card prototype - preproduction stage*

MPD I stage

feasibility study

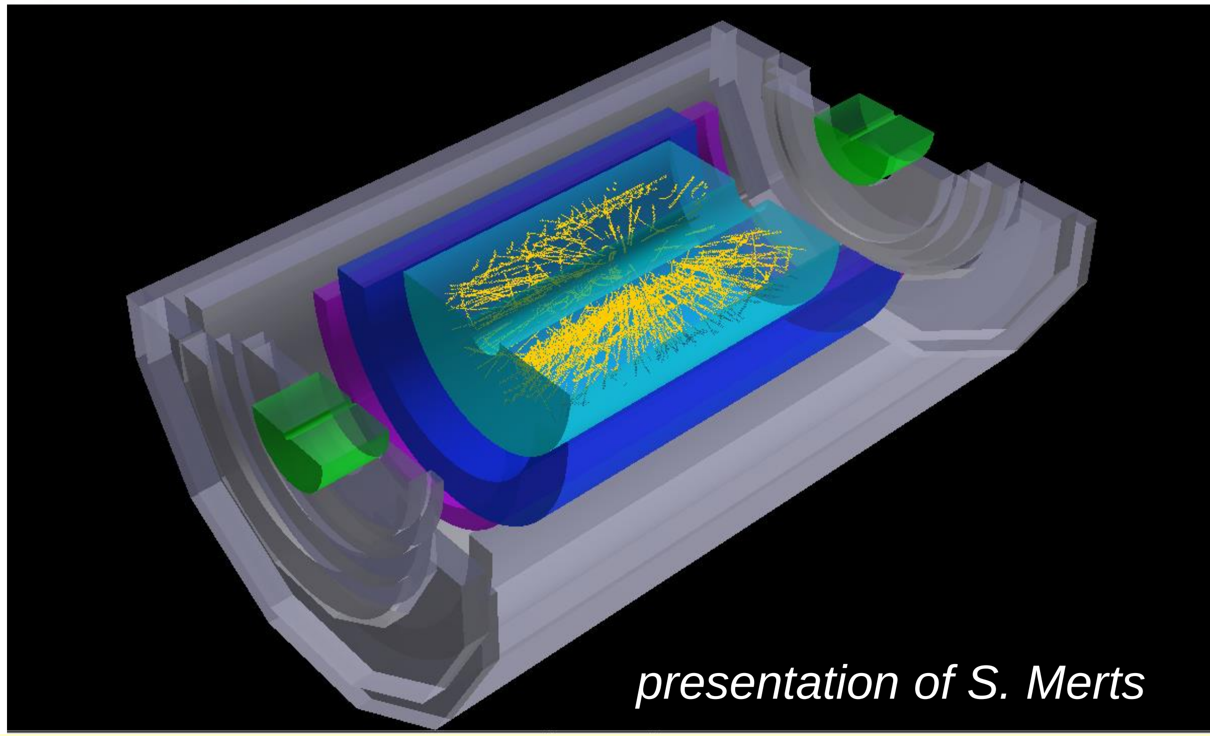
MPD simulation framework

http://mpd.jinr.ru

- ✓ *Software repositories*
- ✓ *Software tests*
- ✓ *Forum*
- ✓ *Information, etc.*

Event generators

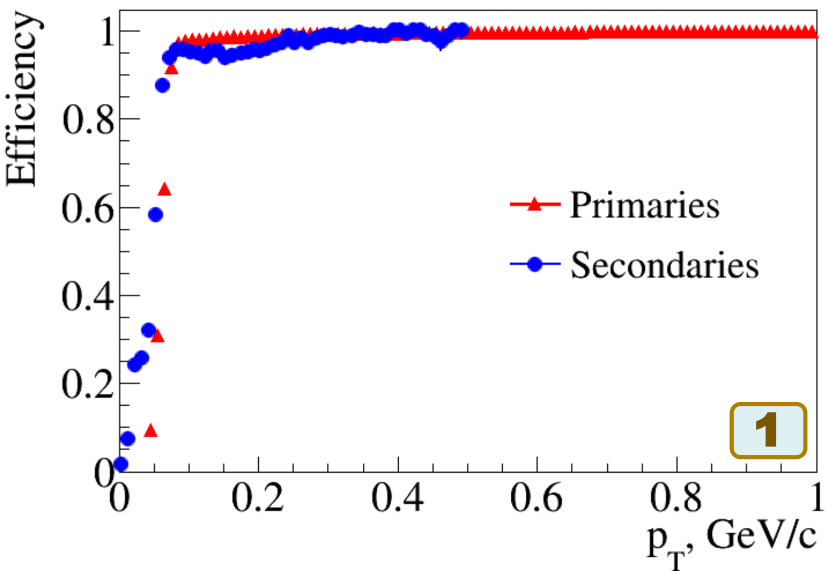
- ✓ *UrQMD 2.3*
- ✓ *LA QGSM*
- ✓ *SHIELD on fly*
- ✓ *PHSD*
- ✓ *UrQMD 3.4*
- ✓ *3FD + particlization*

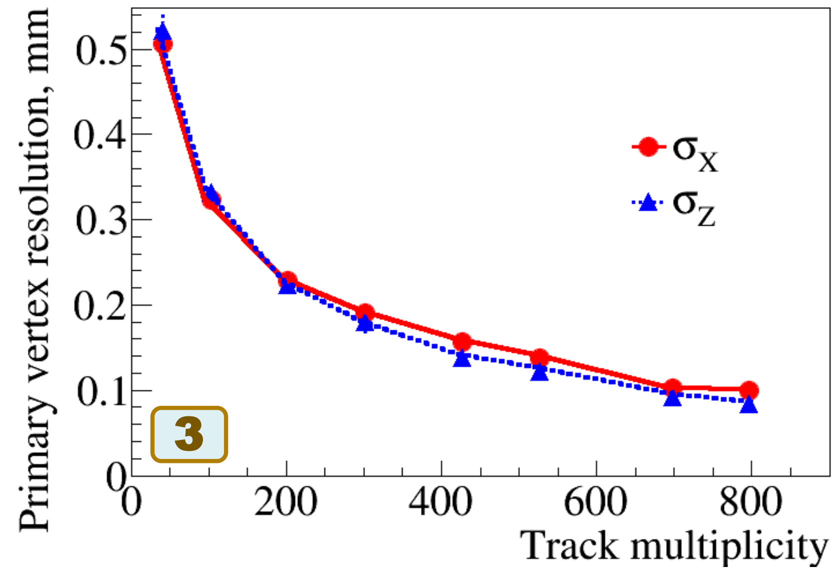


presentation of S. Merts

- inherits basic properties from FairRoot (*developed at GSI*), C++ classes;
- extended set of event generators for heavy ion collisions;
- detector composition and geometry; particle propagation by GEANT3/4;
- advanced detector response functions, realistic tracking and PID included.

MPD tracking performance:





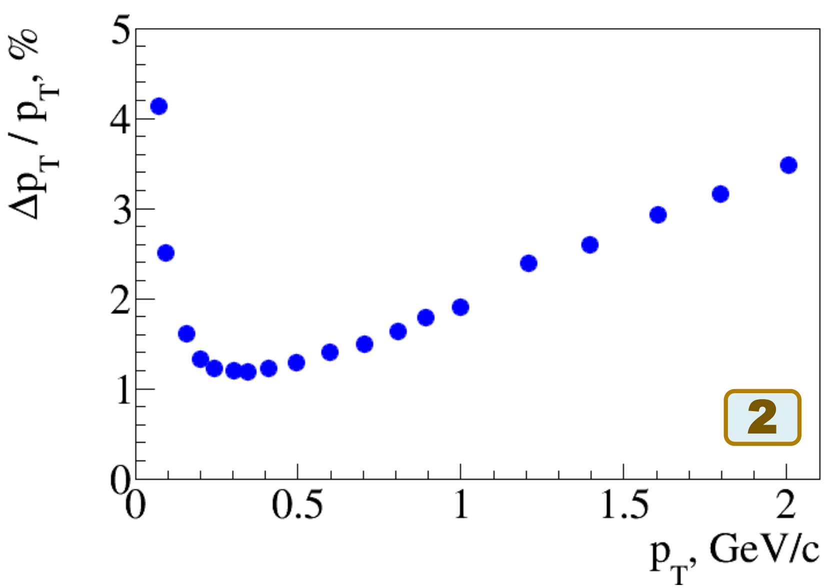


Fig.1: Track reconstruction efficiency:
low acceptance down to 100 MeV/c;

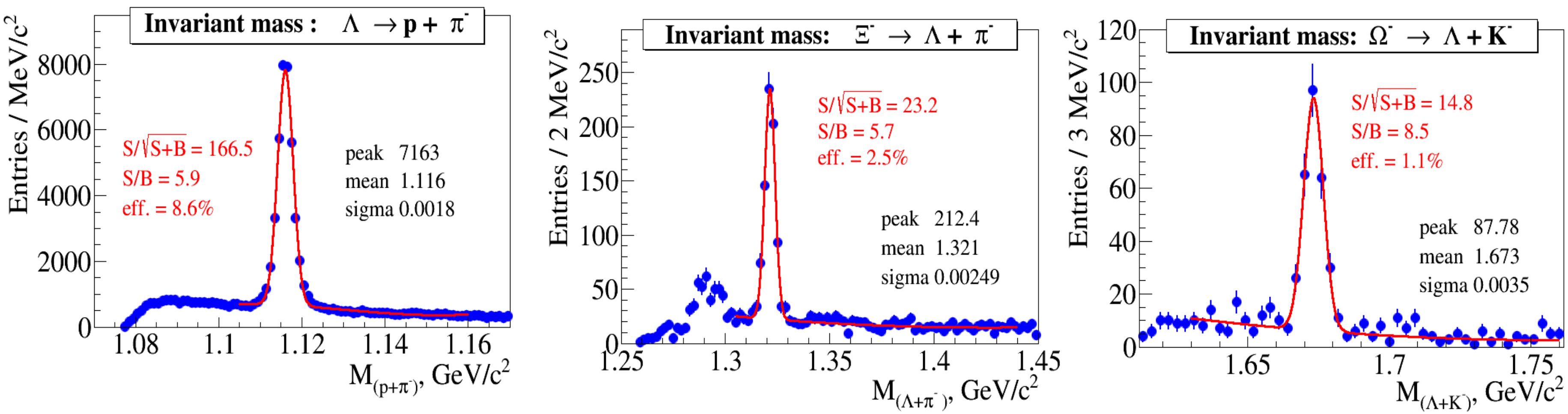
Fig.2: Momentum resolution:
$\Delta p/p < 2\%$ @ $p_T < 1.5$ GeV/c

Fig.3: Primary vertex resolution:
σ_x & $\sigma_z < 0.15$ mm in central collisions (track multiplicity in TPC > 500)

MPD performance: hyperons

Production of multi-strange hyperons to study the properties of the strongly interacting system and signal for QGP

- **Central Au+Au @ 9A GeV (UrQMD) , TPC+TOF barrel**
- **Realistic tracking and PID, secondary vertex reconstruction**



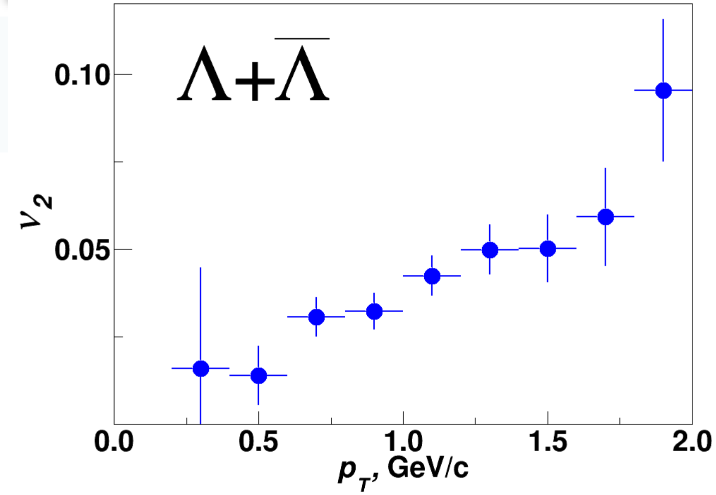
Yields for 10 weeks of running

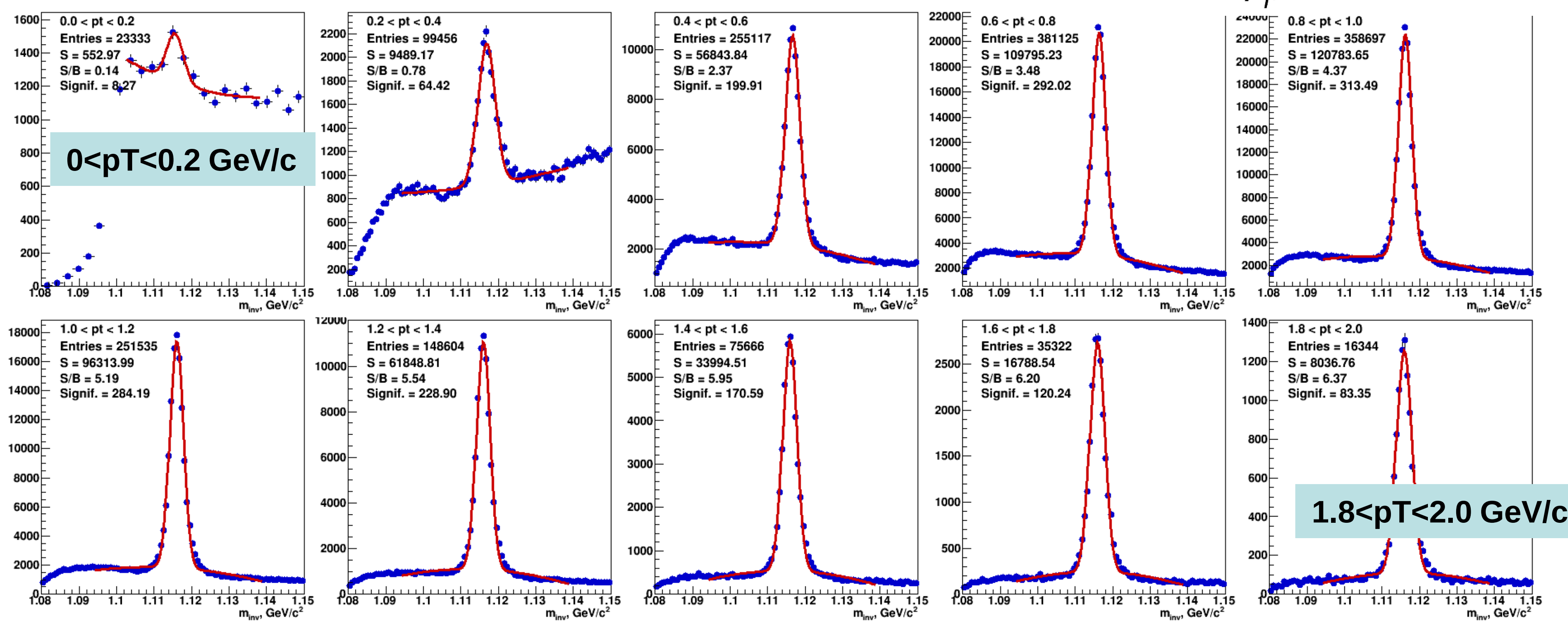
Particle	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-	$\bar{\Omega}^+$
Expected yield	$5.8\cdot10^9$	$7.3\cdot10^7$	$2.9\cdot10^7$	$1.6\cdot10^6$	$1.4\cdot10^6$	$2.9\cdot10^5$

MPD performance: hyperon flow

Momentum anisotropy (elliptic flow) originates from initial spatial anisotropy. V2 depends on matter properties and EOS

- Min. bias Au+Au @ 11A GeV (UrQMD) , TPC+TOF barrel
- Realistic tracking & PID, secondary vertex reconstruction
- Event plane from TPC tracks





MPD performance : ϕ (1020)

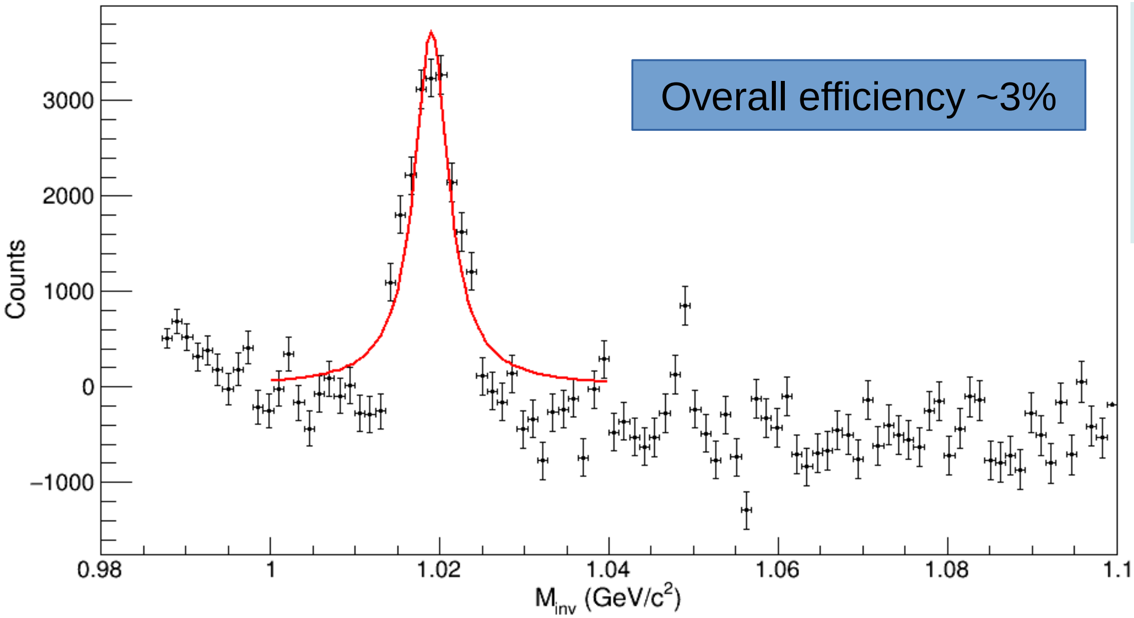
Motivation:

** The lightest bound state of hidden strangeness*

** Low cross-section in nuclear matter and early freeze-out*

Data set and analysis

- *Central Au+Au collisions, at $\sqrt{s_{NN}}$ = 11 GeV (UrQMD)*
- *Channel of decay: $\phi \rightarrow K^+K^-$, realistic tracking and PID (TOF + dE/dx)*



Measured values:

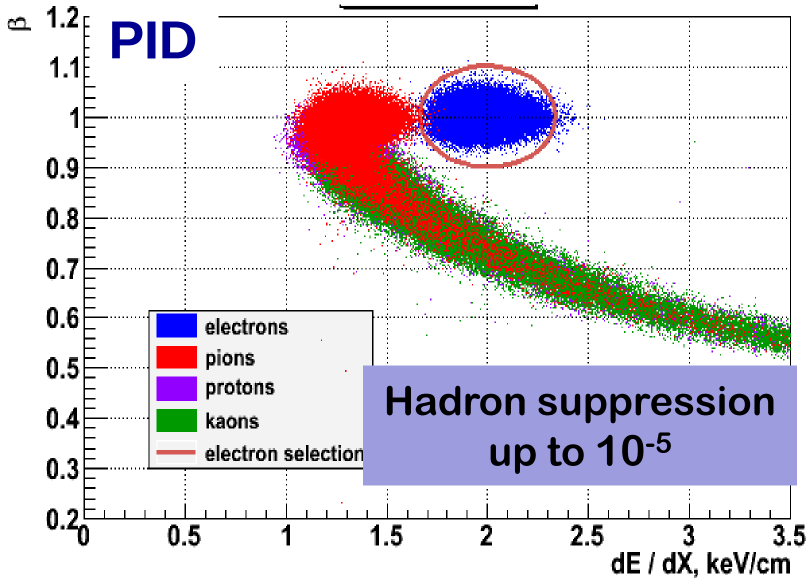
Width = 4.96 ± 0.25 (MeV/c^2)

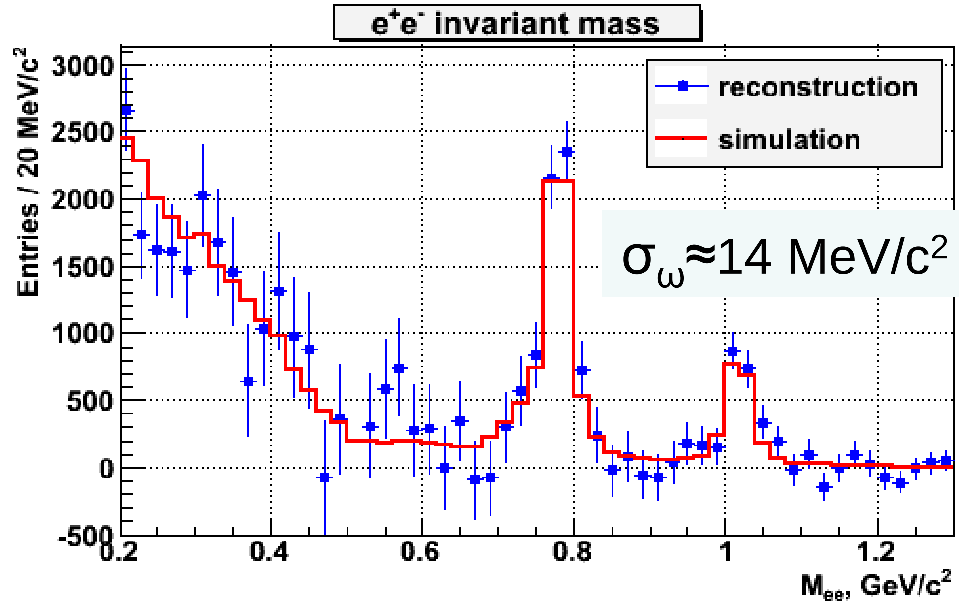
M_{inv} = 1019.03 ± 0.12 (MeV/c^2)

close to ones generated (PDG)

MPD performance for dileptons

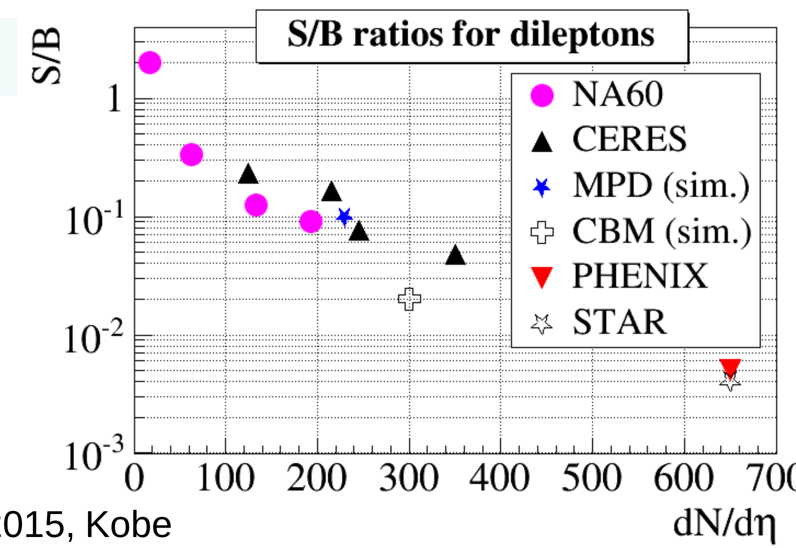
Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density



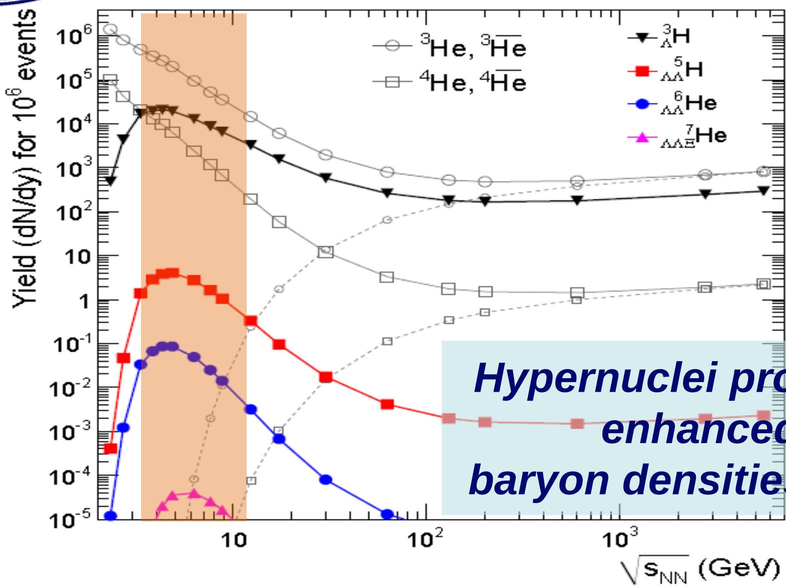


Yields, central Au+Au st $\sqrt{s_{NN}}$ = 8.8 GeV/u

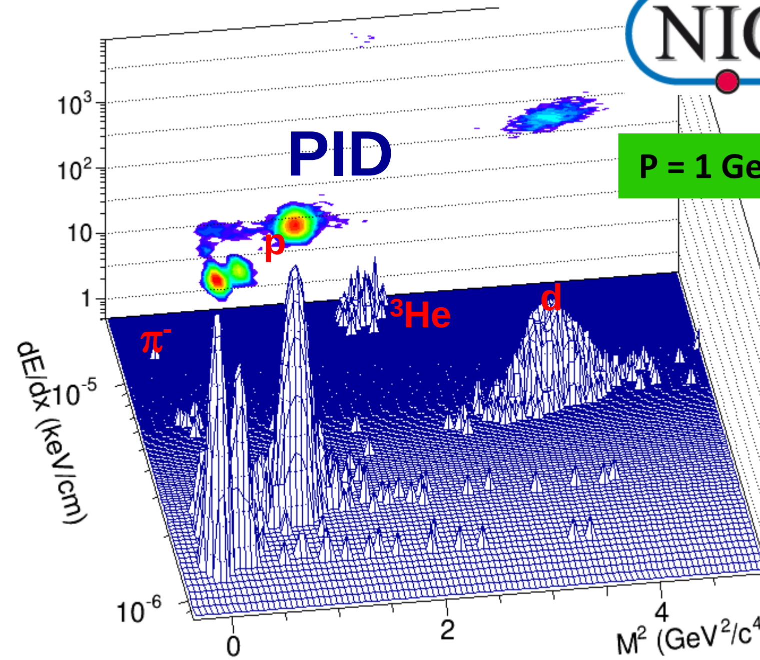
meson	Yields 4π	Yields y=0	Yield/1 w
ρ	31	17	$7 \cdot 10^4$
ω	20	11	$7 \cdot 10^4$
φ	2.6	1.2	$1.7 \cdot 10^4$



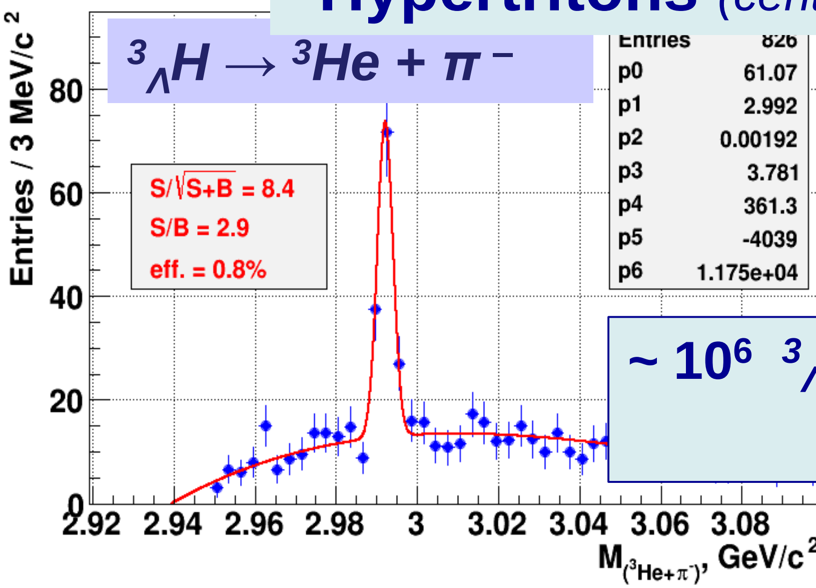
Hypernuclei @ MPD

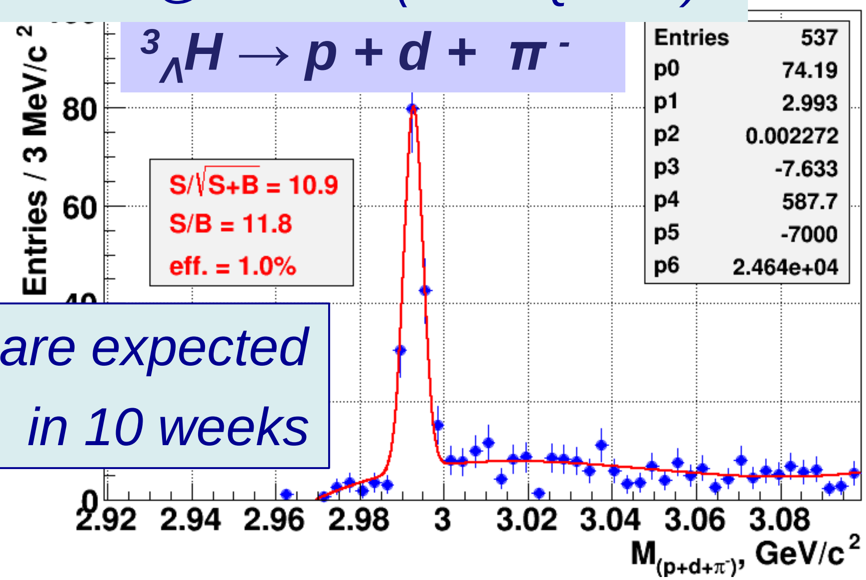


Hypernuclei production enhanced at high baryon densities (NICA)



Hypertritons *(central Au+Au @ 5A GeV (DCM-QGSM))*



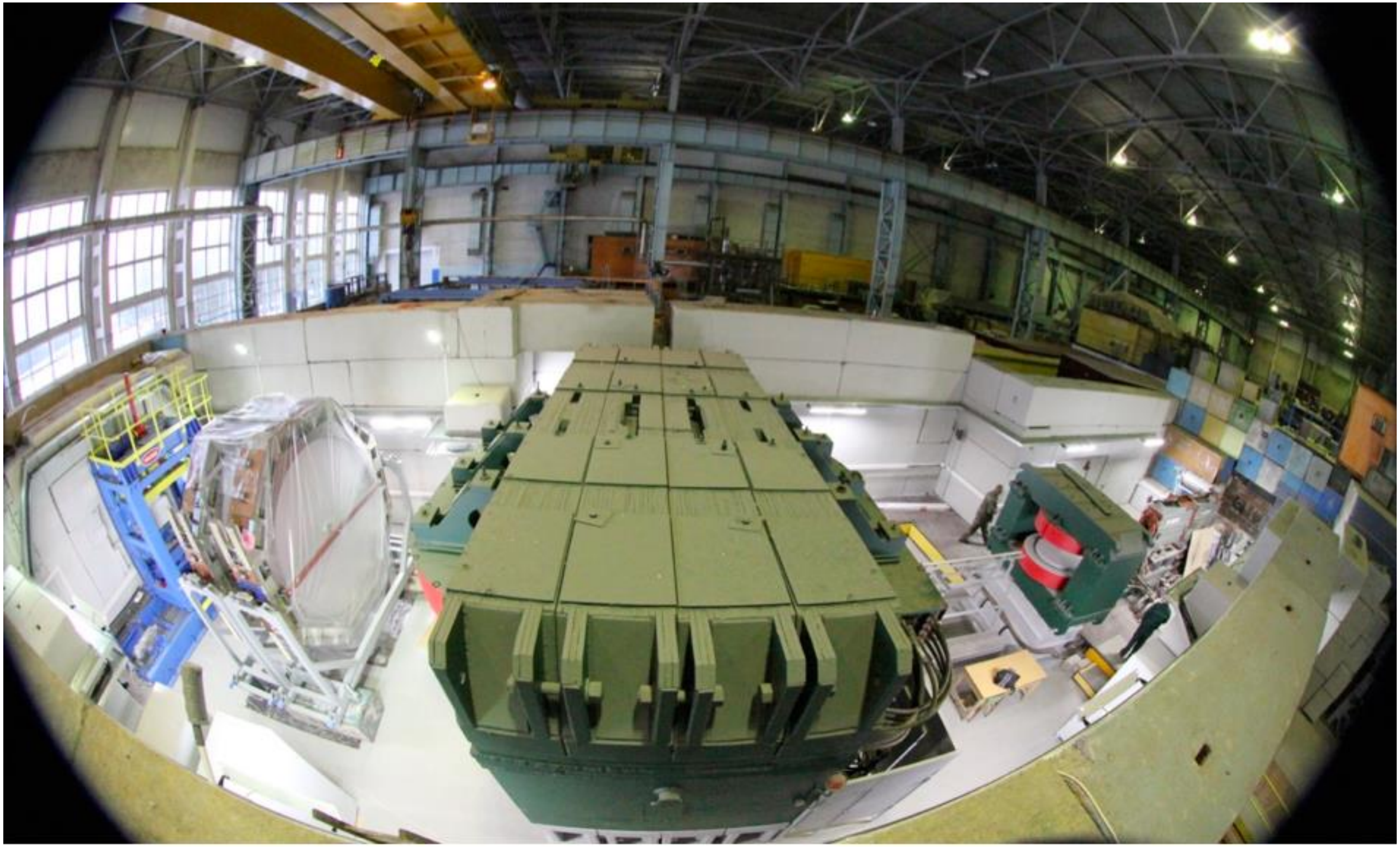


~ 10^6 $^3_\Lambda H$ *are expected in 10 weeks*

Experiments at NICA:

Baryonic Matter at Nuclotron (BM@N)

at the Nuclotron extracted beams



Nuclotron Beams

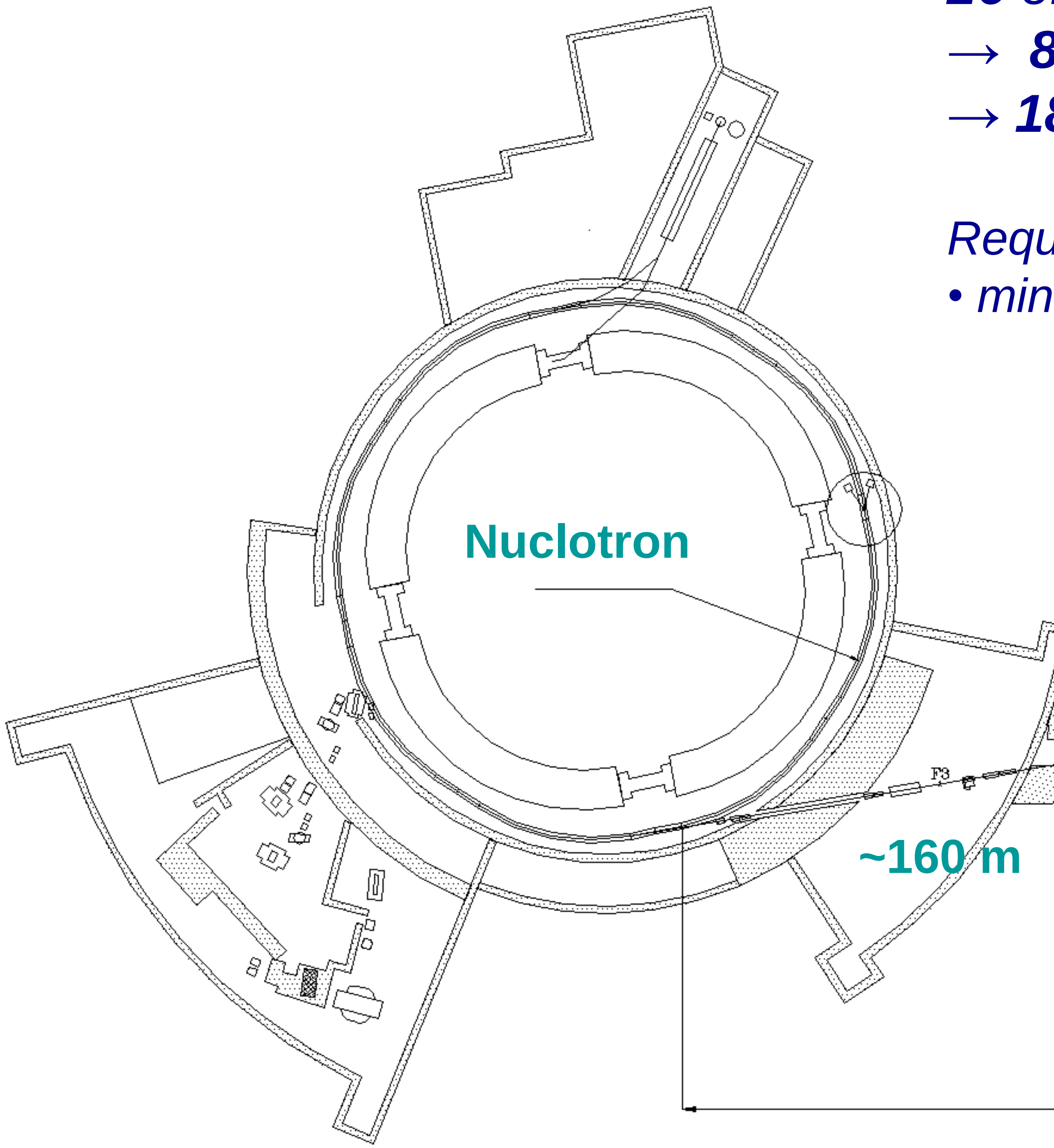
Parameter	Project (2017)	
Magnetic field, T	2.0 ($B\rho$ = 42.8 T·m)	
Field ramp, T/s	1.0	
Repetition period, s	5.0	
	Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	7.0	$5 \cdot 10^{10}$
Heavy ions	*With KRION-6T & Booster*	
$^{40}Ar^{18+}$	5.9	$2 \cdot 10^{10}$
$^{56}Fe^{26+}$	6.4	$1 \cdot 10^{10}$
$^{124}Xe^{48/42+}$	5.0	$2 \cdot 10^{9}$
$^{197}Au^{79+}$	5.5	$2 \cdot 10^{9}$
Polarized beams	*With SPI*	
p↑	12.9	$1 \cdot 10^{10}$ *)
d↑	6.6	$1 \cdot 10^{10}$

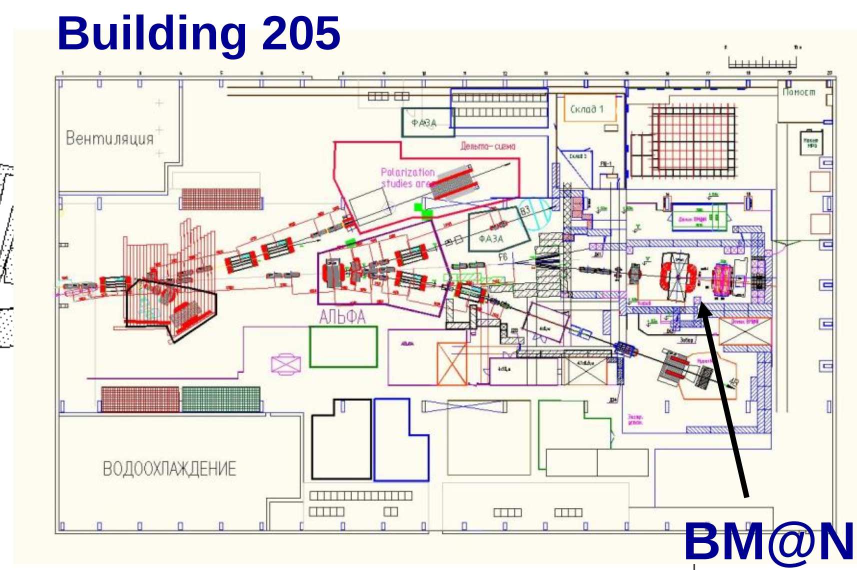
*) *With the Siberian snake*

Nuclotron to BM@N beam line

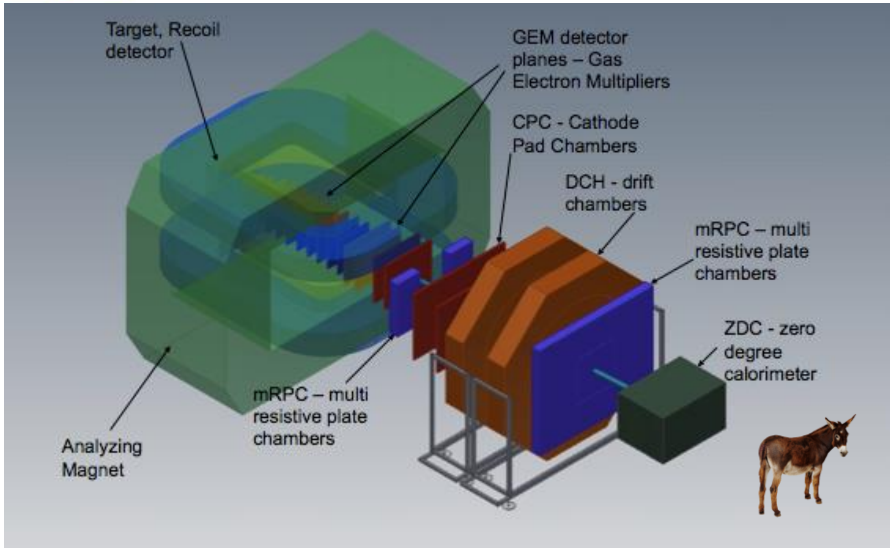
***26** elements of magnetic optics:*
*→ **8** dipole magnets*
*→ **18** quadruple lenses*

Requirements for Au beam:
- *minimum dead material*
  → need to replace air intervals /foils with vacuum





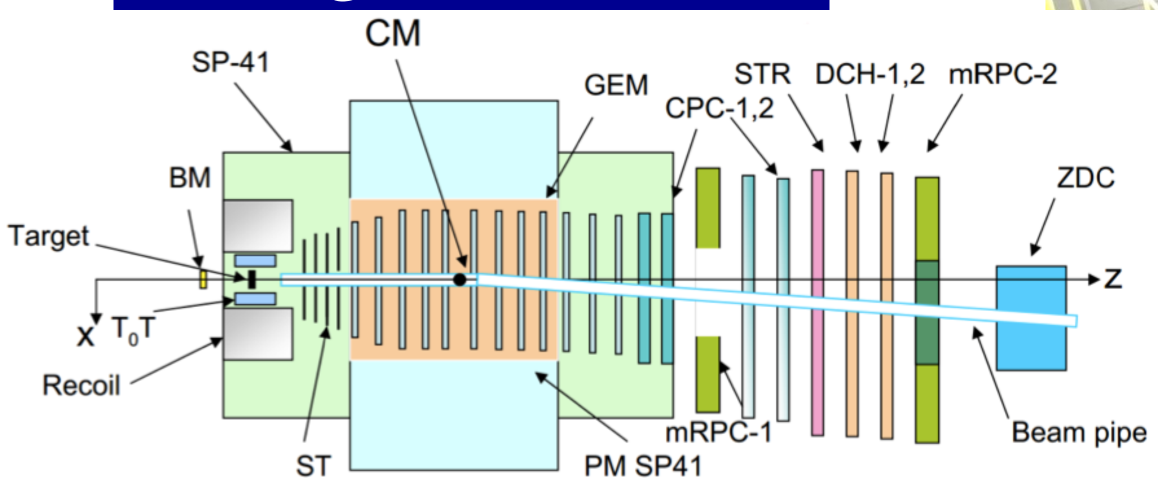
BM@N (Baryonic Matter at Nuclotron): *the 1st stage*

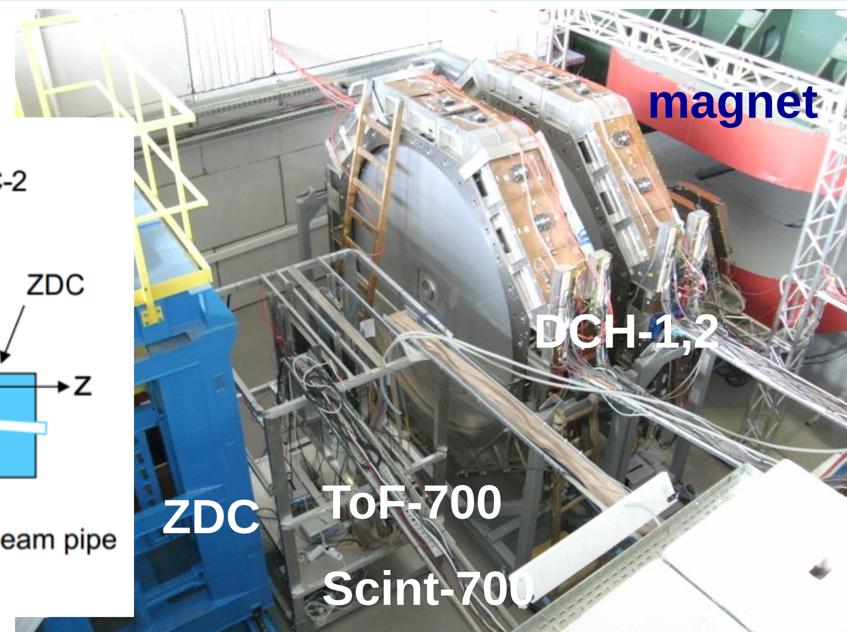


Expression of interest from scientists:
IN, SINP MSU, IHEP + S-Ptr Univ. (RF);
GSI, Frankfurt U., Gissen U. (Germany):
+ CBM-MPD IT-Consortium,

Physics:
- ✓ *hyperon production*
- ✓ *hadron femtoscopy*
- ✓ *in-medium effects for strange & vector mesons*
- ✓ *electromagnetic probes (optional)*

BM@N *schematic view*

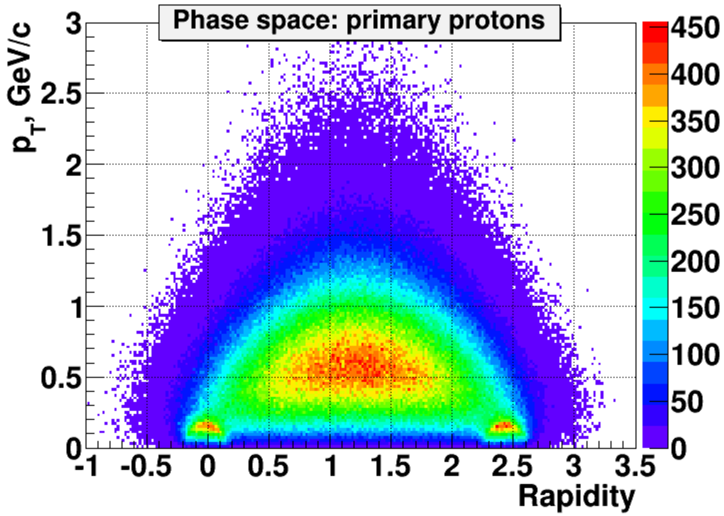


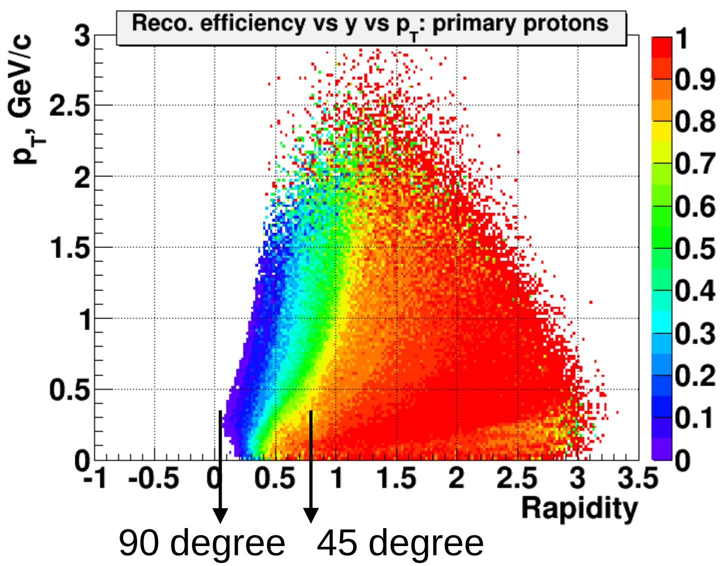


GEM tracker *(12 planes)*

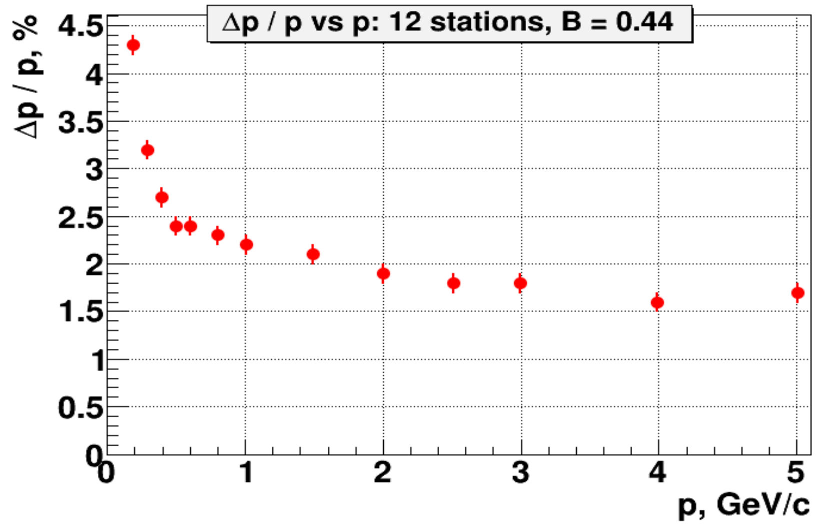
A.Zinchenko

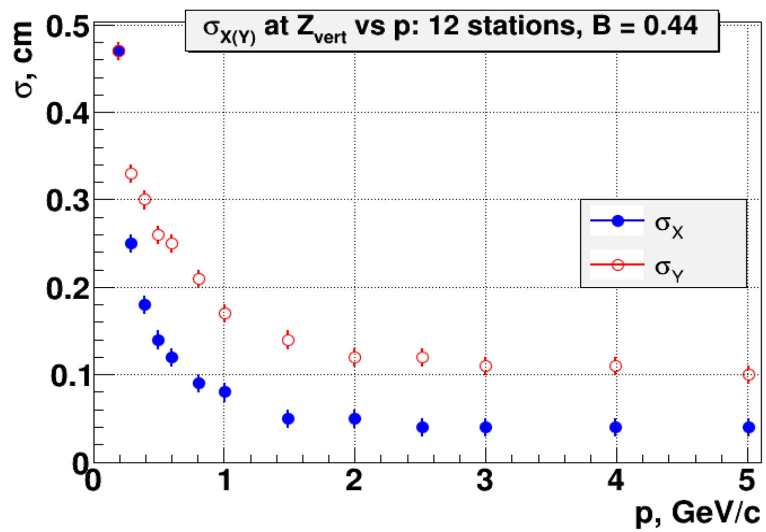
Phase space / acceptance to primary p





Momentum and vertex resolutions



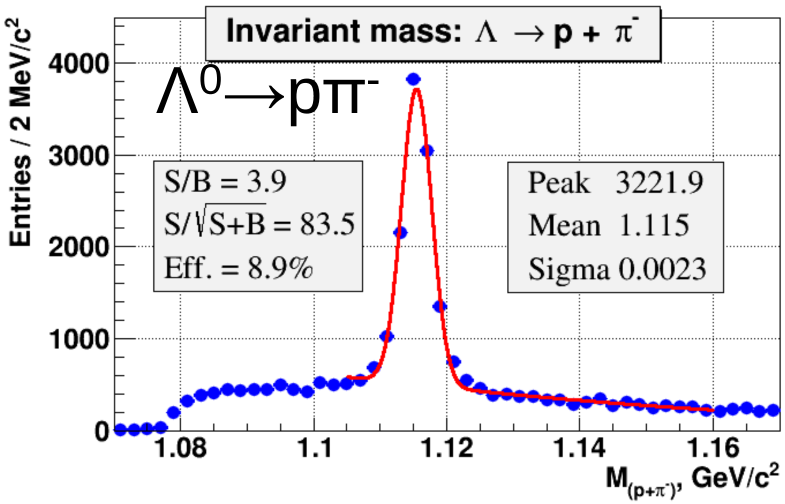


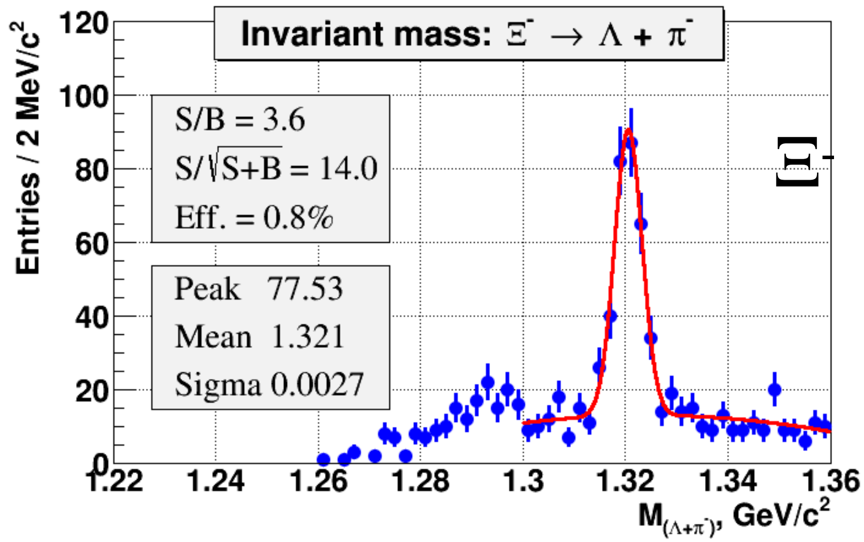
GEM tracker: Λ^0, Ξ^-, ${}^3H_\Lambda$ reconstruction

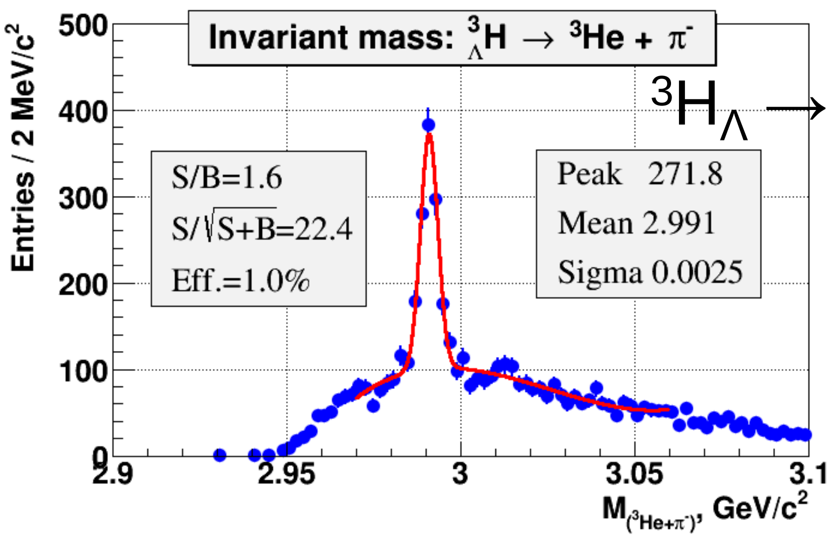
A.Zinchenko, V.Vasendina

12 planes of GEM tracker

UrQMD & DCM-QGSM, Au+Au, $E_{kin.}$ = 4.5A GeV, 2 ×10^6 events;

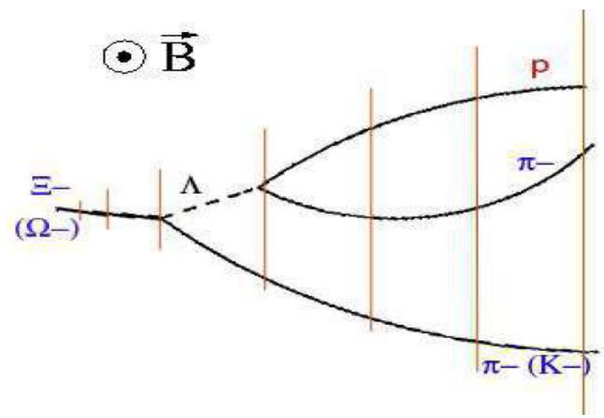






${}^3H_\Lambda \rightarrow {}^3He\ \pi^-$

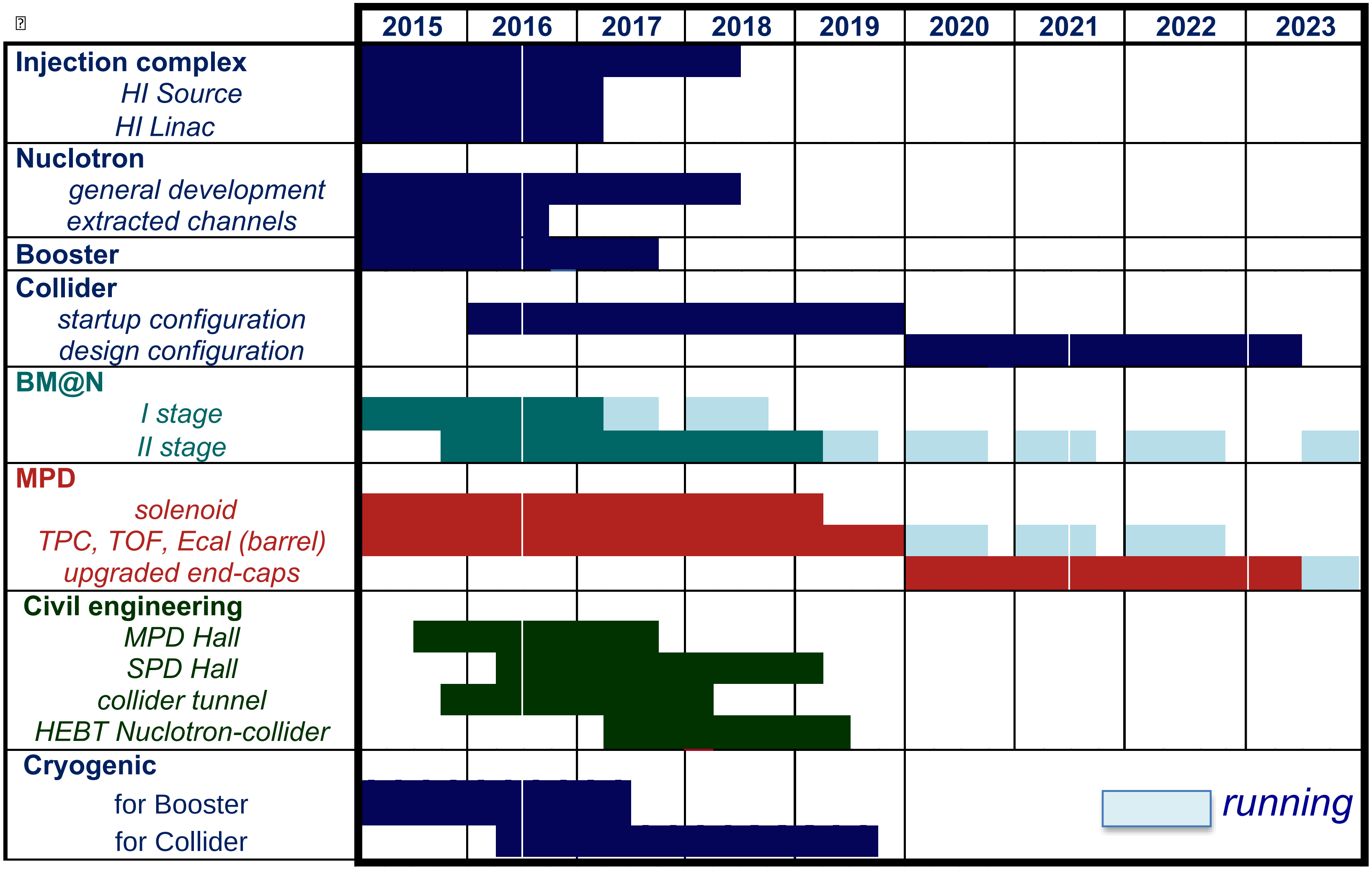
$\Xi^- \rightarrow \pi^- + \Lambda^0 \rightarrow p\pi^-$



BM@N milestones

• **ZDC** *complete configuration*	**2016**
• **DAQ** *complete config.*	*end* **2017**
• **GEM** *8 planes*	*end* **2017**
• **TOF** *complete config.*	*end* **2017**
• **GEM** *12 planes*	*end* **2018**
• **ST** *4 planes*	**2019**
• *technical runs with* ***d, C, Li***	**2015 - 2017**
• *physics run* **BM@N** *(I stage) with* ***p, Xe***	*Nov* **2017**
• *physics run* **BM@N** *(II stage) with* ***Au***	*Feb* **2019**

NICA schedule



International cooperation

Armenia
Australia
Azerbaijan
Belarus
Bulgaria
Brazil
CERN
China
Cuba
Czech
Rep.
DPRK
France
Georgia
Germany
Greece
India

Italy
Japan
Kazakhstan
Moldova
Mongolia
Poland
Romania
RSA
Russia
Serbia
Slovakia
Ukraine
USA
Uzbekistan
Vietnam

Concluding remarks

- **NICA complex has a potential for competitive research** ***in the fields of dense baryonic matter***
- **The construction of both detectors BM@N & MPD** ***is progressing***
- **The international collaboration around the NICA** ***is growing***
- **New partners are invited to join the BM@N & MPD**

Thank you!