# Status of the NICA project

***V.Kekelidze,***

***Joint Institute for Nuclear Research, Dubna***


CREMLIN Kick-off meeting

October 6, 2015

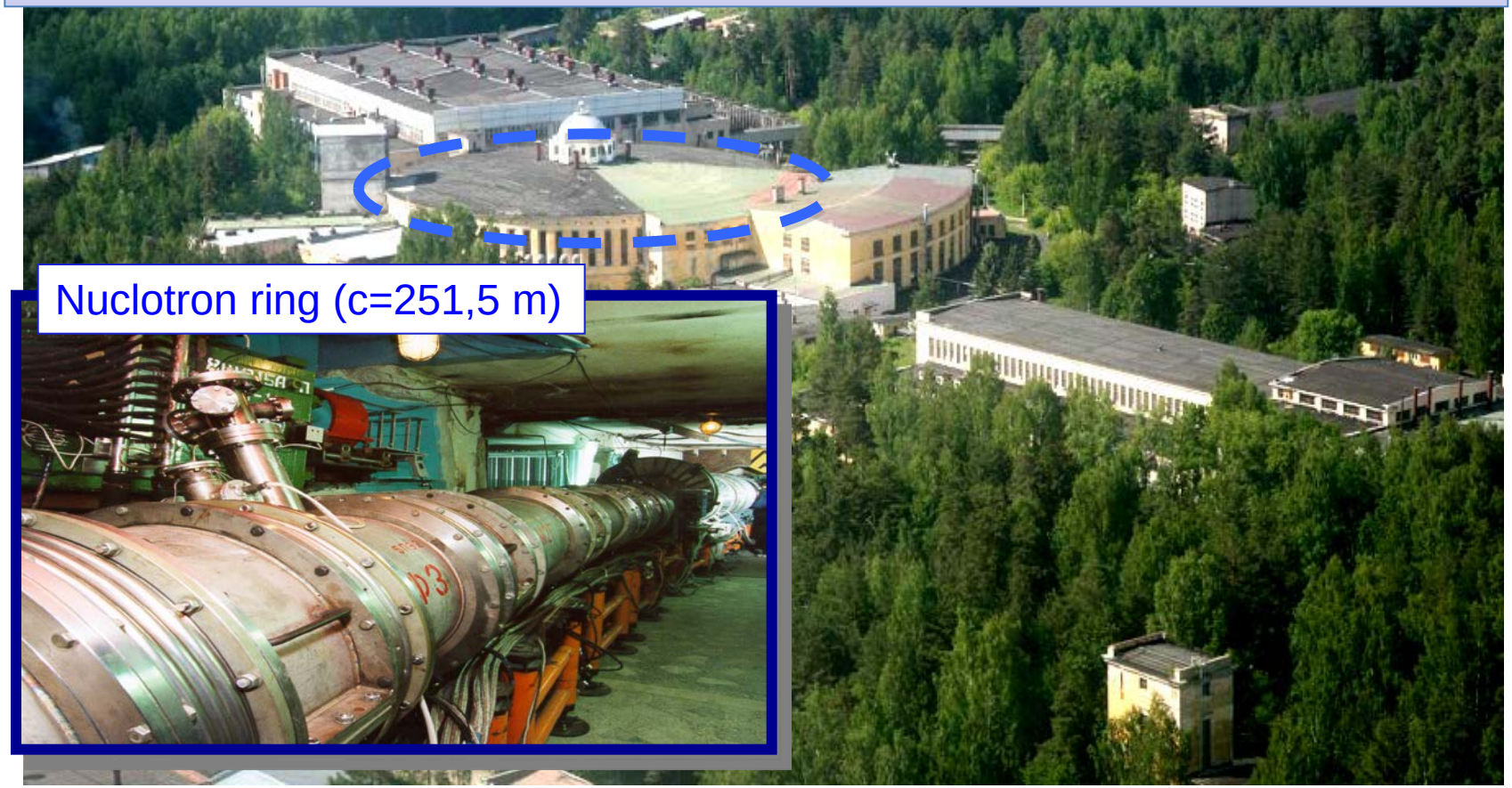
## *NICA (Nuclotron based Ion Colider fAcility) – the flagship project in HEP of Joint Institute for Nuclear Research (JINR)*

**Main targets of the NICA project:**

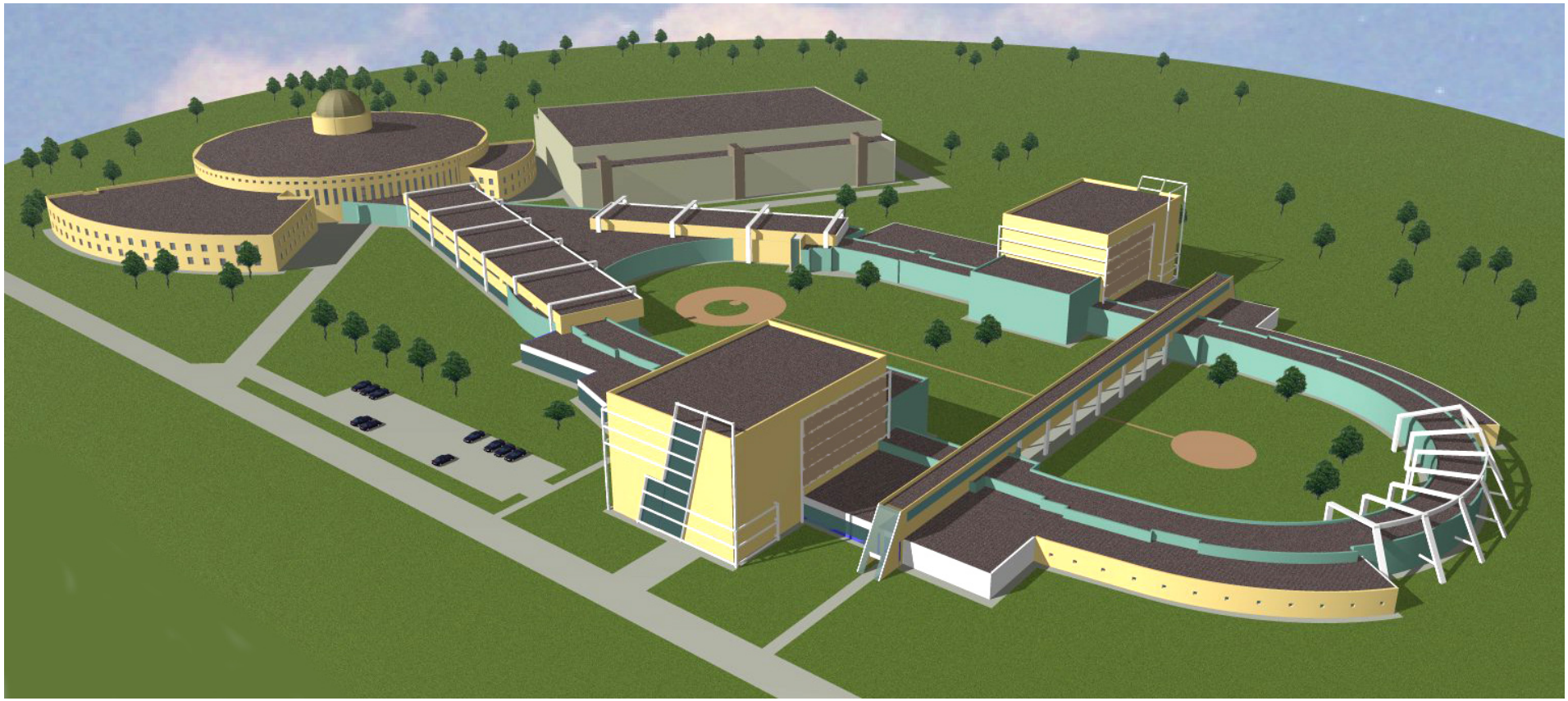
- ***study of hot and dense baryonic matter***
- *investigation of nucleon spin structure, polarization phenomena*
- *development of accelerator facility for HEP @ JINR providing intensive beams of relativistic ions from p to Au polarized protons and deuterons with max energy up to* $\sqrt{S_{NN}}$ *= 11 GeV ($Au^{79+}$) and =27 GeV (p)*

# Synchrotron **Nuclotron** is one of the two SC machines operating in Europe

*It is based on the superconducting fast cycling magnets – technology developed in Dubna*

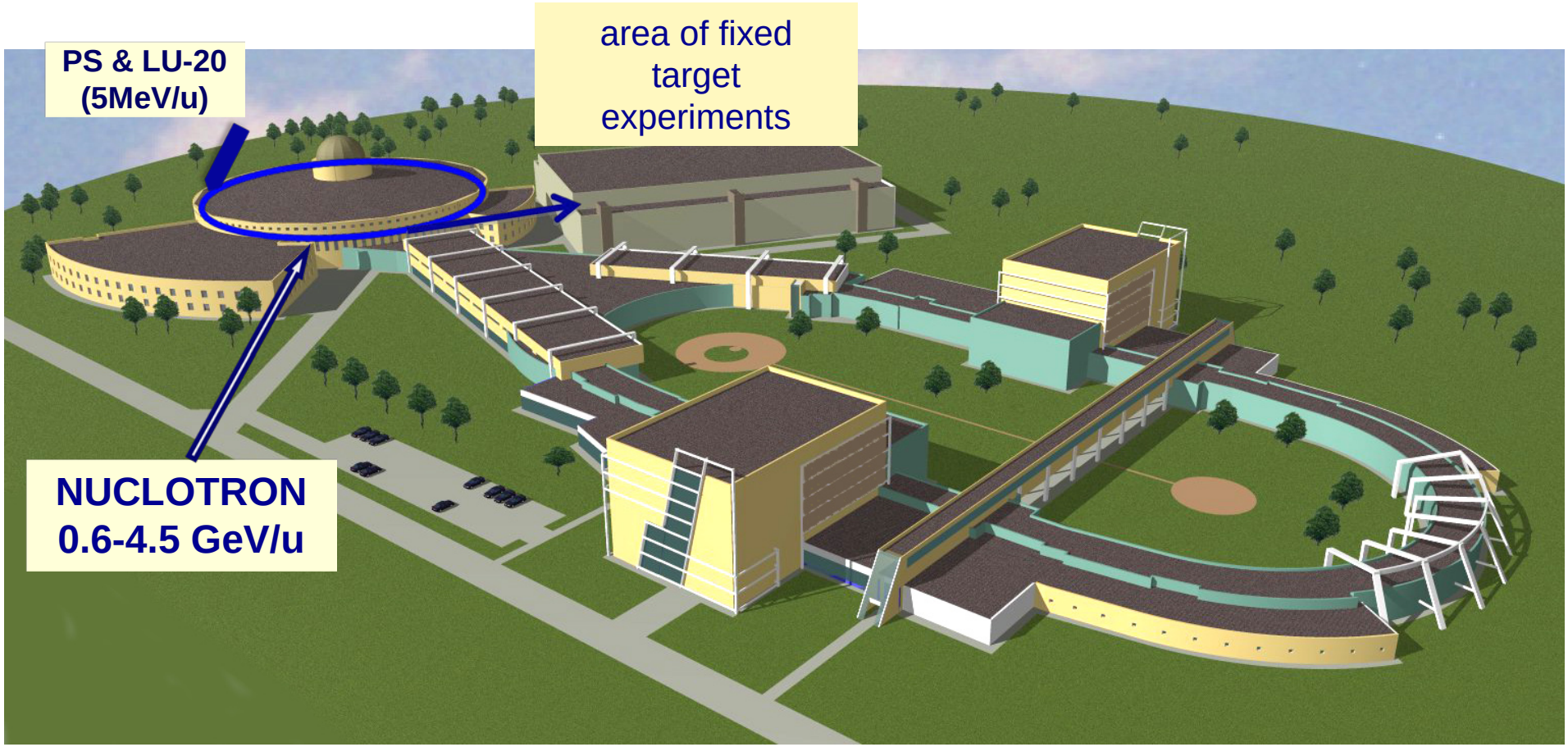


# NICA complex



# NICA complex

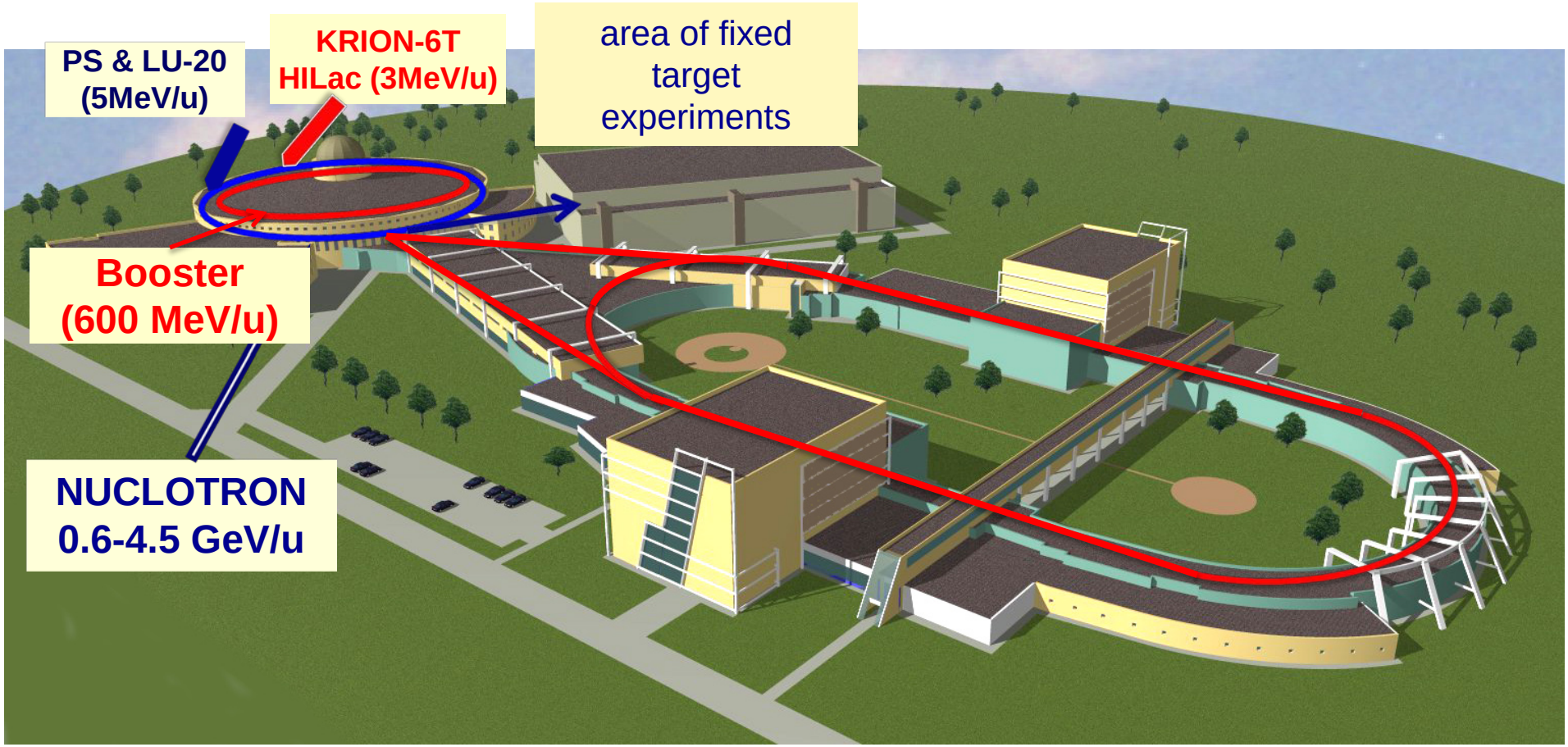
## existing facility



# NICA complex

existing facility

to be constructed



# NICA complex

existing facility

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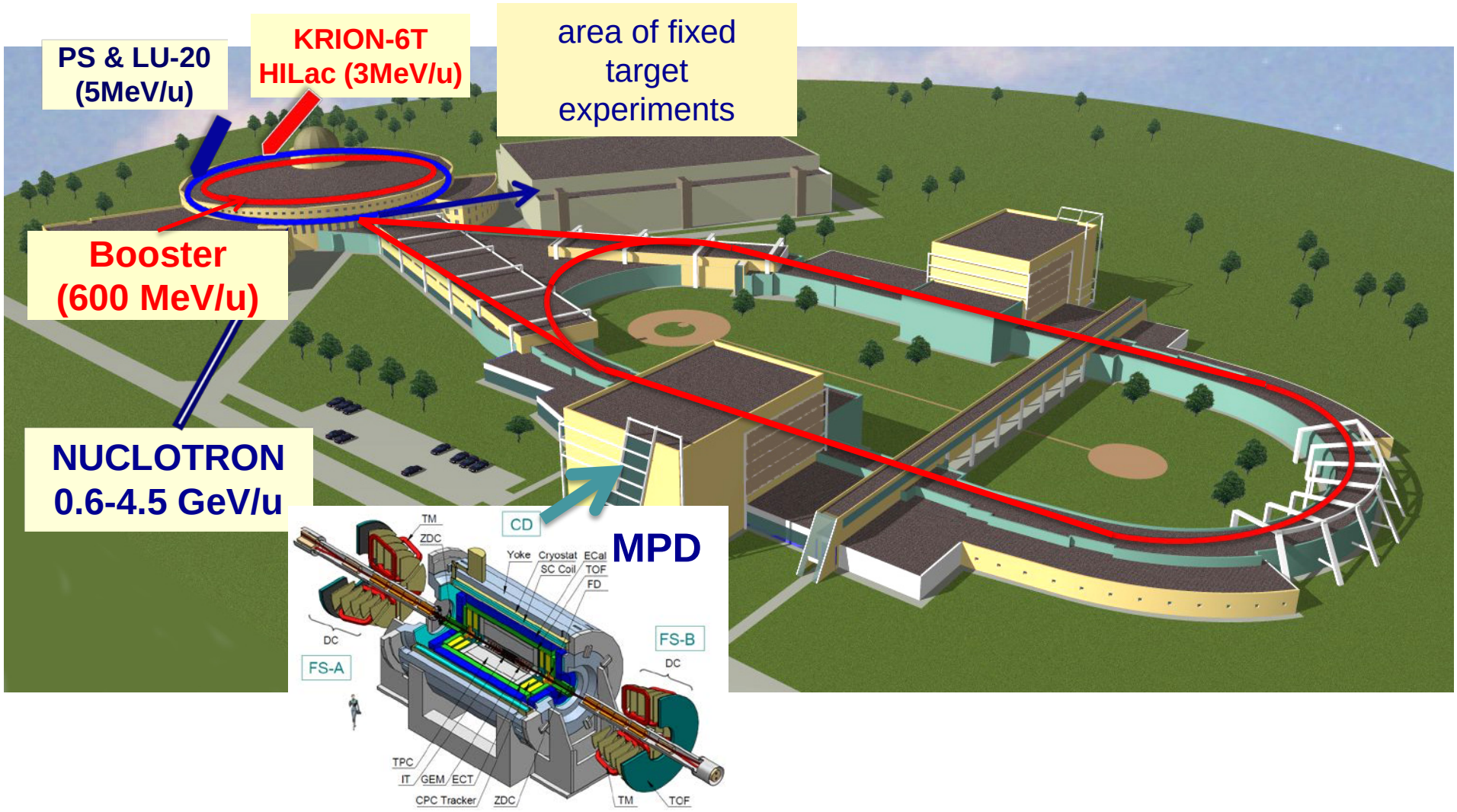
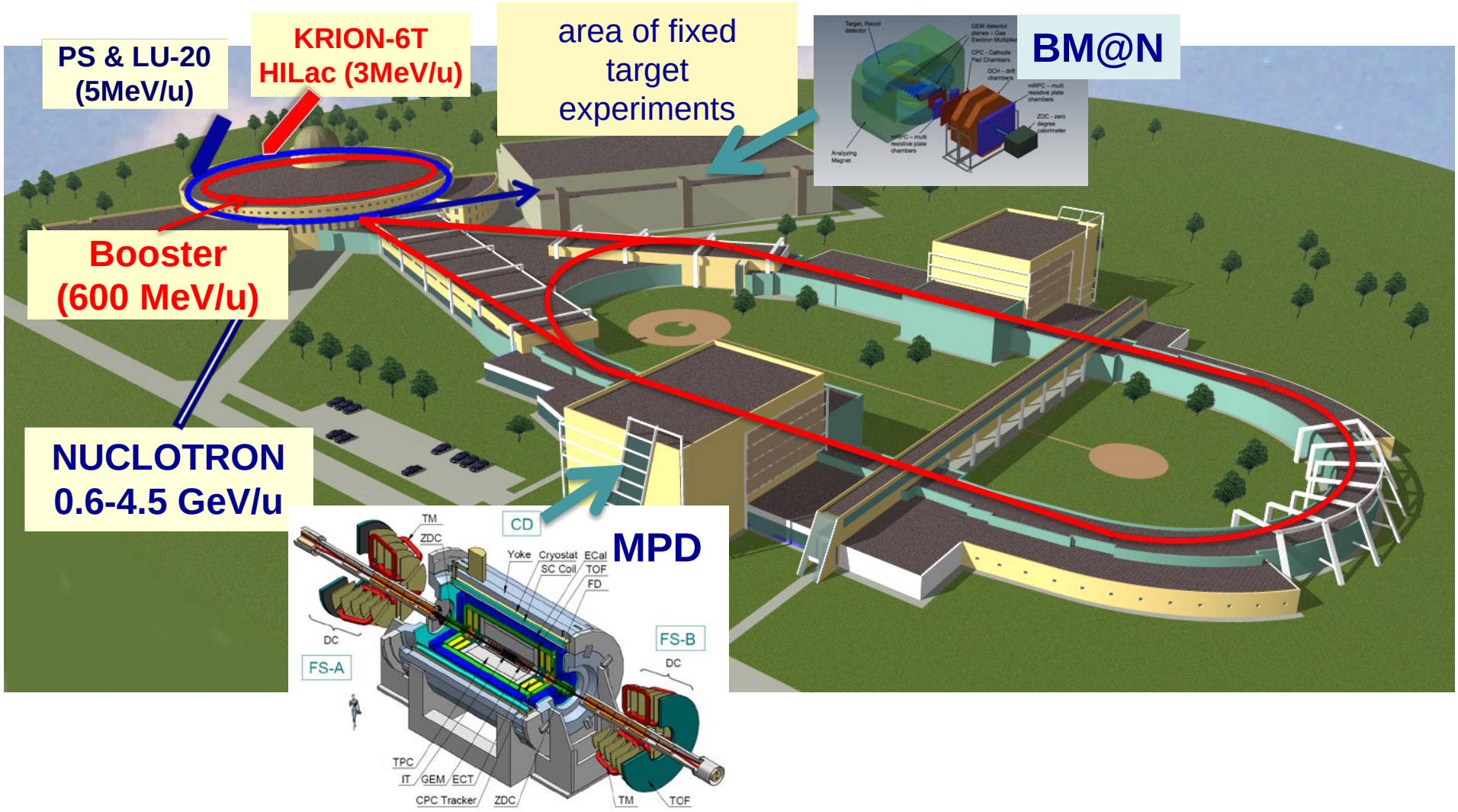


# NICA complex

existing facility

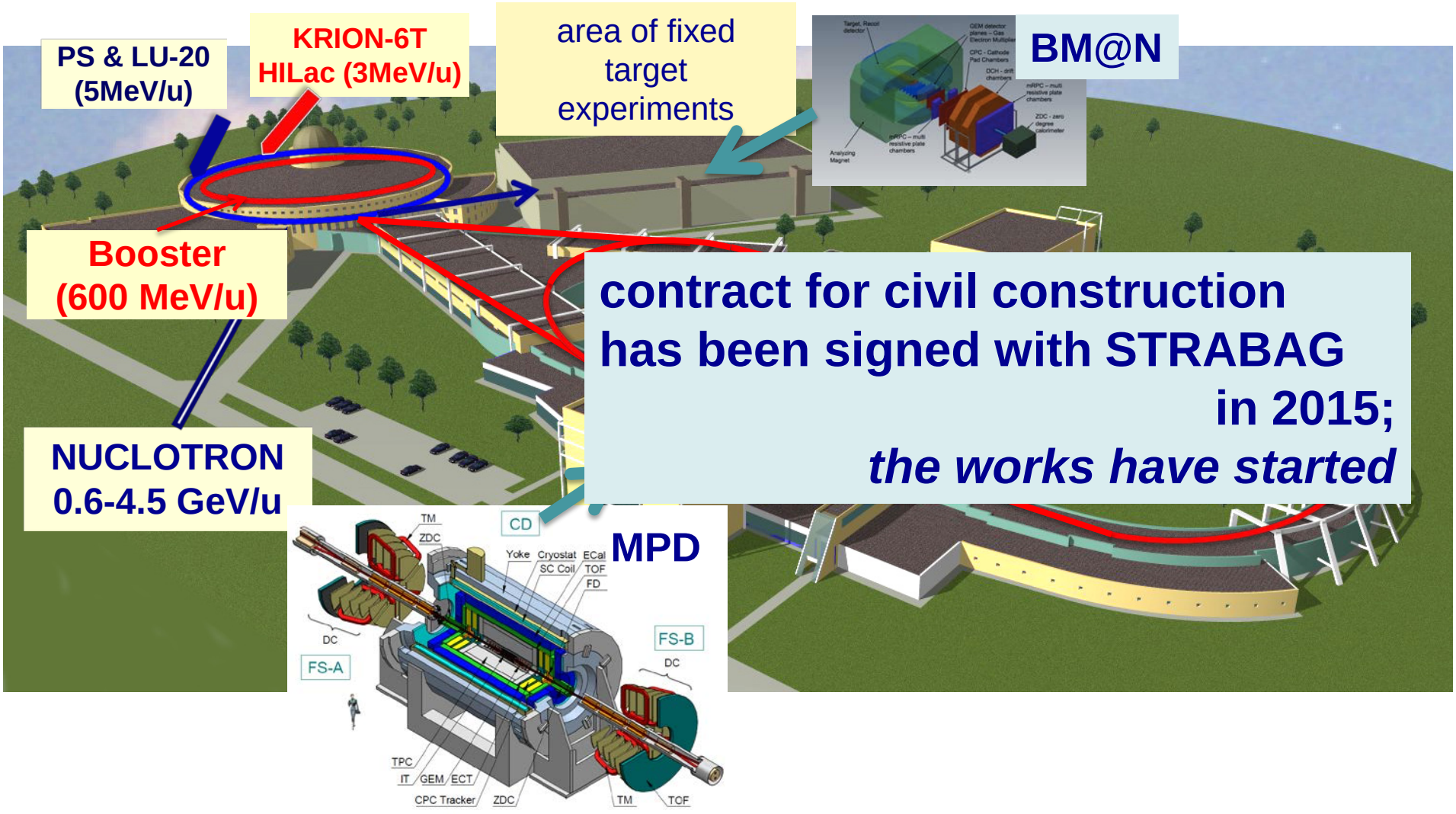
to be constructed



# NICA complex

existing facility

to be constructed



# NICA collider major parameters

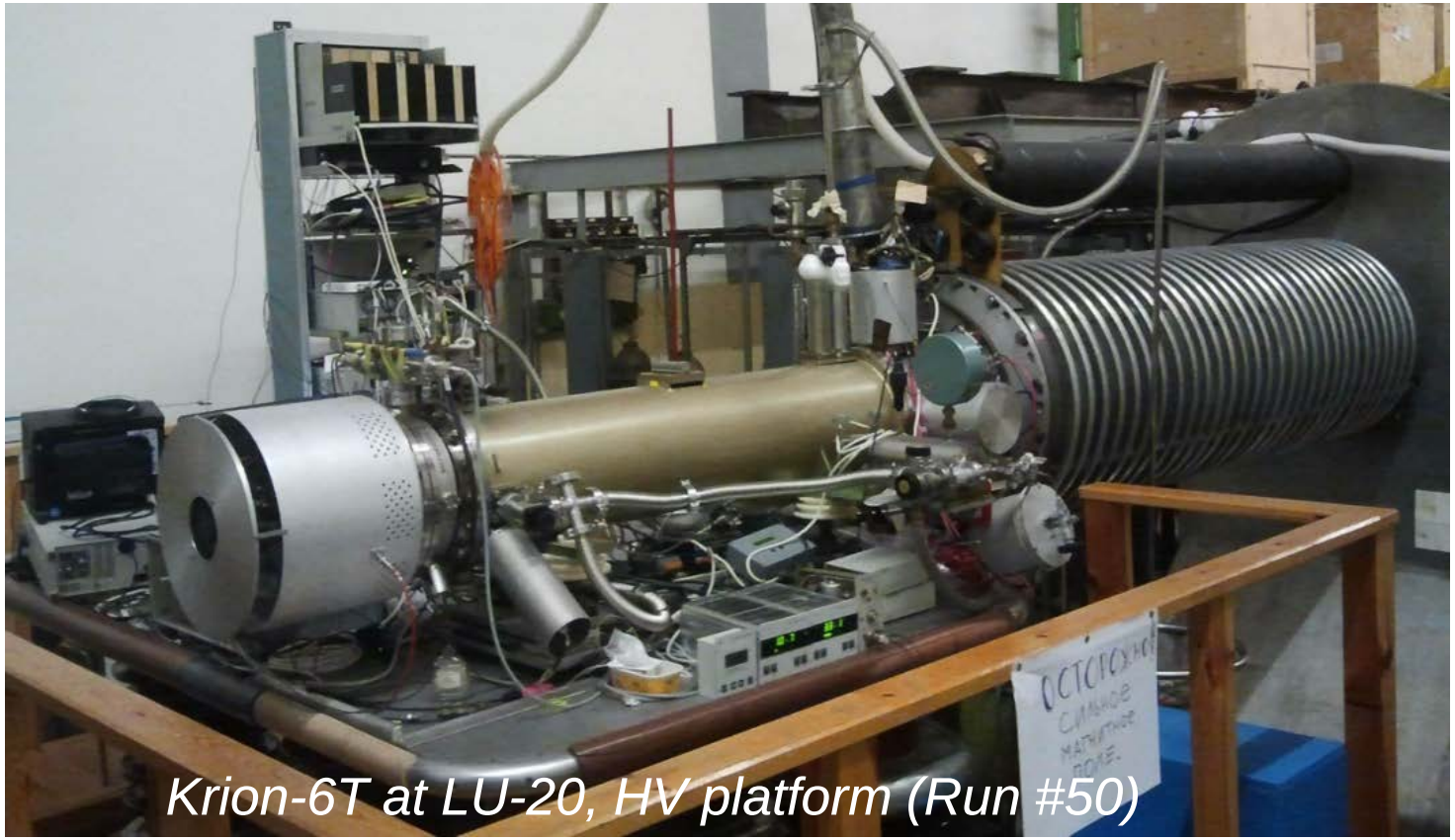
| | |
|---|---|
| *Ring circumference, m* | **503.04** |
| ***heavy ions*** | |
| *$\beta$, m* | **0.35** |
| *energy range for **Au**$^{79+}$: $\sqrt{S_{NN}}$, GeV* | **4 - 11** |
| *r.m.s. $\Delta p/p$, $10^{-3}$* | **1.6** |
| *Luminosity for **Au**$^{79+}$, cm$^{-2}$ s$^{-1}$* | **1x10$^{27}$** |
| **polarized particles** | |
| *max. energy for polarized **p**, Gev* | **27** |
| *Luminosity for **p**, cm$^{-2}$ s$^{-1}$* | **1x10$^{32}$** |

# Status of the accelerator complex

# Krion-6T (*Electron String Ion Source*)

**Project parameters:** *magnetic filed up to 6.0 T, electron energy up to 15 keV*

- *B= 5.4 T reached in a robust regime;*
- *produced beams*: $Au^{30+} \div Au^{32+}$, $6 \cdot 10^8$ ppp, repetition rate 50Hz



*Krion-6T at LU-20, HV platform (Run #50)*

# Source for polarized particles (SPP)

*Source has been assembled; now it is commissioned to achieve*
***$10^{10}$** polarized deuterons pp; the first beam run is foreseen in beg of 2016*

# NICA Heavy ion injector (HILAC)

*RFQ section installation in new hall*

*RF system assembled in new hall (world unique)*

*Design & fabrication by "BEVATECH OHG" Germany,*

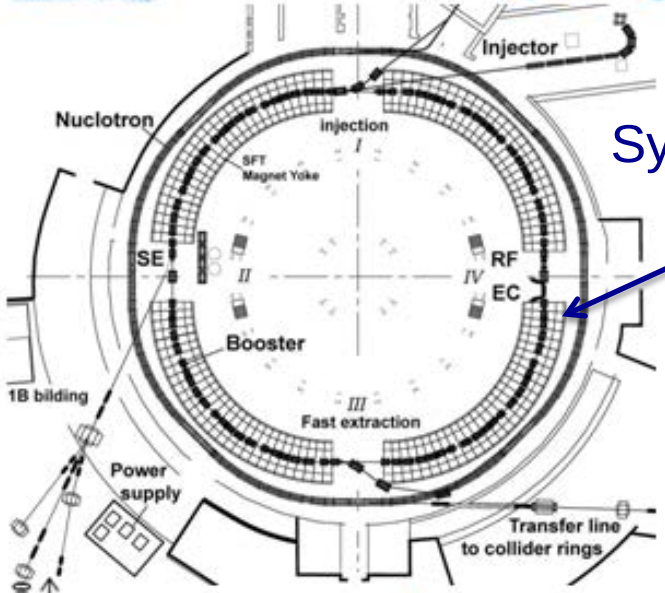
***Commissioning in 2015***

# The Booster

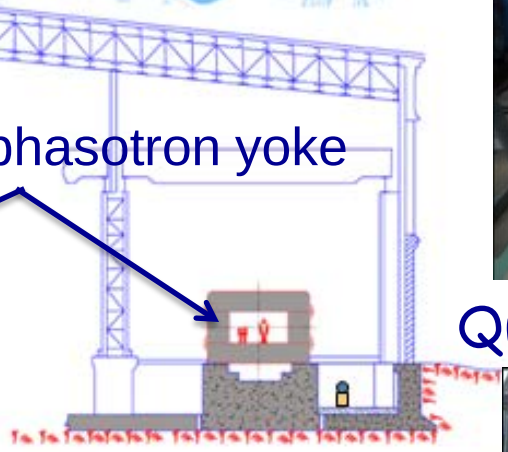
**Booster synchrotron:** *C = 211m,*
*25 T*m, 600 MeV/u for $Au^{31+}$*
*ultra high vacuum, electron cooling*

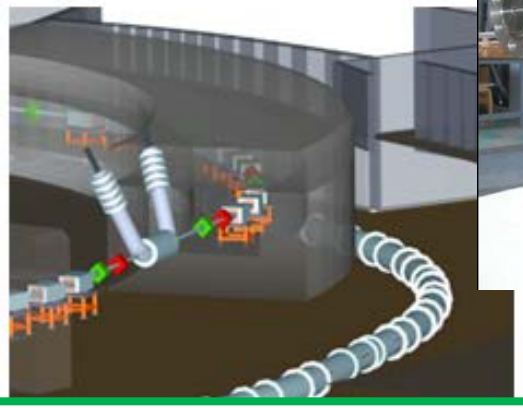
Dipole SC magnet

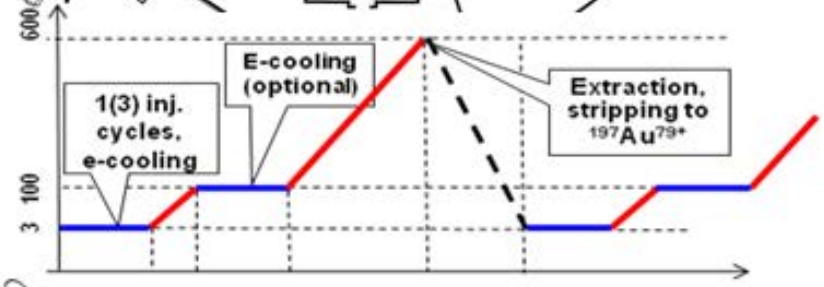
Quadrupole SC magnet




Synchrophasotron yoke



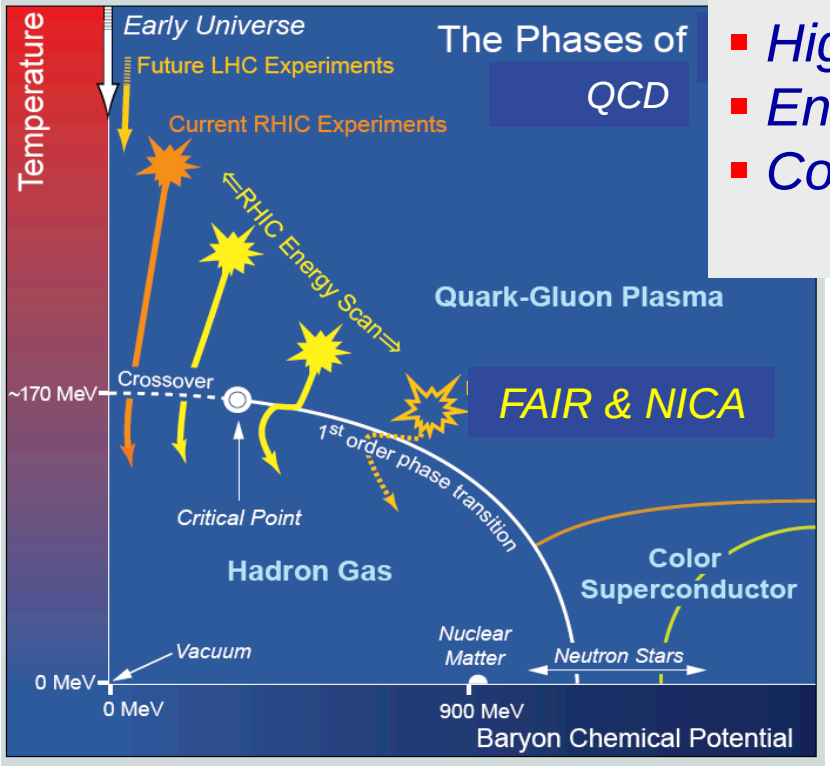




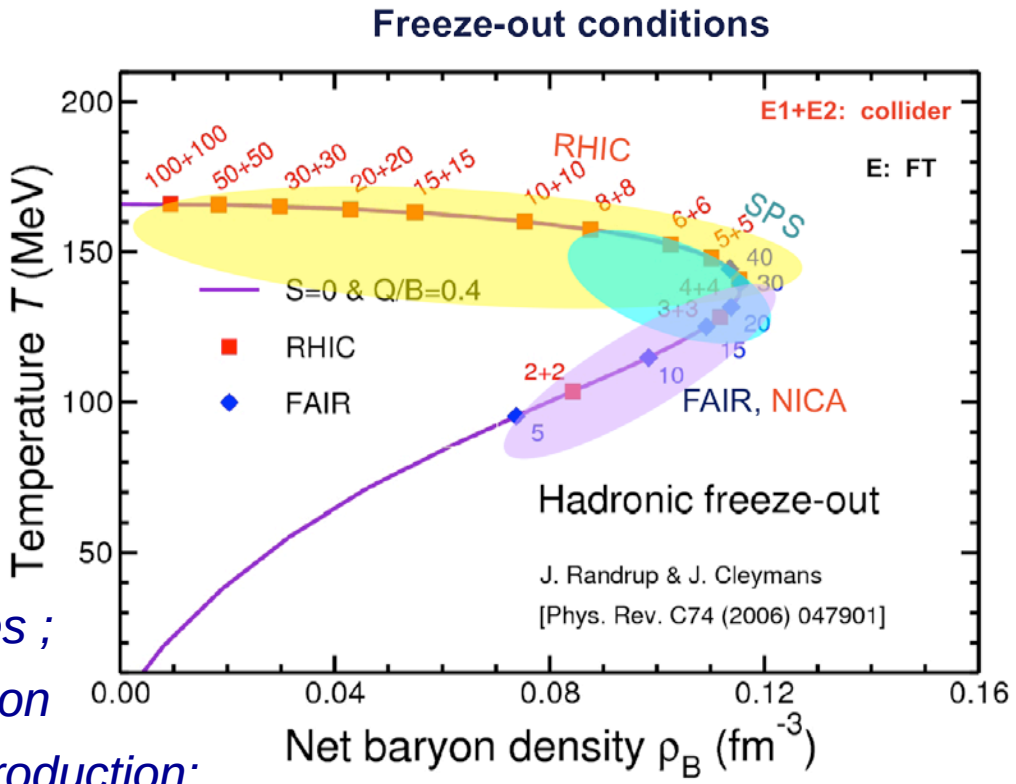
# SC Magnets for Booster, Collider & SIS-100/FAIR workshop at VBLHEP JINR *(joint project **BMBF-JINR**)*

# Physics objectives
# *in heavy ion collisions*

# 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 $\rho_B$ - enhanced strangeness production;*
- *QCD Critical Point - event-by-event fluctuations & correlations;*
- *Strangeness in nuclear matter - hypernuclei*

# *Experimental modes*

**collider** **fixed target**

**advantages:**

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

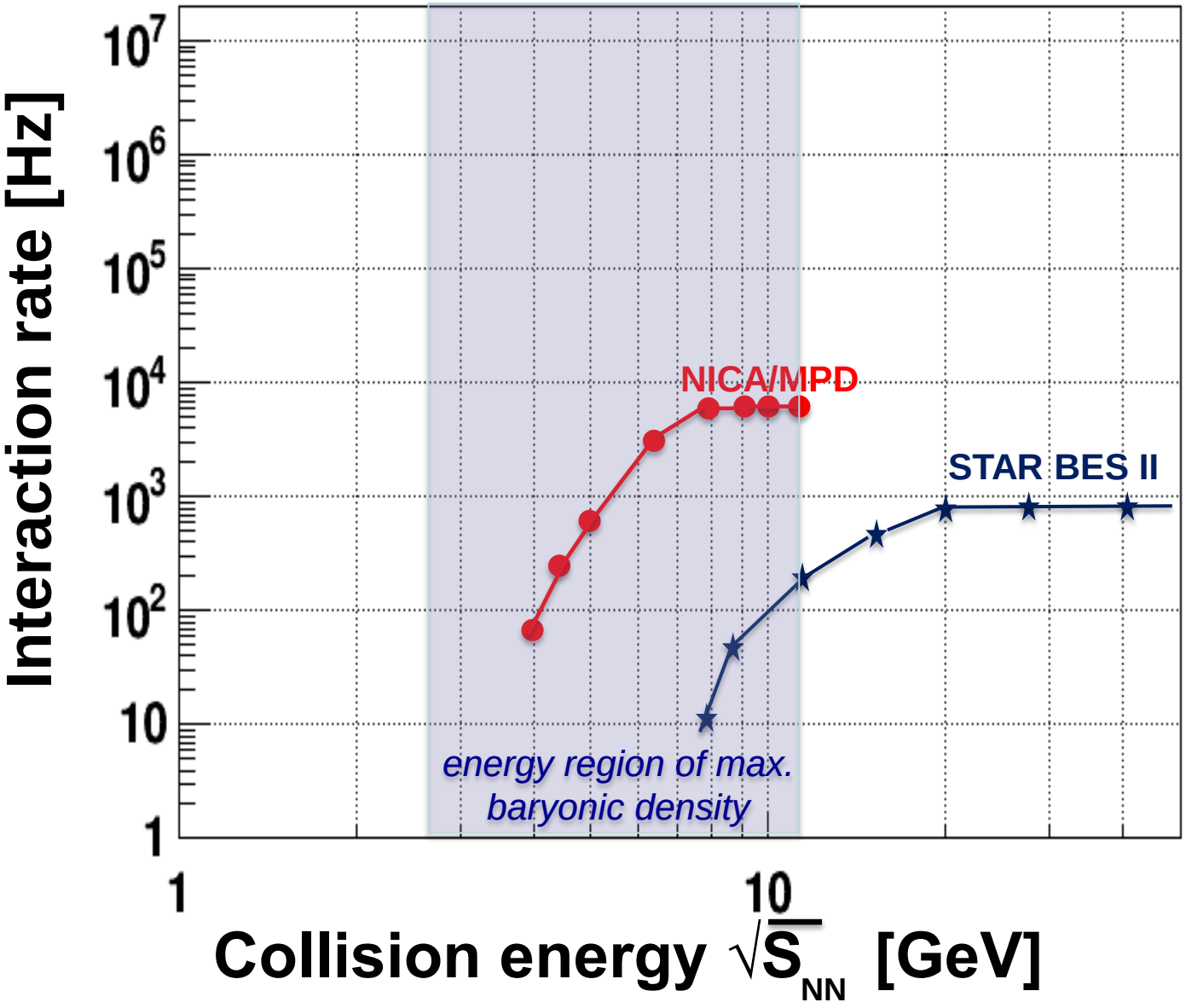
- *rate is limited just by detector capability*
- *easy upgradable*
- *….*

**disadvantages:**

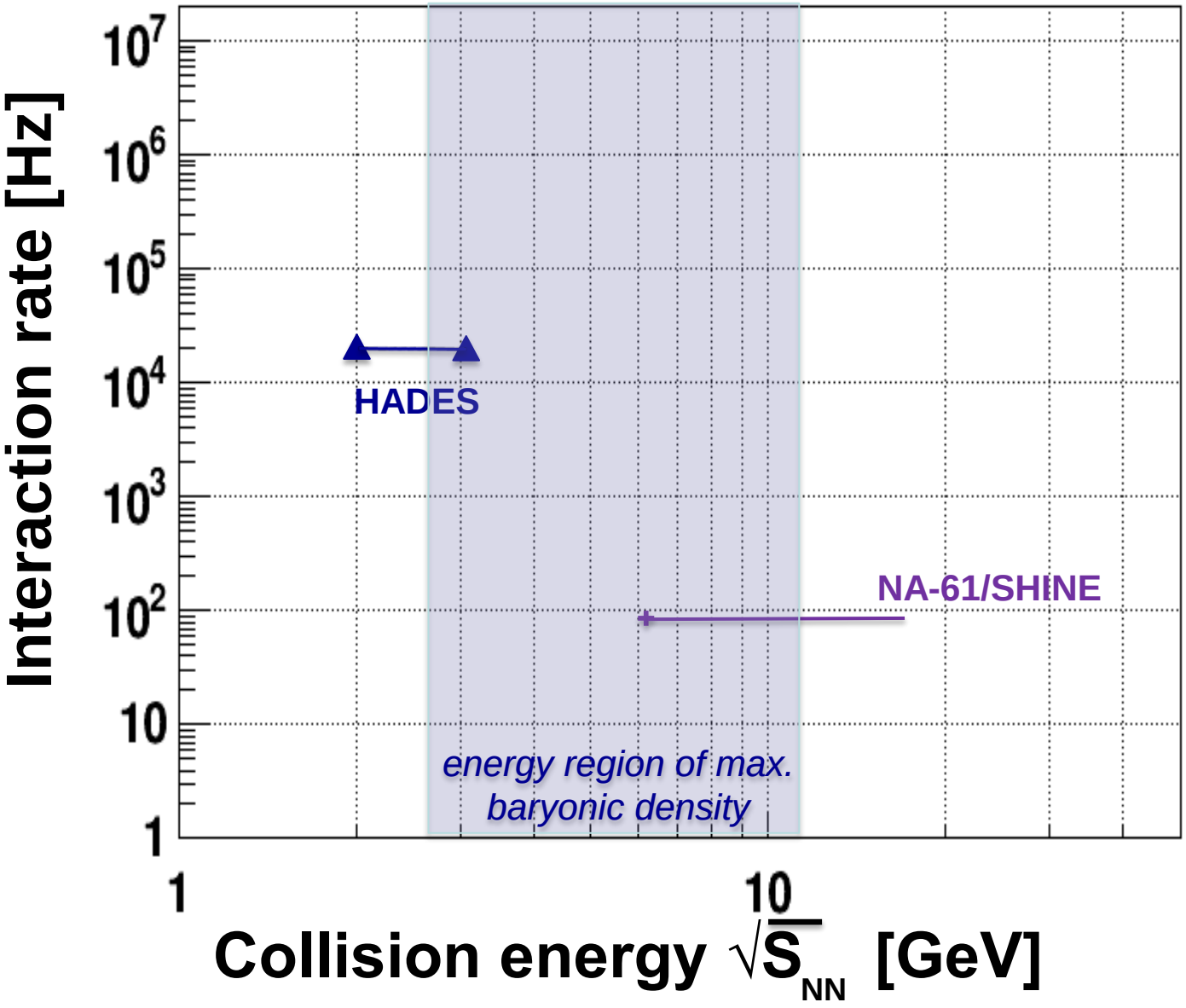
- *rate is limited by luminosity*
- *limited combinations "beam"/"target"*
- *…..*

- *a limited phase space*
- *momentum dependent corrections*
- *target influenced corrections*

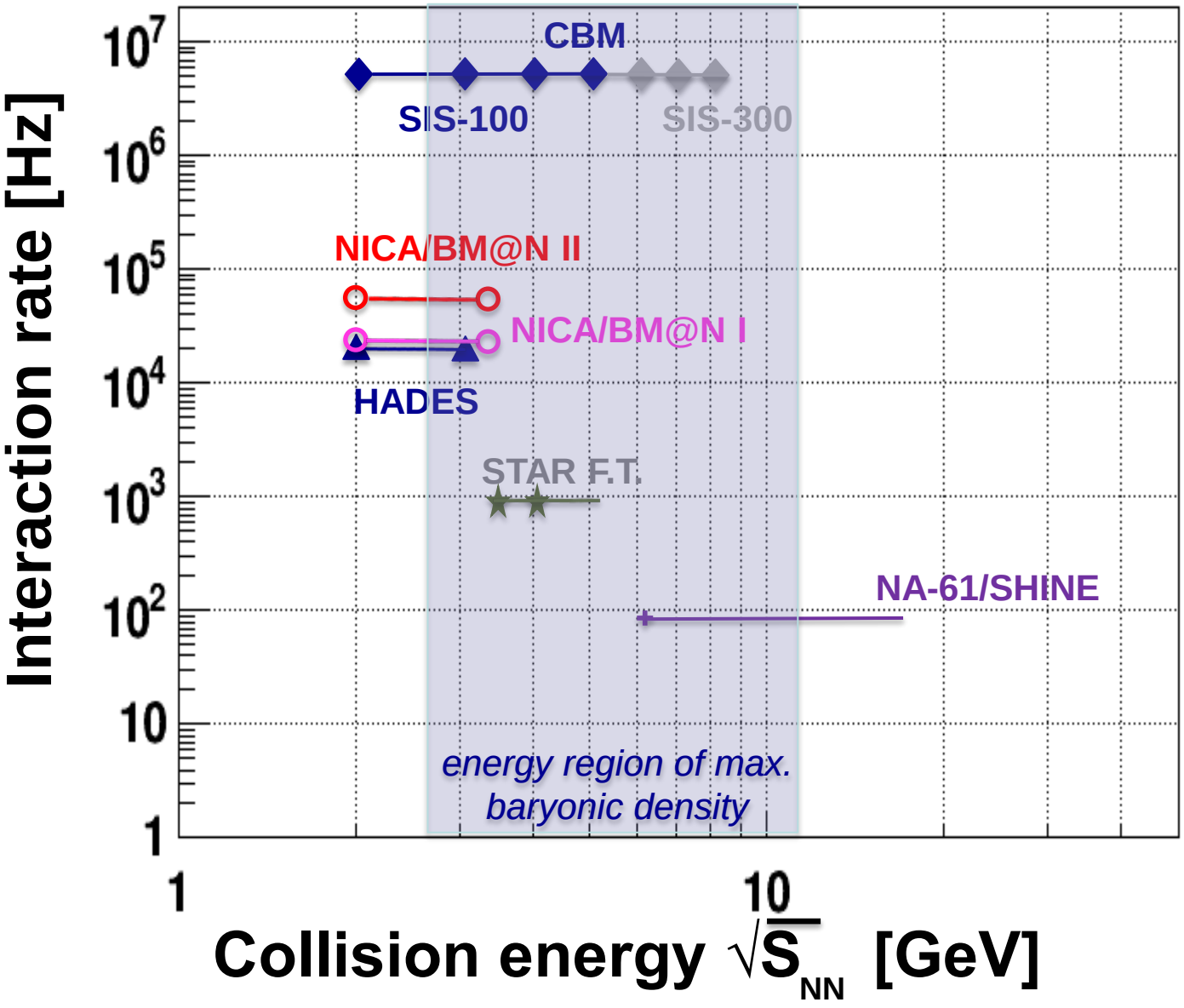
# Present and future HI collider experiments



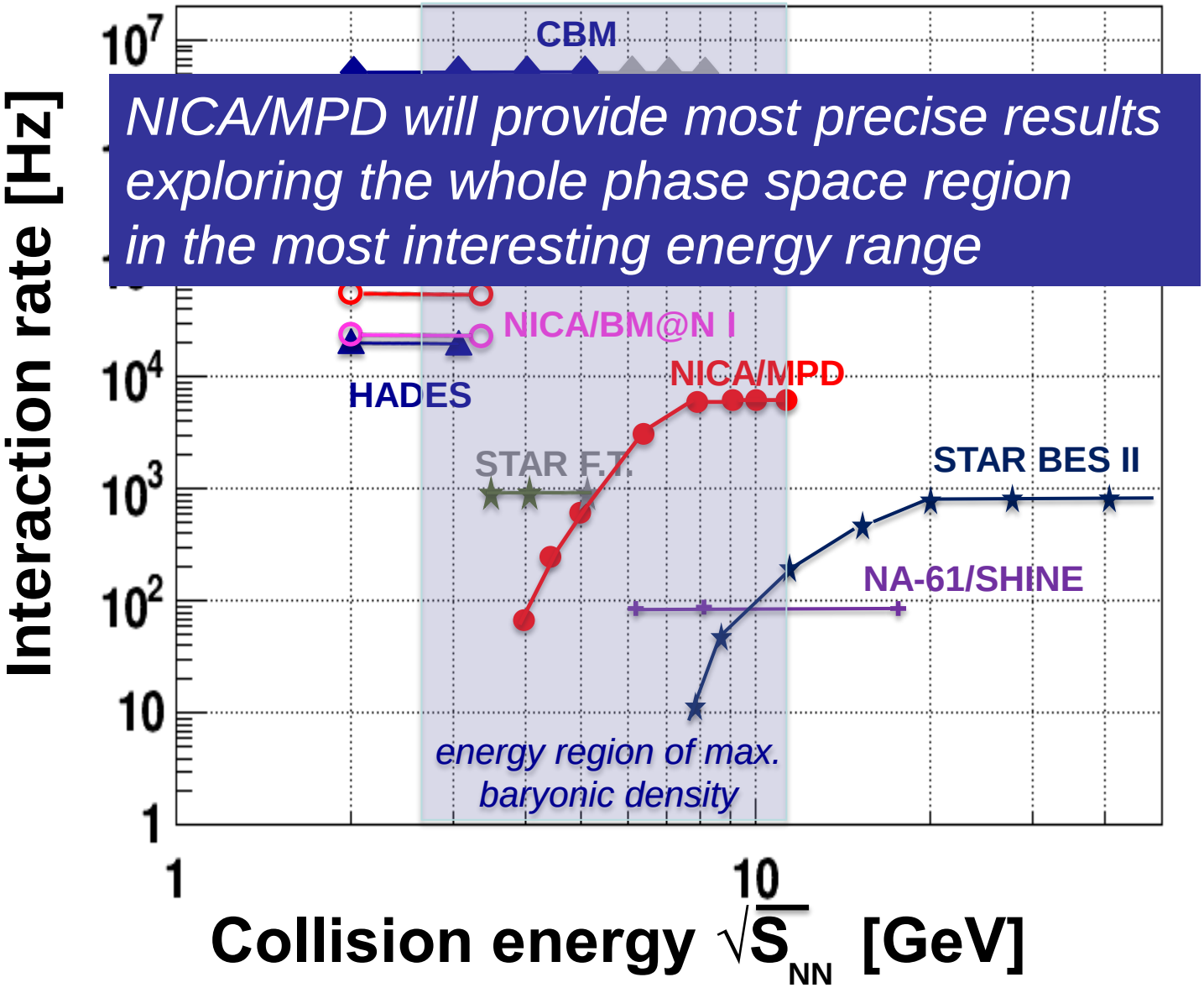
# Present HI F.T. experiments



# Present and future HI F.T. experiments



# Present and future HI experiments/machines



**Both, collider and fixed target approaches,**
**are complementary and necessary**
**for approval of potential discovery**

In this view the **NICA** and **FAIR** projects are complementary and their joined efforts have aimed to discovering and to studying new forms of baryonic matter

# Physics objectives
# *in spin physics*

# Spin Physics

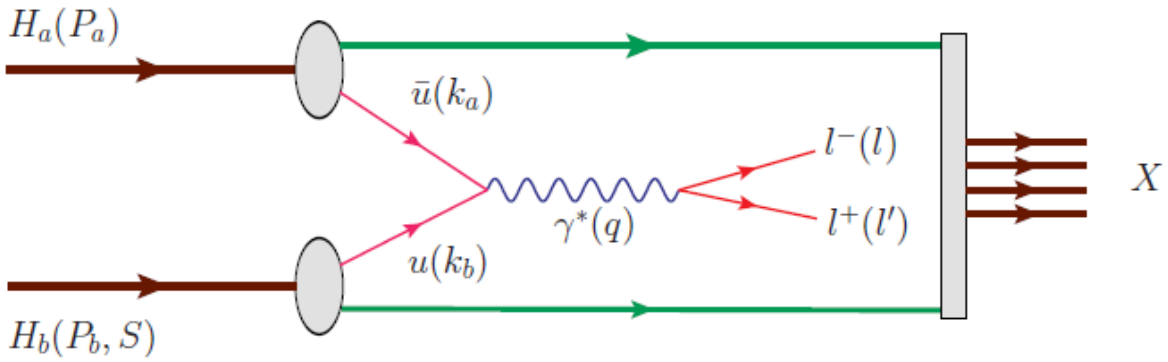
**Nucleon spin structure studies**

**using the Drell-Yan mechanism (new PDFs)**

- *8 intrinsic-transverse-momentum dependent PDFs at leading twist*
- *azimuthal asymmetries with different angular modulations*

*in the hadron and spin azimuthal angles, $\Phi_h$ and $\Phi_s$*

**Direct photons production (gluon polarization)**



# Experiments to study nucleon spin structure

| *experiment* | CERN, COMPASS-II | FAIR, PANDA | FNAL, E-906 | RHIC, STAR | RHIC-PHENIX | NICA, SPD |
|---|---|---|---|---|---|---|
| mode | *F.T.* | *F.T.* | *F.T.* | *collider* | *collider* | *collider* |
| Beam/target | *π- , p* | *anti-p, p* | *π- , p* | *pp* | *pp* | *pp, pd,dd* |
| Polarization:b/t | *0; 0.8* | *0; 0* | *0; 0* | *0.5* | *0.5* | *0.7* |
| Luminosity | $2 \cdot 10^{33}$ | $2 \cdot 10^{32}$ | $3.5 \cdot 10^{35}$ | $5 \cdot 10^{32}$ | $5 \cdot 10^{32}$ | $10^{32}$ |
| √s , GeV | *14* | *6* | *16* | *200, 500* | *200, 500* | *10-26* |
| $x_{1(beam)}$ range | *0.1-0.9* | *0.1-0.6* | *0.1-0.5* | *0.03-1.0* | *0.03-1.0* | *0.1-0.8* |
| $q_T$, GeV | *0.5 -4.0* | *0.5 -1.5* | *0.5 -3.0* | *1.0 -10.0* | *1.0 -10.0* | *0.5 -6.0* |
| Lepton pairs, | *μ-μ+* | *μ-μ+* | *μ-μ+* | *μ-μ+* | *μ-μ+* | *μ-μ+, e+e-* |
| Data taking | *2015* | *>2025* | *2013* | *>2016* | *>2016* | *>2020* |
| Transversity | NO | NO | NO | YES | YES | YES |
| Boer-Mulders | YES | YES | YES | YES | YES | YES |
| Sivers | YES | YES | YES | YES | YES | YES |
| Pretzelosity | NO | NO | NO | NO | YES | YES |
| Worm Gear | NO | NO | NO | NO | NO | YES |
| Direct γ | NO | NO | NO | YES | YES | YES |

**SPD/NICA** will provide unique opportunity

*not available at other facilit*ies

to study all of the PDF in one experiment

and obtain the comprehensive information

on the nucleon spin structure

at high statistical level

with min. systematic uncertainties

# NICA White Paper – International Effort

NICA

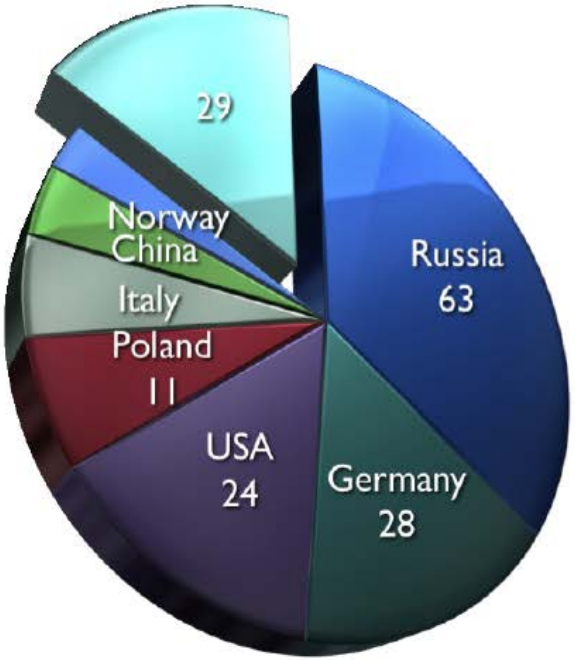
Draft v 8.03
January 24, 2013

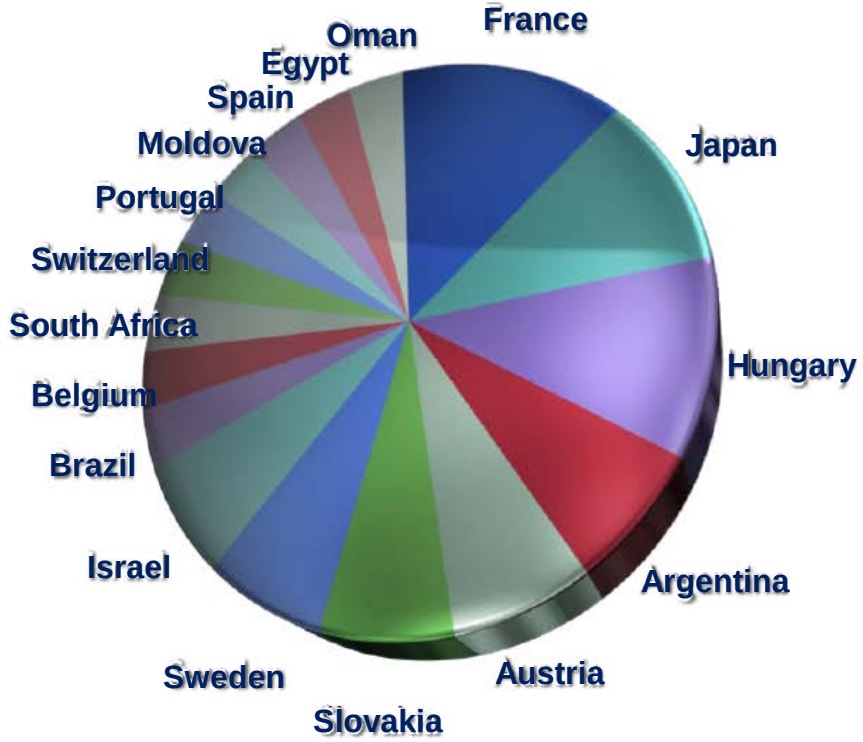
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

*Statistics of White Paper Contributions*

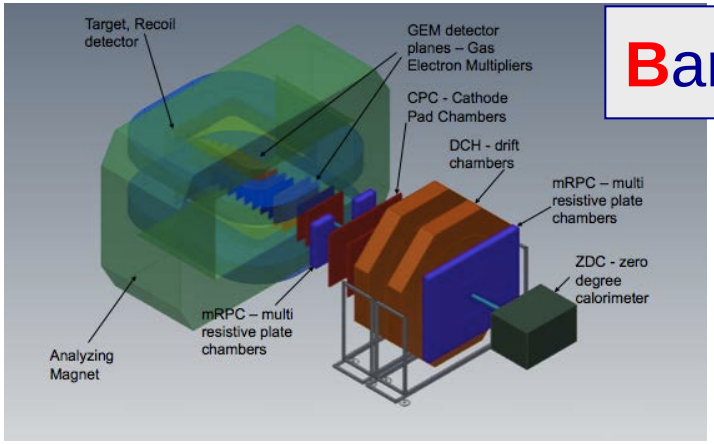
**111** *contributions:*
**188** *authors from* **70** *centers in* **24** *countries*

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



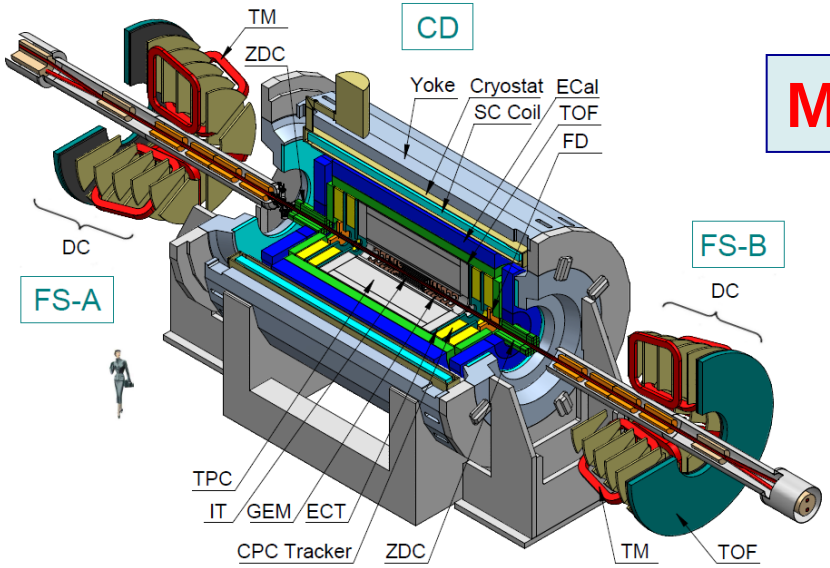
# 3 detectors




**B**aryonic **M**atter at **N**uclotron (**BM@N**)

*the fixed target experiment at the Nuclotron*

**Stage I 2017**




**MultiPurpose Detector (MPD)**

*at the Collider*

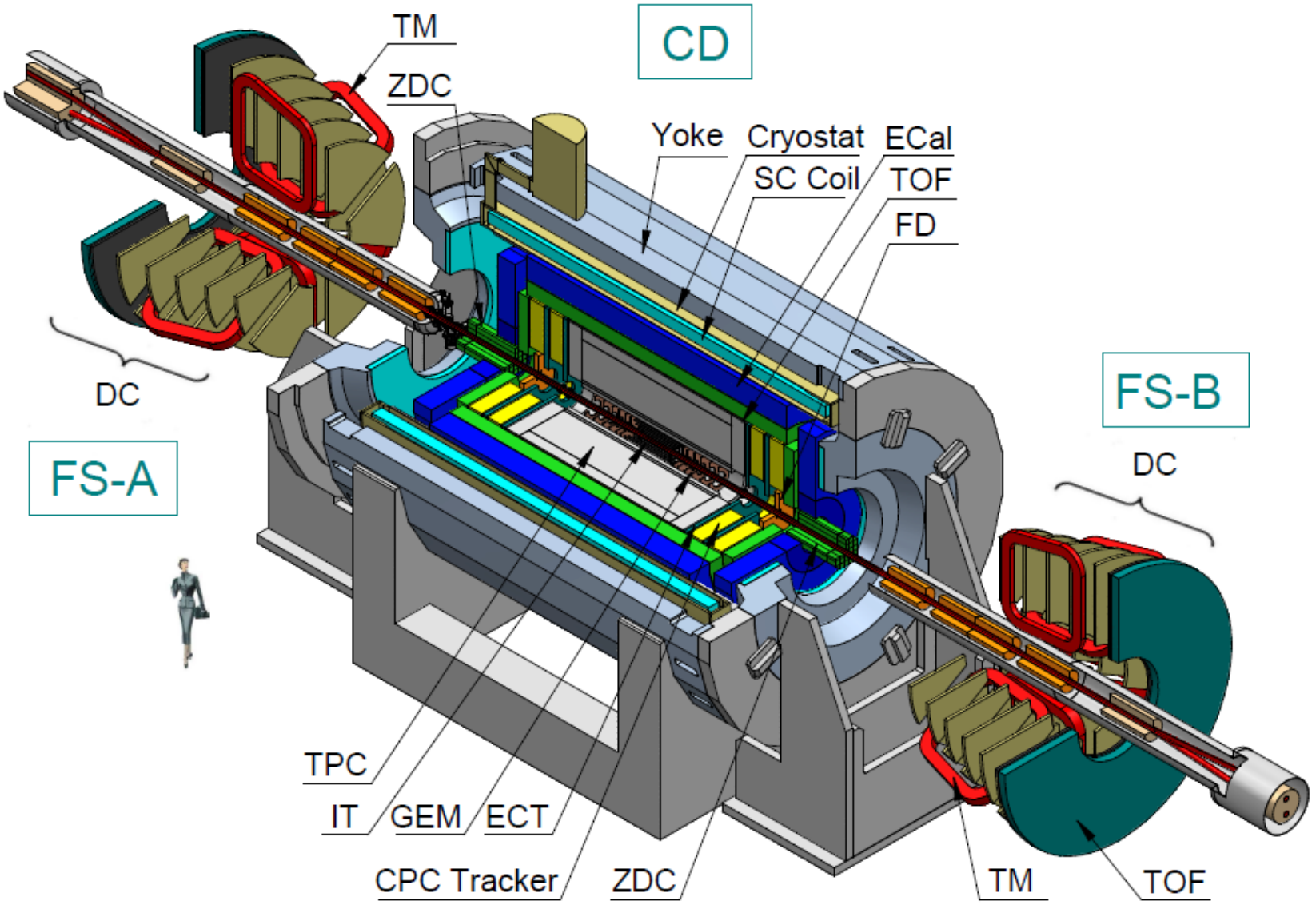
**Stage I 2019**

**SPD (Spin Physics Detector)** *at the Collider*

*project is under preparation*

# MultiPurpose Detector (MPD)

*at the Collider*



# MPD detector for Heavy-Ion Collisions @ NICA

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

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

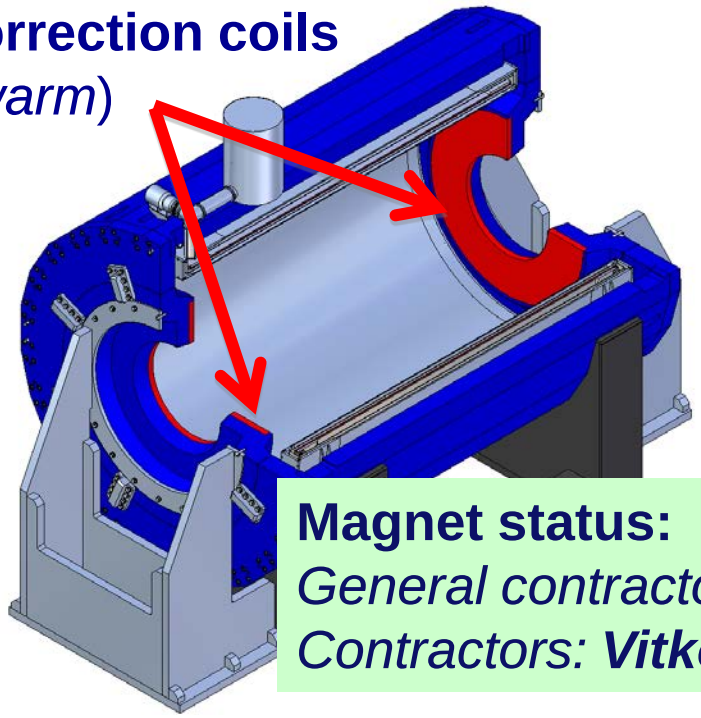
**Stage 2:** IT + Endcaps (tracker, TOF, ECAL)

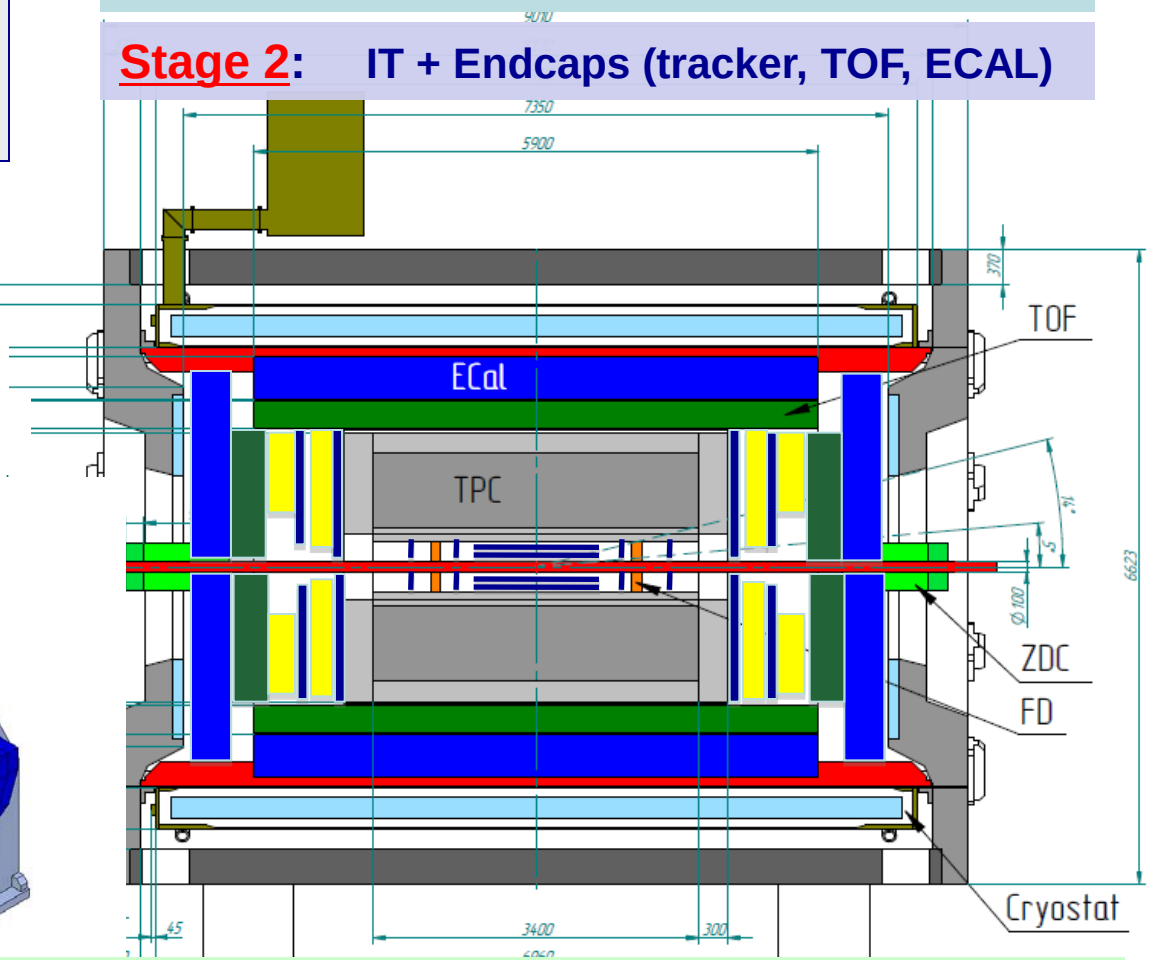
## Superconducting solenoid:

*high level (~ 3x10$^{-4}$) of magnetic field homogeneity*

$B_0$=0.66 T

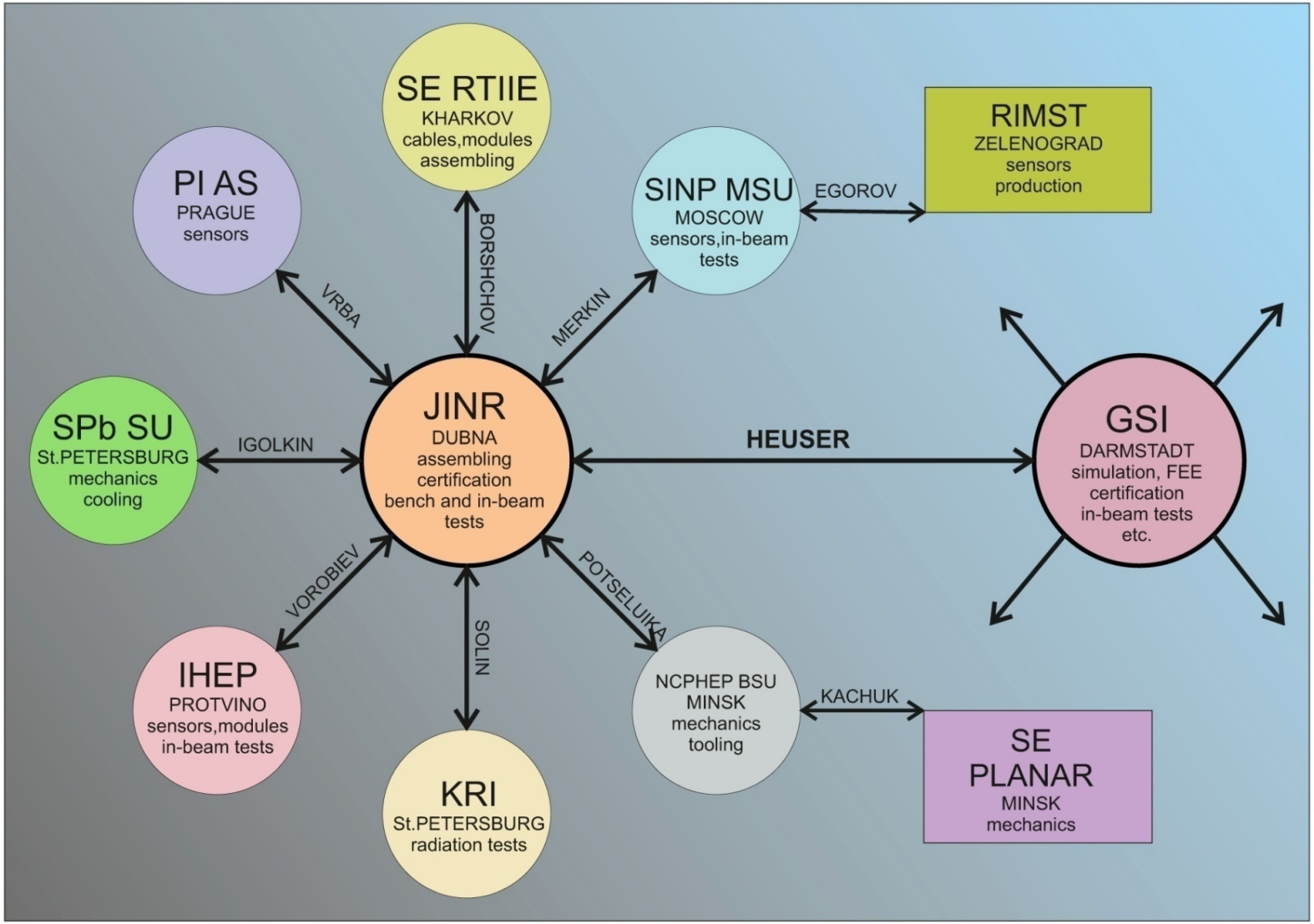
## Correction coils (*warm*)






**Magnet status:** *technical design – completed;*
*General contractor – **ASG superconductor** (Genova, Italy);*
*Contractors: **Vitkovice** (Czech Rep.); **STU** (Tbilisi, Georgia)*

# CBM-MPD consortium structure
## *for R&D and production of IT modules (since 2008)*

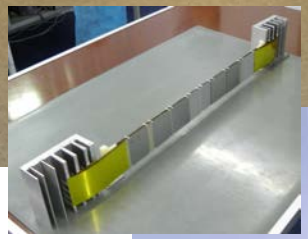


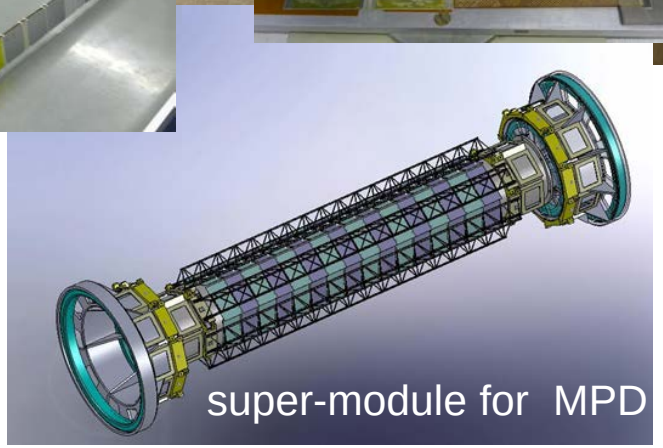
# Workshop for microstrip detector assembly & test

*the clean workshop has started operation in 2015.*

*CBM-MPD Consortium*

***CERN** & **JINR** have signed **MoU** for manufacturing the STS carbon fiber space frames for **NICA** (BM@N & MPD) and **FAIR** (CBM)*

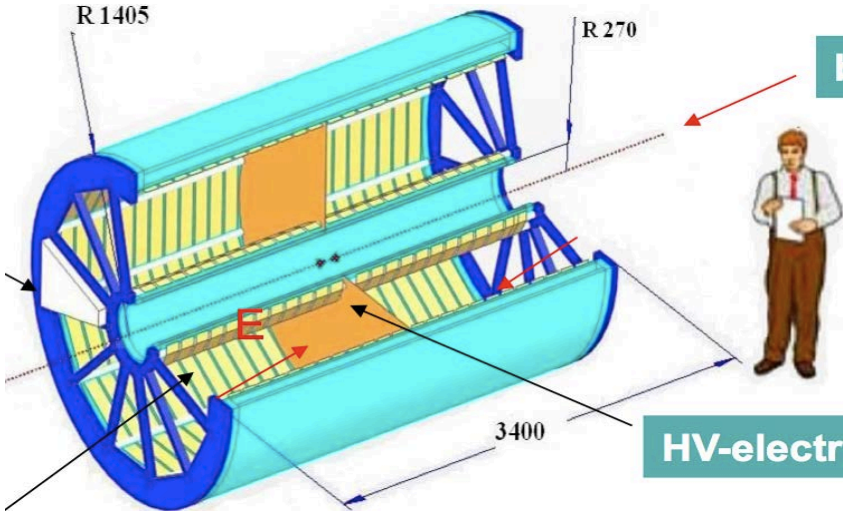





project is developing within the **CREMLIN** framework

# 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)*

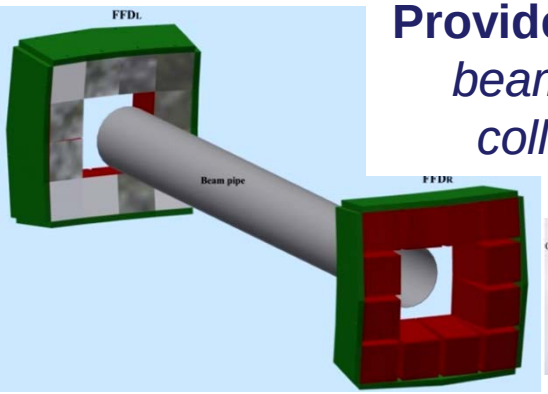
*Cylinder C2, preparation for vacuum tests*


*Cylinder C3 manufactured in Dec. 2013*

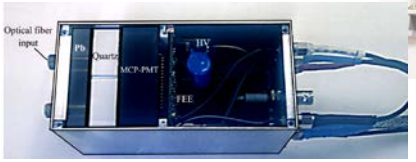
# Time of Flight system (TOF)

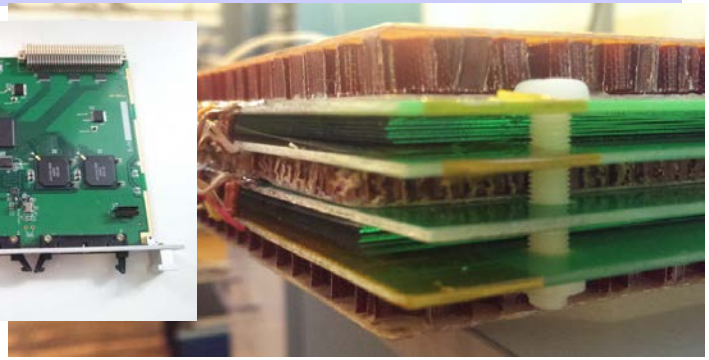
**Fast Forward Detector (FFD):** *production stage*

**mRPC –** TDR has been prepared, *ready for mass production*



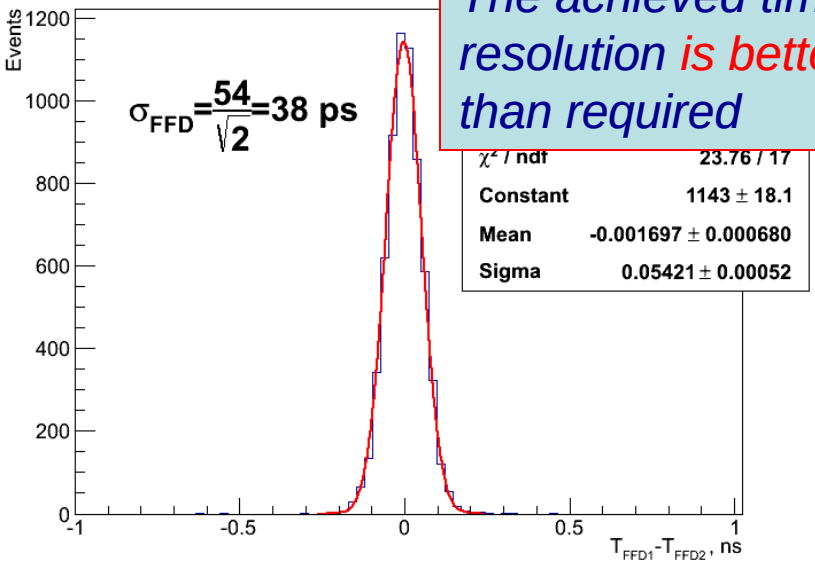

**Provides:** *T0 for TOF, beam adjustment & collision L0-trigger*

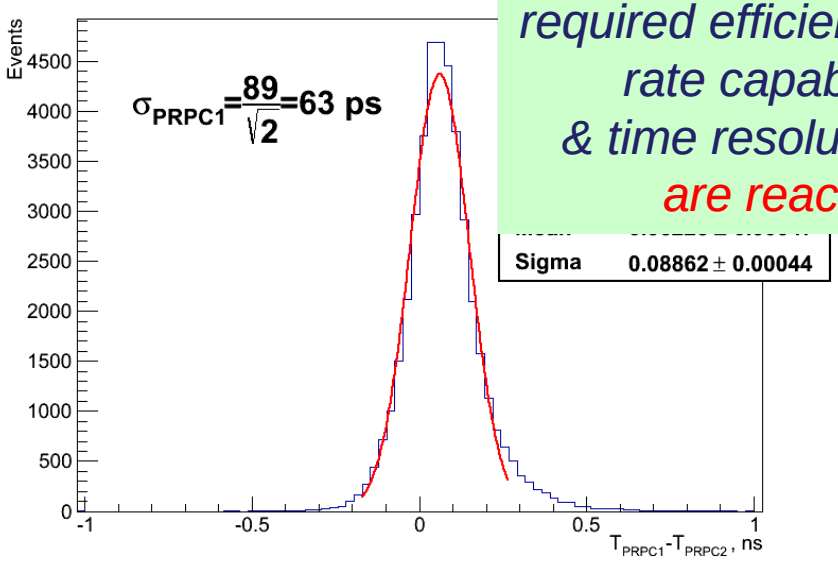


*Zhu Weipinga, Wang Yi, Feng Shengqin, Wang Jingbo, Huang Xinjie, Shi Li, V. Babkin, V. Golovatyuk, M. Rumiantcev, G. Eppley, T. Nussbaum,* ***NIM A 735, 277–282, 2014***

*The achieved time resolution is better than required*



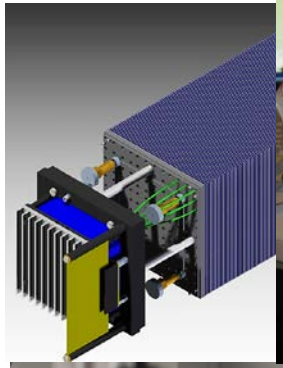

*required efficiency, rate capability & time resolution are reached*

# 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**

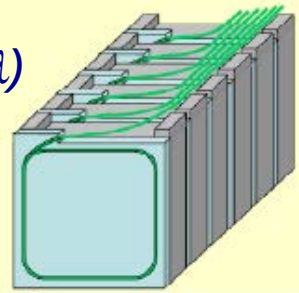


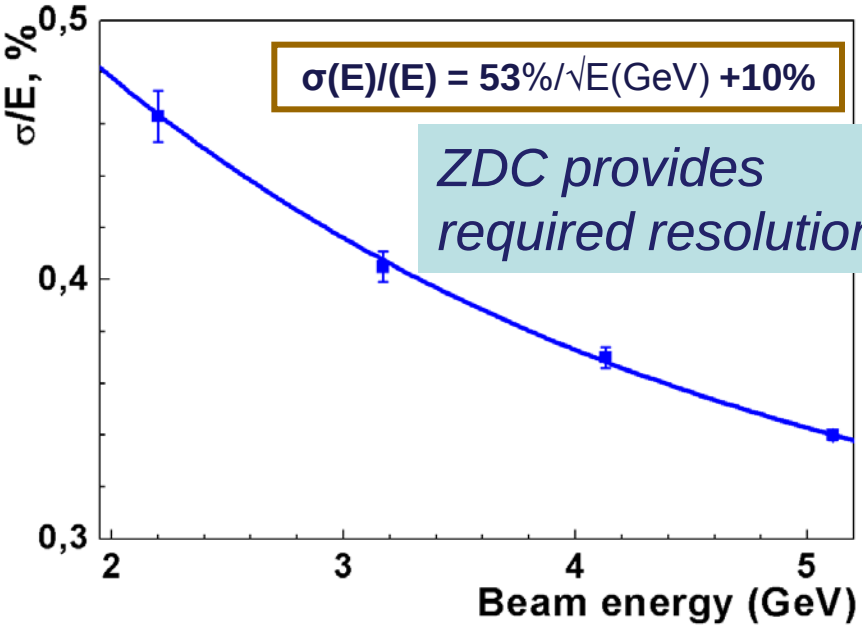

*Preparation for tests with electron beams at DESY (December'13)*

## 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*

# Simulation & analysis framework


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

## Event generators

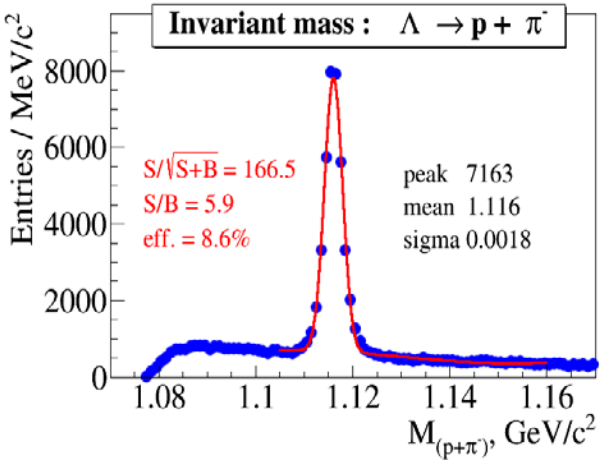
*UrQMD 2.3; LA QGSM; SHIELD on fly*
*pHSD; UrQMD 3.4; 3FD + particlization*

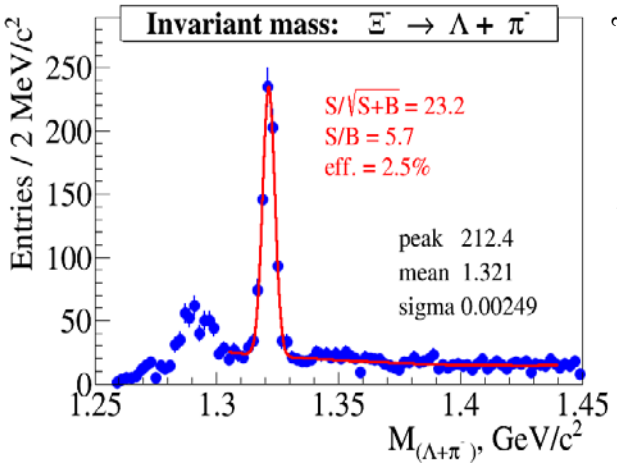
- *inherits basic properties from FairRoot, C++ classes;*
- *extended set of event generators for heavy ion collisions;*
- *detector composition & geometry;*
  *particle propagation by GEANT3/4;*
- *advanced detector response functions,*
  *realistic tracking and PID included.*

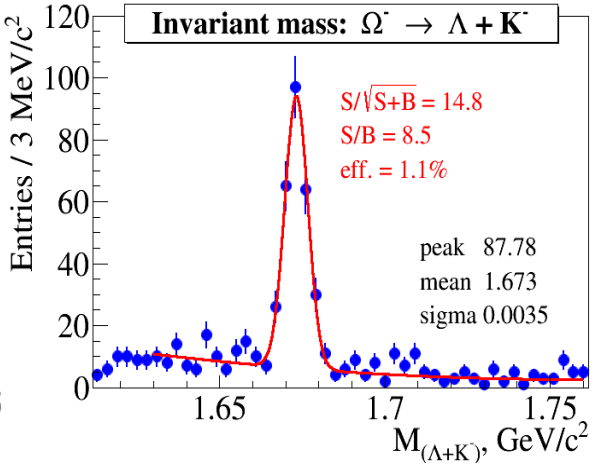
# MPD performance: hyperons

*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

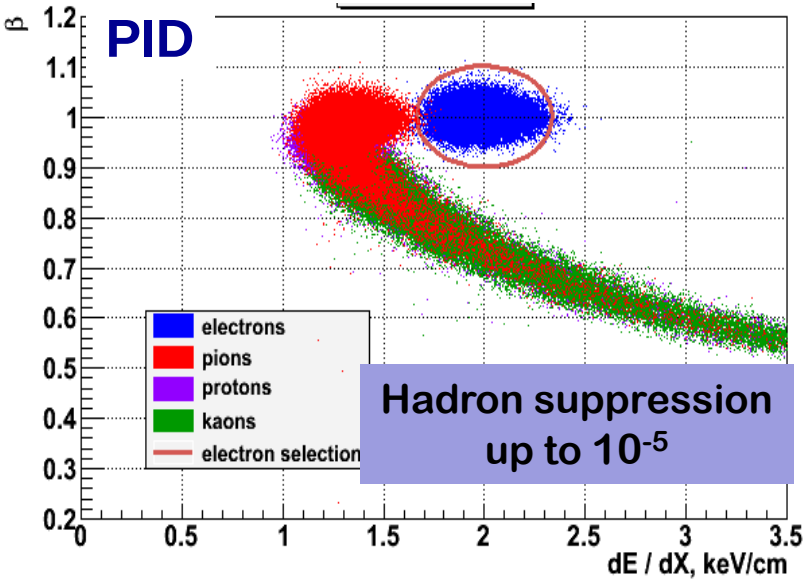
| Particle | $\Lambda$ | $\bar{\Lambda}$ | $\Xi^-$ | $\bar{\Xi}^+$ | $\Omega^-$ | $\bar{\Omega}^+$ |
|---|---|---|---|---|---|---|
| Expected yield | $5.8{\cdot}10^9$ | $7.3{\cdot}10^7$ | $2.9{\cdot}10^7$ | $1.6{\cdot}10^6$ | $1.4{\cdot}10^6$ | $2.9{\cdot}10^5$ |

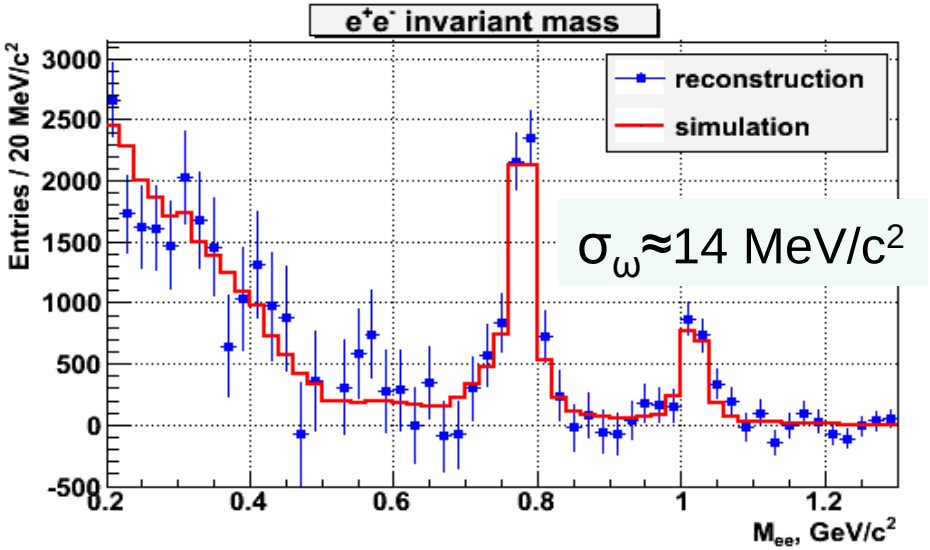
*A. Zinchenko, at "SQM 2015"*

# MPD performance for dileptons

*A. Zinchenko, at SQM-2015*

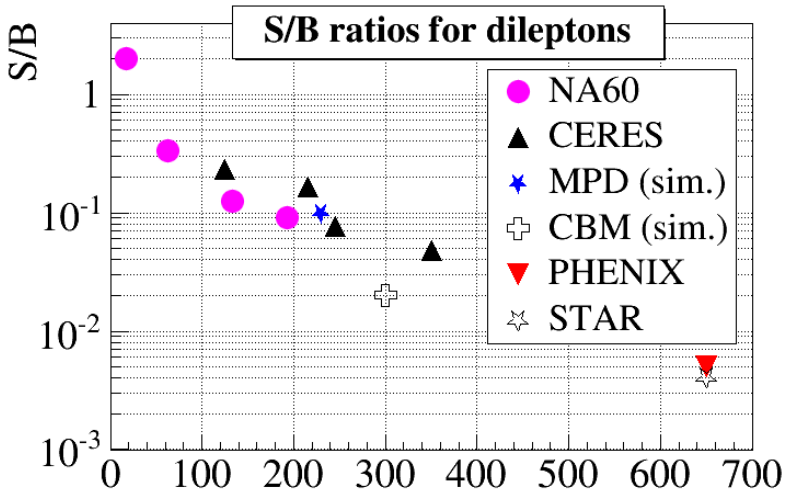
*Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density*



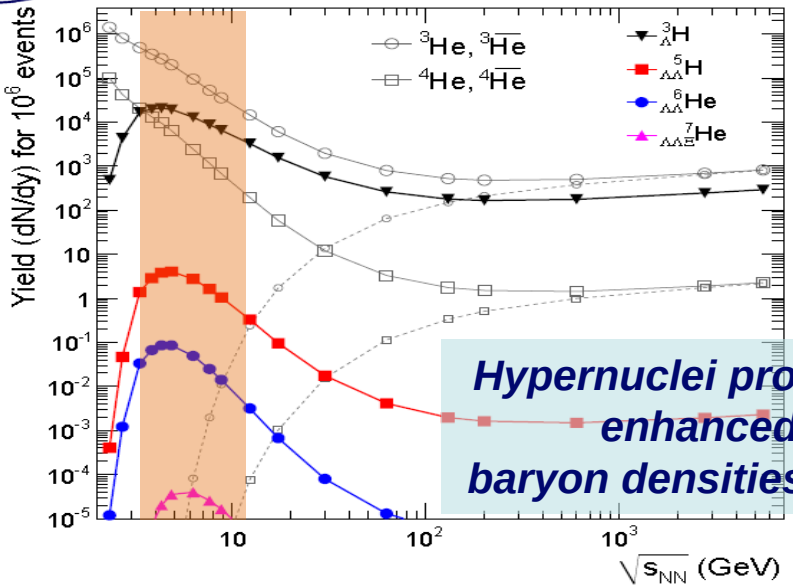

## Yields, central Au+Au st $\sqrt{s_{NN}}$ = 8.8 GeV/u

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

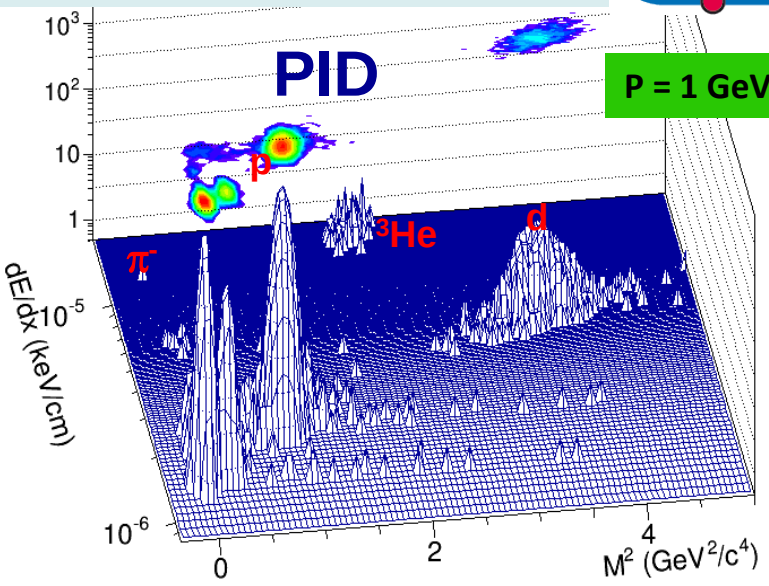


# Hypernuclei @ MPD

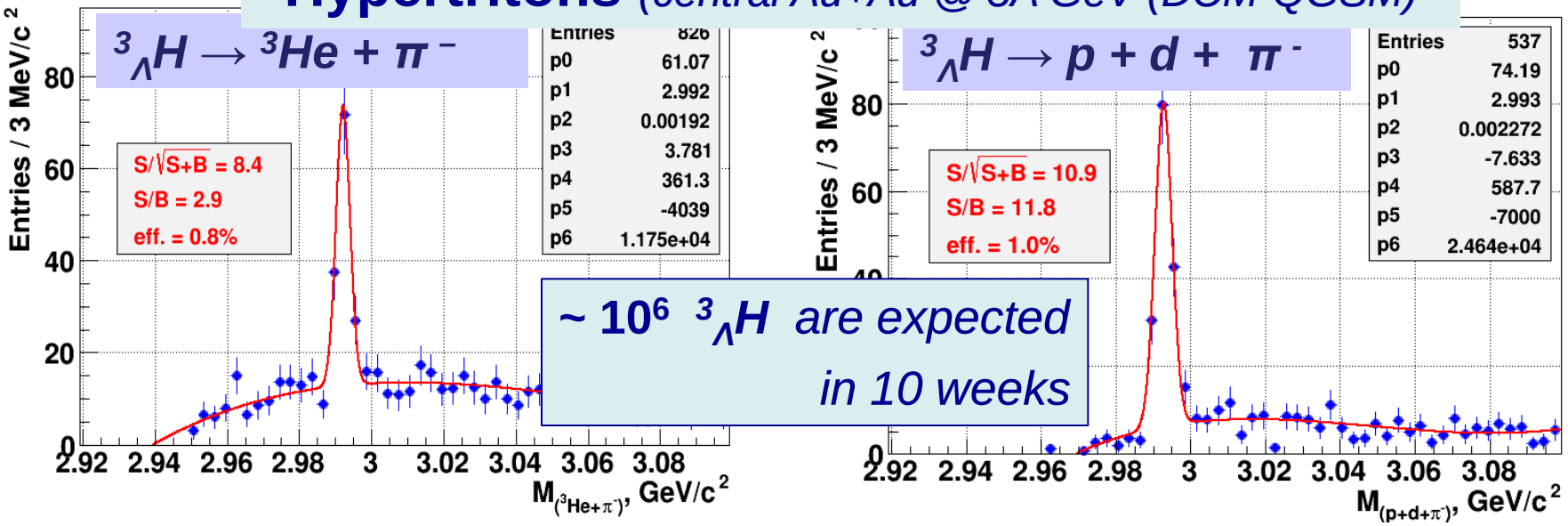
*M. Ilieva, at "SQM-2015"*




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




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



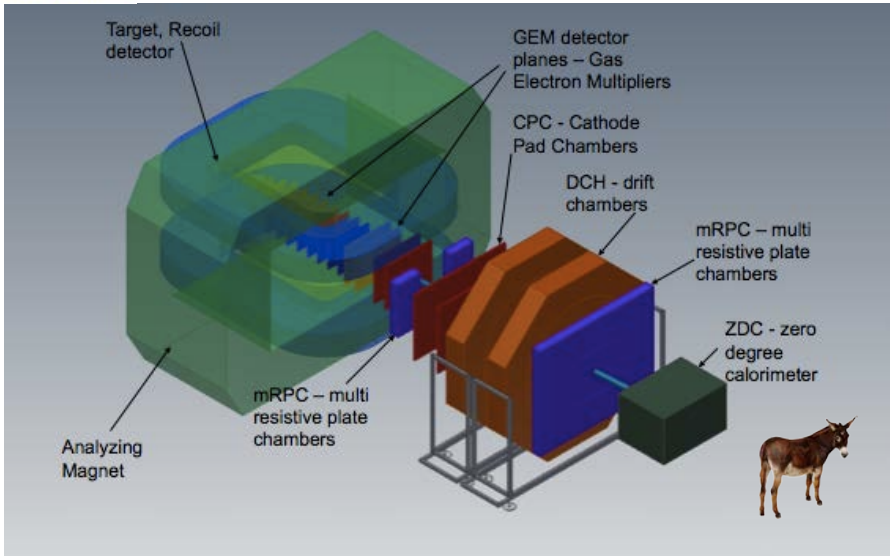

**~ $10^6$ $^3_\Lambda H$ *are expected in 10 weeks***

# Nuclotron Beams

| *Parameter* | *Project (2017)* | |
|---|---|---|
| Magnetic field, T | 2.0 (Bρ = 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*

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



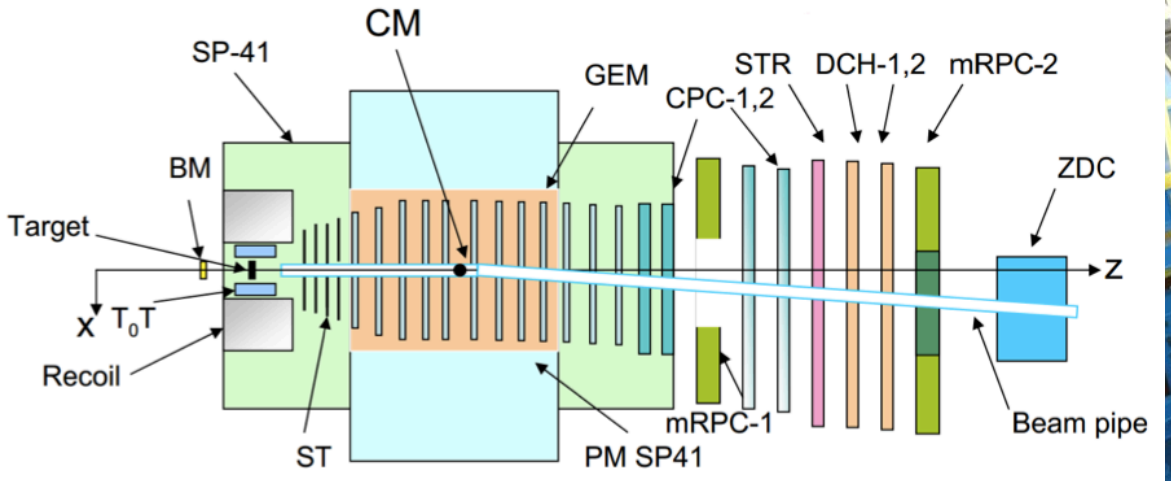

**Expression of interest from scientists:**

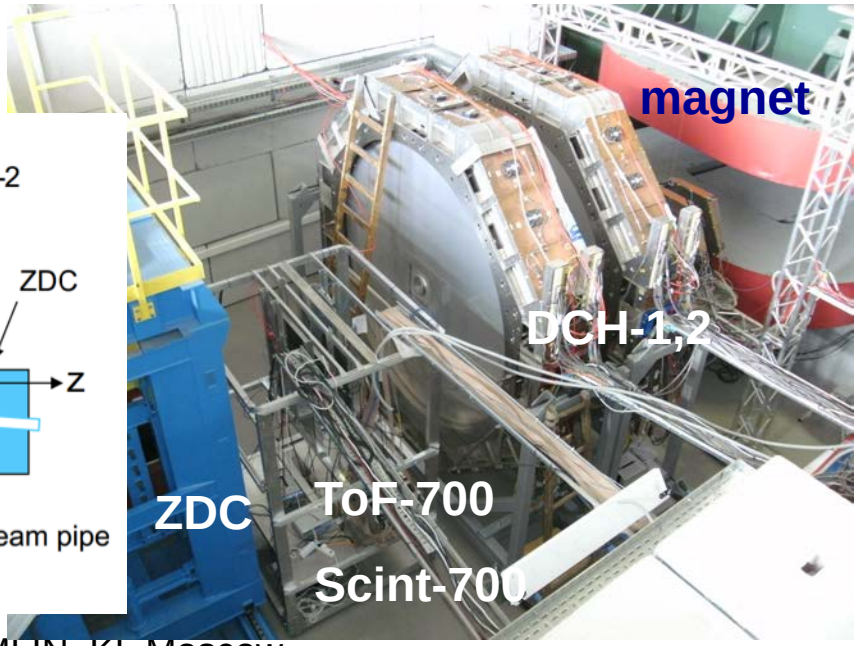
IN, SINP MSU, IHEP + S-Ptr Univ. (RF);
GSI, Frankfurt U., Gissen U. (Germany):
**+ CBM-MPD IT-Consortium,**

**Physics:**

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

## BM@N *schematic view*



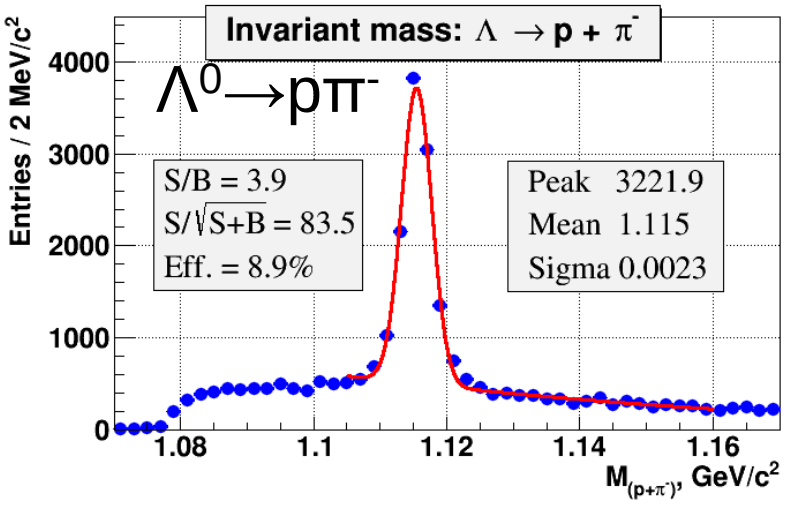



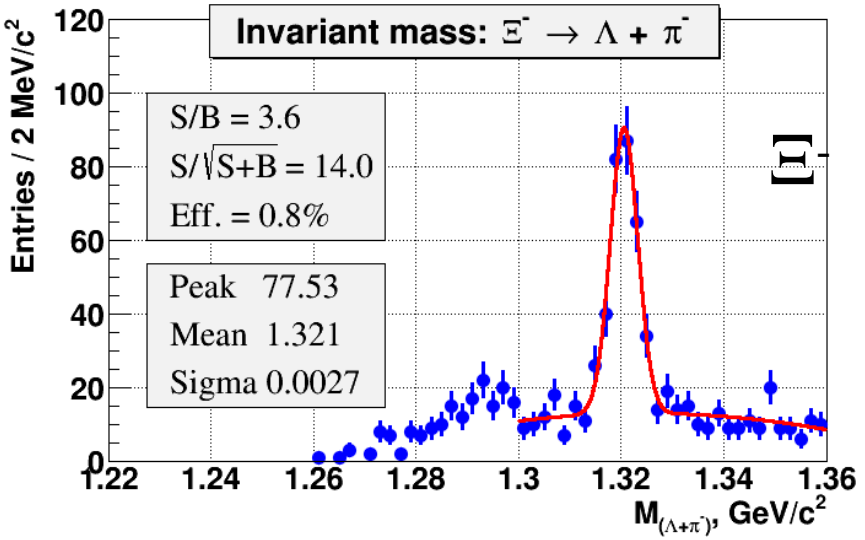
# GEM tracker: $\Lambda^0$, $\Xi^-$, $^3H_\Lambda$ reconstruction

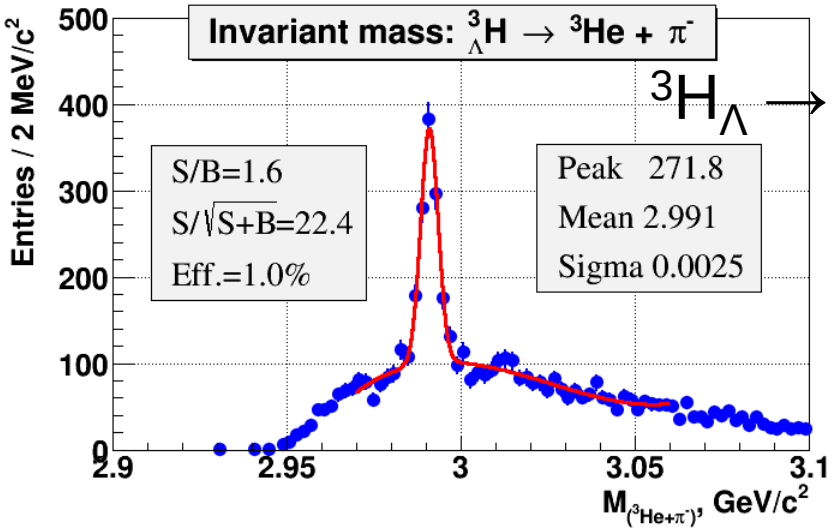
A.Zinchenko, V.Vasendina

*12 planes of GEM tracker*

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

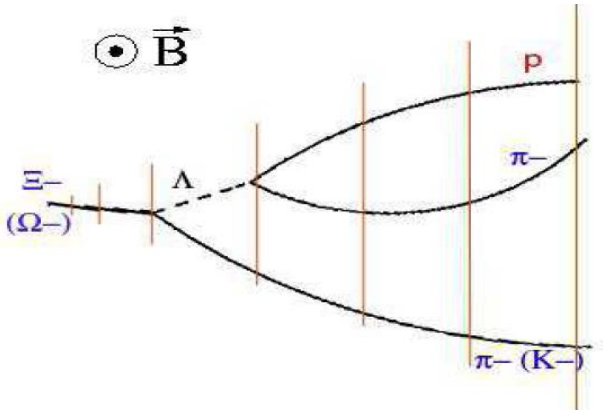


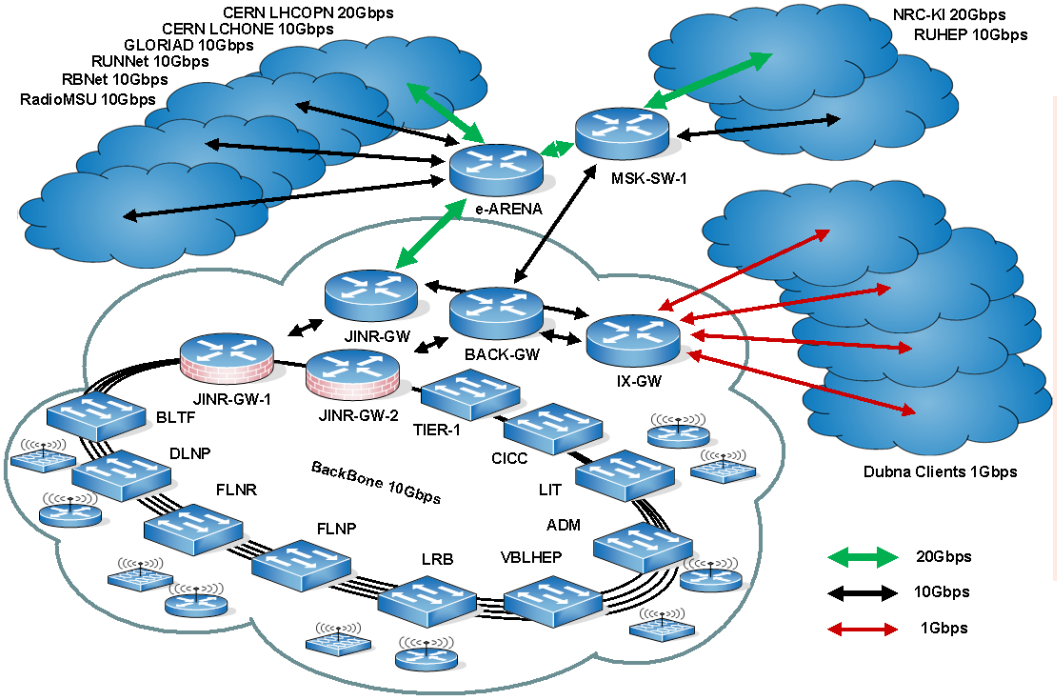

$^3H_\Lambda \rightarrow {}^3He\ \pi^-$

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



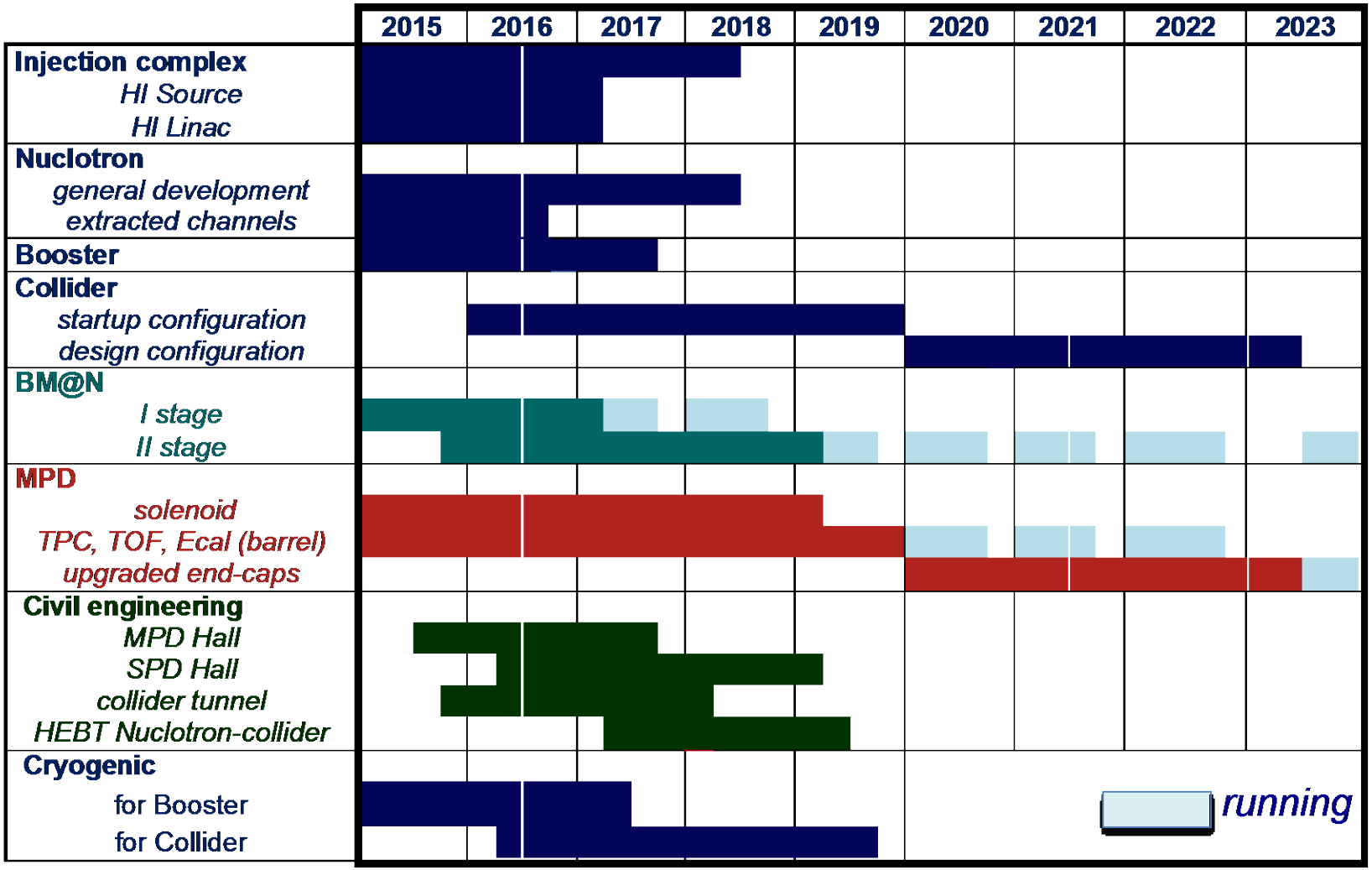
*The current network status:*

- ***10** Gb/s local network;*
- ***20** Gb/s external channel;*
- *connections with different scientific networks*
  - *LHCOPN*
  - *LHCONE*
  - *GEANT.*




*To meet NICA requirements, the performance of existing internal and external channels will be upgraded up to **100 Gb/s**.*

# NICA schedule



# Conclusive remarks

*In the medium-term prospect the NICA complex will be the only facility in Europe providing unique high intensity ion beams (from **p** to **Au**, **p**↑ and **d**↑) **in the energy range** from **~ 10 keV** up to **27 GeV** (c.m.s.), which could be used for both fundamental and applied researches.*

***Researches at the NICA complex will contribute to***

- *discovery and study of new forms of nuclear matter;*
- *comprehensive study of nucleon spin structure;*
- *applied researches, like irradiation of biological objects by heavy ion beams (space mission program) etc.*

***NICA** is supported through relevant European partnership and intergovernmental research organizations.*

***NICA** is a lighthouse project on the **JINR-Roadmap**, established and approved through all of the **JINR member** states including **5** from the **EU**.*

*It is one of the Mega-Science project adopted through Russia, however constructed and operated as **pan-European RI** at the **International Intergovernmental organization JINR** in Dubna.*

**NICA** project has been proposed for inclusion
in the **ESFRI Roadmap**

**NICA** will complement
the new **Research Infrastructure map**
according to the long term needs
of the **European research communities**

The presence of **NICA** in the **ESFRI Roadmap** will ensure:

- *larger European participation to meet the challenges of the complex experiments to be performed in the next decades*

- *strategic long-term research planning*


NICA
Thank you

# Observable asymmetries to measure PDF