The NICA facility and the MPD experiment

ECT* Workshop
Exploring High μ_B Matter With Rare Probes

October 11-15, 2021

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WEIZMANN INSTITUTE OF SCIENCE
מכון ויצמן למדע

Outline

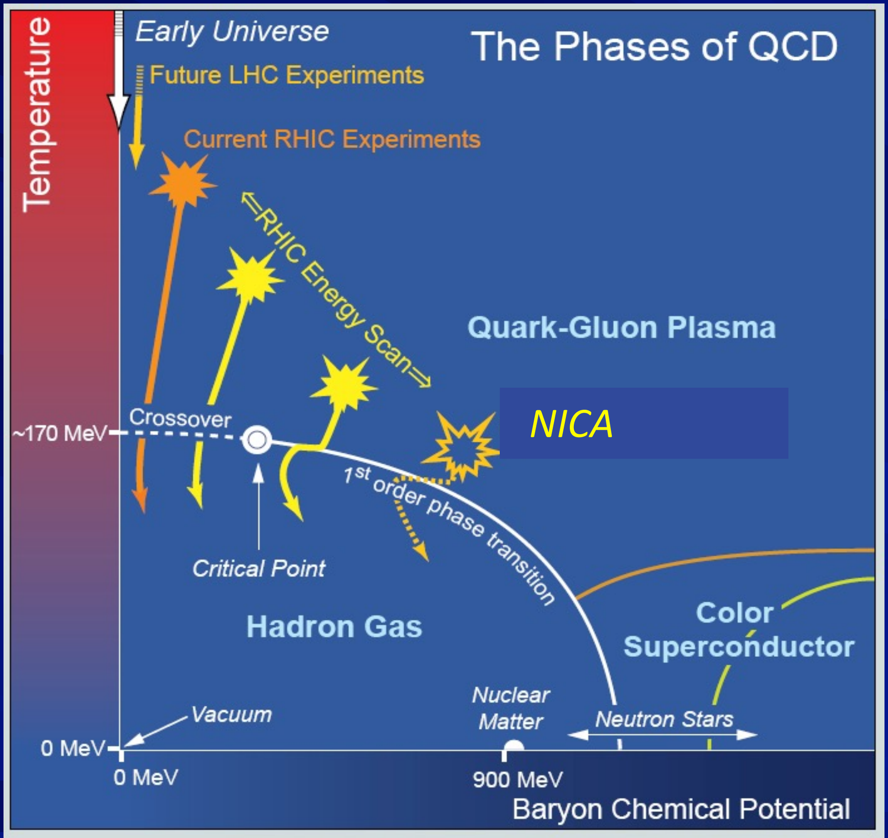
- NICA facility
  - Motivation
  - Description of facility
  - Current status and prospects
- MPD experiment
  - Set-up of Stage-1 configuration
  - Current status
- Dilepton prospects
- Summary

NICA Facility

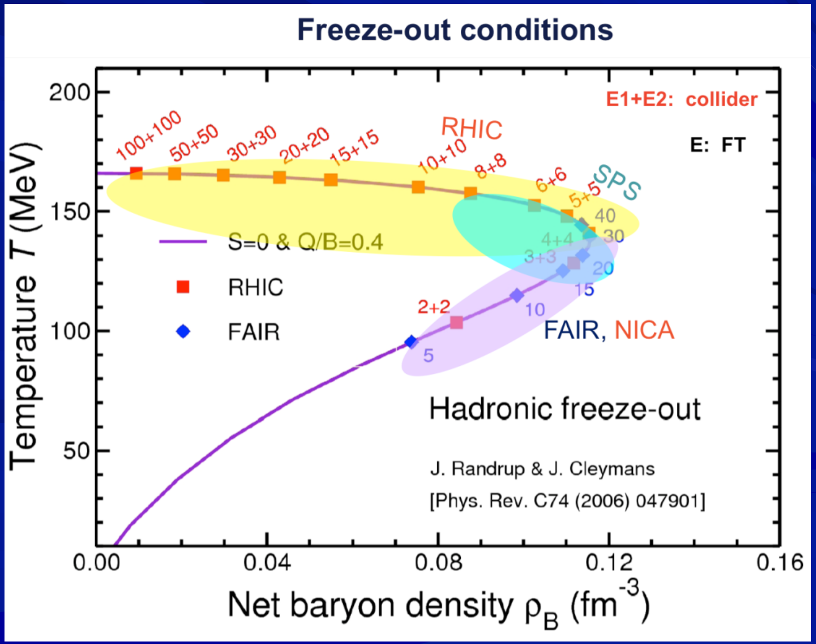
(Nuclotron based Ion Collider fAcility)

- Accelerator complex under construction at JINR, Dubna
- Shall provide high intensity beams :
  heavy ions: Au^{79+} $\sqrt{s_{NN}} = 4 - 11$ GeV, **L ~ 10^{27}** $cm^{-2}\,s^{-1}$
  polarized p and d: $\sqrt{s}$ up to 27 GeV, L ~ **10^{32}** $cm^{-2}\,s^{-1}$

NICA Physics Motivation

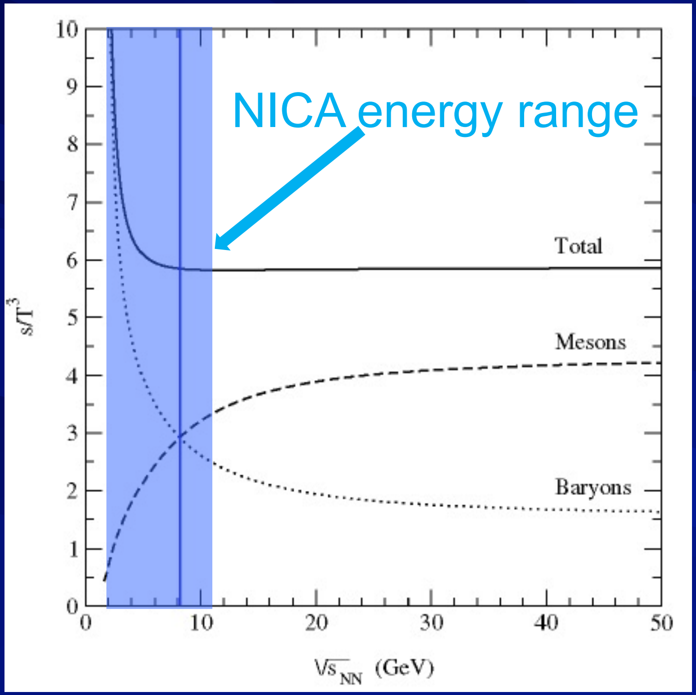


- Explore high μ_B (baryon dominated) matter
- Search for the conjectured critical point and first order phase transition
- NICA's energy range brackets expected onset of deconfinement and chiral symmetry restoration phase transition(s)
- Conditions similar to those expected in merging of neutron stars

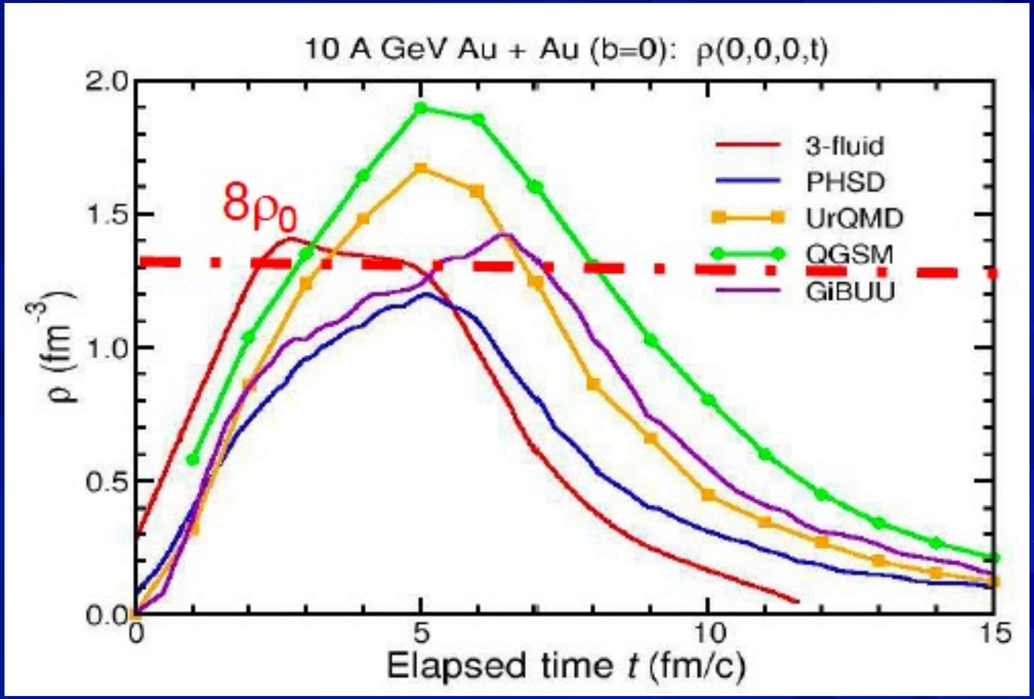


QCD matter at NICA energies

J. Cleymans et al., PLB 615, 50 (2005)



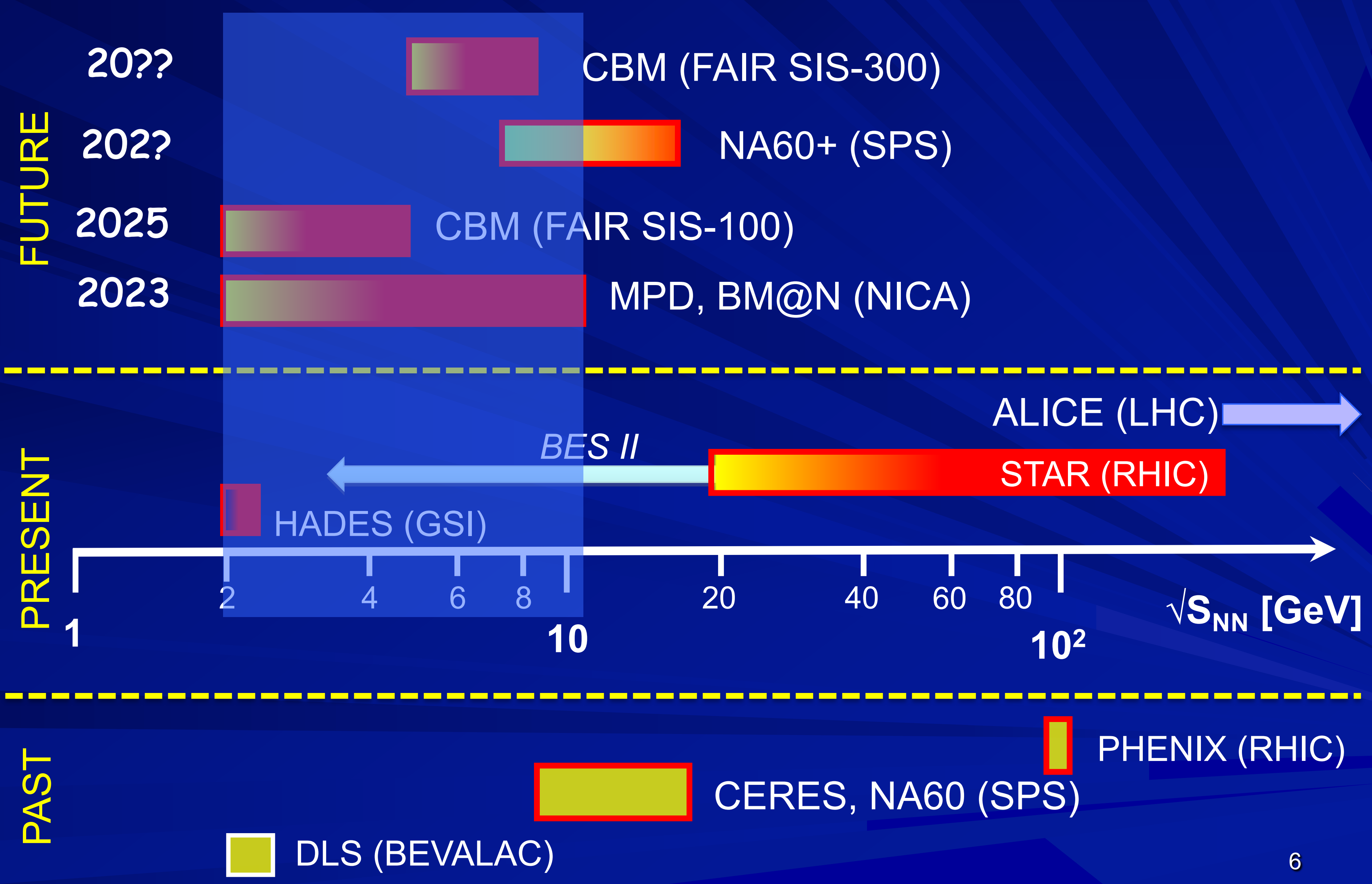
PRC 75, 034902 (2007)



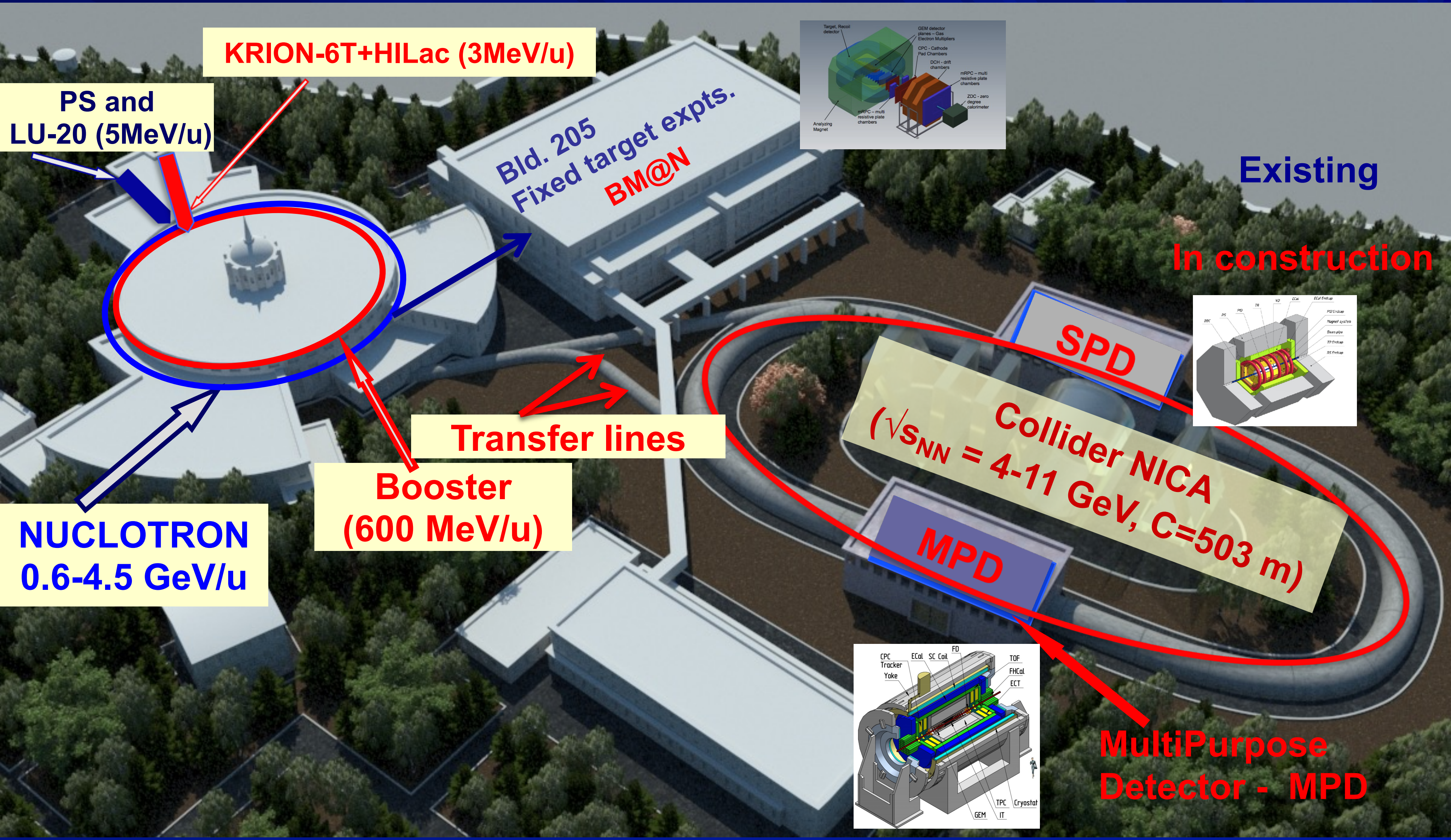
- NICA energy range brackets the transition from baryon to meson dominated matter

- Sizable densities up to O($10\rho_0$)
- Long lifetime

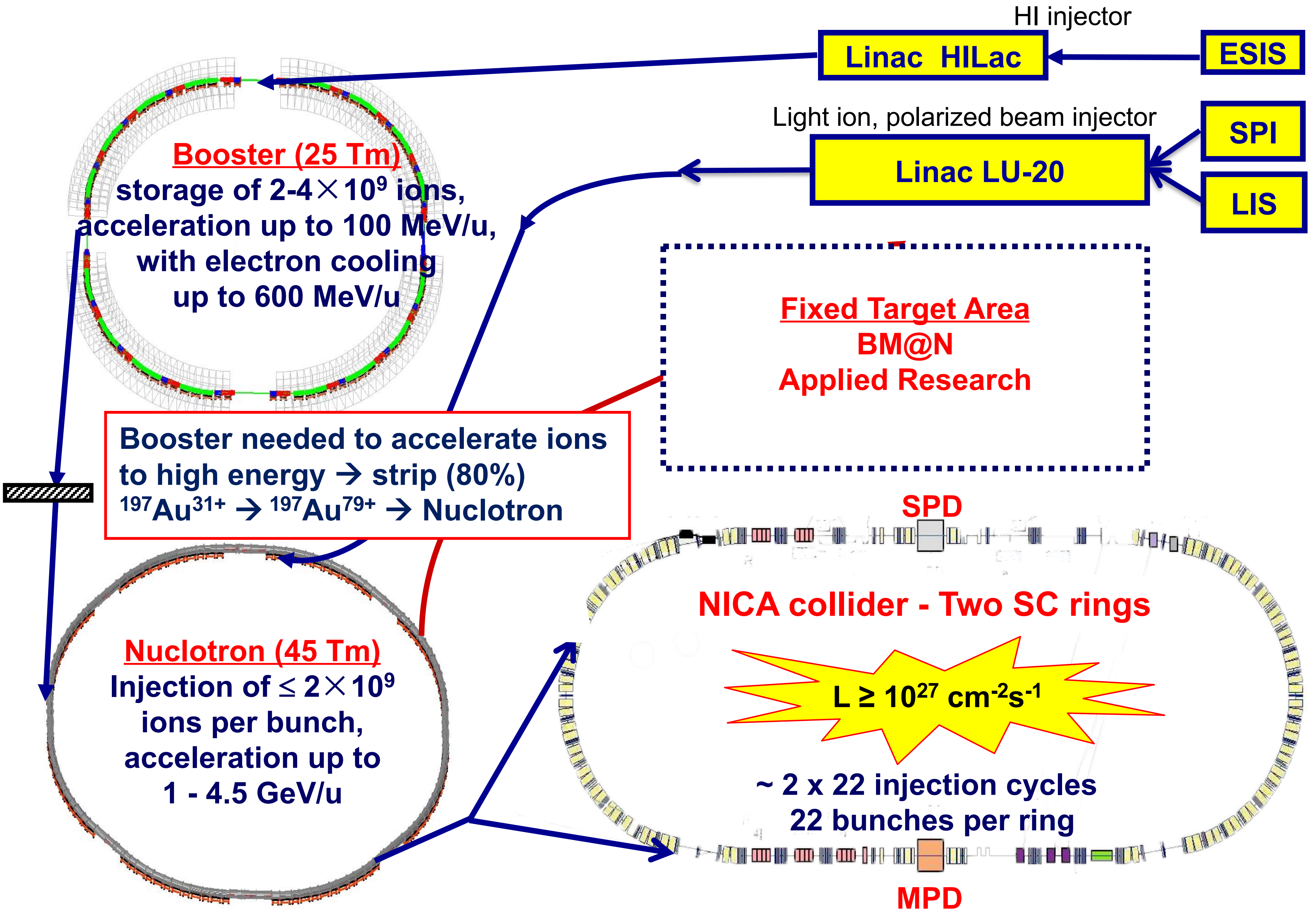
Dilepton experiments at low energies



NICA Complex



NICA acceleration schemes



NICA and Nuclotron beams

NICA collider beams:

- Heavy ion collisions up to $^{197}Au^{79+}$ + $^{197}Au^{79+}$ at:

  $\sqrt{s_{NN}}$ = 4 - 11 GeV , $L_{average}$= 10^{27} $cm^{-2}s^{-1}$

  same or higher $L_{average}$ for lighter ions

- Polarized proton and deuteron collisions:

  $p\uparrow p\uparrow$ $\sqrt{s_{pp}}$ = 12 - 26 GeV L_{max} ≈ 10^{32} $cm^{-2}s^{-1}$

  $d\uparrow d\uparrow$ $\sqrt{s_{NN}}$ = 4 - 13.8 GeV

Nuclotron extracted beams (for fixed target experiments):

- Light ions and polarized beams of p and d:

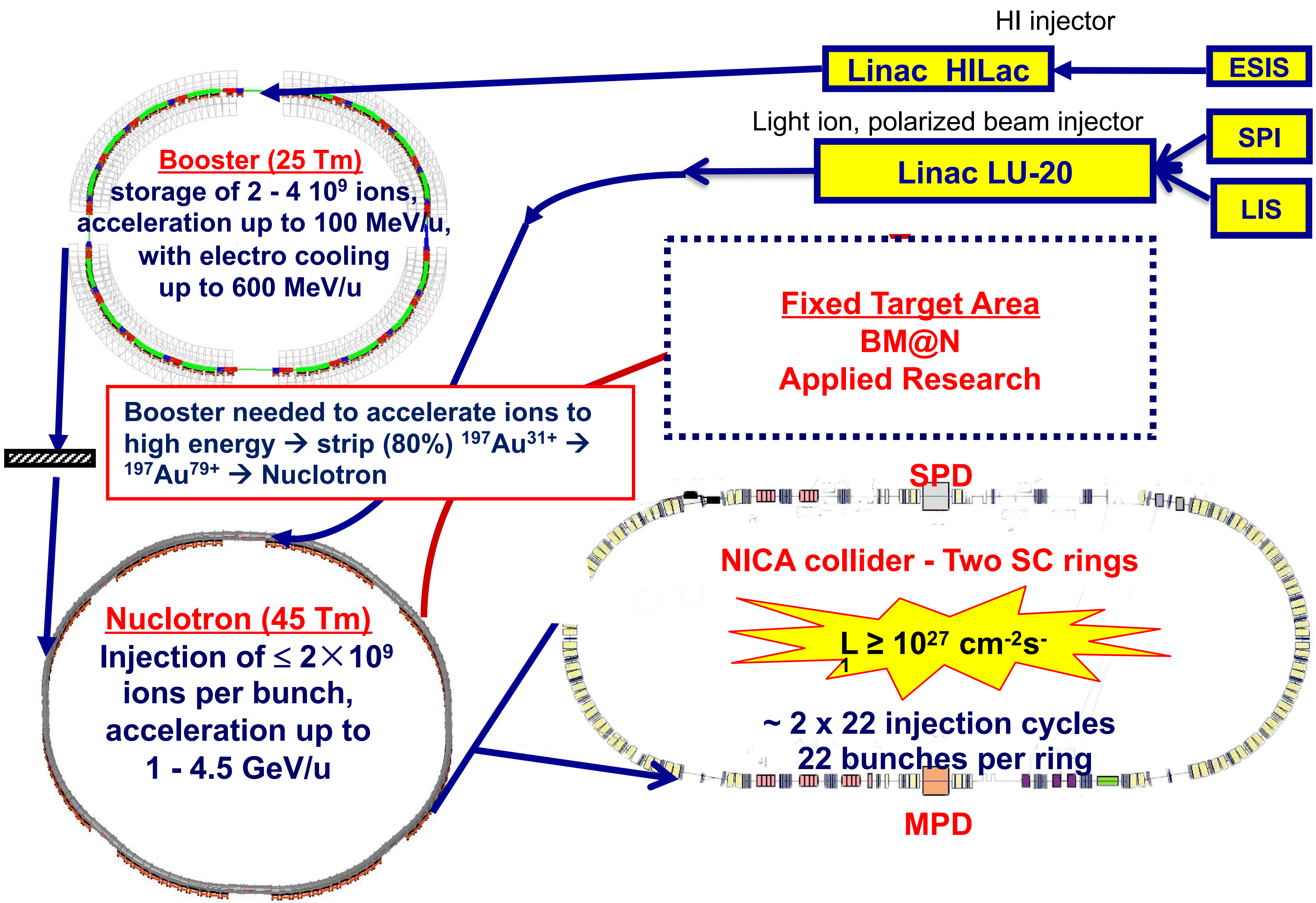
  Li - Au = 1 - 4.5 GeV /u

  $p\uparrow$ = 5 - 12.6 GeV

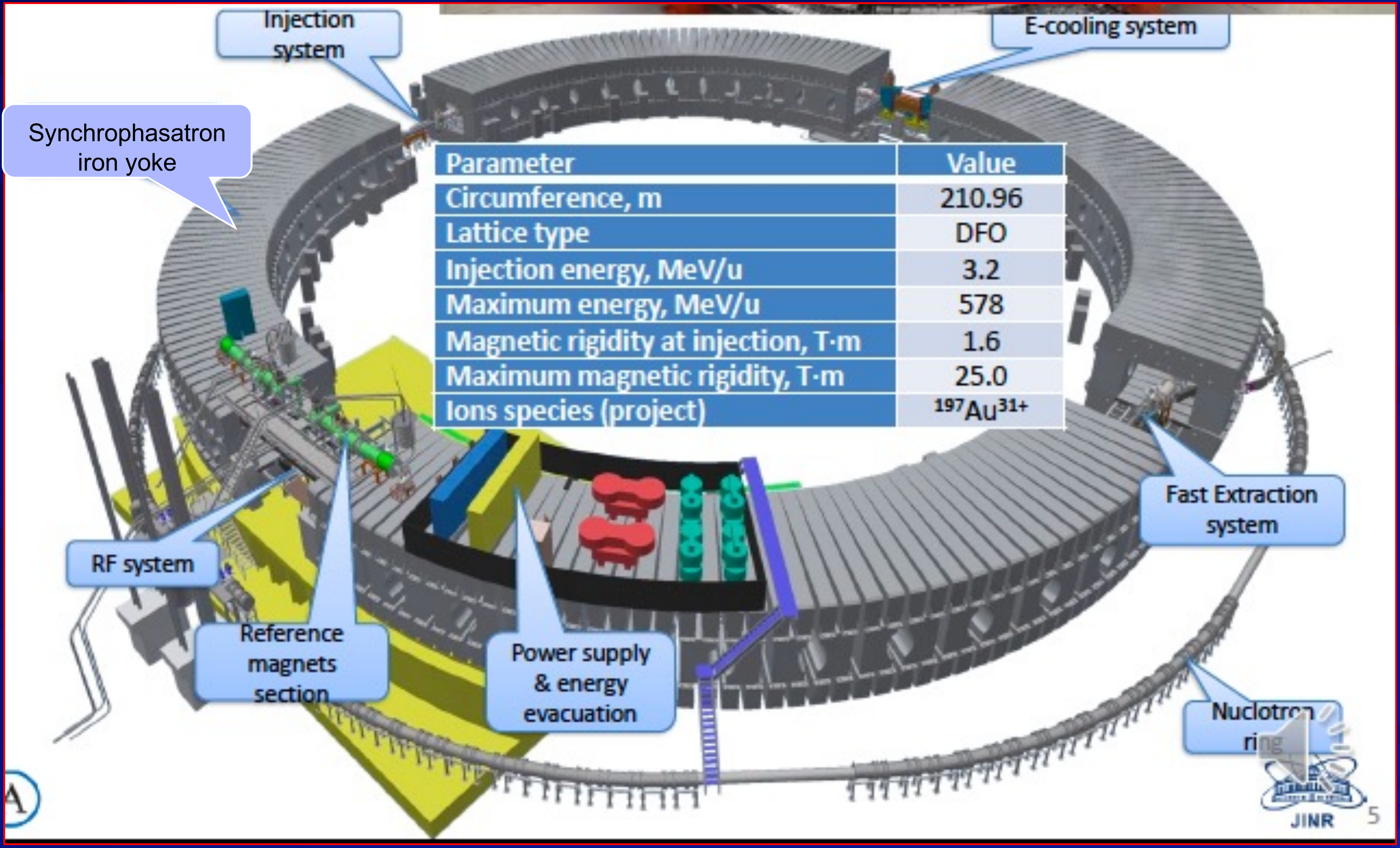
  $d\uparrow$ = 2 - 5.9 GeV/u

Current status

- ❑ Injection system ready
- ❑ Nuclotron fully refurbished
- ❑ Booster fully assembled, commissioning ongoing



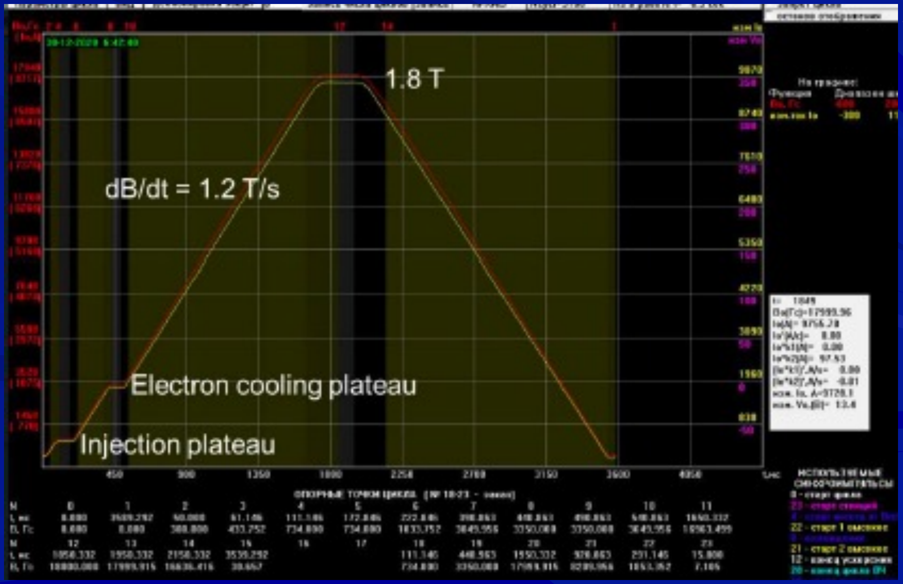
Current status: Booster



Parameter	Value
Circumference, m	210.96
Lattice type	DFO
Injection energy, MeV/u	3.2
Maximum energy, MeV/u	578
Magnetic rigidity at injection, T·m	1.6
Maximum magnetic rigidity, T·m	25.0
Ions species (project)	$^{197}Au^{31+}$

Current status: Booster

First technical run – Dec. 2020
Injected He^{+} at 3. 2 MeV/u 6.5 10^{10} ppp
Accelerated up to 100 MeV/u

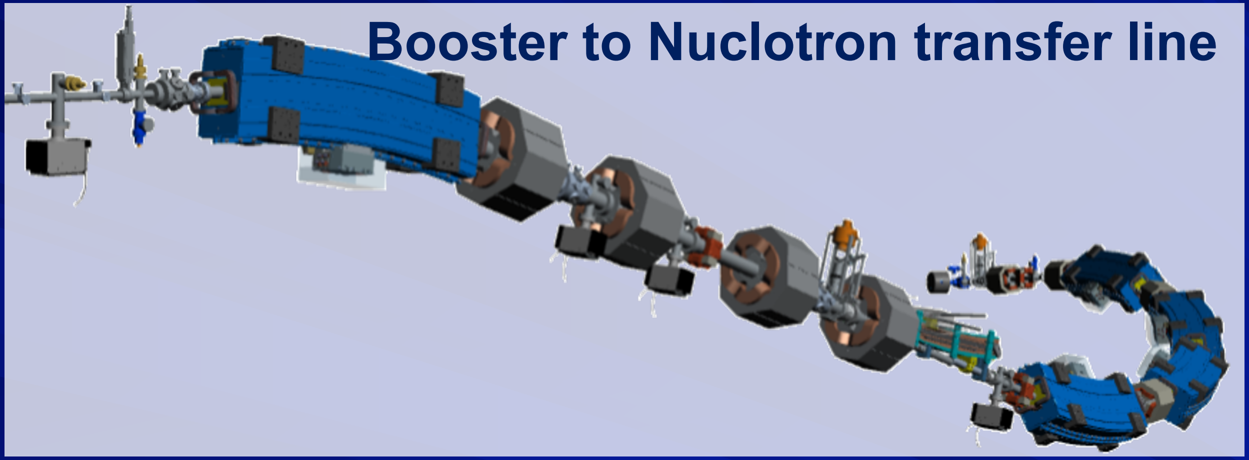


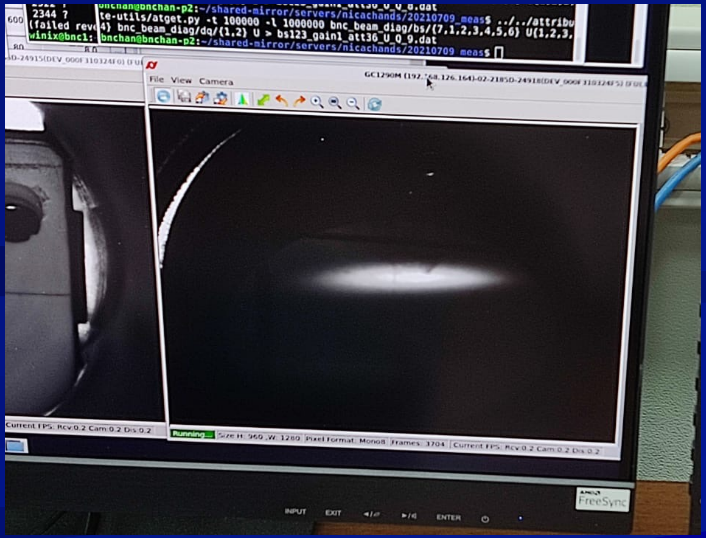
Booster to Nuclotron transfer line

- Transfer line from Booster to Nuclotron assembled

(5 dipole + 8 quadrupoles + 1 septum + 3 steering magnets – in collaboration with BINP)

- ***complicated geometry with 3D-rotation***





2^{nd} technical run – Sept. 2021
Beam of Fe^{14+} ions (240 MeV/u, 3.10^{8} ions) successfully accelerated, extracted from Booster and transferred to Nuclotron as shown by the luminophore (size of beam spot is 20x5 mm^2)

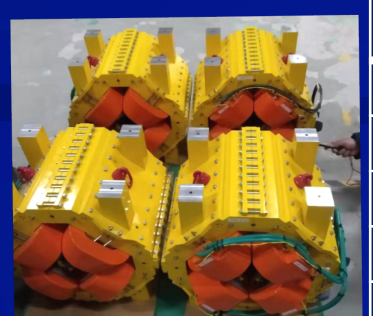
Current status NICA building

Completion of building construction : December 2021
Equipment installation has started

Current status: NICA building

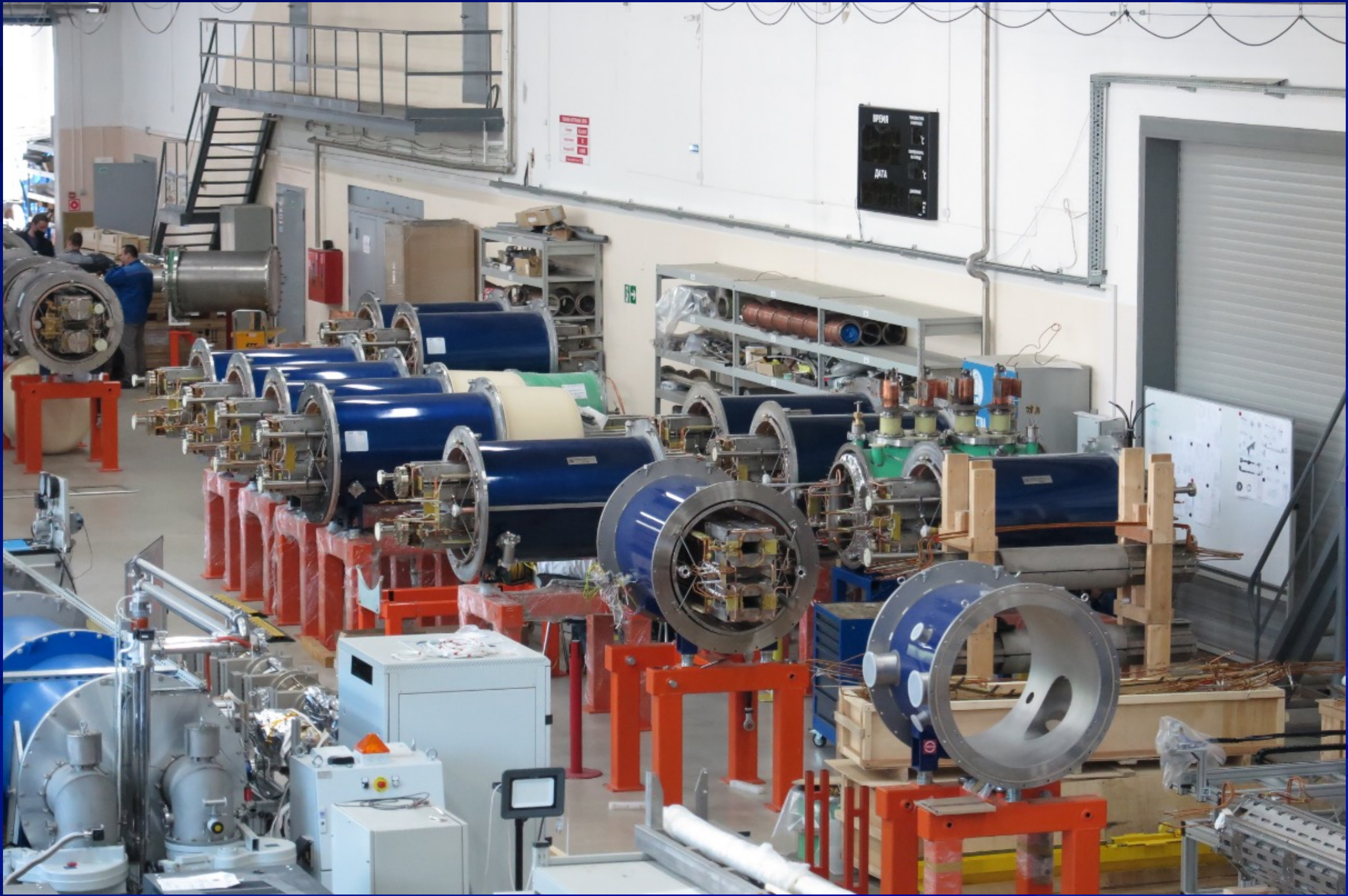
Beam transfer line Nuclotron – Collider *(Sigma-Phi)*

- *magnets* ✓
- *vacuum chamber + …* *delivery March 2022*
- *PS* *delivery March 2022*
- *assembly, commissioning* ***June 2022***



Magnetic element	N	Effective length, m	Max. field, T (T/m)
Long dipole	21	2	1.5
Short dipole	6	1.2	1.5
Quadrupole Q10	22	0.353	31
Quadrupole Q15	6	0.519	31
Steerer	33	0.466	0.114

Collider magnets



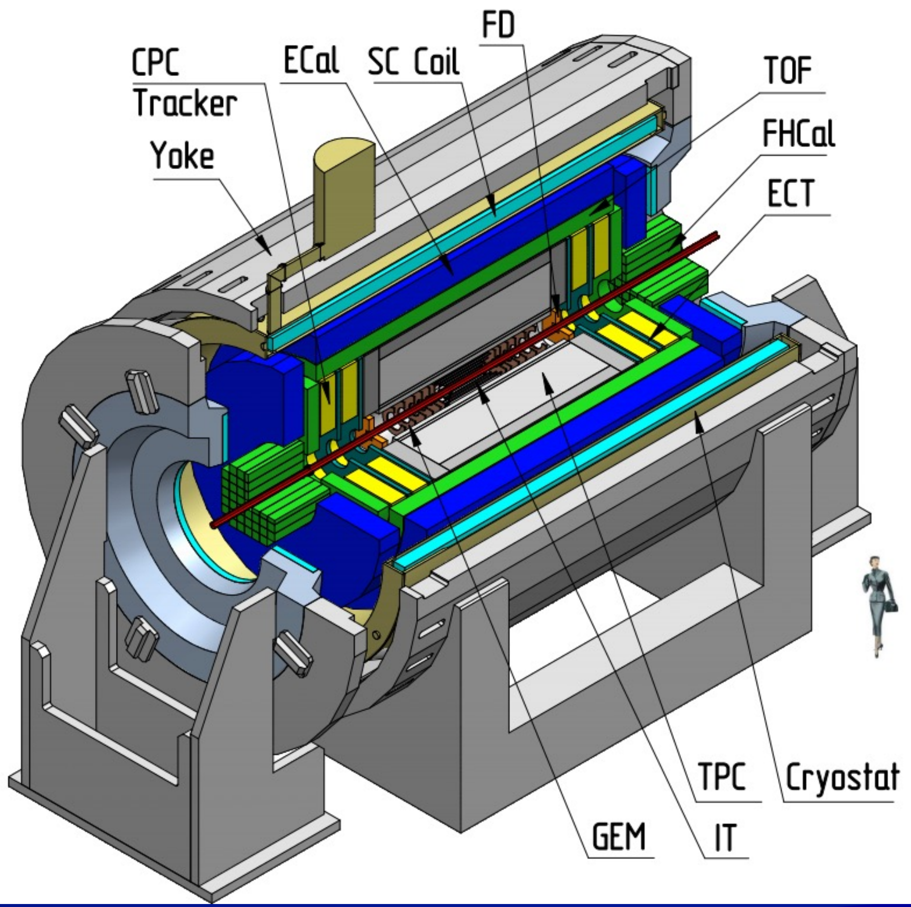
Collider magnets

	total	prod. %
Dipole magnet coil	80+1	100
Quadrupole magnet coil	46+24	100
Corrector magnet coil	124+4	75
Final focus quadrupole coil	12	20
Vertical bending magnet coil	8	20
Dipole magnet heat screen	80+1	100
Quadrupole magnet heat screen	46+12	100
interconnections’ heat screen	181	50
Cryogenic by-pass heat screens	2	20
Heat screens (ref. mag.& feed b-x)	2	80
Temperature sensor @ cold	900	100

Dipole magnets: 100 % tested
Quadrupole magnets: 35 % tested

Stored equipment (including in the SPD hall) ready to be installed

MPD Experiment



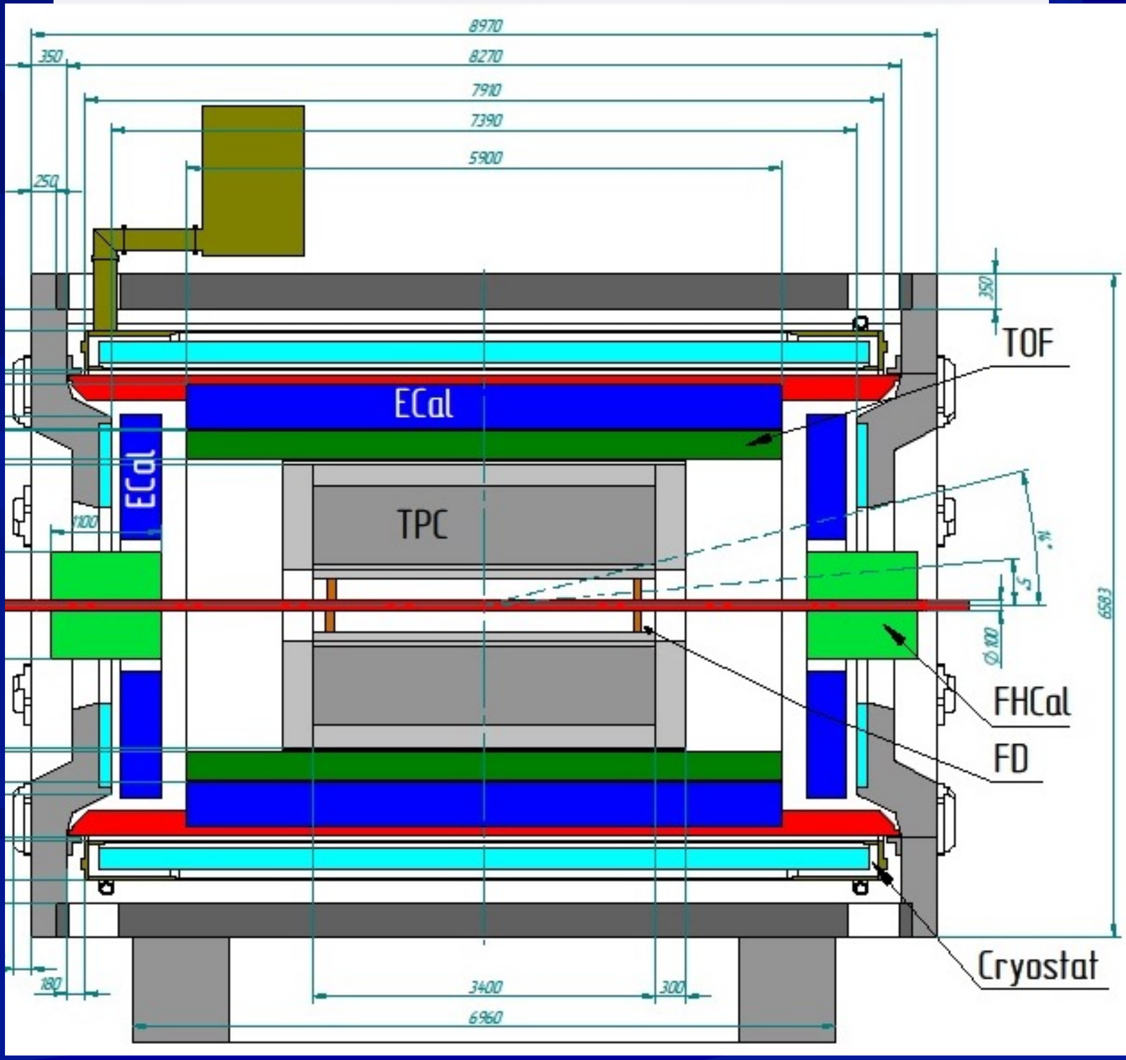
MPD (Multi-Purpose Detector)

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

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

- 9 m long, 6m diameter
- Low material budget
- Good tracking and powerful pid

- Tracking (TPC):
  up to $|\eta|<1.5$, 2π in azimuth
- PID (TOF, TPC, ECAL):
  hadrons, e, γ
- Event characterization (FHCAL):
  centrality & event plane



MPD SC magnet installation

B_0=0.66 T   Weight ~900 tons

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

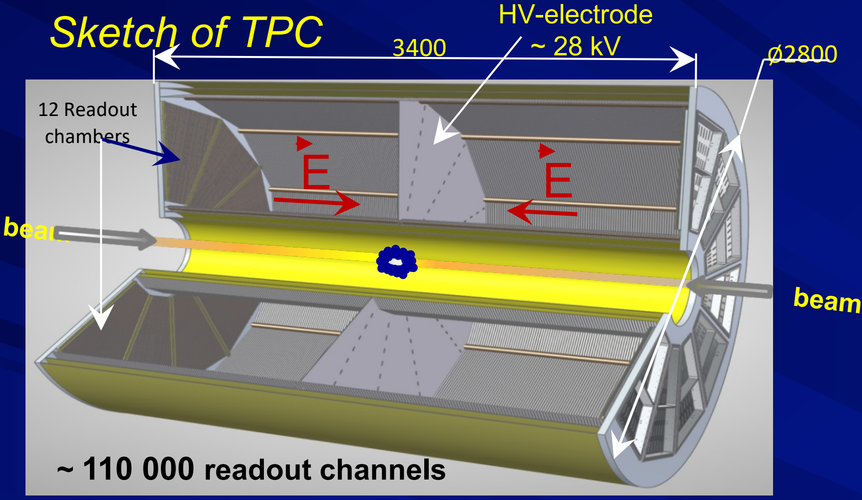
Magnet Yoke assembly

Installation of SC coil inside yoke

- Installation of the Supercoducting coil inside the iron Magnet Yoke **29 July 2021**
- Critical milestone in the assembly of the full MPD apparatus
- Now working on commissioning: cryogenic and electrical tests, before magnetic field measurement

TPC

Main MPD tracking device |η| < 1.5



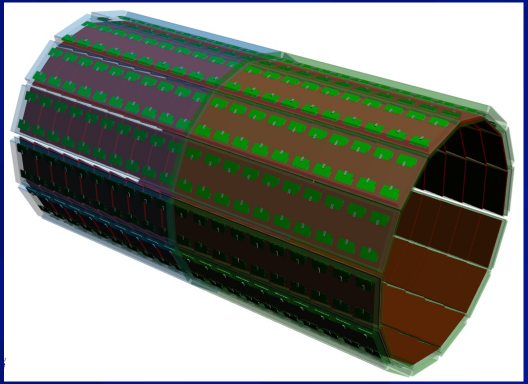
Vessel:
- ✓ HV membrane - tested
- ✓ Assembly of (C1-C2) + (C3-C4) + flanges + HV membrane – **ongoing**

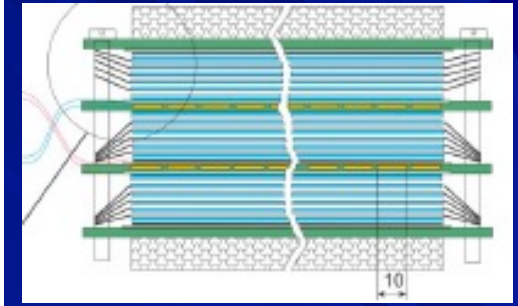
ROC chambers (MWPC):
- ✓ All 26 chambers are produced and tested

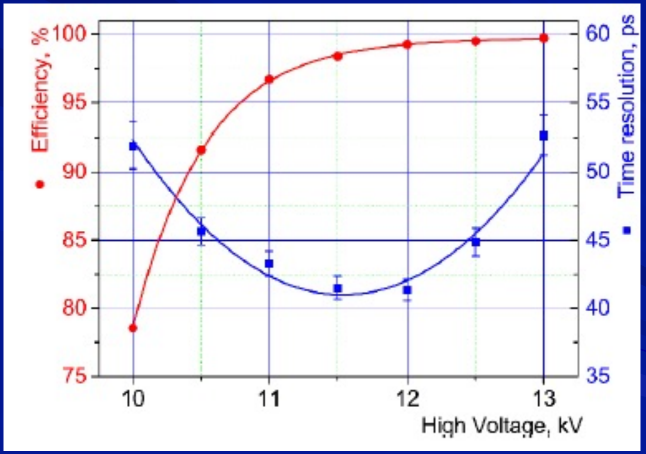
Electronics:
- ✓ 477 pc ready (**32%**), remaining 1011 pc – Q4 2021

TOF - mRPC

- ❑ TOF barrel consists of 280 mRPC arranged in 12 super-modules
- ❑ ~56 m^2 active area - 13824 channels







Single detector time resolution ~ 50 ps

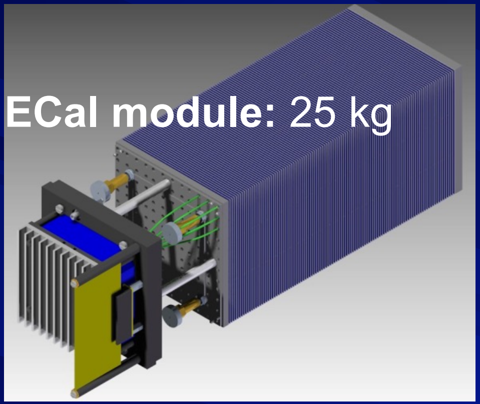
- ❑ 9 / 28 (32%) TOF MPD modules are produced
- ❑ 8 of them are tested with cosmic rays.
- ❑ Production and testing of all modules to be completed by summer 2022.

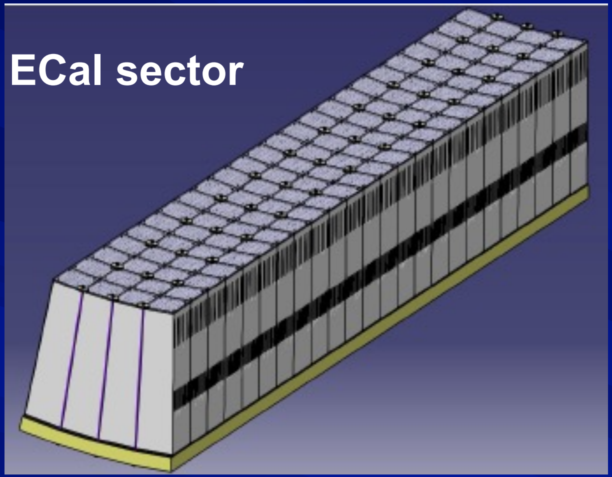
ECal

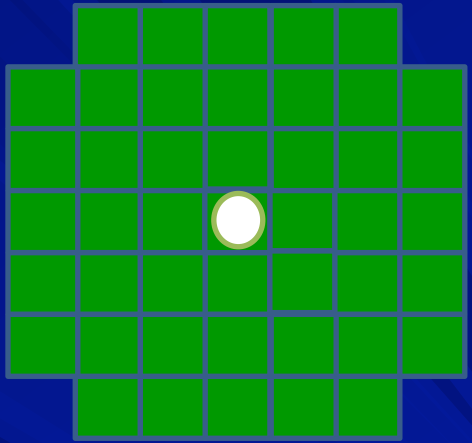
- Shashlik type; Projective geometry
- Module: 220 layers of 0.3 mm Pb + 1.5 mm Scint, L ~35 cm (~ 14 X_0),
- Read-out: WLS fibers + MAPD

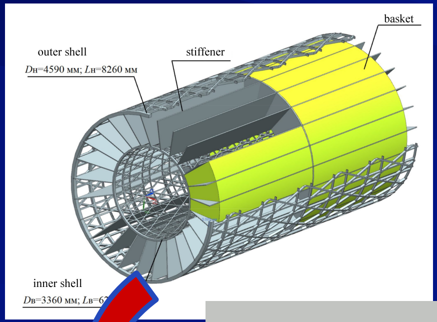
FHCal

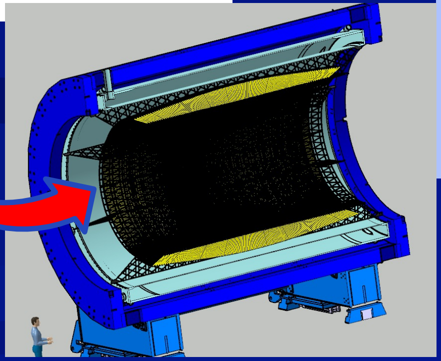
- Centrality and reaction plane
- Two calorimeters at ±3.2 m from interaction point $2.0 < |\eta| < 5.0$
- Each FHCal consists of 45 modules of ~1x1 m2







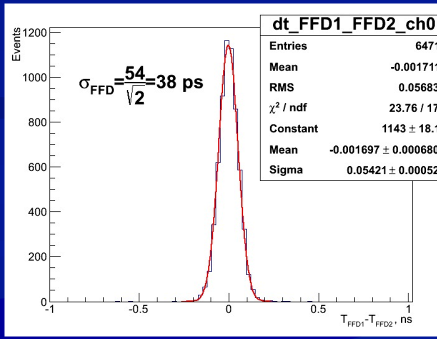


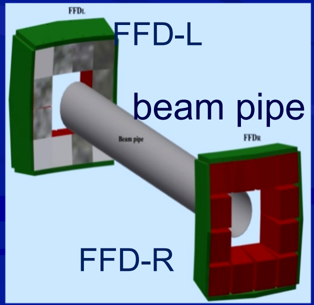


- 350 modules produced, +420 modules will be finished by end of 2021
- FEE produced and under test
- Beam tests of modules underway

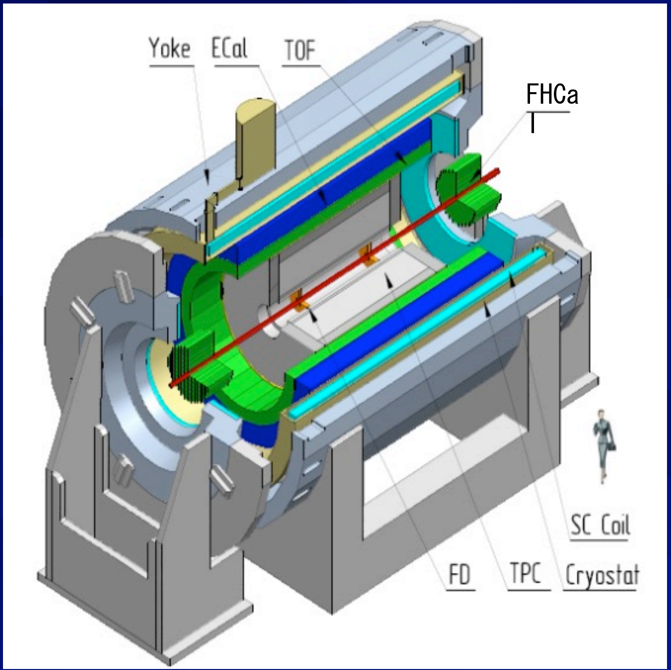
FFD

- Cherenkov detector with quartz radiator
- Provides: T_0 for TOF & L0-trigger





MPD Collaboration



12 Countries, **>500** participants,
42 Institutes and **JINR**

Spokesperson: **Adam Kisiel**
Inst. Board Chair: **Fuqiang Wang**
Project Manager: **Slava Golovatyuk**

Deputy Spokespersons:
Victor Riabov, Zebo Tang

Collaboration established in **2018**
Still growing, open for new member institutions

*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*Plovdiv University Paisii Hilendarski, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Central China Normal University, **China**;*
*Fudan University, Shanghai, **China**;*
*Shandong University, Qingdao, **China**;*
*SNST, UCAS, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics, CAS, Lanzhou, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
***Joint Institute for Nuclear Research**;*
*FCFM-BUAP Puebla, **Mexico**;*
*FC-University of Colima, Colima, **Mexico**;*
*FCFM-UAS, Culiacán, **Mexico**;*
*ICN-UNAM, Mexico City, **Mexico**;*
*CINVESTAV, Mexico City, **Mexico**;*
*Universidad Autónoma Metropolitana, Iztapalpa, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*WUT, Warsaw, **Poland**;*
*NCNR, Otwock – Świerk, **Poland**;*
*University of Wrocław, **Poland**;*
*University of Silesia, Katowice, **Poland;***
*University of Warsaw, **Poland**;*
*Jan Kochanowski University, Kielce, **Poland**;*
*Institute of Nuclear Physics, PAS, Cracow, **Poland**;*
*Belgorod National Research University, **Russia**;*
*INR RAS, Moscow, **Russia**;*
*NRNU MEPhI, Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*NRC Kurchatov Institute, ITEP, **Russia**;*
*Kurchatov Institute, Moscow, **Russia**;*
*St. Petersburg State University, **Russia;***
*SINP, Moscow, **Russia**;*
*PNPI, Gatchina, **Russia**;*
*Vinča Institute of Nuclear Sciences, Belgrade, **Serbia**;*

MPD Physics Programme

G. Feofilov, A. Ivashkin

Global observables
- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

V. Riabov, Chi Yang

Electromagnetic probes
- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

NICA and MPD schedule - milestones

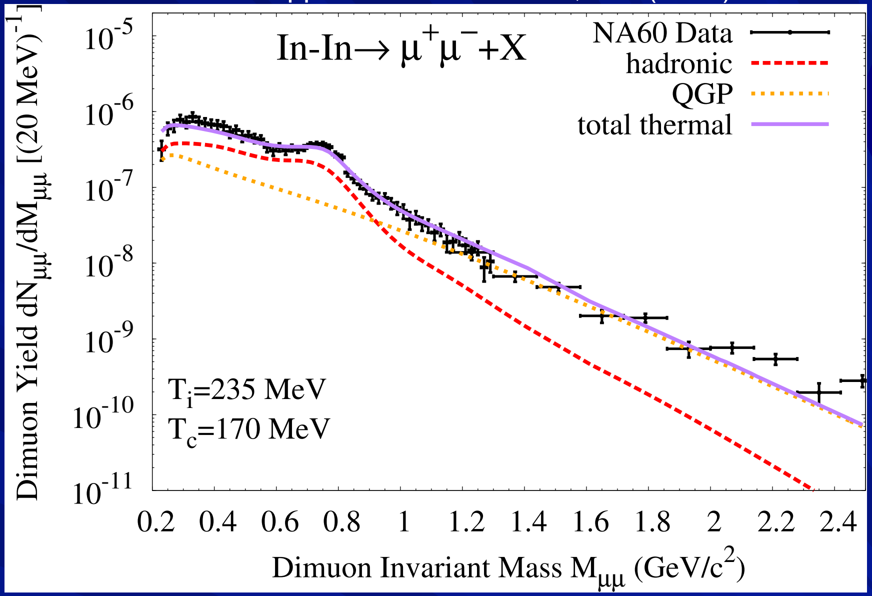
- Year 2021
  - Booster commissioning
  - Booster to Nuclotron transfer line installation and commissioning
  - MPD SC solenoid assembly and commissioning
  - MPD detector sub-systems construction
- Year 2022 – very challenging schedule
  - Fixed target HI run (Fe/Kr/Xe) with the Booster+Nuclotron
  - Completion of the NICA collider assembly including Nuclotron to collider transfer lines – Start commissioning end of 2022
  - Installation of MPD Stage-I configuration
- Year 2023
  - NICA technical run Bi+Bi @ 9.2 GeV with luminosity ~10^{25} $cm^{-2}s^{-1}$
  - MPD run 100 M MB events
- Year 2024-5 and beyond
  - Au+Au collisions at up to design energy 11 GeV and design luminosity 10^{27} $cm^{-2}s^{-1}$

- Dileptons: quo vadis?

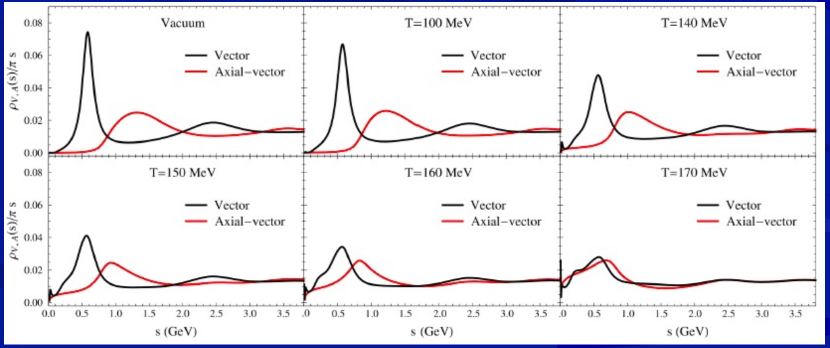
After ~25 years of dilepton measurements

- All HI systems at all energies studied show an excess of dileptons wrt to hadronic sources
- Excess consistently reproduced by microscopic many body model (Rapp et al.)
- LMR:
  - Thermal radiation from HG
    $\pi^+\pi^- \rightarrow \rho \rightarrow \mu^+\mu^-$
  - Track the medium lifetime
- IMR:
  - Thermal radiation from QGP
    $q\bar{q} \rightarrow \mu^+\mu^-$
  - Provides a measurement of <T>
- Emerging picture for the realization of CSR: the ρ meson broadens in the medium, the a_1 mass drops and becomes degenerate with the ρ.

NA60 data: Eur. Phys. J. C61, 711 (2009)
Curves: Rapp and Hees PLB 753, 586 (2016)



Hohler and Rapp PLB 73, 103 (2014)

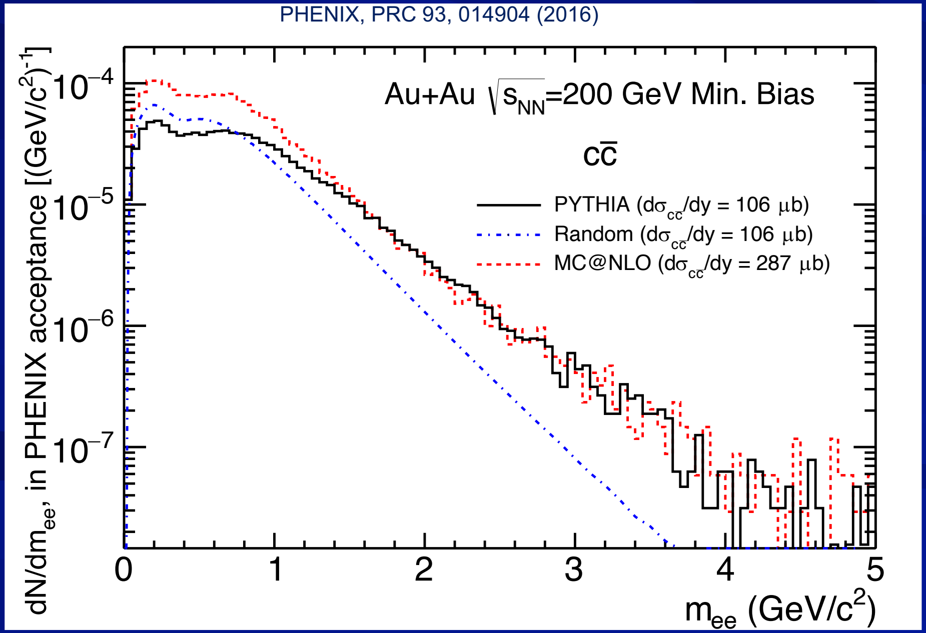


- One of the few effects exclusively observed in AA collisions

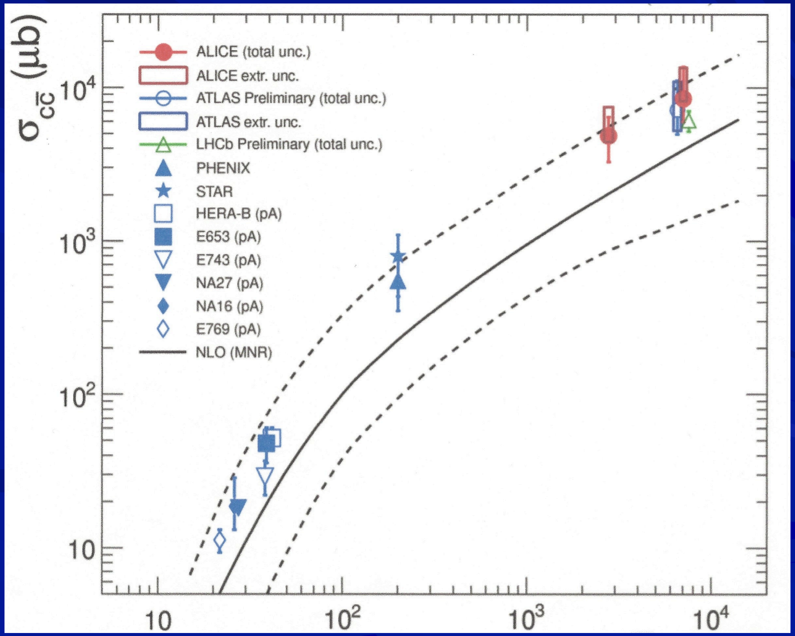
What is missing (I)?

- Confirmation of QGP thermal radiation in the IMR.
  - IMR thermal radiation observed only at SPS by one experiment NA60
  - Difficulties in identifying the QGP thermal radiation at the higher RHIC energies due to a sizable contribution from semi-leptonic decays of charmed mesons
  - Should be easier at NICA energies: charm cross section negligible

Large uncertainties in shape both in the LMR and the IMR



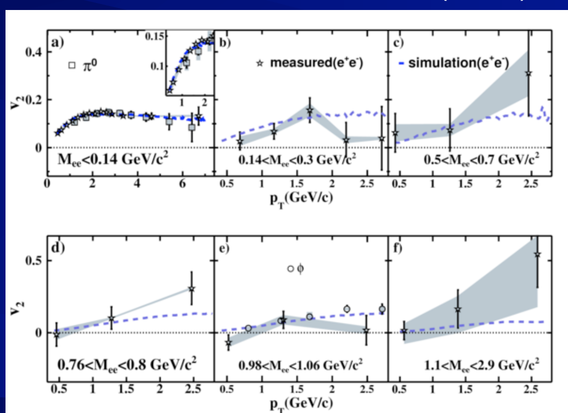
Charm cross section in pp



What is missing (II)?

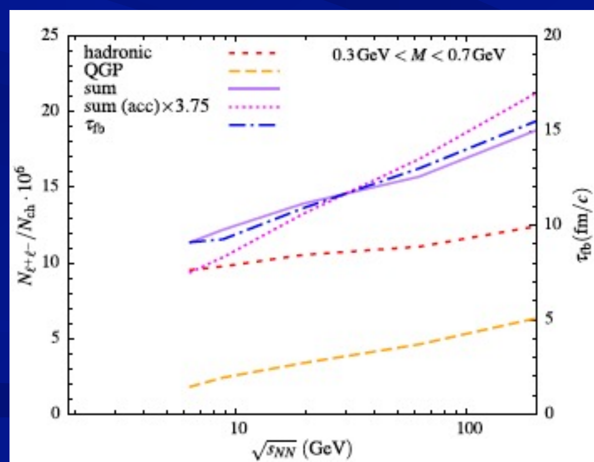
- ❑ Energy scan of dilepton excess: Onset of deconfinement? Onset of CSR? First order phase transition?
  - Inverse slope of the mass spectrum in the IMR provides a measurement of <T>
  - Thermal radiation down to $\sqrt{s_{NN}}$ – 6 GeV ?
  - Integrated yield in the LMR tracks the fireball lifetime
- ❑ v_2 of thermal radiation
  - Very challenging measurement
  - Could provide an independent confirmation about the origin of the thermal radiation

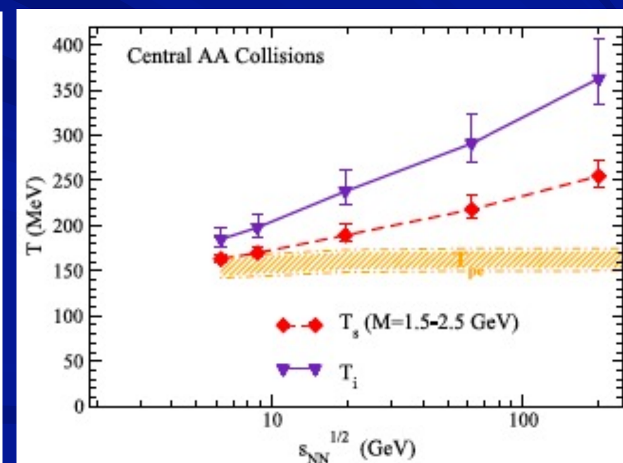
Inclusive dielectron v_2
STAR PRC 90, 64904 (2014)



Challenge: isolate the v_2 of the excess dileptons

Rapp and Hees, PLB 753, 586 (2016)





❑ MPD well suited for all these dilepton studies

Summary

- NICA dedicated HI facility for comprehensive exploration of high μ_B matter
- Construction of the accelerator complex and its associated infrastructure is nearing completion – Commissioning at the end of 2022
- MPD Stage-1 on track to be ready when first beam becomes available
- Exciting dilepton prospects at NICA energies - MPD well suited for dilepton studies
- The international collaboration around MPD is growing. JINR welcomes new partners to join the experiments around NICA.

NICA Center