Санкт-Петербургский
государственный
университет

XXV Всероссийская конференция по ускорителям заряженных частиц

XXV Russian Particle Accelerator Conference

21-25.11.2016

RuPAC
Russia
St. Petersburg
21-25 November
2016

HOSTED BY:

Saint Petersburg University

Joint Stock Company "D.V.Efremov Institute of Electrophysical Apparatus"

Scientific Council of RAS on Charged Particle Accelerators

Interregional Innovative Development Center (INNO-MIR)

WITH SUPPORT OF:

Joint Institute for Nuclear Research

Kurchatov Institute Institute for High Energy Physics

Budker Institute of Nuclear Physics SB RAS

Russian Foundation for Fundamental Research

NIIEFA-ENERGO

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November 25th, 2016

Session dedicated to NICA project

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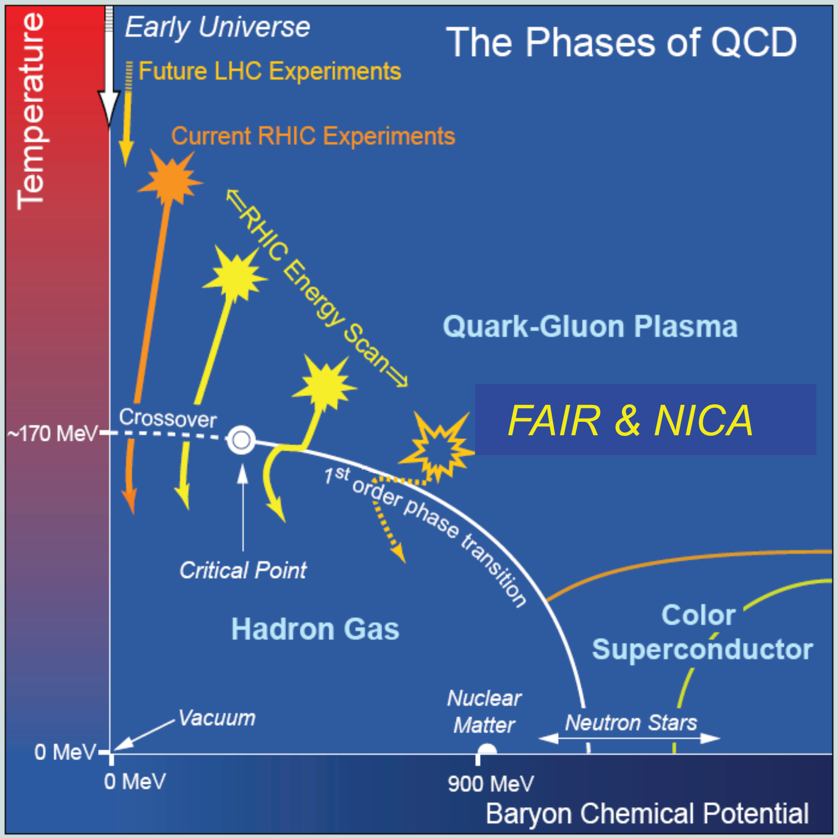
The Nuclotron-based Ion Collider fAcility project at JINR

is aimed at generation of intense heavy ion and polarized nuclear beams for searching the baryonic matter of a high density at high (comparatively) temperature and investigation of polarization phenomena.

NICA Collider basic parameters:

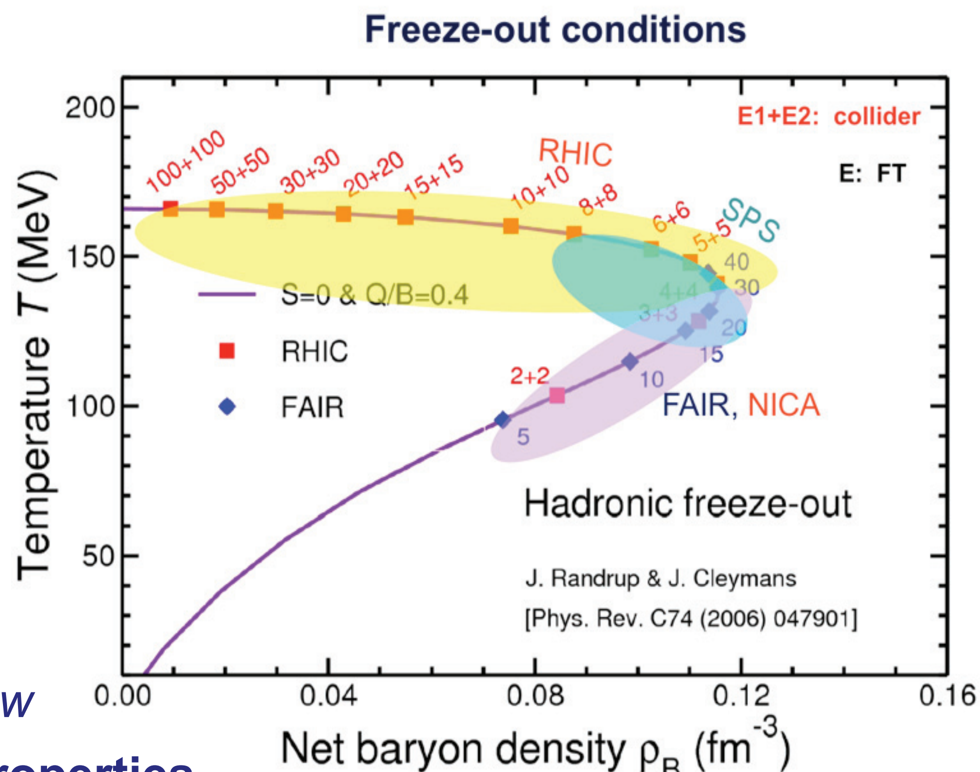
$\sqrt{s_{NN}}$ = 4 - 11 GeV heavy ion colliding beams
at the luminosity L ~ 10^{27} cm^{-2} c^{-1} (Au)
and polarized p↑ (d↑) of $\sqrt{s_{NN}}$ up to 26 (13) GeV at L ~ 10^{32} cm^{-2} c^{-1}

Physics



QCD matter at NICA :

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



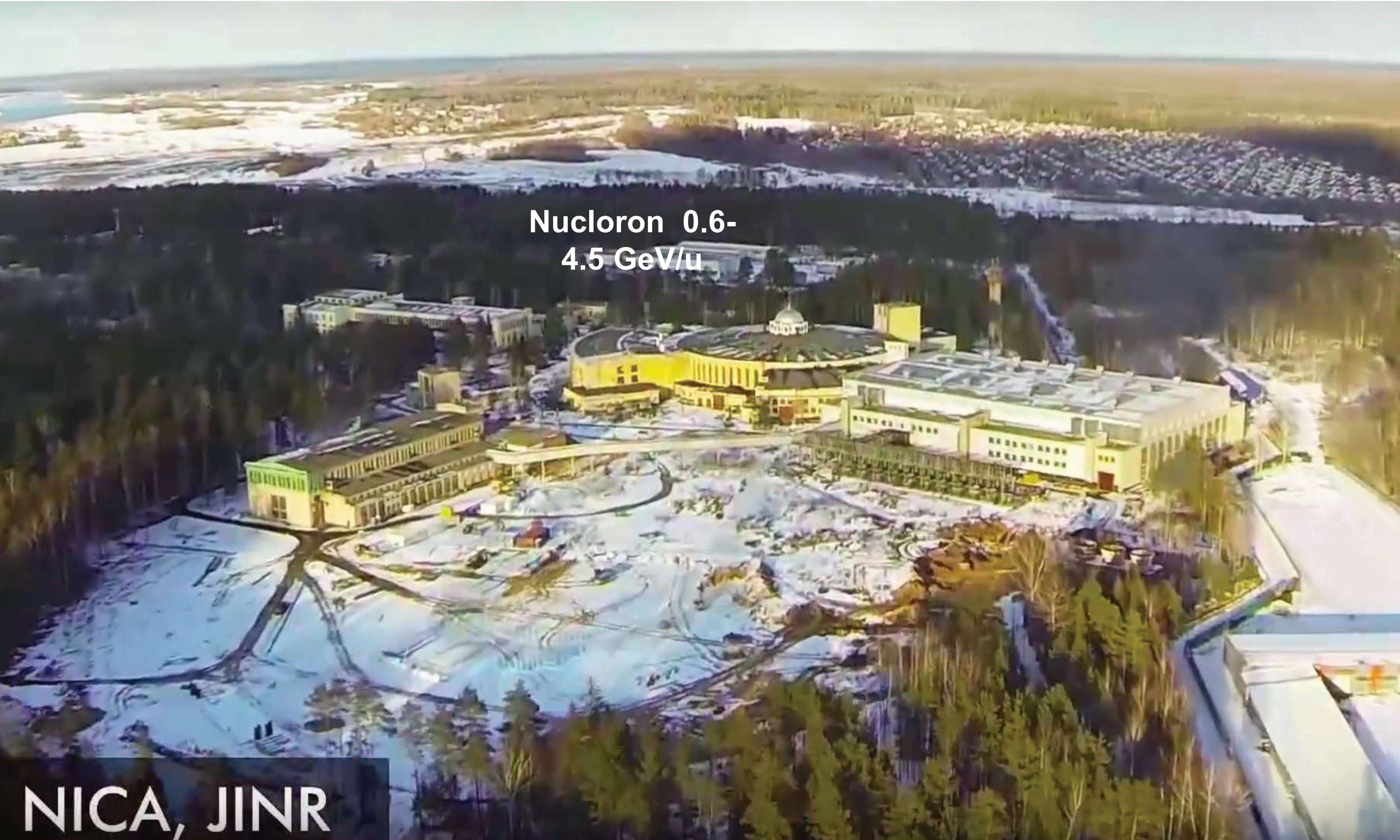
- **Bulk properties, EOS -** *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement, phase transition at high ρ_B** *- enhanced strangeness production*
- **QCD Critical Point -** *event-by-event fluctuations & correlations*
- **Strangeness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

NICA facility

In operation *Under construction*

NICA facility

In operation *Under construction*



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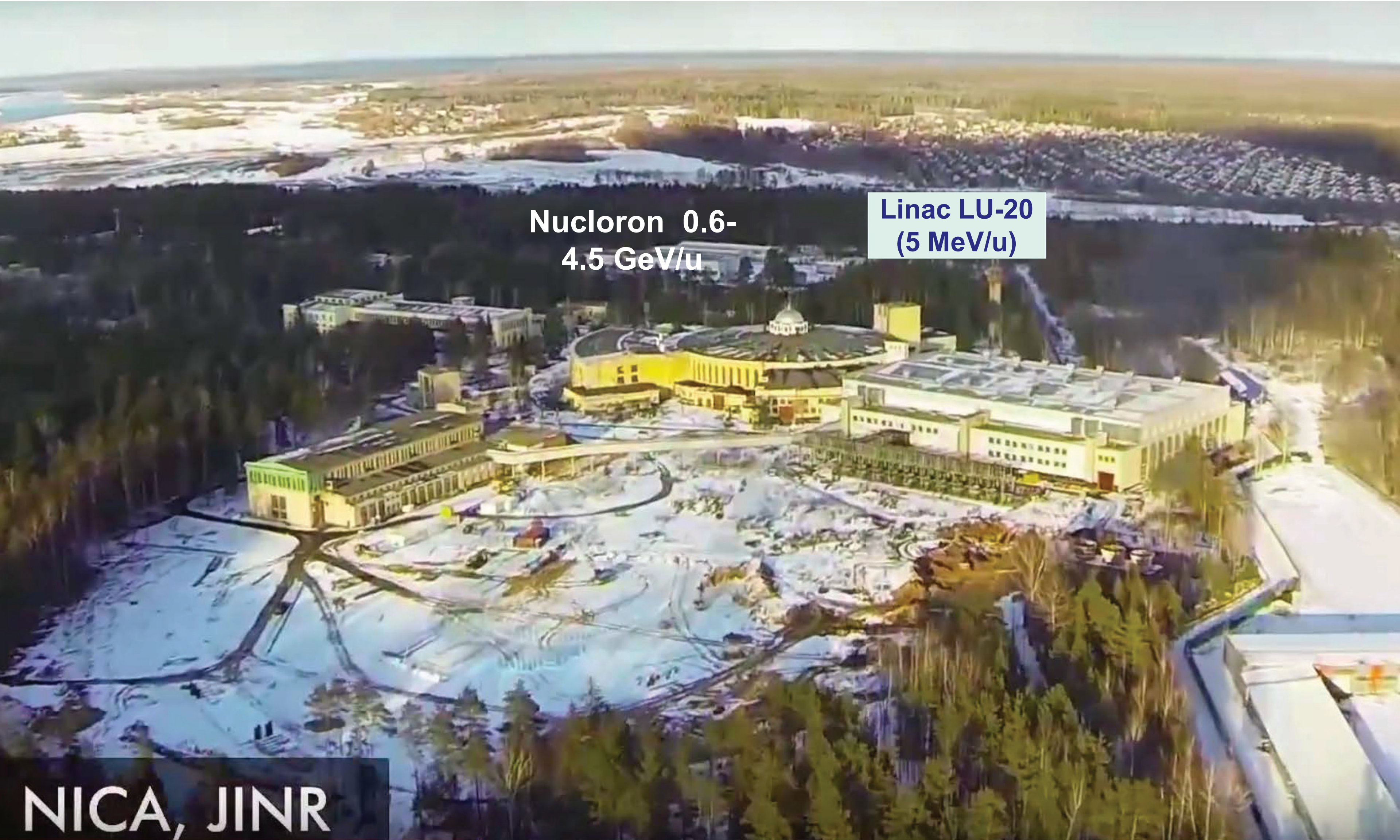

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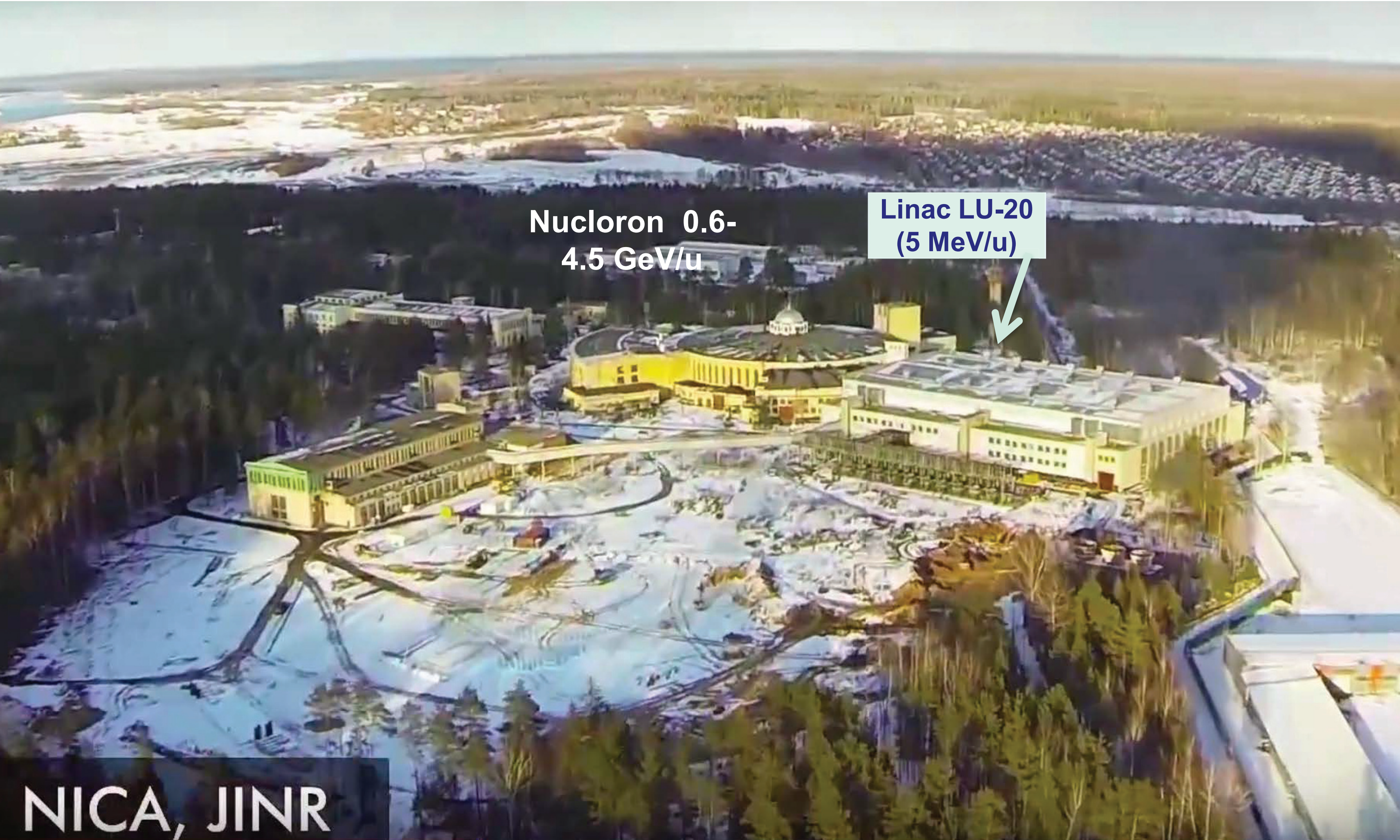

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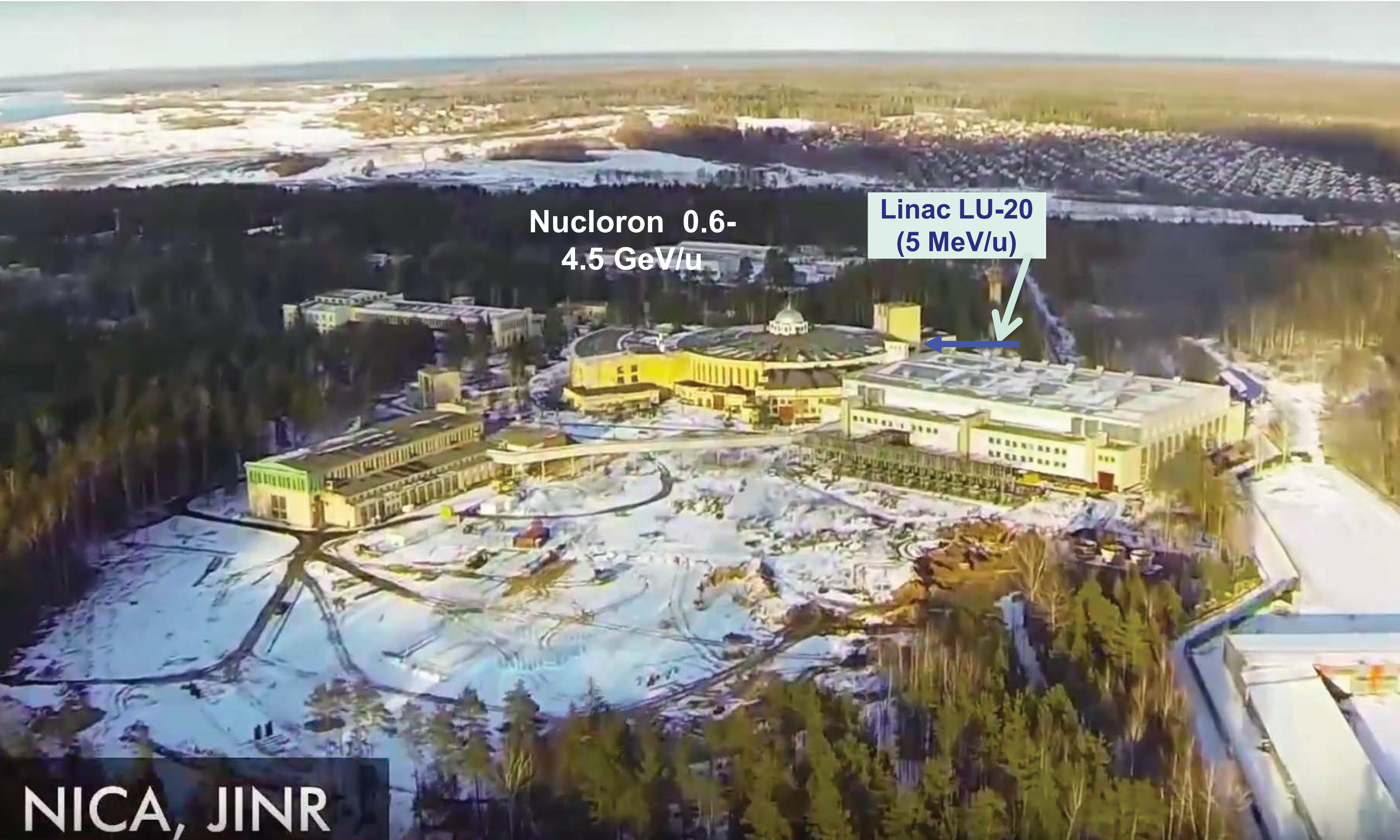

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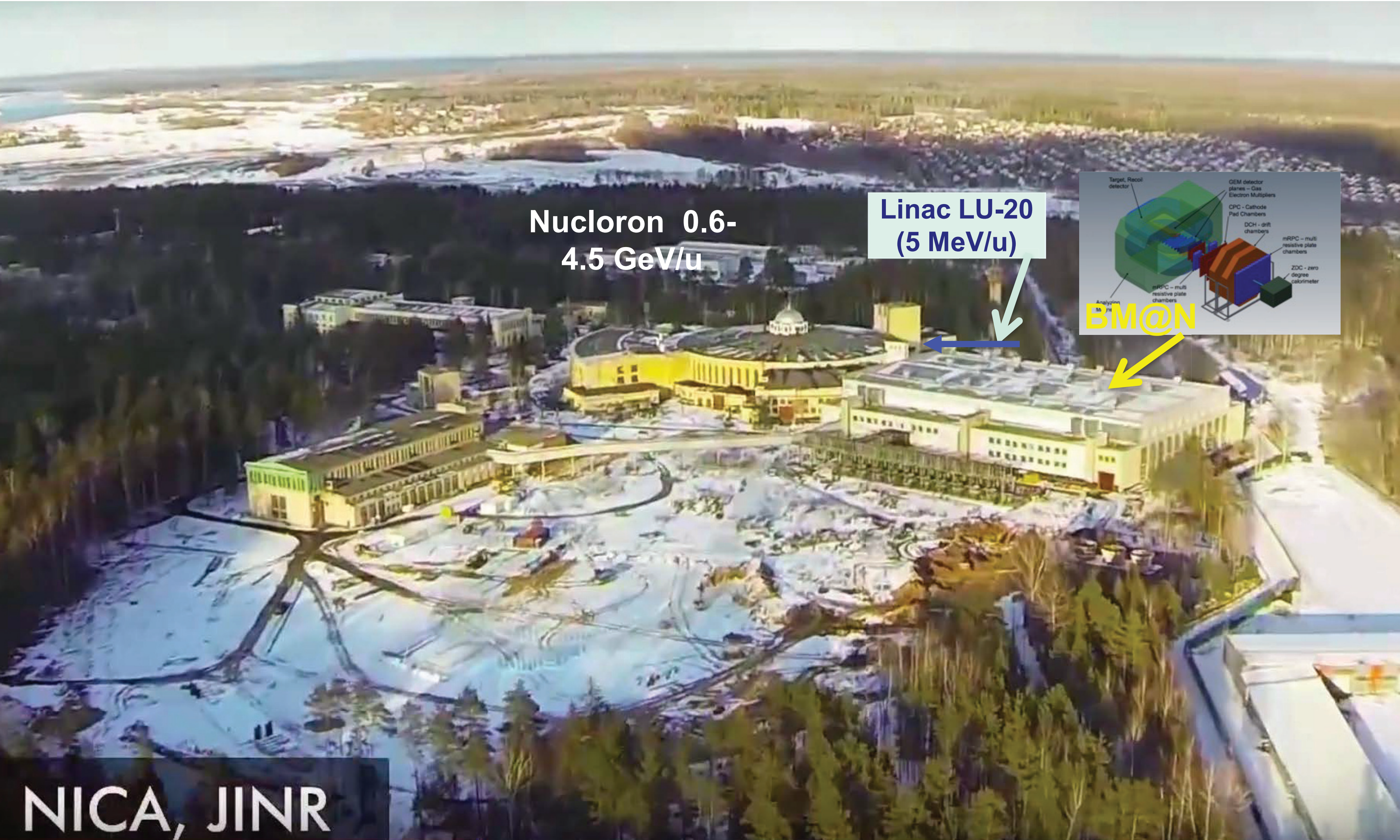

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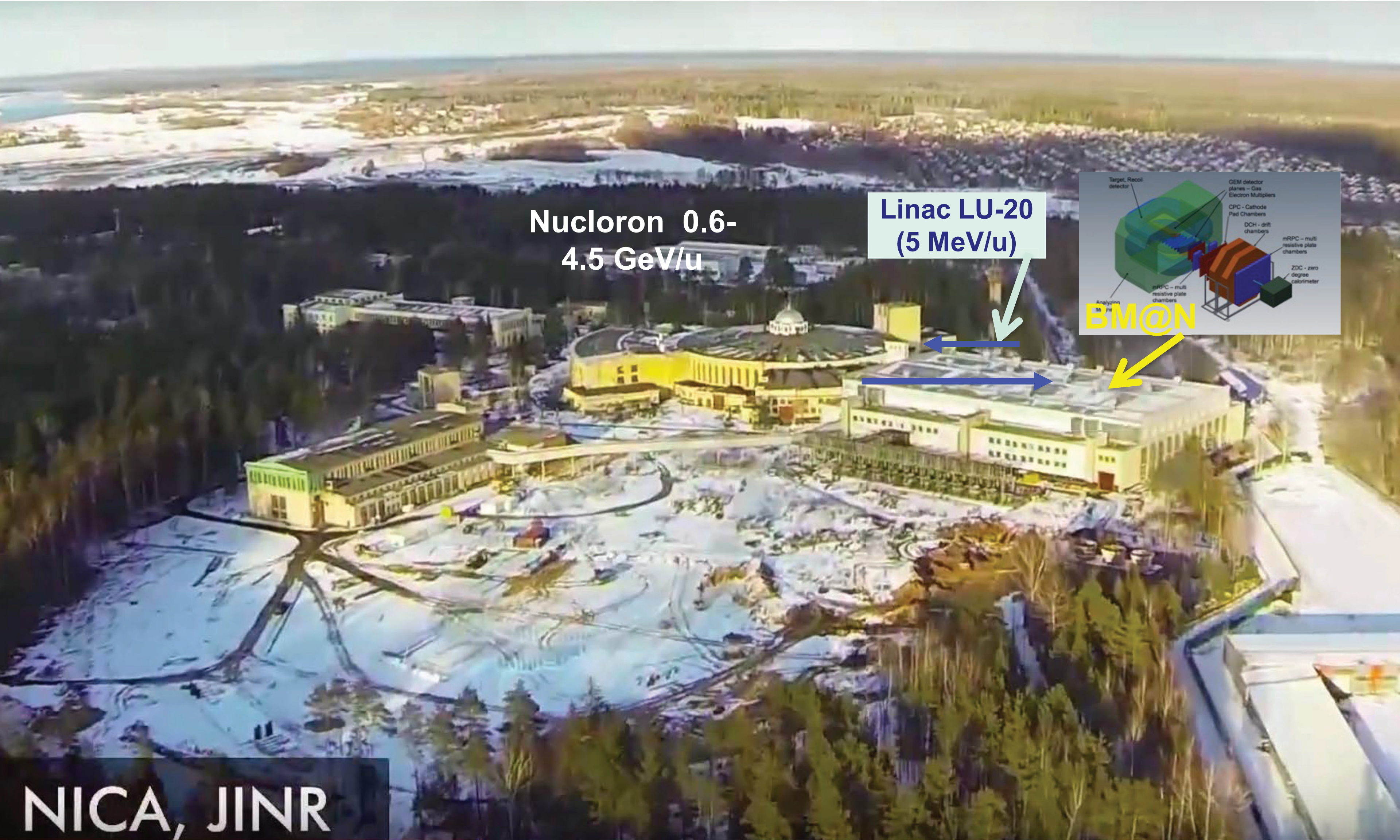

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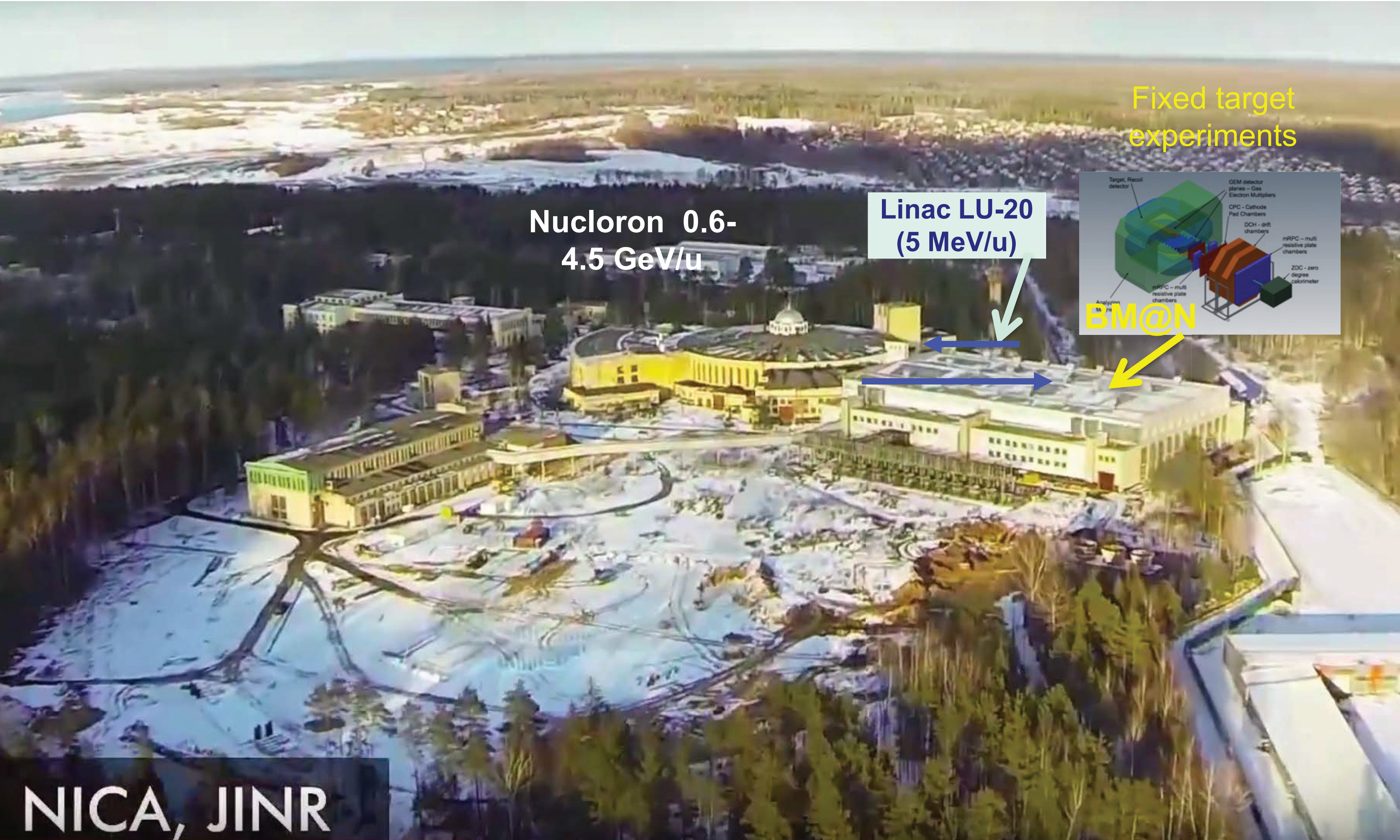

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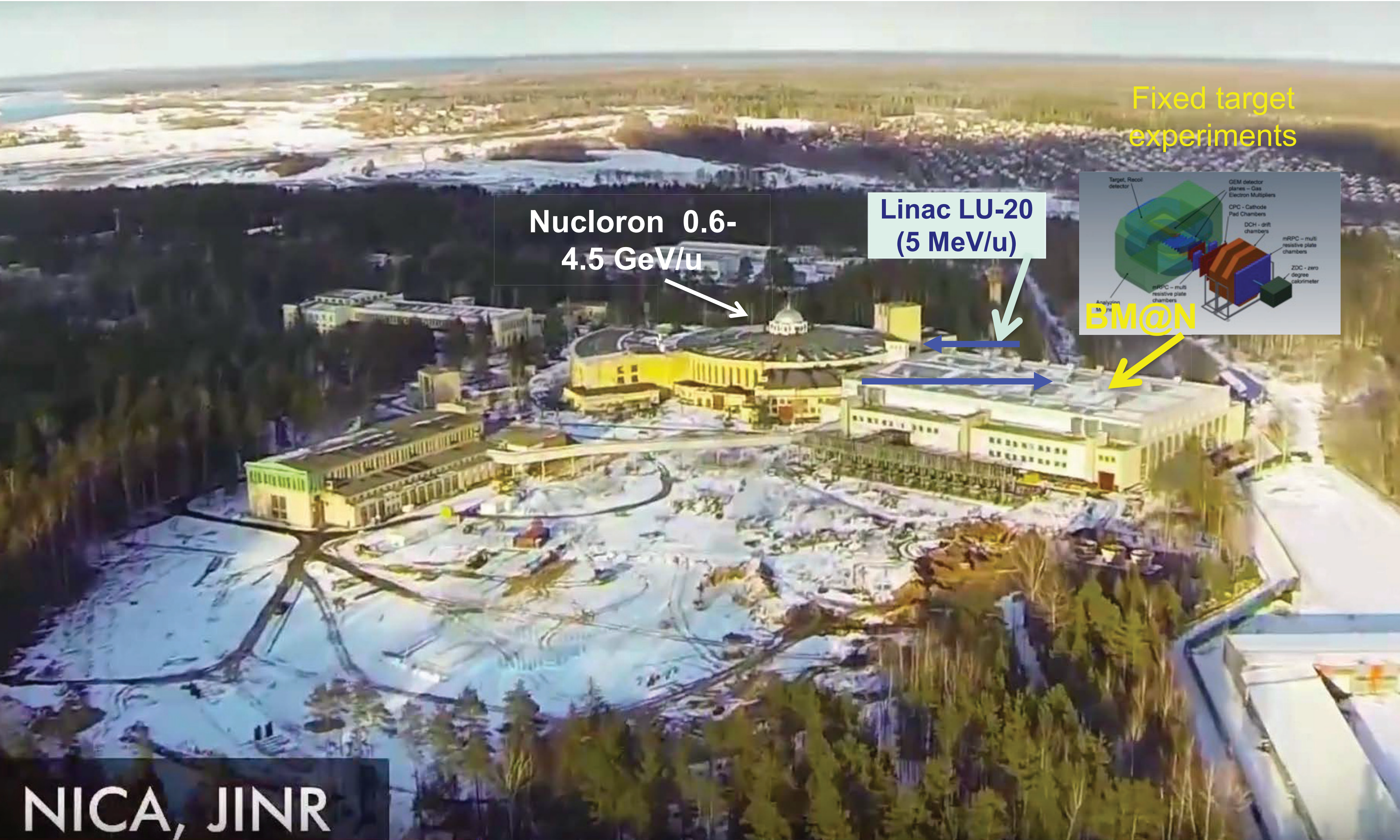

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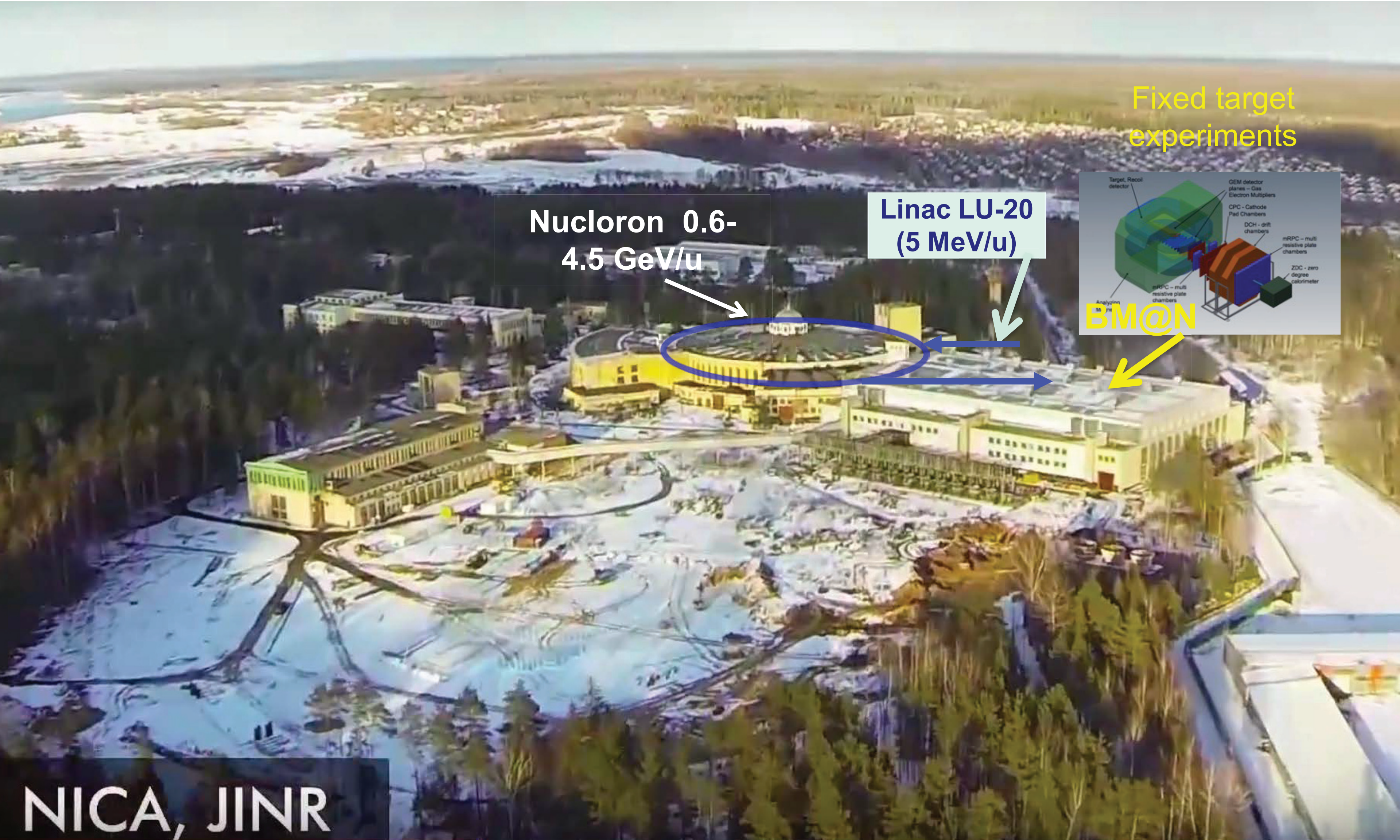

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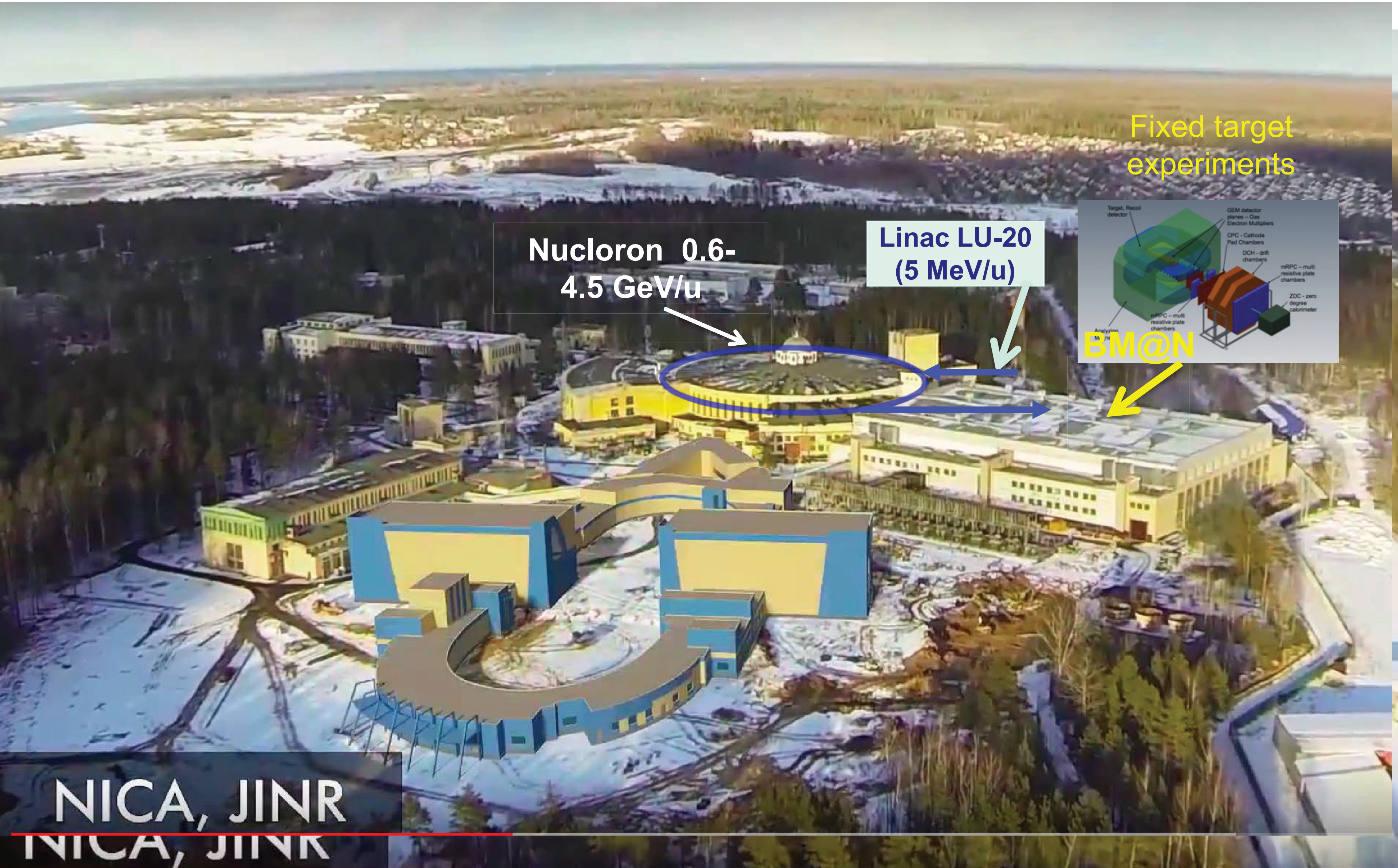

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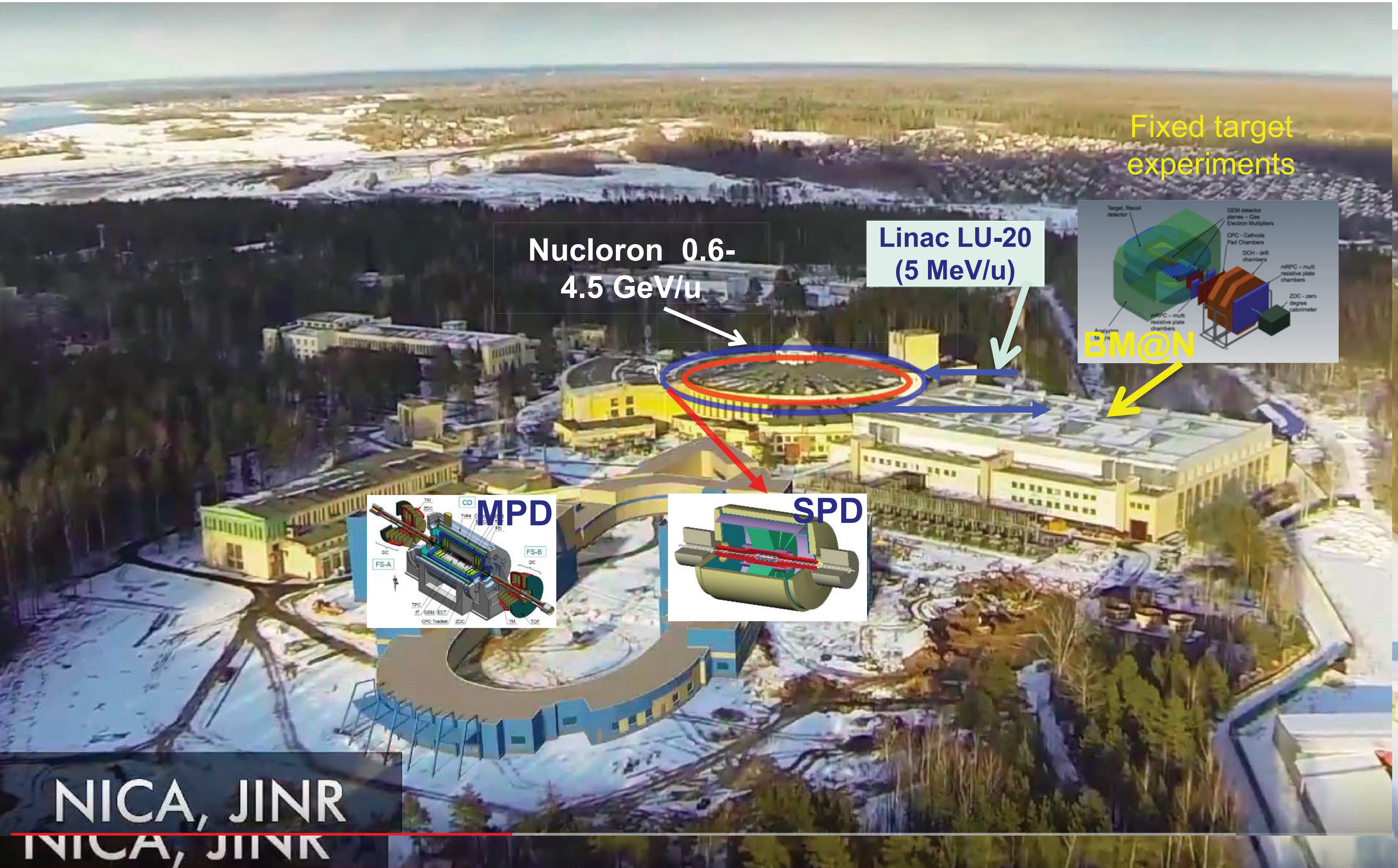

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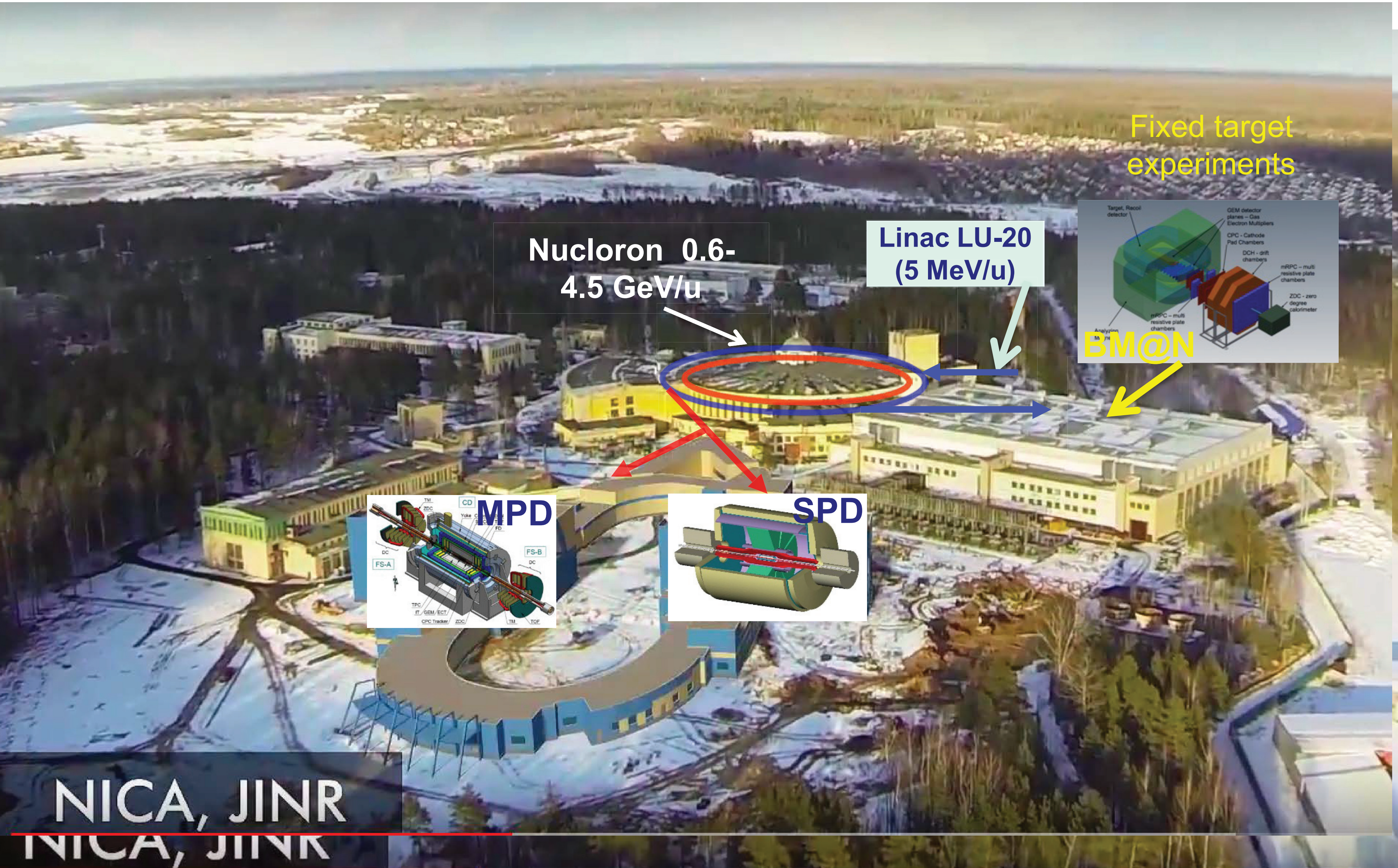

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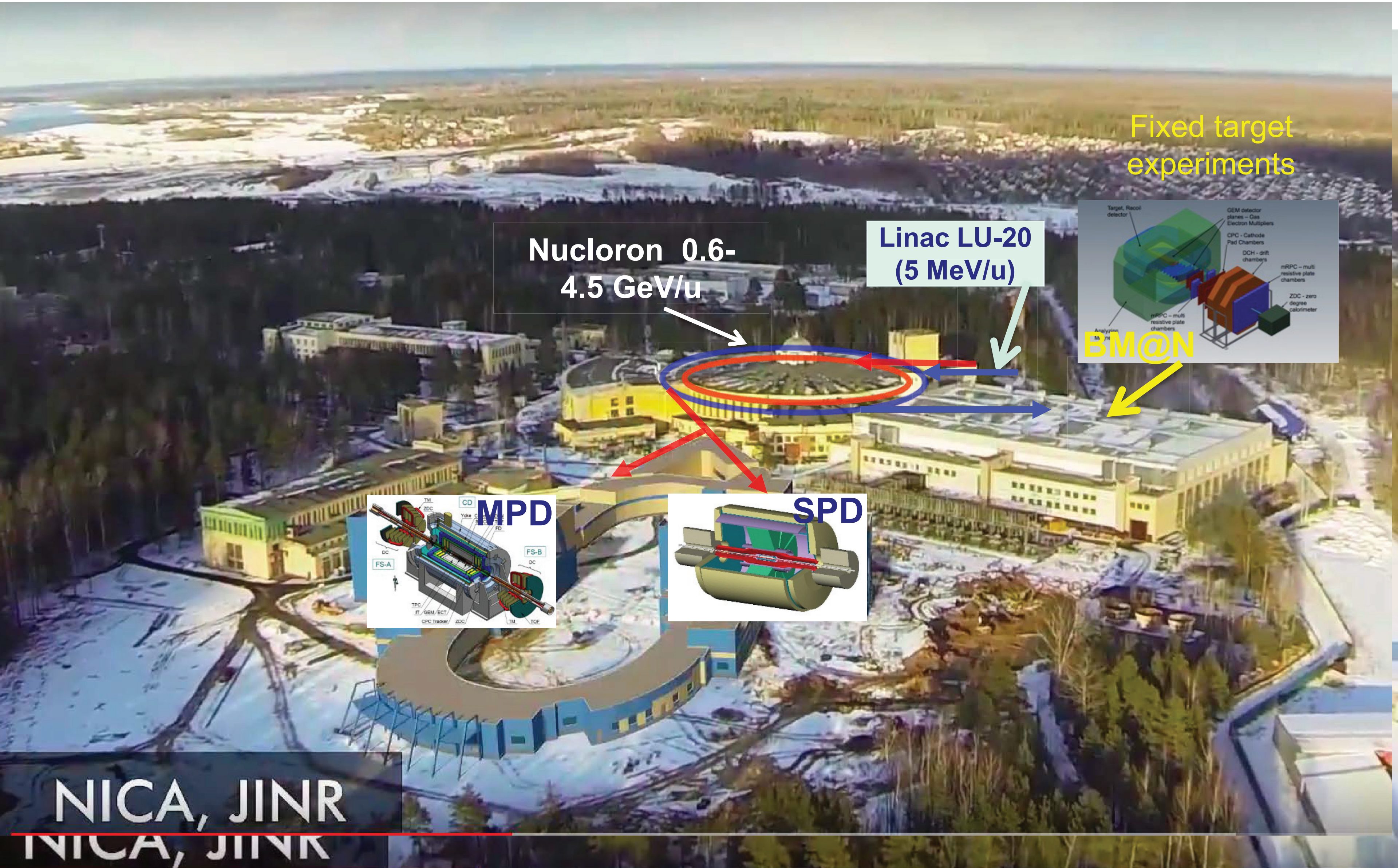
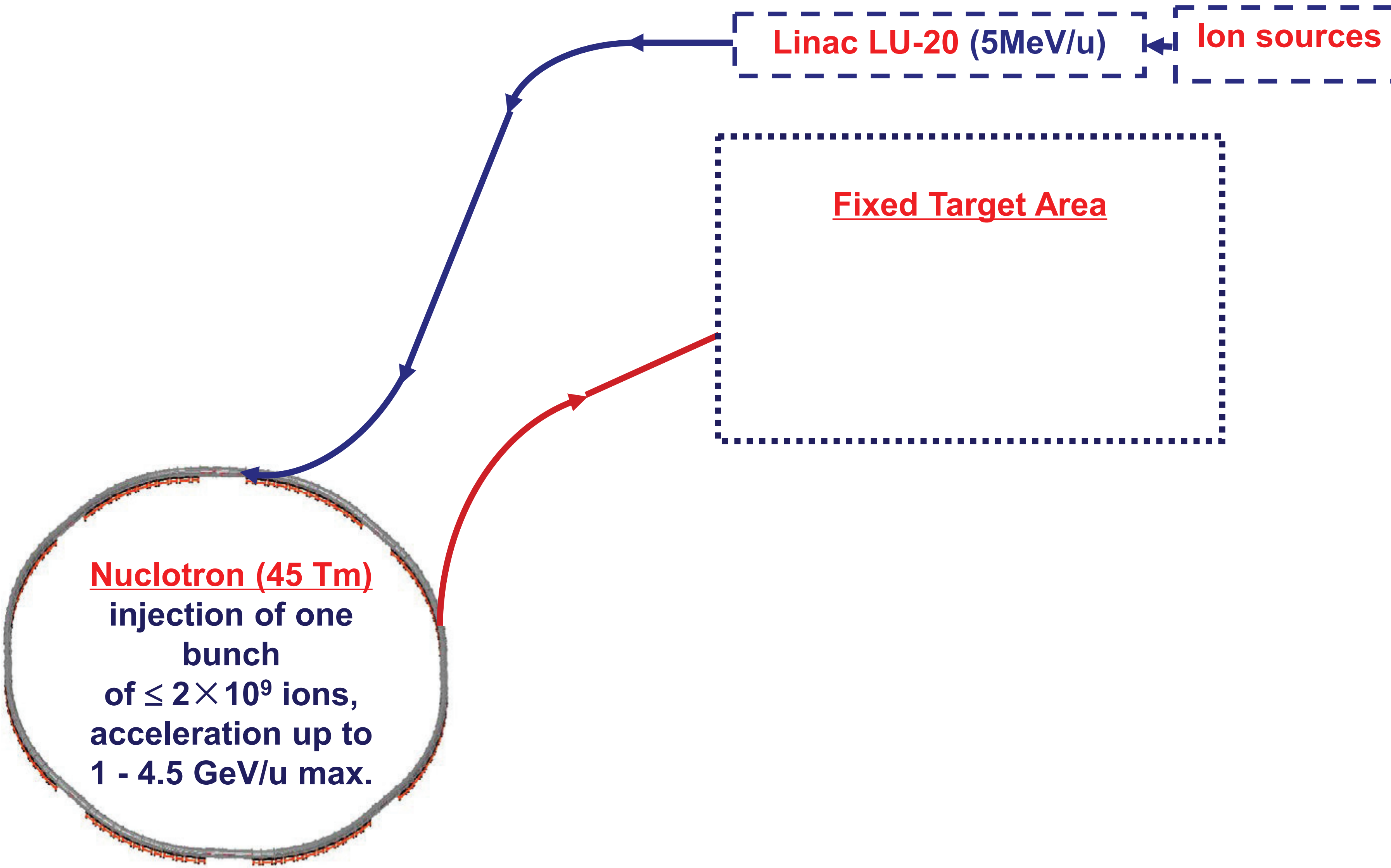


NICA @ Heavy Ion mode



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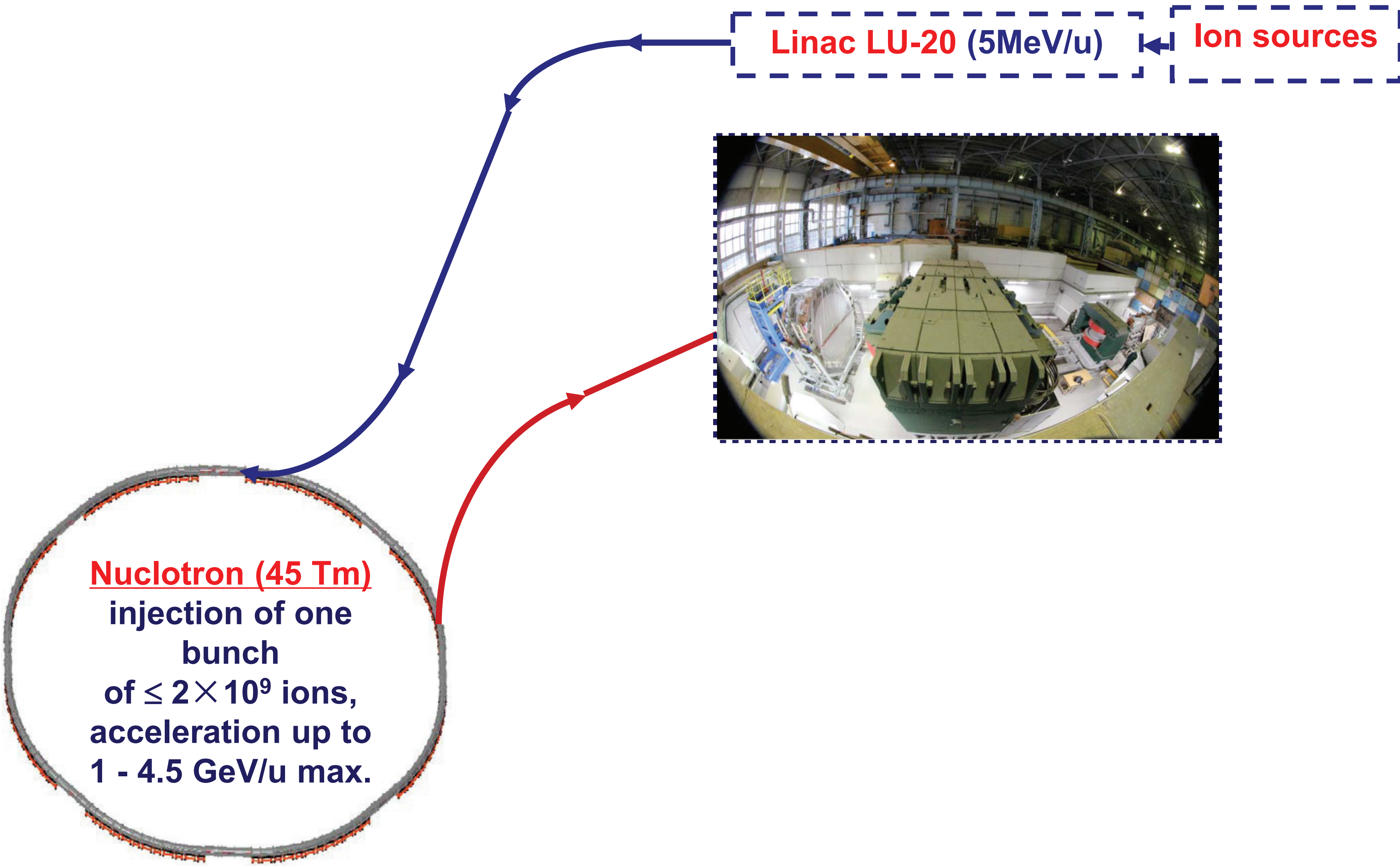


NICA @ Heavy Ion mode

Linac HILac (3.2MeV/u)

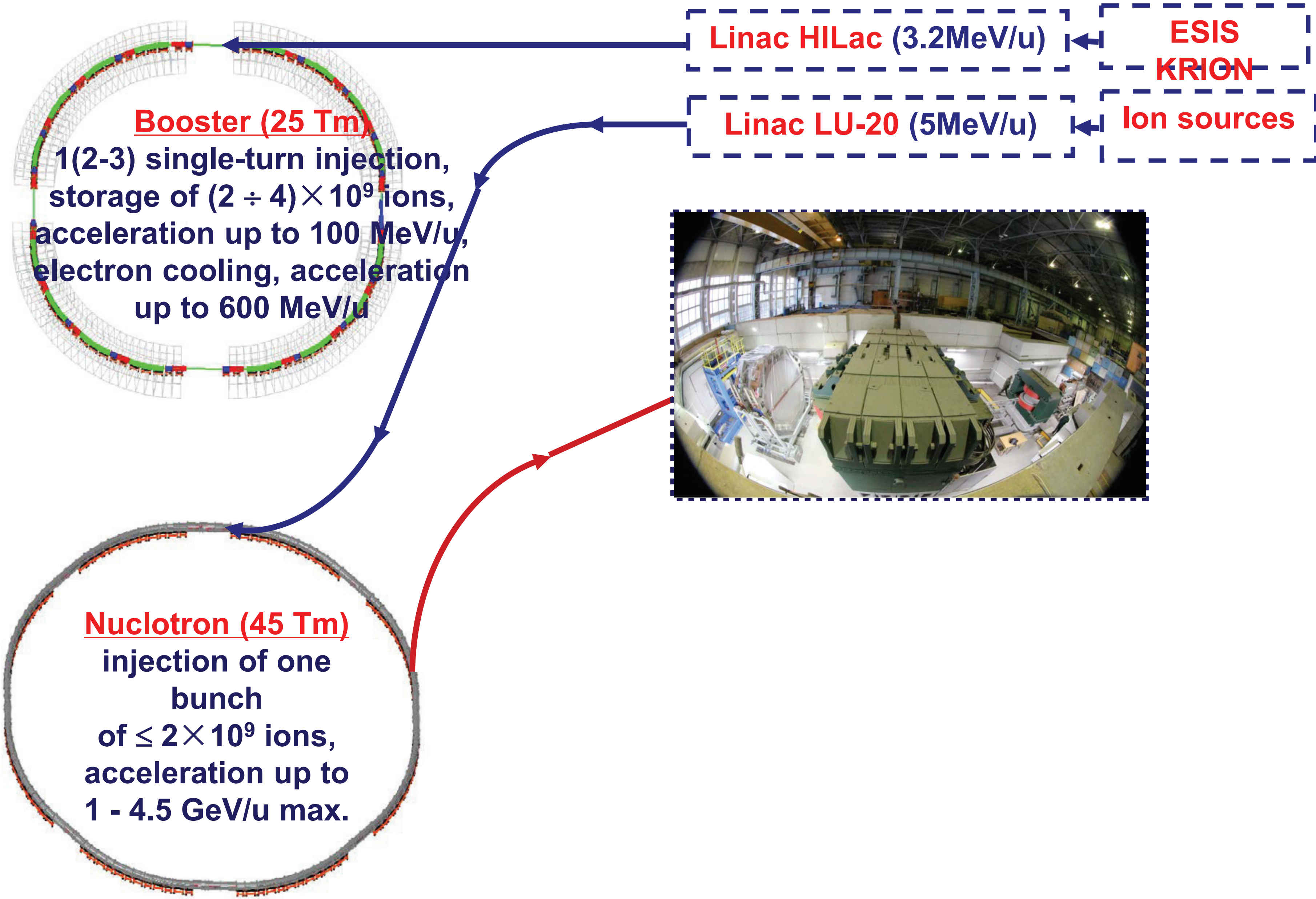
ESIS
KRION

Linac LU-20 (5MeV/u)

Ion sources

Nuclotron (45 Tm)
injection of one bunch
of $\leq 2 \times 10^9$ ions,
acceleration up to
1 - 4.5 GeV/u max.

NICA @ Heavy Ion mode



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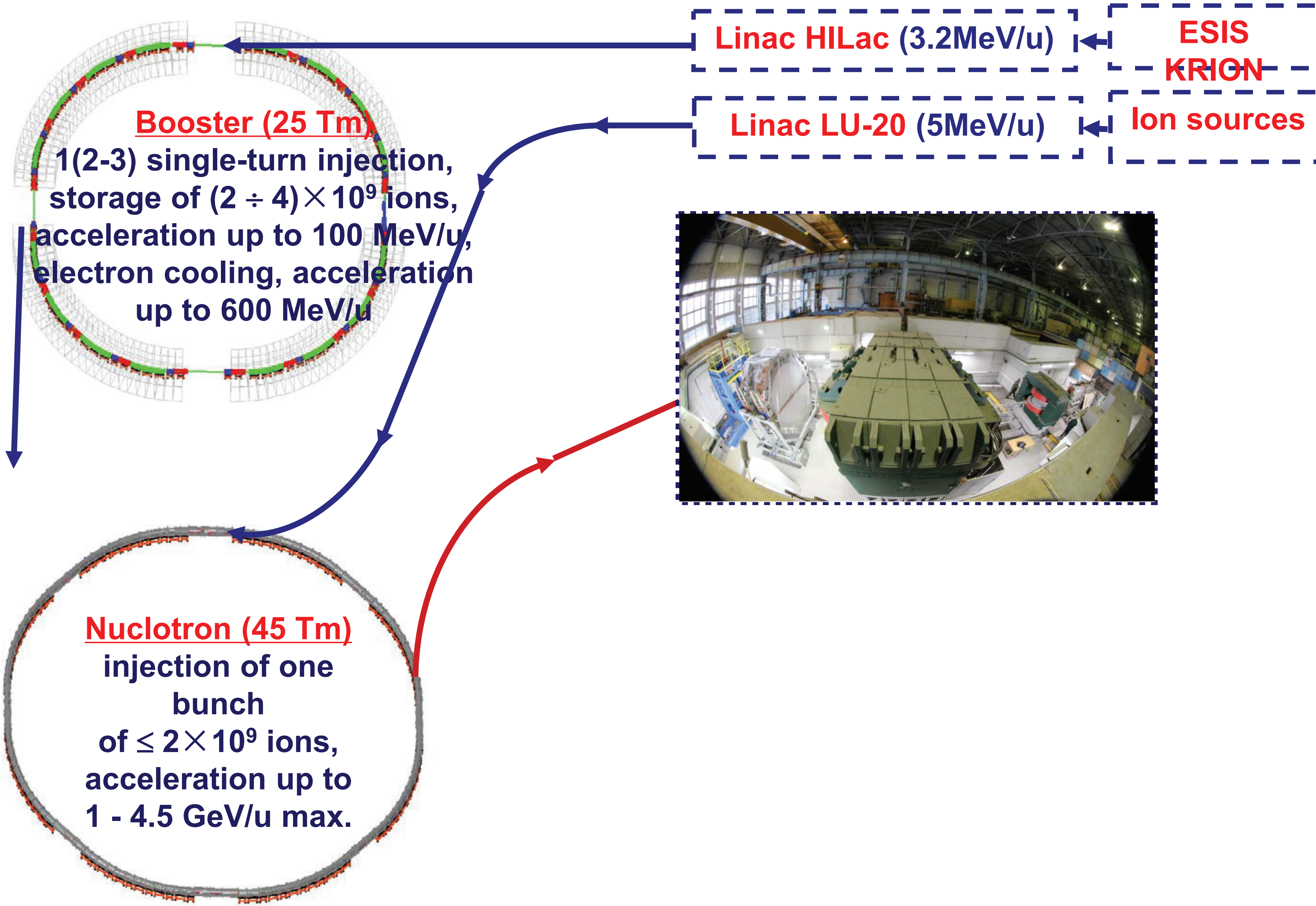

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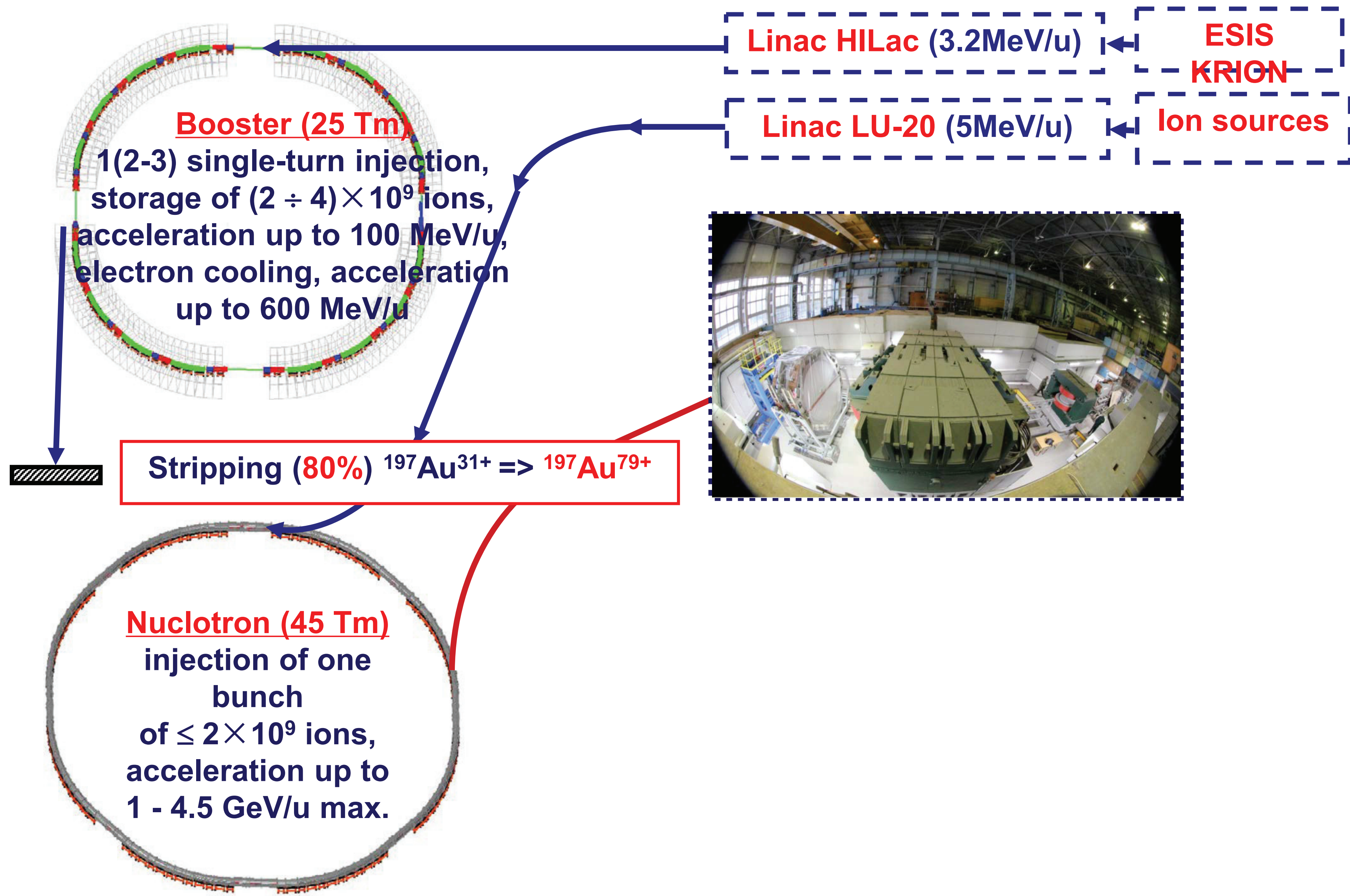

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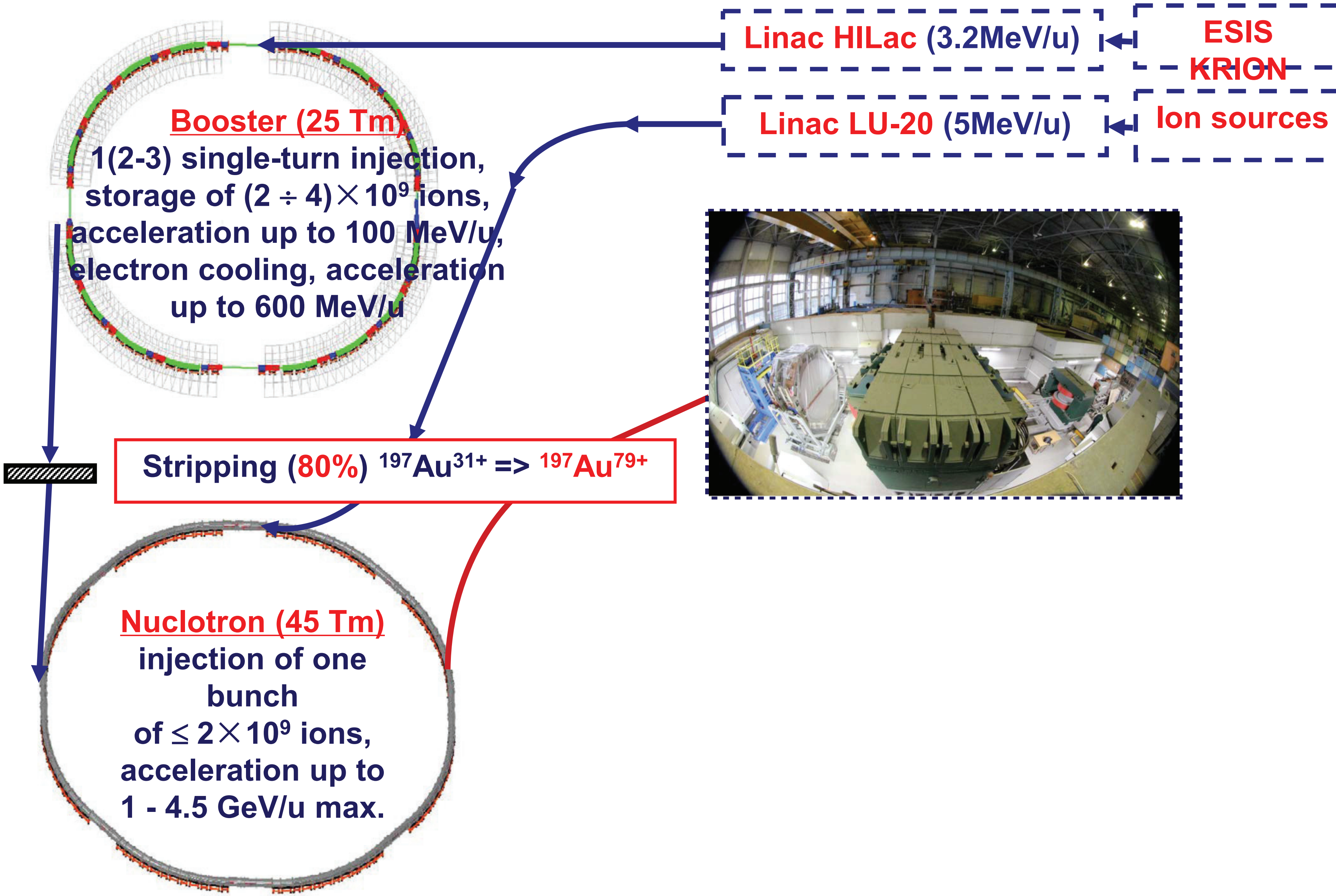

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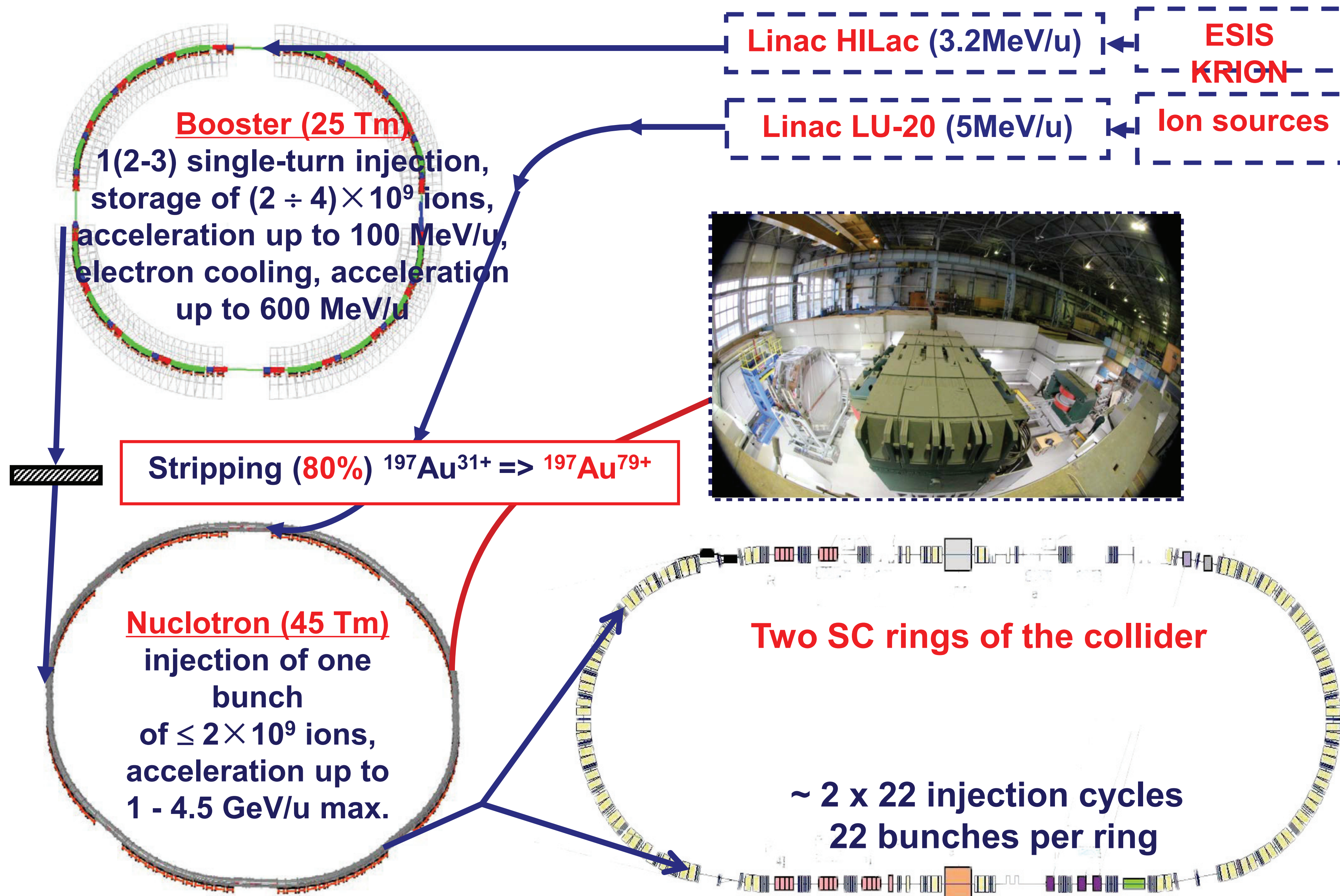


NICA @ Heavy Ion mode

ESIS
KRION

Ion sources

Linac HILac (3.2MeV/u)

Linac LU-20 (5MeV/u)

Booster (25 Tm)
1(2-3) single-turn injection,
storage of $(2 \div 4) \times 10^9$ ions,
acceleration up to 100 MeV/u,
electron cooling, acceleration
up to 600 MeV/u

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

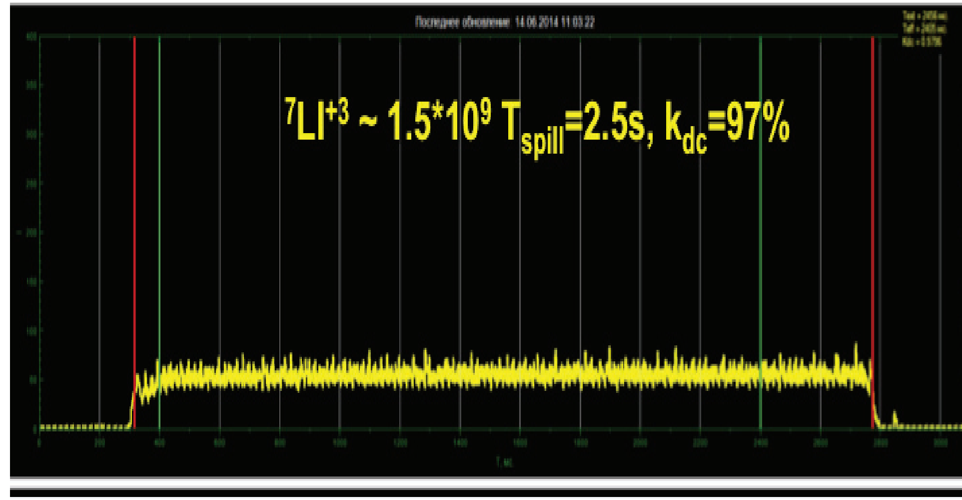
Nuclotron (45 Tm)
injection of one
bunch
of $\leq 2 \times 10^9$ ions,
acceleration up to
1 - 4.5 GeV/u max.

Two SC rings of the collider

$L \geq 10^{27}$ см$^{-2}$с$^{-1}$

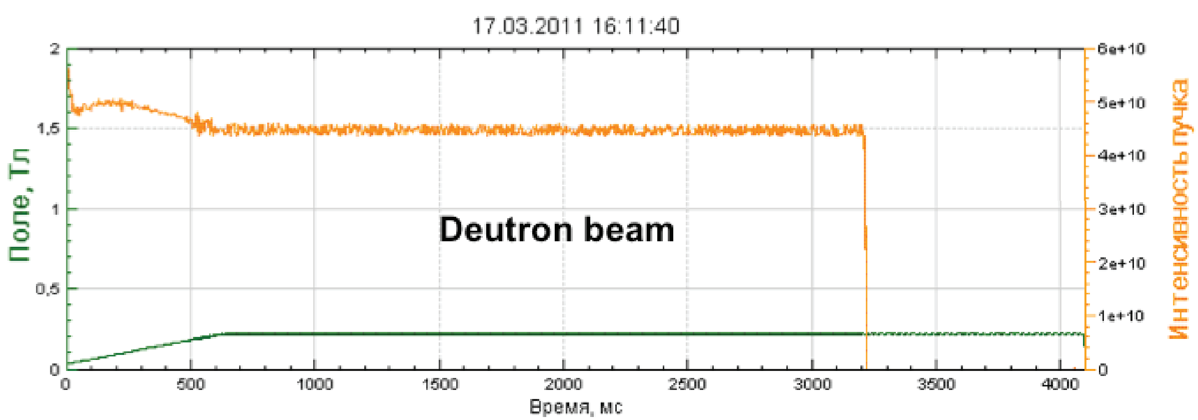
~ 2 x 22 injection cycles
22 bunches per ring

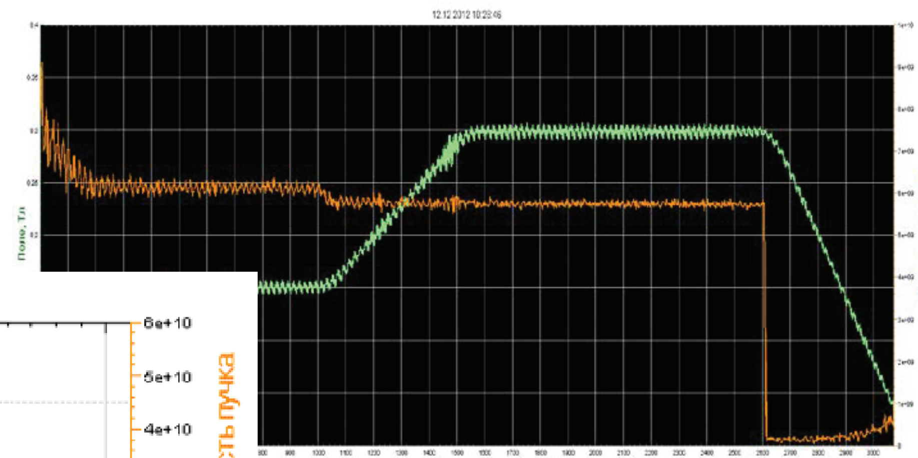
Status of The Nuclotron



Ion beams for fixed target: p, d, Li, C, Ar, Fe, … Xe

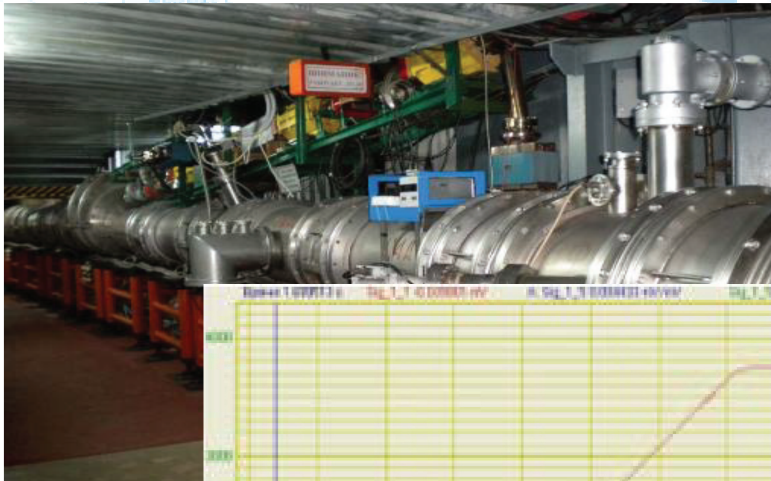
Nuclotron – 4.5 AGeV, 251 m. superconducting synchrotron. Commissioned in 1993, Upgraded in 2011.





Adiabatic debunching and recapture at efficiency of about 95% was demonstrated

Status of The Nuclotron



Ion beams f

Nuclotro
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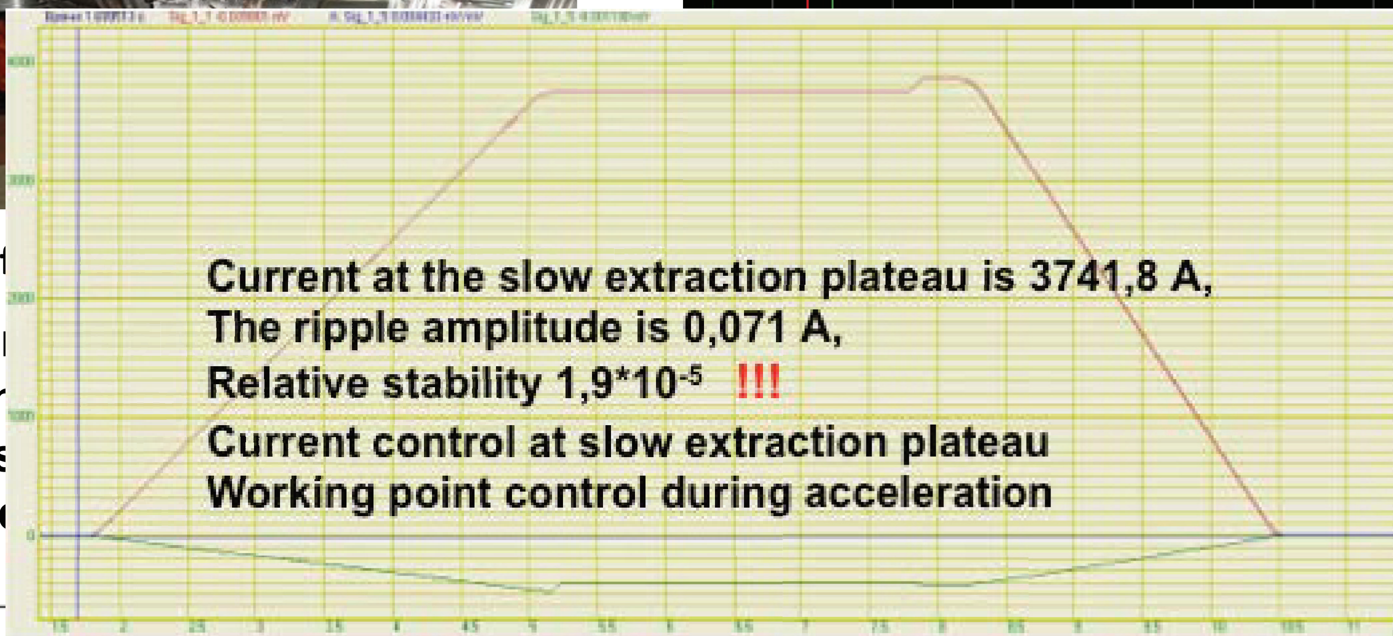
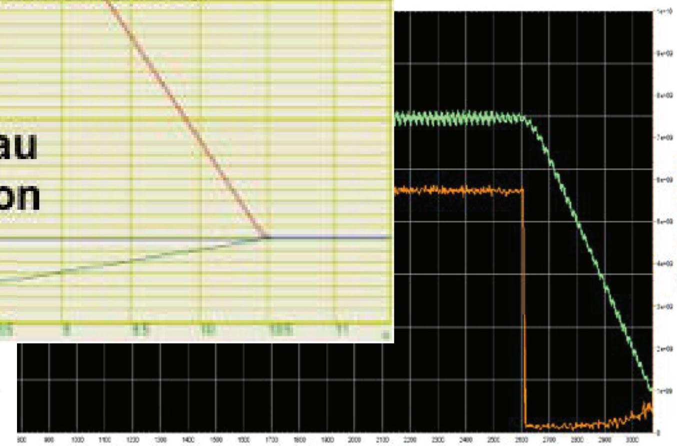
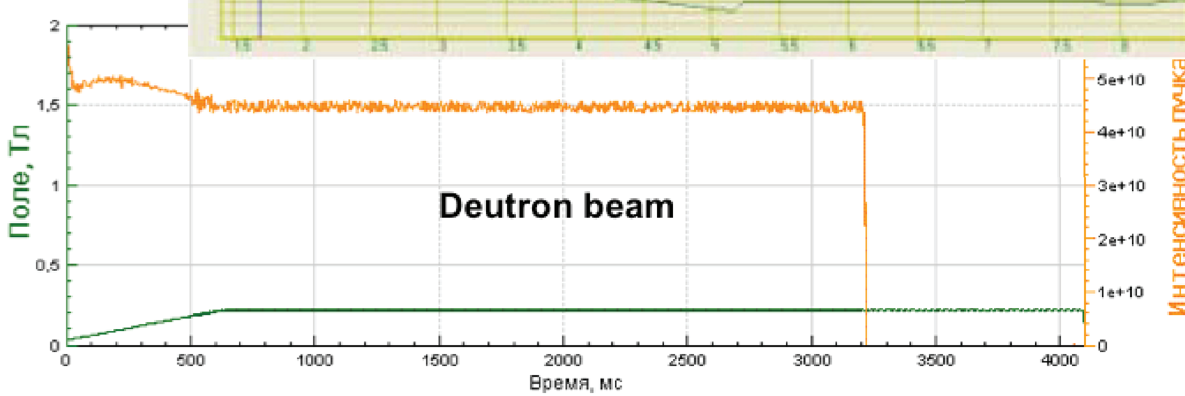
Upgrade

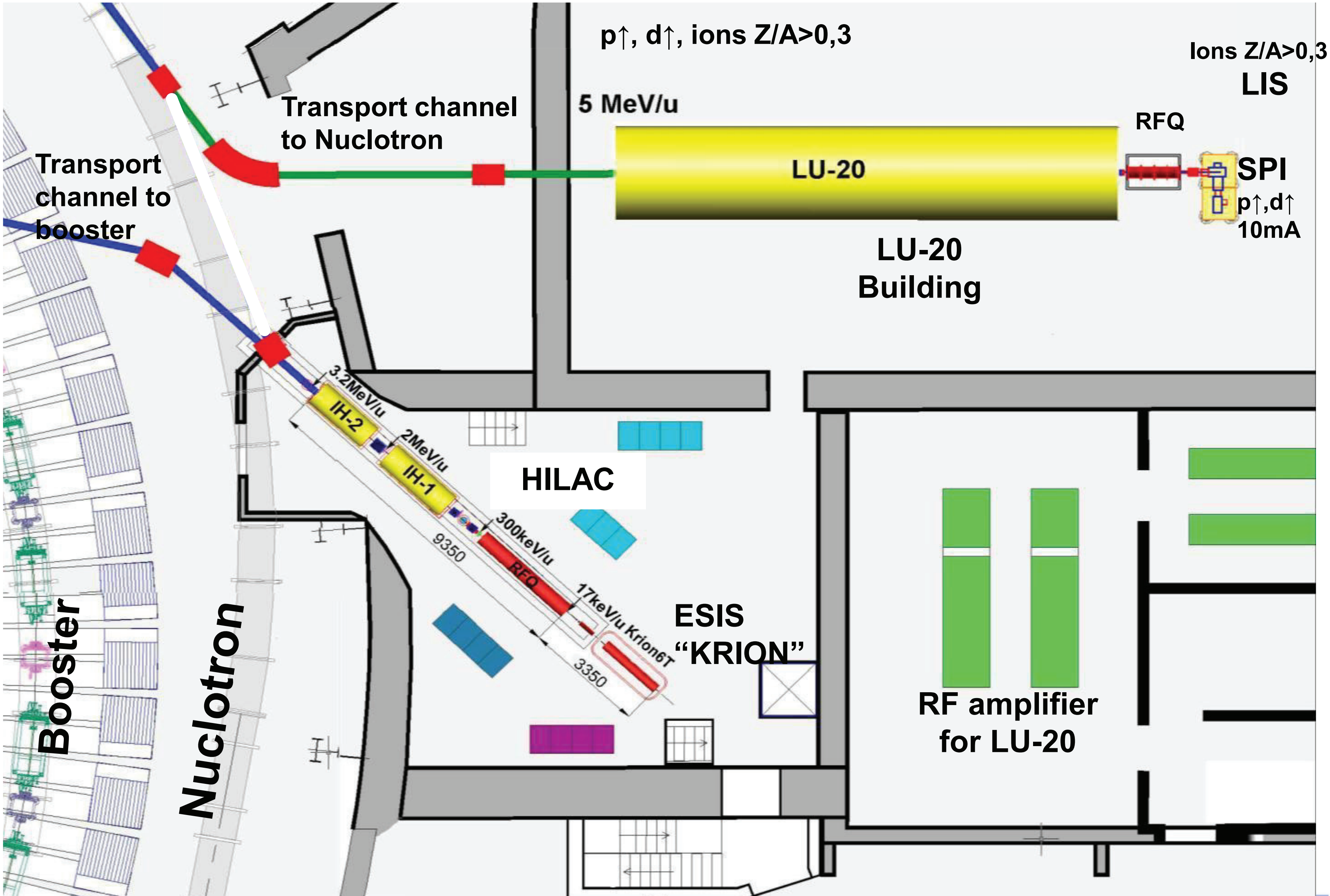






Adiabatic debunching and recapture at efficiency of about 95% was demonstrated

NICA Injection complex



Krion-6T ESIS

Theoretical и achieved parameter:

1) Magnetic field up to B= 6.0 T, (5.0 T, 2015)
2) Energy of electron string $E_e \leq 25$keV ($E_e \leq 12$keV, 2015)

Working element/charge state	Au^{31+} (Au^{51+})
Expected ion int. *N_i*	1÷4 x 10^9 ppp Au^{31+} (5x10^8, 2015) (1÷3 x 10^8 ppp for Tm^{41+} ~Au^{51+})
Repetition rate	50 Hz (for Au^{31+}) 50÷100 Hz, 2015 3÷5 Hz for Tm^{41+}-Au^{51+}, 2015
Extraction time form the ESIS	8 ÷ 30 x 10^{-6} s
RMS emittance	0.6 π mm mrad (for 8 x 10^{-6} s extraction time); 0.15 π mm mrad (for 30 x 10^{-6} s extraction time).
Peak current in pulse	up to 10 mA

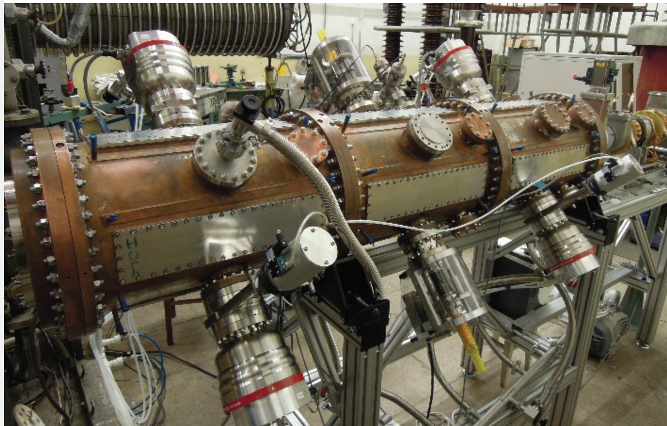
Plans:

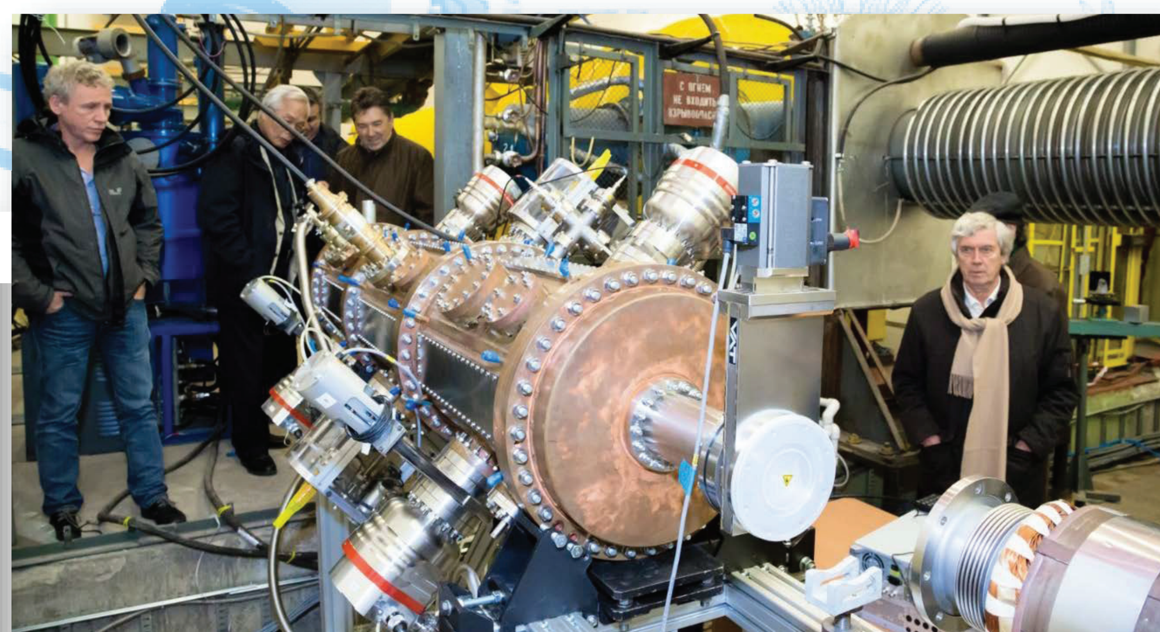
1) Improvement of internal Au injection.
2) Experiments in Au production in в magnetic field upto 6T

NICA

Injection complex: FI RFQ linac (160 keV)

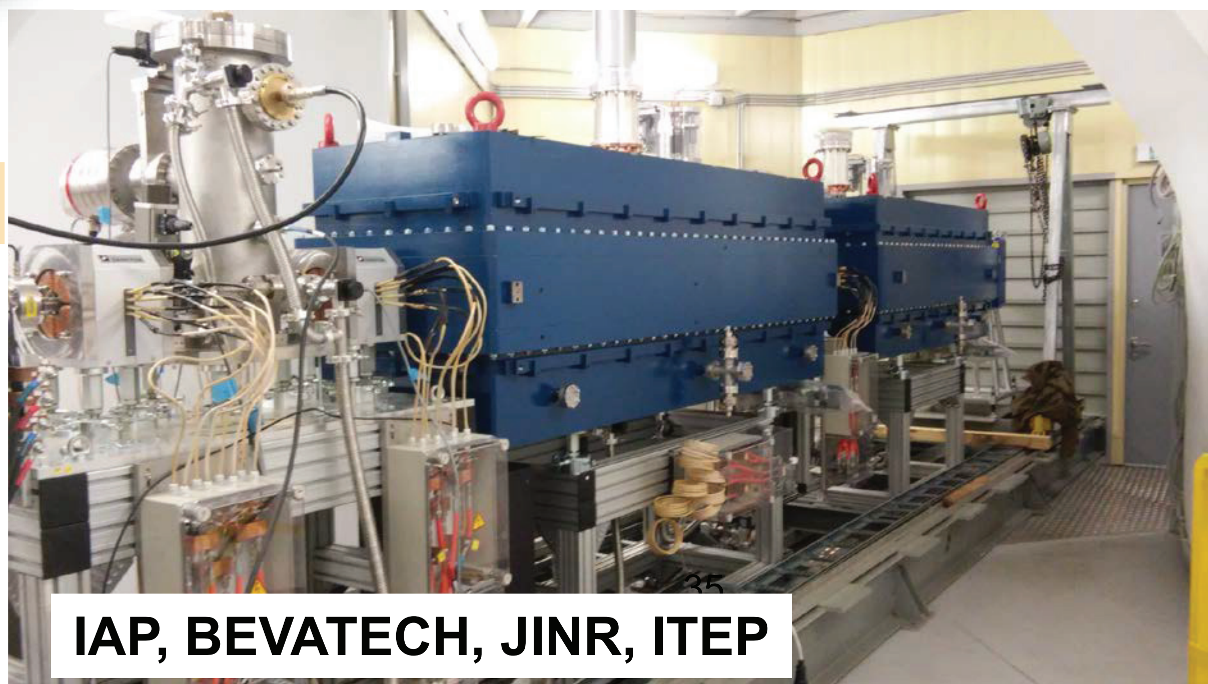
JINR-ITEP-MEPhI-Snezhinsk





NICA Heavy ion injector (HILac) 3.2AMeV (p..U)

RFQ + 2 RFQ DTL sections



IAP, BEVATECH, JINR, ITEP

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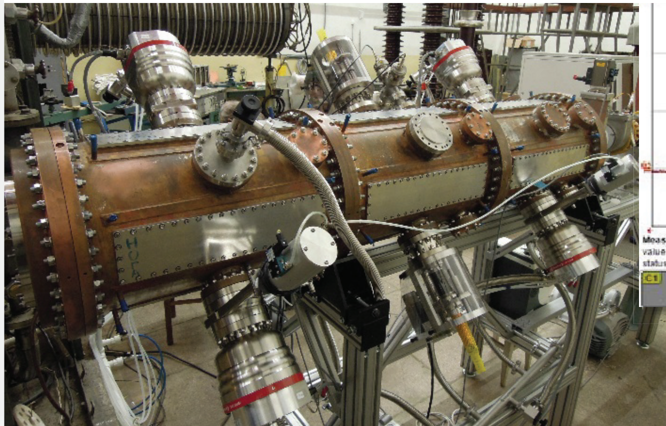

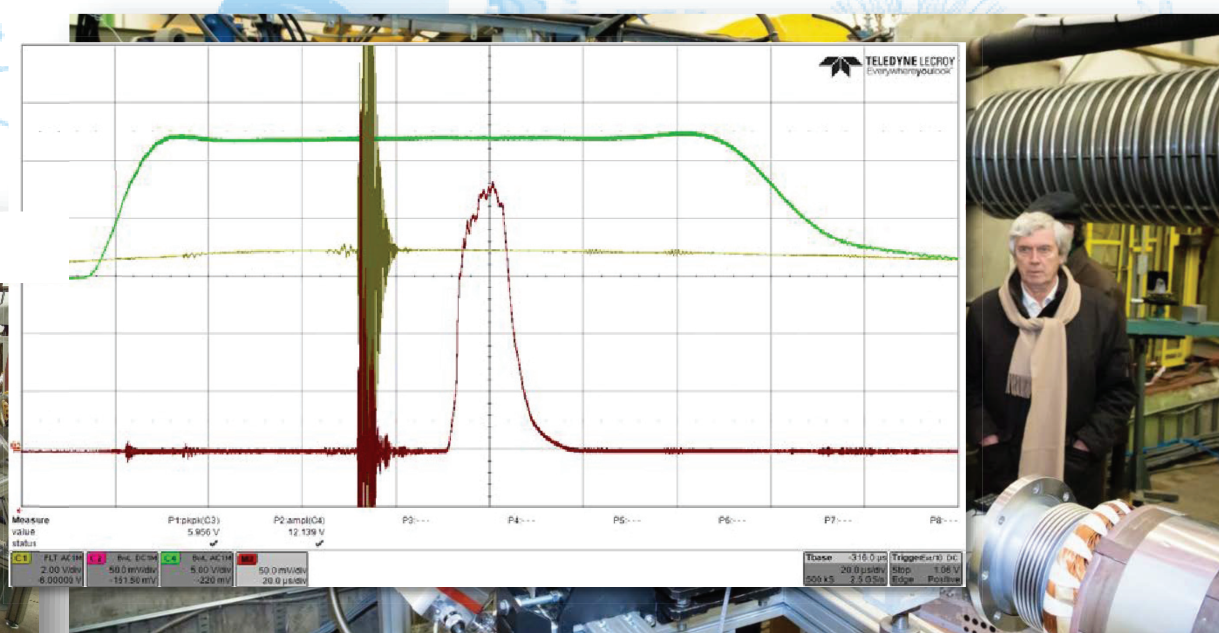

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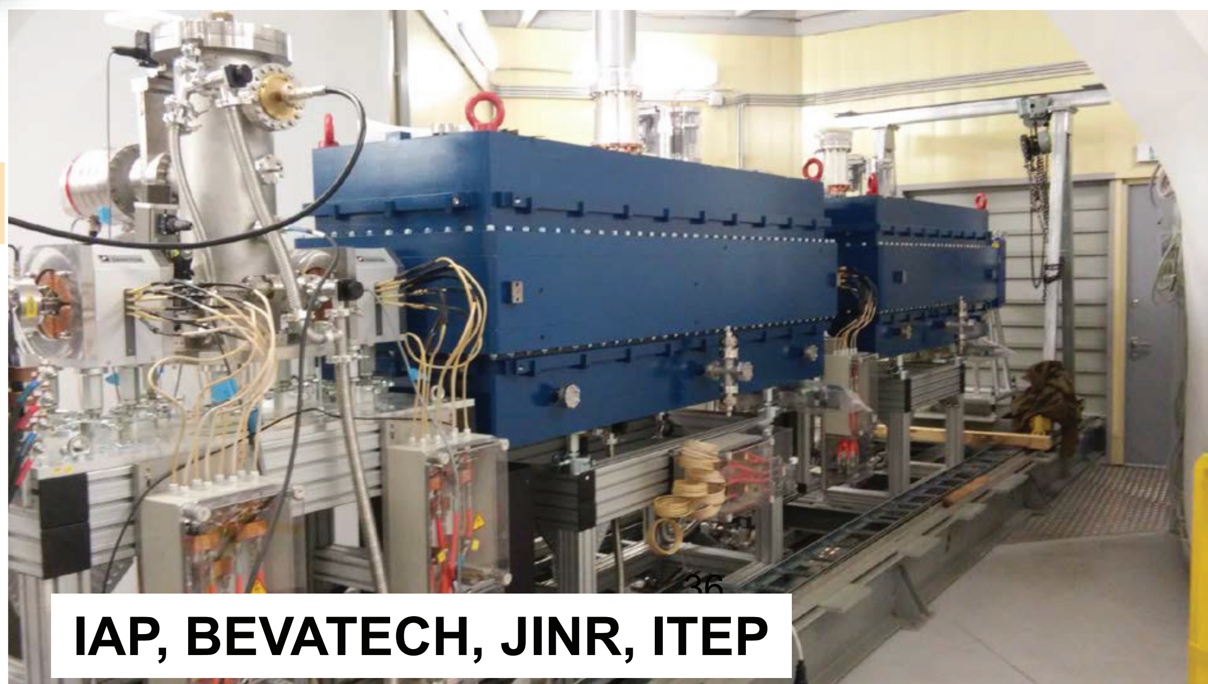

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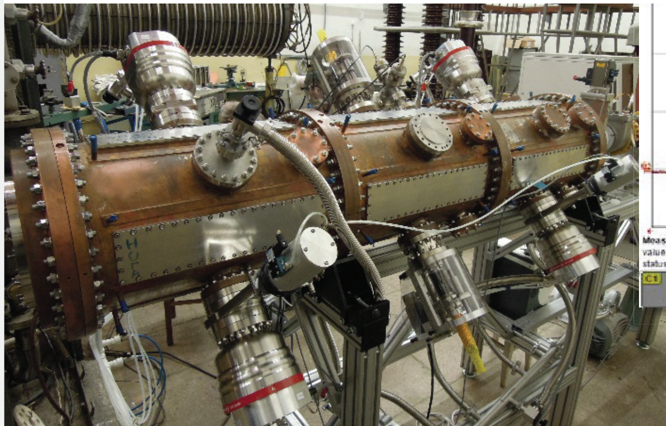

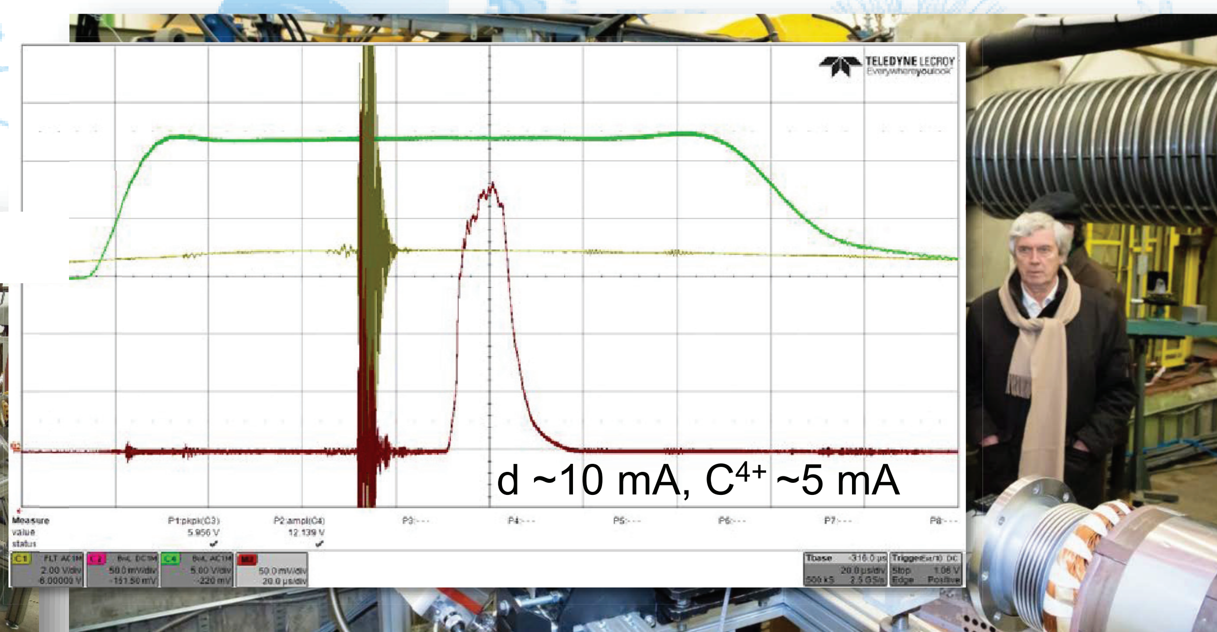

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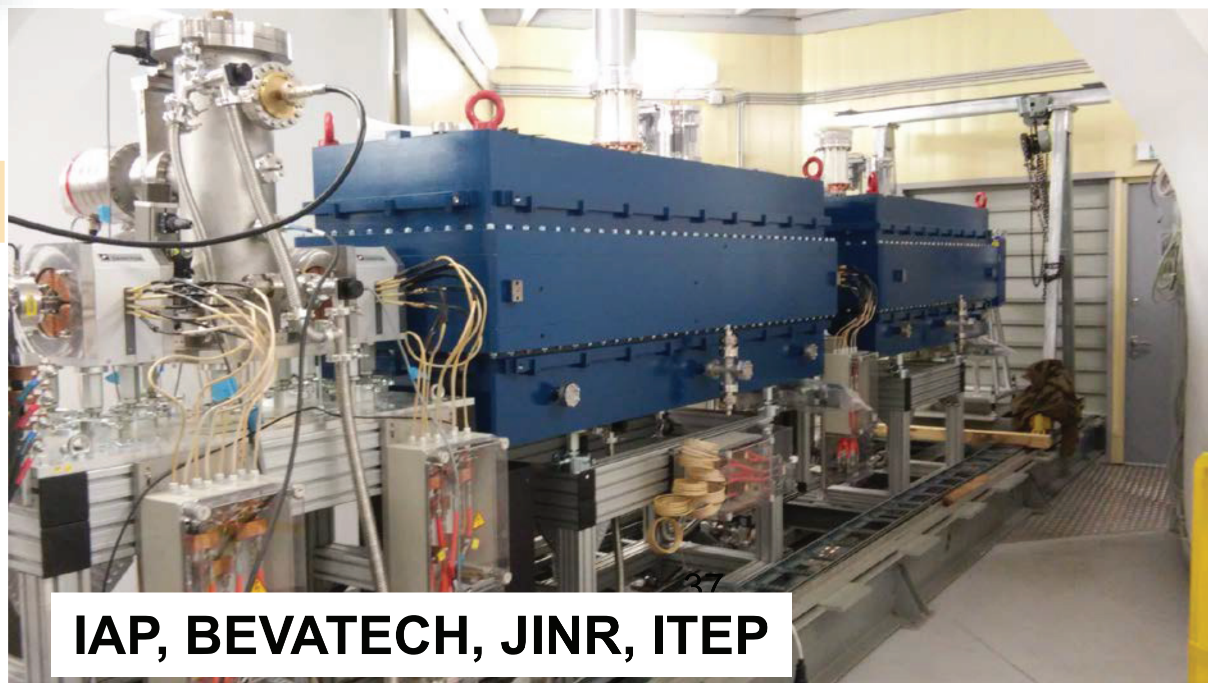

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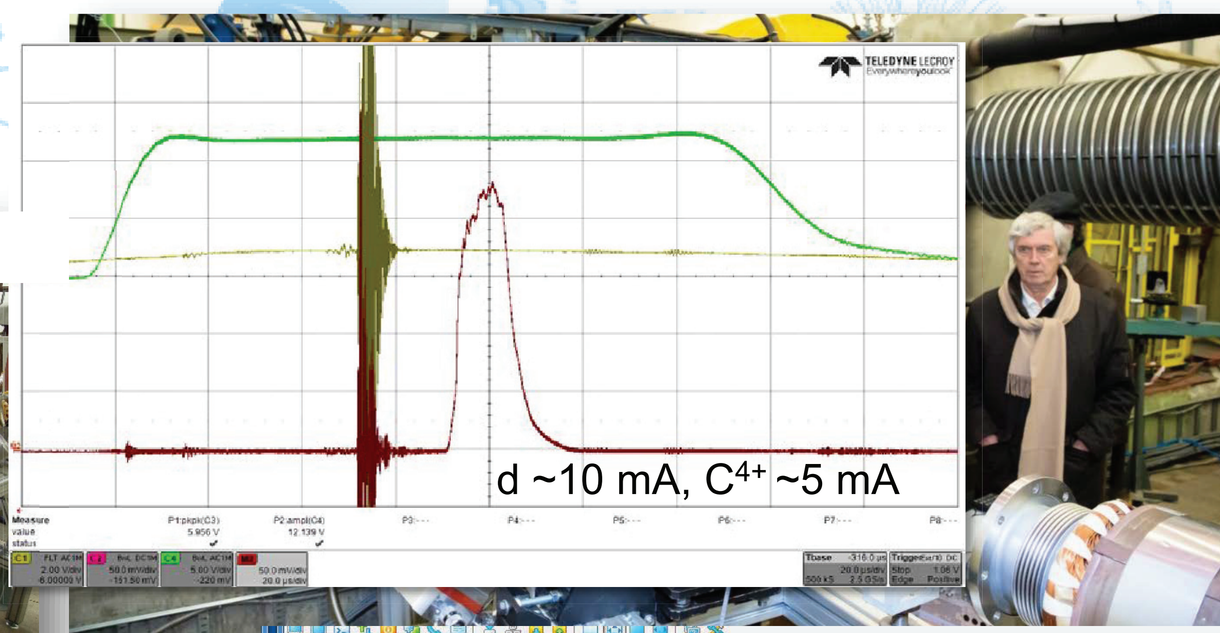
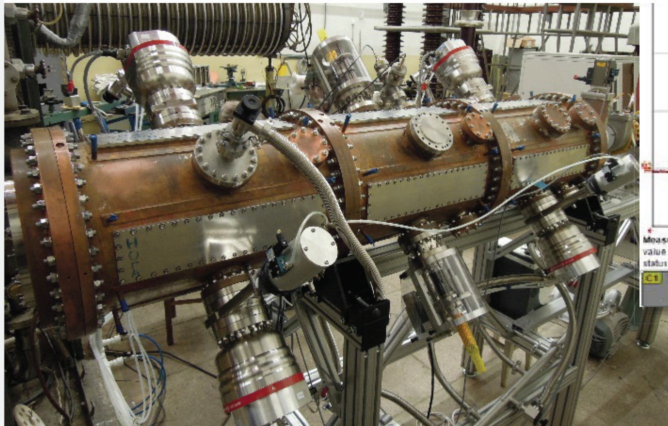


JINR-ITEP-MEPhI-Snezhinsk



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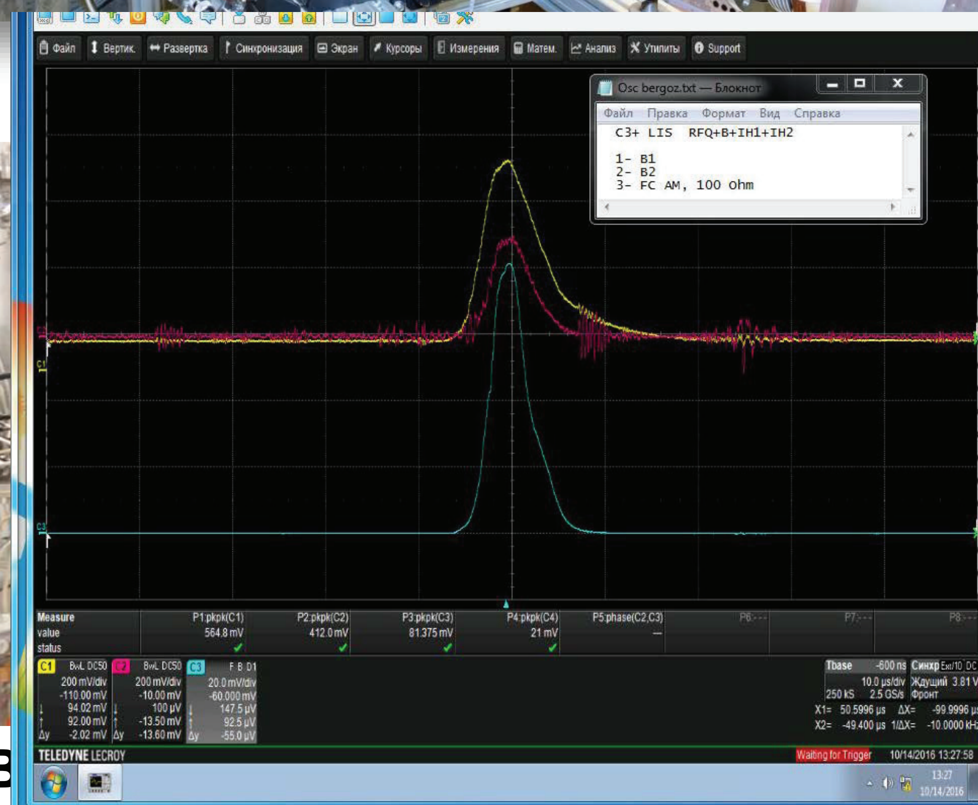
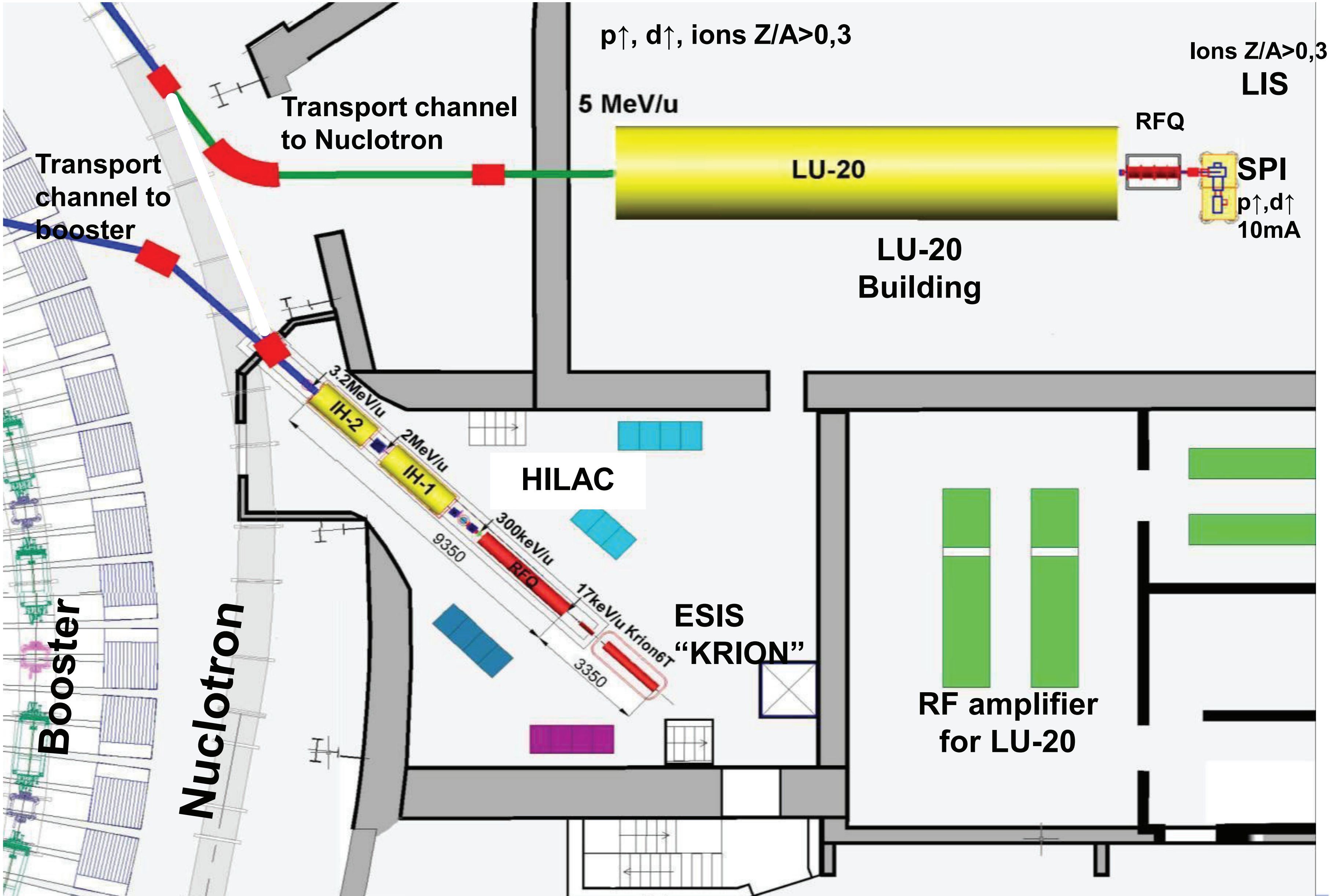


NICA Injection complex upgrade. Plans



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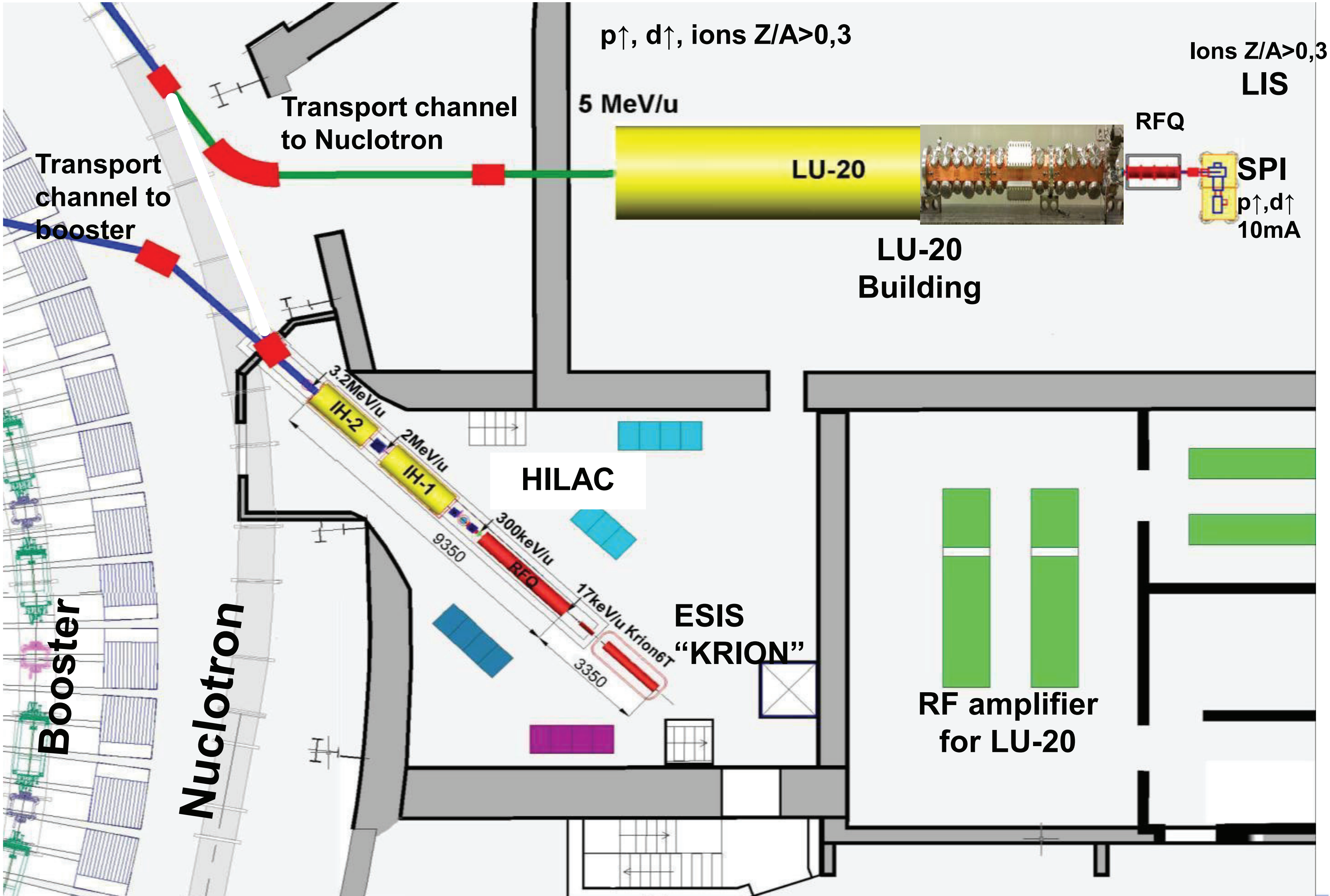

NICA

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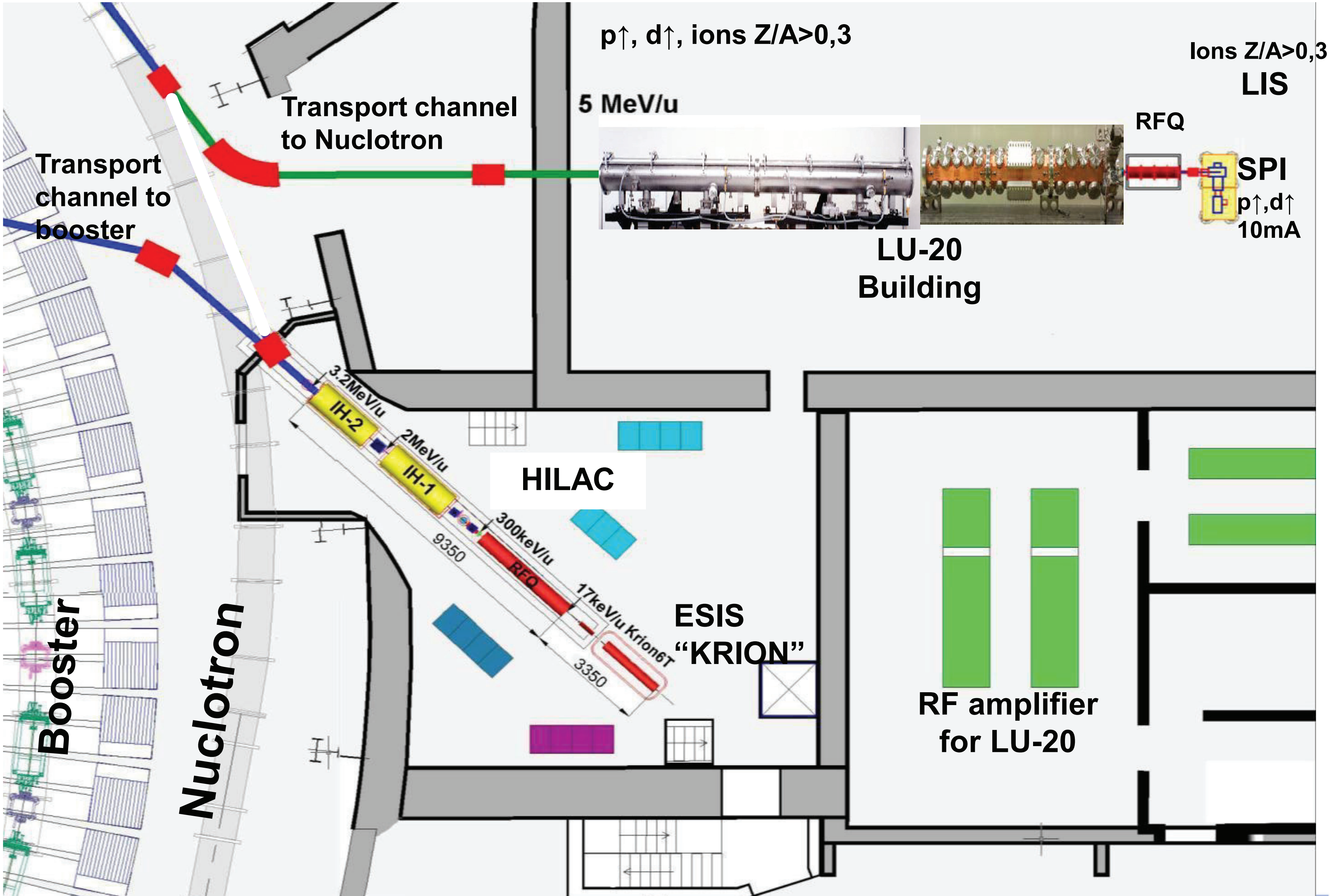
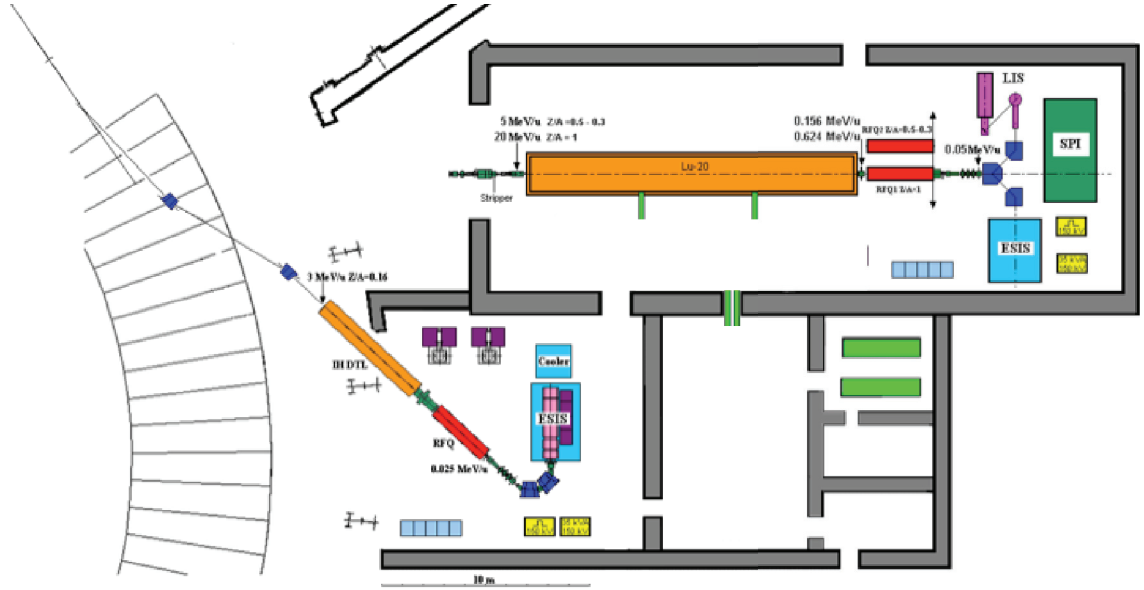
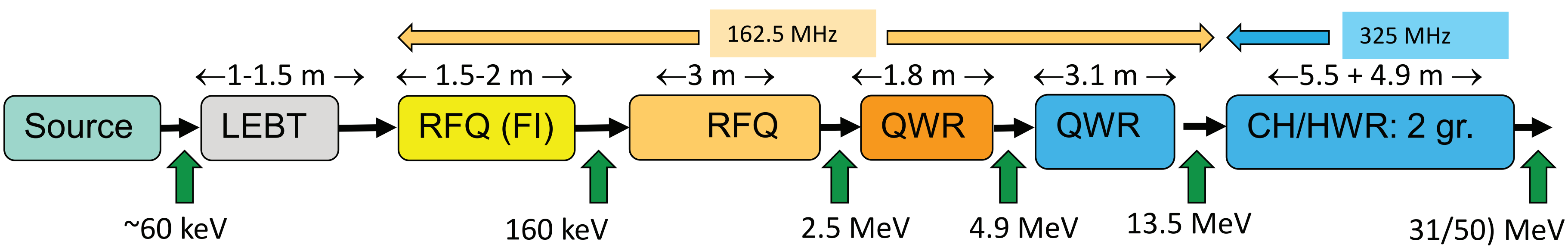


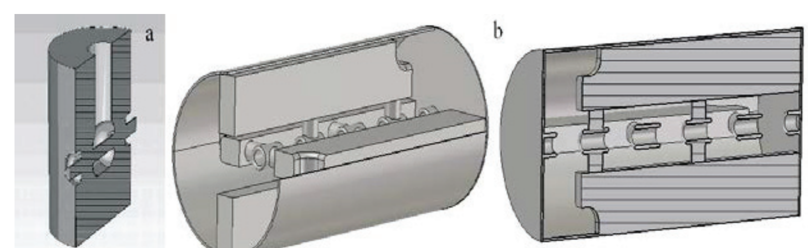
Development of new injector @ VBLHEP JINR

Cavities group	0 *	1	2	3
β_g	0.12	0.12	0.21	0.314
W_{in}, MeV	2.50	4.90	13.47	31.00
β_{in}	0.073	0.102	0.168	0.251
W_{out}, MeV	4.90	13.47	31.00	50.00
β_{out}	0.102	0.168	0.251	0.314
T, %	24	24	24	24
K_T, %	100	100	100	100
F, MHz	162	162	324	324
N_{gap}	2	2	4	4
Φ, deg	–20	–20	–20	–20
L_{res}, m	0.222	0.222	0.39	0.58
E. MV/m	4.50	7.52	7.70	7.76
U_{res}, MV	1.0	1.67	3	4.32
B, T	1.35	1.4	1.9	2.3
L_{sol}, m	0.2	0.2	0.2	0.2
L_{gap}, m	0.1	0.1	0.1	0.1
L_{per}, m	0.622	0.622	0.79	0.98
N_{per}	3	5	7	5
L, m	1.87	3.11	5.53	4.90

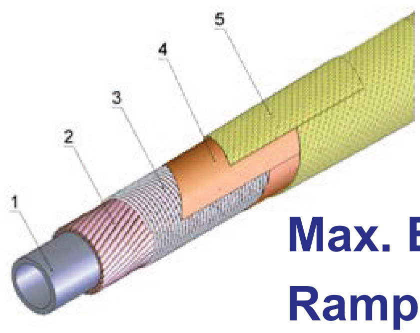




The ion beam motion stability analysis show that with the slipping factor about 17.5% the new SC linac will consists of four groups of cavities having geometrical velocities of β_g=0.07, 0.141, 0.225 and 0.314. First two groups of cavities should be two-gap QWR's and the other – four-gap CH-cavities or Spoke-cavities. The total length of the linac was reduced from 17.8 to 15.5 m and the number of cavities was also reduced from 32 to



Superconducting superferric “Dubna magnets”

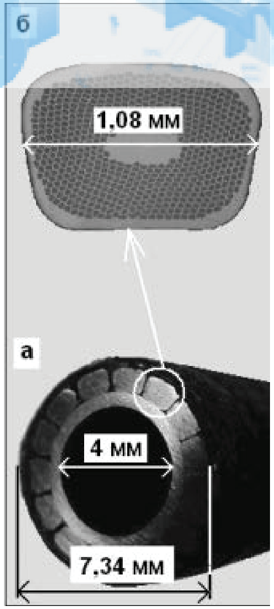


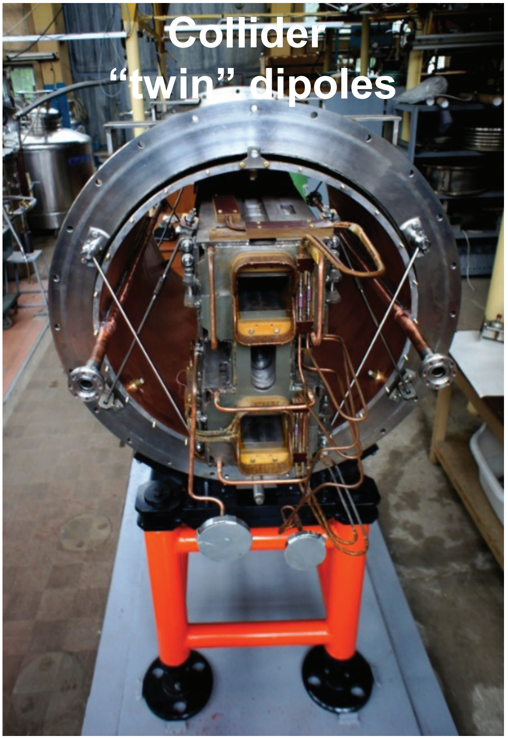
“Nuclotron-type”
SC hollow cable

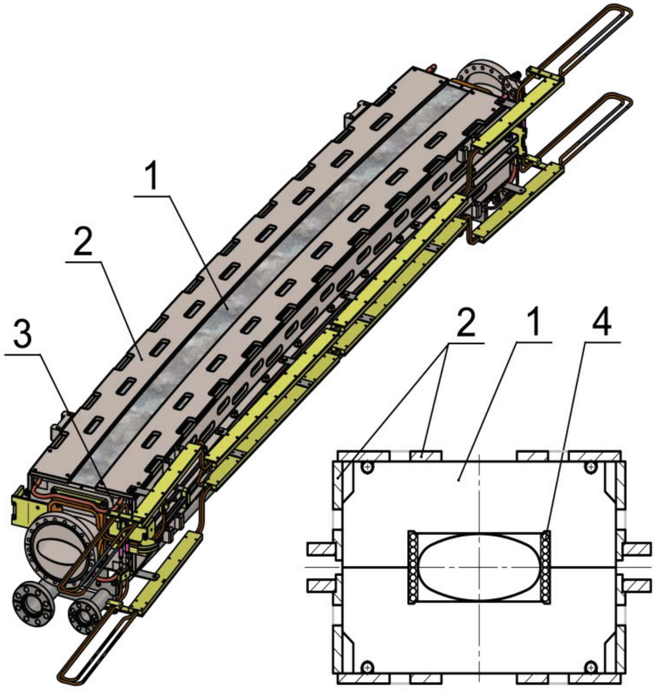
Max. B field = 2T

Ramp rate – up to 4 T/s @ 1 Hz

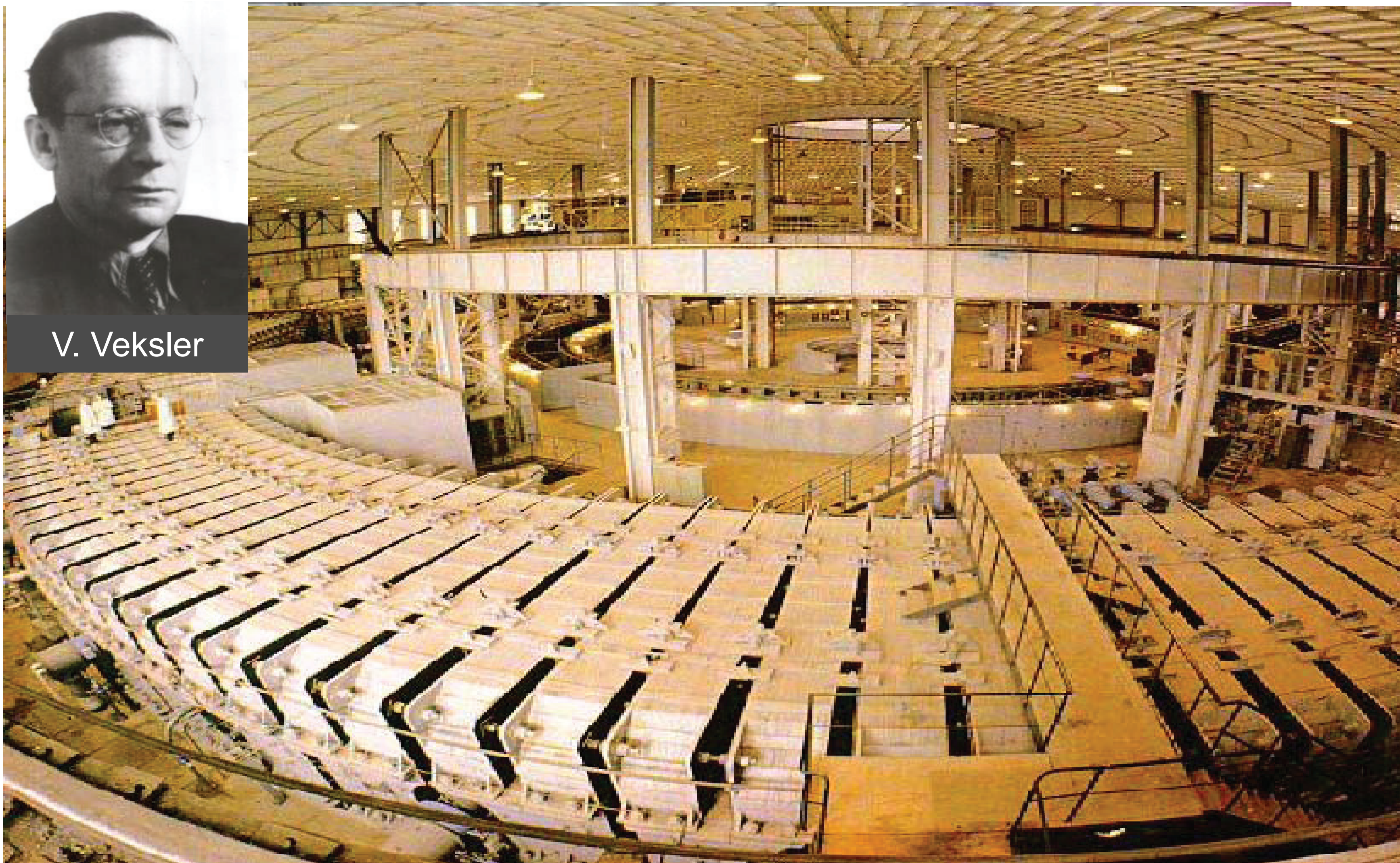
two-phase LHe @ 4.5K





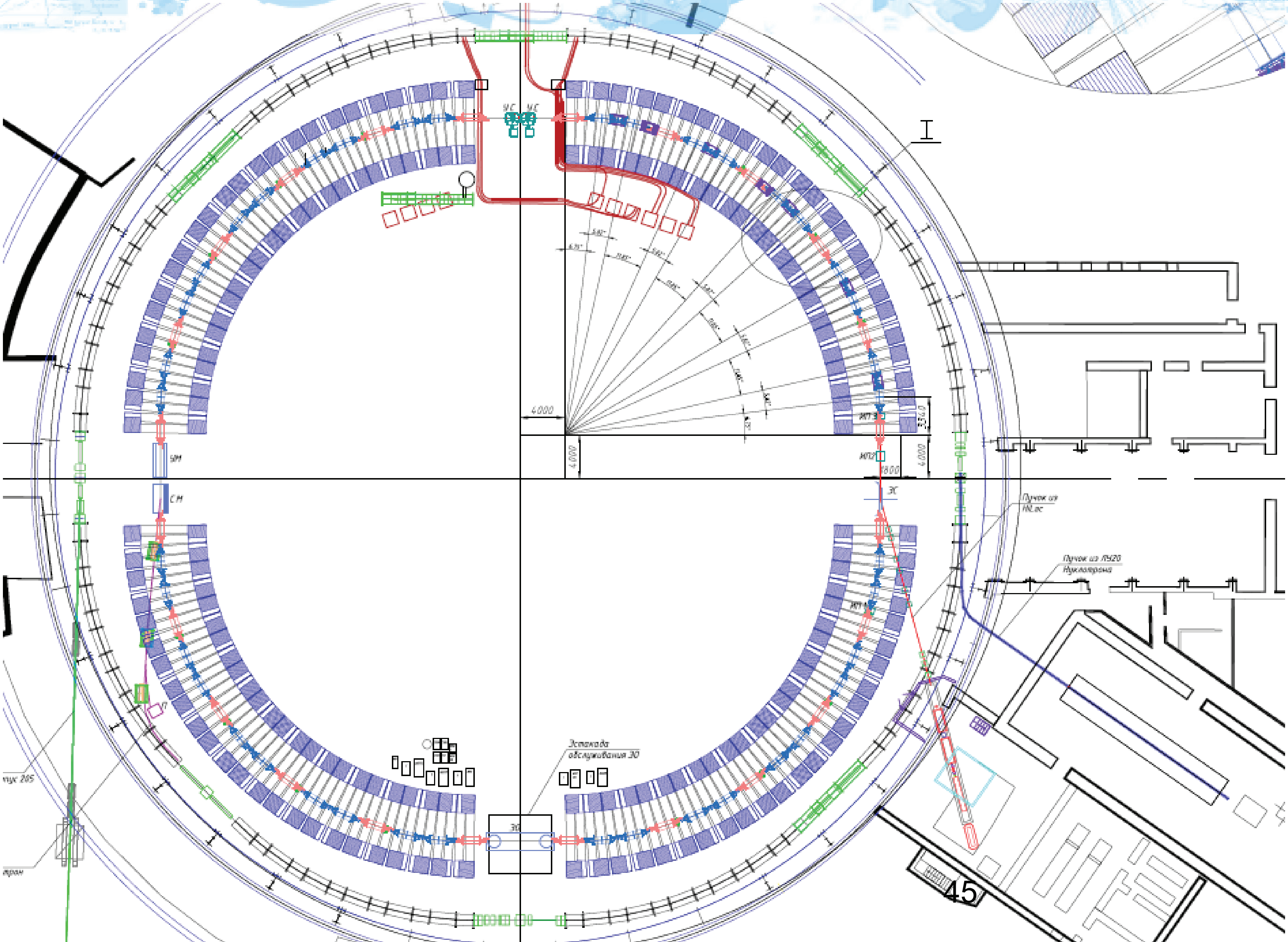


NICA Booster synchrotron



V. Veksler

NICA Booster synchrotron



NICA Booster synchrotron

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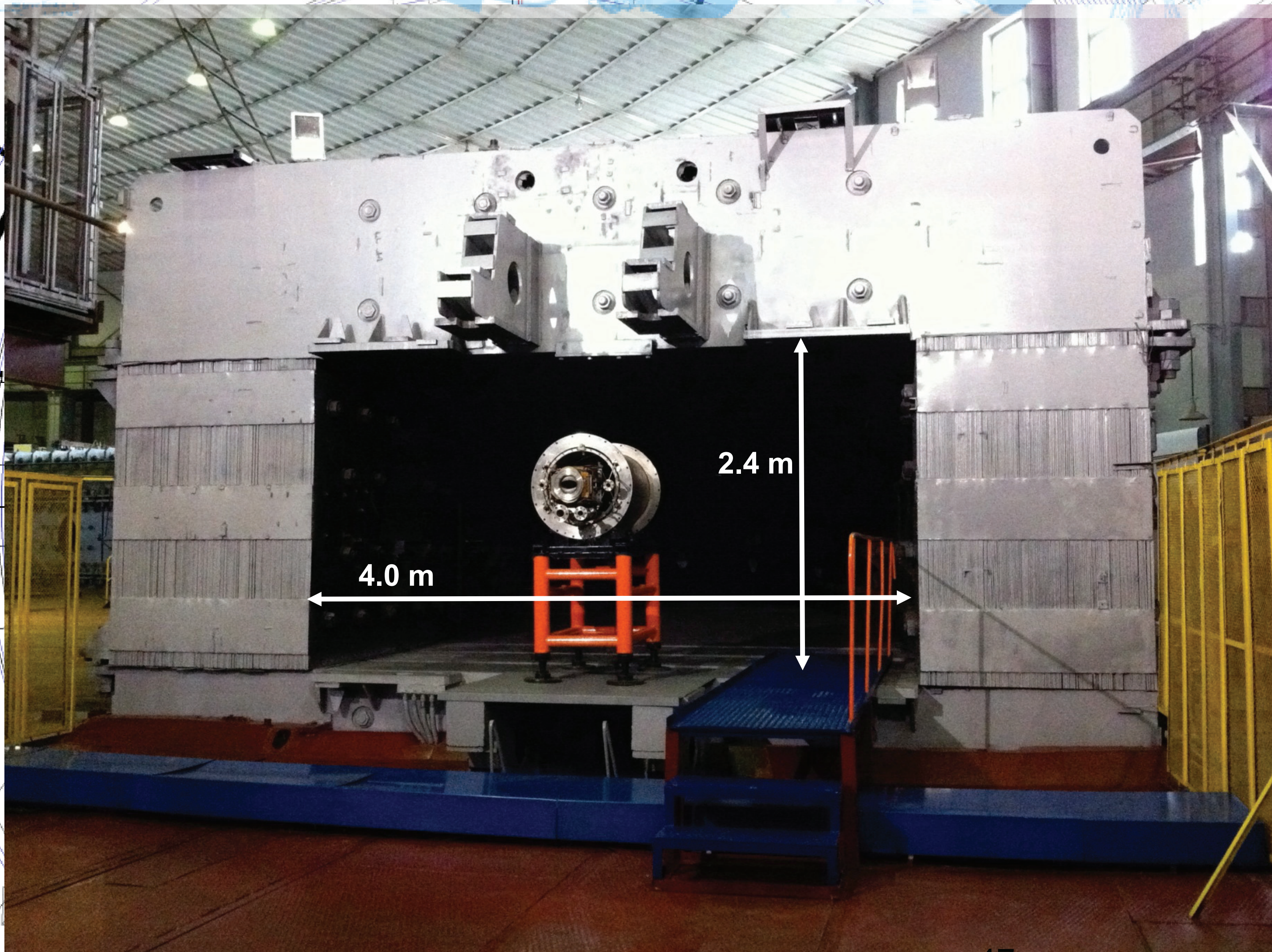
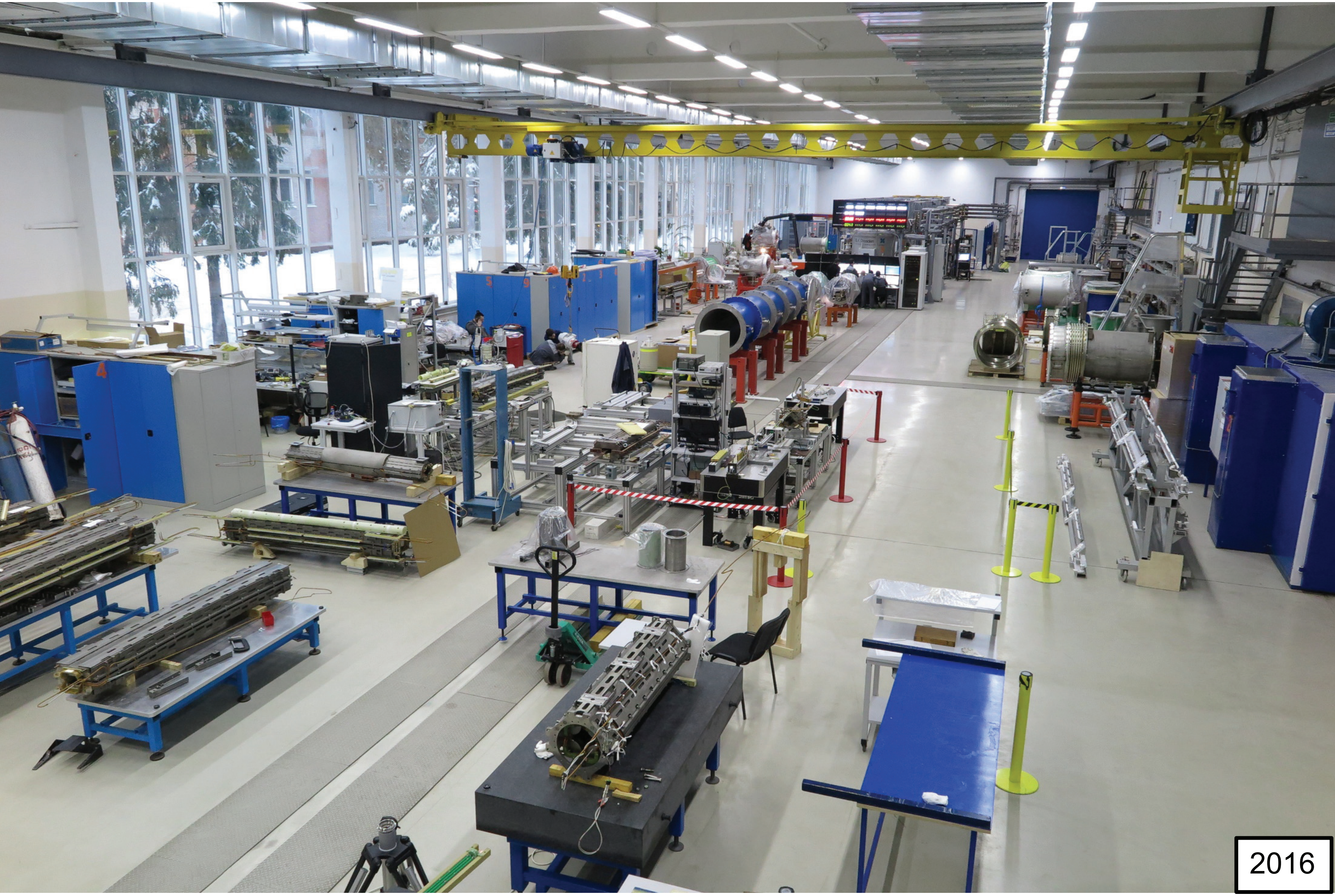



2016

NICA booster magnets. Status

- Yoke of the Dipole Magnets – 24 or 60%
  Coil of the Dipole Magnets - 16 or 40%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 38 or 79%
- Yoke of the Corrector Magnets – 8 or 25%
  Coil of the Corrector Magnets - 2 or 6%

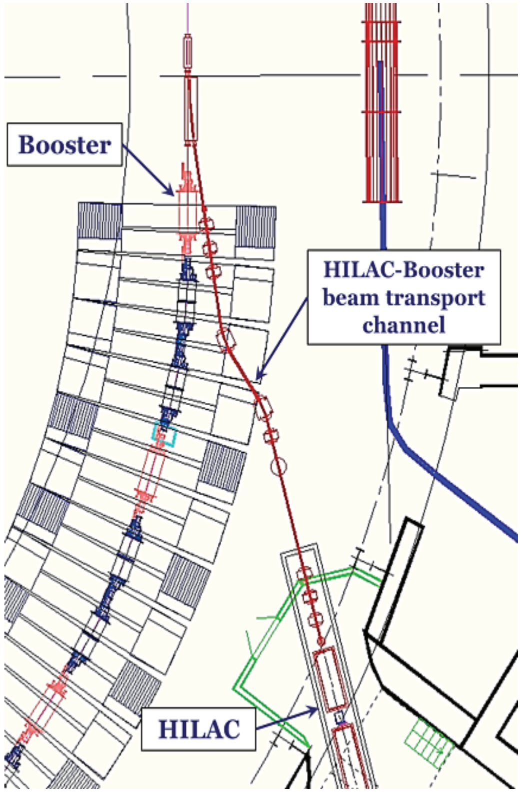
NICA collider magnets

Double-aperture SC Magnets for the NICA collider:

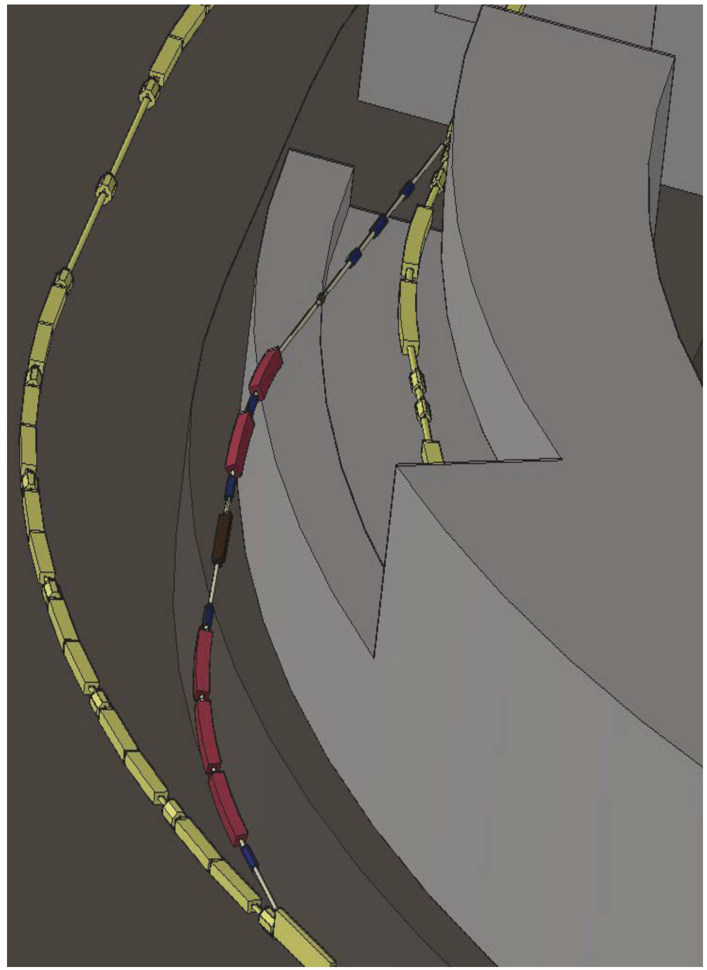
- 80 + 8 Dipole Magnets
- 86 + 12 Quadrupole Lenses
- 88 Corrector Magnets

Start of serial production and cryogenic tests of the magnets is scheduled for 2017.

Heavy Ion beam channels

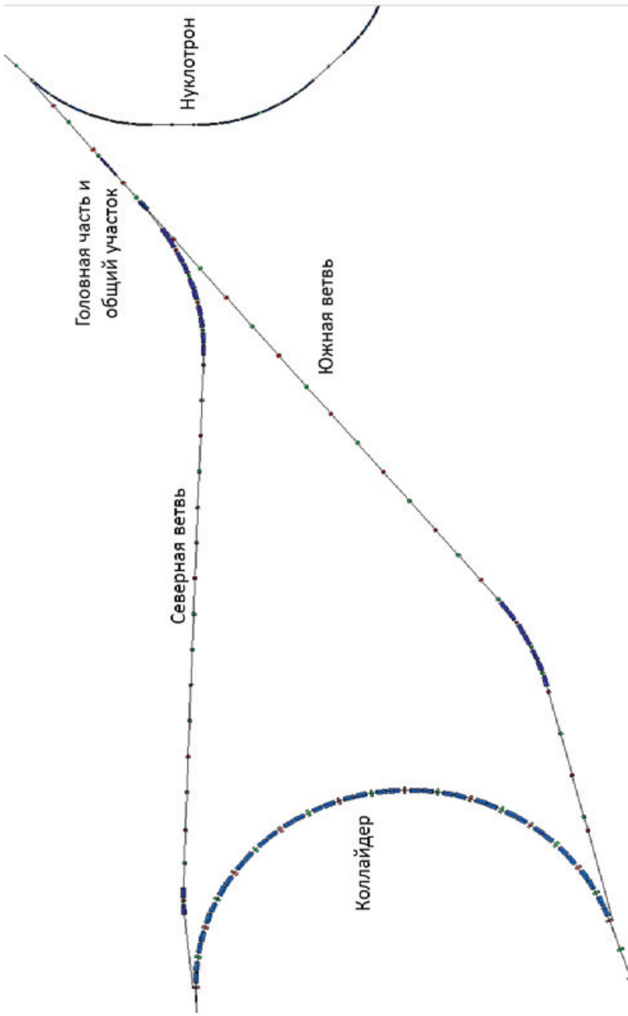


LEBT @ 3.2 MeV/u



HEBT @ 600 MeV/u, stripping.
Complicated 3D geometry, 23 m

HEBT @ 1-4.5 GeV/u, 325 m



The NICA Collider

Collider lattice: FODO, 12 cells x 90^0 each arc

Circumference, m	503.04		
Number of bunches	22		
rms bunch length, m	0.6		
β-function in IP, m	0.35		
Betatron tunes, Q_x/Q_y	9.44 / 9.44		
Chromaticities, Q'_x/Q'_y	-33 / -28		
Ring Acceptance, π mm·mrad	40		
Momentum acceptance, $\Delta p/p$	±0.010		
γ_{tr}	7.088		
Kinetic energy of Au^{79+}, GeV/u	1.0	3.0	4.5
Number of ions per bunch	$2.0 \cdot 10^8$	$2.4 \cdot 10^9$	$2.3 \cdot 10^9$
$\Delta p/p_{rms}$, 10^{-3}	0.55	1.15	1.5
ε_{rms}, (h/v) π mm·mrad	1.1/0.95	1.1/0.85	1.1/0.75
Luminosity, $cm^{-2}\ s^{-1}$	$0.6 \cdot 10^{25}$	$1 \cdot 10^{27}$	$1 \cdot 10^{27}$
IBS growth time, s	160	460	1800
Tune shift, $\Delta Q_{total} = \Delta Q_{SC} + 2\xi$	-0.050	-0.037	-0.011

Strategy of The Project Luminosity Achievement

1. Maximum r.m.s. bunch length is chosen equal to 0.6 m to have the “luminosity concentration” at Inner Tracker (IT) of MPD.

2. Maximum peak luminosity (limited by the beam space charge – the Lasslett tune shift) is achieved at maximum emittance: E_{rms} = 1.1 $\pi\cdot$mm$\cdot$mrad (the beam radius = 1/6 of the ring aperture).

3. Maximum ion number per bunch is limited by the tune shift value $\leq$ 0.05.

4. Number of bunches = 22 => to avoid parasitic collisions of the bunches in the common part of the Collider straight section.

5. RF multiplicity = 3 => separatrix area is by 25 times exceeds the beam longitudinal emittance.

6. The ratio between horizontal, vertical emittances and ion momentum spread is defined by the equilibrium of IBS rates for each degree of freedom.

7. Beam lifetime (if limited by scattering on residual atoms) ~ 10 h

8. “Head-tail” and multibunch instabilities are suppressed by the feed-back systems.

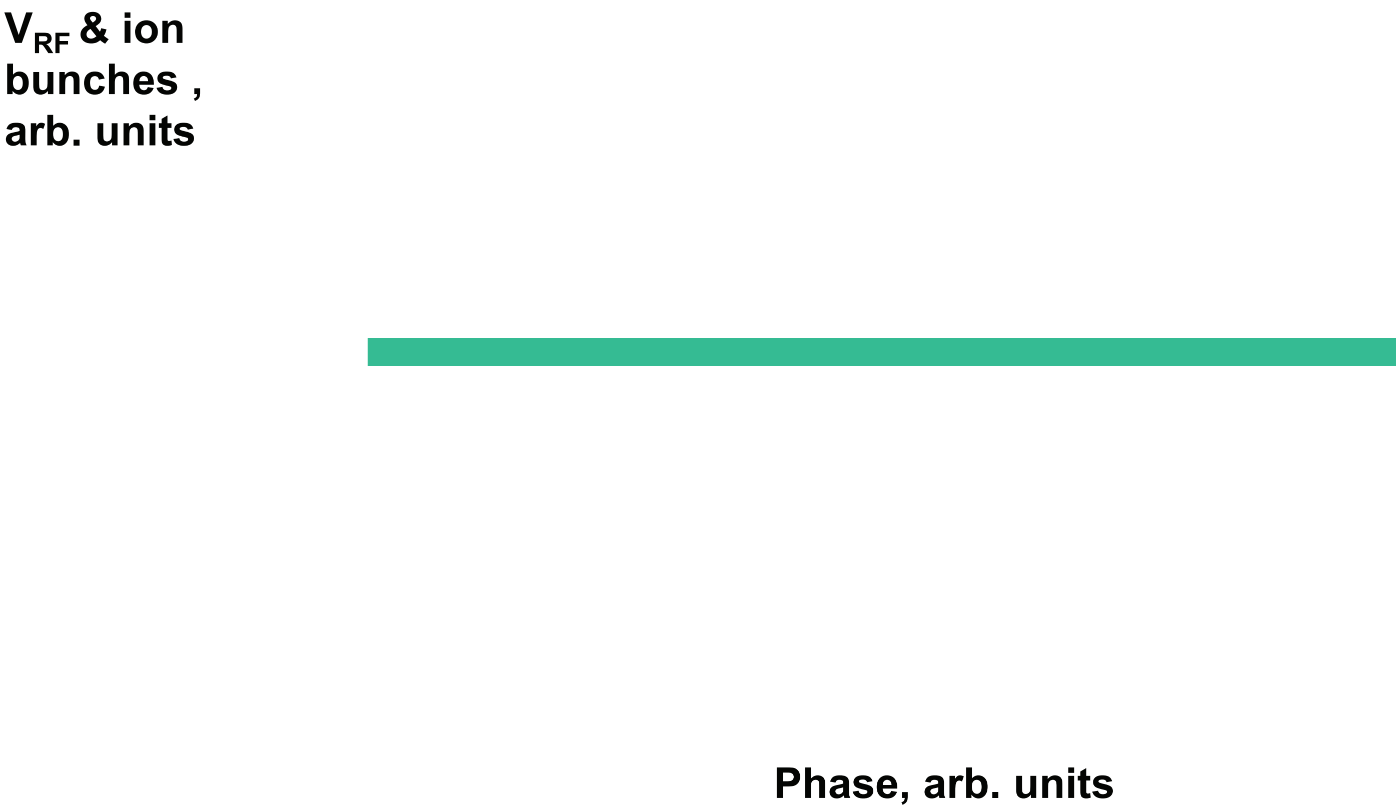
RF Excersises in The Collider

Step 1: Cooling and stacking with RF1 barrier voltage (< 5 kV). Accumulation efficiency ~ 95%, about 110 - 120 injection pulses (55-60 to each ring) every 5 sec. Total accumulation time ~ 10 min. Ion momentum spread is limited by microwave instability.

Steps 2-3. Formation of the short ion bunches at presence of cooling:

RF-2 (100 kV, 4 resonators) => RF-3 (1MV, 8 resonators).

From coasting beam to => 22nd harmonics => 66th harmonics



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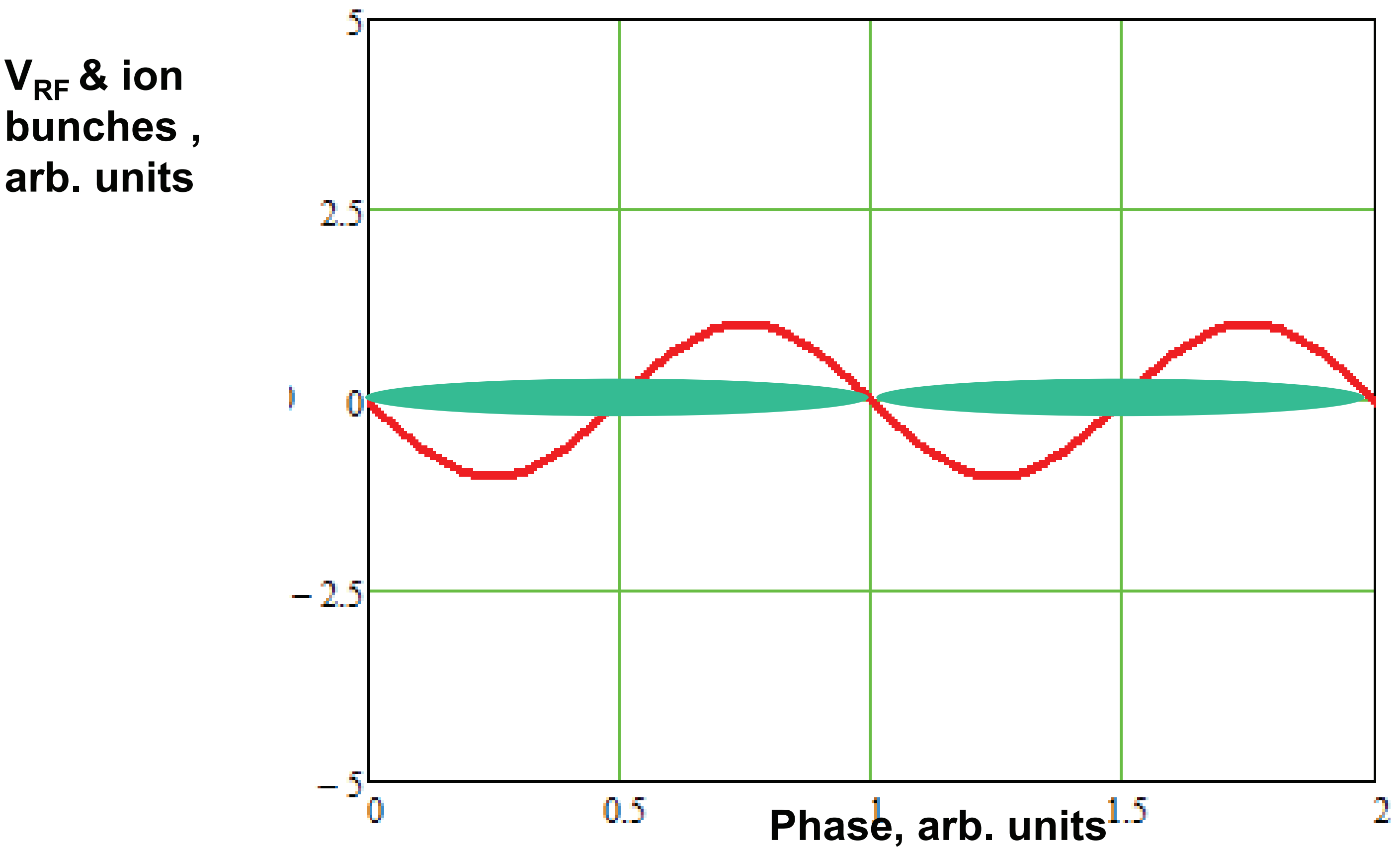

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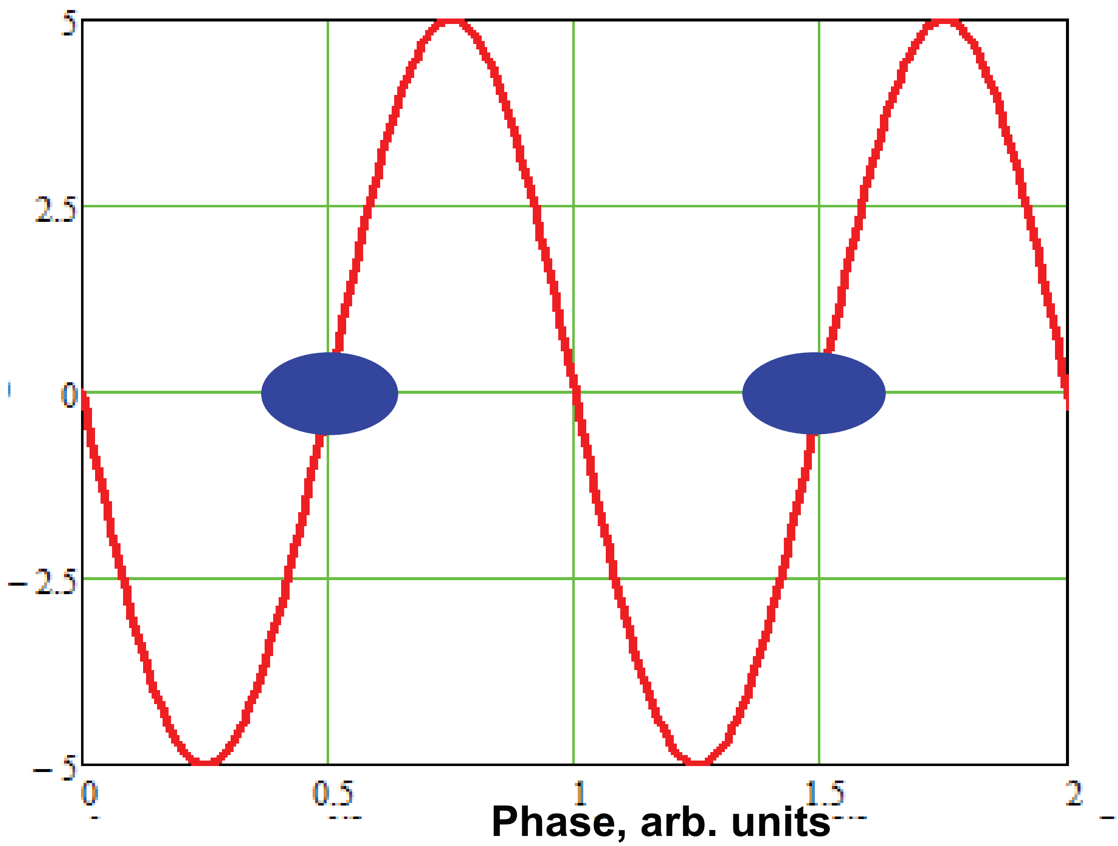

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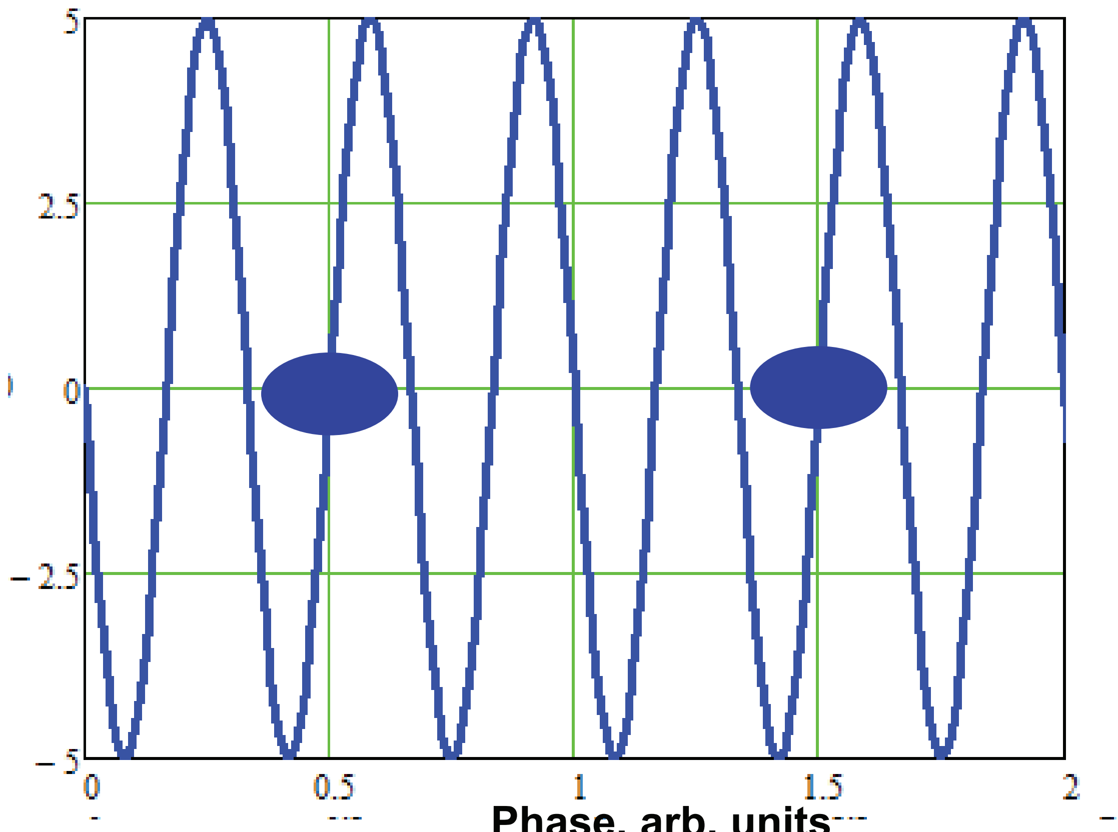

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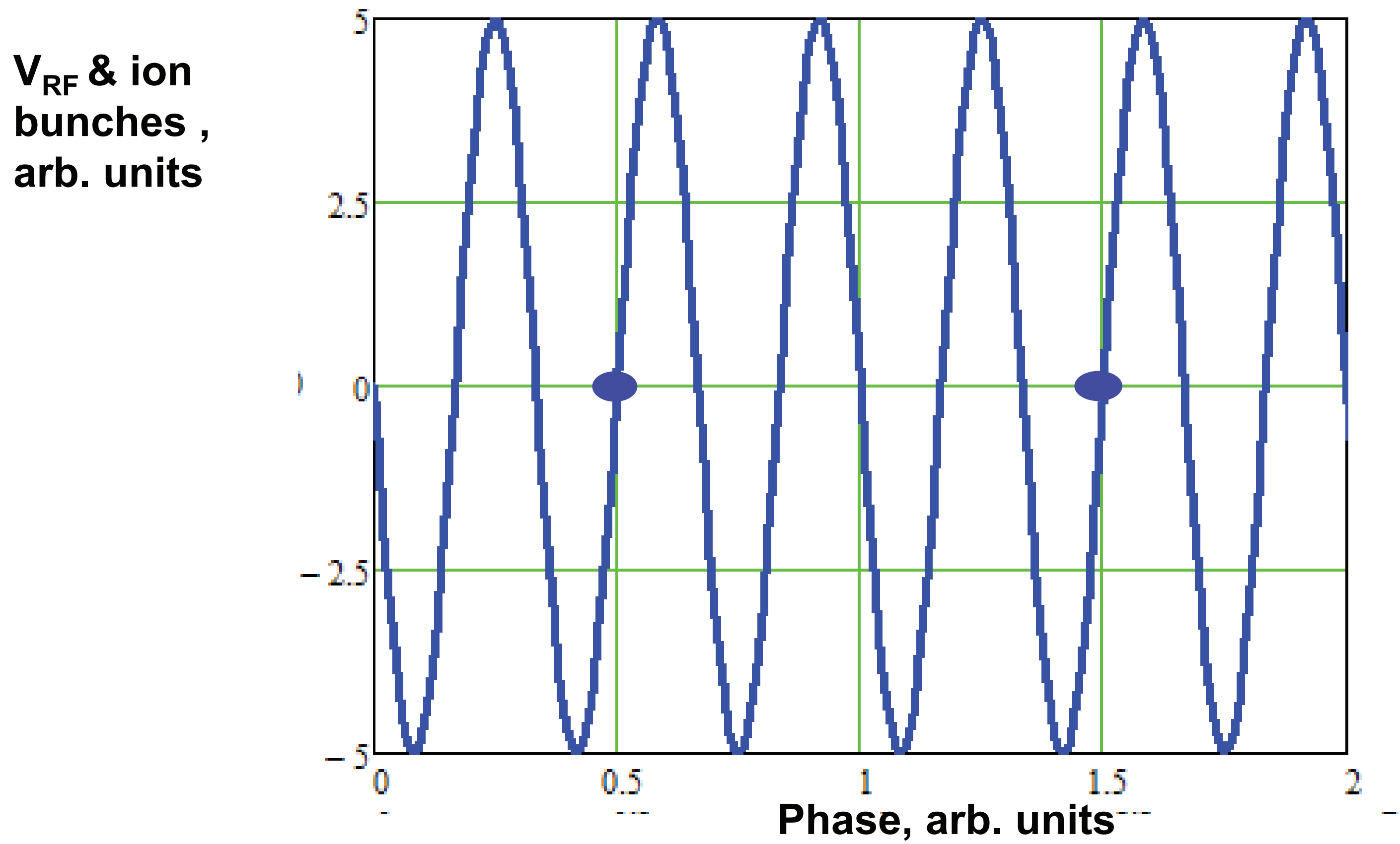
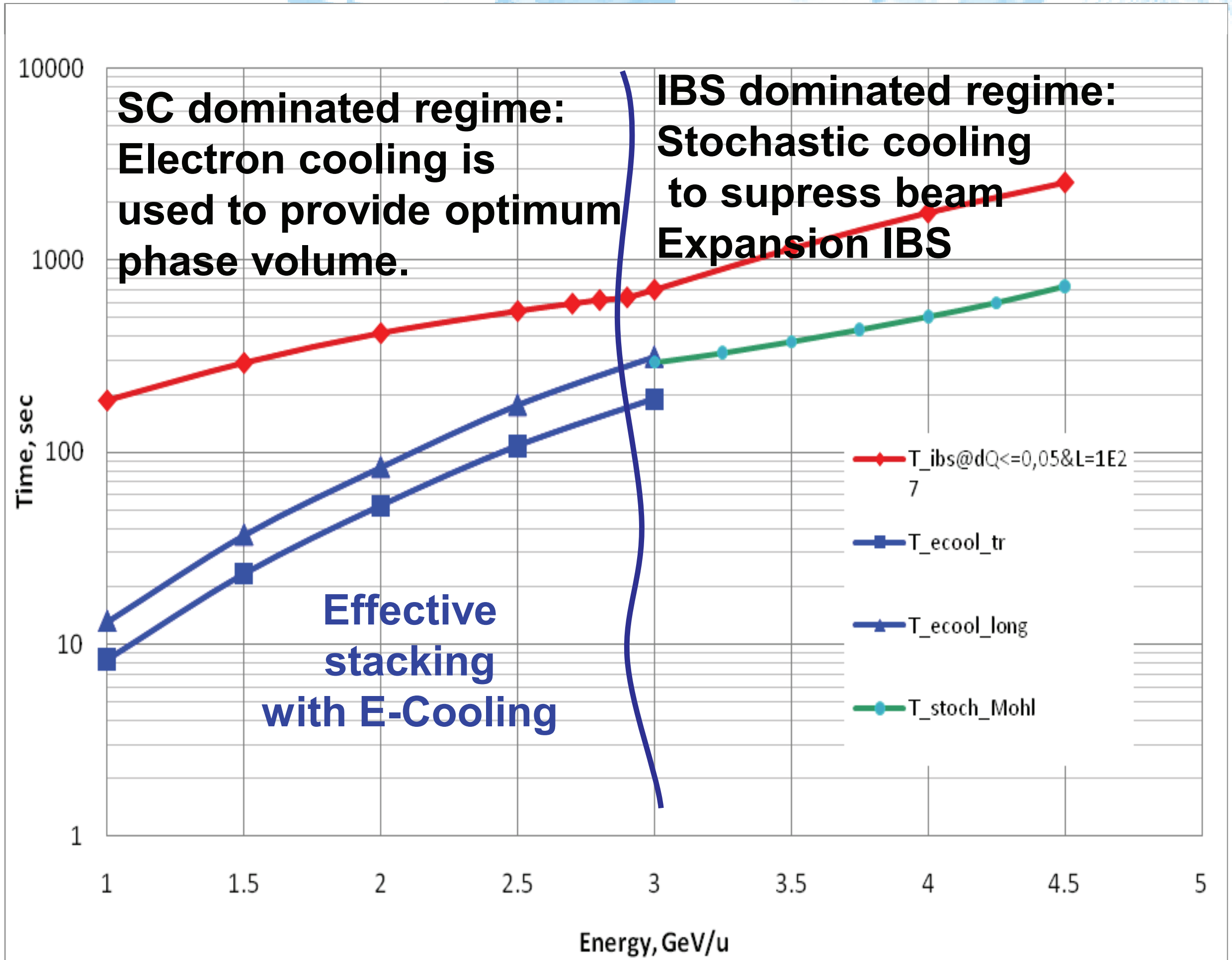


Two modes of the collider operation



Space charge dominated mode (ΔQ ≤ 0.05)	IBS dominated mode $\tau_{IBS,long} = \tau_{IBS,h} = \tau_{IBS,v}$
ε and dP/P are optimized independently. The bunch relaxation is suppressed by cooling.	ε and dP/P are "equi-partitioned", either fast bunch relaxation.
Luminosity is limited by space charge effects	Luminosity can be obtained at small ΔQ<0.05

NICA @ Start-up configuration

The beginning of the NICA accelerator complex commissioning

is scheduled for 2020

The complex will be commissioned with

- Injectors chain
- Transfer channels
- Collider in start up version, i.e:
    - with RF-1 and RF-2, but without RF-3
    - with Stoch. Coolg system - one channel per ring (long. cooling)
    - without Electron Cooler
    - without feed-back system

It will allow us to provide collider operation in the energy range of

$$\sqrt{s_{NN}} = 4 - 6 \text{ GeV } (^{197}Au^{79+} \text{ ions})$$

at the luminosity of

$$L_{start} \leq 5x10^{25} \text{ cm}^{-2} \cdot \text{s}^{-1}$$

Luminosity @ Start-up configuration for various ion species

Energy is 3.7 GeV/u. Optimal energy for stochastic cooling.

	σ_p, 10^{-4}	ε, π·mm·mrad	N_b	L
$_{197}Au^{79+}$	4.14	0.805	$1.49 \cdot 10^9$	$3.05 \cdot 10^{26}$
$_{124}Xe^{42+}$	3.8	0.678	$2.53 \cdot 10^9$	$8.9 \cdot 10^{26}$
$_{84}Kr^{36+}$	4.28	0.86	$3.31 \cdot 10^9$	$1.52 \cdot 10^{27}$
$_{40}Ar^{18+}$	4.39	0.92	$6.75 \cdot 10^9$	$5.53 \cdot 10^{27}$

Expected heating/cooling growth rates: 50 – 200 sec

Advantage in luminosity at full-scale (design) configuration of the NICA collider

Widening energy range due to e-cooling and more powerful stochastic cooling

$$\frac{1}{\tau_{IBS}} = NC_{IBS} \qquad \frac{1}{\tau_{sc}} = \frac{C_{sc}}{N}$$

At equilibrium:

$$\frac{1}{\tau_{IBS}} = -\frac{1}{\tau_{cool}}$$

$$L \sim N^2 \sim \frac{C_{cool}}{C_{IBS}}$$

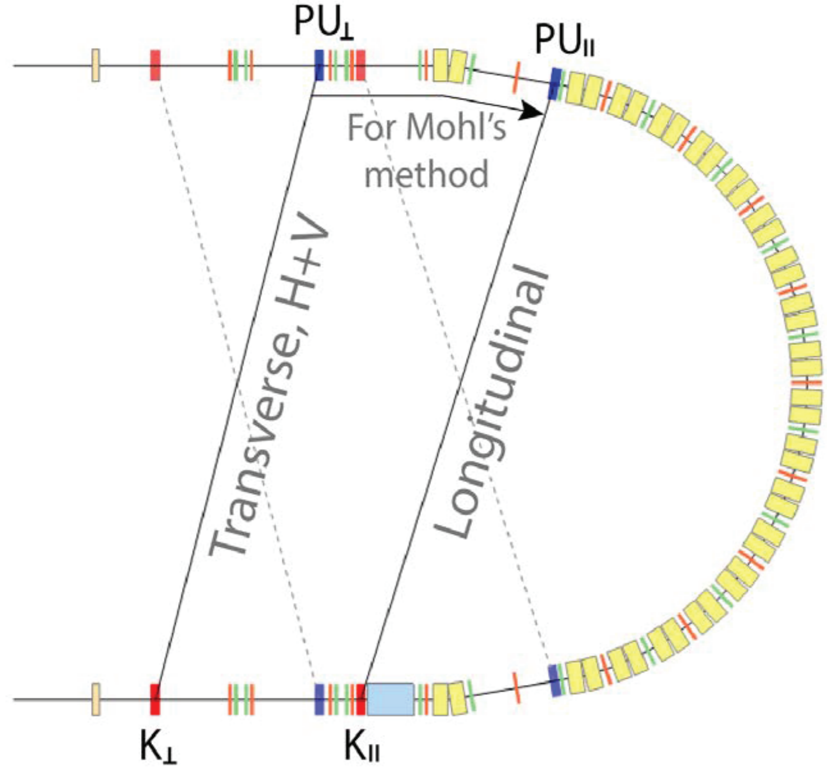
$$\frac{L}{L_{start-up}} = \frac{C_{IBS}}{C_{IBS\_start-up}}$$

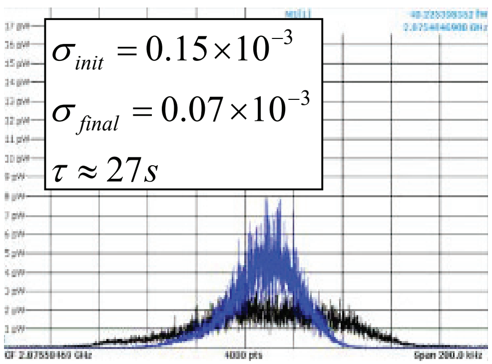
Advantage (factor of):
from 58 (@3 GeV)
to 13 (@4.5 GeV) times

Stochastic Cooling System for NICA

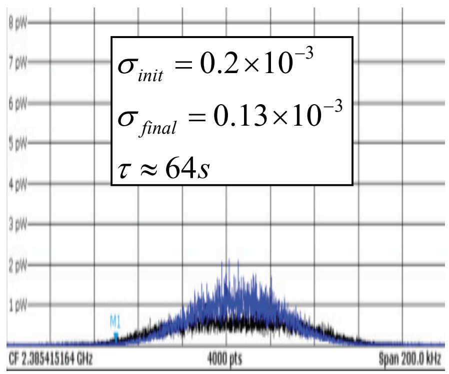
Stochastic Cooling System installed at Nuclotron - prototype for the NICA Collider:
W=2-4 HGz,
P = up to 60 W
Collaboration:
with IKP FZ Juelich

Ring slot-coupler RF structure (design FZJ)





Coasting beam



Bunched beam

C^{6+} beam, E = 2.5 - 4 GeV/u

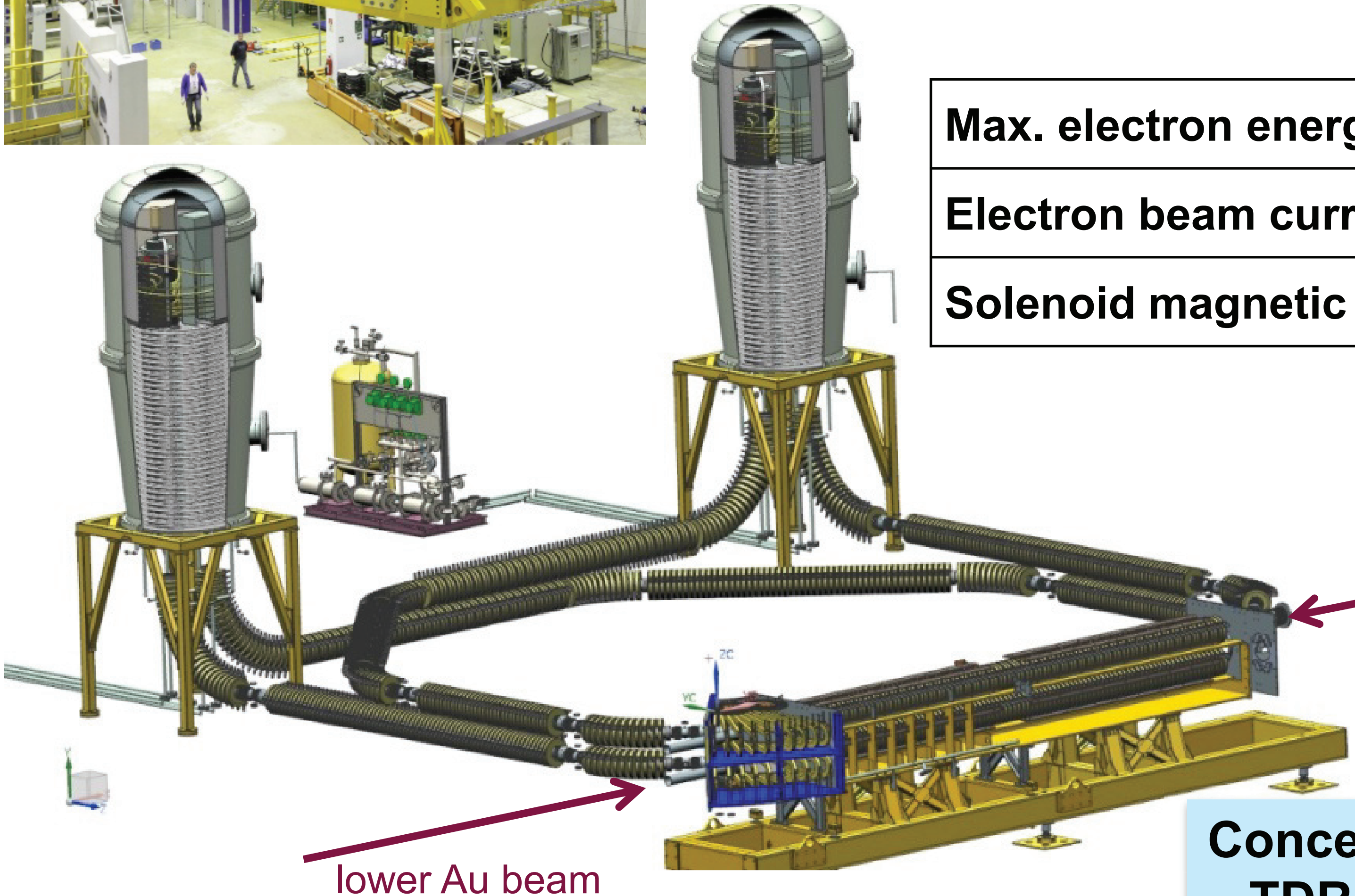
Concept for collider: Max.power ~ 500W
Filter cooling only for E > 3.9 GeV/u
Palmer cooling will be OK at
2.5 < E < 4.5 (t_{cool}: from 250 to 500 s)

Rolf Stassen, Dieter Prasuhn, Nikolay Shurkhno, Ivan Gorelyshev, Anatoly Sidorin, GT

Electron cooling system for NICA: 2.5 MeV

Main base: COSY e-cooler (2 MeV)

Max. electron energy, MeV	0.5 - 2.5
Electron beam current, A	0.1 – 1.0
Solenoid magnetic field, T	0.2



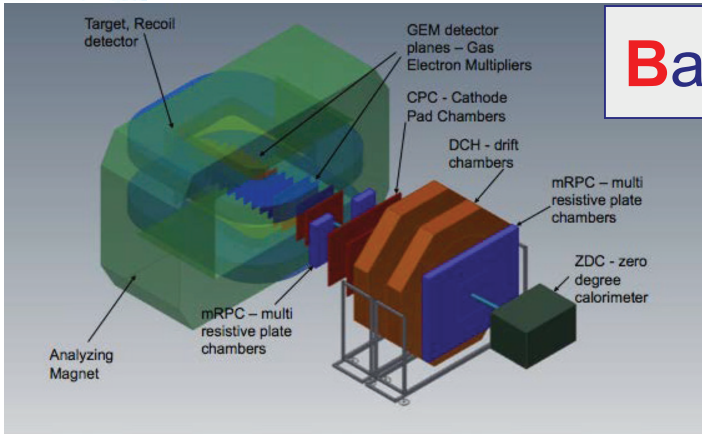
**Concept by Budker INP.
TDR started in 2016.**

- What optimal step energy scan @ NICA could be expected?
- What are optimal heavy ion species for collision? (U x U, or Au x Au, or Pb x Pb, or Bi x Bi, or Xe x Xe, similar or asimmetrical or isobars, p/d x HI, LI x HI)…
- Minimal required detector space @ IP along the beam
- Required modes of data acquisition (limitations, cycle, etc), collimation of the beam, requirements to the background “dead-time of detector”, requirements to the synchronization, are fragments from the pereferical collisions interesting ?
- ….

To do list

- Finalize the lattice with the cooler, polarization system, etc.
- Tune point limitation from BB effects, space charge and polarization.
- Apply numerical optimizer. Driving terms correction. High order chromaticity correction.
- DA with magnet imperfections.
- DA with space charge, BB effects, intrabeam scattering, cooling, etc.
- Different energies, different species.
- Nonlinear dynamics of the injected beam.
- Prediction of the long term DA from the short term one.

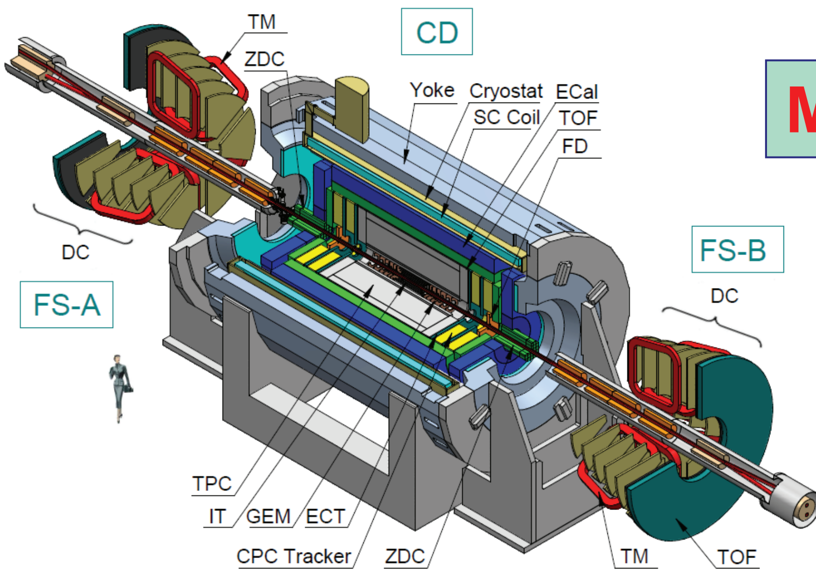
NICA: 3 detectors



Baryonic Matter at Nuclotron (BM@N)

the fixed target experiment at the Nuclotron

Stage I - 2017



MultiPurpose Detector (MPD)

at the Collider

Stage II – 2019/2020

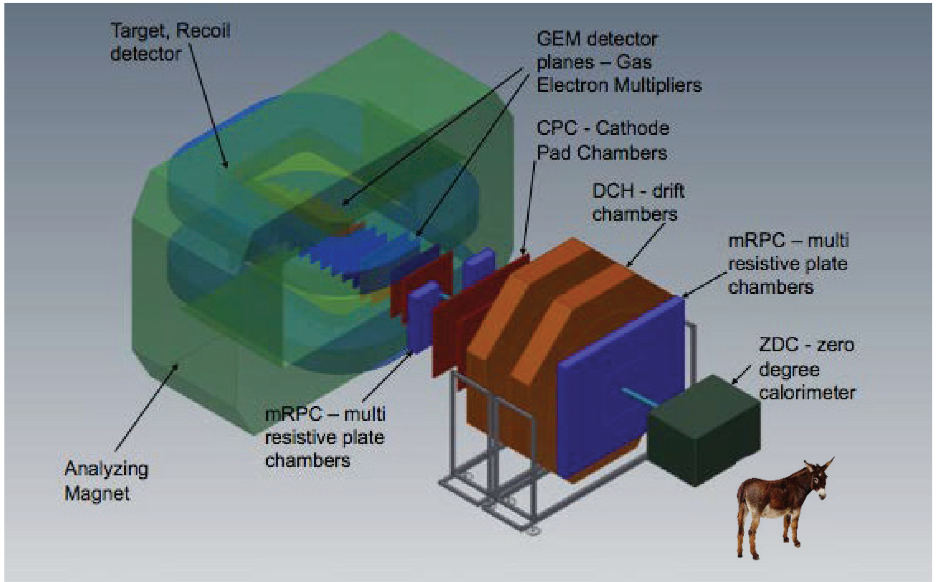
SPD (Spin Physics Detector) ***at the Collider***

Stage III – after 2022

BM@N experiment

Participants from:

Russia: *INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Inst.*
Bulgaria: *Plovdiv University;*
China: *Tsinghua University, Beijin;*
Poland: *Warsaw Tech.Uni.*
Israel: *Tel Aviv Uni.*
Germany: *Frankfurt Uni.*
+ expression of interest from CBM



Physics @ beam kinetic energy from 1 to 4 GeV/u:

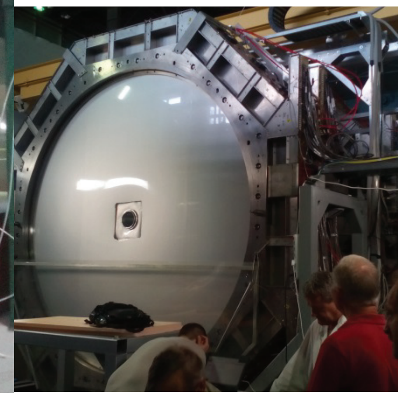
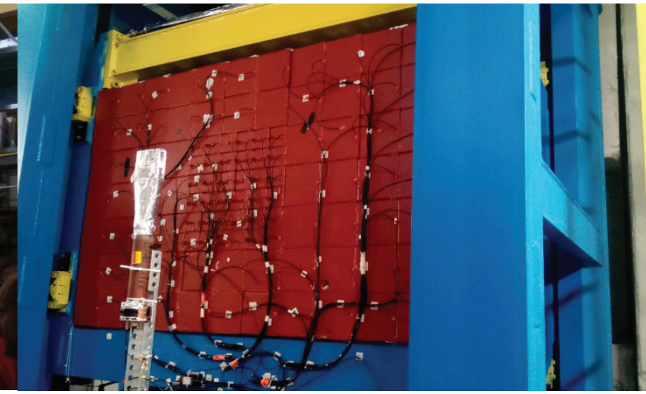
- ✓ *strange / multi-strange hyperon and hypernuclei production at the threshold*
- ✓ *hadron femtoscopy*
- ✓ *in-medium modifications of strange & vector mesons in dense nuclear matter*
- ✓ *electromagnetic probes, states decaying into γ, e (with ECAL)*

BM@N plan

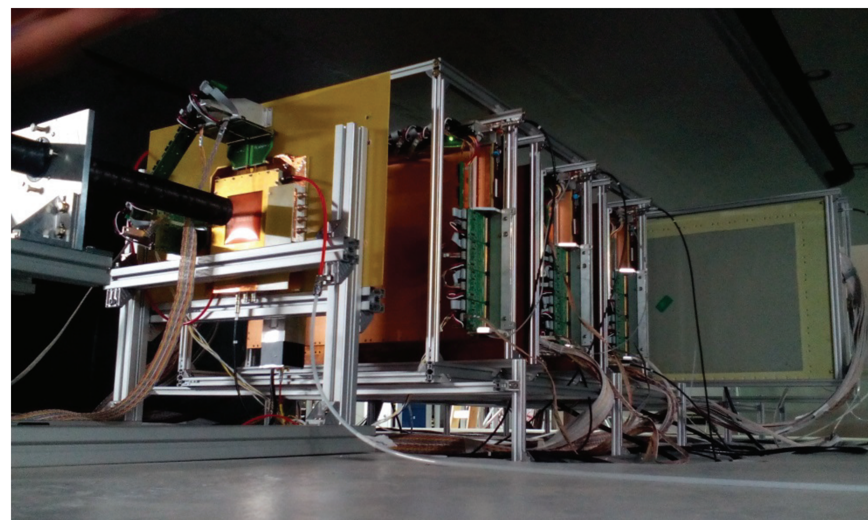
technical runs with ***d, Li, C*** *beams*: **2016 – 2017;**
physics run **BM@N** *(I stage) with* ***Kr*** *int rate 20 kHz:* **IV q., 2017;**
physics run **BM@N** *(II stage) with* ***Au*** *int rate 50 kHz:* **2019.**

BM@N Run 52 (June 2016): *tests & commissioning of GEM CT located inside analyzing magnet*

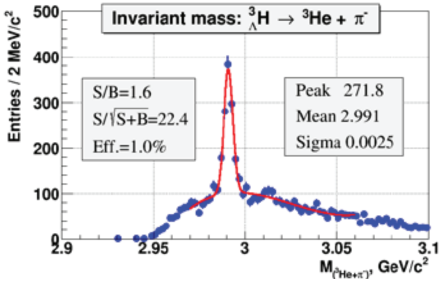
d beam (~5·10^5 /cycle) with 2.94 GeV/n

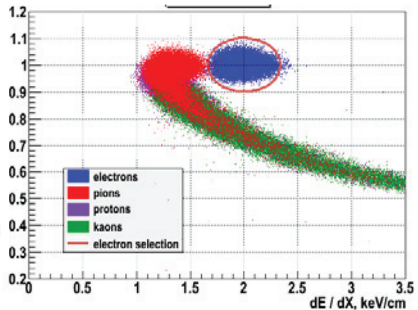




*5 GEM detectors 66 x 41cm^2 + 1 detector **163 x 45** cm^2*

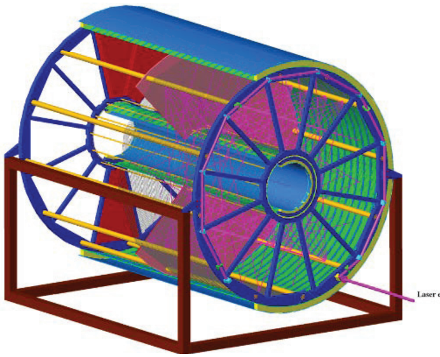



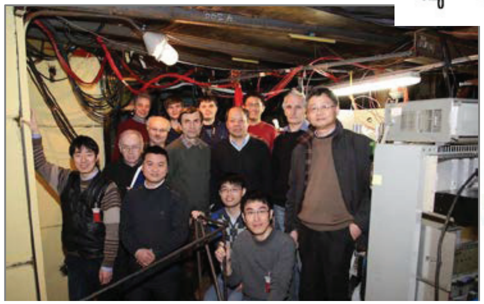
NICA MPD: status of construction

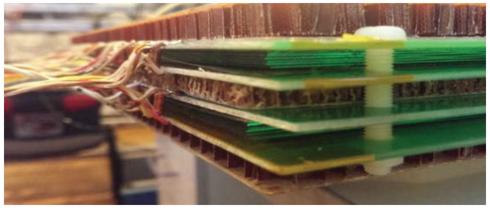


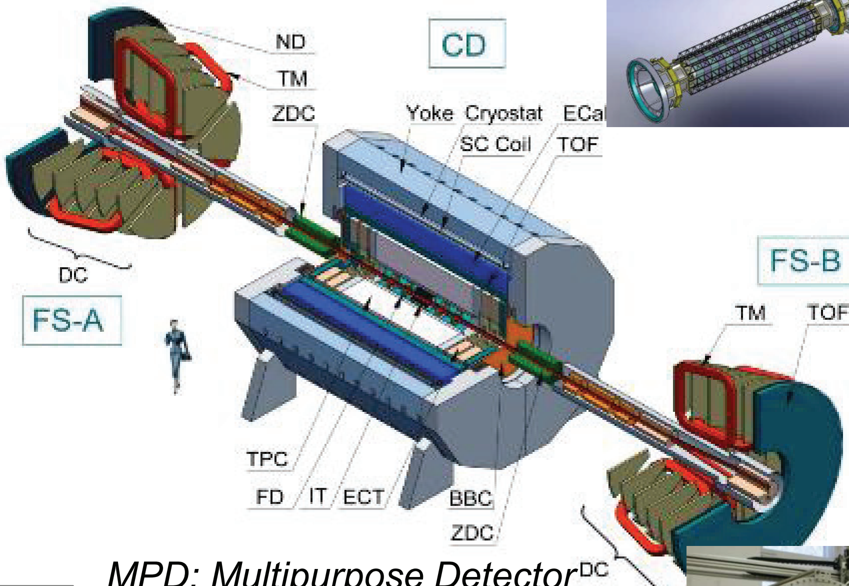


Microstrip detectors (SiT)



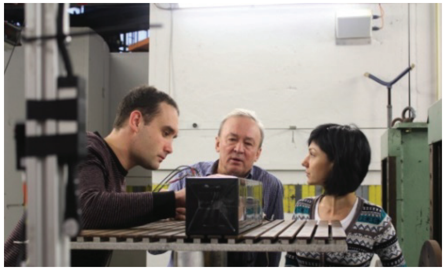






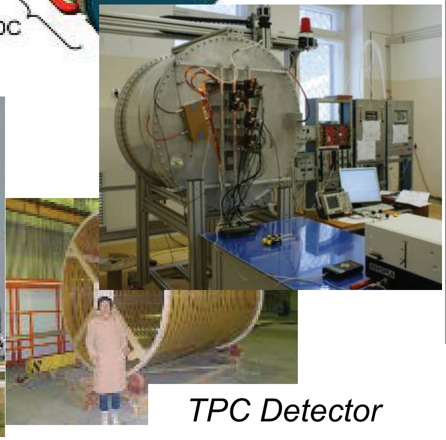
Time of Flight system (TOF)
FF: 38 ps, mPRC: 63 ps

MPD: Multipurpose Detector

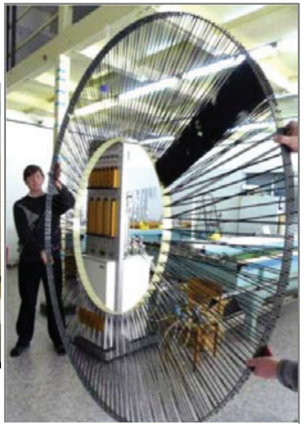


*EM calorimeter: Energy resolution = **2.5% / √E***

Time Projection Chamber



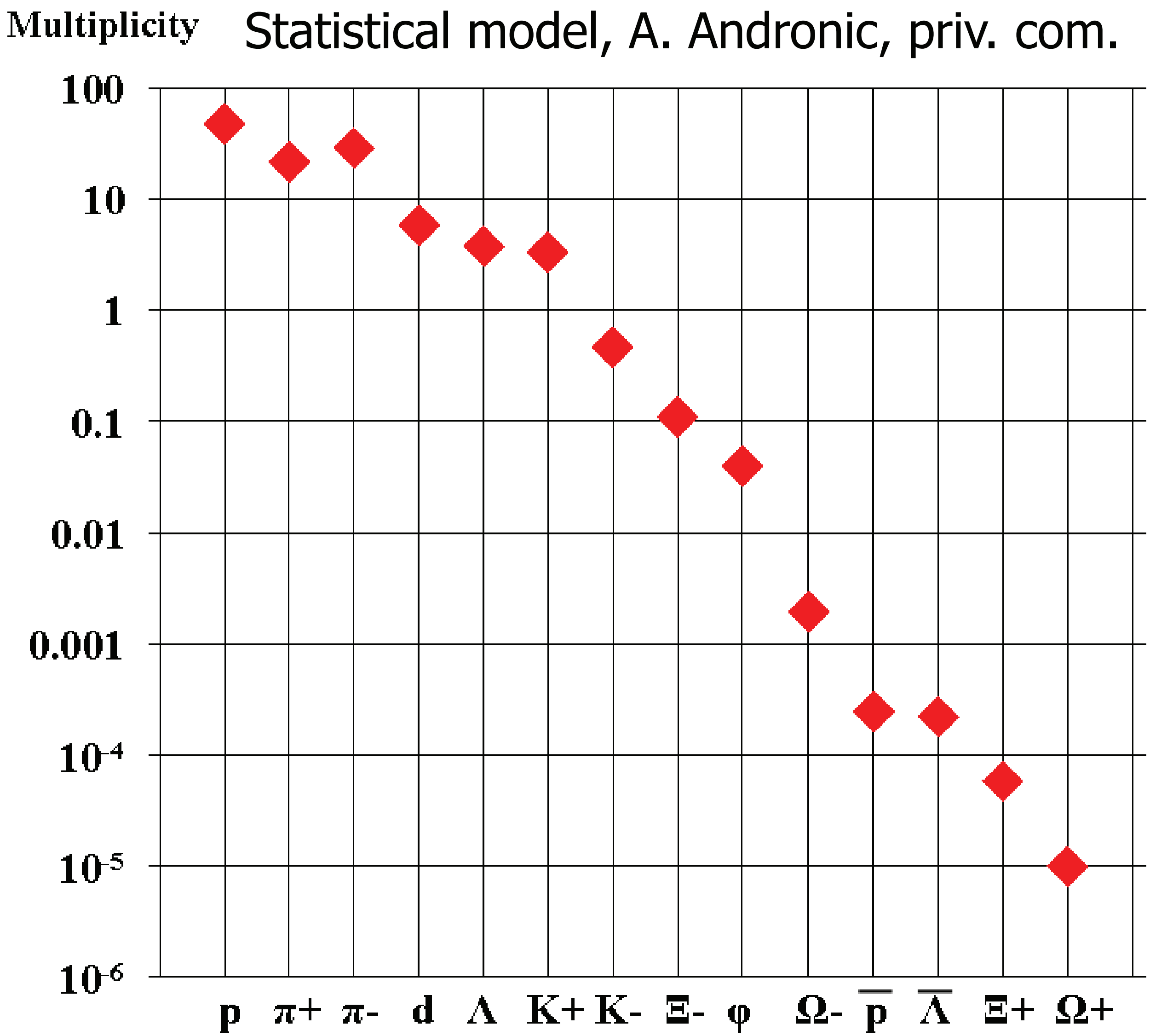
TPC Detector



Straw Detector

Experimental challenges

Particle yields in central Au+Au 4 A GeV

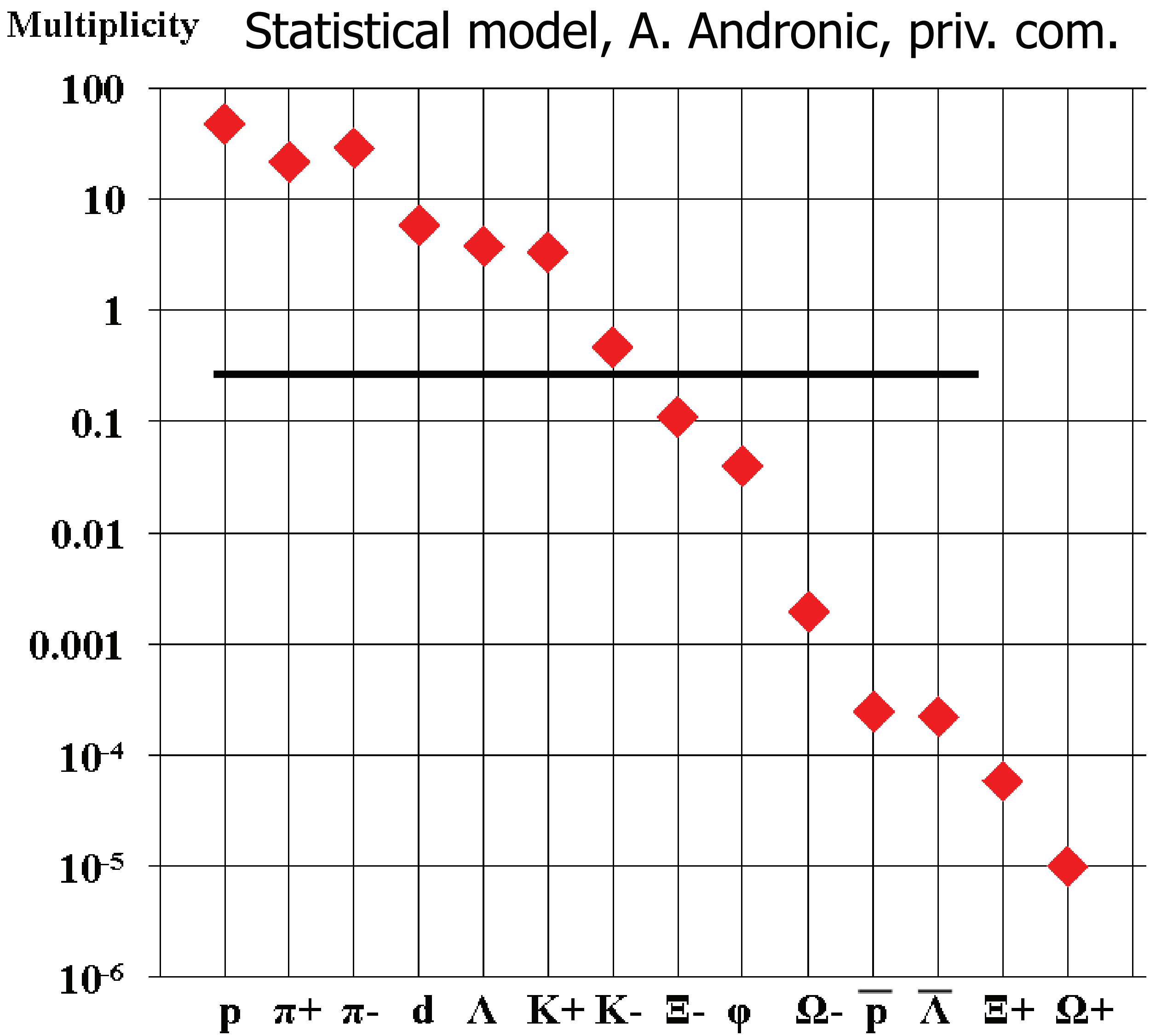


P.Senger

Experimental challenges

Particle yields in central Au+Au 4 A GeV

Statistical model, A. Andronic, priv. com.



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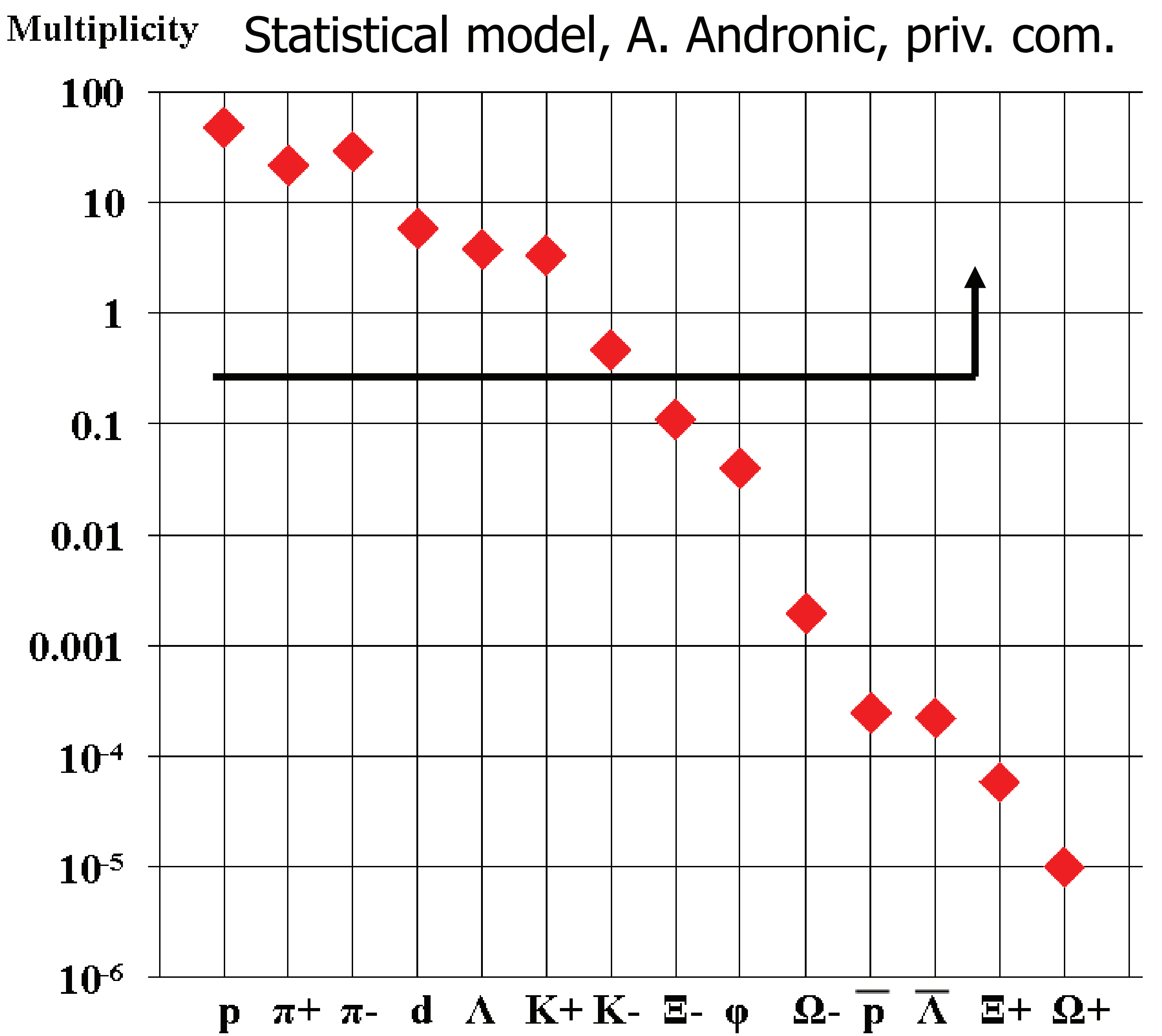

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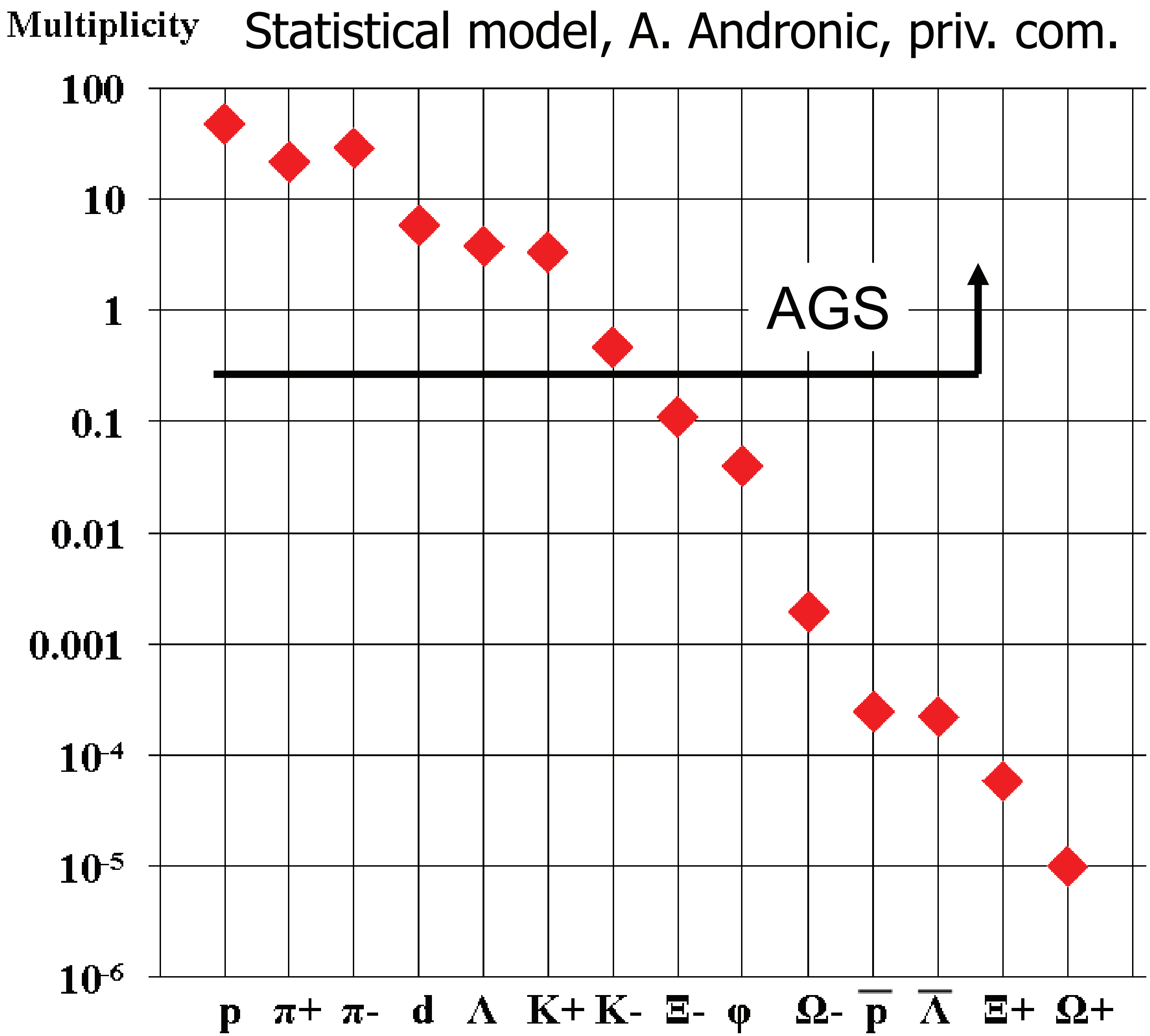

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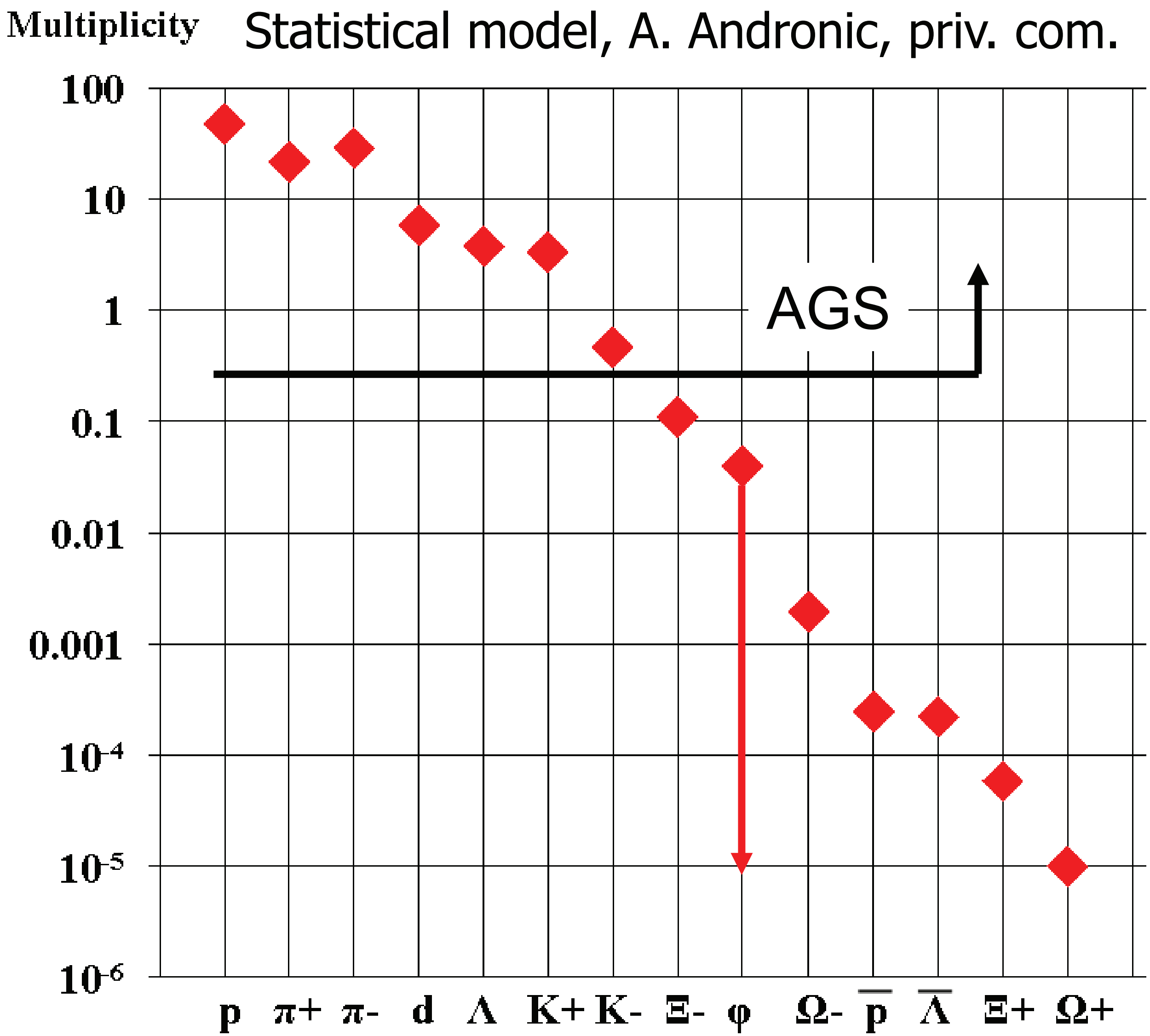

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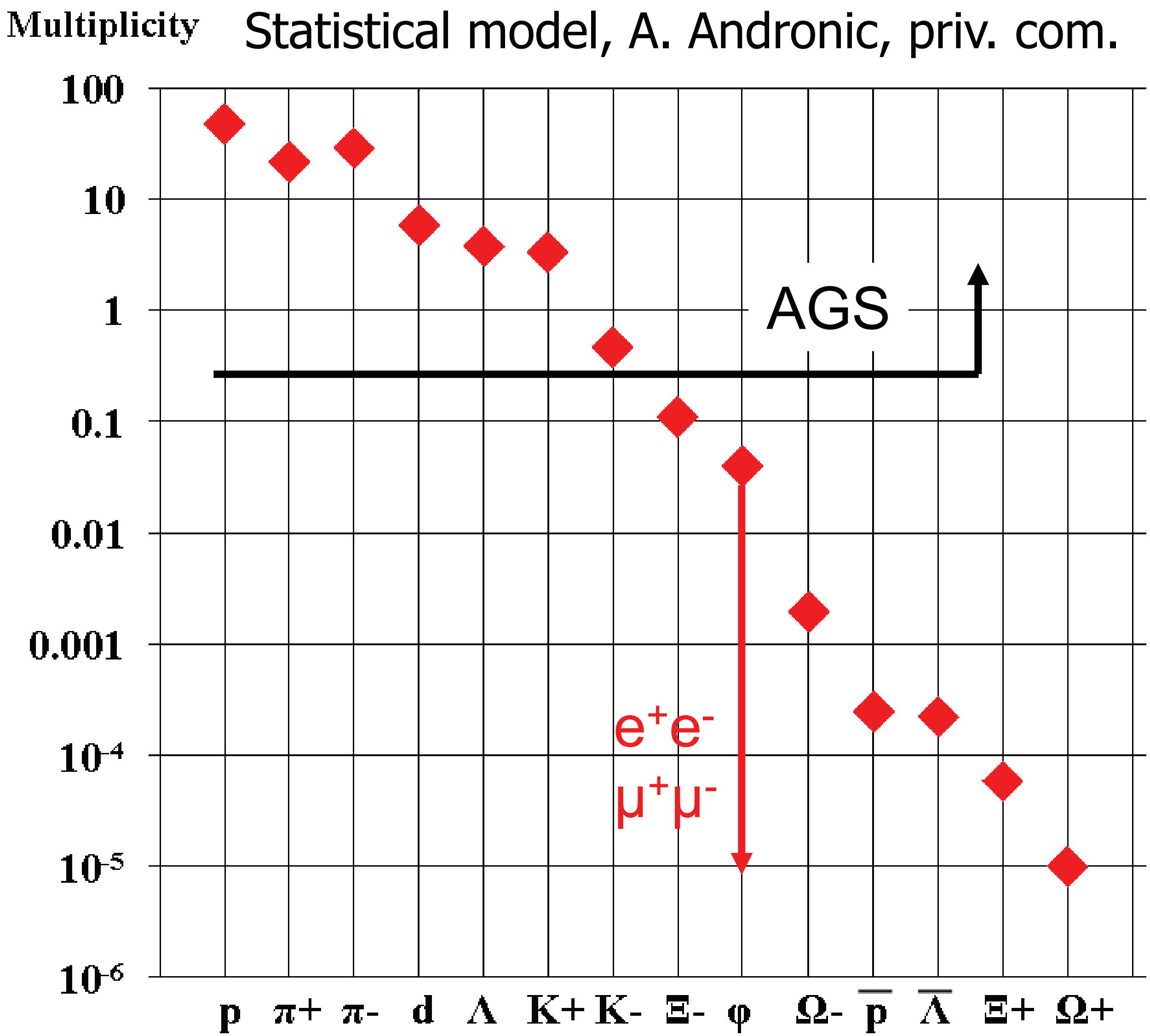

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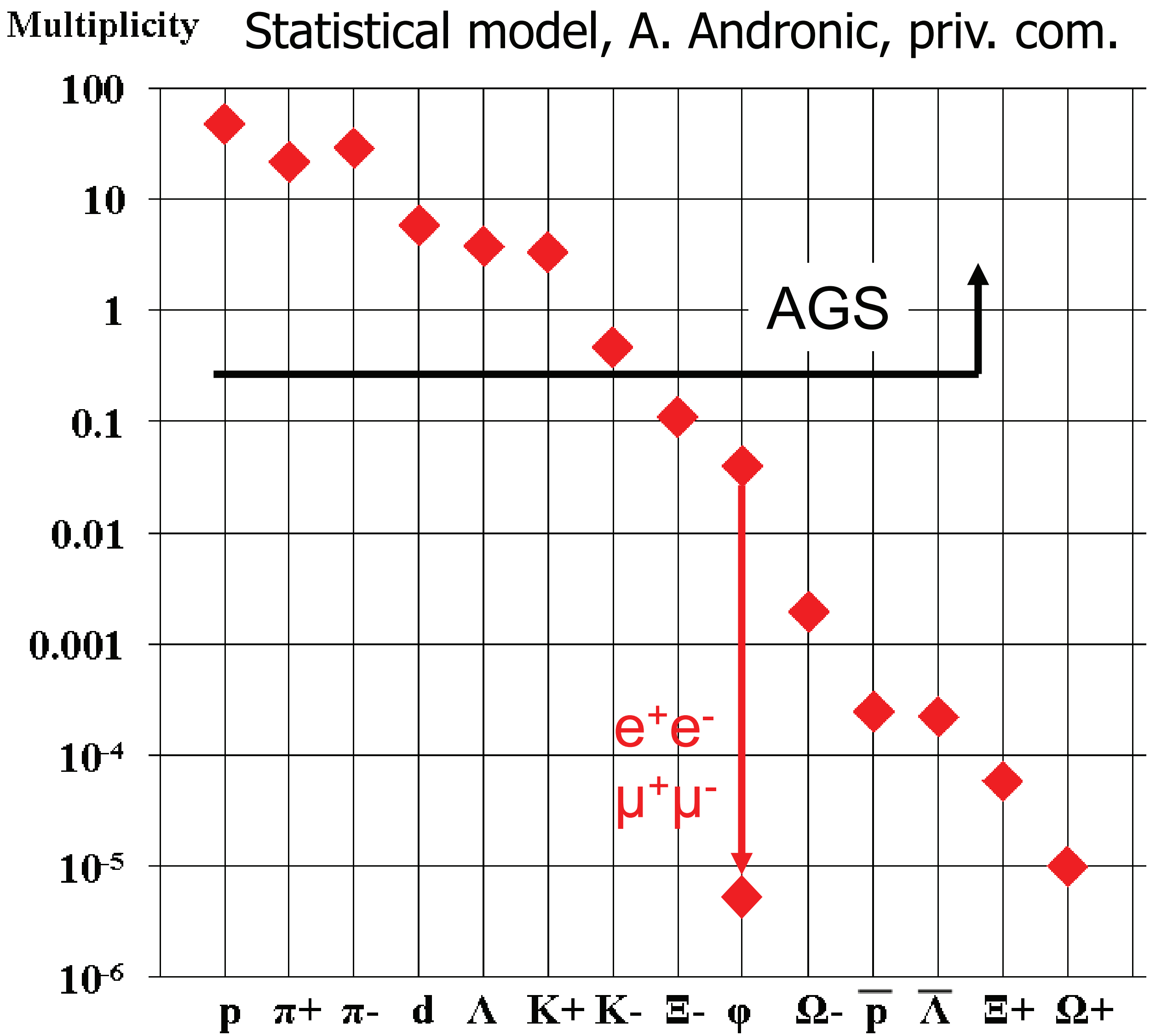

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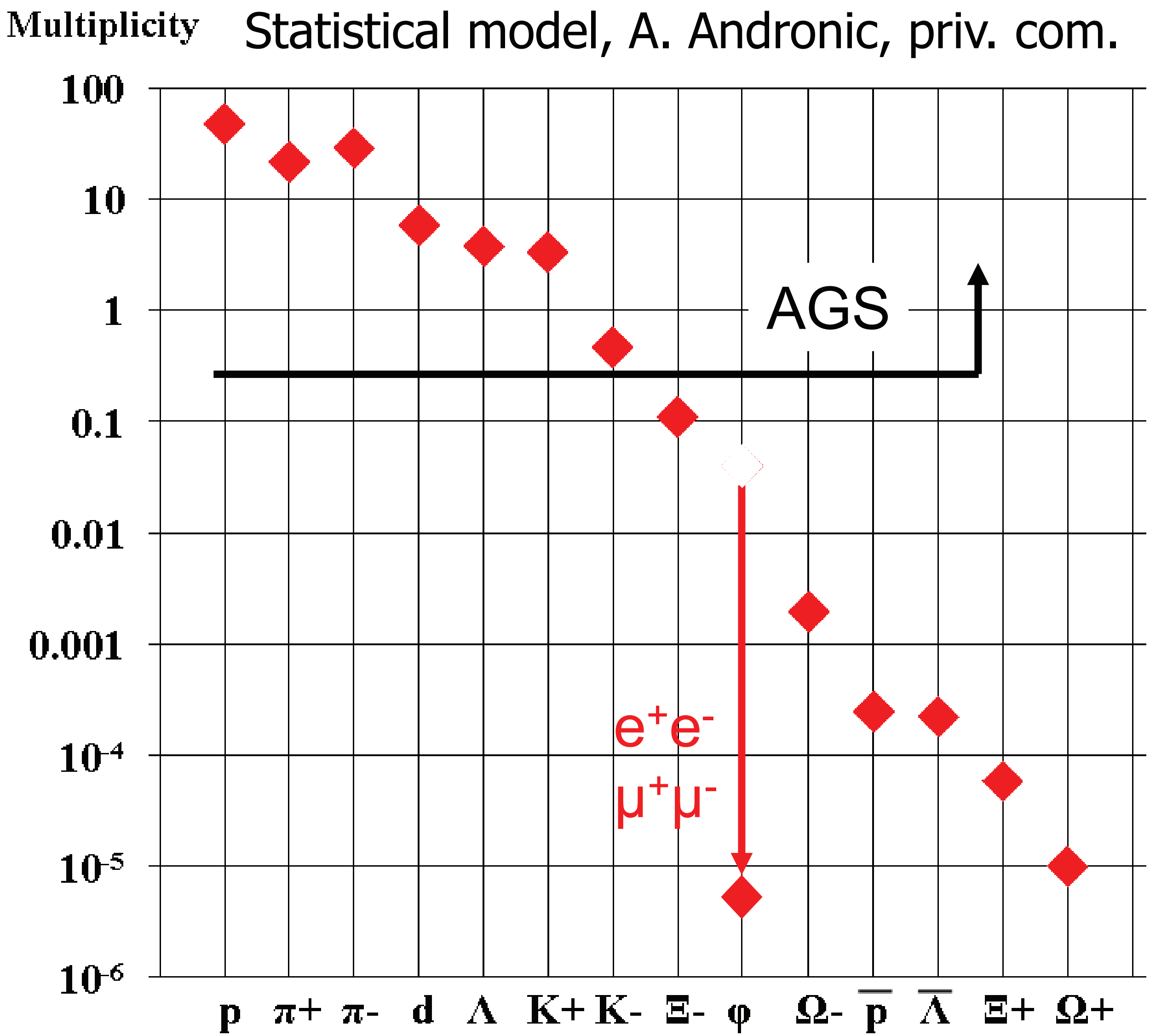

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Experimental challenges

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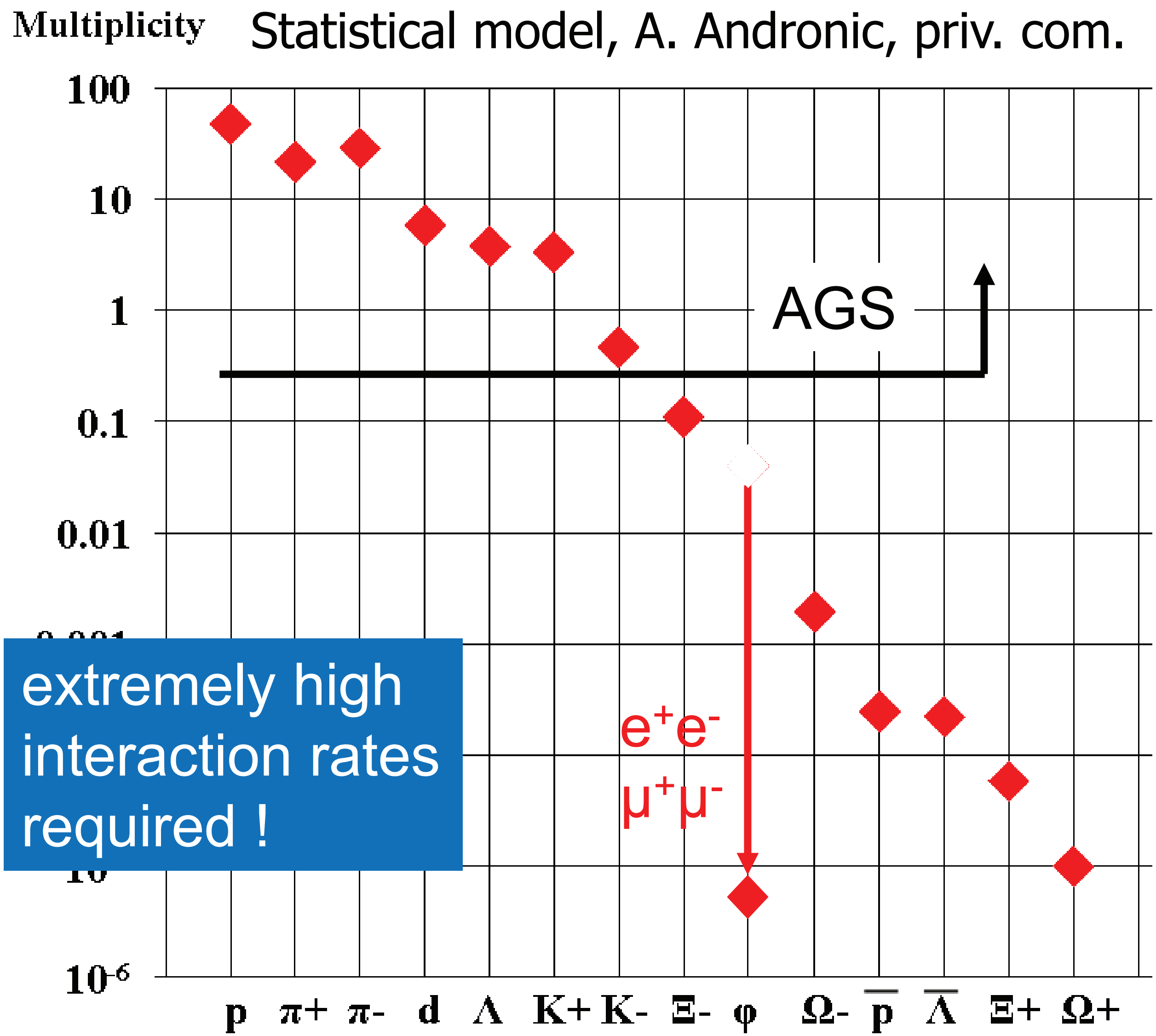


NICA MPD Data rates. Plan

Possible scenario:
*to take data at **8** energies **4, 5, 6, 7, 8, 9, 10, 11** GeV*
*for beam/target combinations: **Au+Au**, **Xe+Xe**, **C+C, p+p***

In total:
***32** data sets (**1** week for each of the top-half energy + **2** weeks for lower energies).*

*We plan (we expect) that in **48** weeks (~**1,5** year) of data taking the **statistics equal to one at RHIC** will be accumulated (duty factor 0.5 is used)*

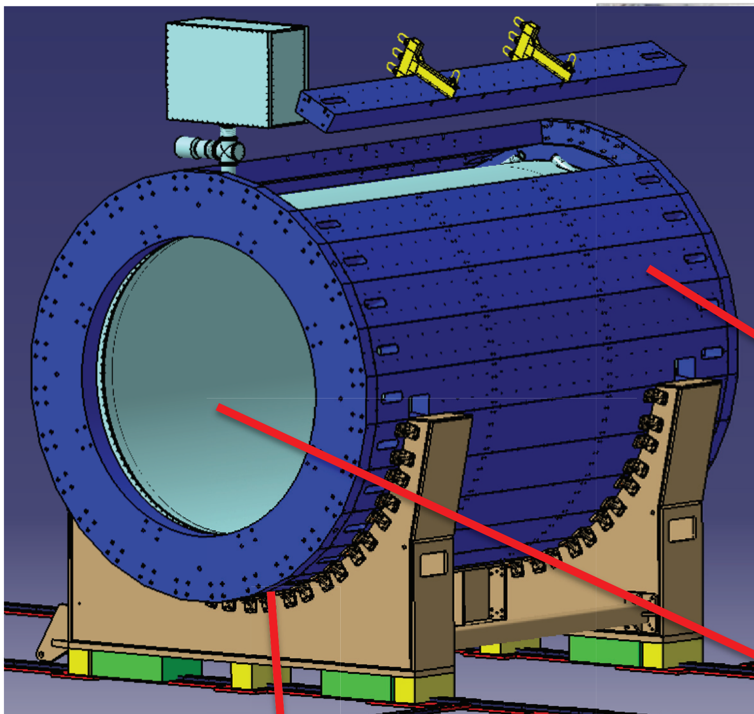
Beam	Luminosity ($cm^{-2}\ c^{-1}$)		Data sample per 1 week at $\sqrt{s}$ = 4 GeV	Data sample per 1 week at $\sqrt{s}$ = 11 GeV
	$\sqrt{s}$=4 GeV	$\sqrt{s}$=11 GeV		
^{197}Au	$7 \cdot 10^{24}$	$5 \cdot 10^{25}$	$9.1 \cdot 10^{6}$	$6.3 \cdot 10^{7}$

Particle yields in Au+Au collisions @ $\sqrt{s_{NN}}$ = 8 GeV (*central collisions*)

one week of running at **L = 5 10^{25}cm^{-2}s^{-1}** *(duty factor = 0,5)*

Particle	Multiplicity	Decay mode	BR	*Efficiency %	Yield /1 w
π^+	293	----	---	61	$7.7 \cdot 10^8$
K^+	59	---	----	50	$1.5 \cdot 10^8$
p	140	---	----	60	$4.2 \cdot 10^8$
Λ	~35	$p+\pi^-$	64%	~10%	$\sim 1 \cdot 10^7$
Ξ^-	~2	$\Lambda+\pi^-$	~100%	1.6%	$1.0 \cdot 10^5$
ρ	31	e+e-	$4.7 \cdot 10^{-5}$	35	$2.5 \cdot 10^3$
ω	20	e+e-	$7.1 \cdot 10^{-5}$	35	$2.5 \cdot 10^3$
φ	2.6	e+e-	$3 \cdot 10^{-4}$	5	$2.0 \cdot 10^2$
Ω	0.14	Λ+K	0.68	2	$9.5 \cdot 10^3$

Yoke production: *all packages are at Vitkovice HM*



VITKOVICE Heavy Machinery, Sept. 5, 2016

The whole Complex comprises several Objects to be commissioned:

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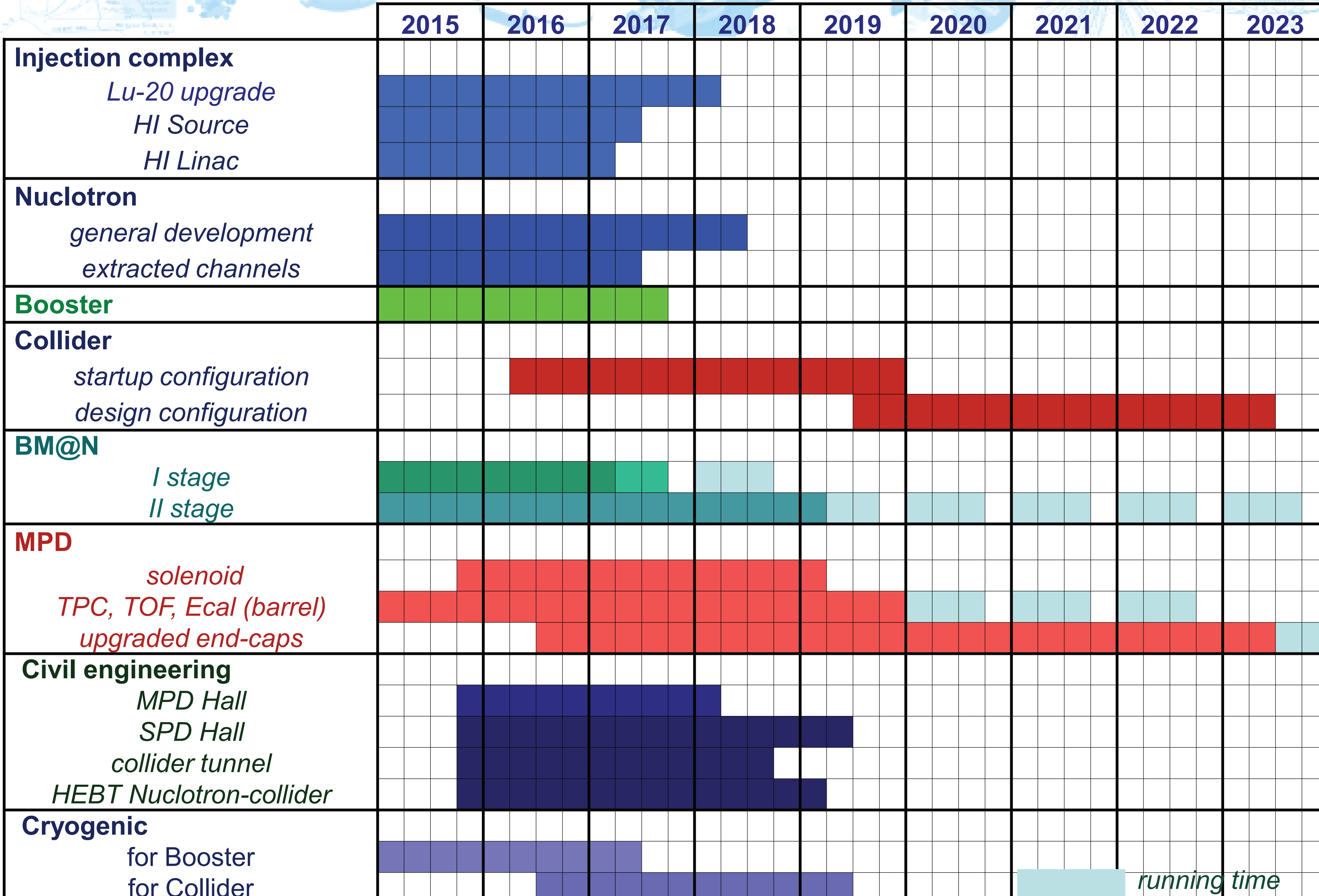
The whole Complex comprises several Objects to be commissioned:

NICA time-line



International mega-project NICA

17 Russian Institutions and Universities + 24 Laboratories abroad RF

МИФИ, МЭИ, МФТИ, КГТУ, СПбГУ,...

ИЯФ СО РАН им.Г.И.Будкера

- Booster RF system, e-cooler
- Collider RF system
- ✓ HV e-cooler for collider
- ✓ Electronics

НПО ГЕЛИЙМАШ

КРИОГЕНМАШ

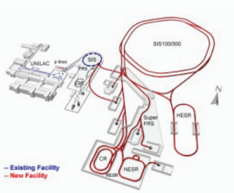
BEVATECH

ИЯИ РАН, Troitsk polarised source, Linacs, beam diagnostics

Всероссийский электротехнический институтHV Electron cooler

ВЭИ

GSI/FAIR
SC dipoles for Booster/SIS-100
beam cooling, diagnostics



РФЯЦ ВНИИТФ, РФЯЦ ВНИИЭФ, ФГУП ЭЗАН, НПО Атом, СМЗ, НПО Исток, НПО Компенсатор, и др.

IHEP (Protvino_
RFQ,beam dynamics, RF,
Feed-back systems

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР «КУРЧАТОВСКИЙ ИНСТИТУТ»

ITEP
Beam dynamics
in the collider,RFQ linac

FZ Juelich (IKP)
HV Electron cooler
Stoch. cooling

CERN
SC technologies, Rad.safety, energetics, beam cooling and dynamics

FNAL:
HV Electron cooler
Beam dynamics,Stoch.cooling

BNL (RHIC)
Beam dynamics,
Stoch. Cooling

Status of the NICA mega-science @ JINR

ПРАВИТЕЛЬСТВО РОССИЙСКОЙ ФЕДЕРАЦИИ

РАСПОРЯЖЕНИЕ

от 27 апреля 2016 г. № 783-р

МОСКВА

О подписании Соглашения между Правительством Российской Федерации и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований о создании и эксплуатации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA

1. В соответствии с пунктом 1 статьи 11 Федерального закона "О международных договорах Российской Федерации" одобрить представленный Минобрнауки России согласованный с МИДом России, Минфином России, Минэкономразвития России и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований проект Соглашения между Правительством Российской Федерации и международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований о создании и эксплуатации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA (прилагается).

2. Поручить Минобрнауки России провести переговоры с международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований и по достижении договоренности подписать от имени Правительства Российской Федерации указанное в пункте 1 настоящего распоряжения Соглашение, разрешив вносить в прилагаемый проект изменения,

During 2013-2016 NICA successfully passed several stages of International expertise, had assembled a wide collaboration (95 participants from 25 countries). Very important step – inclusion NICA into ESFRI Strategy Report on Research Infrastructures and ESFRI Roadmap 2016 Update as complimentary project to ESFRI landmark project FAIR

On 27th April 2016 the RG Prime-minister issued the Governmental Decree about establishment of the NICA mega-science on Russian territory at JINR. Russia and JINR co-invest to the "NICA Complex. Agreement between RF Government and JINR (signed on 2nd June 2016) in the frame of Decree formulates basic principles of the setting and development of the International collaboration "Complex NICA". We assume that in coming years similar Agreements will be prepared, agreed and signed with other countries and International Scientific centers, expressed their interest to participate and contribute to NICA.

We invite to join NICA new countries (Germany, China, …), leading International scientific centers (CERN, FAIR, etc) and Universities.

Concluding remarks:

- NICA complex has a potential for competitive research in dense baryonic matter and spin physics.

- NICA has large international and fruitful cooperation with many physics research centers in Russia and around the World .

- The construction of the NICA collider complex and both detectors BM@N & MPD goes close to the schedule.

We welcome new partners !

Prospects, possible future development of the NICA (after 2025-2030):

Polarized beams = spin physics program

Facility for experiments on the observation of spontaneous electron–positron pair creation in **supercritical Coulomb fields** (new 2 compact SC rings with merging bare Uranium beams)

Mass-spectroscopy of radioactive heavy ion beams in isochronous mode (using booster or collider ring) + measurement of nuclei PDF with **colliding/merging electron-proton beams** (up to 1 GeV)

Increasing of beam intensity (cw SC linac) and beam energy (B > 4.5T) – as NICA development towards QCD MES (up to $\sqrt{S}$ ~ 60 GeV) and/or high-flux neutrino source…

Thank you very much !

NICA

Nuclotron Beams

Parameter	*Achieved*		*Project (2017 - 2020)*	
Magnetic field, T	2.0		2.0 (Bρ = 42.8 T·m)	
Field ramp, T/s	0.8		1.0	
Repetition period, s	8.0		5.0	
	E, GeV/u	Ions/cycle	Energy, GeV/u	Ions/ cycle
Light ions ⇒ d	5.8	$2\cdot10^{10}$	6.0	$5\cdot10^{10}$
Heavy ions	*With KRION-2*		*With KRION-6T & Booster*	
$^{40}Ar^{18+}$	3.5	$5\cdot10^{6}$	4.9	$1\cdot10^{8}$ $2\cdot10^{10}$
$^{56}Fe^{26+}$	2.5	$2\cdot10^{6}$	5.4	$1\cdot10^{8}$ $1\cdot10^{10}$
$^{124}Xe^{48/42+}$	1.5	$1\cdot10^{3}$	4.0	$1\cdot10^{7}$ $2\cdot10^{9}$
$^{197}Au^{79+}$	---	---	4.5	$1\cdot10^{7}$ $2\cdot10^{9}$
Polarized beams	*With Polaris*		*With SPI*	
p↑ **)	---	---	11.9	$1\cdot10^{10}$ **)
d↑	2.0	$5\cdot10^{8}$	5.6	$1\cdot10^{10}$

***) With the Siberian snake and upgraded RF systems*

Nuclotron Beams

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Nuclotron Beams

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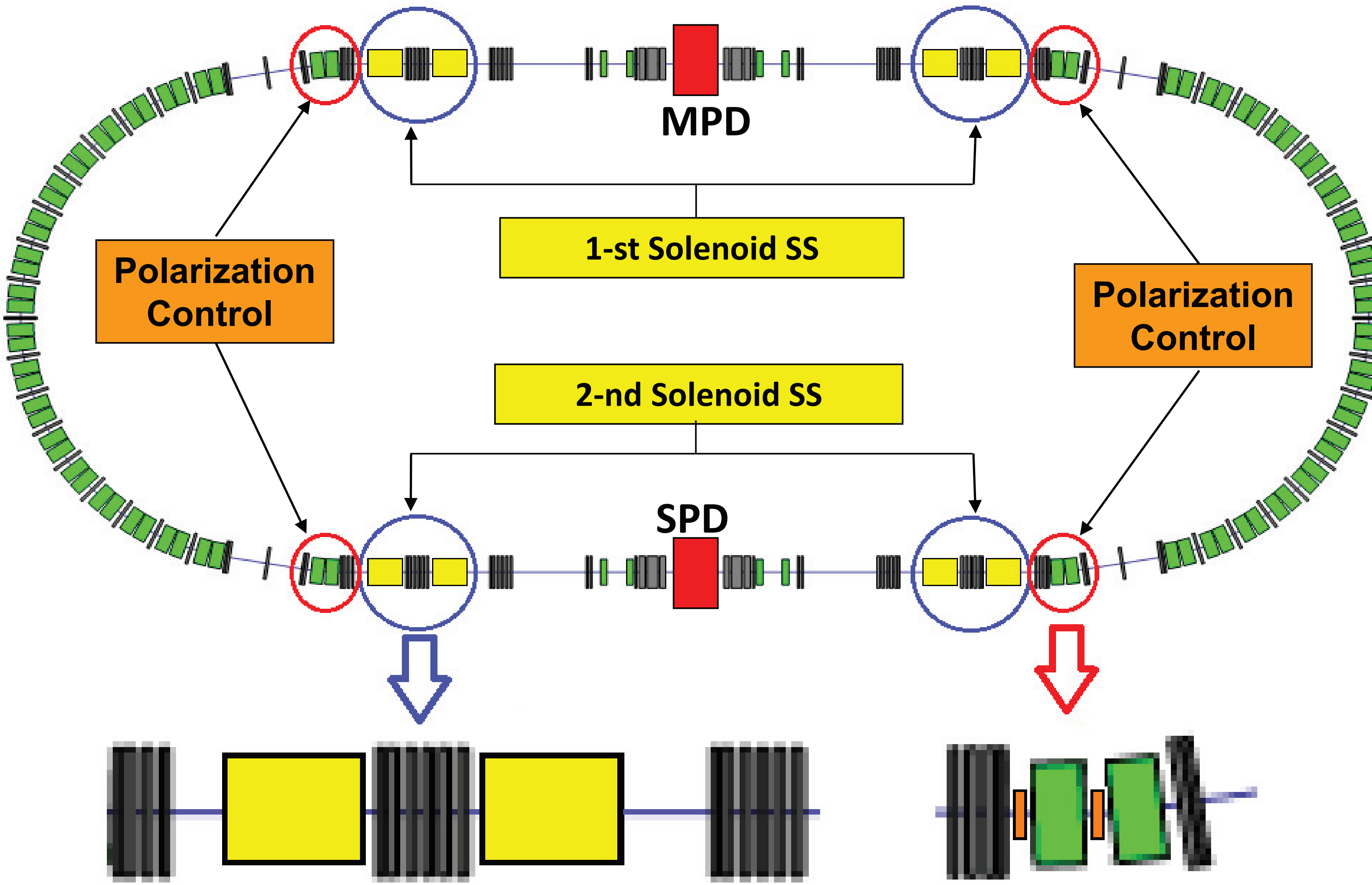
d↑	2.0	$5\cdot10^{8}$	5.6	$1\cdot10^{10}$

NICA Stage II

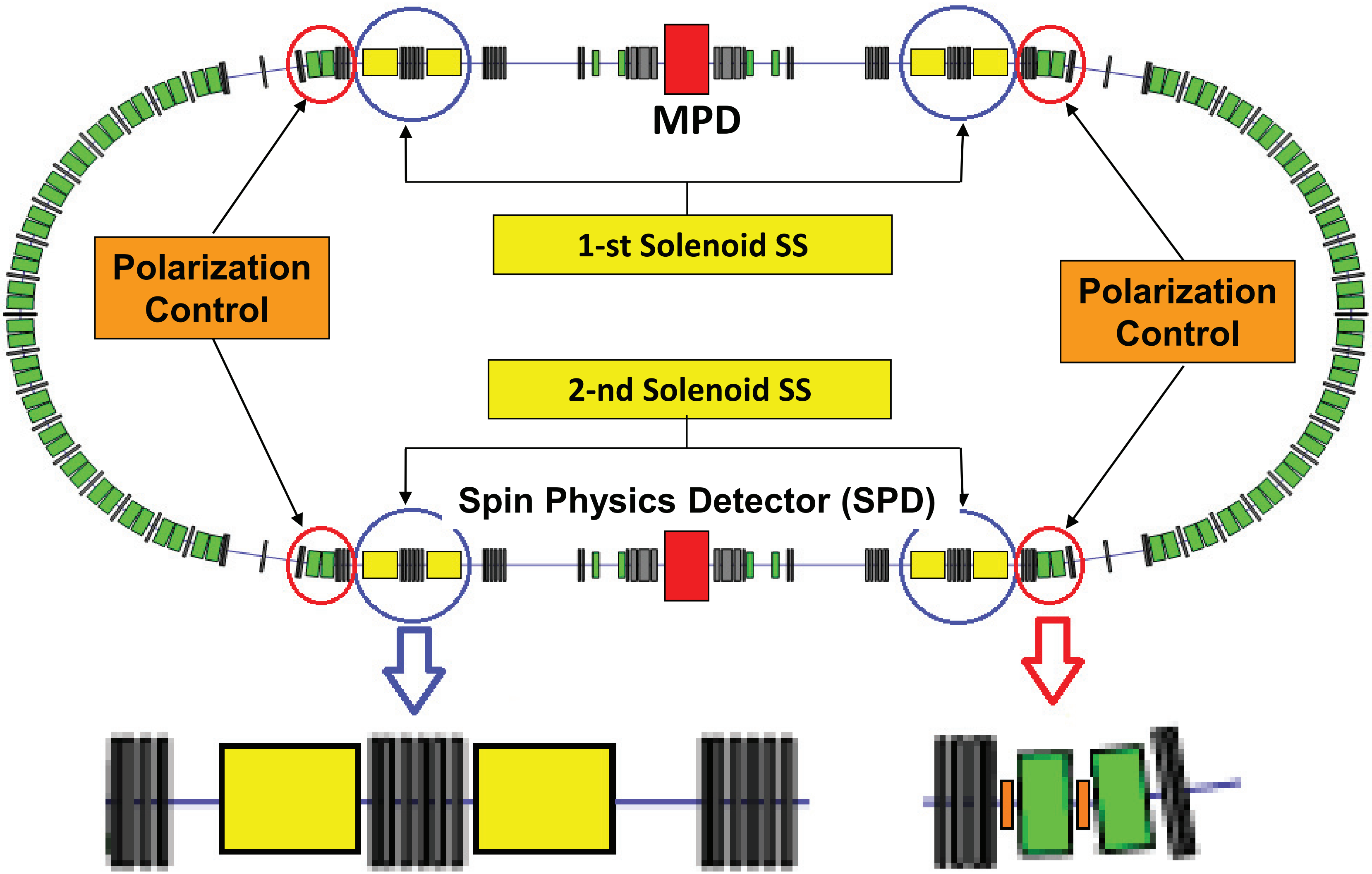
***) With the Siberian snake and upgraded RF systems*

5. NICA – Stage III: Collider of polarized beams



Spin diagnostics + Superconducting solenoids at field < 8 T

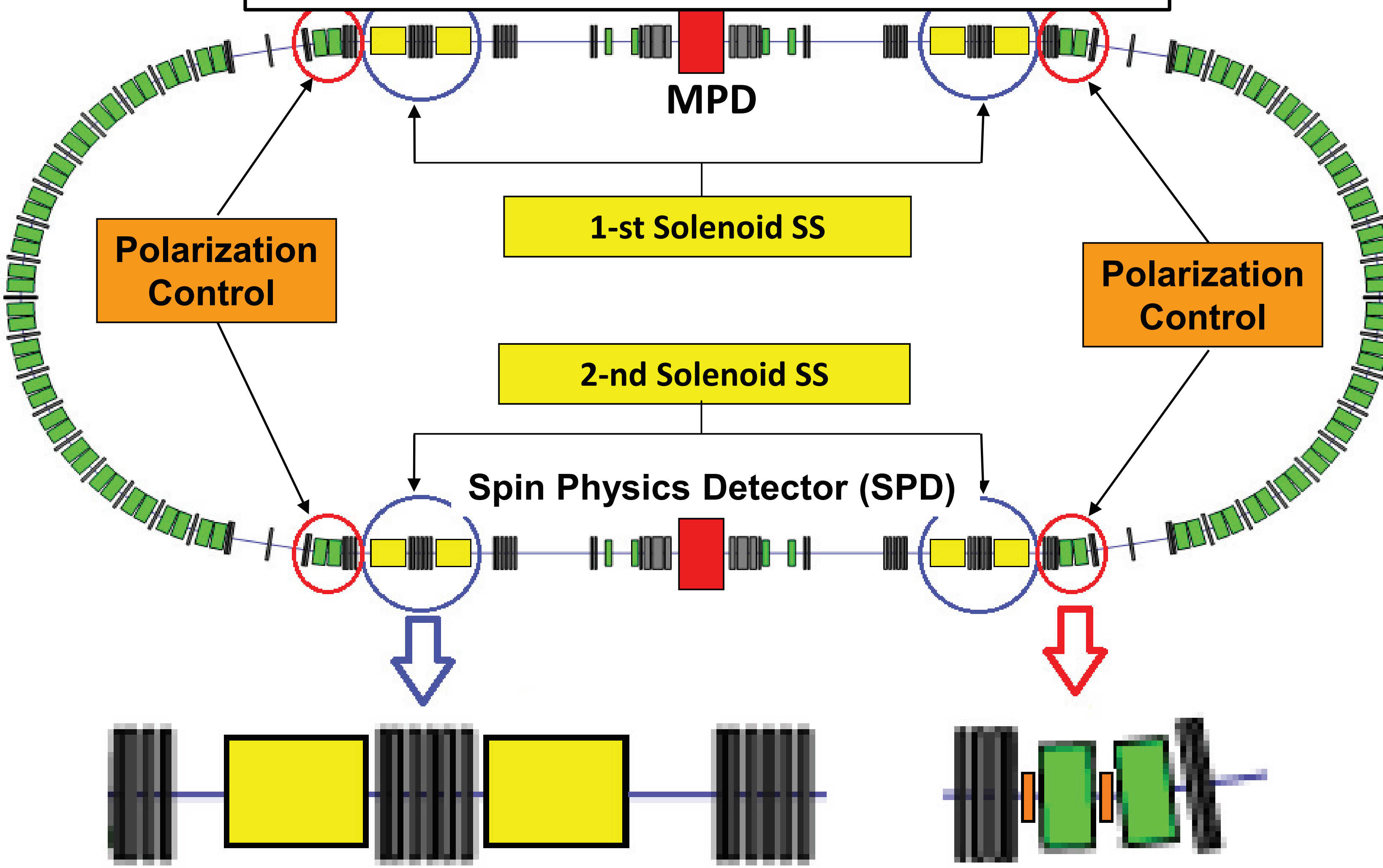
5. NICA – Stage III: Collider of polarized beams



Spin diagnostics + Superconducting solenoids at field < 8 T

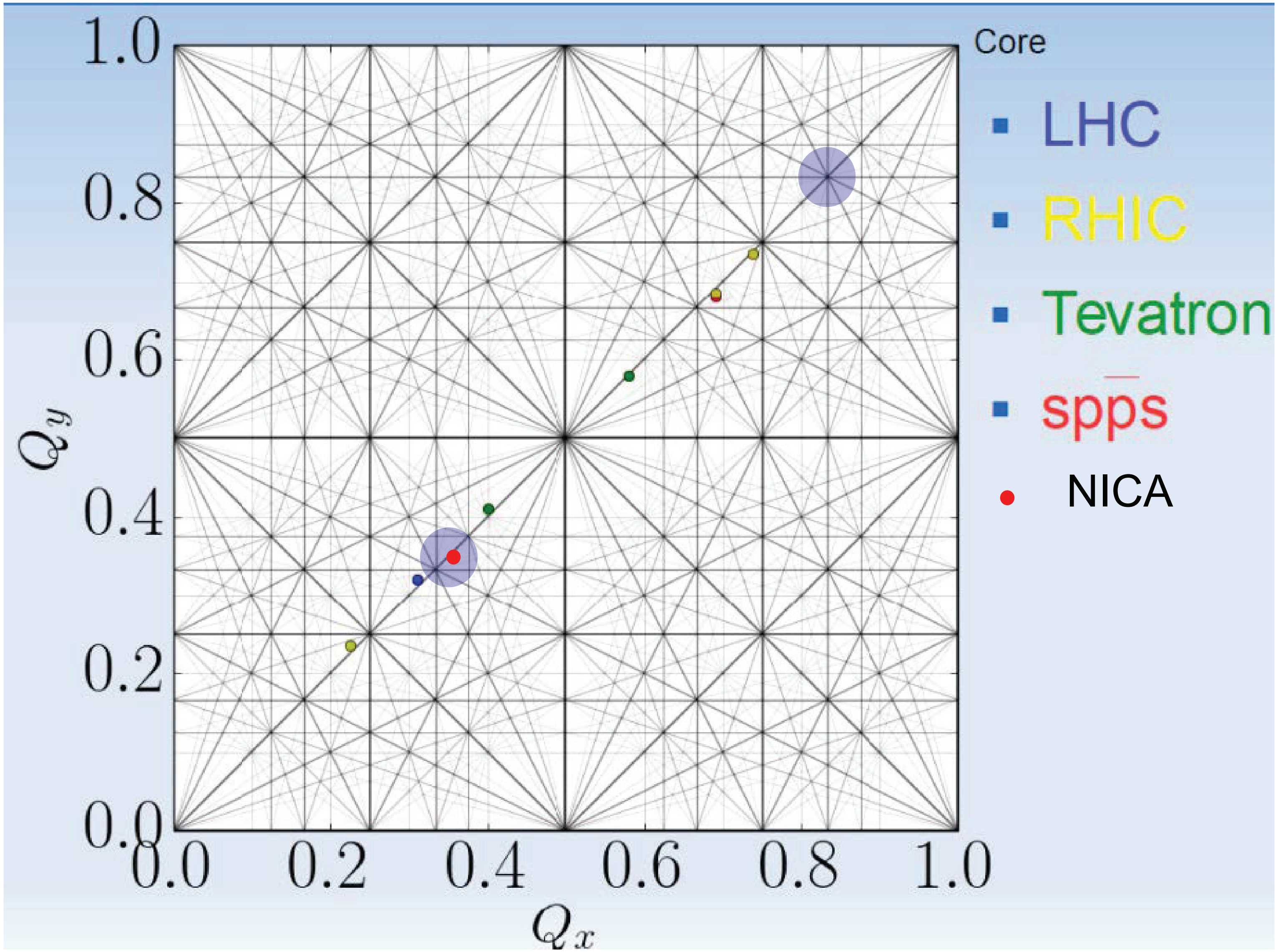
5. NICA – Stage III: Collider of polarized beams

One of very preliminary versions - to be analyzed and developed.



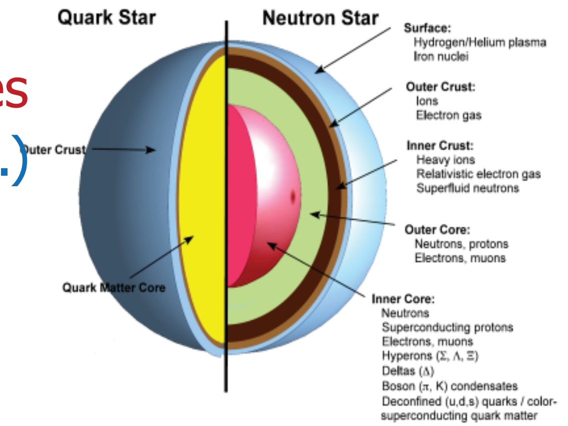
Spin diagnostics + Superconducting solenoids at field < 8 T

Resonance diamond



NICA/FAIR physics case and observables

Day 1 Experiment @MPD, Day 1 Experiment at BM@N

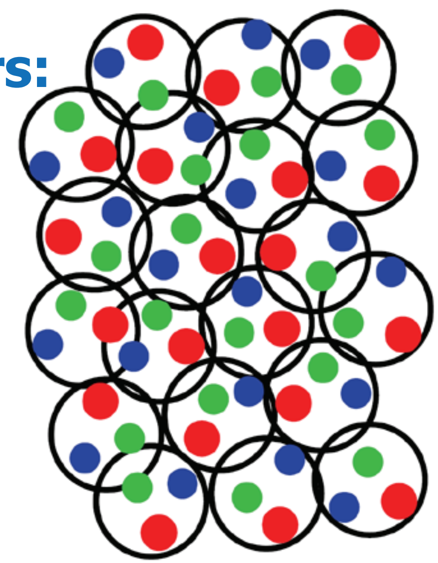


The QCD equation-of-state at neutron star core densities

- **collective flow** of identified particles (π,K,p,Λ,Ξ,Ω,...) driven by the pressure gradient in the early fireball
- particle production at threshold energies via multi-step processes (multi-strange hyperons, charm)

Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point

- excitation function of strangeness: $\Xi^-(dss)$,$\Xi^+(\bar{d}\bar{s}\bar{s})$,$\Omega^-(sss)$,$\Omega^+(\bar{s}\bar{s}\bar{s})$ → chemical equilibration at the phase boundary
- **excitation function (invariant mass) of lepton pairs: Thermal radiation from fireball, "caloric curve"**
- **anisotropic azimuthal angle distributions: "spinodal decomposition"**
- event-by-event fluctuations of conserved quantities: "critical opalescence"

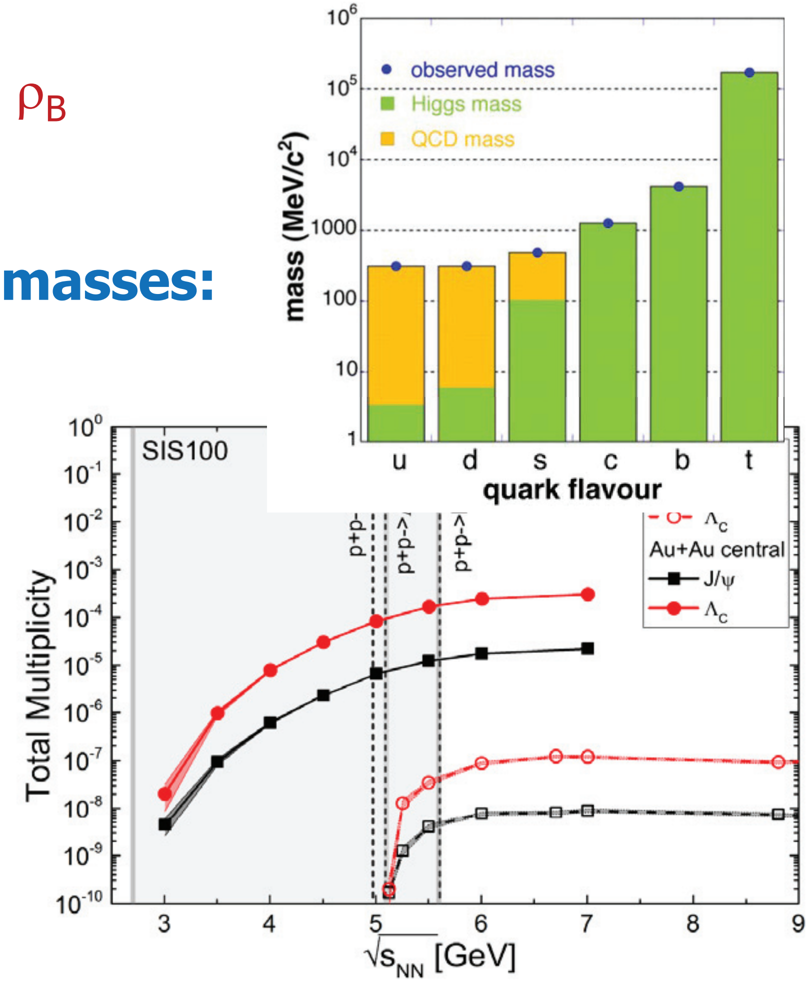


P.Senger, AS, VK, GT

NICA/FAIR physics case and observables

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$)
- **dileptons at intermediate invariant masses: $4\,\pi \rightarrow \rho\text{-}a_1$ chiral mixing**

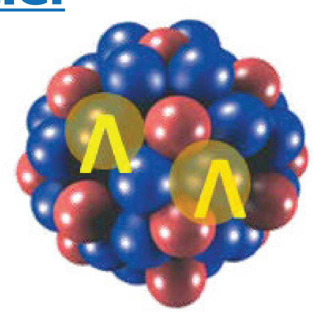


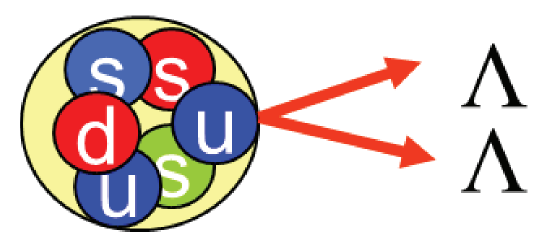
Charm production at threshold energies in cold and dense matter (???)

- excitation function of charm production in p+A and A+A (J/ψ, D^0, $D^{\pm}$)

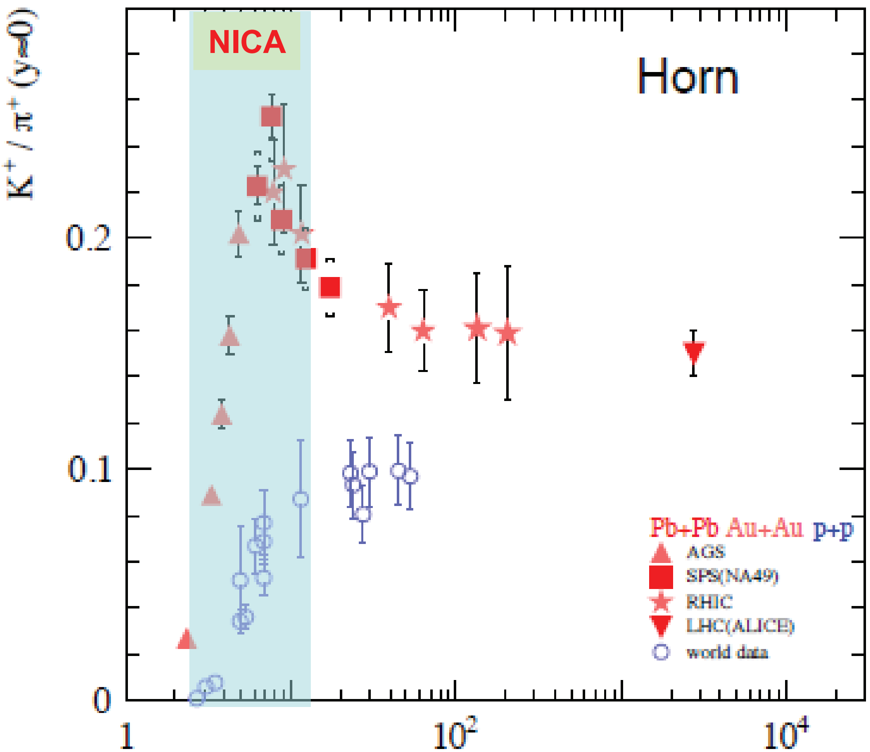
N-Λ, Λ-Λ interaction, strange matter

- **(double-) lambda hypernuclei**
- **meta-stable objects (e.g. strange dibaryons)**

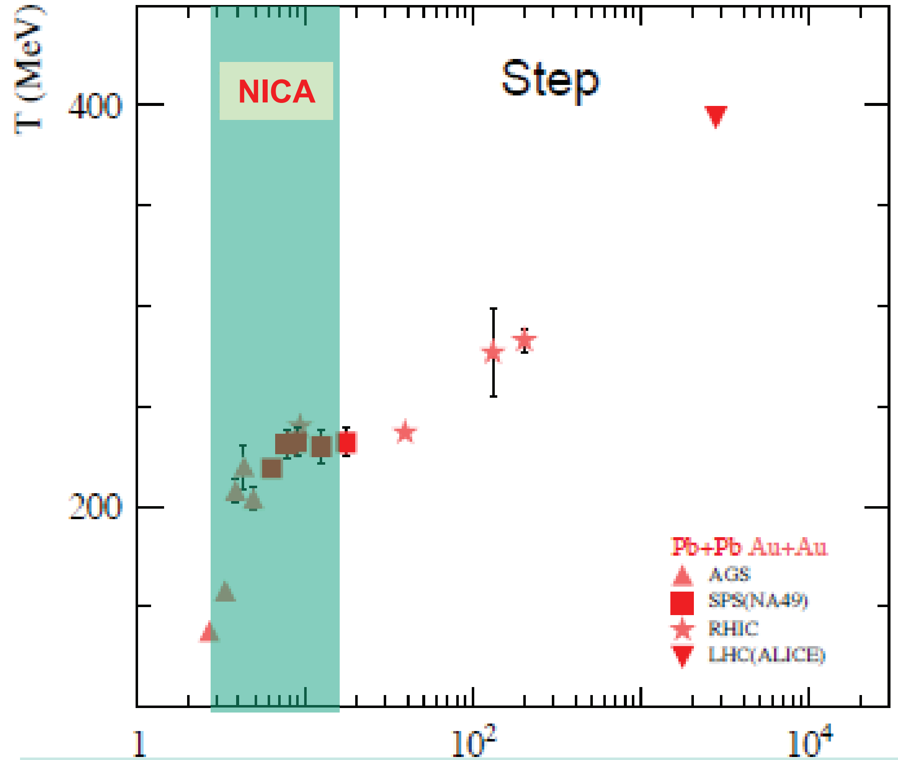




P.Senger, AS, VK, GT



Non-monotonic energy dependence of the K+/π+ ratio ("Horn") – onset of deconfinement?



Plateau in the apparent temperature of the kaon spectra ("Step") – signal of the mixed phase?

- Maximum in K^+/π^+ ratio is in the NICA energy region,
- Maximum in Λ/π ratio is in the NICA energy region,
- Maximum in the net baryon density is in the NICA energy region,
- Transition from a Baryon dominated system to a Meson dominated one happens in the NICA energy region.

BM@N plans

year	2016	2017 spring	2017 autumn	2019	2020 + ..
beam	d (↑)	C, Ar	Kr	Au	Au, p
maximum intensity, Hz	1M	1M	1M	1M	10M
trig. rate, Hz	10k	10k	20k	20k	50k
central tracker	6 GEM half pl.	8 GEM half pl.	10 GEM half pl.	8 GEM full pl.	12 GEM or 8+2Si
expiment status	techn. run	techn. run	physics run	physics stage 1	physics stage 2

European Strategy Forum on Research Infrastructures ESFRI

The Particle Physics accelerators are capable of investigating one of the basic questions of high-energy Nuclear Physics, which is the formation of quark-gluon plasma (QGP) in heavy ion collisions. ……. The study of the hadron-QGP phase transition and the investigation of the properties of strongly interacting baryonic matter will be extended to the lower energy range by the CBM fixed-target experiment at the ESFRI Landmark FAIR and the colliding-beams experiment at NICA in Dubna.

The synergy and complementarity of the NICA and of the ESFRI Landmark FAIR and to some extent of the ESFRI Landmark SPIRAL2 make it very desirable to develop a joint coordinated effort for identifying a strong programme and for offering the best opportunities to international nuclear experimental physics. To this end ESFRI encourages these Ris both to work closely together and to pay special attention to developing NICA as a Global Research Infrastructure concept.

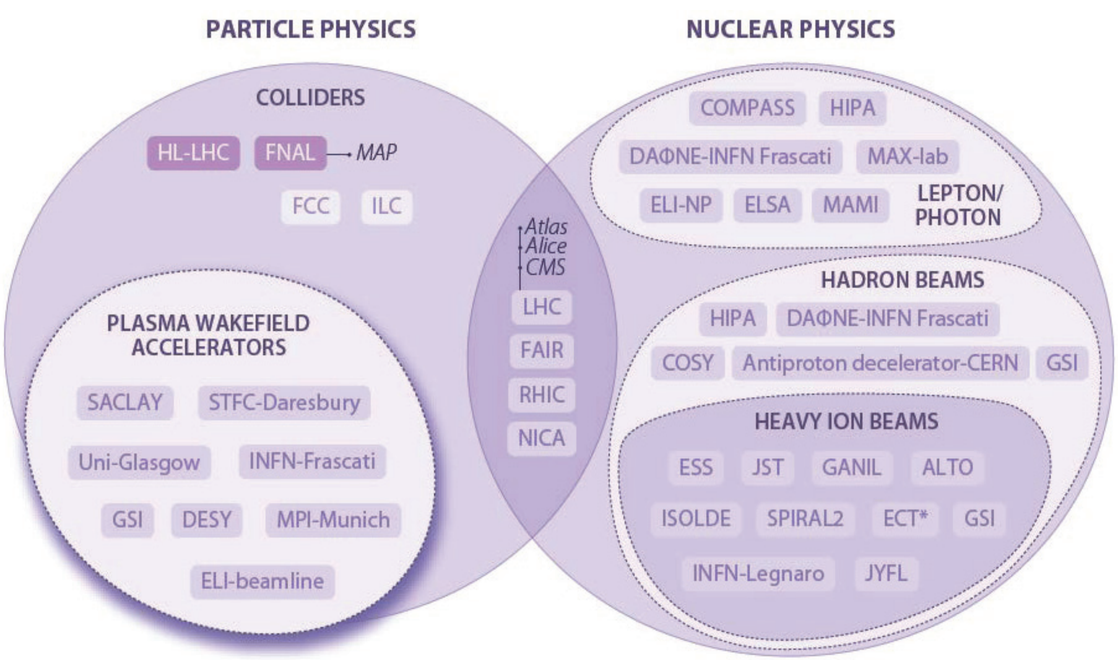


Figure 2B: space and time domain of investigation of the ESFRI Landmarks and Projects.