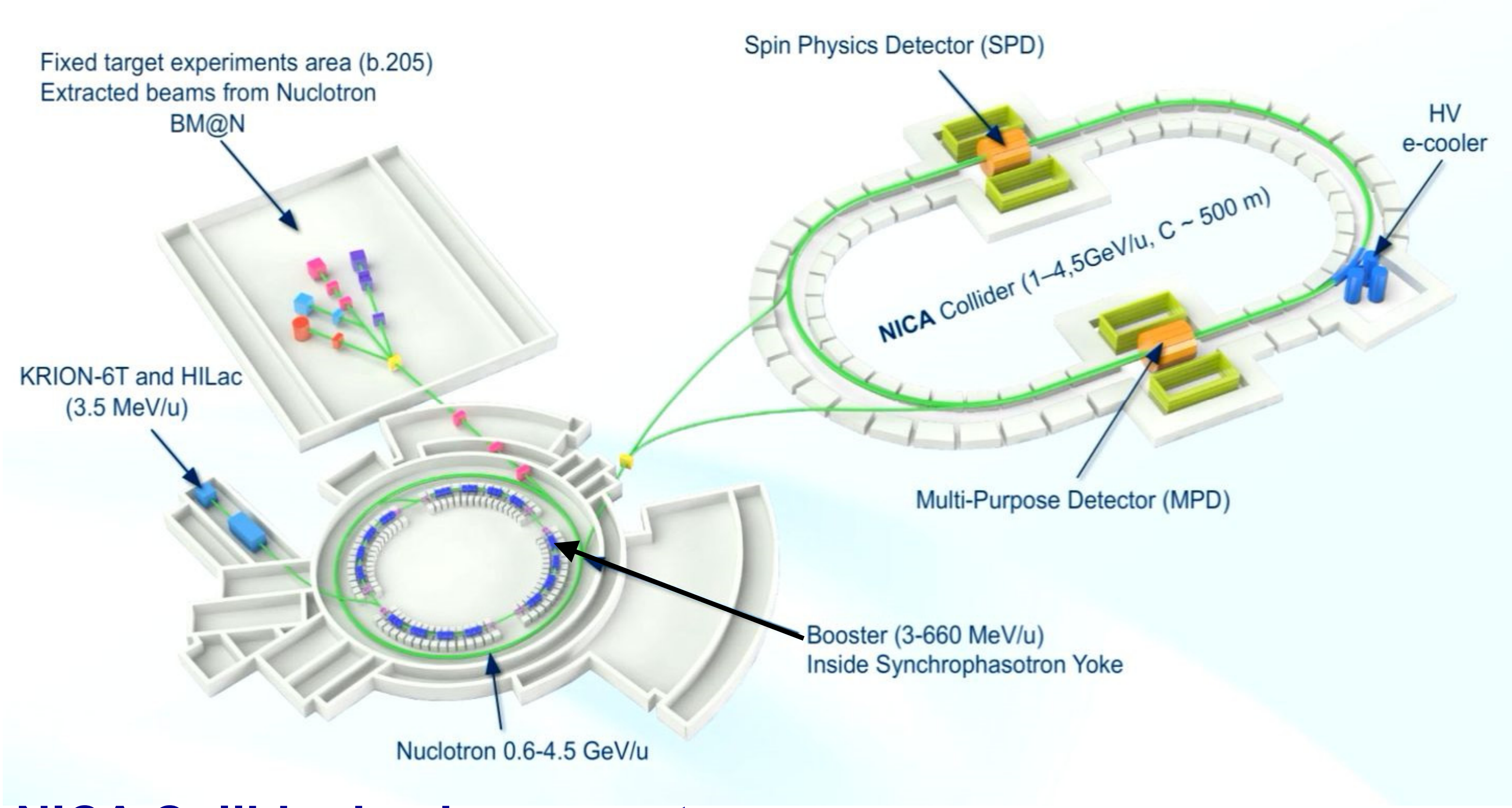
The NICA Project at JINR

Grigory Trubnikov

for the NICA team (JINR, Dubna)

WEZA02

Development of the Facility at JINR for generation of intense heavy ion and polarized nuclear beams aimed at searching for the QCD matter and investigation of polarization phenomena.

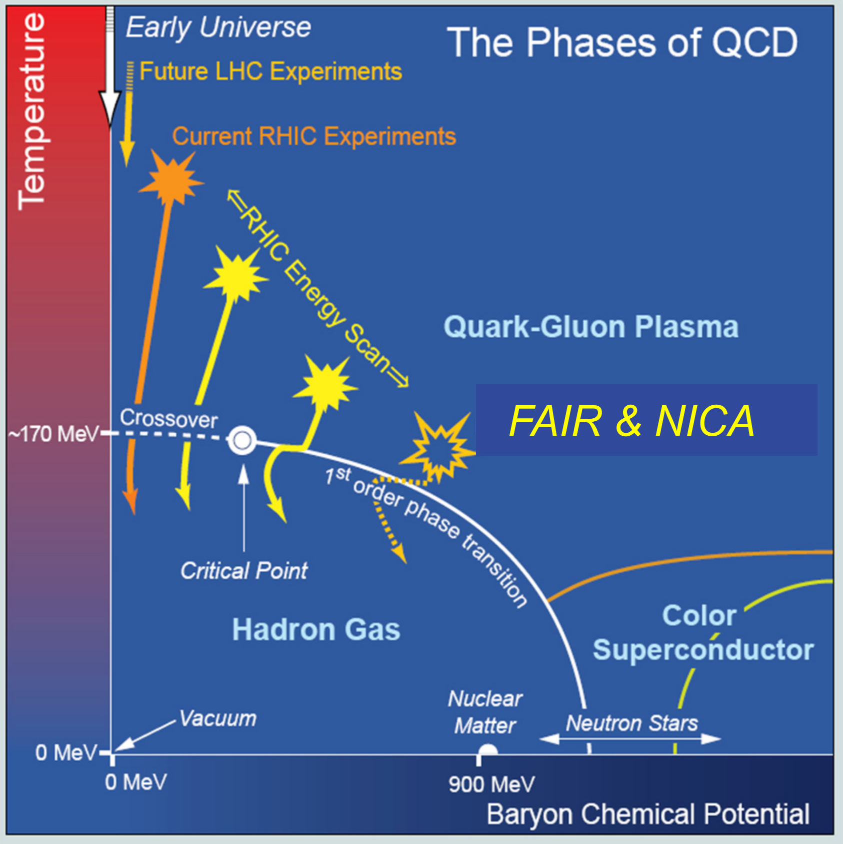


NICA Collider basic parameters:

$\sqrt{s_{NN}}$ = **4 - 11** GeV; ***beams**: from* **p** to **Au**; **L** ~ **10^{27}** $cm^{-2} c^{-1}$ (Au),

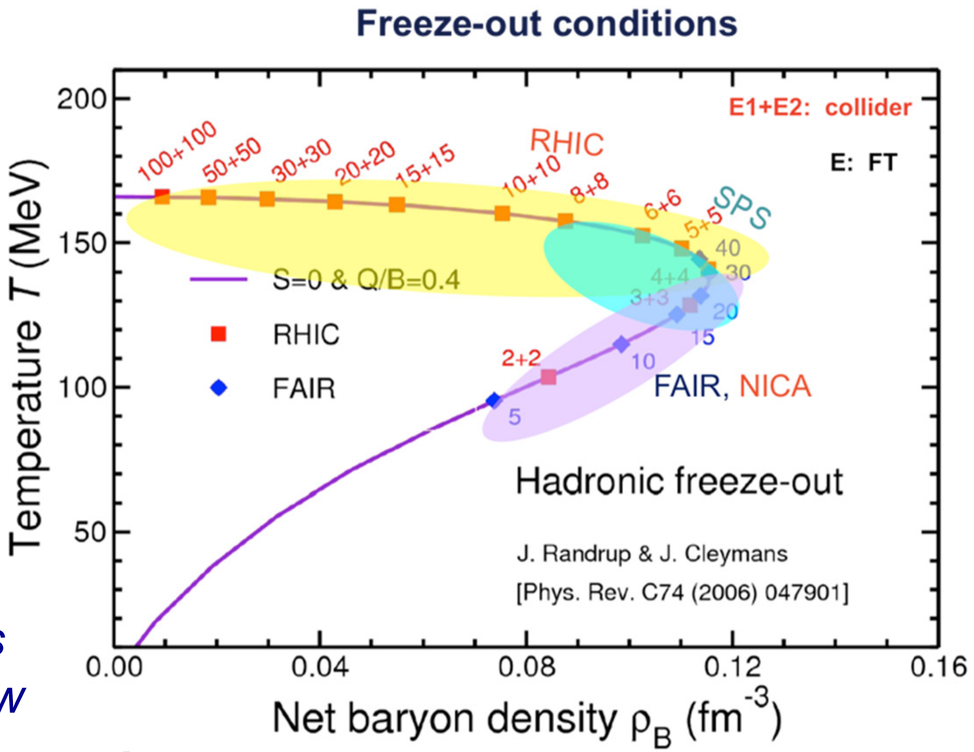
L ~ **10^{32}** $cm^{-2} c^{-1}$ (p↑)

Physics



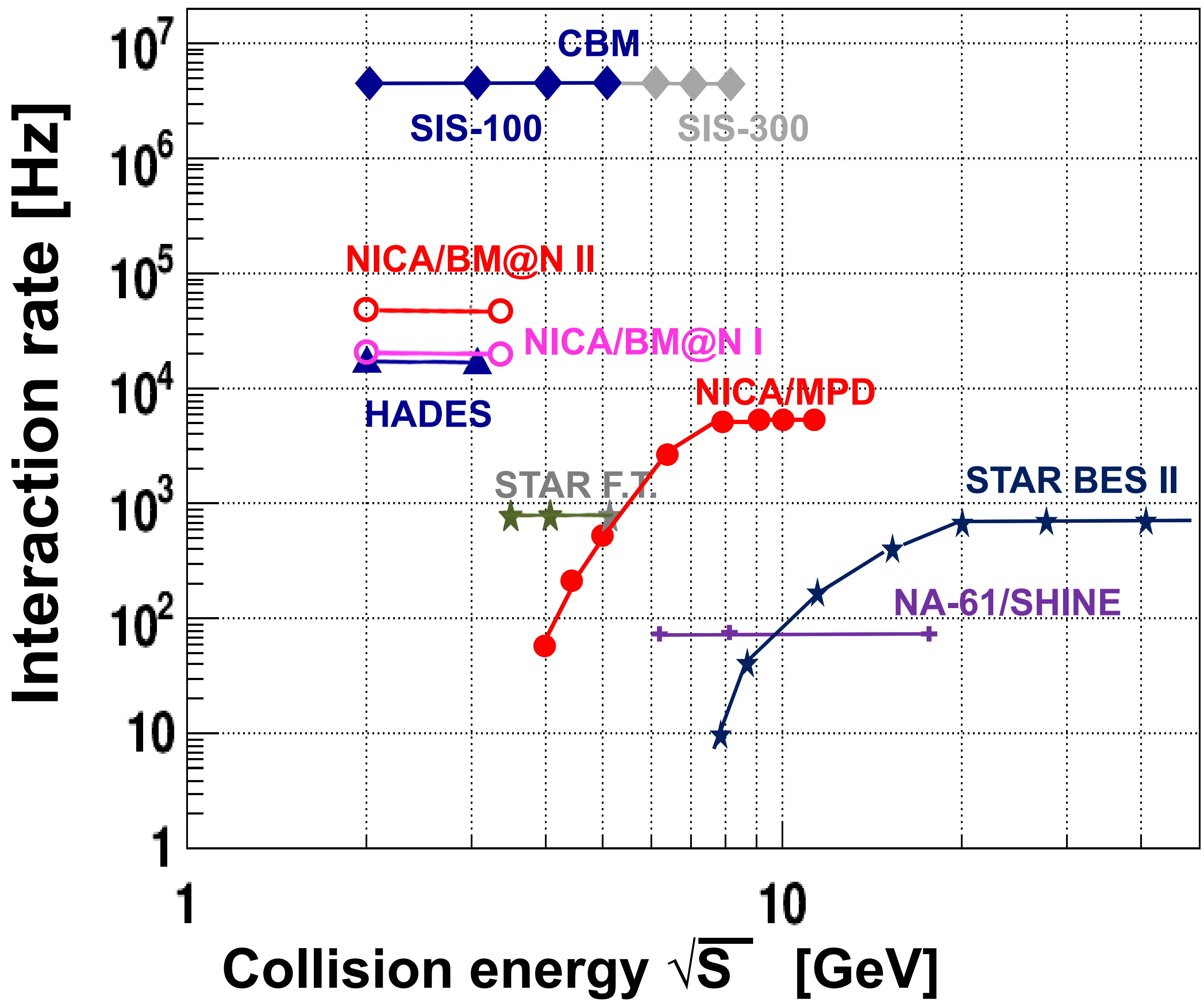
QCD matter at NICA :

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

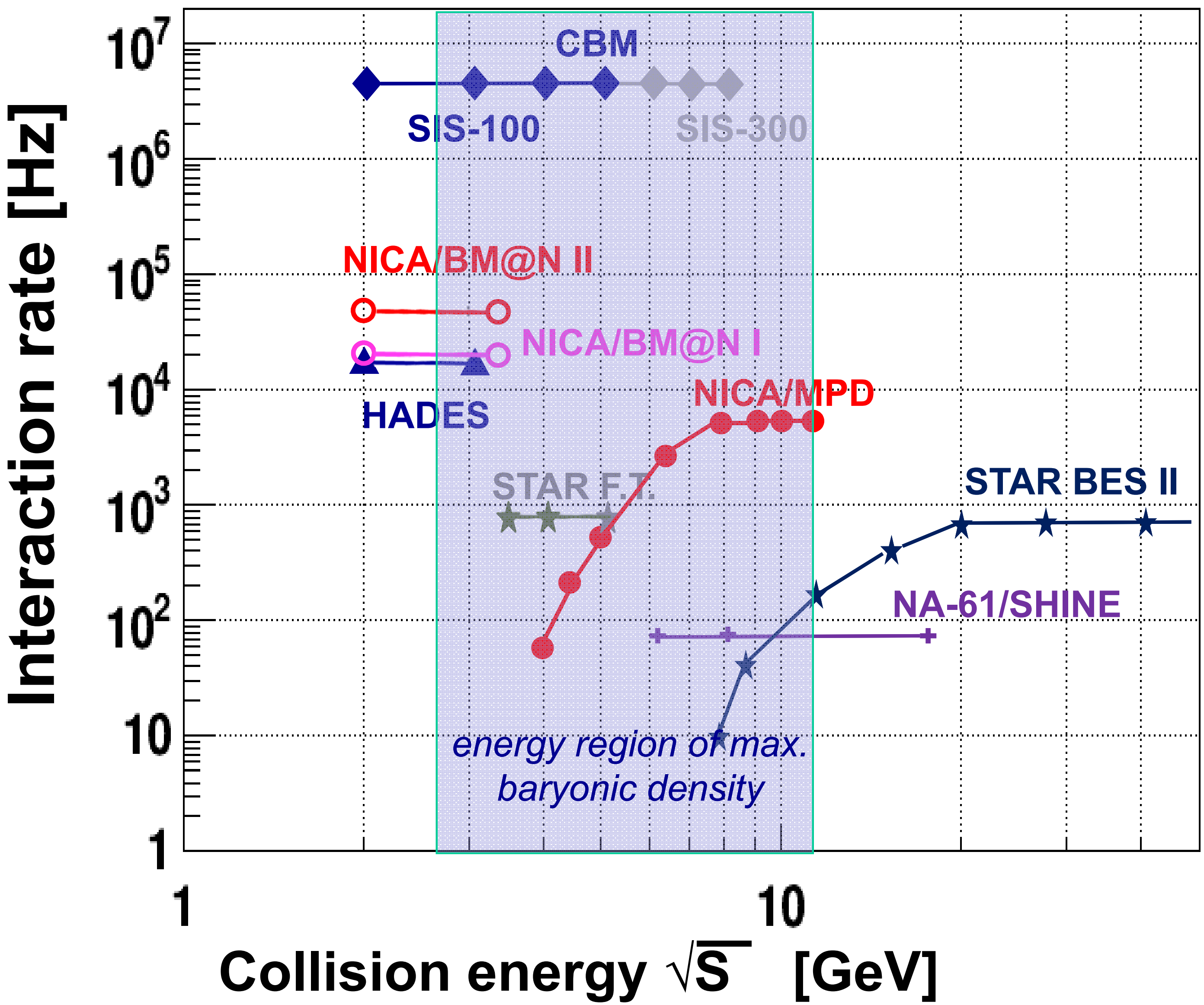


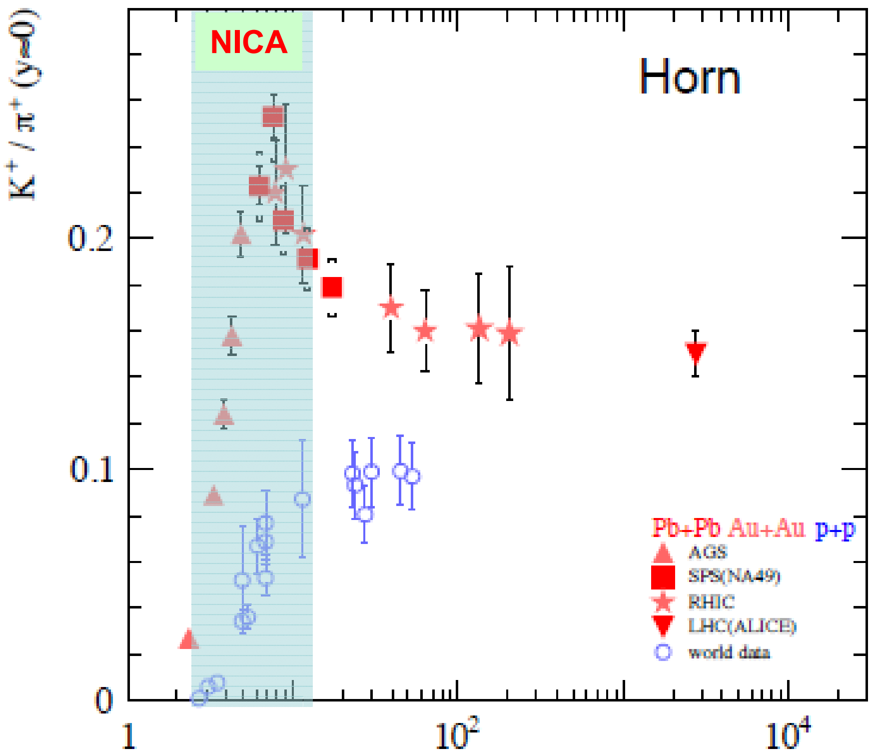
- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement, phase transition at high ρ_B** *- enhanced strangeness production*
- **QCD Critical Point -** *event-by-event fluctuations & correlations*
- **Strangeness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

Present and future HI experiments/machines

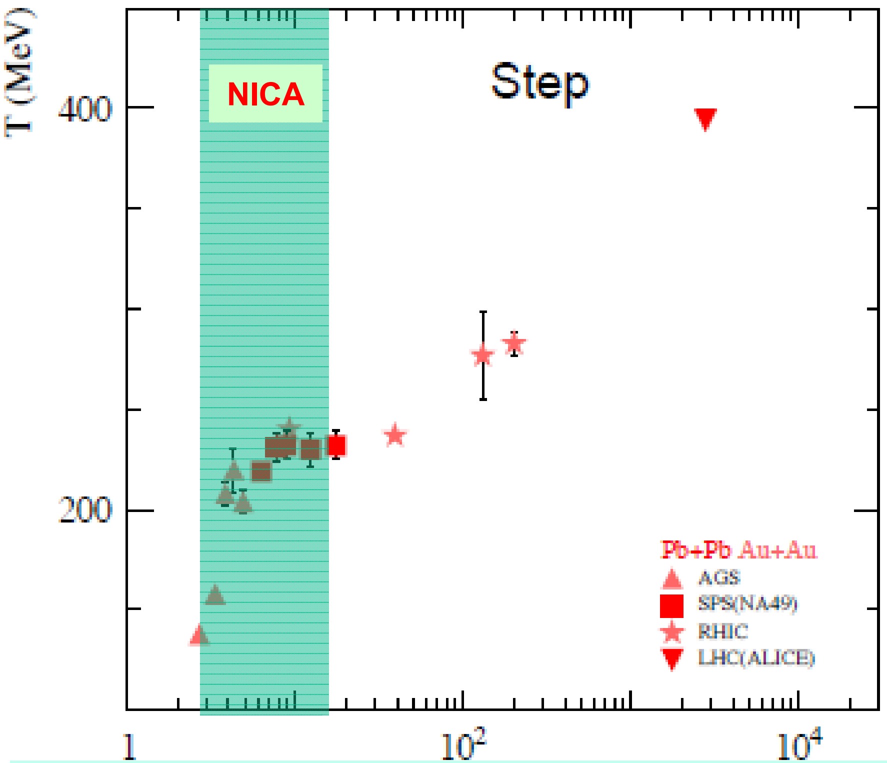


Present and future HI experiments/machines





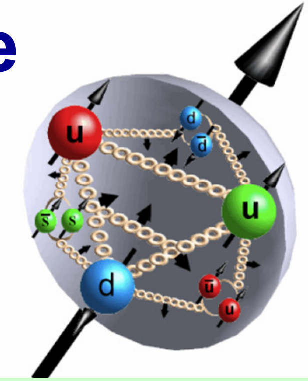
Non-monotonic energy dependence of the K+/π+ ratio ("Horn") – onset of deconfinement?



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.

Study of the nucleon spin structure



must confirm

the sum rule:

$$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g\,.$$

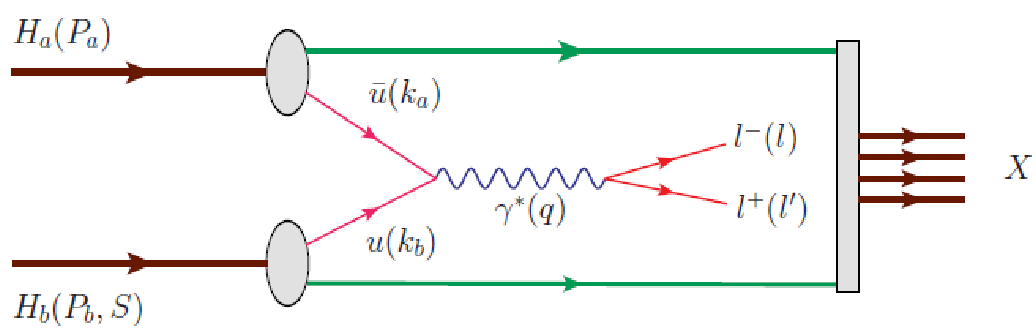
NICA collider will provide collisions of protons and deuterons with all combinations of polarization – *transversal and longitudinal*

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

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

Direct photons production

(*gluon polarization*)

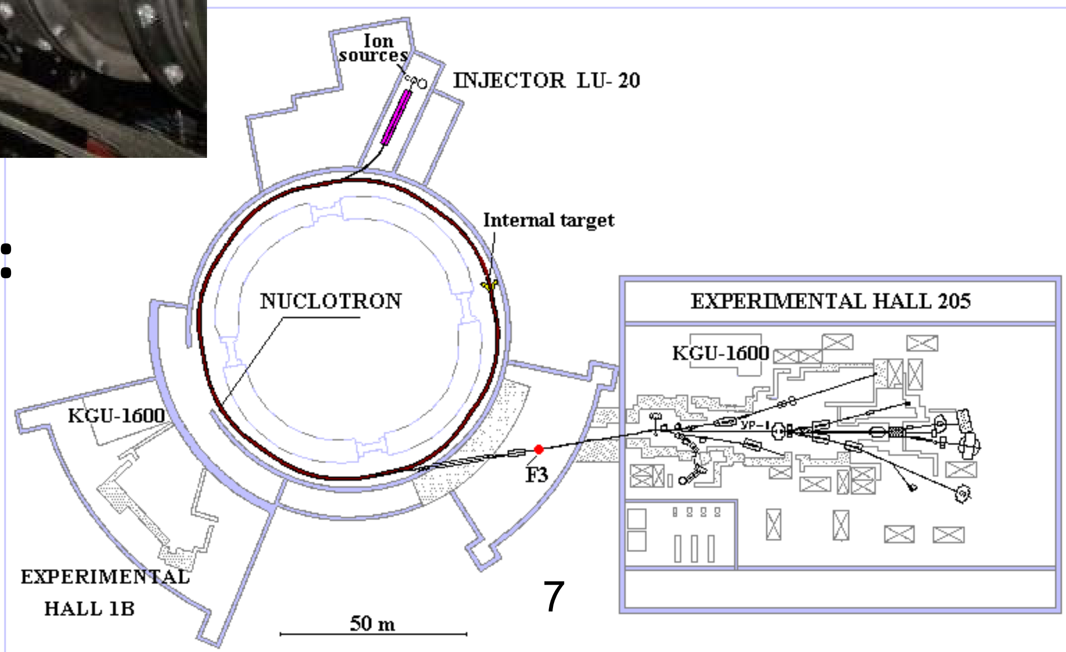


- J/ψ production processes
- Spin effects in inclusive high-pT reactions
- Spin effects in 1- and 2-hadron production processes

NICA: Nuclotron based Ion Collider fAcility

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

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

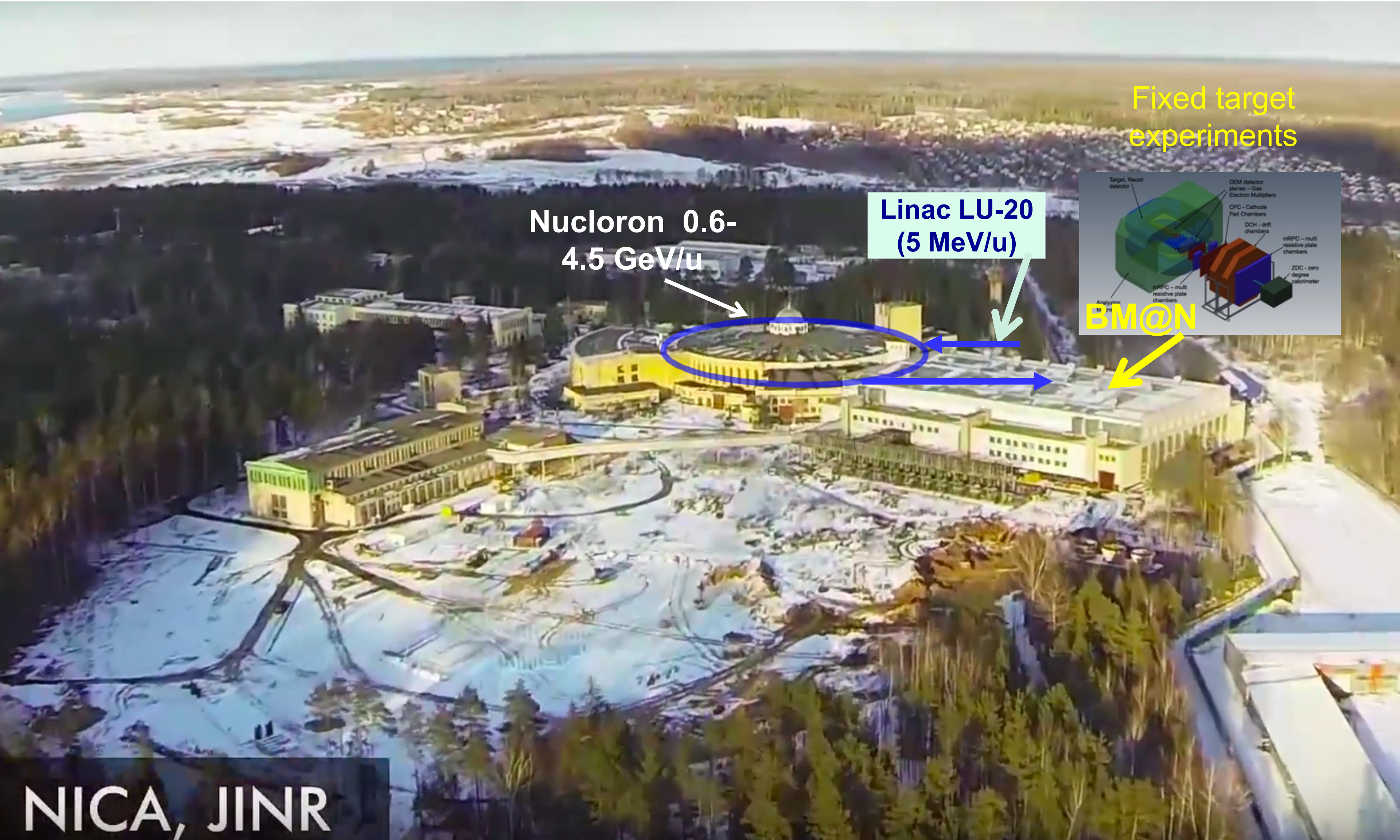


NICA facility

In operation ***Under construction***

NICA facility

In operation ***Under construction***



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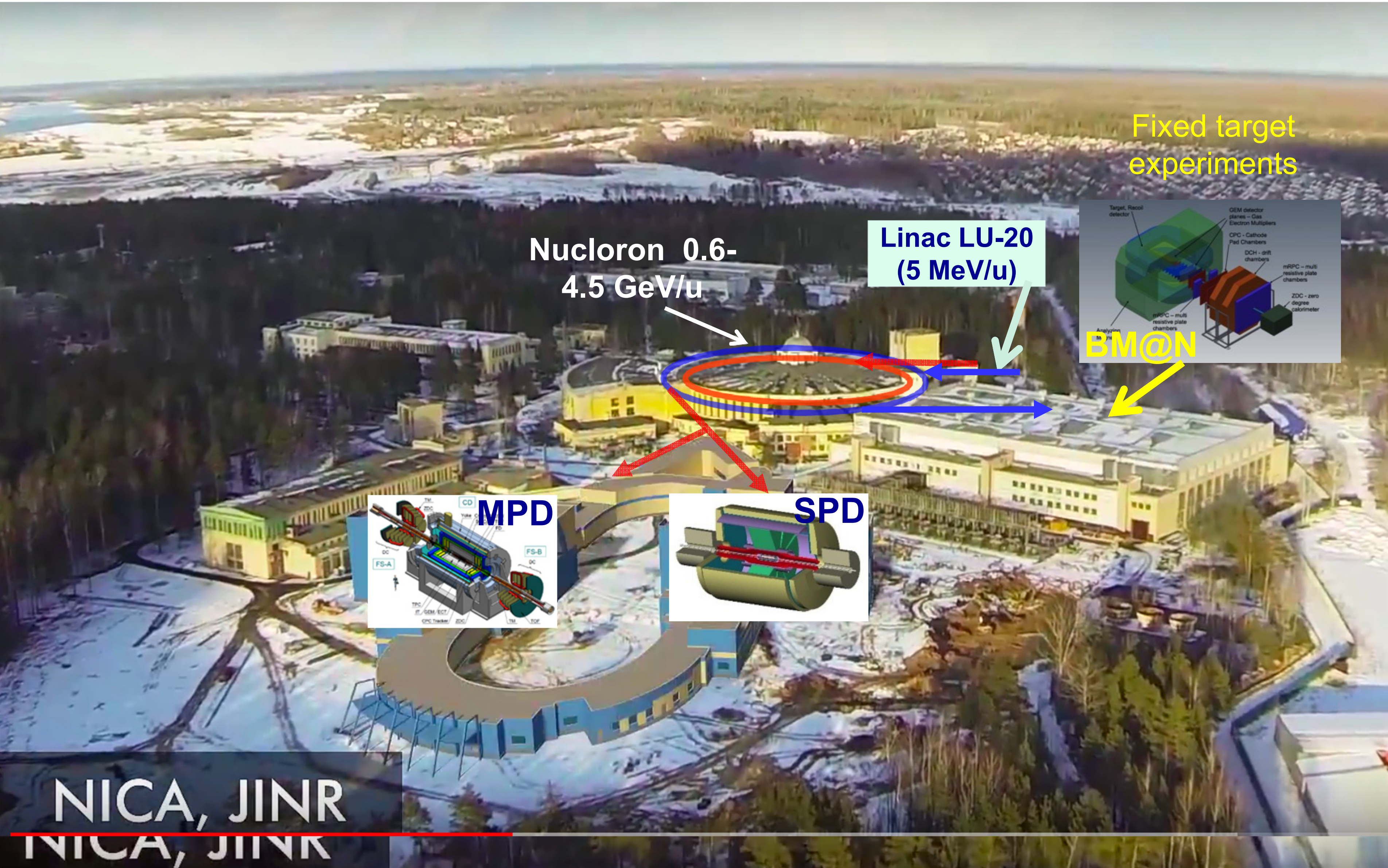
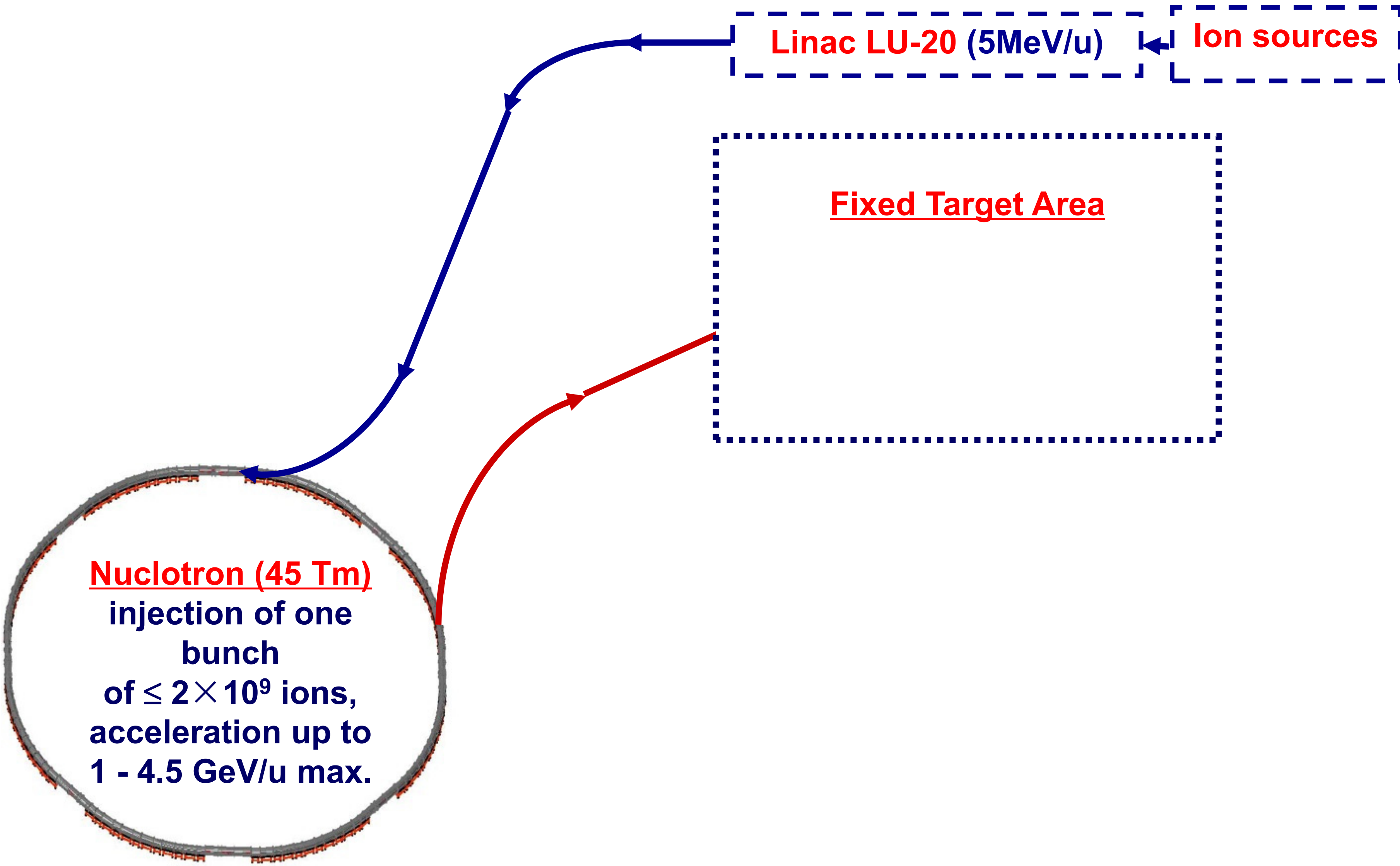


NICA @ Heavy Ion mode



NICA @ Heavy Ion mode

Linac LU-20 (5MeV/u)

Ion sources

Nuclotron (45 Tm)
injection of one bunch
of $\leq 2\times10^9$ ions,
acceleration up to
1 - 4.5 GeV/u max.

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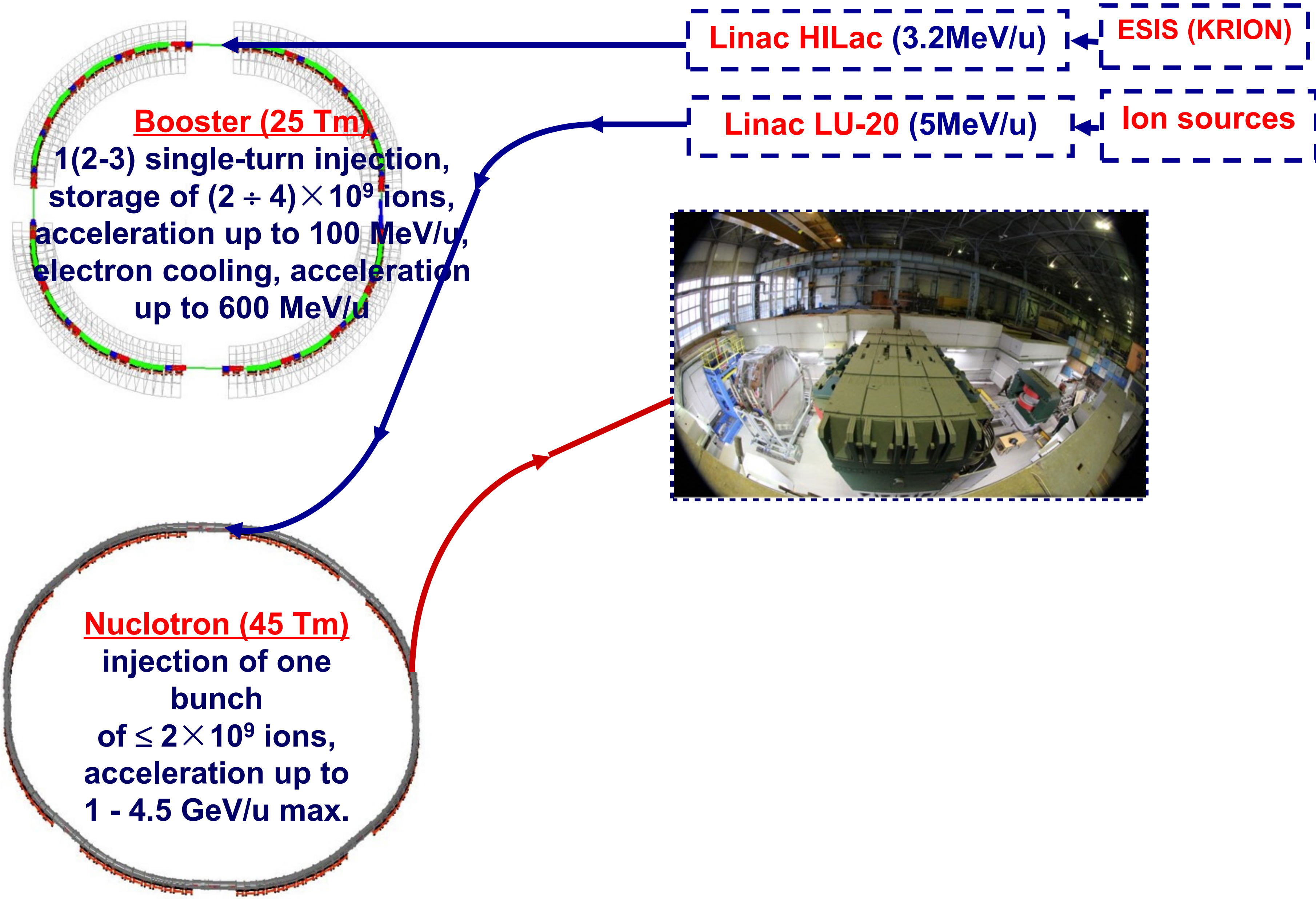

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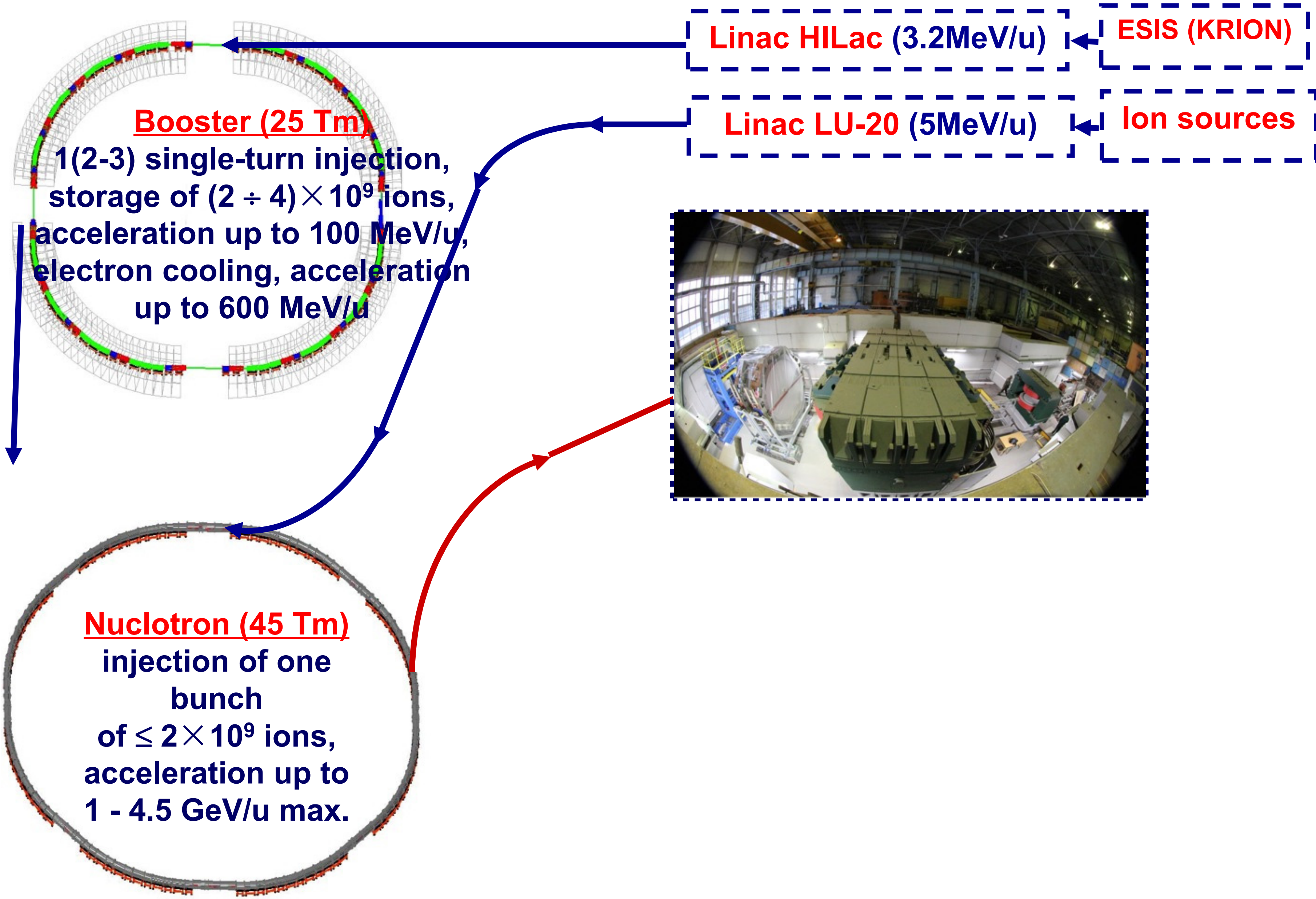


NICA @ Heavy Ion mode

ESIS (KRION)

Linac HILac (3.2MeV/u)

Ion sources

Linac LU-20 (5MeV/u)

Booster (25 Tm)

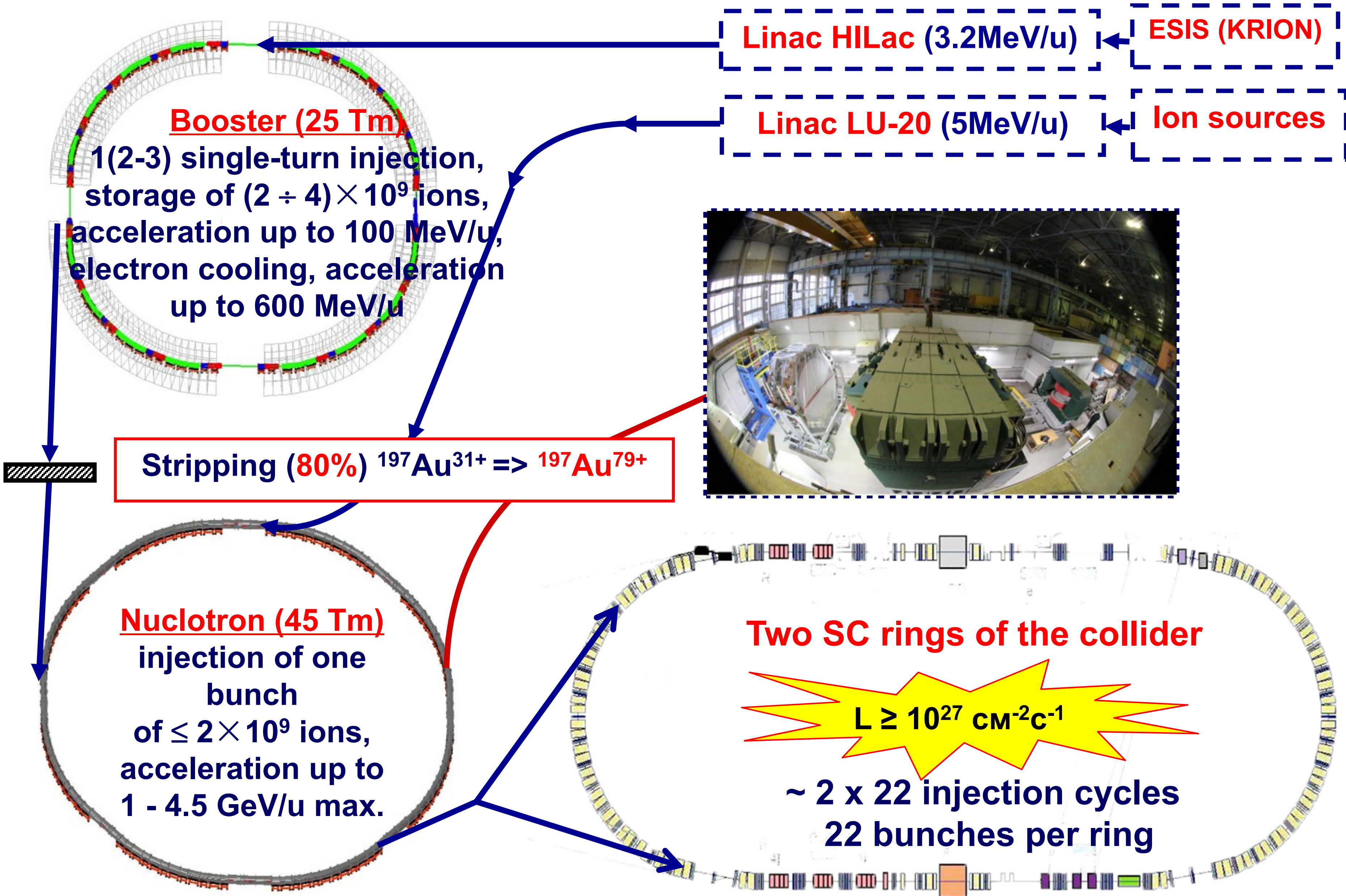
1(2-3) single-turn injection, storage of $(2 \div 4) \times 10^9$ ions, acceleration up to 100 MeV/u, electron cooling, acceleration up to 600 MeV/u

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.

NICA @ Heavy Ion mode



New injection complex of the NICA (Ion sources + HILac)

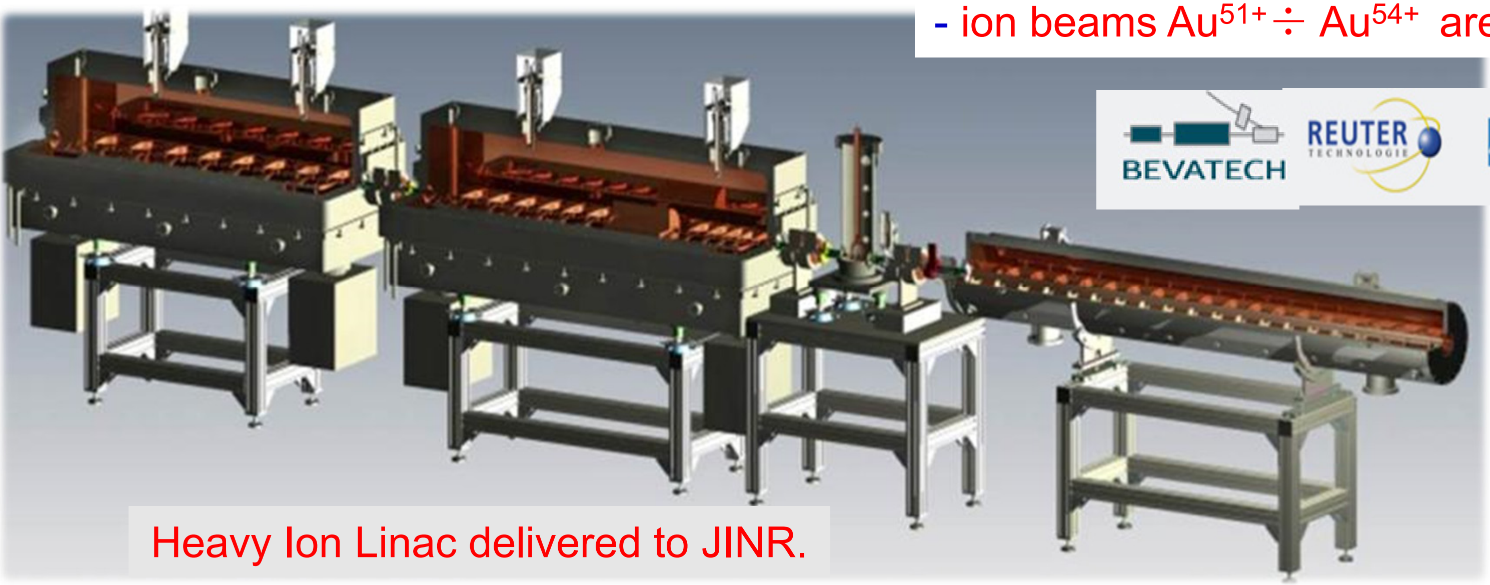
Source for polarized particles (SPP)

Source had been commissioned,
achieved 10^{10} deutrons pp.
First beam run in June 2016

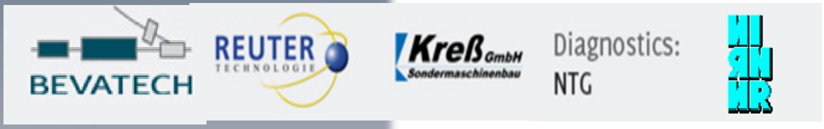
Heavy ion source: Krion-6T ESIS

B= 5.4T reached. Test Au beams produced:

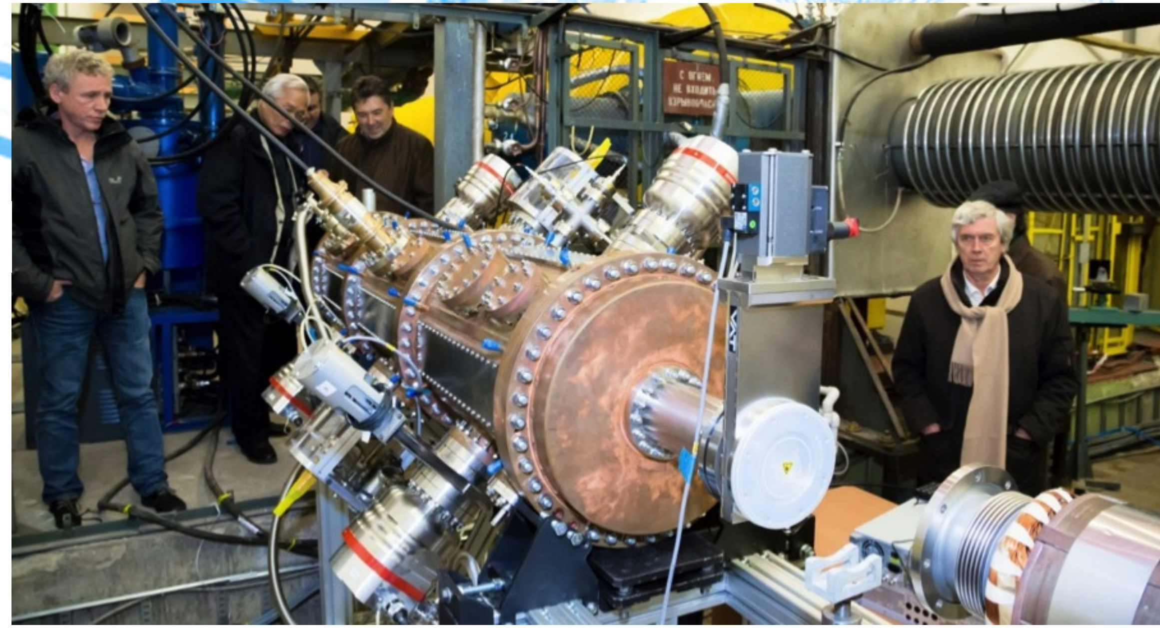
- Au^{30+} ÷ $Au32^{32+}$, $6*10^8$, T_{ioniz}= 20 ms for
- Au^{32+} -> repetition rate 50 Hz.
- ion beams Au^{51+} ÷ Au^{54+} are produced.



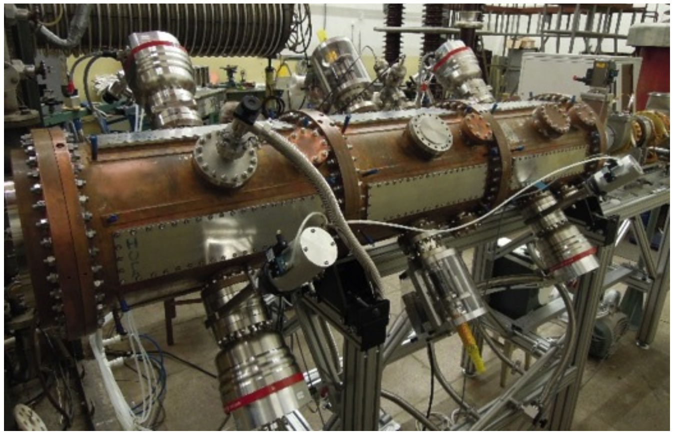
Heavy Ion Linac delivered to JINR.



Injection complex: 2 linacs



JINR-ITEP-MEPhI-Snezhinsk



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

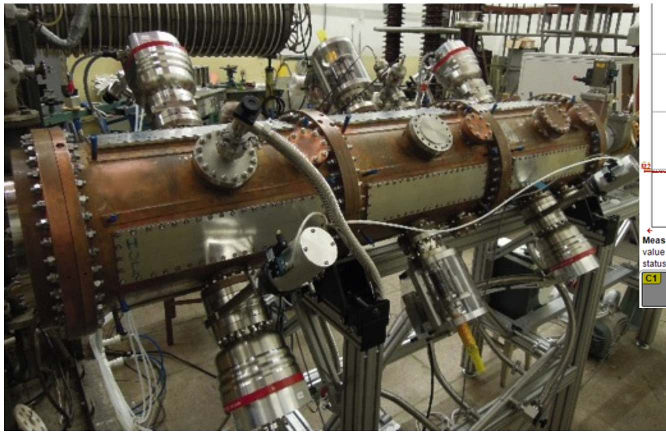
RFQ + 2 RFQ DTL sections

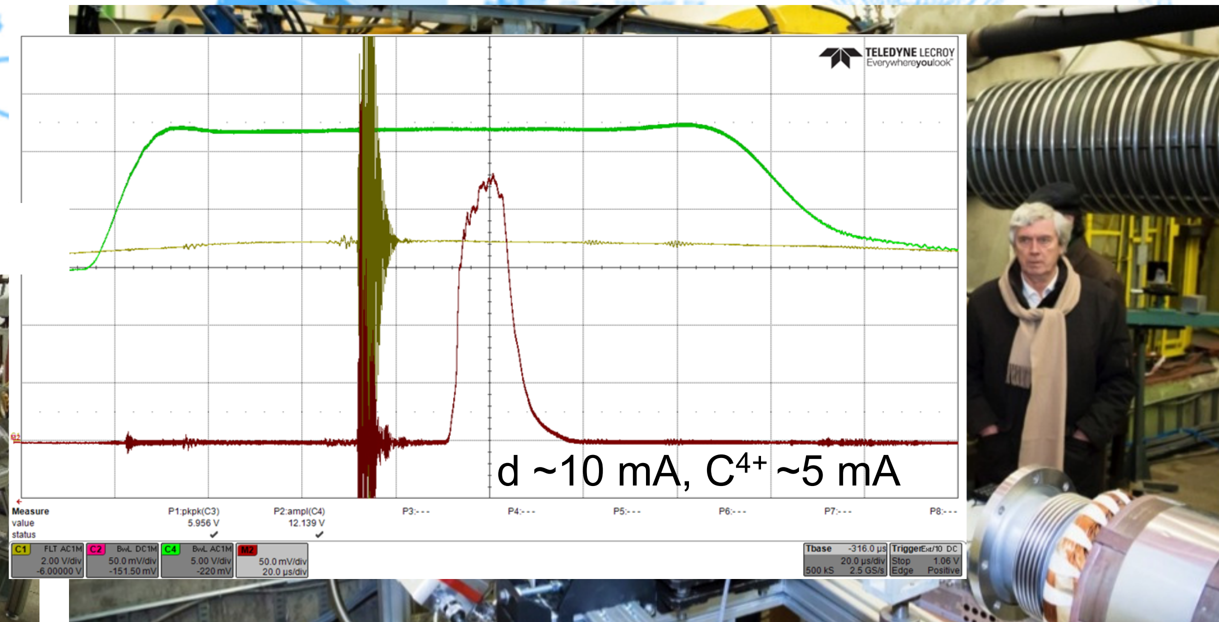
11

Posters: MOPOY041, MOPOY043

Injection complex: 2 linacs

JINR-ITEP-MEPhI-Snezhinsk





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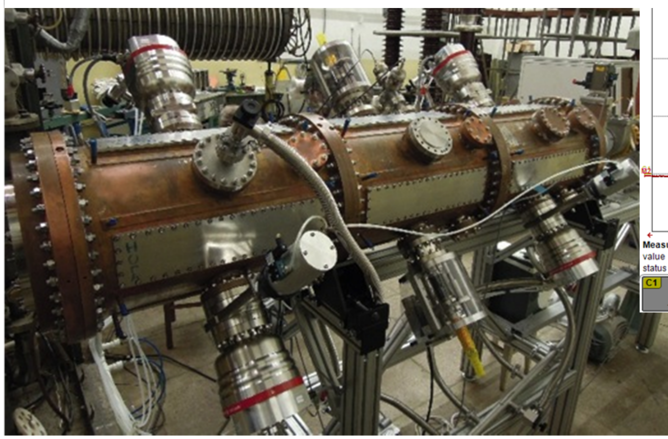
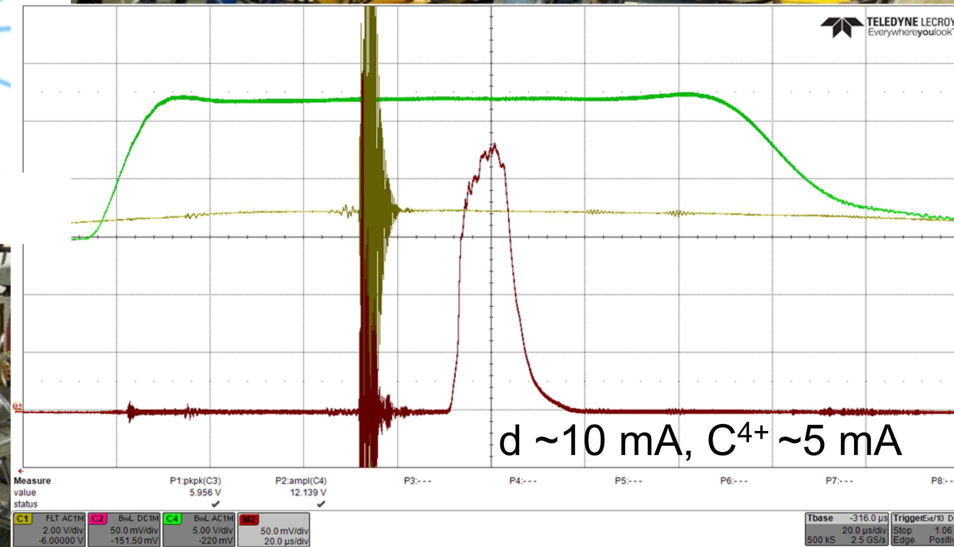
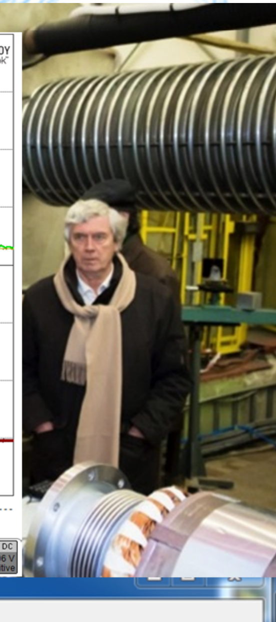
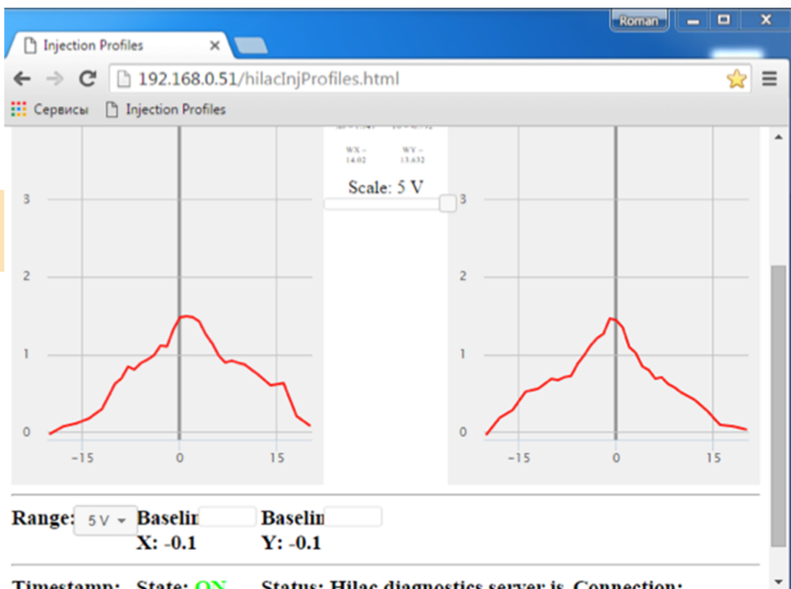
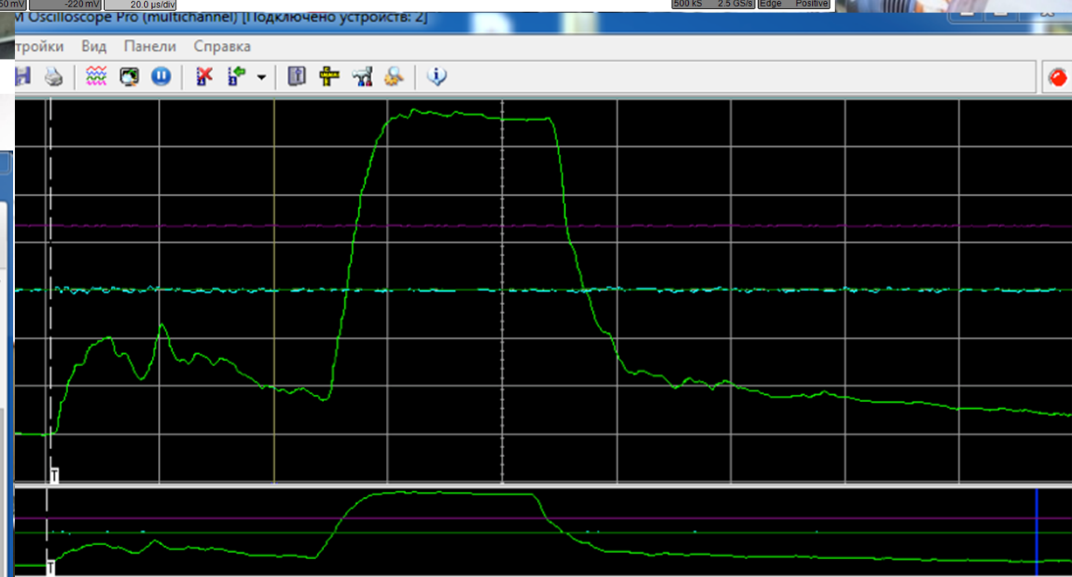




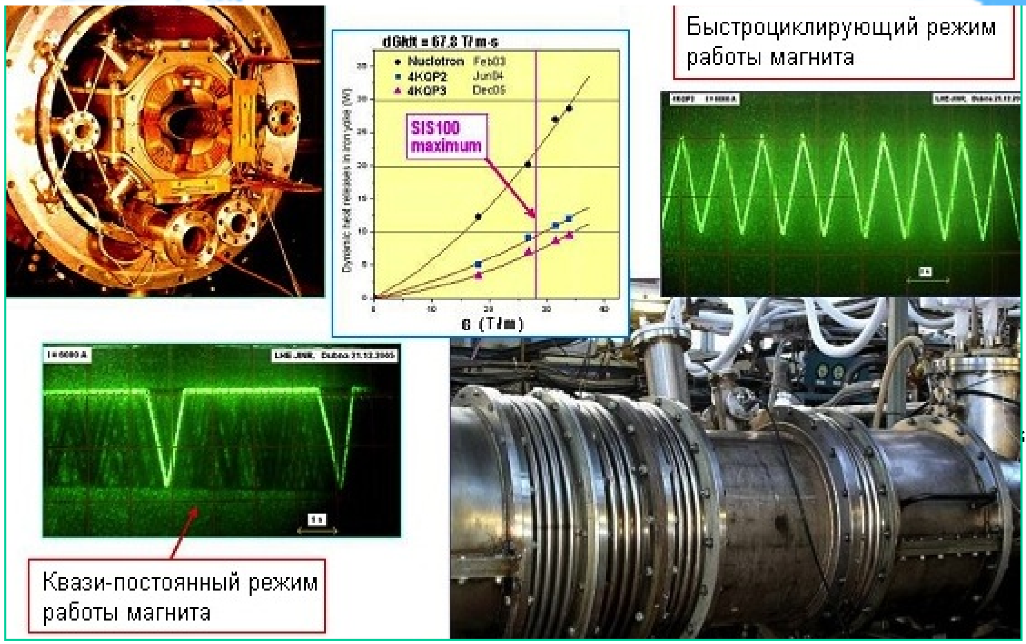


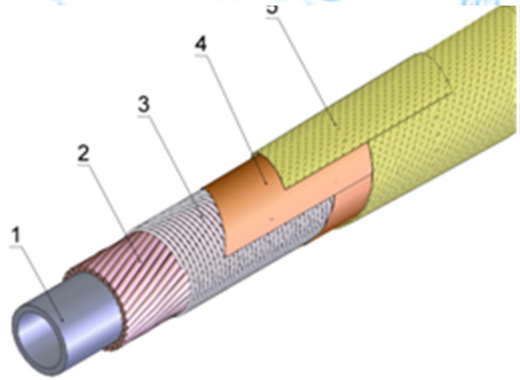




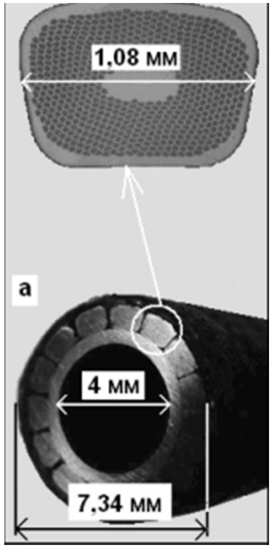
Posters: MOPOY041, MOPOY043

Superconducting superferric "Dubna magnets"





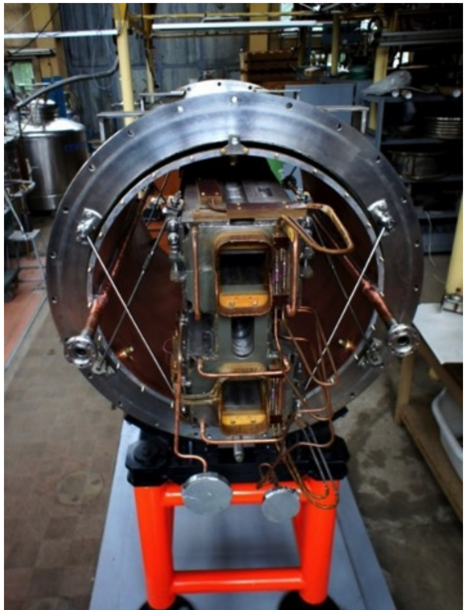
"Nuclotron" SC hollow cable

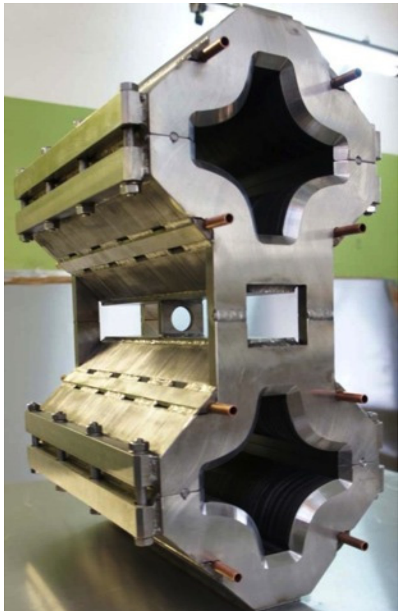


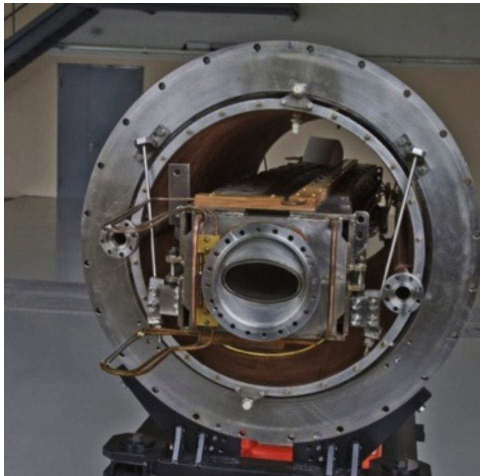
Max. B field = 2T

Ramp rate – up to 4 T/s @ 1 Hz

two-phase LHe @ 4.5K





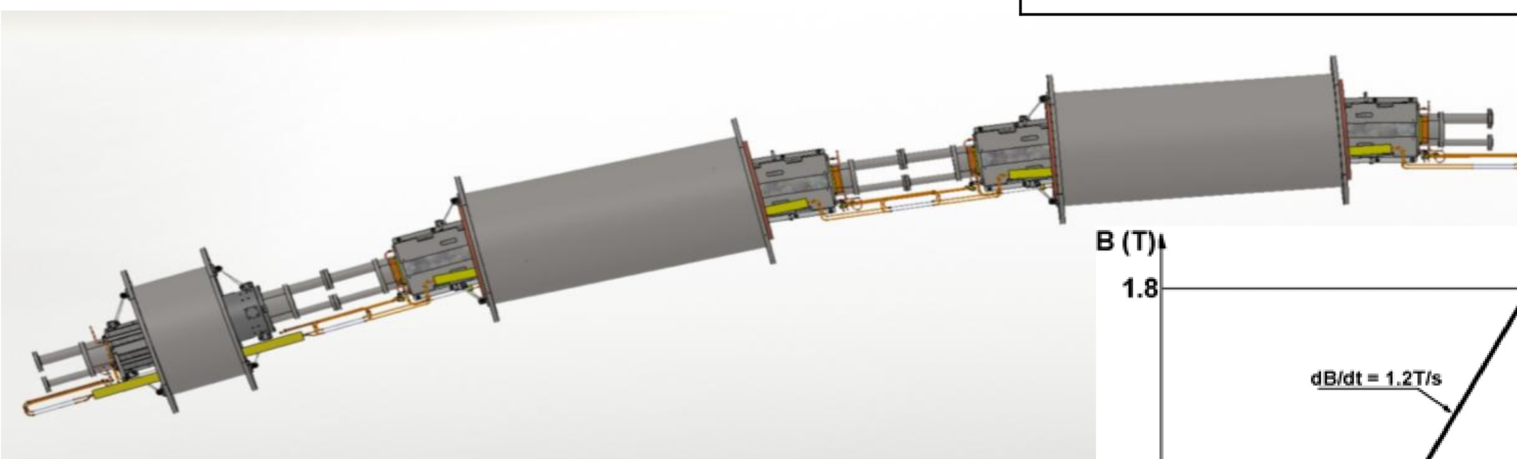


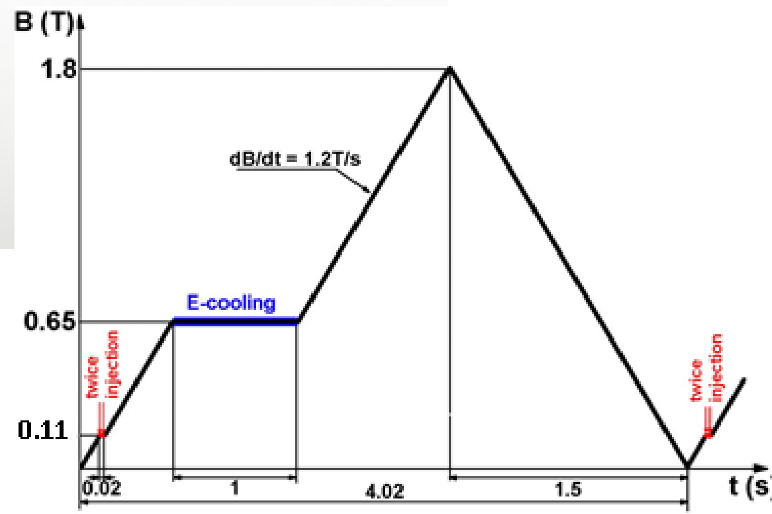
NICA Booster synchrotron

Ions	p	$^{197}Au^{31+}$
Inj. energy, MeV/u	3	
Max. energy, MeV/u	6400	580
Magnetic rigidity, T·m	1.55 ÷ 25.0	
Circumference, m	211.2	

DFO structure

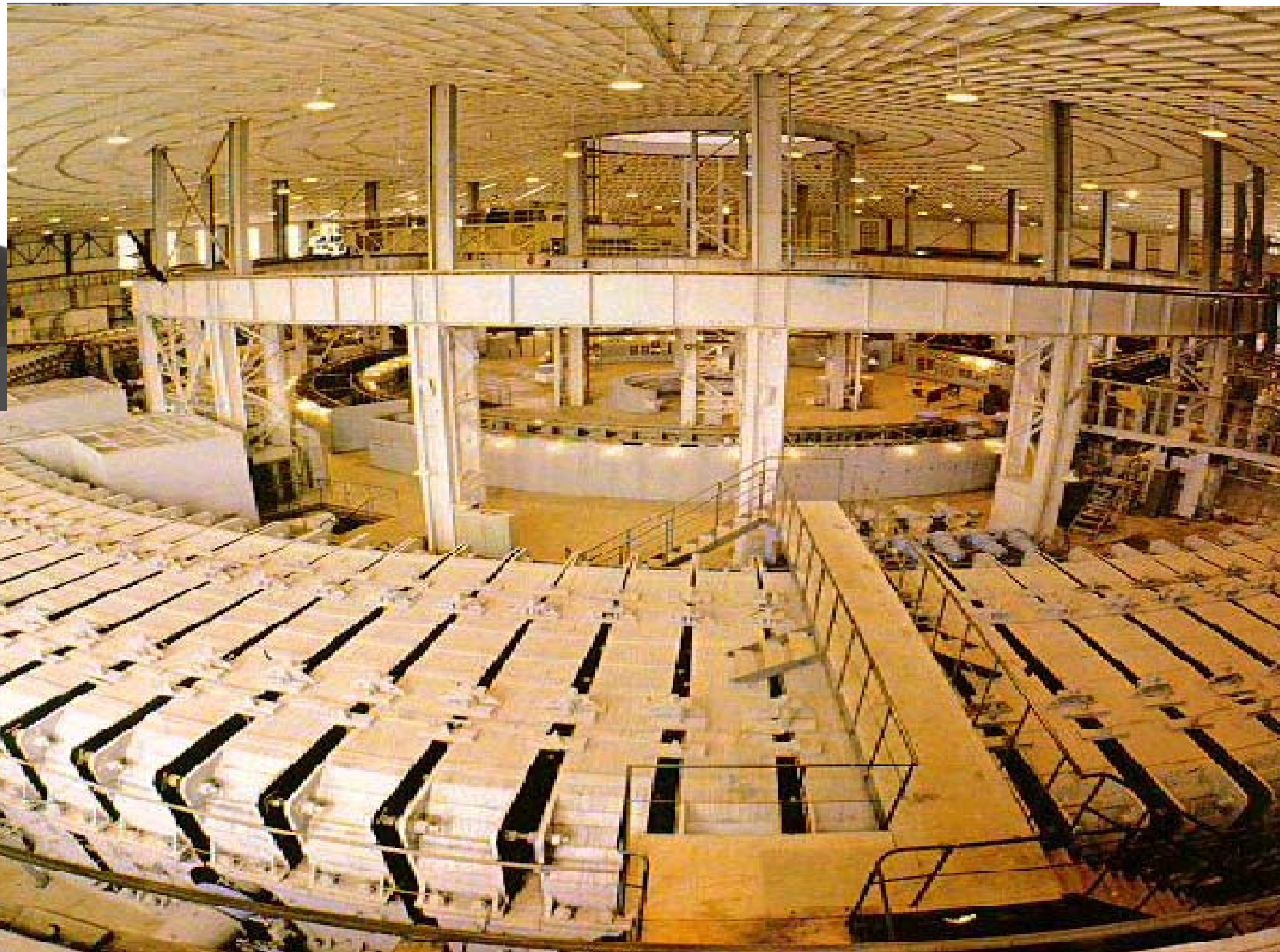
Fold symmetry	4
Number of straight sections	4
Length of straight sections, m	7
Betatron tunes	4.8/4.85
Maximal energy, MeV/u	660





NICA Booster synchrotron

V. Veksler



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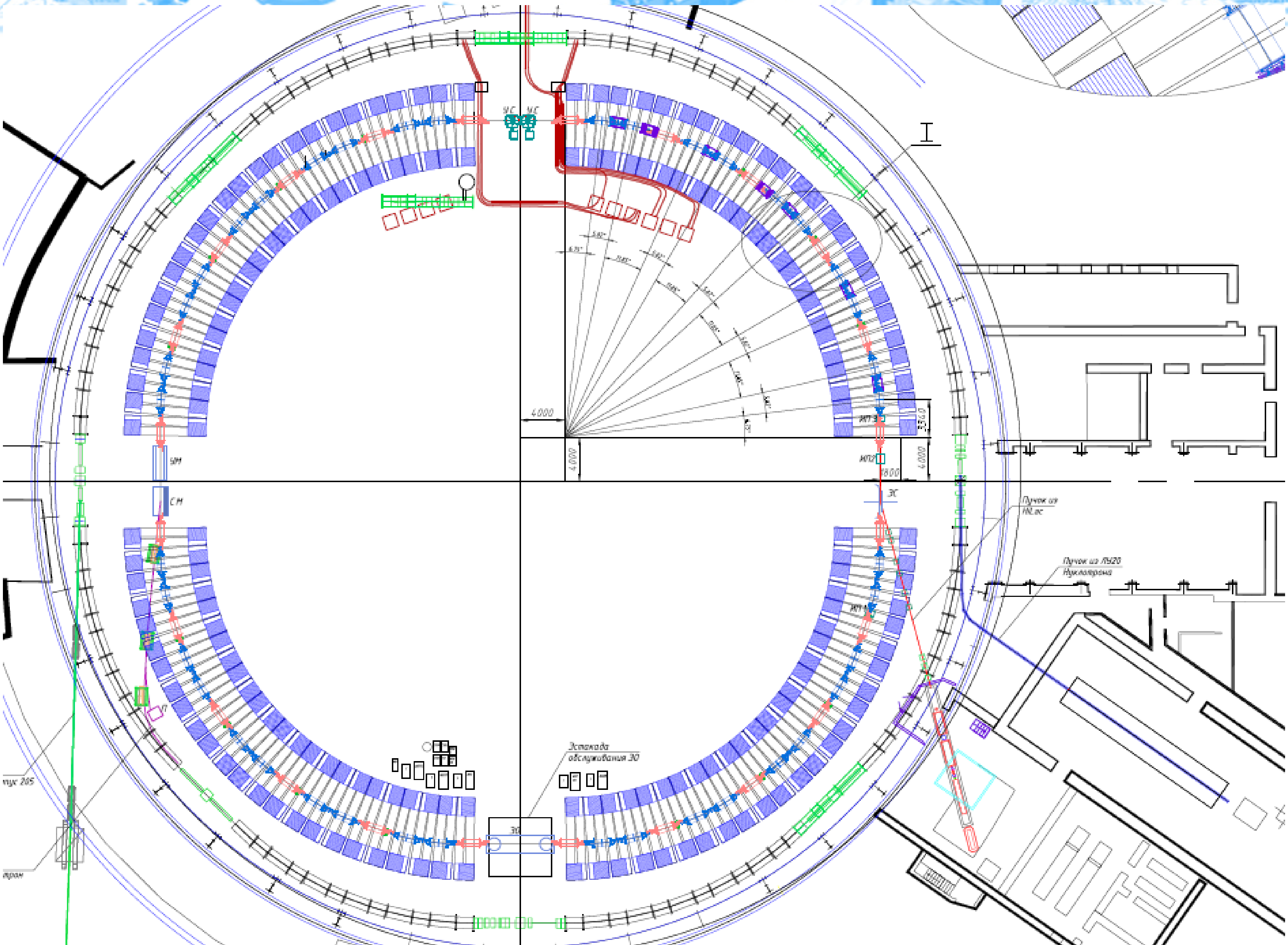

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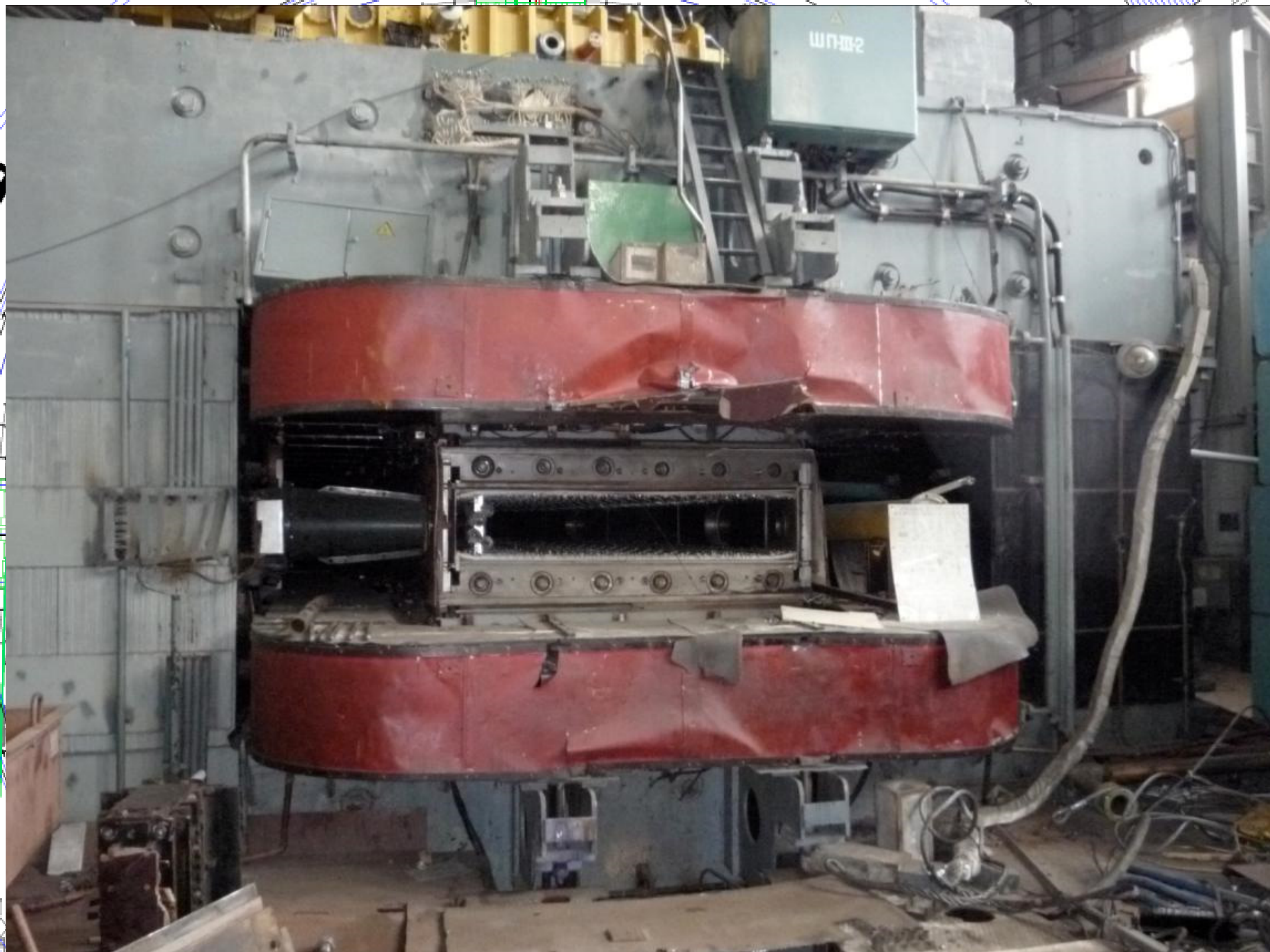

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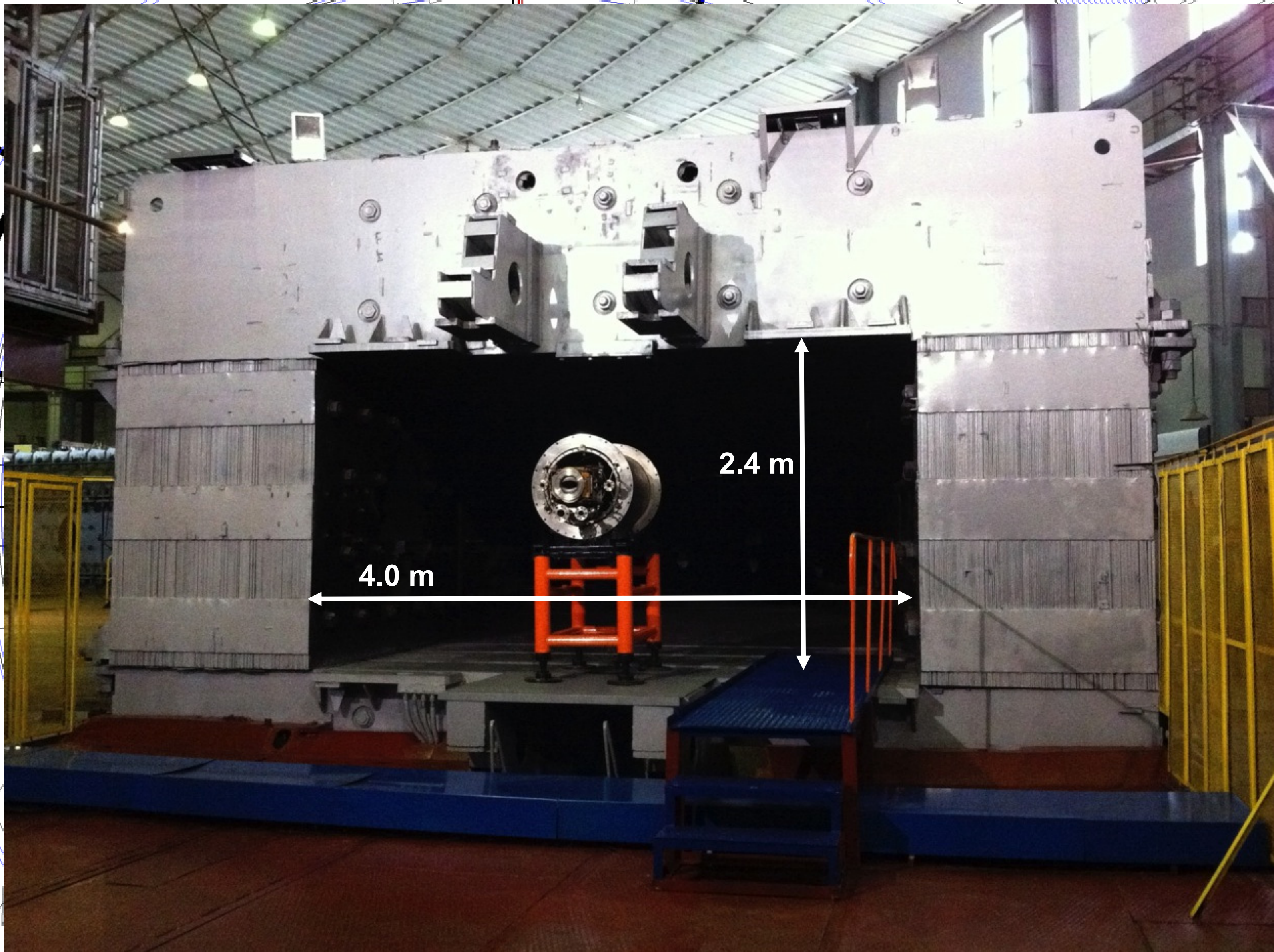


Nuclotron Beams

Parameter	*Achieved*		*Project (2017 2019)*	
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**	**$2 \cdot 10^{10}$**	**6.0**	**$5 \cdot 10^{10}$**
Heavy ions	***With KRION-2***		***With KRION-6T & Booster***	
$^{40}Ar^{18+}$	**3.5**	**$5 \cdot 10^{6}$**	**4.9**	**$1 \cdot 10^{8}$ $2 \cdot 10^{10}$**
$^{56}Fe^{26+}$	**2.5**	**$2 \cdot 10^{6}$**	**5.4**	**$1 \cdot 10^{8}$ $1 \cdot 10^{10}$**
$^{124}Xe^{48/42+}$	**1.5**	**$1 \cdot 10^{3}$**	**4.0**	**$1 \cdot 10^{7}$ $2 \cdot 10^{9}$**
$^{197}Au^{79+}$	**---**	**---**	**4.5**	**$1 \cdot 10^{7}$ $2 \cdot 10^{9}$**
Polarized beams	***With Polaris***		***With SPI***	
p↑	**---**	**---**	**11.9**	**$1 \cdot 10^{10}$ *)**
d↑	**2.0**	**$5 \cdot 10^{8}$**	**5.6**	**$1 \cdot 10^{10}$**

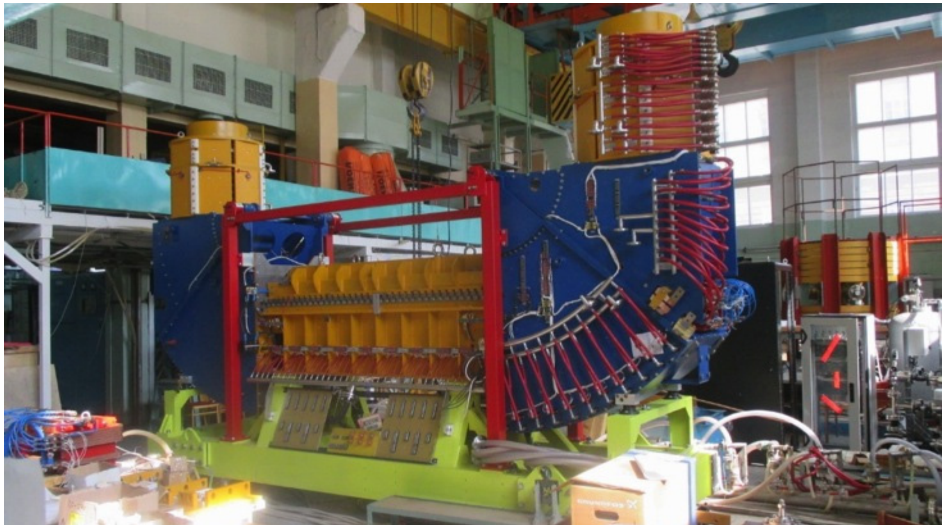
****) With the Siberian snake***

NICA Booster elements. Status

All cryostats delivered

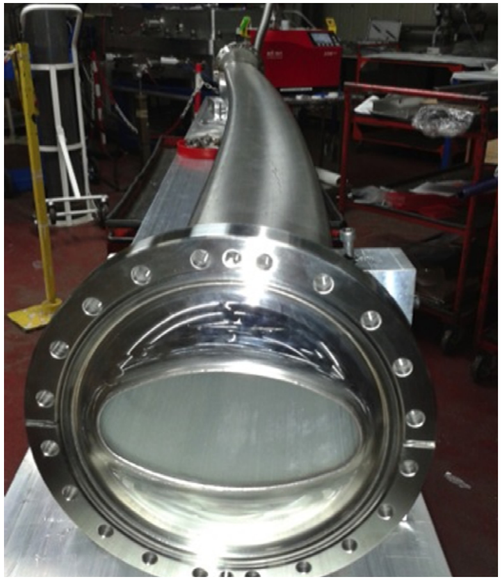
4.5K Magnetic meas.system

RF stations delivered from Budker INP



Electron cooling system (50 keV) commissioned in Novosibirsk (BINP)

HTSC current leads



UHV curved vacuum chambers (10^{-12} Torr)

Test Facility for SC magnets of NICA and FAIR: excellent collaboration of JINR and Germany (GSI/FAIR). Start of operation – December'14.

		2015				2016				2017				2018				2019			
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Booster																					
dipoles	40+3	■	■	■	■	■	■	■													
quadrupoles	48+6	■	■	■	■	■	■	■	■	■	■	■									
multipole correctors	40+4					■	■	■	■	■	■	■									
Collider																					
dipoles	80+5								■	■	■	■	■	■	■	■	■	■	■	■	
quadrupoles	86+5								■	■	■	■	■	■	■	■	■	■	■	■	

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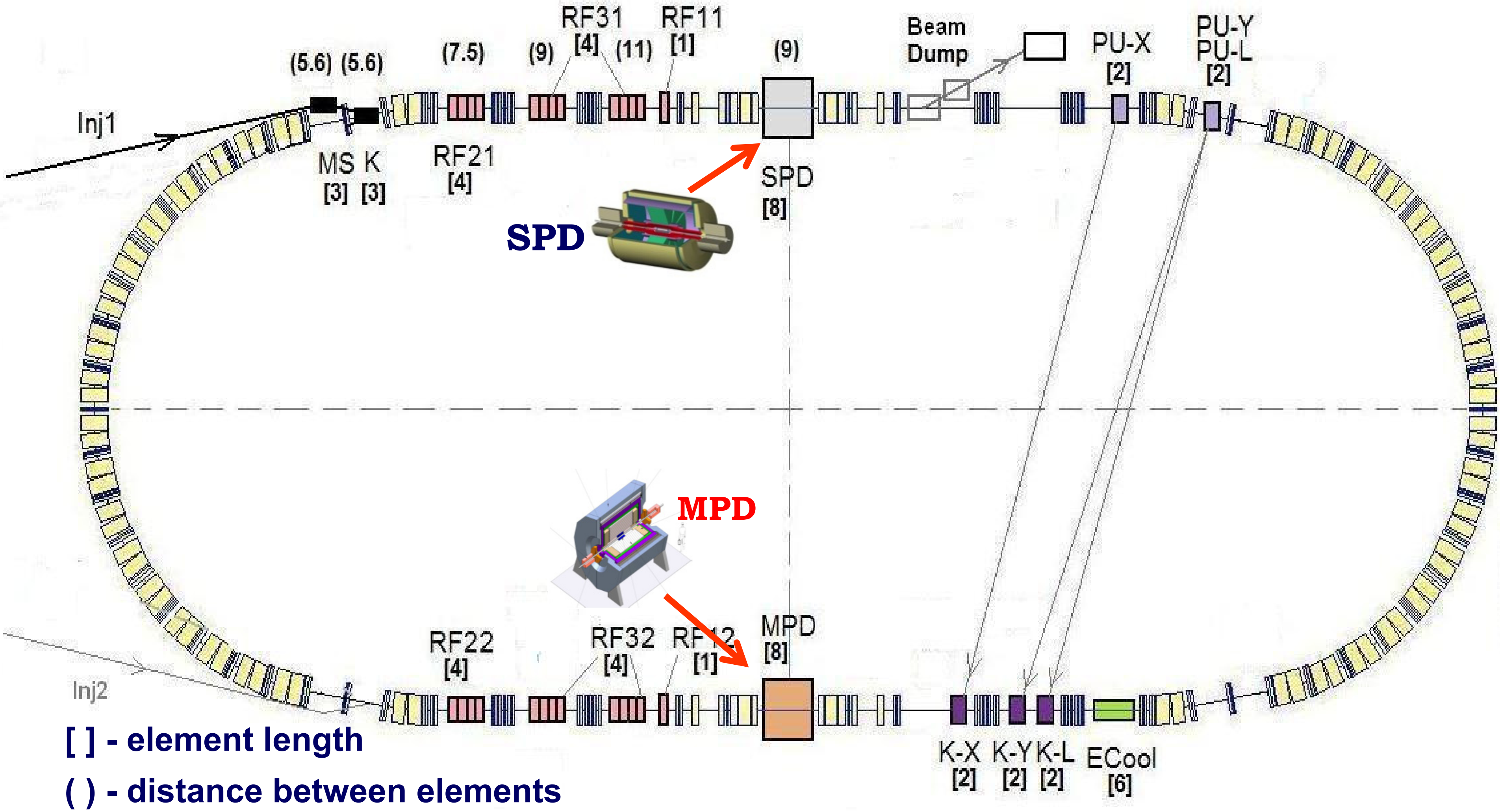
dipoles	
quadrupol	
multipole	
Collider	
dipoles	80+5
quadrupoles	86+5

Collider composition (HI mode)

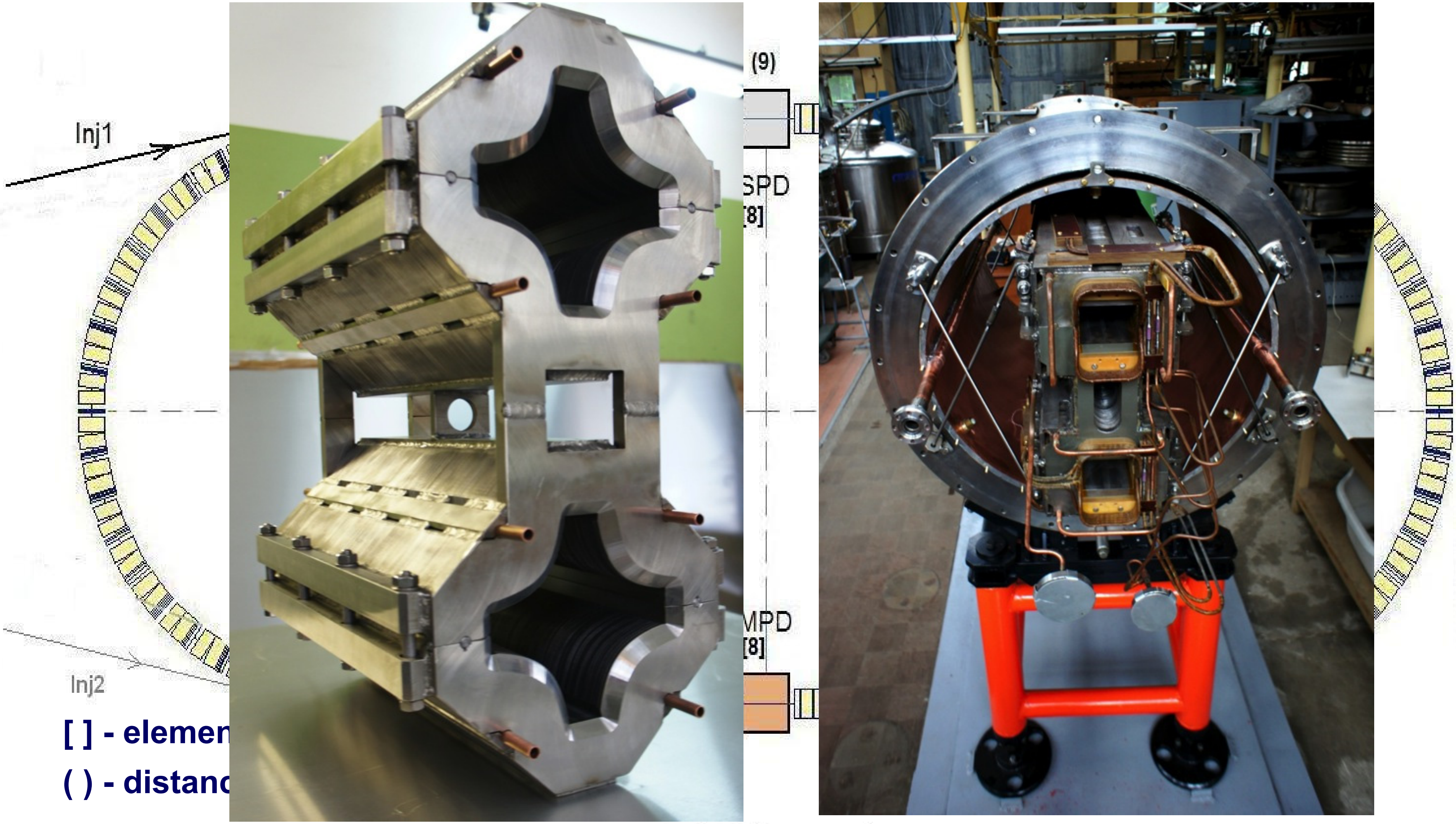


[ ] - element length

( ) - distance between elements

Au(+79) ion mode

Collider composition (HI mode)



[ ] - elemen

( ) - distanc

Au(+79) ion mode

The NICA Collider

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

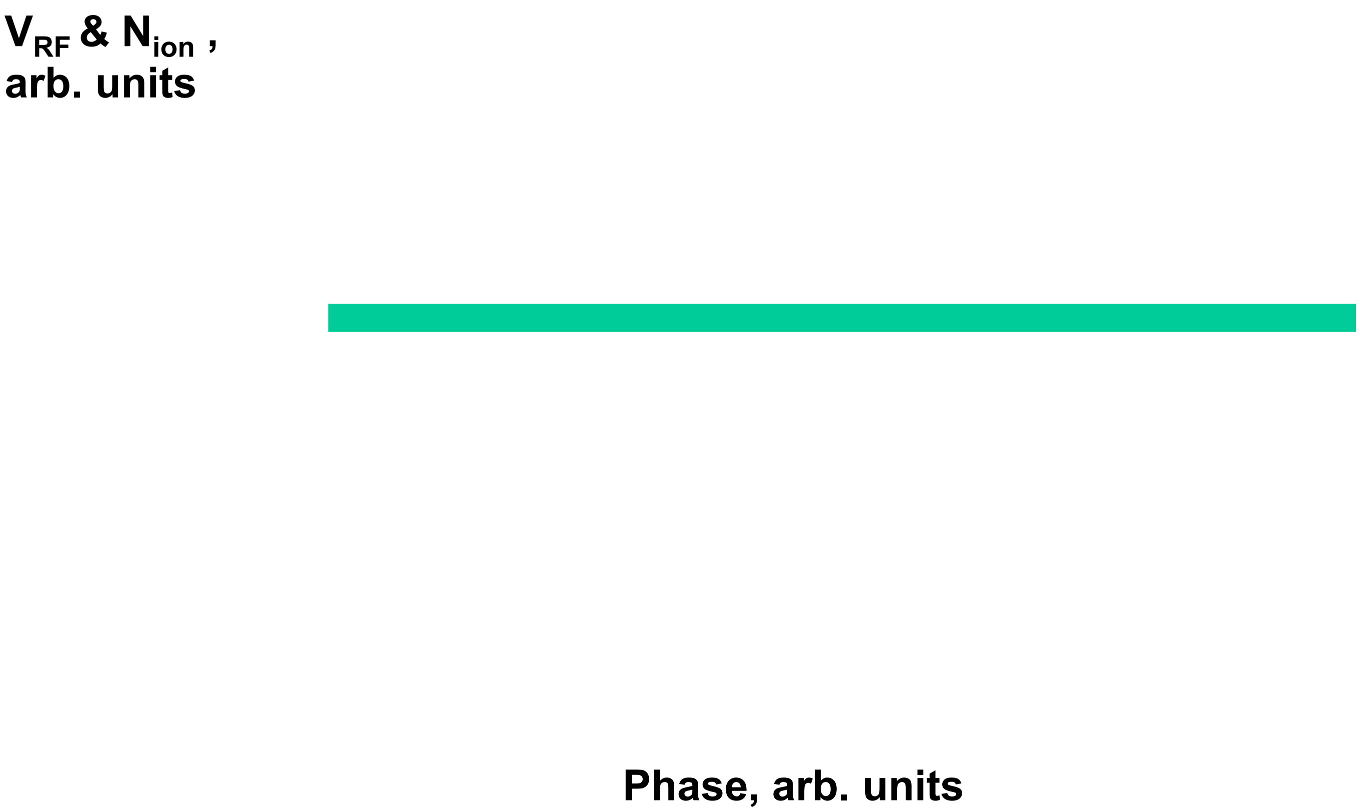
Circumference, m	503.04		
Number of bunches	22		
rms bunch length, m	0.6		
β-function in IP, m	0.35		
Betatron tunes, Q_x/Q_y	9.44 / 9.44		
Chromaticities, Q'_x/Q'_y	-33 / -28		
Ring Acceptance, π mm·mrad	40		
Momentum acceptance, $\Delta p/p$	±0.010		
γ_{tr}	7.088		
Energy of Au, GeV/u	1.0	3.0	4.5
Number of ions per bunch	$2.0\cdot10^8$	$2.4\cdot10^9$	$2.3\cdot10^9$
$\Delta p/p_{rms}$, 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}	$0.6\cdot10^{25}$	$1\cdot10^{27}$	$1\cdot10^{27}$
IBS growth time, s	160	460	1800
Tune shift, $\Delta Q_{total} = \Delta Q_{SC} + 2\xi$	-0.050	-0.037	-0.011

RF gymnastics in collider

Stage 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. dP/p is limited by microwave instability.

Stages 2-3. Formation of the short ion bunches in 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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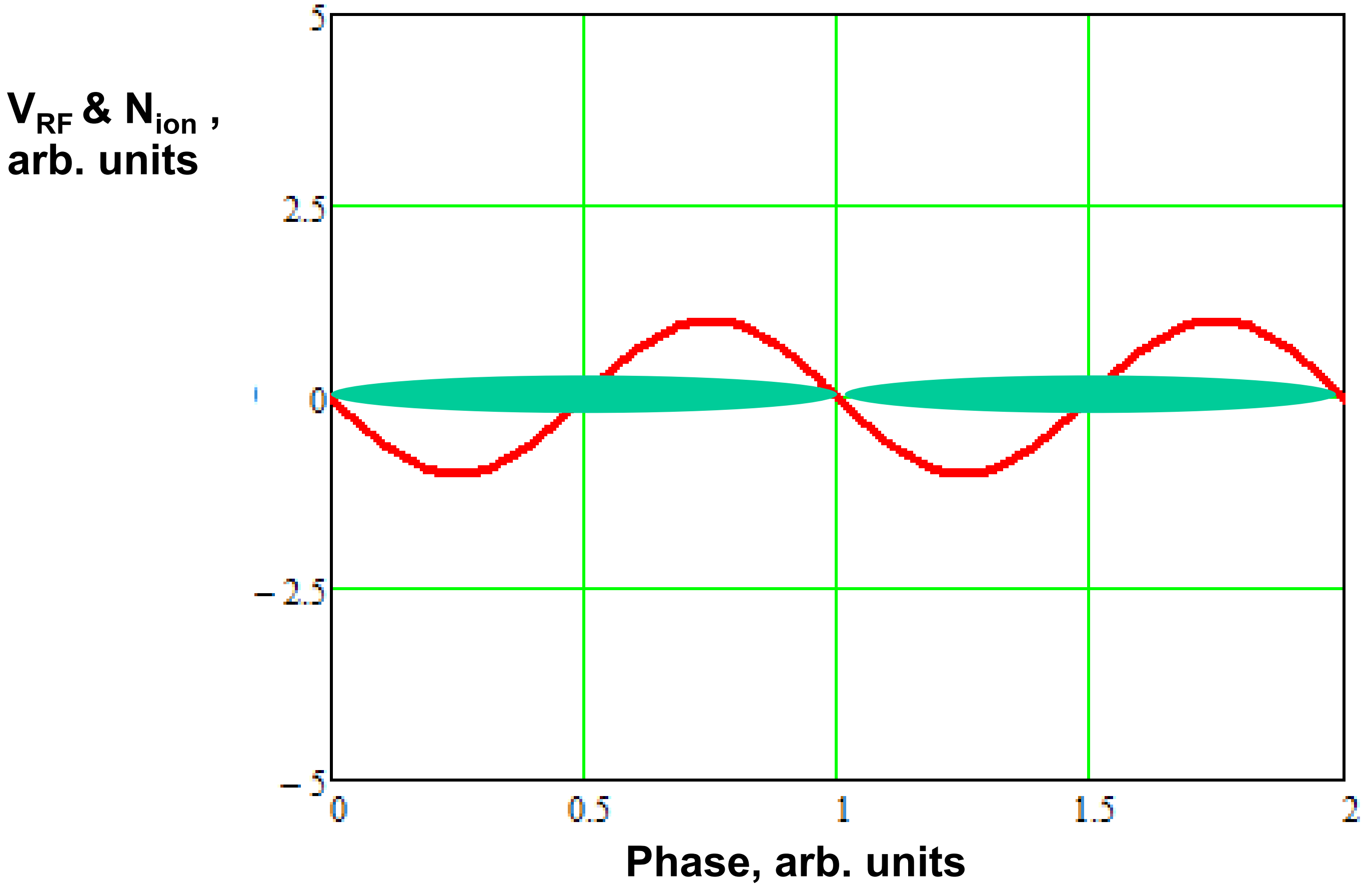

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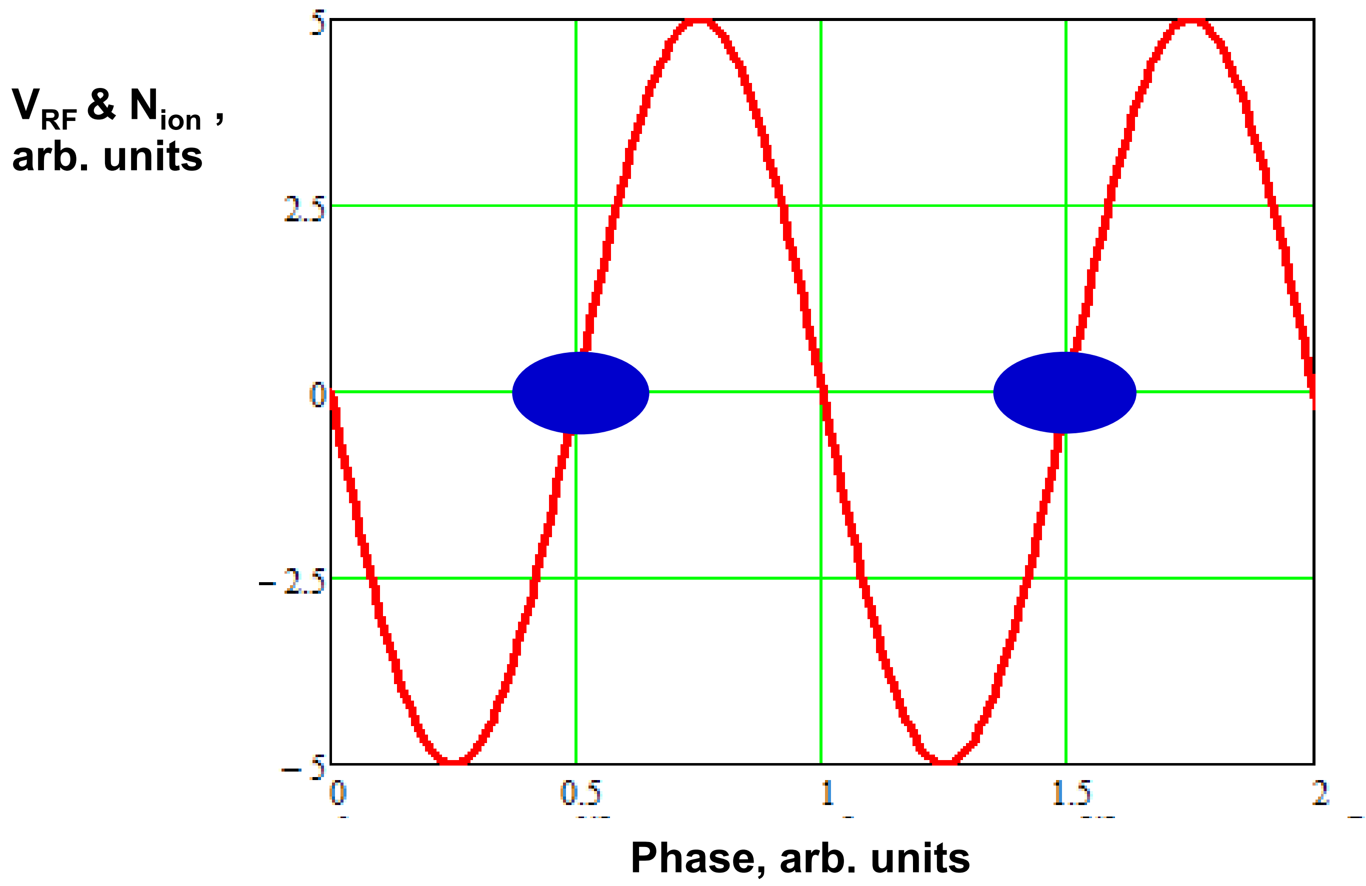

RF gymnastics in collider

Stage 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. dP/p is limited by microwave instability.

Stages 2-3. Formation of the short ion bunches in presence of cooling,

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

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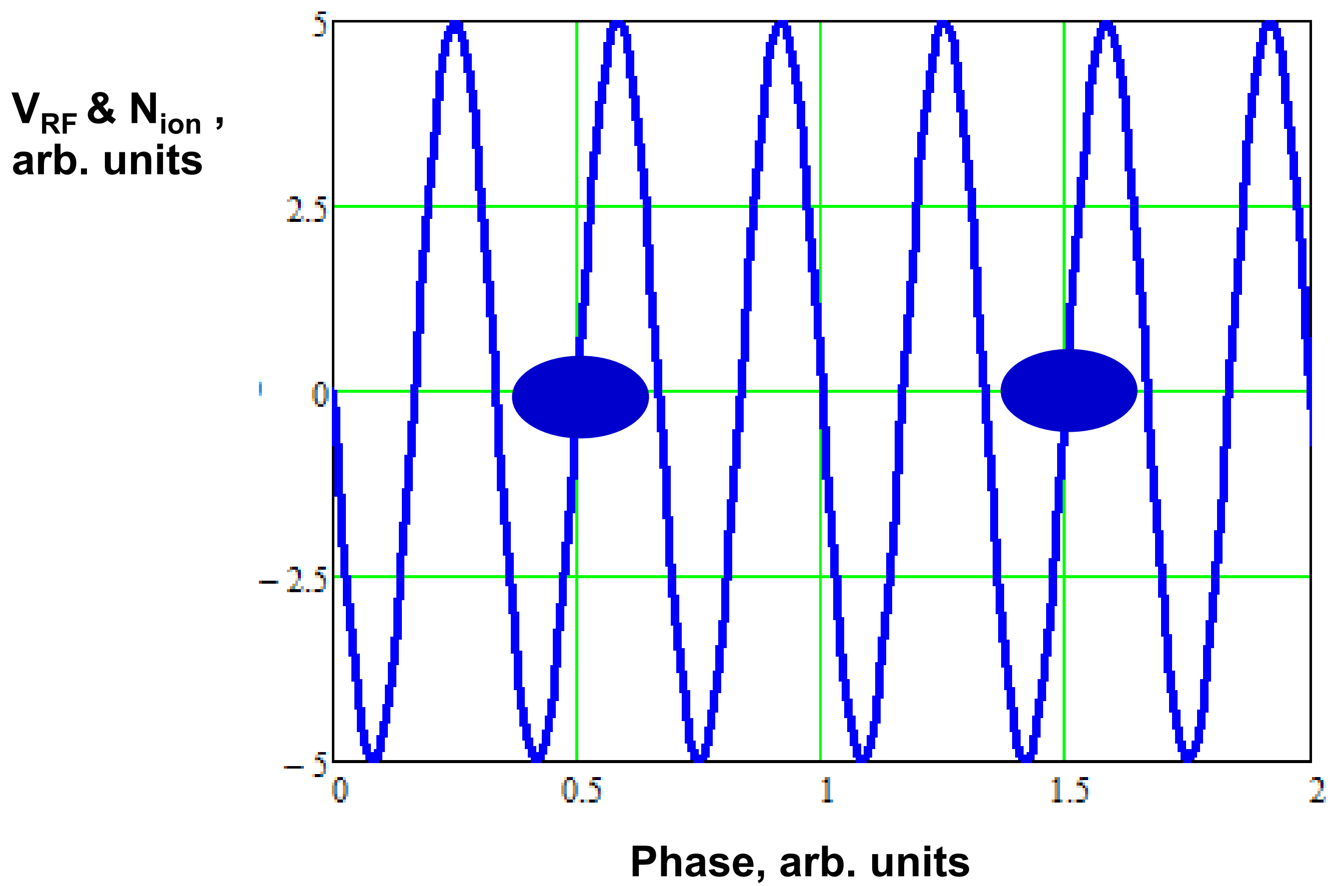

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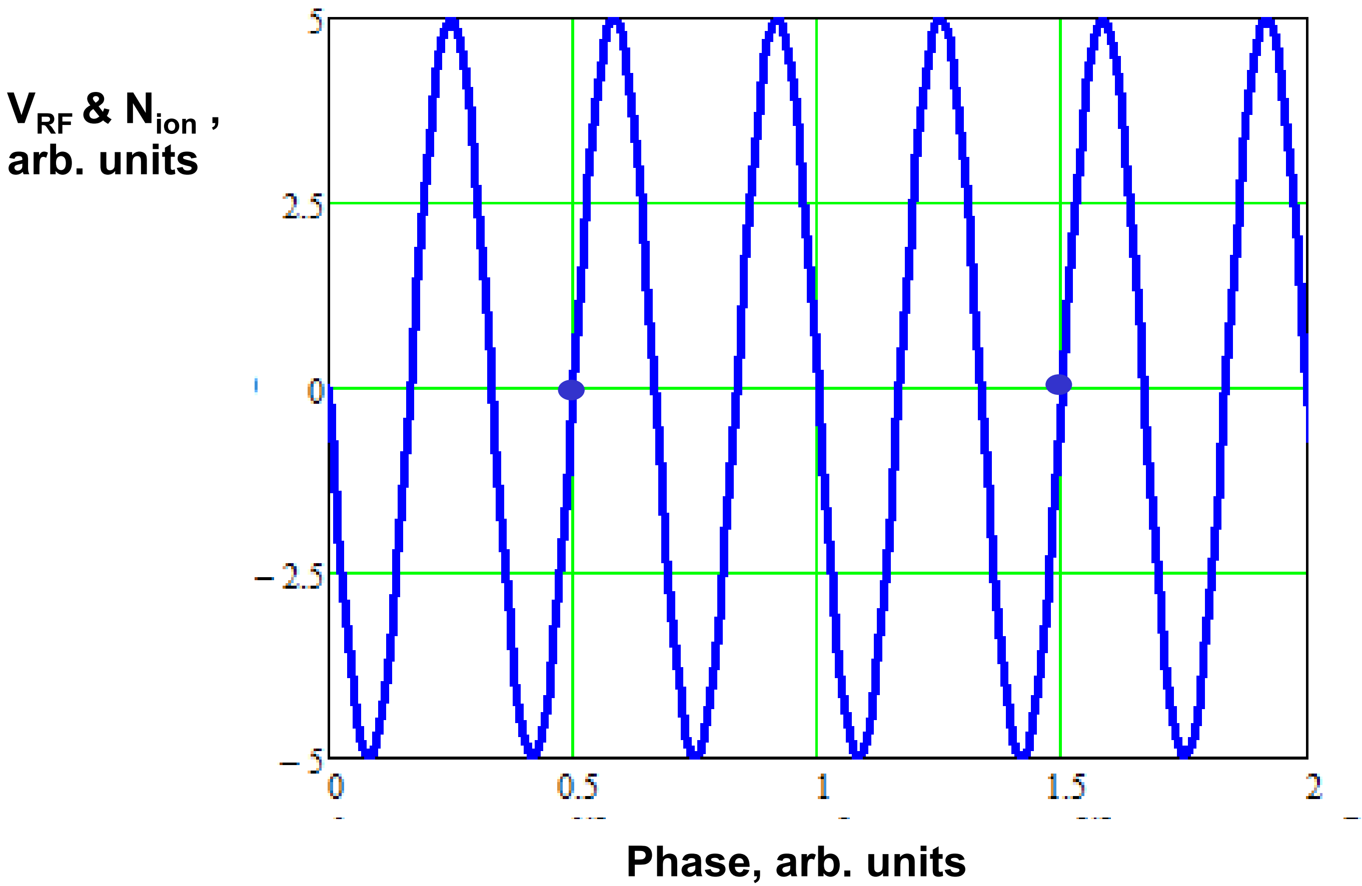
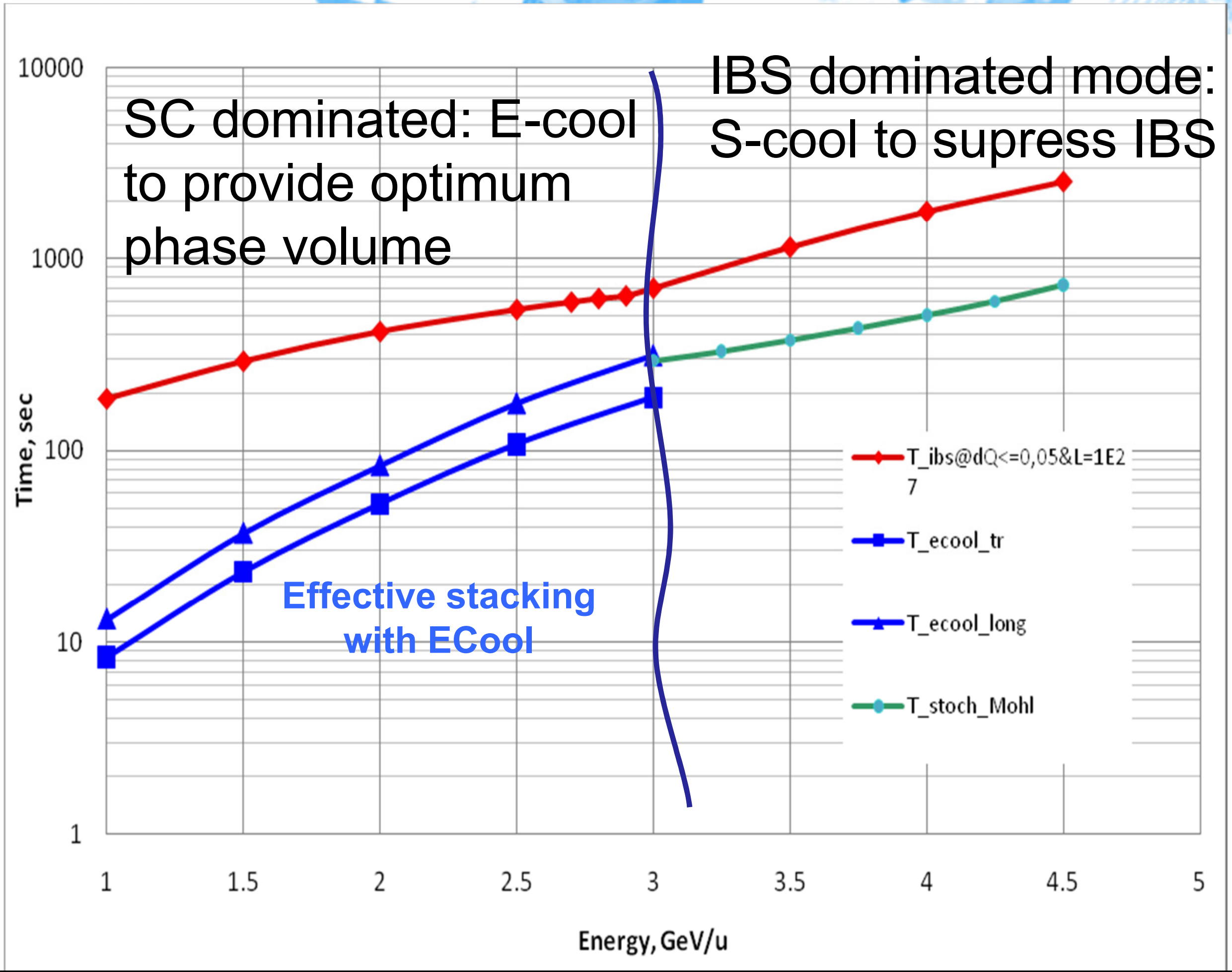


Strategy to achieve luminosity

1. Maximal r.m.s. bunch length is chosen equal to **0.6m** in order to have the “luminosity concentration” at Inner Tracker (IT) of MPD
2. Maximal peak luminosity (limited by Lasslett tune shift) is achieved at maximal emittance: ε_{rms} = 1.1 $\pi\cdot$mm$\cdot$mrad (radius = 1/6 aperture)
3. **The ratio between horizontal, vertical emittances and dP/P is defined from the equillibrium of IBS rates**
4. Maximal number of particles in bunch is limited by tune shift $\leq$ 0.05
5. Number of bunches = 22 -> to avoid parasitic collisions
6. RF multiplicity = 3 -> separatrix area is by 25 times exceeds longitudinal emitance

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

Strategy to keep Average Luminosity

1. Effective scheme of accumulation and bunch formation
2. Beam lifetime (due to scattering on residual atoms) ~ 10 h
3. “Head-tail” and multibunch instabilities are supressed by feed-back systems

4. Supression of the emitance growth due to IBS – by beam cooling systems:

1 – 3 GeV/u – with electron cooling
3 – 4.5 GeV/u – with 3D stochastic cooling (longitudinal – Palmer method)

Start-up configuration

To achieve luminosity @ MPD (for Au-Au) ~ **$3 \cdot 10^{25}$ cm^{-2}s^{-1}**

- No electron cooling.

- No feed-back systems (as soon as beam intensity decreased from $2 \cdot 10^{9}$ down to $5 \cdot 10^{8}$.

- Momentum spread of $4.2 \cdot 10^{-4}$ (instead of $1 \cdot 10^{-3}$).

- Bunch accumulation scheme stays the same.

- "Light" RF-2 composition: 4 -> 2 resonators per ring.

- No RF-3: bunch length = 1.2m (instead of 0.6 m), 50 kV enough.

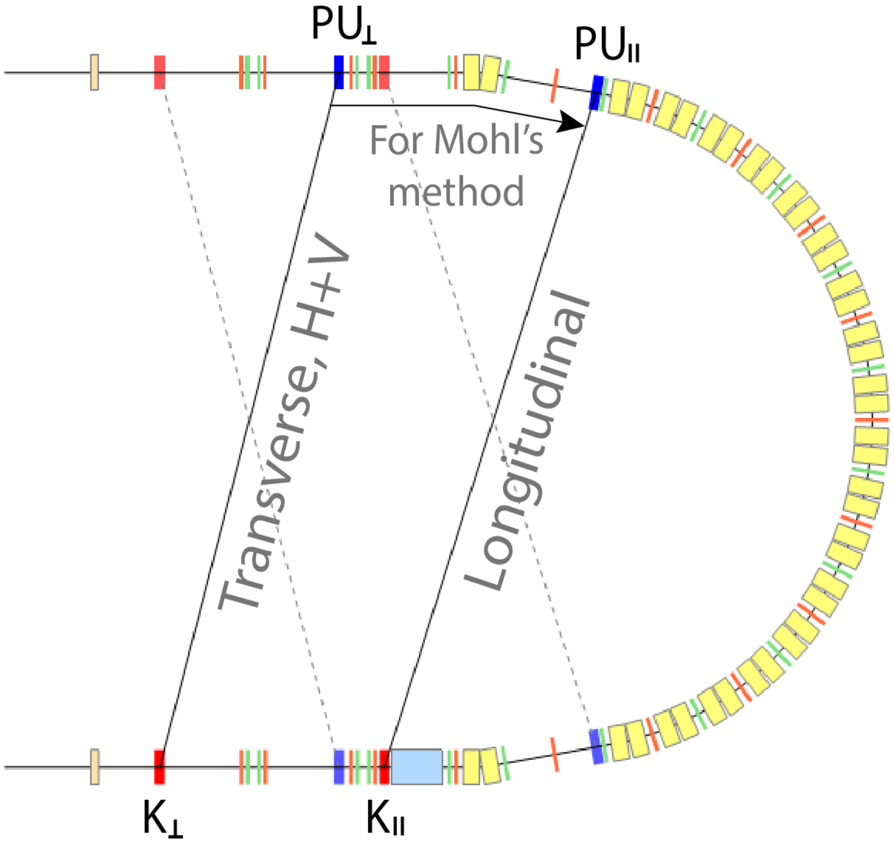
- No transverse stochastic cooling (only 1 long. channel instead of 3 per ring. Filter cooling at E>3.9 GeV/u).

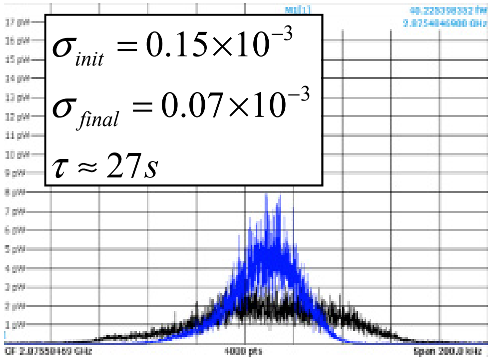
Serial production of collider cryostats, SC magnets and UHV chambers starts in 2016, RF#1 (BB) – in production, RF#2 – TDR + prototyping.

Stochastic Cooling System

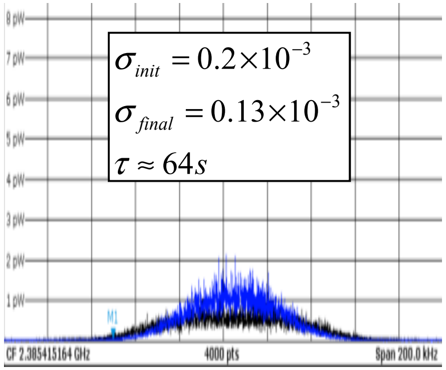
Stochastic Cooling System installed at Nuclotron - prototype for the NICA Collider:
W=2-4 HGz,
P = up to 60 W
Collaboration:
with IKP FZ Juelich

Ring slot-coupler RF structure (design FZJ)





Coasting beam



Bunched beam

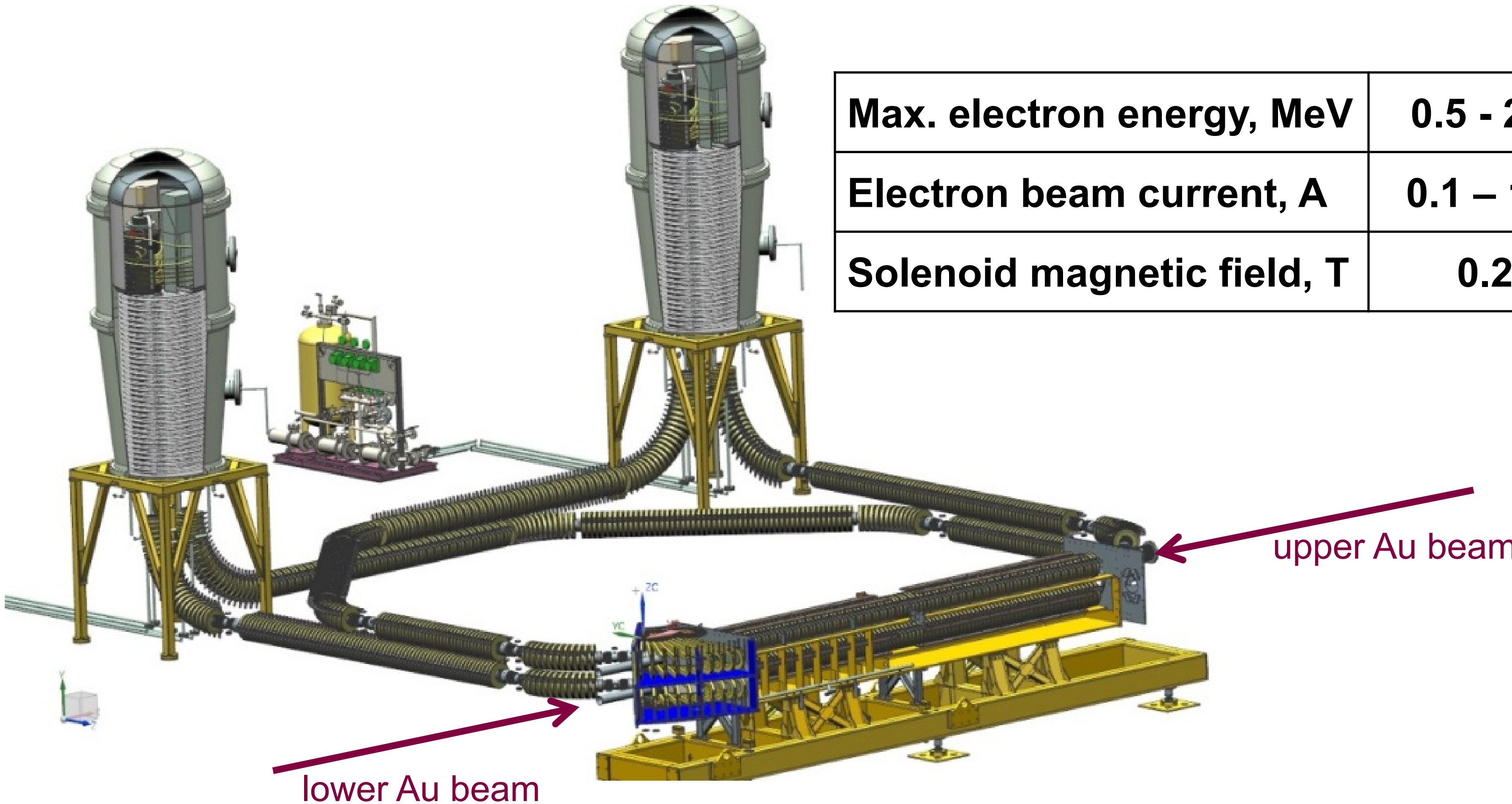
Experimental results (2013): stochastic cooling of the C^{6+} beam, E = 2.5 - 4 GeV/u

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)

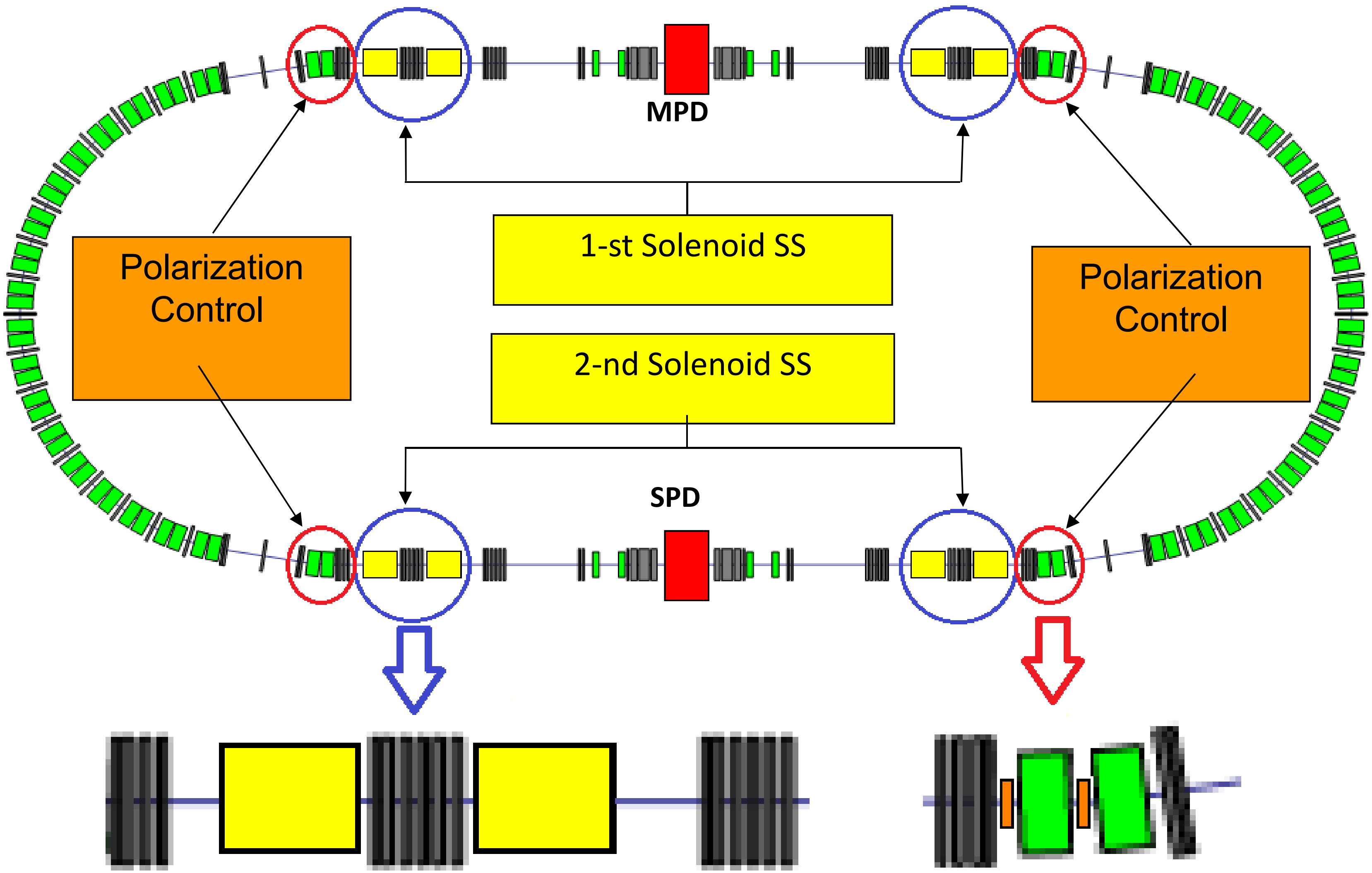
Electron cooling system

Concept by Budker INP.
TDR started in 2016.

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

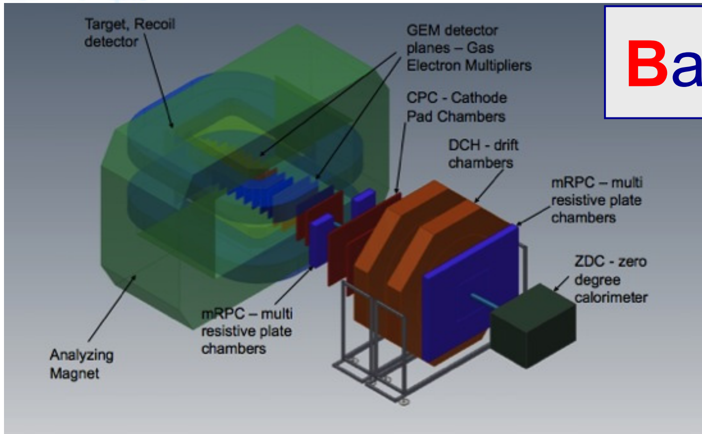


NICA – Stage III: Collider of polarized beams



Spin diagnostics + Superconducting solenoids at field < 8 T

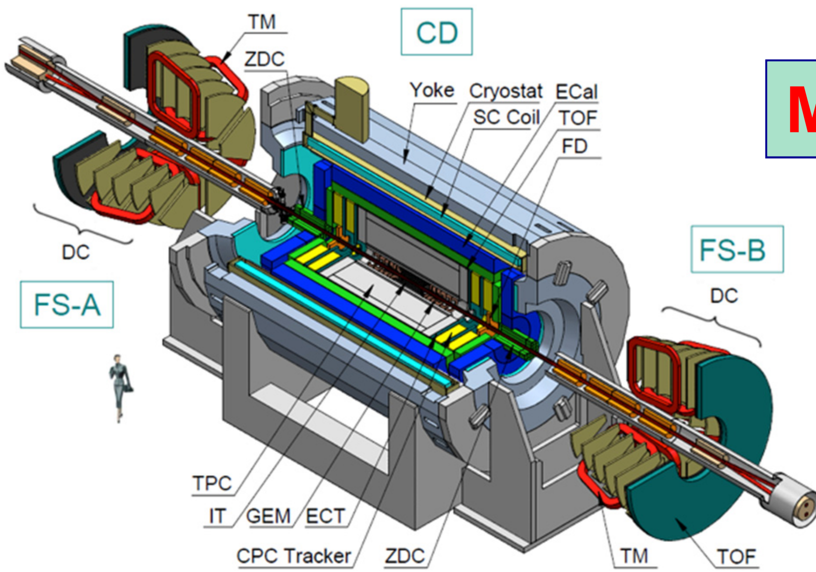
NICA: 3 detectors



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

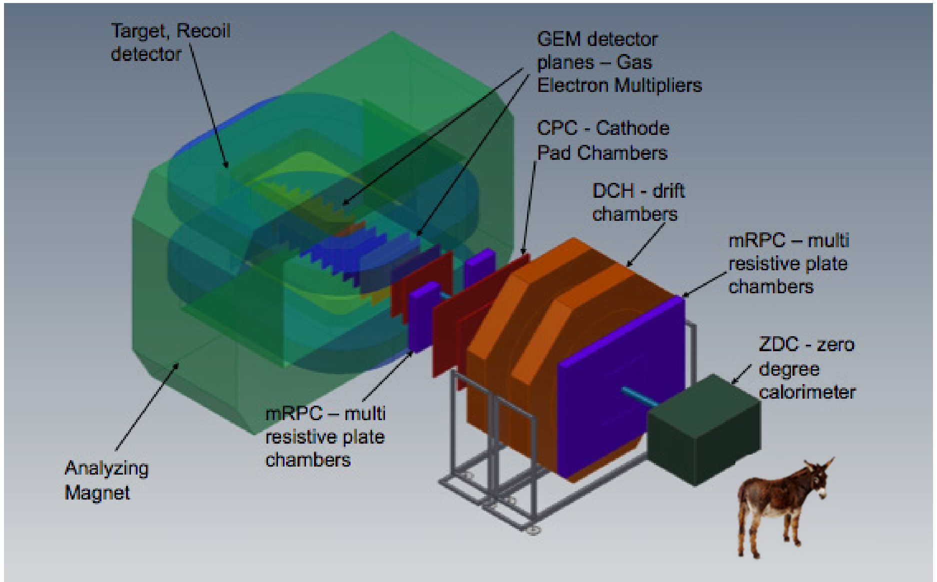
SPD (Spin Physics Detector) *at the Collider*

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.**

MPD detector for Heavy-Ion Collisions @ NICA

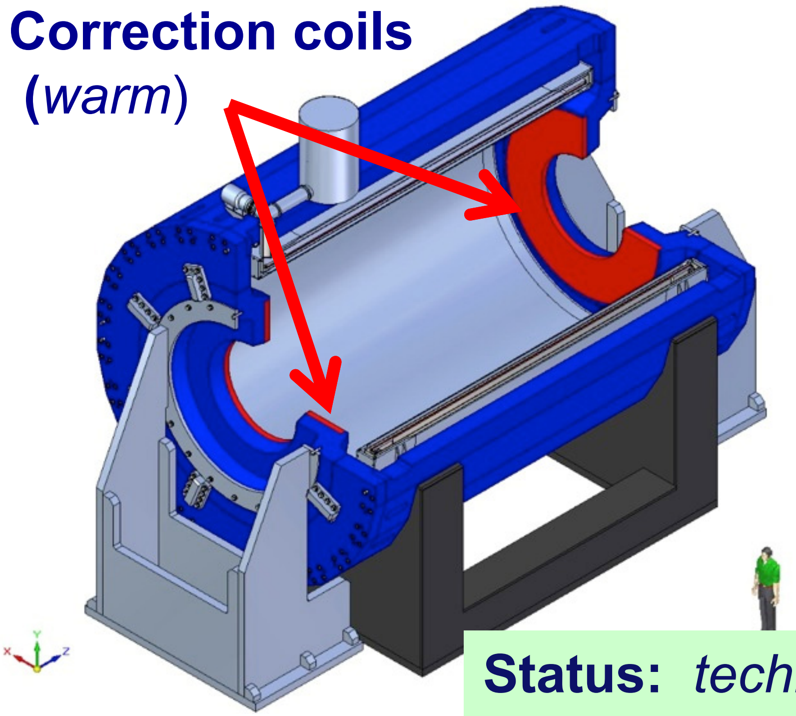
Tracking: up to |η|<2 (TPC)
PID: hadrons, e, γ (TOF, TPC, ECAL)
Event characterization:
centrality & event plane (ZDC)

Superconducting solenoid:

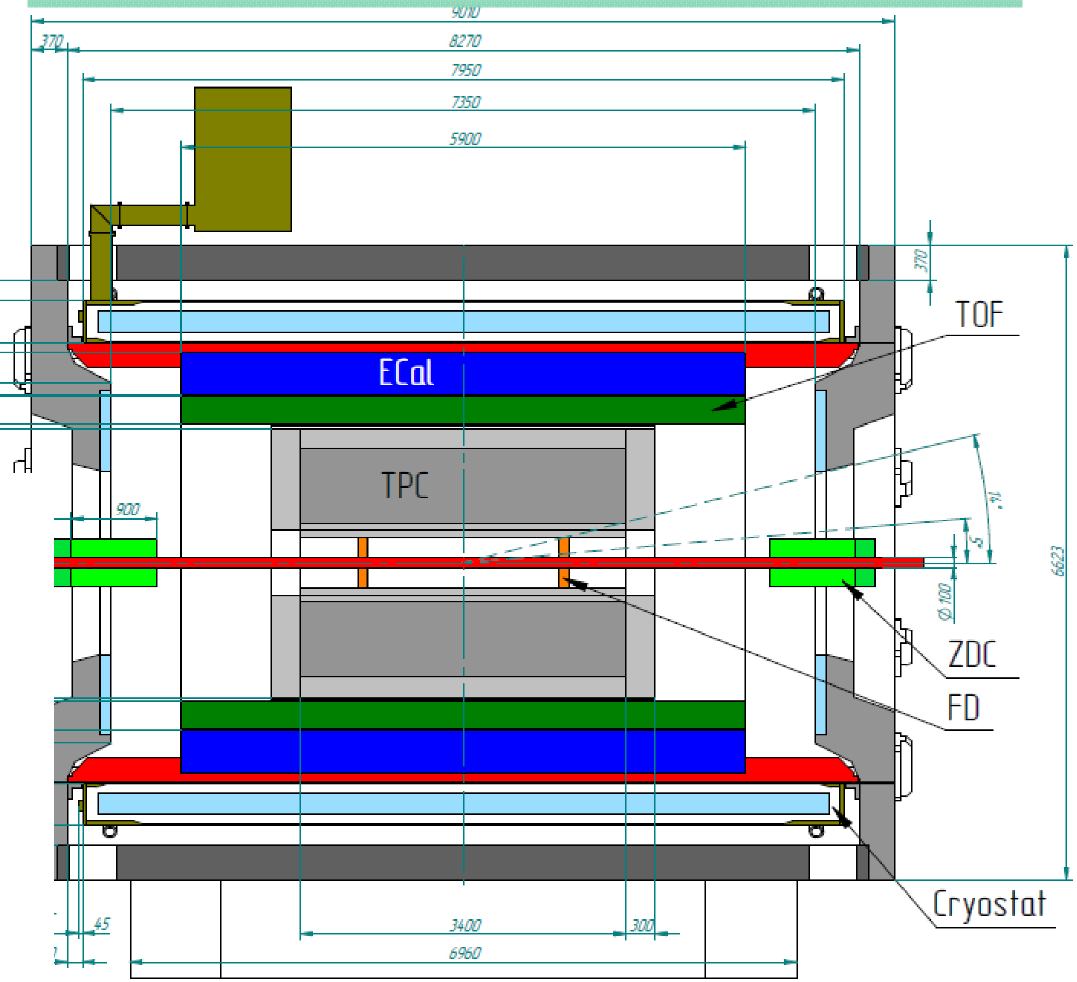
high level (~ 3x10^{-4}) of magnetic field homogeneity

B_0=0.66 T

Correction coils (*warm*)



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



Status: *technical design and detector R&D – completed;*
Mass production is starting for many systems

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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

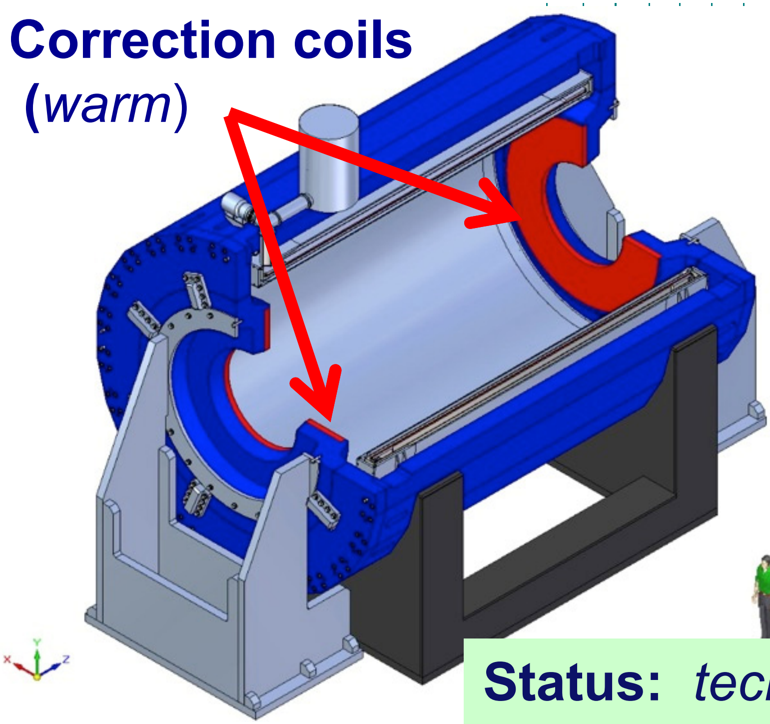
Stage 2: IT + Endcaps (tracker, TOF, ECAL)

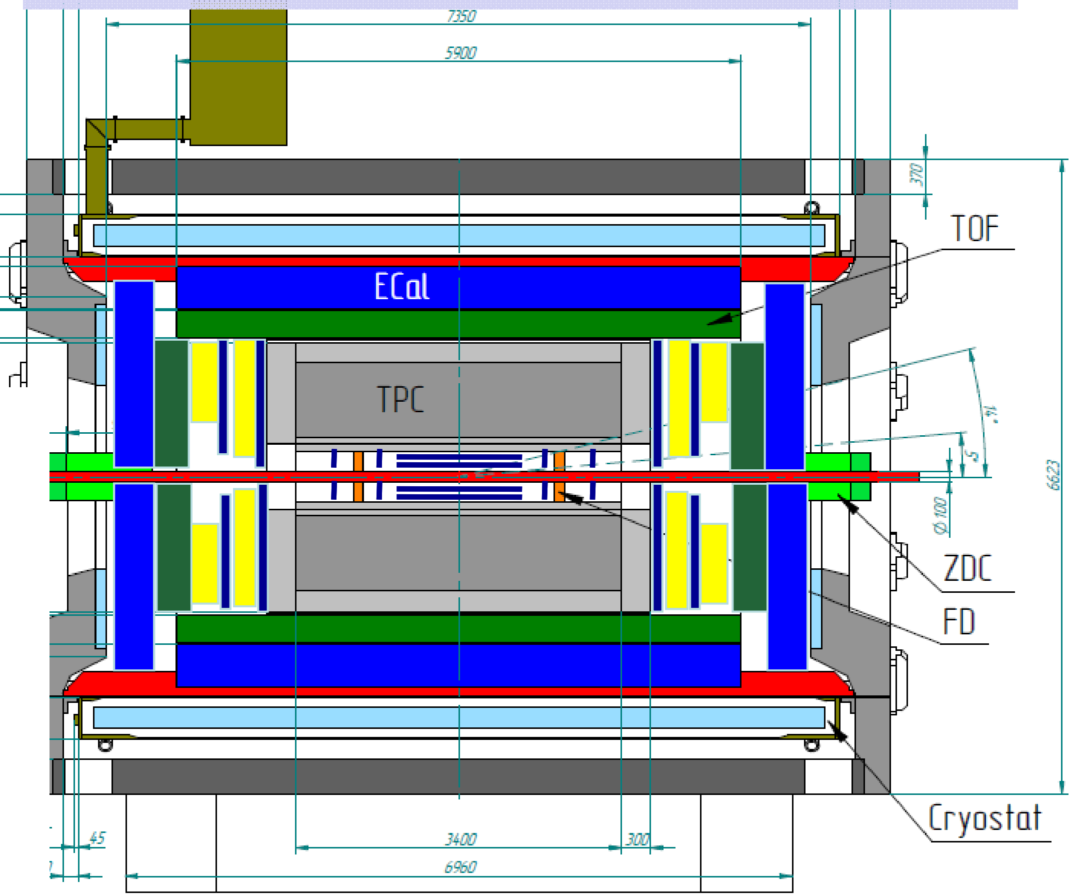
Superconducting solenoid:

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

B_0=0.66 T

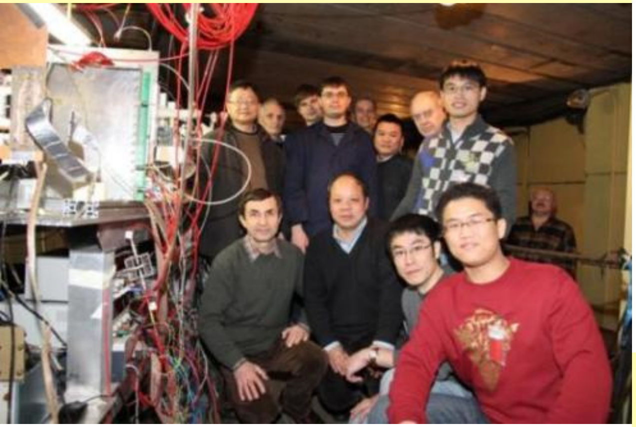
Correction coils (*warm*)





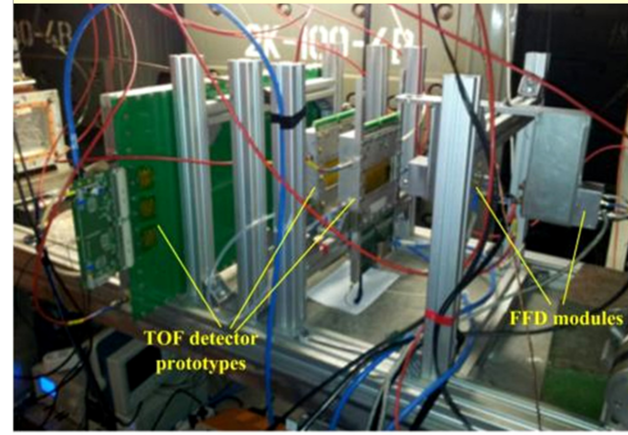
Status: *technical design and detector R&D – completed;*
Mass production is starting for many systems

RPC deam test at NUCLOTRON: cooperation with SPb, China

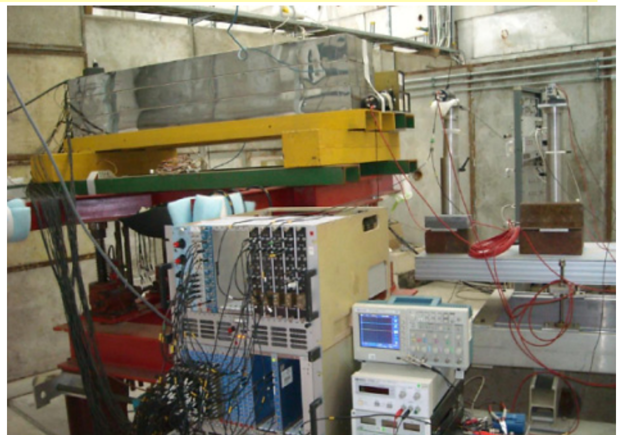


Preproduction ECAL prototypes: co-operation with *Ukraine and China*

FFD tested with beam: achieved time resolution (38 ps) is better than required



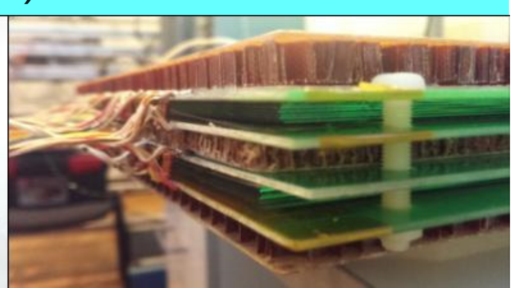
TPC Cylinder C3 manufactured in Dec'13



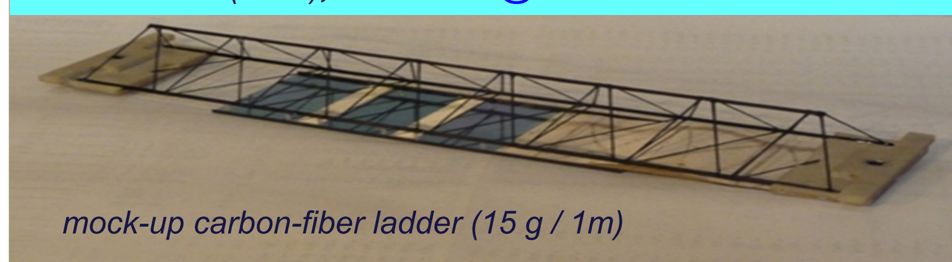
ZDC coverage confirmed: 2.2<|η|< 4.8

Readout Electronics developed for *TPC, TOF, and ECAL* (*64 ch,13-bit,65 MSPS*)

RPC performance : ***required efficiency, rate capability & time resolution (63 ps) had been reached***



The CBM - MPD consortium: *development & production of STS for **CBM** (FAIR), **MPD** & **BM@N***



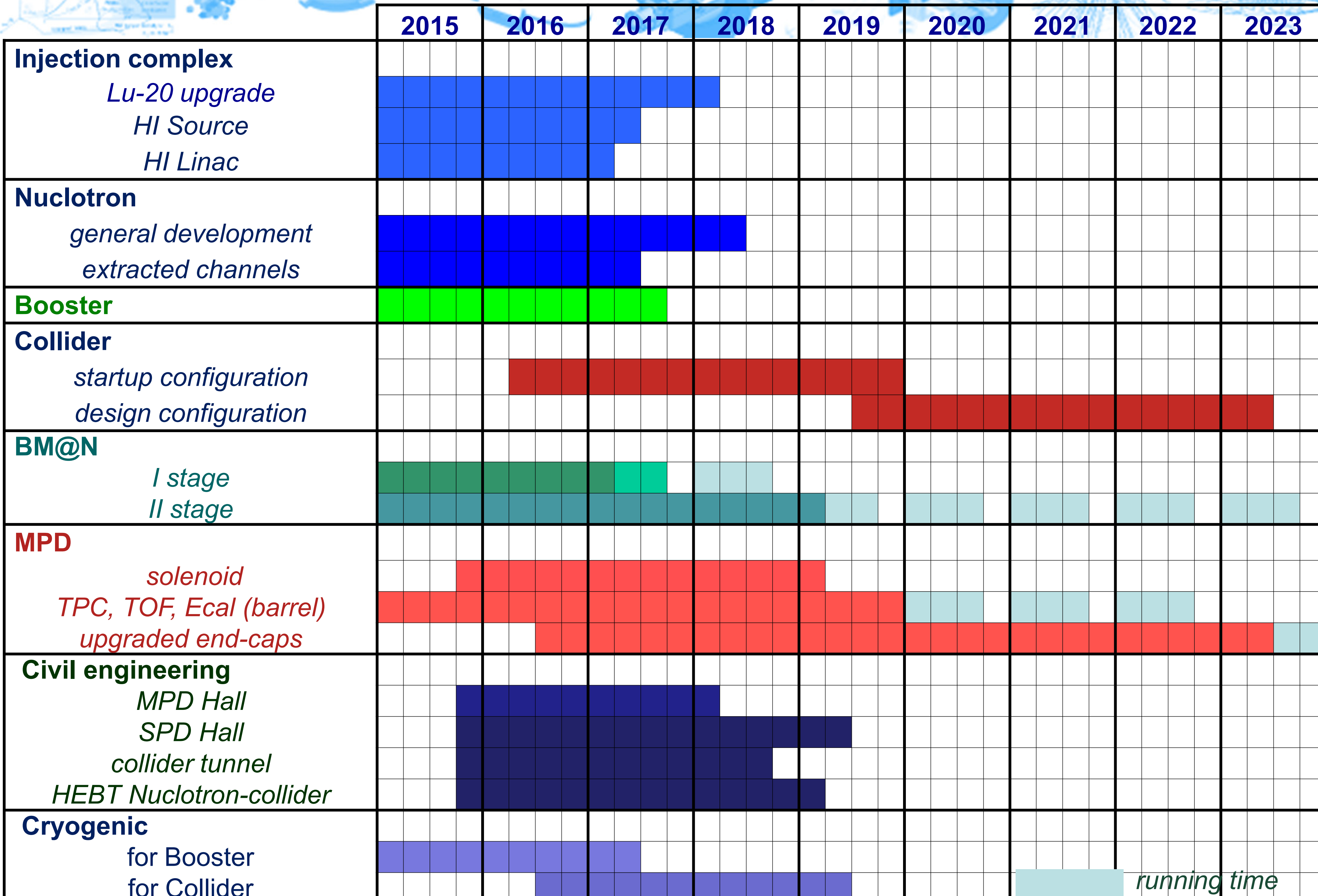
mock-up carbon-fiber ladder (15 g / 1m)

http://nucloweb.jinr.ru/nucloserv/205corp.htm

Contract with Strabag for civil construction signed in Sept'2015. Schedule - mid.2019

NICA "Corner stone ceremony", 25 March 2016 (David Gross and Russian Authorities)

NICA time-line



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.

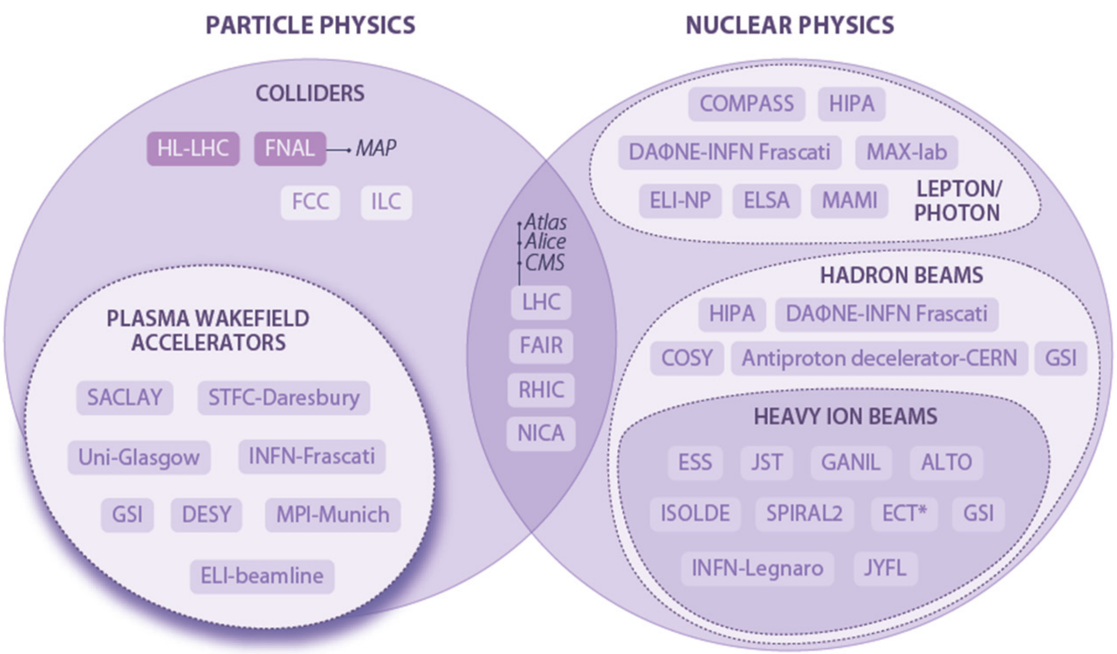
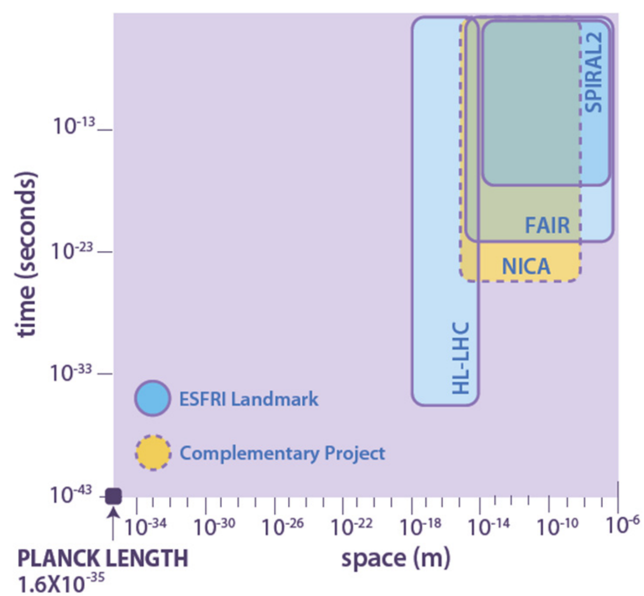


Figure 2B: space and time domain of investigation of the ESFRI Landmarks and Projects.

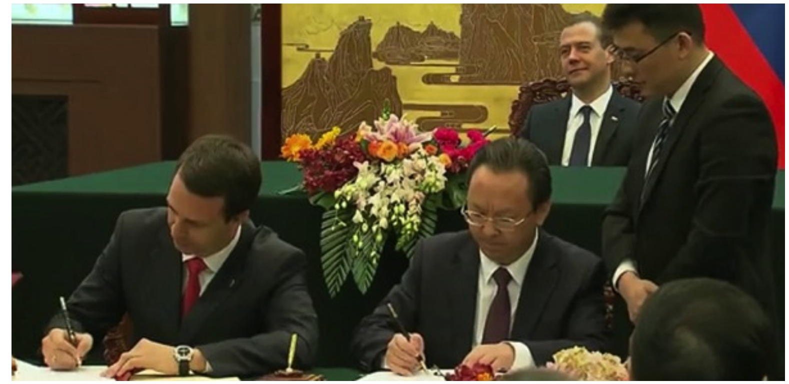


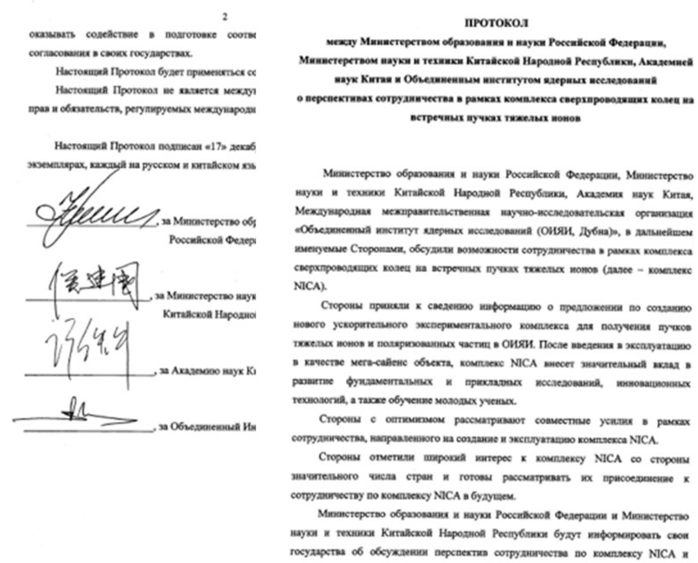
A Quadripartite Protocol signed in China

At the 20th Regular Meeting of Prime Ministers of Russia and China

December 17, 2015, Beijing

The Quadripartite Protocol between the Ministry of Education and Science of Russia (Deputy minister **Natalya TRETYAK**), the Ministry of Science and Technology of China (vice-minister **YIN Hejun**), the Chinese Academy of Sciences (vice-president **HOU Jianguo**) and JINR (vice-director **Grigory Trubnikov**) on the prospects of cooperation in the frames of the NICA project.





2

оказывать содействие в подготовке соотв

согласования в своих государствах.

Настоящий Протокол будет применяться со

Настоящий Протокол не является между

прав и обязательств, регулируемых международ

Настоящий Протокол подписан «17» декаб

экземплярах, каждый на русском и китайском яз

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Российской Федер

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Китайской Народно

__________, за Академию наук Ки

__________, за Объединенный Ин

ПРОТОКОЛ

между Министерством образования и науки Российской Федерации, Министерством науки и техники Китайской Народной Республики, Академией наук Китая и Объединенным институтом ядерных исследований о перспективах сотрудничества в рамках комплекса сверхпроводящих колец на встречных пучках тяжелых ионов

Министерство образования и науки Российской Федерации, Министерство науки и техники Китайской Народной Республики, Академия наук Китая, Международная межправительственная научно-исследовательская организация «Объединенный институт ядерных исследований (ОИЯИ, Дубна)», в дальнейшем именуемые Сторонами, обсудили возможности сотрудничества в рамках комплекса сверхпроводящих колец на встречных пучках тяжелых ионов (далее – комплекс NICA).

Стороны приняли к сведению информацию о предложении по созданию нового ускорительного экспериментального комплекса для получения пучков тяжелых ионов и поляризованных частиц в ОИЯИ. После введения в эксплуатацию в качестве мега-сайенс объекта, комплекс NICA внесет значительный вклад в развитие фундаментальных и прикладных исследований, инновационных технологий, а также обучение молодых ученых.

Стороны с оптимизмом рассматривают совместные усилия в рамках сотрудничества, направленного на создание и эксплуатацию комплекса NICA.

Стороны отметили широкий интерес к комплексу NICA со стороны значительного числа стран и готовы рассматривать их присоединение к сотрудничеству по комплексу NICA в будущем.

Министерство образования и науки Российской Федерации и Министерство науки и техники Китайской Народной Республики будут информировать свои государства об обсуждении перспектив сотрудничества по комплексу NICA и

The protocol was signed with the aim of uniting the efforts of the parties in the frames of cooperation for establishment and use of the NICA complex.

China considers joining the project and notes a wide interest of Chinese research organizations to participate in the project.

NICA collaboration

17 Russian Institutions and 24 Labs from all over the world

MEPhI, MEI, MSU, SPbSU, MPTI,...

Budker INP, Novosibirsk:
- ✓ Booster RF system, e-cooler
- ✓ Collider RF system
- ✓ HV e-cooler for collider
- ✓ Electronics

НПО ГЕЛИЙМАШ

КРИОГЕНМАШ

INR RAS (Troitsk): polarised source, Linacs, beam diagnostics

AREI:
HV Electron cooler

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

VNIITF, VNIIEF

IMP CAS, ASIPP, IHEP, Tsinghua U., Fudan U.

IHEP (Protvino):
beam dynamics, RF,
Feed-back systems

FZ Juelich (IKP):
Stoch. Cooling
HV Electron cooler

CERN
SC magnets and technologies,
energetics, precise metrology,
beam cooling and beam dynamics

FNAL:
HV Electron cooler
Beam dynamics,Stoch.cooling

BNL:
Beam dynamics,
stoch.cooling, e-cooling

ITEP:
RF, beam dynamics in the collider, RFQ linac, SC p-linac

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 GSI/FAIR, FZJ, CERN, FNAL, BNL, CAS, others.

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

- The inclusion of the NICA project to the ESFRI and BRICS RI RoadMaps gave a boost in attracting new participants.

- On 29th April 2016 Russian Government doubled NICA budget providing State funding for NICA by special Decree.

We welcome new partners !

Thank you for your attention !