JINR Scientific Council
23 September, 2010, Dubna

Status of the Nuclotron-M/NICA Project

G.Trubnikov

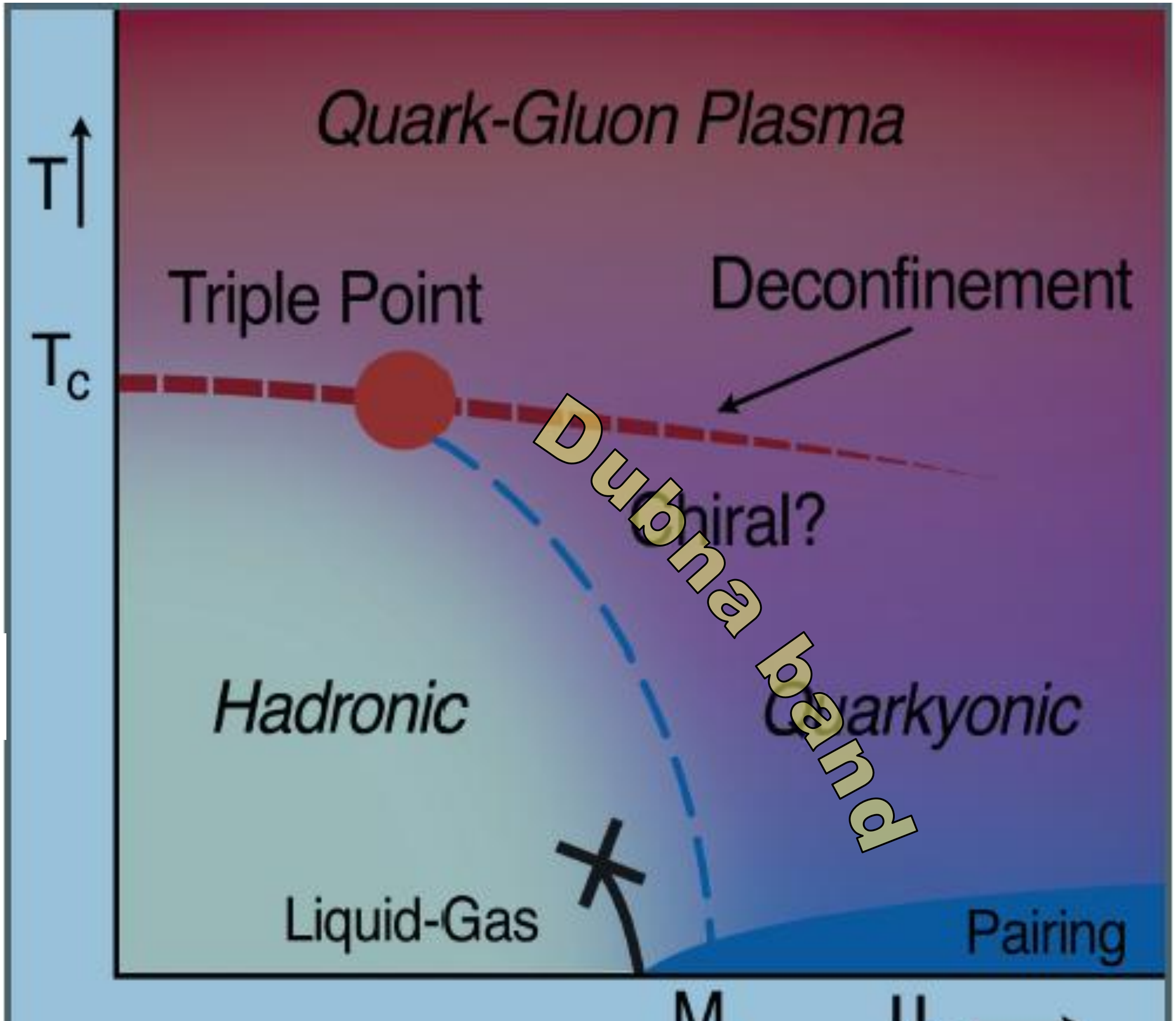
for the team

JINR, Dubna

J.Clemans,
19 Feb. 2010,
JINR SC

L.McLerran,
15 July 2010,
JINR Seminar

CPOD'2010,
August 2010



R. Pisarski and L. McLerran

The goal of the project is

<u>construction at JINR of a new accelerator facility,</u> that provides

1a) Heavy ion colliding beams $^{197}Au^{79+}$ x $^{197}Au^{79+}$ at

$\sqrt{s_{NN}}$ = 4   11 GeV (1   4.5 GeV/u ion kinetic energy)

at $L_{average}$= 1E27 $cm^{-2} \cdot s^{-1}$ (at $\sqrt{s_{NN}}$ = 9 GeV)

1b) Light-Heavy ion colliding beams of the same energy range and luminosity

2) Polarized beams of protons and deuterons in collider mode:

p↑p↑ $\sqrt{s_{pp}}$ = 12   27 GeV (5   12.6 GeV kinetic energy)

d↑d↑ $\sqrt{s_{NN}}$ = 4   13.8 GeV (2   5.9 GeV/u ion kinetic energy)

$L_{average} \geq$ 1E30 $cm^{-2} \cdot s^{-1}$ (at $\sqrt{s_{pp}}$ = 27 GeV)

3) The beams of light ions and polarized protons and deuterons for fixed target experiments:

Li ÷ Au = 1 ÷ 4.5 GeV /u ion kinetic energy

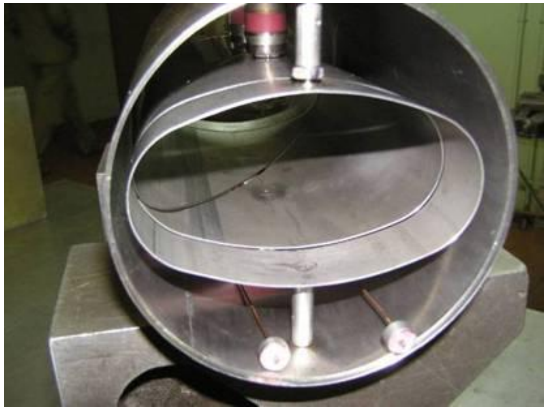
p, p↑ = 5   12.6 GeV kinetic energy

d, d↑ = 2   5.9 GeV/u ion kinetic energy

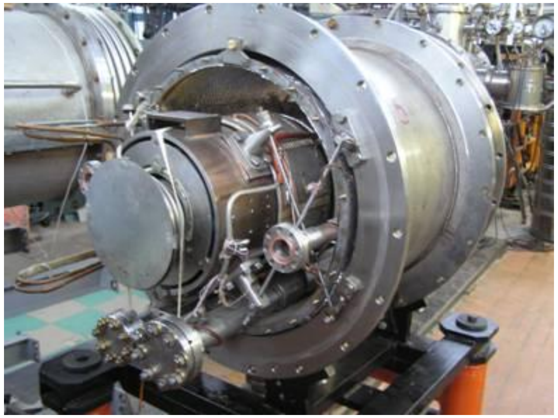
4) Applied research on ion beams at kinetic energy from 0.5 GeV/u up to 12.6 GeV (p) and 4.5 GeV /u (Au)

Nuclotron-M status

- ❑ Upgrade of Nuclotron beam diagnostics system
- ❑ Upgrade of Nuclotron vacuum system



Elliptical pick-up station



Assembled pick-up station

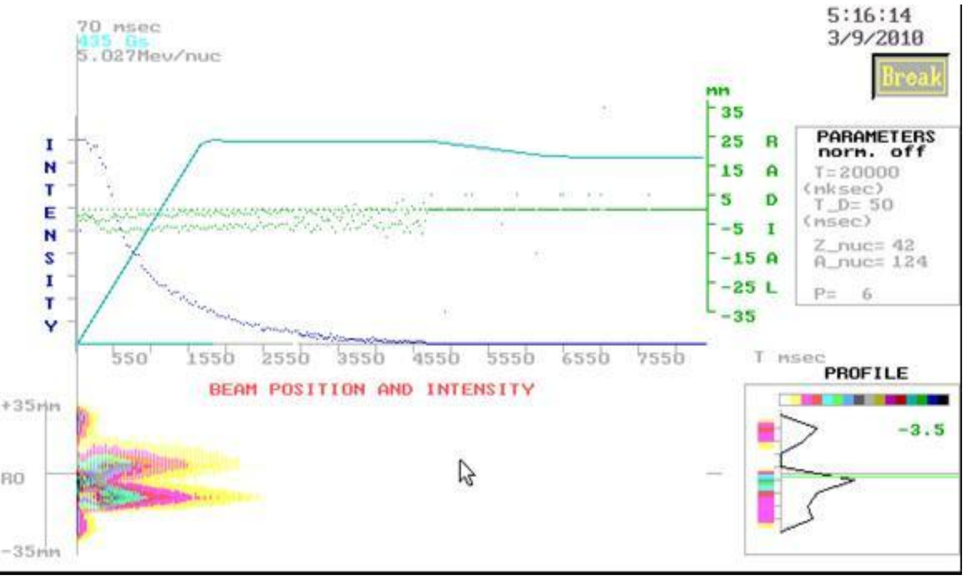
- ❑ Upgrade of the power supplies and energy evacuation system of the SC magnets
- ❑ Beam slow extraction system at maximum energy
- ❑ Upgrade of Nuclotron RF (acceleration) system
- ❑ Upgrade of the cryogenic supply system (towards NICA)

Since July'07 we performed 5 runs (# 37, 38, 39, 40, 41)

Results of the 41st run at Nuclotron 25 Feb - 25 March 2010:

Xe beam (A=124, Z=42+) was accelerated up to 570 MeV/n & 1 GeV/n, and succesfully extracted.

Signal of the Xe beam from low-intensity detector at the ring



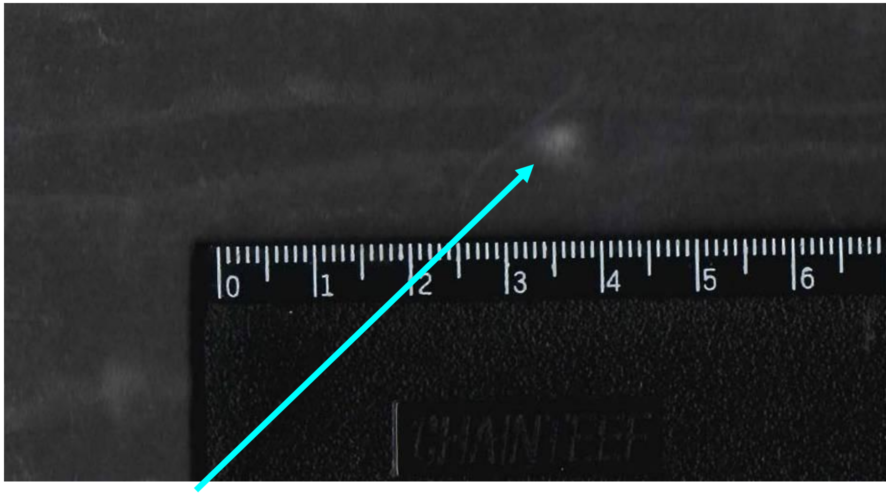
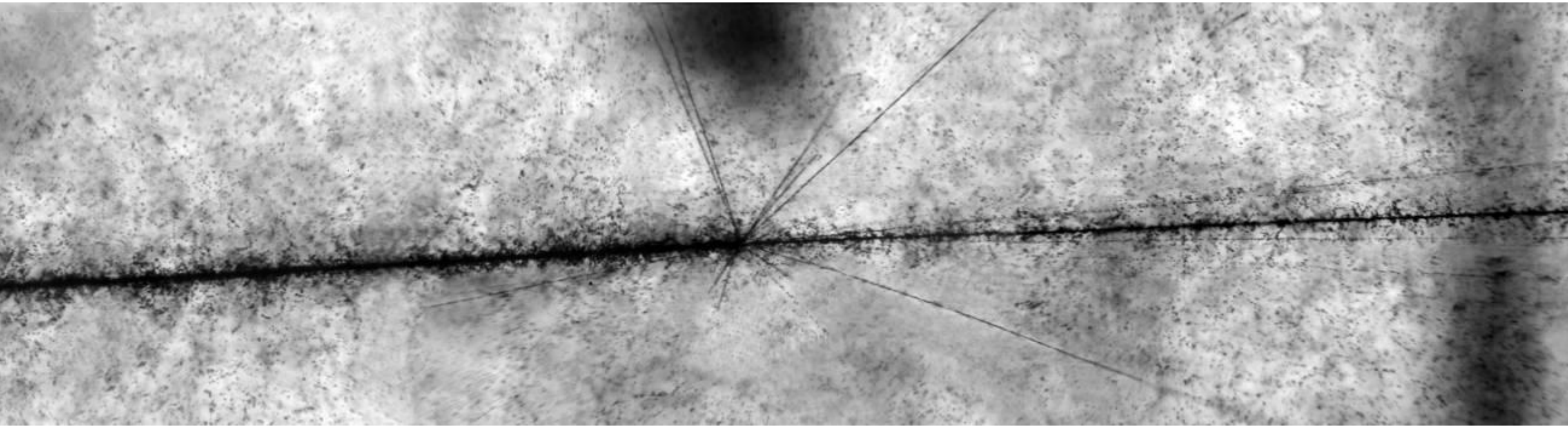


Image of the extracted Xe beam (E = 0,6 GeV/) on photoplate

Magnetic field at Nuclotron was increased up to 1.8 T

In energy it corresponds to:
d (A=2, Z=1) - 5,2 GeV/n
Xe (A=124, Z=42) - 3.3 GeV/n
Au (A=197, Z=79) - 4.05 GeV/n



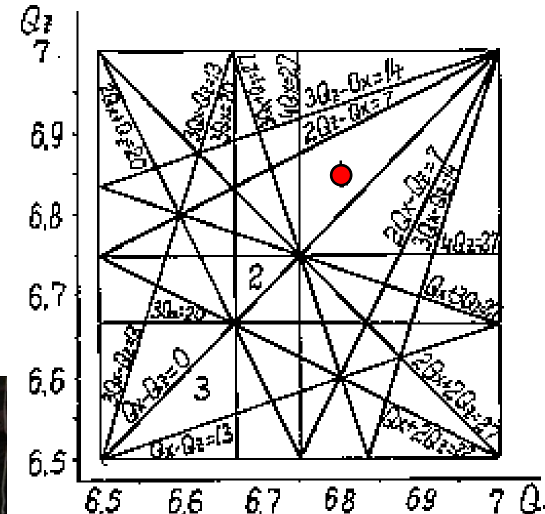
Xe (1 Gev/n) trace on photoemulsion
(experiment “Becquerel”)

Nuclotron

Thorough upgrade since 2007 - after 14 years running

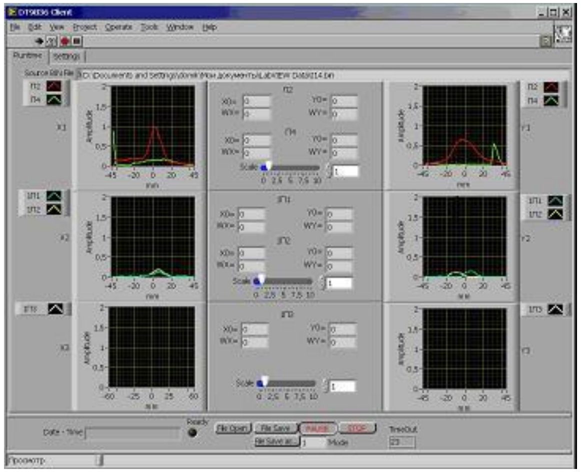
Parameter	Project	Status (Mar. 2010)
Max. magn. field, T	2.0	1.8
Magn. rigidity, T·m	45	39.5
Cycle duration, s	2.0	5.0
B-field ramp, T/s	2.0	1.0
Accelerated particles	p–U, p↑, d↑	p-Xe, d↑
Max. energy, GeV/u	12.6(p), 5.87(d) 4.5($^{197}Au^{79+}$)	5.1(d), 1.0($^{124}Xe^{42+}$)
Intensity, ions/cycle	1E11(p,d), 1E9 (A > 100)	3E10 (p,d), 1E10 (d↑) 1E6 (Xe^{42+})

Full-scale modernization of the Nuclotron power supply system



Modernization of the automation system for control, beam diagnostics and monitoring of parameters of the accelerator complex.

Kit of new power supplies (130 A) for Nuclotron correctors (collaboration with Slovakia)



Automatic system "INJECTION"

One of 30 chips (hi-tech) for automatic system for beam orbit measurement

Run № 42: Nov-Dec 2010

- 500-700 h

- Absolutely new power supply system of the accelerator, magnetic field – up to 1.9-1.95 T;

- Deutrons;

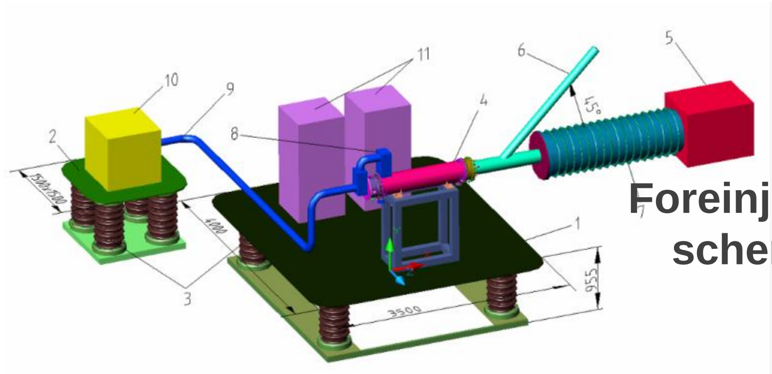
- Fighting with beam losses – intensity increase (new pick-ups, new diagnostics, orbit correction)

Beam	Comparison, particles per cycle			
		Nuclotron-M (2010)	*Nuclotron-N (2012)*	*New ion source + booster (2014)*
p		$8\cdot10^{10}$	$5\cdot10^{11}$	$5\cdot10^{12}$
d		$8\cdot10^{10}$	$5\cdot10^{11}$	$5\cdot10^{12}$
^{4}He		$2\cdot10^{9}$	$3\cdot10^{10}$	$1\cdot10^{12}$
d↑		$2\cdot10^{8}$	$7\cdot10^{10}$ *(SPI)*	$7\cdot10^{10}$ *(SPI)*
$^{7}Li^{6+}$		$7\cdot10^{9}$	$3\cdot10^{10}$	$5\cdot10^{11}$
$^{12}C^{6+}$		$6\cdot10^{9}$	$3\cdot10^{10}$	$3\cdot10^{11}$
$^{14}N^{7+}$		$3\cdot10^{7}$	$3\cdot10^{8}$	$5\cdot10^{10}$
$^{24}Mg^{12+}$		$7\cdot10^{8}$	$4\cdot10^{9}$	$5\cdot10^{10}$
$^{40}Ar^{18+}$		$8\cdot10^{6}$	$2\cdot10^{9}$	$2\cdot10^{10}$
$^{56}Fe^{28+}$		$4\cdot10^{6}$	$2\cdot10^{9}$	$5\cdot10^{10}$
$^{58}Ni^{26+}$				
$^{84}Kr^{34+}$		$2\cdot10^{5}$	$1\cdot10^{8}$	$1\cdot10^{9}$
$^{124}Xe^{48/42+}$		$1\cdot10^{5}$	$7\cdot10^{7}$	$1\cdot10^{9}$
$^{181}Ta^{61+}$				
$^{197}Au^{65/79+}$			$1\cdot10^{8}$	$1\cdot10^{9}$
$^{238}U^{28+}$				

Heavy Ion Source KRION-6T

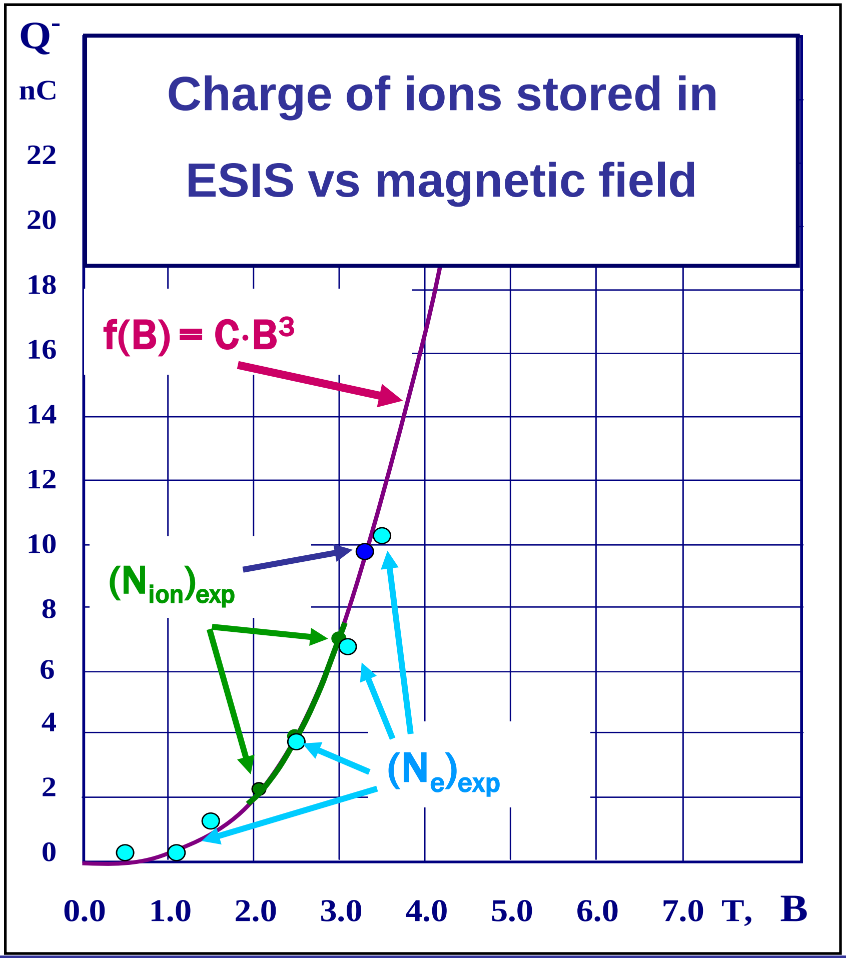
(E.D.Donets, E.E.Donets)

Status: Construction of working prototype



Foreinjector scheme

Assembled vacuum and cryogenic vessels of the KRION-6T



Assembled Source of polarized atoms (deuterons and hydrogen) at the test bench in INR RAS

Alignement nodes for RF and magnets

Vacuum chamber of the dissotiator and constant sextupoles magnets

Sextupole electromagnet

Mass-spectrometer

Vacuum chamber of mass-spectrometer

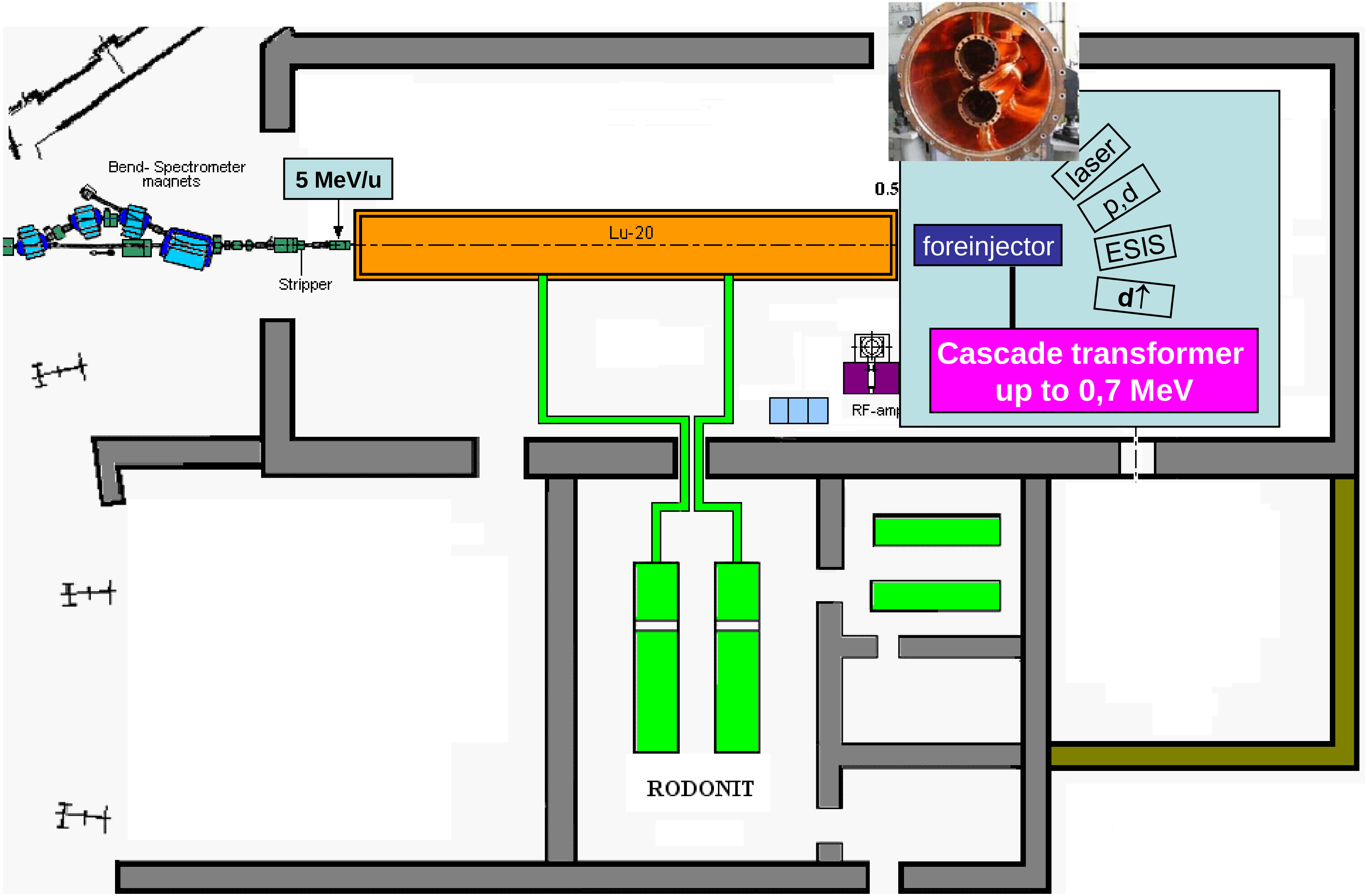
Helium leackage detector

Cryo generator

Dissotiator

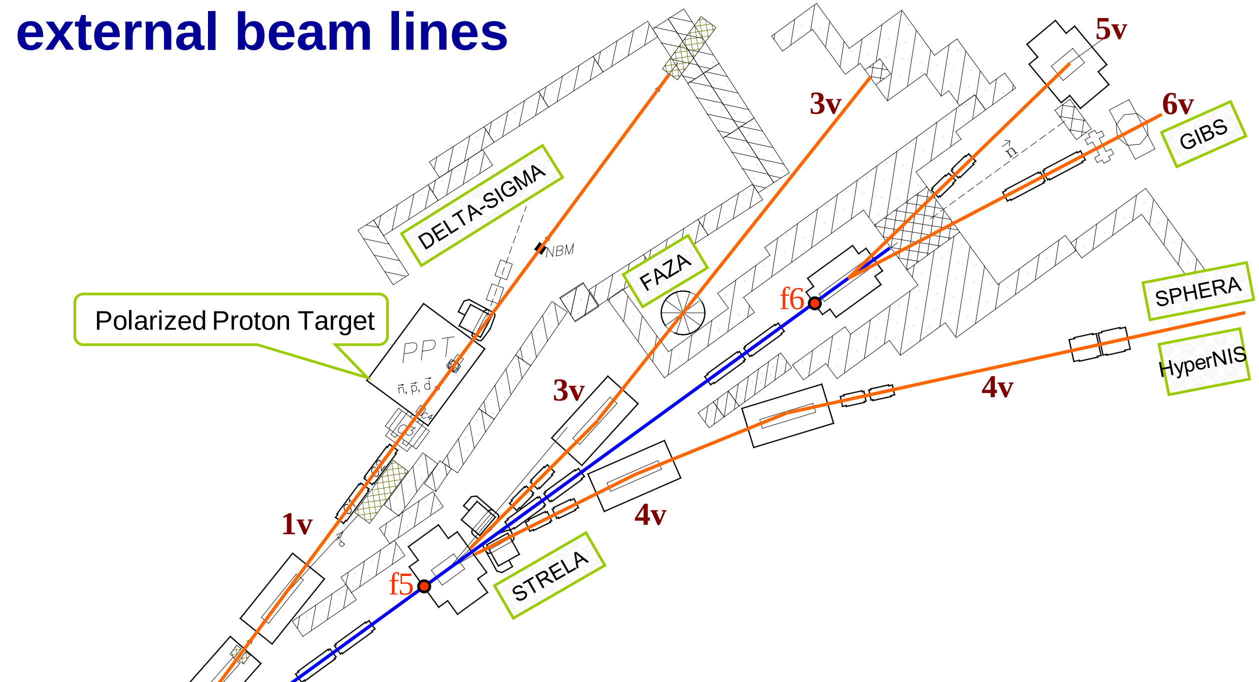
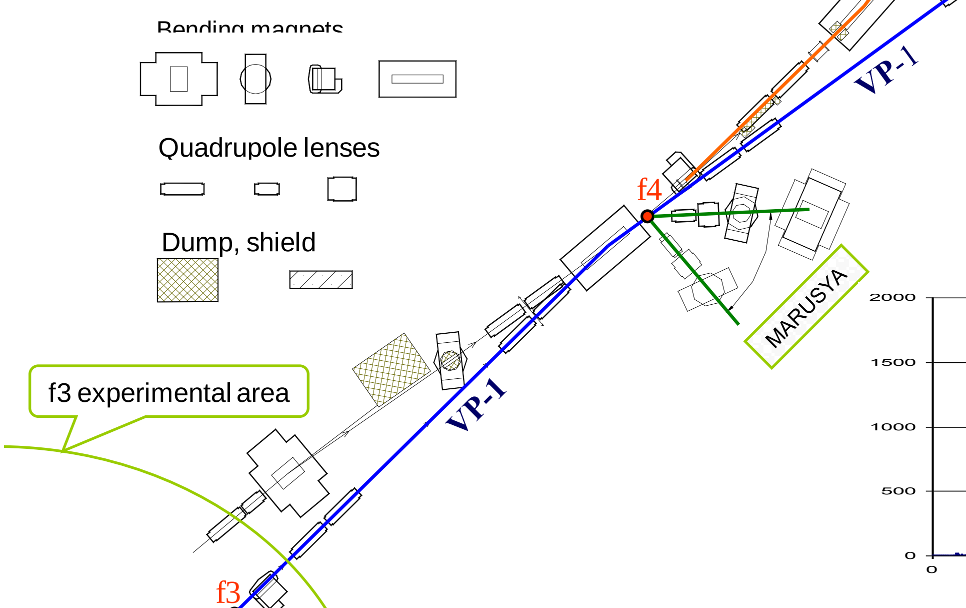
Turbomolecular pump

Baloons for deuterium and oxigen (5l)

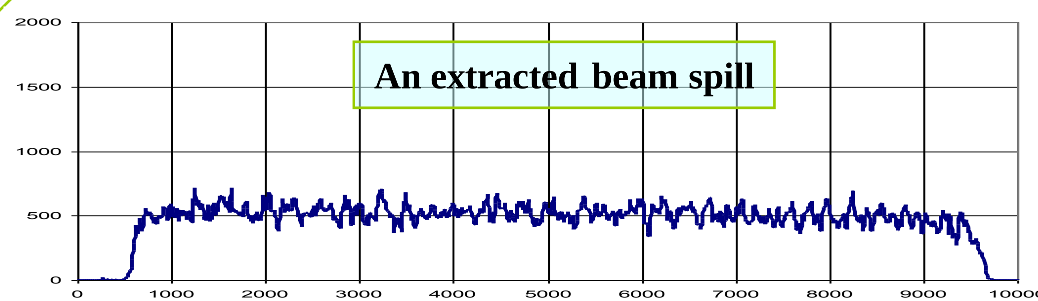

Bend- Spectrometer magnets
5 MeV/u
Stripper
Lu-20
0.5
laser
p,d
ESIS
foreinjector
d↑
Cascade transformer up to 0,7 MeV
RF-amp
RODONIT

Nuclotron external beam lines

Parameter	Value
Momentum range (z/A=1/2), GeV/c/u	0.6 – 6.8
Momentum spread, σ	0.04 – 0.08
Extraction time ,s	10
Beam emittance (max)	2π
Beam size in a waist, σ	≤ 1
Extraction efficiency,%	> 90

Energy range, GeV/amu	**0.2 - 6.0**
Duration, s, from up to	**0.01 - 10**
Extraction efficiency, %	**95**
Cycle	**1 Hz**



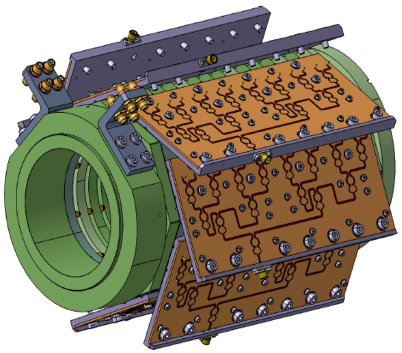
Test experiment on stochastic cooling at Nuclotron

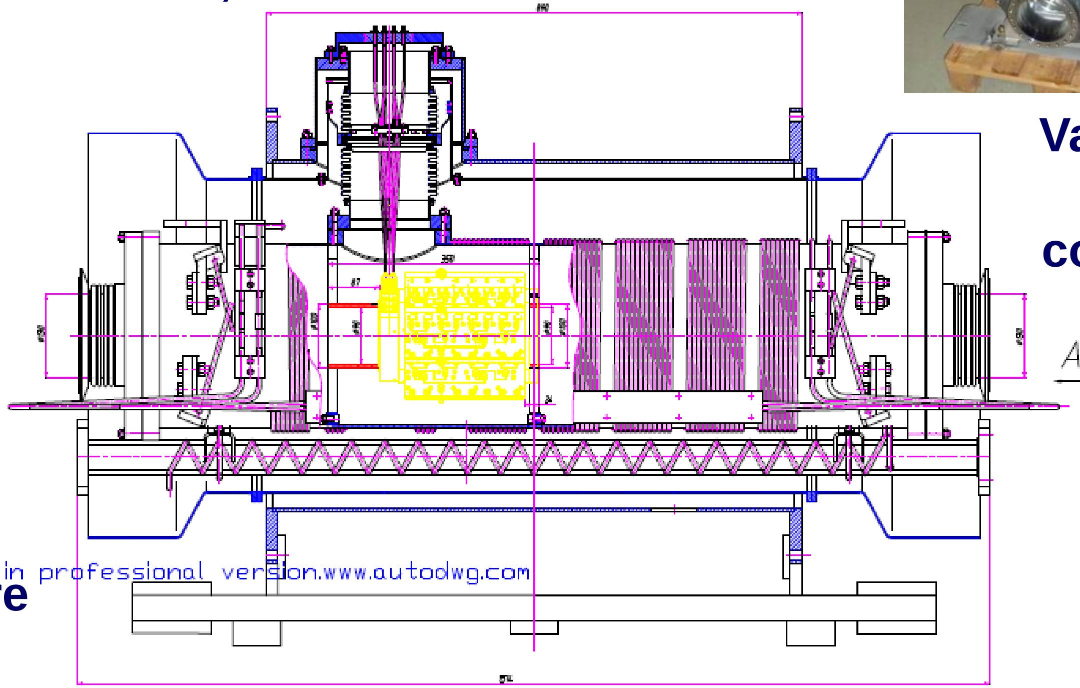
Collaboration JINR / FZ Jülich

Stochastic cooling system prototype at Nuclotron for HESR/NICA

2 ÷ 4 GHz, 100W

Vacuum tank with slot-coupler (FZJ)





Slot-coupler structure (is made at FZJ now

New project to the JINR Topic plan, to be proposed at January 2011 to PP PAC

Nuclotron-M -> Nuclotron-N

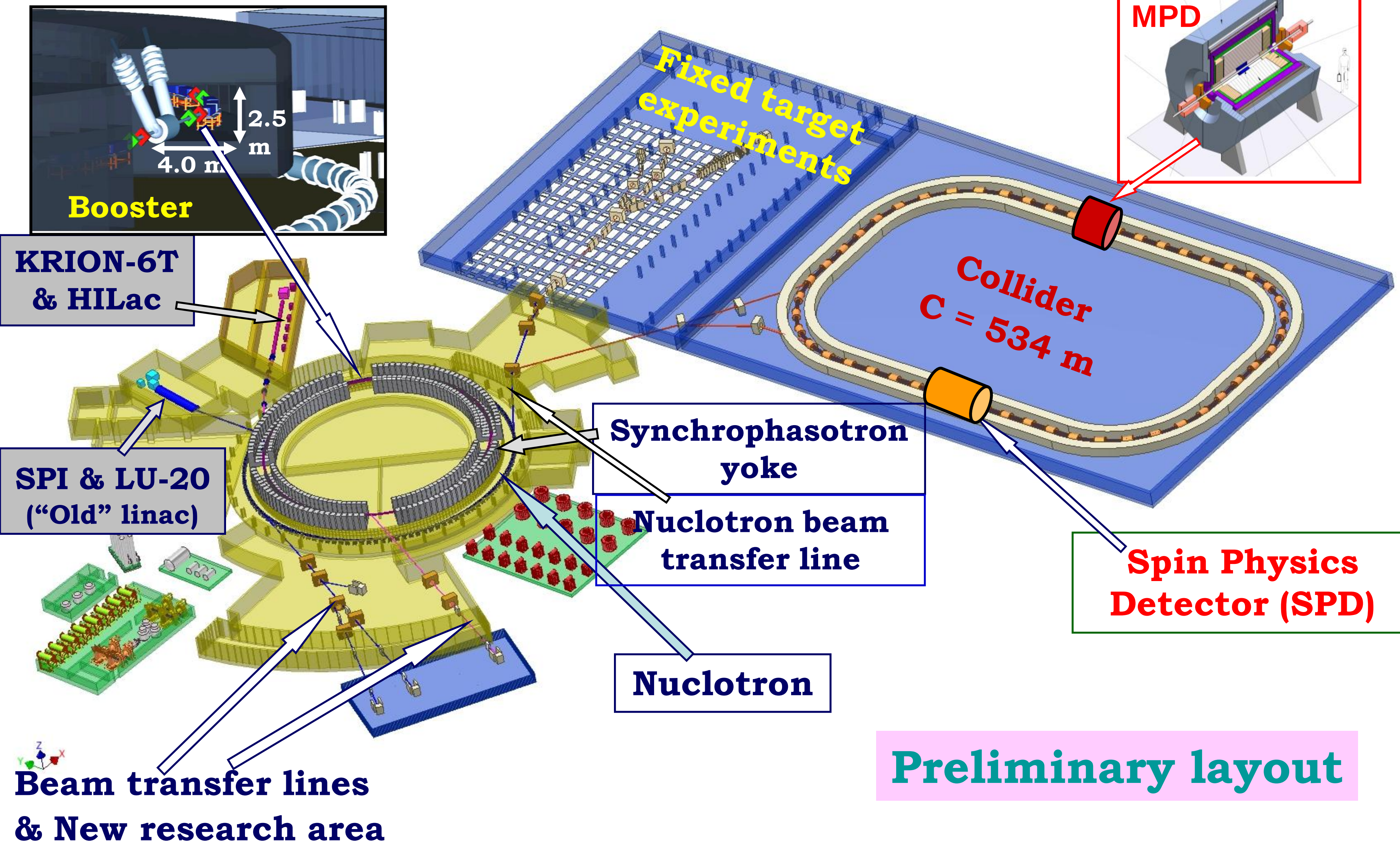
To be designed, constructed and commissioned:

1. **Injection system** (to accept Booster beam)
2. **RF system – new version with bunch compression**
3. **Dedicated diagnostics**
4. **Single turn extraction with fine synchronization**
5. **Polarized protons acceleration in Nuclotron** *)

*) Can be postponed

To be commissioned in 2014

NICA accelerator facility (leader I.Meshkov)



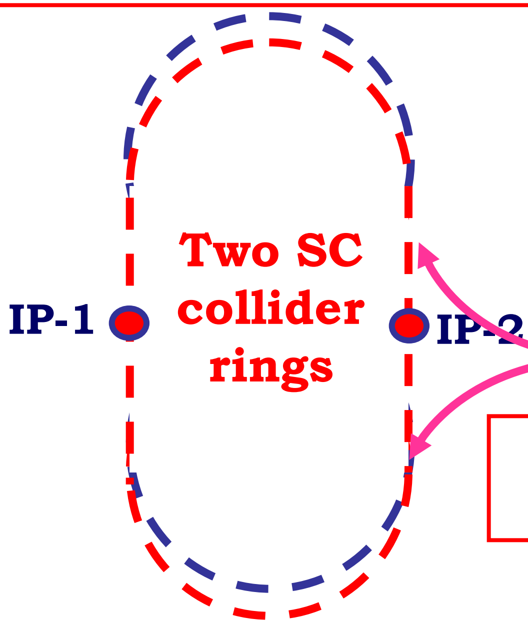
Heavy Ion Mode: Operation Regime and Parameters

Injector: 2 10^9 ions/pulse of $^{197}Au^{32+}$
at energy of 6.2 MeV/u

Collider (45 Tm)
Storage of
26 bunches by ~ $1x10^9$ ions per ring
at 1 - 4.5 GeV/u,
electron and/or stochastic cooling

Booster (25 Tm)
1(2-3) single-turn injection,
storage of 2□(4-6) 10^9,
acceleration up to 100 MeV/u,
electron cooling, acceleration
up to 600 MeV/u

Stripping (80%) $^{197}Au^{32+}$ => $^{197}Au^{79+}$



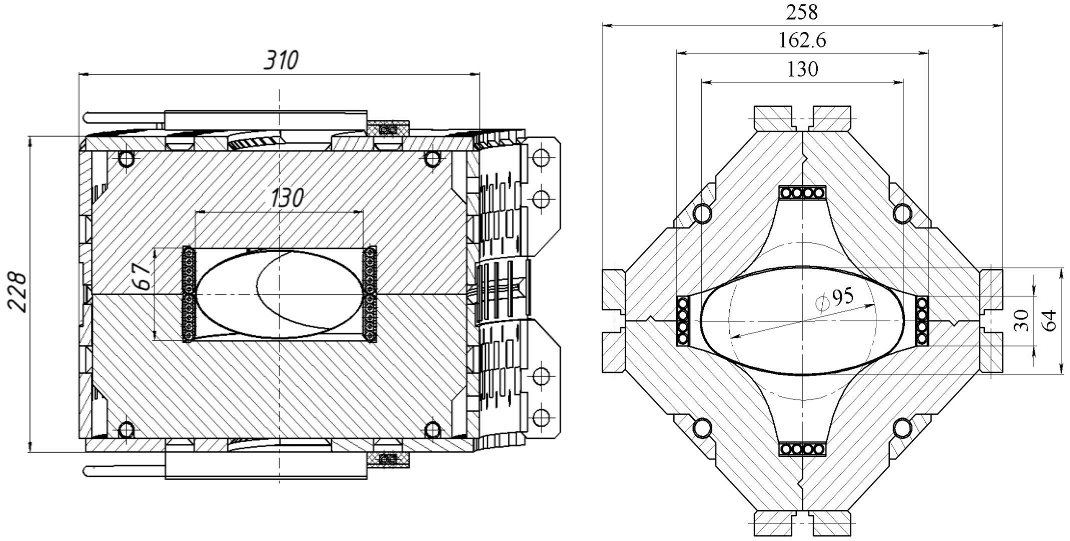
Nuclotron (45 Tm)
injection of one bunch
of 1.1 10^9 ions,
acceleration up to
1 - 4.5 GeV/u max.

2x26 injection cycles

Booster

Booster dipole yoke at assembling

SC magnetic system: manufacturing of magnet prototypes (H.Khodzhibagiyan and team)



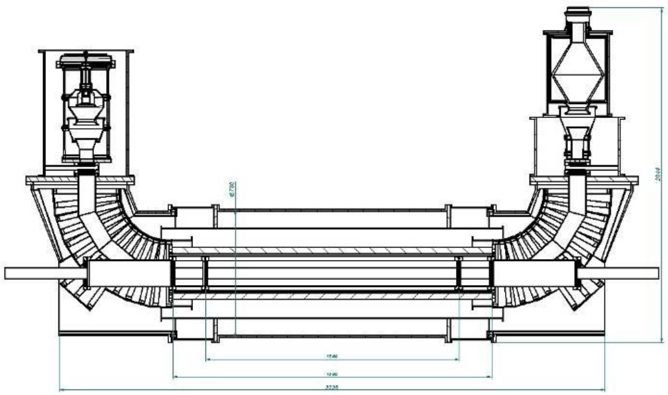
Cross section of the Booster dipole and quadrupole lens

RF system: working design and manufacturing (G.Kurkin and team, Budker INP, by contract)

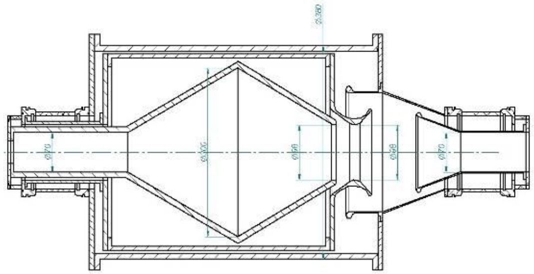
Booster

Electron cooler: working design

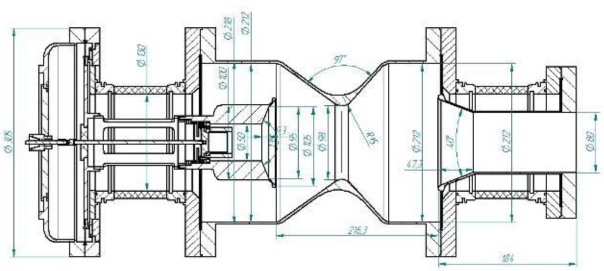
(A.Shabunov, A.Smirnov, N.Topilin, Yu.Tumanova, S.Yakovenko)



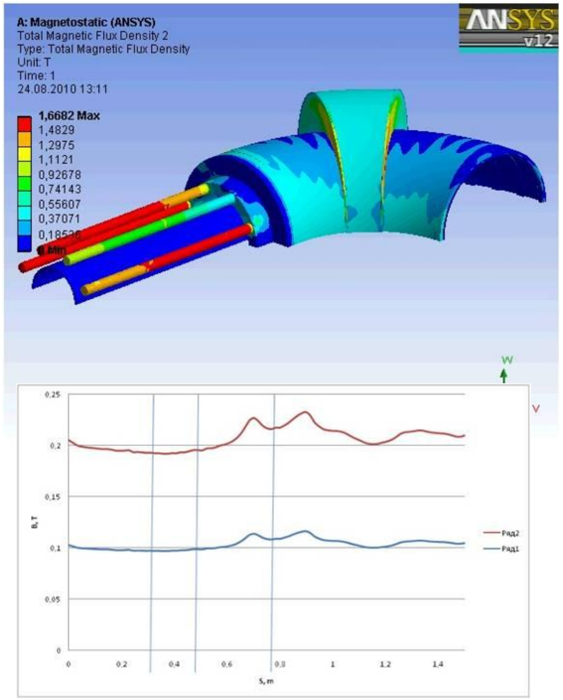
General view of the electron cooler



Electron collector



Electron gun



SC Solenoid field simulation

(R.Pivin)

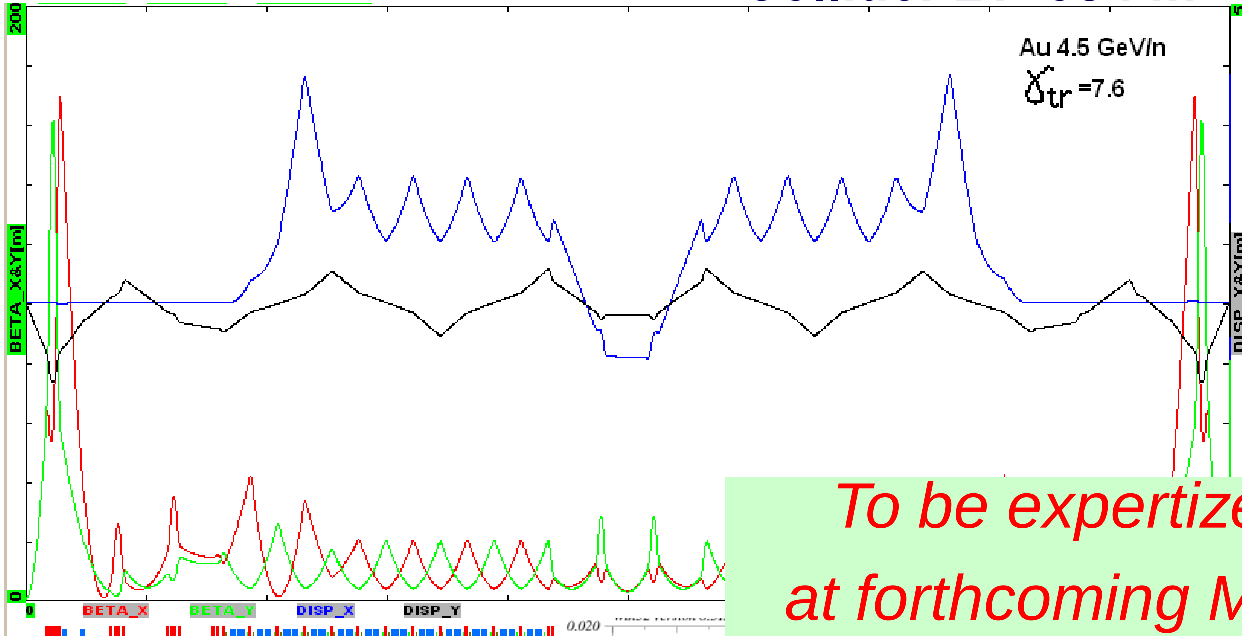
Booster

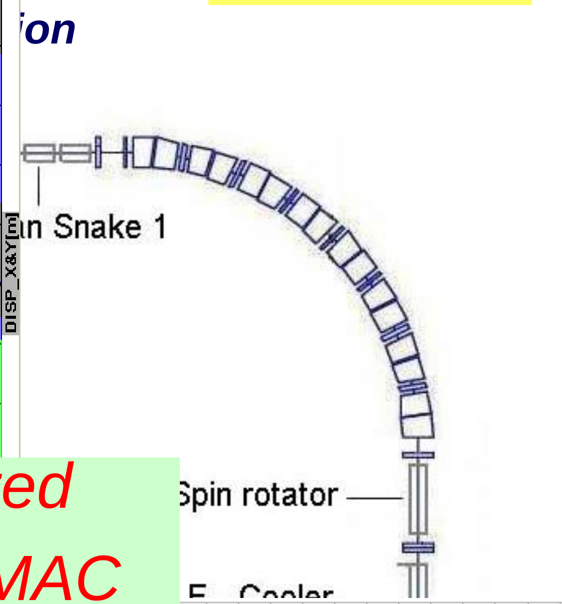
Synchrophasotron dismantling ⇒ in progress

Sept 2010: 2 + 0.5 quadrants are empty

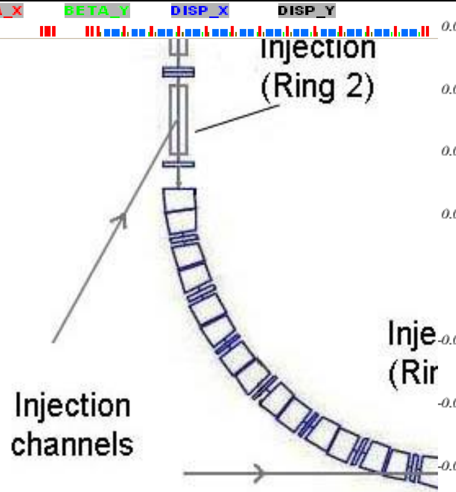
Collider 2T- 534 m

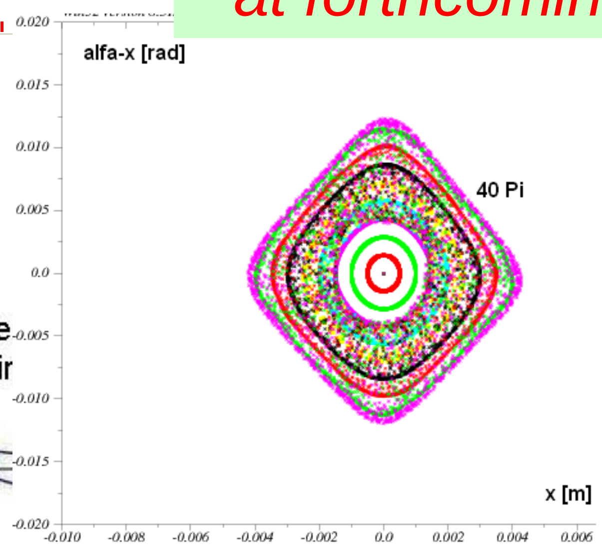
S.Kostromin

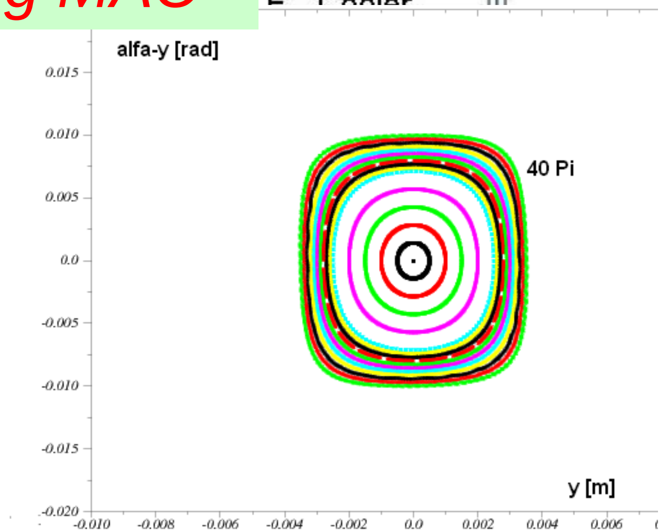




To be expertized at forthcoming MAC







Team of Collider developers during discussion

Luminosity scaling with energy

When ΔQ is fixed the peak luminosity is scaled with energy as the following (two outmost cases):

1. $L_1(E) = Const \cdot \beta^5 \cdot \gamma^6$ if unnormalized ("geometrical") emittance is constant;

2. $L_2(E) = Const \cdot \beta^4 \cdot \gamma^5$ if normalized emittance is constant.

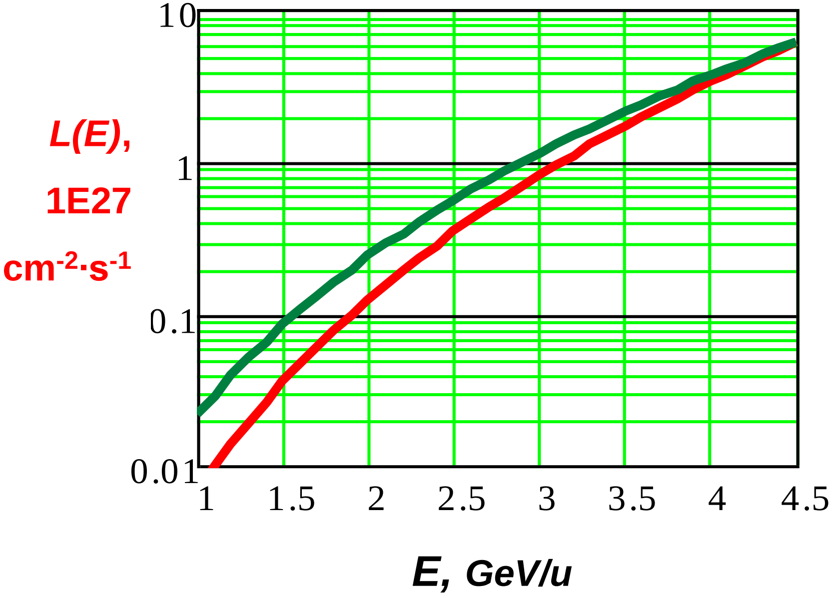
Luminosity scaling

for collider 2T- 534

L(4.5 GeV/u) = 6E27 $cm^{-2} \cdot s^{-1}$

L (3.5 GeV/u) = (1.7÷2.1)E27

L(1 GeV/u) = (0.7÷2.1)E25



Luminosity preservation

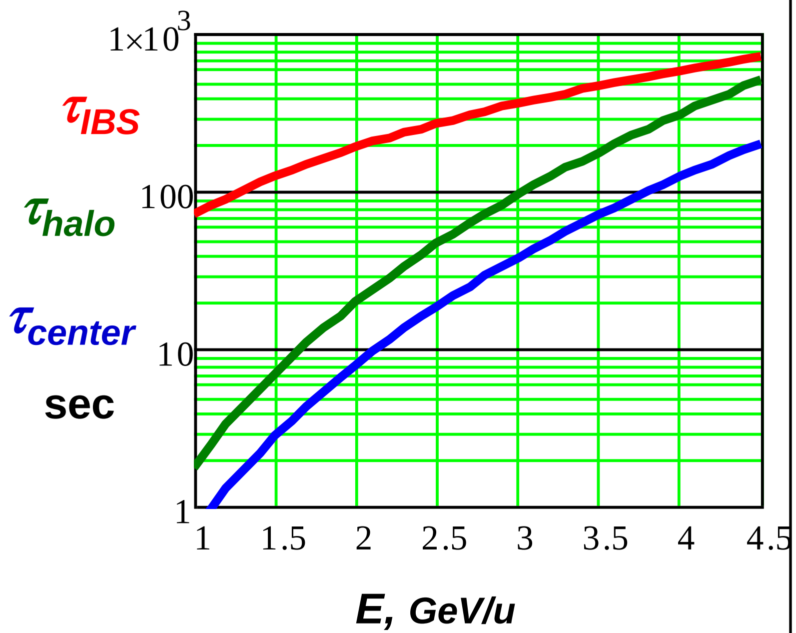
Beam life time defined by IBS

If ΔQ is fixed as before then beam life time by IBS is proportional to

$$\tau_{IBS} \propto \frac{A}{Z^2} \cdot \frac{\beta^2 \gamma^2 \varepsilon_{geom} \cdot (\Delta p / p) \cdot \sigma_s}{\Delta Q} \cdot f(\sigma_x, \sigma_y, \sigma_s, lattice\ functions)$$

Collider 2T - 534

τ_{IBS} and τ_{cool} (I_e = 1 A) vs ion energy



How to resolve the problem?

⇒ Smooth lattice functions to increase τ_{IBS}

(S.Kostromin, JINR & V.Lebedev, FNAL)

⇒ Stochastic cooling at

2.5 GeV/u < E < 4.5 GeV/u

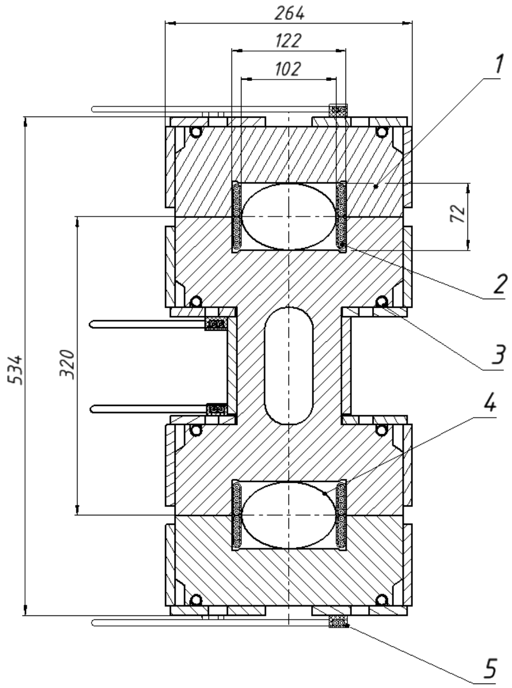
(T.Katayama, G.Trubnikov, N.Shurkhno);

⇒ Electron cooling at

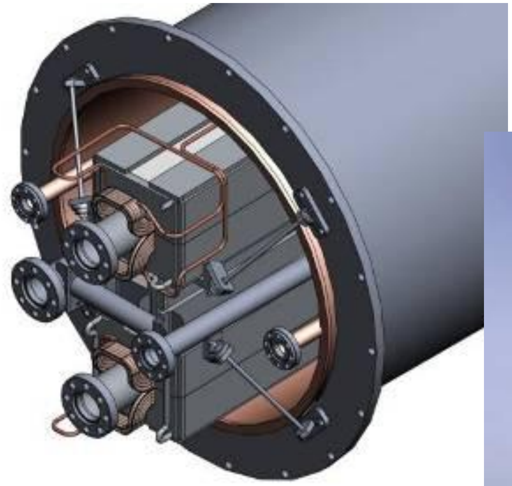
1.0 GeV/u < E < 2.5 GeV/u .

“Twin” magnets of NICA collider:
Max. field - 2T, super-ferric (Nuclotron-like), double aperture

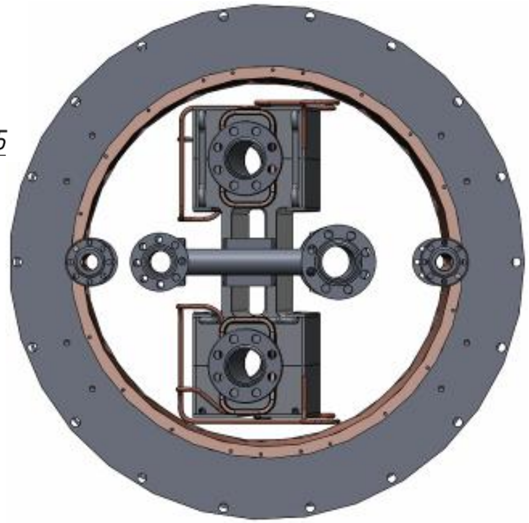
SC magnetic system: manufacturing of magnet prototypes
(H.Khodzhibagiyan and team)

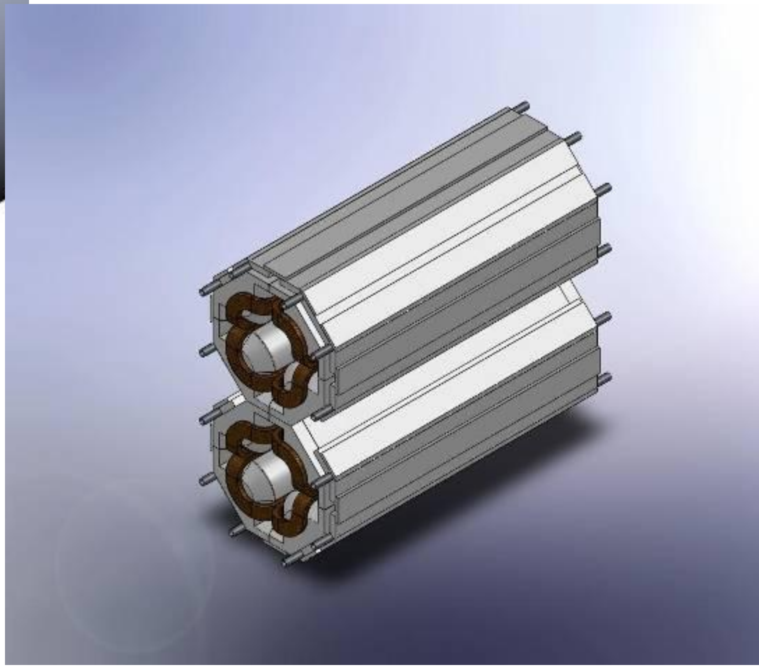


Dipole cross-section



Dipole 3D view



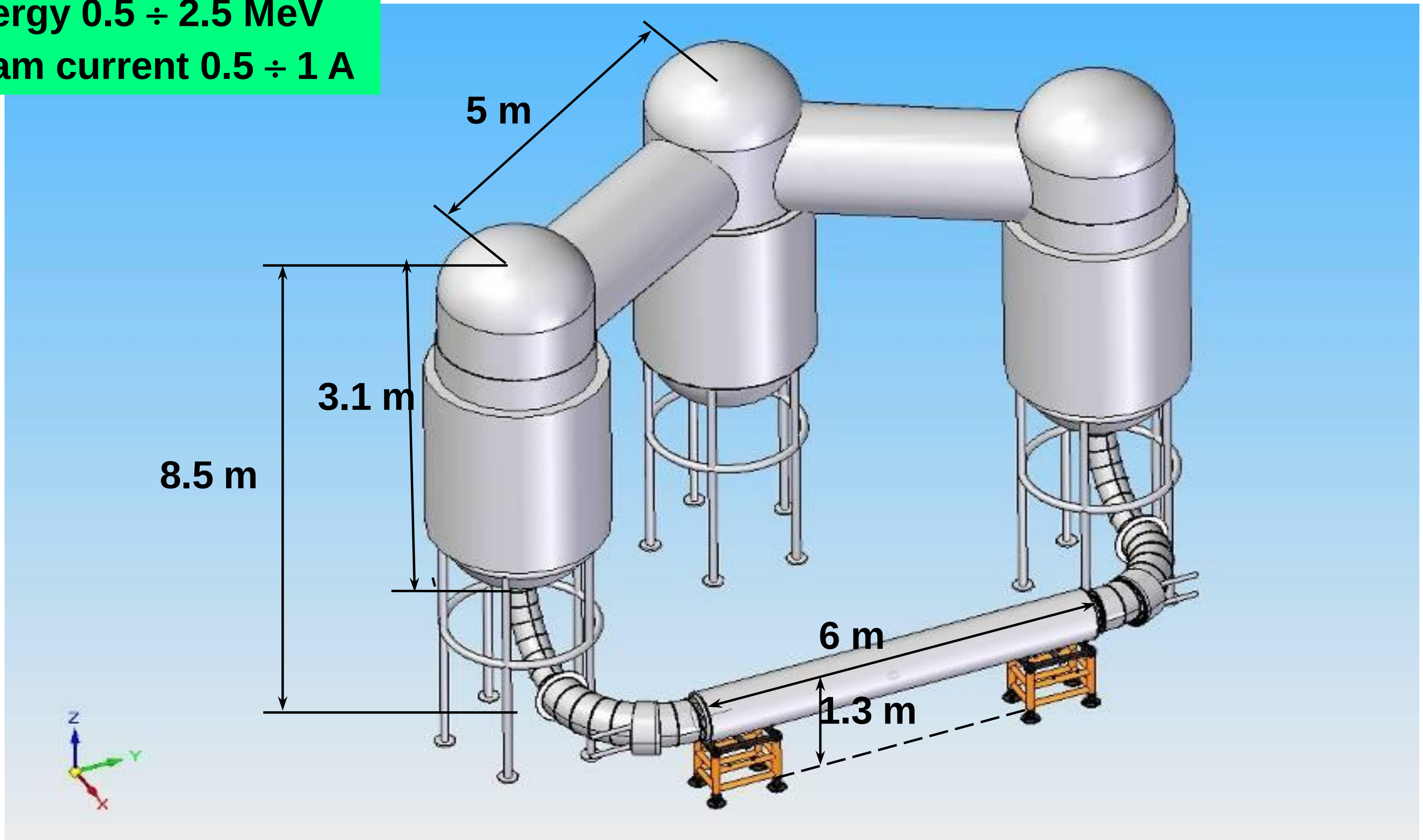


Quadrupole lense

HV Electron cooler: working design

A.Shabunov, A.Smirnov, N.Topilin, Yu.Tumanova, S.Yakovenko – JINR
A.Filippov, M.Pashin, L.Fisher – All-Russian Institute for Electrotechnique

Electron energy 0.5 ÷ 2.5 MeV
Electron beam current 0.5 ÷ 1 A



Collider (Contnd)

- **Stochastic cooling system: conceptual design, test experiment**

  G.Trubnikov, N.Shurkhno, V.Seleznev– JINR, T.Katayama – Tokyo univ., R.Stassen – FZJ, L.Thorndahl - CERN

- **RF systems (Bar. Bucket system, bunching and maintaining RF systems): working design and manufacturing**

  A.Eliseev, JINR

  G.Kurkin and team, Budker INP, by contract

Dedicated run was performed at GSI, ESR (6-11 September 2010) to prove Stacking of the beam with Barrier Backet + stochastic cooling ON (required for HESR and NICA)

Next MAC will be held on October 4-5 at Dubna.

The Committee is asked to review and offer comment/recommendations relative the Nuclotron-M/NICA and the accompanying R&D plan on sub-projects.
In particular we request specific comments/recommendations in the following areas:

-**Does NICA TDR (and namely approved NICA collider concept) describe a configuration that is likely to meet the proposed mission objectives (NICA physics case)?**

- **Does it meet physics demands on beams: possibility of energy scan (optics flexibility) at maximal required luminosity?**

-**Does the execution strategy of Nuclotron-M/NICA mesh with the requirements of NICA project? What recommendations and modifications to the R&D program would be effective?**

The main tasks for the NICA project

In 2010:

- ✓ **Conceptual / working design of the collider,**
- ✓ **Preparation of the project for the state expertise in accordance with regulations of Russian Federation (under preparation at *State Specialized Project Institute*, Moscow),**
- ✓ **Construction of SC magnets prototypes (booster and collider dipoles).**

In 2011:

- ✓ **Passing through the state expertise,**
- ✓ **Beginning of construction of the HILAC, KRION (working version), Booster, Collider elements,**
- ✓ **Stochastic cooling experiment at Nuclotron.**

The NICA Collaboration

Budker INP

Budker INP Novosibirsk

- ✓ Booster RF system
- ✓ Booster electron cooler
- ✓ Collider RF system
- ✓ Collider SC magnets (expertise)
- ✓ HV e-cooler for collider
- ✓ Electronics
- ✓ Injector linac (under discussion)

IHEP (Protvino): Injector Linac

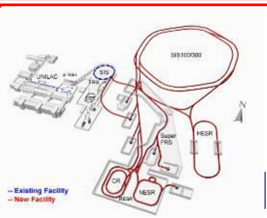
FZ Jűlich (IKP): HV E-cooler & Stoch. cooling

Fermilab: HV E-cooler, Beam dynamics, Stoch. cooling

CERN: Beam dynamics, E-cooling, Acceler. technique

All-Russian Institute for Electrotechnique
HV Electron cooler

BNL (RHIC)
Electron & Stoch. Cooling



GSI/FAIR
ipoles for Booster/SIS-100
ipoles for Collider

ITEP: Beam dynamics in the collider

Corporation "Powder Metallurgy" (Minsk, Belorussia): Technology of TiN coating of vacuum chamber walls for reduction of secondary emission

NICA construction schedule

	2010	2011	2012	2013	2014	2015	2016
ESIS KRION	Design	Manufactrng	Manufactrng	Mount.+commis.	Operation	Operation	Operation
LINAC + channel	Design	Manufactrng	Mount.+commis.	Mount.+commis.	Operation	Operation	Operation
Booster + channel	Design	Manufactrng	Mount.+commis.	Commis/opr	Operation	Operation	Operation
Nuclotron-M	Commis/opr	Operation	Operation	Operation	Operation	Operation	Operation
Nuclotron-M → NICA	Design	Design / Manufactrng	Manufactrng	Mount.+commis.	Commis/opr	Operation	Operation
Channel to collider	Design	Design	Manufactrng	Mount.+commis.	Commis/opr	Operation	Operation
Collider	Design	Design	Manufactrng	Manufactrng / Mount.+commis.	Mount.+commis.	Commis/opr	Operation
Diagnostics	Design	Manufactrng	Mount.+commis.	Mount.+commis.	Commis/opr	Commis/opr / Operation	Operation
Power supply	Design	Manufactrng	Mount.+commis.	Commis/opr	Commis/opr	Commis/opr / Operation	Operation
Control systems	Design	Manufactrng	Mount.+commis.	Commis/opr	Commis/opr	Commis/opr / Operation	Operation
Cryogenics	Manufactrng	Manufactrng	Commis/opr	Commis/opr	Operation	Operation	Operation
MPD	R&D	R&D	Mount.+commis. / Mount.+commis.	Mount.+commis.	Mount.+commis.	Commis/opr	Operation
Infrastructure	Mount.+commis.	Mount.+commis.	Mount.+commis.	Commis/opr	Operation	Operation	Operation

R&D	Design	Manufactrng	Mount.+commis.	Commis/opr	Operation

Conclusion

The NICA design passed the phase of concept formulation and is presently under

- ✓ **detailed simulation of accelerator elements parameters,**
- ✓ **development of working project,**
- ✓ **manufacturing and construction of prototypes,**
- ✓ **preparation of the project for state expertise**

in accordance with regulations of Russian Federation.

The project realization plan foresees a staged construction and commissioning of accelerators forming the facility. The main goal is the facility commissioning in 2016.

Thank you for your attention !