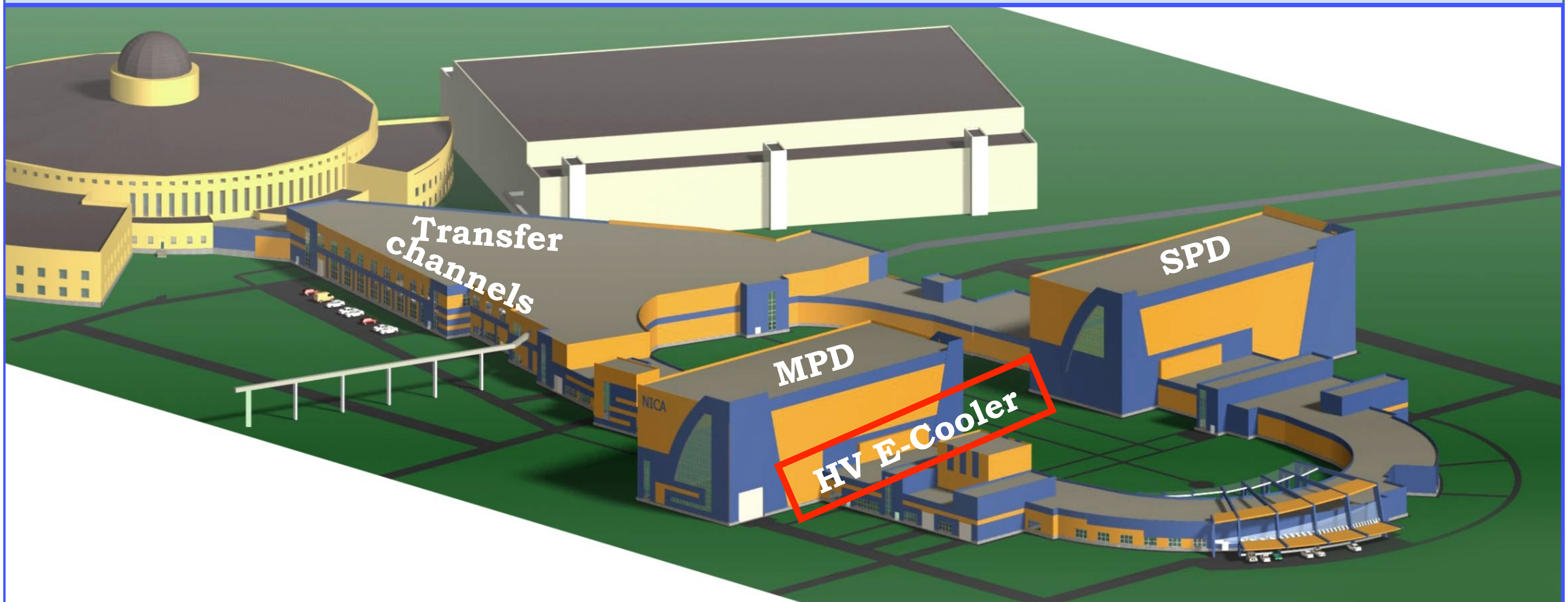
International Workshop on Beam Cooling and Related Topics

COOL'15

HV Electron Cooling System for NICA Collider

I.Meshkov for NICA Team

JINR, Dubna



29 September 2015

Outline

NICA Collider Luminosity

Two Energy Ranges of the Collider and Two Regimes:

A) Space charge (SC) dominated regime => E_{ion} = 1 - 3 GeV/u

Electron cooling is mandatory (!),

acceptance is filled with ions up to $\Delta Q = \Delta Q_{max} = 0.05$,

$L = L_{max} = (0.01 – 1) \times 10^{27}\ \mathrm{cm}^{-2} \times \mathrm{s}^{-1}$

B) Intrabeam scattering (IBS) regime => E_{ion} = 3 - 4.5 GeV/u

$L = 1 \times 10^{27}\ \mathrm{cm}^{-2} \times \mathrm{s}^{-1}$

IBS is suppressed by stochastic and electron cooling,

L is artificially limited by max detector rate at E_{ion} *> 3 GeV/u)*

In this energy range electron and stochastic cooling are supposed to be used in the NICA Collider simultaneously providing a long life time of the Collider luminosity.

See details in: *G.Trubnikov, Thursday, 11:10 - 11:40*

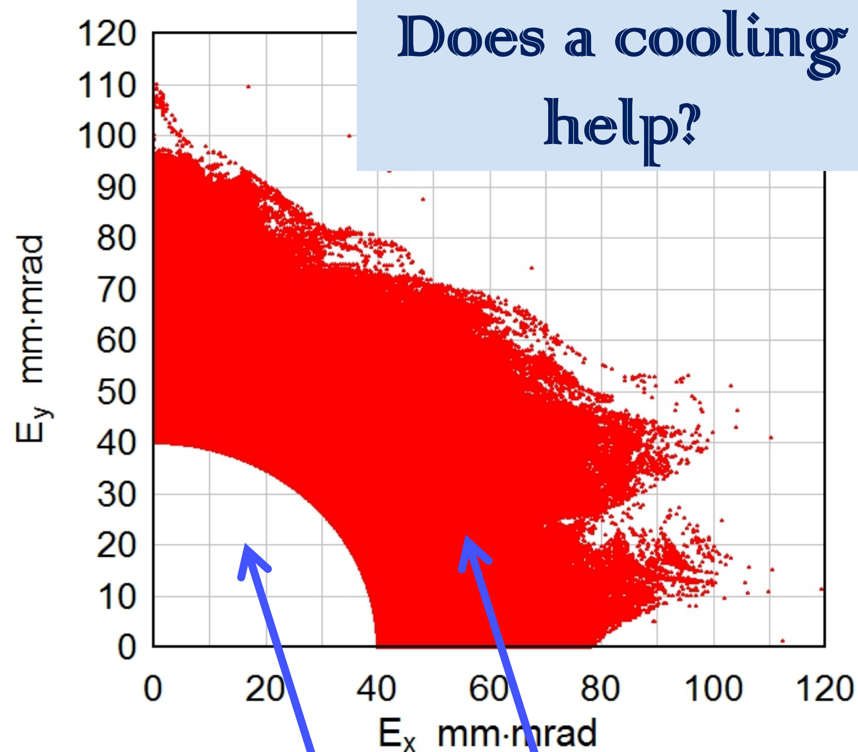
Introduction: Why do we need HV E-Cooler for the NICA Collider

Dynamics aperture of the NICA Collider

A.Bolshakov and P.Zenkevich (ITEP) for NICA

Preliminary

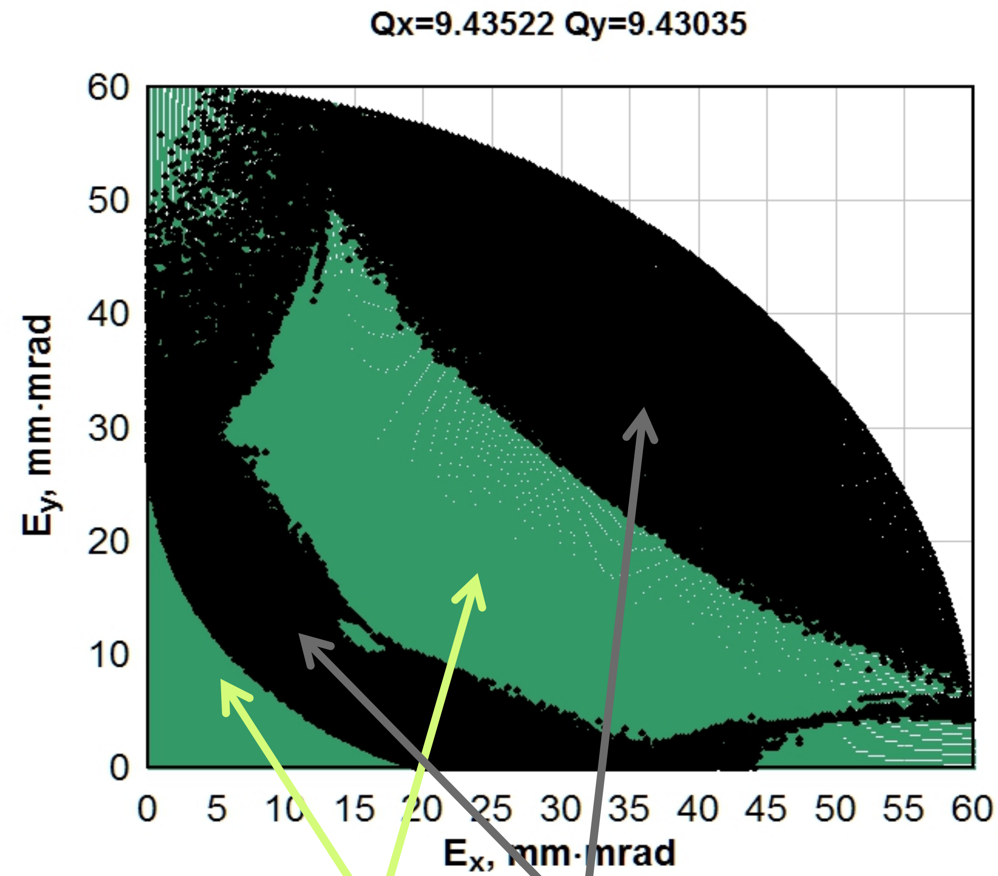
No magnet fringe fields



Does a cooling help?

Stable **Unstable**

Influence of the magnet fringe fields

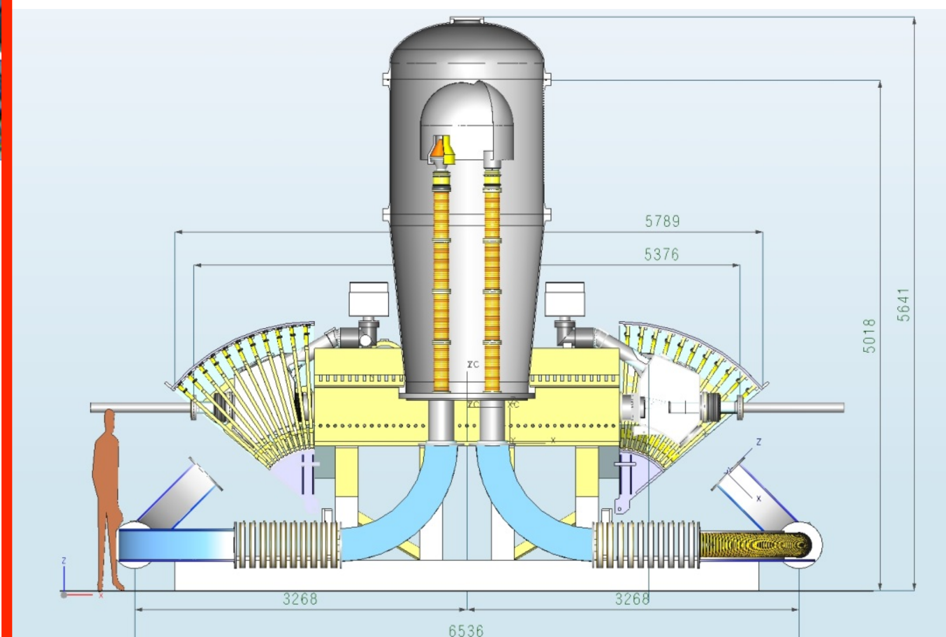


Stable **Unstable**

1. The experience we have

Max. electron energy, MeV   4.3
Working e-beam current, A 0.1 – 0.5 A
Max. e-beam current, A   1.6 (1.9)
Working I_{loss}/I_{beam} , ppm   1.0
HV generator   Pelletron ("Van der Graaf")
Unmagnetized electron beam
[*A.Shemykin et al., FERMILAB-CONF-06-194-AD*]

Max. electron energy, MeV   0.025 ÷ 2
Electron beam current, A   0.1 ÷ 3.0
HV generator   Cascade transformator
Electron beam   magnetized
[*V.Parkhomchuk et al., Sarantsev seminar (Sep. 2015)*]



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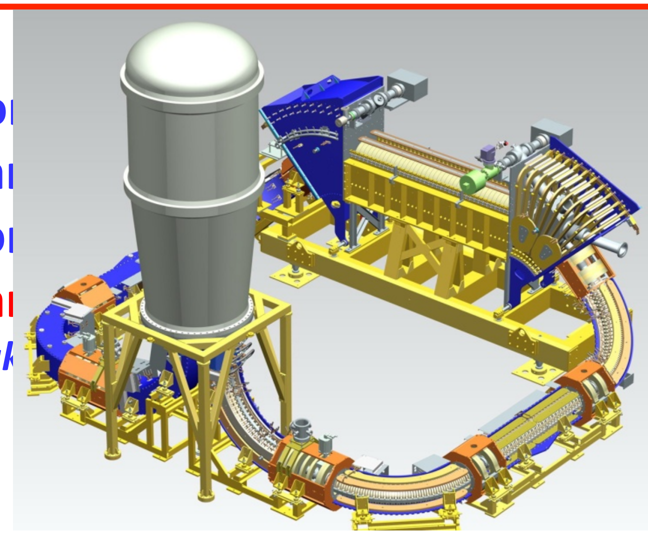
Max. electro

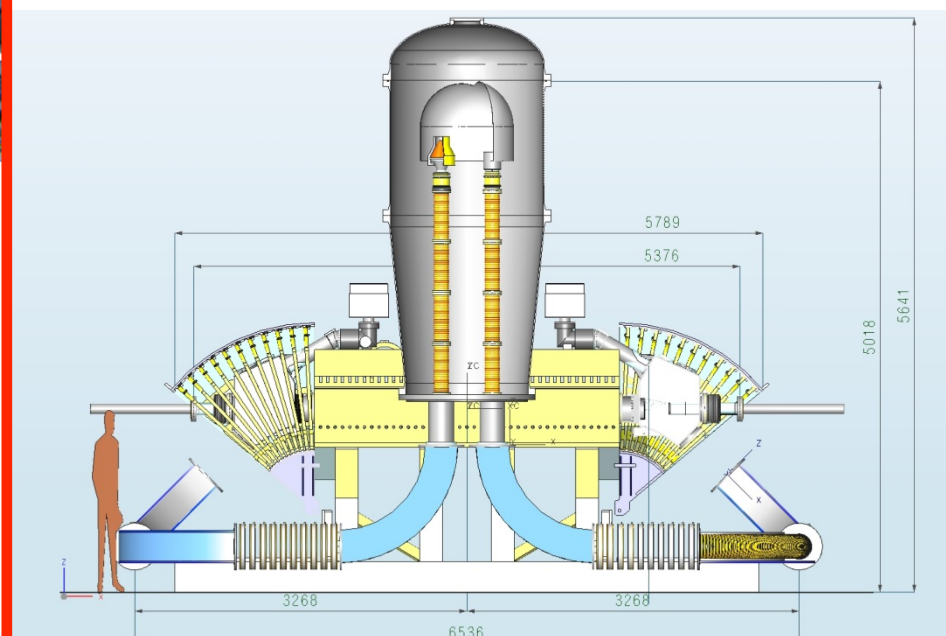
Electron bea

HV generato

Electron bea

[*V.Parkhomchuk*





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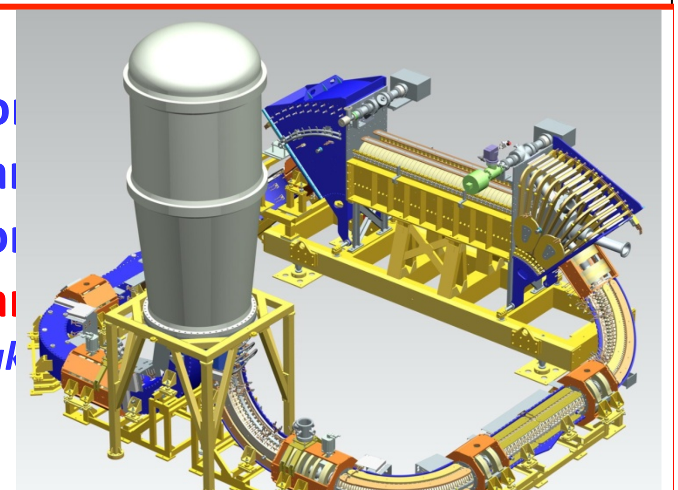
Max. electro
Electron bea
HV generato
Electron bea
[*V.Parkhomchuk*



2. HV and HE electron coolers

1) High Voltage electron coolers – DC HV regime, $1 < E_e < 8$ MeV

Projects under development: COSY (FZJ) NICA (JINR), HESR (FAIR), HIAF (Lanzhou)

2) High Energy electron coolers – RF acceleration, $8 > E_e$:

ERL scheme, coherent e-cooling, optical e-cooling …

Projects under development: RHIC BES (BNL), MEIC (JLab)

At COOL'2015 we have:

6 oral contributions on HV e-coolers,

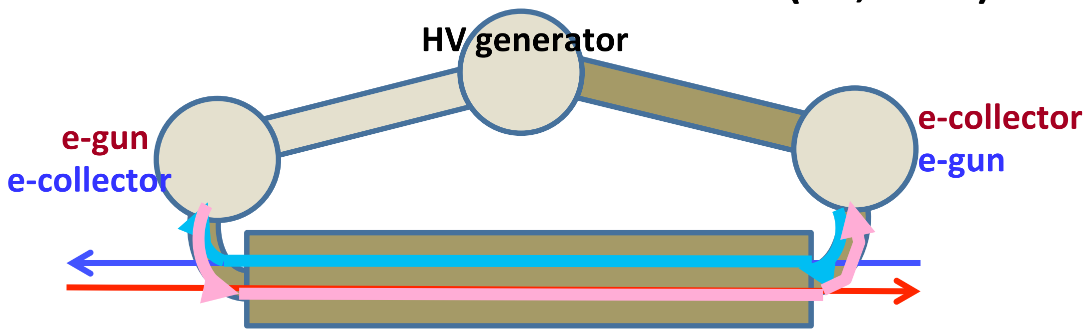
12 oral contributions on HE e-coolers and related topics.

The problem under active development

3. The concepts of a HV e-cooler

3.1. The first concepts – two beams or not…

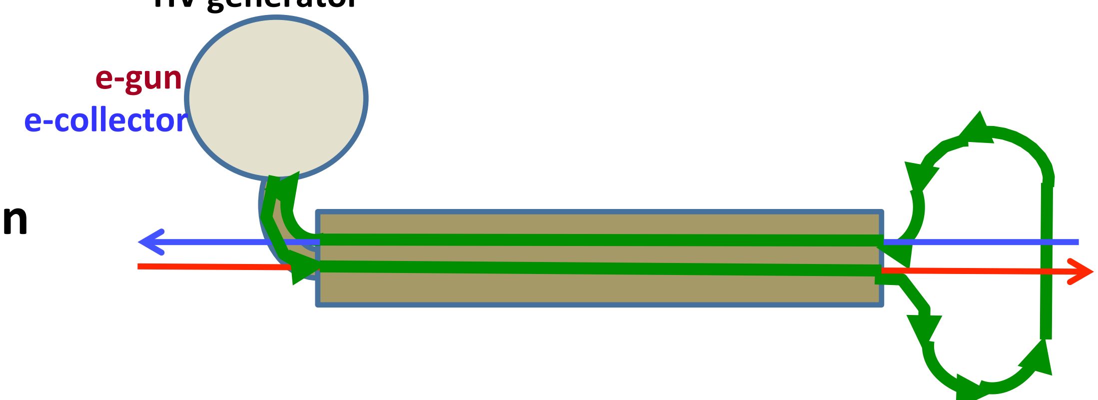
1. Evident scheme – two beams (IM, 2008)



The solution is technically good, however the electron beam is a feed back between two ion beams: an instability in one ion beam excites electron beam that brings the instability signal to another ion beam, i.e. we have

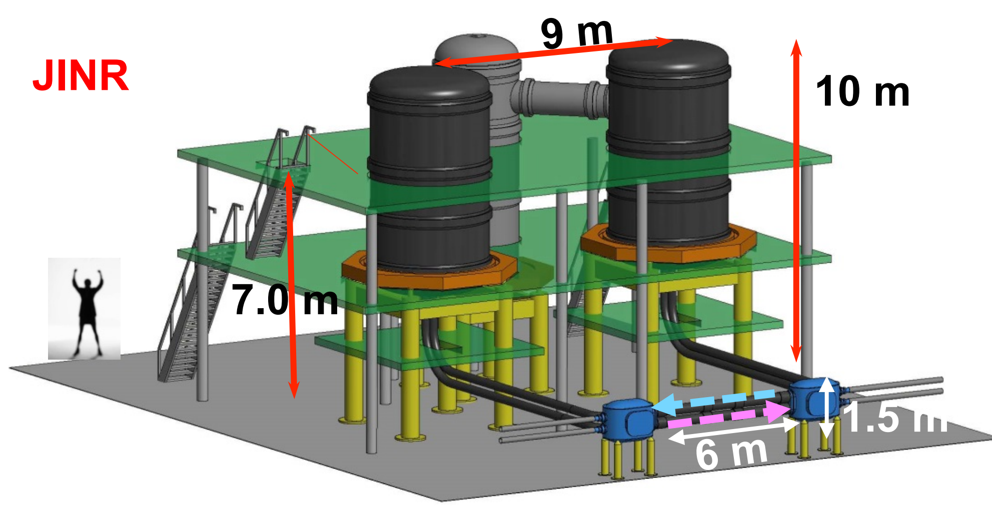
"the three beams' instability"!

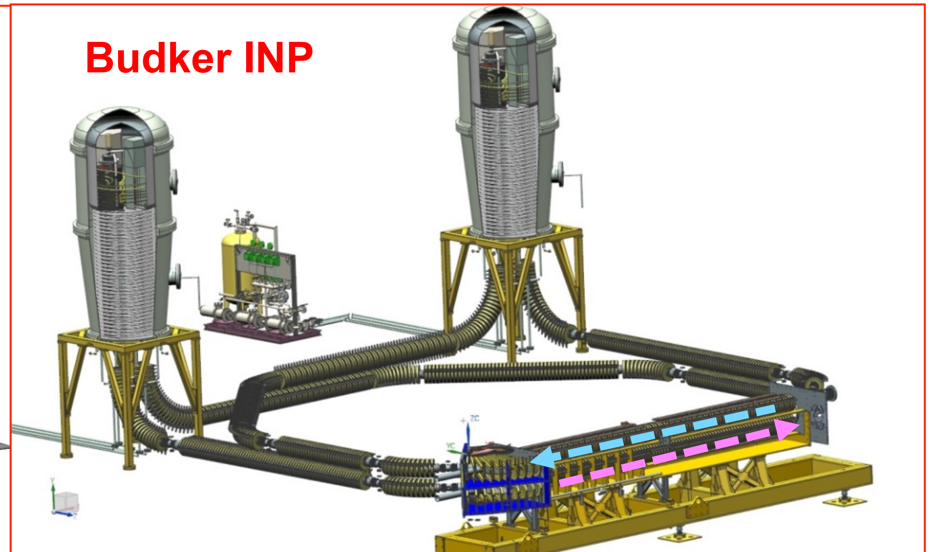
2. More sophisticated scheme –
– one (common) electron beam (VP,2011)



Finally the scheme with common electron beam has been rejected.

3.2. Two concepts of the HV electron cooler with two electron beams





Main parameters of the e-coolers	
DC magnetized (!) electron beam	
Electron energy, MeV	0.5 – 2.5
Electron beam current, Amp	0.1 – 1.0
Solenoid magnetic field, T	0.1 – 0.2
Electron transverse temperature in PRF, eV	1.0 – 5,0
Electron longitudinal temperature in PRF, meV	5,0
Electron energy spread in Lab. system, *σE/E*	1e-5

The solenoids in both concepts are supposed to be superconducting

Warm solenoids in JINR version (4 copper layers winding): P_{total} = 500 kW

3.2. Two concepts of the HV electron cooler with two electron beams

Budker INP

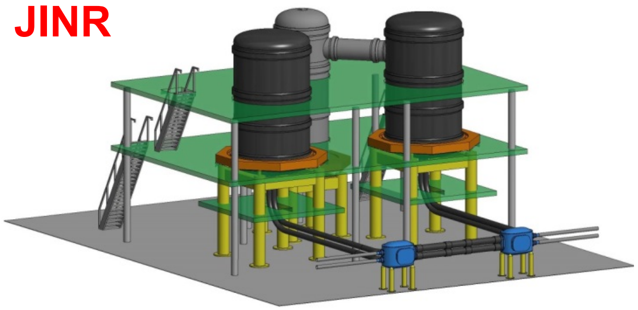
Two "COSY – coolers" with independent solenoid systems

<u>Advantage</u>: COSY Cooler has been constructed and demonstrated its reliability in the first tests *(see yesterday talks by V.Kamerdzhiev and V.Reva)*.

<u>Disadvantages</u>: 1) a long solenoid system

2) Problematic design for SC solenoids inside the tanks (the COSY design is not applicable!

JINR

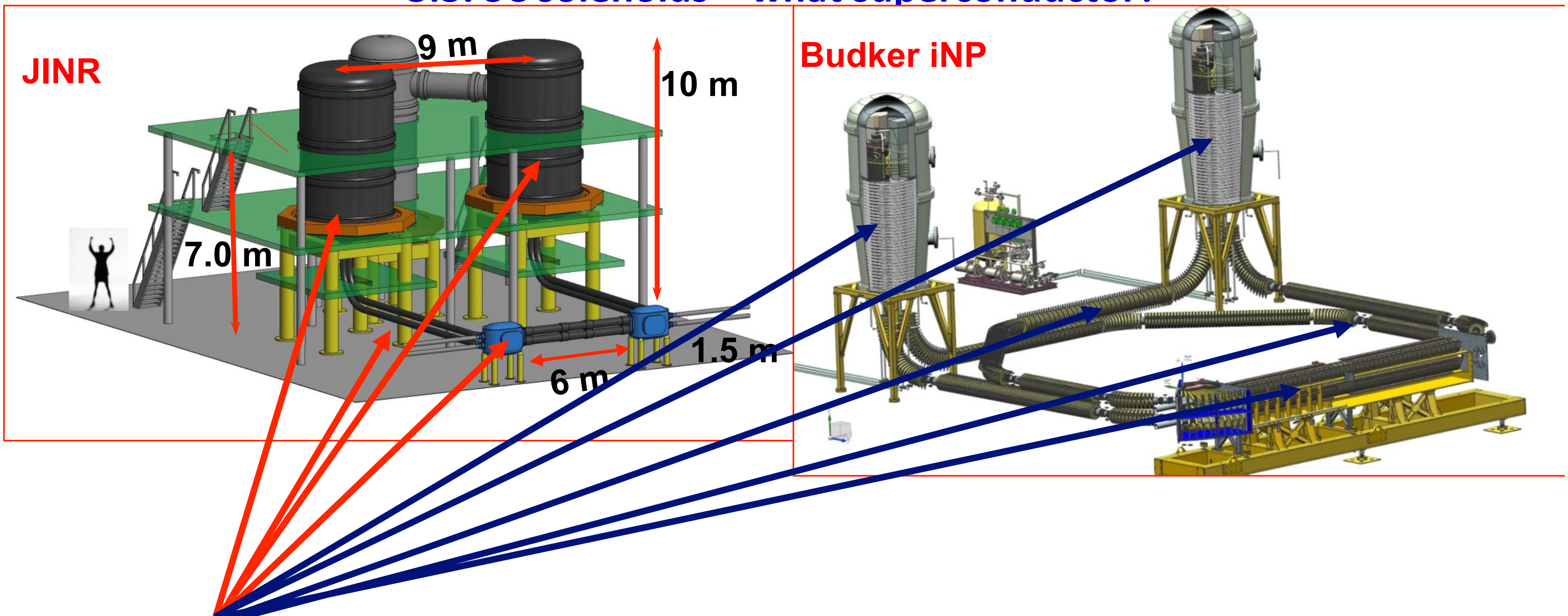


Three tanks system: the leftmost and rightmost tanks contain by two accelerating/decelerating tubes – one with the "blue" beam, another with the beam of the opposite direction – (electron guns and collectors), the middle tank contains the HV generator and terminal with the power supplies for the electron guns and the collectors.

<u>Advantage</u>: a short solenoid system (about twice shorter of the BINP system);
a reliable scheme of the voltage multiplier applied for HV generation.

<u>Disadvantage</u>: probable problems at tuning of the cooler regimes when electron beams are ON.

3.3. SC solenoids – what superconductor?

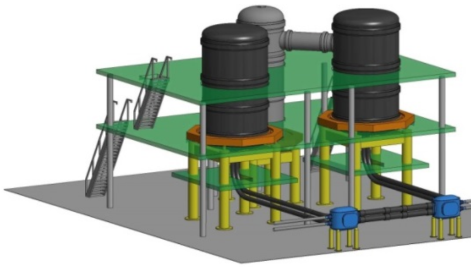


SC solenoids

JINR version

NbTi cable Ø *0.5* мм 0.9 \$/m L = 275 km \$250 k

HTSC tape 12 x 0.5 мм^2 30 \$/m L ≈ 11.5 km \$350 k



4. NICA Electron Cooler Design

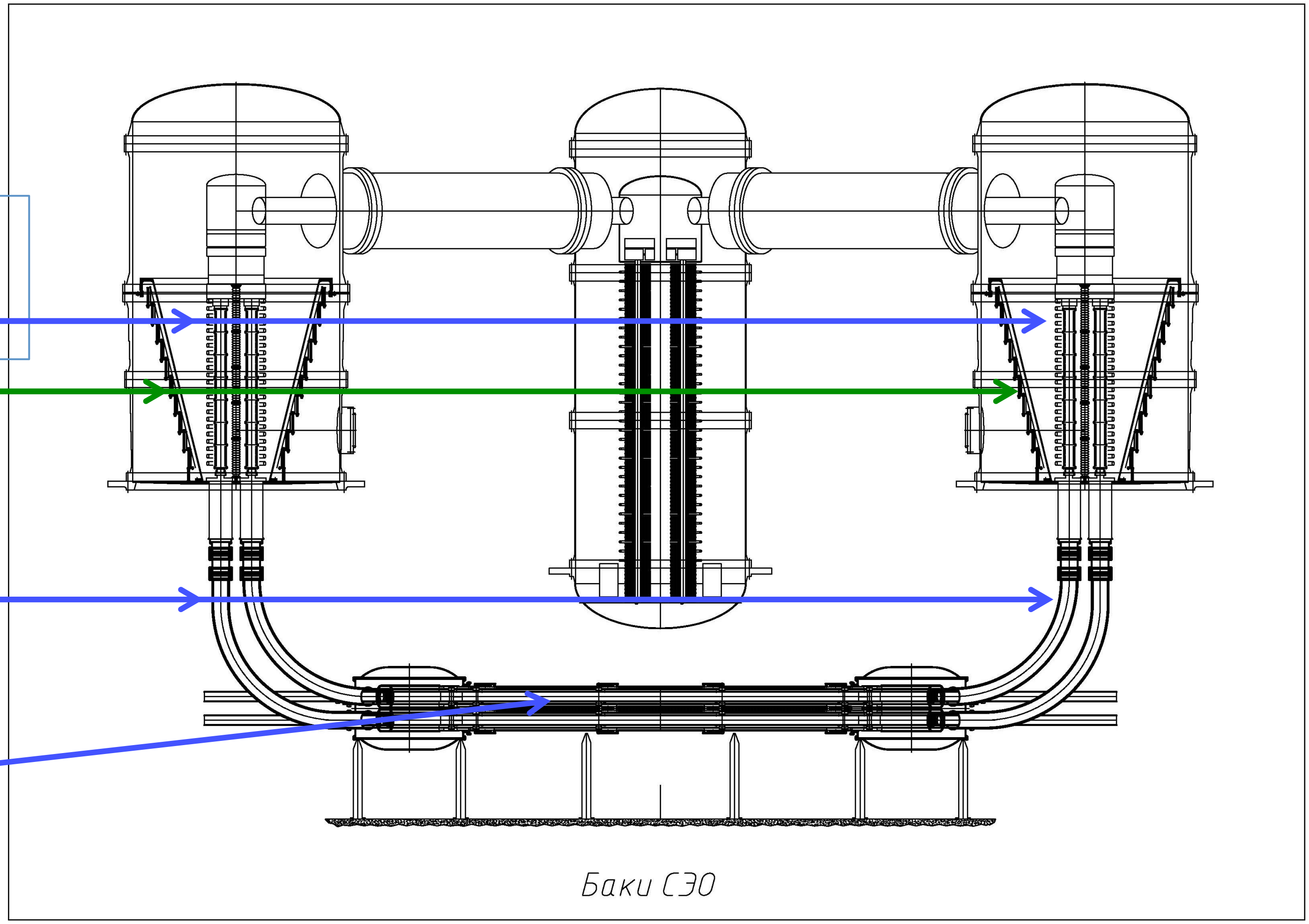
4.1. The General View

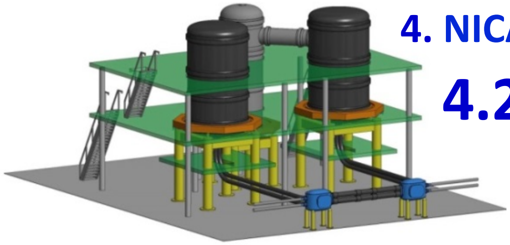
Tanks with the acceleration/deceleration tubes

SC conic solenoids

Toroidal solenoids

Cooling section





4.2. The tank with the acceleration/decelaration tubes

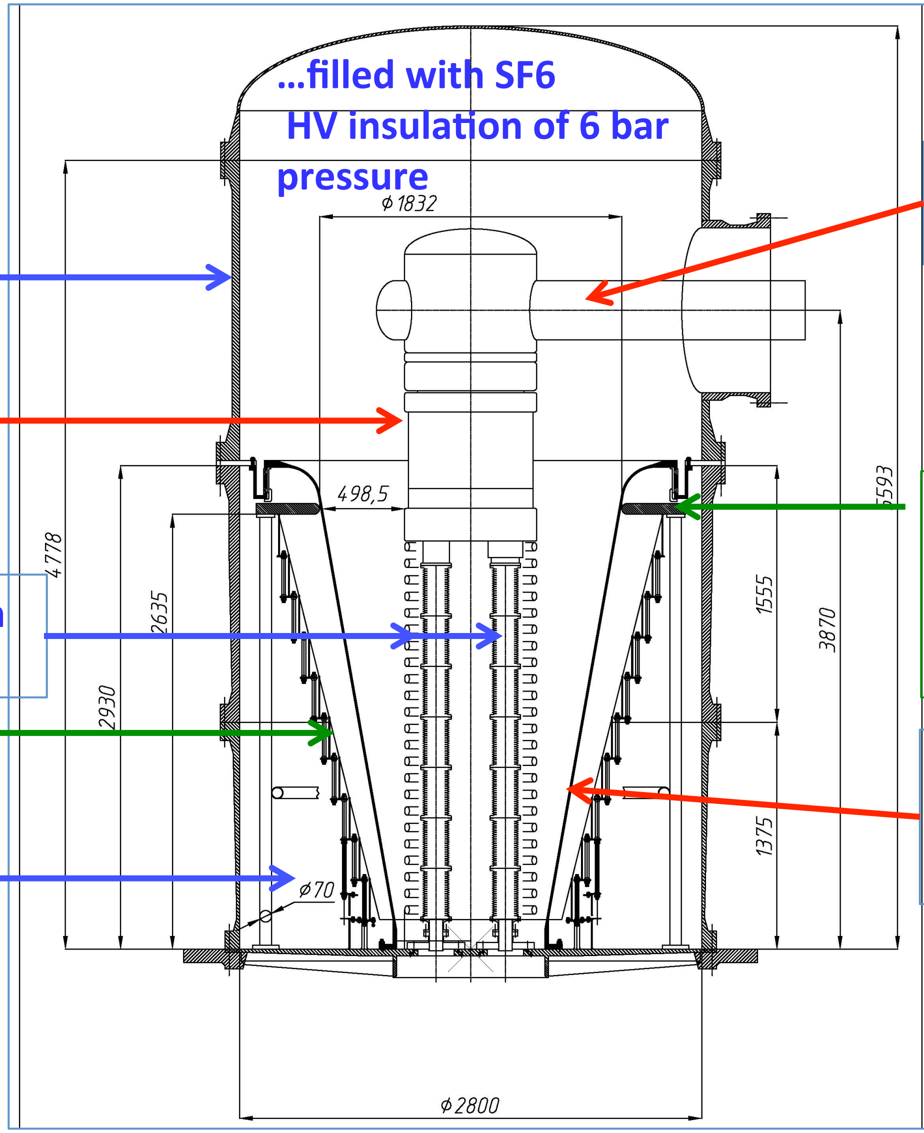
The tank with the acceleration/deceleration tubes…

HV terminal with the gun of the upper beam and the collector of the lower beam

The acceleration/deceleration tubes

Conic HTSC solenoid

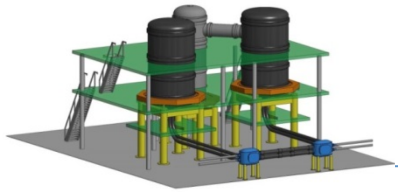
Vacuum space (thermal insulation)



HV coaxial transmission line

Magnetic shield decreasing the magnetic field on the HTSC winding

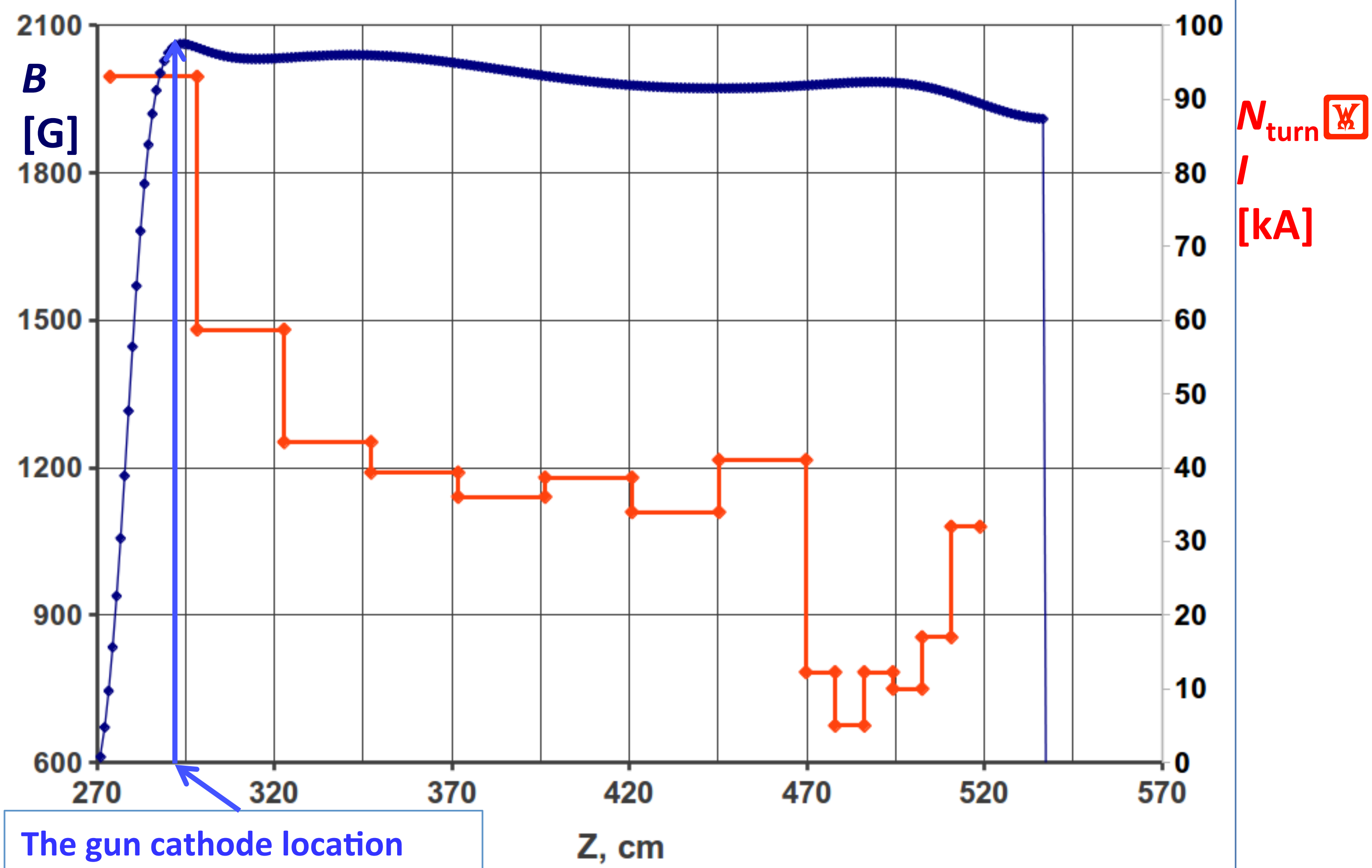
Electrostatic pressurizable screen

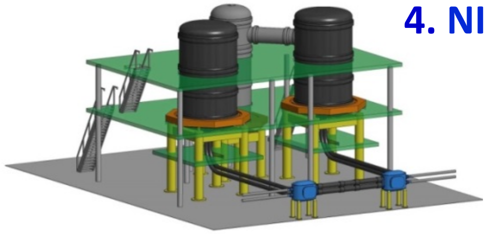


4. NICA Electron Cooler Design

4.3. The conic solenoid

Magnetic field on the conic solenoid axis and the current distribution (kAxTurns) in HTSC coils



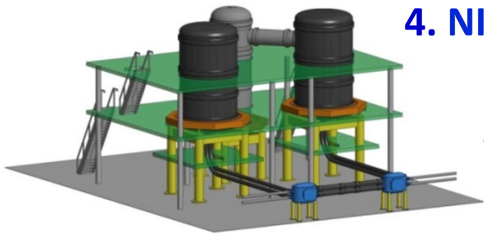


4. NICA Electron Cooler Design

4.3. The conic solenoid

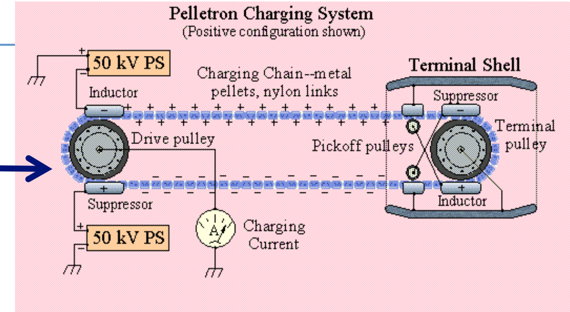
The HTSC winding

Critical magnetic field for the HTSC tapes at 77 K (LN_2)	1.0 T
Maximum magnetic field on the HTSC winding of the conic solenoid	0.4 T



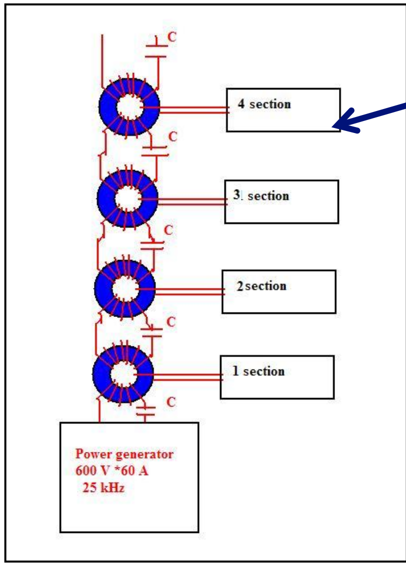
4. NICA Electron Cooler Design

4.4. The HV generator

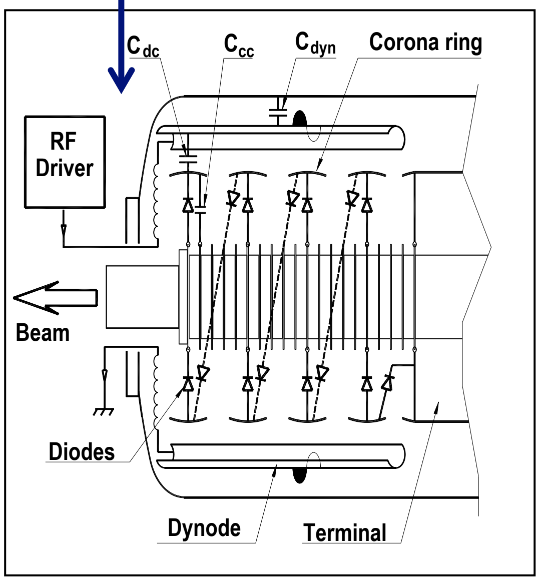


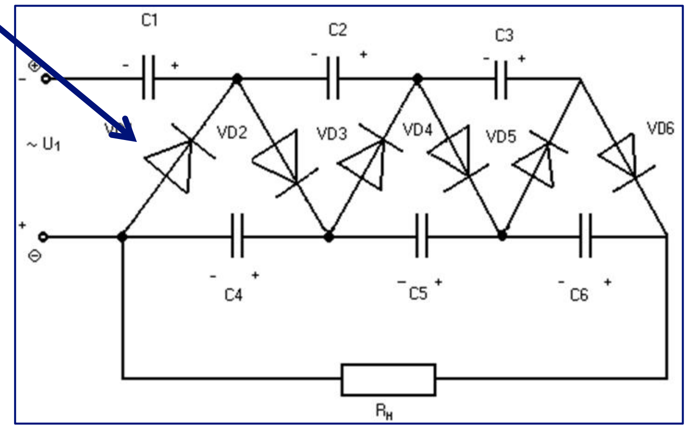
The choice of the HV generator type:

1) Pelletron (van der Graaf)
2) Cascade transformer
3) Dynamitron scheme
4) Voltage multiplier (“Cockroft – Walton”)

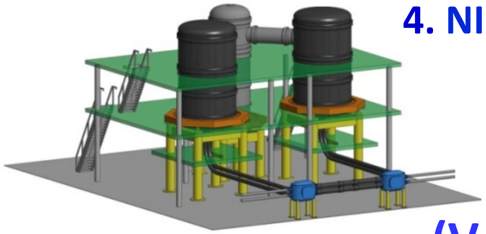


V.Parkhomchuk et al





5) Turbine driven generator (V.Parkhomchuk et al.) – see the next slide

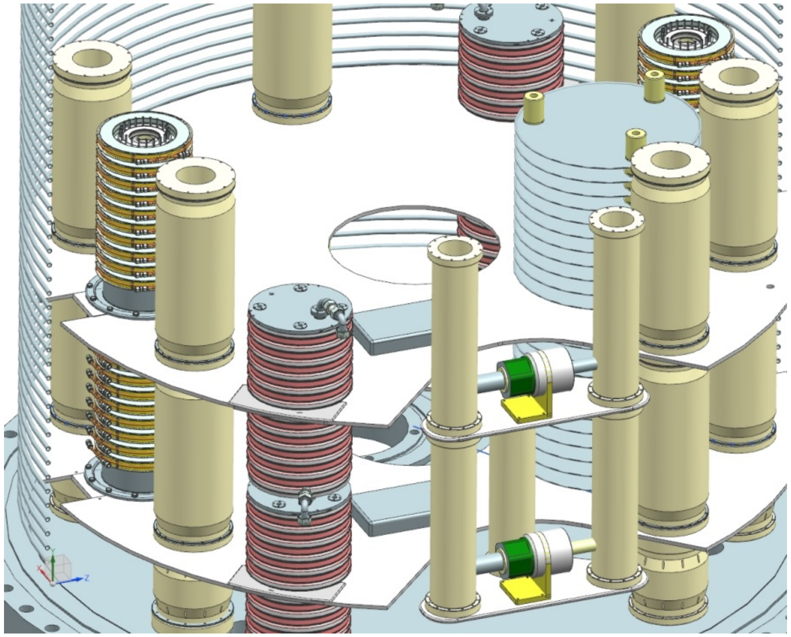


4. NICA Electron Cooler Design

4.4. The HV generator

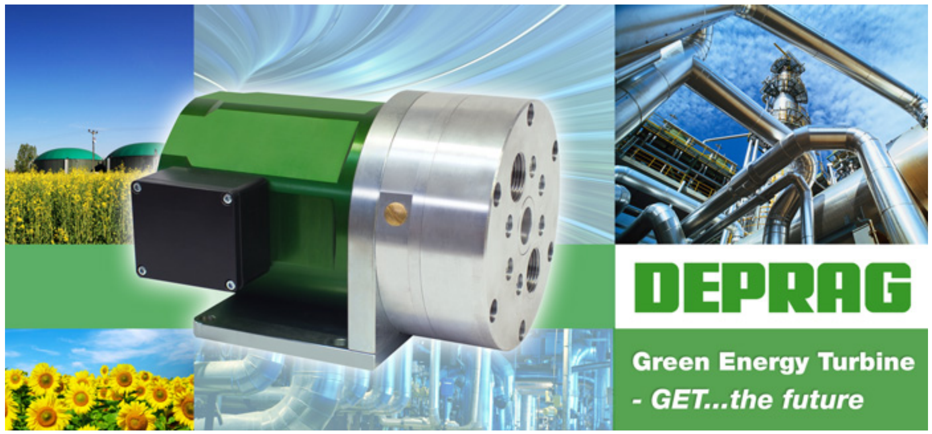
5) Turbine driven generator

(V.Parkhomchuk et al., Sarantsev seminar’2015, Alushta, Crimean, September 2015)



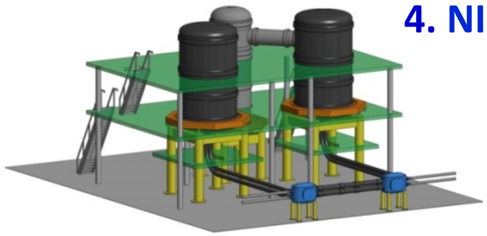
The developmental work on cascade transformers feeding with gas turbine generators of DEPRAG C°

Collaboration BINP – Mainz University



See the poster MOPF02
and

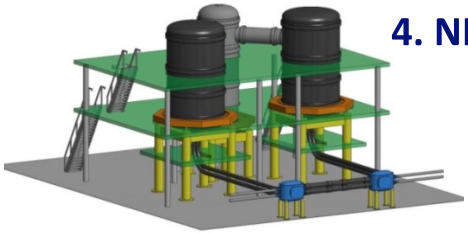
http://accelconf.web.cern.ch/AccelConf/IPAC2014/papers/mopme051.pdf



4.4. The HV generator

Typical parameters of HV generators

Generator type	Max. voltage [MV]	Max. current [mA]	Reliability
1) Pelletron	13.0	0.1 (per chain)	Longstanding experience (Nat. Electrostatic Corp., Madison, USA)
2) Cascade transformer	2.0	1.0 (?)	BINP, commissioning stage
3) Dynamitron	25.0	?	World experience
4) Voltage multiplier	5.0	2.0	ARIE, Moscow, RF (“old” experience)
5) Turbine driven generator	?	?	BINP & Mainz Univ. R & D (very promising)



4. NICA Electron Cooler Design

4.4. The HV generator

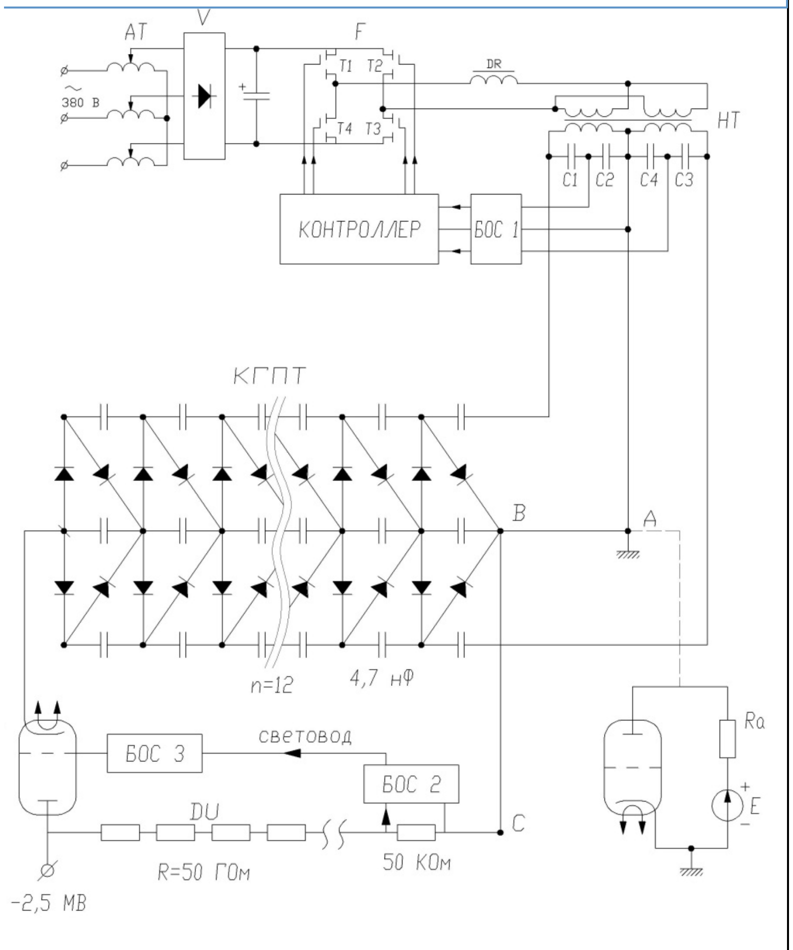
Lenin All-Russian Institute for Electrotechnique (Moscow)

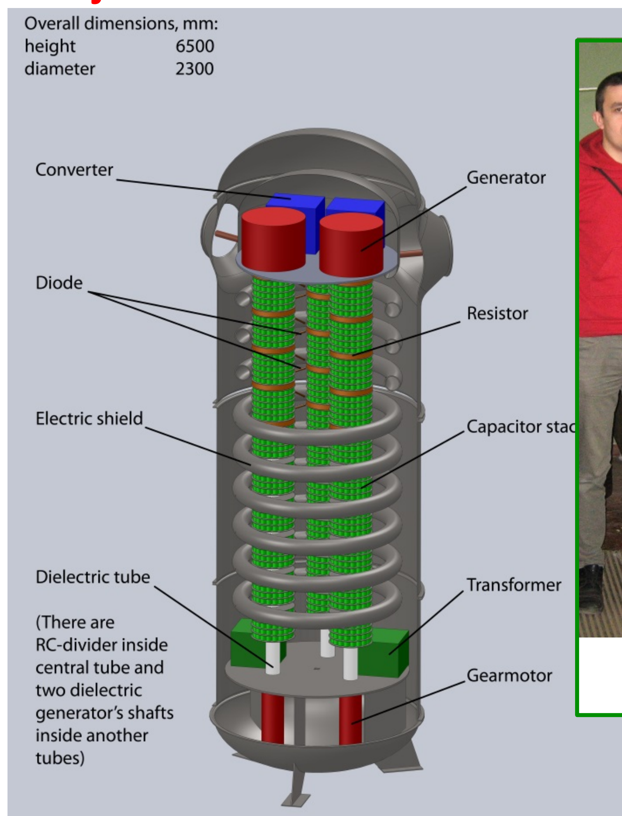
Generator stability $\sigma V / V \sim 10^{-3}$, $0.5 < \sigma V < 2.5$ kV

Feedback via rotor voltmeter and capacity connector provides stabilization level up to $\sigma V / V \sim 10^{-5}$

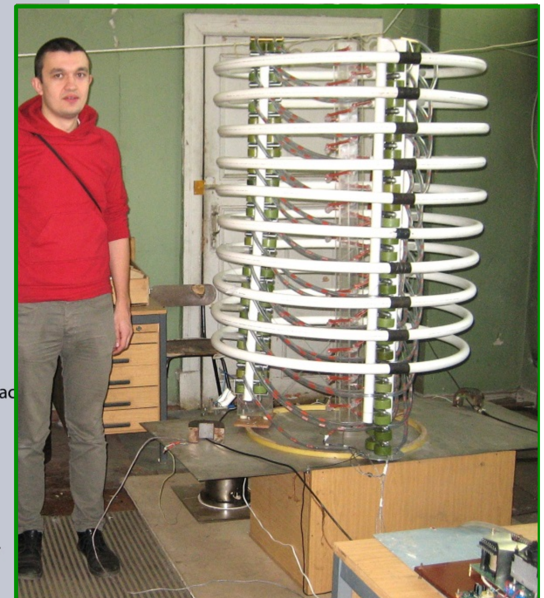
Project electron current 1 mA

Voltage multiplier schematic diagram

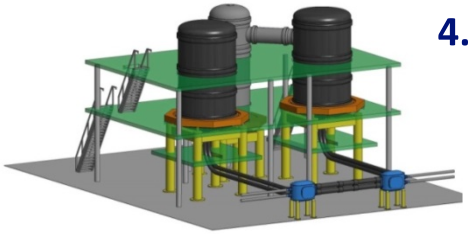




The middle tank of the cooler



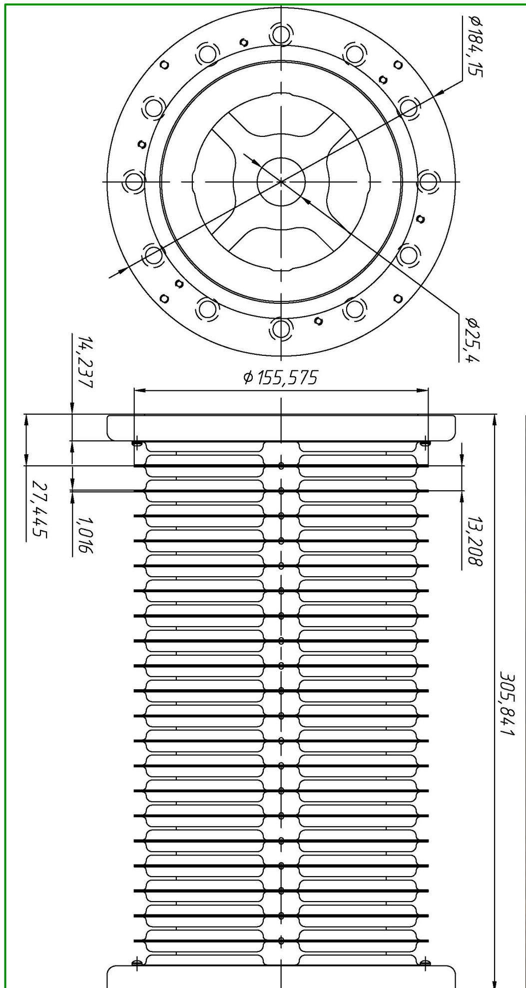
Test model of 350 kV

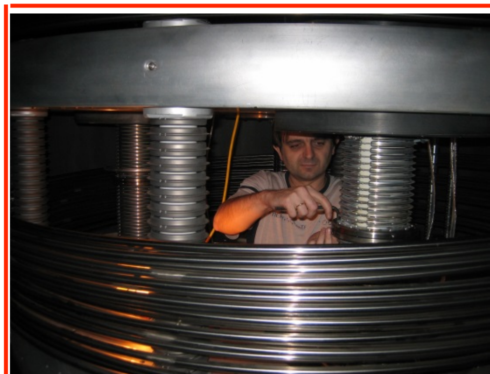


4. NICA Electron Cooler Design

4.5. Acceleration tubes

The sections of the Pelletron/NEC acceleration tubes

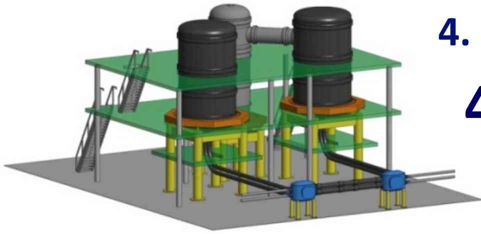




The drawing of the section and its photo

Dismantling and packing of the Pelletron tubes 9 – 10 December 2013

The experts and the porter



4.6. Modeling of the Cooler Elements

The test bench “Recuperator” –

- it was used at the end of the 1980th – beginning of the 1990th for test of the electron collector and electron gun for the electron cooler of LEAR and is used today for development of the elements of HV electron cooler of the NICA Collider.

The test bench is a good training ground for young researchers. The Electron Cooling Group of Dzhelepov Lab. of Nucl. Problems of JINR is developing new schemes of the electron collector and electron gun for the HV electron cooler of the NICA Collider and the methods for testing parameters of these devices.

Concluding remarks

1. HV electron cooler for an ion collider *has to be equipped with* two independent beams of magnetized electrons (preferably),
   which are generated by an electron gun with a “hollow” electron beam and the sectioned “Pierce electrode”. It allows one to avoid/reduce recombination of the ions to be cooled with the cooling electrons and provide electron beam positioning using the beam current modulation and PU electrodes in the beam transfer line.

2. The electron cooler solenoids are to be superconducting. Application of HTSC winding looks realistic presently and is very promising.

3. Application of the HV generator of the voltage multiplier type looks most practical for the moment.

4. The three tanks scheme seems adequate to the parameters of the HV electron cooler for the NICA collider .

Thank you for your attention!