The Electron Cooling for the FAIR project

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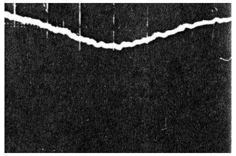
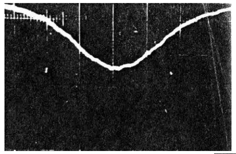
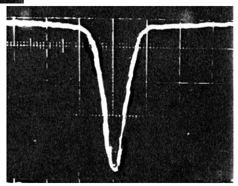
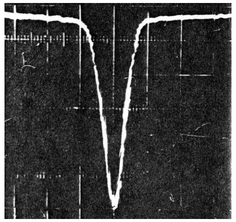
First Cooling Demonstration

- Electron cooling was first tested in 1974 with 65 MeV protons at NAP-M storage ring at BINP (Novosibirsk).



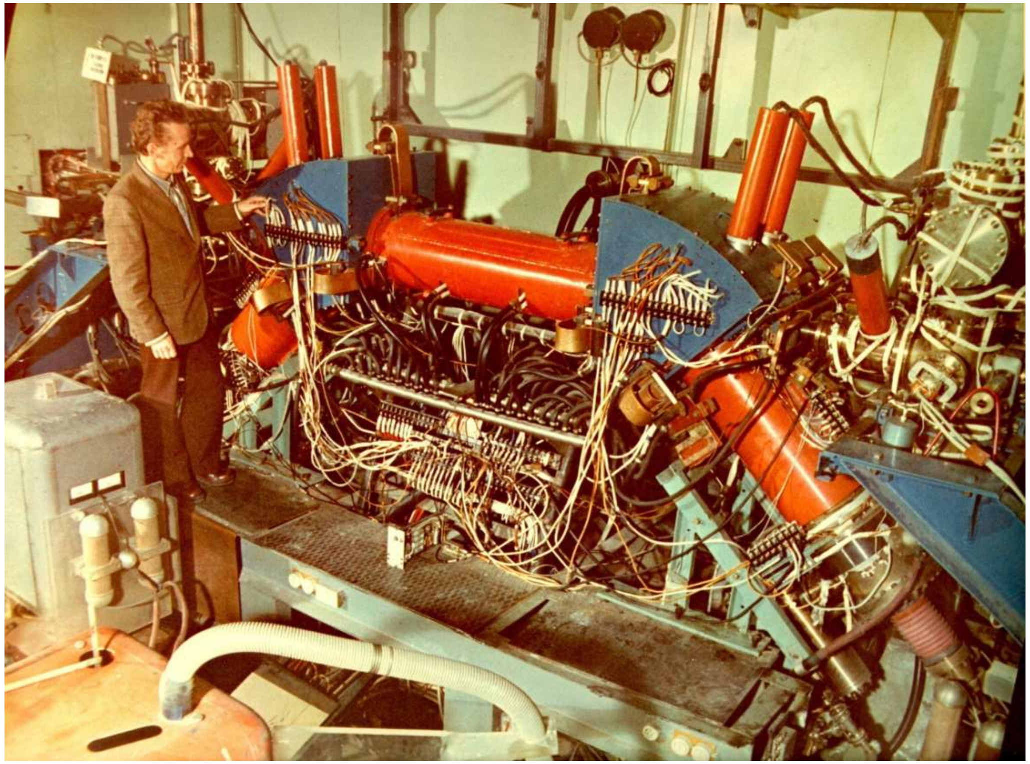






First cooling time was a few seconds

First experiments on electron cooling Proceeding 4 All- Union accelerator conference 1974,v.2. p 309., 1975,IEEE Trans. Nucl. Sci. VS-22, pp. 2093-7



After modernization of the cooler magnet system cooling time go to 0.05 s!

The quality of the magnetic field is key factor

For particle accumulation and decreasing momentum spread some "cooling" process is necessary

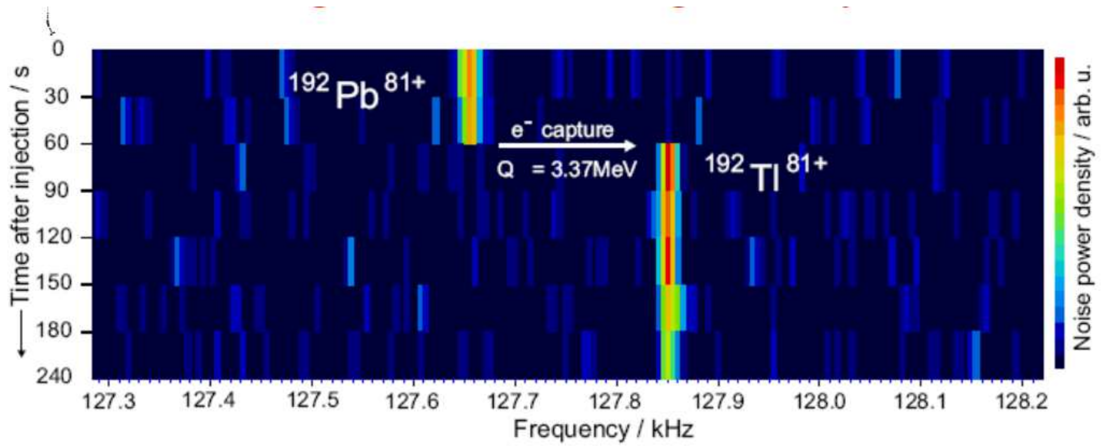
Cooling application is very useful for the accelerator physics

- Injection help: stacking, accumulation, phase-space manipulation etc.
- Working with internal target: suppress emittance grows from target scattering
- Help in beams colliding: suppress beam-beam effects, residual gas scattering
- *Creating precise energy resolution: investigation of narrow states of elementary particle, threshold reactions*

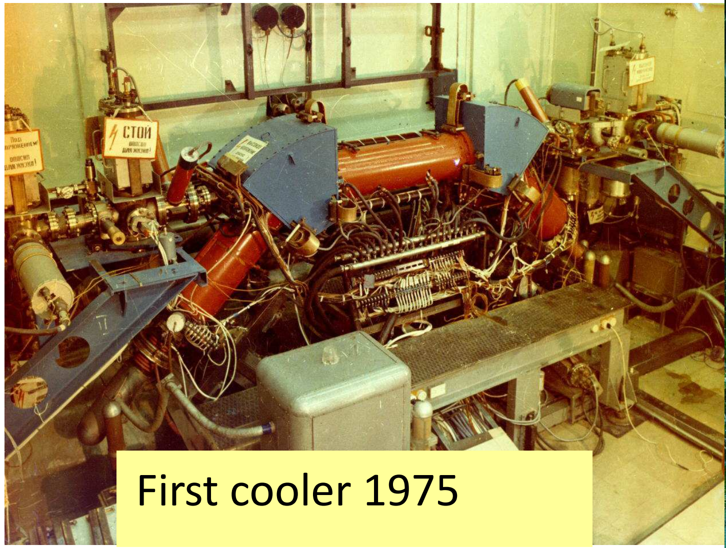
Physics experiments with electron cooling

- fundamental problems of quark - gluon matter;
- atomic spectroscopy rare and high-charge ions;
- generation of exotic nucleus;
- precise measurements of mass of isotopes;
- observation of single ions;

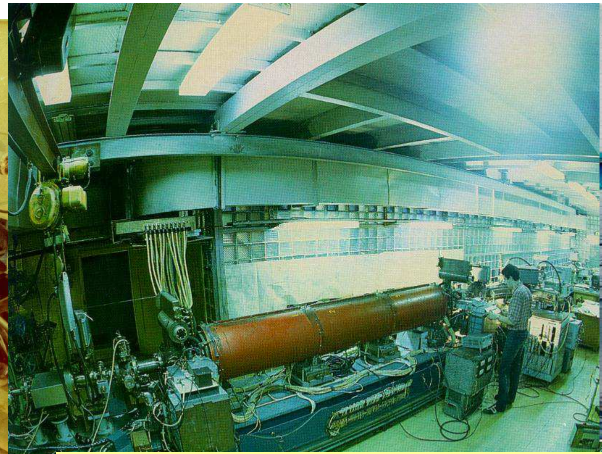
ESR (GSI) uses electron and stochastic cooling profits from stronger Schottky signal so few and even single ions are cooled down and can be detected



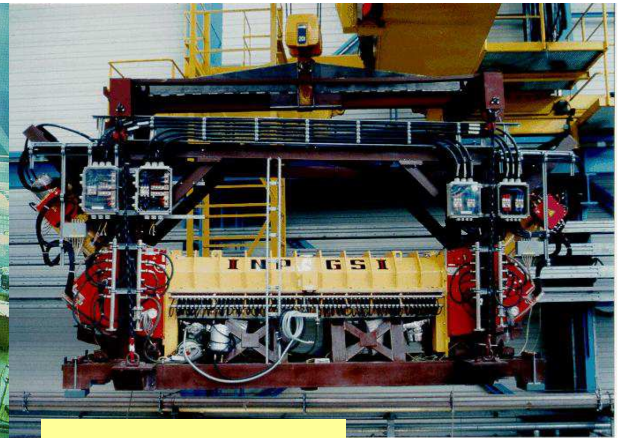
So, there are many experimental and theoretical facts about profit of the electron cooling and BINP produce from 1967 to 2010 many coolers follow the way of magnetized cooling



First cooler 1975



Single pass stand for study magnetization



SIS-18 cooler

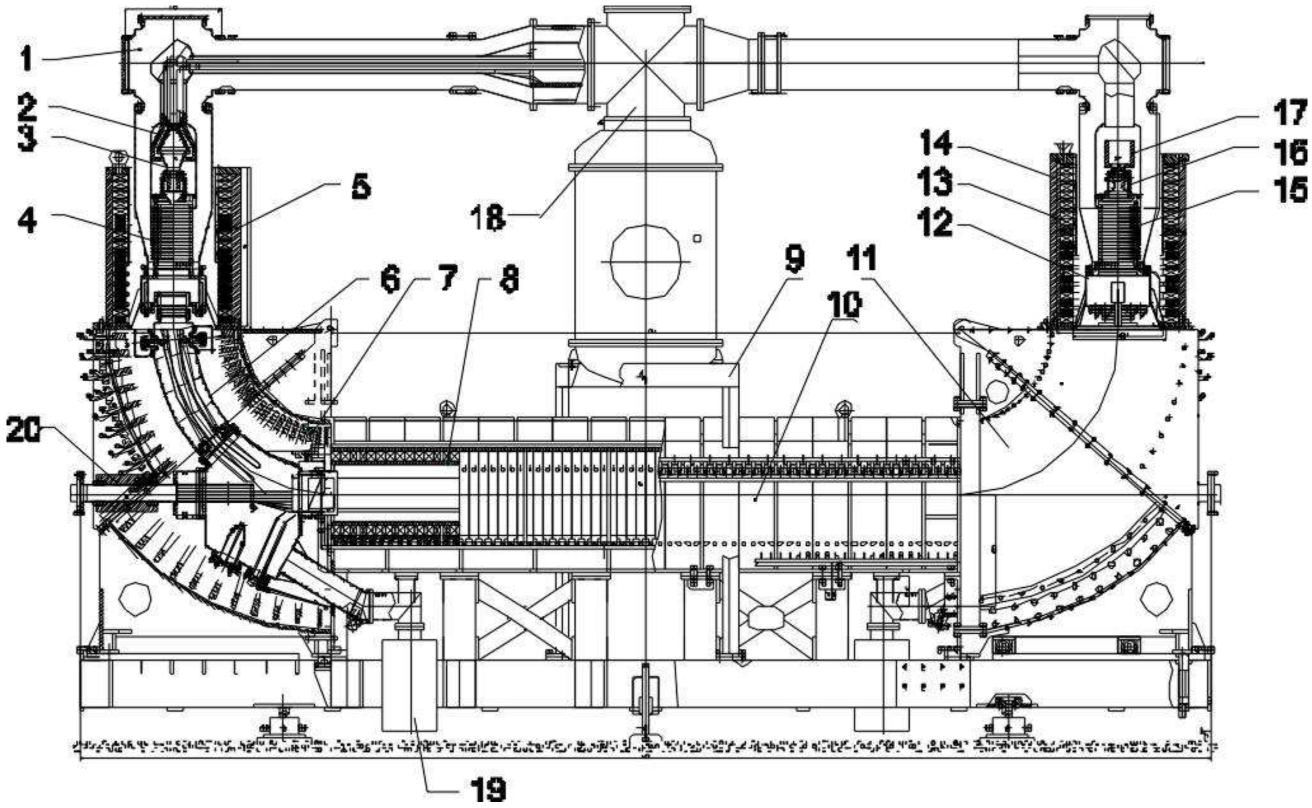
CSRm 35 kV cooler

CSRe 300 kV

LEIR cooler

Basic features of low energy coolers produced by BINP

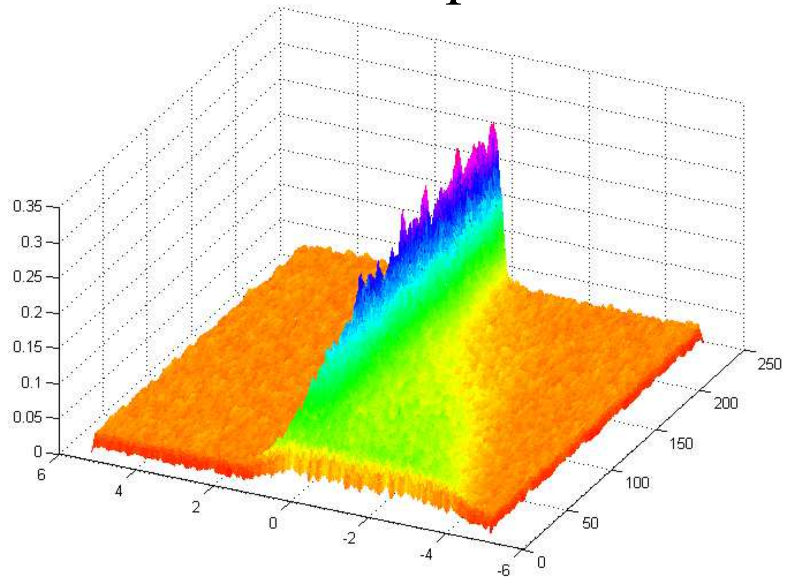
1. Tunable of the coils position for generation precise magnet field at cooling section with straightens about 10^{-5}
2. Magnetized motion of the electron beam from cathode to collector.
3. Variable beam profile of the electron beam
4. High collector efficiency in order avoid the problem with vacuum, radiation, high-voltage stability e t.c.
5. Recuperation energy of the electron beam



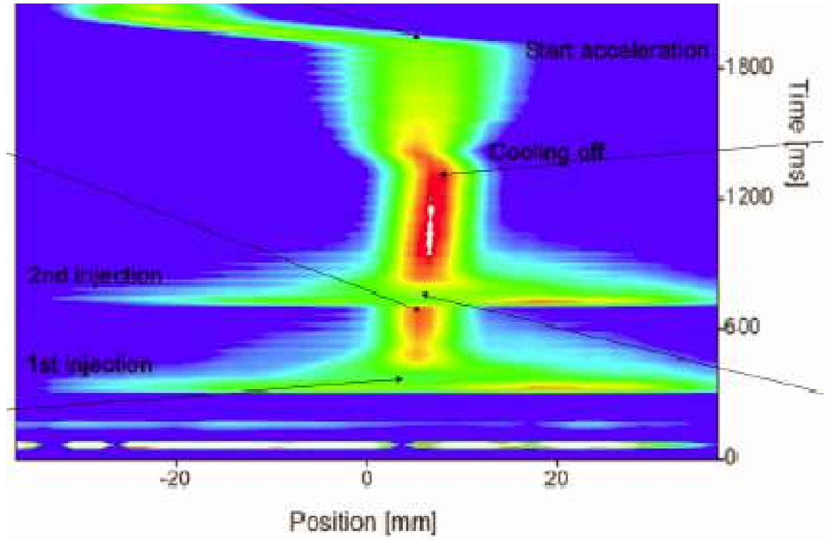
1 – high voltage feeder, 3 – collector, 4 – decelerator tube of collector, 5 – coils of the collector magnetic field, 6 – bend with electrostatic plates, 9 – vessel of the high voltage generator, 15 – accelerator tube of the electron gun, 16 – electron gun, 18 –high voltage terminal

EC-300 electron cooler for CSRe storage ring (Lanzhou, China)

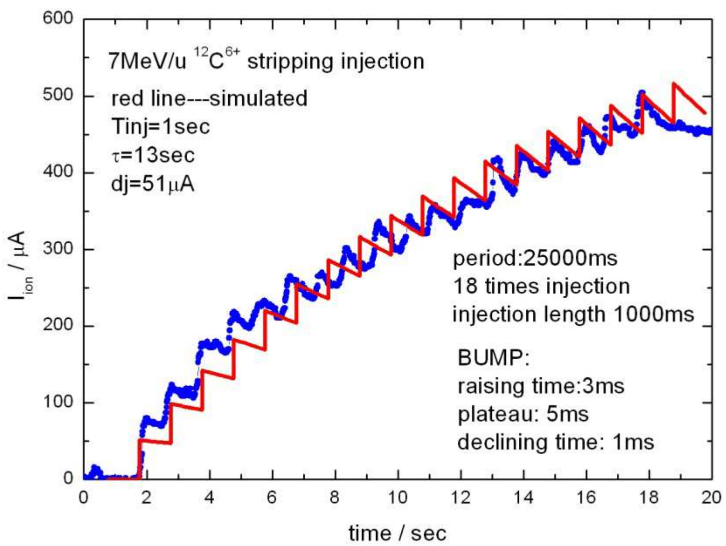
SIS-18, CSRm, CSRe, LEIR coolers
as example of realization ideas of magnetized cooling



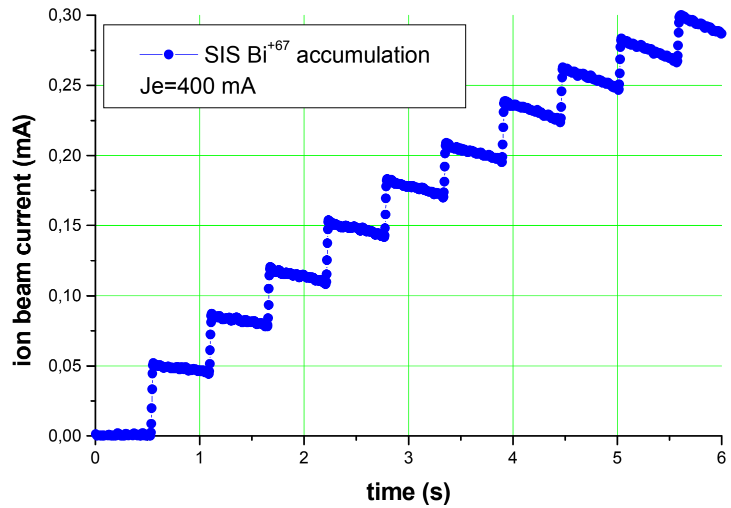
CSRe Carbon 400 MeV/u



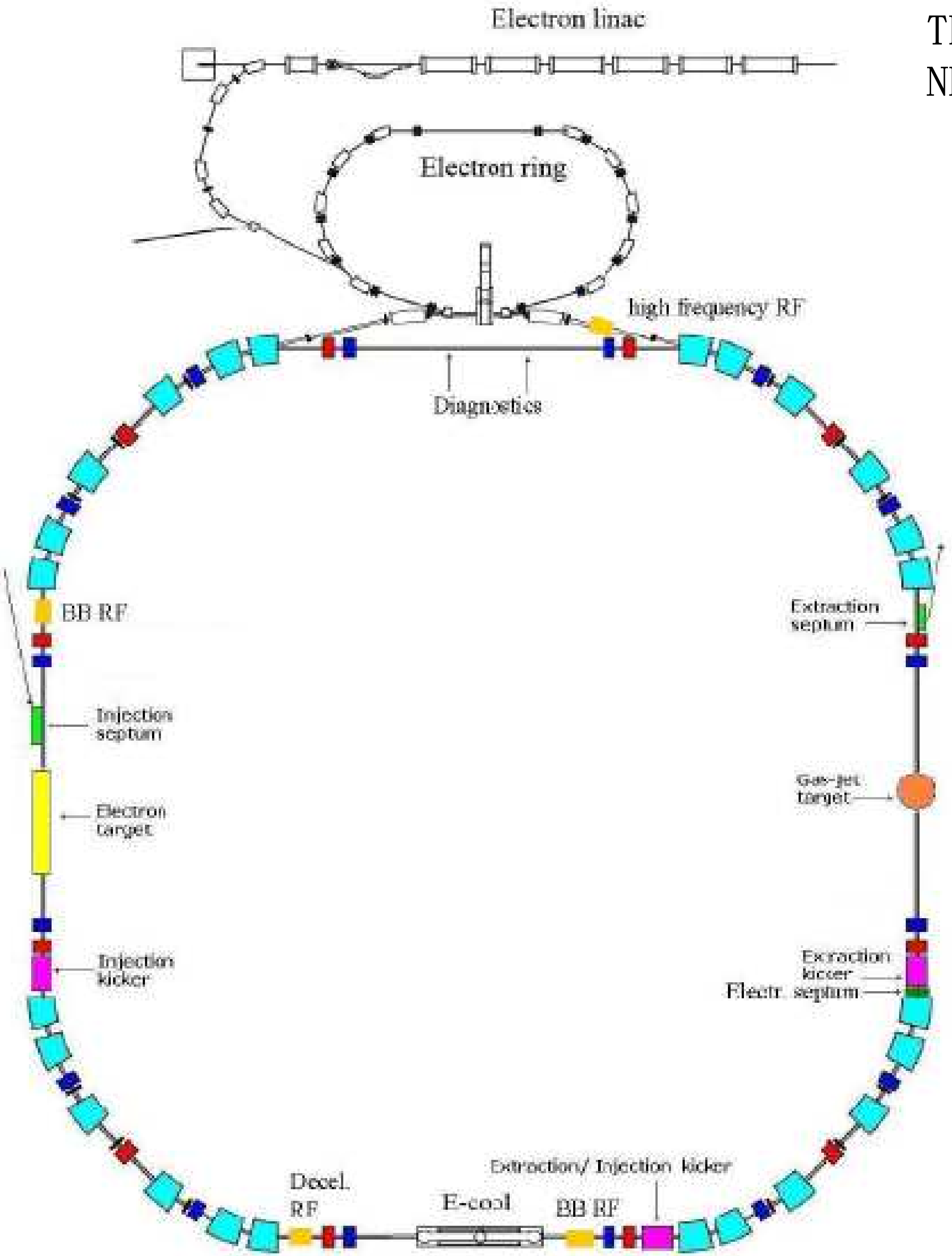
LEIR Lead ion cooling, accumulation, acceleration



CSRm Carbon 7 MeV/u



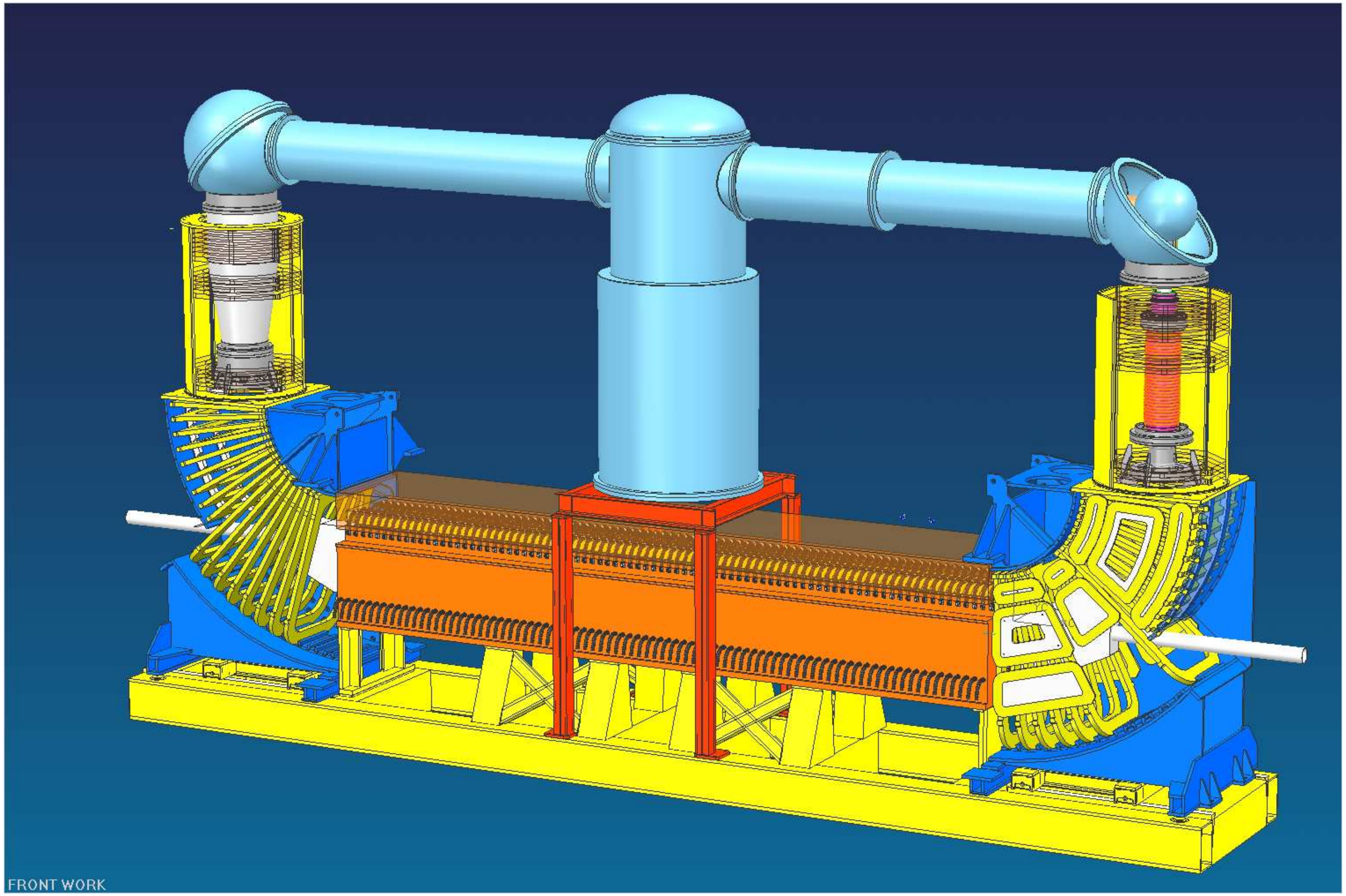
Accumulation of Bi ions at SIS-18



The New Experimental Storage Ring NESR with its instrumentation for atomic physics experiments

1. Electron cooler
2. Electron target

The NESR will be filled with energetic highly-charged heavy ions and with exotic nuclei. At the gas jet target ion-atom reactions as well as the structure of ionized atoms will be studied; x-ray spectroscopy, zero-degree electron spectroscopy, recoil-ion-momentum spectroscopy, and laser spectroscopy will be available. At the electron target the atomic assisted electron-electron interaction may be studied; here also laser techniques and x-ray spectroscopy may support the experiments. Moreover, the highly-charged heavy ions may be decelerated in the NESR down to the MeV/u region and extracted toward a fixed target area. There, atomic reactions with highly-charged ions at low velocities may be performed; x-ray spectroscopic and laser techniques will be applied.



General view of EC500 NESR cooler

HESR storage ring

Modes of operation with PANDA

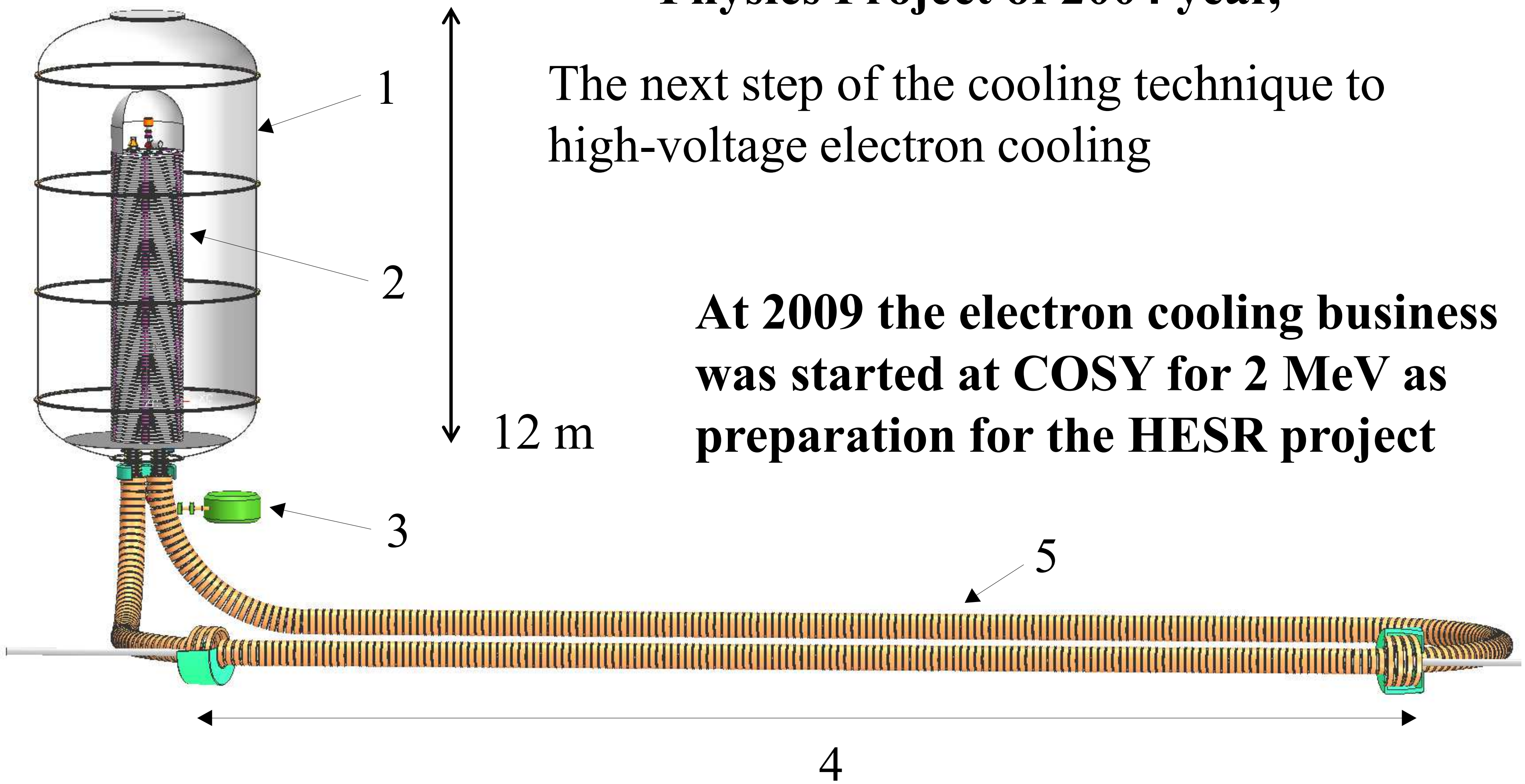
Experiment Mode	High Resolution Mode	High Luminosity Mode
Target	Hydrogen Pellet target with $4 \cdot 10^{15}$ cm^{-2}	
rms-emittance	1 mm mrad	
Momentum range	1.5 – 8.9 GeV/c	1.5 – 15.0 GeV/c
Intensity	$1 \cdot 10^{10}$	$1 \cdot 10^{11}$
Luminosity	$2 \cdot 10^{31}$ cm^{-2} s^{-1}	$2 \cdot 10^{32}$ cm^{-2} s^{-1}
rms-momentum resolution	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$

Layout of the high voltage cooler for HESR (8 MeV)

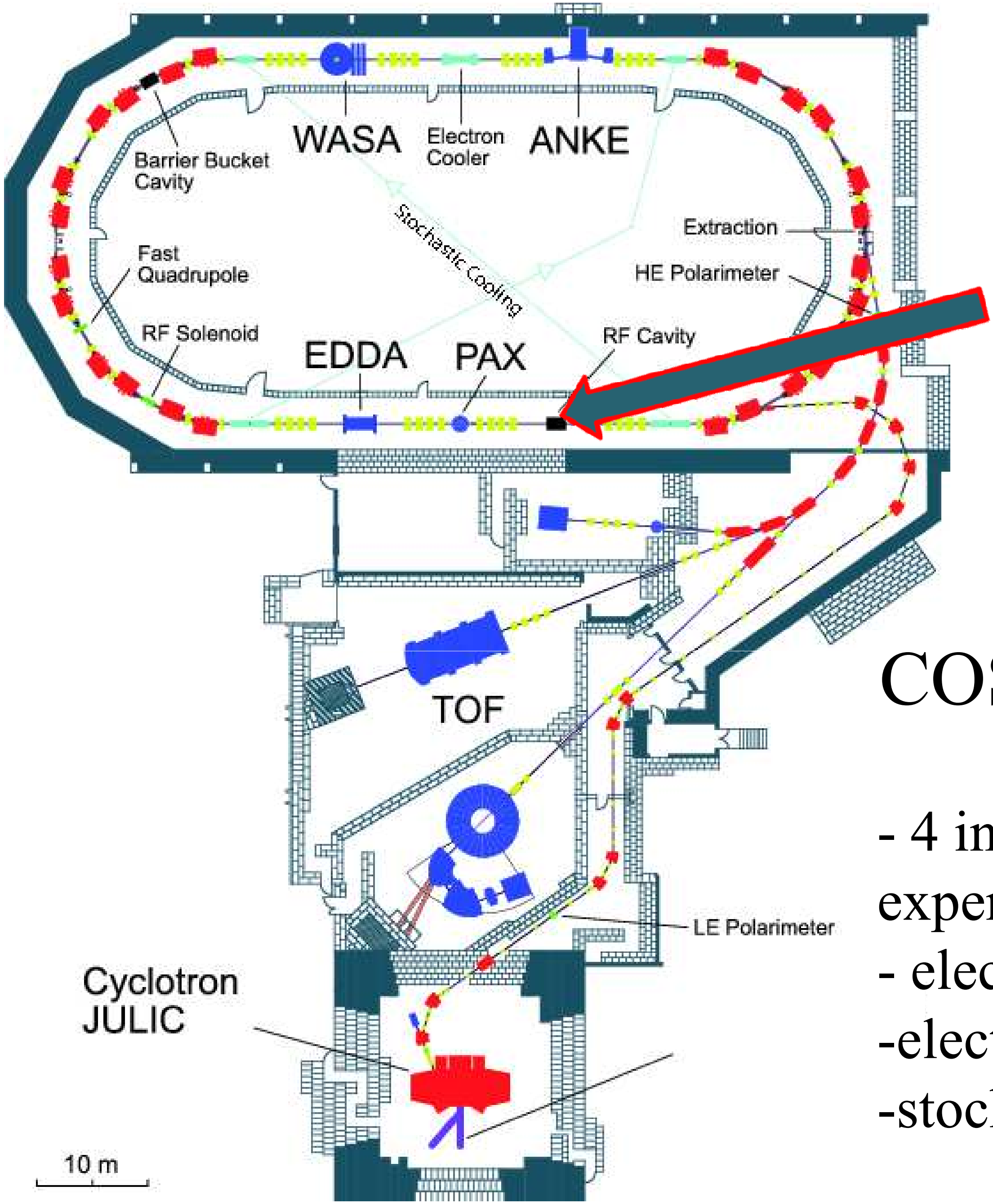
Physics Project of 2004 year,

The next step of the cooling technique to high-voltage electron cooling

At 2009 the electron cooling business was started at COSY for 2 MeV as preparation for the HESR project



1 – high voltage tank; 2 – electrostatic column; 3 – cyclotron for charging of the head of electrostatic column; 4 – cooling section (30 m); 5 – reversal track.

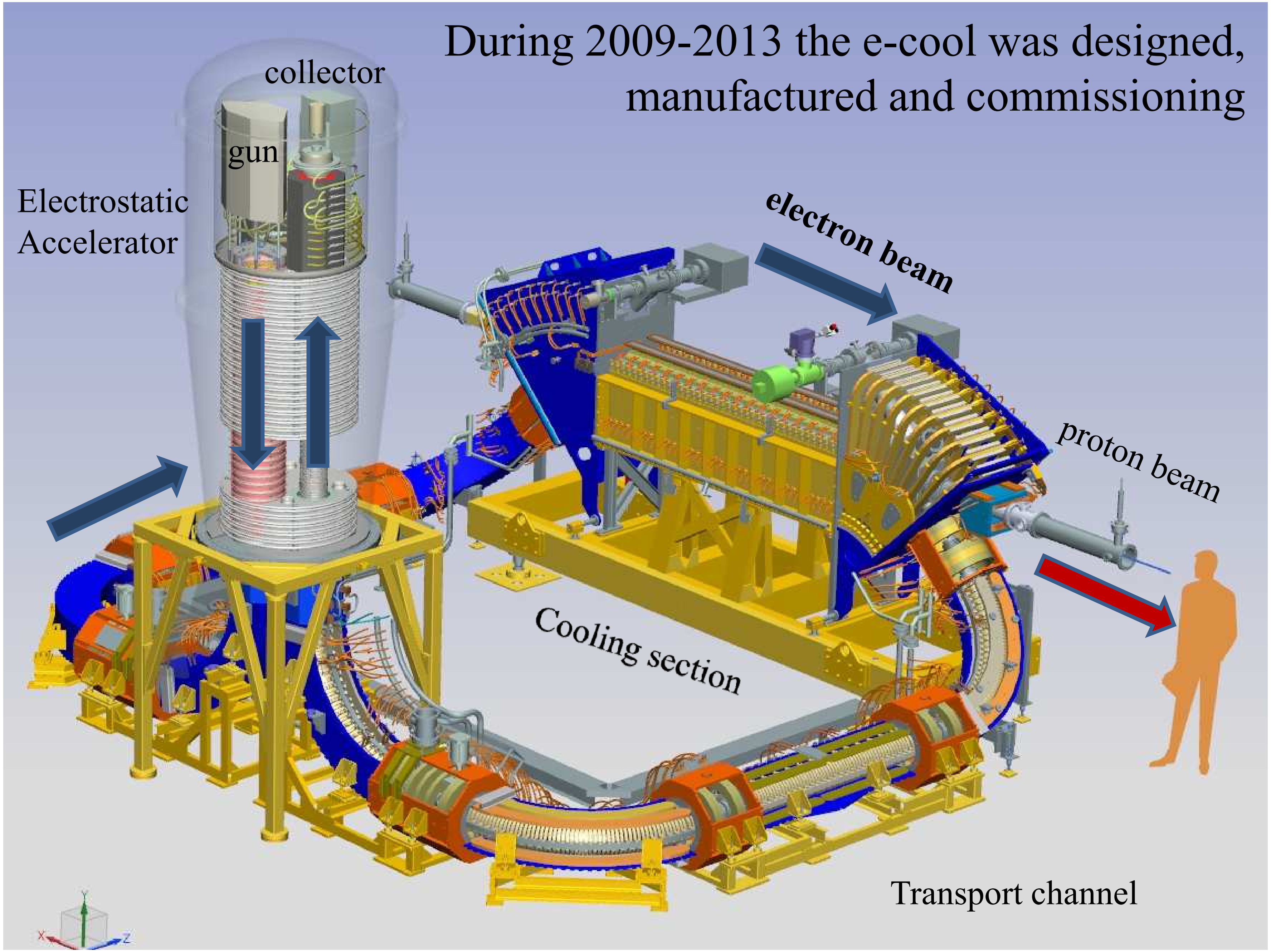


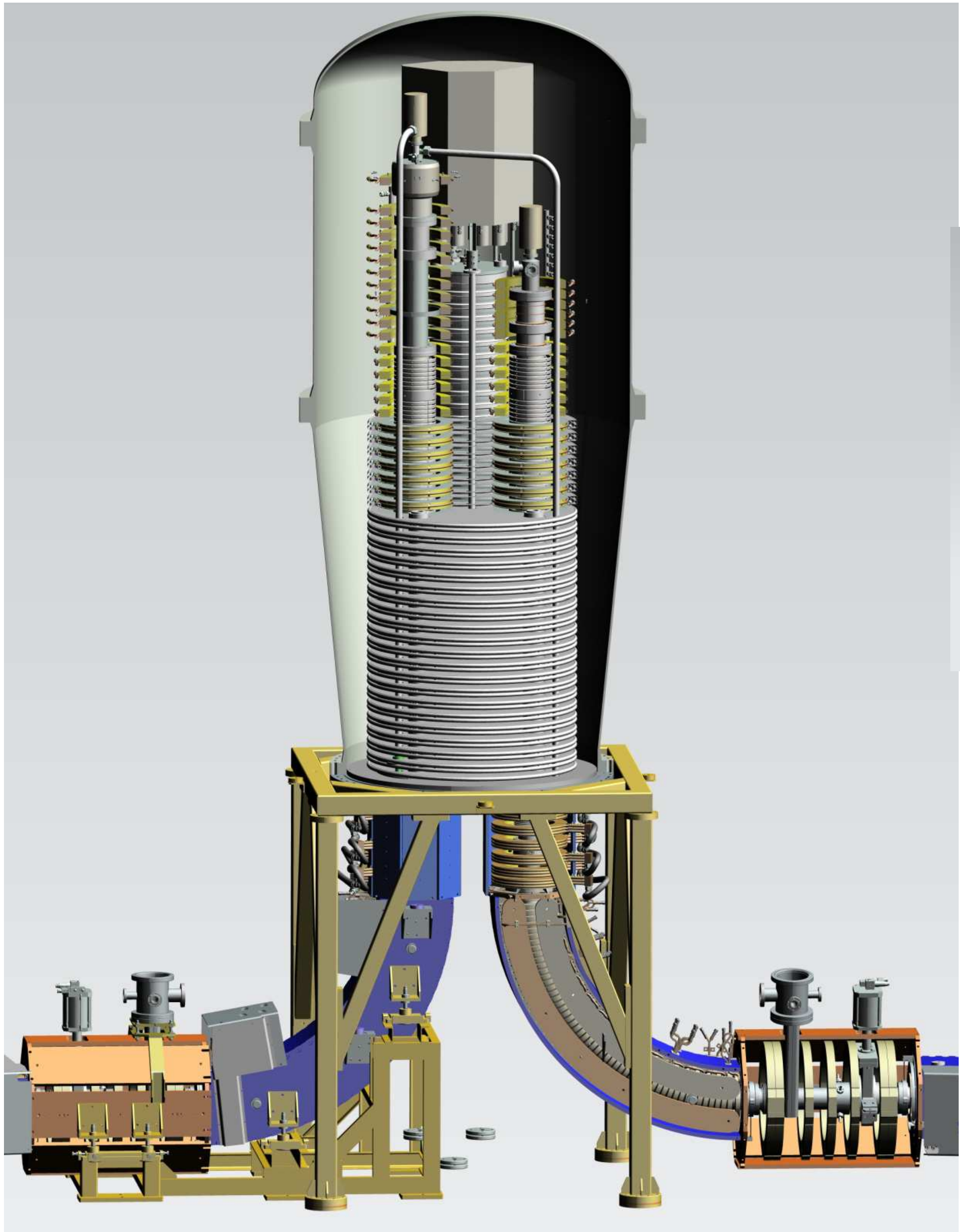
COSY Accelerator Facility

- 4 internal and 3 external experimental areas
- electron cooling at low momenta
-electron cooling at high momenta
-stochastic cooling at high momenta

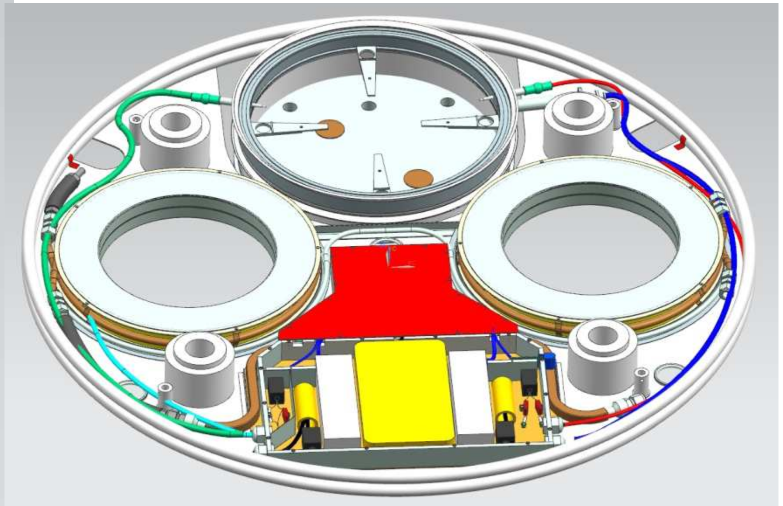
P=183.6 m, E=2880 MeV

3D design of high energy COSY cooler





3D design of Accelerating Column



Each section contains;

- high-voltage power supply +/- 30 kV;

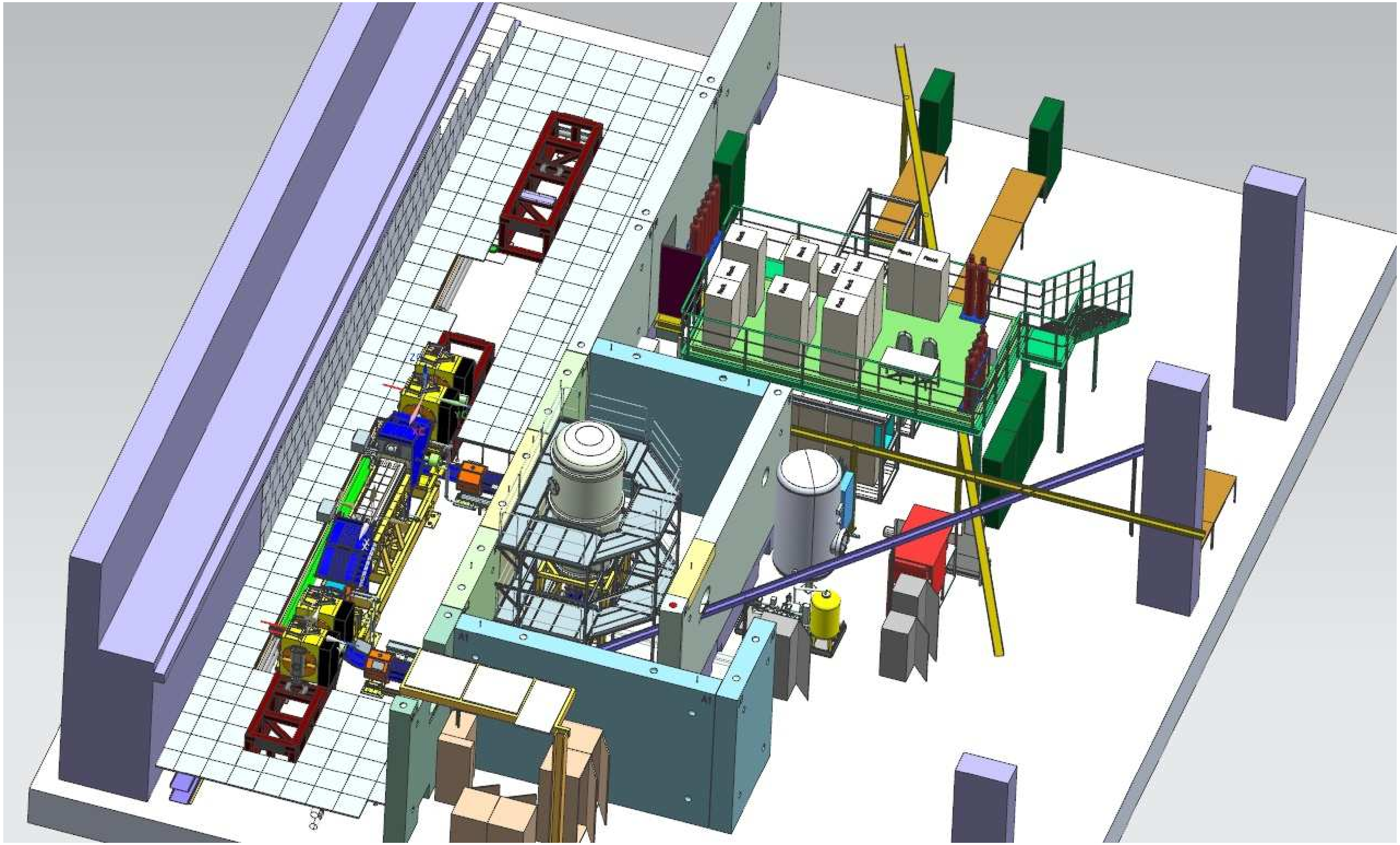
- power supply of the coils of the magnetic field (2.5 A, 500 G);

- section of the cascade transformer for powering of all electronic components;

- control electronics;

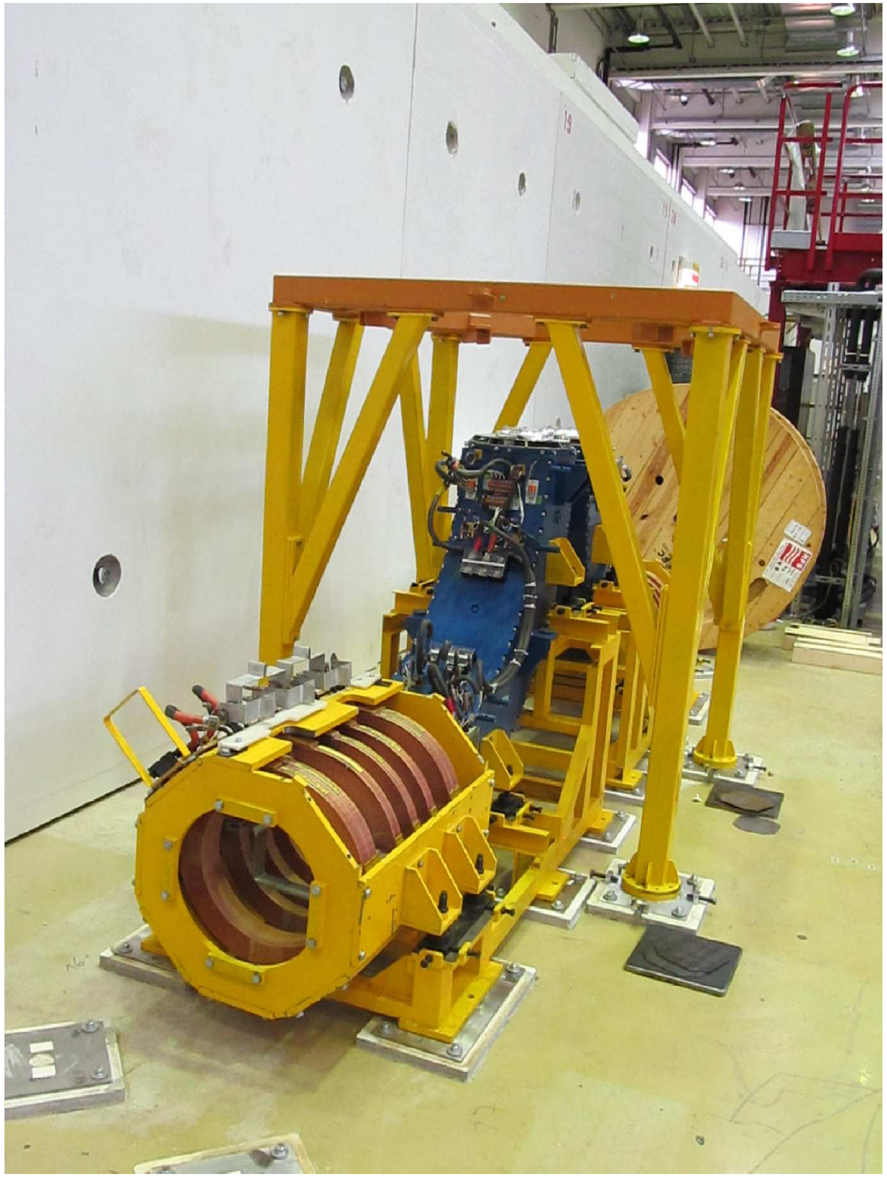
33 high-voltage section

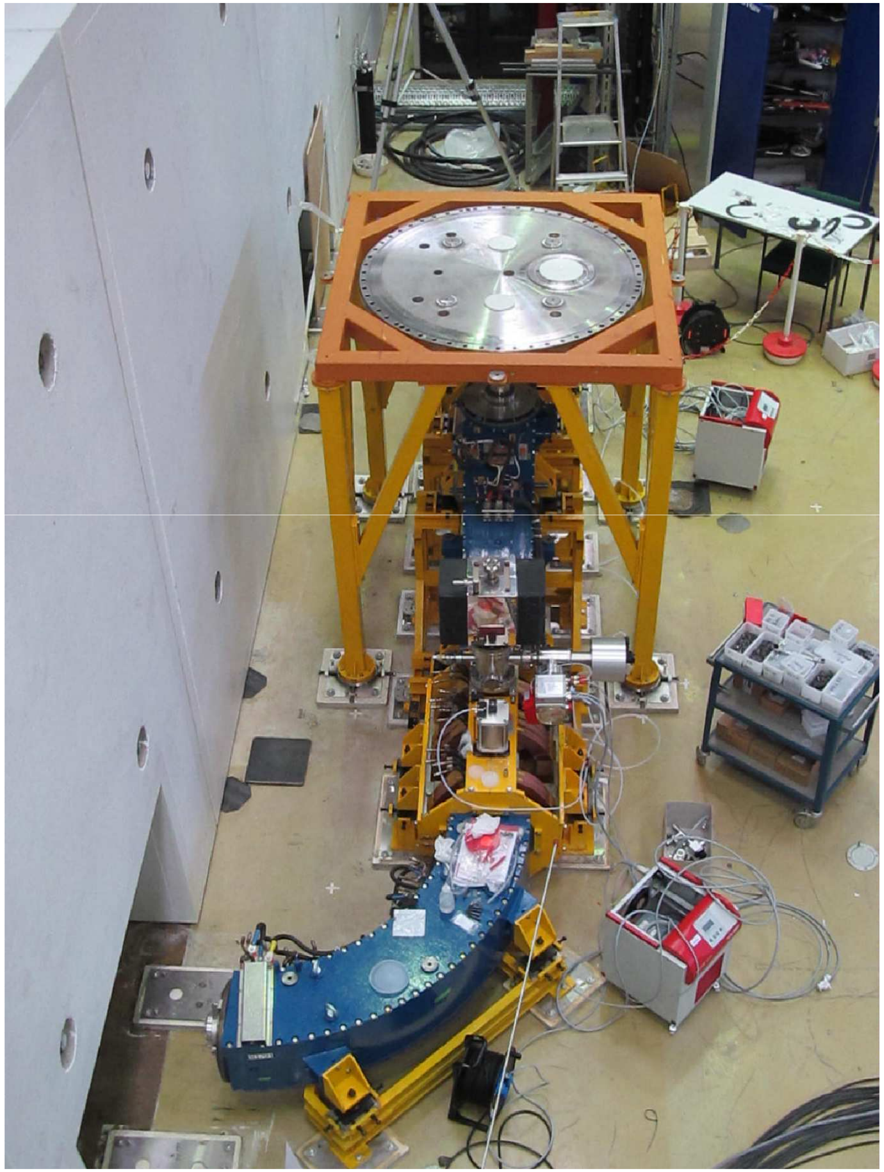
2MeV electron cooler – integration into COSY



Commissioning in COSY, 2013

Start of the assembling



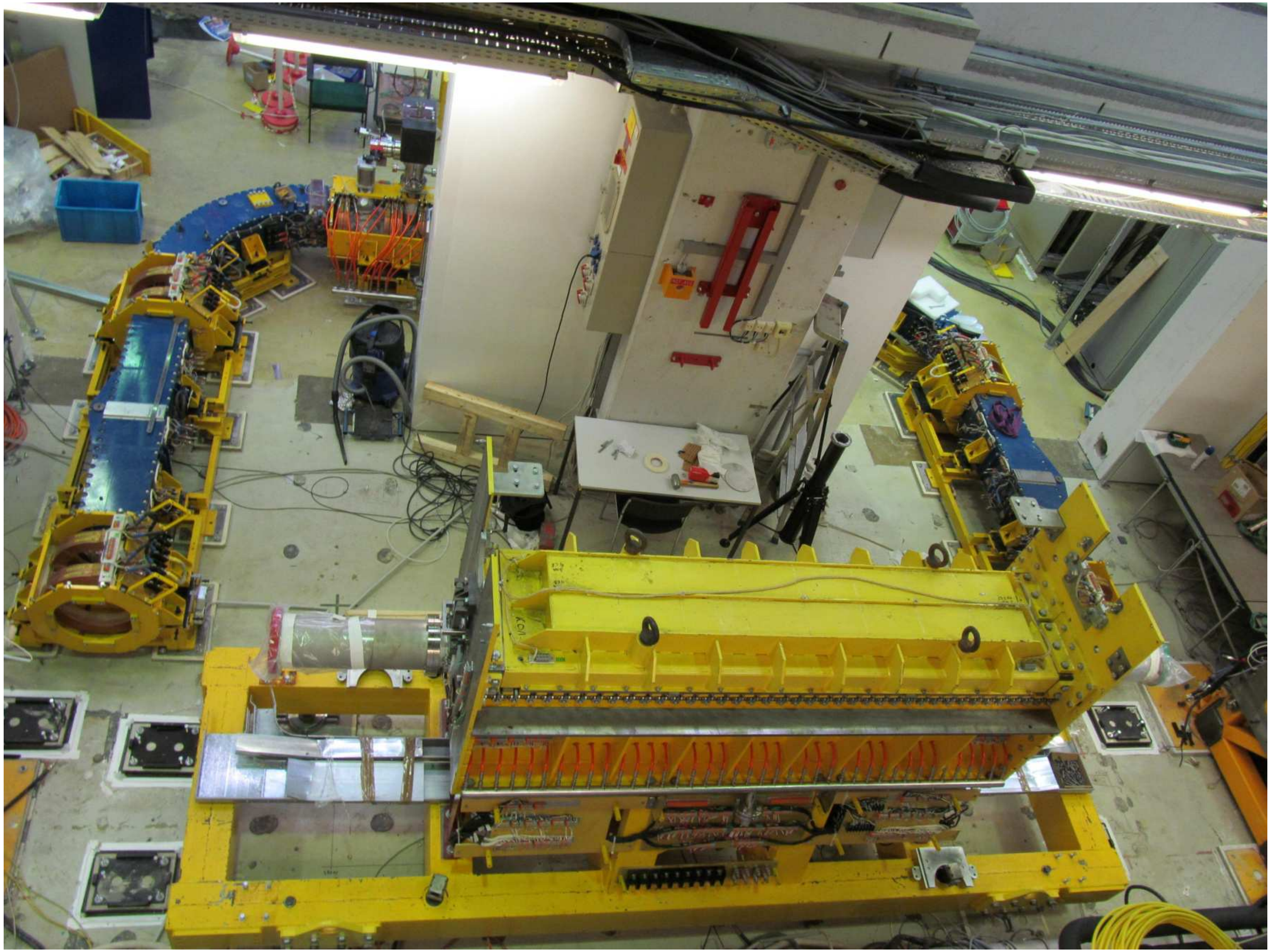


Commissioning in COSY, 2013

Cooling section is transported to the permanent residence

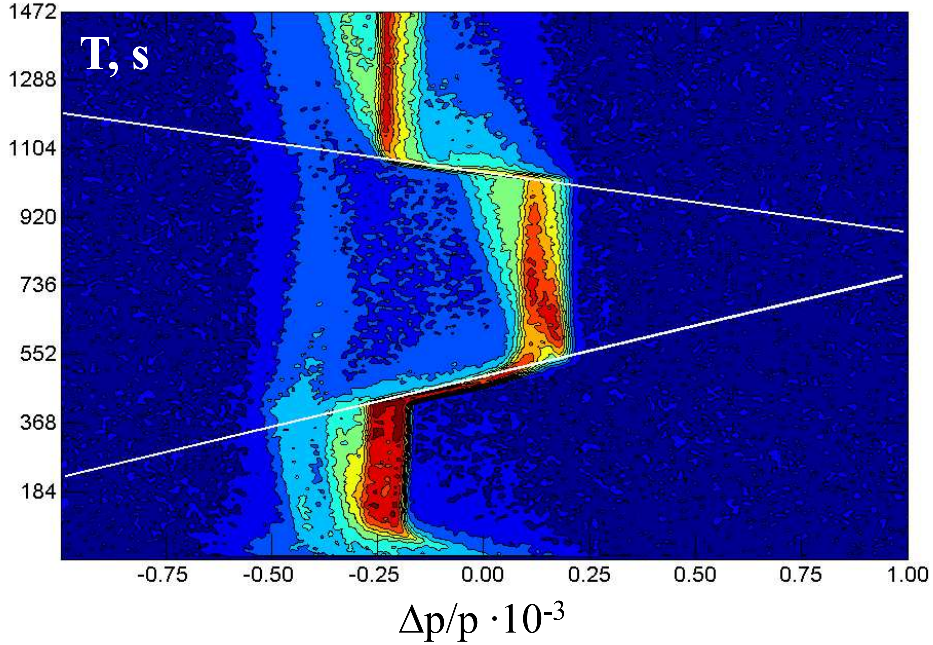
Commissioning in COSY, 2013

Transportation channel is close to finish state



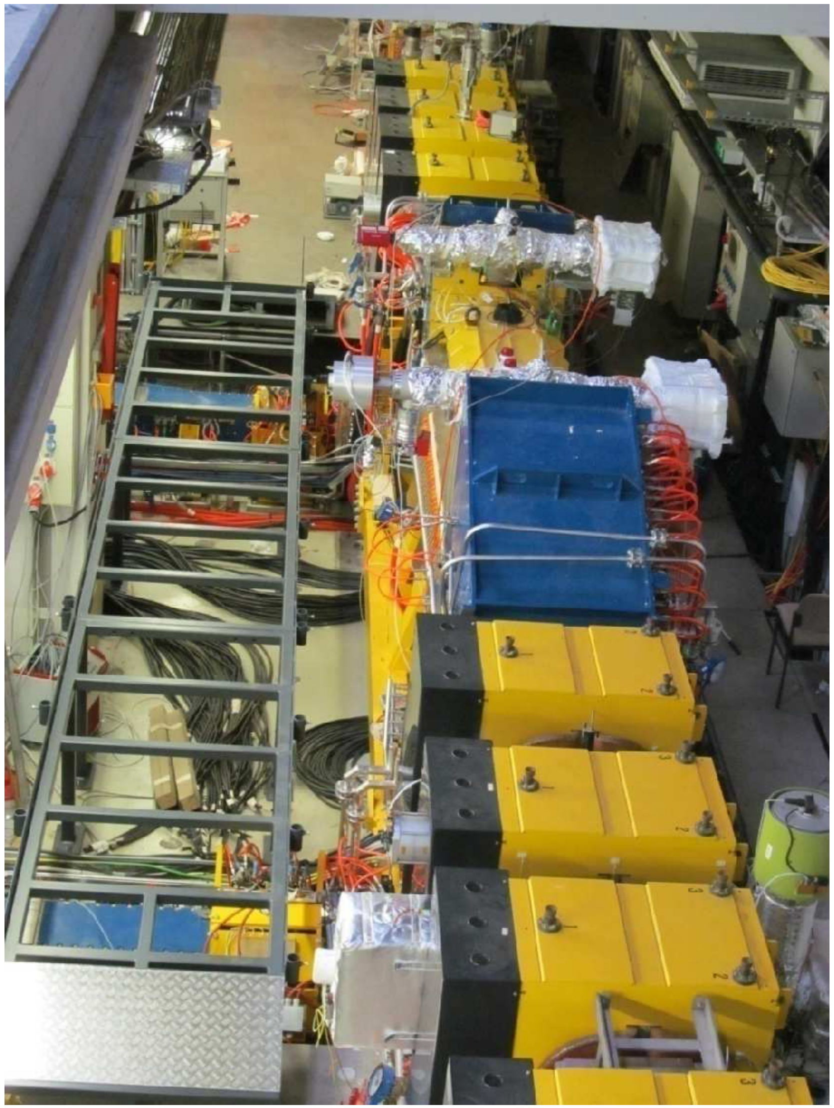
Commissioning in COSY , 2013

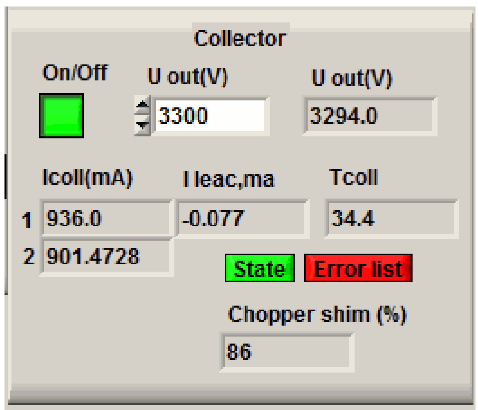
Accelerator column is finished

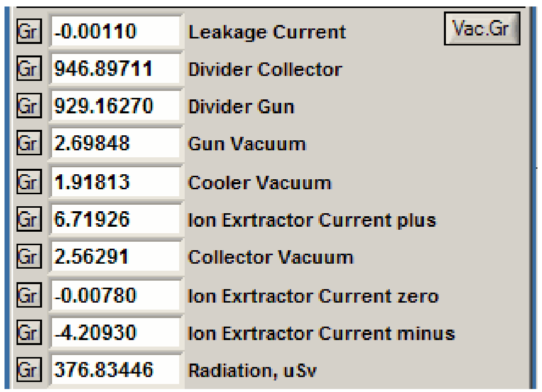


Np=1.5 $\cdot 10^8$, Ee=909.5-910-909.5 kV,
Je=400 mA **$\lambda=\delta p/\delta t=3\text{-}7\ 10^{-6}\ s^{-1}$**

Now in operation in COSY FZJ







Collector current is up to 900 mA at voltage 0.900 MeV and leakage current less 1 mkA

Now using 0.9 A e-current is positive for cooling process

Main feature of cooler COSY

1. Classical design with longitudinal magnetic field;

-very wide range of the operation, the preferable smallest energy is 25 keV, it is injection energy;

2. Section-module principle of the design of the electrostatic accelerator;

-each section contains the high-voltage module and coils of the magnetic field;

3. Possibility for on-line control of the quality of the magnetic field

- in order to have high cooling rate;

4. Cascade transformer for power supply of the magnetic coils;

- smooth longitudinal magnetic field along accelerated tube demands power to many coils;

5. Electron Collector with Wien Filter

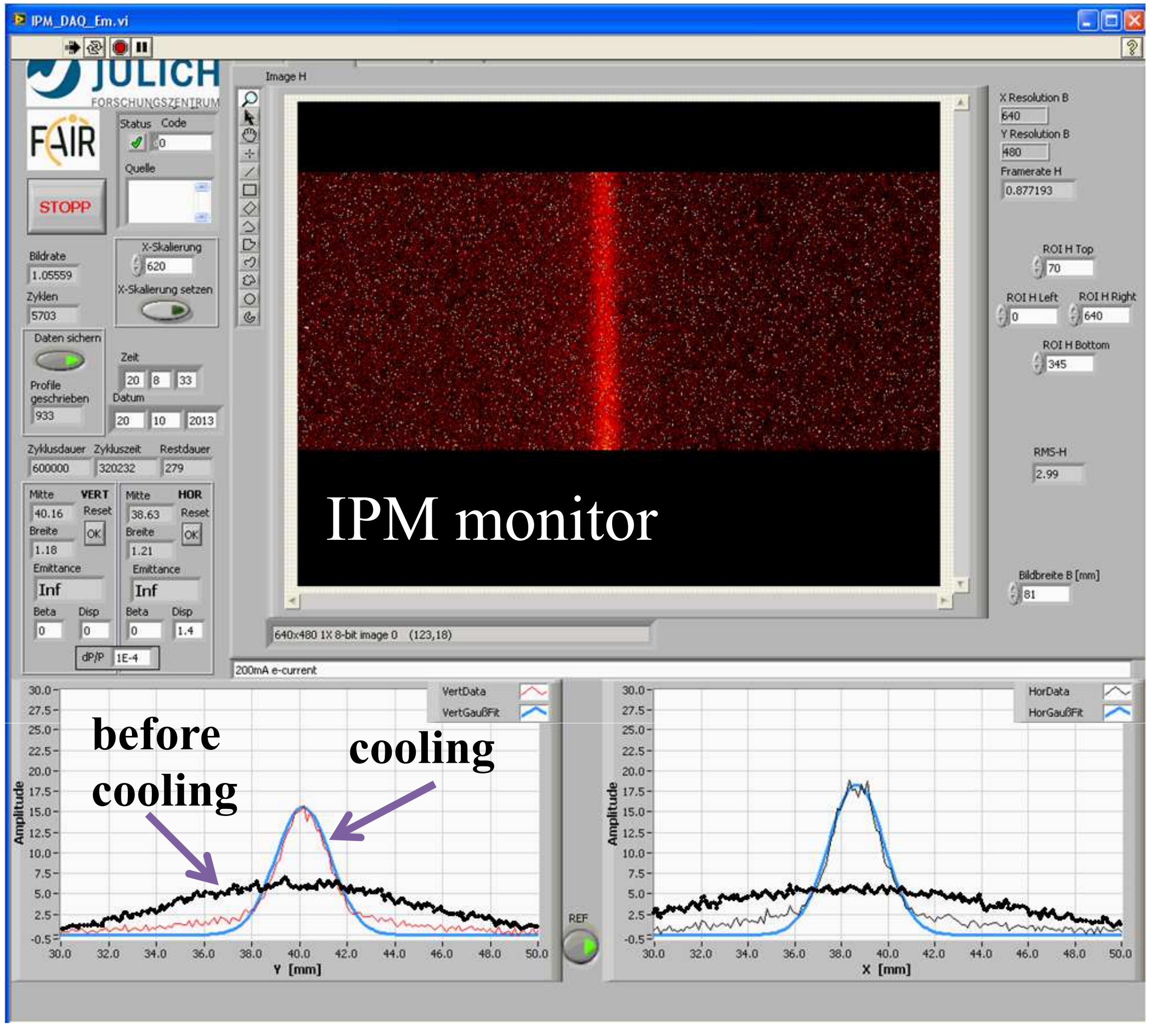
-in order to have small leakage current from the collector

6. "Magnetized" electron motion

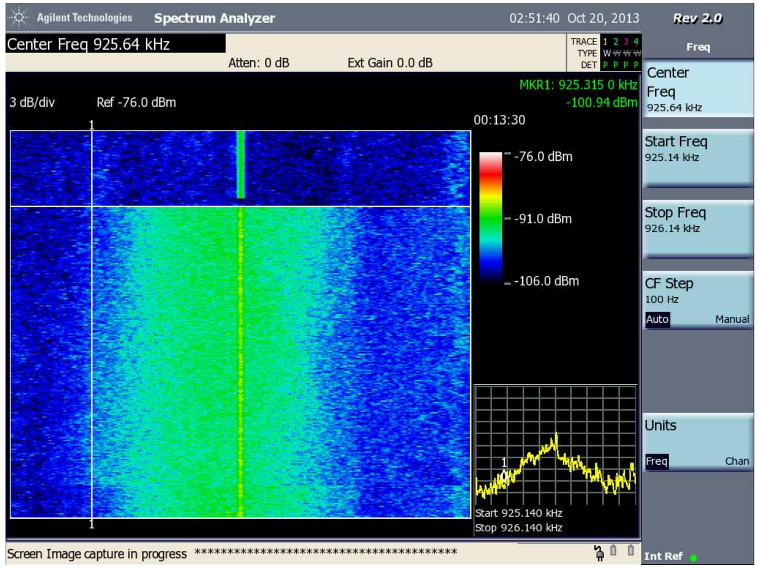
7. "4-sectors" electron gun for diagnostics of the electron beam motion

2 MeV Electron Cooler	Parameter
Energy Range	0.025 ... 2 MeV
Maximum Electron Current	1-3 A
Cathode Diameter	30 mm
Cooling section length	2.69 m
Toroid Radius	1.00 m
Magnetic field in the cooling section	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar
Available Overall Length	6.39 m

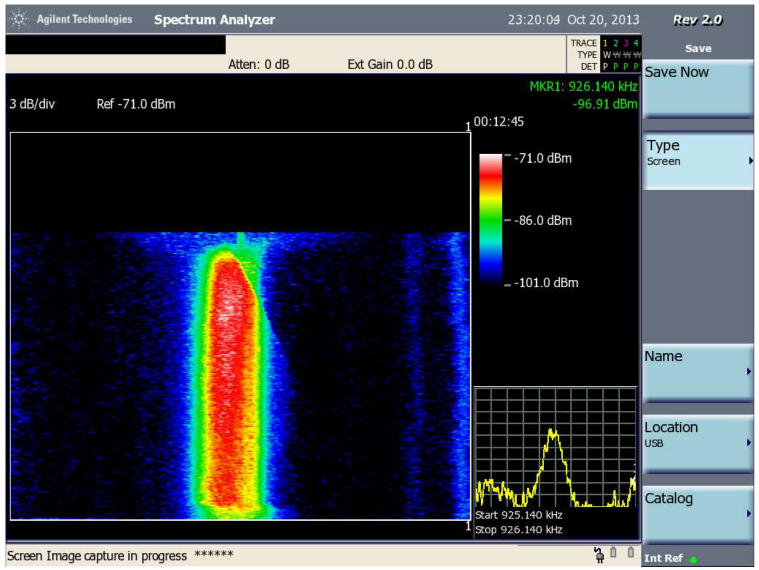
First cooling experiment - cooling at 109 kV



Transverse cooling



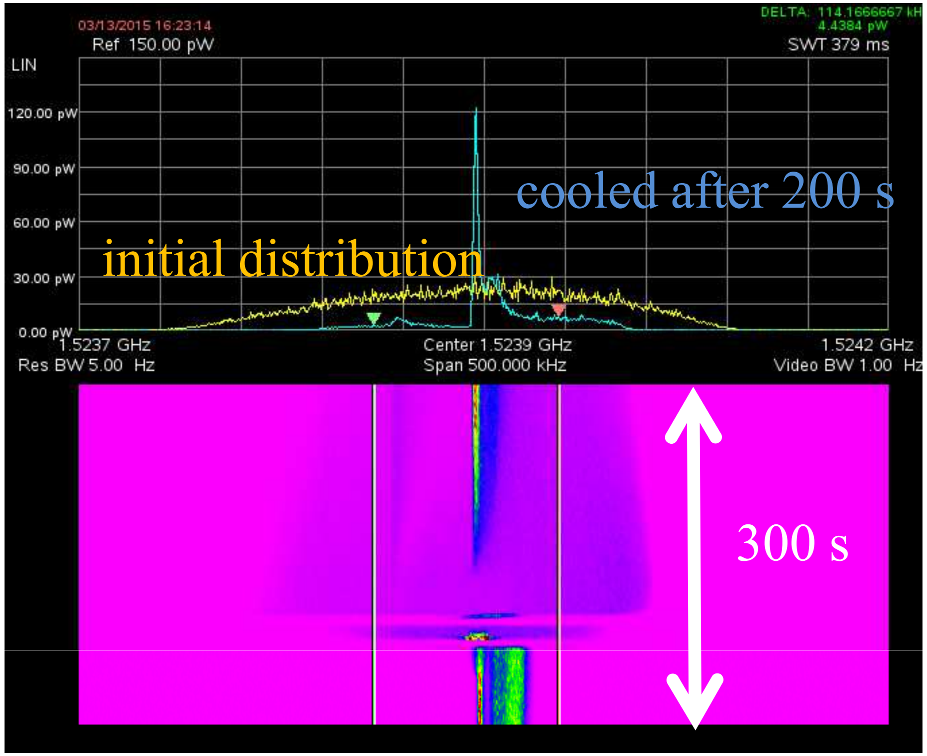
Before cooling

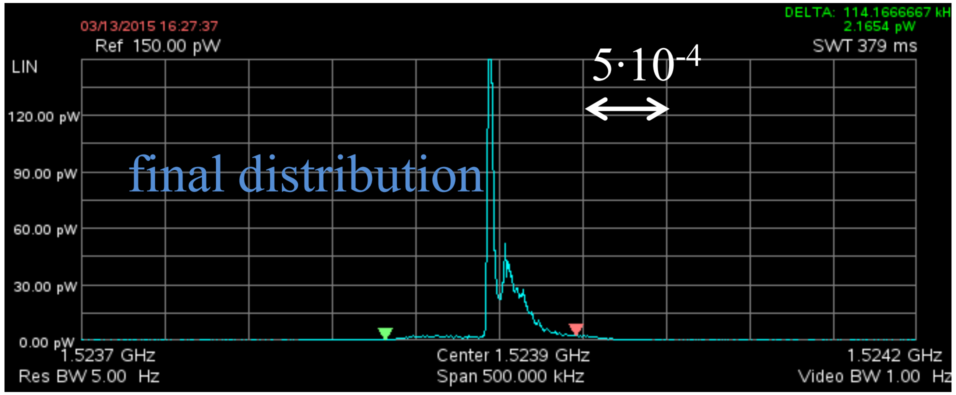


Cooling

Longitudinal cooling

Example of the longitudinal cooling

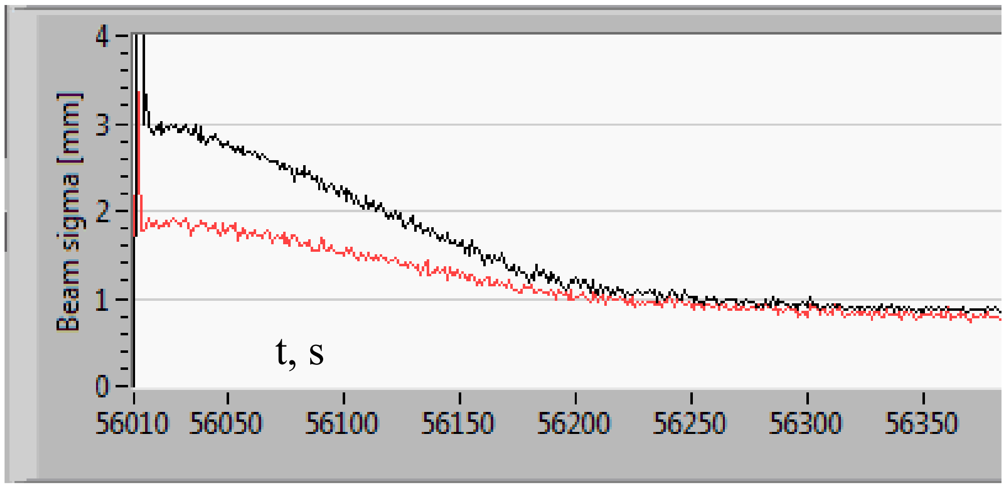




$\Delta p/p = 5.5\ 10^{-3}$

$Np = 7\cdot10^8$, $Je = 400$ mA, $\eta = -0.066$,
Ee=909 kV, $\gamma = 2.77$, $\gamma_{tr} = 2.25$, $\gamma > \gamma_{tr}$

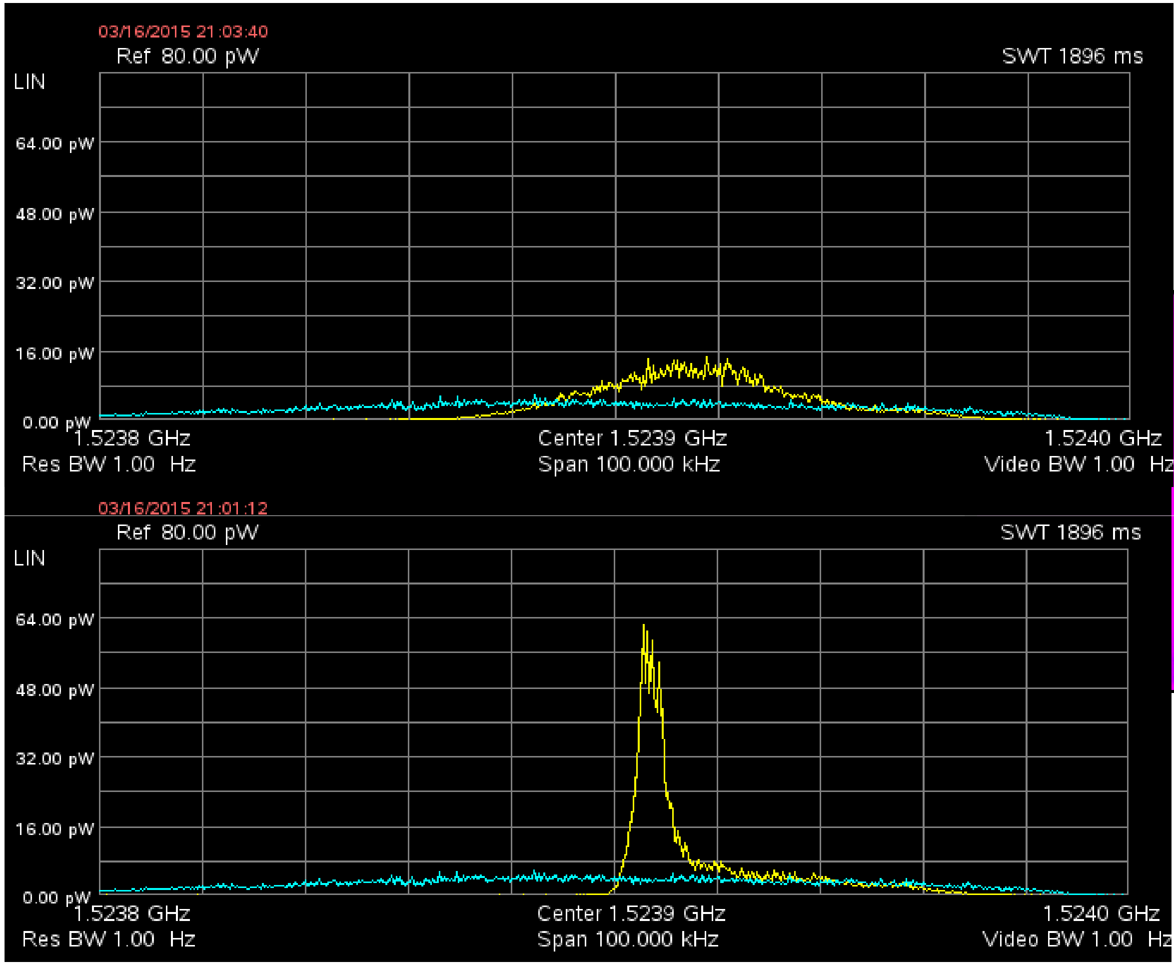
Cooling process is fast enough. The initial proton momentum spread was widened using white noise beam excitation to $\Delta p/p = \pm 2\cdot10^{-3}$, and it was cooled down during 100 s.

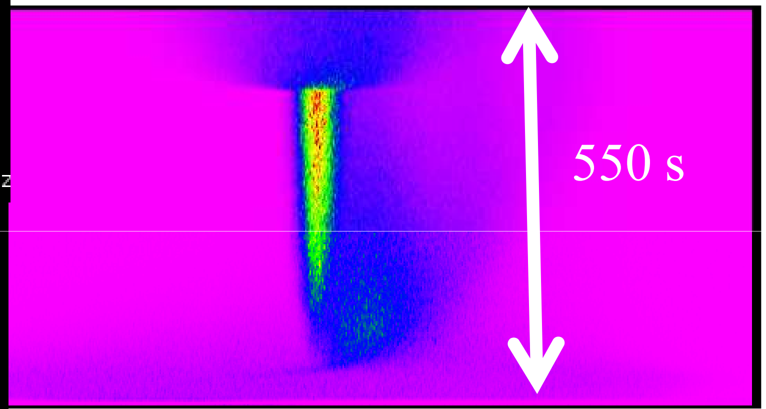


Example of the transverse cooling

$Np = 3\cdot10^8$, $Je = 800$ mA,

Electron Cooling of a proton beam and turning off EC

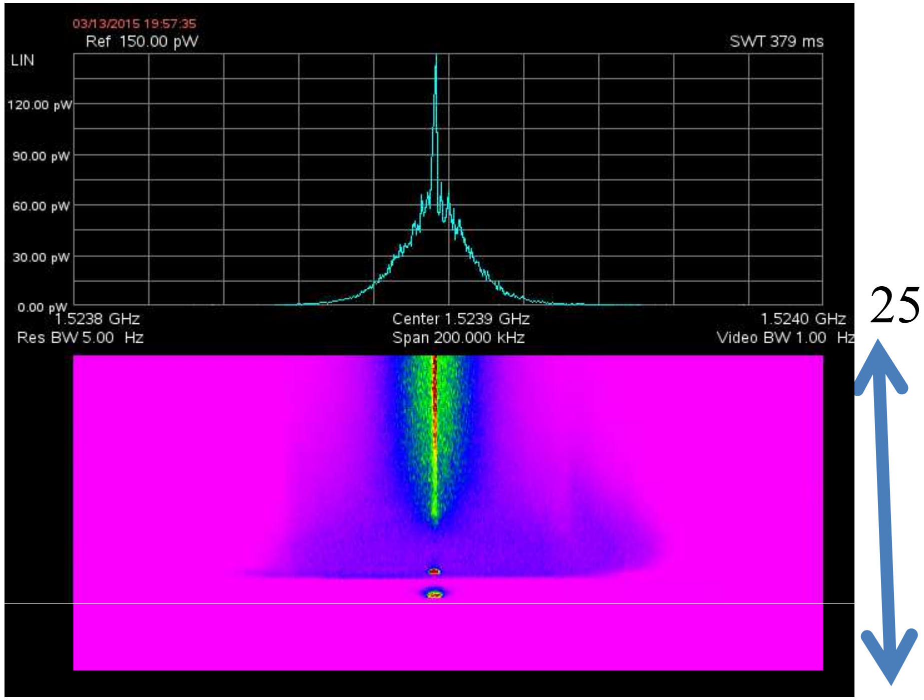




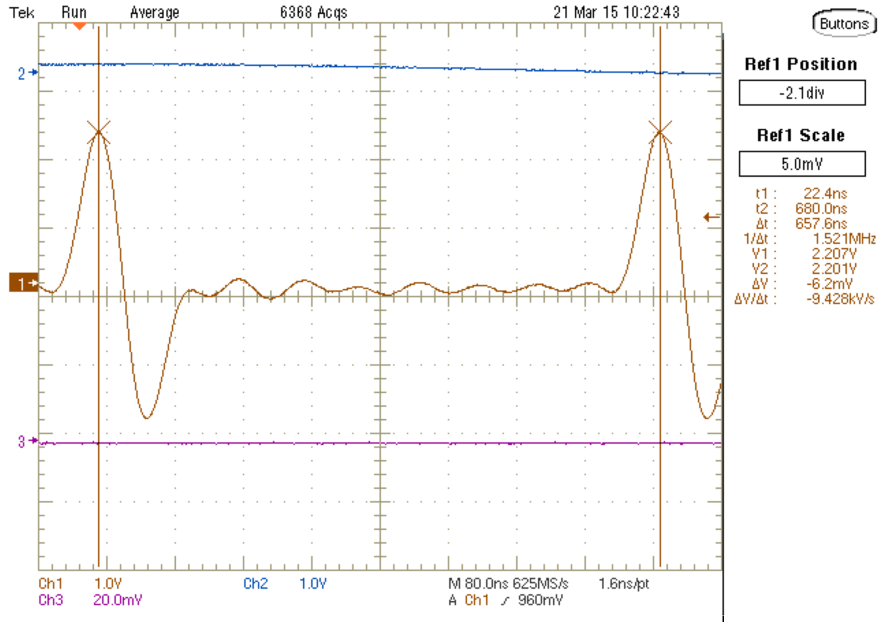
Time span of the color spectrogram 550 s

Longitudinal electron cooling process. e-beam turned off leading to fast $\Delta p/p$ growth. $5 \cdot 10^8$ protons, 1.66 GeV, electron current 0.8 A

e-cool can well operate with barrier bucket RF



250 s

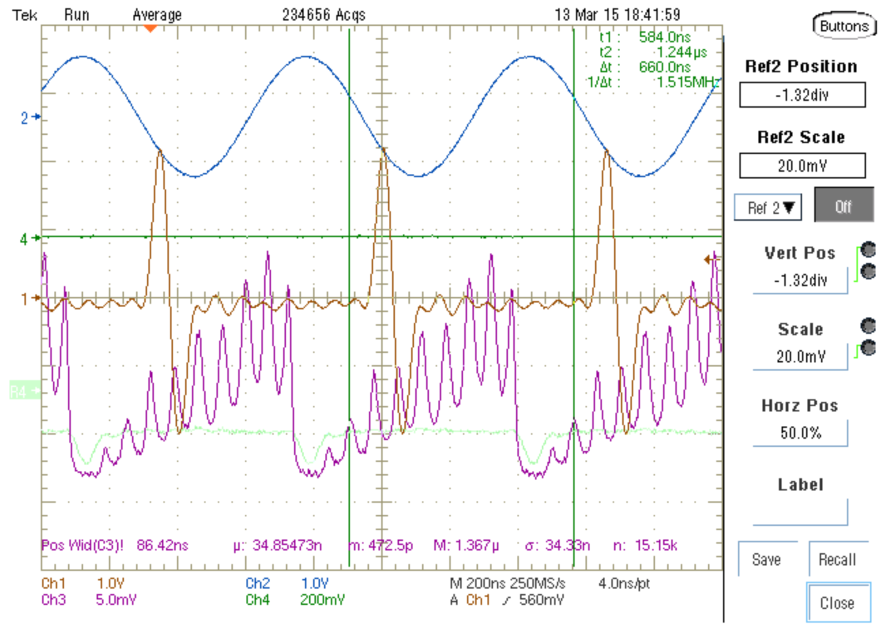


e-cool + barrier bucket RF

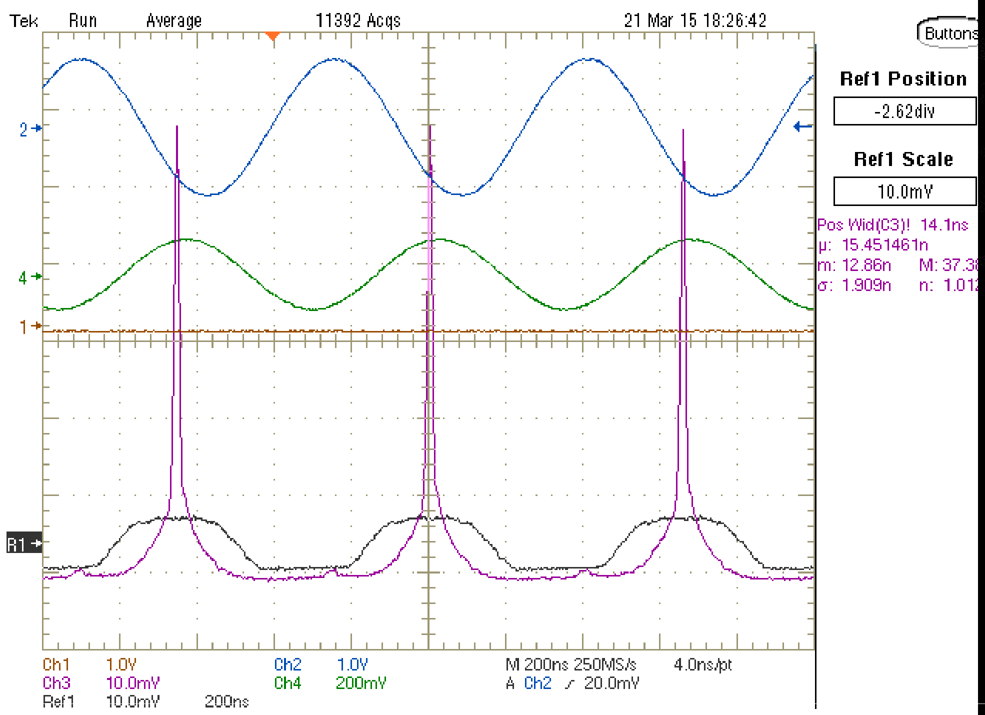
longitudinal cooling at barrier bucket RF voltage

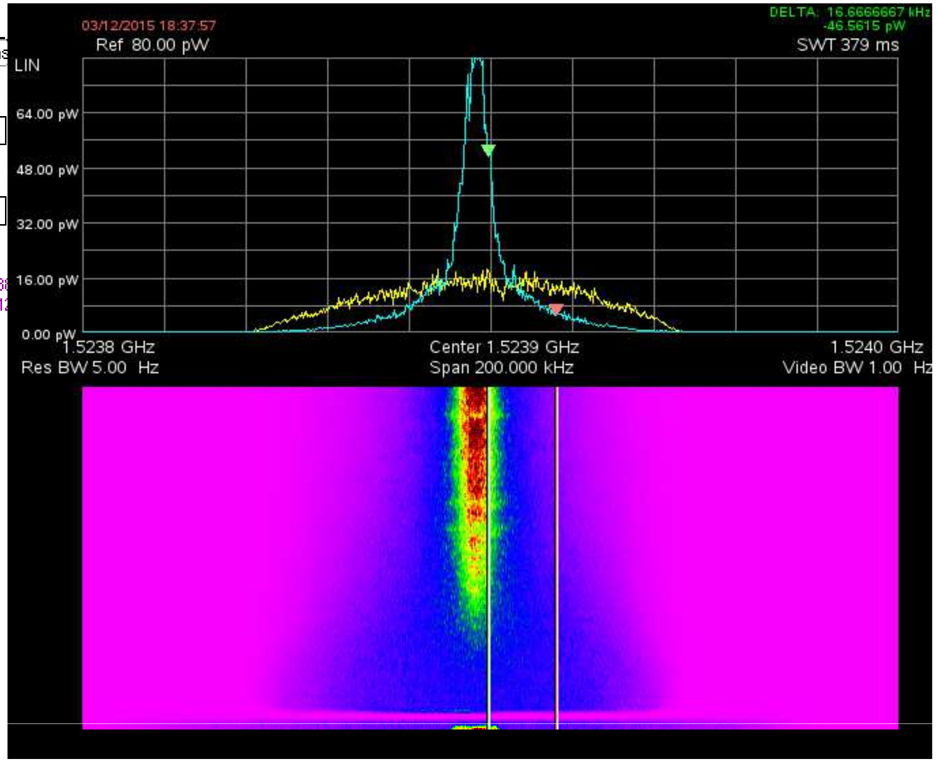
f_{BB}=1.523918 MHz, U_{RF}=240 V

Np=$3\cdot10^8$, Je=550 mA, $\gamma>\gamma_{tr}$ η=—0.066,



Barrier bucket signal and Phase probe signal of p-beam





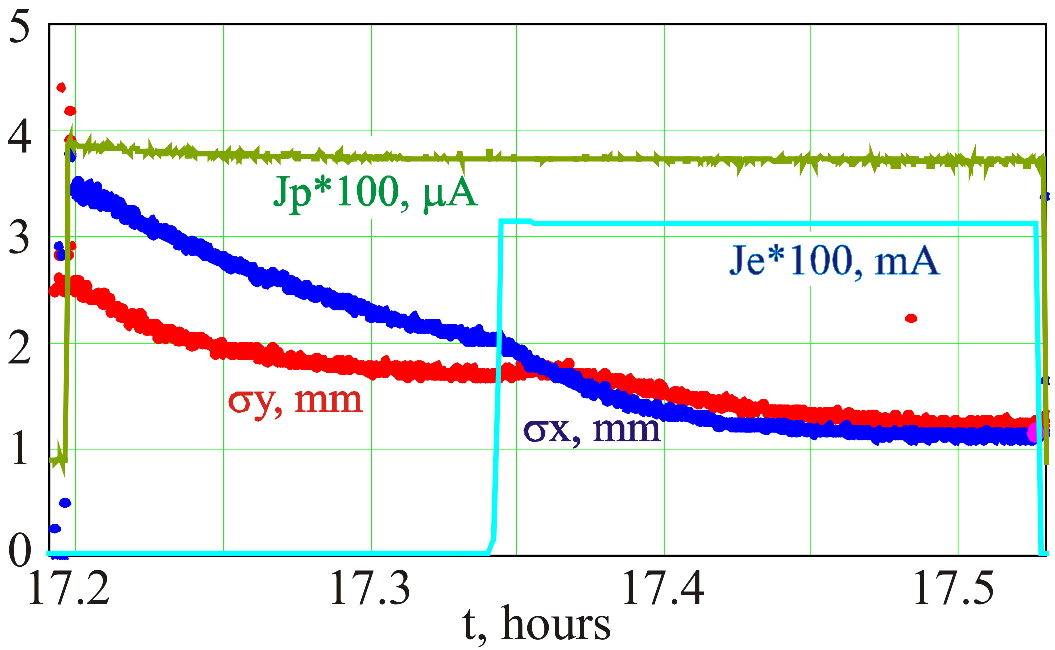
RF of 1st harmonic and Phase probe signal of p-beam

RF on, e-cooling with 550 mA, final $\Delta p/p = 10^{-4}$

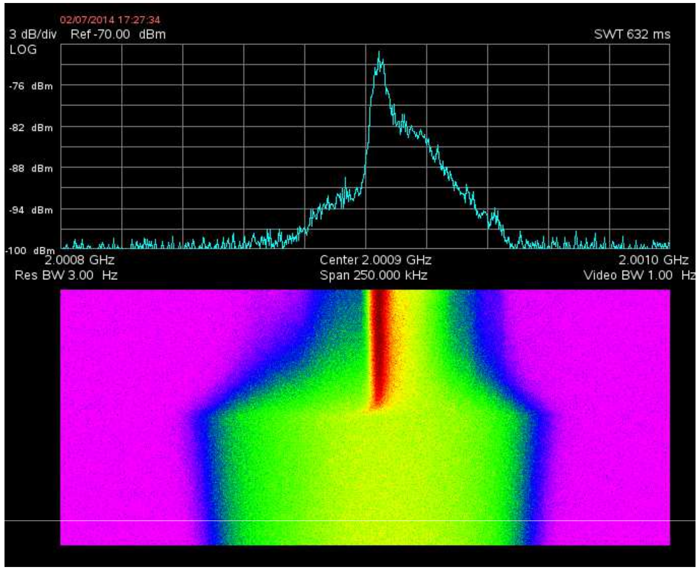
One can see that the combine action of the RF and e-cool produces very short beam with high quality. The off-duty factor of the proton beam is 650 ns/30 ns=20. So, the bunched e-cool of the bunched ion may have the gain of the electron current 20 without increasing average current.

The use of bunched e-beam may be some reserve for improvement of DC e-cool. The use of the e-bunch at the same time proton bunch with larger current can increase cooling rate in 20 times ! Certainly the special pulse e-gun and the collector for higher current should be constructed.
This experiment may be attractive for Jefferson b and RHIC projects.

Combine action of stochastic and electron cooling



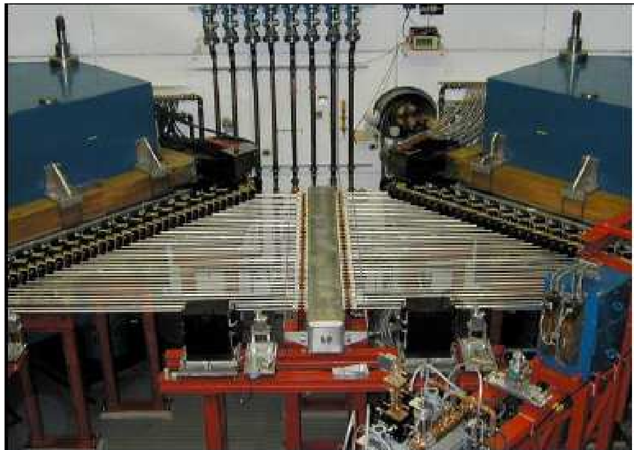
Only stochastic   Stochastic+e-cooling

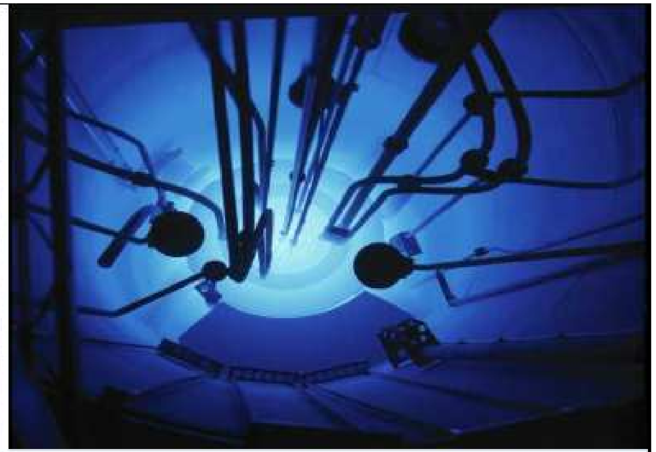


initial no longitudinal cool, after e-cooling

Electron energy	908 keV
Proton energy	1.66 Gev
Stochastic cooling	vertical and horizontal
E-cool time	120 s
Stochastic cooling time	400 s
Beta function x/y	4m/3m

Combination of Stochastic Cooling and Electron Cooling combination will be important in the projects FAIR, HIAF, NICA





Electron cooler related R&D at Helmholtzinstitut Mainz (HIM)

New ways to high energy electron cooling technique

Kurt Aulenbacher

Cool-15, Jefferson-Lab
2015, October,1

The turbine approach

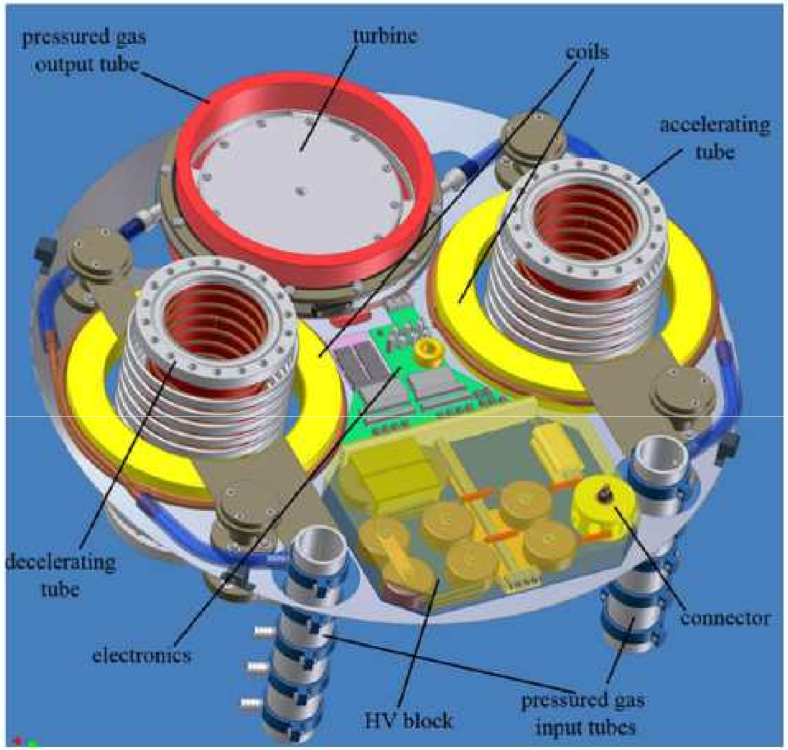
HESR cooler: solenoid channel problem & turbine concept

- Solenoids must be powered by floating power supply.
- Turbines for U>2MV → Suggestion of BINP-Novosibirsk: 60kV/Turbogen (400Watt)
- **Not realized** for Jülich 2MV-cooler…
- German company DEPRAG: Offers turbogenerators in the 5-50kW range - intended for use in the "green energy sector" but also potentially attractive for cooler application.

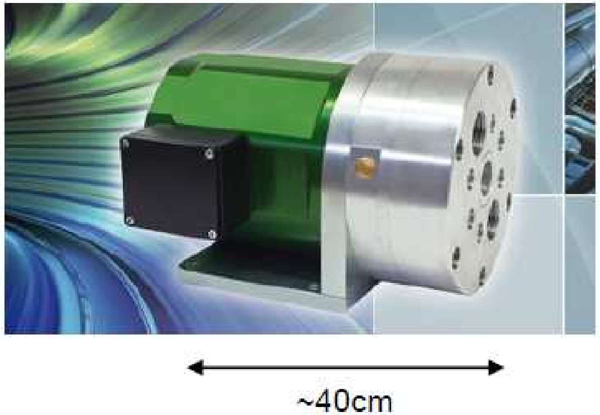
~40cm

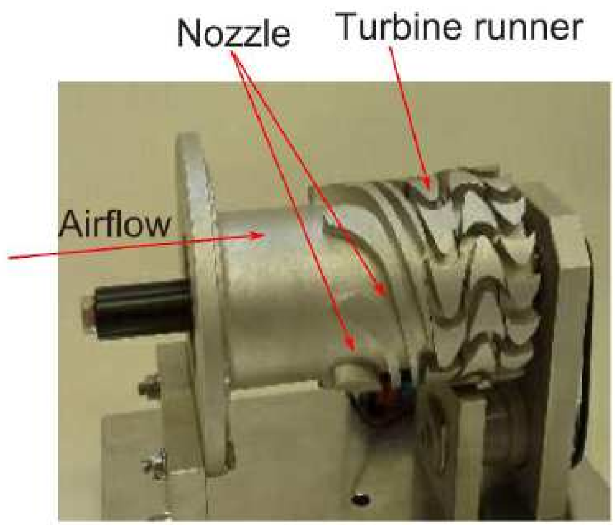
Poster by Andre Hofmann,, Monday

So far, two 5kW Turbogenerators have been purchased



First idea for Jülich Cooler ~600 W Turbogen. Powering 60kV + solenoids

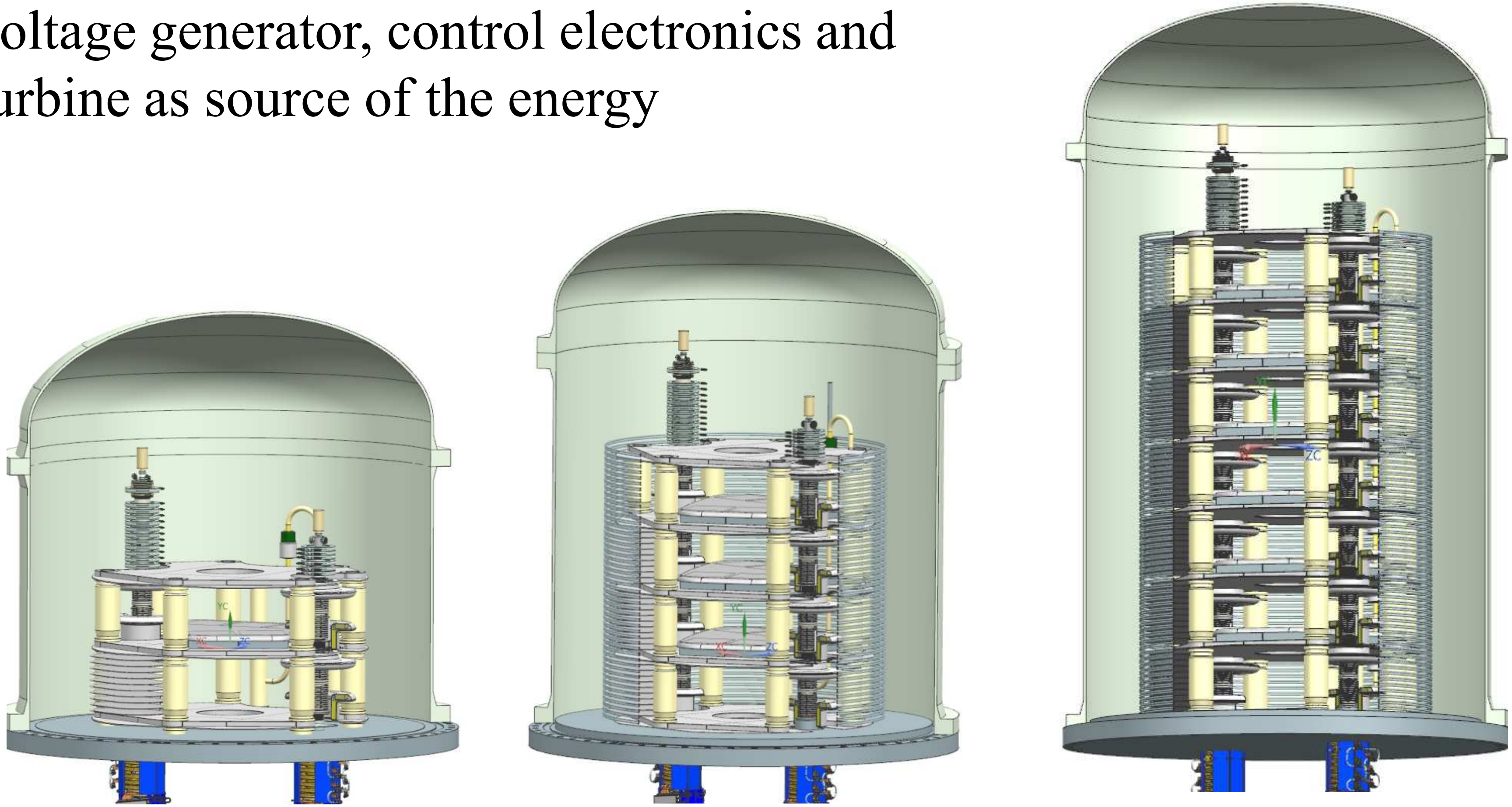




Runner of 5kW Turbine

Unify design for the different coolers with large modules

Each section contains magnetic element, high-voltage generator, control electronics and turbine as source of the energy



Sequence of designs of the high-voltage tanks for 1, 2 and 4 MeV. The design of the bottom is identical. So, the transport channel may be identical too. The size of the bottom is enough for the construction of 8 MeV cooler also.

Summary

- The key problems of the electron cooler 2 MeV (modular approach of the accelerator column, the cascade transformer, the compass base probe located in the vacuum chamber, the design of the electron gun with 4-sectors control electrode) are experimentally verified during commissioning in Novosibirsk and COSY;
- The fine tune of the electron beam with diagnostics and correction schemes allowed for faster cooling

$\Delta p/p = 5*10^{-5}$ in less than 100 s

$\varepsilon_x = 1.1 \rightarrow 0.1$, ε_y : $=1.3 \rightarrow 0.2$ mm·mrad, within 200s (beam core)

- Electron cooling may work well together with stochastic cooling, RF and barrier bucket RF.
- COSY hardware is the best opportunity for expand our understanding of cooling processes and receiving highest possible parameters of e-cool together with stochastic cooling, barrier bucket and RF;
- new project participants may help to do the project of new 2-4-8 MeV cooler more attractive and simple;