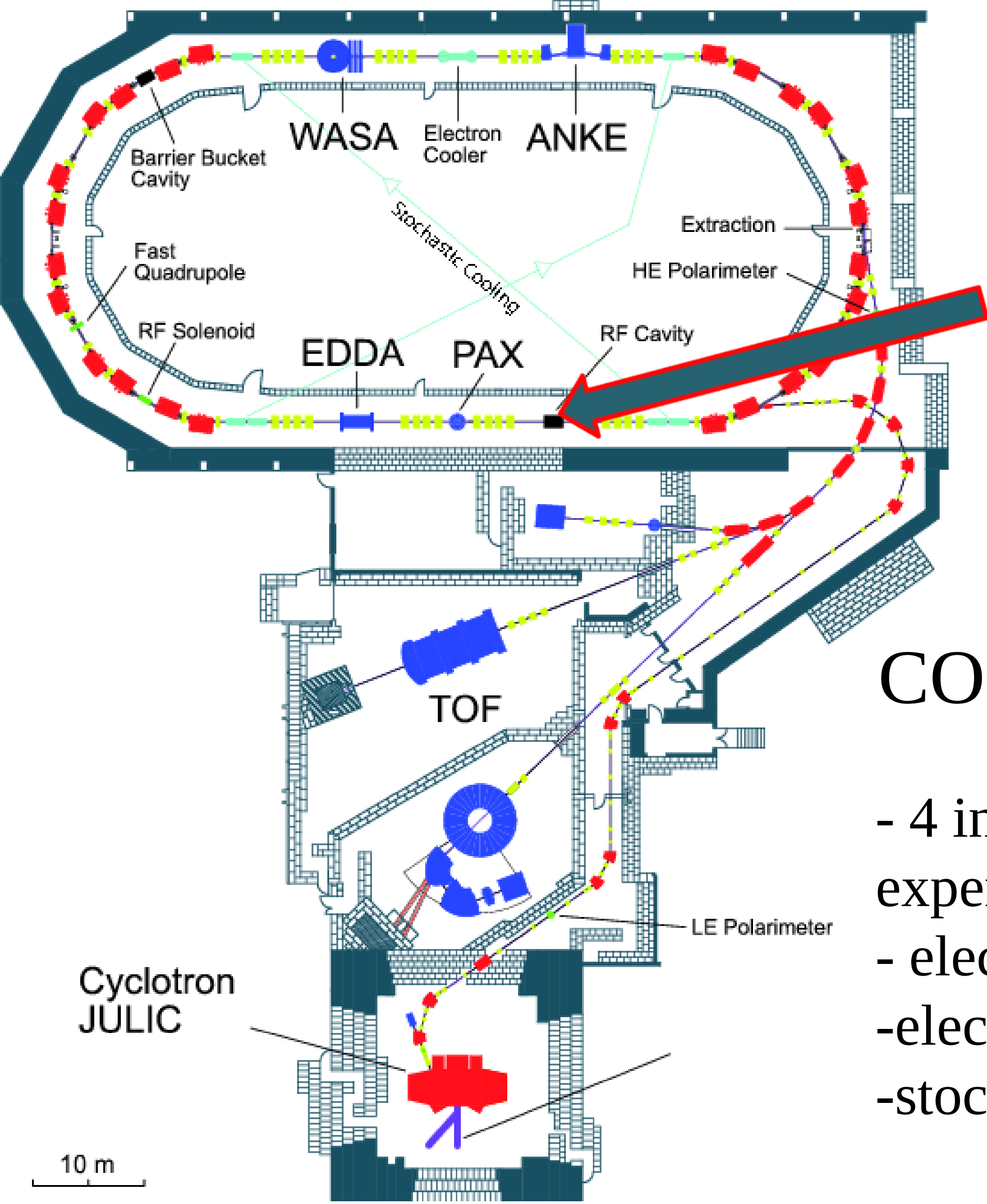
Development and Commissioning of 2 MeV DC Cooler

V. B. Reva + BINP+COSY teams
BINP, Novosibirsk, Russia
Forschungszentrum, Juelich, Germany

Abstract

The 2 MeV electron cooling system for COSY-Julich started operation in 2013 years. The cooling process was observed in the wide range energy of the electron beam from 100 keV to 908 keV. Vertical, horizontal and longitudinal cooling was tested at bunched and continuous beams. The cooler was operated with electron current up to 0.9 A.

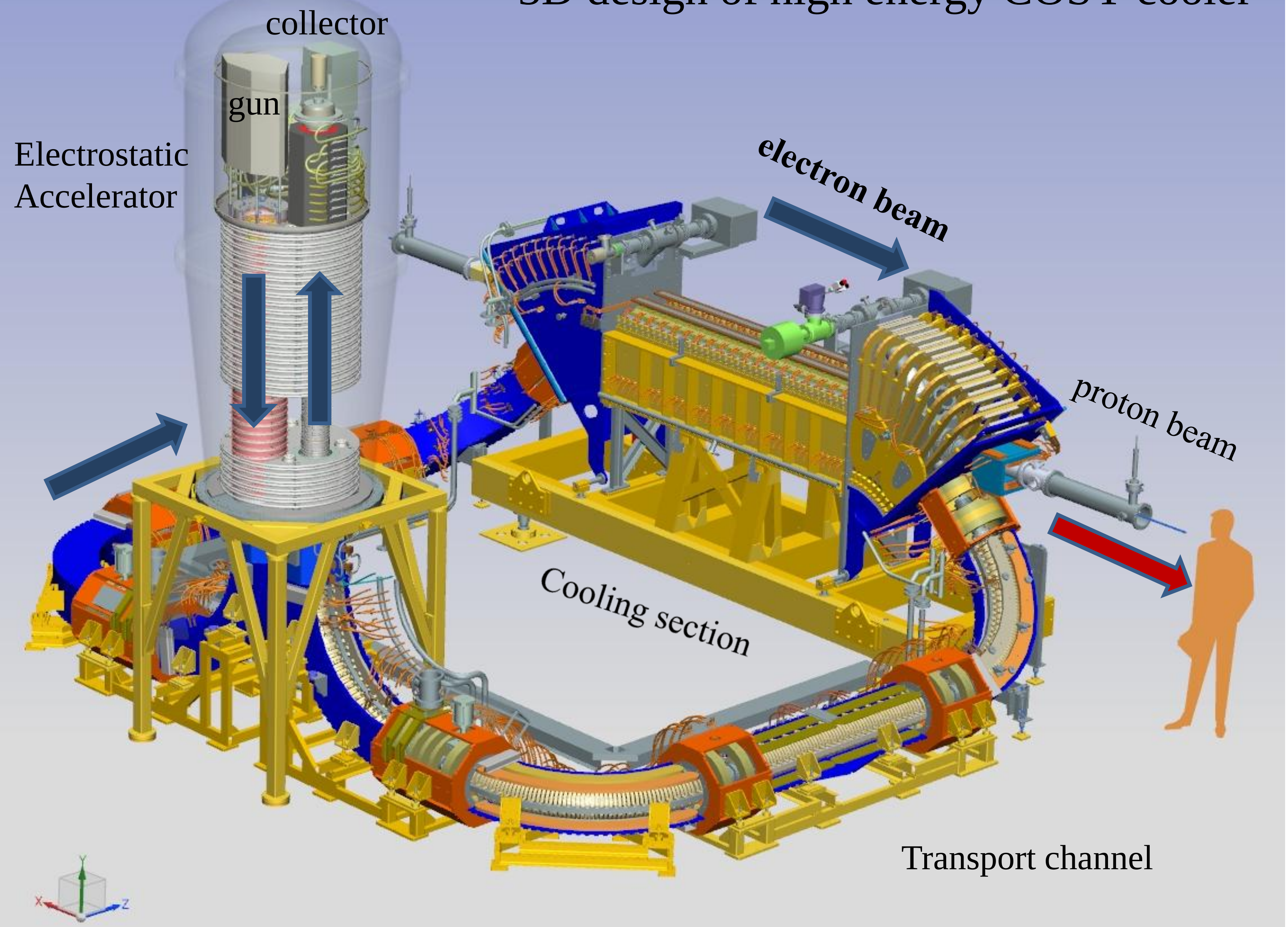


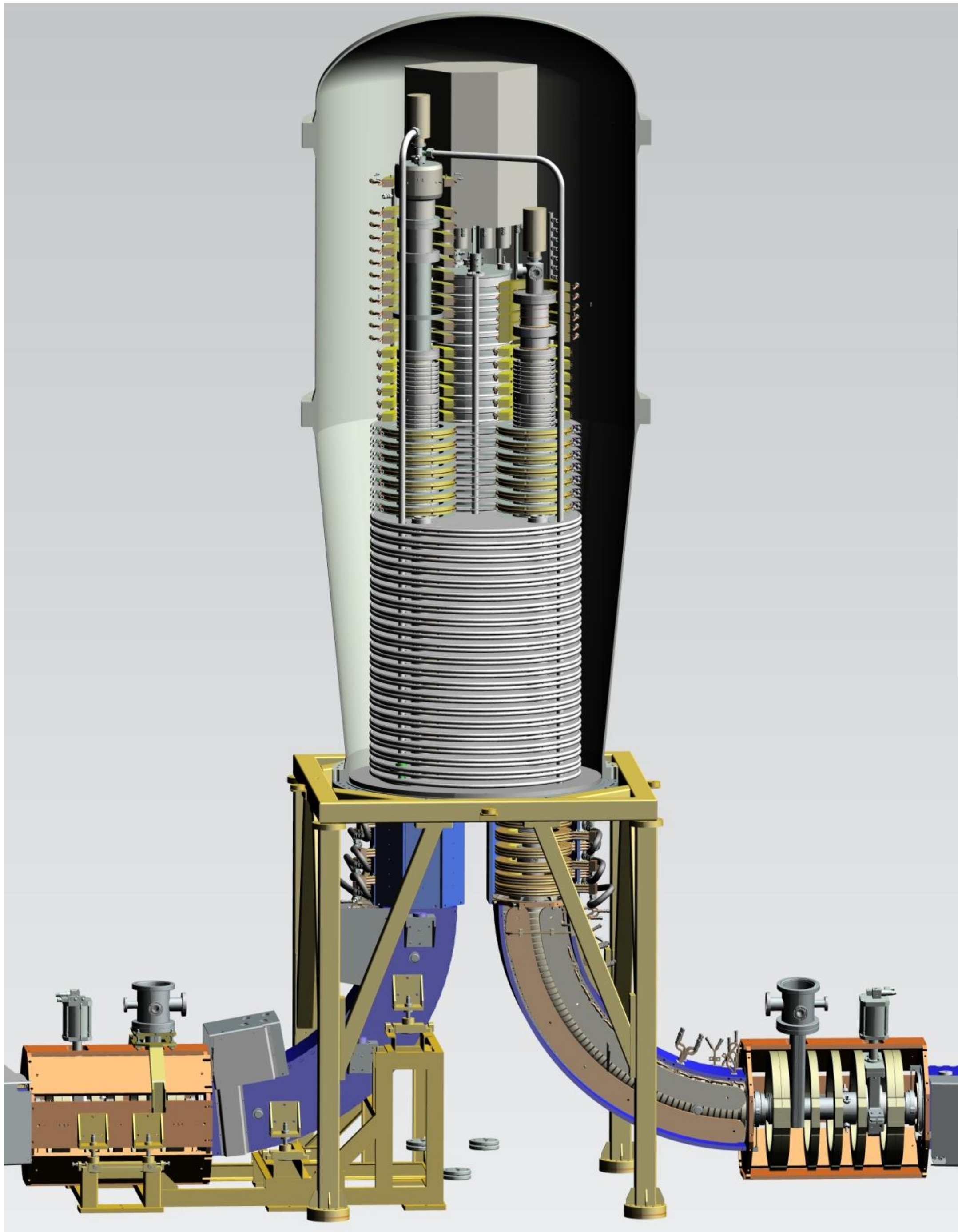
COSY Accelerator Facility

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

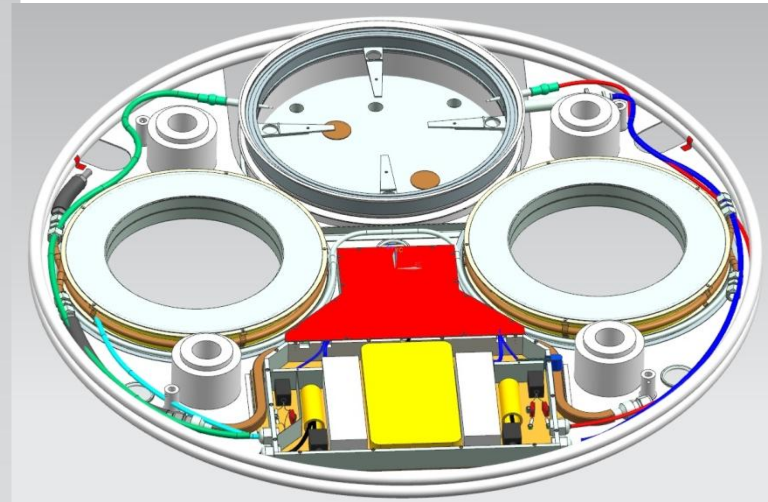
P=183.6 m, E=2880 MeV

3D design of high energy COSY cooler





3D design of Accelerating Column



Each section contains;

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

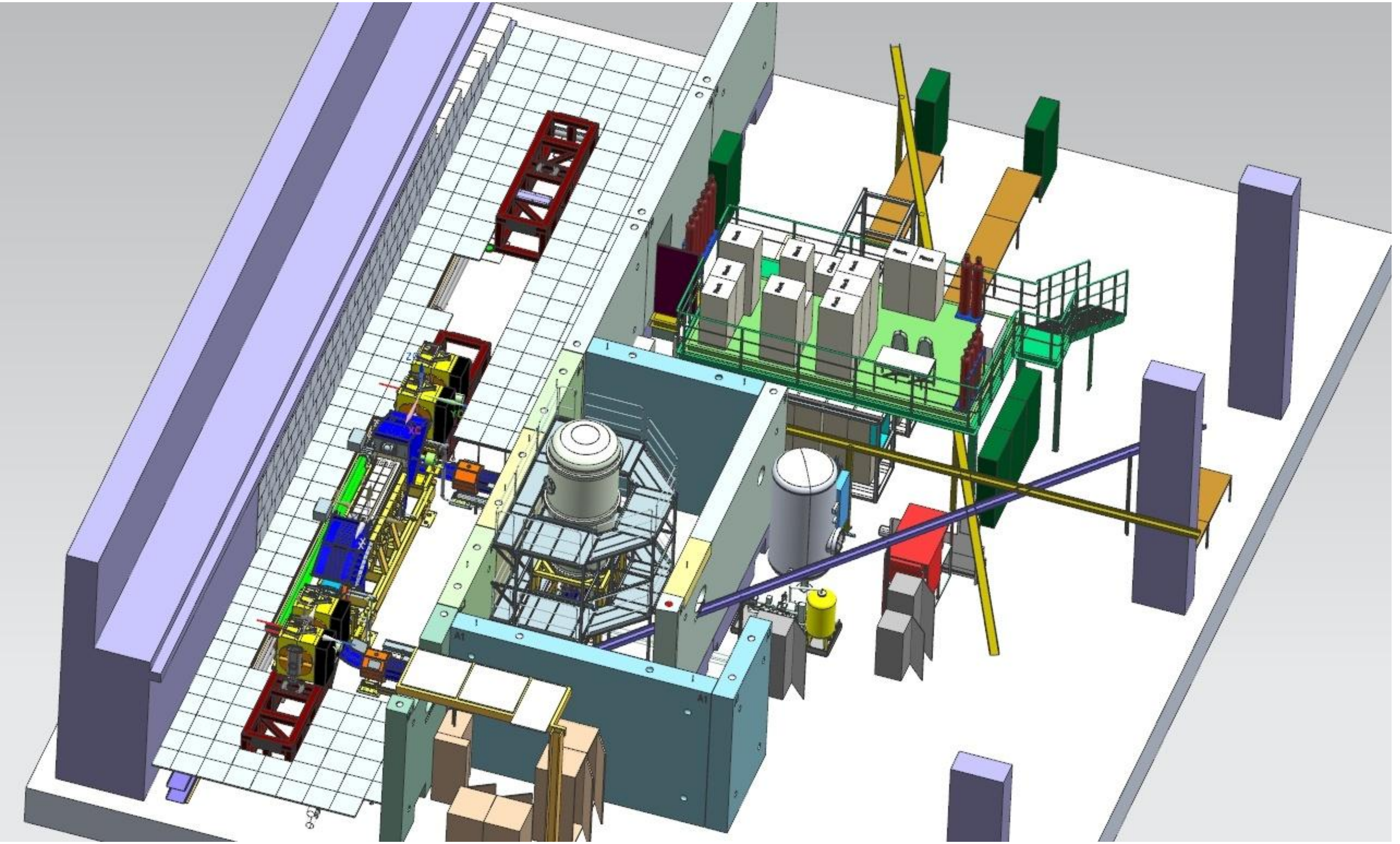
- power supply of the coils of the magnetic field (2.5 A, 500 G);

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

- control electronics;

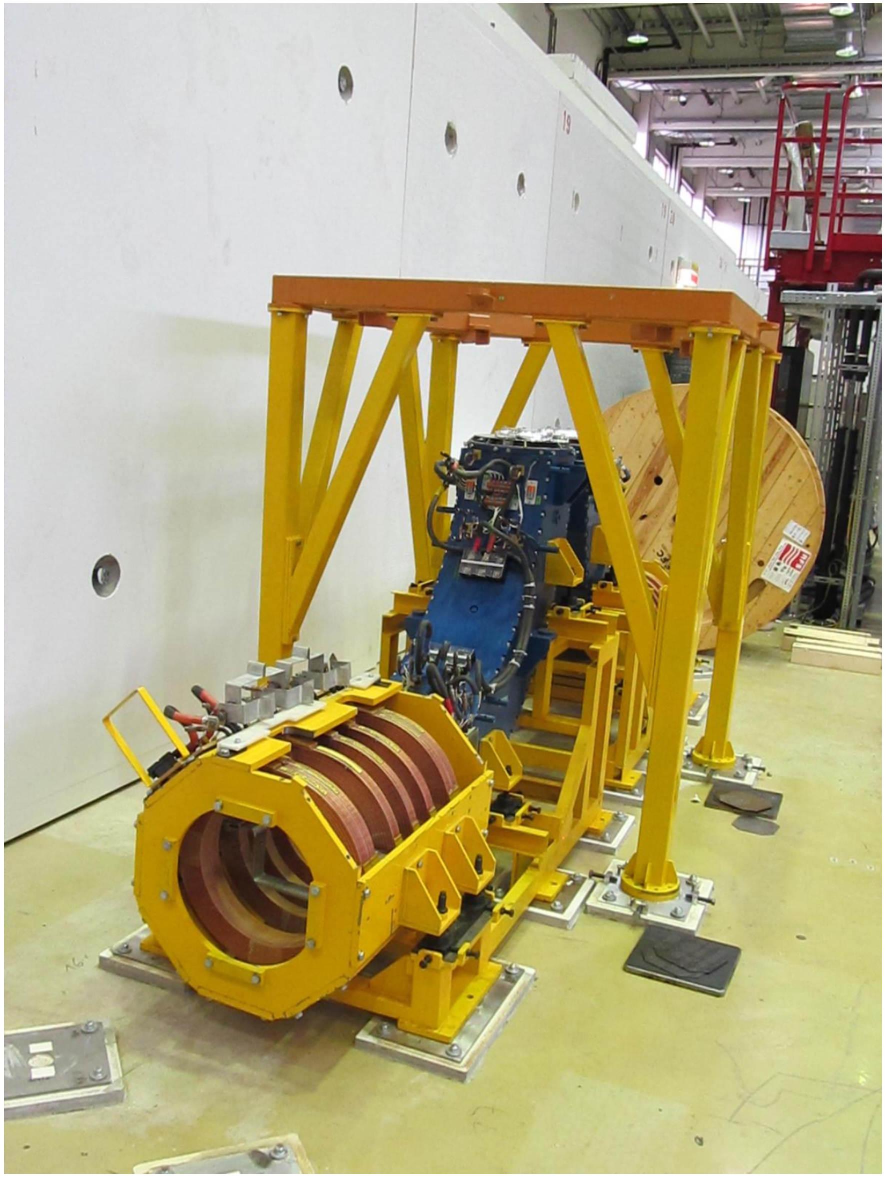
33 high-voltage section

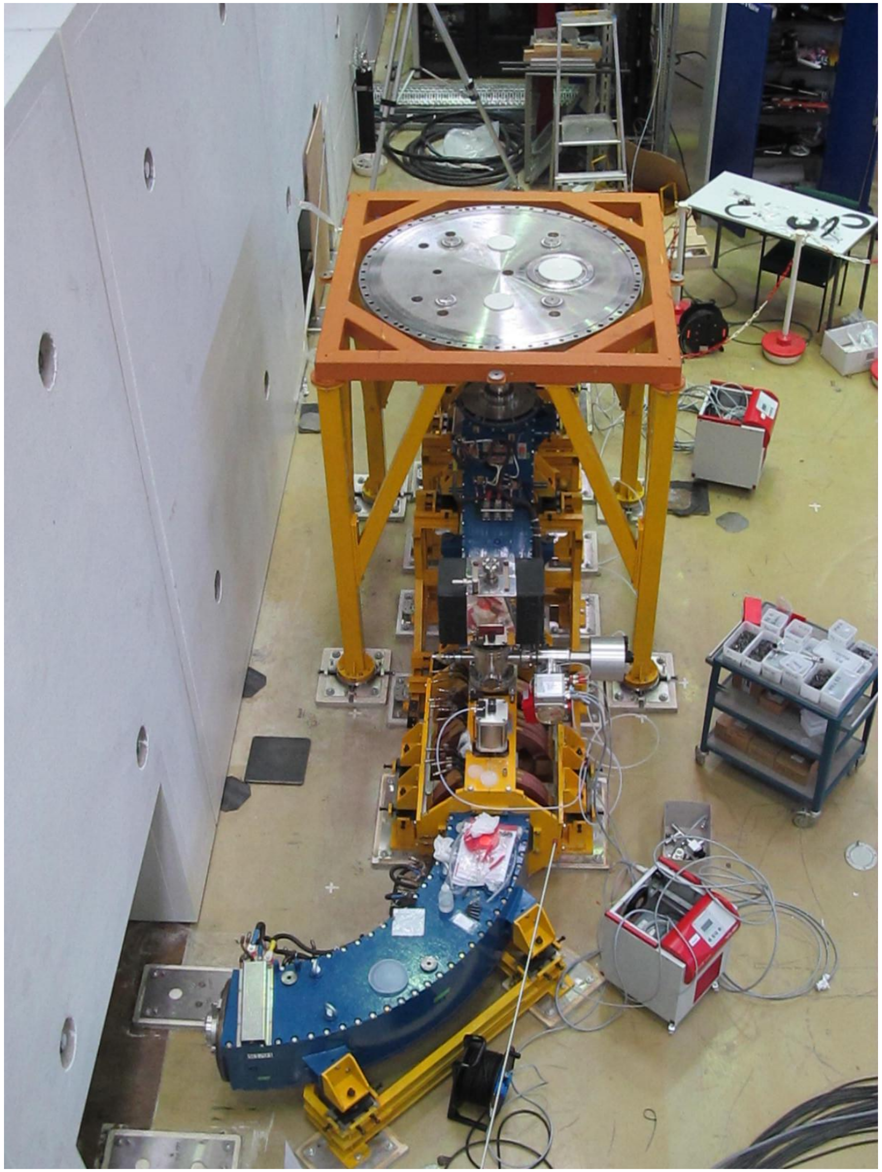
2MeV electron cooler – integration into COSY



Commissioning in COSY

Start of the assembling



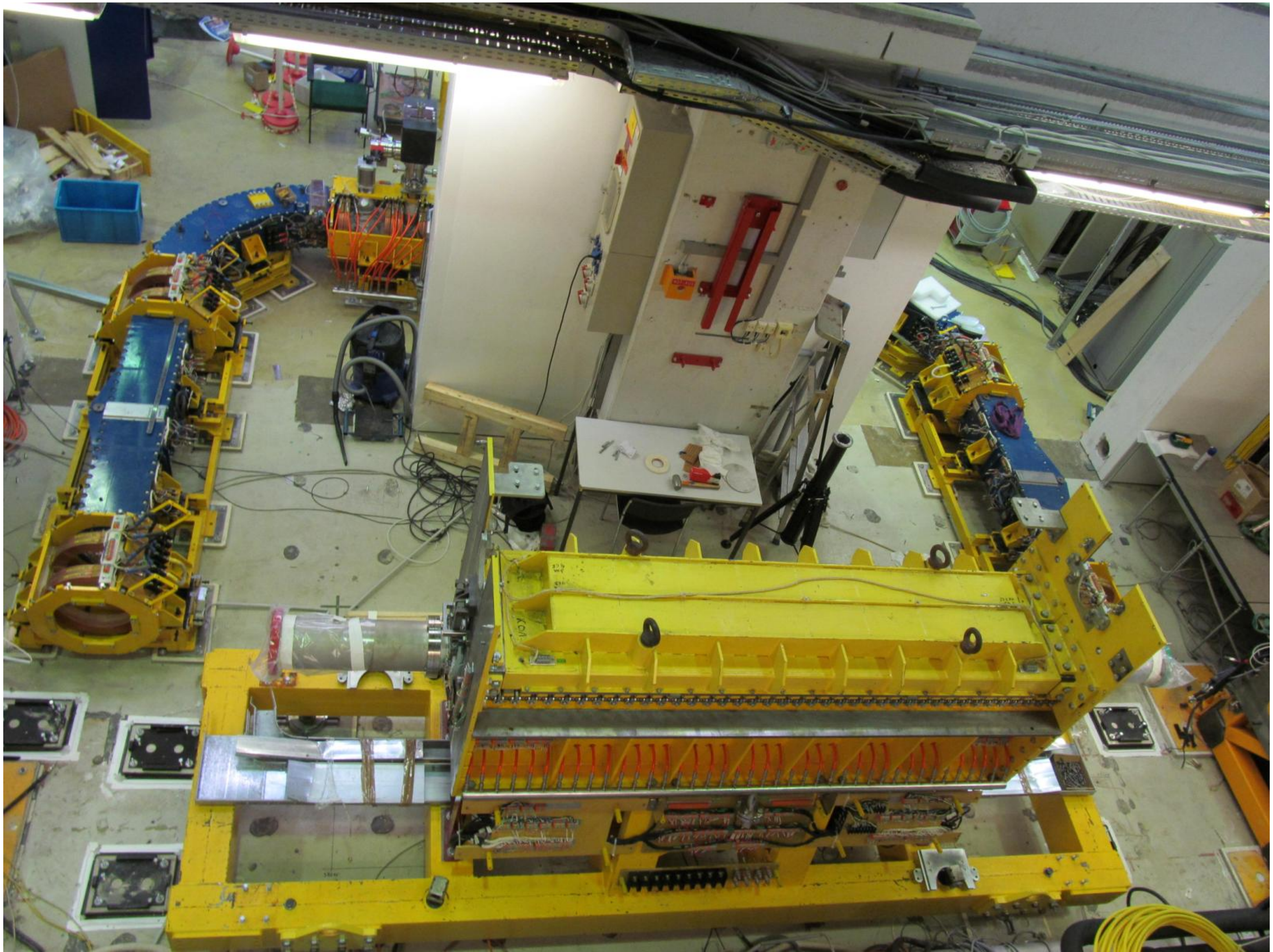


Commissioning in COSY

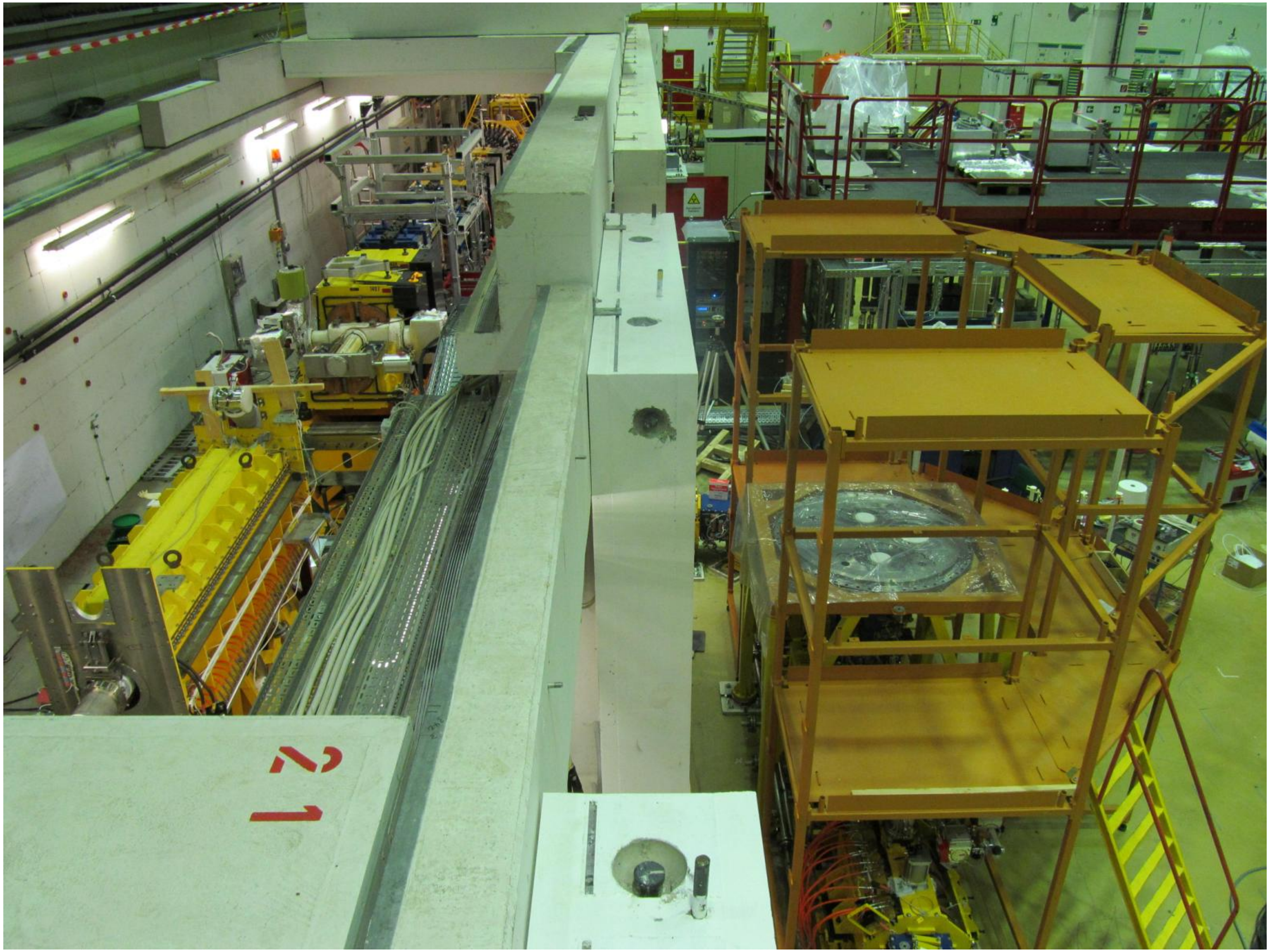
Cooling section is transported to the permanent residence

Commissioning in COSY

Transportation channel is close to finish state



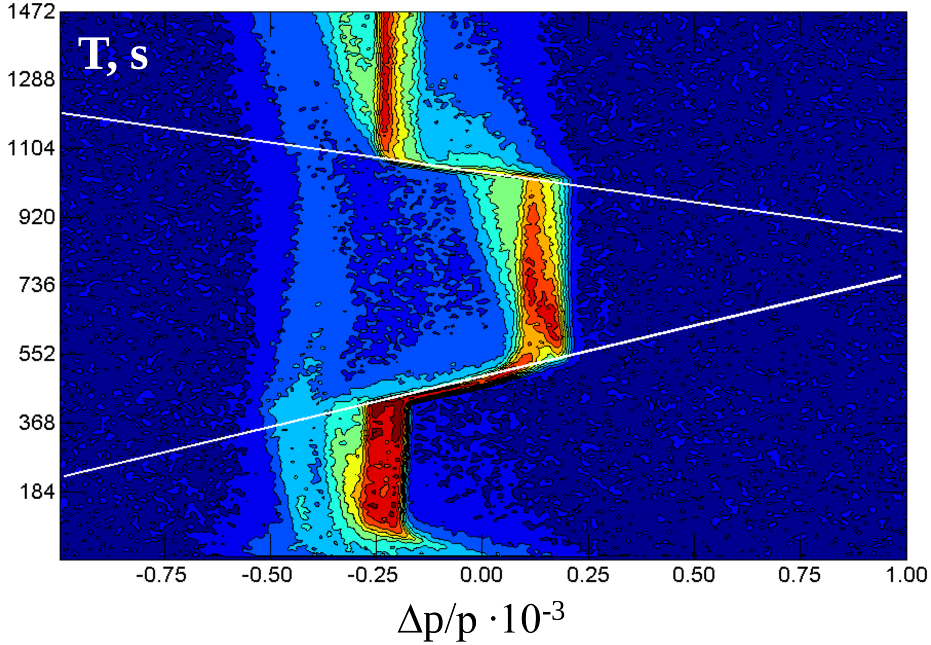
Start assembling of the accelerator



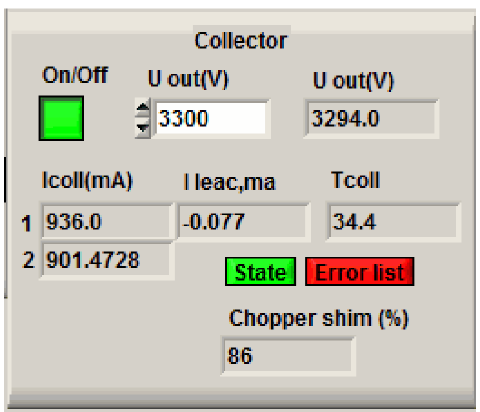
Commissioning in COSY

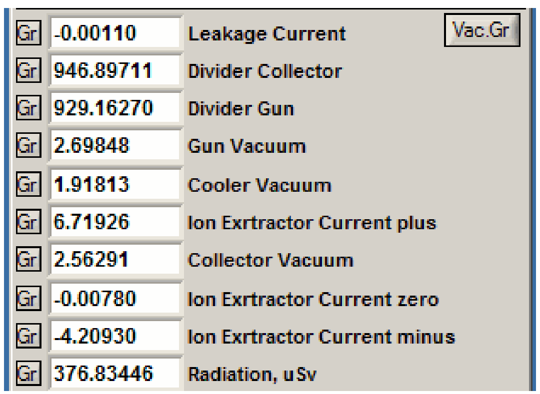
Accelerator column is finished

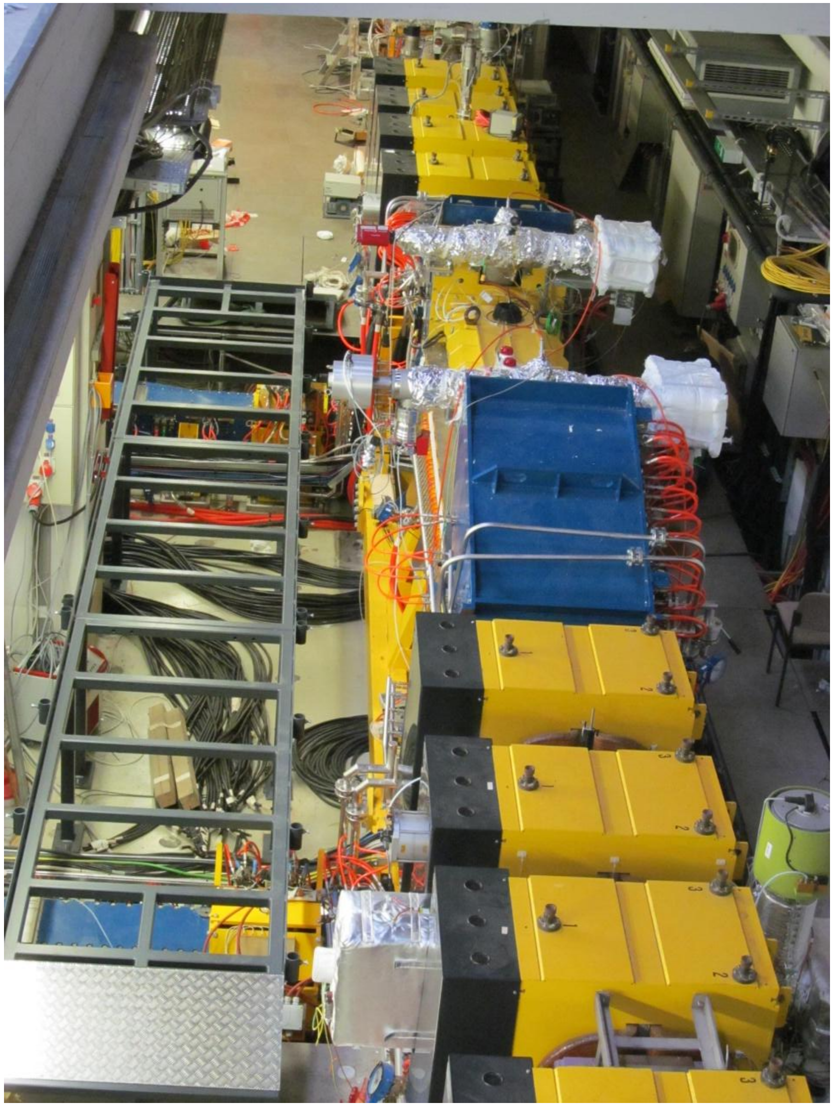
Now in operation in COSY FZJ



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







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

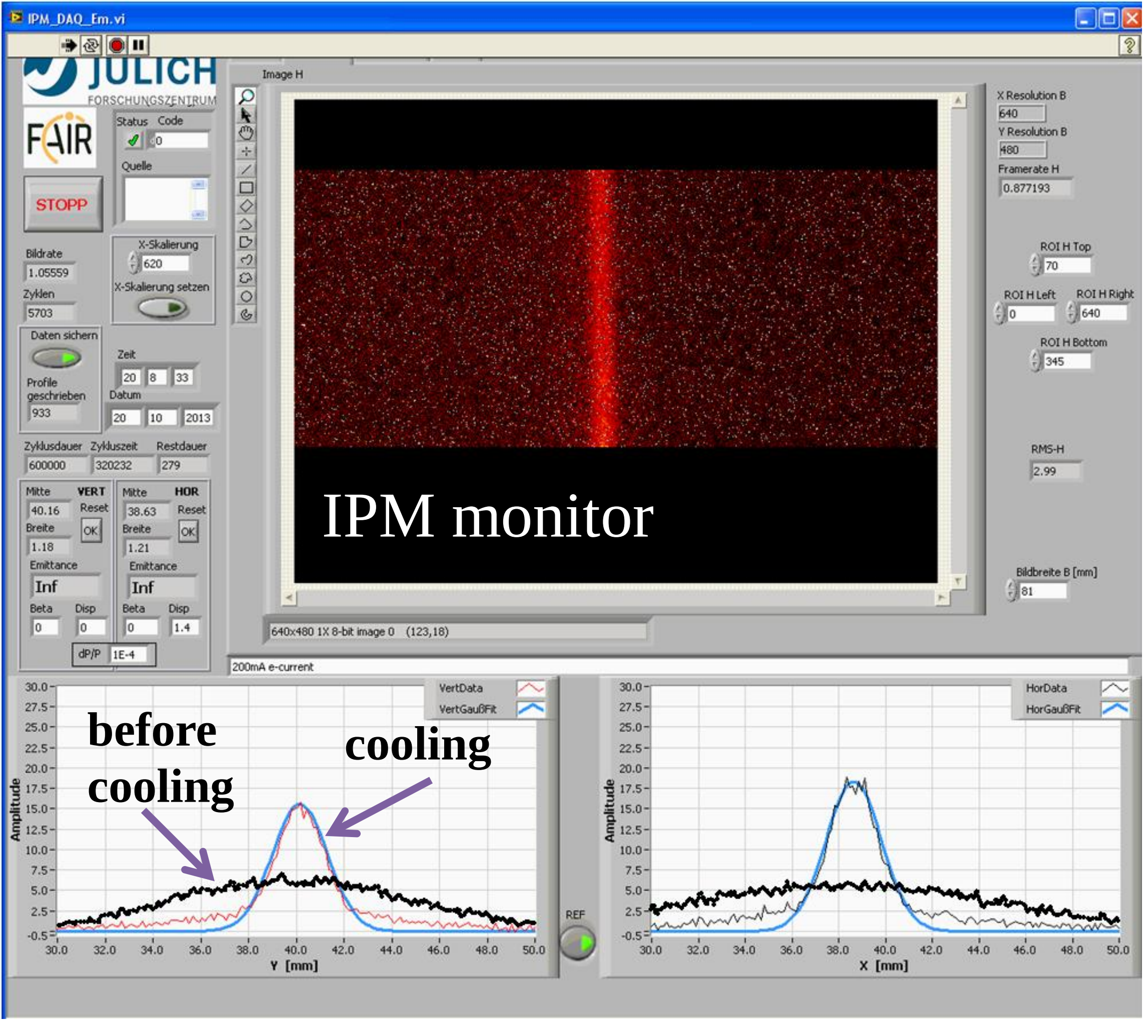
-in order to have small leakage current from the collector

6. “Magnetized” electron motion

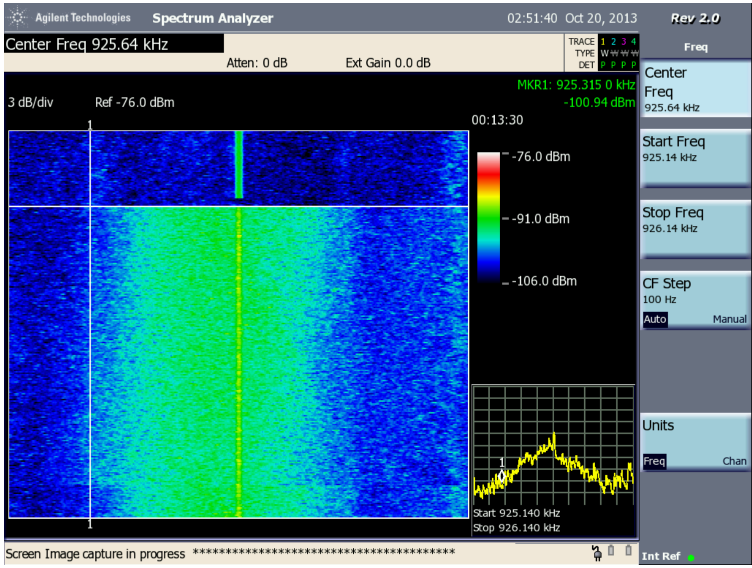
7. “4-sectors” electron gun for diagnostics of the electron beam motion

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

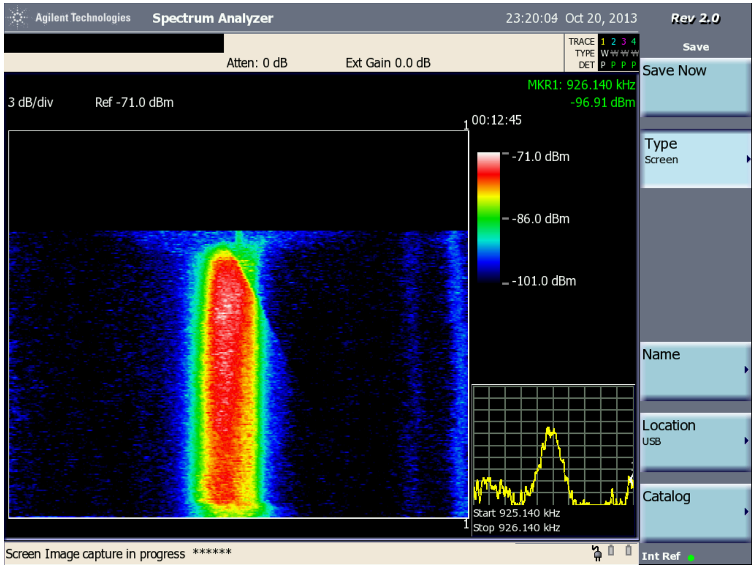
First cooling experiment - cooling at 109 kV



Transverse cooling



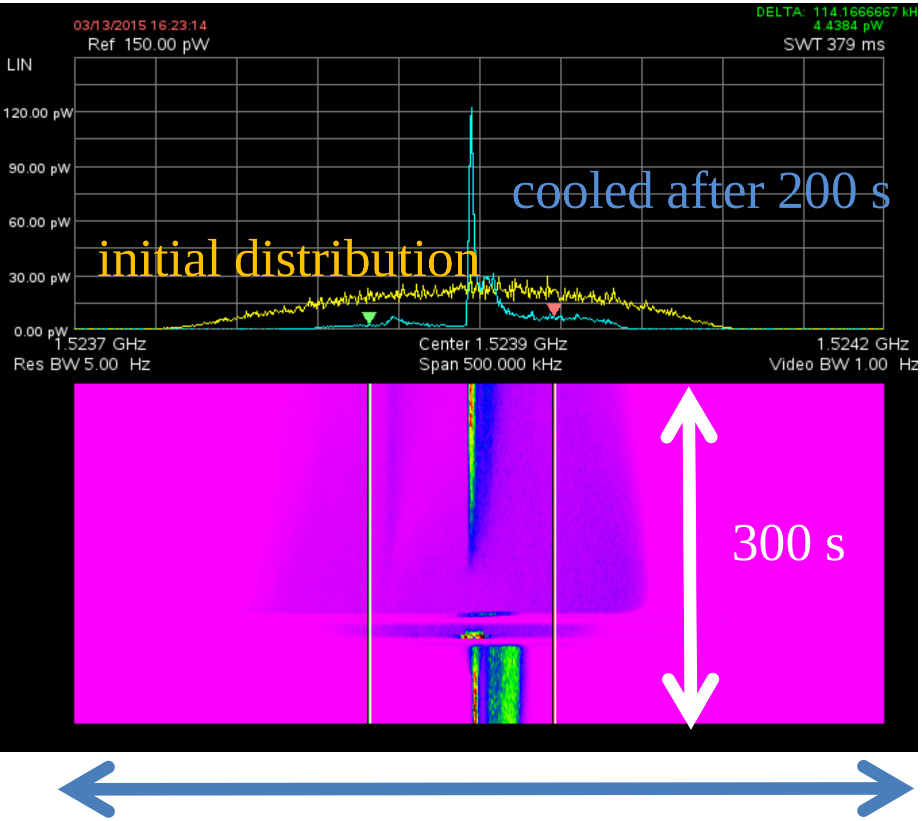
Before cooling



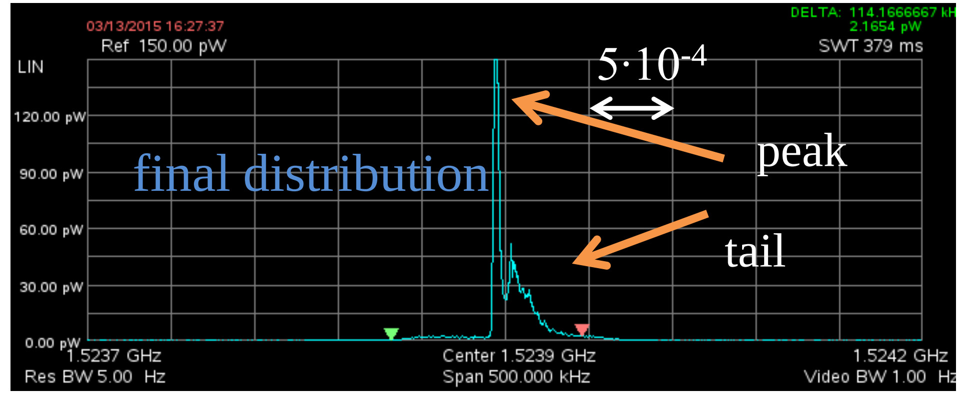
Cooling

Longitudinal cooling

Example of the longitudinal cooling

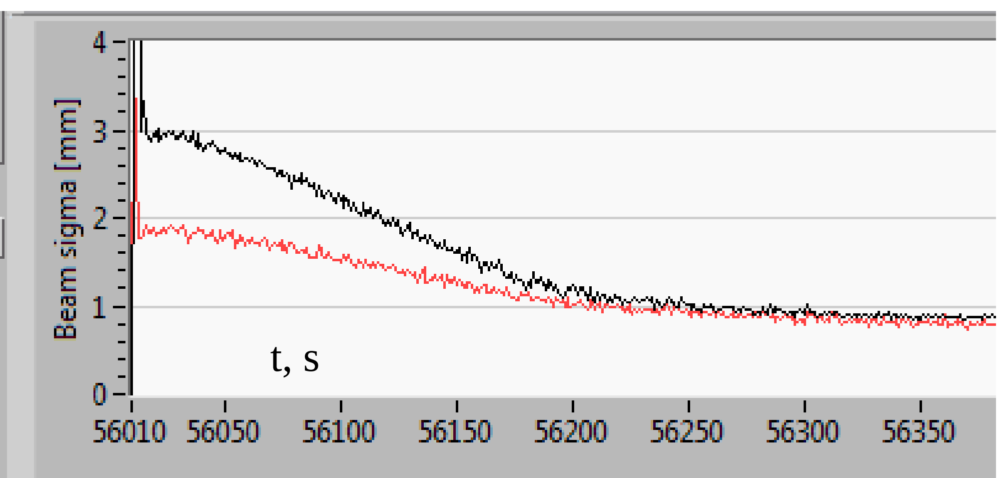


$\Delta p/p = 5.5\ 10^{-3}$



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

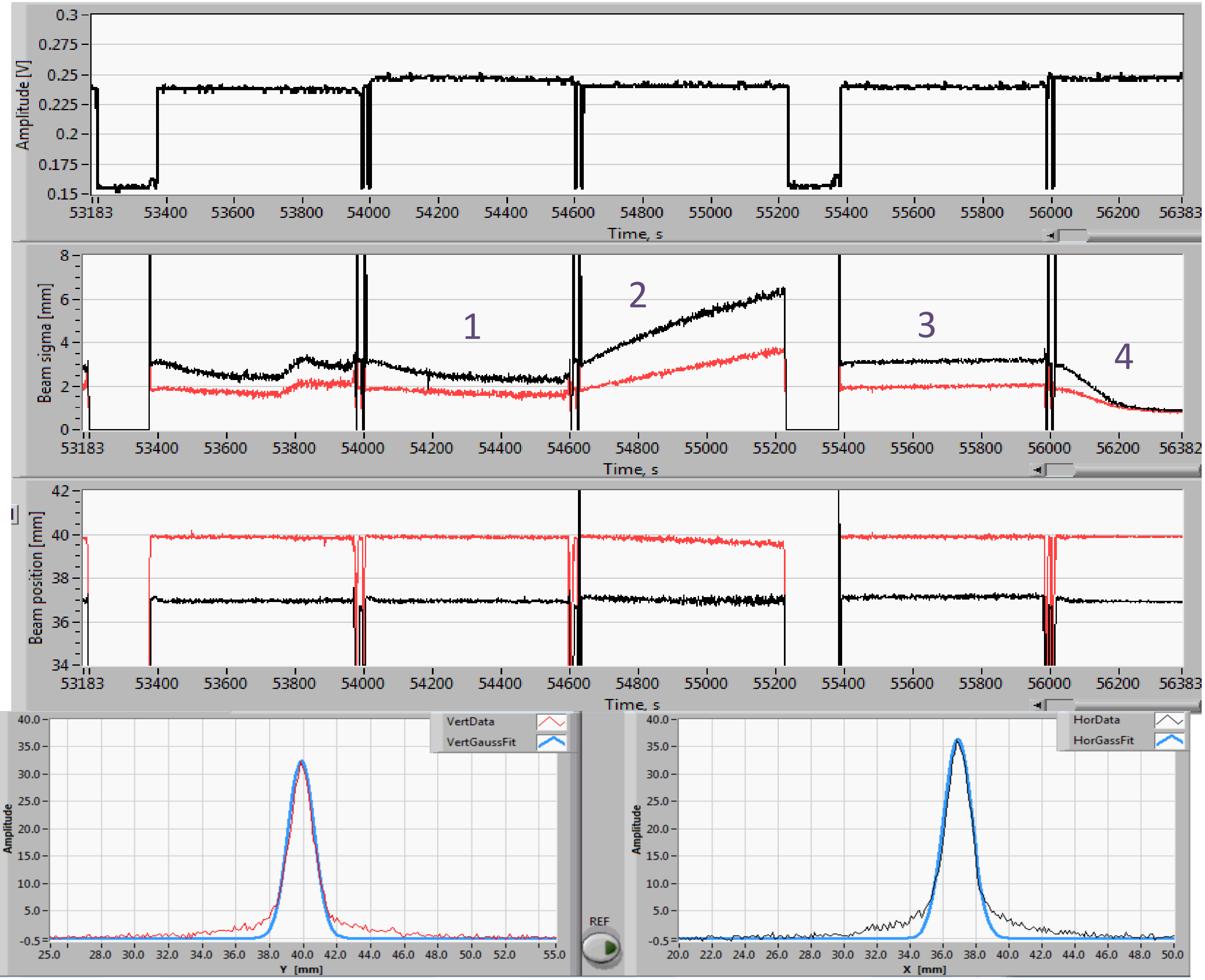
Cooling process is fast enough. The initial proton momentum spread was widened using white noise beam excitation to $\Delta p/p = \pm 2 \cdot 10^{-3}$, and it was cooled down during 100 s.



Example of the transverse cooling

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

Transverse e-cooling



$3.6 \cdot 10^8$ protons
1.66 GeV

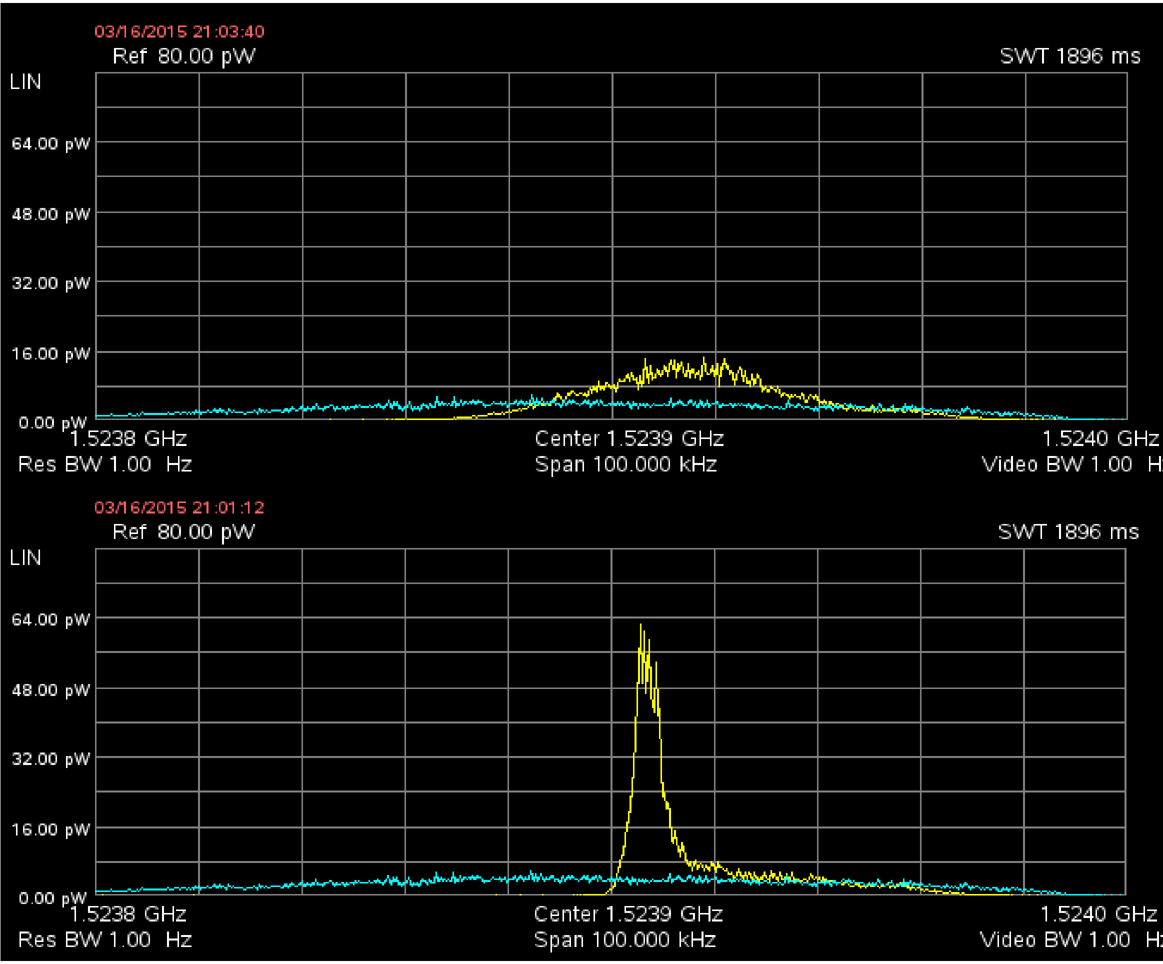
$I_e = 0.8$ A
1.3 kG

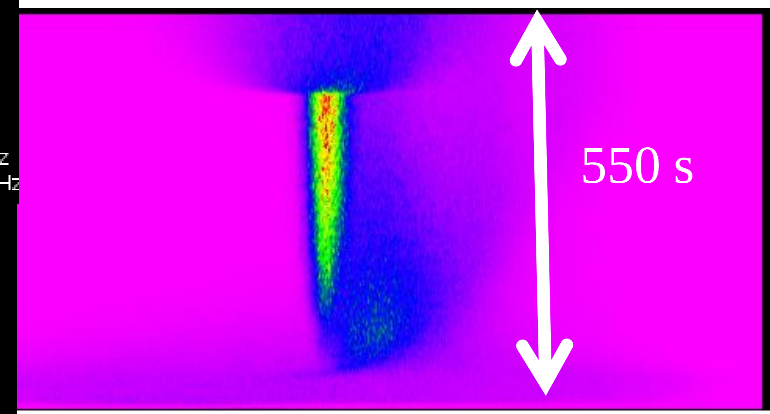
1. Noise + EC
2. Noise only
3. Reference
4. EC

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

IPM screenshot

Electron Cooling of a proton beam and turning off EC

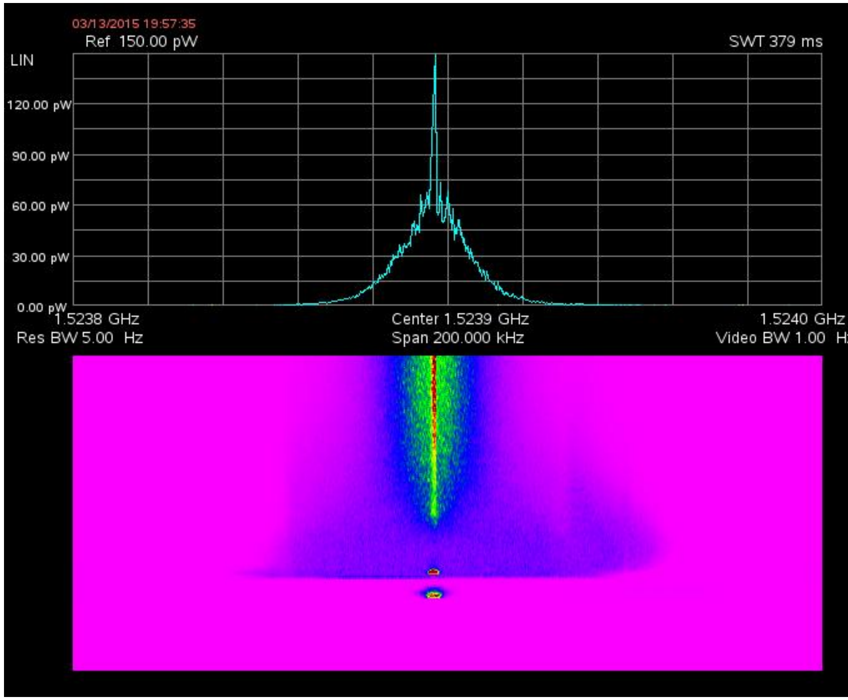




Time span of the color spectrogram 550 s

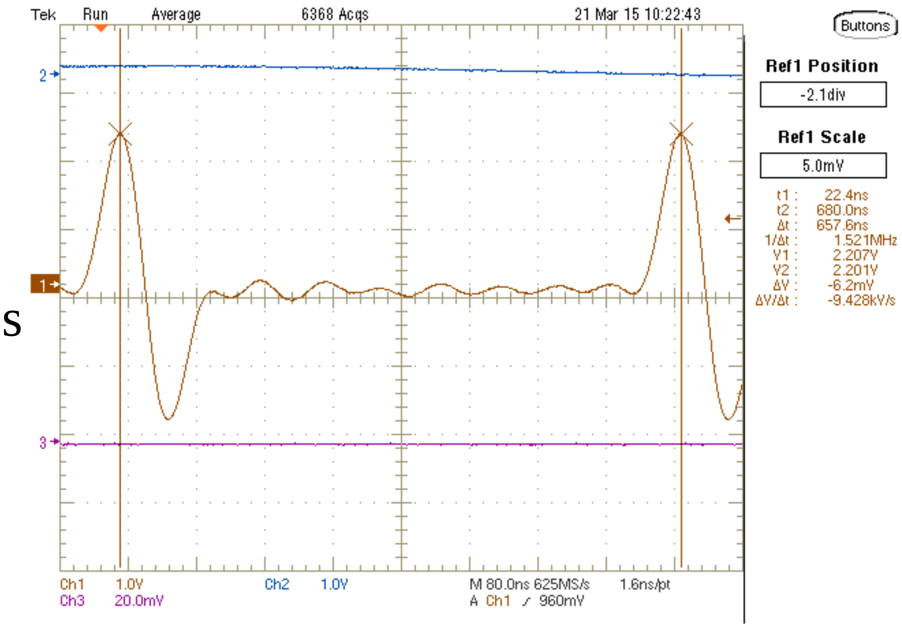
Longitudinal electron cooling process. e-beam turned off leading to fast Δp/p growth. $5 \cdot 10^8$ protons, 1.66 GeV, electron current 0.8 A

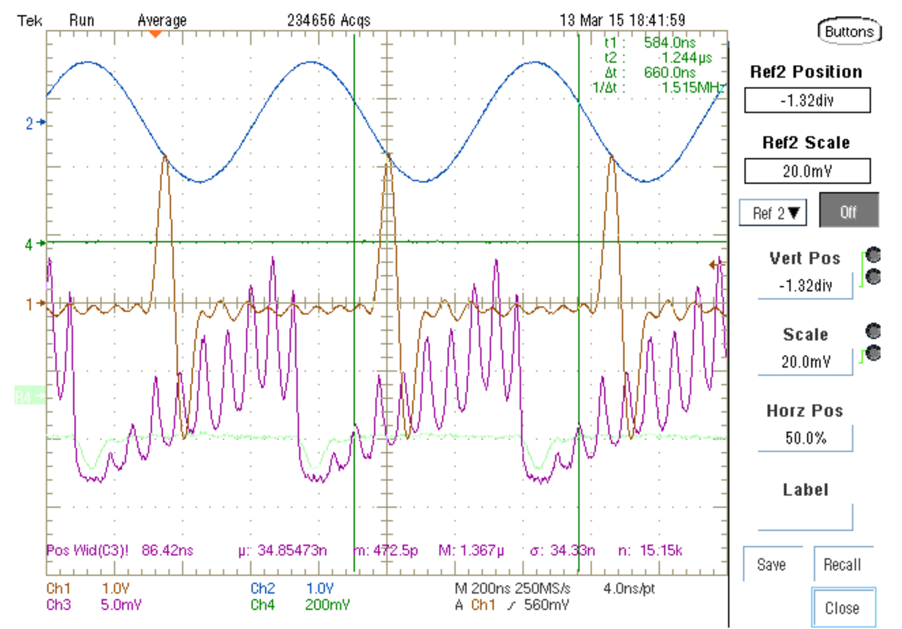
e-cool can well operate with barrier bucket RF



e-cool + barrier bucket RF

250 s



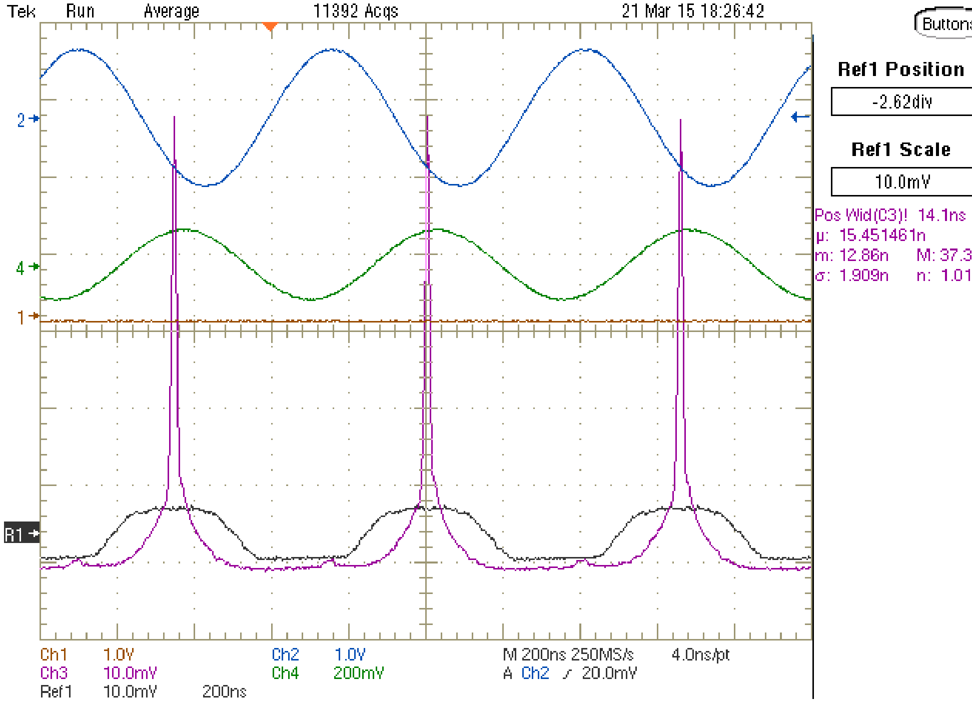


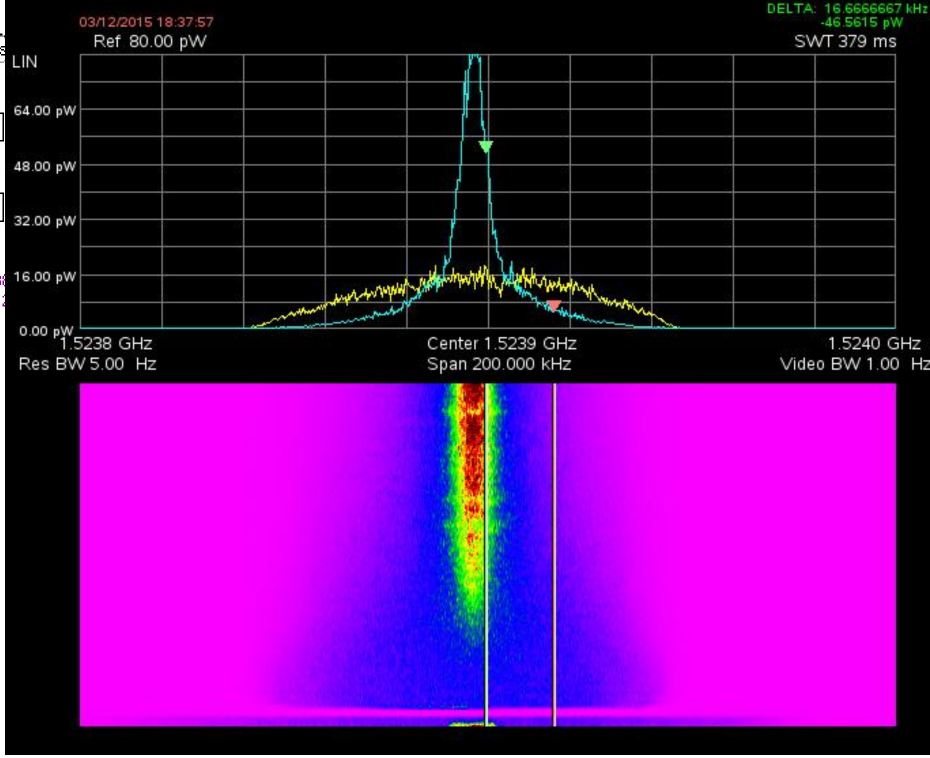
longitudinal cooling at barrier bucket RF voltage

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 $\Delta p/p = 10^{-4}$

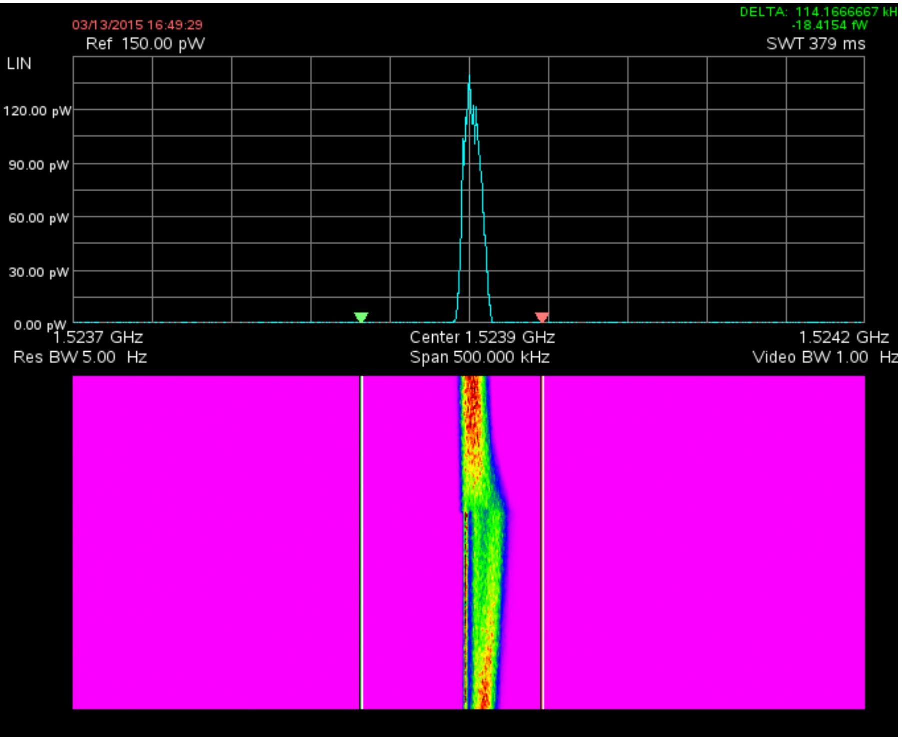
One can see that the combine action of the RF and e-cool produces very short beam with high quality. The off-duty factor of the proton beam is 650 ns/30 ns=20. So, the bunched e-cool of the bunched ion may have the gain of the electron current 20 without increasing average current.

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.

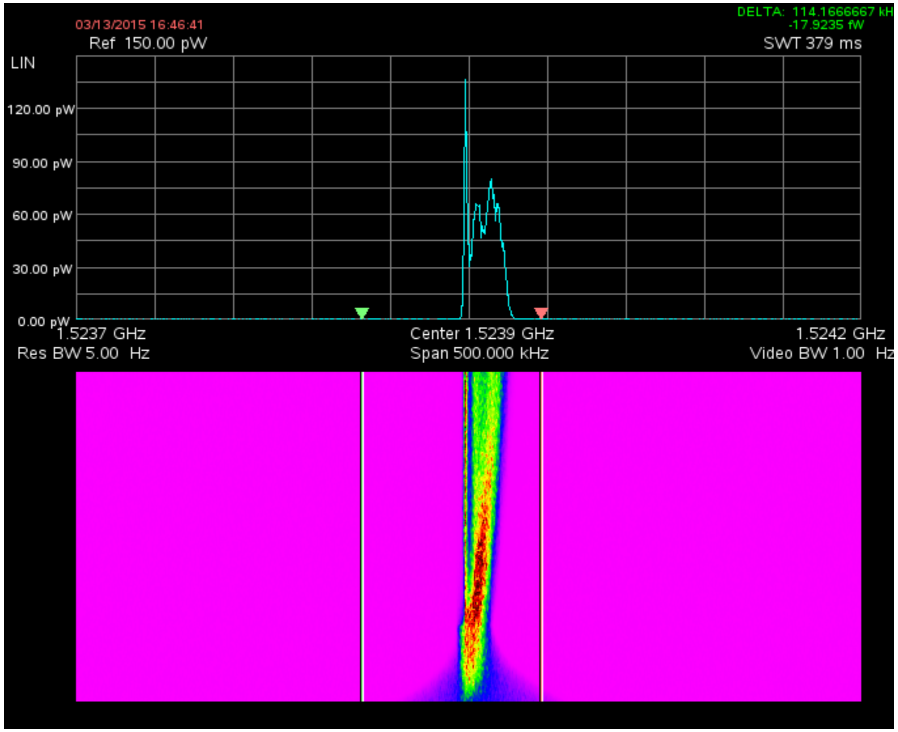
Stochastic cooling + ecool

COSY, Ee=908 kV, Je=400 mA, Np=$7\cdot10^8$

Linear scale



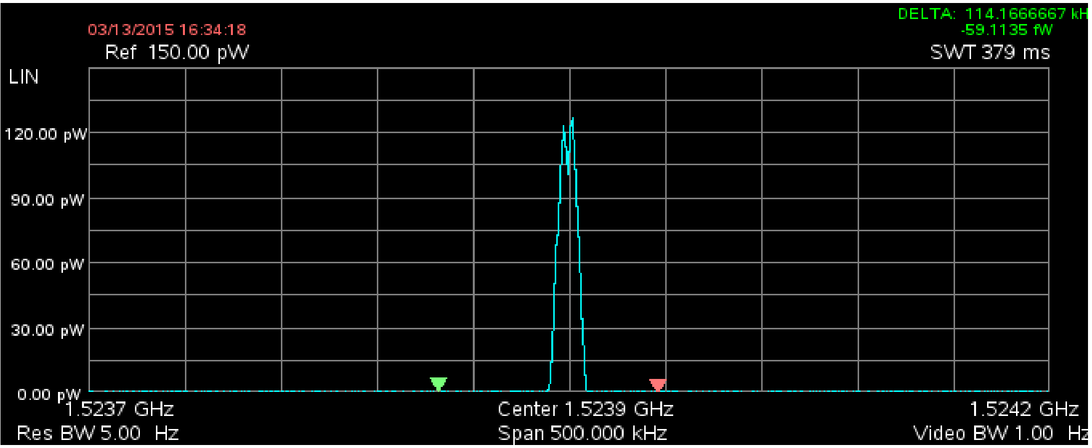
e-cool + stochastic cooling, wide distribution



e-cool only, very narrow central peak

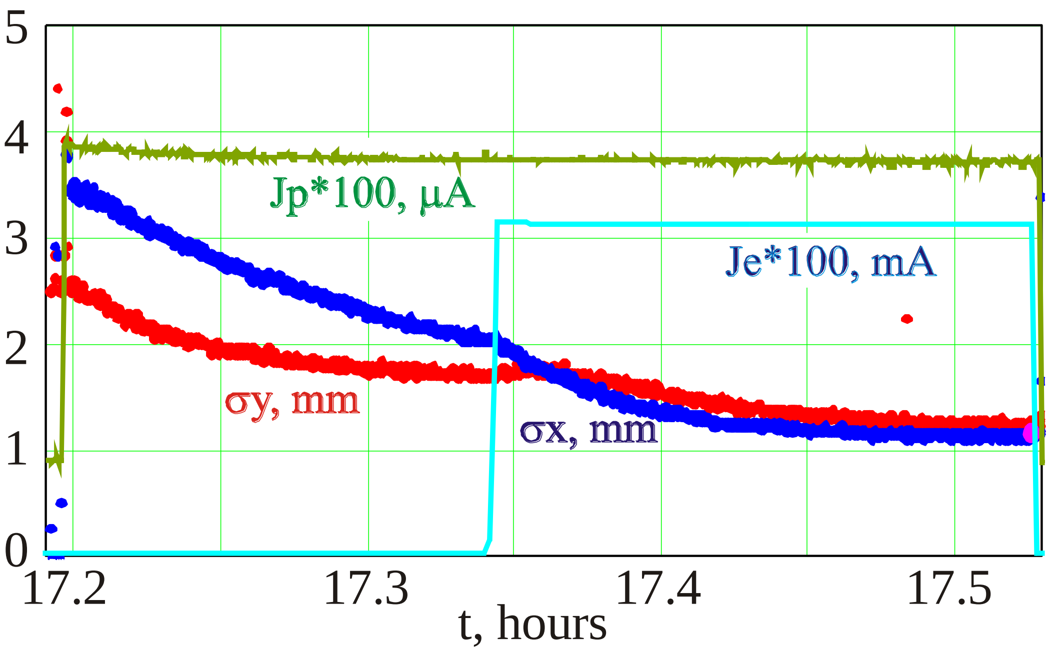
500

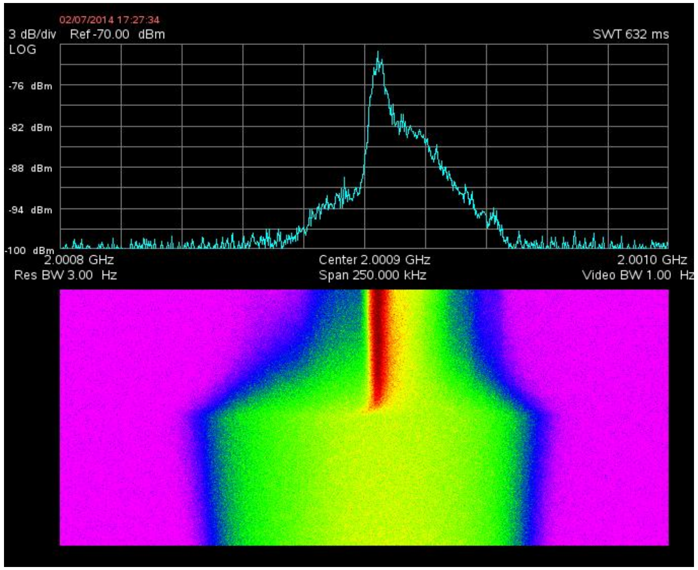
$\gamma > \gamma_{tr}$ $\eta = -0.066$



stochastic cooling only

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

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

$\Delta p/p = 10^{-5}$ 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.

- It is desirable more experimental time in COSY hardware for expand our understanding of cooling processes and receiving highest possible parameters of e-cool.