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Status of the 2 MeV Electron Cooler for COSY- Juelich / HESR

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COOL11 Alushta, Ukraine 12th of September 2011

Outline

Introduction

Motivation

Special Features of High Energy Electron Cooling

Technical development

Progress at BINP Novosibirsk

Progress at FZJ Juelich - COSY

Outlook

Motivation

- **Higher Luminosity at COSY with cooled beams**

Limits of the COSY stochastic cooling system
→ Luminosity **$\leq 10^{31}\ cm^{-2}\ s^{-1}$**

Requests for future COSY experiments
→ Luminosity **$\geq 10^{32}\ cm^{-2}\ s^{-1}$**

Combination of electron and stochastic cooling at the same high beam energy

- **FZJ IKP responsible for the High Energy Storage Ring HESR in the FAIR project**
- **Challenge: Development of the high energy electron cooler for HESR/FAIR (4.5 MeV - 8 MeV)**

Combination of Electron and Stochastic Cooling

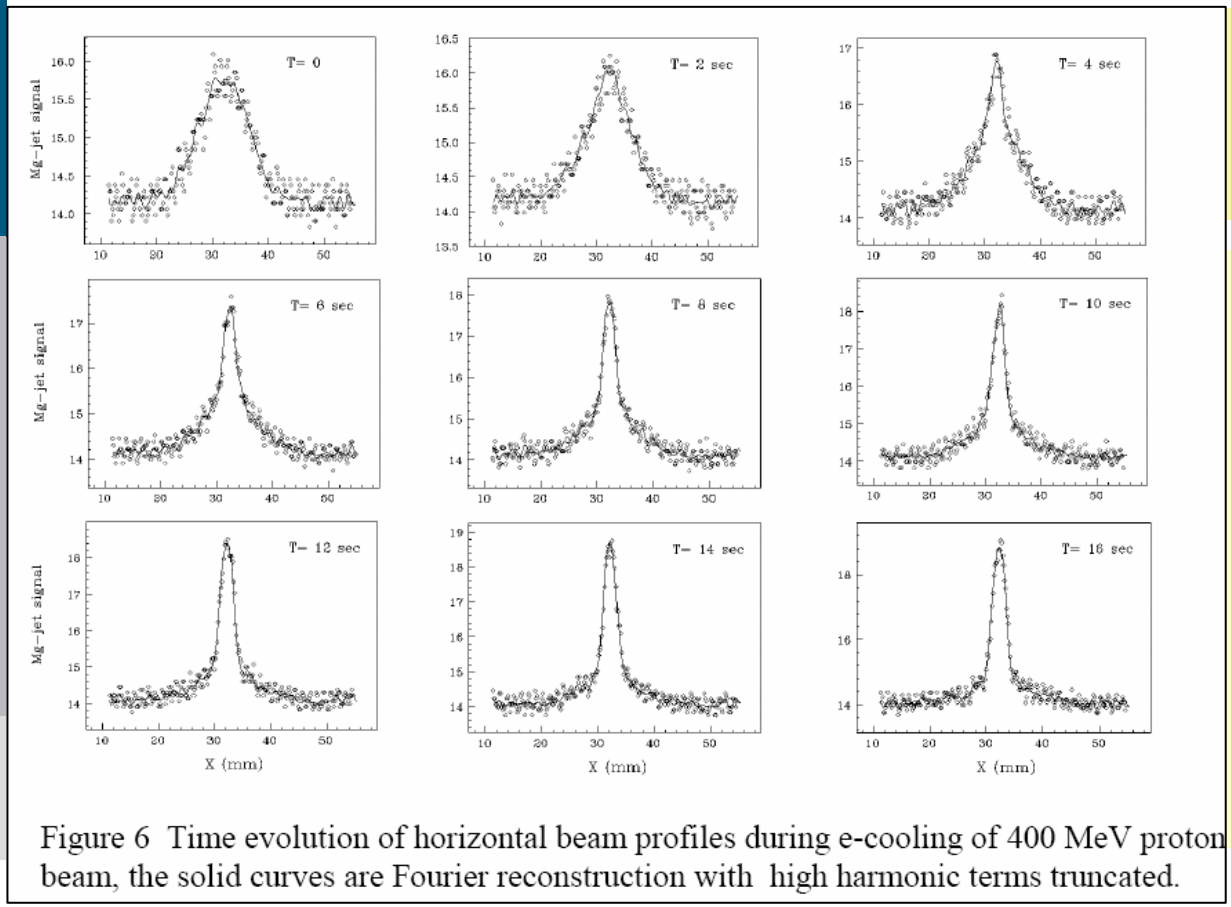
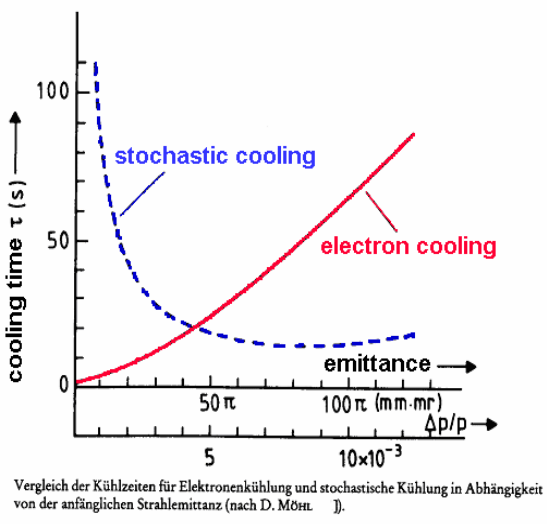


Figure 6 Time evolution of horizontal beam profiles during e-cooling of 400 MeV proton beam, the solid curves are Fourier reconstruction with high harmonic terms truncated.

Electron cooling: core

Stochastic cooling: tails



Vergleich der Kühlzeiten für Elektronenkühlung und stochastische Kühlung in Abhängigkeit von der anfänglichen Strahlemittanz (nach D. Möhl]).

Y.-N. Rao[1], L.Hermansson[2], T. Lofnes, D. Reistad
The Svedberg Laboratory, S-751 21 Uppsala, Sweden

Artist's View FAIR and GSI

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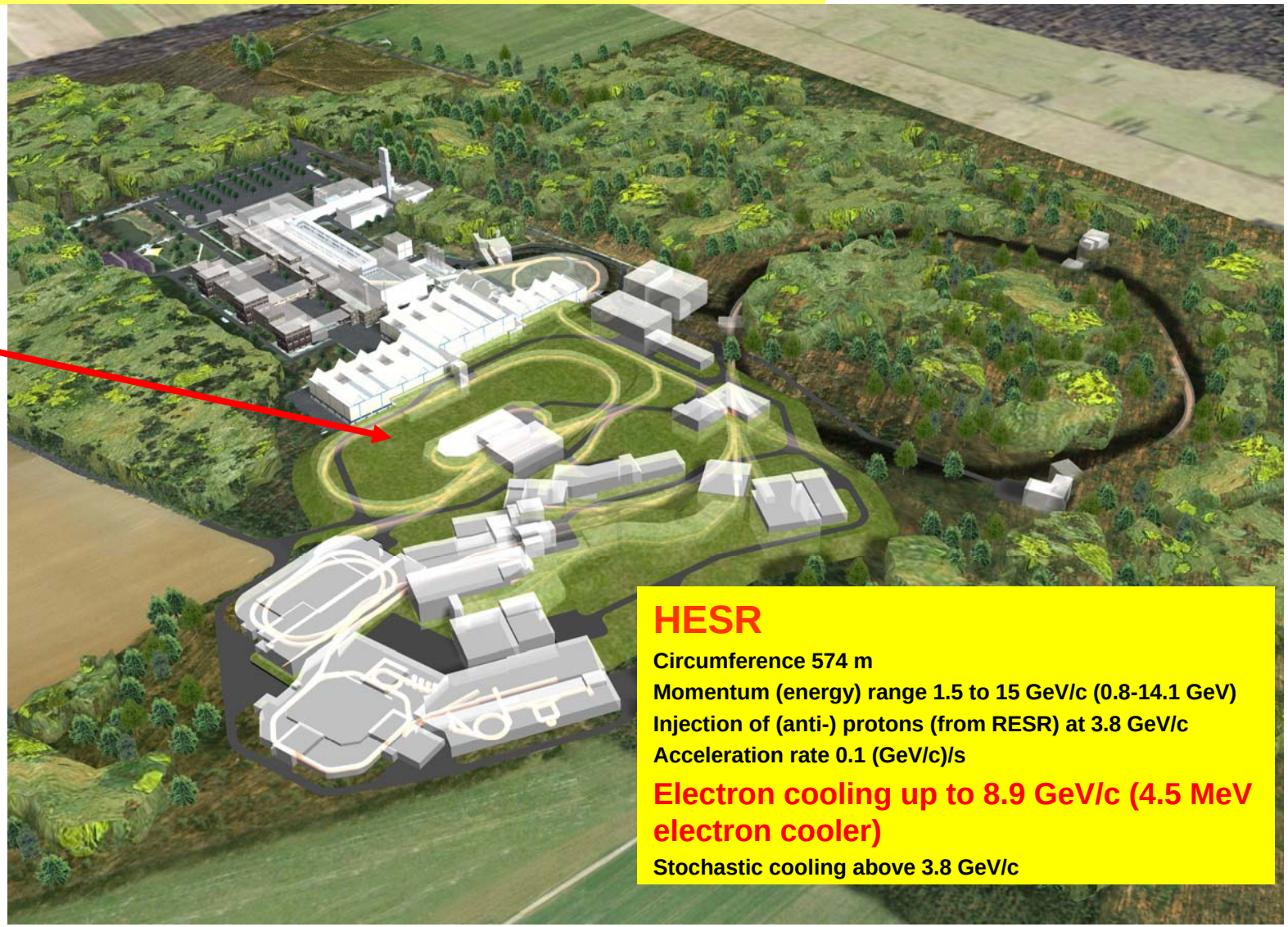
High Energy Storage Ring HESR



Special Features of High Energy Electron Cooling

Technical Challenge:

High Voltage (E_e >0.5 MeV, I_e <3 A, confinment in magnetic field)

Magnetic field quality, straightness in cooling section < 10^{-5}

Decreasing of "corrugation, waviness" of force line of the magnetic field is essential for obtaining maximum of friction force

Essential for experiment with internal target

$$\Delta\vec{p} = \vec{F}\cdot\tau = -\frac{4e^4 n_e \vec{V}\tau}{m_e\left(\sqrt{V^2+V_{eff}^2}\right)^3}\ln\left(1+\frac{\rho_{\max}}{\rho_L+\rho_{\min}}\right)$$

$$V_{eff}^2 = V_{\Delta\Theta}^2 + V_{E\times B}^2 + V_e^2$$

$$V_{\Delta\Theta} = \gamma\beta c\sqrt{\langle\Delta B^2\rangle} \qquad \langle\Delta B^2\rangle$$

"Waviness" of magnetic force line

$\gamma_E\beta_E/\gamma_{30}\beta_{30}$	E, keV
1.9	100
8.0	1000
13.8	2000

Cooling time: $\tau_{long} \propto \gamma^3$ $\tau_{trans} \propto \gamma^{\frac{7}{2}}$

Magnetised or not Magnetised Electron Cooling

The 4.3 MeV electron cooler at the RECYCLER ring (FNAL) achieves cooling time of about 1 h. The new cooler for COSY should provide a few orders of magnitude more powerful longitudinal and transverse cooling that requires new technical solutions.

The basic idea of the new COSY cooler is to use high magnetic field along the orbit of the electron beam from the electron gun to the electron collector.

Power for the coils along the acceleration and deceleration columns:

Rotating shafts (Fermilab)

Gas turbine (idea of BINP)

Cascade transformer (present solution)

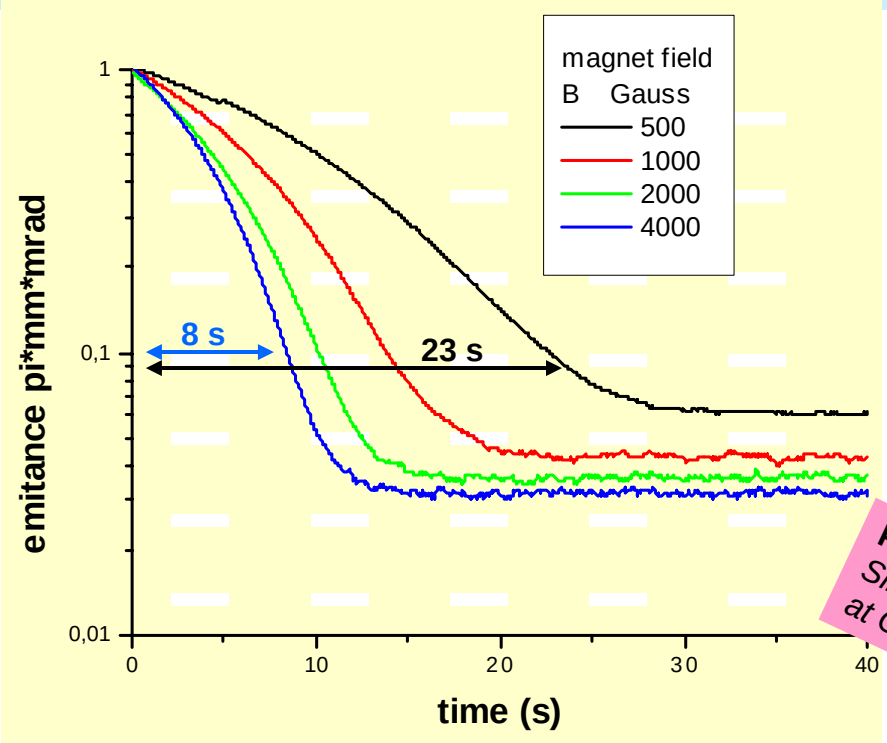
Magnetic Field in the Cooling Section

(magnetized cooling)

Important and practical question:

What is the optimal magnetic field value in the cooling section for 2 MeV cooler ?

Stronger magnetic field improves the cooling. From practical point of view this figure supported choice of 2 kG magnetic field.



Poster L. Mao, FZJ
Simulation of high-energy electron cooling at COSY with BETACOOL code.

Horizontal emittance versus time for different magnetic fields at cooling section.

Technical development

Interims (First) Report, Novosibirsk, 2005

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First report

ELECTRON COOLING FOR COSY

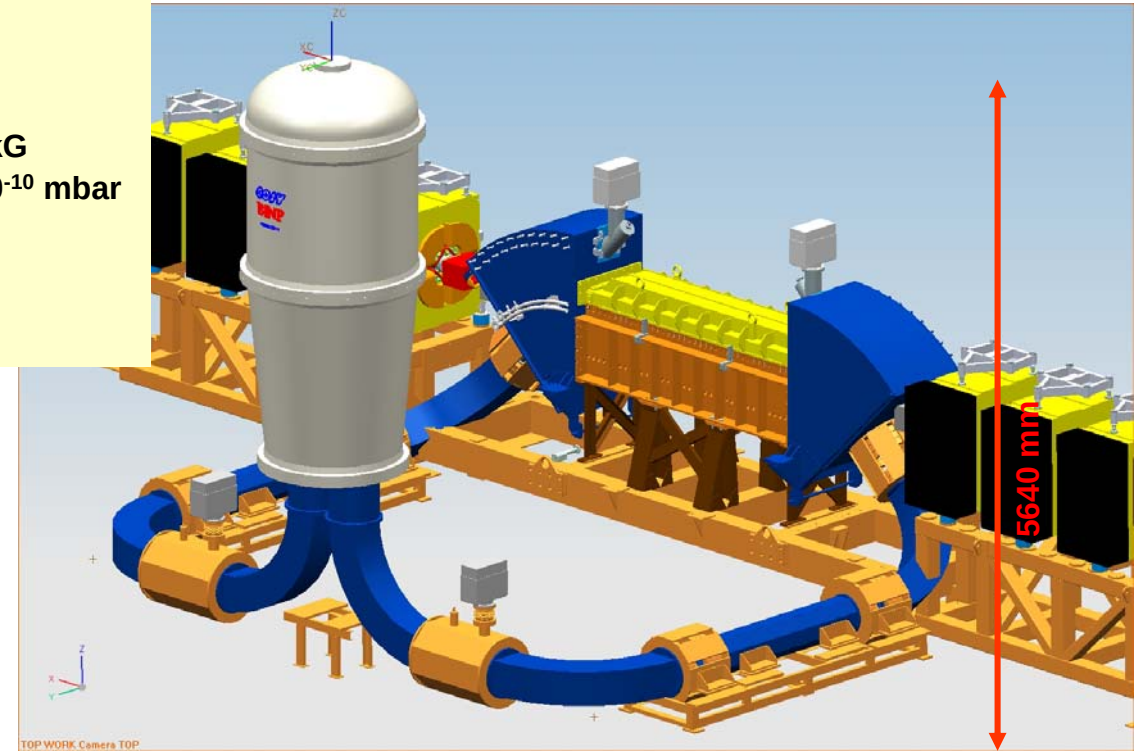
(FEASIBILITY STUDY OF 2 MEV ELECTRON COOLING FOR COSY)

Novosibirsk, 2005

Technical Design – Layout BINP

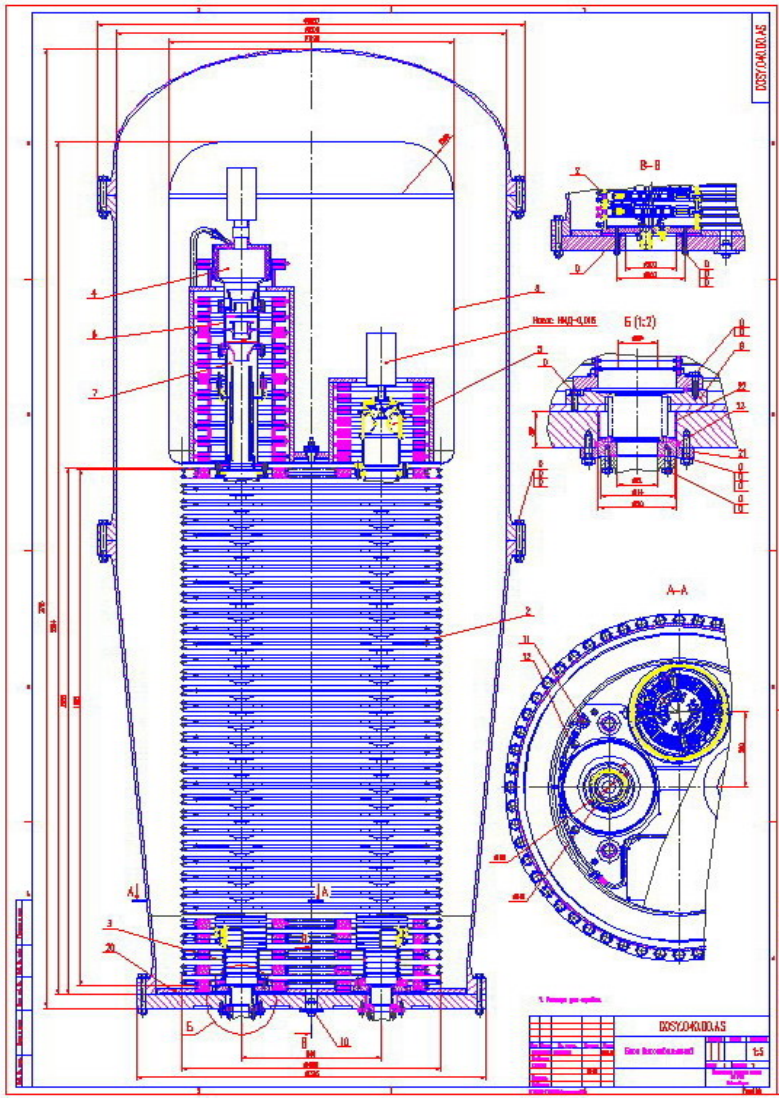
Basic Parameters and Requirements

Energy Range:	**0.025 ... 2 MeV**
High Voltage Stability	**$< 10^{-4}$**
Electron Current	**0.1 ... 3 A**
Electron Beam Diameter	**10 ... 30 mm**
Cooling section length	**2.694 m**
Toroid Radius	**1.00 m**
Variable magnetic field (cooling section solenoid)	**0.5 ... 2 kG**
Vacuum at Cooler	**10^{-9} ... 10^{-10} mbar**
Available Overall Length	**6.390 m**
Maximum Height	**5.7 m**
COSY beam Axis above Ground	**1.8 m**



Final Version from January 2010

High Voltage Tank



Mechanical Stresses and Deformations of the High Voltage Tank

finite element model ,12 bar

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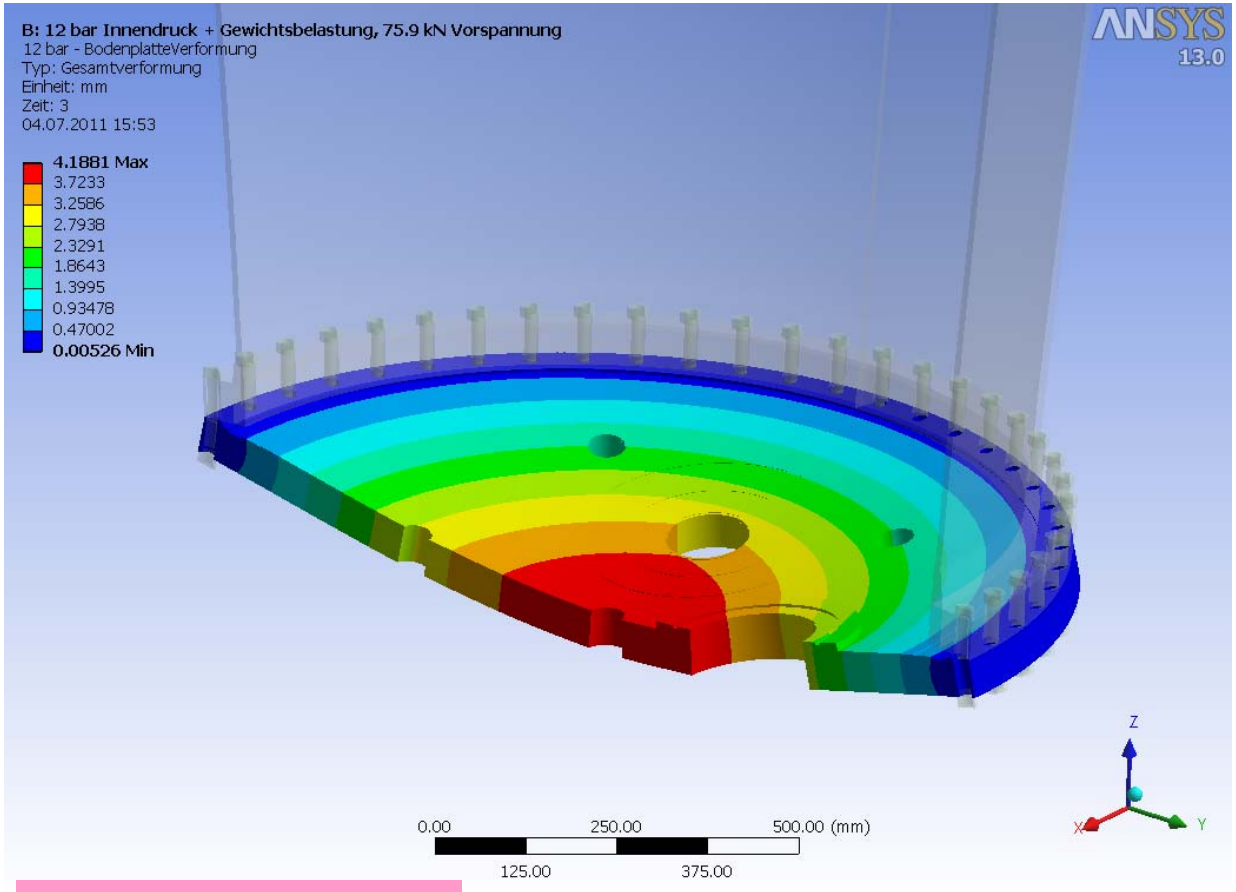
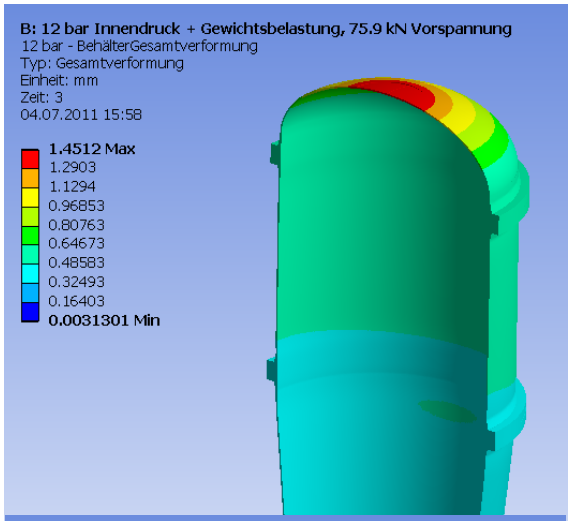
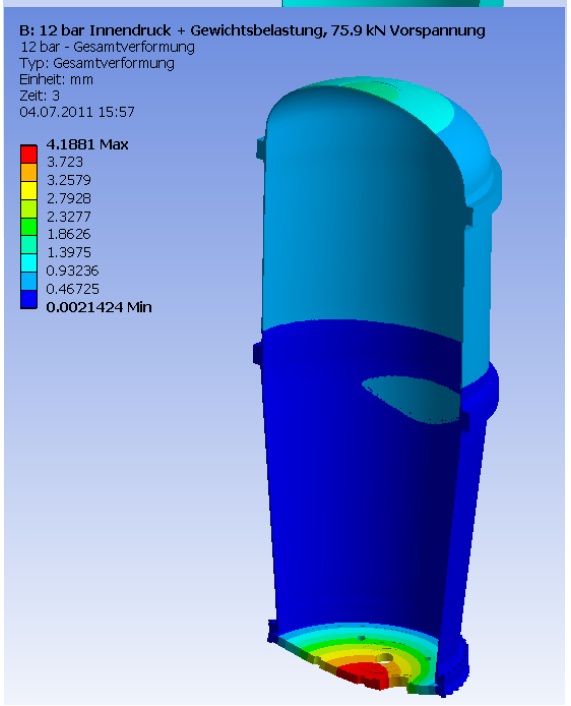
↳ deformations in mm





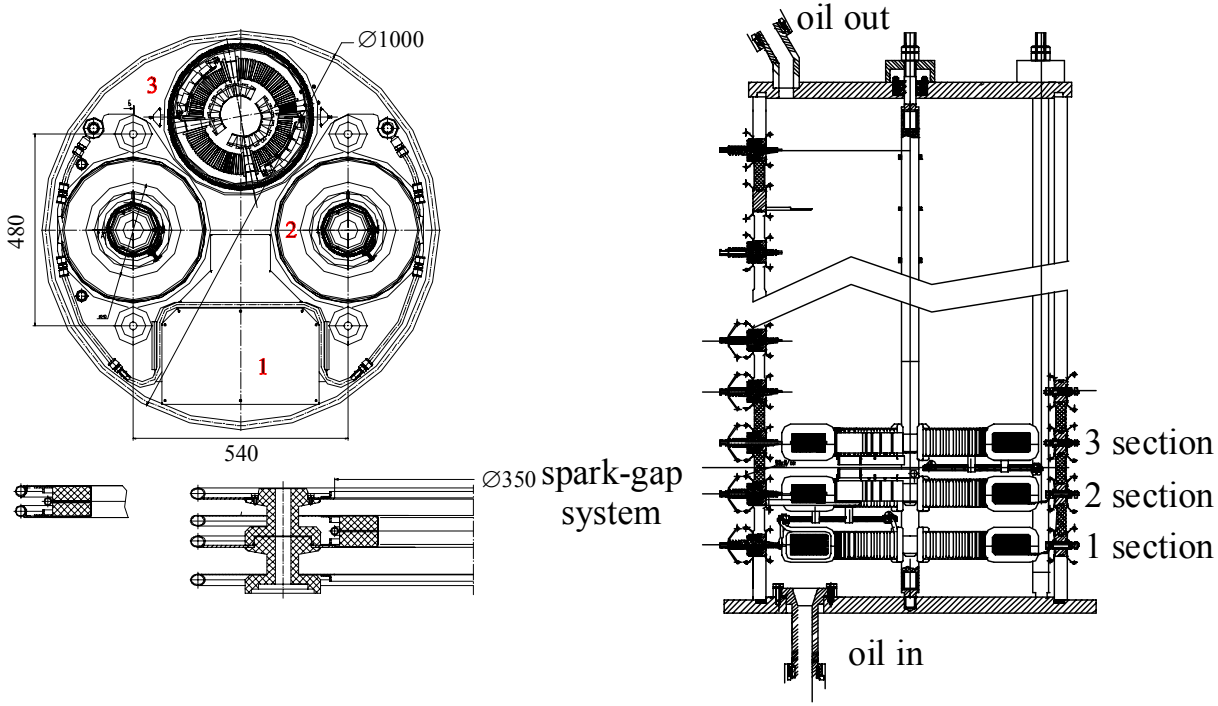


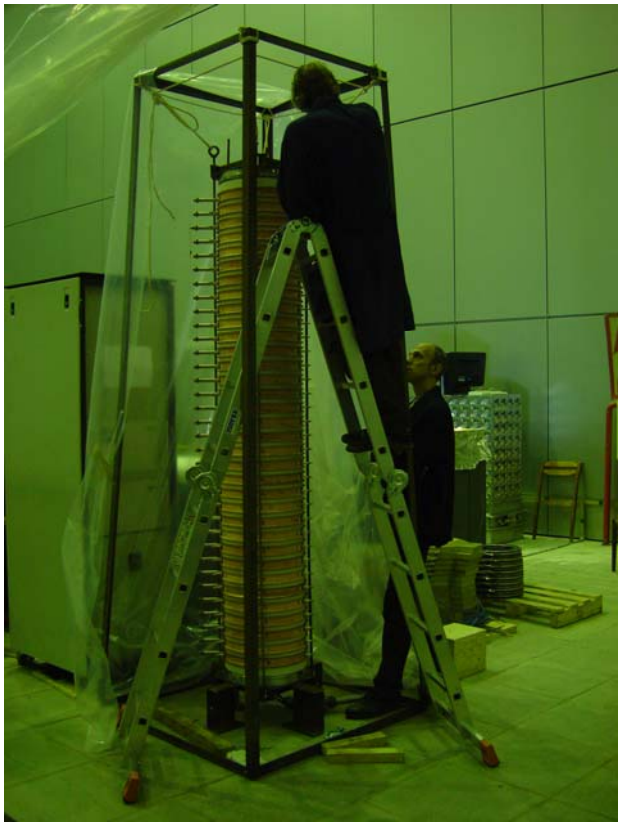
J. Wolters ZAT FZ Jülich

Present Solution

High Frequency Cascaded Resonant Transformer

20 kHz, 40 kW



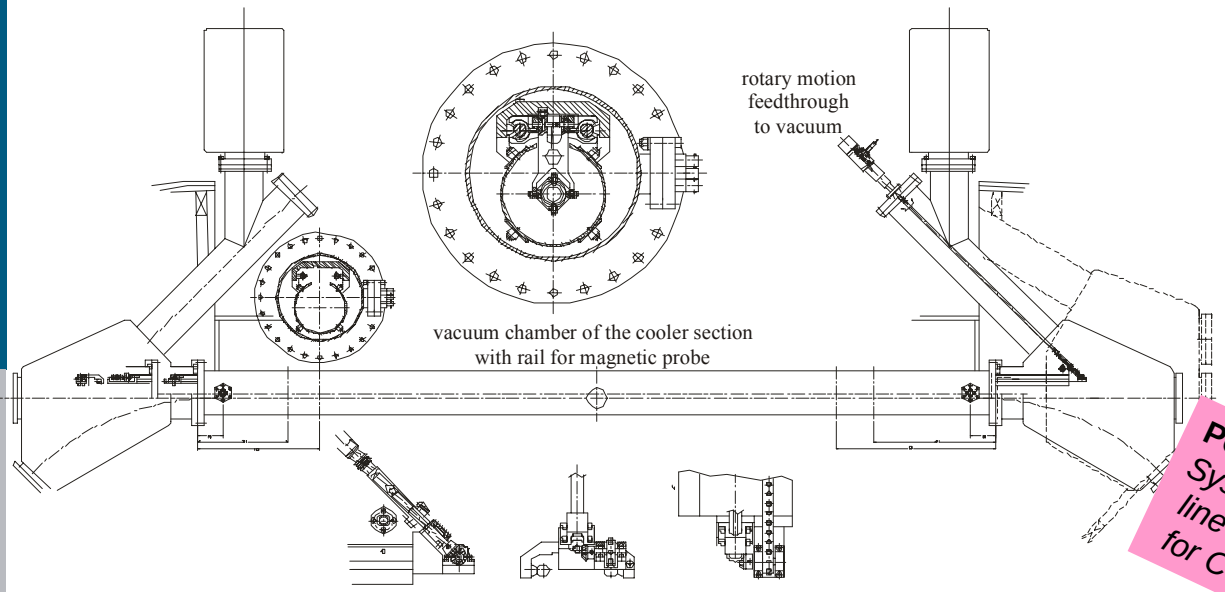


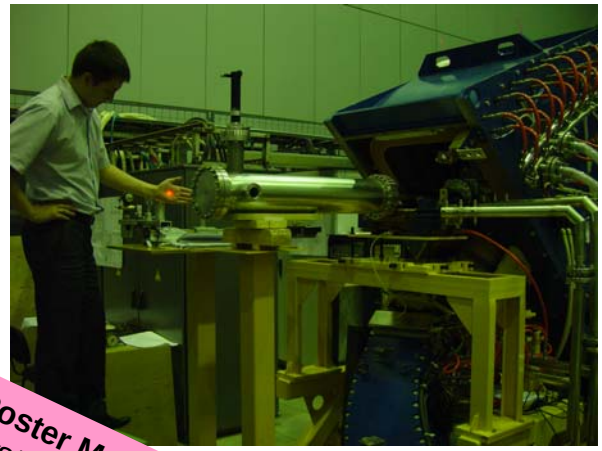
Transformer Column

High Voltage Section

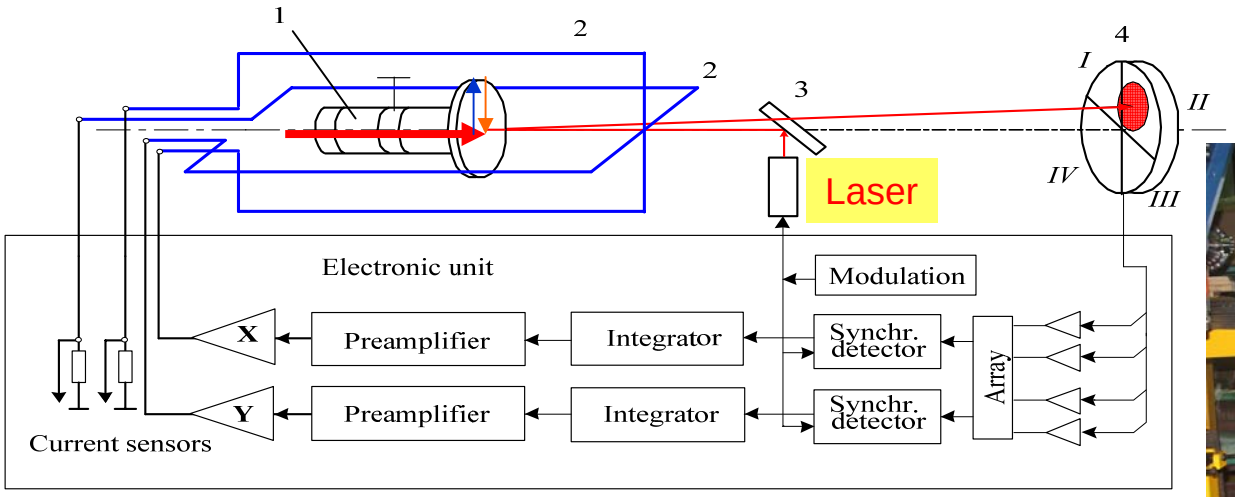
amorphous ferrite foil core, cylinder filled with transformer oil for isolation,high voltage, input-output ceramic feedthrough for connection of HV sections

Magnetic Field in Cooling Section





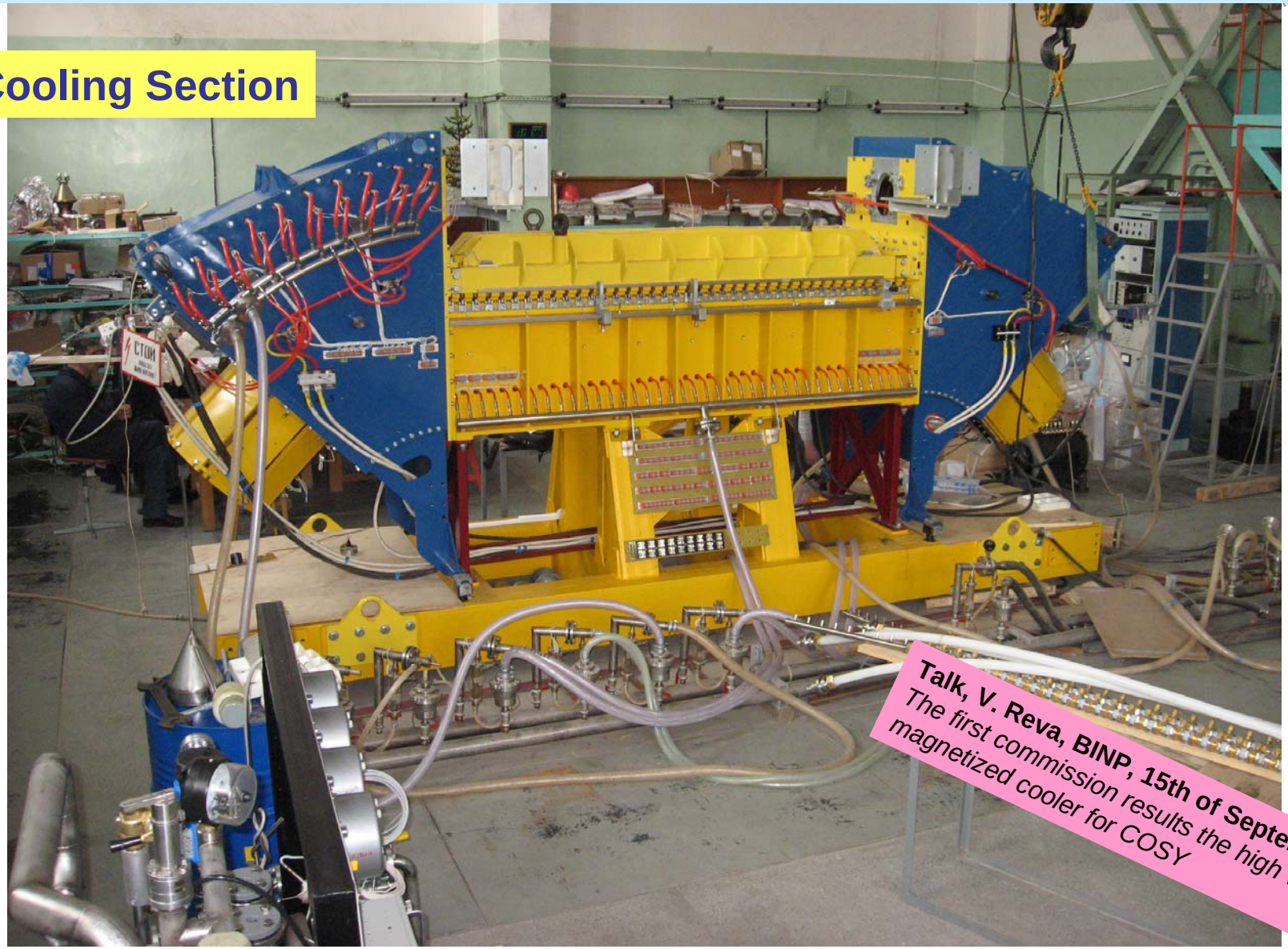
Poster M. Bryzgunov, BINP
System for measurement of magnetic field line straightness in solenoid of electron cooler for COSY



(1) magnetic sensor, (2) conductors of the compensating circuits, (3) beam splitter, (4) photo-detector, (I-IV) photo-detector quadrants, and (X, Y) output current amplifiers.

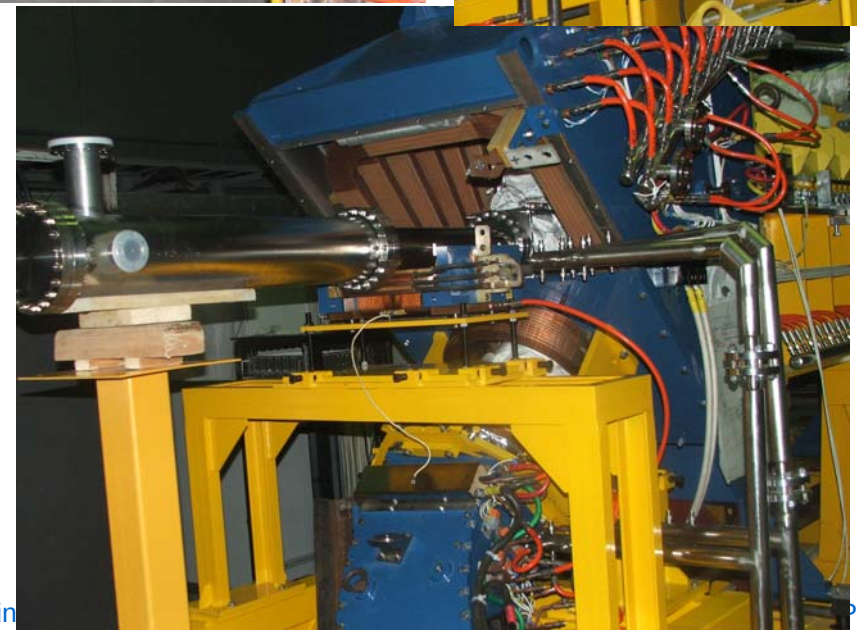
Progress at Budker Institut Novosibirsk

Cooling Section

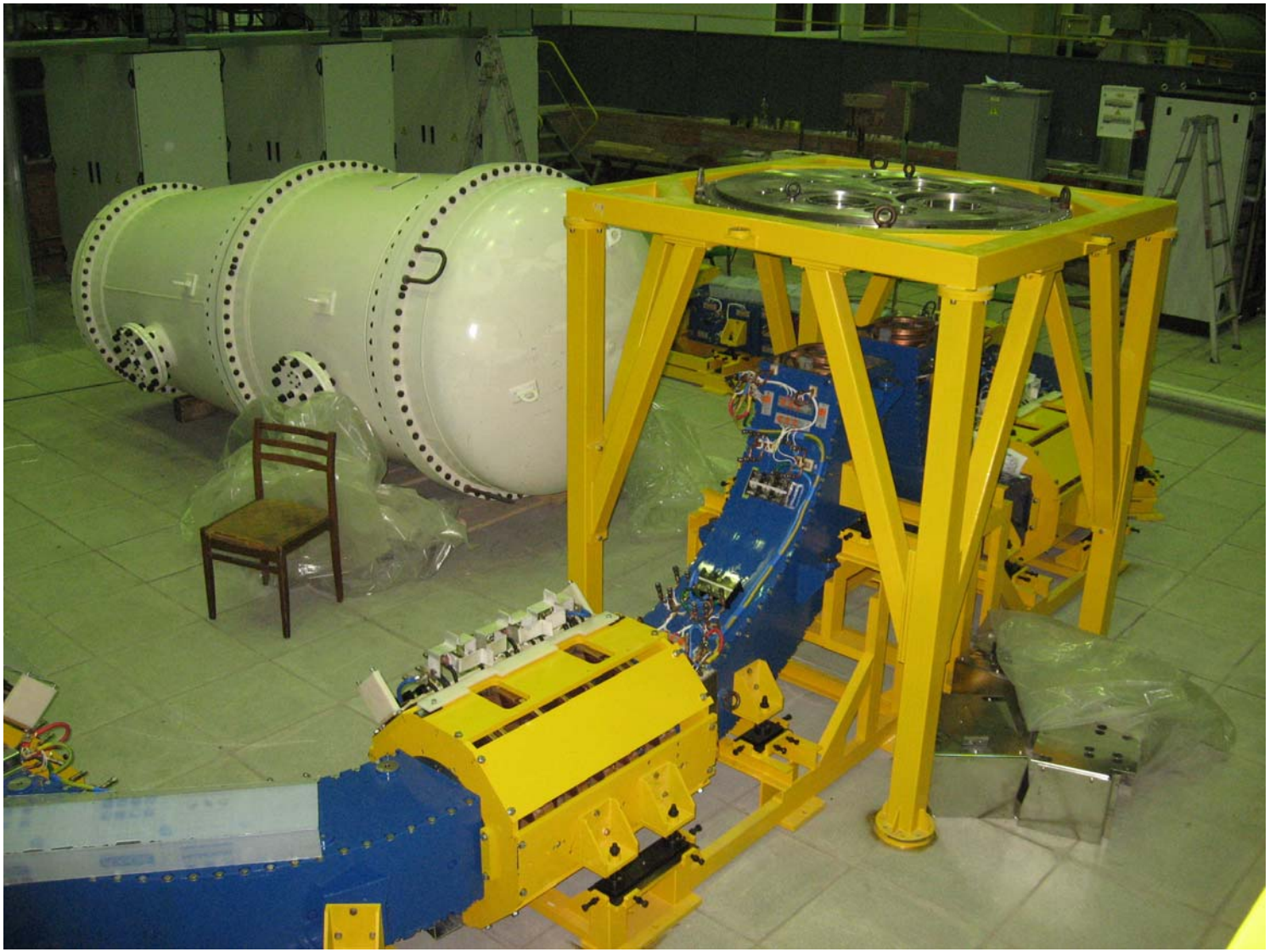


Talk, V. Reva, BINP, 15th of September
The first commission results the high voltage magnetized cooler for COSY

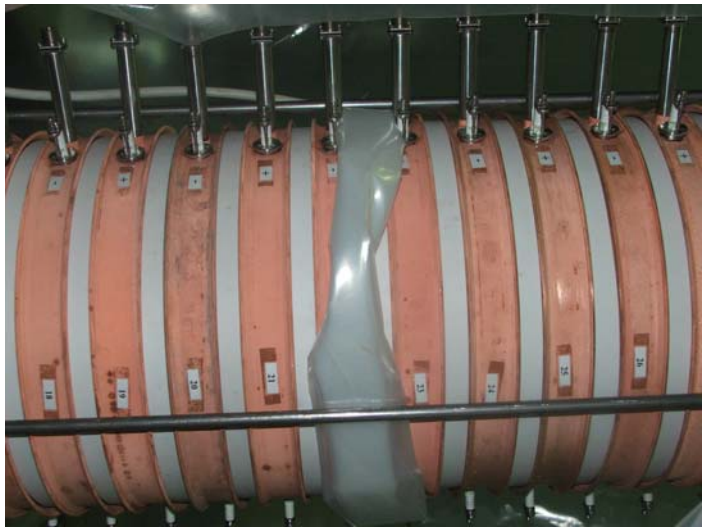
Test Bench for Commissioning with Electron Beam

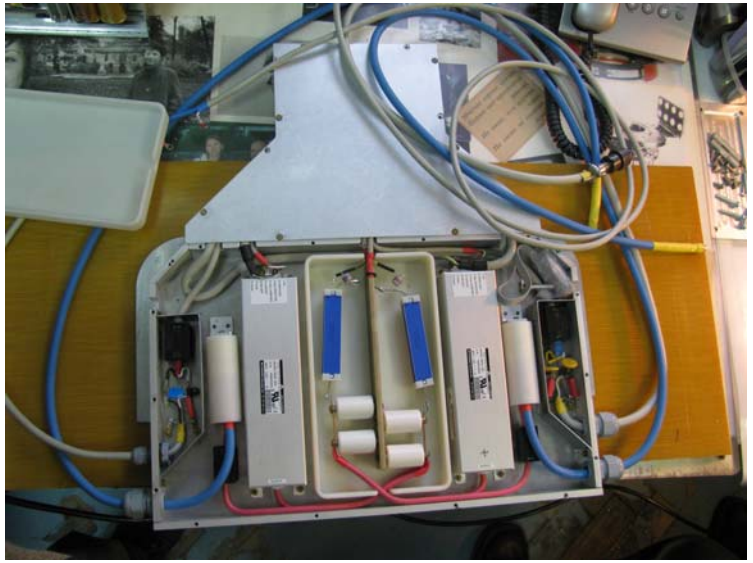


Magnet System Components and HV Vessel

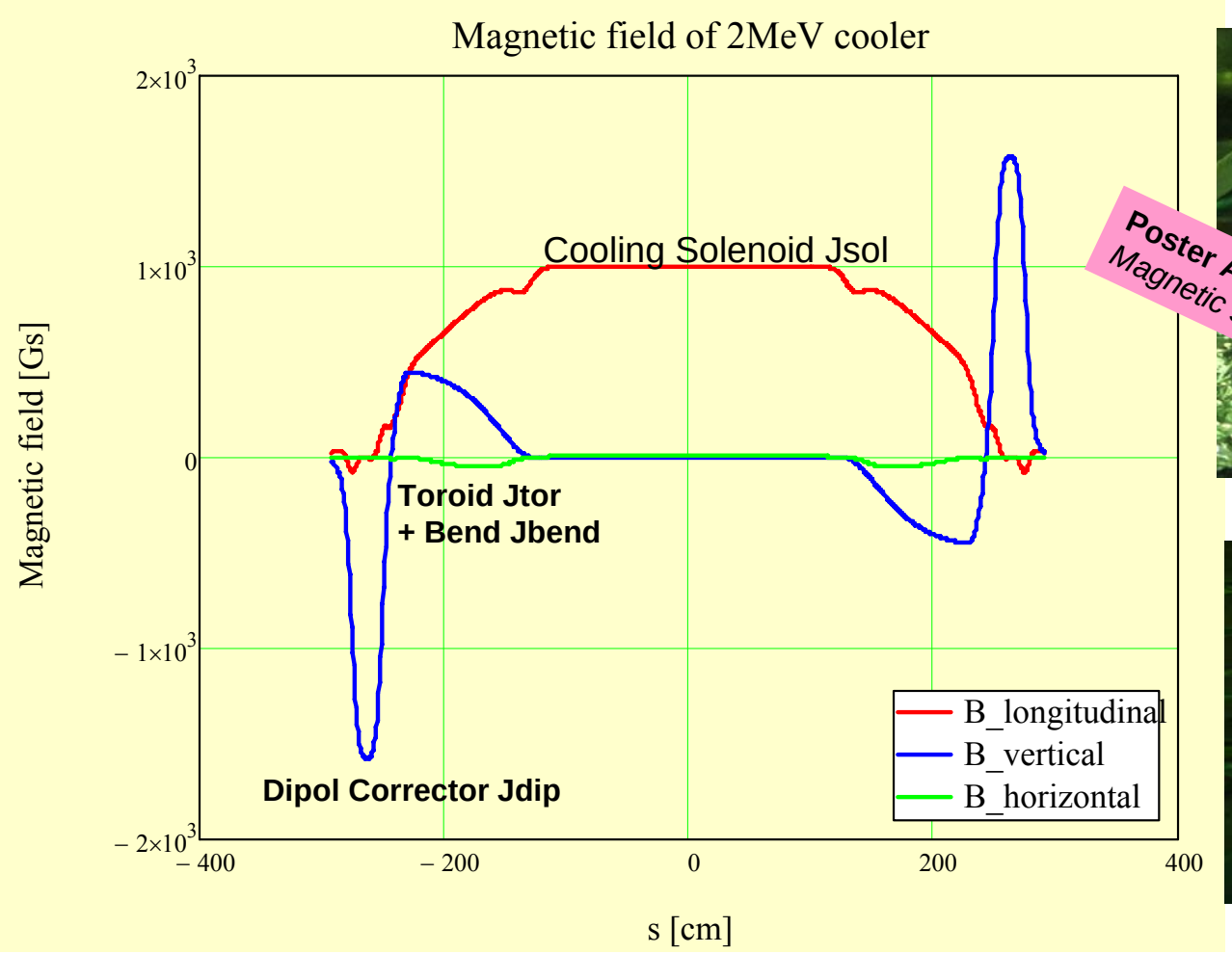


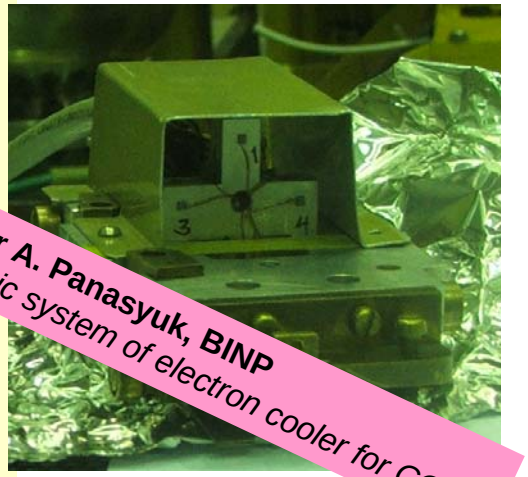
Cascade Generator Test Bench



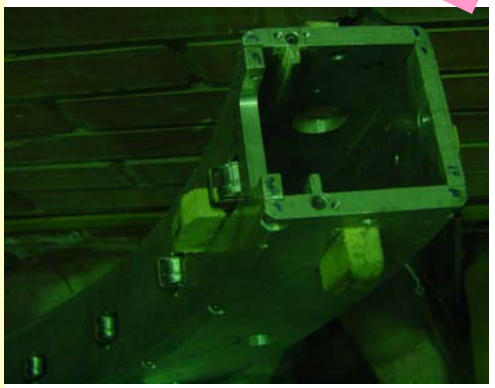


Magnetic Field Measurements – Hall Probes



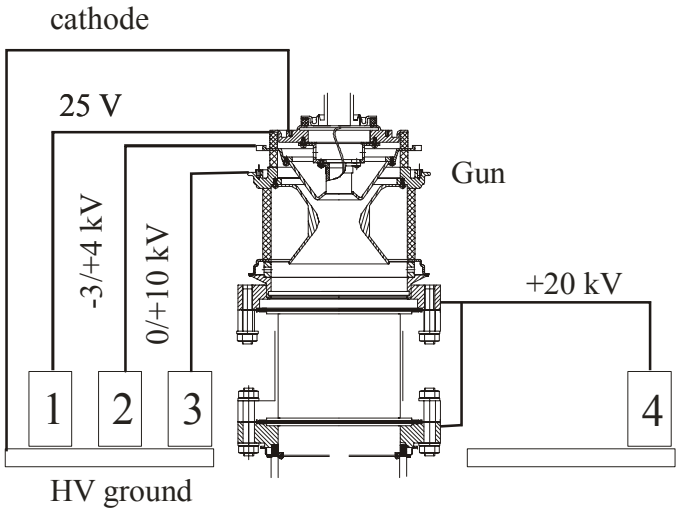


Poster A. Panasyuk, BINP
Magnetic system of electron cooler for COSY



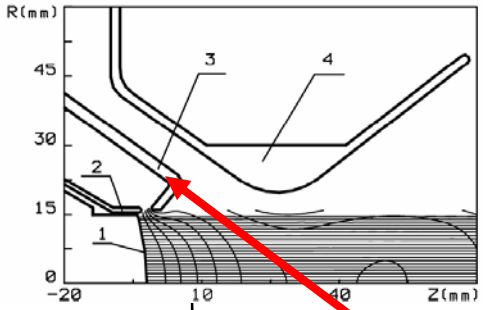
The magnetic field component along the ion beam orbit in cooler, (power : Jsol=175A, Jtor=Jdip=500A, Jbend=200A)

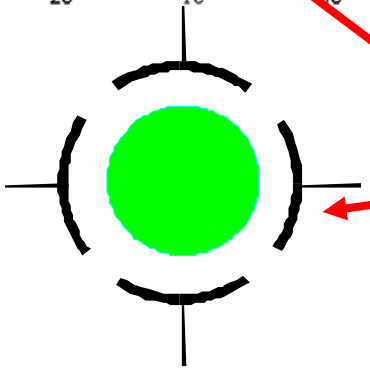
Electron Gun

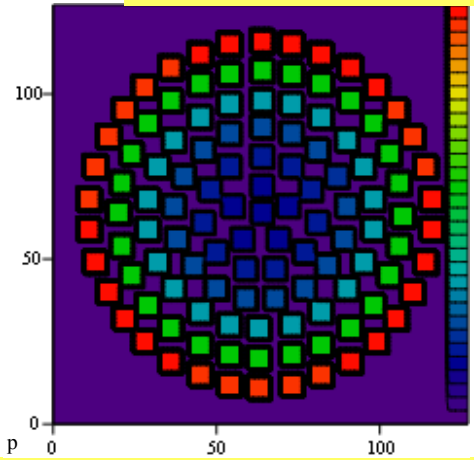


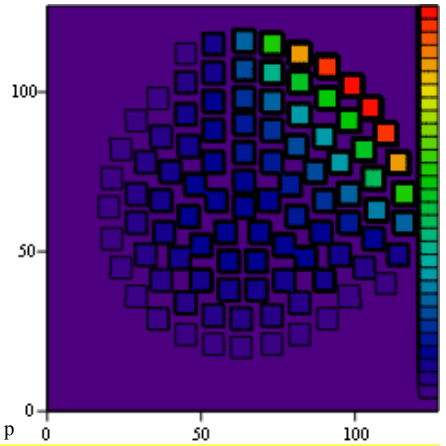
Poster A. Bubley, BINP
Electron gun with variable beam profil for COSY cooler

Profile of the electron beam at different voltages on the control electrode (calculated)



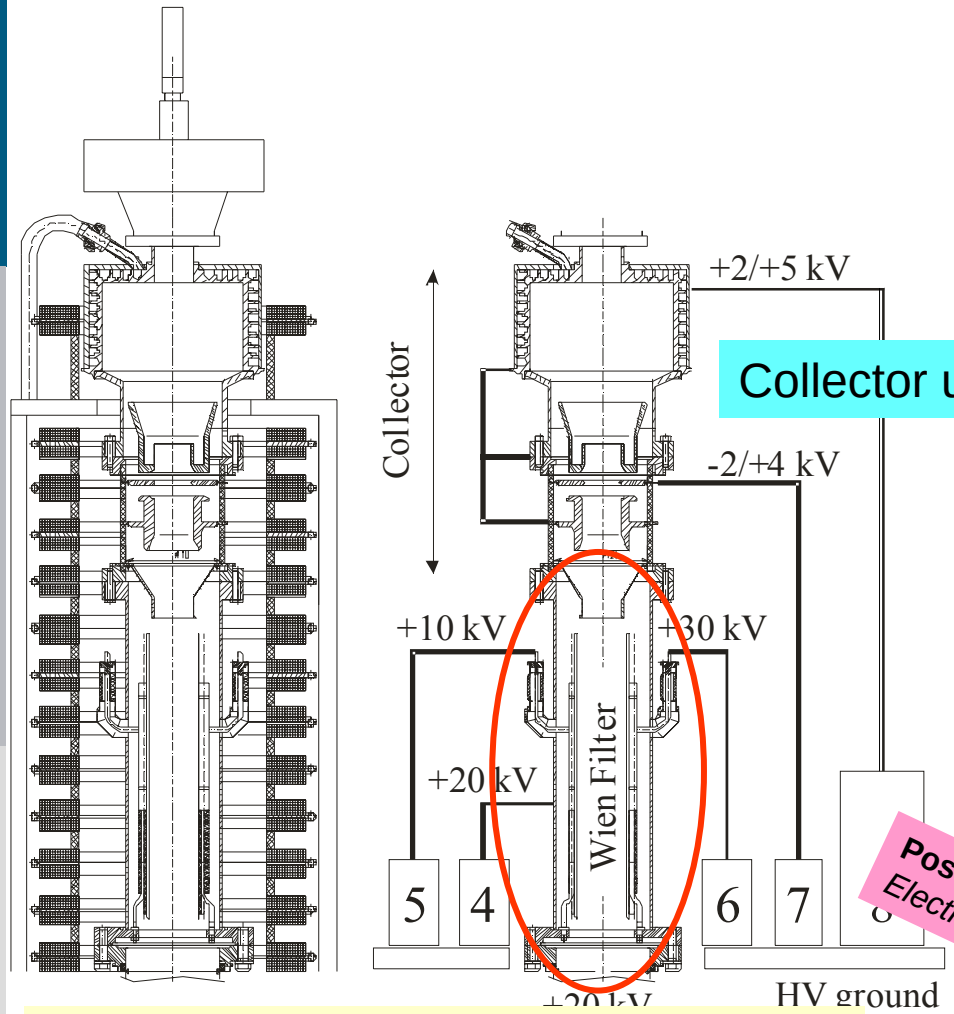






Gun control electrode is assembled of 4 separate sections.
It allows measurements of the beam envelope along the transport section.

New Electron Collector Design with a Wien filter

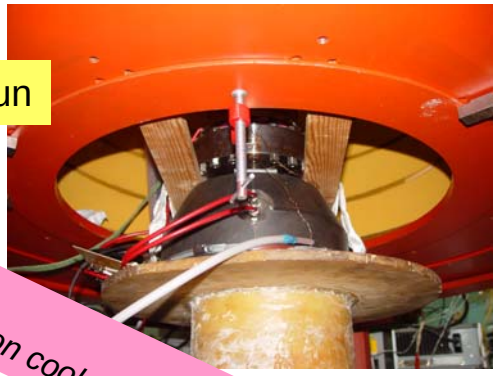


Collector up to 15 kW

Test Bench BINP

Collector

Electron Gun



Poster M. Bryzgunov, BINP
Electron collector for 2 MeV electron cooler for COSY

Wien filter, E x B field, 2.85 kV/cm, 35 G
Minimisation of the number of reflected electrons
efficiency < 10^{-5}.

Progress at COSY-Juelich

Making Space Available in 2010 (shutdown 21.6. -23.7.2010)

Development of Beam Diagnostics for Electron Cooling Optimisation

Profile Monitor IPM and SPM

Electron Beam Profile Measurement in the Cooling Section with Thomson Scattering (HIM)

Closed Orbit Correction at 2 MeV cooler

Ordering (in 2010)**:**

HV pressure vessel (10 bar SF_6)
oil pressure vessel
SF_6 gas system
vacuum components
power supplies (magnetic system)
water hoses
oil pumps
heat exchanger

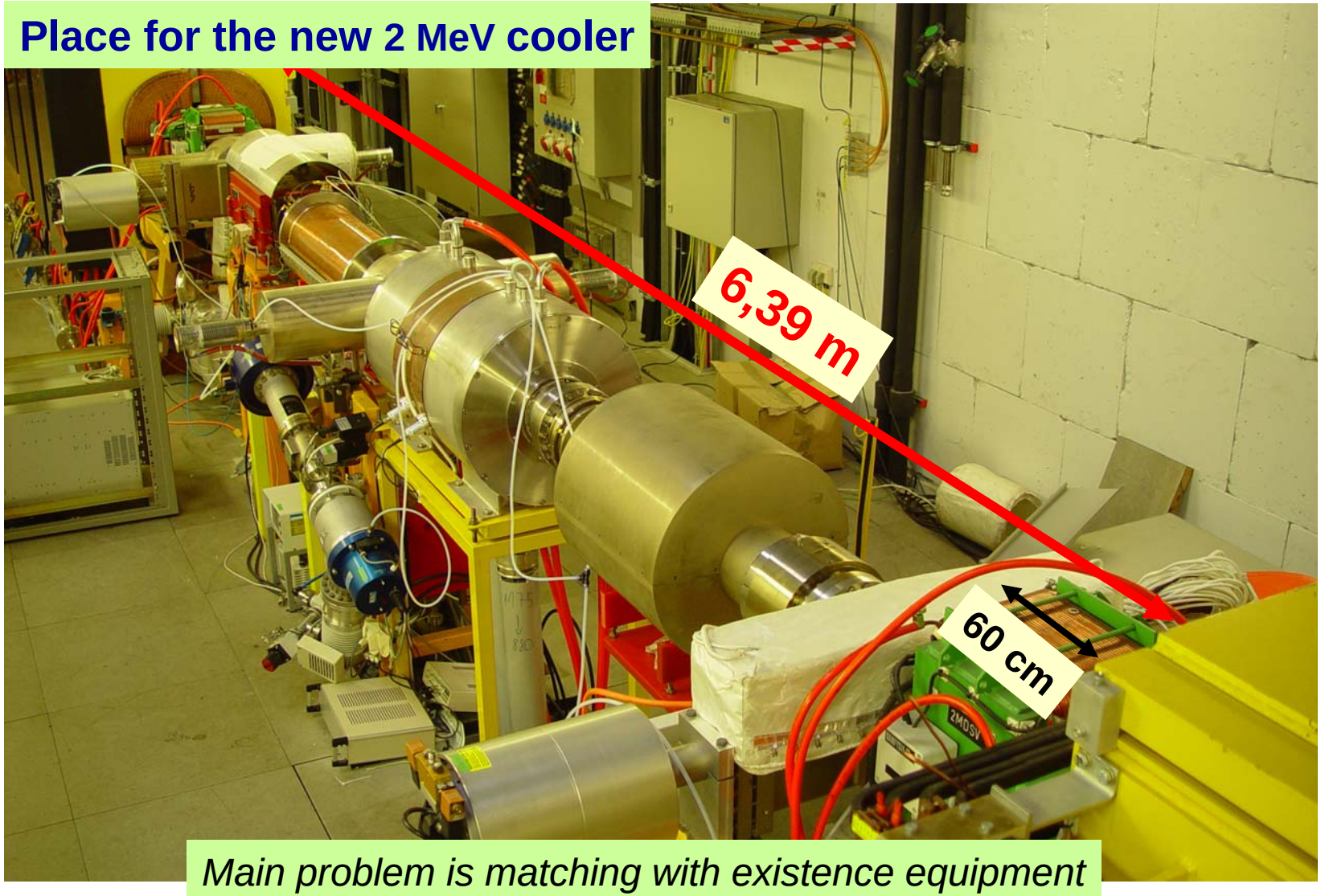
Building application *(Bauantrag an die Stadt Jülich, radiation shielding)*

Radiation safety *(Nachtrag-Verfahren zu COSY-Strahlenschutz-Genehmigung BS2/92)*

Plan of COSY Cooler Location with Shielding Elements

Making Space Available in 2010 (shutdown 21.6. -23.7.2010)

Place for the new 2 MeV cooler



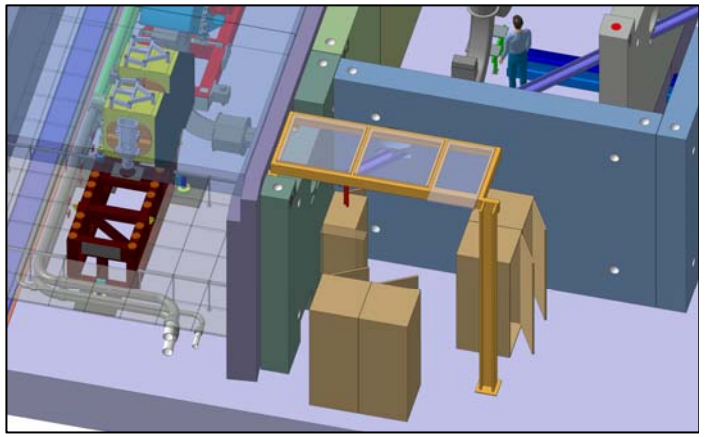
Main problem is matching with existence equipment

Making Space Available in 2010

Removing of excisting components from TP2' (BCT, cavity, WCM)

Changing cabling in the COSY tunnel

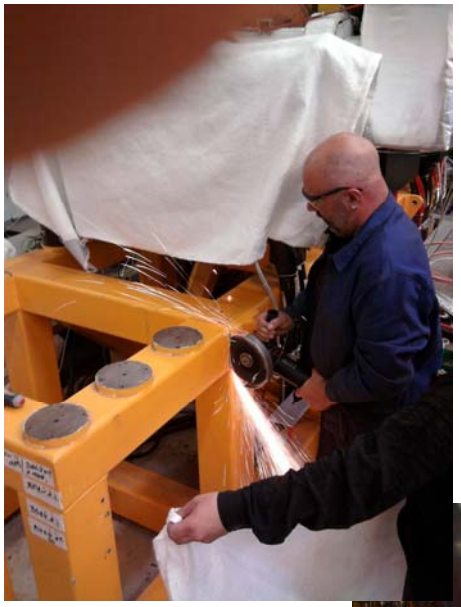
New water cooling pipes for the COSY ring

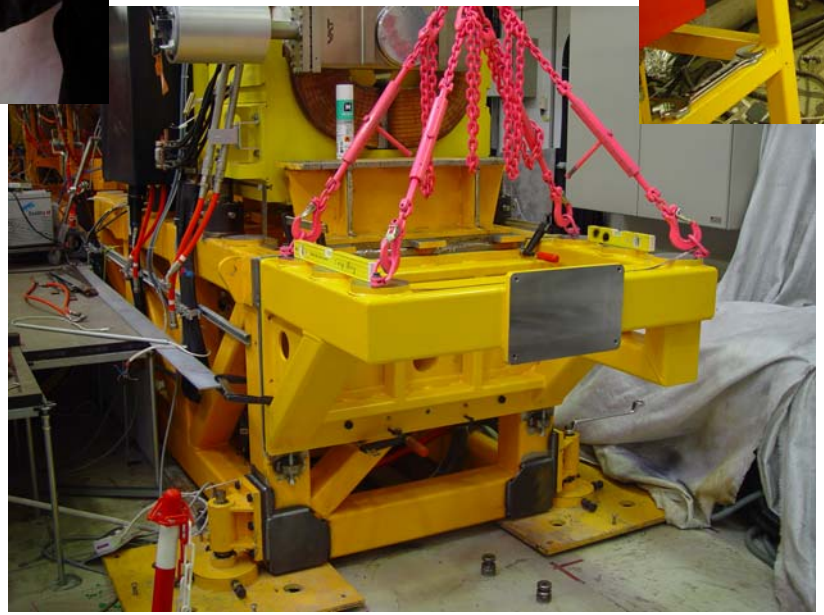


Changing position of racks outside the tunnel

Radiation Shielding

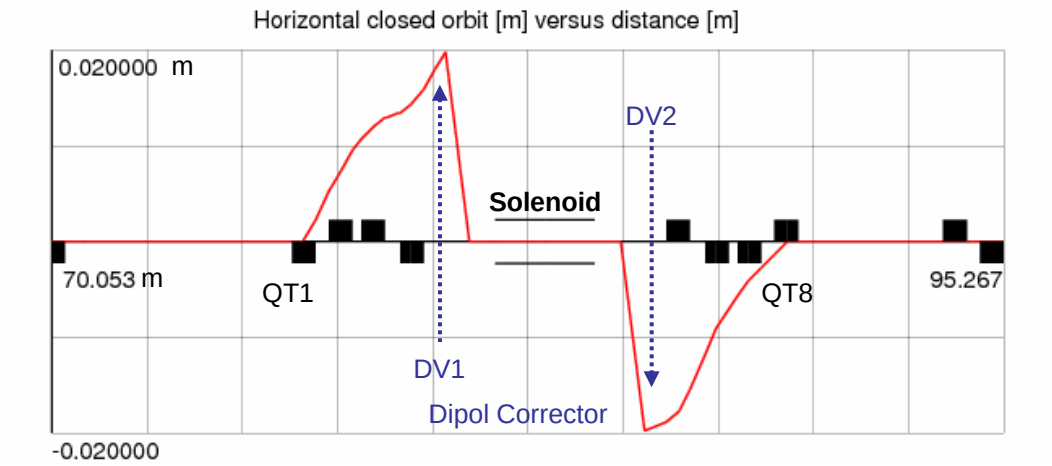
Support of Quadrupoles





Closed Orbit Three Bump Local Correction –

Horizontal Plane



Additional Steerer in the Quadrupoles

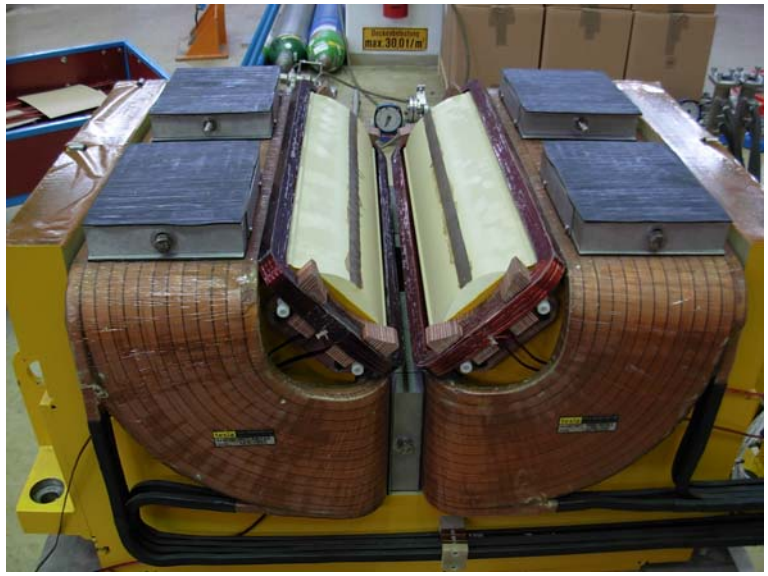
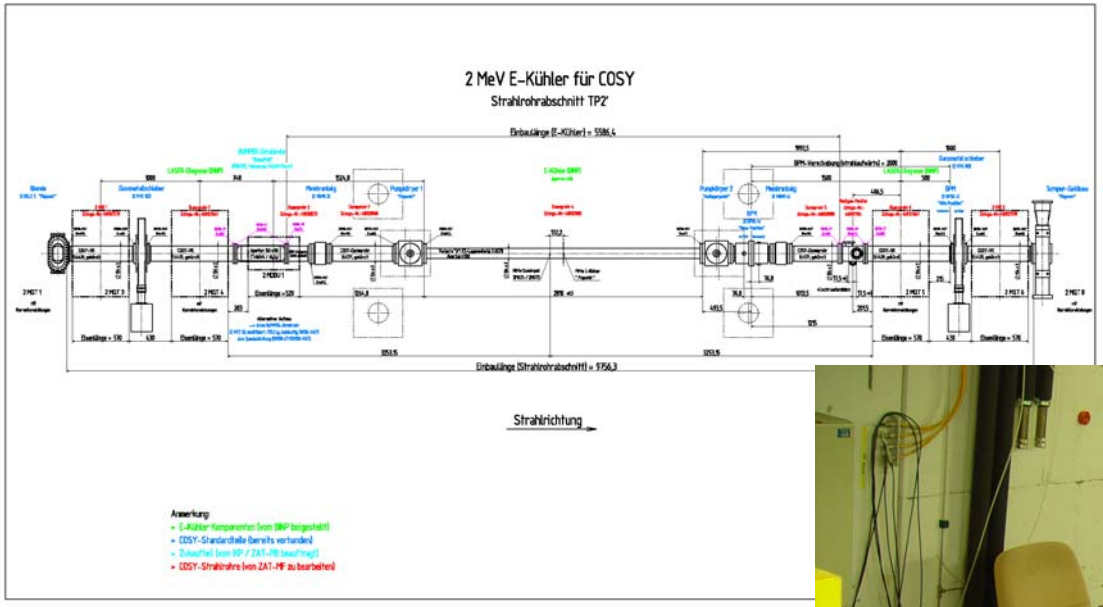


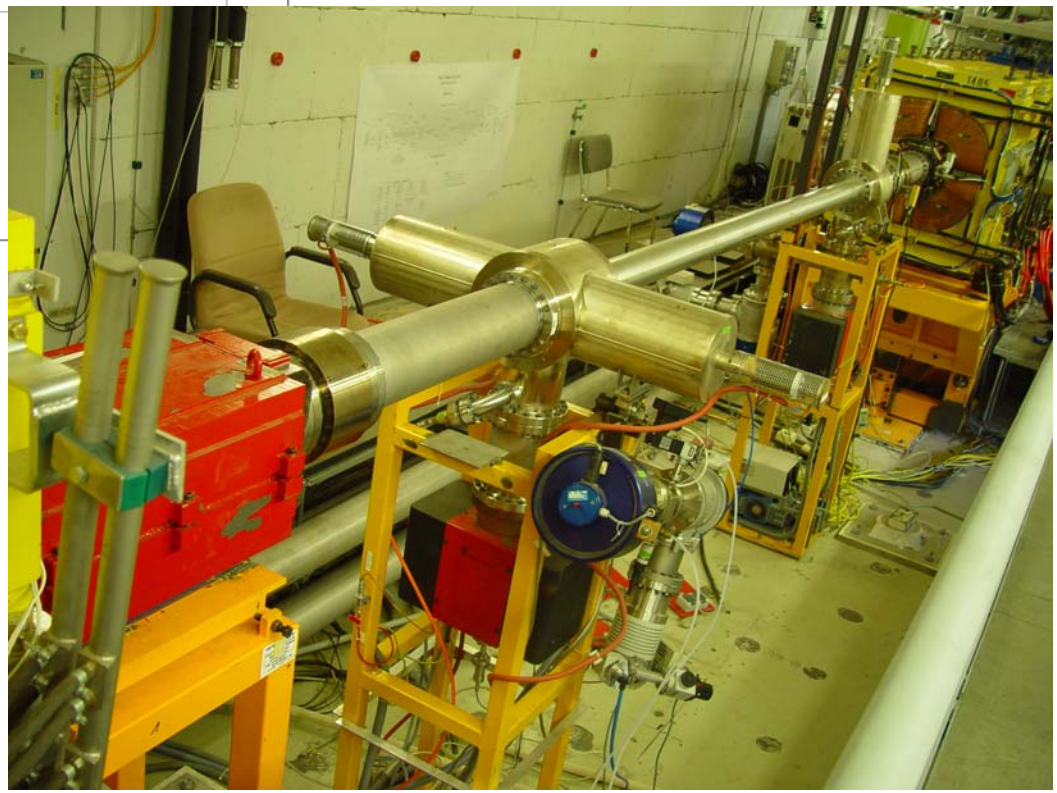
Table : The steerers' parameters for closed orbit correction (1kG)

	MathCAD	Winagile
Steerer in QT1	7.692 mrad	7.559 mrad
DV1 in cooler	-10.6 A	-37.518 mrad (-11.5A)
Toroid 1 and dipole 1	500A	31.0 mrad (500A)
Toroid 2 and dipole 2	500A	-31.0 mrad (500A)
DV2 in cooler	-23.4A	32.586 mrad (-24.4A)
Steerer in QT8	-4.412 mrad	-4.126 mrad

Poster L. Mao, FZJ
Closed orbit correction in 2 MeV electron cooler section at COSY

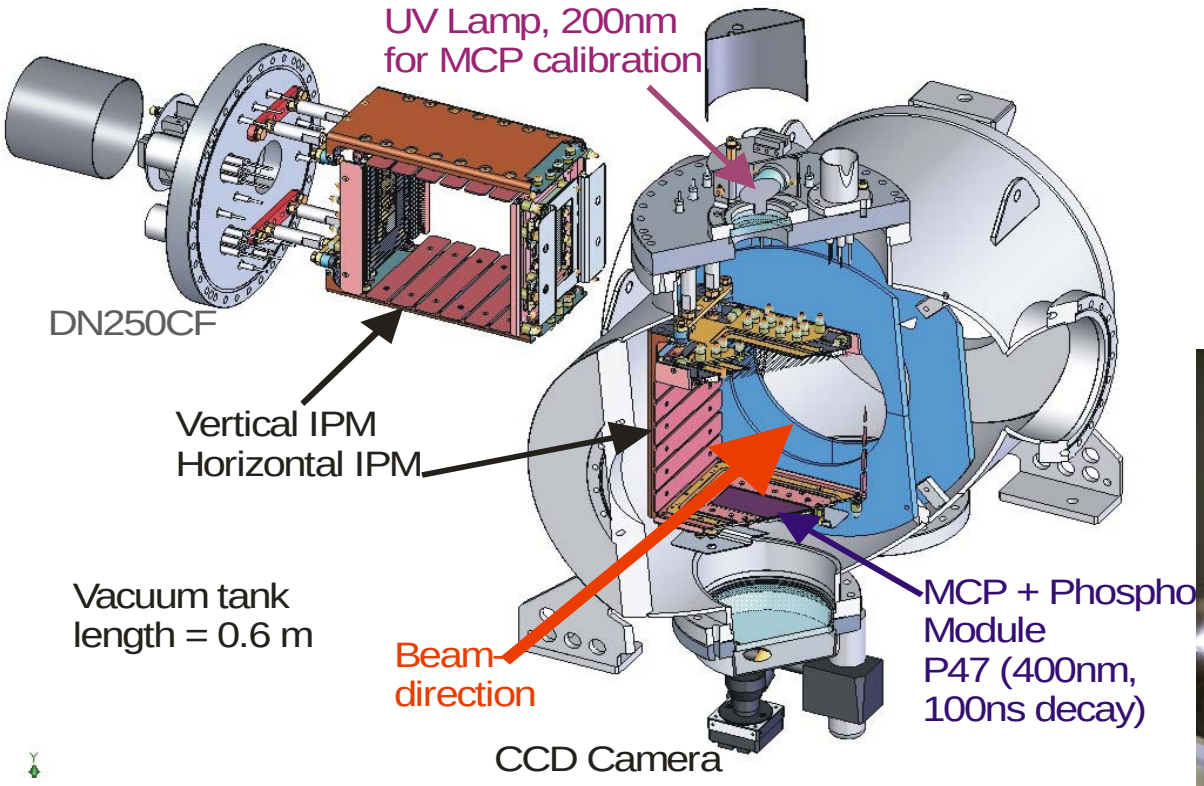
Place for the New 2 MeV Cooler Today

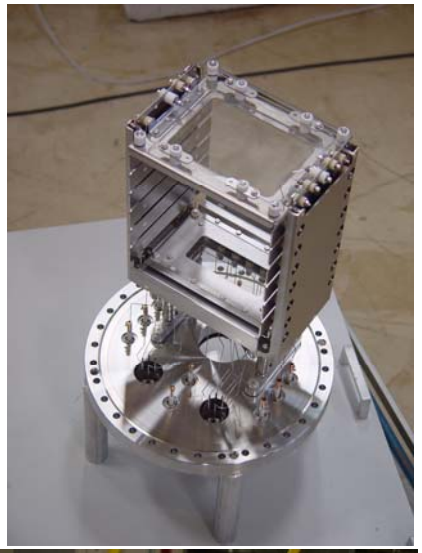


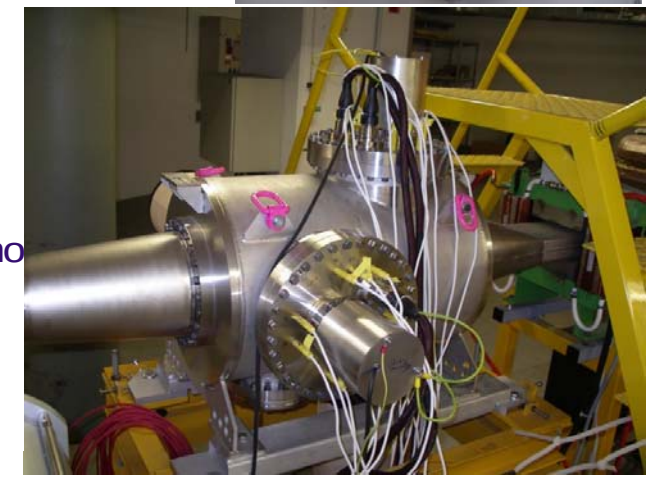


Beam Diagnostic Developments

Ionisation Profile Monitor IPM

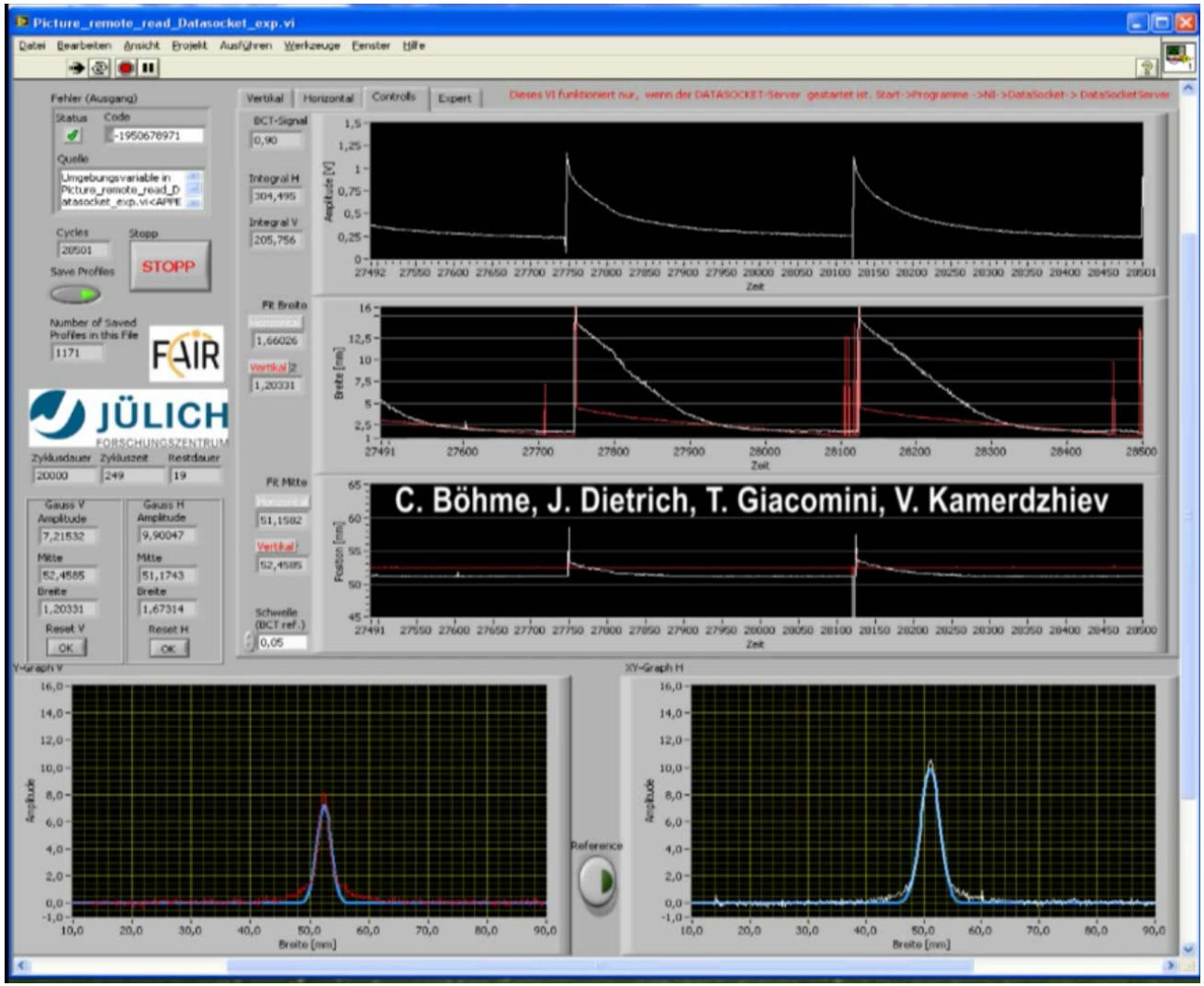






C. Böhme, J. Dietrich, V. Kamerdzhiev, P. Forck, T. Giacomini, D. Liakin
Beam Test of the FAIR IPM Prototype in COSY
Proc. of the 9th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators, DIPAC2009, Basel, Switzerland, May 24-27, 2009.

Electron Cooling at Injection Energy
Proton Beam Profiles (Restgas Ionisation Monitor)



80 mm

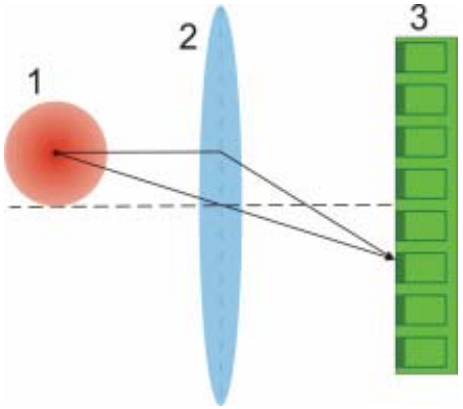
BCT beam current

1σ beam width
white-horizontal
red- vertical

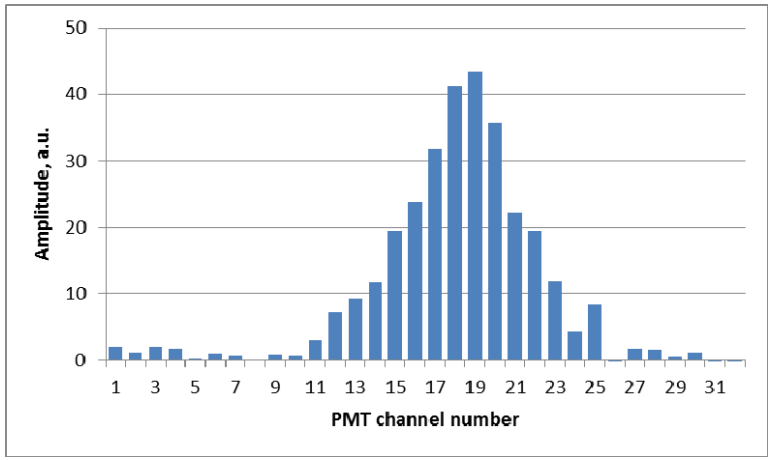
beam position
white-horizontal
red- vertical

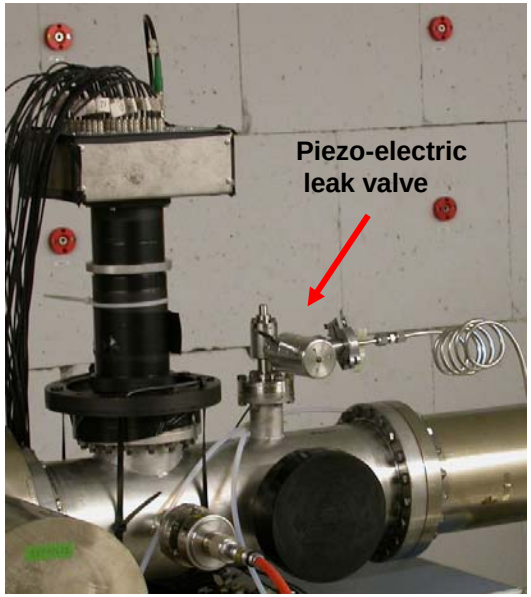
beam profile
white-horizontal
red- vertical
blue – Gauss fit

Scintillation Profile Monitor SPM

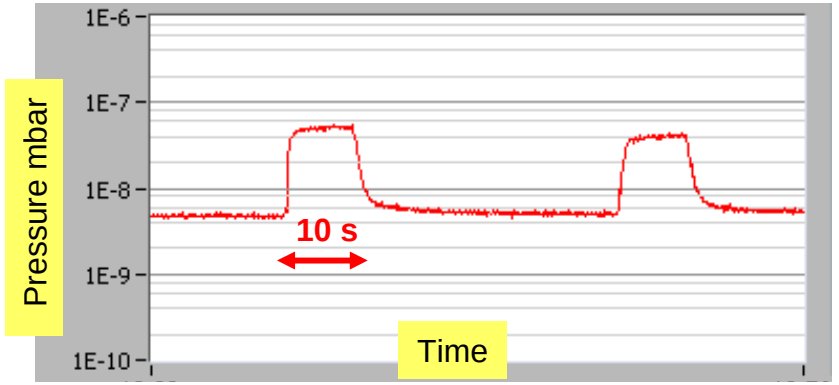


Light from the ion beam (1) is focused with a lens (2) on a multichannel PM (3).





Horizontal beam profile with $1.5 \cdot 10^{10}$ protons , 2.6 GeV/c. Temporary pressure bump at the SPM location amounted to $4 \cdot 10^{-8}$ mbar.

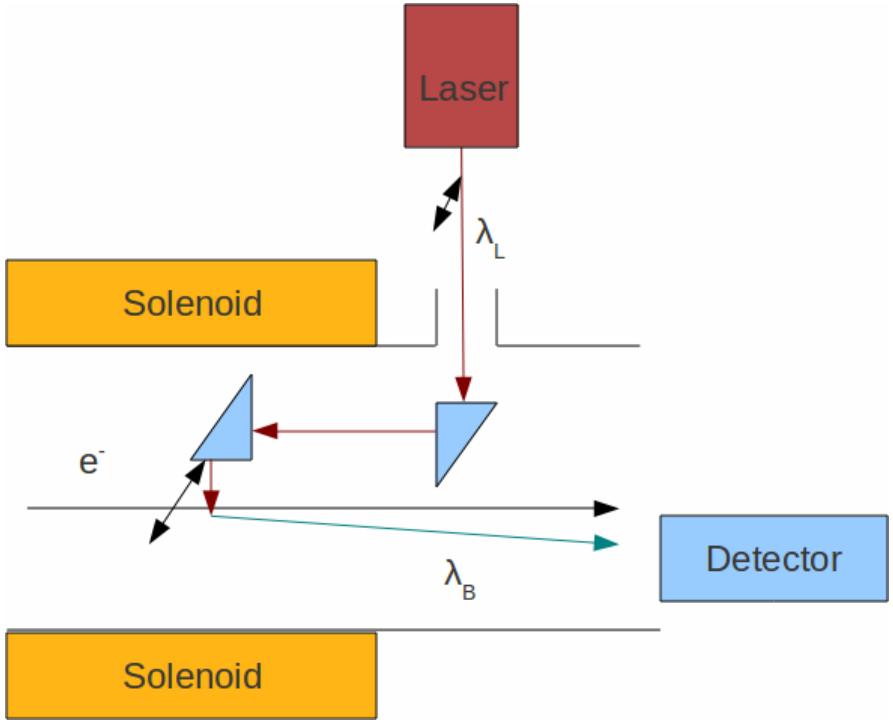


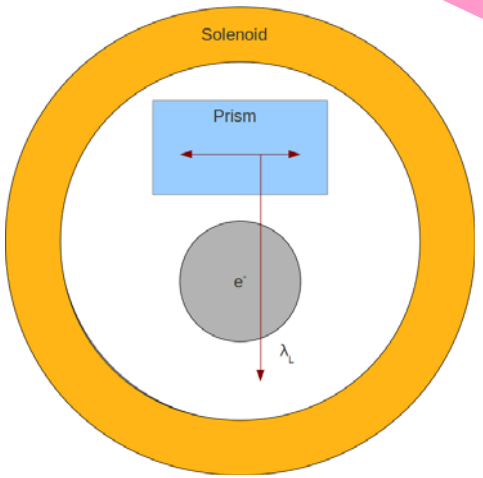
Proposed Electron Beam Profile Measurement in the Cooling Section with Thomson Scattering

T. Weilbach, HIM, Mainz

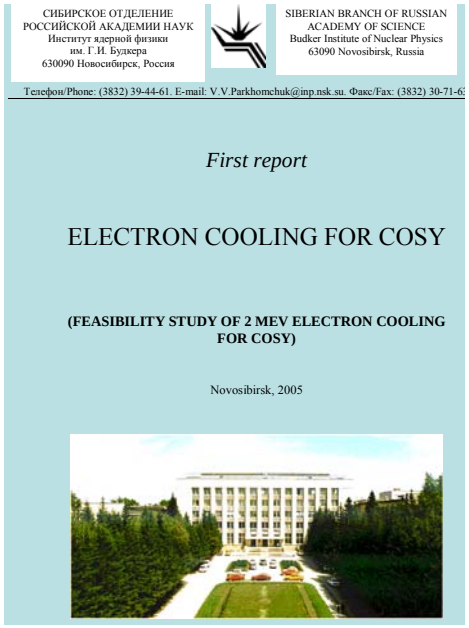
Poster T. Weilbach, HIM, Mainz
Optical electron beam diagnostics for relativistic electron cooling devices

Schematic Measurement Setup





History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First report

ELECTRON COOLING FOR COSY

(FEASIBILITY STUDY OF 2 MEV ELECTRON COOLING FOR COSY)

Novosibirsk, 2005

First idea COSY 2 MV cooler and discussion
BINP Novosibirsk, **2003**

Interims (First) Report, Novosibirsk **May 2005**

The International Workshop on Beam Cooling and Related Topics -- COOL05

Working group on COSY 2 MV Cooler, Thursday, September 22, 2005
Summary report
Sergei Nagaitsev/FNAL (Co-chair COOL05)
Igor Meshkov/JINR (working group convener)

Allocation of Money **March 2009**
ECONOMIC STIMULUS PLAN I in Germany

Contract BINP-FZJ **July 2009**

Conceptual Design Report **December 2009**

e^- -Commissioning at BINP **May 2011**

Installation at COSY **November/December 2011**

Outlook

Last Status at Budker Institut Novosibirsk

Memorandum of visit Jurgen Dietrich in BINP
16-17 March 2011.

The 2 MV electron cooler production finished on near 90%
Now at still under production at BINP workshop:

1. Dipole magnet for ion beam correction
2. The support system for dipole magnet
3. The scaffolding system for cooler assembling
4. The water cooling system for transport magnet system
5. The small correctors
6. Cascade transformer

1. The first commission with low energy electron beam can be started at end of April 2011
2. First commission wit low energy electron beam will be made with the electron gun and collector install directly on the bottom flange
3. The computer system with power supply including MPS-6 should operated near cooler
4. The electron beam diagnostic based on pickup electrodes should be ready to the end April
5. The first visit of COSY team for participated at cooler commission can start from 10 May (2 weeks)
6. The cooler should be send at COSY at beginning October
7. The 2 MV cooler commission at COSY: 10 Nov.-20 Nov. unpacking and elements assembling, 20-30 assembling system, 1 Dec-15 Dec installing cooler section at COSY
8. Question of delivery the power supply MPS-6 should be decide at May after testing on cooler and commission with participation COSY experts
9. The including the payments made at COSY for high pressed vessel, SF6 system and the vacuum elements can be made by decreasing final price but all this documents should be ready before shipments (better at May 2011).

From BINP
Vasily Parkhomchuk

17 March 2011
BINP

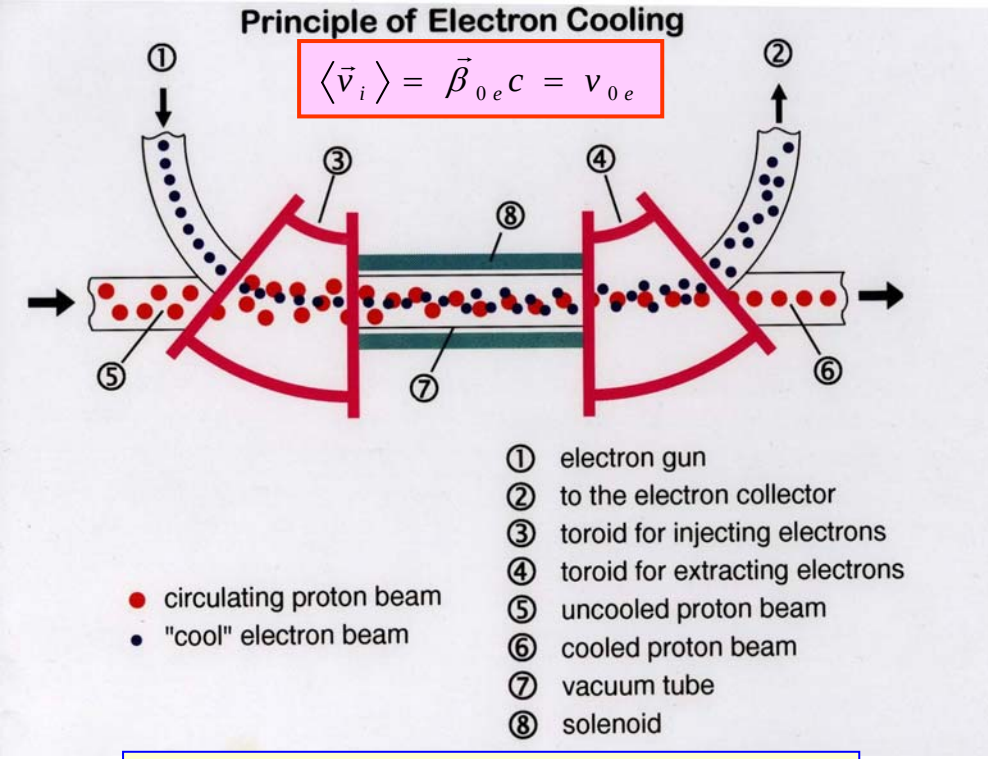
From FZJ
Juergen Dietrich

Thanks to our colleagues from BINP Novosibirsk

V.V.Parkhomchuk, V.B.Reva, V.K. Gosteev,
A.M. Kruchkov, A.A. Putmakov, V.A. Poluhin
M.I. Bryzgunov, A.D. Goncharov, D.N. Skorobogatov .....

Introduction

Electron Cooling at COSY

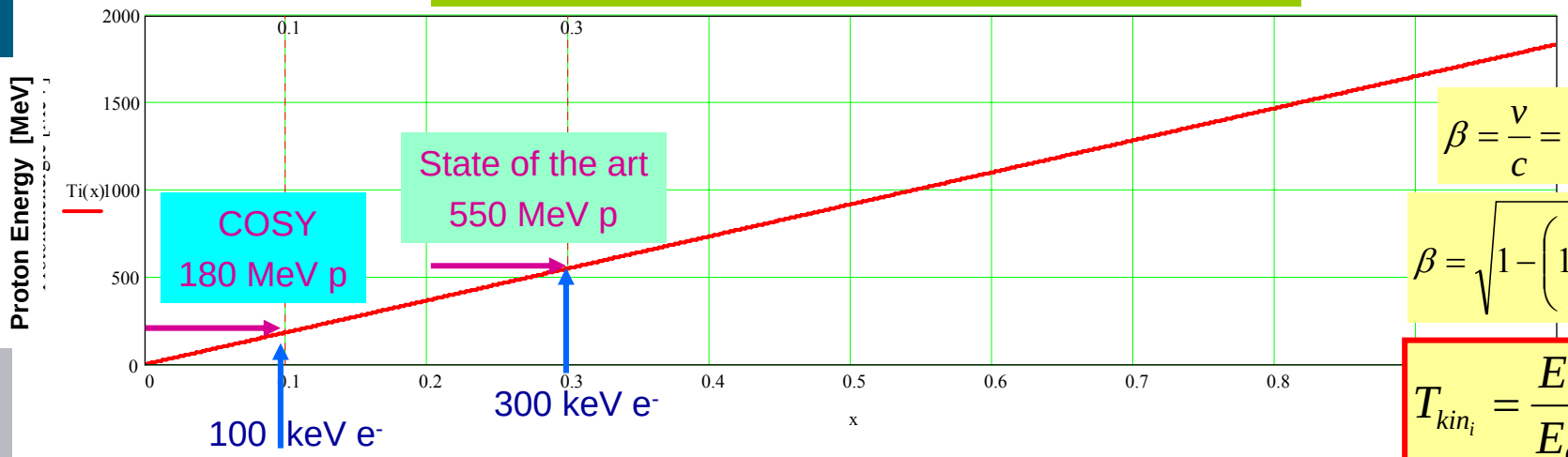


Electron energy:
24.5 - 100 kV
Electron current:
0.2 - 3 A

Accumulation of low intensity beams

Future: High Energy Electron Cooling

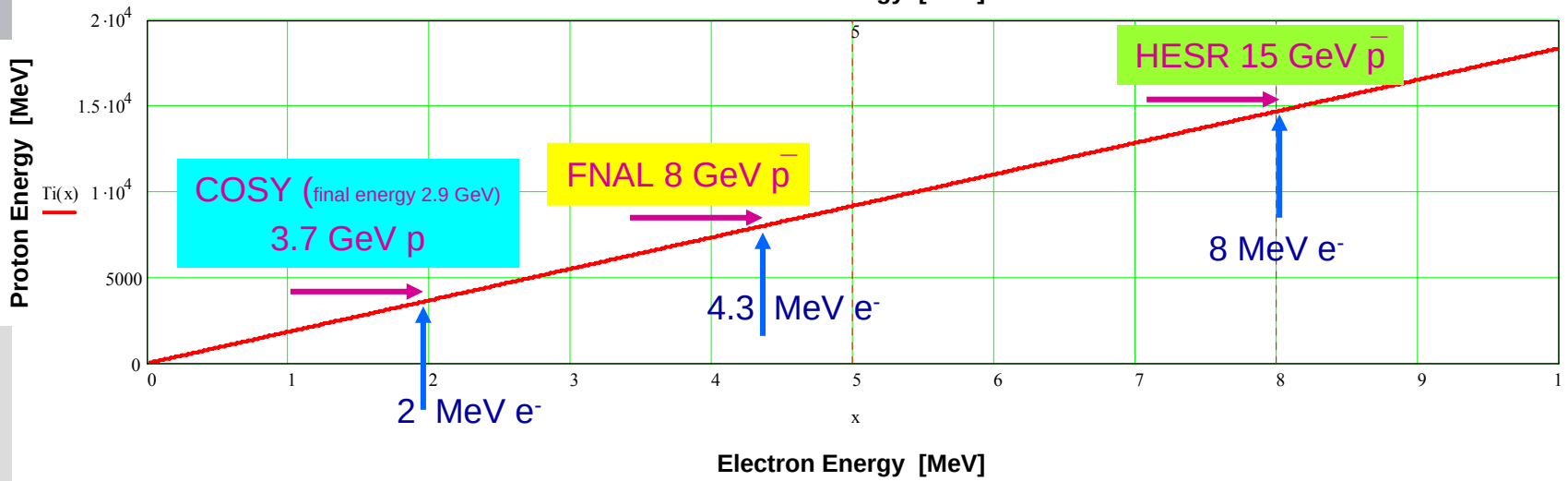
Proton Energy Versus Electron Energy for Cooling $v_i = v_e$



$$\beta = \frac{v}{c} = \beta_e = \beta_i$$

$$\beta = \sqrt{1 - \left(1 + \frac{T_{kin}}{E_0}\right)^{-2}}$$

$$T_{kin_i} = \frac{E_{0i}}{E_{0e}} \cdot T_{kin_e}$$



Electron Cooler - Status

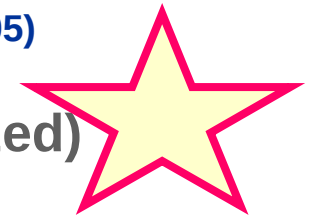
- **In operation**

  25 - 350 kV at CERN, GSI, IMP Lanzhou, FZJ …

- **In operation** (**commissioned September 2005**)

  4.3 MV at FNAL (DC, non-magnetized)

  Longitudinal cooling time > 1h



- **In future**

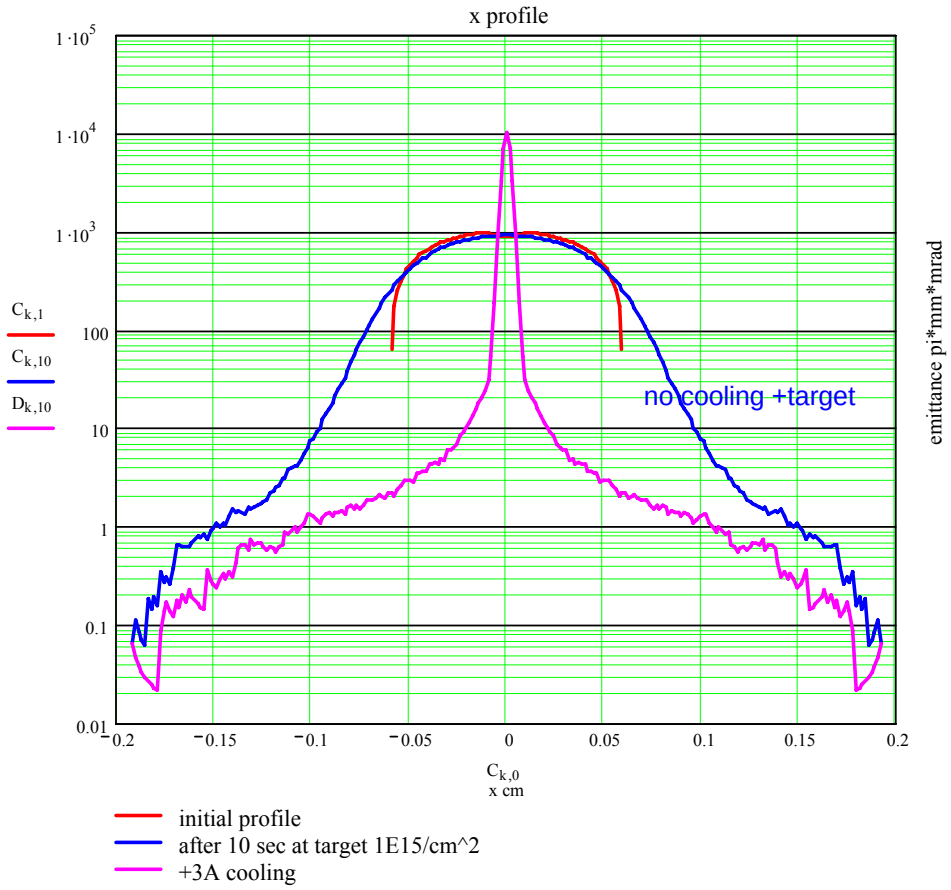
  2 MV for COSY (DC, magnetized), in realisation

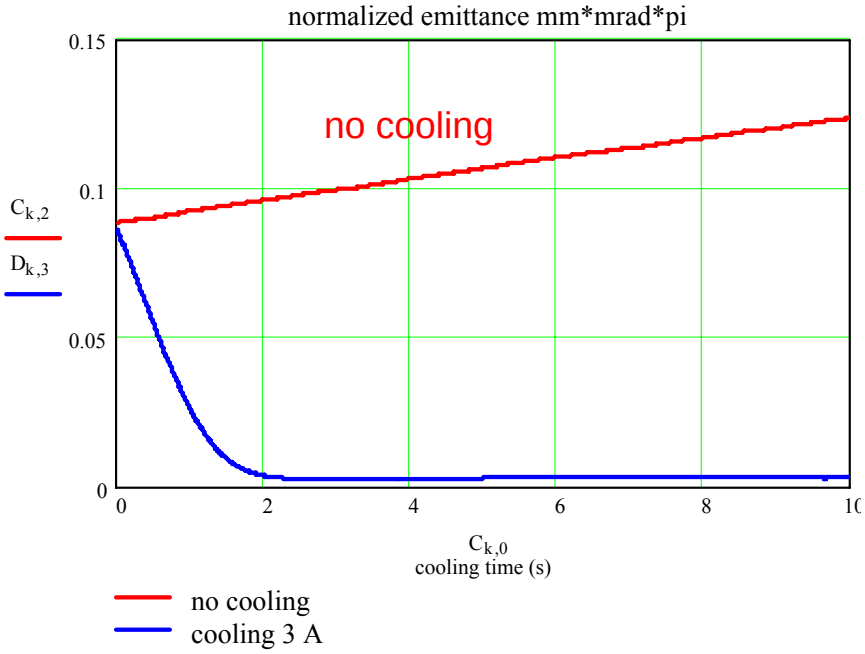
  8 MV (?) for HESR (DC, magnetized)

  54 MV for RHIC (AC) ?

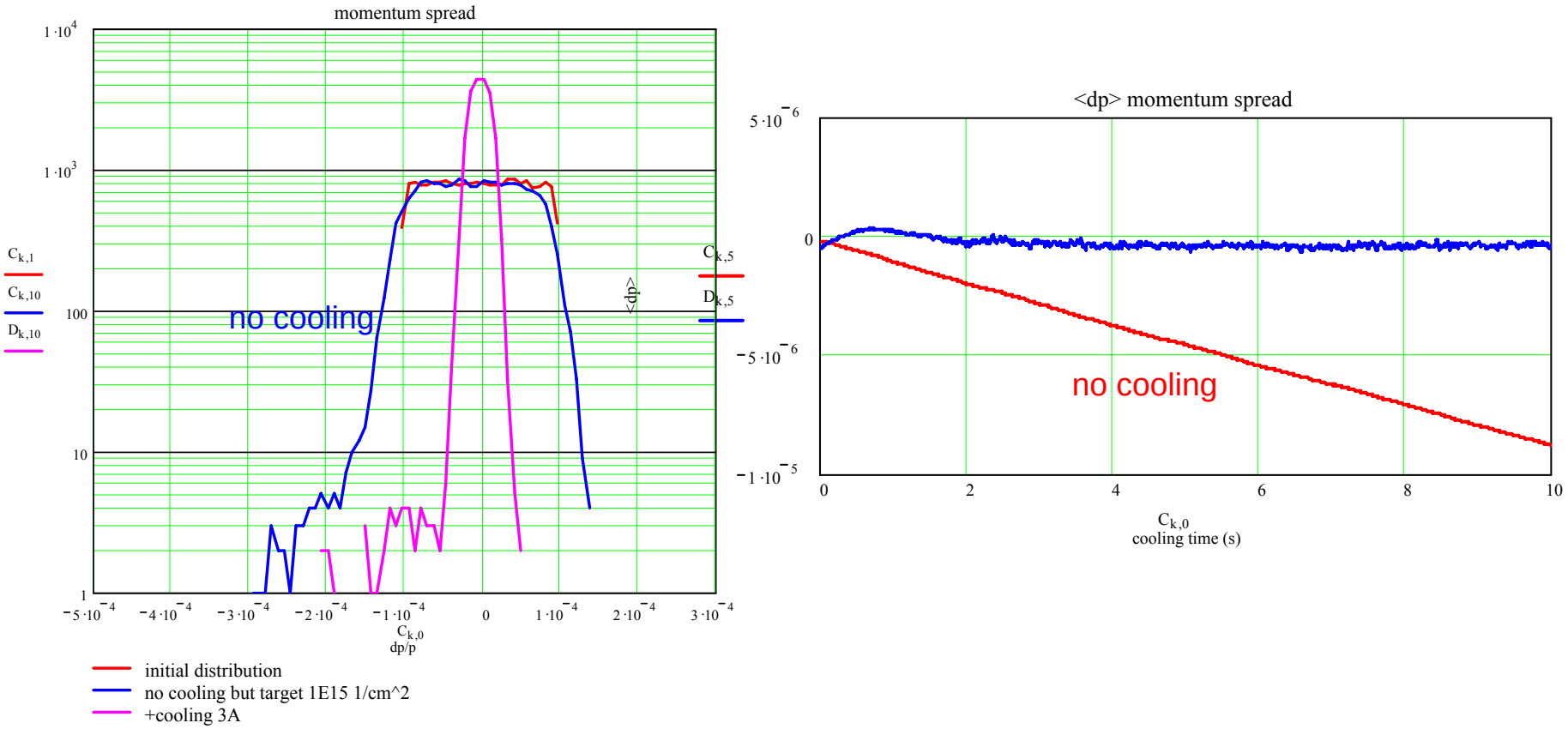
How will act cooler on proton beam in transverse direction with target ?

(proton beam: 2 GeV, $2 \cdot 10^{10}$, electron cooler: r_e = 5 mm, B_c= 2 kG, I_e = 3 A)

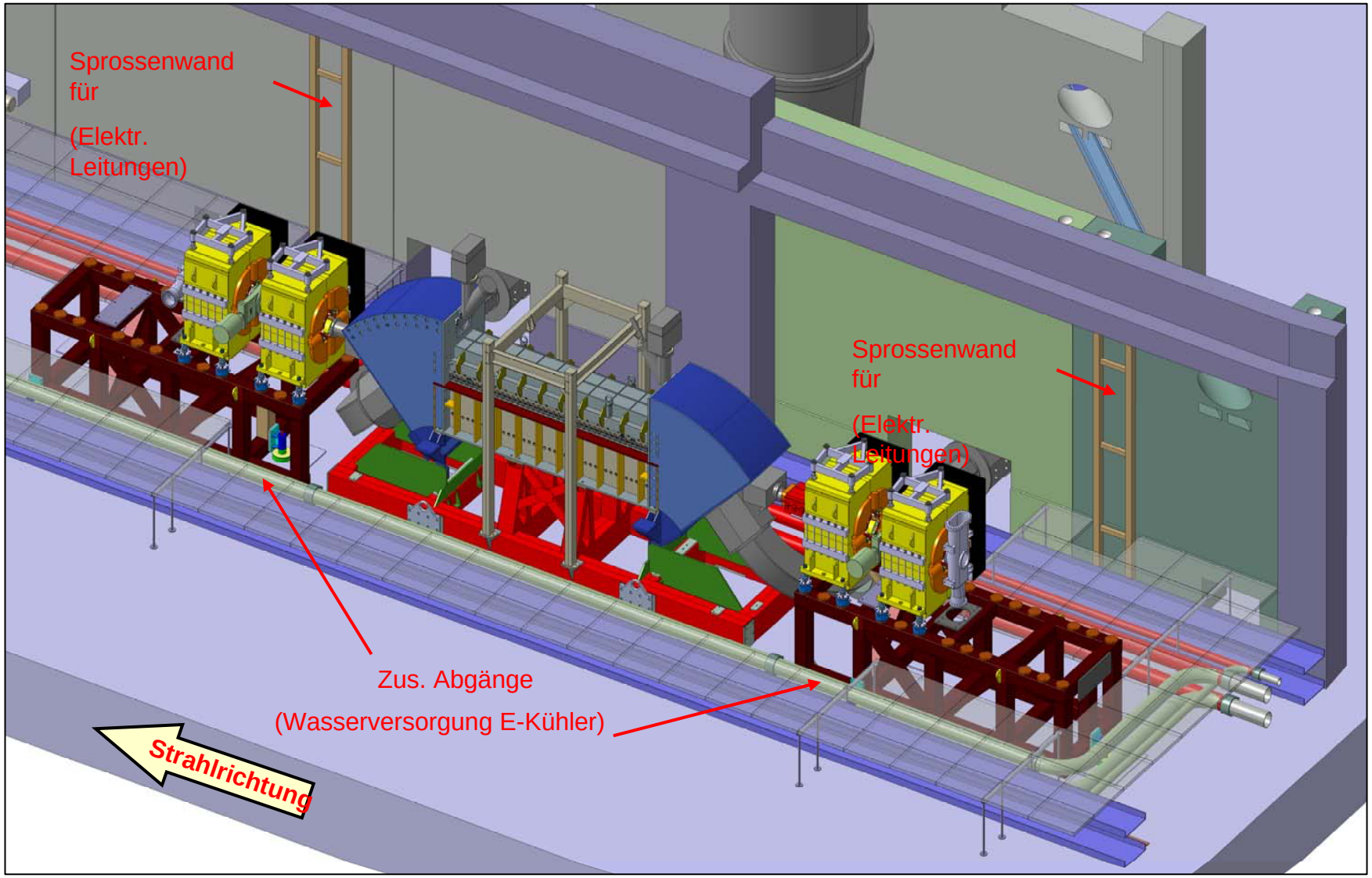




How will cooler act on momentum spread of proton beam with target?



Inside View


Sprossenwand
für
(Elektr.
Leitungen)
Sprossenwand
für
(Elektr.
Leitungen)
Zus. Abgänge
(Wasserversorgung E-Kühler)
Strahlrichtung

Helmholtz Russia Joint Research Group

JÜLICH FORSCHUNGSZENTRUM

HRJRG-106
Development of a High Energy Electron Cooler for Hadron Physics Experiments at COSY and HESR

СИБИРСКОЕ ОТДЕЛЕНИЕ
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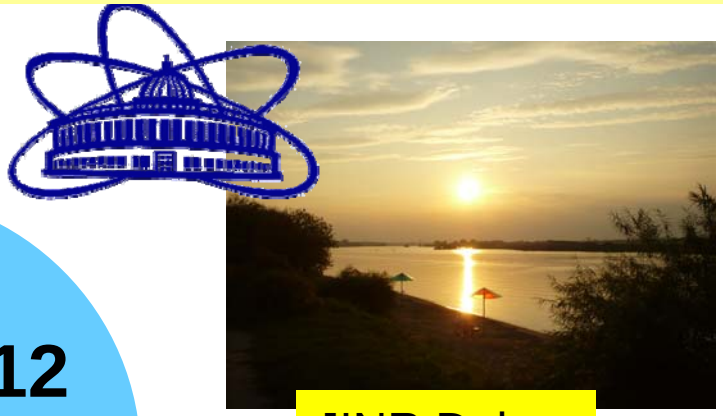
BINP Novosibirsk

2009 -2012

450 K€



JINR Dubna

JÜLICH FORSCHUNGSZENTRUM

INSTITUT FÜR KERNPHYSIK (IKP)

FZJ Jülich

technische universität
dortmund

DELTA

Dortmunder Zentrum für Synchrotronstrahlung /
Dortmunder Elektronenspeicherringanlage DELTA

TU Dortmund