# COSY 2-MeV Cooling System Proposal


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**Galena, September 22nd, 2005**

# Overview

## Introduction

COSY Facility

Existing Beam Cooling

Motivation for the 2 MeV Electron Cooler

## Basic Concept of the 2 MeV Electron Cooler

Requirements

**Interims Report Novosibirsk, May 2005**

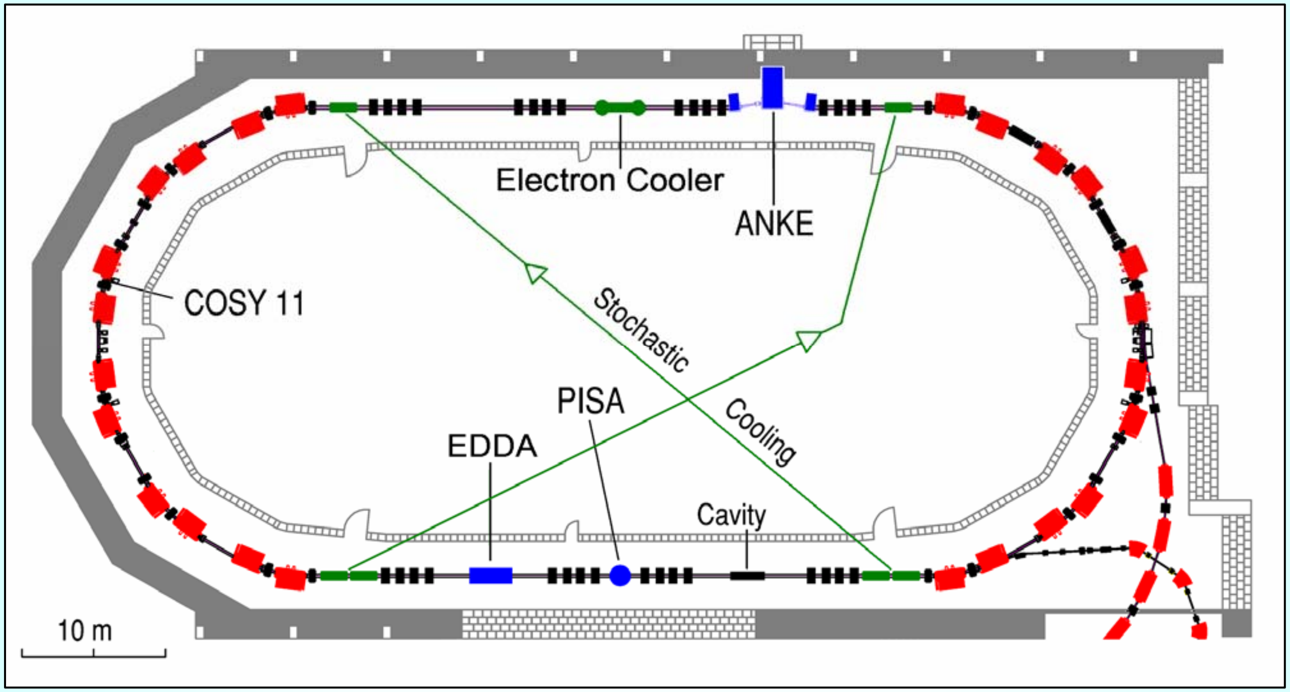
First Calculations with *trubs.exe*

Technical Layout

Gas Driven Turbines

## Cost and Time Estimates

# COSY Accelerator Facility




**Ions: (pol. & unpol.) p and d**

**Momentum:** **300 to 3650 MeV/c for p**
**540 to 3650 MeV/c for d**

**Targets:**

- **Internal: solid, cluster, atomic beam**
- **External: solid, liquid**

**Beam cooling:**

- **Electron cooling at injection (300 MeV/c)**
  **for beam accumulation**
  **high brilliance beams**
- **Stochastic cooling above 1.5 GeV/c for**
  **luminosity preservation**

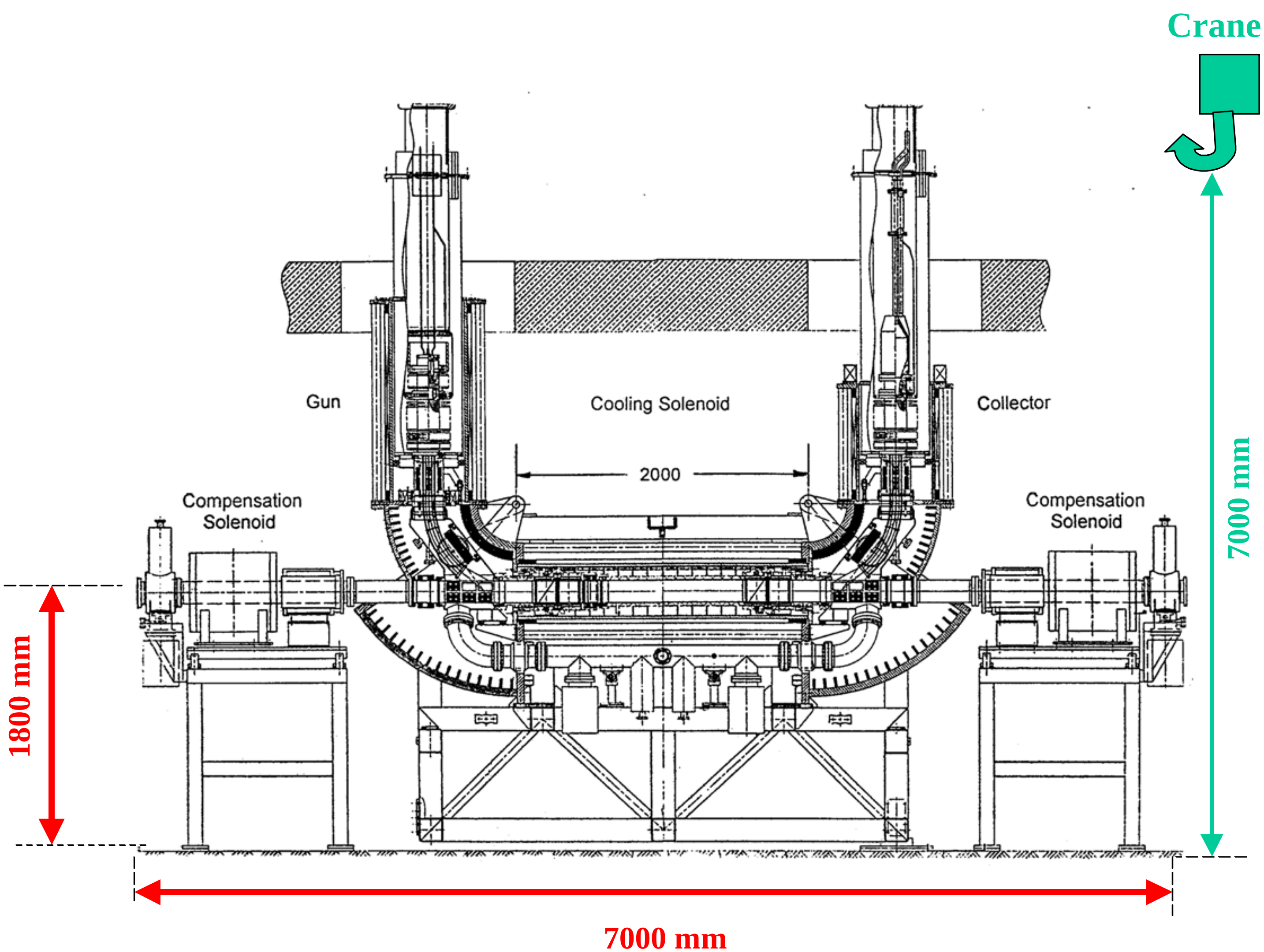
# Present Electron Cooling at COSY

**Design Values:**
**Electron energy:**
**$\leq$ 100 kV**
**Electron current:**
**$\leq$ 3 A**

**Used at injection momentum:**

- **for kicker (fast) extraction**
- **for „halo-suppression“ of stochastic extracted beams**
- **for intensity increase of low intensity beams (polarized beams)**

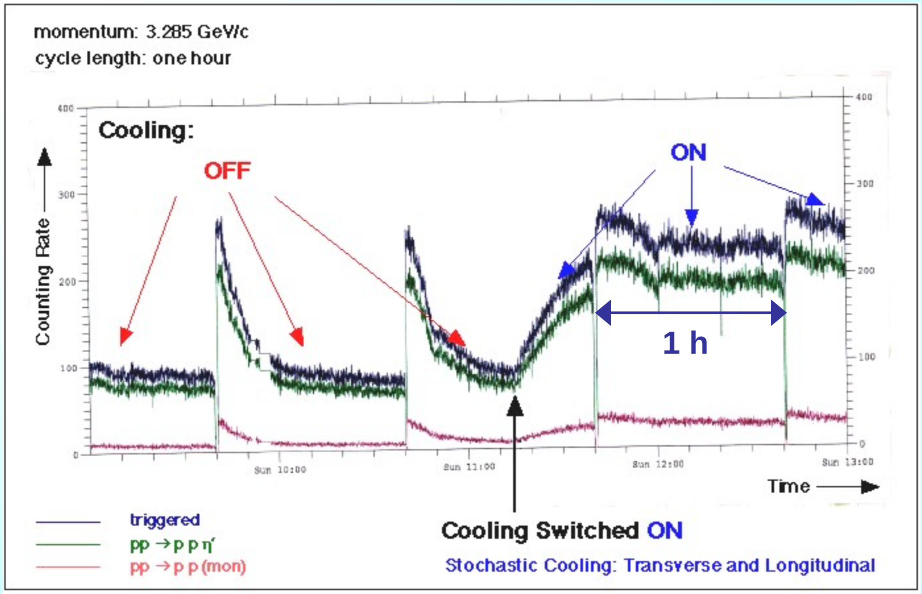
# Existing COSY Electron Cooler



# Stochastic Cooling at COSY

**Compensation of emittance growth and momentum loss due to beam – target interaction**

## Luminosity preservation




**Transverse and longitudinal cooling**

| | |
|---|---|
| **Frequency range:** | **1-3 GHz** |
| | **2 bands** |
| **Installed RF power:** | **500 W** |
| | **per plane** |

# Motivation: Higher Luminosity with Cooled Beams

- **Limits of the COSY stochastic cooling system**

  Cooling time ~ number of particles / bandwidth

  → Luminosity $\leq 10^{31}\ cm^{-2}\ s^{-1}$

  (Typical values: Number of particles $6*10^{10}$
  Cluster target thickness $10^{14}\ cm^{-2}$ )

- **Requests for future COSY experiments**

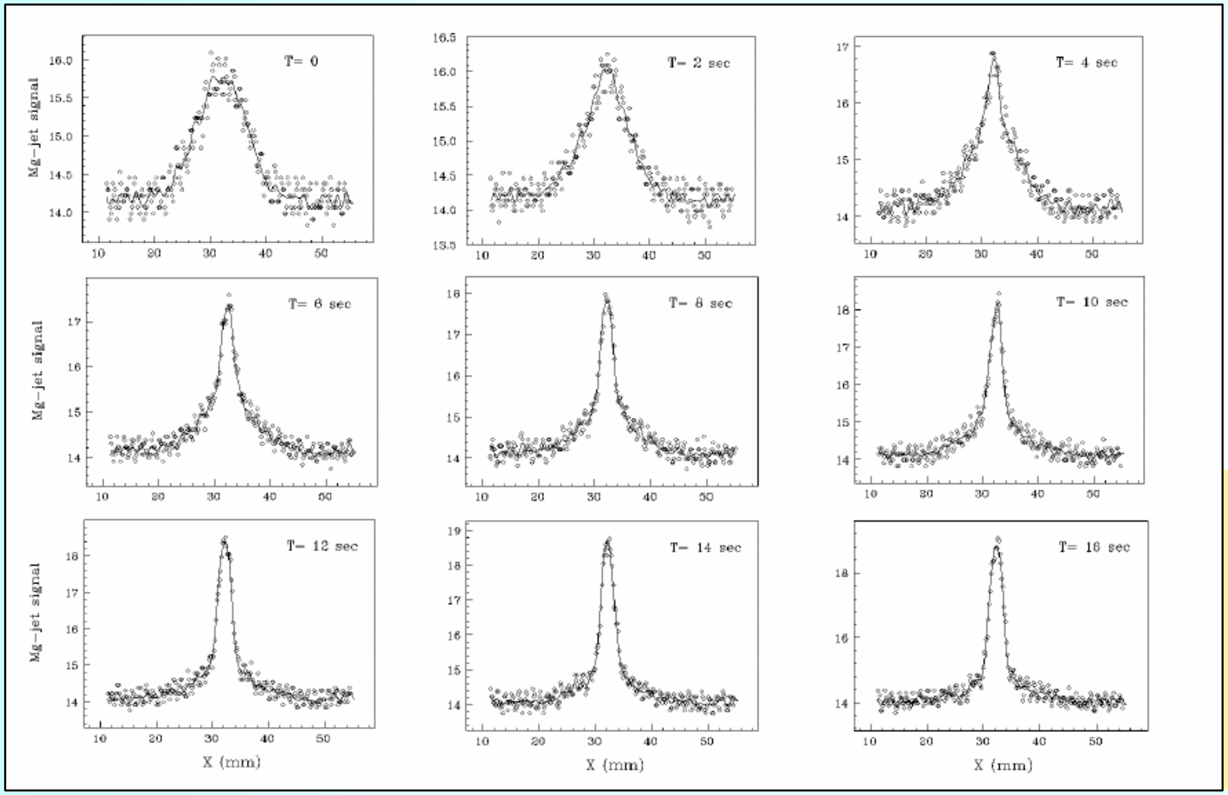
  → Luminosity $\geq 10^{32}\ cm^{-2}\ s^{-1}$

  (Typical values: Number of particles $6*10^{10}$
  Pellet target thickness $10^{16}\ cm^{-2}$ )

- **Possible solutions**
  - Increase bandwidth of stochastic cooling
  - Electron cooling up to maximum momentum

# Combination of Electron and Stochastic Cooling

Time evolution of horizontal beam profiles during e-cooling of 400 MeV proton beam.




**Electron cooling: core**

**Stochastic cooling: tails**

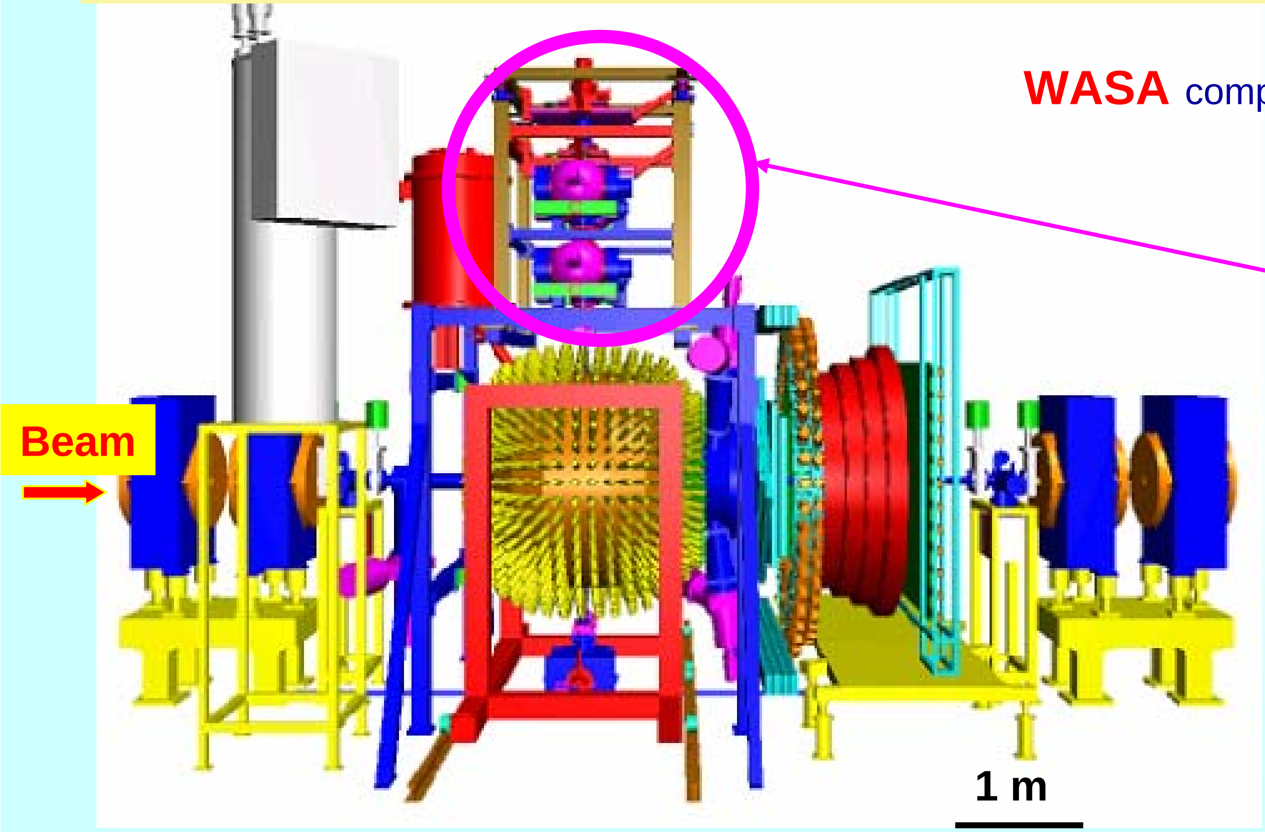

Y.-N. Rao[1], L.Hermansson[2], T. Lofnes, D. Reistad
The Svedberg Laboratory, S-751 21 Uppsala, Sweden

# New Detector in COSY, WASA (Wide Angle Shower Detector)

WASA – a detection system from CELCIUS accelerator of The Svedberg Laboratory (TSL) at Uppsala - will be installed at COSY.

Photon detection is an important window to access the physics of hadronic reactions.

Many of the produced mesons and excited baryonic states have significant decay branches comprising multi-photon final states. At COSY such a detector was missing.




**WASA** comprises the following components:

- **Central Detector**
- **Forward detector**
- **Zero-Degree Spectrometer**
- **Pellet Target**

# 2 MeV Electron Cooler for COSY

## Basic Parameters and Requirements

| | |
|---|---|
| **Energy range** | **: 25 keV ... 2 MeV** |
| **High Voltage Stability** | **: < $10^{-4}$** |
| **Current** | **: 0.1 ... 3 A** |
| **Diameter Electron Beam** | **: 10 ... 30 mm** |
| **Cooling length** | **: 3 m** |
| **Toroid Radius** | **: 1.5 m** |

**Variable magnetic field in the cooling section solenoid (0.5 ... 2 kG)**

| | |
|---|---|
| **Vacuum at cooler** | **: $10^{-8}$ ... $10^{-9}$ mbar** |
| **Available overall length** | **: 7 m** |
| **Maximum hight** | **: 7 m (horizontal arrangement ?)** |
| **COSY beam axis above ground** | **: 1.8 m** |

**Polarization**

# Interims (First) Report, Novosibirsk, May 2005

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*First report*

ELECTRON COOLING FOR COSY

**(FEASIBILITY STUDY OF 2 MEV ELECTRON COOLING FOR COSY)**

Novosibirsk, 2005

V. Reva, BINP
Budker INP Proposals For HESR and COSY Electron Cooling System
next talk after coffee break

# Cooling of a 2 GeV Proton Beam at COSY

## Calculations with the program *trubs.exe*, V.V.Parkhomchuk

**Cooling force** (F)

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

**IBS** (longit. momentum spread Δp/p)

$$\delta\left[\left(\frac{\Delta p_{||}}{p}\right)^2\right] = \frac{4r_i^2 N_i L_{ibs}\Pi}{\gamma^2\beta^4\varepsilon^{3/2}\left\langle\sqrt{\beta_\perp}\right\rangle l_b}$$

**Target** (angular spread Θ)

$$\left\langle\Theta^2\right\rangle = \frac{8\pi e^4 Z_M^2 n_M}{\gamma^2 m_p^2\beta^3 c^3}\,ln\left(\frac{\Theta_{max}}{\Theta_{min}}\right)$$

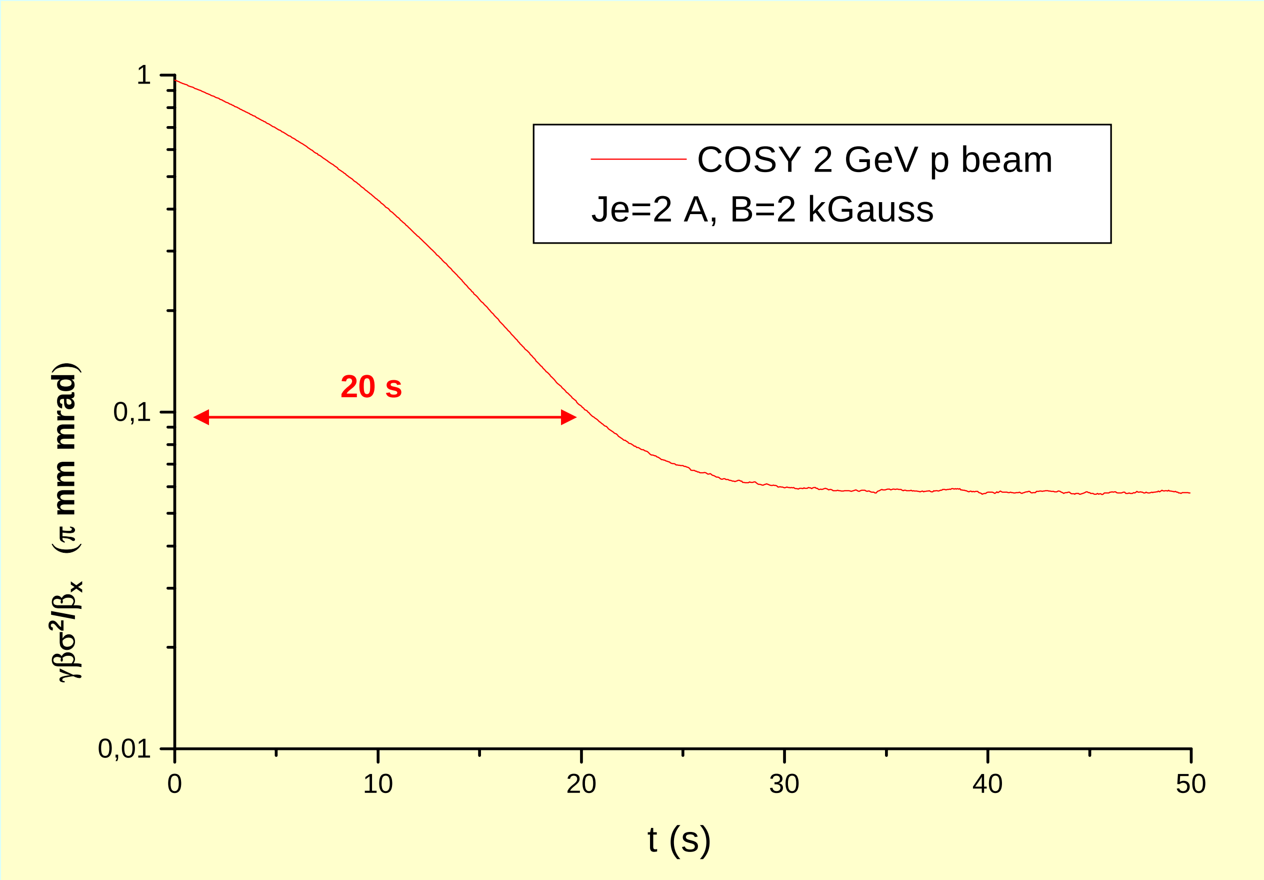
First column correspond to initial conditions and second after cooling close to equilibrium.

| | | |
|---|---|---|
| Beam emittance (normalized 1 σ-values, bothe planes) | $1\cdot10^{-4}$ cm rad | $0.1\cdot10^{-4}$ cm rad |
| Momentum spread (1 σ-values) | $\pm 5\cdot10^{-4}$ | $\pm 1\cdot10^{-4}$ |
| Magnetic field in the cooling section | 2 kG | 2 kG |
| Length of the cooling section | 3 m | 3 m |
| Electron current | 1 A | 1 A |
| Electron beam radius | 0.5 cm | 0.5 cm |

# Normalized Transverse Emittance versus Time

at cooling of 2 GeV proton beam (without target)

trubs.exe

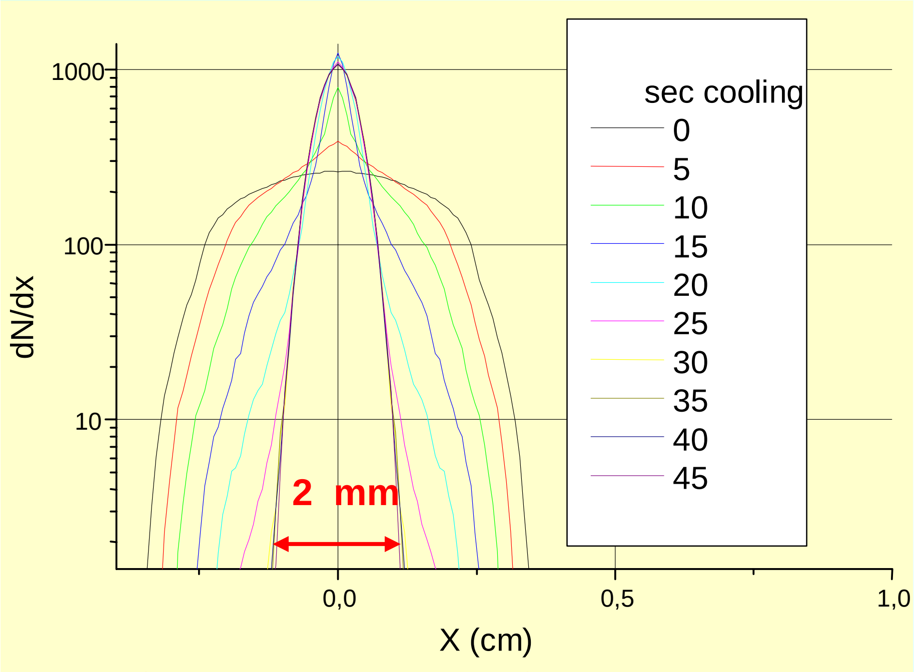


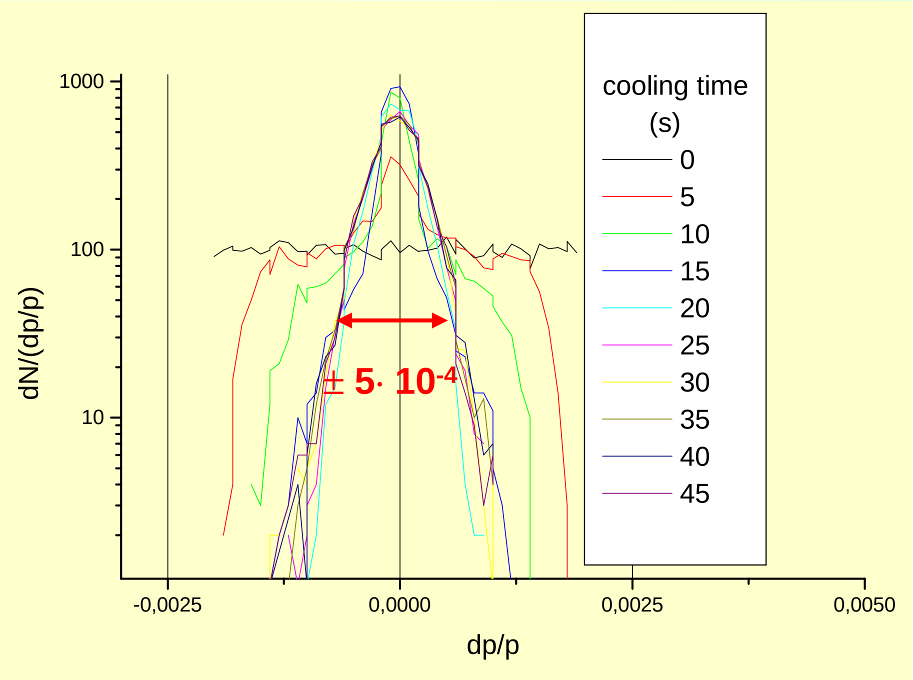

**Parameters:**

**$ß_c$ =13m, $r_e$ = 0.5 cm, $B_c$ = 2 kG, $\varepsilon_{ini}$ = 1 mm mrad, N = $2 \cdot 10^{10}$ (5 mA), IBS included**

# Beam Profile and Momentum Distribution

as function of cooling time (**without target**)



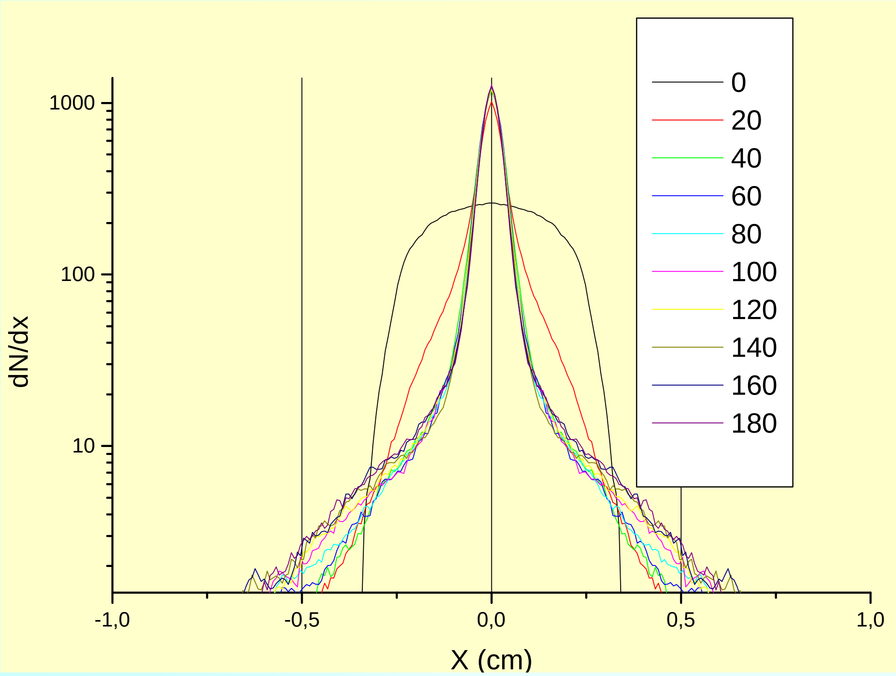



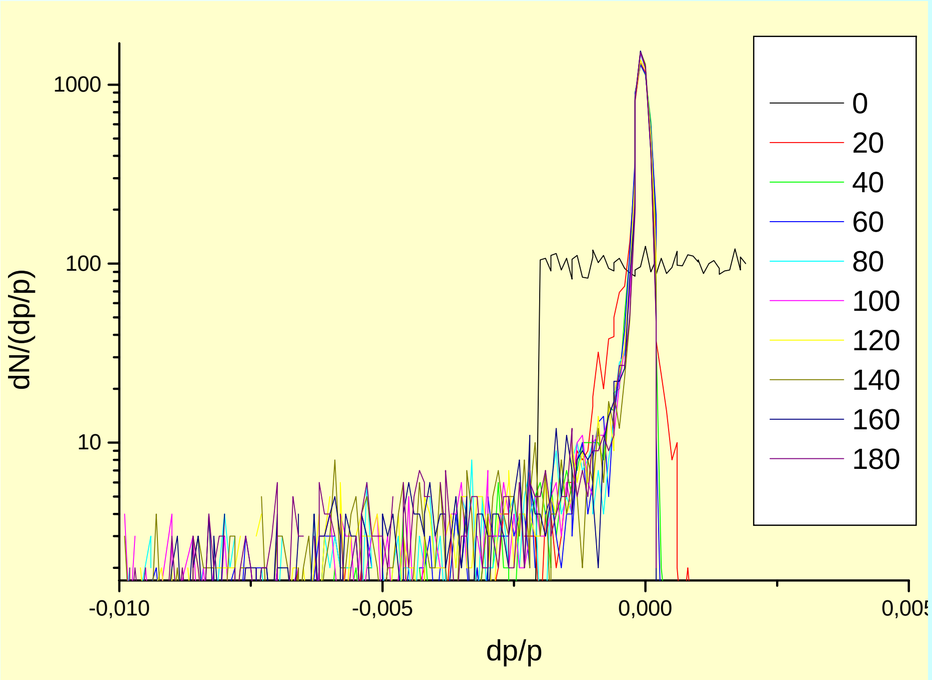

**Initial:7 mm**

**Initial: $\Delta p/p = \pm 2.5 \cdot 10^{-3}$**

# Beam Profile and Momentum Distribution

as function of cooling time (**with target, $4 \cdot 10^{15}$ cm$^{-2}$**)



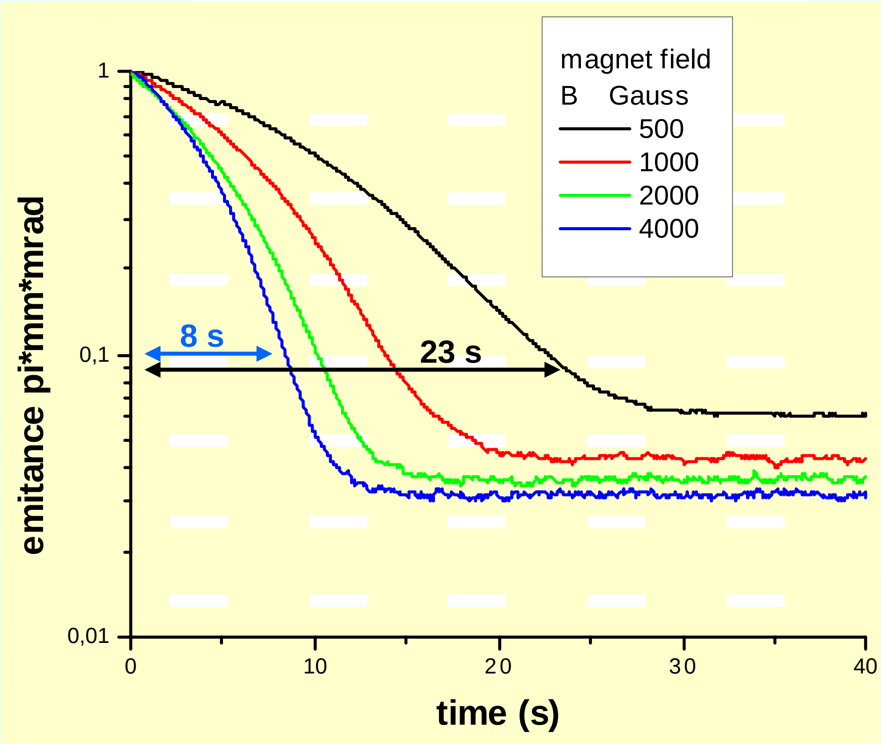

Increasing of the population in the tails.

# Magnetic Field in the Cooling Section (magnetized cooling)

Important and practical question:

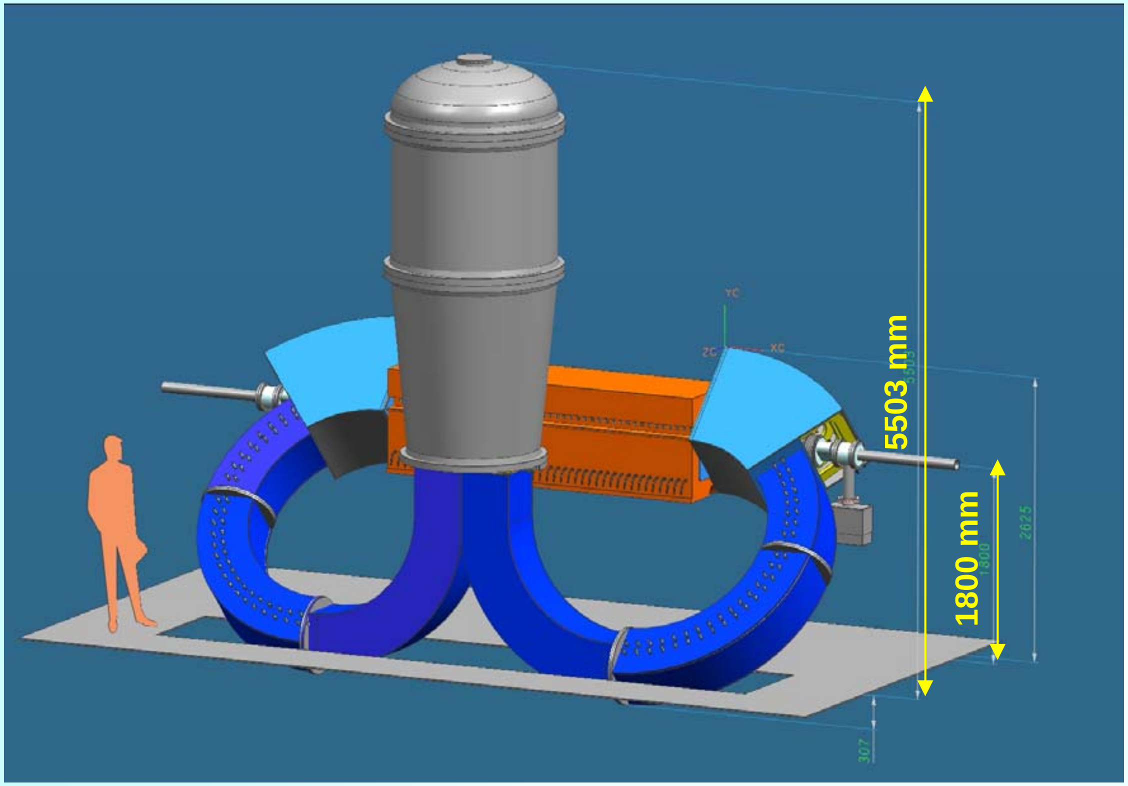
What is the optimal magnetic field value in the cooling section for 2 MeV cooler ?

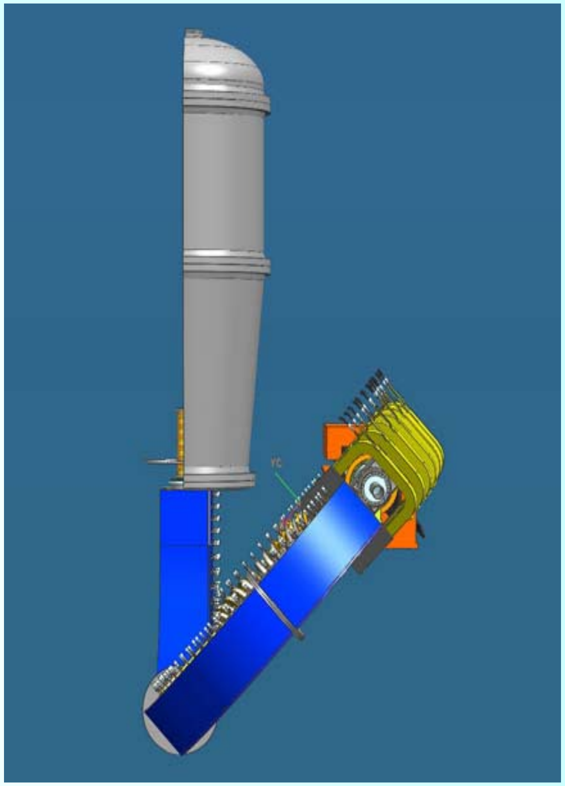
Stronger magnetic field improves the cooling. From practical point of view this figure supported choice of 2 kG magnetic field.




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

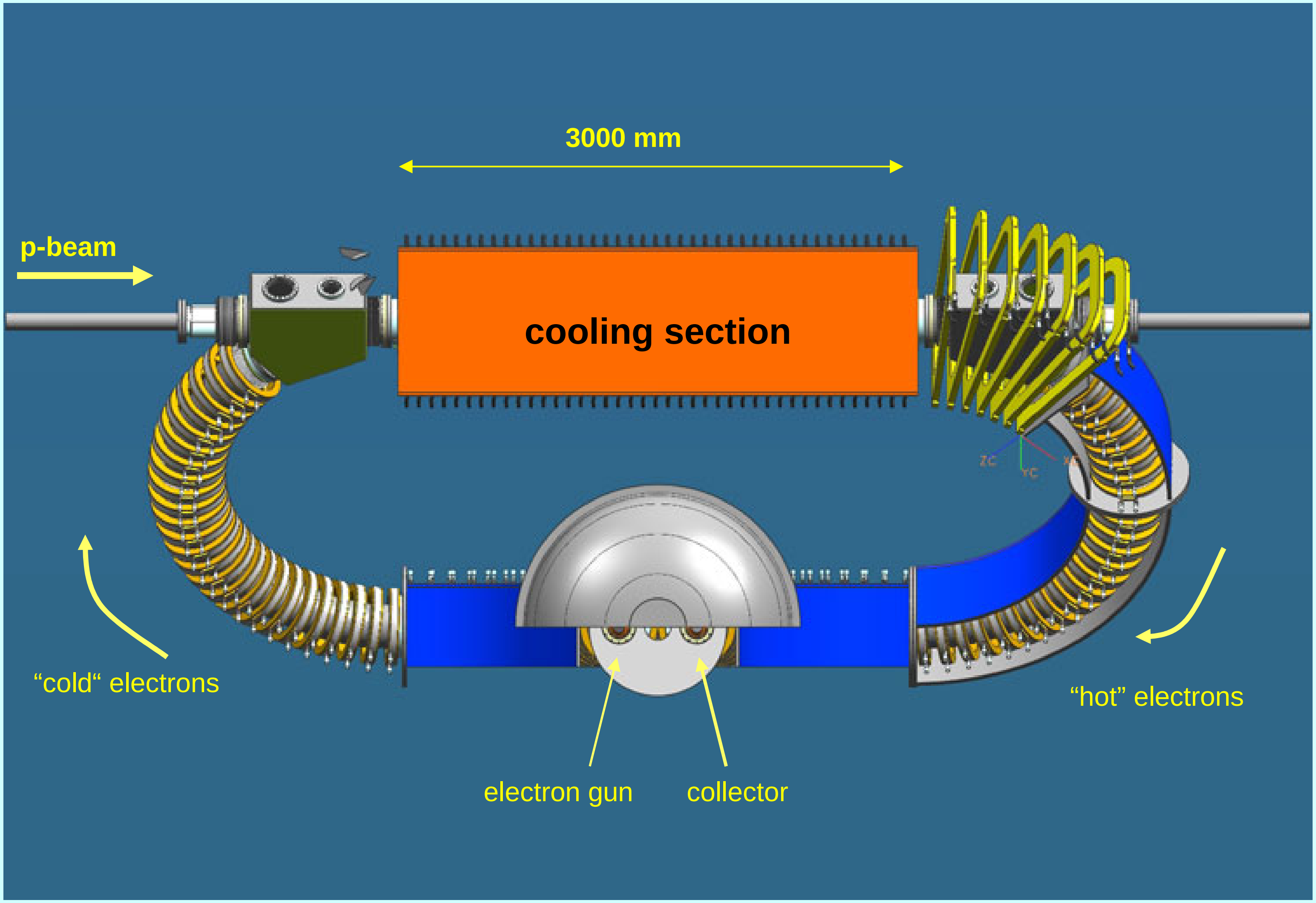
# Preliminary Technical Design - Layout



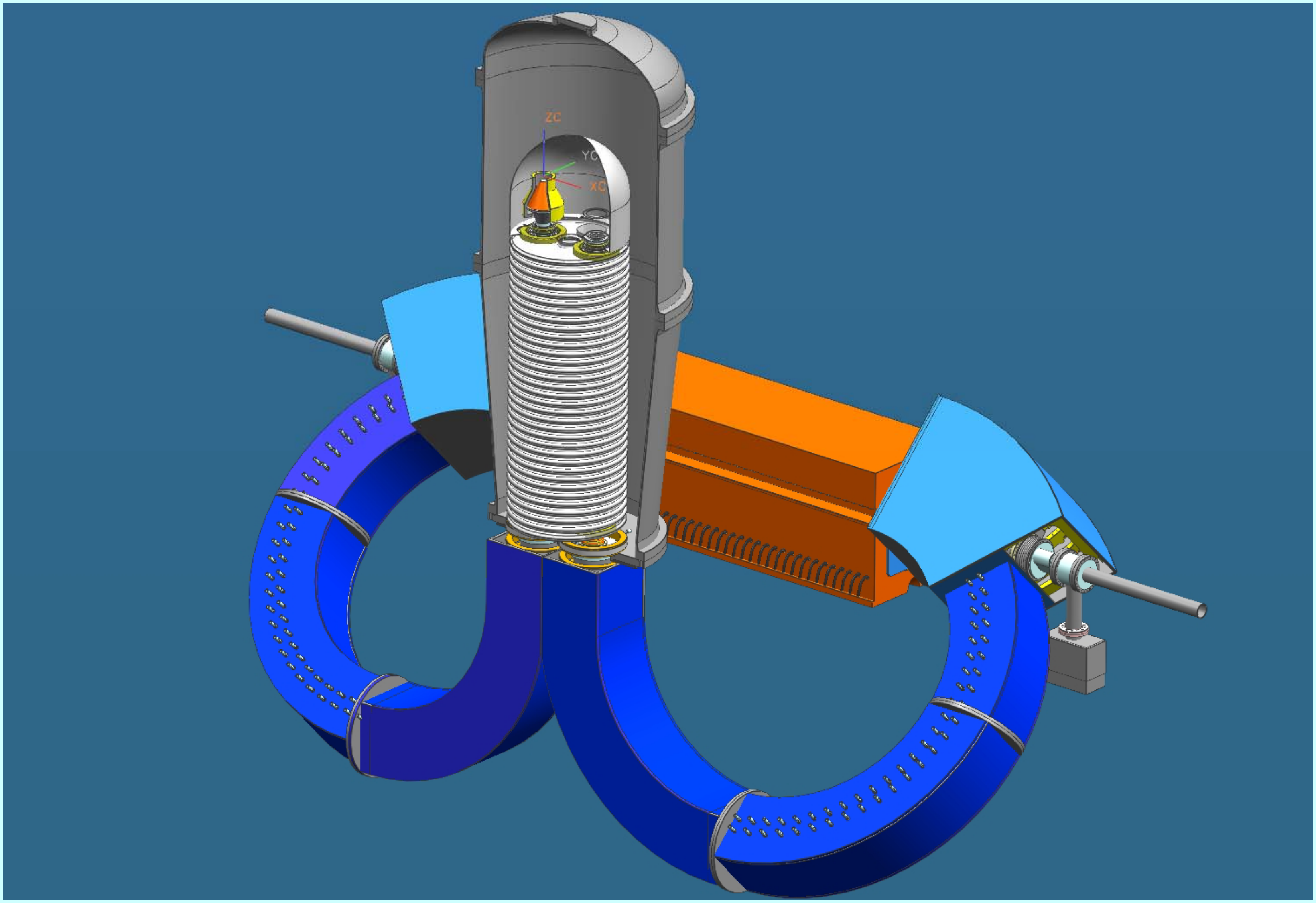



| | |
|---|---|
| Energy | 25 keV – 2 MeV |
| Electron current | 3 A |
| Radius of the electron beam | 0.5 – 1.5 cm |
| Magnetic field | 2000 G |
| Length of cooler section | 300 cm |

# Layout

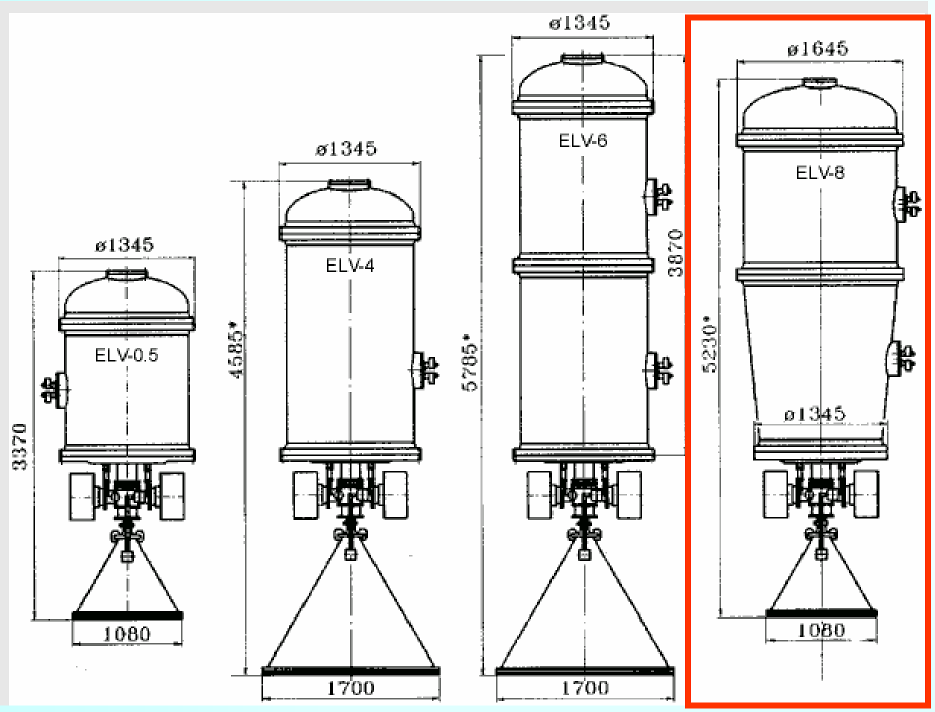

3000 mm
p-beam
cooling section
"cold" electrons
"hot" electrons
electron gun
collector

# Using Vessel from 2.5 MeV 100 kW Industrial Accelerator ELV-8



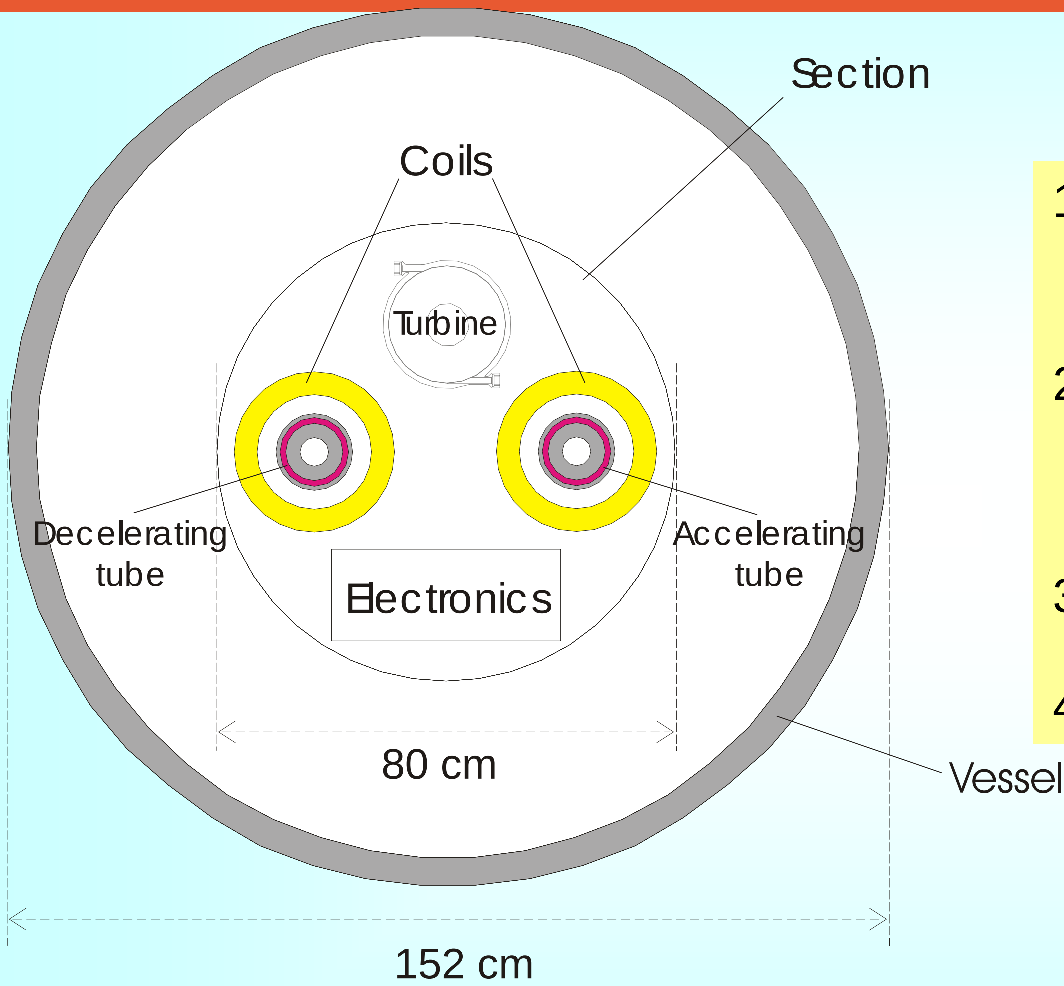
# Industrial Electron Accelerators of ELV Type, Novosibirsk

(basis for the tank)




| Model | Energy range, MeV | Beam power, kW | Max beam current, mA |
|---|---|---|---|
| ELV-mini | 0.2-0.4 | 20 | 50 |
| ELV-0.5 | 0.4-0.7 | 25 | 40 |
| ELV-1 | 0.4-0.8 | 25 | 40 |
| ELV-2 | 0.8-1.5 | 20 | 25 |
| ELV-3 | 0.5-0.7 | 50 | 100 |
| ELV-4 | 1.0-1.5 | 50 | 100 |
| ELV-6 | 0.8-1.2 | 100 | 100 |
| ELV-8 | 1.0-2.5 | 90 | 50 |
| ELV-6M | 0.75-0.95 | 160 | 200 |
| Torch | 0.5-0.8 | 500 | 800 |
| ELV-12 | 0.6-1.0 | 400 | 400 |

# HV Section

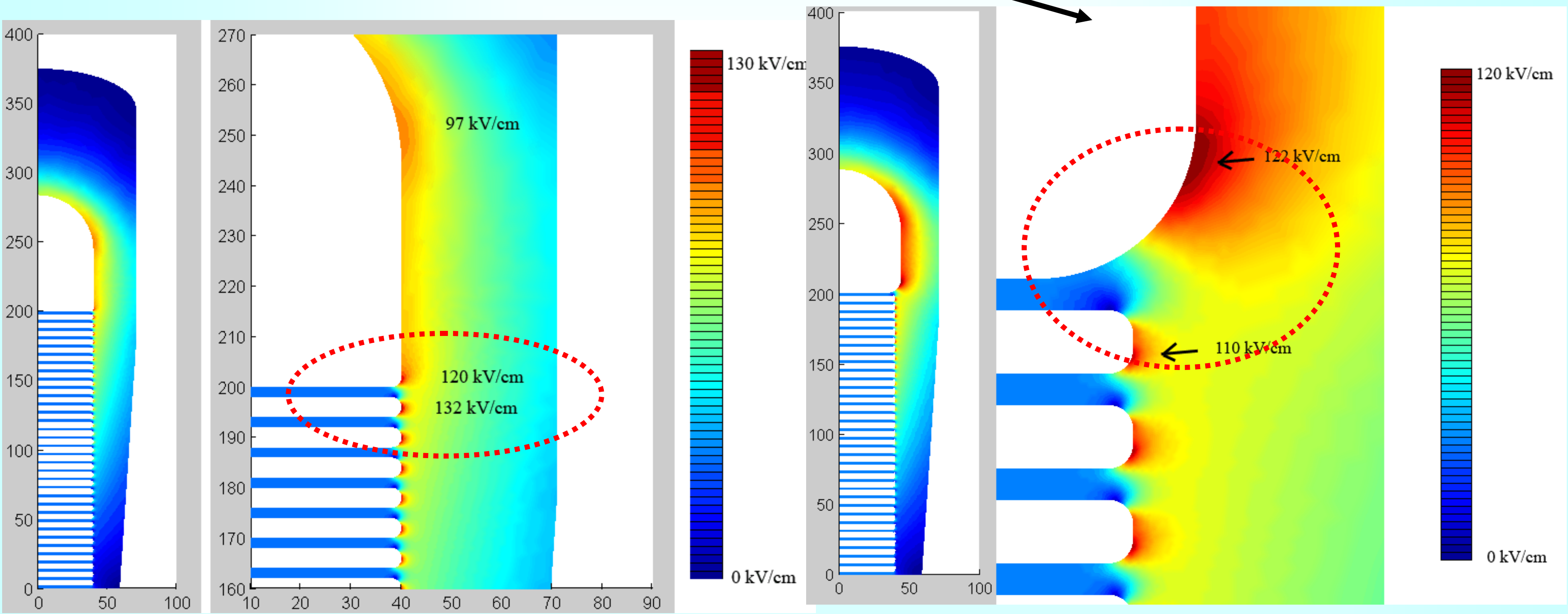



1. Coils for generation of magnetic field 500 Gauss, 300 W
2. High voltage power supply 100 W, max +30 and -30 kV
3. Pressed gas $SF_6$
4. Turbo electric generator 700 W

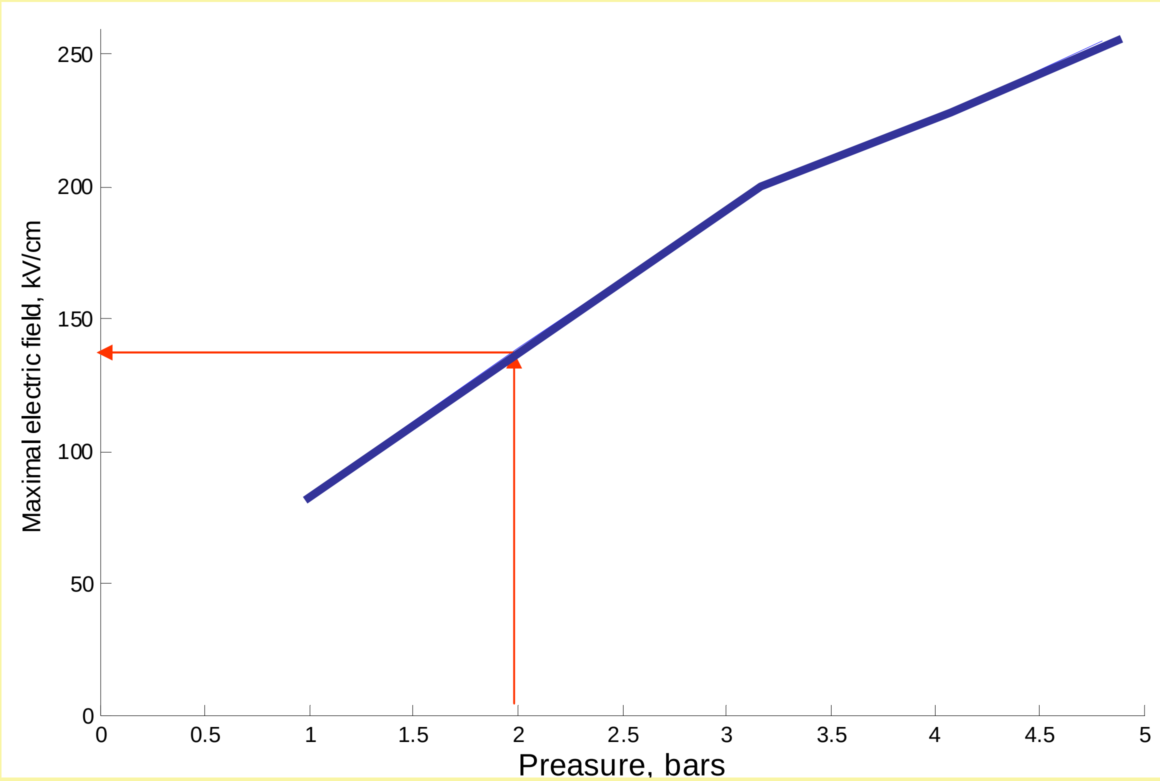
**Problem: power supply for magnetic coils in the high voltage column**

# Electrostatic Column Design (MATLAB)

**Increasing of HV head diameter and changing sections form.**



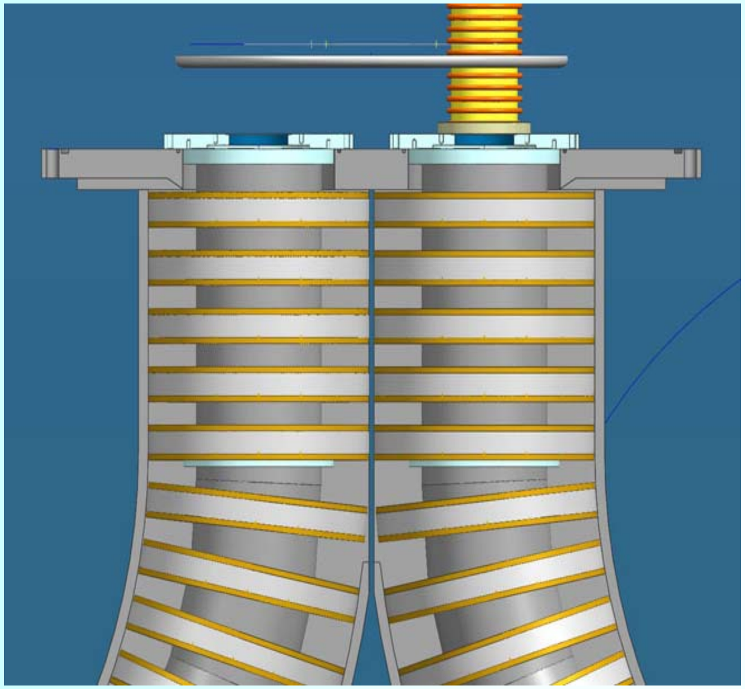
# Maximal Electric Field at Pressed $SF_6$ Gas versus Pressure

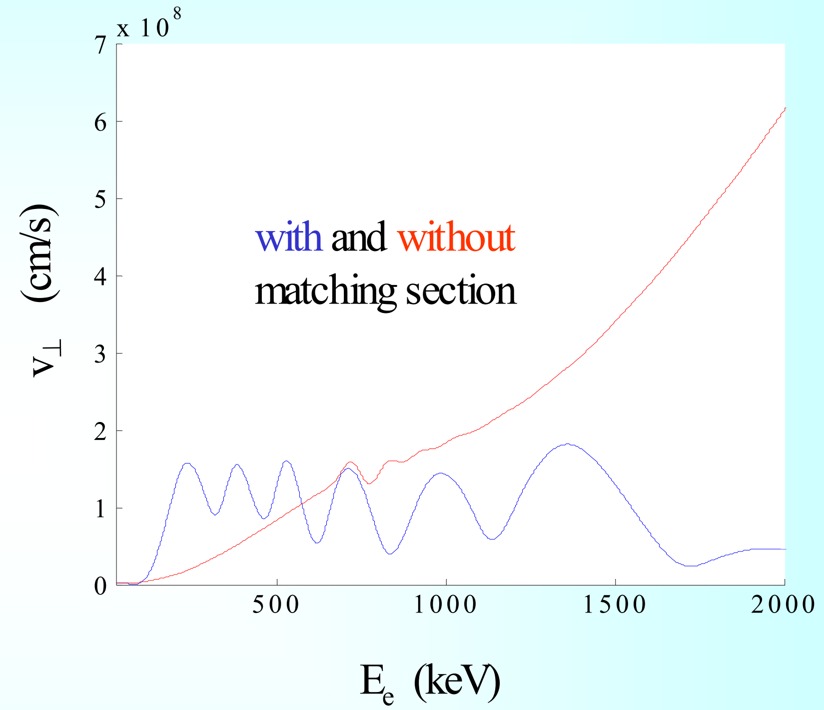




[1] I. M. Bortnik. Physical properties and electric strength of sulfur hexafluoride ($SF_6$). Energoatomizdat 1988.

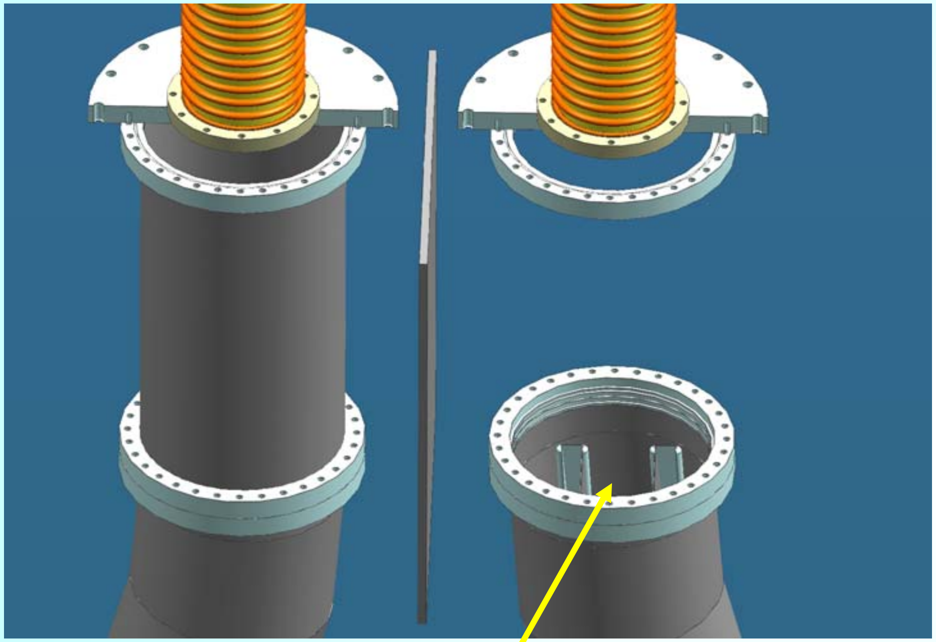
# Matching Section

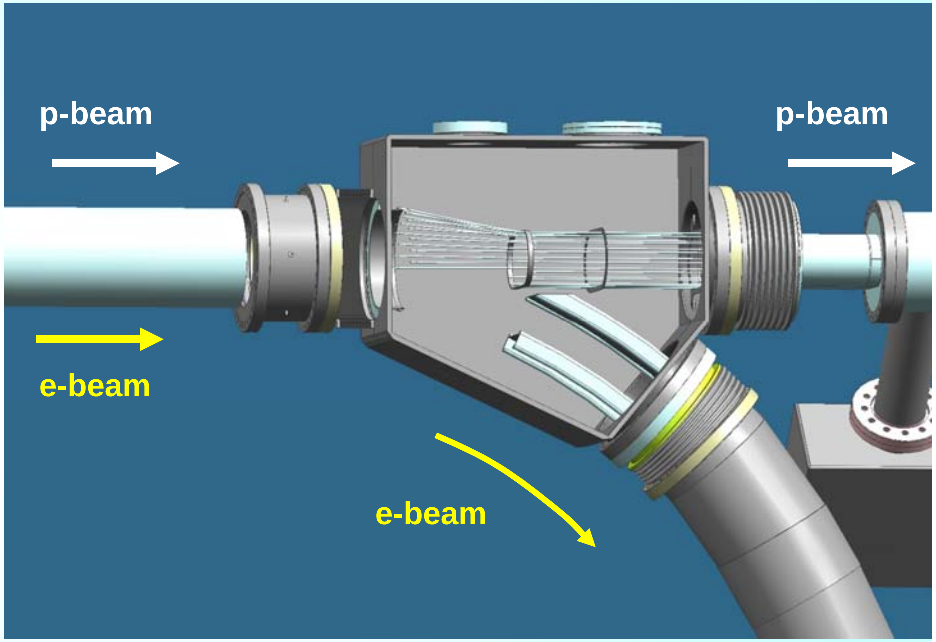





**Matching section.** After acceleration in the longitudinal magnetic field B = 500 G electrons come in the toroid with 2000 G. This transition excites transverse motion to a big electron temperature (unacceptable for electron cooling). Therefore a special matching section is necessary.

# Layout Electrostatic Plates in the Toroids



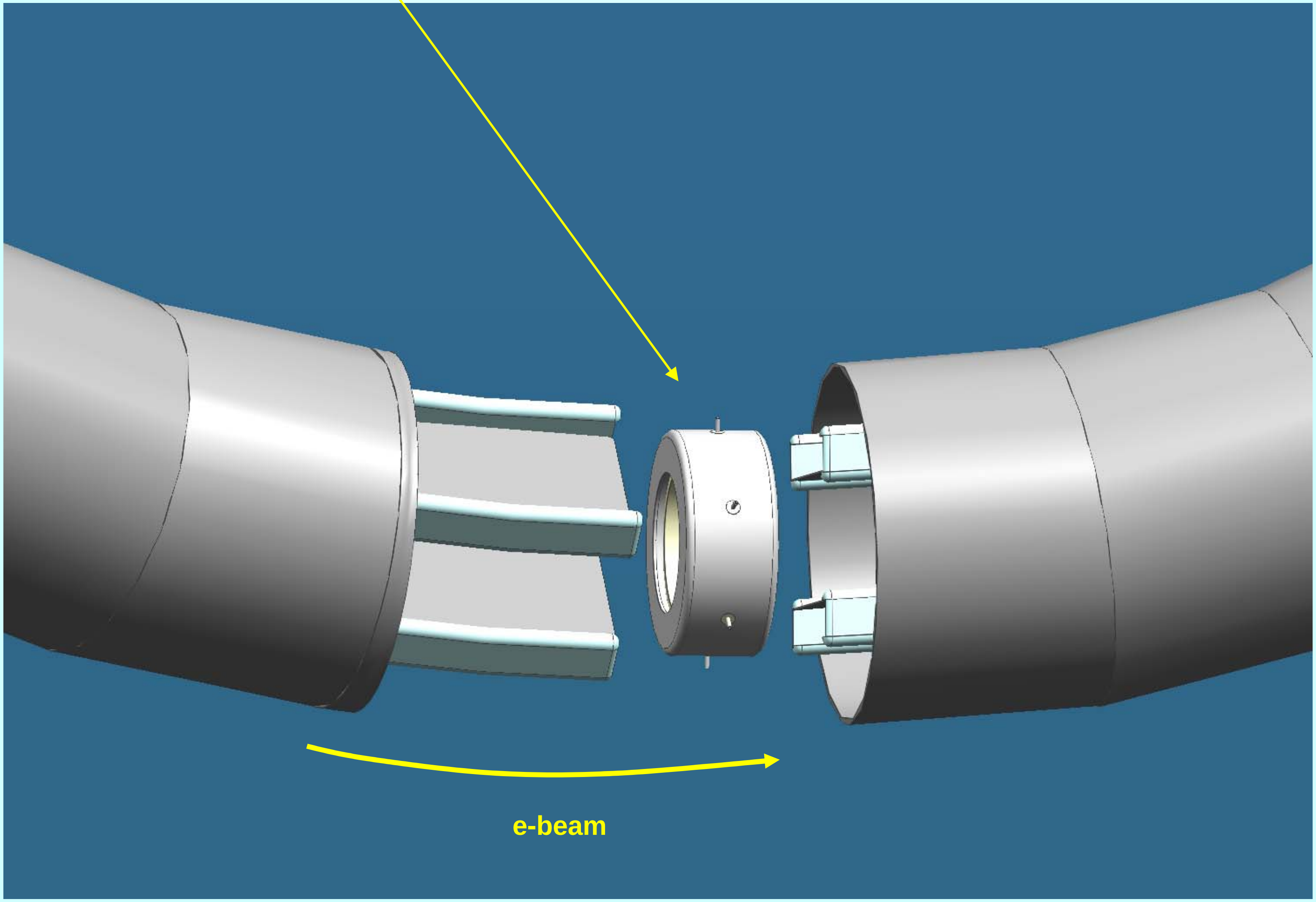



Electrostatic bending for better recuperation efficiency will be used in the toroids.
Gap between the plates: 4 cm, voltage ± 40 kV

Impedance matching

Poster V.V.Parkhomchuk, BINP

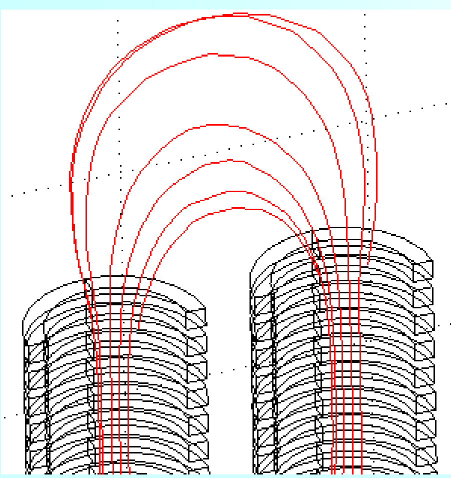
# Layout Beam Position Monitor



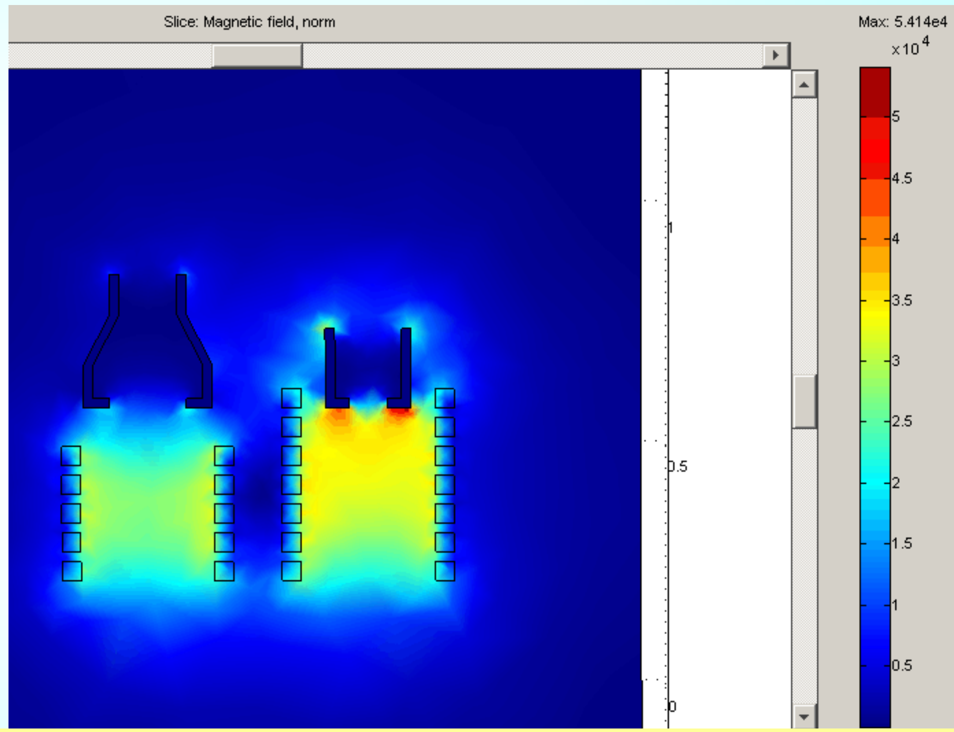
# Magnetic Field in the Collector and Gun Area

Electron beam trajectories (iron shielding)

Magnetic field lines



Magnet field near collector and gun, increasing field at the electron gun and decreasing at collector.




**Optimization of the electron beam radius at cooling section** by changing the magnet field at the electron gun.

**Additional coils at the electron gun.**

Control of the beam profile by changing the electrode potential.

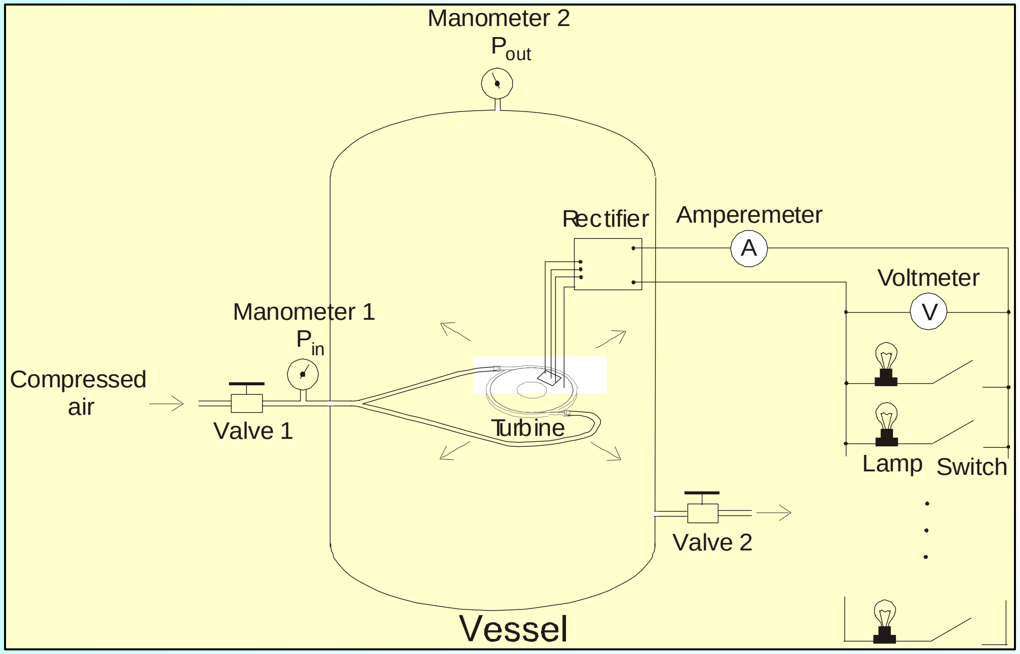
# Magnet System

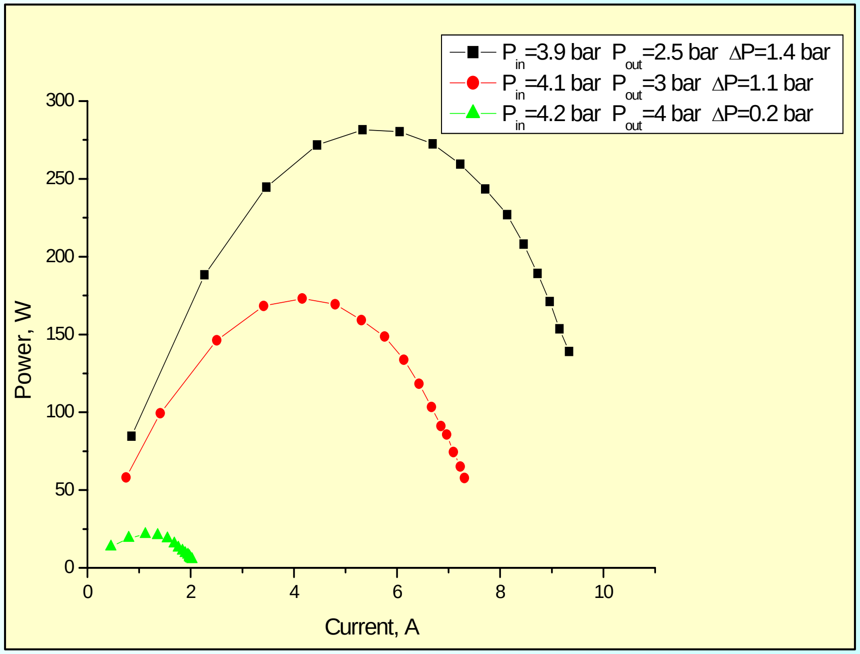
| | Radius<br>cm | Voltage<br>V | Current<br>A | Power<br>kW | Number of turns | Efficiency of cooper filling | Mass of cooper<br>kg |
|---|---|---|---|---|---|---|---|
| One coil of section on 500 G | 12 | 2.7 | 56.8 | 0.153 | 42 | 36 % | 4.5 |
| One coil of toroid and cooling section 2000 G | 18 | 5.1 | 318.3 | 1.614 | 30 | 47 % | 14.3 |
| One big coil of toroid on 2000 G | 50 | 12.8 | 318.3 | 4.086 | 30 | 47 % | 36.2 |
| 74 coils in HV column | | | | 11.3 | | | 334.3 |
| 120 coils in toroid and cooling section | | | | 193.7 | | | 1716 |
| 18 big coils in toroid | | | | 73.5 | | | 651.6 |

**Total power: 279 kW,   total mass of cooper: 2.7 t .**

# Gas Driven Turbine for individual power supplies of solenoid coils in the acceleration column, high voltage generation and cooling of the magnet field coils

## Layout of the Turbine Measurements

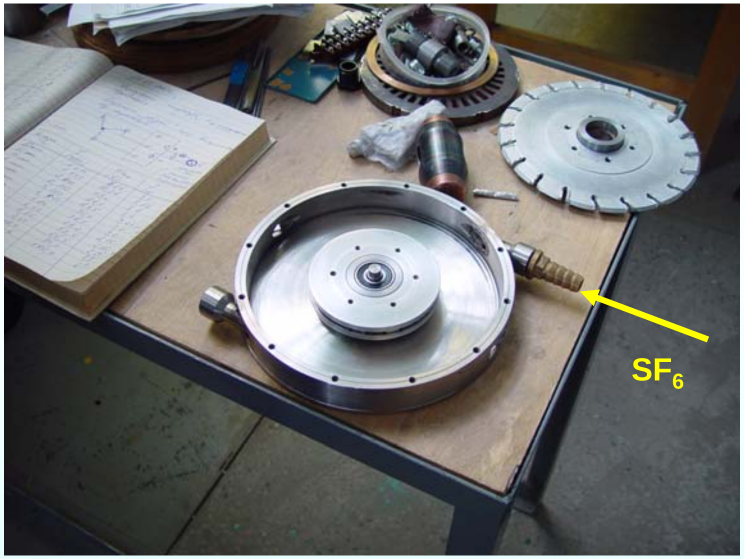


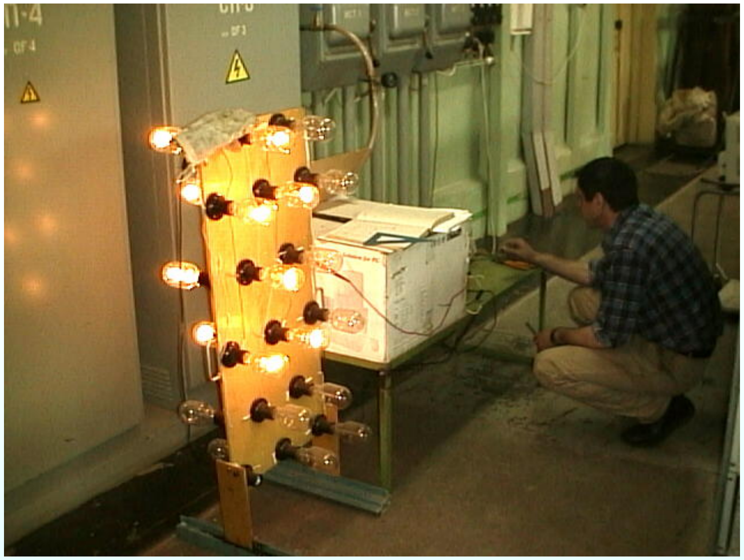



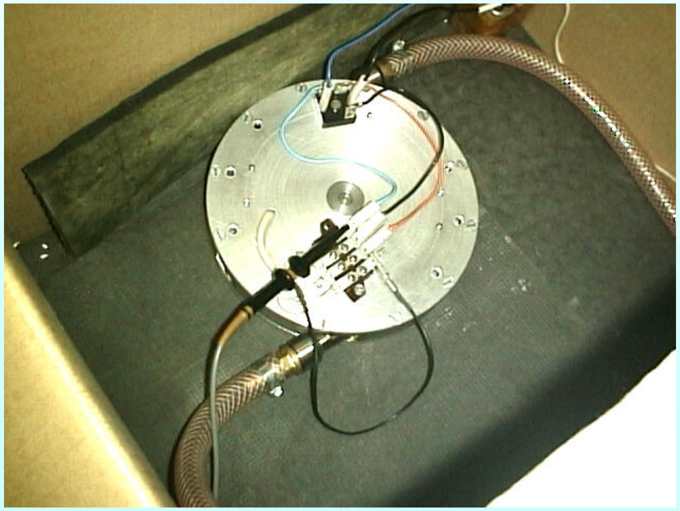

Turbine generates three-phase current. Rectifier transforms the three-phase current to direct current.
By adjustment valve 1 and valve 2 input pressure $P_{in}$, output pressure $P_{out}$ and air flow rate can be changed.

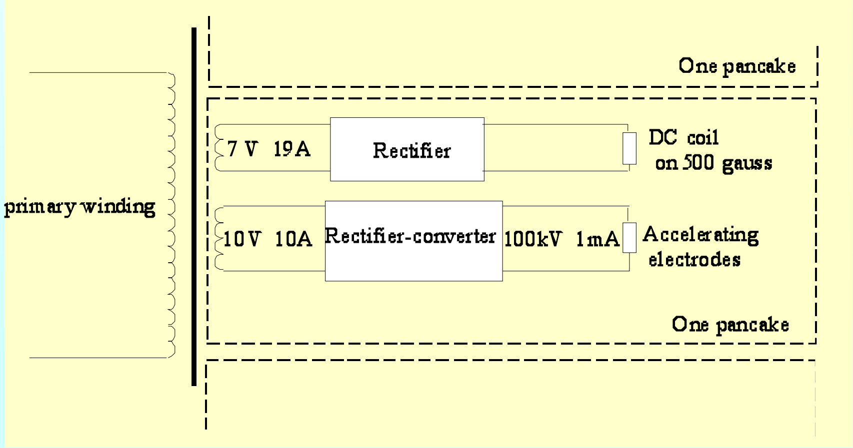
Output power of turbine depending on current with different $P_{in}$ and $P_{out}$.

# Gas Driven Turbine



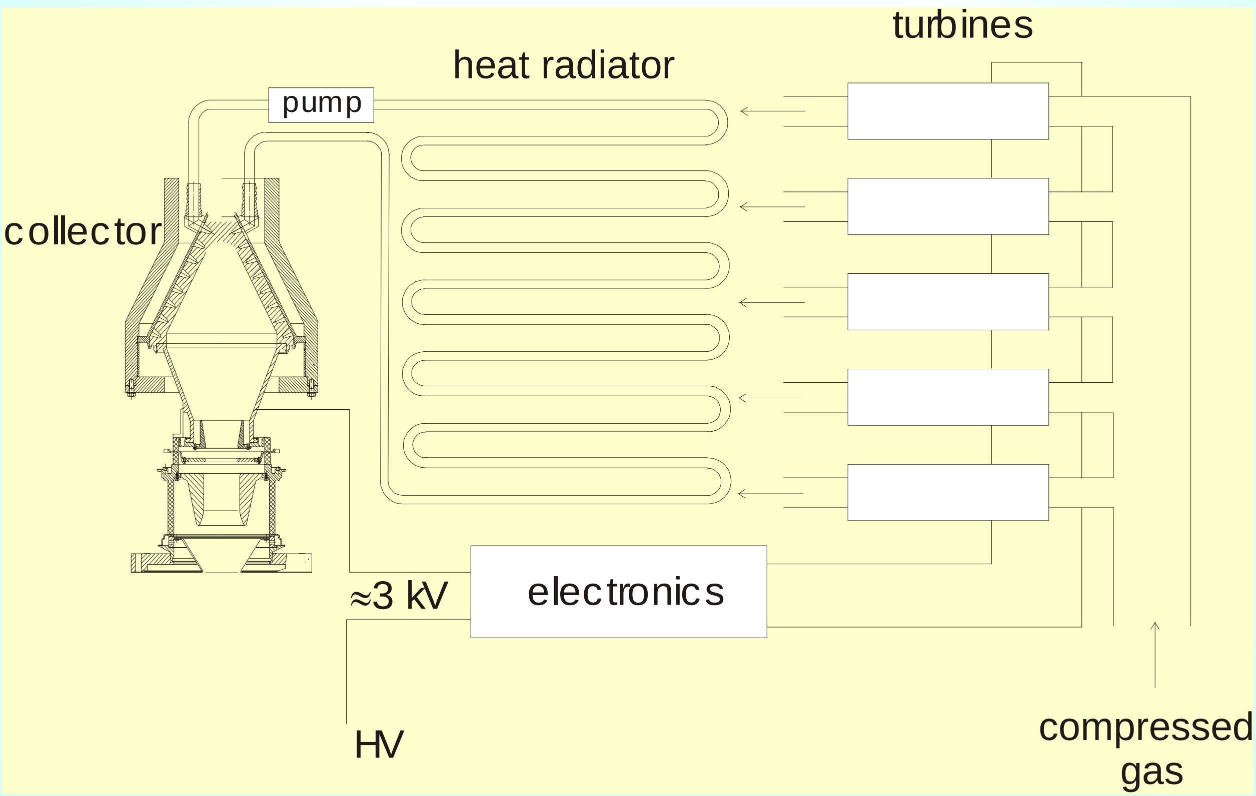







# Collector Cooling

Pressured $SF_6$ gas comes to turbines. Turbines generate electricity. Collector is cooled by water that circulates through collector and heat radiator. Radiator is cooled by gas that comes from turbines.



# Cost, Personnel and Time Estimates

## Mile stones:

| | |
|---|---|
| 2005/2006 | Design and construction |
| 2007 | Assembly and bench testing of components (e.g. gas turbines) |
| 2008 | Assembly completion and test operation in BINP |
| 2009/2010 | Installation and commissioning at COSY<br>Development of special operation modes for various internal targets |

## Personnel and financial requirements:

| | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|
| Personnel (FTE) | 3 | 4 | 4 | 4 | 3 |
| Consumables (50 K€/FTE) | 150 | 200 | 200 | 200 | 150 |
| R&D costs (K€) | 100 | 400 | 400 | 50 | 50 |
| Investments (K€) | 300 | 1500 | 1000 | 500 | 200 |

# Summary

- **Essential for the future COSY physics program**

  **Higher beam quality**

  **Higher luminosity**

- **Step towards HESR Cooler**

  **Technologically (0.3 MV → 2 MV → 8 MV)**

  **Physically (model verification)**

  **Interplay of electron and stochastic cooling**

# Problems ⇒ Working Session

**Importance of an intermediate energy electron cooler (2 MeV) between existing and 8 MeV HESR-cooler !?**

**Importance of interaction studies between high density targets (WASA at COSY, pellet target) and electron cooling !?**

Relevance of **magnetized cooling** for HESR-GSI-FAIR project ?
Technical differences between **magnetized and non-magnetized** electron cooling.
Could we **study a solution of magnetized cooling** at existing electron coolers?
Importance of **combination** of high energy electron cooling and stochastic cooling against target heating.
How important is to have **hands -on direct experience** before committing oneself to irreversible construction ?
The role of **intra beam scattering** in the case of magnetized cooling?
Is the **experience gained with the Fermilab cooler** is already sufficient to plan for the 8 MeV cooler of HESR?
Is it necessary to investigate **scaling laws** in the case of high energy electron cooling (cooling time dependence of ß and $\gamma$, benchmarking etc.) ?

# Working Session

**Thursday, September 22**

**15:50 Working group -- COSY 2MeV cooler**


**COOL 05**

# HV Column and Protection of Sections