On the Way to a Relativistic Electron Cooler

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Outline

- Status, Projects , Motivation
- Special Features
- Engineering Problems
- On the Way to 4-8 MeV Electron Cooler for HESR

Electron Cooler - Status and Projects

- **In operation state of the art**

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

- **Operated** September 2005 – September 2011

  4.3 MV at FNAL (DC, non-magnetized)

  Longitudinal cooling time > 1h

- **Commissioned** at FZ Jülich 2013

  2 MV for COSY (DC, magnetized)

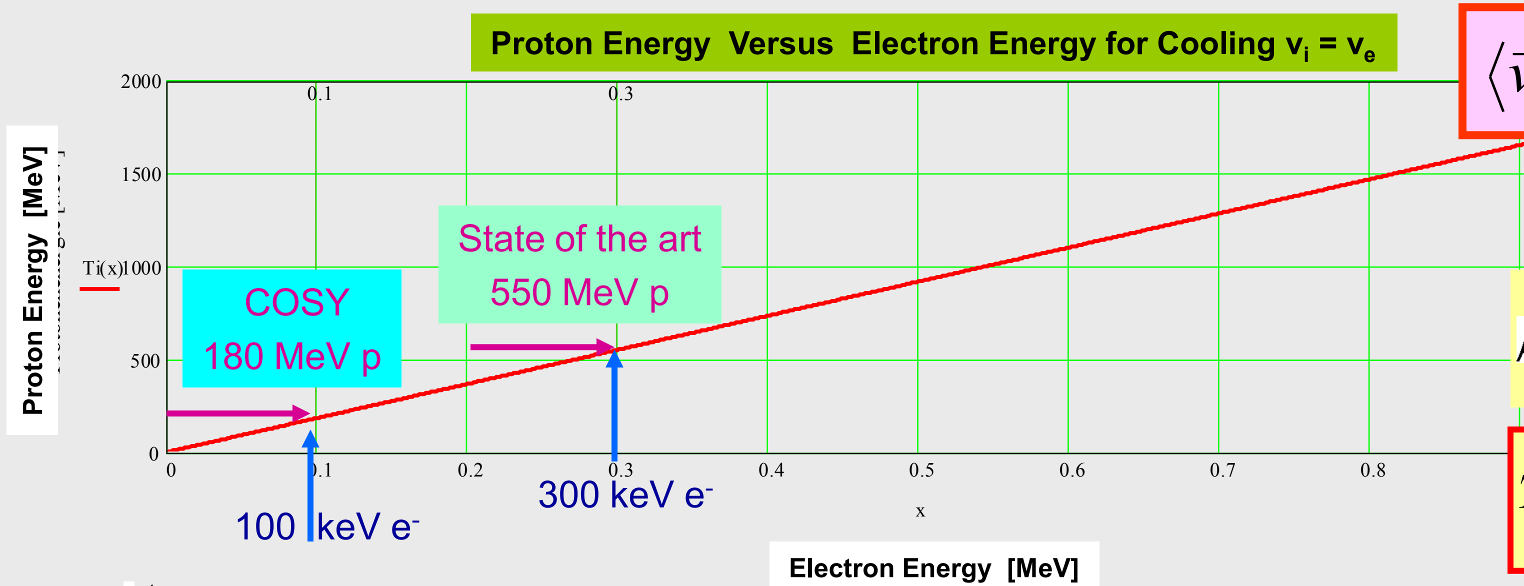
- **Projects**

  2.5 MV for NICA collider (DC, magnetized)

  4-8 MV (?) for HESR, ENC (DC, magnetized)

  (Coherent Electron Cooling – proof of principle?)

Relativistic Electron Cooling

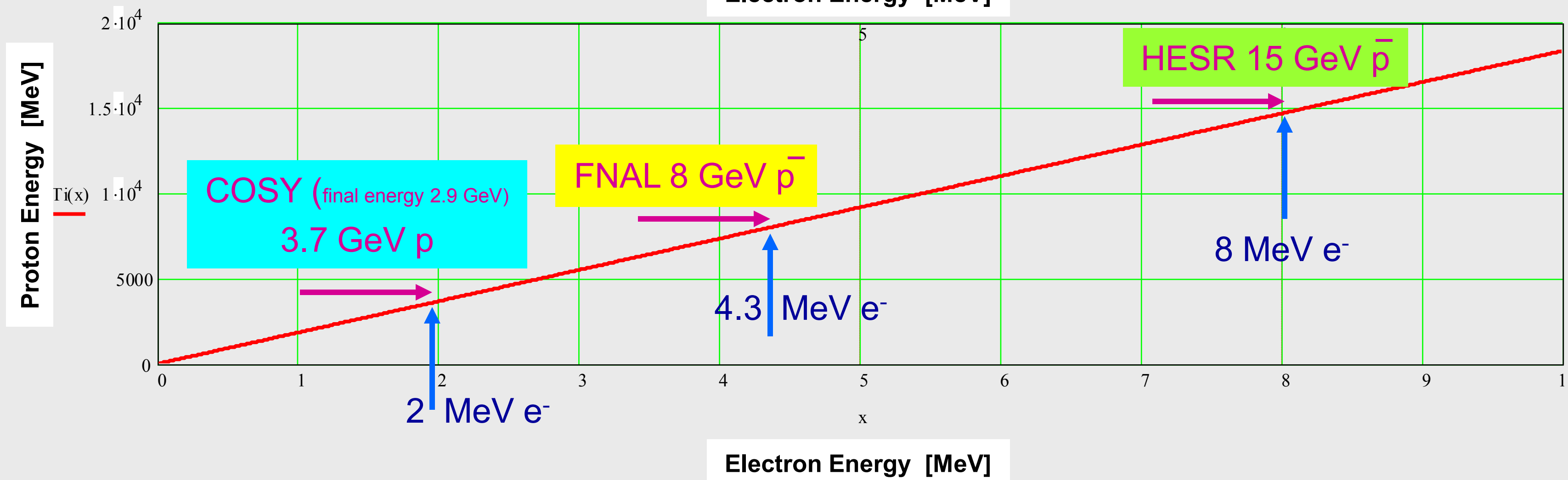


$\langle \vec{v}_i \rangle = \vec{\beta}\ c = \ {}_{0e}$

$\beta = \frac{\ }{c} = \beta = \beta$

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

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



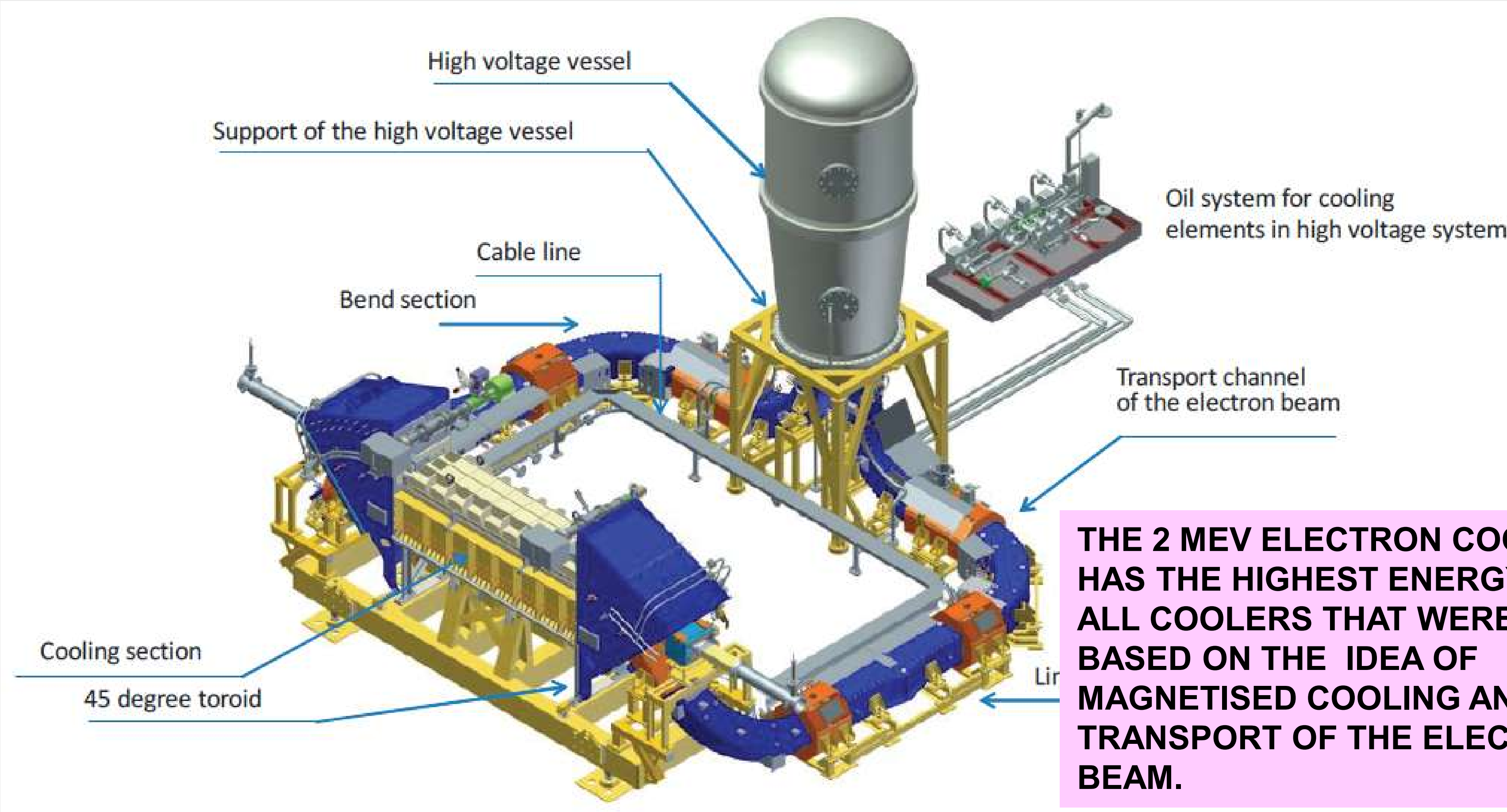
Magnetised or not Magnetised Electron Cooling ?

The 4.3 MeV electron cooler at the RECYCLER ring (FNAL) achieves cooling time of about 1 h.
small longitudinal magnetic field in the cooling section (~100 G
non-magnetized optics

The new coolers for COSY and HESR should provide a few orders of magnitude more powerful longitudinal and transverse cooling **that requires new technical solutions.**

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

Design of the 2MeV Electron Cooler



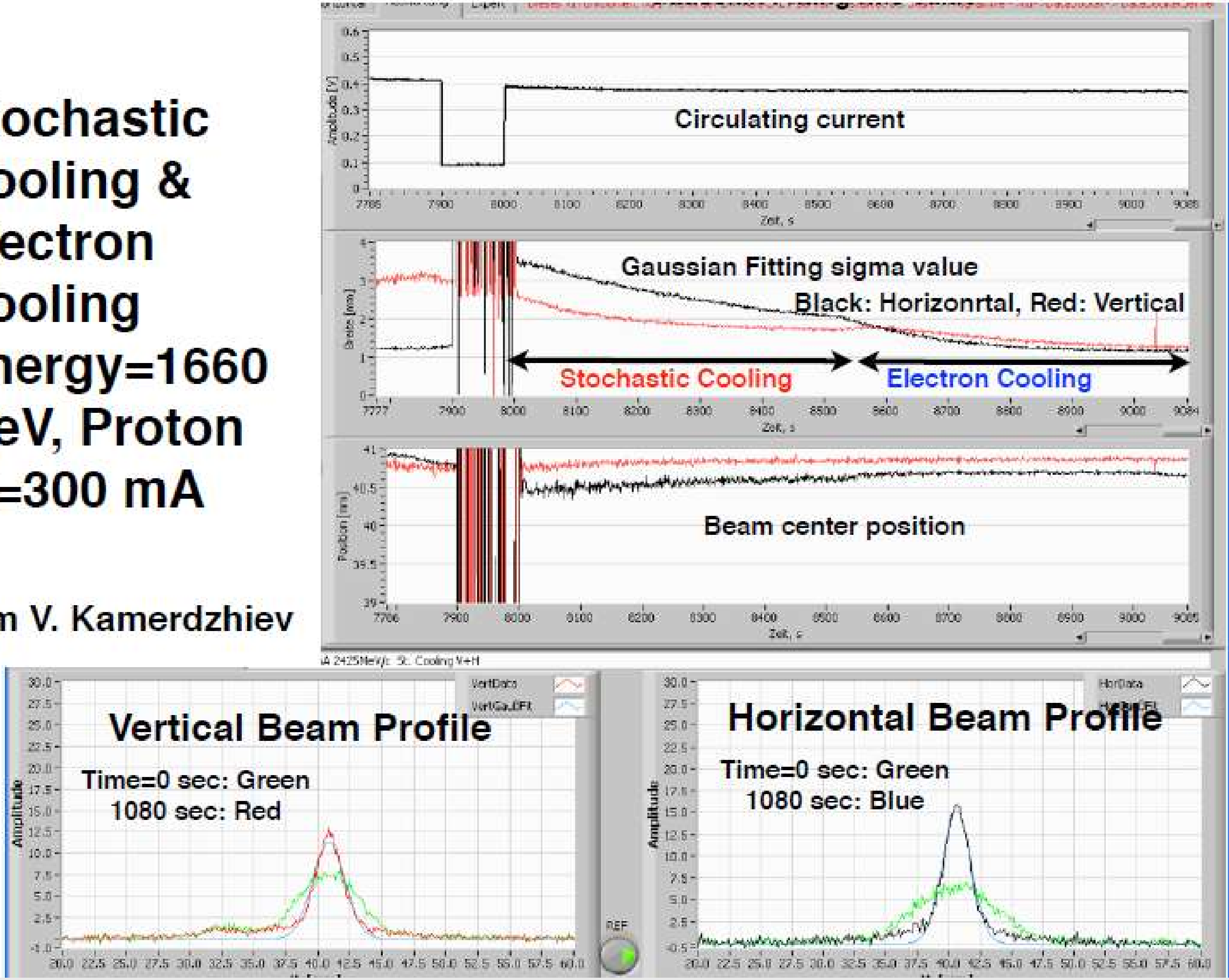
THE 2 MEV ELECTRON COOLER HAS THE HIGHEST ENERGY OF ALL COOLERS THAT WERE MADE BASED ON THE IDEA OF MAGNETISED COOLING AND TRANSPORT OF THE ELECTRON BEAM.

- built at BINP, joint commissioning by BINP and COSY teams at COSY in 2012-2013
- to be used at HESR (at injection energy)


2 MeV electron cooler in COSY commissioned in 2013 at Jülich
17

Stochastic Cooling & Electron Cooling Energy=1660 MeV, Proton Ie=300 mA

From V. Kamerdzhiev



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

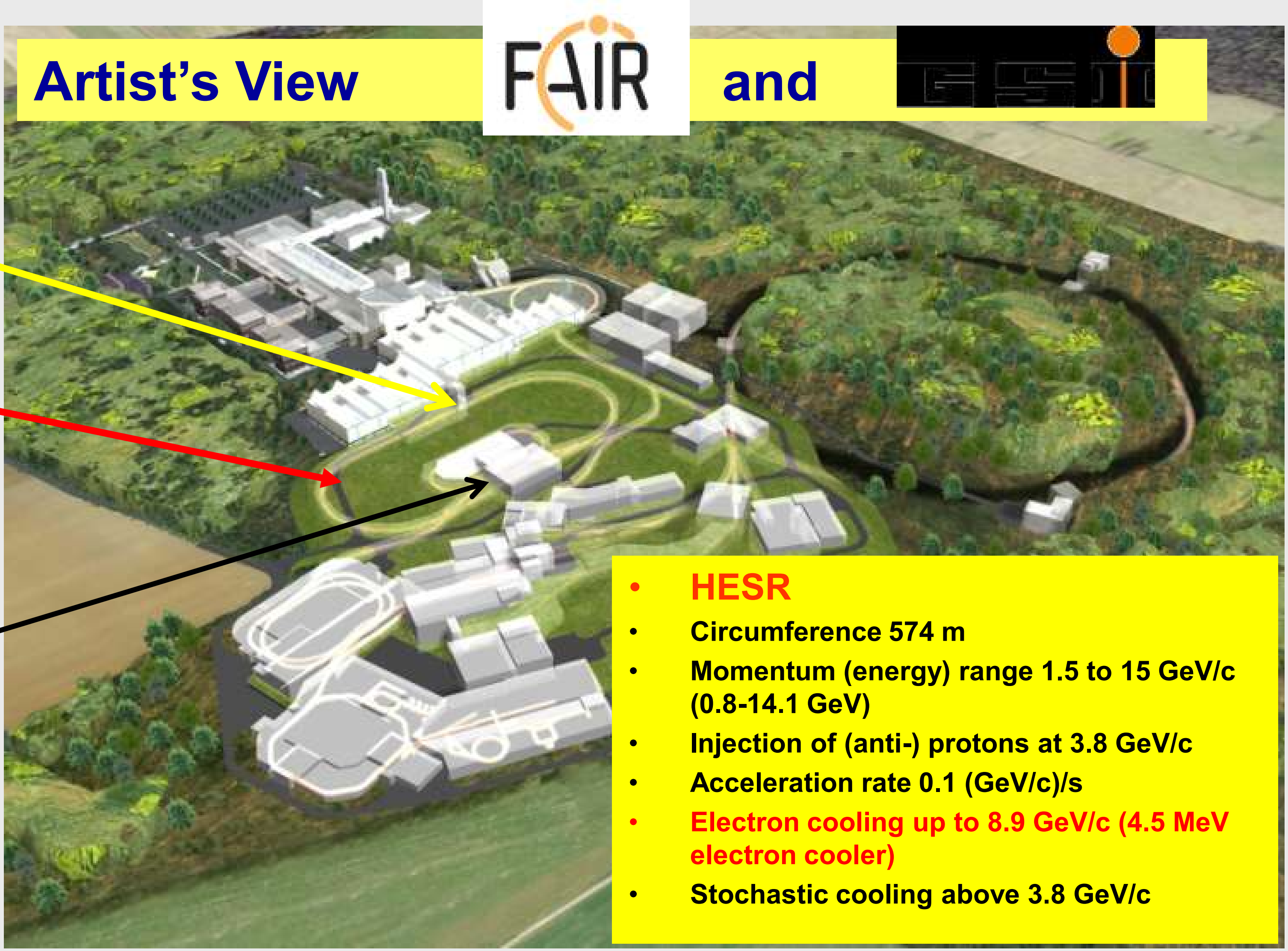
- **Challenge: Development of the high energy electron cooler for HESR/FAIR (4.5 MeV - 8 MeV)**

4 – 8 (?) MeV Electron Cooler for HESR, FAIR Darmstadt

8 MeV Electron Cooler

High Energy Storage Ring, HESR

PANDA experiment



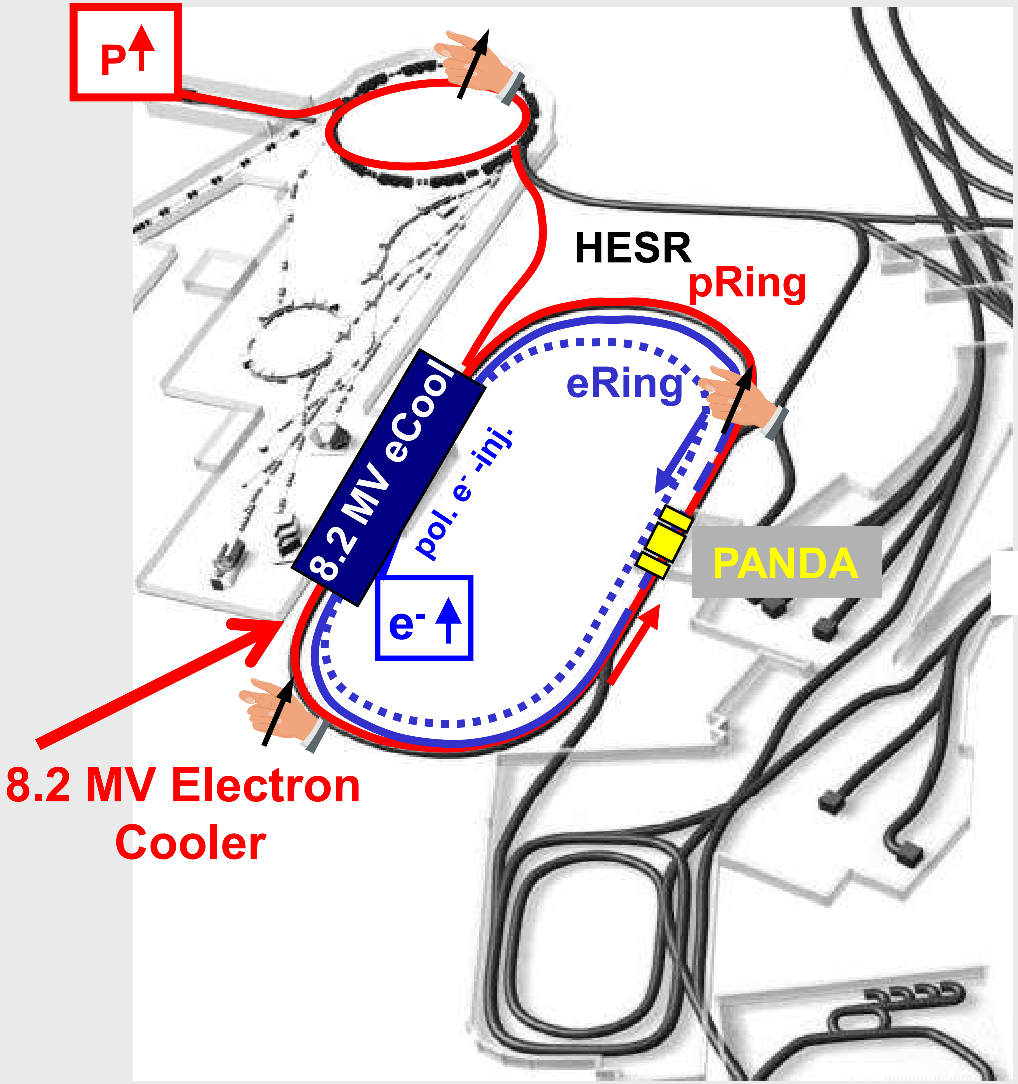
- **HESR**
- **Circumference 574 m**
- **Momentum (energy) range 1.5 to 15 GeV/c (0.8-14.1 GeV)**
- **Injection of (anti-) protons at 3.8 GeV/c**
- **Acceleration rate 0.1 (GeV/c)/s**
- **Electron cooling up to 8.9 GeV/c (4.5 MeV electron cooler)**
- **Stochastic cooling above 3.8 GeV/c**

Modes of Operation with PANDA

JÜLICH
FORSCHUNGSZENTRUM

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

Vision:
Electron Nucleon Collider @ FAIR



Add e⁻-beam@HESR

3 GeV, 2A pol. Electron beam
15GeV, 0.4 A pol. Proton beam
$s^{1/2}$=14GeV (center of mass energy)

HIM
Helmholtz-Institut Mainz

Ion ring and Detector funded and under construction within the FAIR complex:

Extensions & solutions needed:

Protons:
- Polarized proton source
- tune jump Quads in SIS18
- direct SIS-18/HESR beamline
- cooler solenoid+helical dipoles as SNAKE
- electron cooling at maximum energy

Electrons:
- polarized electron source
- full energy injector (synchrotron or pulsed linac)
- electron storage ring (in HESR tunnel?)
- spin lifetime under synchrotron radiation
- increased complexity: e+/e- beam dynamics together with spin stabilization.

Both:

IR + beam separation + polarization

Luminosity: 2-6·10^{32} [cm^{-2} s^{-1}]

Special Features of Relativistic Electron Cooling

Technical Challenge:

High Voltage (E_e >0.5 MeV, I_e <3 A, confinement in a 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

cooling time increases with $\propto$ β

experiment ???

Engineering Problems of Relativistic Electron Coolers

High voltage generators (> 0.5 MV)

High voltage performance

Limiting performance of accelerator tubes

Power transmission to accelerator ˝head˝

Power transmission to magnetic coils (at accel/decel tubes)

Electron current and HV stability (1-3 A, 10^{-5})

Electron beam formation, transportation and recovering

Magnetic field measurement in the cooling section (straightness < 10^{-5})

Electron beam diagnostics

High Voltage Generators

Cockroft-Walton accelerator – up to 1 MV (practically)

˝Electron- Beam Ventil˝ (ELV, BINP Novosibirsk)-
a sophisticated version of insulating core transformer ≤ 2 MV (**COSY 2MV**)

Dynamitron ~ 4 MV max

Van de Graaff accelerators

Pelletron (Fermilab 4.3 MV)

˝Record holder˝ of DC accelerators: Vivitron (Univ. Louis Pasteur, Strasbourg)
⟹ 35 MV project, 25 MV operation

Power Transmission to Magnetic Coils (at accel/decel tubes)

Rotating shafts (Fermilab, Pelletron)

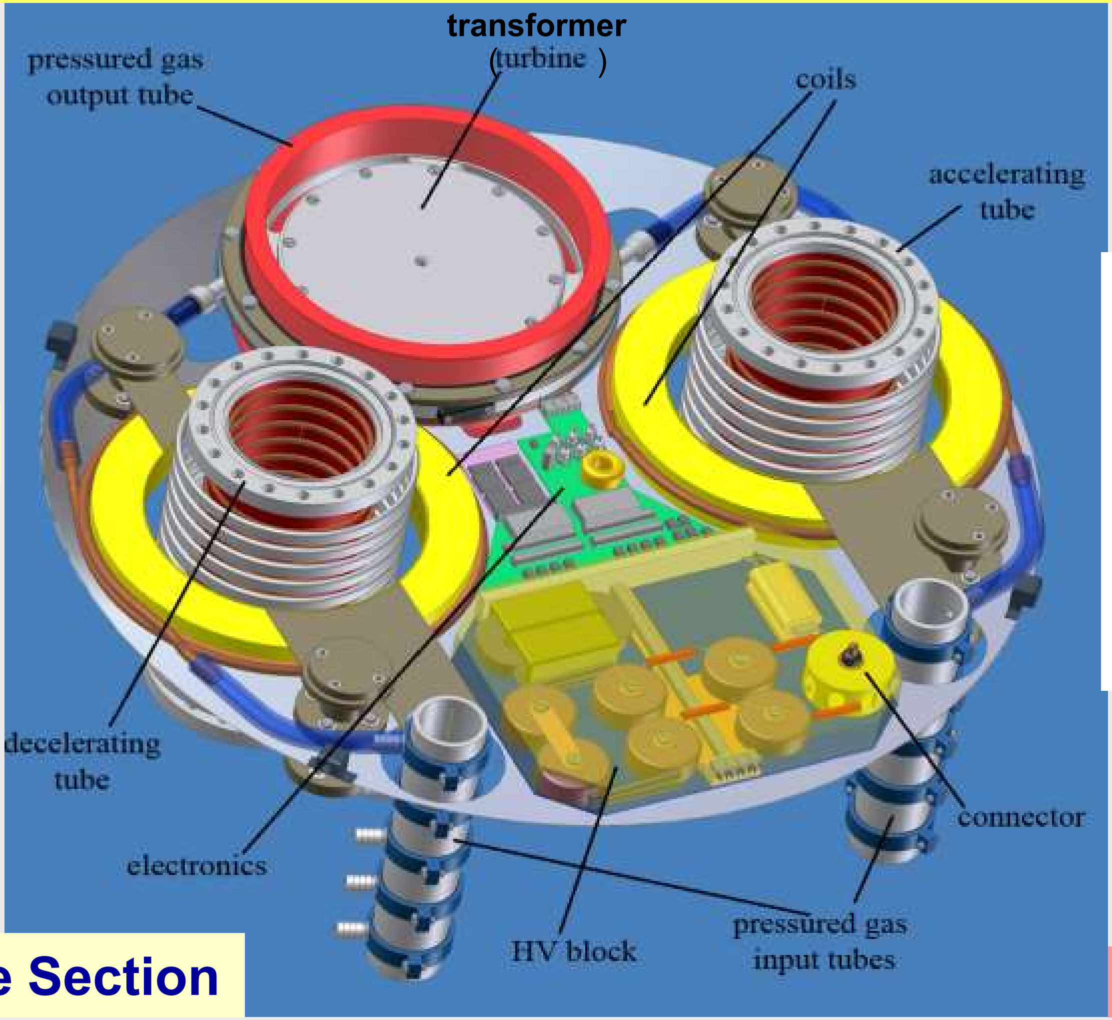
Cascade transformer (solution at 2 MeV COSY)

New:
Gas turbine (idea of BINP)

On the Way to 4-8 MeV Electron Cooler for HESR

Gas Driven Turbine for individual power supplies of **solenoid coils** in **the** acceleration/ deceleration column **and high voltage** generation

Modular concept

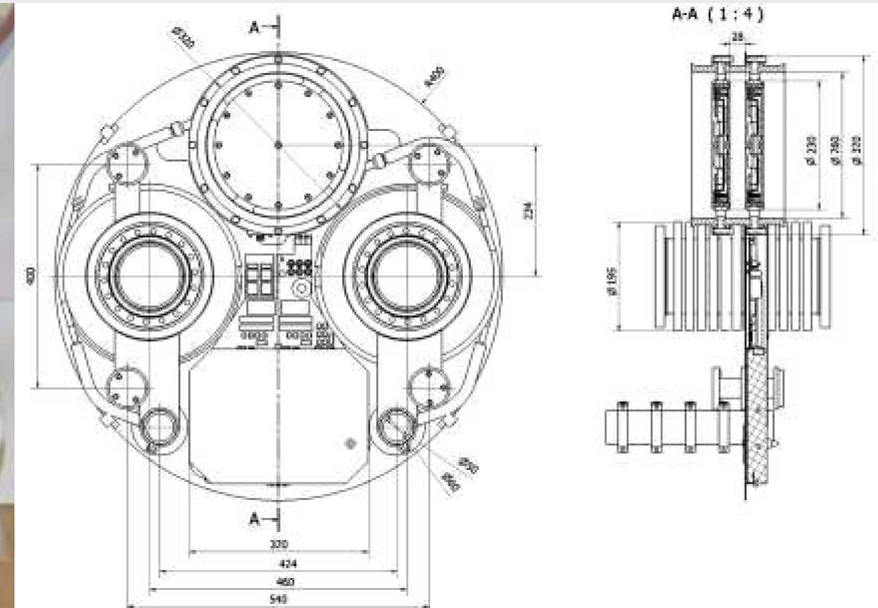


Section thickness	4 cm
Distance between two sections	2 cm
Section period	4+2=6 cm
Electric field between two sections	60 kV / 2 cm = 30 kV/cm
Electric field along tube	60 kV / 6 cm = 10 kV/cm

High Voltage Section

BINP design

Gas Turbine and Generator Coils Ø 300 mm, **600 W**,100 Hz



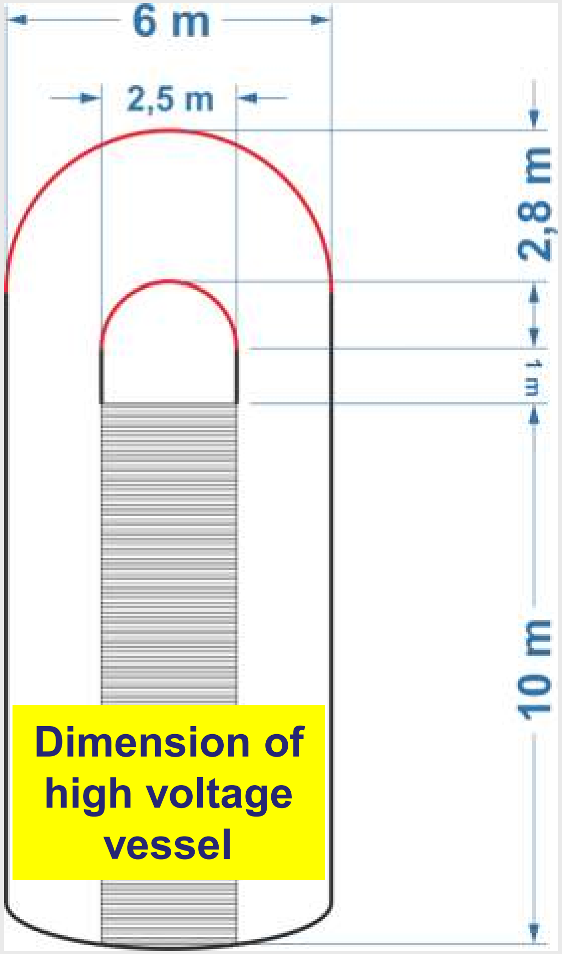
BINP design

Next Step: **using *more powerful* turbines** (reducing the number of turbines) **in combination with cascade transformers *(COSY type)* or direct powering of the HV-solenoids with a turbo generator**

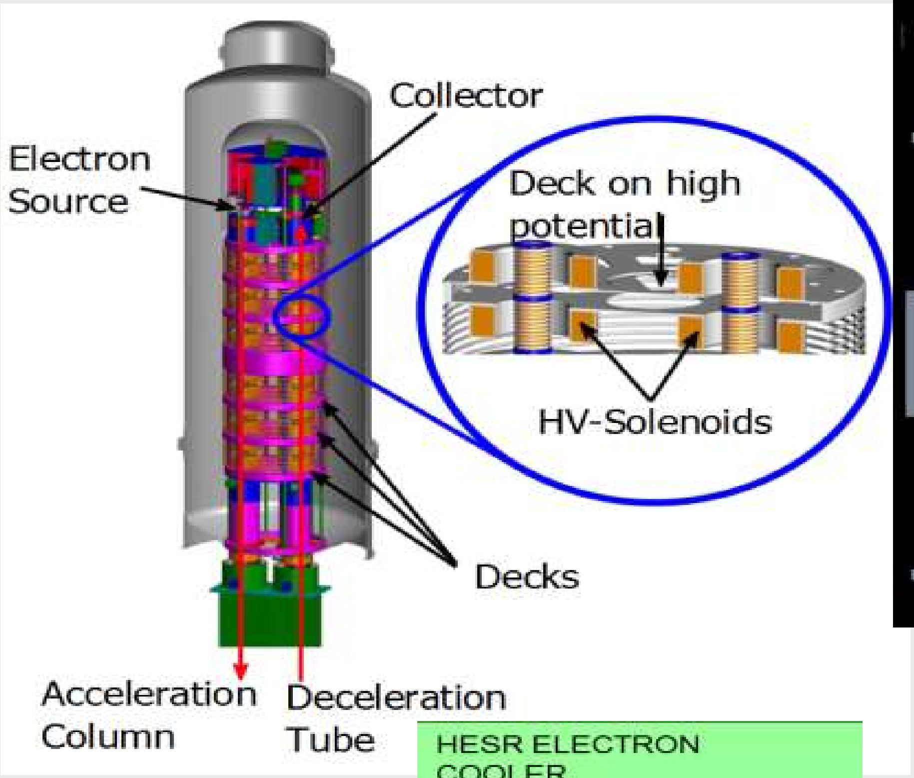
Hybrid System- Combination of Powerfull Turbines (5 kW) and Cascade Transformers

(Helmholtz Institut Mainz)

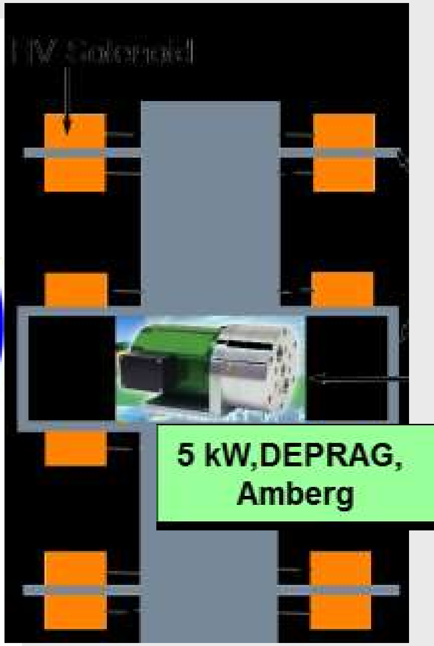
Helmholtz-Institut Mainz



Dimension of high voltage vessel



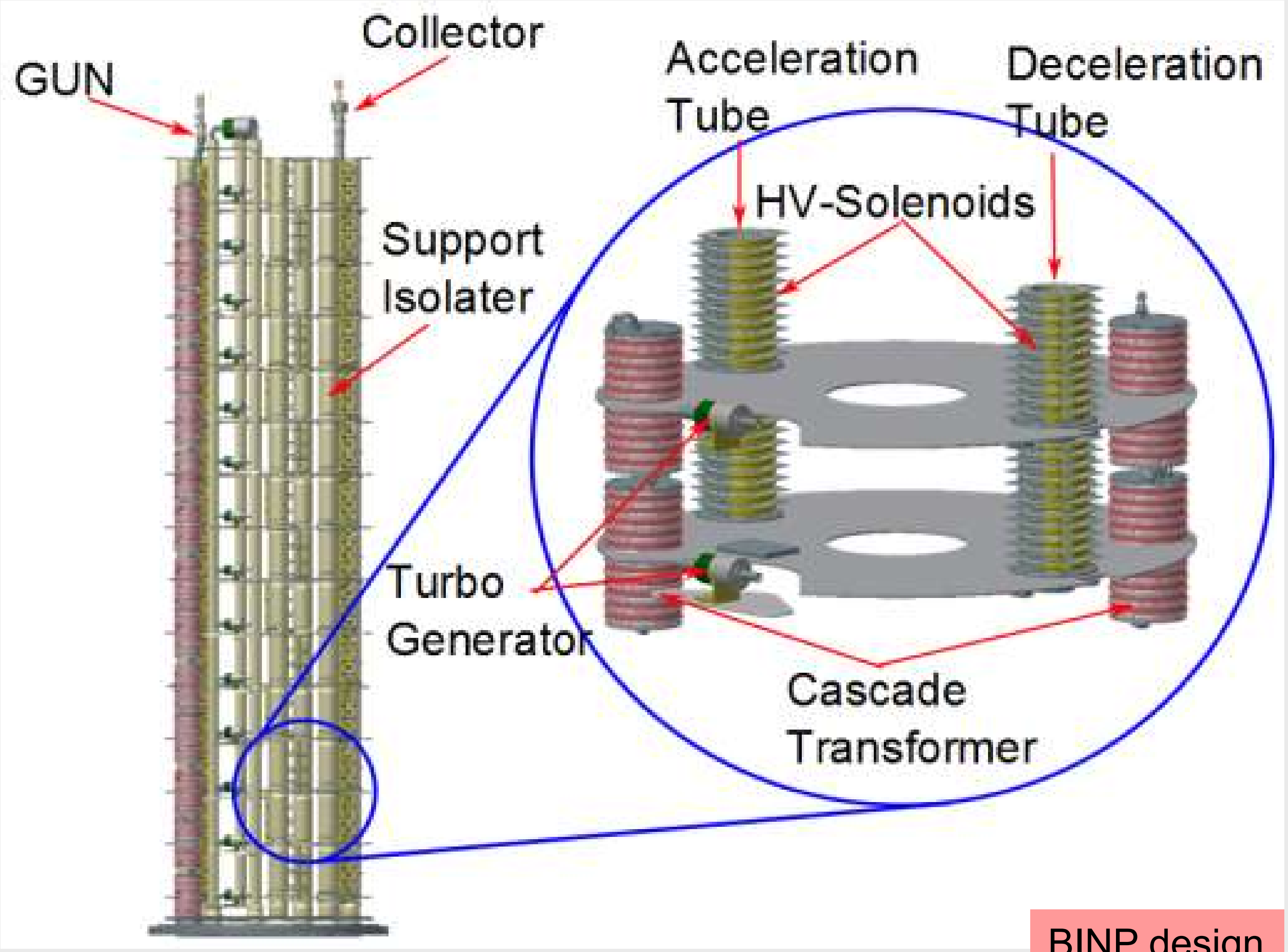
HESR ELECTRON COOLER
Design study
The Svedberg Laboratory
Uppsala University
Uppsala,2009



5 kW,DEPRAG, Amberg

Powering the HV-solenoids with a Cascade Transformer

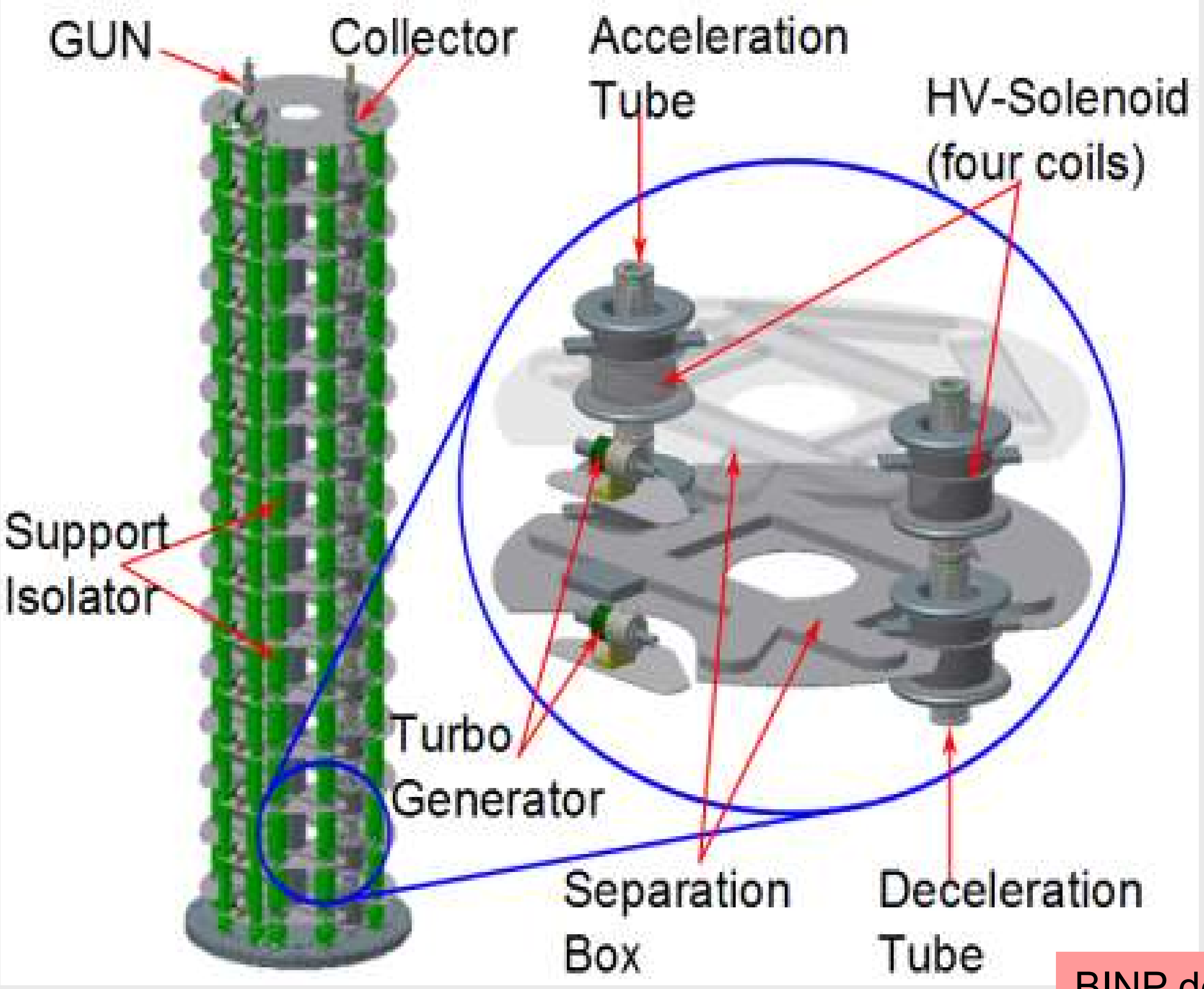
600 kV per modul, several small HV-solenoids (COSY-type)



BINP design

Direct Powering of the HV-solenoids with a Turbo Generator

HV-solenoids consist of four coils, HV generated e.g. by a Cockcroft-Walton-Generator



BINP design

Industrie: Green Energy Turbine (GET)

$$P = 5\,\mathrm{kW}$$
$$p_{in} = 4\,\mathrm{bar}$$
$$\dot{V} = 4\,\frac{\mathrm{m}^3}{\mathrm{min}}$$
$$m = 20\,\mathrm{kg}$$
$$r_{max} = 220\,\mathrm{mm}$$

Turbine Test Bench in HIM Mainz

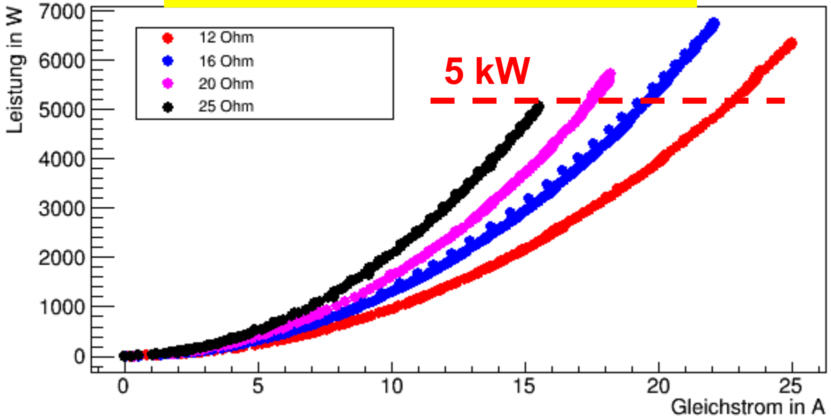
Compressor 40 kW

Pressure tank and turbine

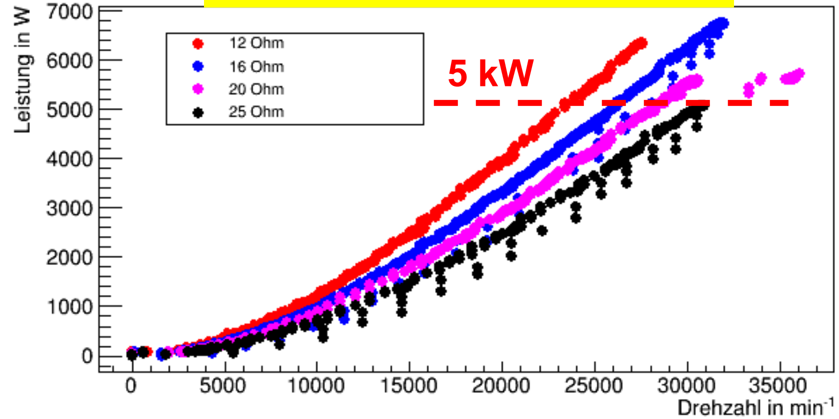
5 kW turbine
DEPRAG

First Measurements with the GET Turbine

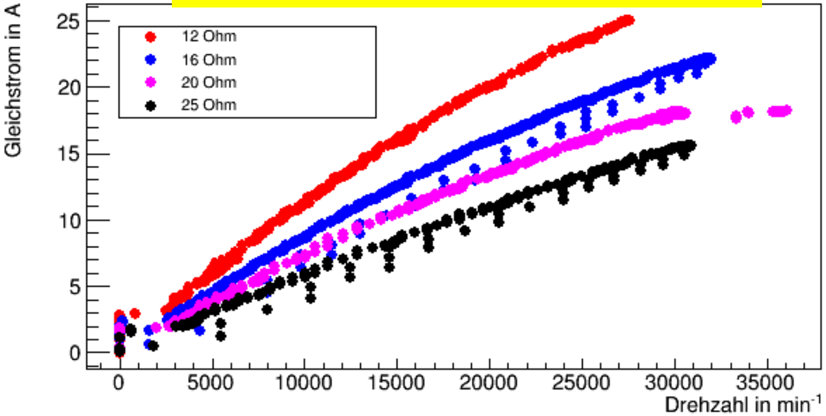
Power as function of DC current



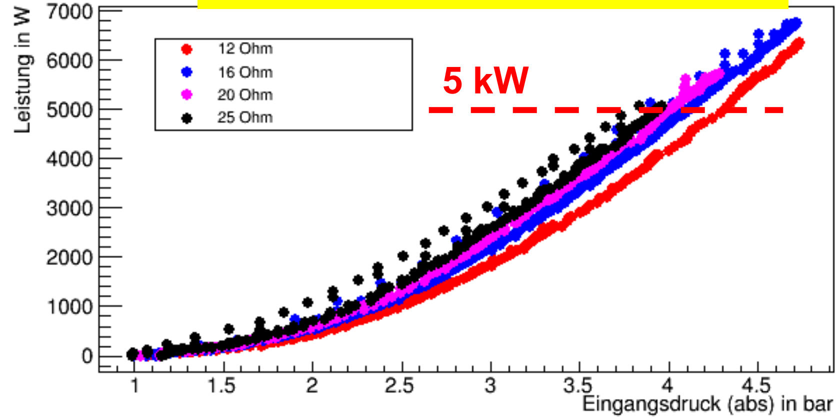
Power as function of frequency



DC current as function of frequency

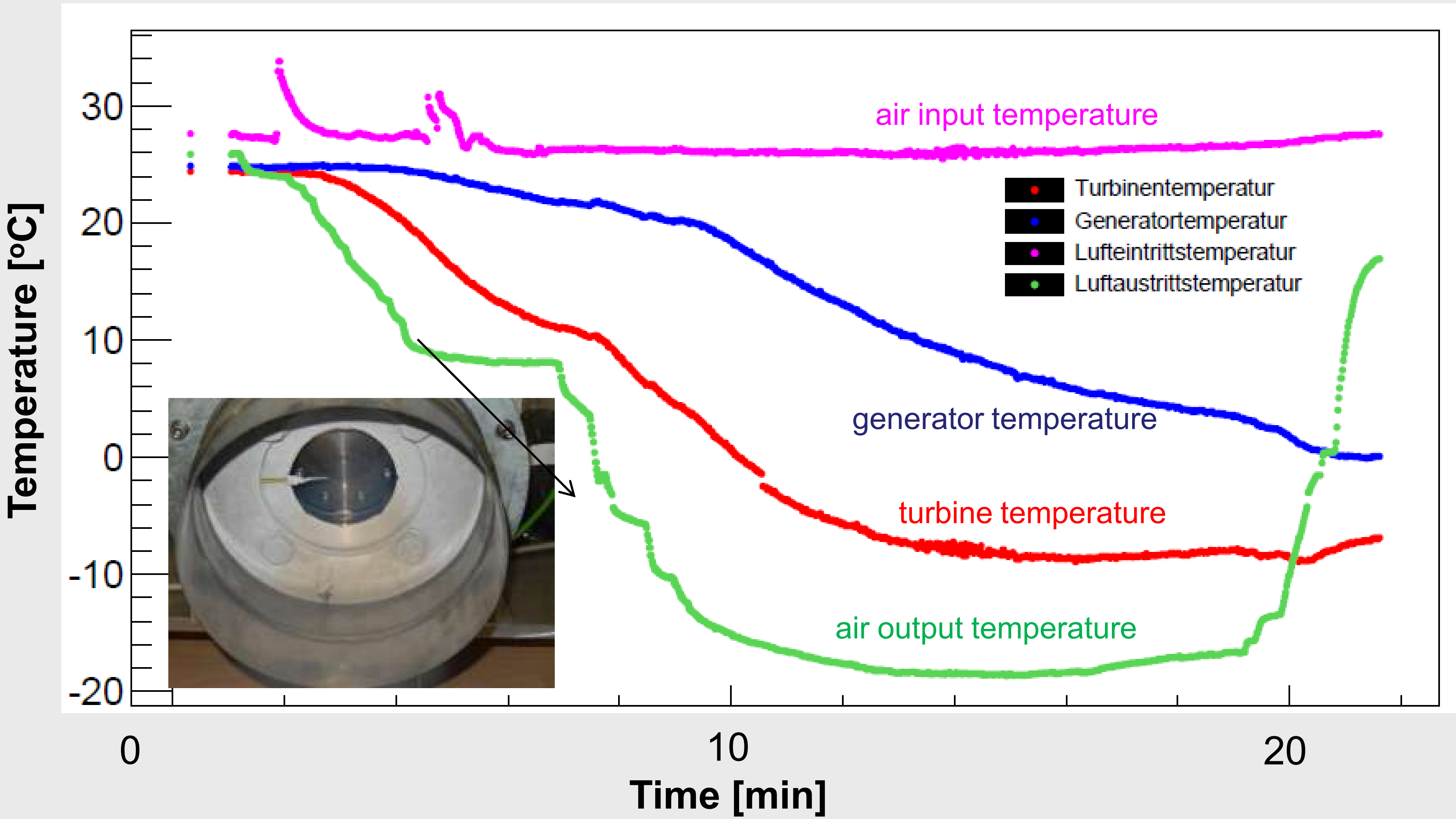


Power as function of input pressure



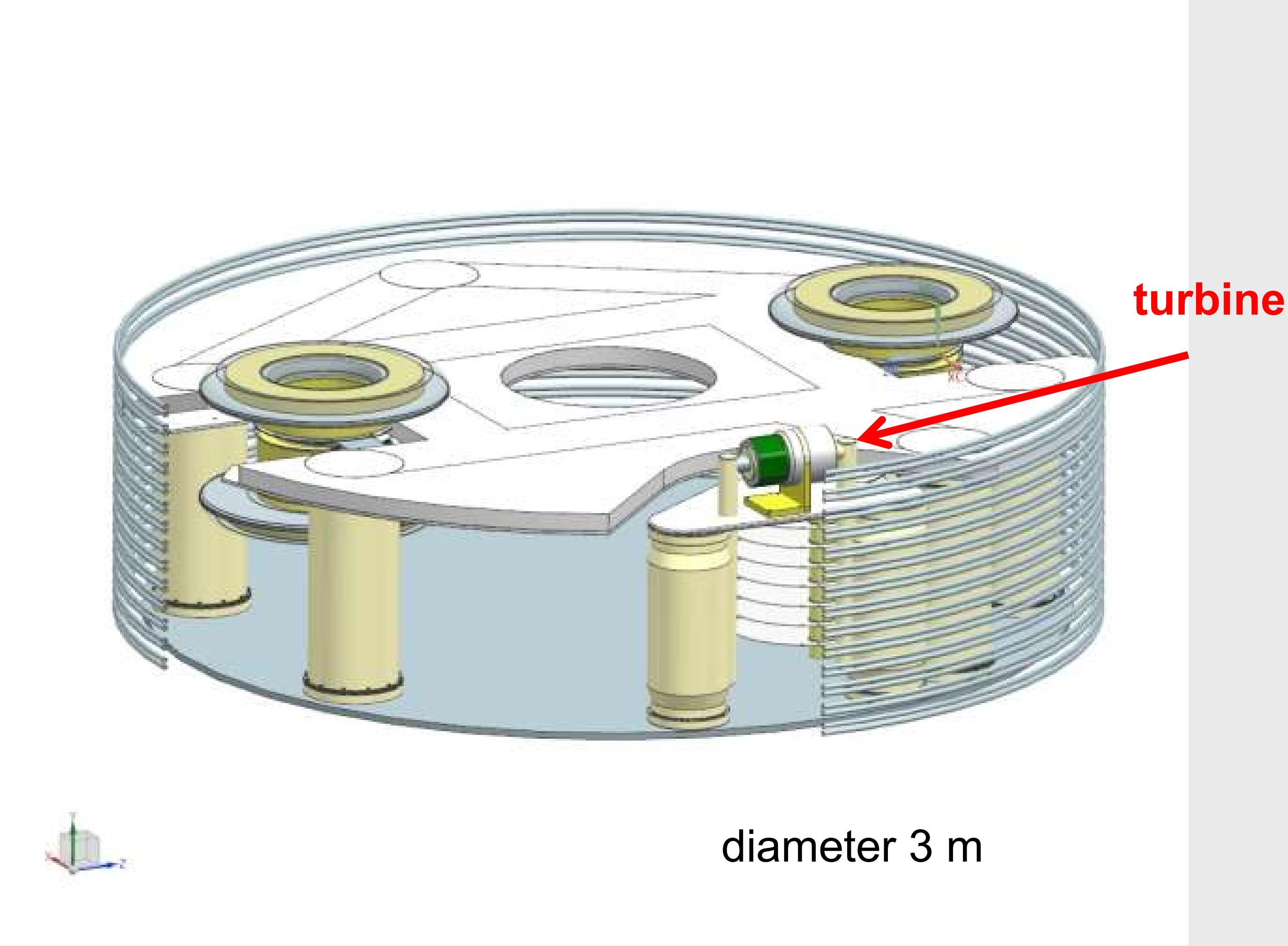
Temperature Regime of the GET Turbine

(using output gas for cooling)



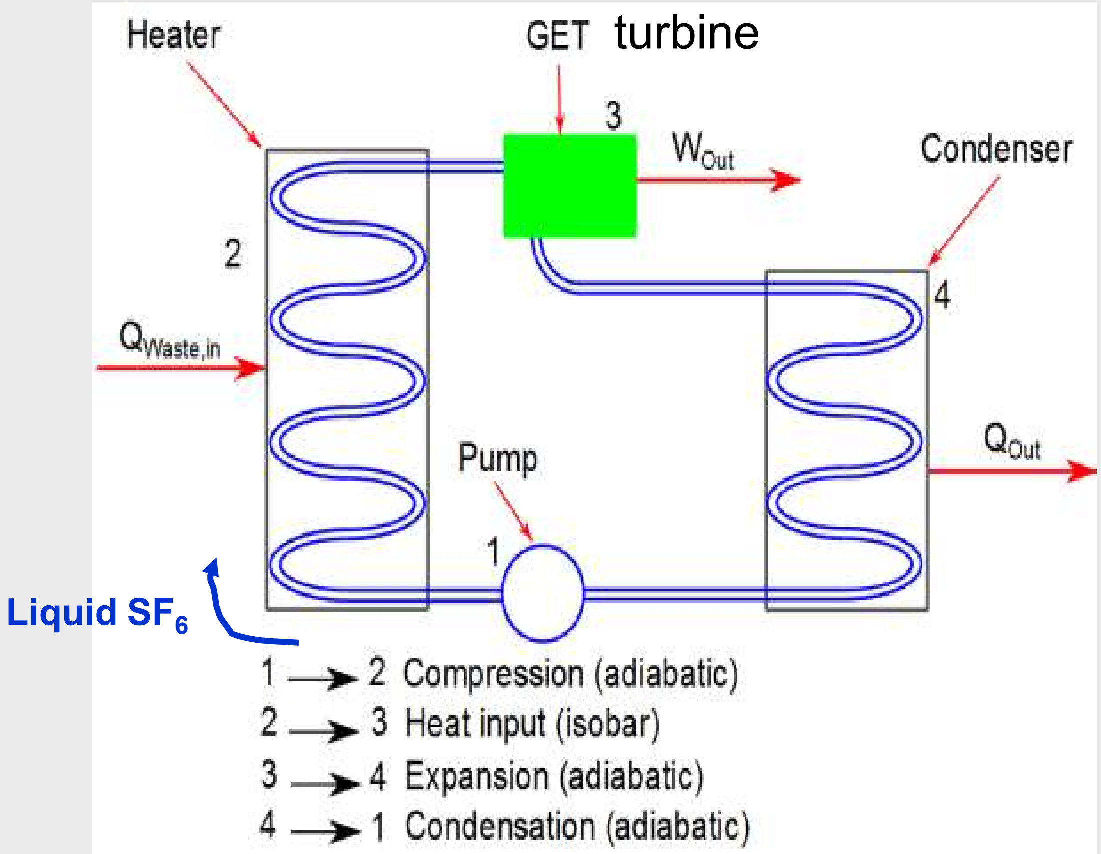
Next Step - one Modul for a 8 MeV Electron Cooler

(generating high voltage 600 kV, and power 2 kW for magnetic coils)



Working Principle of an Organic Rankine Cycle Process

Critical point : **efficient** generation of pressurised gas (turbine input).
Alternativ way to a compressor could be the ORC process.



The advantage in contrast to the compressor is that residual heat of other devices can be used, which would otherwise be wasted. Hence the operational costs could be reduced significantly.

Outlook / Next Steps

- **Studying turbine performance : reliability , life time at HIM Mainz**
- **Oil and fat free bearings - DEPRAG company**
- **Design and construction of a test module at BINP with DEPRAG turbine** (operating with air)
- **Investigation of ORC cycle based on SF_6 at University Bayreuth**
- **Preparation SF_6 test bench at HIM Mainz using BINP module** (operating with SF_6)

Thank you for your attention!

Thanks to my colleagues

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