HELMHOLTZ ASSOCIATION

Helmholtz Institute Mainz

Prototype of turbine driven HV-module for a relativistic electron cooler

Kurt Aulenbacher, Helmholtz Institut Mainz (HIM)

Cool-19, Novosibirsk

2019, September,23

Presenting work by HIM Section ACID-II (K.A. T. Beiser, J. Dietrich and W. Klag),

and Group of V.V. Parkhomchuk, V. Reva at BINP

HELMHOLTZ ASSOCIATION GSI JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

- **Introduction : Accelerator research at HIM**
- **Turbine operation**
- **BINP/HIM Prototype**
- **Near and far future extension plans**

Introduction: What is HIM ?

- **A joint venture between University Mainz & GSI**
- **Founded 2009…(10 years anniversary June 2019)**
- **Scientific focus: Physics which can be performed at GSI & FAIR**
- **Six HIM-research Sections: (1) Hadron-spectroscopy, (2)Hadron-structure (PANDA) (3)Theory (e.g. lattice QCD) (4)Super-Heavy Elements (two sub-sections) (5) Matter & Antimatter**
- **And last but not least: (6) Accelerators and integrated detectors with two subsections ACID-I, -II .**
- **Total staff & students ~ 150 people**

Accelerator research at HIM

Objectives of HIM-section Accelerators and integrated detectors (ACID)

1. **FAIR: HESR-Cooler support: Beyond 2MV:→4-8MV (ACID-II)**
2. **Provide accelerator solutions for SHE research by GSI and JGU groups: low beta SRF ion accelerator cavities (ACID-I)**

Mission…

- ACID cooler group does R&D on small, well defined aspects related to the design of relativistic magnetized coolers
- Such a scale of research is well adapted to the possibilities of HIM (somewhat in between university research and „big science“)
- Ongoing projects: turbines as power generators for higher voltages >2MV
- Test set-ups for collector optimization & control , non invasive beam diagnostics (Poster by Th. Beiser)

How to power solenoid channel & terminal ?

- More cooling power needed due to stronger beam/target interaction
  → Magnetization of beam required!
- Powering of continuous solenoid channel in DC acceleration stage
- Powering of terminal – electronics, source/collector
- Power requirement 50kW or more for supply floating at U>2MV

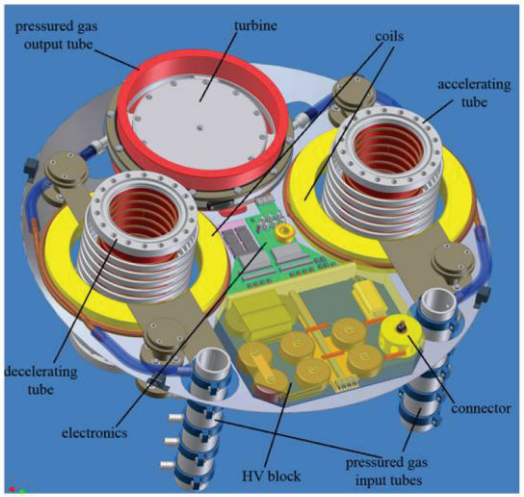
Conventional solutions: transformer/insulating shaft: May become cumbersome or even unfeasible under these conditions

The turbine approach

Solenoids must be powered by floating power supply (e.g. isolated turbogenerator)

- **Not realized** for Jülich 2MV-cooler…
- 19th century technology – but still requires mechanical systems engineering &quality control

→ commercial product should be reliable

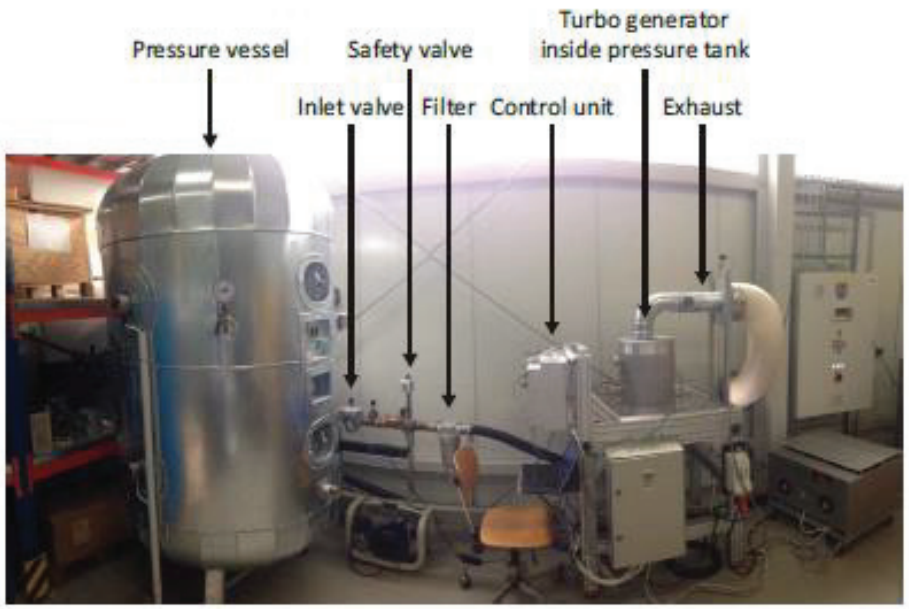


First idea for Jülich Cooler ~600 W Turbogen. Powering 60kV + solenoids

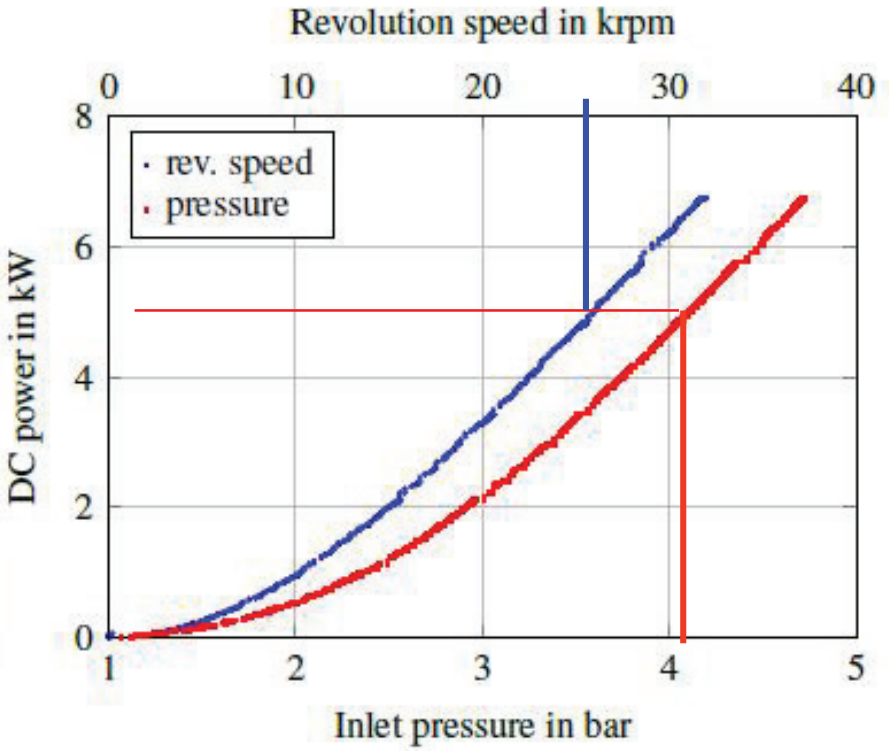
5kW Turbogenerators (company: DEPRAG, product name „green energy turbine“) have been purchased

- **Ball bearings (2014)**
- **Gas bearings (2017)**

Test set –up for long term operation at HIM/Mainz



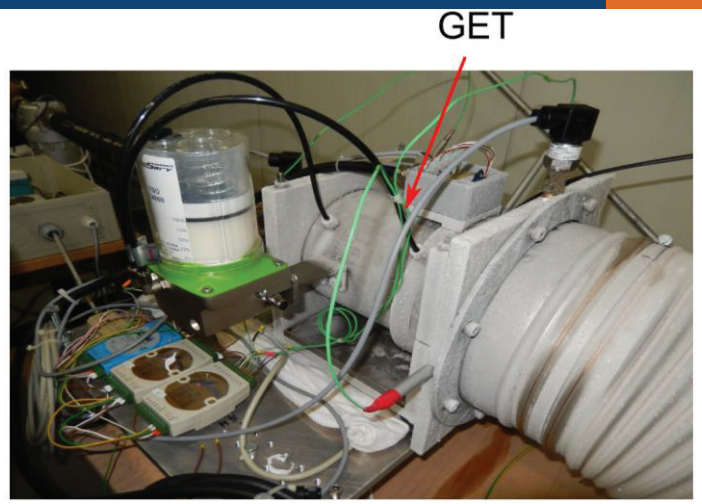
(Compressor not visible)



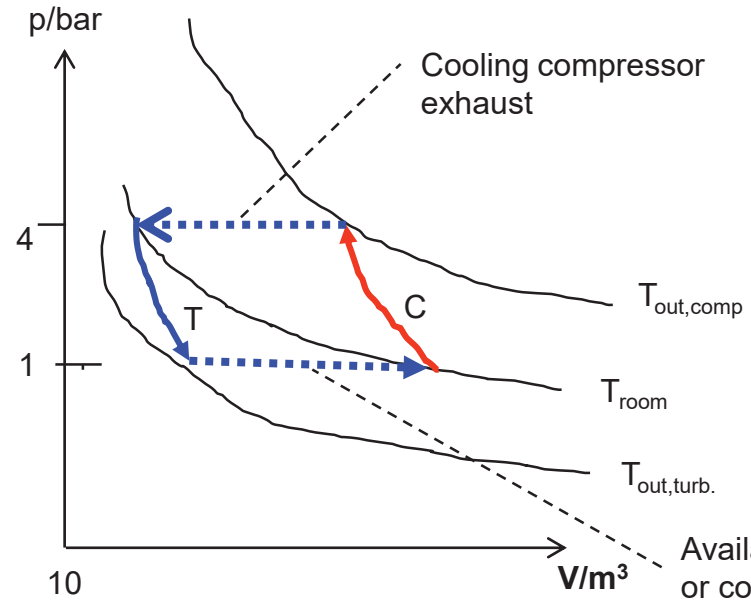
Test Results

- Turbine operated > 1000 hours without failure or relevant wear of bearing at 5kW
- Lubrication of bearings is needed, but minimal (remotely controlled, <0.1 cm^3 once in 1000 hours)
- test of turbine (& lubrication unit) in 10 bar pressurized vessel successful
- Turbine with gas bearings available, if neccesary

Thermal considerations

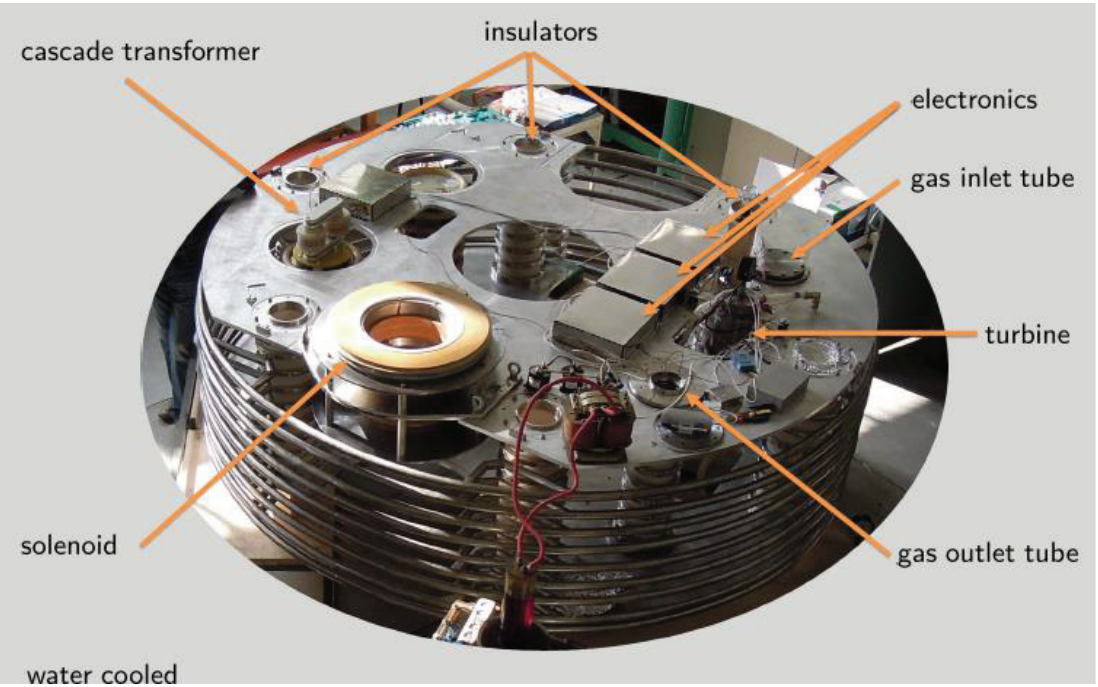


GET after operation($T_{air,out} = -31\,°C$)



- Cooling of compressed gas reduces efficiency.
- But then, exhaust gas is also cooled due to adiabatic expansion which may help dealing with heat generated by loads inside HV-tank
- Wall plug to terminal efficiency: ~20%
- Compressor wall plug requirement for 8MV HESR cooler would be large (300-500kW), but not impractical

HIM-BINP-cooperation 2015-2018



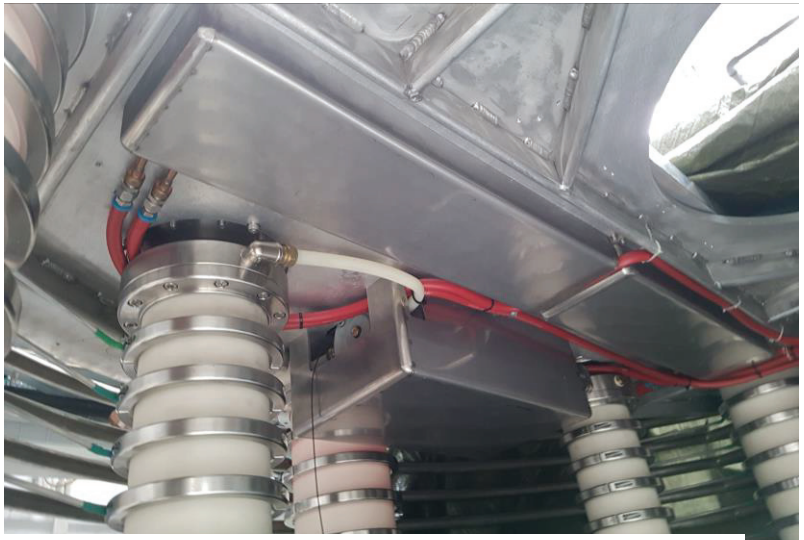
~3m

- Module designed and build by BINP
- Operated at >100kV in air
- Final assembly and testing at BINP
- Transport to HIM in 5/2018
- Re-assembly and system test took place successfully at HIM in September 2018

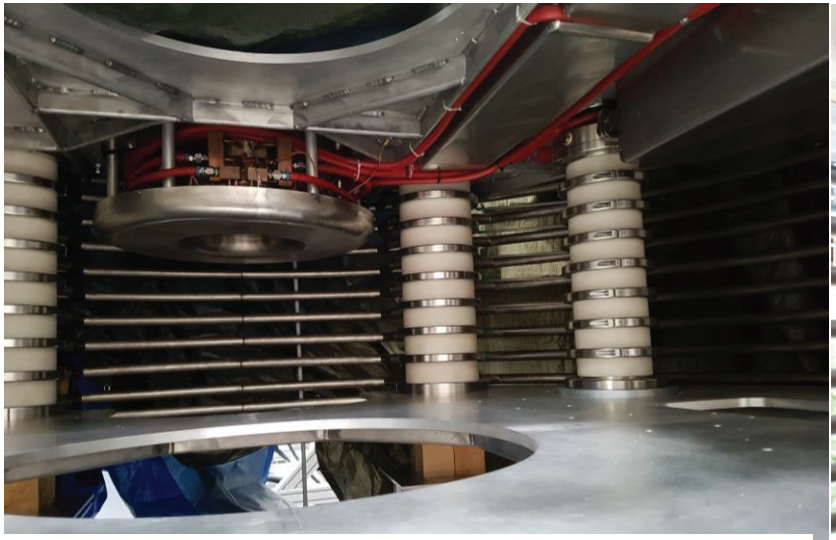
HELMHOLTZ ASSOCIATION
Helmholtz Institute Mainz

Some impressions

Compressor station for up to three turbines



Turbine (in box) hanging from HV-deck



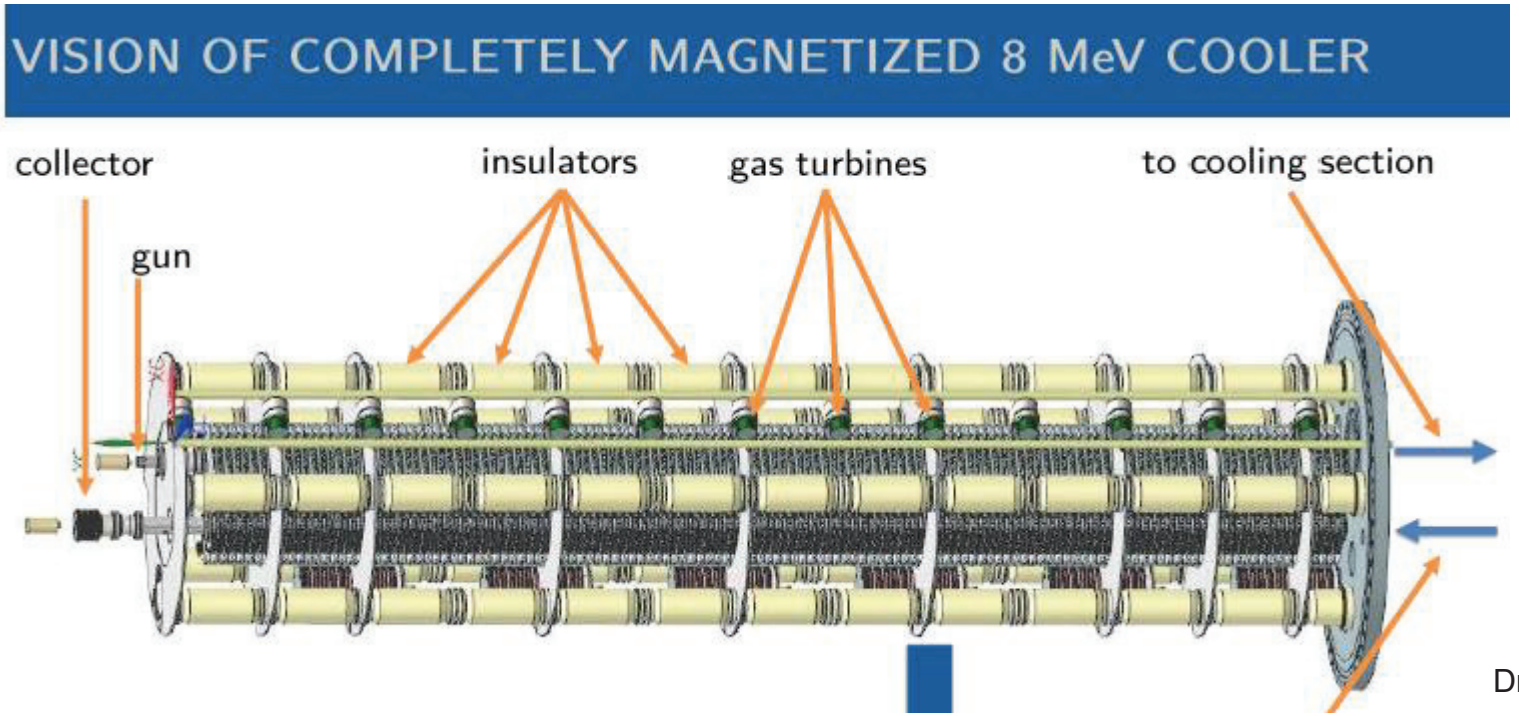
Solenoid hanging from HV-deck

HV-generator

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Scalability?

The 600kV device should be scalable…

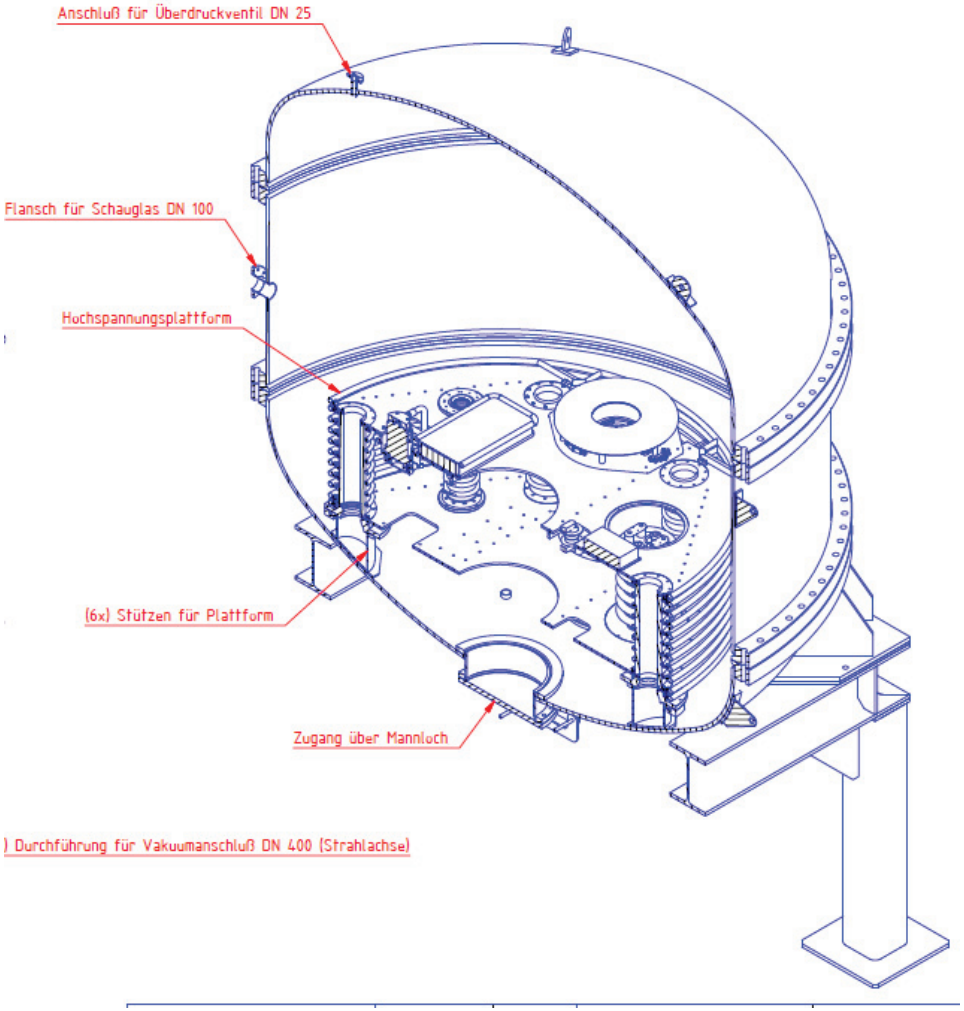


Drawing: V. Reva

..but reliable operation should be demonstrated first…

→ What can be done within the given limitations ?

Preparation for HV-operation



- 2018-2019: Pressure tank specification and ordering via international call for tender.
- Order was placed August 2019, delivery time 11 month.
- Tank can **accommodate two platforms + gun and collector**
- operation with dry air in closed cycle, SF6-admixture under investigation
- Operation of 80kW compressor under variable load requires improved regulation system (under commissioning with help of vendor Atlas Copco)

Preparation for “scalability”

V. Parkhomchuk et al. Design study for the high voltage test bench of 1.2 MeV , BINP 2019

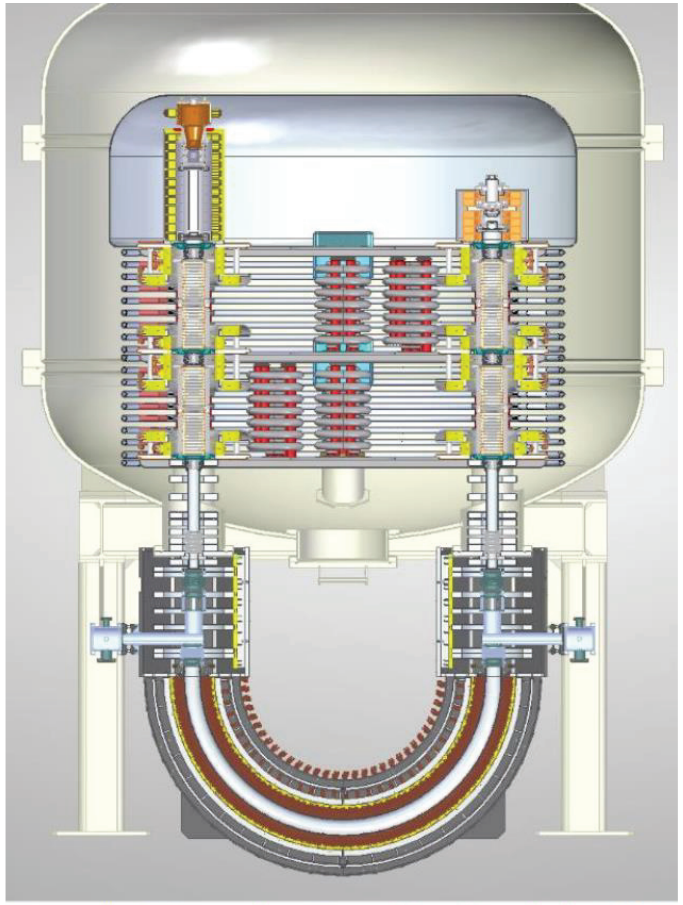


Figure 1.2: General picture of test-bench 1.2 MeV

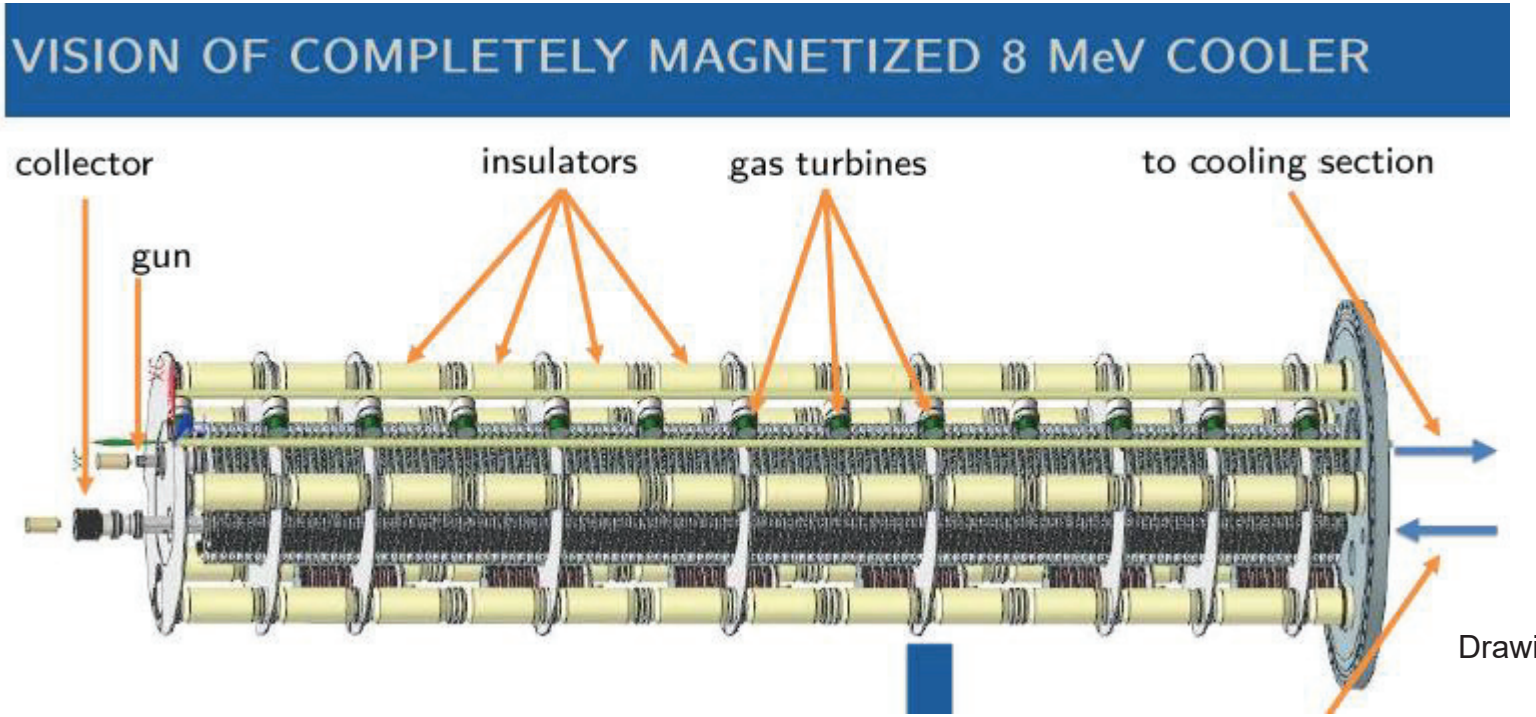
- 2018-2019: Design study by BINP for usage of Prototype stage at HIM
- New project under discussion: fabrication of second platform to test:
  - scalability (2*600kV)
  - heat management
  - machine protection
  - voltage stability
  - acceleration tubes & vacuum
- Not yet part of project:
  - electron souce & collector
  - return beam line

Conclusion

- Turbines are qualified as floating power generator for electron coolers
- BINP has produced turbine driven HV-Generator for 600 kV+ several kW of floating power on terminal
- Extensive testing at HIM planned for 2020
- Qualified system should be scalable towards HESR energies

The long term perspective

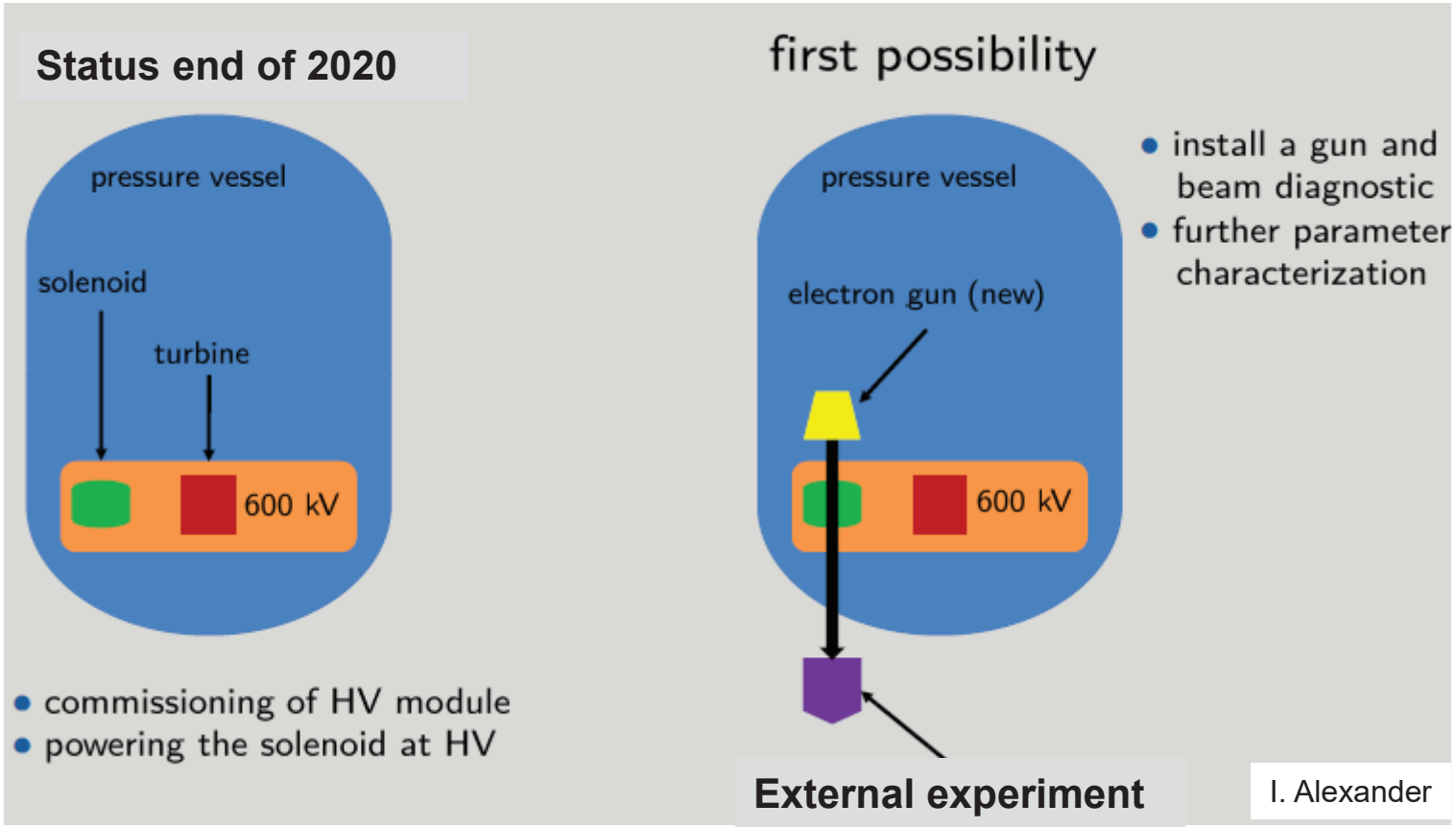
The present speed of development is limited by availability of resources, in particular manpower. Could change in a few years from now when HESR materializes. Research results from HIM would enter the design of a 4.5-8MeV cooler.



Drawing: V. Reva

What will we do with the prototype, then?

Future extension plans

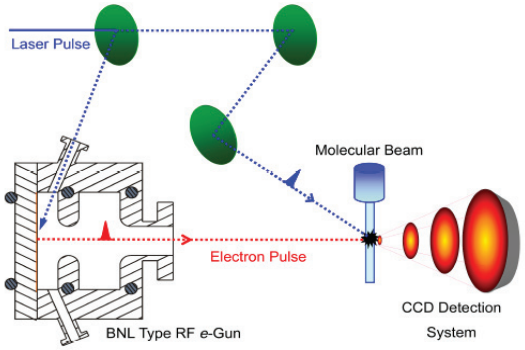


Is there "new" research that can be done with such a device ?
Advantages wrt to exisiting devices: thermal management and flexible floating power distribution
Application-idea: SUED-beams (Spin-polarized ultrafast electron diffraction)

Benefits with MeV electrons

TRANSPARENCY from:
RENKAI LI, Tsinghua Univ.
EWPAA workshop
PSI, Thu 12.9. 2019

- Tremendous advances with keV UEDs in the past decades
- ***Significant Benefits* with MeV *e-***



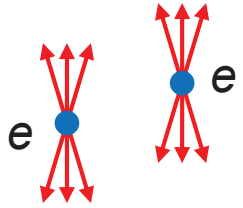
Active R&D field around the world!

X. J. Wang, Z. Wu, H. Ihee, PAC'03, 420-422 (2003).

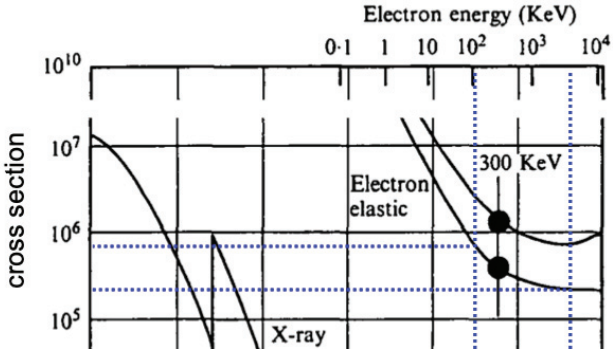
P. Musumeci and R. K. Li, ICFA BD Newsletter No. 59 (2012).

Space charge effects $\frac{1}{\beta^2\gamma^3}$

- ✓ Shorter bunch
- ✓ Higher charge

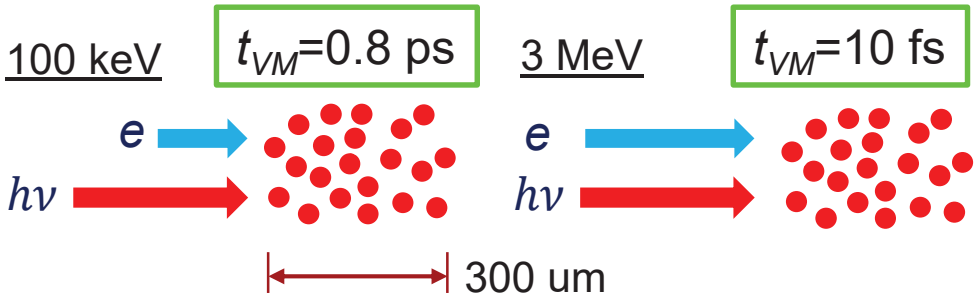


Penetration/multiple scattering

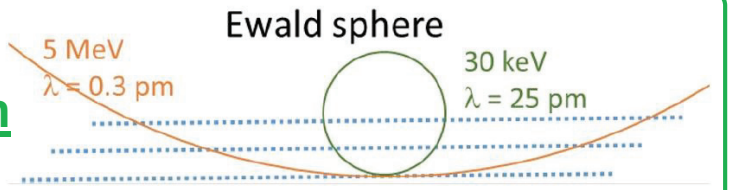


R. Henderson, Q Rev. Biophys. 28, 171 (1995)

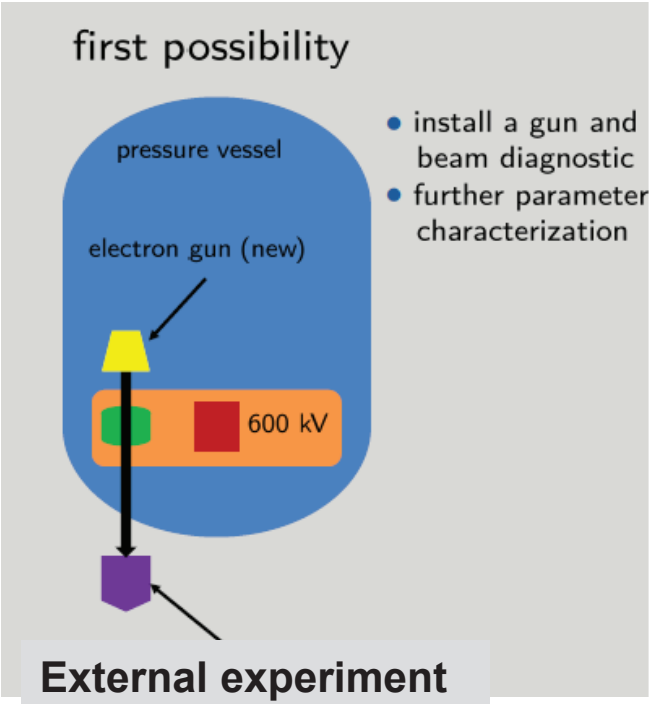
Velocity mismatch



Shorter wavelength



Future extension plans



- Present research in the field of UED aims at extremely high extraction fields → Rf-gun
- If high repetition rates are desired → SRF-gun
- spin polarized beams so far not generated from Rf/SRF guns

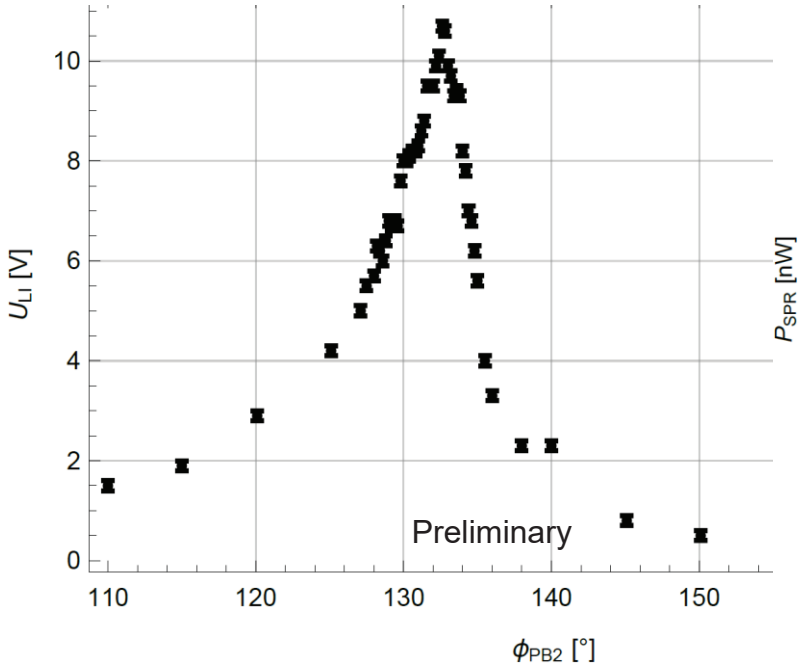
→Produce SUED-beams by using a d.c. spin-polarized photogun – and bunch during acceleration

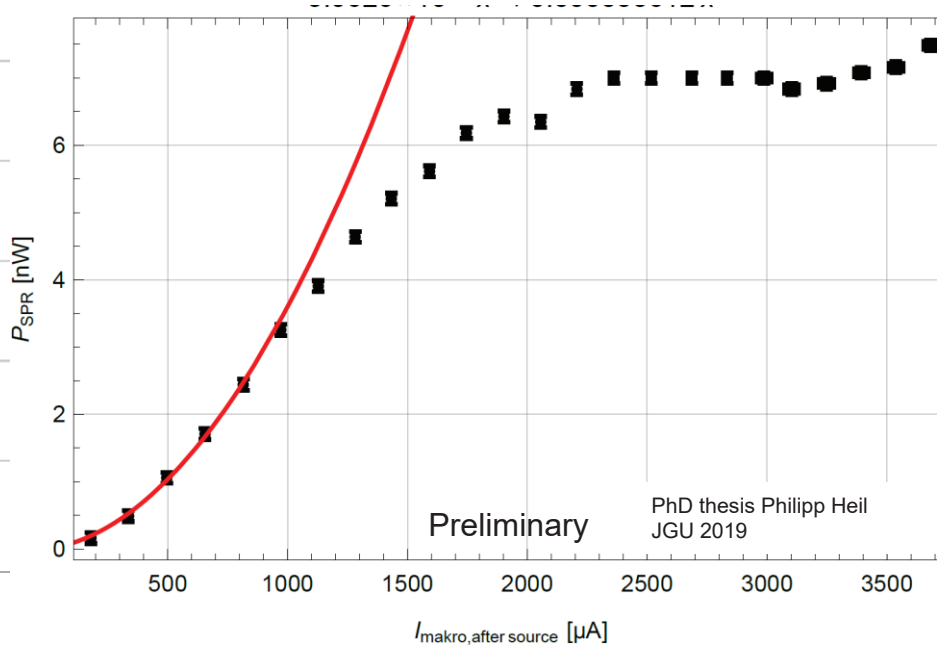
Advantage of huge d.c. acclerator vessel with enough power:

- Bulky Spin polarized photosource can be installed and maintained.
- Velocity bunching with small energy modulation feasible

Future extension plans-preliminary results

Production of few ps long spin polarized bunches at the 100keV MESA source, detected by Smith-Purcell radiation.
Left: Coherent intensity vs. buncher phase Right: Saturation at bunch charge of ~1pC. Energy definition:$\Delta E/E$= ~$5*10^{-3}$

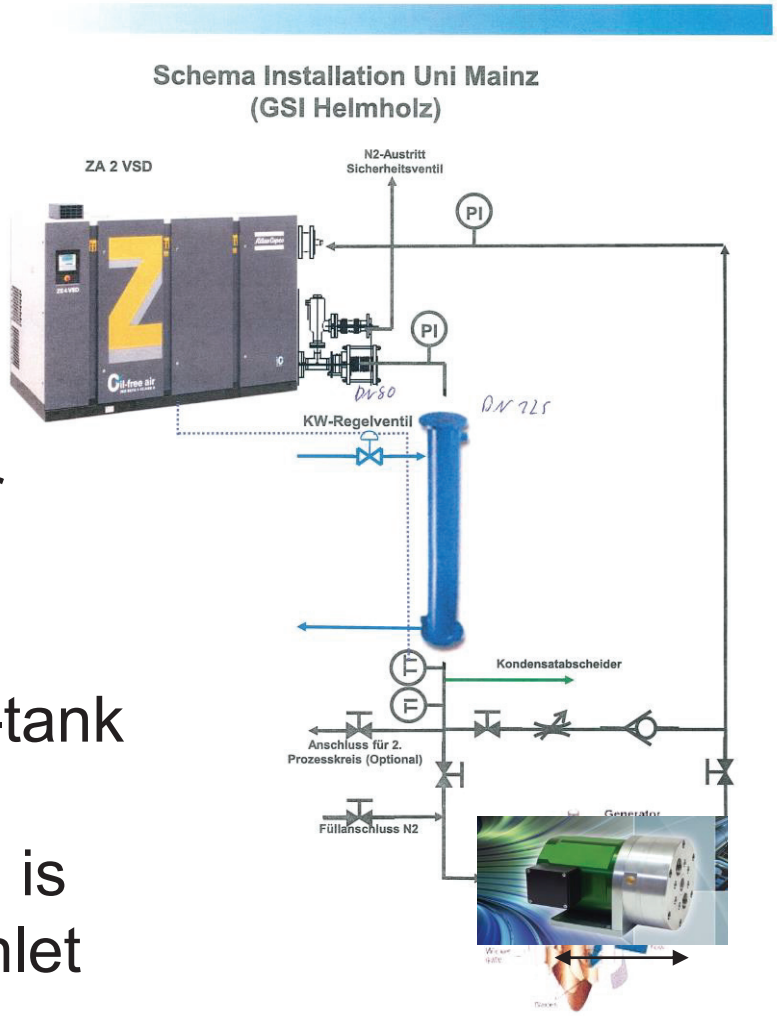




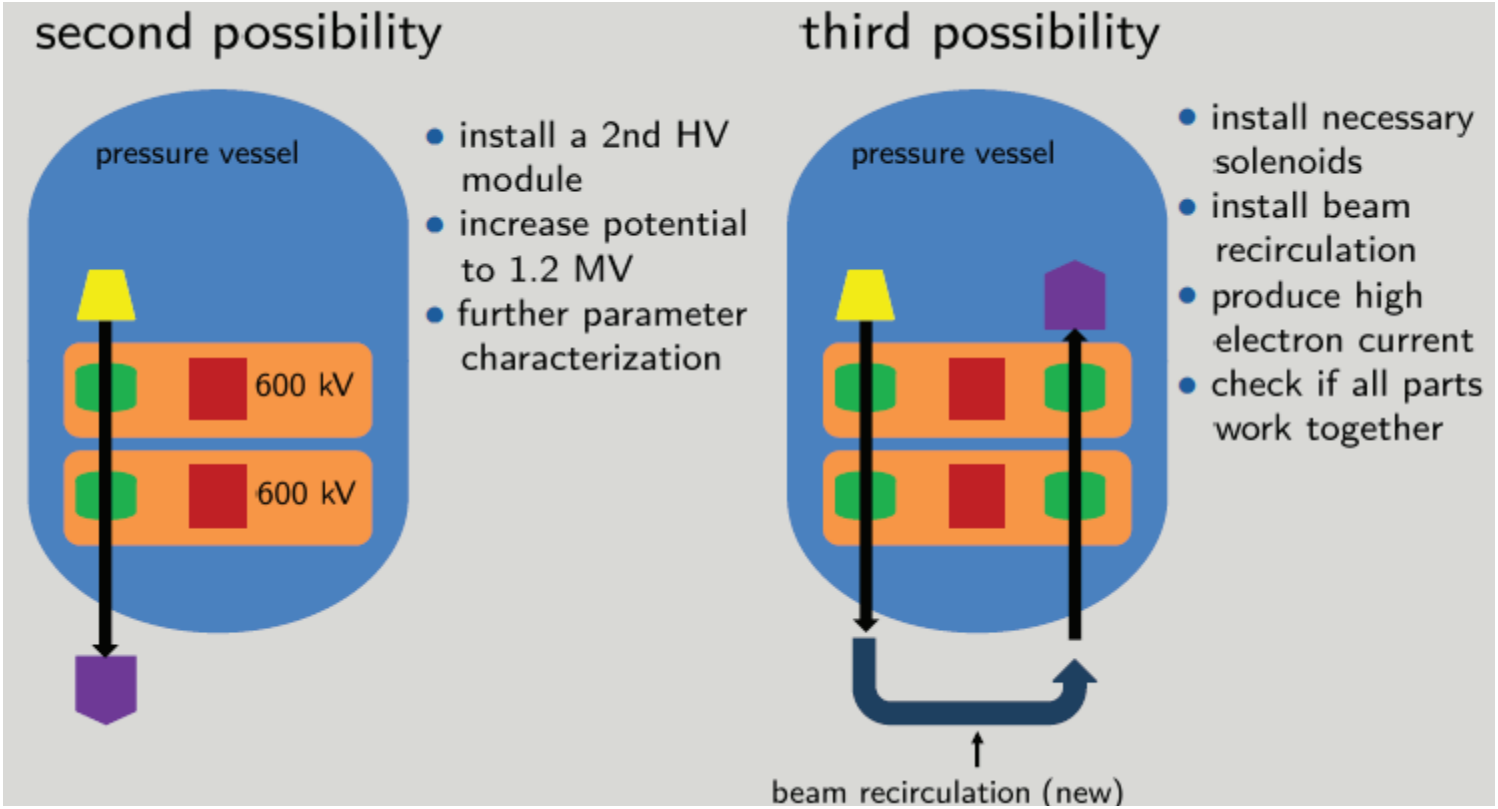
Thank you!

The turbine approach

- standard screw compressor generates pressurized medium (dry air or others)
- Guided into pressurized HV-tank (insulating pipes in tank)
- Gas expands in turbine and is redirected to compressor inlet



Near (and far) future extension plans



Conclusion

- Turbines are qualified as floating power generator for electron coolers
- BINP produces turbine driven HV-Generator for 600 kV+ several kW of power on terminal
- Extensive testing at HIM planned beginning 2018
- Extension towards real electron beam operation will follow
- Qualified system will be scalable towards HESR energies

Spares

Investigation of critical cooler issues at HIM/KPH:

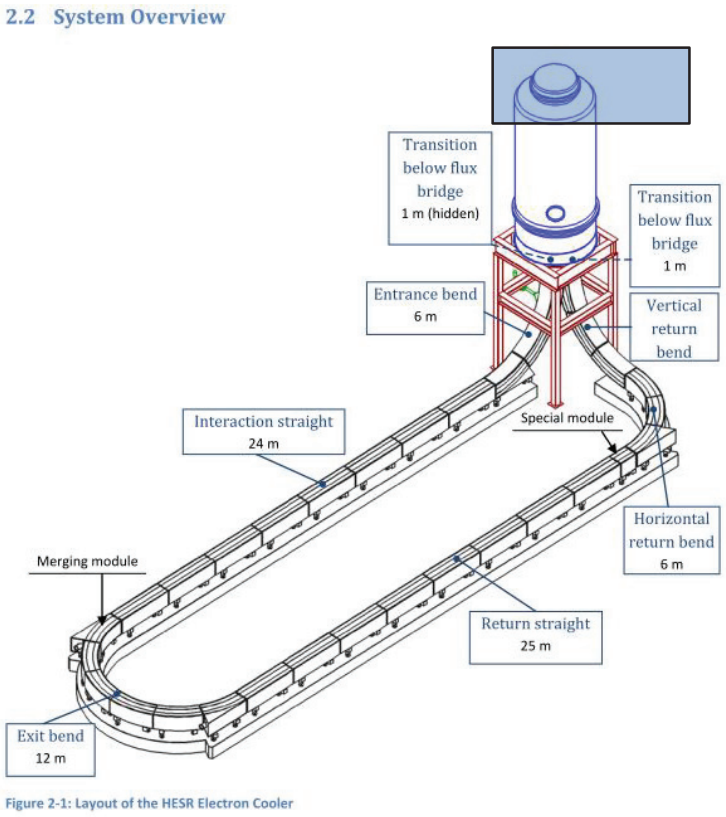


Figure 2-1: Layout of the HESR Electron Cooler

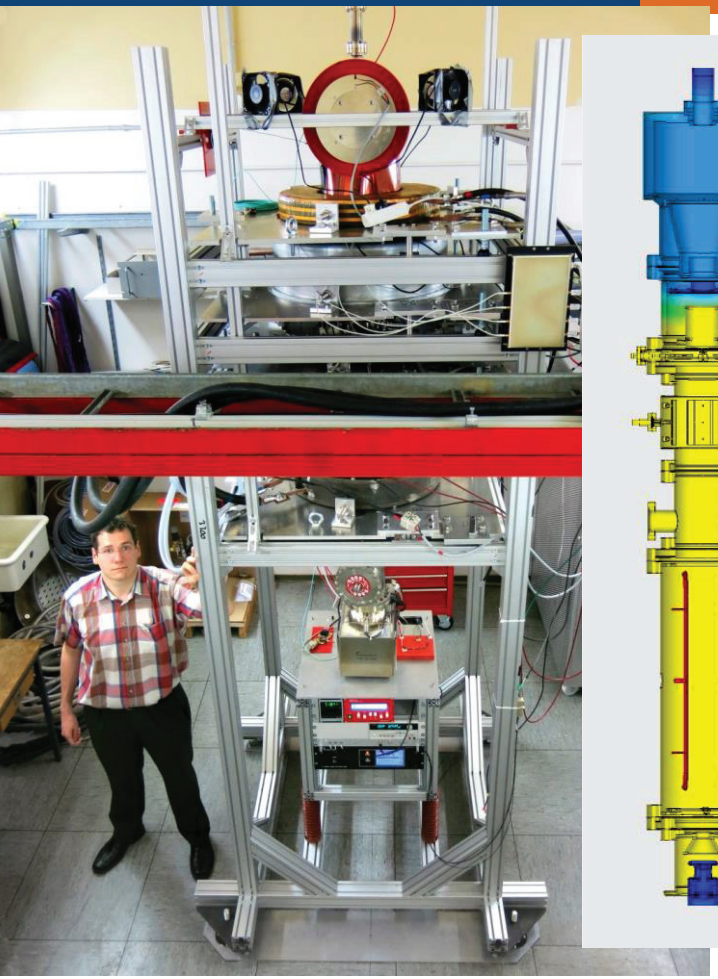
Idea:

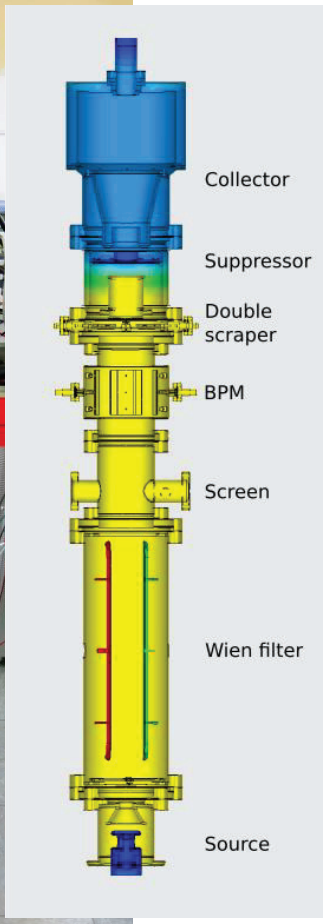
- Investigate source/collector system in order to define expected operation conditions at 8MV!

- Only the blue part
  –source and collector –
  has to be build for these investigations
  (no MV part is needed)

→ Build cooler test stand at HIM

Test-stand

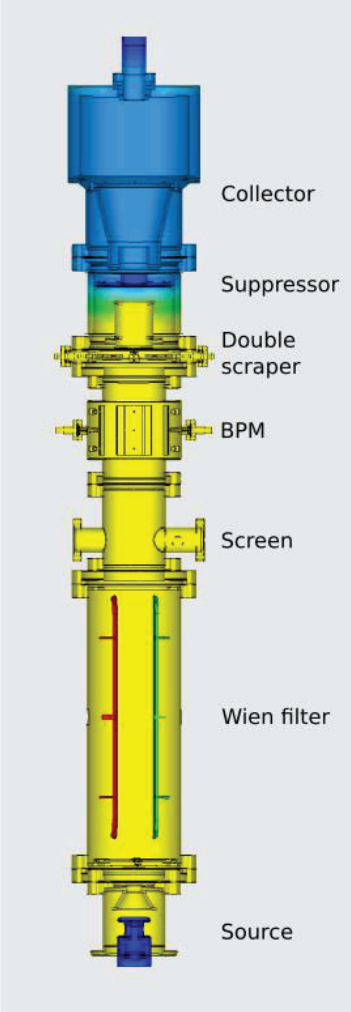


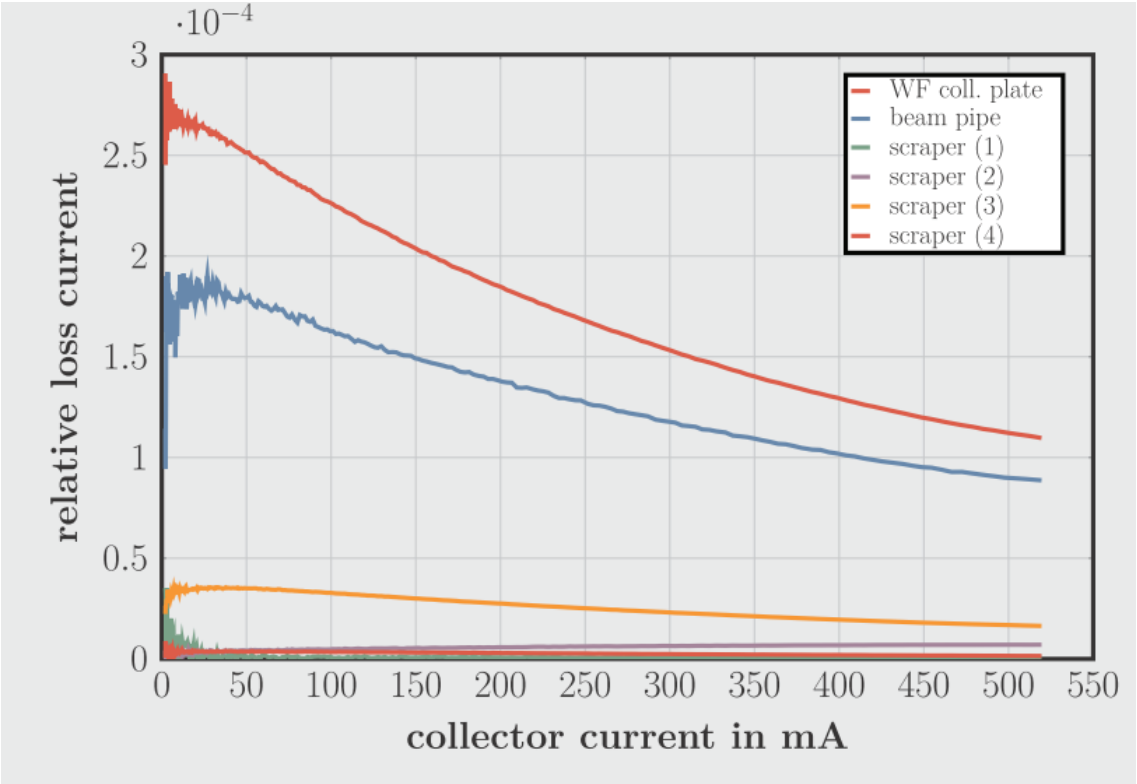


Selected results

- Long term stable operation with magnetized beam
- No significant vacuum increase due to desorption in collector
- Demonstration of effective capture of backstreaming electrons from collector
- Investigation of magnetron like discharges (due to unsuitable geometry in gun region)

oster by . ax ruker , Monday

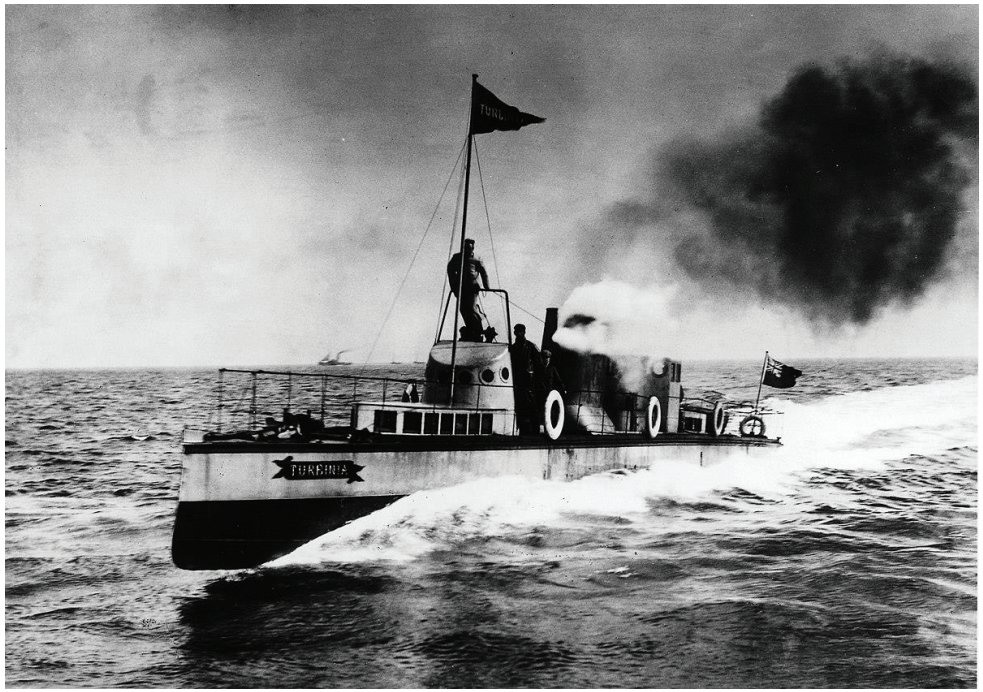




oster by . ax ruker , Monday

Loss is believed to be due to scraping of secondary beam on aperture at collector entrance (ground potential)
After modifaction „true“ loss could be measured with nA resolution

Turbines (?) !



First Steam-Turbine driven ship
Charles Parsons –Turbinia (1897)
Source: Wikipedia

- Use of “turbogenerators” (gas/steam turbine + electrical generator?)