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Scalable HV-modules for a magnetized relativistic electron cooler and possible applications

Kurt Aulenbacher, Helmholtz Institut Mainz (HIM)

Cool-21, Novosibirsk

2021, November, 3

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

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GSI

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Outline

- **Introduction : Accelerator research at HIM**
- **BINP/HIM turbine powered prototype for HESR cooler**
- **Using the prototype for physics programme**

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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, head: Kurt Aulenbacher)**
2. **Provide accelerator solutions for SHE research by GSI and JGU groups: low beta SRF ion accelerator cavities (also research for NICA project) (ACID-I, head Winfried Barth)**

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Mission…

- ACID-II 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“)
- Test set-ups for collector optimization & control , non invasive beam diagnostics (Talk by Th. Beiser)
- Ongoing projects: turbines as power generators for higher voltages >2MV
- Multi-platform design to achieve several MV range for HESR (2022-2026)
- Joint effort to have „full energy“ antiproton cooler at HESR (2026+)
- Applied/fundamental research with Multi-Platform (2022+)

HESR Relativistic cooler - details to be covered

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 many kW for supply floating at U>2MV

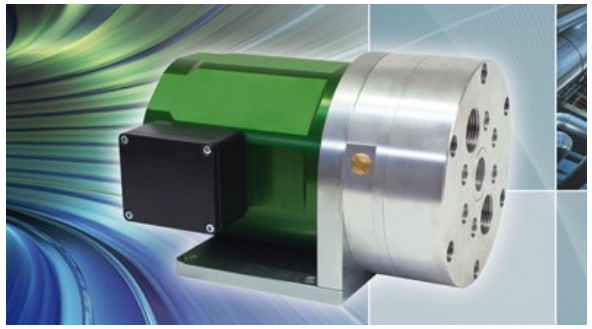
Conventional solutions: transformer/insulating shaft: May become cumbersome or even unfeasible under these conditions

The turbine approach - old results

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

- 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

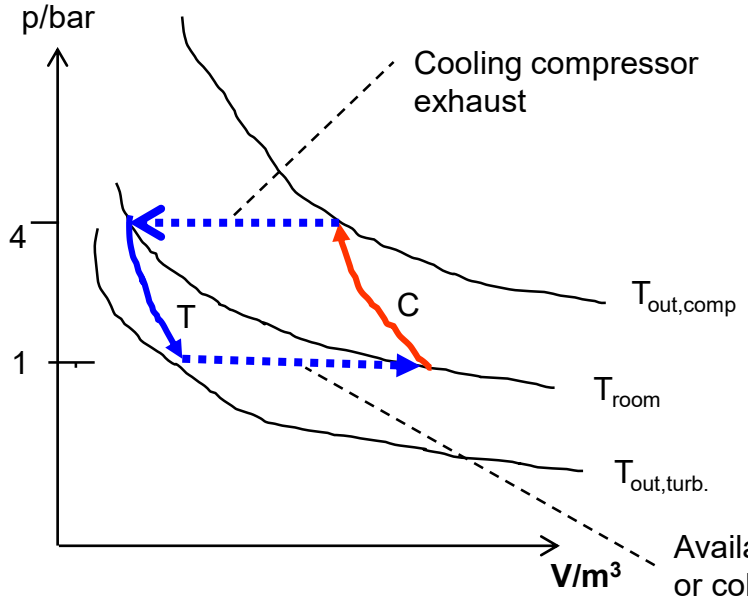


~40cm

5kW Turbogenerators (company: DEPRAG, product name „green energy turbine“) have been purchased
- **Ball bearings (2014)**
- **Gas bearings (2017)**
- **See our contributions to the cooler conferences**

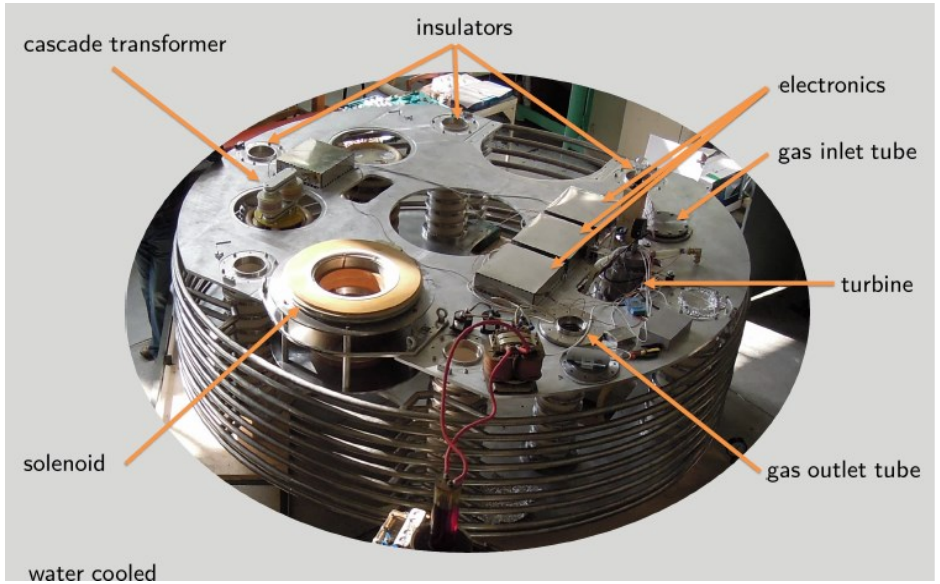
Thermal considerations

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 2015-2022



~3m

Second stage, including acceleration stage (not source) is in fabrication at BINP

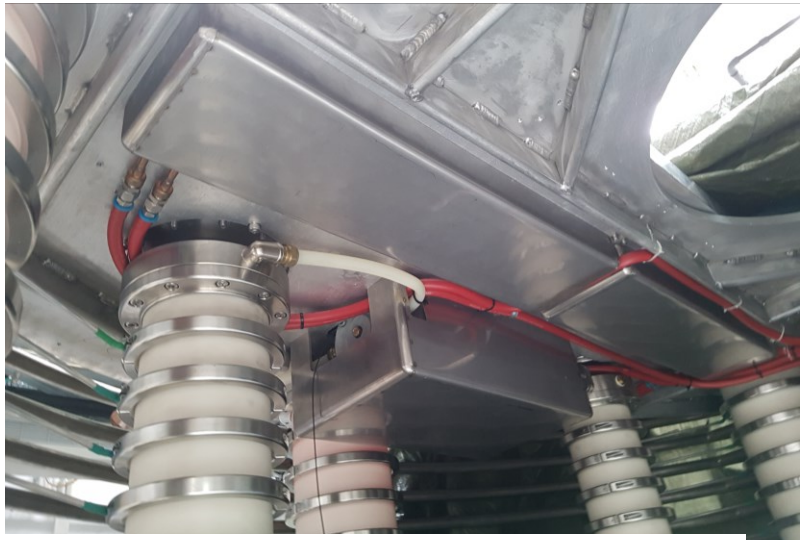
- First 600kV Module designed and build by BINP
- Operated at >100kV in air
- Final assembly and testing at BINP
- Transport to HIM in 5/2018
- Re-assembly and system test took place successfully at HIM in September 2018

See: 12th Workshop on Beam Cooling and Related Topics COOL2019, Novosibirsk, Russia JACoW Publishing

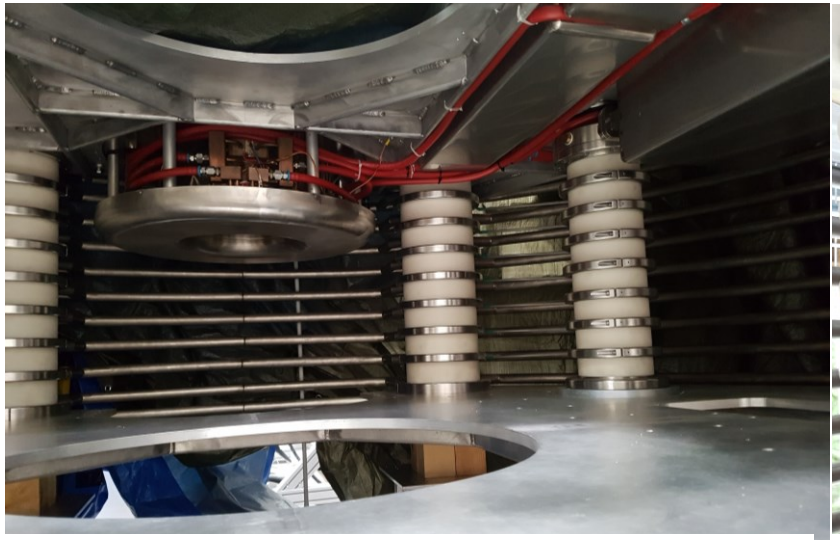
doi:10.18429/JACoW-COOL2019-MOX02

Some impressions

Compressor station for up to three turbines



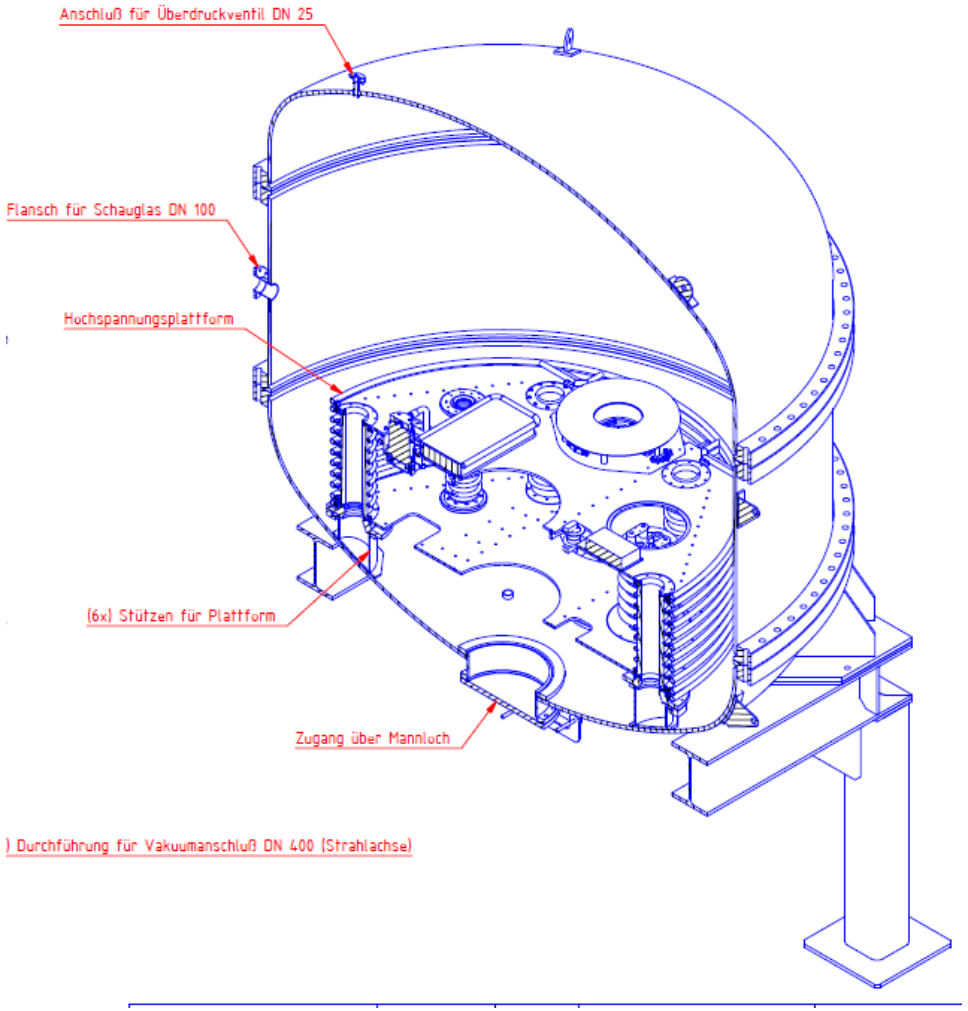
Turbine (in box) hanging from HV-deck



Solenoid hanging from HV-deck

HV-generator

HV-tank



- 2018-2019: Pressure tank specification and ordering via international call for tender.
- Order was placed August 2019, predicted delivery time 11 month.→
- 3/2020 start of pandemic lockdowns
  → severe delays, delivered in Mai 2021

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The “BIG Blue Bubble” HV-Tank

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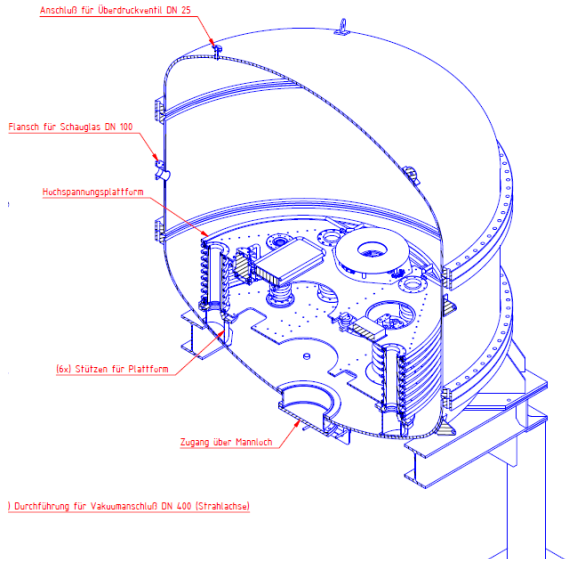
Preparation for HV-operation



Schaltschema des Turbinenkreislaufs

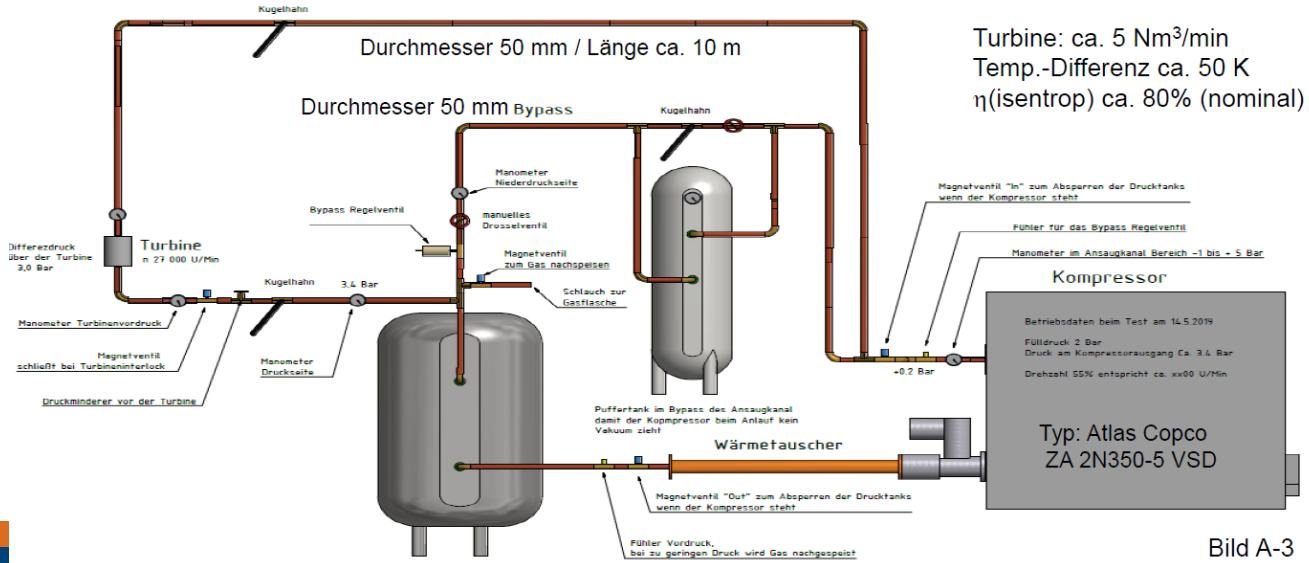
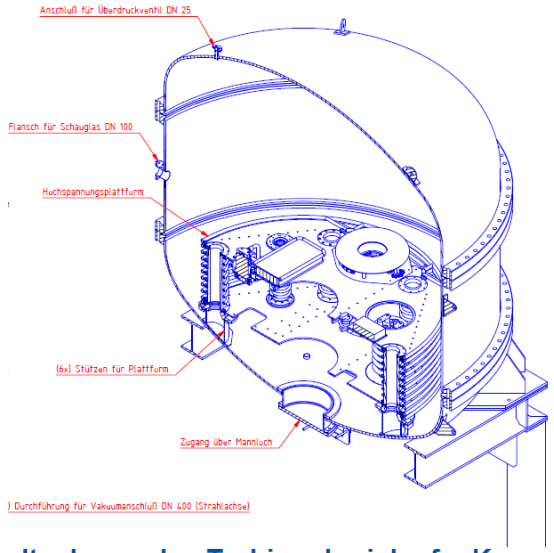


Bild A-3

- Tank can **accommodate two platforms + gun and collector**
- operation with Nitrogen in closed cycle,
- Operation turbine circuit investigated by M. Wirsum, Institut für Kraftwerkstechnik, RWTH Aachen
- Instrumentation is currently being installed,
- Turbine tests in tank beginning early 2022

Preparation for HV-operation



Schaltschema des Turbinenkreislaufs: Komponenten und Bezeichnung

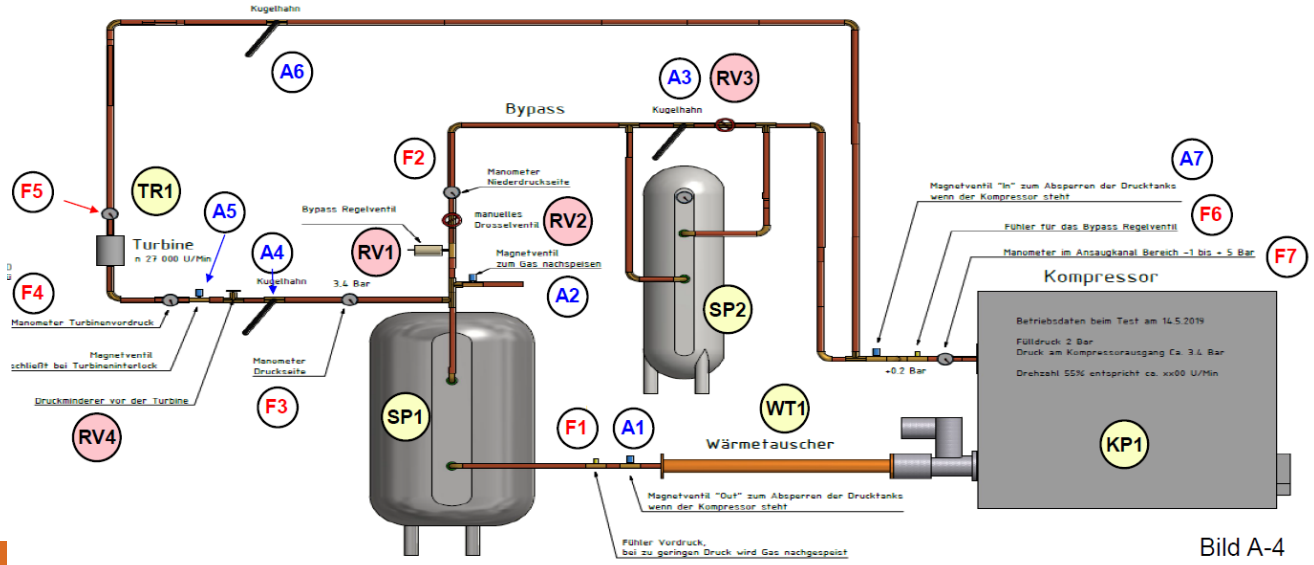


Bild A-4

- Tank can **accommodate two platforms + gun and collector**
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Preparation for “scalability”

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

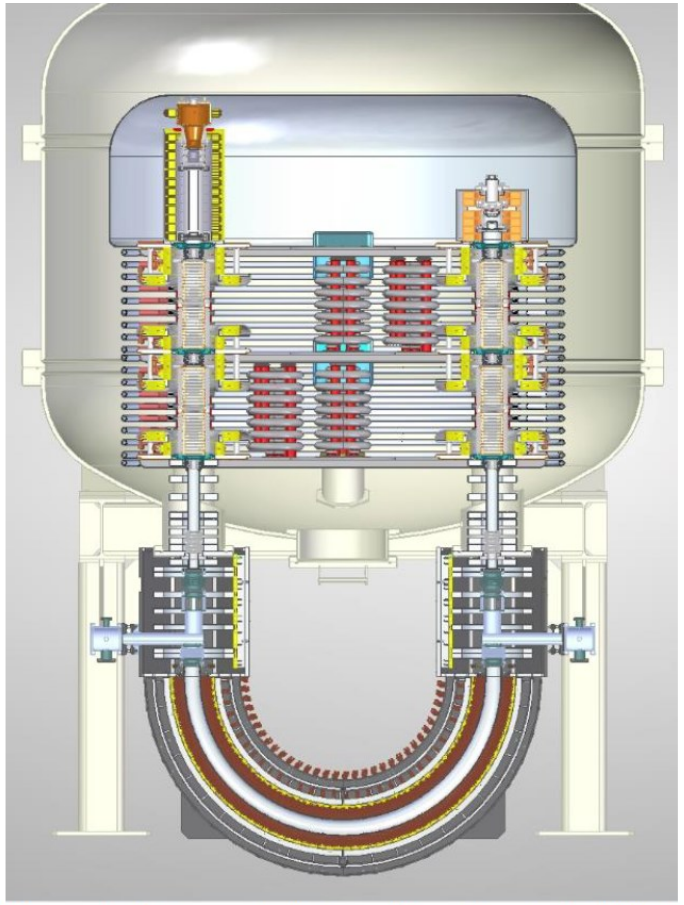
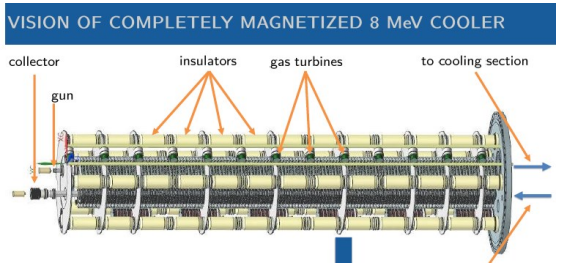


Figure 1.2: General picture of test-bench 1.2 MeV

- 2018-2019: Design study by BINP for usage of Prototype stage at HIM
- New project: 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 2022
- Qualified system should be scalable towards HESR energies



However, Electron cooler presently not "top priority" at FAIR
What will we do with the prototype, until HESR becomes available?

Device presently is a „technology platform“
→ Can it used for something „scientific“ ?

Using the device for applied/fundamental research ??

There are many 600kV DC- accelerators in the world, but….
“Big Blue Bubble” has special features.

- Large power/good cooling available on terminal

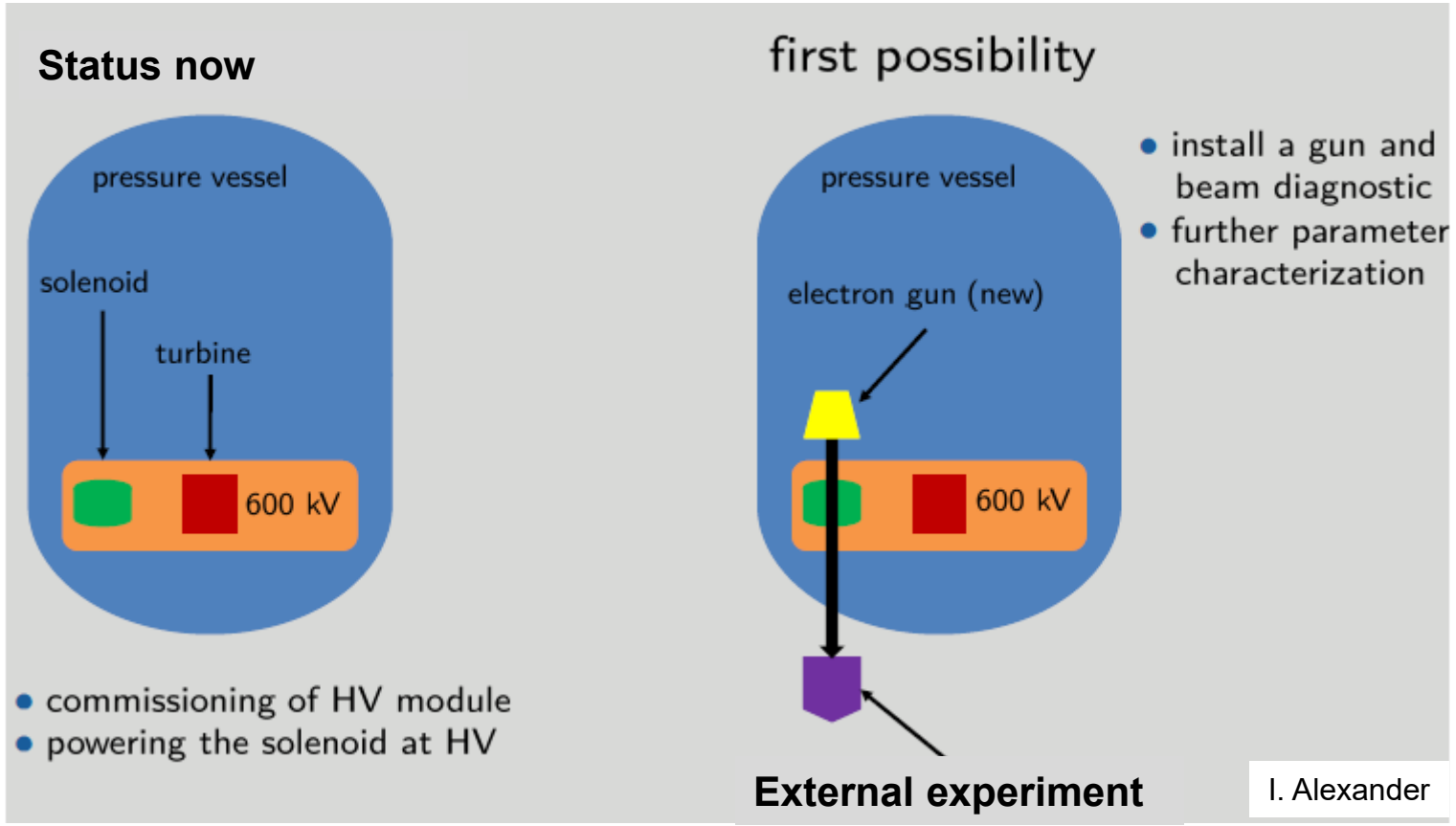
- Lot of space at the terminal

- No SF6 needed.

- Accessibility relatively good

What could we do with it?

Future extension plans: Medical research

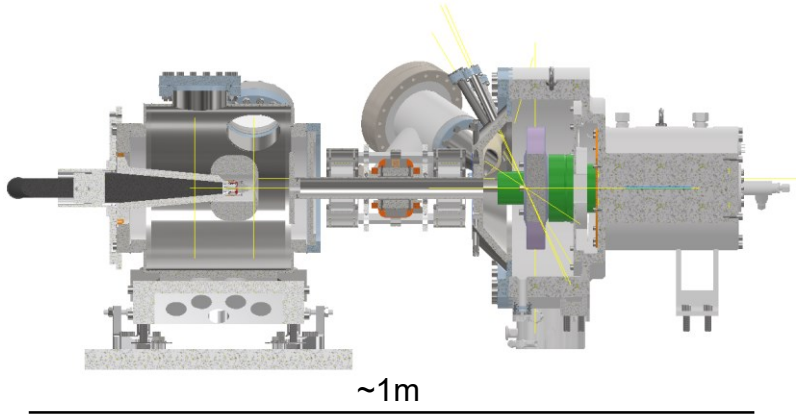


Recent Funding proposal: Xray “flash guidance dosimetry”

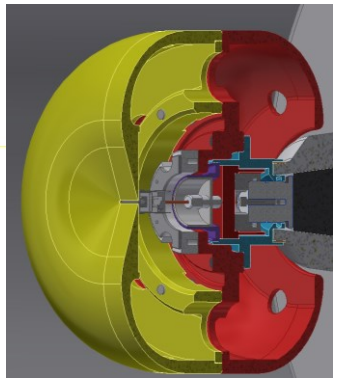
Principle of “Microflash” radiation therapy

J. Winter at al. Physics and Imaging in Radiation Oncology 14 (2020) 74–81

beam is focused towards highly eccentric beam spot
15*0.05 mm
- “microstructured” radiation field after collimator
- Cooling in anode is done by electron scattering, not conductivity (heat capacity limit vs. conductivity limit)



300keV, 30mA
Preclinical protoype (TU Munich)

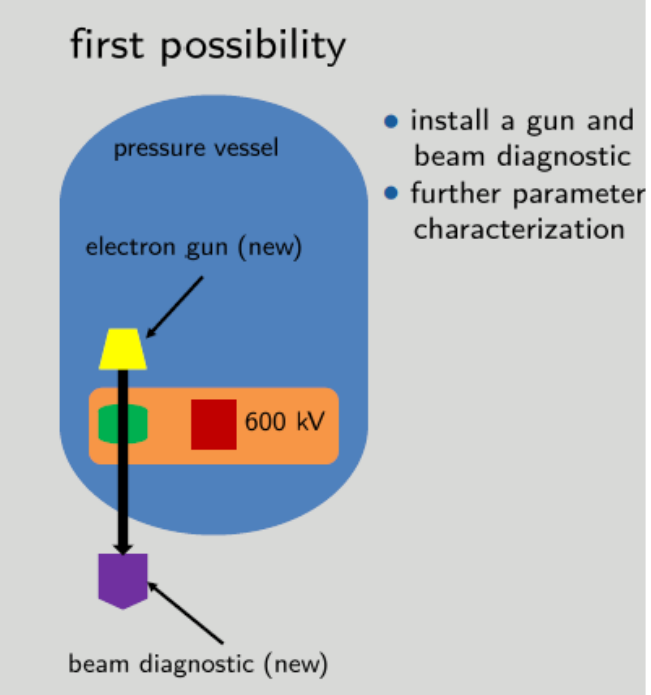


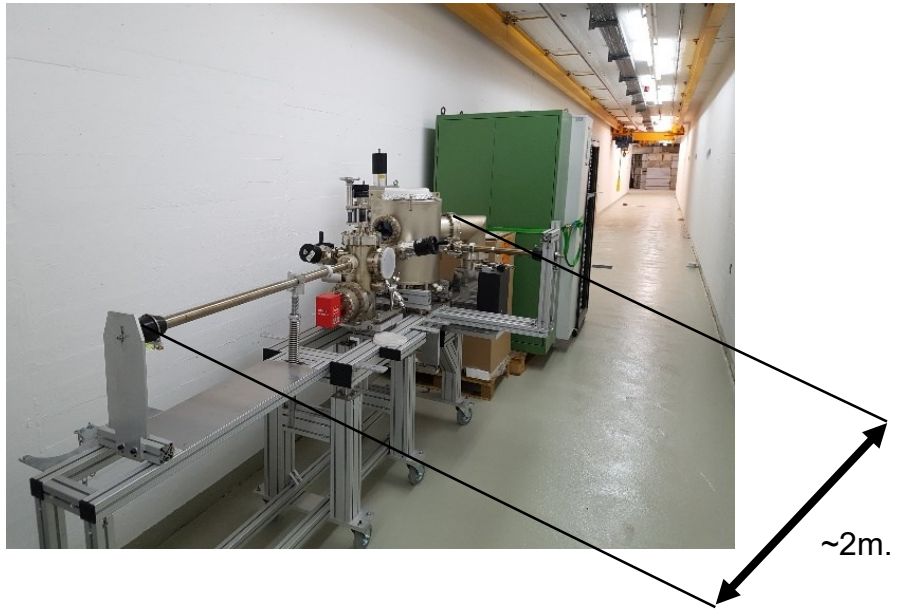
Cathode assembly

Imminent problem of such devices:

Dosimetry & targeting

Applied research at Big Blue Bubble?





Photosource “STEAM”

-will be used with very low duty cycle
- 5ns pulses, 2.5 A, 1-10Hz
- Home build K2CsSb cathode
- “Cheap” 2nd harmonic Nd:Yag Laser needed

→ Flash dosimetry

External experiment: Dosimetry of X-ray flashes (ns, >100 Gray/s peak dose rate)

Particle Physics at Big Blue Bubble?

A photosource can also produce spin-polarized beams.

Interesting projects, discussed at SPIN 2021

(both profit from Mott polarimtry with good in the ~1MeV energy range)

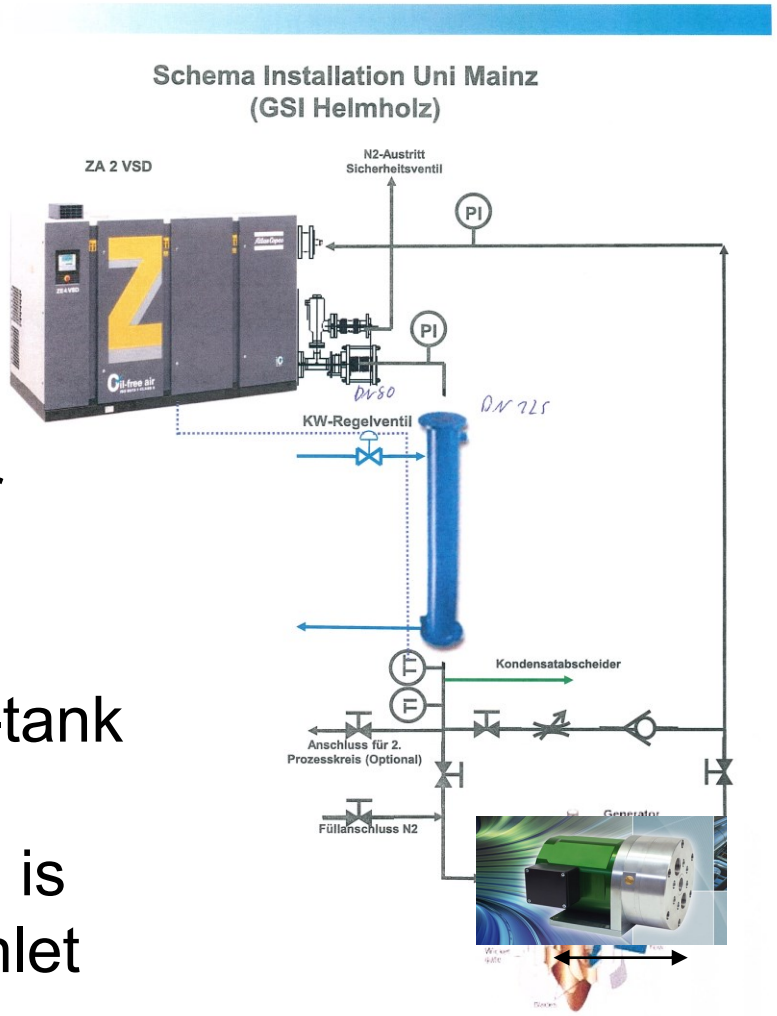
- Spin correlations in Moller scattering of relativistic particles (already performed at MAMI, 3.5MeV):
  Michał Dragowski et al.: Measurement of Polarization Transfer in Møller Scattering

- Electron EDM in all electrostatic ring with two energies (300keV, 600keV), suggestion from JLAB:
  R.Suleiman, V.S. Morozov and Ya. S. Derbenev: EDM in small rings

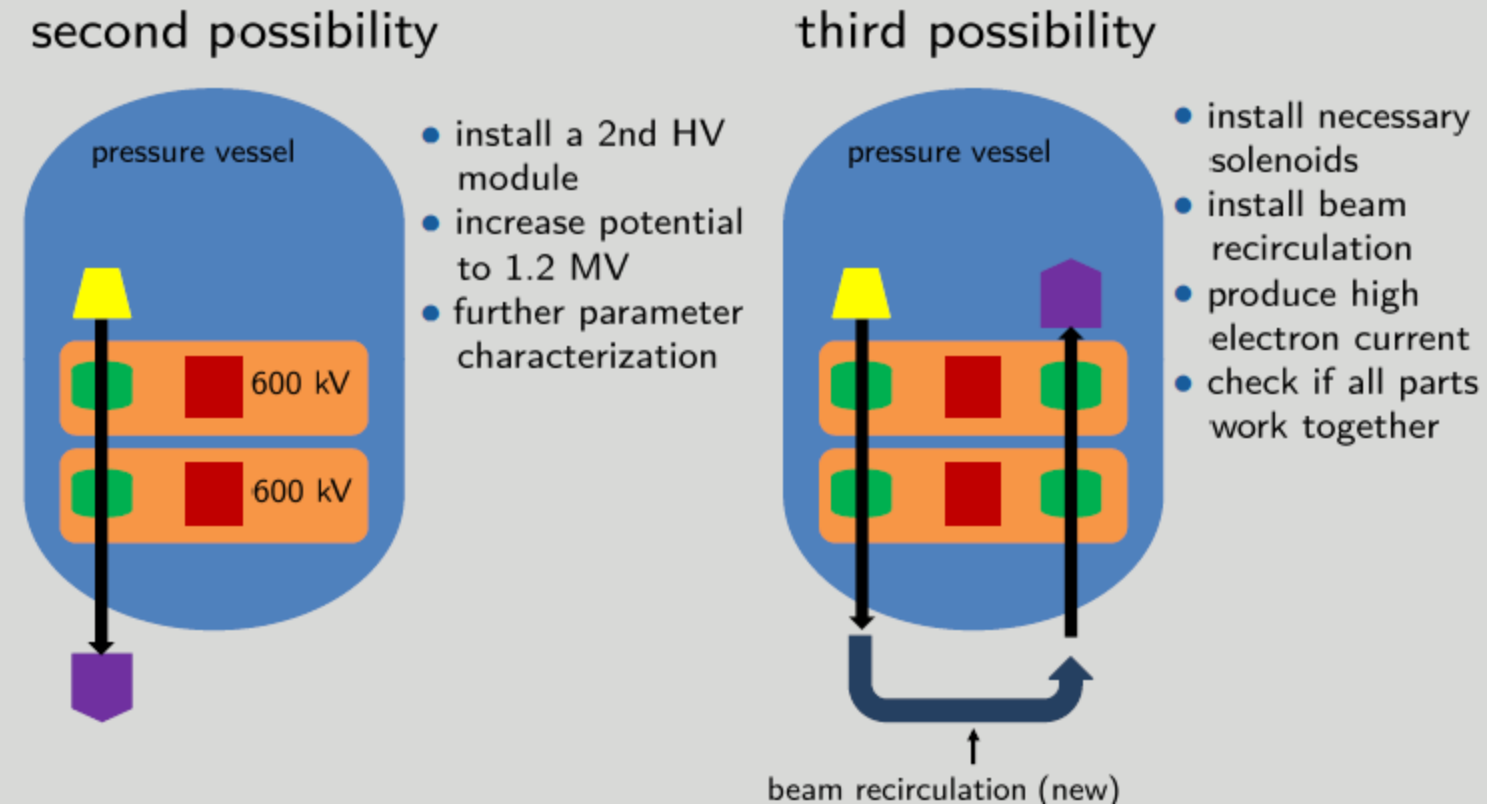
Thank you!

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:

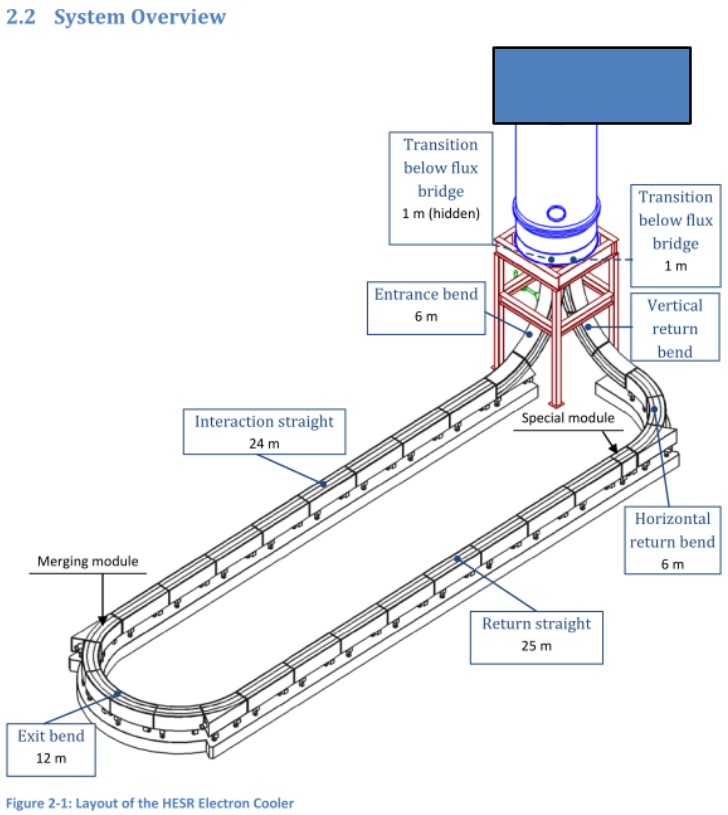


Figure 2-1: Layout of the HESR Electron Cooler

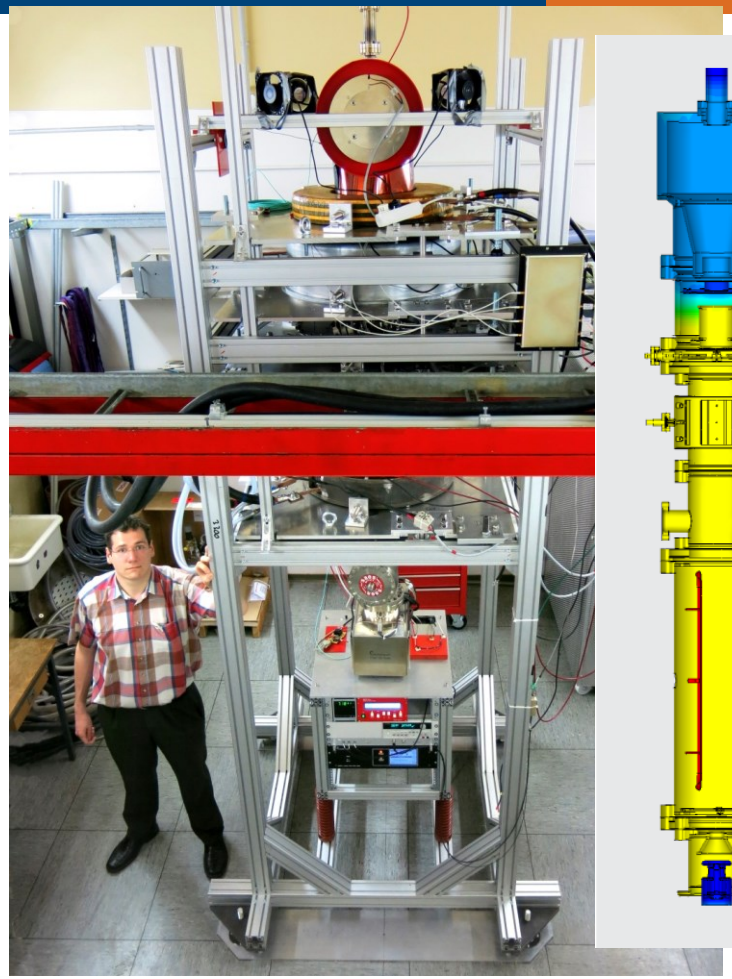
Idea:

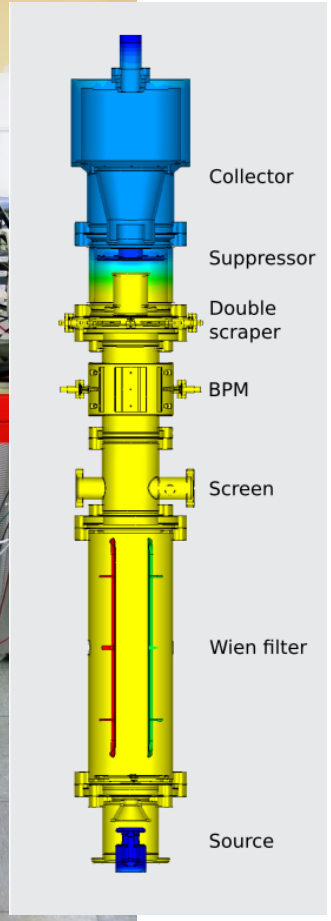
- Investigate source/collector system in order to define expected operation conditions at 8MV!

- 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

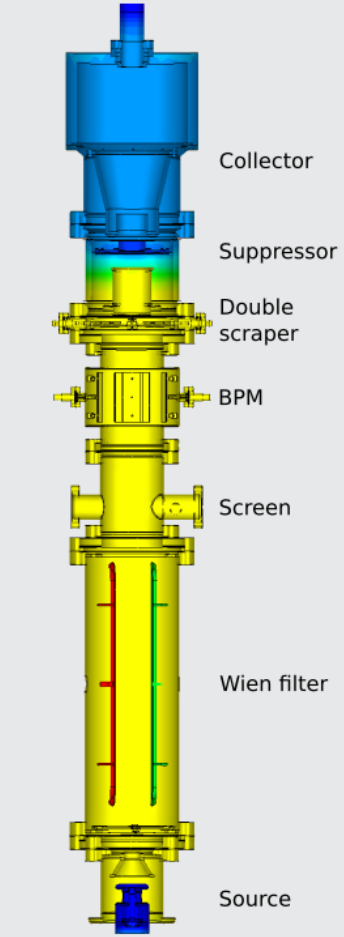


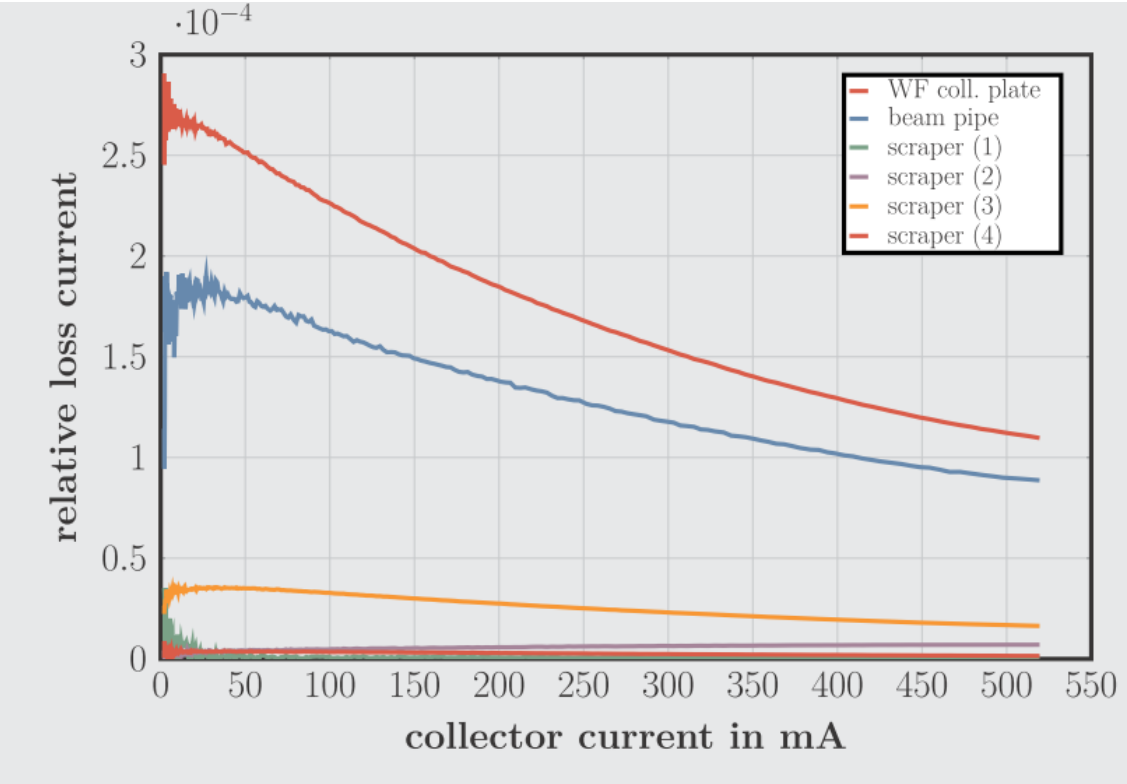


Selected results

- 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)

Poster by Max Bruker , Monday

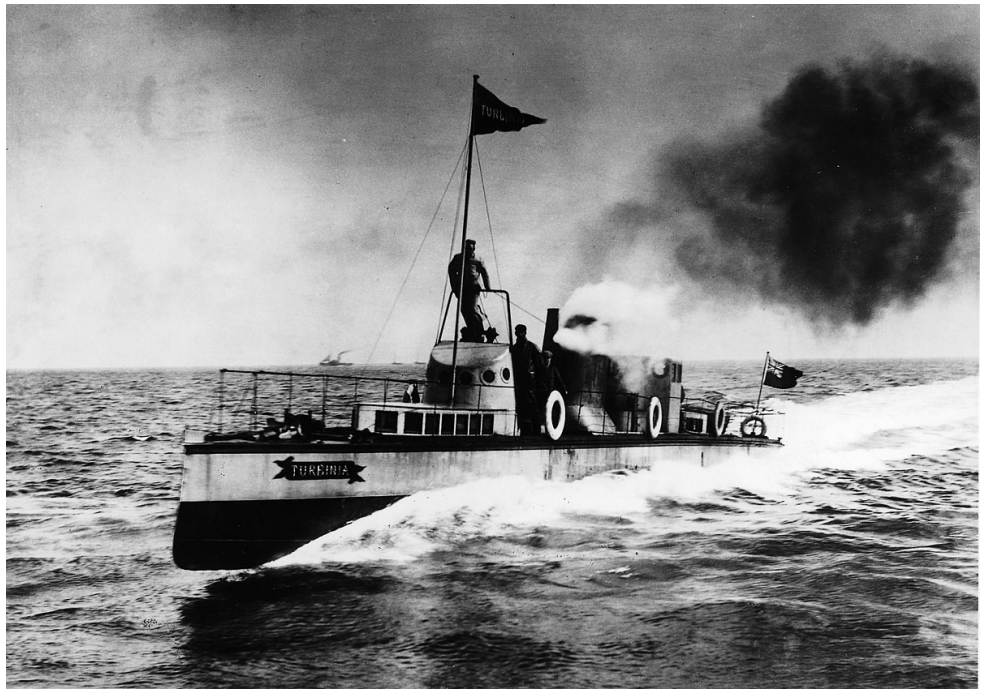




Poster by Max Bruker , Monday

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?)