Karlsruhe Institute of Technology

Progress in the cryogenics work package

InnovEEA Project Meeting, 30.03.2022

Jonas Arnsberg, Steffen Grohmann

Throwback to the results in November

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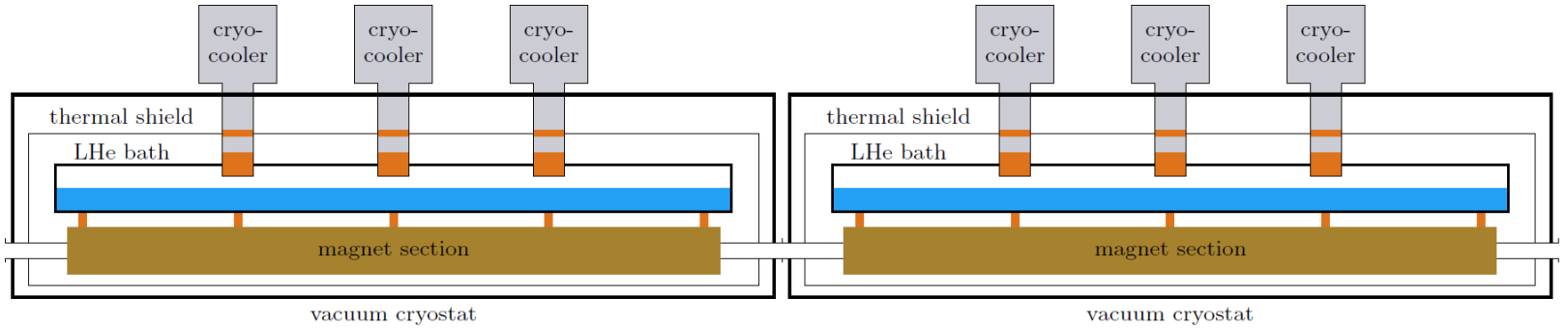
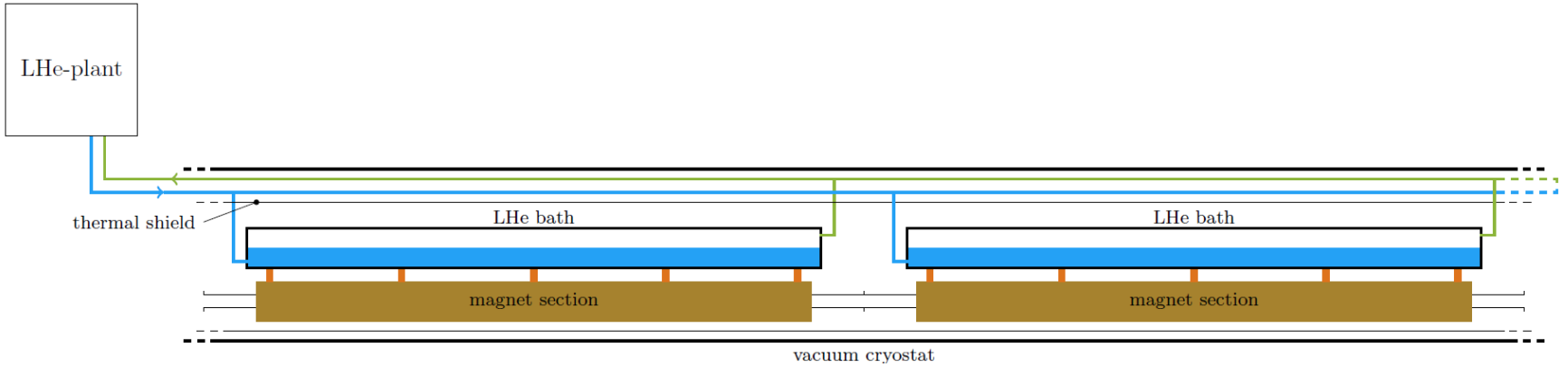
SC System Technology

Throwback to the results in November

- CompactLight design study comparing cryostat designs
  - Cryoocooler-cooled design:



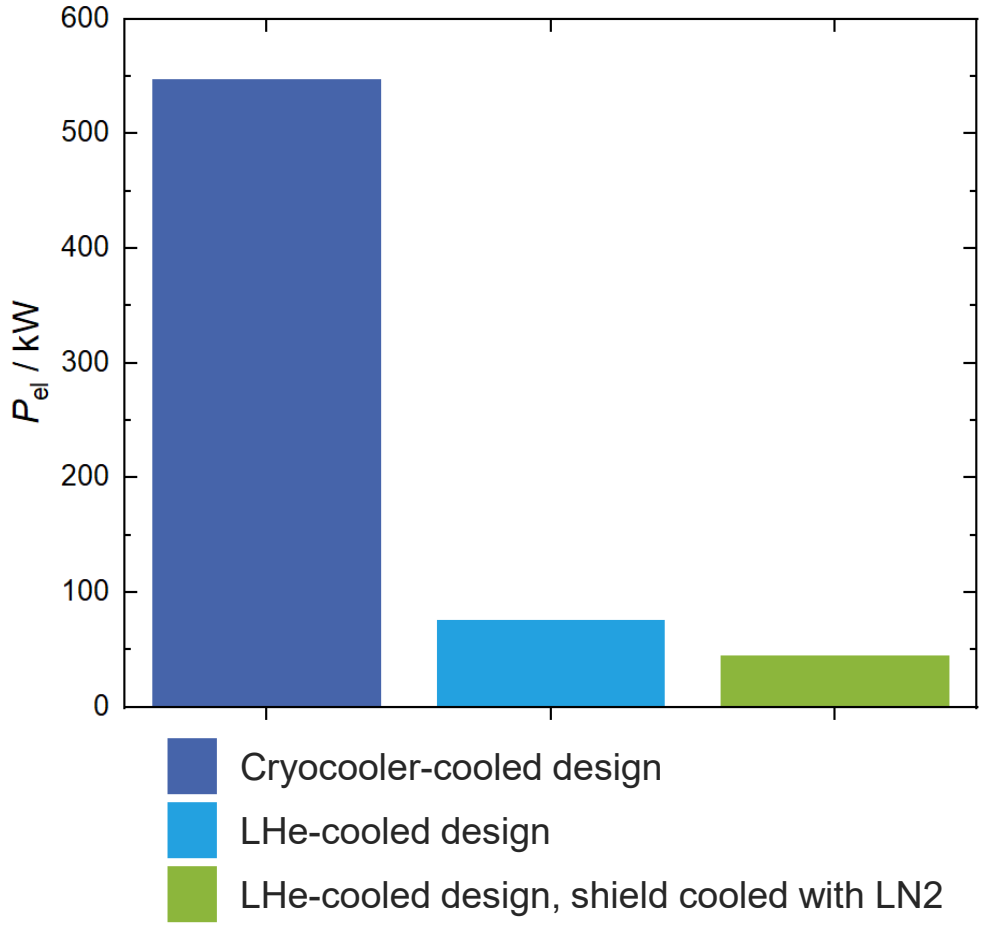
  - LHe-cooled design:



Throwback to the results in November

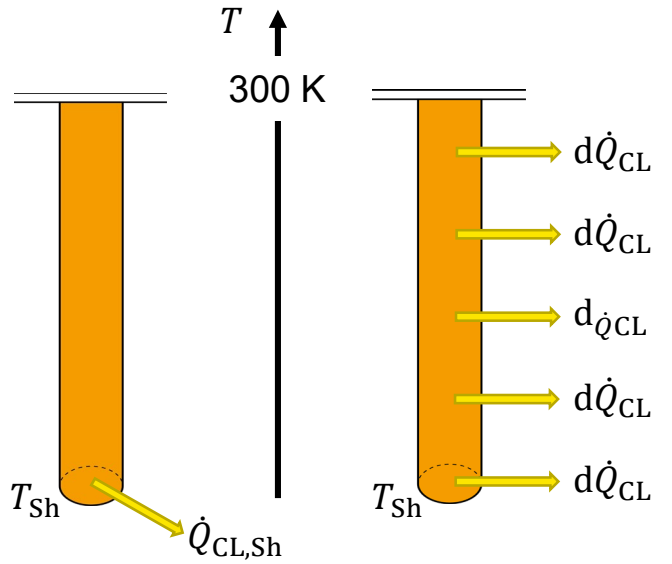
- Heat load estimation for both cryostat designs
  - Cryoocooler-cooled design
  - LHe-cooled design
- Comparison of required **power input** for cooling
- Heat load estimation showed **75 %** of cryogenic heat load arising from 18 current leads per segment

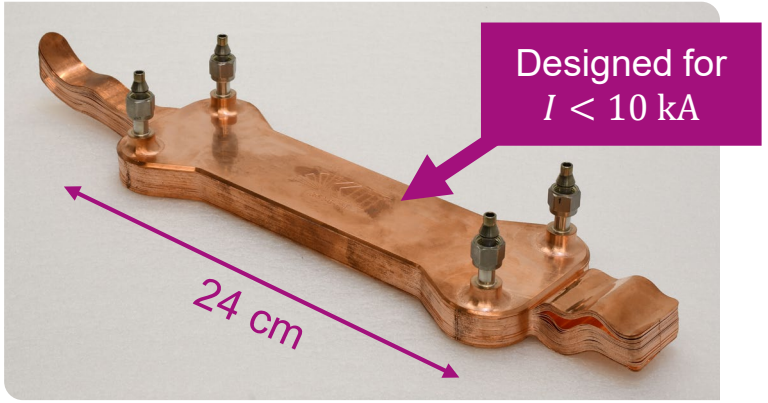
High potential for optimization!



Throwback to the results in November

- Comparison of current lead cooling designs
  - (Classical) conduction cooled current leads with heat absorption at the cold end
  - (Novel) mixed-refrigerant cooled current leads with continous heat absorption
- Current leads cooled by mixed-refrigerant cycles promise **reduction of power demand by ⅔** [1]
- Development of **microstructured mixed-refrigerant cooled current lead** prototype
  - Ultra compact – 24 cm long
  - Ultra efficient – heat absorption at the source
  - Scalable, fitting the specific application





[1] Shabagin, 2022.

Compact Accelerator Systems Test Stand (COMPASS)

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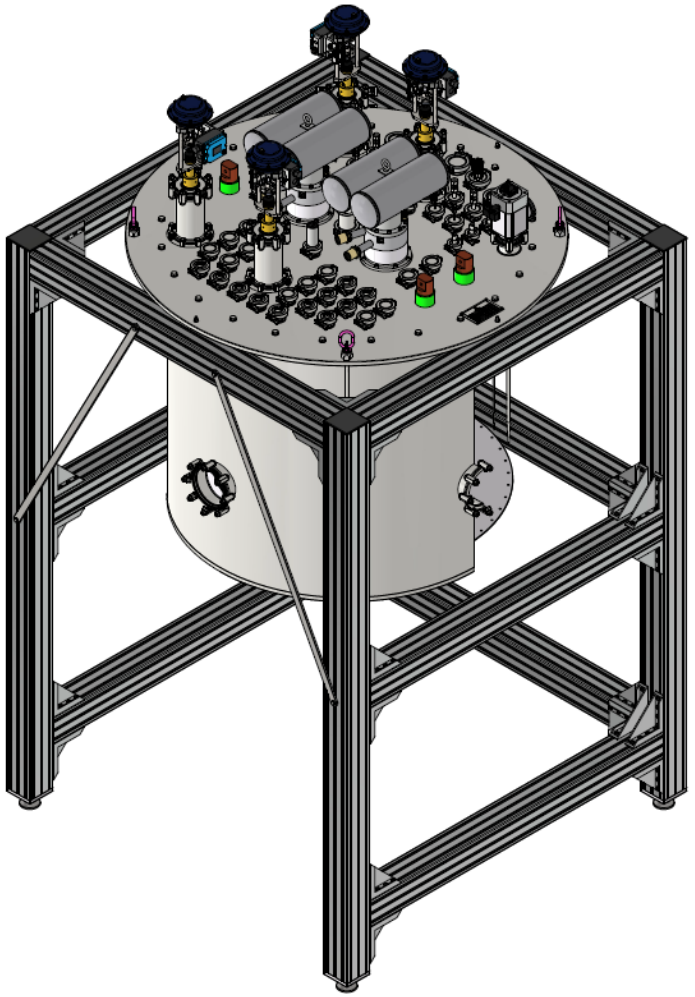
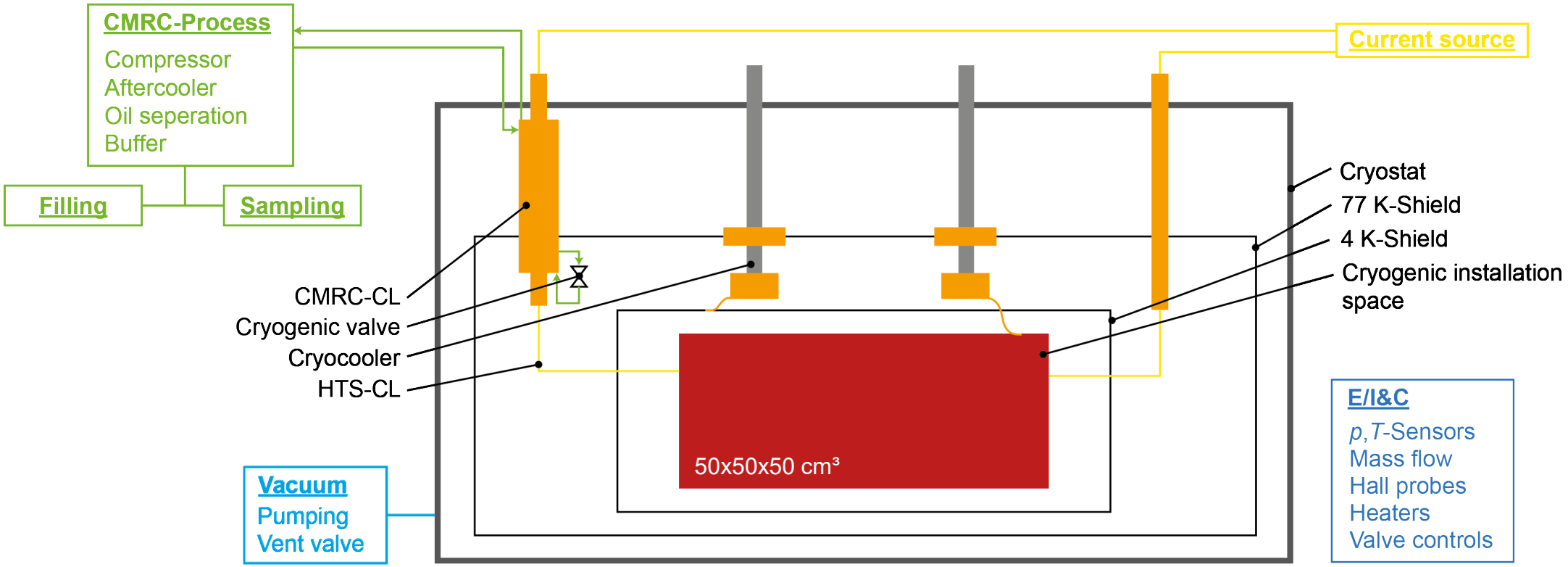
COMPASS – General aspects

- Dedicated experimental facility to study compact accelerator components
  - Microstrutured mixed-refrigerant cooled current leads (MSCL)
  - Superconducting magnets and undulators
  - SC-cavities
- Two mixed-refrigerant cycles to cover broad power spectrum
  - Supply currents for superconducting systems from a few 100 A to 10 kA
  - Testing mixed-refrigerant cascades[2], for providing cooling power at $T \ll 78\ \mathrm{K}$



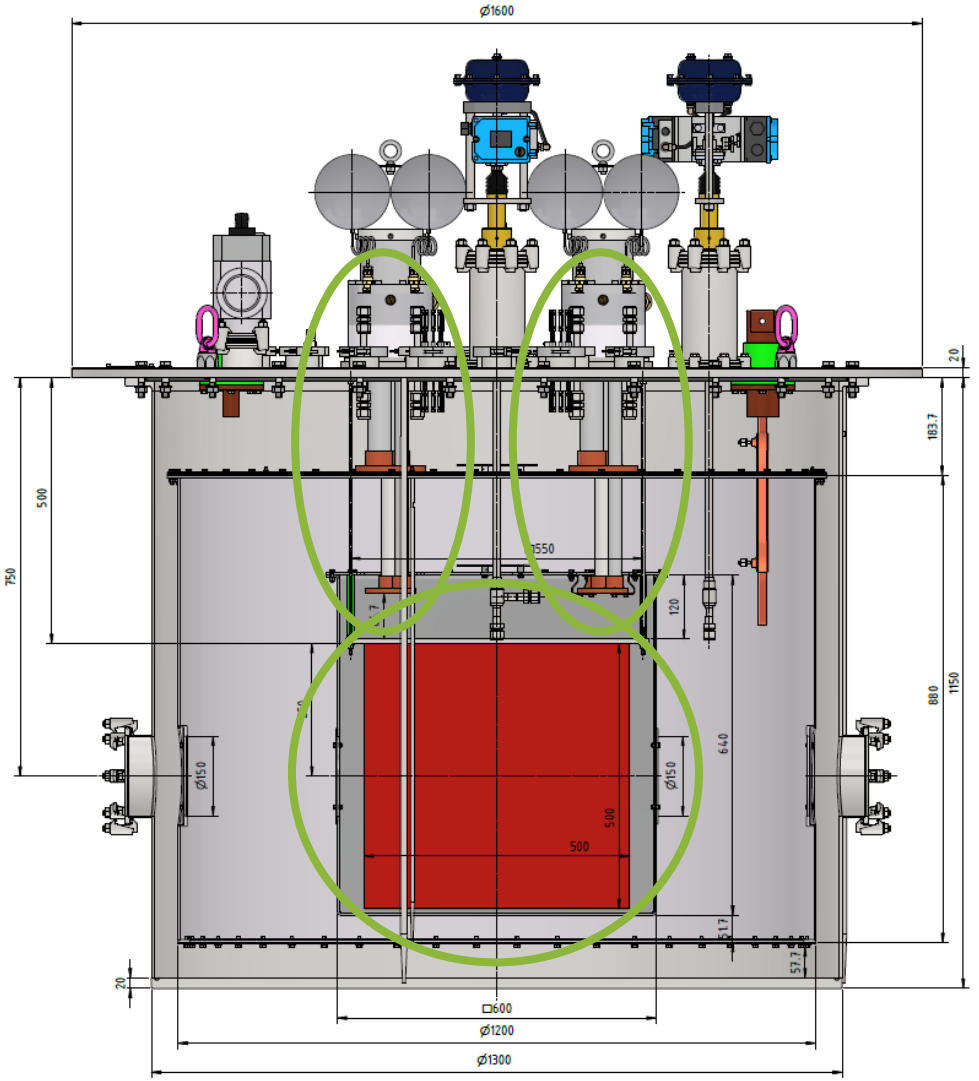
[2] Kochenburger, 2019.

COMPASS – Schematic overview



COMPASS – Cryostat design

- Cryostat vessel of 1300 mm diameter
- Shields cooled by two Cryocoolers (PT425, Cryomech[3])
  - 77 K-shield cooled by 1st stages
  - 4 K-shield cooled by 2nd stage
- Field measurements in LTS-magnets or cavities possible
  - Installation space for cold mass 50x50x50 cm³



[3] www.cryomech.com.

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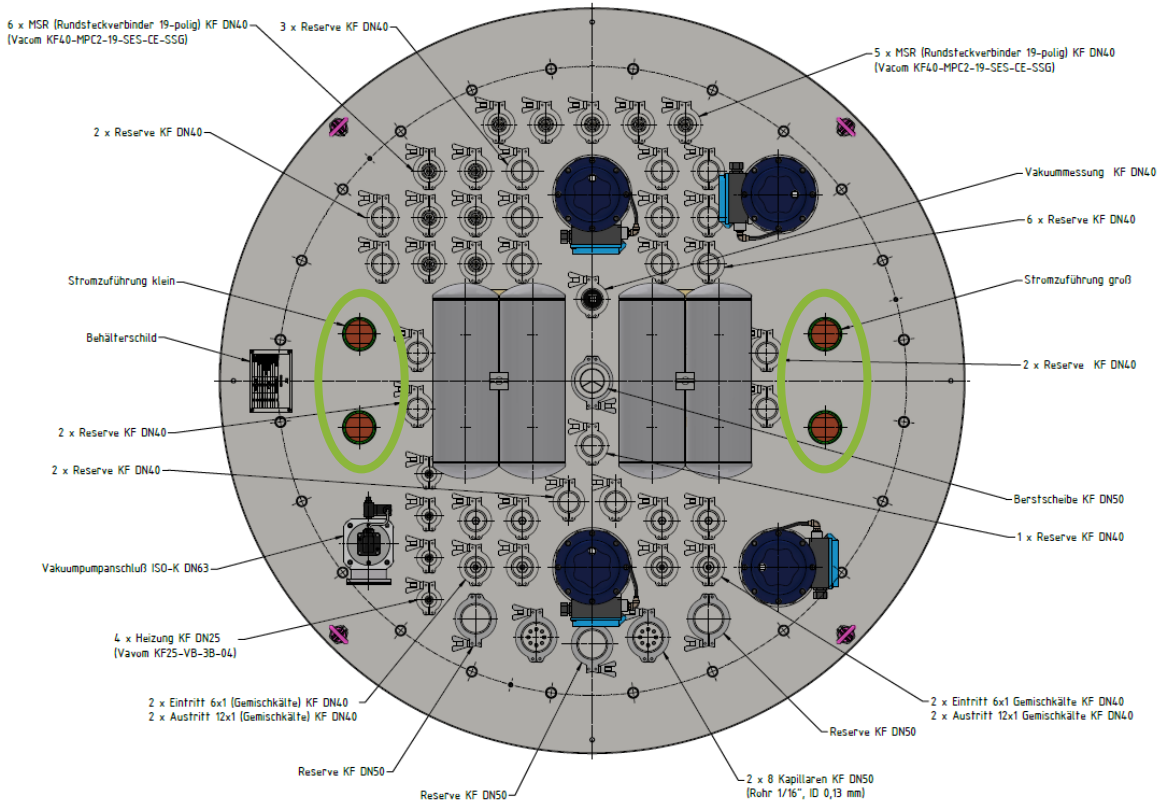
  - CMRC-cooled and classical conduction cooled current leads



[3] www.cryomech.com.

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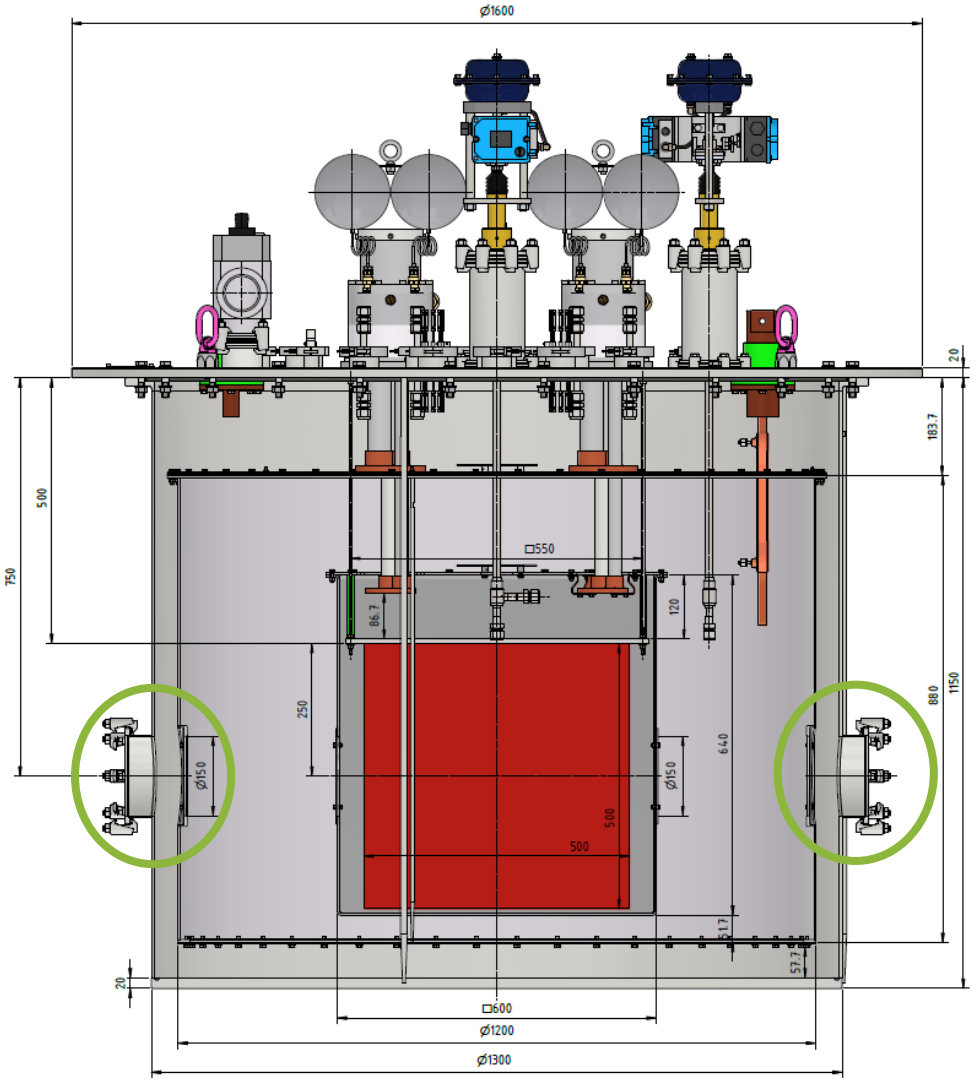
  - Optical access from four sides



[3] www.cryomech.com.

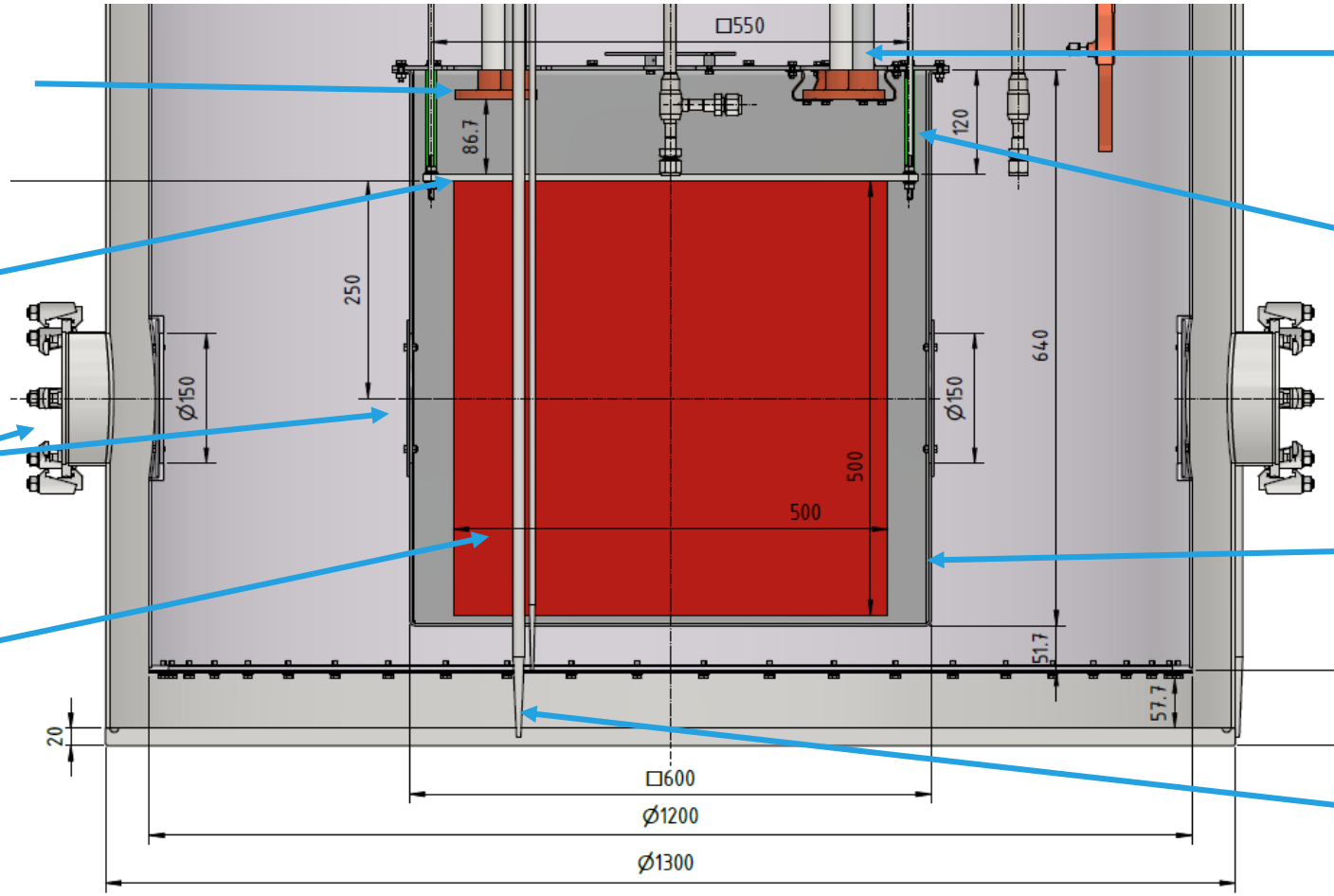
COMPASS – cryogenic installation space

Cryocooler for cooling of test systems (2.7 W @ 4.2K)

Suspension for cryogenic test systems

Optical accesses (DN150)

Installation space



Cryocooler for shield cooling (2.7 W @ 4.2K)

Insulation of suspension by GFK-shells

4 K-shield

Detachable guiding rods for shield and vessel

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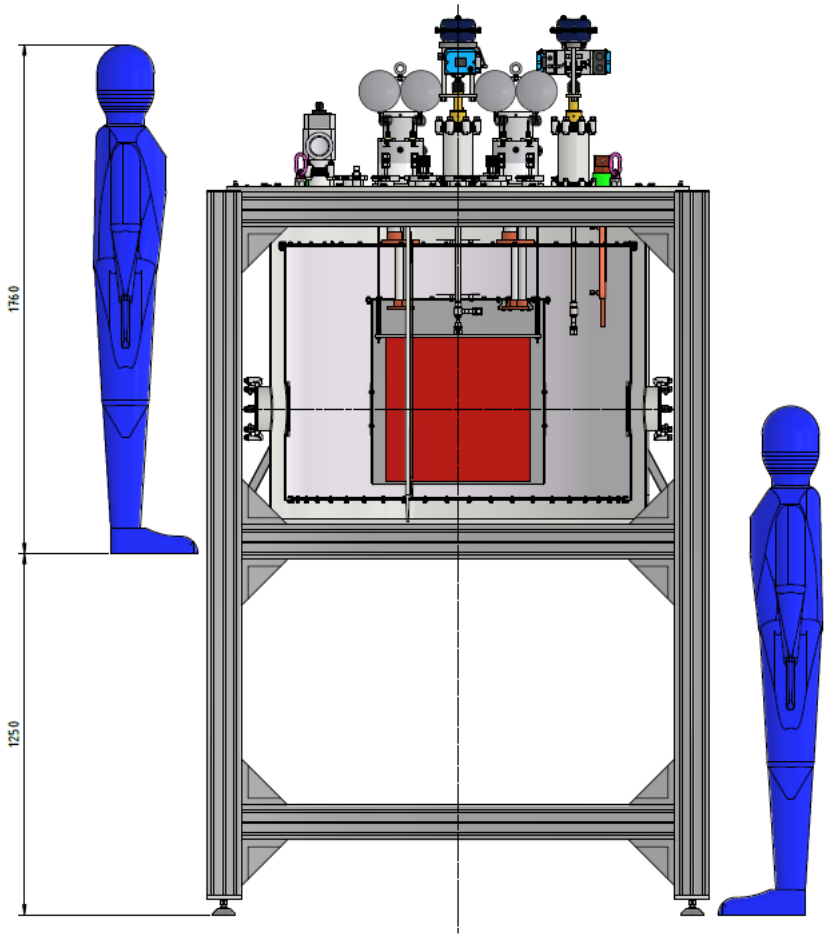
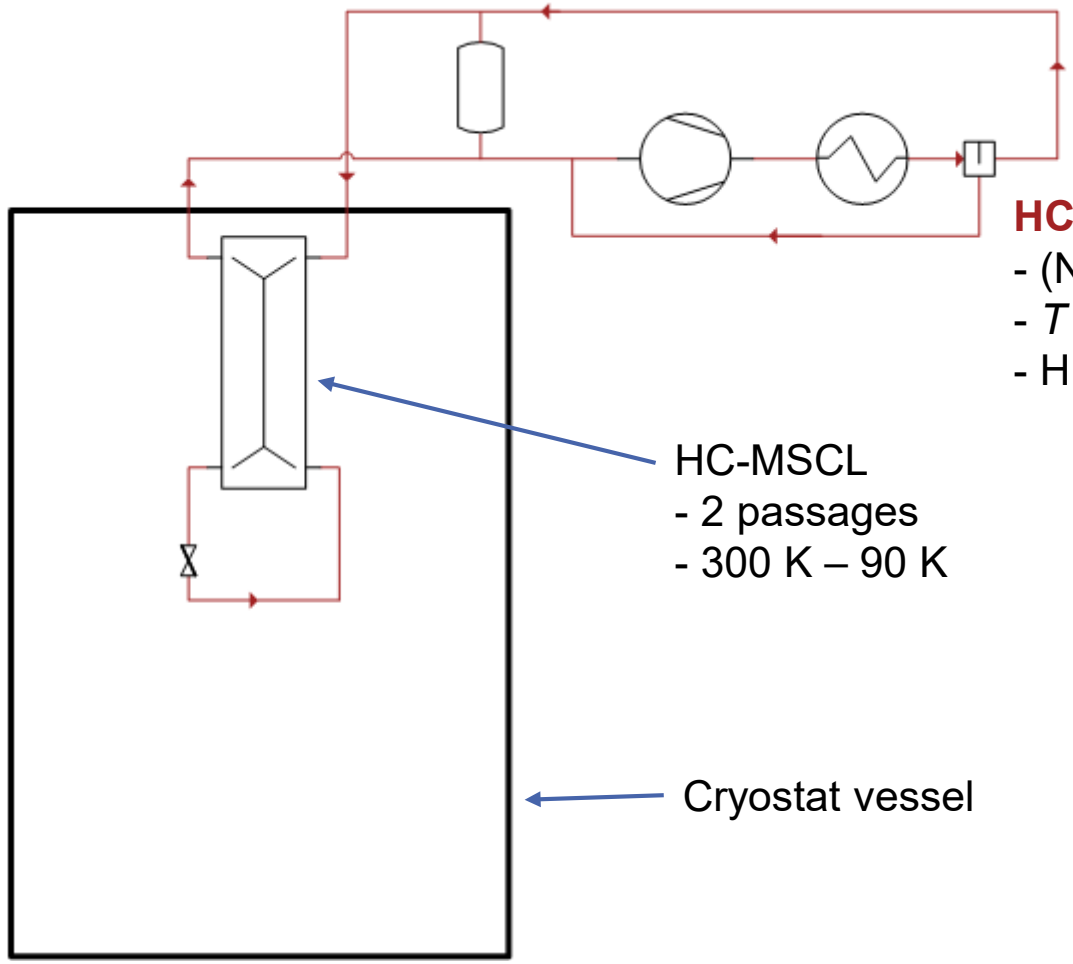
COMPASS – Cryostat set-up

- Cryostat in hanging set-up
  - Lid attached to frame 2.5 m above ground
  - Cryostat vessel to be attached and detached from below
  - Lowering of the vessel by lifting cart
  - ➢ No movement of the lid
  - ➢ Permanently installed wiring
  - ➢ Avoiding leakage of pipings and capillaries
- ITEM-frame dimensioned for total load of 2500 kg
- Working platform to reach cryostat lid



CMRC-Process

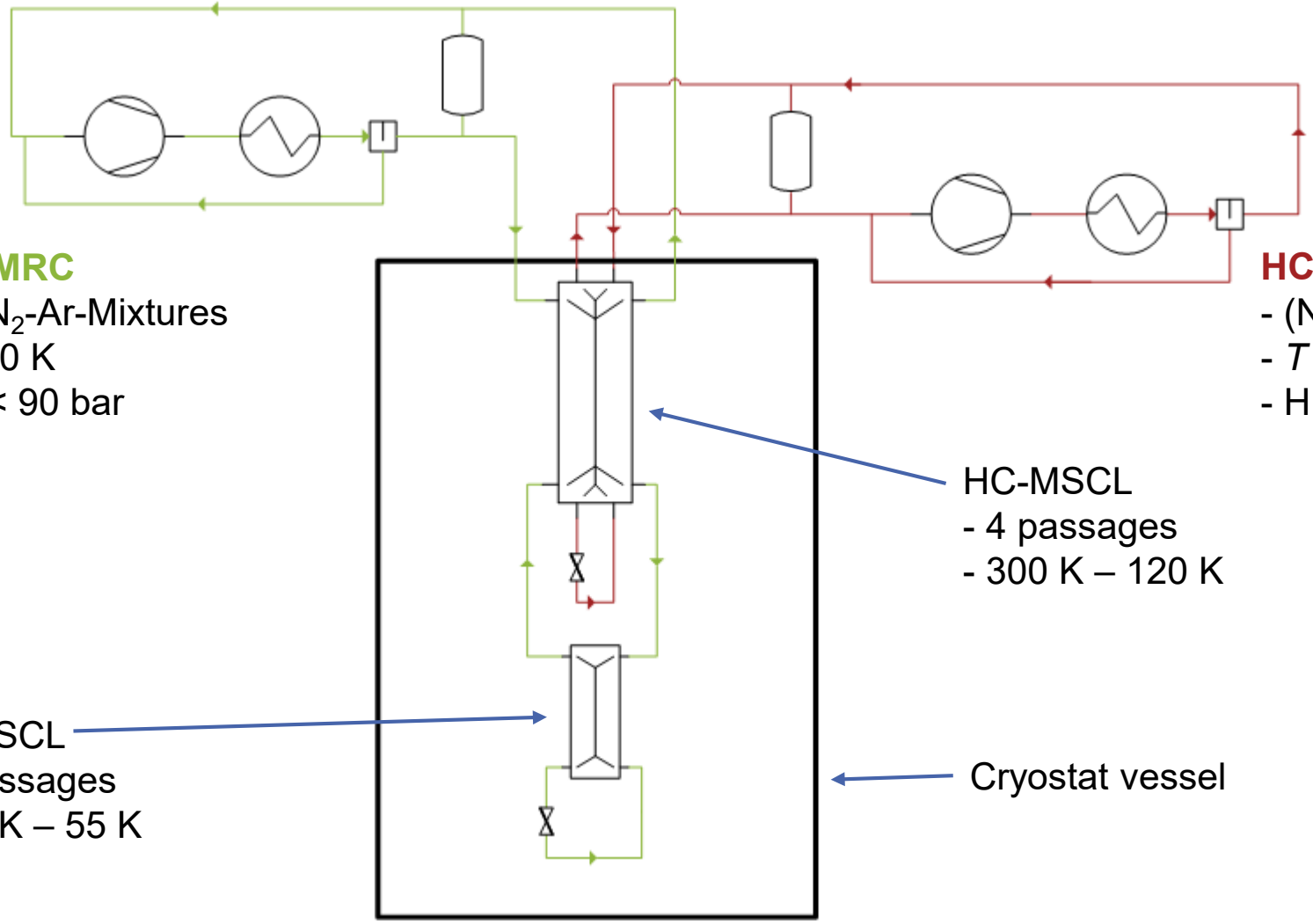


HC-CMRC
- (Ne-)N_2-HC-Mixtures
- T < 90 K
- HP < 30 bar

HC-MSCL
- 2 passages
- 300 K – 90 K

Cryostat vessel

CMRC-Cascade



LC-CMRC
- Ne-N_2-Ar-Mixtures
- T< 60 K
- HP < 90 bar

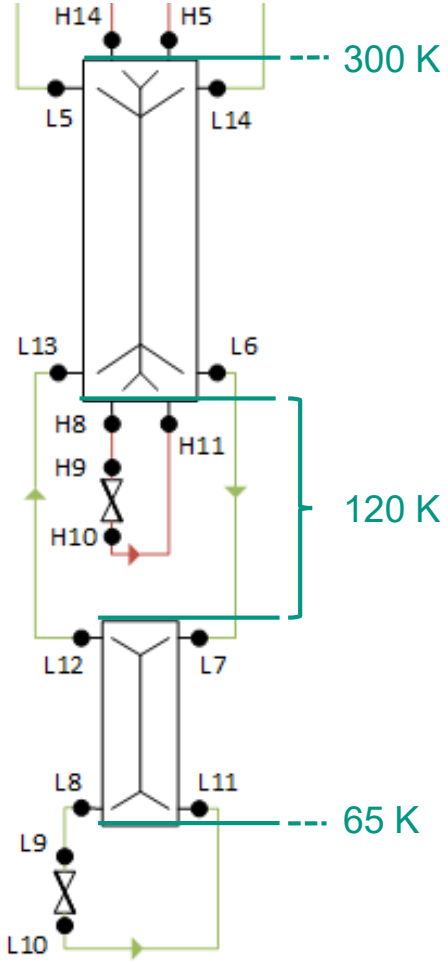
HC-CMRC
- (Ne-)N_2-HC-Mixtures
- *T* < 90 K
- HP < 30 bar

HC-MSCL
- 4 passages
- 300 K – 120 K

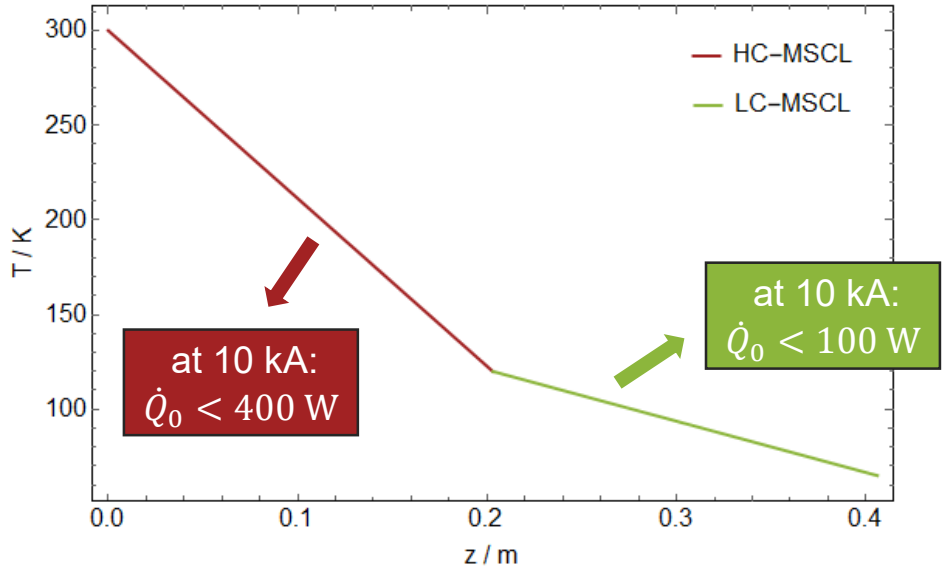
LC-MSCL
- 2 passages
- 120 K – 55 K

Cryostat vessel

Cooling power estimation



- Calculation of heat load due to ohmic losses and parasitic heat conduction
- Assumptions
  - Linear temperature profile in both CMRC-MSCLs
  - Geometry of mechanical prototype for both CMRC-MSCLs



Required cooling powers:
- HC-CMRC: 500 W
- LC-CMRC: 100 W

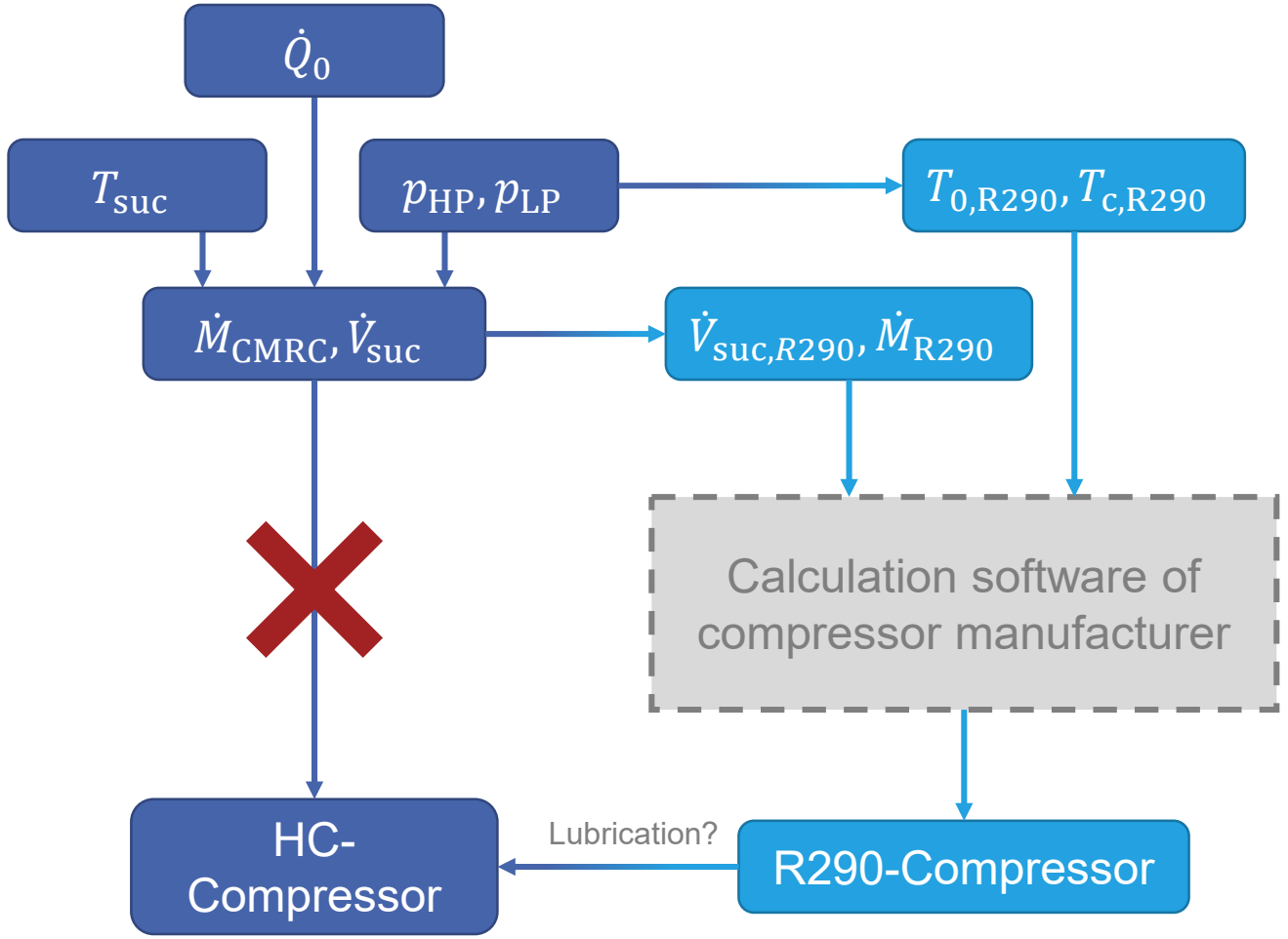
Compressor choice

- Basis: required cooling power
- Boundary conditions: $p_{\mathrm{HP}}, p_{\mathrm{LP}}, T_{\mathrm{suc}}$

- Problem: No commercially available compressor for specific mixtures

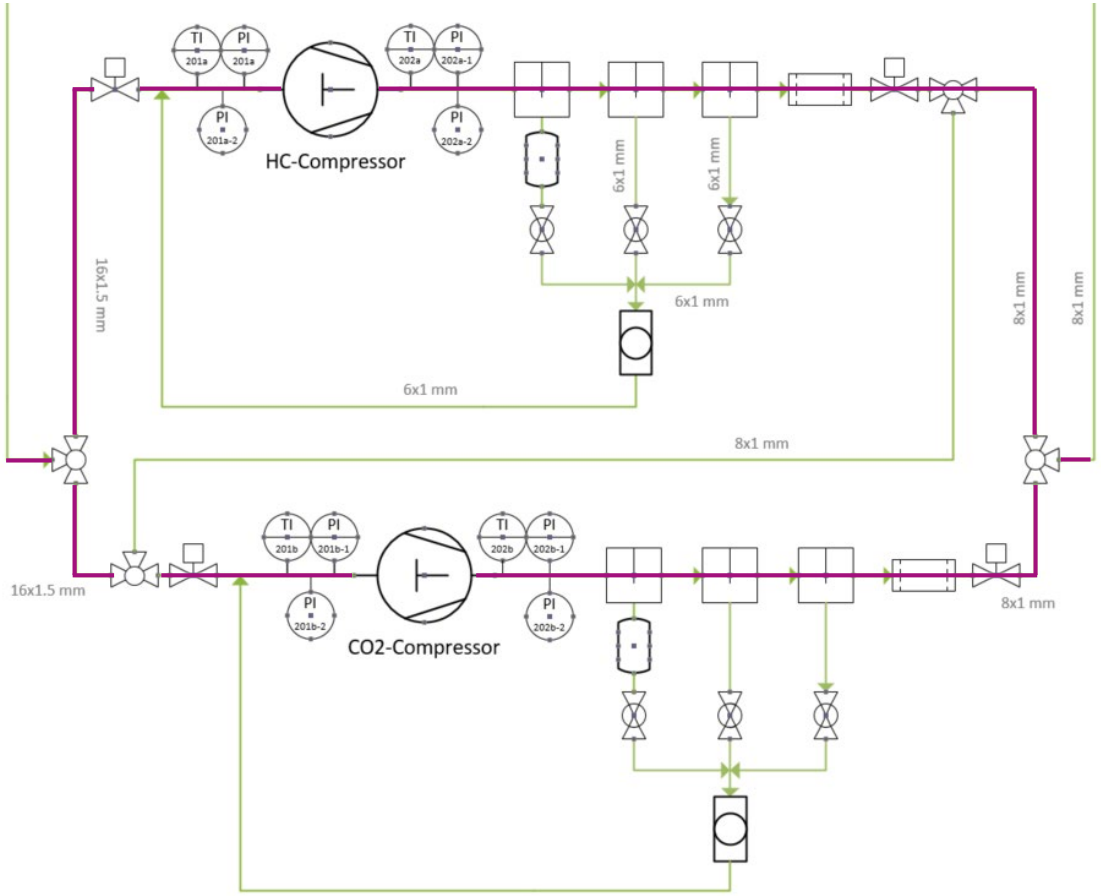
➢ Propane-(R290)-compressor for HC-CMRC
  - Conversion of boundary conditions for CMRC to pure fluid properties required
  - Type of compressor oil must fit mixed refrigerant

➢ CO_2-Compressor for LC-CMRC providing high pressures



LC-CMRC – flexibility for smaller heat loads

- Additionally to the CO_2-compressor, a smaller R290-compressor is integrated
- Compressor operation
  - Individual, R290- or R744-compressor



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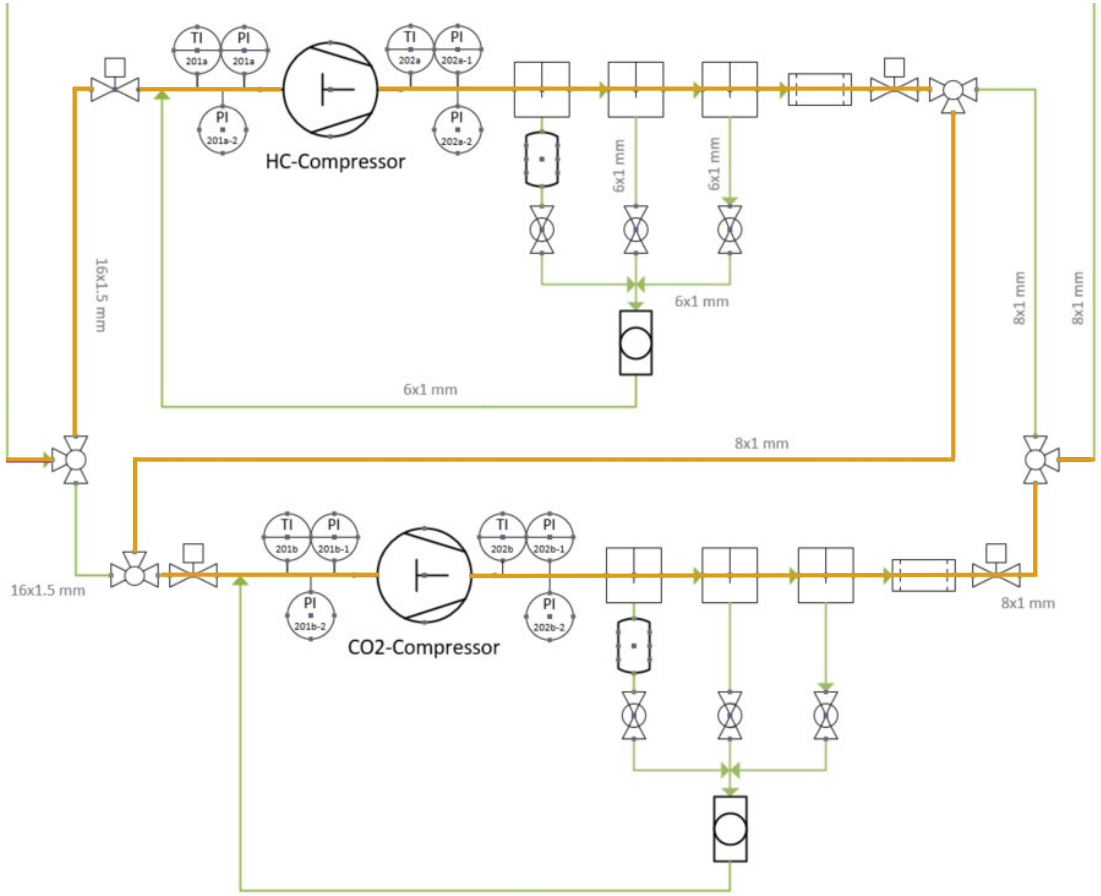
  - Serial, R290- as pre-stage for R744-compressor



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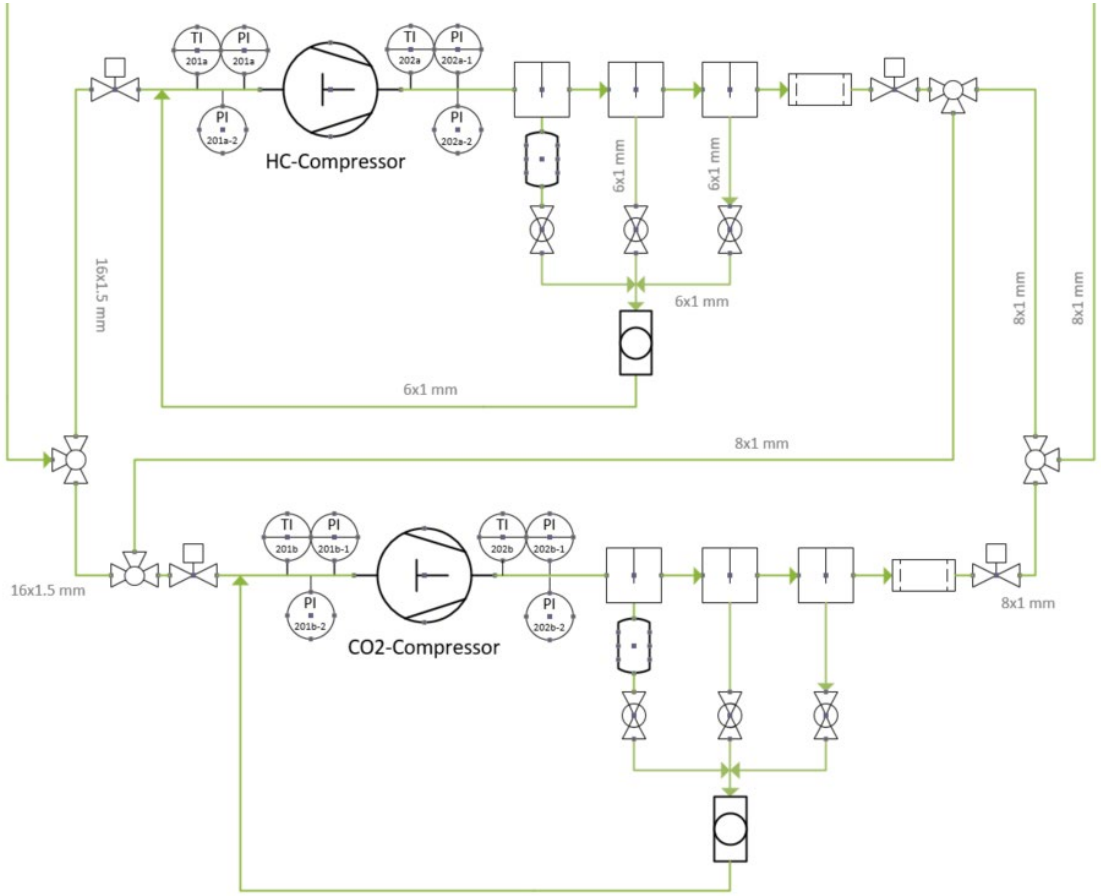
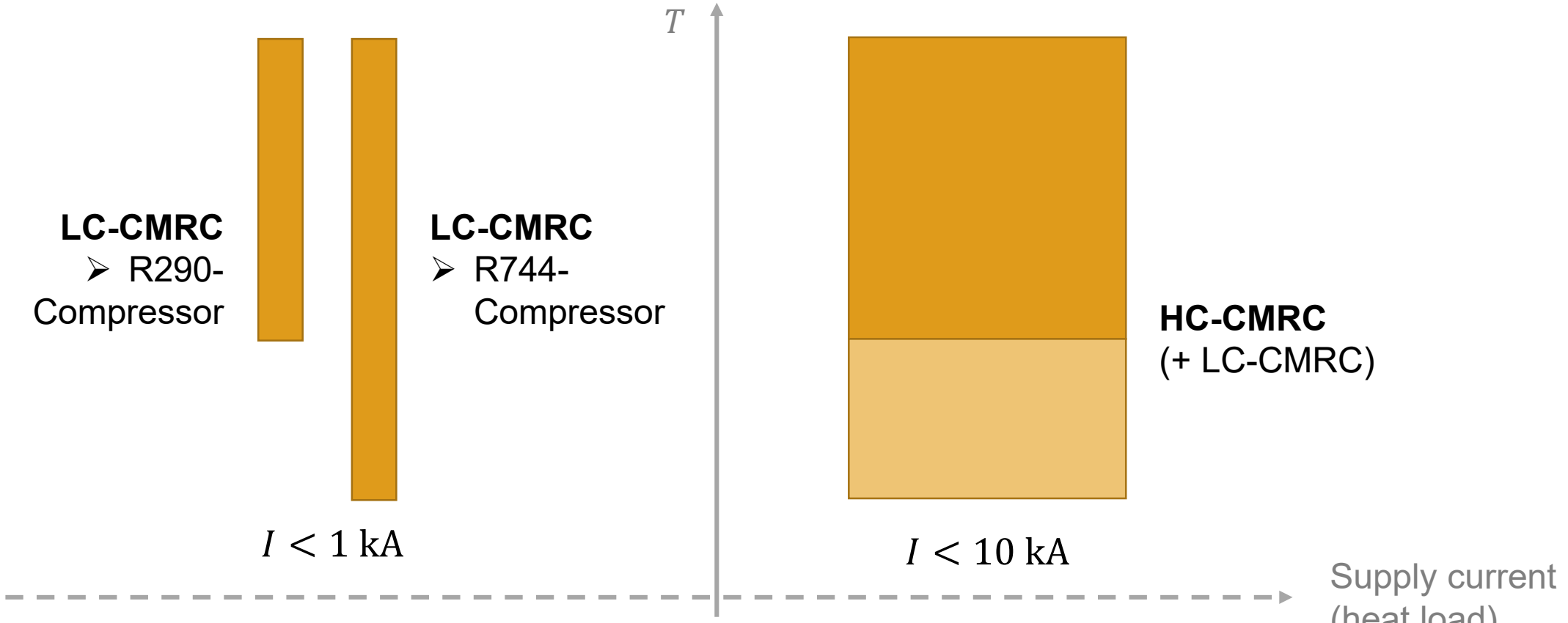
- Compressor operation
  - Individual, R290- or R744-compressor
  - Serial, R290- as pre-stage for R744-compressor
- Allowing operation of the LC-cycle for a heat load of 100 W with conventional pressures ($p_{\mathrm{HP}} < 25\ \mathrm{bar}$)



Adjustable operating conditions

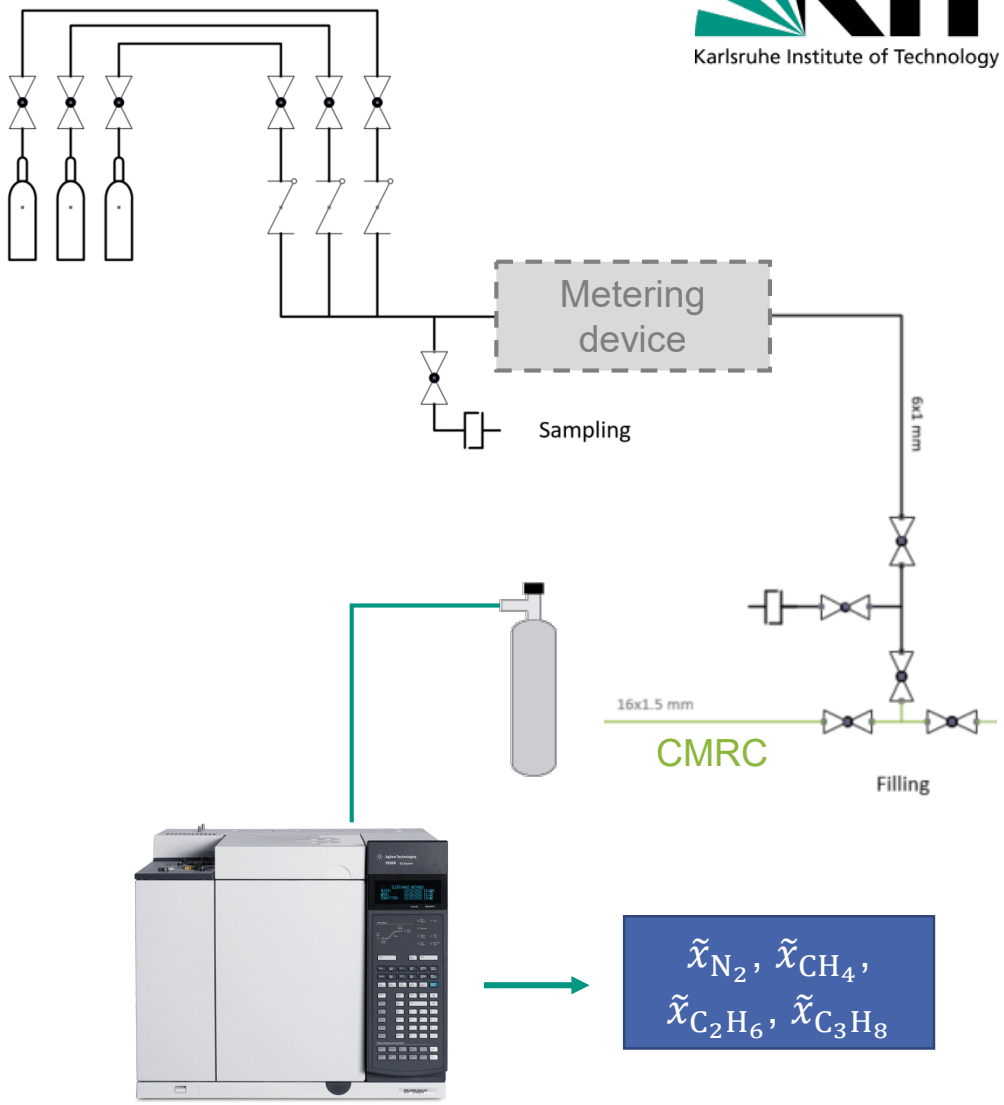


Maximum flexibility in terms of operating conditions

Filling & Sampling

- Filling directly from gas cylinder cabinet via leakage-proof pipe connections
- Metering device for precise dosing of single components
- Manual valves for sampling in sample cylinders
- Offline composition analysis via in-house gas chromatography

Exactly determined mixture compositions



[3] www.agilent.com

Summary & Outlook

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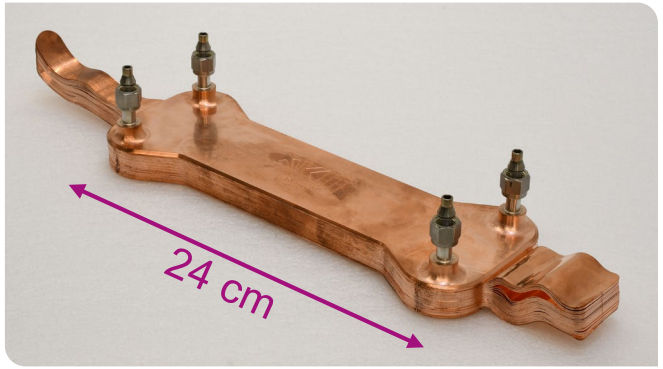
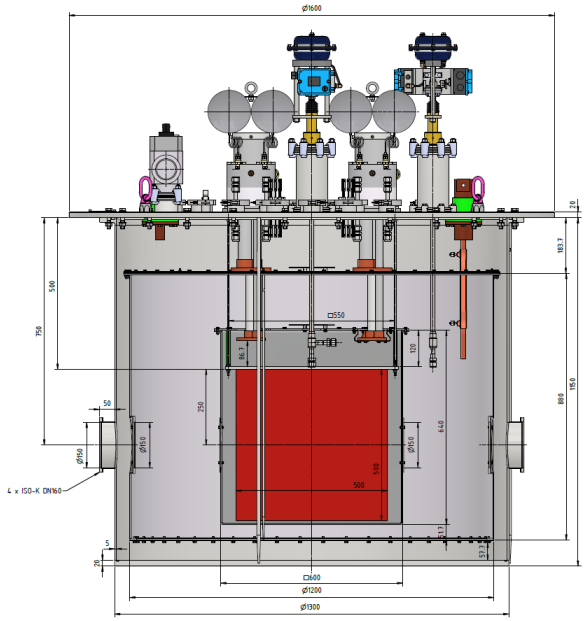
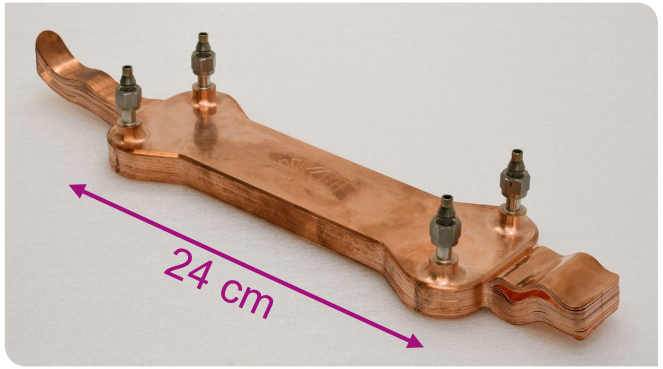
- Current leads cooled by mixed-refrigerant cycles promise **reduction of power demand by ⅔**
- **Mechanical prototype** of micro-structured CMRC-cooled current lead **available**
- **COMPASS Test Stand** for experimental investigation of current leads and magnet systems under development
  - **Broad power range** from a few hundred to 10 kA
  - **Highly flexible** for testing magnet components and MSCLs
  - Croygenic installation space of **50x50x50 cm³**

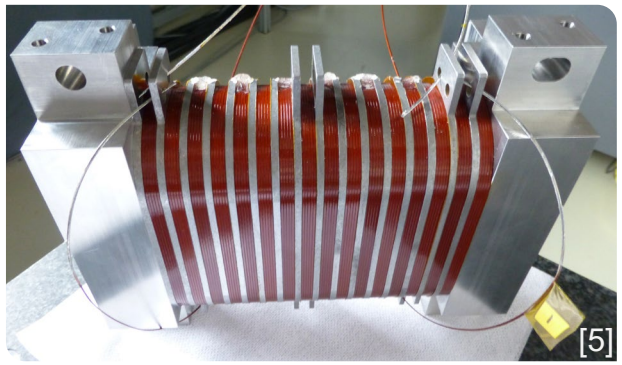


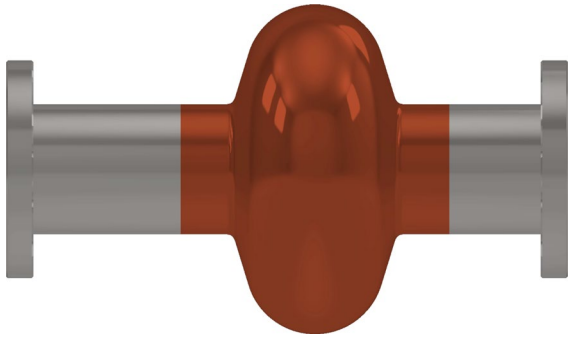


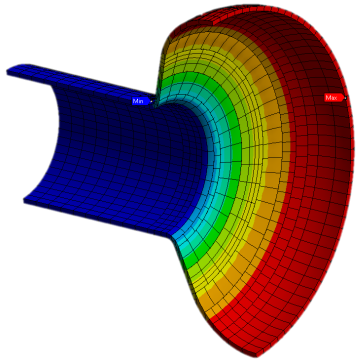
Summary & Outlook

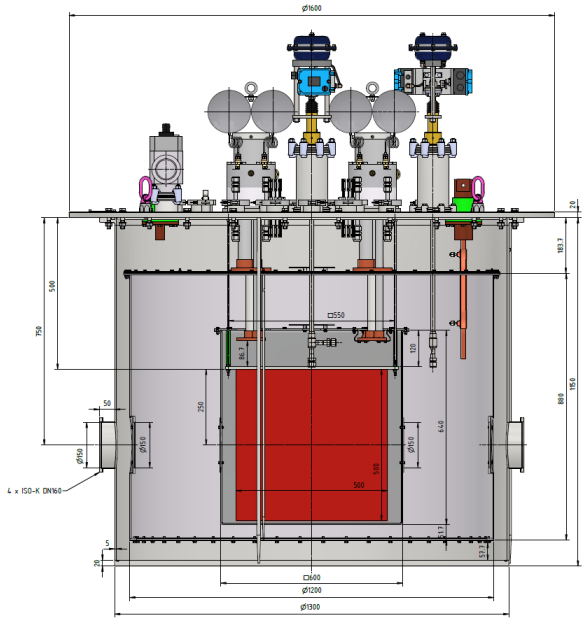
- Development of thermally **optimized MSCLs** with numerical tools
- **Experimental investigation** of MSCLs **in COMPASS**
- Experimental investigation of thermal behaviour of **sc magnets and cavities** in cryogenic installation space











[5] David Saez de Jauregui, 2022.

Thank you! Questions?

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Literature

[1] E. Shabagin, „Development of a CMRC cooled 10 kA current lead for HTS applications, PhD thesis, Karlsruhe Institute of Technology, Karlsruhe, 2022.

[2] T. Kochenburger, „Kryogene Gemischkältekreisläufe für hochtemperatursupraleitende Anwendungen“, PhD thesis, Karlsruhe Institute of Technology, Karlsruhe, 2019.

[3] https://www.cryomech.com/products/pt425/, last checked 24.03.2022.

[4] https://www.agilent.com/en/product/gas-chromatography/gc-analyzers/energy-chemical-gc-analyzers/liquefied-petroleum-gas-analyzers, last checked 03.11.2020.

[5] David Saez de Jauregui, personal communication, 2022.