Karlsruhe Institute of Technology

Heat Load Budgeting of a Superconducting Induction Heater's Commercial Cryocooler-Based Cryostat

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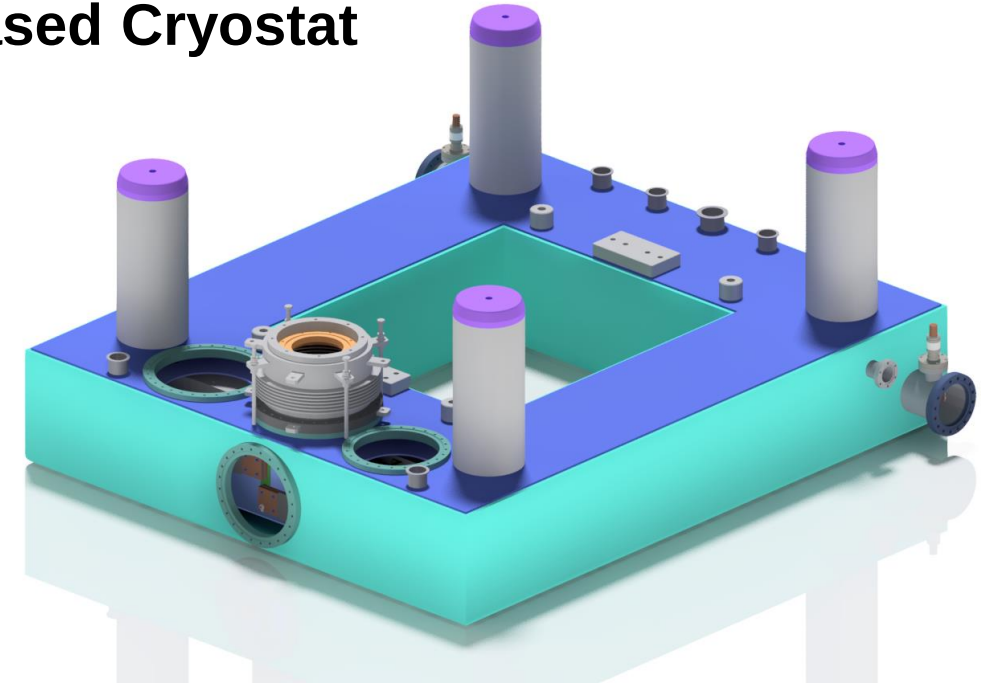


Presentation Outline

1. Project Introduction
2. Technology’s Status Quo
3. Theoretical Background & Design Methods
4. Results
5. Conclusions
6. Prospects

Partners & Funding

Bültmann GmbH

Theva Dünnschichttechnik GmbH

Beck Maschinenfabrik GmbH

Bundesministerium für Wirtschaft und Technologie

Projektträger Jülich Forschungszentrum Jülich

Metal Hot Forming

Image: dbu.de

Billet Heating:

Al → 500 °C
Cu → 1000 °C


Image: sms-group.com

Extrusion Press

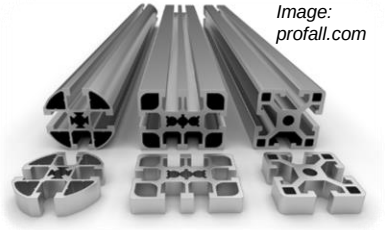


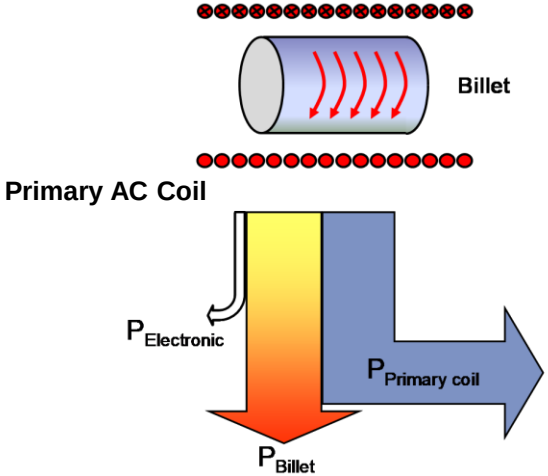
Image: profall.com

Metal Profiles

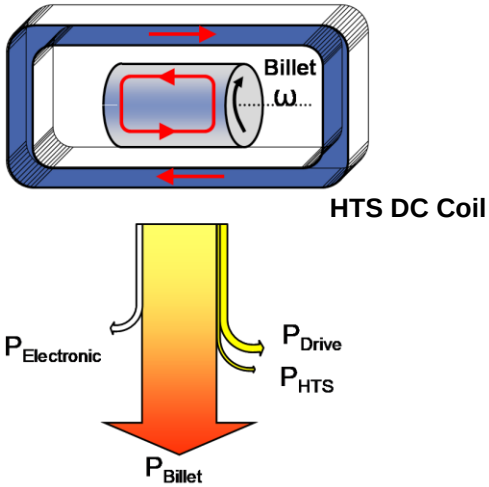
Germany: ca. 600 $\mathrm{kilotons\ Al/_a} \approx 73\ \mathrm{GWh/_a}$

Heating Principle Comparison

Conventional Induction Heating

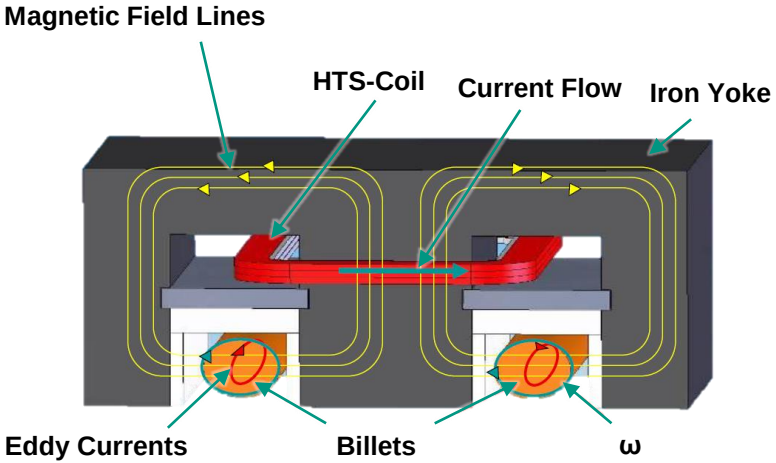


HTS-Induction Heater

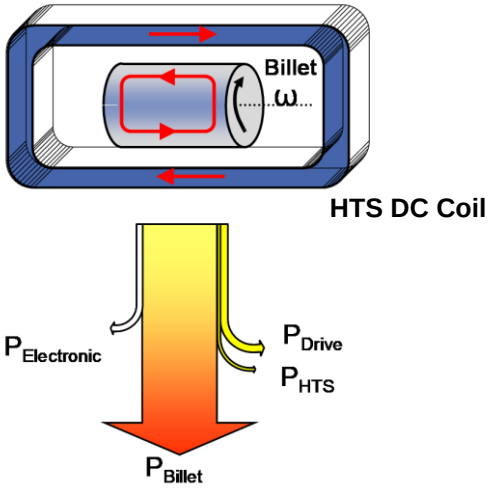


Energy Efficiency: **50…60 %** **70…80 %**

Heating Principle Comparison



HTS-Induction Heater



Energy Efficiency: **70…80 %**

Current Technology Status

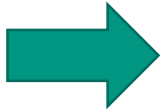
Existing HTS-Induction Heaters	Notes
2008: Predecessor Project Prototype Bültmann GmbH, Zenergy Power GmbH  Image: Bültmann GmbH	Improvement potential in current project: - Maintenance Downtimes - Magnetic Field Strength - Manufacturing Cost Effectiveness
2017: Supercoil® Trial Run Publication Supercoil Co., Ltd. (S. Korea)  Images: Choi, J. (2017)	"Supercoil has a target to realize these superconducting induction heater technologies for industries." *(Supercoil CTO J. Choi at MT25 Conference 2017)*

Contribution Aim

Cryostat Heat Load Budgeting

Boundary Conditions

- HTS-coil operation
  - Ca. 500 A
  - 20 K
  - Strong EM-forces
- Iron Yoke given
- Max. 15° Tilt
- Intermediate Thermal Shield
  - 2-stage GM-cryocooler



Desired Cryostat Properties

- Cost-effective
- Low-maintenance
- > 10 years lifetime

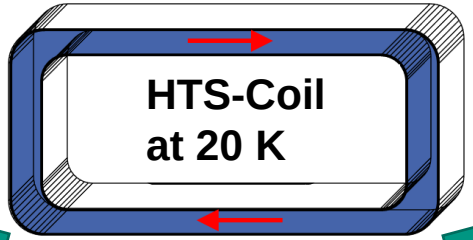
Theoretical Background – Heat Loads

$p \approx 10^{-5}$ mbar

300 K

$\dot{Q}_{\text{Joule}}$

$$I^2 \cdot \int_{T_{\text{warm}}}^{T_{\text{cold}}} R_{\text{el}}(\theta)\, d\theta$$



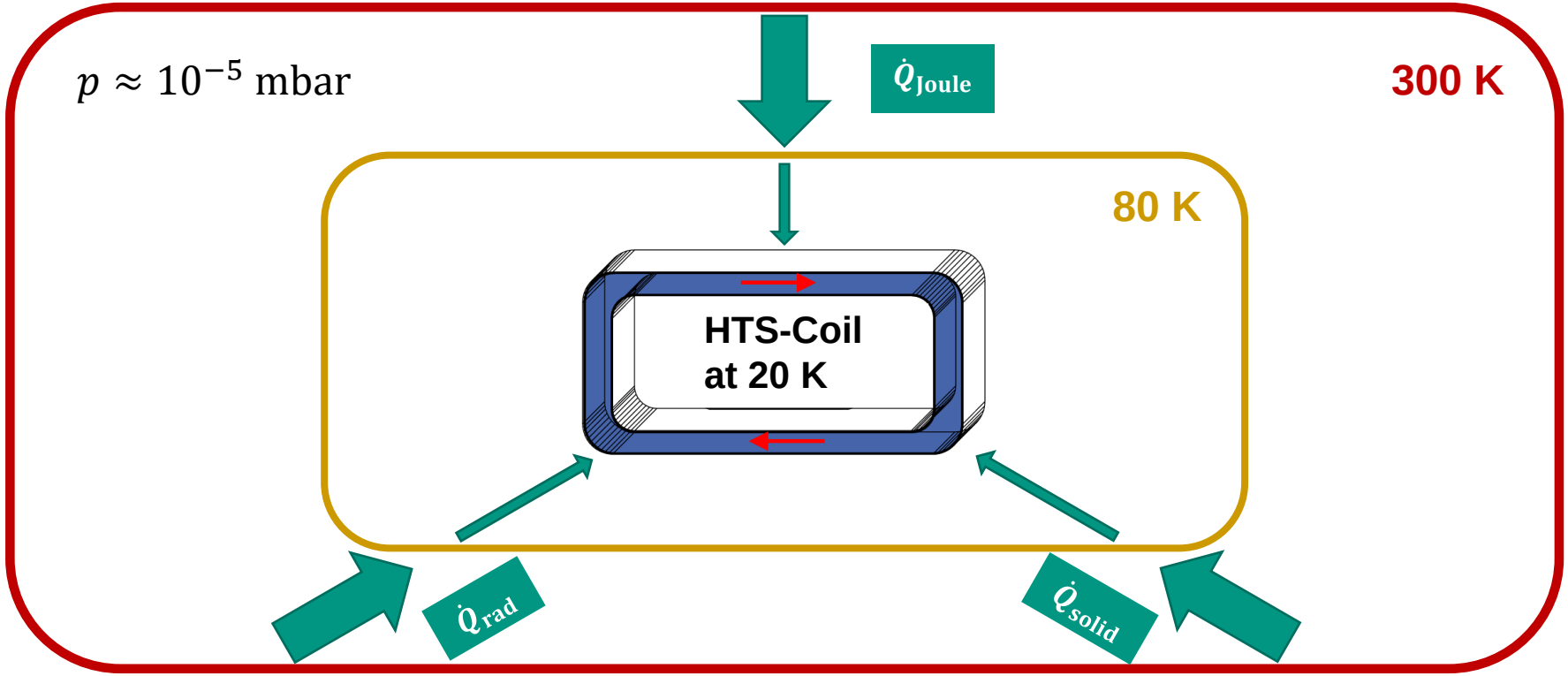
$\dot{Q}_{\text{rad}}$

$$e_r \cdot A_{\text{cold}} \cdot \sigma \cdot \left(T_{\text{warm}}^4 - T_{\text{cold}}^4\right)$$

$\dot{Q}_{\text{solid}}$

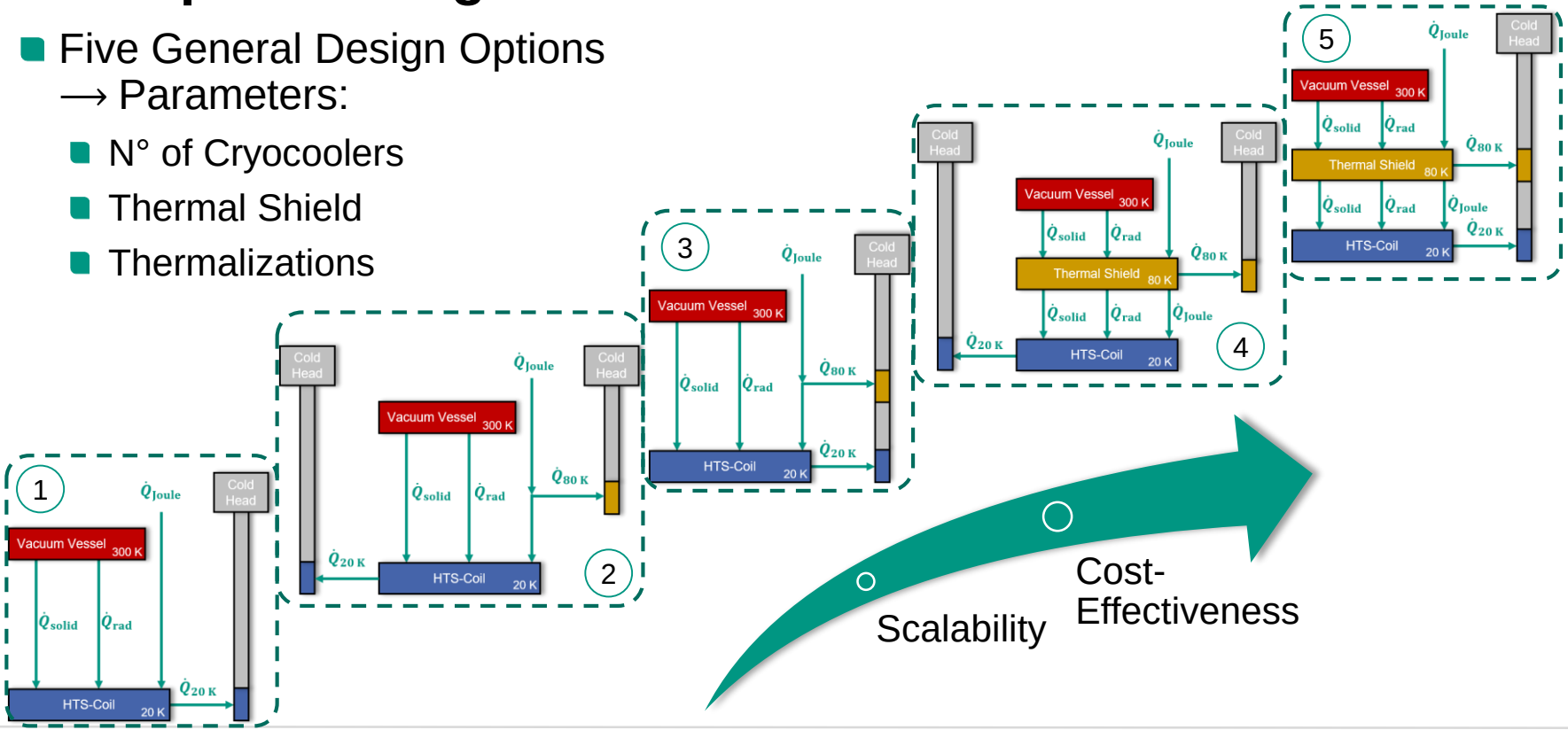
$$\frac{A_{\text{cross}}}{l} \cdot \int_{T_{\text{warm}}}^{T_{\text{cold}}} \lambda(\theta)\, d\theta$$

Theoretical Background – Heat Loads

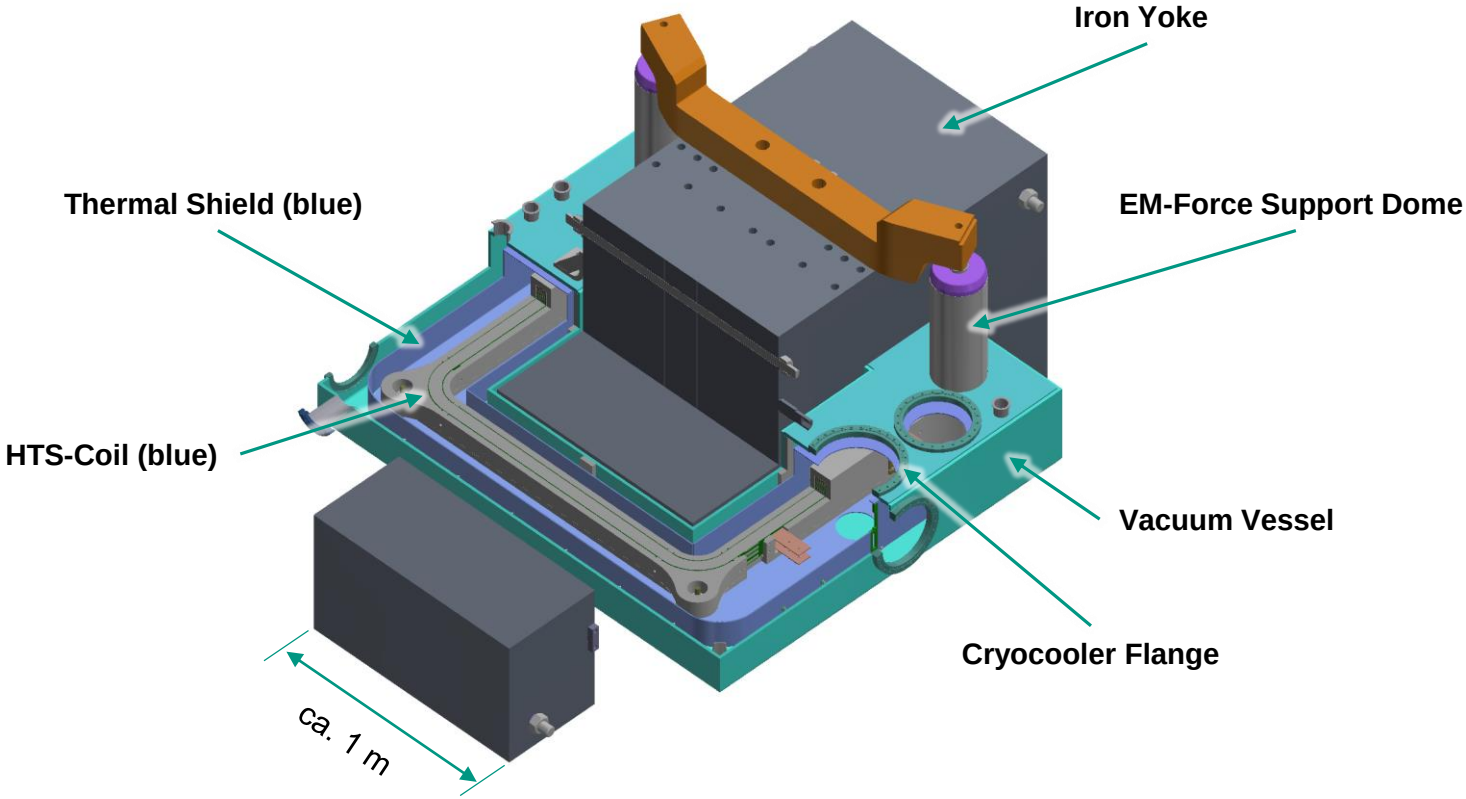


Conceptual Design Considerations

- Five General Design Options
  ⟶ Parameters:
  - N° of Cryocoolers
  - Thermal Shield
  - Thermalizations

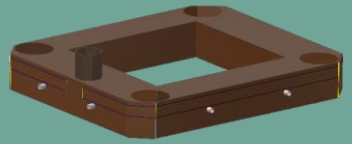


Conceptual Design



Design Methods

CAD-Software



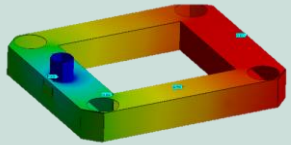
- 1D-Gradients
- Constant Cross Sections

- Complex Geometries
- 3D-Distributions

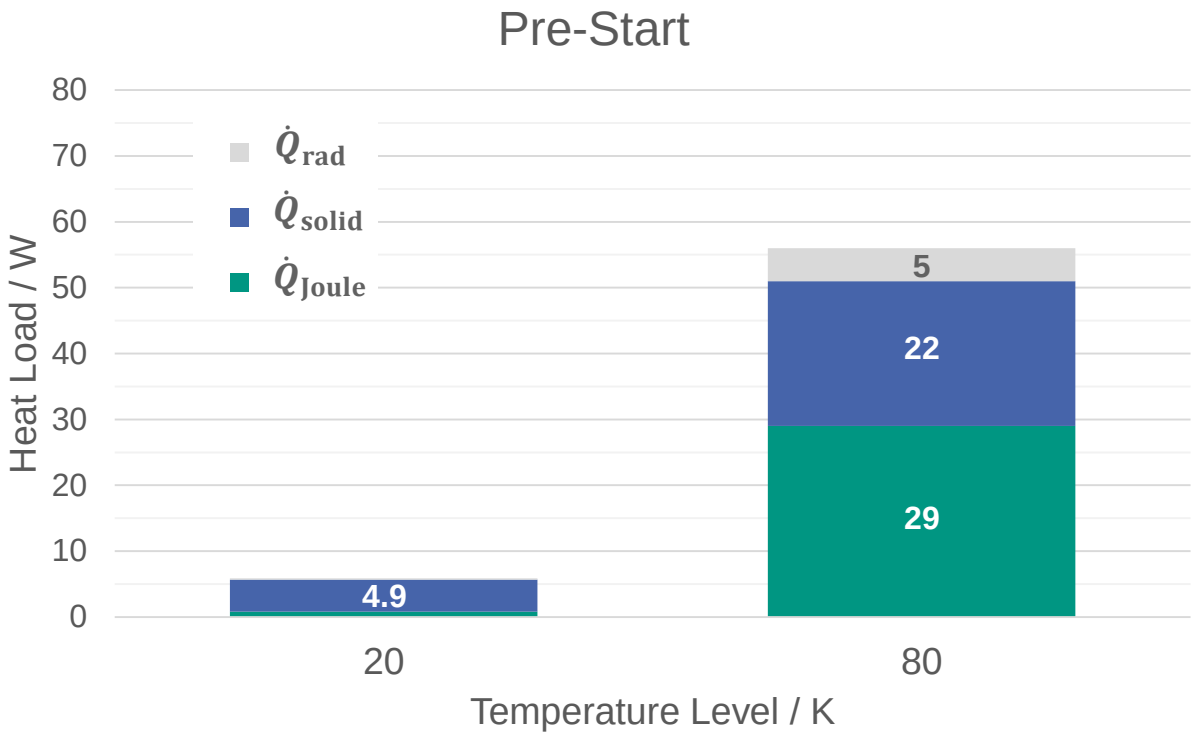
Analytical Solutions

$\dot{Q}_i$

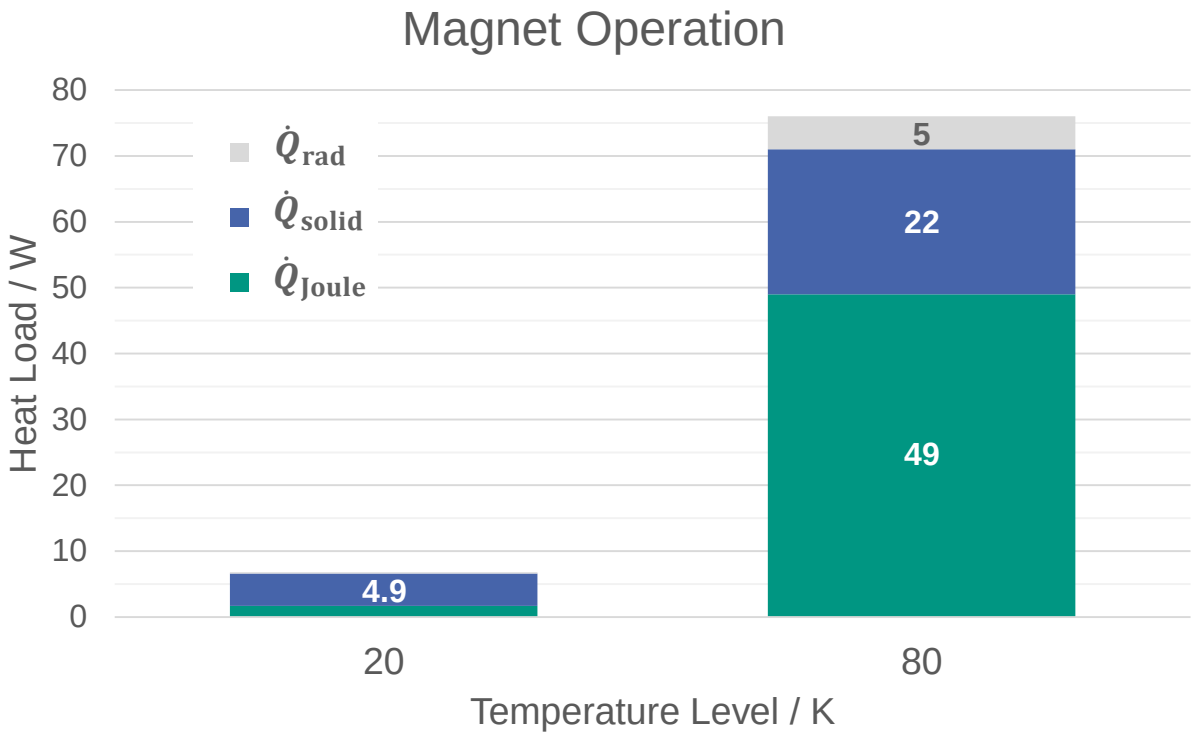
Numerical Solutions



Results – Heat Loads



Results – Heat Loads

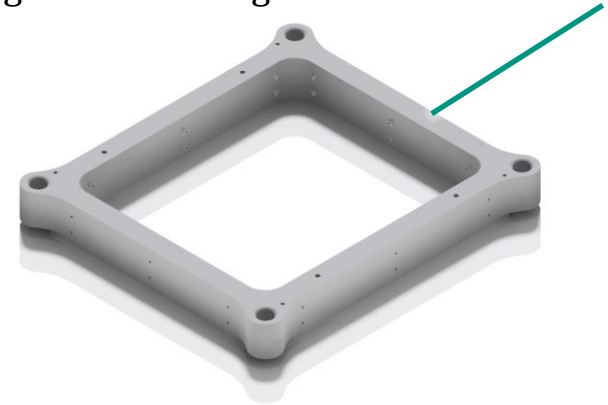


Conclusions – Heat Load Redistribution

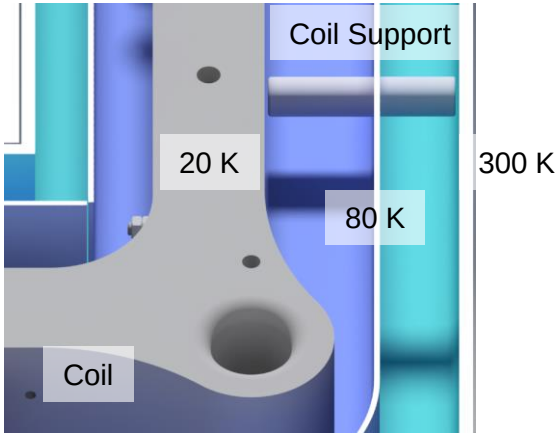
Possibilities:

- Change Emissivities

$$\dot{Q}_{\text{rad, stage 2}} \approx -\dot{Q}_{\text{stage 1}} = f(e_{\text{warm}}, e_{\text{kalt}})$$



- Thermalize Heat Conductors

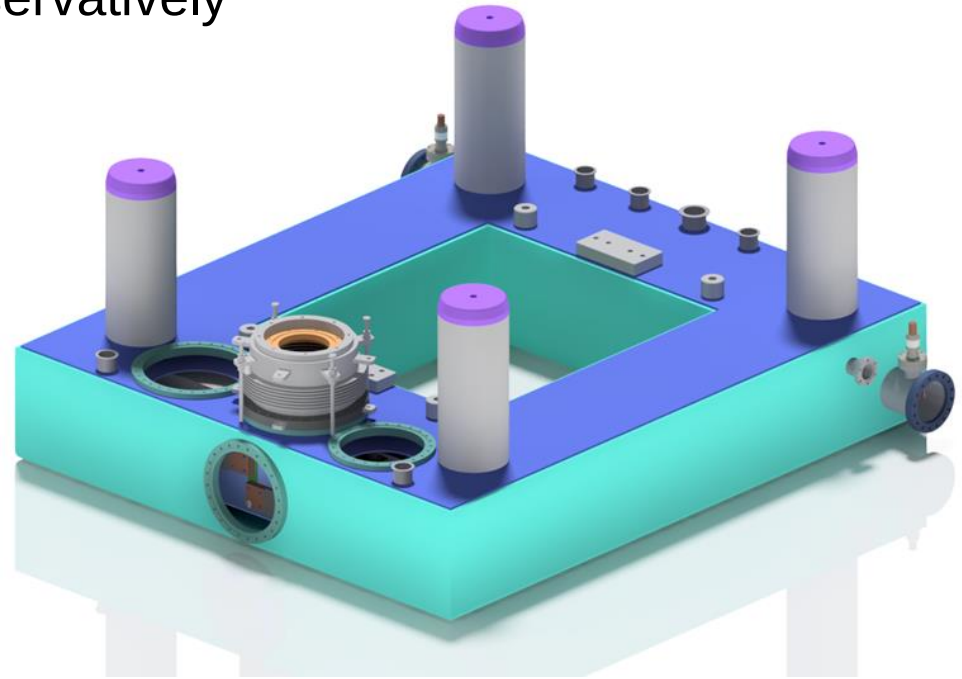


Conclusions – Eligible Cryocoolers

Manufacturer		CSIC Pride Cryogenic Technology Co., Ltd.		Leybold GmbH		Sumitomo Heavy Industries, Ltd.	
Cold Head Model		KDE412SA		COOLPOWER 10 MD		CH-210L	
1st Stage at 80 K							
Cooling Power	Margin	95 W	**25 %**	110 W	**45 %**	90 W	**18 %**
2nd Stage at 20 K							
Cooling Power	Margin	15 W	**120 %**	18 W	**165 %**	9.5 W	**40 %**

Conclusions – Summary

- Heat loads approximated conservatively
- Respective Distribution eligible for Single Cryocooler
- Highly cost-effective cryostat design finished



Prospects

- Measure Cryocooler Performances
  - 80 K & 20 K
  - Higher Temperatures → Better Cooldown Estimation
- Detail Engineering
- Induction Heater Assembly
- Prototype Test Run

Cryocooler Test Vessel