

Matter Competence Team (MCT) “Technologies for Fusion Energy and Frontiers of Optics” (FEOPT)

Malte Kaluza, HI Jena

Taking up the challenge....

MCT – Technologies for Fusion Energy and Frontiers of Optics



Our initial vision (~1...2 years ago)



Advanced optical technologies as key enablers for scientific breakthroughs



Pathways toward (also commercial) applications (e.g. inertial confinement fusion, ICF)



Increased Visibility

Strengthen and increase visibility of optical technologies across Helmholtz and beyond



Collaboration

Foster closer collaboration between activities across different programs



Integration

Link existing fusion activities with broader optical technology development

Organizational cornerstones

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MCT Coordination



Malte Kaluza, HI-Jena



Matthias Fuchs, KIT



Dominik Kraus, Rostock



Administrative Anchoring

FEOPT coordinators guests in MT/MML Management Management Boards



Reporting Structure

Integrated within PPRs and Scientific Annexes



Localization in MT but ties to all Matter programs:

Subtopics as “anchors” into each of the MT topics to coordinate the contributions to optical technologies and to fusion

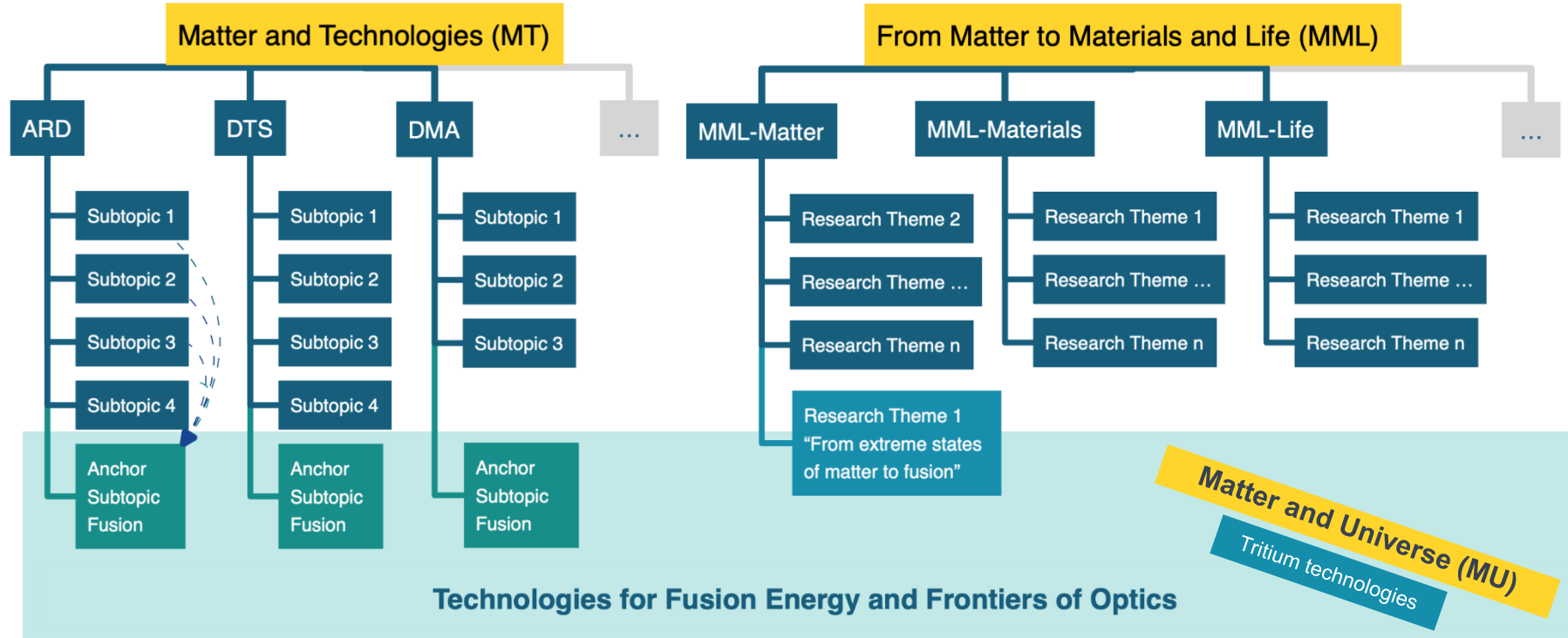


Key Resource Principles:

- ✓ Maintains organizational flexibility
- ✓ Preserves existing funding structures
- ✓ Ensures clear accountability
- ✓ **Additional funding through Pact Resources (2026) (2026)**

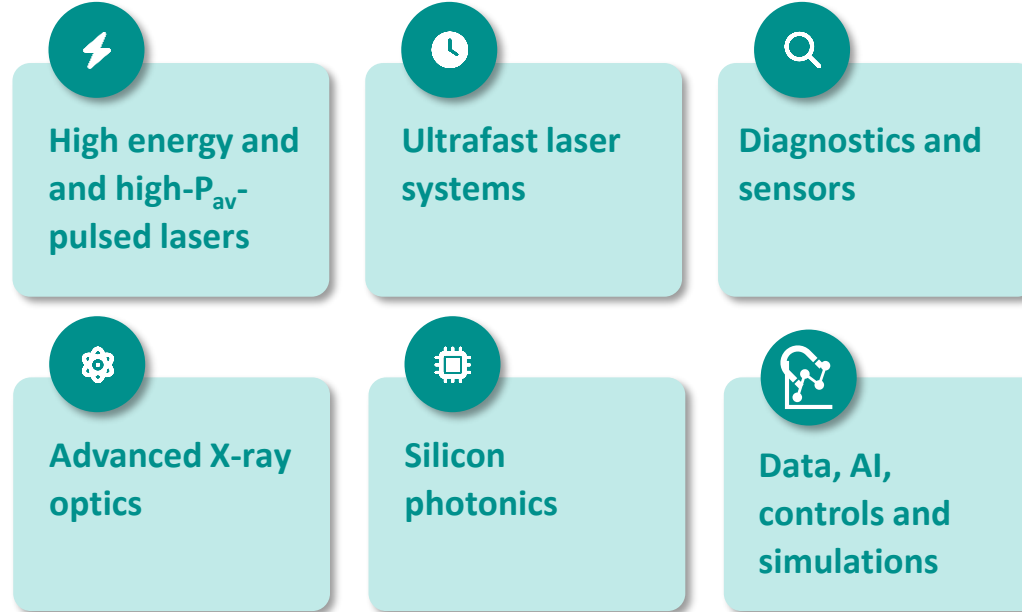
Embedding in existing Structure of Matter

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In addition: links to Helmholtz Energy and Information, links to universities and other research institutions (FhG, Leibniz,...) and industry foreseen

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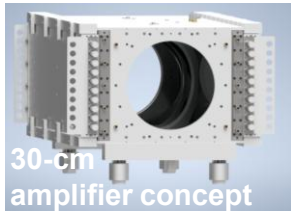
These innovation areas will have major impact on our facilities and Germany's technological sovereignty in research and innovation.

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High energy and
high- P_{av} - pulsed
lasers

High-energy laser development



GSI

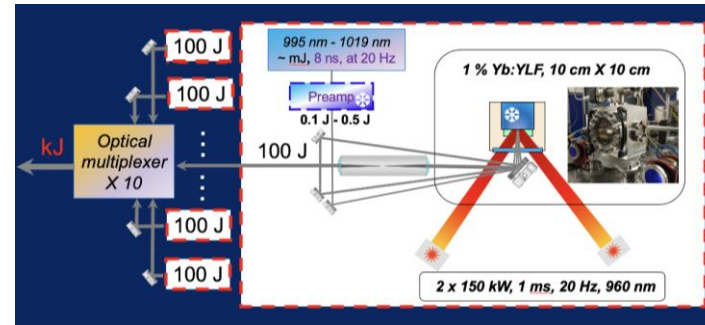
T H R I L L

- High-energy kJ amplifiers
- Broadband ns-lasers for LPI mitigation



High rep-rate pump laser development

- Demonstrate high efficiency (>25%), 100 J, 10 Hz rep-rate modules that can be multiplexed to 1 kJ



- IFuEL Program, started 01/2026

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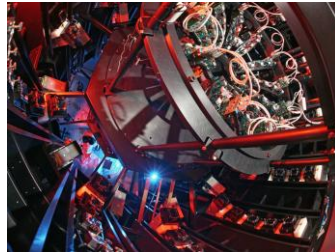


High energy and
high- P_{av} - pulsed
lasers

High energy and high P_{av} diode pumped laser systems: POLARIS @ HI-Jena

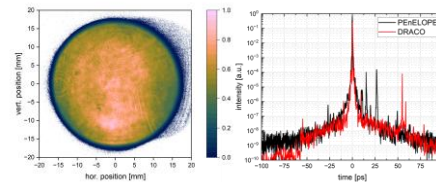
- Yb:Glass/Yb:CaF₂ system
- 17J, < 100 fs @ 1/50 Hz
- exp. program on LPA
- synchronized
15 fs probe pulse
- 54 J amp demonstrated,
- upgrade of infrastructure
for 400 TW

HI JENA
Helmholtz Institute Jena

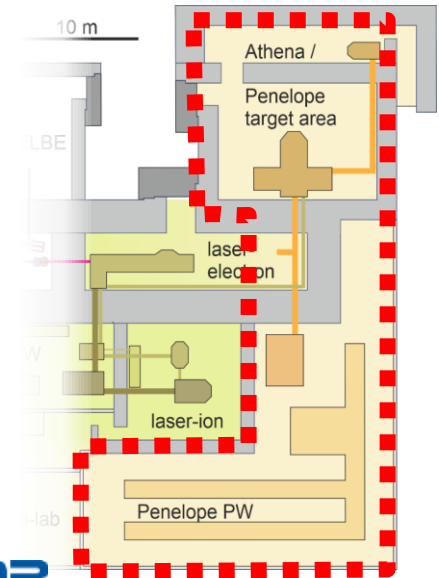


High energy and high P_{av} diode pumped laser systems: ATHENA/PEnELOPE @ HZDR

- Yb:CaF₂ with soft-cryo
He gas cooling
- 10 J amplifier @ 1 Hz
- compression in air
demonstrated
- 150 J amplifier under
construction



ATHENA **HZDR**
The Helmholtz-Project for
Laser-Plasma-Acceleration



Key Technology Areas

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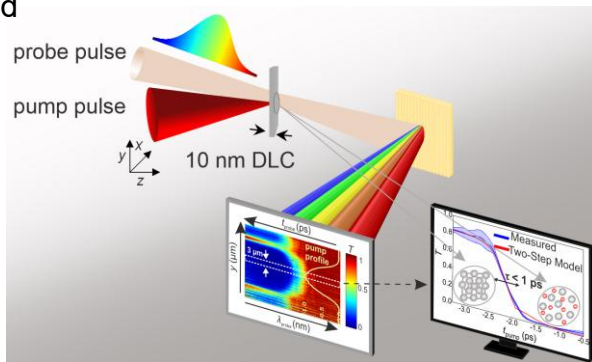
Laser and particle diagnostics and sensors

Sensors (DTS)

- High-speed, high resolution sensors for beam diagnostics and for light sources;
- quantum sensors for high-resolution x-ray detection: development for and use in plasma diagnostics

Probing of plasma formation

- Record movies of interaction with chirped probe pulse:
- Online spatially resolved contrast measurement on target surface

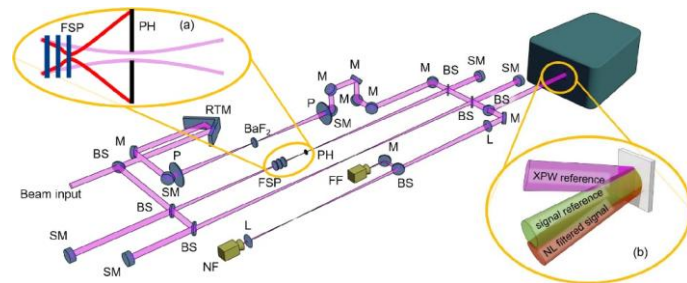


Y. Azamoum *et al.*, Nature: Light – Science & Applications **13**, 109 (2024)

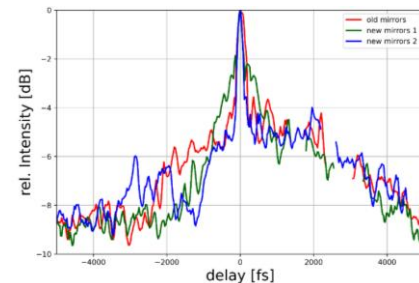
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2D-resolved laser contrast measurement

- Tilted beams (signal, filtered signal, and reference) for 2D interferometry („2D version“ of Wizzler)



S. Bock *et al.*, Optics Express **33**, 42401 (2025)
T. Oksenhendler *et al.*, HPLSE online (2025)
T. Oksenhendler *et al.*, Sci. Rep. **15**, 17729 (2025)



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Laser and particle
diagnostics and
sensors

Plasma-based secondary sources

- Develop laser-based, short-wavelength radiation sources (e.g. betatron radiation): broadband, keV, fs-time resolution

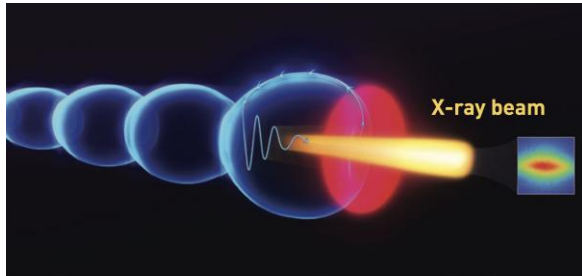
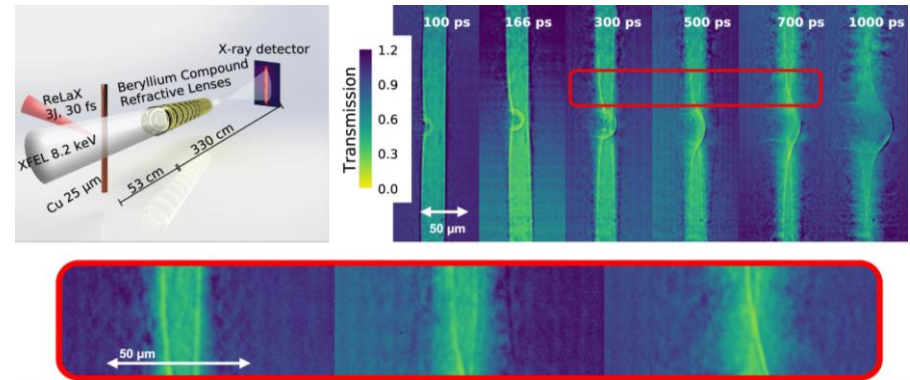


image: F. Albert

Plasma diagnostics with X-ray sources

- Develop diagnostics suitable for short-wavelength radiation (e.g. betatron or X-FEL): Connection to MML: probing techniques with X-FEL radiation to probe HED/IFE-relevant states of matter

HiBEF
HZDR



- Establish unique platform for IFE research

A. Laso Garcia et al., Nature Commun. 15, 7896 (2024)

Key Technology Areas

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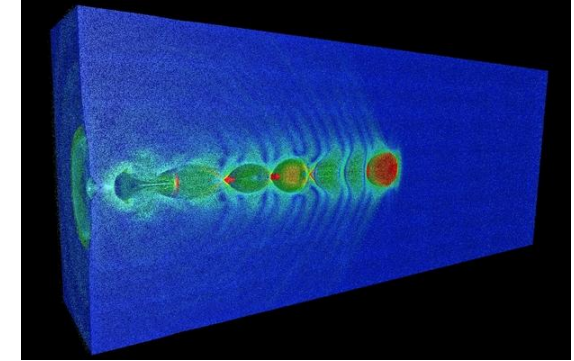
Data, KI,
controls and
simulations

Laser-plasma simulations

- Multi-scale, multi-physical simulations: understand, control and improve fundamental processes (e.g. for fusion)
- Comparability with experiments is essential

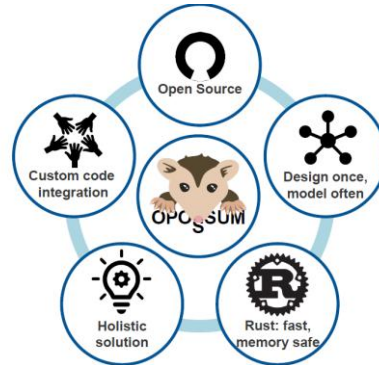


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Laser simulations

- Laser simulations
/Advanced laser
architectures:
YIG LaseFuse



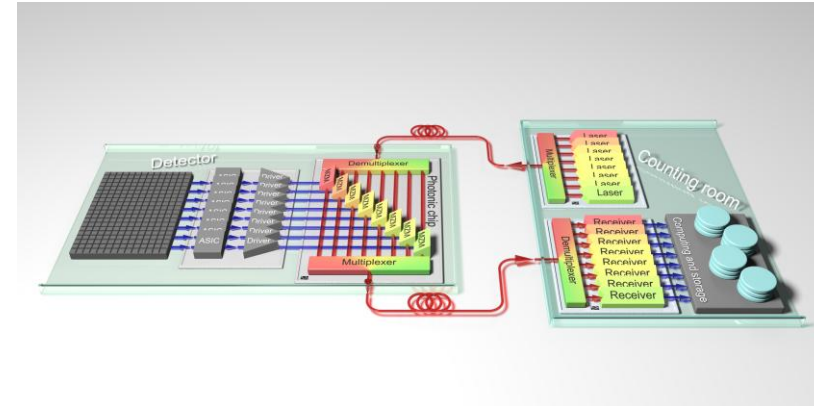
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Silicon photonics

Silicon Photonics (MT-DTS, MML)

- key technology for future data transmission.
- major impact in advanced detector technologies, ultrafast laser systems, electron beam diagnostic and high speed, high resolution digital to analog conversion.
- materials research addressing limits of quantum technologies.
- potential for use in large scale facilities
- innovation transfer to the research areas information, health and transportation as well as to industry



Key Technology Areas

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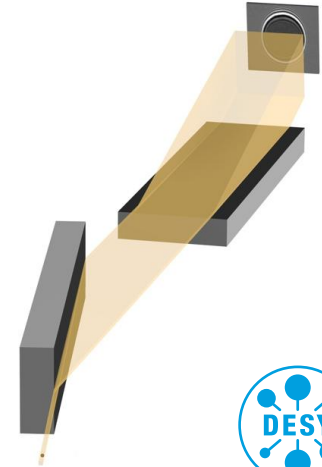


Advanced X-ray optics

Advanced X-ray optics (DTS, MML)

- technologies developments key in efficient use of large scale photon sources and exploiting their full science capabilities.
- push imaging resolution limits at XFELs and synchrotrons
- diffractive X-ray optics: multilayer Laue lenses
- improved spatial resolution at lower dose, crucial for biological materials
- imaging of thicker samples
- laser machined diamond to replace beryllium optics
- production scaled to thousands of lenses for the beamlines of the future PETRA IV and other synchrotrons

Bragg (de-) magnifier



Additional Funding Through Pact Resources

Proposal for additional funding for Fusion-related Research (2026–2030)
submitted 07/2026, coordinated by U. Schramm, HZDR:

Strategic, PoF-V-complementary, 26 M€ in total, 3.25 M€ for HI-Jena to be evaluated after 3 years, funding to become permanent in 2031

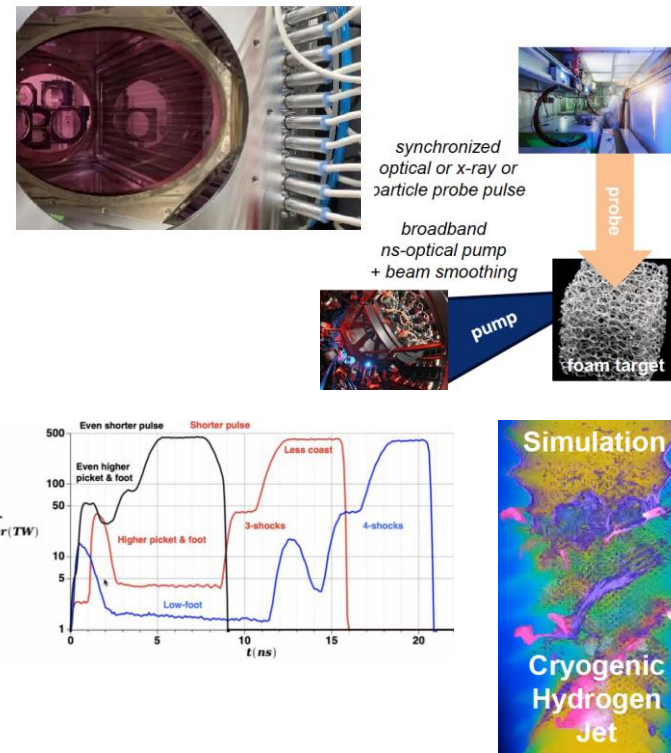
Research topics/work packages:

- Advanced high-power laser technology, high-reprate, broadband laser material, advanced thermal management, multi-beam target areas
- Fusion-relevant pump-probe capabilities (e.g. 1st compression phase)
- Fusion-relevant plasma heating, advanced ignition concepts
- Synthetic diagnostics of microphysics of WDM and HED plasmas
- Tritium technology and handling
- Plasma-facing materials
- Fusion modeling and digital twins

Pact funding will provide

- Coordinated development of distributed Helmholtz infrastructure for fundamental and applied IFE research
- Training and education of dedicated work-force
- Strong Helmholtz-contribution to Fusion Hubs and Fusion 2040

Evaluation on September 18th 2026,



HELMHOLTZ

-related Research (2026–2030)

1 Scientific and Strategic Relevance

The research framework for implementing the project is strong. The Helmholtz participants in the area of laser-related R&D have extensive and relevant expertise, and the research infrastructure of the participating research centers within Helmholtz is excellent.

Strengthening of Fusion Research

Review Report

Applying Helmholtz Centers	HZDR, DESY, GSI / HI-Jena, KIT
Research field	MATTER

Date: September 28, 2026

Thank you for
your attention!

4 Overall Assessment and Recommendations

The review panel supports the approach of the proposal, which is seen as an excellent opportunity to strengthen the laser-related IFE activities of high scientific and strategic relevance. The proposed research scope is ambitious, but rightly so. The Principal Investigators have a lot of expertise and access to excellent facilities. Synergies with efforts within Helmholtz ENERGY are well identified in the

- The IFE scope is tailored to the available infrastructure. While this is a sensible starting point, it constrains the range of physics questions that can be addressed; accordingly, the accessible but relevant questions, such as laser-plasma interaction (LPI) mitigation with broadband lasers, should be prioritized within this time.

Helmholtz infrastructure for

force

ubs and Fusion 2040

