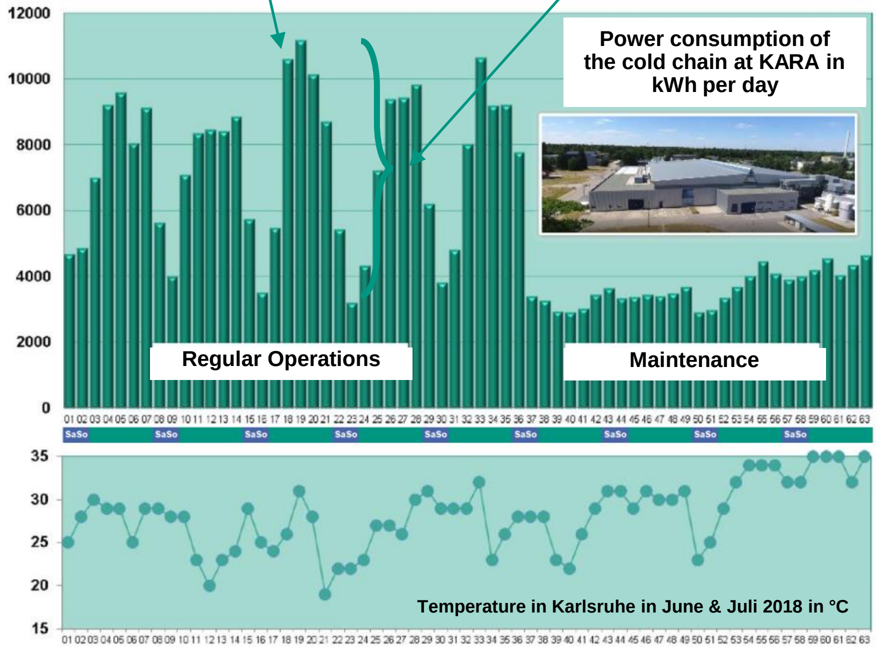
Investigating next generation of accelerators: The KITTEN test facility for sustainable research infrastructures

TT-Prof. Dr.-Ing. Giovanni De Carne, Prof. Dr. Anke-Susanne Müller, Dr. Falastine Abusaif, M.Sc. Mashid Zadeh, Dr. Erik Bründermann, Dr. Julian Gethmann
Karlsruhe Institute of Technology - 14/04/2023

The starting point

11GWh ≈ 10.000 citizens city

Variable consumption ≈ 8 MWh



X High power demand
X High carbon footprint

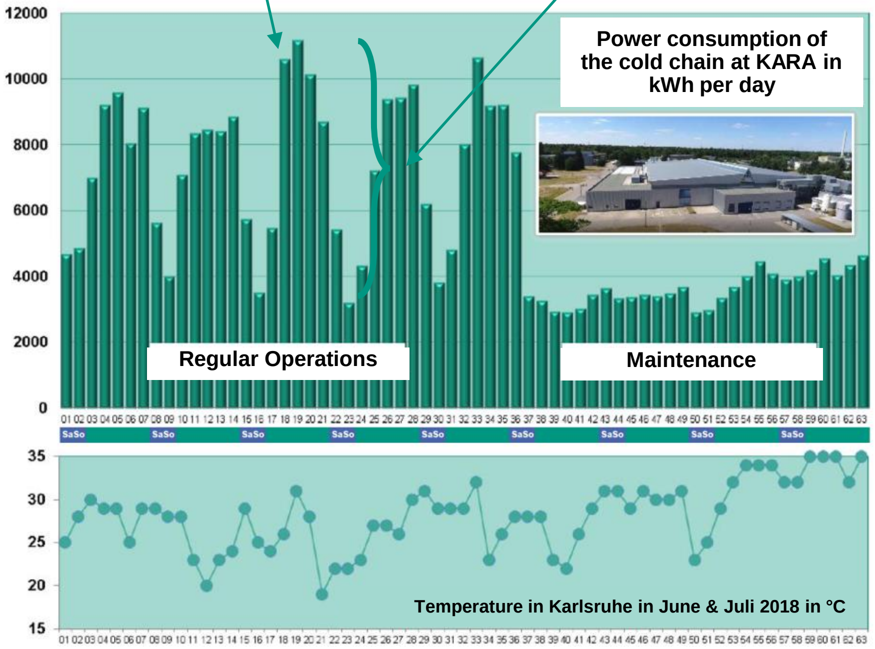
X Need for a stable grid

X High energy costs

The starting point

11GWh ≈ 10.000 citizens city

Variable consumption ≈ 8 MWh



✓ Highly efficient

✓ Rely on green energy

✓ Flexible, offer services to the grid

We need to propose new solutions for sustainable research infrastructures in a comprehensive and systematic way

KITTEN

KIT Testfeld für Energieeffizienz und Netzstabilität in großen Forschungsinfrastrukturen

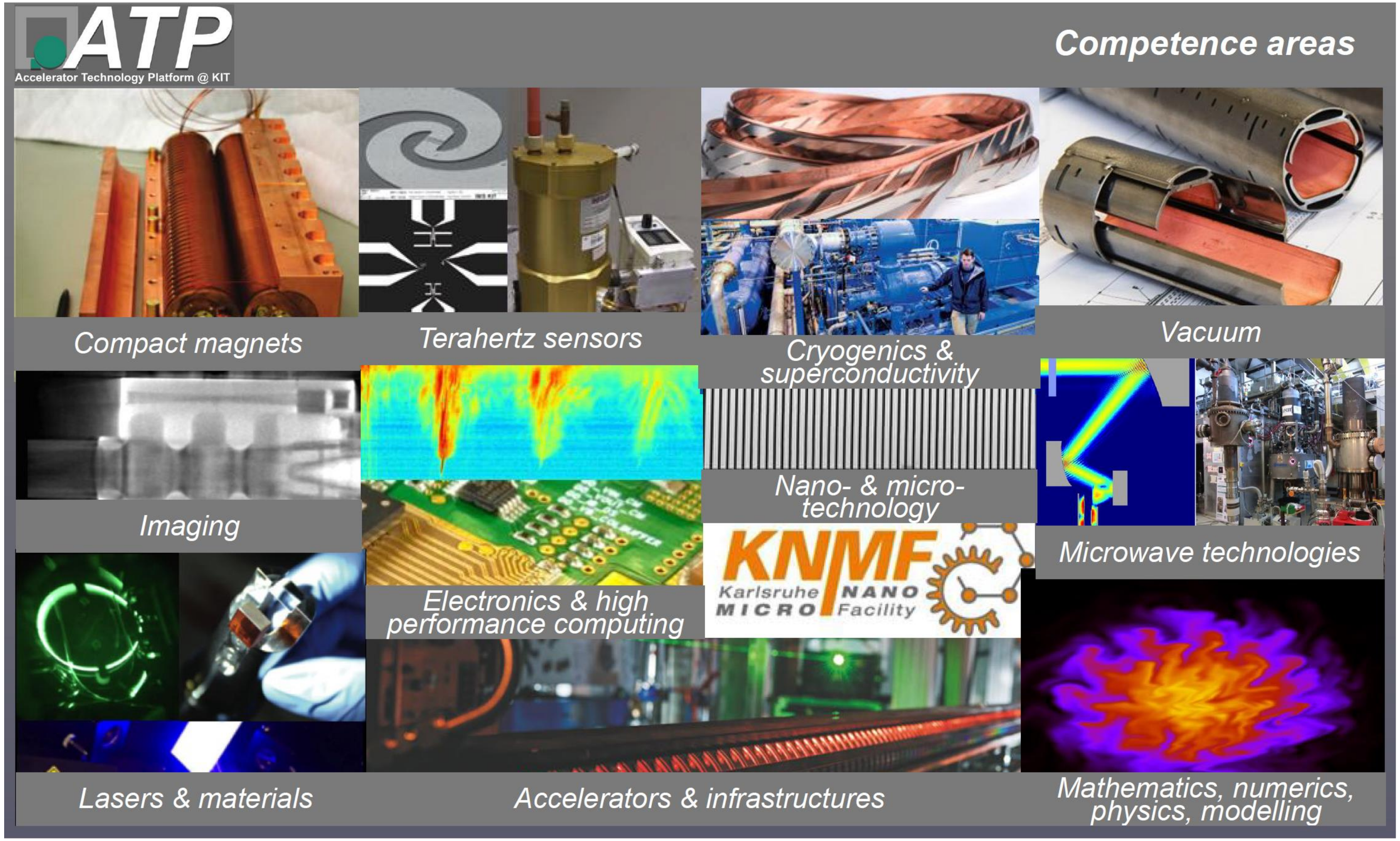
A joint venture between the accelerator **KARA** and the test-field **Energy Lab 2.0** to improve the energy use and power quality in large research infrastructures.

Accelerator Technology Platform

ATP Accelerator Technology Platform @ KIT

KIT Karlsruhe Institute of Technology

- 230 Researchers @ KIT
- R&D
- Consulting/QA
- Pilot projects
- Large test facilities
- Technology-transfer
- Bridge between
  R&D-Companies-Labs



Addressing energy-responsible accelerators
strengthening the link to Research Field ENERGY

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- Prerequisite for future mid- and large-scale (accelerator-based) research infrastructures
- Helmholtz-wide consortium (lead KIT)

MT ARD

InnovEEA
Innovation pool project
for Energy Efficient Accelerators

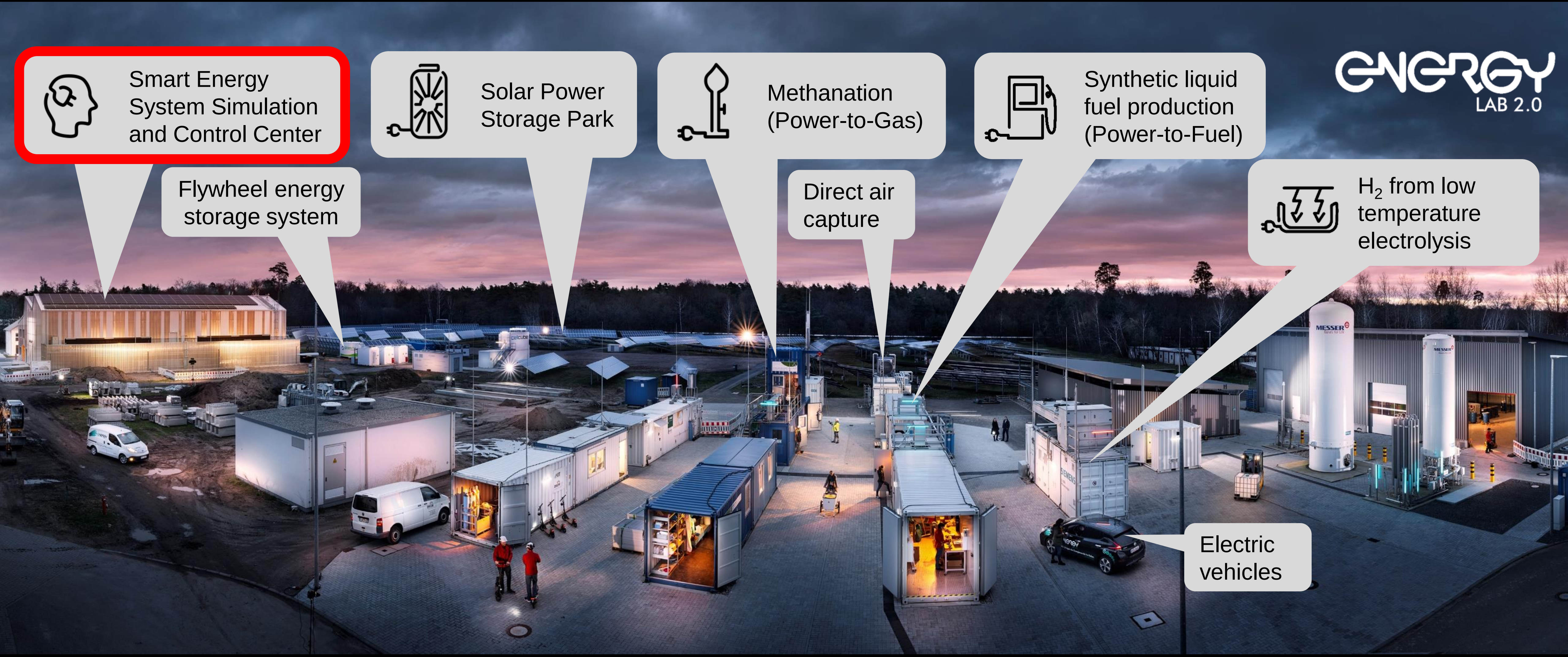
- Investigate, develop & demonstrate new concepts from components to systemic solutions

Superconducting materials and cryogenics approaches
InnovEEA – Innovation pool project for Energy Efficient Accelerators

Magnets and current leads
InnovEEA – Innovation pool project for Energy Efficient Accelerators

Energy-efficient system design and load management
InnovEEA – Innovation pool project for Energy Efficient Accelerators

Operation modes, grid stability & low-carbon footprint (pilot: **KITTEN**)



Geothermal energy plant

Living Lab experimental buildings

HT thermal storage

Solid oxid fuel cell

Gas turbines

Power Hardware In the Loop lab – Energy Lab 2.0

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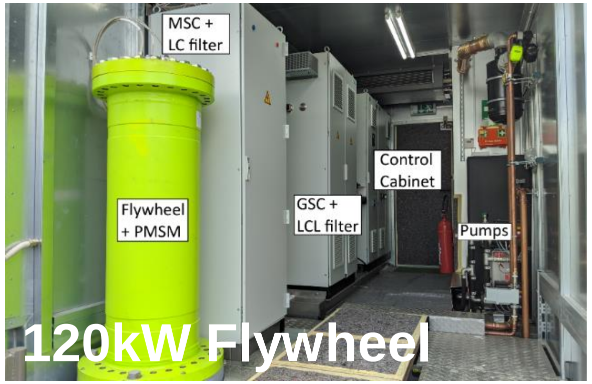
- **Large testing facility:**
  - 1MVA PHIL Testing Hall
  - 45kW & 2x15kW PHIL Setup
- **Large set of energy resources**
  - 120kW high-speed flywheel
  - 500kW Supercaps system
  - 50kW Liquid Hydrogen energy plant

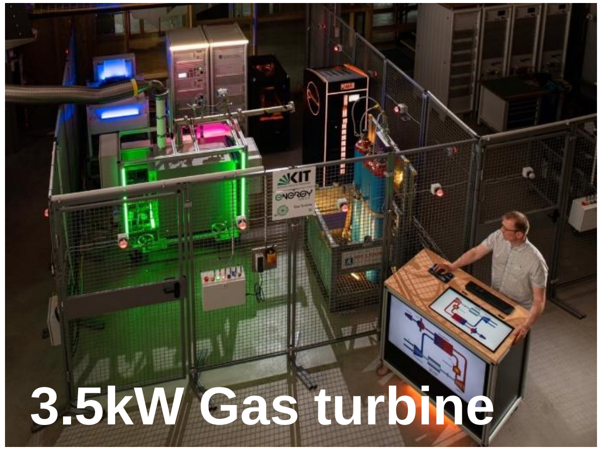
1 MVA PHIL Testing Hall


45kW PHIL Testing setup



120kW Flywheel

500kW Supercaps


3.5kW Gas turbine

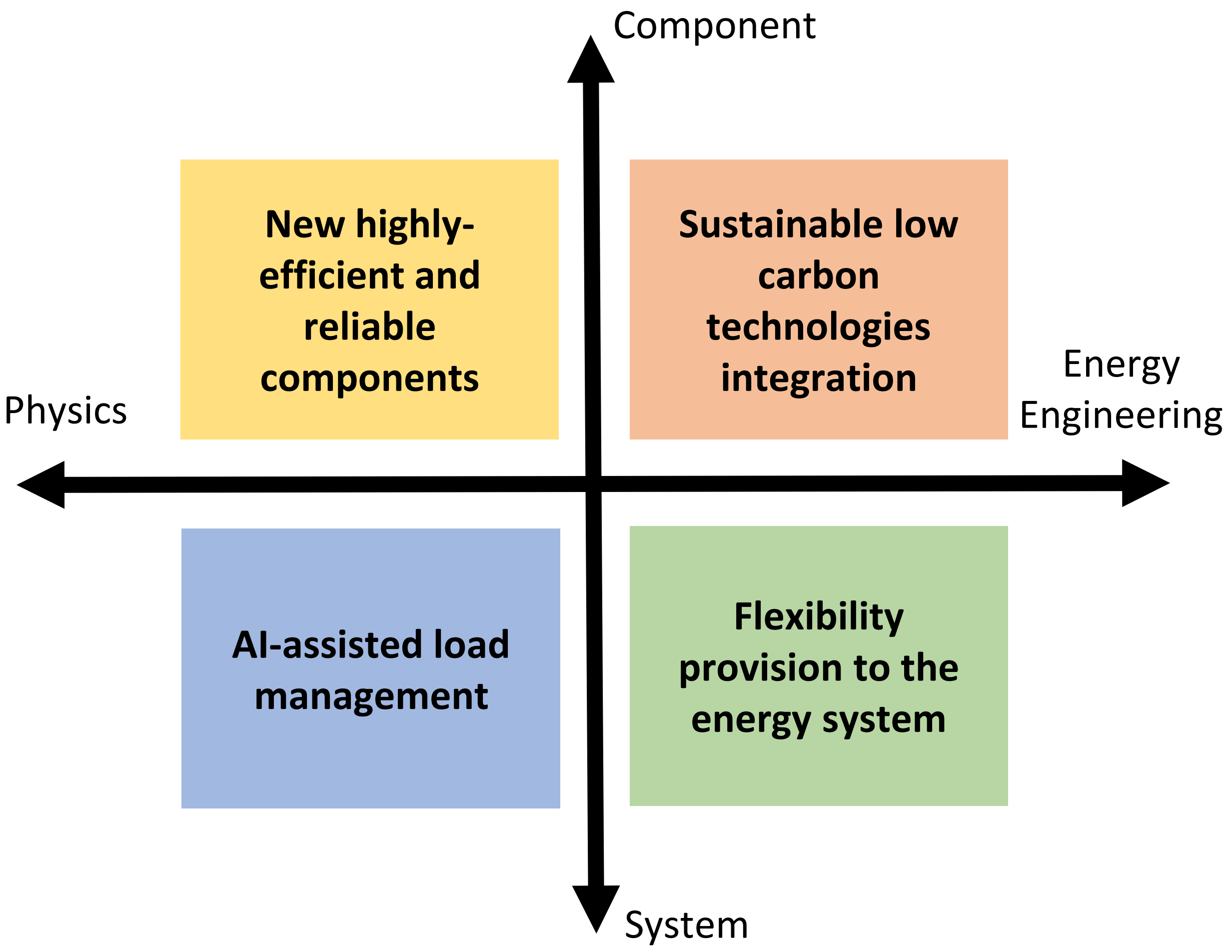

50kW LH2 Energy Plant

https://www.itep.kit.edu/rtset/english/index.php

The KITTEN Approach

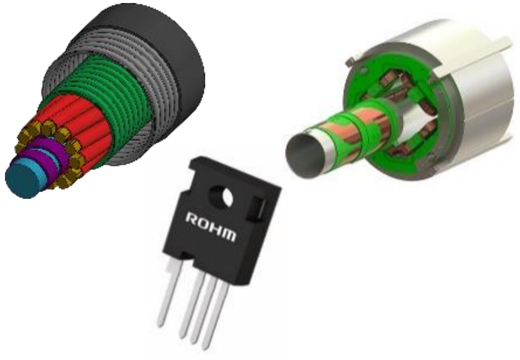
Need to work on 4 different levels

- **Physics / Component** level: new materials and components targeting an efficiency increase
- **Energy / Component** level: integration and optimal operations of sustainable low carbon technologies (e.g., energy storage, renewables)
- **Physics / System** level: improve the efficiency operations in large research facilities using AI
- **Energy / System** level: increase the sustainability of large research facilities in the electrical system



Potential improvements in the energy solutions*

New highly-efficient and reliable components



- HTS-Superconductors
- Variable permanent hybrid magnets
- New cooling concepts
- SiC / GaN-based power electronics

AI-assisted research infrastructure load management

- Real time digital twin of accelerators
- Optimized energy consumption by AI
- Adjustable power demand

Low carbon technologies integration

- Optimal integration of ESS with RES
- Sector-coupled Energy management
- Green high power computing
- Geothermal as cooling source

Flexibility provision to energy system

- 100% Renewable energy sources target
- Power demand flexibility
- New business models for flexibility provision

The Impact – 4 target groups

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TG1 – Large research facilities (current and future ones)

Actors: Particle accelerators, data centers

Expected impact:
- Electricity costs reduction (≥10-25%)
- 100% renewable energy supply
- Fully digitalized infrastructure

TG2 – System operators

Actors: Grid operators (TenneT), eng. companies

Expected impact:
- Power flexibility strategies for accelerators and computing centers (≥10-25%) for reduced consumption

TG3 – Technology manufacturers

Actors: Manufacturers, software and AI companies

Expected impact:
- Improved magnets, power electronics, (TRL 1-3 → 4-6, -20% consumption)

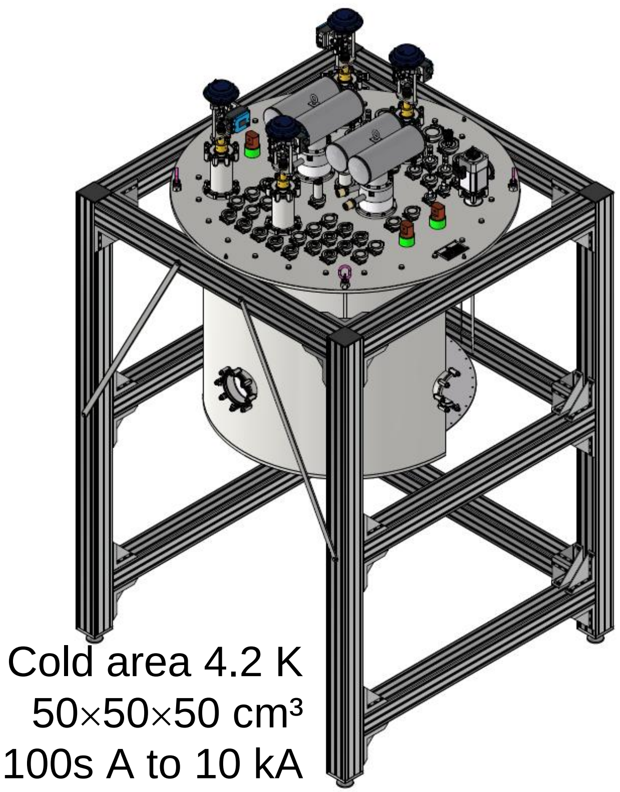
TG4 – General Society

Actors: medical facilities, schools, public buildings, computing centers

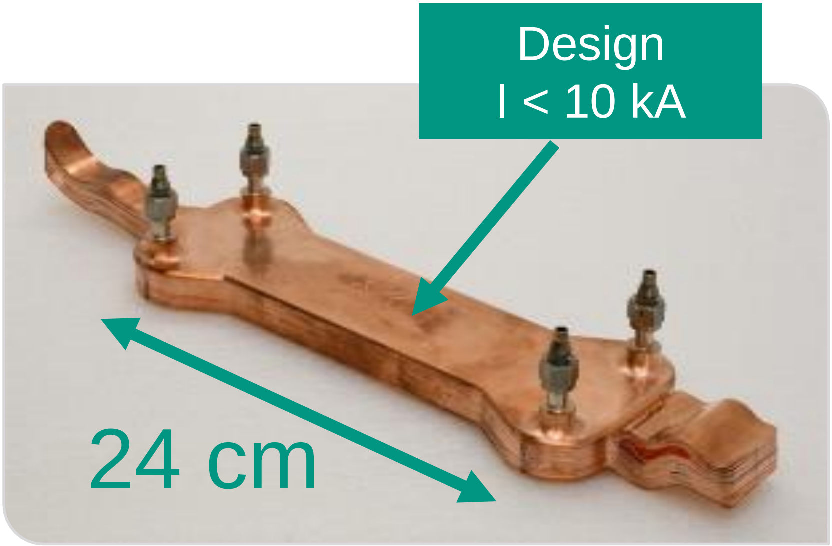
Expected impact:
- Higher awareness of sustainable energy solutions
- Training of public managers by means of demonstrators, schools, and workshops.
- Reduction of operation costs for public (hospitals, schools) and private (industry) facilities
- Open-access data & Benchmark results

Ultra-efficient, ultra-compact, scalable components

Compact accelerator systems test stand (COMPASS)



- Superconducting magnets and undulators
- Micro-structured mixed-refrigerant cooled current leads
- Superconducting cavities
- **Develop energy-efficient components**



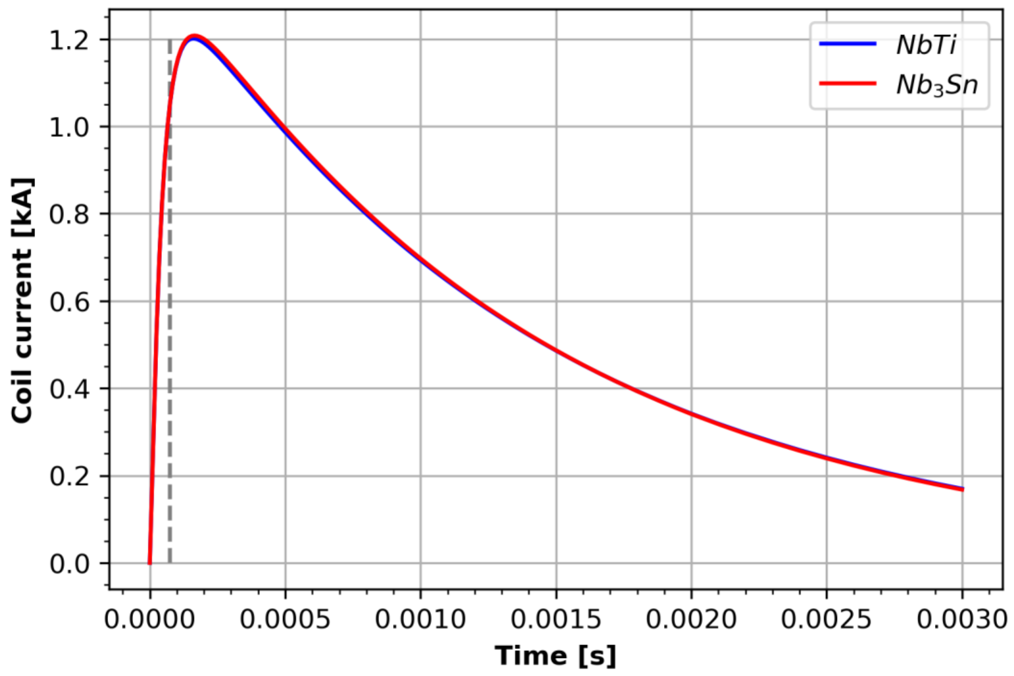
Patented current leads
Power demand reduction by ⅔

InnovEEA
Innovation pool project for Energy Efficient Accelerators

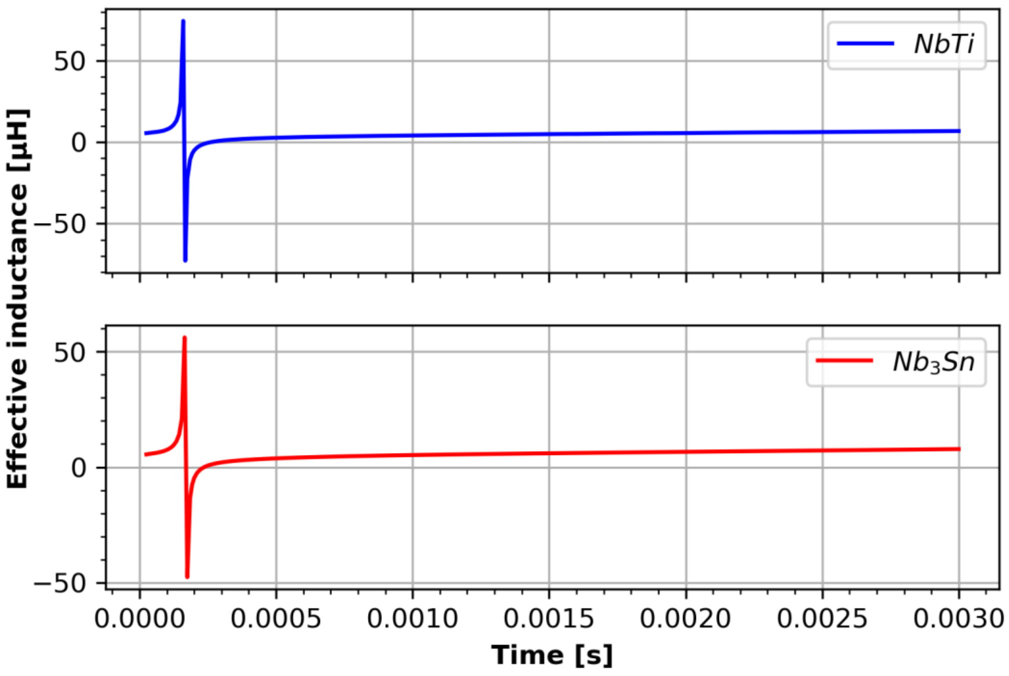
J. Arnsberg, S. Grohmann, Innovationspool III. InnovEEA Meeting, Mar 2022 - https://indico.scc.kit.edu/event/2646/
E. Shabagin, Development of a CMRC cooled 10 kA current lead for HTS applications. PhD dissertation, KIT, Apr 2022 - https://doi.org/10.5445/IR/1000144514

Investigations on superconducting racetrack coils under pulsed-current excitation

Pulse wave-forms



Effective inductance

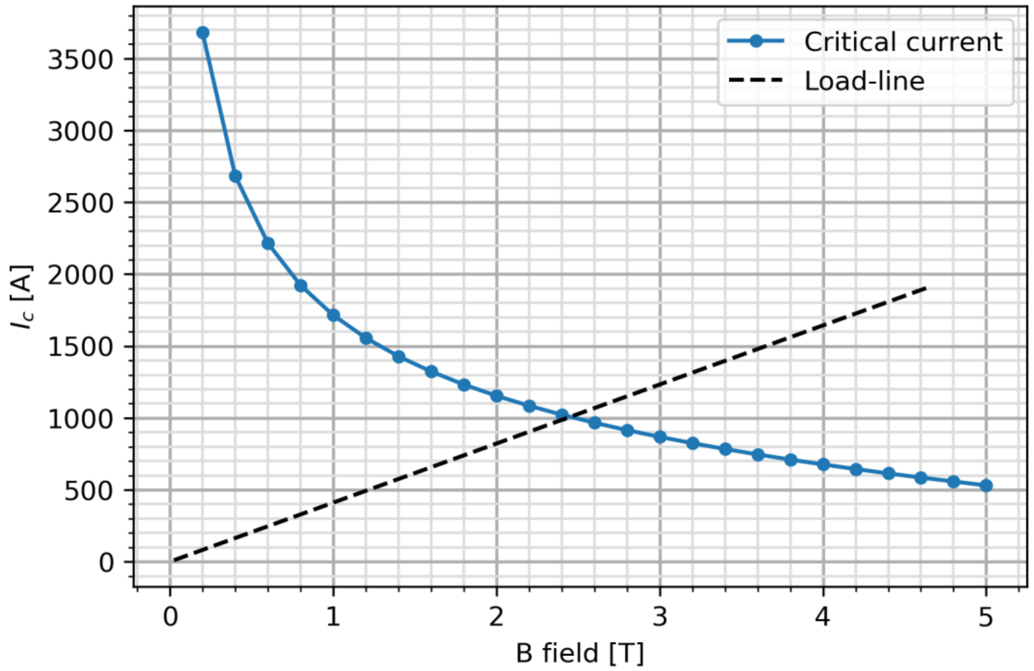


- Quench only in NbTi
- Transition time: $\sim 70\ \mu s$

$$L_{eff} = \frac{V - \left(\frac{P}{I}\right)}{\frac{dI}{dt}}$$

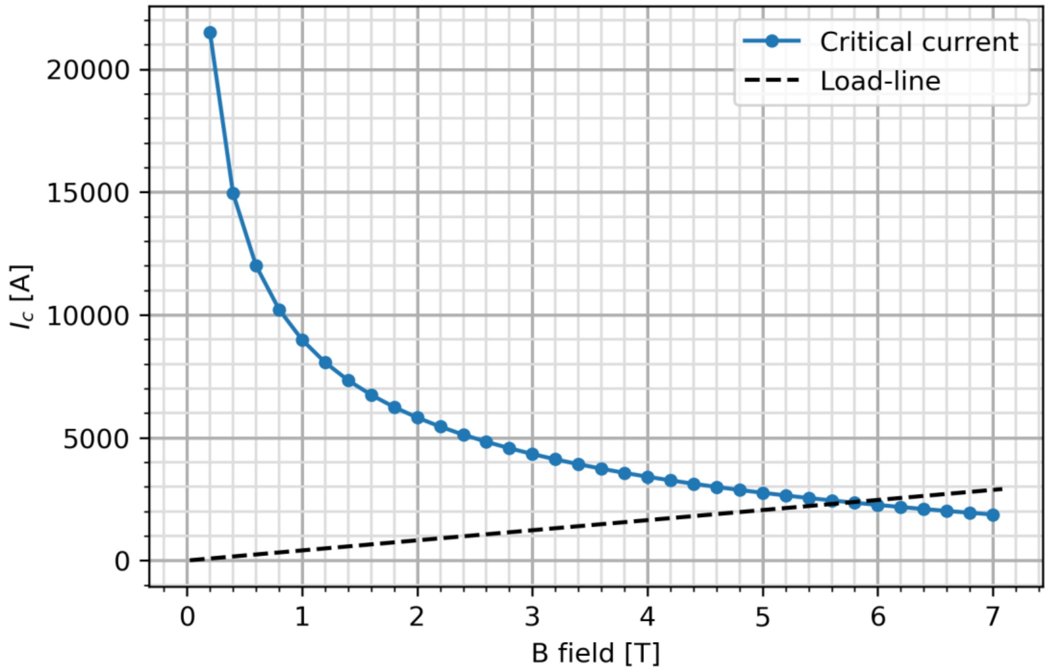
Nb_3Sn vs. $NbTi$

$NbTi$



- First resistive mode $\sim 15\ \mu\Omega$
- Quench $\sim 70\ \mu s$
- $I_c = 1.054\ kA$

Nb_3Sn



- No quench
- $I_c > I_{pulse}$

Falastine Abusaif, falastine.abusaif@kit.edu

What can we conclude?

- Nb_3Sn is about 1 order of magnitude more expensive than $NbTi$
- Compare existing $NbTi$ model with a new model for Nb_3Sn (with less SC material)
  - reduced number of turns (two layers instead of four)
- However, HTS costs are dropping due to improvements of manufacturing technology and supply chain

What will take into account in the next steps

- Manufacturing complexity
  - How many companies can produce it? What is its reliability?
  - Investment costs vs. operation costs reduction under same conditions → comparison with HTS
  - Carbon footprint of coil during its whole lifetime

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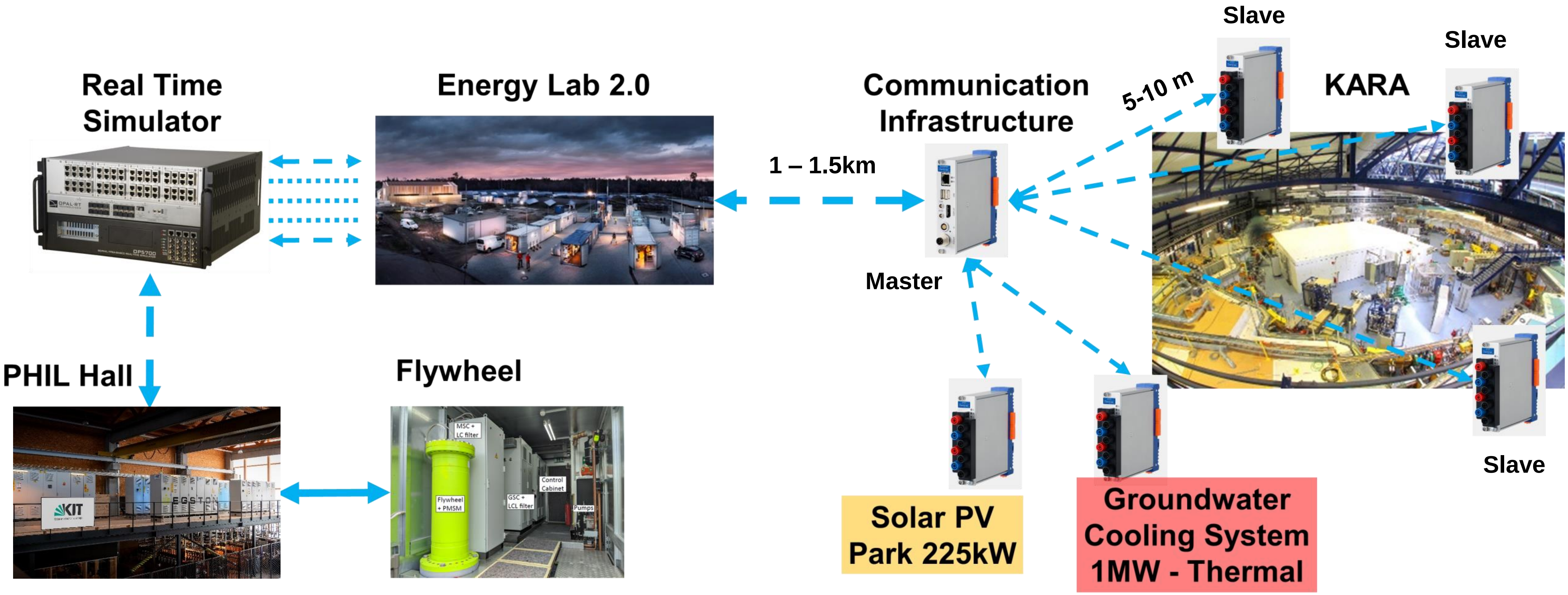
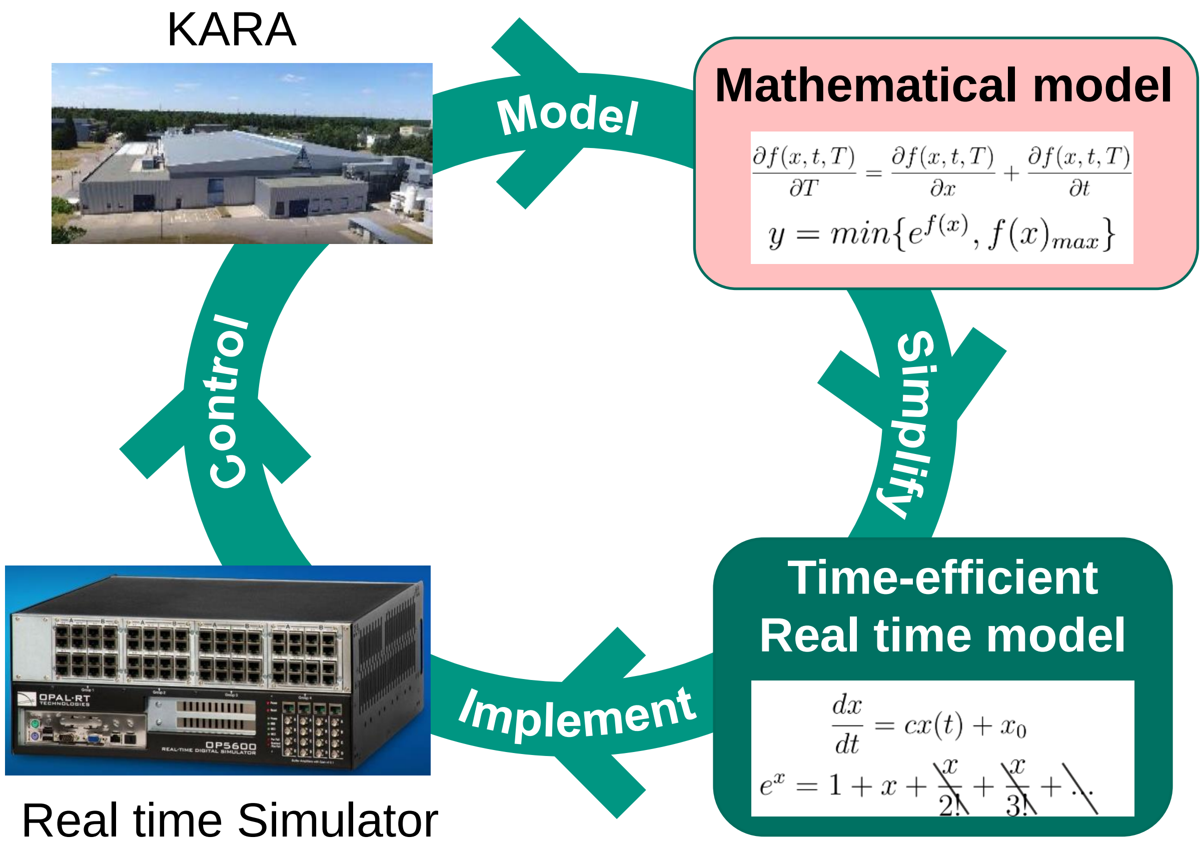
KITTEN experimental setup



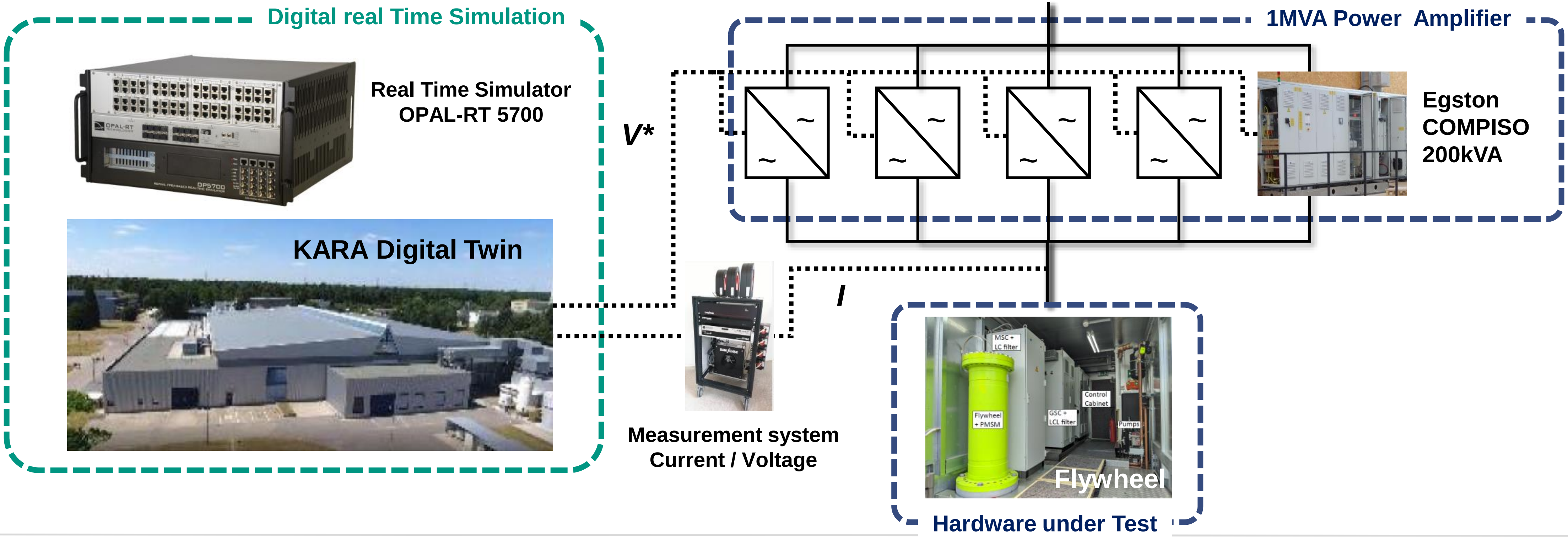
KITTEN next accelerators concept

- **Goal**
  - Develop solutions for stable, efficient and safe operations of accelerators (and not only!)
- **How to achieve it?**
  - KARA→ large field measurement availability
  - Data-drive models of KARA → IBPT experience is important!
  - Time-efficient real time modelling → EL2.0 experience is important!
  - Control feedback to KARA
- **Expected outcome**
  - Digital Twin of KARA to be employed for analyzing, developing and testing future energy solutions for accelerators



Unique selling point: Validation by means of Power Hardware In the Loop

- **Digital real time simulator**: simulate the KARA electrical grid
- **Power amplifier**: reproduce a point of the simulated grid in lab (e.g., measured voltage)
- **Hardware under Test**: this is the technology, which performances we want to test



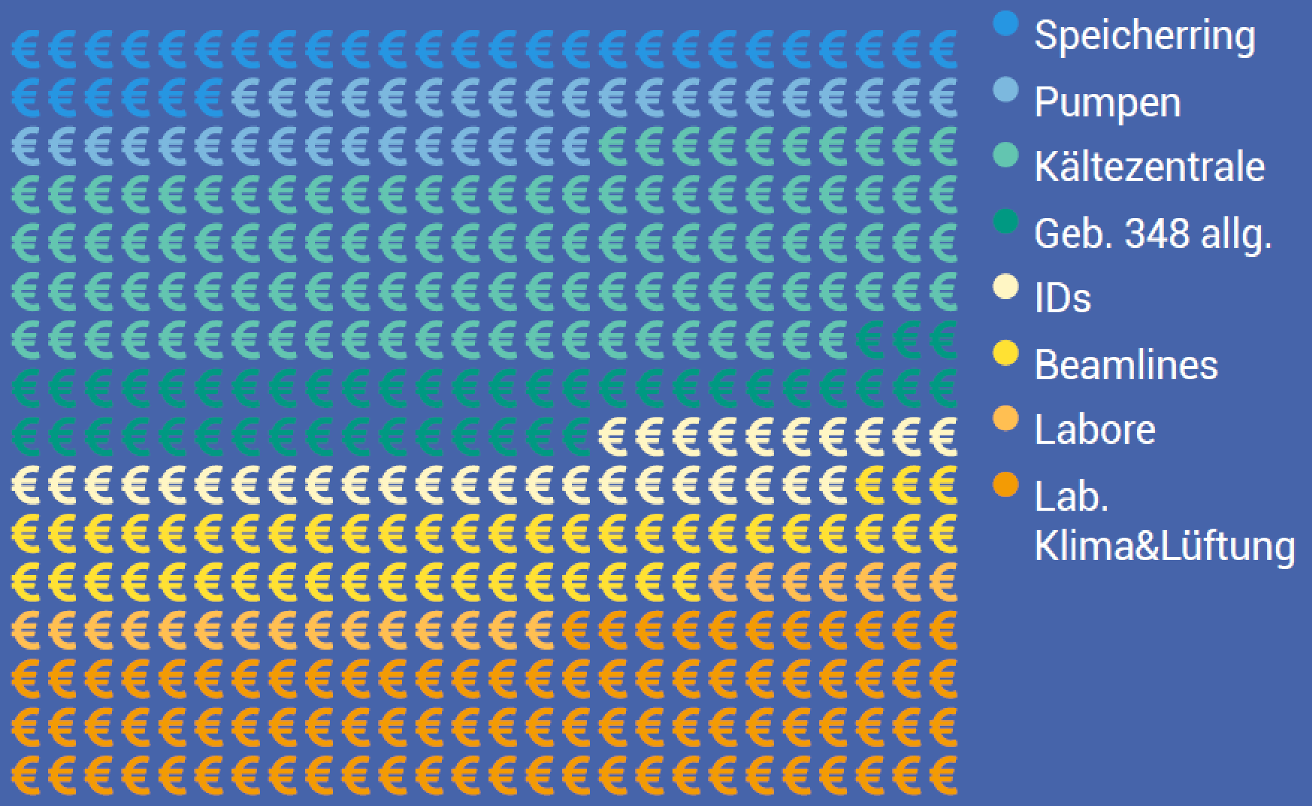
Cost analysis for KARA – a first analysis

Base Load

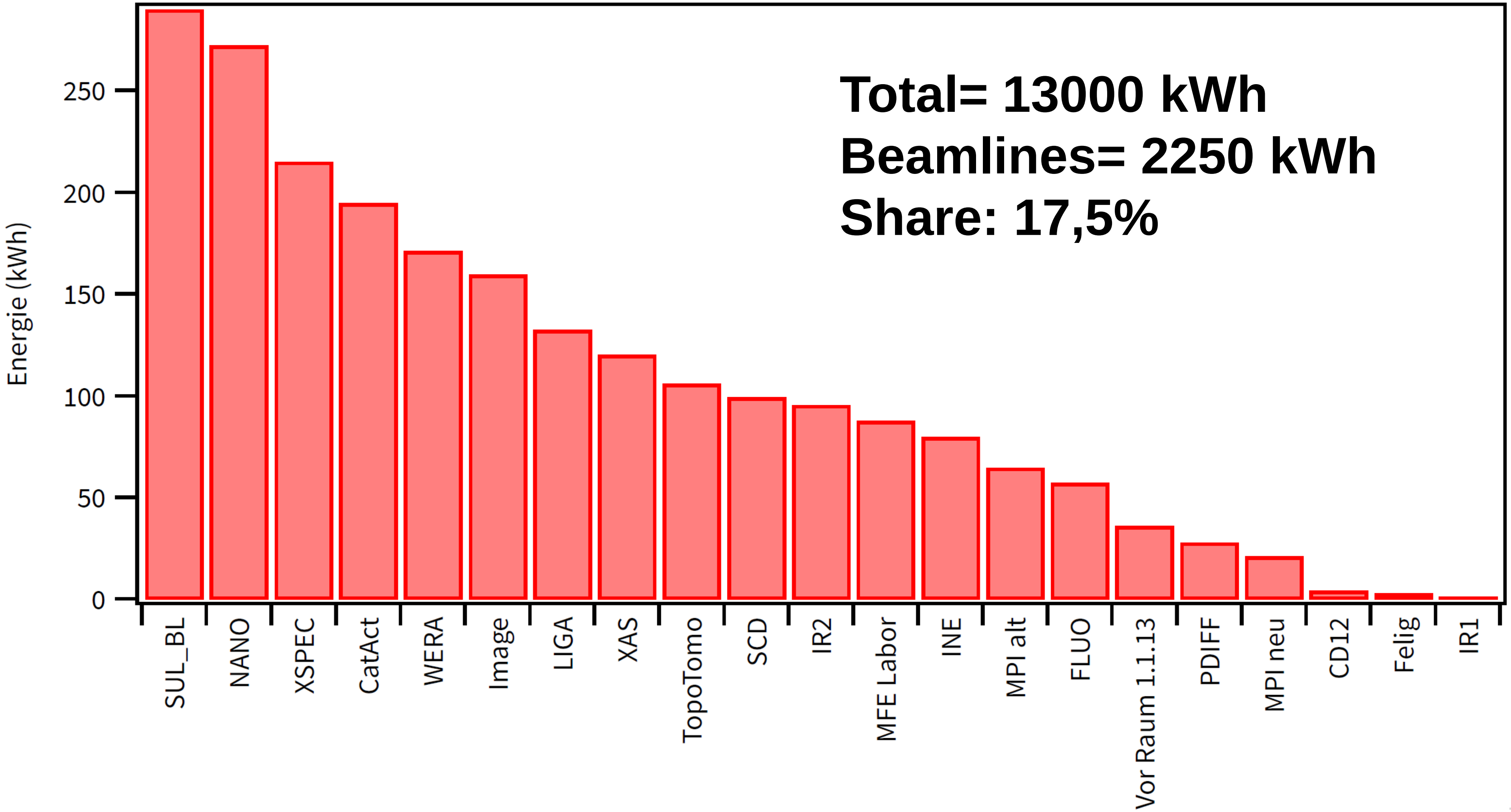
Around 40% of the base load of 7GWh is related to labs and beamlines. 8% for the insertion devices.

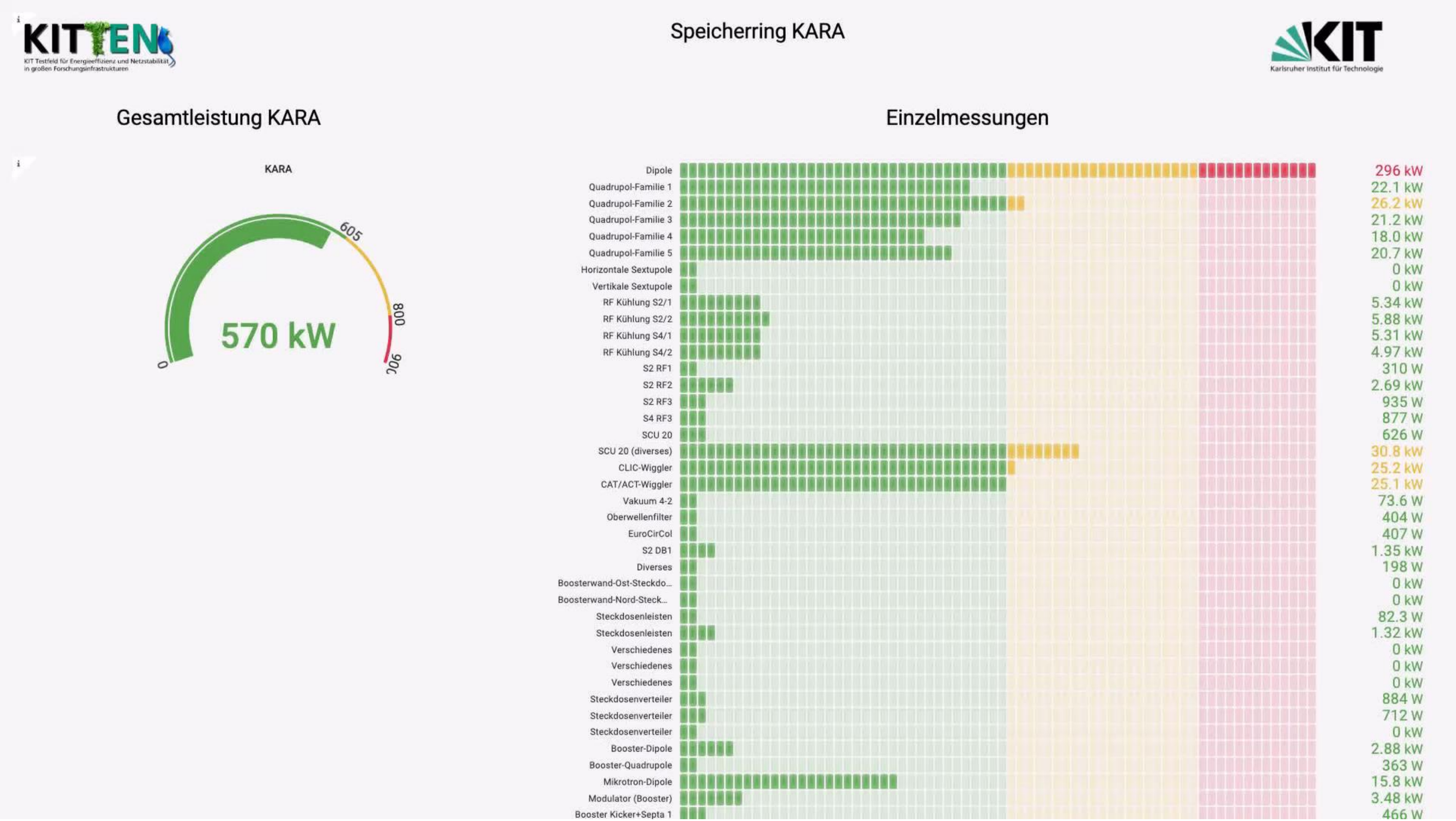
Around 40% goes for the building power and the cooling system.

The storage ring and pumps take only 8% of the base load.



Beamlines energy consumption – 14.09.2022

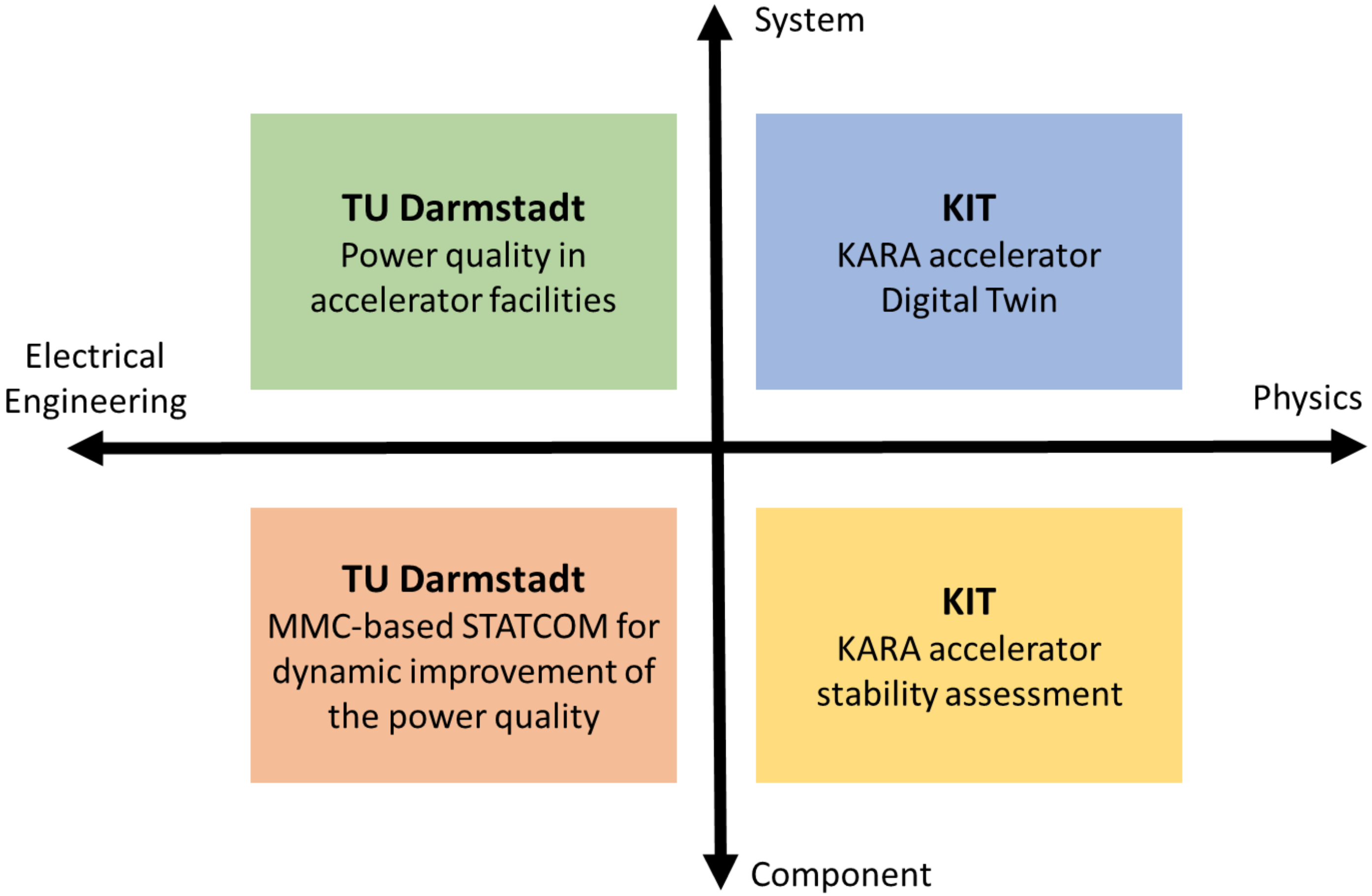




KIT Testfeld für Energieeffizienz und Netzstabilität in großen Forschungsinfrastrukturen
Speicherring KARA
Karlsruher Institut für Technologie
Gesamtleistung KARA
KARA
0
605
800
900
570 kW
Einzelmessungen
Dipole 296 kW
Quadrupol-Familie 1 22.1 kW
Quadrupol-Familie 2 26.2 kW
Quadrupol-Familie 3 21.2 kW
Quadrupol-Familie 4 18.0 kW
Quadrupol-Familie 5 20.7 kW
Horizontale Sextupole 0 kW
Vertikale Sextupole 0 kW
RF Kühlung S2/1 5.34 kW
RF Kühlung S2/2 5.88 kW
RF Kühlung S4/1 5.31 kW
RF Kühlung S4/2 4.97 kW
S2 RF1 310 W
S2 RF2 2.69 kW
S2 RF3 935 W
S4 RF3 877 W
SCU 20 626 W
SCU 20 (diverses) 30.8 kW
CLIC-Wiggler 25.2 kW
CAT/ACT-Wiggler 25.1 kW
Vakuum 4-2 73.6 W
Oberwellenfilter 404 W
EuroCirCol 407 W
S2 DB1 1.35 kW
Diverses 198 W
Boosterwand-Ost-Steckdo... 0 kW
Boosterwand-Nord-Steck... 0 kW
Steckdosenleisten 82.3 W
Steckdosenleisten 1.32 kW
Verschiedenes 0 kW
Verschiedenes 0 kW
Verschiedenes 0 kW
Steckdosenverteiler 884 W
Steckdosenverteiler 712 W
Steckdosenverteiler 0 kW
Booster-Dipole 2.88 kW
Booster-Quadrupole 363 W
Mikrotron-Dipole 15.8 kW
Modulator (Booster) 3.48 kW
Booster Kicker+Septa 1 466 W

ACCelerator Energy System Stability - ACCESS

- Call „Erforschung von Universum und Materie – ErUM“ - “Materie 2022-2025”
- KIT and Technical University Darmstadt common work
- Years 2022 – 2025
- Budget ≈ 1100k€
- The ACCESS project targets the provision of a reliable power supply for large accelerator infrastructures under modified grid conditions based on the development of advanced power electronics, management and control approaches.



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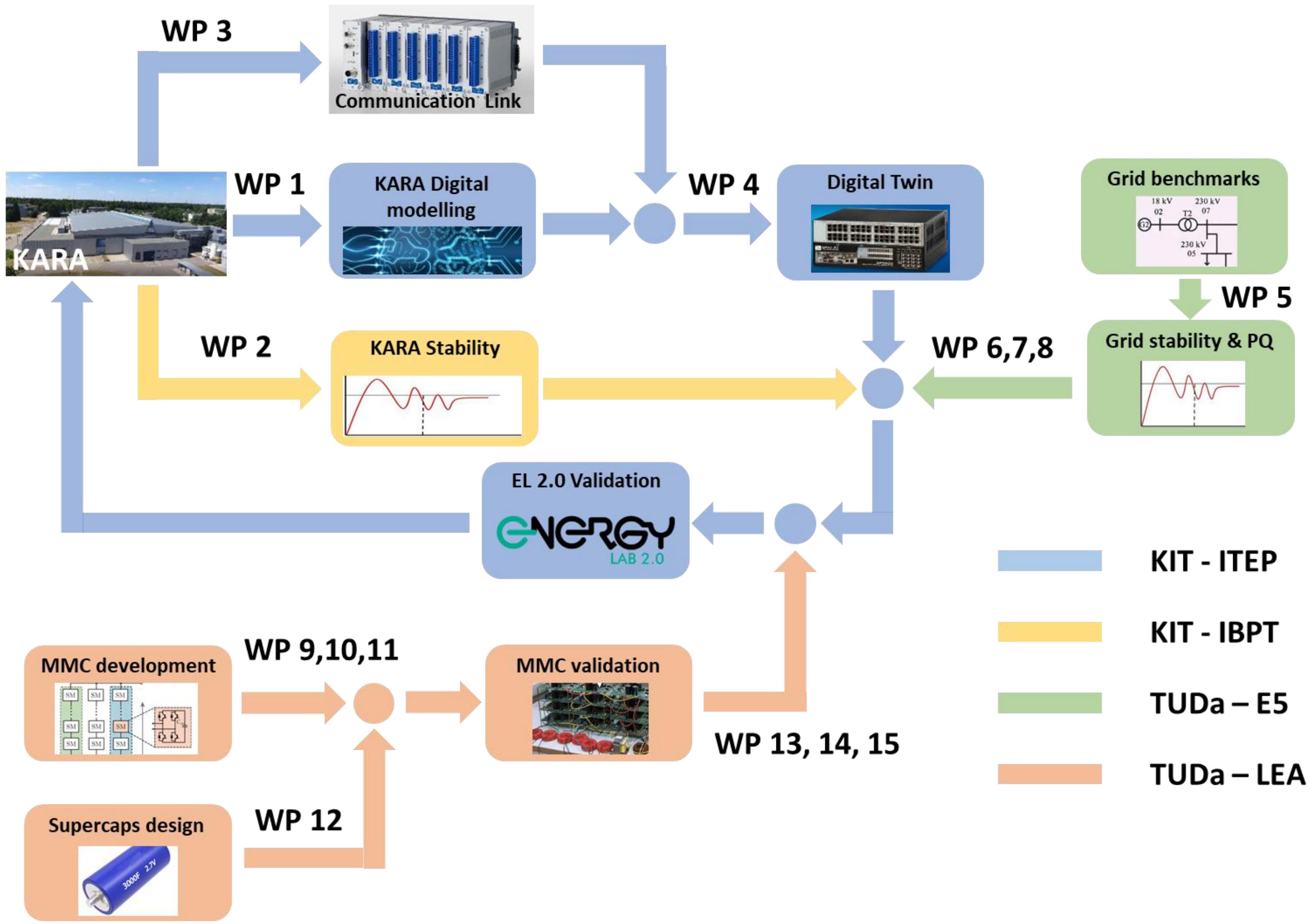
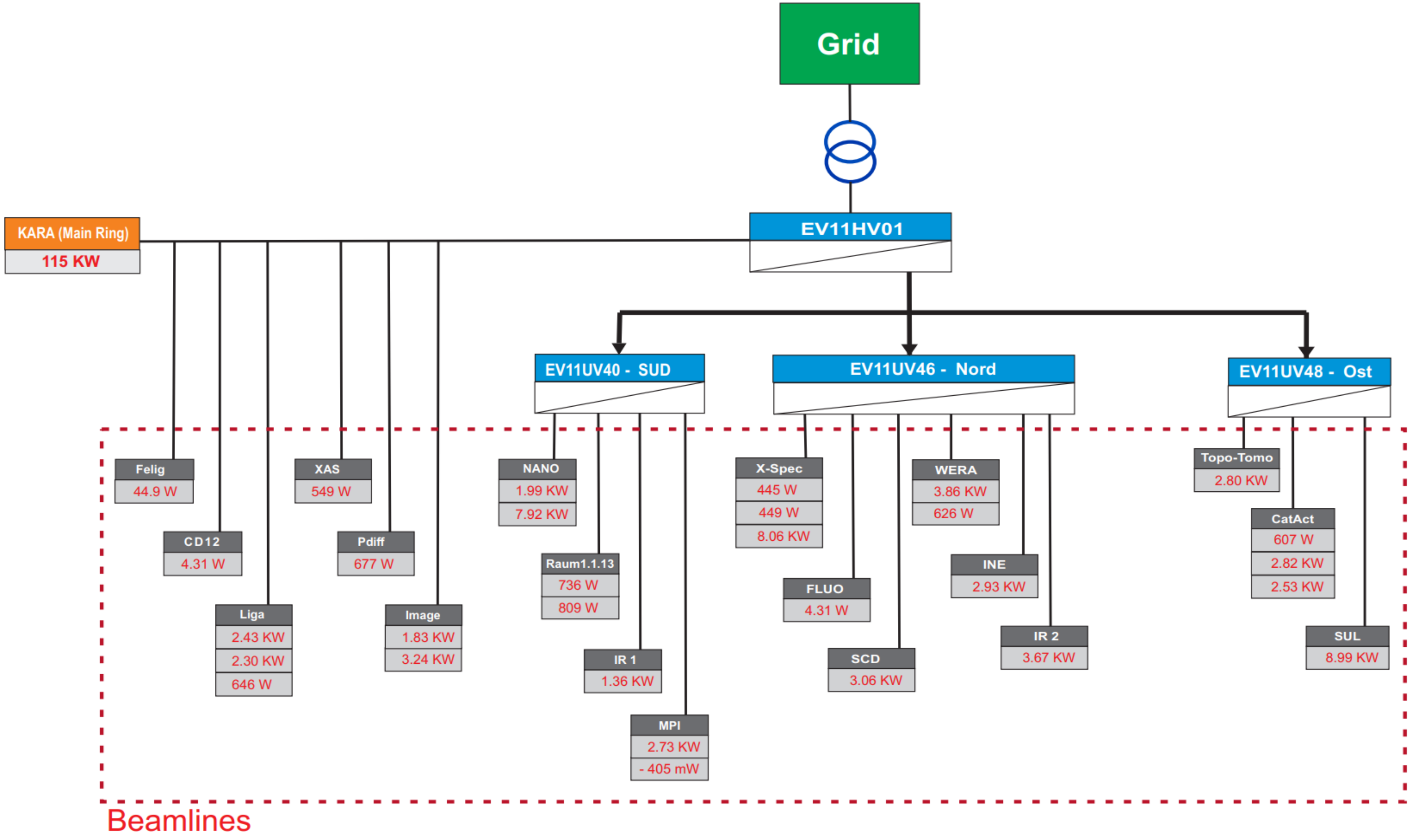
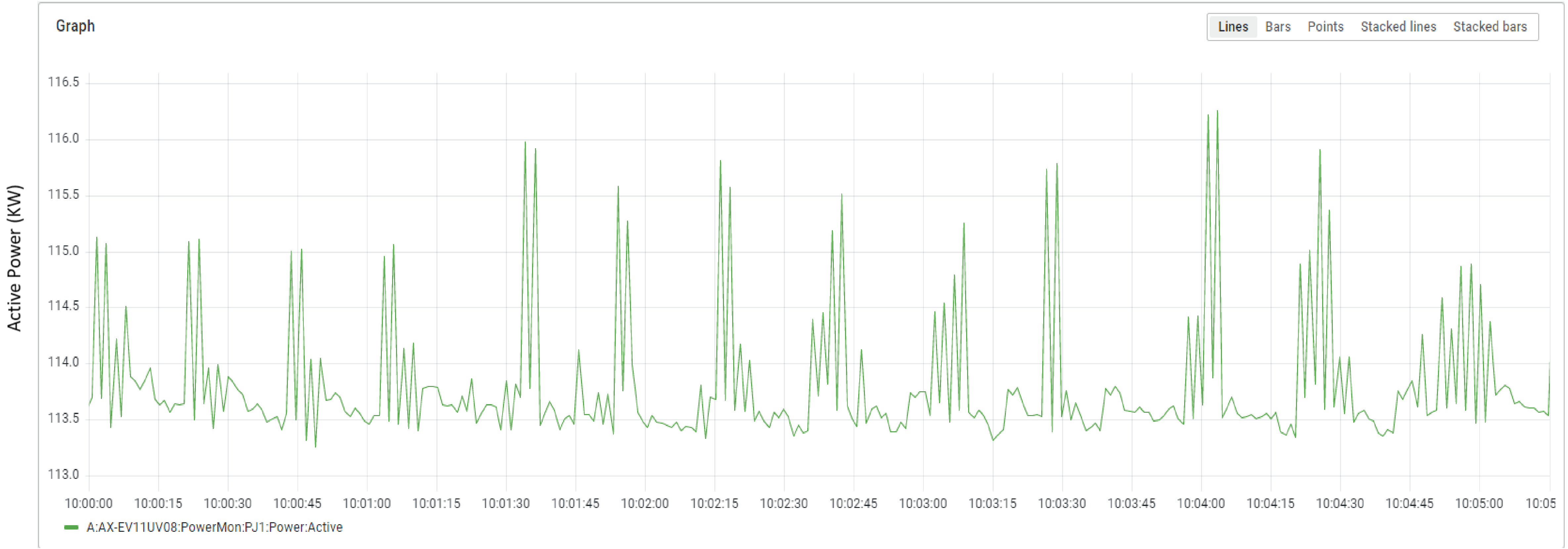


Strand scheme of main ring and Beamlines

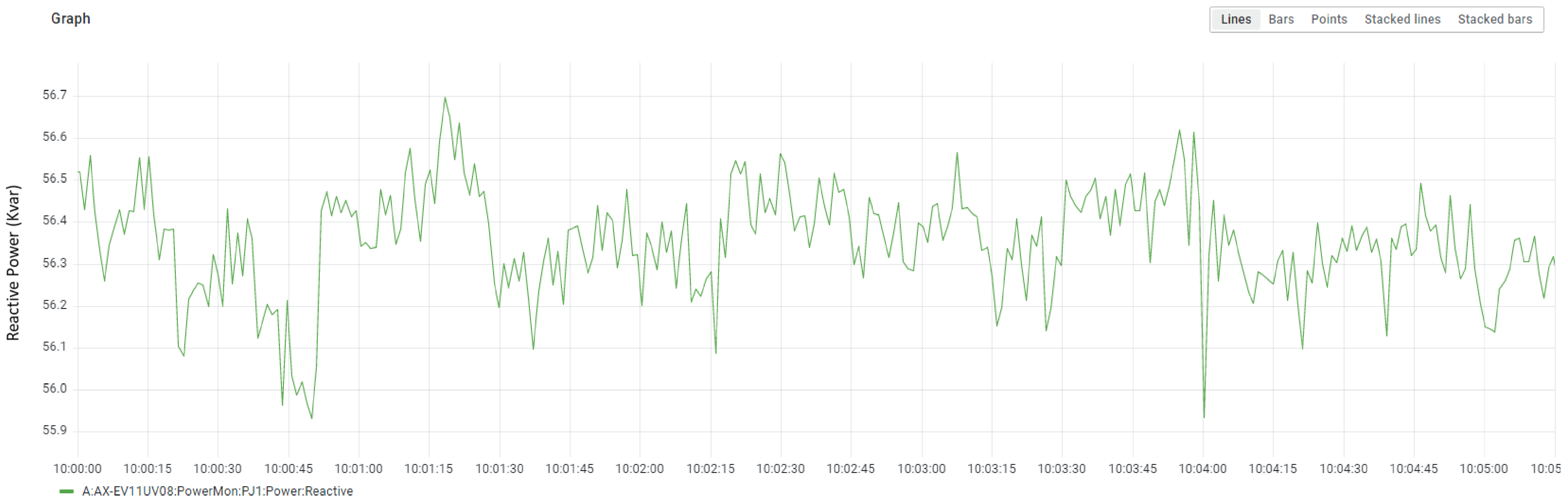


Active Power Profile of main ring



2023-03-01 10:00:00 to 10:05:15

Reactive Power Profile of main ring



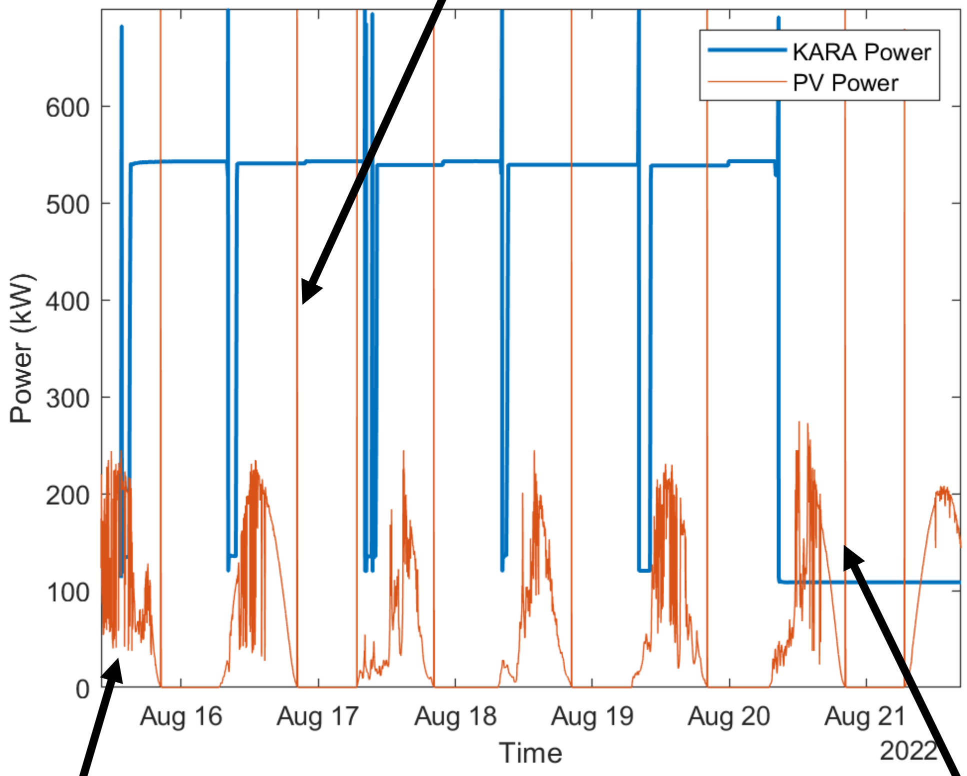
2023-03-01 10:00:00 to 10:05:15

Voltage Profile of main ring

2023-03-01 10:00:00 to 10:05:15

First power analysis for KARA – Solutions and challenges

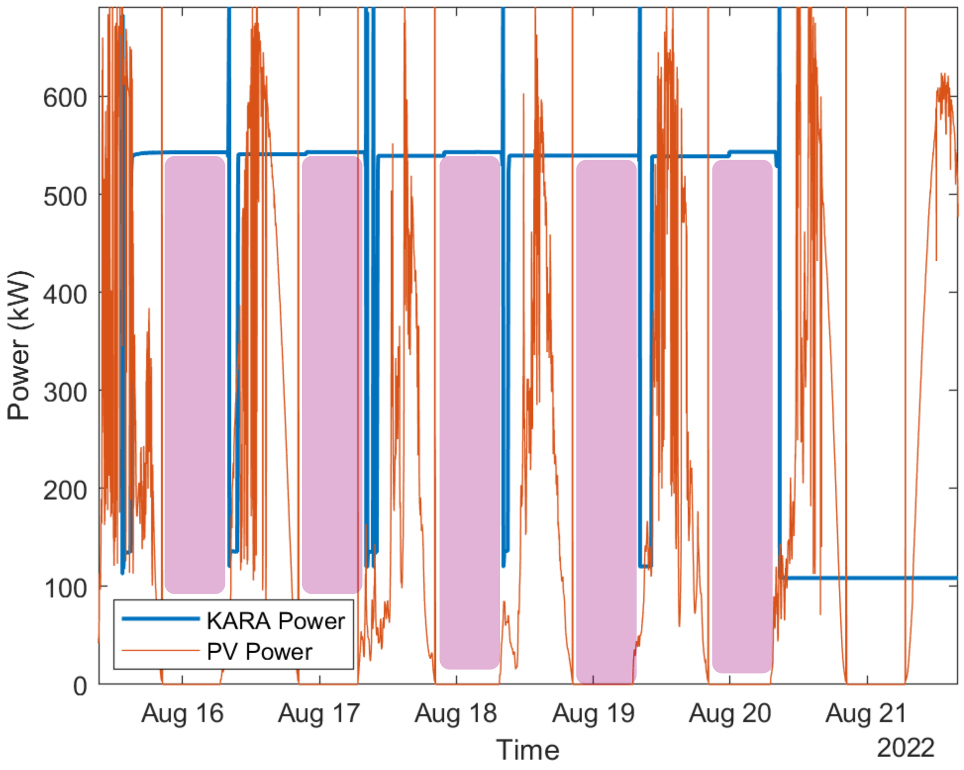
Not sufficient power



Not synchronized PV production and consumption

PV power exceeding the consumption during weekend

PV Plant 3 times bigger



Missing everyday 550kW for ca. 10 hours = 5550kWh

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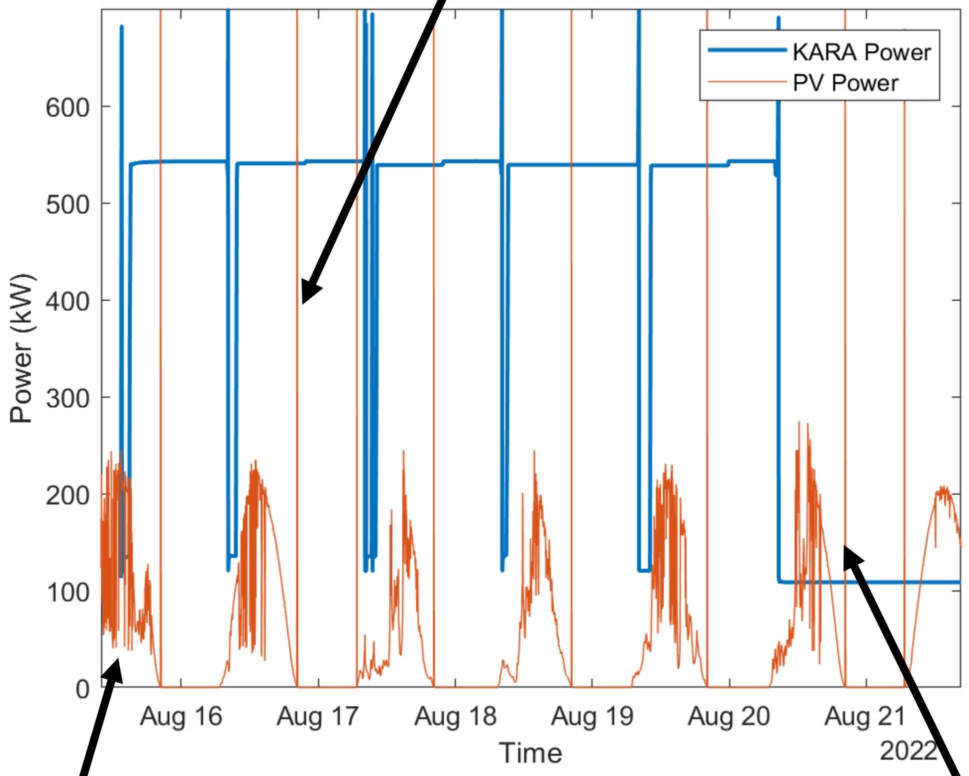

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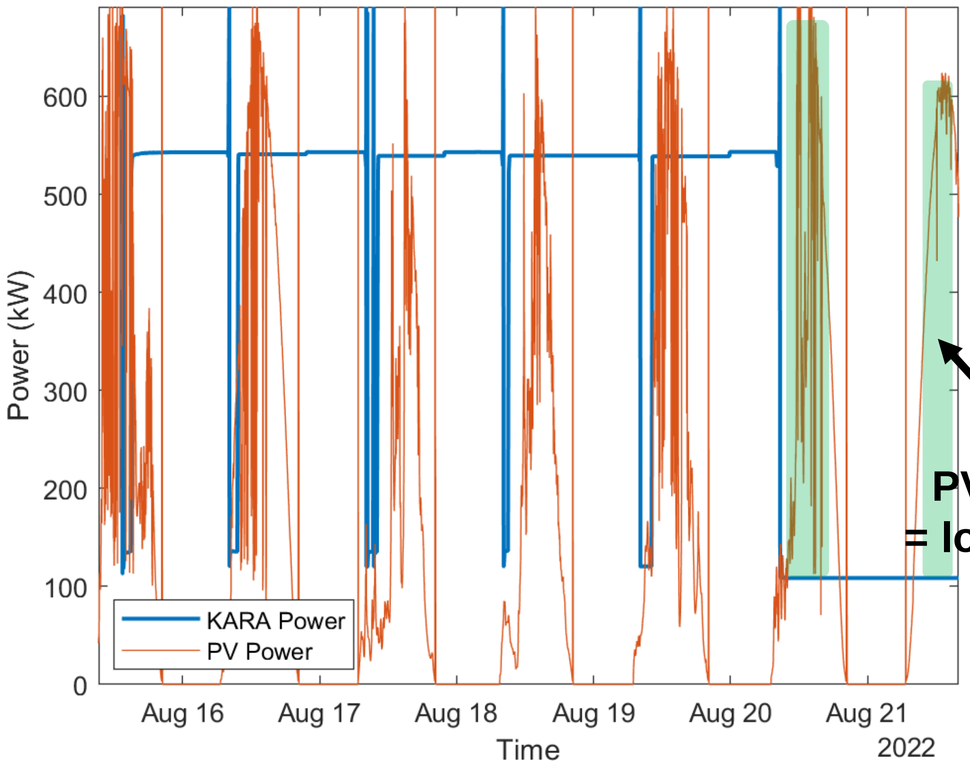
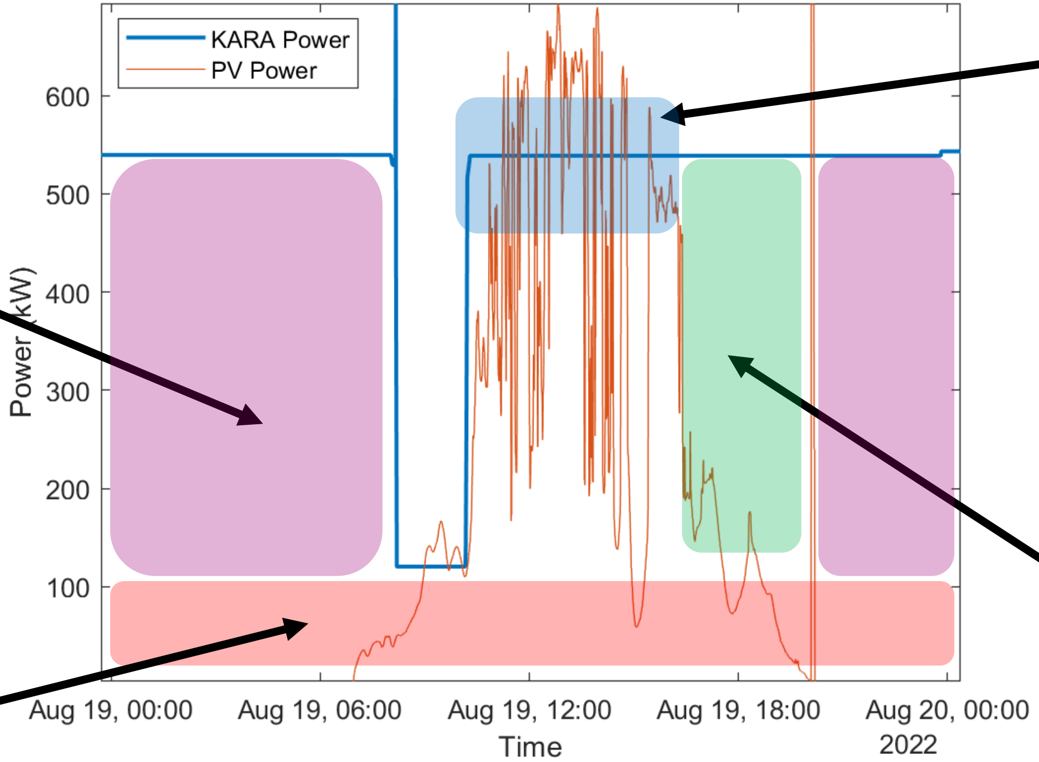


PV capping = lost revenue

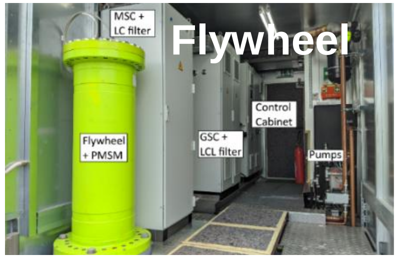
450kW for ca. 16 hours missed revenue

Energy storage solutions for accelerators

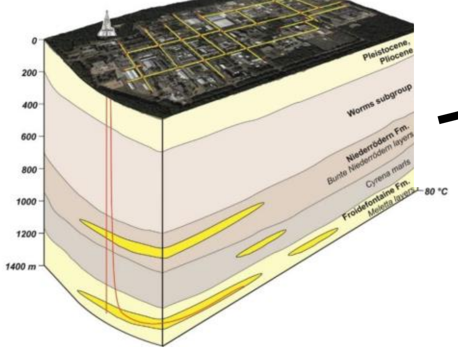
Long-term (>12 hours) storage solutions



Fast dynamics solutions



Geothermal

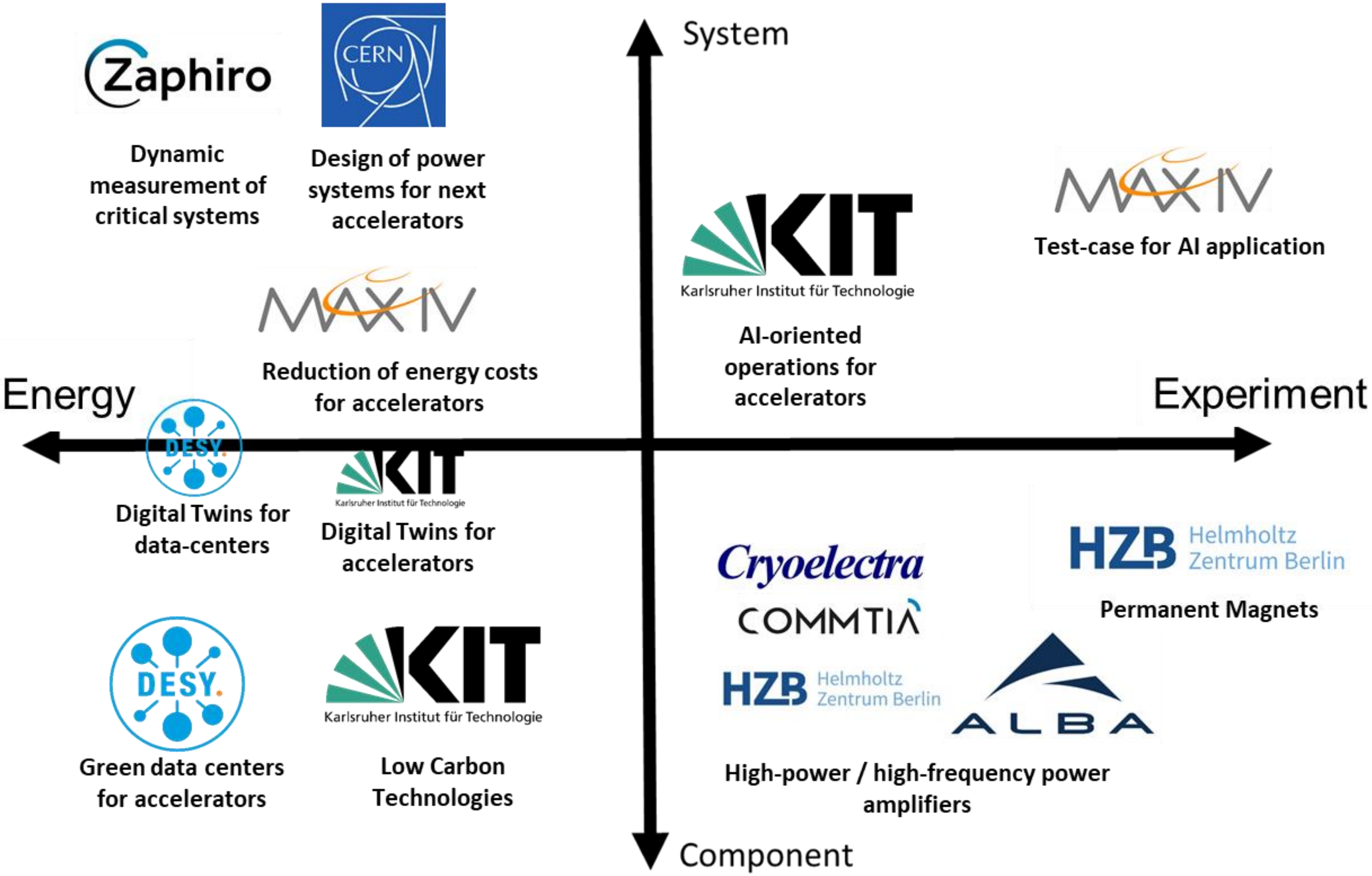


Seasonal energy storage solutions

Medium-term solutions

HORIZON-INFRA-2023-TECH-01-01: New technologies and solutions for reducing the environmental and climate footprint of Ris

- **Innovative technologies and solutions which reduce the environmental and climate footprint of Ris through the full life cycle of research infrastructures.**
- New Technologies and solutions for research infrastructures enabling transformative resource efficiency (e.g., energy consumption) and reduction of environmental (including climate-related) impacts.
- Validation and prototyping



HORIZON-INFRA-2023-TECH-01-01: New technologies and solutions for reducing the environmental and climate footprint of Ris

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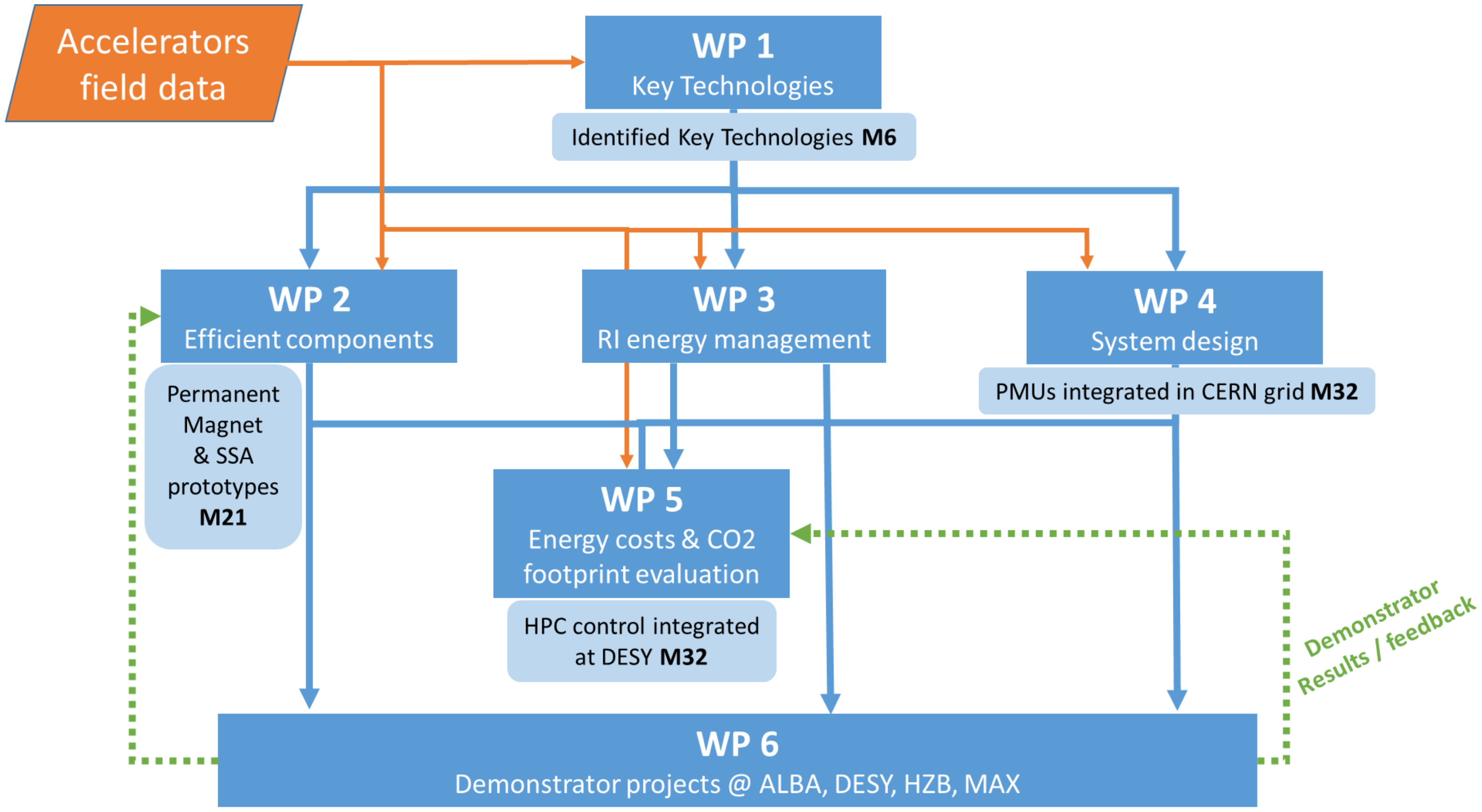

HIRING!!!
Looking for talented
PhDs and Post-docs
to work on the topic!

Karlsruhe Institute of Technology

THANK YOU
Questions?

TT.-Prof. Dr.-Ing. Giovanni De Carne
Head of „Real Time System Integration“ group
Helmholtz young investigator group leader

Karlsruhe Institute of Technology
Institute for Technical Physics (ITEP)

Phone: +49 721 608-25924
Email: giovanni.carne@kit.edu

www.itep.kit.edu