HELMHOLTZ

RESEARCH FOR GRAND CHALLENGES

Research Field Matter

Matter and Technologies

Topic 2 – Detector Technologies and Systems

Silvia Masciocchi (GSI), Heinz Graafsma (DESY), Frank Simon (KIT)

MT Annual Meeting

November 4, 2025

Detector Technologies and Systems

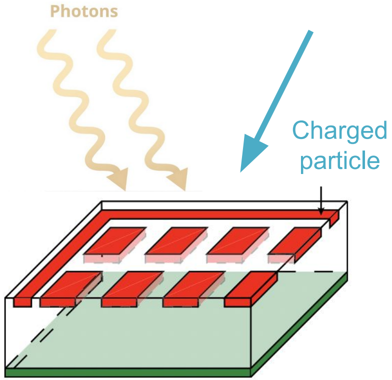
Advancing discovery through world-leading detector innovation

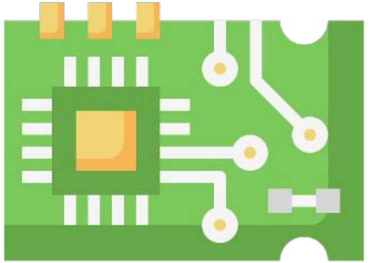
Detector Technologies and Systems

MT-DTS in one sentence

MT-DTS drives **world-leading innovation** in detector technologies,
providing **end-to-end expertise** − from component design to full system integration −

SENSOR **ELECTRONICS** **SYSTEMS**





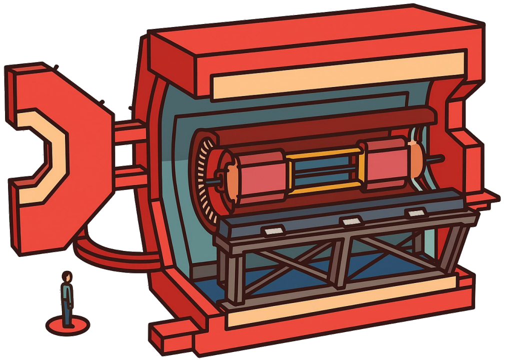


Image: P. Fischer

Detector Technologies and Systems

MT-DTS in one sentence

MT-DTS drives **world-leading innovation** in detector technologies,
providing **end-to-end expertise** – from component design to full system integration –
thus powering **cutting-edge discoveries** in science
and enabling a **broad range of applications**, in Helmholtz-Matter and beyond.

Photon Science

Astro-physics

Particle Physics

Nuclear physics

Atomic Physics

Beam Diagnostics

Medical Applications

MT-DTS: Helmholtz centers involved

DESY, GSI & HIJ, KIT

DESY.

GSI

HIJ
HELMHOLTZ
Helmholtz-Institut Jena

KIT
Karlsruhe Institute of Technology

Research Field Helmholtz Matter

MT ARD

MT DMA

MU

MML

Detector Technologies and Systems

Develop detection technologies to enable science

POF IV

Speakers: M. Weber, S. Masciocchi

M. Caselle, M. Deveaux, S. Spannagel

M. Guthoff, A. Kopmann

P. Gasik, C. Wunderer

Detection and Measurement

approaching the physical limits of resolution

System Technologies

coping with the data deluge

Science Systems

demonstrator projects for effective link across Matter

Center Representatives
DESY: H. Graafsma
GSI: C. Schmidt
KIT: F. Simon

Detector Technologies and Systems

POF IV Center Evaluation

Scientific achievements and impact:	**OUTSTANDING**
Originality and innovation:	**EXCELLENT**
International standing and competitiveness:	**EXCELLENT**

Recommendations include:

- Increase personnel, particularly in the area of ASIC design
- Reconsider the establishment of a Distributed Detector Laboratory (DDL) as previously proposed by GSI, DESY and KIT

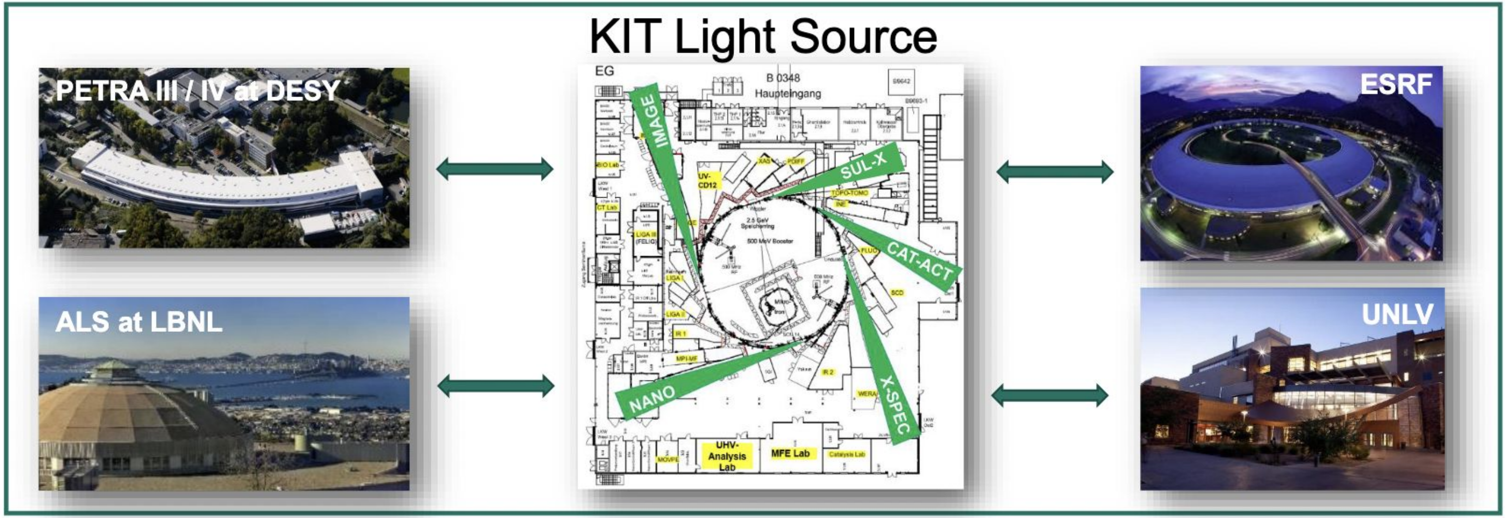
More KIT teams join DTS for POF V

T. Baumbach, C. Heske

Photon Science and Synchrotron Radiation Research

enabled by combining the strengths of

- the Beamlines and Labs at the KIT Light Source
- complementary experimental stations at low-emittance photon facilities



providing a unique portfolio

- for pioneering method development and fundamental research
- for systematic, large comparative studies
- as a **unique home-court advantage** for KIT Programs and Centers

More KIT teams join DTS for POF V

T. Baumbach, C. Heske

MML Matter FROM MATTER TO MATERIALS AND LIFE

KIT Karlsruher Institut für Technologie

Photon Science and Synchrotron Radiation Research

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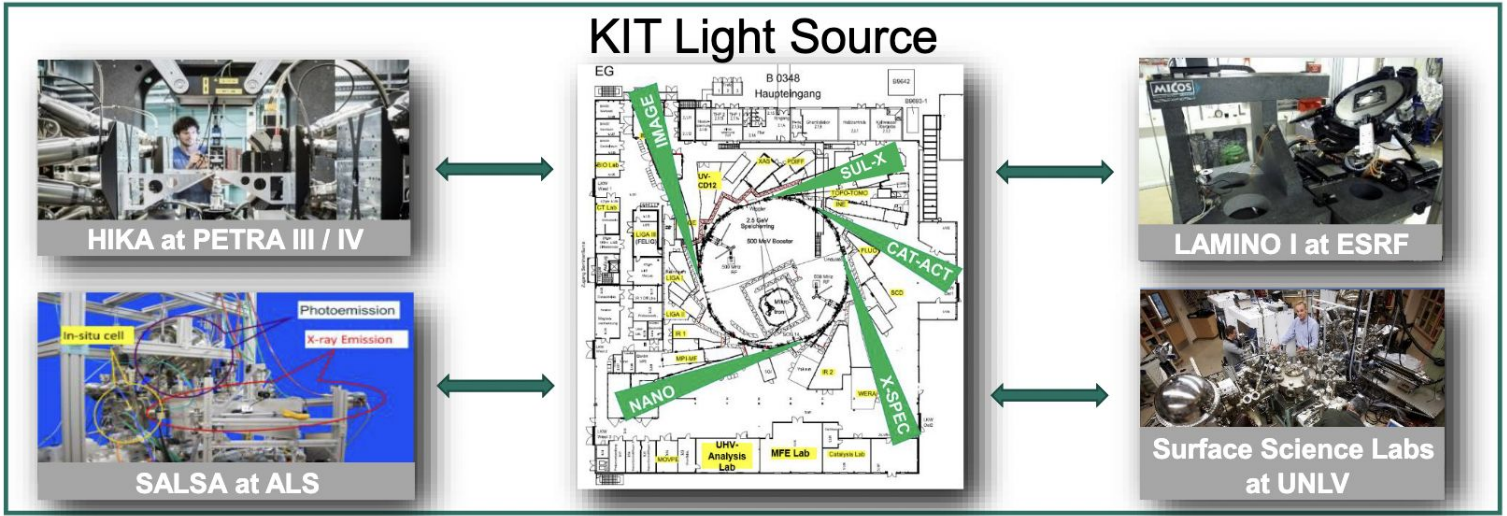
- the Beamlines and Labs at the KIT Light Source and
- complementary experimental stations at low-emittance photon facilities



providing a unique portfolio

- for pioneering method development and fundamental research
- for systematic, large comparative studies
- as a **unique home-court advantage** for KIT Programs and Centers

MT-DTS: new spins

Development of **methods**

Inspiration: pioneering method developments

Combination of:

- ➢ Advanced detection technologies
- ➢ Very high rate data transport
- ➢ Facilities: light sources, particle beams, low noise env.
- ➢ Advanced interconnectivity
- ➢ Artificial Intelligence to optimize system design
- ➢ Etc. etc.

NEW METHODS !!!

➡ **New subtopic organization**

MT-DTS is growing (DESY and GSI too)

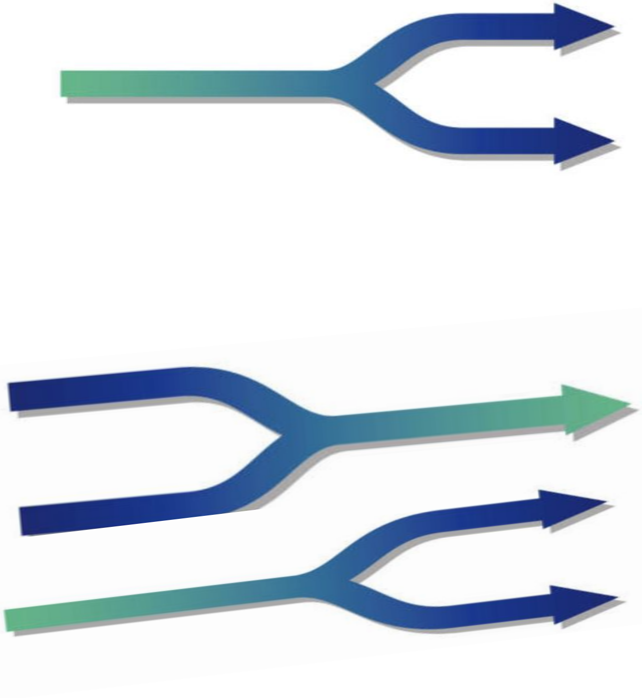
→ From 3 to 4 sub-topics in POF V

POF IV

ST1 Detection and Measurement

ST2 System Technologies

ST3 Science Systems



POF V

ST1 Sensing and Detecting Technologies

ST2 Quantum Technologies — NEW!

ST3 Systems and their Technologies

ST4 Detection Methods — NEW!

MT-DTS is growing

From 3 to 4 sub-topics in POF V

NEW!

NEW!

ST1 Sensing and Detecting Technologies

ST2 Quantum Technologies

ST3 Systems and their Technologies

ST4 Detection Methods

“Develop versatile sensing technology to realize intelligent, next-generation detector modules for extreme environments”

“Establish large scale, high energy resolution quantum detectors and explore new quantum sensing technologies”

“Combine novel technologies into sustainable detectors and highest-rate data processing systems.”

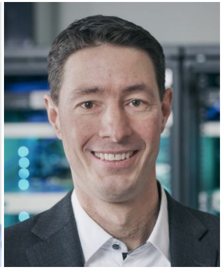
“Integrate advanced detector systems into multidimensional modalities and AI-assisted methods for scientific discovery.”

Detector Technologies and Systems

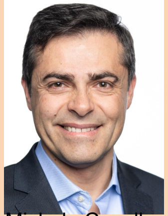
The new team


Silvia Masciocchi


Heinz Graafsma


Frank Simon

ST1


Michele Caselle


Michael Deveaux


Simon Spannagel

ST2


Sebastian Kempf


Peter Micke


Steven Worm

ST3


Piotr Gasik


Moritz Guthoff


Andreas Kopmann

ST4


Clemens Heske


David Pennicard

Center contacts


Cornelia Wunderer


Christian Schmidt


Andreas Kopmann

Detector Technologies and Systems: ST1 & ST3

Ex. 1: CMOS pixel sensors for tracking detectors

Challenges:
- Large area trackers
- High timing resolution
- Extreme radiation hardness

Applications:
ALICE 3 @LHC (60m^2), upgrades at FAIR
LHCb Upgrade IIb
Higgs Factory (FCC-ee)

Proposed projects:

65 nm CMOS MAPS

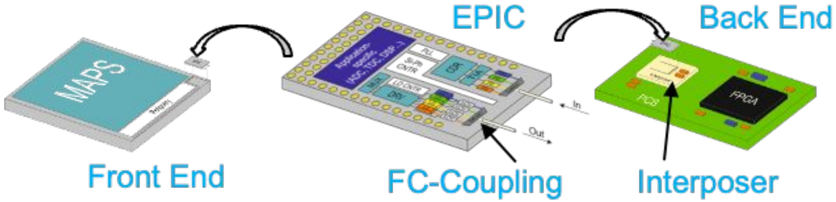
OCTOPUS MANTA

- 3(10) µm resolution
- 5(100) ns timing resolution
- 20(<500) mW/cm^2
- 10^{15} n_{eq}/cm^2

ECFA DRD 3

SOPHIE

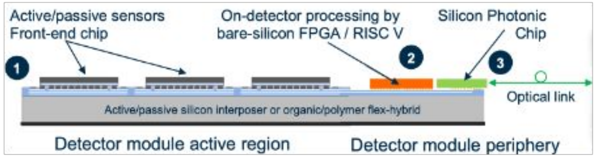
Optical data transmission, silicon photonics (InnoPool)



On-detector intelligence

intelligent detector modules that integrate compact, high-speed logic, low-power and AI capabilities: silicon interposers, ultra-compact FPGAs, no-backend electronics

DRD 7

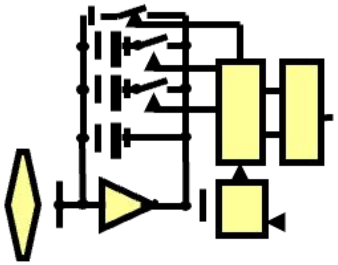


Detector Technologies and Systems: ST1 & ST3

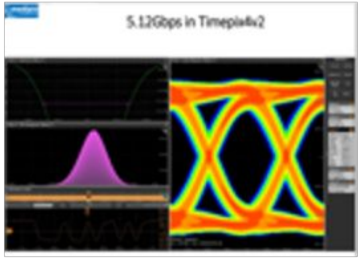
Ex. 2: Mega-Hertz X-ray imager

Challenges: continuous frame-rates, minimal dead area in imaging plane, > 10^5 dynamic range, high photon-energies, huge data rates, on the fly data reduction, …

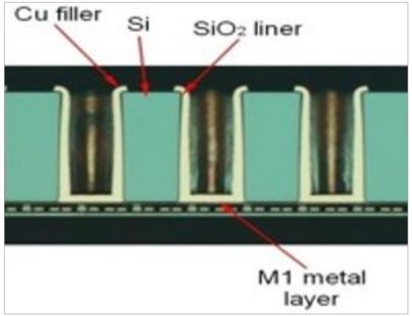
Adaptive gain for large dynamic range



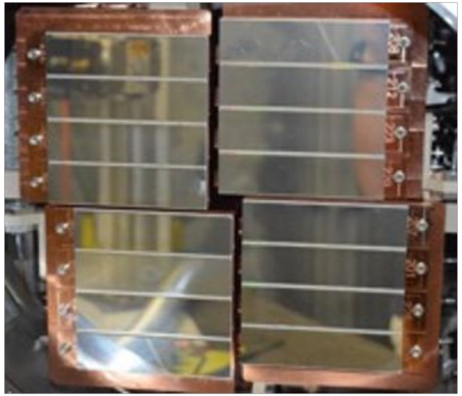
Silicon photonics for fast I/O



TSV technology for "gapless" tiling



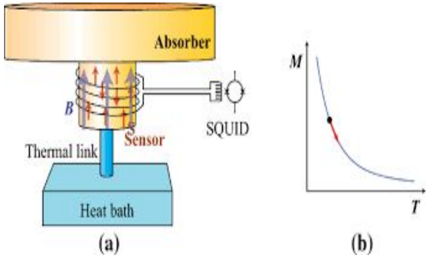
Combined expertise in Helmholtz centers and beyond

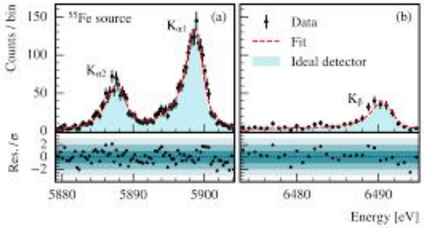


Detector Technologies and Systems: ST2

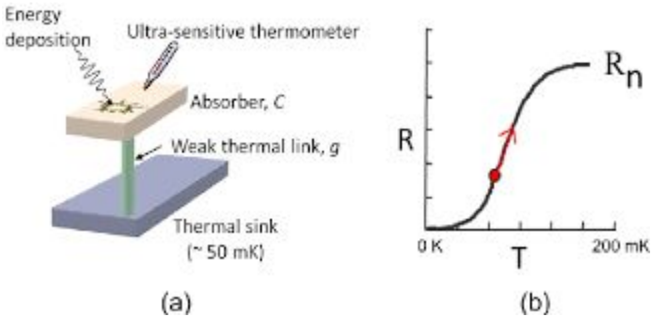
Quantum technologies

Magnetic Micro Calorimeter (MMC)





Transition Edge Sensor (TES)



- Variety of sensors: Metallic Micro Calorimeters (MMC), Transition Edge Sensors, Single Tunnel Junctions
- Realize sensor arrays with up to 10^6 pixels, with relative readout (e.g. SQUID multiplexers, etc)
- Develop source-coupling techniques (warm electrons or warm photons to cryogenic detectors)
- Develop new small-scale experiments using quantum sensors
- Operate modern multi-channel quantum sensors

Detector Technologies and Systems: ST2

Production of Quantum Sensors

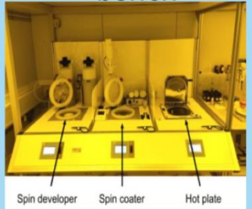
Built up during PoF IV, a corner stone for the PoF V in Quantum sensors and 2.5/3D-Integration:

Competence Center for Superconducting Sensors (HSS)

Photolithography

Maskless aligner

Custom-built wet bench



Deposition Systems

UHV sputter cluster

ICP-PECVD

Etching Systems

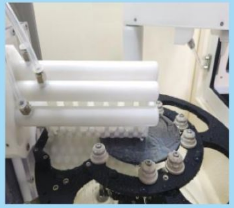
2x ICP-RIE (fluorine)

ICP-RIE (in operation without chlorine)

Layer Planarization

Chemical mech. polishing

Post-CMP scrubber



In operation

Delivered

Detector Technologies and Systems: ST2

Quantum technologies

Sensors for X-ray spectroscopy at light sources:

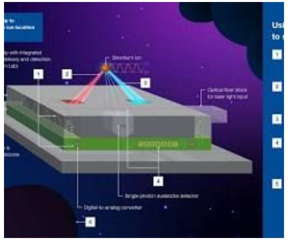
- P01 beamline at PETRA
- X-SPEC beamline at KIT light source,
- XFEL

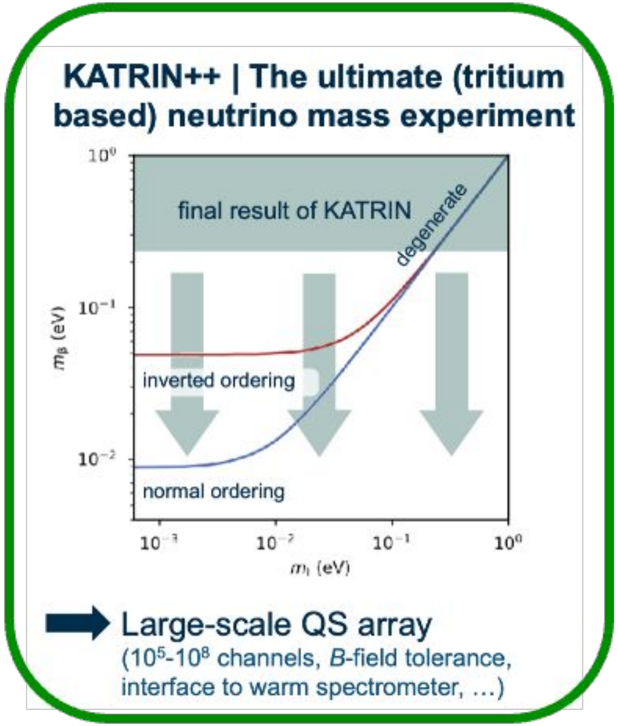
Dark Matter searches:

- Ultra-low noise for dark matter detection limits
- DELight: Direct search Experiment for Light Dark Matter
- Atomic-clock experiment to search for ultra-light dark matter

QS4Physics InnoPool

- Quantum Sensing R&D linking six Helmholtz Centres

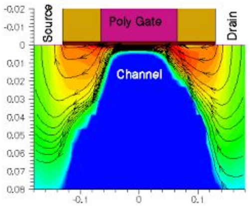


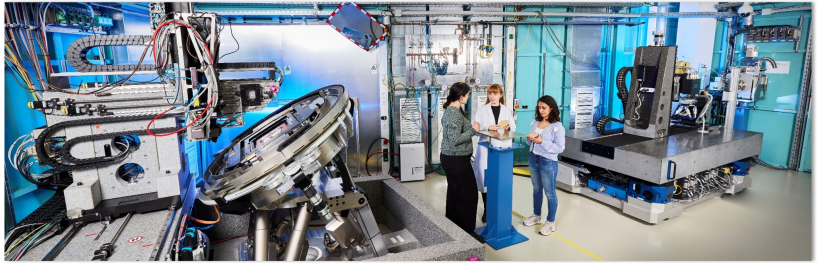


Detector Technologies and Systems: ST4

Detection Methods

Conceptual designs (low TRL)
Simulations
Multi-modal systems
Data handling concepts
Holistic approach to synchrotron experiments
Detection in autonomous experiments





Contributions to Matter Competence Team FEOPT

Activities extending beyond Matter

Main areas with connections to DTS.

Contributions to Matter Competence Team FEOPT

DTS Competences serving FEOPT Activities

Diagnostics and Sensors

- 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

Silicon photonics

- A key optical technology for future data transmission. Capitalize on DTS interconnect know-how and capabilities.

Advanced X-ray Optics

- Essential for the realization of imaging techniques at next-generation light sources. Extension of capabilities of existing detection systems.

Detection System Competence

- The backbone for diagnostics and sensor systems, including:
  - High-performance DAQ
  - Mechanical, electrical and thermal system integration
  - Interconnection techniques

Responding to the HighTech Agenda of Germany

Building on DTS research and beyond

A “flagship project” in development - building on expertise in *Helmholtz Matter*.

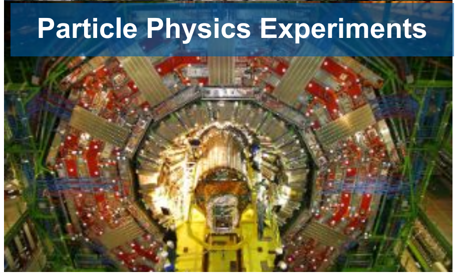
Main thrust:
Microelectronics, and the intimately linked key technologies **Artificial Intelligence** and **Quantum Technologies** are central elements for Germany’s competitiveness.

For DTS: an opportunity to deliver on the recommendation to realize a common technology platform, received in the center reviews of DESY, GSI and KIT.

Maintaining and Attaining Leadership

How can *Helmholtz Matter* contribute to Technological Sovereignty

- Disruptive developments with significant societal impact often originate from fundamental research.
- Fundamental research in Germany relies on world-wide unique infrastructures of *Helmholtz Matter.*
- Our vision: Further develop and extend competences, ensure access to cutting-edge technology, open up infrastructures to industry and universities, structural strengthening of transfer culture.



Core Topics and Competences

Mapping Helmholtz Matter onto the Hightech Agenda

Microelectronics
is the key technology shaping everyday life and driving cutting-edge experimental research.

Quantum Technologies
are disruptive technologies of the future.

Artificial Intelligence
will be indispensable for advanced chip design and fundamental for data-driven science.

- Helmholtz Matter operates world-wide unique **experiments with extreme requirements** – highest precision in challenging environments.
- Our competences range from design and characterisation of **sensors** and **integrated circuits**, to **quantum technologies**, integration and interconnect technologies and r**eal-time data processing** – all with applications of AI.
- We train the **next generation** of high-tech specialists.

Responding to the HighTech Agenda

Main Goals

Microelectronics

- Enable highly capable ASICs “designed in Germany”, contribute to leadership within Europe.
- Increase technological sovereignty.

Quantum Technologies

- Develop quantum sensors and open up fields of applications in fundamental research, medicine, civil security..
- Build a strong base of experts in quantum technologies.

Artificial Intelligence

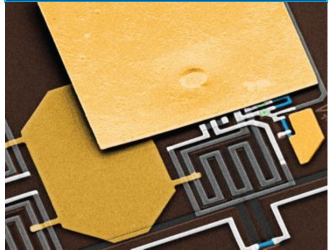
- Turn AI into a versatile tool in central fields of research and application.
- Develop AI capabilities (algorithms, software tools, computing and AI chips) for science and research.
- Be a central player for the next AI generation.

Responding to the HighTech Agenda

Strategic Fields of Action

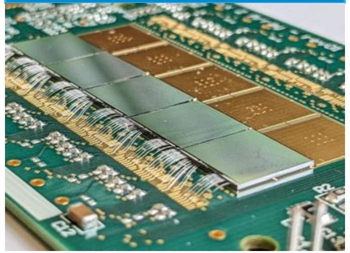
1. World-class Research

International experts, microelectronics design group, access to cutting-edge technology.



2. Spin-offs and Transfer

Networking and connections with industry, support for spin-offs.



3.Training future Experts

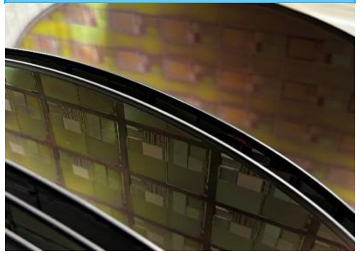
From advancement of technical subjects to PhD students and junior researchers.

4. Research Infrastructures

Clean rooms for fabrication, integration and characterisation "open access".

5. Regional Connections

Consulting and expertise for the region, networking with universities.



Detector Technologies and Systems

In brief

- DTS very successful in POF IV: strong evaluation, very attractive research program (size x2)
- Strong program for POF V: 4 sub-topics, fresh forces, smashing plans
- With **microelectronics**, **quantum technologies** and advanced use of **Artificial Intelligence**, DTS at the core of the High Tech Agenda
→ upcoming proposal

Join DTS to enable discoveries !

Detector Technologies and Systems

Thank you Marc !!!

Thank you

- for your passion for detectors and technologies
- for shaping DTS
- for guiding us all until today
- for remaining a true DTS person always
- for keeping still an eye on DTS

SPARES

MT-DTS Research Policy Objectives (FoPoZi)

3 DTS goals

Ziel: Halbleiterdetektoren und analog-digitale integrierte Schaltkreise bei höchster Integrationsdichte sind ein primäres Ziel von DTS. Die Etablierung von hochkompakten 2,5D und 3D Integrationstechnologien, die auch die direkte optische Kommunikation über eingebettete photonische Strukturen ermöglich, sollen in den Aufbau eines vollständig integrierten Demonstrationssystem münden.

Ziel-Datum: 2031

Für die Zielerreichung verantwortliches Zentrum: DESY, **GSI**, KIT

Ziel: Der Zugang zu disruptiven Technologien, wie kryogene Quantensensoren [A1] als Zukunftstechnologie, ist für die Helmholtz-Gemeinschaft zu sichern. Dies beinhaltet die Weiterentwicklung innovativer Sensorkonzepte inklusive der skalierbaren Auslese von großflächigen Sensoren mit tausenden bis Millionen von Pixeln, sowie die Bereitstellung von Produktions- und Testkapazitäten.

Ziel-Datum: 2030

Für die Zielerreichung verantwortliches Zentrum: DESY, **GSI**, KIT

Ziel: Technologien- und Methoden für den automatisierten Betrieb und die Datenanalyse von Instrumenten z.B. in der Hochdurchsatzmessung in den Material- und Lebenswissenschaften sind anhand konkreter Hochratendetektorsysteme für den Einsatz an Photonenquellen wie PETRA IV mit integrierter Auslese zu entwickeln.

Ziel-Datum: 2035

Für die Zielerreichung verantwortliches Zentrum: DESY, KIT