View from the Detector Platform

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Detector activities in FH

- Detector activities are formally part of **MT-DTS** and **MU-FPF**.

- **MT-DTS: Detector R&D**
  - Silicon detector R&D: CMOS based Pixel and Strips
  - Silicon photonic transceiver (InnoPool SoPhie)
  - Calorimeter developments
  - Advanced cooling techniques
  - …..

- **MU-FPF: Detector construction for experiments**
  - ATLAS and CMS Phase-2 upgrade
  - Belle-II PXD2 (completed)
  - TES for ALPS

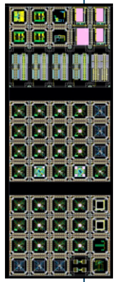
Transition from R&D to prototyping and construction involves transition of research programme.

R&D goals in MT-DTS should be aligned with plans in MU-FPF.

Topics of Interest & Connections to DRDs

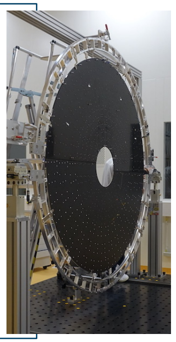
Silicon detector development is a strong focus of our interest

- Monolithic CMOS
- Novel sensors (ELAD, digital SiPM, …)
- Software tool developments
- Involvement in DRD3 (Silicon)



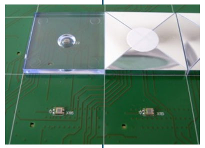
Integration

- Detector integration center
- R&D on light weight mechanics, local cooling and cooling systems
- Involvement in DRD8 (Integration)



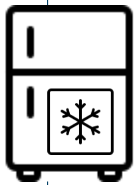
Calorimeter developments

- Highly granular SiPM on tile calorimeter
- Involvement in DRD6 (Calo)



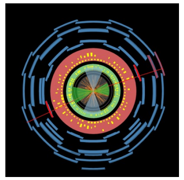
Cryogenic detectors

- Transition Edge Sensors
- Developments for axion/dark matter experiments
- Involvement in DRD5 (Quantum sensors)



Data transfer

- Silicon photonics
- Advanced interconnects
- Involvement in DRD7 (Electronics)



Infrastructure

- Detector Assembly Facility
- Test beam

Cross topic goal: Build a demonstrator vertex detector based on CMOS technologies

Forschungspolitische Ziele 1

- **DTS:** Das zentrale Anliegen von DTS ist es, maßgeschneiderte Detektorsysteme beruhend auf innovativen Detektortechnologien für den Forschungsbereich Helmholtz Matter zu entwickeln. Ein **besonderer Fokus soll dabei auf hochsegmentierten und hochauflösenden Systemen**, sowie auf **Quantentechnologien** und der **Implementierung von (künstlicher) Intelligenz nahe am und im Sensor sowie in der gesamten Signalkette** liegen. DTS soll seine **besondere Rolle bei der Entwicklung, dem Bau und der Inbetriebnahme von komplexen Detektorsystemen** für **z.B. die Teilchen-**, Astroteilchen- und Schwerionenphysik, die Forschung an Lichtquellen, für zukünftige Präzisionsmessungen und Experimente mit extremen Datenraten weiter ausbauen. Dies beinhaltet insbesondere **intelligente Auslese-, Trigger- und Echtzeitprozessierungskonzepte**. **Synergien mit den anderen Forschungsbereichen**, z.B. in den Feldern Medizin und Quantencomputing sowie mit industriellen Anwendungen sind zu nutzen. **Kritische Infrastrukturen zur Sicherung der Technologiesouveränität sind strategisch aufzubauen**, zu ergänzen und zu erweitern. Dazu soll DTS zu Beginn der kommenden Förderrunde ein Entwicklungskonzept vorlegen.

Forschungspolitische Ziele 2

- **Spezifische Ziele** sind:
- **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 (DESY, GSI, KIT; 2031).
- Der Zugang zu **disruptiven Technologien, wie kryogene Quantensensoren 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** (DESY, KIT; bis 2030).
- 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 (DESY, KIT; 2035).

Potential Silicon Detector Contributions to Experiments

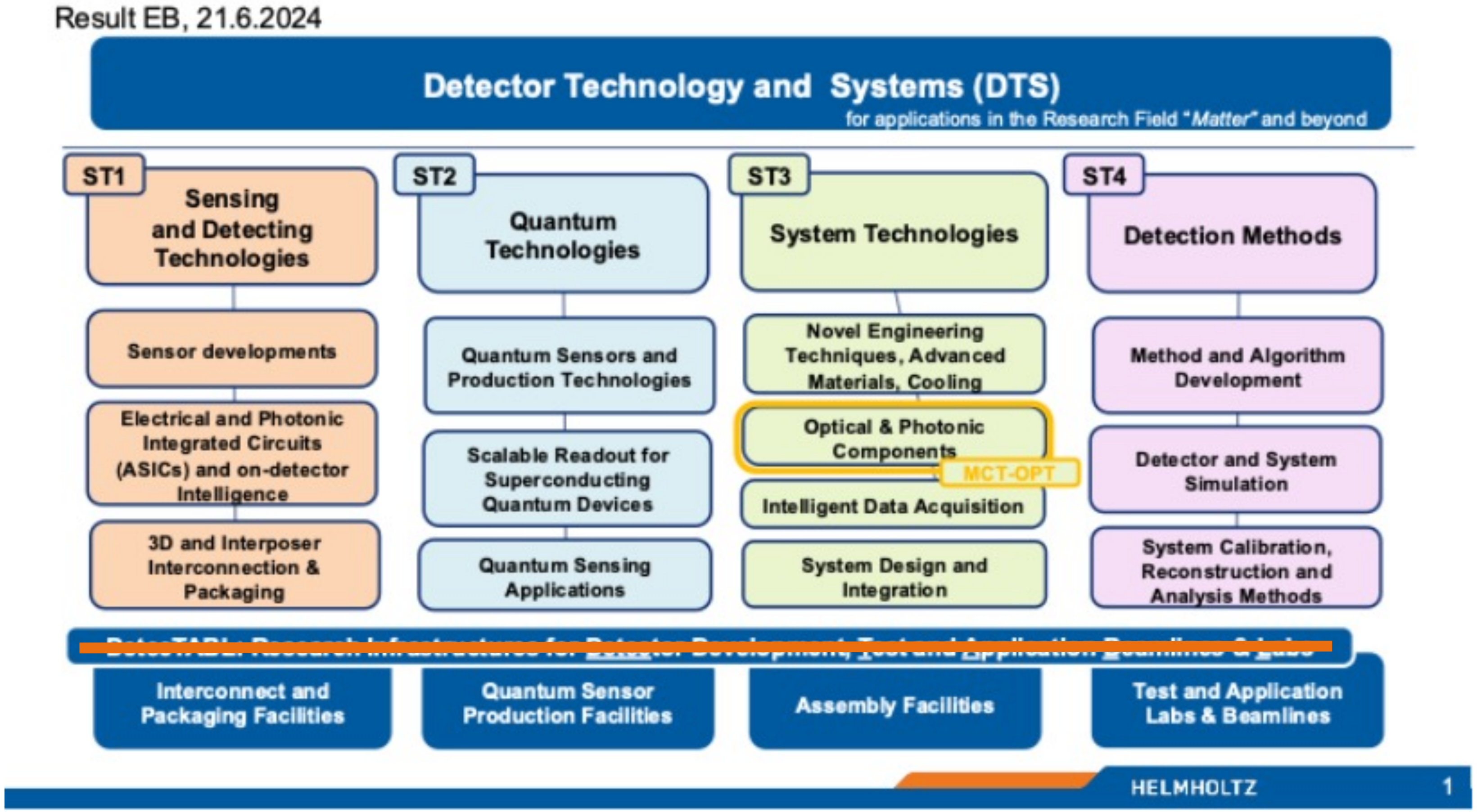
Experiment	Timescale (start run)	Certain	(MAPS) R&D compatible	System expertise	Si size	DESY involved?	DESY as German hub
P2 Spectrometer @ MESA	In construction	yes	No	?	small	Chip charact.	EC: Prisma++
INSIGHT @ ELSA	2027	yes	No	yes	small	no	EC: Colour meets Flavour
LOHENGRIN @ ELSA	~2030	yes	Maybe Needs also HCAL	yes	10s cm2	no	EC: Colour meets Flavour
LUXE upgrade	Middle 2030ies	no	yes	yes	~200 cm2	On-site	?
Belle-2 tracker upgrade	2034 Decis. 2028	no	Probably not (Obelix)	yes	VTX: 10s cm2 ITT: several m2	yes	yes
KOTO-2 veto	2034	likely	maybe	yes	20*20 cm2	no	No?
KOTO-2 Tracker	2034 or ~8 years later	no	One proposal based on MightyPix	yes	Large, in vacuum	no	No?
LHCb Upgrade 2 MightyTracker	2036	yes	No, will use MightyPix	yes	10s m2	no	yes
newAstrogam	Launch 2041 Decis. 2030	no	No, will use AstroPix	yes	~10 m2	AP project	?

BACKUP

Strategic overview for MT-DTS

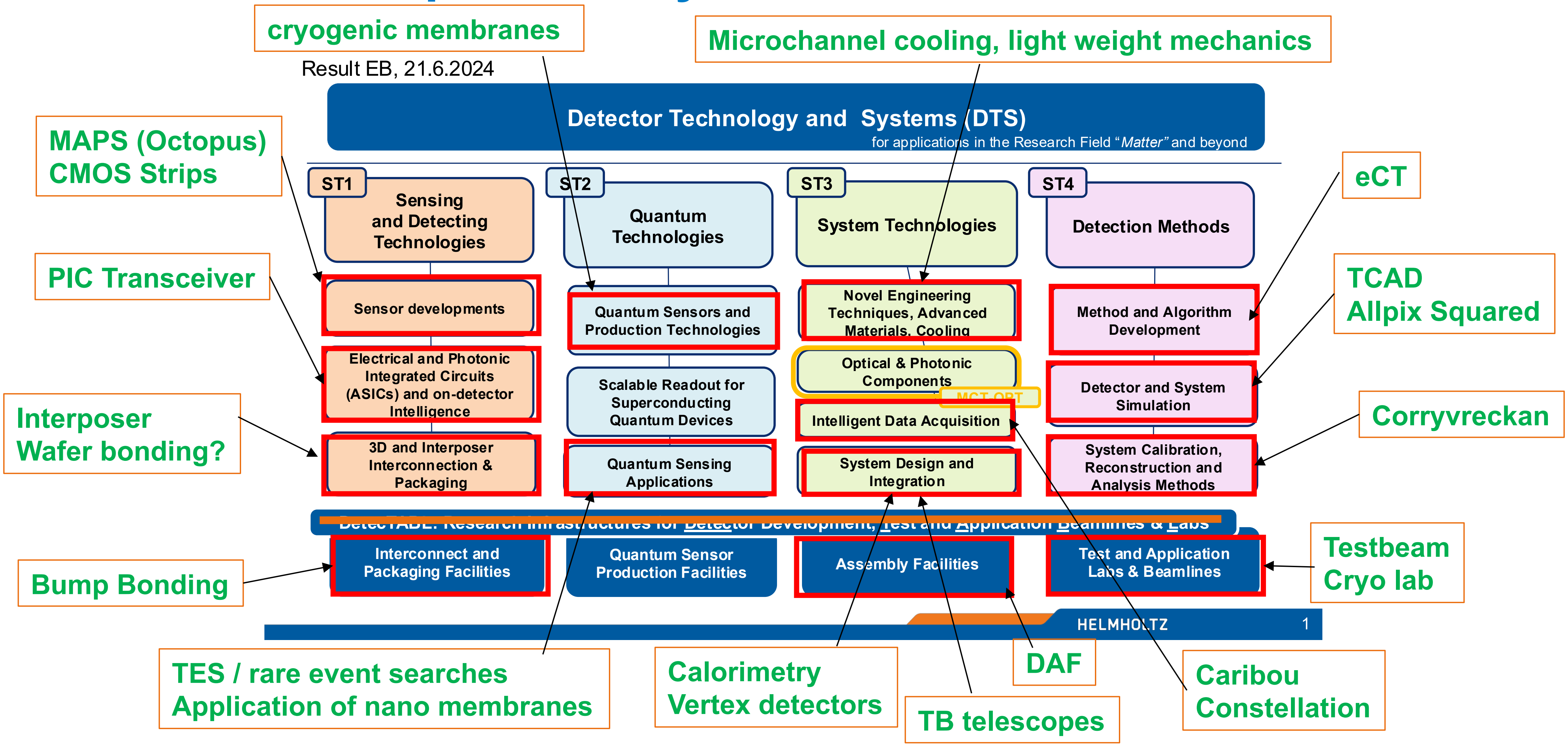
- Next generation **trackers** and **calorimeters** are required to provide **high resolution**, additional measurements such as **timing** and **energy**, while consuming **little power** at **reduced non-detection related mass**.
  - High resolution in space and time lead to high data volumes and power consumption.
- Maximising **data processing on the detector** is paramount to achieve performance targets and to keep the needed data transfer under control.
- Strategy:
  - High level of integration allows for scalability while keeping system complexity under control
  - High bandwidth data transfer at low power consumption
- Key technologies to address these challenges
  - CMOS based sensors
  - Photonic transceivers
  - Advanced interconnects and wafer bonding
  - Advanced cooling techniques

Preliminary MT-DTS PoF V structure



Exact shaping what belongs to which pillar is still ongoing for ST3 and ST4

FH activities in preliminary PoF V structure



Silicon detector contributions to Experiments

- Long term vision of Higgs Factory detector shares detector requirements with many intermediate projects

- MAPS developments (Octopus) suitable for LUXE Tracker at higher intensities.
- Belle-2 Tracking detector upgrade.
  - Strong interest to participate if approved.
- Smaller German experiments as part of the new excellence clusters.
  - Insight, Lohengrin, P2 Spectrometer
- MightyPix (based on TelePix2) detectors: LHCb, KOTO-II
  - Large systems expertise
- AstroPix for AP satellite experiment (Astrogam)
  - Same technology as CMOS Strips

- Plans and strategy to be aligned with MU-FPF

ECFA DRD involvements

- **DRD3 (Semiconductor Sensors)**
  - MAPS development (WG1), Allpix Squared (WG4) and Caribou DAQ development (WG5)
- **DRD5 (Quantum sensors)**
  - Transition edge sensors (WP3b)
  - Optomechanical membranes (WP4c)
- **DRD6 (Calorimeters)**
  - Main interest: Development of a CALICE-style calorimeter for a circular collider.
- **DRD7 (ASICs):**
  - Main interest in development of silicon photonic transceivers (Project 7.1a).
- **DRD8 (Tracker mechanics)**:
  - Contribution to the material properties database.
  - Cooling technologies and microchannel cooling.

Silicon Detector R&D

Next FH talk by Simon will cover:

- CMOS sensor R&D
- Silicon Photonics
- Software tools

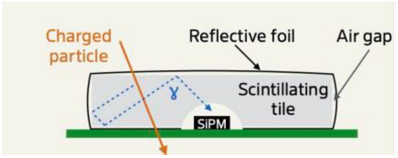
Calorimeter R&D

Highly granular SiPM-on-Tile hadron calorimeter

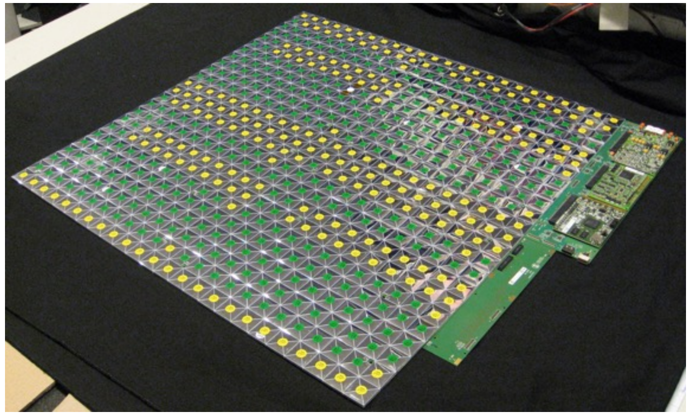
- Small (a few cm^2) scintillator tiles individually read out by SiPMs
- Developed at DESY to reach jet energy resolution at a future e+e- Higgs factory
  - Several generations of prototypes built and tested 2006 – 2022
  - Electronics optimized for ILC bunch structure (power pulsing)
- Application in CMS HGCAL endcap calorimeter upgrade for HL-LHC
  - New challenges: radiation hardness, data rates, operation at -30 degree
  - Less stringent requirements on energy resolution
  - Production of tile modules expected 2025 – 2026
- Adaptations and R&D needed for a circular collider
  - Expected data rates between ILC and HL-LHC
  - Need to evaluate need for active cooling
  - For Z-pole running: evaluate / re-optimize detector geometry
  - Activity within DRD6
- Technology also applicable for other detectors (DUNE, …)

Other calorimeter technologies under consideration at DESY

- MAPS ECAL
- Chromatic calorimetry with quantum dots



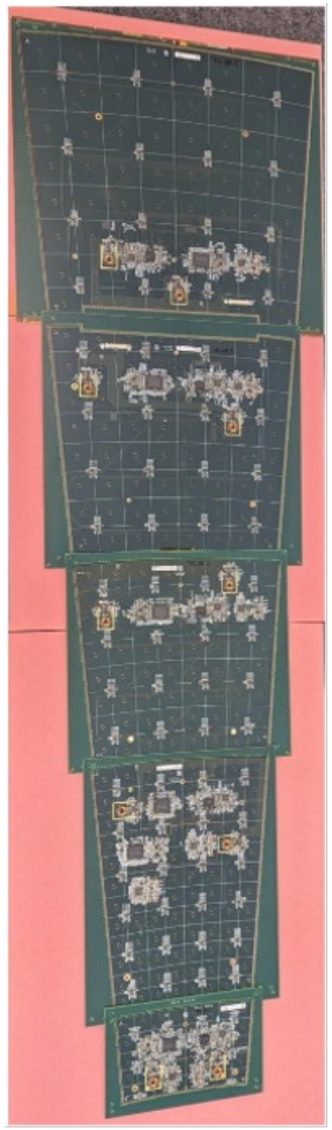
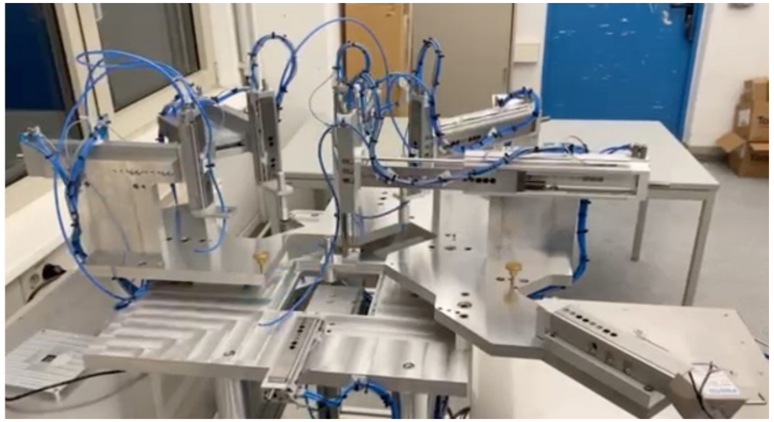
close collaboration with Uni Hamburg

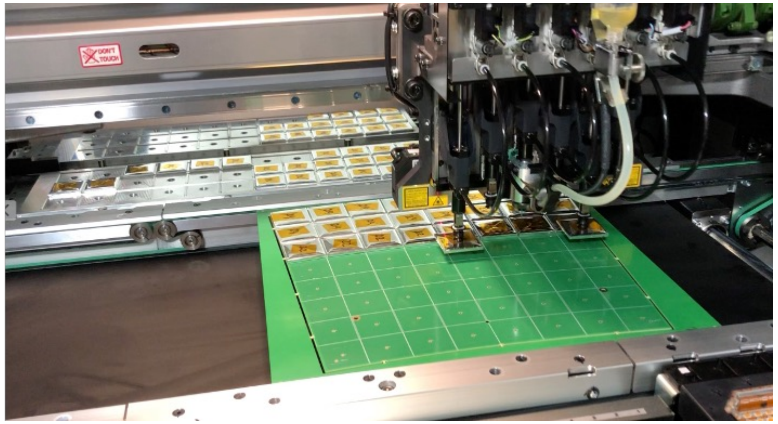


SiPM-on-Tile technology in HGCAL

Capitalise on our expertise from AHCAL:

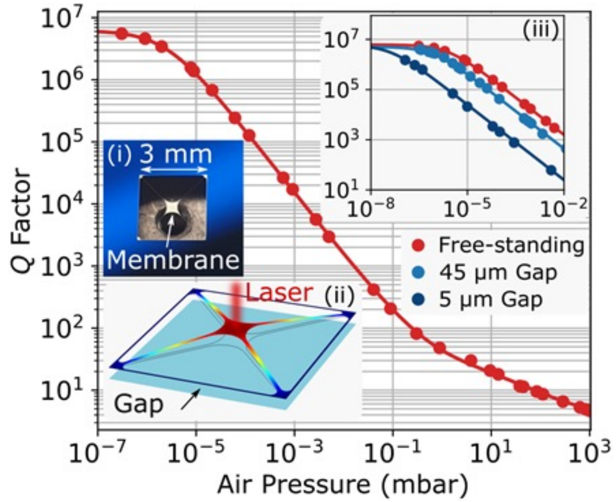
- Board level design for SiPM-on-tile readout boards ("Tileboards")
    - Test & characterization of Tilemodules in beam tests and climate chamber
    - Tests with irradiated SiPMs
- Development of production and test procedures
    - Reflector foil handling, tile wrapping, module assembly
    - Setup of QC stations & protocols
- Assembly of ~half of all Tilemodules in cooperation with other groups

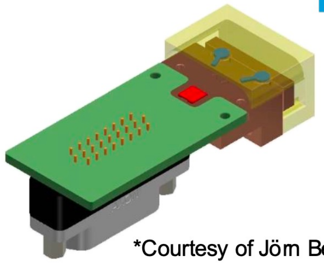



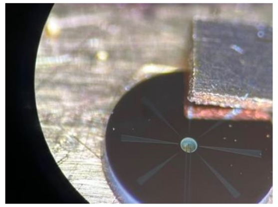



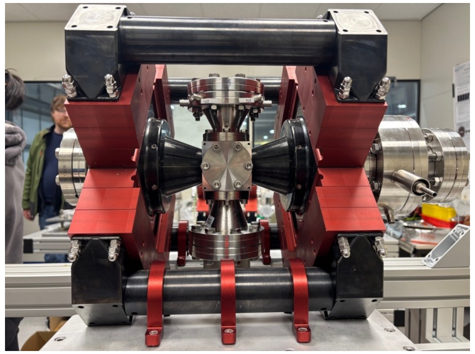
Quantum technologies

- Currently exploring possibilites of Quantum sensing
  - InnoPool QS4Physics
  - Active member of DRD5
  - Infrastructure for Quantum R&D in Hamburg and in Zeuthen.
  - Part of ERC grant DarkQuantum
- **Quantum Sensor and Production Technologies**
  - Cryogenic Membranes
    - Gas pressure sensor UHV to ambient with gas identification
    - High frequency GW detection.
- **Quantum Sensing Applications**
  - Rare particle searches using Transition Edge Sensor systems.
    - Reaching DM detection limits through ultra low noise
  - Atomic clock-based experiment to search for Ultra-Light Dark Matter



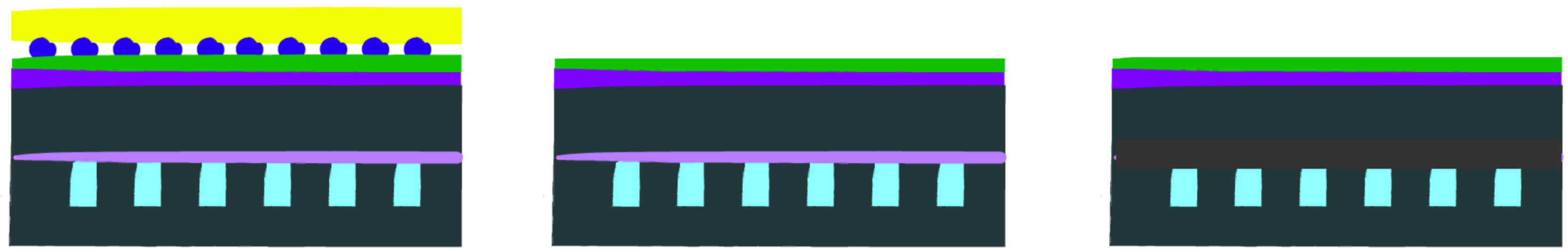

*Courtesy of Jörn Beyer, PTB


*Courtesy of Adriana Lita, NIST


DESY electron beam ion trap (EBIT)

Cooling technologies

- Intelligent systems consume power and produce heat.
  - On detector intelligence must be balanced against cooling performance.
- Cooling systems under development are $scCO_2$ for warm operation or Krypton for cool operation.
  - No FH involvement yet, but long term interest.
- Highly integrated microchannels are a key technology for detector cooling.
  - Active study of samples together with FD-DS
  - Interest to further develop Silicon microchannel to sensor integration.



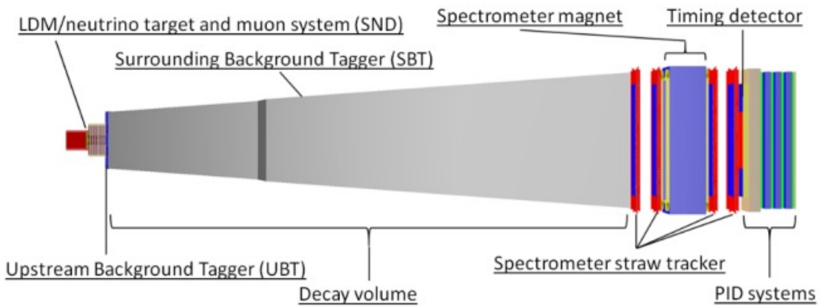
Infrastructure for Detector R&D

- **Test beam:** Essential work horse for detector development in particle and nuclear physics. National and international.
  - Currently available test beams: 1-6 GeV electrons. 3 beam lines
  - With PETRA IV, a new test beam facility is needed, concepts are being developed
  - New beam telescopes: synergy with detector technology development

- **Detector Assembly facility (DAF)**
  - Currently fully in use for LHC upgrades (expected until 2027)
  - Large clean rooms with equipment for detector assembly, testing, mechanical integration, cooling tests, metrology etc.
  - Formally belongs to MU-FPF

Ship

ShiP Detectors



DESY Interest?

- Excellent sensitivity to FIPs
- Lots of German University groups interested
- Detectors:
  - No silicon in the tracking
  - PID system contains scintillator-SiPM calorimeter
  - Spectrometer detector layers are huge (~5*10m2)
- Timeline:
  - Detector construction probably overlaps with HL-LHC upgrades

Timeline