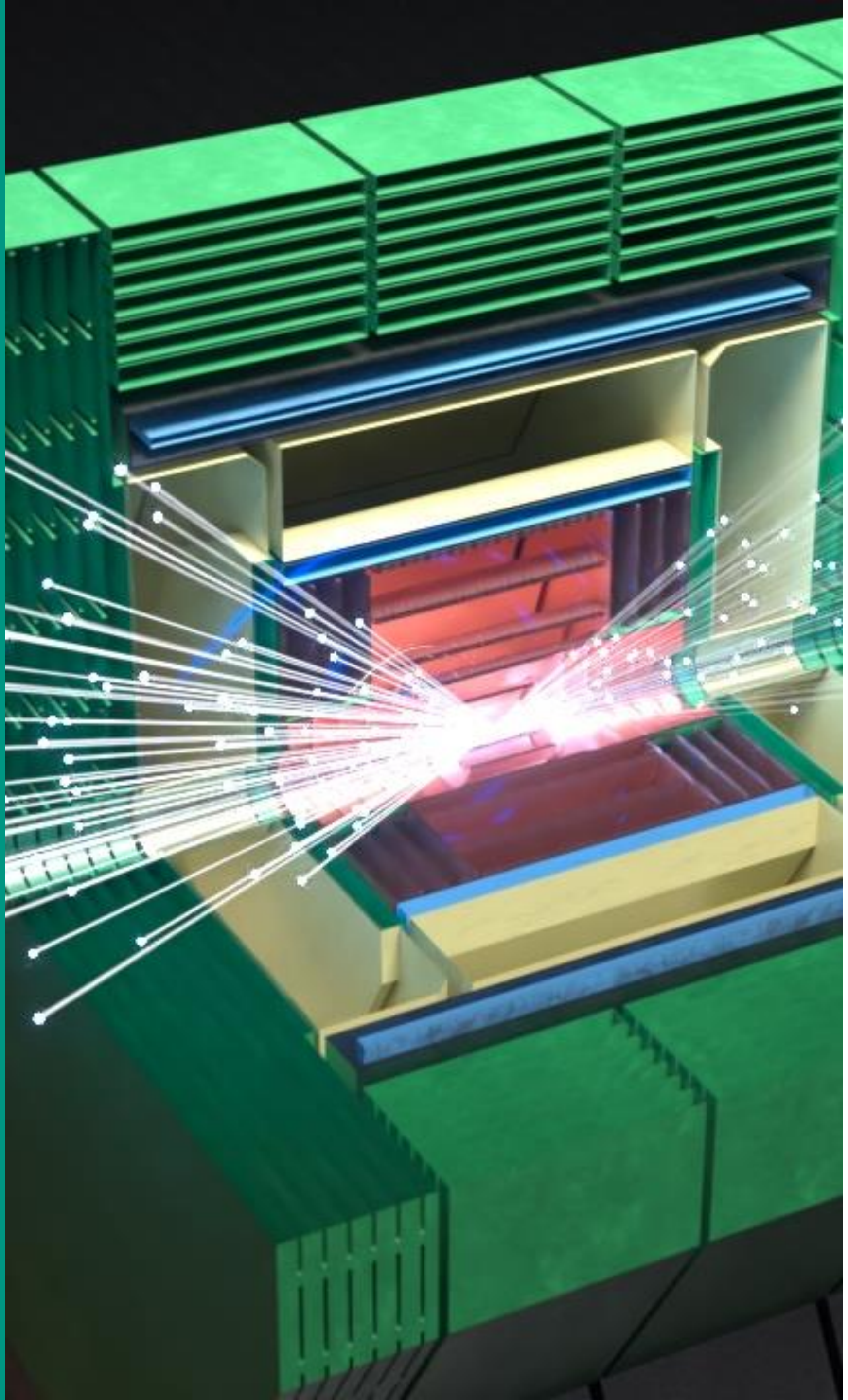
Electronics & Integration

4th US-FCC Meeting
SLAC, 09/2026

DRD7
ELECTRONICS AND ON-DETECTOR PROCESSING

DRD8

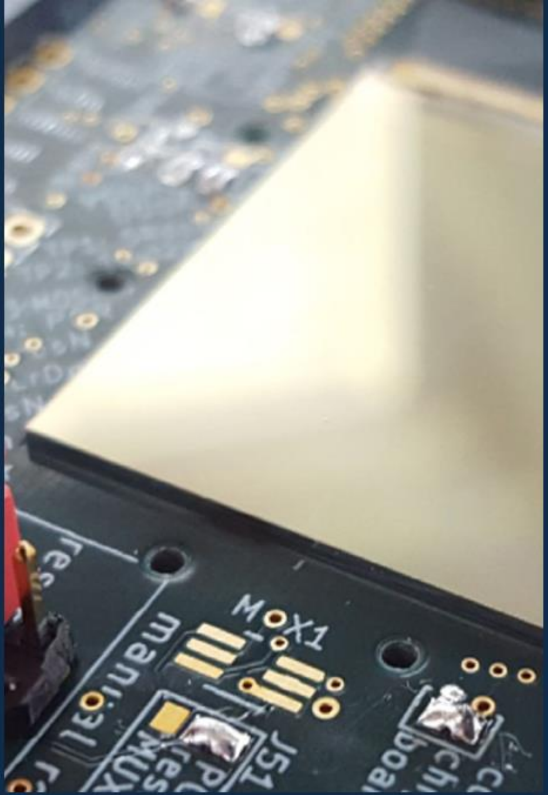
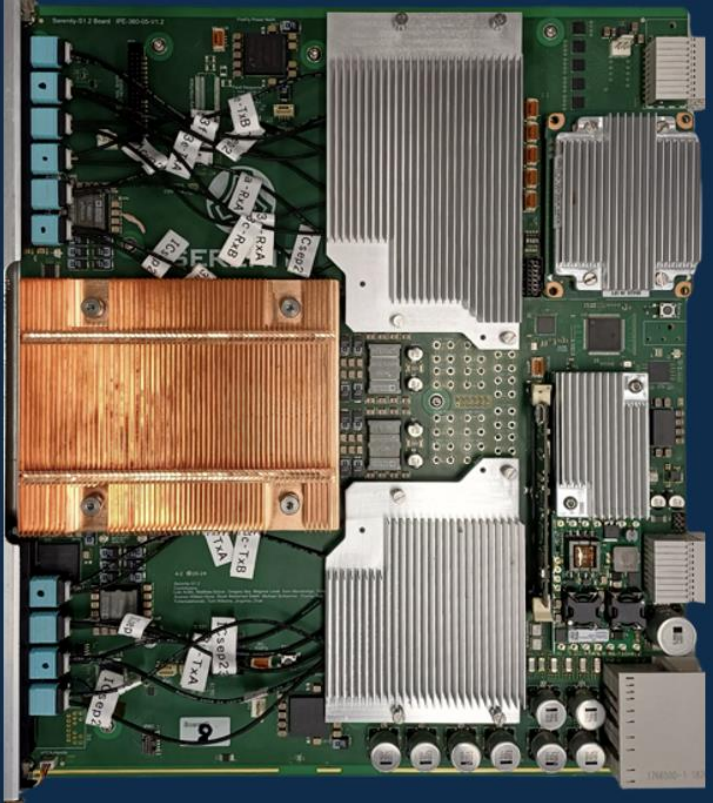


Frank Simon

Karlsruhe Institute of Technology
Institute for Data Processing and Electronics

Content



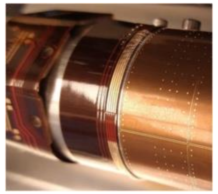
Setting the Stage: Introduction

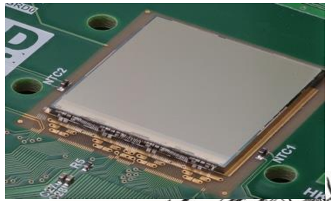
01

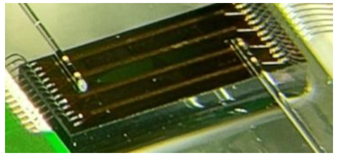
The Role of Electronics and Mechanics in HEP
Motivation

No particle physics experiments without electronics and mechanics.

Sensor & front-end data processing ASICs

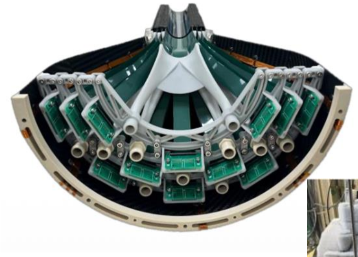




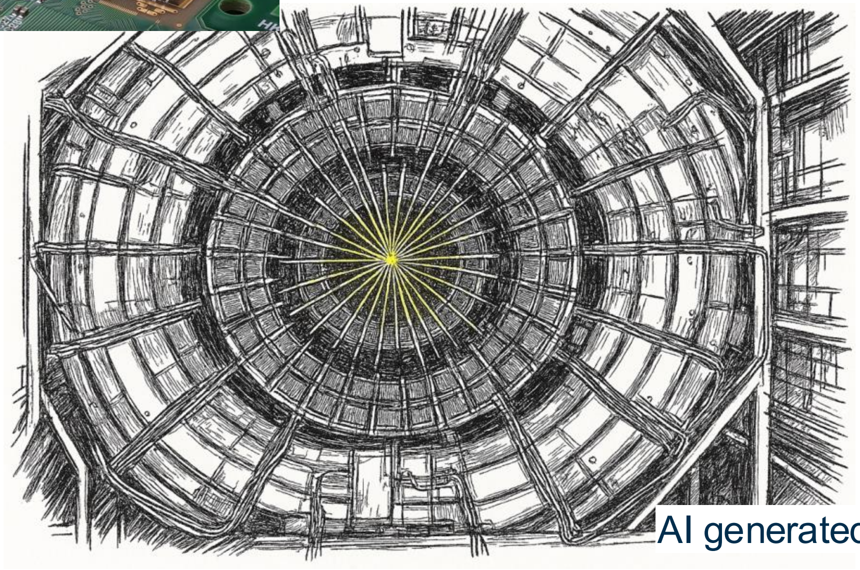


Signal and data transmission

Mechanical support structures

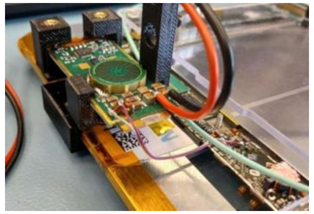


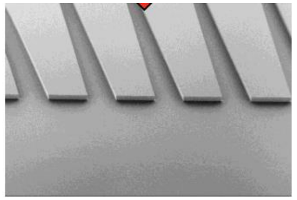
Cooling and thermal management



AI generated

Powering, detector system integration





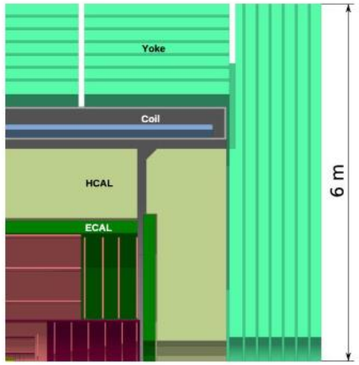
Trigger, data acquisition online processing

Design tools for electronics and mechanics, material data bases and material development

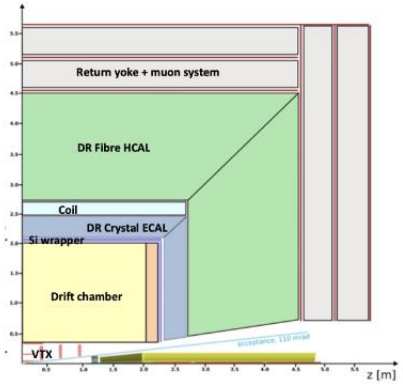
Performance and capability of electronics, mechanical support structures, cooling and integration concepts on all levels determine experimental capabilities.
Forward-looking development essential for future upgrades and experiments.

FCC-ee Detector Concepts

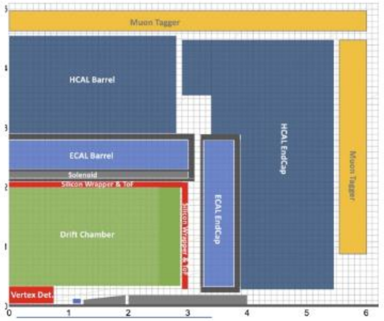
Technological Directions



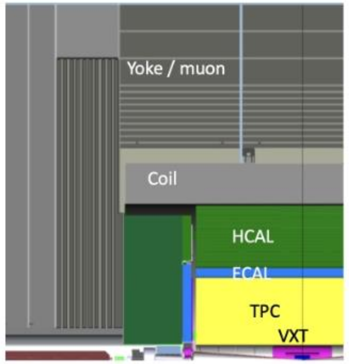
CLD



IDEA

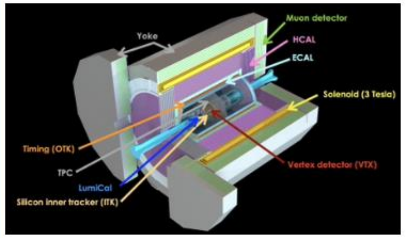


ALLEGRO



ILD

ALFA



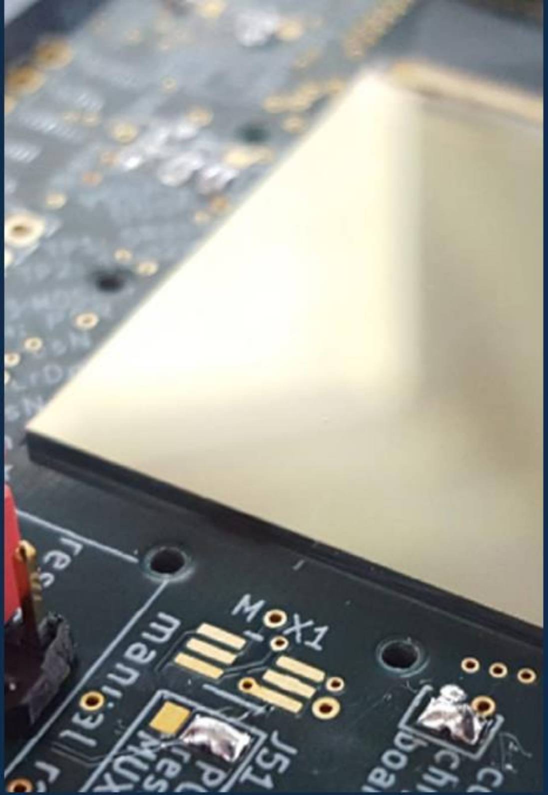
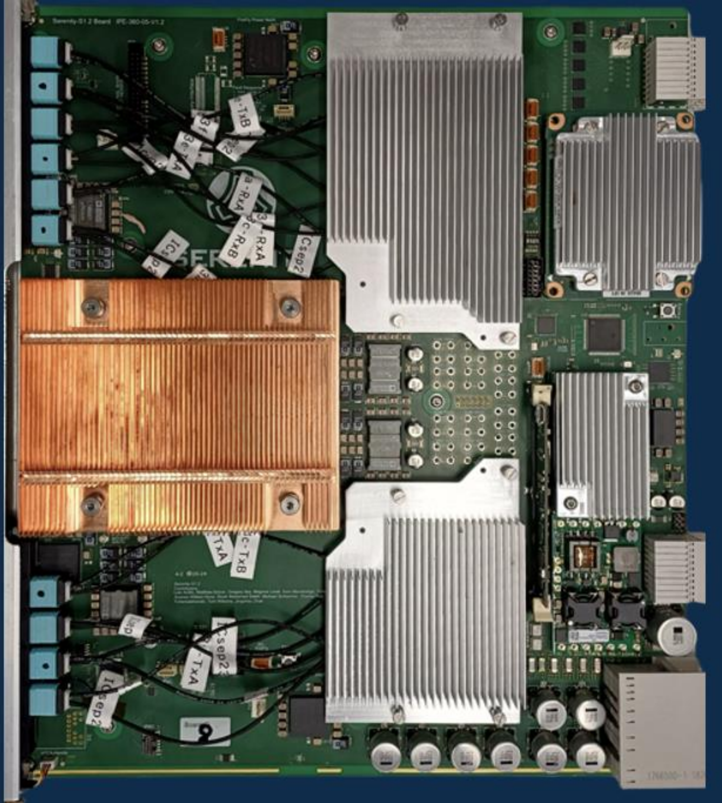
AGORA

Gowing diversity in detector concepts – but also a lot of common ground:

- Ultra-light silicon-based vertex detectors
- Large main tracking systems – including large-area silicon tracking

and all need data transmission and DAQ, powering, cooling, alignment, ...



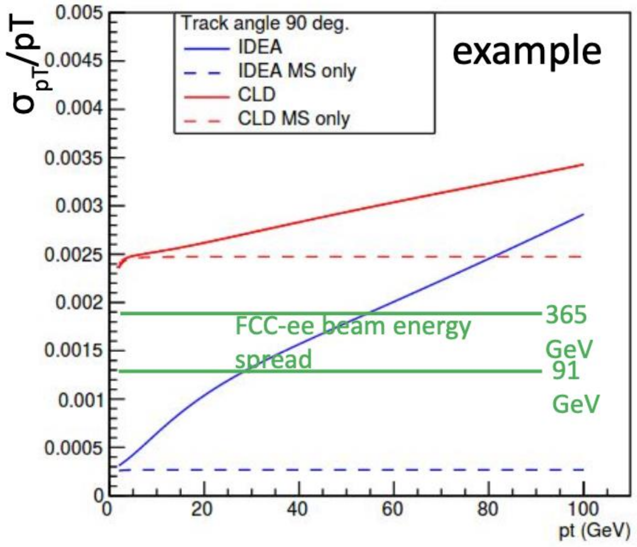



Mechanics
Selected Topics – Primarily DRD8

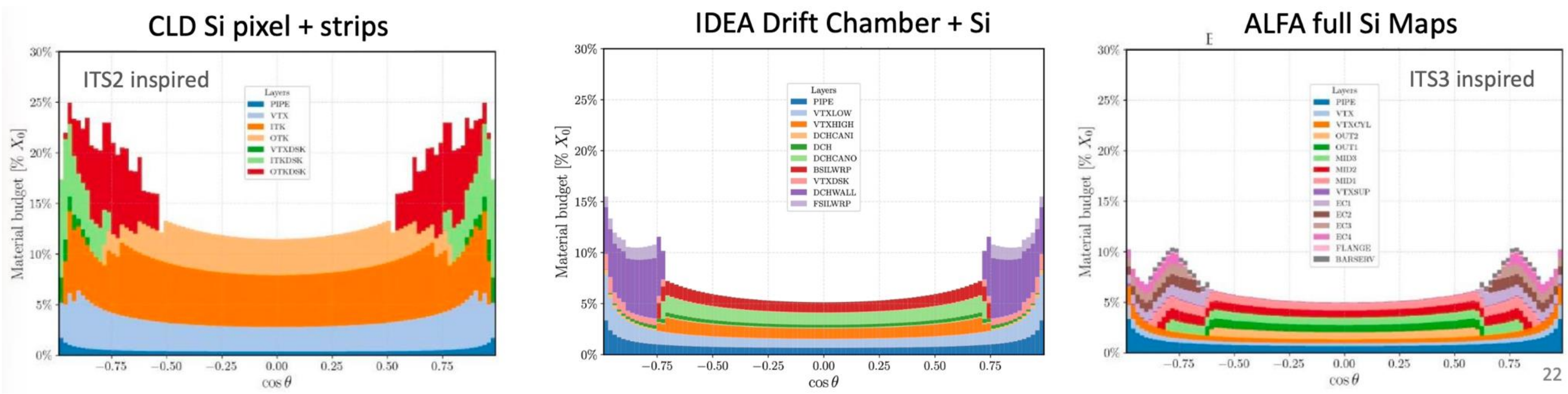
02

Lightweight Tracker Mechanics
Relevance for FCC-ee Detectors

Material matters:



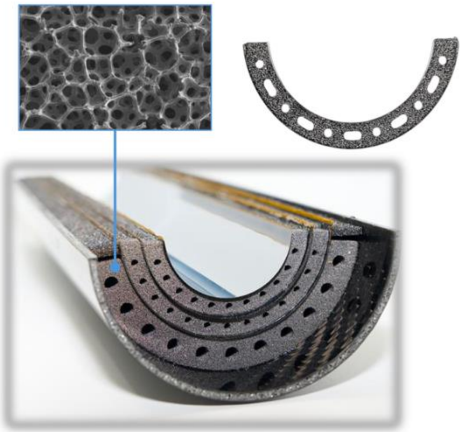
Influenced by detector technology, mechanics and integration concept:

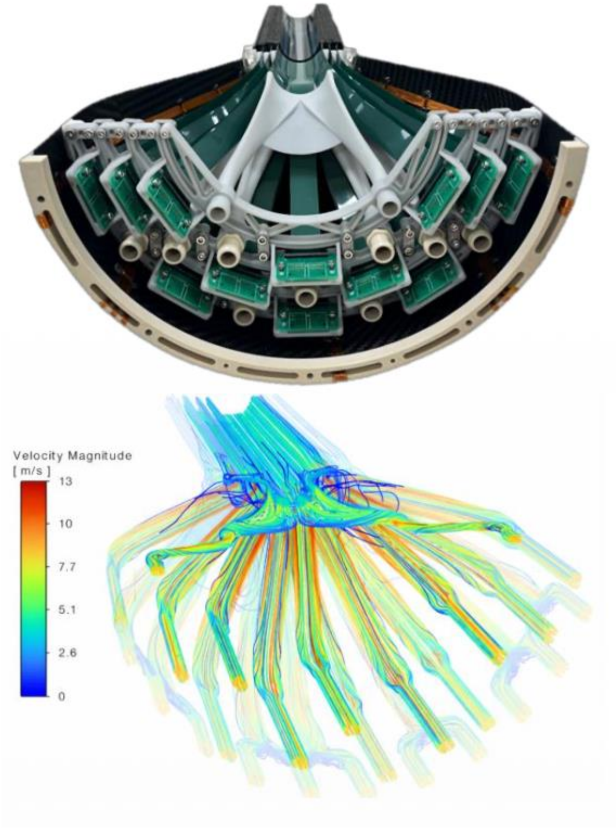


Advances in concepts and technologies, and optimization are crucial:

- CLD based on a 3 TeV detector – and an “old” design with “conventional” silicon – first full FCC-ee concept
- ALFA building on ALICE ITS3 and ALICE 3 developments

Light-weight Tracker Mechanics
Selected R&D Activities





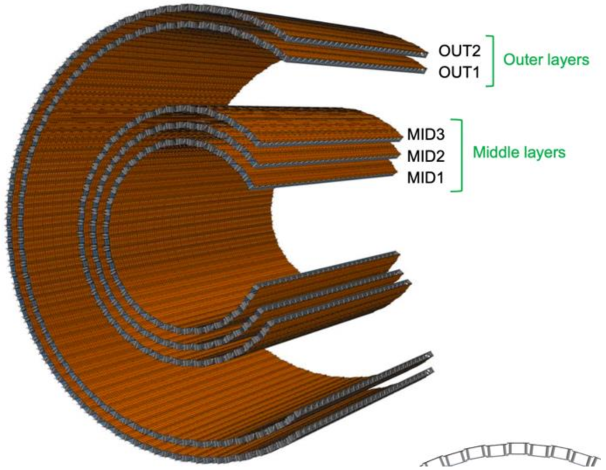
Vertex detectors:

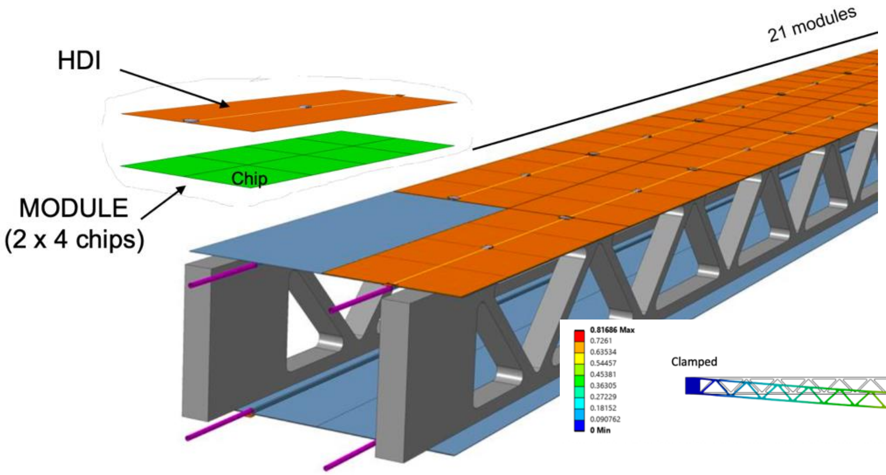
- Bent silicon MAPS, carbon foam support structures
  Pioneered by ALICE ITS3 project, now in construction
- Air cooling concept

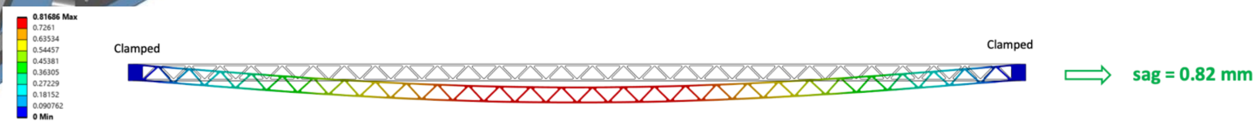
ALFA concept

Large-area MAPS-based tracking:

- Carbon-based cold plate with integrated cooling pipe







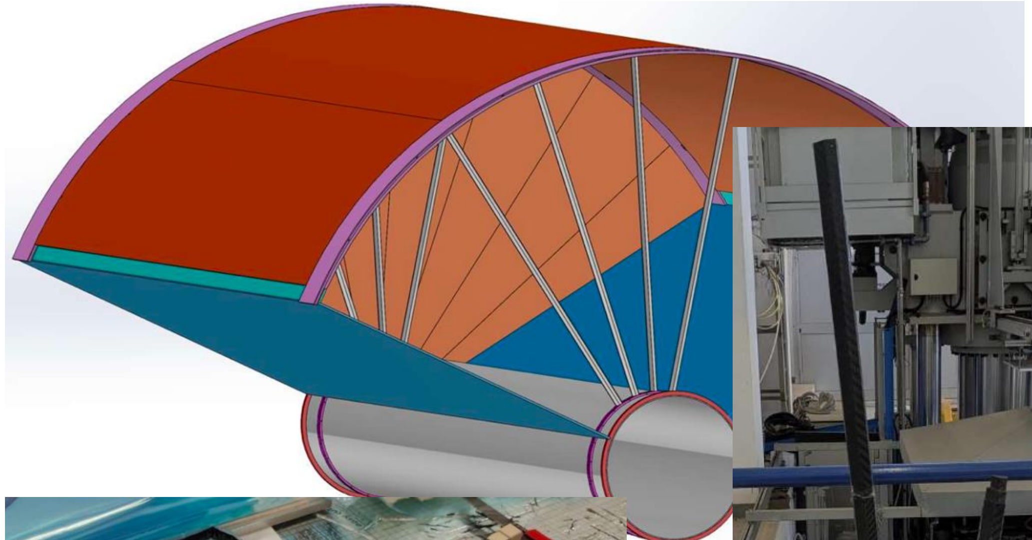
Low-material Gaseous Trackers
Selected R&D Activities

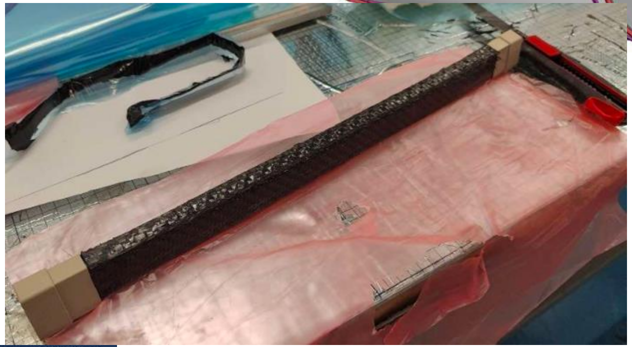
Large-volume drift chamber (IDEA)

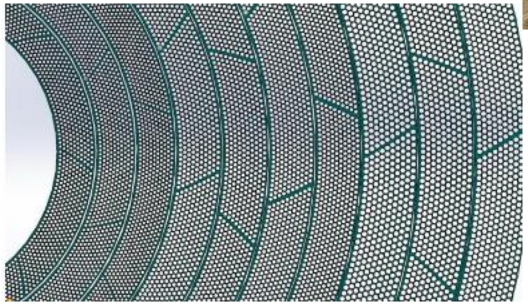
- Full-size prototype in development, with spoke based on epoxy-carbon and pre-preg, barrels on aluminum
- Exploring lower-mass ultra-thin (20-40 µm) wire solutions
  - gold-plated W, Mo
  - carbon filament / gold-plated carbon fiber

Straw tube tracker (ALLEGRO)

- specific solutions for tubes and end-plugs







Materials and multi-functional Structures
Basics and new Ideas

Support structures can do much more than just holding stuff in place:

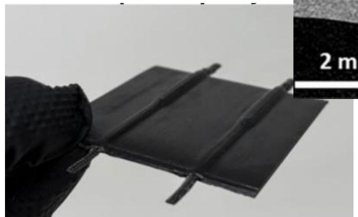
- **Thermal** properties: part of the cooling concept
- **Electrical** properties: part of overall powering and grounding scheme
- **Alignment** features

addressed with composite structures, specific materials

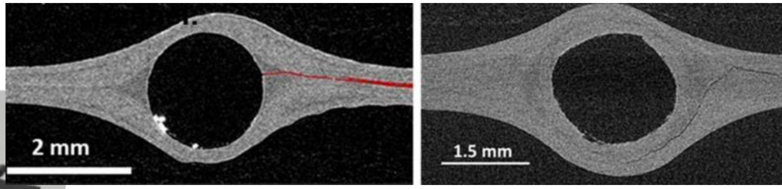
Enablers and challenges:

- Understanding material properties:
  Building a **material data base** for HEP needs.
  Based on LLMs to provide a tool for users to identify the most suited materials.
- **Availability** of materials, competition with other areas, in particular military
- Availability and interest of possible **vendors**

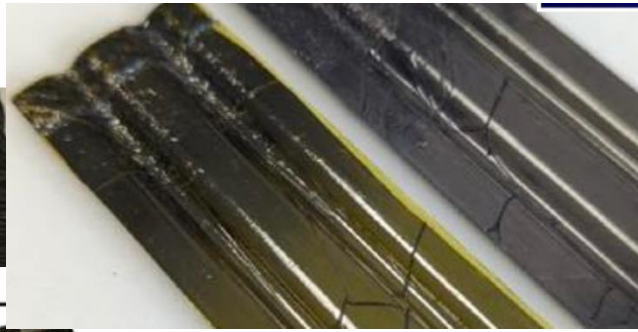
Unit costs of support structures surprisingly stable over time:



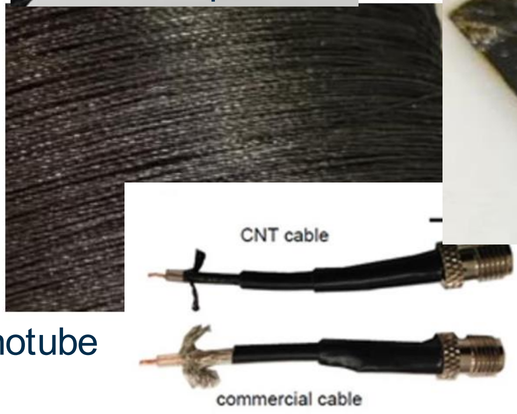
composite



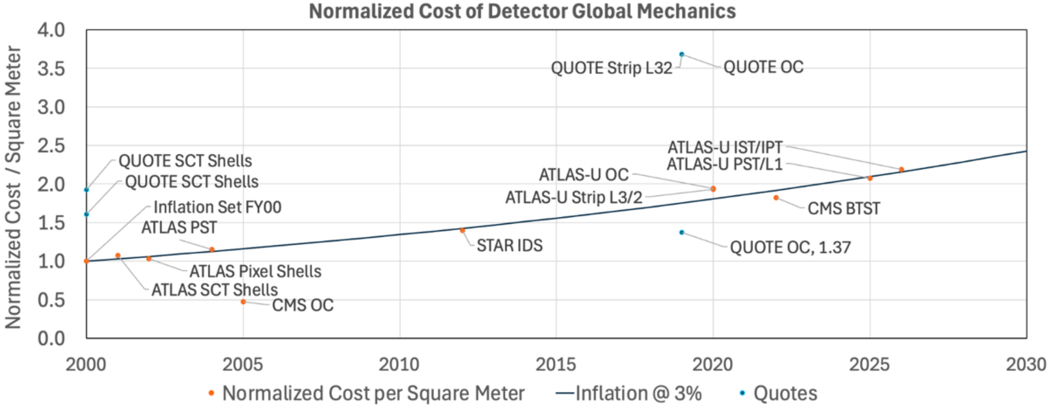
carbon laminate



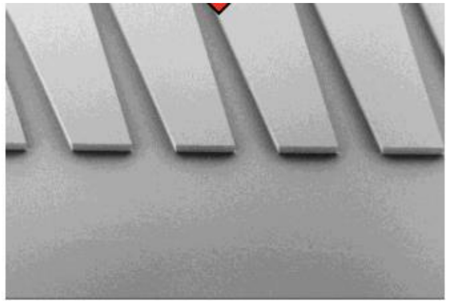
ultralight unidirectional structure

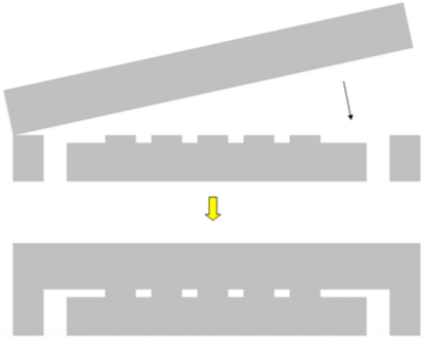


carbon nanotube cables



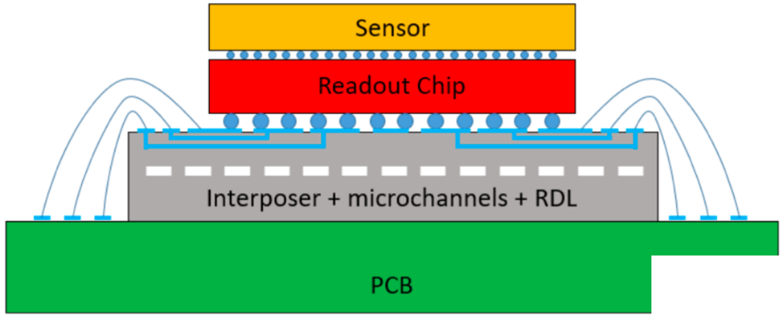
Microchannel Cooling
Between Sensors and Electronics



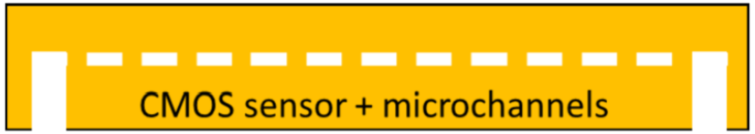


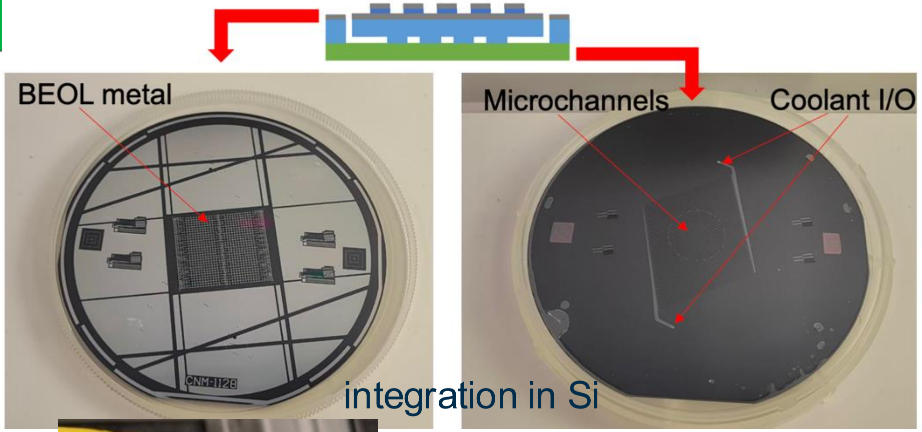
Developing different technologies – covering different use cases

Heterogeneous integration

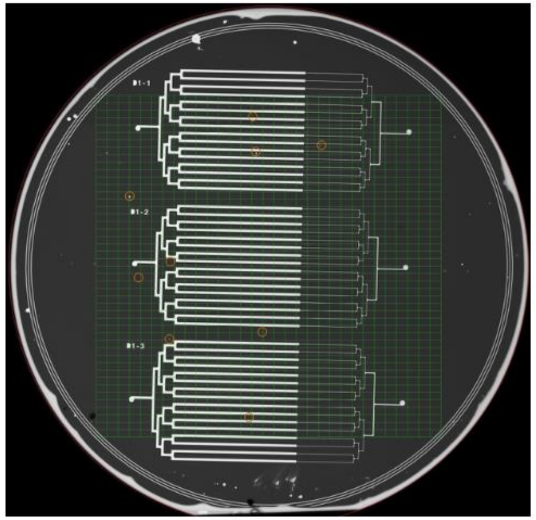


Monolithic integration





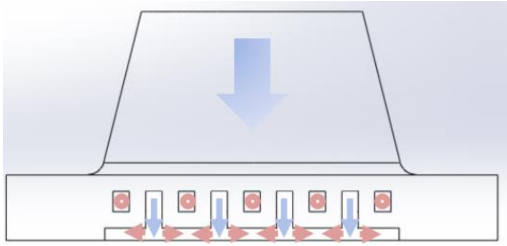
integration in Si

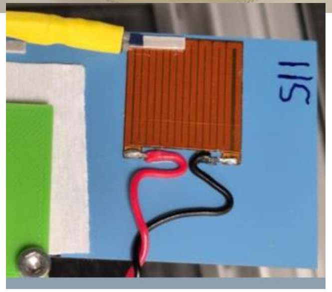


Si cooling plate

- Heterogeneous integration in silicon
- Silicon micro-channel cooling plates
- Ceramic micro-channels as proof-of-principle
- Liquid CO_2 jets as option for FPGA cooling
- ...

CO_2 jets

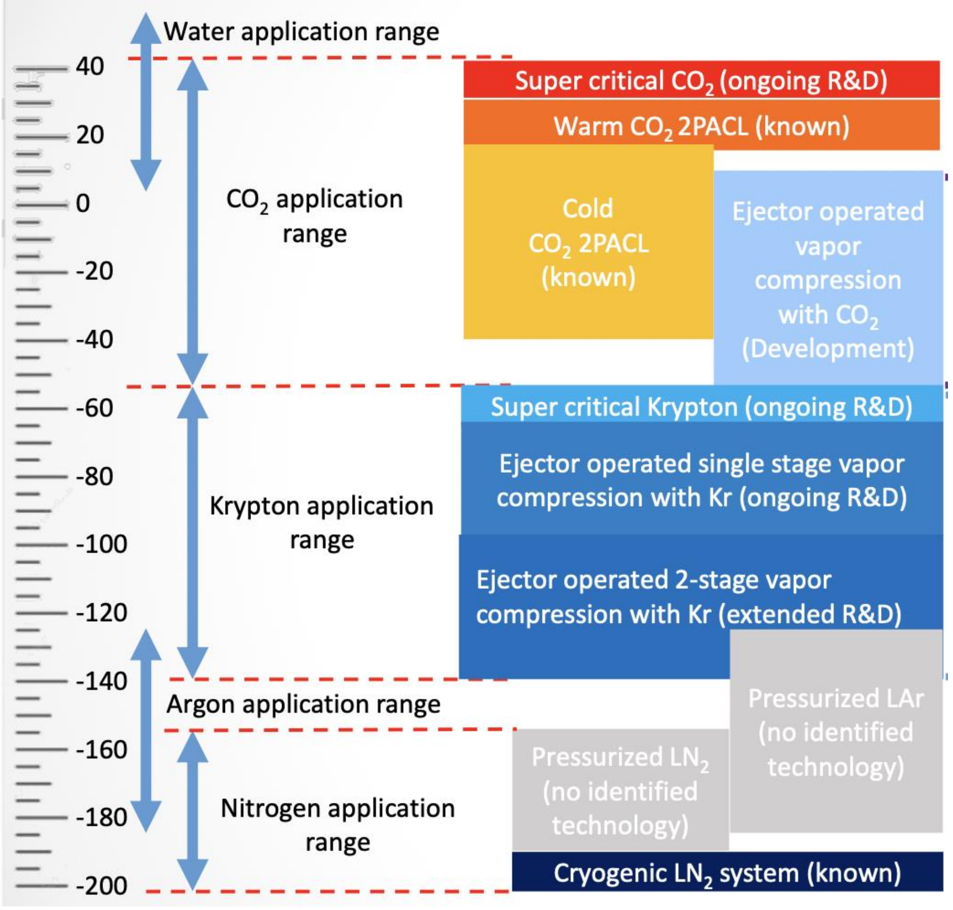




Ceramic micro-channels

Cooling Concepts
Current and Future Technologies

Cooling technologies for different temperature ranges:



path to **higher temperatures** with single-phase system

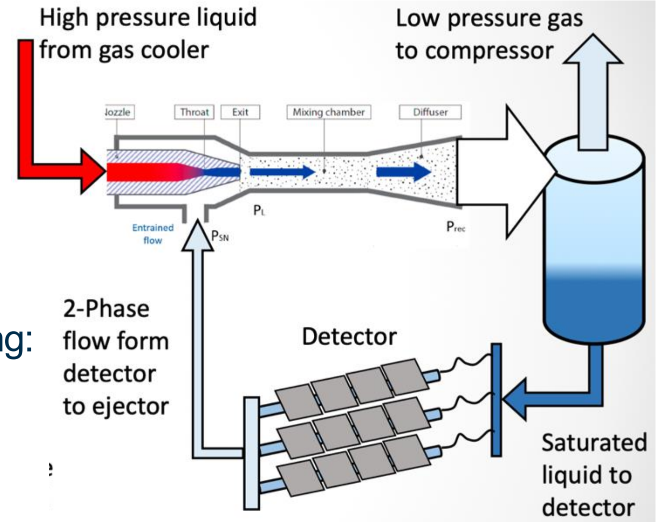
established solution for Phase II upgrades

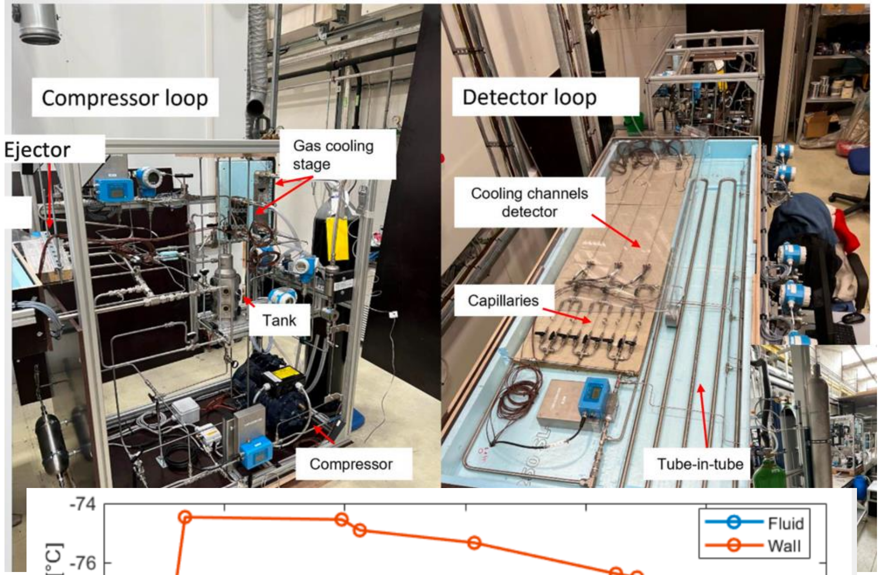
Krypton:
path to **lower temperatures**:
e.g. SiPM-based systems

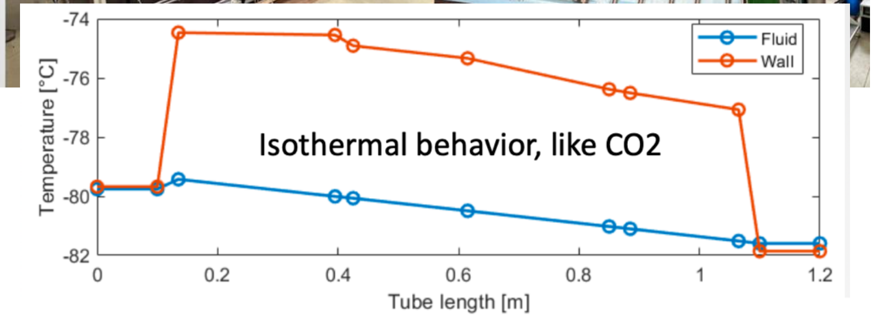
established cryogenic solution

Krypton cooling:

concept and demonstrator





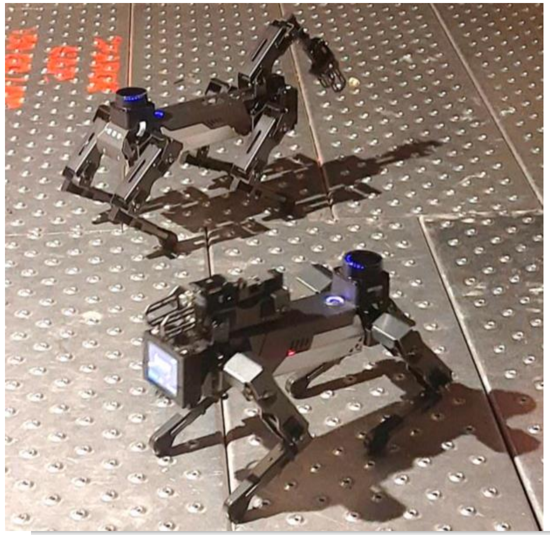


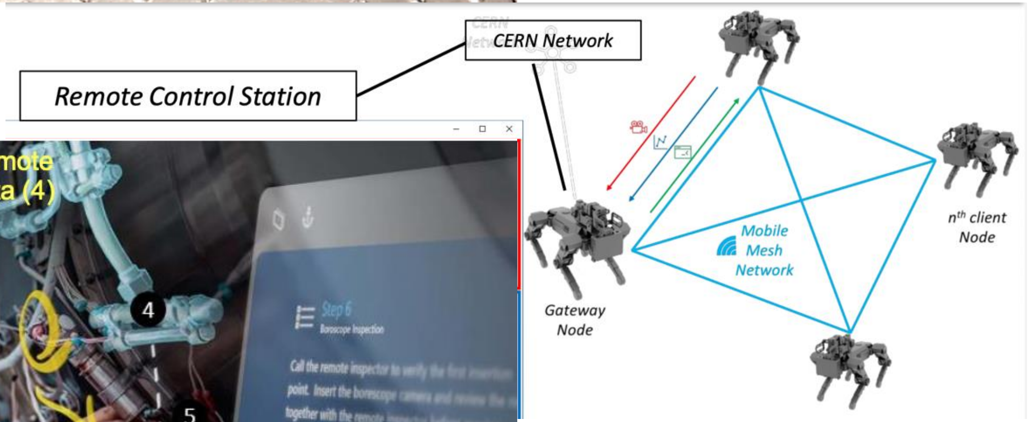
KIT

Novel Technologies for Integration and Maintenance
Robotics and Virtual Reality

Robots in experimental cavern

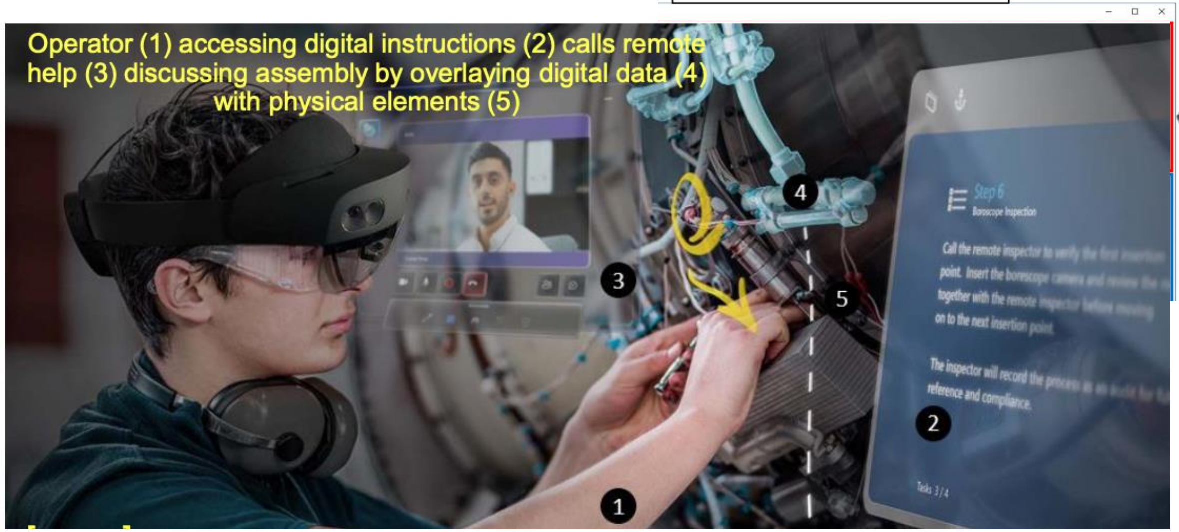
- Development of network and telemetry technology
- Enables interventions in confined spaces, with presence of magnetic fields and radiation



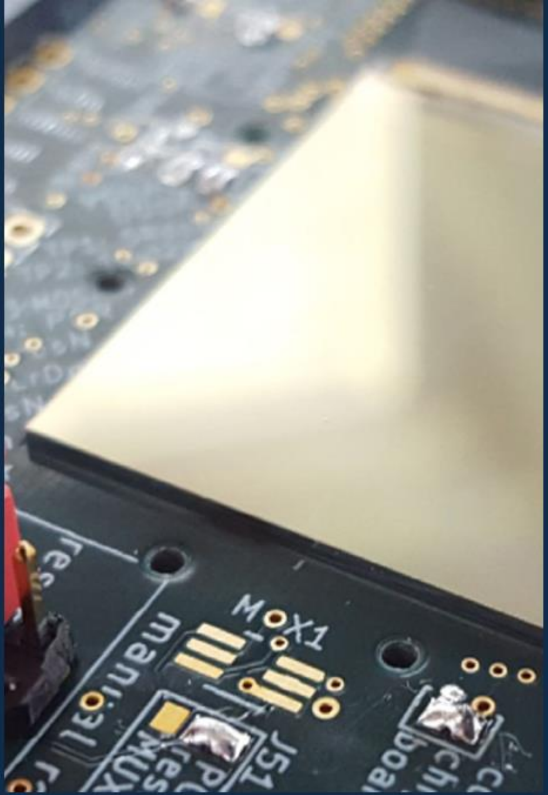
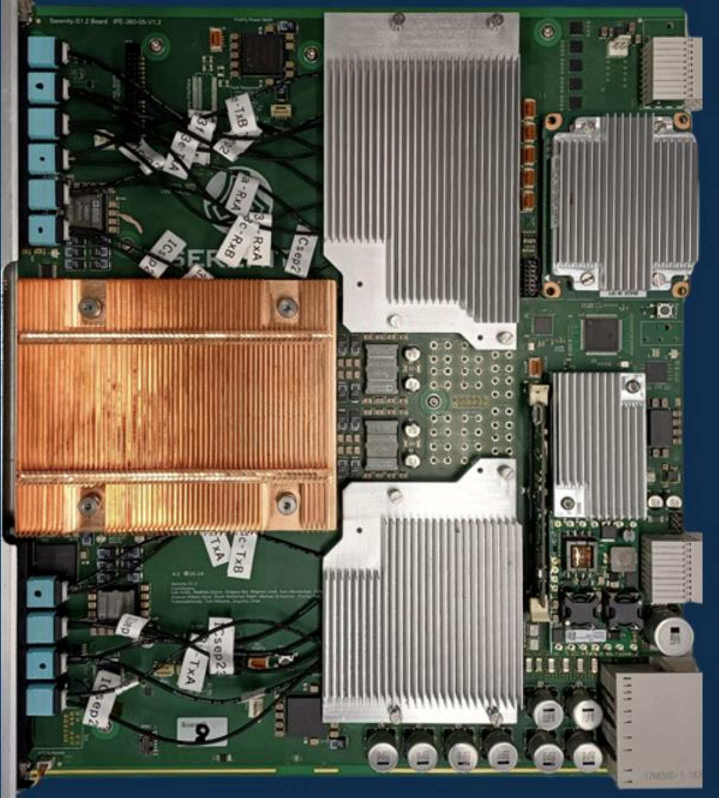


Augmented-, Mixed- and Virtual Reality (AR, MR, VR)

- Supporting detector integration and installation activities: Field operator assistance, remote collaboration
- Extensions to intervention planning and training (including in radiation environments), safety training, outreach,...





Electronics
Selected Topics – Primarily DRD7

03

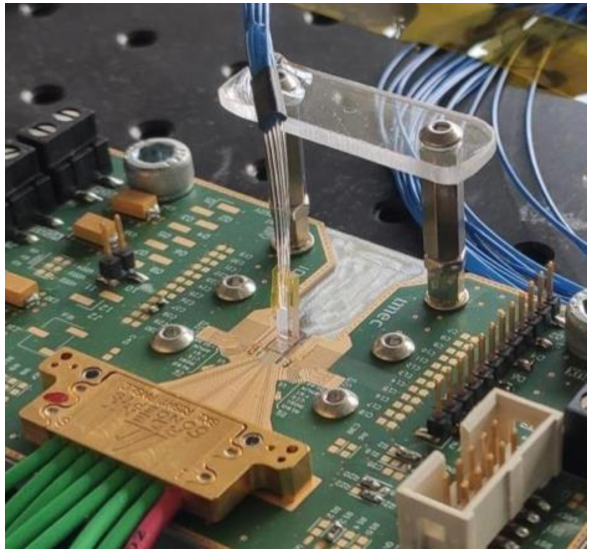
Data Transmission and Powering
Bringing Data from Sensor to DAQ, and Power to Sensors

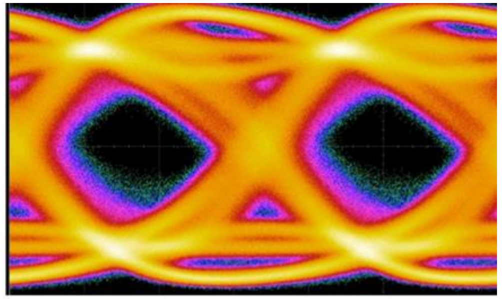
Developing the next generation of data and power transmission technologies for detector systems

- New technologies for data transmission:
  Silicon photonics transceiver development
- Power distribution and voltage / current regulation for detector modules:
  Powering for next generation detector systems
- Concepts for wireless solutions:
  Wireless power and data transmission

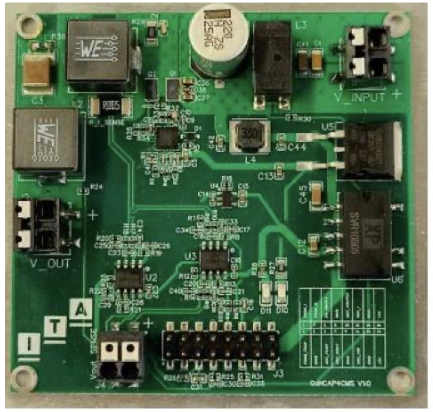
Driving vision for future experiments:

- High-speed optical data transmission with low power in radiation environments.
- Efficient powering of highly integrated detector modules.
- Reduced need for services / materials in detectors

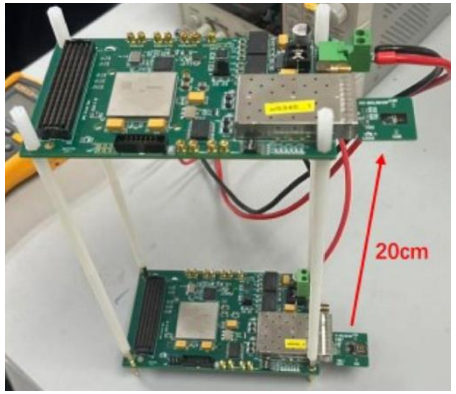




Data-rate	56 Gb/s
Optical power @ photo-RX	-0.5 dBm
ER	2.7 dB



GaN as possible technology for DC-DC converters



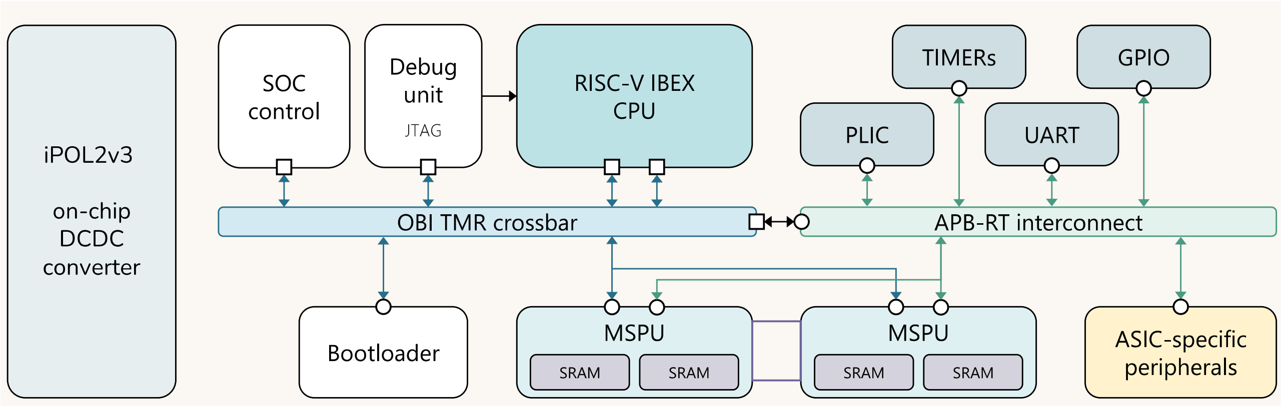
Integrated and Intelligent Front-Ends
Bringing Sensors and Processing together

Processing data right at the detector in challenging environments

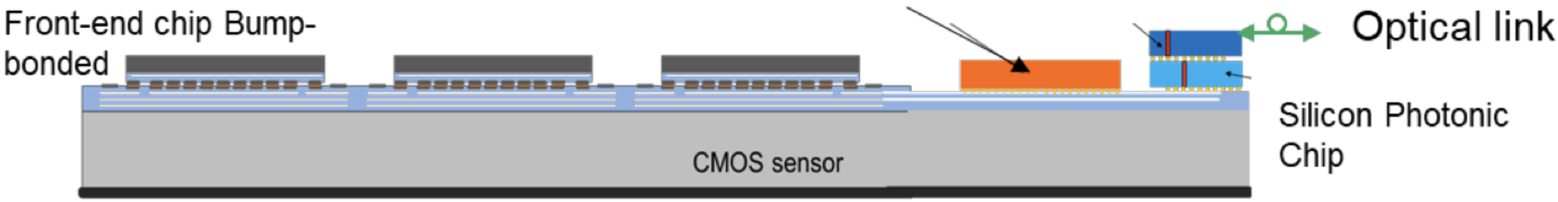
- Embedded systems for on-detector use in radiation environments:
  Radiation Tolerant RISC-V SoC
- Developing 2.5D and 3D integration, interconnect and packaging technologies:
  Shared access to 3D integration

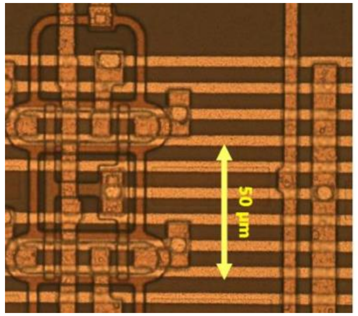
Driving vision for experiments:

- Bringing data processing, including AI, direct to the detector front-ends: More efficient data handling and reduction / elimination of losses due to selection and transmission bottlenecks.
- Fully integrated detector front-ends combining data processing, transmission and detector control and powering.

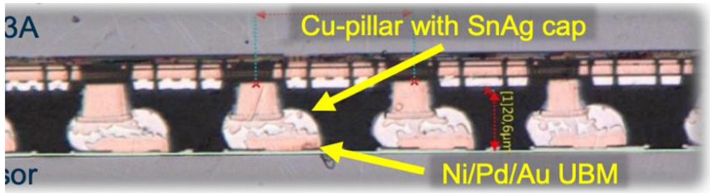


Novel potential for on-detector data processing by bare-silicon FPGA / RISC V





Ti:W/Cu RDL on wafer level



4D & 5D Techniques, Advanced ASICs
Precision Timing and advanced Technology Nodes

Technologies for 4- and 5-dimensional detectors (space, time, energy)

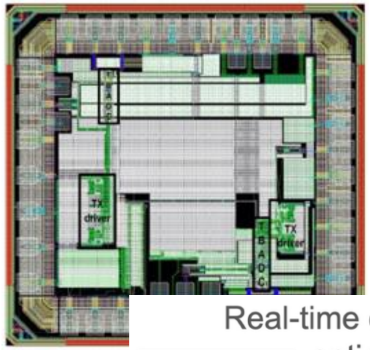
- Building blocks for compact, high-dimensional detectors:
  High performance TDC and ADC blocks at ultra-low power
- Timing technologies: Timing distribution for timing at system level, timing calibration

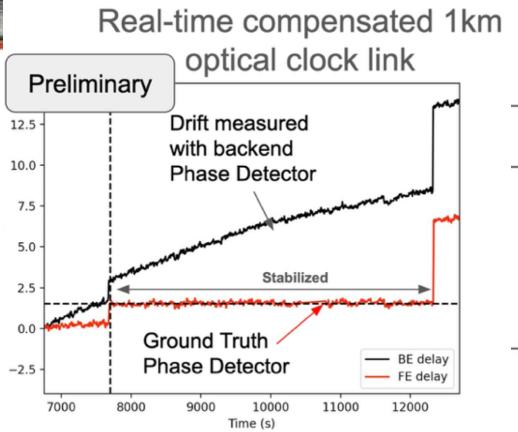
Driving vision for experiments:

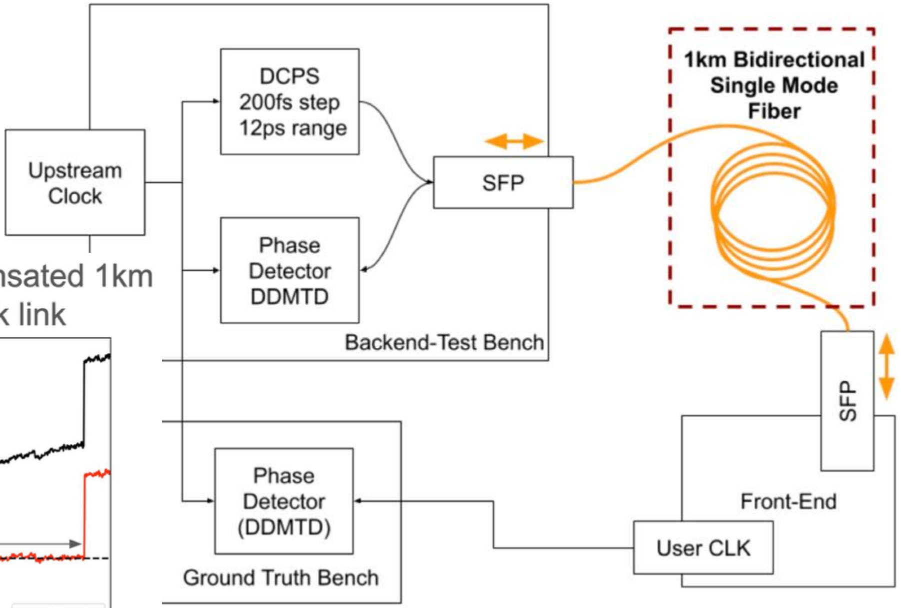
- Enabling routine 4D tracking and 5D particle shower measurements in large detector systems

Providing access to processes for sensor ASICs for the community to facilitate R&D; common coordinated submissions

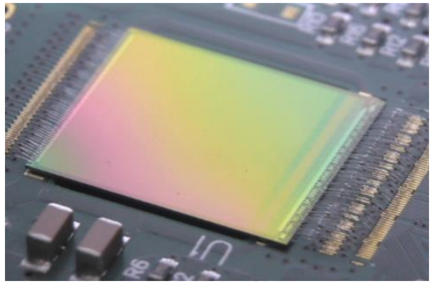
- 180 nm, 110 nm and 65 nm technology

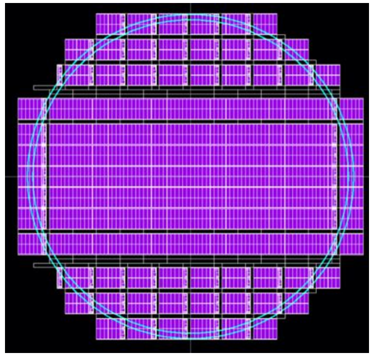






Stabilization Characteristics:
Std.Dev ~ **120 fs**
Peak to Peak ~ **650 fs**





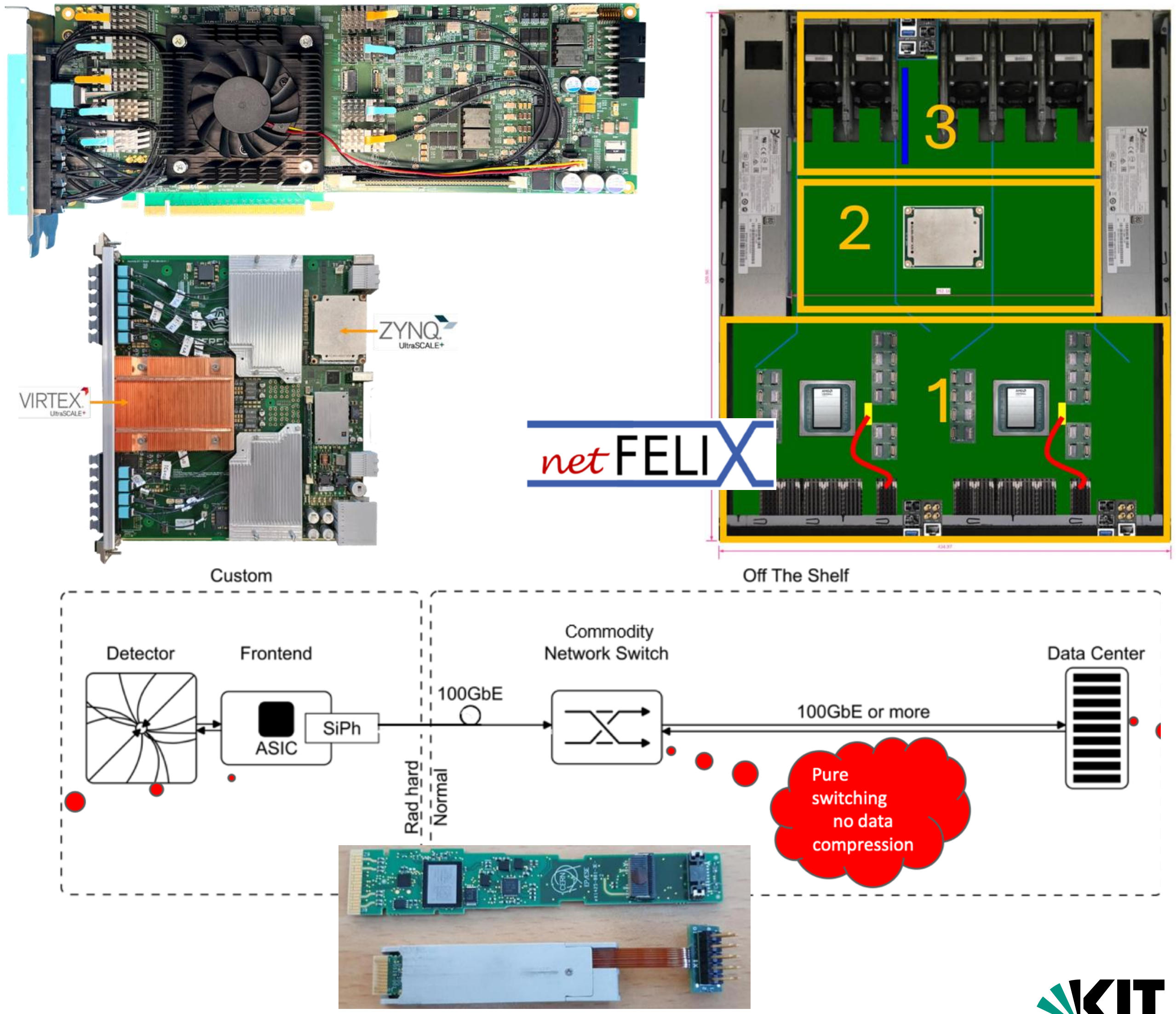
Data Acquisition Technology
Exploiting digital Processing and Data Transmission

Technologies and concepts for future data acquisition systems

- Leveraging the power of commercial off-the-shelf electronics components and systems for data acquisition and processing
- Developing DAQ systems with standard protocols close to the detector – going to 100 Gb Ethernet as early as possible – on detector front-ends – intermediate solution with protocol translators on the input to network switches

Driving vision for experiments:

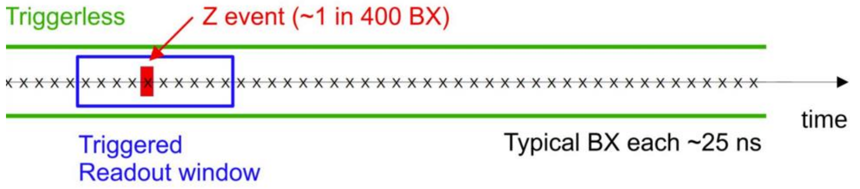
- Profiting from AI-enabled system-on-chip devices in trigger and DAQ systems for more capable online selection and processing.
- Data acquisition without dedicated backend boards – commercial network technologies beyond the detector front-end.



Data Acquisition Concepts
Considerations for FCC-ee

The key question: Are we talking about **TDAQ** or **DAQ?** Do we need/want a **trigger**?

- **The pros**: Substantial reduction in data volume, easier (re-)processing, …
- **The cons**: Loss of some events inevitable, challenging modeling of trigger effects and efficiencies to achieve FCC-ee precision goals, extra trigger paths in electronics, …



Likely the main (only?) factor: Can all the data be gotten out of the detector within the tolerable material and power budget?

- A key element to the answer: Size of *empty events* – (beam background, detector noise) – touches physics, accelerator, MDI, detector/sensor, front-end, …

Generic "core" DAQ system consists of:

- **Data transmission** off detector
- Receiving layer ("**back end**")
- Some form of **event building**
- **Storage**
- **Compute**

Use COTS

Seems familiar? -> DRD7 activities

- On-detector processing
- Data transmission: Silicon photonics, wireless r/o
- Back-ends with COTS-components, network-based solutions

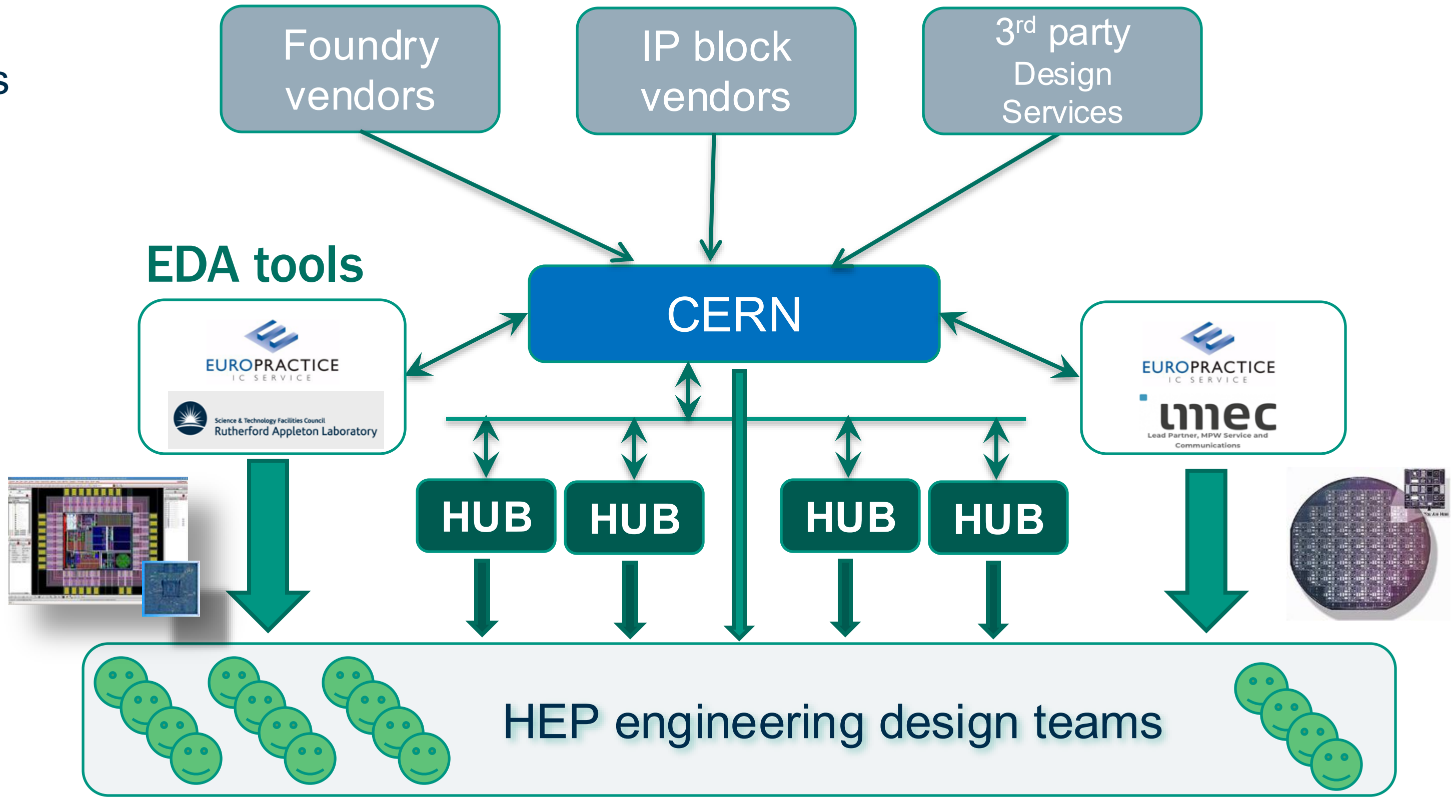
Rapidly evolving technologies: Too early for concrete solutions. But: *Need concepts, and common standards / interfaces early on!*

The Microelectronics Challenge
Keeping up with and profiting from Technology Evolution

Design of complex ASICs in modern technology nodes is increasingly complex and costly: Often beyond the capabilities of single groups / experiments.

DRD7 is proposing a **hub-based model** to:

- Establish and maintain access to cutting-edge technologies and EDA software tools.
- Ensure a professional approach to prototyping and fabrication cycles.
- Facilitate collaborative work across distributed teams and enable IP block sharing.
- Implement rigorous project review and submission processes to manage risks and control changes.



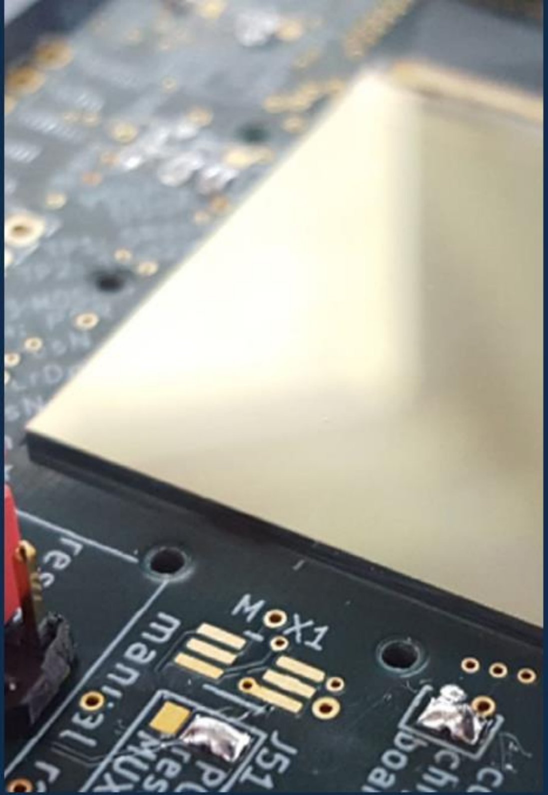
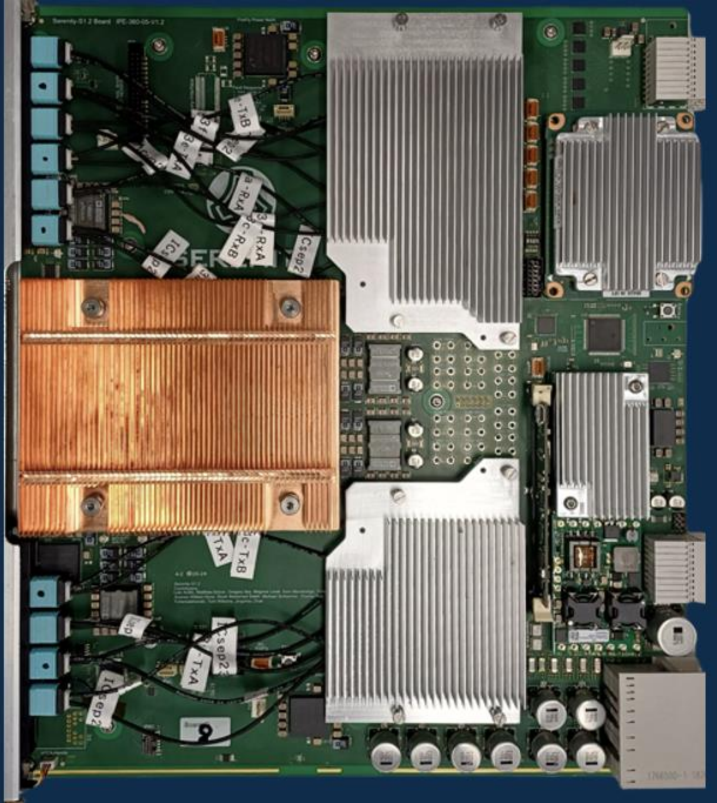
Currently: Exploring possibilities – expect flexible and scalable model.

A challenge:
Funding of regional hubs, and hub services.

Different classes of regional hubs – with CERN as central hub

- Service Hub – *design, verification, foundry access*
- Design Hub – *design, verification*
- Specialist Hub – *focus on a narrow domain*



Outlook & Conclusions

04

DRD7 & DRD8
Collaborative Frameworks for R&D

DRD7
ELECTRONICS AND ON-DETECTOR PROCESSING

Resources Coordination
Coordinator: H. Chen

DRD7 Project Management
Spokesperson: F. Simon
Deputy: A. Rivetti

Collaboration Board
Chair: A. Andreazza
Deputy: C. Fernandez Bedoya

Steering Committee
J. Baudot, M. French, D. Gascon Fora,
K. Klein, R. Kluit, A. Rivetti, F. Simon, F. Vasey

Technical Committee

WG 7.7: Tools and technologies
A hub-based structure for ASIC developments
Conveners: K. Kloukinas, X. Llopart Cudie, M. Willoughby

WP 7.1: Data density and power efficiency
Conveners: S. Kulis, J. Prinzie, J. Troska

WP 7.2: Intelligence on the detector
Conveners: D. Ceresa, F. Crescioli

WP 7.3: 4D and 5D techniques
Conveners: J. Galindo, M. Idzik

WP 7.4: Extreme environments
Conveners: G. Borghello, M. Da Rocha Rolo, O. A. de Aguiar Francisco

WP 7.5: Back-end systems and commercial off-the shelf components
Conveners: F. Alessio, C. Fitzpatrick

WP 7.6: Complex imaging ASICs and technologies
Conveners: M. Barbero, M. Caselle, I. Sedgwick, W. Snoeys

Projects
Project leaders

7.1.a: *Silicon photonics tranceiver development* | J. Troska
7.1.b: *Powering detector systems* | M. Karagounis, S. Michelis
7.1.c: *WADAPT* | E. Locci

7.2.a: *Virtual electronic system prototyping* | D. Ceresa, M. Kachel
7.2.b: *Radiation tolerant RISC-V SoC* | K. Kloukinas, L. Marien

7.3.a: *TDC & ADC blocks at ultra-low power* | M. Idzik, M. Menouni
7.3.b: *Sources impacting timing* | L. d'Eramo, G. Zecchinelli
7.3.c: *Timing distribution techniques* | S. Baron, J. Galindo

7.4.a: *Cryogenic CMOS PDKs & IP* | M. Da Rocha Rolo
7.4.b: *Radiation resistance of CMOS nodes* | G. Borghello

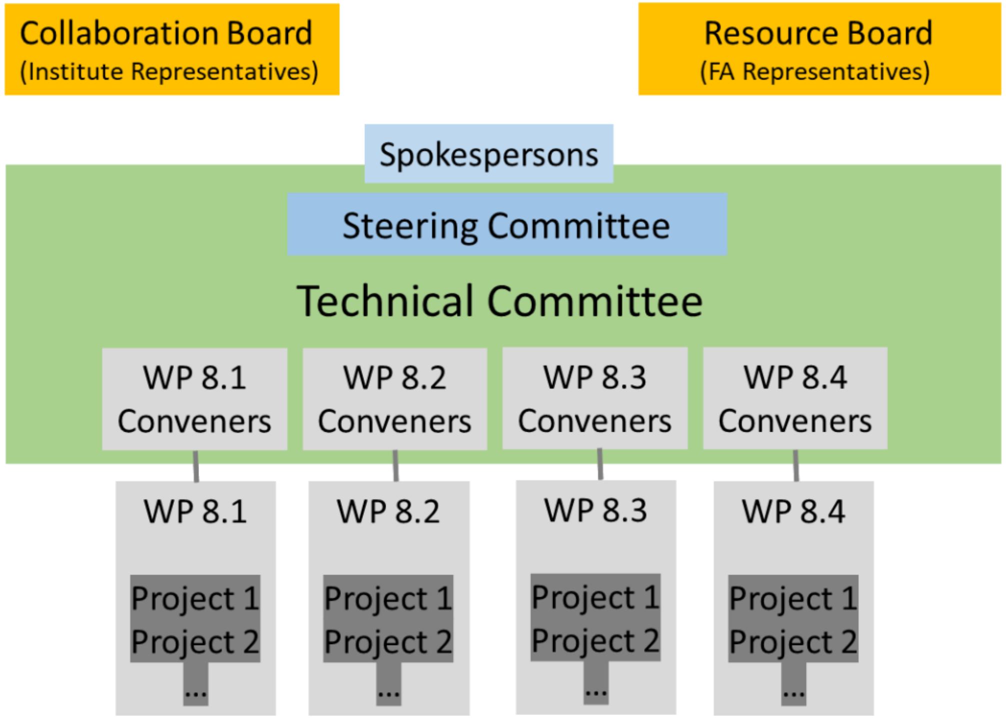
7.5.a: *DAQOverflow* | Y.-T. Lai
7.5.b: *From FE to BE with 100 GbE* | F. Alessio, A. Pellegrino

7.6.a: *Common access to selected imaging technologies* | M. Barbero, M. Da Rocha Rolo, I. Sedgwick, W. Snoeys
7.6.b: *3D integration access* | M. Caselle, L. Andricek, S. Charlebois

DRD7 & DRD8
Collaborative Frameworks for R&D

DRD8

- **WP1: Global system design and integration**
  - P1: The Vertex Region of Future Collider Experiments
  - P2: Robotics in the HEP Experimental Caverns
  - New P3: The Central Tracking Region of Fut. Coll. Experiments
- **WP2: Low-mass mechanics and thermal management**
  - P1: Advanced Mechanical Tracker Structures
  - P2: Characterisation of Material Properties and Database Development
- **WP3: Detector cooling**
  - P1: New Evaporative Cooling Fluids and Systems
  - P2: Microchannel Cooling Substrates
- **WP4: Design and qualification tools**
  - P1: Extended Reality (XR) Development
  - P2: Connection of Engineering Design Tools with Physics Simulation Software



Conclusions

A broad **strategic R&D** portfolio in electronics, mechanics and detector integration technologies.
Addressing the recommendations and detector R&D themes of the **ECFA Detector R&D Roadmap**.

- In part concretely FCC-ee themed – in particular in DRD8
- Often connected to concrete near-term projects – Phase Iib Upgrade of ALICE, LHCb, others
- Universally relevant for FCC-ee efforts

Status of DRD7 & DRD8:

- Collaborations formed – but some formalities still in development, in particular MoU
- Renewal for next 3-year period coming up: Preparation of proposals starting
- Well-established R&D direction – and room for new ideas
  Additional contributions to existing and new projects very welcome!