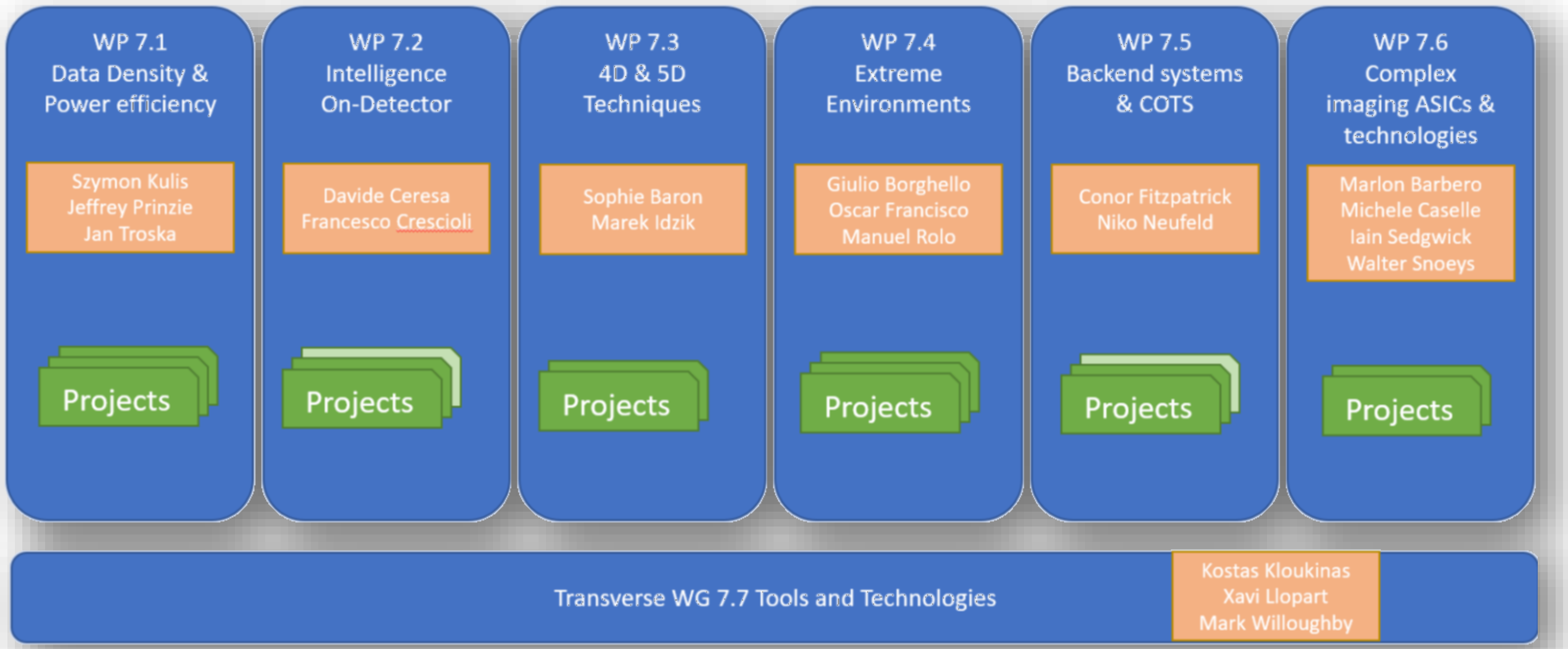
DRD 7.6b
Shared Access to 3D Integration

Ladislav Andricek and Michele Caselle

DRD7 (Electronics and On-detector Processing) – worldwide collaboration



- 68 Universities & research centers involved
- Research area: Data Density, Power efficiency, Intelligent On-Detector, 4D & 5D techniques, rad-tolerant and cryo-tolerant electronics, backed electronics/systems and COTS (Commercial-Off-The-Shelf), complex imaging ASICs & 3D-technologies
- 15 confirmed projects cover a wide range of novel detector technologies

DRD7 (Electronics and On-detector Processing) – worldwide collaboration

WP 7.1 Data Density & Power efficiency	WP 7.2 Intelligence On-Detector	WP 7.3 4D & 5D Techniques	WP 7.4 Extreme Environments	WP 7.5 Backend systems & COTS	WP 7.6 Complex imaging ASICs & technologies
Szymon Kulis Jeffrey Prinzie Jan Troska	Davide Ceresa Francesco Crescioli	Sophie Baron Marek Idzik	Giulio Borghello Oscar Francisco Manuel Rolo	Conor Fitzpatrick Niko Neufeld	Marlon Barbero Michele Caselle Iain Sedgwick Walter Snoeys
Projects	Projects	Projects	Projects	Projects	Projects

Transverse WG 7.7 Tools and Technologies — Kostas Kloukinas, Xavi Llopart, Mark Willoughby

18 countries

- 68 Universities & research centers involved
- Research area: Data Density, Power efficiency, Intelligent On-Detector, 4D & 5D techniques, rad-tolerant and cryo-tolerant electronics, backed electronics/systems and COTS (Commercial-Off-The-Shelf), complex imaging ASICs & 3D-technologies
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DRD7.6 – Complex imaging ASICs and technologies

- Working Group 6 deals with complex technologies merging multiple functionalities such as sensor and processing, multi-tier (2.5D and 3D) assemblies

- **Project 7.6a** ➡ *W. Snoeys, "ECFA DRD 7.6a Working Group: Future Detector Requirements"*
  - This project aims to provide common access to advanced imaging technologies through the organization of common fabrication runs. These are initially envisaged for the TowerJazz 180 nm, TPSCo 65 nm and the LFoundry 110 nm CMOS imaging technologies

- **Project 7.6b (Shared access to 3D integration)** ➡ *This talk*
  - This project aims to develop essential technologies for both 2.5D and 3D integration that can be quickly transposed to wafer-to-wafer 3D integration for a wide range of future particle physics applications, ranging from low-temperature neutrino detectors to high-radiation environment HL-HLC pixel detectors

Evolution of the collaboration within 7.6b project

Centro Nacional de Microelectrónica IMB

- *CNM new contributor*. 9 institutes, 5 large national labs with well-renowned experience in interconnection technology and detector production

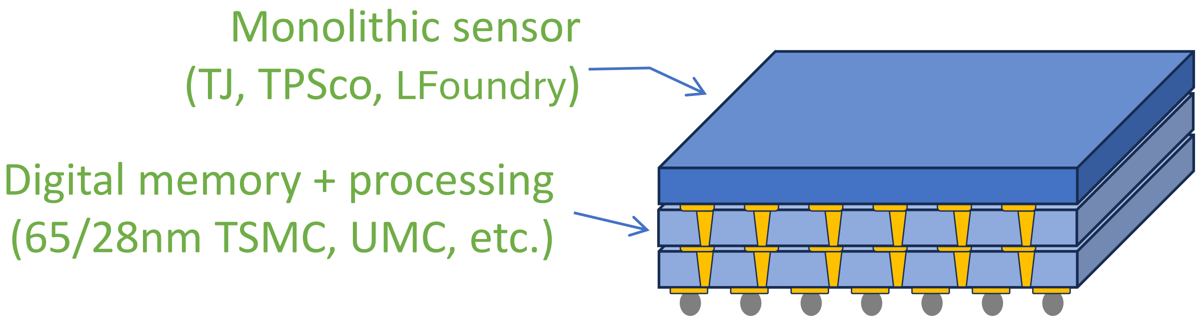
DRD7.6b

Which detector technologies are likely to reshape the landscape and influence development strategies?

3D-Integrated and Stacked ASIC Detectors

- 3D-ASIC integration on a single die as a low-cost, low-risk demonstrator that paves the way to future large-area 3D-ASIC detector modules assembled via (expensive) wafer-to-wafer (W2W) bonding

- Fast prototyping of 3D-ASICs using MPW-friendly D2W/D2D bonding, postponing costly W2W engineering runs until large-scale detector production

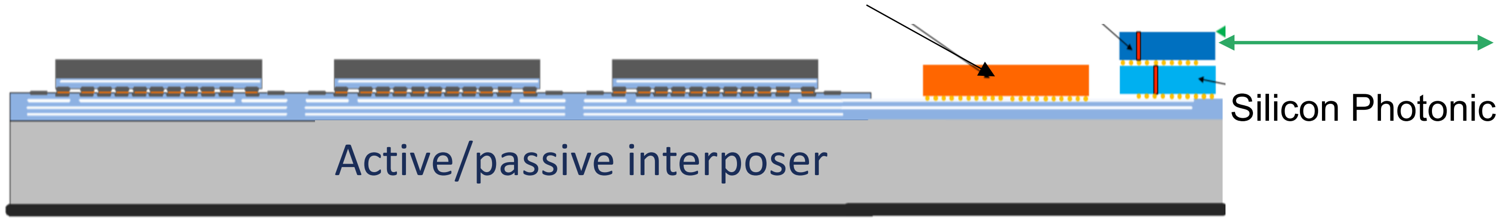


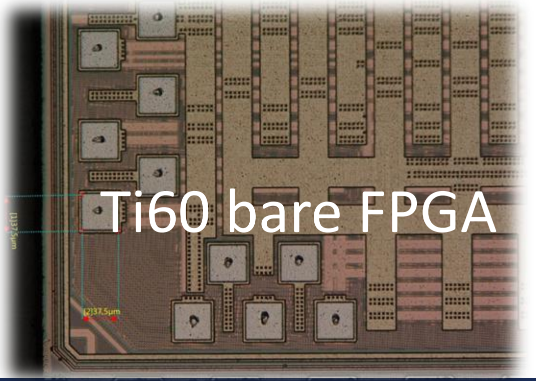
- Risks & mitigation: demonstrator validates partitioning, power distribution, clocking, BER, and thermal, the parts that dominate risk in W2W, before scaling to reticle-stitched, W2W bonding

Provide access primarily through in-house infrastructure

2.5D active/passive silicon interposer

- Silicon interposers are the key enabler to integrate sensors, ASICs, FPGA/AI, and photonics from multiple CMOS nodes into a scalable detector module
  - Enable co-packaging of electronics and photonics → compact, low-power optical uplinks/downlinks
  - Offer system-on-detector approach: interposer becomes the substrate that unifies all domains (sensor, readout, data transmission, on-detector processing)



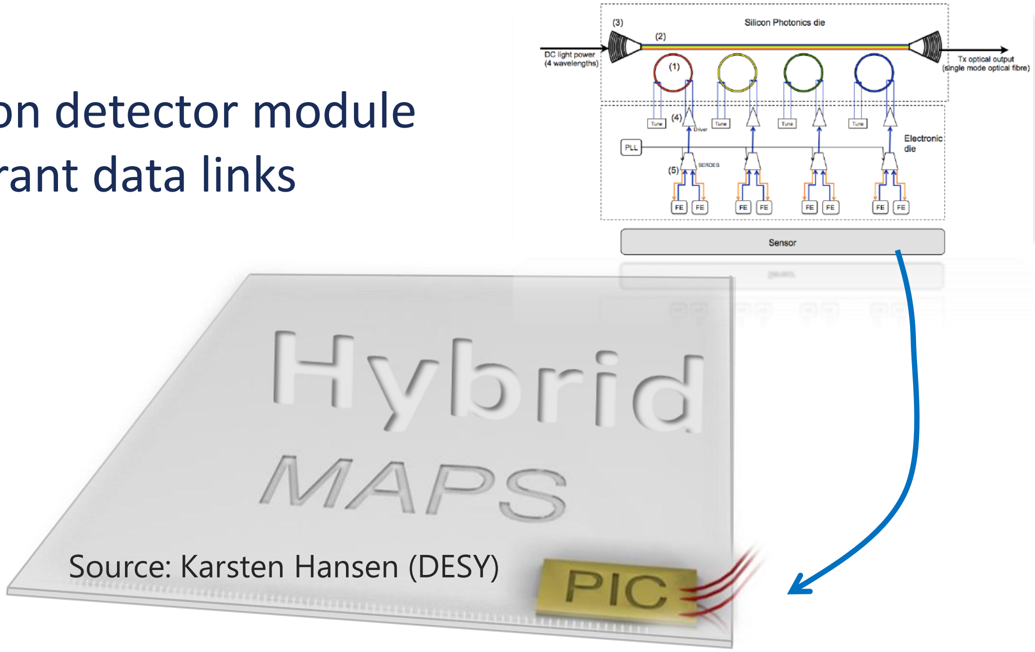


➡ *M. Karagounis, “RISC-V and FPGA Integration on Detector”*

➡ *F. Kluge, “Efinix: Technologies and Future Outlook”*

Integration of SiPh chip and optical packaging on detector module

- Compact, high-bandwidth, and low-power data transmission in detectors as a scalable solution for large detector systems
  - Direct integration of silicon photonics (SiPh) transceivers on detector module
  - Coupling with optical fibers for high-speed, radiation-tolerant data links
- It requires an advanced packaging
  - **Heterogeneous integration**: Co-packaging of sensor, ASIC, and SiPh transceiver on common substrate. *Flip-chip*: SiPh die bonded to ASIC or readout interposer
- Potentially reshape the design of future of DAQ
  - **Streaming data directly from Front-End to the COTS** (*No backend" approach*) over Ethernet
  - Attractive for readout systems of future detectors, less experiment-dependent, paving the way for **common DAQ infrastructure**



Source: Karsten Hansen (DESY)

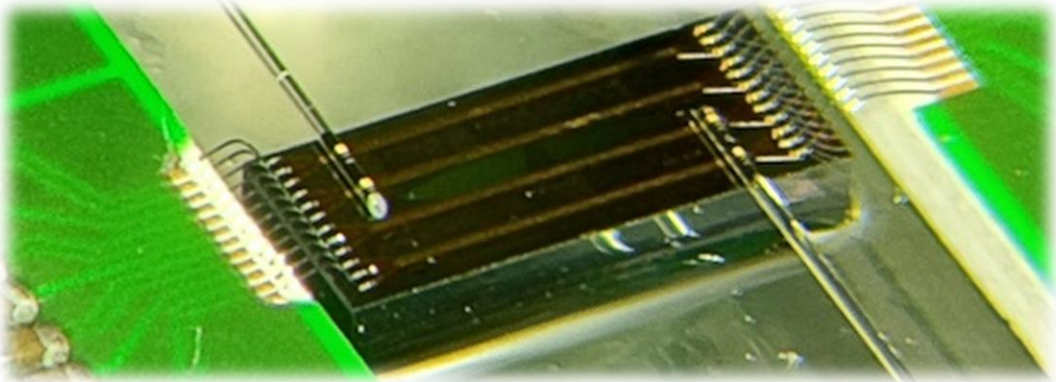
DRD 7.1 <-> DRD 7.6

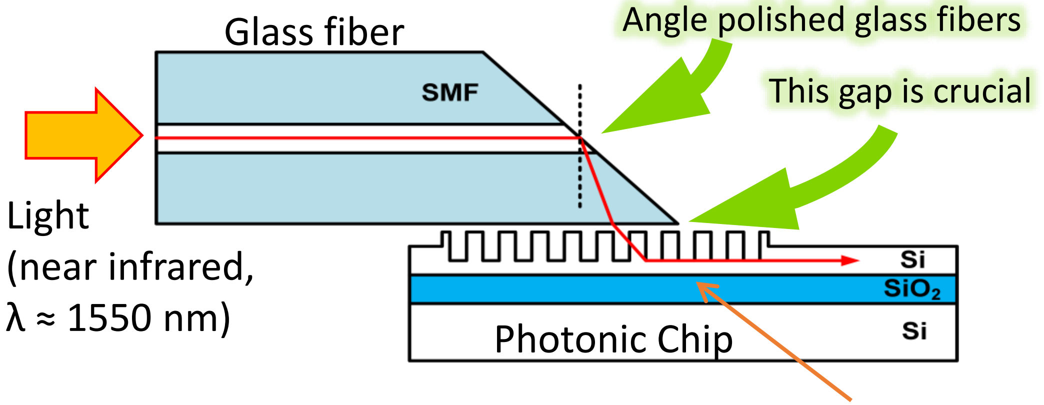
SiPh Packaging & Fiber Attachment

→ *IPE clean room visit, tomorrow*

- SiPh packaging and fiber-attachment, at detector-module or wafer level, are essential for next-generation optical data links. Automated fiber alignment using pick-and-place machines further enhances assembly precision and throughput.

- Coupling geometries (SiPh ↔ fiber)
  - **Edge couplers**: high coupling efficiency, broadband and negligible polarization dependence, but more complex passive alignment (sub-micron lateral tolerance)
  - **Grating couplers**: compatible with wafer-level testing and probing, simple vertical fiber access, but higher insertion loss, higher insertion loss, narrow bandwidth, polarization sensitive





DRD7.6b

Detector packaging technologies for large-area detector modules

- Advanced packaging is vital to achieve ultra-low mass, precise assembly, and robust high-speed power/data links required for large-area detectors in future experiments
  - **Ultra-light material** budget: Aluminum–polyimide flex hybrids
  - **High-precision pick-and-place assembly:** Automated die attach & bonding with <10 µm accuracy
  - **Power distribution:** Low-drop, low-noise delivery along extended module chains by DC-DC conversion or serial powering to minimize cable mass
  - **High-speed data transmission:** (Gb/s per channel) Multi-Gb/s differential lines routed across flex/hybrid
  - **Optical transition:** at module or stave edge for meter-scale transmission
  - **Signal Integrity** (SI) & Power Integrity (PI) → Careful impedance-controlled routing on flex for minimal reflections, low cross-talk
  - **Decoupling** strategies and ground return optimization for stable power rails

➡ *A. Lega "FBK Platform for Flexible PCB Manufacturing"*

➡ *Synergy DRD 7.6a <-> DRD 7.6b*

➡ *A. Ulm, "Low-material pixel modules: All-silicon and thin hybrid modules"*

DRD7.6b

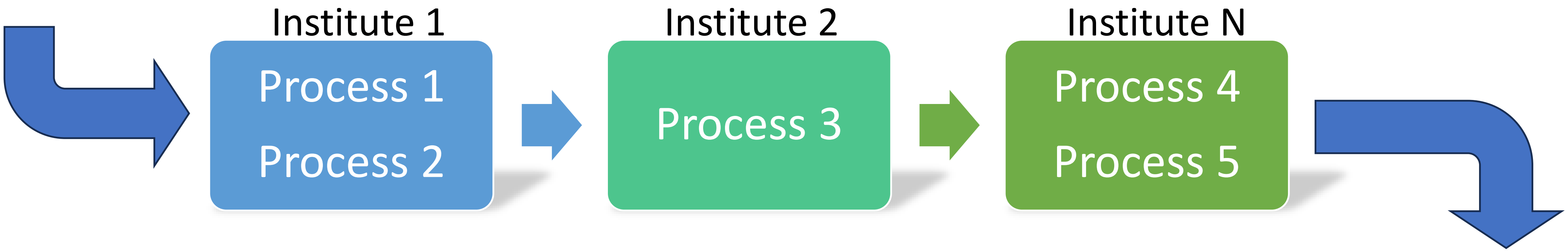
Which strategies has DRD 7.6b agreed on to tackle these challenges and secure long-term access to advanced detector technologies?

International Distributed Detector Laboratory

- Establish a distributed laboratory that operates as a hub-service for the community
- Each institute highly specialized in one or more technological processes

From community:
- Request of process/service
- Rapid prototyping of new detector
- Detector production (large-scale)

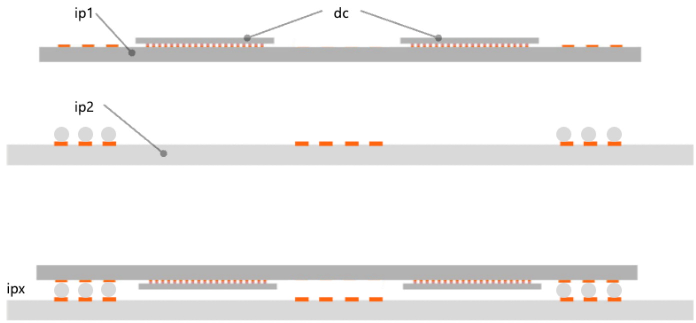
The key idea is synergy: working together as a unique worldwide detector laboratory, leveraging complementary expertise



Maintaining a strong connection with application/experiment requirements

To community (institute/experiment)

PilotProject



- **Validate and implement distributed production workflows** – Ensure all production steps are proven and effectively exercised.

- **Define interfaces across institutes and laboratories –** Develop clear and standardized communication channels, processes, and operational protocols to ensure seamless collaboration and integration.

- **Identify potential incompatibilities** – Detect mismatches in processes, technologies, or tools early in the workflow.

- **Develop and implement solutions** – Address incompatibilities with efficient and practical resolutions to maintain production consistency.

➡ *Dedicated discussion on PilotProject is scheduled for this afternoon*

Impact

- Key objective of DRD 7.6b is to **establish a distributed detector laboratory,** enabling cost-effective access to 3D and advanced integration technologies for the detector community

- **Milestones**, include development of Through-Silicon Vias (TSV) and multi-layer Redistribution Layers (RDL) on both front and back sides, integration of advanced silicon photonics and optical packaging directly on detector modules

- Interplay between **DRD3-WG7** and **DRD7.6b**, map areas of common interest on 2.5D and 3D integration

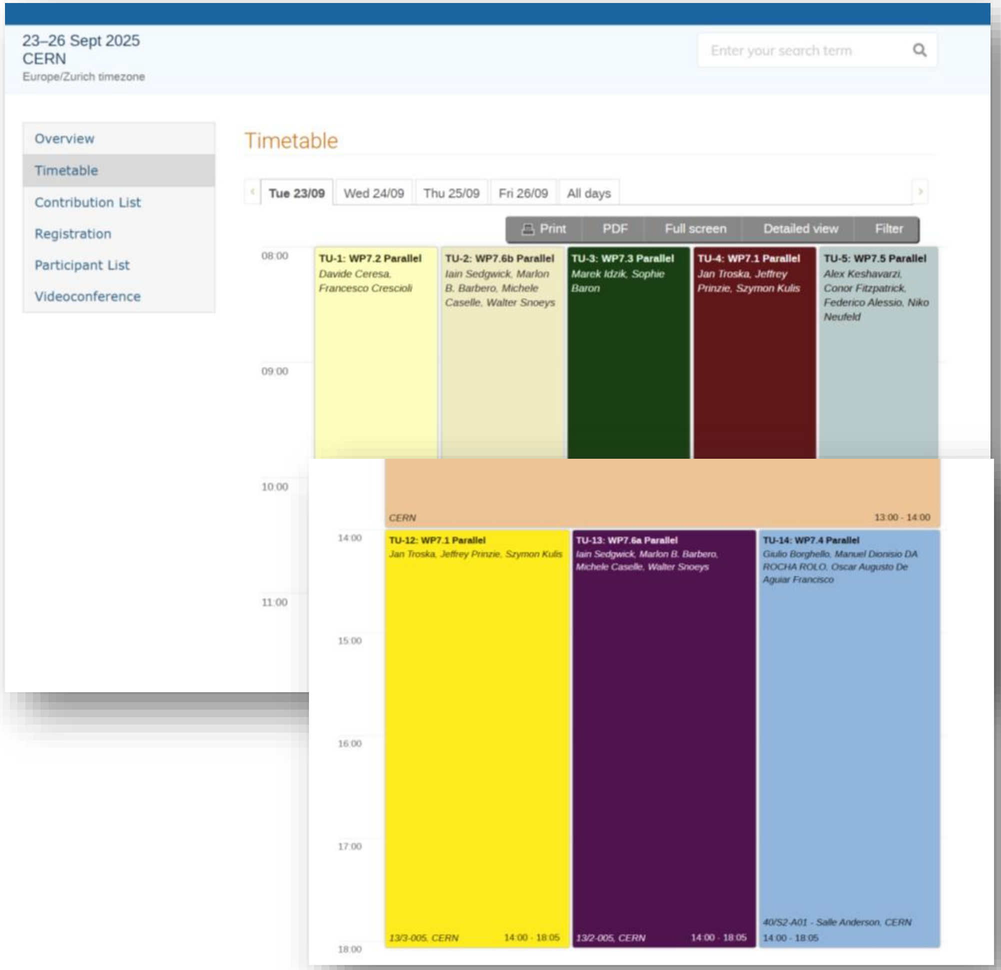
➡ *G. Calderini, "Status Update of DRD3 – WG7 Integration Technologies"*

ECFA

European Committee for Future Accelerators

DRD7.6b

DRD 7 annual workshop, indico: [DRD7 annual workshop (23-26 September 2025): Overview · Indico]



DRD 7.6b → parallel session 23/09 (morning)
DRD 7.6a → parallel session 23/09 (afternoon)

You are warmly invited to participate in person and contribute your ideas. If you would like to give a talk, please let us know in advance.

This is a unique opportunity to share your expertise, exchange insights with peers worldwide, and help shape the future of detector integration, interposer technologies, and TSV development

Thank you very much for your attention