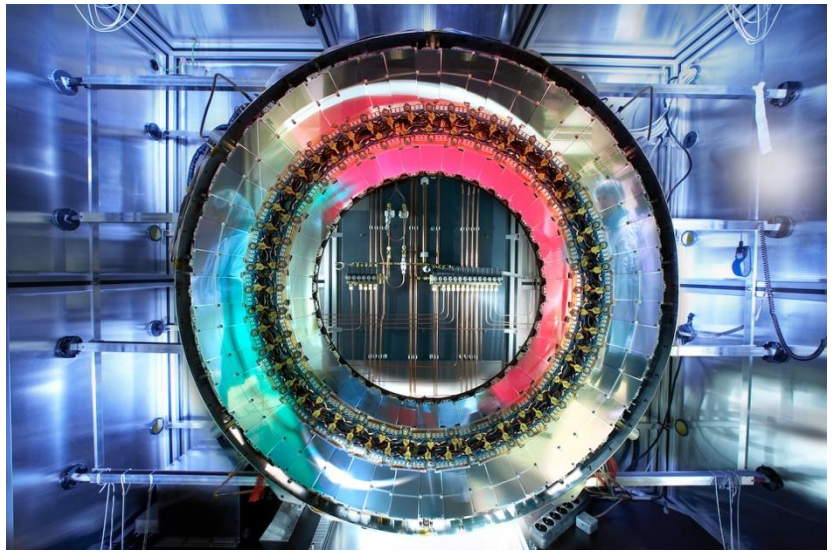
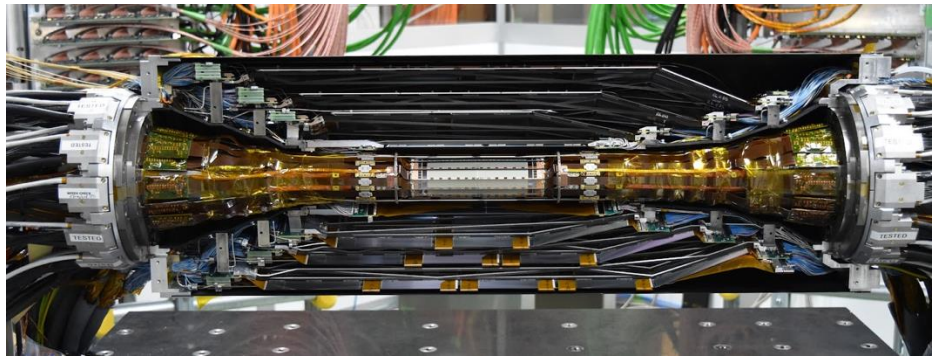
R&D on Semiconductor Detectors – DRD3

C. Marinas, S. Martí-García

Short IFIC's History in Silicon Developments





IFIC has long-standing experience in the development of large semiconductor detector systems

We develop technologies for HEP and their applications

Two examples:

- ATLAS SCT Endcap (evolving into ITK-Strips) at CERN
- Belle II PXD (evolving into VTX-CMOS) at KEK

Involvement from early R&D stages through comprehensive system development, integration, commissioning, and data acquisition.

Examples of leadership in large collaborations:

- ATLAS ITK-Strips Deputy Project Leader, Level 3 Coordinators
- Belle II Deputy Spokesperson, Technical Coordinator, Upgrade Coordinator, VTX Project Leader, Deputy Run Manager

Context

DRD3 evolves from ***RD50*** - *Radiation Hard Semiconductor Devices for Very High Luminosity Colliders* and ***RD42*** - *Diamond Tracking Detectors for High Luminosity Experiments at the LHC*

Created in 2001, RD50 ended the journey at its 43rd workshop in December 2023.

IFIC was one of the founding members and organized the Collaboration meeting in Valencia in 2021

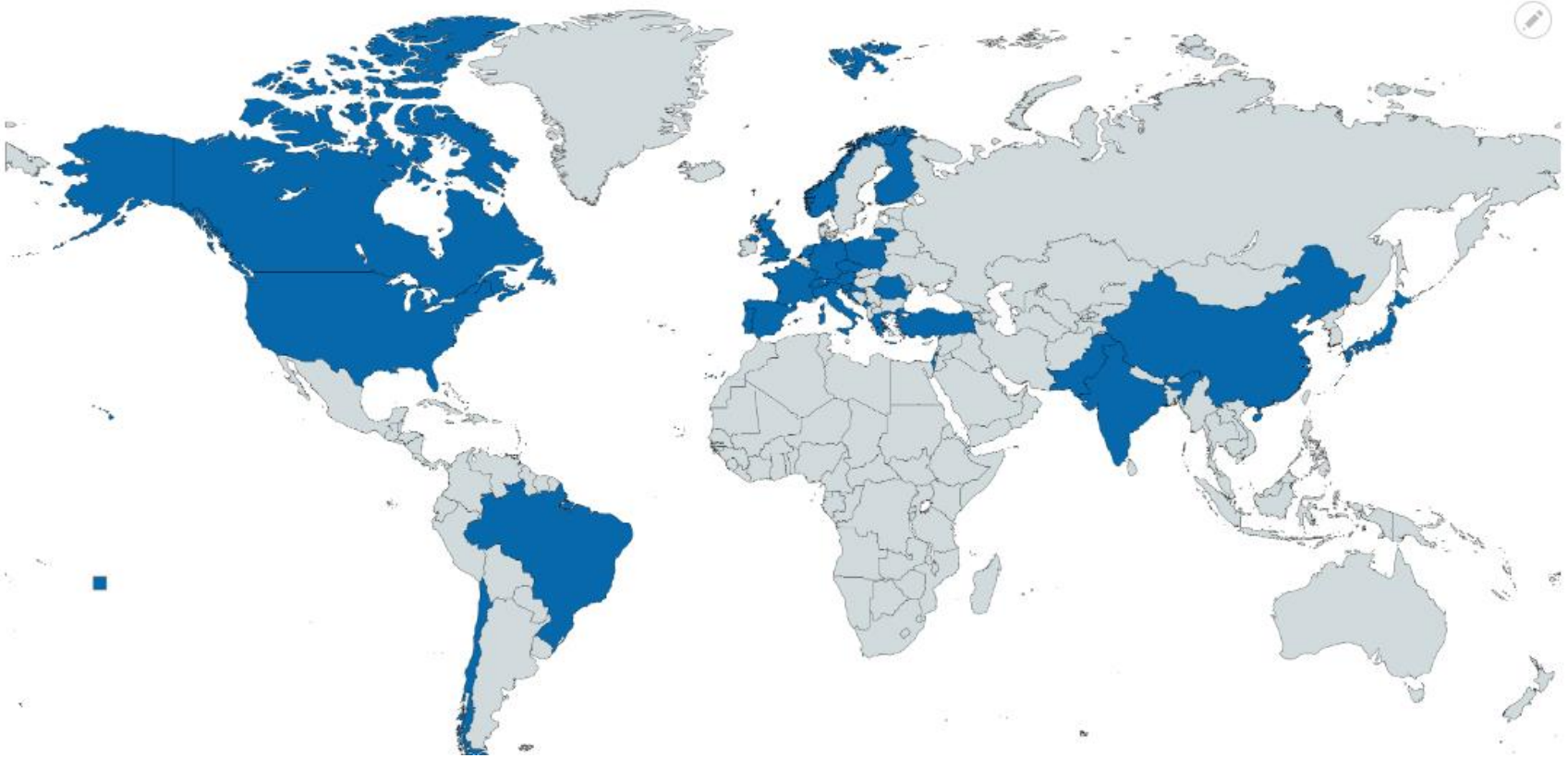
Participating Institutes

DRD3 Collaboration:

- 143 Institutions
- 29 Countries
- 571 Participants

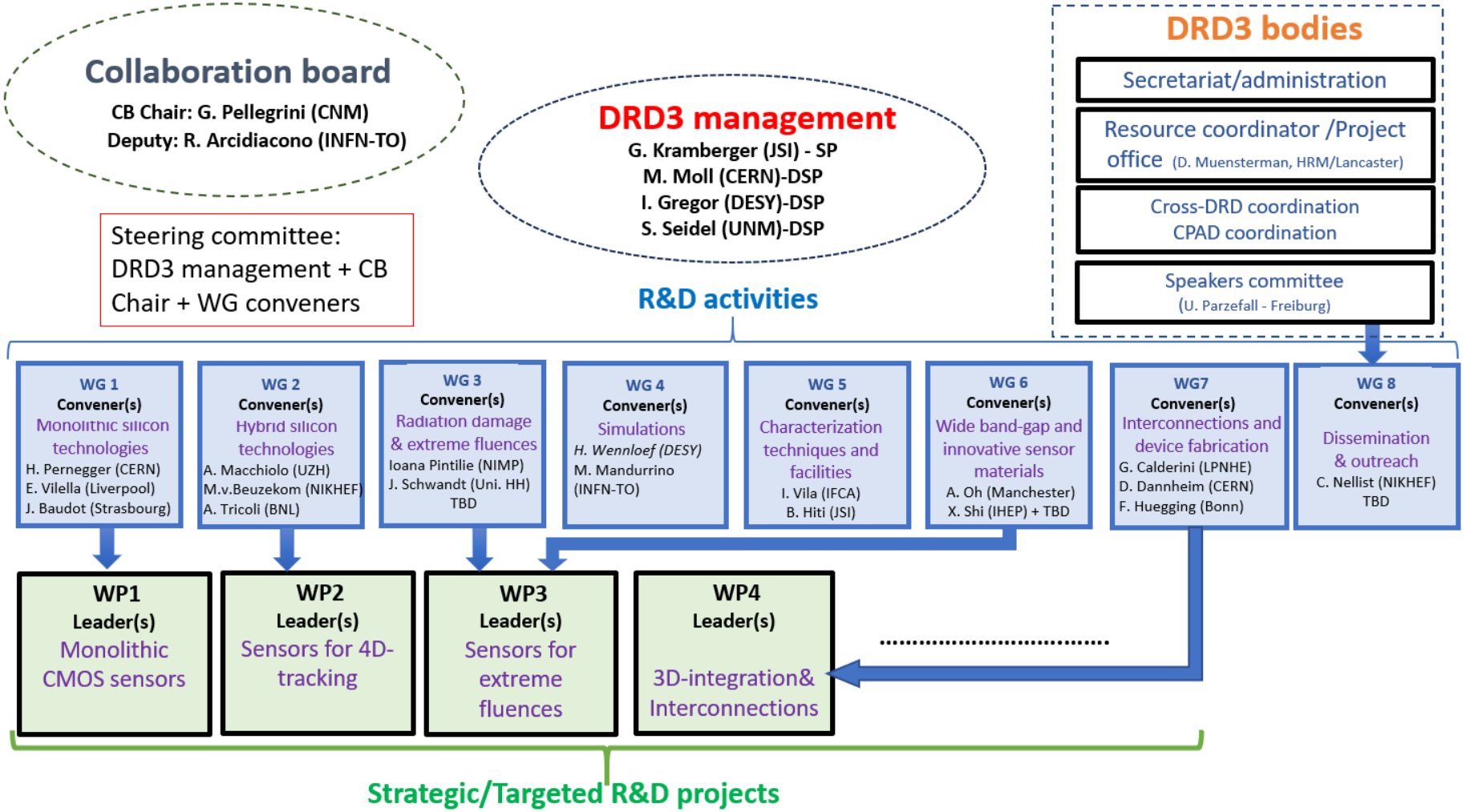
Spain:

- CNA – C. Jimenez-Ramos
- CNM – G. Pellegrini
- U. Sevilla – R. Palomo
- IGFAE – A. Gallas
- IFAE – S. Grinstein
- IFCA – I. Vila
- ITAINNOVA – F. Arteche
- IFIC – C. Marinas, S. Martí-García



https://drd3.web.cern.ch/

Collaboration Structure



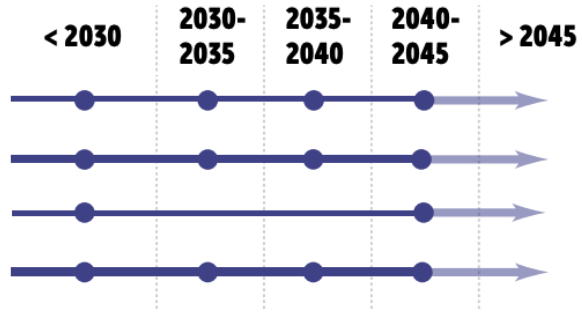
Goals

The DRD3 collaboration has the dual purpose of pursuing the realization of the strategic developments outlined by the Task Force 3 (TF3) in the ECFA roadmap and promoting blue-sky R&D in the field of solid-state detectors.

Detector R&D Themes

Solid state

- **DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- **DRDT 3.2** Develop solid state sensors with 4D-capabilities for tracking and calorimetry
- **DRDT 3.3** Extend capabilities of solid state sensors to operate at extreme fluences
- **DRDT 3.4** Develop full 3D-interconnection technologies for solid state devices in particle physics



→ CMOS technologies
→ Tracking + Timing
→ Radiation hardness
→ Advanced packaging

Key collider projects: Belle II upgrade considered the steppingstone towards the Higgs Factory

→ Defines our roadmap too

Working Groups

Working group (WG) = Organizational structure of the work which should have a long term horizon

WG 1 Monolithic Silicon Technologies	WG 2 Hybrid Silicon Technologies	WG 3 Radiation damage characterization	WG 4 Simulations	WG 5 Characterization Techniques and Infrastructures	WG 6 Wide Bandgap and Innovative Sensor Materials	WG 7 Interconnect Technologies	WG 8 Dissemination and outreach
• Investigate Monolithic Active Pixel Sensors (MAPS) than may achieve very high spatial • Resolution and very low mass. • Understand radiation hardness limits of MAPS. • Investigate the use of State-of-the-art commercial CMOS in tracking and vertex detectors. • Explore the use of passive CMOS as a complement to standard sensors.	• Develop ultra-fast detectors, enabling 4D tracking to deal with multiple interactions occurring within a bunch crossing (pile-up). • Understand the ultimate limit of precision timing in sensors, with and without internal multiplication. • Investigate new semiconductor and technology processes with faster signal development and low noise readout properties.	• Undestrand microscopic properties of detectors at extreme fluences. • Understand the limit of semiconductors at high fluences. • Study innovative materials • Characterization of defects in semiconductors	• Verify and prepare the TCAD tools for use in various DRDTs • Improve and develop MC tools • Develop and implement new radiation hardness models and device parametrizations • Design common tools for data processing (digitization, electronics)	• Explore the use of new techniques to characterize detectors • Develop common DAQ tools • Irradiation facilities, including extreme fluences. • Test beams • IBIC studies	• Understand the detailes of the damage of the WBG semicondcuntos • Develop methods for characterization and fabrication of detectors from innovative materials	• Advanced Integration Technologies. • Process capabilities for different wafer sizes and sensor material types. • Alternative bonding technologies for ultra-thin wafers. • Reduction of interconnection pitches	• Participation in congress • Explore other applications (Nuclear physics, Astrophysics, Fusion) • Contact industrial partners. • Participation in EU or similar funding projects • Website

Working Groups

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Main Development Lines

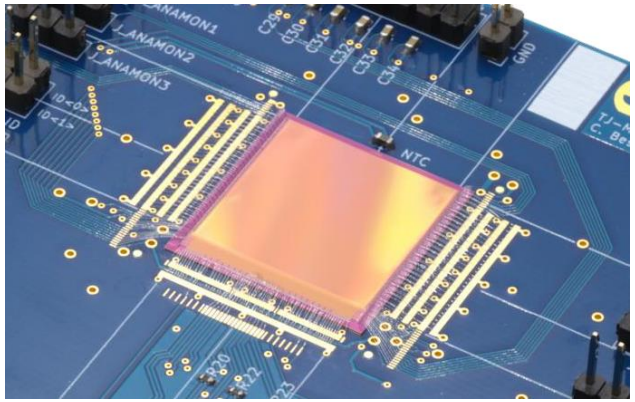
IFIC's main R&D lines lay on WG1, WG5 and WG7

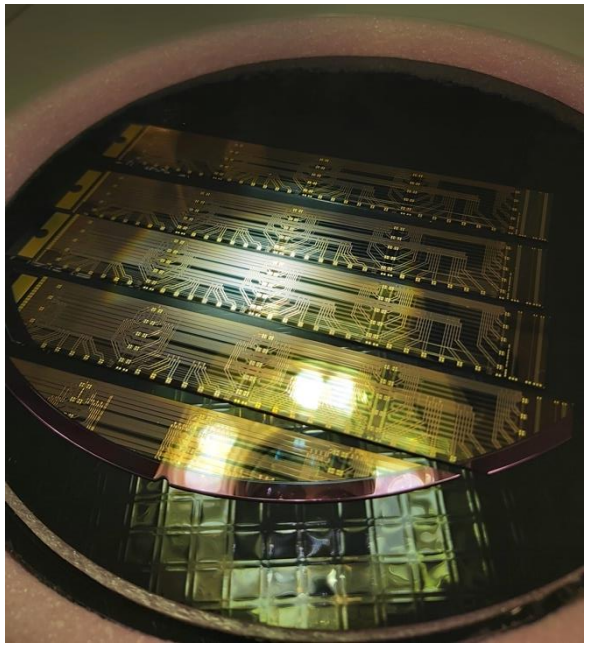
- WG1: Monolithic silicon technologies
  Full reticle CMOS chips, FE architectures

- WG5: Characterization techniques and infrastructure
  Particle beam telescope
  Common DAQ systems
  TPA-TCT laser system

- WG7: Interconnect technologies
  Wafer postprocessing, redistribution layers

Note: Synergies with DRD7 and DRD8





Monolithic Silicon Developments

CMOS technologies from 65 nm to 180 nm feature sizes
Different levels of involvement

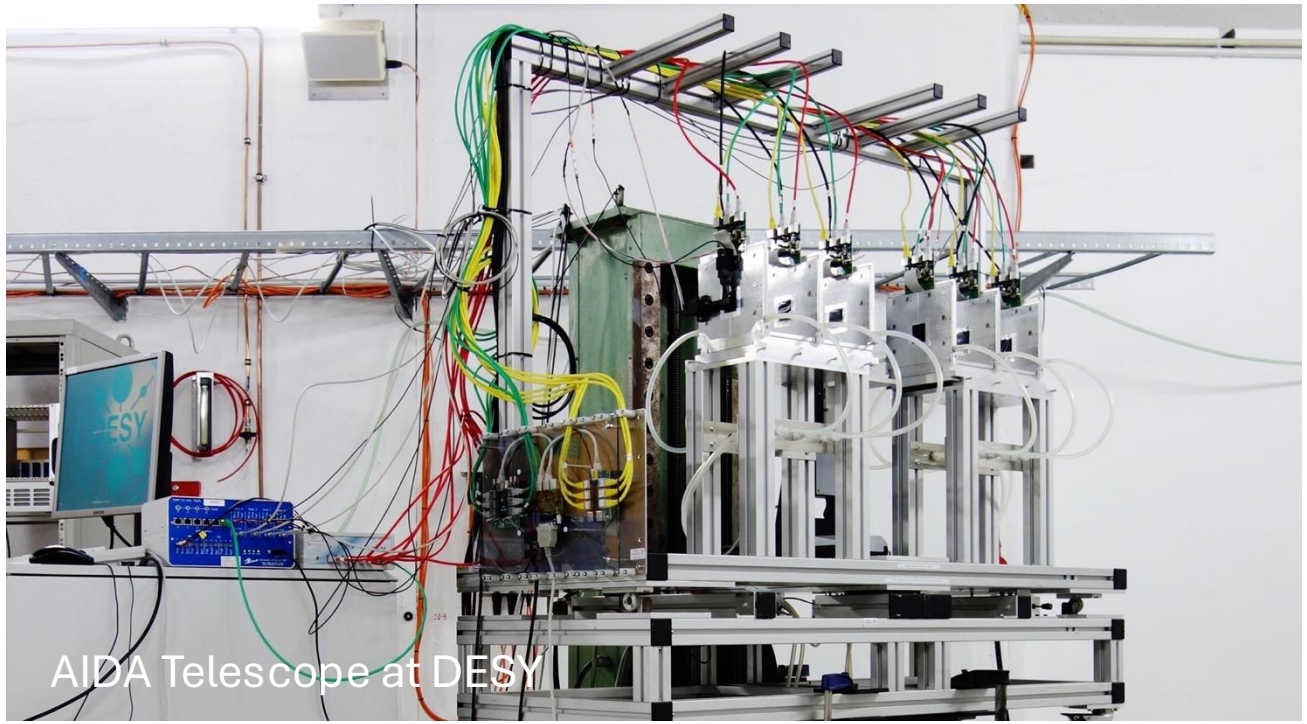
- OBELIX (Tower Semiconductor 180 nm - Vertex): Spatial resolution, large track density, triggering capabilities and radiation hardness
  Belle II Vertex detector – Production chip

- MANTA (TPSCo 65 nm - Trackers): Versatile pixel grouping, power consumption
  Alice 3, CBM, LHCb, FCC, Belle II - R&D

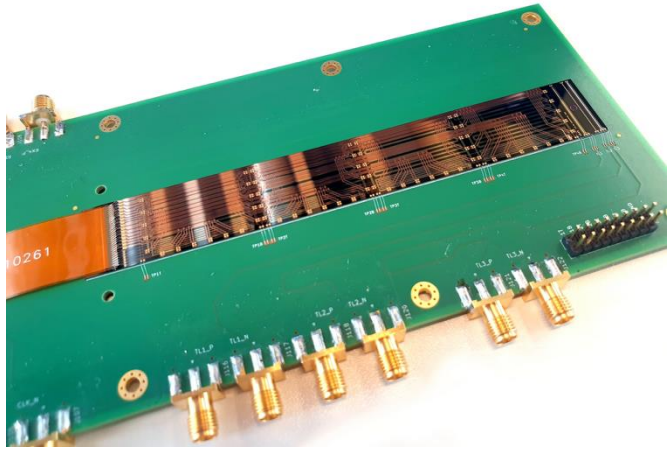
- MONSTERA (LFoundry 150 nm - Tracker): Monolithic CMOS strips
  Belle II Tracker – R&D

OBELIX Telescope

A large area DMAPS particle beam telescope
→ Future vertex detector demonstrator



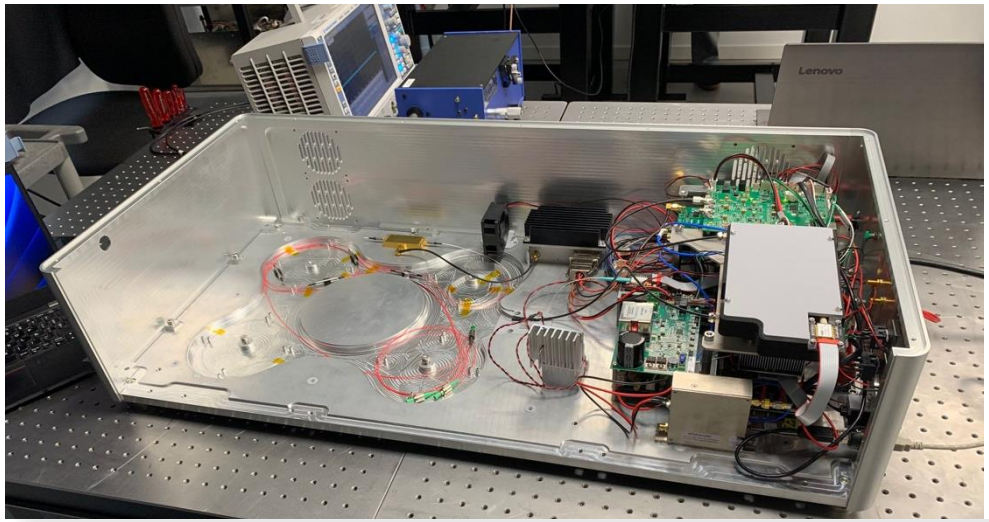
AIDA Telescope at DESY

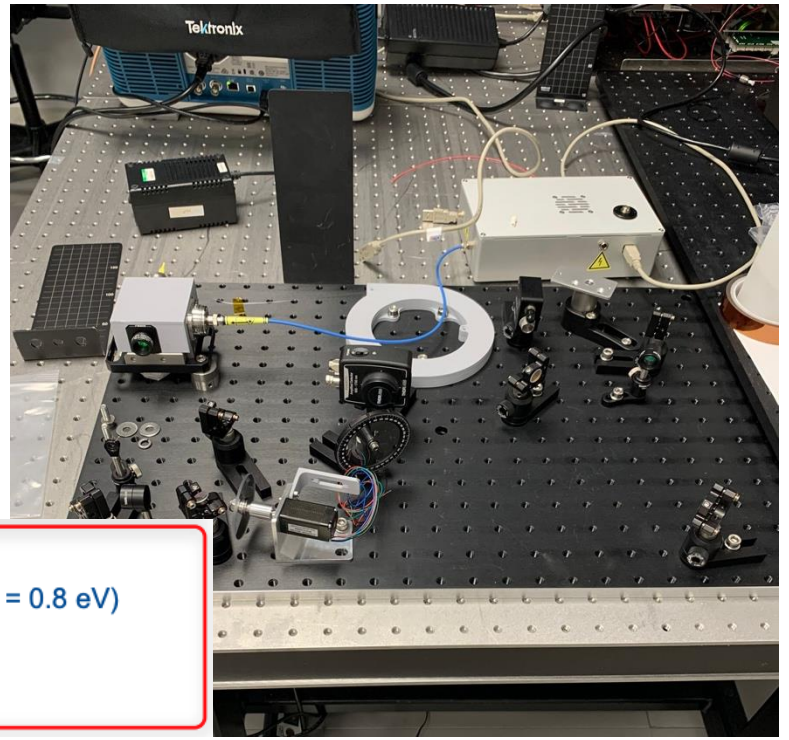


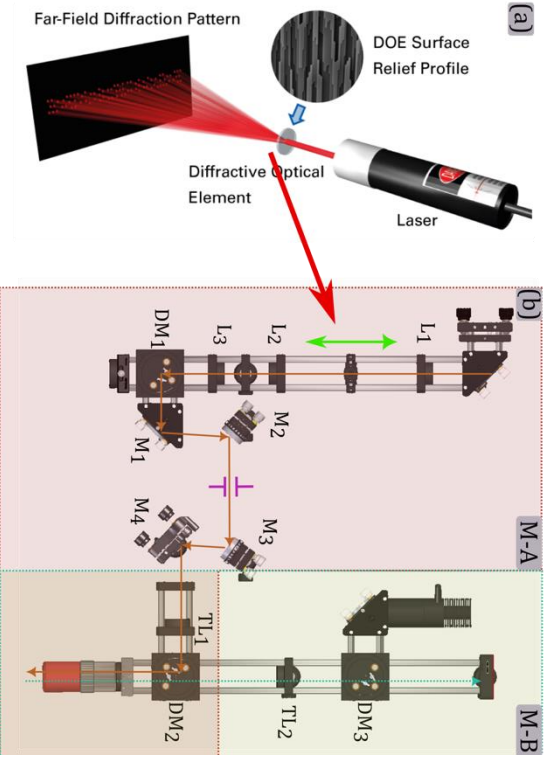
- 6 large area high-resolution detector planes
- DAQ and TRG
- Compact integration
- Software, monitoring, interlocks, …

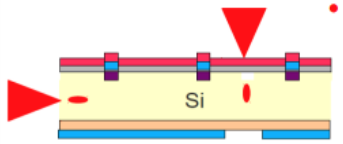
Permanent location at CERN SPS H6 line and new test beam line at KEK. DESY test beam infrastructure for development and commissioning.

TPA-TCT Laser System

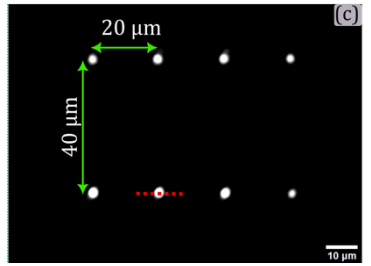








- **TPA-TCT (far infrared)**
  - No single photon absorption in silicon (1550nm = 0.8 eV)
  - 2 photons produce one electron-hole pair
  - Point-like energy deposition in focal point
  - **3D** spatial resolution (**1.5 x 1.5 x 15 μm³**)



TPA-TCT: Two Photon Absorption – Transient Current Technique

Pulsed laser induced signal by generation of charge carriers inside DUT (not only Si)

Conduction over optical fiber

Multi-point array via diffractive pattern

→ Joint venture with our industrial partner FYLA Lasers, UJI and IFCA

Roadmap

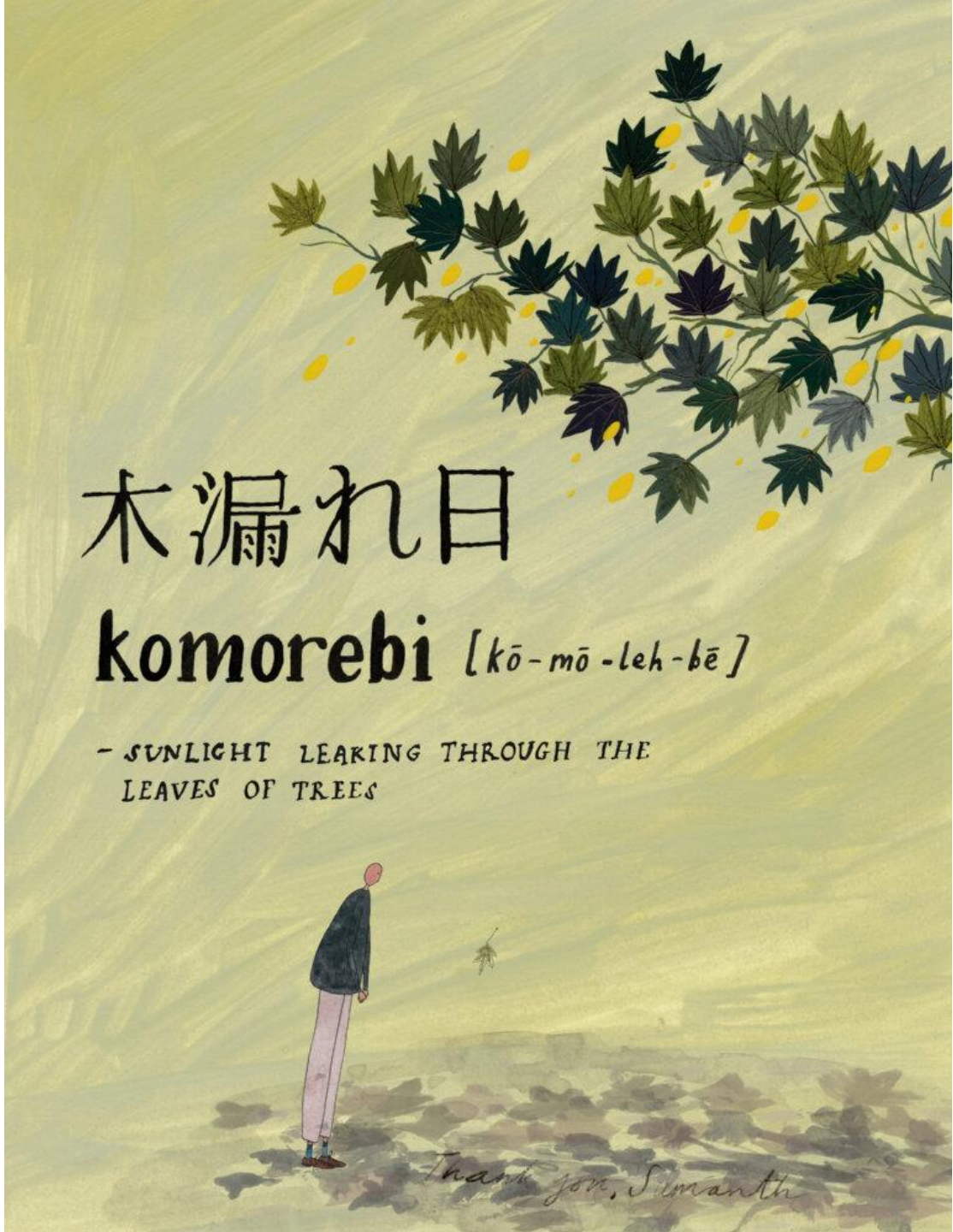
- December 2021: ECFA detector R&D road map documents
- June 2022: Formation of the DRD3 proposal teams
- March 2023: Scientific preparatory meeting
- December 2023: Provisional approval
- January 2024: Formation of CB
- March 2024: Election of SP
- April 2024: Formation of WGs

- June 2024: **Approval** Scientific Proposal – First DRD3 Week

- October 2024: Approval DRD3 Rules
- December 2024: Second DRD3 Week
- February 2025: First DRDC Review
- June 2025: Third DRD3 Week
- November 2025: Fourth DRD3 Week

- December 2025: Finalization of MoU (!?)

cmarinas@ific.uv.es



MoU Preparation

Very confusing procedure. So far, only ‘General Rules’ apply.

Core MoU almost ready.

Annexes still under discussion: Unclear models and level of commitments by Funding Agencies

CSIC should sign the MoU but the Team Leader needs to be the Funding Agency representative **(!)**

2000 CHF/y Common Funds per Institution

Summary

DRD3 is a large fully functional collaboration with MoU in the last preparation phases

IFIC's contribution spans over several DRD3 working groups, and in synergy with DRD7 and DRD8

Our R&D has the Higgs factory in sight, with Belle II upgrade efforts as intermediate steppingstone

Work coordinated with the major Spanish solid state stakeholders

We need to put together the complete list of IFIC's researchers to join the Collaboration (DRD3+CNID)

Signing MoU and securing funding is still an issue

DRD3 TCT School

We already profited from WG8 activities

TCT School organized at CERN in September 2025: https://indico.cern.ch/event/1565703/

D. Galacho participated with CNID's grant

One Final Note

CNID: CPAN Network on Instrumentation and Detectors aims to bring together the Spanish scientific community within the CPAN consortium to jointly explore the current state and future prospects of R&D in the field of detectors and instruments.

The CNID will act as a discussion forum to streamline the Spanish contribution to the different existing international collaborations in detector R&D among the different CPAN communities, in particular, the DRD collaborations.

→ In summary, a bit like a National expanded DRD3 effort. Large overlaps do exist.

Thanks

TCT: Transient Current Technique

TCT: Pulsed laser induced signal by generation of charge carriers inside DUT (not only Si)

- Study of electric field inside the sensor, charge collection efficiency, homogeneity, gain, …
- Benchmark simulation tools (eg signal formation)
- Measure physical parameters (eg mobility)