WP4
Upgrade of Irradiation and Characterization Facilities

Fernando Arteche (ITAINNOVA), **Federico Ravotti** (CERN)

AIDAinnova Final Meeting - Plenary Session, Prague (Czech Republic), May 8th, 2025

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

Outline

- Introduction to WP4
  - Goal, Structure, Partners, Summary of MS & D, etc.
- WP4 Parallel Session Summary
  - Task-by-task review (focusing on achievements)
- Highlights & Achievements
- Conclusion

WP4 Goal

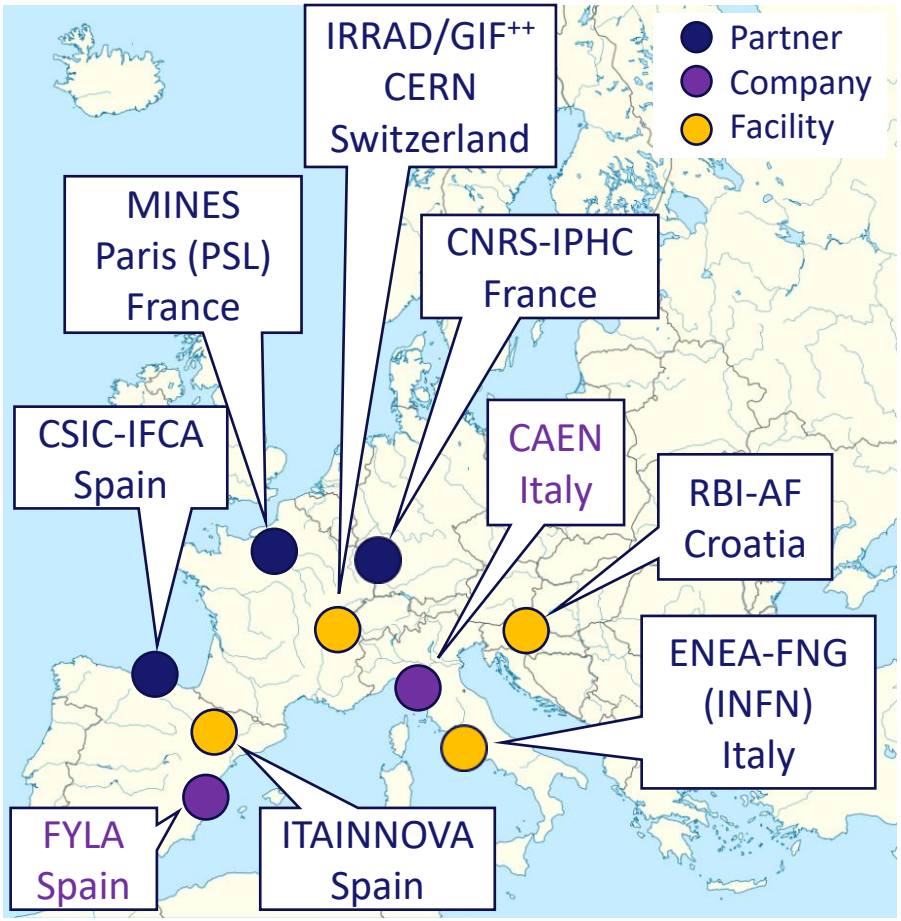
- **Irradiation and characterization tests** required for the R&D on next generation of particle detectors **demand more accurate and reliable procedures**, as well as a **higher efficiency in their execution**

- The main goal of WP4 is to ***develop & standardize common tools for testing to ensure the readiness of the detector support infrastructure for high TRL levels*:**
  - Improve facilities, systems and methods

- The activities are covered by different partners:
  - Academia
  - Industry
  - Research and Technology Organizations (RTOs)

WP4 Structure & Partners

- **Task 4.1:** Task Coordination
  (CERN, ITAINNOVA)
- **Task 4.2:** Micro-beam Upgrade at RBI Accelerator Facility
  (RBI)
- **Task 4.3:** Common Tools for Irradiation Facilities QC: Data Management, Traceability, Dosimetry and Activation Measurements
  (CERN, *MINES*(*), INFN, *ENEA*(*), CAEN)
- **Task 4.4:** Design & Development of a New Sensor Characterization System based on TPA-TCT Technique
  (CERN, CSIC-IFCA, FYLA)
- **Task 4.5:** Design & Development of a New Electronics Characterization System for EMC Control
  (ITAINNOVA(+), CNRS-IPHC)



(*) *Collaborating Institute*
(+) RTO

WP4 Milestones

Milestone or Deliverable	Description	Lead Beneficiary	Month
Task 2	Micro-beam upgrade at RBI accelerator facility (RBI-AF)		
MS12	Upgrade RBI-AF infrastructure for detector characterisation, SEE, micro hardness testing	RBI	M23
D4.1	Integrate the data acquisition and control system at RBI-AF	**RBI**	M40
Task 3	Common tools for irradiation facilities Quality Control: Data Management (DM), Traceability, Dosimetry and Activation measurements		
MS13	Define requirements, global architecture and design the extended DM system for ENEA-FNG and CERN-GIF++	CERN	M18
MS14	Extend IDM for FNG, GIF++ and communication with CAEN DigiWaste and CANBERRA Apex-Gamma Platforms	CERN	M36
MS15	Test RFID tagging for irradiation facilities	INFN	M42
D4.2	Evaluate Non-Ionizing Energy Loss (NIEL) of irradiation facilities with dedicated dosimeter structures	**CERN**	M42
D4.3	Deploy full prototype for irradiation facilities data management with sample tagging and spectrometry features	**CAEN**	M45
Task 4	Design & Development of a new sensor characterization system based on TPA-TCT technique		
MS16	Commission a complete TPA-TCT system	FYLA	M23
D4.4	Support the implementation of TPA-TCT systems and contribute to the evaluation of new sensors technologies	**CERN**	M46
Task 5	EMC Characterization		
MS17	Apply TF test bench to FEE prototypes	ITAINNOVA	M23
D4.5	Develop a conductive noise test bench for irradiation facilities	**ITAINNOVA**	M44

- **6 Milestones** (MS): M18 – M42
  - **all achieved** (last one, MS15 in Sep. 2024)

WP4 Deliverables

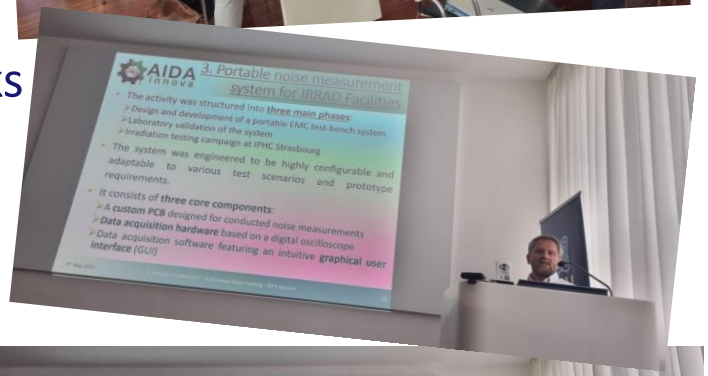
Milestone or Deliverable	Description	Lead Beneficiary	Month
Task 2	Micro-beam upgrade at RBI accelerator facility (RBI-AF)		
MS12	Upgrade RBI-AF infrastructure for detector characterisation, SEE, micro hardness testing	RBI	M23
D4.1	Integrate the data acquisition and control system at RBI-AF	RBI	M40
Task 3	Common tools for irradiation facilities Quality Control: Data Management (DM), Traceability, Dosimetry and Activation measurements		
MS13	Define requirements, global architecture and design the extended DM system for ENEA-FNG and CERN-GIF++	CERN	M18
MS14	Extend IDM for FNG, GIF++ and communication with CAEN DigiWaste and CANBERRA Apex-Gamma Platforms	CERN	M36
MS15	Test RFID tagging for irradiation facilities	INFN	M42
D4.2	Evaluate Non-Ionizing Energy Loss (NIEL) of irradiation facilities with dedicated dosimeter structures	CERN	M42
D4.3	Deploy full prototype for irradiation facilities data management with sample tagging and spectrometry features	CAEN	M45
Task 4	Design & Development of a new sensor characterization system based on TPA-TCT technique		
MS16	Commission a complete TPA-TCT system	FYLA	M23
D4.4	Support the implementation of TPA-TCT systems and contribute to the evaluation of new sensors technologies	CERN	M46
Task 5	EMC Characterization		
MS17	Apply TF test bench to FEE prototypes	ITAINNOVA	M23
D4.5	Develop a conductive noise test bench for irradiation facilities	ITAINNOVA	M44

- **5 Deliverables** (D): M40 – M46
  - **D4.1 achieved** in M40 (Jul. 24)
  - **D4.2:** M42 (Sep. 24), **postponed to M45** (Dec. 24) → **M52** (Jul. 25) [**draft report exists**]
  - **D4.3:** M45 (Dec. 24), **extended to M52** (Jul. 25)
  - **D4.4:** M46 (Jan. 25), **achieved** in M48 (Mar. 25) [**report submitted**]
  - **D4.5:** M44 (Nov. 24), **postponed to M51** (Jun. 25) but **already achieved** [**report submitted**]

Task 4.1: WP Coordination

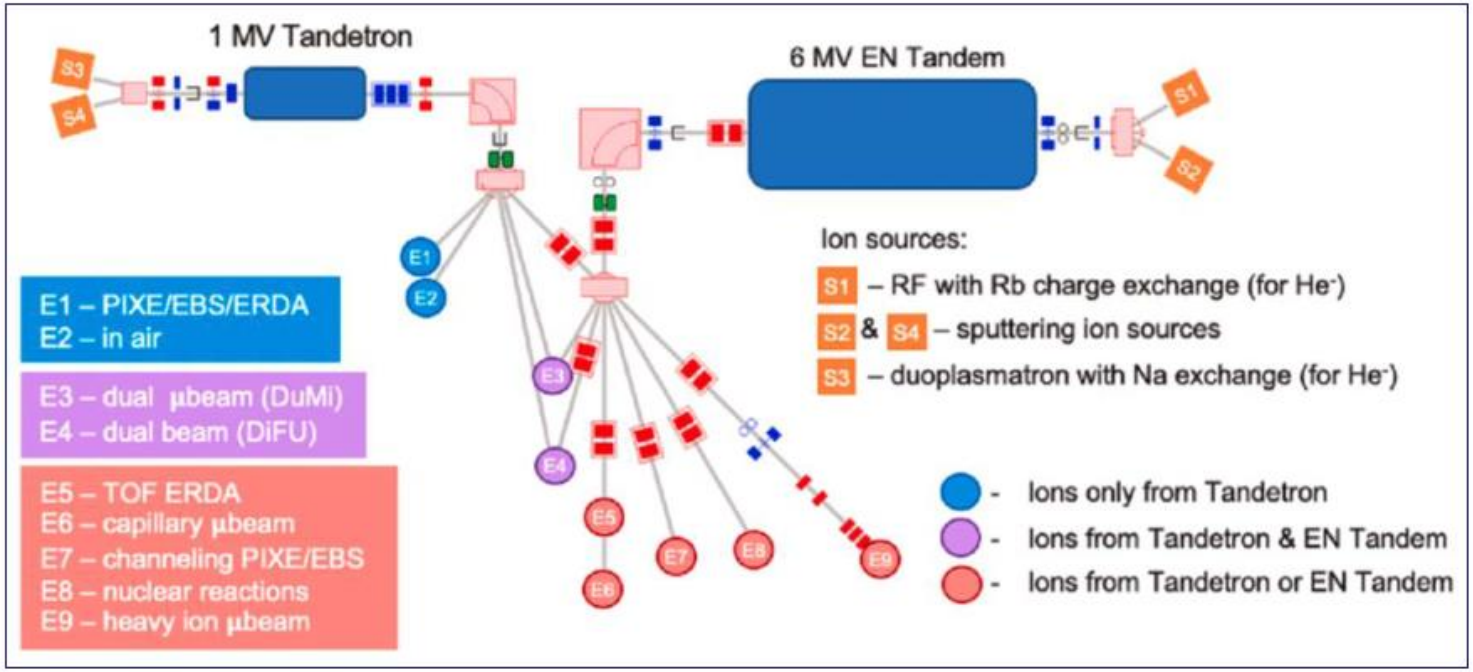
- **16 publication records** for WP4 in Zenodo
  - **9 other than MS/D reports** (articles, etc.)
  - + (at least) 2 in the pipeline
- Monday afternoon WP4 session:
  - **16 participants** at maximum (+ 6 via Zoom)
  - review of (basically all already completed) tasks

	WP4.1: Introduction by WP Coordination Slovanka Dvorak hall, FZU	Federico Ravotti et al. 14:30 - 14:40	
	WP4.3 - Common Tools for Facilities QC: Data Management, Traceability & Activation Meas. Slovanka Dvorak hall, FZU	Dr Ferdinando Giordano 14:40 - 15:00	W4.3 – Obj. 1/2
zoom	WP4.3 - Common Tools for Facilities QC: Dosimetry (NIEL project) Slovanka Dvorak hall, FZU	Michael Moll 15:00 - 15:10	W4.3 – Obj. 3
zoom	WP4.4 - Design & Development of a New Sensor Characterization System based on TPA-TCT Technique Slovanka Dvorak hall, FZU	Michael Moll 15:10 - 15:40	
	Coffee break Bar 1st floor	15:40 - 16:20	
	WP4.2: Micro-beam Upgrade at RBI Accelerator Facility Slovanka Dvorak hall, FZU	Georgios Provatas et al. 16:20 - 16:50	
	WP4.5 - Design & Development of a New Characterization System for EMC Control Slovanka Dvorak hall, FZU	Fernando Jose Arteche Gonzalez 16:50 - 17:20	
	WP4 - Session Wrap-up Slovanka Dvorak hall, FZU	Federico Ravotti et al. 17:20 - 17:25	



Task 4.2: Micro-beam upgrade at RBI accelerator facility

The RBI-AF: Laboratory For Ion Beam Interactions

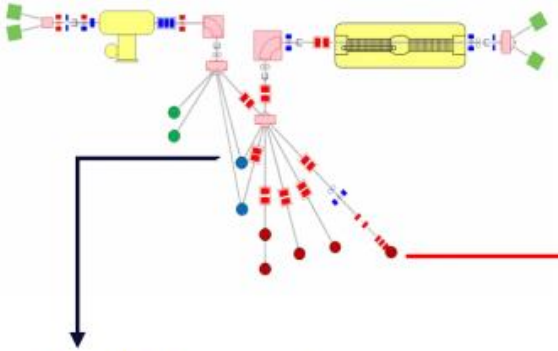


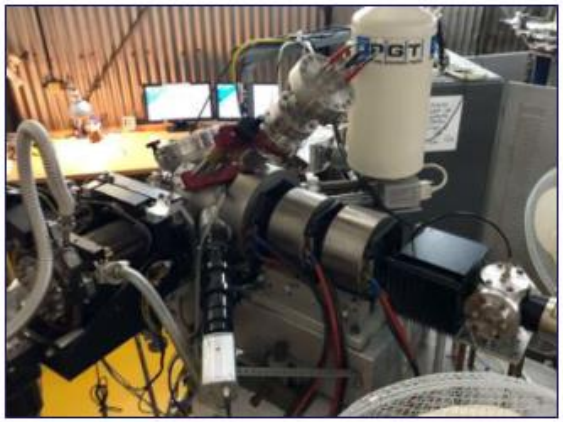
CERIC
Central European Research Infrastructure Consortium

ReMade @ ARI

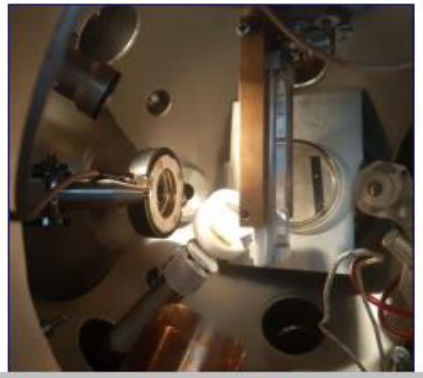
EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

Task 4.2: Micro-beam upgrade at RBI accelerator facility





The RBI microprobe



Dual Microprobe

Upgrades during AIDAinnova

- Beam spots down to 120 nm
- Precise irradiations from low (few Hz) to high current (nA) modes.
- Scanning and imaging possibilities of areas up to several cm.
- In-house DAQ Software SPECTOR.
- Target positioning using nm precise piezo-stages.
- Alignment of samples for angular resolved studies/channeling.
- Available temperatures from <40K up to 1000 K
- Probing and damaging using two simultaneous microbeams

Upgrades achieved early in the project (M40)

Task 4.2: Dual Micro-beam Upgrade Example

Task 4.2: Micro beam upgrade at RBI accelerator facility

- Upgrade the two existing ion micro-beam end stations
  - Upgrade of microprobes with precise target positioning systems
  - Sample cooling option for the old microprobe

Present target positioning in DuMi

Bigger small piezo-stage:

Travel range: 100x100x50 mm ✓

Payload: 5 N

Resolution: 1 nm ✓

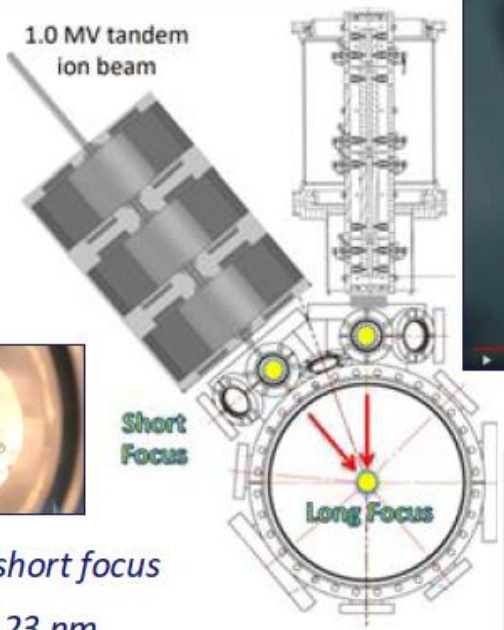
In 2021 target positioning

With small piezo-stage:

Travel range 10x10x5 mm

Used now in short focus

Beam spots 123 nm



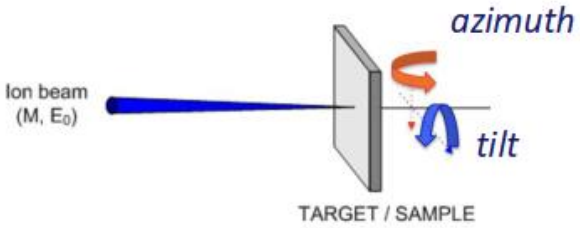
Developed StepMotion software incorporated in SPECTOR ✓

Task 4.2: Dual Micro-beam Upgrade Example

Task 4.2: Micro beam upgrade at RBI accelerator facility

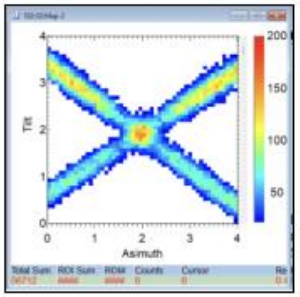
- Upgrade the two existing ion micro-beam end stations
  - Upgrade of microprobes with precise target positioning systems
  - Sample cooling option for the old microprobe

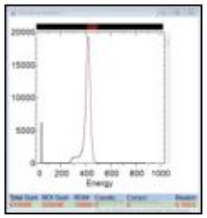
Addition of 2 axis rotation piezo-stage

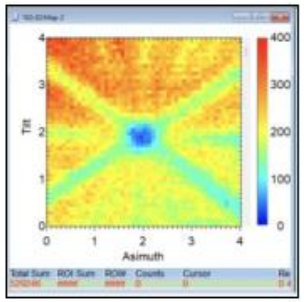


Ion Beam Induced Charge (IBIC) microscopy for detector testing and characterization

Development of Channeling-IBIC technique (G. Provatas – RBI)





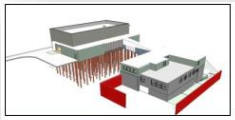


Diamond membrane detector alignment in channeling mode. In the basis of pulse height. Less than 10^6 ions are enough to align the crystal to the beam axis. ***Non-destructive channeling.***

Task 4.2: Achievements

Upgrades performed within AIDAinnova **significantly improved testing capabilities** at RBI-AF:

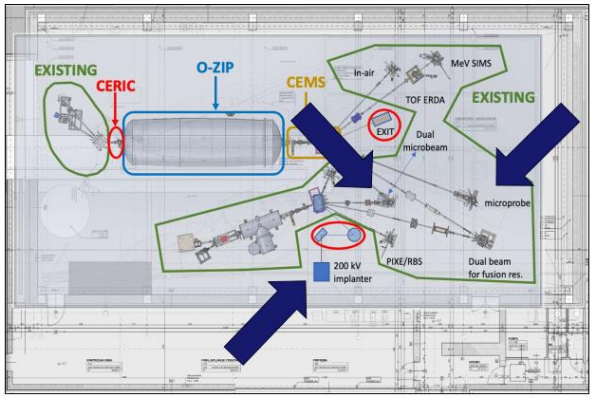
- **Time for** sample **precise positioning** and micro-analyses on areas of interest is **significantly decreased**;
- IBIC **maps of detectors larger than the max beam scan size** (10x bigger range) can now be easily obtained;
- **Precise irradiations** can be carried out at well defined detectors positions (ex. nanowires-probing was not possible before!, etc.);
- Patterning on position sensitive detectors;
- IBIC **cryogenic studies down to <40k** (recently also down to 9k!)



Moving to the new site starts in Summer 2025!

New 5MV tandem accelerator.

The future of RBI microprobes



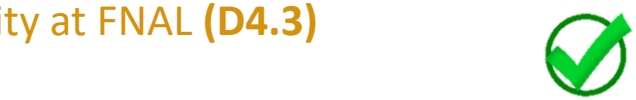
New possibilities in the new laboratory:

- *New highest energy 10 MeV for protons. Deeper penetration up to ~mm in Silicon*
- *In air beam spots of 1um will be achieved.*
- *Collimated microbeams obtained from the 200 kV implanter. IBIC with 50 keV ions*

Task 4.3: Common Tools for Irradiation Facilities QC: Data Management, Traceability, Dosimetry, Activation Measurements

- **Objective 1** - *Generalization of the IRRAD Data Manager* (IDM) including new facilities & improving data sharing:
  - Define requirements and architecture **(MS13)**
  - Extend IDM to new facilities and enable data exchange with traceability & spectrometry systems **(MS14)**

- **Objective 2** - *Development of an integrated system prototype for induced activation & traceability* data management:
  - Test various types of RFID tags **(MS15)**
  - Deploy a full prototype of data management system at the new ITA facility at FNAL **(D4.3)**



- **Objective 3** - *Produce a common NIEL dosimetry* calibration set for facilities cross-comparison:
  - Evaluate the NIEL of irradiation facilities with dedicated dosimeter structures **(D4.2)**

CERN IRRAD Proton Facility GIF++

Detector development, irradiation, characterization (CH)

FRASCATI NEUTRON GENERATOR

INFN Istituto Nazionale di Fisica Nucleare

Irradiation/testing of electronics (IT)

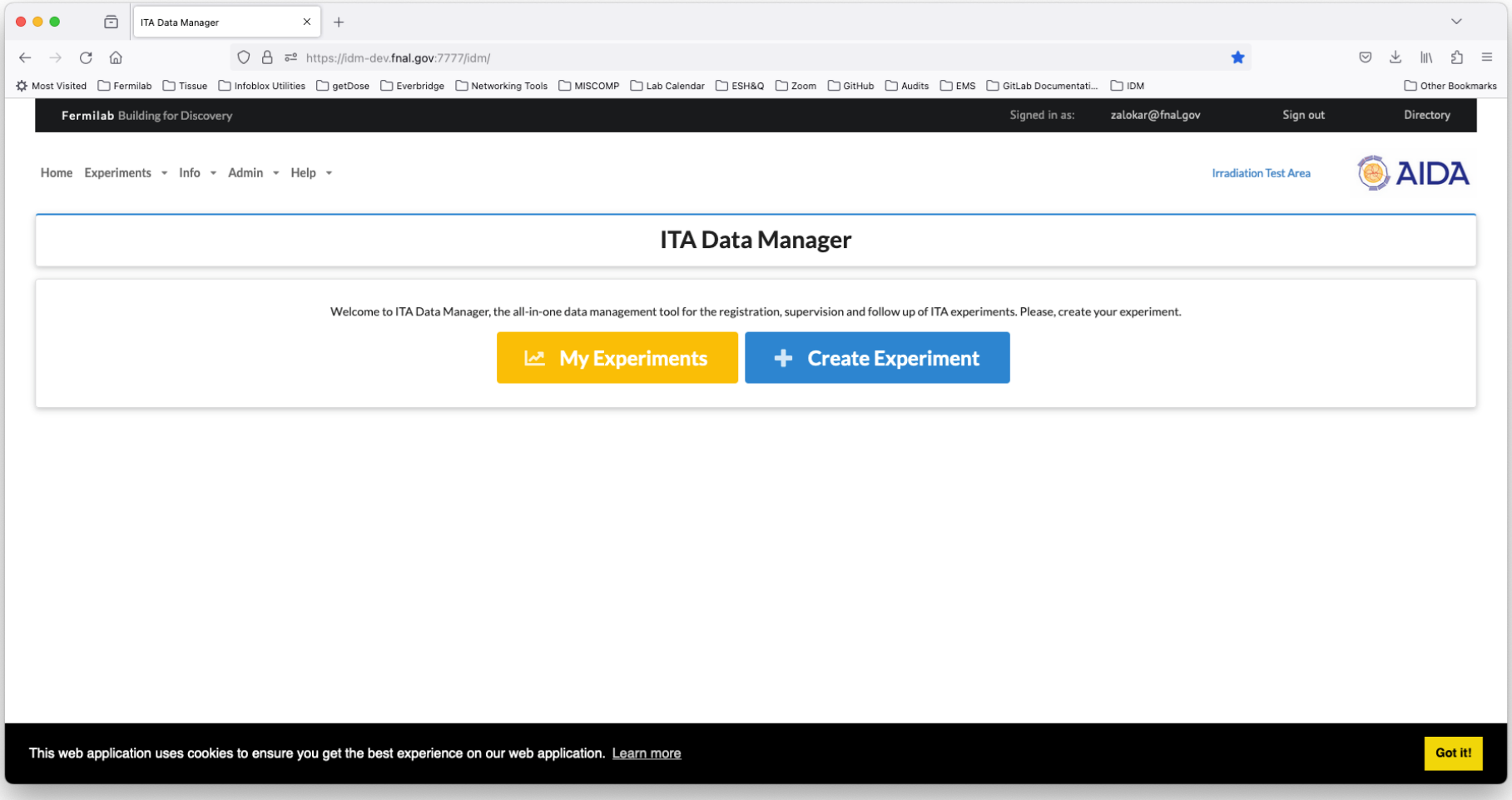
CAEN SyS

Electronic Instrumentation for Nuclear and PP (IT)

MINES ParisTech PSL

Data management SW, ontologies and ML (FR)

Task 4.3-1: Data Manager (DM) Extension for New Facilities

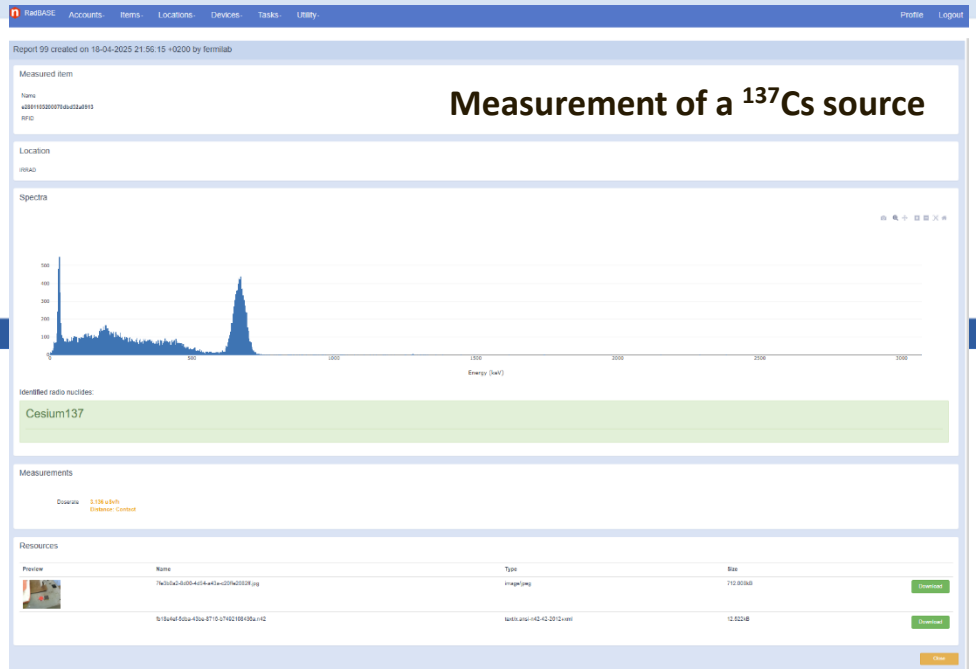


- Successful **deployment of an instance of IDM also at FNAL** (new testing facility)

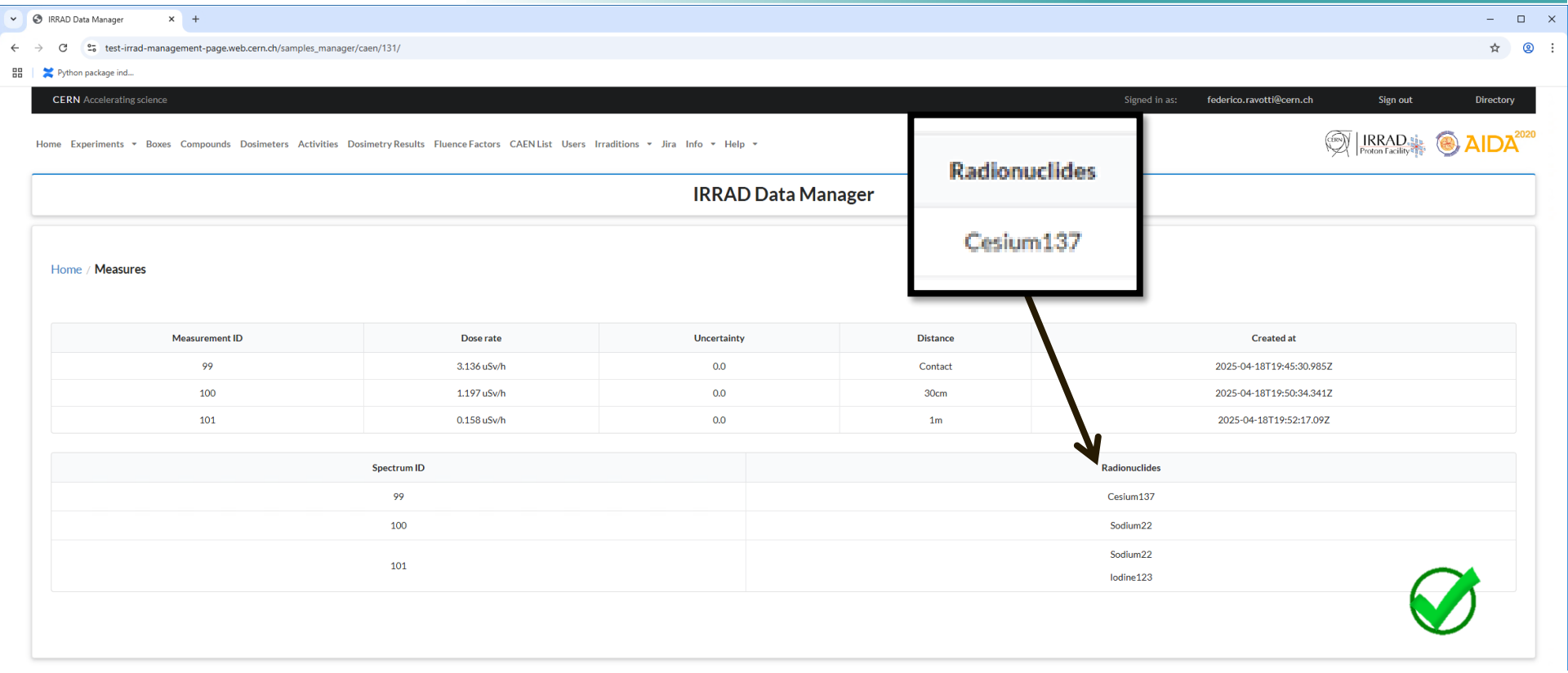
Task 4.3-2: Induced Activation & Traceability Management in IDM

- CAEN **RadHAND** device delivered and being tested at FNAL
- **RadBASE interface** configured with new location
- Several **DB items created** by the FNAL colleagues recently

List of locations



Task 4.3-2: Induced Activation & Traceability Management in IDM

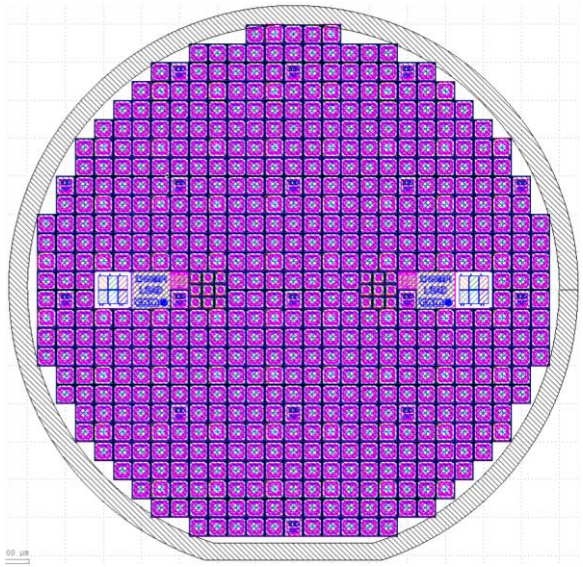


- RadHAND measurements at FNAL **successfully synchronized with IDM application!**
- We continue collaborating with FNAL to **further validate our platform**: testing is scheduled to conclude in the coming weeks, to **ensure the timely submission of the D4.3 report** (June 2025).

Task 4.3-3: Dosimetry cross-comparison (NIEL calibration set)

- **NIEL sensors:**
  - Produce a set of identical pin sensors that will be used to:
    - **(a) study more profoundly the NIEL Hypothesis in dependence of particle type / energy**
      - Measurement of damage parameters: Diode (leakage, depletion) & material (defect spectroscopy)
    - **(b) inter-compare radiation facilities in terms of their 'hardness factors'**
      - Measurement of leakage current after exposure and specified annealing [alpha-value]

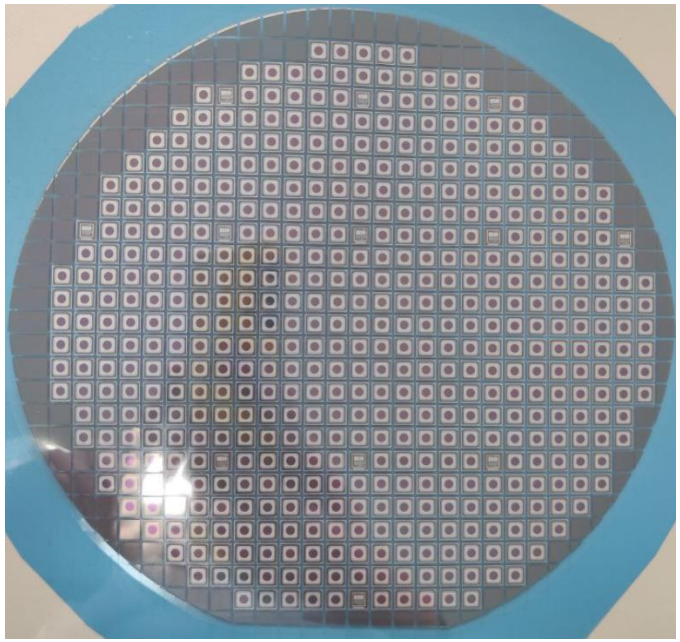
- **A set of Silicon Sensors (n-in-p) has been produced at CNM, Barcelona:**



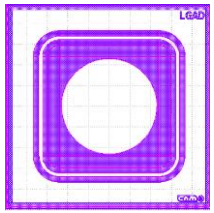
- Cost effective production:
  - use of existing mask set with one new mask
  - simple design: 8 mask levels (150 mm wafer)
- 536 devices of 3.3x3.3 mm^2 per wafer
- 10 wafers ordered (2 broken during production)
  - 1.5 wafers will go to Ljubljana reactor
  - 1.5 wafers will go to CERN IRRAD
  - 5 wafers for in-depth NIEL studies
- **Status:** production finished in early 2025
  - Wafers at CERN for testing before distribution

Task 4.3-3: Dosimetry cross-comparison (NIEL calibration set)

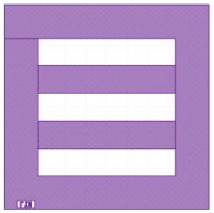
- **Sensor characterization**



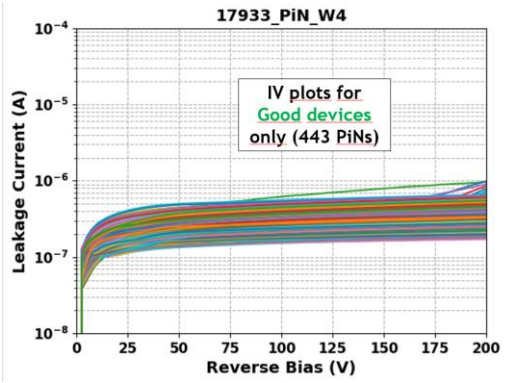
- Foto of frontside of the wafer (150 mm)



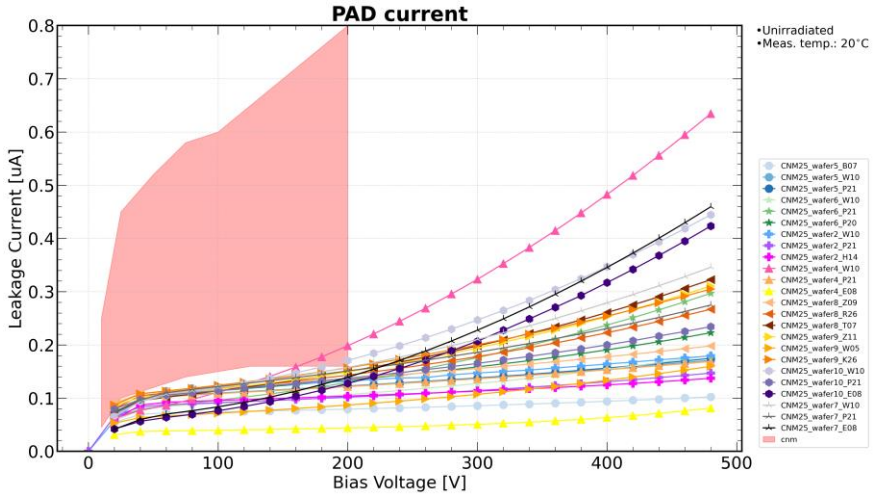
frontside



backside



- Leakage current as measured on wafer 4 at CNM



- Measurement after dicing at CERN shows lower current when guard ring connected to ground
- **Sensors can be used as dosimeters (NIEL measurement)**

Task 4.3-3: Dosimetry cross-comparison (NIEL calibration set)

- Task achievements:
  - Geant4 and FLUKA simulations for NIEL curves successfully reproduced and algorithm for identifying clustered vs point defect damage implemented
  - **Benchmarking** simulations with measurements data **is ongoing and will continue** beyond AIDAinnova also **using this calibration set**

V. Subert PhD Thesis (synergy with EP-RD)

- Deliverable D4.2:
  - Deliverable date was postponed from M42 to M52 due to delayed sensor production
  - Cost effective solution for production of silicon sensors for NIEL measurements was found and **production was completed**; First **measurements confirm that sensors can be used for dosimetry**
  - Distribution of sensors in May/June to irradiation facilities (IRRAD, JSI)
  - **Deliverable report in writing and to be timely submitted**

Task 4.4: TPA-TCT System Development

- **Since 2015:** TPA-TCT measurements performed at laser facility in Bilbao
  - Proof of concept, demonstration of 3D resolution and feasibility to study irradiated sensors
- **2017: CERN KT-fund** approves & funds a project to develop a table-top TPA-TCT system
  - 2017-18: development of specs, discussions with laser experts, market survey, …..

- 03/2018 Call for Tender
- 06/2018 Order to Fyla
- **04/2019** 1st prototype arrived at CERN, installation problem & transport damage
- 07/2019 2nd delivery; installation successful, commissioning, system debugging..
- 10/2019 power cut damages laser, repair
- 12/2019 replacement of components
- 07/2020 power stability issues detected, laser returned to FYLA, upgraded
- **01/2021 new generation prototype delivered to CERN; since then: data taking**

selection of company → FYLA WE LASER THE NEW INDUSTRY

laser development

Fyla LFC1500X

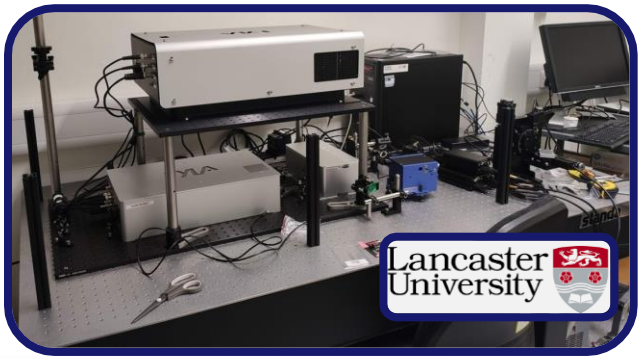
AIDAinnova WP4.4
further improvements & user community
system development & all fiber laser system

Task 4.4: TPA-TCT Systems

TPA-TCT systems have been set up at several institutes

FYLA WE LASER THE NEW INDUSTRY

LFC1500X



The new AIDAinnova TPA-TCT laser (see following slides) has been distributed as well

FYLA WE LASER THE NEW INDUSTRY

Pulsar

UNIVERSITY OF OXFORD

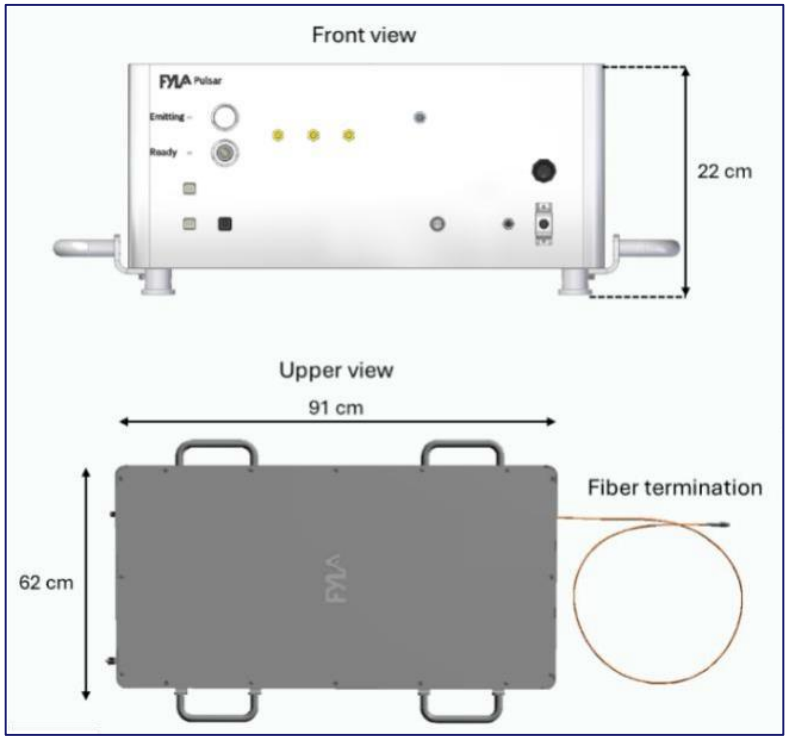
Task 4.4: TPA-TCT New System PULSAR (Laser Improvement)

Status 2025

- **The new "Pulsar" laser system is commercially available at Fyla**
  - The system **fully integrates** the laser pulse source (LPS), the pulse management module (LPM) and the dispersion compensation module (D-scan) **in a single box** component
  - The system presents **better robustness and stability in optical and temporal properties** compared to the previous laser system.
  - It provides **beam delivery through several meter of hollow core optical fibres** (Kagome fibres) preserving the pulse shape during propagation.
  - The coupling efficiency into the fibre is ~70%.

"Pulsar" system specifications

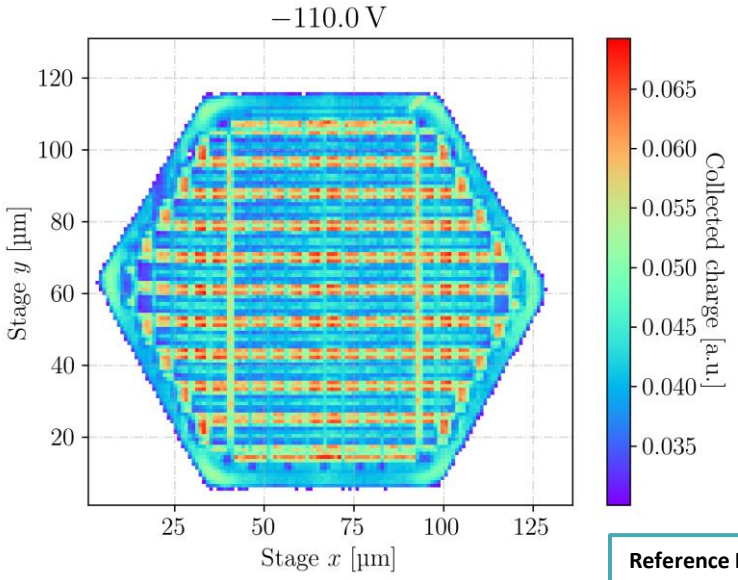
- **LPS:** Laser Pulse Source
  - All-fiber CPA femtosecond pulses generation
  - Pulse rep rate selection. **1 Hz to 10 MHz**
- **LPM**: Laser Pulse Management module
  - Pulse energy modulation: **10pJ to 10nJ**
  - Synchronized shutter, **rise/fall time < 1µs**
- **D-SCAN:** Dispersion scanning
  - Pulse duration tuning: **300fs to 600fs**
  - Pulse temporal properties characterization



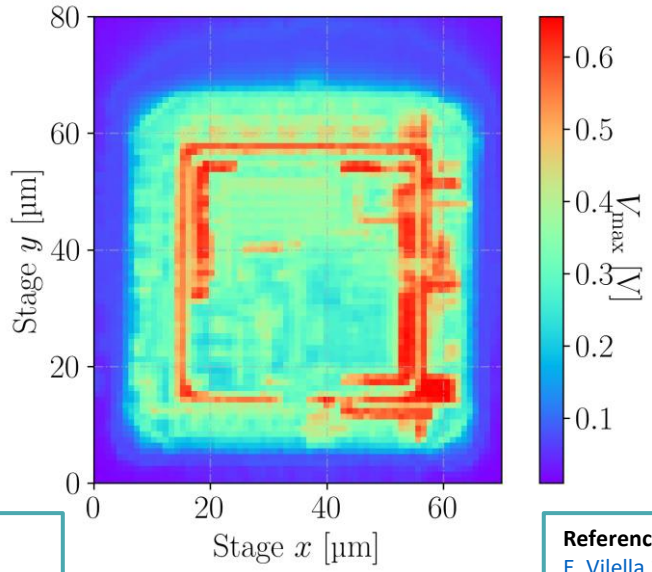
Pulsar laser system

Task 4.4: TPA-TCT Community

- Several **measurement technique improvements & application examples presented**
  - Many tests performed for the community with the available test-benches!
- The **examples below** show the probing of the top side metals of monolithic detectors. Regions with metal have an increased charge collection due to reflection:
  - Features in the µm scale are well resolved (~60 x 60µm pixels)!



Reference PicoAD:
M. Milanesio et al. 2023
R.Cardella et al. 2022



Reference MPW2:
E. Vilella 2022

Task 4.4: TPA-TCT School

- **THE FIRST DRD3 AND AIDAINNOVA TCT SCHOOL** [web-site]
  - **Participants**:
    - 12 lecturers, tutors, organizers
    - 18 participants (selected out of >50 applications)
      - *….from 13 different countries*
  - Hands-on training
    - 6 groups of 3 students worked hands-on guided by tutors on different laser-setups

photos available on CERN CDS: http://cds.cern.ch/record/2925863

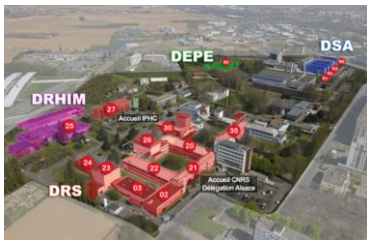
Task 4.4: TPA-TCT Achievements

- **TPA-TCT technology:**
  - **Advancements in methodology, analyses and simulation**; documented in publications and **MS16 and D4.4 report already achieved**
  - Wide range of **use-cases demonstrates the usefulness of this new-technology**
  - Extension towards other than silicon devices (SiC, Diamond, …)
- **Laser system development:**
  - **New, more compact and stable, "Pulsar" laser** commercially available
- **User community:**
  - **TPA-TCT lasers delivered by Fyla:** "LFC1500X" at CERN, IFCA (ES), JSI Ljubljana (SI), NIKHEF (NL), Lancaster (UK); "Pulsar" at Oxford (UK); Support provided for setting up systems at the institutes
  - Established a **school on TCT** that will be continued in framework of DRD3 collaboration
- **Outlook:**
  - TPA-TCT common effort presented as example for collaborative efforts for new R&D collaboration (DRD3) in ECFA Detector R&D roadmap implementation plan.
  - Consortium will continue work on the technology (if possible, in the framework of follow-up EU-project)

Task 4.5: Design & development of a new characterization system for EMC control

- **Goal:** upgrade Electromagnetic Compatibility (EMC) tests in order to improve the support for detector electronics designers.
  - Noise studies were greatly demanded on previous AIDA 2020 project
- **Activities:**
  - Design and develop an automatic EMC test bench to measure the noise transfer functions (TF) of physics detectors.
  - Design and develop a portable test bench to perform in-situ EMC conducted emission measurements of power units in irradiation facilities.
- **Innovative Approach:**
  - Introducing unique systems for measuring detector Transfer Functions (TF) against electromagnetic noise and a novel portable test bench for on-site noise emission assessments of DC-DC converters and small power units

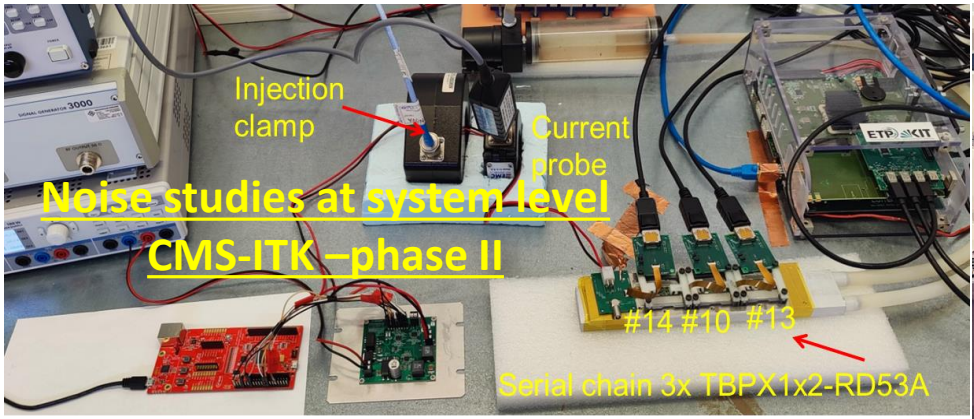
ITAINNOVA
INSTITUTO TECNOLÓGICO DE ARAGÓN

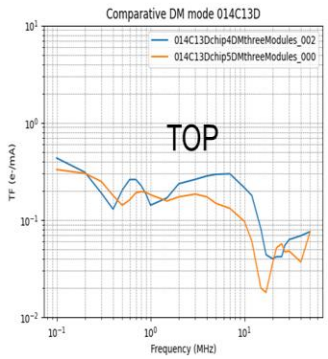


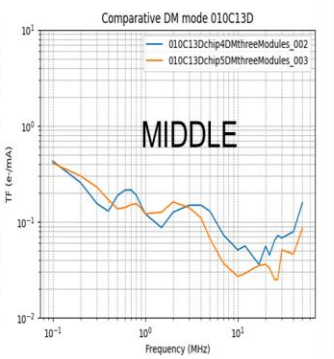
IPHC
Institut Pluridisciplinaire Hubert CURIEN
STRASBOURG

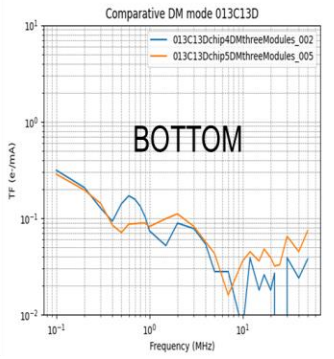
Task 4.5.1: Automatic noise TF measurement system

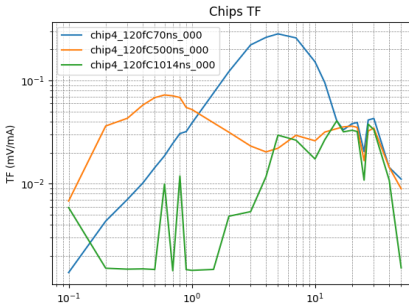
- This activity is completed
  - **MS17 completed & submitted**
- The system is being used regularly today – EUROLABs project

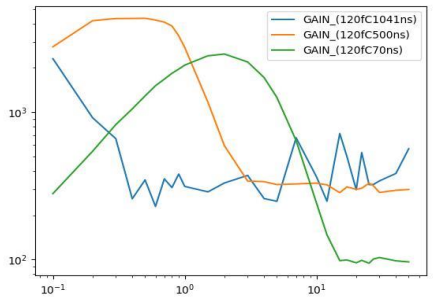






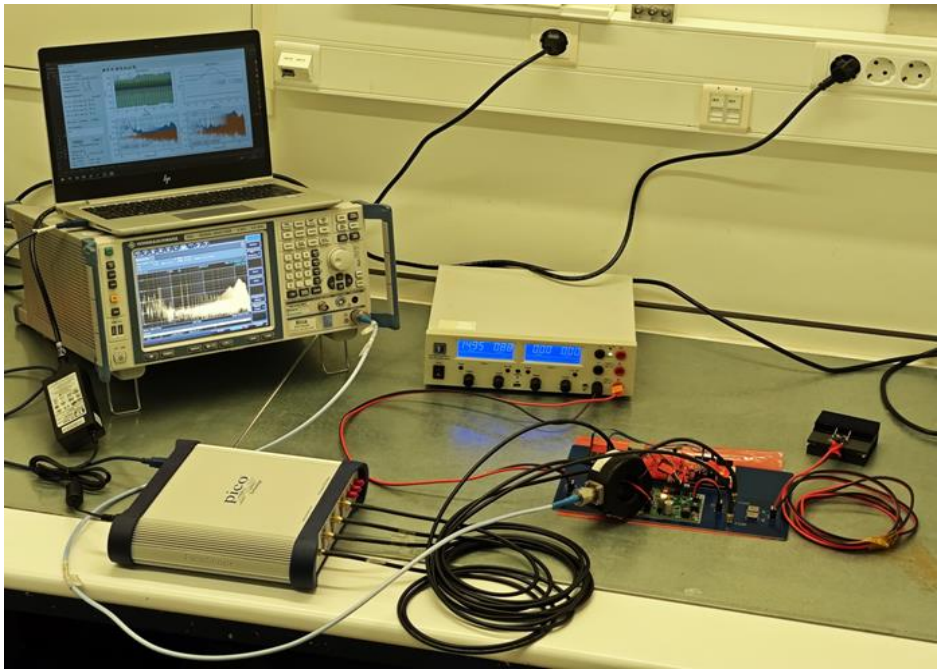






Task.4.5.2 Portable noise measurement system for Facilities

- **Final validation** took place during a **radiation campaign at IPHC-CNRS in Strasbourg**.
- The test aimed to verify system performance, robustness, and stability under real irradiation conditions.



- A GaN-based DC-DC current source, developed by ITAINNOVA, was used as the device under test (DUT).
- The system successfully captured real-time conducted noise emissions from the DUT during irradiation.

Task 4.5: Design & development of a new characterization system for EMC control

- **WP4.5 activities** have been **completed**
  - New **TF measurement system** for particle detectors.
  - A **portable test bench** for power supply noise emission measurements.
- **All milestone and deliverable** have been **completed**
  - **MS17 completed and submitted**
  - **D4.5 completed (ahead of schedule!) and under review**
- **Excellent collaboration between IPHC Strasbourg and ITAINNOVA**, with active involvement from both teams in all phases of the project
- **The updates** developed in this project have already been **used** by users **in the EUROLABS** project
- These updates are ready to support DRD activities

Highlights & Achievements

- **Task 4.2:**
  - **Micro-beams upgrade at RBI accelerator facility fully completed**. Variety of application examples showed the testing capabilities of the micro-beams are significantly improved.
- **Task 4.3:**
  - IRRAD Data Manager System **(IDM) extended with new features and for new facilities**; prototype of the **integrated RFID-based system CAEN DigiWaste platform** operational: **deployed at CERN-IRRAD and being validated also at FNAL-ITA** → report M52
  - NIEL calibration set **produced, received at CERN, successfully characterized** and soon being distributed to facilities → report M52
- **Task 4.4:**
  - **Advancements in TCT-TPA methodology, analyses and simulation**. New, more compact and stable, "Pulsar" **laser commercially available**. Several TPA-TCT **lasers delivered** by Fyla. **Support provided** for setting up systems and performing measurements. **Established a school on TCT**.
- **Task 4.5:**
  - **Both new EMC test-benches were developed**. The portable **test-bench for in-situ EMC measurements of power units** in irradiation facilities **is now also validated**. These **upgraded tools are now been regularly used** by users in the EUROLABS project.

Conclusions

- The WP4 goal to **develop & standardize common tools for testing infrastructure** was **reached for all tasks**:
  - **All technical work completed**
  - Project extension was profitable to **fully complete/extend validation & testing**
  - Last two reports (D4.2, D4.3) will be **delivered to meet the extended deadline**
- The **collaboration with industrial partners within WP4** proved to be **key ingredient for success**. **Excellent feedback** received from all participants with companies deeply engaged in task development
- **Implemented updates have already yielded positive results**, **enhancing user testing efficiency**, providing **access to novel data** and **some being regularly used** (also via other access programs)
- **WP4 is completed!** We would like to **thank all WP4 participants**, the **AIDAinnova management** and we already look forward to continue working together in a possible follow-up project!