WP4
Upgrade of Irradiation and Characterization Facilities

Fernando Arteche (ITAINNOVA), Federico Ravotti (CERN)

AIDAinnova 3rd Annual Meeting - Plenary Session, CATANIA (Italy), 20th March 2024

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

Outline

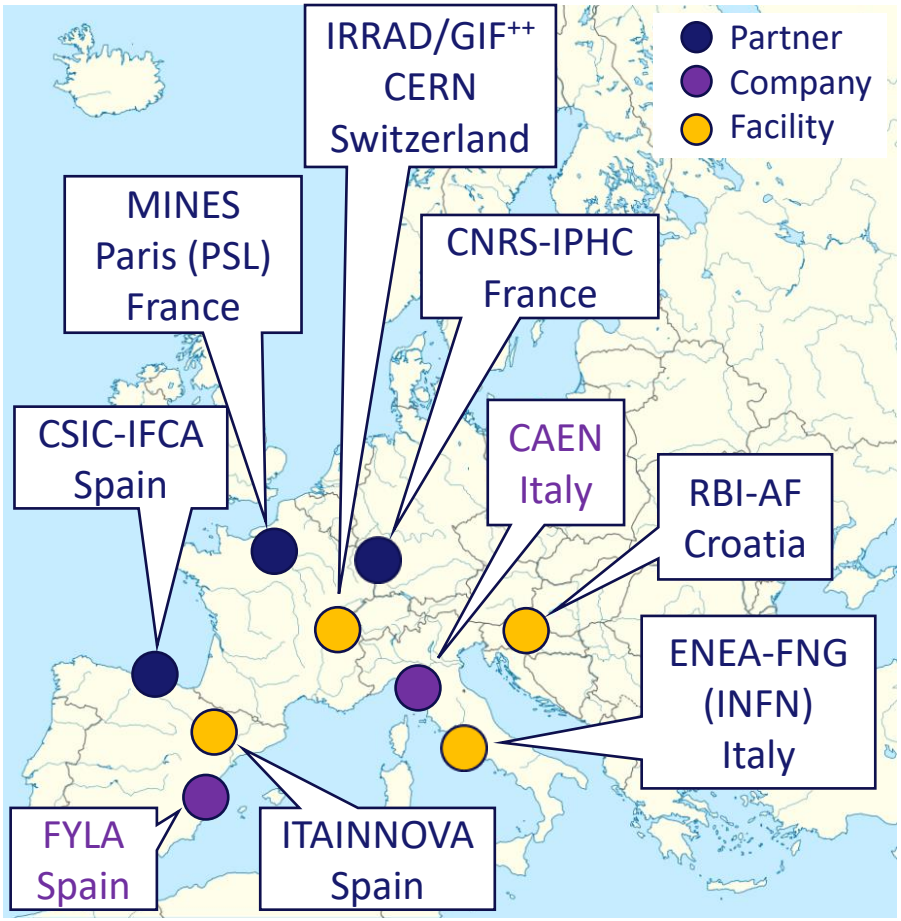
- Introduction to WP4
  - Goal, Structure, Partners, Organization, MS/D, etc.
- WP4 Parallel Session Summary
  - Task-by-task review
- Conclusion & Highlights

WP4 Goal

- Irradiation and characterization tests required for the 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 infrastructure to better support the next detector generation***
  - Improve facilities and systems
- The activities are covered by different partners:
  - Academia
  - Industry
  - Research and Technology Organizations (RTO)
- This good combination of partners aims to ensure the readiness of the detector support infrastructure for high TRL levels

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

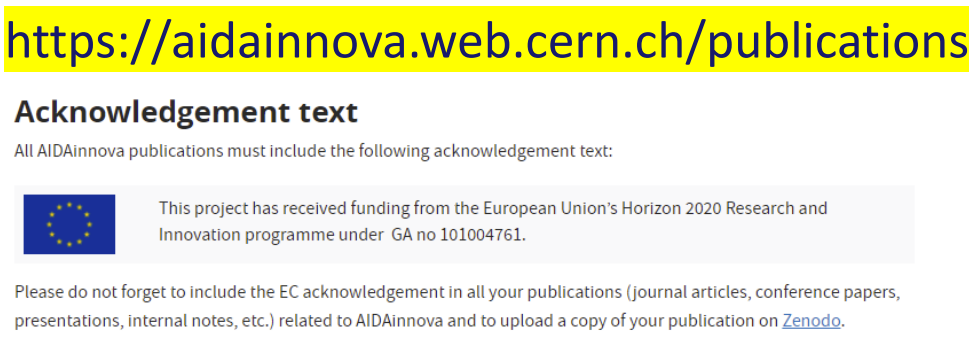
WP4 Deliverables/Milestones

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	ITAINNOV	M23
D4.5	Develop a conductive noise test bench for irradiation facilities	**ITAINNOVA**	M44

- **6 Milestones** (MS): M18 – M42: 5/6 completed
  - M36: **MS14** achieved during the last year (March 2024)
  - M42: **MS15** is the last one (September 2024)
- **5 Deliverables** (D): M40 – M46

Task 4.1: WP Coordination

https://aidainnova.web.cern.ch/publications

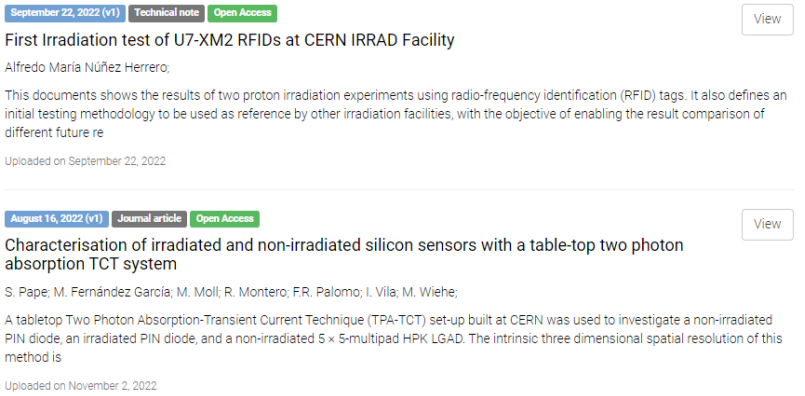


Acknowledgement text

All AIDAinnova publications must include the following acknowledgement text:

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA no 101004761.

Please do not forget to include the EC acknowledgement in all your publications (journal articles, conference papers, presentations, internal notes, etc.) related to AIDAinnova and to upload a copy of your publication on Zenodo.



September 22, 2022 (v1) | Technical note | Open Access — View

First Irradiation test of U7-XM2 RFIDs at CERN IRRAD Facility

Alfredo María Núñez Herrero;

This documents shows the results of two proton irradiation experiments using radio-frequency identification (RFID) tags. It also defines an initial testing methodology to be used as reference by other irradiation facilities, with the objective of enabling the result comparison of different future re

Uploaded on September 22, 2022

August 16, 2022 (v1) | Journal article | Open Access — View

Characterisation of irradiated and non-irradiated silicon sensors with a table-top two photon absorption TCT system

S. Pape; M. Fernández García; M. Moll; R. Montero; F.R. Palomo; I. Vila; M. Wiehe;

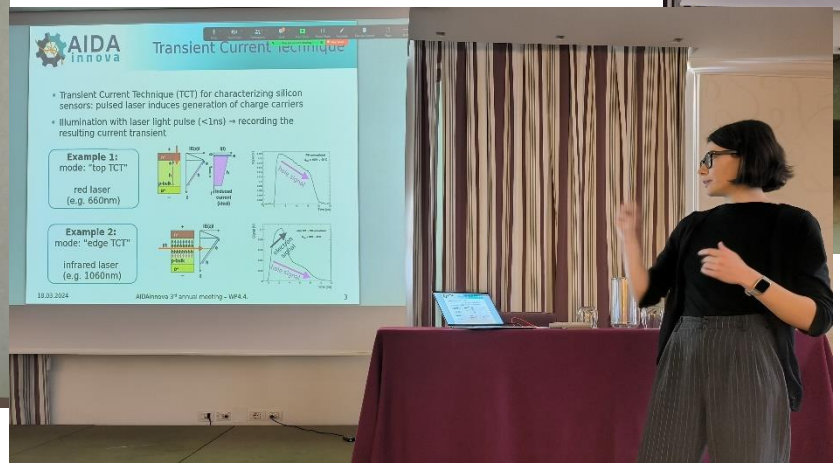
A tabletop Two Photon Absorption-Transient Current Technique (TPA-TCT) set-up built at CERN was used to investigate a non-irradiated PIN diode, an irradiated PIN diode, and a non-irradiated 5 × 5-multipad HPK LGAD. The intrinsic three dimensional spatial resolution of this method is

Uploaded on November 2, 2022

- **12 publication records** for WP4 in Zenodo
  - **7 other than MS reports** (articles, notes, presentations, etc.)
  - 1 in the pipeline for task 4.3, other 7 still pending to be uploaded in Zenodo
- e-groups to communicate with TLs and WP4 members
- INDICO category to host WP- and Task-related meetings:
  - https://indico.cern.ch/category/13502/ (**14 events**)
- Monday afternoon WP4 session agenda:
  - https://indico.cern.ch/event/1307202/sessions/502040/#20240318

Task 4.1: WP Coordination

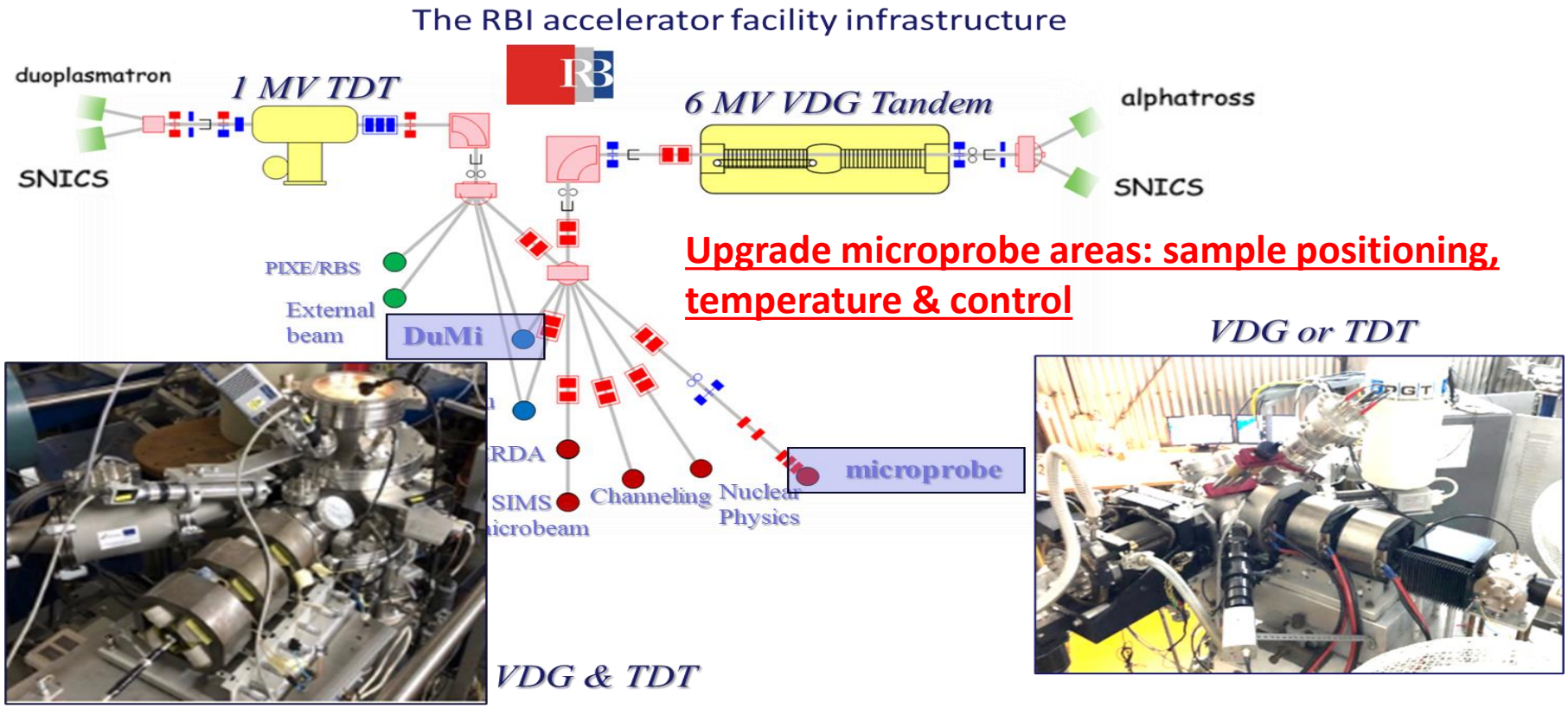
- WP4 session on Monday (14 participants including Zoom)
  - All Task Leaders (TLs) reports



- Very useful review about all task
  - Good review about all task and good identification of the activities to complete the project
  - Interesting final discussion about what to do next

Task 4.2: Micro-beam upgrade at RBI accelerator facility

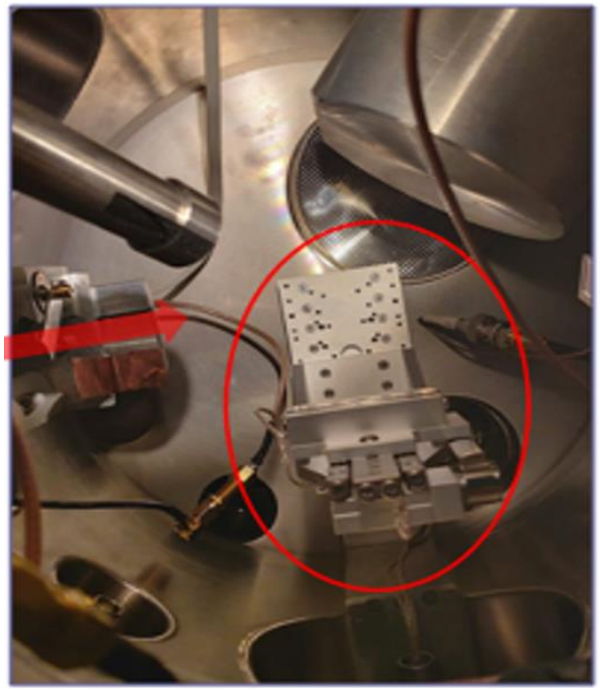
- The **RBI-AF** is regularly used for **detector characterization** by means of the IBIC technique and **detectors/materials hardness studies** and fabrication by means of precise irradiations



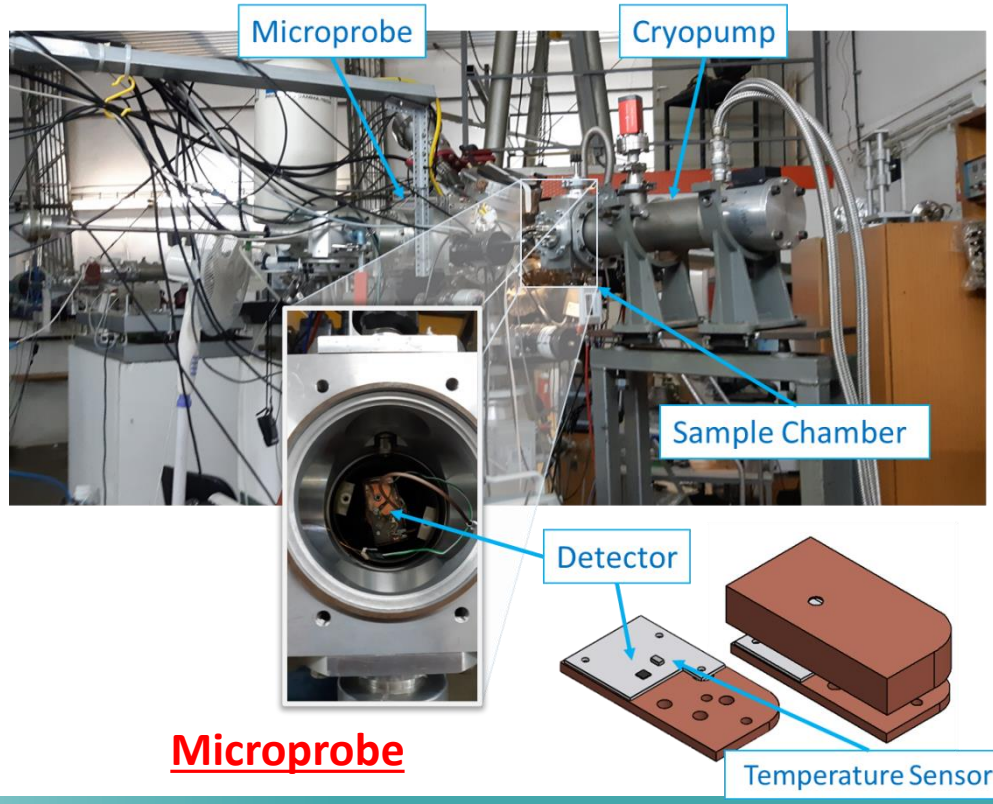
Task 4.2: Micro-beam upgrade at RBI accelerator facility

- New precise and monitored sample positioning (*1nm to tenths nm*) & software control –SPECTOR upgrade **(MS12) - Done**

- Sample cooling (low Temp)
  - The present setup for low temperatures **can achieve temperatures ~ 40-50 K**



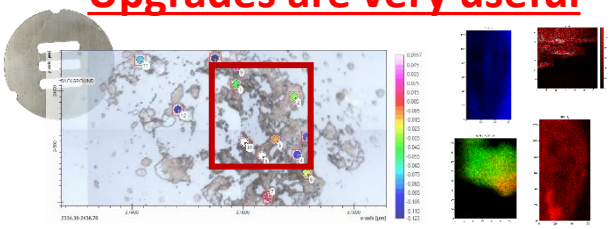
Dual Microprobe Area

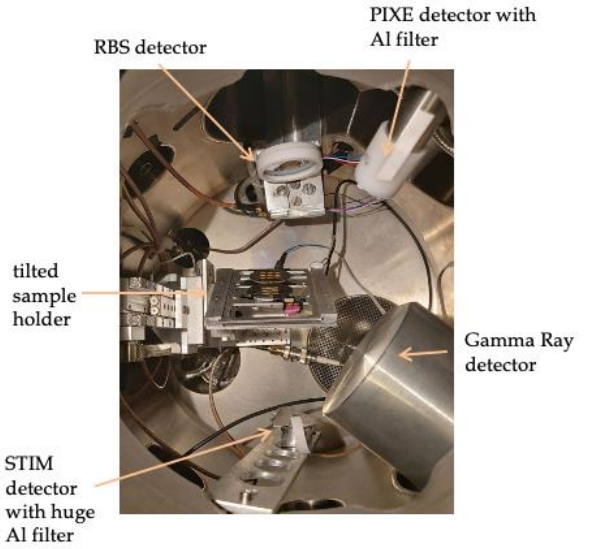


Microprobe

Task 4.2: Micro-beam upgrade at RBI accelerator facility

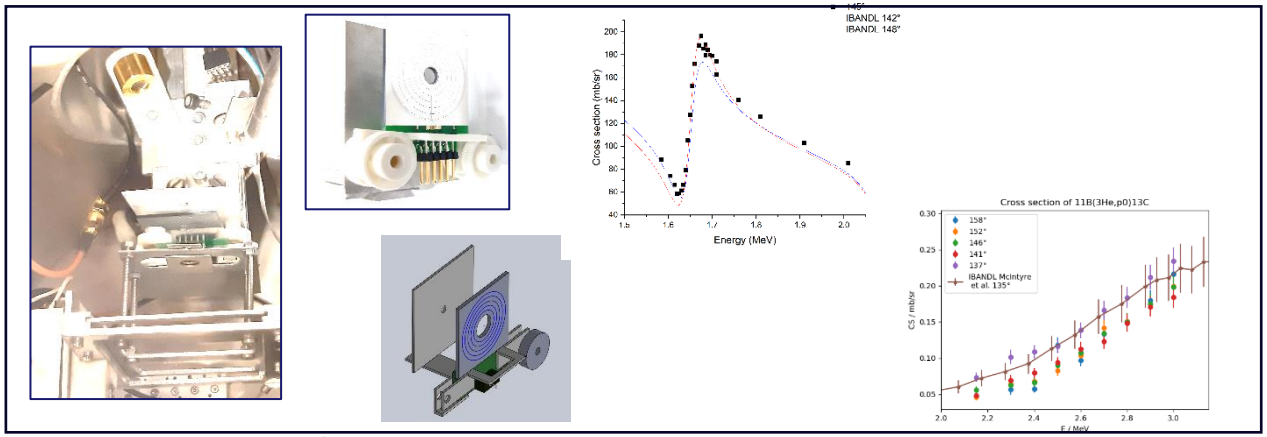
Upgrades are very useful





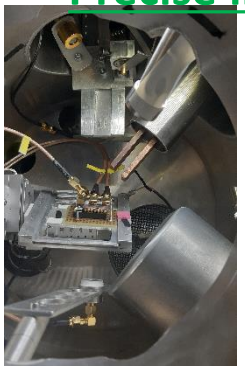
Time for sample precise positioning and micro-analyses on areas of interest is significantly decreased

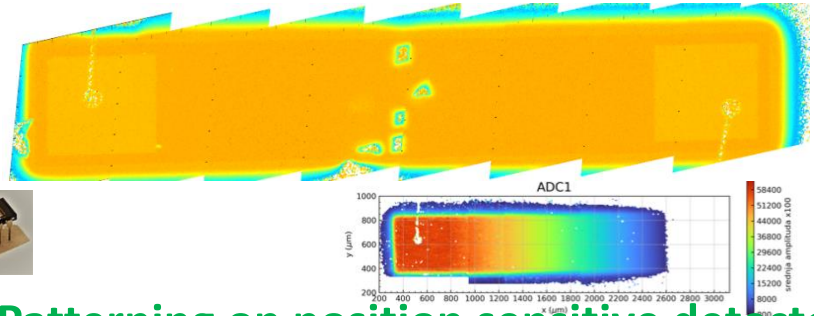
Well defined geometry can be obtained, enabling the measurement of 3He reactions cross section measurements.



IBIC maps of detectors larger than the max beam scan size can be easily obtained.

Precise irradiations can be carried out at well defined detectors positions



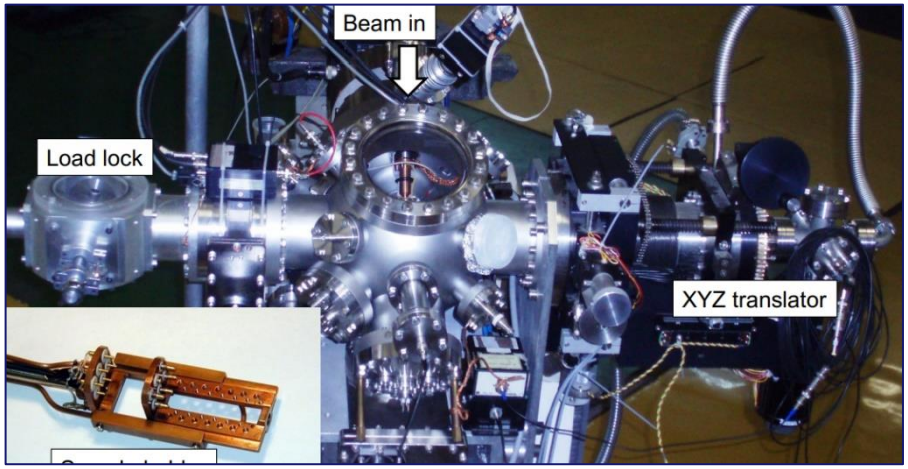


Patterning on position sensitive detectors.

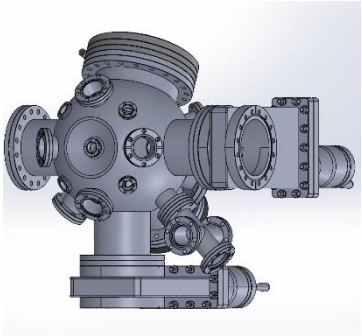
Task 4.2: Micro-beam upgrade at RBI accelerator facility

- To complete the activity

Microprobe Area



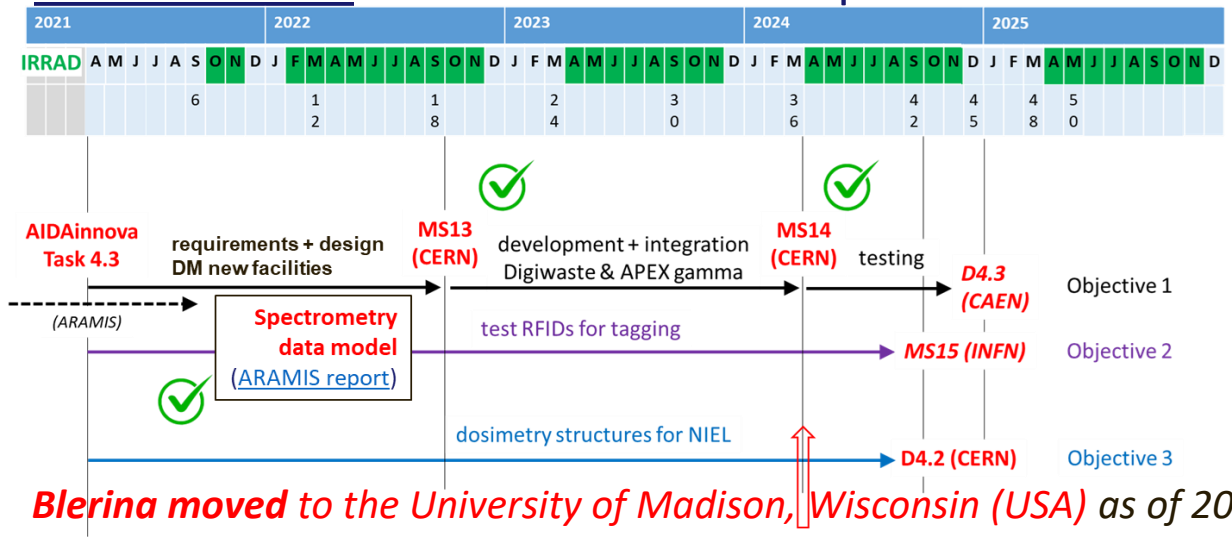
- Future – This autumn they move to a new building



A new XYZ piezo stage has been purchased and is in delivery. The stage has 29 mm travel range and nm resolution. Appropriate software for control will be made and incorporated to RBI's in-house DAQ, SPECTOR.

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
- Objective 2: *Development* of an integrated *system prototype* for induced activation & traceability data management
- Objective 3: *Produce a common NIEL dosimetry* calibration set for facilities cross-comparison



- ***Blerina moved*** *to the University of Madison, Wisconsin (USA) as of 2024- She will continue as CERN user to Support activities*
  - ***Paola Garosi (CAEN) is the new task leader!***

Detector development, irradiation, characterization (CH)

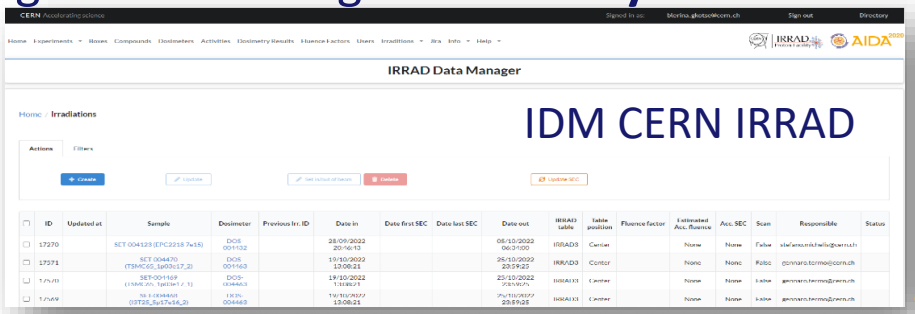
Irradiation/testing of electronics (IT)

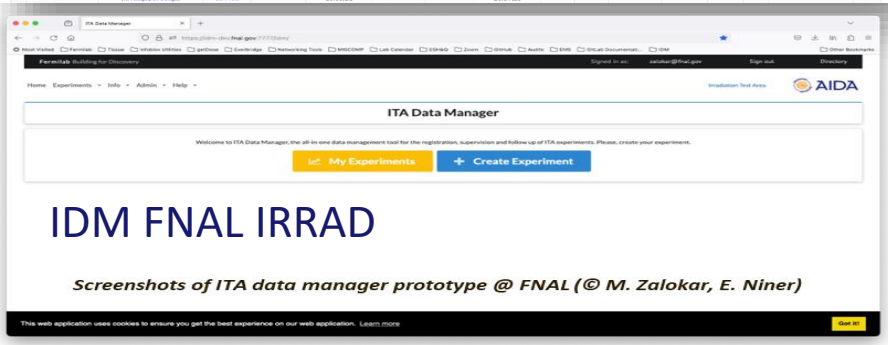
Electronic Instrumentation for Nuclear and PP (IT)

Data management SW, ontologies and ML (FR)

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

- For irradiation run 2024, **new version of IDM deployed** implementing the recommendations gathered during the **usability session:**





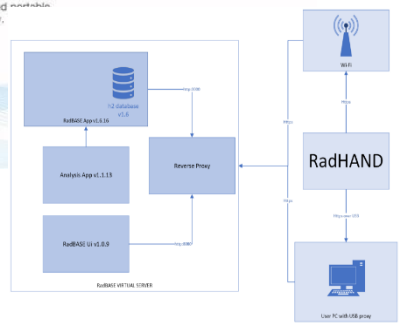
- IDM specifications for deployment to new facilities finalised (MS13)
- Deployment @ GIF++ finalized
- Deployment @ FNAL ongoing (D4.3)

- **Change of target facility for D4.3**

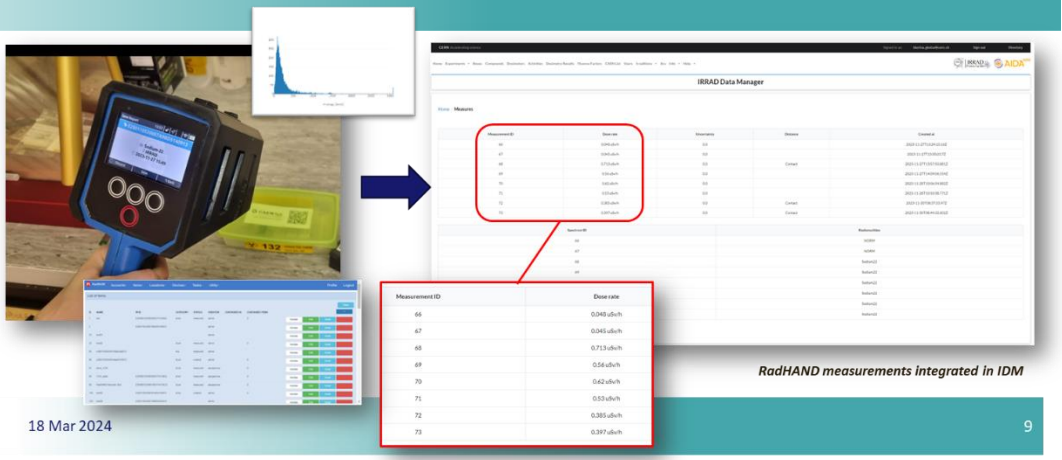
- The goal of ENEA-FNG's contribution to D4.3 is to demonstrate IDM's applicability in facilities beyond CERN, highlighting the software's generalization capabilities.
- The extension of the IDM to CERN-GIF++ is complete, but the departure of key staff at ENEA-FNG in Rome halted the software deployment work required for D4.3.
- Due to the challenges at ENEA-FNG, **it's proposed to shift the software deployment from ENEA-FNG to the Fermilab-ITA proton irradiation facility** in the USA, with the change not affecting the original scope or objectives of D4.3

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

- CAEN **RadHAND** device delivered at CERN
- **RadBASE interface** configured, and workflow tested for IRRAD



DigiWaste platform



RadHAND measurements integrated in IDM

- New integrated system RFID-based is being tested at IRRAD
  - RadHAND device used with RFID tags tested within AIDAinnova
- Complete workflow tested using the RadHAND device:
  - **Data acquired with RadHAND integrated in IDM** using CAEN API

Milestone MS14 **completed** and **released**

Including a Video **MS14**

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

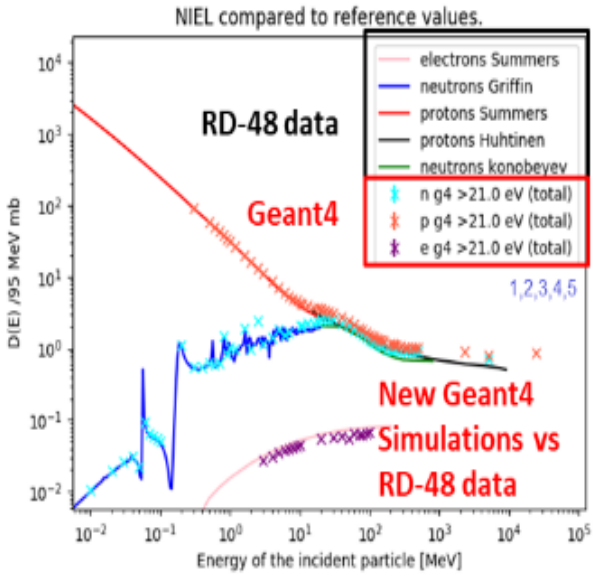
- Investigating the suitability of RFIDs to be used in radiation environment:
  - one model chosen at the beginning of the project (size, packaging, etc.)
  - **photons:** bibliography data exist
  - **protons at IRRAD** (AIDAinnova):
    - Report (also in Zenodo): https://edms.cern.ch/document/2680300/
  - **neutrons at ENEA-FNG** (AIDAinnova) funded by RADNEXT TA:
    - Report (also in Zenodo): https://edms.cern.ch/document/2884302/
  - **mixed-field at CERN**: planned in 2024

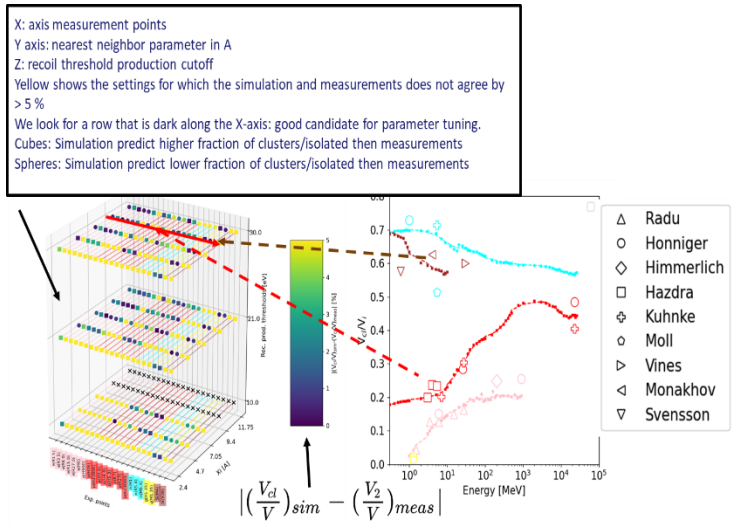
- Summary of these investigations to be compiled in form of MS report by M42

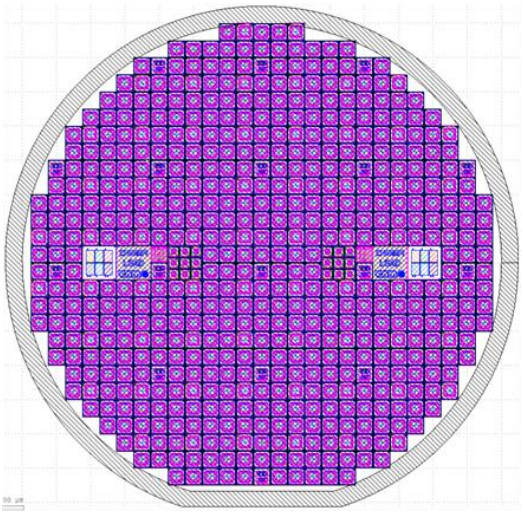
MS15 (M42)

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

- Produce a common dosimetry calibration set for cross-comparing irradiation facilities by evaluating, with dedicated dosimeter structures, the Non-Ionizing Energy Loss (NIEL) of their particle beam



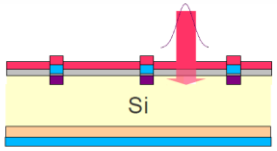




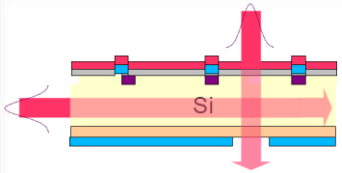
- Geant4 and FLUKA simulations for NIEL curves successfully reproduced and algorithm for identifying clustered vs point defect damage implemented
- Benchmarking simulations with measurements data is ongoing
- A set of Silicon Sensors (n-in-p) are in production at CNM, Barcelona (D4.2)

Task 4.4: TPA-TCT System Development

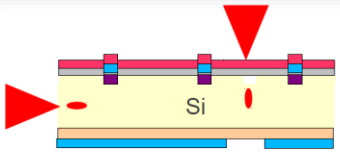
- **TCT:** Pulsed laser induced generation of charge carriers inside detector
  - Study of E-field in sensor, charge collection efficiency, homogeneity, ..
  - Benchmark simulation tools, e.g. signal formation,
  - Measure physics parameters e.g. mobility, impact ionization, ..



- **TCT (red laser)**
  - short penetration length (650nm = 1.9eV)
  - carriers deposited in a few µm from surface
  - front & back TCT: study electron & hole drift separately
  - 2D spatial resolution (5-10µm)



- **TCT (infrared laser)**
  - long penetration (1064nm = 1.17 eV)
  - similar to MIPs (though different dE/dx)
  - top and edge-TCT
  - 2D spatial resolution (5-10mm)



- **TPA-TCT (far infrared)**
  - No single photon absorption in silicon (1550 nm= 0.8 eV)
  - 2 photons produce one electron-hole pair
  - Point-like energy deposition in focal point
  - **3D** spatial resolution (1 x 1 x 10 μm^3)

TCT "invented": 1996

edge-TCT invented within RD50: 2010

TCT commercialized: 2013

TPA-TCT: Proof of concept presented by RD50 in 2015

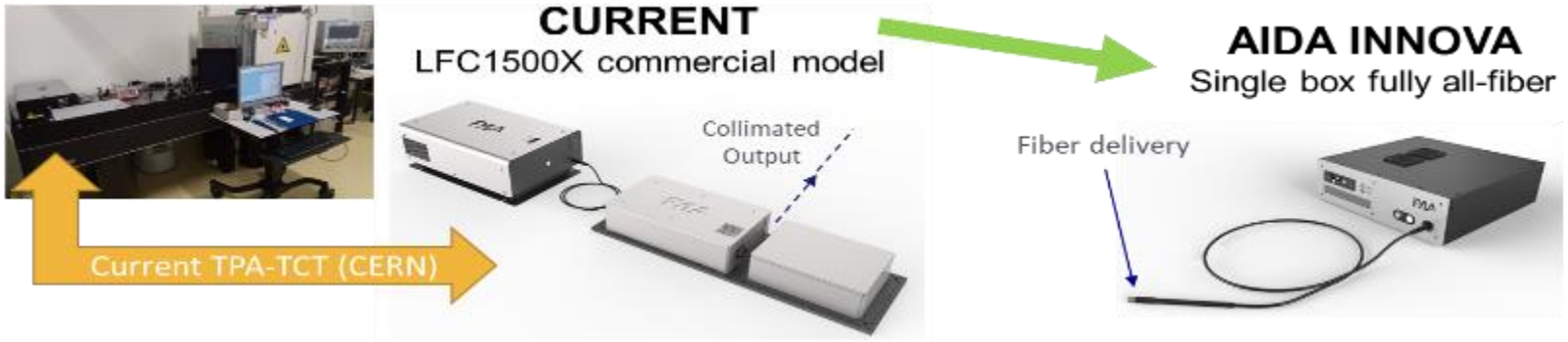
Table-top TPA-TCT laser commercialized: 2020/21

Table-top TPA-TCT system

All fiber based table-top TPA-TCT laser/system

Task 4.4: TPA-TCT System Development

- **Scope:** Development of a customizable and user friendly Two Photon Absorption – Transient Current Technique (TPA-TCT) system for the characterization and test of silicon devices.
- **Beneficiaries:** CERN (task leader), CSIC-IFCA (Santander,ES), Fyla (Valencia, ES)

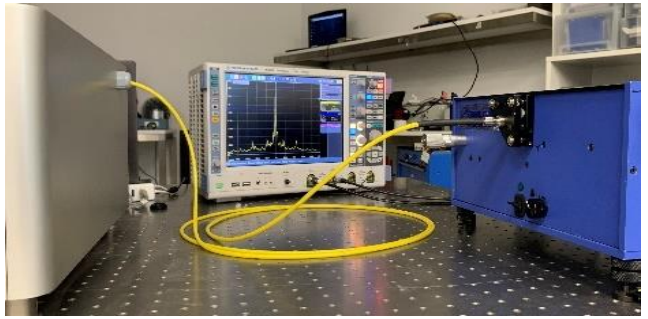


- Deliverables/Milestones:
  - MS16 (M23–February 2023) – Commissioning of complete TPA-TCT system
    [Done] Milestone Document report: https://zenodo.org/records/8027093
  - D4.4. (M46–January 2025) Publications & systems operational at several institutes [Well on track]

Task 4.4: TPA-TCT System Development (Laser Improvement)

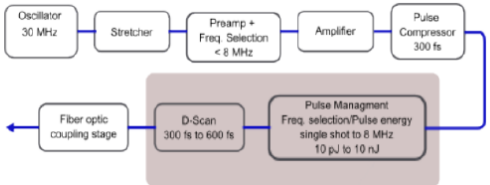
- Since 2023 Re-designed Laser system at Fyla
- The new “Pulsar” laser system was manufactured
- The system fully integrates the laser pulse source (LPS), the pulse management module (LPM) and the dispersion compensation module (D-scan) in a single box component with fiber optic beam delivery.
- The system “Pulsar” presents robustness and great stability in optical and temporal properties.
- “Pulsar” provides beam delivery through 3m of optical fiber with coupling efficiency of ~70% (under test)

Beam delivery through optical fibre (Kagome fibre)



“Pulsar” system specifications

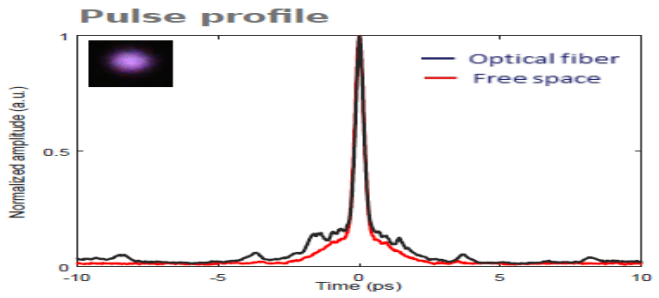
- **LPS:** Laser Pulse Source
  - All-fiber CPA femtosecond pulses generation
  - Pulse rep rate selection. **Single shot to 8MHz**
- **LPM**: Laser Pulse Management module
  - Pulse energy modulation: **10pJ to 10nJ**
  - Synchronized shutter, **rise/fall time < 1µs**
- **D-SCAN:** Dispersion scanning
  - Pulse duration tuning: **300fs to 600fs**
  - Pulse temporal properties characterization

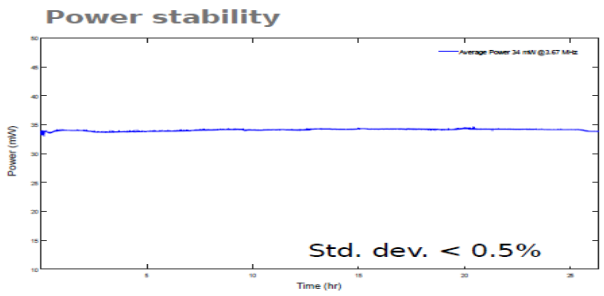


PULSAR

Dimensions:

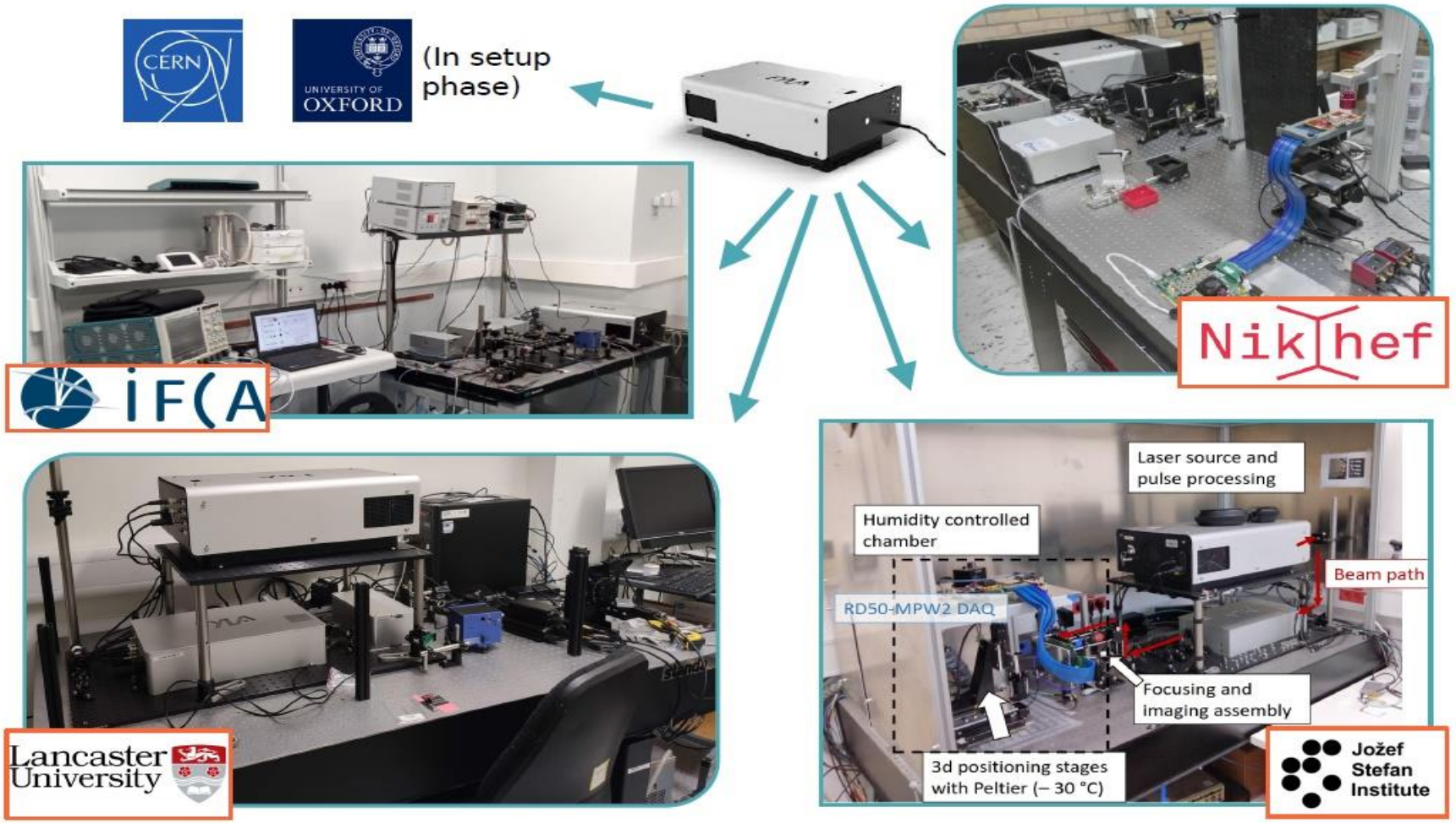
Length: 91 cm
Width: 62 cm
Height: 22 cm





Task 4.4: TPA-TCT System Development (TPA-TCT community)

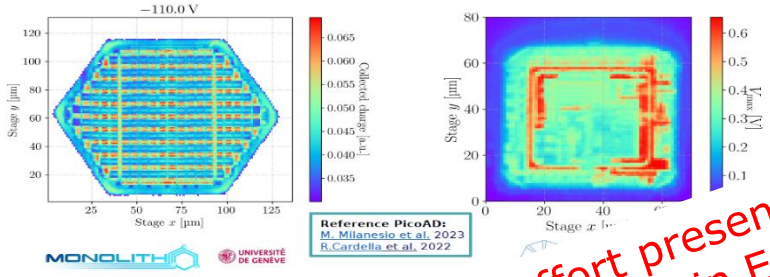
TPA-TCT systems with the LFC1500X or new "Pulsar" laser system at several institutes:



Task 4.4: TPA-TCT System Development (TPA-TCT community)

TPA-TCT as high precision scanning tool

- The examples 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 60µm² pixels)!



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

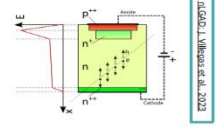
MONOLITH

UNIVERSITÉ DE GENÈVE

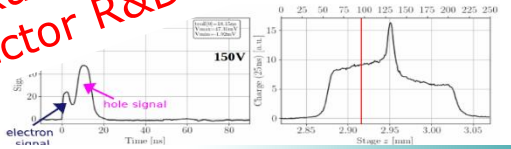
TPA-TCT testing of nLGADs

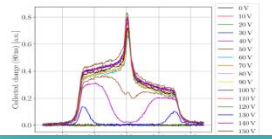
- Low Gain Avalanche Detectors (LGAD), implemented as n^{++}–p^{+}–p, show outstandin… performance when detecting high-ener… particles
- Due to the difference in mul… for holes and electrons … for low penetratin… or soft x-rays
- A nove… d… …e nLGAD, was … and first tested at …ons

New nLGAD concept



nLGAD, I. Mikhaylov et al., 2023

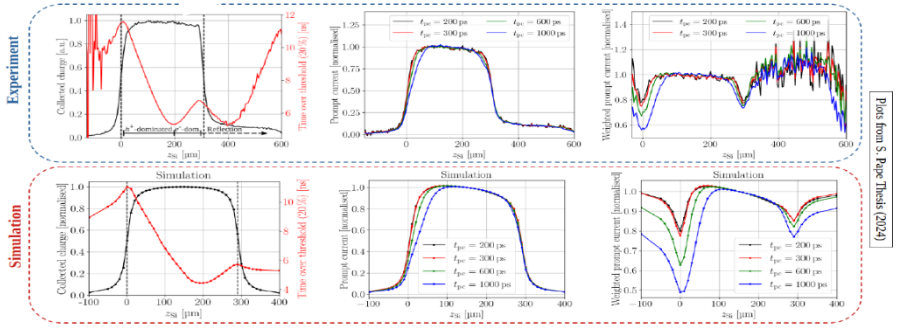




TPA-TCT common effort presented as example for collaborative efforts for new R&D collaboration (DRD3) in ECFA Detector R&D roadmap implementation plan

Advances in TCAD simulations

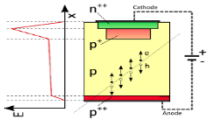
- Compar… … from experimental current transien… …tracted from simulated transients taken on a 300… …N sensor



Plots from S. Pape Thesis (2024)

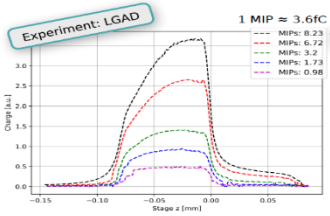
Advances in TCAD simulations

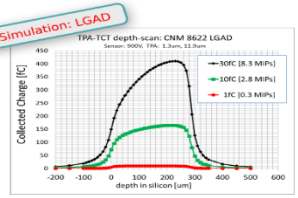
- Gain suppression in LGADs:
  - The gain in Low Gain Avalanche Diodes (LGADs) depends on the charge density entering the Gain Layer (GL)
  - **Low charge density** in GL: negligible gain suppression
    High charge density in GL: drop in the E-field (less amplification)
    → reduction in the gain
  - Effect relevant for characterization and operation of LGADs for the HL-LHC ATLAS/CMS timing experiments



TPA-TCT measurements and simulations on CNM 8622 devices (illumination from top)

M. Moll, 43rd RD50 Workshop



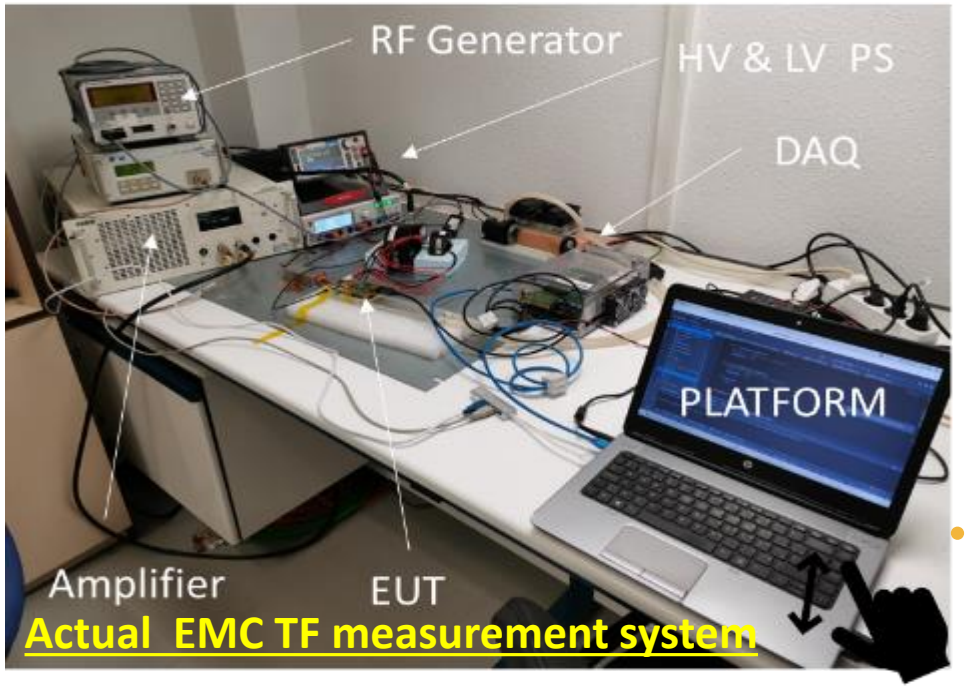


Task 4.5: Design & development of a new electronics characterization system for EMC control

- **Goal:** The main goal of this activity is to 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:** Two activities are planned
  - 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.
- One Milestone and deliverable are planned:
  - MS17: Apply TF test bench to FEE prototypes [M23 -Done]
  - D4.5 : Develop a conductive noise test bench for irradiation facilities [M44]

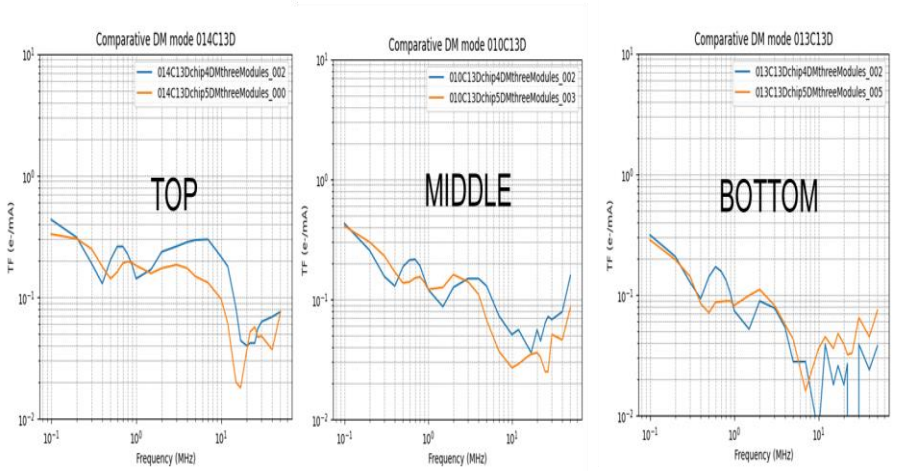
Task 4.5.1: Automatic noise TF measurement system

- Developing an automated EMC test bench to accurately measure the noise TF of physics detectors
- This activity is completed
- The system is being used regularly today



Actual EMC TF measurement system

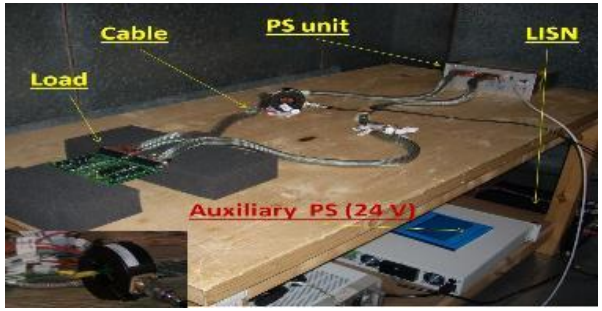
Noise studies at system level CMS-ITK –pase II



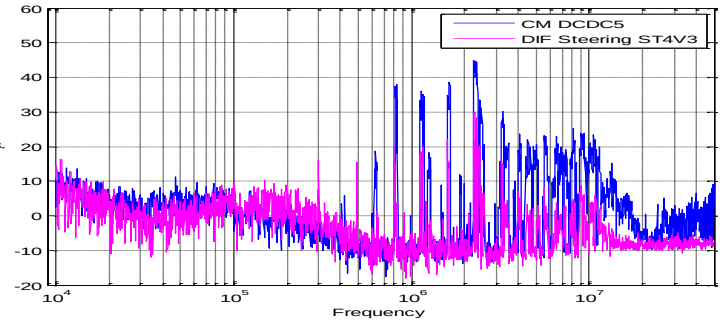
- New upgrades will be implemented soom

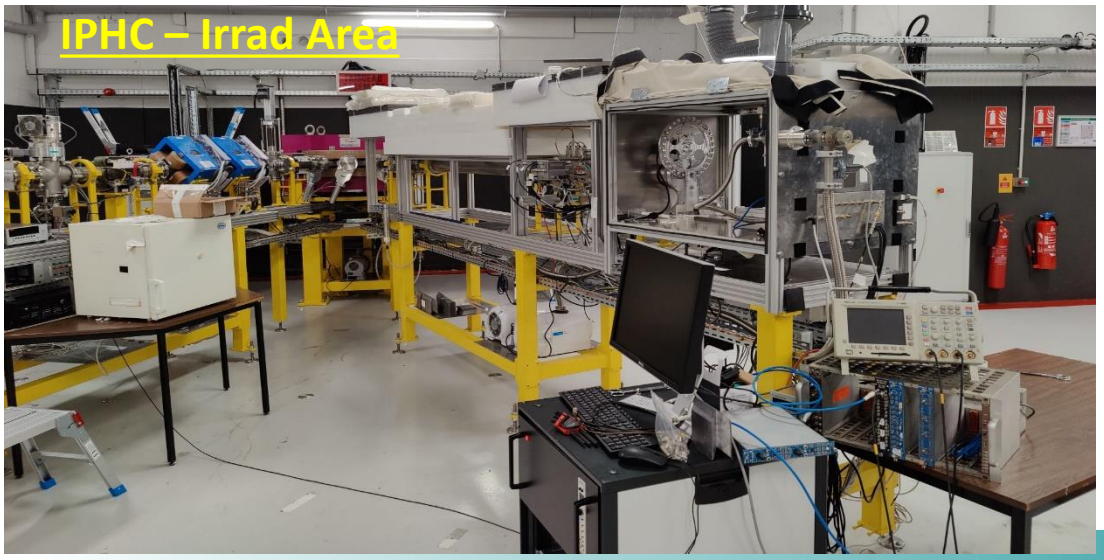
Task.4.5.2 Portable noise measurement system for IRRAD Facilities

- During the third year, the development of a customized portable test bench, designed to perform in-situ conducted EMC emission measurements of power supplies in IRRAD configurations, has been initiated.



Standard test bench for PS conducted emissions





Task.4.5.2 Portable noise measurement system for IRRAD Facilities

- A **meeting** was held last summer **with IPHC** in Strasbourg to define the test set-up.
- The measurement method and components have been selected and designed.
  - **Hardware and software development** is ongoing, including a dedicated PCB set for submission this month.
  - **Integrating a 4-channel oscilloscope** with high resolution and sampling rate, alongside Python-based software, to automate and improve the precision of noise analysis and signal processing.
- The **PCB test-bench's design ensures portability**, facilitating repeated and automated noise measurements, while the **oscilloscope's inclusion allows transients measurement**.
- Final test phase scheduled for the upcoming summer or autumn.

Conclusions & Highlights

- WP4 aims to **develop & standardize common tools for testing infrastructure** and **better support the next detector generation R&D**
  - Improve facilities, systems and methods
- The **collaboration with industry partners within WP4** continues to **receive excellent feedback**, with companies deeply engaged in task development.
- WP4 is **progressing according to plan**
- **All tasks are in the process of completing final project activities** and focusing on the preparation of deliverables.
  - Some activities are already ahead of what promised in the deliverable
- **Implemented updates have already yielded positive results**, enhancing user testing efficiency and providing access to novel data..

Conclusions & Highlights

- **Highlights in the third year of AIDAinnova:**
  - **Task 4.2:**
    - Micro-beam upgrade at RBI accelerator facility almost completed. The time required for running micro-analysis of areas of interest on various sample types is significantly decreased!
  - **Task 4.3:**
    - Change of target facility for D4.3 – ENEA to FNAL
    - IDM extended for new facilities and prototype of an integrated RFID-based system communicating with CAEN DigiWaste platform operational → Achieve MS14!
  - **Task 4.4:**
    - New compact laser system manufactured. TPA-TCT lasers delivered to 6 HEP institutes becoming an example of collaborative efforts for new R&D collaboration (DRD3) in ECFA Detector R&D roadmap implementation plan
  - **Task 4.5:**
    - Launched the development of a specialized portable noise measurement system for irradiation facilities, with hardware production in progress and final testing anticipated by year's end