Instrumentation, engineering and technology transfer

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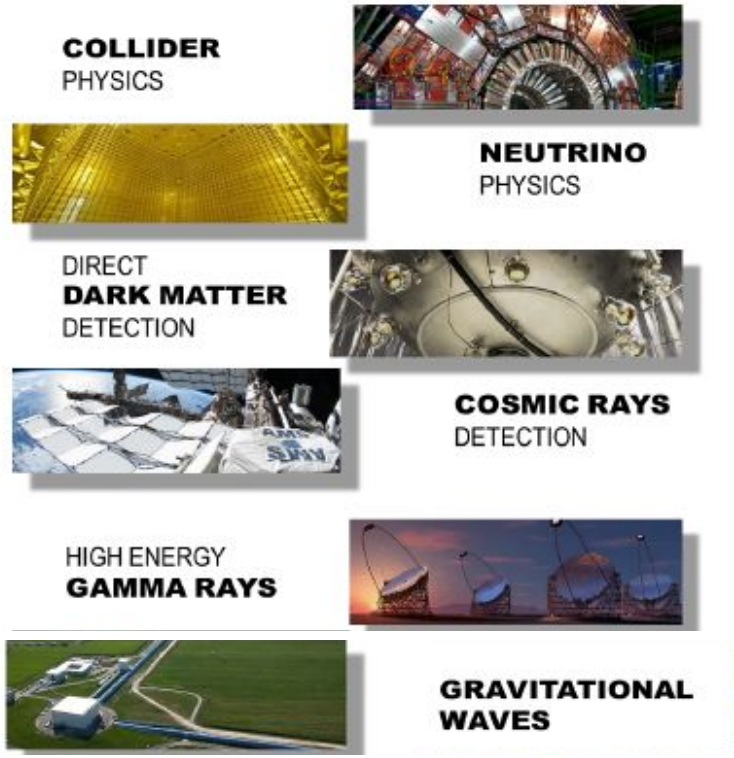
*does not cover computing (dedicated talk)

Experimental Physics: our instruments



Detector construction takes place in almost all of the **research lines** in the department.

Contributions to major experiments are **highly valued by the international community**.

These activities cannot be treated as off-the-shelf procurements; they **require continuous involvement** throughout the entire lifetime of the experiments:

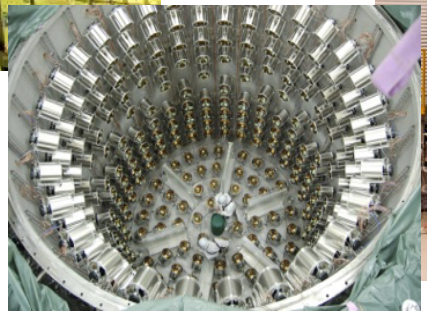
including **maintenance**, **upgrades**, and **repairs** over periods that often span **several decades.**

Detector (sensor) technologies expertise

Gaseous detectors

Liquid detectors

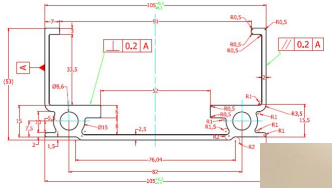
Photo-detection

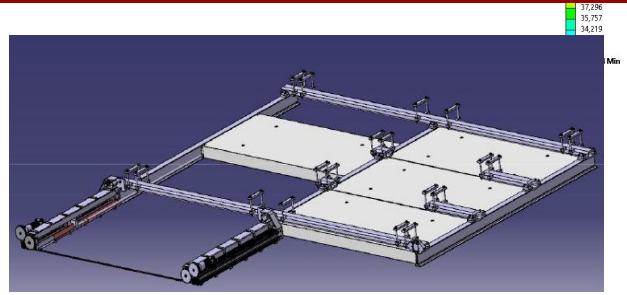


Technological capabilities in the Unit

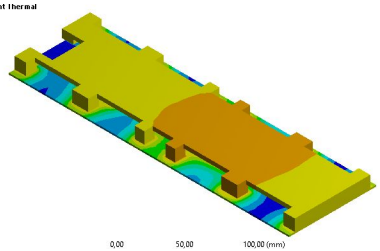
Our unit has developed **advanced** technological capabilities
Enable us to address the **challenges** associated with particle and astroparticle detectors.

Mechanical design





Thermal and structural analysis



Additive manufacturing

Cryogenic and vacuum facilities

Assembly halls

Precision Metrology

Technological capabilities in the Unit

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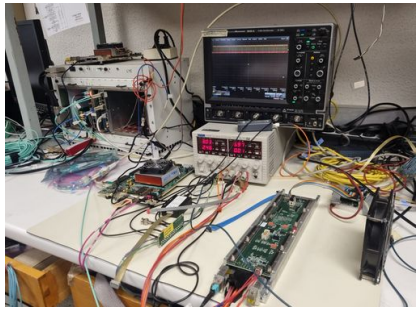
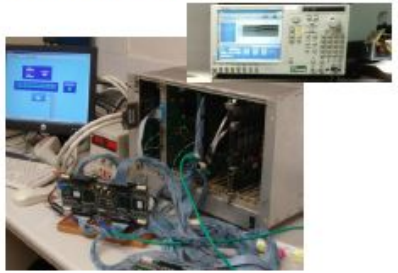
Enable us to address the **challenges** associated with particle and astroparticle detectors.

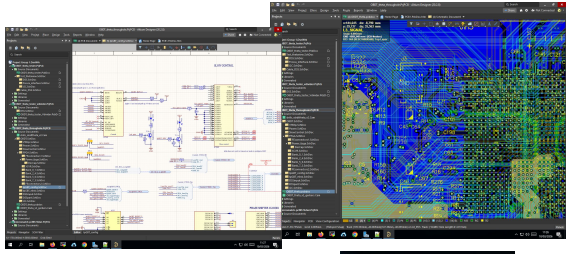
Electronics labs



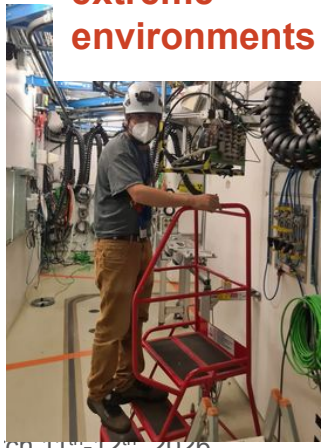
Electronics inspection and validation



High performance electronics design

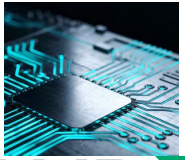


Design and validation in extreme environments



Manufacturing and prototyping

Firmware and embedded systems



AMD

Photodetector characterization (radiactive sources, monochromator, light sources..)

Data acquisition and control software development

LabVIEW

python

Engineering activities across the detector lifecycle:

End to End project management (E2E)

- Project conception: requirements definition, R&D
- mechanical and thermal design
- front-end electronics design (analog, ASICs)
- digital electronics design: data acquisition chain
- firmware and embedded systems
- online software and detector control
- prototyping and validation
- production engineering and industrialization
- assembly and integration
- quality assurance and environmental qualification
- installation and commissioning
- operation, maintenance, upgrade

Our contribution needs to cover all phases of the project

Highlights in engineering

CTA Observatory

LST Camera and Telescope Systems

- Installation of the LST-04 camera and execution of the engineering commissioning phase
- Installation of the Azimuth Locking System (ALS) on telescopes LST-02, LST-03 and LST-04, in collaboration with IAC
- Upgrade of control systems for the Star Imaging Screen (SIS) and camera shutter systems for LST and MST telescopes

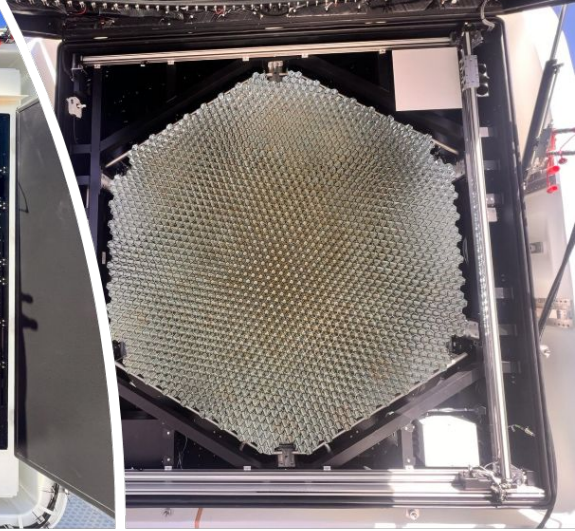
Virgo Gravitational Wave Detector

Optical and Thermal Control Systems

- Successful CDR (Critical Design Review) of the Heat Ring system for active mirror curvature control
- Progress in the design of anti-reflection baffle systems for the main optical benches

Engineering Impact

- Contribution to **installation, commissioning and operational readiness** of major astrophysics infrastructures
- Development of **precision opto-mechanical and control systems** for next-generation observatories



Highlights in instrumentation: photodetection

- Joint effort with **Hamamatsu Phot. and F. Bruno Kessler** to improve SiPM efficiency for DUNE.
- Development of **cryogenic test** systems to measure **sensor efficiency vs wavelength** and temperature (**down to –196 °C and 128 nm VUV**).
- Extensive **characterization of photodetectors** (PMTs, SiPMs, APDs), including long-term stability tests of VUV-sensitive PMTs in liquid nitrogen.
- **Design and validation of large-area light sensors (light guides + SiPMs)** and installation and performance monitoring in detector operations.

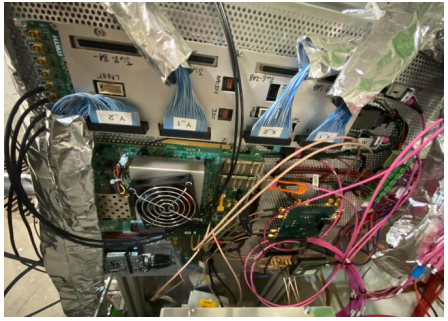
Setup for PMTs long-term stability in LN2

Highlights in electronics: Versatile TrigDAQ chain

- Expertise in **high-performance digital electronics design** for the highest bandwidths
  - Board designed for CMS Upgrade (OBDT-theta+backend system):
    - **rad-tolerant, programmable high speed interconnection**
- **Versatility allows it to be repurposed** for other experiments.
  - SND@LHC
  - DRD 1 : readout electronics for gas detector
  - DRD 7.3. Timing applications
  - R&D of new detectors for future colliders
  - DRD7.5: AI on FPGAs, timing closure

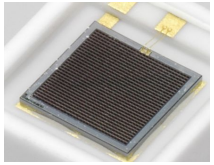
SND experiment@LHC

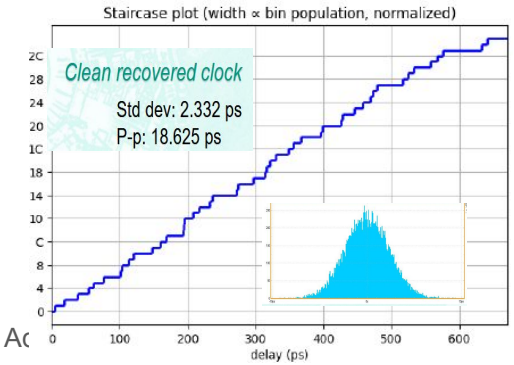
- Very forward LHC neutrinos and other feebly interacting particles
- One OBDT-theta TDAQ chain has been taken data last year for the muon tagger



R&D for FCC experiments

- OBDT-theta for MPPC (Multi-Pixel Photon Counter) readout chain





DRD7.3 timing applications

- Validated timing distribution reliability (jitter recovered clock σ ~ 2.3 ps)
- Time digitization inside the OBDT-theta achieved ~40 ps resolution

Technology Transfer

Patent ES3024883B2 on Gaseous detectors (2025)

- Innovative concept for the fabrication of a high-resolution gaseous detector using **additive manufacturing techniques**.
- At present completing first demonstrator.
- Engagement with potential industrial partners will follow (muography, ion mobility spectrometry)

EIC-Pathfinder project with nuclear industry

- AntiMatter-OTech **European innovation** project (HORIZON-EIC-2021-PATHFINDEROPEN-01/101047028)
- **LiquidO innovative detector**: antineutrinos as a direct probe into the functioning of industrial nuclear reactors.
- **EDF (Électricité de France) as industrial partner** in Double Chooz nuclear plant.
- The activity during 2024 and 2025 has been focused on the **engineering design and its validation with simulations.**

Technology Transfer to Industry for CTA Project

Engineering transfer to industry enabling the industrial production of CTA telescope instrumentation.

In close collaboration with CTA partners and industry

- Transfer of the **complete mechanical and system design of the LST cameras** to industry
- **Industrial support for manufacturing, integration and system testing** of all camera subsystems (excluding main electronics, including slow control and auxiliary systems)
- Engineering support to establish **industrial production procedures and quality assurance**

Industrial production enabled

- **3 LST Cameras** (North Observatory)
- **2 LST Cameras** (South Observatory)
- **8 MST telescope mechanical structures** produced
- **8 MST Front Doors + Shutter systems** manufactured

Impact

- Transfer of know-how that **trained industry to build large-scale Cherenkov telescope observatories**.

Camera electronics

- **Research service contract with industry** (together with **Scientific Inst. Div.)**
- **Transfer of hardware and firmware designs** for the **Trigger and Clock Distribution System** of the LST cameras
- **Quality control and technical support** for mass production (2000 units)

Technology Transfer

Improving laser and electron beam soldering capabilities in the industry

- Within the framework of the **CALICE collaboration**
- Collaboration with **LORTEK** and **AIMEN** technology centers, and **ARQUIMEA**
- Definition of **laser welding procedures on 304L stainless steel**.
- Aim to achieve similar **construction tolerances** as with the electron beam welding investigated previously with ARKU and CERN.

- In addition, collaboration with **ARQUIMEA**
- R&D on welding process to **minimize deformation in magnetic shields**
- Needed for the photodetector shield in **DUNE-VD detector**

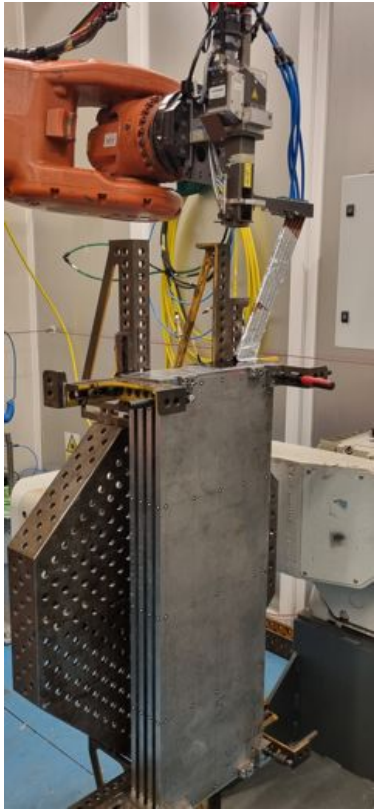


Figure 3.4: Laser soldering tests at AIMEN for the structure of the CALICE calorimeter structure.

Technology and knowledge transfer

Proof of concept Project (AEI): Fibrometro

- **Instrumentation for civil engineering**: **optical fibers instrument** for measuring large structures deformation.
- **Utility model protected ES1308248 U. 24/08/2024** and software registered.
- Collaborations with **CIEMAT´s Eolic Unit** (renewable energies) and IMDEA materials (composite materials fabrication), agreement to pursue a test on their new Eolic unit

Artificial Intelligence and data science

Application of the Unit's expertise in intelligent data analysis techniques.

Synergistic collaboration with the Molecular Oncology Unit at CIEMAT.

- Ongoing studies in **bladder, ovarian, and oral cancer** using real patient data from **Hospital 12 de Octubre (Madrid)**.

Sanevec project

- Development of an **agent-based simulator** to study **electric vehicle charging infrastructure** in urban environments.
- Analysis of related effects: **traffic congestion, air quality and carbon footprint**.

CIEMAT as a technological center

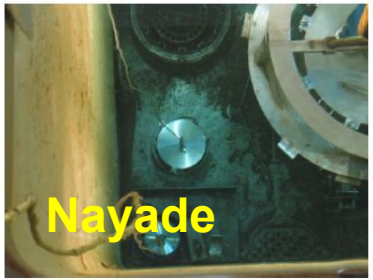
CIEMAT grants us **access to some facilities** useful for the development of our experiments.

Beyond this, we maintain a **close partnership with the Scientific Instrumentation division.**

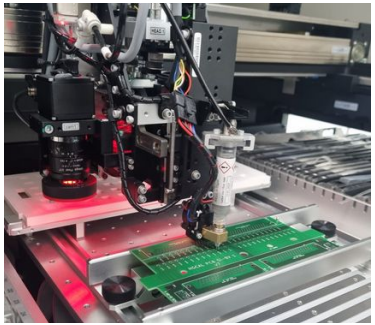
This partnership includes not only access to facilities but also **human resources fully integrated in our projects.**

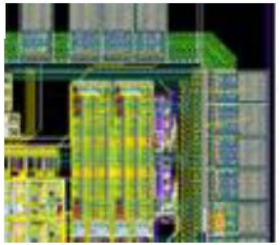
Unidad Fabricación y Apoyo (General Mechanical Workshops)

Access to radiation facilities

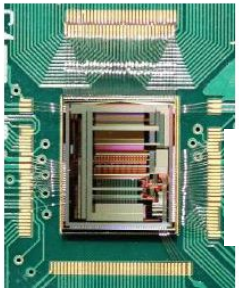


Automatic electronic assembly





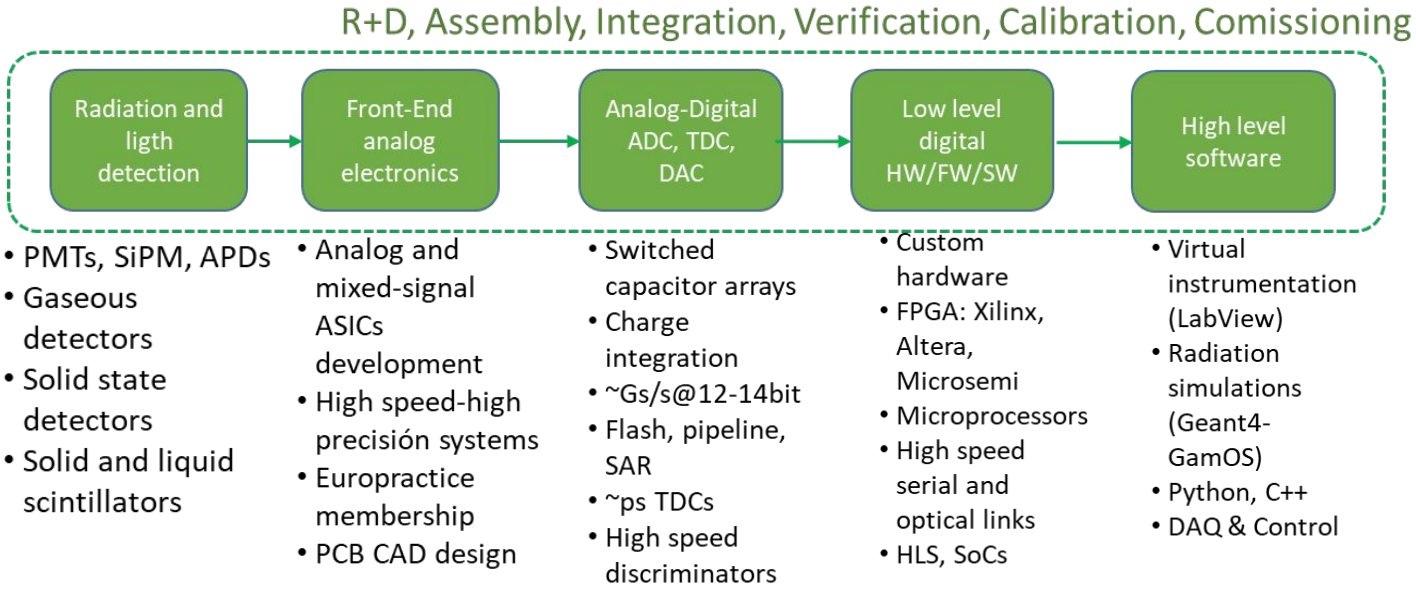
Analog and digital ASIC design



Electronics reparation, soldering stations (BGA)

Wire bonding

- Critical collaboration with Technology Department
- Group of **electronics engineering** devoted to scientific instrumentation
- Expertise in space and demanding environments
- ~5 engineers + 3 technicians



Scientific Instrumentation Division. Technology Department.

- >300m2 of general purpose and specific laboratories
- Wide pool of advanced high performance instrumentation

Climate chambers

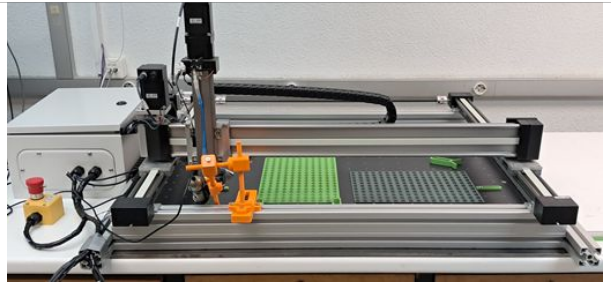
Automatic Pick and Place Machine

Vapor phase soldering oven

Semi-automatic micro-bonding

Automatic PCB micro-milling

Custom XYZ robot for automatic ASIC testing



Funding

- HORIZON-EIC-2021-PATHFINDEROPEN-01/101047028 ~814 k€
- PDC2021-121715-C22 (Fibrometro) ~75 k€

People: FTE working on these activities

~6 physicists
~6.5 engineers (2.5 mech., 4 elect.)
~4 technicians (2 about to retire)

with intense activity in up to 7 research lines.

0.3-0.5 eng FTE/project

Difficulty in replacing technical personnel: 3 engineers and 3 technicians have left

Need for timely generational renewal to ensure long-term continuity of these activities.

In connection with technician academic centers (internships, even from abroad).

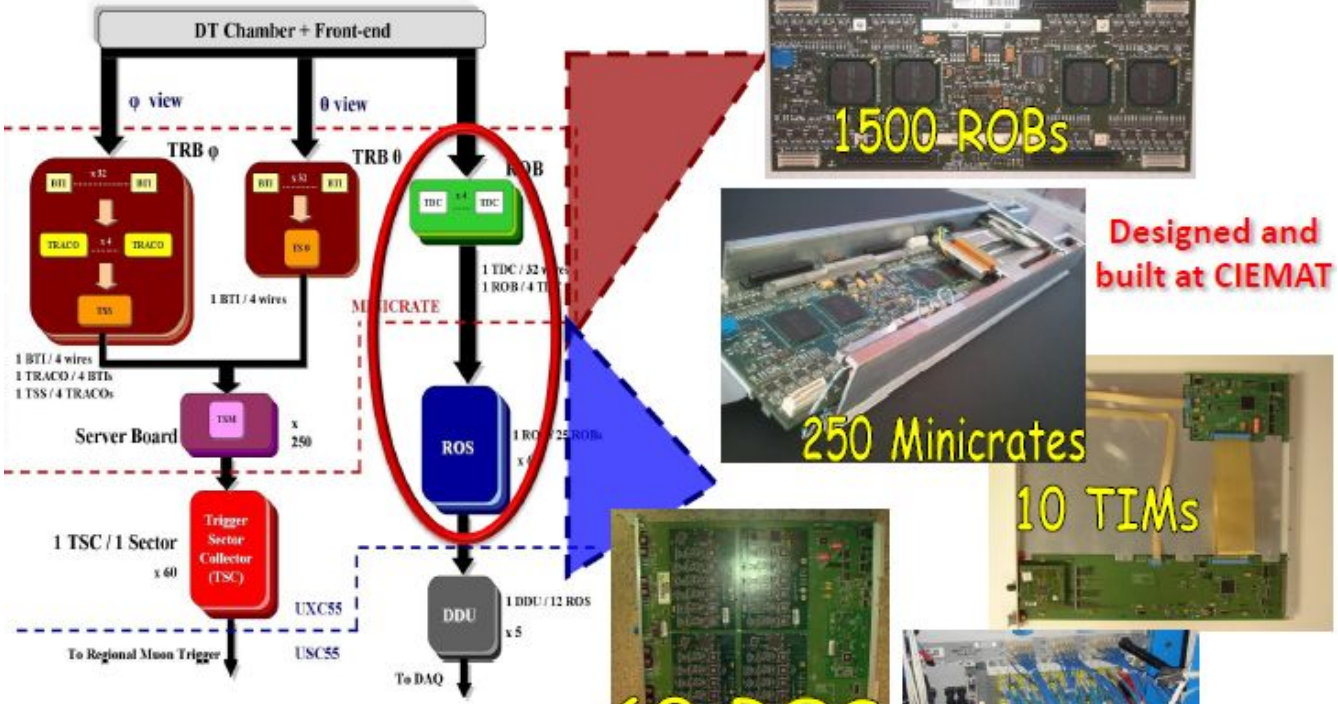
Lack of career for technical profile does not encourage attracting good talent.

Summary

- The CIEMAT-FP Unit has **strong expertise** in the development of instrumentation for particle and astroparticle physics experiments.
- Internationally, we are **recognized as a reference center**, and our hardware contributions to experiments are highly valued.
- However, the situation is becoming increasingly **critical with regard to lack of technical manpower**.
- On the positive side, our **technology transfer activities** (including both intellectual property protection and collaboration with industry) have improved significantly over time.

BACK-UP

Drift Tubes Read Out Electronics Run 1



DT Phase 1: SC relocation (LS1 2013-2014)

OFCU-RO

J2-OFCU

TIMBUS-OFCU

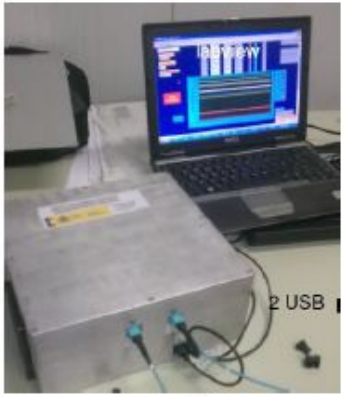
VME_patch

TSC_rear

Optical Fibers irradiation tests

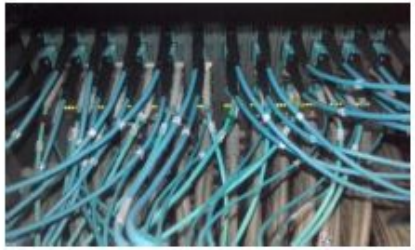
Designed and built at CIEMAT

OFCU-RO test stand



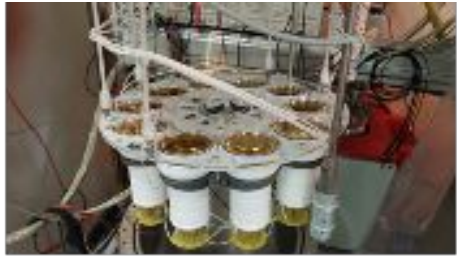
Precise system for measuring OF length

TRIDAS IB - June 21st 2017



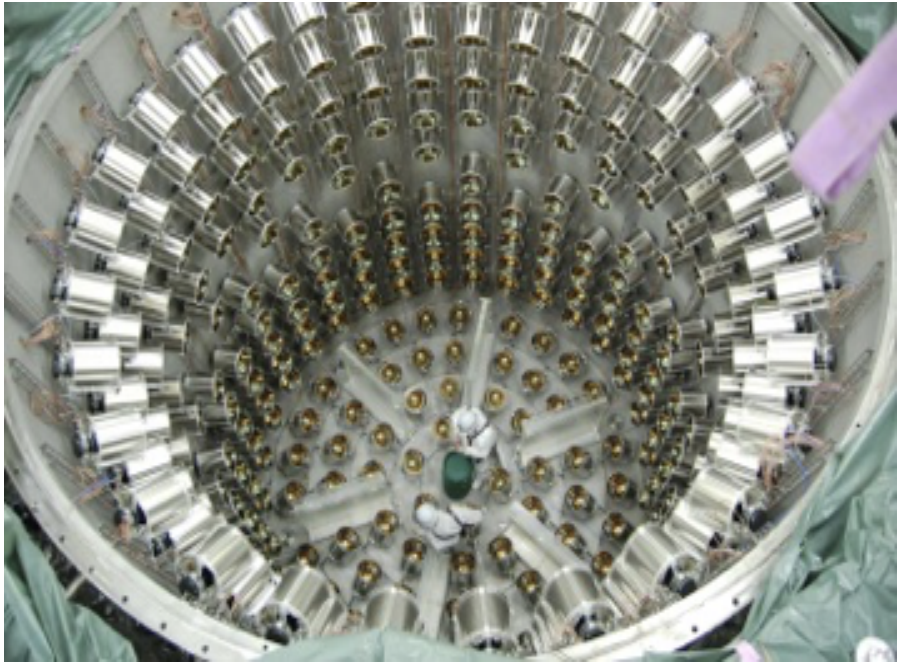
Installation in the CMS detector

Light Sensors Characterization

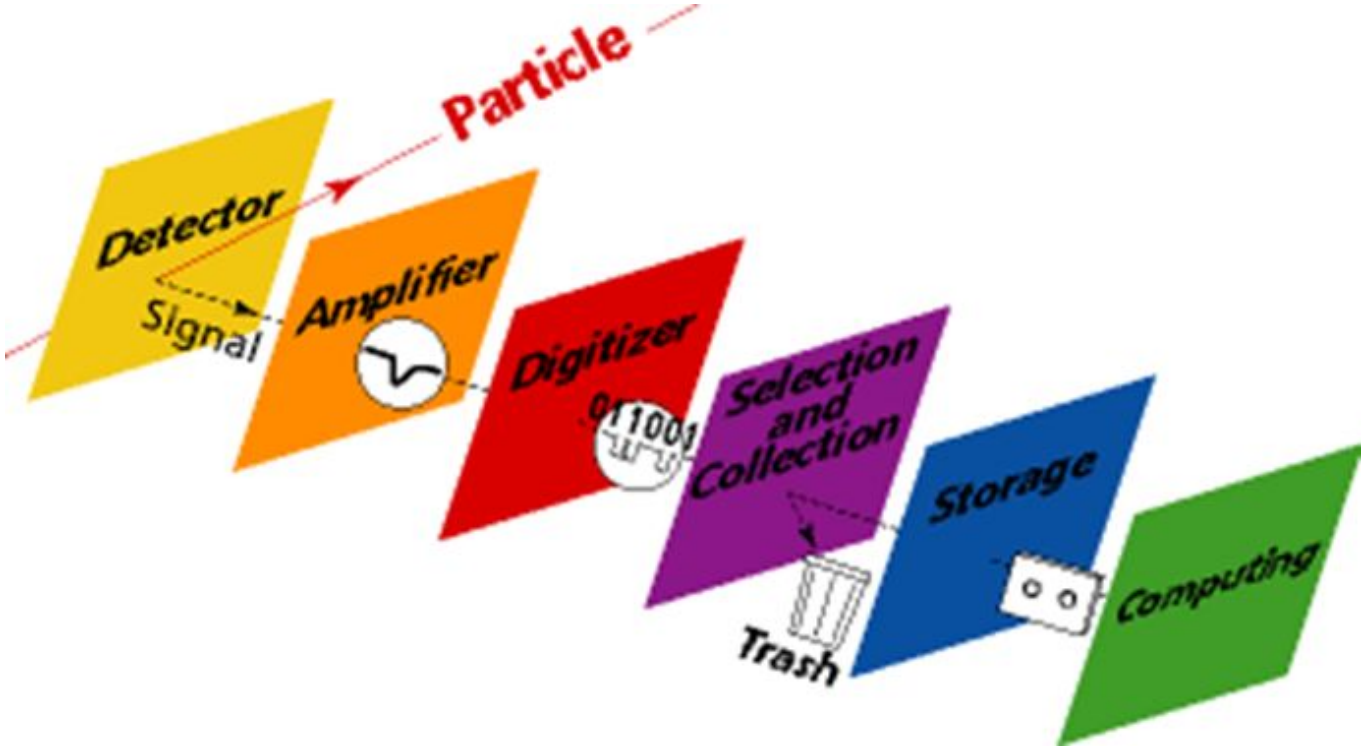


Setup for PMTs long-term stability in LN2

Light Sensors Installation



Technological Capabilities by areas



Light Sensors

- Wide experience with Vacuum tubes (PMTs), silicon (SiPMs, APDs) and large área sensors based on light guides + SiPMs

- Characterization and feasibility study for use in the experiments:

•Construction of specific test systems to explore the limits of the sensors in terms of temperature (down to -196C) and detection wavelength (down to 128nm).

•Design of the electronics required for the tests and software programming for data acquisition and control of the cryogenic systems.

•Measurements of sensor efficiency versus wavelength, temperature, and stability over time.

Light Sensors

- Collaboration with manufacturers for the characterization and optimization of sensors at cryogenic temperatures (se puede pasar a TT).

- Study and characterization of light guides and wavelength shifters for the construction of large-area sensors based on small sensors (SiPMs) sensitive to VUV light in cryogenic environments.

- Fabrication and validation of large-area modules.

- Design, validation and installation response monitoring systems of the sensors for use during the detector operation.

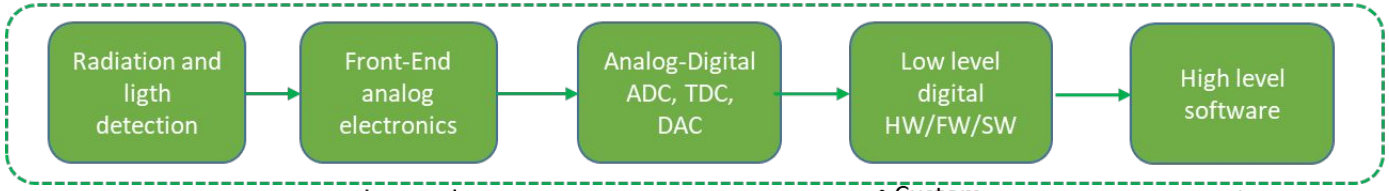
- Installation and monitoring of their performance in the detectors.

Scientific Instrumentation Division. Technology Department.

- Critical collaboration for instrumentation development with Technology Department (5~6 FTE).
- Group of electrical engineering devoted to scientific instrumentation, from sensors to high level software
- Expertise in space and demanding environments.

- **Lluis Freixas Coromina, AMS/HERD-50%**
- **Jesús Marín Muñoz, AMS/HERD-50%**
- **Gustavo Martínez Botella, CTA-90%, AMS/HERD-10%**
- **Javier Sastre Álvaro, CMS-90%, CTA-10%**
- **Antonio Verdugo de Osa, Neutrinos- 100%**
- **Juan de Vicente Albendea, COSMO-100%**

R+D, Assembly, Integration, Verification, Calibration, Comissioning



- PMTs, SiPM, APDs
- Gaseous detectors
- Solid state detectors
- Solid and liquid scintillators

- Analog and mixed-signal ASICs development
- High speed-high precisión systems
- Europractice membership
- PCB CAD design

- Switched capacitor arrays
- Charge integration
- ~Gs/s@12-14bit
- Flash, pipeline, SAR
- ~ps TDCs
- High speed discriminators

- Custom hardware
- FPGA: Xilinx, Altera, Microsemi
- Microprocessors
- High speed serial and optical links
- HLS, SoCs

- Virtual instrumentation (LabView)
- Radiation simulations (Geant4-GamOS)
- Python, C++
- DAQ & Control

Electronics (propuesta)

Project planning and management

Design (specific to the different types of sensors)

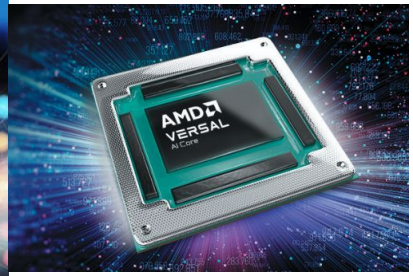
- Analog circuits (amplifiers, signal conditioning, power supplies)
- ASICs
- FPGAs
- A/D converters
- Data reduction/optimization

Prototyping and validation

Manufacturing

Production control

Installation and maintenance



Artificial Intelligence on FPGAs

- Collaboration with UCM, Oviedo, IFIC
- Some projects requested:
  - Misiones (CDTI) AI on satellites for fire detection
  - Proof of concept: TRIDAQ and IA on FPGAs for Space
- TFM just presented (Muon trigger algorithms, DNN, Spiking Neural Networks)
- Activity on the rise with many industrial partners interested (Quasar, INDRA (Deimos), etc)

Technology Transfer

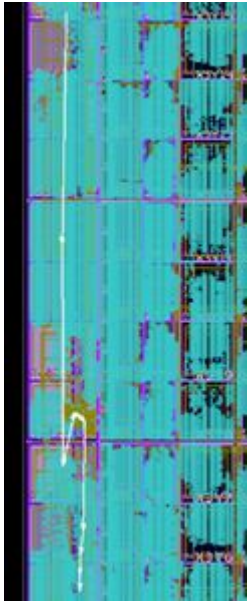
Industrialization of the LST for CTAO

- **Research service contract with Arquimea** signed for the construction of the CTAO telescopes.
- In close collaboration with the **Scientific Instrumentation Division (Technology Department)**
- **Transfer of hardware and firmware designs** for the **Trigger and Clock Distribution System** of the LST cameras
- Definition of **quality control setup and procedures** for production
- **Technical support for the mass production of 2,000 units**
- Execution of **automated in-house robotic quality control tests**
- Delivery validation for **2,000 units of the L1 Trigger Decision ASIC**, developed at **CIEMAT** for the **LST Camera Trigger system**

Highlights in electronics: Trigger and FPGAs

Contribution to the DRD7.5 DAQOverflow

- Challenging algorithm for the CMS Muon Trigger has evolved into useful tools for the firmware community.
  - Development of a sw suite for advanced FPGA placement and timing closure



Artificial Intelligence on FPGAs

- Collaboration with several groups in Spain Red COMCHA
- Some projects requested
- Activity on the rise with many industrial partners interested (Quasar, INDRA (Deimos), etc)