CNID Strategic Planning
WG9 - Scintillators and photodetectors
Contributors (Conveners and groups)

1 Executive Summary

This document outlines the strategic landscape for national research groups working with scintillators and photodetectors. The participating groups demonstrate world-class expertise in several areas including development of state-of-the-art scintillator detectors for calorimetry, fast-timing techniques, neutron detection, medical applications. Expertise extends to electronics and ASIC design, ultra-low background methods for rare event searches and other fields. Key application domains range from fundamental physics experiments to high-impact medical imaging and space instrumentation. The community is supported by strong infrastructure, including clean room facilities and comprehensive optical and electronic characterization laboratories. Despite these strengths, critical bottlenecks do exist, particularly regarding the availability of engineering staff and access to specialized experimental facilities. Strategic priorities therefore focus on strengthening knowledge and technology transfer activities, in particular regarding stronger synergies between working groups in readout electronics and detector mechanics and fostering applications to the medical field and other areas of interest.

2 Findings and strategic recommendations

2.1 Scientific and Technical Focus Areas

- Development, characterization, and operation of inorganic scintillators (e.g., NaI(Tl), CsI) in combination with advanced photodetectors, including calorimetry, operation in ultra-low background environments, fast-timing techniques for precision measurements in nuclear physics, among others. **There is a clear complementarity with several WGs that require scintillators and photodetectors, mainly: WG4 Calorimetry, WG8 Applications and WG12 Low-Background experiments**.

- Design and implementation of low-noise, high-speed analog, digital, and mixed-signal ASICs for photosensor readout, including SiPMs, PMTs, and MCPs. **There is strong overlap with the Electronics WG6 in ASIC development, front-end readout, and DAQ systems**. For ASICs, this overlap is to be expected, as they are inherently application-specific and hence both WG are involved. However, close coordination will be essential to optimize resources and avoid duplication of effort. DAQ systems can be probably shared and reused.

- Development of high-throughput, dead-time-free data acquisition systems, including pile-up mitigation strategies and the integration of machine learning methods for real-time event discrimination.

- Strong involvement in major international experiments across particle, nuclear, astroparticle, and neutrino physics: ANAIS, CERN ISOLDE, CERN n TOF, CERN LHCb, CTA, DarkSide, FAIR NUSTAR, R3B, GANIL-NA2STARS, IGISOL, LIDAR, LiquidO, MRR-HISTARS, MRR-NTOF, NTOF-9, PATRIC, REMO, RIKEN, T2K.

- Involvement in consolidated and emerging applications in medical and space instrumentation.

2.2 SWOT Analysis

2.2.1 General

Strengths	**Weaknesses**
• **Advanced electronics design:** High proficiency in front-end electronics, particularly mixed-signal, low-noise, and high-speed ASICs tailored to specialized detector systems. • **State-of-the-art infrastructure:** Access to advanced facilities, including clean rooms (up to class 1,000), specialized optical laboratories, automated ASIC testing platforms, and dedicated computing resources for electronic design. • **International collaboration:** Active participation in major international experiments, demonstrating strong integration within global research efforts. • **Knowledge and technology transfer:** Established track record of collaboration with industry and the creation of spin-offs supporting technology commercialization.	• **Personnel constraints:** Limited availability of engineering and technical staff, leading in some cases to delayed or suspended projects. • **Structure of personnel:** High ratio of temporary researchers and students relative to permanent staff, potentially affecting long-term continuity. The significant shortage of permanent engineering and technical positions in universities is particularly problematic. • **Dependence on external infrastructure:** Reliance on external irradiation facilities, particle accelerators, and dedicated beam times for detector characterization.
Opportunities	**Threats**
• **Expansion in medical imaging:** Strong potential for developing advanced detector technologies for PET, CT, and proton therapy, particularly within the One Health framework. • **Access to competitive funding:** Availability of major European and international funding schemes, as well as space-related programs, supporting growth and innovation.	• **Project discontinuity risks:** The planned decommissioning of major experiments may disrupt research continuity if not matched by timely new initiatives. • **Competitive funding environment:** High dependence on competitive grants and industrial partnerships introduces financial uncertainty.

2.2.2 WG9 specific

Strengths	Weaknesses
• **Deep technical expertise:** Strong capabilities in the design, characterization, and implementation of detectors based on photosensors (SiPM, PMT, MCP) and scintillators, including inorganic, liquid, and opaque materials.	• **Lack on national fabrication capability:** There is no industrial capability in Spain for the fabrication of photosensors—whether solid-state, vacuum-based, or nano-engineered—as well as for ASIC development. This gap is only partially addressed by the R&D activities of certain public foundries and research labs.
Opportunities	**Threats**
• **Next-generation scintillators:** Opportunities for innovation in opaque scintillators and ultrafast materials such as Lu_2O_3Yb. • **Technological transition:** Ongoing shift from traditional PMTs to SiPM-based systems enables modernization of both scientific and industrial instrumentation.	• **Technical integration challenges:** Risks associated with adopting new technologies, including maintaining signal integrity and performance in demanding environments such as ultra-low background conditions.

2.3 Infrastructure and Capability Mapping

The community benefits from a robust and well-developed infrastructure supporting detector research and development. This includes access to cleanroom facilities, automated platforms for large-scale ASIC characterization, and underground laboratories for ultra-low background experiments. In addition, laboratory environments are equipped with advanced optical setups, fast electronics instrumentation, and calibrated light sources, enabling comprehensive detector testing and validation. Strong electronic design capabilities are further supported by industry-standard EDA tools and dedicated computing resources, allowing full-cycle ASIC development from concept to implementation.

- Catalogue of instrumentation infrastructures.

Infrastructure	**External access**	**Description**
ANAIS / Zaragoza Detector Facilities	–	Test bench for scintillator assembly and operation; large glove box; cryogenic facility (down to ∼100 K); underground experiment infrastructure (ANAIS-112, being decommissioned).
CIEMAT Nuclear Innovation group	–	Different types of scintillators (LaBr3, LaCl3, CeBr3, CLYC, EJ200, EJ276D, EJ301) fully digital DAQ system, electronics equipment, glovebox and laboratory with radioactive sources, pulsed laser source access to climatic chamber and intense gamma and neutron sources (LMRI-CIEMAT), Mechanic workshops
ICCUB Photodetector and Electronics Labs	–	Optical setups for photodetector characterization (light-tight boxes, lasers, LEDs, optical benches); general-purpose electronics labs (oscilloscopes, generators, digitizers); A prototype workshop; clean room (class 1,000–10,000); Microfocus 150 kV X-Ray Tube
ICCUB Automated Quality control	–	Robotized set-up for quality control of ASICs in mass production (150,000 units tested so far).
IFIC Medical Imaging and Detector Facilities	–	Compton camera; small-animal PET/CT; dead-time-free DAQ systems; instrumentation lab; climatic chamber; clean room; liquid radioactive source handling facilities.
IFIC Nuclear Spectroscopy Detector Arrays	–	Total Absorption Spectrometers (NaI, BaF_2); Compton camera arrays ($LaCl_3$(Ce)-SiPM); neutron/gamma detector systems (CLYC, CLLBC); scintillator arrays (stilbene, R3B setups).
IFAE Gamma-ray Instrumentation Lab	–	Electronics lab (function generators, oscilloscopes, attenuators); optical setups; custom fast readout electronics for high-rate applications.
IFAE Optical and Electronics Laboratories	–	Optical laboratory and electronics development facilities for detector characterization and readout systems.
i3M (XLAB) Imaging and Spectroscopy Infrastructure	–	Fluorescence spectrometer; streak camera (planned); PET and gamma camera characterization setups; prototype CT imaging system (up to 70 kV).
IRIS / Fiber and SiPM Characterization Setups	–	Optical laboratory setups (laser/LED sources, dark boxes) for characterization of scintillating fibers and SiPMs, including space-oriented detector R&D.
UPC Electronics Instrumentation Laboratory	–	550 m^2 high-speed instrumentation lab (up to 20 GHz) with oscilloscopes, spectrum/network analyzers, RF equipment; IC design infrastructure with computing cluster; EDA tools (Cadence, Synopsys, Siemens via Europractice).

- Capabilities and expertise in software frameworks (several groups): Europractice, CAD tools for ASIC and FPGA design, GEANT4, etc.

2.3.1 Human Resources

The participating groups exhibit a heterogeneous distribution of human resources, ranging from small nodes contributing fractional effort to instrumentation R&D to larger, more structured teams. Across the landscape, there is a strong reliance on PhD students, postdoctoral researchers, and hired engineers to carry out core research and development activities. While this model provides flexibility and adaptability, the relatively limited number of permanent technical staff may constrain long-term continuity and the sustained development of complex instrumentation projects.

2.4 Current and Potential National Collaborations

A mature ecosystem for knowledge and technology transfer is already present, supported by sustained collaboration with industrial partners and the creation of some spin-off companies. These partnerships highlight the strong translational potential of the technologies developed within the community. At the technical level, important synergies have been identified, particularly in the transition from PMT- to SiPM-based systems, which requires close coordination between detector development and front-end electronics. Further integration with complementary working groups, especially in mechanics and system integration, is expected to play a key role in advancing detector deployment and system-level optimization.

2.4.1 Industry, Hospitals, and Knowledge & Technology Transfer (KTT) Actors

The WG9 community has established multiple interactions with industry, hospitals, and non-academic actors through both formal collaborations and targeted KTT activities. Several groups are actively engaged in technology transfer in the domains of medical imaging, nuclear instrumentation, and environmental monitoring.

In particular, strong links with the medical sector are evidenced by the development of PET detectors, gamma cameras, and CT imaging prototypes, often in collaboration with hospitals and clinical research environments. Examples include ongoing public-private partnerships for PET detector calibration systems and medical imaging instrumentation, as well as projects under the One Health framework spanning human, veterinary, and environmental applications.

Industrial engagement is further reinforced through:

- Spin-off companies (e.g., Pulsensing), focusing on the commercialization of photodetector-based instrumentation.
- Participation in national microelectronics initiatives such as MicroNanoSpain, fostering collaboration with SMEs and industry.
- Contracts with industry in areas such as radiation detection, environmental monitoring, and nuclear instrumentation.

These activities demonstrate a strong translational potential of WG9 technologies, particularly in detection systems, fast electronics, and advanced scintillation-based instrumentation.

2.4.2 Cross-WG Collaboration Opportunities

The activities of WG9 show significant overlap and complementarity with other CNID Working Groups, particularly:

- **Electronics WG:** Strong synergy in ASIC design, front-end electronics, FPGA-based DAQ systems, and high-speed signal processing.
- **Mechanics and Integration WG:** Collaboration opportunities in detector packaging, thermal management, and large-scale system integration.

- **Solid-State and Quantum Sensors WGs:** Shared interests in next-generation photosensors (SiPMs, novel materials) and advanced detection concepts.
- **Low-Background and Rare Event WGs:** Complementarity in ultra-low background techniques, scintillator development, and detector shielding.

Several needs identified in WG9, such as multi-channel low-noise readout, irradiation testing, and scintillator development, require coordinated efforts across WGs. In particular, the development of full detector systems—from sensor to electronics and integration—naturally demands cross-disciplinary collaboration.

2.4.3 Concrete Inter-WG Project Ideas

Based on the identified capabilities, needs, and ongoing activities, several concrete inter-WG project opportunities emerge:

- **High-channel-count SiPM readout platform:** A joint effort with the Electronics WG to develop scalable, low-noise ASICs and FPGA-based DAQ systems for large-area SiPM arrays, targeting applications in medical imaging and high-energy physics.
- **Next-generation scintillator detector prototypes:** Collaboration with materials-focused WGs to develop and test opaque and ultrafast scintillators (e.g., Lu_2O_3:Yb), combined with integrated readout and system-level optimization.
- **Radiation hardness and irradiation testing platform:** A coordinated initiative across WGs to establish access to irradiation facilities and develop standardized protocols for SiPM and ASIC qualification under radiation damage conditions.
- **Integrated detector systems for medical imaging:** Joint development of full imaging systems (PET, Compton cameras, proton CT) combining detector physics, electronics, and system integration, in collaboration with hospitals and industry.
- **Space instrumentation demonstrators:** Development of compact, radiation-tolerant scintillator-based detectors for space missions, leveraging synergies between WG9, electronics groups, and space-oriented research teams.
- **Test-beam validated detector prototypes:** Construction and validation of large-scale prototypes (e.g., opaque scintillator calorimeters) requiring coordination with infrastructure and beam-test facilities across WGs.
- **Security:** Neutron dosimeters based on scintillators, waste characterization devices.

These projects align naturally with international R&D priorities and provide a strong basis for joint funding applications (ERC Synergy, EIC Pathfinder, Horizon Europe), while addressing critical gaps identified in the WG9 community.

2.5 Internationalization

The WG9 groups are strongly embedded in international research networks and play active roles in major experimental collaborations across particle, nuclear, and astroparticle physics. Their participation in competitive international funding schemes and multidisciplinary projects enhances both their scientific visibility and their capacity to contribute to large-scale initiatives. This level of international integration is a key asset for maintaining competitiveness and fostering innovation.

WG9 activities are strongly aligned with the CERN ECFA Detector R&D roadmap, particularly DRD4 (Photon Detectors) and DRD7 (Electronics and On-Detector Processing). Expertise in scintillators, SiPM-based systems, fast timing, and mixed-signal ASIC development directly contributes to the scientific and technological priorities of these frameworks.

WG9 groups have also been actively involved in European and international projects over the past five years, including initiatives such as AIDAInnova and related EU programs in detector development, medical imaging, and space instrumentation. Continued participation in Horizon Europe, ERC Synergy, and EIC Pathfinder proposals further strengthens the international position and visibility of the community.

3 Recommendations

3.1 Strategic Priorities for the WG (5-Year Horizon)

Over the next five years, strategic efforts should focus on the development of scalable, low-noise readout electronics for high-channel-count SiPM systems, with a particular emphasis on continuous acquisition and sub-nanosecond timing capabilities. Another are of interest is in large area SiPMs based systems. In parallel, research on next-generation scintillation materials, including ultrafast and opaque scintillators, should be consolidated to enhance detector performance across a wide range of applications. Strengthening local capabilities in detector characterization, particularly through dedicated metrology and irradiation infrastructures, will be essential to support these advanced developments. Another key strategic priority could be fostering partnerships with research institutions and innovative companies that have the capability to develop next-generation photosensor technologies—particularly in solid-state sensing, nanomaterials, and graphene-enabled devices.

3.2 Infrastructure and Resource Optimization

A coordinated approach to infrastructure access is required to maximize efficiency at the national level. In particular, streamlined access to specialized irradiation facilities, such as proton therapy beams and accelerator-based sources, will be critical for detector qualification and radiation damage studies. Complementary investments in shared high-end instrumentation—including high-bandwidth digitizers, advanced optical systems, and high-vacuum environments—are necessary to sustain competitiveness in timing and precision measurement domains.

3.3 Training and Talent Development

Addressing the shortage of engineering and technical personnel is a top priority, as it currently represents a key bottleneck for both basic research and knowledge transfer activities. Establishing stable career pathways and dedicated funding mechanisms will be essential to attract and retain highly qualified staff. At the same time, targeted training in enabling technologies—such as mixed-signal ASIC design, FPGA-based readout systems, and high-performance computing for real-time data processing—should be heavily promoted to ensure the continued development of critical expertise.

3.4 Strategic Risks and Mitigation Measures

A major risk identified across the community is the potential slowdown of R&D activities and reduced knowledge transfer due to insufficient technical staffing. This risk could be effectively mitigated through the implementation of dedicated funding lines aimed specifically at recruiting and retaining experienced engineers and specialized researchers, thereby ensuring long-term continuity and operational efficiency, but no mechanisms for such funding lines have been identified.

3.5 Knowledge and Technology Transfer (KTT)

Building on successful applications in medical imaging, KTT efforts must accelerate the translation of fundamental research into high-impact industrial applications. The inherent dual-use nature of photodetector and scintillator technologies offers substantial commercial opportunities beyond healthcare. Strategic initiatives should explicitly target homeland security (e.g., non-destructive cargo scanning, radiation monitors) and the energy sector, which increasingly relies on precise, radiation-hardened instrumentation. Furthermore, our specialized expertise in high-speed readout electronics and low-noise ASICs is directly transferable to space exploration, environmental monitoring, and automated industrial inspection. Diversifying our KTT portfolio across these domains will foster sustainable public-private partnerships and unlock diverse external funding streams. The CNID could serve as a framework to foster collaboration among groups with complementary expertise, including ideas on applications, detector technologies, scintillators, photosensors, ASIC and front-end electronics, back-end systems, and more.

3.6 Internationalization

Continued and reinforced participation in major European and international programs is essential to maintain the community's visibility and competitiveness. A primary strategic objective must be the active integration into the newly established Detector R&D (DRD) frameworks at CERN. Specifically, aligning national research milestones with DRD4 (Photon Detectors and Particle Identification) and DRD7 (Electronics and On-Detector Processing) will guarantee access to shared technological resources and solidify our position within next-generation high-energy physics experiments. Furthermore, future international proposals should strongly emphasize the dual-use nature of our detector technologies. Highlighting their direct relevance to both fundamental science and high-impact industrial applications—such as space exploration, security domains, and medical imaging—will make consortia applications significantly more competitive. To achieve this, the community must actively pursue leadership roles and concerted participation in PathfinderOpen, EIC, ERC Synergy, and ITN network calls to sustain collaborative, cross-border R&D.

3.7 Funding

The current funding portfolio reflects a balanced combination of national and international projects, spanning fundamental research, detector development, and applied domains such as medical imaging. Significant investments in advanced imaging technologies demonstrate the strong potential for translation toward societal and industrial applications, while continued participation in large-scale scientific projects ensures sustained support for core instrumentation activities.

Diversifying our funding sources is essential to maintain long-term stability, resolve current staffing shortages, and keep our technology moving forward. To fund applied research more effectively, we need to work more closely with private companies and specialized institutes. Building on our successful track record in medical imaging—and expanding into sectors like security and energy—will help us secure public-private partnerships and unlock new regional and national innovation grants. Instead of relying strictly on traditional fundamental physics grants, we should also pursue emerging opportunities in space, defense, and advanced instrumentation. For example, EU orbit demonstration calls are a direct fit for our current work on next-generation photodetectors, ASICs, and scintillators. Above all, we must actively push for stable, dedicated funding for instrumentation R&D at both the national and European levels. It is critical that these funds explicitly support the hiring and retention of experienced engineers, since the lack of technical staff is currently our biggest obstacle to taking on complex, multi-year projects.

3.8 Additional Recommendations

- **Alignment with CERN DRD Collaborations:** We advise fostering better integration with the corresponding Detector R&D (DRD) collaborations at CERN (such as DRD4 for Photon Detectors). Aligning national R&D milestones with these European frameworks will strengthen international presence and improve access to shared technological resources.
- **Cross-Disciplinary Synergies:** There is a critical need to actively search for and formalize synergies across different working groups. In particular, we strongly encourage deeper in-

tegration with the Mechanics and Electronics Work Packages (WP). Co-developing detector encapsulations, lightweight holding systems, and readout electronics concurrently will prevent system-level bottlenecks down the line.

- **Transition to SiPM-Based Systems:** To support the ongoing transition from PMT- to SiPM-based systems without compromising performance, it is highly recommended to organize a dedicated technical workshop. Bringing together experts in photodetectors, front-end electronics, and system integration will facilitate the alignment of technical requirements and accelerate the development of optimized, system-level solutions.

4 Contributing Groups and Contact Points

Group (Organisation)	Contact person	Email
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Table 1: Alphabetically ordered list of groups, contact persons and emails