CNID Strategic Planning
WG6 - Group Topic

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1 Executive Summary (Recommended: one page maximum)

Spanish groups within WG6 demonstrate strong and well-established expertise in detector electronics, with a clear concentration on FPGA-based architectures, data acquisition (DAQ), trigger systems, and signal processing, complemented by capabilities in front-end electronics and full system integration. Their activities span the complete electronic chain, from sensor readout to backend processing. While specialised domains such as ASIC design, RF/microwave electronics, EMC, and power systems are present, they are concentrated in a limited number of groups. Emerging areas include heterogeneous computing, real-time processing, machine learning, and SoC-based platforms, indicating a transition towards more advanced and intelligent detector systems.

R&D activities are aligned with the needs of next-generation experiments, focusing on fast-timing electronics (high-resolution TDCs, synchronisation, calibration) and high-rate DAQ systems with real-time and ML-based processing. Additional efforts include low-noise front-end electronics, ASIC development, power-efficient systems, RF-based readout, and advanced detector integration. These capabilities support a broad range of major international experiments (e.g. CERN, neutrino, astroparticle and nuclear physics), covering developments from front-end electronics to full system-level integration.

The WG6 ecosystem is collaborative but fragmented, with strong nodes (IFIC, IFAE, CIEMAT, IFCA) and multiple national collaborations in areas such as timing, DAQ, ASIC design, and RF systems. There is also growing interaction with industry, particularly in medical imaging, radiation detection, and instrumentation. However, technology transfer remains limited and uneven.

From a strategic perspective, key strengths include a robust digital electronics base, strong participation in international experiments, and complementary expertise across institutions. However, several structural weaknesses persist: limited capacity in advanced ASICs, RF, and power electronics, shortage of skilled engineering staff, lack of standardised design and QA methodologies, and insufficient long-term funding aligned with electronics development cycles. The instability of engineering positions is identified as a critical issue, leading to loss of expertise.

Opportunities lie in better national coordination, development of shared infrastructures (design, test, integration), and stronger alignment with European initiatives (e.g. DRD programmes). There is also potential to expand into emerging domains such as on-detector intelligence, advanced integration technologies, and applications in medical, quantum, and industrial fields. Increased collaboration with RTOs and industry could significantly enhance impact and technology transfer.

Key risks include fragmentation of efforts, loss of talent to industry, insufficient and short-term funding, and potential misalignment with European strategic priorities. Addressing these challenges will require coordinated action, including reinforcement of engineering capacity, consolidation of critical technological areas (ASICs, RF, power), and development of a long-term national strategy for detector electronics within CNID.

2 Findings (Recommended: 4 pages maximum)

2.1 Scientific and Technical Focus Areas

If there is thematic overlap with other WGs, explicitly indicate it in the text. This type of overlap occurs mainly with the Electronics WG; conveners should identify and flag the affected topics.

- Main technological domains and expertise of the participating groups (e.g., tracking detectors, calorimetry, timing, photon detection).

  Spanish groups exhibit a broad and well-distributed set of technological capabilities in detector electronics, with a clear concentration on core digital and readout systems. The most widespread expertise lies in FPGA-based architectures, data acquisition (DAQ), trigger and signal processing, which form the backbone of electronic developments across institutions. These capabilities are complemented by strong activity in front-end electronics and detector-related technologies, including characterization, PCB design, high-density interconnects, detector packaging, and system-level integration, encompassing multi-domain aspects such as mechanical, thermal, and optical coupling.

  More specialized domains, such as ASIC design, advanced microelectronics, RF/microwave electronics, electromagnetic compatibility (EMC), and power distribution—are also present, although concentrated in a smaller number of groups. In addition, there is emerging expertise in heterogeneous computing architectures and real-time processing, including the use of machine learning techniques and System-on-Chip (SoC) platforms in DAQ environments.

- Main R&D topics pursued by the participating groups (e.g., radiation-tolerant vertexing, 5D calorimetry).

  The R&D activities of Spanish groups focus on key technological challenges associated with next-generation detectors. A central line is the development of fast-timing techniques, including high-resolution TDCs, precise synchronization, and calibration methods. In parallel, there is strong activity in high-rate DAQ and trigger systems, incorporating real-time processing and machine learning techniques on heterogeneous computing architectures. Other major topics include ASIC designs, low-noise front-end electronics and power-efficient detector systems. Additional research lines address RF-based readout for quantum and astroparticle applications, as well as advanced integration of calorimetry and tracking systems. Several groups also contribute to multi-detector platforms for nuclear and medical applications.

- Main experiments (if any) targeted by the group's R&D (e.g., FCC, Belle-II, DUNE, n_TOF, ISOLDE, FAIR-NUSTAR, AGATA).

  WG6 electronics efforts support DUNE, Hyper-K, KM3NeT, CTAO, ATLAS, CMS upgrades, LHCb, FAIR-NUSTAR, ISOLDE, n_TOF, ILL, AGATA, NEXT, DarkSide, ProtoDUNE , SBND, IAXO, RADES, CADEX, Virgo, Belle II, RD53, and FCC ranging from FEE to DAQ and system-level integration.

2.2 SWOT Analysis

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
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General:

- Active participation in major international experiments and collaborations.

WG-specific:

- Strong national expertise in FPGA, DAQ, trigger systems, and fast-timing electronics (sub-ns resolution).
- Presence of leading centres (IFIC, IFAE, CIEMAT, IFCA) with full system integration capabilities.
- Complementary and distributed ecosystem, covering most of the electronics chain (front-end → DAQ → processing).
- Access to advanced infrastructures (microelectronics, RF/EMC, detector characterisation and testing).

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General:

- Shortage of skilled technical personnel (engineers and laboratory technicians).
- Low level of technology transfer and insufficient collaboration with industry.
- Fragmentation of advanced capabilities and dependence on a few key centres.

WG-specific:

- Limited national capacity in ASIC design, RF/microwave engineering and EMC/EMI testing.
- Lack of standardized design, validation, tools, and QA workflows across groups.

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<tr><th>Opportunities</th><th>Threats</th></tr>
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General:

- Stronger national coordination through CNID structures and joint roadmapping.

WG-specific:

- Creation of national clusters aligned with European priorities (e.g. DRD7/ECFA).
- Development of a shared national facility for electronics (design, testing, integration).
- Expansion towards new application domains (medical, nuclear, quantum, space, industrial sensing).
- Positioning in emerging technologies: on-detector intelligence (ML).

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General:

- Risk of duplication and misalignment without stronger national coordination.
- Loss of skilled personnel to industry due to unstable career paths.
- Insufficient and short-term funding, limiting long-term planning.
- Slow equipment renewal leading to reduced technological competitiveness.
- Potential misalignment with European strategic priorities if coordination is not reinforced.

WG-specific:

- Dependence on external semiconductor foundry cycles (Europractice, MPW slots) delaying ASIC development.

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2.3 Infrastructure and Capability Mapping

Catalogue of instrumentation infrastructures to be listed in the table below.

Infrastructure	External access	Description
Semiconductor laboratory	Yes	Probe stations; LCR meters and sourcemeters; wire bonders; automatic visual inspection machines.
RF/EMC laboratory	Yes	Semi-anechoic chambers with network and spectrum analysers; ASIC and RF characterisation setups.
Timing and fast-electronics laboratory	Yes	White Rabbit development kits and low-jitter switches; picosecond laser systems for timing calibration; high-speed digitisers and fast-timing test benches.
FPGA/SoC development platform	Limited	Xilinx/AMD FPGA, SoC and RF-SoC development platforms for trigger and DAQ prototyping.
PCB design and assembly service	Yes	PCB fabrication, SMD assembly and BGA reworking facilities.
Electronics workshop	Limited	NIM/VME/custom DAQ chains; bench instrumentation; prototyping support.
ASIC design service (Europractice)	Yes	EDA tool suites for full-custom and semi-custom ASIC design via Europractice access.
Environmental qualification laboratory	Yes	Climatic and thermal chambers for component qualification.

Access to or participation in open/shared facilities (test beams, irradiation facilities, laser facilities, underground labs, RIB facilities, TOF facilities).

Infrastructure	ICTS?	Type of equipment / service
CNA (Seville) – ICTS-IABA ion microbeam (3 MV Tandem)	Yes	Ion microbeam line for Ion Beam Analysis (IBA) and irradiation, supporting techniques such as micro-PIXE, PIGE, RBS, and IBIC for materials/detector characterization.
ITA RF/EMC chambers (Zaragoza)	No	Semi-anechoic chambers open to collaborative EMC characterisation campaigns for detector electronics.
GPU/HPC clusters at large institutions (e.g. IFIC-Artemisa, CIEMAT)	No	High-performance GPU computing for ML-based trigger and reconstruction development.

Capabilities and expertise in software frameworks: Europractice, TCAD, CAD, LabVIEW, ANSYS, COMSOL, MCNP, GEANT4, etc.: Expertise includes Europractice/EDA tools for full-custom and semi-custom ASIC design, FEM modelling for EMC and thermal analysis (ADS, COMSOL, ANSYS), CAD/CAE, Altium, MATLAB and full detector simulation (GEANT4, MCNP, GARFIELD++). FPGA and SoC toolchains, LabVIEW and Python-based DAQ and control frameworks, LabView; and ML frameworks (TensorFlow, Pytorch) deployed on FPGAs for real-time trigger applications.

2.4 Current and Potential National Collaborations

- Existing collaborations among national groups. Explicitly state collaborations with technical groups (technical universities, technological centers, others).

  Extensive national collaboration links the surveyed groups along several electronics-specific axes: CIEMAT-CMS–IFIC–Oviedo on CMS trigger and DAQ R&D, including COTS evaluation on Versal platforms; ITA–IFCA–CIEMAT-CMS on timing distribution and White Rabbit systems; ICCUB–UPC–I3M–USE–LHCb-IFIC forming a de facto ASIC design ecosystem, though not yet formally coordinated; ITA–IMB-CNM–IFCA on front-end electronics and sensor characterisation; IFIC-VEGA–ITA on sub-ns synchronisation systems; and CIEMAT-DivTIC providing electronics and microelectronics design support across multiple CIEMAT groups and external collaborators. Technical universities (UPC, USE, UPV-I3M) supply specialised microelectronics, RF and embedded systems expertise to the wider community. A more in detailed list of the existing collaborations is:

  - In electronics developments there are collaborations between the IFIC and the UGR in a coordinated project for KM3NeT electronics developments.
  - IFCA–IMB-CNM–ITA collaborate in three national projects and AIDAInnova, focusing on timing, tomography, and front-end electronics (FEE) design for pixel detectors.
  - ITA–UNIZAR–UB collaborate in a coordinated national project and in the RADES and IAXO initiatives, with a focus on RF-based readout systems for quantum detectors.
  - Oviedo-IFIC-CIEMAT collaborate on trigger and DAQ R&D including COTS evaluation on Versal platforms.

- Existing collaborations (including KTT projects) with the industrial sector and other non-academic actors (e.g., hospitals).

  Electronics-related industrial partnerships include: USE with Alter Technology and ESA on radiation-robust microelectronics; ITA with industry on power converters and RF systems; UCM-IPARCOS and UCM-Nuclear on embedded AI for PET electronics; I3M with the Valencian health network on DAQ for medical imaging; and CIEMAT-neutrinos with Hamamatsu on readout electronics for cryogenic photosensors. Multiple groups hold patents on electronics designs, and USE and ITA report active technology transfer pipelines in electronics. A more in detailed list of the existing collaborations is:

  - ITA–IMB-CNM and ITA are involved in proof-of-concept developments in muon and proton tomography, with collaborations including Muon Systems and the Hospital Universitario Marqués de Valdecilla..

- Identify synergies among groups requiring coordination.

  Clear synergies for consolidation appear in: ASIC design (pooling ICCUB, UPC, I3M, USE, LHCb-IFIC capabilities and EDA tool access); FPGA firmware and ML acceleration (Oviedo, CIEMAT-CMS, ITA, I3M); RF/EMC characterisation (ITA, USE, IFIC-AITANA); timing and synchronisation (ITA, IFIC-VEGA, CIEMAT-CMS, UCM-IPARCOS); readout electronics for photosensors (LHCb-IFIC, ICCUB, UCM-IPARCOS, CIEMAT-neutrinos); and PCB/packaging/integration (CIEMAT-DivTIC, IMB-CNM, IGFAE).

- Identify possibilities for cross-WG or inter-WG teams addressing a specific small or blue-sky R&D project (e.g., a cross-WG team including groups from the WG on calorimetry and the WG on mechanics; an inter-WG team with groups expert in CMOS and hybrid sensors to develop a high-precision spatial and timing telescope).

  A highly transversal activity that directly impacts the work of WG1–WG5, WG9 and maintains a close relationship with WG7 (mechanical integration), WG10 (detector characterization), and WG8 (applications).

2.5 Internationalization

- How do national priorities align with:

  - ECFA Detector R&D strategy (e.g., DRD3, DRD6).

- Roadmaps of the Coordinating Panel for Advanced Detectors (CPAD) of the Division of Particles and Fields, American Physical Society.
- ApPEC and NuPECC roadmaps.
- Topics of Horizon Europe or other EU instruments.

  WG6 groups align strongly with ECFA DRD priorities through their electronics work. The 11 groups active in DRD7 contribute to five work packages: WP7.1 (data density and power efficiency—ITA, IGFAE), WP7.3 (timing distribution—CIEMAT-CMS, ITA), WP7.4 (interconnect—IMB-CNM), WP7.5 (backend systems and COTS—Oviedo, UCM-IPARCOS, IFIC-TileCal, CIEMAT-CMS) and WP7.6 (packaging—IMB-CNM). Additional electronics- relevant DRD involvement includes DRD1-WG5 (electronics for gaseous detectors—CIEMAT- CMS), DRD3-WG7 (interconnect—IMB-CNM), and DRD6-WP1 (calorimeter electronics—IFIC-TileCal, CIEMAT-Future Colliders). WG6/DRD7 also supports Horizon Europe themes on microelectronics sovereignty, AI-enhanced real-time systems and quantum technologies (WG5/DRD5).

- what is the participation in international European R&D projects in the last five years (e.g., AIDAInnova, EUROLABS, DRD, EUROATOM).

  WG6 maintains significant involvement in DRDs, AIDAInnova, EURO-LABS, Pathfinder and collaborations with CERN, KEK, DESY, FAIR, GANIL, JRC-Geel and ILL, ensuring sustained presence in European detector-innovation networks. Coordination within DRD7 is growing but requires strengthening to increase national visibility and secure leadership positions in work package governance.

3 Recommendations (Recommended: 3 pages maximum)

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

- Key technologies the WG should focus on. Identify key national contributions to R&D programs and enabling technologies in global projects (e.g., FCC-ee, DUNE, NUSTAR-FAIR, n_TOF, ISOLDE, DONES).

  WG6 should focus on electronics technologies with strong national impact and international demand: front-end ASIC design consolidation (analogue, mixed-signal, TDC); FPGA/SoC real-time processing with ML acceleration; high-throughput DAQ and trigger systems exploiting next-generation COTS (Versal and beyond); sub-nanosecond timing distribution and synchronisation (White Rabbit and custom TDCs); RF/microwave readout and processing electronics; power distribution and power-pulsing for large detector systems; radiation-tolerant electronics design and validation; and back-end electronics standardisation aligned with DRD7 work packages.

- Activities or capabilities needing consolidation.

  Consolidation is required in ASIC design, RF/microwave engineering, radiation-hard electronics, dense interconnects and packaging. Stronger engineering support and coordinated access to clean rooms, bonding tools, cryogenic labs and irradiation facilities are needed, together with harmonized methodologies and test procedures.

- Areas where resources should be directed.

  Priority areas include: increasing engineering and technical staff; upgrading shared electronics and sensor; characterization labs; creating national test infrastructures for timing, DAQ/trigger, irradiation and cryogenic/optical systems; supporting microelectronics design cycles and Europractice access; reinforcing participation in DRD actions and European R&D programmes.

- Recommendations to create cross-WG or inter-WG teams addressing a specific small or blue-sky R&D project.

  Promising inter-WG actions include: WG3–WG6–WG7, compact high-precision timing/tracking telescope; WG6–WG9–WG10, national SiPM/PMT characterization facility; WG1–WG4–WG6, ML-enabled FPGA/SoC trigger and DAQ demonstrator; WG5–WG6–WG8, exploratory quantum-enhanced readout concepts. These teams should operate through focused task groups with shared milestones.

- Recommendations of mission-oriented task forces to address a specific critical gap identified in the SWOT's analysis. This task force should bring together the necessary national expertise and resources to close the gap. The task force activities could be partially supported through a focused mini-workshop to define scope, milestones, and required infrastructure or training (in connection with recommendations in 3.3)

  Task forces should address national gaps in ASIC design, RF systems and engineering capacity: – *ASIC Task Force*: IMB-CNM, UPC, IFAE, US and IFIC; – *Timing/Synchronization Task Force*: ITA, IFIC, CIEMAT, IFCA; – *Electronics Integration Task Force*: PCB, EMC/EMI and packaging; – *FPGA/Trigger Task Force*: to coordinate ML-on-FPGA and COTS evaluation for next-generation triggers – *Engineering Workforce Task Force*: training, mobility and retention. Annual workshops should define objectives, milestones and resource needs.

3.2 Infrastructure and Resource Optimization

- Recommendations for promoting the shared usage of infrastructures.

  WG6 should implement shared-access rules for clean rooms, bonding/packaging tools, and laser systems. A coordinated scheduling system and shared training procedures would improve efficiency, with major labs serving as national hubs.

- Equipment investments required to boost competitiveness.

  Investments should prioritize bonding/packaging tools, probe stations, RF/EMC instrumentation, high-speed digitizers, cryogenic benches and shared FPGA/SoC and RF-SoC evaluation platforms, together with enhanced irradiation and optical/VUV facilities,. And shared computing resources for firmware simulation and ML training.

3.3 Training and Talent Development

- Areas of expertise needed (e.g., highly qualified personnel in microelectronics, cryogenics).

  Priority expertise includes ASIC design, RF engineering, firmware/SoC acceleration, timing, cryogenics, packaging, radiation testing and precision mechanics.

- Suggestions for joint training actions (schools, workshops) or to support already existing actions.

  WG6 should promote national schools on FPGA firmware development and ML-on-FPGA, microelectronics design workshops,, complemented by CNID-wide workshops on DAQ frameworks, White Rabbit, and electronics integration best practices.

- Supporting mobility of staff, technicians, or students for training.

  A mobility scheme should enable short-term exchanges for students, technicians and engineers across national hubs and European labs, facilitating transfer of practical expertise.

3.4 Strategic Risks and Mitigation Measures

- Risks to achieving the scientific and technical goals of the WG.

  Loss of trained firmware and ASIC engineers to industry due to non-competitive salaries and contract instability (flagged by ¿80% of groups); funding cycles mismatched to multi-year ASIC design timescales; fragmented EDA tool access limiting design capacity; dependence on external foundry schedules for MPW runs; overcommitment of electronics engineers to approved-experiment construction leaving no capacity for R&D; and risk of know-how loss when key personnel depart.

- Mitigation proposals.

  Long-term engineering contracts with dedicated electronics R&D funding lines; creation of a CNID-recognised "electronics engineer" career track; a national EDA licence pool and coordinated Europractice submission calendar; multi-institution proposals pooling electronics design resources; institutional recognition of electronics engineering contributions in research evaluation; and streamlined administrative procedures for hiring engineers.

3.5 Knowledge and Technology Transfer (KTT)

- Opportunities for knowledge or technology transfer.

  Strong opportunities exist in medical imaging, industrial tomography, neutron detection, cryogenic photodetectors, radiation-hard electronics, RF systems and microfabrication, supported by collaborations with hospitals, companies and multiple spin-offs. Improve and consolidate the relationship with RTOs, engaging them in the WG for long-term engineering and technology transfer support.

3.6 Internationalization

- Actions to promote participation in international R&D projects (e.g., AIDAInnova, EURO-LABS, DRD).

  G6 should strengthen national co- ordination within DRD7 work packages (currently 11 groups across WP7.1, 7.3, 7.4, 7.5, 7.6), increase participation in electronics-related tasks of DRD1–DRD6, expand involvement in Horizon Europe and Chips Act electronics programmes, and pursue leadership in DRD7 WP coordination roles where Spanish groups have critical mass (backend systems, timing distribution).

- Actions to promote participation in international decision-making bodies.

  Encouraging leadership roles in DRD, CPAD, ECFA and collaboration boards—and recognising this engagement institutionally—will increase national influence.

3.7 Funding

- How to foster increased funding levels specifically for instrumentation.

  Dedicated multi-year instrumentation lines, joint multi-institution proposals, co-funded infrastructure upgrades, and support for microelectronics MPW runs are essential to sustain competitiveness.

3.8 Additional Recommendations

A long-term CNID instrumentation roadmap should be developed, integrating WG6 with other WGs and ensuring coordinated national representation in European initiatives. The creation of a national instrumentation forum or yearly CNID instrumentation week would strengthen collaboration, visibility and student engagement.

A Contributing Groups and Contact Points

This appendix lists the groups contributing to the Working Group (WG) and their primary contact points.

Group / Organization	Contact name	Email
CMS Upgrade / CIEMAT	Cristina Fernández Bedoya	cristina.fernandez@ciemat.es
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