Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

INCANTO

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InNovative CAlorimeters for New Topologies and Operation

Ivano Sarra, PI and LNF Local Coordinator

14 July 2025, LNF – Preventivi 2025

Overview & Goals -1-

- **Design and validate innovative ECAL and HCAL prototypes addressing the demands of future collider detectors and high-intensity experiments**

- Guide detector design and reconstruction from the start through detailed **Geant4 simulations**, including optical photon transport and full digitization chains

- **Develop two longitudinally segmented ECAL modules** using dense, fast, radiation-hard crystals (PbF_2 and PWO-UF)
  - One with SiPM matrices for compact, low-power readout in magnetic fields
  - One with fast PMTs for use in high-rate environments (e.g. KOTO-II SAC)

- **Build a ~1.5 λI semi-digital HCAL prototype based on MPGD technology** (MicroMegas and/or μRWELL)
  - High spatial and timing resolution using absorber/sampling layers
  - Improve time resolution (~1 ns) via drift gap and gas optimization, compliant with climate targets

Overview & Goals -2-

- **Implement dedicated front-end electronics**
  - Mix of commercial (e.g. CAEN) and custom solutions
  - Fast timing (sub-100 ps), low noise (~1000 e^-), wide dynamic range (1–100 fC)
  - Shared DAQ with FPGA-based real-time clustering and background rejection
- **Execute extensive test beam campaigns**
  - Validate individual components and integrated ECAL+HCAL systems
  - Benchmark simulation outputs and guide hardware improvements
  - Focus on particle ID, shower reconstruction, and time-resolved energy measurements

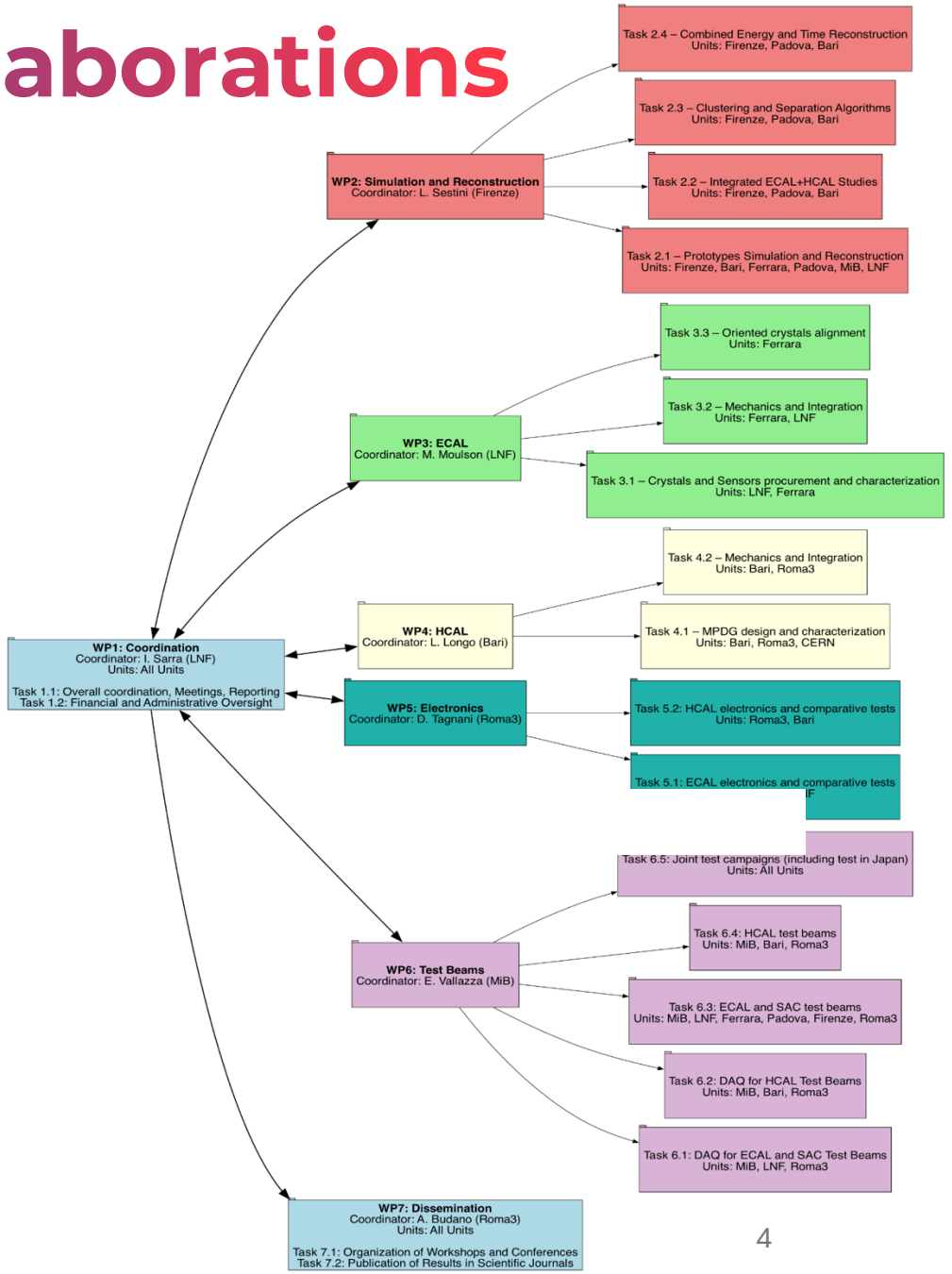
❑ Create **a unified Italian calorimetry community**, **combining expertise in detector development, electronics, simulations, and data analysis**, thus positioning itself at the forefront of global calorimeter R&D efforts.

Project Structure & Collaborations

- INFN Units: **LNF, Ferrara, Firenze, Roma3, Bari, MiB, Padova.**
- International: CERN, Weizmann, J-PARC/KOTO-II, Khalifa Univ.
- Industrial: Hamamatsu (SiPMs), CAEN (electronics).

Work Packages: WP2(Simulation), WP3 (ECAL), WP4 (HCAL), WP5 (Electronics), WP6 (Test Beams).

Ricercatori: 33 (~ 11 FTE)
Tecnologi: 9 (~ 2 FTE)
Tecnici: 7



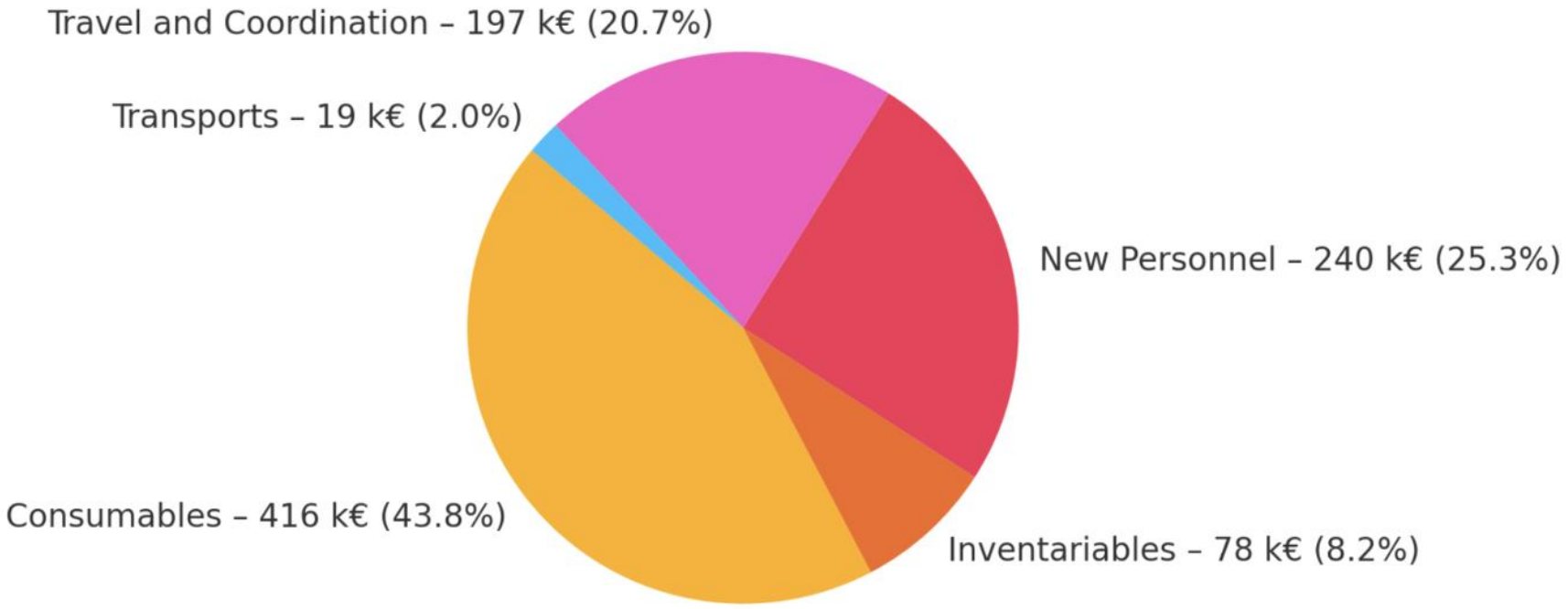
Budget & Timeline

- The total requested budget for the three-year INCANTO project amounts to **950 k€**, distributed across the years as follows:

2026: 279 k€
(74 k€ @ LNF)

2027: 438 k€
(87 k€ @ LNF)

2028: 233 k€
(53 k€ @ LNF)

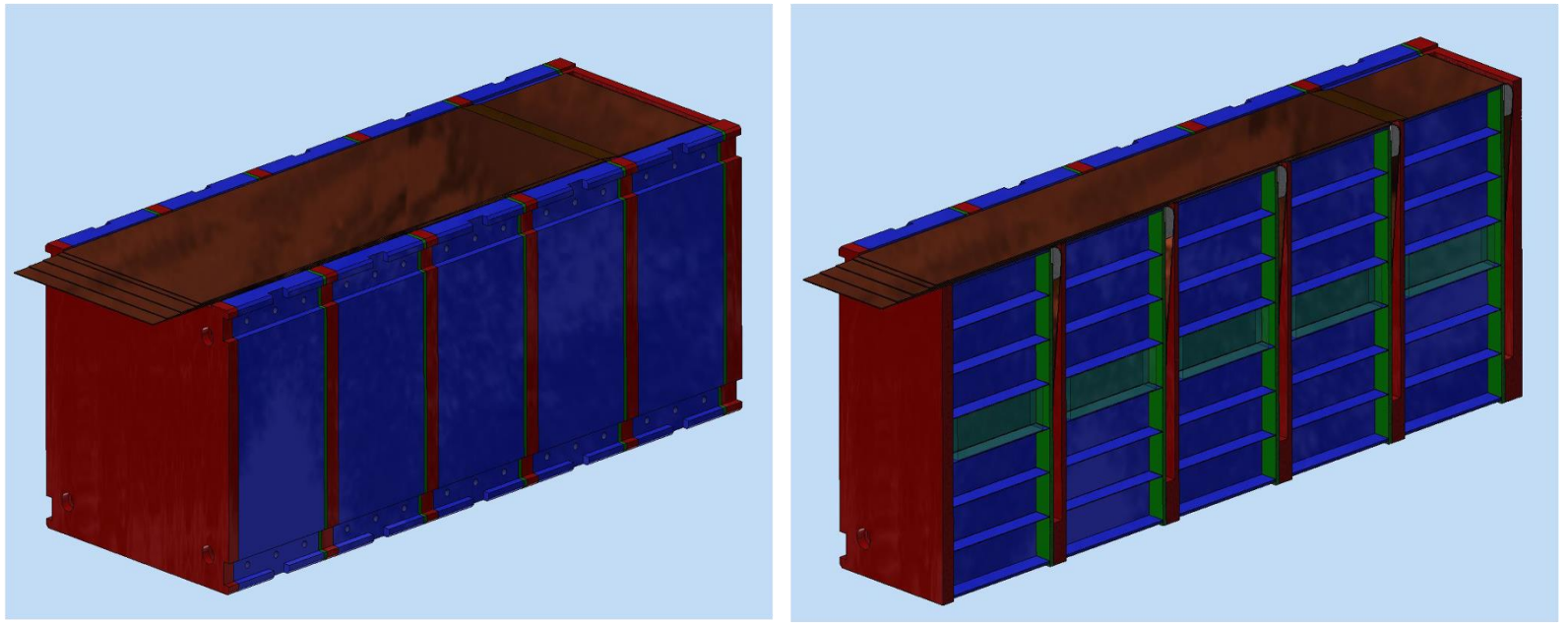


RELEVANT RUNNING PROJECTS

Project	Corresponding INCANTO WPs	Funding source and type	Duration (Start–End)	Still Active in 2026
RD_MUCOL	WP2, WP3, WP4	INFN Commissione 1	from 2021	yes
OREO	WP3, WP6	INFN Commissione 5	2023 - 2025	no
DRD6	WP3, WP4	INFN Commissione 1 e 5	2024 - 2026	yes
DRD1	WP4	INFN Commissione 1	2024 - 2026	yes
PRIN2022 CALORHINO	WP2, WP3, WP4	MUR - PNNR	2024 - 2025	no
MUCOL	WP2	Commissione Europea	2023 - 2027	yes
AIDAinnova	WP3	Commissione Europea	2022 - 2025	no

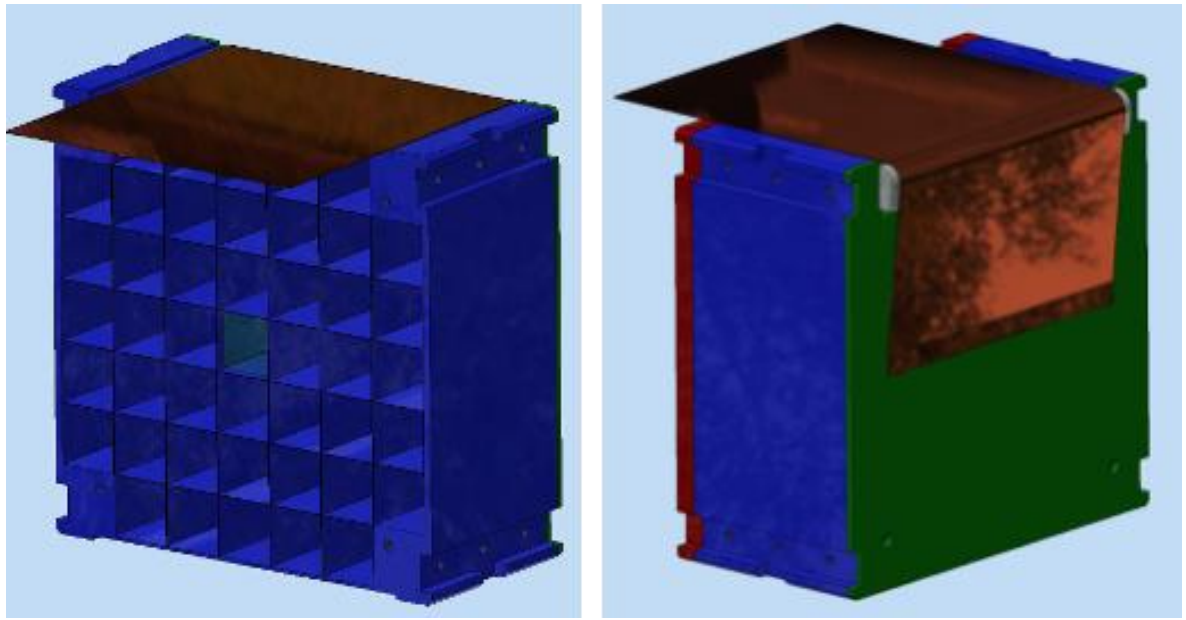
INCANTO @ LNF: CRILIN

- Longitudinally segmented readout allows a detailed reconstruction of the shower development, improving both particle identification and pileup rejection
  → **Concept from the CRILIN calorimeter, conceived and developed at LNF within the RD_Mucol group (Group 1).**



@ LNF: new readout

- Within the frame of the call, a new, improved electronics readout will be developed, with signals from SiPMs transmitted via impedance-matched traces on rigid-flex Kapton PCBs, minimizing space usage while preserving signal quality.



- 150 μm aluminum honeycomb foils for crystal housing and support (left) and detail of rigid-flex readout per layer (right)

@ LNF: HIKE-SAC for KOTO-II

- Longitudinally segmented readout can be adapted to the physics case.

- **For the SAC of KOTO-II, the INCANTO focus is on ultra-fast PMT readout and both oriented and non-oriented PWO-UF crystals for photon vetoes in high-intensity environments.**

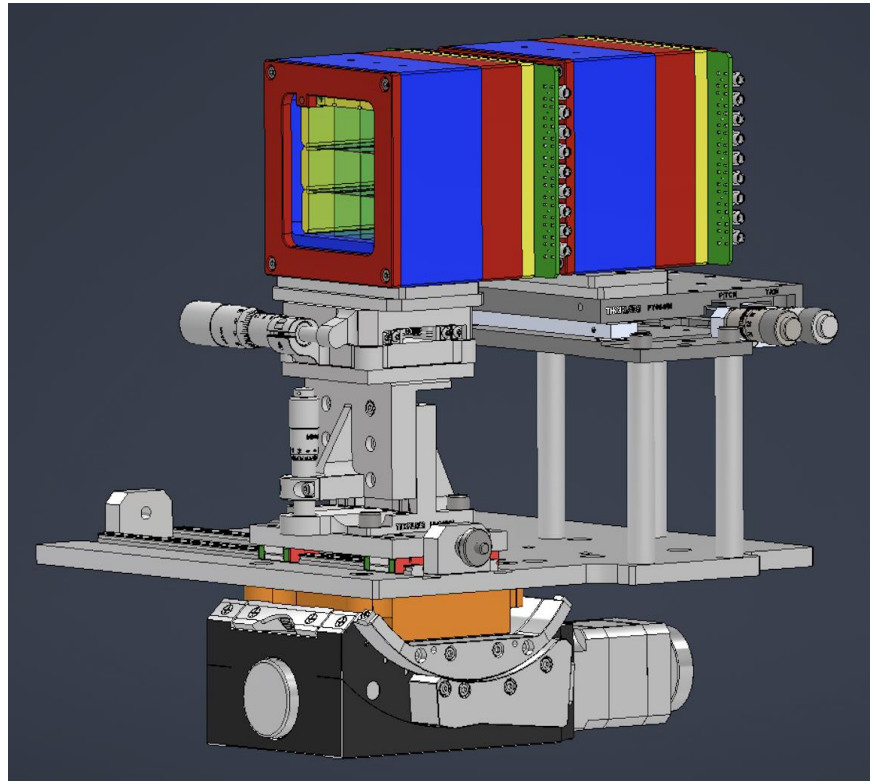
- This design has been firstly proposed within the context of the HIKE experiment proposal at CERN

- The CSN5 ORiEnted calOrimeter (OREO) project has shown that aligning **PWO or PbF_2 crystals with their main lattice axes along the beam direction** (within a few mrad, up to ~1°) **significantly accelerates electromagnetic shower development**.

Test beam in Japan

- A dedicated test campaign is also foreseen at J-PARC, under the neutral beam line of the KOTO experiment, to evaluate the performance of the SAC and MPGD-HCAL prototypes in a realistic high-intensity environment.

- The ECAL prototype will demonstrate the benefits of crystal orientation for compactness and angular resolution. Layers of crystal matrices are aligned along the longitudinal axis via linear and rotational stages.



SiPM at cryogenic temperatures

- Silicon photomultipliers (SiPMs) and photomultiplier tubes (PMTs) will be **tested and characterized** under various operating conditions, **including operation at cryogenic temperatures at the COLD Lab of LNF for SiPMs**.

- We will extensively test new-generation SiPMs from Hamamatsu, **including radiation-tolerant and IR-extended versions originally developed for the automotive sector**.

- The **radiation tolerance** of different photosensors in isolation and photosensor/crystal test assemblies will be studied at gamma-ray and hadron-beam irradiation facilities.

- Collaboration with Hamamatsu will enable access to cutting-edge sensor technologies, including extended-wavelength and radiation-tolerant SiPMs.

LNF Research unit

Research unit	Name	Position	FTE 2026	FTE 2027	FTE 2028	Expertise useful for the project
LNF	Ivano Sarra	Tecnologo	0.4	0.4	0.4	INCANTO PI, Local and WP1 coordinator, expert in calorimeter development and front-end electronics
	Matthew Moulson	Primo Ricercatore	0.2	0.2	0.2	WP3 coordinator, expert in calorimeter development and data analysis
	Fabio Happacher	Primo Ricercatore	0.2	0.2	0.2	Expert in calorimeters' mechanical integration.
	Stefano Miscetti	Dirigente di Ricerca	0.1	0.1	0.1	Expert in calorimeter development, DAQ, and data analysis
	Silvia Martellotti	Ricercatore	0.2	0.2	0.2	Expert in calorimeter development, simulation, and data analysis
	Simone Bini	Tecnologo	0.2	0.2	0.2	Vacuum and cooling expert
	Elisa Di Meco	Post Doc	0.3	0.5	0.5	CRILIN, DAQ, and data analysis expert
	Vittoria Ciccarella	PhD	0.3	0.3	0.3	CRILIN, and data analysis expert
	Sergio Ceravolo	Tecnico	0.3	0.3	0.3	Head of LNF electronic design unit
	Alessandro Russo	Tecnico	0.3	0.3	0.3	Head of LNF detector development unit
	Hiring personnel	Post Doc	-	1	1	Testing of calorimeter components and data analysis

- **10 people – 2.5 FTE** (2026)
- **11 people – 3.7 FTE** (2027-2028)

The project foresees the recruitment of postdoctoral researchers to support key R&D activities, particularly in simulation, detector development, and test beam operations.

LNF Financial Request

	WP	Item Description	Required funds (k€)			Type
			2026	2027	2028	
LNF	3,6	Material transportation to CERN, JPARC, INFN Sections	-	1	2	Trans.
	3	60 Crystals for SAC	45	-	-	Cons.
	3	20 PMT Hamamatsu R9880	-	20	-	Cons.
	3	PMTs PCB for 3 layers	-	5	-	Cons.
	3	R&D IR SiPMs for cryogenic studies	4	-	-	Cons.
	3	LHe for two cool down: 6 keuro	6	-	-	Cons.
	3	Pass-through, fibers, and components	5	-	-	Cons.
	3,5,6	CAEN FEE board DT5204	8	-	-	Inv.
	3,6	Cables for SAC and ECAL	-	10	-	Cons.
	2,3,6,7	Human resources (PostDoc)	-	30	30	PostDoc
	1,2,5,7	Coordination, meetings, and conferences	6	6	6	Travel
	6	Test beams	-	15	15	Travel
		Total LNF	**74**	**87**	**53**	**214**

- Additional €30k allocated to ECAL electronics at Roma3 (in 2026).

COMMITMENT REQUIRED TO LNF SERVICES

Unit	Service	Commitment Required per year
LNF	Local Administration	Purchasing and Travel Procedures
	Electronics and Automation	4 M.U
	Detector Development	4 M.U
	COLD Lab	30 days

Backup slides

COMMITMENT REQUIRED TO INFN

Unit	Service	Commitment Required per year
LNF	Local Administration	Purchasing and Travel Procedures
	Electronics and Automation	4 M.U
	Detector Development	4 M.U
	COLD Lab	30 days
Bari	Local Administration	Purchasing and Travel Procedures
	Mechanical design and workshop	2 M.U
	Electronics	1 M.U
	Computing resource	Use of the data center ReCaS-Bari
Ferrara	Local Administration	Purchasing and Travel Procedures
	Mechanical design and workshop	4 M.U
Roma3	Local Administration	Purchasing and Travel Procedures
	Mechanical design and workshop	1 M.U
	Electronics	4 M.U
MiB	Local Administration	Purchasing and Travel Procedures
Firenze	Local Administration	Travel procedures
	Computing resource	Use of local computing resources
Padova	Local Administration	Travel procedures
	Computing resource	Use of local computing resources

INCANTO risk assessment

Risk	RPN	Mitigation	Backup Plan
Delay in the delivery of crystals, SiPMs, PMTs, or electronics	2	Early orders, use of backup suppliers, and tests with available components	Focus on simulations and algorithm development while waiting
Delay or issues in the development of new commercial electronics for the MPGD HCAL and ECAL	2	Start custom electronics design early and collaborate with DRD1 for MPGD and DRD6 for ECAL	If delays occur, use fallback electronics for initial validation and focus on mechanical prototyping and simulation
Underperformance of detector prototypes	2	Test different readout options, improve mechanics and electronics, and validate with lab setups	Use the best-performing design; reduce complexity for the test beam
Delay or cancellation of beam tests (e.g., at CERN SPS)	2	Prepare for multiple facilities; do preliminary tests in local labs	Reschedule tests or focus on offline studies if the beam time is not available
Poor performance of reconstruction or ML-based trigger algorithms	1	Start algorithm development early with test and MC data; collaborate with DRD6 experts	Adjust goals to focus on reachable performance (e.g., timing only)
Lack of manpower or coordination issues between partners	1	Clear task sharing, regular meetings, and redundancy in critical roles	Reassign tasks internally; delay non-essential work if needed
Budget is tight, and some component costs are uncertain	2	Most estimates are recent; external groups are expected to contribute resources	Reduce secondary activities; support from CSN 1 or associated collaborations if needed

Financial Request: Total

	WP	Item Description	Required funds (k€)			Type
			2026	2027	2028	
LNF	3,6	Material transportation to CERN, JPARC, INFN Sections	-	1	2	Trans.
	3	60 Crystals for SAC	45	-	-	Cons.
	3	20 PMT Hamamatsu R9880	-	20	-	Cons.
	3	PMTs PCB for 3 layers	-	5	-	Cons.
	3	R&D IR SiPMs for cryogenic studies	4	-	-	Cons.
	3	LHe for two cool down: 6 keuro	6	-	-	Cons.
	3	Pass-through, fibers, and components	5	-	-	Cons.
	3,5,6	CAEN FEE board DT5204	8	-	-	Inv.
	3,6	Cables for SAC and ECAL	-	10	-	Cons.
	2,3,6,7	Human resources (PostDoc)	-	30	30	PostDoc
	1,2,5,7	Coordination, meetings, and conferences	6	6	6	Travel
	6	Test beams	-	15	15	Travel
		Total LNF	**74**	**87**	**53**	**214**
Bari	4,6	Material transportation to CERN, JPARC, INFN Sections	2	2	5	Trans.
	4	Gas	5	5	5	Cons.
	4,5	Test ASIC	15	-	-	Cons.
	4,5	Evaluation Board	20	-	-	Cons.
	4	MPGD Prototype Cathode Production	5	-	-	Cons.
	4	MPGD Cathode Production	-	25	-	Cons.
	4	HV CAEN SY + HV Board		25		Inv.
	4	Cables	-	10	-	Cons.
	4,5,6,7	Human resources (PostDoc)	-	30	30	PostDoc
	1,2,4,5,7	Coordination, meetings, and conferences	3	3	3	Travel
	6	Test beams	-	15	15	Travel
		Total Ba	**50**	**115**	**58**	**223**
Ferrara	3,6	Material transportation to CERN, JPARC, INFN Sections	-	1	2	Trans.
	3	Mechanics for ECAL		5		Cons.
	3	Ingots of scintillating crystals for Oriented ECAL prototype	30	-	-	Cons.
	3	Robotic gripper for crystal handling	8	-	-	Inv.
	3	Vision system for a robot	12	-	-	Inv.
	3	Movable stages (rotational/linear) for relative alignment between the oriented layers	4	-	-	Cons.
	3	UV curable glue	2	-	-	Cons.
	2,3,7	Human resources (PostDoc)	-	30	30	PostDoc
	1,2,3,7	Coordination, meetings, and conferences	3	3	3	Travel
	6	Test beams	-	12	12	Travel
		Total Fe	**59**	**51**	**47**	**157**
Roma3	3,5	ECAL custom front-end electronics production	30	-	-	Cons.
	4,5	Cooling plates and pipes for elec. chips HCAL	-	10	-	Cons.
	4,5	mini Chiller	-	10	-	Inv.
	4,5	Mechanical support for electronics HCAL	-	-	10	Cons.
	4,5	HCAL front-end elec. production	30	90	-	Cons.
	1,3,4,7	Coordination, meetings, and conferences	3	3	3	Travel
	6	Test beams		10	10	Travel
		Total Roma3	**63**	**123**	**23**	**209**
MiB	6	Material transportation to CERN, JPARC, INFN Sections	-	2	2	Trans.
	3,6	CAEN V2751 FADC for SAC acquisition	15	-	-	Inv
	6	Development of modules for test beams	10	10	-	Cons.
	1,2,7	Coordination, meetings, and conferences	2	2	2	Travel
	6	Test beams	-	5	5	Travel
		Total MiB	**27**	**19**	**9**	**55**
Firenze	2,6,7	Human Resources (PostDoc)	-	30	30	PostDoc
	1,2,7	Coordination, meetings, and conferences	4	3	3	Travel
	6	Test beams		5	5	Travel
		Total Firenze	**4**	**38**	**38**	**80**
Padova	1,2,7	Coordination, meetings, and conferences	2	2	2	Travel
	6	Test beams	-	3	3	Travel
		Totale Padova	**2**	**5**	**5**	**12**
		TOTAL SUM	279	438	233	**950**

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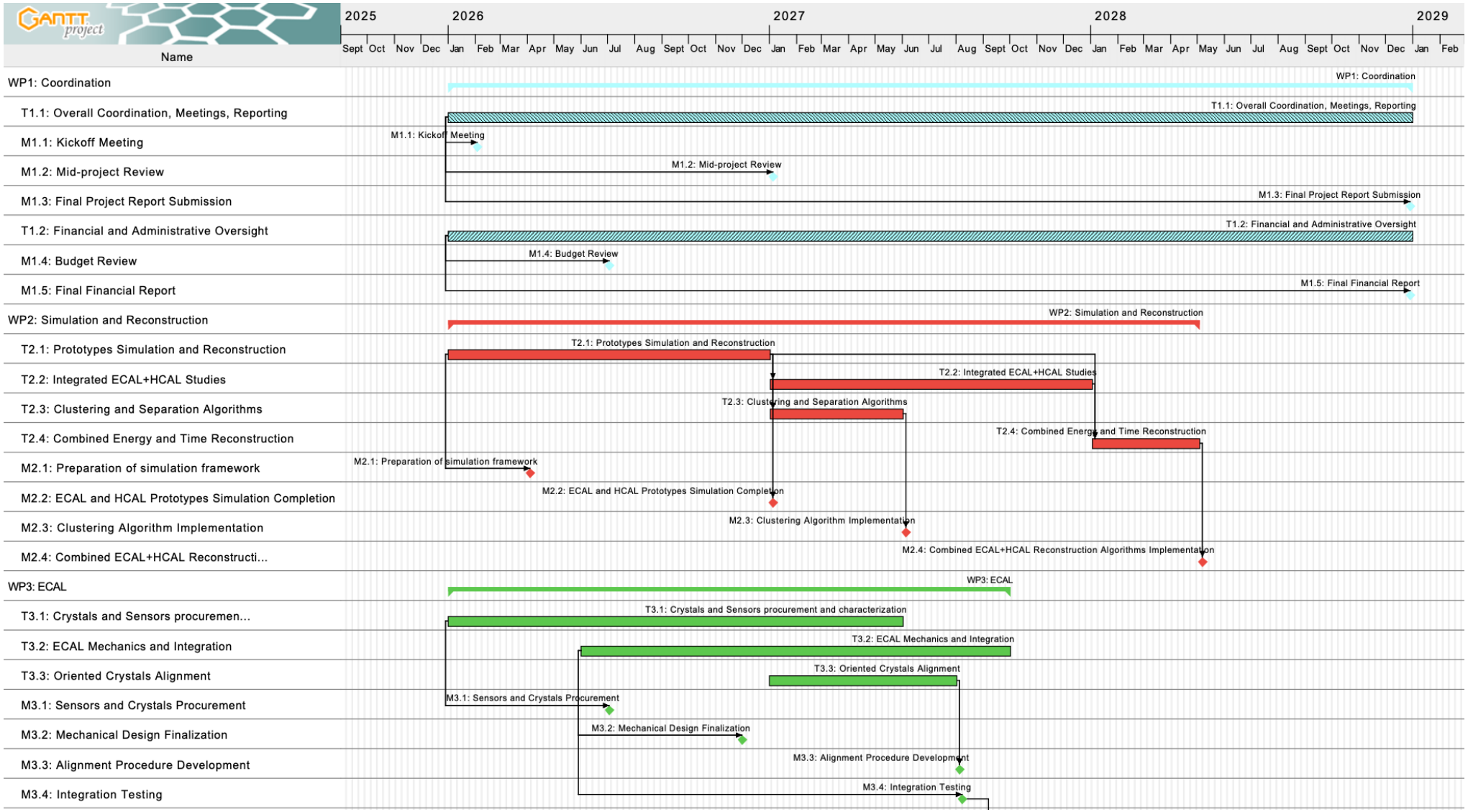
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Name
WP1: Coordination
T1.1: Overall Coordination, Meetings, Reporting
M1.1: Kickoff Meeting
M1.2: Mid-project Review
M1.3: Final Project Report Submission
T1.2: Financial and Administrative Oversight
M1.4: Budget Review
M1.5: Final Financial Report
WP2: Simulation and Reconstruction
T2.1: Prototypes Simulation and Reconstruction
T2.2: Integrated ECAL+HCAL Studies
T2.3: Clustering and Separation Algorithms
T2.4: Combined Energy and Time Reconstruction
M2.1: Preparation of simulation framework
M2.2: ECAL and HCAL Prototypes Simulation Completion
M2.3: Clustering Algorithm Implementation
M2.4: Combined ECAL+HCAL Reconstructi...
M2.4: Combined ECAL+HCAL Reconstruction Algorithms Implementation
WP3: ECAL
T3.1: Crystals and Sensors procuremen...
T3.1: Crystals and Sensors procurement and characterization
T3.2: ECAL Mechanics and Integration
T3.3: Oriented Crystals Alignment
M3.1: Sensors and Crystals Procurement
M3.2: Mechanical Design Finalization
M3.3: Alignment Procedure Development
M3.4: Integration Testing

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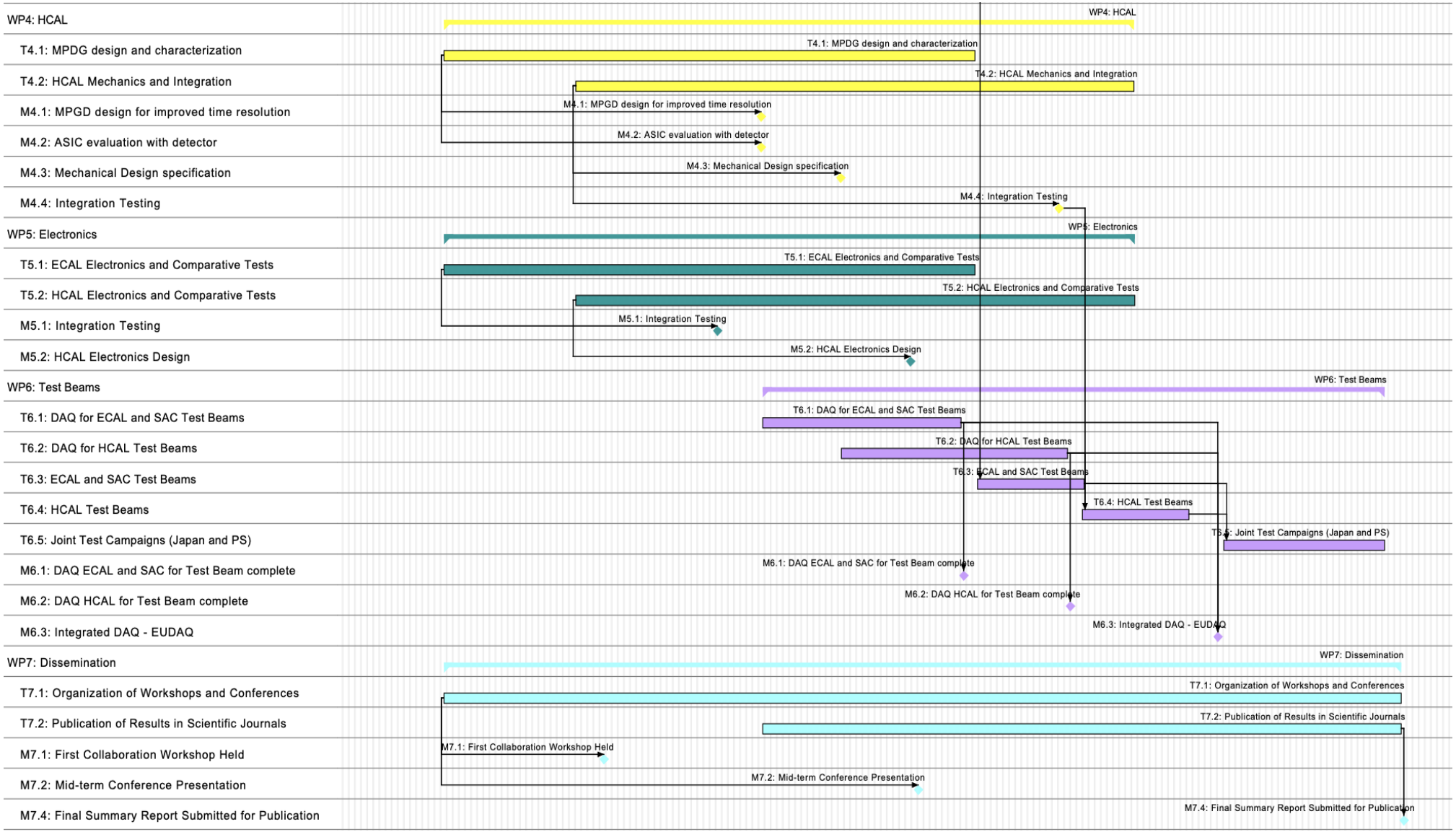
WP4: HCAL
T4.1: MPDG design and characterization
T4.2: HCAL Mechanics and Integration
M4.1: MPGD design for improved time resolution
M4.2: ASIC evaluation with detector
M4.3: Mechanical Design specification
M4.4: Integration Testing
WP5: Electronics
T5.1: ECAL Electronics and Comparative Tests
T5.2: HCAL Electronics and Comparative Tests
M5.1: Integration Testing
M5.2: HCAL Electronics Design
WP6: Test Beams
T6.1: DAQ for ECAL and SAC Test Beams
T6.2: DAQ for HCAL Test Beams
T6.3: ECAL and SAC Test Beams
T6.4: HCAL Test Beams
T6.5: Joint Test Campaigns (Japan and PS)
M6.1: DAQ ECAL and SAC for Test Beam complete
M6.2: DAQ HCAL for Test Beam complete
M6.3: Integrated DAQ - EUDAQ
WP7: Dissemination
T7.1: Organization of Workshops and Conferences
T7.2: Publication of Results in Scientific Journals
M7.1: First Collaboration Workshop Held
M7.2: Mid-term Conference Presentation
M7.4: Final Summary Report Submitted for Publication