Open Call 2020 - HiDRa

Title: High-Resolution Highly Granular Dual-Readout Demonstrator – HiDRa

Area: Detector development

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Abstract

The project aims at designing, constructing and qualifying a prototype of a longitudinally unsegmented, highly granular, fibre-sampling dual-readout calorimeter to assess:

a) a hadronic resolution, for both single hadrons and jets, around 30%/√E or better, while maintaining a resolution for isolated electromagnetic (*em)* showers close to 10%/√E;

b) a transverse resolution of O(1 mrad)/√E and a longitudinal one of a few cm;

c) a modular construction and assembly technique;

d) an innovative readout architecture based on SiPMs.

Dual-readout sampling calorimetry has emerged as the likely most promising technology to overcome the most limiting factor in hadron calorimetry. i.e. the fluctuations in the hadronic-shower *em* fraction, and achieve high-resolution results in both *em* and hadronic shower measurements.

Moreover, the advancements in solid-state light sensors such as SiPMs has opened the way for highly granular detectors with the capability to resolve the shower angular position at the mrad level or better. Readout ASICs providing timing information with ~100 ps precision may allow to resolve the longitudinal shower position with ~5 cm precision, but the large number and density of channels call for an innovative readout architecture. New digital devices (digital SiPMs, dSiPMs) could pave the way for simplifying it.

Our ultimate goal is to demonstrate that a longitudinally unsegmented calorimeter with highly granular readout is technically feasible and can provide outstanding performance for hadrons and jets as well as electrons and photons, as required in future e^+e^- colliders. Several novel technologies are being developed to achieve this goal. New analysis techniques exploiting the large amount of information provided are also being studied.

1. Scientific Proposal

1.1 State of the art

High-resolution high-granularity calorimetry is one of the main components of any experimental programme at future high-energy colliders. All heavy-boson factories rely on the capability to correctly resolve complex final states containing several non-isolated objects. In cases like H/Z/W→jj or H→ZZ/WW→4j, the final states have very similar kinematic properties. In order to discriminate among them, excellent energy and spatial resolution for all detector objects are a key requirement.

For hadronic showers, the energy resolution is normally dominated by the event-by-event fluctuations of the *em* fraction, f_{em}. For many years, there have been two main lines of research to tackle the problem. The first [1] exploits Particle Flow Algorithms (PFA), employing very-high-granularity 3D/4D calorimetry systems, to unfold neutral- and charged-particle contributions and use the inner tracker measurements to estimate the latter one.

The second approach [2] is based on the measurement of all the energy deposits through two different processes, namely scintillation (S) and Čerenkov (C) light emission, the former produced by all ionising particles, the latter only by relativistic charged particles (i.e., mostly electrons and positrons). After calibration with electrons, the combination of the two signals allows the event-by-event measurement of f_{em}, therefore dramatically improving the hadron-shower energy measurement. The DREAM/RD52 collaboration, over 20 years, built and tested both crystal [3-5] and fibre-sampling solutions [6-9].

They demonstrated that the principle works and that an excellent e/π separation can be obtained [10] but the hadronic performance was seriously limited by the lateral leakage. The most advanced prototype consisted of a ~28×28×250 cm^3 Pb matrix containing ~37k longitudinally running fibres. Because of its effective radius of 0.55 λ_I, the resolution was found to be ~70%/√E, still far from the interesting range and dominated by lateral leakage fluctuations and light attenuation effects. Geant4 simulations support the statement that a resolution of ~30%/√E would be reachable when removing them.

The impact of time stamping in the reconstruction of the longitudinal shower position and in particle ID was explored with test-beam data. Using a set of 4 observables (C/S ratio, lateral shower profile, time of arrival, charge-to-amplitude ratio) a 500 rejection power against pions was measured at a ~99% electron efficiency.

A huge step forward was recently made thanks to the advent of solid-state light sensors that allow to readout each of the high density of fibres in the transverse plane. A very small brass-fibre prototype (~1.2×1.2×100 cm^3) was equipped with Hamamatsu SiPMs and tested with electrons and muons [11]. The lateral profile of *em* showers was reconstructed with unprecedented resolution showing very interesting features (a core so surprisingly narrow that a single scintillating fibre may carry about 10% of the total signal). It was also proven that the huge number of channels can be successfully reduced with analogue grouping but this critically requires a linear sensor response over the full operating range.

Digital SiPMs could provide an even more appealing solution and several implementations have been proposed in the last 10 years [12-16]. However this technology has not yet reached maturity and so far, almost all the scientific applications are based on PMTs and analogue SiPMs. The main reasons for this delay in the adoption of CMOS-based SiPMs are due on one hand to their performance, that requires extreme customisation of the processes to be optimised, and on the other hand to the ease of use of analogue detectors if compared to the digital counterpart. More recently, commercial applications, like laser ranging, have triggered the interest in integrated Single-Photon Avalanche Diode (SPAD) sensors from several companies for working on the optimisation of CMOS production processes. Thus, the currently available portfolio of SPAD-enabled CMOS processes is steadily increasing. The detector performance has considerably improved, with peak detection probabilities approaching 50% and Dark Count Rates (DCR) lower than 1 MHz/mm^2 [17]. The use of highly scaled technologies brings the benefit of fast, compact and low-power electronics and is fostering the introduction of time-tagging circuits with a resolution of the order of 10s of ps [18].

Readout electronics has many open questions and possible answers. Commercial ASICs are available for either signal integration or sampling. Together with total charge, additional information on timing and signal shape may provide powerful input for event reconstruction. It would also enable PFAs to be applied to dual-readout detectors.

Preliminary studies showed that the Citiroc 1A [19] has good performance in terms of dynamic range, linearity and multi-photon quality even with SiPMs with wide dynamic range (i.e. 15 and 10 μm pitch size) and small gain (i.e. 1-3×10^5). This ASIC, integrated into the CAEN A5202 multipurpose board, may provide a ~100 ps resolution timestamp. In the FERS 5200 scalable platform, it would enable to handle and read out a large number of SiPMs. Still the possibility of extracting additional information from the sensors and the need to sum analogue SiPM signals has a high relevance for the project. Thus also alternative ASICs will be qualified and in case integrated into similar readout systems in collaboration with CAEN.

About mechanics, many different strategies have been considered for the construction of single elements and module assembly. None is yet solid as needed for mass production but the gluing of capillary tubes, for the construction of O(10×10 cm^2) modules, looks affordable and reliable. It is being followed for the construction of an *em* prototype.

1.2 Scope and research methodology

The scope of the project is to set a clear milestone in hadronic calorimetry, close a 20-year-long R&D programme on the dual-readout technique and offer to the community a solid way for designing detectors with unprecedented performance. Furthermore, a longitudinally-unsegmented detector is far simpler to be understood and calibrated. Ideally, only a global calibration constant (at the *em* scale) is required and the longitudinal shower position can be reconstructed using timing information.

The project aims to:

- develop the technology for successfully building a Hadronic-Scale Prototype (HSP) made of 17 Hadronic-Scale Modules (HSM), ~13×13×200 cm^3 each, 2 modules would be equipped with SiPMs, the rest with PMTs;

- develop a scalable readout system with the capability to reconstruct the 3D shower position with a transverse resolution of O(1 mrad)/√E and a longitudinal resolution of a few-cm;

- demonstrate a hadronic resolution, for both single-hadrons and jets, around 30%/√E or better, together with a resolution for *em* showers close to 10%/√E. The constant terms should be ~1% or below. This requires the sampling fraction and frequency to be both high and constant over the full detector.

An innovative readout system is needed in order to extract the required information and reduce the data volume at a manageable level. Both charge-integrator and waveform-sampling ASICs will be qualified in a scalable commercial platform. Digital SiPMs may allow to strongly reduce both cost and system complexity and will be explored in a small prototype setup.

An accurate task breakdown has been built over the ongoing experience of a collaboration of INFN, Croatian, British and Korean groups, for constructing an *em* prototype with capillary tubes.

1.2.1 Module construction

The main goal is the construction of a modular full-containment hadronic prototype. Experience (in the members of the DREAM/RD52 collaboration) exists and understanding is improving but a scalable effective solution has not yet been established.

We plan to use the first year of the project for deciding:

- absorber material (brass, iron and lead being the options);

- dimensions and construction method of the building elements;

- dimensions and assembly procedure of single towers with a self-supporting structure.

As absorber material, brass is our baseline option for both mechanical and shower development properties. It is being used for the construction of an *em* prototype, ~10×10×100 cm^3, which was meant to be tested at the end of 2020. Commercial capillary tubes with 2 mm outer diameter will be glued together to build 9 modules, 1m long. The assembly of the 9 modules in a 3×3 structure will form the *em* prototype. The main issue is the precision required to guarantee the uniformity of both the single modules and the overall structure. Thanks to the excellent mechanical tolerance, a simple solution with quickly piling up and gluing the layers is being exploited. Assuming the method works, it will have to be scaled up for the construction of the HSMs that will form the HSP.

Alternatives to the usage of capillary tubes, based on molding, extruding, rolling or even 3D printing solutions, will be investigated by our Korean colleagues, in the frame of a National Research Foundation grant on dual-readout calorimetry.

We also plan to develop, at the design level only, a realistic design of projective towers in a 4π geometry. Besides construction issues, a key requirement is to minimise and understand the impact of dead space and sampling-fraction changes at the boundary between towers. An engineering design of a full detector will be implemented and analysed, including the impact of global support structures and other services.

In the first year, we plan to investigate (semi-)automatic techniques for fibre insertion. Both custom solutions and commercial products from FIMT (Fibre in Metal Tube) companies will be considered. Efficient ways to collect and interface fibres to sensors would be needed on the same time scale.

1.2.2 Fibre optimisation and qualification

Fibre and couplings need to be optimised to increase S signal attenuation length, improve the C light yield and minimise optical cross-talk of S in C signals. Thanks to the very large S yield, a tuned light filtering should be sufficient to reach an appropriate attenuation length. Other possible improvements may come from depositing an aluminised surface on the inner face. The C light yield can be improved by increasing the numerical aperture or again with light reflection at the inner face.

Identifying candidate solutions is to be done during the first year.

The quality control of fibres, optical couplings and light sensors requires know-how to be expanded and spread. Light yield, spectral response and attenuation length are the main parameters to analyse.

1.2.3 Light sensors

Solid-state sensors allow for a significant step toward high granularity in fibre-sampling calorimetry. For their different properties, S and C signals may be better exploited with specific sensor choices such as yellow-tuned (for S) or UV-enhanced (for C). A linear response up to a few k of photoelectrons is also required, to afford analogue signal grouping. Experience with Hamamatsu SiPMs has been highly positive but progress is needed in order to have sensors with wide dynamic range (10 or 15 μm pitch), reduced dead area (in compact SMD package to allow the one-to-one connection with fibres) and reasonably low costs. In this respect, options from different vendors will be investigated (i.e. Hamamatsu, KETEK and NDL from Beijing) together with a long-prospective custom-design sensor based on a digital SiPM architecture, that would greatly reduce the readout complexity.

The proposed dSiPM implementation will be based on an array of SPADs with pixel-level signal digitisation and on-chip counting and timing functions. SPAD arrays with an overall area of the order of $1 mm^2$ will be designed, focusing on the maximisation of the PDE in the blue region, with the constraint of a maximum cell size between 15 and 25 μm in order to provide a high dynamic range. A deep submicrometer process optimised for the integration of optical sensors and SPADs will be employed (LFoundry being a possible candidate for). If needed, the cell layout will be refined with the help of TCAD simulations and the setup of optimised processing options will be discussed with the foundry. Since in a single MPW the typical minimum area is several mm^2, different versions of the chip, with different cell sizes and including conservative and aggressive design rules will be designed. The option of monolithically integrating more sensors within a single chip will also be considered, to ease the construction of the final system.

The integrated electronics will include the basic circuitry for time-tagging each event with a programmable threshold and for counting the number of cells fired within an event. A latch will be included in each cell to disable defective SPADs, thus improving the overall Signal-to-Noise ratio. Packaging constraint will be accounted for in the definition of the layout.

To account for possible problems in the first fabrication run and to fine-tune the design, a second run is foreseen for the second year of the project.

A readout board for the qualification of the produced dSiPM will be designed and fabricated, and the qualification procedures will be shared with the collaboration. A thorough electro-optical characterisation will be carried out on selected samples, and a minimum set of basic measurements will be defined and performed on all the produced sensors, in order to select a set of 64 sensors that will be integrated in a large tile. We will compare the performance at the single-sensor level and on beam using a small (~$1\times1\times100$ cm^3) 64-sensor demonstrator.

1.2.4 Front-end electronics and readout system

The operation of a large number of SiPMs poses a series of system-integration challenges: the reduced space available on the rear end of the calorimeter, the number of channels and the costs. The optimal solution would be the custom design of a SiPM with on-board intelligence. This is the reason why the investigation of dSiPMs is part of the project.

ASICs integrated into a scalable architecture are needed for investigating system issues while also assessing the HSP performance. Both charge integrators and waveform samplers with Feature EXtraction (FEX) are available on the market and we plan to qualify at least two of them: the Citiroc 1A (already integrated in the CAEN FERS system) and the SiREAD.

Channel grouping would allow us to save space and costs. We are considering a flexible design based on a dedicated board to be possibly compliant with future evolutions. Depending on sensors or packages, the grouping could also be implemented at a different stage, either using an adaptor front-end board or an ASIC like MUSIC.

Most relevant for FEX is the definition of the optimal set of information. We are presently considering: total charge, ToA, ToT and also time and value of current peak. The performance (i.e. the measurement resolution) that could be obtained is under study with detailed simulations. Qualifying each-item impact and the correlations is the first step. We also want to analyse the performance of neural networks for triggering purposes. Offline studies for the identification of τ-decay final states have started and first results look promising.

The outcome of this activity will be the system specification definition, the selection on the market of the ASIC that better fits requirements and boundary conditions, and the qualification of the readout boards and the data collector needed to operate the central HSP core.

1.2.5 Performance and data analysis

An integral part of the program is the evaluation of the detector performance both through comparison of detailed simulations with test-beam data and through the reconstruction of fully simulated events for an e^+e^- collider.

To this purpose, a Geant4 simulation program is under development, with two different geometries: one replicating the shape of the HSMs to build and test, and one describing a projective 4π detector. The aim of the HSM simulation is the validation of the Geant4 predictions for hadronic showers through detailed comparison with data. A robust assessment of the performance in any realistic experiment relies on it.

To allow a meaningful comparison, the simulation of the energy deposition in the calorimeter is complemented with a detailed simulation of the light propagation in the fibres, and of the response of SiPMs and electronics chain.

The main performance benchmarks will be:

1. Energy resolution for both single particles and hadronic jets;

2. Angular and position resolution, in particular for the identification of the two γs from π^0 decays;

3. Reconstruction of the longitudinal shower development position through timing measurements;

4. Particle id of single particles, both isolated and within jets;

5. Identification and reconstruction of final states from τ decays;

6. Identification and reconstruction of final states from $Z/W/H \to jj$, $H \to ZZ^*/WW^* \to 4j$, $HZ \to 6j$, $H \to \gamma\gamma$, $Z/H \to \tau\tau$ decays.

1.2.6 Data selection and processing with deep-learning algorithms

The dual-readout technique has the potential for achieving a groundbreaking precision in the measurement of the Higgs decay products at future e+e- colliders.

This precision is a result of its excellent properties combined with the flexible readout granularity which, with solid-state sensors, can be pushed up to the single-fibre level. This corresponds to a huge amount of information that should be better exploited with deep-learning algorithms. Thus we started working at the implementation of convolutional neural networks for data selection and processing. A detailed simulation of the detector response convoluted with the SiPM transfer function was developed and τ-decay samples were produced for the first training and performance assessment with a reduced granularity. Preliminary results are very encouraging. Next steps will consist in adding background processes and increasing the network and information complexity. Other topics which can be addressed with ML techniques are the calibration of single particles and jets, the determination of position and direction of photons and particle identification.

Over the full project, the performance assessment will ultimately address the points described in the previous section, as well as its dependence on the readout granularity, necessary for the cost/performance optimisation of a future detector.

This plan is being developed in Pavia, Como, Sussex and Roma. In particular the Roma group holds an advanced know-how on machine-learning techniques which will be exported to other groups in the course of the project.

1.3 Research team

Solid and fairly diverse and complementary expertise is distributed in the different groups. The Pavia, Pisa and Milano groups were part of the DREAM/RD52 project for dual-readout calorimetry, now closed. The activity is continuing in the context of the IDEA proposal, in collaboration with the University of Sussex, RBI and a cluster of Korean universities. The groups of Roma 1, Catania and Bologna joined those efforts during last year.

Long-standing expertise in detector R&D and high-qualified support from technical services is very well distributed in the collaboration. Bologna, Catania, Milano and TIFPA will be mainly focused on the sensor and readout system qualification, Pavia and Pisa on the mechanical issues and Roma 1 on the implementation of neural network architectures. The total manpower amounts to ~6.3 FTE that, with postdocs, is expected to evolve in average to ~10 FTE but half of the additional manpower will be charged on external funds.

Table 1.3.1 summarises, for each research unit, the expected FTE commitment including added resources. The work package assignment, responsible, role and competences and infrastructures for each research unit are described in Table 1.3.2. A sketch of the proposed geometry is in Figure 1.3.1.

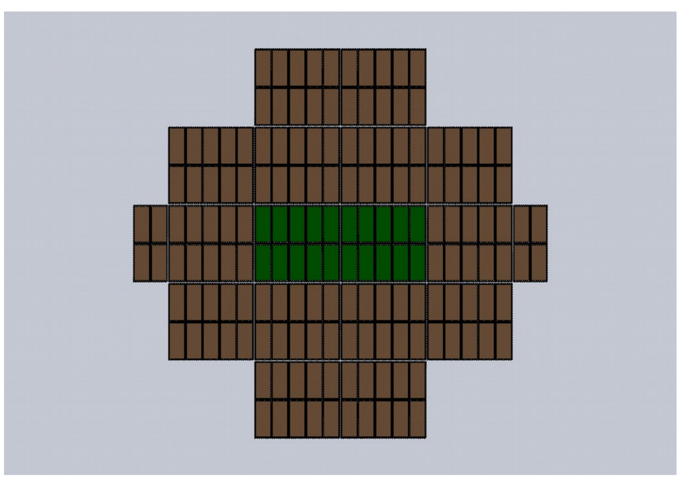

Figure 1.3.1. A possible geometry for the Hadronic-Scale Module.

RU	FTE and Numer of people (without AdR requests)						FTE and Numer of people (with AdR requests)					
	2021		2022		2023		2021		2022		2023	
	FTE	People	FTE	People	FTE	People	FTE	People	FTE	People	FTE	People
Bologna	0,7	2	0,7	2	0,7	2	1,7	3	1,7	3	0,7	2
Catania	0,6	3	0,6	3	0,6	3	0,6	3	1,6	4	0,6	3
Milano	1	3	1	3	1	3	1	3	2	4	2	4
Pavia	1,8	7	1,8	7	1,8	7	2,3	7,5	2,8	8	2,3	7,5
Pisa	0,8	4	0,8	4	0,8	4	0,8	4	1,8	5	1,8	5
Roma 1	0,2	1	0,2	1	0,2	1	1,2	2	1,2	2	0,2	1
TIFPA	1,2	3	1,2	3	1,2	3	1,2	3	1,2	3	1,2	3
Total	6,3	23	6,3	23	6,3	23	8,8	25,5	12,3	29	8,8	25,5

Table 1.3.1. Summary of FTE per each RU during the 3 years of the project.

Research Unit	Local coord.	WP Tasks	Role and Contributions	Competences and Infrastructures	Intl. Collabs.
Bologna	P. Giacomelli	2,3	Test setup preparation, design of interface boards and flat cables for modules equipped with SiPM and dSiPM, qualification of ASICs and dSiPM	Detector construction, data acquisition, trigger and readout electronics for SiPM-based detectors. Clean room, mechanical workshop, gas detector and electronic labs.	CMS, AIDA-2020, RD_FA
Catania	S. Albergo	2, 3	Tests of ASICs performances in SiPM readout, SiPM qualification tests	Solid state detectors and photosensors (rad-hardness; sensor and hybrid tests; bonding; qualification), trigger, data analysis and simulation. Large clean room - Electronic Lab.	CMS, ATLAS, RD48, RD_FA
Milano	R. Santoro	1, 2, 3, 4	Analogue and Digital SiPM qualification, ASICs comparison and readout system specification and qualification	Silicon detector development and qualification. Silicon detector and optics lab, electronics service and clean room in Milano and Como	RD_FA, ARCADIA, ORIGIN (H2020)
Pavia	G. Gaudio	1, 3, 4	QAQC calorimeter components and construction. Definition of the RO system specification. Simulation and data analysis	Detector construction, compensating calorimetry in particular, data acquisition and data analysis. Mechanical workshop, Electronic lab and large size clean room and lab area	NOMAD, ATLAS, DREAM/RD52, RD_FA
Pisa	F. Bedeschi	1	Mechanical design engineering, tooling development and QAQC of mechanical elements	Detector construction, of calorimeters in particular. Mechanical workshop, Electronic lab and large size clean room and lab area. Mechanical engineer pool.	CDF, NOMAD, DREAM/RD52, ATLAS, RD_FA, GMINUS2
Roma 1	S. Giagu	4	AI algorithms for feature extraction, particle id and recontruction. Performance and detector design optimisation.	Data analysis, Machine Learning and Deep Learning (real time and offline applications). Trigger and offline software design for HEP experiments. AI supercomputer (2 petaFlops), Electronic Lab, Mechanical workshop.	CDF, ATLAS, NEPTUNE, MUCCA
TIFPA	L. Pancheri	2, 3	Digital SiPM design and qualification and readout system specification and qualification	Modelling, layout design, electrical and functional characterization of silicon integrated detectors. Available facilities include probe stations and standard electronic instrumentation for radiation detector characterization.	ATLAS, ARCADIA

Table 1.3.2. Synopsis of participants, WP task, description and management.

1.4 External contributions

We expect to have small funding for running expenditures from CSN 1, for the RD_FA activities and to find some local support (e.g. for readout or HV boards) for test-beam running needs.

We also assume to have all the AdR positions 50:50 co-funded. Being part of the EU AIDAinnova proposal, with a specific sub-task on dual-readout calorimetry, we will get some funds, in case of success, mainly meant for covering post-doc positions.

As previously stated, we are already (or even better, always) making our developments in an international context. Since the closure of the RD52 project, we are aiming to establish a new official collaboration among the engaged groups. All groups are highly motivated for staying committed to the evolving programme, of course with a specific role, responsibility and funding. Our European partners are planning to apply for national funds both in Croatia and in the UK (Royal Society) and we are sure that an approval of this proposal will trigger positive feedback.

In Korea, an R&D fund of about 2M USD over 5 years (2020-2025), has been recently granted by the National Research Foundation (NRF) to our collaborator, prof. Hwidong Yoo, for building a full-hadronic-scale projective prototype, addressing the main engineering, operating and readout issues. The schedule foresees 3 years of pure R&D followed by 2 years of construction of the prototype. Additional soft funding is also available for simulation study to support postdoc positions and graduate students in each Korean institute (Kyungpook National Univ., Seoul National Univ, Univ. of Seoul, Yonsei Univ.). We fully agree that we need to identify and exploit all possible synergies and share as much as possible developments and results, while having a different horizon and target. This would strongly help in avoiding useless duplication of efforts and optimising the success rate of each program. The plan is to constitute a partnership and possibly an official collaboration.

1.5 Active or recently closed programs on the same field

In the 2013-2018 period, the DREAM/RD52 program was running only with US funding. The activity was closed with the test of the small "~1 cm^2" prototype equipped with SiPMs. Since then, we started planning the "~100 cm^2" module with a SiPM core within the CSN 1 RD_FA project. The module is under construction with funds from INFN (~40 k€), RBI (~15 k€) and University of Sussex (~5 k€). The design and assembly of the proof of concept pertaining to the mechanical structure is ongoing at RBI, in collaboration with members of the ERA Chair PaRaDeSEC project.

Progress has been substantially slowed due to the COVID-19 crisis but the results should arrive within ~6-10 months. The actual schedule is unknown but the final test with beam at DESY should likely happen in less than one year from now.

1.6 Relevance and impact of potential results

We are convinced that the demonstration that a single-volume fibre-sampling calorimetry system may provide unprecedented hadronic performance without sacrificing any other relevant feature would be a significant step forward for the experimental programme at e^+e^- colliders. Hadronic calorimetry would be able to reach a precision of few % in a range that is crucial for today's particle physics. The fact that the detector needs to be calibrated at the *em* scale only would greatly simplify detector commissioning and operation. Moreover, the high granularity achievable with SiPM readout could also be exploited in Particle Flow Algorithms where tracking and calorimetry measurements would be combined with the best possible resolution. Last but not least, the validation of the Geant4 hadronic simulations with a precision level that could only be reached with compensation would also be a benefit for the HEP community.

On the other hand, even if at present, we do not have in mind applications outside HEP, the technical developments on the digital SiPMs and on the readout system are of a very general and broad interest. We think that the endorsement letters from FBK and CAEN strengthen this view. In particular, digital SiPMs can foster a change of paradigm in many application domains and provide the basis for many future developments of detector systems.

1.7 Risk assessment and reduction

The current description of the detector layout and baseline material is based on the present developments in the RD_FA project. Success in reaching the required tolerances will be assessed in the next months. In case of failure, alternatives solutions will be considered both at the level of: 1) tools and assembly procedure; 2) absorber design and production. In this respect, studies on possible mechanical structures were done in the past. Some of them were limited, and therefore not conclusive, due to fund shortness, but can be further investigated as alternative solutions. Similar studies will also be performed in parallel by the Korean colleagues and the exploitation of the results will be shared among the collaboration. We will study different independent methods and this should maximise the success probability.

The strategy considered for the readout is quite challenging but the proposed strategy should mitigate the risks allowing the possibility to investigate prospective solutions. The detector design has been thought to maximize the chances to assess the pure calorimetric performance by instrumenting the majority of the modules (all but 2) with consolidated light sensors (PMTs) in a readout schema largely experienced in the DREAM/RD52 projects. On the other hand, to meet the request for high granularity and longitudinal position reconstruction, we started to investigate solutions where each single fibre is coupled to a dedicated SiPM. A certain expertise in the field has been acquired in the past years when the collaboration succeeded in demonstrating the feasibility of the technique identifying and overcoming some issues i.e. light cross-talks among scintillating and Čerenkov signals and a better understanding of the requirements in terms of SiPM dynamic range. The next beam test, scheduled at the end of this year, should consolidate the results obtained so far. In fact, 320 SiPMs will be read out with a system based on the Citiroc 1A ASIC. This project would represent a further large step forward: 1) an important scaling in numbers of SiPMs to be read out, with the goal of addressing all the challenges related to system integration and performance; 2) a visionary solution which would allow to demonstrate the possibility of using dSiPMs: SPADs implemented in CMOS technology with on-board intelligence which could have an impact on reducing costs and readout complexity. In this schema, the proposal is to equip two modules with SiPMs to minimise the risks and to guarantee a proper assessment of the challenges discussed before and, only a proof of concept will be addressed, at this early stage, for the dSiPMs. In fact, even if the latter is highly prospective, the collaboration will design and produce only a small quantity of these sensors to be qualified and compared with standard SiPMs together with the possibility of assembling a small prototype based on 64 dSiPM.

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2. Project Organisation

The work plan is scheduled over the period 2021-2023, for a duration of 3 full years. In the event of a substantial delay on the scientific achievement due, e.g., to technical or even external problems, we may consider the possibility to extend the project duration by one more year. Such extension would be handled without further funding requests.

The project implementation is organised in 4 Work-Packages and the management of the resources and tasks assigned to each participating Research Unit is defined by the WP Responsible. The activity, resources, deliverables and milestones of each WP are described herein.

2.1 Work Package 1: Mechanics and fibre characterisation

WP1 Responsible: Gabriella Gaudio

WP1 Contributors: MI, PI, PV

WP1 Activity: Choice of baseline options for scintillating and Čerenkov fibres, choice of baseline options for absorber material and layout, choice of PMTs for external ring readout. Definition of construction procedure, including the coupling of fibres to light sensors. Construction of prototypes and modules for full-containment calorimeter. Qualification on test-beam.

WP1 Description of Work and Role

- T1.1. Identification of candidates for Čerenkov and scintillating fibres [M1-12][MI,PI,PV]
- T1.2. Definition of Quality Control (QC) procedure and criteria for Čerenkov and scintillating fibres [M1-12][MI,PI,PV]
- T1.3. Absorber material choice [M1-12][PI,PV]
- T1.4. PMTs choice and layout optimization [M1-12][PI,PV]
- T1.5. Definition of QC procedure and criteria for PMTs [M1-12][PI,PV]
- T1.6. Dimensions and construction method of the building elements [M6-18][MI,PI,PV]
- T1.7. Dimensions and assembly procedure of single towers with a self-supporting structure [M12-18][PI,PV]
- T1.8. Definition of QC procedure and criteria for single towers [M12-18][MI,PI,PV]
- T1.9. Engineering design of projective towers [M18-28][PI]
- T1.10. Construction of full-containment modules [M18-30][PI,PV]
- T1.11. Qualification on test-beam [M30-36][MI,PI,PV]

WP1 Milestones

- M1.1. Identification of baseline options: absorber, fibres and PMTs choice [M12]
- M1.2. Identification of baseline constructing method [M18]
- M1.3. Construction of final modules [M30]
- M1.4. Performance assessment [M36]

WP1 Deliverables

- D1.1. Full characterisation of chosen baseline options [M12]
- D1.2. Single tower of final dimension built with the selected absorber and with the final procedure [M18]
- D1.3. Percentage of the module to be built should be defined based on agreement with Korean colleagues [M30]
- D1.4. Results of TB with performance assessment [M36]

2.1 Work Package 2: Light Sensors

WP2 Responsible: Massimo Caccia

WP2 Contributors: BO, CT, MI, TIFPA

WP2 Activity: Light sensors qualification. The aim of the work package is the study of two light-sensor technologies capable of equipping the highly granular calorimeter in the respect of the expected performances. The sensors of interest are the analogue and digital SiPMs. The first option (baseline) is based on a mature technology that would immediately allow to equip and operate the core (~10000 sensors) of the demonstrator, while the second (a proof of concept) is a prospective solution that, in case of success, would allow to reduce the cost of the sensors and the readout complexity with comparable and in some cases better performance (i.e. timing).

WP2 Description of Work and Role

- T2.1. Definition of a qualification protocol [M1-3][CT,MI,TIFPA]
- T2.2. Test setup preparation to qualify the different sensors [M1-6][CT,MI,TIFPA]
- T2.3. Procurement and qualification of SiPMs produced by different vendors (i.e. Hamamatsu, Ketek, NDL) [M3-15][CT,MI]
- T2.4. dSiPM design and fabrication (includes 2 runs) [M5-20][MI,TIFPA]
- T2.5. dSiPM qualification [M12-24][BO,MI,TIFPA]
- T2.6. Test of all the SiPMs needed to equip the central part of the demonstrator [M18-30] [CT,MI]
- T2.7. Test of the 64 dSiPMs used to equip the small 64-fibre prototype [M24-30] [BO,MI,TIFPA]

WP2 Milestones

- M2.1. Definition of a list of SiPMs of interest [M3]
- M2.2. Definition of a SiPM characterization protocol [M3]
- M2.3. Definition of a dSiPM specification for Run1 [M6]

M2.4. Selection of the SiPM that will be used to equip the central part of the calorimeter [M15]

M2.5. Definition of a mass production characterization protocol [M18]

M2.6. Definition of a dSiPM specification for Run2 [M16]

WP2 Deliverables

D2.1. Qualification protocol ready [M3]

D2.2. Setup to qualify SiPMs ready [M6]

D2.3. Setup to qualify dSiPMs ready [M14]

D2.4. Test of all SiPMs needed to equip the central part demonstrator completed [M30]

D2.5. Test of the 64 dSiPMs needed to equip the small module-prototype, completed [M30]

2.1 Work Package 3: Front-end and DAQ development

WP3 Responsible: Romualdo Santoro

WP3 Contributors: MI, TIFPA, BO, PV, CT

WP3 Activity: ASIC qualification and readout board production. This work package will qualify the different ASICs designed for SiPMs available on the market. Candidates of interest for this kind of application are Citiroc 1A, SiREAD and MUSIC. After a full qualification, the ASIC that better fits all requirements and constraints will be integrated into the flexible readout system (FERS) designed by CAEN. This system will allow the calorimeter to be operated in a beam test. Thanks to the experience gained during the qualification phase, the team will contribute to the definition of the readout specification and system qualification. The 20 boards needed to readout the core of the demonstrator will be delivered to the collaboration for the final test on beam.

WP3 Description of Work and Role

T3.1. Definition of the ASIC qualification protocol [M1-3][BO,MI,PV]

T3.2. ASIC procurement with the proper evaluation board [M1-8][BO,MI]

T3.3. Design and production of a series of passive boards and cables needed to interface the SiPMs to the evaluation boards [M1-8][BO,MI]

T3.4. ASIC qualification and performance comparison in response to the SiPMs of interest for the application [M6-12][BO,CT,MI]

T3.5. Setup preparation to qualify the dSiPMs [M6-12][BO,MI,TIFPA]

T3.6. Definition of the readout system specification which will integrate the selected ASIC [M6-12][BO,MI,PV]

T3.7. Design and production of the interface boards and flat cables required to equip the central part of the calorimeter [M12-18][BO,MI]

T3.8. Prototype readout board qualification [M18-24][BO,CT,MI]

T3.9. Final readout board qualification [M24-30][BO,CT,MI]

T3.10. Design and production of the interface boards and flat cables required to equip the small prototype with dSiPMs [M24-30][BO,MI]

T3.11. Final qualification on beam [M30-36][BO,CT,MI,PV,TIFPA]

WP3 Milestones

M3.1. Definition of a list of ASICs of interest [M1]

M3.2. Definition of the ASIC characterization protocol [M3]

M3.3. Selection of the ASIC that will be integrated into the readout system [M12]

M3.4. Definition of the readout system specification [M12]

WP3 Deliverables

D3.1. ASIC qualification protocol ready [M3]

D3.2. ASIC setup station ready [M6]

D3.3. Setup to qualify the dSiPM [M12]

D3.4. Prototype readout board [M18]

D3.5. Interface boards and cables to equip the calorimeter with SiPMs [M24]

D3.6. Final readout board [M24]

D3.7. Interface boards and cable to equip the small prototype with dSiPMs [M30]

2.1 Work Package 4: Performance assessment

WP4 Responsible: Giacomo Polesello

WP4 Contributors: MI, PV, RM1

WP4 Activity: Evaluation of the performance of the proposed calorimeter both through comparison of detailed detector simulations with the data from the test beam modules and through the reconstruction of fully simulated events from an e+e- collider. Validation of Geant4 hadron interaction models. Development of ML algorithms for the identification of hadronic τ decays.

WP4 Description of Work and Role

T4.1. Development of a Geant4 simulation of the modules with testbeam geometry [M1-12] [PV]

T4.2. Development of a detailed simulation for light propagation, SiPM response and related electronics chain [M1-12][MI]

T4.3. Comparison of the simulation with test beam data and validation of the Geant4 hadronic model [M12-36][PV]

T4.4. Development of a Geant4 simulation of a 4pi geometry solution [M1-12][PV]

T4.5. Development of a calibration strategy for single particles and jets, both analytical and based on ML algorithms [M12-18][PV]

T4.6. Assessment of the energy resolution for single particles and jets [M18-24][PV]

T4.7. Angular and position resolution for photons (in particular for non-pointing ones) [M24-36][PV]

T4.8. Identification of single particles, both isolated and within jets [M24-36][MI,PV]

T4.9. Identification and reconstruction of heavy-boson decays in 2-photon, 2-tau, 2-, 4-, 6-jet final states [M24-36][PV]

T4.10. Development of a baseline DNN architecture based on Convolutional models [M1-12][RM1]

T4.11. Development of an evolutionary DNN based on combined Recurrent and Convolutional NNs [M12-21][RM1]

T4.12. Development of novel DNNs based on Graph NNs optimised for a realistic detector simulation [M21-30][RM1]

T4.13. Study of an optimised design of the DNN model developed for real-time applications (trigger, feature extractions) [M30-36][RM1]

T4.14. Test beam data analysis [M30-36][MI,PV,RM,]

WP4 Milestones

M4.1. Full simulation of TB module running and validated [M12]

M4.2. Full simulation of a 4pi detector running and validated [M12]

M4.3. Performance studies for single particles [M20]

M4.4. Jet performance studies [M24]

M4.5. Trained and optimised CNN model ready [M8]

M4.6. Trained and optimised RNN+CNN model ready [M20]

M4.7. Novel GNN deployed [M29]

M4.8. Results of TB with performance assessment [36]

WP4 Deliverables

D4.1. Full simulation of TB modules [M12]

D4.2. Full simulation of a 4π detector [M12]

D4.3. Simulation of readout [M12]

D4.4. Full calibration procedure for single particles and jets [M24]

D4.5. Validation of Geant4 hadronic model [M36]

D4.6. Physics performance assessment on benchmark physics processes [M36]

D4.7. Baseline performances obtained with the best CNN model [M12]

D4.8. Assessment of performances wrt design readout strategy based on evolutionary models [M24]

D4.9. Final physics performances assessment for the selected DNN model and its deployment for general use [M24]

2.2 Funding Requests

The detailed description of the requested funding, per RU, WP type and FY is depicted in Table 2.2.1 while in Figure 2.2.1 there is the breakdown of the costs over the different activities.

#	Title	Given Work	Given Earliest Start
0	**HiDRa**		**01/01…**
1	**WP1: module construction**		
2	T1.1 Identification of candidates for Cerenkov and scintillating fibres	12 months	
3	T1.2 Definition of Quality Control (QC) procedure and criteria for Cerenkov and scintillating fibres	12 months	
4	T1.3 Absorber material choice	12 months	
5	T1.4 PMTs choice and layout optimization	12 months	
6	T1.5 Definition of Quality Control (QC) procedure and criteria for PMTs	12 months	
7	T1.6 Dimensions and construction method of the building elements	12 months	01/07/2…
8	M1.1: Identification of baseline options: absorber, fibres and PMTs choice		01/01/2…
9	T1.7 Dimensions and assembly procedure of single towers with a self-supporting structure	6 months	01/01/2…
10	T1.8 Definition of QC procedure and criteria for single towers	6 months	01/01/2…
11	M1.2: Identification of baseline constructing method		01/07/2…
12	T1.9 Engineering design of projective towers	10 months	01/07/2…
13	T1.10 Construction of full-containment modules	12 months	01/07/2…
14	M1.3 Construction of final modules		01/07/2…
15	T1.11 Qualification on test-beam	6 months	01/06/2…
16	M1.4 Performance assessment		31/12/2…
17	**WP2: light sensors**		
18	T2.1 Definition of a qualification protocol	3 months	
19	T2.2 Test setup preparation to qualify the different sensors	6 months	
20	M2.1 Definition of a list of SiPMs of interest		01/04/…
21	M2.2 Definition of a SiPM characterization protocol		01/04/…
22	T2.3 Procurement and qualification of SiPMs from different vendors		
23	M2.3 Definition of a dSiPM specification for Run1		01/06/…
24	M2.6 Definition of a dSiPM specification for Run2		02/05/…
25	T2.4 dSiPM design and fabrication (includes 2 runs)	15 months	01/06/…
26	T2.5 dSiPM qualification	1 year	01/01/…
27	M2.4 Selection of the SiPM that will be used to equip the central part of the calorimeter		01/01/…
28	T2.6 Test of all the SiPMs needed to equip the central part of the demonstrator	12 months	01/07/…
29	M2.5 Definition of a mass production characterization protocol		01/07/…
30	T2.7 Test of the 64 dSiPMs used to equip the small 64-fibre prototype	6 months	01/01/…
31	**WP3: Front-end and DAQ development**		
32	T3.1 Definition of the ASIC qualification protocol	3 months	01/01/…
33	M3.2 Definition of the ASIC characterization protocol		01/04/…
34	M3.1 Definition of a list of ASICs of interest		01/02/…
35	T3.2 ASICs procurement with the proper evaluation board	8 months	01/02/…
36	T3.3 Design and production of a series of passive boards and cables needed to interface the SiPMs to the evaluation boards	8 months	
37	T3.4 ASIC qualification and performance comparison in response to the SiPMs of interest for the application	6 months	
38	T3.5 Setup preparation to qualify the dSiPM	6 months	01/07/…
39	T3.6 Definition of the readout system specification which will integrate the selected ASIC	6 months	01/07/…
40	M3.3 Selection of the ASIC that will be integrated into the readout system		01/01/…
41	M3.4 Definition of the readout system specification		01/01/…
42	T3.7 Design and production of the interface boards and flat cables required to equip the central part of the calorimeter	6 months	03/01/…
43	T3.8 Prototype readout board qualification	6 months	01/07/…
44	T3.9 Final readout board qualification	6 months	02/01/…
45	T3.10 Design and production of the interface boards and flat cables required to equip the small prototype with dSiPMs	6 months	02/01/…
46	T3.11 Final qualification on beam	6 months	03/07/…
47	**WP4: performance and data analysis**		**01/01…**
48	T4.1 Development of a Geant4 simulation of the modules with testbeam geometry	12 months	
49	M4.1 Full simulation of TB module running and validated		03/01/…
50	T4.2 Development of a detailed simulation for light propagation, SiPM response and related electronics chain	12 months	
51	T4.3 Comparison of the simulation with test beam data and validation of the Geant4 hadronic model	24 months	01/01/…
52	T4.4 Development of a Geant4 simulation of a 4pi geometry solution	12 months	
53	M4.2 Full simulation of a 4pi detector running and validated		03/01/…
54	T4.5 Development of a calibration strategy for single particles and jets, both analytical and based on ML algorithms	6 months	01/01/…
55	T4.6 Assessment of the energy resolution for single particles and jets	6 months	01/07/…
56	M4.3 Performance studies for single particles		01/11/2…
57	M4.4 Jet performance studies		02/01/…
58	T4.7 Angular and position resolution for photons (in particular for non-pointing ones)	12 months	02/01/…
59	T4.8 Identification of single particles, both isolated and within jets	12 months	02/01/…
60	T4.9 Identification and reconstruction of heavy-boson decays in 2-photon, 2-tau, 2-, 4-, 6-jet final states	12 months	02/01/…
61	T4.10 Development of a baseline DNN architecture based on Convolutional models	12 months	
62	M4.5 Trained and optimised CNN model ready		01/09/…
63	T4.11Development of an evolutionary DNN based on combined Recurrent and Convolutional NNs	9 months	03/01/…
64	M4.6 Trained and optimised RNN+CNN model ready		01/09/…
65	T4.12 Development of novel DNNs based on Graph NNs optimised for a realistic detector simulation	9 months	03/10/…
66	M4.7 Novel GNN deployed		30/06/…
67	T4.13 Study of an optimised design of the DNN model developed for real-time applications (trigger, feature extractions)	6 months	01/07/…
68	T4.14 Test beam data analysis	6 months	01/07/…
69	M4.8 Results of TB with performance assessment		28/12/…

Researcher	RU	FTE	Contribution to Work Packages (months)			
			WP1	WP2	WP3	WP4
P. Giacomelli	BO	0,10		1,1	2,2	
I. Lax	BO	0,60		4,4	15,4	
AdR (50% on project funds)	BO	0,67		6	16	
S. Albergo	CT	0,20		5	1,6	
G. Cappello	CT	0,20		4	2,6	
A. Di Mattia	CT	0,20		2	4,6	
AdR (50% on project funds)	CT	0,33		11		
R. Santoro	MI	0,50	2	5	8,5	1
M. Caccia	MI	0,30	1	5,9	2	1
RUTD-a	MI	0,20		2	2	2,6
AdR (50% on project funds)	MI	0,67		11	11	
F. Bedeschi	PI	0,20	6,6			
C. Roda	PI	0,20	6,6			
V. Cavasinni	PI	0,20	6,6			
A. Basti	PI	0,20	6,6			
AdR (50% on project funds)	PI	0,67	22			
G. Gaudio	PV	0,20	3,6			3
J. Agarwala	PV	0,30	5			4,9
R. Ferrari	PV	0,50	6,5		5	5
A. Negri	PV	0,10				3,3
L. Pezzotti	PV	0,30	4			5,9
G. Polesello	PV	0,20				6,6
S. Sottocornola	PV	0,20	2			4,6
AdR (50% on project funds)	PV	0,67	16			6
S. Giagu	RM1	0,20				6,6
AdR (50% on project funds)	RM1	0,67				22
L. Pancheri	TIFPA	0,20		5,6	1	
A. Taffelli	TIFPA	0,80		18	8,4	
T. Corradino	TIFPA	0,20		5	1,6	

Table 2.1.1. Synopsis of Participants and Personnel/Month
(normalised to 11 months/yr) assignment to each Work-Package.

Unit	WP	Item Description	Required funds (k€)			type
			2021	2022	2023	
BO	3	D-SiPM: Readout Boards	5	5		inv
	2	SiPM: Test station	15			inv
	3	FERS	20	50	50	inv
	2,3	Human resources (AdR)	12.5	12.5		AdR
	2,3	meetings, conference	1	1	0.8	travel
	2,3	test beam			1.4	travel
		Total Bologna	**53.5**	**68.5**	**52.2**	**174.2**
CT	2	SiPM: Test station	15			inv
	2	Human resources (AdR)		12.5		AdR
	2,3	meetings, conference	1	1	0.4	travel
	2,3	test beam			1.2	travel
		Total Catania	**16**	**13.5**	**1.6**	**31.1**
MI	2	D-SiPM: Design	40			cons
	2	D-SiPM: Production	20	20		cons
	2	D-SiPM: Test		20		cons
	2	A-SiPM: Procurement	30.3	45		cons
	2	SiPM: Test station	15			inv
	3	Adapter boards, grouping and cabling	10	10	5	cons
	2,3	Human resources (AdR)		12.5	12.5	AdR
	2,3	meetings, conference	1	1.5	1.5	travel
	2,3	test beam			2	travel
		Total Milano	**116.3**	**109**	**21**	**246.3**
PV	1	fibres		40	14.7	cons
	1	capillary		23	13.5	cons
	1	Mech: sample for material choice	9.2			cons
	1	Mech: calorimeter box			2	cons
	1	Mech: patch pannel			9	cons
	1	Mech: assembly system		15		inv
	1	Mech: fibres qaqc	5			inv
	1	Mech: calorimeter QAQC	2			cons
	1,4	Human resources (AdR)	6	12.5	6.5	AdR
	1,4	meetings, conference	2.4	2	2	travel
	1,4	test beam			3.2	travel
	all	Project Coordination	2	2	2	travel
		Total Pavia	**26.6**	**94.5**	**52.9**	**174**
PI	1	PMT	10.2	30	30	inv
	1	fibres		40	15	cons
	1	Mech: sample for material choice	9.2			cons
	1	Mech: assembly system		15		inv
	1	Mech: fibres qaqc	5			inv
	1	Human resources (AdR)		12.5	12.5	
	1	meetings, conference	1.1	1.1	1	
	1	test beam			1.6	
		Total Pisa	**25.5**	**98.6**	**60.1**	**184.2**
	4	Human resources (AdR)	12.5	12.5		AdR

RM 1	4	meetings, conference	0.4	0.4		travel
	4	test beam			0.4	travel
		Total Romal	**12.9**	**12.9**	**0.4**	**26.2**
TIFPA	2	SiPM: Test station	15			inv
	2,3	meetings, conference	1.6	1.6	1.6	travel
	2,3	test beam			2.4	travel
		Total TIFPA	**16.6**	**1.6**	**4**	**22.2**
		Total requested funds	267.4	398.6	192.2	858.2

Table 2.2.1. Detailed expense profile and funding request.

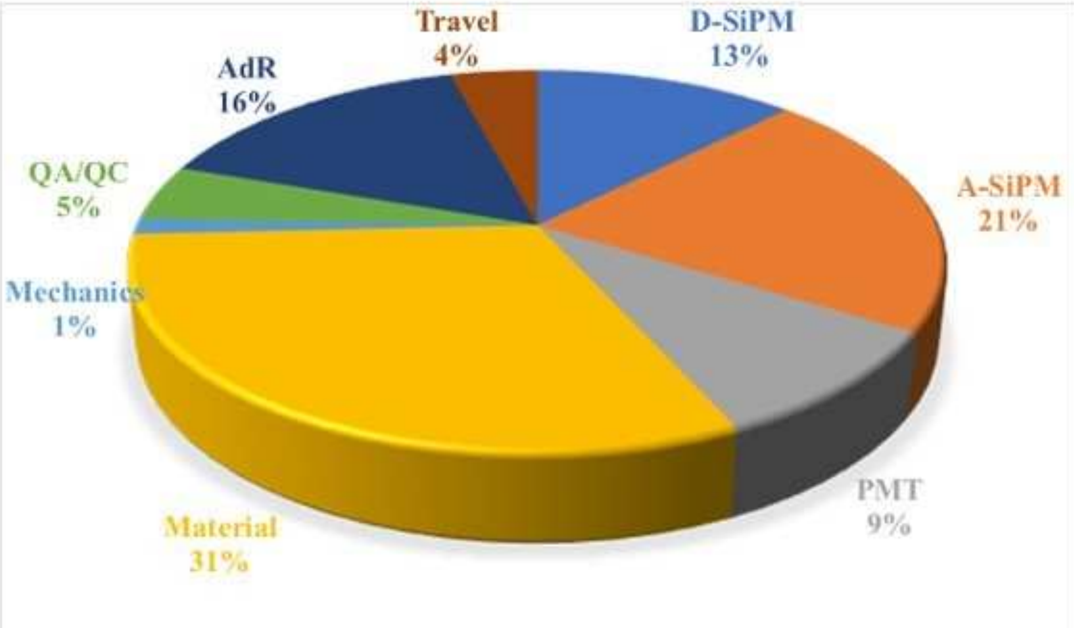

Figure 2.2.1. Budget breakdown.

Dr. Hwidong YOO

Associate Professor

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To Whom It May Concern,

With this letter, I would like to support the INFN HiDRa proposal to the fifth National Committee, with Roberto Ferrari as Principal Investigator, for the development of a Dual Readout calorimeter for future lepton colliders.

To introduce myself, I am an associate professor at Yonsei University in South Korea and have participated and played leading roles in the past and present major experiments such as BELLE at KEK (2000 – 2002), D0 at Fermilab (2002 – 2008), CMS at CERN (2008 – present). I am currently a Non-member state (Asia/Pacific) delegate to Advisory Committee of CERN Users (ACCU) since 2018. Also I am leading Korean consortium of Dual-Readout (DR) R&D team for future collider projects as Principal Investigator, with national R&D funding (about $2M from 2020 to 2025).

Korean DR R&D team shares completely common physics and research goals for the DR R&D project with INFN and European R&D consortium. Both teams have variety of expertise and knowhow for not only DR calorimeter but also many other relevant detectors in experimental particle physics. We are working together with certainly efficient scientific strategy to explore various options and methodologies for the DR calorimeter in order to get a maximum synergy from the collaboration. Such strategy should be expected to bring us the ultimate design and construction of the DR Calorimeter for future collider projects.

For instance, INFN team is mainly focusing spaghetti-style module construction with commercial capillary tubes, while Korean team is alternatively focusing on the possibility to build a module based on metal 3D printing or molding. Furthermore, the R&D on both digital SiPMs and the readout system looks very prospective. We have certain synergic and orthogonal approaches for all other aspects of the DR Calorimeter R&D program as described in their proposal. Besides, we have a regular working meeting together to share all the progress and plan. We believe the bright future of the powerful and fruitful DR Calorimeter for future collider projects and the contribution on the dramatic improvement of physics and detector knowledges for the entire world-wide HEP community.

Conclusively I am very happy to support their scientific proposal fully and strongly. Please do not hesitate to contact me at +82-2-2123-2613 or hdyoo@yonsei.ac.kr if you have further questions.

May. 30th, 2020

Professor Hwidong YOO

UNIVERSITY
OF SUSSEX

29 May 2020

To whom it may concern:

The School of Mathematical and Physical Sciences at the University of Sussex welcomes the HiDRa proposal with Roberto Ferrari as Principal Investigator as a milestone of our common work towards the development of a Dual Readout calorimeter for future lepton colliders. Members of our Experimental Particle Physics group (Iacopo Vivarelli, Antonella De Santo, Fabrizio Salvatore) are already collaborating with Roberto Ferrari and colleagues in a proto-collaboration involving, besides INFN and Sussex, institutes from Croatia and Korea. The current activities focus on the construction of a prototype to be put on beam in 2020 to test a new concept of mechanical assembly and readout, and on the development of the simulation and reconstruction software. We are contributing to the prototype with the purchase and characterisation of the optical fibres. Vivarelli is also one of the persons in charge of the calorimeter software development.

HiDRa is clearly the right step forward: after many years of test beam work (members of our Experimental Particle Physics group were involved in 2017 and 2018), the concept of the Dual Readout is now based on solid experimental ground. The challenge is scaling the system to a full-scale prototype, bearing in mind the challenges that the future construction of the full detector and its integration in a particle-physics detector will impose. HiDRa aims to address these challenges, being therefore not only a high-profile scientific project, but also timely and highly relevant for the future development of our common efforts.

We are therefore extremely pleased by this proposal submission of our Italian partners, and we look forward to continuing our fruitful collaboration in order eventually to offer to the scientific community a calorimeter with unprecedented performance.

Yours sincerely,

Prof. Philip Harris
Head of School of Mathematical and Physical Sciences

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To whom it may concern

Subject: Support Letter for the HiDRa research proposal

I am writing this letter in support of the HiDRa proposal, submitted to INFN CSN 5, for building a highly granular dual-readout hadronic demonstrator. Members of the project team of the Horizon2020 project PaRaDeSEC are convinced that dual-readout fibre-sampling calorimetry may provide a very powerful way for dealing with the physics cases at e+e- Higgs factories. It may provide at the same time high 3D granularity and high energy resolution. Dual-readout may push the hadronic resolution down to an unprecedented level. Fibre sampling coupled to solid-state sensors may provide an amazing transverse readout granularity and compelling longitudinal information. Moreover, the proposed studies on sensors and readout system will have benefits far beyond this use case.

Our interest for this project is clearly demonstrated by the fact that members of our research team are actively participating into the present developments for an electromagnetic prototype built with capillary brass tubes.

The INFN groups are ideally placed to make a pivotal contribution through this R&D proposal, addressing all significant open issues. There is world-leading expertise across all areas: on mechanics, on sensors, on front-end electronics and readout systems, on data simulations and data analysis.

I see excellent prospects for future collaboration of the INFN groups with RBI as a result of this proposal.

In summary, this proposal identifies key technical challenges for high-resolution high-granular calorimetry at future e+e- colliders, has assembled world-leading expertise to address these challenges, and the results will be of general interest.

This proposal has strong support of key PaRaDeSEC researchers and we look forward to collaboration between our project team and the proponents of this project.

Yours faithfully,

N. Soić

Dr.sc. Neven Soić, senior scientist
Project leader of Horizon2020 ERA Chair project PaRaDeSEC
Division of Experimental Physics, RBI Zagreb

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Spett.le
Dott. Roberto Ferrari
I.N.F.N Sezione di Pavia
Via Agostino Bassi, 6
27100 Pavia (PV)

Viareggio, 29 maggio 2020

Oggetto: Manifestazione di interesse per il progetto HiDRa - High-Resolution Highly Granular Dual-Readout Demonstrator

Egr. Dott. Ferrari,

il progetto da voi proposto prevede lo studio di soluzioni di read-out alternative basate su alcune tipologie di ASIC di front-end.

CAEN, avendo una linea di prodotti di read-out per rivelatori basati su ASIC e chiamata **FERS Platform**, comprendente già un'ampia lista di prototti basati su chip di Weeroc, Nalu Scientific e altri, ha inoltre nella sua roadmap di sviluppo l'implementazione su questa piattaforma di eventuali altri ASIC utilizzati nella comunità della fisica delle alte energie.

Dai colloqui intercorsi abbiamo capito che tra gli scopi principali del vostro progetto c'è quello di confrontare le soluzioni migliori di read-out per la calorimetria altamente granulare realizzata con rivelatori tipo Silicon Photomultipliers.

Confermiamo che l'attività in corso di CAEN consiste nel realizzare nel breve-medio periodo una famiglia di prodotti in grado di gestire un'ampia varietà di rivelatori presenti negli attuali e nei futuri esperimenti, ivi compresi i calorimetri.

Con la presente confermiamo pertanto il nostro interesse verso la vostra iniziativa e a valutarne i risultati.

Cordiali saluti,

Ing. Franco Vivaldi
Vicepresidente di CAEN SpA

Research Funding Office
via Sommarive, 18 - 38123 Povo (TN)
tel. (+39) 0461 314 379 - fax. (+39) 0461 314 588

Prot. n. 30/2020-UFR

Trento, 28 May 2020

INFN **-** Sezione di Pavia
Via Agostino Bassi, 6
27100 Pavia (PV)

To the kind attention of Roberto Ferrari

Subject: Letter of endorsement for the proposal "High-Resolution Highly Granular Dual-Readout Demonstrator – HiDRa", to be submitted to the Call INFN GR5 by the Principal Investigator Roberto Ferrari, INFN Pavia

The undersigned Prof. Gianluigi Casse, acting as Director of the Centre for Materials and Microsystems, on behalf of Fondazione Bruno Kessler confirms that Fondazione Bruno Kessler endorses the proposal "High-Resolution Highly Granular Dual-Readout Demonstrator – HiDRa", to be submitted to the Call INFN GR5 by the Principal Investigator Roberto Ferrari, INFN Pavia.

In case of acceptance of the project proposal and prior signature of a specific agreement on the terms and conditions, I undertake that Fondazione Bruno Kessler (IRIS research unit, Matteo Perenzoni will be the contact person) will support and assist the work planned in the project proposal through:

1) participation to HiDRa call for tender for the design and realization of digital SiPM devices in CMOS technology;
2) use of background knowledge for research purposes within the project consortium for the digital SiPM devices realization.

Yours sincerely,

Centre for Materials and Microsystems
Director
Prof. Gianluigi Casse

Istituto Nazionale di Fisica Nucleare
SEZIONE DI BOLOGNA
IL DIRETTORE

Bologna, 28 maggio 2020

Al Presidente della Commissione Scientifica Nazionale V

Dr. Valter Bonvicini

della Sezione.

Oggetto: Progetto HIDRA

Caro Valter,

in relazione al progetto HIDRA presentato come Call della Commissione Scientifica Nazionale V (responsabile nazionale: Dr. Roberto Ferrari della Sezione INFN di Pavia; responsabile locale per Bologna: Dr. Paolo Giacomelli), desidero comunicarti il mio parere positivo sull'iniziativa.

Questo progetto si inserisce perfettamente nella *roadmap* della Sezione per i prossimi anni, che ha tra le prorità lo sviluppo di nuove tecnologie e in particolare i rivelatori basati sul silicio. Oltre allo sforzo del test dell'ITK di Atlas ci sono infatti vari esperimenti che fanno uso di SiPM (DarkSide, Dune, Ship, etc) e la sezione sta cercando di potenziare le proprie infrastrutture per supportare al meglio gli esperimenti. Assicuro pertanto non solo il mio nulla osta per quanto riguarda l'utilizzo di risorse e/o strumentazione dell'INFN-Bologna per lo svolgimento del progetto, ma anche un fattivo sostegno all'iniziativa.

Un caro saluto,

ISTITUTO NAZIONALE DI FISICA NUCLEARE
SEZIONE DI BOLOGNA
IL DIRETTORE
(Dott. Eugenio Scapparone)

Istituto Nazionale di Fisica Nucleare
SEZIONE DI CATANIA

Al Presidente della
Commissione Scientifica Nazionale V
INFN
Egr. Dr. Valter Bonvicini

Oggetto: Progetto **HiDRa**

Catania, 01 giugno 2020

Caro Valter,
in relazione al progetto HiDRa presentato come Call della Commissione Scientifica Nazionale V (responsabile nazionale: Dr. Roberto Ferrari della Sezione INFN di Pavia; responsabile locale per Catania: Prof. Sebastiano Albergo), desidero comunicarti il mio parere positivo sull'iniziativa, e in particolare assicurarti che nulla osta per quanto riguarda l'utilizzo di risorse e/o strumentazione della Struttura da me diretta per lo svolgimento del progetto.

Cordiali saluti,

Digitally signed by TRICOMI ALESSIA RITA SE
C=IT
O=ISTITUTO NAZIONALE DI FISICA NUCLEARE

Istituto Nazionale di Fisica Nucleare
codice fiscale 84001850589

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tel. +39 095 3785211 - email: prot@ct.infn.it
PEC: catania@pec.infn.it

Istituto Nazionale di Fisica Nucleare
Sezione di Milano

Milano, 30 Maggio 2020
Trasmissione via mail

Alla Cortese Attenzione del
Presidente della Commissione Scientifica Nazionale V
Dott. Valter Bonvicini

E p.c.:
ai referenti locali

Oggetto: Parere del Direttore in merito all'adesione della Sezione di Milano al Progetto HiDRa

Caro Valter,

in relazione al progetto HiDRa presentato come Call della Commissione Scientifica Nazionale V con responsabile nazionale: Dr. Roberto Ferrari della Sezione INFN di Pavia, responsabile del WP2 Prof. M. Caccia e responsabile del WP3 e responsabile locale per Milano Prof. R. Santoro, desidero comunicarti il mio parere positivo sull'iniziativa, e in particolare assicurarti che nulla osta per quanto riguarda l'utilizzo di risorse del Servizio di Elettronica e/o strumentazione della Struttura da me diretta per lo svolgimento del progetto.

Con i migliori saluti

Il Direttore

Mauro Citterio

Mauro Citterio

Istituto Nazionale di Fisica Nucleare
SEZIONE DI PAVIA
Il Direttore

Pavia, 29 maggio 2020

Al Presidente della
Commissione Scientifica Nazionale V
INFN
Egr. Dr. Valter Bonvicini

Oggetto: Progetto **HiDRa**

Caro Valter,
in relazione al progetto HiDRa presentato come Call della Commissione Scientifica Nazionale V (responsabile nazionale: Dr. Roberto Ferrari della Sezione INFN di Pavia; responsabile locale per Pavia: Dr.ssa Gabriella Gaudio), desidero comunicarti il mio parere positivo sull'iniziativa, e in particolare assicurarti che nulla osta per quanto riguarda l'utilizzo di risorse e/o strumentazione della Struttura da me diretta per lo svolgimento del progetto.

Cordiali saluti,

Valerio Vercesi

Digitally signed by
VERCESI VALERIO ITALO
C=IT
O=ISTITUTO NAZIONALE
DI FISICA NUCLEARE

Istituto Nazionale di Fisica Nucleare
SEZIONE DI PISA
Servizio di Direzione

Pisa, 28 maggio 2020

Al Presidente della
Commissione Scientifica Nazionale V
INFN
Egr. Dr. Valter Bonvicini

Oggetto: Progetto HiDRa

Caro Valter,

in relazione al progetto HiDRa presentato come Call della Commissione Scientifica Nazionale V (responsabile nazionale: Dr. Roberto Ferrari della Sezione INFN di Pavia; responsabile locale per Pisa: Dr. Franco Bedeschi), desidero comunicarti il mio parere positivo sull'iniziativa, e in particolare assicurarti che nulla osta per quanto riguarda l'utilizzo di risorse e/o strumentazione della Struttura da me diretta per lo svolgimento del progetto.

Cordiali saluti,

IL DIRETTORE
Dott. Marco Grassi *

Digitally signed by GRASSI MARCO
C=IT
O=ISTITUTO NAZIONALE DI FISICA NUCLEARE

* Documento informatico firmato digitalmente ai sensi della legge 241/90 art. 15 comma 2, del testo unico D.P.R. 28 dicembre 2000 n. 445, del D.Lgs. 7 marzo 2005, n. 82 e norme collegate, il quale sostituisce il testo cartaceo e la firma autografa.

Trento Institute for
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Dr. Giuseppe Battistoni
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Tel: +39 0461 283294

Trento, 28 Maggio 2020

Al Presidente della
Commisione Scientifica Nazionale V INFN
Prof. V. Bonvicini
INFN Trieste

Oggetto: ***CALL CSN5 2020 – Progetto HiDRa***

Caro Presidente

Ti scrivo in relazione alla proposta denominata HiDRa (High-Resolution Highly Granular Dual-Readout Demonstrator) presentato come Call della Commissione V (responsabile nazionale: Dr. Roberto Ferrari, Sezione INFN di Pavia; responsabile locale per TIFPA: Dr. Lucio Pancheri).
Desidero comunicarti il mio parere positivo sull'iniziativa, e in particolare assicurarti che nulla osta per quanto riguarda l'utilizzo di risorse e/o strumentazione del TIFPA per lo svolgimento del progetto.

Cordiali saluti,

Il Direttore

Dr. Giuseppe Battistoni