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Book of Abstracts

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Poster Session & Lunch / **16**

Caribou - A versatile data acquisition system for silicon pixel detector prototyping

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Caribou is a versatile data acquisition system used in multiple collaborative frameworks (CERN EP R&D, DRD3, AIDAinnova) for both bench-top and test-beam qualification of novel silicon pixel detector prototypes. The system is built around a common hardware, firmware and software base shared accross different projects, thereby drastically reducing the development effort and cost. The current version consists of a custom Control and Readout (CaR) board and a commercial Xilinx Zynq 7000 series Sytem-on-Chip (SoC) platform. The CaR board provides a hardware environment featuring various services such as powering, slow-control and high-speed data links that can be used by the target detector prototype. The SoC platform is based on a ZC706 evaluation board running a fully featured Yocto-based Linux distribution (Poky) and a custom data acquisition software (Peary). Migration to a Zynq UltraScale+ architecture is ongoing with the additional objective of merging the SoC and the CaR board into a single hardware platform. This poster describes the current Caribou system architecture, its capabilities, the user integration workflow, and the foreseen system upgrade.

Poster Session & Lunch / **17**

Exploring the novel nLGAD concept

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Low Gain Avalanche Detectors (LGADs), implemented as ++−+−, show outstanding precision timing performance when detecting high-energy charged particles and will be used in the timing

detectors for the upcoming High Luminosity LHC detector upgrades. However, due to the difference in multiplication mechanisms for holes and electrons, the detection performance for low penetrating particles (e.g low-energy protons or soft x-rays) is significantly reduced. A novel design of an LGAD detector, the nLGAD (⌧++−⌧+−⌧), was designed and fabricated at CNM and first tested at the SSD laboratory at CERN.

Extensive studies were conducted to understand the performance of nLGAD detectors, using techniques such as the Two Photon Absorption −Transient Current Technique (TPA-TCT) to probe the nLGAD response with 3D resolution. Investigations also covered impact ionization and its temperature dependence, as well as gain reduction mechanisms. Gain response measurements were performed using laser light of different wavelengths. Another interesting aspect is the irradiation of nLGADs with different types of particles (neutrons and protons) to study basic material properties, for example whether donor removal occurres in the gain layer equivalent to acceptor removal in high-energy physics LGADs.

Poster Session & Lunch / 18

The Silicon Electron Multiplier Sensor

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The Silicon Electron Multiplier (SiEM) sensor is a novel concept for minimum ionizing particle (MIP) detection, aiming for excellent time and spatial resolution with fine pitch and internal gain. Metal electrodes embedded in the silicon substrate, obtained with a MEMS technique, form the gain layer that can be controlled by applying a high electric field to the electrode contacts. Such a structure aims to overcome the typical gain deactivation mechanism due to irradiation that may affect performance in other sensor technologies such as LGAD and APDs, where the gain layer is realised via ion implantation. The SiEM is expected to withstand fluences of up to 10ˆ16 neq/cmˆ2, targeting applications for future colliders with a challenging radiation-hard environment. The simulations on the first structure show gain values higher than ten and a timing centroid of O(40ps). The production of the first strip demonstrators with the DRIE technique is ongoing. These new structure geometries are being implemented in TCAD to extend the study on their time and gain capabilities matching the production process. The first samples will be delivered and characterized with a laser setup and in test beams in the next few months.

Poster Session & Lunch / 19

Advanced Data Set Composition with RNTuple

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RNTuple, the successor to ROOT's TTree I/O subsytsem, is currently close to reaching production-level maturity and adoption in experiment core software as well as other analysis frameworks is well underway. As the (experimental) uses of RNTuple in production environments increases, the number of available data sets resulting from different production steps does as well, each with their own schemas. This presents the opportunity to start working towards more elaborate RNTuple access patterns. A common practice used across different stages in HEP workflows, is the in-memory vertical and horizontal composition of data sets. In the context of TTree, these compositions are referred to as "chains" and "friends", respectively. To successfully implement such compositions in RNTuple, several factors need to be taken into careful consideration. Importantly, (in)compatibility between different data sets needs to be handled transparently. Moreover, the rules that determine how the data sets can be composed have to be clearly defined. In this contribution, we will present the ongoing work to support composability of RNTuples. We will discuss the main design considerations through a selection of concrete use cases, and the steps necessary to make these designs fit naturally in the broader RNTuple implementation.

Poster Session & Lunch / 20

Self-Protected High-Temperature Superconducting Demonstrator Magnets for Particle Detectors

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A high temperature superconducting (HTS) demonstration magnet has been developed in the frame of the Experimental Physics Department Research and Development program on Experimental Technologies at CERN.
Two small partially insulated, radiation transparent demonstrator coils were successfully built using additive manufacturing technology (3D-printing) applied to the aluminium alloy support structure. The first HTS coil, with five turns and an open bore diameter of 230 mm, was measured to be superconducting at 4.4 kA and up to 40 K. The second demonstrator coil has a larger bore diameter of 390 mm, with 15 turns corresponding to 19 meters of a HTS conductor consisting of a stack of four ReBCO tapes. The characteristics of the coils were measured at 77 K and 4.2 K.
We have experimentally and numerically validated that using an aluminium alloy as a stabiliser for HTS tapes can result in a stable, lightweight and transparent magnet.
This detector magnet technology may be used in future particle detector magnets, such as the AMS-100 solenoid, where one of the key design requirements is a passive self-protection by partial-insulation which ensures continuous operation and stable magnetic field even with a locally damaged conductor.

Poster Session & Lunch / 21

Future Robotic Residents in Experimental Caverns

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EP-R&D WP4 Robotics for Detector is devoted to introducing robotic systems in future high energy physics experiments to assemble, maintain, inspect, and operate particle detectors. The harsh cavern environment constitutes a challenge for these systems, which will have to deal with high radiation levels and magnetic field intensities. The first step to reach this goal is to deploy these robots for cavern inspection, alarms verification, and environmental mapping during beam run. To this end, several mobile platforms with specific payloads have been identified. Both ground and aerial solutions are currently being developed.

Quadruped robots have been recognized as a suitable solution for ground inspection tasks, for their agility and capabilities to climb intricated ladders and steps. The mobility and controllability of these quadrupeds have been successfully tested within the detector cavern. Moreover, the tested robot was also able to withstand relatively weak magnetic field intensities.

Furthermore, we are investigating the use of a swarm of small quadruped robots (few centimetres in size) specifically designed for inspecting confined and cluttered spaces, aiming at detecting leaks or anomalies in between intricate detector services that have triggered alarms. Within these areas, CERN network is usually unavailable; therefore, a mobile mesh network protocol is under development to guarantee an uninterrupted and efficient communication within the swarm and between the swarm and the remote operator.

To complement our ground-based inspection, we are developing autonomous flying vehicles, such as blimps, equipped with sensors for an accurate aerial environmental mapping of the detector cavern. A blimp prototype has already been designed and tested in collaboration with Windereiter. The software incorporating guidance, navigation, and control algorithms is currently under development, and focus is given to magnetic disturbance rejection.

In parallel with the cavern inspection, we are working on developing robotic-friendly particle detectors integrating interfaces for quick and controlled interactions between detector and robotic systems. In this framework, an innovative design concept for an automatic detector modules insertion/extraction has been proposed and will be further developed, using the future ALICE 3 detector as reference.

The employment of the aforementioned robotic solutions promises to streamline the processes, reduce personnel exposure to radiation, and increase the beam run time, improving both safety and efficiency.

Poster Session & Lunch / **22**

Flex-PCB board design for SiPM readout at cryogenic temperatures

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During the High-Luminosity LHC phase, the LHCb RICH detector will face challenges arising from increased particle multiplicity and high occupancy. Therefore, enhancing the detector granularity and introducing sub-100ps time information will be crucial to maintaining its excellent particle identification (PID) performance. The 150 ps intrinsic time resolution of the Multi-Anode Photomultiplier Tubes (MAPMTs), currently installed in the detector, will not be sufficient during LHC Run 5. Consequently, the LHCb RICH collaboration is exploring new photodetector options with improved timing and smaller pixel sizes. A strong candidate is the silicon photomultiplier (SiPM). However, radiation damage to SiPMs poses a significant challenge, necessitating operation at cryogenic temperatures.
This work presents a PCB design for the readout of a Hamamatsu 64-channels SiPM. The PCB is a 3-layer fully flexible board that will be integrated into a liquid-nitrogen cryostat demonstrator,

currently under development at CERN. The board employs high-density long traces to separate the SiPM (to be cooled at cryogenic temperatures) from the readout electronics (operating at room temperature). The aim is to prove the principle of a small-scale SiPM module at cryogenic temperatures with flex-PCB technology to bring the signals to the front-end readout electronics at higher temperatures. The high-density traces (with 200 μm of width and spacing) have been designed to match the requirements to scale the prototype to the RICH detector dimensions. Furthermore, the board implements features to ensure compatibility with the RICH upgrade readout electronics and its integration into the cryostat. The overall thickness of the board is 450 μm, with a stack-up designed to match 50-100 Ω impedance. The SiPM bias has negative polarity with an RC-filter per channel for decoupling purposes. The board implements two pulse injection circuits: one near the SiPM and one at the front-end connectors. These circuits will be used to evaluate the difference in signal integrity between a long and a short trace. Then, the board will be coupled to the RICH testbeam electronic chain, a FastIC+picoTDC-based readout, and tested in a picosecond pulsed laser setup. The time resolution and signal integrity of the SiPM pulses will be measured, first at room temperature and then in a cold chamber at -20°C. Finally, the PCB will be integrated into the cryostat demonstrator, anticipated for the second half of 2025.

Poster Session & Lunch / **23**

ALICE ITS3 WAFER-SCALE ON-CHIP READOUT ARCHITECTURE

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The ALICE collaboration is developing the new Inner Tracker System 3, a novel detector that uses the stitching technique to construct a single-die monolithic active pixel sensor. For material budget, flexible cables are minimized. This forces all the data to be transferred on-chip to the left edge, responsible for communication with the outside world. These long-distance on-chip communication links require careful optimization of throughput, area, and power consumption. Additionally, the yield must be contained.

To achieve this on-chip readout architecture, the following tasks were performed and will be presented in this contribution:
- Design of a custom DFM standard cells library to achieve the yield.
- Model of the on-chip readout architecture to optimize the various design parameters.
- Create the readout architecture at RTL level.

Poster Session & Lunch / **24**

Thermalisation of HTS-based current leads using a single-stage GM cryocooler

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Cryocooler-based cooling technology promises compactness and modularity. Moreover, it allows for avoiding investment costs related to building large cryogenic plants. This makes it particularly attractive in the context of cooling future detector magnets for HEP experiments. Nevertheless, this technology features a modest cooling capacity which requires a dedicated design to reduce heat inleaks to the cold system.
Current lead is a crucial component of a superconducting magnet because it connects it to the powering system but also transfers heat from ambient temperature to the cold mass. Therefore, a significant part of the heat has to be intercepted at an intermediate temperature level. This poster presents the design of 3kA HTS-based current leads for a Low-Temperature Superconductor detector magnet and the dedicated cooling system with a cryocooler. The leads are thermalized at 50K by helium gas circulating in a closed loop that operates with a single-stage Gifford-McMahon cryocooler and a cold circulator. Following the design and construction phases of the thermal exchangers, the demonstrator is currently being assembled and instrumented before the testing campaign starting next summer

Poster Session & Lunch / 25

A cold ejector-supported krypton system for future highly irradiated detectors

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A future upgrade of the Large Hadron Collider (LHC) at CERN will expose silicon-based particle detectors to higher radiation levels requiring temperature levels below than what is currently attainable with the CO2 cooling system (2PACL). A fluid-based approach suggests the noble gas krypton as a promising cooling agent for thermal management of detectors within the range -60 to -80℃. Its thermo-physical properties, together with the controlled and slow cooldown to avoid thermal shock of the sensors requires to completely revise the cooling technology. Motivated by this, a new ejector system has been developed to provide cooling, starting from ambient conditions and gradually lowering the temperature to the levels required for conducting physics experiments.

Poster Session & Lunch / 26

Mitigating Emissions in Gaseous Particle Physics Detectors: CO2 as an Eco-Friendly Alternative for RPC Detectors

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High-Pressure Laminate Resistive Plate Chamber (HPL-RPC) detectors are a type of gaseous detector that identifies particles using a mixture of greenhouse gases (GHG) consisting of 95.2% $C_2H_2F_4$ (R-134a), 4.5% i-C_4H_{10}, and 0.3% SF_6. Notably, the high Global Warming Potential (GWP) of this mixture

results in the HPL-RPC detectors being one of the main contributors to CERN's emissions. To fulfil its environmental objectives, CERN has emphasised the need to reduce the emissions from these detectors. One strategy implemented by the gas group is to look into the search for alternative eco-friendly gas mixtures for RPC's use.

After extensive mixture characterisation studies in the laboratory, test beam campaigns, and ongoing ageing tests, the addition of CO_2 to reduce R-134a consumption was found to maintain experimental parameters such as efficiency, time, and spatial resolution while reducing the CO_2-equivalent (CO_2e) emissions. The results from the 2023 data acquisition campaigns and ageing tests will be presented in the following.

Our results demonstrate the potential of introducing CO_2 to reduce the amount of R-134a, which has a lower GWP than the usual gases used in the RPC mixture. We proposed the addition of 30% CO_2 and 1% SF_6 as an effective solution for reducing emissions. Additional fine-tuning, such as increasing the CO_2 percentage to 40% or reducing the SF_6 amount to 0.5%, which can further reduce emissions, will be presented. Other lower-GWP gases are also being investigated.

The mixture has been successfully validated and is now in use in the ATLAS experiment, resulting in a commendable 15% reduction of emissions. This represents a significant step forward in our collective efforts to mitigate emissions in the particle physics research community. The adoption of this solution can impact our environmental footprint, instilling motivation for further developments.

Poster Session & Lunch / **27**

Modular nitrogen boiling thermosyphons for multi-kiloampere current lead cooling

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A high cooling power, low-complexity and inexpensive system for pre-cooling of multi-kiloampere current leads based on nitrogen boiling thermosyphon flow in a modular heat interceptor part is presented. This heat interceptor module can be placed between the resistive and high temperature superconductive part of the current leads to minimize thermal loads to a connected cold mass. Two prototype heat interceptors with similar cross-sectional areas and wetted boiling surface areas but different coolant channel geometries were designed, manufactured, and characterized with artificial heat loads simulating current lead heat loads. The prototypes displayed a bottom temperature below 79 K up to top heat loads of (0.90 ± 0.09) kW for the wide-channel design and (1.25 ± 0.05) kW for the thin-channel design. The results show relatively simple designs of heat interceptor modules that offer cooling capacities sufficient for intercepting heat loads from high-power current leads using a passive system. These modules can form a cheap, compact, and passively safe current lead heat interception system for superconductive experiments. The system can be especially beneficial when combined with low-capacity cryocoolers or may be used as an additional or backup cooling system in current leads for large-scale high-current superconducting experiments such as ATLAS and CMS. A small storage Dewar can supply enough cooling power for a slow discharge of a cold mass in case of a power failure .

Poster Session & Lunch / **28**

Virtual prototyping of pixel detectors with PixESL framework in High Energy Physics

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PixESL pioneers a virtual prototyping framework for future particle detectors in high-energy physics. Developed at CERN under the EP R&D Work-Package 5, this framework enables high-level abstraction, simulating the full detector chain from particle interaction to data packet readout. It facilitates early optimization of chip and system architecture, which is critical for meeting experiment specifications. PixESL models crucial components such as analog front-end, digital circuitry, and data readout networks, empowering designers to analyze interactions and optimize performance. Leveraging SystemC, PixESL offers rapid simulation runtime and above-RTL abstraction, presenting a pivotal tool for advancing particle detector design and verification.

Poster Session & Lunch / 29

SOCRATES: a Radiation-Tolerant SoC Generator Framework

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As front-end ASIC complexity in HEP experiments grows, there is a shift towards more modular, programmable, and cost-effective designs. This work introduces the SOCRATES platform, a radiation-tolerant SoC generator toolset, centered on SoCMake, a hardware/software build system that automates SoC assembly and verification. Utilizing existing IP blocks, SoCMake generates the interconnects and the software framework to run application code. The platform includes radiation-tolerant IPs and supports fault-tolerant extensions for redundancy and error correction. A prototype ASIC based on the RISC-V Ibex processor, created using SOCRATES in a 28nm CMOS process, validates the toolset through SEE and TID testing.

Poster Session & Lunch / 30

PICOSEC Micromegas precise-timing gaseous detectors and studies on robust photocathodes

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The PICOSEC Micromegas (MM) detector is a precise-timing gaseous detector based on a Cherenkov radiator coupled with a semi-transparent photocathode and a MM amplifying structure, targeting a time resolution of tens of picoseconds for minimum ionising particles. Initial single-pad prototypes have demonstrated a time resolution below σ = 25 ps, prompting ongoing developments to adapt the concept for physics applications. The objective is to build robust multi-channel detector modules suitable for large-area detection systems requiring exceptional timing precision.

Extensive R&D activities within PICOSEC have covered all areas from simulations, design, production, and assembly to measurements in laboratory conditions, as well as with 150 GeV/c muon beams. One significant advancement was the improvement of time resolution to σ = 13 ps for a single-pad detector through design optimization. Regarding stability, a resistive PICOSEC MM of 20 MΩ/□ was introduced, obtaining comparable results. In the pursuit of a robust alternative to Cesium Iodide, comprehensive measurements of carbon-based photocathode samples, including Diamond Like Carbon (DLC) and Boron Carbide (B4C) are ongoing. Preliminary results from detectors equipped with DLC and B4C photocathodes exhibited a time resolution below σ = 30 ps. Scaling up the prototype to a 100-channel detector with a 10x10 cm2 active area yielded a time resolution below σ = 18 ps for individual pads, validating that the excellent timing performance of the single-pad proof of concept can be transferred to the 100-channel prototype. Furthermore, successful measurements of the complete read-out chain utilizing RF pulse preamplifiers and a SAMPIC digitiser confirmed the system' s suitability for studying multi-channel detector response.

Efforts dedicated to improving detector stability and robustness, enlarging its coverage, and integrating scalable electronics enhance the feasibility of the PICOSEC MM concept for large experiments requiring sustained performance while maintaining exceptional timing precision.

Poster Session & Lunch / **31**

Modelling signal induction in detectors with resistive elements

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A growing proportion of detector technology development incorporates resistive materials into their readout architectures to improve performance and stability in order to meet the stringent requirements for measurement precision under increasingly challenging conditions in High Energy Physics (HEP) experiments. With the rising prevalence of these resistive detectors, updating modeling capabilities to reflect this progress is essential. With Garfield++ and a finite element method-based approach a new numerical framework was developed to calculate the induced signal in the presence of resistive elements that is applicable to a wide range of detectors, most of which are inaccessible through analytical means.

By applying an extended form of the Ramo-Shockley theorem, we investigated the induced current response of various devices, including (Multi-gap) Resistive Plate Chambers (MRPCs), Resistive Silicon Detectors, and resistive strip Micromegas. Different techniques were developed to obtain the key quantity of the time-dependent weighting potential of the readout electrodes, particularly for large area structures. In addition, laboratory and test beam measurements were performed to calibrate and validate the simulation framework, which was subsequently used to inform the design of innovative detector readout structures.

Through simulation and measurement, we have explored novel solutions in MRPCs, Micro Pattern Gaseous Detectors, and solid-state sensors incorporating materials with finite conductivity. These studies can be employed for advancing the design and optimization of future detectors, tailored to meet the specific demands of HEP experiments and other applications.

Poster Session & Lunch / **32**

100GbE2FE –Evaluation of Ethernet as a detector front-end readout link

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New-generation detectors are creating a need for flexible, high-speed datalinks. As a part of EP RnD WP6 and in collaboration with WP9, an examination of commercial-grade Ethernet as a front-end readout link is underway, potentially enabling off-the-shelf hardware to be used in data readout systems and cutting down complexity using modern datacenter technologies.
We present the encouraging first results of this RnD effort, evaluating 100Gb/s Ethernet for data readout in the context of typical High-Energy Physics detector requirements. Due to asymmetries in data rate requirements in up- and downlinks, unidirectional Ethernet is examined. Results from a recent radiation study, allowing a preliminary assessment of radiation hardness via statistical analysis, are provided. The application is verified with realistic traffic using a demonstrator to translate from lpGBT to Ethernet and a roadmap for future demonstrators is presented.

Poster Session & Lunch / 33

WarTPC: A High-Pressure Time Projection Chamber

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DUNE, the next generation of neutrino detectors is due to come online in the 2030s. In the meantime, R&D is needed. The Warwick Time Projection Chamber (WarTPC) is a High Pressure Gaseous TPC (HPgTPC) that will operate under the same conditions as ND-GAr at DUNE. The WarTPC aims to develop and optical readout platform at high pressure, and will also perform gas studies to aid in the DUNE program.

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Towards detector agnostic Fast Simulation

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Recently, there have been numerous machine learning-based models developed to address the need for fast calorimeter shower simulation tools. However, most of these models are detector-dependent, i.e., these models are separately trained for each detector or experiment. This leads to the consumption of considerable resources during the designing and training of these models, both in terms of compute and manpower. In this poster, we present preliminary results for a transformer-based diffusion model that is trained on multiple detectors and can be adapted to a new detector with a significant reduction in the training time (up to 25x) and data (less than 50%).

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Key4hep: a Turnkey Software Framework for Future Accelerator Experiments

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Key4hep is a software framework designed to facilitate the design, optimization and data analysis of detectors for future accelerator experiments. With the goal of fostering collaboration and resource sharing, the Key4hep community has been growing and now includes the FCC, CLIC, ILC, EIC and other experiments. Thanks to reusing developments across experiments, Key4hep significantly reduces duplication efforts and helps to improve the quality of the software, as many users with various needs work on its development or use it.

In this poster, the components of Key4hep are explained. Key4hep integrates all the steps in the typical offline pipeline: generation, simulation, reconstruction and analysis. The central component is a common event data model, called EDM4hep. There are also interfaces to existing tools; for example, for reconstruction, Key4hep leverages Gaudi, a proven framework already in use by several experiments at the LHC, to orchestrate configuration and execution of reconstruction algorithms. The list of components also includes interfaces to Monte Carlo generators and other tools for simulation, as well as analysis facilities. The interplay between the different components, interfaces and the usage and development in Key4hep are explained.

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MiniMALTA3 DMAPS

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MALTA3 DMAPS, last prototype of MALTA family, will be designed in the standard TOWER 180 nm technology with numerous process modifications, as well as front-end changes in order to boost the charge collection efficiency after the targeted fluence of 1 × 10E15 1 MeV neq/cm 2.
The effectiveness of these changes have been demonstrated with recent measurements of the full size MALTA2 chip. With the original MALTA concept being fully asynchronous, a small-scale MiniMALTA demonstrator chip has been developed with the intention of bridging the gap between the asynchronous pixel matrix, and the synchronous DAQ. This readout architecture will serve as a baseline for MALTA3, with focus on improved timing performance. The synchronization memory has been upgraded to allow clock speeds of up to 1.28 GHz, generated by a PLL pushing the technology

to its limit, with the goal of achieving a sub-nanosecond on-chip timing resolution.
The data output protocol will be upgrated with analysed data serialization discussed in the context of the overall sensor architecture.

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Perfomance studies and design optimization of Spaghetti Calorimeter prototypes

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This R&D effort aims to develop Spaghetti Calorimeters (SpaCal) with O(10) ps time resolution, energy resolution with 10% sampling and 1% constant term, and fine granularity. The SpaCal modules will use several novel technologies, including radiation-hard scintillating materials, hollow light guides, and ultra-fast photodetectors.

R&D activities include laboratory measurements, Monte-Carlo simulations, and test beams. Several SpaCal prototypes were assembled at CERN and evaluated during test beam campaigns. Two components of the prototype design influencing the energy resolution are the linearity of photodetectors and spatially uniform light collection, and dedicated test benches were set up to study and optimize them.

This work presents the energy and time resolution measured in test beams, a performance comparison to detailed Ray-Tracing simulations, and the laboratory measurements for prototype optimization.

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3D PRINTED PIPES INCLUDING SENSORS AND HEATERS FOR THERMAL MANAGEMENT SYSTEMS IN SPACE AND ON EARTH

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The AHEAD (Advanced Heat Exchange Devices) project has been launched in the frame of the ATTRACT Phase 2 project, which is one of the main partners of the EP R&D program. Among the AHEAD partners, CERN focuses on the implementation of the AHEAD's technology on the detectors'thermal management systems, relying on carbon dioxide refrigeration. In such systems, sensing of local flow parameters is essential for optimized heat exchange across the thermal circuit. However, in the detector's environment, mass and volume can be limited and therefore the integration of sensors might not be trivial. The use of Additive Manufacturing-produced elements within these hydraulic systems provides the necessary freedom of design to address these constraints, while the inclusion of embedded sensing capabilities allows for the precise monitoring of vital parameters throughout the thermal management system. Furthermore, the integration of Energy Harvesting devices provides standalone and wireless monitoring, which can significantly reduce the amount of cabling required in such systems. In this contribution a part of the AHEAD technology is presented which focuses on the development of pipe segments including temperature sensors, heaters and energy harvesters directly integrated into the pipe thanks to advanced processes of Additive Manufacturing.