CALOR 2022 - 19th International Conference on Calorimetry in Particle Physics

Sunday 15 May 2022 - Friday 20 May 2022

University of Sussex

Book of Abstracts

Contents

1

Silicon Photomultiplier dual-readout calorimeter for future electron-positron colliders

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The next step in the high-energy physics programme will likely be based on a circular electron-positron collider to allow for in-depth exploration of the Z, W, H boson properties. This programme is calling for a new generation of experiments aiming at extreme precision measurements of trajectories and energies for all the possible final-state particles produced in the collisions. IDEA (Innovative Detector for Electron-positron Accelerators) is a detector conceptual design that has selected a dual-readout fibre calorimeter to match the requirements, for both electromagnetic and hadronic shower energy measurements, with a single integrated detector.

The dual-readout calorimetric technique reconstructs the event-by-event electromagnetic fraction of hadronic shower through the simultaneous measurement of the scintillating (S) and the Cherenkov (C) light produced in the shower development. The new generation of prototypes based on SiPM readout is adding an unprecedented granularity to the well-known energy resolution performance. A first small prototype has been tested on beam from 2016 to 2018 demonstrating 1) the viability of the concept with this readout, 2) a good linearity response in a large energy range even if a special care has to be applied to eliminate any cross-talk effects among fibres.

A new prototype, designed to fully contain an electromagnetic shower with a core readout by 320 SiPMs, is under construction. It opens the way to assess a series of challenges which will bring the proof a concept to a scalable solution optimized for the next-generation experiments. The tests performed with an ASIC-based readout boards, the new assembly concept and the preliminary commissioning performed in view of the next beam test will be discussed.

2

Towards a Large Calorimeter based on LYSO or LaBrCe Crystals for Future High Energy Physics

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State of the art research in particle physics at the precision frontier aims at finding evidence of physics beyond the standard model by measuring prohibited or suppressed processes and quantities with an unprecedented accuracy. For such experiments it is common to search for a faint signal in a waste amount of backgrounds.
In the field of charged lepton flavour violation (cLFV), one is investigating various decays, some of which contain photons in the final state. To discriminate between a signal of new physics beyond the standard model and standard model background, detectors providing excellent resolutions in all particle variables are crucial. Muon decays are of special interest as they are at comparably low energy and easier to produce with respect to tau leptons. The photons in muonic charged lepton flavour violating decays are expected to be on an energy scale in the range of 10 MeV to 100 MeV. The state of the art technique to detect these is a calorimeter based on a scintillating material coupled to photosensors of various kind.
Two very promising materials for a future calorimeter are on the one hand LYSO and on the other hand Lanthanum Bromide. Recent progress in the crystal growing process makes it feasible to build a prototype with a crystal of about 10 cm length and 7.5 cm diameter in near future and to test its response to photons of the expected energy scale of future high precision experiments.
Coupling such a crystals to $\mathcal{O}(100)$ silicon photomultipliers results in a granular detection of the

optical photons. This provides geometrical information about the distribution of the light amongst the photon sensors and hence allows for a three dimensional reconstruction of the position of the first interaction between the incident γ-photons and the scintillator. The candidate SiPMs for the prototype and potential future applications have been recently characterised and the obtained results will be shown.
The simulated response of both, $LaBr_3$:Ce and LYSO prototypes fired by gammas of an energy of 55MeV had been studied previously and very promising results were obtained. More specifically, for a prototype using a LYSO crystal of 10 cm length and 7.5 cm diameter an energy resolution around 1.7%, time resolutions below 30 ps and position resolutions around 5 mm are suggested.
In this contribution we will discuss for the first time the extension to a large calorimeter made of several of such a basic units for covering a large solid angle for a straight application to a high energy physics experiment. The response
of the SiPMs in combination with the whole data acquisition system is validated with the data obtained from the SiPM characterisation.

3

The NNBAR Calorimeter

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The existence of baryon number violating processes is one of the Sakharov conditions considered necessary to explain the matter-antimatter asymmetry in the universe, but is yet to be observed. The NNBAR experiment, planned to be housed at the European Spallation Source (ESS) will perform a search with free neutrons for neutron-antineutron oscillations with a gain in sensitivity of three orders of magnitude compared to the most recent search with free neutrons. To achieve this, a detector is needed to reconstruct multi-pion final states with an invariant mass < 2 GeV from neutron-antineutron annihilations and discriminate against spallation and non-spallation backgrounds. The key component in the detector is the calorimeter. The energy regime for calorimetry at the experiment is challenging due to large fluctuations in energy deposition in the showers which disfavour a sampling calorimeter solution. The NNBAR collaboration has developed a novel hadronic range followed by full absorption calorimeter concept. Simulation and construction of a prototype calorimeter is underway. The prototype is planned to be deployed at testbeams in 2021, and ultimately installed at the ESS testbeam area in 2023 for in-situ studies of neutron backgrounds from the ESS beamline. This talk will present the novel NNBAR calorimeter concept, as well as ongoing work towards a prototype calorimeter at Stockholm University.

Poster Session / 5

Trigger-DAQ and slow control systems in the Mu2e experiment

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The muon campus program at Fermilab includes the Mu2e experiment that will search for a charged-lepton flavor violating processes where a negative muon converts into an electron in the field of an aluminum nucleus, improving by four orders of magnitude the search sensitivity reached so far.
Mu2e's Trigger and Data Acquisition System (TDAQ) uses {\it otsdaq} as its solution. Developed at Fermilab, {\it otsdaq} uses the {\it artdaq} DAQ framework and {\it art} analysis framework, under-the-hood, for event transfer, filtering, and processing.
{\it otsdaq} is an online DAQ software suite with a focus on flexibility and scalability, while providing a multi-user, web-based, interface accessible through a web browser.
The detector Read Out Controller (ROC), from the tracker and calorimeter, stream out zero-suppressed data continuously to the Data Transfer Controller (DTC). Data is then read by a software filter algorithm that selects events considering data flux that comes from a Cosmic Ray Veto System (CRV).
A Detector Control System (DCS) for monitoring, controlling, alarming, and archiving has been developed using the Experimental Physics and Industrial Control System (EPICS) open source Platform. The DCS System has also been integrated into {\it otsdaq}.
A prototype of the TDAQ and the DCS systems has been built at Fermilab's Feynman Computing Center. We report the developments and achievements of the integration of Mu2e's DCS system into the online {\it otsdaq} software.

6

Status of ADRIANO2 R&D in T1604 Collaboration

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A novel high-granularity, dual-readout calorimetric technique (ADRIANO2) is under development as part of the research program of the T1604 Collaboration[1]. The building block of such a calorimeter comprises a pair of optically isolated, small tiles made of scintillating plastic and lead glass. The prompt Cerenkov light from the glass can be exploited to perform high resolution time measurements while the high granularity provides good resolution of the spatial components of the shower. Dual-readout compensation and particle flow techniques applied to the plastic and lead glass sections should provide excellent energy resolution as well as PID particle identification, making ADRIANO2 a 6D detector suited for High Energy as well as High Intensity experiments.
A report on the ADRIANO2 project, current and future R&D plans by T1604 Collaboration, and the construction status of a new prototype will be presented.

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References
1. http://www-ppd.fnal.gov/FTBF/TSW/PDF/T1604_mou_signed.pdf (2019)

8

Design and construction status of the Mu2e crystal calorimeter

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The Mu2e experiment at Fermi National Accelerator Laboratory searches for the charged-lepton flavor violating neutrino-less conversion of a negative muon into an electron in the field of an aluminum nucleus. The dynamics of such a process is well modelled by a two-body decay, resulting in a mono-energetic electron with energy slightly below the muon rest mass (104.967 MeV). Mu2e will reach a single event sensitivity of about 3x10−17 that corresponds to four orders of magnitude improvement with respect to the current best limit.
The calorimeter requirements are to achieve an energy resolution better than 10% and a timiong resolution better than 500 ps at 100 MeV in order to provide the needed □/e particle identification, an online trigger filter while aiding the track reconstruction capabilities. It consists of two disks of un-doped CsI crystals, each one read out by two large area UV-extended SiPMs.
In this talk, the status of construction and QC performed on the produced crystals and photosensors, the development of the rad-hard electronics and the most important results of the irradiation tests done on the different components are summarized. The production of electronics is underway and we will summarize the QC test performed on the analog electronics and on the integrated SIPM+FEE units. Construction of the mechanical parts is also progressing well. Status and plans for the final assembly are also described. We expect to start assembly of the disk in summer 2021 assuming that the pandemics status will allow the INFN team to be present at Fermilab.
In the meanwhile, a complete vertical slice test with the final electronics is in progress on the large calorimeter prototype, dubbed Module-0, at the Frascati Cosmic Rays test stand. First calibration and performance results will be shown.

9

QuARC: A Quality Assurance Range Calorimeter for Proton Therapy

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Proton therapy offers highly localised dose distribution and better healthy tissue sparing over conventional radiotherapy. Crucial in optimising patient safety is the proton range: this is the largest source of uncertainty in proton therapy and prevents full advantage being taken of the superior dose conformality. In the clinic, daily Quality Assurance (QA) is performed each morning before patient treatment, including verification of the proton range in water (a proxy for human tissue) for specific beam energies. This process however, often compromises between speed and accuracy. Recently, there has been increased interest in FLASH: a high dose rate form of radiotherapy offering even

greater healthy tissue sparing. However, standard detectors used in QA become unusable at FLASH dose rates.

The Quality Assurance Range Calorimeter (QuARC) is currently under development at UCL with our industrial partners Cosylab to provide fast, accurate, water-equivalent proton range measurements for daily QA, with the capability to operate at FLASH dose rates. Based on plastic scintillator developed for the SuperNEMO experiment, the detector is a series of optically isolated scintillator sheets that sample the proton energy deposition along its path. Light from each sheet is measured by a series of photodiodes: this light output is proportional to the deposited energy. An analytical depth-light model is used to fit the data and measure the proton range to sub-mm precision.

Two preliminary beam tests at UCLH with proton pencil beams between 70-110 MeV found that the QuARC is able to consistently recover proton ranges with good accuracy, even at low light levels. Fast curve fitting enables stable real-time range reconstruction at 40 Hz, as protons are delivered to the detector. Due to large dynamic range, the detector can be scaled up to FLASH dose rates. Further measurements are required to fully characterise detector performance and light output with FLASH.

10

Using artificial intelligence in the reconstruction of signals from the PADME electromagnetic calorimeter

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The PADME apparatus has been built at the Frascati National Laboratory of INFN to search a dark photon (A') produced via the process e+ e− ⟶ A'γ.
The central component of the PADME detector is an electromagnetic calorimeter made of 616 BGO crystals dedicated to the measurement of the energy and the position of the final state photons.
The high beam particle multiplicity over a short bunch duration requires reliable identification and measurement of overlapping signals.
A regression machine learning based algorithm has been developed to disentangle with high efficiency, close-in-time events and precisely reconstruct the amplitude of the hits and their time with a sub-nanosecond resolution.
The performance of the algorithm and the sequence of improvements leading to the achieved results will be presented and discussed.

11

FERS-5200: a distributed Front-End Readout System for multidetector arrays

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Modern physics experiments usually rely on very big experimental setup where it is possible to find a wide variety of detectors: silicon microstrip trackers, plastic scintillator calorimeters, LAr cryostats readout by a Time Projection Chamber, spectrometers composed of several drift tubes and resistive plate chambers. Moreover, other large and medium scale setups for the search of neutrinos and astroparticles use thousands of scintillation detectors read out by photomultipliers or SiPMs.

Nowadays, waveform digitizers and/or ASIC-based front-end cards are well-established readout electronics to build a reliable system hosting many readout channels.
The FERS-5200 is the new CAEN Front-End Readout System, answering the challenging requirement to provide flexibility and cost-effectiveness in the readout of huge detector arrays. FERS-5200 is a distributed and easy-scalable platform integrating the whole readout chain of the experiment, from detector front-end to DAQ. It is based on compact ASIC-based front-end cards integrating A/D conversion and data processing, which can be ideally spread over a large detector volume without drawbacks on the readout performance. Synchronization, event building and DAQ is managed by a single Concentrator board, capable of sustaining thousands of readout channels.
Using the appropriate Front-End, the solution perfectly fits a wide range of detectors such as SiPMs, multianode PMTs, GEMs, Silicon Strip detectors, Wire Chambers, Gas Tubes, etc, thus matching the requirements of different applications.

12

Scintillating sampling ECAL technology for the Upgrade II of LHCb

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The aim of the LHCb Upgrade II is to operate at a luminosity in the range of 1 to 2 x 10^{34} cm^{-2} s^{-1} to collect a data set of 300 fb^{-1}. This will require a substantial modification of the current LHCb ECAL due to high radiation doses in the central region and increased particle densities. The ECAL has to provide good energy and position resolutions in these conditions. Timing capabilities with tens of picoseconds precision for neutral electromagnetic particles and increased granularity with denser absorber in the central region are needed for pile-up mitigation.
Several scintillating sampling ECAL technologies are currently being investigated for this purpose: Spaghetti Calorimeter (SpaCal) with garnet scintillating crystals and tungsten absorber, SpaCal with scintillating plastic fibres and tungsten or lead absorber, and Shashlik with polystyrene tiles, lead absorber and fast WLS fibres. Results from an ongoing R&D campaign to optimise the Upgrade II ECAL are shown. This includes studies of radiation-hard scintillation materials, performance optimisation using detailed simulations and test beam measurements. The presentation also includes an overview of the overall plans for the Upgrade II of the LHCb ECAL.

13

Test Abstract

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This is just a test abstract to check that the system works

14

FASER's Electromagnetic Calorimeter Test-Beam Studies

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FASER, or the Forward Search Experiment, is a new experiment at CERN designed to complement the LHC's ongoing physics program, extending its discovery potential to light and weakly-interacting particles that may be produced copiously at the LHC in the far-forward region. New particles targeted by FASER, such as long-lived dark photons or dark scalars, are characterized by a signature with two oppositely charged tracks or two photons in the multi-TeV range that emanate from a common vertex inside the detector. The experiment is composed of a silicon-strip tracking-based spectrometer using three dipole magnets with a 20-cm aperture, supplemented by four scintillator stations and an electromagnetic calorimeter. The full detector was successfully installed in March 2021 in an LHC side-tunnel 480 meters downstream from the interaction point in the ATLAS detector. FASER is planned to be operational for the upcoming LHC Run 3.
The FASER electromagnetic calorimeter is constructed from four spare LHCb calorimeter modules. The modules are of the Shashlik type with interleaved scintillator and lead plates that result in 25 X0 and ~1% energy resolution for TeV electromagnetic showers. In 2021 a test beam campaign was carried out using one of the CERN SPS beam lines to set up the calibration of the FASER calorimeter system in preparation for physics data taking. The relative calorimeter response to electrons with energies between 10 and 300 GeV, as well as high energy muons and pions, have been measured under various high voltage settings and beam positions. The measured calorimeter resolution, energy calibration, and particle identification capabilities are presented.

15

The development of a highly granular scintillator-steel hadron calorimeter for the CEPC

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Based on the particle-flow algorithm, a highly granular sampling hadron calorimeter (HCAL) with scintillator tiles as active layers and stainless steel as absorber is proposed to achieve an unprecedented jet energy resolution to address major challenges of precision measurements at future lepton colliders, including the Circular Electron Positron Collider (CEPC). A wide range of R&D efforts are being carried on with a major aim to construct a scalable HCAL prototype for the CEPC. This talk will present the latest progress of the prototype development, with highlights from optimization studies of the HCAL design based on the evolving CEPC Particle Flow Algorithm "Arbor", mass production and test of scintillators, quality test of SiPMs, design and production of the whole prototype's mechanics, the function verification using single layer and the cosmic ray test using a few layers.

16

25 Years of Dual-Readout Calorimetry

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Twentyfive years ago, at the CALOR1997 conference in Tucson, the idea of dual-readout calorimetry was first presented.
In this talk, I will discuss the considerations that led to that proposal, and describe the developments that have since taken place,

to the point where dual-readout calorimetry is now considered a major candidate for experiments at future colliders.

17

Mu2e crystal calorimeter front-end electronics: design, characterisation, and radiation hardness

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The Mu2e experiment at Fermi National Accelerator Laboratory will search for charged-lepton flavour violating neutrino-less conversion of negative muons into electrons in the coulomb field of an Al nucleus. The conversion electron has a monoenergetic 104.967 MeV signature slightly below the muon mass and will be identified by a complementary measurement carried out by a high-resolution tracker and an electromagnetic calorimeter (EMC), reaching a single event sensitivity of about $3 \cdot 10^{-17}$, four orders of magnitude beyond the current best limit. The calorimeter, composed of 1348 pure CsI crystals arranged in two annular disks, has high granularity, 10% energy resolution and 500 ps timing resolution for 100 MeV electrons and will need to maintain extremely high levels of reliability and stability and in a harsh operating environment with high vacuum, 1 T B-field and high radiation exposures.

Each crystal is readout by two custom UV-extended SiPMs (Mu2e-SiPM), each one corresponding to a separate readout channel. Each Mu2e-SiPM is coupled to a custom front-end electronics (FEE) board, mounted directly behind the SiPM, which will provide individually programmable bias voltages for each photosensor, perform signal amplification, while monitoring currents and temperatures. Each Mu2e-SiPM is composed of 6 individual cells, wired in two parallel connections of three elements each. Two fast, low-input impedance transimpedance stages combine SiPM pulses and feed them to a buffer stage, which in turn drives a pole-zero compensator, followed by a pulse stretching stage comprising a 3-pole Bessel filter, guaranteeing more than 5 sampled points on the rising edge available to the 250 Msps digitizer boards. A final balanced differential driver transmits the signals to the digitizing section. The FEE has selectable gain (2 or 4). A pulsed green laser is distributed via fiber optic to each Mu2e-SiPM to perform gain equalization. Each FEE will also handle all slow control functions via an SPI bus, by implementing a high-voltage, high stability linear regulator with local DAC, and readout systems for SiPM bias, temperature, and current monitoring.

The FEE design was validated for operation in vacuum and under magnetic fields. An extensive radiation hardness certification campaign, carried out with photons from Co-60, 14 MeV neutron beams, and 200 MeV protons certified the FEE design for doses up to 100 krad, neutron fluences up to $10^{12} n_{1MeV}/cm^2$ and for single-event effects occurrences and correction.

18

Mechanical Design of an Electromagnetic Calorimeter Prototype for a Future Muon Collider

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Crilin (crystal calorimeter with longitudinal information) is a semi-homogeneous calorimeter proposed for the future Muon Collider. It is based on Lead Fluoride (PbF2) crystals readout by surface

mounted UV extended Silicon Photomultipliers (SiPMs). Crilin has a modular architecture made of stackable and interchangeable submodules composed of matrices of 10x10x40 mm3 PbF2 crystals, where each crystal is individually readout by 2 series of 2 UV-extended surface mount SiPMs each. It can provide: high response speed, good pileup capability, great light collection hence good energy resolution throughout the whole dynamic range, resistance to radiation, and fine granularity which is also scalable with SiPMs pixel dimensions. To complement measurements of scintillation properties in the picosecond and sub-picosecond ranges carried out at the test bench facilities of the other partners, the INFN Frascati/Torino/Padova collaborators are developing techniques for the measurement of the timing properties of crystal calorimeter components and small prototypes at test beam facilities. This provides important feedback information to assist in the extrapolation of test bench measurements to estimate the potential for instruments constructed with candidate detector materials to achieve 30 ps time resolution in the real world.
In order to validate the design choices relative to the optoelectronic, mechanical, and cooling architecture of the calorimeter, the proposal is to build a prototype (Proto-1) made of two layers of 3x3 PbF2 crystals each. The layers are arranged in a series and assembled by bolting, thus obtaining a compact and small calorimeter: this solution allows easy assembling of the calorimeter with submodules arranged in series obtaining any configuration needed.
Each crystal matrix is housed in a light-tight case which also embeds the front-end electronic boards and the heat exchanger needed to cool down the SiPMs.

The on-detector electronics and SiPMs must be cooled during operation, so as to improve and stabilize the performance of SiPMs against irradiation. Our design is capable of removing the heat load due to the increased photosensor leakage current after exposure to the expected 1014 n1MeV /cm2 fluence, along with the power dissipated by the amplification circuitry. The total heat load was estimated as 350 mW per channel. The CRILIN cooling system consists of a cooling plant and a cold plate heat exchanger in direct contact with the electronic board. It will provide the optimum operating temperature for the electronics and SiPMs at 0/-10 ⊠C.

The cooling plant supplies the cold plate with a glycol-based water solution at the required flow, temperature, and pressure.

The main features of the cooling plant are:

1. Primary cooling circuit (chiller, pump, electrical heater, valves): it supplies the cooling power which is used by the secondary circuit.
2. Secondary circuit: it is this circuit that supplies the cooling power required to remove the heat generated by the electronic board and SiPMs. The fluid used is a glycol-based water solution.
3. The hydraulic connectors, transport dry gas into the individually sealed modules. The dry gas is fluxed inside the active volume of the prototype to prevent condensation.

To improve the thermal performance of the cold plate, a micro-channel fin structure has been chosen to provide high thermal performance in a compact size. Micro-channels are formed on the top side of the base of the cold plate; the cold plate is made by brazing a cover onto the base. The coolant inlet pipe and the outlet pipe are also connected to the cold plate by brazing. The micro-channel fins on the top side of the base part enable the cold plate to cool effectively.

19

Noble Liquid calorimetry for a future FCC-ee experiment

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Noble liquid calorimetry is a well proven technology that successfully operated in numerous particle physics detectors (D0, H1, NA48, NA62, ATLAS, ⋯). Its excellent energy resolution, linearity, stability, uniformity and radiation hardness as well as good timing properties make it a very good

candidate for future hadron and lepton colliders. Recently, a highly granular noble liquid sampling calorimeter was proposed for a possible FCC-hh experiment. It has been shown that, on top of its intrinsic excellent electromagnetic energy resolution, noble liquid calorimetry can be optimized in terms of granularity to allow for 4D imaging, machine learning and - in combination with the tracker measurements - particle-flow reconstruction. This talk will discuss the ongoing R&D to adapt noble liquid sampling calorimetry for an electromagnetic calorimeter of an FCC-ee experiment with a focus on signal extraction, noise mitigation and cryostat material budget. First electrical tests on a high granularity PCB prototype and performance studies realized with the FCCSW full simulation framework will also be presented.

20

Crilin: a semi-homogeneous calorimeter for a future Muon Collider

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Crilin (CRystal calorImeter with Longitudinal InformatioN) is a semi-homogeneous calorimeter proposed for the future Muon Collider. It is based on Lead Fluoride (PbF_2) crystals readout by surface mounted UV extended Silicon Photomultipliers (SiPMs). Muon colliders have great potential for high energy physics especially in the TeV range. However, one of the main problem is given by the beam induced background which is mainly due to the $\mu \rightarrow e\,\nu_\mu\,\nu_e$ decay and following neutrinos interactions. From the detection point of view the discrimination of the signal from background in jet identifications requires high granularity and great energy resolution but also timing could help with the rejection: all this demands can be achieved with Crilin.
Crilin has a modular architecture made of stackable and interchangeable submodules composed of matrices of PbF_2 crystals, where each crystal is individually readout by 2 series of 2 UV-extended surface mount SiPMs each. It can provide: high response speed, good pileup capability, great light collection hence good energy resolution throughout the whole dynamic range, resistance to radiation and fine granularity which is also scalable with SiPMs pixel dimensions.
In 2021 a dedicated test beam was realized for the first prototype (Proto-0) made of two PbF_2 crystals coupled with 4 SiPMs. Samples were exposed to electron beams of energy 20-120 GeV, tagged photon beams derived from the 120 GeV electron beam, and 150 GeV muon beams. The analysis is still in progress but it already highlights a stochastic contribution to the time resolution that is less than $100\,ps$.
Is now under construction a bigger prototype (Proto-1) made of two layers of 3x3 PbF_2 crystals each: one layer will be realized with 15 μm pixels 3x3 mm^2 active area MPPC from Hamamatsu, while in the second layer, while in the second layer, SiPMs with 10μm pixel will be used in order to withstand fluences of neutrons $\sim\,10^{14}\,n_{1MeV}/cm^2$ without reduce energy and timing resolution. Test were already run over these new SiPMs using an ultrafast blue laser and a new electronic front-end that showed a dynamic range from 0 to $2\,V$, a rise time of $\sim\,2\,ns$ with a full signal in $\sim\,70\,ns$ and a $\sigma_t\,<\,50\,ps$ even at low charges $(50\,pC)$. For this second prototype the operational temperature will be 0/-20\textdegree C and Proto-1 will be tested in a dedicated test beam at Cern before end 2022.

21

Particle Identification for Dual-readout Calorimeter using Deep Learning

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Deep learning methods are being applied to high-energy physics widely. We are investigating deep learning implementations for the dual-readout calorimeter. The dual-readout calorimeter, proposed for future colliders (FCC and CEPC), consists of scintillating and Cerenkov fibers readout together to measure hadronic showers with high energy resolution. Particle and jet identification has always been a challenging problem, especially when relying only on the calorimeter system. Typically, spatial energy distribution in the calorimeter is used to help identify the different types of particles. However, the dual-readout calorimeter captures both scintillating and Cerenkov radiations, which not only helps improve the hadron energy resolution but provides additional pivotal information for particle identification. We present both particle and jet identification performance using image-based deep learning techniques optimized for the dual-readout calorimeter system.

22

Proton energy reconstruction with ASTRA

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There has been a sharp uptake of proton beam therapy in recent years as it can potentially offer improved treatment for cancers of the head and neck and in paediatric patients. However, treatments are currently planned using conventional x-ray computerized tomography (CT) images due to the absence of devices able to perform high quality proton CT (pCT) under realistic clinical conditions. Recently, A Super Thin RAnge Telescope (ASTRA), inspired by recent developments in neutrino plastic scintillator detectors, has been proposed with the potential to overcome most of the limitations in currently available technologies. Simulations conducted using GEANT4 yield an excellent expected proton energy resolution, reconstructed with a hybrid tracking and calorimetric method, similar to 0.5%. Additionally, ASTRA is expected to be able to deal with proton rates as high as 10^8 protons/s and due to its geometry has the potential to reconstruct multiple 3D proton tracks simultaneously. Here, the novel ASTRA detector concept is presented focussing on its calorimetric capabilities and its expected energy reconstruction performance.

23

Calibrating the Deep Underground Neutrino Experiment

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The Deep Underground Neutrino Experiment (DUNE) will further our understanding of neutrino properties and their role in particle physics and the evolution of the Universe. The physics goals of the experiment include measuring CP violation in the lepton sector through neutrino oscillation measurements, core-collapse supernova detection and searches for Beyond the Standard Model phenomena such as proton decay. The experimental setup consists of an $\mathcal{O}$(GeV) wide-band beam which will be produced in close proximity to a near detector at Fermilab, and a modular far detector located 1.5 km underground, 1,300 km away from the near detector in Lead, SD, USA. Both the near and far detectors will make use of the liquid argon time projection chamber (LArTPC) technology. Accurate calibration of every aspect of the detector, from energy reconstruction to timing information, is required in order to maximise the precision and sensitivity of every physics measurement. Many hardware and software-based calibration techniques are therefore under development across the DUNE experiment. This talk will discuss the complexities involved in operating such a vast experimental setup, and introduce the substantial DUNE calibration program which aims to address and mitigate them.

24

3D shower shape reconstruction with the dual-readout calorimeter

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In modern-day calorimetry, the shower shape reconstruction technique is rapidly evolving based on the outstanding achievements of the particle-flow algorithm in LHC experiments, leaving the question of feasibility to reconstruct longitudinal shower shapes for fiber-sampling calorimeters. Therefore, there were several efforts to speculate longitudinal shower shape for such calorimeters by utilizing timing information from photodetectors during the last decade. The dual-readout calorimeter is one of them, a next-generation calorimeter of the IDEA detector concept proposed for future e+e- colliers, including FCC-ee and CEPC. We explore the possibility of 3D shower shape reconstruction by combining lateral and longitudinal information and potential application to the particle-flow technique with a longitudinally unsegmented dual-readout calorimeter using signal processing on the silicon photomultipliers' timing information.

25

homogeneous dualreadout electromagnetic calorimetry

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In the past, homogeneous electromagnetic calorimeters have allowed precision measurements of electrons and photons, while high-granularity, dual-readout, and compensating calorimeters have been considered promising paths for improving hadronic measurements. In this talk, the possibility of using a homogeneous high-granularity crystal electromagnetic calorimeter using SiPMs with a spaghetti hadronic calorimeter using clear and scintillating fibers is explored using simulation. By employing wavelength and timing measurements in both calorimeters, the excellent electromagnetic resolution typical of crystal calorimeters is preserved, and the excellent hadronic resolutions are enabled for important physics measurements at future Higgs factories. We also discuss past studies and future plans.

28

Status of Timing-SDHCAL Development

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The CALICE technological RPC-based SDHCAL prototype that fulfils all the requirements of compactness, hermeticity and power budget of the future lepton accelerator experiments, has been extensively tested and has provided excellent results in terms of the energy resolution and shower separation.
New phase of R&D to validate completely the SDHCAL option for the International Linear Detector (ILD) project of the ILC and also the Circular Electron Positron Collider (CEPC) has started with the conception and the realization of new prototypes.
One of the new prototypes proposes to exploit the excellent time resolution provided by RPC and more precisely the multigap version (MRPC) detectors in order to better build the hadronic showers with the aim to better separate them and also to single out the contribution of delayed neutrons.
To exploit the excellent time precision of RPC/MRPC an electronic readout system using the PETIROC ASIC with its internal TDC (50-100 ps time resolution) on a board equipped with 1 cm X 1cm or 2 cm X 2 cm pickup pads.
The progress realized on the detector and the readout electronics conception will be presented and the future steps will be discussed.

29

Welcome and Introduction

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30

Talk 1

31

Talk 2

32

Talk 3

33

Talk 4

34

Coffee Break

35

Talk 4

36

Talk 5

37

Talk 7

38

Lunch

39

Overview talk

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40

Talk 6

41

Talk 7

42

Coffee Break

43

Talk 9

44

Talk 12

45

Upgrade of the CMS Barrel Electromagnetic Calorimeter for LHC Phase 2

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The High Luminosity upgrade of the LHC (HL-LHC) at CERN will provide unprecedented instantaneous and integrated luminosities of around 5 x 10ˆ34 /cm2 /s and 3000/fb, respectively, from 2027 onwards. During this period, an average of 140 to 200 collisions per bunch-crossing (pileup) is expected, posing a challenge to the capability of the Compact Muon Solenoid (CMS) detector to maintain. In order to cope with the extreme pileup conditions, harsh environment, and increased data rates, CMS is undergoing a significant Phase II upgrade program.

In the barrel region of the CMS electromagnetic calorimeter (ECAL), the lead tungstate crystals and avalanche photodiodes (APDs) will keep performing well and will therefore be maintained, while the entire readout and trigger electronics will be replaced. A dual gain trans-impedance amplifier and an ASIC providing two 160 MHz ADC channels, gain selection, and data compression will be installed. The noise increase in the APDs, due to radiation-induced dark current, will be contained by reducing the ECAL operating temperature from 18 deg C to around 9 deg C.

We review the design and R&D studies for the CMS ECAL barrel crystal calorimeter upgrade and present the results of test beam studies performed in the CERN SPS H4 beam line. We present test beam results of the new readout and trigger electronics, which must be upgraded due to the increased trigger and latency requirements at the HL-LHC. In addition, particle detectors with a timing resolution of around 30 ps can significantly improve event reconstruction at high luminosity hadron colliders. The CMS ECAL barrel upgrade will achieve a timing resolution of around 30 ps for high energy photons and electrons. The benefits of precision timing for the ECAL event reconstruction at HL-LHC will be discussed in this presentation. Simulation and test beam studies carried out for the timing upgrade of the CMS ECAL barrel will also be presented, and the prospects for a full implementation of this option will be discussed.

48

The impact of crystal light yield non-proportionality on a typical calorimetric space experiment: beam test measurements and MonteCarlo simulations.

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Calorimetric space experiments have been employed for direct measurements of cosmic-ray spectra above the TeV region. According to several theoretical models, relevant features in both electron and nuclei fluxes are expected. Unfortunately, sizable disagreements between current results of different space calorimeters are presents. In order to improve future experiment accuracy, it is fundamental to understand the reasons of these discrepancies, especially since they are not compatible with the quoted experimental errors. Few articles of different collaborations suggest that a systematic error of few percent related to the energy scale calibration could explain these differences. In this work we analyze the impact of the non-proportionality of scintillating crystals light-yield (also known as "quenching") on the energy scale of typical calorimeter. Space calorimeter are usually calibrated by employing minimum ionizing particles (MIP), e.g. non-interacting proton or helium nuclei, which feature different ionization densities with respect to particles included in showers. By using the experimental data obtained by the CaloCube collaboration, and a simplified model of the light-yield as a function of the ionization density, several scintillating crystals (BGO, CsI(Tl), LYSO, YAP, YAG and BaF2) are characterized. Then, the response of each crystal is implemented inside a Monte Carlo simulation of a typical space calorimeter: the latter is used to check the energy deposited by electromagnetic and hadronic showers. The results of this work show that energy scale obtained by MIP calibration could be affected by sizable systematic error if the non-proportionality of scintillation light is not properly taken into account.

49

Tracker-In-Calorimeter (TIC) project: a calorimetric new solution for space experiments

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A multi-messenger, space-based cosmic ray detector for gamma rays and charged particles poses several design challenges due to the different instrumental requirements for the two kinds of particles. The optimization of the detector, to have a good angular resolution needed for gamma rays, and a good geometric factor needed for charged particles is the main purpose of the Tracker-In-Calorimeter (TIC) project. In cosmic rays experiments, such as Fermi-LAT, the direction of the incident particle is reconstructed using an external tracker made of passive layers (like tungsten) and active position-sensitive layers (such as a silicon microstrip detector). In this case, the angle of the gamma rays is indirectly measured from the tracks of the electron-positron pair formed by conversion in passive layers. The main disadvantage of this configuration is that the acceptance is limited by the large level arm between silicon layers needed to have good track reconstruction performances. In addition, tungsten layers require an additional allocation of a fraction of the mass budget that could instead be used to increase the size of the calorimeter. Passive layers also induce fragmentation of nuclei, thus worsening charge reconstruction performances. All these drawbacks are solved by the TIC approach, where silicon detectors are moved inside a highly-segmented calorimeter, except for a couple of external layers dedicated mainly to charge and tracking reconstruction of charged particles. This solution exploits the scintillator layers to develop the shower and the silicon detectors to measure the lateral profile. In this case, the angle of the gamma rays is reconstructed indirectly from the lateral profile of the shower sampled at different depths in the calorimeter.
The effectiveness of this approach has been studied with Monte Carlo simulations and has been validated with test beam data of a detector prototype.
The results of these studies will be presented.

50

Calorimetry in a neutrino observatory: the JUNO experiment

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The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose experiment under construction in southern China, expecting to begin data taking in 2023. The detector consists of a target mass of $2 \cdot 10^7$ kg of an organic liquid scintillator contained in a spherical acrylic vessel, which is located about 650 m underground and submerged in a water pool to shield it from environmental radioactivity. The water pool serves also as an active Cherenkov detector for muon veto.
JUNO is a homogeneous calorimeter able to detect (anti)neutrinos from various natural and artificial sources. The scintillation and Cherenkov light emitted after the interaction of (anti)neutrinos with the liquid scintillator is seen by a compound system of 20-inch large-PMTs and 3-inch small-PMTs, with a total photo-coverage of 78 %; a large photo-coverage is essential to reach a light yield greater than 1300 photoelectrons (PE) per MeV of deposited energy. A dual calorimetry technique is developed based on the presence of the two independent photosensor systems which are characterized by different average light level regimes, resulting in different dynamic ranges: the small-PMT system relies mainly on photon-counting with PMTs operating primarily in the single-photoelectron regime; on the other hand, the large-PMT system relies on charge measurement, with each PMT operating in the 0 to 100 PE range. Thanks to this novel technique, the high light yield, and in combination with a comprehensive multiple-source and multiple-positional calibration campaign, JUNO is expected to reach energy-related systematic uncertainties below 1 % and an effective energy resolution of 3 % at 1 MeV.
Thanks to its competitive characteristics, JUNO will be able to address many topics in neutrino and astroparticle physics. JUNO will provide precise energy measurement of reactor antineutrinos, solar neutrinos, and geo-neutrinos at the MeV scale, and good track reconstruction of GeV-scale events, from, *e.g.*, atmospheric neutrinos.
In the talk, I will present an overview of the JUNO detector and the status of the construction, along with the most significant physics results that can be achieved.

51

LiquidO Novel Detection Technology

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Upon the neutrino discovery by Reines & Cowan (1956), they also paved the ground behind much of today's neutrino detection technology. Large instrumented volumes for neutrino detection have been achieved via a key (implicit) principle: detection medium transparency and high purity. Many other technologies, such as noble liquid/gases TPCs rely on a similar basis. Reines-based technology has yielded historical success over several decades, including several Nobel prizes, where the discovery of the neutrino oscillation phenomenon —an important modification of the Standard Model of Particle Physics. Despite the stunning success, the "transparent technology", like the pioneering liquid scintillator detectors, this technology is known to suffer from key limitations such as little (or none) topological particle identification (PID) ability, typically enabling active background rejection. Solving this issue, while keeping the detector scalability for neutrino, has long remained an impossible challenge. Hence, the only way to reduce those otherwise overwhelming backgrounds today is via an expensive passive shielding strategy, including in some cases going kilometres deep underground.

In this presentation, we shall introduce the novel LiquidO technology, under final stages of R&D demonstration, whose rationale exploits detection in media of extreme opacity, thus breaking with the need for transparency. LiquidO main goal is to yield unprecedented event-wise "sub-atomic imaging"that can be exploited for active PID, thus allowing the active tagging of background events and enabling the relaxation of passive shielding; i.e. less deep underground laboratories dependency. LiquidO working principle was conceived in 2013, while released in mid-2019, upon the first detection proof-of-principle, and now published in Communication Physics (https://www.nature.com/articles/s42005-021-00763-5). The technology is developed by an international scientific consortium with 70 scientists in 22 institutions over 10 countries.

53

The overall electronics chain (powering and readout) of the CMS HGCAL

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The endcap calorimeters of CMS will be upgraded to a single High Granularity Calorimeter (HGCAL) for the HL-LHC, including both silicon sensors and scintillator tiles with on-tile SiPMs as active elements. The readout of the active elements is performed by the HGCROC ASIC (using 130nm CMOS technology) that measures the amplitude and arrival time of the signals. The amplitude is measured over a large dynamic range to allow calibration with single particles and the measurement of TeV showers. The time of arrival of high-energy showers will be measured with a precision of around 30 ps. A second pair of "concentrator"ASICs –ECON-D and ECON-T –takes the data from the HGCROC channels and packages them for transmission via optical links to the off-detector electronics. The ECON-D transmits concentrated data packets at up to 1 MHz, upon reception of a level-1 trigger signal. The ECON-T transmits trigger data at 40 MHz, to form part of the CMS Level-1 trigger. In addition to these ASICs, HGCAL will use modified versions of common HL-LHC electronics developments for the power chain and the optical control/readout. The dense nature of the HGCAL provides additional challenges for the electronic boards and cabling. The back-end readout system is also based on a common development: ATCA boards called "Serenity", featuring optical inputs and FPGA-based processing. We present the overall HGCAL electronics scheme, including the latest performance of the HGCROC.

54

TAO: The Taishan Antineutrino Observatory

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JUNO aims at simultaneously probing the two main frequencies of three-flavor neutrino oscillations, as well as their interference related to the mass ordering, at a distance of ˜53 km from two powerful nuclear reactor complexes in China. The present information on the reactor spectra is not meeting the requirements of an experiment like JUNO, with a design resolution of 3 % at 1 MeV. Unknown fine structures in the reactor spectrum might cause severe uncertainties, which could even make the interpretation of JUNO's reactor neutrino data impossible. TAO is aiming for a measurement of the reactor neutrino spectrum at very low distances (< 30 m) to the core with a groundbreaking resolution better than 2 % at 1 MeV. Furthermore, TAO will make a major contribution in the investigation of the so-called reactor anomaly. Present calculations of the reactor neutrino spectrum indicate a deficit of approx. 3 % in the measured reactor fluxes. Currently, these anomalies can be interpreted as indications for the existence of right-handed sterile neutrinos. Beyond that, the reactor neutrino spectra recorded by Double Chooz, Reno and Daya Bay show an excess in the neutrino flux from 5 MeV to 6 MeV of unknown origin. This can be considered as one of the most-puzzling questions in the physics of reactor neutrinos today. The TAO experiment will realize the unprecedented neutrino detection rate of about 2000 per day, which is approximately 30 times the rate in the JUNO main detector. In order to achieve its goals, TAO is relying on cutting-edge technology, both in photosensor and liquid scintillator (LS) development which is expected to have an impact on future neutrino and Dark Matter detectors. The experiment will realize an optical coverage of the 2.6 tons of Gd-loaded LS close to 95 % with novel silicon photomultipliers (SiPMs), with a photon detection efficiency (PDE) above 50 %. To efficiently reduce the dark count of these light sensors, the entire detector will be cooled down to -50 ℃. The combination of SiPMs with cold LS will lead to an increase in the photo electron yield by a factor of 4.5 compared to the JUNO central detector. In this talk, the design of the TAO detector with special focus on calorimetry with this novel high-resolution liquid scintillation detector technology will be discussed. In addition, an overview of the progress currently being made in the R&D for both SiPM and LS technology in the frame of the TAO project will be presented.

55

Photodiode read-out system for the calorimeter of the HERD experiment

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The HERD experiment is a future space experiment which will be installed on the Chinese Space Station in 2027. The detector is based on a 3D, homogeneous, isotropic, deep and finely segmented calorimeter, and it will be capable to detect particles from every direction. Thanks to its large acceptance and energy resolution, it will expand the measurements of proton and nuclei fluxes up to the cosmic ray knee region (about 1 *PeV*), and *electron+positron* flux up to tens of *TeV*.
The calorimeter will be composed by about 7500 LYSO cubic crystals. Every crystal is coupled with two independent read-out systems: the first is based on wavelength shifting fibers coupled to Intensified scientific CMOS, the second one is based on a system of two photodiodes coupled to a specifically designed front-end electronics. The two photodiodes have different responses with respect to scintillation light, in order to increase the dynamic range of the read-out system. This is also expanded by the use of the front-end electronics chip HiDRA2, which features a very high dynamic range, low noise and small power consumption. The latter is a necessary requirement for a space experiment due to the limited power budget. All these characteristics are necessary to obtain a dynamic range higher than 10⁷, in order to measure signals ranging from the small MIP energy deposit for calibration purposes to typical releases caused by hadronic showers induced by *PeV* protons.
In this poster we will describe the main characteristics of the photodiode read-out system and we will discuss the performances of the first prototypes that were tested so far.

56

Design and performance studies of the electromagnetic calorimeter for STCF

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The Super Tau-Charm Facility (STCF) is a future electron-positron collider in China, which is proposed as a unique platform to study tau-charm physics. The peaking luminosity of STCF is beyond 0.5×10ˆ35 cmˆ(-2)·sˆ(-1), and the center-of-mass energy range is 2˜7 GeV. The high luminosity will pose a great challenge to the radiation tolerance, event pileup and background suppression of electromagnetic calorimeter (EMC).
We will present the conceptual design of EMC, which is based on pure CsI crystals with avalanche photodiodes used as photodetectors. A geometric model design for EMC consisting of 8670 pure CsI crystals with defocus operation will be presented. Based on GEANT4, the performance of EMC is simulated in detail. We will present a summary of the results of the performance simulation, as well as introduce the software framework and reconstruction algorithm. The waveform fitting method was used to reduce the influence of MHz rate background on signal measurement. The results show that after considering several main factors, the energy resolution of the EMC can achieve 2.5% @1 GeV. In addition, the time response of the EMC also will be introduced.

57

Talk 11

58

Talk 12

59

Talk 13

60

Coffee Break

61

Talk 14

62

Talk 17

63

Talk 18

64

Lunch Break

65

Talk 15

66

FERS-5200 (CAEN)

67

Talk 10

68

Reception at Horatio's Bar (brighton Pier)

69

Talk 16

70

Talk 17

71

Coffee Break

72

Talk 19

73

Talk 20

74

Talk 21

75

Talk 22

76

Coffee Break

77

Talk 23

78

Talk 24

79

Excursion at Arundel

80

Talk 25

81

Talk 26

82

Talk 27

83

Coffee Break

84

Talk 28

85

Talk 29

86

Lunch Break

87

Poster Session

88

Talk 28

89

Talk 30

90

Coffee Break

91

Talk 31

92

Talk 32

93

Conference Dinner (Brighton Beach Club)

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94

Talk 33

95

Talk 34

96

Talk 35

97

Coffee Break

98

Talk 36

99

Talk 37

100

Lunch Break

101

Talk 38

102

Talk 39

103

Talk 40

104

Coffee Break

105

Concluding Remarks, Prizes and Thanks

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106

Talk 41

107

Talk 42

110

ATLAS Tile Calorimeter time calibration, monitoring and performance in Run 2

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The Tile Calorimeter (TileCal) is the central section of hadronic calorimeter of the ATLAS experiment at the LHC. This sampling device uses steel plates as absorber and scintillating tiles as active medium and its response is calibrated to electromagnetic scale by means of several dedicated calibration systems.
The accurate time calibration is important for the energy reconstruction, non-collision background removal as well as for specific physics analyses. The initial time calibration using so-called splash events and subsequent fine-tuning with collision data are presented. The monitoring of the time calibration with laser system and physics collision data is discussed as well as the corrections for sudden changes occurred before the recorded data are processed for physics analyses. Finally, the cell time resolution as measured with jet events in Run 2 is presented.

111

A Burn-in test station for the ATLAS Phase-II Tile-calorimeter low-voltage power supply transformer-coupled buck converters

Author: Augusto Santiago Cerqueira[1]

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The Tile Calorimeter (TileCal) is a sampling hadronic calorimeter covering the central region of the ATLAS experiment, with steel as absorber and plastic scintillators as active medium. The High-Luminosity phase of LHC (HL-LHC), delivering five times the LHC nominal instantaneous luminosity, is expected to begin in 2029. To prepare TileCal for the new conditions of the HL-LHC, a Phase-II upgrade will be required. The upgrade will take place during the long shutdown from December 2025 until the beginning of 2029. It will encompass the replacement of both on- and off-detector electronics, the implementation of new on-detector mechanics as well as the replacement of Photomultiplier tubes located in the most exposed regions of the detector. The on-detector electronics of the Tilecal are powered by 256 Low-Voltage Power Supplies (LVPS) which themselves contain eight transformer-coupled buck converters known as Bricks. These Bricks function to step-down bulk 200 V DC received from off-detector to the required 10 V DC. A Brick failure will result in the front-end electronics to become offline for a commensurate time. Therefore, the reliability of the LVPS Bricks is of the utmost importance as access to them is limited to approximately once per year due to them being located within the inner barrel of ATLAS detector. To ensure the reliable operation of 2048 Bricks once on-detector an extensive quality control procedure is to be implemented which includes Burn-in testing. The Burn-in procedure subjects the Bricks to sub-optimal operating conditions which function to stimulate failure mechanisms within the Bricks. This results in components that would fail prematurely within TileCal failing within the Burn-in apparatus, known as a Burn-in station, thereby allowing for their replacement which subsequently improves the reliability of the Brick population. The Burn-in station is of a fully custom design in both its hardware and software due to the unique nature of its application. The development of the Burn-in station as well as the Burn-in procedure that it employs will be explored in detail, culminating in preliminary Burn-in results of the latest LVPS prototypes produced.

112

Graph Neural Networks and the reconstruction of pions and electrons in the CMS HGCAL

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As part of the development of the CMS High Granularity Calorimeter (HGCAL), a series of beam tests have been conducted using prototype segmented silicon detectors. In a test conducted at the CERN SPS H2 beam line in 2018, the performance of a prototype calorimeter equipped with ≈12,000 channels of silicon sensors (for the 28-radiation-length, one interaction length electromagnetic section and an additional four-interaction-length hadronic section), supplemented with the CALICE AHCAL (Analogue Hadronic Calorimeter) prototype scintillator+SiPM sampling calorimeter. Together this configuration is close to the final design of the HGCAL. Data were taken with beams of high-energy electrons, pions and muons with momenta ranging from 20 to 300 GeV/c. The measured performance is compatible with the HGCAL design specifications.

The reconstruction of the events observed has been carried out using both a traditional weights-based methods and an advanced deep-learning algorithm based on detailed low-level hit information. The deep-learning method uses dynamic graph neural networks (GNN) and effectively images the shower development in three spatial dimensions, while also measuring the corresponding energy deposition in the active elements. The results obtained with the GNN show a significant improvement in the relative energy resolution for pions compared to the weights-based reconstruction technique.

113

The SiD Digital ECal Based on Monolithic Active Pixel Sensors

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The SiD Collaboration has had a long interest in the potential for improved granularity in the tracker and ECal; a study of MAPS in the SiD ECal was described in the ILC TDR. Work is progressing on the MAPS application in an upgraded SiD design, both for the ECal and tracking. A prototyping design effort is underway for a common SiD tracker/ECal design based on stitched reticules to achieve 10 x 10 cm^2 sensors with 25 x 100 micron^2 pixels. Application of large area MAPS in these systems would eliminate delicate and expensive bump-bonding, provide possibilities for better timing, and should be significantly cheaper due to being a more conventional CMOS foundry process. The small pixels significantly improve shower separation. Recent simulation studies confirm previous results, indicating electromagnetic energy resolution based on digital hit cluster counting provides better performance than the SiD TDR analog design based on 13 mm^2 pixels. Furthermore, the two shower separation is excellent down to the millimeter scale. Geant4 simulation results will be presented demonstrating these expectations.

114

WSF read-out and calibration light source of the 3-D crystal array of HERD calorimeter

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The High Energy cosmic-Radiation Detection (HERD) has been proposed as a space experiment which will be installed on the China's Space Station (CSS) around 2027. The main scientific goals of HERD are searching for dark matter particles, study of cosmic ray chemical composition and high energy gamma-ray observations.
HERD will consist of a calorimeter (CALO), a fiber tracker (FIT), a plastic scintillator detector (PSD), a silicon charge detector (SCD) and a transition radiation detector (TRD). The CALO is a homogeneous and 3D segmented calorimeter made of about 7500 LYSO cubic scintillators, corresponding to about 55 radiation lengths(X0) and 3 nuclear interaction lengths in all directions.
The scintillation light of each cube is read-out by two independent systems: the first one consists of Wavelength Shifting fiber (WSF) coupled to Intensified scientific CMOS (IsCMOS) cameras, the

second one is made of photo-diodes (PD) connected to customized front-end electronic chips named HIDRA. This design can significantly improve the reliability of the data by cross calibration between the double read-out systems.
Two pieces of WSFs are winded and attached to one face of the LYSO cube with different contacting areas. Two fiber ends which belong to different WSFs are routed to IsCMOS cameras, while the other two opposite ends are connected to the trigger system. The requirement on the dynamic range of the read-out system is up to 10^7. A set of LEDs is mounted on the side of WSFs on every LYSO tray as a fast calibration light source of IsCMOS. Expected upper limit of calibration energy is ~3*10^6 MeV. The PD read-out system is introduced in P. Betti's poster of this conference.

116

A novel approach to understanding hadronic showers using machine learning technique

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The development and improvement of different models implemented in the simulation of particle interactions with matter rely on comparisons of theoretical predictions with test beam data. The highly granular calorimeters provide a set of calorimetric observables, in particular topological, which can help in our understanding of the source of discrepancies between data and simulations. In this work, we show the relationships between calorimetric observables and properties of secondaries generated by Geant4 during the propagation of hadronic shower initiated by a single pion through the model of the highly granular CALICE analogue hadron calorimeter. A deep neural network with several calorimetric observables as input features is trained using a supervised learning to predict the properties of secondary particles in a shower. The achieved performance of the regression model is demonstrated. The perspectives of implementation of the proposed approach for validation of hadronic shower simulations at secondaries level is also discussed.

118

Design and test-beam results from the FoCal-H demonstrator prototype

The forward calorimeter (FoCal) of ALICE, planned to be operational for LHC Run 4, will cover pseudorapidity region $3.4 \leq \eta \leq 5.8$ allowing to probe the unexplored region of Bjorken-x down to 10^{-5}. The hadronic section of the FoCal (FoCal-H) will be based on scintillating fibers inserted in copper capillary tubes, with light read out by Silicon photomultipliers (SiPM). A "proof of concept" demonstration prototype was built and tested in the H6 beamline at the CERN SPS in the beginning of October, 2021, exposing it to an unseparated charged particle beam with energy in the interval 20 GeV –80 GeV. The design of the prototype as well as the results of the energy reconstruction will be presented and the validation with a GEANT4-based simulation will be discussed.

119

Talk 43

120

Talk 44

121

Talk 45

122

Talk 46

123

Engineering challenges in constructing the CMS High-Granularity Calorimeter (HGCAL

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The CMS Collaboration is preparing to build replacement endcap calorimeters for the HL-LHC era. The new high-granularity calorimeter (HGCAL) is, as the name implies, a highly-granular sampling calorimeter with 47 layers of absorbers (mainly lead and steel) interspersed with active elements: silicon sensors in the highest-radiation regions, and scintillator tiles equipped with on-tile SiPMs in regions of lower radiation. The active layers include copper cooling plates embedded with thin pipes carrying biphase CO2 as coolant, front-end electronics and electrical/optical services. The scale and density of the calorimeter poses many engineering challenges that we discuss here. These include: the design & production of 600 tonnes of stainless-steel absorber plates to very-high physical tolerances; the development of the CO2 cooling system to maintain each 220-tonne endcap at -35oC whilst the electronics dissipate up to 140kW; the need to cantilever the calorimeters from the existing CMS endcap disks, using titanium wedges; the production of a thin but strong inner cylinder to take the full weight but have little impact on physics performance; the integration of all on-detector services in a restricted volume with only a couple of mm height. We give an overview of the design of HGCAL, focusing on the materials and techniques being used to overcome the many challenges for this world's first calorimeter of its type at a hadron collider.

124

R&D status of a novel high granularity crystal electromagnetic calorimeter

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Future electron-positron collider experiments, aiming at precise measurement of the Higgs boson, electroweak physics and the top quark, set a high demand on the calorimetry system. Based on the particle-flow paradigm, a novel highly granular crystal electromagnetic calorimeter (ECAL) is proposed to address major challenges from jet reconstruction and to achieve the optimal EM energy resolution of around $2-3\ \%/\sqrt{\mathrm{E(GeV)}}$ with the homogenous structure. Plenty of R&D efforts have been carried on to evaluate the requirements and potentials of the crystal calorimeter concept from sensitive detection units to a full sub-detector system. The requirements on crystal candidates, photon sensors as well as readout electronics are parameterized and quantified in Geant4 full simulation. Experiments including characterisations of crystals and silicon photomultipliers (SiPMs) have been followed to validate and improve the simulation results. Physics performance of the crystal ECAL has also been studied with the particle-flow algorithm "ArborPFA" which is also being optimised. A dedicated reconstruction software is also being developed for a detector layout with long crystal bars arranged to be orthogonal to each other in every two neighbouring longitudinal layers. Furthermore, a small-scale detector module with a crystal matrix and SiPM arrays is under development for future beam tests to study the performance for EM showers. This contribution will present the latest results on the detector simulation and reconstruction, hardware developments and physics potentials.

125

Development of a novel highly granular hadronic calorimeter with scintillating glass tiles

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Based on the particle-flow paradigm, a novel hadronic calorimeter (HCAL) with scintillating glass tiles is proposed to address major challenges from precision measurements of jets at the future lepton colliders, such as the Circular Electron Positron Collider (CEPC). Tiles of high-density scintillating glass, with a high energy sampling fraction, can significantly improve the hadronic energy resolution in the low energy region (typically below 10 GeV for major jet components at Higgs factories). The hadronic energy resolution of single hadrons and the effects of key parameters (e.g. density, doping, intrinsic light yield, energy threshold, etc.) of scintillating glass have been evaluated in the Geant4 full simulation, followed by the physics benchmark studies on the Higgs boson with jets in the final state. R&D efforts of scintillating glass materials are ongoing within a dedicated collaboration since 2021 with an aim to achieve high light yield, high density and low cost. Measurements have been performed for the first batches of scintillating glass samples including the light yield, emission and scintillation spectra, scintillation decay times and cosmic responses. An optical simulation model of a single scintillating glass tile has been established to provide guidance for the development of scintillating glass. Highlights of the expected detector performance and latest scintillating glass developments will be presented in this contribution.

126

Resistive Plate WELL Detectors as DHCAL sampling elements

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In search for physics Beyond the Standard Model (BSM), the foreseen program of the High-Energy Physics community relies on the precision measurements of the Higgs, W, and Z bosons. Existing collider experiments and their foreseen upgrades are limited in the precision by which various BSM processes could be measured. Thus, future collider experiments pose stringent requirements on the performance of their detectors. In particular, significant improvement is needed in the jet energy resolution. This could be achieved by employing a Particle Flow approach based on highly granular calorimeters.
This motivates the development of (semi)Digital Hadronic Calorimeter ((s)DHCAL). The (s)DHCAL concept is mostly studied with sampling elements based on Resistive Plate Chambers (RPC). However, studies towards sampling elements based on Micro-Pattern Gaseous Detector (MPGD) have shown their potential advantages compared to the RPC.
This contribution is focused on an ongoing R&D effort towards the development of (s)DHCAL sampling elements based on Resistive Plate WELL (RPWELL) detectors. Several groups work in this direction and demonstrate that WELL-based sampling elements could meet the DHCAL requirements in terms of detection efficiency and average pad multiplicity.
We will present the design and measured performance of a medium size, $50 \times 50\ \mathrm{cm}^2$, RPWELL prototype along with test beam results obtained with a small MPGD-based DHCAL prototype. The expected performance of a full size RPWELL-based DHCAL was studied using dedicated MC simulation and will be presented as well.

127

Radiation damage studies for phenyl-based plastic scintillators

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Plastic scintillators are one of the most versatile and inexpensive particle detection options available which is why the largest particle physics experiments, CMS and ATLAS, are using them. A challenging aspect of scintillators is their relatively low radiation hardness which might be inadequate for the HL-LHC program. In this study, results on the effects of ionizing radiation on the signal produced by plastic scintillating rods manufactured by Eljen Technology company are presented for various matrix materials, dopant concentrations, fluors (EJ-200 and EJ-260), anti-oxidant concentrations, scintillator thickness, doses, and dose rates. The light output before and after irradiation is measured using an alpha source and a photomultiplier tube, and the light transmission by a spectrophotometer. Assuming an exponential decrease in the light output with dose, the change in light output is quantified using the exponential dose constant D. The D values are similar for primary and secondary doping concentrations of 1 and 2 times, and for antioxidant concentrations of 0, 1, and 2 times, the default manufacturer's concentration. The D value depends approximately linearly on the logarithm of the dose rate for dose rates between 2.2 Gy/hr and 70 Gy/hr for all materials. For EJ-200 polyvinyltoluene-based (PVT) scintillator, the dose constant is approximately linear in the logarithm of the dose rate up to 3400 Gy/hr, while for polystyrene-based (PS) scintillator or for both materials with EJ-260 fluors, it remains constant or decreases (depending on doping concentration) above about 100 Gy/hr. The results from rods of varying thickness and from the different fluors suggest damage to the initial light output is a larger effect than color center formation for scintillator thickness $\leq$1 cm. For the blue scintillator (EJ-200), the transmission measurements indicate damage to the fluors. We also find that while PVT is more resistant to radiation damage than PS at dose rates higher than about 100 Gy/hr for EJ-200 fluors, they show similar damage at lower dose rates and for EJ-260 fluors. Finally, the oxygen penetration depth is measured using the color change of

the irradiated rods. The results show that the oxygen permeation coefficient is different for PS and PVT, and for irradiations at $-30°$ C and room temperature.

128

Energy reconstruction with the Semi-Digital HCAL

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After the construction and the successful operation of the first technological prototype of The Semi-Digital Hadronic CALorimeter (SDHCAL), developed within the CALICE collaboration, the prototype has been extensively tested in beam test facilities. Refined analysis techniques are being developed to improve the energy and shower reconstruction. In particular, combining advance reconstruction techniques like in shower tracking by Hough transform with use of TMVA's Boosted Decision Tree, allows to select high purity pion samples down to a few GeV. With such a selection, pion energy reconstruction capacity with the SDHCAL have been extended down to 3 GeV.
In addition the prototype has been exposed to pion beams with various incidence angles. A better treatment of the particle incidence angle in the energy reconstruction has been established.
The talk will present these analysis techniques and the SDHCAL pion energy reconstruction performance.

129

Performance Study of a New Cluster Splitting Algorithm for the Reconstruction of PANDA EMC Data

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For high momentum pi0 mesons, the angle between the two final-state photons decreases with the increase of the momentum of the pi0, which enhances the probability of overlapping electromagnetic showers. The performance of the cluster splitting algorithm in the EMC reconstruction is crucial for the mass resolution measurement of the pi0 at high momenta. If there are several local maxima in a cluster, it is considered as a superposition of multiple showers. It is necessary to split the cluster according to the number of maxima. The classical cluster splitting algorithm is based on the theoretical lateral distribution of electromagnetic showers which can be described as a (multi-)exponential function. In a realistic electromagnetic calorimeter, considering the granularity of the detector, the measured energy in a cell is actually the integral of the theoretical energy deposition, which deviates from the exponential function. Based on the simulation of the barrel EMC of the PANDA experiment, the cluster splitting algorithm is updated using a new lateral energy measurement function which depends on the dedicated granularity of the detector. The mass resolution of the pi0 has been improved in the high momentum range compared with the previously used method.

130

The Status of the DAMPE BGO calorimeter in space

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The Dark Matter Particle Explorer (DAMPE) is a Chinese cosmic-ray detection satellite and was launched into a sun-synchronous orbit at an altitude of 500 km. It is in continuous data taking since its successful launch at the end of 2015. DAMPE consists of four sub-detectors: a plastic scintillator strip detector, a silicon–tungsten tracker–converter, a BGO calorimeter, and a neutron detector. The BGO calorimeter, a key sub-detector of DAMPE, is a total absorption-type calorimeter composed of 308 BGO crystals. It contains 14 layers (~32 radiation lengths, ~1.6 nuclear interaction lengths), and each layer consists of 22 BGO crystal bars with dimensions of 25 mm×25 mm×600 mm. The BGO crystal bars of neighboring layers are arranged orthogonally, and PMTs are coupled to each end of BGO crystals to signal readout. The BGO calorimeter is designed to precisely measure energy, distinguish efficiently electron/hadron showers, and provide the trigger for the DAMPE. I will introduce the performance of the BGO calorimeter based on orbit data, which includes the calibration in space, the energy measurement, and electron/proton separation power. The recent results will also be presented.

131

Including calorimeter test-beams into geant-val - the physics validation testing suite of Geant4

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The Geant4 simulation toolkit is widely used in particle physics experiments, including the LHC major ones. In this talk, we will present the first results of a one-year-old validation program carried out by the Geant4 Collaboration based on calorimeters test-beam data. The Monte Carlo ability to reproduce several hadronic and electromagnetic shower features has been tested against results from the ATLAS hadronic end-cap calorimeter, the CALICE silicon-tungsten calorimeter and the bucatini-based Dual-Readout calorimeter. This work targets results deployment within geant-val, the Geant4 validation and testing suite that allows to openly share any test with the particle physics community. The geant-val main features, the instructions for contributing to it and the next steps for Geant4 validation will be presented as well.

132

Development and Performance of a highly granular scintillator-tungsten ECAL prototype for the CEPC

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The Circular Electron Positron Collider (CEPC) is a future Higgs factory. The baseline CEPC magnetic spectrometer is designed based on particle flow algorithm (PFA), which requires the jet energy resolution to reach 30%/sqrt(E (GeV)). The highly granular electromagnetic calorimeter (ECAL) is one of the important sub detectors of the PFA spectrometer. In order to study the performance of the ECAL, an ECAL scheme based on small unit plastic scintillator strip and tungsten plate is proposed. In the laboratory, an ECAL prototype has been developed. It has 32 sampling layers, and each layer has 210 channels. The whole prototype measures around 600*600*400 mmˆ3 in dimensions and roughly 250 kg in weight. A long time cosmic ray test has been carried out and studied to quantitatively evaluate the key performance, including the position resolution and cell-to-cell response calibration, etc. The results show that the position resolution of each layer is better than 2 mm, and the detector efficiency is better than 90%. In addition, time measurement will also be introduced.

133

RADiCAL: Precision-timing, Ultracompact, Radiation-hard Electromagnetic Calorimetry

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To address the challenges of providing high performance calorimetry in future hadron collider experiments under conditions of high luminosity and high radiation (FCC-hh environments), we are conducting R&D on advanced calorimetry techniques suitable for such operation, based on scintillation and wavelength-shifting technologies and photosensor (SiPM and SiPM-like) technology. In particular, we are focusing our attention on ultra-compact radiation hard EM calorimeters, based on modular structures (RADiCAL modules) consisting of alternating layers of very dense absorber and scintillating plates, read out via radiation hard wavelength shifting (WLS) solid fiber or capillary elements to photosensors positioned either proximately or remotely, depending upon their radiation tolerance. The RADiCAL modules provide the capability to measure simultaneously and with high precision the position, energy and timing of EM showers. This paper provides an overview of the instrumentation and photosensor R&D associated with the RADiCAL program.

134

A high-performance electromagnetic calorimeter for neutrino physics in the DUNE Near Detector complex

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DUNE is a long-baseline neutrino oscillation experiment, which will observe neutrinos produced by a high-power, broadband neutrino beam by means of 70 kton mass liquid argon time-projection chambers. The Far Detector will be installed at the Sanford Underground Research Facility (SURF), located at a depth of 1500 m in South Dakota (USA). The Near Detector complex, located at Fermilab, is necessary for monitoring possible variations of the neutrino beam, for constraining neutrino cross-section at GeV energy and for reducing systematics due to neutrino flux uncertainties.

Within the Near Detector complex, the SAND (System for on-Axis Neutrino Detection) detector, whose primary goal is the beam monitoring, will benefit of a high-performance electromagnetic calorimeter, designed and built for the KLOE experiment, running from 1999 to 2018 at Laboratori Nazionali di Frascati for observing kaon decays from the DAFNE Phi-factory.

The calorimeter has demonstrated excellent energy and temporal resolution, together with high efficiency for neutrons and charged particles. All these properties make it well exploitable for neutrino experiments.
In this talk the fundamental role of the electromagnetic calorimeter in the SAND design will be described, together with the expected performance of the Near Detector complex for data-driven neutrino interaction studies and for the CP violation measurement.

135

Laser response variation during 10 years of CMS ECAL operation and prospects for HL-LHC

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The CMS Electromagnetic Calorimeter (ECAL) is made of 75848 lead-tungstate scintillating crystals. The excellent intrinsic energy resolution of the CMS ECAL is preserved with the aid of a precise light monitoring system. The high radiation doses from the LHC collisions in the ECAL crystals and photodetectors affects the light output. Crystal and photodetector response changes are monitored in real time by a sophisticated apparatus using lasers and LEDs. Soon after data are collected, a computer farm processes the laser and LED monitoring events and computes precise corrections to be used in the event reconstruction within 48 hours of data-taking. Similar corrections are also applied at trigger level.

The ECAL light monitoring system has been operational since the start of LHC Run 1 (2010-2013). During LHC Run 2 (2015-18), CMS recorded data corresponding to an integrated luminosity of more than 160 fb-1 at 13 TeV. The Run 2 luminosity increase compared to Run 1 has caused correspondly higher response losses, which have been tracked and corrected for using this system.

High-Luminosity running at the LHC, which is planned for 2028 and beyond, will imply an order of magnitude increase in radiation levels and particle fluences with respect to the present LHC running conditions. The mitigation of ageing is an important goal for the upgrade of the laser light monitoring system. This talk describes the key components of the ECAL monitoring system, discusses the evolution of the response of the ECAL crystals and photodetectors in Run 1 and Run 2 data, the monitoring plans for LHC Run 3 (2022-25) and outlines the proposed monitoring system upgrade for HL-LHC (2028-).

136

The SiPM-on-tile system of the CMS HGCAL

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For the CMS High-Granularity Calorimeter (HGCAL) for HL-LHC, scintillator tiles, readout with individual on-tile silicon photomultipliers (SiPMs), will be used where the radiation levels are expected to be less than 5 x 10ˆ13 n/cmˆ2. The scintillator tiles will be mounted on highly-integrated "tileboards"(typical area 30 x 30 cmˆ2) that host up to 108 tiles and their SiPMs, as well as front-end electronics, control and powering components. A dedicated LED system will be implemented to monitor stability effects. We present recent developments for the HGCAL scintillator material and SiPMs, including quantification of the scintillator and SiPM radiation-damage impact, modeling of SiPM noise and its evolution with time, SiPM production testing and quality control plans, and tests of tileboards in laboratories and beam-tests.

137

The CMS Level-1 Calorimeter Trigger for the HL-LHC

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The High-Luminosity LHC will open an unprecedented window on the weak-scale nature of the universe, providing high-precision measurements of the standard model as well as searches for new physics beyond the standard model. Such precision measurements and searches require information-rich datasets with a statistical power that matches the high-luminosity provided by the Phase-2 upgrade of the LHC. Efficiently collecting those datasets will be a challenging task, given the harsh environment of 200 proton-proton interactions per LHC bunch crossing. For this purpose, CMS is designing an efficient data-processing hardware trigger (Level-1) that will include tracking information and high-granularity calorimeter information. The current conceptual system design is expected to take full advantage of FPGA and link technologies over the coming years, providing a high-performance, low-latency computing platform for large throughput and sophisticated data correlation across diverse sources. The envisaged L1 system will more closely replicate the full offline object reconstruction instead to perform a more sophisticated and optimized selection. Algorithms such as particle flow reconstruction can be implemented and complemented by standalone trigger object reconstruction. The expected performance and physics implications of such algorithms are studied using Monte Carlo samples with hıgh pile-up, simulating the harsh conditions of the HL-LHC. The trigger object requirements are not only driven by the need to maintain physics selection thresholds to match those of the Phase-1, the selection of exotic signatures including displaced objects must be provided to help expanding the physics reach of the experiment. The expected acceptance increase on selected benchmark signals obtained by the upgraded CMS Phase-2 Level-1 Calorimeter Trigger will be summarized in this presentation.

138

Commissioning of the CALICE SiW Ecal prototype

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The next generation of collider detectors will make full use of Particle Flow Algorithms, requiring high precision tracking and full imaging calorimeters. The latter, thanks to granularity improvements by two to three orders of magnitude compared to existing devices, have been developed during the past 15 years by the CALICE collaboration and are now reaching maturity. This contribution will focus on the commissioning of a 15-layer prototype of a highly granular silicon-tungsten electromagnetic calorimeter that comprise 15360 readout cells. Each layer has a dimension of 18x18 cm2 and is composed of 4 silicon sensors of 9x9 cm2 and thicknesses between 320 and 650um, The silicon sensors are readout out by the SKIROC2a ASICs designed for self-triggering and low power. The interface between ASICs and is provided by complex PCBs that ensure small parasitic capacitances in order to maintain a low noise level.
The prototype has been exposed in November 2021 and March 2022 to a beam test at DESY. The contribution will give a general overview on the prototype and will highlight technical developments necessary for its construction. It will introduce the individual components like the front end electronics, PCBs and the compact readout electronics and construction steps such as gluing of sensors or developed techniques for the encapsulation of bare ASICs. This contribution is the first of a series of contributions on the performance of the prototype and the outlook onto the future of the R&D.
Let us add that in March 2022 a common data taking with the analogue hadron calorimeter of CALICE has been been tested. We will report on the first experience obtained in this test.

140

Simulation of the performances of a highly-granular Silicon-Tungsten electromagnetic calorimeter

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The optimisation of the calorimeters for Future Higgs factory experiments is a central task in evaluating their performance and cost. A reliable simulation of the calorimeters, based on realistic assumptions, if possible based on existing devices, is critical. Beyond the GEANT4 description, which provides the energy deposited in the sensitive medium (here silicon), a realistic simulation must include a proper modelling of the charge generation and collection and of their electronics treatment, a step dubbed digitisation. We describe in this contribution the digitization, its key criteria, their adjustment on the current CALICE SiW ECAL prototype and its possible future iterations. The effect of some non-uniformities of the prototype (e.g. masked cells, threshold adjustment, various sensor thicknesses) on the energy resolution and electromagnetic shower description are discussed.

141

Design and Power management issues in the CALICE SiW ECAL base elements

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Performant electromagnetic calorimeters suited for a Particle Flow approach rely on their granularity and compactness to unravel the contributions of nearby showers. For practical reasons, their readout electronics must be close to the sensors, hence present a very low power dissipation, in a scalable geometry allowing for long (˜1.5–1.8 m) detector cassettes serviced from a single end. To

do so, near linear colliders, detector electronics can be pulsed. The aforementionned requirements apply to the very front-end ASICs but equally to the supporting PCB's. The technological prototype of the CALICE SiW ECAL is testing solutions for an ILC-like environnement, based on 18×18 cm² front-end boards, holding 16 SKIROC2 ASICs and 4 matrices of silicon diodes. Five versions of these boards, using either packaged or naked chips, have been integrated, and recently tested in beam, in a stack of 15 single-board layers, and in long layer of 8 boards. Lessons learned from these tests will be discussed in this contribution, as well as the new, improved, design, including on-board power regulations.

142

Hadron-Induced Radiation Damage in Fast Heavy Inorganic Scintillators

Authors: Chen Hu[1]; Liyuan Zhang[2]; Ren-Yuan Zhu[2]

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Future HEP experiments at the energy and intensity frontiers present stringent challenges to fast and heavy inorganic scintillators in radiation tolerance. Up to 500 Grad and 5×10^{18} n_{eq}/cm^2 of one MeV equivalent neutron fluence are expected by the forward calorimeters at the proposed Future Hadron Circular Collider (FCC-hh). This paper reports results of investigations of neutrons and protons induced radiation damage in fast and heavy inorganic scintillators, such as LYSO:Ce crystals, LuAG:Ce ceramics and BaF_2 crystals for applications in ultracompact, radiation hard, sampling calorimetry and precision time of flight systems. Applications for Gigahertz hard X-ray imaging will also be discussed.

143

Inorganic Scintillators for Future HEP Experiments

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Future HEP experiments at the energy and intensity frontiers present stringent challenges to inorganic scintillators in radiation tolerance, ultrafast time response and cost. This paper reports recent progress in radiation hard, ultrafast, and cost-effective inorganic scintillators for future HEP experiments. Examples are LYSO crystals for a precision time of flight detector, LuAG ceramics for an ultracompact, radiation hard shashlik sampling calorimeter, BaF2:Y crystals for an ultrafast calorimeter, and cost-effective scintillators for a homogeneous hadron calorimeter. Applications for Gigahertz hard X-ray imaging will also be discussed.

144

Value of Timing in Calorimetry

Authors: Adil Hussain[1]; Christopher Cowden[1]; Jordan Damgov[1]; Nural Akchurin[1]; Shuichi Kunori[1]

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We studied the performance of a Convolutional Neural Network (CNN) for energy regression using fast signal (< 5 ns) in a finely 3D-segmented calorimeter simulated using GEANT4. We trained a CNN solely on a sample of pions. Compared to conventional approaches, it achieved substantial improvement in energy resolution for both single pions and jets. It maintained good performance for electron and photon reconstruction. We also studied a Graph Neural Network (GNN) with edge convolution to illustrate the importance of signal timing information below the nano-second range for improved energy reconstruction. We present the comparison of several reconstruction techniques: a simple energy sum, dual-readout analog, CNN, and GNN with timing information.

145

The (Un)reasonable Effectiveness* of Neural Networks in Cherenkov Calorimetry

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We report a greater than factor of two improvement in the hadronic energy resolution of a simulated Cherenkov calorimeter by estimating the energy with machine learning over traditional techniques. The prompt signal formation and energy threshold properties of Cherenkov radiation provide identifiable features that machine learning techniques can exploit to produce a superior model for energy reconstruction. We simulated a quartz-fiber calorimeter in the GEANT4 framework to study the reconstruction techniques in single and multi-hadron events. We compared the machine learning-based reconstruction performance to that of traditional and dual-readout techniques. We describe the reasons for this improvement and game-changing approach to Cherenkov hadron calorimetry as well as our plans for a dedicated beam test to validate these findings with a fast, radiation-hard hadron calorimeter prototype.

(*) inspired by E. P. Wigner

146

Development of an Argon Light Source as a Calibration and Quality Control Device for Liquid Argon Light Detectors

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The majority of future large-scale neutrino and dark matter experiments are based on liquid argon detectors. Since liquid argon is also a very effective scintillator, these experiments also have light detection systems. The liquid argon scintillation wavelength of 127 nm is most commonly shifted to the visible range by special wavelength shifters, or read out by the 127 nm sensitive photodetectors

that are under development. The effective calibration and quality control of these active media is still a persisting problem.

In order to respond to this need, we developed an argon light source which is based on plasma generation and light transfer across a MgF_2 window. The light source is designed as a small, portable and easy to operate device to enable the acquisition of performance characteristics of several square meters of light detectors. Here we will report on the development of the light source and its performance characteristics.

147

Novel Ultrafast Lu2O3:Yb Ceramics for future HEP Applications

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Inorganic scintillators activated by charge transfer luminescence Yb3+ are considered promising ultrafast medium to break the ps timing barrier for future HEP applications. Inorganic scintillators in ceramic form have also attracted a broad interest due to its lower fabrication temperature, effective usage of raw material, and no need for aftergrowth mechanical processing. Lu2O3:Yb and Lu2xY2(1-x)O3:Yb scintillating ceramic samples fabricated by Radiation Monitoring Devices Inc., was investigated at Caltech HEP Crystal Lab. All samples show photoluminescence and x-ray excited luminescence peaked at 340 and 370 nm respectively with 0.6 ns decay time measured by using microchannel plate-photomultiplier tubes (MCP-PMT). Combined with their high density (9.4 g/cm3) Lu2O3:Yb ceramics is promising for future HEP calorimetry and time of fight (TOF) applications. Results of their optical and scintillation quality and radiation hardness and plans for further development will be presented.

148

Digital Hadron Calorimetry

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Extreme spatial granularity is the key component for the full exploitation of Particle Flow Algorithms, which attempt to measure each particle in a hadronic jet individually. In this context, the CALICE Collaboration developed the Digital Hadron Calorimeter (DHCAL). The DHCAL uses Resistive Plate Chambers as active media and is read out with 1×1 cm^2 pads and digital (1-bit) resolution. In order to obtain a unique dataset of electromagnetic and hadronic interactions with unprecedented spatial resolution, the DHCAL went through a broad test beam program. In addition to conventional calorimetry, the DHCAL offers detailed measurements of event shapes, rigorous tests of simulation models and various analytical tools to improve calorimetric performance. Here we report on the results from the analysis of DHCAL data and comparisons with the Monte Carlo simulations across

various test campaigns. We will also discuss the near future plans which include further tuning of the Monte Carlo parameters to improve the simulation of single particle response and electromagnetic interactions, and further tests of the hadronic interaction models.

149

Systematic Study of LED Stimulated Recovery of Radiation Damage in Optical Materials

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The radiation damage in optical materials mostly manifests itself as the loss of optical transmission. This loss can recover to some extent in the presence of natural light, and at a faster rate in the presence of stimulating light. On the other hand, the systematic study of the dynamics of the recovery as a function of the stimulating light parameters such as its wavelength, intensity and exposure duration and method has not been performed in detail so far.

We established an LED recovery station which provides pulsed and continuous light at various wavelengths at custom geometries. The study starts with the irradiation of soda lime glass samples at various gamma doses at a rate of 87.5 Gy/min. The optical transmittance of the samples are then measured in 200 nm - 1000 nm range for an extended period of time and significant findings on the dynamics of the recovery were obtained.

Here we report on the details of the irradiation and recovery setups, and the results of recovery from radiation damage under different light exposure mechanisms.

150

Development of Novel Designs of Resistive Plate Chambers

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Resistive Plate Chambers (RPCs) are the key active media of the muon systems of current and future collider experiments as well as the CALICE (semi-)digital hadron calorimeter. The outstanding issues with the RPCs can be listed as the loss of efficiency for the detection of particles when subjected to high particle fluxes, and the limitations associated with the common RPC gases.

We developed novel RPC designs with: low resistivity glass plates; a single resistive plate; a single resistive plate and a special anode plane coated with high secondary electron emission yield material. The cosmic and beam tests confirmed the viability of these new approaches for calorimetric

applications. The chambers also have improved single-particle response, such as a pad multiplicity close to unity.

Here we report on the construction of various different glass RPC designs, and their performance measurements in laboratory tests and with particle beams. We will also discuss the future test plans which include the long term performance tests of the newly developed RPCs, investigation of minimal gas flow chambers, and the feasibility study for the large size chambers.

151

Secondary Emission Calorimetry

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Electromagnetic calorimetry in high-radiation environments, e.g. forward regions of lepton and hadron collider detectors, is quite challenging. Although the total absorption crystal calorimeters have superior performance as electromagnetic calorimeters, the availability and the cost of the radiation-hard crystals are the limiting factors as radiation-tolerant implementations. The sampling calorimeters utilizing Silicon sensors as the active media are also favorable in terms of performance but are challenged by high radiation environments. In order to provide a solution for such implementations, we developed a radiation-hard, fast and cost effective technique, secondary emission calorimetry, and tested prototype secondary emission sensors in test beams. In a secondary emission detector module, secondary emission electrons are generated from a cathode when charged hadron or electromagnetic shower particles penetrate the secondary emission sampling module placed between absorber materials. The generated secondary emission electrons are then multiplied in a similar way as the photoelectrons in photomultiplier tubes. Here we report on the principles of secondary emission calorimetry and the results from beam tests as well as the Monte Carlo simulations of projected, large-scale secondary emission electromagnetic calorimeters.

152

Energy Reconstruction and Calibration of the MicroBooNE LArTPC

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The Liquid Argon Time Projection Chamber (LArTPC) is increasingly becoming the chosen technology for current and future precision neutrino oscillation experiments due to its superior capability in particle tracking and energy calorimetry. In LArTPCs, calorimetric information is critical for particle identification, which is the foundation for the neutrino cross-section and oscillation measurements as well as searches for beyond standard model physics. One of the primary challenges in employing LArTPC technology is characterizing its performance and quantifying the associated systematic uncertainties. MicroBooNE, the longest operating LArTPC to date, has performed numerous such measurements, including studies of detector physics and electromagnetic shower reconstruction. Here we present results on the operation and performance of the detector during its data

taking, highlighting accomplishments toward calorimetric reconstruction, calibration, and detector physics.

153

Talk 47

154

Talk 48

155

Talk 49

156

Talk 50

157

Talk 51

158

Talk 52

159

Talk 53

160

Talk 54

161

Talk 55

Session 1 - LHC 1 / 162

Ten years of operations of the CMS ECAL

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Session 1 - LHC 1 / 163

Scintillating sampling ECAL technology for the Upgrade II of LHCb

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Session 1 - LHC 1 / 164

Design and test-beam results from the FoCal-H demonstrator prototype

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Session 1 - LHC 1 / 165

Performance and calibration of the ATLAS Tile Calorimeter

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Session 2 - Neutrino 1 / 166

Calibrating the Deep Underground Neutrino Experiment

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Session 2 - Neutrino 1 / 167

Calorimetry in a neutrino observatory: the JUNO experiment

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Session 2 - Neutrino 1 / 168

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Session 2 - Neutrino 1 / 169

Energy reconstruction and calibration of the MicroBooNE LArTPC

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Session 3 - New Technologies 1 / 170

LiquidO Novel Detection Technology

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Session 3 - New Technologies 1 / 171

R&D of a novel high granularity crystal ECAL

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Session 3 - New Technologies 1 / 172

Towards a Large Calorimeter based on LYSO or LaBrCe Crystals for Future High Energy Physics

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Session 3 - New Technologies 1 / 173

Mu2E Electromagnetic calorimeter

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Session 3 - New Technologies 1 / 174

Novel ultrafast Lu2O3 ceramics for future HEP applications

Session 3 - New Technologies 1 / 175

The NNBAR Calorimeter

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Session 4 - Future Colliders 1 / 176

Noble Liquid calo for FCC-ee

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Session 4 - Future Colliders 1 / 177

Design and performance studies of the electromagnetic calorimeter for STCF

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Session 4 - Future Colliders 1 / 178

The SiD Digital ECal Based on Monolithic Active Pixel Sensors

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Session 4 - Future Colliders 1 / 179

Crilin: a semi-homogeneous calorimeter for a future Muon Collider

Session 4 - Future Colliders 1 / 180

RADiCAL: Precision-timing, Ultracompact, Radiation-hard Electromagnetic Calorimetry

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Session 5 - Calorimeter Technologies for Future Colliders 1 / 181

25 Years of Dual-Readout Calorimetry

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Session 5 - Calorimeter Technologies for Future Colliders 1 / 182

Energy reconstruction with semi-digital HCAL

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Session 5 - Calorimeter Technologies for Future Colliders 1 / 183

SiPMs for dual-readout calorimetry

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Session 5 - Calorimeter Technologies for Future Colliders 1 / 184

Digital Hadron Calorimetry

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Session 6 - Calorimeters using crystals/scintillators/ceramics / 185

Using artificial intelligence in the reconstruction of signals from the PADME electromagnetic calorimeter

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Session 6 - Calorimeters using crystals/scintillators/ceramics / 186

FASER's Electromagnetic Calorimeter Test-Beam Studies

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Session 6 - Calorimeters using crystals/scintillators/ceramics / 187

The impact of crystal light yield non-proportionality on a typical calorimetric space experiment: beam test measurements and MonteCarlo simulations

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Session 6 - Calorimeters using crystals/scintillators/ceramics / 188

The Status of the DAMPE BGO calorimeter in space

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Session 7 - Applications of Calorimetric Techniques 1 / 189

QuARC: A Quality Assurance Range Calorimeter for Proton Therapy

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Session 7 - Applications of Calorimetric Techniques 1 / 190

FERS-5200: a distributed Front-End Readout System for multidetector arrays

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Session 7 - Applications of Calorimetric Techniques 1 / 191

Proton energy reconstruction with ASTRA

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Session 7 - Applications of Calorimetric Techniques 1 / 192

Including calorimeter test-beams into geant-val - the physics validation testing suite of Geant4

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Session 7 - Applications of Calorimetric Techniques 1 / 193

Systematic Study of LED Stimulated Recovery of Radiation Damage in Optical Materials

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Session 8 - New Technologies 2 / 194

Status of ADRIANO2 R&D in T1604 Collaboration

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Session 8 - New Technologies 2 / 195

FASER's Electromagnetic Calorimeter Test-Beam Studies

Session 8 - New Technologies 2 / 196

Novel ultrafast Lu2O3 ceramics for future HEP applications

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Session 8 - New Technologies 2 / 197

Performance Study of a New Cluster Splitting Algorithm for the Reconstruction of PANDA EMC Data

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Session 8 - New Technologies 2 / 198

Radiation damage studies for phenyl-based plastic scintillators

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Session 8 - New Technologies 2 / 199

Resistive Plate WELL Detectors as DHCAL sampling elements

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Session 9 - Calorimeter Technologies for Future Colliders 2 / 200

Crilin: a semi-homogeneous calorimeter for a future Muon Collider

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Session 9 - Calorimeter Technologies for Future Colliders 2 / 201

Development of Novel Designs of Resistive Plate Chambers

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Session 9 - Calorimeter Technologies for Future Colliders 2 / 202

Particle Identification for Dual-readout Calorimeter using Deep Learning

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Session 9 - Calorimeter Technologies for Future Colliders 2 / 203

The CALICE SiW ECAL Prototype

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Session 10 - Calorimeter Technologies for Future Collider 3 / 204

Performance at testbeam andsimulation of the CALICE SiW ECAL prototype

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Session 10 - Calorimeter Technologies for Future Collider 3 / 205

3D shower shape reconstruction with the dual-readout calorimeter

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Session 10 - Calorimeter Technologies for Future Collider 3 / 206

Homogeneous dual-readout electromagnetic calorimetry

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Session 11 - LHC 2 / 207

Development of the ATLAS Liquid Argon Calorimeter Readout Electronics and Machine Learning for the HL-LHC

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Session 11 - LHC 2 / 208

The ultimate CMS ECAL calibration and performance for the legacy reprocessing of LHC Run 2 data

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Session 11 - LHC 2 / 209

Upgrade of CMS barrel calorimeter for LHC Phase-II

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Session 11 - LHC 2 / 210

Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC

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Session 12 - Applications of calorimetric techniques 2 / 211

A novel approach to understanding hadronic showers using machine learning technique

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Session 12 - Applications of calorimetric techniques 2 / 212

Tracker-In-Calorimeter (TIC) project: a calorimetric new solution for space experiments

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Session 12 - Applications of calorimetric techniques 2 / 213

WSF read-out and calibration light source of the 3-D crystal array of HERD calorimeter

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Session 12 - Applications of calorimetric techniques 2 / 214

Value of Timing in Calorimetry

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Session 12 - Applications of calorimetric techniques 2 / 215

Secondary Emission Calorimetry

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Session 13 - LHC 3 / 216

Level-1 Triggering on High-Granularity Calorimeter information at the HL-LHC

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Session 13 - LHC 3 / 217

The overall electronics chain (powering and readout) of the CMS HGCAL

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Session 13 - LHC 3 / 218

ATLAS LAr Calorimeter Commissioning for LHC Run-3

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Session 13 - LHC 3 / 219

Machine learning techniques for calorimetry

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Session 13 - LHC 3 / 220

The SiPM-on-tile system of the CMS HGCAL

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Session 14 - Future Colliders 2 / 221

The development of a highly granular scintillator-steel hadron calorimeter for the CEPC

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Session 14 - Future Colliders 2 / 222

Status of Timing-SDHCAL Development

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Session 14 - Future Colliders 2 / 223

Development of a novel highly granular hadronic calorimeter with scintillating glass tiles

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Session 14 - Future Colliders 2 / 224

Development and Performance of a highly granular scintillator-tungsten ECAL prototype for the CEPC

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Session 15 - Applications of calorimetric techniques 3 / 225

Mu2e crystal calorimeter front-end electronics: design, characterisation, and radiation hardness

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Session 15 - Applications of calorimetric techniques 3 / 226

(Un)reasonable effectiveness of NN in Cherenkov calorimetry

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Session 15 - Applications of calorimetric techniques 3 / 227

A high-performance electromagnetic calorimeter for neutrino physics in the DUNE Near Detector complex

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Session 15 - Applications of calorimetric techniques 3 / 228

Development of an Argon Light Source as a Calibration and Quality Control Device for Liquid Argon Light Detectors

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Session 16 - New technologies 3 / 229

The NNBAR Calorimeter

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Session 16 - New technologies 3 / 230

Resistive Plate WELL Detectors as DHCAL sampling elements

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Session 16 - New technologies 3 / 231

Radiation damage studies for phenyl-based plastic scintillators

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Session 16 - New technologies 3 / 232

Secondary Emission Calorimetry

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Poster Session / 233

Mechanical Design for an Electromagnetic Calorimeter for Muon Collider (online)

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Poster Session / 234

Design and power management issues of CALICE SiW ECAL base elements

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Poster Session / 235

Photodiode read-out system for the calorimeter of the HERD experiment

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Poster Session / 236

Trigger-DAQ and slow control systems in the Mu2e experiment (online)

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Poster Session / 237

Engineering challenges in constructing CMS HGCAL

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Session 4 - Future Colliders 1 / 238

Crilin: a semi-homogeneous calorimeter for a future Muon Collider

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Poster Session / 239

A Burn-in test station for the ATLAS Phase-II Tile-calorimeter low-voltage power supply transformer-coupled buck converters (online)

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240

Zoom Details for day 1

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Session 8 - New Technologies 2 / 241

Hadron-Induced radiation damage in fast heavy inorganic scintillators

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Session 4 - Future Colliders 1 / 242

Inorganic Scintillators for future HEP experiments

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Session 13 - LHC 3 / 243

Status and Overview of the CMS High Granularity Calorimeter

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Poster Session / 244

Resolution studies in simiulation for the IDEA dual-readout calorimeter

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Poster Session / 245

FERS-5200: a distributed Front-End Readout System for multidetector arrays

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246

Info about excursion

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247

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Poster Session / 248

The CMS Level-1 Calorimeter Trigger for the HL-LHC

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Session 14 - Future Colliders 2 / 249

Mechanical Design for an Electromagnetic Calorimeter for Muon Collider (poster)

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