IDTM Workshop - Innovative Detector Technologies and Methods

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Book of Abstracts

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Optimizing experiment design with differentiable programming (zoom)

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In physics and other disciplines, future experimental setups will be so complex that it will be unfeasible for humans to find an optimal set of design parameters. We parameterize the full design of an experiment in a differentiable way and introduce a definition of optimality based on a loss function that encodes the end goals of the experiment. Crucially, we also account for construction constraints, as well as budget, resulting in a constrained optimization problem that we solve using gradient descent.

In this seminar, I will describe our activities and goals as the MODE Collaboration, focussing on our ongoing work on the optimization of a muon tomography experiment.

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New developments in timing RPCs

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This talk will cover recent developments of timing RPCs focused mainly on the work developed in the LIP RPC R&D group. The talk will address recent developments in large-area, low-cost and high-performance timing RPCs capable to provide timing precision below 50 ps sigma, together with an efficiency higher than 98%, for modules of around 2 m². These results were obtained with a full-scale prototype of the timing detector of future SHiP experiment, where a very good timing precision and affordable cost are needed to cover tens of square meters. In addition, the capability to measure simultaneously with time the 2D position, with sub-millimeter precision, will be shown in a prototype of 0.1 m².

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Design, simulation and characterization of innovative Low-Gain Avalanche Diodes for High Radiation Environments

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LGAD sensors have proven to be an excellent solution for 4D-tracking in HEP experiments thanks to the presence of internal gain that provides good time resolution also at high fluences (up to ~2·10¹⁵ n_{eq}/cm²). However, approaching 10¹⁶ n_{eq}/cm², the internal gain is completely lost due to the acceptor removal effect, leading to a deterioration of the time performances. In order to have a predictive insight into LGAD electrical behavior and charge collection properties, state-of-the-art Synopsys Sentaurus TCAD tools have been adopted and equipped with a well-validated radiation damage numerical model, called the "University of Perugia model". The model can reproduce experimental data with high accuracy, and the model has been applied to optimise one innovative paradigm for the design of LGAD sensors for 4D tracking: compensated LGAD. This innovative design of silicon sensors able to withstand very high fluences while keeping excellent timing performances will be presented and discussed. This technological solution has been implemented in the most recent R&D batch produced at FBK. Preliminary results on the sensors'characterization will be presented and discussed.

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High performance computing in HEP (zoom)

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We discuss the status of HPC usage and exploitation in the context of high energy physics, within the context of several experimental collaborations. We discuss in particular the progress and organization of these activities within the Italian community, in the context of the recently funded center for HPC, Big Data and quantum computing.

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Quantum sensors for particle physics: the NAMASSTE project

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Answering the most puzzling questions in fundamental physis posed by HEP drives a continuous quest for improvements in current particle detection techniques as well as for the development of new ones. Among the novel detection approaches under investigation, the development of innovative devices based on exploiting the extreme sensitivity of quantum systems is considered to have promising potentialities. After an introduction to this rapidly-developing interdisciplinary field, the INFN R&D project NAMASSTE is presented as an example in a wide range of quantum technologies and methodologies which are currently being actively explored for the development of new detection techniques.

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SND@LHC: a new neutrino detector at LHC

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SND@LHC is a compact and stand-alone experiment to perform measurements with neutrinos produced at the LHC in the pseudo-rapidity region of $7.2 < \eta < 8.6$, complementary to all the other experiments at the LHC.
The experiment will be located 480~m downstream of the ATLAS interaction point, in a previously unused LHC service tunnel. The detector is composed of a hybrid system based on an 830~kg target mass with tracking capabilities, followed downstream by a calorimeter and a muon system. The target region is composed of bricks of emulsion cloud chambers and scintillating fibre tracker layers with good spatial and time resolution. The Veto, HCAL and Muon detector use scintillating bars with different geometries and photodetectors optimised for the physics performance. All active detectors are read out by silicon photomultipliers connected to a custom read-out electronics based on the TOFPET2 ASIC. It allows threshold-based noise suppression, and amplitude and time information measurement.
The data acquisition system operates in a trigger-less fashion, by sending all recorded hits to a central server, where online event building and noise suppression is performed.
The experimental configuration allows to efficiently distinguish between all three neutrino flavours, opening a unique opportunity to probe physics of heavy flavour production at the LHC in the region that is not accessible to ATLAS, CMS and LHCb.
The detector has been commissioned and installed in 2021-2022. A first set of data has been collected starting from April 2022, and it is currently being analysed, aimed at providing the first observation of neutrinos produced at a collider.
The first phase aims at operating the detector throughout LHC Run 3 to collect a total of 250~fb^{-1}.
A thorough detector upgrade is foreseen for Run 4.

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Design and optimization of a MPGD-based HCAL for a future experiment at Muon Collider

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In the context of the European strategy for particle physics, a multi-Tev muon collider has been proposed as an interesting alternative to investigate the Standard Model with unprecedented precision, after the full exploitation of the High-Luminosity LHC. Such a collider will indeed allow to accurately measure the Higgs coupling with other Standard Model particles, as well as the trilinear and quadrilinear Higgs self-coupling. Being muons not stable particles, the main foreseen challenge is to distinguish collisions from the background radiation induced by decaying muons in the beam; high granularity, superb energy resolution and precise timing are therefore the fundamental aspects of a detector at muon collider.
In this context, an innovative hadronic calorimeter (HCAL), based on Micro Pattern Gas Detectors (MPGD) as active layers, has been designed. MPGDs represent the ideal technology, featuring high rate capability (up to 10 MHz/cm2), spatial and good time resolution, good response uniformity (30%).
Being more specific, resistive MPGDs, such as resistive Micromegas and microRWELL, demonstrate excellent results for spatial resolution, operational stability (discharge quenching) and detector uniformity, which make them ideally suited for calorimetry. Moreover, gaseous detectors have the advantage of being radiation hard and allow for high granularity (1x1 cm2 cell size).
Being the first time that such calorimeter design is proposed, dedicated studies are needed to assess and optimize the performance, as well as the development of medium scale prototypes for performance measurements. In particular, the response of HCAL to the incoming particles is studied and presented in this contribution with Monte Carlo simulations performed using GEANT4; preliminary test on small detector prototypes with minimum ionizing particles at CERN SPS in order to measure the efficiency, cluster size, hit multiplicity, spatial and time resolution are also shown.

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High Granularity Calorimetry at the LHC: Challenges in energy and timing measurements

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The CMS Collaboration is preparing to build a replacement endcap calorimeters for the Phase II of the LHC. This new high-granularity calorimeter (HGCAL) is designed to operate in the harsh radiation environment at the HL-LHC, where the average number of interactions per bunch crossing is expected to exceed 140 simultaneous collisions and neutron fluences can achieve >10¹⁶ 1 MeV n_{eq}/cm². A total of approx. six million single sensors, distributed in 47 sampling layers, will be used to separate spatially and measure the energy and time of arrival of both electromagnetic and hadronic showers, providing adequate physics performance for the reconstruction of photons, taus and jets, essential objects for the physics programme of Phase II LHC. In this talk we review the status of the HGCAL project, the many lessons learnt so far, and the challenges ahead as the project enters its construction phase.

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The CMS Outer Tracker for the HL-LHC

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The LHC machine is planning an upgrade program which will smoothly bring the instantaneous luminosity to about $5 - 7.5 \times 10^{34}$\,$\mathrm{cm}^{-2}\mathrm{s}^{-1}$, to reach an integrated luminosity of $3000 - 4000$\,fb^{-1} by the end of 2039. This High Luminosity LHC scenario, HL-LHC, will require an upgrade program of the LHC detectors known as Phase-2 upgrade. The current CMS Tracker, already running beyond design specifications, and CMS Pixel Detector will not be able to survive HL-LHC radiation conditions and CMS will need completely new devices, in order to fully exploit the HL-LHC data which will be recorded under highly demanding background conditions.

The Phase-2 Tracker will be made of two sections, an Inner Tracker and an Outer Tracker. Both detectors will feature increased radiation hardness, higher granularity and capability to handle higher data rate and longer trigger latency in order to ensure at least the same performances of the current detector, in terms of tracking and vertex reconstruction capabilities, at the high pileup (140-200 collisions per bunch crossing) expected at HL-LHC. Moreover the Phase-2 Outer Tracker will have also trigger capabilities since tracking information will be used at L1 trigger stage.

This report is focusing on the replacement of the CMS Outer Tracker system, describing new layout and technological choices together with some highlights on research and development activities.

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The Mu2e straw tracker

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The Mu2e experiment in Fermilab will search for the coherent neutrinoless conversion of a muon into an electron in the field of an aluminum nucleus, improving sensitivity by 4 orders of magnitude over existing limits and indirectly probing new physics beyond the reach of current or planned high energy colliders. To achieve a single conversion event sensitivity better than 3e-17, the experiment requires a high precision measurement of the ~105 MeV/c electron momentum while reducing to negligible all background contributions in the signal window. The primary detector element is a low-mass straw tracker chamber, comprising ~21,000 thin straw drift tubes of 5 mm diameter, arranged in a 3 m long cylinder of radius 700 mm, and operated in a magnetic field of 1 T and in vacuum. The tracker is designed to reconstruct the momentum of conversion electrons with a resolution of <180 keV/c. The distance of an electron track from the straw sense wire must be extracted within 200 µm from a TDC timing measurement, while time division yields the hit position along the straw within 3 cm. The straws are also instrumented with an ADC for dE/dx capability to separate electrons from highly ionizing protons. We will present the construction status and design of the tracker.

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Design and construction status of the Mu2e crystal calorimeter and its future upgrade

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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 mono-energetic
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 3×10^{-17}, four orders of magnitude beyond the current best limit.

The calorimeter is composed of 1348 pure CsI crystals, each read by two custom UV-extended SiPMs, arranged in two annular disks. The EMC 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 in a harsh operating environment with high vacuum, 1 T magnetic field and radiation exposures up to 100 krad and
10^{12} $n_{1MeV_{eq}}/cm^2$.

The calorimeter design, along with the custom front-end electronics, cooling and mechanical systems were validated through an electron beam test on a large-scale 51-crystals prototype (Module-0). Extensive test campaigns were carried out to characterise and verify the performance of crystals, photodetectors, analogue and digital electronics, including hardware stress tests and irradiation campaigns with neutrons, protons, and photons. After completing the QC phase for crystals and SiPMs, starting from summer 2022, the installation of the disk started. At the moment of writing, one disk in completely assembled with crystals and photosensors, while the stacking procedure for the crystals on the second disk in ongoing. Commissioning and first calibration tests will be also summarised.

In view of a possible Mu2e upgrade - Mu2e-II - relying on the existence of a more powerful source of protons from PIP-II, under construction at Fermilab, the R&D for the calorimeter has already started. The future experiment will try to salvage and refurbish as much of Mu2e infrastructure as possible, upgrading Mu2e components required to handle higher beam intensity.
The Mu2e-II calorimeter should have the same energy and time resolution as Mu2e and withstand neutron fluences of $10^{13}/cm^2$ and TID up to 10 kGy. The crystals and photosensors of the front calorimeter disk will be largely replaced. A possible crystal candidate is BaF_2 because of the high

radiation resistance and the 220 nm fast component. However, R&D on UV sensitive, solar-blind photosensors is necessary to suppress the slow component at 300-320 nm. Other solutions are under development with other possible crystal candidates under test, like LYSO, PbF_2, CRY18.

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Eco-friendly Resistive Plate Chambers for HL-LHC and beyond

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Resistive Plate Chambers are widely used in present High Energy Physics experiments, and are foreseen to constitute an important part of the muon systems which will equip the experiments at the future colliders, like CEPC or FCC. However, they are operated filled with gases which, because of their large Global Warming Potential, are progressively being phased out, also according to regulations by the European Community. This has led to an important R&D program to find suitable replacements, which is being currently carried out in the framework of the RPC EcoGas@GIF++Collaboration, a joint effort across the ALICE, ATLAS, CMS, LHCb/SHiP and CERN EP-DT RPC communities. Here the latest results and prospective given by a series of tests performed with various detector layouts and electronics, operated with eco-friendly gas mixtures, and irradiated by an intense gamma background which simulates the conditions at HL-LHC and beyond, are presented and discussed in details.

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MONOLITH - picosecond time stamping capabilities in fully monolithic highly granular silicon pixel detectors

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The MONOLITH H2020 ERC Advanced project aims at producing a monolithic silicon pixel ASIC with 50µm pixel pitch and picosecond-level time stamping. The two main ingredients of the project are fast and low-noise SiGe BiCMOS electronics and a novel sensor concept, the Picosecond Avalanche Detector (PicoAD). The PicoAD uses a patented multi-PN junction to engineer the electric field and produce a continuous gain layer deep in the sensor volume. The result is an ultra-fast current signal with low intrinsic jitter in a full fill factor and highly granular monolithic detector.

Testbeam measurements of the proof-of-concept PicoAD prototype, based on a 2019 ASIC design, shows full efficiency and time resolutions of 13ps at the center of the pixel and 25ps at the pixel edge, for an average of 17ps over the pixel surface.

A new monolithic prototype with improved SiGe BiCMOS electronics was produced in 2022 on a 350Ωcm substrate. Although this ASIC does not have an internal gain layer, it provided 20ps time resolution in a testbeam with pions. This prototype was irradiated with 70MeV protons with the electronics on. Laboratory measurements with a 90Sr source for a detector irradiated with 10^16 n_eq/cm^2 show a time resolution of 50ps at a sensor bias voltage of 200V, and 40 ps at 325 V.

These results give confidence that SiGe BiCMOS processes could be considered as a candidate for the production of very high time resolution detectors for future colliders and other disciplines that involve very high radiation environments.

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The Muon Collider: Challenges and prospects

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Following the 2020 update of the Strategy for Particle Physics, the European Large National Laboratories Directors Group (LDG) initiated a new International collaboration to progress on the studies for the feasibility of a Muon Collider at 10+ TeV towards the goal of publishing a CDR in time for the next ESPPU at the end of the decade. The Collaboration elaborated a detailed resource loaded R&D roadmap necessary to prove the technologies involved, and is addressing the most urgent points on both the machine and detectors. The Collider aims at producing an integrated luminosity of 10 ab-1 at 10 TeV, with an intermediate step at 1.5 TeV delivering 1 ab-1. The muon collider presents several challenges, starting from a production target that will have to sustain a deposited power of 2÷4 MW, Superconducting Solenoids with large field on axis (5÷40 T) and subject to heavy irradiation, RF acceleration in magnetic fields, fast acceleration to cope with the short lifetime of muons, and finally the need to keep under control the neutrino radiation on surface. In this talk I will give a brief overview of all those challenges and provide examples of how the Collaboration is addressing them.

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Tracking at the Future Circular Collider (FCC)

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New scintillators for FCC

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Fast timing electronics for the CMS MIP Timing Detector

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Timing electronics with LGADs

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ETROC: An ASIC for precision timing detecctors

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3D detector + frontend integration (zoom)

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PPS experimental program at the LHC

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Perspectives in 4D-Tracking: the TimeSPOT project and beyond (Zoom)

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Fast timing with gaseous detectors

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PPS Upgrade: Fast timing with silicon detectors

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Timing detectors at LHC with BTL/MTD

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Data analysis for DCR mitigation

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Diamond timing detectors (TBC)

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Synergies between Astroparticle and HEP (zoom)

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DarkSide: A direct DM search experiment

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Particle detection with qubits (zoom)

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New techniques in data analysis: a differential vertexing algorithm

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FPGAs in HEP (zoom)

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A scintillating fibre tracker for neutrino physics at LHC

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SND@LHC is a compact and stand-alone experiment that performed the first collider neutrino observation at the LHC.
The detector, located 480 m from the ATLAS interaction point, is composed of a target region, followed downstream by a hadronic calorimeter and a muon identification system.
The target region is instrumented with five walls of emulsion cloud chambers, each followed by a scintillating fiber (SciFi) tracker plane, whose function is to assign a timestamp to the reconstructed neutrino events and measure the energy of electromagnetic showers.
Both the scintillating fiber layers and the multichannel SiPM arrays of the SciFi modules were originally developed for the LHCb SciFi tracker and are here also exploited to perform timing and calorimetric measurements for the first time.
The read-out electronics, based on the TOFPET2 ASIC, has been therefore optimised to meet the stringent time resolution requirements and to allow the measurement of signal amplitudes from the photo-detectors.
After an overview of the SND@LHC detector, the talk will focus on the SciFi tracker, the read-out electronics, and the characterisation of their performance, particularly in terms of time resolution and energy measurement.

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Search for high frequency GWs with bulk acoustic cavities

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Cryogenic Bulk Acustic Wave (BAW) cavities can be used as narrow band and high resolution antennas for high frequency GWs (1 MHz - 1 GHz). Such GWs might be produced by several cosmological sources: from the merging of compact binary objects to the annihilation of QCD axions close to a black hole. Based on studies conducted at University of Western Australia, I'll describe how: a BAW can be sensitive to GW, lattice vibrations can be converted and amplified as an electrical signal, the BAW sensitivity evolves as a function frequency and operating temperatures. Finally, a preliminary characterisation of commercially available quartz BAWs, conducted at University of Milano Bicocca, will be reported along with plans towards the construction of an array of optimized antennas providing wide-band sensitivity in a range from 1 MHz to a few tens of MHz."

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Welcome

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