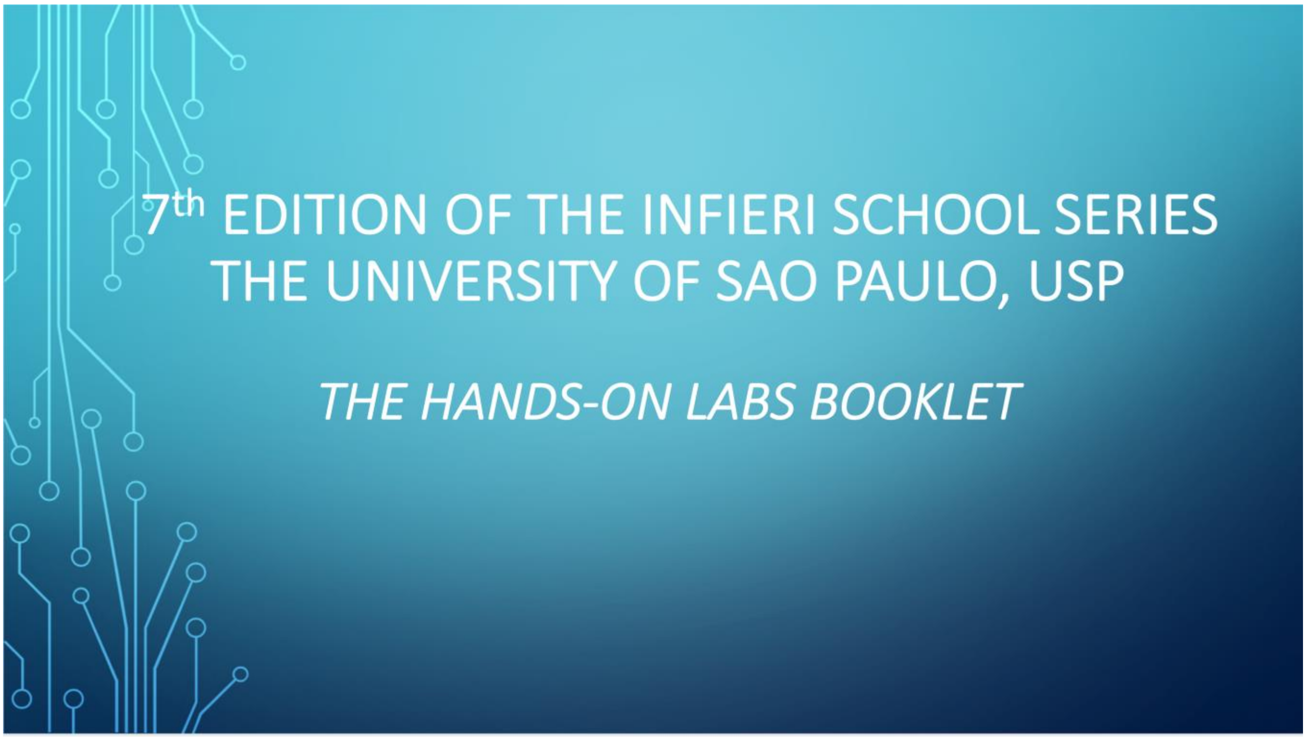
INFIERI 2023



7th EDITION OF THE INFIERI SCHOOL SERIES
THE UNIVERSITY OF SAO PAULO, USP

THE HANDS-ON LABS BOOKLET

Hands-on Labs authors

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CEA-IRFU, Universite Paris-Saclay and CNRS/IN2P3

- *Lab 1.1: Ricardo d'Elia Matheus (IFT-UNESP, BR) et al.*
- *Lab 1.2: Vinicius Njaim Duarte (Princeton Plasma Physics Laboratory, USA) et al.*
- *Lab 2.1: S.G. Alberton, V.A.P. Aguiar, N. Added, E.L.A. Macchione and N.H. Medina (Institute of Physics, USP, São Paulo, SP) and M.A. Guazzelli, A. Villas-Bôas (Centro Universitário FEI, São Bernardo do Campo, SP).*
- *Lab 2.2.: Yoshinobu Unno (KEK, Japan) with contribution of Hamamatsu Photonics, KK (Japan)*
- *Lab 2.3: Artur W. Carbonari, Anastasia Nikolaevna Burimova, Frederico Genezini, Hyperfine Interaction Lab, Nuclear & Energy Research Institute - IPEN-CNEN, BR*
- *Lab 3.1: Ian R. Tomalin (Rutherford-Appleton Laboratory, UK), Carlos Ruben dell'Aquila (NCC-UNESP Universidade Estadual Paulista, Brazil)*
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INTRODUCTION:

As the tradition in this school series, most of the Labs are organized by teams from academia, research Labs, not from the host University Campus..

In this school edition at USP, Labs are organized by teams from: IMT-MAUA, IPEN-CNEN (Hyperfine Interactions Lab, Laser application Lab, Reactor) UNESP-IFT and UNESP-NCC, UFSCAR, UNICAMP, in São Paulo metropolitan área or State.
Labs are likewise organized by people from abroad: Belgium (Gent University and IMEC), France (CEA-IRFU), Italy (LNF-Frascati, Rome), Japan (KEK and HPK), UK (Kings College of London, RAL and SKAO) and USA (Fermi National Lab).
At USP, the teams organizing Labs are from IF-USP (Pelletron and Plasma Physics groups) and POLI (C4I and INOVA-USP)..

The INFIERI school series publishes Proceedings in the *Journal of Instrumentation, JINST,* a peered international Journal. The submitted contributions to the Proccedings, if accepted by international reviewers, are published as independent articles. The topics covered by the Journal range from the theoretical aspects to the most technological ones, in different scientific fields from fundamental to most applied domains.

The school series awards certificates to the Lab organizers, in recognition of the time and work to set-up the Lab and run it during the whole duration of the school.

The Labs are held at IMT-Maua (São Paulo Metropolitan área) with transportation organized, in three different Labs of the IPEN-CNEN Campus (within the USP Campus: a Campus in the Campus), the Pelletron accelerator Lab of the Physics Institute, the Plasma Lab of the Physics Institute (including the TCABR Tokamak), the C4AI (Center for Artificial Intelligence at the INOVA-USP Center) and different locations in the INOVA Center.

I. THEORETICAL HANDS-ON LABS

Dedicated Masterclasses on Theoretical Pillars of this school

To be held at the INOVA-USP Center for Innovation

The hands-on Labs, also labelled as “masterclasses”, on the theoretical Physics fundaments of the scientific topics covered by the school initiated at the former edition at UAM in Madrid. Because of the success and interest of the students, this year the “theoretical” hands-on Labs will cover Particle Physics and Plasma Physics.
The masterclass is aimed to introduce the non-expert in the field, of course based on the high-level Physics background of the school attendants.

LAB 1.1: MASTERCLASS on HIGH ENERGY PHYSICS

A Masterclass is prepared around the Feynman diagrams in HEP: brief introduction, and developing a complete example case around a production process at LHC, the corresponding Feynman diagrams and their calculation based on Madgraph computing tool also stressing its limits.

LAB 1.3: MASTERCLASS on PLASMA PHYSICS

Plasmas, the fourth state of matter, are collections of freely moving charged particles (mainly electrons and ions) in which collective phenomena, such as waves, dominate the system's behavior. Plasmas are essential to many high-technology applications indeed tackled in this school (e.g. Fusion, galactic plasma). Plasmas are usually created by heating a gas until the electrons become detached from their parent atom or molecule. This so-called ionization can also be achieved using high-power laser light or microwaves.
Plasma Physics is made up by many disciplines we study in Physics at the University: classical and quantum mechanics, electricity and magnetism, fluid dynamics, hydrodynamics, atomic physics, applied mathematics, statistical mechanics, and kinetic theory.

Abstract of the masterclass, by Dr. Vinicius Njaim Duarte (Princeton Plasma Physics Laboratory, USA)

This masterclass on theoretical plasma physics will introduce and derive from first principles some key overarching concepts that describe fundamental characteristics of plasmas. The presentation will be simple and no previous knowledge on the subject will be assumed. First, the classical model of electrical resistivity, first derived by Spitzer and Härm, will be presented along with a brief review of the Rutherford scattering. The students will learn that, unlike in solids, in plasmas the resistivity is inversely proportional to its temperature. Second, an intuitive derivation of Alfvén's theorem, or the frozen-in flux theorem, will be shown. This theorem states that electrically conducting fluids and embedded magnetic fields are constrained to move together in the limit of small resistivity. Finally, the lecturer will discuss implications and current lines of research in thermonuclear fusion that utilize the concepts introduced during the class.

II. ADVANCED MICROELECTRONICS AND SEMI-CONDUCTOR TECHNOLOGY LABS

Lab 2.1 CHARACTERIZATION OF ELECTRONIC DEVICES:Single Event Effect in a Commercial MOSFET

With focus on semiconductor circuits equipping HEP or space instruments
Held at LAMFI-USP Lab. Using the Pelletron-Tandem

S.G. Alberton, V.A.P. Aguiar, N. Added, E.L.A. Macchione and N.H. Medina
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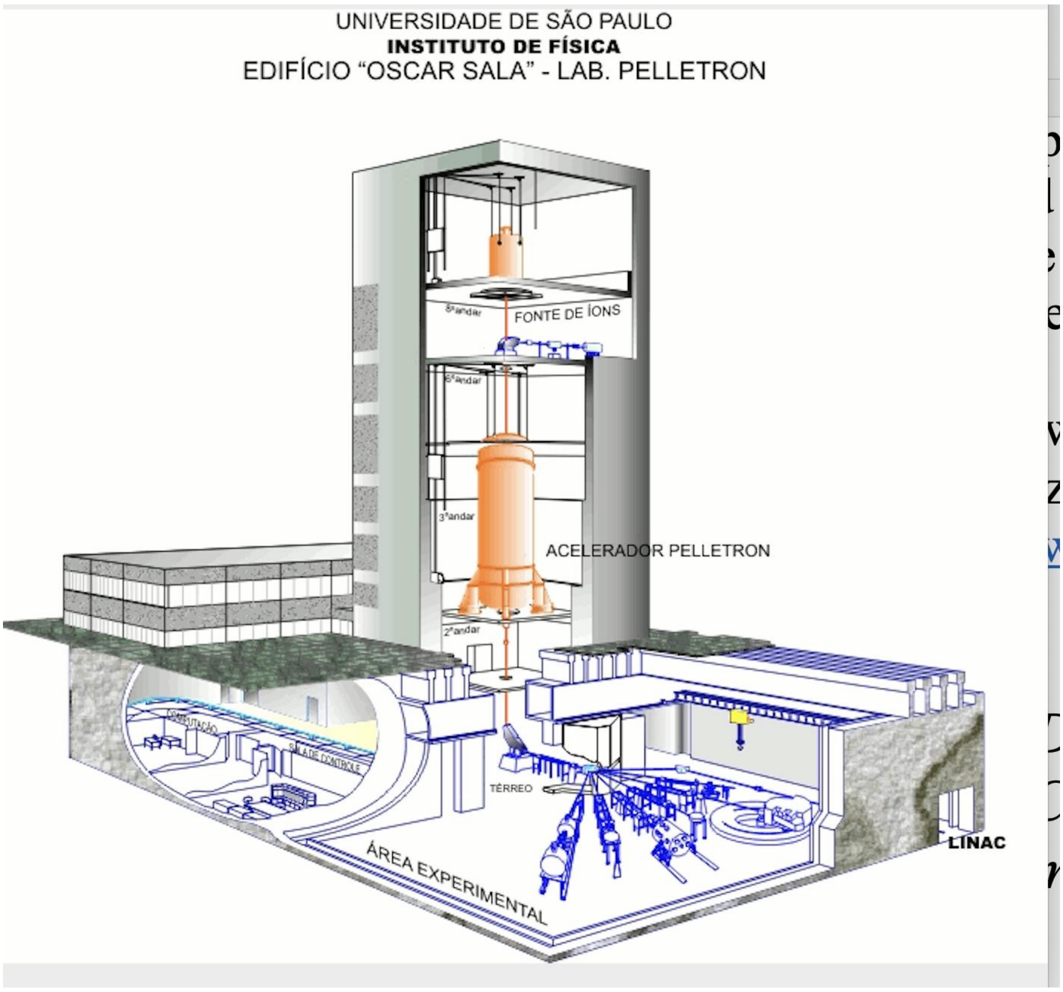
Electronic devices can experience operational malfunctions or physical harm when exposed to radiation environments [1]. The effects of radiation on electronic devices are categorized as Single-Event Effects (SEEs), wherein a single energetic particle strike leads to an observable change in the device's state.

Presently, ion-induced SEEs are recognized as the primary radiation effect in spacecraft electronics [2]. Power Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) are commonly utilized in electronic systems designed for space applications. However, when functioning in the outer space setting, these devices are vulnerable to destructive radiation effects, such as Single-Event Burnout or Single-Event Gate Rupture [3]. Physicists and engineers assess the risk of such failure modes in these devices by conducting tests in ground-level facilities [4]. Recently, new FET technologies have emerged, and there is a growing interest in employing commercial off-the-shelf (COTS) devices for applications that require a high level of reliability, including aerospace, avionics, and even certain ground-based applications like autonomous driving systems.

In this experimental activity, which will be conducted at the Instrumentation labs of the São Paulo Pelletron accelerator, the susceptibility of SEEs in a power MOSFET under alpha particle irradiation in vacuum will be assessed. The SEE failure cross sectionwill be measured by counting the radiation-induced errors with a NIM electronic system.

1] R. D. Schrimpf and D. M. Fleetwood, Radiation Effects and Soft Errors in Integrated Circuits and Electronic Devices (Selected Topics in Electronics and Systems), vol. 34. World Scientific, 2004.
[2] E. Petersen, Single Event Effects in Aerospace. John Wiley & Sons, 2011.
[3] F. W. Sexton, "Destructive single-event effects in semiconductor devices and ICs," IEEE Transactions on Nuclear Science, vol. 50, no. 3, pp. 603–621, 2003.
[4] V. Aguiar, N. H. Medina, N. Added, E. L. A. Macchione, S. Alberton, A. Leite, F. Aguirre, R. Ribas, C.Perego, L. Fagundes, et al., "SAFIIRA: A heavy-ion multi-purpose irradiation facility in Brazil," Review of Scientific Instruments, vol. 91, no. 5, p. 053301, 2020.



Pelletron Lab and Photo of the building

LiDAR based Lab

Lab 2.2: LiDAR: Light Detection And Ranging

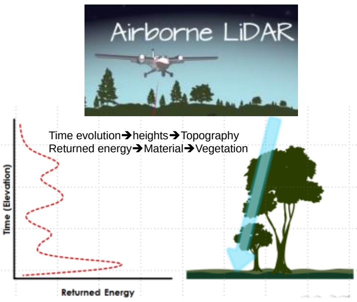
Prof. Yoshinobu Unno (KEK) with contribution of
Hamamatsu Photonics K.K.

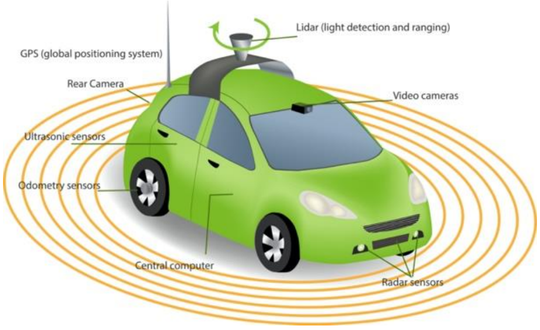
Held at the INOVA-USP Center for Innovation

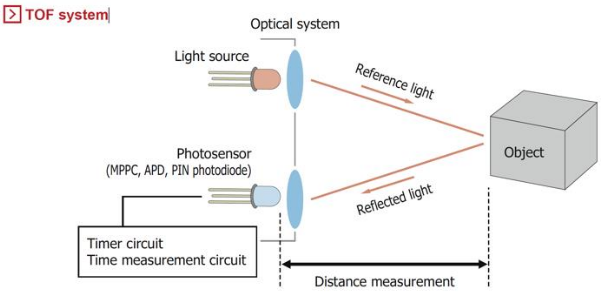
Introduction

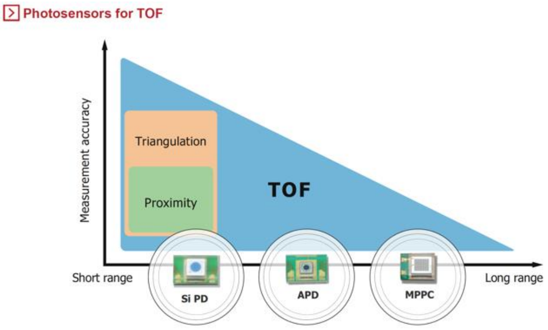
LiDAR (Light Detection and Ranging) is a technology to measure the distance to an object by using a laser light, and amount of reflection from the object. It is used widely for medium range ranging (m to km) such as air-borne remote sensing, 3D mapping, and even in a household appliance, a laser distance meter. The latest and rapidly developing is the application to automotive driving assistance system (ADAS).

The hands-on lab is made of two sections: (1) overviewing the technology, and (2) a laboratory where we operate a LiDAR setup. In the section (1), we learn the "basics" of the LiDAR, applications, and key devices, the "cutting-edge" solid-state laser diode and silicon photomultiplier. In the section (2), we learn "real stuff" by using a LiDAR setup, a simple desktop LiDAR setup developed by Hamamatsu photonics K.K. (HPK), adapted for the hands-on lab in collaboration with the author. The LiDAR setup is a direct time-of-flight LiDAR equipped with a 905 nm laser diode and a 16-ch MPPC photon counting image sensor.









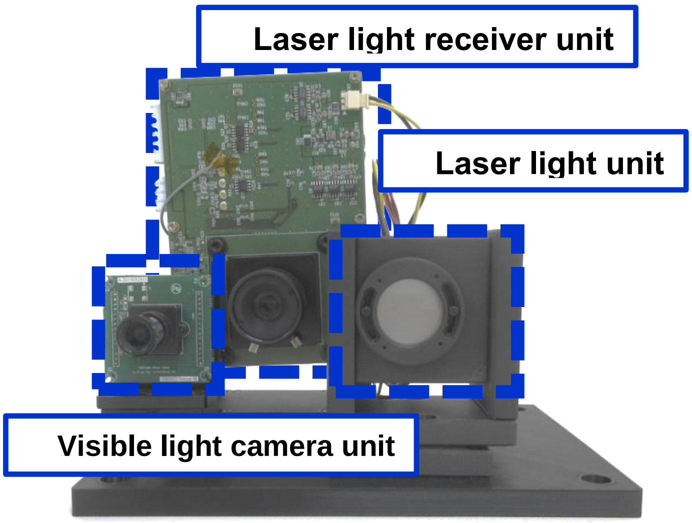
LiDAR setup

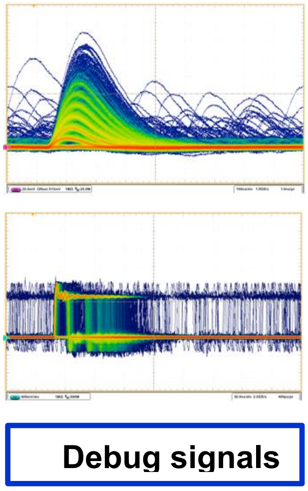
We use a simple desktop setup, prepared in collaboration with Hamamatsu Photonics (HPK). The device is to measure distance, in 16 channels in parallel, using Time-of-Flight (TOF) technique with a total viewing angle of 30 degrees. The setup is made of cutting-edge semiconductor / solid-state devices:

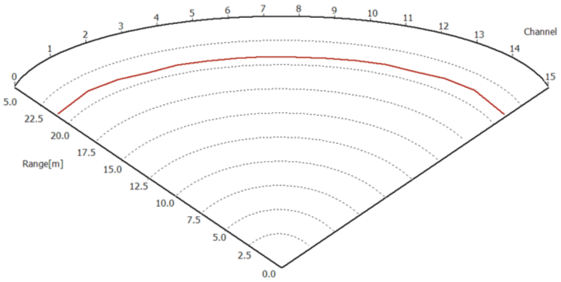
- Light emitter: Pulsed solid-state laser (infra-red light of 905 nm) and
- Light receiver: Linear-array (16 channel) MPPC (silicon photomultiplier (SiPM)), together with a general-purpose CMOS visible-light camera for viewing objects and, in dark, even the laser light. The camera is made of silicon imager which is less but still sensitive to the infra-red light.

The MPPC is wire-bonded to a 16-ch ASIC that does signal processing. The analog pulses are amplified, pulse-shaped, and transformed into logic pulses with comparators. The time difference between a trigger logic pulse to the laser diode and a logic pulse of the received signal is the TOF. Another chain of circuitry transforms the analog pulses into logic pulses of the width over threshold. The width is the measure of the strength of returned lights. The technique is called as "Time over Threshold (TOT)". Those TOF and TOT logic pulses are transformed into digital data and further processed digitally and transferred to a computer, controlled by a field-programmable-gate-array (FPGA) ASIC.

The hands-on lab is made of two sections: (1) lectures on the setup and the devices where we learn the basics of LiDAR, laser diode, and silicon photomultiplier, and (2) operation of the device where we learn how-to of verifying the image of laser light, cross-correlation of visual imaging and laser ranging (in general, called as "aiming"), visualizing the ranging (distance, cross-passing person, ...), and finally we look into the signal processing of TOF and TOT electrically with an oscilloscope, and try to optimize the signal-to-noise ratio, etc.







Range display

Visual image

References
[1] N. Statt, "LIDR is the Latest Game-Changing Advancement for Autonomous Vehicles", IEEE Innovation at work, 1 Oct 2018.
[2] HPK, "Photodetectors for LiDAR", Photodetector_lidar_kapd0005e.pdf, Oct. 2020

Lab 2.3 Hyperfine Interactions Laboratory

An Experiment Beyond Fine: Hyperfine Interactions in Material Research

Prof. Dr. Artur W. Carbonari, Dr. Anastasia Nikolaevna Burimova,
Dr. Frederico Genezini

Hyperfine Interaction Lab, Nuclear & Energy Research Institute - IPEN-CNEN

Held at the Hyperfine Interaction Lab at IPEN

The number of methods used to investigate the structure of materials is indeed huge. But what about the methods that can tackle materials at diverse conditions, like extreme temperatures, gaseous atmosphere, high pressures, magnetic fields or liquid environment? How many of them are non-destructive? Which of them require only a small amount of sample? Do those left provide any exclusive information? In our Lab you'll have the chance to get acquainted with a rare technique that satisfies all these criteria - the perturbed angular correlation spectroscopy or PAC.

PAC exploits the phenomenon of hyperfine interactions, interactions between electromagnetic moments of nuclei and their surroundings in a material. For an excited nucleus, these interactions may affect the probability distribution of the emission from it. Hence, recording and then "decoding" the emission pattern from such a nucleus should reveal the information about its local environment, like that on magnetic fields and charge distribution at the nuclear site. In the hyperfine environment of our labs, you will perform a time differential PAC experiment, including data collection and processing. You will learn about the methods of the active nuclei incorporation into the material prior to the experiment. We will provide you with tips on how to conclude on the symmetry of the environment of the nucleus by a glance at a PAC spectrum, as well as on how to distinguish between an electric and magnetic interaction. Beyond that, you’ll witness the evolution of data recording equipment in nuclear research, from exclusive antique modules to the newest digitizers!

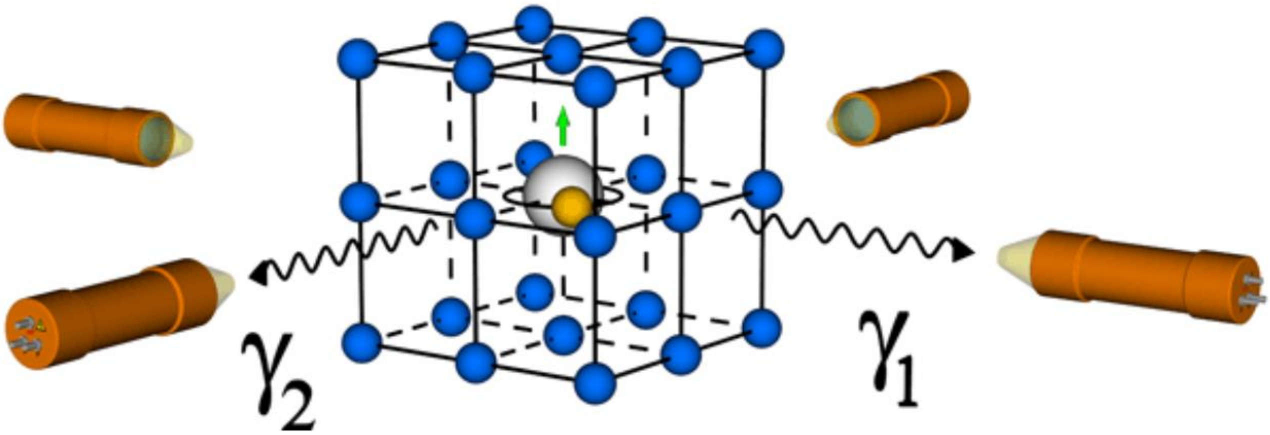


Fig. 1. Basic principles of PAC measurements: the nuclear spin of the probe nucleus embedded into the material is oriented by detecting the first gamma emission (g1) in the gamma cascade, whereas the detection of g2 in two different directions in the detector’s plane is affected by the hyperfine interactions on the nucleus. [https://tdpac.hiskp.uni-bonn.de/pac/]

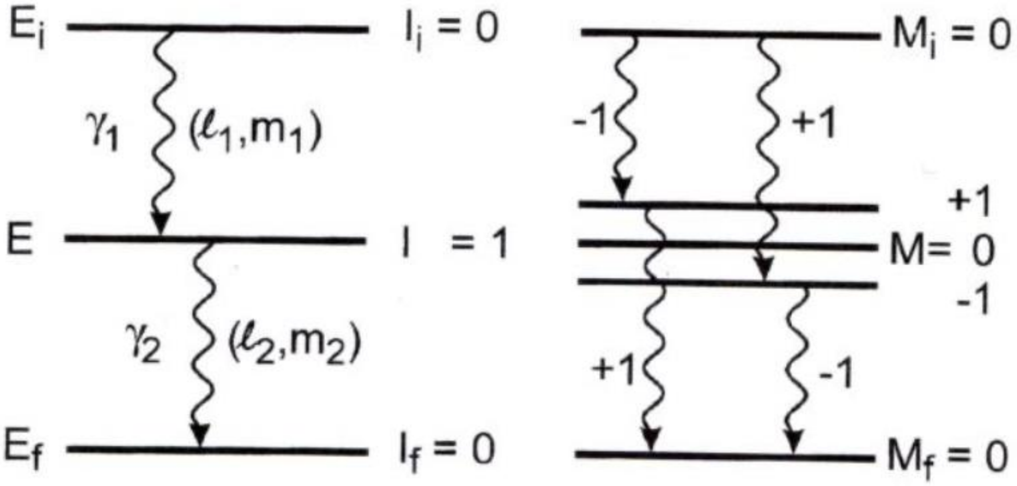


Fig. 2. (left) decay in cascade of a probe nucleus with intermediate spin I = 1.
(right) quantum effect of hyperfine interactions on the intermediate spin 1

III. PROTOTYPES FOR NEW INSTRUMENTS

Lab 3.1 Charged Particle Track Reconstructionin an FPGA

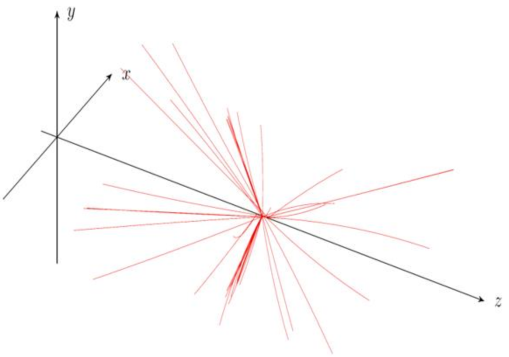
Ian R. Tomalin (Academic Senior Researcher from Rutherford-Appleton Laboratory, UK)
Carlos Ruben dell’Aquila (NCC-UNESP Universidade Estadual Paulista, Brazil)

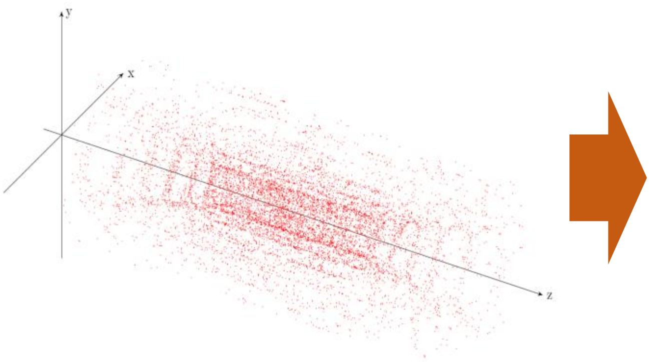
Held at the INOVA-USP Center for Innovation

Introduction

Reconstructing rapidly all charged particle trajectories produced by a particle physics experiment is challenging. However, it can greatly improve the ability of trigger systems to select interesting events.

At the High-Luminosity LHC, which starts in ~2029, the CMS experiment aims to reconstruct within 4μs the charged particles recorded in its tracker sub-detector, so that they can be used to by its trigger system to help identify the interesting events. The proton-proton bunches collisions occur every 25 ns, with each producing many particles, so this is immensely challenging, requiring the processing of 1 trillion data points per second. The algorithm must play a game of "join-the-dots", to interpret the "hits", which are produced as particles cross the layers of silicon inside the tracker, as track trajectories. CMS will run it on programmable FPGA chips. Similar techniques could be used in other future experiments.

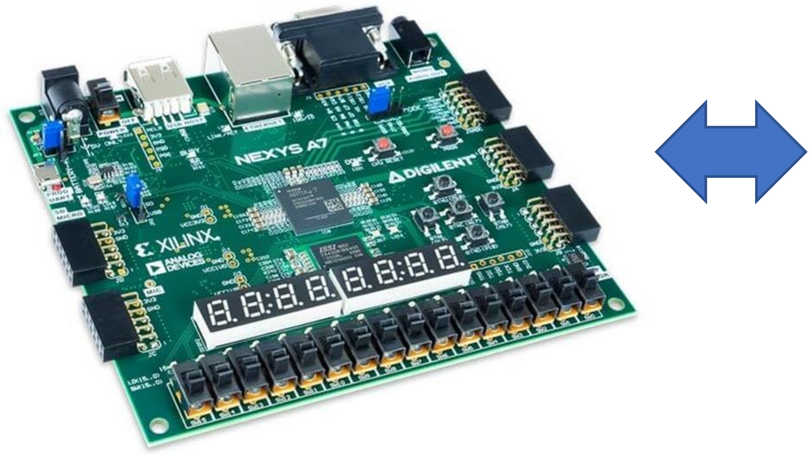




Goal of this Lab.

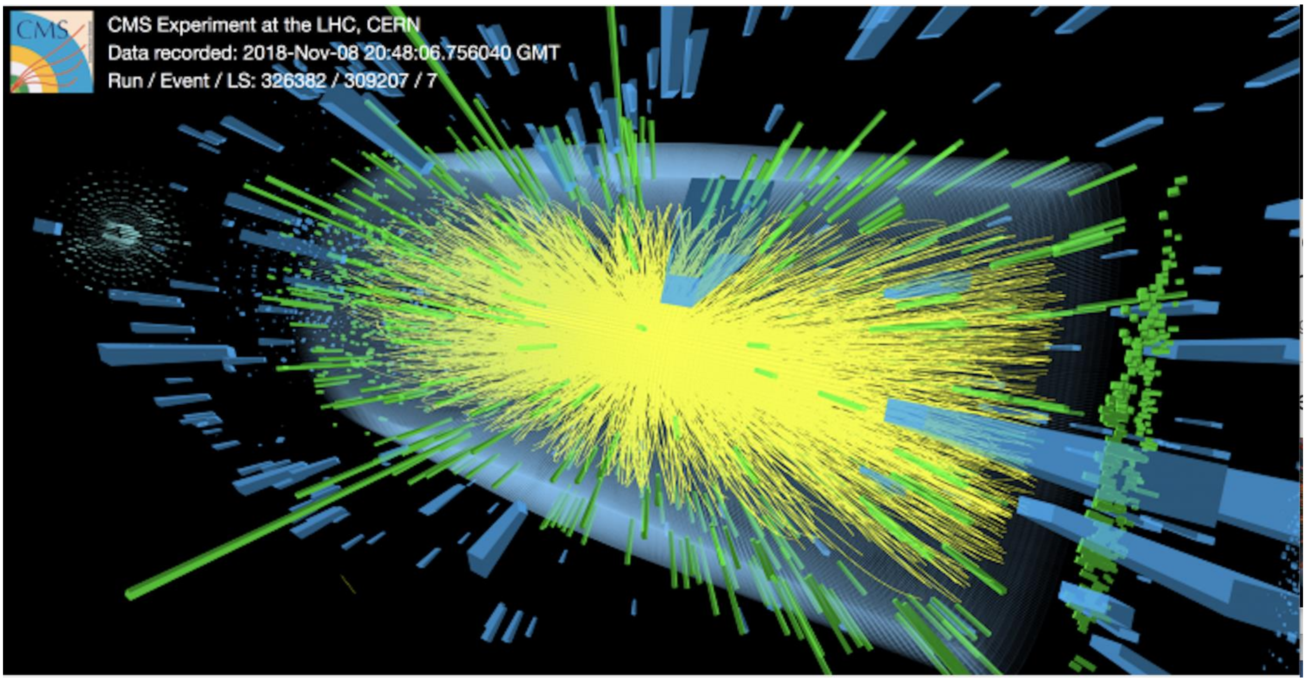
You will program an FPGA to reconstruct the tracks, using the HLS programming language, compiled with the computer program Vivado. HLS & Vivado are widely used in the world, both in industry and in research, to program FPGAs. No previous knowledge of these is required, though you should be familiar with either C or C++.
The algorithm used is a simplified version of one of those that the CMS experiment has proved viable for this task. This is indeed the result of an extensive R&D for running this tracking system under the harsh environmental conditions of the High Luminosity LHC.

You can optimise the algorithm design with Vivado simulation, striving to minimise your algorithm's latency, whilst maximising its data throughput, and maintaining good tracking performance. You can then run your code on a Xilinx Artix-7 FPGA mounted on a Nexys A7 evaluation board, (which is a commercial product of the company Xilinx), and transmit information about the tracks found to the LCD display on the board and/or to the Linux PC.

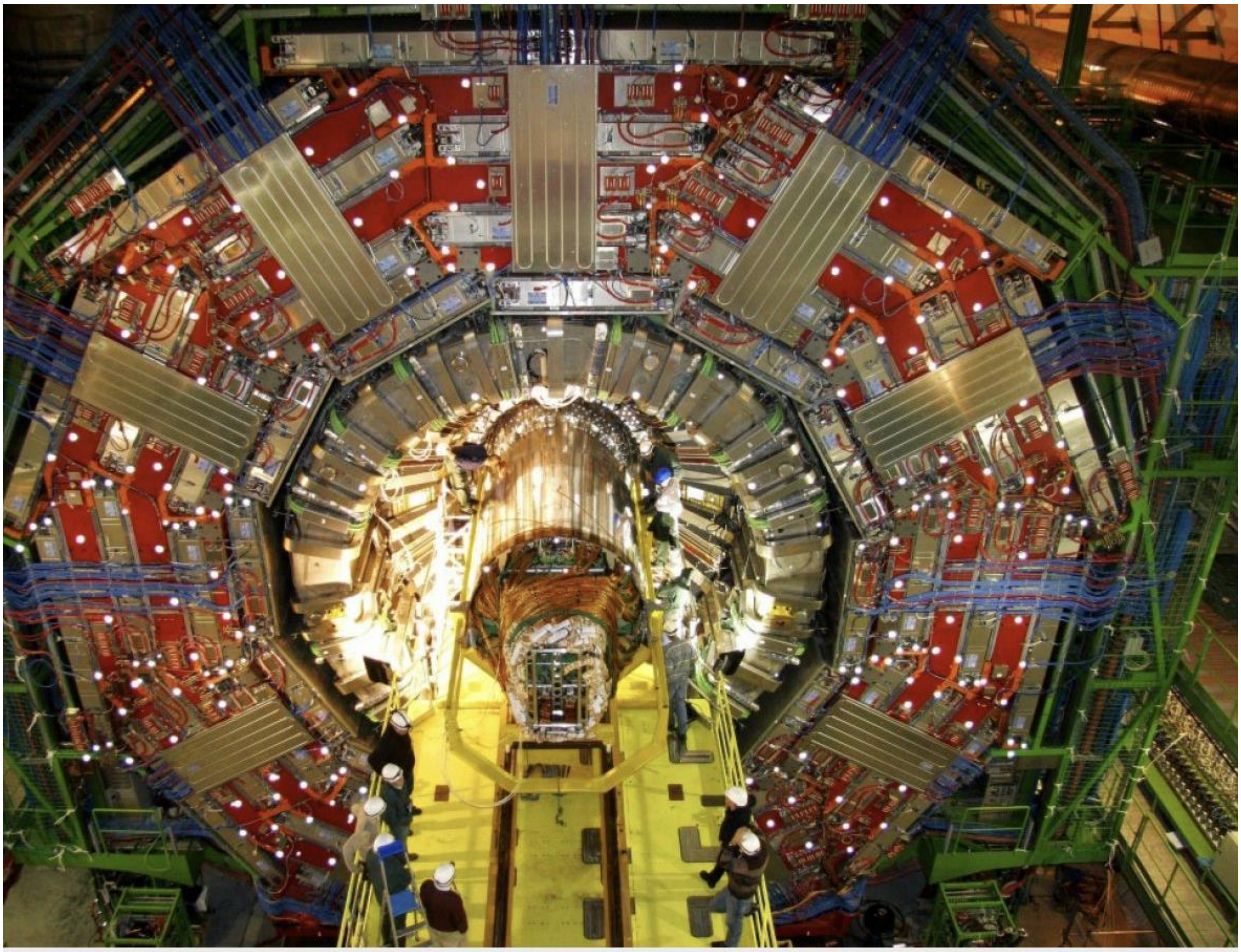


Optional background reading

1. Brief introduction to FPGAs **this_web_link**



The “typical event” produced at the collision of the two proton beams in CMS at LHC to be measured and reconstructed



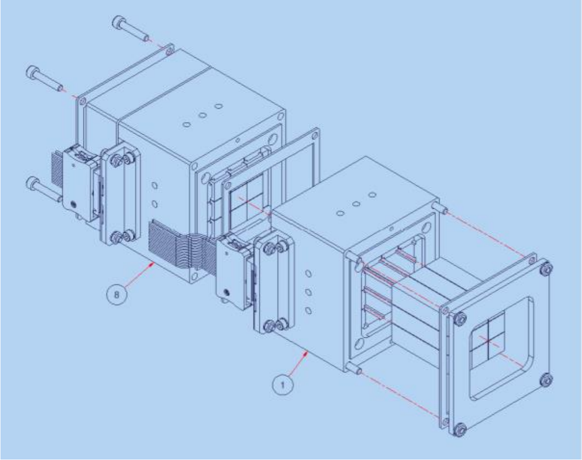
In the central part the tracking detector made of an enormous number of Silicon pixels in the central part near the beam pipe i.e. close to the collision point and at larger radius by very small Silicon microstrips. This is what is used in this hands-on Lab.

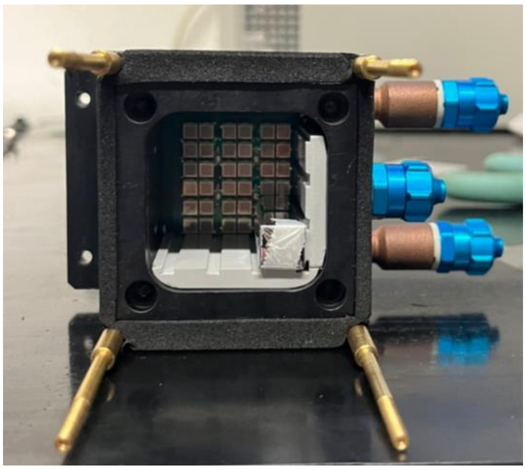
Lab 3.2 Characterization of innovative scintillating materials and data analysis introduction

Elisa Di Meco, Eleonora Diociaiuti, Ivano Sarra
Laboratori Nazionali di Frascati – INFN LNF

Held at the Pelletron Lab

Calorimeters, like other detectors, must face the increasing performance demands of the new energy frontier experiments. For example, at the future Muon Collider, the main challenge is given by the Beam Induced Background (BIB) which may pose limitations to the physics performance. However, it is possible to reduce the BIB impact by exploiting some of its characteristics by ensuring high granularity, excellent timing, longitudinal segmentation, and good energy resolution. The proposed design, the Crilin calorimeter is based on Lead Fluoride Crystals (PbF_2) with a surface-mount UV-extended Silicon Photomultipliers (SiPMs) readout with an optimized design for a future Muon Collider.





Crilin has a has a modular architecture made of stackable and interchangeable submodules allowing high response speed, good pileup capability, high light collection hence good energy resolution throughout the whole dynamic range,

resistance to radiation and fine granularity, also scalable with SiPMs pixel dimensions.
In July 2023 a test beam performed at the Beam Test Facility of the National Laboratory of Frascati with 450 MeV using two 3x3 crystal matrix with transverse and longitudinal dimensions of 0.7 R_M and 8.5 X_0 (~0.3 λ) respectively.

In the first part of this laboratory, the optical properties of two innovative scintillating materials GAGG and CRY18 will be evaluated; we will thus realize a complete readout chain, based on SiPMs, electronics, and these high Light Yield Crystals, showing the capability to detect low-energy X-rays.

In the second part of experience, the students will perform a simplified data analysis on the test beam data acquired in 2023. Goal is to evaluate the timing and energy performances of the CRILIN prototype, giving them a hint of the incredible possibilities that can be exploited for future experiments.

LAB 3.3 HYPERKAMIOKANDE NEUTRINO EXPERIMENT IN JAPAN:

Hands-on lab with photon counting by a photo-multiplier tube

Teppei Katori (King College of London, KCL, UK)

Hiroshi Nunokawa (PUC-Rio, RJ, BR), Alexander Quiroga (Federal University of Latin American Integration, PA, BR), Francesca di Lodovico (KCL, UK), Sara Bolognesi (CEA-IRFU, Paris Saclay University, FR)

Held at the INOVA-USP Center for Innovation

Hyper-Kamiokande experiment

The Hyper-Kamiokande detector will be constructed 600 m underground at the Kamioka Mine in Hida City, Gifu Prefecture, for the purpose of observing neutrinos, proton decay, and other physics.

It is based on a huge “water Cherenkov detector.” The experiment will be conducted in a huge cylindrical water tank, 68 meters in diameter and 71 meters deep, filled with extremely clear “ultrapure water.” It is the world’s largest underground water tank. The Hyper-Kamiokande detector is filled with 260,000 metric tons of ultrapure water. The detector fiducial volume of Hyper-K is 8.4 times larger than that of the present Super-Kamiokande experiment (picture, left). The ultrasensitive photo-sensors allow us to measure a very weak Cherenkov light, generated from nucleon-decays and neutrino interactions, precisely.

https://www-sk.icrr.u-tokyo.ac.jp/en/hk/about/detector/.

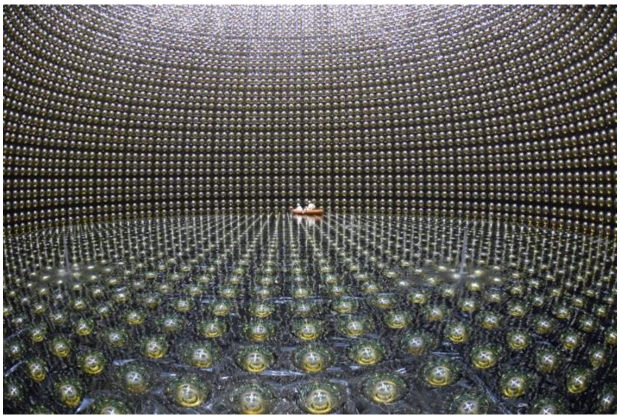
The Hands-on Lab will give the opportunity to the students to operate the candidate photo-sensor (picture, right), 3-inch photo-multiplier tube (PMT), that will be used for the Hyper-Kamiokande Outer Detector.

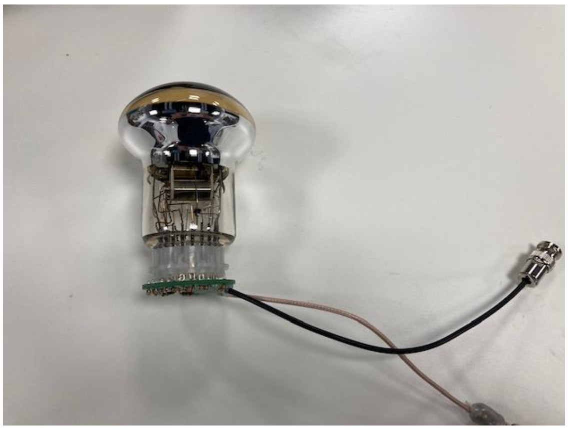
The Outer Detector (OD) consisting of PMTs mounted behind the Inner Detector PMTs and facing outwards to view the outer shell of the cylindrical tank, would provide topological information to identify interactions originating from particles outside the ID. The OD is an essential element of Hyper-K

Students will learn how weak light, as low as one photon, can be detected by a PMT and data are processed.

Expected number of photons from nucleon decays or neutrino interactions are very few and the data exhibit the randomness of nature which obeys the Poisson distribution.

Through this lab, students learn the way to extract information from data using underlying statistical distribution.



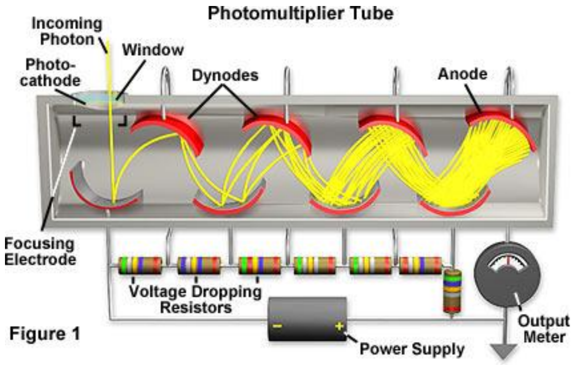


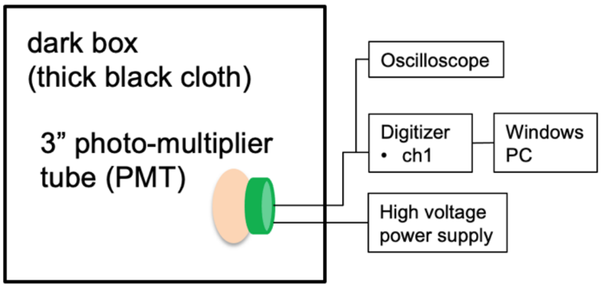
Set up

A PMT is a vacuum-sealed glass bulb (figure, left). The inside of the glass window is coated by photo-cathode material, and incident photons through this window will be converted to photo-electrons. Then the electric field focuses these photo-electrons on metallic plates called dynodes. The collision of photo-electrons with the first dynode produces more electrons, then they collide with the second dynode, and so on. After all collisions with all dynodes, 1 photo-electron is multiplied by 10^6 to 10^7.

The operation of a PMT requires the following setting (figure, right). First, a PMT must be operated in a dark environment to avoid too many photons. Second, the operation of a PMT requires a high-voltage (HV) power supply. A PMT has 2 outputs, for the signal and the HV power. This PMT requires roughly 900-1100 V, however, the required current is very small and it is a low-power safe device. An expected signal is a negative electric pulse. The first task is to observe this signal. We will estimate the number of photo-electrons in this data.

The second part will use a device called a digitizer to record data from many pulses. In this way, we can see the statistical ensemble of many photons. The detection process of photons obeys the Poisson distribution, and by assuming that, information can be extracted from the data. The distribution of the integrated pulses makes a Gaussian-like bell shape. By utilizing this is Poisson distribution, we will estimate both the number of photo-electrons and the gain of this PMT.





3.4 SKA – LOFAR EVENT RECOGNITION

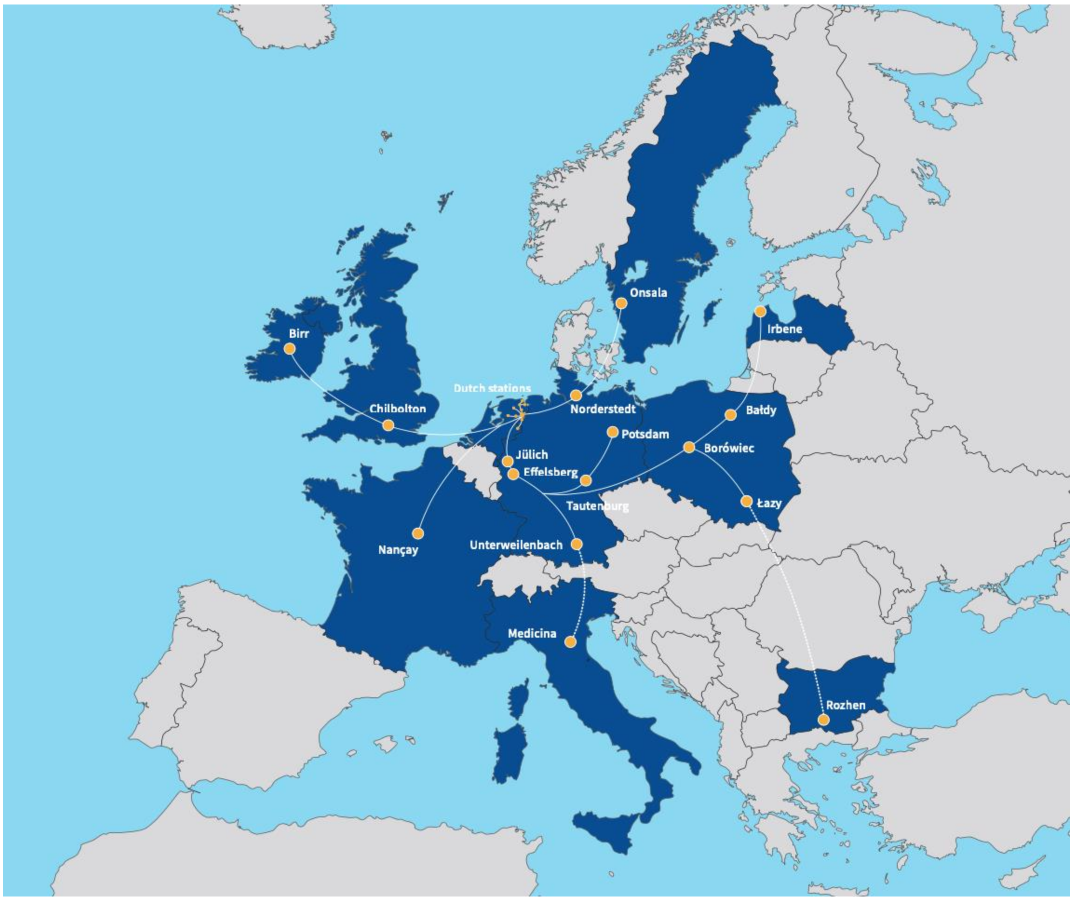
Dr. Wendy Williams (Research Scientist at the SKA Headquarters, Jodrell Bank, UK)

This Lab will use data recorded at the LOFAR (Low Frequency Array), currently the largest radio telescope operating at the lowest frequencies that can be observed from Earth. Unlike single-dish telescope, LOFAR is a multipurpose sensor network, with an innovative computer and network infrastructure that can handle extremely large data volumes.

LOFAR, designed and built by ASTRON in the Netherlands is a distributed research infrastructure enabling world-leading radio astronomical research. During a decade of continuous operation, it has grown to a pan-European scale, with a diverse and expanding set of partners (presently in nine countries).

https://www.astron.nl/telescopes/lofar/

This distributed research infrastructure prefigures (pathfinder) the SKAO case. This Lab will use the recorded LOFAR “real’’ data, to analyze them, extracting/recognizing the events of interest and reconstructing them.



IV.NEW ENERGIES LABS

Lab 4.1 Experimental evaluation of internal combustion engine efficiency comparing pure gasoline and bio-ethanol as fuels

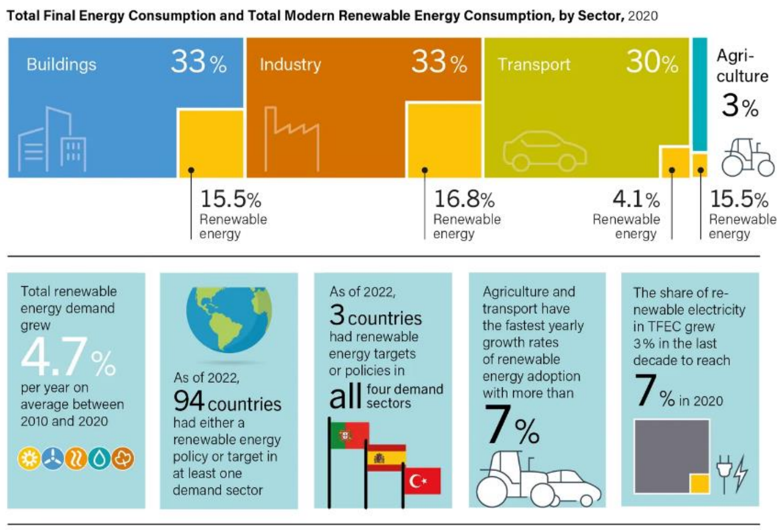
Held at the Institute Maua of Technology

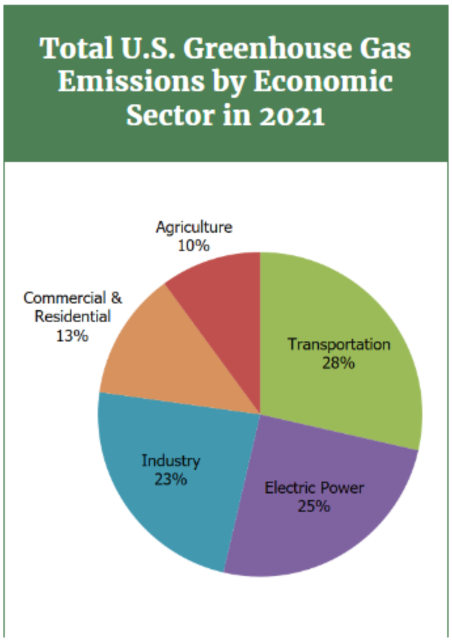
Clayton B. Zabeu, Renato Romio, Gustavo Cassares Pires, Jácson Antolini
Institute Maua of Technology (*https://maua.br/en*)

Decarbonization of Earth´s atmosphere requires that several areas of human activity reduce the net emission of greenhouse gases. Currently almost 25% of equivalent CO_2 emitted yearly to the atmosphere is produced by the transportation sector, which corresponds roughly to 30% of energy consumed in the world.

Figure 1.

Renewables in Energy Demand





Among the alternatives technically and economically available today to quicky reduce the net CO_2 footprint of the transportation sector, the usage of fuels derived from biomass is one of the most promising. Several countries have already adopted the addition of bio-ethanol and/or bio-diesel to fossil fuels as a way to gradually minimize the CO2 net emissions.

The objective of this laboratory activity is to allow scholars to perform experimental evaluation of a single-cylinder, spark-ignited, internal combustion engine running on pure gasoline and on bio-ethanol, comparing fuel consumption and overall energy conversion efficiencies. Pressures, temperatures, flows will be measured and recorded for subsequent calculation of overall engine efficiency for both fuels.

The Lab organizers will introduce the students to main internal combustion engine fundamentals and explain experimental setup, instruments and methodologies used in R&D labs and in the industry. Demonstration of efficiency limiters such as mixture detonation/knock and ways for its mitigation will be explored.

Students will then calculate net CO2 emissions and conversion efficiencies for both fuels.

Lab infrastructure and equipment:

- Test cell with a Honda single cylinder spark-ignition engine
- Engine dynamometer for brake torque and power measurement
- Gravimetric fuel consumption measurement
- In-cylinder pressure measurement with high-acquisition rate equipment
- Excel, Matlab or Octave for postprocessing

LOGISTICS:

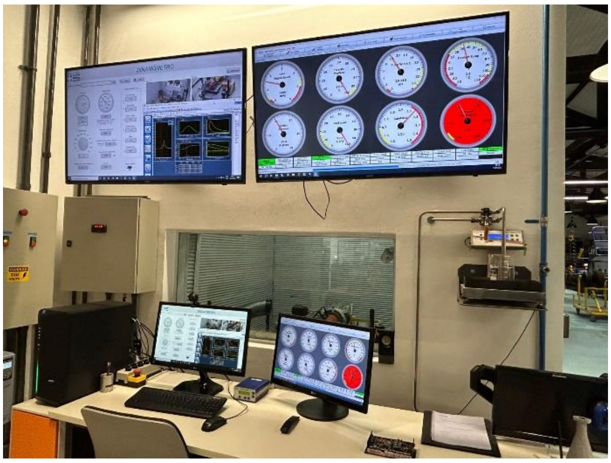
This Hands-on Lab will be organized each day apart the inaugural day where all the Labs are presented in the afternoon plenary session and the last school day (Posters presentation and mini-workshop on High Tech/Fundamental Research)

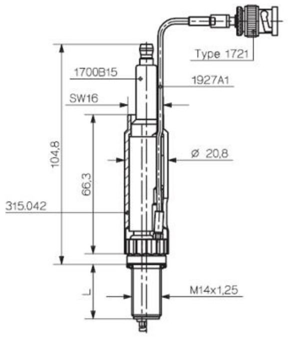
Mon Aug 28th	Tue Aug 29th	Wed Aug 30th	Thu Aug 31st	Fri Sep 1st	Sat Sep 2nd
☒	☑	☑	☑	☑	☑
Mon Sep 4th	Tue Sep 5th	Wed Sep 6th	Thu Sep 7th	Fri Sep 8th	Sat Sep 9th
☑	☑	☑	☑	☑	☒

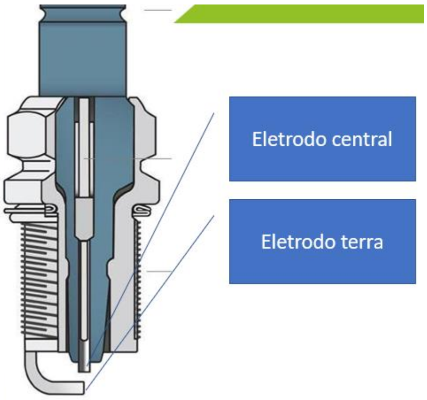
A detailed schedule is organized to allow student to perform in time the overall Lab session and to go back and forth: USP <-> IMT-Maua in Metropolitan Sao Paulo area. The transport will be held by taxi and taken in charge by IMT-Maua.

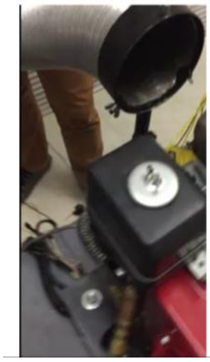
Time	Local	Activity
13h30 to 14h15(45 min)	USP to IMT	Transportation (IMT to provide a cab for up to 3 students)
14h15 to 14h55 (40min)	IMT room A4	Introductory presentation about the internal combustion engines and lab activities with explanation of expected deliverables
14h55 to 16h05 (70 min)	IMT lab B3	Experiments at engine test cell and data recording
16h05 to 16h15 (10 min)	IMT room A4	Wrap-up
16h15 to 17h15 (60 min)	IMT to USP	Transportation (IMT to provide a cab for up to 3 students)

Laboratory details:









References:

REN21. 2023. Renewables 2023 Global Status Report collection, Renewables in Energy Demand https://www.ren21.net/gsr-2023/modules/energy_demand

Environmental Protection Agency https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

IV.NEW ENERGIES LABS

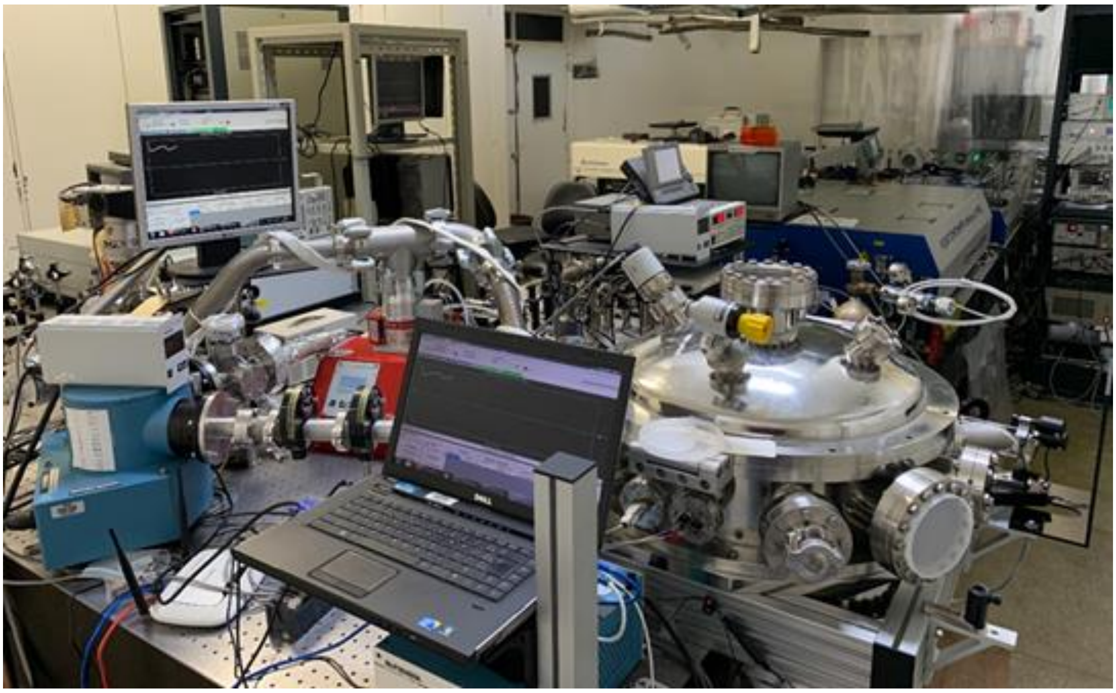
Dedicated Hands-on Lab on New Energies: Plasma Induced Laser
Held at Lasers and Applications Center at IPEN-CNEN

Lab 4.2: Measuring the temporal evolution of a plasma induced laser

Dr. Ricardo Elgul Samad and Dr. Jhonatha Ricardo dos Santos
Lasers and Applications Center at IPEN-CNEN

Particle accelerators are machines of great relevance for science and medicine, among other applications. They act in the frontier of knowledge and provide diagnostic and treatment for millions of patients annually. A drawback of these devices is their size, which can reach kilometers in length or circumference, and consequently, high complexity and costs. An alternative approach that has seen great advancement in recent years is the acceleration of particles by lasers. The peak power of lasers has been growing since its invention, and nowadays they can reach intensities of 1023 W/cm2. At relativistic intensities (>1018 W/cm2), lasers can create plasmas that sustain electric fields 3 orders of magnitude higher than in conventional accelerators, reducing the acceleration length by 1,000 times. Nowadays, electrons can be accelerated by lasers to energies of a few GeV in tens of centimeters, opening the field of particle physics to conventional laboratories, and benefitting and increasing the reach of nuclear medicine.

Laser particle accelerators are based on laser induced plasmas that have a periodic spatial charge distribution, which originate longitudinal electric fields that accelerate electrons forward. The Hands-on-Lab students will be presented to femtosecond lasers, and will use ultrashort pulses to create a plasma in air, and measure its density and temperature temporal evolution in a time interval ranging from <50 fs up to almost 1 ns, using interferometric techniques. The activity will include optimizing the plasma, operating an interferometer to get good quality fringes, and applying mathematical methods to obtain the plasma density and temperature from measured interferograms.



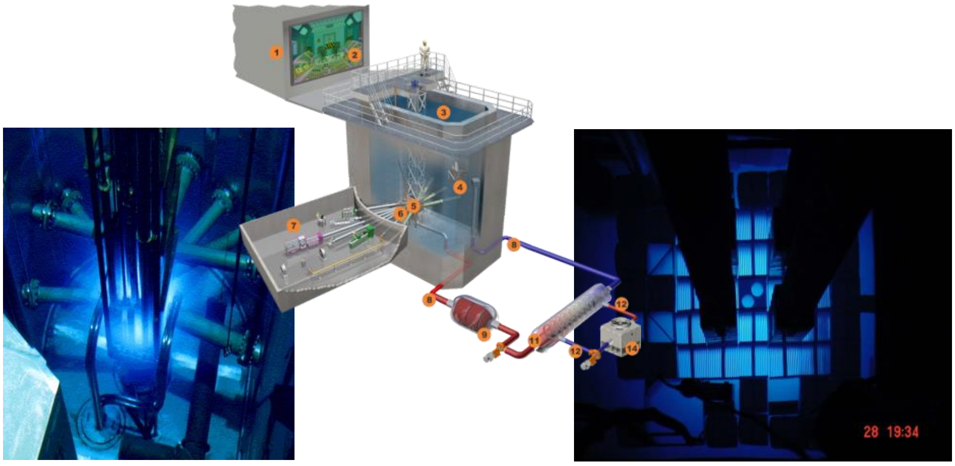
General view of the Plasma induced Laser Lab

Lab 4.3 Determination of U and Th using Neutron Activation Analysis

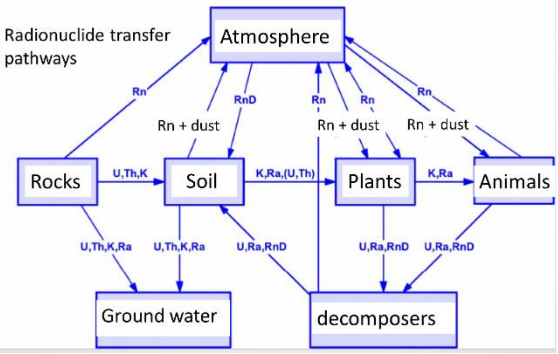
Drs. Guilherme S. Zahn, Paulo S. C. Silva, Edson G. Moreira,
Horacio M. S. M. D. Linhares, Frederico A. Genezini
Research Reactor Center – IPEN-CNEN/SP

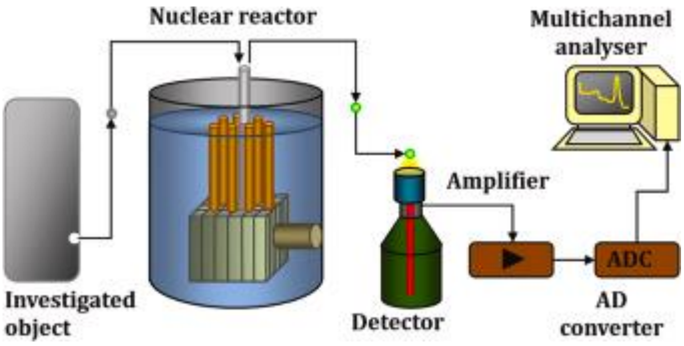
Held at the Research Reactor Center – IPEN-CNEN

With a maximum thermal neutron flux of 10^{14} $cm^{-2}.s^{-1}$ and a licensed operational power of up to 5 MW_{th}, IEA-R1 is the most powerful nuclear research reactor in Brazil. It is a pool-type research reactor with a conventional MTR core and fuel components based on 19.75%-enriched U_3Si_2 (Al). This reactor is employed in research and development, producing radioisotopes for use in industry and medicine, as well as for teaching and personnel training. Among several research groups using IEA-R1, the activation analysis laboratory is one of the most traditional, and their studies are among the best illustrations of research reactor applications.



Uranium and thorium are two key elements, both for their economic importance as possible fuel for nuclear plants [1] and for their relevance in the ambient dose to which all living beings are subjected throughout their lives [2]. At the same time, Brazil has vast reserves of both minerals [3], as well as urban areas with considerably high uranium and thorium concentration in soil [4]. Although there are several analytical techniques used to determine uranium and thorium, Neutron Activation Analysis (NAA) is very well-suited to this task, due both to its high sensitivity and to the fact that ^{238}U can be determined directly, without assuming equilibrium with its progeny [5].





In this lab students will perform a full hands-on analysis on both an unknown sample and a certified reference material (CRM), in order to understand the steps required and evaluate the sensitivity and reliability of the NAA technique. The samples, a CRM and a comparator, irradiated with neutrons in the IEA-R1, will inspect their gamma radioactivity to locate and quantify the gamma-ray emissions from radionuclides produced by neutron capture in ^{238}U and ^{232}Th. Then, using these experimental results, they will calculate the concentration of Th and U in both the sample and the CRM. After that they will learn how to use the CRM results to evaluate the reliability of the method, as well as how to determine the sensitivity of the method. The experimental activities will include the gamma analysis of the samples (to be performed in HPGe detectors) and the full calculation process, as well as a descriptive tour to the laboratories where the previous steps were performed – sample preparation, weighting, and irradiation.

REFERENCES

1. UNECE, Guidelines for Application of the United Nations Framework Classification for Resources (UNFC) to Uranium and Thorium Resources. United Nations, New York (2017).
2. United Nations Scientific Committee on the Effects of Atomic Radiation - UNSCEAR 2000 SOURCES AND EFFECTS OF IONIZING RADIATION. United Nations, New York (2000).
3. M. McNeil, Brazil's uranium/thorium deposits: geology reserves potential. United States: New York, 1979.
4. R. Veiga *et al*, Measurement of natural radioactivity in Brazilian beach sands. Radiation Measurements **41**, pp. 189-196 (2006).
5. R. B. Ticianelli *et al*, Determination Of Uranium And Thorium By Neutron Activation Analysis Applied To Fossil Samples Dating. In: International Nuclear Atlantic Conference - INAC2011, Belo Horizonte, 2011.

Lab 4.4 Measuring the electron distribution function in the edge of TCABR plasmas using Langmuir probes

Prof. Gustavo Paganini Canal
Institute of Physics of the University of São Paulo

Held at the Plasma Physics Lab at the Institute of Physics at USP

The role of the tokamak edge plasma in influencing the fusion energy gain in present tokamaks is now widely recognized. This is particularly reflected in the increasing efforts devoted to the experimental and theoretical study of the so-called scrape-off (SOL) layer physics. Of particular concern are aspects of the plasma-surface interaction leading to impurity production and the subsequent impurity transport and contamination of the core plasma. The distributions of the charge state and energy of the ion flux incident on limiter or divertor plate surfaces are the most important factors determining the magnitude of impurity release by physical sputtering. Chemical sputtering, however, is dependent on the constituent elements of the surface and of the impinging plasma, and the plate surface temperature. The impurity transport depends strongly on the background properties of the SOL plasma, such as temperatures, densities, transport coefficients and flow velocity.

Among the various diagnostics that can be used to investigate plasma properties, Langmuir probes are one of the oldest and simplest kind of electrostatic probe that can be used to determine the electron distribution function, and consequently the electron temperature and density, floating potential, and Mach number, in the edge of a tokamak plasma. Essentially, a Langmuir probe is a small electrode, usually a tungsten or platinum wire, that is inserted into the plasma and connected to a power supply capable of polarizing it with positive and negative voltages relative to the plasma. From the measurement of the current collected by the tip of the probe as a function of the applied potential, the so-called I-V characteristic, Figure 1, it is possible to obtain local information of the plasma parameters listed above.

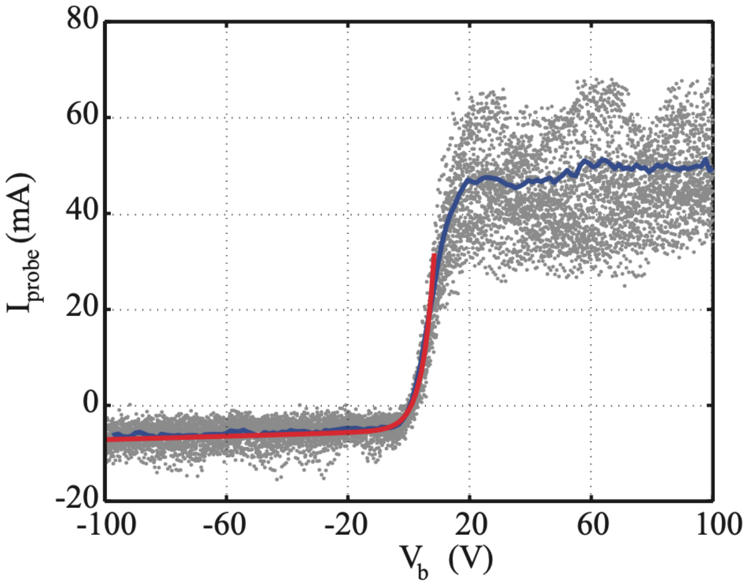


Figure 1: Typical I-V characteristic obtained from a Langmuir probe.

In this hands-on lab, the students will be able to measure the properties of the plasma edge in TCABR plasmas. The TCABR tokamak is a machine operated at the Institute of Physics of the University of São Paulo, Figure 2. This work includes manipulating a set of Langmuir probes, preprocessing and calibrating crude data to obtain a calibrated I-V characteristic, application of smoothing and fitting techniques to extract the plasma parameters of interest.

Figure 2: (a) The Plasma Physics Laboratory in which (b) the TCABR tokamak is operated.

V. HIGH PERFORMANCE COMPUTING LABS

Lab 5.1: GPU Programming with OpenMP

Hermes Senger (Federal University of São Carlos - UFSCar)
Roussian Gaioso (University of São Paulo)
and support by Alfredo Goldman (IME-USP) and Rogerio Iope (NCC-UNESP)

Held at the INSTITUTE OF MATHEMATICS and STATISTICS, IME-USP

1. Abstract

GPUs have emerged as essential hardware accelerator for many scientific and industrial energy efficiency. As of June 2023, seven out of the ten top clusters of the Top500 list [1] derive the lion's share of their compute power from GPUs. Currently, GPUs expedite computational workloads in cutting-edge scientific research in areas such as Physics, Chemistry, Bioinformatics, Climate Modeling, Machine Learning, and many others.

Although GPUs can exceed the performance of high-performance CPUs in tens to thousands of times, applications need to be properly designed or optimized to achieve good performance on GPUs. OpenMP provides an application programming interface that can be used in a Fortran, C or C++ application code to create a parallel program. Its main approach is to facilitate the implementation of new applications as well as the parallelization and optimization of legacy applications by introducing compiler directives. In C/C++, the directive is based on the **#pragma omp target** construct to offload code for GPUs.

In this hands-on lab, we will cover the introductory steps for exploiting the massive parallelism of GPUs and optimizing the data movement between the host and device, reaching more productive and advances optimization constructs for numerical applications.

2. Contents

- OpenMP overview
- Early steps with OpenMP
- The host/device model
- Moving data to/from the device
- Supporting massive parallelism
- Code optimization exercises

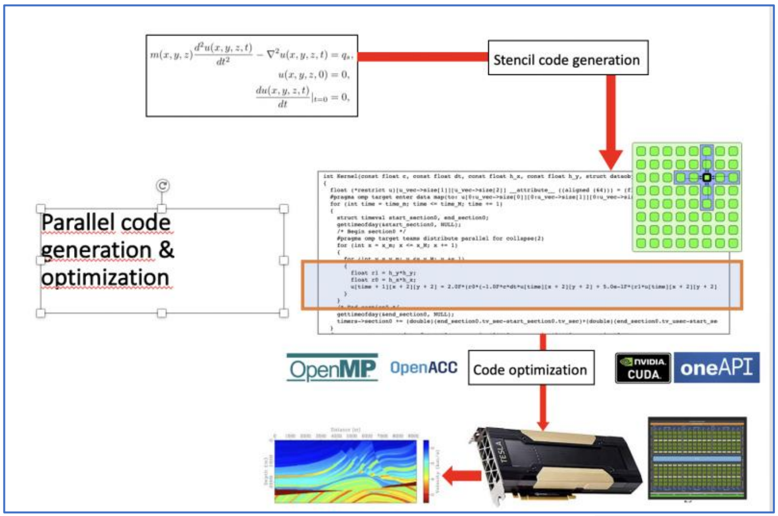
3. Hardware and software requirements

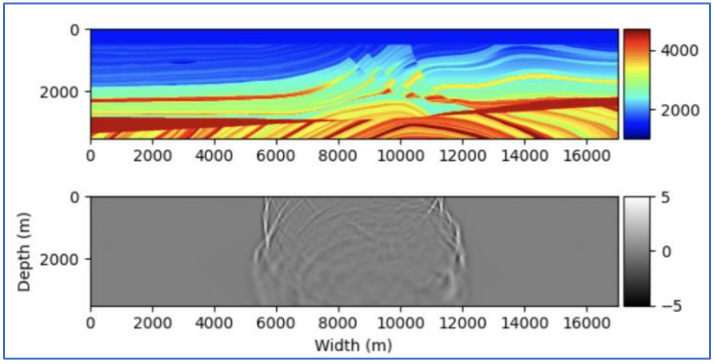
- A personal computer or laptop with a web browser and access to the internet
- A Google login will be necessary for students to access GPUs from the colab environment for the hands-on sessions.

4. References

[1] Author's github repository: https://github.com/HPCSys-Lab/Curso-OpenMP-GPU

[2] Using OpenMP—The Next Step Affinity, Accelerators, Tasking, and SIMD By Ruud van der Pas, Eric Stotzer and Christian Terboven, MIT Press, 2017.





Lab 5.2: FPGA-based acceleration of scientific applications using OpenMP cluster

Held at the INSTITUTE OF MATHEMATICS and STATISTICS, IME-USP, with the support of the FPGA Cluster at University of Campinas, UNICAMP

Sandro Rigo, Hervé Yviquel, Márcio Pereira (University of Campinas)

Cluster operation and support: Pedro Rosso (University of Campinas) *and support by Alfredo Goldman (IME-USP) and Rogerio Iope (NCC-UNESP)*

Parallel and distributed programming in clusters has been an intensely researched topic lately. Many domain-specific problems require many resources and computing performance, making developing solutions a very complex task, often requiring a combination of multiple tools, like programming models, languages, and specialized runtimes. As largely discussed in the literature, a key point for wider adoption of FPGA-based solutions is the introduction of tools to ease its programmability, especially by domain-specialized individuals without hardware programming expertise. The OpenMP Cluster program (OMPC) is a task-based framework created with that objective in mind. OMPC abstracts mostly the stack needed for developing these kinds of applications by hiding all the distributed computing under the OpenMP tasking model, which is the parallel programming model adopted. This way, the developers only need to use OpenMP standard annotations to program their solutions, avoiding most of the complex parts, especially when it comes to distributed computing. With OMPC, applications can be easily developed and distributed to many nodes in a cluster without effort. With the same code, users can run the solution in a single node or thousands of nodes on a cluster by changing how the application is launched. Recently, efforts have been made to enable heterogeneous computing in OMPC, which consists of using multiple architectures to accelerate an application. It is often achieved using GPUs, with another option being the acceleration through FPGAs. FPGAs gained space because of their programmability, enabling the development of specialized hardware according to the application. FPGAs are also known for their energetic efficiency, requiring less energetic power when compared, for example, to GPUs. Using OMPC, developers can effortlessly accelerate their applications with FPGAs by encapsulating the FPGA kernels into the OpenMP tasks. This simple step enables developers to plug ready-to-go FPGA kernels into their application easily just by changing how it is compiled.

In this hands-on lab, we will introduce the OpenMP task-based parallel programming model and show how OMPC builds upon this well-known standard to enable cluster execution of scientific applications. Then students will learn how to annotate their code to enable the execution in our A-Machine, an FPGA accelerated cluster.

2. Contents
- OpenMP overview
- OpenMP Cluster overview
- Introducing FPGA as accelerators
- Integrating FPGA in OpenMP Cluster code
- How to run your code in an FPGA accelerated cluster

3. Hardware and software requirements
- A personal computer (preferably Linux-based) or laptop with access to the internet and SSH for connection with the A-cluster

VI. PHOTONICS LABS

Lab 6.1 **Introductory Computer Lab to Photonic Integrated Circuits**

Wim BOGAERTS (wim.bogaerts@ugent.be)
Ghent University – IMEC, Department of Information Technology, Photonics Research Group

Held at the INOVA-USP Center for Innovation

Photonic Integrated Circuits

Photonic integrated circuits manipulate the flow of light on the surface of a chip. They have been in use, mostly for fiber-optic communication, since the late 1970s. But the technology developments of the past 2 decades have given birth to a large diversity of photonic chip platforms that are not just useful for topical transmitters and receivers, but also for different types of sensors. Materials used for photonic chips include, silicon ("silicon photonics'), III-V semiconductors, Silicon nitride, polymers, glasses and other dielectrics, or perovskites such a lithium niobate.

Like electronic circuits, photonic circuits are constructed from building blocks connected by signal lines. But in a photonic circuit the signals consist of propagating light waves, and the 'wires' are implemented as dielectric waveguides, where light is confined by a strong contrast in refractive index. These optical signals are modulated onto one or more high-frequency carrier waves (~200THz), so the signals are complex numbers, with a phase and amplitude. This large bandwidth means that optical waveguides can carry a lot of information, which is a key reason why optical communication is so widely used.

The functional building blocks in a photonic circuit are different from the transistor-based blocks in an electronic circuit. Typical photonic functions on a chip include light sources, signal modulation (where an electrical signal is imprinted on an optical carrier wave), splitting and distribution, wavelength filtering, and detection. By combining these functions into more complex circuits it is possible to build optical transmitters, receivers, spectrometers, interferometers, switches or even complex photonic circuits for computations.

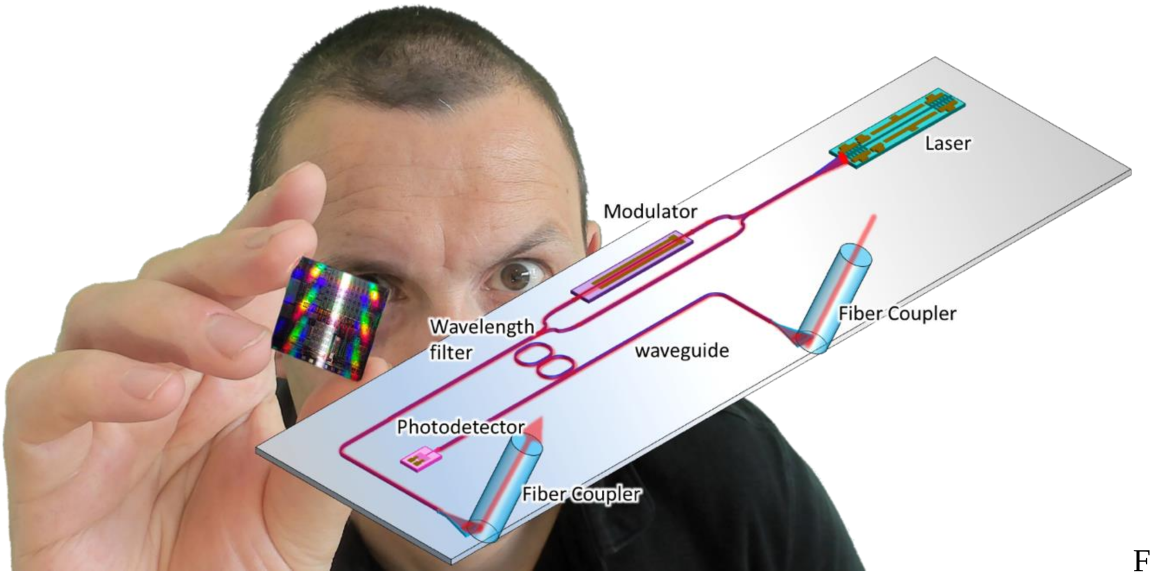


Figure 1: Photonic chips combine a lot of optical functionality onto the surface of a small chip.

Computer lab exploring photonic circuits

To get familiar with the concepts of photonic integrated circuits we will use a set of computer labs based on Jupyter Notebooks. The labs contain a full design suite that allows you to build a photonic circuit, simulate is, and even send it off for fabrication (although this last part will not be done as part of this course). In this computer lab, we will look at the basic functioning of the photonic waveguide, and then use these waveguides to construct simple circuits.

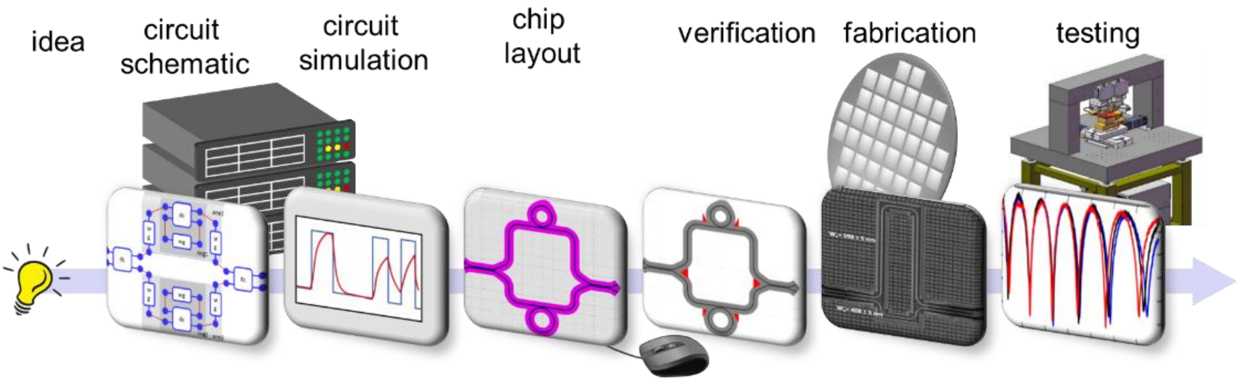
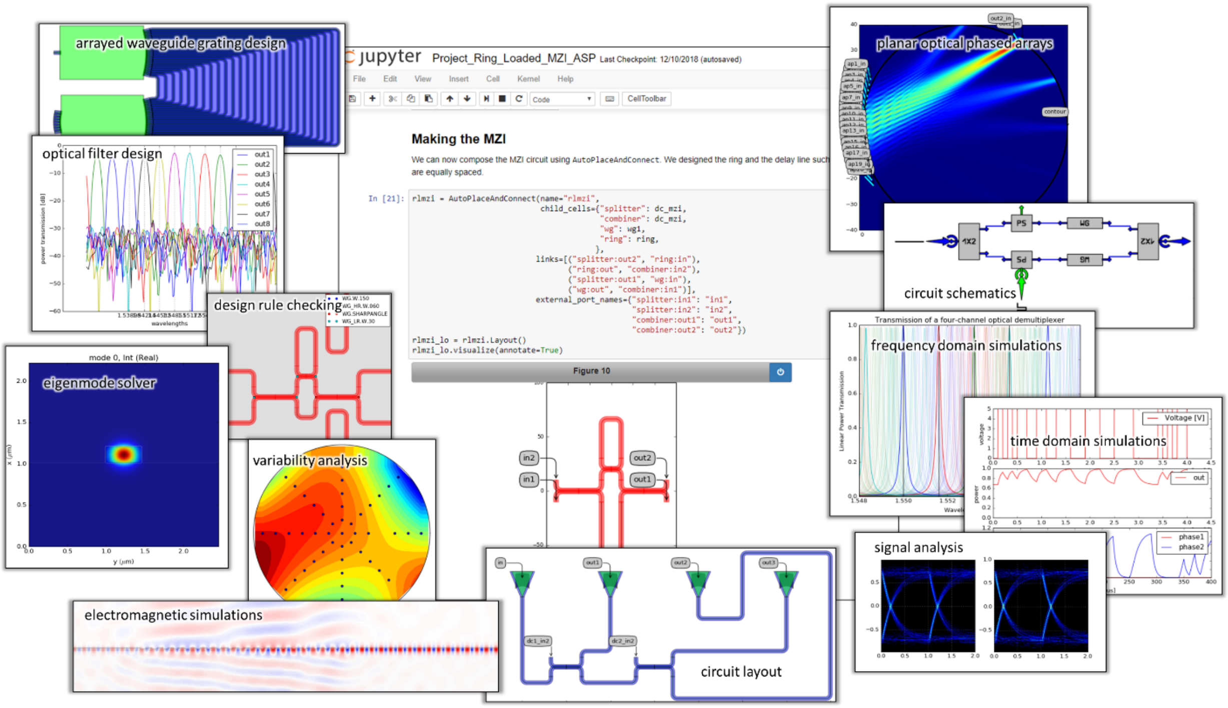


Figure 2: Building a new photonic chip goes through various stages of design and simulation.

The Jupyter notebooks use Python scripting as an interface language to interactively create photonic building blocks, control the simulation and visualize the results. The labs will be accessible through a web browser (no need to install software on your PC) and you will be able to continue experimenting on this platform in the weeks after the school.



Making the MZI

We can now compose the MZI circuit using `AutoPlaceAndConnect`. We designed the ring and the delay line such
are equally spaced.

```
In [21]: rlmzi = AutoPlaceAndConnect(name="rlmzi",
                                     child_cells={"splitter": dc_mzi,
                                                  "combiner": dc_mzi,
                                                  "wg": wg1,
                                                  "ring": ring,
                                                 },
                                    links=[("splitter:out2", "ring:in"),
                                           ("ring:out", "combiner:in2"),
                                           ("splitter:out1", "wg:in"),
                                           ("wg:out", "combiner:in1")],
                                    external_port_names={"splitter:in1": "in1",
                                                         "splitter:in2": "in2",
                                                         "combiner:out1": "out1",
                                                         "combiner:out2": "out2"})
         rlmzi_lo = rlmzi.Layout()
         rlmzi_lo.visualize(annotate=True)
```

Figure 3: Explore photonic circuits using Jupyter Notebooks

[1] W. Bogaerts, L. Chrostowski, Silicon Photonics Circuit Design: Methods, Tools and Challenges, Lasers & Photonics Reviews 12(4), p.1700237 (29 pages) doi:10.1002/lpor.201700237 (2018)
[2] W. Bogaerts, Teaching photonic integrated circuits with Jupyter notebooks: design, simulation, fabrication, Proc. SPIE: Fifteenth Conference on Education and Training in Optics and Photonics: ETOP 2019, 11143, Canada, p.111430D doi:10.1117/12.2518401 (2019)

VII. ARTIFICIAL INTELLIGENCE LABS

Lab 7.1 **Artificial Intelligence-on chip: Physics driven hardware co-design**

Held at the INOVA-USP Center for Innovation

Javier Campos (Fermi National Laboratory, FNAL, Batavia, Il, USA)
Nhan Tran (Fermi National Laboratory, FNAL, and Northwestern University, Illinois, USA)

This Lab will provide an opening to embedding Machine Learning tools within the design of microelectronics “intelligent” circuits. These circuits will process the information provided by sometimes very challenging devices, developed in fundamental sciences as well as in many applied fields. This will be introduced in the lecture by Dr. Nhan Tran. The summary of the Lab here below will be still updated before the start of the school.

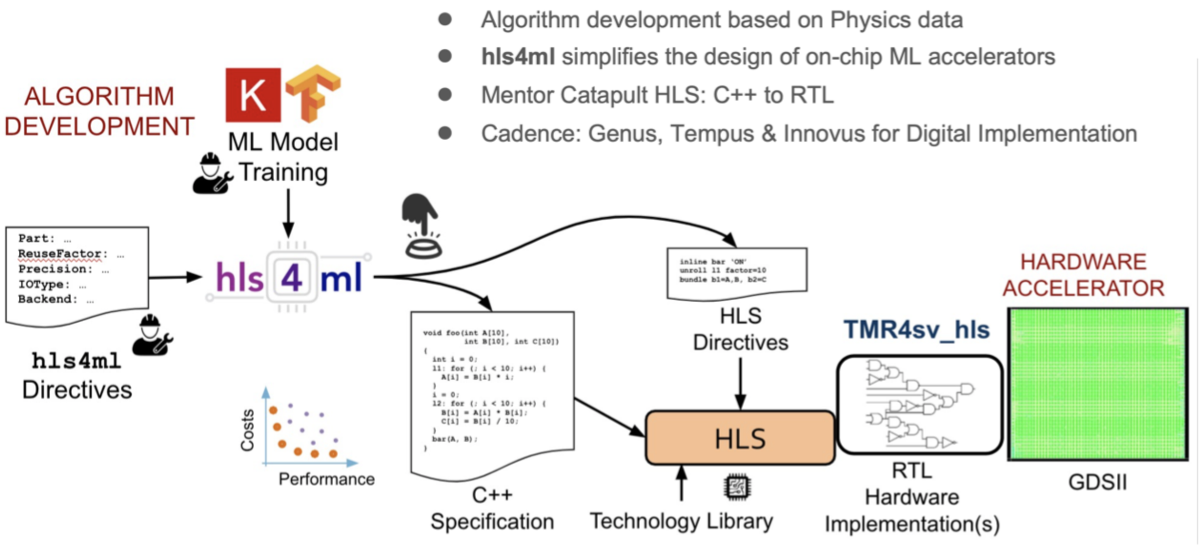
The Lab organizers will introduce the students to a new design methodology in Physics driven hardware co-design for ASICs (Application-Specific Integrated Circuits). The Lab organizers have created and entire tool flow to go from algorithm development to ASIC implementation: including the following steps that will be performed during this hands-on Lab session:

1. Machine Learning Physics algorithm developed on **Keras and Tensor flow (Python-software)** by model training and based on Physics data.
2. Which then feeds into **hls4ml** tool (An Open-Source Codesign Workflow to Empower Scientific Low-Power Machine Learning Devices), developed by FNAL and collaborators. It essentially provides a set of directives to simplify the design of on-chip accelerators.
3. This output feeds into a commercially available High-level synthesis tool such as **Catapult HLS** to generate, from C/C++functions, ***Register Transfer Level***, **RTL,** for digital implementation.
4. We can implement ***Triple Modular Redundancy***, **TMR, *(triple modular redundancy,*** *is a fault-tolerance form of N-modular reduncdancy, in which three systems perform a process and that result is processed by a majority-voting system to produce a single output. If any one of the three systems fails the other two systems can correct and mask the fault)* at this stage, along with adding other RTLs.
5. Finally leading to digital implementation and layout for manufacture using **CADENCE** Tools (**Genus synthesis** is a next-generation RTL synthesis tools with a number of key-features and benefits such as **Cadence Innovus** implementation system: timing and wirelength between the tools and **Cadence Tempus** Timing Signeoff solution)
6. Results will appear on **GDS II** (***Graphic Data System***), a Database file format and graphic representation of the circuit.

The design flow is schematized in the Figure here below

The Software environment provided for this Lab includes;

- Q-Keras
- Mentor Catapult HLS
- Cadence - Digital Implementation tools (Genus, Tempus, Innovus)



- Algorithm development based on Physics data
- **hls4ml** simplifies the design of on-chip ML accelerators
- Mentor Catapult HLS: C++ to RTL
- Cadence: Genus, Tempus & Innovus for Digital Implementation

```
Part: …
ReuseFactor: …
Precision: …
IOType: …
Backend: …
```

```
void foo(int A[10],
         int B[10], int C[10])
{
  int i = 0;
  l1: for (; i < 10; i++) {
    A[i] = B[i] * i;
  }
  i = 0;
  l2: for (; i < 10; i++) {
    B[i] = A[i] * B[i];
    C[i] = B[i] / 10;
  }
  bar(A, B);
}
```

```
inline bar 'ON'
unroll l1 factor=10
bundle b1=A,B, b2=C
```

VII.2 EXPERIENCING AI,
AT THE C4AI CENTER
FOR ARTIFICIAL INTELLIGENCE, AT THE INOVA-USP

Physics-Informed Neural Networks for the solution of Differential Equations

Fabio Gagliardi Cozman, Head of C4AI Center and Marlon Sproesser Mathias,
both Professors at the Polytechnic School USP

Held at the C4AI at the INOVA-USP Center

A Center for Artificial Intelligence in Brazil, C4AI, is located at the INOVA-USP Innovation Center. It includes several examples of research activities as described in https://c4ai.inova.usp.br/.

Hands on Lab abstract:

Physics-Informed Machine Learning (PIML) integrates the principles of physics with data-driven methodologies. Among the diverse facets of PIML, Physics-Informed Neural Networks (PINNs) can provide solutions for Partial Differential Equations (PDEs), found in various scientific and engineering domains, such as fluid mechanics, structural analysis, wave propagation, heat diffusion and so on. One feature of PINNs is their ability to either use governing equations alone or to incorporate previously known data, rendering them particularly valuable in scenarios with sparse data availability. In this course, participants will receive a concise overview of PIML strategies, followed by a hands-on implementation of a PINN using Python and PyTorch for a PDE of their choice, equipping them with the essential tools to tackle other PDEs.

Here below an image (Fig 1.) of some PDEs that the lecturer has solved using PINNs and that will be used as examples in the hands-on lab

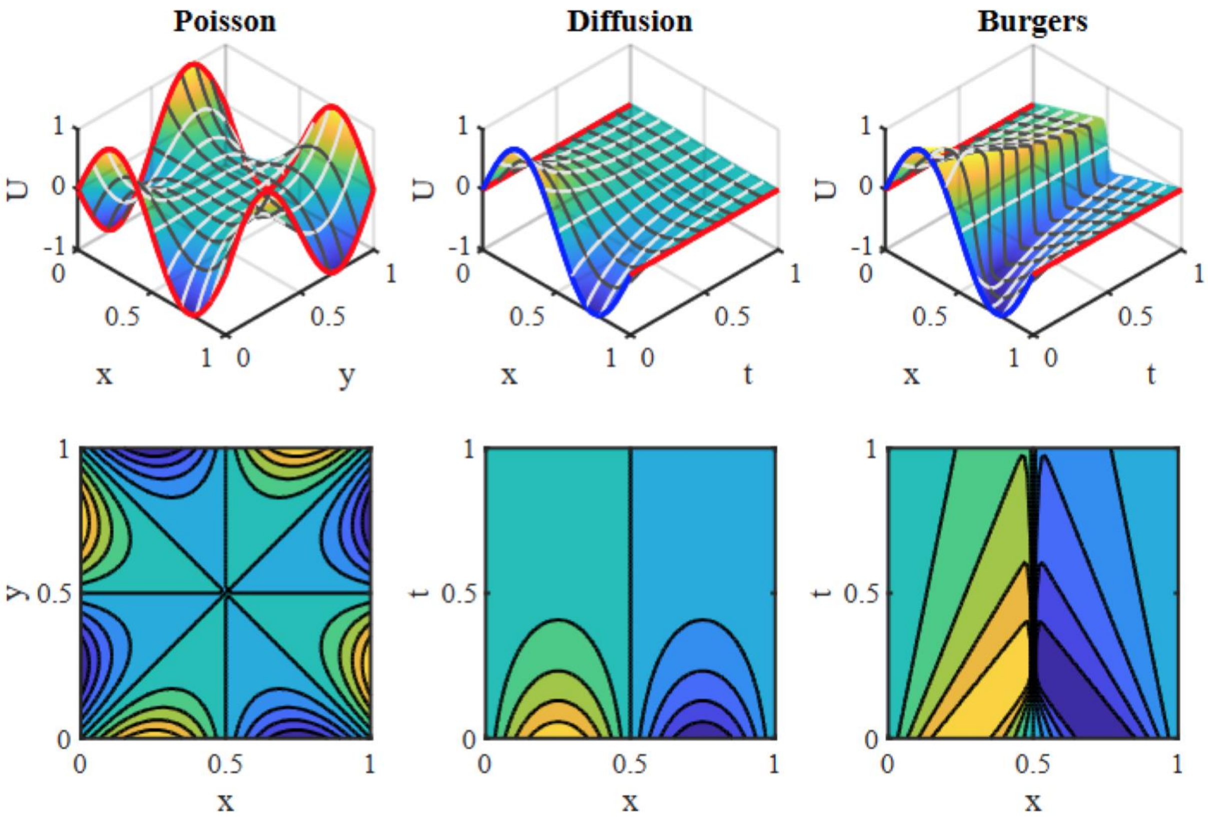


Fig 1: Image of some PDEs that the lecturer has solved using PINNs to be used as examples in the hands on Lab

VII.3 FUNDAMENTALS ON NEURAL NETWORKS

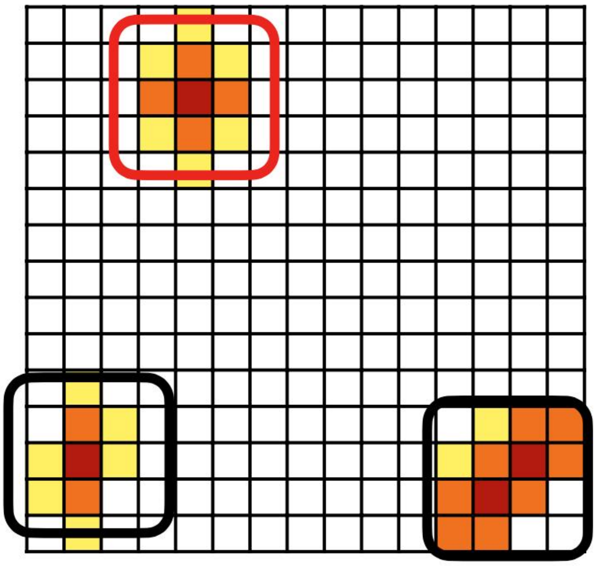
Dr. Ozgur Mehmet Sahin,

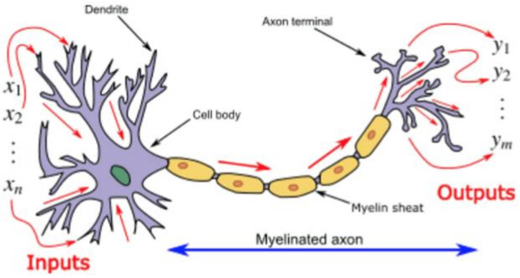
CEA-IRFU, University PARIS-SACLAY, FR

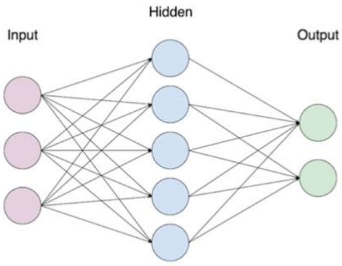
Held at the INOVA-USP Center for Innovation

Description:

This comprehensive tutorial is designed to introduce you to the core concepts and foundations of neural networks, the building blocks of today's AI and machine learning technologies. Whether you're a physics student delving into the BSM, an aspiring electronics engineer, or a computer science student eager to dive into machine learning, understanding neural networks is crucial.This tutorial aims to provide a solid foundation in neural networks to enable you to understand how they function and how they can be applied in various domains.







What You'll Learn:

Introduction to Neural Networks:

Learn what neural networks are, and why they are so essential in today's technological landscape.

Basic Architecture:

Discover the components that make up a neural network—nodes, layers, weights, and biases—and how they interact.

Activation Functions:

Understand the role of activation functions and explore commonly used types like Sigmoid, ReLU, and Tanh.

Loss Functions: Familiarize yourself with the concept of loss functions and why they are crucial for training neural networks.

Loss Minimization: Grasp the underlying math and algorithms that allow neural networks to 'learn' from data.

Training a Neural Network: Step-by-step guide on how to train a neural network with a hands-on example.

Optimize hyperparameters: A practical example illustrating how to fine-tune your model for optimal performance.

The tutorial is divided into two parts, spanning a total of three hours. In the first part, we will establish the framework and provide the necessary background information. In the second part, we will troubleshoot a malfunctioning neural network code and optimize it to achieve the best performance.

8.1 INTRODUCTION TO QUANTUM COMPUTING USING THE ATOS QLM (QUANTUM MACHINE SIMULATOR)

The Lab will be held at the INOVA-USP Center with support from EVIDEN/ATOS at SENAI-CIMATEC and EVIDEN South America

Gleydson de Fernandes de Jesus and Otto Menegasso Pires (SENAI-CIMATEC/LAQCC), Genaro Costa, Eviden/Atos R&D Labs at SENAI-CIMATEC, Adhvan Furtado, EVIDEN South America Sales Director.

Held at the INOVA-USP Center for Innovation

Quantum computing is considered one of the most promising possibilities for accelerating processing. If the algorithm fits the quantum computing model, it promises exponential speedup, both in processing and storage. Atos has developed a quantum computing simulator called QLM – Quantum Learning Machine. The idea of this simulator is to allow the simulation of quantum computing independently of its implementation.

The same quantum circuit may need different changes to run in real implementations, such as the IBM QX4 (superconducting qubits) or in the implementation of the AQTION project (trapped ions). With the promise of having quantum accelerators available in 3 to 5 years, we need to understand which algorithms can benefit from this technology, as well as the effects of noise on these devices.

In this hands-on lab we will present a basic introduction of the concepts of quantum computing using the QLM. We will start from the programming model used in quantum computing, including the basic gates and their mathematical representations, as well as examples of implementations of end-to-end quantum circuits, using both myQLM and QLM as tools.