

6TH EDITION OF THE
INFIERI SCHOOL
AT UAM, MADRID:

THE LAB SESSIONS



<p>FEE-oriented Labs</p> <p><i>Local: Prof. Jose Luis Pau (UAM)</i></p> <p><i>From Abroad Dr. A. Savoy-Navarro (IRFU-CEA, Paris Saclay/CNRS, FR)</i></p>	<p>1 RD53 Pixel Front-End Characterization by Profs. V. Re and L. Gaioni (Bergamo U. & INFN, IT) at UAM</p> <p>2 FD-SOI Pixel Detector by Prof Y. Unno, KEK, JP and Dr.K. Androsov, EPFL & ETH Zurich, CH, at UAM</p> <p>3 Thin Moderate Gain Ultrafast Timing detectors by Drs N. Moffat and G. Pellegrini, IMB-CNM, CSIC and Prof. S. Grinstein and Dr. P. Fernandez-Martinez IFAE-UAB, SP, at UAM</p> <p>4 Introductory Computer Lab to Silicon Photonics Integrated Circuits by Prof. W. Bogaerts (Ghent University & IMEC, BE) at UAM</p> <p>5 Artificial Intelligence-on Chip Physics Driven Hardware Co-design by Drs F. Fahim and N. Tran (FNAL, USA), G. Di Guglielmo (Columbia, N.Y. USA), M. Valentin, R. Shi, Prof. S. Ogrenci Memik (Northwestern U, Chicago, USA) at UAM</p>
<p>Data Transmission</p> <p><i>Local: Jose del Peso (UAM)</i></p>	<p>1 Quantum Communication Lab by Prof. V. Martin, Drs. J.P. Brito Mendez, L. Ortiz (UPM), at UAM</p> <p>2 Fast clock transmission systems for HL-LHC by Dr. O. Sahin, (IRFU-CEA, U. Paris Saclay, FR) at UAM Physics Dept</p> <p>3 Light Detection & Ranging (LiDAR) by Prof. Y. Unno (KEK, JP) & HPK support at UAM Physics Dept</p> <p>4 Getting started with μcontrollers by Dr. L. Calligaris (UNESP, BR) at UAM Physics Dept</p>
<p>Test Bench-Marking Platforms</p> <p>1- Particle Physics</p> <p><i>From Abroad: Dr. Carlos Lacasta (IFIC, U. Valencia)</i></p>	<p>1 EASy-Silicon Strip Sensor Testbench, by Drs. C. Garcia and C. Lacasta (IFIC, U. Valencia) at UAM</p> <p>2 Charged Particle Track Reconstruction in an FPGA by Drs. I. Tomalin (RAL, UK) & G. Fedi (Imperial College, UK) at UAM</p> <p>3 Allen: A high level trigger on GPUs for LHCb: Dr. D. Martinez Santos, U. Santiago de Compostela, Prof. X. Vilasis Cardona (Llull U. Barcelona) at UAM</p> <p>4 AI tools and the real-time HEP Trigger, by Drs. S. Jindariani, B. Hawks, J. Mitrevski, J. Ngadiuba (FNAL, USA)</p>

<p>2- Astrophysics/Cosmo</p> <p><i>Local: Dr. Santiago Avila Perez (IFT-UAM)</i></p> <p><i>From Abroad: Dr. Jean Gabriel Cuby (CNRS/INSU, FR)</i></p>	<p>at UAM</p> <p>5 High Granularity Calorimeter Signal Processing, with M.L. based Reconstruction in the CMS HGCAL by Drs. A. Zabi & Shamik Ghosh (LLR, Ecole Polytechnique, FR) at UAM Physics Dept</p> <hr/> <p>1 Dark Energy Spectroscopic Instrument (DESI): Quasar Identification, by Dr. I.Perez-Rafols, LPNHE, CNRS/IN2P3, Paris, FR. at UAM</p> <p>2 Characterization of a CCD (Charge-Coupled Device) Camera, by Drs J-G. Cuby and A. Le Van Suu, Aix-Marseille U. & CNRS/INSU, FR at UAM</p> <p>3 Remote Astronomical observations with a 50 cm Telescope at Observatoire de Haute Provence (IRiS), After Lab hours (night) by Drs. J-G. Cuby and A. Le Van Suu, Aix-Marseille U. & CNRS/INSU, FR at UAM Observatory</p>
<p>Medical Labs</p> <p><i>Local: Prof. Jose del Peso (UAM)</i></p> <p><i>From Abroad: Prof. Nicola d'Ascenzo (HUST, CN & NEUROMED, IT)</i></p>	<p>1 Clinical Positron Emission Tomography/Magnetic Resonance Imaging: Acquisition and Quantification, by Profs N.Malpica & A. Torrado Carvajal at URJC & HM Hospital</p> <p>2 In Silico Study of Deep Brain Simulation (DBS), by Dr. D. Ortega, Ponce, at IMDEA (UAM Campus)</p> <p>3 Irradiation of a Biomaterial using a Proton Beam and characterization of the damage produced for proton-therapy pre-clinical studies, by Dr. M. Crespillo, Profs. M.D. Ynsa & M. Manso (UAM) and Drs. G. Garcia and S. Vinals (CMAM), at CMAM at UAM</p> <p>4 Digital Positron Emission Tomography, by Prof. N. D'Ascenzo (HUST, CN) at UAM</p> <p>5 Electronics for Portable Reflectance Pulse Oximetry and Electrocardiography systems by Profs. J.L. Pau, A. Redondo and B.J. Garcia (UAM) at UAM</p>
<p>Accelerators-Technology</p> <p><i>Local: Dr. Concepcion</i></p>	<p>1 Designing a Superconducting Magnet, by Drs. L. Garcia-Tabares and C. Oliver (CIEMAT) at CIEMAT</p> <p>2 Applied Superconductivity by Drs. L. Tabares Garcia and</p>

<p>Oliver (CIEMAT)</p> <p><i>From Abroad: Dr. Pierre Vadrine (IRFU-CEA/DACM, Paris Saclay, FR)</i></p>	<p>C. Oliver (CIEMAT) at CIEMAT</p> <p>3 Beam Dynamics for CMAM Accelerator by Drs. G. García (CMAM), A. Arteché, L. Nevay, W. Shields (Royal London Univ.), C. Oliver (CIEMAT), at CMAM at UAM</p>
<p>Theory Masterclass</p> <p><i>Dr. Alberto Casas (IFT-UAM/CSIC)</i></p>	<p>1 Can We Feel The Dark Matter? by Dr. D. Cerdeno (UAM) at IFT-UAM</p> <p>2 Higgs Physics in the Standard Model and beyond by Dr. S. Heinemeyer (IFT, UAM-CSIC) at IFT-UAM</p>
<p>Computational Labs:</p> <p><i>Local: Prof. Gonzalo Martinez (Politechnic School, UAM)</i></p> <p><i>From Abroad: Dr. Rogerio Iope (UNESP Sao Paulo, BR)</i></p>	<p>1 Massive Parallel Computing: Fundamentals of parallel programming using INTEL Architecture and Software tools, by Dr. R. Iope (UNESP, BR) & (INTEL, USA) at UAM Politechnic School</p> <p>2 Quantum Computing Lab: Enjoying the IBM Quantum Experience by Prof. G. Sierra and Dr. E. Lopez Manzanares (IFT, CSIC-UAM) at IFT-UAM</p> <p><i>Machine Learning and Deep Learning is introduced through different applications (see other sections here above)</i></p>

The list of Lab organizers (some, in blue letters, are also Lecturers)

- *Konstantin Androsov*, EPFL & ETH-Zurich, CH.
- *Alberto Arteché*, Royal University London, UK.
- *Santiago Avila* Institute of Theoretical Physics, IFT, at UAM-CSIC, SP
- *Juan Pedro Brito Mendez*, Research Group on Quantum Information and Computing, Universidad Politecnica de Madrid, UPM, Madrid, SP
- *Alberto Casas*, Institute of Theoretical Physics, IFT, UAM-CSIC. Madrid, SP.
- *David Cerdeño*, Department of Theoretical Physics, Faculty of Sciences, UAM. Madrid, SP.
- *Miguel Crespillo*, Center for Microanalysis of Materials (CMAM), UAM, Madrid, SP.
- *Jean-Gabriel Cuby*, Astrophysics Laboratory of Marseille (LAM), Centre National de la Recherche (CNRS), Institute of Sciences of the Universe (INSU), FR.
- *Nicola d'Ascenzo*, Life Sciences Dept, Huazhong U. of Science and Technology (HUST), Wuhan (CN) and NEUROMED, IT.
- *Jose del Peso*, UAM Faculty of Sciences, Madrid, SP.
- *Giuseppe di Guglielmo*, Columbia University, New York, USA.
- *Farah Fahim*, Fermi Quantum Institute, Fermi National Laboratory (FNAL), USA.
- *Giacomo Fedi*, Imperial College, London (UK).
- *Pablo Fernandez-Martinez*, Institute for High Energies, IFAE, Autonoma University in Barcelona, SP.
- *Carmen Garcia*, IFIC-CSIC and Valencia University, Valencia, SP.
- *Gaston Garcia*, Center for Microanalysis of Materials (CMAM), UAM, Madrid, SP.
- *Luigi Gaioni*, Bergamo University and INFN, Bergamo, IT.
- *Shamik Ghosh*, Leprince Ringuet Lab. at Ecole Polytechnique, Palaiseau, CNRS/IN2P3, FR
- *Sebastian Grinstein*, Institute for High Energies, IFAE, Autonoma University in Barcelona, SP
- *Sven Heinemeyer*, Institute of Theoretical Physics, IFT, UAM-CSIC. Madrid, SP.
- *Rogério Iope*, Center of Scientific Computing (CSC), State University of Sao Paulo (UNESP), and INTEL Parallel Computing Center INTEL-UNESP, BR.
- *Carlos Lacasta*, IFIC-CSIC and Valencia University, Valencia, SP.
- *Auguste Le Van Suu*, University Aix-Marseille and CNRS, FR
- *Esperanza Lopez Manzanares*, Institute of Theoretical Physics, IFT, UAM-CSIC, Madrid, SP.
- *Norberto Malpica*, Medical Image Analysis & Biometry Lab, King Juan Carlos University (URJC) in Madrid, SP.
- *Miguel Manso*, Applied Physics Dept, Faculty of Science, UAM & CMAM, Madrid, SP
- *Vicente Martin*, Research Group on Quantum Information and Computing, Universidad Politecnica de Madrid, UPM, Madrid, SP.
- *Diego Martinez Santos*, IGFAE, University of Santiago de Compostela, SP.
- *Gonzalo Martinez*, UAM Polytechnic School, Madrid, SP.
- *Sedi Menik*, Northwestern University, Chicago, USA
- *Neil Moffat*, Center of Microelectronics of Barcelona, IMB-CNM, CSIC, SP
- *Concepcion Oliver Amoros*, Division of Electrical engineering, Accelerators Unit, Center of Research in Energy, Environment and Technologies (CIEMAT), Madrid, SP.
- *Daniel Ortega Ponce*, University of Cádiz, Institute of Research & Innovation in Biomedical Sciences of the Province of Cádiz, INIBICA, and IMDEA Nanoscience, Madrid, SP.
- *Jose Luis Pau Vizcaino*, Applied Physics Department, Faculty of Science, UAM Madrid, SP.
- *Giulio Pellegrini*, Center of Microelectronics of Barcelona, IMB-CNM, CSIC, SP
- *Ignasi Pérez-Ràfols*, LPNHE, CNRS/IN2P3, Paris, FR
- *Andres Redondo*, Applied Physics Dept, Faculty of Science, UAM & CMAM, Madrid, SP
- *Laura Ortiz*, Research Group on Quantum Information and Computing, Universidad Politecnica de Madrid, UPM, Madrid, SP
- *Mehmet Ozgur Sahin*, IRFU-CEA, University Paris Saclay, Gif-Sur-Yvette, FR.

- *Giulio Pellegrino*, National Center for Microelectronics, CNM-CSIC, Barcelona, SP
- *Valerio Re*, Bergamo University and INFN, Bergamo, IT
- *Aurore Savoy-Navarro*, IRFU-CEA, University Paris Saclay, Gif-Sur-Yvette & CNRS/IN2P3, FR.
- *Rui Shi*, Northwestern University, Chicago, USA.
- *German Sierra*, Institute of Theoretical Physics, IFT, UAM-CSIC, Madrid. SP.
- *Luis García-Tabarés*, Head of the Electrical Engineering Division of CIEMAT
- *Ian Tomalin*, Particle Physics Department STFC, Rutherford Accelerator Laboratory (RAL), UK.
- *Angel Torrado Carvajal*, Medical Image Analysis & Biometry Lab, King Juan Carlos University (URJC), Madrid, SP.
- *Nhan Tran*, Fermi National Laboratory (FNAL), USA
- *Yoshinobu Unno*, Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization, KEK, Tsukuba, JP.
- *Manuel Blanco Valentin*, Northwestern University, Chicago, USA.
- *Xavier Vilasis Cardona*, la Salle-URL and Data Science for the Digital Society Research Group (DS4DS), Barcelona, SP.
- *Silvia Viñals*, Center for Microanalysis of Materials (CMAM), UAM, Madrid, SP
- *Maria Dolores Ynsa*, Applied Physics Dept, Faculty of Science, UAM & CMAM, Madrid, SP
- *Alexandre Zabi*, Leprince Ringuet Lab. at Ecole Polytechnique, Palaiseau, CNRS/IN2P3, FR

Lab session on RD53 pixel front-end characterization

Profs. V. Re and L. Gaioni (Bergamo U. & INFN, IT)

The focus of the lab will be the experimental characterization of a small matrix (16x16) of front-end channels for pixel detectors in a 65 nm CMOS technology. The front-end has been designed in the framework of the RD53 Collaboration which is developing pixel readout chips for the High-Luminosity upgrades of the CMS and ATLAS experiments at the LHC.

In pixel-based detectors developed in many fundamental and applied research domains, pixel front-end ASICs are found at the very beginning of the signal processing chain, being connected to the detector itself. The testing of front-end circuits in advanced microelectronic technologies is thus a crucial aspect of the deployment of modern radiation detection systems.

During the laboratory session, after a short introduction on the device under test (DUT) (Fig.1) and the test set up (Fig.2), students will learn how to use LabView Virtual Instruments specifically developed for the characterization of the DUT (Fig. 3), and will get familiar to the main analog performance parameters (such as noise, threshold dispersion, time-walk, time-over-threshold) associated with the tested front-end channels. The DUT will be physically located at the University of Bergamo and will be remotely controlled and tested with virtual instruments.

While no previous experience in pixel front-end characterization is required, basic knowledge on electronic circuit operation and data analysis/visualization can be of some help.

Required software

- Anydesk (<https://anydesk.com>) for remote controlling of the Labview Virtual Instruments.
- Generic scientific software (e.g. Python, Matlab, KaleidaGraph, Excel, ...) for data analysis/visualization.

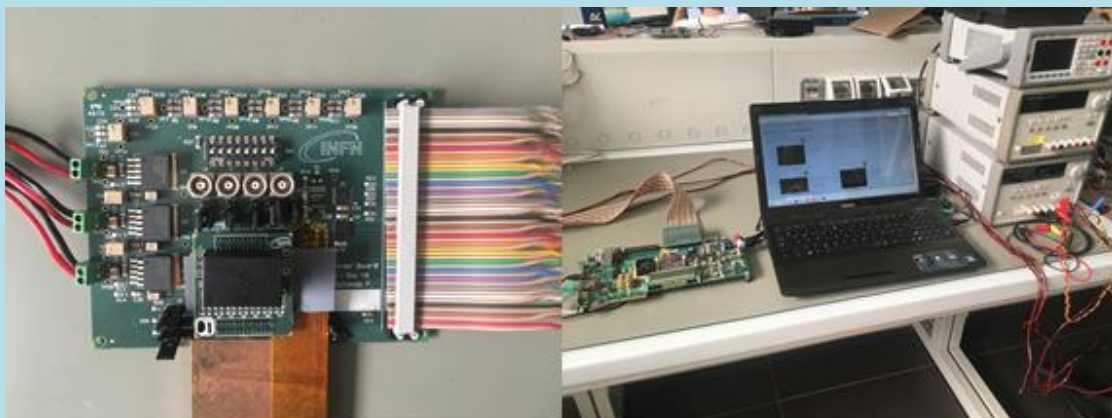


Fig.1

Fig.2

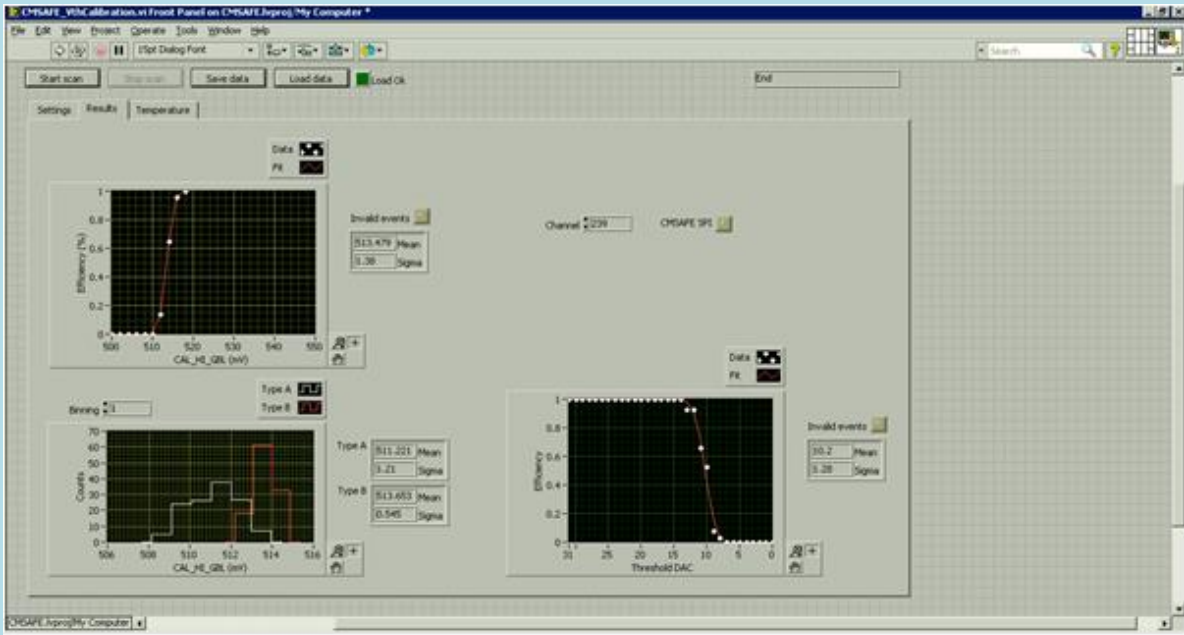


Fig.3

FD-SOI pixel detector

K. Androsov, EPFL and ETH-Zurich, CH,
Y. Unno, Institute of Particle and Nuclear Study, High Energy Accelerator Research
Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

1. Abstract

FD-SOI pixel detector is a “monolithic” pixel detector (cf. “hybrid”) (Fig. 1). The section of pixel sensors and the section of (frontend) readout electronics are fabricated in a wafer as a one-piece device. FD-SOI is an abbreviation of Fully-Depleted (FD)-Silicon-On-Insulator (SOI). SOI is a type of silicon wafer where a thin (40 nm, e.g.) silicon layer for transistors is electrically isolated with a thin (200 nm, e.g.) silicon oxide layer (called “buried oxide” layer) from a thick (300 to 700 m) supporting wafer. In a thin silicon layer being depleted in full thickness, CMOS (complementary metal oxide semiconductor) transistors can operate in high speed, low power, low latch-up, etc., due to low capacitance around the transistors. In the FD-SOI pixel detectors, the section of “supporting wafer” is replaced with a “high resistivity, high quality” silicon wafer. By processing biasing electrodes in the supporting wafer (in the top and the back side), the supporting wafer can be depleted fully. The full thickness (300 m, e.g.) can be sensitive (cf. a few tens of microns in other “monolithic” CMOS pixels). The abbreviation of “FD” represents implicitly of “Full Depletion” in the thin SOI layer as well as in the “sensing” layer in the supporting wafer.

In the lab course, we use a type of FD-SOI pixel detector, called INTPIX4 - An integration type pixel detector (of 4th layout) [1], that has been fabricated in the SOIPIX collaboration. The detector is mounted on a daughter printed circuit board (PCB). The daughter PCB is then mounted on a data acquisition (DAQ) PCB, called SEABAS DAQ board (Fig. 2). SEABAS (Soi EvAluation BoArd with Sitcp) is the DAQ board, developed by the SOIPIX collaboration (SOIPIX: Silicon-On-Insulator PIXel detector), which is a FPGA-based (one for user-device control, and the other for communication with the hardware emulation of TCP/IP protocols in FPGA (SiTCP [2])). The DAQ board is connected to a PC for a control of INTPIX4, collecting data, and displaying the events in the INTPIX4 (Fig. 3).

The hands-on experience includes

- Lectures on FD-SOI pixel detector and DAQ system
- Operation of DAQ software
- Response to laser light with a red and a green laser pointers, with a demonstration of transparency of silicon
- Charge/Signal collection vs Bias voltage
- Cosmic ray events accumulation (1 hour)

2. Lab space and equipments

We use a lab space of one desk (1.8 0.9 m²) with a total space of 3 3 m²) ((Fig. 4).

The hardware that the lecturer is to bring in are (We expect no import/export paperwork is applicable):

- 1 INTPIX4-SEABAS DAQ board (25 x 15 x 1 cm³)
- 1 Laptop PC
- 2 DC power supply cables
- 2 laser pointers (red and green)

The softwares to bring in are (installed in the laptop PC)

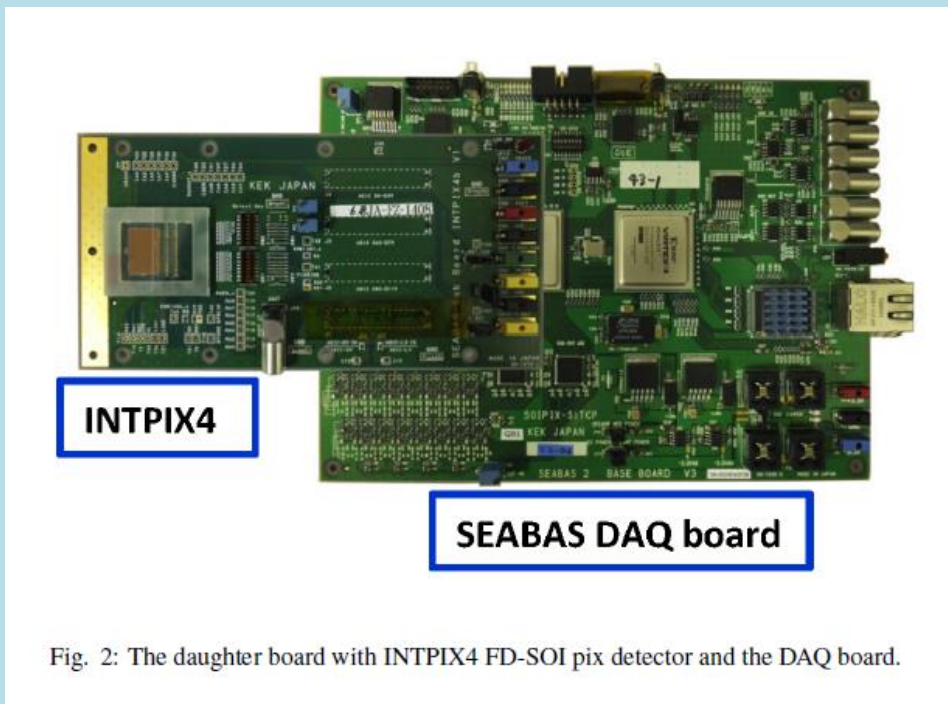
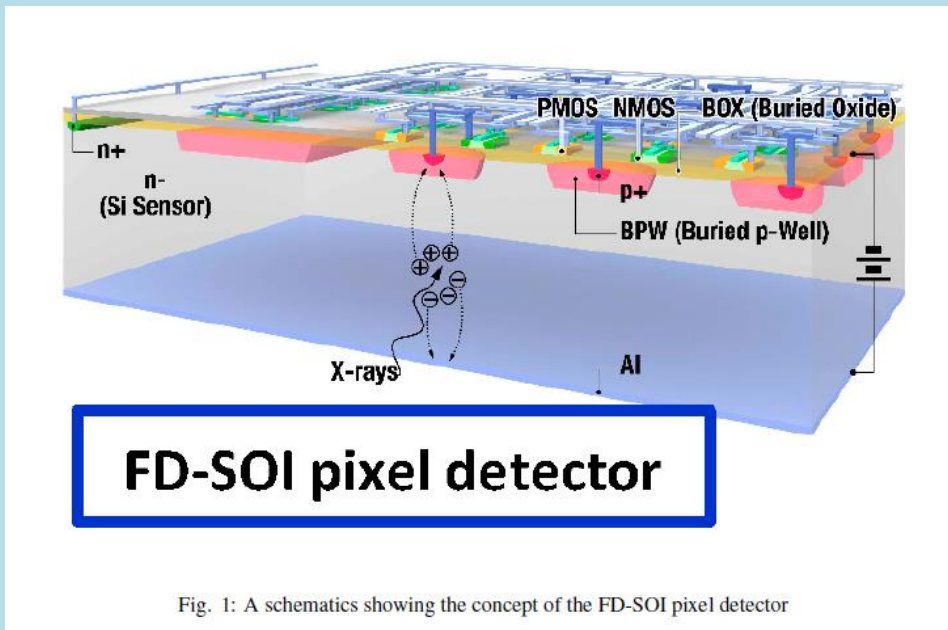
- DAQ software
- INTPIX4OCV

We use the hardwares available at hosting campus:

- 13.6-5.0 V DC power supply (PS) (for DAQ board)
- 1100 V DC power supply (PS) (for INTPIX4 pix sensor biasing)
- 1AC power outlet cable tap/adaptor (100-240 V) for 2-prong plug (A type)

References

- [1] Y.Arai, INTPIX4 User's Manual, <https://soipix.jp/content/files/documents/INTPIX4docv032.pdf>, in Japanese
 [2] About SiTCP, <https://www.bbtech.co.jp/en/sitcp/>



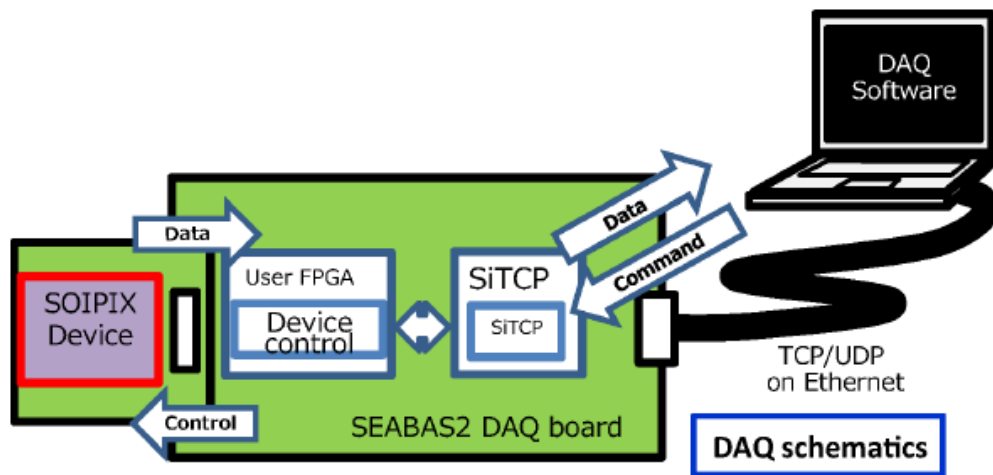


Fig. 3: An image of the full setup with a schematics of data acquisition.

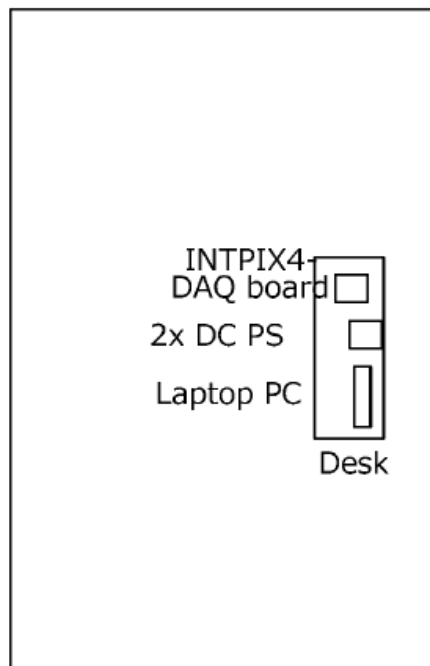


Fig. 4: A schematics of the lab space and equipments.

Thin Moderate Gain Ultrafast Timing detectors

G. Pellegrini, S. Grinstein, P. Fernandez, N. Moffat

1 High Energy Physics Experiments

In high energy physics (HEP) experiments such as at Large Hadron Collider (LHC), particles are collided at extremely high energy in order to study the fundamental physics of atoms from the properties of the collision products. One of the key elements in these studies is to track the trajectories of the charged particles produced in the collisions. Typically to measure this trajectory requires a detector with high 2D spatial resolution; such as that found in a pixel array. The trajectory taken by a particle at a typical HEP collider experiment can be reconstructed by information obtained by a series of pixel detectors arranged at increasing distance from the origin of the track. Although there are many events occurring in a short time window, the density of events is relatively low as they occur in different locations. This means that the information obtained by traditional pixel detectors is sufficient to reconstruct every event.

However, the LHC is to be upgraded in the coming years, such that the expected rate of events is to increase by an approximate factor of 5 compared to the typical luminosities of LHC Run-2. The track density will increase significantly and miss-identification of pixels hits to the trajectory of the original particle will occur only if traditional sensors are used for the tracking. The recent development of Low Gain Avalanche Detectors (LGAD's) shows the possibility of providing an improvement in the measurement of track arrival times, with the goal being the simultaneous high spatial resolution by fine segmentation and the capability of collecting data at a fast rate with good time resolution.

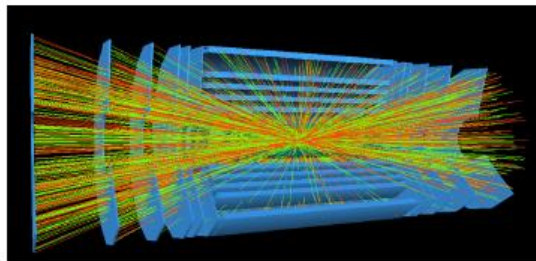
2 Low Gain Avalanche Detector

The Low Gain Avalanche Detector (LGAD), invented at CNM Barcelona, is a silicon photodiode with internal gain and excellent time resolution. This internal gain is provided by a high E_{field} region present at the junction between a highly doped n-type region and a medium doped p-type region. After a charge particle interacts within the detector, generating e/h pairs, electrons drift through this high field region causing impact ionization and an increase in charge. The gain can be controlled by the doping concentration to provide a gain of between 5-20. The internal multiplication process multiplies the signal and noise, and in fact tends to increase the sensor noise more than the signal. However if the sensor noise is kept low, by having low values of gain, the noise contribution of the detector will be dominated by the electronic noise and not the sensor noise. This produces a final Signal to Noise Ratio (SNR) which is increased for devices with low gain.

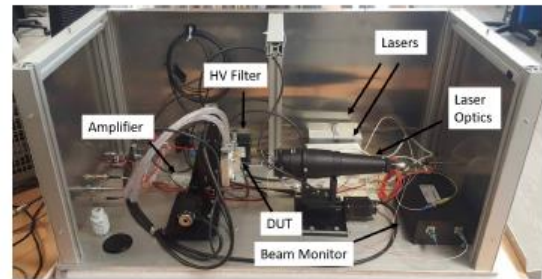
The lab is setup to allow the investigation of LGAD's, in order to determine their gain and time resolution using the Transient Current Technique (TCT). TCT is an extremely powerful tool used to map the charge collection response of a detector, by using a focused pulsed laser. The position of the detector can be controlled to allow a 2D raster scan to be performed in order to map the response. This setup can be modified to allow the timing resolution to be determined, providing fast characterisation of the detectors.

3 Objectives

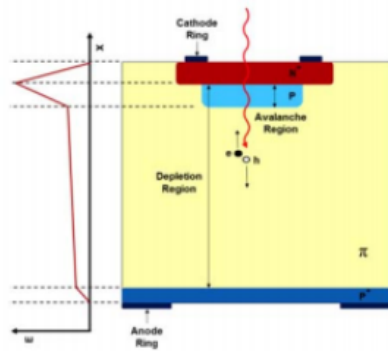
- Understand Photon detection mechanisms in LGAD Detectors using TCT.
- Measure the gain of an LGAD as function of position and bias voltage.
- Gain practical skills in data acquisition using specialised program PSTCT.
- Understand the benefit of using timing detectors within High Energy Physics.
- Perform timing measurements using the TCT timing setup.
- Understand and analyse the timing data in order to determine the time resolution of an LGAD detector.



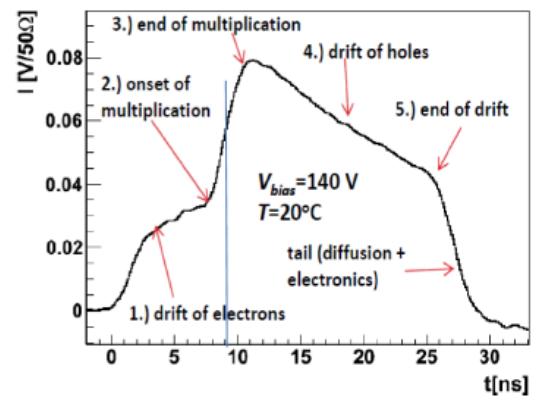
(a) Graphical representation of the density of charged particle tracks at the LHC.



(b) Components and setup of TCT system provided by Particulars



(a)



(b)

Figure 2: a Schematic representation of an LGAD detector (not to scale; the n+-p+ layers are typically ca. 1-3 μm thick); established electric field profile shown on the left; b) a typical pulse from an n+-p detector, resulting from back side illumination.

Introductory Computer Lab to Photonic Integrated Circuits

Wim Bogaerts (wim.bogaerts@ugent.be), Lukas Van Iseghem

Ghent University – IMEC, Department of Information Technology, Photonics Research Group

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 as 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 ($\sim 200\text{THz}$), 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.

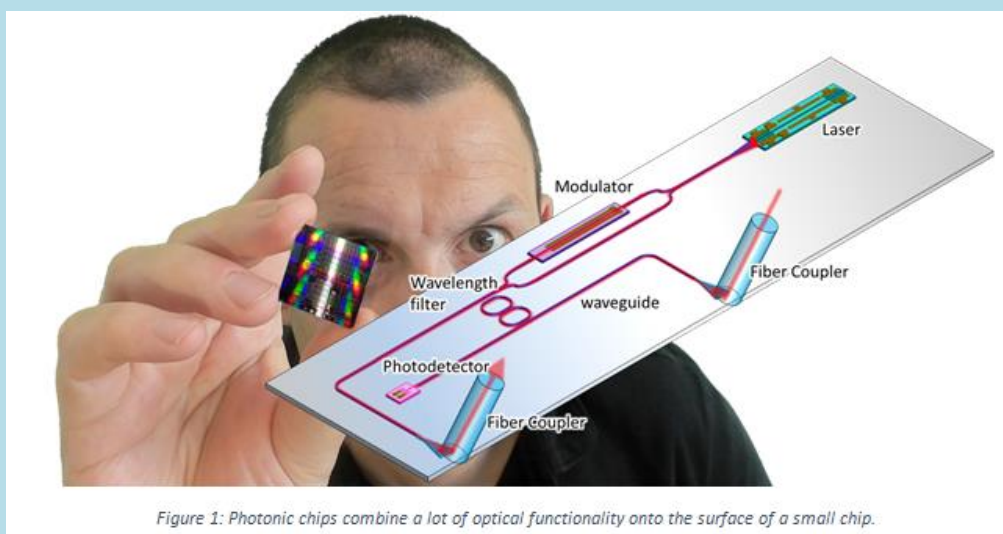
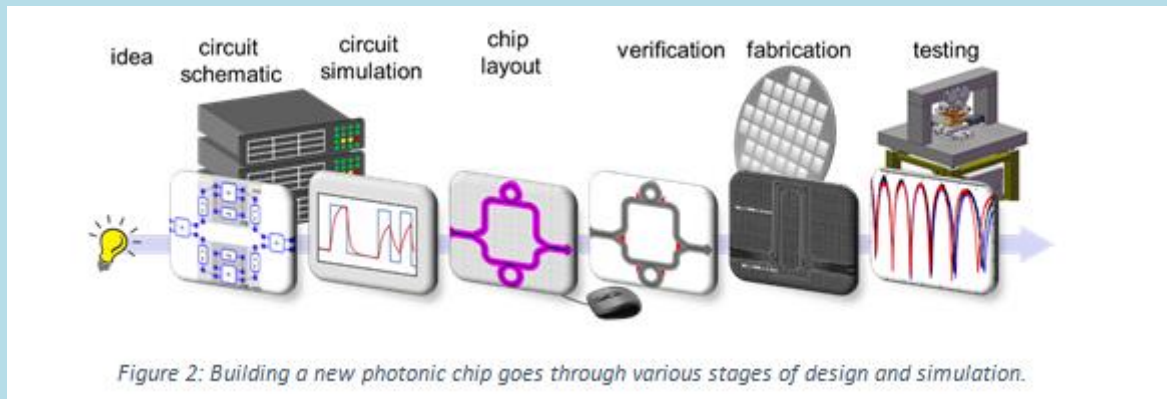


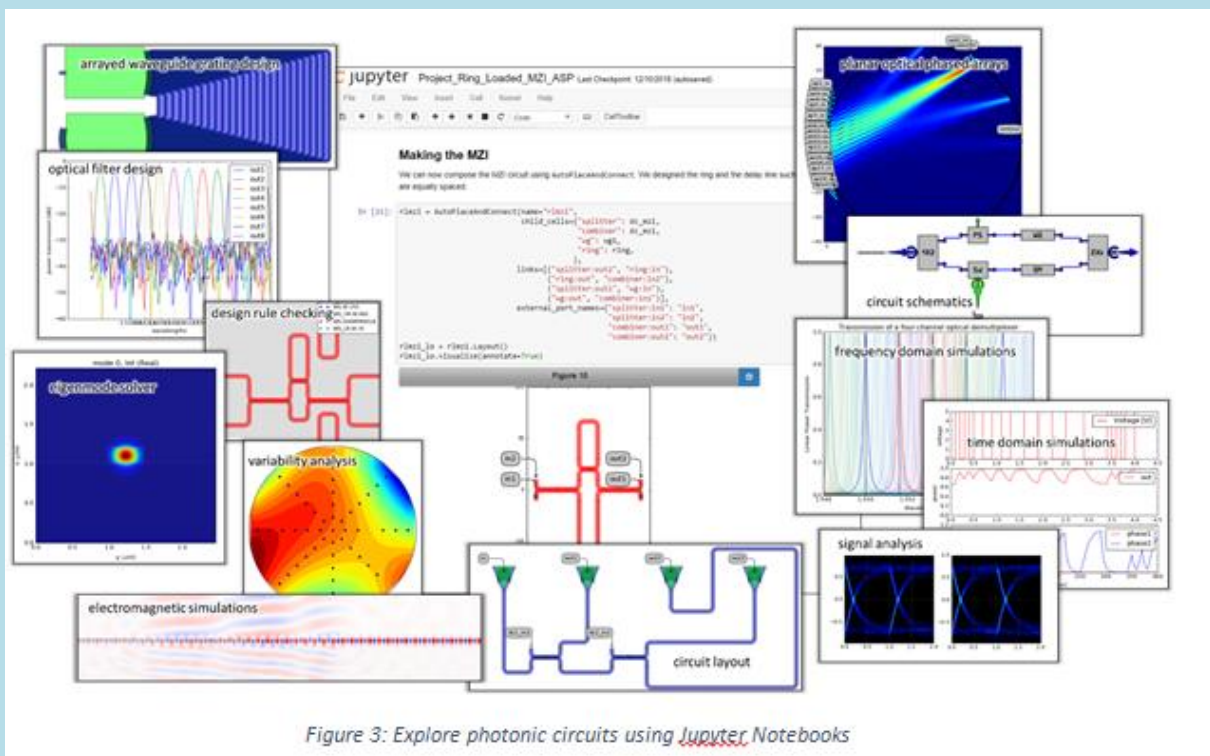
Figure 1: Photonic chips combine a lot of optical functionality onto the surface of a small chip.

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 it, 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.



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.



[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)

ARTIFICIAL INTELLIGENCE-ON CHIP: PHYSICS DRIVEN HARDWARE CO-DESIGN

Farah Fahim, Nhan Tran (FNAL, Batavia, Ill, USA), Giuseppe Di Guglielmo (Columbia, University, New York, USA), Manuel Valentin, Rui Shi, Seda Memik (Northwestern University, Chicago, USA)

Across many scientific disciplines and applied fields, the request on high precision and high speed as well as real-time diagnoses and decisions is impacting on the strong demands on programmable logic capabilities. The increasing use of Artificial Intelligence (AI) Machine Learning (ML) tools based on Neural Networks (NN) is demonstrating its successful application in many fields both in fundamental research as well as in applied domains (Medicine, Biology, and even day-to-day life). This is presented in several lectures at this School as well as a few dedicated Labs.

This Lab session introduces the students to an innovative use of AI ML tools at the hardware level by teaching her/him to the hardware design of AI-on chip. It is related to the lecture given at this school by Dr. Farah Fahim.

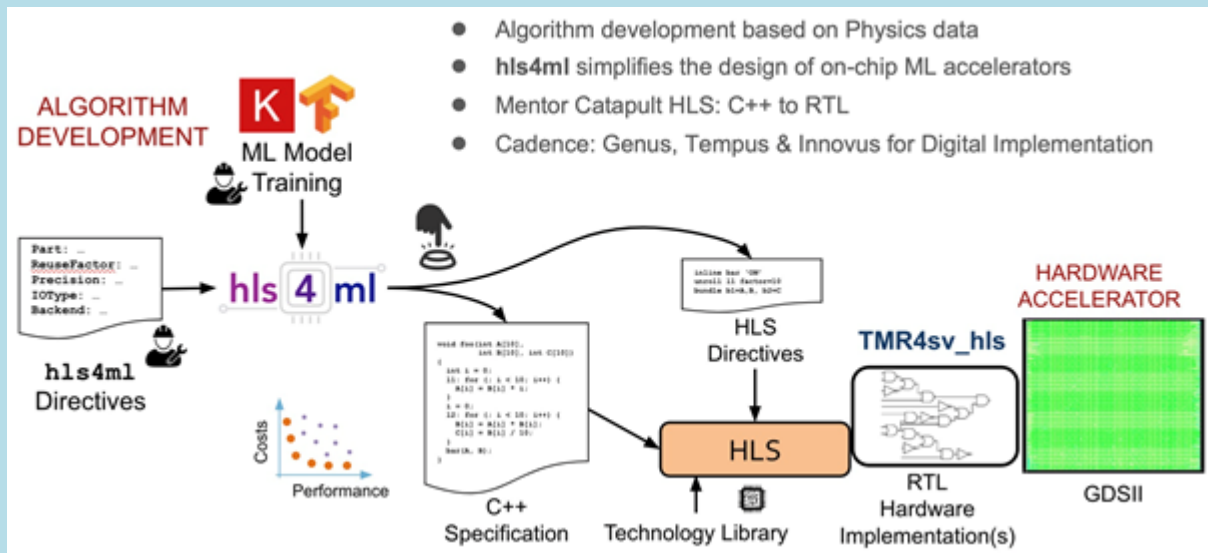
The Lab organizers will introduce the students to a new design methodology in Physics driven hardware co-design for ASICs (Application-Specific Integrated Circuits). The Lab organizers have created an entire tool flow to go from algorithm development to ASIC implementation: including the following steps 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 redundancy, 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 Signoff 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)



Quantum Communication Lab

Vicente Martín, Juan P. Brito, Laura Ortiz,
Universidad Politécnica de Madrid

Quantum communication is gaining importance in the last years. Based on Quantum Physics and applied to the information processing it is emerging as one of the most promising techniques to protect information channels against eavesdropping.

The lab on quantum communication consists in developing software components that simulates most known protocols for quantum communication. An example of this is BB84 (Bennet-Bassard,1984) which is a quantum key distribution (QKD) scheme. Another protocol that can be studied is Teleportation, the transfer of information without going through the physical space between the emitter (Alice in Fig. 1) and the receiver (Bob in Fig. 1)

A brief explanation of each protocol to share quantum key and a template to proceed in the programming will be given. Also, the increase of security against a listener (Eve in Fig.1) with respect to classical protocols will be understood.

New specific platforms designed for Quantum Communications and processing will be used to easier writing the code to implement these protocols. Based on these primitives, high-level services will be implemented, such as One Time Pad.

Furthermore, as the real QKD devices (from Huawei and ID Quantique (IDQ), shown in Fig.2) will be still running in Madrid Quantum Network (MQN) at that time, students will be able to extract real key to perform the services they have already implemented.

Moreover, the MQN (shown in Fig. 3) has a peculiarity which makes it unique. It is defined within the paradigm of the Software Define Network (SDN). The flexibility of this scenario fits perfectly with the aim of integrating classical and quantum communications in the same network.



Fig. 1: Alice, Eve, Bob



Fig. 2: Real QKD devices from IDQ and Huawei.

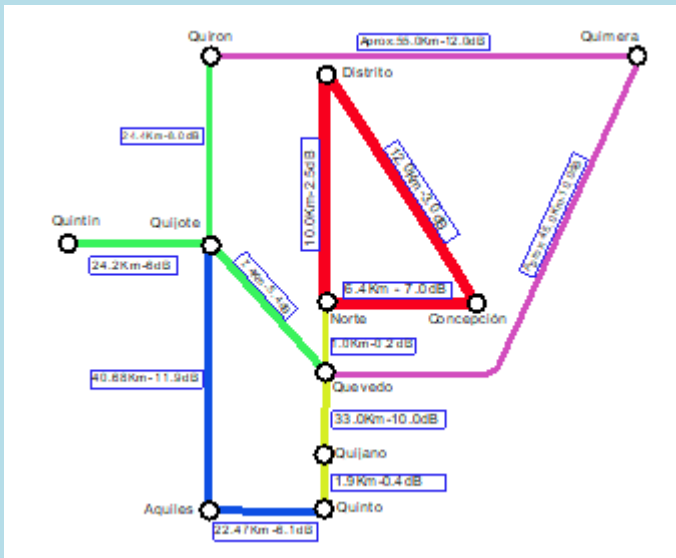
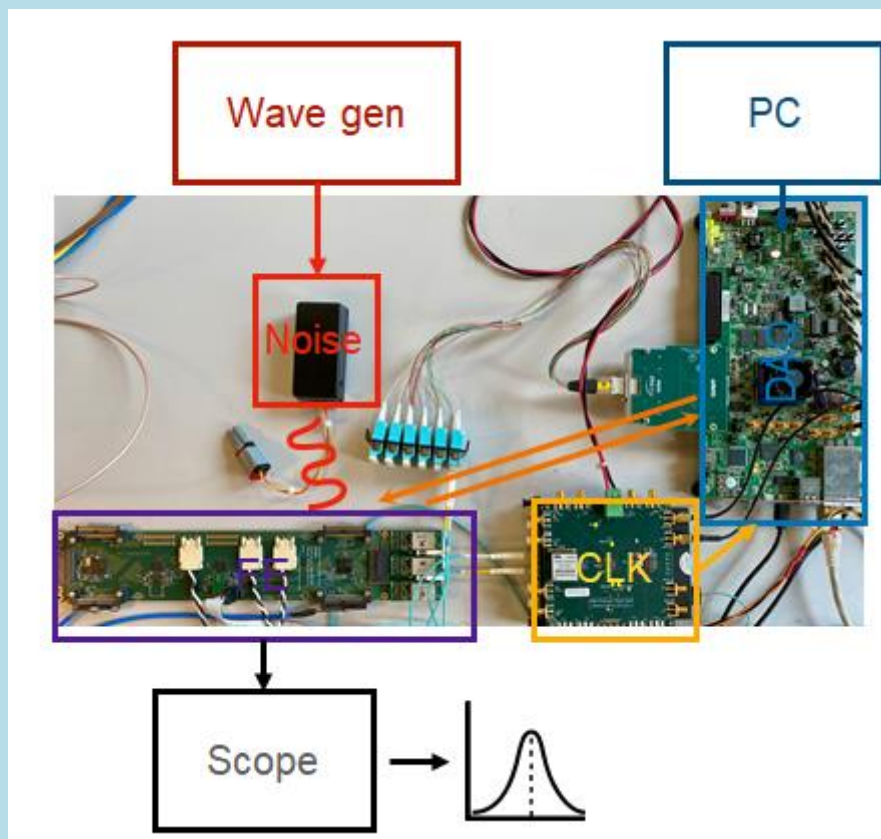


Fig.3: Map of Madrid Quantum Network

Fast clock transmission systems for HL- LHC

O. Sahin (IRFU-CEA, U. Paris Saclay, FR)

- Timing precision to be achieved in the HL-LHC: ~ 30 ps
 - Goal: synchronization of the detectors with a precision clock distribution with over more than 10000 links of 50m fibers as low as 10 ps RMS jitter under harsh HL-LHC conditions.
 - The clock signal will be embedded into high-speed data stream and recovered -by the FE components.
- Components:
 - DAQ system: Emulated with Xilinx KCU105 board and 10 Gb/s optical transceivers (VTRx+ and FireFly)
 - HPTC precision clock generator: less than 1 ps RMS jitter
 - CMS MIP Timing Detector Barrel layer Frontend Concentrator Card prototype: lpGBT
 - Custom noise generator
- Goals of the exercise:
 - Characterize the clock distribution tree
 - Inject power noise and estimate the jitter per mV
 - Quantify the impact on the timing resolution
 - Try to mitigate the low frequency components of the jitter



Light Detection and Ranging (LiDAR)

Y. Unno

Institute of Particle and Nuclear Study, ³ High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

1. Abstract

Light Detection And Ranging (LiDAR) is a technique that transmits pulses of a laser light and detects the reflected pulses, measures the “time of flight” of the pulses and translates the time to the distance. The technique has been used for long for a number of applications, e.g., a remote sensing of topographical and vegetation maps. The latest and topical application is an “eye” of advanced driving assistance and automated driving systems in the automotive world, which is made possible partly due to availability of miniature semiconductor devices.

In the lab course, we use a simple desktop/lab setup (Fig. 1). The setup is made of cutting-edge semiconductor/solid-state devices in one package: the light emitter with a pulsed solid-state laser (infrared wave length of 905 nm), the light receiver with a linear-array MPPC (a product name out of the initials of Multi-Pixel Photon Counter, a solid-state photomultiplier), a visual imager with a visible-light camera (yet sensitive to infra-red light), and a data acquisition system with a Field-Programmable Gate Array (FPGA)-Personal Computer (PC) chain. The setup measures the range from a meter to a few tens of meters with a viewing angle of 30 degrees. With appropriate magnification of the lenses, it may measure a long-range up to 100 m or more.

The hands-on experience includes, (1) Lectures on the setup and the devices, (2) Verification of image of laser light, (3) Cross-correlation of visual imaging and laser ranging (viewing angle) (Fig. 2), (4) Visualization of ranging (distance, cross-passing person, ...) (Fig. 3), (5) Observation of electrical signals with oscilloscope (Fig. 4), (6) Optimization of signal-to-noise ratio with aperture of receiver lens, etc.

In the lectures, we will learn the principles of the devices. A laser diode[2] is made of Gallium-Arsenide (GaAs) and the infrared light is used for safety and other reasons such as less scattering and absorption. The gallium arsenide diodes release energy in the form of light or photons during recombination, while silicon diodes not. MPPC[3] is a matrix of Geiger-mode Avalanche Photo Diode (APD) elements (called pixels) connected in parallel on a monolithic silicon wafer. Each pixel can detect down to a single photon and a MPPC as a whole detects multiple of photons in one measurement frame. Through the operation and observation of signals, we will learn issues associated with the LiDAR system.

2. Lab space and equipments

We use a lab space of an open space (5-10 x 5-10 m² to a wall) and one desk (1.8 x 0.9 m²) ((Fig. 5). An clear open space is the best but some obstacles are acceptable.

The hardware that the lecturer is to bring in are:

- 1 LiDAR setup (a size of 20 x 15 x 10 cm³). The laser is a class 1 laser with a wavelength of 905 nm
- 1 USB hub (with AC power adaptor (100-240V, 2-prong plug (A type))
- USB cables (1 USB2 TypeA-TypeB, 1 USB3 TypeA-MicroB connections)

We expect no import/export paperwork is applicable.

The softwares to bring in are of Windows OS (Windows 8.1 or Windows 10).

For the control of the LiDAR setup:

- HPK C15122-1005 Ver1.00/AsicController.exe
- HPK MPPC ASIC driver software (DriverSetup 64bit.exe)
- Microsoft VisualStudio2015 (mfc140u.dll)

For the visual camera:

- Artray VisualCameraVer1.00/Bin/Viewer.exe

- Artray Camera driver software (ARTCAM-036MI2-WOM-DRV-V2021)

We use the hardware available at hosting campus:

- 1 Desktop/laptop PC (Windows 8.1 or Windows 10) and a display (>2560 x 1600 pixels)
- 1 Oscilloscope
- 1 AC power outlet cable tap (100-240 V) for 2-prong plug (A type)

References

[1] T. Ito, S. Iwashina, Hamamatsu Photonics K.K., 1126-1 Ichino-cho, Higashi-ku, Hamamatsu-shi 435-8551, Japan

[2] Pulsed Laser Diode, https://www.hamamatsu.com/resources/pdf/lsr/L11854-336-05_E.pdf

[3] MPPC, https://www.hamamatsu.com/resources/pdf/ssd/mppc_kapd9005e.pdf

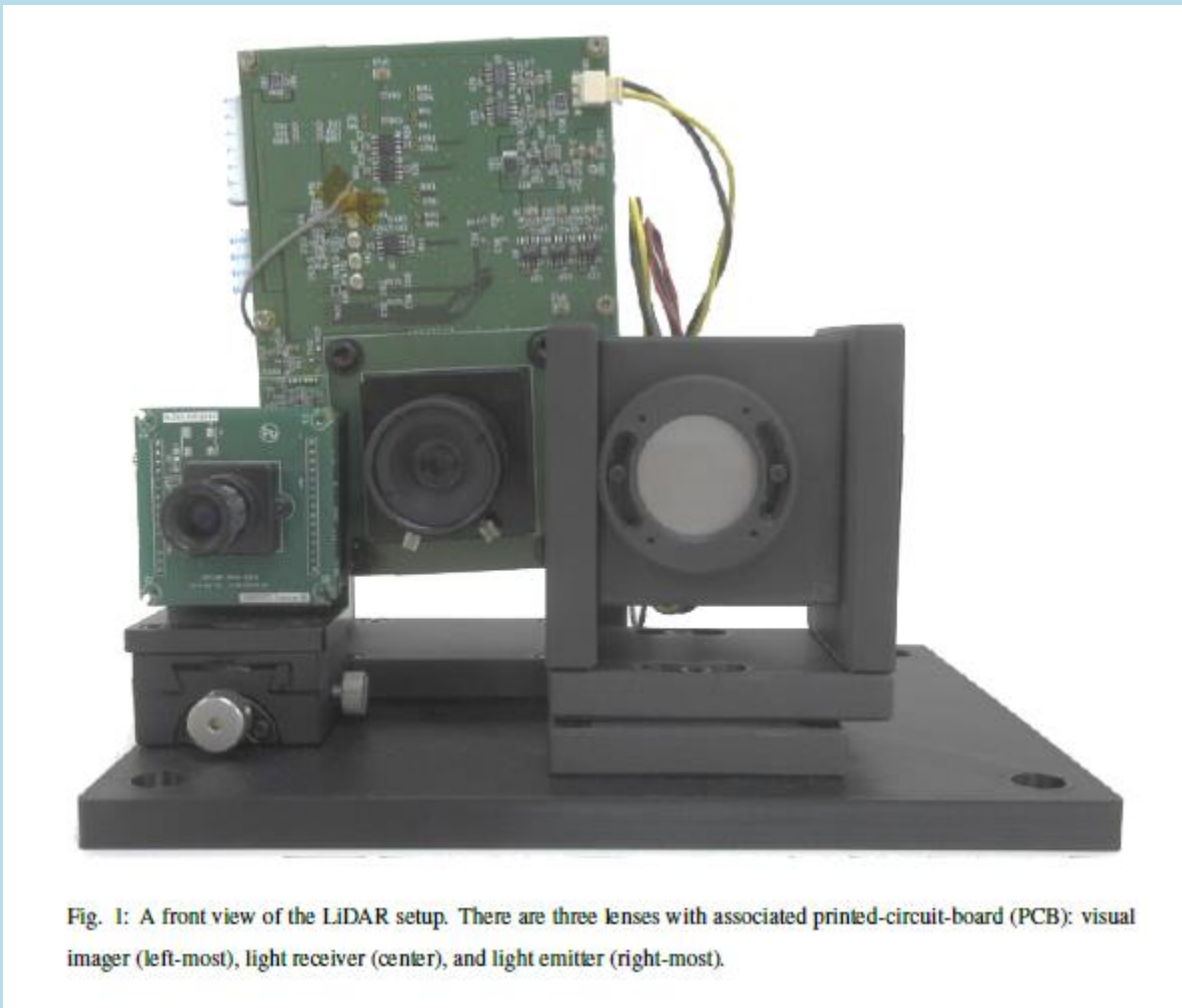


Fig. 1: A front view of the LIDAR setup. There are three lenses with associated printed-circuit-board (PCB): visual imager (left-most), light receiver (center), and light emitter (right-most).



Fig. 2: An image of the visual imager display screen. The area with red square is an indication of the detection area where it is ranged with 16 channels of the MPPC.

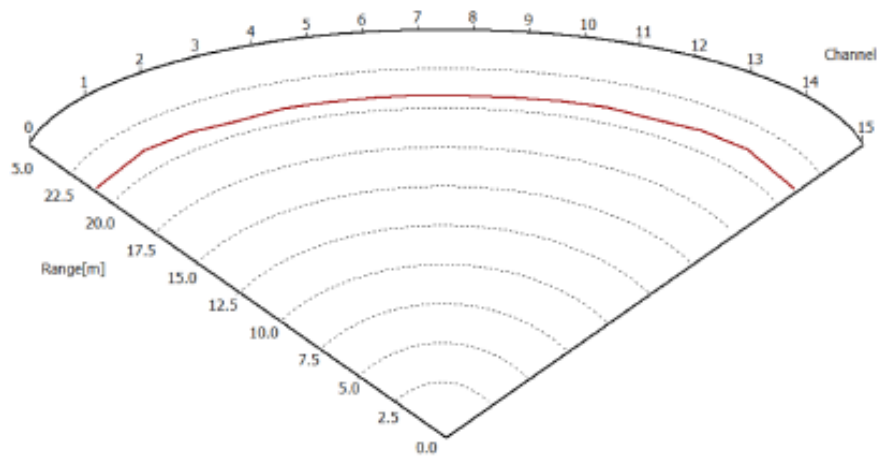


Fig. 3: An example of range display. The red line is a distance to a wall.

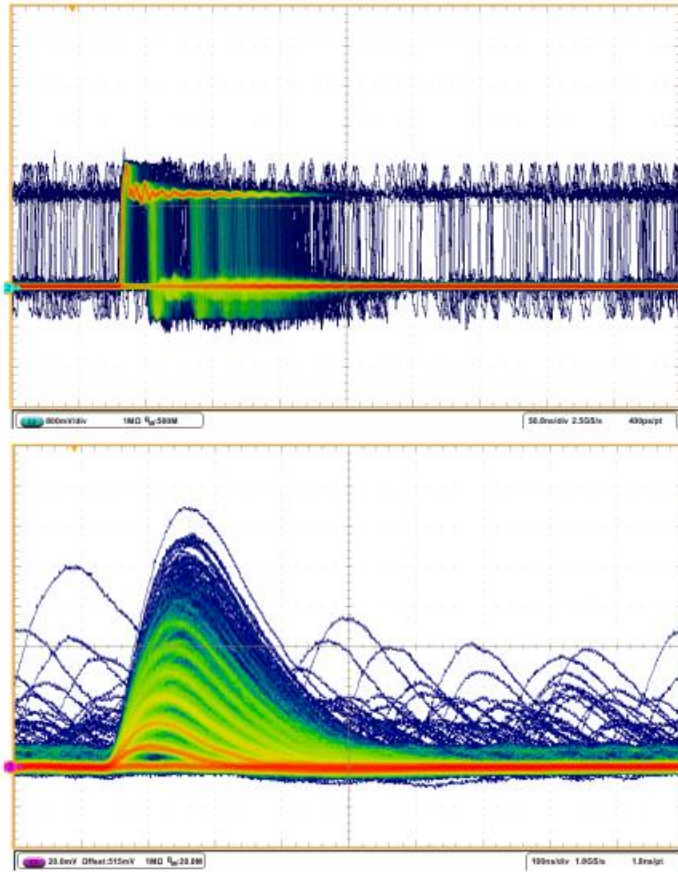


Fig. 4: An example of “debug” signals monitored by an oscilloscope: timing (top) and pulse height (bottom).

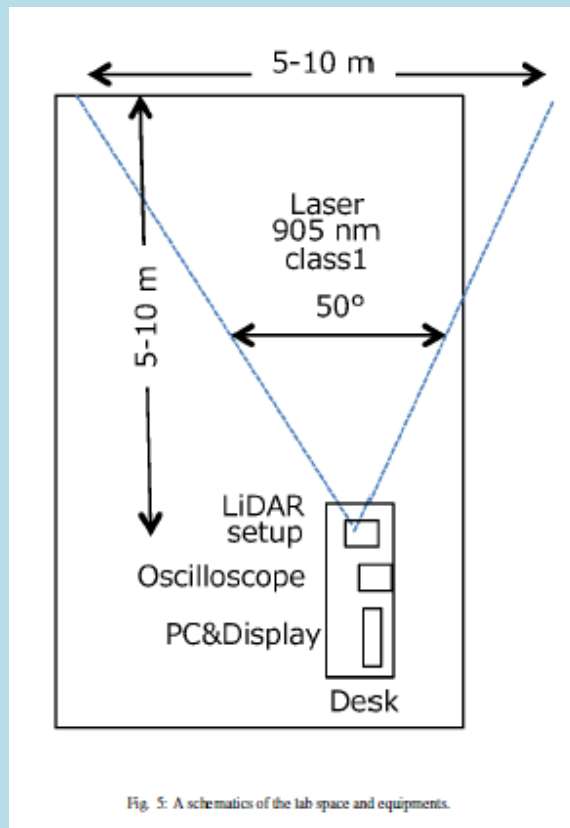


Fig. 5: A schematics of the lab space and equipments.

¹An equipment prepared by Hamamatsu Photonics (HPK)[1] for a demonstration purpose

Getting started with microcontrollers

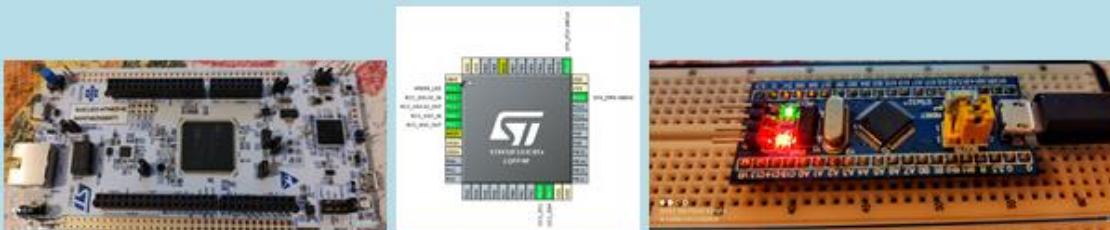
Dr. Luigi Calligaris (UNESP - São Paulo)

Whenever you need to process data or operate hardware with reasonable requirements in your application, there is likely one or more mass-produced microcontrollers that can solve your problem quickly and cheaply. They can be a formidable Swiss army knife in your toolbox.

This laboratory introduces you to microcontrollers and their use in different applications. We use widely available and cheap microcontrollers such that, if you are interested in the topic and want to develop on it further, you will be able to do so on your own in the lab and even at home. All the software used in the lab is free to use, does not require paid licenses, and runs on Linux and Win.

You will learn to set up your environment to get started, the use of the various microcontroller peripherals, the use of bare metal applications vs. real-time operating systems, how to interface the microcontroller with external peripherals and how to debug your application.

We plan to focus on popular STM32 and ESP32 devices. The student is expected to have some proficiency in C coding.



EASy-Silicon Strip Sensor Testbench

Carmen García, Carlos Lacasta
IFIC (CSIC-Universidad de Valencia)

1. INTRODUCTION:

The Alibava Educational System (EASY), a plug-and-play educational system, is a portable, compact and complete system for microstrip sensor characterization, ideal for making basic or complex experiments with silicon microstrip detectors. The students will be introduced to high-energy physics and particle detectors with hands-on experiences. They will get familiar with concepts such as MIP (Minimum Ionization Particles), charge collection, full depletion and charge sharing in strip detectors, among others concepts.

2. THE EASY SYSTEM COMPONENTS

The components of the EASY systems are the Control Unit (system's main board) and the Sensor Unit (containing the detector board), see figure 1. The Control Unit is the heart of the system communicating with the sensor unit and the Computer software. It contains the Data Acquisition Control and it is also in charge of processing the sensor data and trigger inputs. In addition, it contains an adjustable High Voltage unit for microstrip sensor bias, with voltage and current display and Includes the laser source. The Control Unit communicates with computer software via USB.

The Sensor Unit accommodates a p-on-n silicon micro-strip sensor, the same type of sensor used by the ATLAS detector at the LHC (figure 2). P-on-n strip detectors consist typically of an around 300 μ m thick n-type bulk. On one side, a thin layer segments form strips out of p-type material, whereas the back implant is n+. The abrupt junctions are formed between the strips and the bulk silicon. The depletion zone grows from the strips to the backplane so that, the device can operate partially depleted and the movement of holes forms the signal. The Easy silicon micro-strip sensor is segmented in 128 strips

3. CHARGE COLLECTION FOR A MIP PARTICLE.

A Minimum Ionizing Particle (MIP) that traverses a silicon detector loses energy mainly by ionization. When the ionizing particle passes through a silicon atom in the lattice, this will tend to liberate a loosely bound valence electron generating an electron-hole pair. The free charge carriers formed by ionization in the silicon will move in the detector field in the depleted part of the detector (figure 3). This is because the ionization in the depleted region is not recombined but accelerated by the electric field. While in the non-depleted part, there is not electric field and charge will be reconvened. Therefore, only the charge generated in the depletion part will contribute to the signal. The signal generated in silicon detectors is generally of small amplitude (around 24000 electrons for full depleted 300 μ m sensor), hence amplification and shaping stages are required for its further processing. The read out and amplification of the detector signal is done by the BEETLE chip, a low noise ASIC developed for CERN/LHC experiments.

The Sensor Unit also generates trigger signals, which are useful to indicate the exact time at which a particle crosses the micro-strip sensor. One of the possible trigger modes of the EASY system is the diode trigger mode (figure 3). It consists in discriminating a signal

generated by a low noise silicon diode mounted underneath the micro-strip sensor with a gap of few millimeters.

The students will investigate the charge collected by a silicon micro-strip sensor when a Minimum Ionizing Particles (MIP) goes through it and triggering the diode behind it. The MIPs used are 0.546 MeV electrons irradiated by a Sr90 source.

Before studying the charge formation in a silicon sensor, the student should understand the concept of pedestal, noise (its dependence with the reverse voltage bias) and the common noise. And therefore, the student will understand how the signal is obtained from the raw data. Figure 4 shows the charge spectrum collected after pedestal and noise subtraction.

Since only the charge generated in the depletion area will contribute to the signal, by measuring the more probable charge for different bias voltage, the student can calculate the voltage need to reach full depletion as shown in figure 5.

4. STRIP STRUCTURE AND CHAGE SHARING.

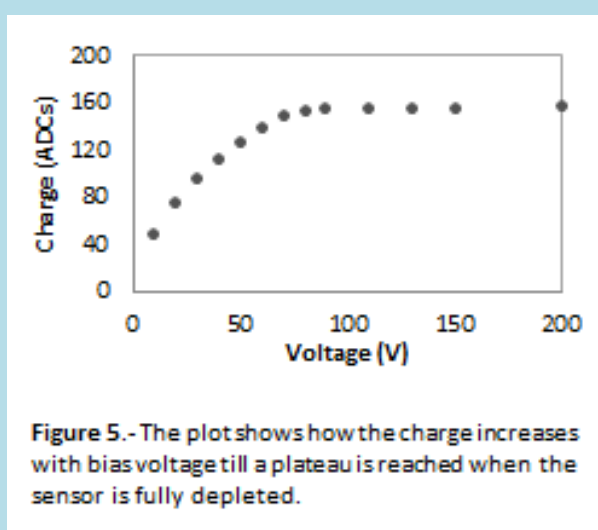
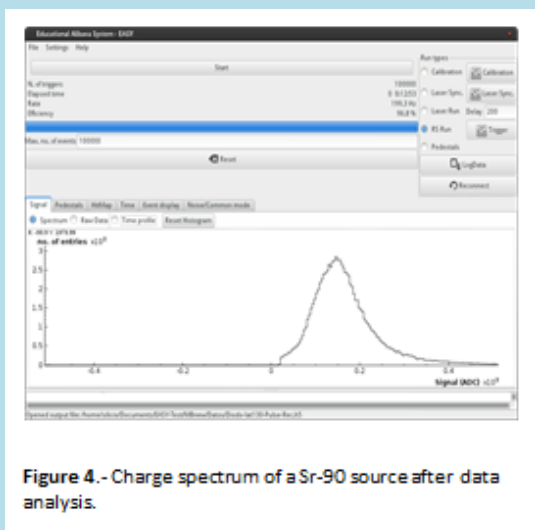
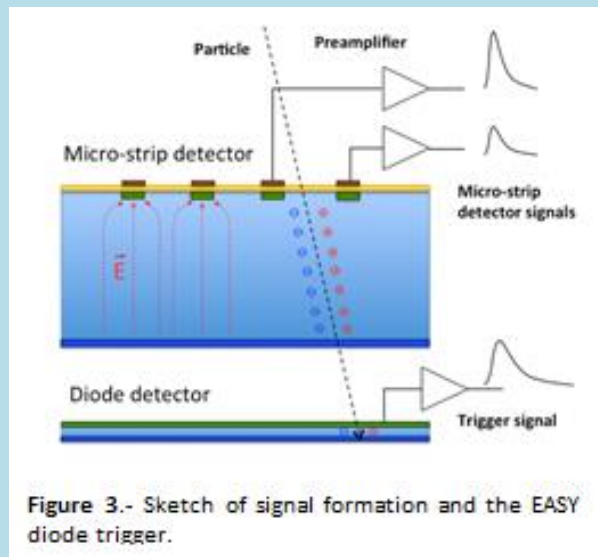
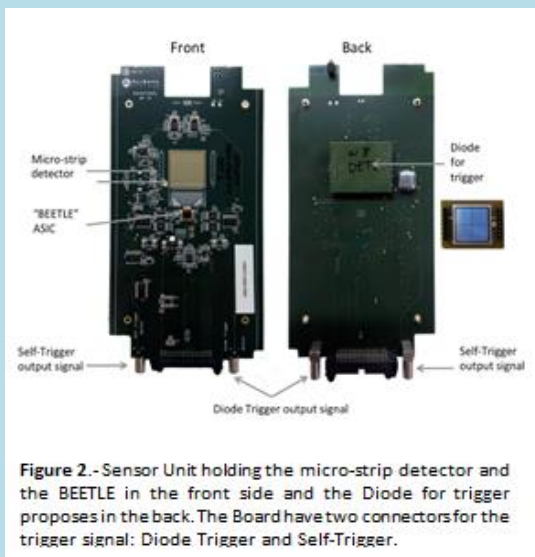
EASY system incorporates a 980 nanometers pulsed laser, to induce charge in the micro-strip sensor, mimicking the incidence of a charged particle in the detector. Two micro-positioner screws allow to move the laser lent by 10 micro-meter steps, horizontally and vertically. The laser beam can be moved perpendicular to the strip. By plotting the charge collected by three adjacent strips (figure 6), it is possible to illustrate how the charge is shared between strips and prove the strip structure. The colors of the curve on figure 6 correspond to the charge collected by each strip for every laser beam position. From the charge distribution one can determinate the strip width, laser path without signal collected, and the micro-strip pitch, the distance between two minima of collected charge.

5. CONCLUSIONS.

EASY is a complete instrumentation system dedicated to Silicon micro-strip Radiation Detectors, representing the state-of-the-art in detector characterization. The aim of this system is to illustrate the operation of a silicon strip detectors, ideal for making basic or complex experiments with silicon microstrip detectors.

The “Activity Book for Students” provides a full description of EASY device, data Acquisition system and 10 exercises to guide the student in the basic principles of micro-strip silicon sensors.

The system is commercialized buy ALIBAVA SYSTEM (www.alibavasystems.com)



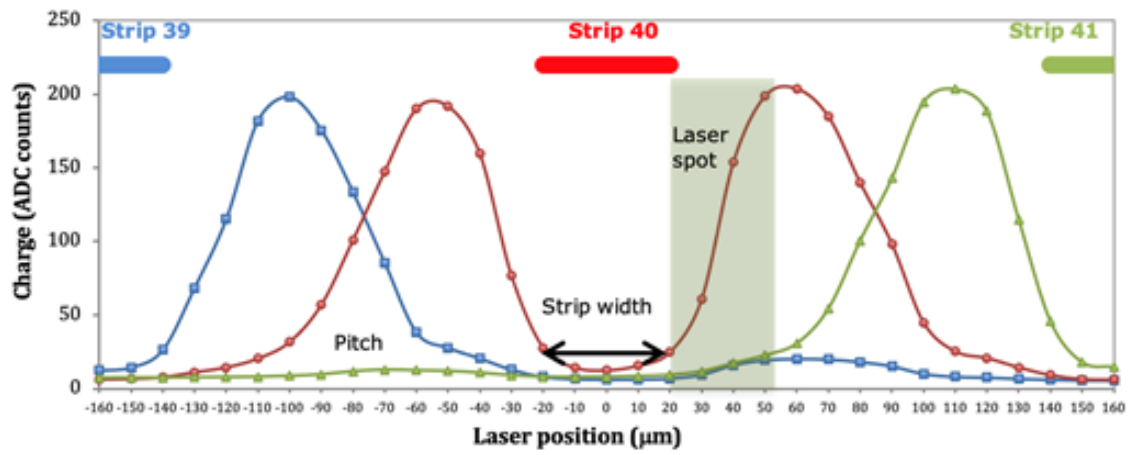


Figure 6.- Signal deposition of the laser charge in three consecutive strips obtained by moving the laser in 10 μ m steps perpendicular to the strips. The signal recorded by strip 39 is represented in blue, in red the signal in strip 40 and in green the signal in strips 41. In the top of the figure the strip structure is represented.

Charged Particle Track Reconstruction in an FPGA

Giacomo Fedi (Imperial College, UK)

Ian Tomalin (Rutherford-Appleton Laboratory, UK)

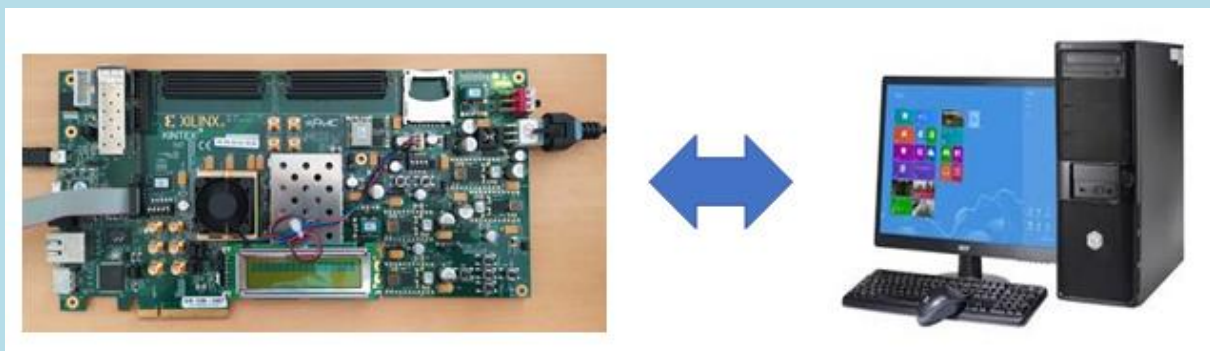
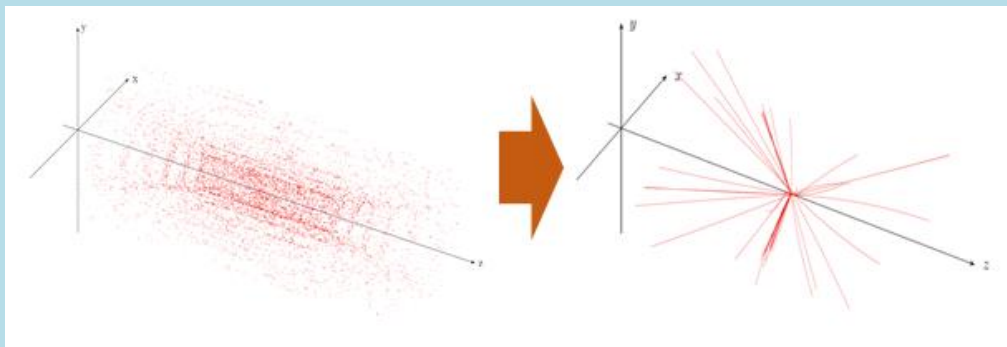
Introduction

At the High-Luminosity LHC, which starts in ~2027, the CMS experiment aims to reconstruct within 4 microseconds 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.

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++.

You can optimise your 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 an FPGA mounted on a KC705 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.



Allen: A high level trigger on GPUs for LHCb
Diego Martinez Santos (USC, Santiago de Compostela),
Xavier Vilasis Cardona (R, Lull University, Barcelona)

Allen is the name given to a fully GPU-based implementation of the first level trigger for the upgrade of the LHCb detector, at the LHC at CERN. It can process the 40 Tbit/s data rate of the upgraded LHCb detector and perform a wide variety of pattern recognition tasks. These include finding the trajectories of charged particles, finding proton–proton collision points, identifying particles as hadrons or muons, and finding the displaced decay vertices of long-lived particles. Allen can be implemented in around 500 scientific or consumer GPU cards, that it is not I/O bound, and can be operated at the full LHC collision rate of 30 MHz.

Allen is the first complete high-throughput GPU trigger proposed for a HEP experiment.

The task will consist on implementing a small sequence in Allen using the Multi Event Scheduler. This will allow the students to see how Allen allows working with different lists of events depending on the needs of the HLT line being implemented. A small algorithm for track combinations will be implemented inside Allen.



AI Tools and the realtime HEP trigger

S. Jindariani, B. Hawks, J. Mitrevski, J. Ngadiuba (FNAL, USA)

Description: Machine Learning techniques executed in FPGAs can be very powerful tools for the realtime data processing. The hls4ml package allows to translate trained neural network models into synthesizable FPGA firmware. The firmware library targets efficient, ultrafast inference for its original application in real-time processing in particle physics. However, the generality of the package makes it applicable to a wide range of scientific and industry areas in which real-time processing on-device is needed.

In this tutorial we will give hands on experience with the workflow, including:

- Demonstration of the easy to use, yet deep customisation options hls4ml provides, including tunable parallelism and quantization.
- Model pruning, observing the impact on the resource usage of the inference.
- Quantization-aware training, resulting in low precision weights and activations and enabling very lightweight inference without loss of model accuracy.
- Synthesizing the FPGA firmware and evaluating the relevant metrics.

Attendees should have basic familiarity with Python, machine learning concepts, and ideally hands on experience with ML frameworks. Knowledge of FPGAs is advantageous, but not essential.

Prerequisites: We will authenticate participants to our interactive tutorial notebooks using Github accounts. If you intend to take part in the tutorial, and do not already have a Github account, please sign up for one: <https://github.com/>

HIGH GRANULARITY CALORIMETER SIGNAL PROCESSING, WITH M.L. BASED RECONSTRUCTION IN THE CMS HGCal

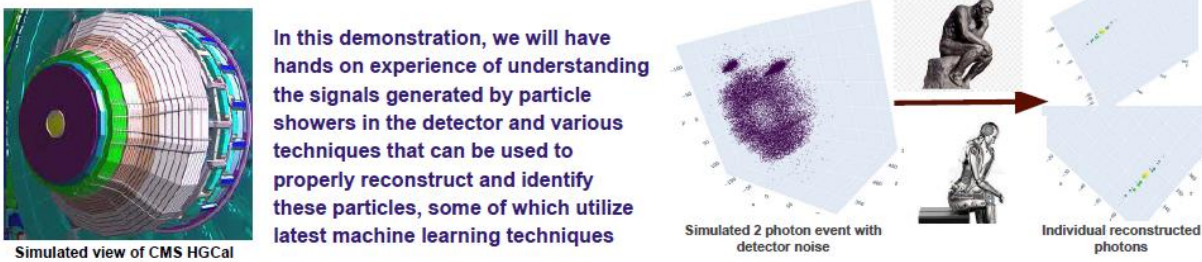
Shamik Ghosh | Alexandre Zabi, LLR - Ecole Polytechnique, CNRS, France

Description: HGCal offers an unprecedented possibility of performing calorimetry with tracker like granular information. With highly granular 5D (position(3), energy, time) signals coming out of the detector, it is a pattern-recognition challenge to fully utilize this information to extract physics objects out of the detector. Various algorithms based on nearest neighbours and shower geometry are being explored including techniques based on deep learning. The scope of these algorithms are rather general and can be applied to a wide range of particle detectors.

Pre-requisites: Familiarity with python and machine learning libraries would be advantageous for making full use of the hands on session, but not a necessity to understand the concepts

Requirements :

- Laptops/workstations with ubuntu which we can manually set up beforehand



Simulated view of CMS HGCal

In this demonstration, we will have hands on experience of understanding the signals generated by particle showers in the detector and various techniques that can be used to properly reconstruct and identify these particles, some of which utilize latest machine learning techniques

Simulated 2 photon event with detector noise

Individual reconstructed photons

DARK ENERGY SPECTROSCOPIC INSTRUMENT (DESI): Quasar identification

Ignasi Pérez Ràfols, LPNHE, CNRS/IN2P3, Paris, FR

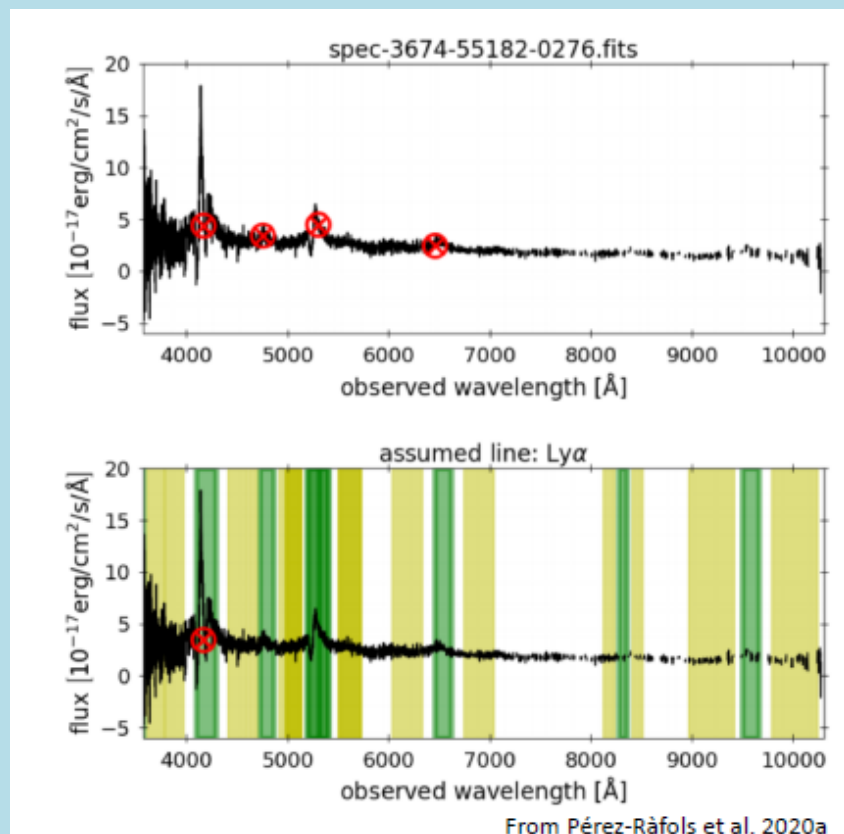
The Dark Energy Spectroscopic Instrument, DESI, has been built to measure the effect of dark energy on the expansion of the Universe. The DESI survey is conducted on the Mayall 4-meter telescope at Kitt Peak National Observatory in the USA.

Identifying and measuring the redshift of distant quasars has been a key contribution in order to map the Large-Scale Structure of the Universe. Quasars represent one of the main targets for DESI in order to put cosmological constraints and to better understand the nature of dark energy.

In the last couple + decades we have gone from having a few tens of spectra of quasars to having hundreds of thousands of them. New surveys such as DESI now provide tens of hundreds of spectra every night so visual inspection of all the spectra is no longer viable to identify quasars. Thus, we are moving to an automated quasar identification using machine learning algorithms. But, what are the best (combination of) algorithms to find these quasars? How can we improve them?

The laboratory will include:

- Studying the main properties of quasar spectra
- Learning about existing quasar classifiers
- Performing an actual classification using real data
- Assessing the performance of the different classifiers and learning about the typical classification issues



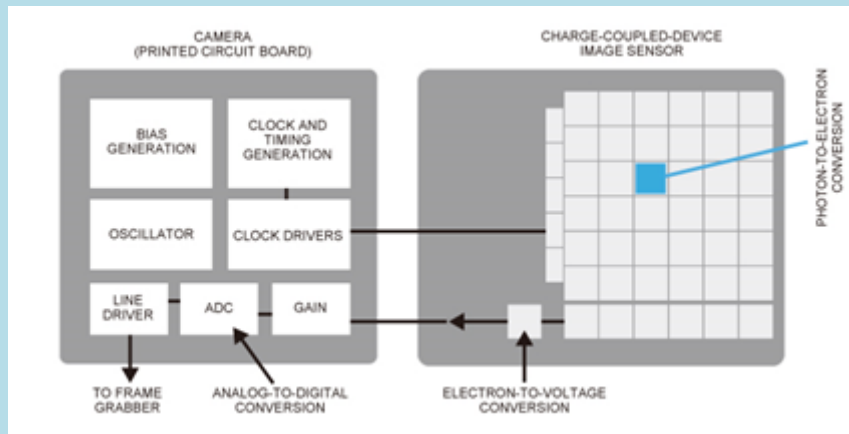
Characterization of a CCD camera

Jean-Gabriel Cuby and Auguste Le Van Suu
Aix-Marseille University & CNRS, France

Introduction

Large silicon detectors (CMOS or CCD) are ubiquitous in scientific instrumentation and in everybody's life (smartphones, laptops, etc.). The images recorded by these devices end up in computers as digital images. To each pixel of these digital images corresponds a number encoding the intensity of the recorded signal. Note that color images are made from physically different pixels recording the intensity through three different filters.

The pixel intensities are related to the number of electrons generated by the illuminating photons within the pixel potential wells. These charges are subsequently converted into voltages, amplified and converted into digital units. The numbers measuring pixel intensities are therefore expressed in dimensionless analog-to-digital units (ADUs). Note that in the absence of illumination, the pixel intensities vary as a result of readout noise, described as a random variable R defined by its standard deviation σ_R expressed in e^- (rms) per pixel.



In many scientific applications, you need to recover the radiometric information of the input signal from the pixel intensities in ADUs. More specifically, what you can recover is the number of electrons that were stored in each pixel. The conversion factor, g , is called the detector gain and is expressed in e^- ADU $^{-1}$.

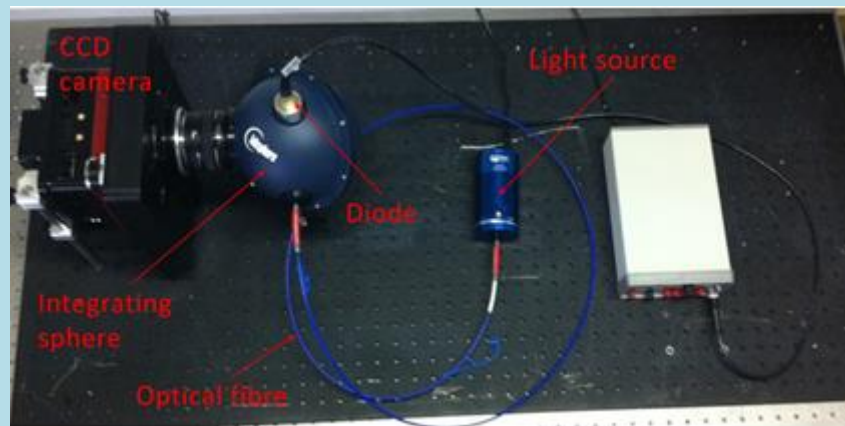
The main purpose of the lab is to determine the detector gain g in e^- ADU $^{-1}$ and the readout noise σ_R in e^- from the Poisson statistics of a constant photon illumination.

Equipment

A CCD camera is directly illuminated by an integrating sphere providing a flat illumination of the detector. The light source is a stable LED feeding the integrating sphere through an optical fibre.

The camera settings are controlled through a dedicated interface on a laptop. The camera control interface allows the user to setup the CCD readout parameters (exposure time, readout mode, number of images), the detector temperature and the shutter operation.

When the image is acquired, it is stored on disk and displayed in a quick-view window. Basic statistical measurements can be performed on image sub-areas, such as average, median, standard deviation, etc. Any image analysis applications can be used to analyse and process the images stored on disk.



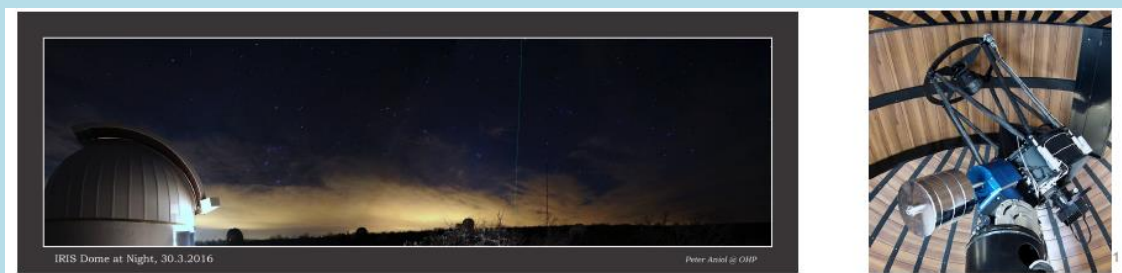
Activities

- Learn how to use the camera: define control parameters and take images
- Perform basic image processing (bias and dark frame subtraction, flat-fielding)
- Perform basic statistical analyses (histograms, average, standard deviation)
- Study the statistical properties of the dark current at different temperatures
- Study the CCD linearity range
- Determine the gain g in e^- ADU⁻¹ and the readout noise σ_R in e^- of the CCD from the statistical properties of the measured signal

Remote astronomical observations with a 50-cm telescope at Observatoire de Haute Provence (IRiS)

Drs. J-G. Cuby and A. Le Van Suu, Aix-Marseille U. & NSU, FR

- Observations will take place in real time, weather allowing
- Be prepared for short nights
- Prepare your targets
- More at <http://iris.lam.fr/> (mostly in French)
- Simulators <http://iris.lam.fr/observer-sur-iris/controle-du-telescope>



Equipment

Characteristics	Value
Telescope diameter	50 cm
Beam speed / numerical aperture	f/8
Pixel size (on sky)	0.7 arcsec pixel ⁻¹
Field of view	24 arcmin
Camera	E2V 42-40
Size	2048 x 2048 pixels
Minimum integration time	5 s (for shutter safety)
Filters	g, r, i et z, H-alpha, OII



Images taken and processed by INFIERI students, 2019
Left to right: M51, M81, M22

Clinical PET/MR imaging: Acquisition and quantification

Ángel Torrado, Norberto Malpica (Universidad Rey Juan Carlos / Hospital HM Puerta del Sur)

PET/MR hybrid scanners allow the simultaneous acquisition of Positron Emission Tomography and Magnetic Resonance imaging studies in a single scanner, allowing to obtain complex multimodal anatomical and functional image in a single session. The analysis of these data is changing the way diagnosis are performed in several disciplines, oncology and neurology among them.

To obtain high quality data, several processing steps need to be carried out: PET Image reconstruction, attenuation correction and multimodal image processing and analysis.

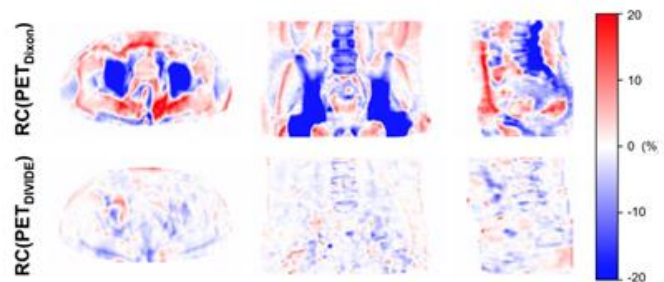
This Lab session introduces the students to the clinical use of PET/MR technology and the different data analysis techniques that allow to obtain high quality data and to process and extract biomarkers from the data.

Equipment

- The clinical center is equipped with a Siemens Biograph mMR scanner. Acquisition will take place in the scanner console
- Image processing lab will take place in a Teaching Room equipped with laptops and specialized software

Activities

- Lectures on PET/MR physics and technology
- Complete acquisition of a real clinical study in the MR/PET scanner with Q&A
- Image reconstruction: The student will learn how to reconstruct the PET image from the acquired positron data and how to correct PET attenuation using the MR data.
- Processing and analysis of a hybrid study: Image super-resolution, quantification, radiomics, machine learning



***In silico* study of deep brain stimulation (DBS)**

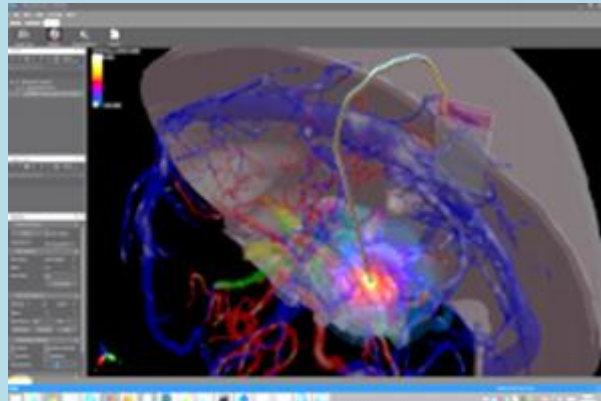
Dr. Daniel Ortega Poce (U. Cadiz and IMDEA), with collaboration of Zurich Med Tech

The practical session entails carrying out computer simulations of a deep brain stimulation (DBS) therapy, a neurostimulation technique used to treat essential tremor, Parkinson's disease, dystonia, chronic pain, partial restoration of the vision, etc. The response of the brain to the electrical impulses emitted by an implanted pulse generator will be simulated, studying the possible effects of the electric field distribution over the brain, possible tissue heating effects, as well as the transmission of nerve impulses under different treatment conditions.

The DBS treatment analysis is facilitated by the head model with incorporation of the Morel stereotactic atlas of the thalamus

The software needed will be provided by the manufacturer, including:

- SIM4LIFE simulation software temporary fully functional license
- Detailed human brain virtual phantom (MIDA model) containing 116 different structures
- The simulations, in principle, will be adequate so they can be run in a regular laptop/desktop



Irradiation of a biomaterial using a proton-beam and characterization of the damage produced for proton-therapy pre-clinical studies

Miguel Crespillo¹, Gaston Garcia², Miguel Manso¹, Silvia Viñals², Maria Dolores Ynsa¹

¹Applied Physics Department, Faculty of Science, UAM, Madrid, SP

²Center for Microanalysis of Materials (CMAM), UAM, Madrid, SP

This Lab will be held at the CMAM Center for Micro Analysis of Materials at UAM

1. Introduction

When preparing a radiotherapy treatment, a crucial point is to determine the effects of the radiation into the healthy tissues. In order to reduce the damage to the tumor surrounding healthy tissues, the energy deposition of the irradiation must be known. In the recent years, with the development of proton beam facilities, the most complicated tumours such as pediatric, ocular or brain tumours can be treated with protons instead of gamma-rays. In those cases, the deposition of energy in the tumor tissues is maximized while in the healthy tissues it is minimized, reducing the risk of suffering a second cancer as compared to the intensity-modulated radiotherapy (IMRT). Despite the improvement in the irradiation of the healthy tissues, a small error in the prediction of the deposition of energy can cause a major impact on healthy tissues. From this point of view, the validation of the proton range is mandatory.

At CMAM, there is a line that can offer external beams, mandatory for the irradiation of samples that cannot be irradiated under vacuum conditions such as cells. Moreover, irradiating in air conditions facilitates the extrapolation of the results for a clinical treatment.

2. Objectives

The objectives of the lab are, first of all, make the students familiar with the proton-therapy treatment and its benefits with respect to traditional radiotherapy, including a brief description of how the treatment plan is performed and which are the goals.

The second objective is to give the chance to the students to perform an irradiation experiment, showing them the facility and the complementary labs that get involved in each experiment.

The third objective is to visually see what are the differences of the damage produced in a protein environment by the irradiation, comparing the free radicals that are generated by the protons in the protein chains by using the Fourier Transform InfraRed spectroscopy (FTIR) technique.

3. Hands-on

During the session, the students will manufacture a protein hydrogel at the lab as a sample for irradiation. These hydrogels allow us to study the break-up of the protein chains in an easy-to-be-irradiated system, as it can be moved, cut and placed without the difficulties of a cell culture.

Later, the hydrogels done at the lab will be irradiated at the EuB (External Micro-Beam) line with a 10 MeV proton beam, monitoring the dose that the sample will receive.

By using the SRIM (Stopping and Range of ions in Matter) software, the students will determine the proton range of the beam that will be used (10 MeV) and will develop a

planning of a treatment, obtaining the characteristics of the beam such as energy and intensity of the beam.

Finally, the students will have to compare and identify the more characteristic radicals that are produced in the hydrogel by comparing the spectra obtained with FTIR techniques as a function of the irradiation depth, verifying the characteristic deposition of energy of the protons (Bragg's peak).

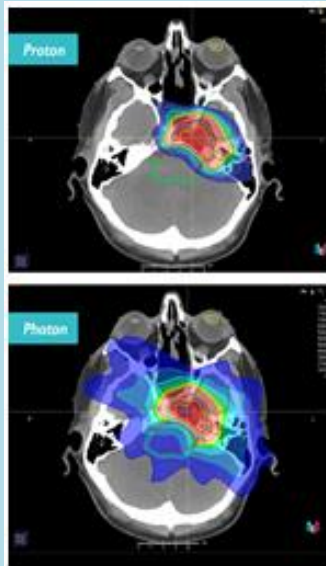


Fig. 1: Differences on the radiation distribution between a proton and a photon treatment

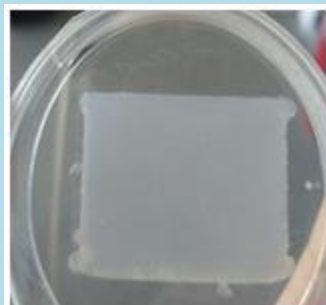


Fig. 2: Photo of a protein hydrogel.

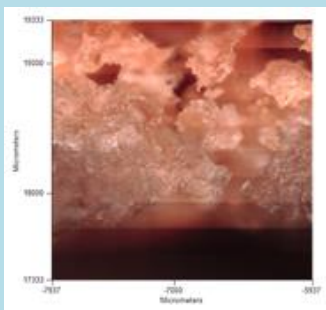


Fig. 3: IR photo of an irradiated hydrogel

Digital Positron Emission Tomography

N. D'Ascenzo (HUST University, Wuhan, CN and NEUROMED, IT)

- **Digital PET**
 - Prototype of 2-heads PET system composed of LySO/SiPM with MVT readout
 - Measure the key-parameters of a PET system: energy resolution, time resolution, coincidence time resolution, sensitivity, spatial resolution
- **The setup:**
 - Digital Multi Voltage Threshold readout
 - Silicon photomultipliers and scintillator crystals
- **The lab includes:**
 - Lecture and handout about digital signal processing for modern digital PET
 - Verification of the MVT readout system
 - Data collection and analysis



Electronics for Portable Reflectance Pulse Oximetry and Electrocardiography Systems

Jose Luis Pau, Andrés Redondo, Basilio Javier García

Dpto. Física Aplicada, Facultad de Ciencias, Francisco Tomás y Valiente 7, Madrid 28049, Universidad Autónoma de Madrid

This lab includes two different setups aiming at gaining insight on the design of a portable biomedical system.

The first setup consists of a reflectance pulse oximeter based on an integrated circuit optoelectronic sensor that enables heart rate monitoring and the measurement of peripheral oxygen saturation (SpO₂). The sensor include a set of light emitting diodes that, under forward biasing, emit light that can penetrate into the skin, and be reflected in the blood vessels. These vessels change their thickness with the heart beat, producing a variation in the light absorbed by them and, therefore, in the amount of light that is reflected back to the sensor [1]. The reflectance variations can be qualitatively measured using a photodiode and a current-to-voltage converter with an adjustable gain that is connected to an Arduino board to determine the heart rate. Furthermore, the light absorption differences at the red and infrared ranges between oxyhemoglobin and deoxyhemoglobin are used to monitor oxygen saturation in blood.

The second setup includes the basic electronics to develop a three lead electrocardiogram (ECG). The recorded signal is the result of the heart beat physiology. Initially, the muscle tissue cells of the heart are polarized: the interior is loaded negatively while the outside is positively charged. Then, an electrical impulse runs through all the cells progressively, stimulating them and causing its depolarization and its contraction. Finally, the cells repolarize, returning to their initial state. The total cycle produces a characteristic signal dominated by the QRS complex, composed of three deflections, the first and third negative, while that the middle one is positive [2]. The setup includes an instrumentation amplifier to monitor the signal and different filters for signal conditioning and readout.

[1] B. Venema, N. Blanik, V. Blazek, H. Gehring, A. Opp, and S. Leonhardt, Advances in reactive oxygen saturation monitoring with a novel in-ear sensor system: Results of a human hypoxia study, IEEE Transactions on Biomedical Engineering 59, 2003 (2012).

[2] D. Dubin, Rapid Interpretation of EKG's, 6th edition, Cover Publishing Company (2020).

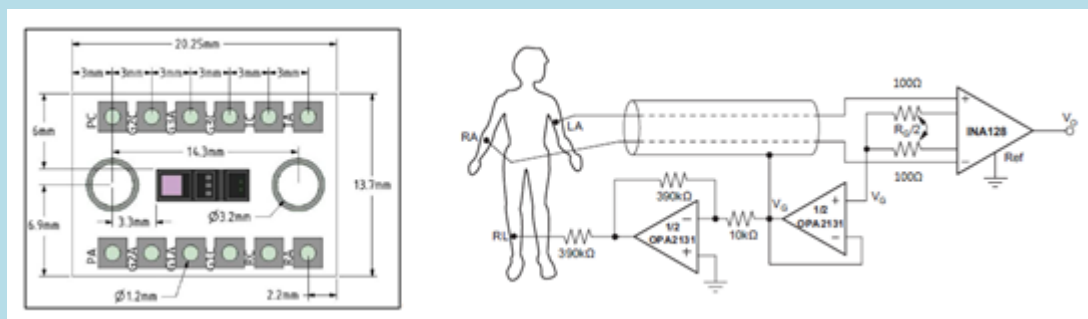


Figure 1. (Left) BioMon Osram Sensor board used in reflectance pulse oximetry. (Right) Schematic of the portable electrocardiograph based on the INA128 instrumentation amplifier of Texas Instruments

DESIGNING A SUPERCONDUCTING MAGNET LAB

Luis García-Tabarés, Concepción Oliver, CIEMAT

Superconducting magnets are one of the key components to achieve cutting-edge beam parameters as those required in the modern large High Energy Physics accelerators but they also play a crucial role in the development of compact accelerators for societal applications, as those used in medical applications, for instance.

This lab will introduce the student into the design of a superconducting magnet according to the following methodology:

- Introduction to superconductivity: Summary of basic concepts
- The role of magnets in particle accelerators: Types of magnets according to the geometry of field that they produce.
- Magnetic Design of a Superconducting Magnet
- Mechanical Design of a Superconducting Magnet
- Quench analysis of a Superconducting Magnet

MATERIAL:

- One laptop provided by CIEMAT with one or several FEM codes installed to perform the calculations in a collaborative form between all the students and the tutor.
- PPT presentation with explanations and guiding remarks
- Videos



APPLIED SUPERCONDUCTIVITY LAB

Luis García-Tabarés, Concepción Oliver, CIEMAT

Nowadays superconductivity finds many applications in different fields spanning from basic science to energy, transportation or medical devices. In most of the cases the superconductors are used in the form of magnets but they can also be used in other devices as magnetic bearings, for instance.

This hands on lab will introduce the student into the operation of two superconducting devices, according to the following scheme:

- Introduction to superconductivity: Summary of basic concepts (Complementary to the “*Designing a Superconducting Magnet*” Lab)
- Description of the most relevant applications of Power Superconductivity
- Study case I: A HTS prototype magnet working at the lab: Cooling down, powering, etc.
- How a Superconducting magnet is fabricated
- Study Case II: A Kinetic Energy Storage with Superconducting Levitation: Description of a practical case.

MATERIAL:

- Experimental set-up with a small magnet prototype working at cold
- Experimental set-up with a kinetic energy storage system working at cold
- PPT presentation with explanations and guiding remarks
- Superconducting magnet manufacturing videos



BEAM DYNAMICS FOR CMAM ACCELERATOR

G. García (CMAM), A. Arteche, L. Nevay, W. Shields (Royal London Univ.), C. Oliver, CIEMAT

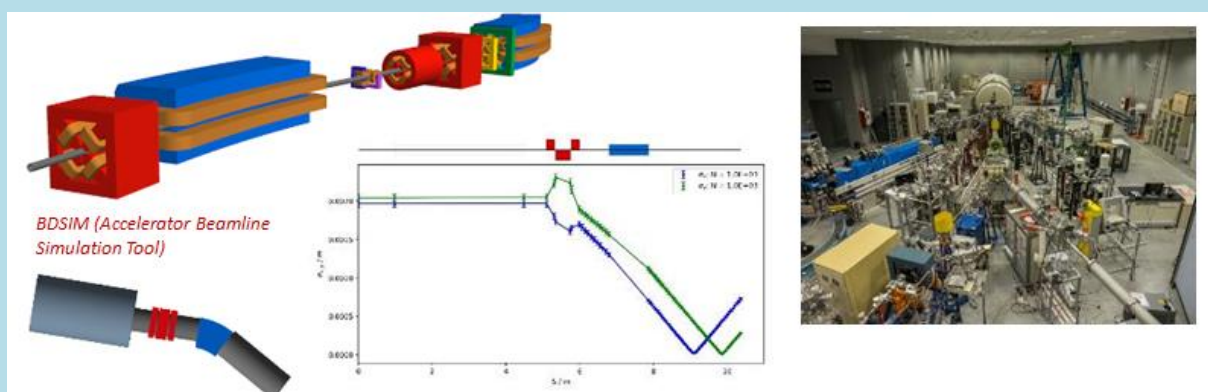
Beam dynamics studies aim at the analysis of the beam acceleration and transport under the different electromagnetic fields produced by the accelerating structures and focusing elements integrated in an accelerator. By optimizing the properties of such components, an optimum output beam can be obtained according to the user requirements. This hands on lab will be held at the CMAM electrostatic ion accelerator, devoted to the analysis and modification of materials.

During this lab, the students will be introduced into the beam dynamics of particle acceleration, according to the following scheme:

- Introduction to main concepts of beam dynamics
- Description of the BDSIM (Accelerator Beamline Simulation Tool) software for beam dynamics studies
- Calculation of beam dynamics of CMAM accelerator using BDSIM code
- Comparison with experimental results

MATERIAL:

- Computers with BDSIM code already installed
- CMAM accelerator lines
- PPT presentation with explanations and guiding remarks

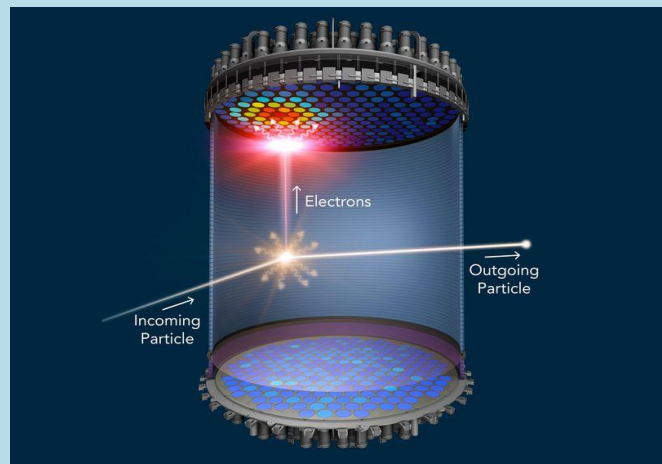
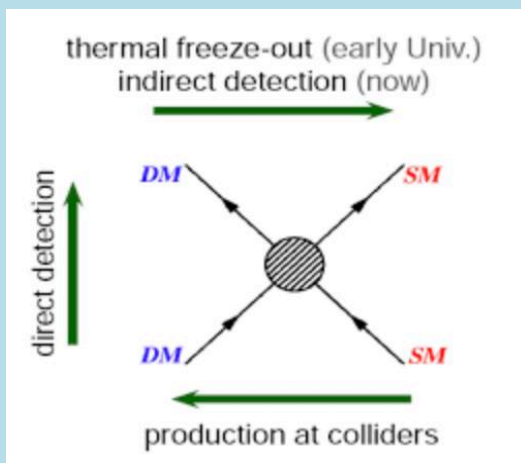


Can we feel the dark matter? Dr. David Cerdeño (UAM)

Dark matter particles from the Milky Way halo are passing through our bodies in large amounts. Yet, we are completely unaware, as they do not seem to produce any effect that we can feel. In particle physics terms, this happens because the interactions between dark matter particles and ordinary ones are very weak. In this laboratory we will further investigate into this question: considering the human body as some sort of detector, is there any way that we can observe (feel) the dark matter? If this is not the case, what kind of experiment would we need to design?

The laboratory will include:

- Studying and discussing the properties of the dark matter in the Milky Way
- Reviewing different dark matter interactions with ordinary particles
- Learning about detection techniques and calculating the rate of dark matter interactions
- Simulating an observation in the SuperCDMS detector



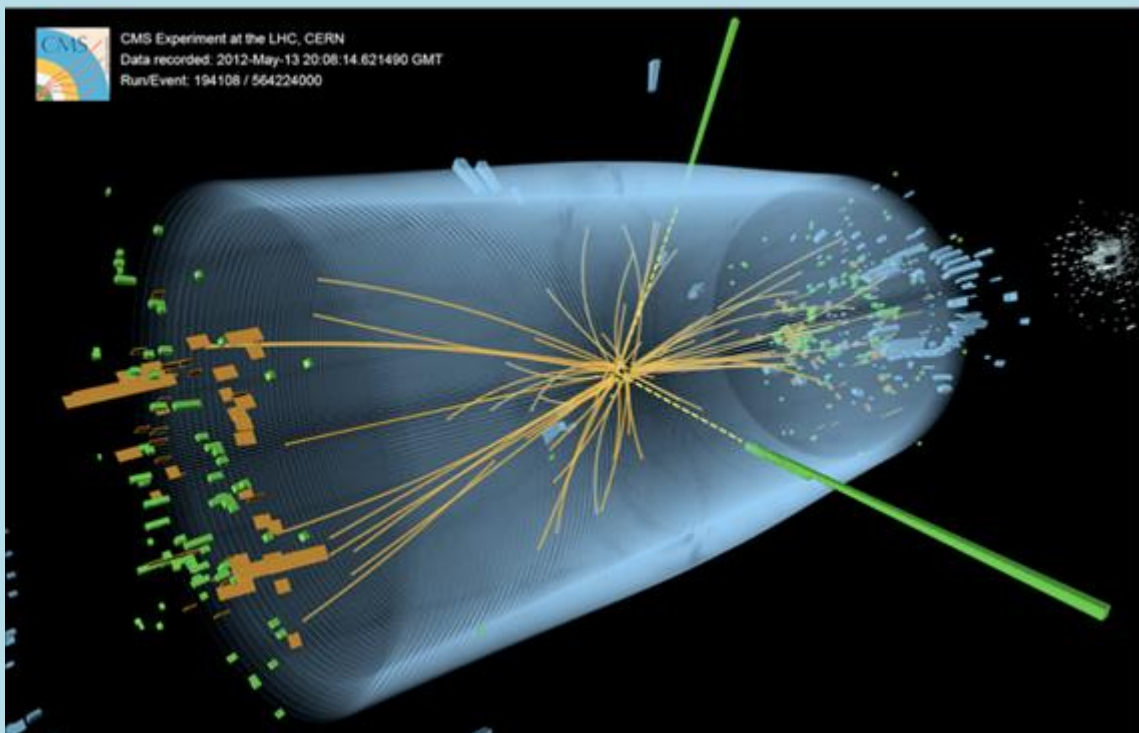
Higgs physics in the Standard Model and beyond

Dr. Sven Heinemeyer (IFT-CSIC)

The Higgs boson is a key piece in the Standard Model (SM) building. In this lab we will first recall the formulation of the Higgs mechanism in the SM and discuss why the theory requires the presence of a particle with Higgs-boson characteristics for its consistency. Then we will reflect on the naturalness problems associated with the Higgs sector and possible cures. Finally we will discuss the modification of the Higgs sector in theories beyond the SM, focussing on supersymmetric theories. In that context we will evaluate the supersymmetric prediction for the Higgs mass in the Minimal Supersymmetric Standard Model (MSSM)

The lab will include

- * Formulation of the Higgs potential and the Higgs mass in the SM
- * The Higgs sector in the MSSM. Higgs potential in the MSSM and mass matrices for the Higgs states
- * Estimation of the quantum corrections for the mass of the Higgs boson in the MSSM
- * Stop masses to get the experimental value of the Higgs mass (125 GeV)



Fundamentals of Parallel Programming using Intel Architecture and Software Tools

Rogério Iope

São Paulo State University (UNESP)

- This hands-on training program aims to offer a comprehensive, practical introduction to the fundamentals of parallel programming. By using Intel architecture and software tools, attendees will learn how to achieve the full processing power of modern multi/many-core architectures.
- Session 1 starts with a brief discussion of the fundamental concepts of parallelism and an overview of the small-size HPC cluster that will be used. Hands-on activities begin with detailed instructions and examples on how to compile and execute trivially simple C/C++ programs.
- In Session 2, attendees will explore the various levels of parallelism: data parallelism through vectorization, shared-memory parallelism with OpenMP (Open Multi-Processing), and distributed-memory parallelism with MPI (Message-Passing Interface) through a high-speed network.
- During the hands-on activities, the trainees will be exposed to code optimization techniques, which will show them how to achieve the highest possible utilization of all available cores of a modern multicore server and how to efficiently use its memory subsystem.

Pictures of the small-size HPC cluster (I)



Pictures of the small-size HPC cluster (II)



Quantum Lab: Enjoying the IBM quantum experience
Lecturers: Esperanza López and Germán Sierra (IFT, CSIC)

Abstract: In May 2016, the IBM company provided cloud access to a variety of quantum computers. They are still small and noisy, but can be used to learn the basic concepts and techniques of quantum computation and information.

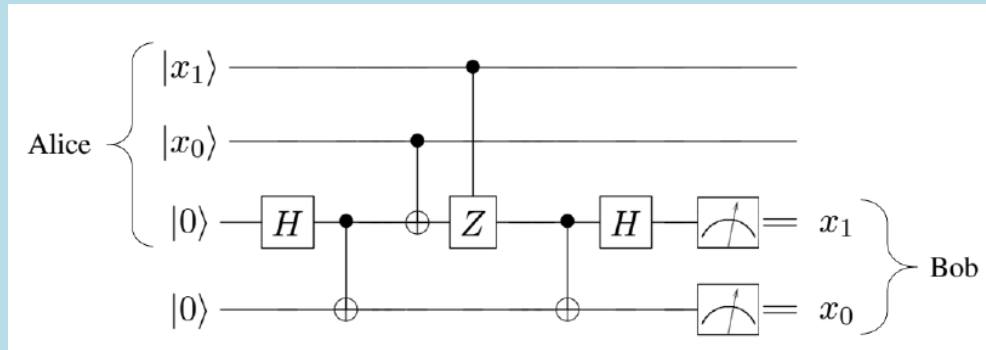


Left: It shows the circuitry of one of the first IBM quantum computers made of 5 qubits (Q_i), the 5 Readout lines (R_i) of the qubits and the connections B_1 and B_2 between qubits that define the topology. Right: A graphical representation of the topology of this quantum computer prototype. In this design, an arrow indicates a Controlled NOT, CNOT(*) gate between a control qubit (origin) and a target qubit (end).

In this lab we will show how to program and run some of the IBM quantum computers through the following examples:

- Dense coding is a protocol that allows two bits of classical information to be transmitted between two partners (Alice and Bob) that share an entangled pair of qubits (EPR) by performing local operations on just a single qubit (Alice's) of the entangled pair, which is then eventually sent to Bob.
- Quantum Fourier is a basic unitary transformation in the field of Quantum Computation. It will be implemented for three and four qubits.
- Quantum copying machine. The no-cloning theorem forbids the perfect duplication of an arbitrary qubit state. However, one can produce two imperfect copies with a quality that is independent on the state.
- The prime state is the superposition of all the computational-basis states that correspond to prime numbers up to a certain value $N = 2^n - 1$. We describe the circuits that generate the states for $n=3$ and 4.

- Variational quantum eigensolver: It is a quantum/classical hybrid algorithm that can be used to find eigenvalues of a matrix. We shall consider simple examples from quantum chemistry.



Example: Circuit for the implementation of dense coding.

(*) In computer science, the CNOT gate is a quantum logic gate that is an essential component in the construction of a gate-based quantum computer. It can be used to entangle and disentangle Bell states)

Requirements: a laptop and a personal account at <https://quantum-computing.ibm.com>

Location of this Lab: Instituto de Física Teórica (IFT) UAM-CSIC, Universidad Autónoma de Madrid Cantoblanco, C/ Nicolás Cabrera, 13-15, 28049 Madrid.