INFIERI

http://infieri-network.eu

INtelligent
Fast
Interconnected and
Efficient devices for Frontier Exploitation in
Research and
Industry

What is INFIERI?

INFIERI is an inter-disciplinary and multi-national **network, aimed to train young physicists and engineers** in developing, designing and managing intelligent devices and tools for cutting-edge applications in the fields of **Astrophysics, Particle Physics, Medical Physics**, and **Telecommunications**, also exploiting their technological spin-offs and cross-field synergies.

The network gathers leading academic institutes, European laboratories (NIKHEF, RAL), high-tech companies (PHILIPS, THALES) as full partners. Associated partners in Europe (CERN, several leading companies and Universities), the USA (FNAL, Purdue University, Tezzaron Semiconductor) and Korea (Seoul National University, SAMSUNG SAIT) bring advanced and complementary scientific and technological expertise.

Full Partners

Associated Partners

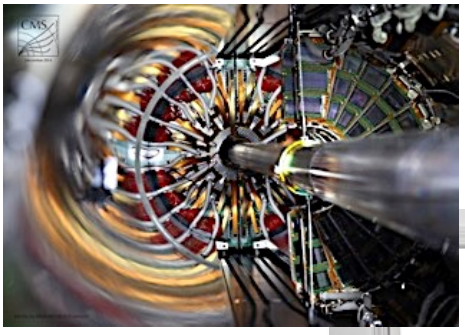
INFIERI Keywords

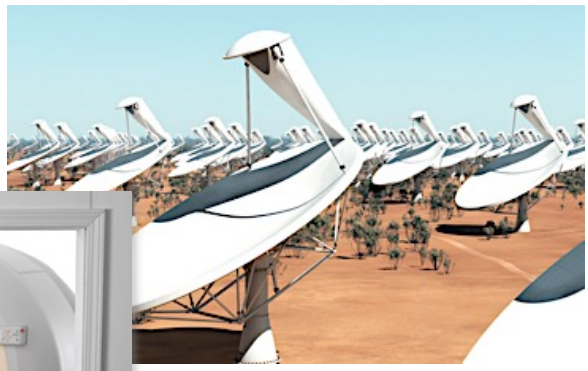
Astrophysics, Medical Imaging, Particle Physics, Very Deep Sub Micron CMOS Technology, 3D and 3D Interconnect novel Technologies, advanced Front End Processing, High Speed and High Flux Data Transfer, Real Time Algorithms, Massive Parallel and High Performance Computing.

INFIERI has received funding from the People Programme (Marie Curie Actions) of the European Union's - Seventh Framework Programme FP7/2007-2013/ under REA grant agreement n° [317446] INFIERI "INtelligent Fast Interconnected and Efficient Devices for Frontier Exploitation in Research and Industry".

INFIERI Research & Training Goals

The **Research & Training program** is focused on specific case applications, which require **innovative technical solutions** for an **extremely fast on-instrument signal processing,** a **proficient event selection phase,** an **efficient transmission** and a **final step of high-level data filtering:** these are the goals of the Research & Training of INFIERI. To achieve such goals the **project activities have been organized into nine work packages** (WP's).





The project started on February 1st 2013 and will last 4 years. It provided so far **19 job positions** (**14 Early Stage Researchers** and **5 Experienced Researchers**) to work and be trained on the topics covered by the project by internationally recognized leading experts in their fields from **Academy** and **Industry**. The EU Fellows are spending exciting **internships** in the network laboratories (including Industrial Firms) and being co-authors of the patents associated to their work. They are participating in the new series of **International Summer Schools** organized by the network with among the lecturers, from the network and outside, major world experts.

The highly multi-disciplinary approach provides the trainees with **unique ways of career development**, besides the opportunity to strengthen important research partnerships and establish new relationships with leading firms worldwide.

INFIERI has a special focus on knowledge transfer and dissemination.

The project will help Europe to maintain its leadership at the forefront of the top research fields and high technology domains it addresses.

INFIERI received **4.054 millions of Euros** as funding by European Commission, FP7 Marie Curie Action.

Contact: Aurore Savoy-Navarro: asavoy@cern.ch
More information : http://infieri-network.eu

APPLICATIONS

The three main applications on which the INFIERI program is focused are:

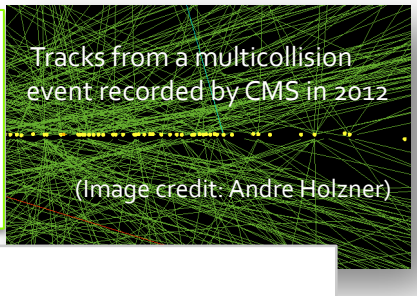
1. The **new ways to exploit the tracking system information** in **real-time trigger filters** for exploring New Physics in the harsh environment of the **Large Hadron Collider (LHC)** a**t CERN**, running at the highest luminosity in the next decade.

2. The **next largest terrestrial telescopes array data systems**, made of numerous detectors spread over kilometres, for **Astrophysics**.

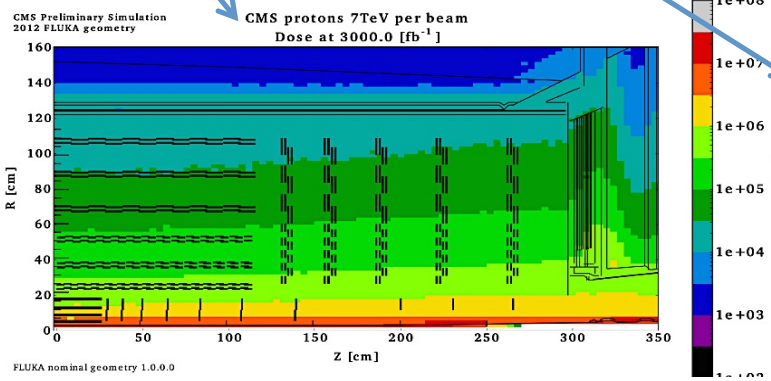
3. The use of **advanced Silicon sensors** and **Silicon photomultipliers technology** with **advanced data processing** for **Positron Emission Tomography** in **Medicine, Astrophysics and Particle Physics**.

High Luminosity LHC (HL-LHC)

HL-LHC (start 2025)
- **140-200 head-on collisions** at each crossing of the proton bunches: increase by a factor ~10/ current LHC

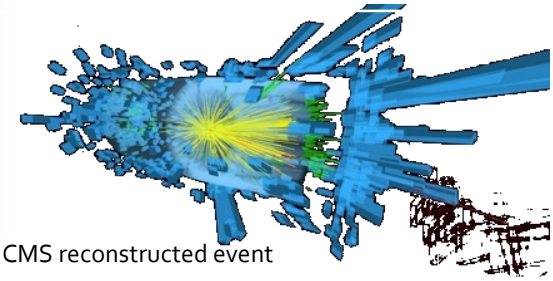


Challenges:
- extremely **fast** and **effective decisions** (triggering) to be taken at extremely **high rates: 40MHz readout rate; 0.5-1 MHz event rate; 12.5 μs latency for real time decision taking (Level-1 trigger)**
- **"intelligent" detectors**
- **information transfer** at unprecedented levels both in **size** and **speed**
- **high radiation** environment



Ex: New CMS Tracker (under development)
- 220m² silicon
- 48M strips and 217M macro-pixels
- 1 Giga-pixels for the vertex detector

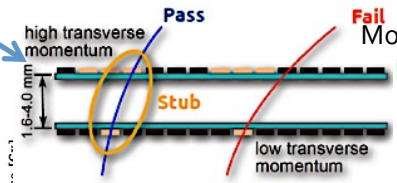
Physics Motivations:
- search for what lies beyond the Standard Model (BSM) of Particle Physics through
  - rare particle decays
  - particles predicted by BSM theories
  - deviations from expected SM behaviour
- measure the properties of the Higgs boson.



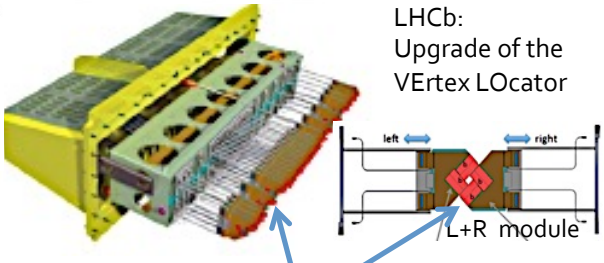
CMS reconstructed event

Large Area Si Tracking Systems (pioneered by CMS)

Huge digital camera: finely segmented silicon sensors (strips & pixels) enable **charged particles** to be **tracked** and their **momenta** to be measured. They also reveal the **positions** (vertices) at which long-lived unstable particles **decay**.



Module Design with High Momentum discrimination



LHCb: Upgrade of the VErtex LOcator

L+R module

Half Left VELO: 26 left modules

CMS: http://cms.web.cern.ch/
ATLAS: http:// ATLAS.ch/

LHCb: http://lhcb.web.cern.ch /
RD53: http://rd53.web.cern.ch/

ASTROPHYSICS: SKA & CTA

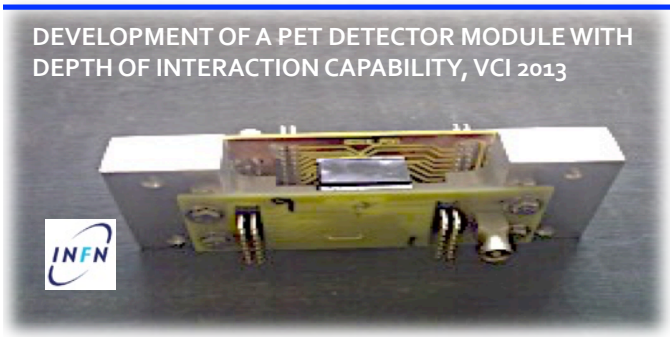
Scientific goals

- Origin of cosmic rays and their role in the Universe
- Nature and variety of particle acceleration around black holes
- Formation of large scale structure and the first luminous objects
- Origin of magnetic fields in the Universe
- Gravitational Waves from black hole mergers and possibly from the Big Bang
- Transient phenomena at very fast time scales (e.g. Bursts from Active Galactic Nuclei)
- Nature of Dark Energy and the limits of General Relativity
- Ultimate nature of matter and physics beyond the Standard Model

Advanced Technology

- A square kilometer of collecting area for each of three frequency bands
- SKA Low frequency 50MHz to 450MHz to be built in Western Australia
- SKA Mid and High frequency 450MHz to 14GHz to be built in the Karoo desert of South Africa
- Over 107 antenna elements. Digitization of over a million Radio Frequency signals
- Digital signal transport 100 times today global internet traffic
- Super computers with 10^{17} flops (operations per second) capability
- Exabyte data archive
- Two observatories to be built in the southern and the northern hemispheres, with arrays of telescopes of three sizes (Large: 24 m; Medium: 10-12 m; Small: 4-6 m)
- Large telescope frames built with composite material
- Schwarzschild-Couder aplanatic two mirrors optical system on some Medium and Small telescopes
- High speed sampling (1 GHz) of analog signals
- Signal synchronization at 1 ns accuracy over a square kilometer area
- Large usage of custom ASIC chips for digitization and signal conditioning

MEDICAL PHYSICS



Scientific Goals

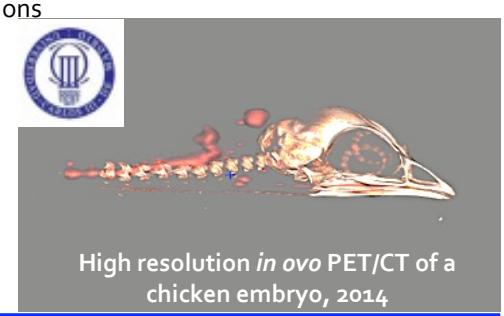
Modern Nuclear Medicine requires **efficient data reduction** based on a deep understanding of the physics underlying the imaging process, and on real time processing of the data stream produced by the sensors. **The quality of the diagnoses** depends on the imager capabilities for providing the best possible data. Major technological breakthroughs in the front-end detectors, electronics and data processing will have a direct impact on these outcomes.

Technologies developed in this project include:

- High sensitivity semiconductor light sensors for radiation detectors
- Single channel, light, portable devices with spectroscopic and dosimetry capabilities
- Multichannel data acquisition systems for advanced, high-throughput, high-resolution imagers, imaging systems
- Dedicated ASICs and FPGA-based systems for pattern recognition at the detector level
- Optical Wireless Communications (OWC) system for multimodality applications
- High-performance parallel processing for high quality image reconstruction

The scenarios selected to test and validate these technologies are:

- Handheld imagers used in Image Guided Surgery procedures
- Multimodal PET-MRI systems
- Dedicated (head, paediatric, whole-body…) PET imagers
- Very high-resolution (spatial and temporal preclinical scanners)



High resolution *in ovo* PET/CT of a chicken embryo, 2014

SKA: https://www.skatelescope.org
CTA: https://portal.cta-observatory.org/

MediPiX: http://medipix.web.cern.ch/

WORKING PACKAGES (WP)

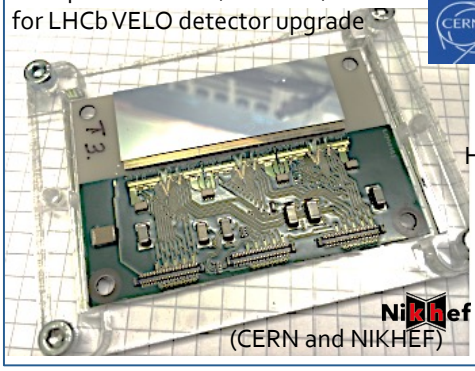
WP1: Intelligent Front-End (on-instrument) Processing

Goals and technological challenges

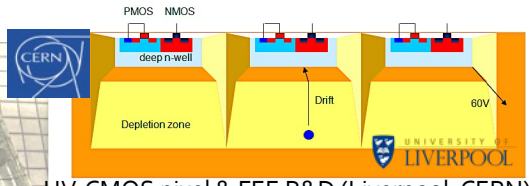
Develop advanced signal processing on the Front End Readout Electronics (FEE) on-detector for Astrophysics, High Energy Physics (HEP) and Medical Imaging Instruments for performing, in sometimes very harsh conditions, an **efficient data reduction** and **selection**, based on a **real time** understanding of the **Physics** and **diagnoses**.

This early stage decision making implies major technological breakthroughs, in the Front-End Electronics circuits based on advanced microelectronics that process the signals from Photomultiplier Tubes (PMTs) or **Silicon PM's** (SiPMs) and **Silicon sensors both based on most advanced technologies**.

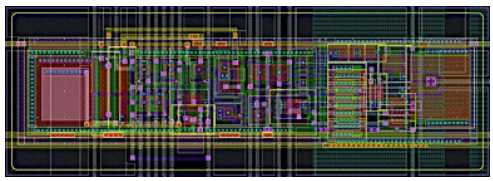
New pixel and FEE (VELOPIX) R&D for LHCb VELO detector upgrade

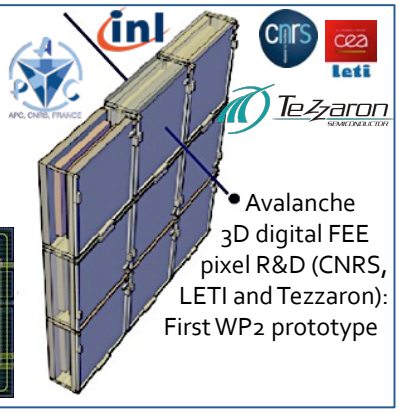


(CERN and NIKHEF)

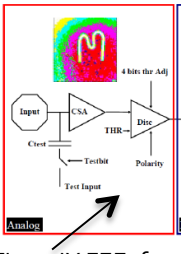


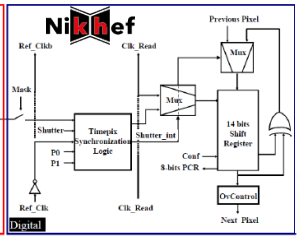
HV-CMOS pixel & FEE R&D (Liverpool, CERN)

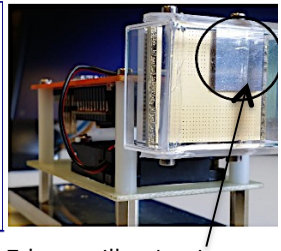




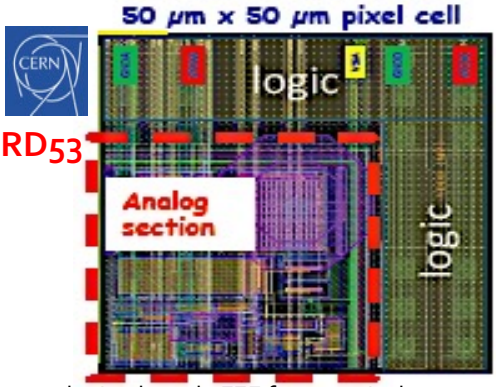
Avalanche 3D digital FEE pixel R&D (CNRS, LETI and Tezzaron): First WP2 prototype



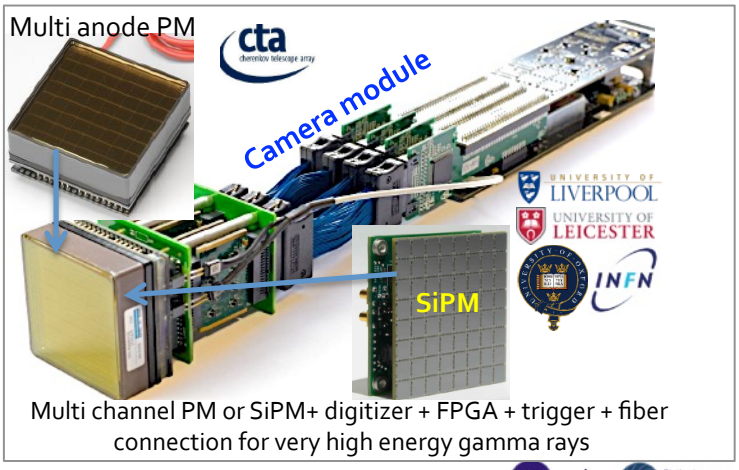




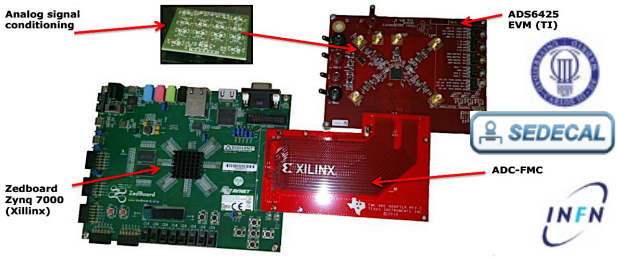
TimepIX FEE, from MedipiX ASIC, applied to Edge-on Illuminating photon counting pixel based detector for Computed Tomography



Advanced mixed-mode FEE for new pixels in 65nm CMOS (**CERN**, CNRS,FNAL, INFN, NIKHEF)

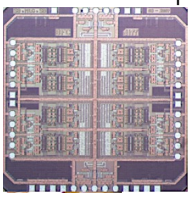


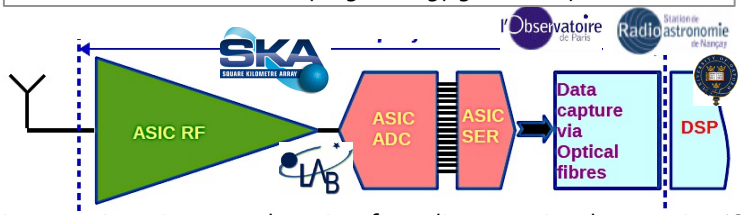
Multi channel PM or SiPM+ digitizer + FPGA + trigger + fiber connection for very high energy gamma rays



Full signal processing prototype for PET-MRI (UC3M, SEDECAL, INFN)

Beamformer chip



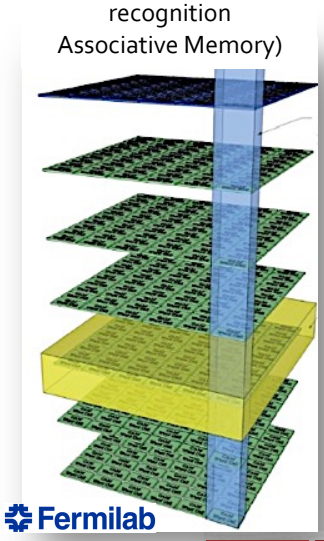


Aperture Array integrated receiver for radiowaves signal processing (Observatoire)

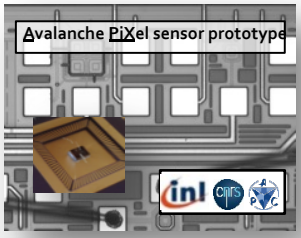
RD53: http://rd53.web.cern.ch/

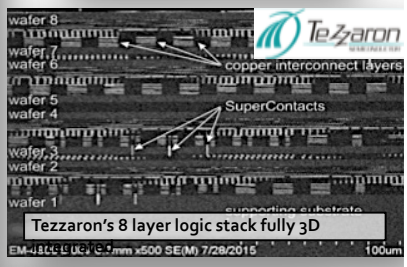
WP2: R&D and Applications of New Interconnect Technologies

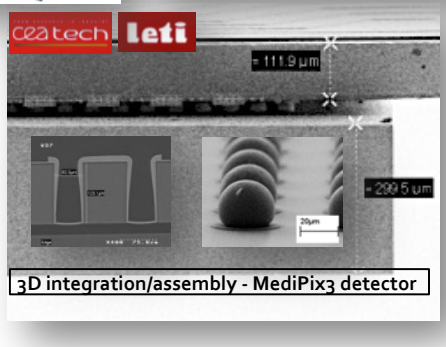
3D-VIPRAM (Pattern recognition Associative Memory)



WP2 INFIERI 1st prototype







Development of **3D** vertically interconnected devices:

"enabling **extreme compactness** and **very high speed** for future CMOS architectures"

3D Integration can create intelligent detectors and data processing elements with unprecedented capabilities.

A new intimate mixing of technologies, achievable only within 3D integrated circuits, permits **per-pixel processing** and evaluation circuitry that **reduces power and increases detector sensitivity**.

Entirely new advances in detector technology are made possible.

KEY TO SUCCESS:

Strong collaboration among partners

Academics: CNRS (APC and INL)
High-Tech Institutes and Firms: FNAL, CEA-LETI and Tezzaron Semiconductors

WP3: New Data Transmission Technologies

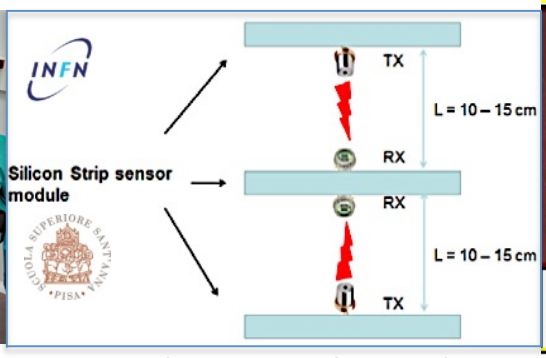
Goals: Transfer of data from detector modules to the far-end processors, High-rate data transfer, in harsh environments, is vital to future experiments and a number of real-life appplications:

WP3 targets unprecedented transfer rates with low mass, radiation hard devices, novel optical wireless communication, and, given the large number of data links, their interconnectivity.

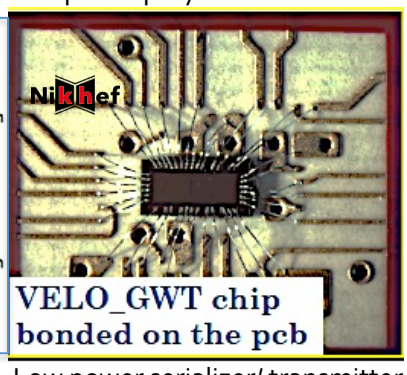
Explored Technologies:

- **Radio wireless links** with extremely high frequency technology. This relies on VDSM techno, low power 60 GHz transceivers as well as compact low mass directional antennas for 60 GHz.
- **Advanced optical fibre sensor technologies** for distributed and discrete monitoring of various parameters (strains, temperature, humidity, pressure etc.), in harsh environments.
- **Advanced Optical Wireless Communication** system solutions, using either visible or infrared for high data rate transmission, as a viable alternative to RF wireless for reliable and rapid deployment.

Handheld OWC for Medical Imaging



OWC signal transmission between layers of a Silicon tracking system



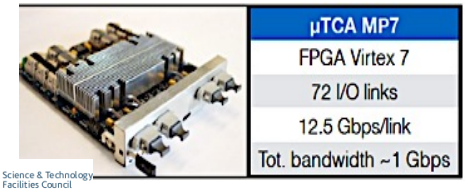
Low power serializer/ transmitter for VELO upgrade (LHCb)

WP4: Massive Parallel & High Performance Computing

The High Level Trigger of a **large area telescope system** will combine and appropriately handle the information from all the individual components (telescopes) of the network.
Innovative aspect for the **Medical application** includes a high level processing to treat the information delivered by the highly pixelated Imaging device.
HEP Level 1 Trigger will require matching the charged tracks with the calorimeter or the muon system information for identifying peculiar features of interesting Physics processes. It implies developing and testing the use of new advanced technology.

Mezzanine card with 16 Associative Memory (AM) chips linked to FPGA (INFN)

Advanced TCA board to locate A.M. mezzanine cards (FNAL)

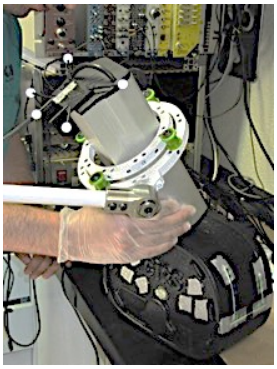


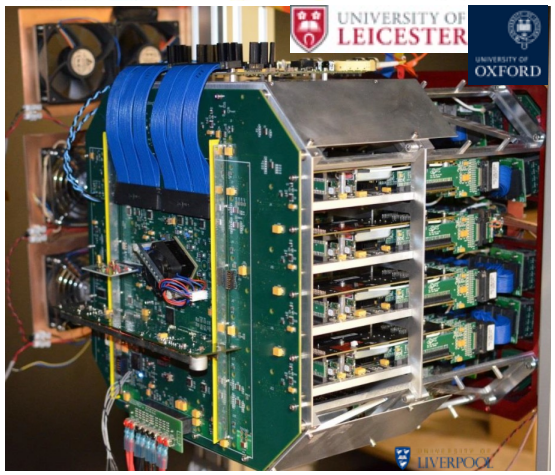
Science & Technology Facilities Council
Rutherford Appleton Laboratory

Track trigger demonstrator all-FPGA version with Virtex 7 in µTCA crates

INTEL Xeon Phi for Medical Image processing (Philips)

Intraoperative gamma-imager with real time signal processing





First Gamma Cerenkov Telescope Camera for CTA (Oxford, Leicester, Liverpool)

This WP is closely related to **Massive Parallel Computing developments (hardware & firmware)** and to **Advanced Telecommunications Computing Architecture** (ATCA).

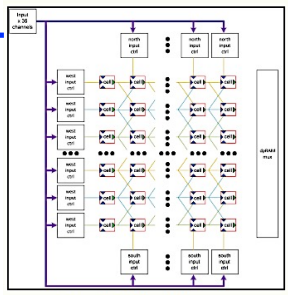
WP5: Advanced Tools

A series of tools of use for various WPs are **developed with the corresponding transfer of knowledge:**

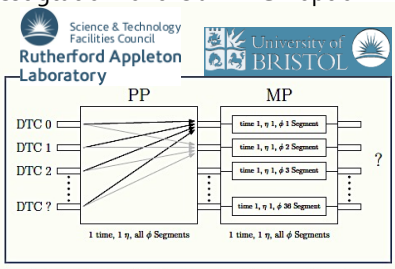
- **Kit tools** for design and layout of micro-circuits in Very Deep Sub Micron (VDSM) CMOS technology
- Different **simulation studies** and **real time algorithms**
- Complex **pattern recognition software** packages
- **Dedicated Lab test bench** with hardware and software based tools (including test beams) for characterizing specific components or technologies.

These tools are made **available via the complementary expertise among the ITN** including industrial partners.

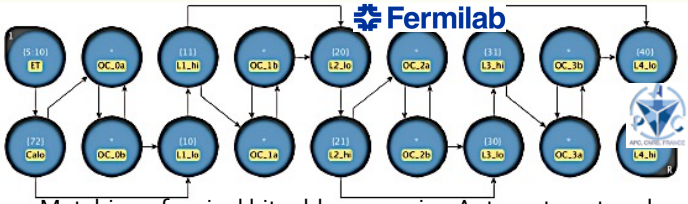
Two firmware under investigtation for the all-FPGA option



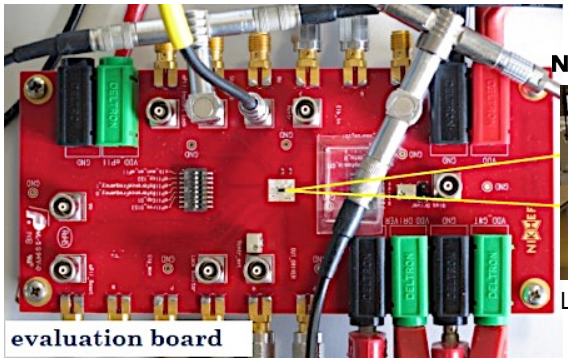
Systolic Array



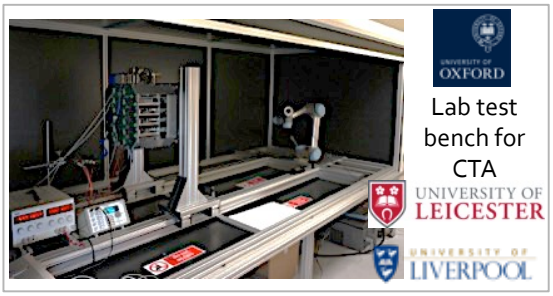
Regional Hough Transform



Matching of 4 pixel hit addresses using Automata network with new MICRON Automata Processor



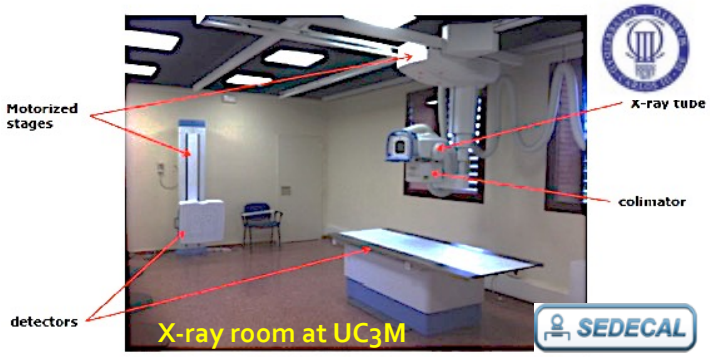
Lab test bench for GWT evaluation at NIKHEF



WP6: Realistic Test Platforms/Benches for system integration studies

- **Simulation based study of the system integration** related issues in each of the applications
- **Design and construction of a mock-up/demonstrator** of one or more components of the "intelligent data processing chain"
- **Lab test benches or test beams with these prototypes, mimicking the real-life** functioning of the component
- **Performance evaluations**
- **Important transfer of knowledge potential**

CTA Telescope prototype at Meudon



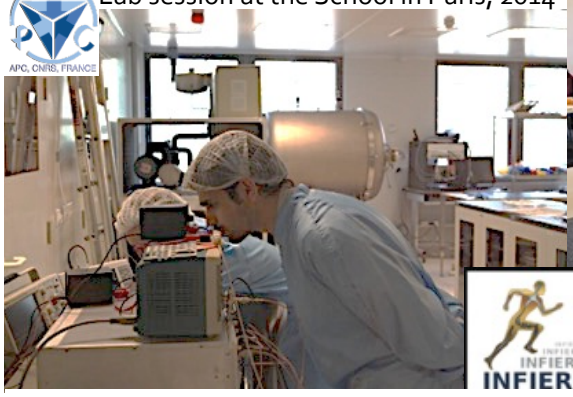
Test beam at CERN with telescope made of a set of Silicon detectors for testing new Pixels & Front End Microcircuit (ASIC).
(LHCb VELO pixel & VELOPix ASIC)

Preclinical imaging suite installed at Hospital Maranon, Madrid

The prototypes are based on novel technologies, thus developing & running the corresponding test benches imply using or building new hardware and software tools.

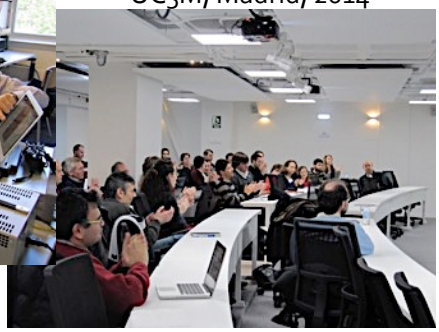
WP7 Knowledge Transfer

Lab session at the School in Paris, 2014



Lab sessions at the School in Hamburg, 2015

3rd INFIERI Workshop at UC3M, Madrid, 2014

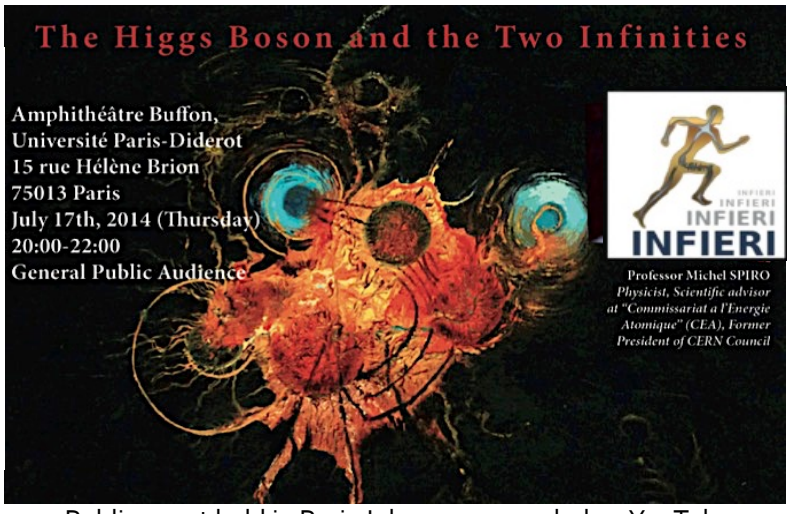


A core component of our vision is the knowledge sharing and transfer. To this aim **a new series of International Summer Schools** on ***"Intelligent Signal processing for Frontier Research and Industry"*** launched in Oxford, July 2013. gathers an international attendance and benefits from worldwide expert lecturers and Lab organizers. This series is part of the **INFIERI legacy**. **Biannual Workshops**, are a **forum** where EU fellows and all the INFIERI participants meet and share their work progress. The INFIERI fellows **training** also includes their **internship and secondments** to **both the academic and the industrial partners**.

6th INFIERI Workshop at Pisa, October 2015

WP8 Dissemination & Outreach

WP8 organizes the **dissemination** of the scientific results achieved by this project, as well as scientific **outreach** by undertaking external communication and promotional activities, including supporting work on science communication and public engagement.



Public event held in Paris July 2014, recorded on YouTube

Contact: Aurore Savoy-Navarro: asavoy@cern.ch
More information: http://infieri-network.eu

ENROLLED INFIERI EU FELLOWS

(Field, WP's, Host Institution)

G. Fedi
Particle Physics
WP1, WP4, WP5

L. Calligaris
Particle Physics
WP4, WP6

T. Dey
Medical Physics
WP4, WP6

A. García Fernández
High Performance & Massive computing
WP4, WP6

W. Lopes
WP4, WP6

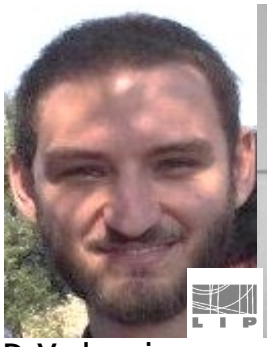
B. Nodari
Microelectronics
WP1, WP2, WP5, WP6

A. Sashala Naik
Applied Physics
WP1, WP4, WP5, WP6

M. Vignetti
Microelectronics
WP2, WP3, WP5, WP6

M. Doni
Medical Physics
WP1, WP5, WP6

E. Dall'Occo
Particle Physics
WP1, WP6



D. Vadruccio
Particle Physics
WP1, WP6

S. Poulios
Astrophysics,
WP1, WP4, WP5, WP6

E. Kostara
Medical Physics
WP4, WP6

G. Konstantinou
Medical Physics
WP1, WP3, WP5

A. Wajahat
Telecom Engine
WP3, WP5, WP6

A. De Franco
Astrophysics
WP1, WP6

D. Cieri
Particle Physic
WP4, WP5, WP6

C. Zhang
Astrophysics
WP1, WP5, WP6

K. Laurel
Astrophysics
WP1, WP6

INFIERI: some key numbers

19
Recruitments (14 ESRs & 5 ERs)

20
ER/ESR Publications as main authors

83
ER/ESR poster and talks at International Events

185
ER/ESR talks at collaboration meetings

~ 400
Publications co-authored by ERs and ESRs

2
Best Poster Awards won by ESRs at International conferences
IEEE-NSS 2015 Conference and ACAT 17th International workshop on Advanced Computing and Analysis Techniques in physics research

~ 20
Outreach events

1
Video clip per EU-Fellow

2
Brochures
1 general public, 1 scientific oriented public (in 7 INFIERI languages)

1
INFIERI YouTube channel

INtelligent **F**ast **I**nterconnected & **E**fficient devices
for Frontier Exploitation in **R**esearch and **I**ndustry

INFIERI

in fieri, in becoming, 되고 있는, à devenir,
aan de gang, em tornar-se, deviniendo

More information
http://infieri-network.eu

Contact: Aurore Savoy-Navarro
asavoy@cern.ch

The websites of the ATLAS, CMS, LHCb, CTA, SKA. MEDIPIX and RD53 collaborations herein referred to, are Experiments or R&D International Collaborations to which INFIERI members including EU Fellows are participating to.