Medical application readout electronics @ MicRhAu:

- Integrated Readout Electronics for Real-Time Ion Range Monitoring in Hadrontherapy
- Integrated Readout Electronics for 3 photon imaging System

Compton camera : Outline

- **Introduction : physics context**
  - Hadrontherapy
  - Compton camera system
  - Front End Electronics specifications
- **Compton camera Silicon Scatterer Integrated Circuit (SICASIC)**
  - Block diagram and architecture of a single readout channel
  - switched reset Charge Sensitive Amplifier (CSA)
  - test and characterization setup
- **Beam Hodoscope Integrated Circuit (HODOPIC)**
  - A complete system (final version?) :
  - composition and architecture of a single readout channel
  - tests and characterization of the design
- **Conclusions and outlook**

Compton camera : Introduction

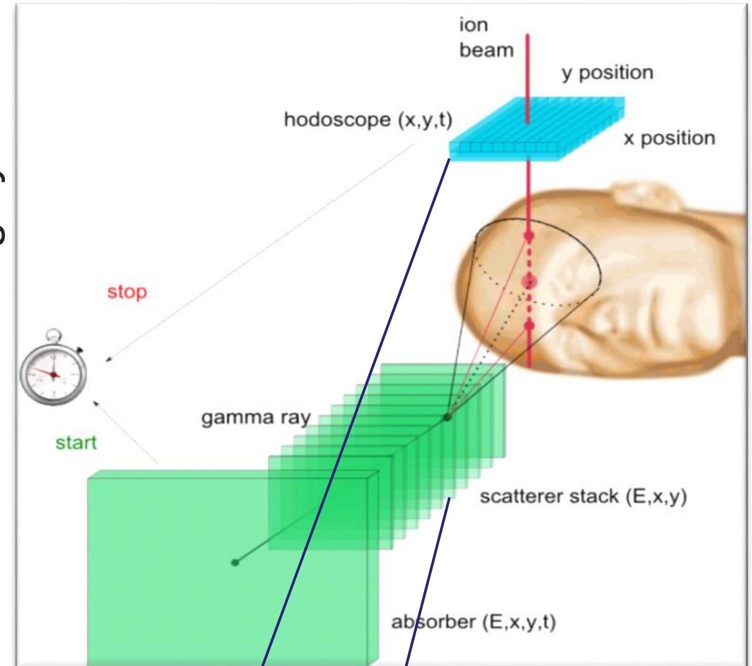
- **Hadrontherapy** is a radiotherapy technique which consists in irradiating tumorous cells with protons or ions :

  ➔ Prompt-γ can be used to monitor online the ion range

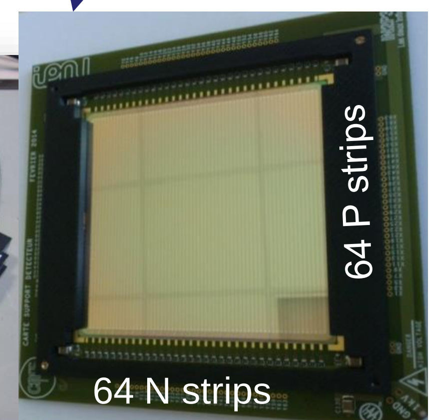
  ➔ **A Compton camera detecting system is expected to be a very efficient and fast technique for the online dose control and high resolved 3D image reconstruction**

- **In the proposed system,**
  - **the scatter detector :** a stack (10 plans) of 2 x 64 trips 2 mm thick Double-sided Silicon Strip Detector (DSSD) :
    - it provides (x, y, z, t) coordinates and the energy deposited by γ-rays in the silicon
  - **the beam tagging hodoscope :** an array of 2x128 scintillating fibers (1 mm x 1 mm) which are coupled to multichannel photomultipliers (PM) :
    - It provides position (x,y coordinates) and timing of the incident ions
    - goal : count rates up to 10^8 1/s

Online monitoring system

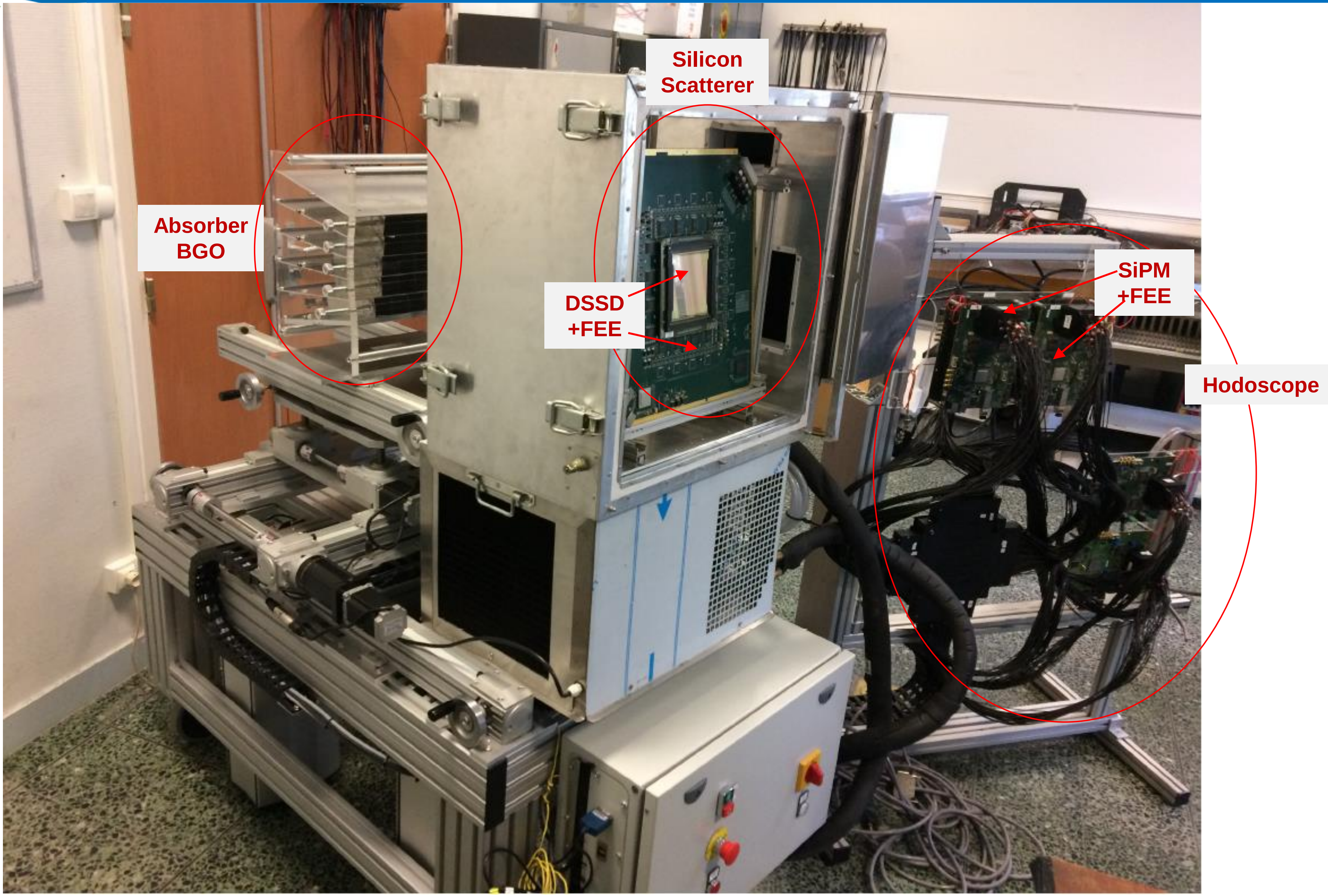


Hodoscope

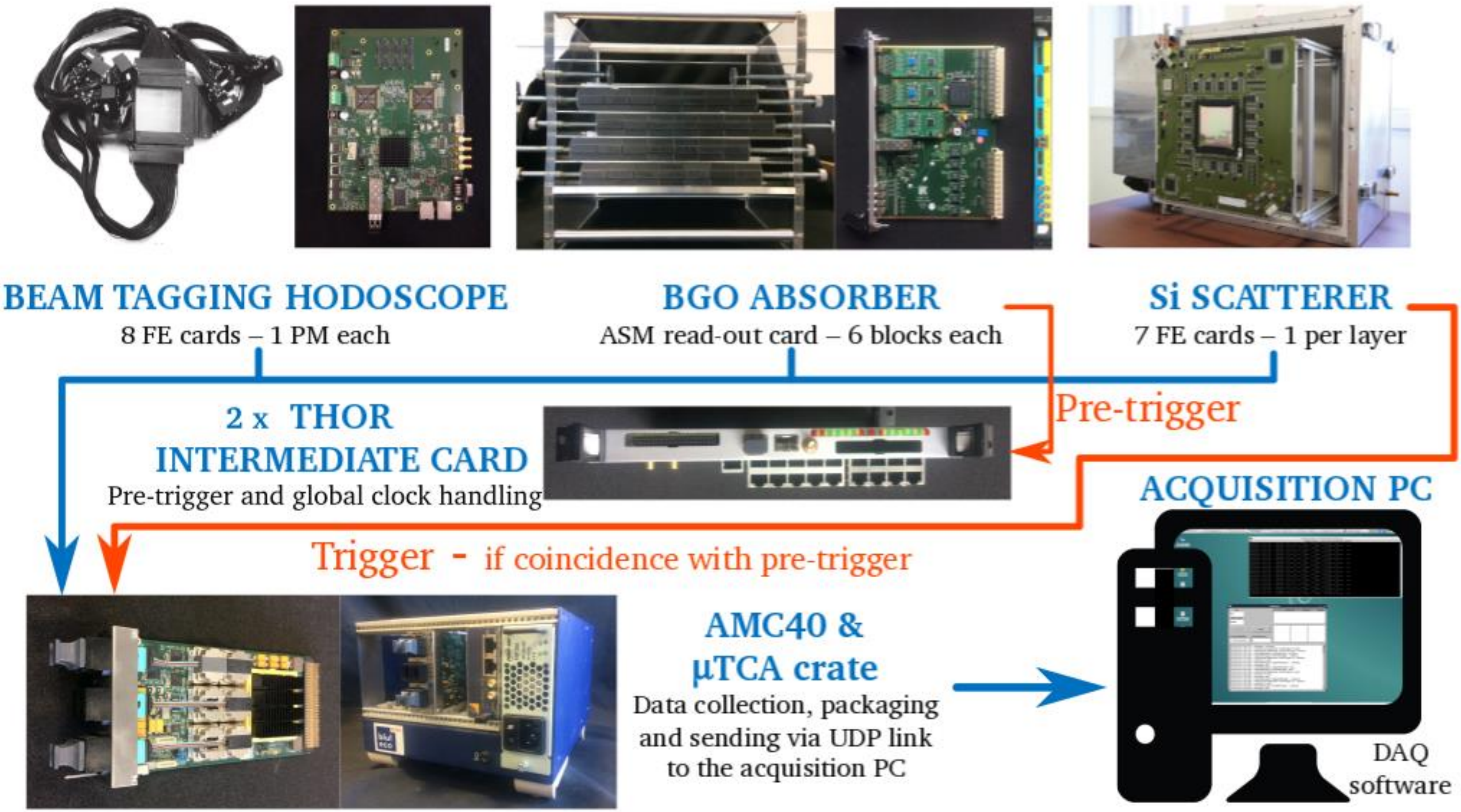


DSSD mounted on a PCB

Compton camera : setup

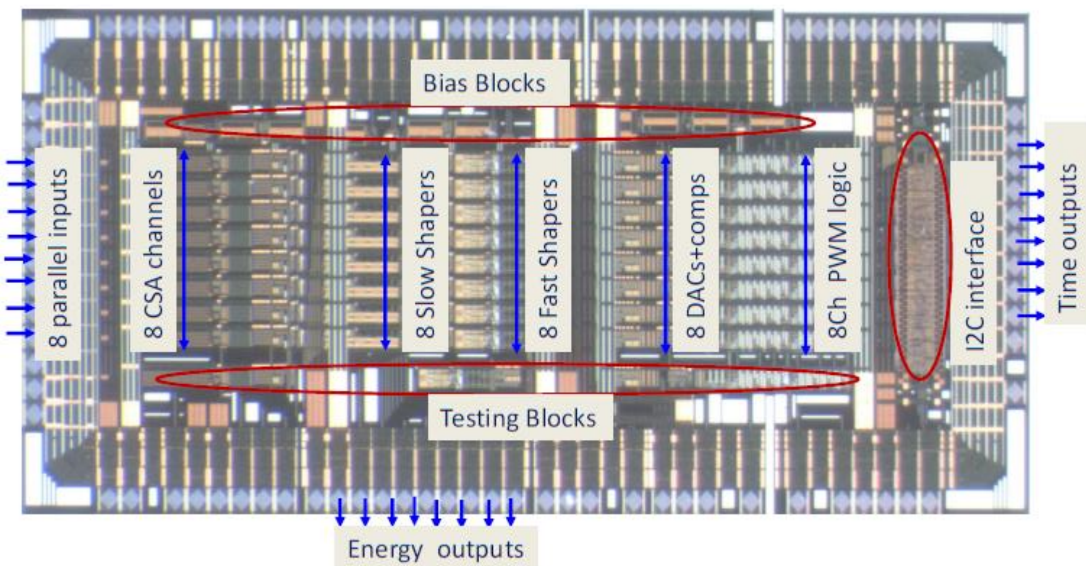


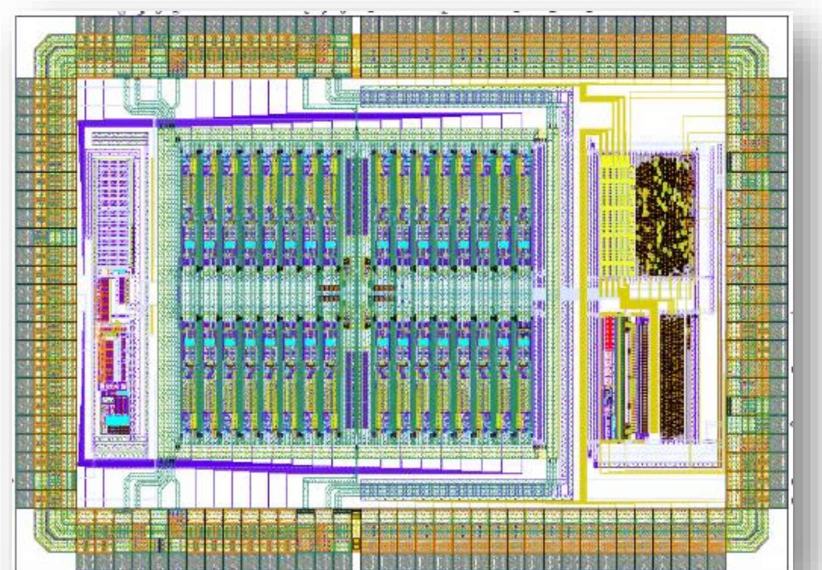
Compton camera : complete system



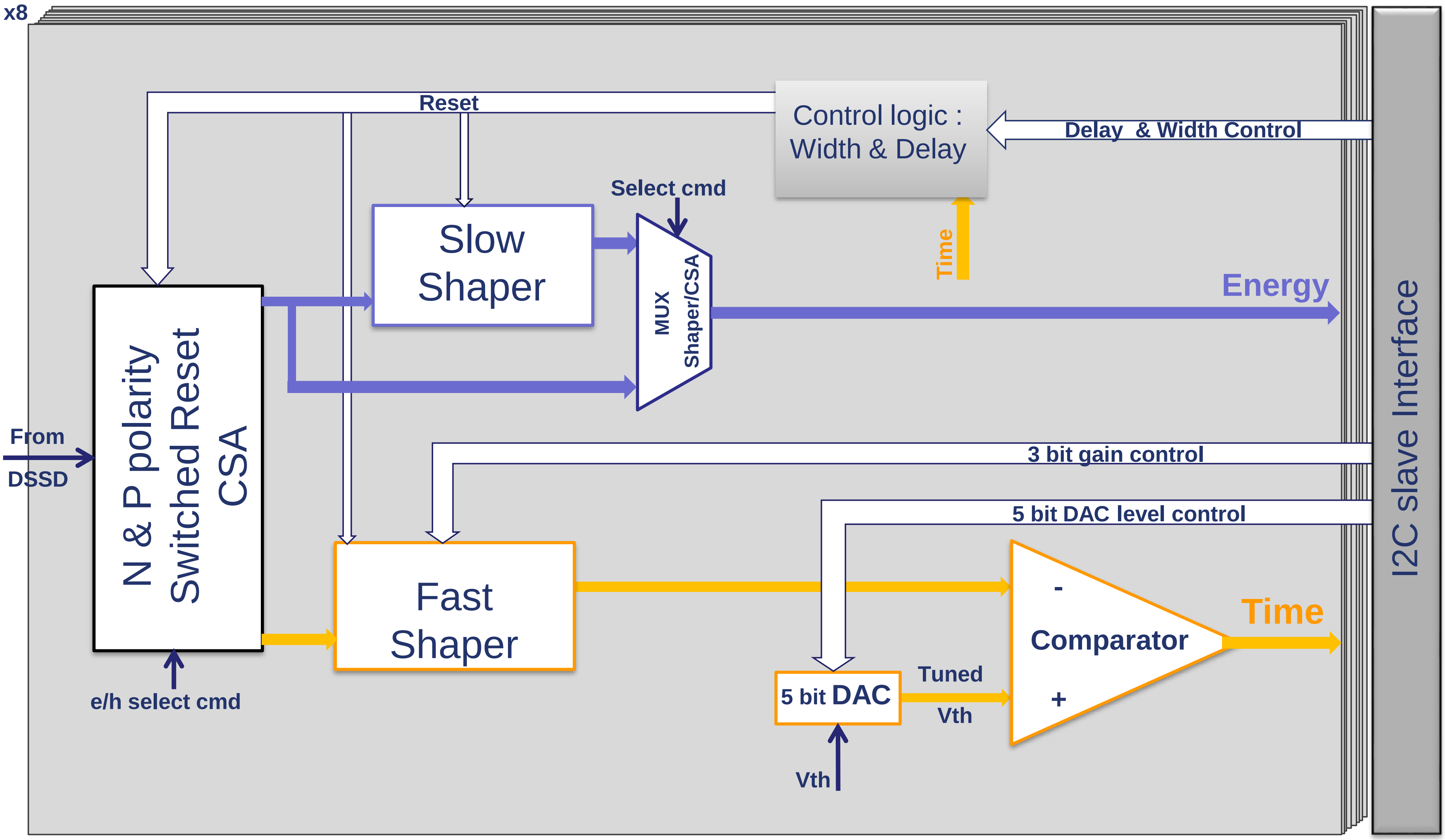
Compton camera : SICASIC and HODOPIC specifications

SICASIC : an ASIC for Silicon Scatterer	HODOPIC : an ASIC for beam Hodoscope
AMS CMOS 0.35 µm	AMS BiCMOS 0.35 µm
Double-sided SSD readout N and P polarities	Hamamatsu SiPM, 64 channels each (8x8 matrix)
(Cdet = 10 pF/strip)	65 pF/PAD
8 input channels	32 analog inputs (current mode)
0,48 fC (3 ke-) – 480 fC (3000 ke-)	200 µA – 1 mA
counting rate : 10^5 hit/s/strip	100 MHz max input rate
Noise : ENC = 120 e- rms	Time stamping resolution : 140 ps rms
Foundry 25 chips + Production of 200 chips	Foudery of 25 chips
Package MQFP100	Package CQFP120



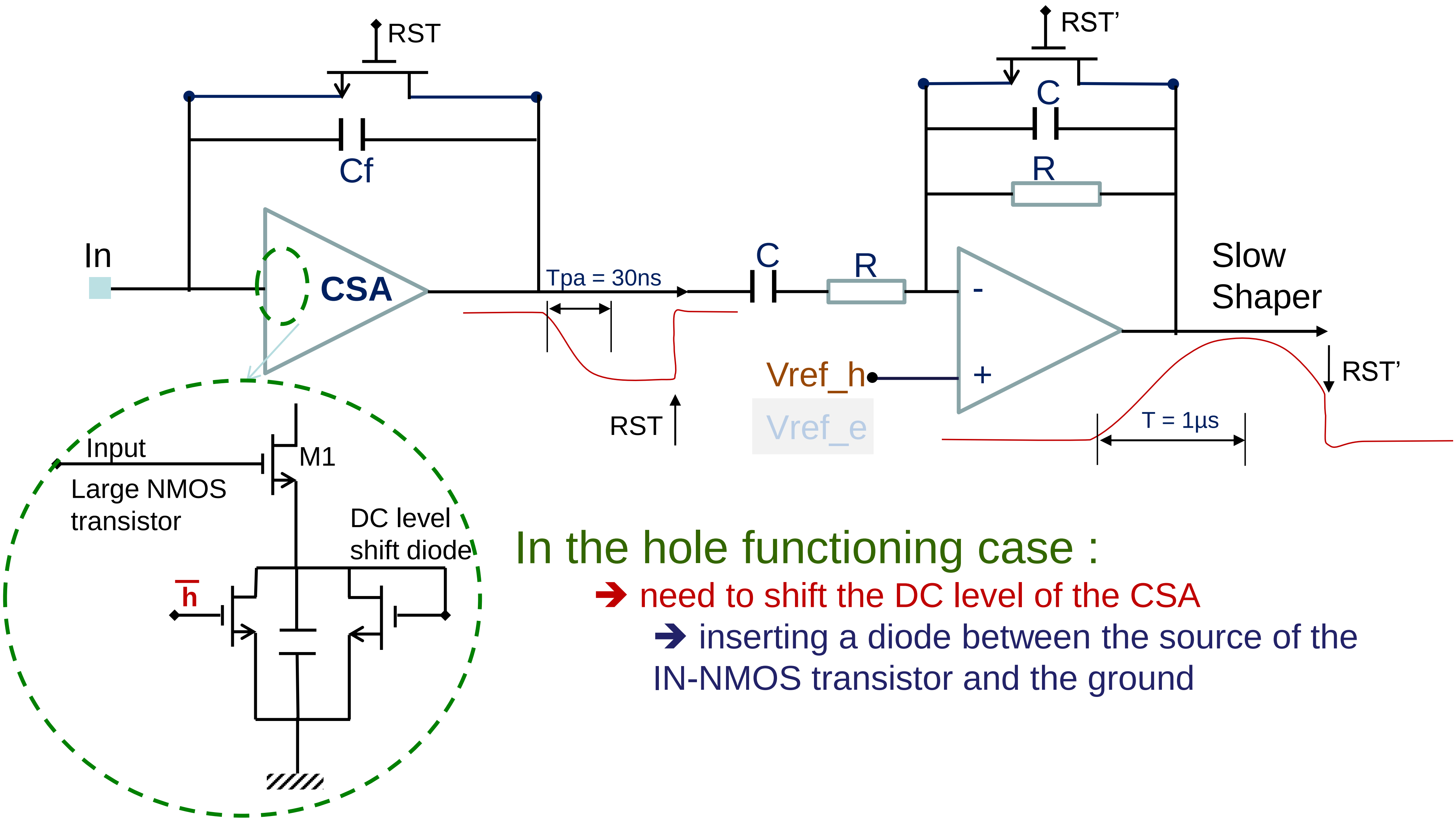


Compton camera : SICASIC block diagram



Compton camera : CMOS switch reset feedback of SICASIC

Energy path : hole readout configuration

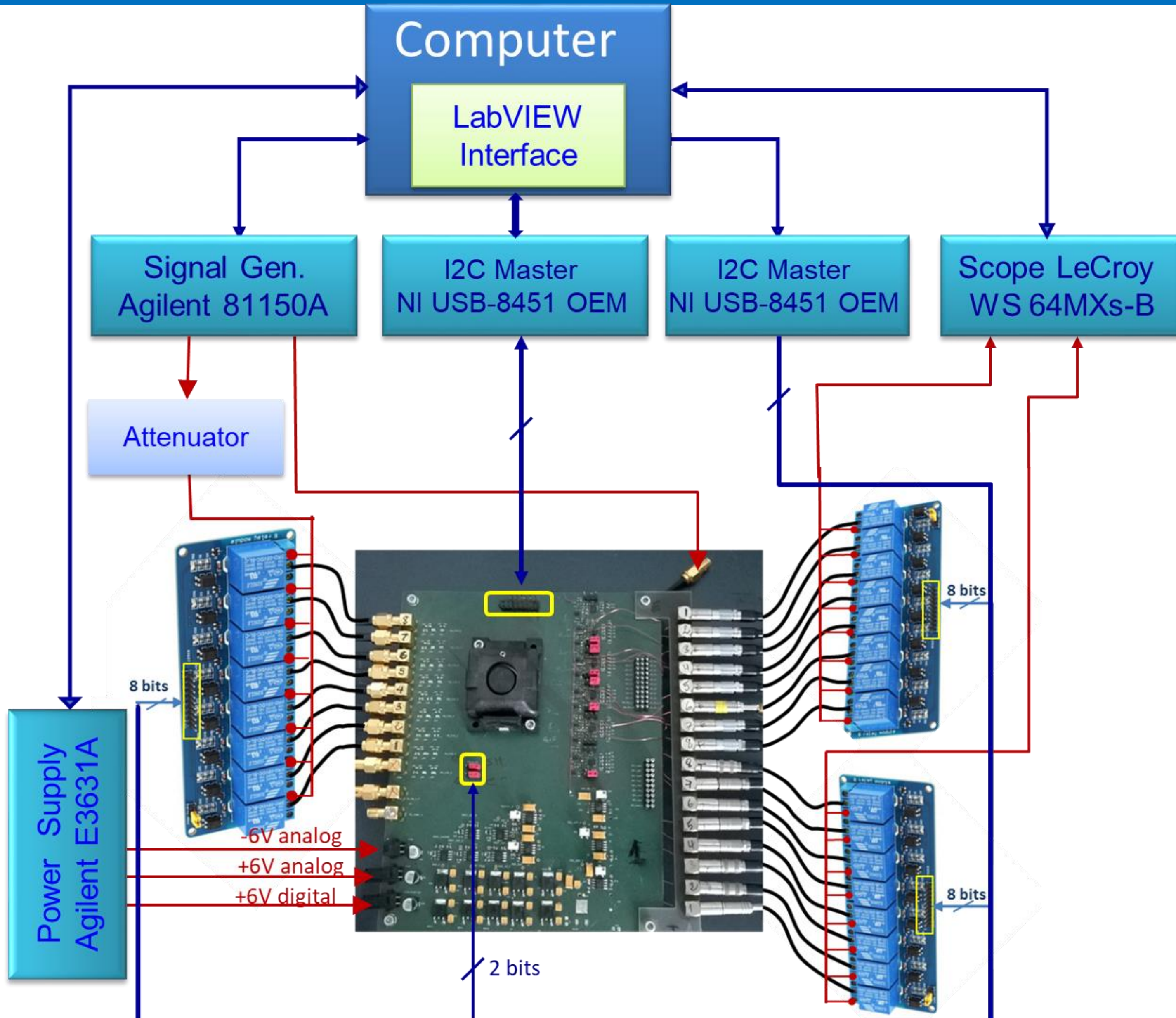


In the hole functioning case :

➔ need to shift the DC level of the CSA

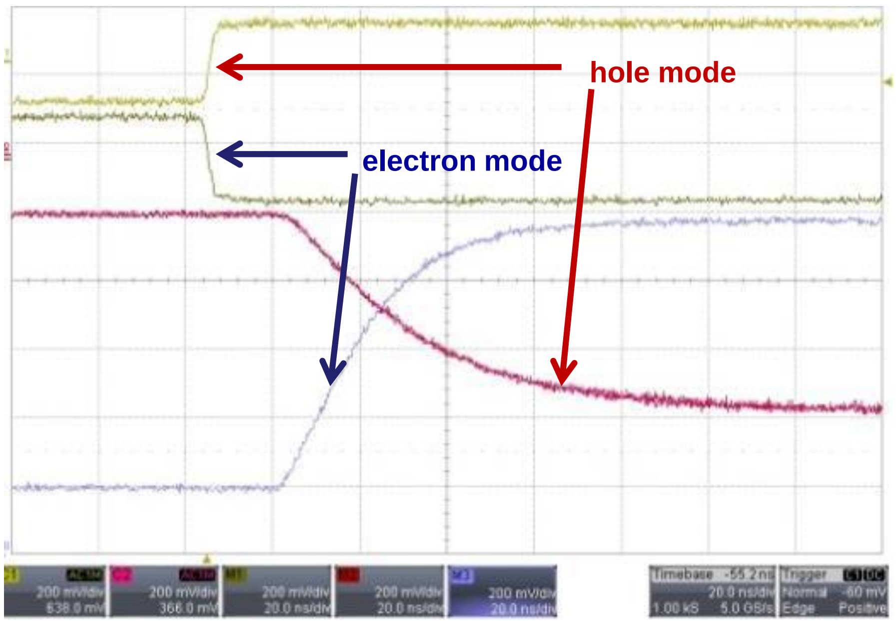
➔ inserting a diode between the source of the IN-NMOS transistor and the ground

Compton camera : SICASIC automated setup for series tests

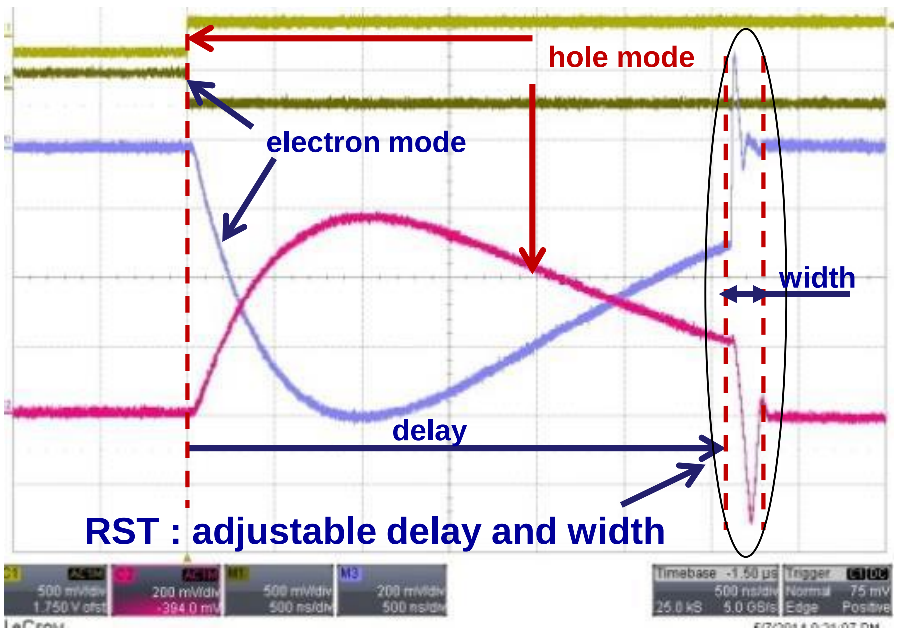


Compton camera : SICASIC test results (functionality)

Circuit response to a voltage pulse : CSA output



Circuit response to a voltage pulse : Slow shaper output



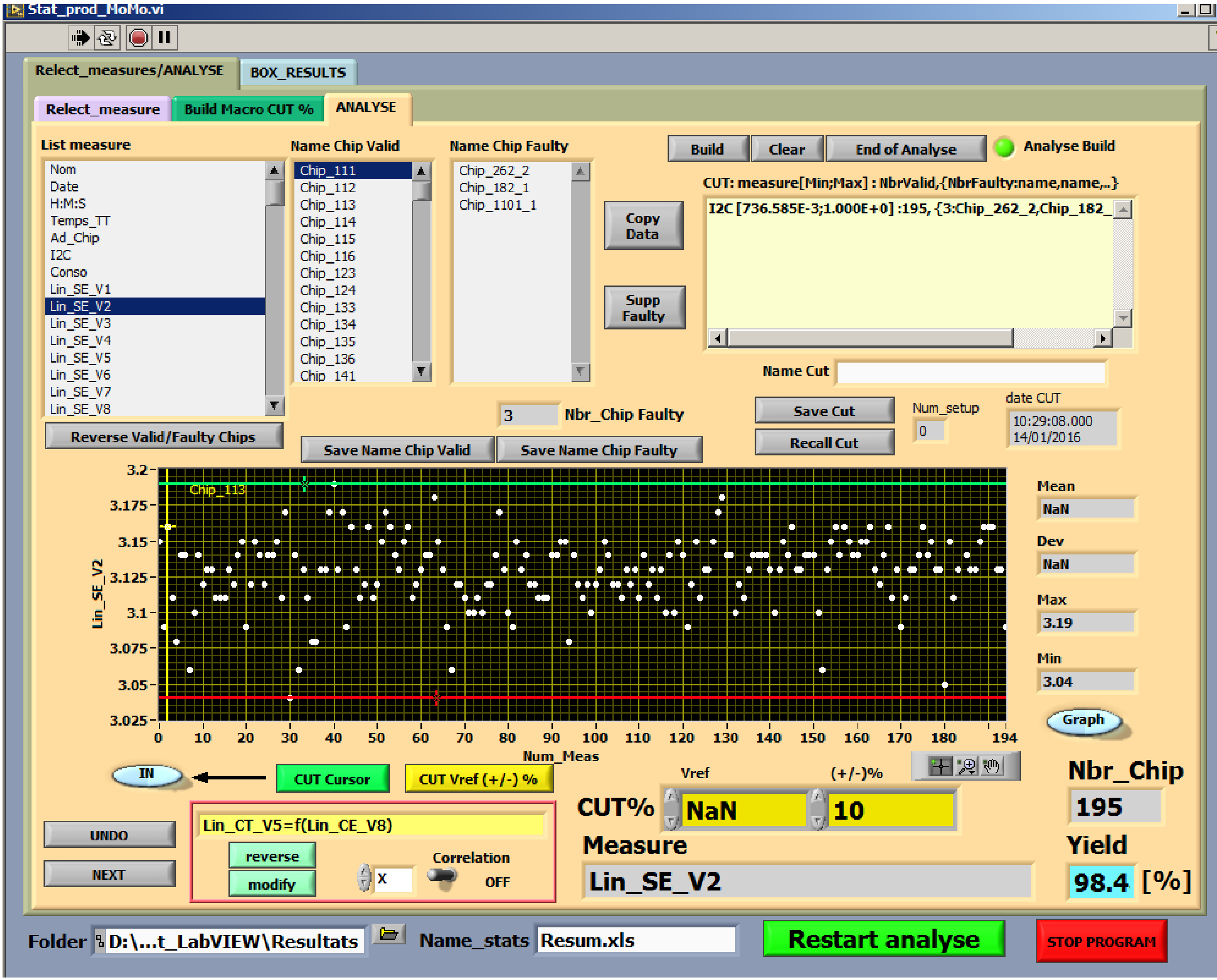
A scope snapshot of the circuit functioning for P and N polarities

- **The I2C bloc is controlled by a LabVIEW interface through a “NI USB-8451 OEM I2C/SPI” circuit**
- **The communication with the core of the ASIC has been successfully verified**

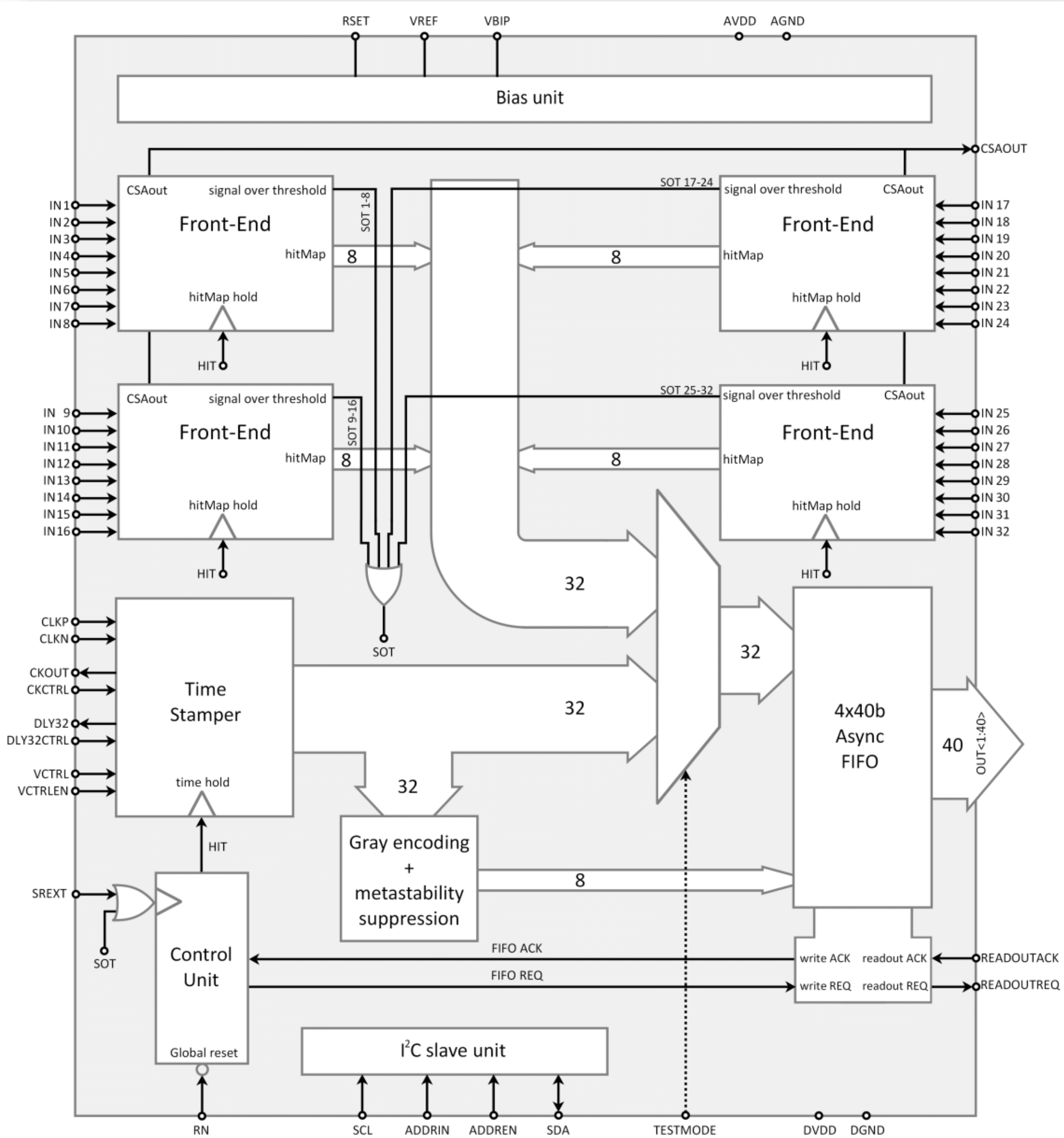
Compton camera : Result of series test of 195 SICASIC chips

- **Applying a filter (CUT) program to discriminate faulty ASICs depending on :**
- Power consumption
- Noise (ENC) for e- and holes signals
- Linearity of the analog signal (energy)
- Jitter of the digital signal (timing)
- I2C interface

Yield : 98,4%

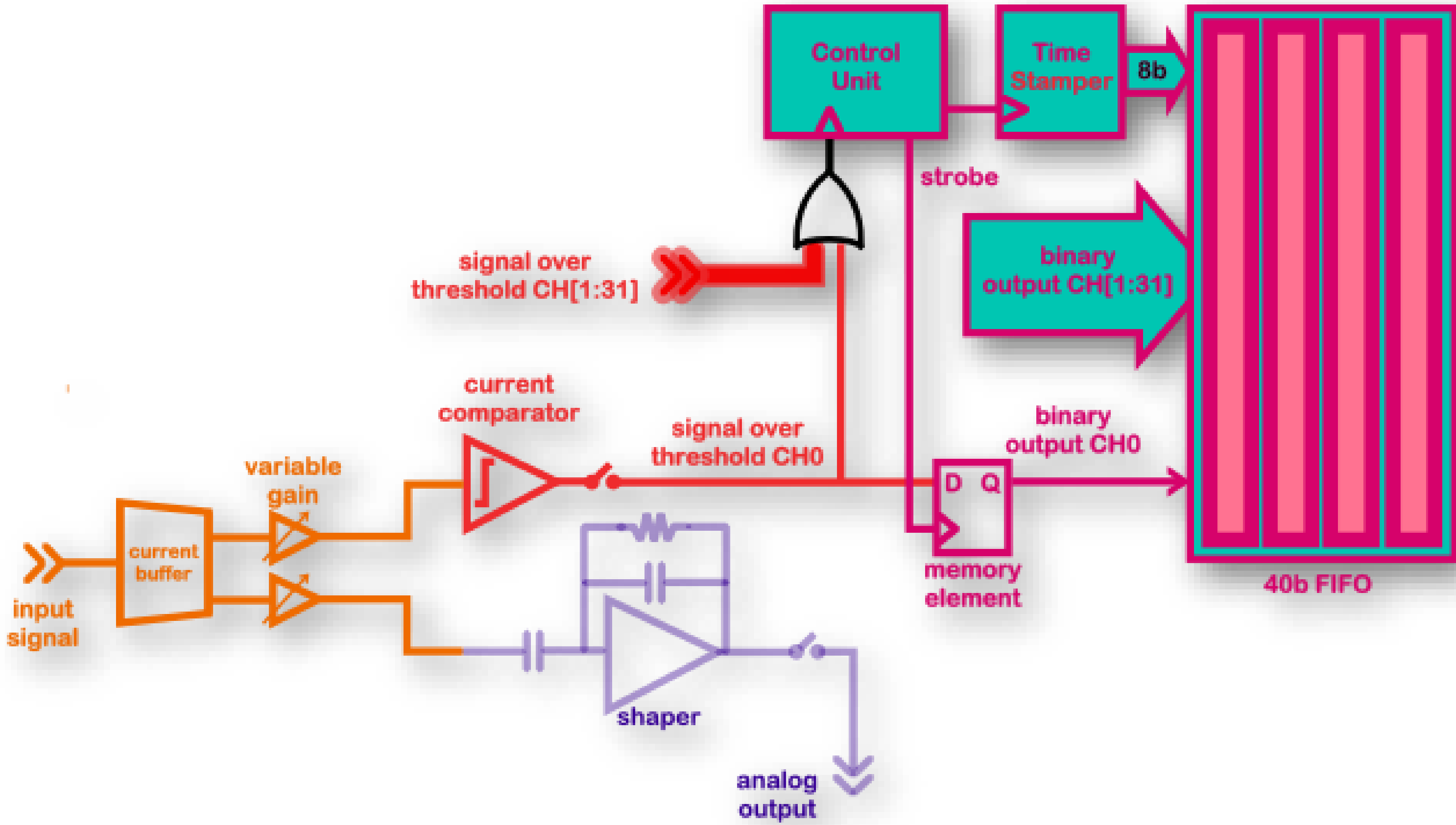


Compton camera : HODOPIC block diagram



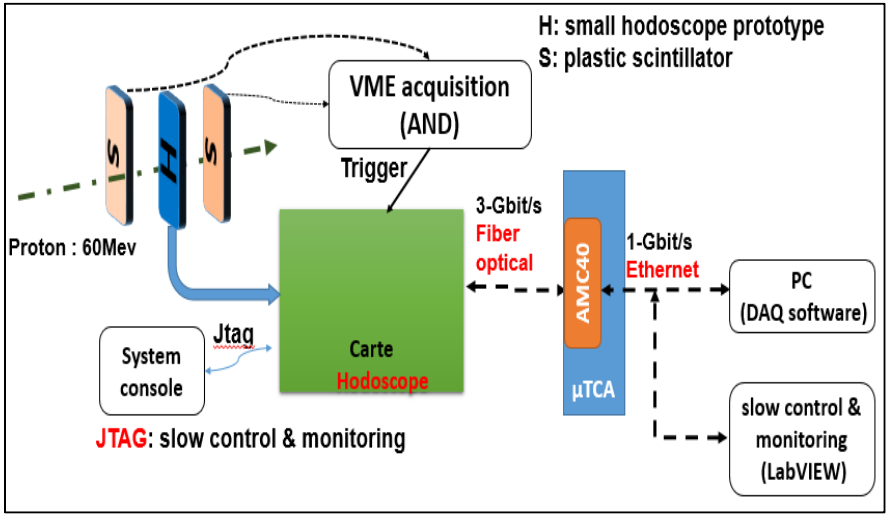
- **data driven front-end**
- **Front-End building block**
- **Time-Stamper building block**
- **asynchronous architecture**
- **internal storage in 4-level FIFO**

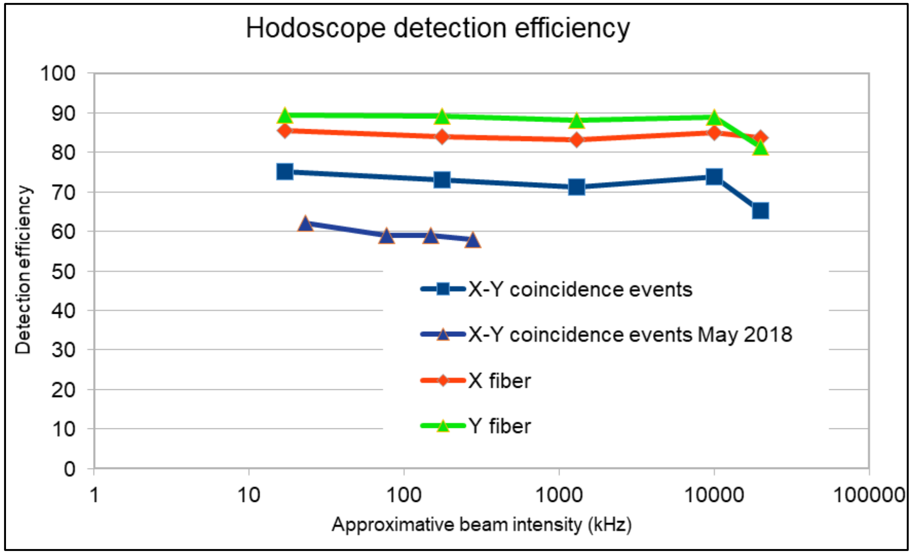
Compton camera : channel compostision of HODOPIC



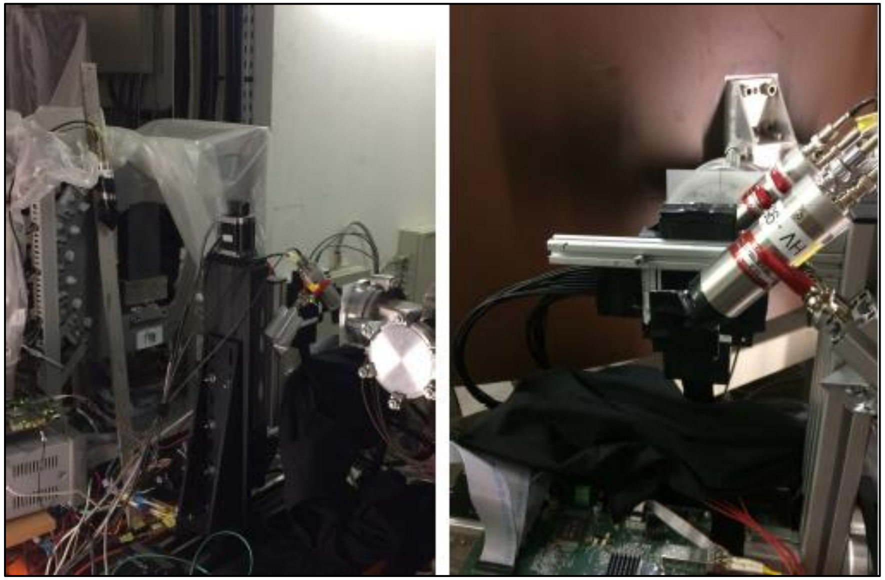
Compton camera : experimental measurements on proton beam at Centre Antoine Lacassagne Nice – March 2019

Experimental setup and data acquisition chain





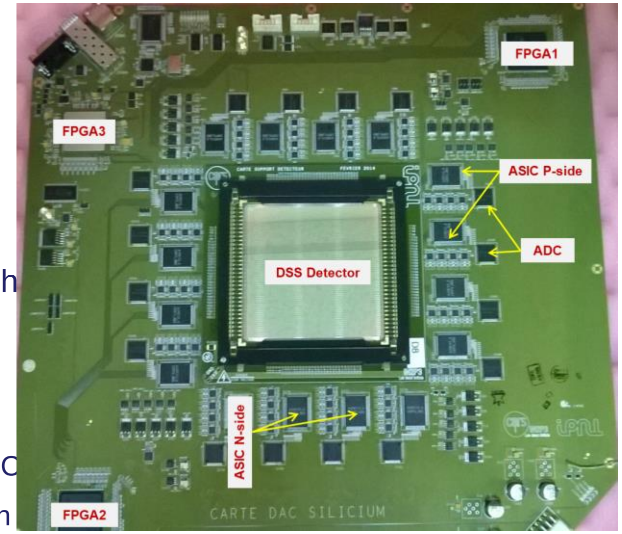
Nice Centre Antoine Lacassagne: 60 MeV protons



- Micro-structure with **proton bunches**.
- Bunch width is of ~**2 ns**
- Beam period is close to **40 ns.**
- Detection efficiency with singles is around 90% (close to the specifications).
- Detection efficiency with X-Y coincidence is **~75%** (frequency**<20MHz**).
- Detection efficiency improvement thanks to the **optimization of FE** board **gains and thresholds**.

Compton camera : conclusions and outlook

- **SICASIC :**
- An 8-channel CSA-Shaper was realized in 0.35 µm CMOS process of AMS
- 200 additional chips were produced, characterized and mounted on 7 planes of the Compton camera Scatterer
- To do :
- Developing of complete DAQ Firmeware and a user interface software in order to Characterize each one of the 7 planes
- Publication on this work:
- M. Dahoumane *et al*, " A Low Noise and High Dynamic Range CMOS Integrated Electronics associated with Double Sided Silicon Strip Detectors for a Compton Camera gamma-ray Detecting System" ; 2014 IEEE NSS/MIC
- M. Dahoumane *et al,* "A Low Noise and High Dynamic Charge Sensitive Amplifier-Shaper Associated with Silicon Strip Detector for Compton Camera " ; 2012 IEEE NSS/MIC



Hamamatsu SiPM

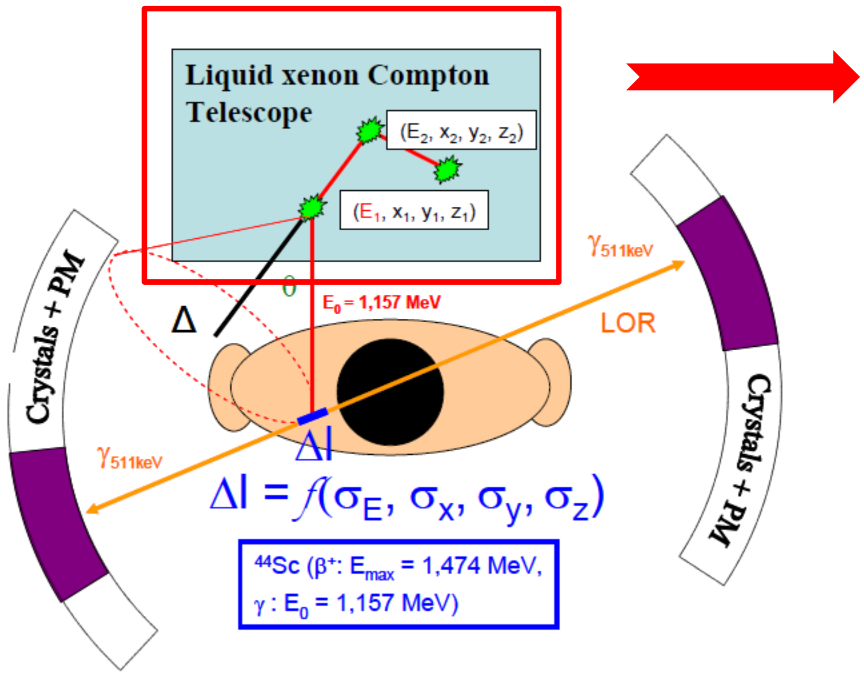
- **HODOPIC :**
- A 32 channel ASIC was realized in 0,35 µm BiCMOS process of AMS.
- 16 chips were mounted on 8 Custom electronics cards to readout 8 Hamamatsu SiPM of the Hodoscope
- Small hodoscope prototype ((32+32 fibers) characterization was achieved using only one FE card
- To do:
- Characterize the 7 remaining FE cards
- Synchronization of several FE cards and test of the 128+128 fiber hodoscope prototype
- Publication on this work:
- S.Deng *et al*,"Front-end, multi-channel pmt-associated readout chip for hodoscope application", NIM A, Vol.695, No.0, 2012

Xemis : Outline

- Introduction : physics context
  - 3 photon medical imaging system
- Xemis TPC Readout for Acquisition of Charge and Time (XTRACT)
  - Readout electronics specifications
  - Xtract block diagram
- Complete Readout Electronics system of Xemis
- Conclusions and outlook

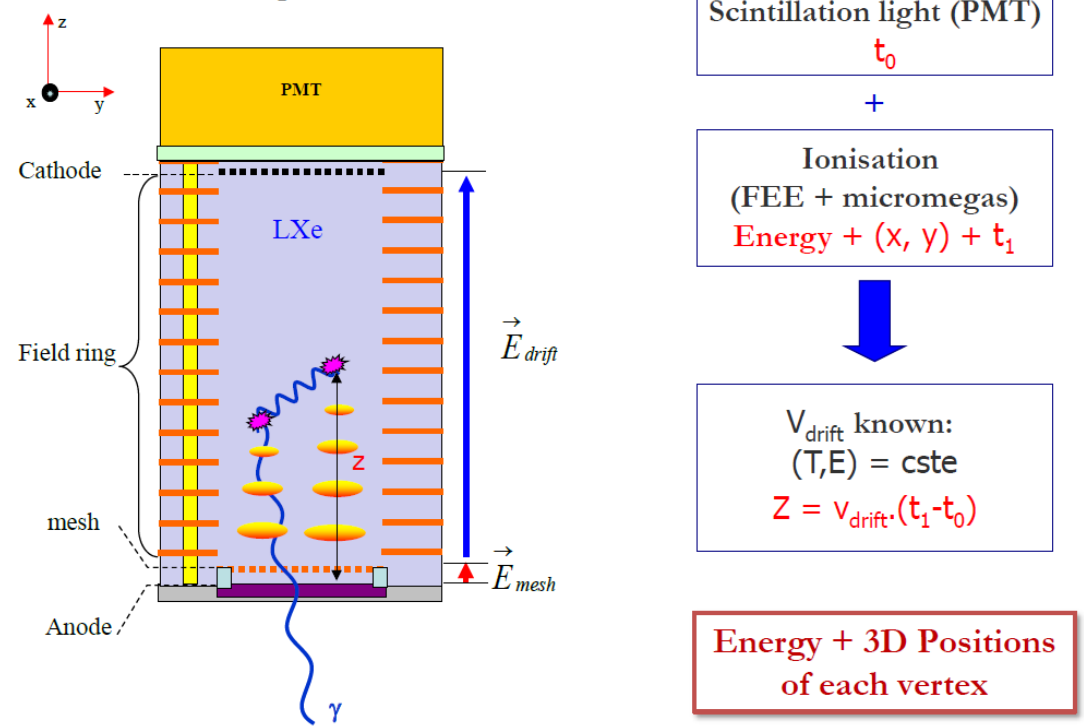
Xemis : project

- Project supported by **Subatech** laboratory at Nantes
- **Objective**: developing of a new functional **nuclear imaging** technique based on the use of ^{44}Sc radionuclide emitting two annihilation γ rays and a third high energy γ ray simultaneously and the use of a **liquid xenon Compton camera.**
- → **injected dose is reduced by a factor >20**
- **3ϒ imaging principle:**
  - 511 keV ϒ detection: conventional PET
  - 3^{rd} ϒ detection: **Compton telescope (LXe TPC)**



Δ angle: function of E0 et E1
LOR: Line Of Response

Photon interaction creates both scintillation and ionization in liquid xenon

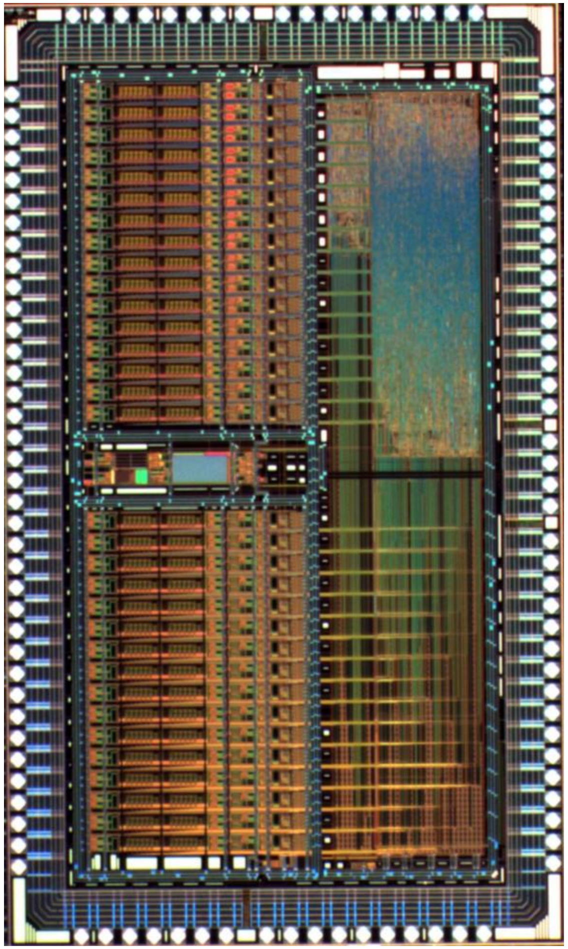


Jean Pierre Cussonneau SUBATECH

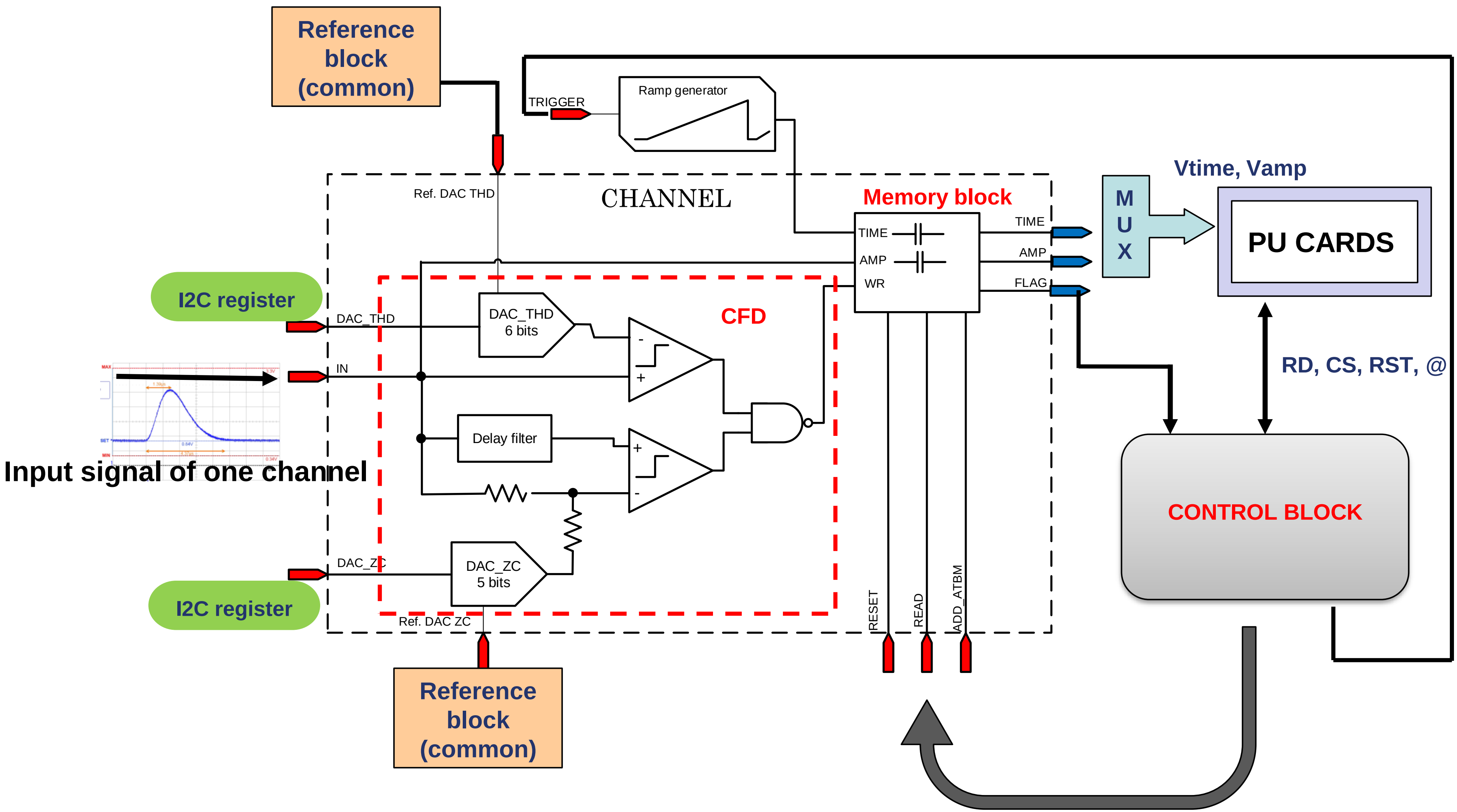
Xemis2 : readout electronics Specifications

XTRACT: Xemis TPC Readout for Acquisition of Charge and Time

Xtract : an ASIC Xemis project
Power consumption: < 50mW @ 3,3V for 32 channels
Time resolution: <300 ns rms @ SNR=3 Interesting signal amplitude is near to noise level (3σ)
Linearity error of Time measurement ≤ 0,5% (0 à 9µs)
Precision on amplitude measurement < 1%
Working temperature: environ -80° C
AMS 0,35 is a limiting process only 4 metal layers
Multichannel circuit (x32), mixte
Asynchronous logic



Xemis2 : Xtract channel synoptic

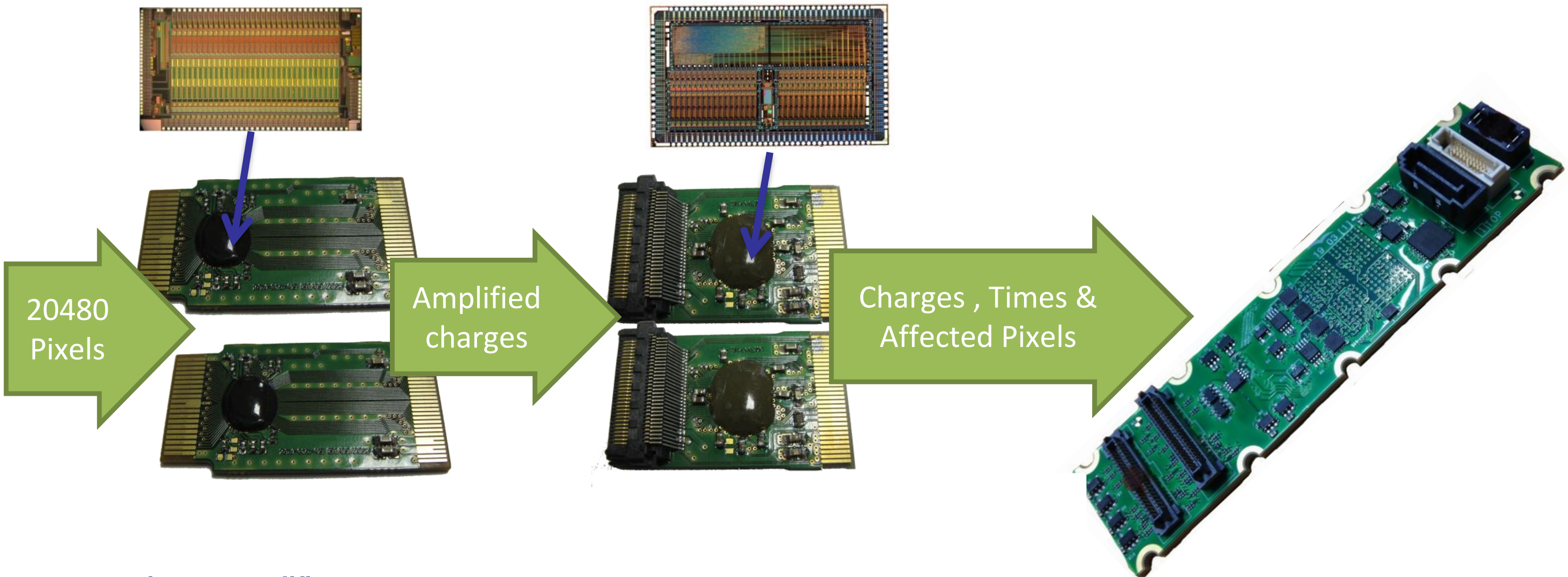


Xemis2 : complete readout electronics chain

640 x IDEF-XHD_Lxe
IRFU – SUBATECH

640 x XTRACT
MICHRAU - SUBATECH

80 x PU
SUBATECH

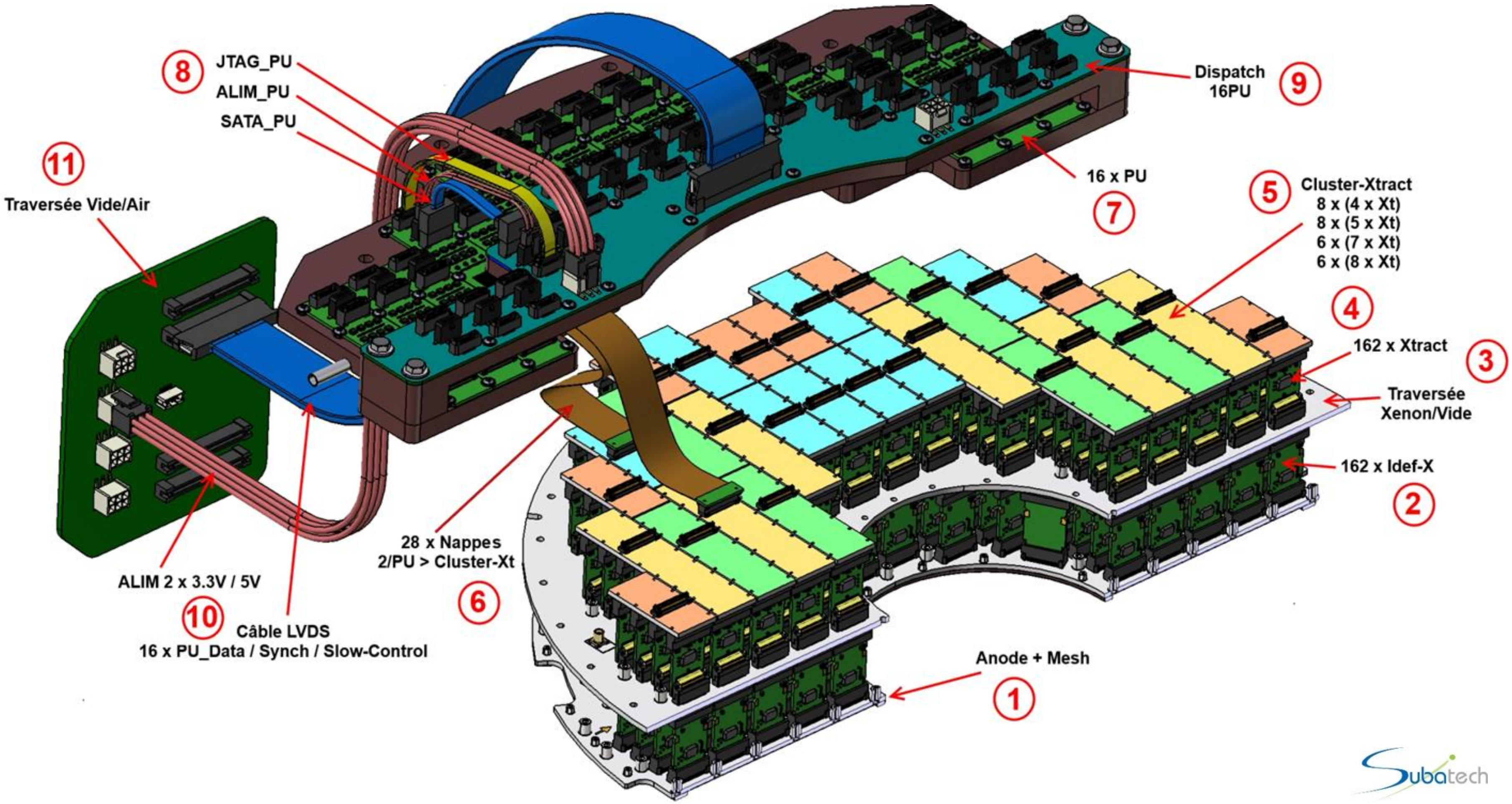


Charge Amplifier
Noise = 80^{e-}
Peaking Time 1.39µs
Range 50 000^{e-}

Measure :
- **Charge**
- **Time**
- **Address pixel**

Conversion Charge & Time
(ADC 12bits/5MHz)
~ 64 bits / Charge
(Time/Charge/address pixel)
FLUX > 1 Mevents/s
(by 512 pixel -> 70*70 mm2)

Xemis : XEMIS2 electronics



Xemis2 : Highlights XEMIS2@CIMA

Ongoing installation at « CHU »

Purification Loop | ReStoX | Cryostat

Purification Loop | ReStoX | Cryostat

Installation in progress at CIMA since March 2019

Authorization for Installing the cryogenic system on Mai 2019

Tests and qualification until July 2019

Highlights:

200 kg of Liquid Xenon

No human assistance 24/24

Xemis2 : Conclusions and outlook

- **Summary:**
- Xtract was realized in 0.35 µm CMOS process of AMS and was successfully characterized @ Subatech
  - The circuit fulfil all the requirements
  - However, comparator Hysteresis dispersion was observed on a few channels
  - This should be corrected using a complex digital processing
- 800 needed chips were fabricated
- Test cards were designed by Subatech
- **To do :**
- The 800 chips will be bonded direclty on PCB test cards at IPHC
- Characterization of all circuits will start
- The PU card is designed and is being tested at Subatech
- Production of all PU cards is expected on June 2019
- **Publication and valorization :**
- J.P. Cussonneau et al. “3γ Medical Imaging with a Liquid Xenon Compton Camera and 44Sc Radionuclide”. Acta Phys. Pol. B Vol. 48, No. 10, 2017.
- Patent :**28779. (FR3063410) CIRCUIT D'ACQUISITION ANALOGIQUE DE SIGNAUX PROVENANT DE RADIATIONS ET APPAREIL DE PRODUCTION D'UNE IMAGE REPRESENTATIVE DE CES RADIATIONS**

Thank you for your attention !