The Diaphane project: readout design and telescopes upgrades

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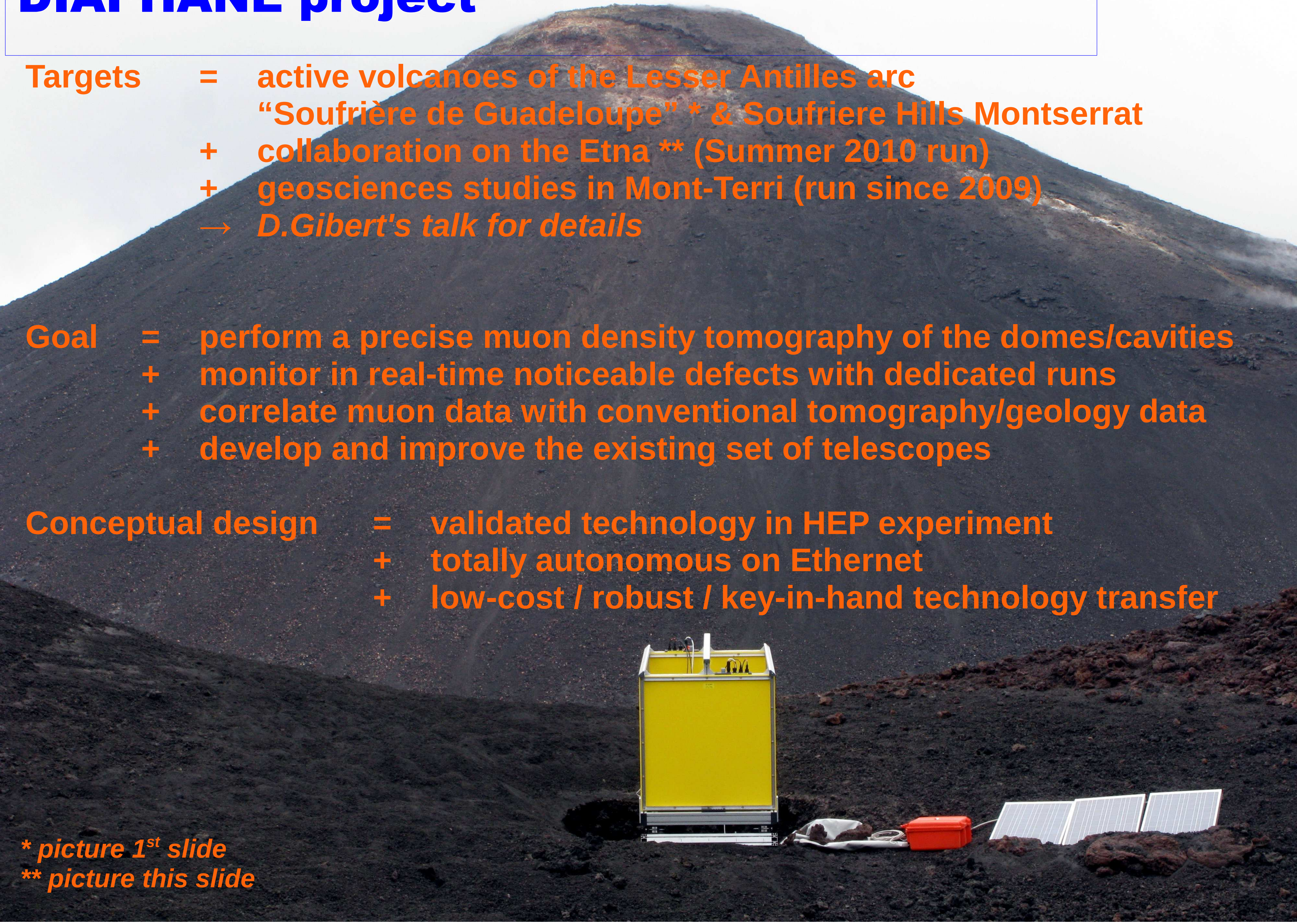
DIAPHANE collaboration :

- IPG Paris : D.Gibert, N.Lesparre (post-doc), O.Sirol, J-J.Sibilla, J-C.Komorowski, S.Deroussi, M.Diament
- Géosciences Rennes : B.Kergosien, F.Nicollin, P.Rolland
- Observatoire Volcanologique de la Soufrière de Guadeloupe (OVSG)
- Swisstopo Institute, Mont-Terri underground laboratory, Switzerland

MNT 2012
Clermont-Ferrand

DIAPHANE project



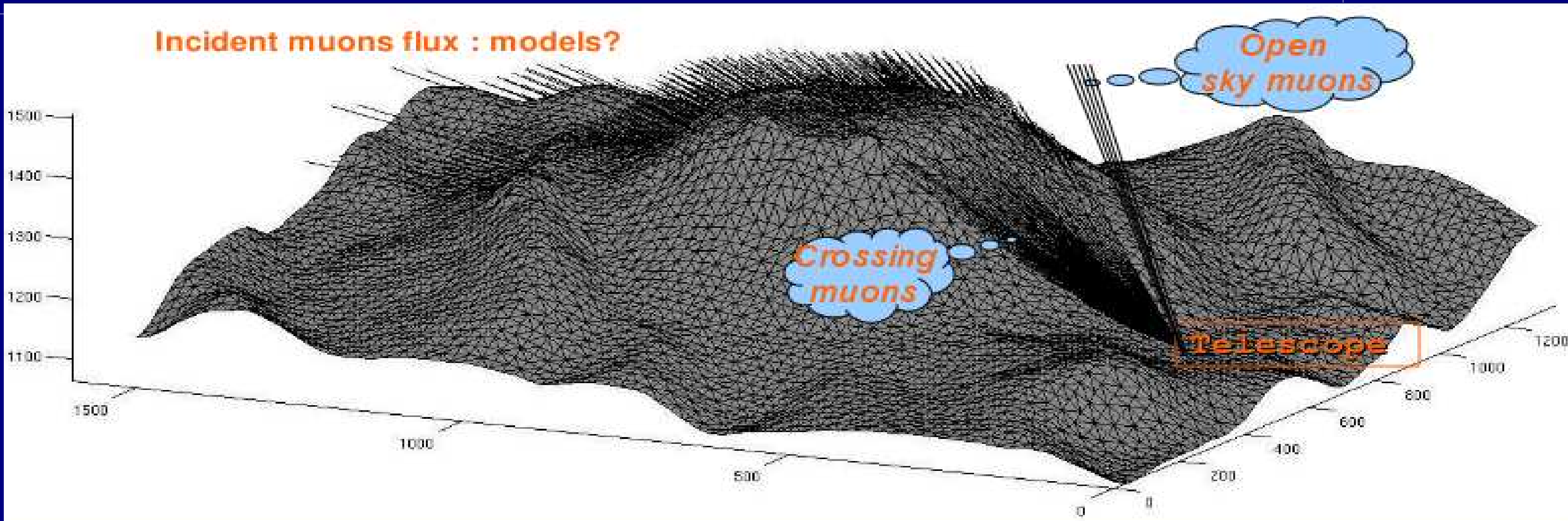
Targets = active volcanoes of the Lesser Antilles arc
“Soufrière de Guadeloupe” * & Soufriere Hills Montserrat
\+ collaboration on the Etna ** (Summer 2010 run)
\+ geosciences studies in Mont-Terri (run since 2009)
→ *D.Gibert's talk for details*

Goal = perform a precise muon density tomography of the domes/cavities
\+ monitor in real-time noticeable defects with dedicated runs
\+ correlate muon data with conventional tomography/geology data
\+ develop and improve the existing set of telescopes

Conceptual design = validated technology in HEP experiment
\+ totally autonomous on Ethernet
\+ low-cost / robust / key-in-hand technology transfer

** picture 1st slide*
*** picture this slide*

Parametrization

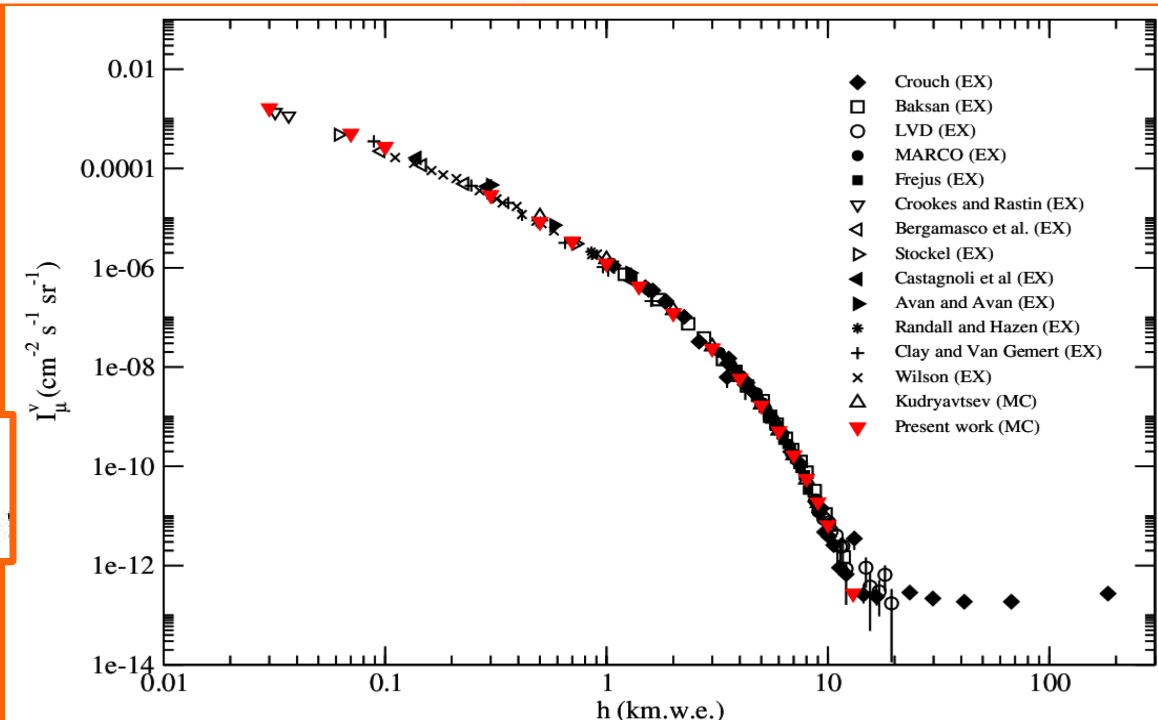


Exiting muons flux

$$I[\varrho, \theta] = \int_{E_{\min}(\varrho)}^{\infty} \Phi(E_0, \theta) \mathrm{d}E_0 \ (\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}).$$

Number of muons detected

$$N(\varrho) = \underbrace{\Delta T}_{\text{data taking duration}} \times \underbrace{\mathcal{T}}_{\text{acceptance}} \times \underbrace{I(\varrho)}_{\text{flux}}.$$



Field telescope concept & design

Given the desired resolution on the density one has to design in principle a telescope with an acceptance such that the data taking duration is below a threshold...

$$\Delta T \times \mathcal{T} \times \frac{\Delta I^2(\varrho_0, \delta\varrho)}{I(\varrho_0)} > 1.$$

(e.g. 0.5g/cm³ resolution on Etna in June-Oct)

theory / reality

Wheather conditions

Transportation – Access

Network

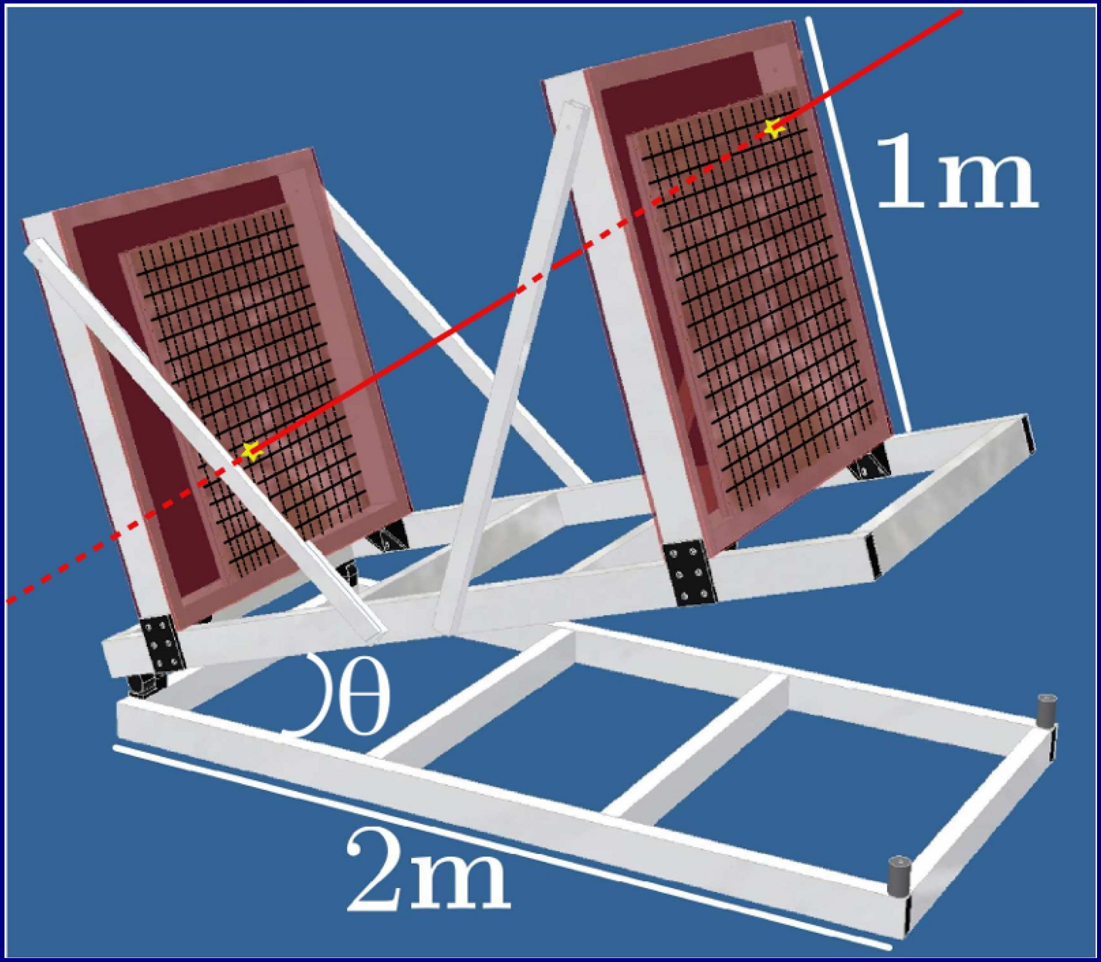
Integration

Field telescope concept & design

The design should be compatible with the harsh conditions

- choice of a robust technology
- ... modular, scalable, cheap
- low power consumption
- ... easy to move
- compatible with network/wifi
- embedded local processing

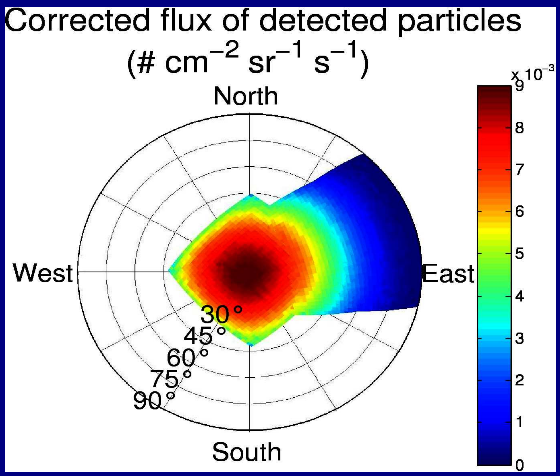
Plastic scintillator hodoscope
+ WLS fibres
+ clear fibres connectors
+ MaPMT
+ OPERA r/o electronics (analogic/digital)

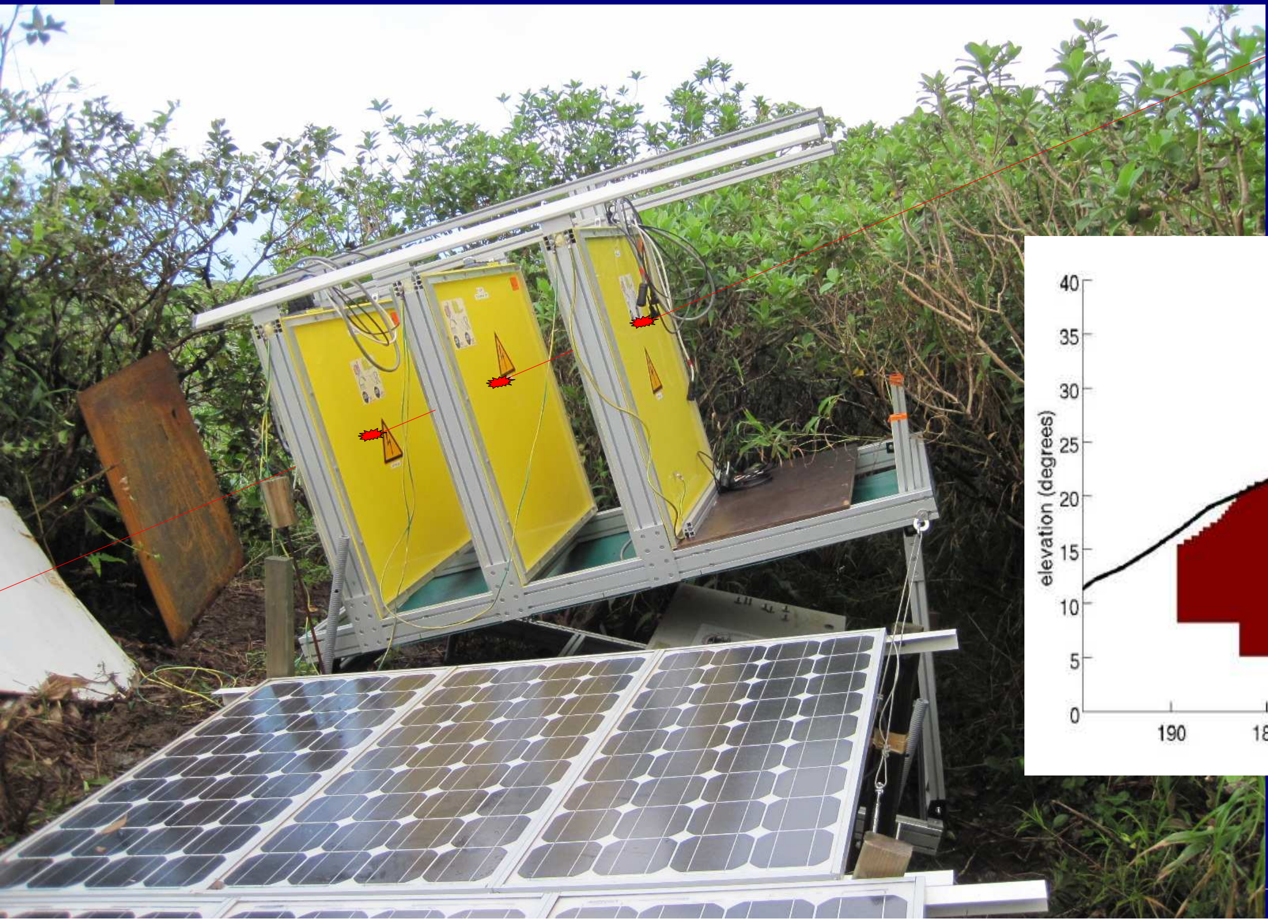


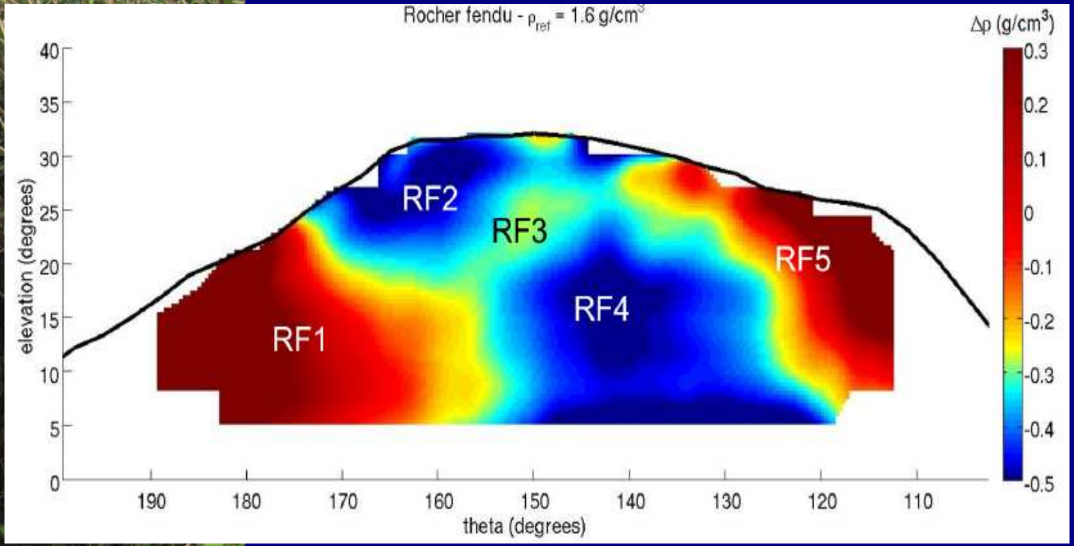
Concept, R&D and construction :
IPG Paris + IPN Lyon + Géosciences Rennes.

Telescopes detection features

- Controlled acceptance and angular resolution
- Muons detection in triple coincidence :
  - XY coincidence required at the plane level
  - Majority = 2 planes required at the telescope level (coincidence window = 10 ns)
  - T.o.f. performed with new TDC facility
- Possible runs with or without shielding in front of the detection planes

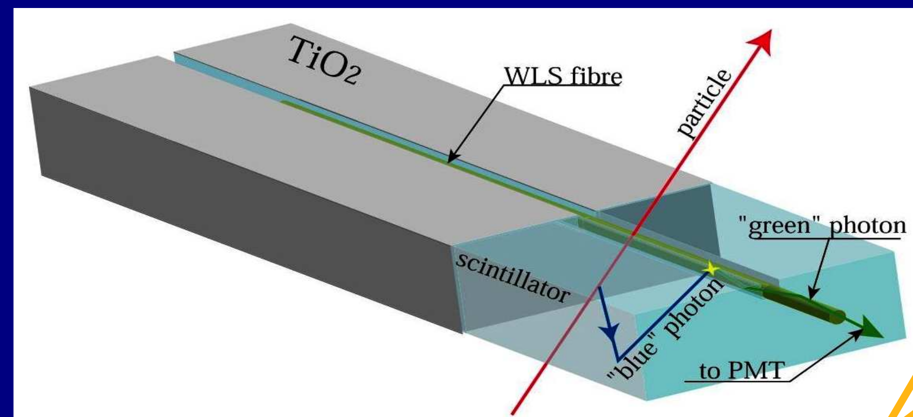


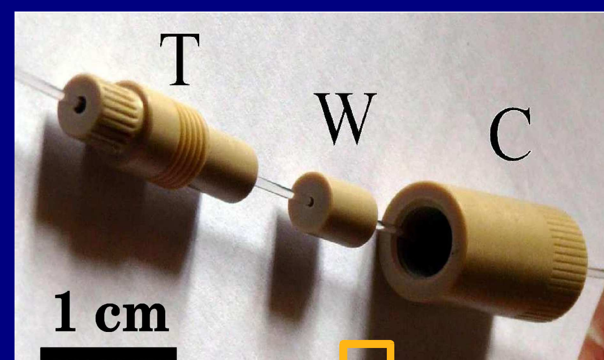




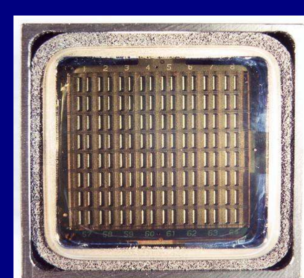
Detection planes

- 2 XY biplanes (32 channels per biplane)
- Fermilab scintillator bars + 1mm WLS + 1mm clear fibres
- Photosensor : Hamamatsu MaPMT (H8804) or MPPC (S10362-11-050C)





MultiAnode PMT

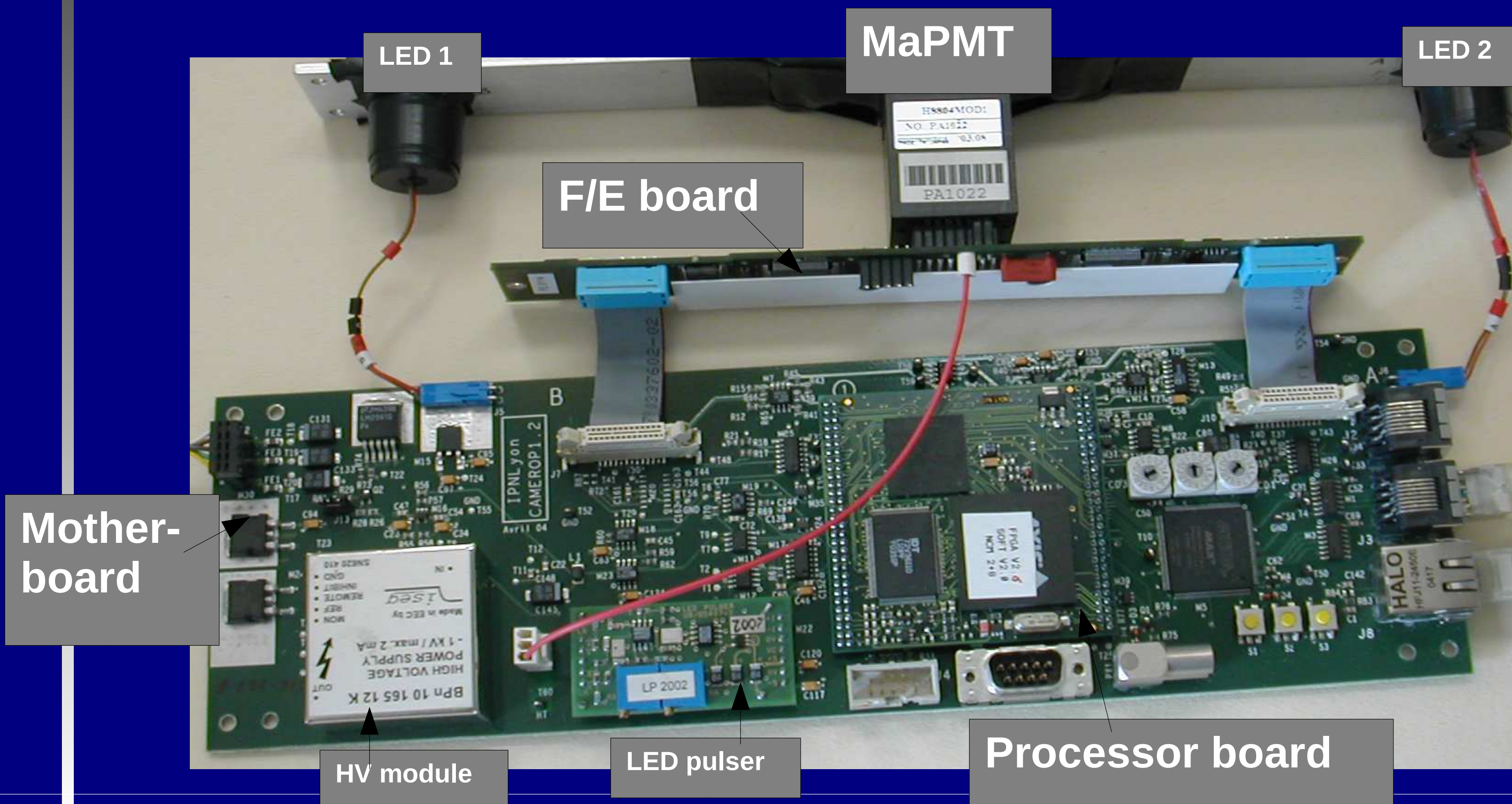


Q.E.

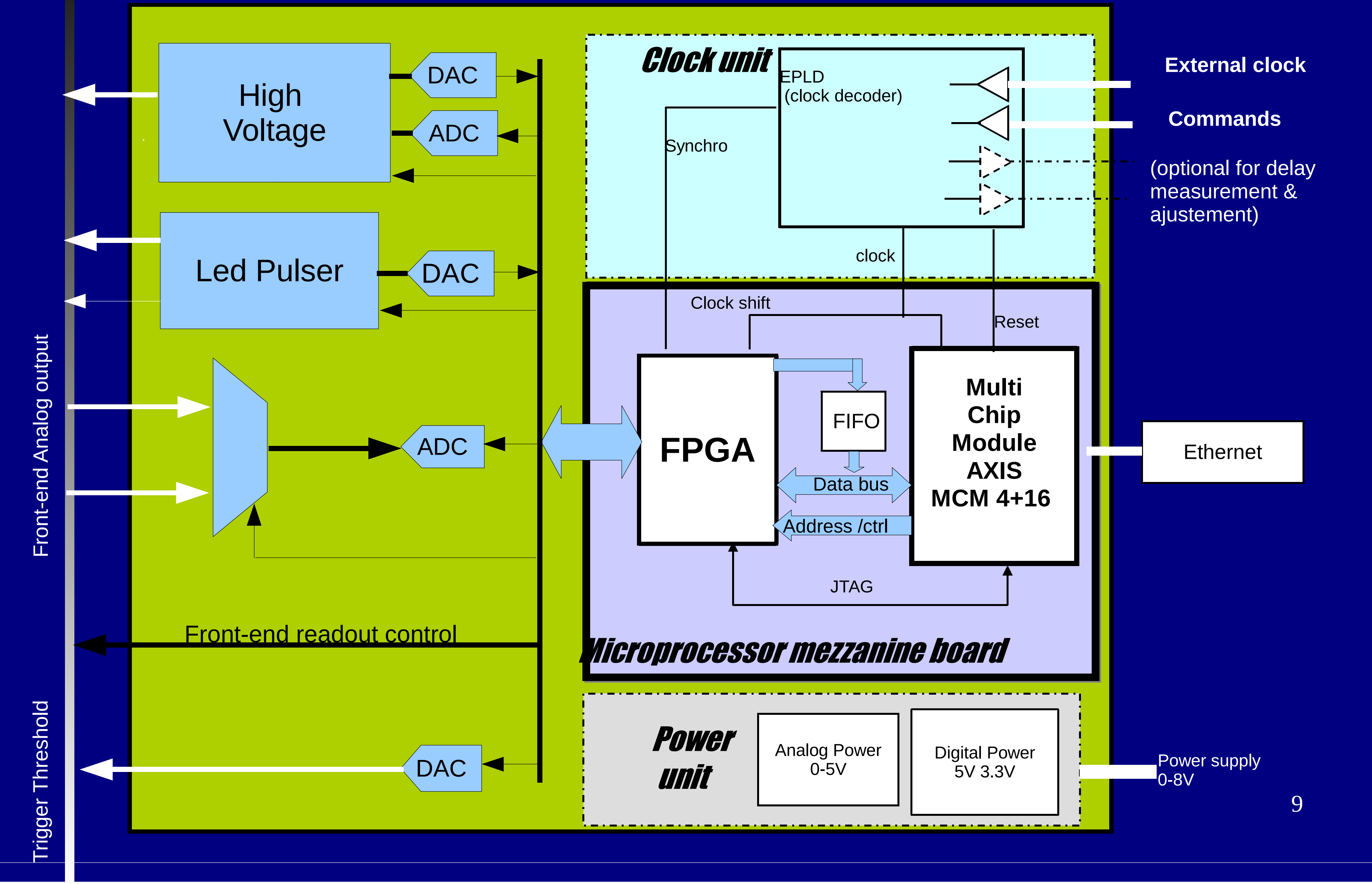
MultiPixels PhotoCounter

Readout opto-electronics

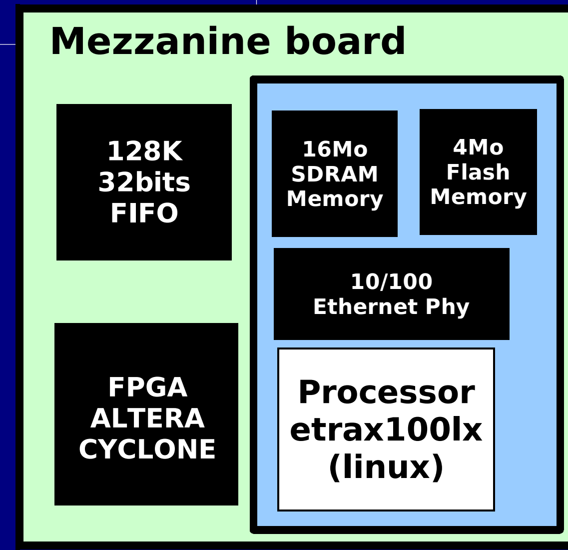
- Hamamatsu “H8804-200mod”, 64 2mm×2mm pixels, <10Hz dc at 0.5 pe
  + 30% quantum efficiency w.r.t. OPERA PMT
- Auto-triggerable F/E with channel-to-channel gain compensation (1→ 4)
- Ethernet DAQ system with embedded Linux
- Motherboard hosting HV module, LED pulser, 12 bits ADC, slow control
- Event timestamp with 10ns accuracy, upgraded down to 1ns



Readout opto-electronics (Bloc diagram)



DAQ general features



- <u>The DAQ is based on distributed smart sensors on Ethernet.</u>

The basic "element" of the system is a daughter board, called "mezzanine" hosting:
- FPGA of the Altera Cyclone type
- 128Kx32 FIFO
- 4Mo Flash, 16 Mo SDRAM Memory
- AXIS Etrax100lx µProcessor in Multi Chip Module (MCM) form

- <u>Each individual node runs a local 100MHz clock derived from a common clock.</u>

- <u>The client/server protocol used relies on the CORBA standard implemented in C++.</u>

This software is completely object oriented and uses the Interface Description Language (IDL) to describe the distributed objects independantly of the programming language. InterORB protocols guarantee interoperability.

- <u>Sensor fully reconfigurable remotely.</u>

- **Successful operation since 2008 of this opto-electronics readout chain :**
  - **basis of further developments (MPPC)**
  - **implementation of "hard-wired" TDC to**
- **improve the timing resolution**
- **Upgrades common with other projects**

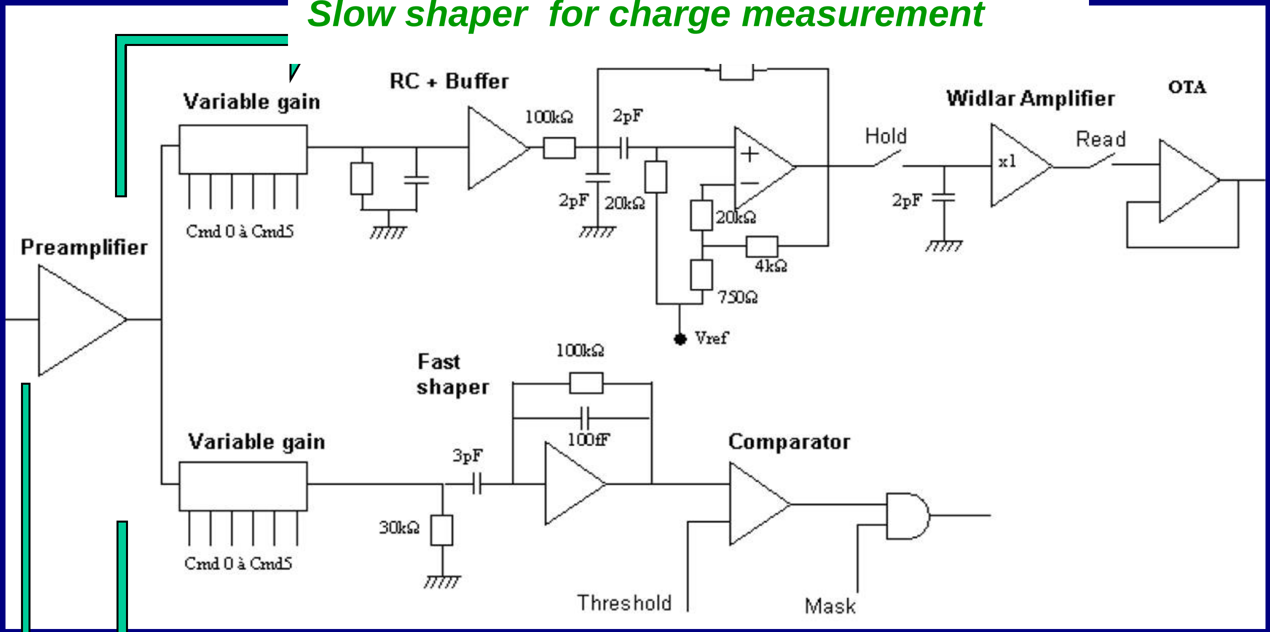
Front-end stage

LAL (IN2P3) chip: OPERA-ROC

- 1st generation x-ROC chips

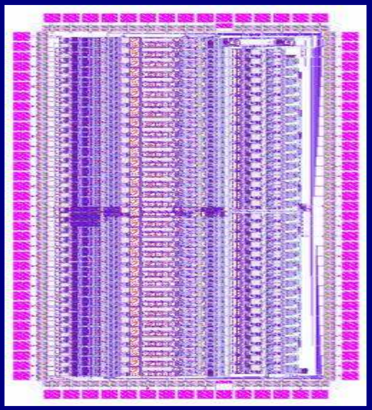
- robustness validated on many samples

Slow shaper for charge measurement

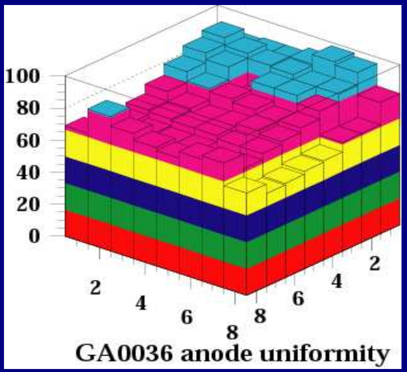


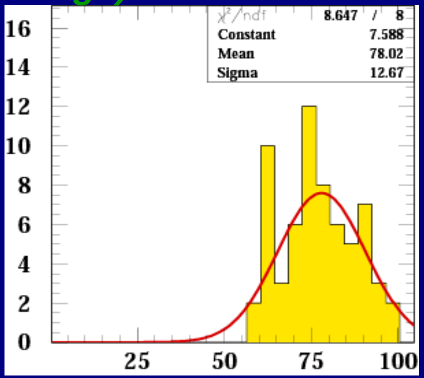
Fast shaper for triggering

channel to channel gain adjustment (1:4 range)



- Technology: AMS BiCMOS 0.8 μm
- Chip area : 10 mm^2
- Package : QFP100
- Power consumption : 185 mW





Typical gain spread on H8804 PMT

R/O electronics : current developments on MPPC (Silicon Photo multiplier)

- Hamamatsu MPPC type S10362-13-050C
- Auto-triggerable F/E based on SPIROC-2 / EasyROC
- Ethernet DAQ system with embedded Linux
- Motherboard hosting HV module
- Tests successful in external trigger mode

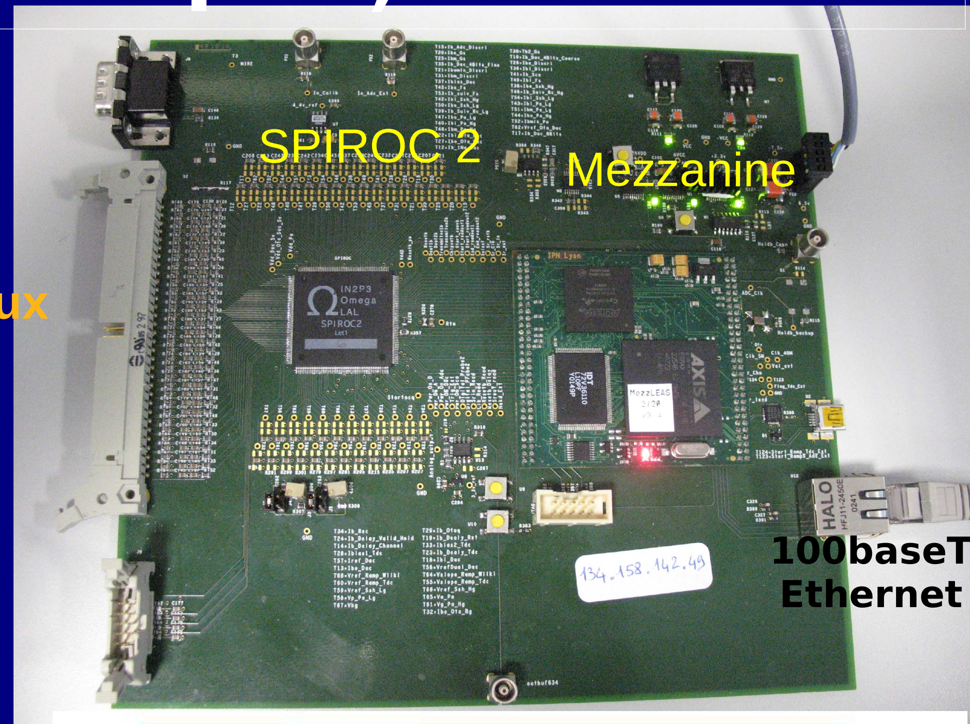
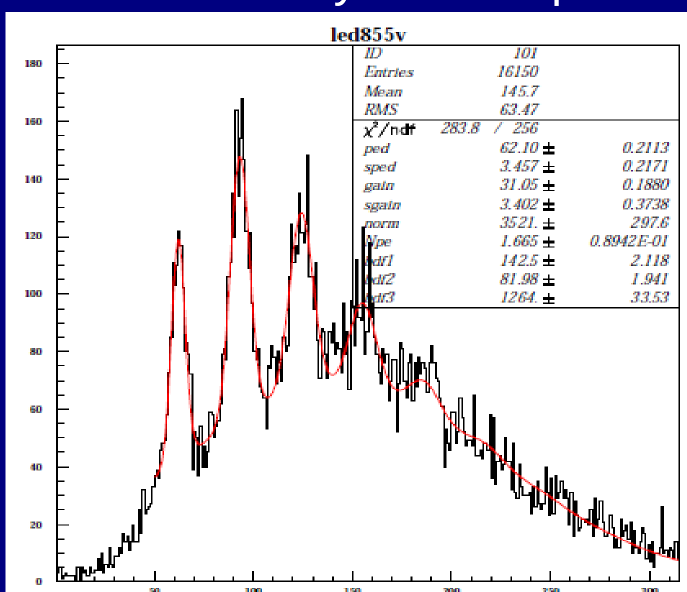
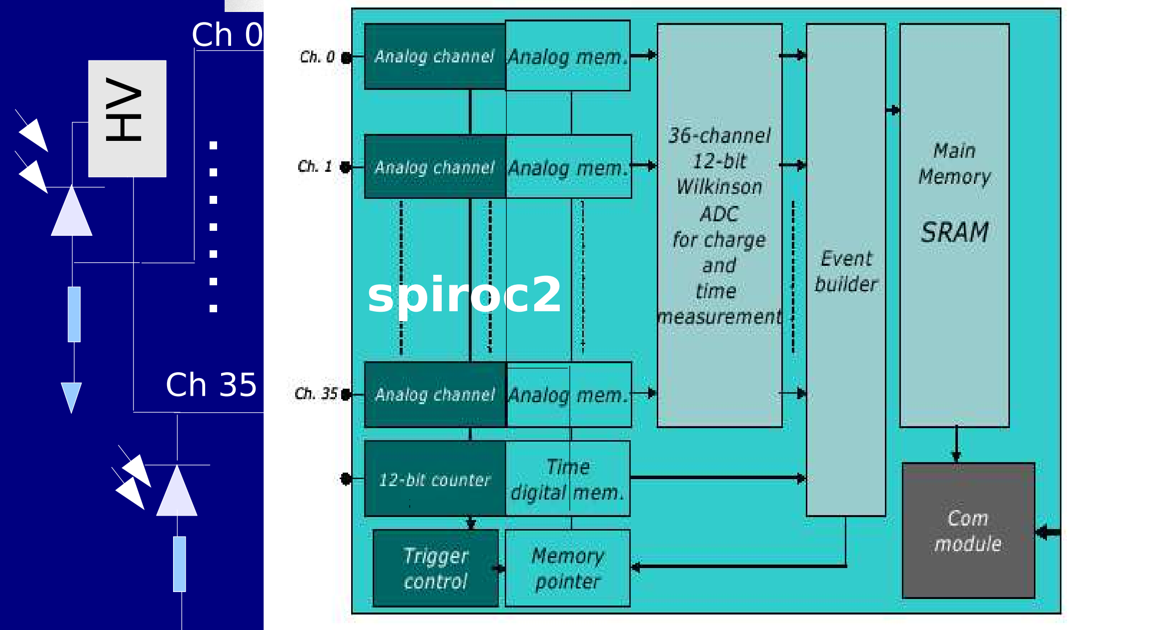


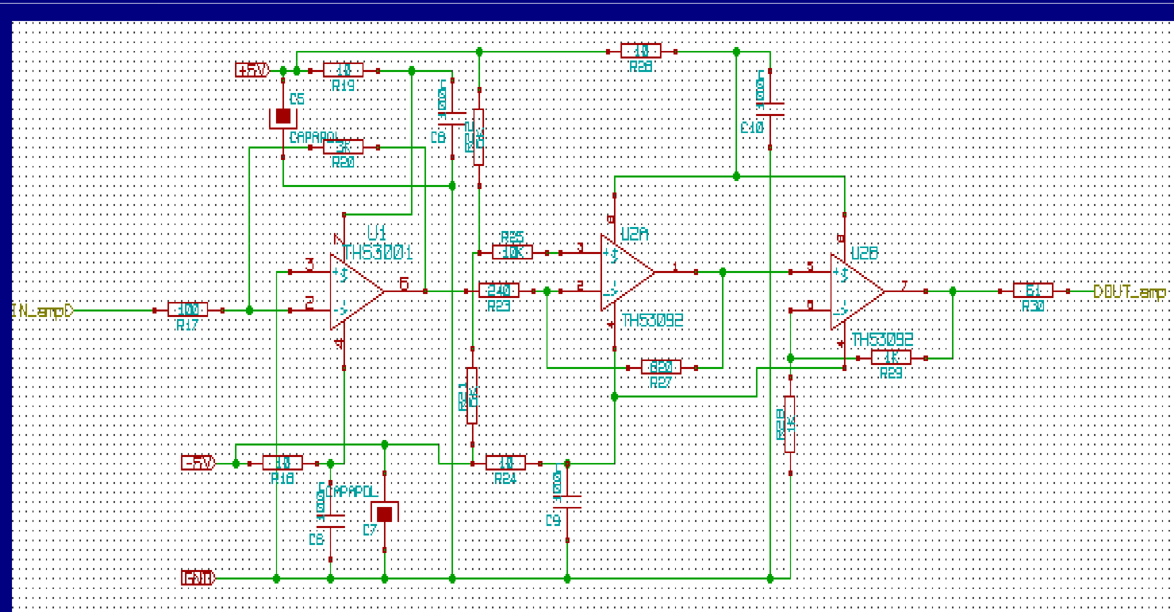
Photo electron spectrum obtained with Easy ROC chip





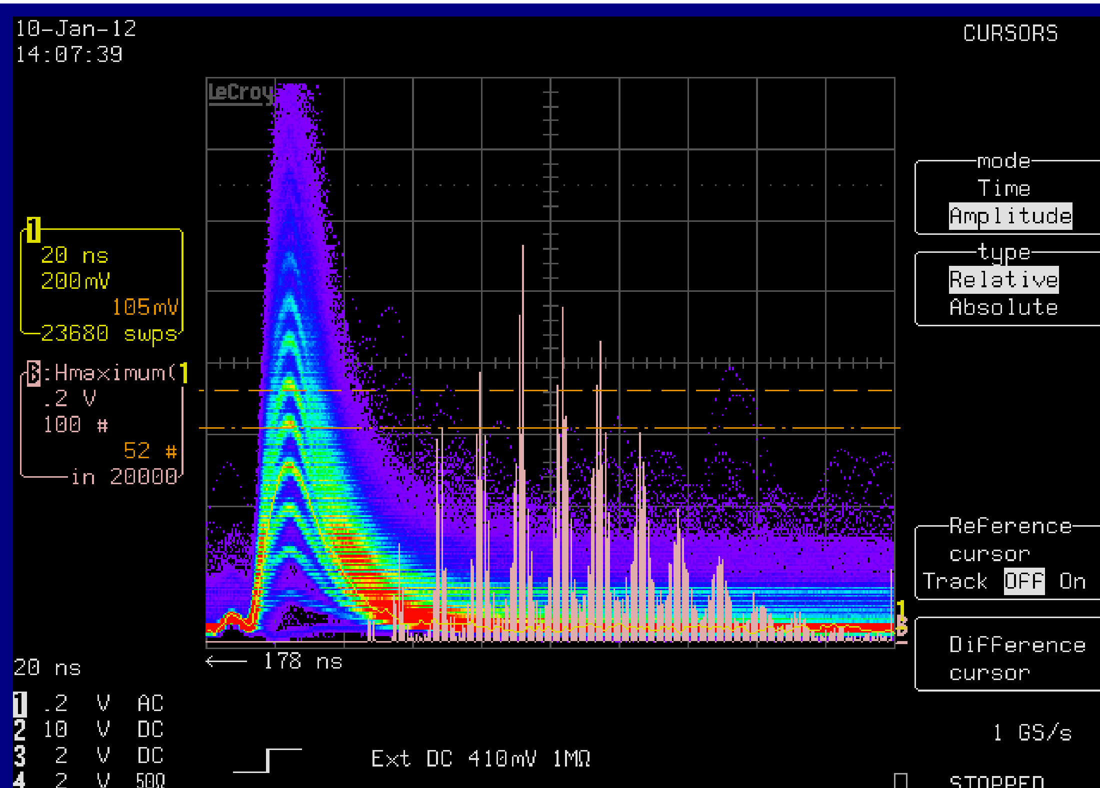
R/O electronics : current developments on MPPC

- New (lighter) design based on a simplified chain (P.E. counter) with a robust, high gain amplifier



- Successful operation in external/auto-trigger mode

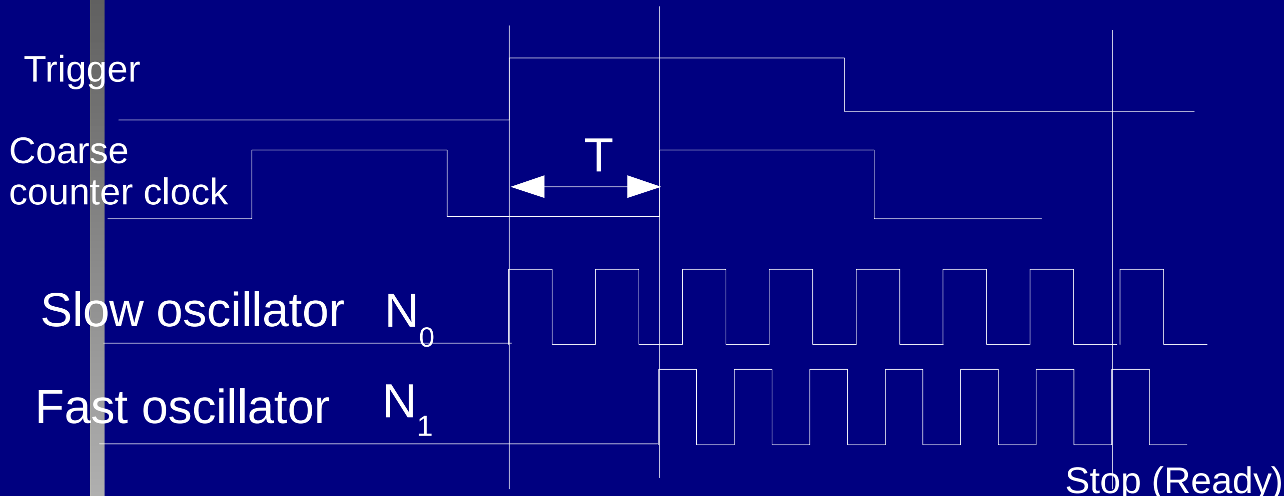
- Currently the baseline option to equip a test matrix with MPPC to run with PMT matrices (hybrid telescope)

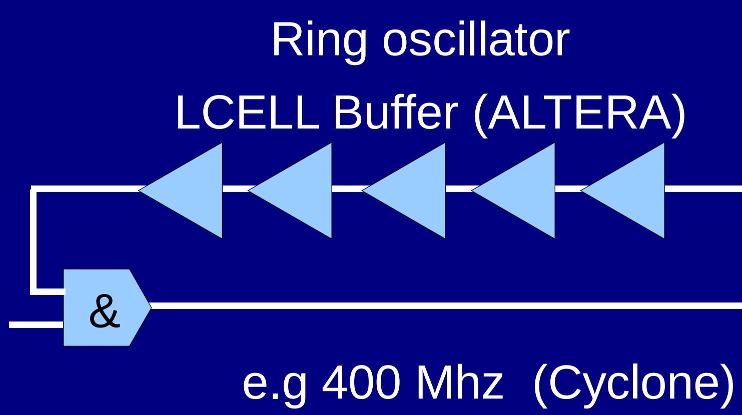


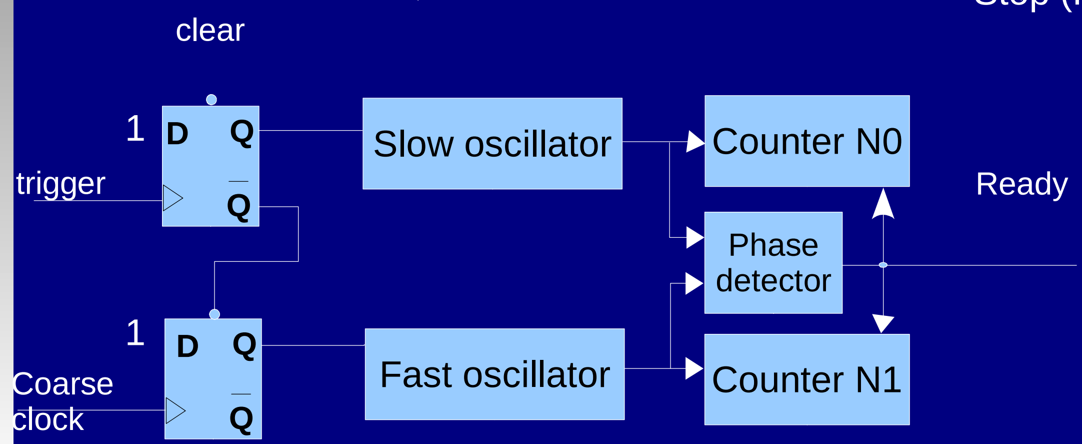
- Possibility to use simple comparators to count photoelectrons directly without charge measurement

R/O electronics : Ring oscillator TDC in FPGA

- Better time stamp resolution to allow a better Background rejection
- Goal => TDC FPGA implementation (without additionnal hardware)
- Possible solution Ring oscillators TDC (low area, low power)
- Autocalibration of T0 and Δt (using external common reference clock)







$$T = N_0 T_{slow} - N_1 T_{fast}$$

$$\Delta t = T_{slow} - T_{fast}$$

$$T = (N_0 - N_1).T_{slow} + N1.\Delta t$$

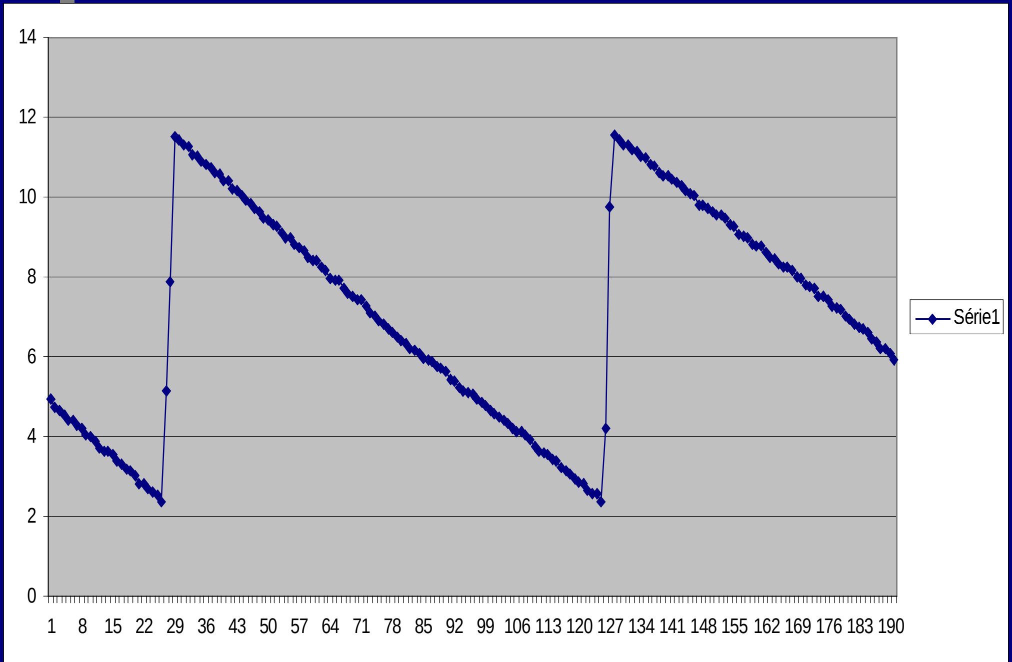
Preliminary results TDC

Remote implementation on telescope : First tests are very positive

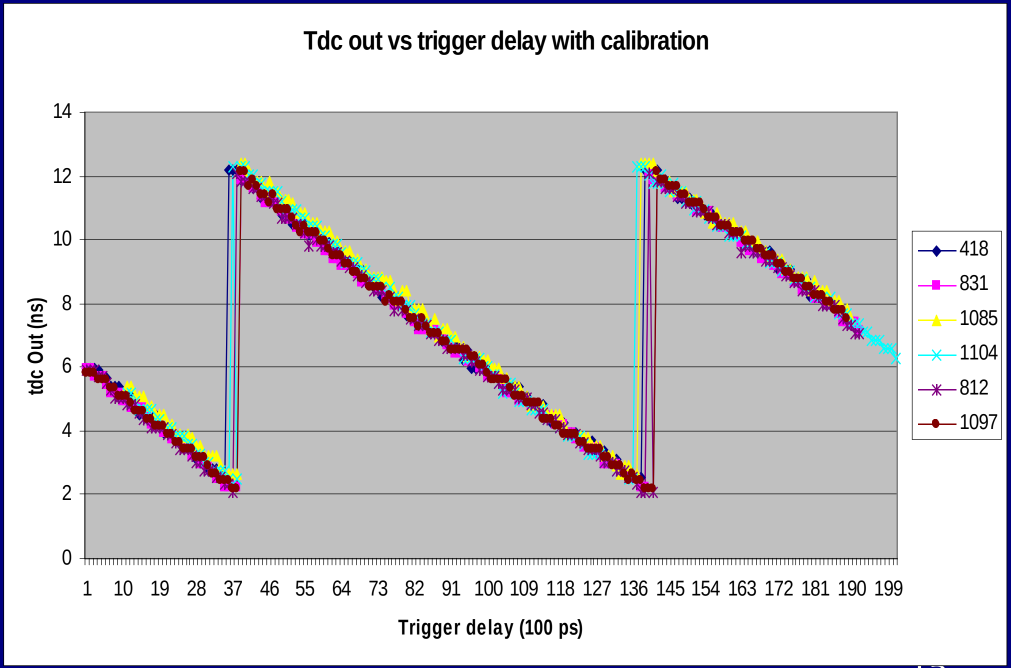
Coarse counter clock period = 10 ns

Trigger step 100 ps

TDC response (mean of 10 measurements)



TDC response comparison on 6 FPGA



Conclusions & perspectives

- **Performing a 3D tomography**

  Challenging operations

  Requires reliable hardware techniques

  Requires software images processing

- **DIAPHANE project operating since 2008**

  HEP techniques

  Adaptation to harsch weather conditions

  Validates the autonomous « unmanned » sensors concept

- **Optimizing the detector design**

  Larger acceptance / efficiency / resolution

  Depends on the application, telescope location wrt volcano

  R&D started on the basis of current state-of-the-art running telescopes

- **Upgrading the existing**

  MPPC to improve the muon detection efficiency

  Requires a robust readout scheme : options under study

  Implementing TDC inside FPGA : promising tool to improve the timing resolution

Thank you for your attention and meet you there :

European Geosciences Union General Assembly 2012
Austrian Center VIENNA (ACV)
April 22-27, 2012

Geophysical tomography with high-energy particles: recent developments and applications

The session is meant to make a state-of-the-art account of the emerging geophysical tomography techniques using high-energy particles (cosmic muons, neutrinos). This session will also be a community forum for discussions on both methodological and applicative issues (volcanology, archaeology, monitoring of underground repositories, hydrology). Presentations and discussions that span different measurement approaches and applications in various geological environments are welcome.

R/O electronics : TDC implementation in FPGA

- Build two oscillators with very low Δt (e.g few 100 ps to 10 ps)
  - Possible by manual floorplanning in FPGA
- Calibration T_0 and Δt
  - Possible by using the precise external coarse counter clock.
  -
- Dispersion due to FPGA production batch are well detected
- Remote implementation on telescope . First preliminary tests very positive

T0 calibration ratio between Tref and T_0

$T_0 = N*Tref / N_0$

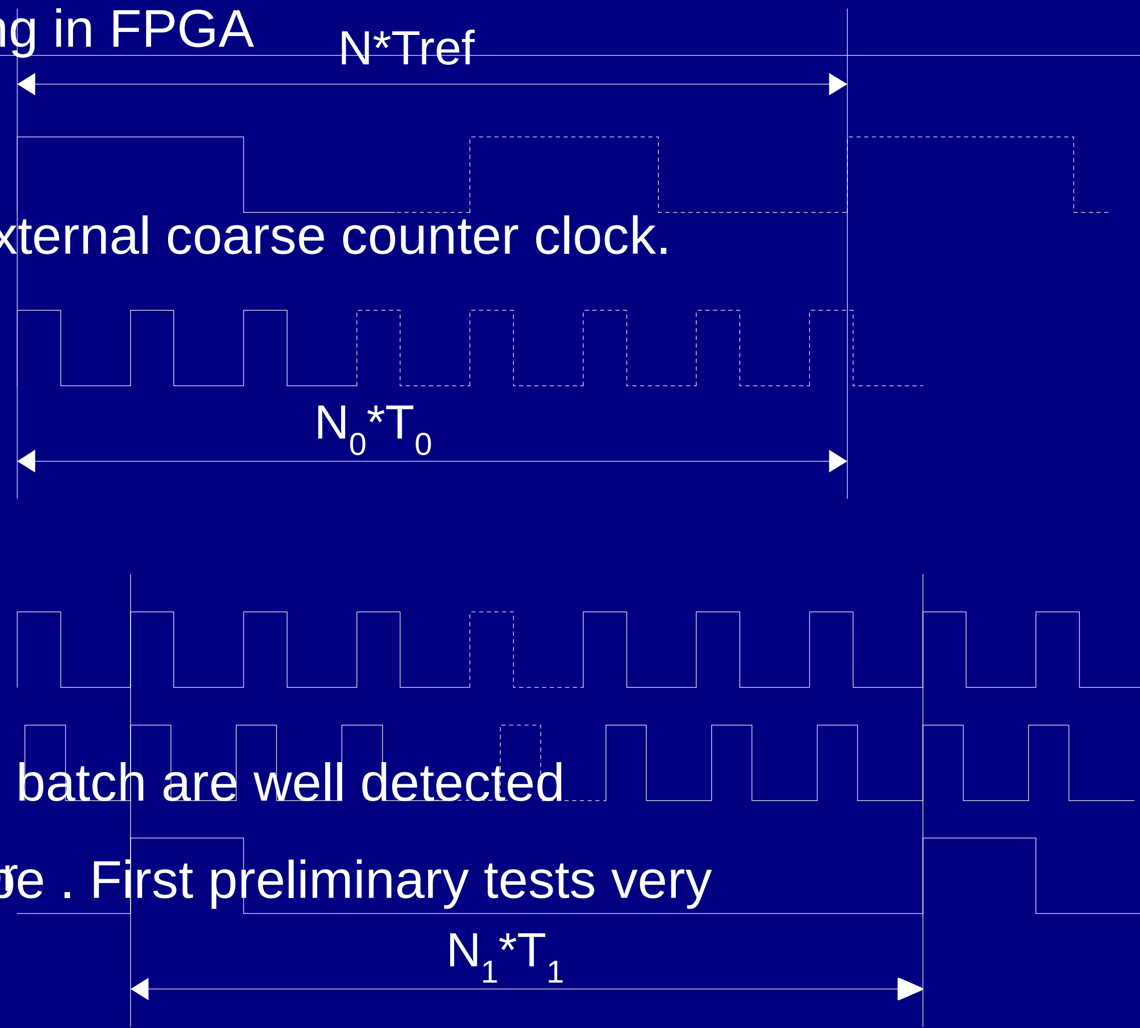
T0 = N0 *Tref / 255

T1 = T0 / N1

Dt calibration :
Count of T1 between two phase
Detection in free running mode

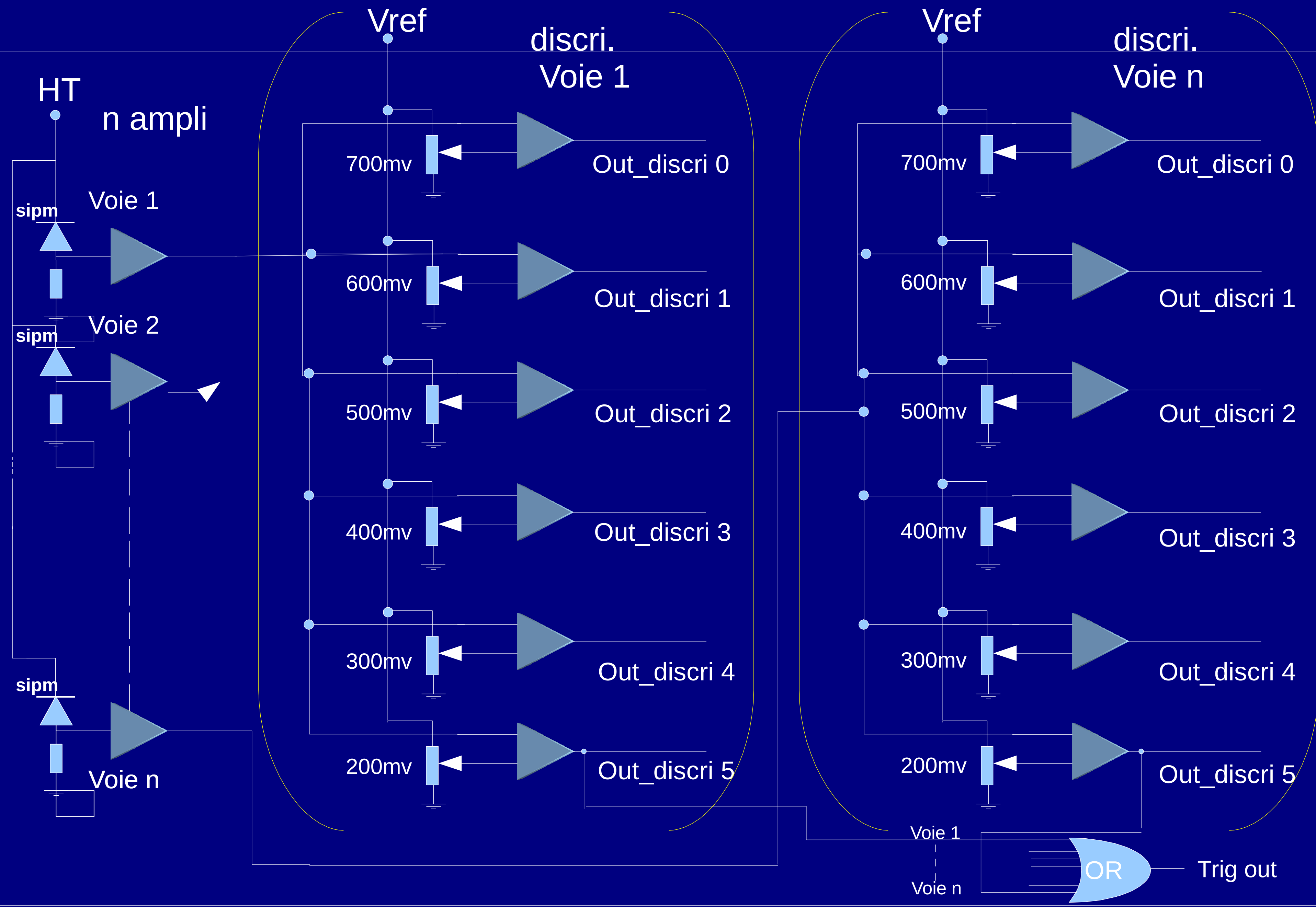
Phase detector

$\Delta_t = T_0 / N_1$



R/O electronics : current developments on MPPC

- New option using discrete components



Transition : from *Ravine Sud* to *Roche Fendue*

R/O electronics : TDC implementation in FPGA

- Method existing on many FPGA architecture (Altera, Xylinx)
- Implemented for tests on the FPGA cyclone (OPERA mezzanine) => gives a 200ps resolution
-
- Dispersion of the 2 oscillators depending on the hardware (e.g. FPGA production batch) since this is hard-wired
- Calibration procedure required at the level of each mezzanine
- Remote implementation. First preliminary tests very positive.
- Goal = ~1ns resolution for a larger background rejection