"Analogic Sampling Module (ASM) for sampling at high frequency: application to a prototype of a on-line TEP in hadrontherapy"

Workshop on picosecond photon sensors for physics and medical applications

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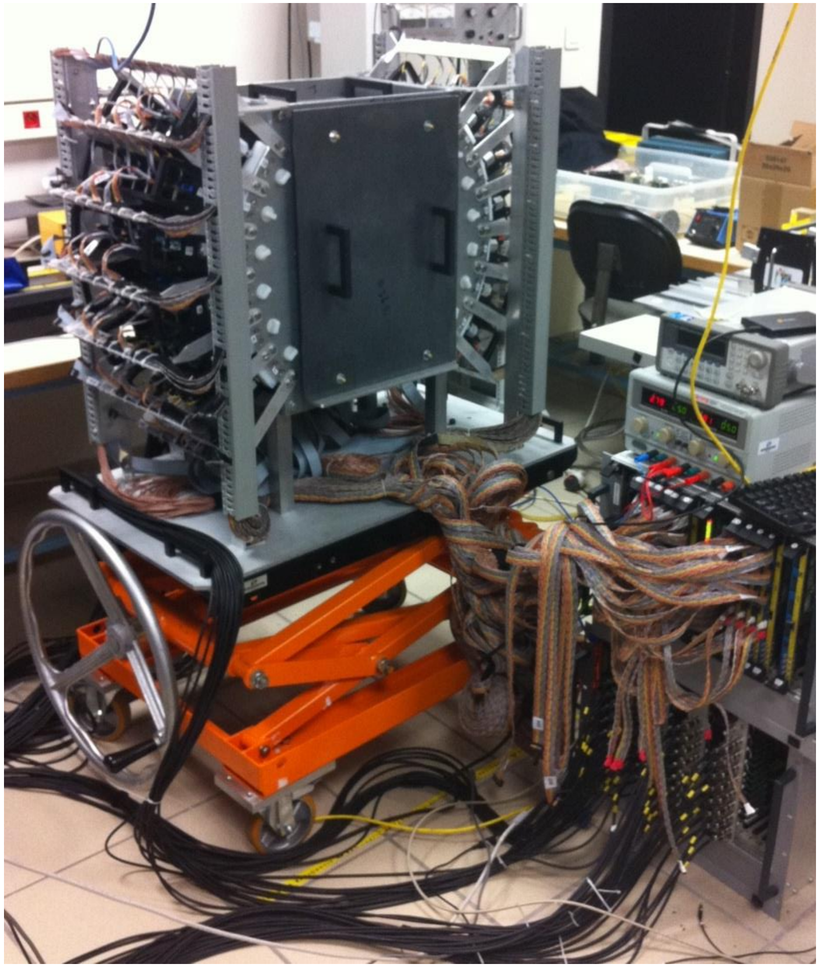
Force Paul, Insa Christophe , Lambert Daniel ,Lestand Loic, Magne Magali , Martin Frank, Montarou Gerard, Rozes Arnaud,

LPC Clermont-Ferrand (France)

magne@clermont.in2p3.fr

Outlines

- Context : The DPGA detector
- ASM technical functionality
- Experiments feed-back
- Conclusions & Perspectives

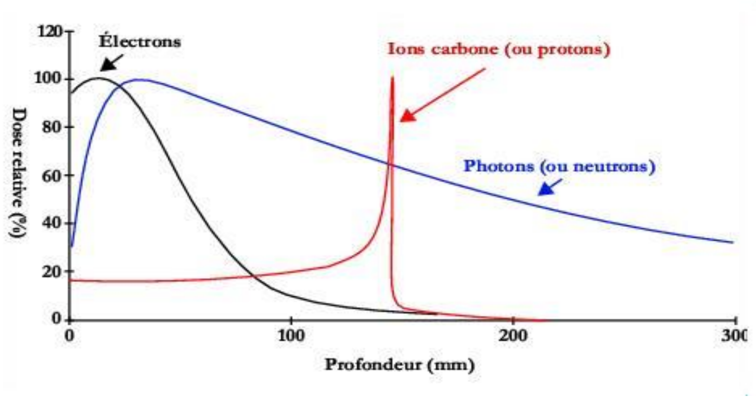


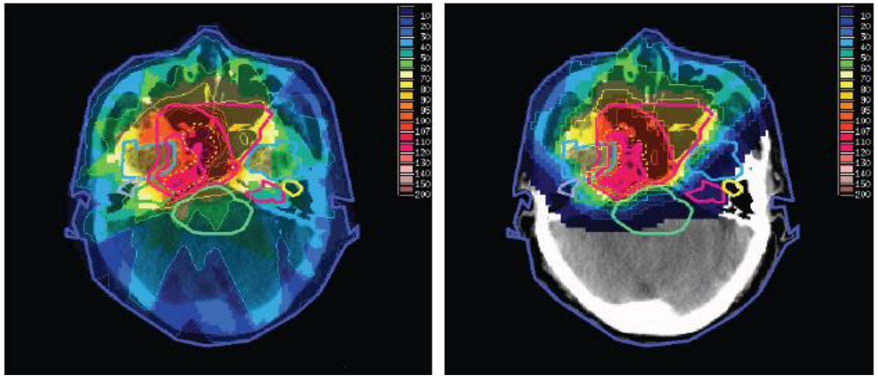
The DPGA detector

Pixelized detector to test technical concepts for a in-line PET for hadrontherapy.

Hadrontherapy

- treatment of radioresistant tumors close of organ at risk by particle beam (proton and light ion).
- use of the Bragg peak to target the best the tumor while protecting surrounding healthy tissues





RCMI vs Protonthérapie : carcinome du nasopharinx [Taheri-Kadkhoda et al.,2008]

Advantage of the use of proton and carbon

- Increase the accuracy of the dose delivery through the Bragg peak phenomenon
- Low dose deposition into the healthy tissues around the tumour.
- Higher biologic efficiency of hadron particle in biological tissu in comparison of conventional radiotherapy (X and electrons)

DPGA Measures base :

In-line PET is a specific application of PET technic: in real time measurement of the positron emitting nuclei produced at Bragg peak by incoming beam particles in the patient

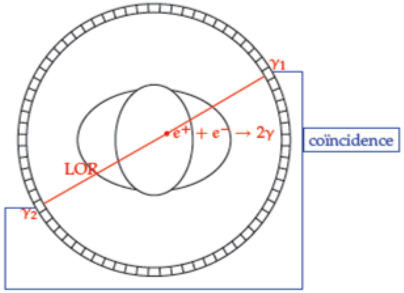
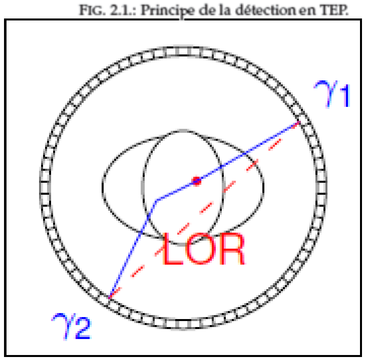


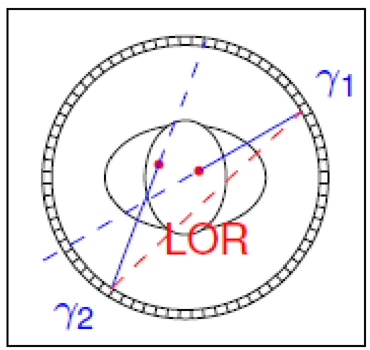
FIG. 2.1.: Principe de la détection en TEP.

Signal : annihilation photon pairs

- β^+ decay ➔ 2 back to back γ photons
  ➔ 511 keV each

- Detection of the coincidences gives line of response (LOR)

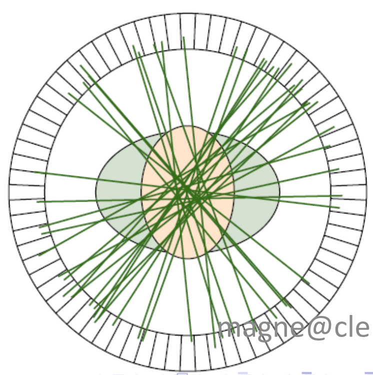




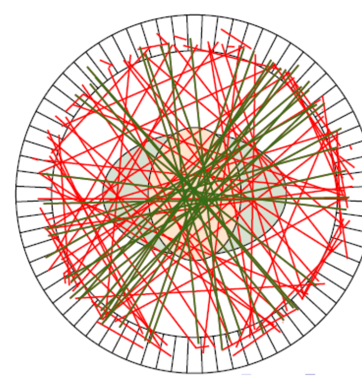
Noise:

- prompt particles γ (mainly gammas from excited nuclei with a large energy spectra, from few hundred of keV to MeV)

Just Signal



Reality is Signal + Noise



What are the advantages of using the high frequency sampling technique

1. Acquisitions during irradiation is very noisy

   (prompt gammas correlated in time with beam spill)

   ➔ need for random coincidences rejection

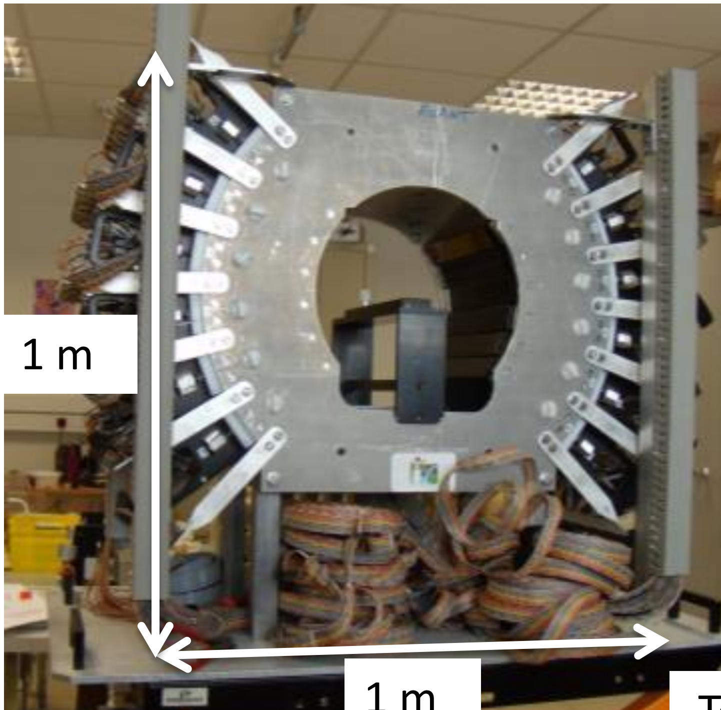
1. Improve trigger selectivity, off-line event selection

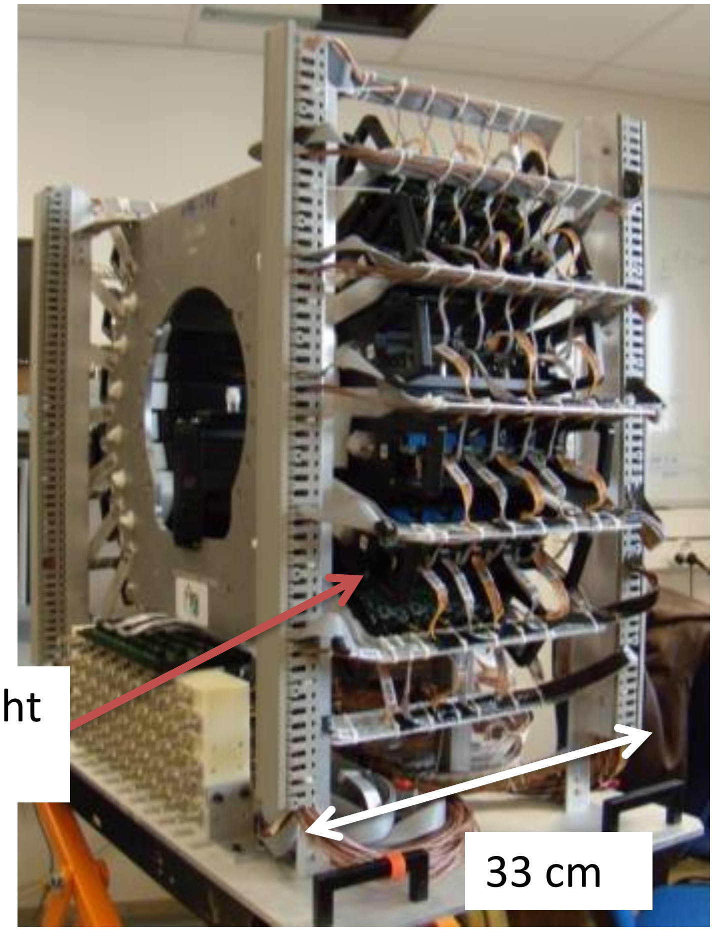
   ➔ data sampling allows to reprocess and refine trigger off-line(not possible with TDC+QDC)

2. Read-out electronics should be generic for several photo sensors

The DPGA detector

- An homemade detector





Total weight
130Kg

Detector with 240 PMT sensors

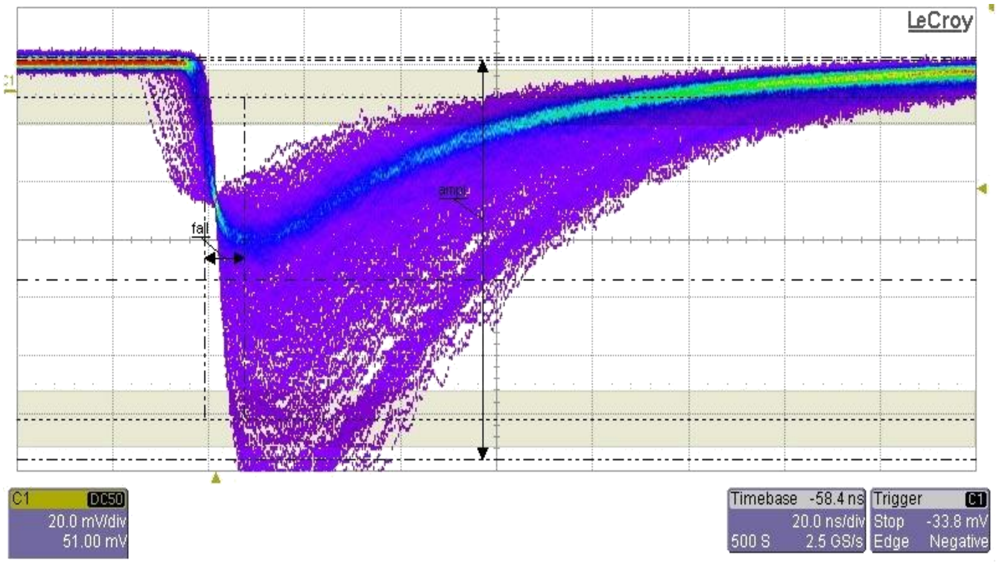
Box with 5 quartets
of
PMT & Scintillators

Requirements

- <u>Signal to be acquire by the board:</u>

The picture below is a capture of the anode for a 511keV gamma in a scintillator, read-out by a PMT.

The High Voltage divider circuit include a differential amplifier with a gain .

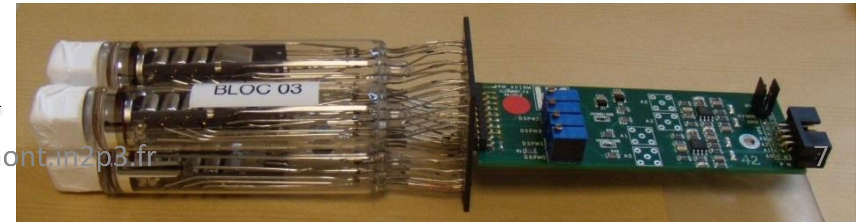


Width : 200 ns
Amplitude : 0 to 200 mV
Rise time : 8 ns

The measure is done with a source Na22

Quartet of PMTs with its High Voltage divider

LYSO Scintillators

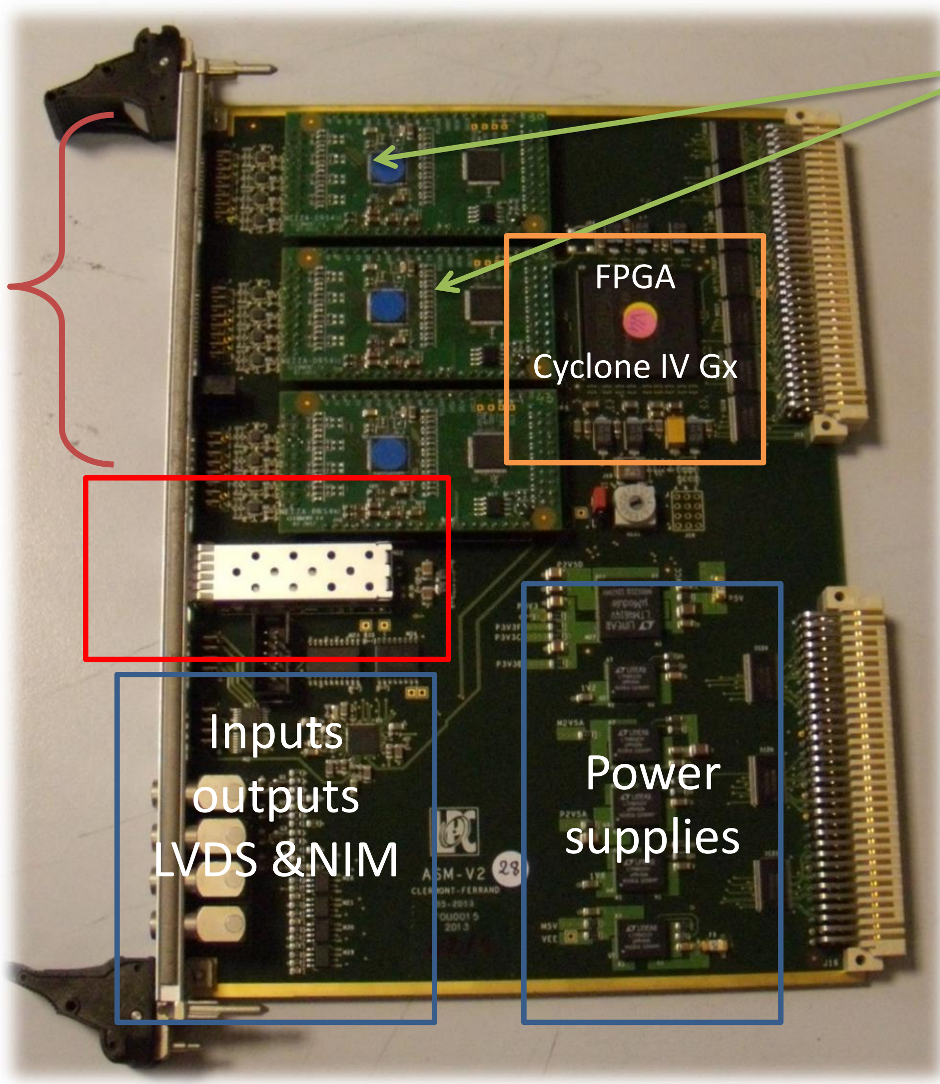


ASM Board

Main ASM Characteristics

- ASM for “Analog Sampling Module”
- Generic electronic board
- 24 differentials analog inputs (600mV amplitude)
- VME 6U board format (compatible VME 64x) (160*234 mm)
- Scalable system
- Functions:
  - sampling data at 5 GHz on a windows up to 1000 samples.
  - Generate its own trigger detection by channel and by board.
- Data acquisition used VME BLT protocol or by optical fiber to an ATCA system

ASM specifications



3 Sampling & digitizing mezzanines

24 differential analog inputs

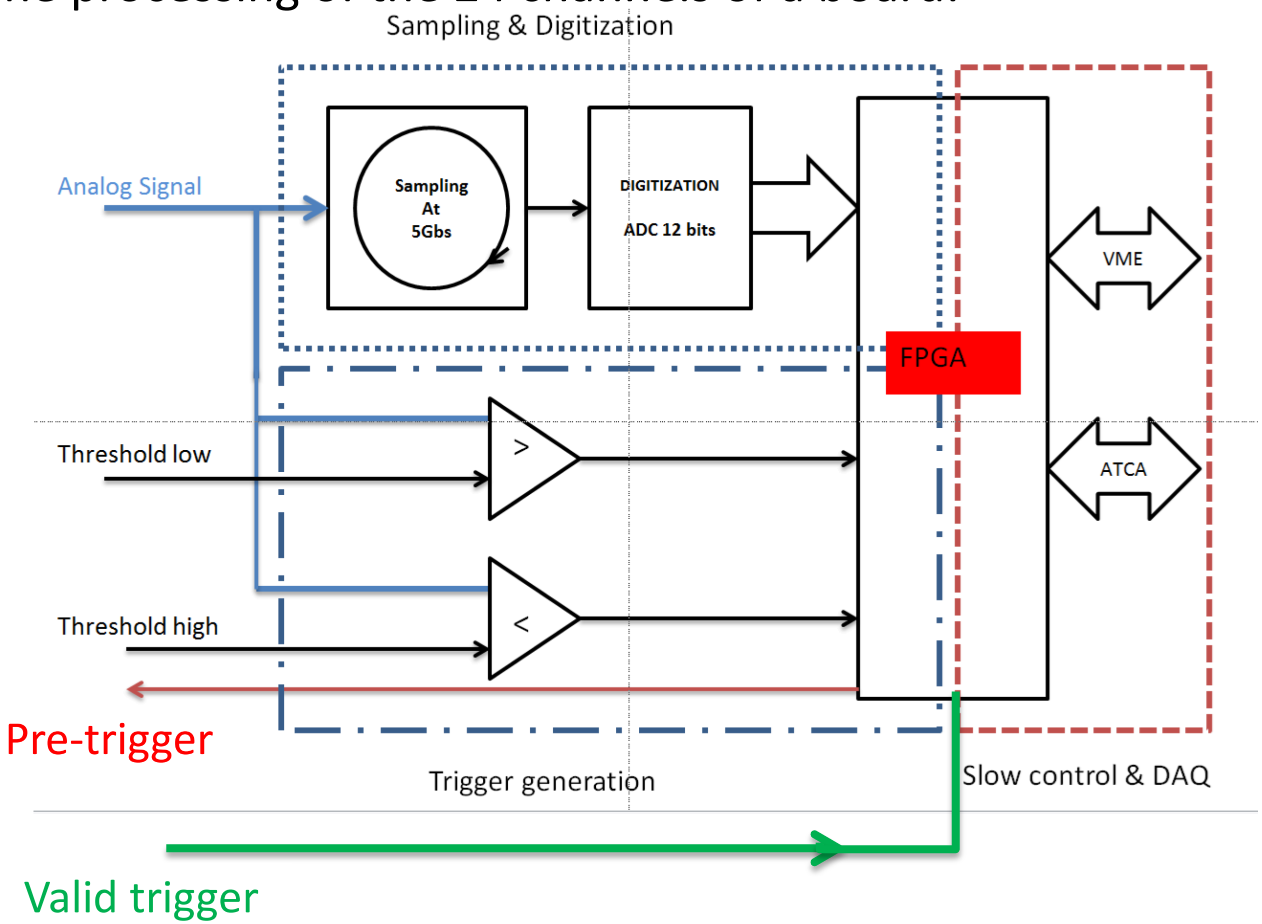
under mezzanines Analog trigger generation part

Optical Tx/ Rx 3 Gbs

Connectors to VME Backplane

ASM board functional diagram

The processing of the 24 channels of a board:

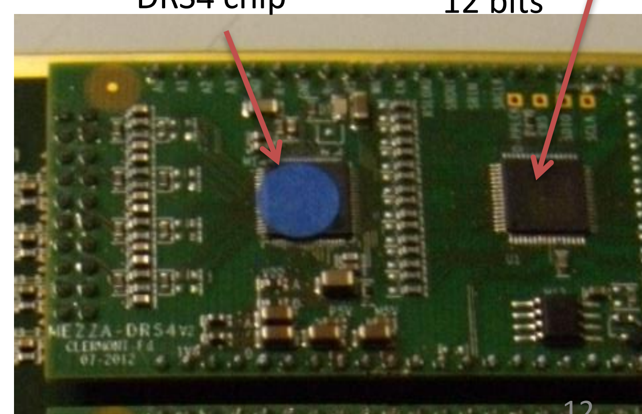


Sampling & digitization

- Used DRS4 chips coupled with an ADC 12 bits

- By configuring VME register: one determines :
  - Buffer size 10 to 1000 samples
  - Sampling frequency (for stand alone work)
  - Select internal sampling frequency or external LVDS clock for multiple boards can be adjusted.

  - Each mezzanine can be individually configured.

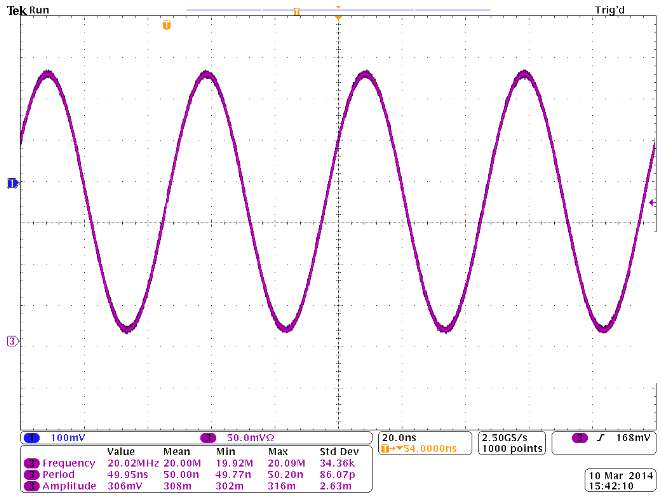


Sampling & digitizing
mezzanine

Sampling at high frequency with the DRS4 component

- The DRS4 is designed and produced at PSI (Willigen)
- It's an analog to analog signal component.
- it allows a shift frequency of the signal because it samples at 5 GHZ and gives out the same signal at 25 MHz (from our specific design).
- With this output frequency, it's easy to used commercial ADC.
- It's based on Switched capacitors array(SCA) technology.

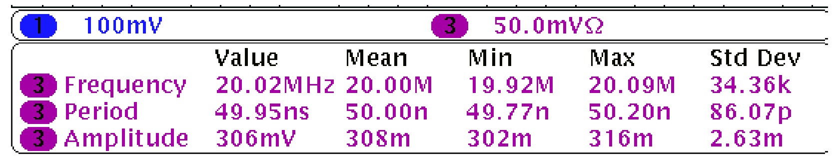
signal read by an oscilloscope



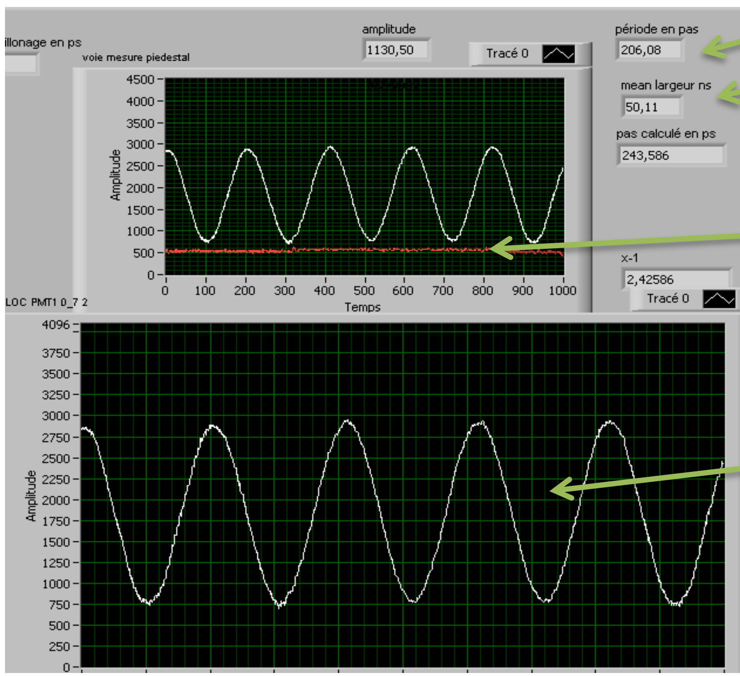
Input signal :

sinusoidal signal : 50ns period

Amplitude 300mV single ended



Same signal view by ASM test bench acquisition& triggered by channel 0



Calculate period in step (206.08)

Equivalent period in ns (50.11 ns)

Calculated step value (243.5 ps)

View of channel 0 & 1

View of channel 0
Subtract to channel 1
Pedestal pattern

Result :

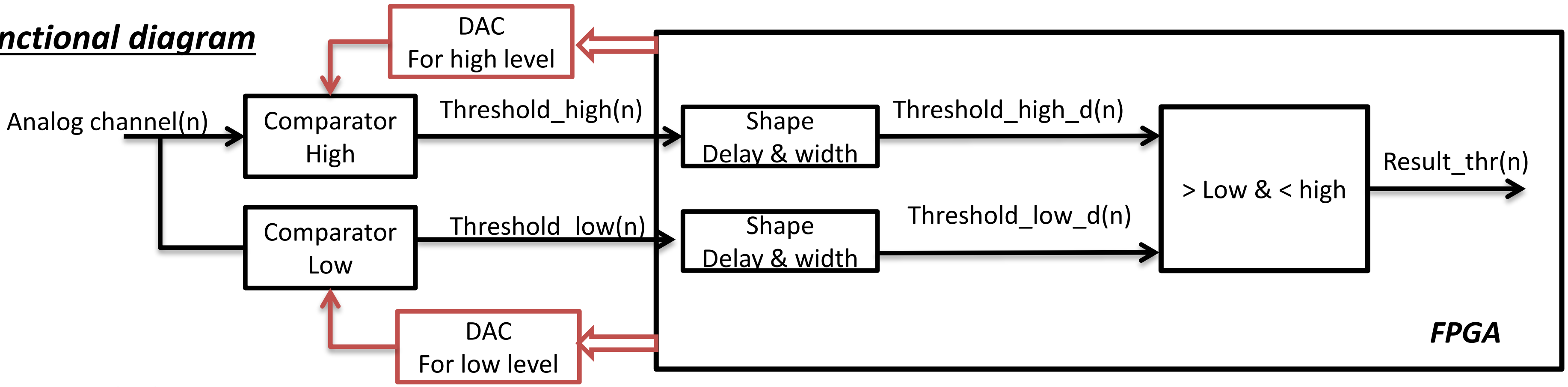
Amplitude 120 µV / ADC step

1269 *(120µV *2) =304 mV

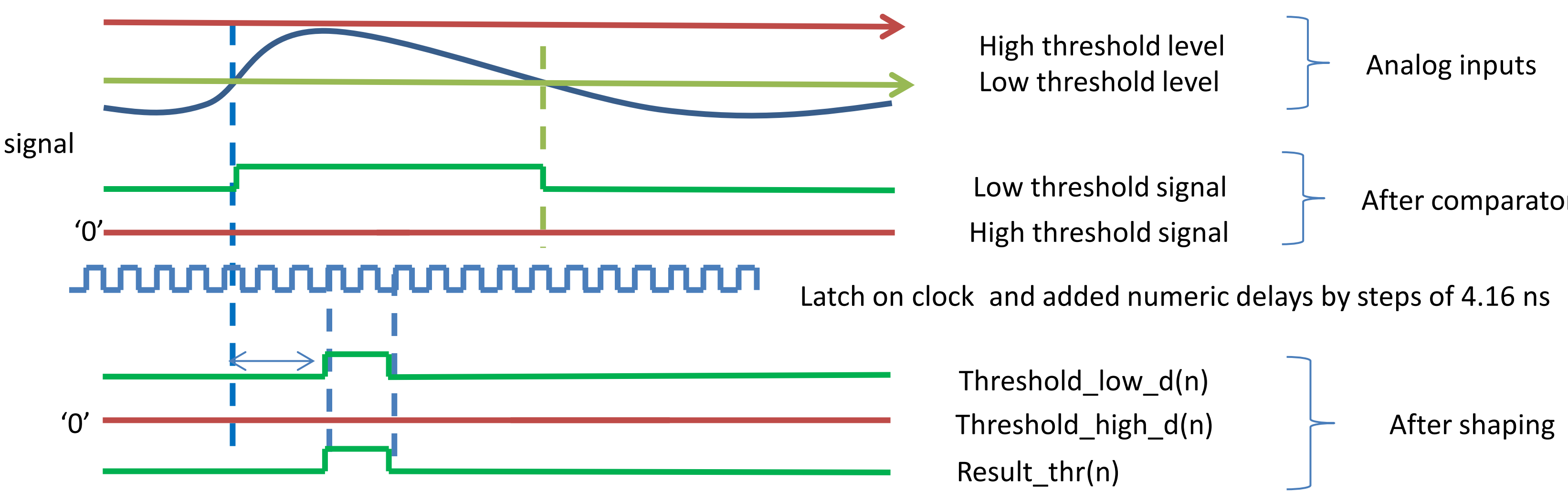
Thresholds detection to trigger signal

First step : individual trigger generation

Functional diagram



Functional plot

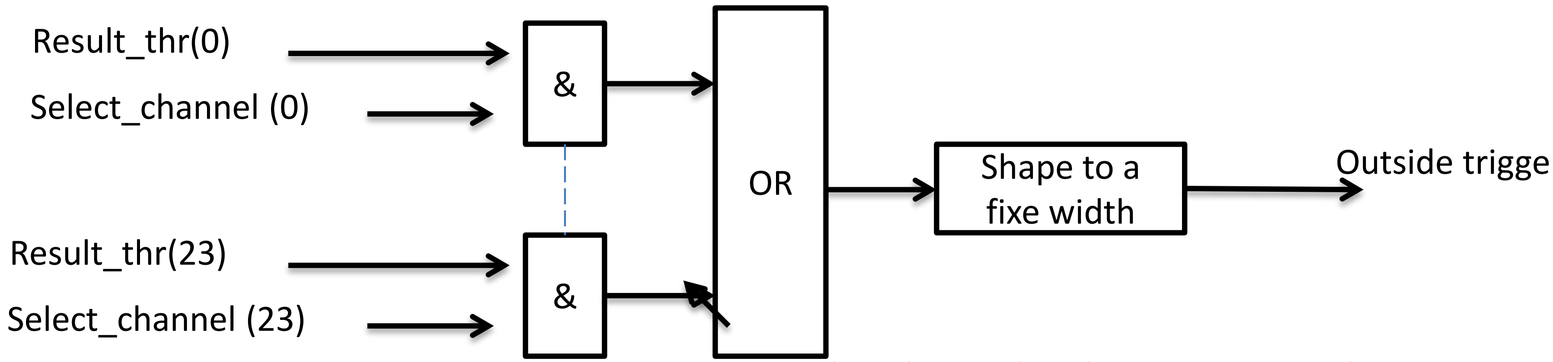


magne@clermont.in2p3.fr

Thresholds detection to trigger signal

Second step: board trigger generation

- each channel of the board can be selected to be included in the trigger



This shaper has been added to be sure to have the right signal to stop the sampling

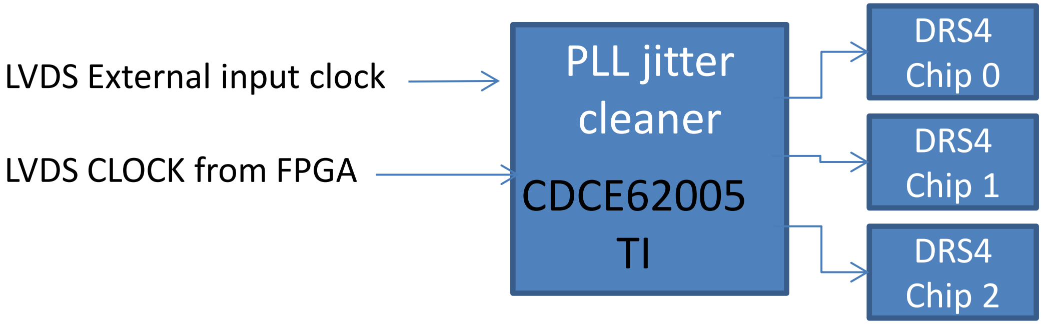
The signal trigger can be read outside the board to be used in an external trigger logic (coincidences with other board's triggers)

and allow to produce a BUSY signal of each board involved in the trigger equation when using more than one ASM boards

Sampling Clock network

- The PLL jitter cleaner allow to select on 2 inputs clock and generate 3 clocks for the 3 DRS4 chips.

Functional sampling clock network



- The PLL jitter cleaner ensure the low jitter between the 3 chips.
- The tracks on the PCB have been carefully studies .
- LVDS External input clock is used on ours detectors to all DRS are well synchronize.

Data acquisition

At the output of the ADC the data of 2 channels are set in a FIFO (24 bits) (to be compatible with 32 bits VME bus).

For the first step of the acquisition data we used VME BLT protocol :

The acquisition time is function of numbers of channel read, numbers of samples by channel and digitization time .

- ***<u>DATA VME OUTPUTS : (available solution)</u>***
- Worst case : If you read 24 channels with 1000 samples each :
- **818 HZ Max** readout frequency ➔ Result in experiment **500 Hz** by board

  (to be divide if the number of board is increase)

- ***<u>Next STEP : optical link(in progress)</u>***
- The next step is to used the optical link : for the same example we hope a max readout of **6 KHz by board & for all the detector**

Conclusion & Perspectives **for the ASM boards**

- **Conclusion:**

- This board has begin to give his performances
- The firmware are now stable and permit to make tests to well qualified it.
- Calibration must be add to current setup to hope to obtain low jitter permit by the DRS4 chip.

More results in the next month

Perspectives

- Increase the data rate acquisition by implementing optical link to ATCA.
  - In progress
- Achieve complete characterization of the boards.
  - In progress

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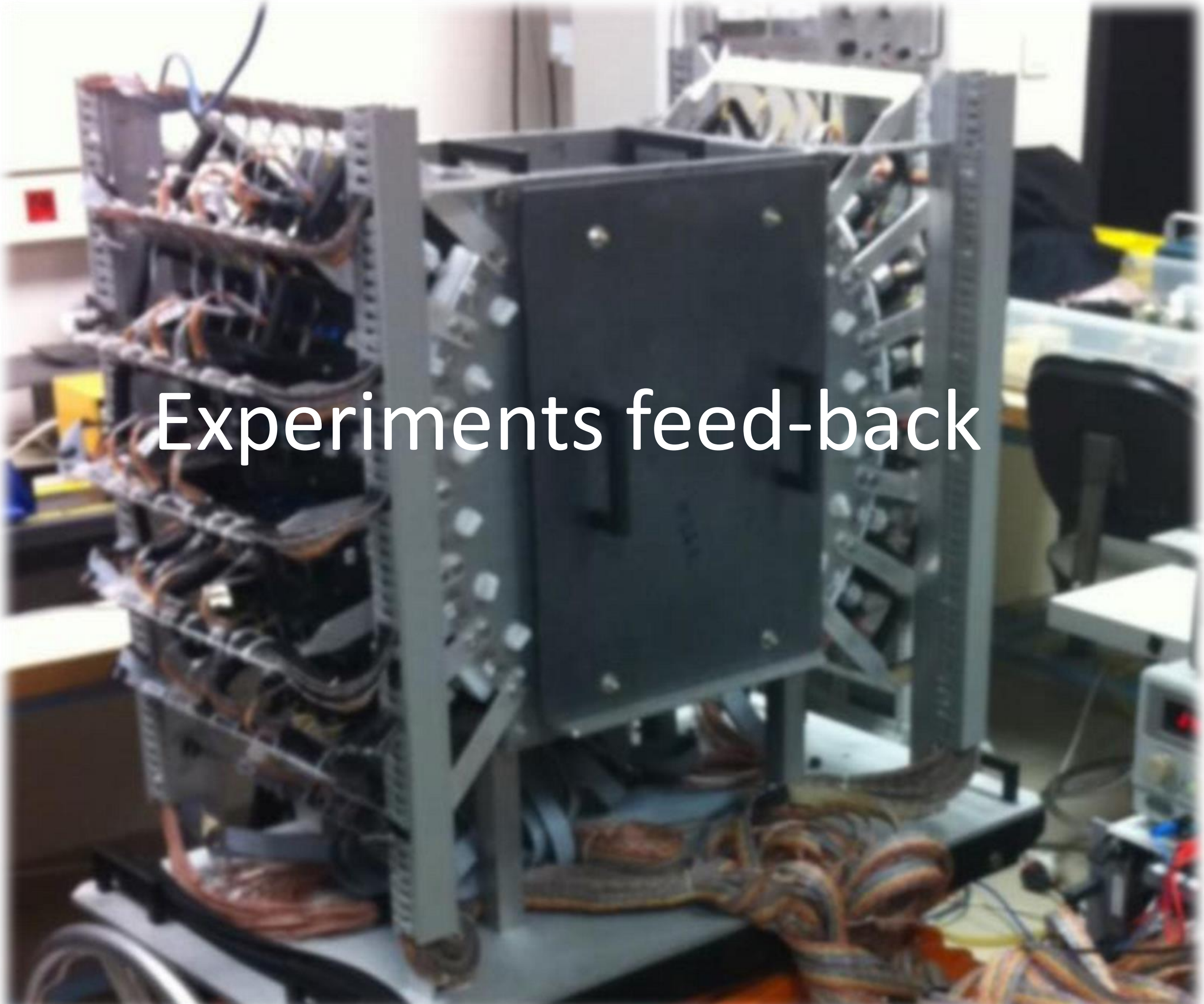
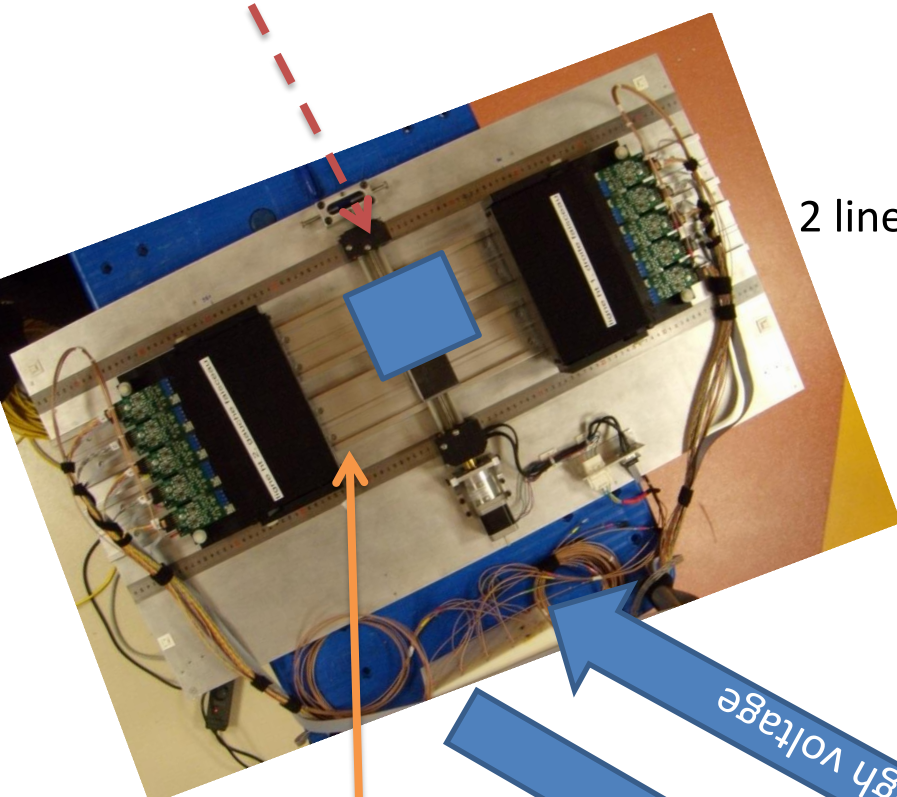
Experiments feed-back



First test beam setup

end 2013 to autumn 2014

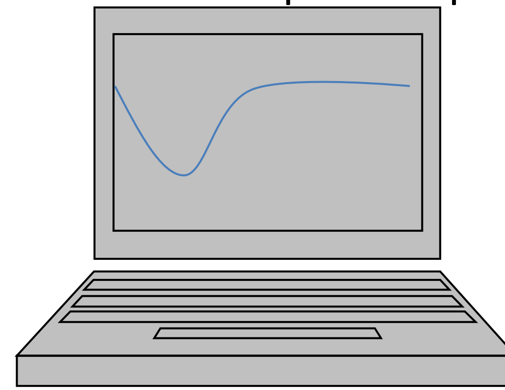
Beam



2 lines of 20 PMT each

PMMA target or Na22 source

A custom acquisition program



Ethernet Link

High voltage

data

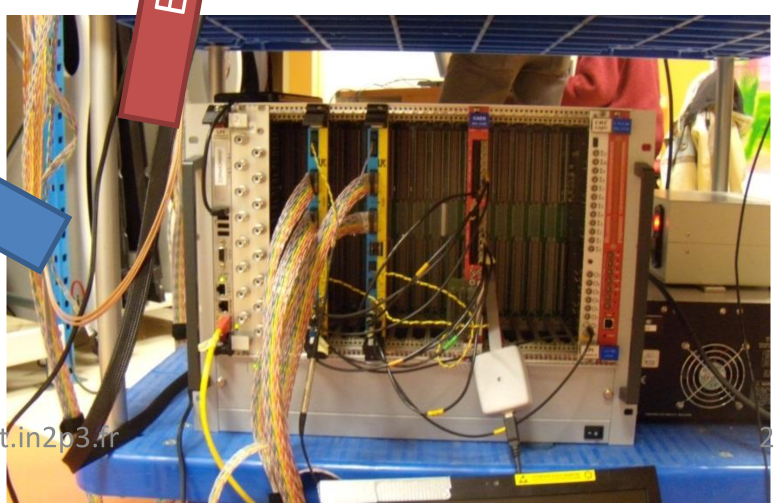
Compact acquisition system

VME CPU

2 High Voltage boards

2 ASM boards

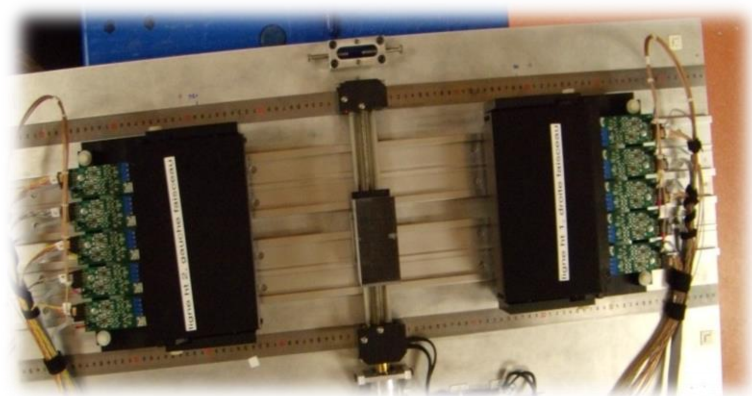
1 VME logic board(CAEN V1495)



First test beam setup

- Some test has been done with this setup on several during the last year :
  - At Lab with a Na22 source
  - At CPO with a proton beam ..
  - At Ganil with a Carbon Beam (ions)
  - At Heidleberg carbon ions & proton beams

- <u>Results:</u>
- This tests permit to debug the electronics and to well knowing the detector …



On-line PET contraints

- In line PET has very different constraints from clinical TEP ;
- Clinical configuration ➔ not a full ring configuration

- Noisy environment➔ must produced particles through ion fragmentation
- 511 keV gammas from positron annihilation
- But a lot of nuclear “prompt” gammas from excited nuclei decay

- 511 keV are emitted continuously in time (fixed energy, time coincidence)

- “prompt” nuclear gammas emitted with the beam spill (broad energy spectra from 100 keV to 10 MeV)

- Contribution of “prompt” gamma’s is so dependent of the beam time structure and so of the accelerator

➔ You should take this constraint when designing and testing in-beam TEP for hadrontherapy

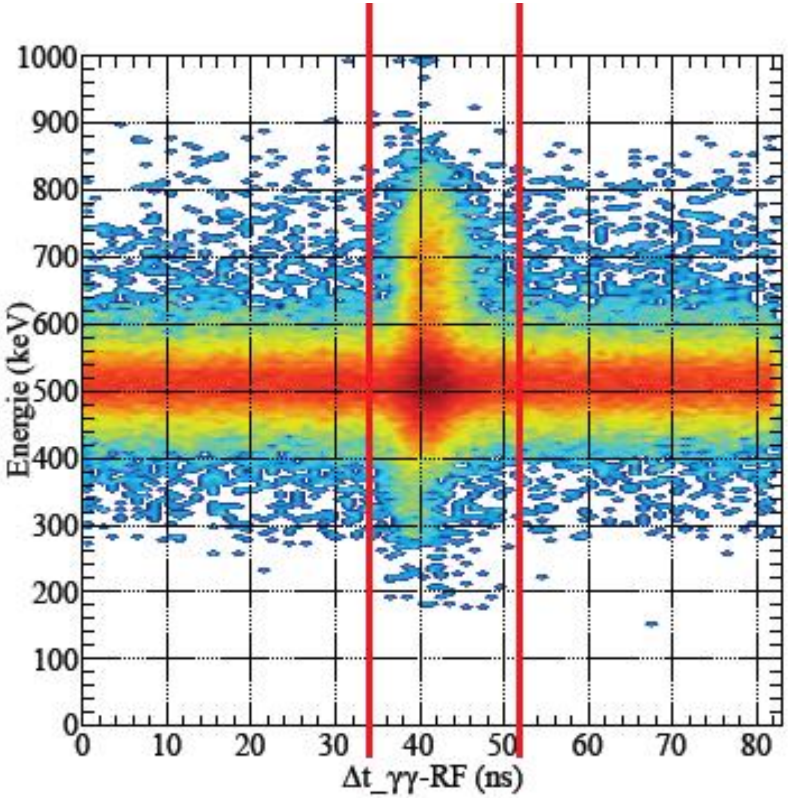
➔ Very limited indication from in lab source experiment

magne@clermont.in2p3.fr

Pulsed beam at GANIL

Etalement (mm)	Energie ($MeV.u^{-1}$)	Intensité $ions.s^{-1}$	Période RF (ns)	Parcours dans PMMA (mm)
X=8, Y=12	75	1.10^8	83	~ 15

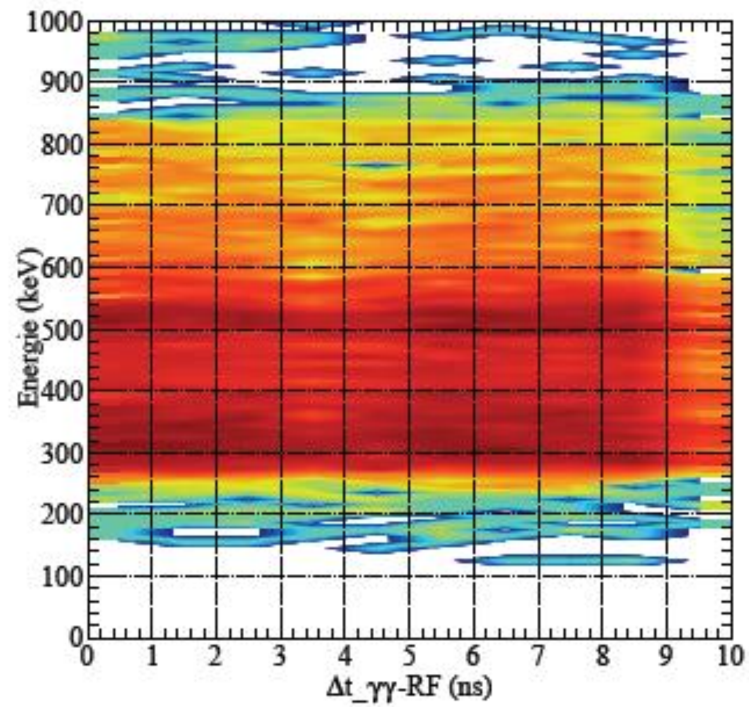
On GANIL beam we have time to get sufficient statistic of "good" events between two successive beam's spills



Continuous beam at CPO Orsay

(isochronous 230 MeV IBA Cyclotron)

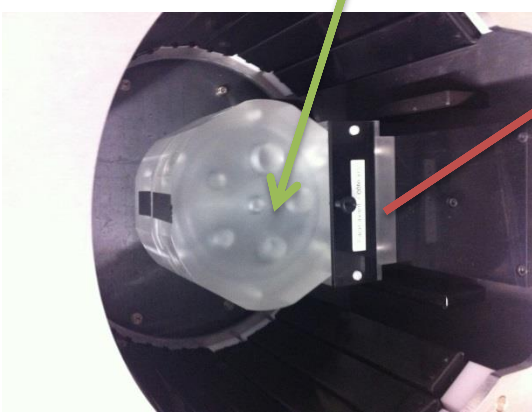
Diamètre (mm)	Energie (MeV)	Intensité à l'injection ions.s^{-1}	Période RF (ns)	Parcours dans PMMA (mm)
25	86	$6{,}25.10^{11}$	9,4	~ 50

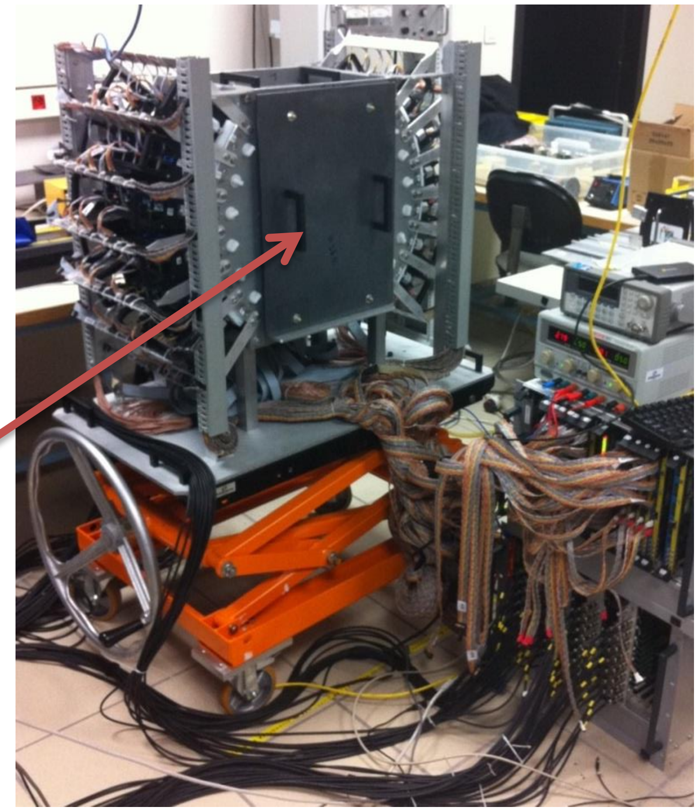


On continuous CPO beam
we get a lot of "random coincidences"
As well as a large DAQ dead time

Last tests beam setup

- This setup is available between last autumn.
- Some test has been done at the CJP (Centre Jean Perrin at the Clermont Ferrand hospital) with radioactive liquid 18F (fluor)

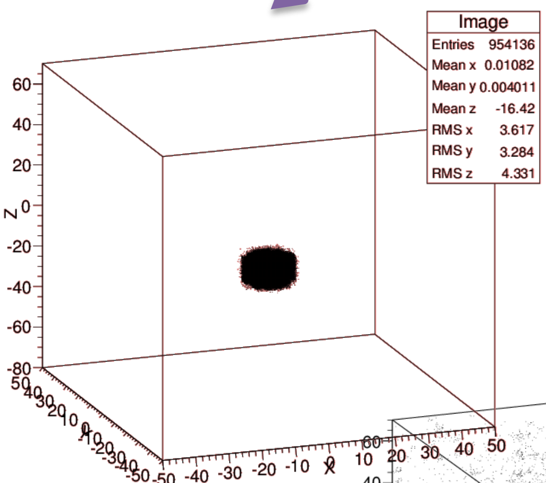


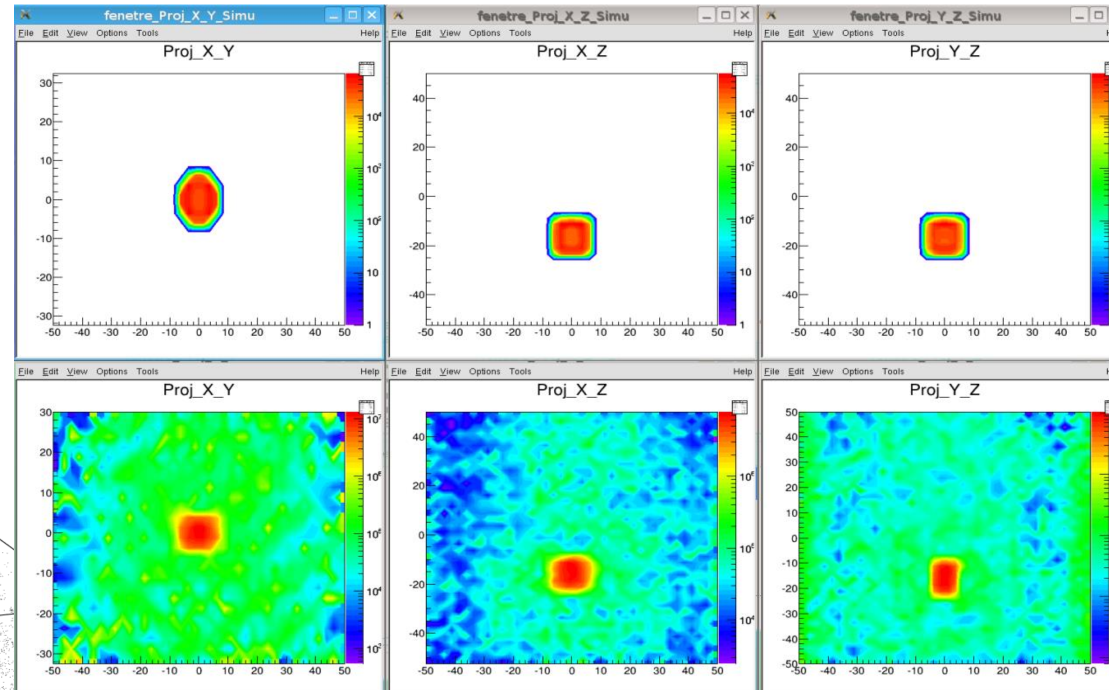


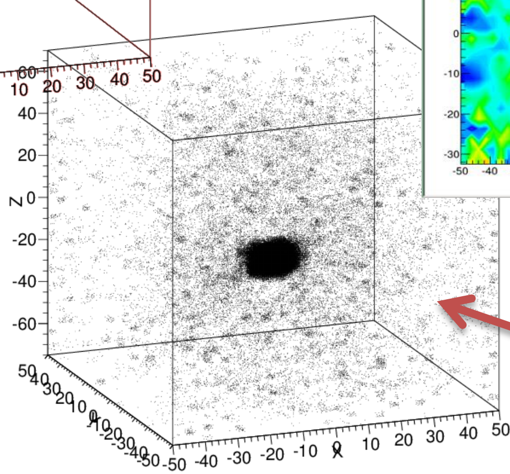
Inside the detector : a phantom with several cavity available for radioactive liquid to allow to emulated several size barrel with several coordonate.

Final detector: Preliminary results

annihilation position by MonteCarlo simulation







<u>Middle Cavity</u>

square : 10 mm

length :10 mm

annihilation position reconstruct with raw data without noise filter.

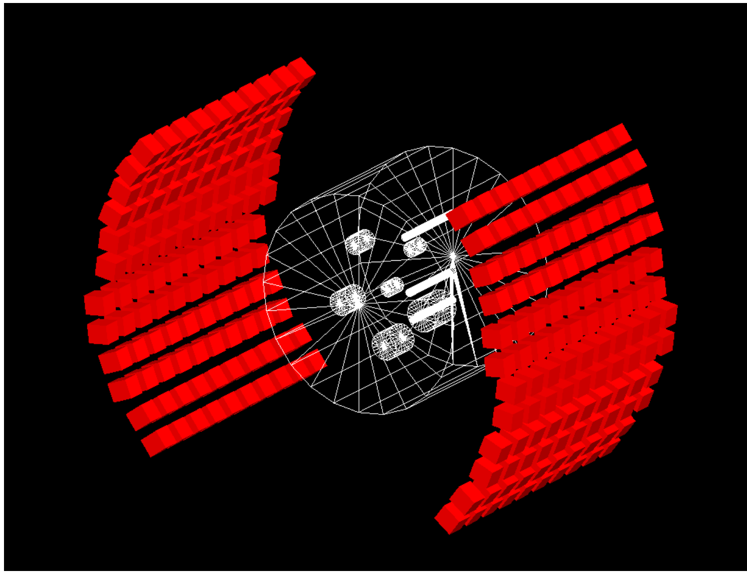
Conclusion & Perspectives for the DPGA detector

Perspectives

- At the winter of this years and during 6 months this detectors will be implemented at "Centre Lacassagne" Nice with 230MeV proton Beam.

First status:

This detector has begin to show the feasibility of reconstruction with partial acceptance but in an off-line mode



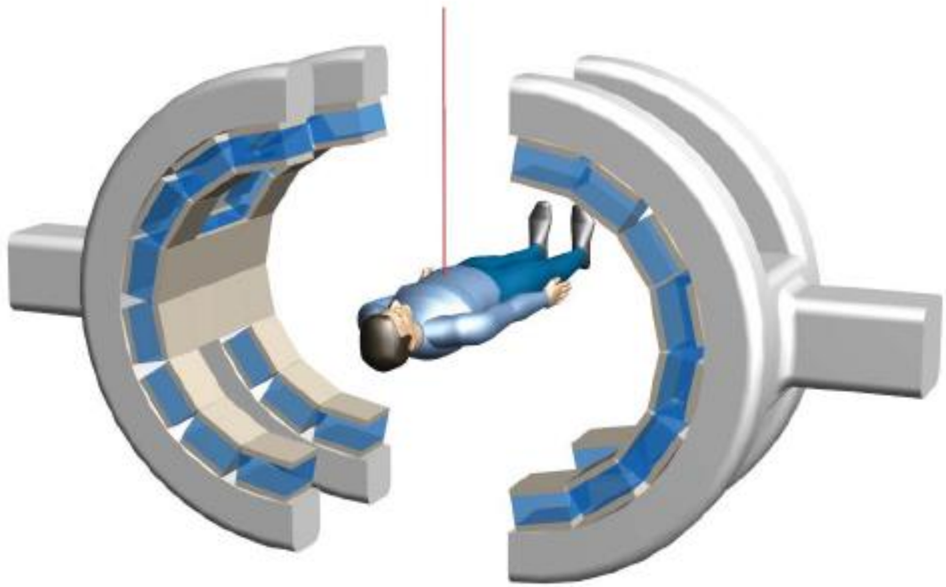
Next test the :

– On-line trigger selectivity,
– On-line good event selection,
– On-line reconstruction

And for the future an other study is in progress,
to improve the performances.

Perspectives

1°)Need for a large acceptance, clinical compatible, in-beam PET

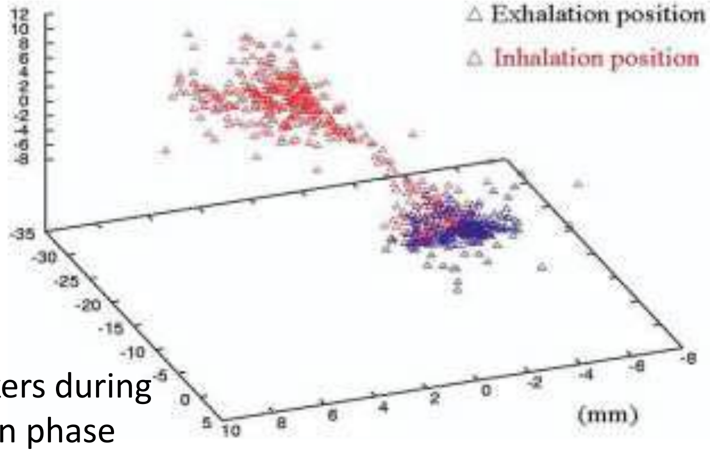


➔OpenPET bridged configuration

Perspectives

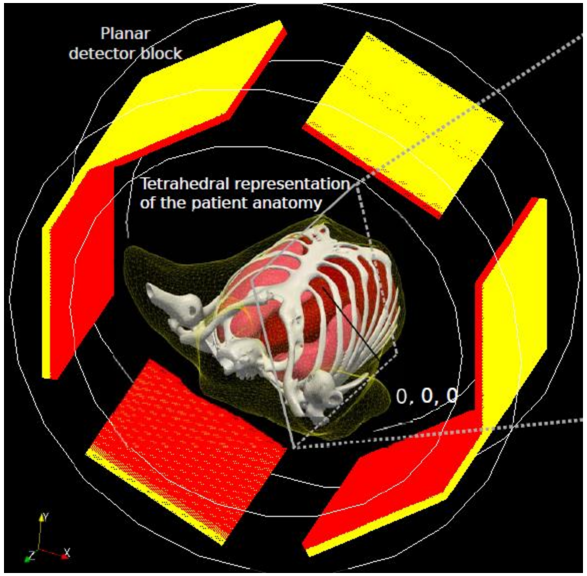
2°)Need for a 4D in beam PET to take into account motion of the tumour (lung cancer)

Non regular movement of the tumor



Position of internal markers during Inspiration and Expiration phase

The beam should follow these movements using a morphomologic and dynamic model of each patient



➔4D TEP acquisition (+ time) for off line control imaging of the dose delivery

Thanks

Questions … Comments