

## R&D mémoires analogiques au SERDI

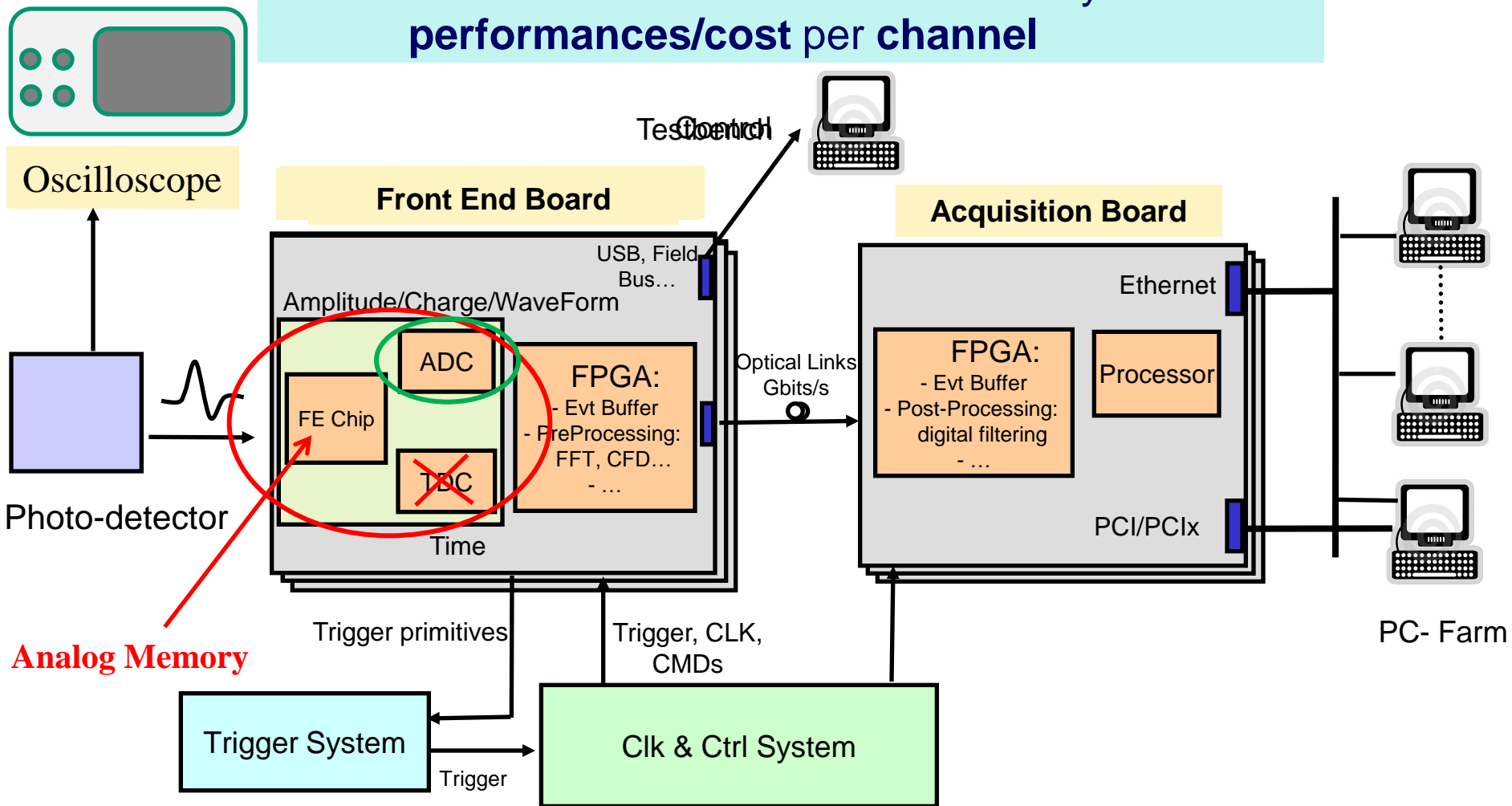
D.Breton, J.Maalmi, P.Rusquart (LAL Orsay), E.Delagnes, H.Grabas (CEA/IRFU)



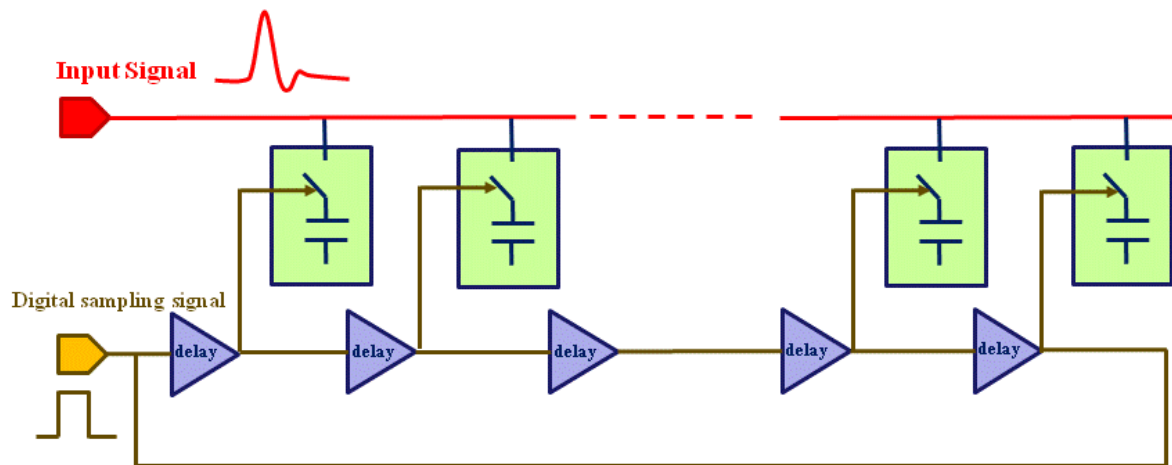
- **Many types of detectors** are implied in projects our lab works in. Associated electronics can be used either for their **characterization** (test benches) or for their **readout** (experiments).
- For **test benches**:
  - Ultimate performance of the electronics is requested
  - If the number of channels is small ( $\leq 4$ ), then high-end oscilloscopes can be used, but they are expensive.
  - Dedicated hardware/software can also be very useful and effective
  - If the **number of channels increases**, and if one wants to study all of them in parallel, difficulties occur.
- For **physics experiments**:
  - Usually, **dedicated ASICs** are used
  - They shape the signal and measure Amplitude, Charge and/or Time
- But, what happens if:
  - **Time measurement** precision has to be (much) **better than 30ps rms** ?
  - One wants to **measure A, Q and/or T**, but also see the **waveforms** on demand ?

# The measurement chain

Choice of measurement chain is driven by the ratio  
**performances/cost per channel**



An analog memory can record waveforms at very high sampling rate ( $\gg$ GS/s)  
After trigger, they are digitized at a much lower rate with an ADC ( $\sim 20$  MHz)



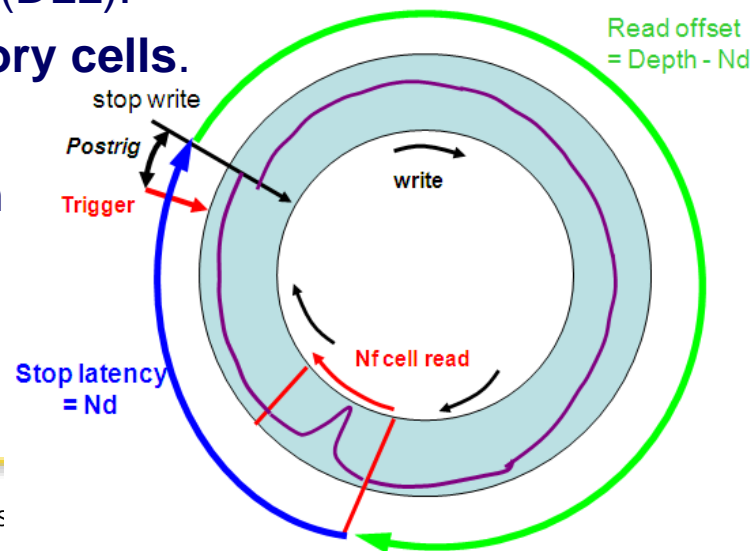
- A write pulse is running along a folded **delay line** (DLL).

- It drives the recording of signal into **analog memory cells**.

- Sampling stops upon **trigger**.

- **Readout** can target an area of interest, which can be only a **subset** of the whole channel

- **Dead time** due to readout has to remain as small as possible ( $< 100$ ns / sample).

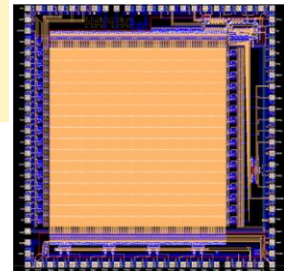




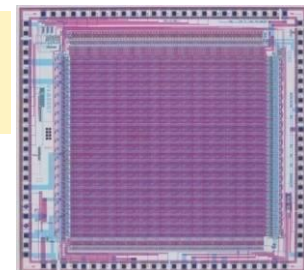
# Our favourite solution: a Sampling Matrix

- We started designing analog memories in 1992 with the first prototype of the Switched Capacitor Array (SCA) for the ATLAS LARG calorimeter. **80000 chips** produced in 2002, now **on duty on the LHC**.
- Since 2002, 3 new generations of fast samplers have been designed (ARS, MATAcq, SAM): total of more than **30000 chips in use**.

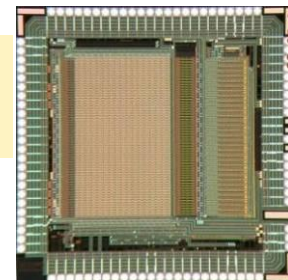
HAMAC  
1998-2002



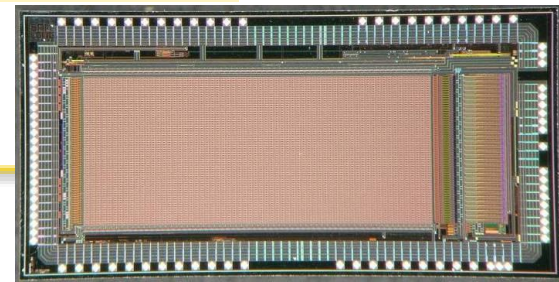
MATAcq  
2000-2003



SAM  
2005



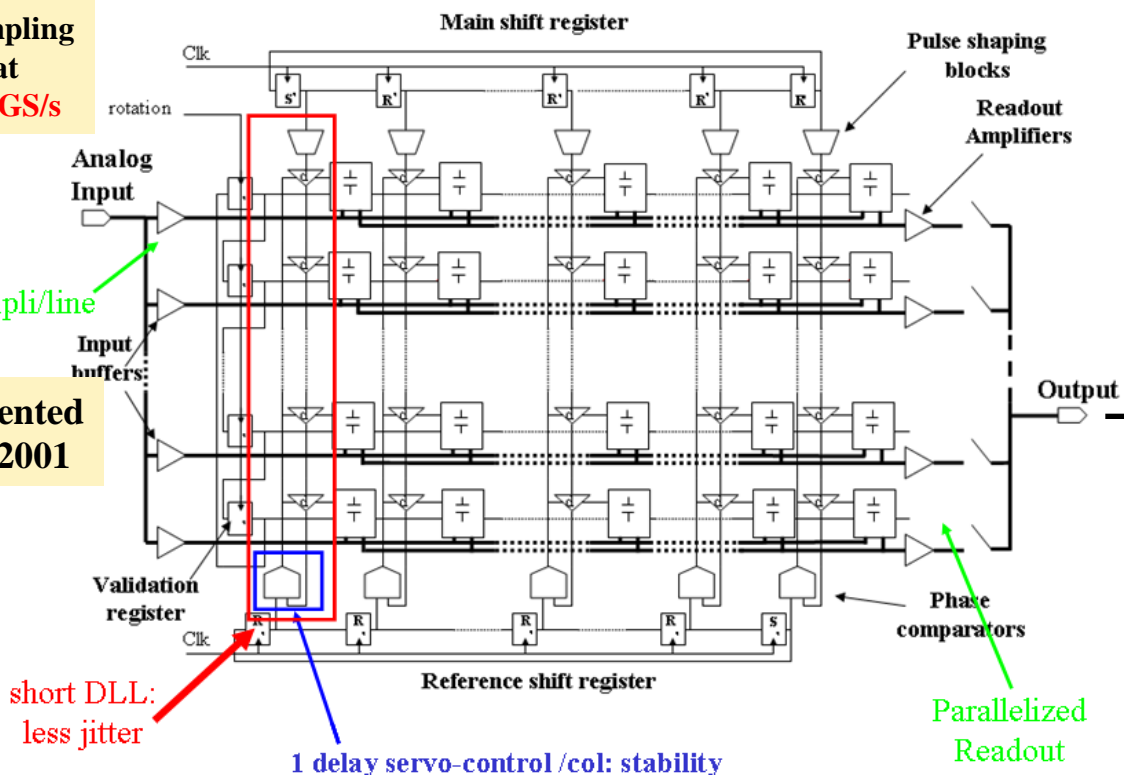
SAMLONG  
2010-2012



Sampling  
at  
**3.2GS/s**

1 ampli/line

Patented  
in 2001



Readout  
12 bits  
**20 MHz**

- **Analog memories** actually look like perfect candidates for **high precision measurements at high scale**:
  - Like ADCs they catch the **signal waveform**
  - **TDC is built-in** (position in the memory gives the time)
  - Only the useful information is digitized (vs ADCs) => **reduced dataflow and power**
  - **Any type of digital processing** can be used
  - Main difficulty is less sampling frequency than signal **bandwidth**
- Their drawbacks:
  - The limited recording **depth**
  - The readout **dead-time** limiting the input rate
- But:
  - Only a few samples/hit can be read => this may limit the dead time
  - **Simultaneous write/read** operation is feasible, which may further reduce the dead time

# The USB\_WaveCatcher board (V6)

Pulsers for reflectometry applications

1.5 GHz BW amplifier.

Board has to be powered by USB  
 $\Rightarrow$  power consumption  $\leq 2.5W$

Reference clock:  
 200MHz  $\Rightarrow$  3.2GS/s

2 analog inputs.  
 DC Coupled.



$\mu$  USB

Trigger input

Trigger output

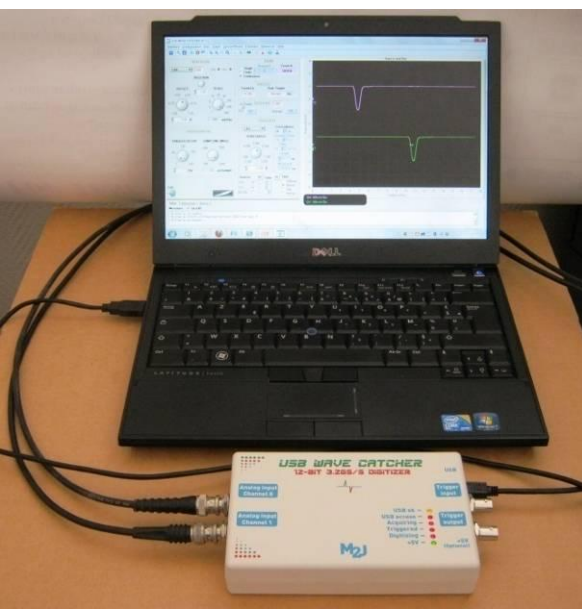
+5V Jack plug

SAM Chip

Trigger discriminators

Cyclone FPGA

Dual 12-bit ADC



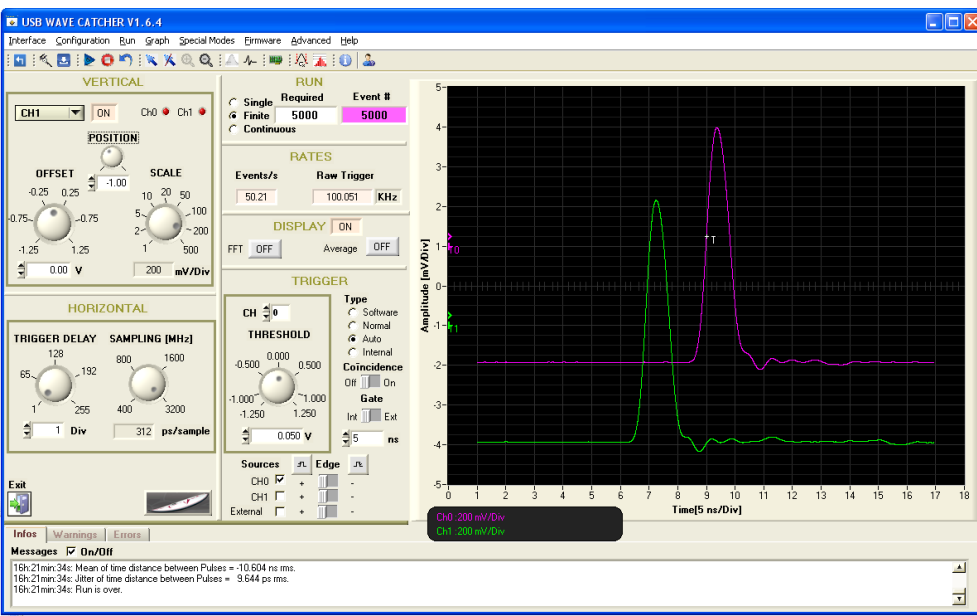
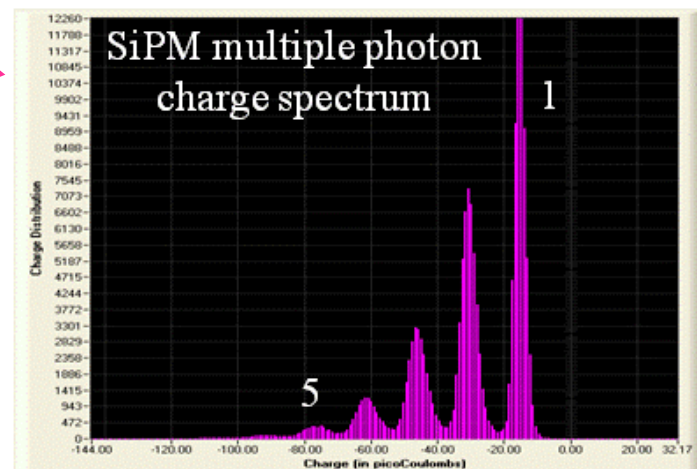
The module

The autonomous test bench

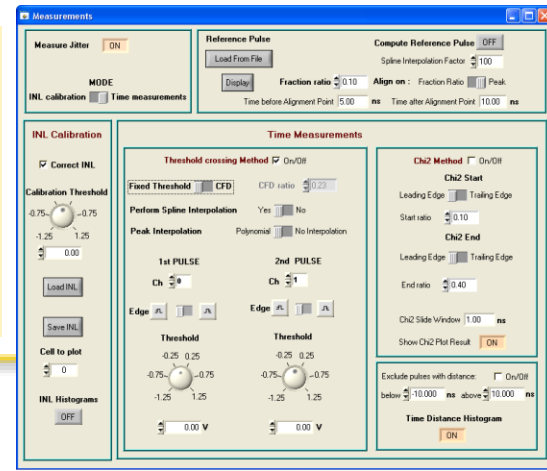




- ❖ Possibility to add an **individual DC offset** on each signal
- ❖ Individual **trigger discriminator** on each channel
- ❖ External and internal trigger + numerous modes of **triggering on coincidence** (11 possibilities including two pulses on the same channel) => useful for afterpulse studies
- ❖ **Real time trigger counting** independent of acquisition rate
- ❖ **Embedded charge mode** (integration starts on threshold or at a fixed location) => high rates (~ 7 kEvents/s)
- ❖ **Embedded pulse generators** for reflectometry applications

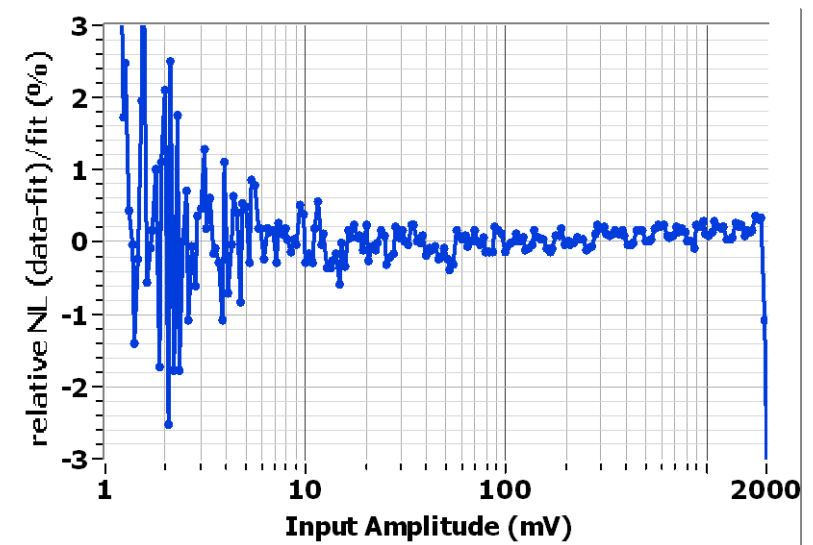
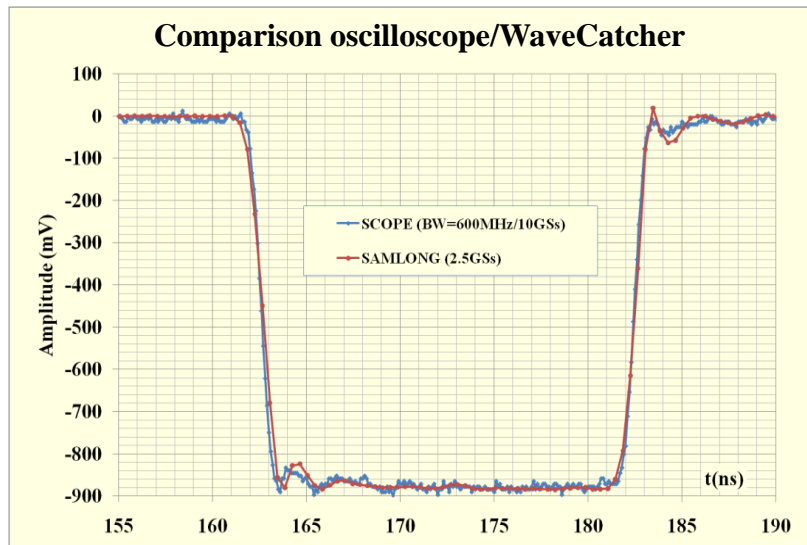
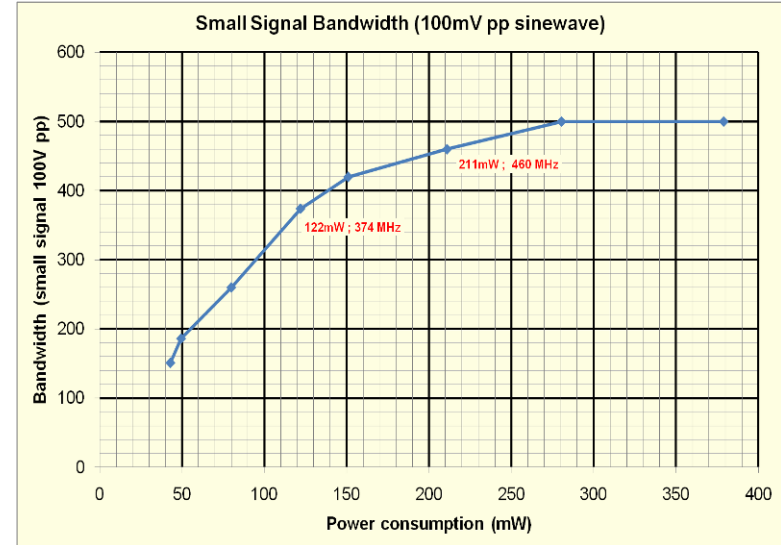
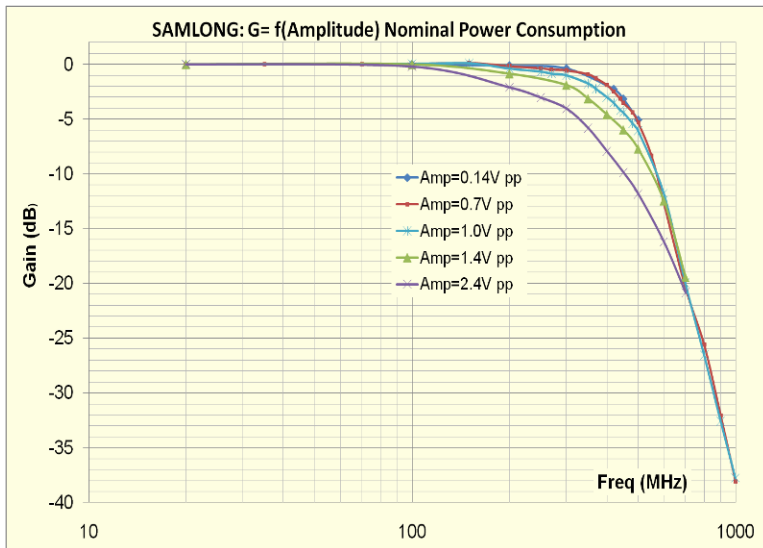


This
   
 oscilloscope-
   
 like software
   
 was developed
   
 by the team.





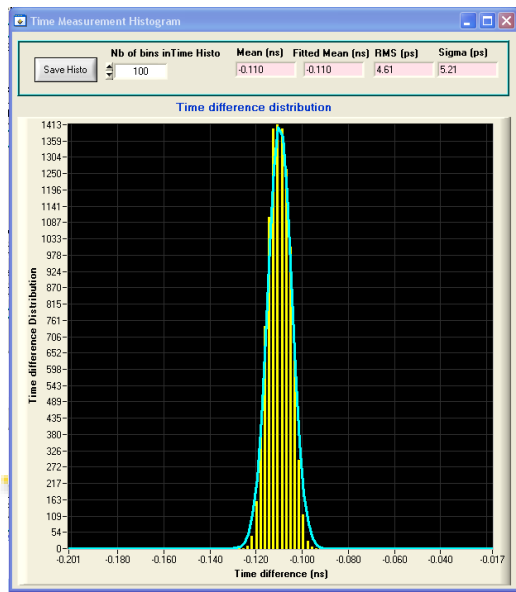
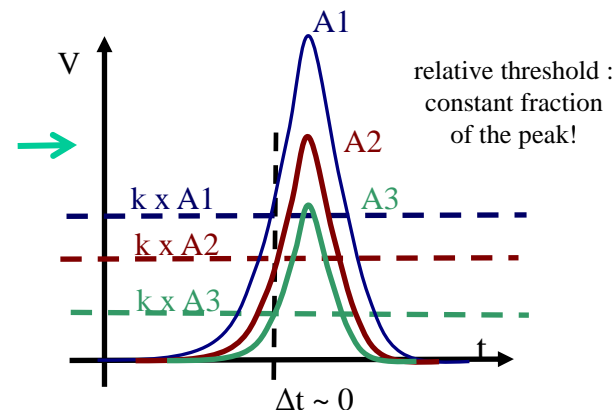
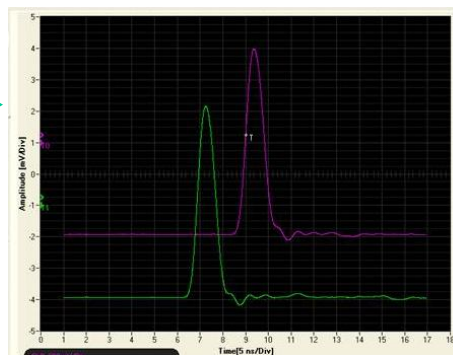
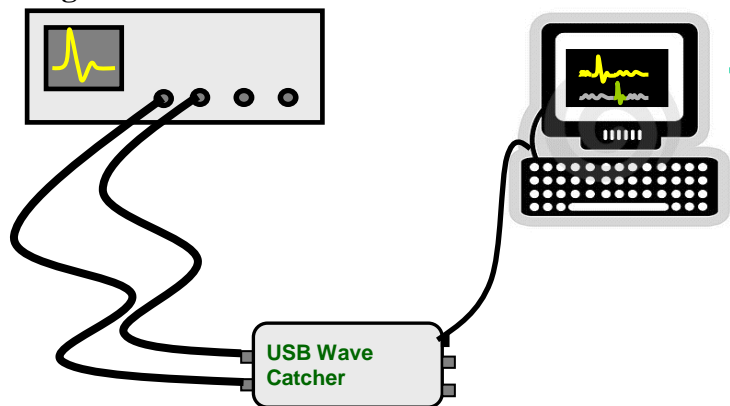
# Board performances: examples



- **Source: randomly distributed** set of two positive pulses
- Results are the same with negative pulses or distance between arches of a sine wave

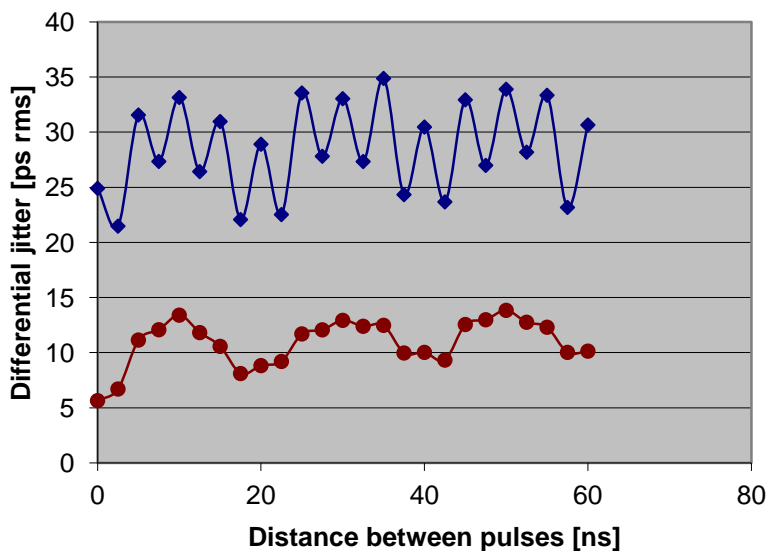
## Constant Fraction Discriminator

Agilent 81110/12/12



D. Bretor

## Differential jitter between 2 pulses with and without time calibration



**Differential jitter  
after calibration  
<14ps rms  
⇒ <10ps  
for single pulse**

- ◆ WaveCatcher V4 without INL correction
- WaveCatcher V4 with INL corrected

- 2 DC-coupled **1024-deep channels** with 50-Ohm active input impedance
- **1.25V** dynamic Range, with full range 16-bit individual tunable offsets
- 2 individual **pulse generators** for test and reflectometry applications.
- On-board **charge integration** calculation.
- Integrated **raw trigger rate** counters
- **Bandwidth ~ 500MHz**
- **Signal/noise ratio: 11.8 bits rms**  
(noise = **650  $\mu$ V RMS**)
- **Sampling Frequency: 400MS/s to 3.2GS/s**
- Max consumption on +5V: **0.5A**



- **Absolute time precision** in a channel (typical):
  - without time calibration: ~20ps rms (3.2GS/s)
  - after time calibration **~10ps rms** (3.2GS/s)
- **Relative time precision** between channels: **<5ps rms**.
- **Trigger sources**: software, external, internal, threshold on signals,
- **11 modes of trigger** coincidence
- Acquisition rate (**full events**) Up to **~1 kHz** over 2 full channels
- Acquisition rate (**charge mode**) Up to **~7 kHz** over 2 channels

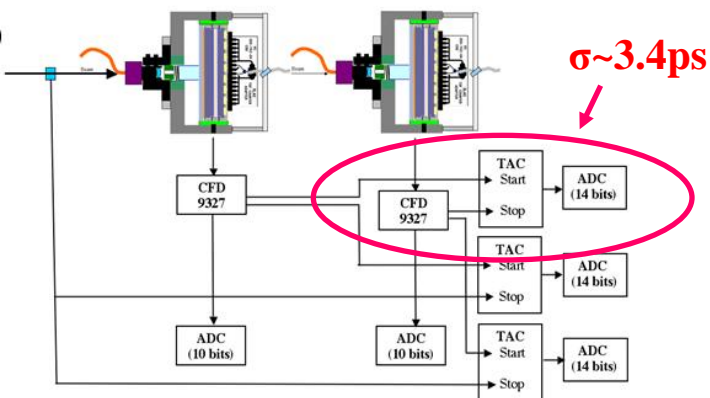
# Applications to photo-detectors: a few examples



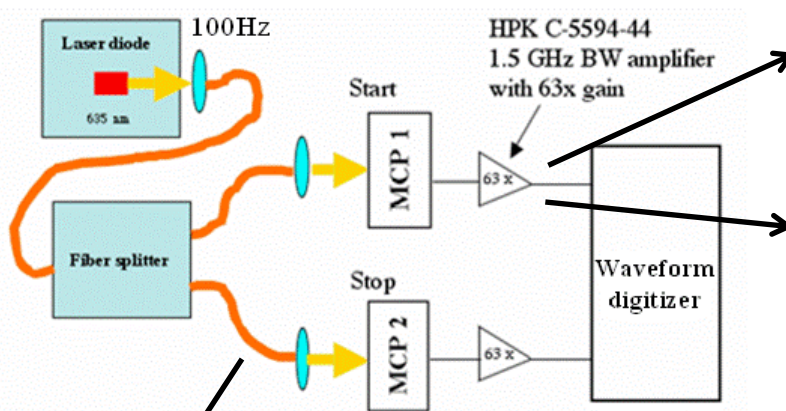


Goal was to compare different electronics for measuring the signal time difference between 2 MCP-PMTs => NIM paper A 629 (2011) 123-132

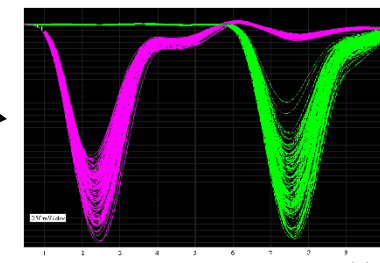
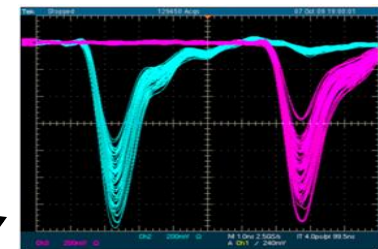
## Using Ortec modules



## Using Waveform Digitizers

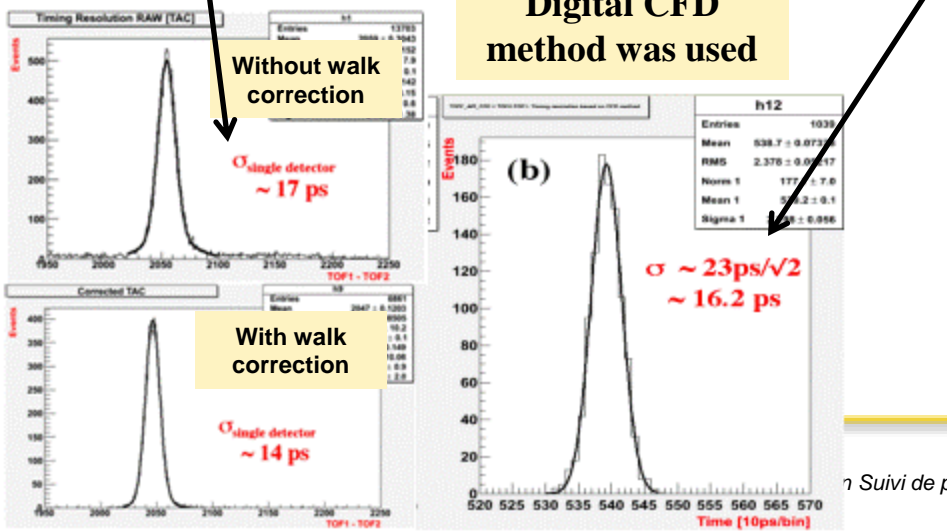


## Tektronix oscilloscope

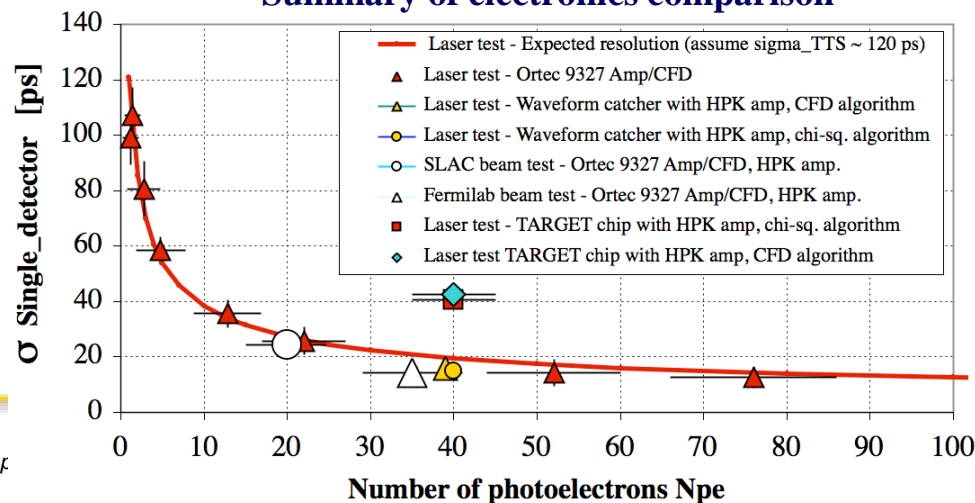


## WaveCatcher board

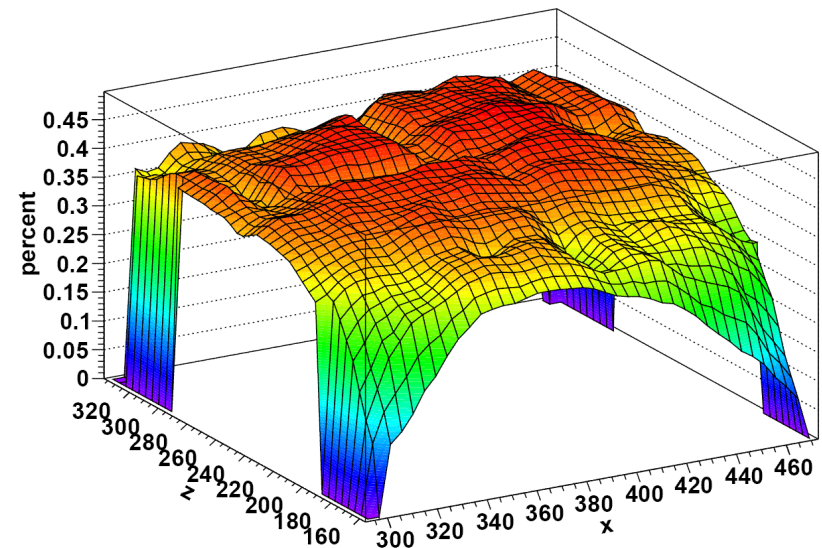
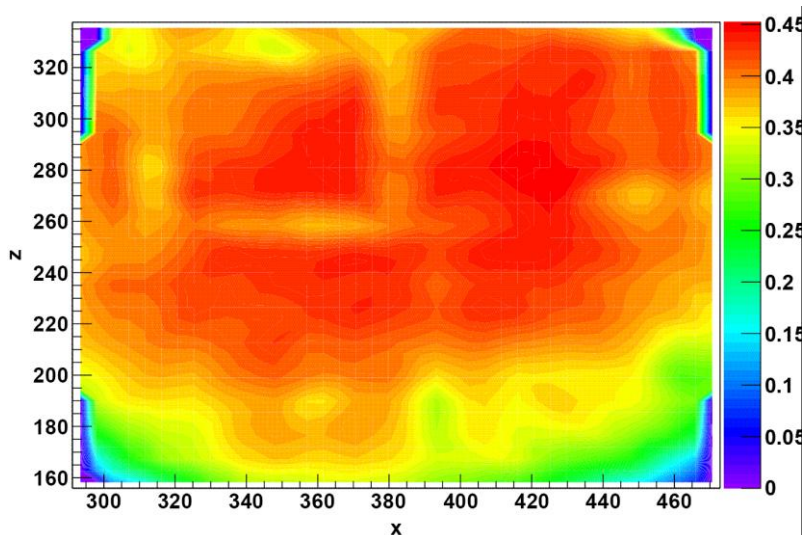
## Digital CFD method was used



## Summary of electronics comparison



- Goal is to precisely characterize the Antares opto-modules in single photoelectron mode
- **1,000,000 triggers** per measurement step
- 0.45% of triggers give a photoelectron ( $\Rightarrow$  ~1.5% of statistical error)
- There are 289 measurement steps spaced by 1cm (3 degrees of aperture on the optical module) starting from its center
- Using the **integrated charge mode**, reading out the 289,000,000 events took only 2h30 with V4.

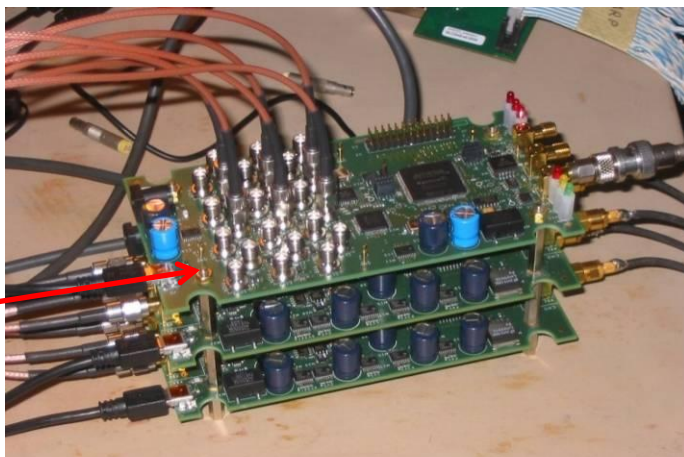




# Increasing the number of channels ...

- To validate the principle, we decided to build a synchronous **16-channel** acquisition system based on **8 two-channel WaveCatcher V5** boards
- Technical challenge: to **keep the 10ps time precision** at the crate level

4-channel  
prototype

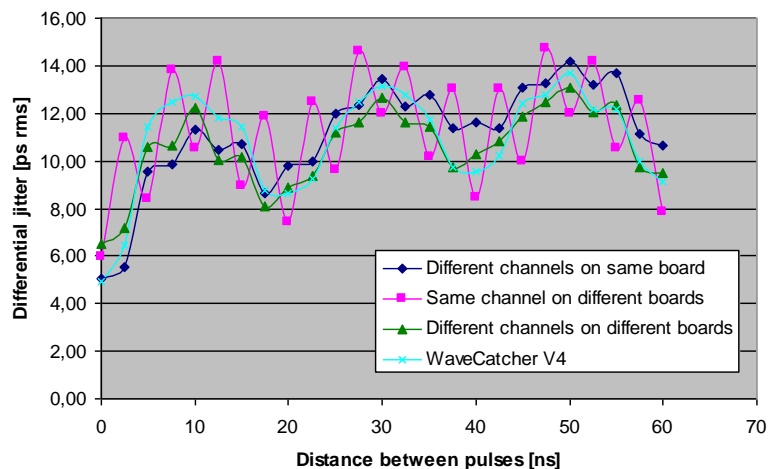


New controller  
board

16-channel crate

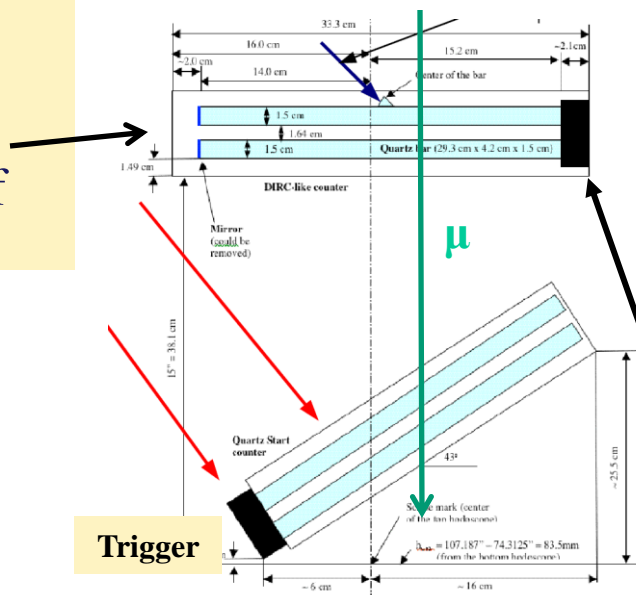


Differential jitter between 2 pulses  
in a multi-board system

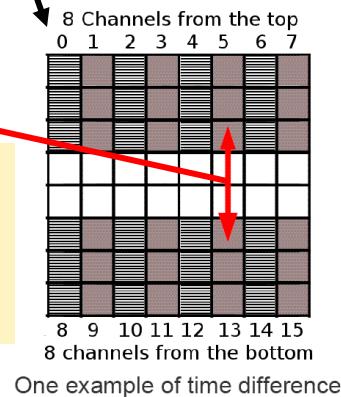
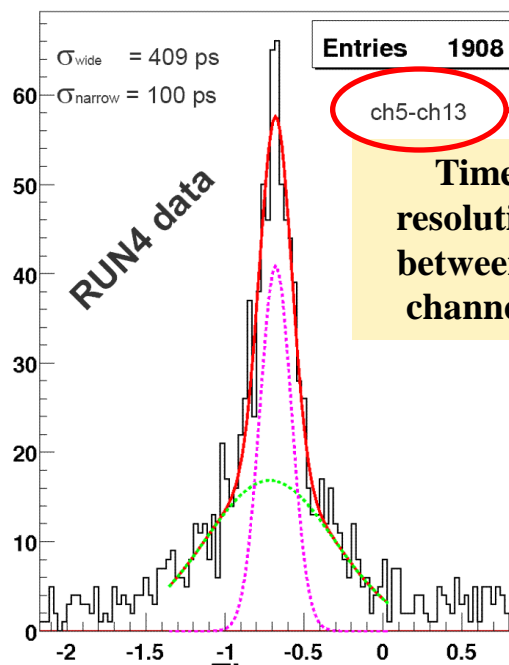
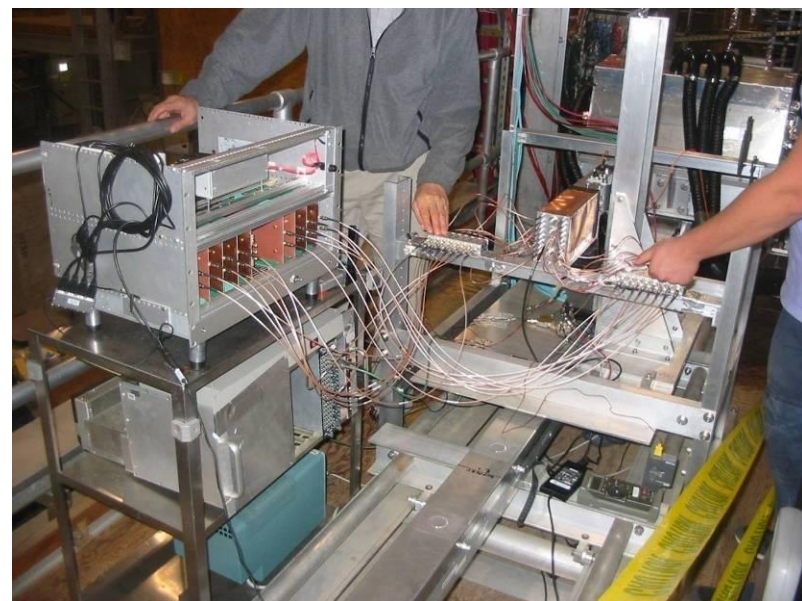


Mean  
differential jitter  
is of about 12ps  
rms which  
corresponds to  
**8.5 ps rms** of  
time precision  
per pulse

- TOF experimental setup on the CRT
- Goal was to measure the time difference in cosmic muon detection between the two quartz bars in view of SuperB FTOF prototype



More than  
adequate for final  
physics goal  
of 50 ps with 5 to  
10 photoelectrons

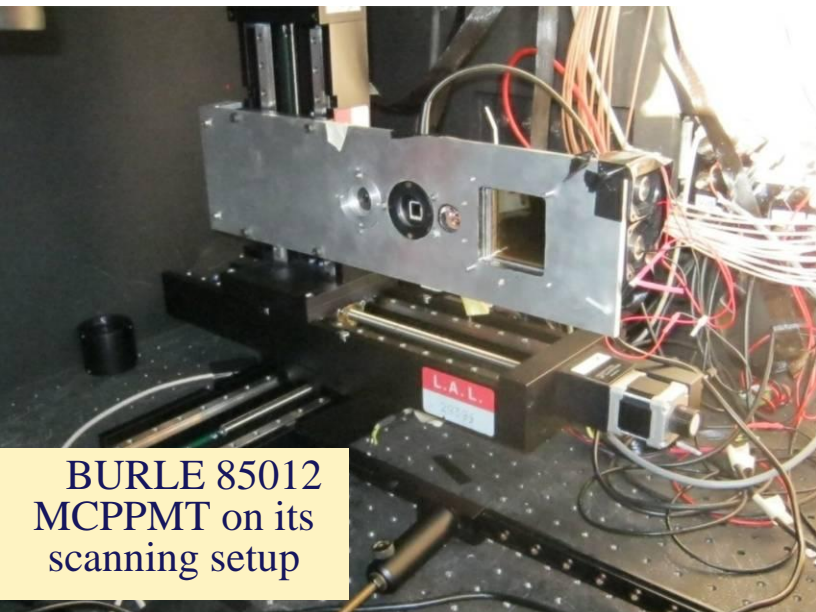


Time  
resolution  
between 2  
channels

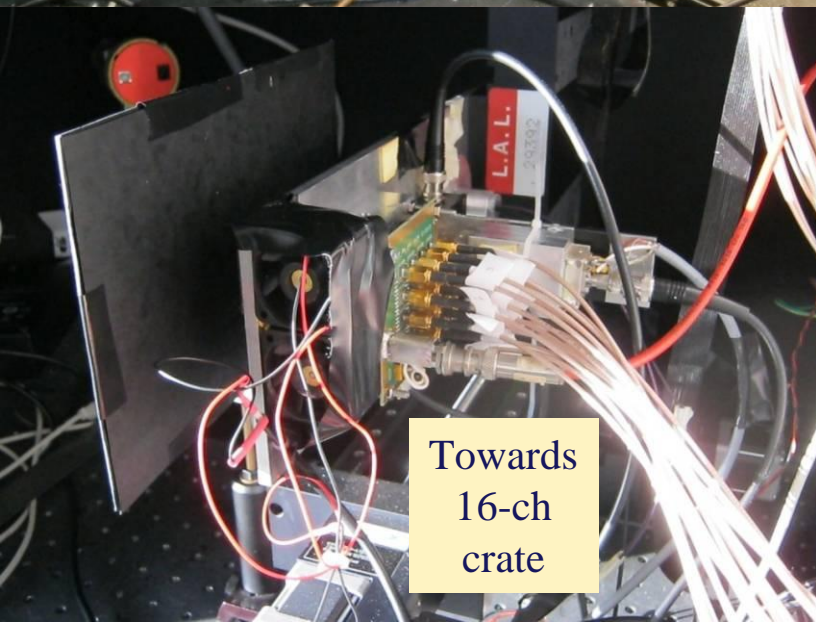
$$\sigma_{\text{narrow}}/\sqrt{2} \sim 70 \text{ ps}$$

New 8-board  
acquisition  
software



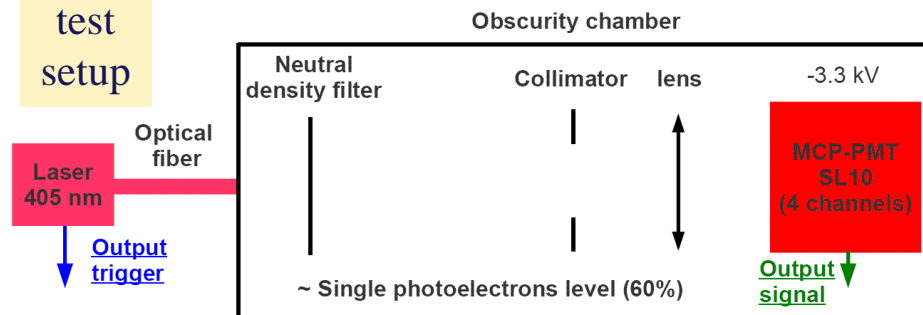


BURLE 85012  
MCPPMT on its  
scanning setup

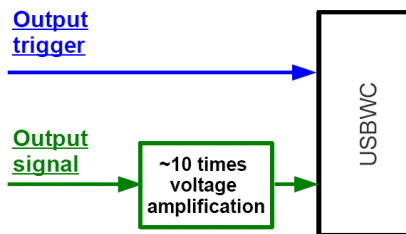


Towards  
16-ch  
crate

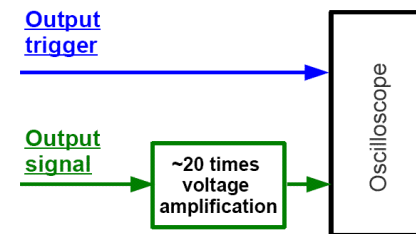
## SL10 test setup



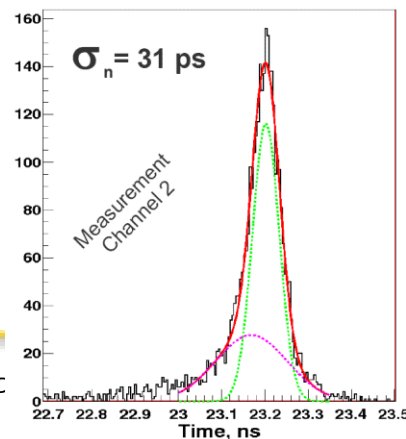
### USB wave catcher (16 channels)



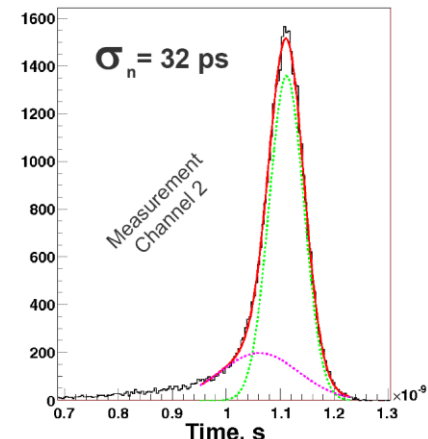
### LeCroy oscilloscope wavepro 740zi



### USB wave catcher (16 channels)



### LeCroy oscilloscope wavepro 740zi



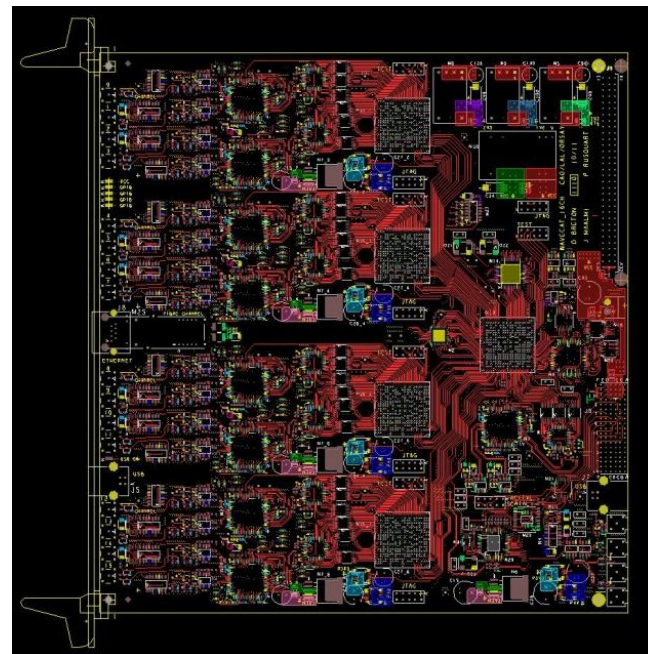
## SL10 test results

# Latest developments

2010



2011



...

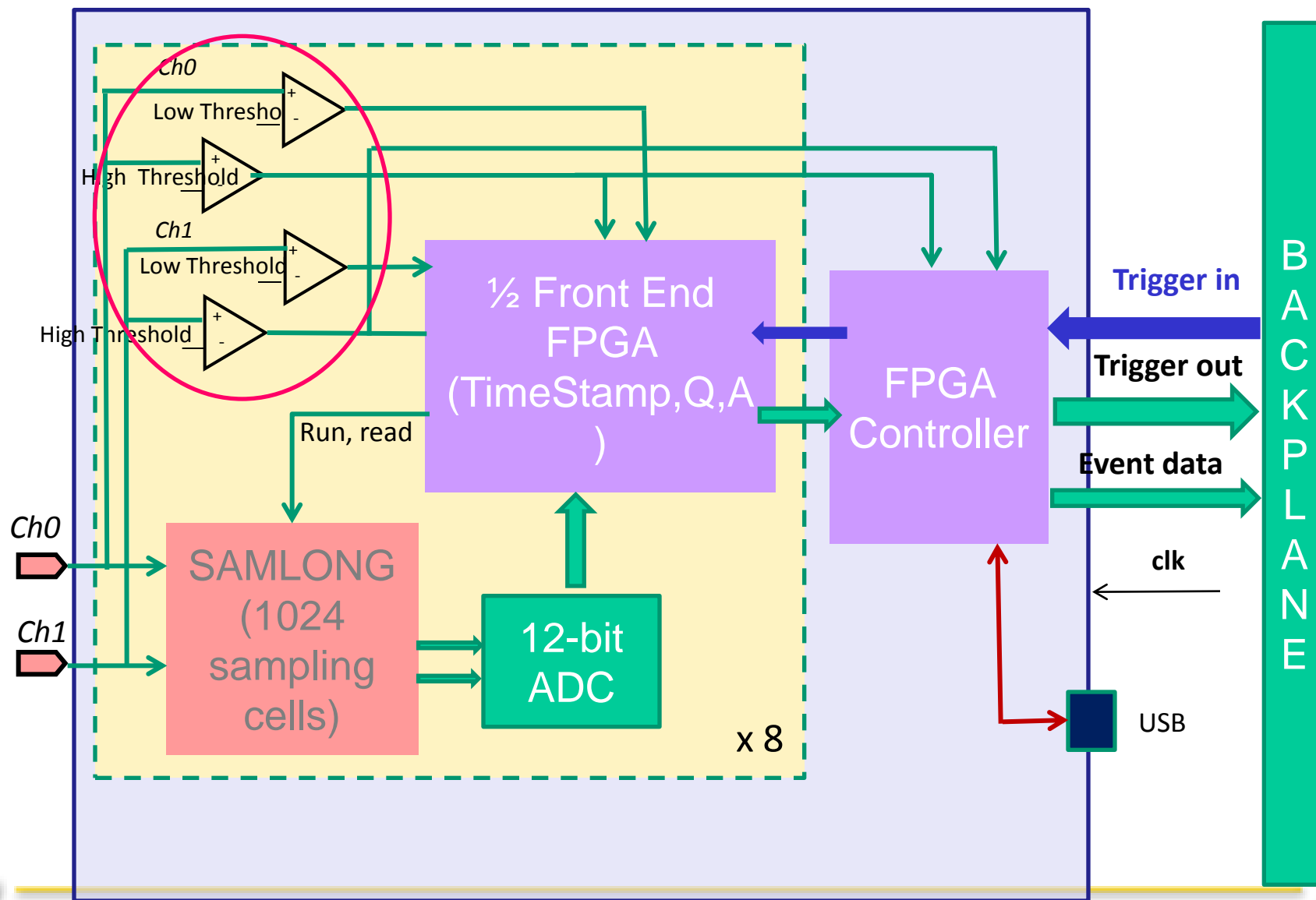


## The 16/18-channel board

- 1.6mm thick
- 10 layers
- 233 x 220 mm<sup>2</sup>
- **3200 components**
- 25 power supplies (5 global, 20 local)
- 4 **4-channel blocks** (can be used as **mezzanines** on other boards)
- 2 channels dedicated to digital signals

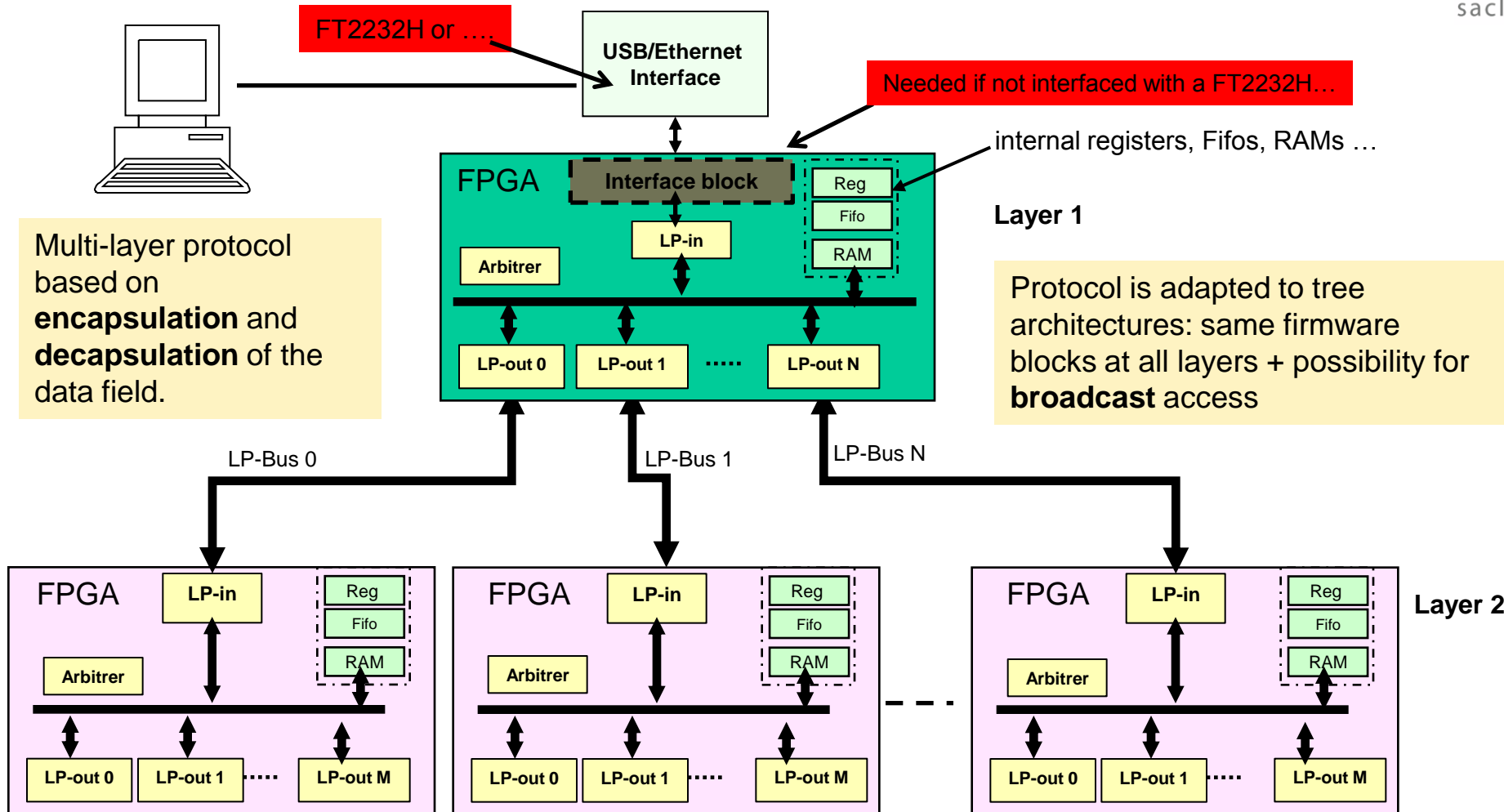


# 2-channel front-end diagram





# A flexible architecture thanks to LP-BUS

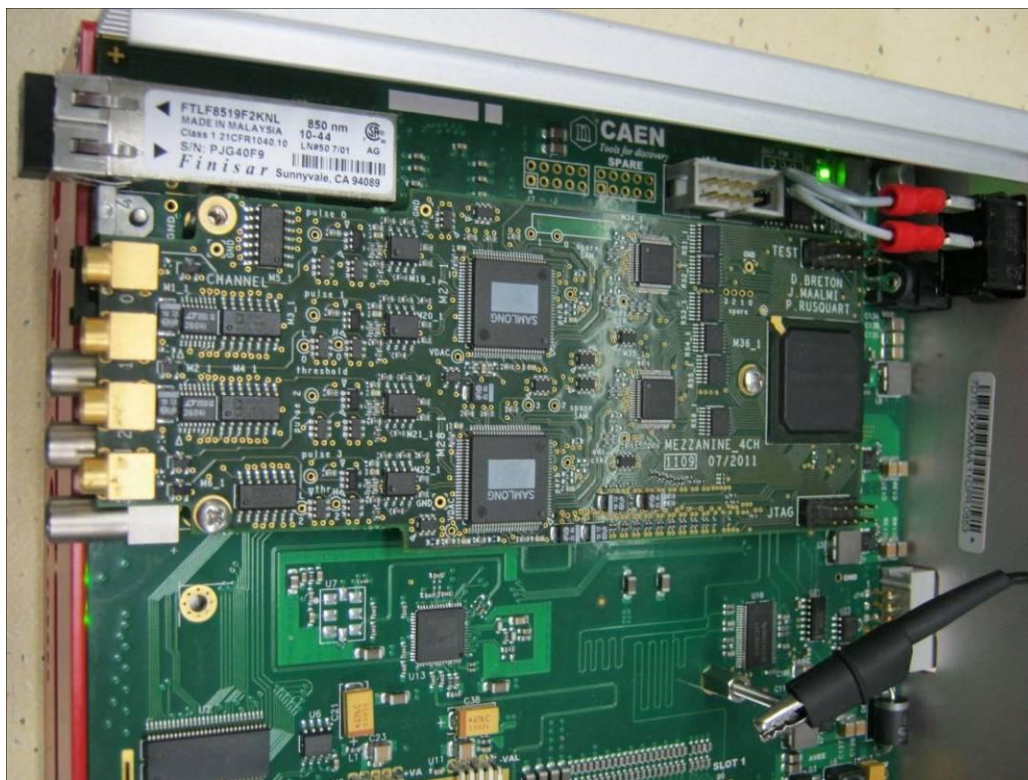


Event fragments are **pushed** towards USB => this permits a **sparsified readout**  
=> can be based on the dual signal threshold

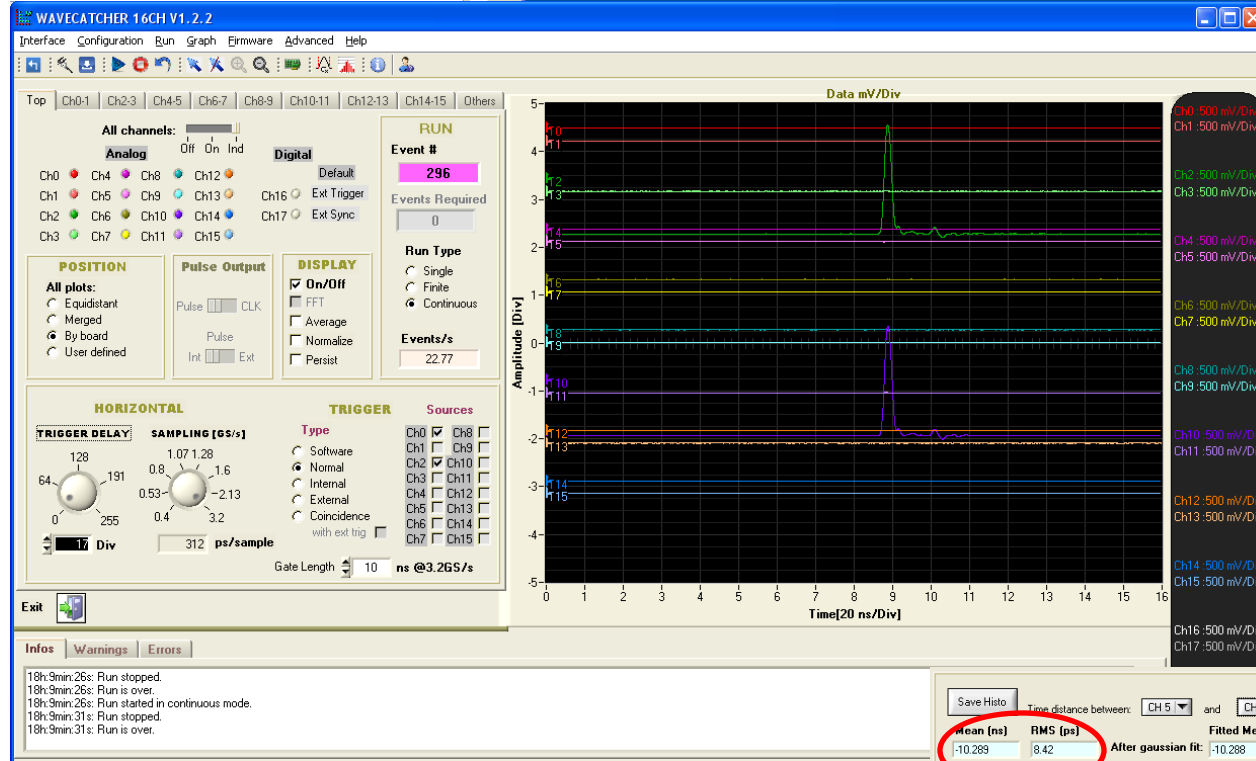
- ❖ Possibility to add an **individual DC offset** on each signal
- ❖ **2 individual trigger discriminators** on each channel
- ❖ External and internal trigger + numerous modes of **triggering on coincidence**
- ❖ **Embedded charge mode** (integration starts on threshold or at a fixed location) => high rates (~ 3.5 kEvents/s)
- ❖ **2 extra memory channels** for digital signals
- ❖ One **pulse generator** on each input
- ❖ **External clock** input for multi-board applications
- ❖ Embedded **USB** and Serial Lite/Fibre Channel/Conet interfaces
- ❖ Possibility to program the FPGAs via **USB/Backplane/Altera Blaster**
- ❖ Possibility to chain channels by groups of 2
- ❖ **Embedded digital CFD** for time measurement
- ❖ **Embedded signal amplitude** extraction

# Front-end block can be used as a mezzanine

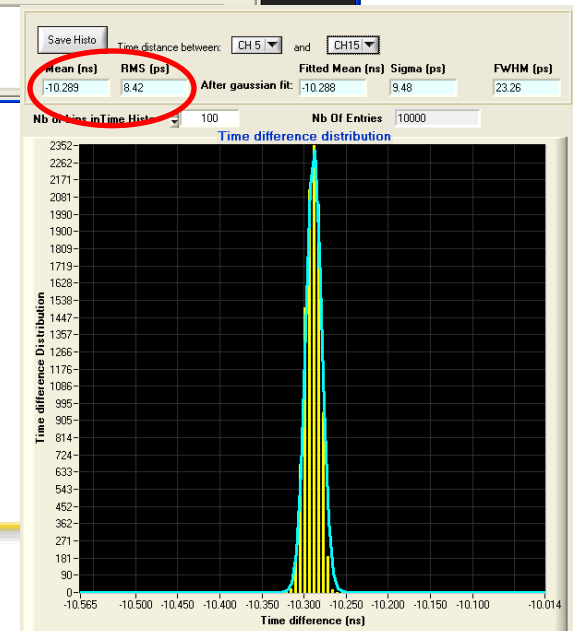
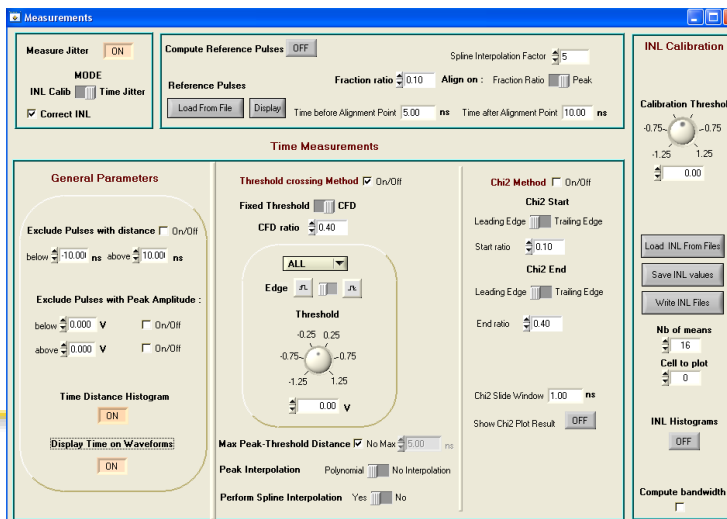
- ❖ The latter has been mounted on a **CAEN** USB-driven digitizer motherboard
- ❖ Almost fully validated!
- ❖ Measurements results are equivalent to those of the WaveCatcher module: noise level : **0.72 mV**, signal bandwidth ~ **500 MHz**, time precision < **10ps rms**



Main panel:  
oscilloscope  
like, but 16  
channels



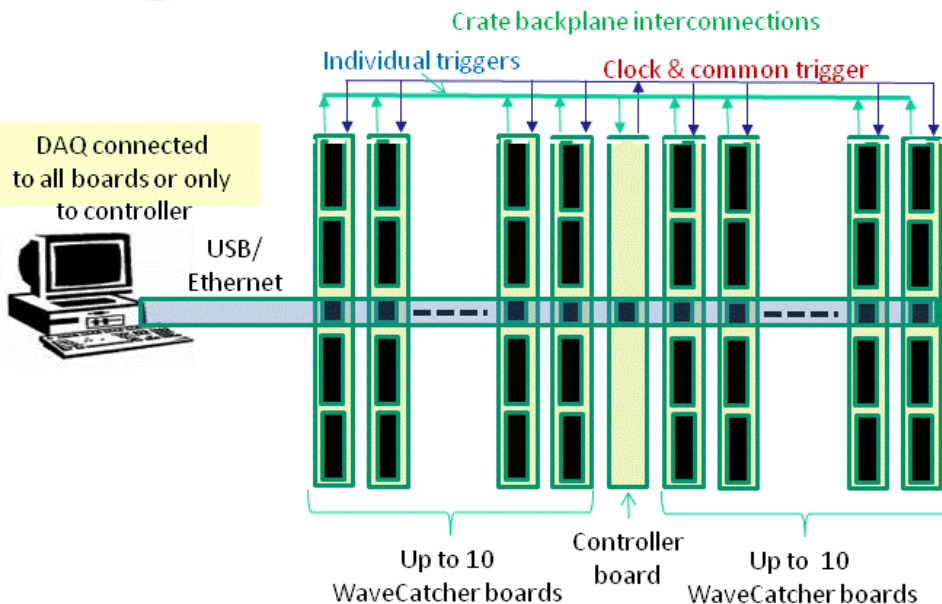
Time  
measurement  
panel



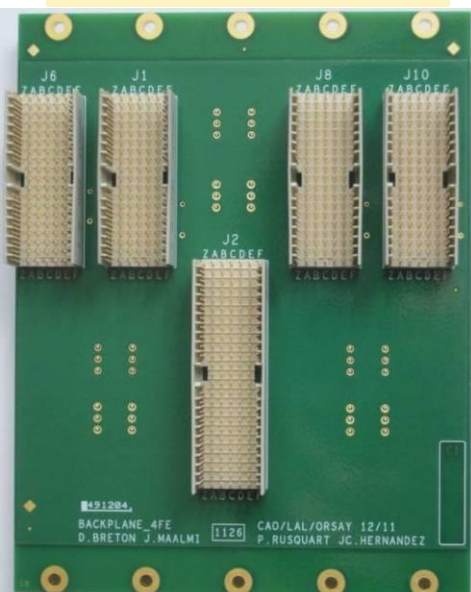
Septembre 2012



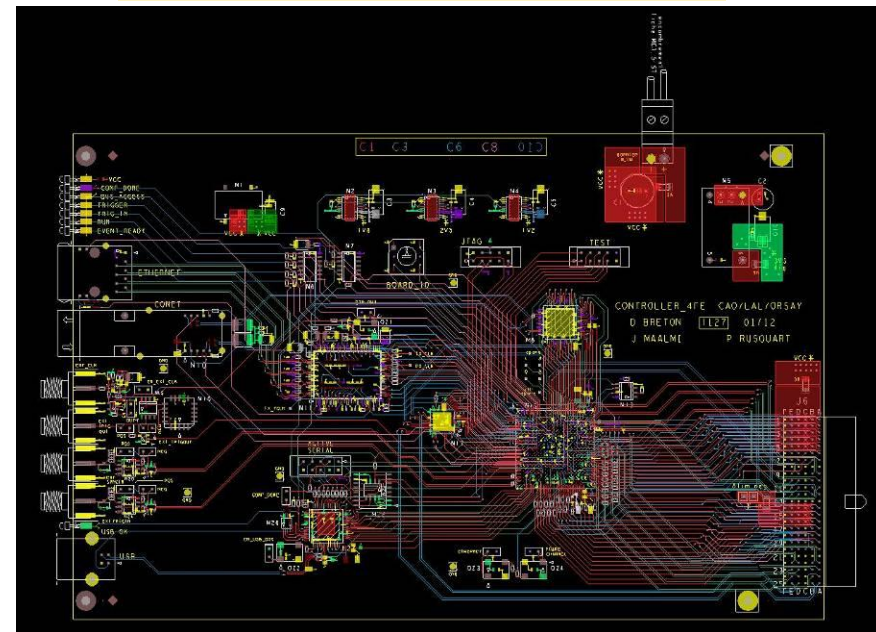
# Building large scale systems



## 64-channel backplane

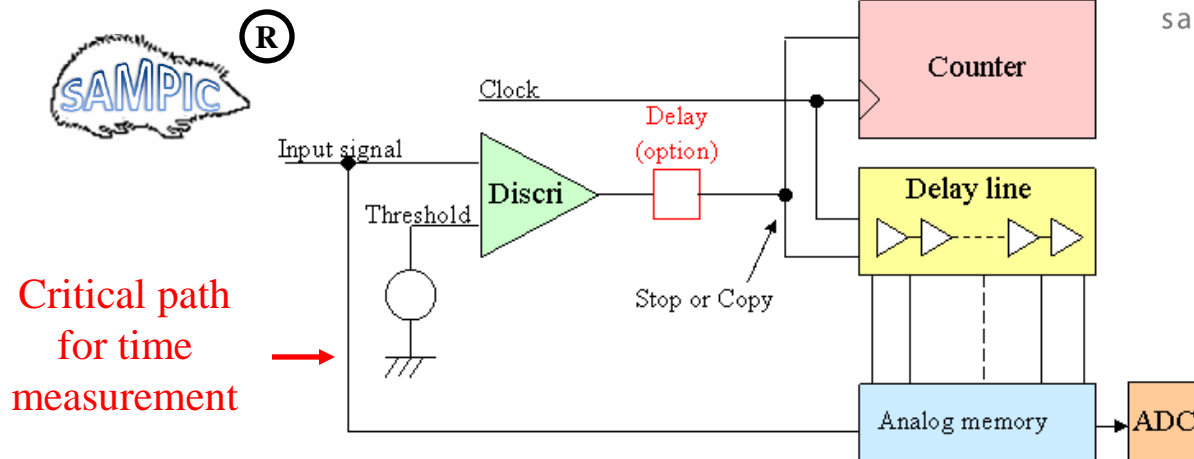


## Layout of the controller board

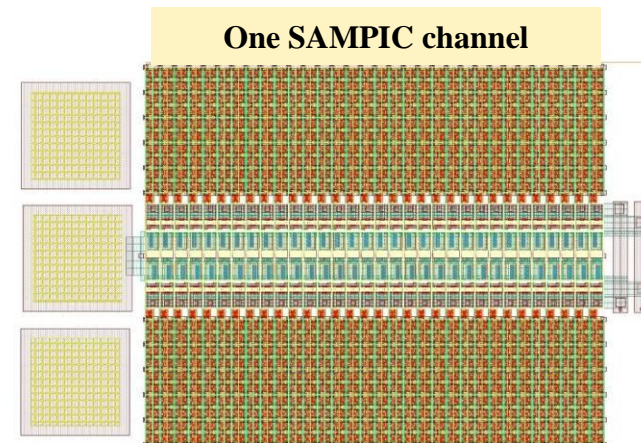


- To synchronise N boards a controller board is needed + backplane for the interconnections
- we are building a very compact 64-channel system:
  - will soon be used for the CORTO Cosmic Ray Telescope at Orsay
- we are also building a 320-channel system in 6U-crate (SuperNemo experiment)

- Works on **analog** signals
- Produces **time** and digitized **waveform** !



- We started designing the SAMPIC ps TDC six months ago  
⇒ This ASIC makes use of the new AMS 0.18  $\mu\text{m}$  CMOS technology
- First version will house 8 blocks of 64 analog memory cells  
⇒ Sampling is performed between 2 and  $\sim 10$  GS/s  
⇒ Signal bandwidth is  $\sim 1$  GHz
- Digitization will be performed inside the chip with a parallel 10-bit Wilkinson ADC running at 2 GHz in each cell  
⇒ The 2-GHz clock is not distributed to the cells but runs a unique gray counter  
⇒ The cells house a fast comparator and a latch
- Submission is targetted for October 2012  
⇒ First tests should take place in January 2013



- Electronics associated to detectors can be used either for their **characterization** (test benches) or for their **readout** (experiments).
- For **test benches**:
  - if the number of channels is small ( $\leq 4$ ), then high-end oscilloscopes are commonly used. For small budgets, analog memory-based acquisition boards can do the job for cheap.
  - If the **number of channels increases**, and if one wants to study all of them in parallel, analog memories are good candidates for a reasonable price
- For **physics experiments**:
  - Dedicated A/Q/T ASICs are a natural option
  - But to see the **waveforms**, or if **time measurement** precision has to be (much) **better than 30ps rms**, analog memories seem to be the right answer
- The 2-channel USB Wave Catcher module is used worldwide, together with the software we developed here.
- The 16-channel board is already used at CERN on UA9, at IRFU on a germanium detector, and on CORTO. It will be soon used for testing MPRCs at CERN, on SuperNemo and SuperB, and maybe on EUSO.
- R&D is going on: the multi-channel **SAMPIC TDC** will soon produce both **5-ps timing** and **signal waveforms** ...