R&D for Fast Timing Photon Detector System

(D_RD_10)

26-28.May.2014 TYL Workshop, Bordeaux, France

中村勇/高工研

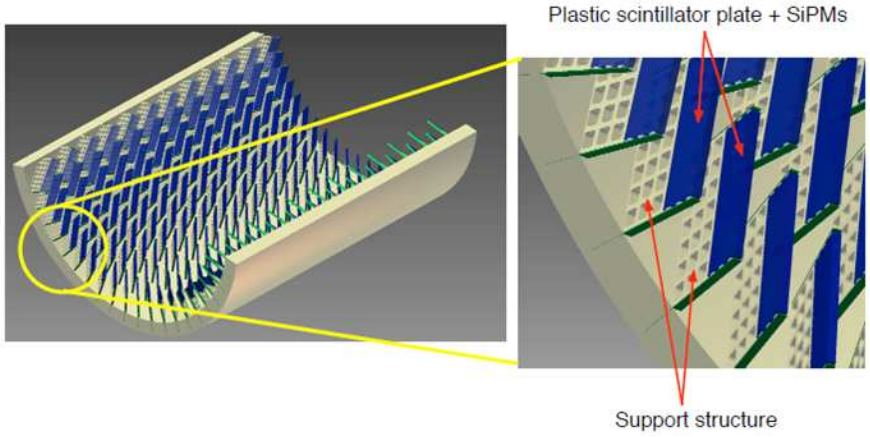
for

OMEGA/IN2P3/WEEROC/KEK/Shinshu/Kyoto/Osaka/Tokyo/Okayama

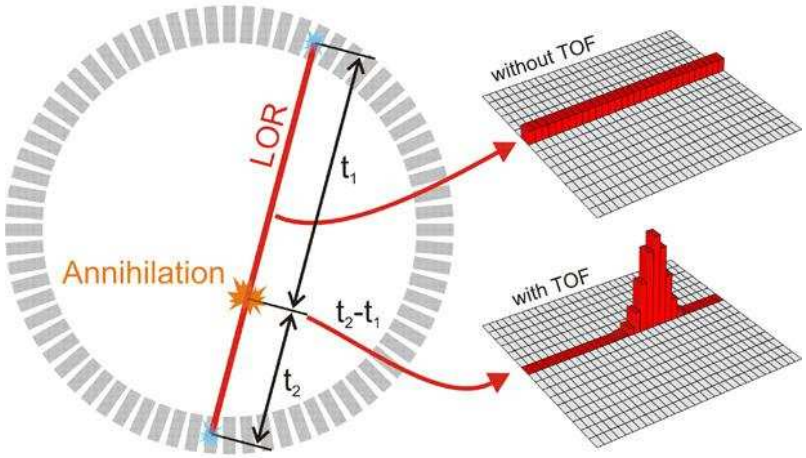
Photon Detection with Timing Information

- Importance of Timing Measurement
- in High Energy Physics
  - Time-of-Flight (PID)
  - Background Reduction
  - Trigger
- Medical Application
  - TOF PET
- Device Development
  - optimization for timing
- utilize MPPC/PPD/SiPM...

MEG2 Timing Counter (Tokyo)

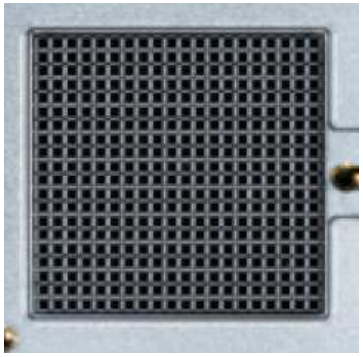


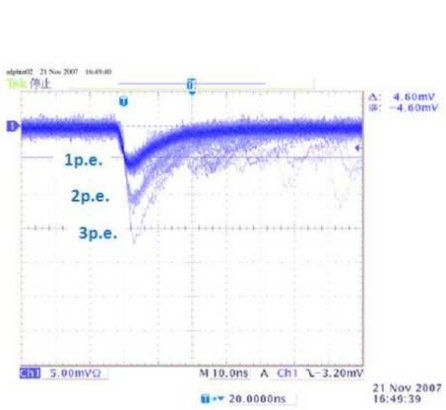
TOF-PET

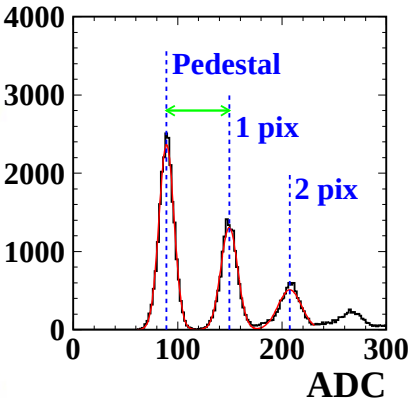


What's MPPC(PPD, SiPM, GAPD)

- What's MPPC(PPD, SiPM, GAPD)?
  - A photon sensor consists of many pix-elated Geiger-mode APDs
  - commercially available around 2006
  - many attractive feature
    - High Gain ~ 10^6
    - insensitive to B-field
    - Time resolution (~100 ps@1γ)
    - Low bias voltage
    - ....
  - good for Scintillator with Fiber readout
  - many applications
    - High Energy Physics
    - Nuclear Physics
    - Astrophysics
    - Medical, Vulcanology
    - .....

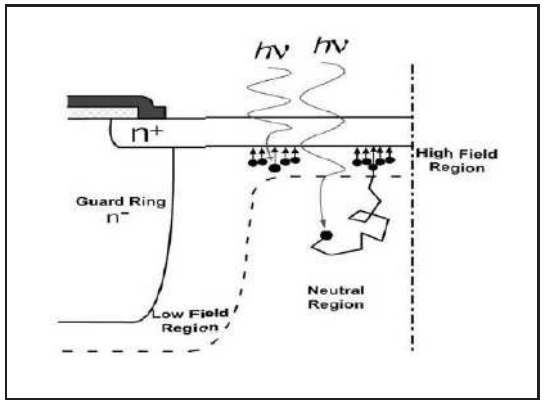


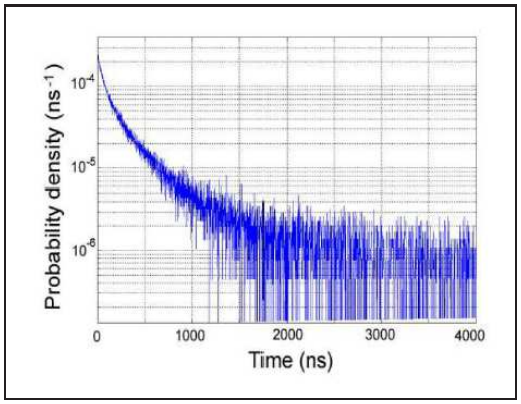


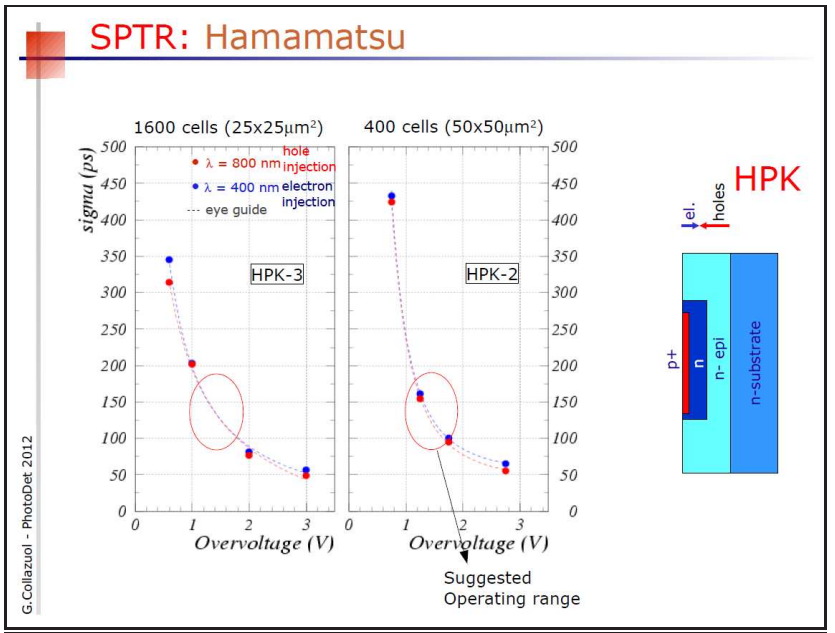


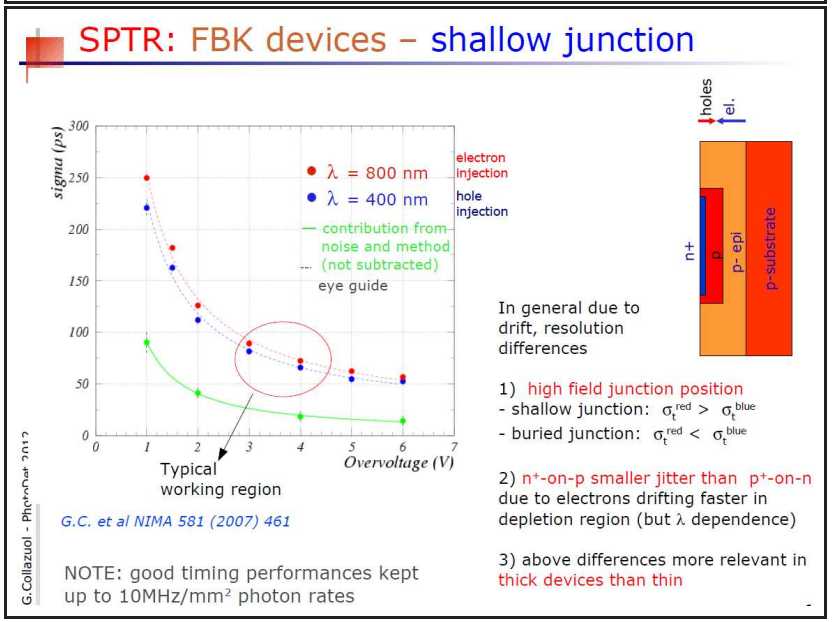
Timing characteristics of MPPC(PPD, SiPM, GAPD)

- Basically Very Fast
  - Avalanche Process (O(100) ps)
- Slow component from diffusion
  - Diffusion (O(1) ns)
  - Device Structure
- possible good timing detector









Collazuol(Photodet2012)

France – 日本 Collaboration

- Collaboration since 2008, support from FJPPL since 2010
- Developpeing ASIC for MPPC(PPD) and readout system for long time
- Successful 4-year R&D FJPPL project for readout electronics
- France
  - Strong expertise in microelectronics
  - SPIROC
  - EASIROC
  - PETIROC
- 日本
  - Demand for reading out MPPCs
  - Tohoku (E40 nuclear physics experiment)
  - Shinshu (ILC SW/Sc ECAL)
  - R&D for new application
  - Shinshu (TOF-PET)
  - Tokyo (Timing Detector)
  - Technology for network based DAQ (SiTCP/KEK)

PETIROC

GHz SiGe preamp test results :

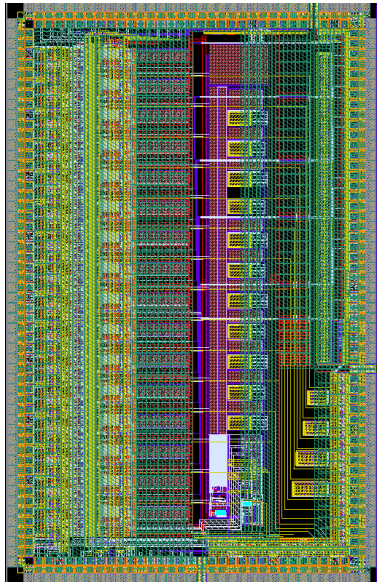
Testboard #3	RF (Common Emitter)	Common Base	Super Common Base
With 100pf/50 Ohm injector (SiPM emulation)		Vb_cb : 400 #DAC	Vb_scb : 1023 #DAC
Noise floor (pedestal)	185-187 #DAC / 1.196V	216-224 #DAC / 1.259V	340-342 #DAC / 1.514V
Signal value @ 10pe	235 #DAC / 1.300V	137 #DAC / 1.085V	115 #DAC / 1.038V
Signal amplitude @ 10pe (signal minus pedestal)	50 #DAC / 110mV	83 #DAC / 174mV	226 #DAC / 476mV
Gain (mV/pe)	**10.4mV/pe (5 #DAC/pe)**	**17.4mV (8.3 #DAC)**	**47.6mV/pe (22.6 #DAC/pe)**
Jitter - threshold 1 pe @10pe	**13ps RMS**	**6ps RMS**	**8ps RMS**
Jitter - threshold 3 pe @10pe	**8ps RMS**	**6ps RMS**	**8ps RMS**
With 100nF DC block (for voltage gain & BW meas.)	**18mV injection**	**18mV injection**	**7mV injection**
Signal Value	267 #DAC / 1.371V	41 #DAC / 0.884V	192 #DAC / 1.2V
Signal amplitude (signal minus pedestal)	81 #DAC / 175mV	179 #DAC / 375mV	150 #DAC / 320mV
Voltage gain (before 50 ohm bridge => factor of 0 .5)	**4.86 V/V**	**10.4 V/V**	**22.5 V/V**
Bandwidth, after discriminator (Δt 10% T50% meas.)	**Δt : 150ps / 660MHz**	**Δt : 360ps / 280MHz**	**Δt : 400ps / 250MHz**

With 1pe-=160 fC

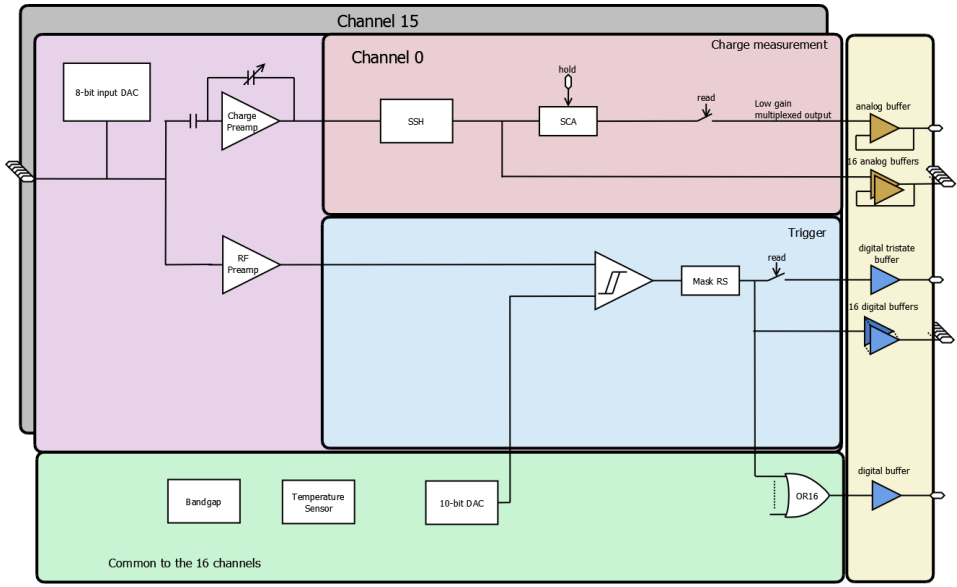
=> DESIGN of PETIROC: 16 channels with RF amplifiers

PETIROC1

- Analog readout chip for physics applications where high resolution time is needed and also Time of Flight or preclinical
  - 16 channels prototyping ASIC
  - 16 discriminator outputs, 16 charge output, MUX charge output
  - Power consumption 3.5mW/ch
- Fast timing front-end
  - 10GHz GBWP common emitter SiGe , DC coupled to detector
  - GHz SiGe discriminator
  - Low power
  - Low noise amp+shaper for charge measurement
    - Adjustable peaking time (25ns, 50ns, 75ns, 100ns)
    - Low gain for high swing : 360uV/pe

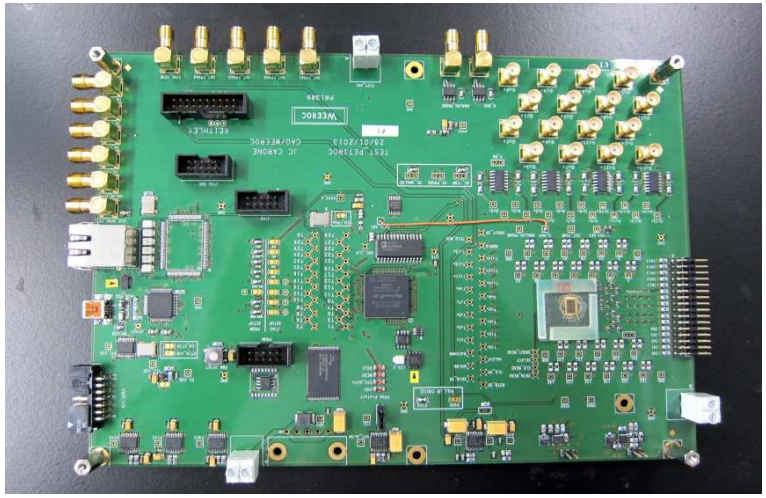


weeroc



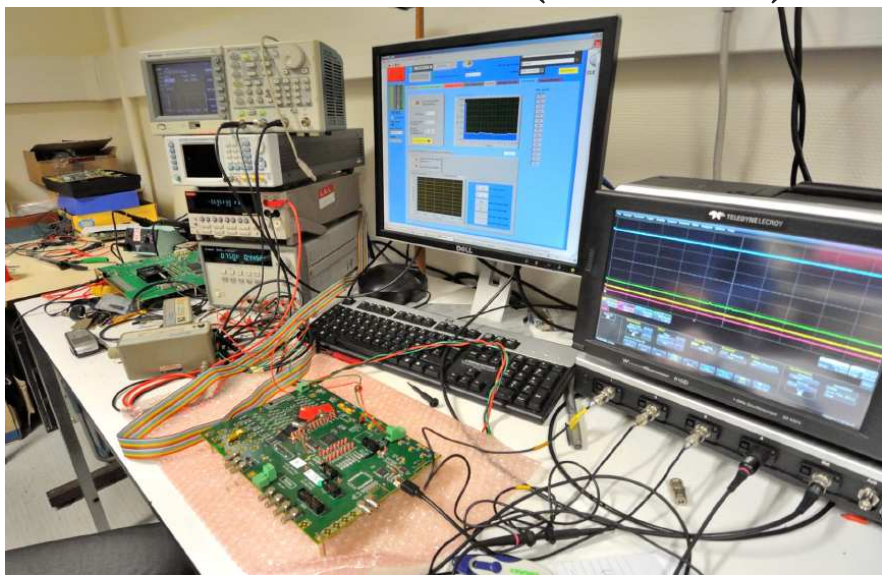
PETIROC @ Testbench

- PETIROC Evaluation Board
  - Produced both in France/Japan
  - controled with LabVIEW
- Test Bench
  - LLR(OMEGA), France
  - Shinshu Univ. (日本)

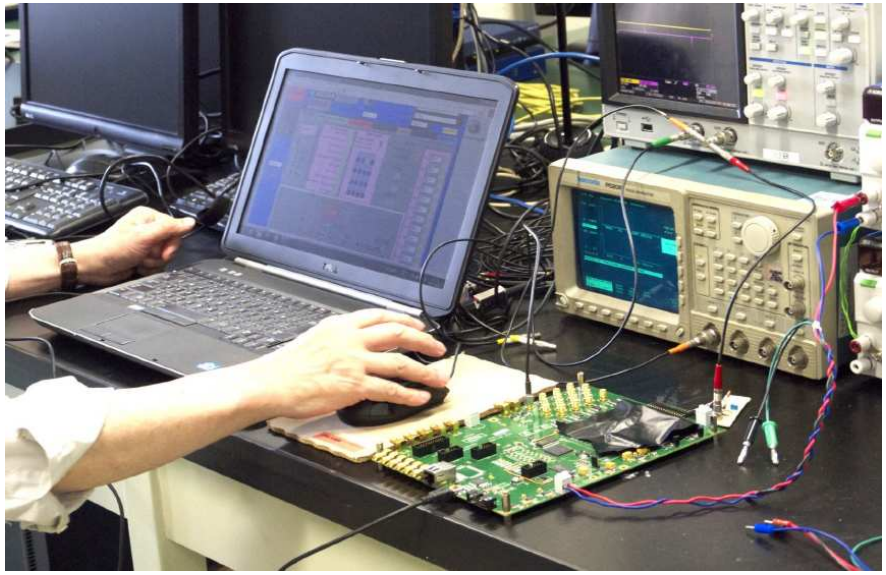


PETIROC Evaluation Board

Testbench @ LLR(OMEGA)

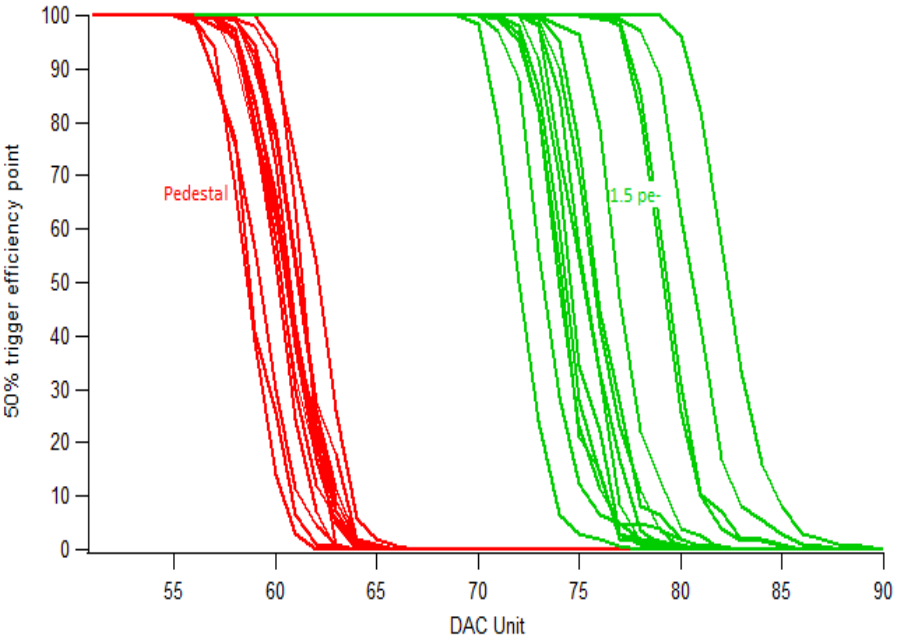


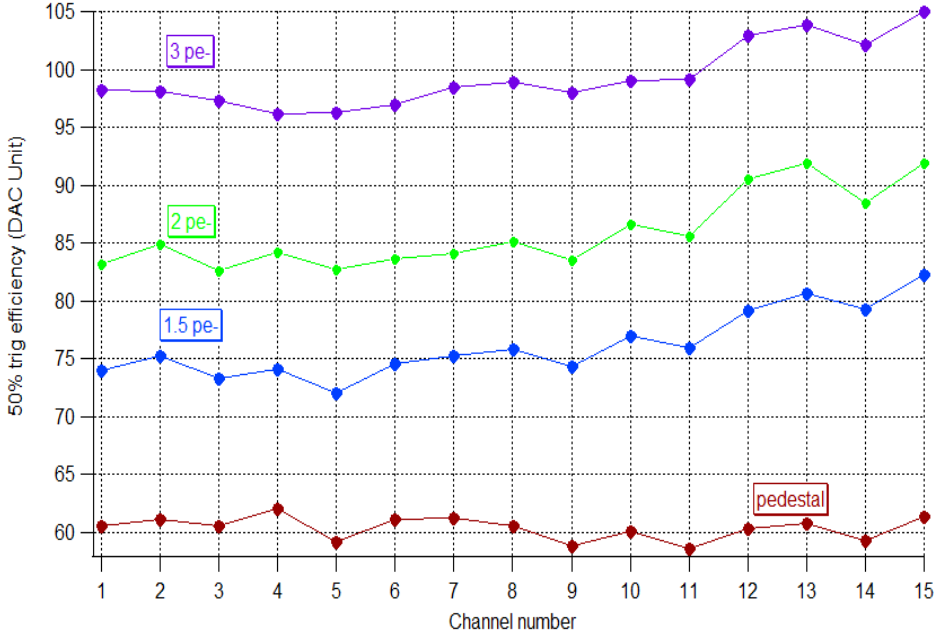
Testbench @ Shinshu



PETIROC1: S curves

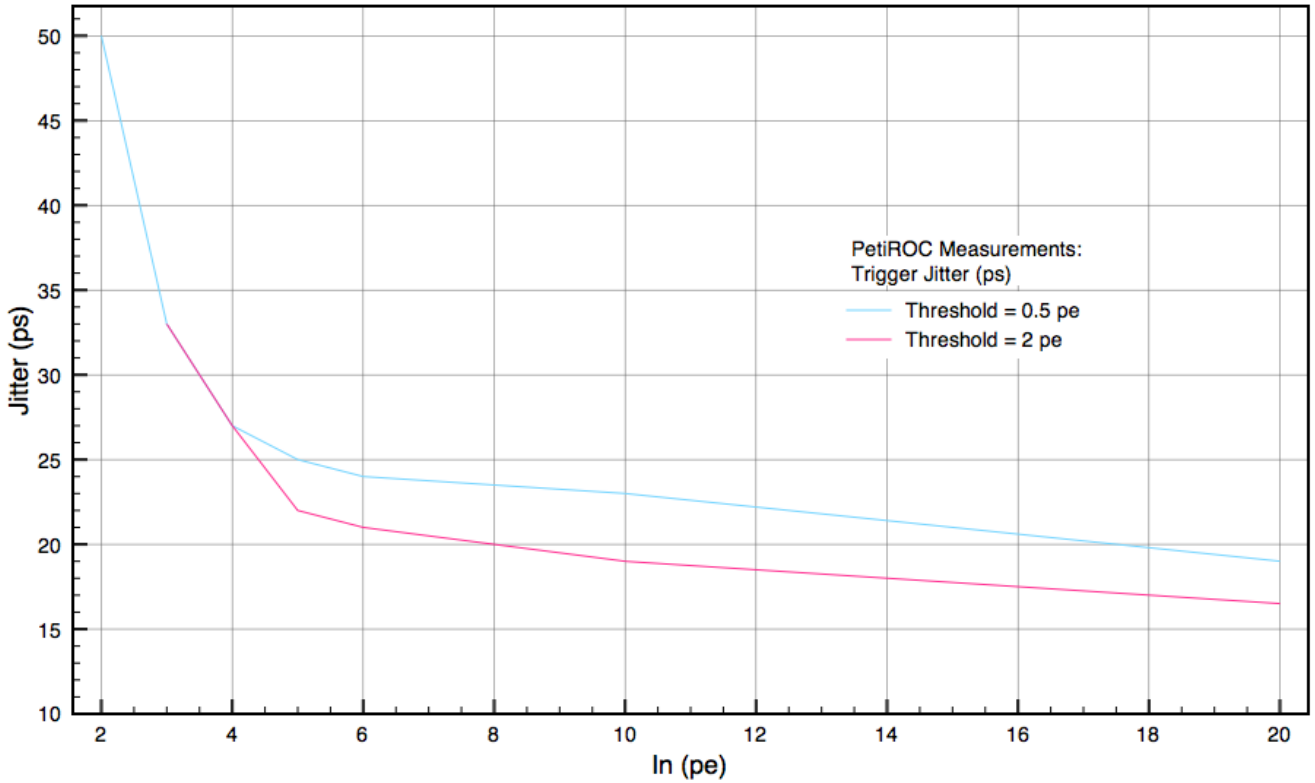
- S curve : trigger efficiency versus threshold
  - For every channel of Petiroc
  - Measured for pedestal and 1.5pe injection
- 50% trigger efficiency
  - For every channel of Petiroc
  - Pedestal, 1.5pe, 2pe and 3pe





PETIROC1: Time measurement

- Jitter vs threshold & injection
- Jitter improve with signal
- Very close to testbench time resolution
- Jitter below 20ps → lower than SiPM time resolution



Injection (pe)	Jitter (ps)
2	50
3	33
4	27
5	25
6	24
10	23
20	19

0.5pe trigger threshold

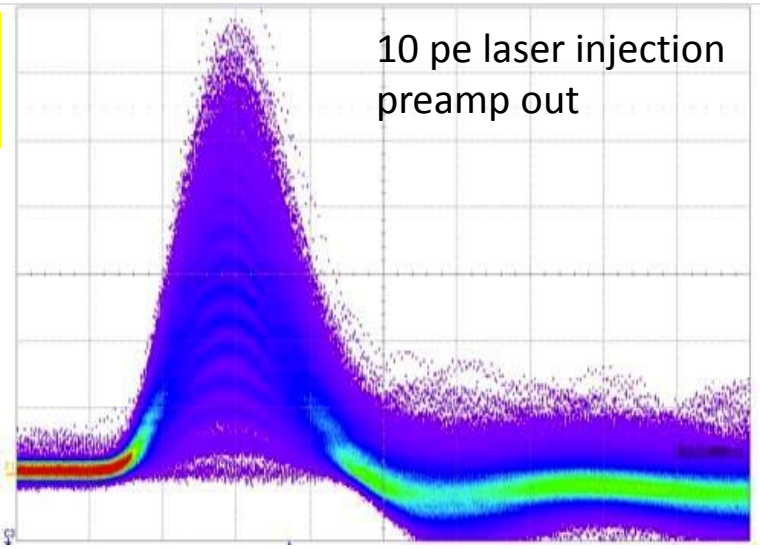
Injection (pe)	Jitter (ps)
3	33
4	27
5	22
6	21
10	19
20	16.5

2pe trigger threshold

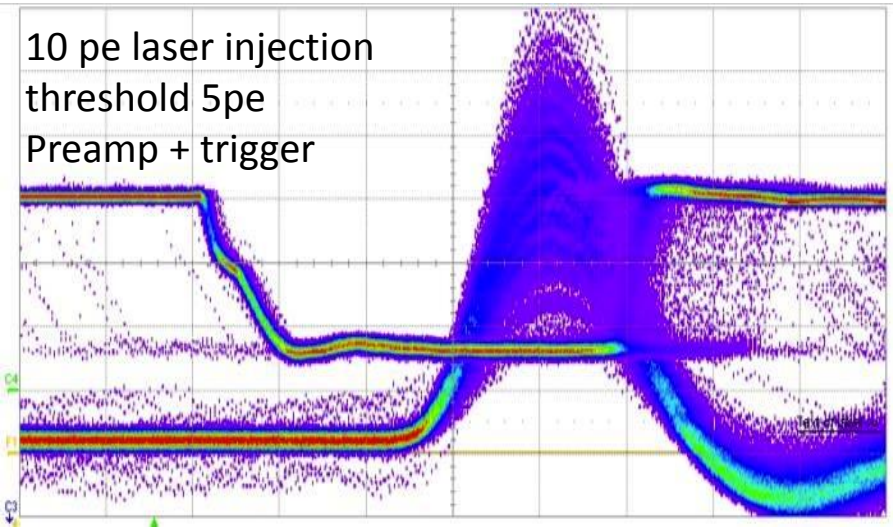
TESTS with SiPM

- 1x1mm SiPM Hamamatsu
- Laser for low light injection
  - 405nm
  - Jitter : 28 ps FWMH
- Low trigger mandatory for good timing resolutior
- Petiroc can trigger on first photoelectron
- Petiroc is low noise : single photon identification

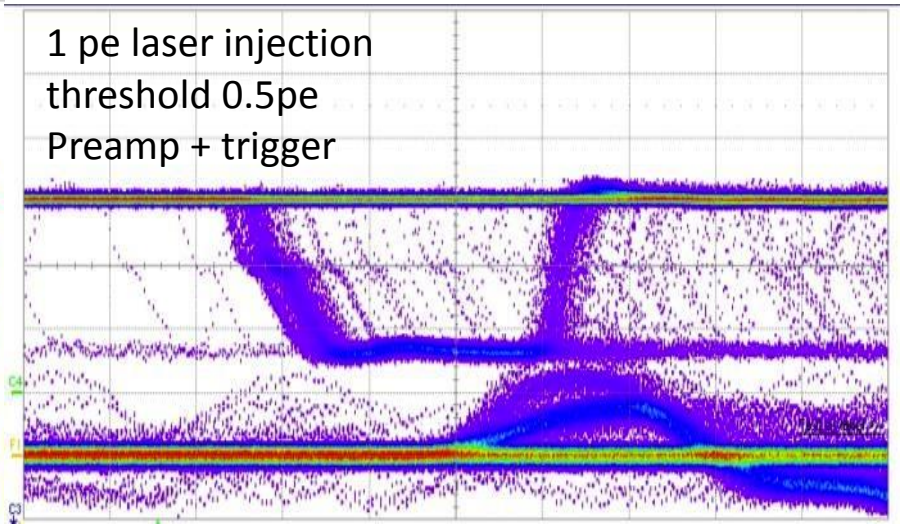
Thanks to
David Brasse – IPHC – IN2P3
Jacques Wurtz– IPHC – IN2P3



2 ns/div



2 ns/div

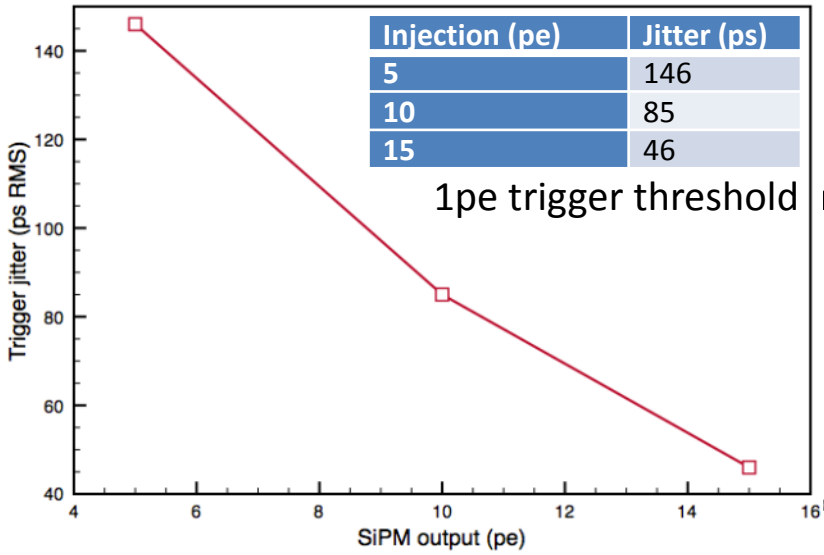


2 ns/div

Time measurement with SiPM

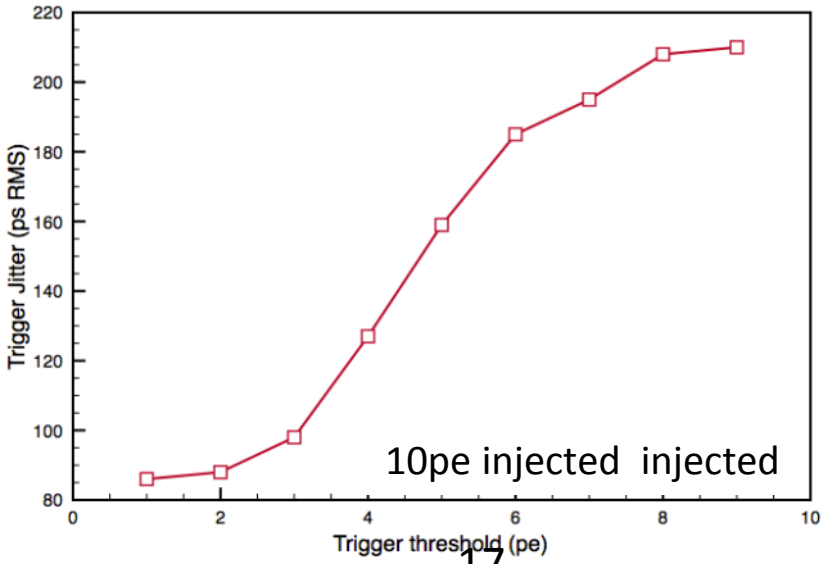
- Jitter vs injection
  - Laser illumination of 1x1mm SiPM
  - 5 →15 pe, threshold 1pe
  - Jitter improves with signal, down to 50ps
- Jitter vs threshold
  - Laser illumination of 1x1mm SiPM
  - 10pe, threshold 1pe→9pe
  - Jitter improve with lower threshold

Injection (pe)	Jitter (ps)
5	146
10	85
15	46



1pe trigger threshold

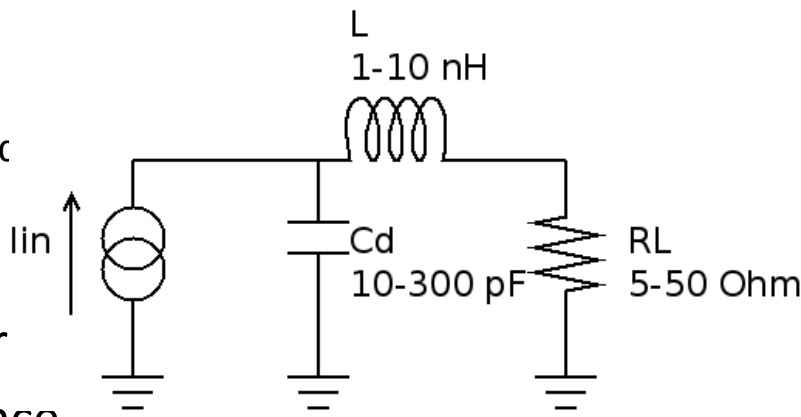
reshold

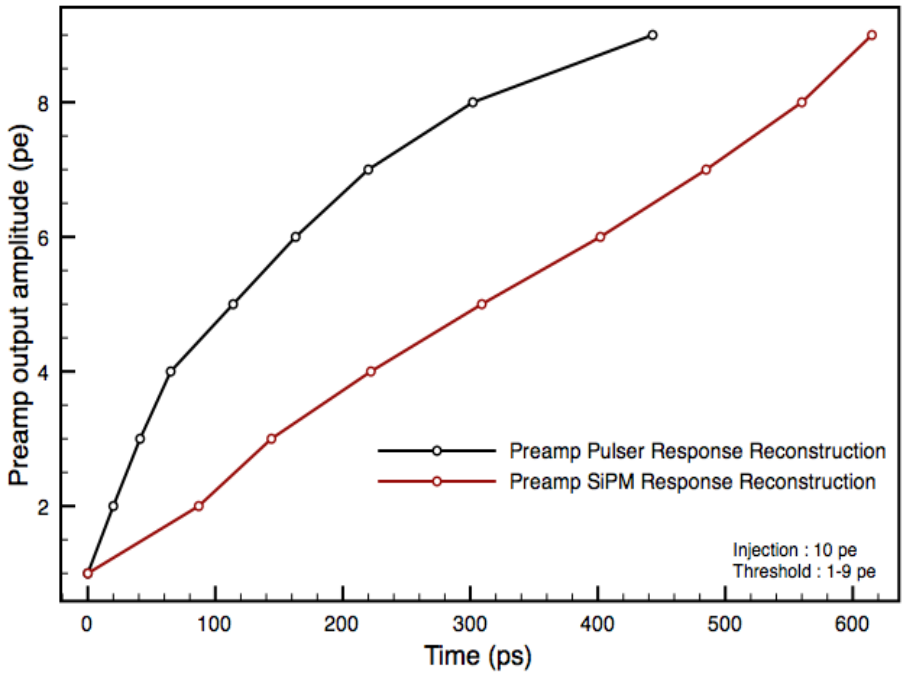


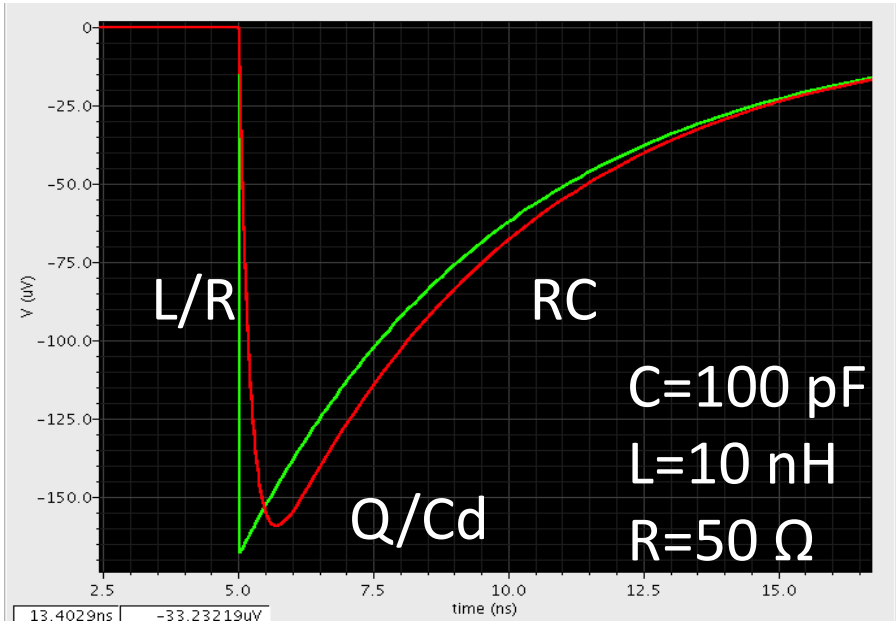
10pe injected injected

PETIROC1: BW

- Pulser vs SiPM comparison
- SiPM is significantly slower than Petiroc
  - Pulser with 100pF injection capacitance, 10pe injectec
  - SiPM illuminated with laser pulse, 10pe measured
  - Threshold from 1pe to 9pe
- Petiroc bandwidth meas. : 877MHz with pulser
- With SiPm: limitation due to the stray inductance



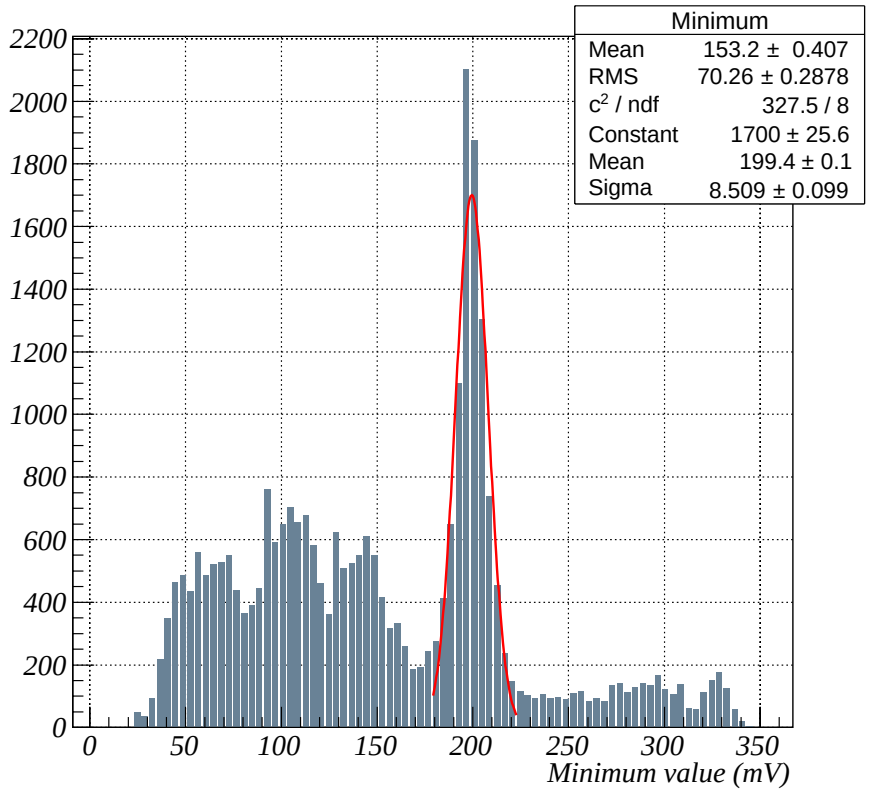




PETIROC1: Energy resolution

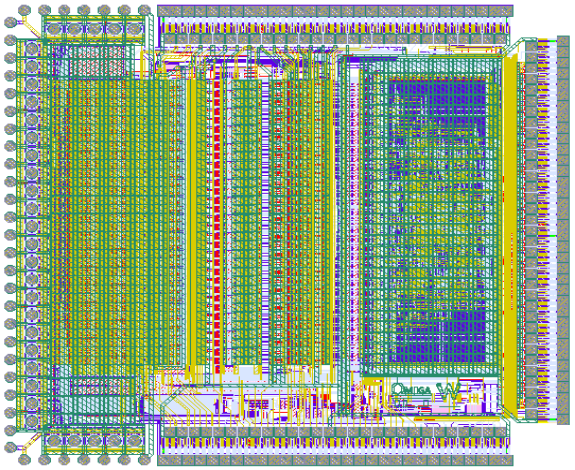
- Preliminary meas, raw data, no correction for non linearities
- Using 3x3x5mm LYSO:Ce crystal & 3x3mm Ketek SiPM
- Na22 source
- Petiroc self-triggered (threshold 5pe)
- Energy resolution: 9.5% FWMH

Thanks to
David Brasse – IPHC – IN2P3
Jacques Wurtz– IPHC – IN2P3
For their kind support for the SiPM-based measurements

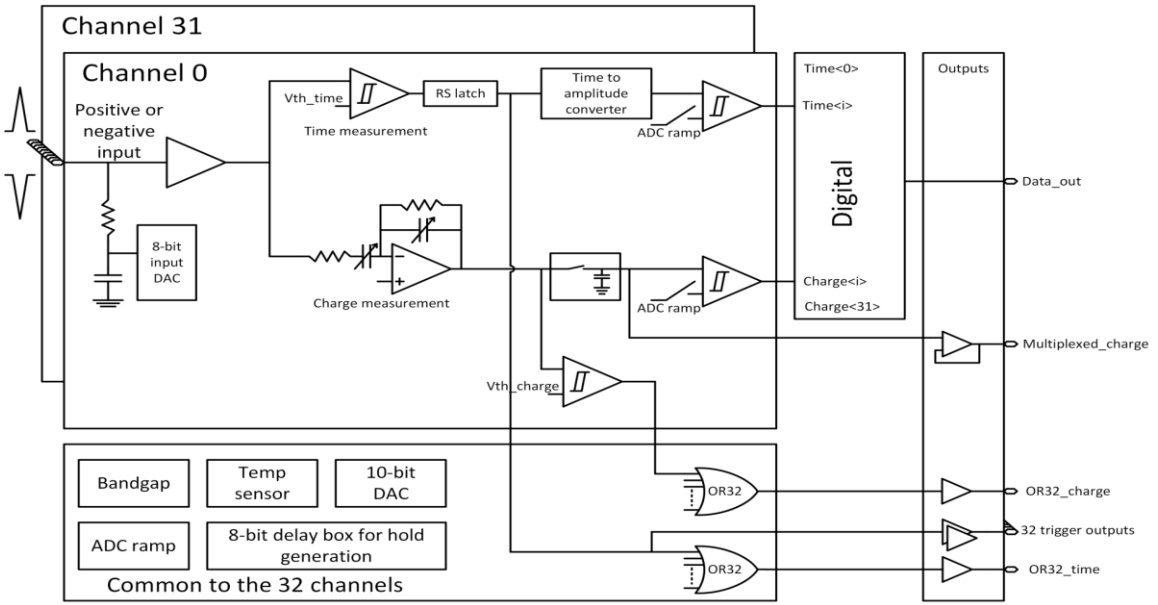


PETIROC2

- Time of Flight read-out chip with embedded TDC (25 ps bin) and ADC
- Dynamic range: 160 fC up to 400 pC
- 32 channels (negative input)
  - 32 trigger outputs
  - NOR32_chrage
  - NOR32 time
  - Charge measurement over 10 bits
  - Time measurement over 10 bits
  - One multiplexed charge output
- Common trigger threshold adjustment and 6bit-dac/channel for individual adjustment
- Variable shaping time of the charge shaper
- 32 8bit-input dac for SiPM HV adjustment
- Power consumption 6 mW/ch
- Front-end
  - common emitter SiGe fast amplifier, DC coupled to detector
  - Fast SiGe discriminator

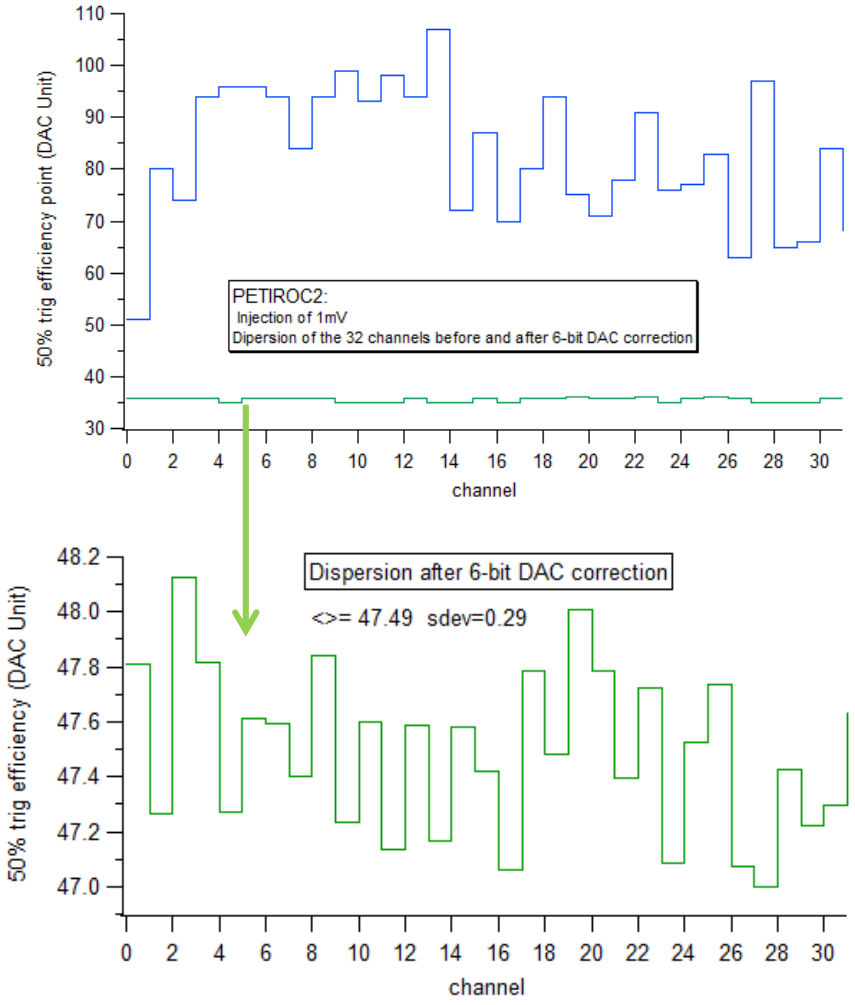


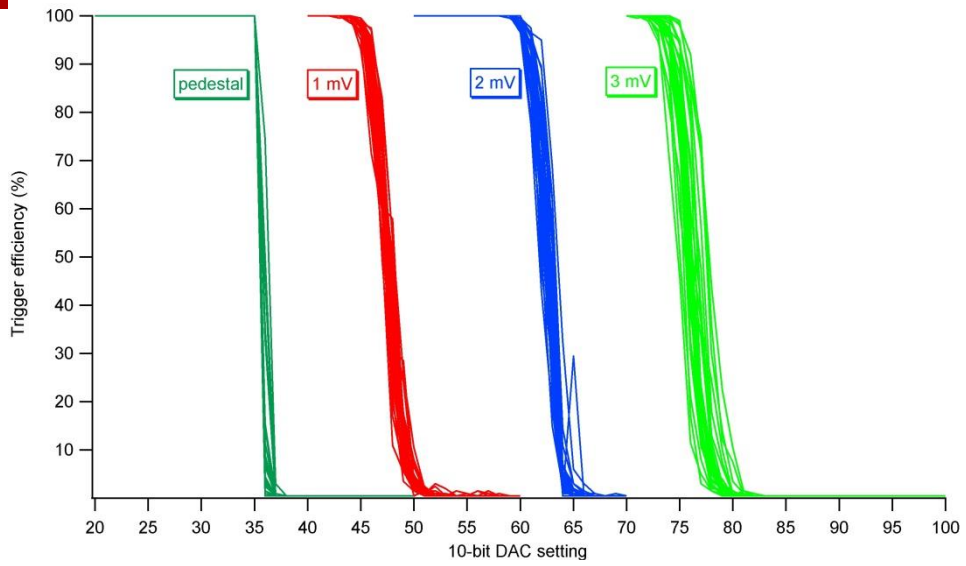
weeroc

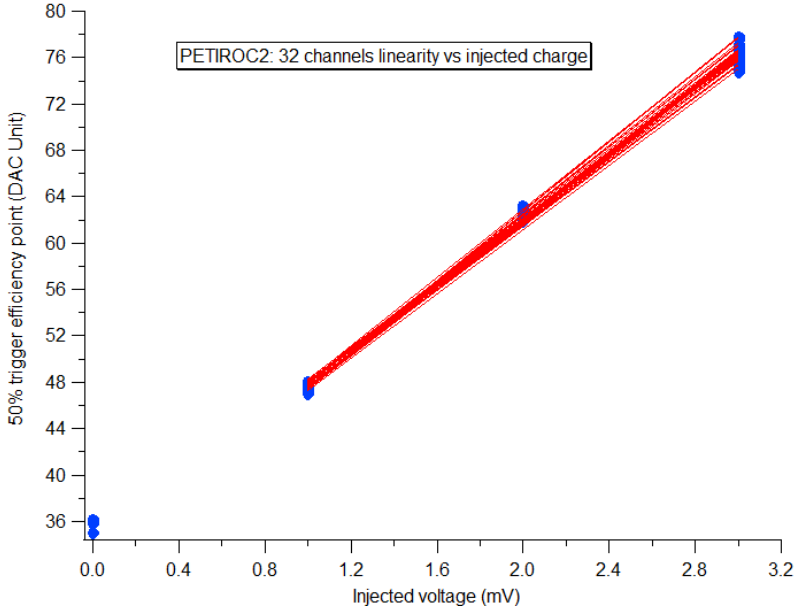


PETIROC2: Scurve measurement

- Trigger efficiency measurements:

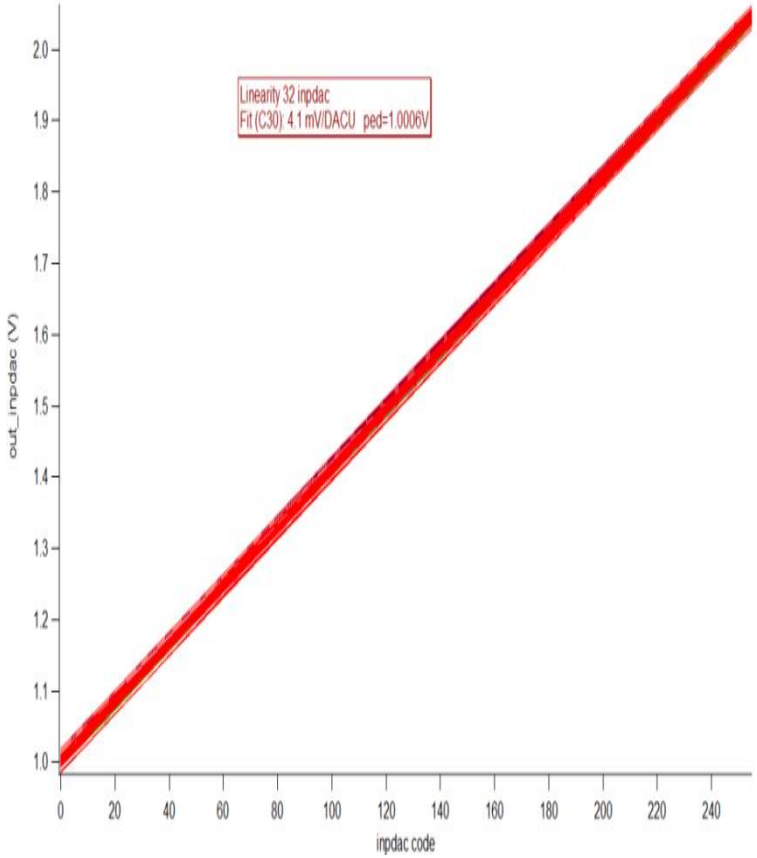




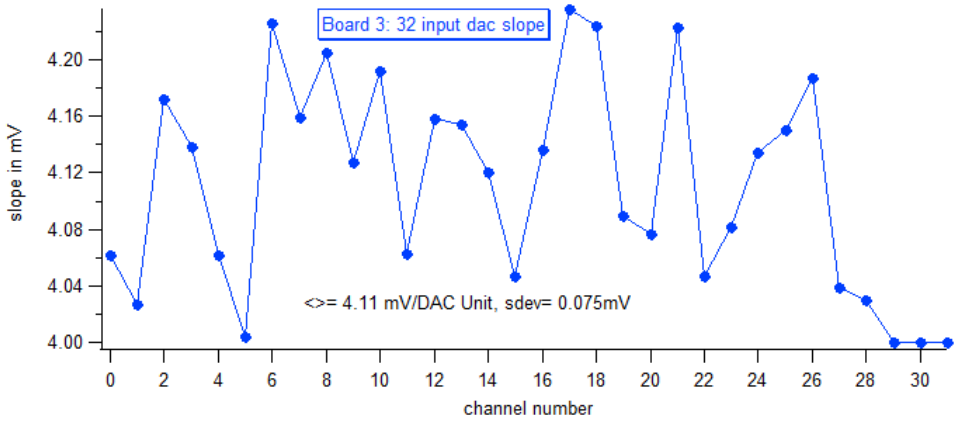


PETIROC2: Input DAC uniformity

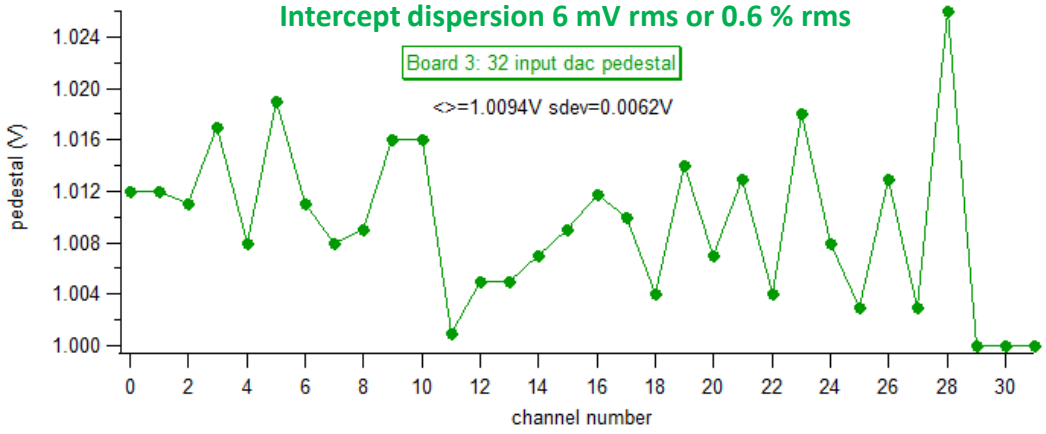
- Linearity and dispersion of the 32 8-bit input DAC



Slope dispersion 75 uV rms or 2% rms

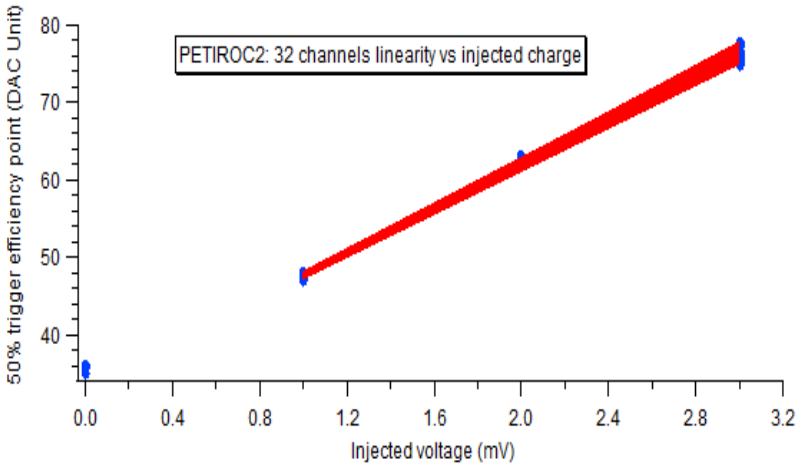


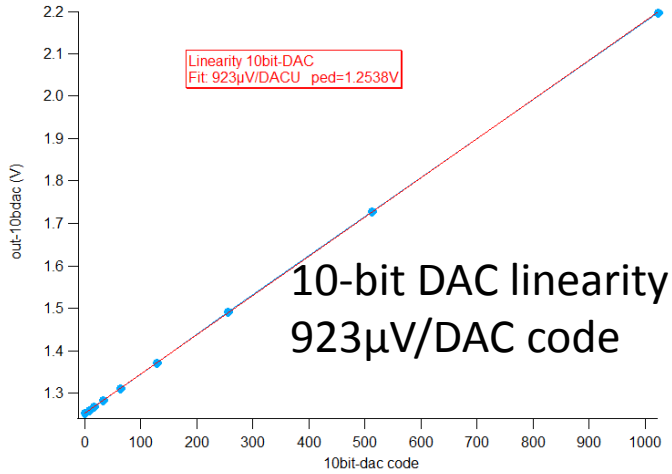
Intercept dispersion 6 mV rms or 0.6 % rms



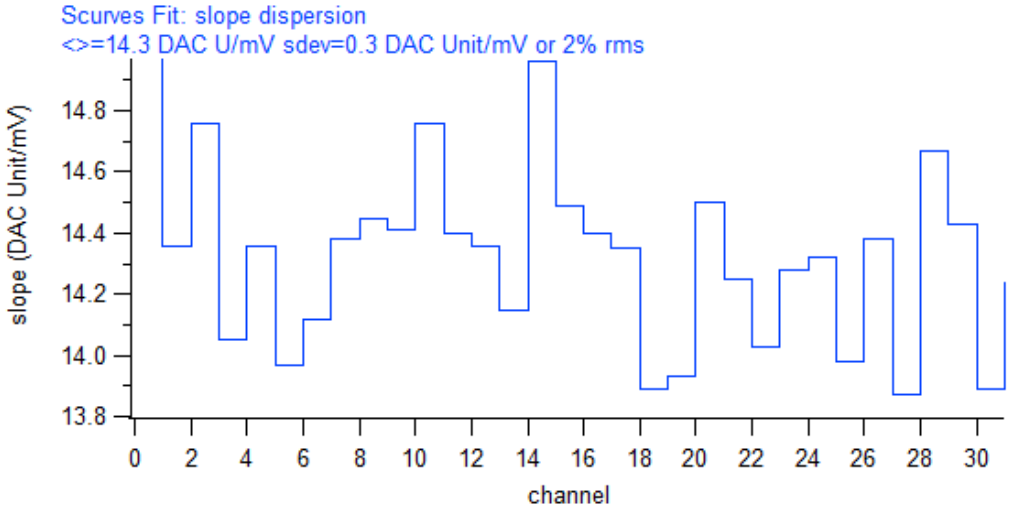
PETIROC2: efficiency uniformity

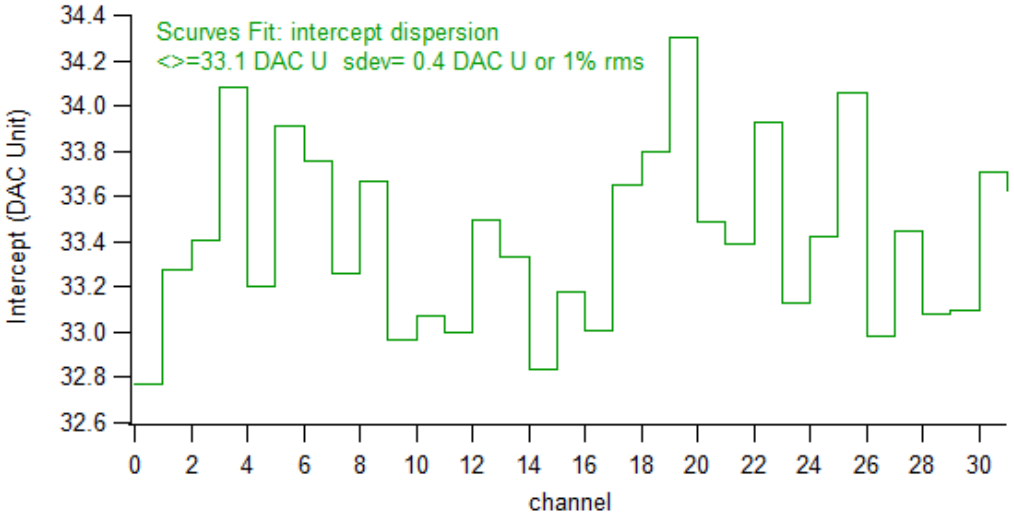
- Trigger efficiency measurements: Linearity
- One 10-bit DAC Unit= 923 µV





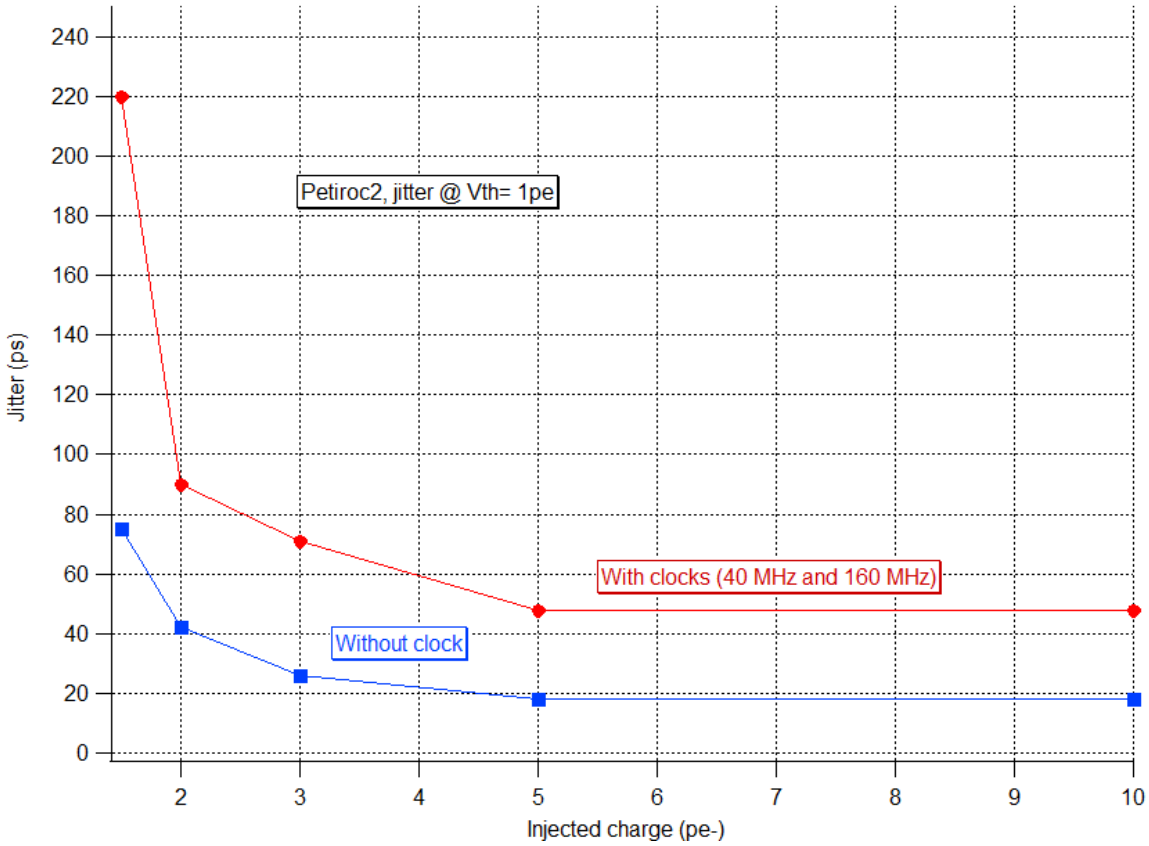
10-bit DAC linearity
923µV/DAC code





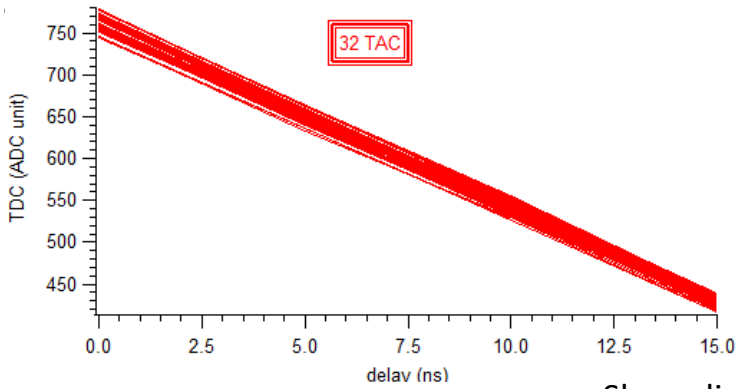
PETIROC2: Time measurement

- Jitter vs threshold & injection
- Jitter improves with signal
- Clock couplings (understood)
- Jitter below 20ps

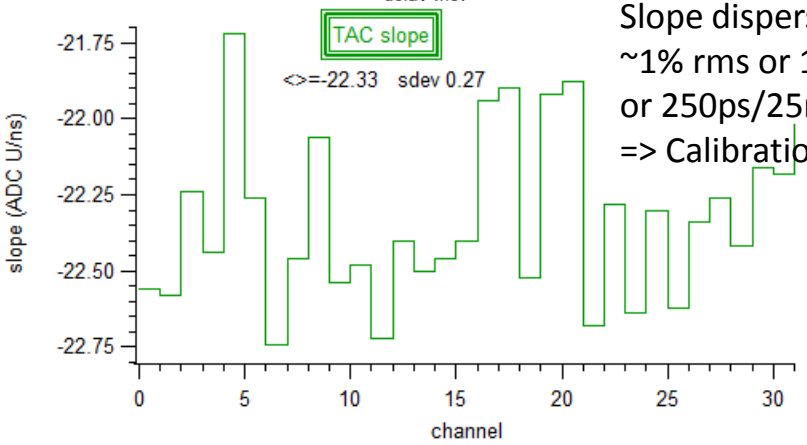


PETIROC2: TAC measurement

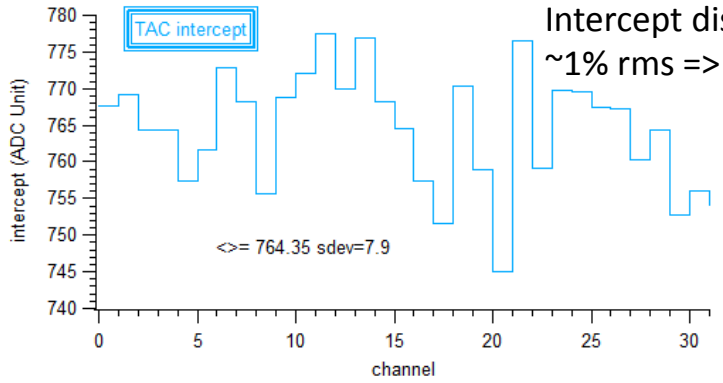
Omega



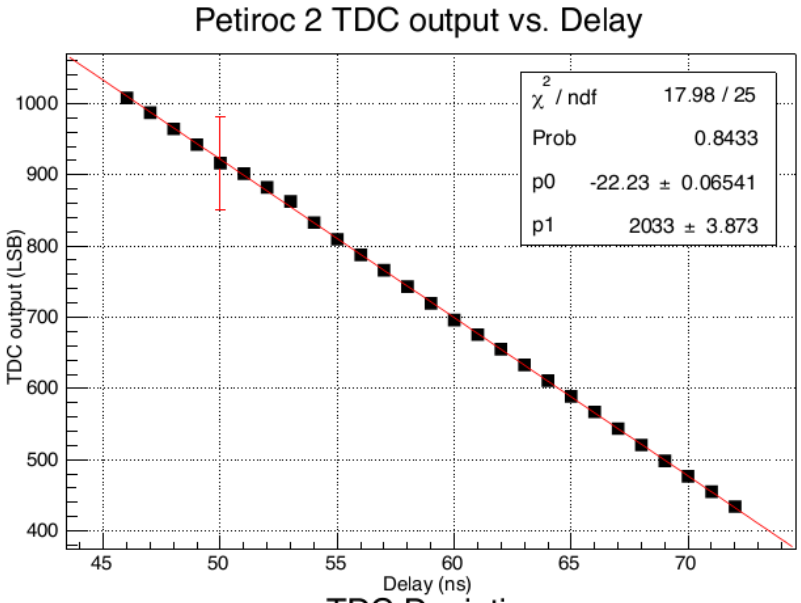
weeroc

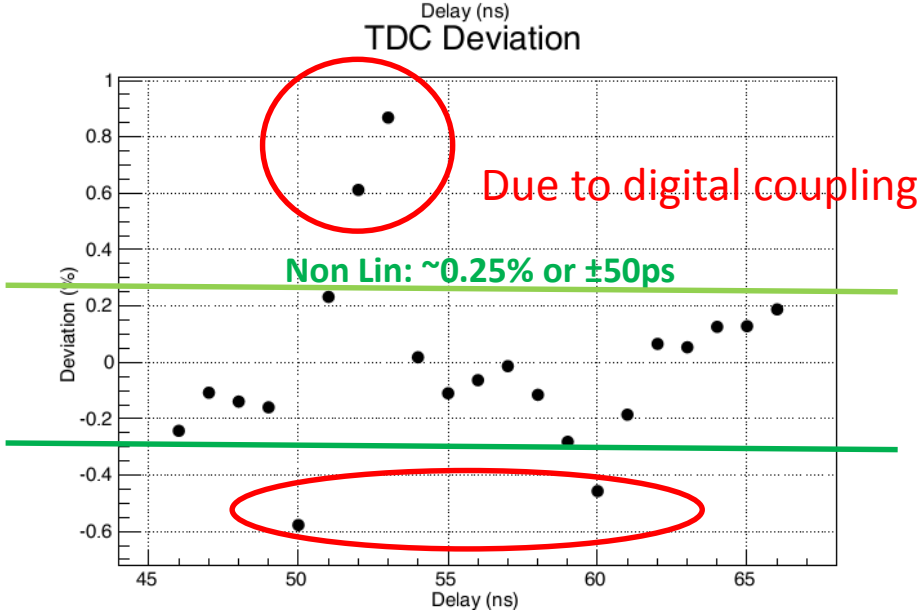


Slope dispersion:
~1% rms or 10ps/1ns
or 250ps/25ns
=> Calibration



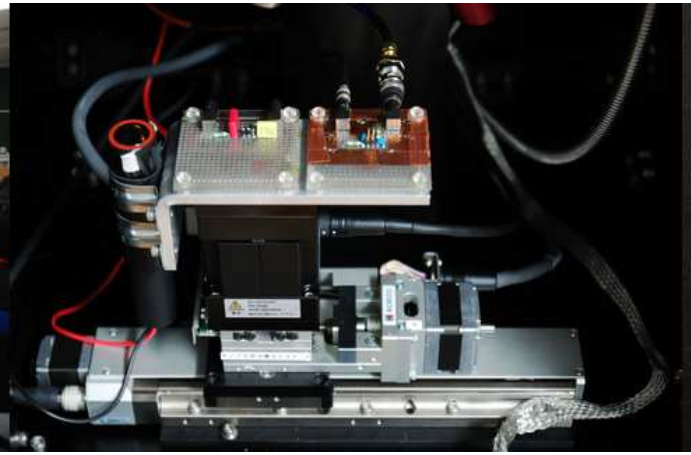
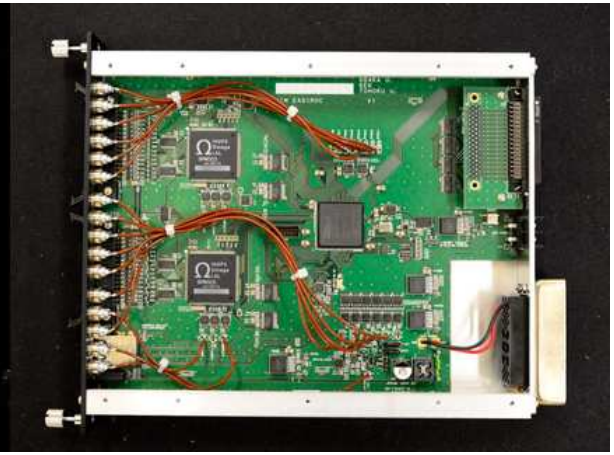
Intercept dispersion:
~1% rms => Calibration





KEK RD-Photon

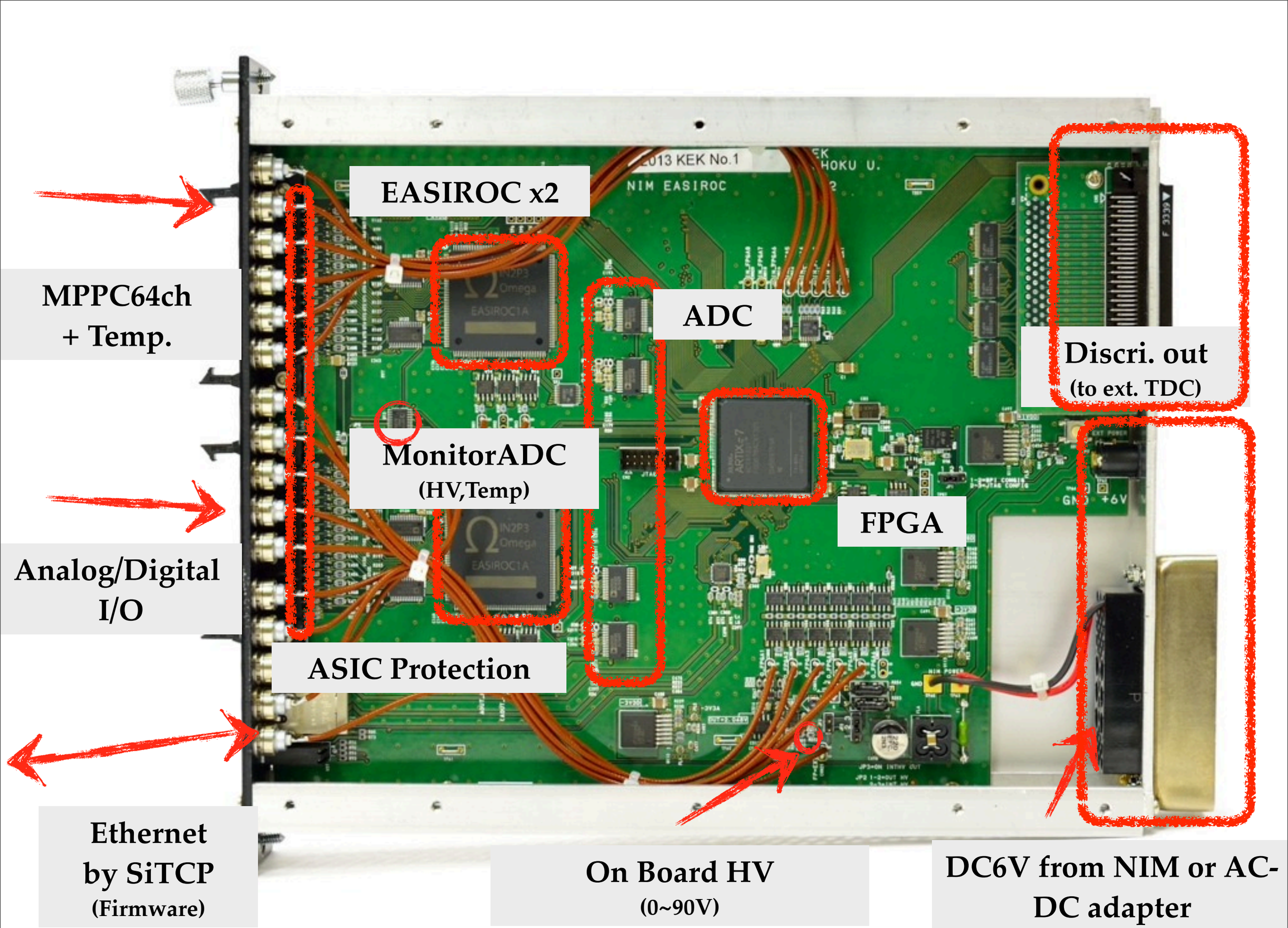
RD-Phpton/KEKDTP

- community among Japan's MPPC(PPD) users supported by KEK
- helping to share informations/investigations among users
  - Domestic/Internatinal workshop for Photon Sensor
- Providing Laser Test Facility
  - Variable Wavelength Pulse Laser Microscope
- Developping Readout electronics
  - EASIROC board and module

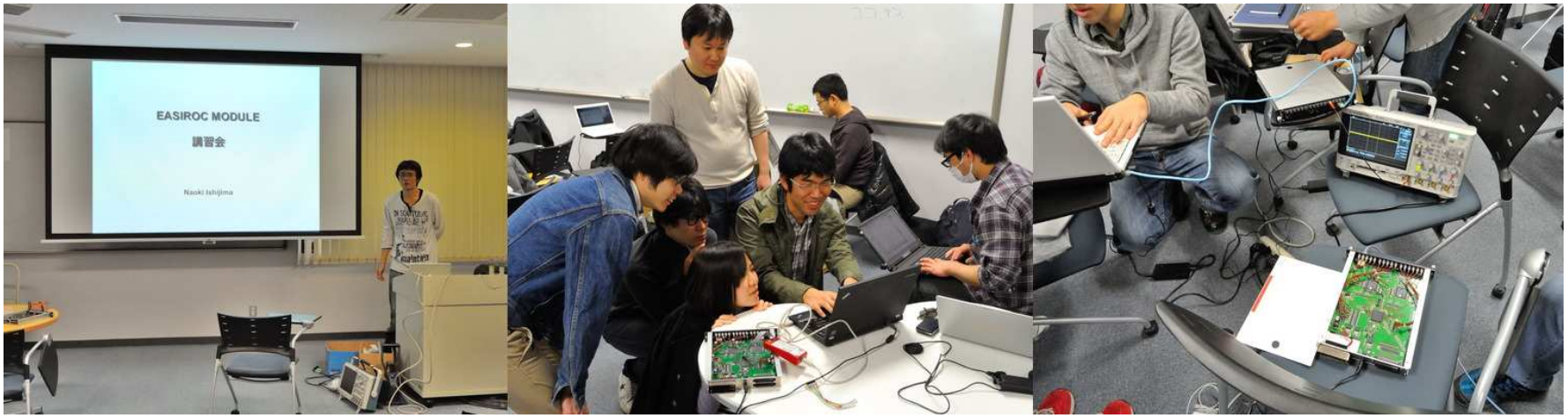
64ch EASIROC Module

- EASIROC ASIC by OMEGA/France
- Developped by Osaka/KEK with KEK Electronics System Group
- 30 modules produced and sold


EASIROC x2
MPPC64ch
+ Temp.
ADC
Discri. out
(to ext. TDC)
MonitorADC
(HV,Temp)
FPGA
Analog/Digital
I/O
ASIC Protection
Ethernet
by SiTCP
(Firmware)
On Board HV
(0~90V)
DC6V from NIM or AC-
DC adapter

EASIROC Module Tutorial

Tutorial @ Osaka Univ. March 2014



- Many users
  - Tohoku, Shinshu, KEK, Chiba, Tokyo, Tokyo Tech, Waseda, Kyoto, Osaka, Kushu ....
- Variety of application
  - Education, Beamtest, Test Bench, Small Experiment, Vulcanology .....
- Tutorial Session
  - ~20 Users (~10 modules)
  - 18-19.Mar.2014 @ Osaka
  - Lectured by developper (Ishijima-san, Osaka)

纏め

- Photon detection with accurate timing
- MPPC(PPD) is New Photon Sensor with Good time resolution
- PETIROC ASIC for PPDs is being developped in Omega group
- France–日本 collaboration is playing an important role in development of Japan's MPPC(PPD) readout system

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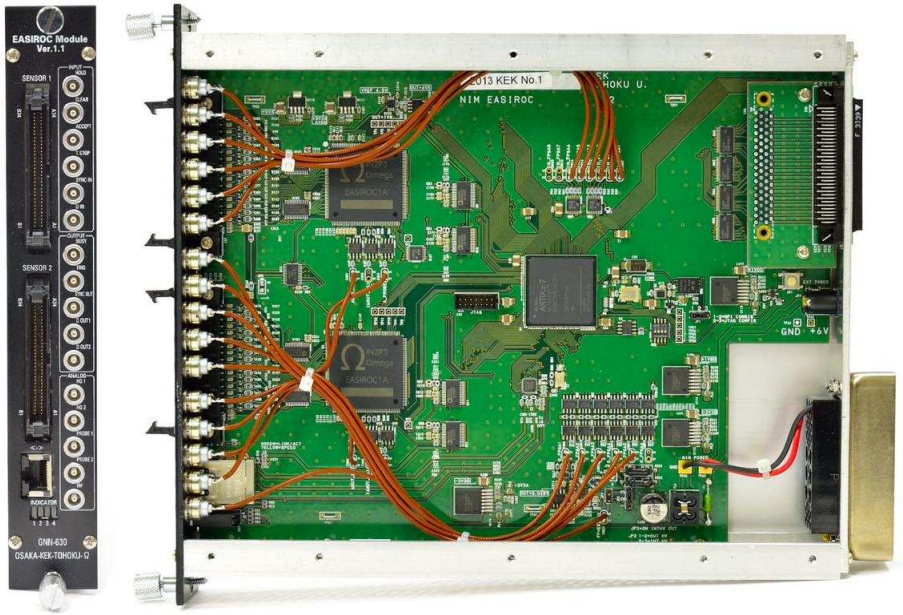
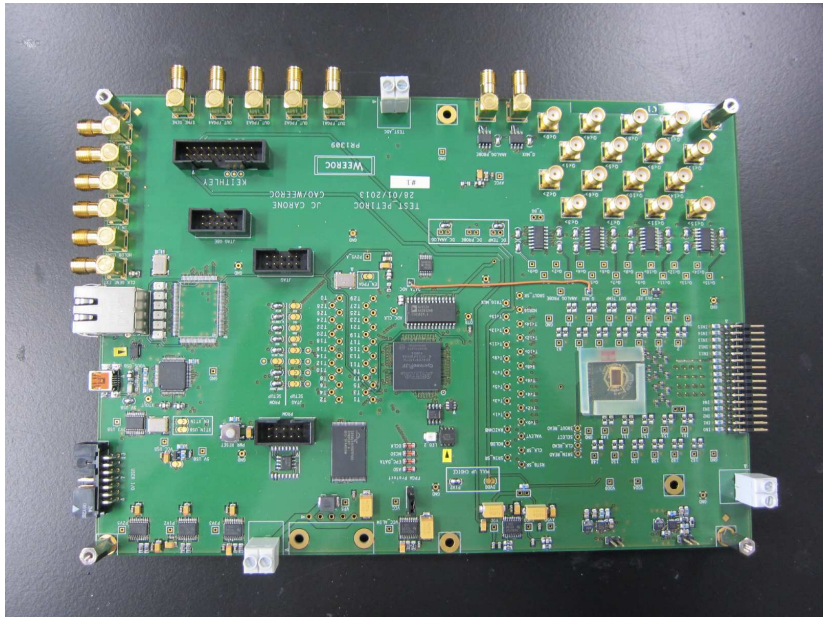


EASIROC module

France



PETIROC Evaluation Board