Large Photomultipliers

for the next

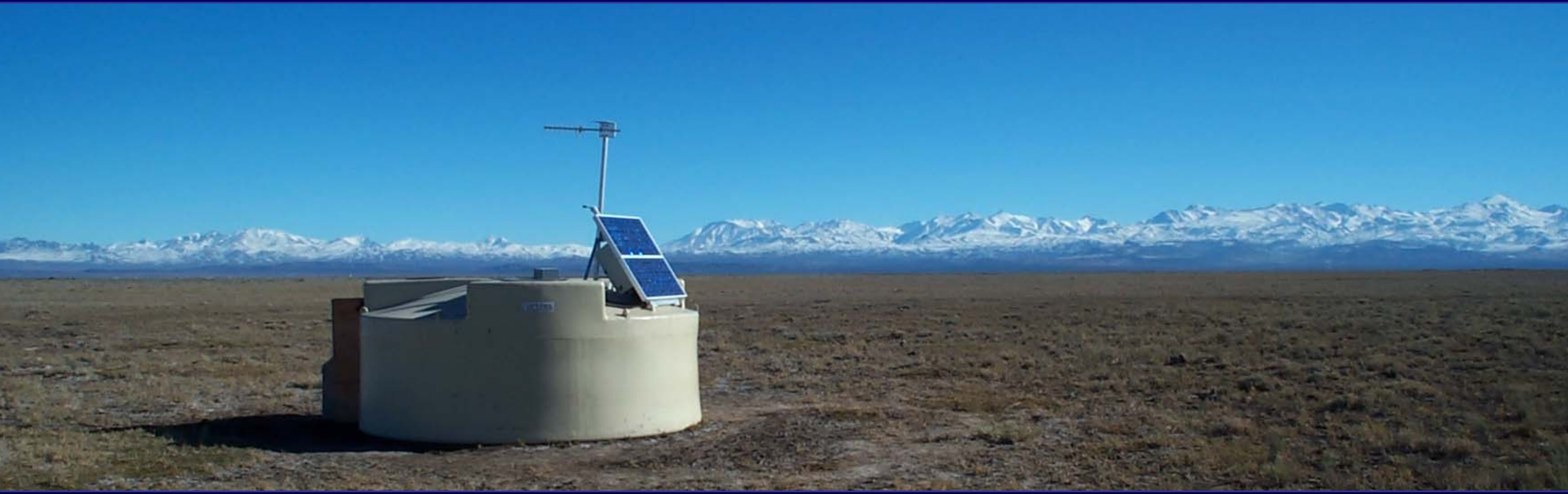
Astroparticle Physics Experiments

Challenges and consequences on the associated electronics

Joël Pouthas IPN Orsay France

Photodetectors - Requirements

UHCR (Ultra High energy cosmic ray)



Pierre Auger Observatory (Argentina)

Very high dynamic range

Future

AUGER
North site (Colorado)

Low after pulse rate

Photodetectors - Requirements

Deep underwater neutrino telescopes

[Dumand (Hawaï)]

Baikal Lake (Russia)

ANTARES (France)

NESTOR (Greece)

NEMO (Italy)

Future
KM3 Net (Mediteraneen Sea)

Deployment
Ice Cube (South Pole)

Large area
with maximum efficiency

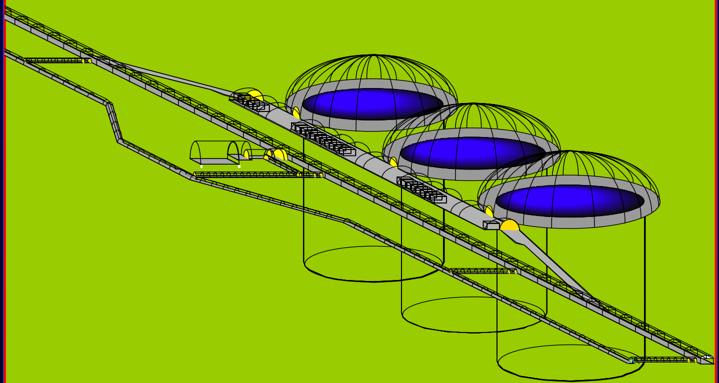
Good SER
(Single electron response)
in charge and time

Photodetectors - Requirements

Nucleon decay and neutrino detectors

Future

UNO
Hyper Kamiokande
Memphys



10 to 20 times Super K

200 000 to 300 000
Large PMTs !!!

KamiokaNDE

Super KamiokaNDE

KamLAND

(Japon)

SNO (Canada)

MiniBooNE (USA)

Borexino (Italie)

Large area
with maximum efficiency

Good SER
(Single electron response)
in charge and time

Low noise

IPN Orsay / Photonis Collaboration

Start with AUGER Surface Detectors

PMT : PHOTONIS XP 1805 (9")

Base design : IPN Orsay (End of 2000)
Production : 5000 pieces (2001-2005)
Photonis, IPN Orsay, INFN Torino

Continue with R&D Program on large Photomultipliers

Year 1 (Sept 03-Sept 04)

- Definition and construction of the test benches
- Validation on reference PMTs

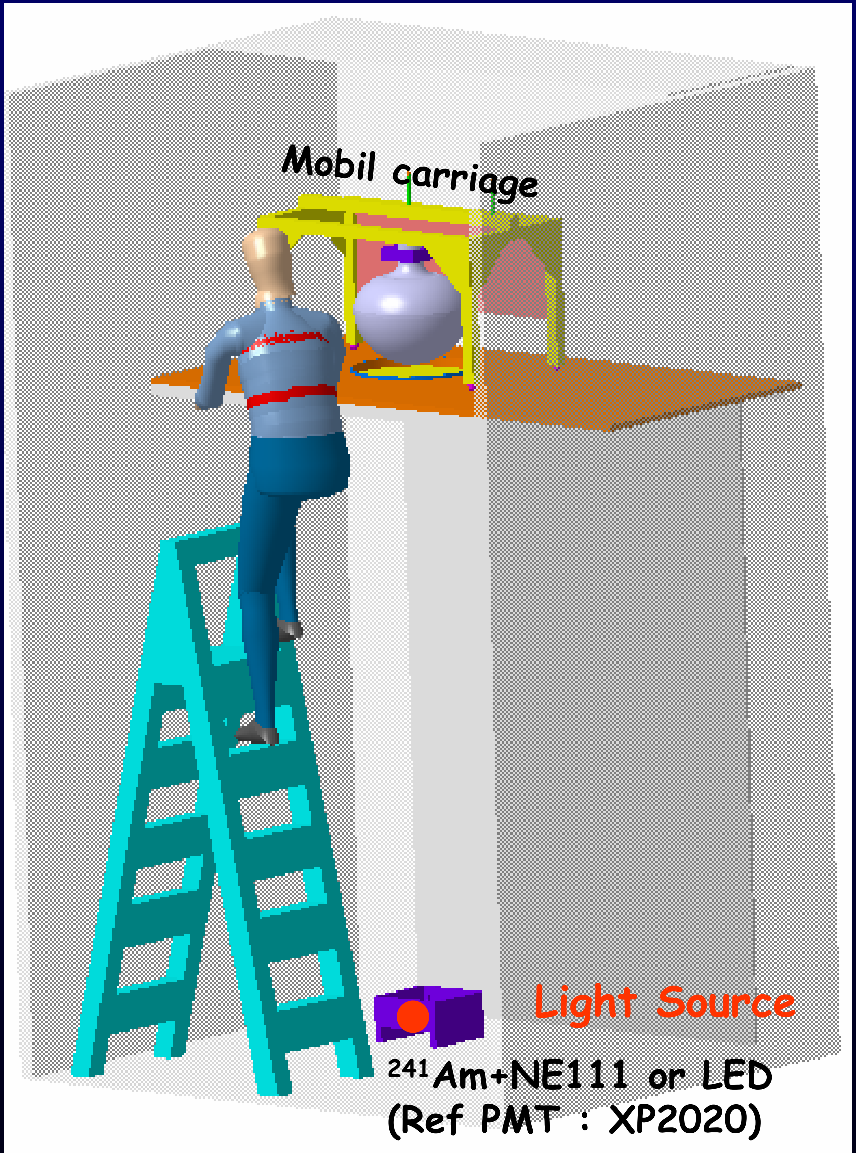
Year 2 (Sept 04-Sept 05)

- Construction and measurements on different PMTs (5",8",9",10")
- Photocathode characterization. Afterpulse measurements

Year 3 (Sept 05-Sept 06)

- End of measurements on standard PMT
- Afterpulse studies : detailed simulations and measurements

IPN Orsay / Photonis Collaboration



Test Bench 1

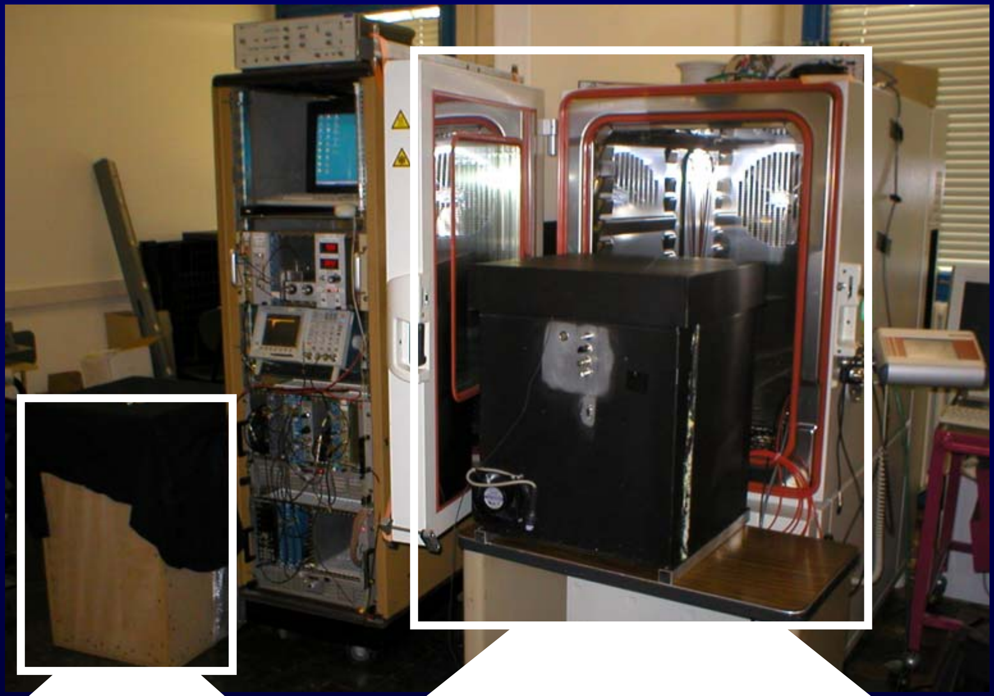
Single electron response
(SER and P/V)

Timing characteristics

Photocathode uniformity

Detection efficiency (relative)

IPN Orsay / Photonis Collaboration



Test Bench 2

Noise

After pulses

Variation with temperature

Magnetic field effects

Black box
(Wood)

Climat cabinet

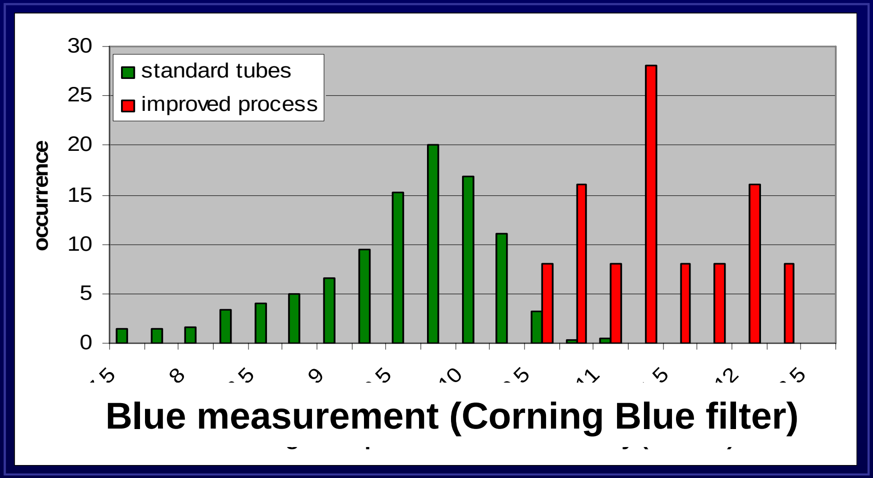
(Voestch VC4034)
+ Black box (Al)

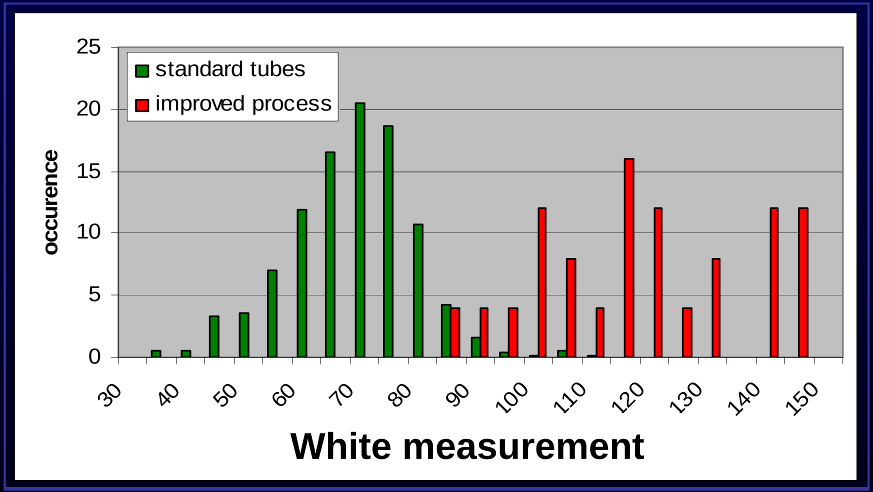
(-40° à +50°)

Data Acquisition

CAMAC
Oscilloscope
MATAC (2GHz, 12bits)

IPN Orsay / Photonis — Overview on results





Improved photocathode

D. Dornic et al, Beaune Conference, France, June 2005
Nucl. Instr. and Meth. A567 (2006) 527

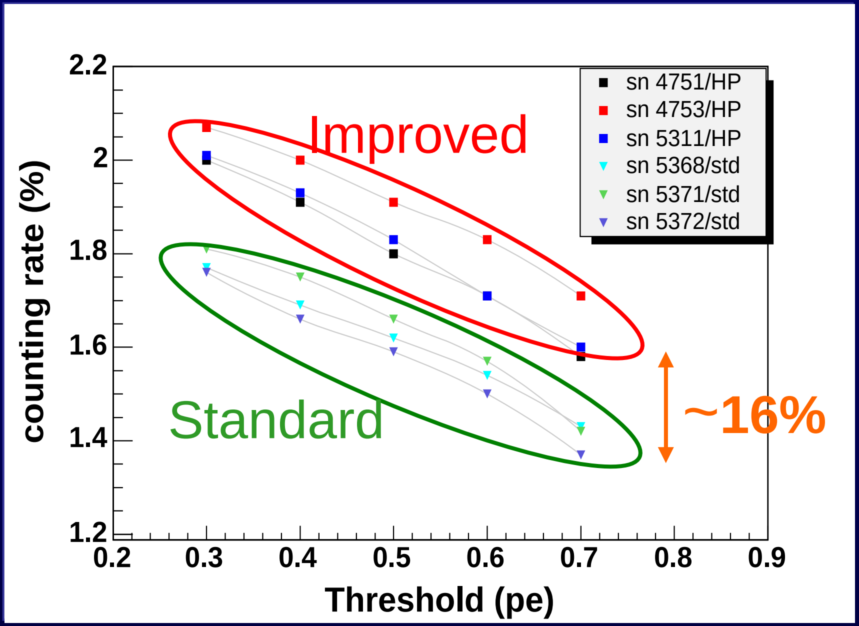
XP1805 (9", AUGER PMT)

Standard (~800 PMTs)
- Sk CB: 9.32 µA/lmF
- Sk White: 68. 37 µA/lm

Improved (~25 PMTs)
- Sk CB: 11.35 µA/lmF
- Sk White: 118.00 µA/lm

Increase of Sk CB: ~19%
Increase of Sk White: ~42%

IPN Orsay / Photonis — Overview on results

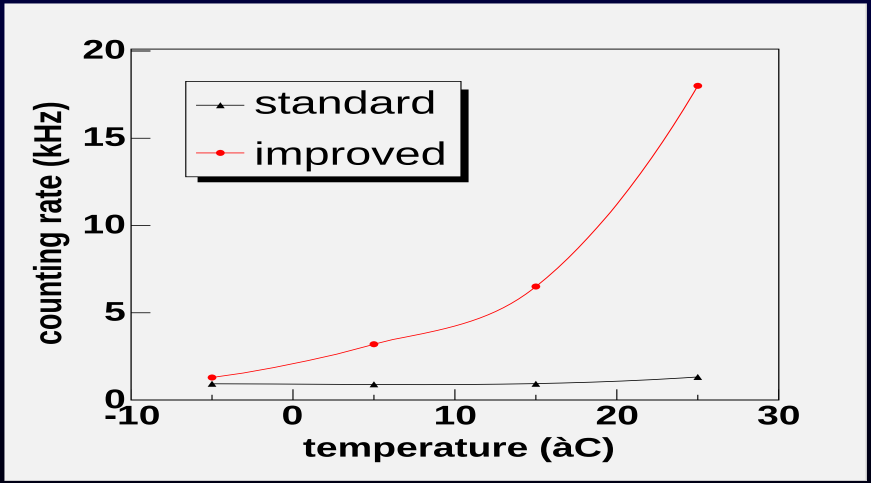


Improved photocathode

D. Dornic et al, Beaune Conference, France, June 2005
Nucl. Instr. and Meth. A567 (2006) 527

Quantum efficiency (400 nm)
Standard ~26%
Improved ~32%

Control by
Pulse measurements in SER
(Relative detection efficiency)



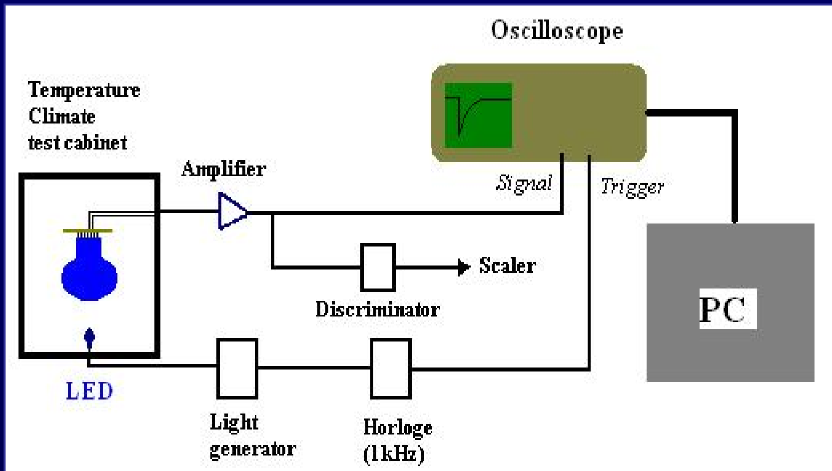
Drawbacks ?

Dark count rate

Same at low temperature
Increase with temperature

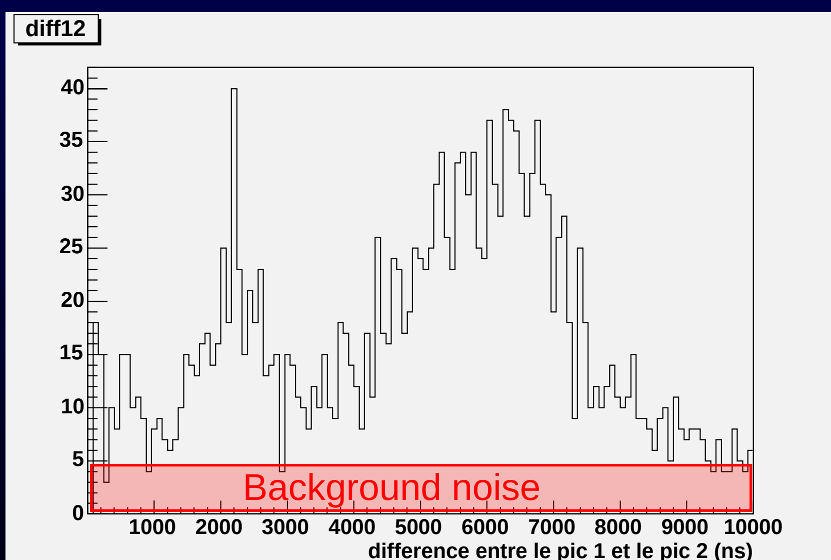
IPN Orsay / Photonis —— Overview on results

After-pulses

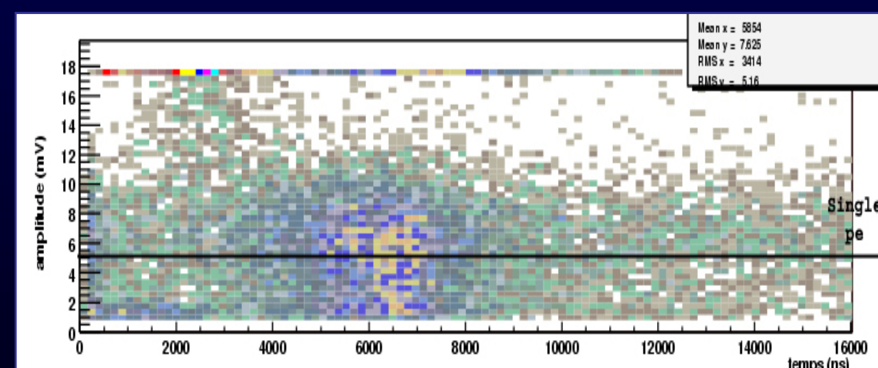


Digital Oscilloscope + PC

100 ns to 20 μs
Sampling : 0.5 GSPS
500 Events/s

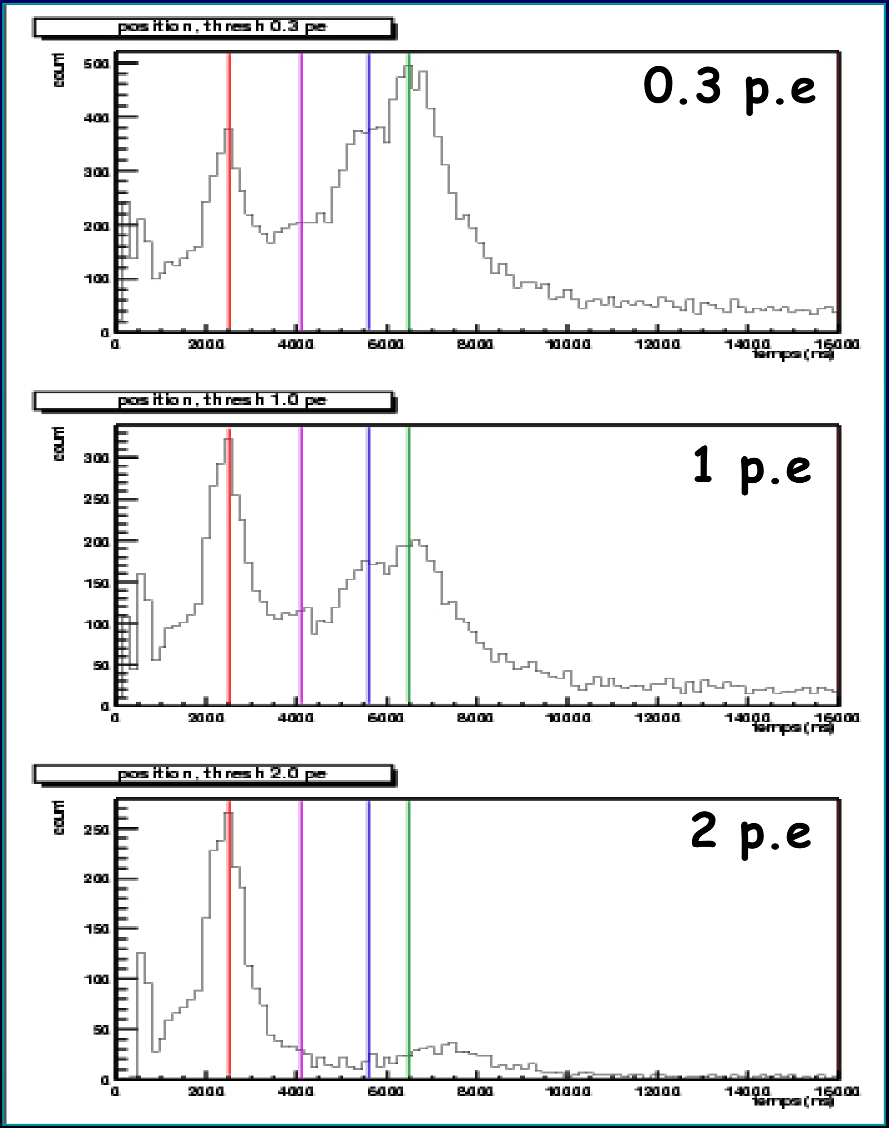


Time distribution

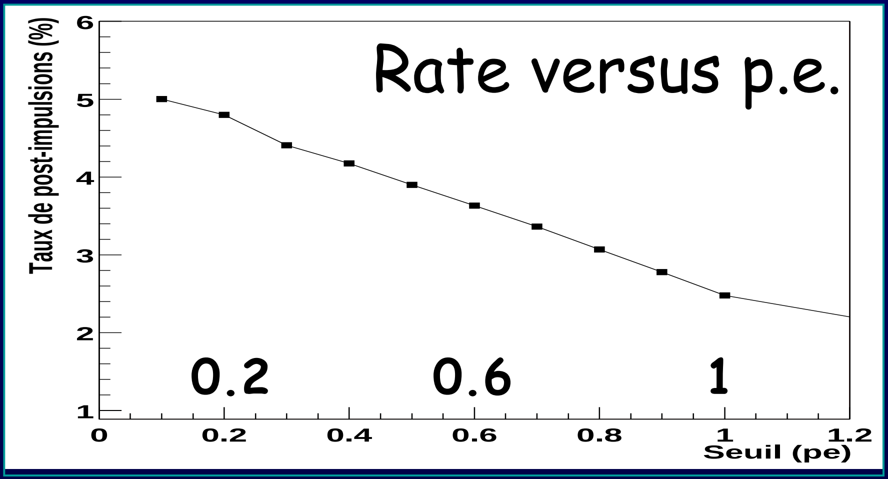


2D : Amplitude versus time

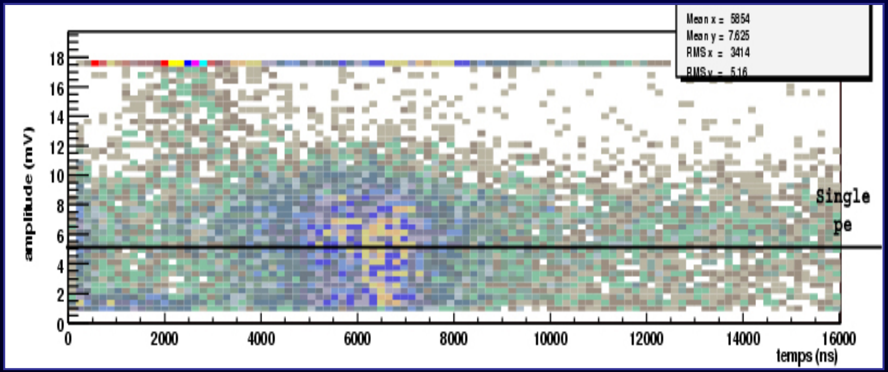
IPN Orsay / Photonis — Overview on results



After-pulses



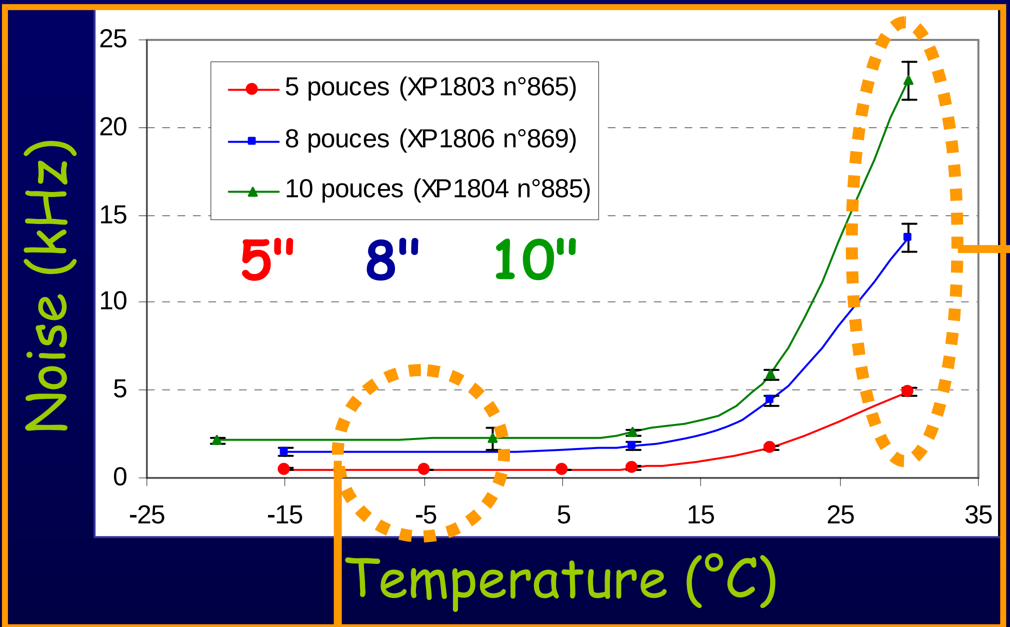
Time distribution

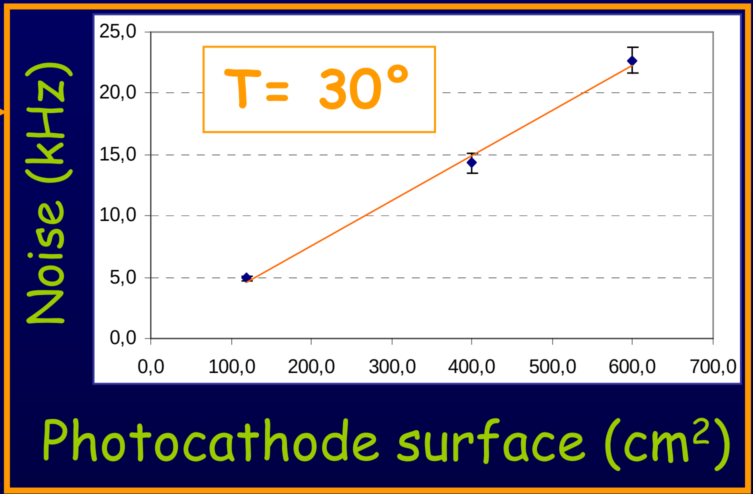


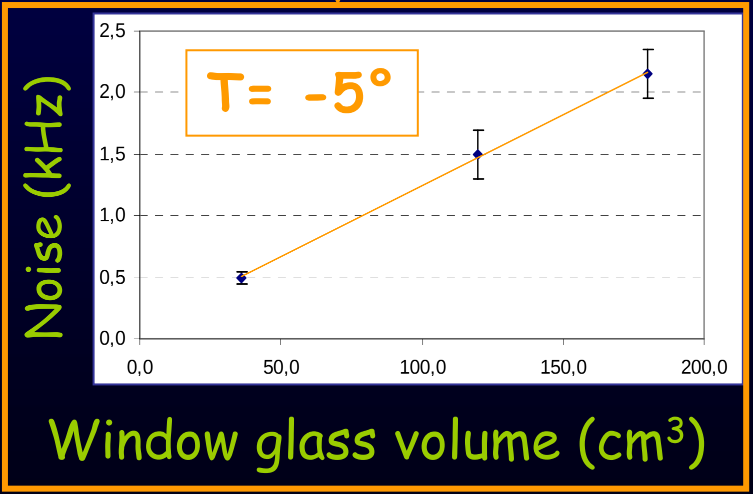
2D : Amplitude versus time

IPN Orsay / Photonis — Overview on results

Noise (dark pulses)







All the main results in

PhD of D. Dornic , 09 – 29 - 06

First remark

Requirements on photodetectors

generally ask for the best characteristics

But…

…parameters are often correlated…

… And

a hierarchy with priorities

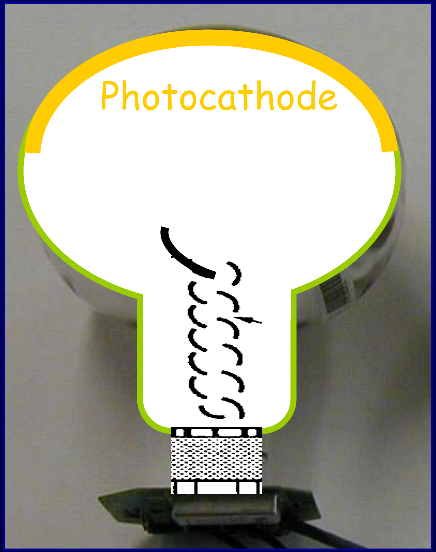
(coming out from impact on physics)

must be introduced

in the requirements to manufacturers

IPN Orsay / Photonis Collaboration

New 3 years R&D Program (2006 – 2009)



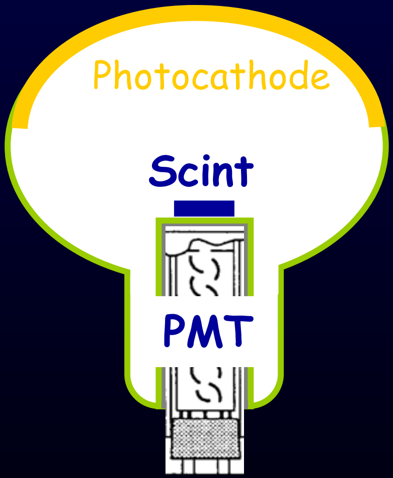
Standard PMTs

More detailed studies on :

SER (Single Electron Response)
"Late pulses" (T < 100 ns) with a laser

End of the "scaling" studies

Parameter correlations (5" to 12") , (No 15")
New types of multipliers



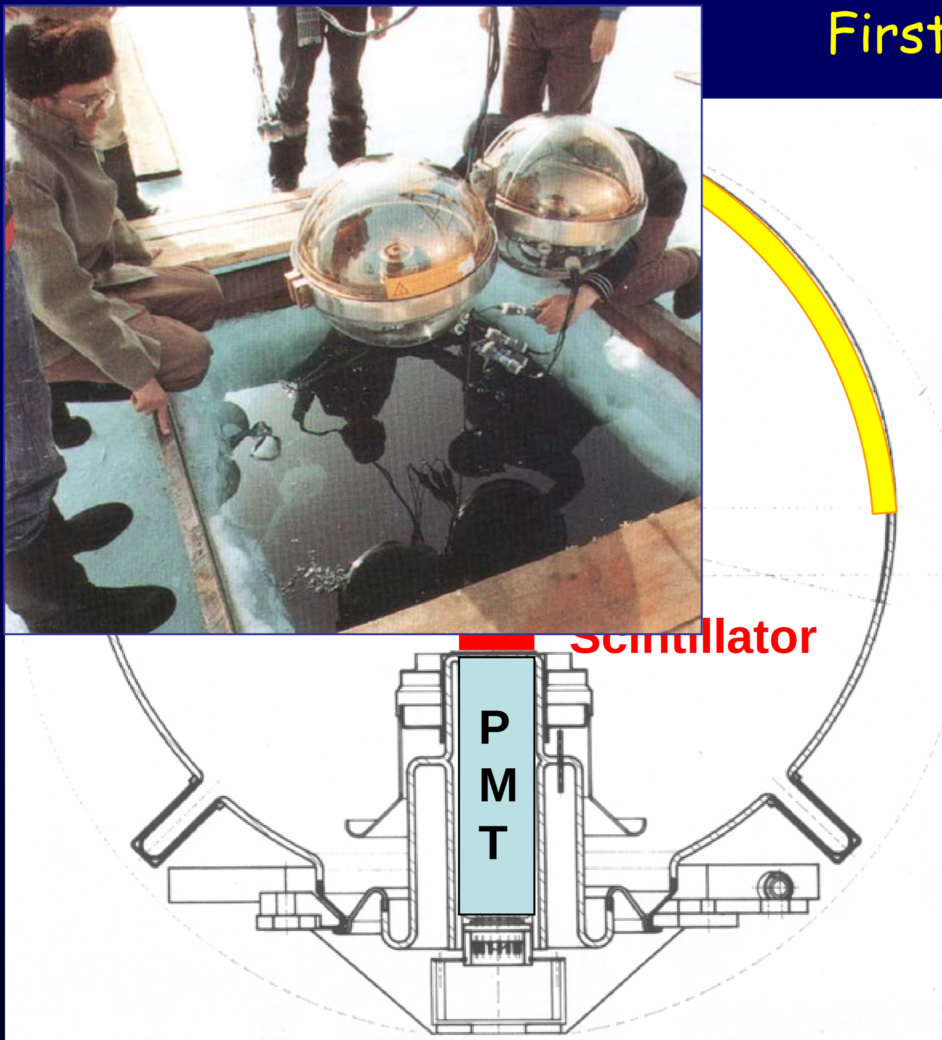
Hybrid PMTs

"Smart Tube" type (Scintillator)

Comparison with standard PMT
(Same size, 10" or 12")

R&D for Memphys

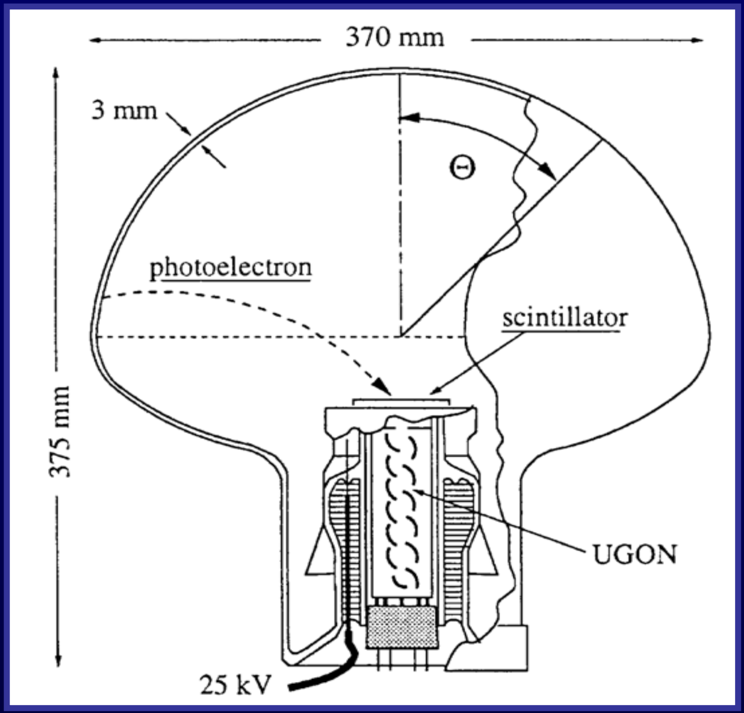
Baikal neutrino experiment



First developments (1983)

"SMART Tube"
Philips XP 2600
Dumand project & Baikal

Baikal neutrino experiment



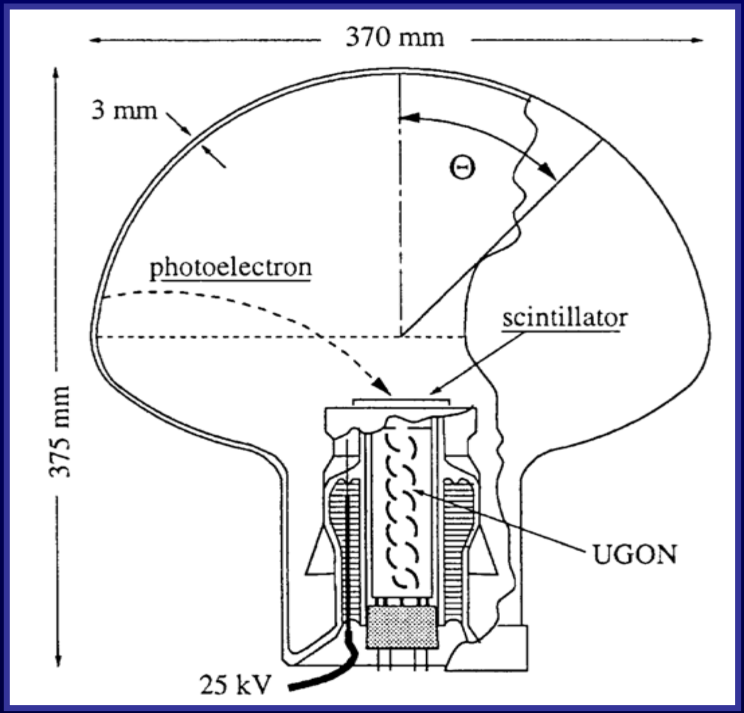
First developments (1983)

"SMART Tube"
Philips XP 2600
Dumand project & Baikal

Then in Russia

Baikal experiment
Quasar 300 ; Quasar 350
Quasar 370

Baikal neutrino experiment



Quasar 370

Glass bulb
Photocathode (SbKCs)

Acceleration PE (25 kV)
Scintillator (YSO)

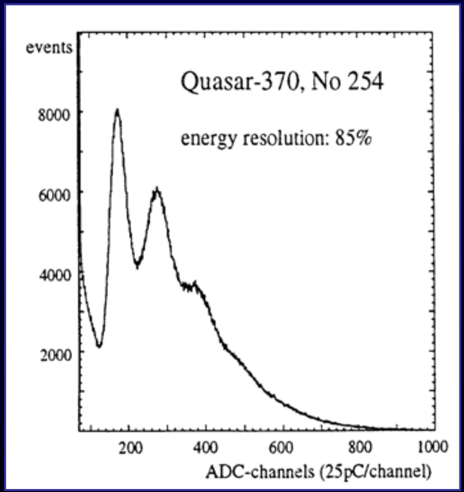
Conventional PMT (UGON)

Characteristics

Large area

Good SER (Gain 1st stage : 25)

Good TTS : 2.5 ns (FWHM)



SMART Tube @ Photonis

C. Marmonier, NNN05, France, April 2005
LIGHT06, Israel, January 2006

Status

Philips/Photonis invested 1 M€ and made ~30 pieces

200 Quasars operating for many years -> Proof of life time

No ongoing production !

On-going R&D

In collaboration with European Labs

Reproduce and improve former tubes

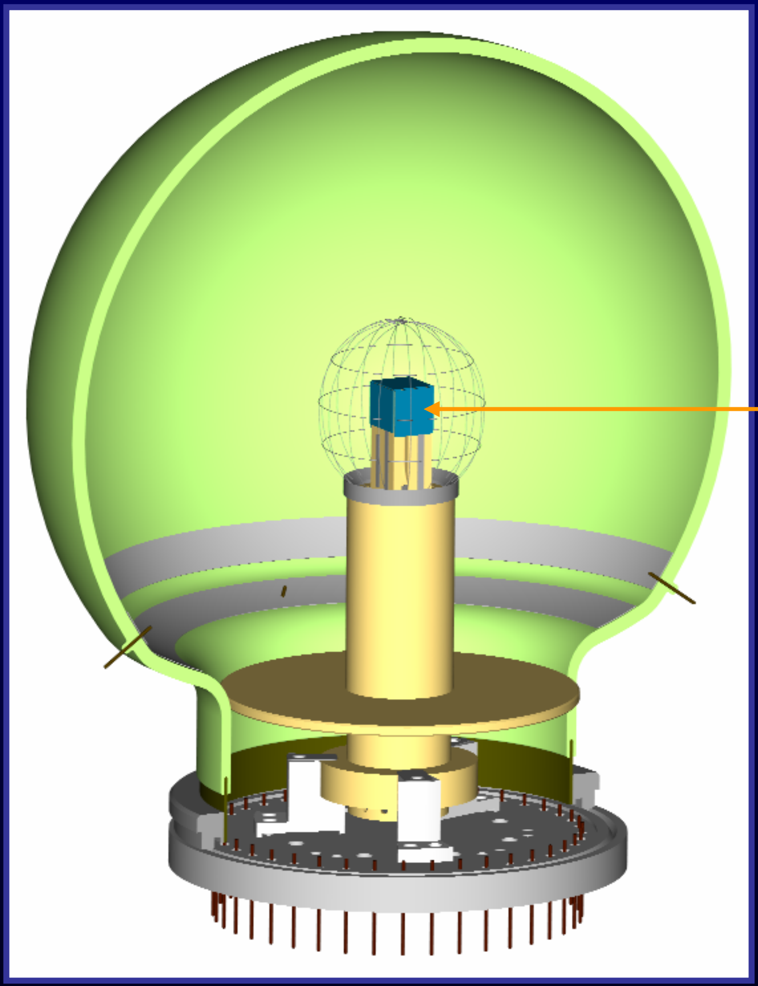
Redesign

- Better scintillator (LSO:Ce, YAP:Ce, ZnO:Ga, $LaCl_3$…)
- Multi-anode multiplier (rough localization)

HPD Team @ CERN

C. Joram et al., CERN-PH-EP/2006-025, August 2006
Nucl. Instr. and Meth. A581 (2007) 469

The X-HPD – Conceptual Study of a Large Spherical Hybrid Photodetector



“Artistic view” of
the half-scale prototype

Cubic scintillator
+
Small PMT

HPD Team @ CERN

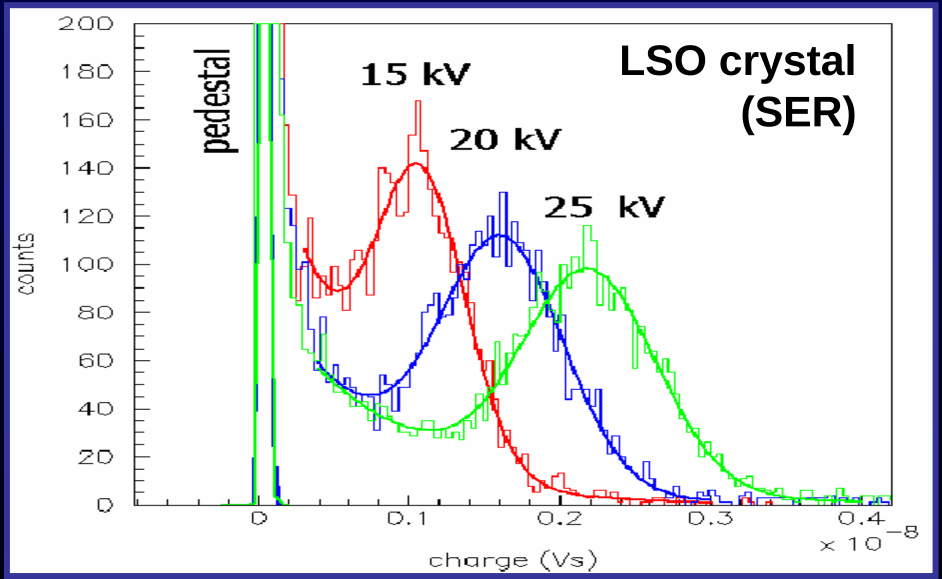
C. Joram et al., CERN-PH-EP/2006-025, August 2006
Nucl. Instr. and Meth. A581 (2007) 469

The X-HPD – Conceptual Study of a Large Spherical Hybrid Photodetector

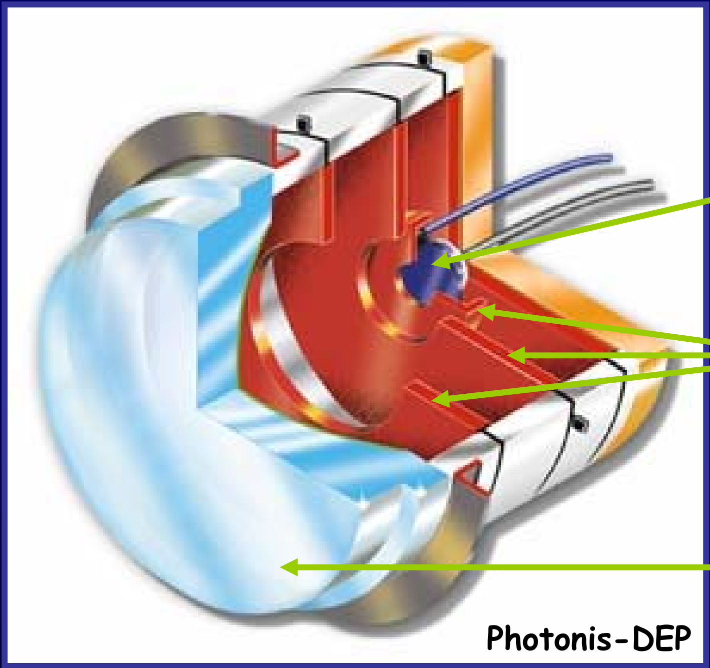
Prototype (208 mm glass envelope)

Cubic metal anode

Test bench for scintillators



Hybrid Photon Detector (HPD)



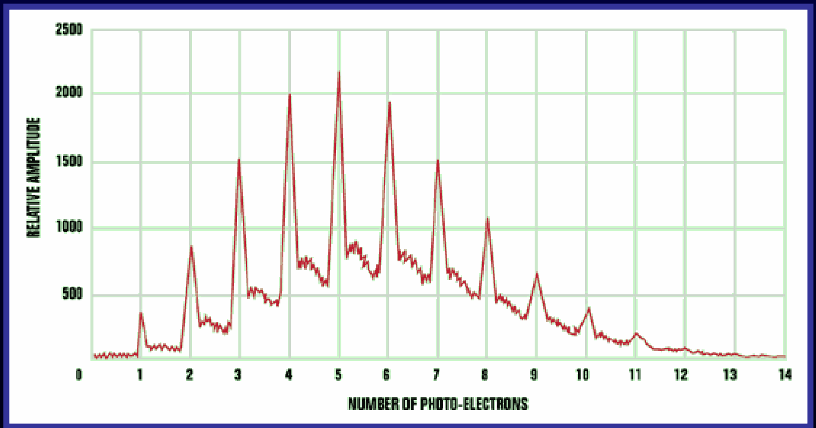
Silicon PIN diode
(2 mm diameter)

Focussing electrodes
(Total HV : - 15 kV)

Phocathode (18 mm usefull)

Excellent photon resolution
(Very good SER)

Low gain : 3500 @ 15 kV
(needs low noise electronics)



HAPD @ Hamamatsu

H. Nakayama, Beaune Conference, France, June 2005
Nucl. Instr. and Meth. A567 (2006) 172

5" prototype

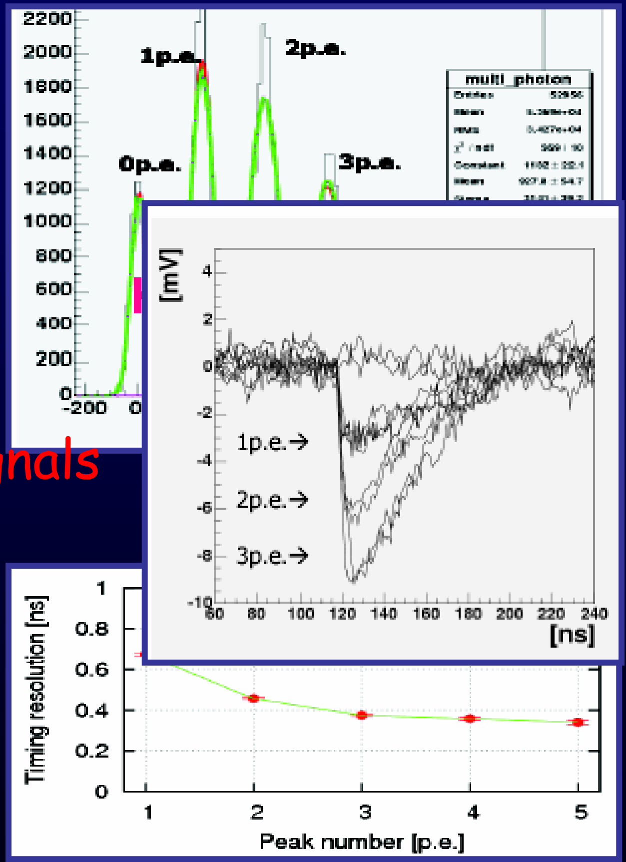
Replace the PIN by an APD

13" prototype

Very good SER

But … still weak signals

Very good timing



Second remark

All ideas on

photodetection designs are certainly interesting

But…

…if a mass production is foreseen

Constraints from industry

must be considered from the beginning

Particularly on the costs

Cost approach

Photonis at NNN05

C. Marmonier, NNN05, France, April 2005
LIGHT06, Israel, January 2006

Size (Diameter)	20	20(17)	12	Inch
Photocathode area	1660	1450	615	cm^2
Quantum efficiency	20	20	24	%
Collection efficiency	60	60	70	%
Cost	2500	2500	800	€
	12.6	14.4	7.7	€ $/PE_U/cm^2$

Cost/cm² per useful photoelectron

Cost / (cm^2 x QE x CE)

12" is better in SER and timing

12" provides a higher granularity

But, the number of channels is increased

R&D program for Memphys

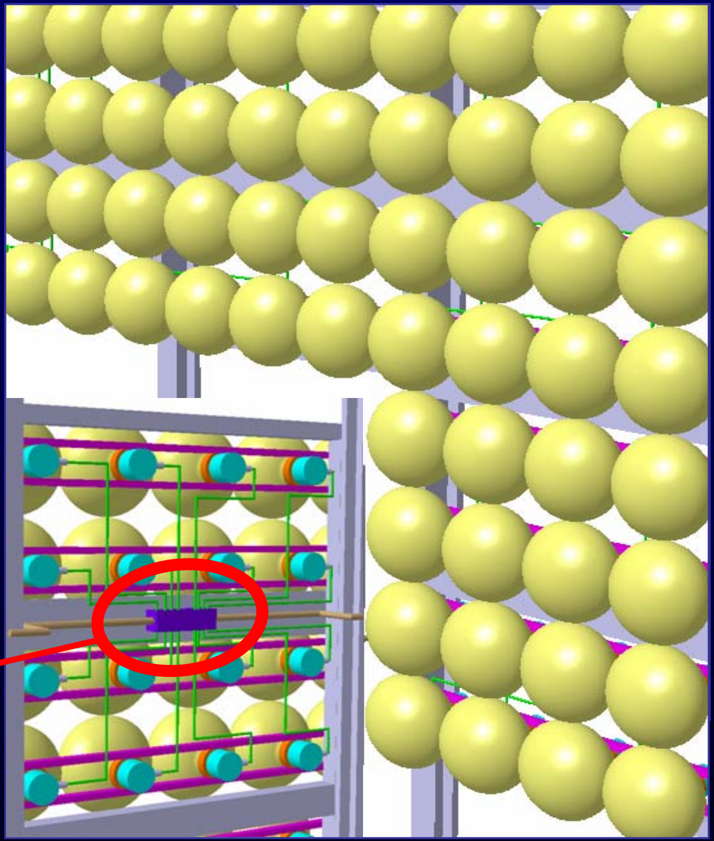
"PMm2" (2006 - 2009), granted by the ANR (National Agency for Research)

LAL Orsay, IPN Orsay, LAPP Annecy and Photonis

Megaton water tanks

Huge amount of
very large photodetectors

(PMTs of 20" size)

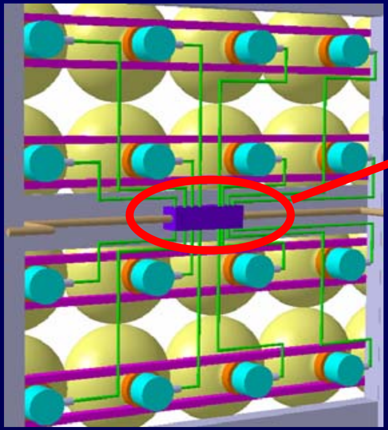


Proposition

Replace large PMTs (20")
by groups of smaller
ones (12")

Integrated electronics (Multichannel, close to the PMTs)

R&D program PMm^2



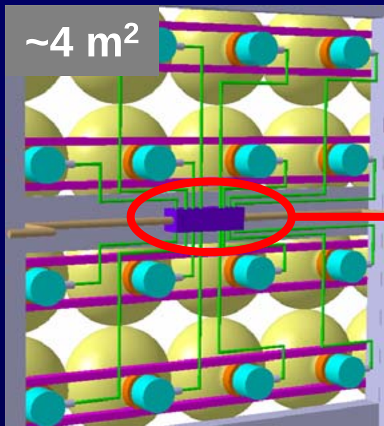
Electronics

> "No possible local coincidence"
> (low energy event 10PMs/MeV over 81000 PMTs)
> ⇓
> TRIGGER LESS

Front-end requirements

- Variable gain to equalize photomultipliers response and operate with a common high voltage
- High speed discriminator for Auto Trigger (100 % efficiency @ 1/3 pe)
- Digitization of charge (Dynamic range up to 300 pe ?)
- Digitization of time of arrival (Resolution 1 ns)
- Common Data out

PMm^2 Electronics



“Local” (16 channels)

FE-ASIC | Monitoring | HV

FPGA + µC

Network Controller

“No possible local coincidence”
(low energy event
10PMs/MeV over 81000 PMTs)

⇓

TRIGGER LESS

Twisted pairs cables for

Clock Synchronization
Digitized Data
Power

“Outside”

Ethernet switches + server

DAQ

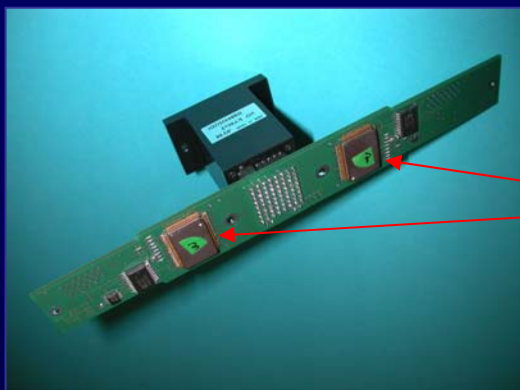
GPS receiver

FEE Electronics

Micro Electronics ASIC

LAL Orsay

PMT 64 ch. Readout (OPERA)



Variable gain (0-4, 5 bits)
Charge multiplexed output (0.1-100 pe)
32 channels chip, 180 mW
2000 chips

AMS 0.8 μm

PMT 64 ch. Readout (ATLAS Luminometer)

Variable gain (0-4, 6 bits)
Charge multiplexed output (0.1-100 pe)
64 channels chip, 500 mW
3 thresholds

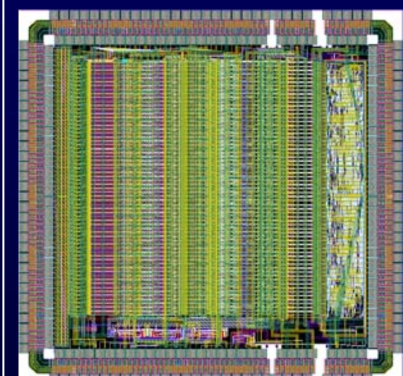
AMS SiGe 0.35 μm

FEE Electronics

Micro Electronics ASIC

Orsay Micro Electronic Group Associated

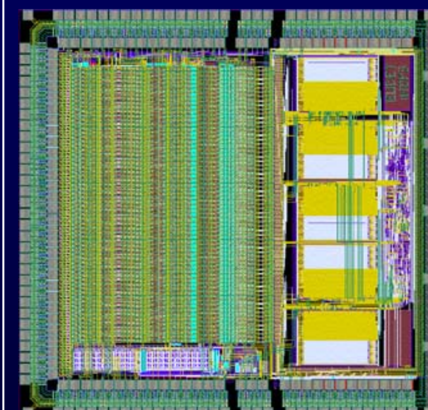
2006 MAROC2



ATLAS
Luminometer

PMT
64 channels

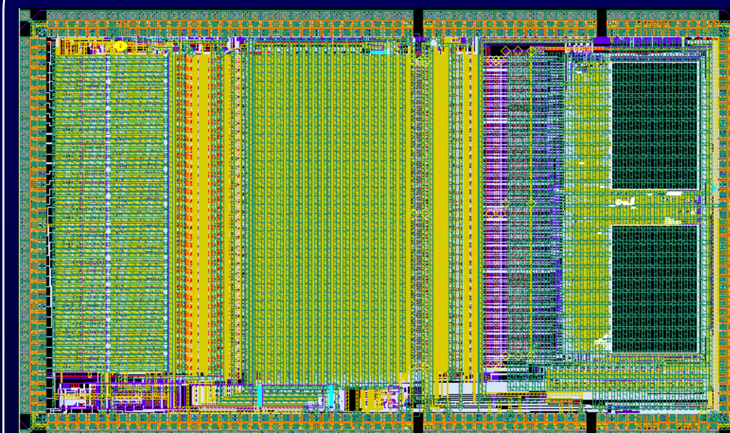
2006 HARDROC



ILC Calorimeter
CALICE

RPC DHCAL
64 channels

2007 SPIROC

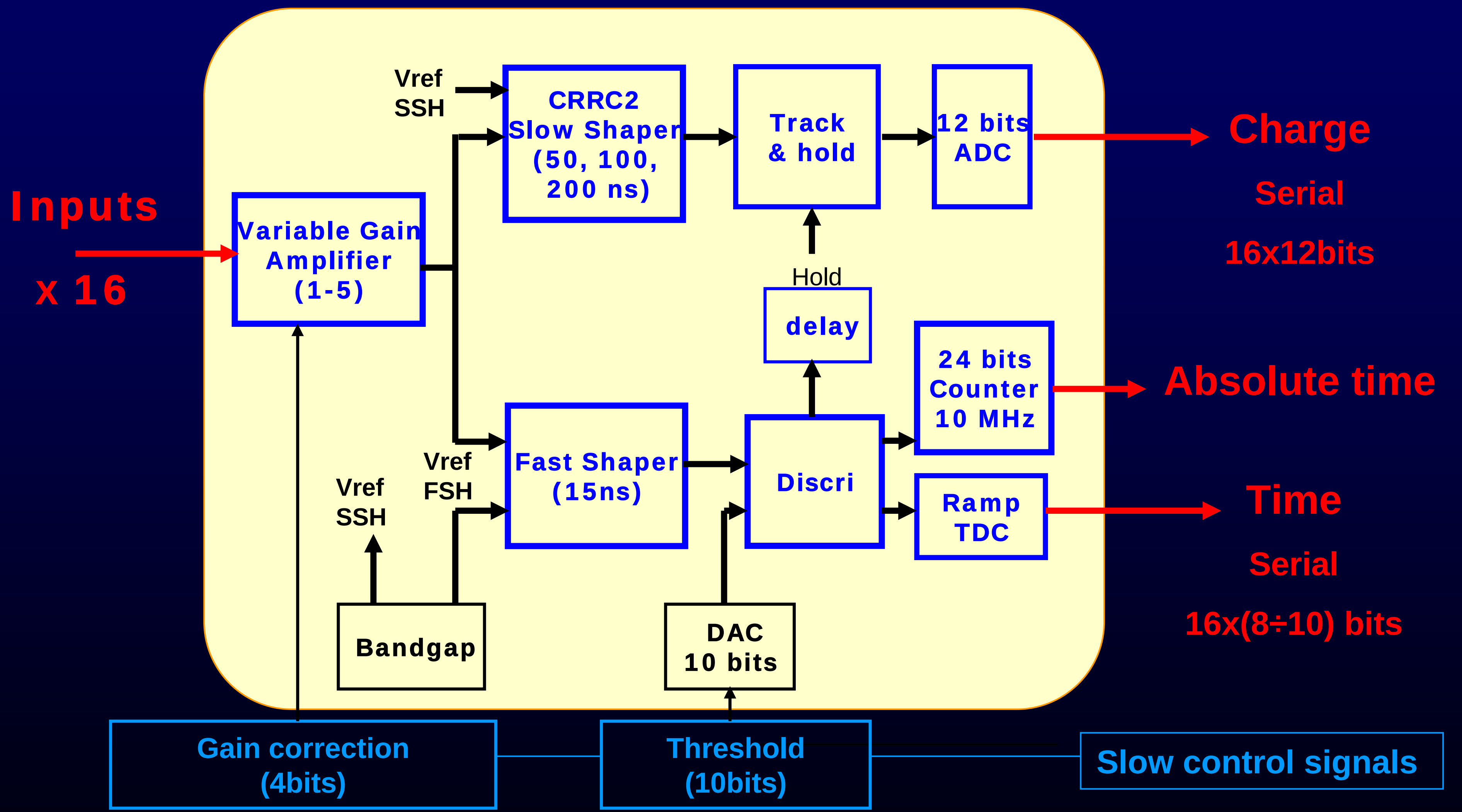


ILC Calorimeter
CALICE

AHCAL
36 channels

PMm² Electronics

Micro Electronics ASIC

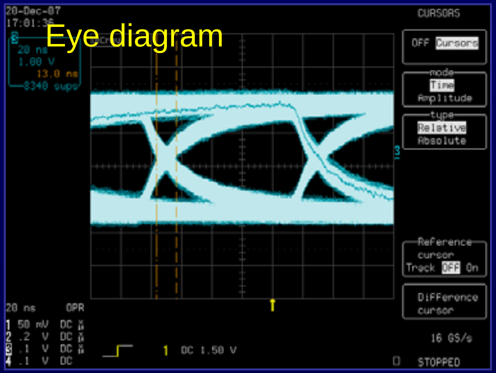


PMm² Electronics

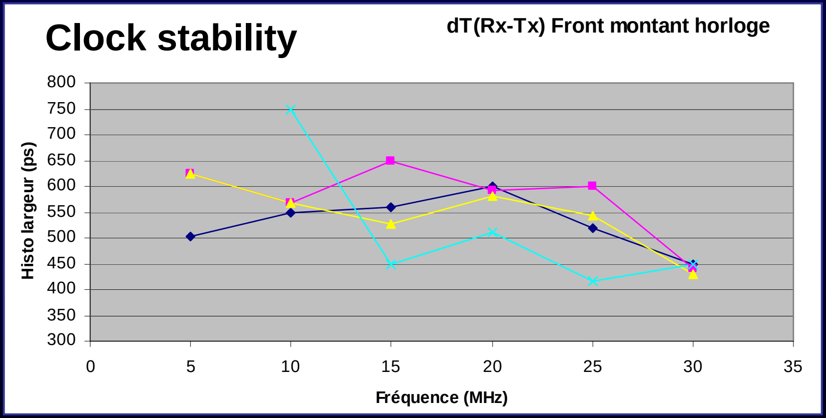
Power, Clock, DATA Transmissions

LAPP Annecy

Cable 100 m (Twisted pairs)



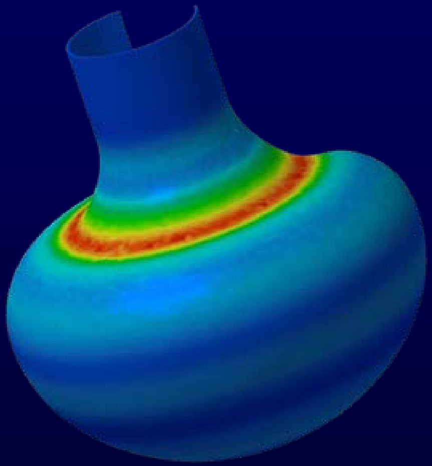
First tests on DATA and Clock transmission



PMm^2 Photomultipliers Integration

Parameter correlation studies

Signal/Noise @ 1pe (SER) versus Dark current
and Quantum & Collection Efficiencies — Optimum ?



Photomultipliers @ 10 bars

Glass shape optimization
Water pressure test facility

Water tightness

Base potting and HV cables
Electronics tight box (16 inputs, digital outputs)

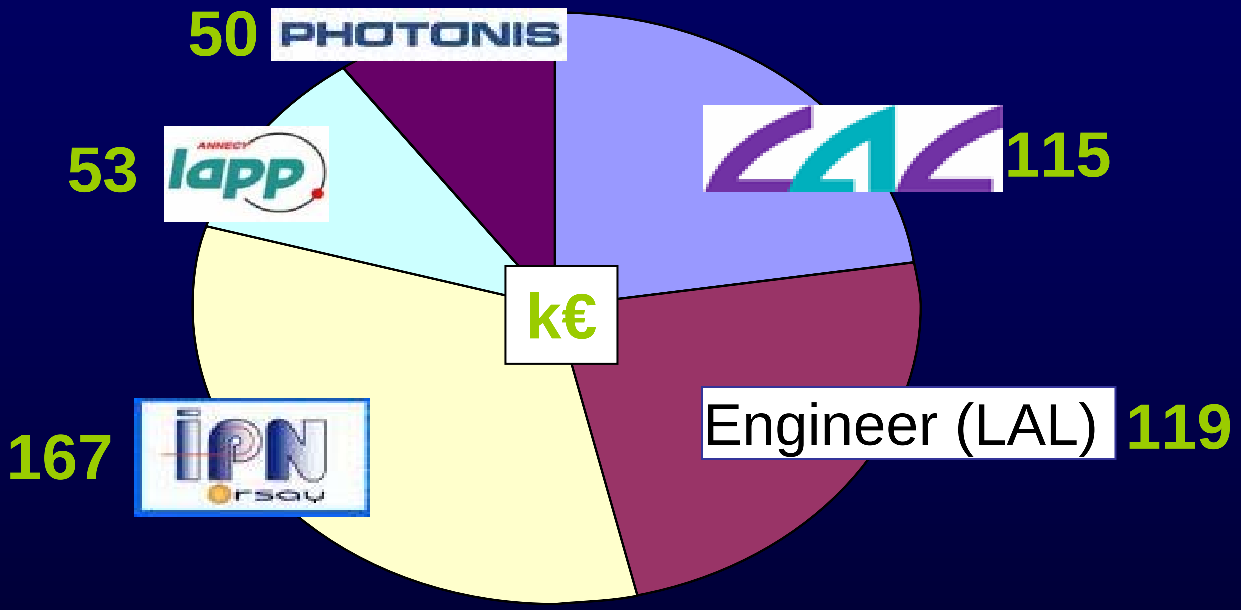
Mechanics of the Demonstrator

A tank; 16 photomultipliers; Integrated electronics — Definition ?

R&D program PMm²

PMm²

http://pmm2.in2p3.fr



500k€/3yrs

funded by new French Agency (ANR)

Started officially 25 Jan. 07

R&D program PMm^2

- P. Barillion, S. Blin, F. Dulucq, J.E Campagne, Ch. de La Taille, G. Martin-Chassard, L. Raux
- S. Conforti (since Sept. 07 for 2 years)

- B. Genolini, Th. Nguyen Trung, C. Perinet, J. Peyré, J. Pouthas, E. Rindel, Ph. Rosier

- N. Dumont-Dayot, D. Duchesneau, J. Favier, R. Hermel, J. Tassan-Viol

PHOTONIS

- B. Combettes, F. Fouché

Coordinator
Group leader
Student

Concluding remarks

Most of the photodetectors follows
a standard design

Some R&D are (or will be) performed on
HPD (Hybrid Photon Detector)

The design must include electronics
Micro-electronics (Asic)

Collaboration with industry is mandatory
Mass production and cost are key parameters

The best is generally not the cheapest … But …

Do we always need the best ?