R & D on

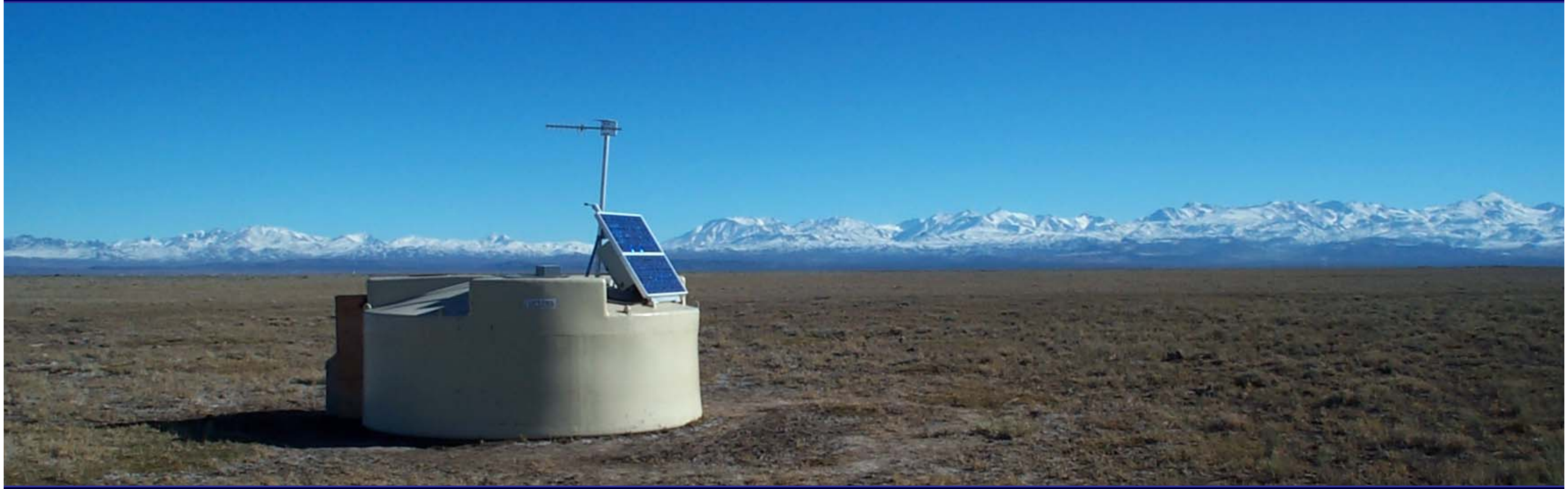
Large Photodetectors

for MENPHYS

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)

A le)

Large area
with maximum efficiency

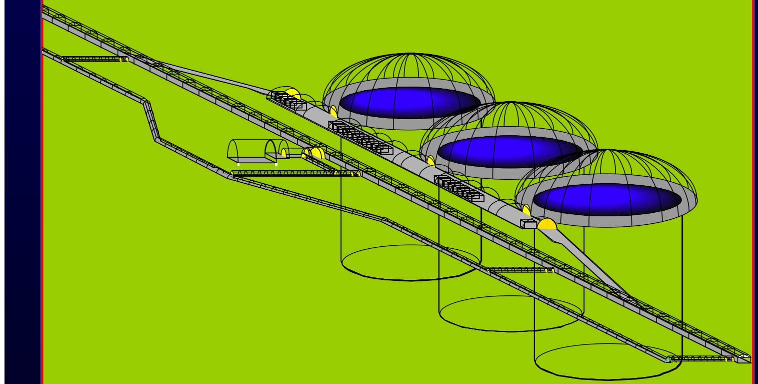
Good SER
(Single electron response)
in charge and time

Photodetectors - Requirements

Nucleon decay and neutrino detectors

Future

UNO
Hyper Kamiokande
Menphys



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

First remark (Same as NNN05)

Nearly all the present experiments make use of :

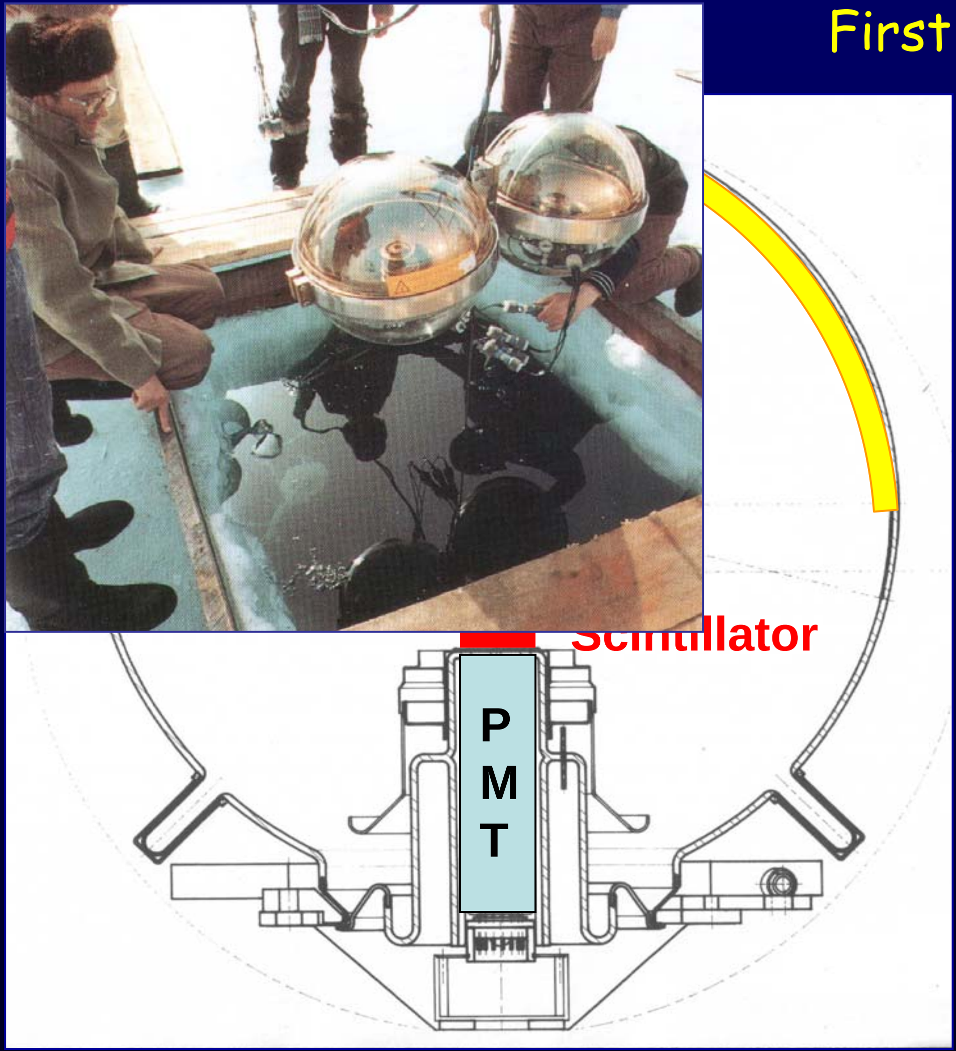
A standard design of PMT

Vacuum glass bulb
Bialcali photocathode
Dynode multiplier

Hamamatsu

… with an interesting exception …

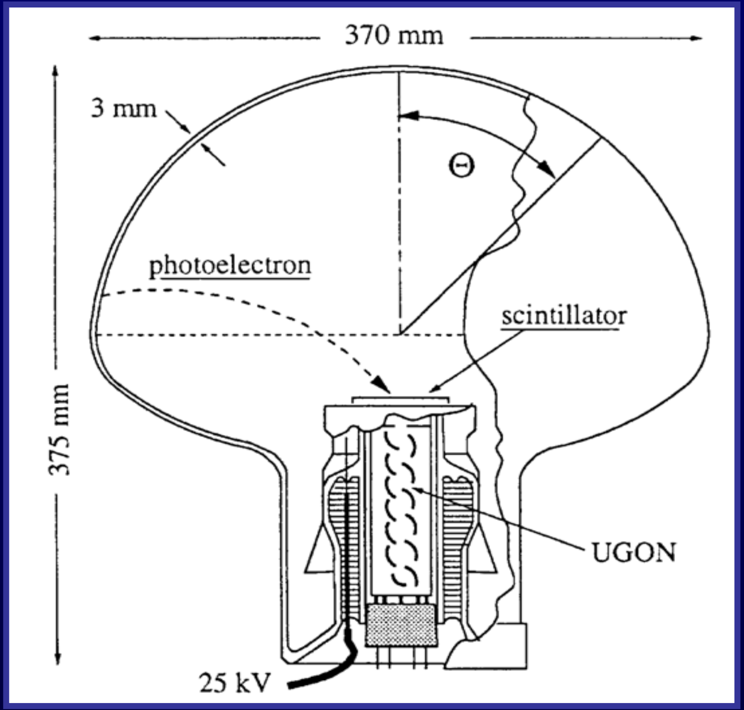
Baikal neutrino experiment



First developments (1983)

"SMART Tube"
Philips XP 2600
Dumand project & Baikal

Baikal neutrino experiment



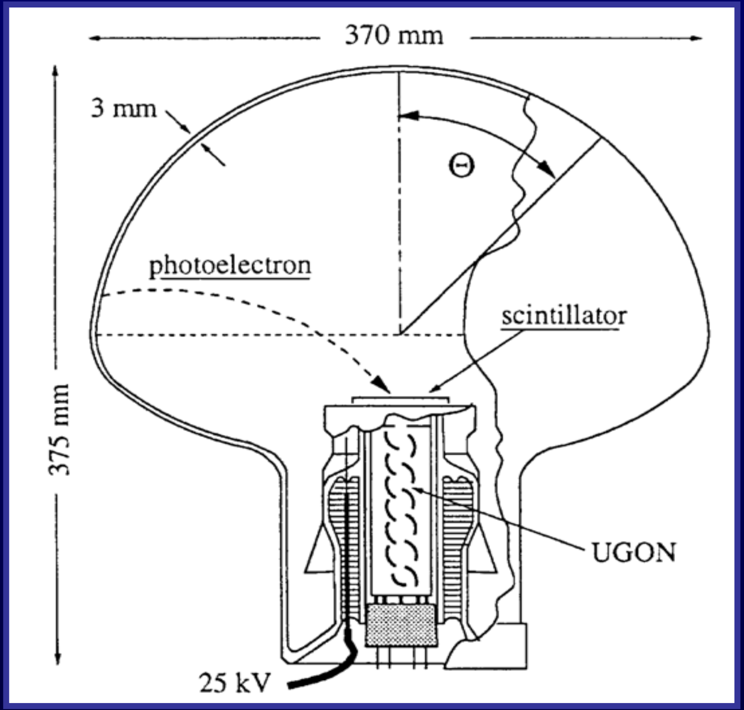
First developments (1983)

"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)

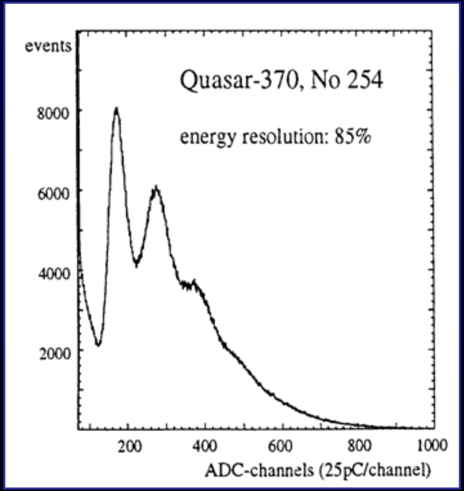
Conventional PMT (UGON)

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)

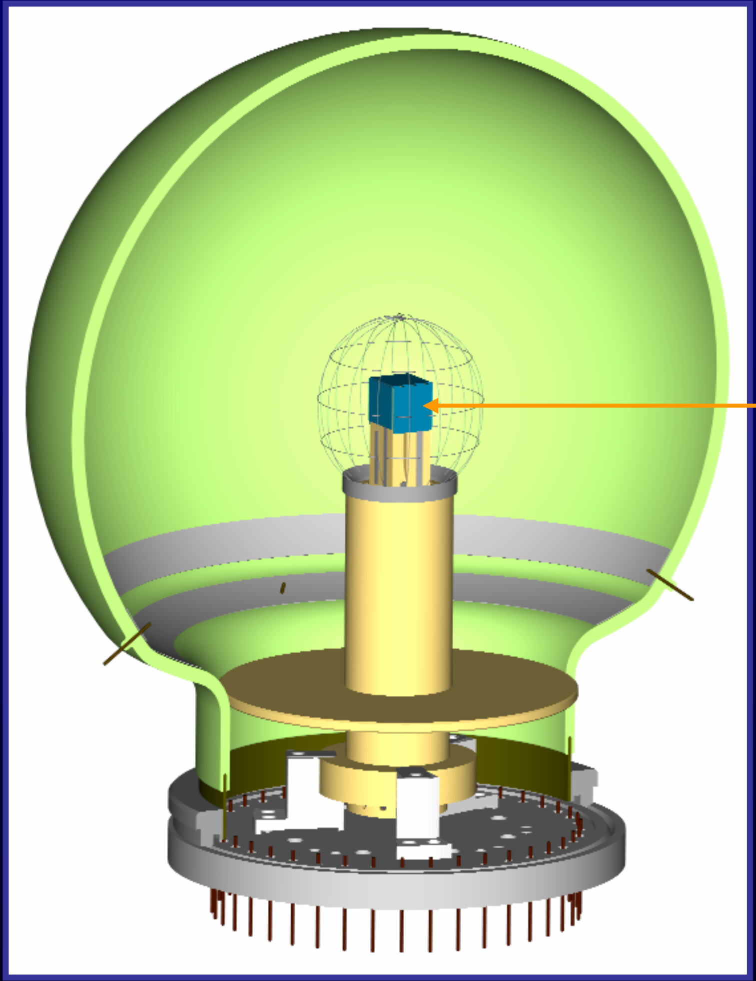
HPD Team @ CERN

C. Joram for the C2GT Team, RICH 2004, Mexico , Nov 2004
Nucl. Instr. and Meth. A 553 (2005) 85

C2GT Project (in the Golf of Taranto)

Detection in a sphere of 432 mm

Photodetector 380 mm



"Artistic view" of
the half-scale prototype

5 Silicon sensors (12 x 13.2 mm²)
in a grounded field cage

PIN

Weak signals

Signal at 20 kV: 5 $\cdot 10^3$ e, G = 1

(very) high capacitance

C_d = 35 pF/cm^2 , ENF ~ 1

APD

Very low noise electronics

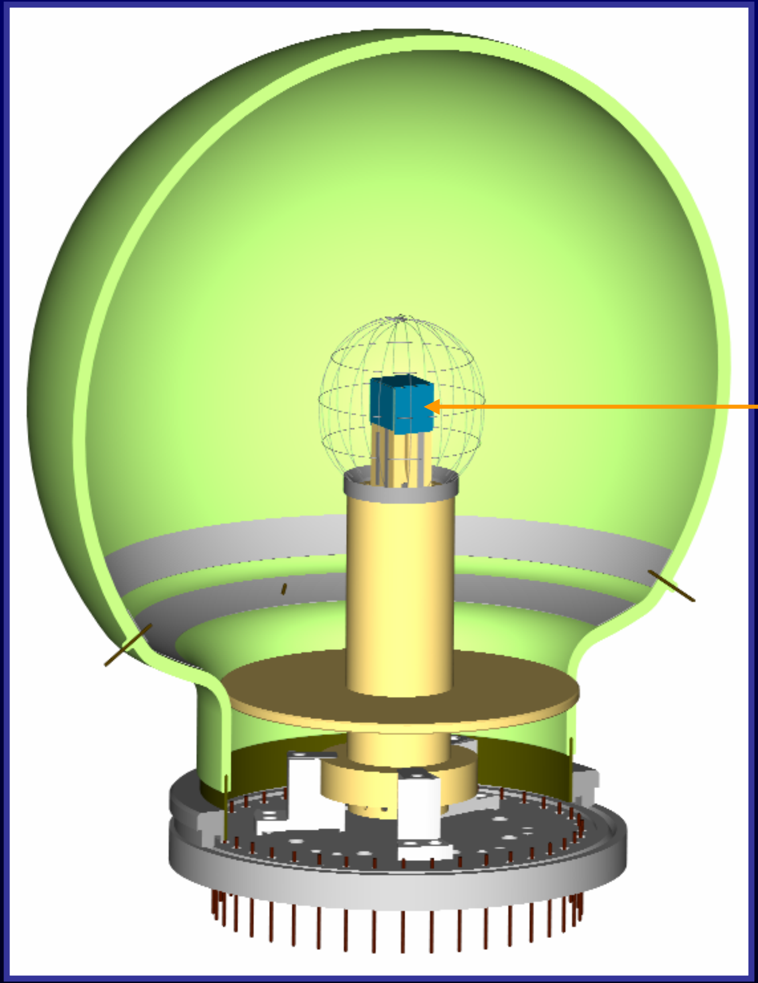
2-3 $\cdot 10^5$ e, G ~ 50

Close to the silicon device

C_d = 300 - 1500 pF/cm^2, ENF = 2 - 5

HPD Team @ CERN

C. Joram et al., CERN-PH-EP/2006-025, August 2006



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

Cubic scintillator
+
Small PMT

HPD Team @ CERN

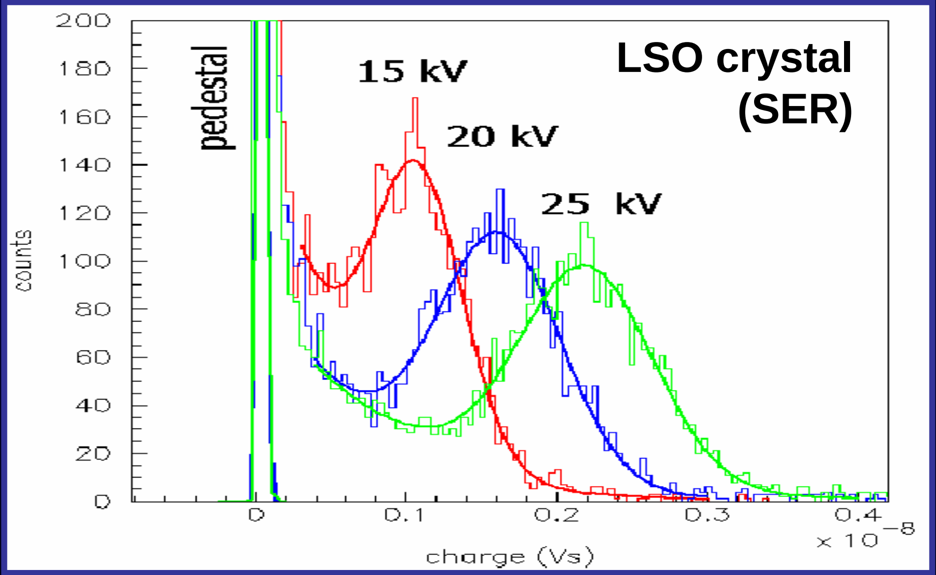
C. Joram et al., CERN-PH-EP/2006-025, August 2006

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

Prototype (208 mm glass envelope)

Cubic metal anode

Test bench for scintillators



Second remark (Same as NNN05)

All ideas on

photodetection designs are certainly interesting

But…

…if a mass production is foreseen

Constraints from industry

must be considered from the begining

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

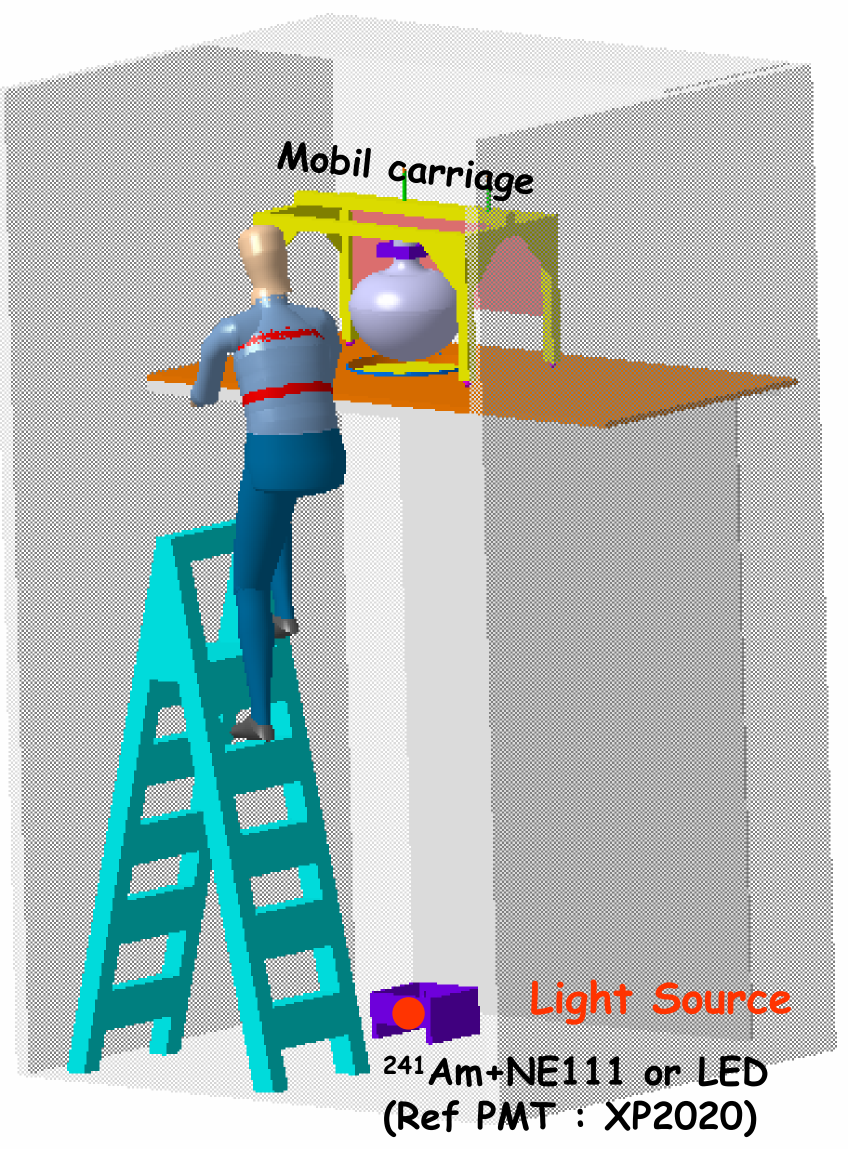
Year 2 (Sept 04-Sept 05)

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

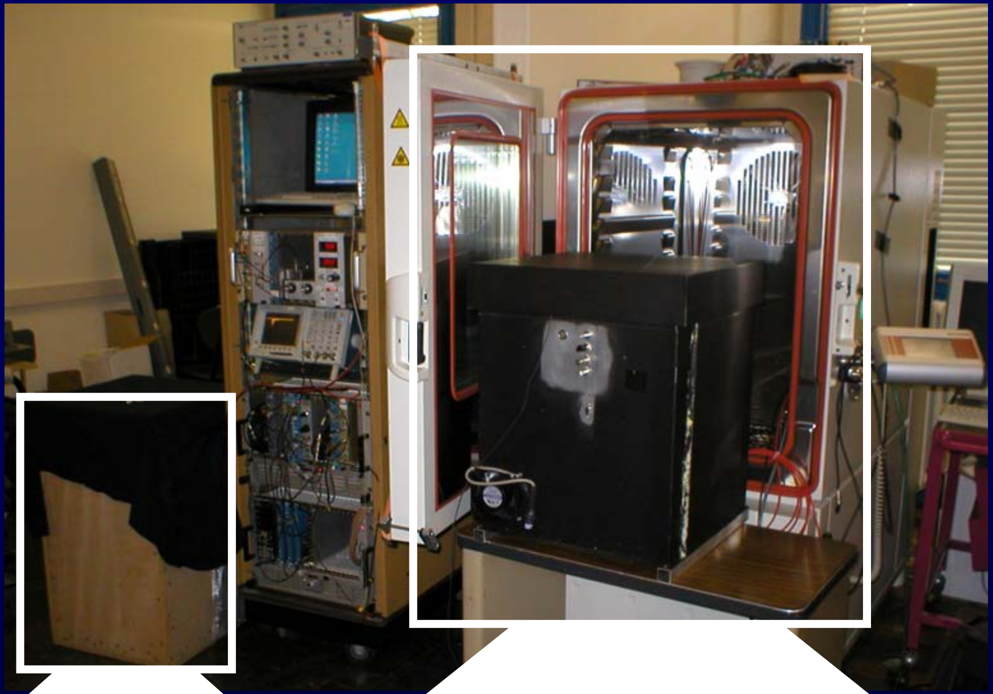
Single electron response
(SER and P/V)

Timing characteristics

Photocathode uniformity

Detection efficiency (relative)

IPN Orsay / Photonis Collaboration



Black box
(Wood)

Climat cabinet

(Voestch VC4034)
+ Black box (Al)

(-40° à +50°)

Test Bench 2

Noise

After pulses

Variation with temperature

Magnetic field effects

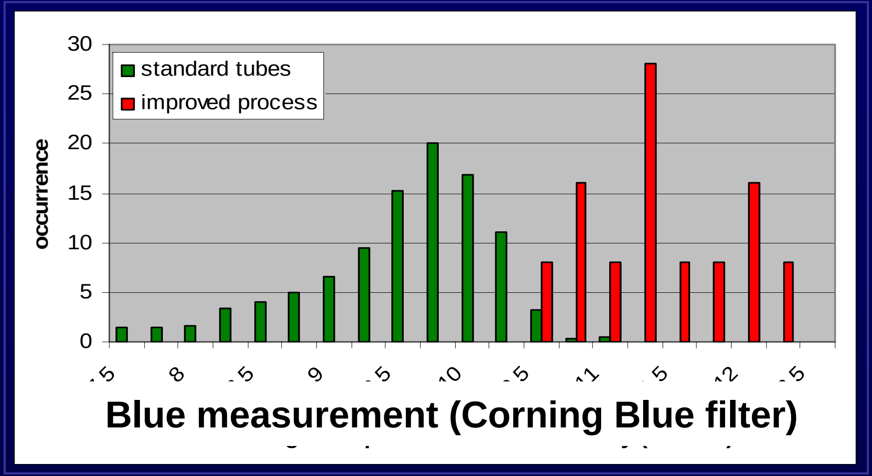
Data Acquisition

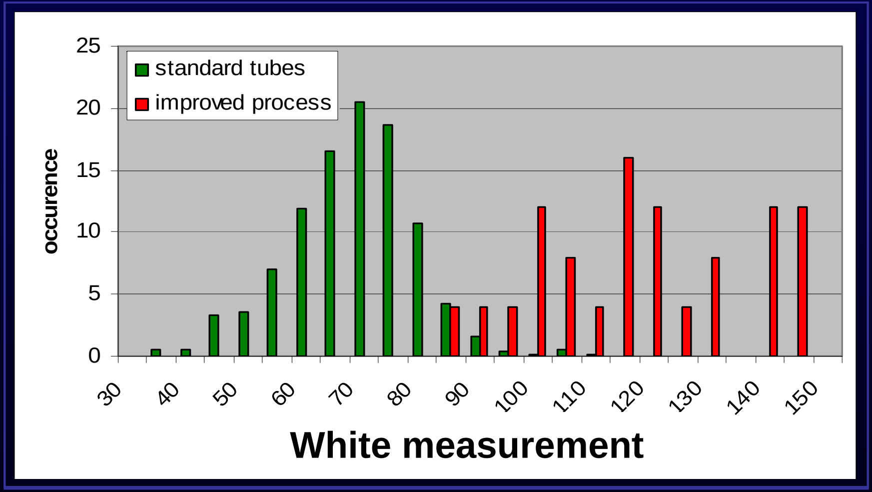
CAMAC
Oscilloscope
MATAC (2GHz, 12bits)

IPN Orsay / Photonis — Overview on results

Improved photocathode

D. Dornic et al, Beaune Conference, France, June 2005
In press in Nucl. Instr. and Meth.





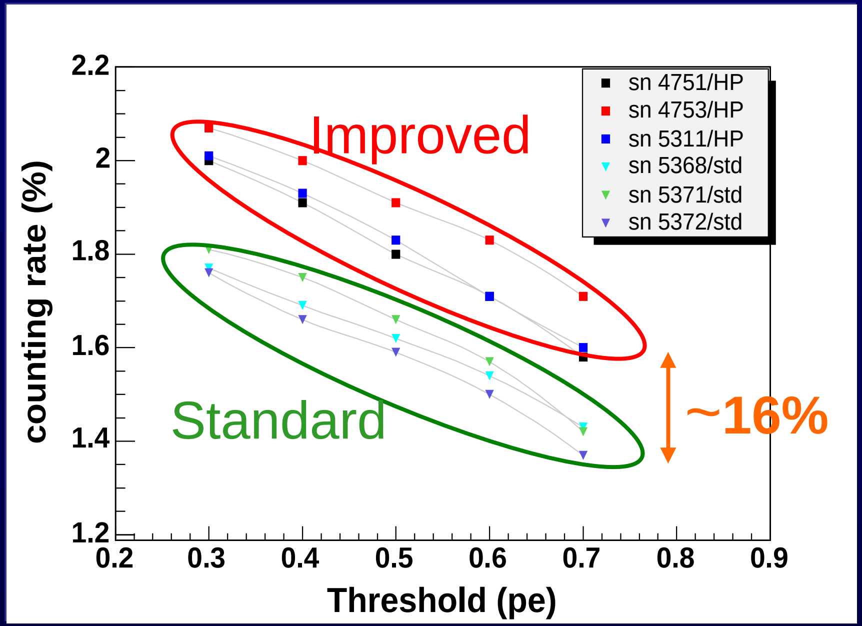
XP1805 (9", AUGER PMT)

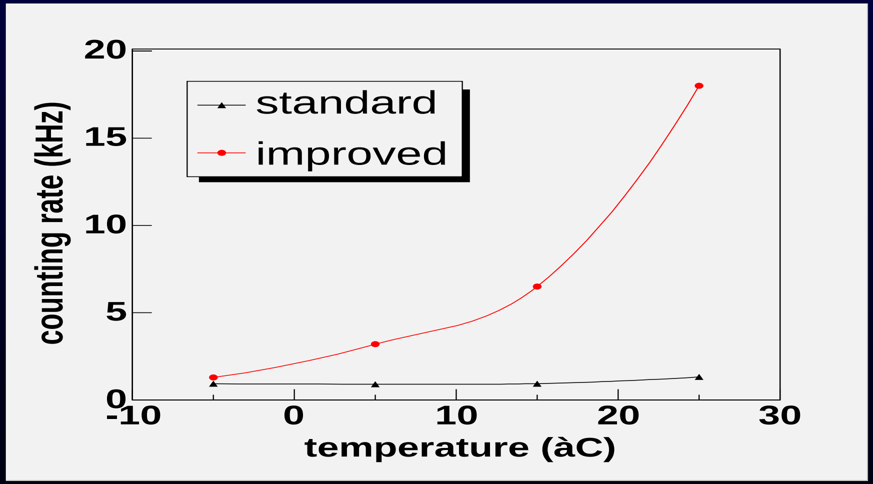
Standard (~800 PMTs)
Sk CB: 9.32 µA/lmF
Sk White: 68. 37 µA/lm

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
In press in Nucl. Instr. and Meth.

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

Control by
Pulse measurements in SER
(Relative detection efficiency)

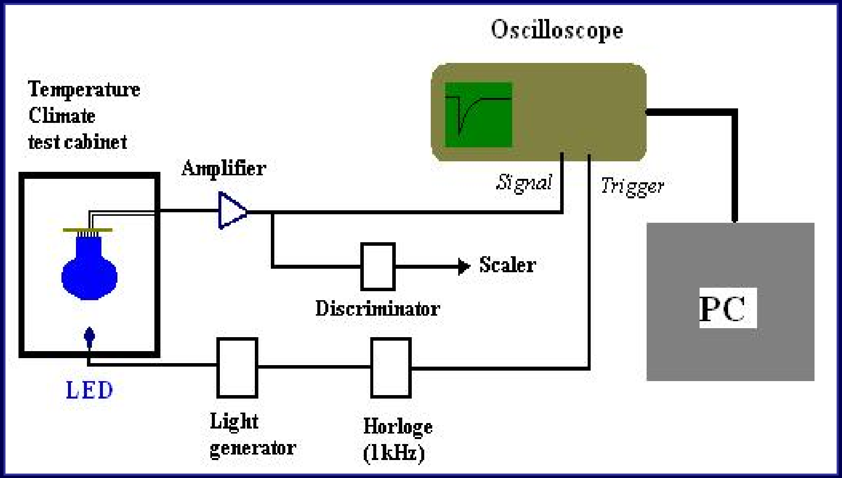
Drawbacks ?

Dark count rate

Same at low temperature
Increase with temperature

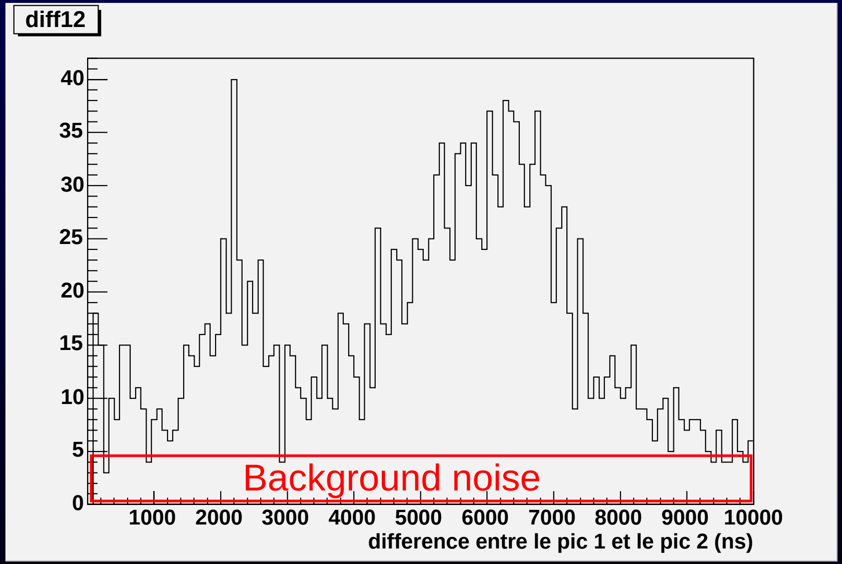
IPN Orsay / Photonis — Overview on results

After-pulses

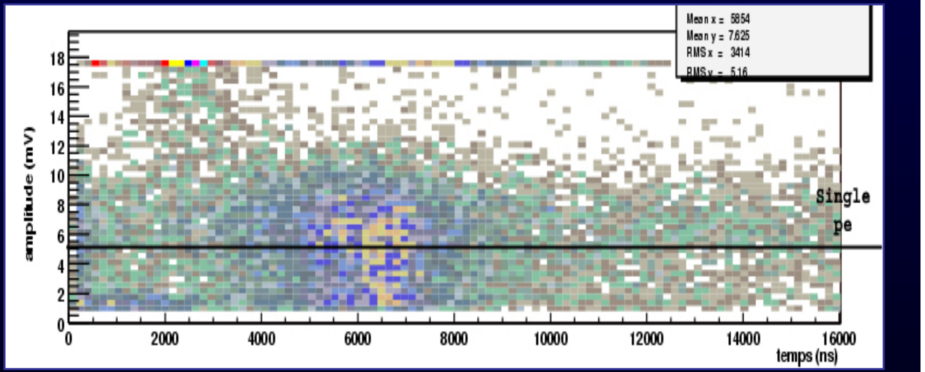


Digital Oscilloscope + PC

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

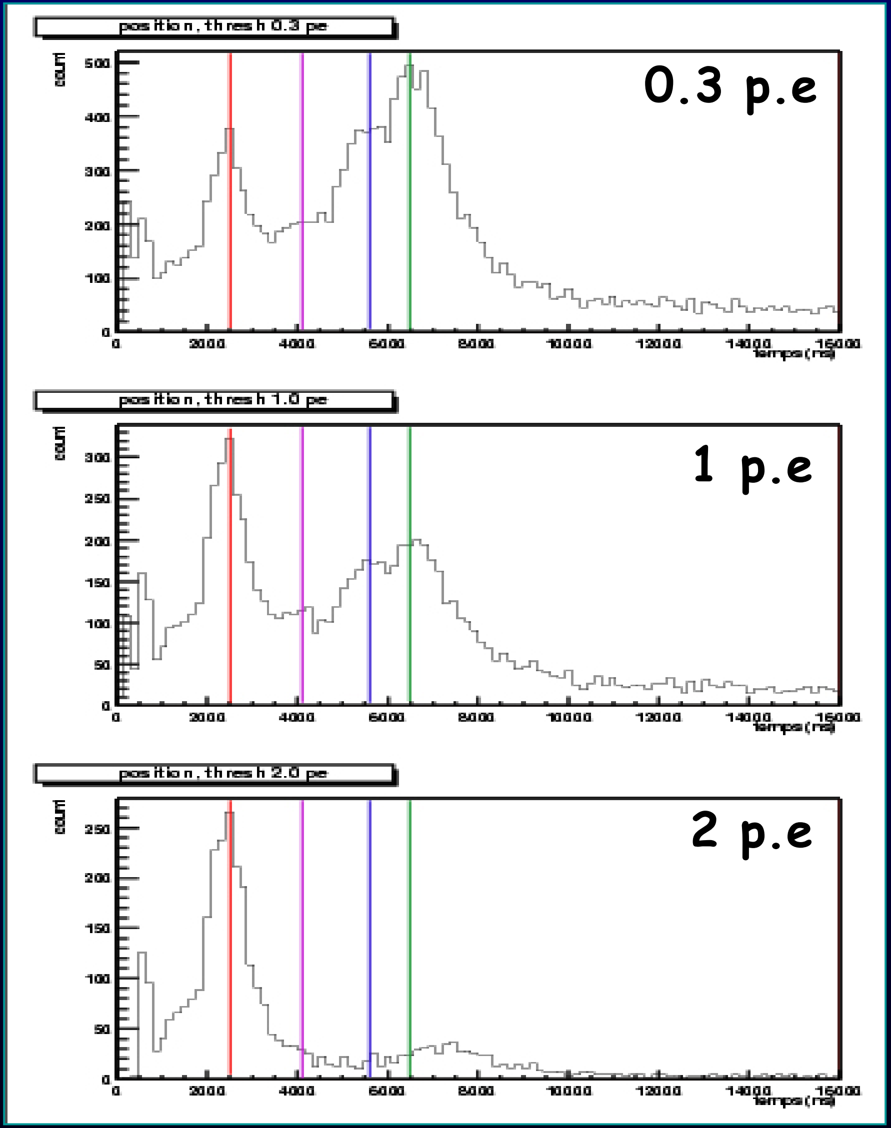


Time distribution

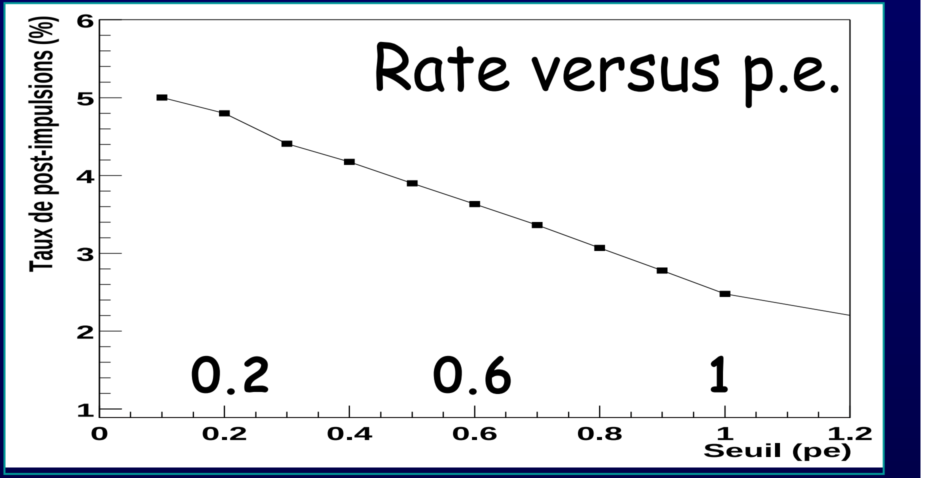


2D : Amplitude versus time

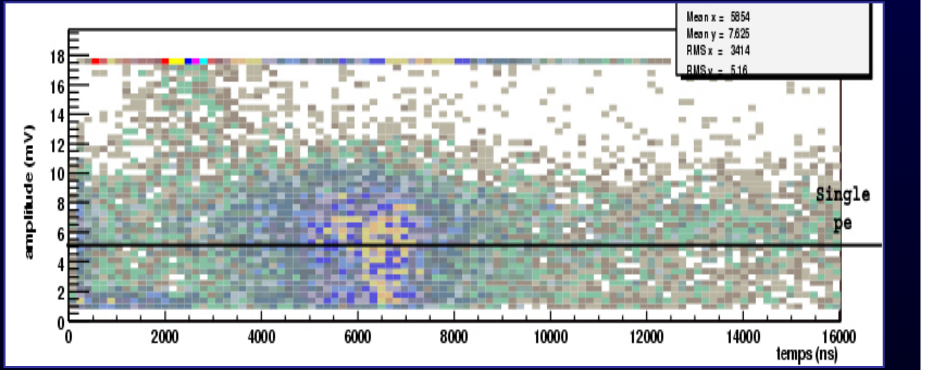
IPN Orsay / Photonis — Overview on results



After-pulses



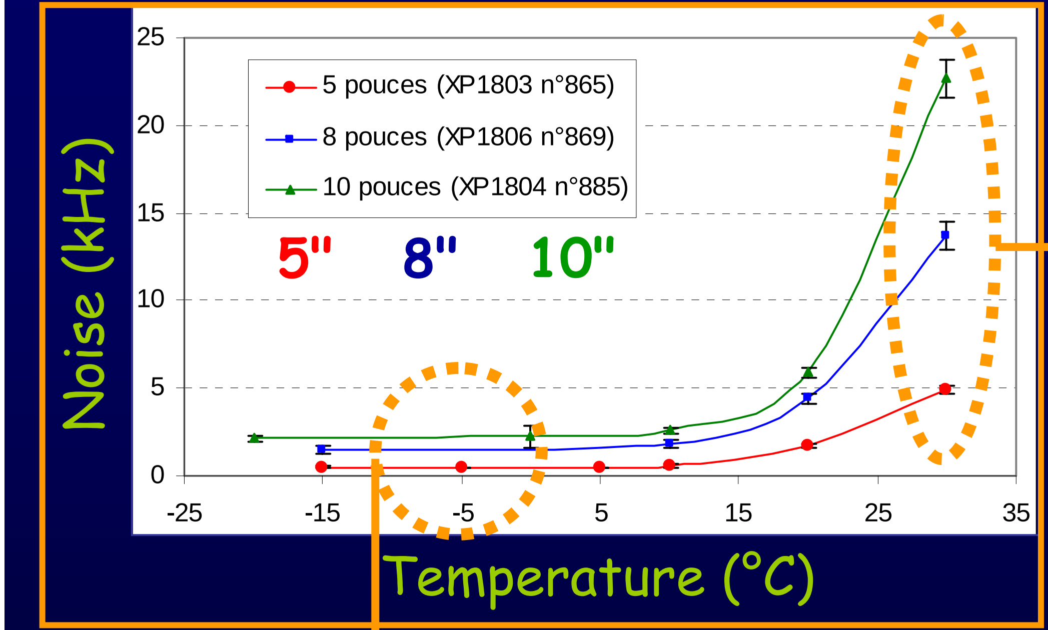
Time distribution

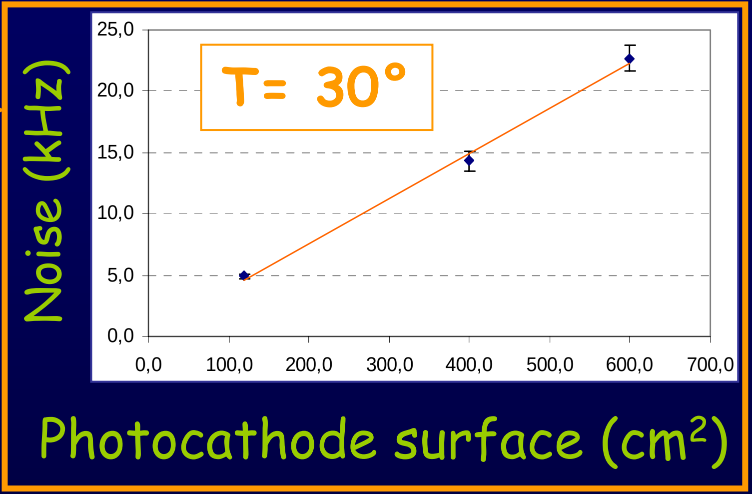


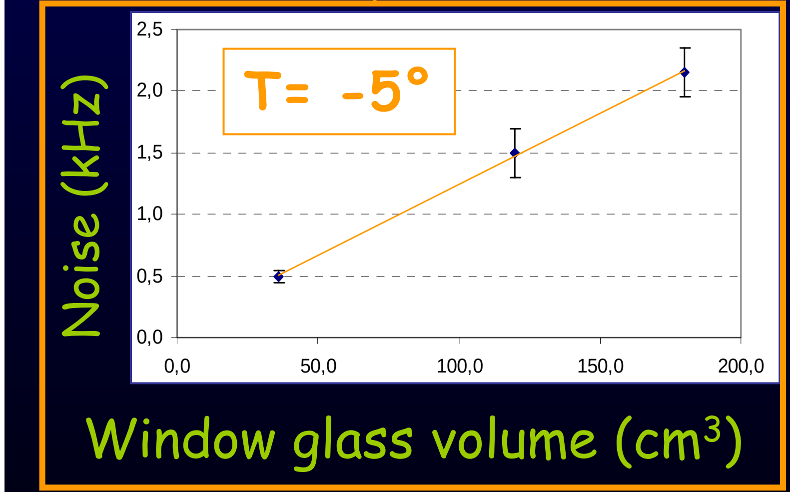
2D : Amplitude versus time

IPN Orsay / Photonis — Overview on results

Noise (dark pulses)





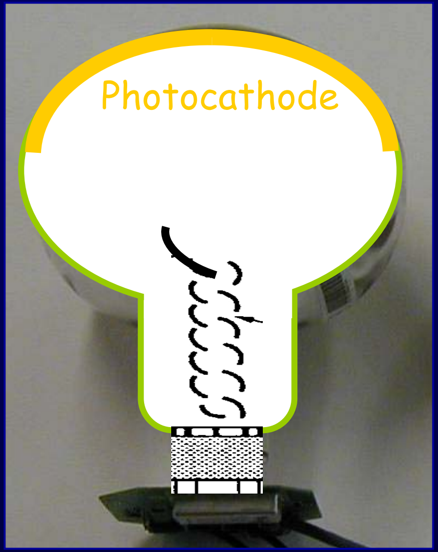


All the main results in

PhD of D. Dornic , 09 – 29 - 06

IPN Orsay / Photonis Collaboration

New 3 years R&D Program (2006 – 2009)



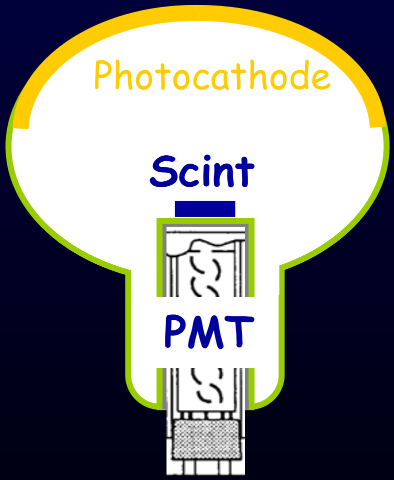
Standard PMTs

More detailed studies on :

"Late pulses" (T < 100 ns) with a laser
Glass noise (time structure)

End of the "scaling" studies

Parameter correlations (5" to 12") , (15" ?)
New types of multipliers



Hybrid PMTs

"Smart Tube" type (Scintillator)

Comparison with standard PMT
(Same size, 8" or 10")

R&D for Menphys

Third 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

together with the cost considerations

Cost approach

Photonis at NNN05

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

Zise (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	€ $/PE_U/cm^2$

<u>Cost/cm² per useful photoelectron</u>

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

Fourth remark

With a very large number
of photodetectors

The whole system
must be considered

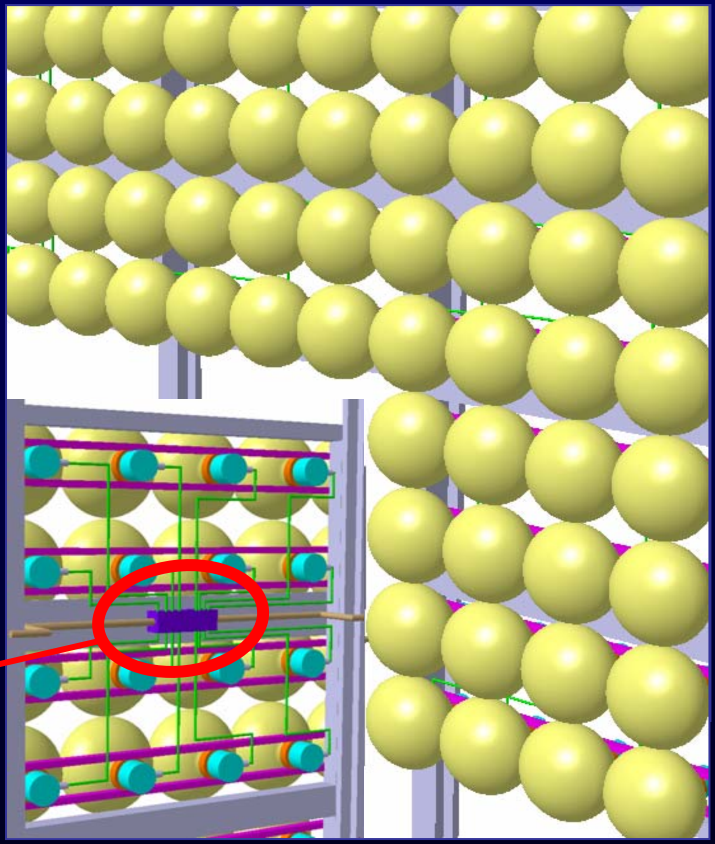
and particularly

Electronics and its integration

R&D program for Menphys

"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

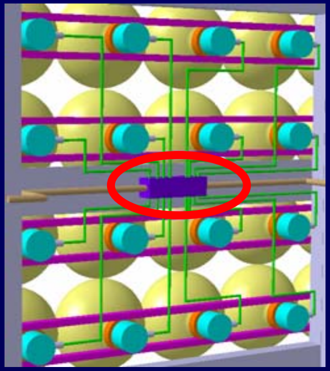
(PMTs of 20" size)

Proposition

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

Integrated electronics (Multichannel, close to the PMTs)

Electronics for Menphys



LAL Orsay

Multi channel ASIC

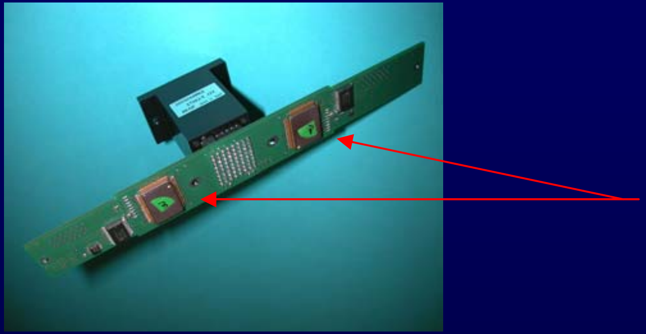
Front-end requirements

- Variable gain to equalize photomultipliers response and operate with a common high voltage
- High speed discriminator for autotrigger on single photoelectron
- Coincidence logic to reduce dark current counting rate ?
- Digitization of charge (over 12 bits ?)
- Digitization of time of arrival to provide nano-second accuracy
- Data out wireless

Electronics for Menphys

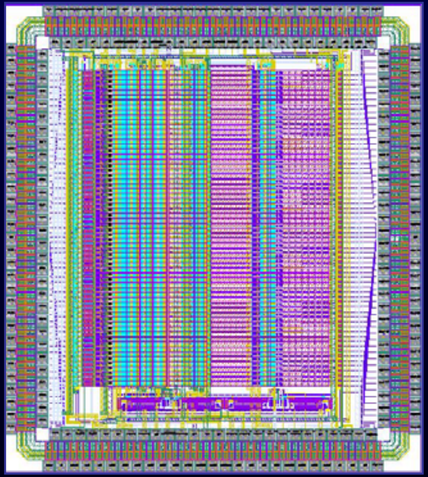
LAL Orsay

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)

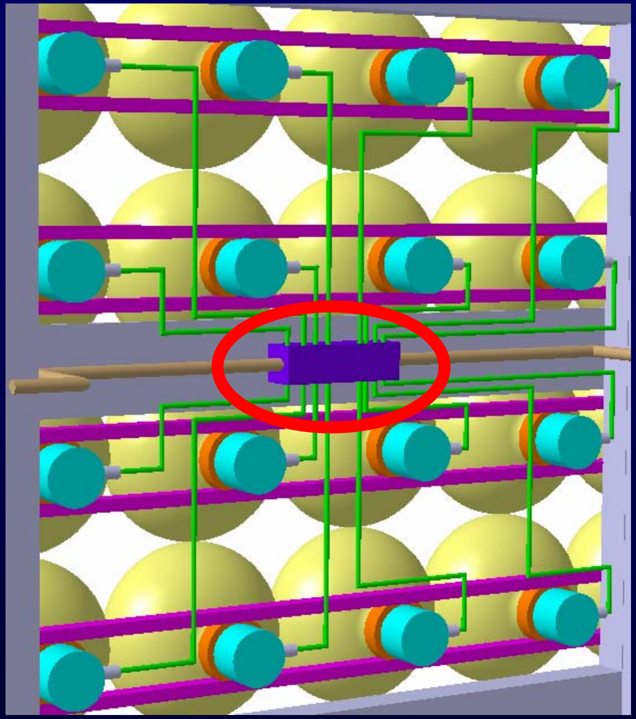


Variable gain (0-4, 6 bits)
Charge multiplexed output (0.1-100 pe)
64 channels chip, 500 mW
3 thresholds
Submitted June 05
AMS SiGe 0.35 µm

Electronics for Menphys

LAL Orsay

Roadmap



What already exists

Front-end (OPERA_ROC & MAROC)

What remains to be done

Charge and time digitization
Wireless (LAPP Annecy)

Some characteristics still to be fixed

Possible use of a local coincidence ?
depends of the energy threshold (related to the dark noise of the photodetectors)

Digitization of all signals ? Dynamic range ?

Then…

Chip on Board

Tests on a prototype (16 PMTs 8")

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 really need the best ?