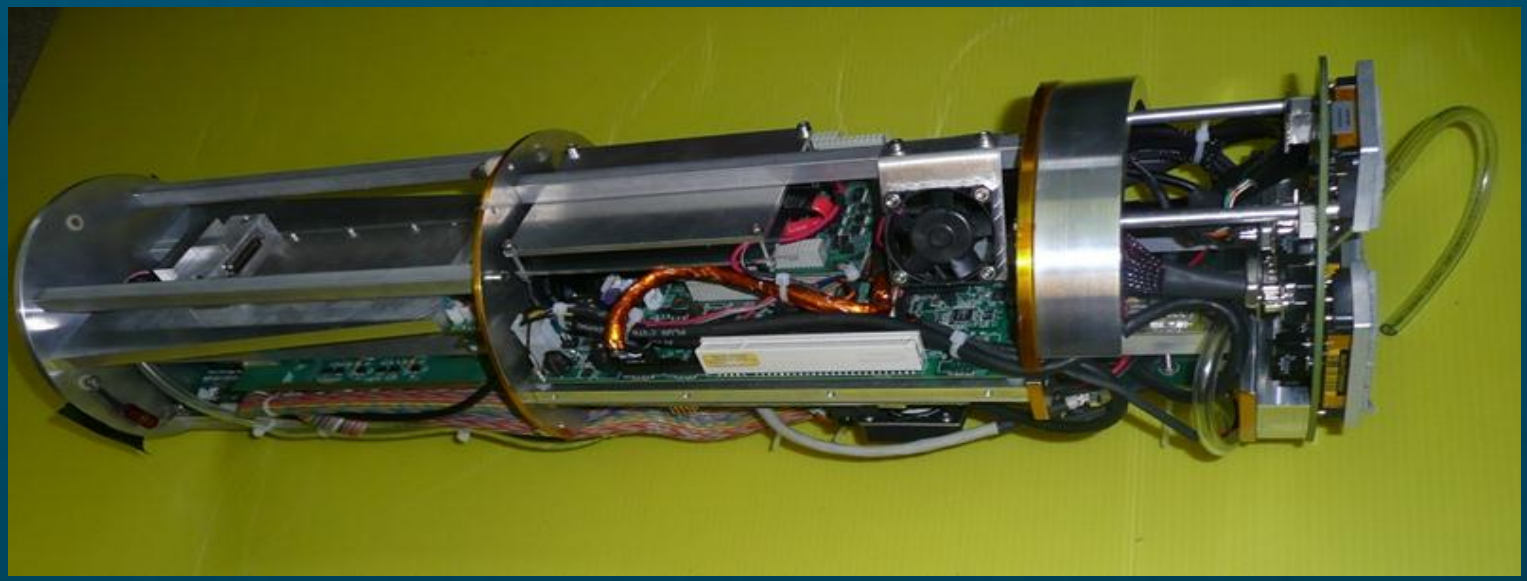
An ebCMOS camera system for marine bioluminescence observation: the « LuSeapher » prototype.

IPNL ebCMOS group
R. Barbier, T. Cajgfinger, P. Calabria, E. Chabanat, D. Chaize, A. Dominjon, C. Guérin, J. Houlès, D. Quang Tuyen, L. Vagneron

CPPM Antares/Biocam
M. Ageron, M. Billault, J. Brunner

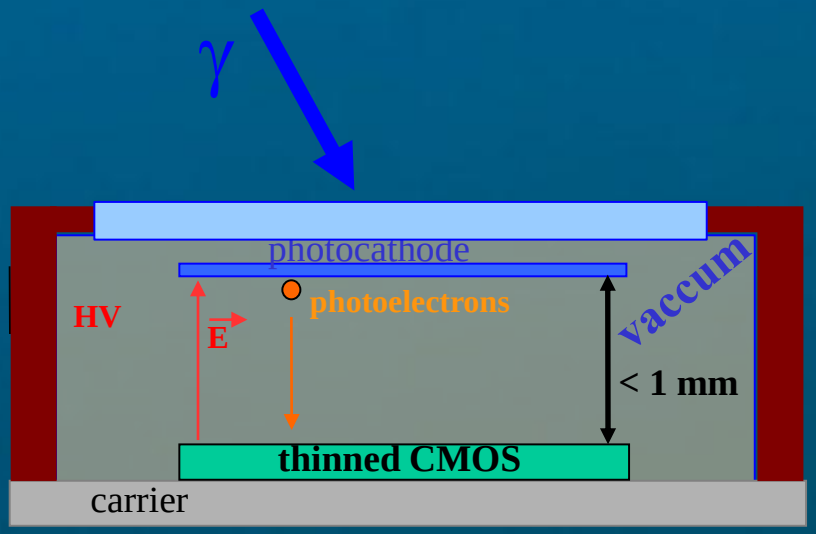


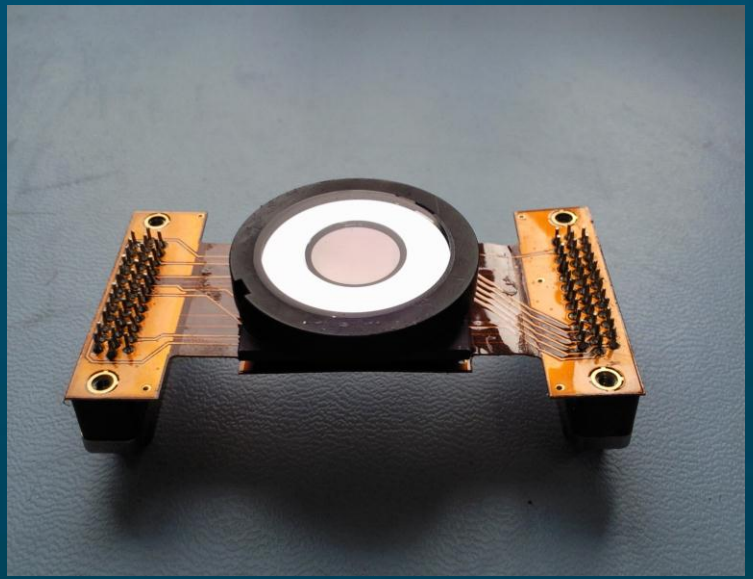
Detector R&D in collaboration with IPHC Strasbourg and PHOTONIS

General ebCMOS Camera System

- ebCMOS : *electron bombarded Active Pixel Sensor CMOS*
  - Photoconversion: Photocathode vacuum tube proximity focusing
  - Multiplication gain: accelerating electric field
  - Readout: back thinned APS CMOS array
- Detection of a **low light** source in dark environment with ultra low noise detector
  - Dark Count: less than 10^{-4} photon/pix/frame.
  - Single-Photon sensitivity and photon counting capability
- High readout speed: pixel clock = 2.5-40 MHz, Frame rate = 62-500 Hz
- « LuSeapher » is the final camera system

ebCMOS working principle

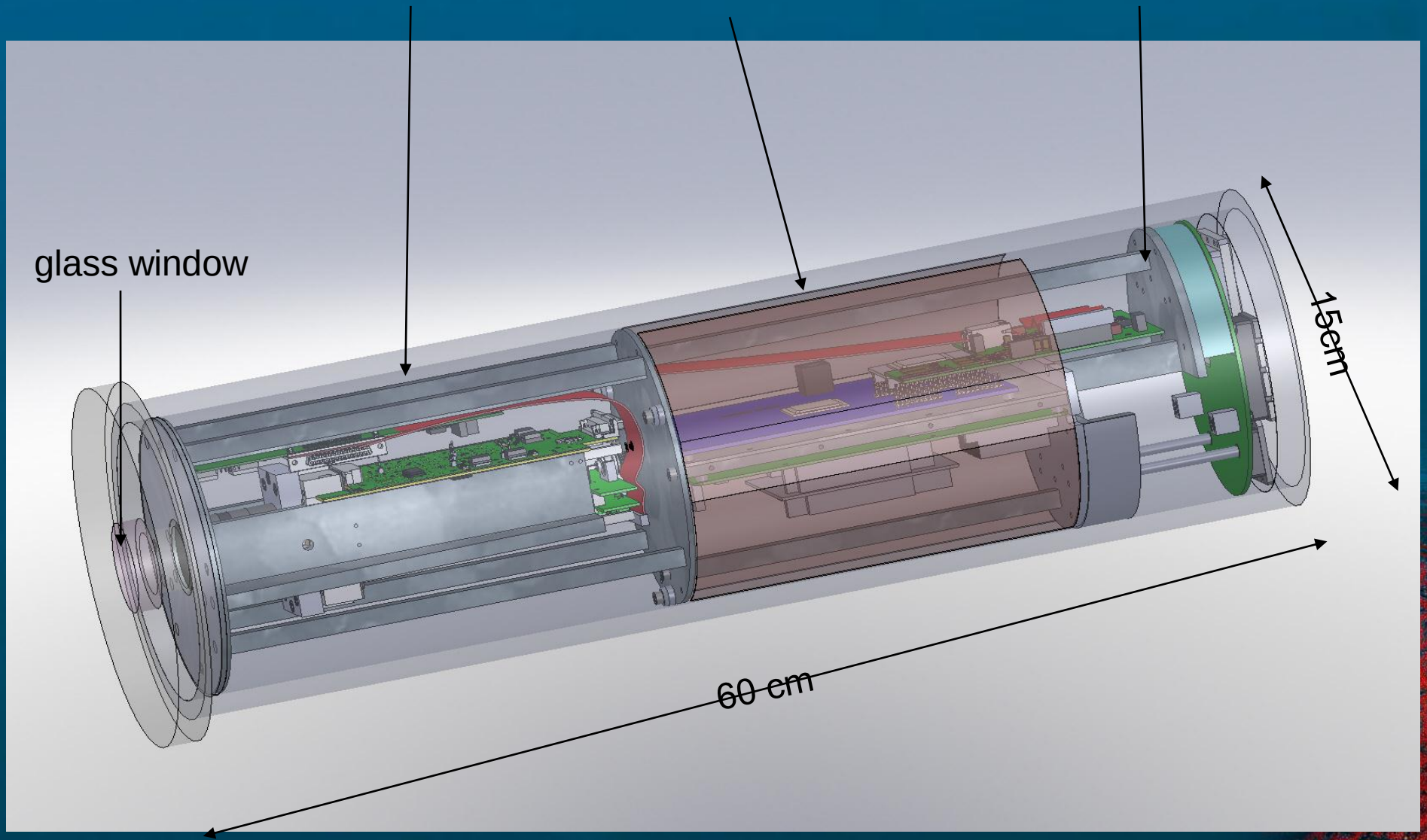




- 400x400 pixels chip (0.25 micron)
  - 10 μm pixel pitch, 3T architecture
  - detection size : 16 mm^2
  - 80 nm dead layer (1.2 keV), 8μm sensitive layer
- gain with HV 2.8 kV
  - SinglePhotoelectron Gain: (2.8-1.2)keV/3.6 eV=444 e^-
  - Charge Collection efficiency = 60%
  - Coll. Time ≈ 100 ns
  - Fake photon due to CMOS noise: **10^{-5}**
- S20 (Multialkali) cathode
  - 25% @ 450 nm

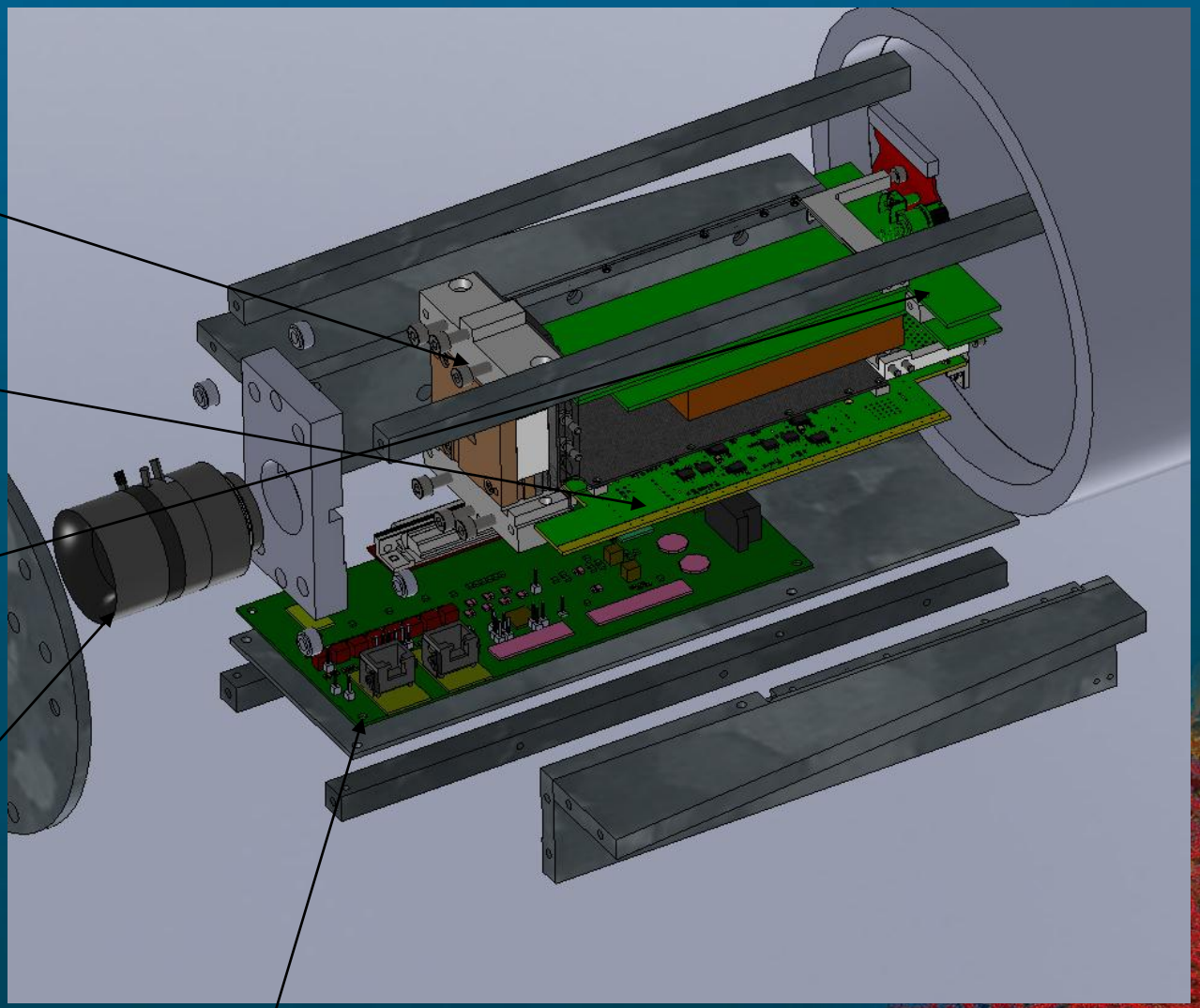
Smart Camera System's design

Titanium waterproof tube : 15cm diameter and 60cm long
3 main parts : lens and ebCMOS, DAQ and CPU boards and power supply

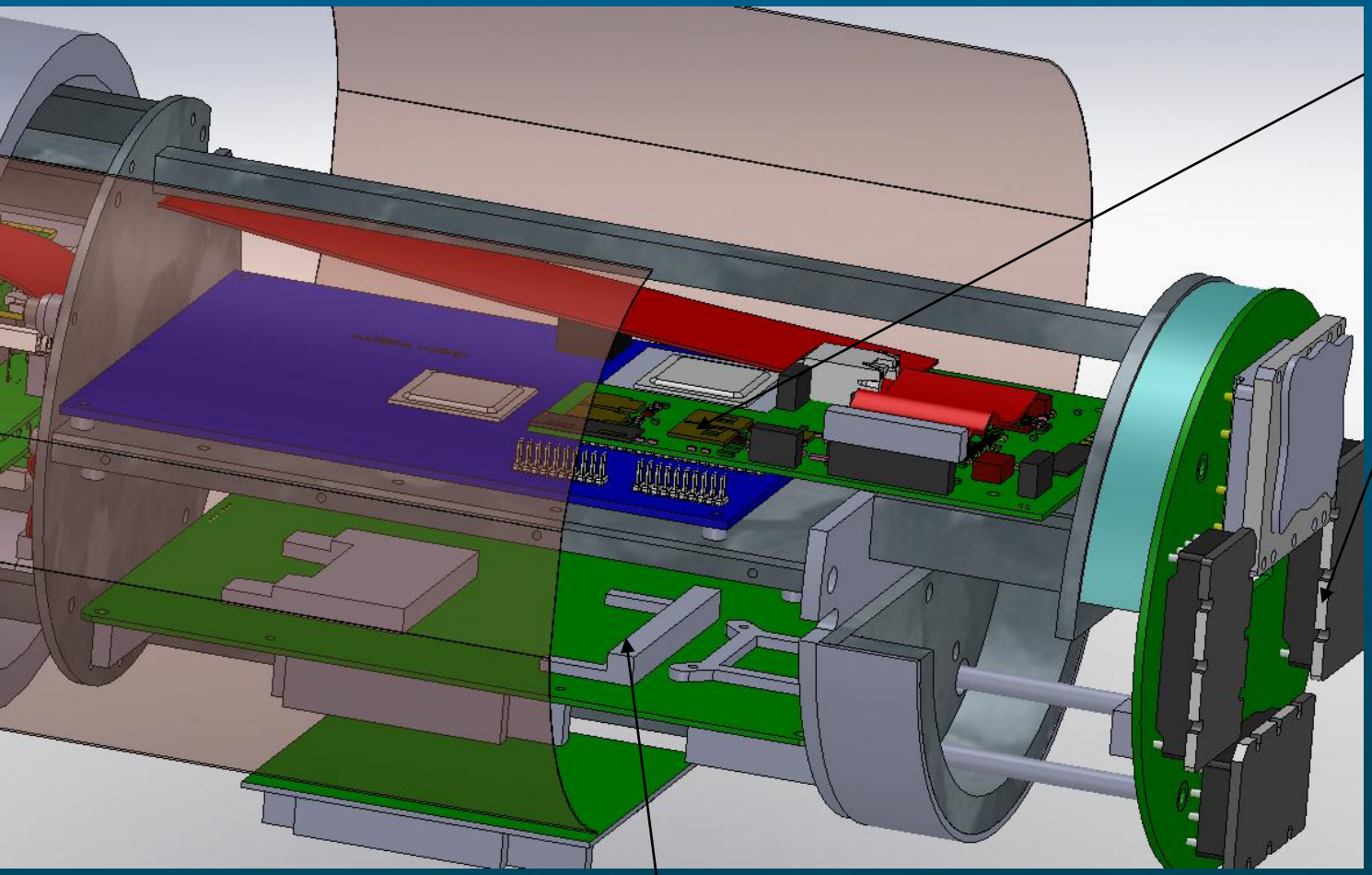


Analog part

- ebCMOS
  - 400x400
  - 3 kV
  - S20 photocathode
  - cooled : 15° C
- sensor frontend board
- control board
  - CMOS operating voltage settings
  - chip temperature control
  - HV control
  - PS management
  - monitoring
- varifocal lens (Tamron)
  - focal 6 mm
  - F/D=1.2
  - d_{min} = 30 cm



DAQ part



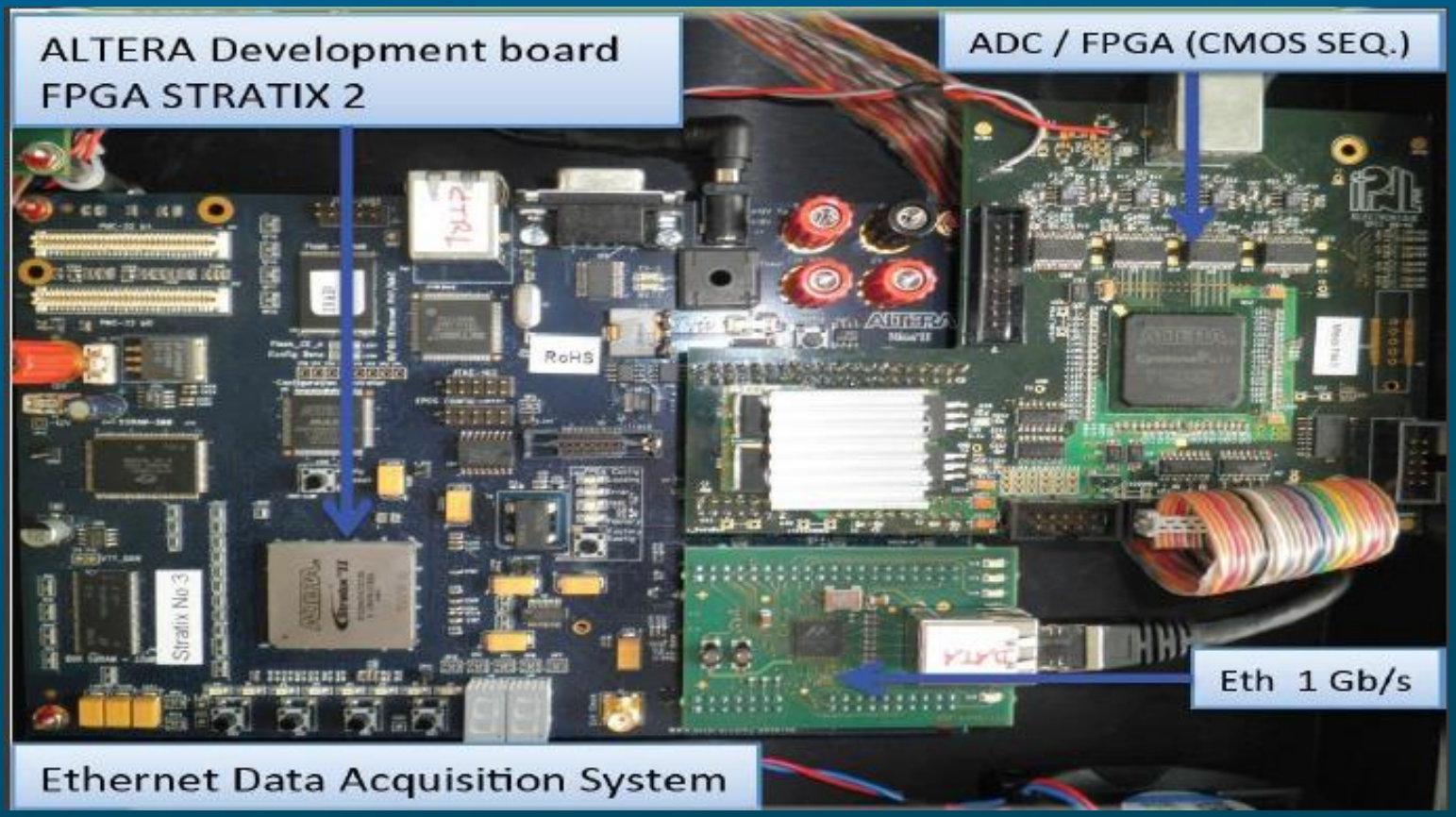
- DAQ (next slide)
- PS units
  - input: 48V
  - PC 12V
  - DAQ: 12V,9V,3.3V…
  - Slowcontrol : 12V
- power consumption : 100 W

PCM 9562 Single Board Computer

Atom D510 dual core 1.67 GHz

2 GB RAM, 32GB CF card for OS, 64 GB SSD for data

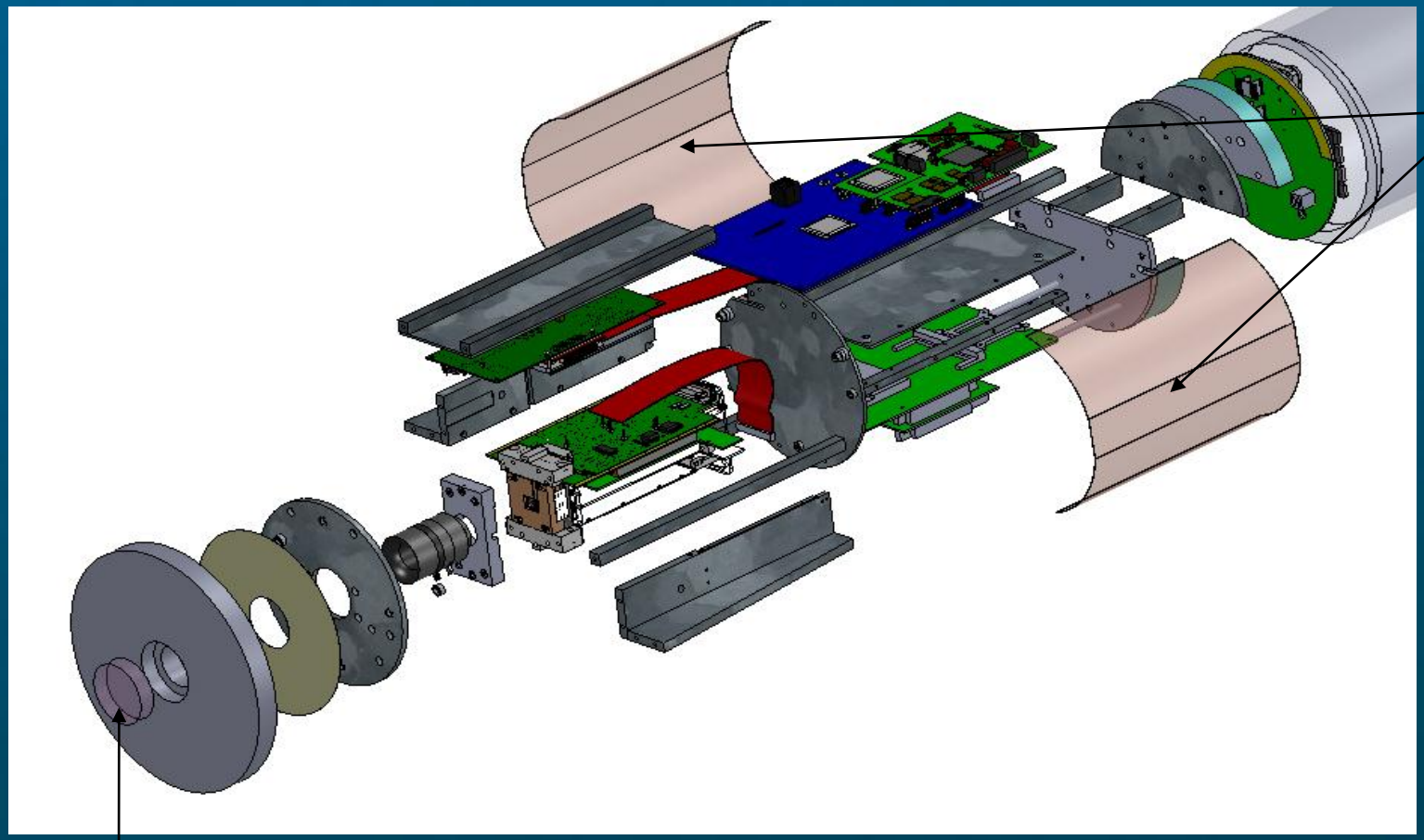
DAQ board



low 5 MHz readout with 4 channels for 400x400 pixels gives 125 fps framerate, 2 frames needed for CDS substraction → 62.5 fps framerate

2 mezzanines : 4 ADCs 12 bits, 1 ethernet 1Gbit/s

Spread View

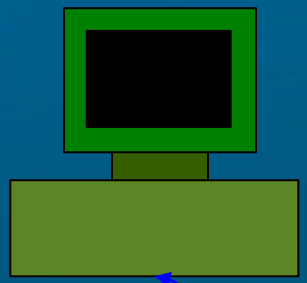


heat dissipation by contact with Titanium and 12° sea water

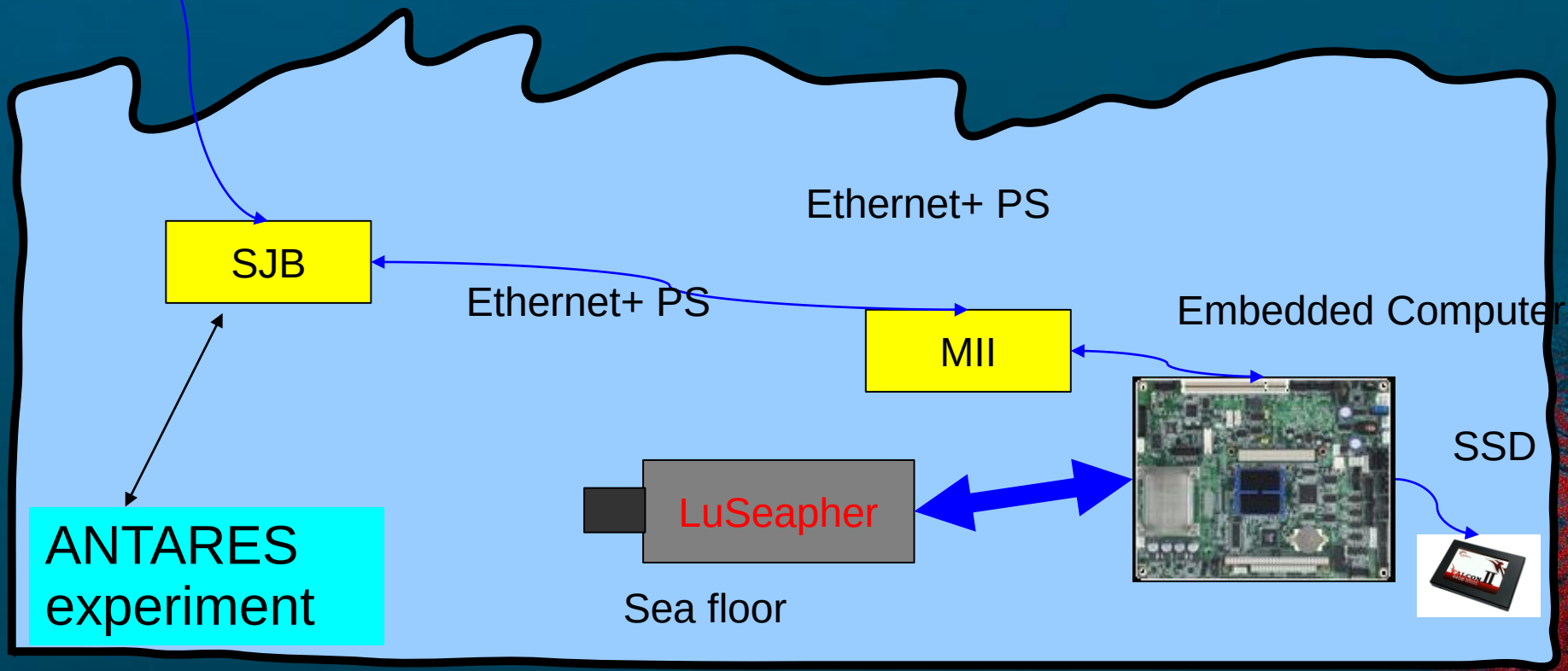
CEM isolation from tube

3cm diameter glass window : small FOV

schematic view



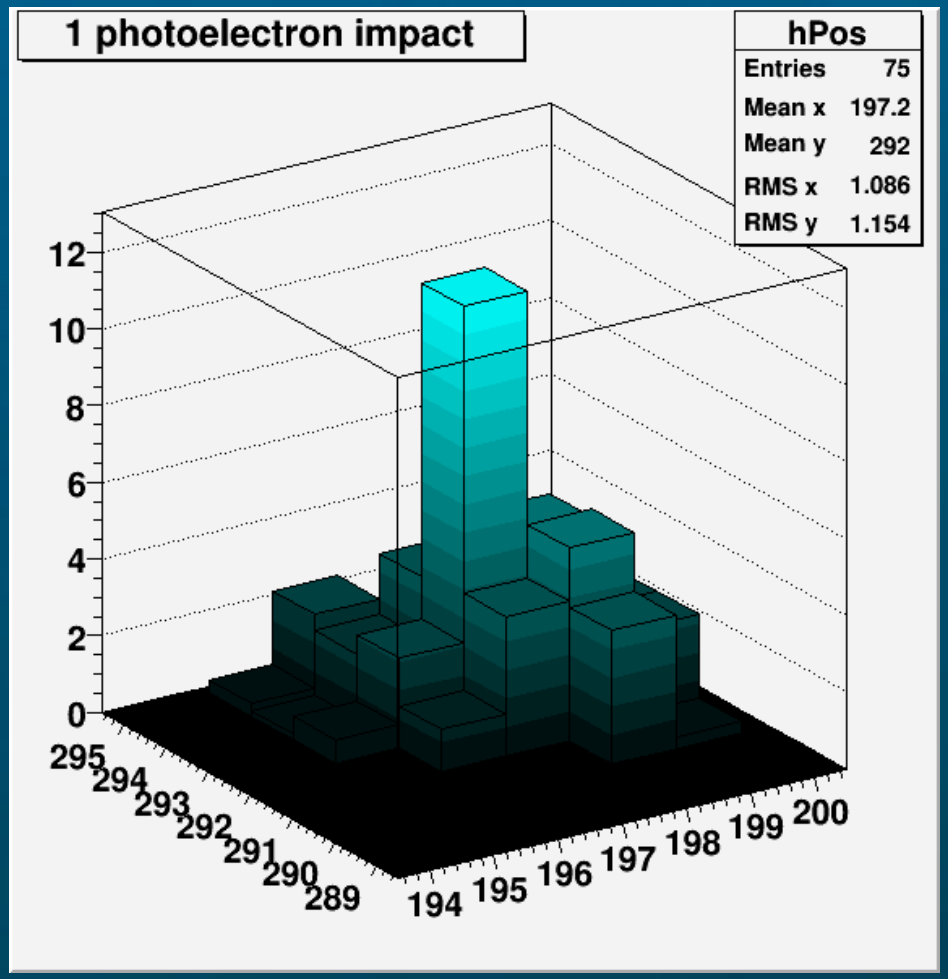
- Antares is a cabled sea-floor observatory dedicated to neutrino physics. it's located 2500m depth off the mediterranean sea near Toulon (France).
  LuSeapher device is connected to the SJB nearby.
- MII is a multidisciplinary experiment connected to the BJS
- The ebCMOS is one of the sensor put on the MII



operating mode

- bioluminescence observation in sea darkness
- due to a limited bandwidth, stream readout cannot be stored on disk (400x400 pixels @ 62.5 fps with 1 byte/pixel is equivalent to 600 MB/min or 80 Mbits/s).
- gain (HV) is ON and data are buffered on local (SSD) disk until the next trigger, then the circular buffer is read out while signal remains above the threshold.
- the trigger is very simple : no assumption on the size or the form of the signal. Data transfer if the number of reconstructed photons is above 14.
- Data storage 50 (1s) frames before trigger and 300 (5s) frames after the object comes out the field of view.
- typical duration : 1s + 1s (real event) + 5s = 7s, 70 Mbytes

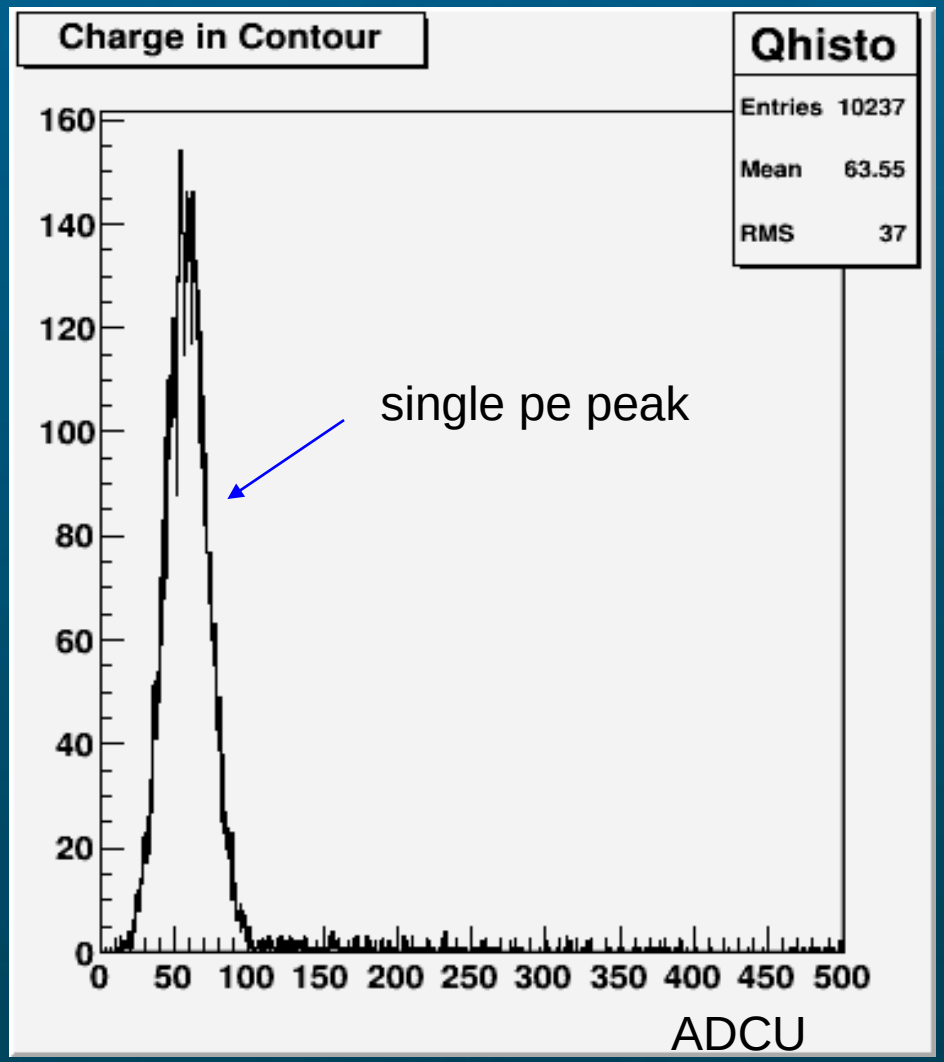
photons reconstruction



R. Barbier, et al., Nucl. Instr. and Meth. A (2011), doi:10.1016/j.nima.2011.04.018

- 5x5 pixels cluster for one photoelectron (pe)
- photoelectron pattern
  - 1 central seed Q>3 ADCU
  - 30% of pixels > 50% Qseed
  - 50% of pixels > 30% Qseed
- efficiency, purity : 96%
- CMOS temporal noise contribution to p.e. trigger rate is removed by this simple pattern recognition.
- Center of Gravity (COG) calculation gives 2μm resolution (20% pitch)

photoelectron noise measurement



- dark count → 0.78 pe /frame
- Ion feedback (residual ions in vaccum tube hitting the photocathode) additionnal signal less than 5e-3/frame (0.3 Hz)
- trigger threshold : 14 pe (could be less with Ion feedback identification algo)

Results

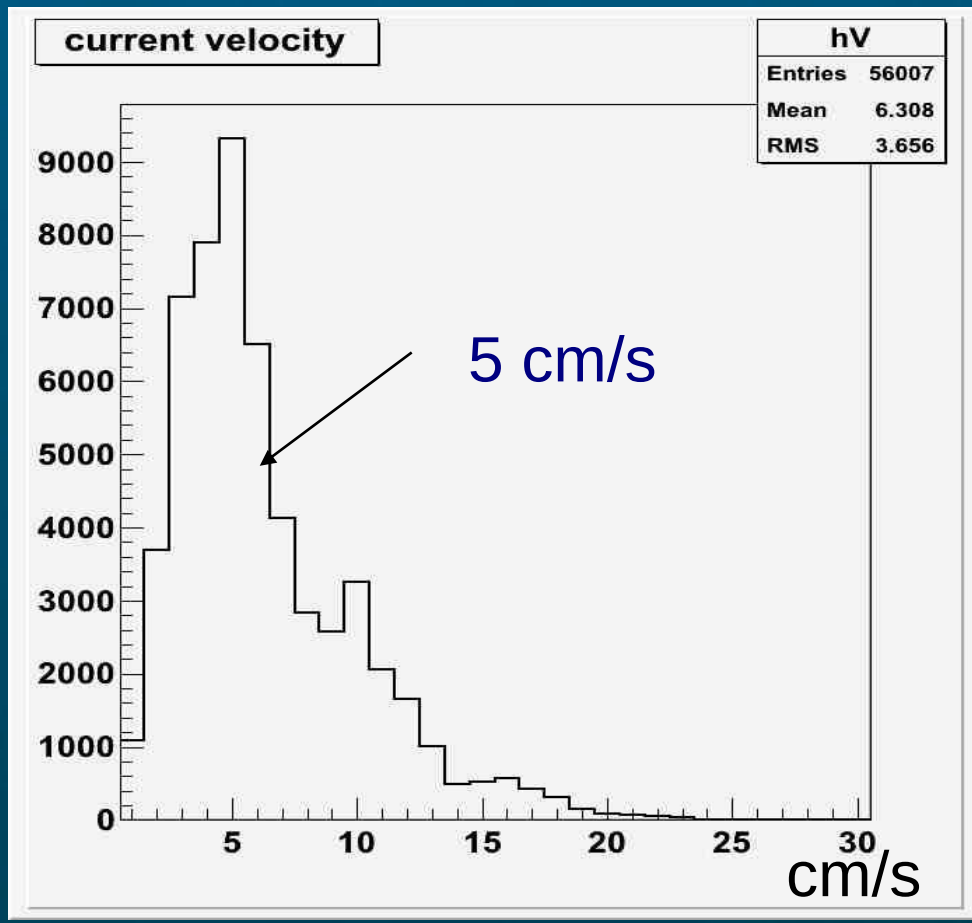
- LuSeapher is fully fonctionnal since middle of december
- photon counting imaging experiment :
  - photoelectron position (X,Y) at a function of time
    (it's the new contribution from this luseapher version)
  - Number of photoelectrons vs time
- about 4000 events occurs, drastic selection :
  - 65% of the total are 1 frame event → rejected
  - 15% are bad events (acquisition defaults,
    bad pedestals substraction, sensor's saturation)
  - 5% are not synchornized (peak at t=70 frames)
  - 622 events (15%) are kept for the analysis

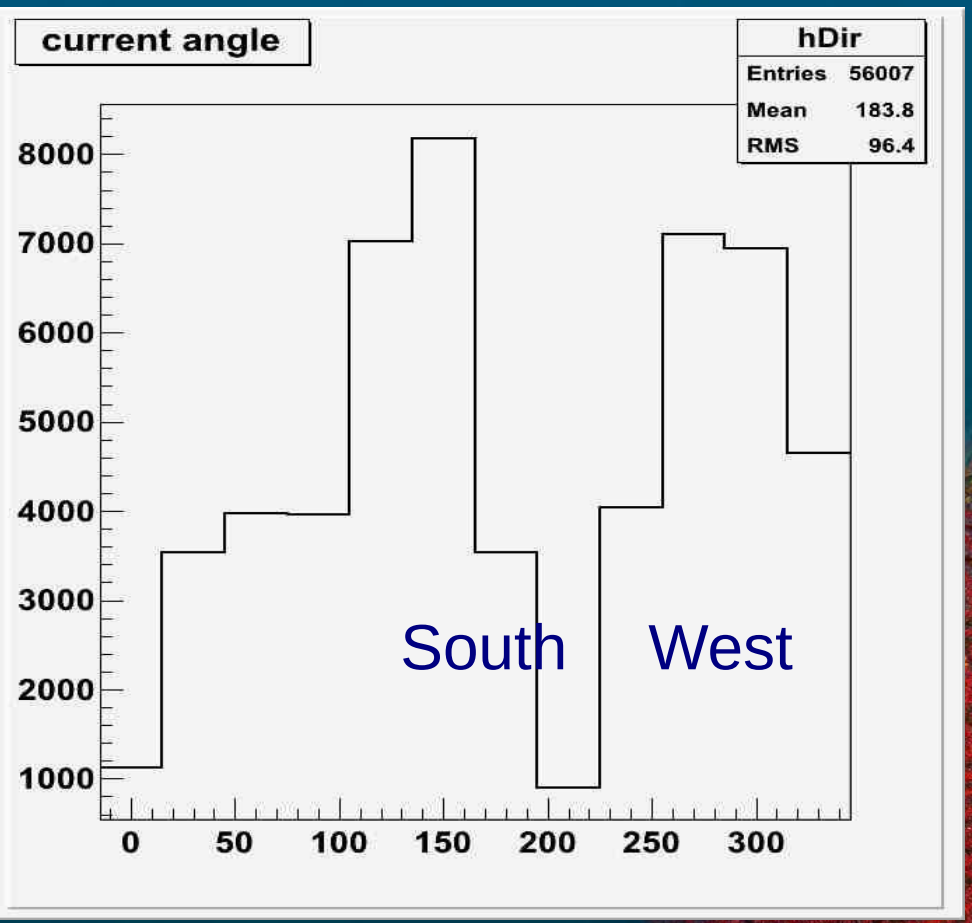
goal :

- ✓ characterization and identification of the observed patterns (size and relaxation time)
- ✓ find correlation with oceanographics conditions (sea current velocity and direction)

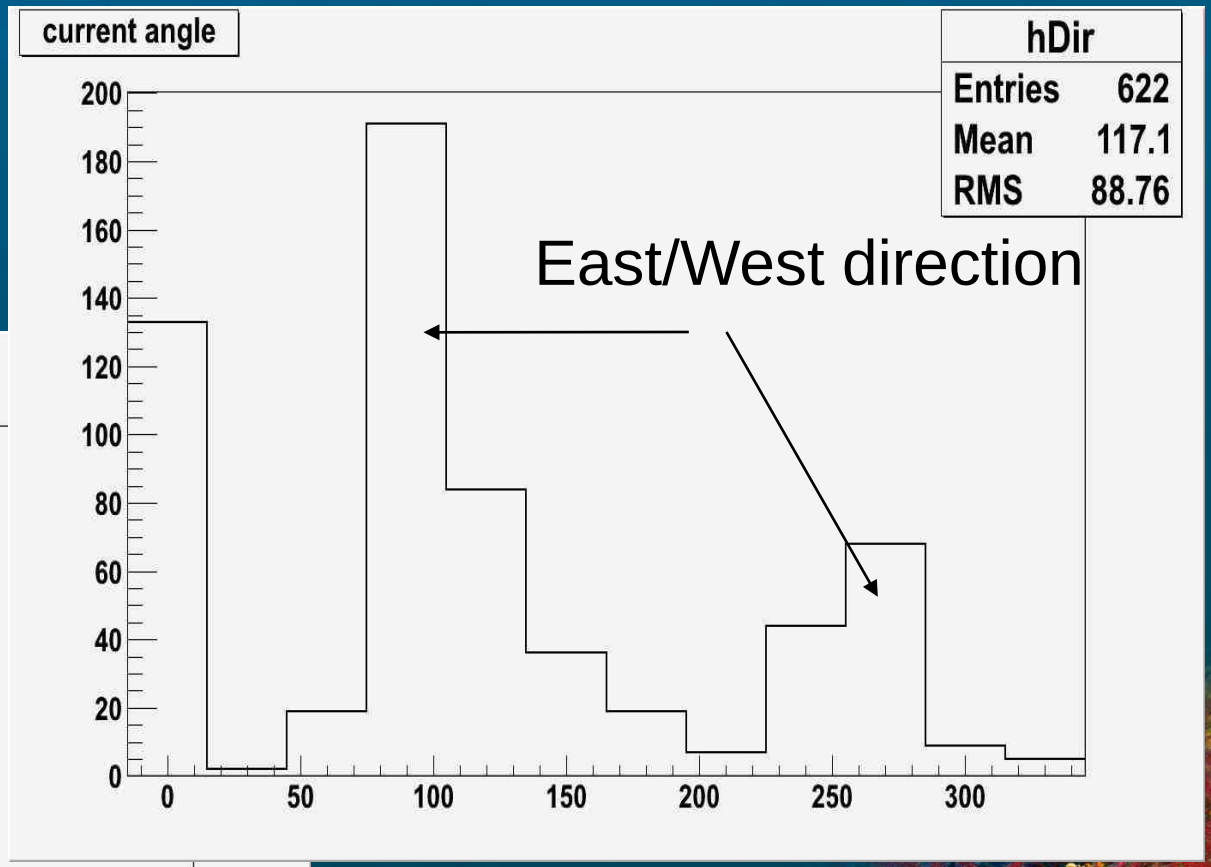
Basic Oceanographics conditions

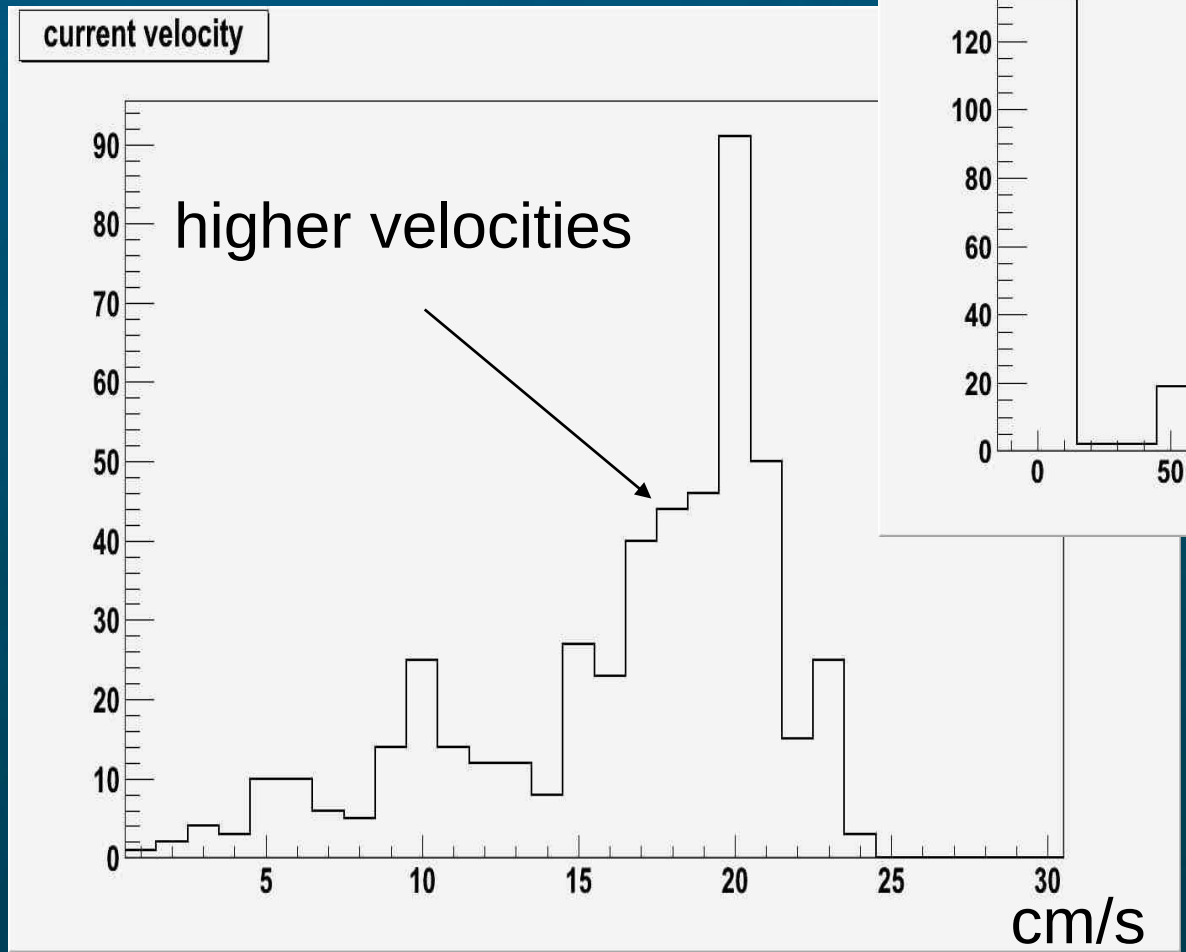
- From Antares experiment
  - sea current velocity (several cm/s)
  - current direction
- full set of data since 1st jan 2011.
- might be correlated with our events.



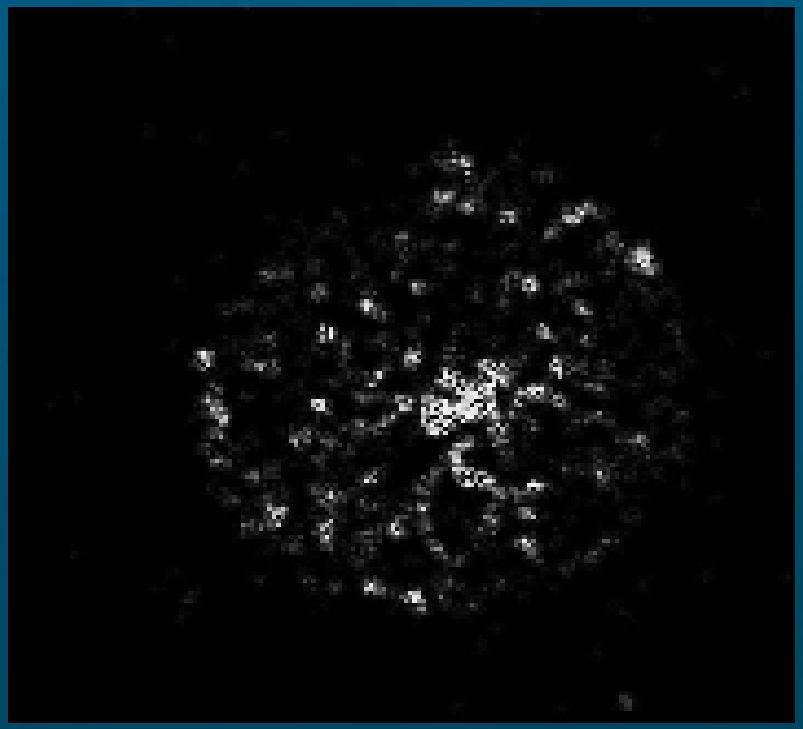


Oceanographics conditions for LuSeapher selected events





typical event



Integrated picture of 200 frames.

more to see on videos
...

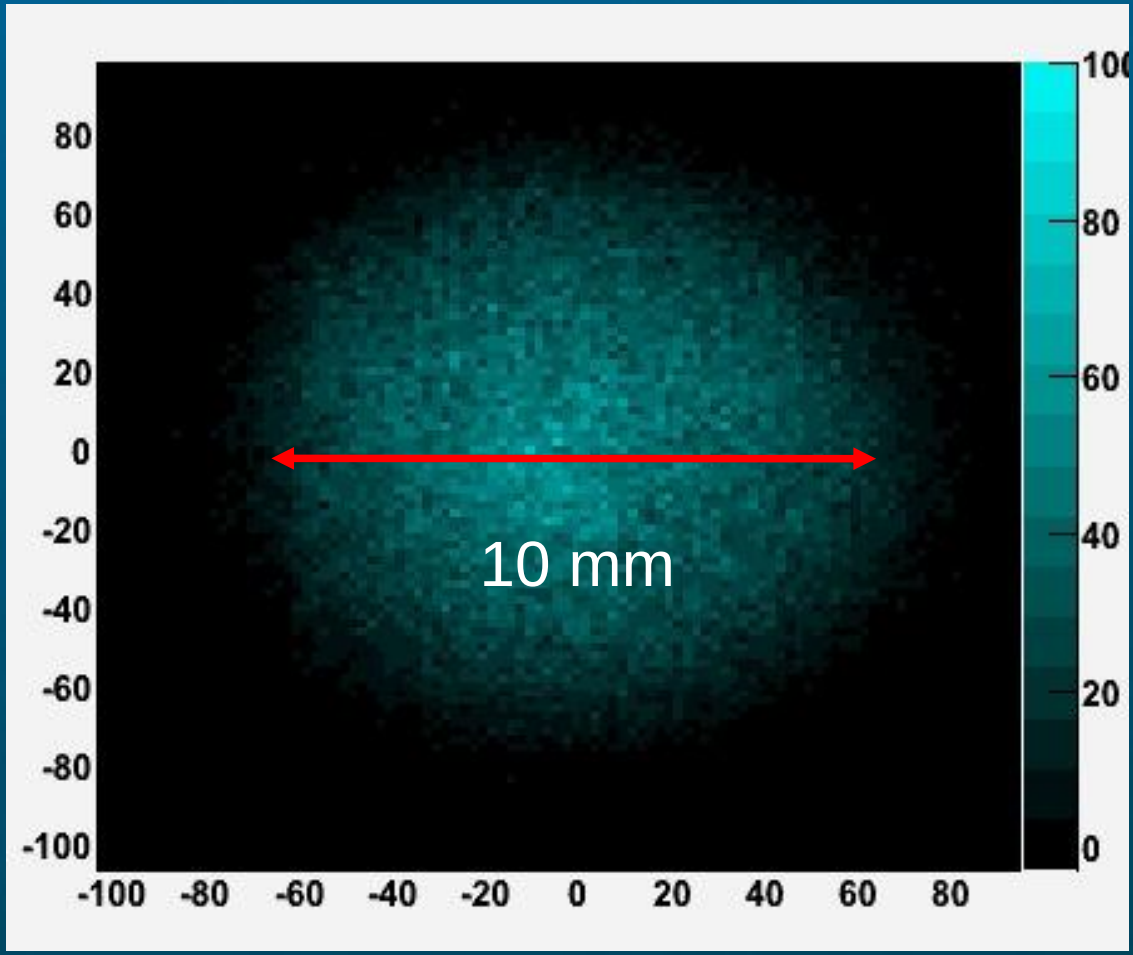
main features:
about 15 pixels central part
about 120 pixels halo part

objects present **one or several flashes** of about 0.3 seconds

kind of filaments structure

all objects exhibit similar patterns and all objects can be piled up in order to extract a typical size.

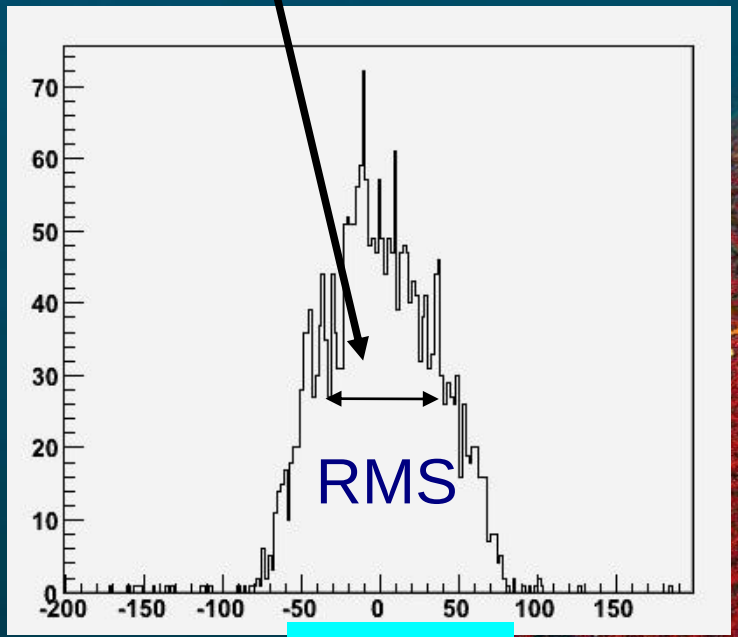
Object's size on glass window



- a typical size is extracted
- from the RMS of the distribution :
- **36 pixels**.

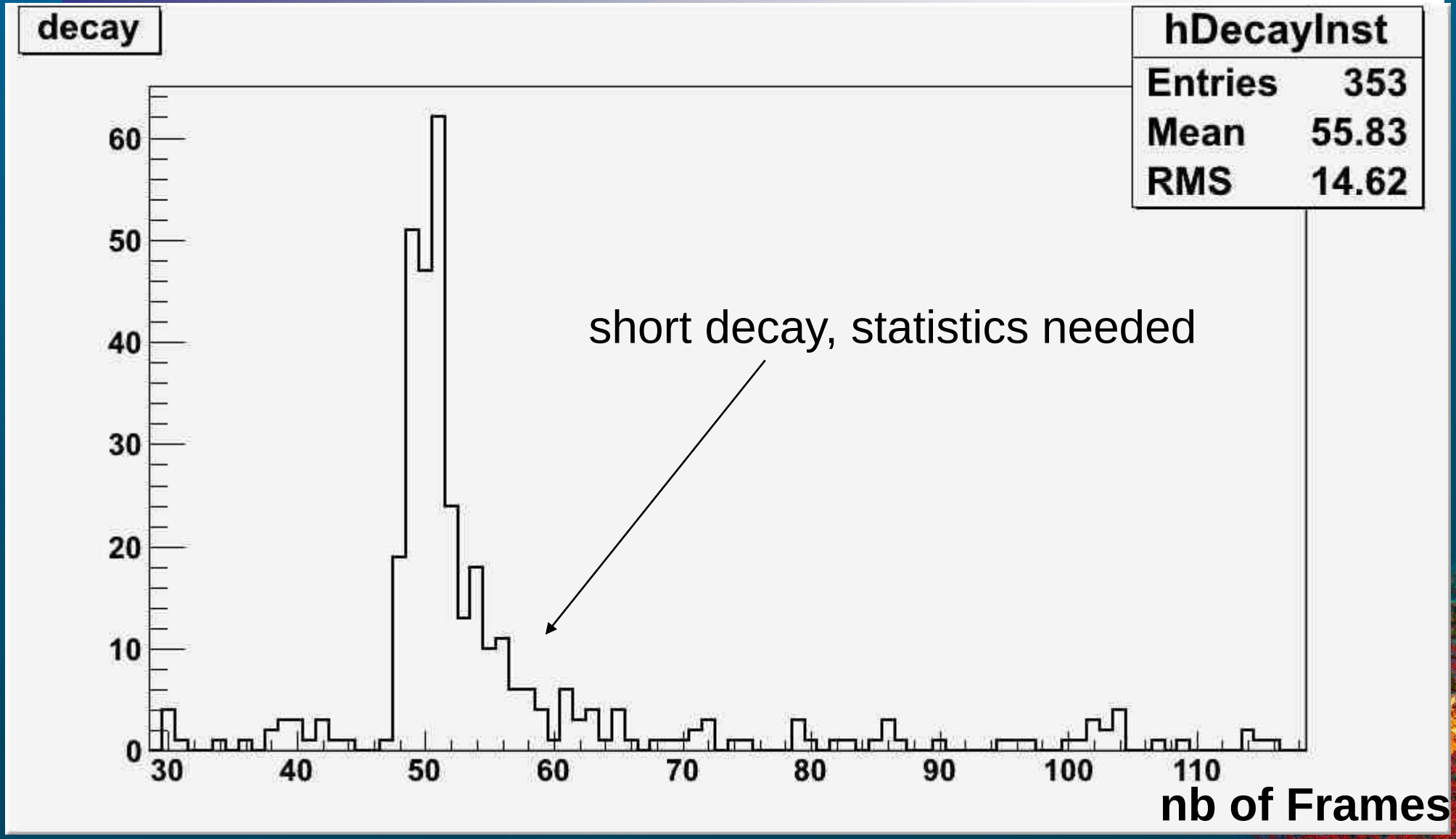
- taking into account lens magnificati (8) , the real object RMS size is ~ **3 mm**

- max extension of the object : ~ **10 mm**



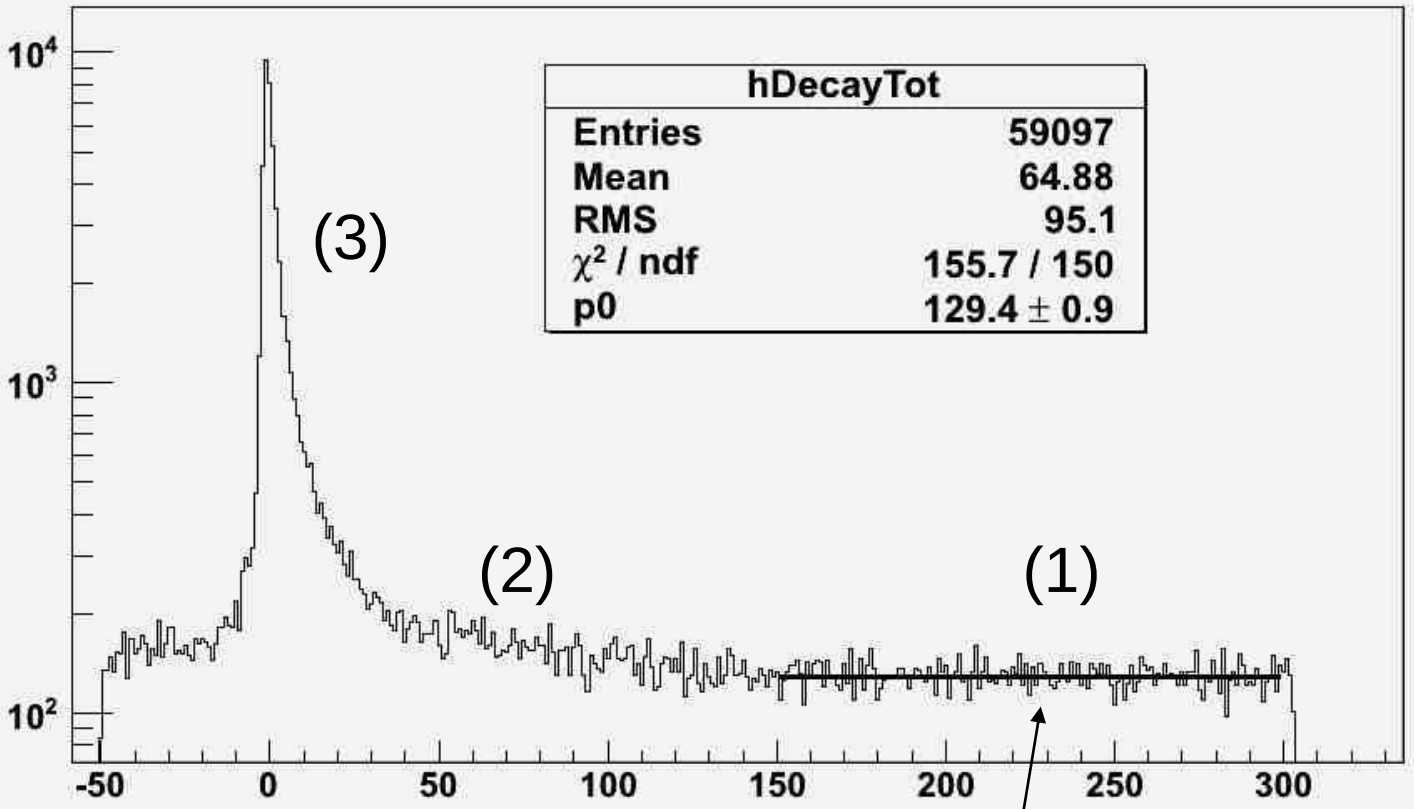
all events statistics, hit positions centered around C.O.G.

time dependency



new event selection : Single flash, no motion of the object's C.O.G
→ 165 events

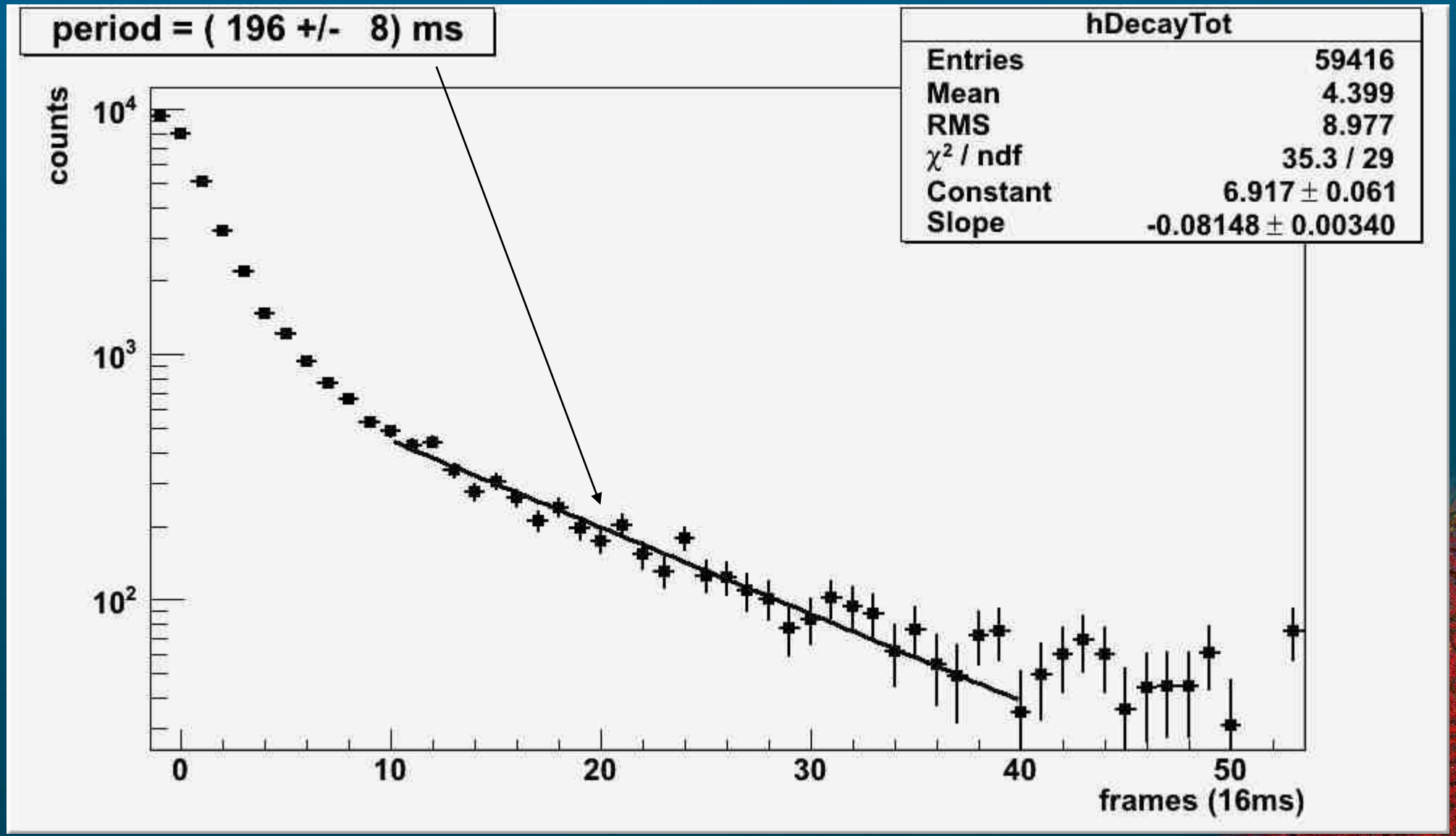
Bioluminescence decay (1) : photoelectron noise determination



noise : 129 p.e. for 165 events → 0.78 p.e. per frame.
p.e noise is consistent with previous determination (slide 13)

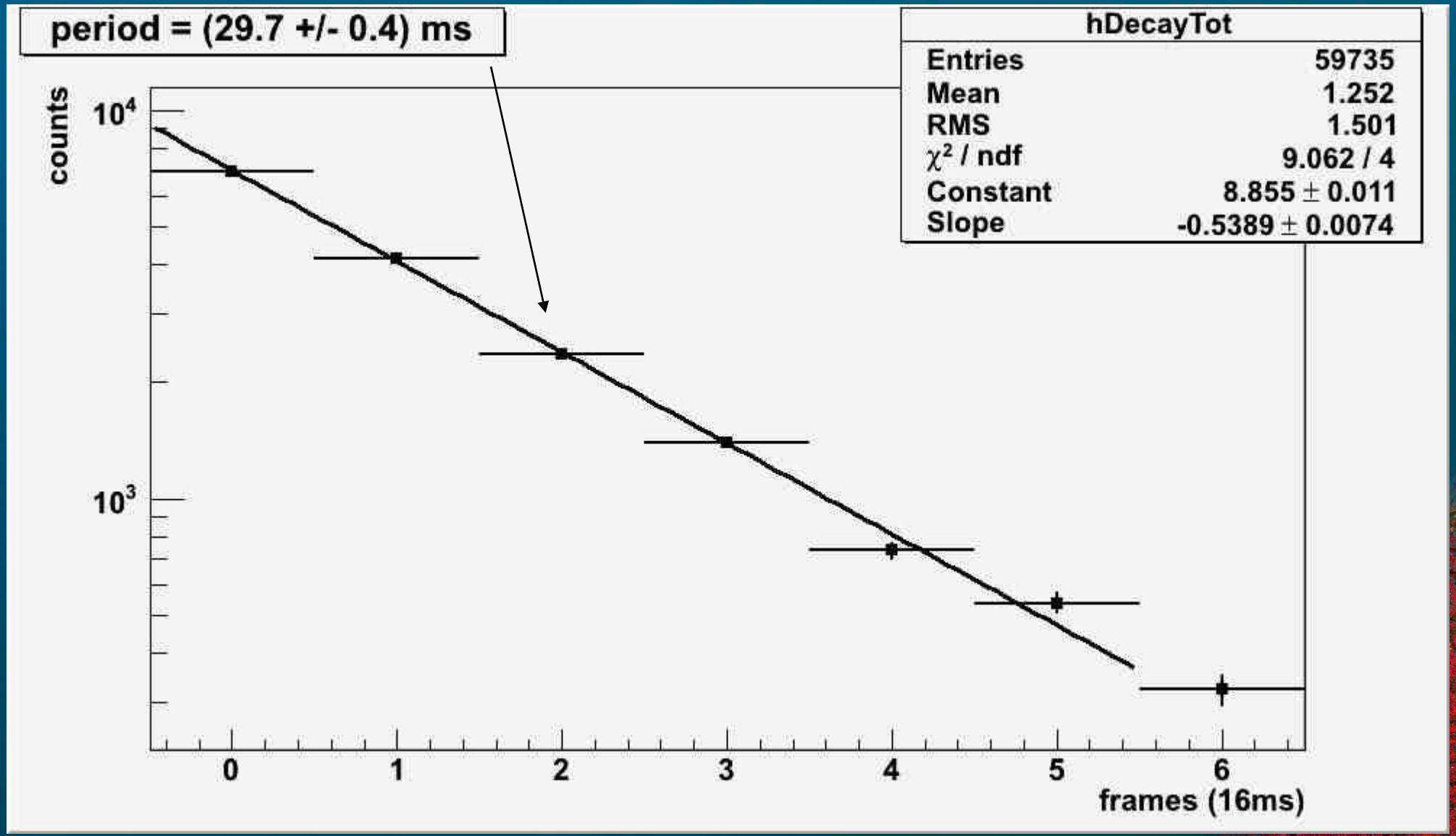
bioluminescence decay

(2) : noise is substracted, long period part



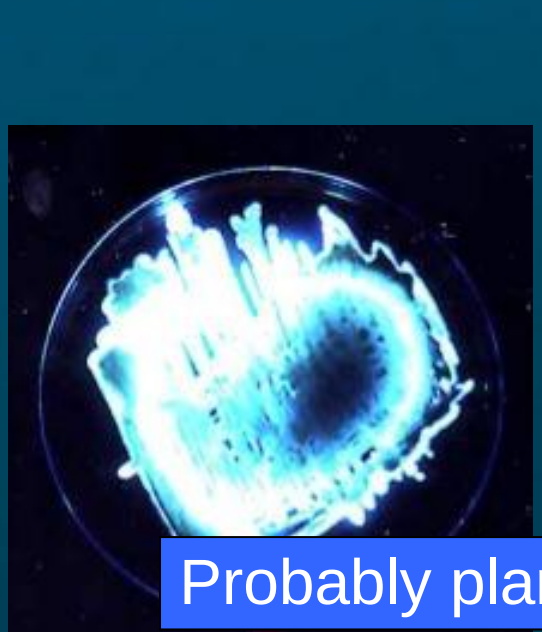
Bioluminescence decay

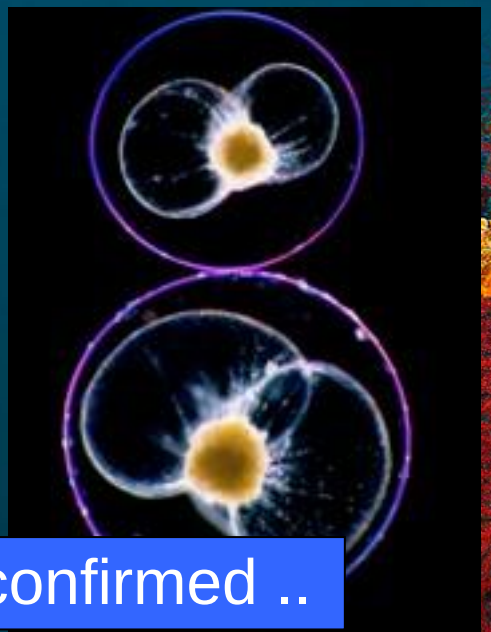
(3) : long period is substracted, short period part



bioluminescence decay summary

- 165 selected events, 59.000 photoelectrons
  - static events (cog velocity = 0)
  - 1 single flash
- A few mm object's size
- 2 mixed decays are found :
  - T_{long} = (196 ± 8) ms
  - T_{short} = (29.7 ± 0.4) ms

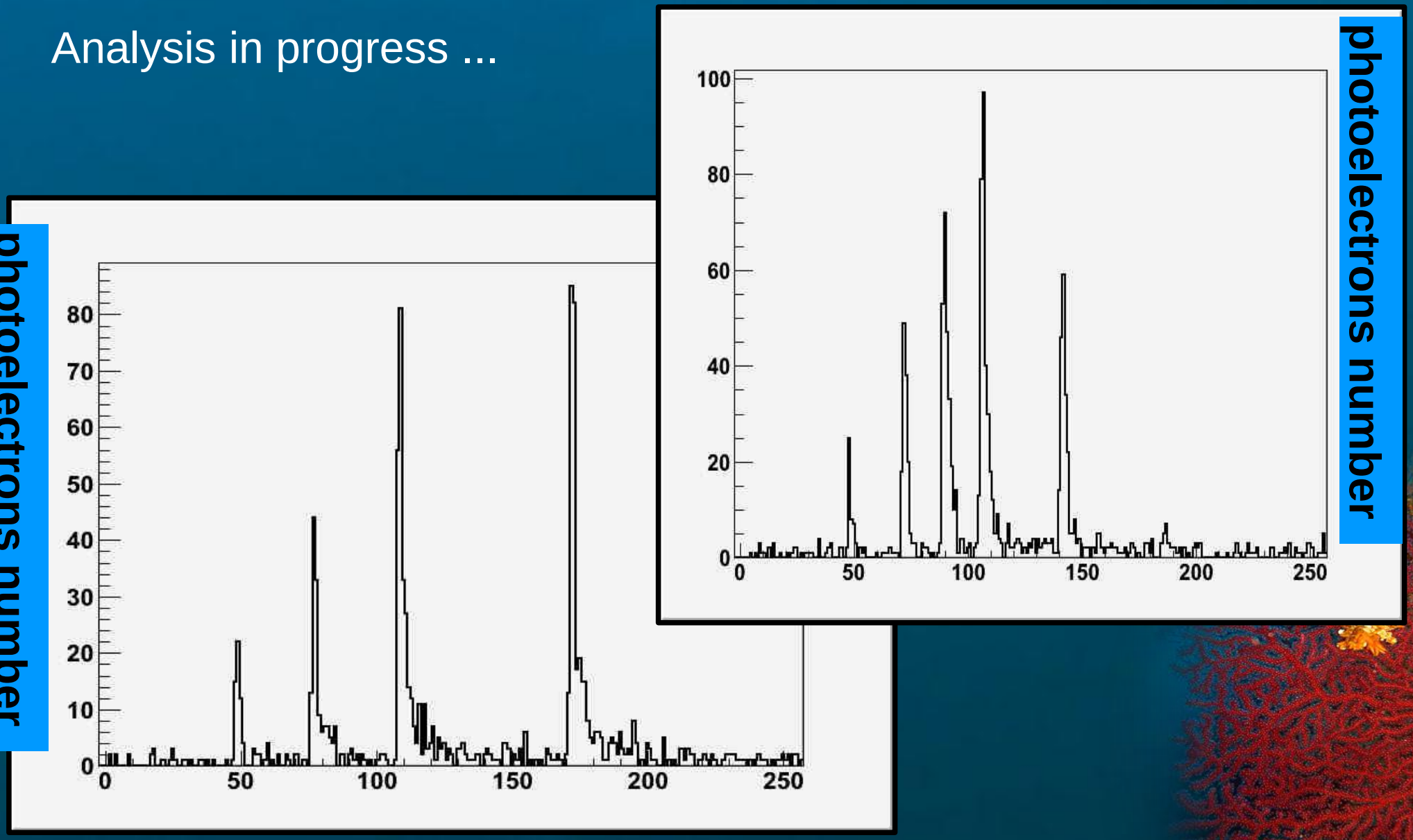




Probably plankton bioluminescence, to be confirmed ..

flashing events

Analysis in progress ...



Conclusion

- cam has been successfully produced in 4 months (instr. electronic, DAQ, computing)
- it's working 24h/24h :
  - only 14 photons are needed to trigger one event
- bioluminescense events are observed and are still under study
  - further studies are in progress to reach a full identification of these objects :
  - optical part has to be improved, are objects well focused or not ?
  - consequences on the real size (critical for the identification)
- correlation between images and sea conditions (current speed and direction, temperature) is in progress thanks to a granted access to ANTARES data (JB) even though it's 500m far from MII and few hundreds meters upper
- Upgrade next year :
  - Lens change to improve field of view
  - Real calibration of sizes, autofocus ?