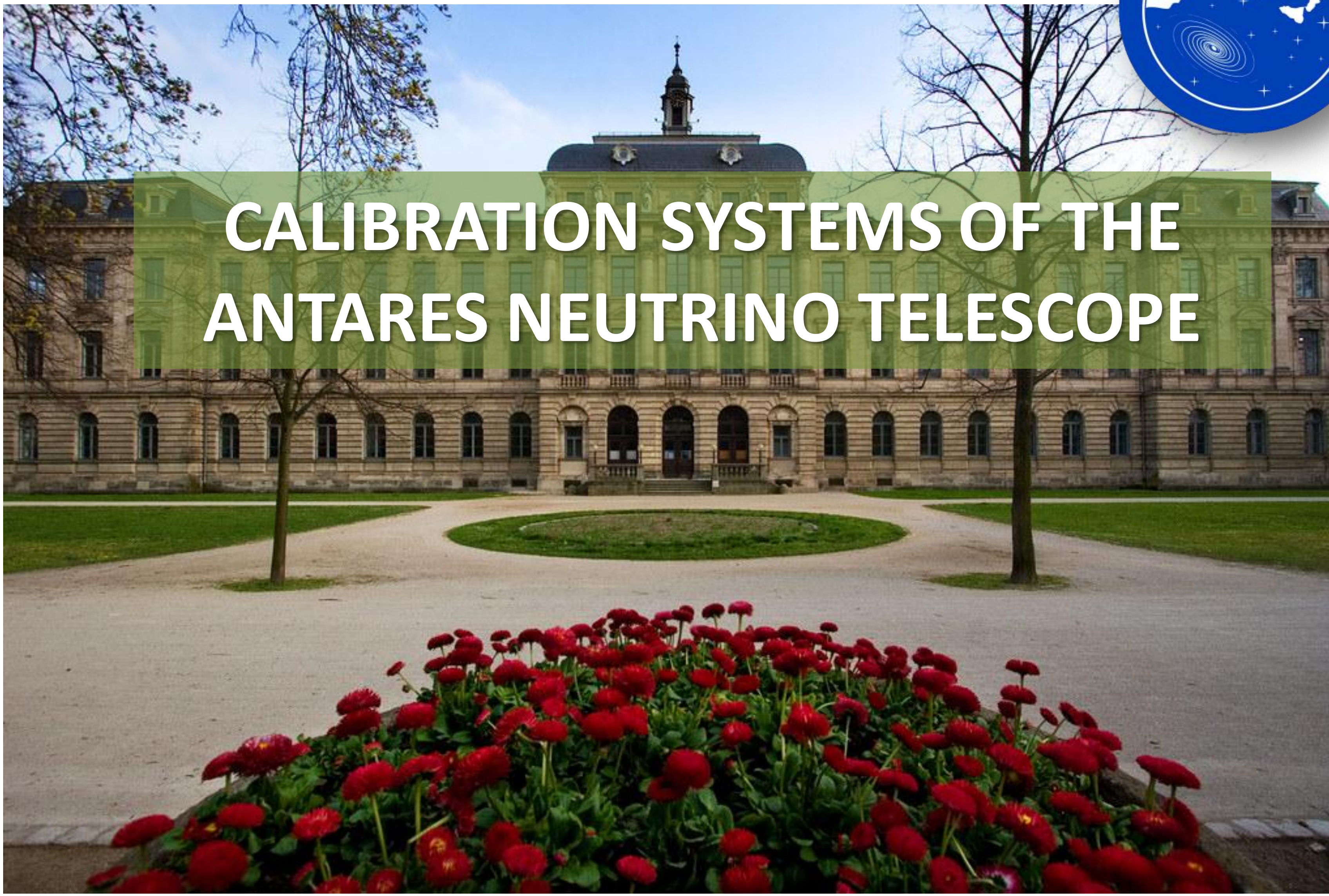
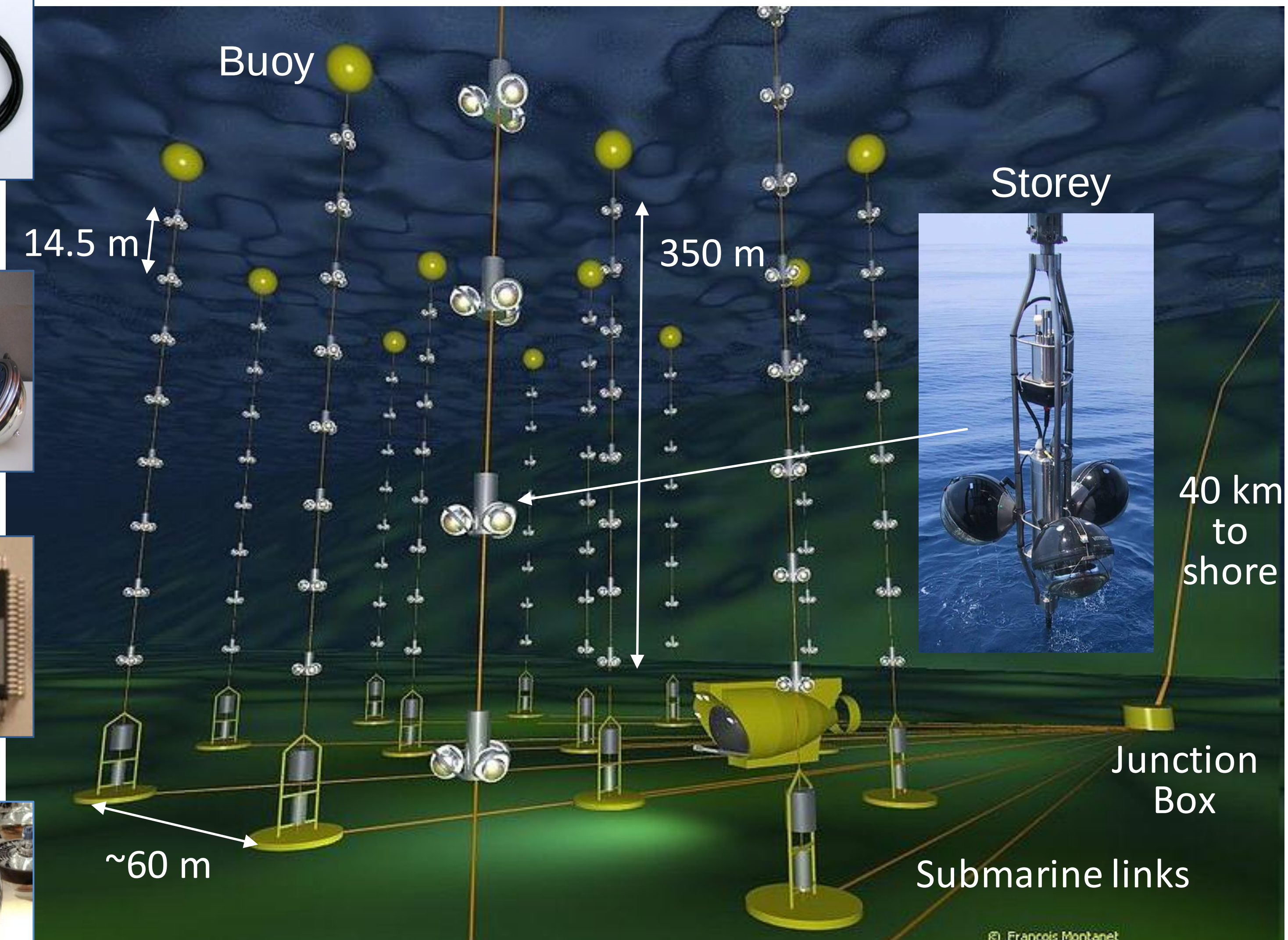
ANTARES

CALIBRATION SYSTEMS OF THE ANTARES NEUTRINO TELESCOPE



Juan Pablo Gómez González (on behalf of the ANTARES Collaboration)

Largest deep-sea Neutrino Telescope in operation

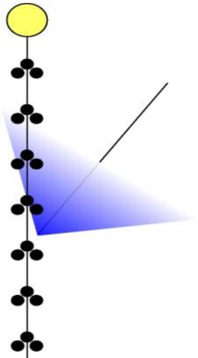


To achieve good angular resolution (0.3º for E_ν>10 TeV) we need precise

Position calibration: OM positions monitoring , as lines are displaced due to the sea current [σ~10cm]

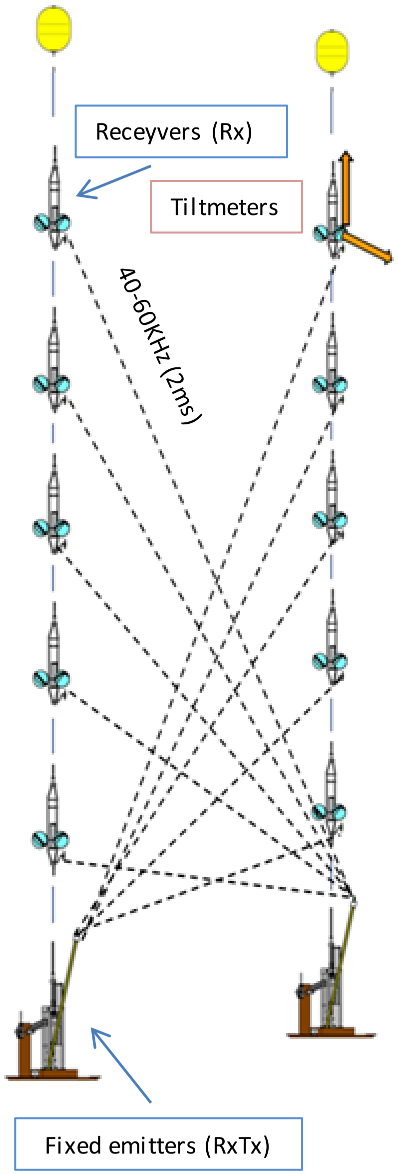
Time calibration: to allow high detector performances an optimal time resolution is required [σ ~0.5ns]

Charge calibration: enables to translate signal amplitudes into number of photo-electrons



Capability of background rejection and of point source discovery:
Astronomy with high energy neutrinos

POSITION CALIBRATION



Acoustic system

5 acoustic receivers along each line + 1 emitter-receiver at the bottom of each line → the relative positions of the hydrophones is obtained by triangulation

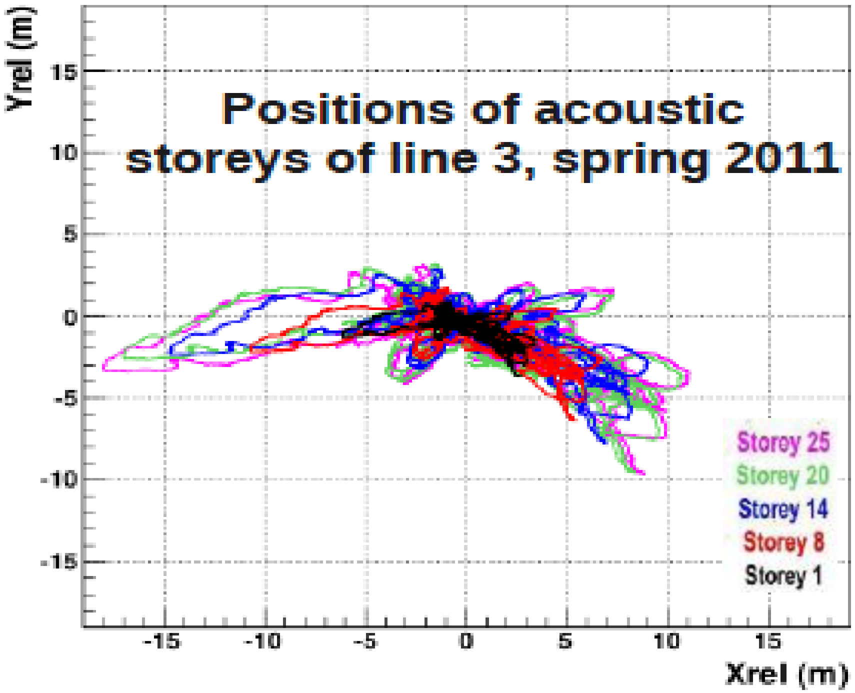
Tiltmeter-Compass sensor board

1 per storey → the local tilt and heading angles of each storey with optical modules is obtained

Additional devices provide independent sound velocity measurements

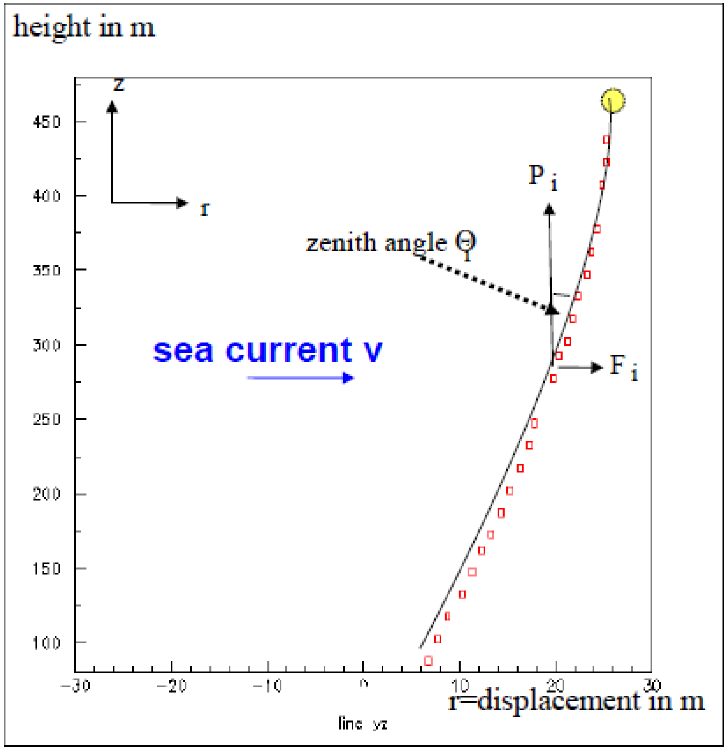
These measurements are performed every 2 minutes

Displacement in the horizontal plane of the 5 hydrophones at different heights/storeys



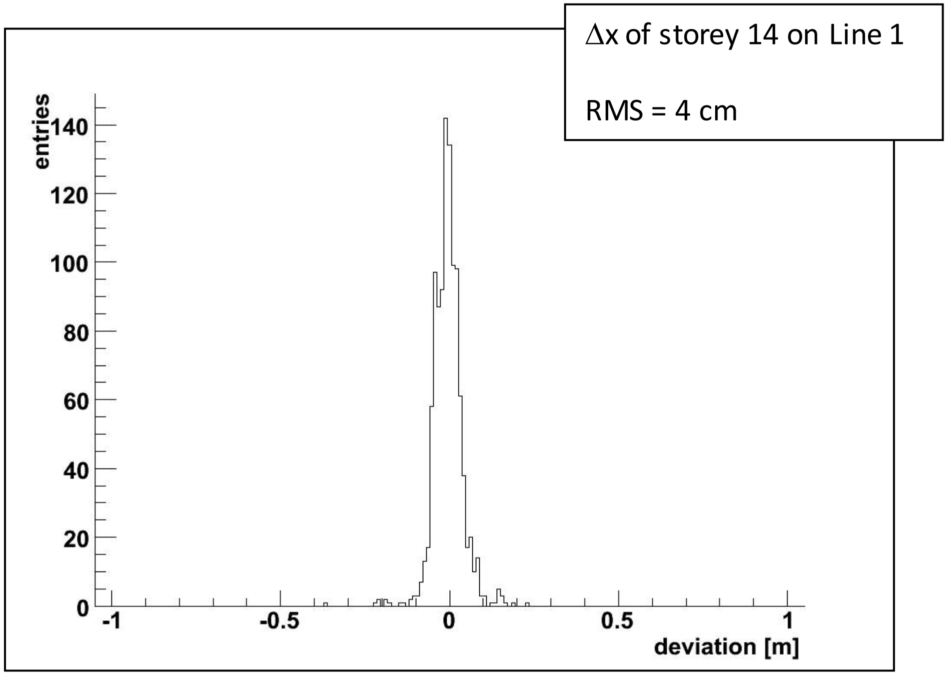
APS: triangulation of AS travel times according to a least mean square minimization algorithm

Line shape reconstruction



$$r = (a z - b \ln[1-cz])\, v^2$$

Using all sensors information and based on a model which predicts the mechanical behaviour of the line

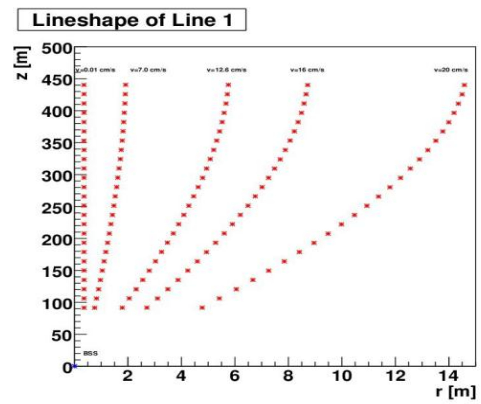


Δx = x(Hydrophone) - x(Linefit)

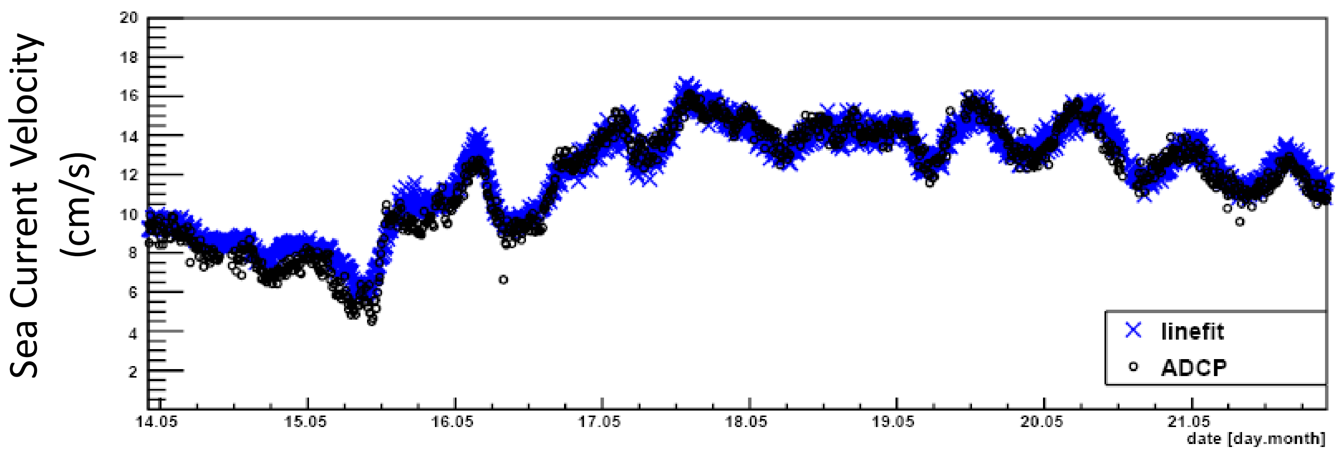
Resolution achieved

$<\Delta x> \leq 10$ cm

(within the specifications)



Sea current velocity comparison →

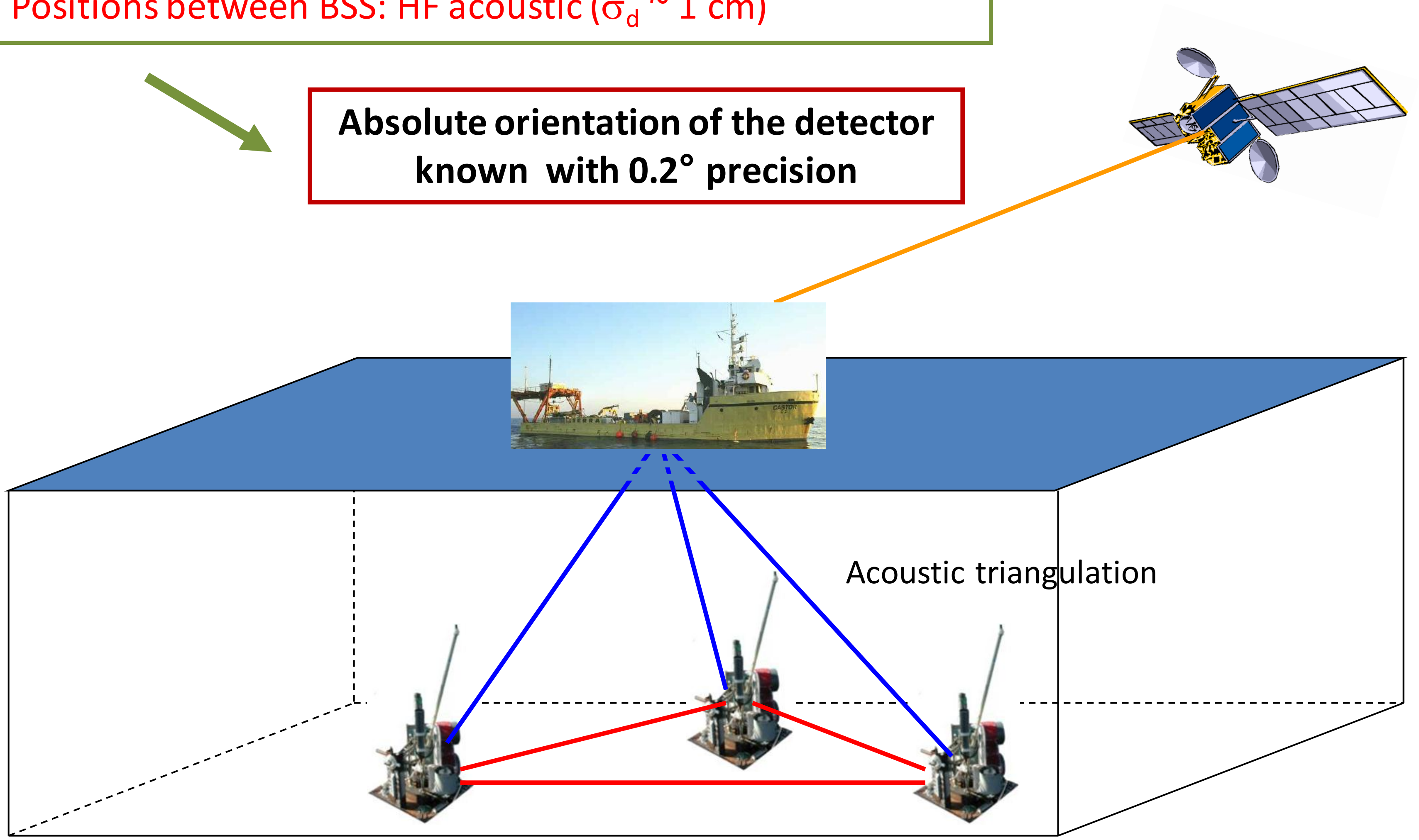


Position of the boat: DGPS (σ_x, σ_y ~ 1 m)

Postion of BSS in respect to boat: LF acoustic (σ_x, σ_y ~ 1m)

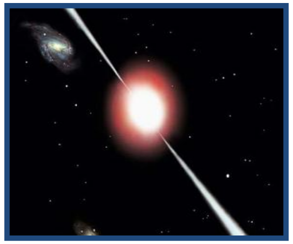
Positions between BSS: HF acoustic (σ_d ~ 1 cm)

Absolute orientation of the detector known with 0.2° precision



TIME CALIBRATION

Absolute time calibration



Correct time-stamping of the physiscs events. A precision **~1 ms** is required to correlate detected signals with astrophysical transient events

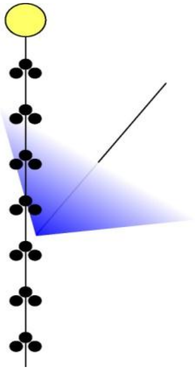
Relative timing resolution

$$\sigma^2 = \frac{\sigma_{TTS}^2}{N_{pe}} + \frac{\sigma_{water}^2}{N_{pe}} + \sigma_{elec}^2$$

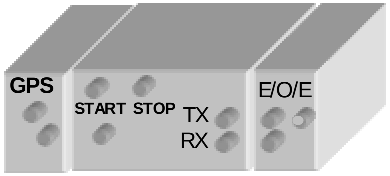
- σ_{TTS} transit time spread (TTS) of the PMTs (σ~1.3 ns)
- σ_{water} coming from optical properties of the sea water: light scattering, chromatic dispersion (σ~1.5 ns for 40 m distance)
- σ_{elec} coming from electronics (**σ<0.5 ns**)

↓

In order to achieve the best angular accuracy attainable



•A 20 MHz **clock signal** is generated on shore and distributed throughout the detector



•The clock signal is synchronized with GPS and a timestamp is assigned to the data with precision of **~ 10 μs**

•The time offsets between all storeys is determined with a resolution of **~ 100 ps**

Timing calibration with clock system fulfills perfectly well the requirements

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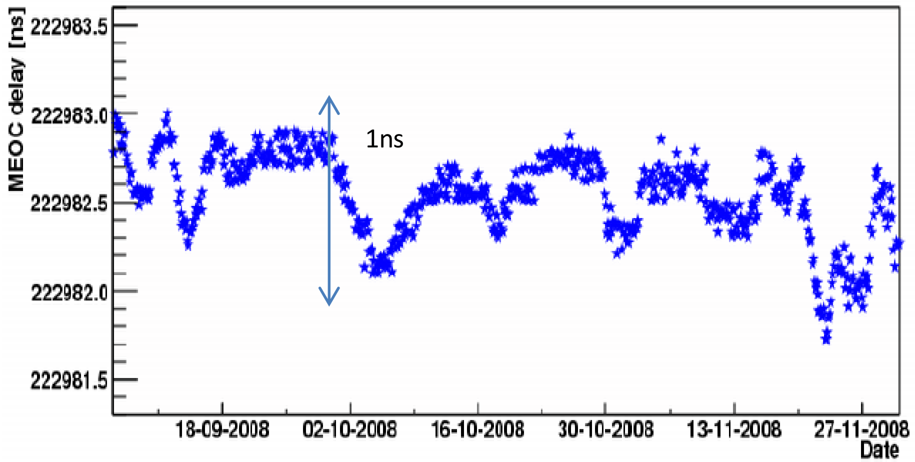
Absolute timing resolution is ~ 10 μs



Round trip of the CS between shore and one electronic module. The stability and accuracy of the measurements are at the sub-nanosecond level

Before deployment the relative time-offsets between OMs are measured at the integration site

→ Common light signal sent to every board through optical fibres

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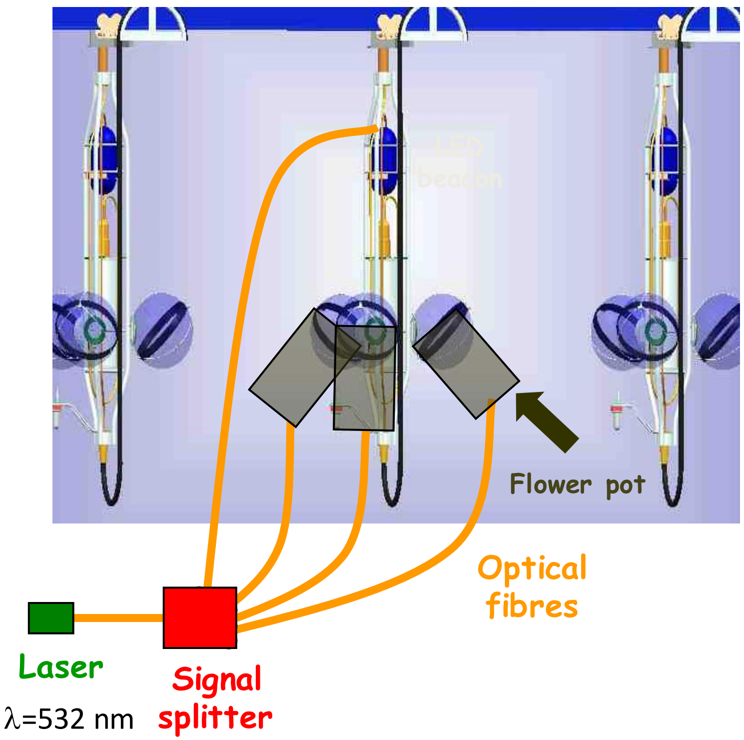
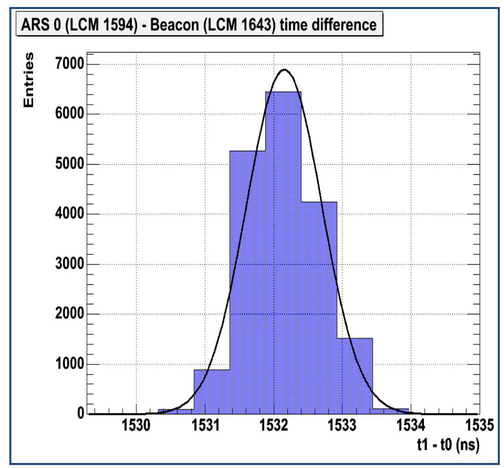
Time difference between both emission and signal recording (corrected by the fibre path) gives the relative time offset





Example of LED OB time offset calculation

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All the offsets are referred to a particular OM

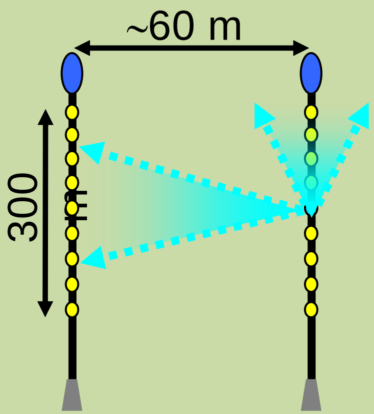
→ relative offsets correction

Offset = T_{REF} - $T_{OM/LOB}$ - clock_ph – fibre_path

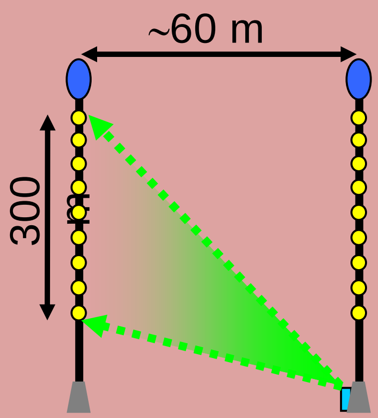
The Optical Beacons are controlled sources of light with a **well-known time emission**

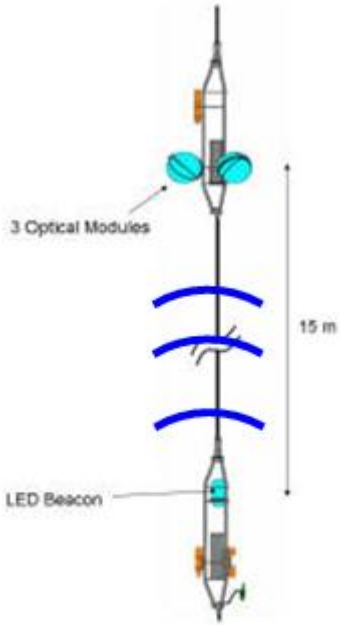
There are two kinds of OB: Laser and LED

- 4 **LED Beacons** are placed along each line
- 2 **Laser Beacons** are placed at the bottom of two central lines



36 individual blue LEDs (λ= 472nm)



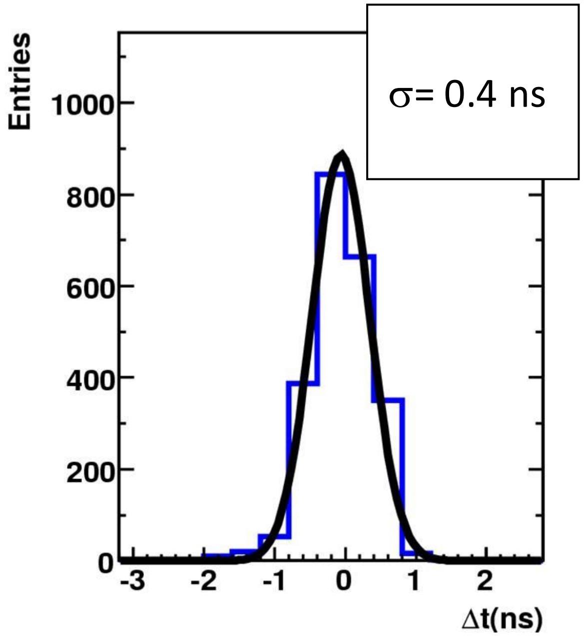


Time difference between the LED OB and and one closer OM

$$T_o = t_{OM} - t_{OB} - \frac{d(OB, OM)}{c_{water}}$$

$$\sigma^2 = \frac{\sigma_{TTS}^2}{N_{pe}} + \frac{\sigma_{water}^2}{N_{pe}} + \sigma_{elec}^2$$

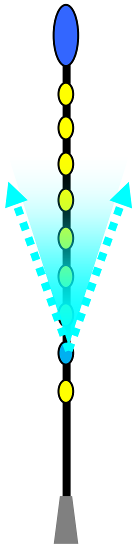
T0 distribution



During special OB runs N_{pe} is large → electronic timing resolution is obtained

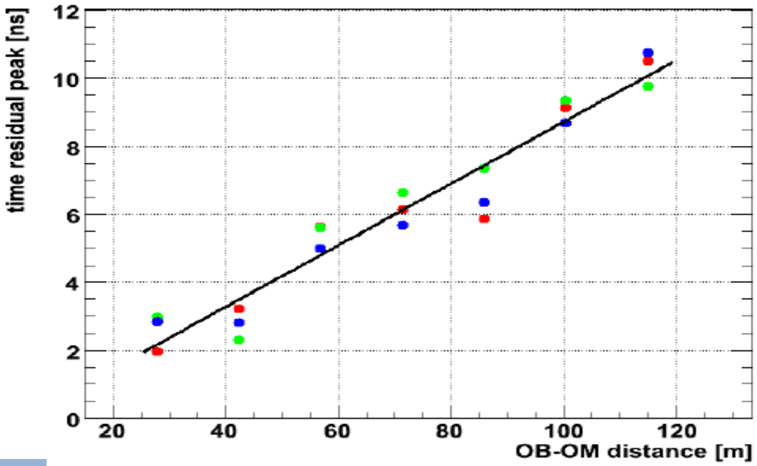
Electronics contribution less than 0.5 ns

$$T_o = t_{OM} - t_{OB} - \frac{d(OB, OM)}{c_{water}}$$

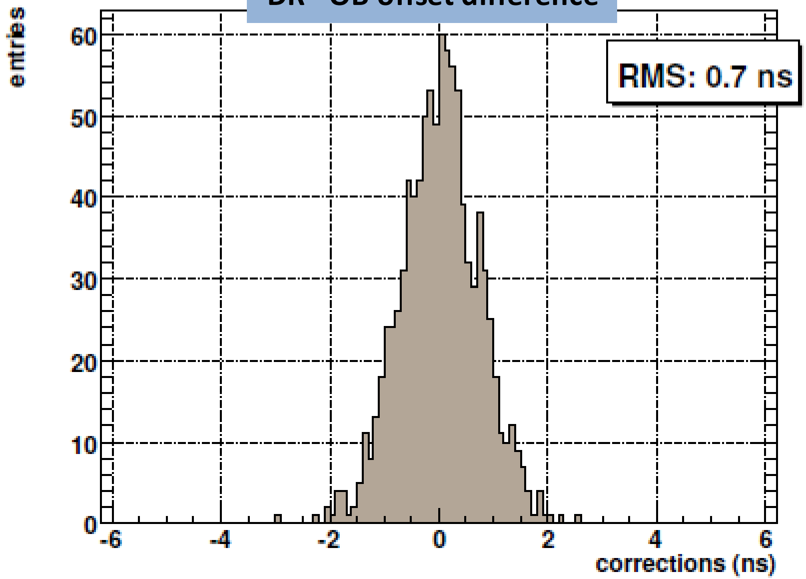


•Linear trend due to the early photon effect

•Straight line fit is used to calculate the correction on the time offsets measured on shore

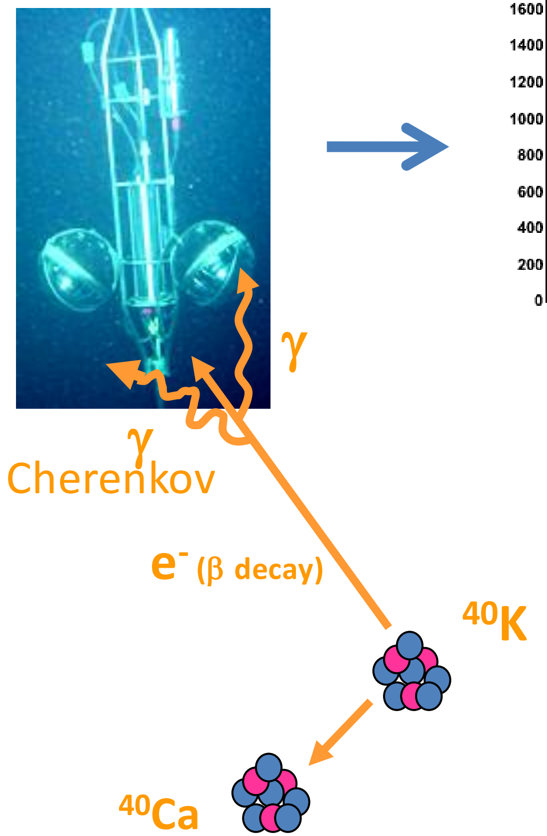


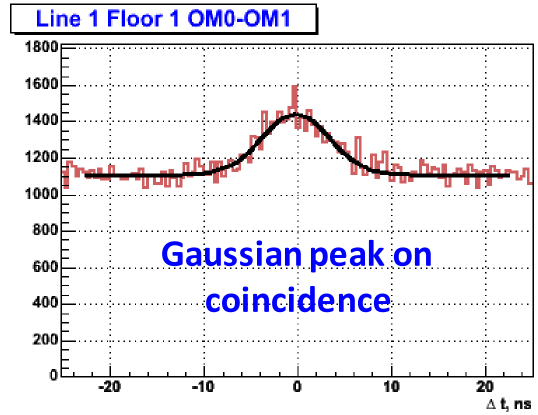
DR - OB offset difference



Only for ~15% of cases the corrections to apply are larger than 1 ns

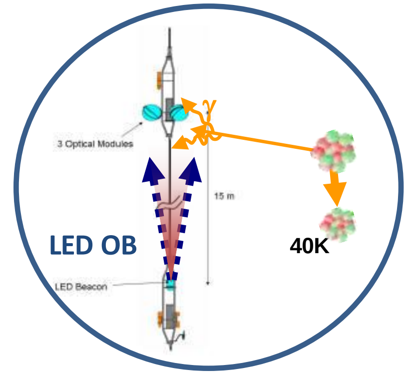
Coincidence peak of time distributions for different pairs of PMTs

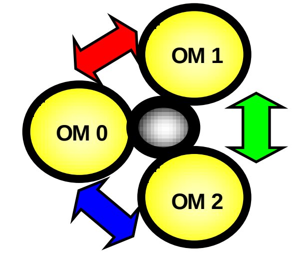


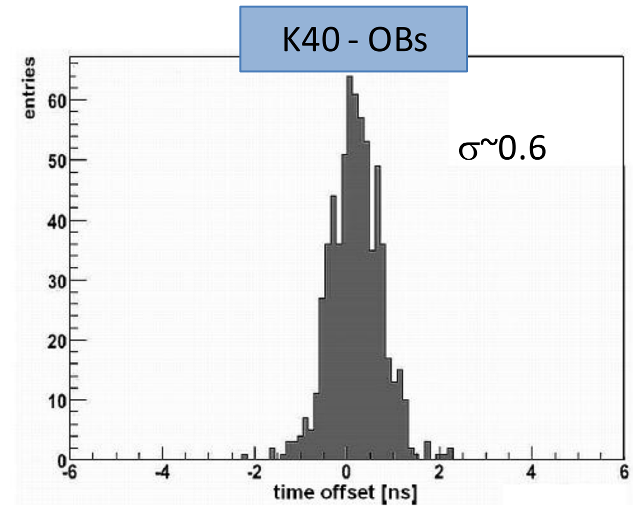


Peak offset

Cross check of time calibration



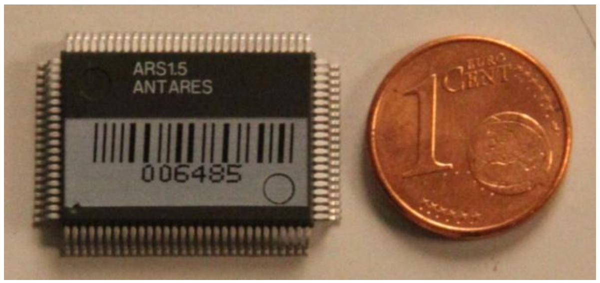




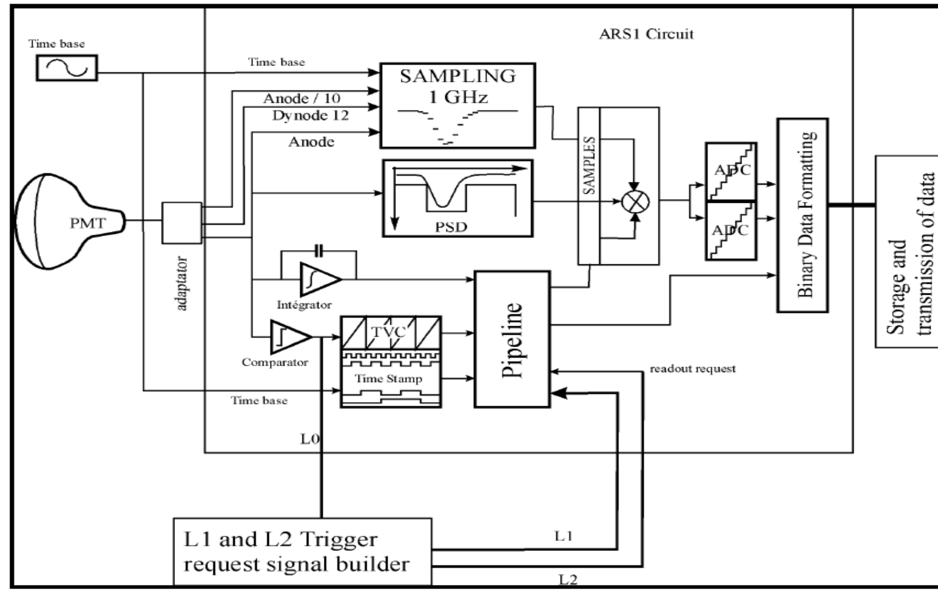
The offsets calculated with the LED OBs are validated by the ^{40}K (independent calibration procedure)

CHARGE CALIBRATION

The charge calibration enables to translate signal amplitudes into number of photo-electrons which is relevant information for track and energy reconstruction



2 ARS chips in “token ring” configuration on each OM



Can acquire signals in two different modes:

A) integrating pulse and transmit digitized signal to shore (AVC) [default mode]
B) sampling the full waveform of the OM signal

(settings of each individual chip can be remotely configured from shore)

Perform regular calibration runs to convert AVC counts into photo-electrons

Pedestal runs: triggering the front end in the absence of signal

SPE runs: obtained by background events (^{40}K and bioluminescent bacteria produce single photons at the photocathode level)

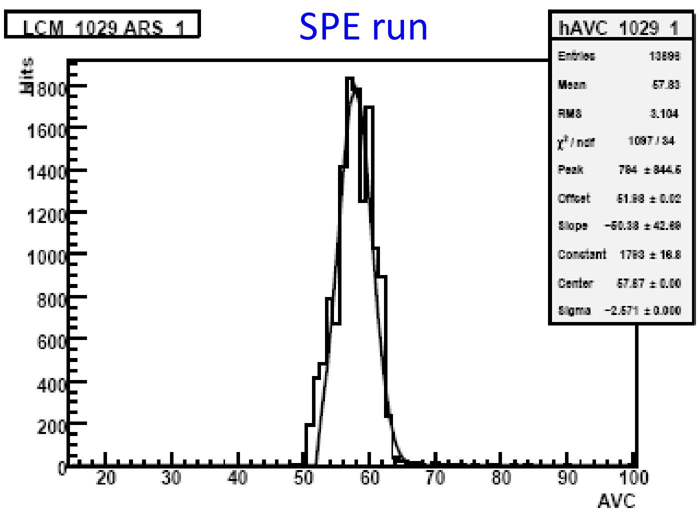
Parametrization of charge distribution

$$Ae^{-\alpha(x-x_{th})} + Be^{\frac{-(x-x_{pe})^2}{2\sigma^2}}$$

Effective threshold

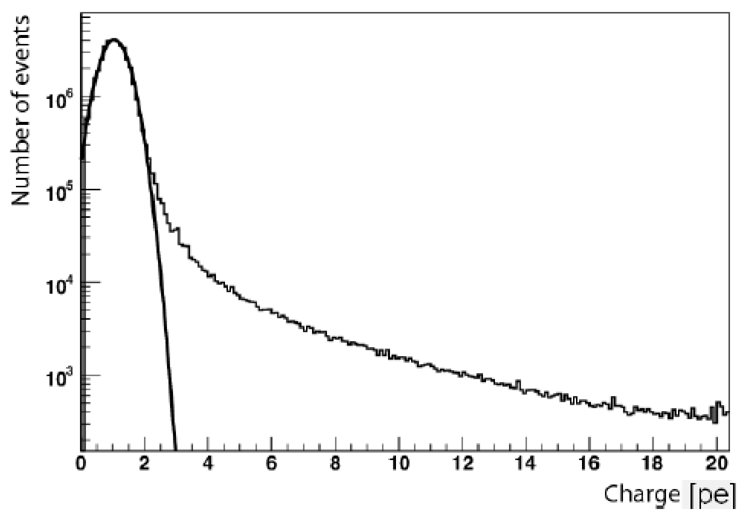
Photo-electron peak

SPE run



Charge distribution for a particular ARS

x885 (OM)
X2 (ARS)



Calibrated charge dist. combining all PMTs

CONCLUSIONS

Calibrations are performed regularly in situ

The required spatial reconstruction is achieved [$\Delta x \leq 10$ cm]

Time resolution is stable and within the specifications [Δt(elec)=0.5 ns]
Cross-checks with the 40K method

Charge calibration is checked daily and retuned when needed

→ Expected performance validated

Ongoing investigations to determine:

The absorption length at the ANTARES site (see H. Yepes talk)
The OM angular acceptance
Absolute pointing with moon shadow