Timing calibration in ANTARES

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(for the ANTARES collaboration)

Workshop on Technical Aspects of a VLVνT in the Mediterranean Sea
NIKHEF, Amsterdam, October 5–8, 2003

Timing Requirements

- **Absolute timing (i.e. w.r.t. UTC)**
  - Compatible with available systems (GPS, synchronization)
  - Physics requirements ⇨ ~1 ms (coherent source of 300–km size)
- **Relative timing (i.e. among OMs)**
  - Limited by intrinsic detector processes

    event to event fluctuations:
    - TTS of PMTs ($\sigma \sim 1.3$ ns)
    - Light propagation in water ($\sigma \sim 1.3$ ns) More info? ☞
    - Electronics ($\sigma < 1$ ns)
  - Goal ⇨ $\sigma = 0.5$ ns (in average relative ? t_0's)

Timing calibration systems

- *In-situ* calibration systems:
  - Clock calibration system
  - LEDs in Optical Modules
  - Optical Beacons
  - Down-going muon tracks

} Built-in systems

- Calibration before immersion:
  - Laser–fibre system
  - Clock calibration
  - LEDs in Optical Modules

← Laboratory specific

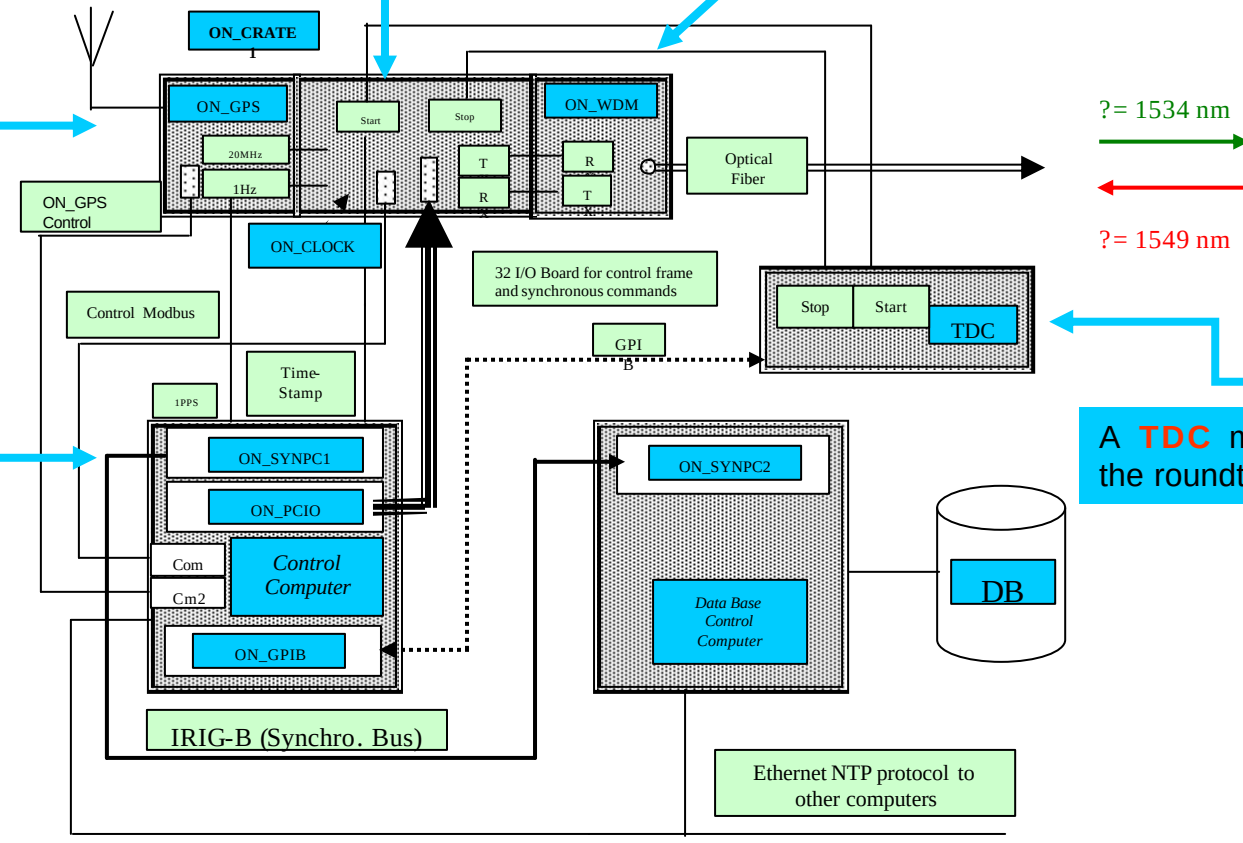
Clock calibration system

Clock system on-shore

A high accuracy **20-MHz** clock signal synchronized with the **GPS** system is generated

Start an **stop** signals are generated and sent to the **TDC**. Commands can be superimposed. Interfaces with the control **PC**.

The clock **electrical** signal is converted to an **optical** signal and sent to the detector by **W**ave **D**ivision **M**ultiplexing.

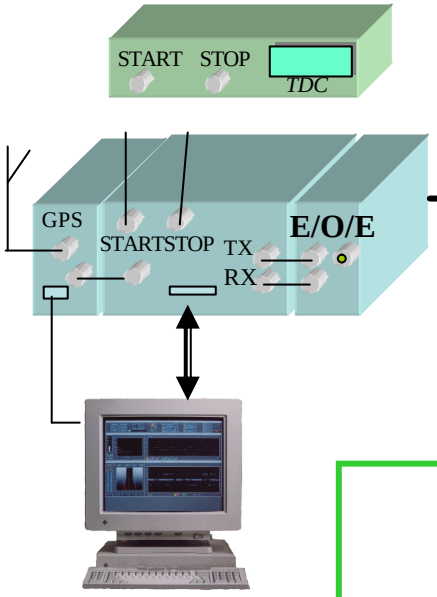


A **TDC** measures the roundtrip delay.

The overall system is controlled by a **PC**. Its internal clock is synchronized to the one **p**ulse **p**er **s**econd signal provided by the **GPS**. The adequate **Time Stamping** format is provided.

Clock distribution

On-shore Station



Junction Box
1–16 passive splitter

Link Cables
200-500 m fibre

1534 nm⇆1549 nm

1310 nm⇆1550 nm

1534 nm⇆1549 nm

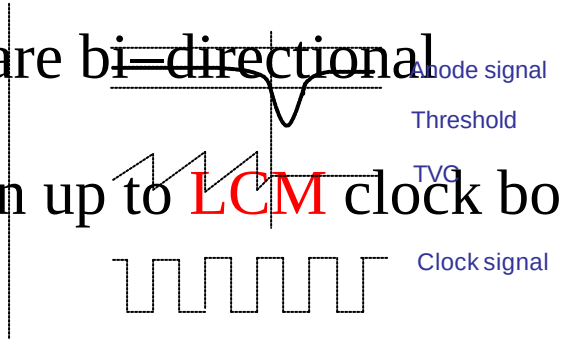
Main Electro-Optical Cable
40 km
from shore to Junction Box
Single bidirectional fibre
(1534 nm / 1549 nm)

String Control Module
BIDI modules
O/E and E/O converters
by sectors (5 storeys)

Local Control Modules
LCM clock boards

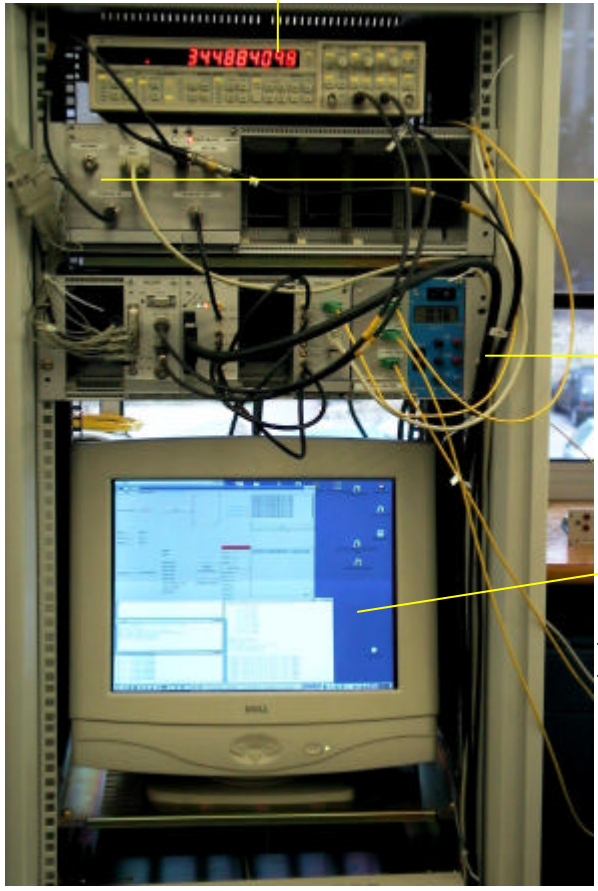
Time calibration through the clock system

- Each ARS (readout chip) has its own local time counter
- The ARS uses the LCM clock board for Time Stamping
- A general Reset Time Stamp order to all ARS every 0.8 s (max)
- A TVC ramp gives time w.r.t. each clock cycle
- Clock boards at SCMs and at LCMs are bi-directional
- Roundtrip delay ⇨ relative calibration up to LCM clock boards

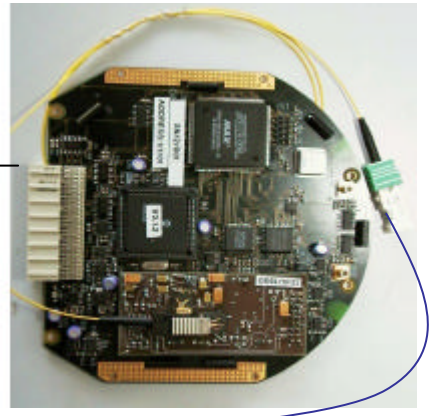


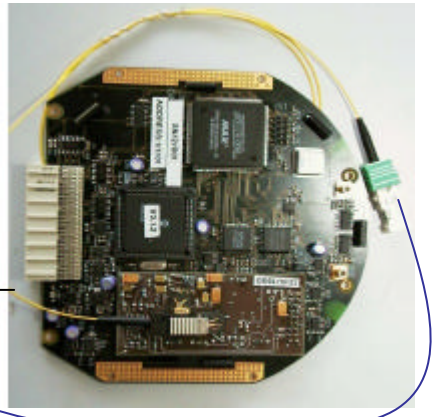
Echo-based clock calibration (Tests)

Phase Jitter between 2 cards
(Roundtrip delay).



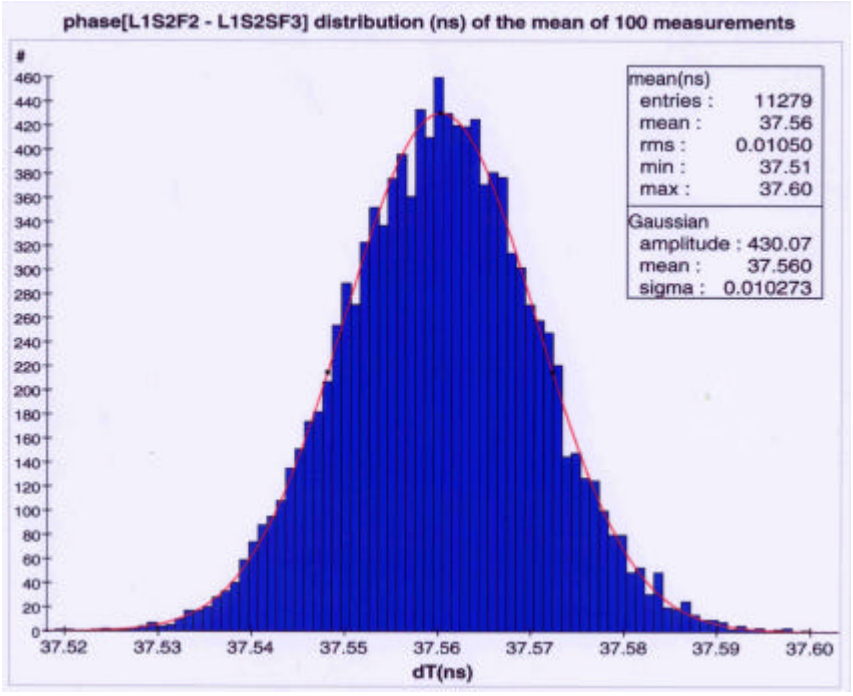
Reference

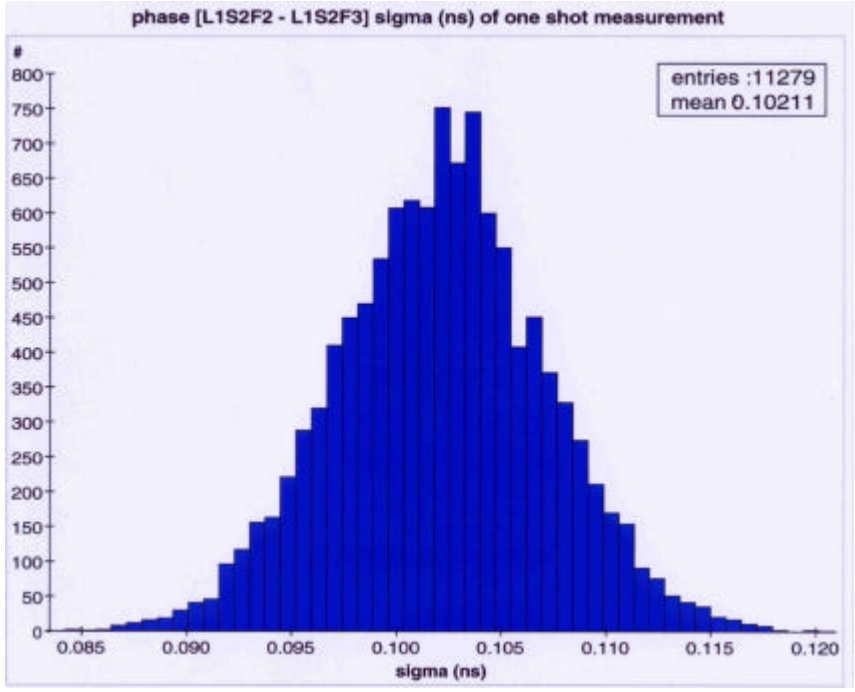




On Test

Clock calibration test results





Average of 100 measurements:

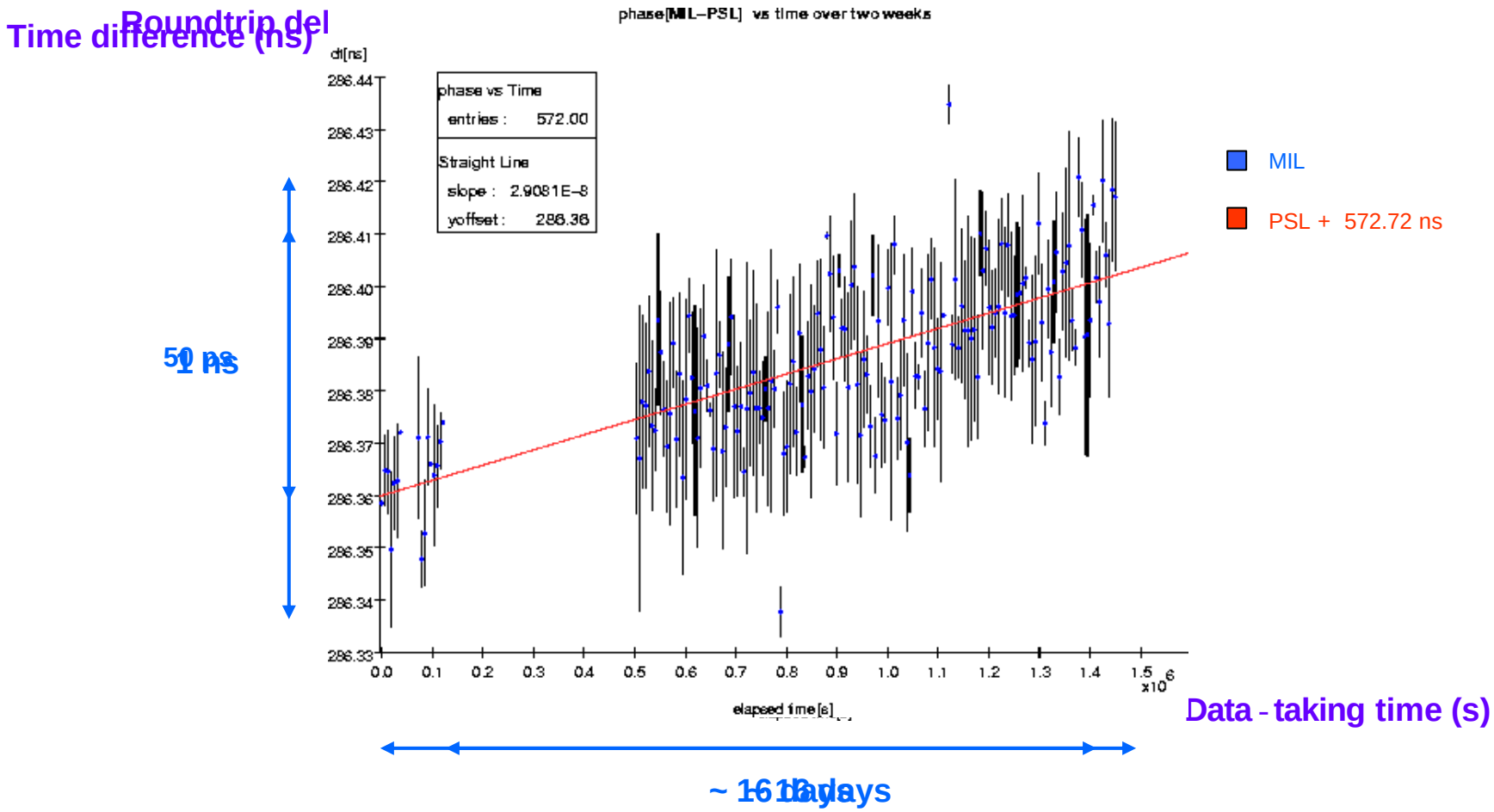
s~10 ps

One–shot difference:

<?> ~ 100 ps

Pre- Production Sector Line and Mini Instrumentation Line results

(Clock only reached SCMs due to broken fibre)



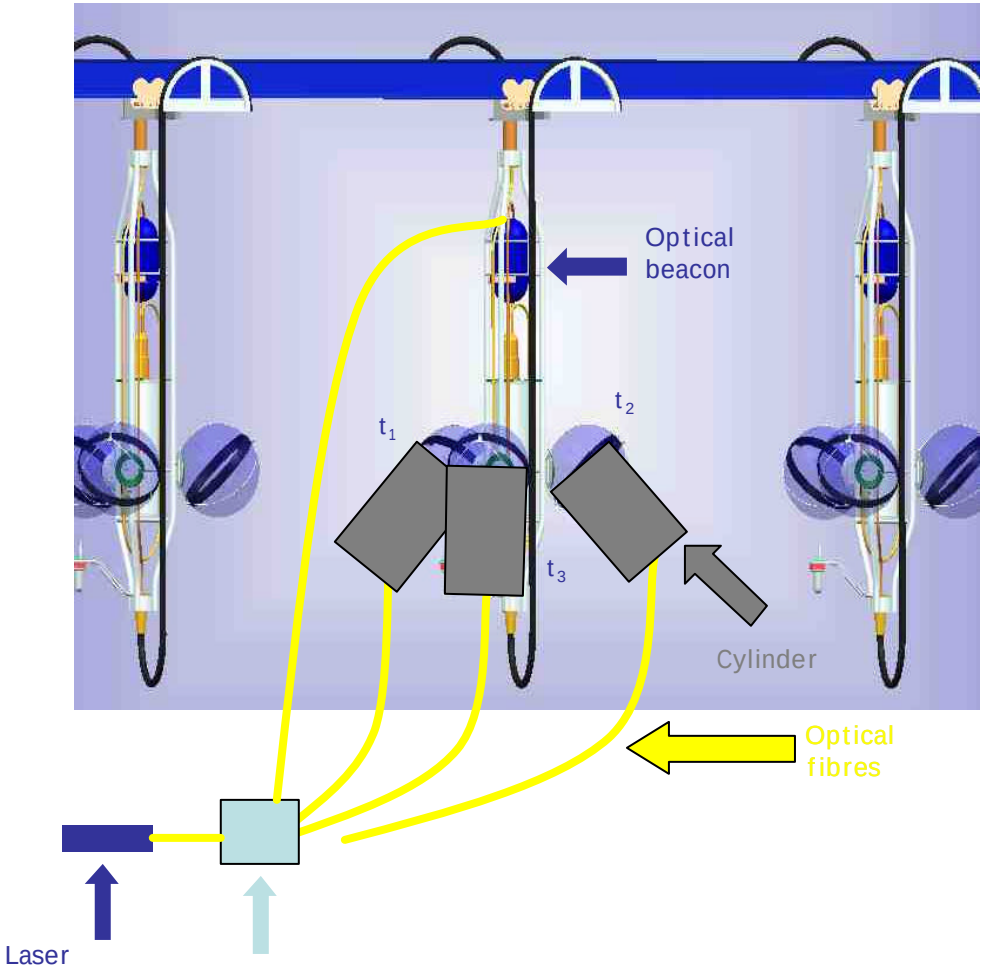
Roundtrip Time difference: ~420 ps + Total shift: ~286 ns ~800 ps Drift: ~60 ps Precision: 100 ps

Calibration in the Laboratory

Timing calibration in a dark room

- Before immersion the strings will be calibrated in a dark room at CPPM (Marseilles).
- Some of the built-in systems are used.
- A dedicated laser-fibre system is also employed.
- Once in the sea, the in-situ calibration will have these results as a reference.
- Dark room calibration with Pre-production Sector Line (PSL)

Laser calibration at the CPPM dark room

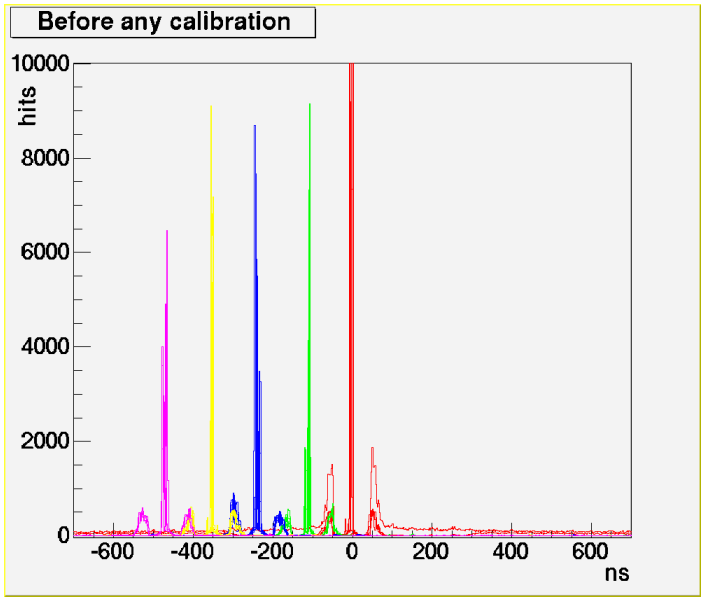


Time calibration in the Laboratory (results)

Time difference of laser pulses between ARS

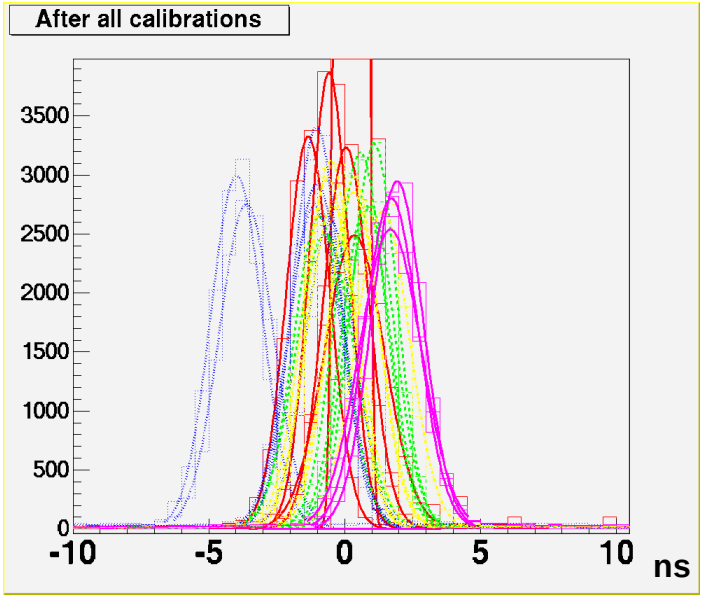
raw data Clock and TVC calibrations ☞ after

Nhits



A few 100 ns between two consecutive storeys due to difference in clock delay

Nhits



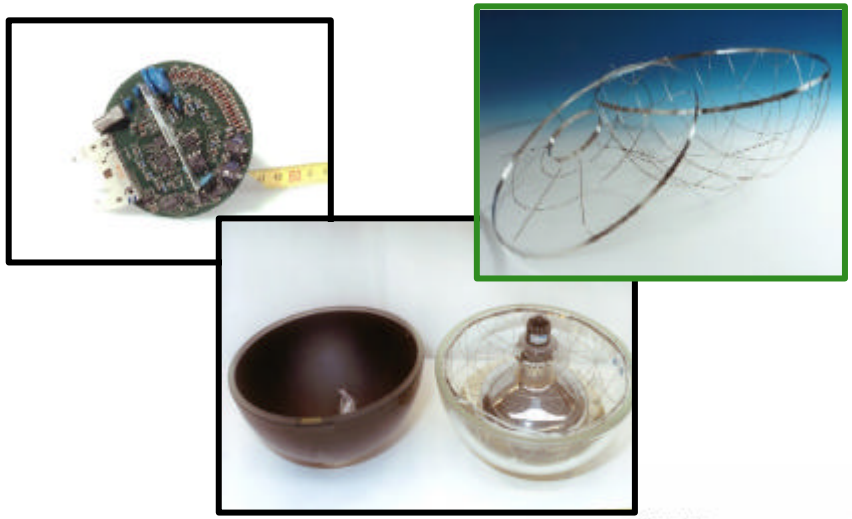
Differences due to TT and cables OM/LCM

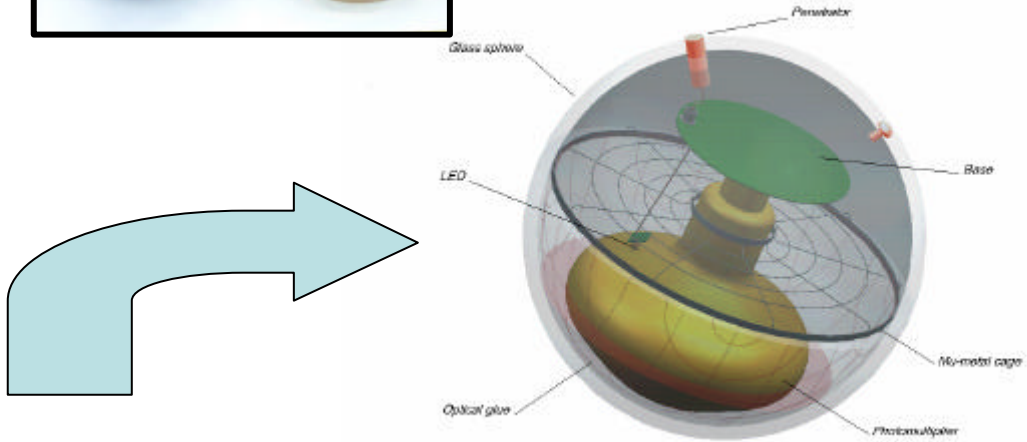
Pulsed LED

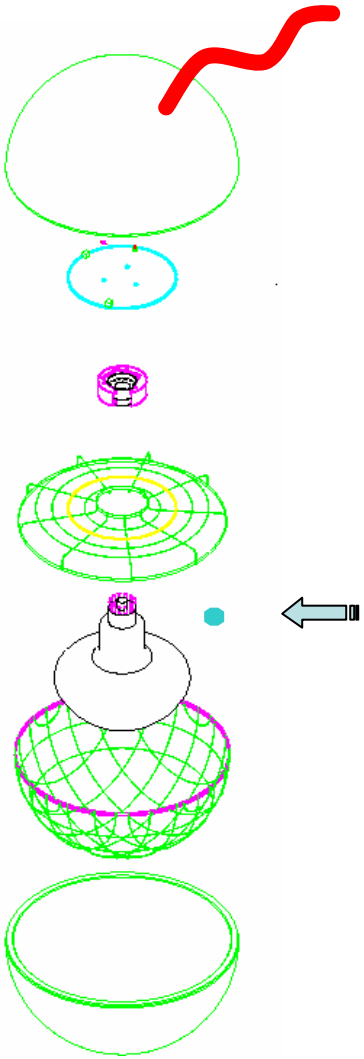
in

Optical Module

LED in Optical Module

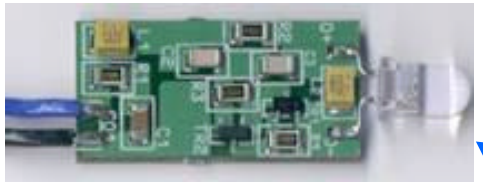






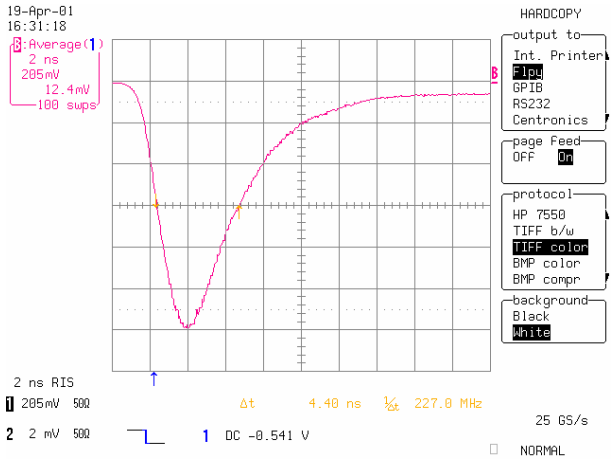
LED in OM
allows to monitor
Transit Time of PMT

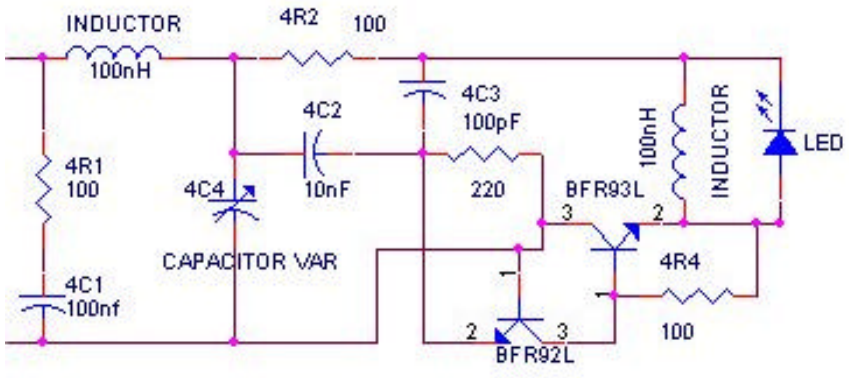
LED pulser



Sheffield pulser

Blue LED
Agilent
HLMP-CB15





based on Kapustinsky et al.
NIM A214, 612

Pulse rise time: ~ 2 ns
(10%–90%)

Pulse width: 4.5 – 6.5 ns

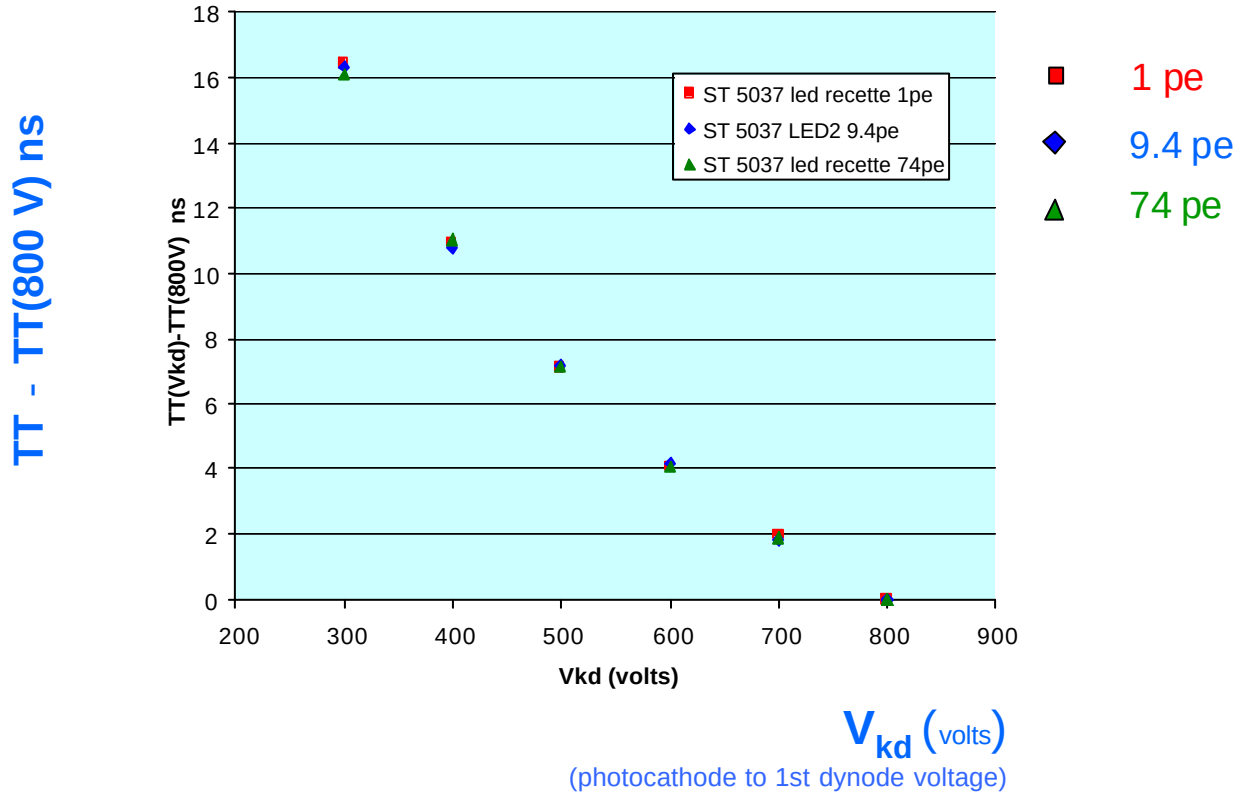
Jitter: ~100 ps

Light yield: 0–40 pJ/pulse
(attenuated by housing and Al coating)

Energy stability: ± 5%
(pulse-to-pulse)

Transit Time monitoring by the LED in the OM

Vda fixed (1025V)

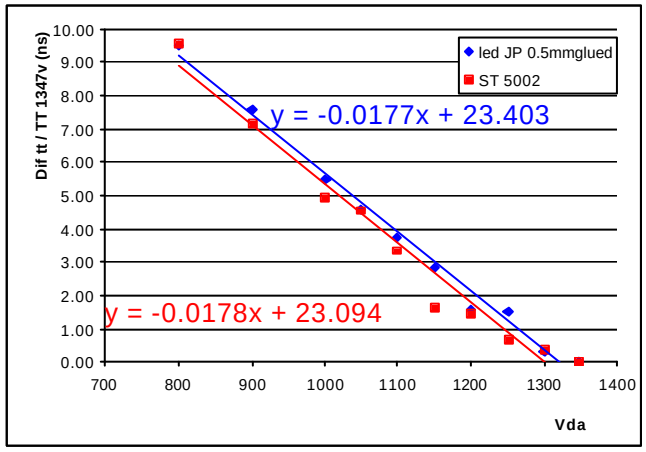


$TT(V_{kd})$ slope does not depend on N_{pe}

Transit Time monitoring by the LED in the OM

~3 pe

Vkd fixed (800V)

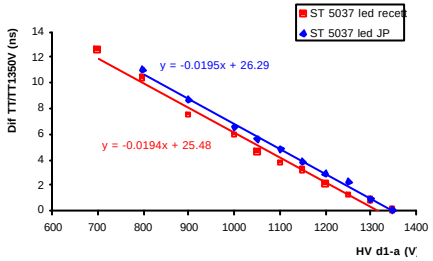


TT - TT(1347 V) ns

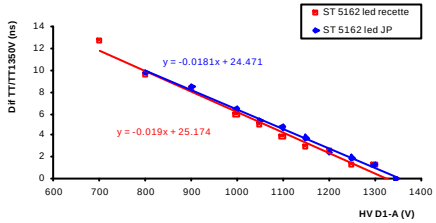
V_{da}(volts)

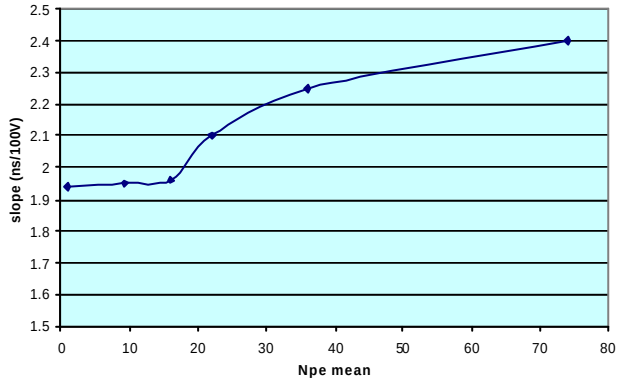
(1st dynode to anode voltage)

~10 pe



~21 pe





Slope (ns/100 V)

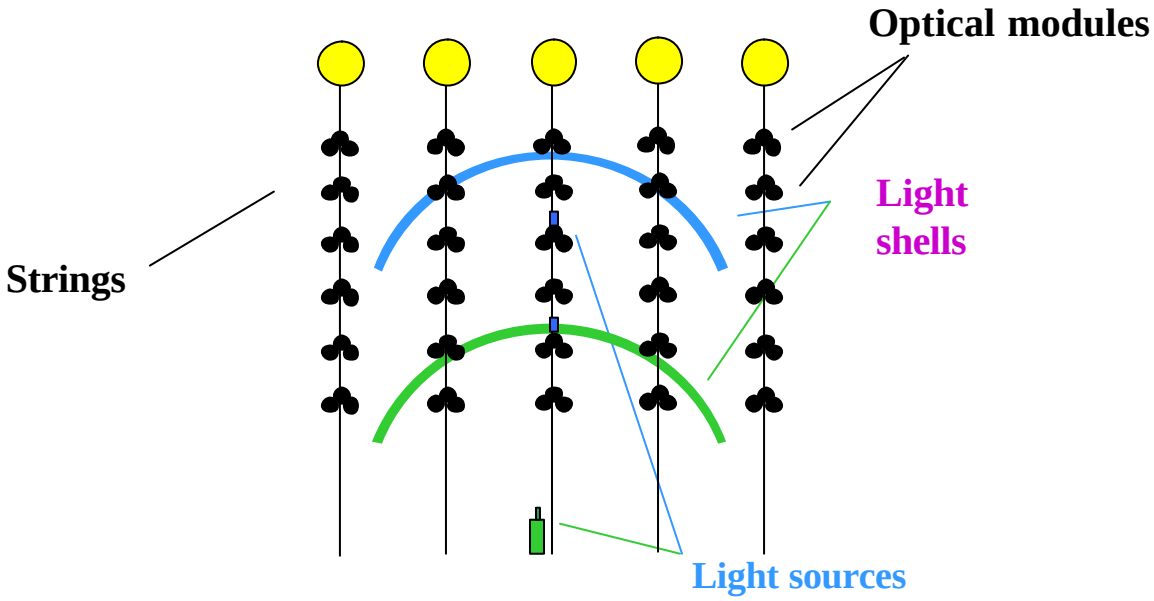
Average Npe

$TT(V_{da})$ slope does not change for $N_{pe} < 20$

$TT(V_{kd})$ and $TT(V_{da})$ can be reproduced to ±0.5ns

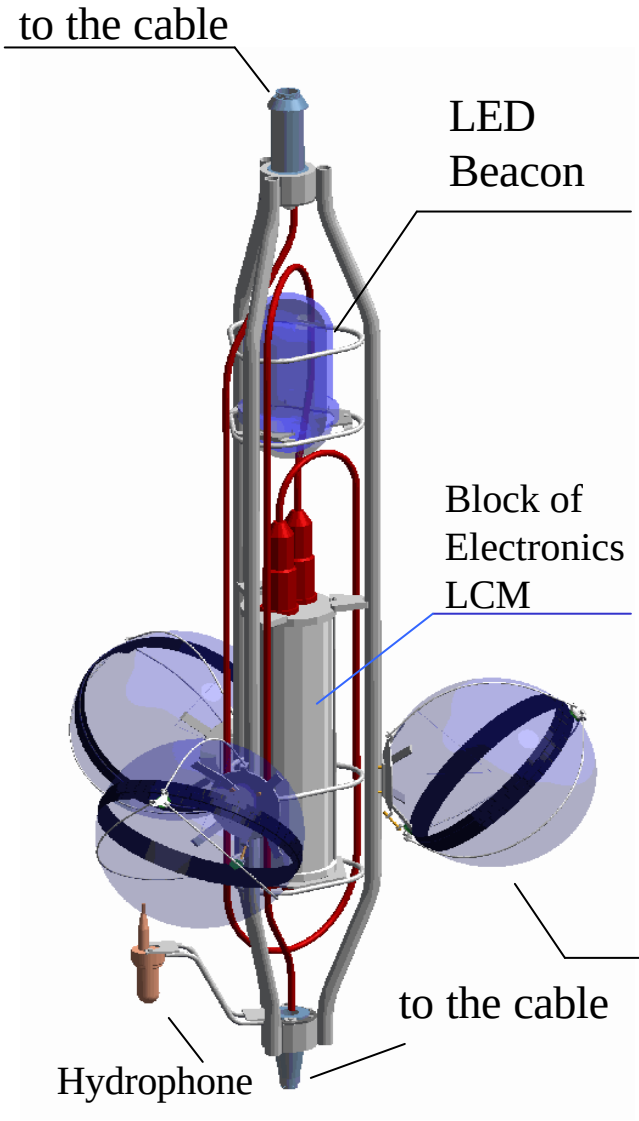
Optical Beacons

Optical Beacons

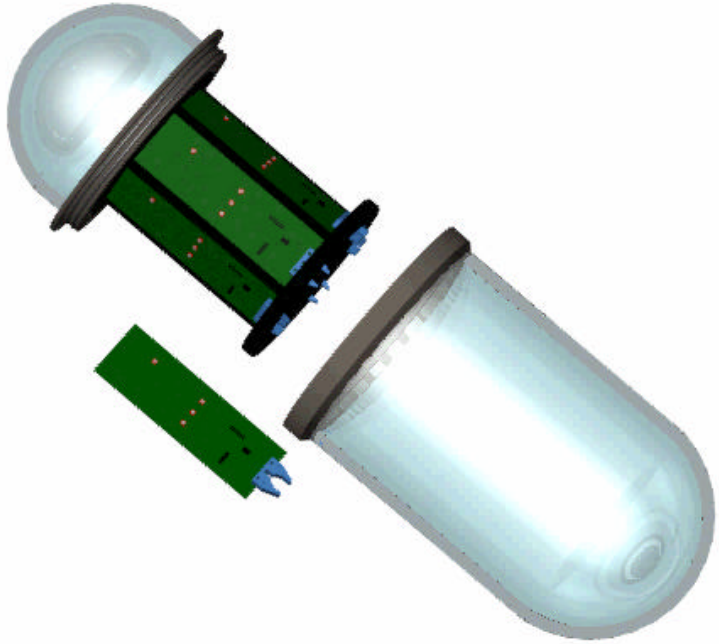


- Use well-controlled, external (pulsed) light sources
- Scattering and absorption ⇨ OB –OM distance = $?_{abs}$ or $?_{scat}$
- In ANTARES:
  - One LED beacon every 4/5 storeys.
  - Laser beacons at bottom of some strings.

LED Beacons in Sector Line

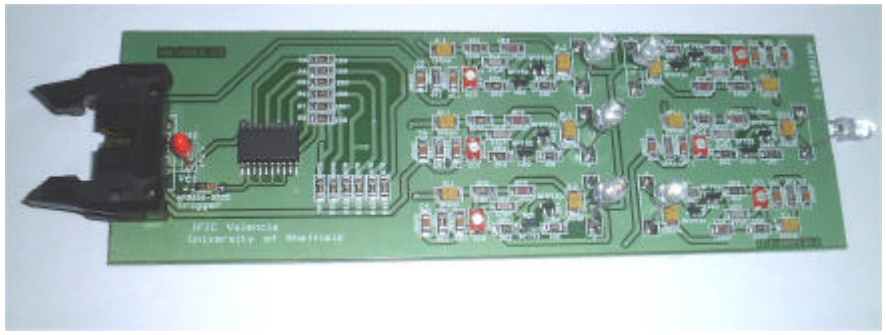


LED beacon

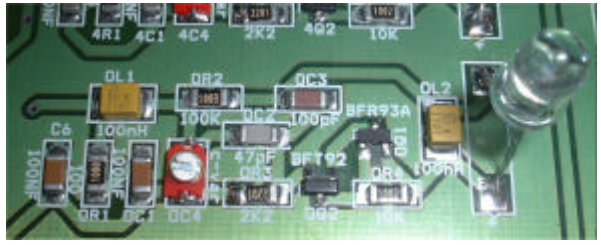


LED beacon components

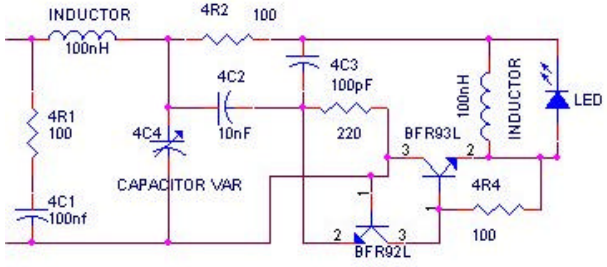
Hexagonal mounting
(six vertical faces)



Six LEDs per face
(one looking upwards)

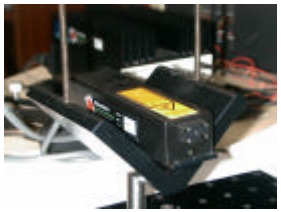


Sheffield pulser

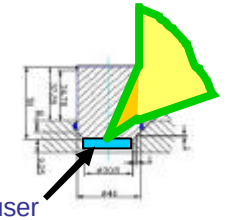


Laser beacon

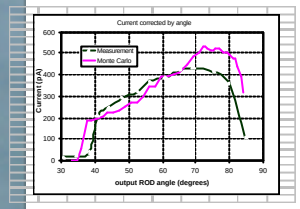
Laser beacon



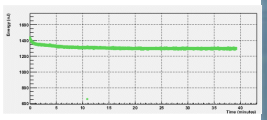
Nd-YAG laser
?= 532 nm (green)



Light exits through diffuser + quartz rod
(avoids sedimentation)



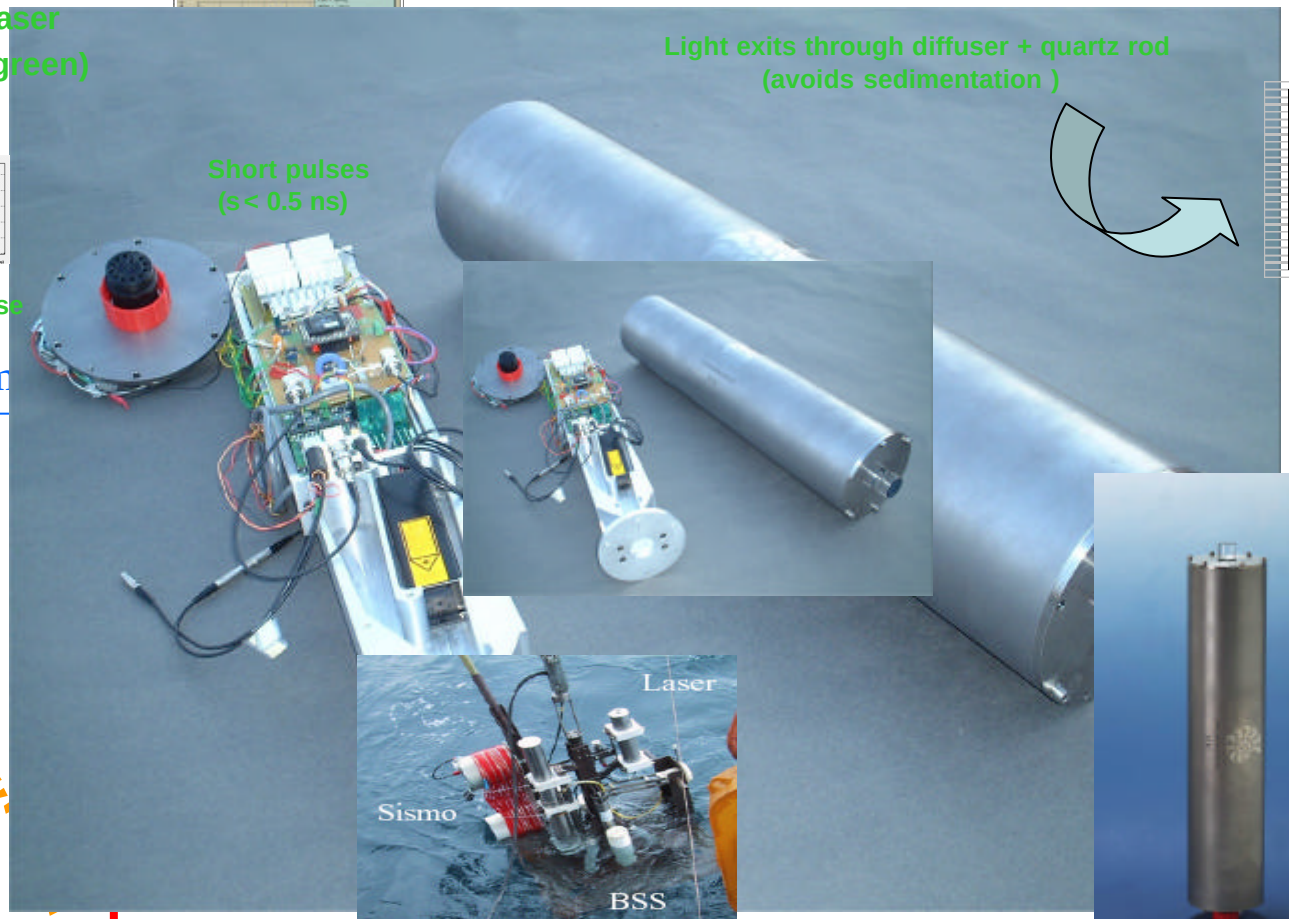
~ cos ?



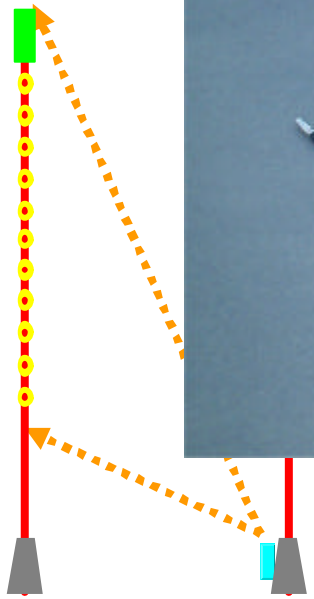
Stable energy per pulse
(after warm-up)

Short pulses
(s < 0.5 ns)

~60 m



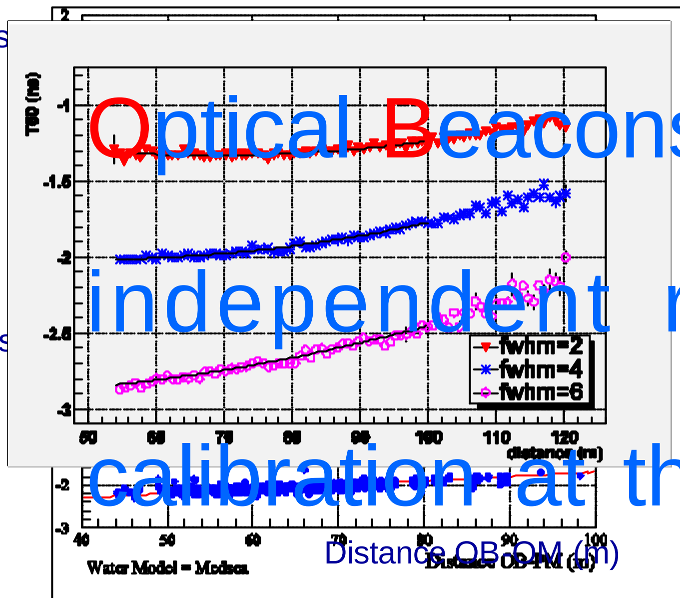
300 m

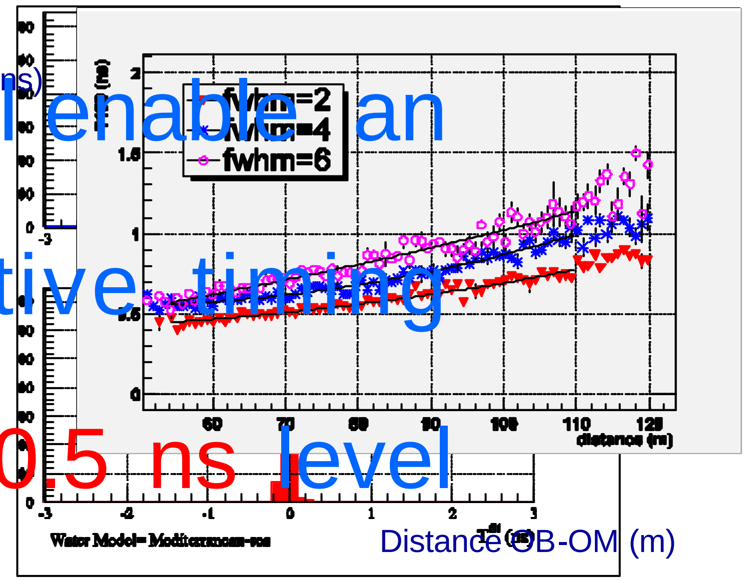


Laser Beacon at Bottom String Socket

Points upwards to
nearby strings

Optical Beacons - Monte Carlo results





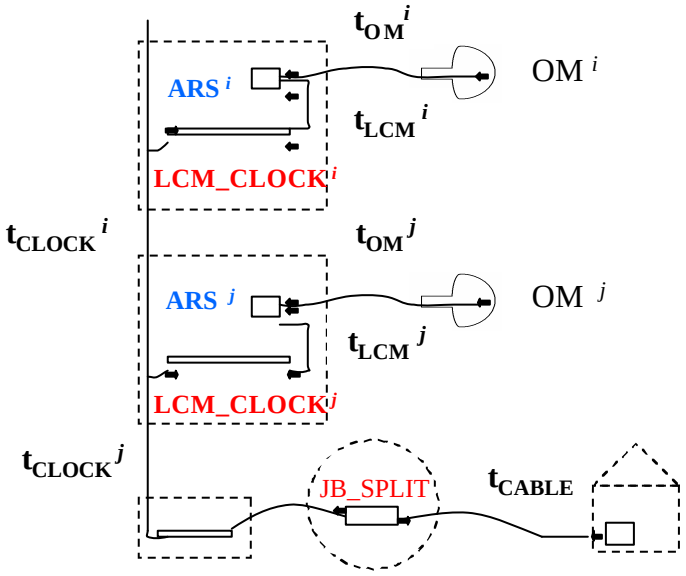
Optical Beacons will enable an independent relative timing calibration at the ~0.5 ns level

Source full width: 2 ns 4 ns 6 ns

T50, T90, T100 = Time at 50%, 90%, 100% of peak in the rising-edge

(if gaussian: X(a(%))= ±s v(-2•ln a(%)))

Off-sets, drifts and fluctuations…



	Photocathode ? ARS TVC	ARS TVC? LCM clock	LCM clock ? JB splitter	Master Clock ? JB splitter
Delay	~100 ns	~10ns	2–4 µs	~400 µs
Stability	~2 ns	<0.2 ns	<0.5 ns	~2 ns
Jitter	~1.3 ns	<0.8 ns	<0.1 ns	<0.1 ns
Dark Room,	✓	?	✓	–
Clock	–	–	✓	?
LED in OM	✓	?	?	–
Opt. Beacons	✓	?	?	–
Muons	✓	?	?	–

t_{OM} = PM cath to ARS TVC
t_{LCM} = ARS in to LCM clock
t_{CLOCK} = LCM clock to splitter in JB
t_{cable} = Sea and land cables

Defs.: Delay = ? t ; Off-set = t_0 ;
Stability = Labo-site calib change or drift with time
Jitter = event to event fluctuation

Calibs.: ✓ = from the very start (for this calibration system)
? = in the middle (contributes to this system)
– = no handle (for this system)

More info? ☞

Summary

- Timing calibration goals of **ANTARES**:
  - ~1 ms in absolute timing (internal clock w.r.t. UTC)
  - = 0.5 ns in relative timing (between OMs)
- Intrinsic (event by event) fluctuations:

$$s \sim 1.3 \text{ (PMT)} \oplus ? \text{ (medium)} \oplus 1.3 \text{ (electronics)} \oplus ? \text{ (medium)} \oplus 1 \text{ (electronics)} \quad \text{ns}$$

- Several complementary systems will be used. Cross-checks will be possible. Relative calibration of average t_0's will reach $s = 0.5$ ns

END OF TALK

HYPERLINKS and BACKUP SLIDES

ON_GPS

HP58540A:
10 MHz (± 10^{-11}/day) +
1 pps (UTC s~100 ns)
TLC2932 EVM:
20 MHz (frequency doubler)

ON_CLOCK

-Interface of PC clock with WDM
- START (to SYNPC and TDC) and STOP (TDC)
- Superimpose commands
- Monitoring

ON_WDM

Electro-optical converter uses
Wavelength **D**ivision **M**ultiplexing
?= 1534 nm (to JB)
?=1549 nm (from JB)

ON_SYNCPC1

PC - GPS synchronization via 1-pps signals

ON_CLOCK PC

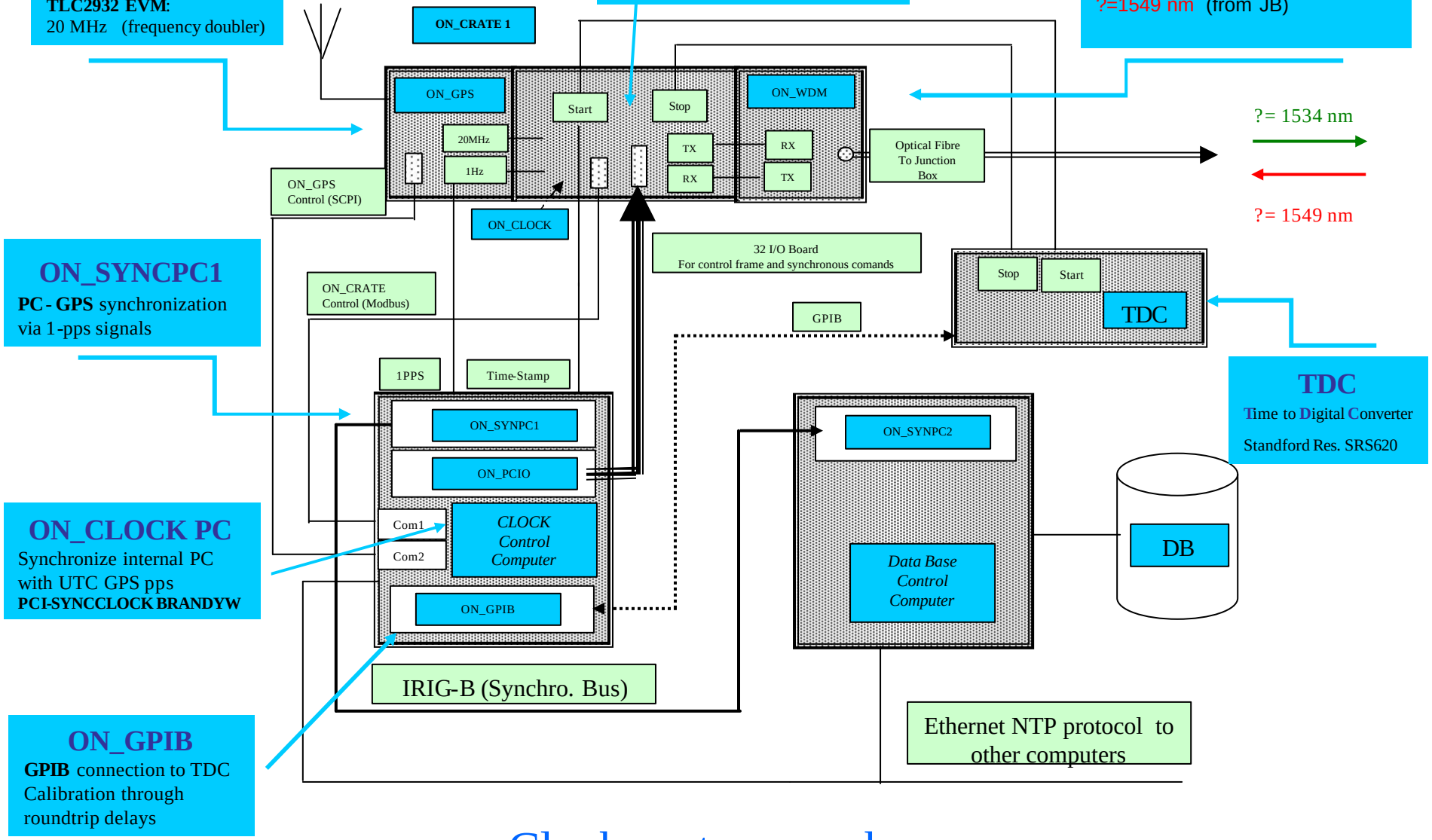
Synchronize internal PC with UTC GPS pps
PCI-SYNCCLOCK BRANDYW

ON_GPIB

GPIB connection to TDC
Calibration through roundtrip delays

TDC

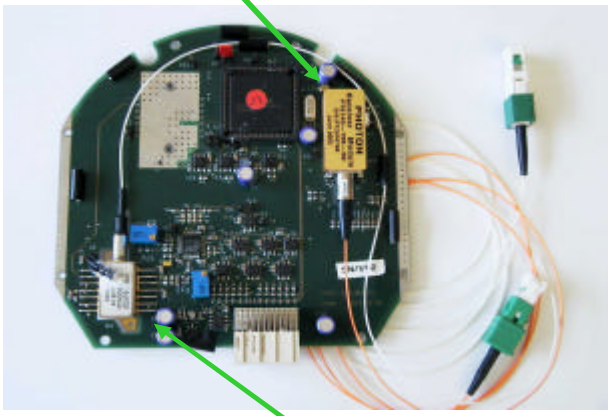
Time to **D**igital **C**onverter
Standford Res. SRS620



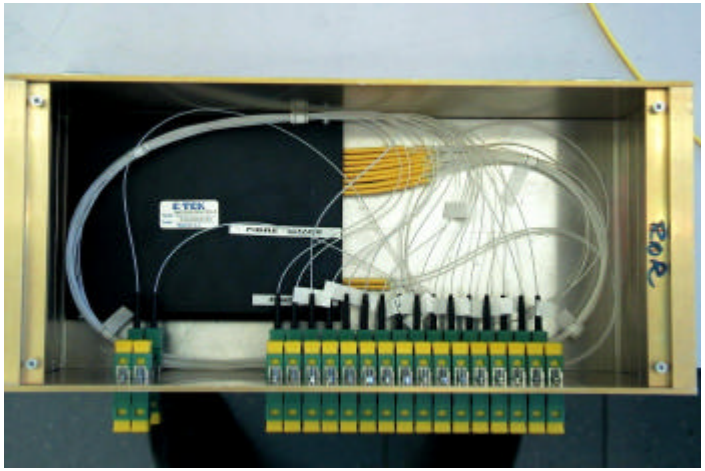
Clock system on-shore

Components of the clock system

PIN diode receiver module



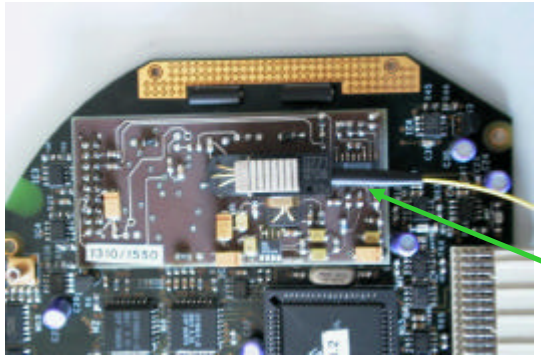
WDM laser module



Input from MEOC

Output to SCMs

Junction Box
Passive Splitter

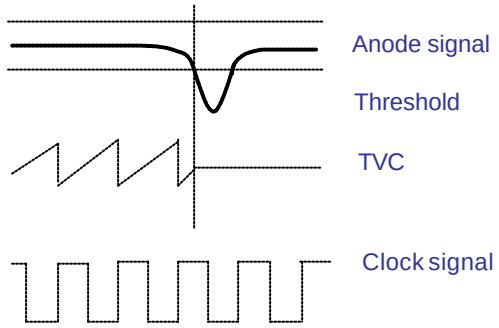


BIDIANT board
(SCM and LCM Containers)

Off-sets, drifts and fluctuations (more info)

t_{OM} = PM cath to ARS TVC
t_{PM} = 48 ns @ V_{kd} =800 V
57 ns @ V_{kd} =362 V
Vkd dependence ~33 ps/V
TTS = 1.3 ns (Vkd ~ –1ps/V)
V_{kd} time stability 0.16 V
Expected variations:
Channel-to-channel: ~10 ns
Labo to Sea: ~5 ns
Time drift: ~ 2 ns

t_{ARS}
s < 0.8 ns
Variations mostly due to TVC
Stability ? 4.3 ns/V + 33 ps/°C
(0.1 ns ⊕ 0.6 ns)



t_{LCM} - due to electronics and cables
Delay ~ 10 ns
Stability <0.2 ns

t_{CABLE}
Temperature variation 35 ps/K/km
Part in the Sea ? very stable (<0.5 ns)
Land cable: ~ 1ns
(contributes to absolute timing only)

t_{CLOCK}
Stability: s < 0.05 ns
Variations mostly due to TVC
Stability ? 4.3 ns/V + 33 ps/°C
(0.1 ns ⊕ 0.6 ns)
Clock to GPS precision: 1.3 ns

Light absorption and diffusion

Water transparency:

- **Blue light (470 nm)**

  $\lambda_{abs} \sim 60 \pm 8$ m

  $\lambda_{scat\ eff} \sim 265 \pm 30$ m

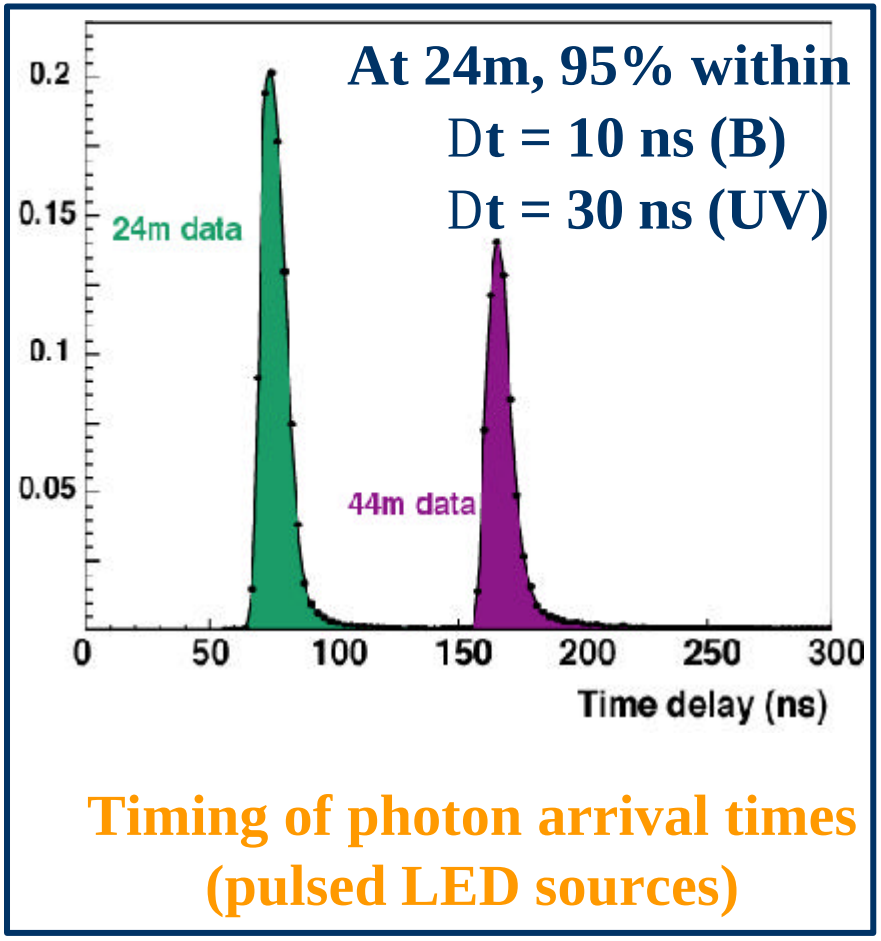
- **UV light (370 nm)**

  $\lambda_{abs} \sim 26 \pm 2$ m

  $\lambda_{scat\ eff} \sim 120 \pm 4$ m

(Errors reflect variations between different measurements)

$$\lambda_{scat\ eff} = \frac{\lambda_{scat}}{1 - \langle \cos\theta \rangle}$$



Timing of photon arrival times (pulsed LED sources)

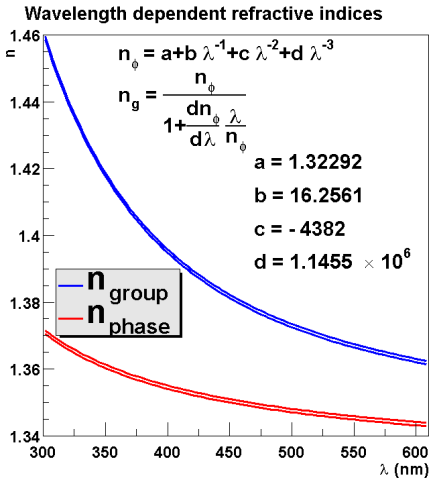
Chromatic dispersion

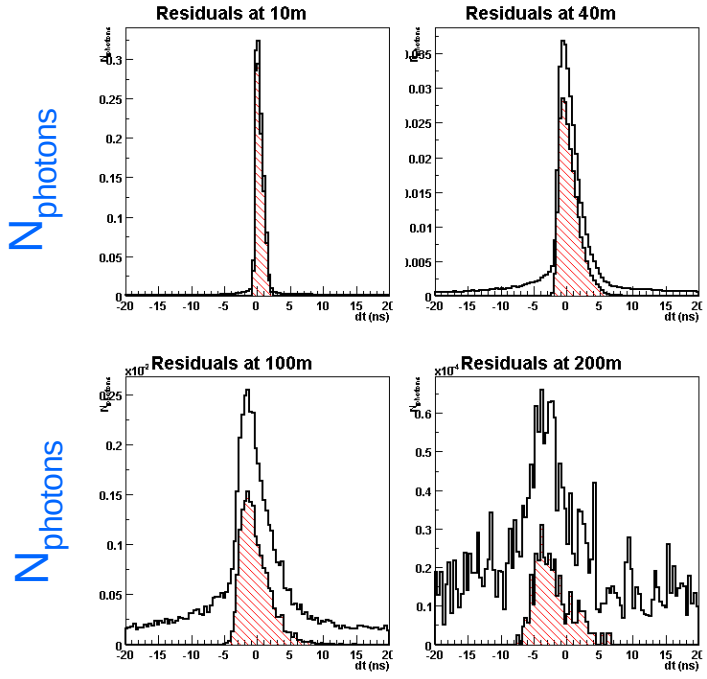
- Cherenkov angle is determined by phase refractive index, propagation time by group velocity (i.e. group refractive index):

$\cos ?_c = 1/ ß \cdot n_f \qquad v_g = c/n_g \qquad$ where: $\qquad n_g = \dfrac{n_f}{1 + \dfrac{l}{n_f}\dfrac{dn_f}{dl}}$

- Our detector is colour blind: a definite ? must be chosen (we use ?=460 nm). This introduces time shifts (can be corrected) and spreads (depend on distance)
- Monte Carlo shows that scattering does not introduce an additional spread up to distances of 50 m (it makes the light less “chromatic”).

Overall chromaticity + scattering effects





residuals ($t - L_c \times n(460\ nm)/c$)

Distance from track (m)	s_{medium} (ns)
10	0.68
40	1.3
100	2.8
200	5.9

Pieces, parts and spares