STRAW

STRINGS FOR **A**BSORPTION LENGTH IN **W**ATER

PATHFINDER FOR A POTENTIAL NEW NEUTRINO TELESCOPE SITE IN THE PACIFIC OCEAN

PD18, Tokyo

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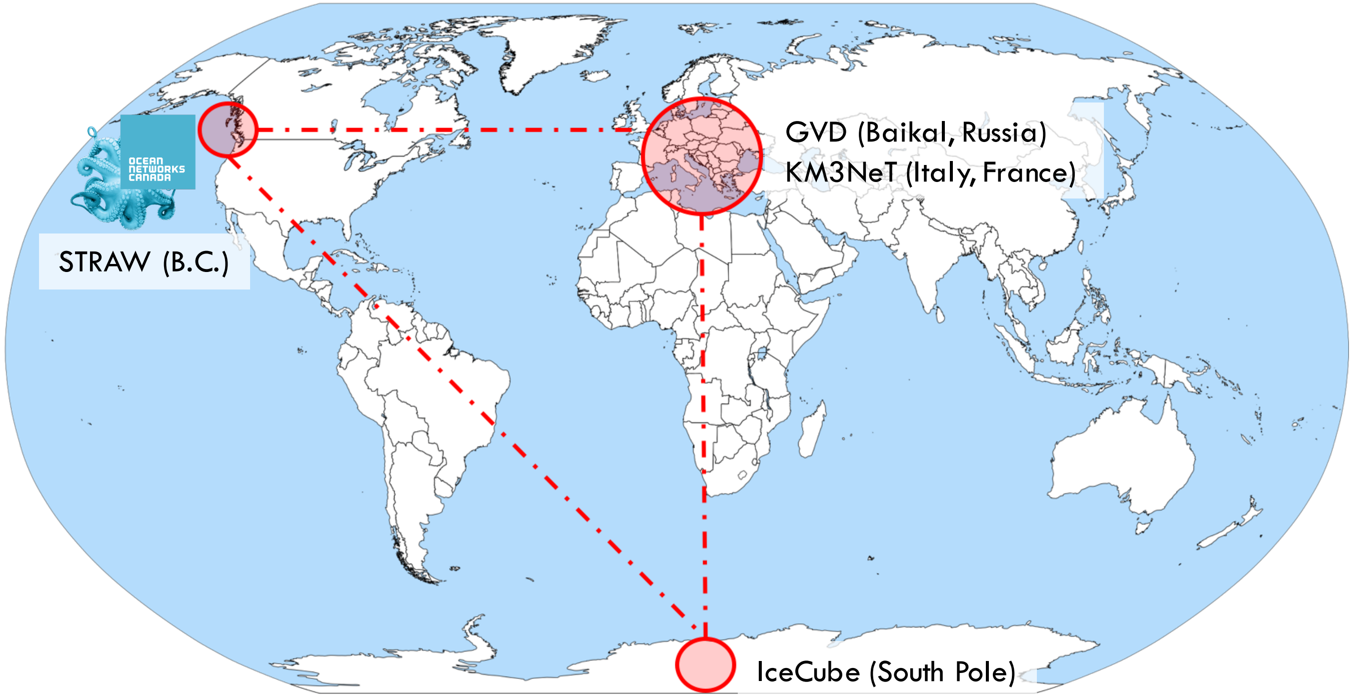
SFB 1258 Neutrinos Dark Matter Messengers
Technische Universität München

OVERVIEW

- Neutrino Telescopes
- STRAW - Concept and design
- Instrumentation - POCAM and sDOM
- PMT characterization
- Bioluminescence and preliminary measurements
- Summary

NEUTRINO TELESCOPES

- Astrophysical neutrinos: ideal messenger particle.
- To detect a significant number of neutrinos it would be necessary to increase the size of these telescopes by several orders of magnitude
- EXTEND and CONNECT: global collaborative network of cubic-kilometre neutrino telescopes → right framework for STRAW



STRAW – CONCEPT AND DESIGN

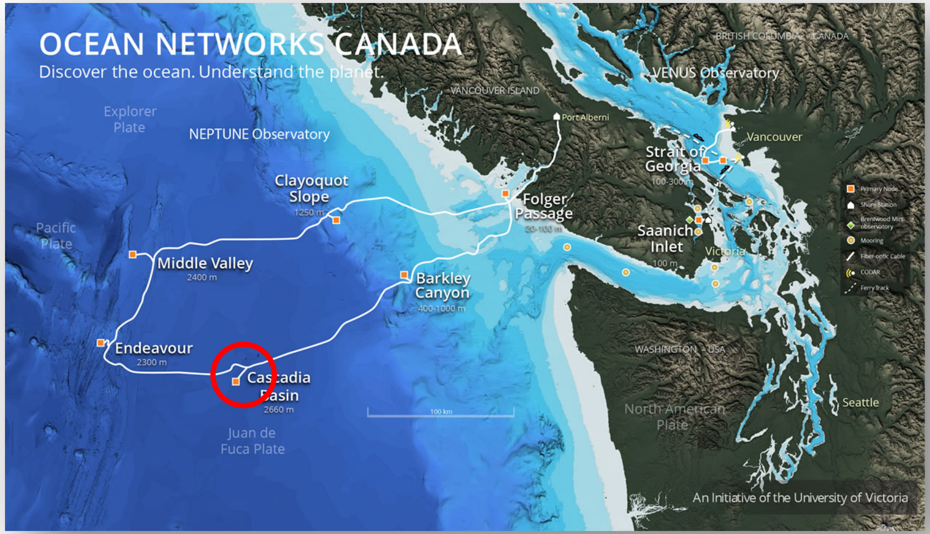
STRAW: investigation of deep-sea water optical properties (scattering length, absorption length, evironmental background)

feasibility studies for a large scale *Neutrino Telescope* at Cascadia Basin (2600m b.s.l.)

⬇

Ocean Networks Canada (ONC)
http://www.oceannetworks.ca/

- site is already cabled with large sub-sea infrastructure
- ~10 y of experience with deep sea deployments/operation

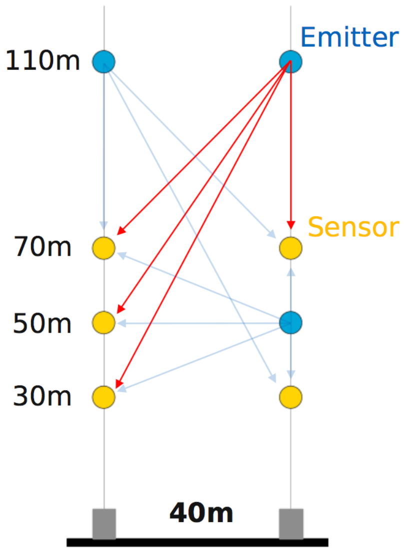


August 2017: idea — 24th June 2018: deployment — July 2018: data taking

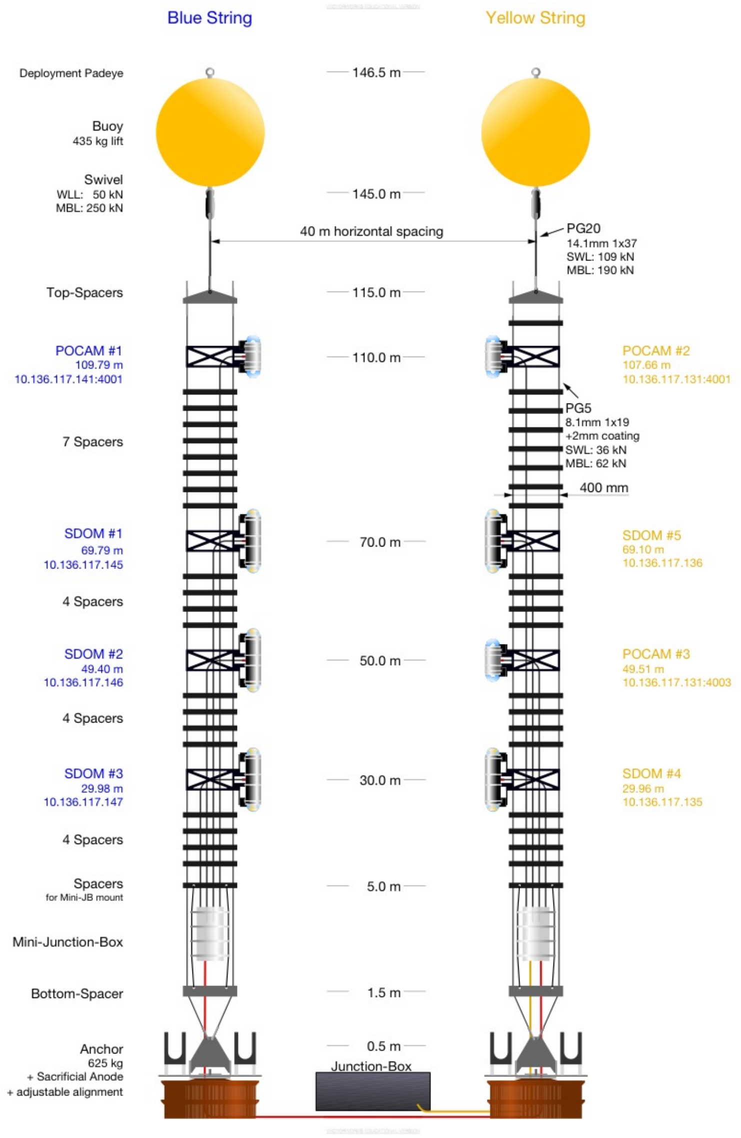
STRAW timeline

STRAW – CONCEPT AND DESIGN

- 120 m length two-string detector with 8 instruments
- **3 light sources** - POCAM, Precision Optical Calibration Module
- **5 light sensors** - sDOM, Straw Digital Optical Module

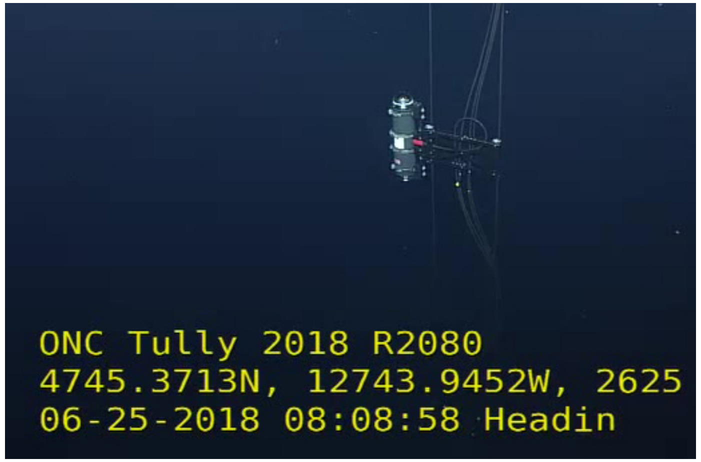


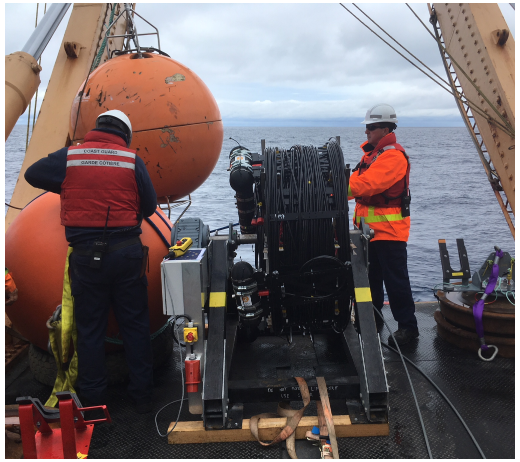
The expected maximum value for the absorption length in water is around 50 m, therefore STRAW geometry has been chosen in order to cover distances from 20 m to 90 m.

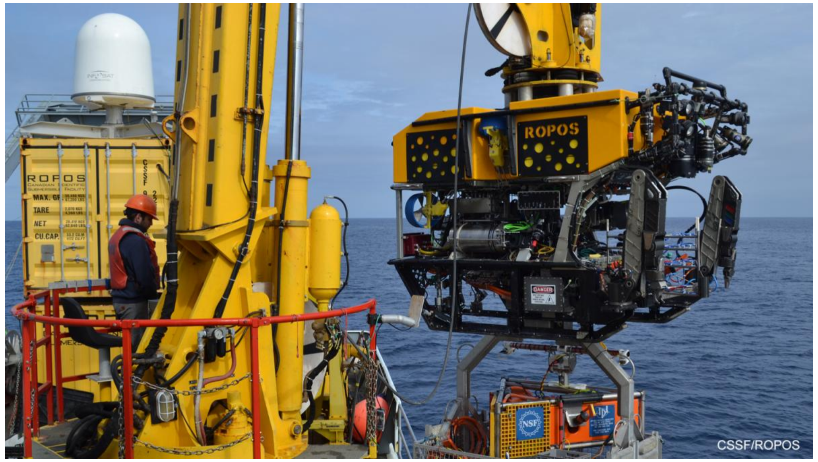


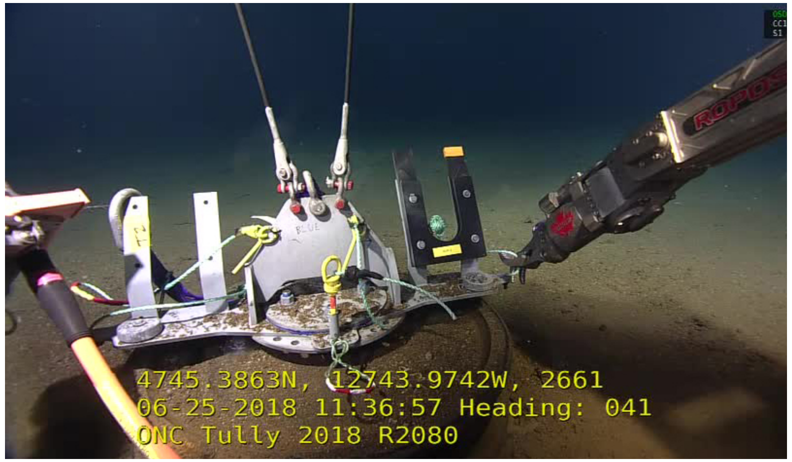
DEPLOYMENT

- Motorized spooling system for shipment and deployment
- Rotational anchor for ROV alignment of the strings
- Post-deployment rotation
- Mechanical design minimizes bending and rotation in currents







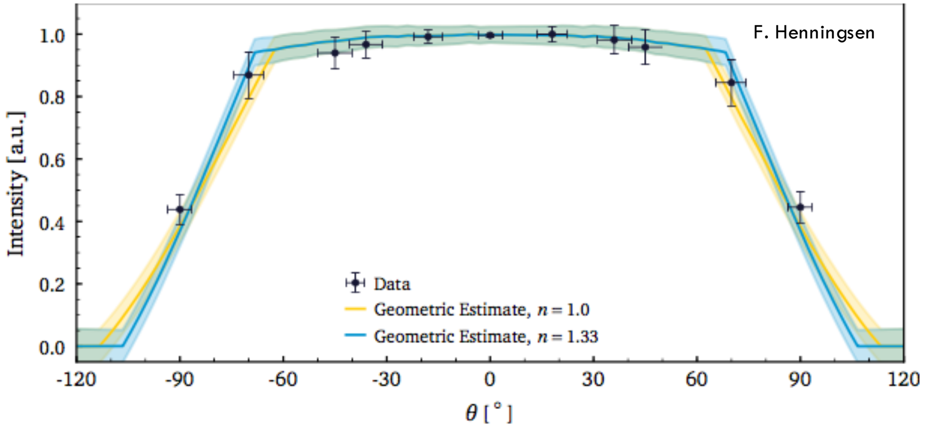


POCAM - CALIBRATION UNIT

Precision **O**ptical **CAL**ibration **M**odule

The science goal: reduction of systematic uncertainties by improving the calibration of individual DOMs and understanding the optical properties of the ice/water (IceCube Gen2 will deploy several POCAMs in the first 7 new strings for the upgrade 2020-2022)

- Create isotropic nanosecond light flashes using a PTFE inverted integrating sphere coupled to an LED matrix
- Multi-wavelength emission for spectral studies
  GVD: 470, 525 nm
  STRAW: 365, 405, 465, 525, 605 nm
- The light output is monitored by dedicated photosensors (SiPM, Photodiode)



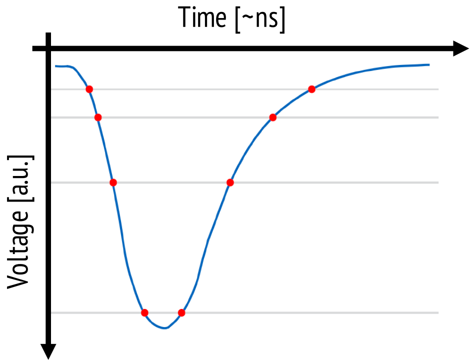
Preliminary POCAM hemisphere emission profile in air. Shown are measured and expected isotropy with respect to polar angle in air (yellow) and water (blue) as outer medium with indicated refractive indices.

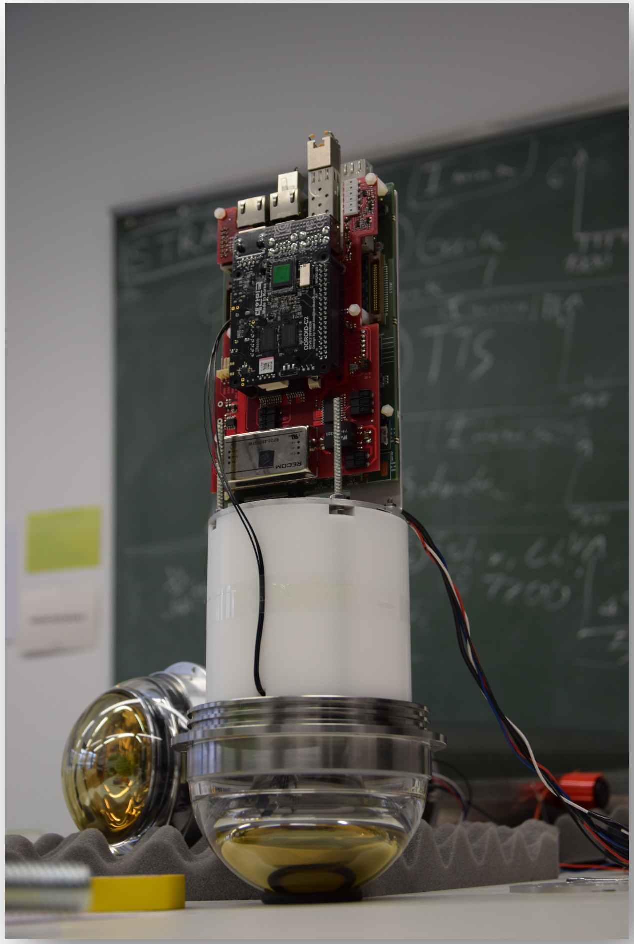
SDOM

STRAW **D**igital **O**ptical **M**odule

The science goal: measuring bioluminescence (main emission spectrum 440-540 nm), ^{40}K decay (Cherenkov light), POCAM Light

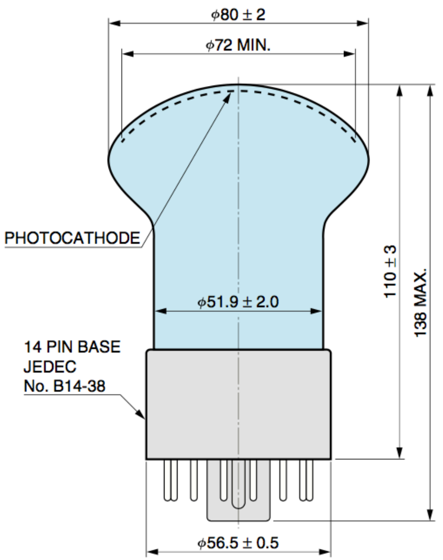
- Titanium housing based on proven POCAM design (longer for electronics) - qualified up to 600 bar
- 3“ PMTs with optical gel in both ends glass hemisphere
- Readout with TRB3 and PaDiWa (TDC designed by GSI): http://trb.gsi.de/
- Control via Ethernet and single board computer Odroid C2
- 4 channels for each PMT

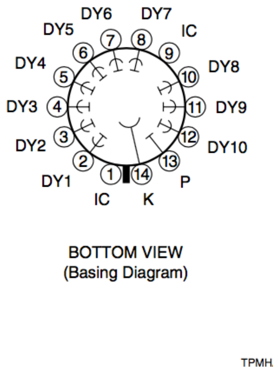




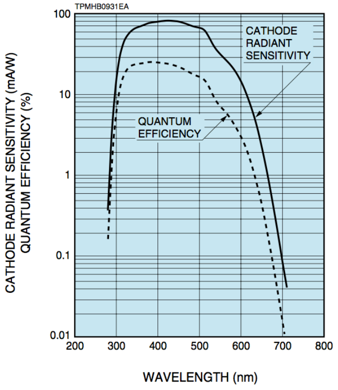
PMT – HAMAMATSU R12199

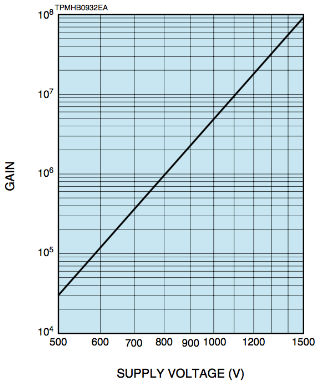
The PMT chosen is the R12199 from Hamamatsu powered with the active base C12842-02 MOD





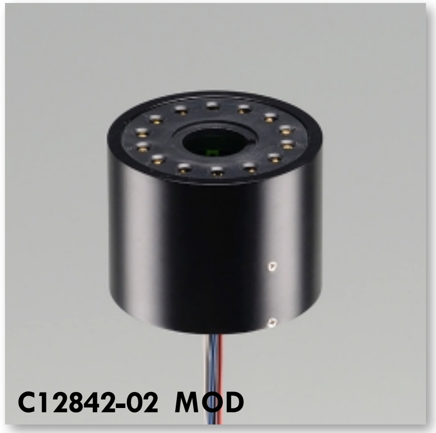
Parameter		Description / Value		Unit
Spectral Response		300 to 650		nm
Wavelength of Maximum Response		420		nm
Window Material		Borosilicate glass		—
Photocathode	Material	Bialkali		—
	Minimum Effective Area		72	mm
Dynode	Structure	Circular and linear-focused		—
	Number of Stages	10		—
Base		JEDEC No. B14-38		—
Operating Ambient Temperature		-30 to +50		°C





Supply Voltage	Between Anode and Cathode	1500	V
	Between Anode and Last Dynode	300	V
Average Anode Current		0.1	mA

C12842-02 MOD
Cockcroft-Walton type high voltage power supply: ensures high output linearity of photomultiplier tube while maintaining low power consumption.



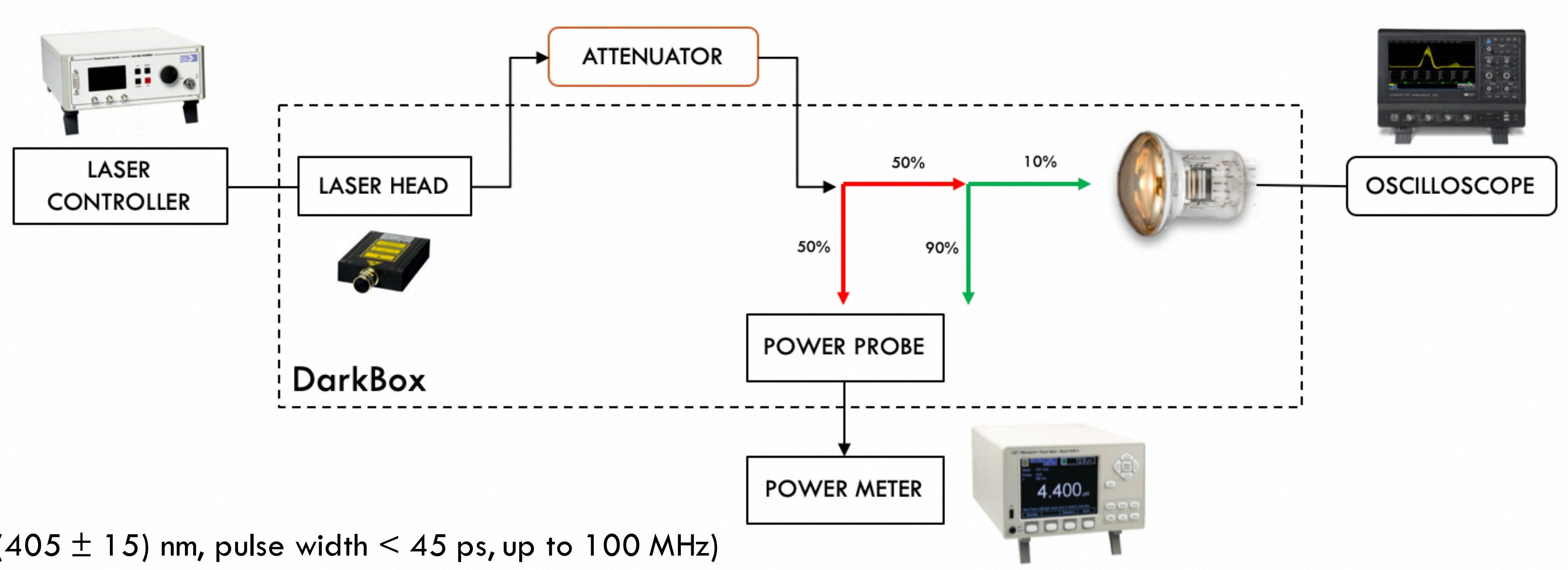
PMT CHARACTERIZATION

As a preliminary step, an extensive characterization campaign on the adopted PMT has been carried out.
Goal: find the optimal working point for the PMTs, tailored on application features

In order to achieve a homogeneous response of the system, all the PMTs have been set at the same **gain**

Measured quantities:

- single photon-signal amplitude/charge
- gain
- dark counts
- TTS
- linearity



Setup used:

- picosecond pulsed laser (PiLas, λ =(405 ± 15) nm, pulse width < 45 ps, up to 100 MHz)
- optical attenuator (PiLas, attenuation range 0 to -80 dB)
- two different optical fiber splitters (50% and 10-90% emission ratio)
- power meter (Newport 2936-R) with power probe (Newport 918D-UV-OD3R)
- oscilloscope (Teledyne LeCroy HDO6054, 500 MHz, 2.5 GS/s).

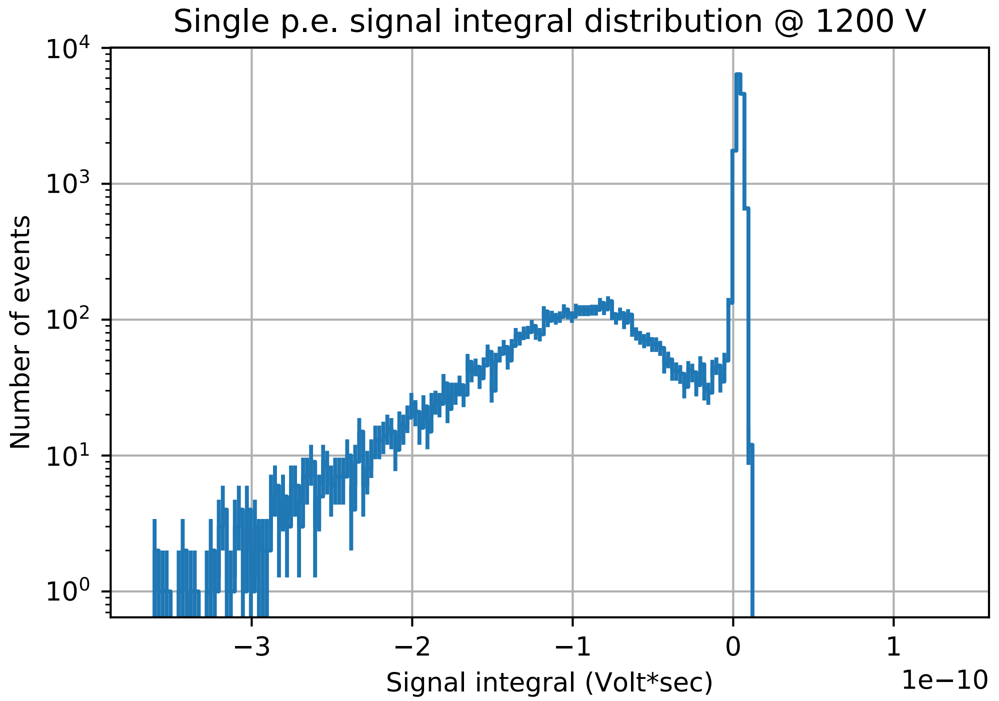
Insertion losses and attenuation of the overall system have been measured with the calibrated power probe

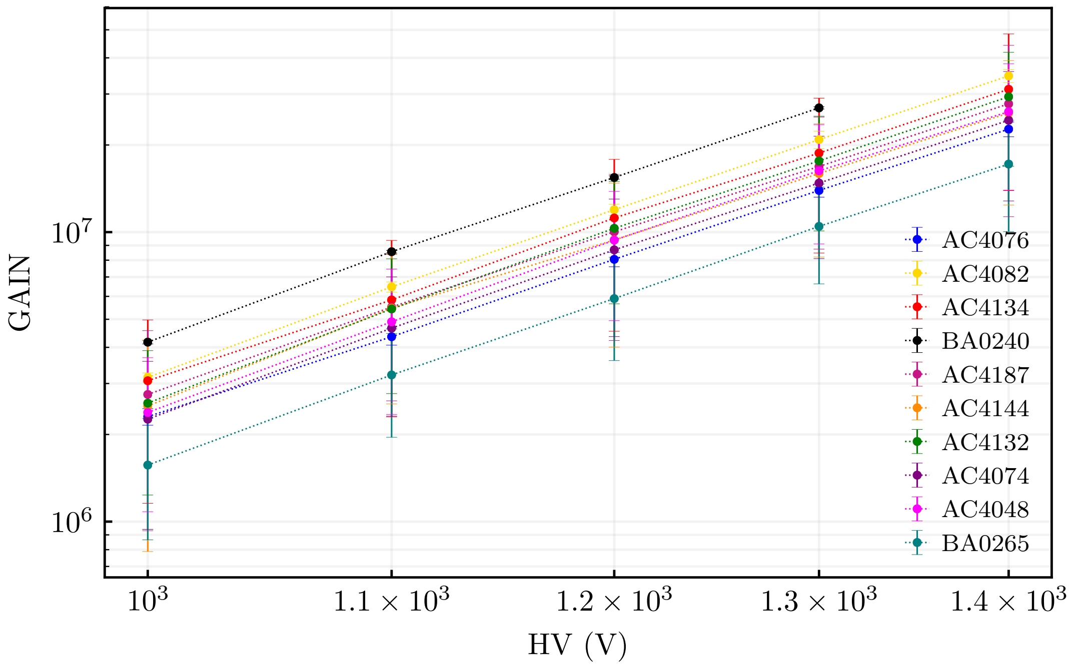
PMT - GAIN

Gain:

- The first step has been measuring the single photoelectron charge at different HV values in order to calculate the gain of the PMTs: this has been done after scaling down to the single photon level the laser light emission.
  The acquisition has been done by the oscilloscope using the external trigger provided by the laser source.

- Gaussian fit of the single photon peak.



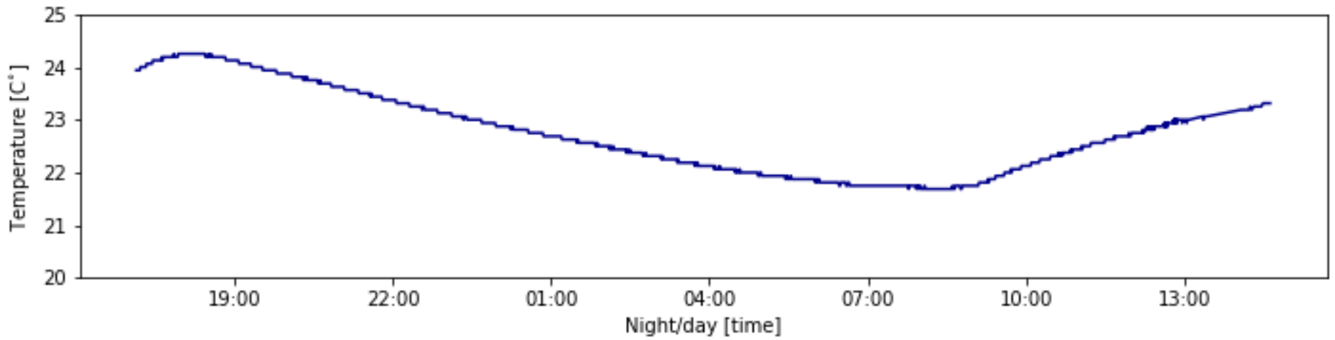


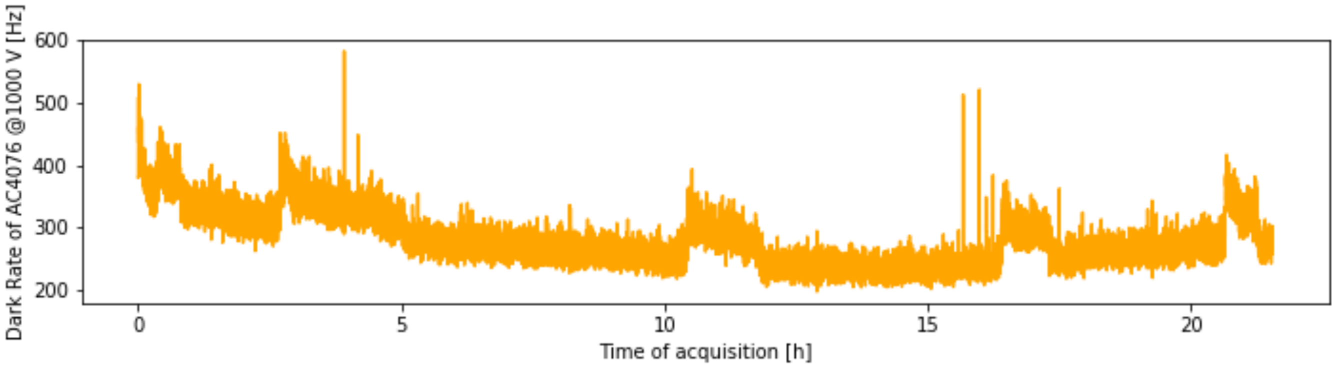
Each PMT has been tested with its own socket.

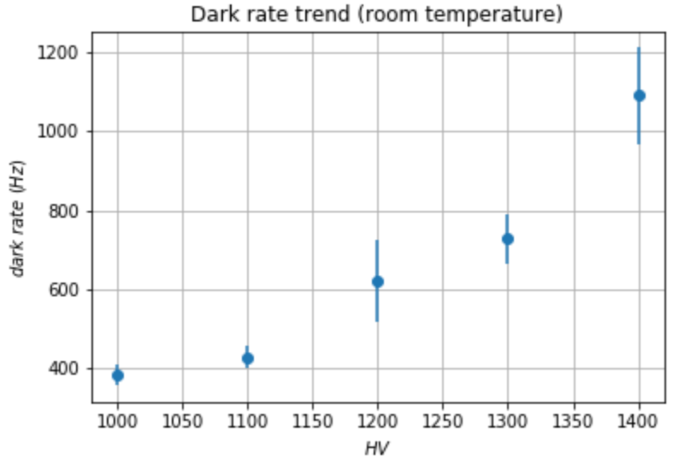
PMT– DARK COUNTS

Dark counts:

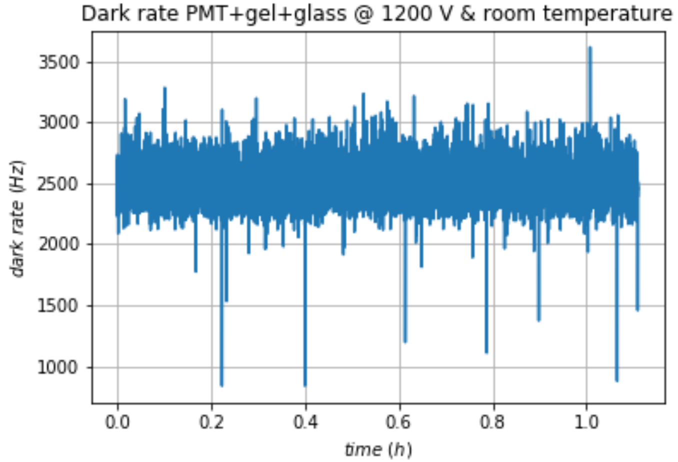
- long-term monitoring of the dark rate trend revealed a day-night modulation induced by a slight temperature change in the laboratory.
- this modulation is no matter of concern: in final working conditions (2600 m depth b.s.l.) STRAW will operate at a (stable) temperature of about 2◦C.





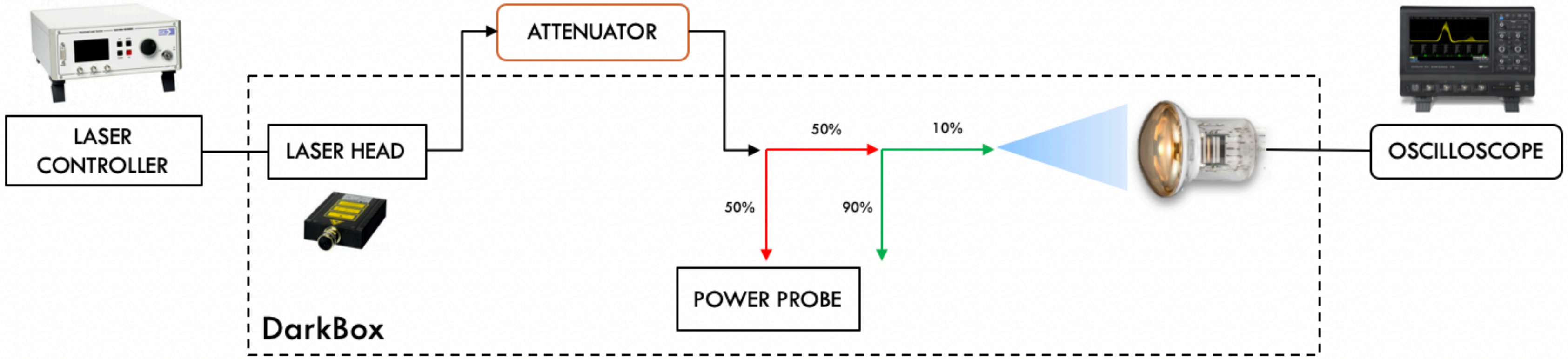


Measures taken after 24h of pre-darkening and with 1/3 p.e. threshold

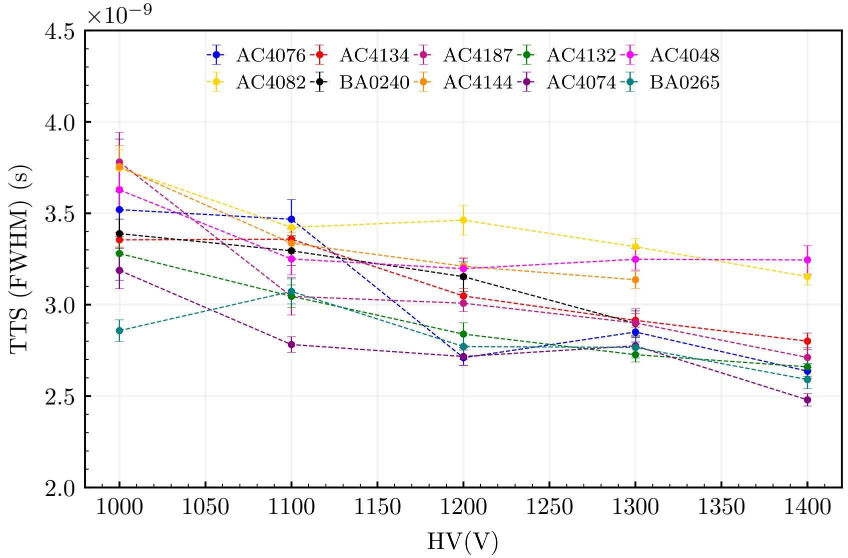


Due to the radioactivity of the glass.

PMT – TRANSIT TIME SPREAD



- Photocathode fully illuminated with single photons
- The external trigger of the Laser Controller is used as START
- The output from the PMT is fed as STOP signal via a discriminator
- Measure the time interval between the "start" and "stop" signals (TTS is the FWHM of the distribution)



Results are in agreement with Datasheet and with the TTS measurements done by the KM3NeT collaboration on the same type of PMTs. [S. Aiello et al. Characterisation of the Hamamatsu photomultipliers for the KM3NeT Neutrino Telescope. *JINST*, 13(05):P05035, 2018].

Each PMT has been tested with its own socket: the high voltage power supply of the PMT is enabled after setting the control voltage of the socket.

PMT – LINEARITY AND DYNAMIC RANGE

Mandatory to define the working point of the PMTs

- The dynamic range of the PMTs is expected to decrease with higher HVs (due to current saturation effects)
- Based on the expected amount of light emitted by POCAM, the ideal working point for the PMTs must meet the needs of high gain and linear regime.

The number of incoming photons has been measured directly with the power meter, scaling for the calibrated attenuations and insertion losses of the system.
The number of photoelectrons at the first dynode has been calculated as follows:

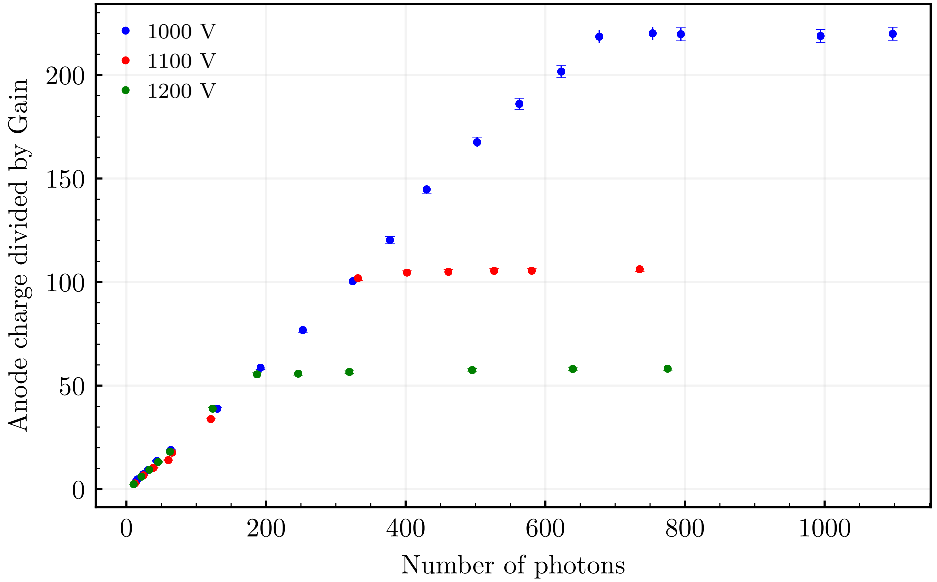
$$N_{pe@1st\ dynode} = \frac{Q_{tot}}{G \cdot q_e}$$

where G is the measured Gain, Q_{tot} is the measured total anode charge and q_e is the electron charge.

In the linear region: the slope of the fitted lines is the ratio between the number of photoelectrons that reach the first dynode and the number of incoming photons on the photocathode

$$\frac{N_{pe@1st\ dynode}}{N_{ph}} = QE \cdot CE$$

that is the overall efficiency (product of Quantum Efficiency and Collection Efficiency) of the PMT



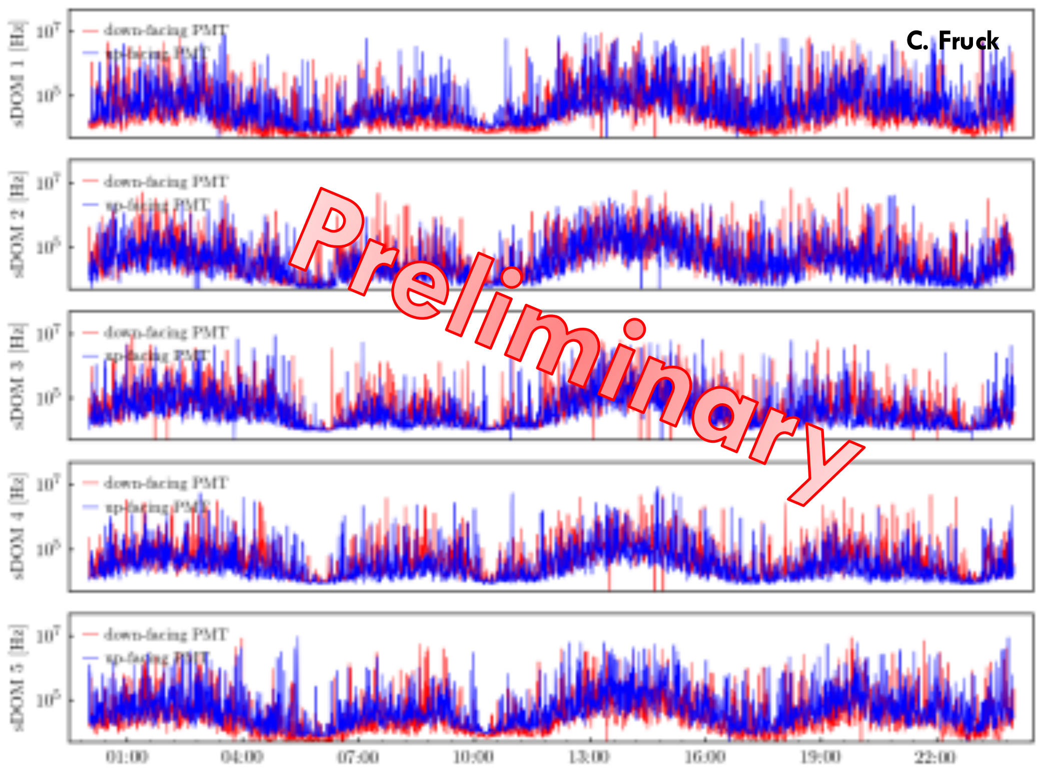
The error bars take into account just statistic errors (systematic errors are not considered).

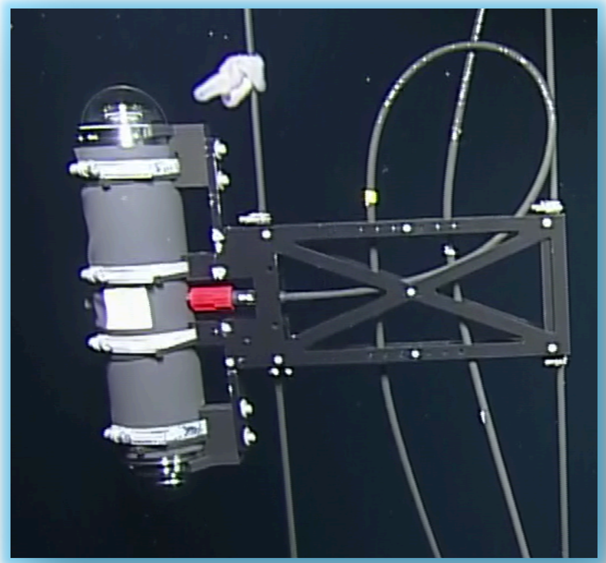
The extrapolated fit value for the total efficiency is around 29% , in good agreement with what expected from the manufacturer

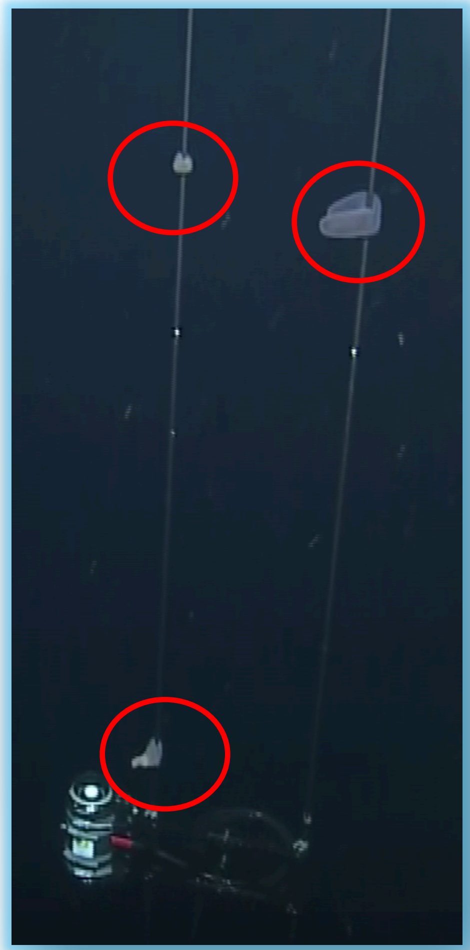
BIOLUMINESCENCE AND PRELIMINARY RESULTS

sDOMs measured rates are from 10 kHz to a few MHz:

- structure on a time scale of several hours in the dark rates
- **investigation on biolumenescent phenomena**



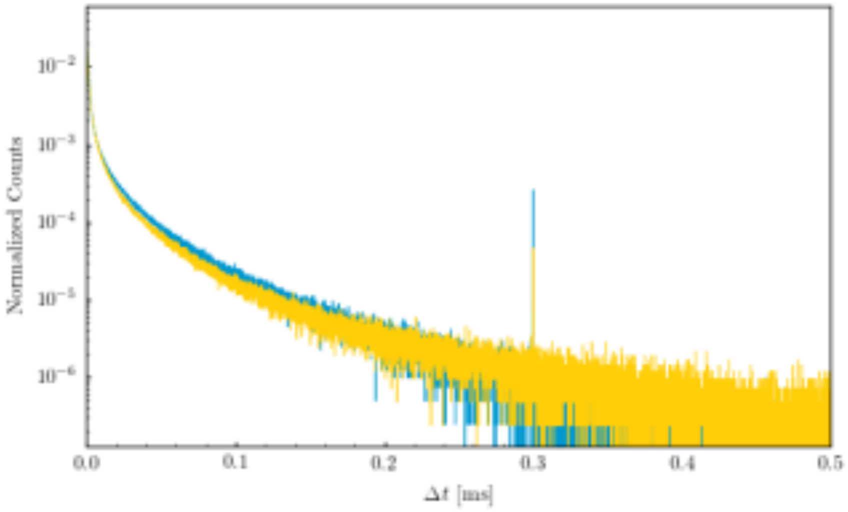




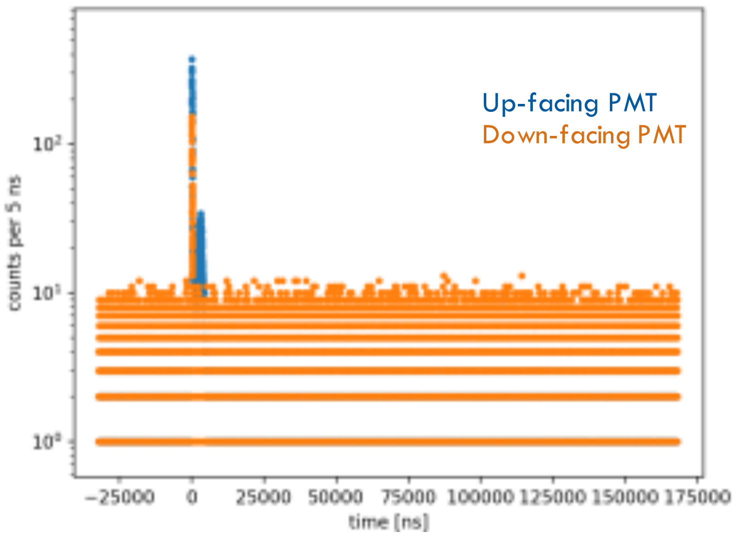
BIOLUMINESCENCE AND PRELIMINARY RESULTS

Analysis strategy (C. Fruck):

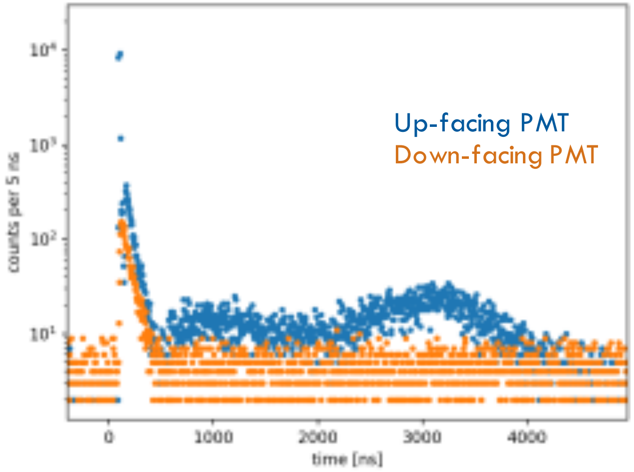
- since sDOMs are syncronized and POCAMs are not, to reveal POCAM pulses it needs to look into a temporal distribution of 2 following events: Δt histogram
- knowing the POCAM emission frequency, in this example 3 KHz, look for excess of events in the sDOMs at that frequency: POCAM flashes identified via periodicity search (frequency fit)



zoom



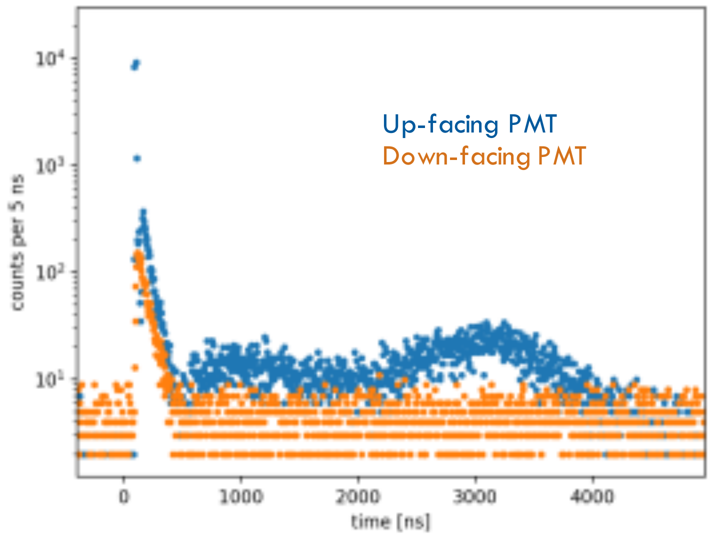
zoom

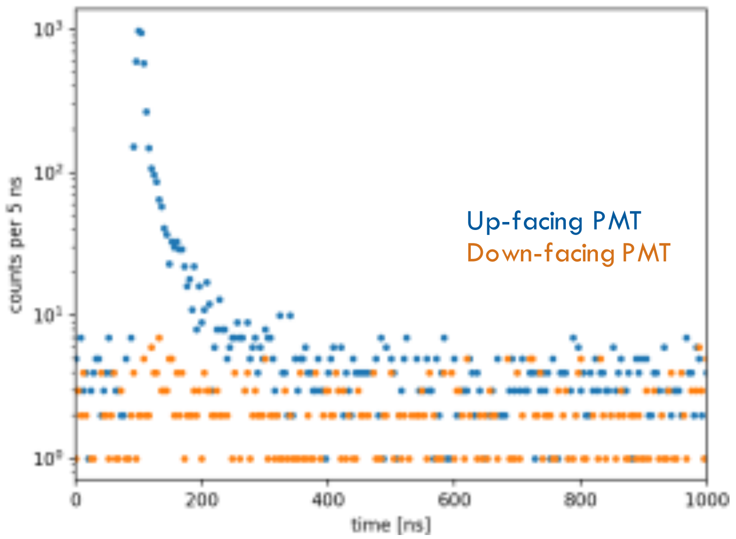


BIOLUMINESCENCE AND PRELIMINARY RESULTS

Analysis strategy (C. Fruck):

- direct signal can be extracted from time window of a few ns in the phasogram
- recording for a few tens of seconds is sufficient when flashing the POCAM with known frequency of a few KHz



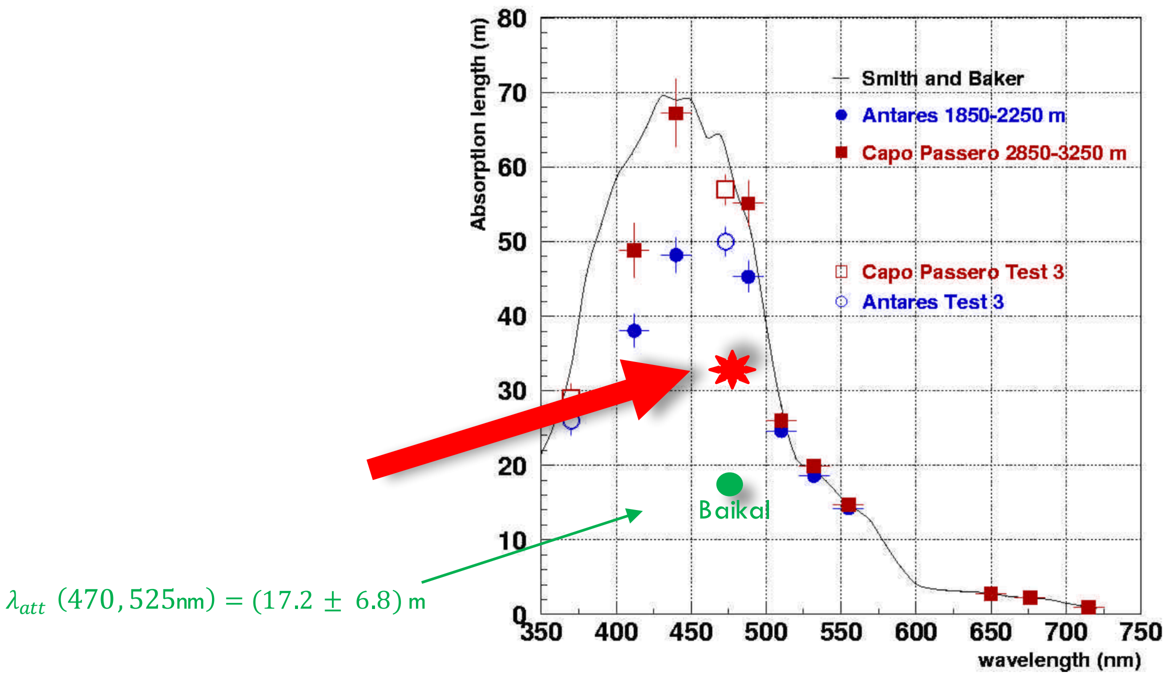


Searching for signal periodicity
200100.30816036806
…………………………………………….
Total time: 10.71062
Emitted flashes: 53553
Detected flashes: 4059
Photons det. per flash: 0.0788
#########################
0.0757939 → hit fraction
#########################

from the hit fraction → reconstruction of distances → absorption lenght

BIOLUMINESCENCE AND PRELIMINARY RESULTS

- Seasonal variations in sedimentation in the sea water might induce variations in the optical parameters.



picture from: **High-Energy Astrophysics with Neutrino Telescopes** (T. Chiarusi, M. Spurio)

λ_{abs} (465 nm): **31.4** m $\pm$ **3.0** m (stat.) $\pm$ **5.0** m (sys.)

Preliminary

First results look promising!

- waiting for confirmation by AC9 measurements
- measurements at different wavelengths ongoing

SUMMARY

- STRAW: designed, build (in less then 1 year) and deployed 2 instrumented strings to investigate on Cascadia Basin as possible future site for a large scale neutrino telescope
- Successful deployment: all instruments are alive and taking data
- Preliminary results look promising, looking farward for the final data analisys.
- **Future**: Summer 2019 deployment of a third string (400 m length) instrumented with calibration devices (project and final design to be defined soon)

Paper draft:

STRAW (STRings for Absorption length in Water): pathfinder for a neutrino telescope in the deep Pacific Ocean
(arXiv:1810.13265)

Vancouver Island – B.C., Canada