Analysis status WOM

- Physics and Engineering of the WOM
- Problems
- Bioluminescence: Lomb Scargle analysis in frequency space
- Bioluminescence: statistical analysis of rise and fall times
- Base rate and 40-K
- A glimpse at analyses of „special data sets“
- Summary

P-One Meeting
Dec 14-15, 2020

Lutz Köpke

University of Mainz

THE PHYSICS IDEA BEHIND THE WOM …

Basic concept

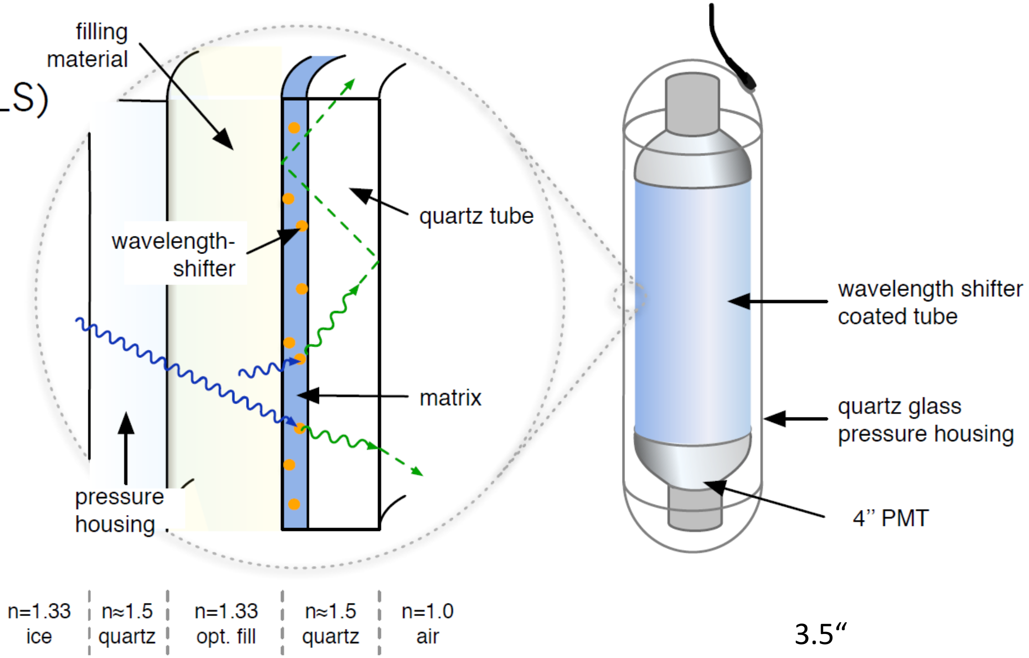
- Wavelength shifters (WLS)
  - concentrate light

Features

- large collection area
- better UV sensitivity
- low noise rate (few Hz)
- cost effective

Disadvantages

- Larger absorption length
- Somewhat worse timing



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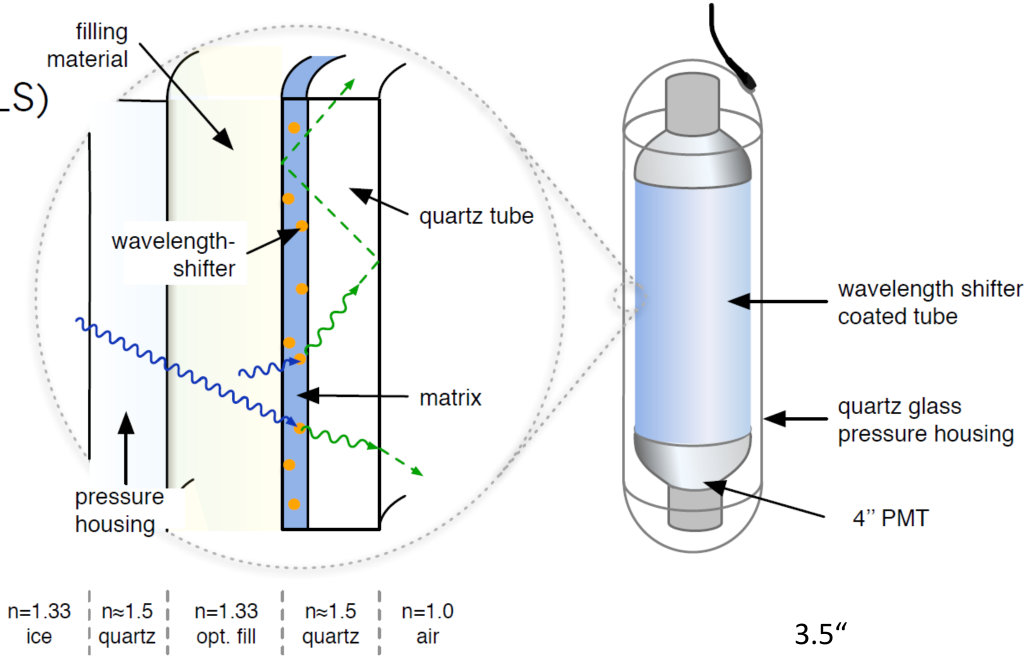
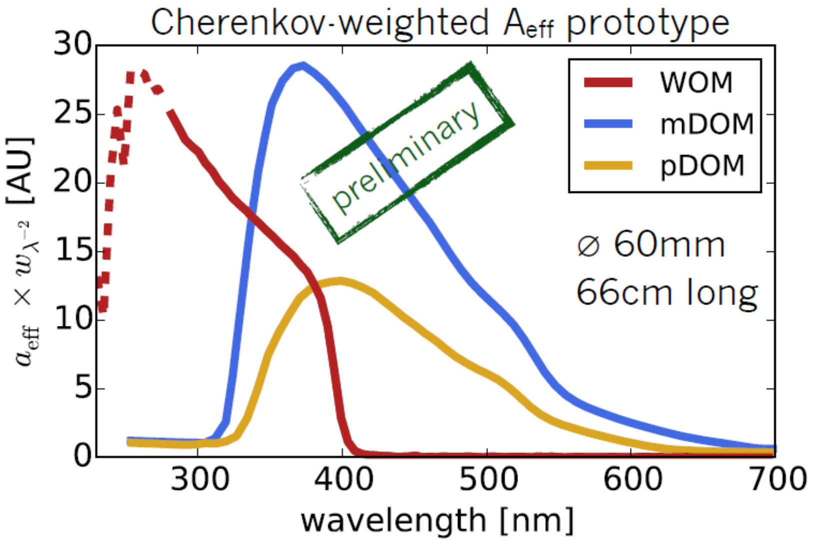


Effective area comparison between

- straw-b prototype,
- 10" IceCube and
- 24-PMT I3-upgrade optical module



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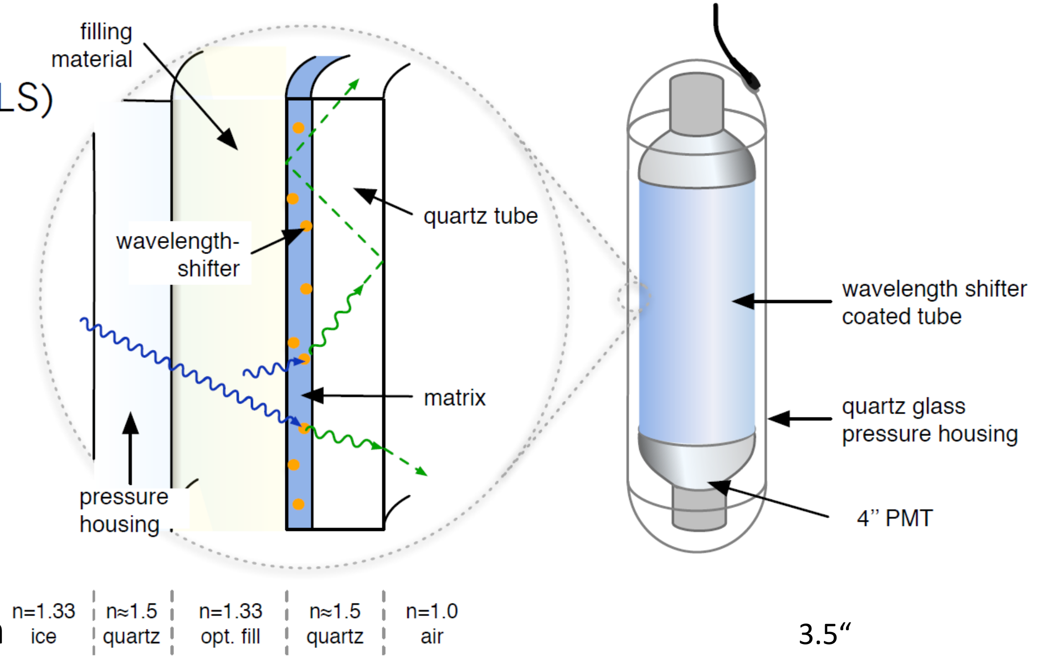

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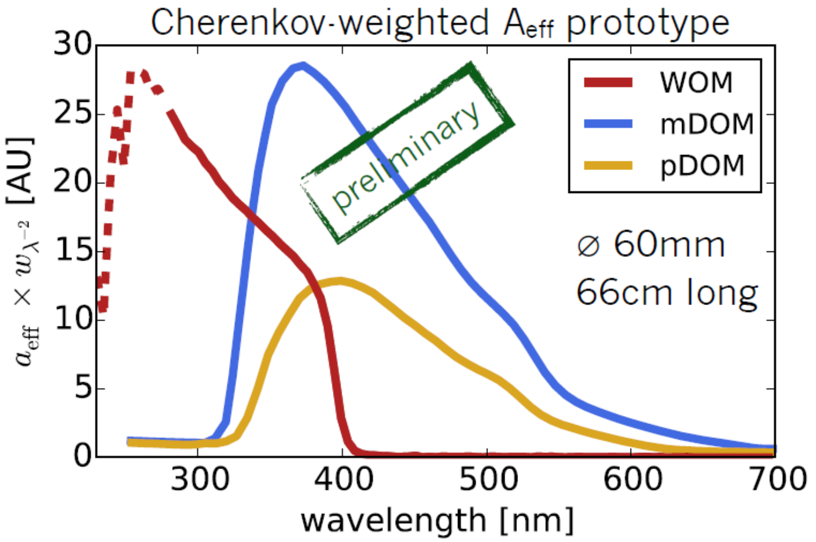
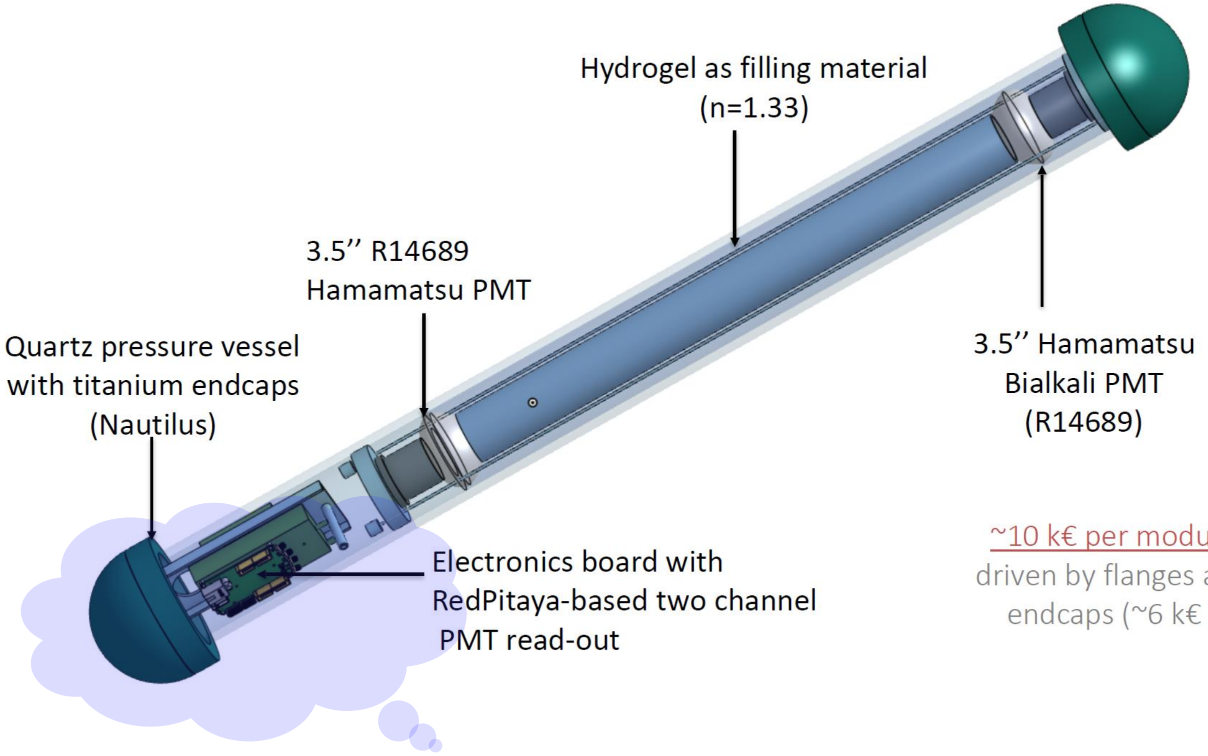


Why is test in STRAW-b important?

- *First deployment of WOM:* understand properties in situ (pressure/rates/effective volume ….)
- Study bioluminescence in UV regime (pretty much uncharted …)

THE ENGINEERING PART ....

~1.5 m overall length
~0.7 m wave length shifter
~0.1 m outer diameter



~10 k€ per module
driven by flanges and
endcaps (~6 k€)

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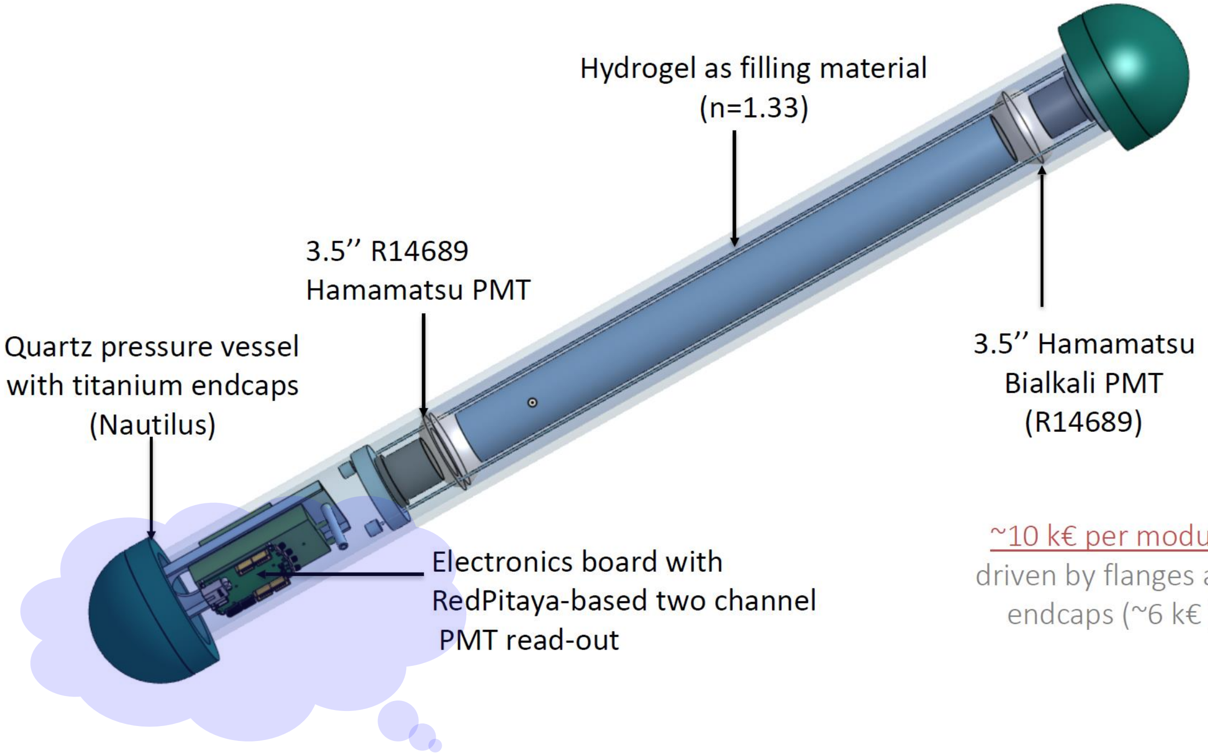

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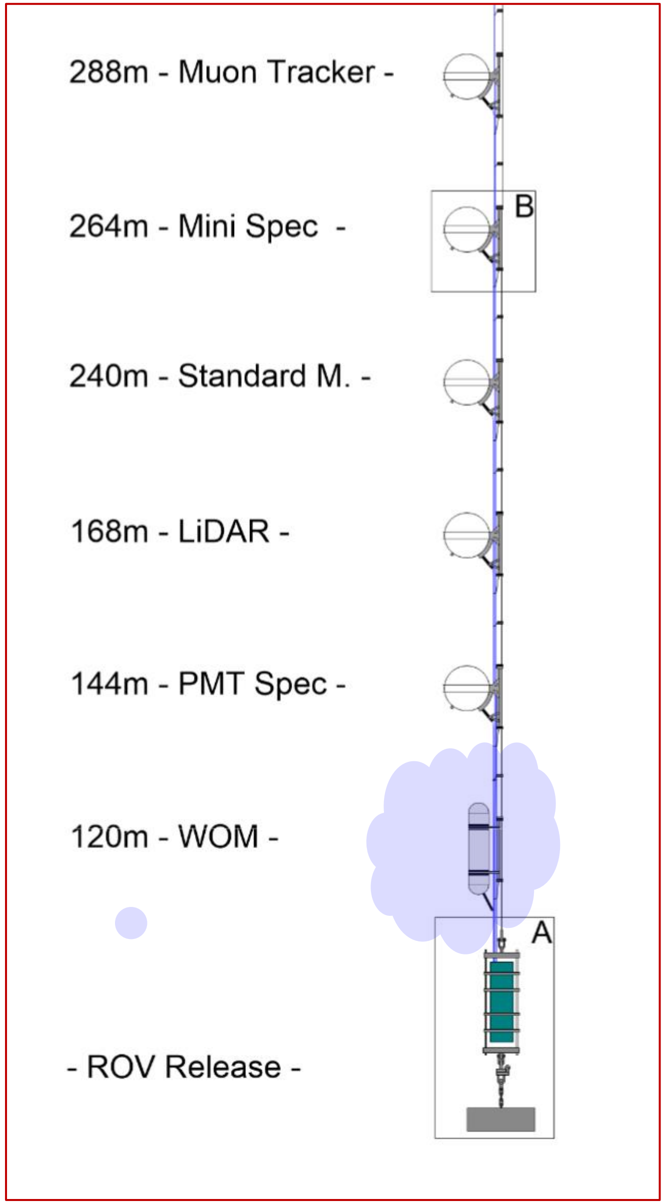

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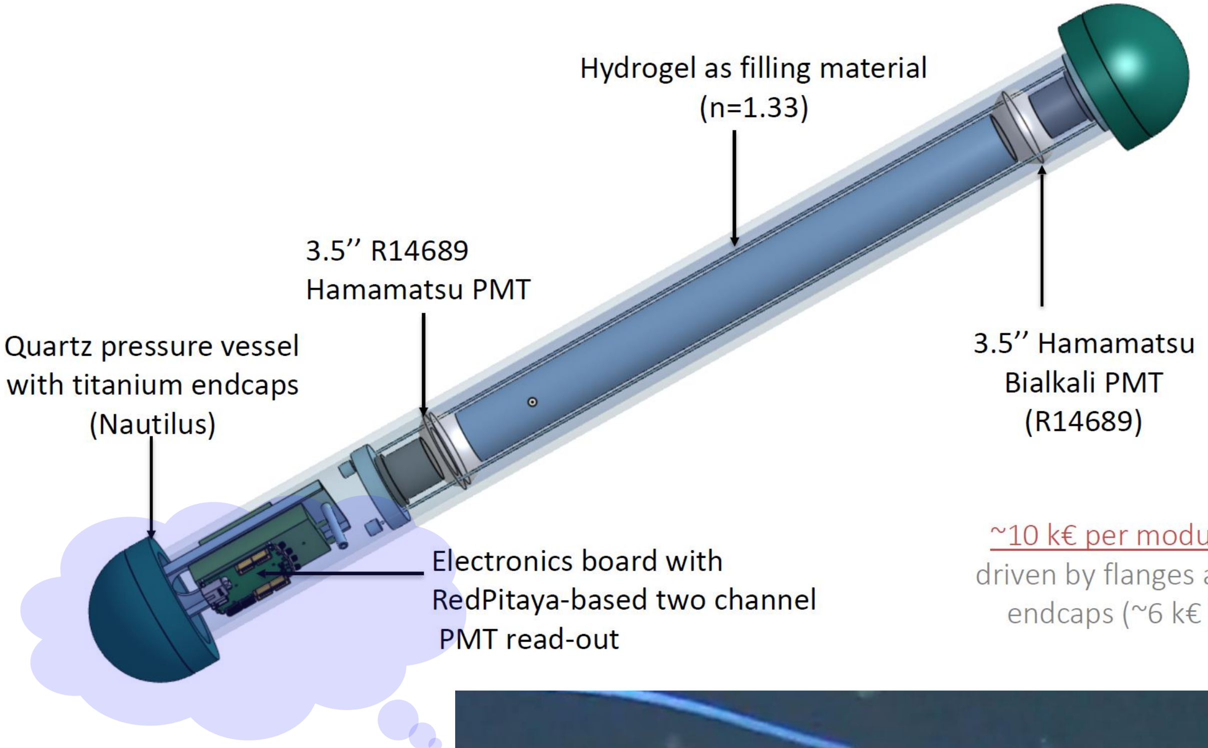

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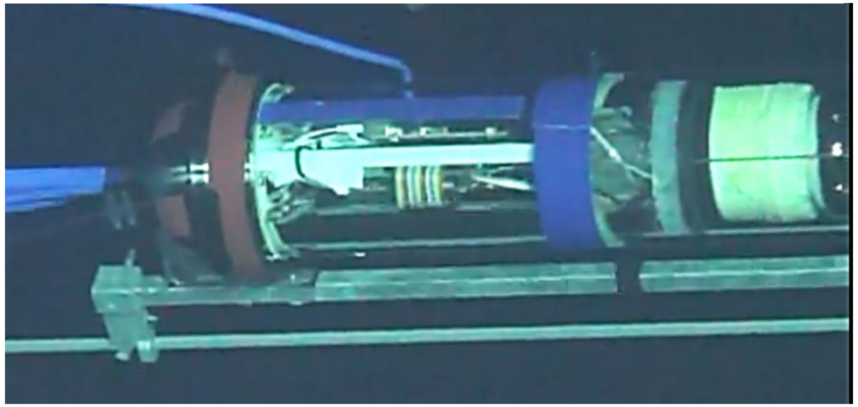

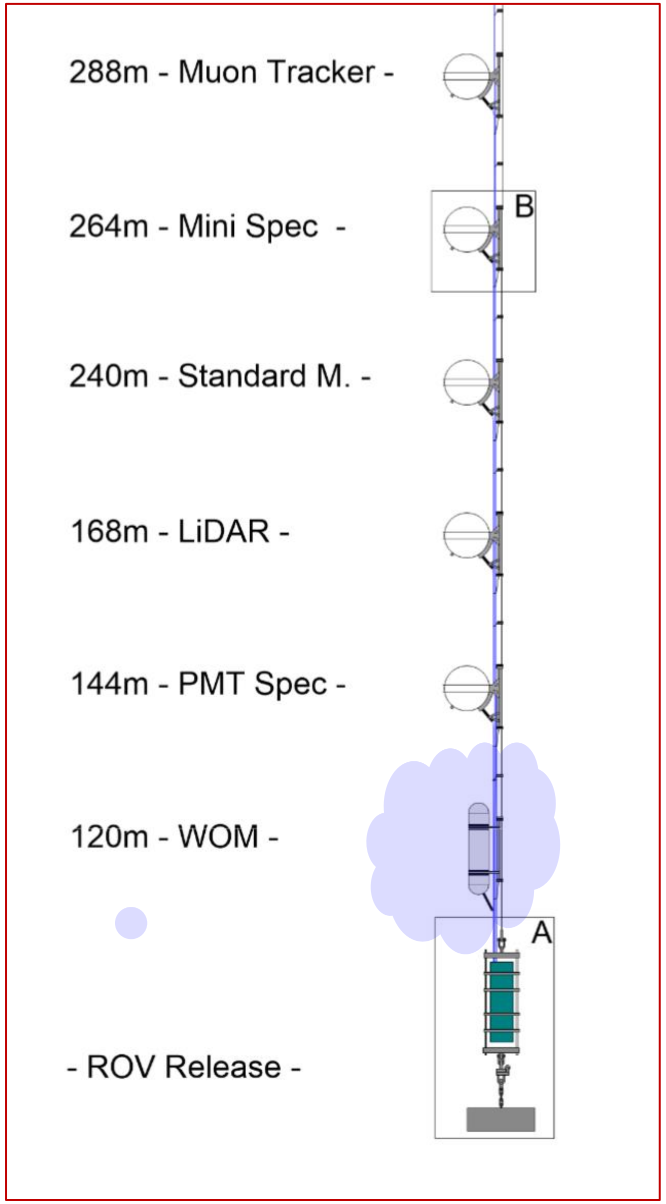

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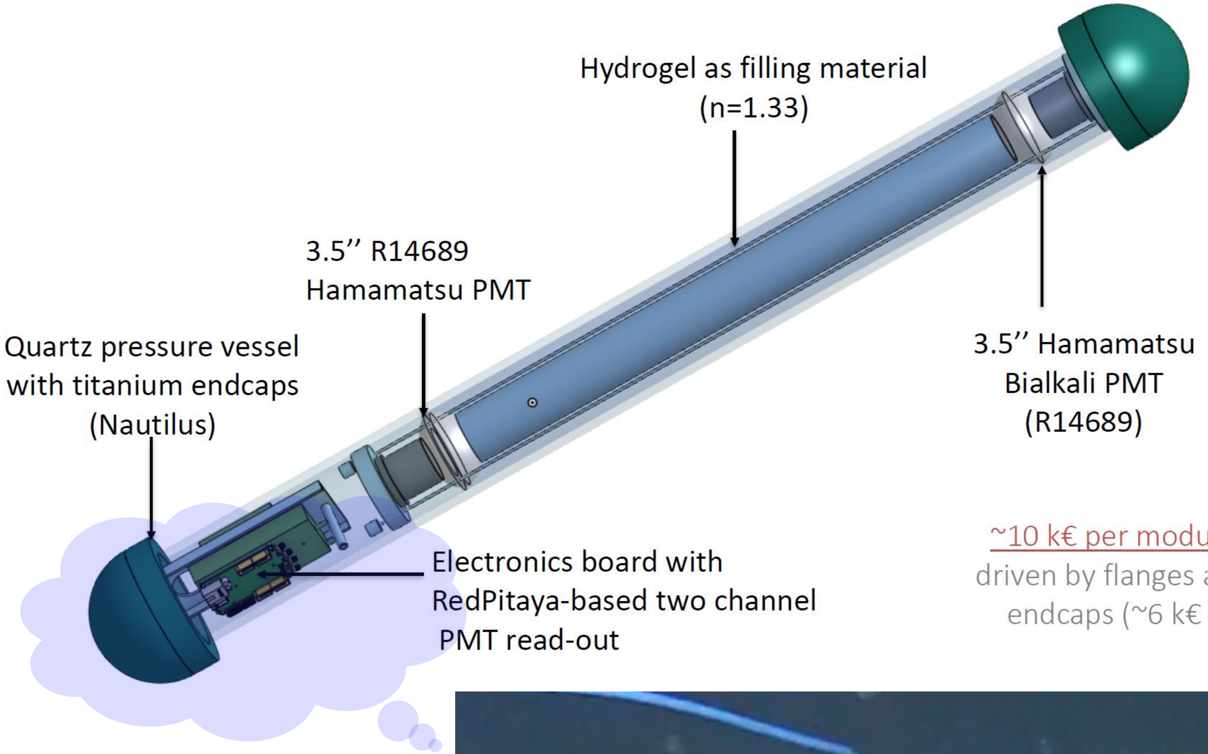

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~0.7 m wave length shifter
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Zynq/FPGA readout
pretty configurable:
→rate/window/threshold
+ coincidence mode

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driven by flanges and
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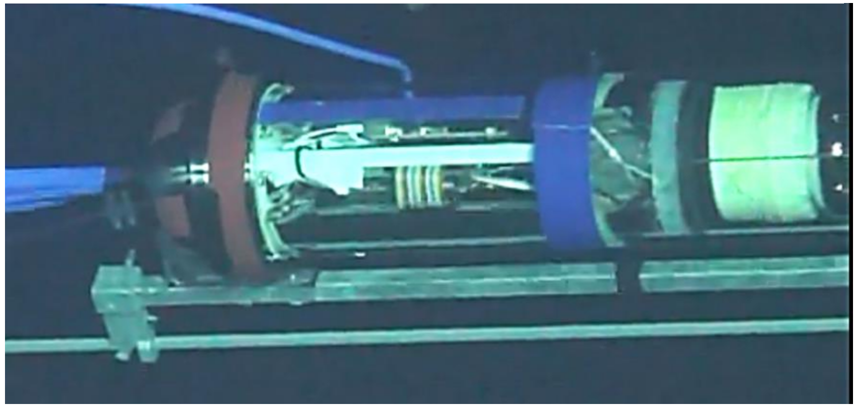
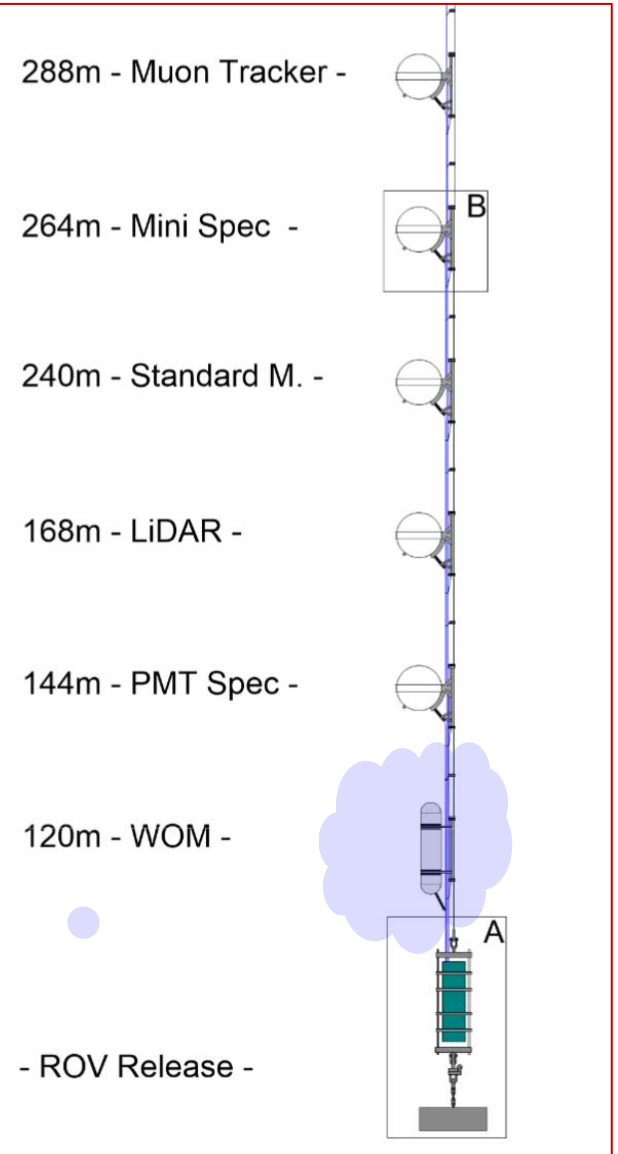
enhanced WOMs
to be deployed in
IceCube upgrade





SEVERE PROBLEMS

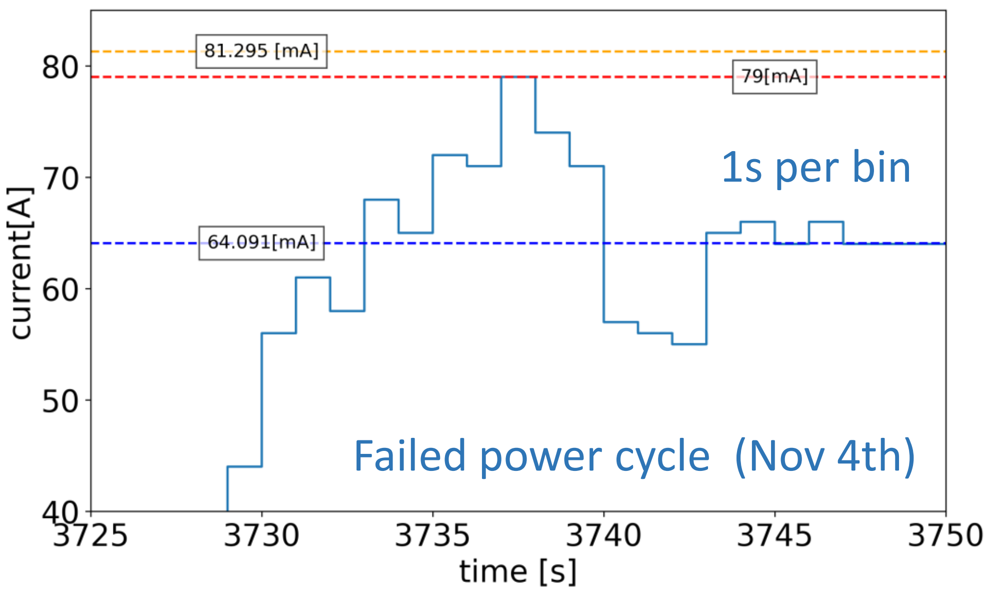
August: connection to PMT 2 broken (observed in sat water tank test); decided not to repair

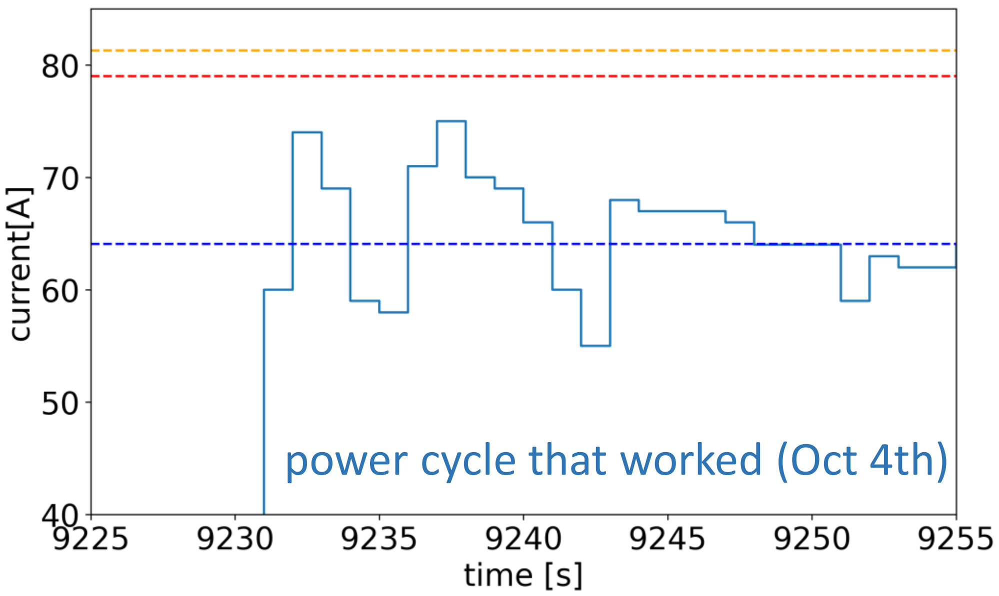
Oct 30: Power tripped building main (Port Alberni)

→ WOM is no longer responsive to pinging; several attempts to power cycle failed

→ WOM still seems to boot (detailed investigations of currents and boot sequence)

→ no success with rapid pinging (0.2 s) during power cycle





SEVERE PROBLEMS

August: connection to upper PMT 2 broken (seen in salt-water tank test); decided *not* to repair

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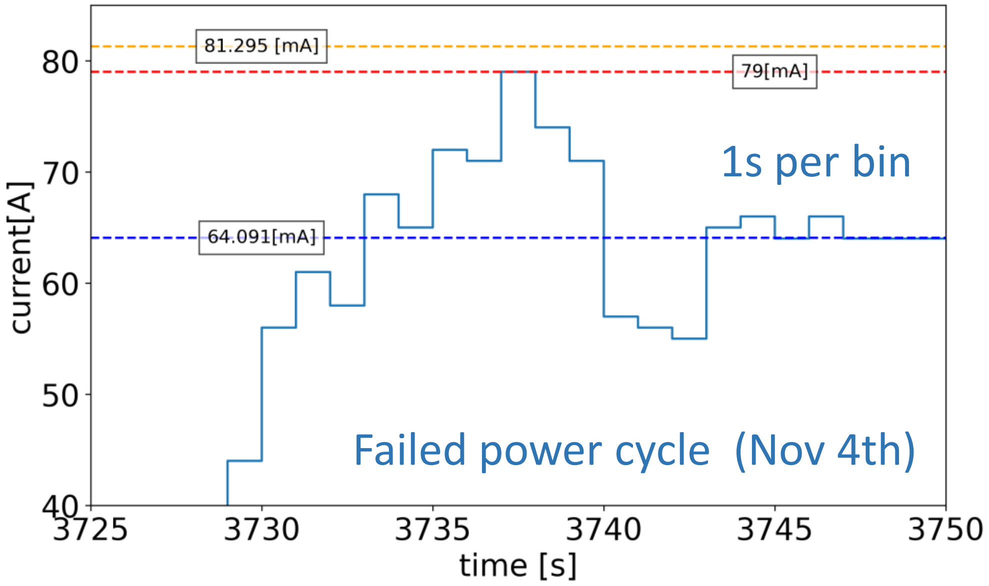
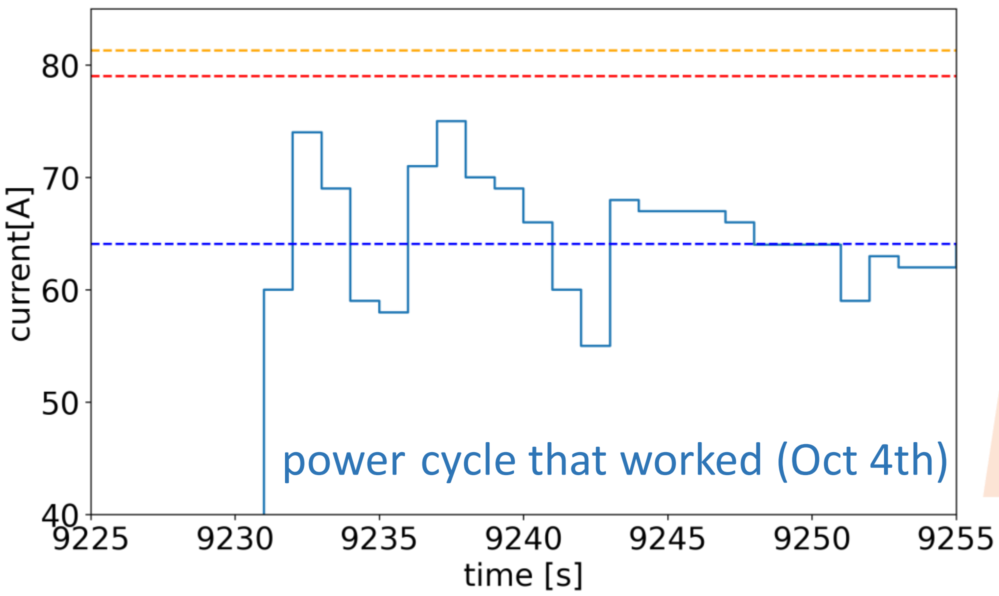
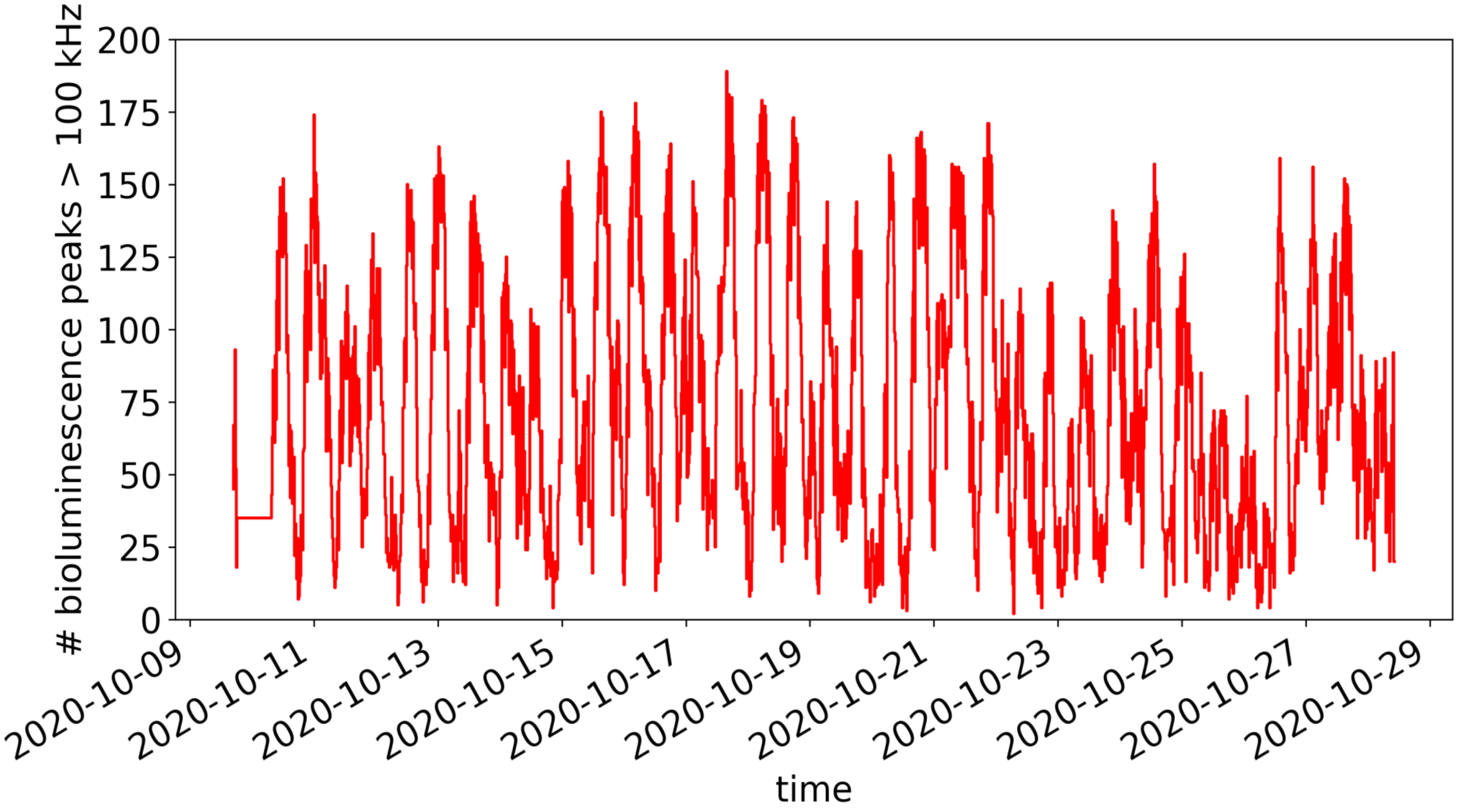




Left with 18 days of data taken

DATA ANALYSIS

MEASURED RATE OF BIOLUMINESCENCE (18 DAYS)

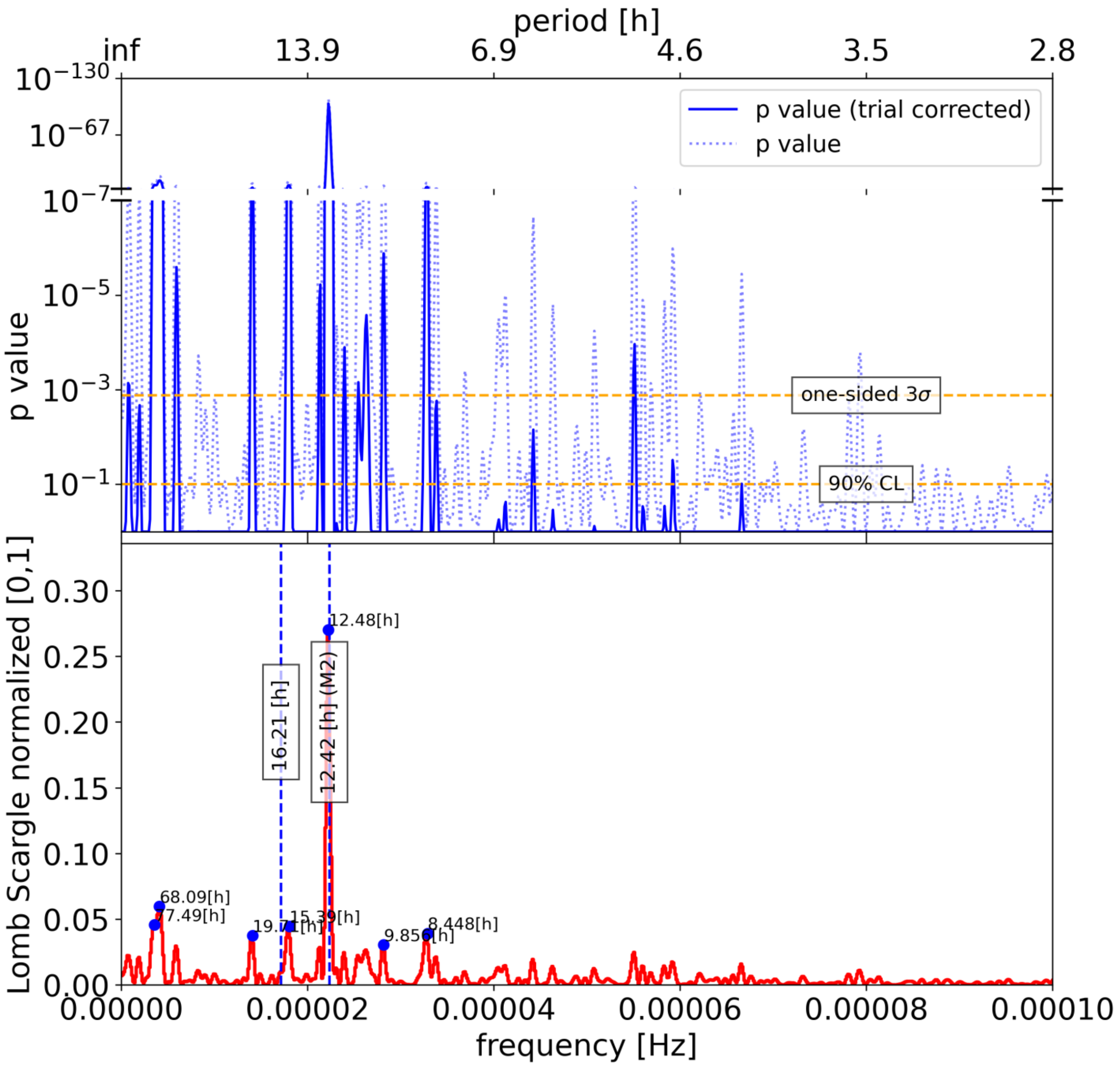


- **Current induced oscillations + bioluminescence variations**
- Latitude ODP 1027C: 47.7567°
- Inertial cycle (Coriolis): $\rightarrow$ 12h/sin(latitude)=16.21 h
- semidiurnal lunar tide M2: $\rightarrow$ 12.4206012 h
- + many more frequencies! (beats, harmonics, sun …)

FREQUENCY SPACE

- Lomb-Scargle transformation
- Estimate p-value [astropy]
- Trial correction still analytical
  → use Toy MC in future

- Perfect match for semidiurnal lunar
- Some deviation for inertial cycle
- Can explain some features with beats



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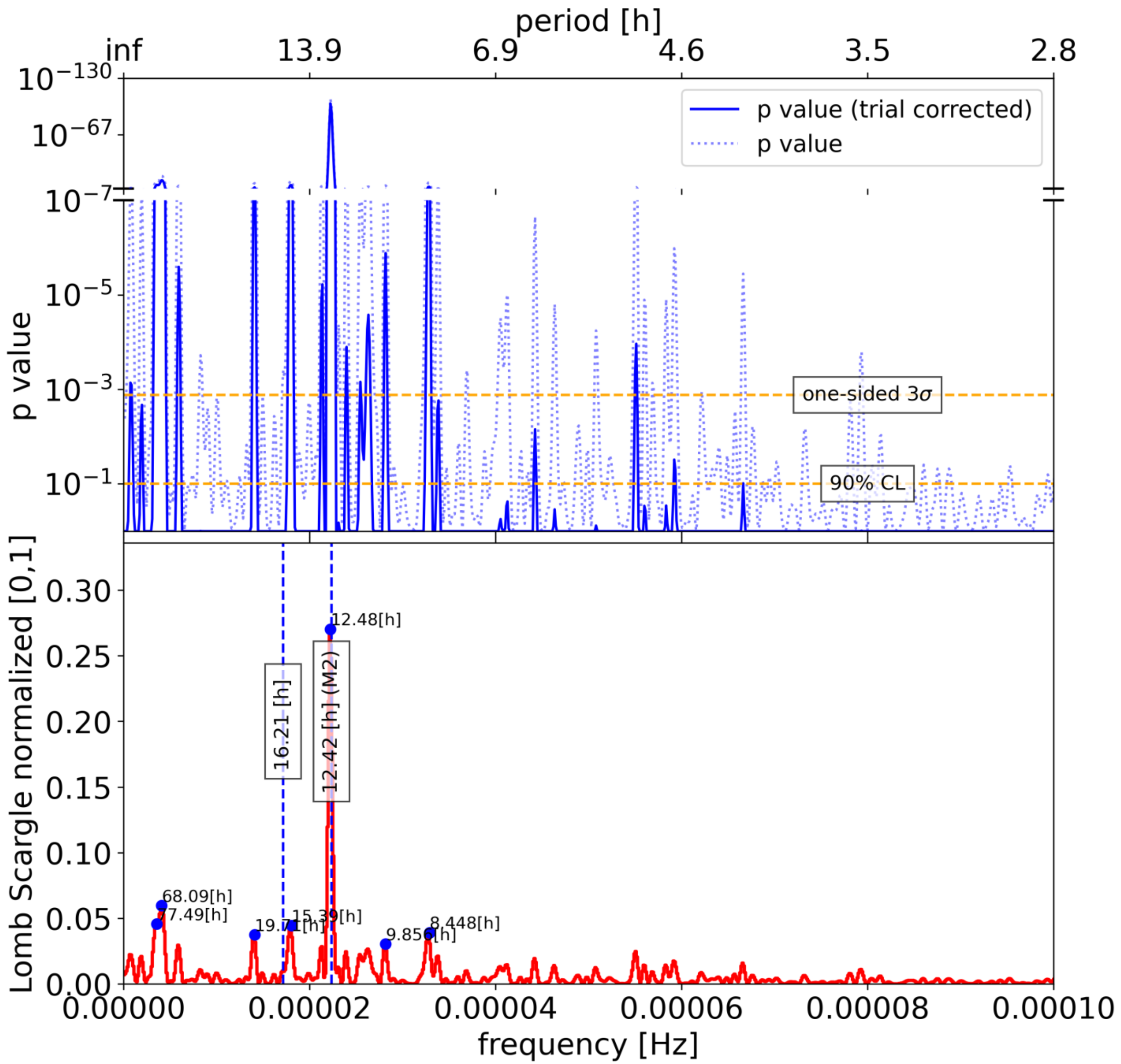
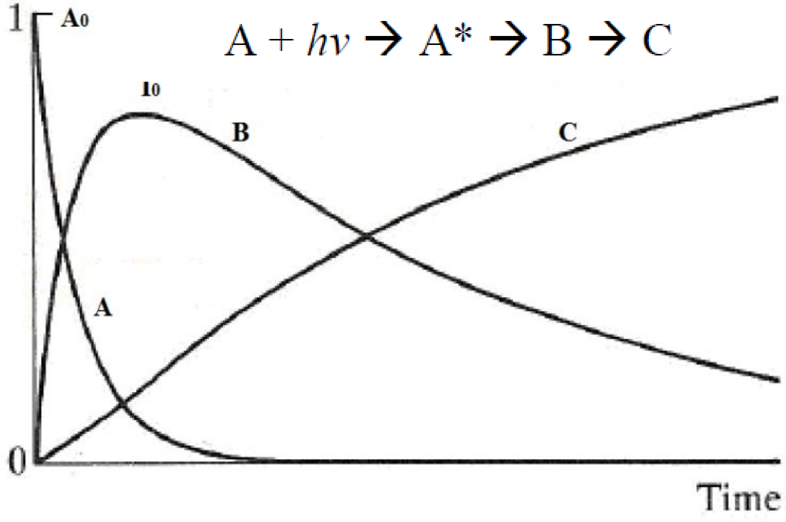
source	T [h] Pred.	T[h] meas.	Beat | f_A-f_B | T[h]
lunar	12.42	12.42	64.4
inertial	16.21	15.39	



UNDERSTAND „CHEMISTRY" OF BIOLUMINESCENCE

- Observation: some „light curves" look rather clean, others are complex due to multiple emissions
- Fit „simple curves" to minimal kinetic „ABC model":

$$B = k_A . A_0 \{\exp(-k_A . t) - \exp(-k_B . t)\} / \{k_B - k_A\},$$



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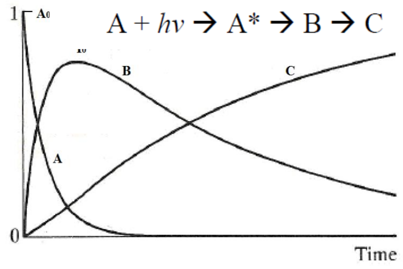
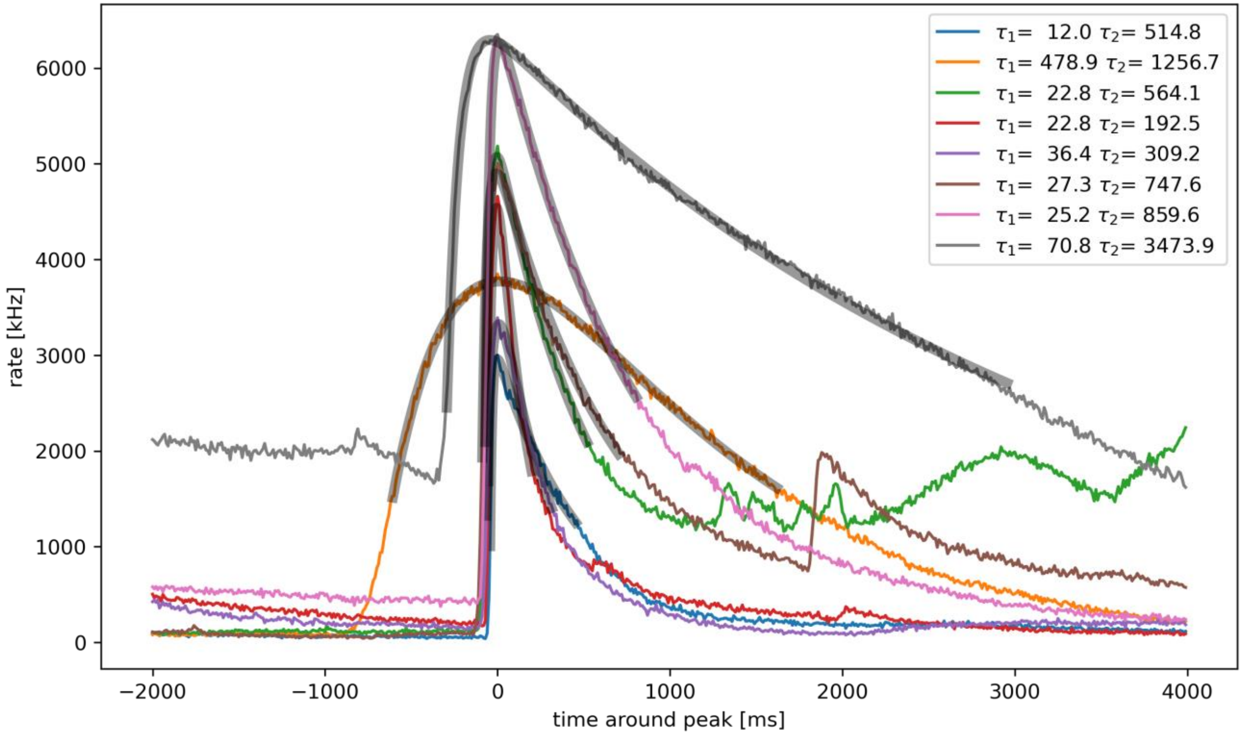
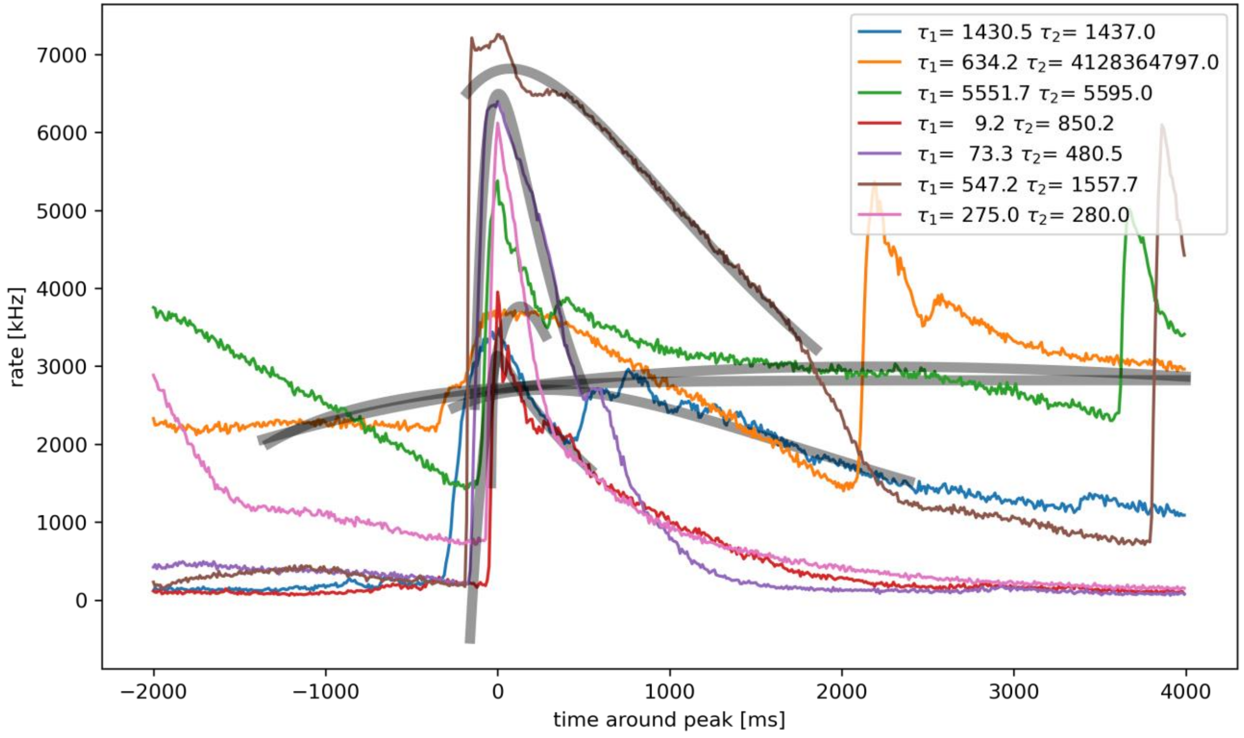


„simple“ wave forms (good fit χ^2)



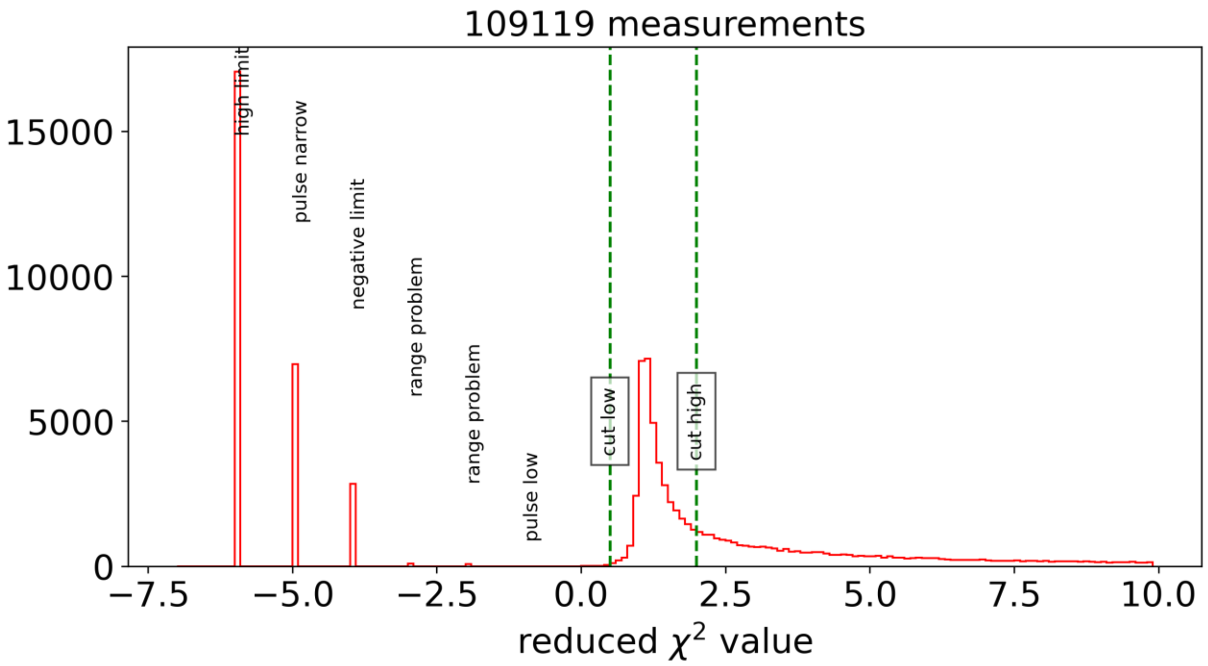
„complex“ wave forms (bad fit χ^2)



JG|U

FIT RESULTS

- ~ 30% of fits have reasonable χ^2
- Some „edge classes“ rejected
- fits typically better for rise time τ_1 than for fall time τ_2
- some tail in χ^2 observed



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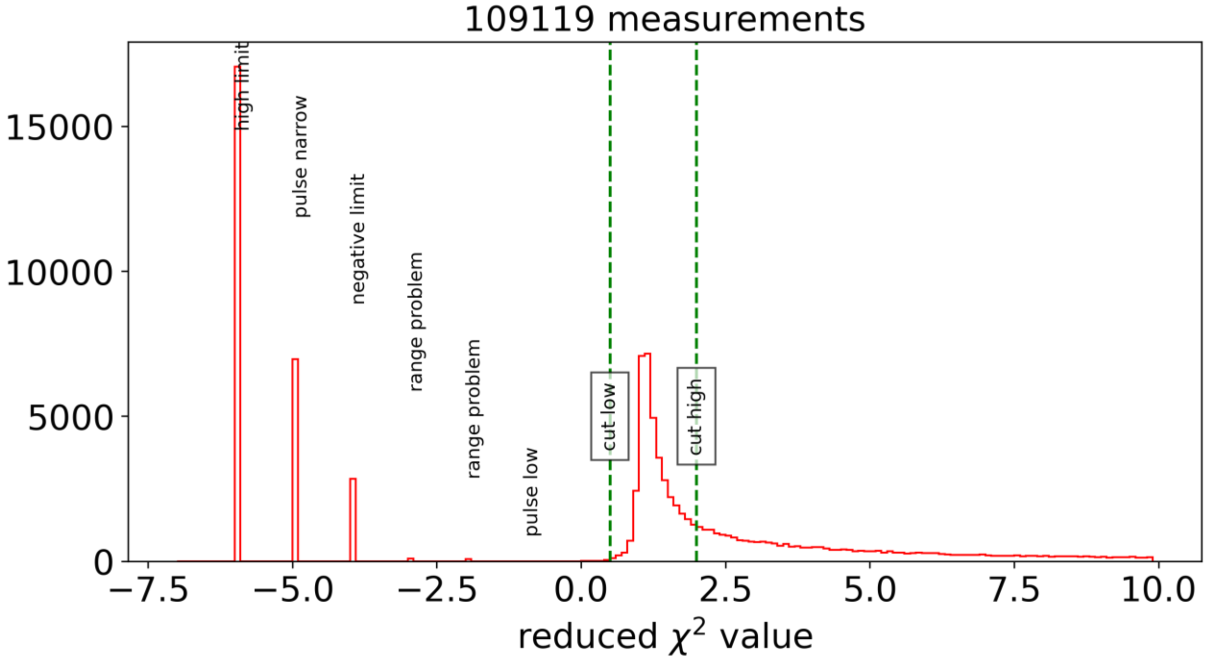
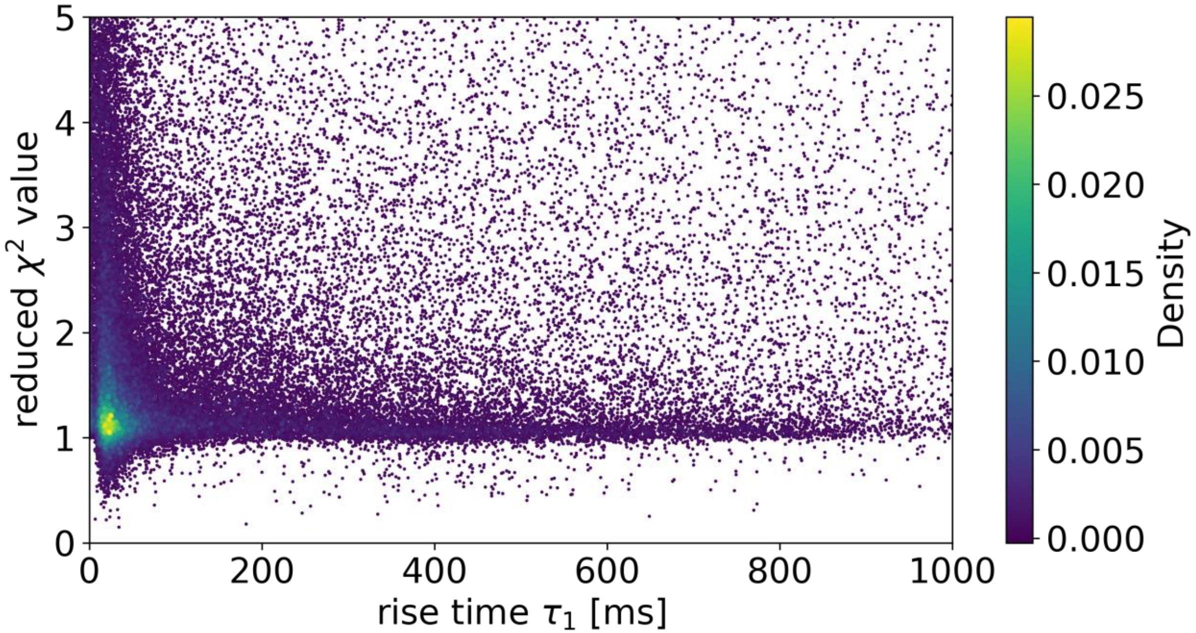
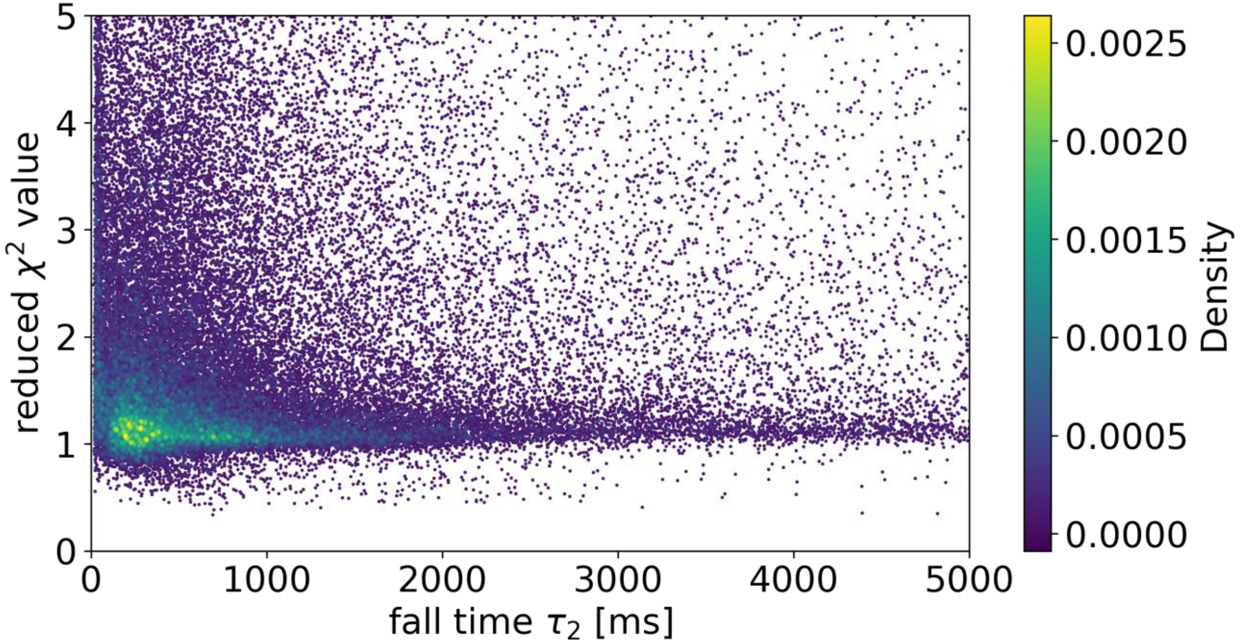
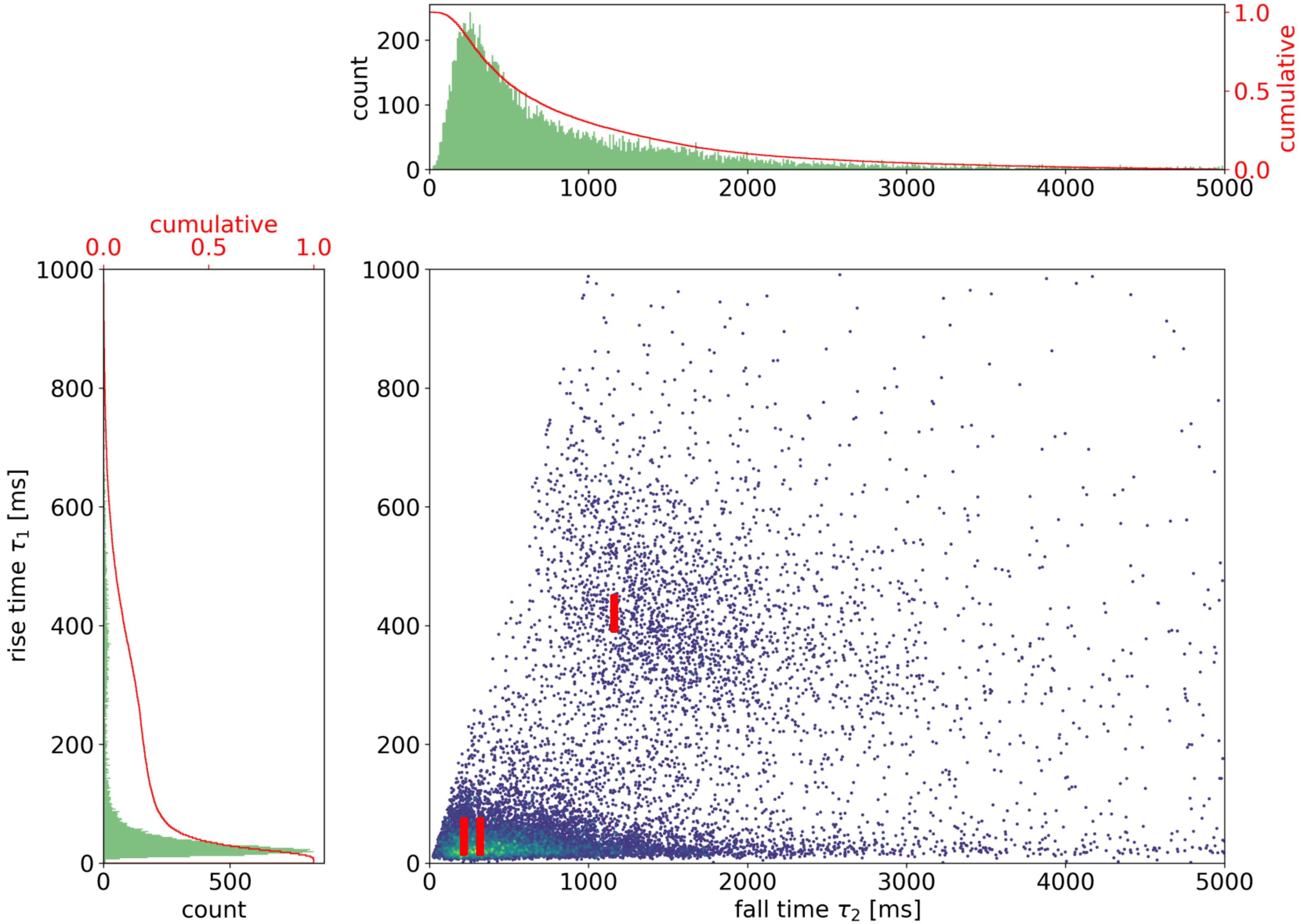






16806

CORRELATION τ_1-τ_2



CORRELATION τ_1-τ_2

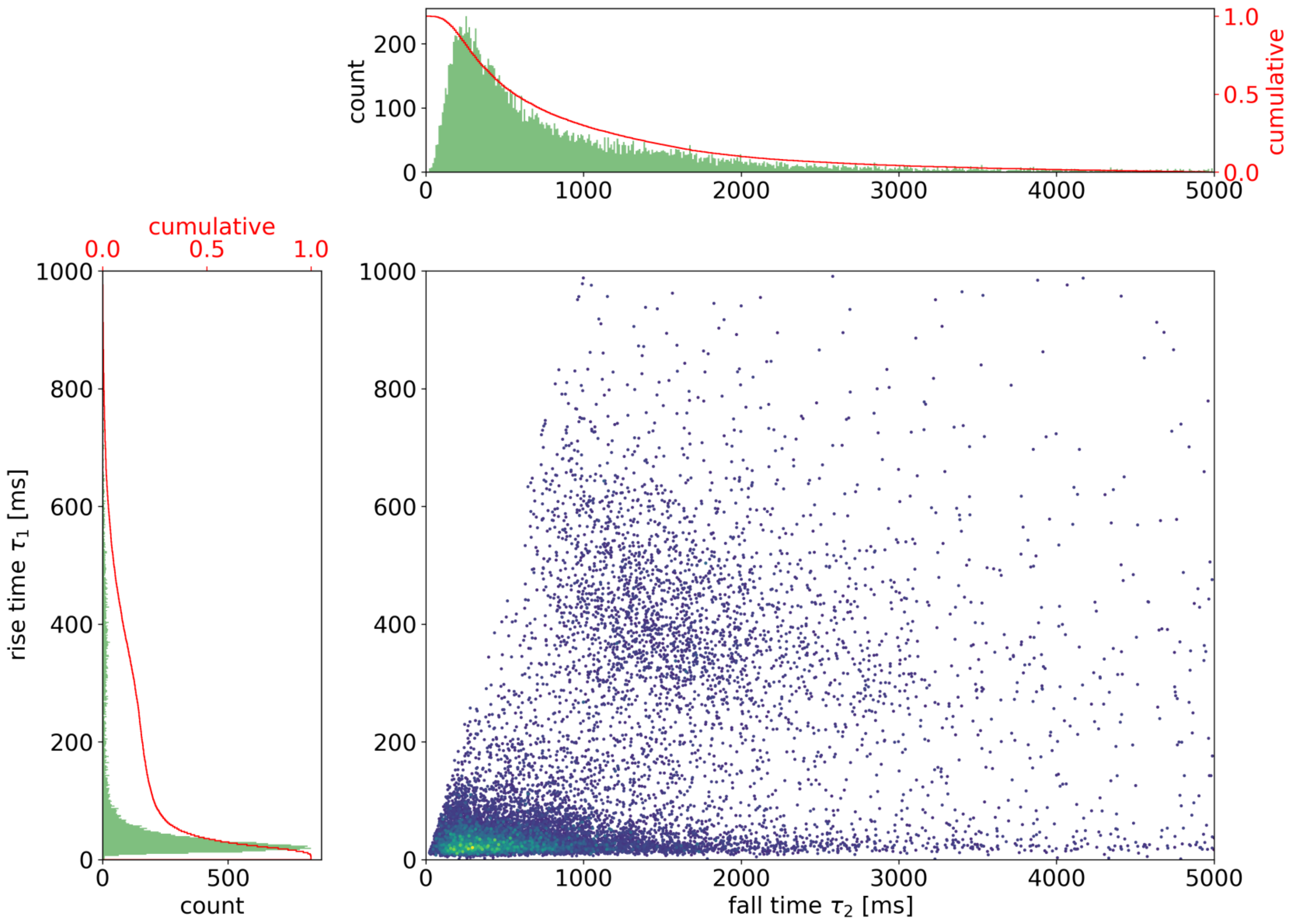
- From ~10^5 attempted fits, ~15%
- selected for analysis (~16000 fits)

- **2 populations I, II**:

I : $<\tau_1>$ ~ 36 ms, : $<\tau_2>$ ~ 660 ms
II: $<\tau_1>$ ~ 560 ms, : $<\tau_2>$ ~ 1950 ms (~18%)

- Only seen in fits with good χ^2

- Method can stil be improved ….

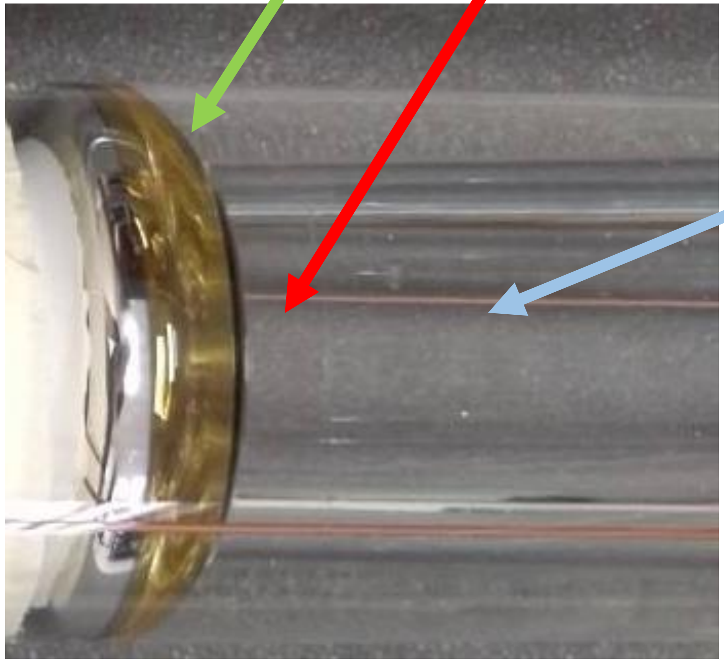


DO WE REALLY SEE LUMINESCENCE IN UV?

Direct light on PMT (~55 %)

Direct light on PMT for λ > 400 nm through WOM tube (~< 20%?)

Light < 400 nm caught in WOM tube (per PMT ~400 %)



Active diameter 3.5“ R14689 PMT : **81 mm**
Length WOM tube: **630 mm**
Diameter WOM tube: **55 mm**

Expect roughly **4 x PMT acceptance through WOM tube per PMT**

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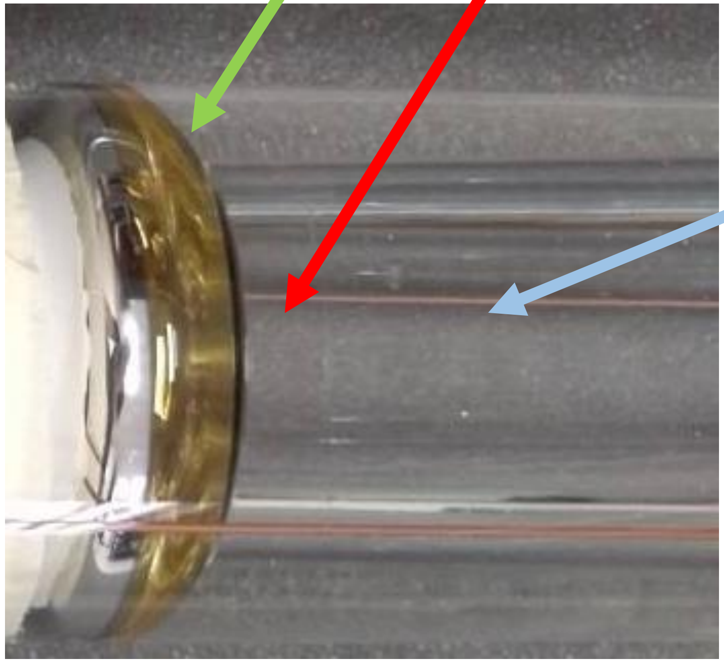

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WOM quartz tube glued to PMT with NOA61 glue – micro cracks?

K-40 FOR ABSOLUTE CALIBRATION?

Implications of optical properties of ocean, lake, and ice for ultrahigh-energy neutrino detection

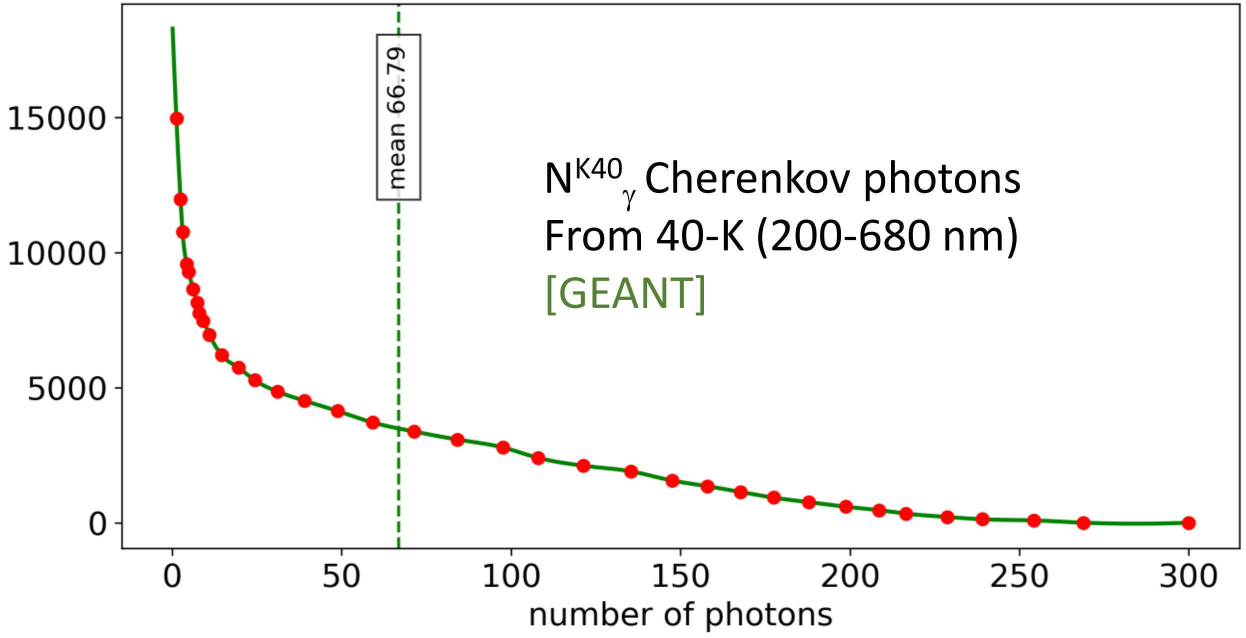
P. Buford Price

See also talk by Mathew this morning …

Constant density emitters (ρ=11000/m^3):

$\mathbf{R_\gamma} = N^{K40}_\gamma \, \rho \, A_{eff} / \pi / \mathbf{a(\lambda)} \times (1-\exp(-a(\lambda) * d_{max}))$ [absorption only]

diffuse case more complicated ….
back on the envelop estimate ….



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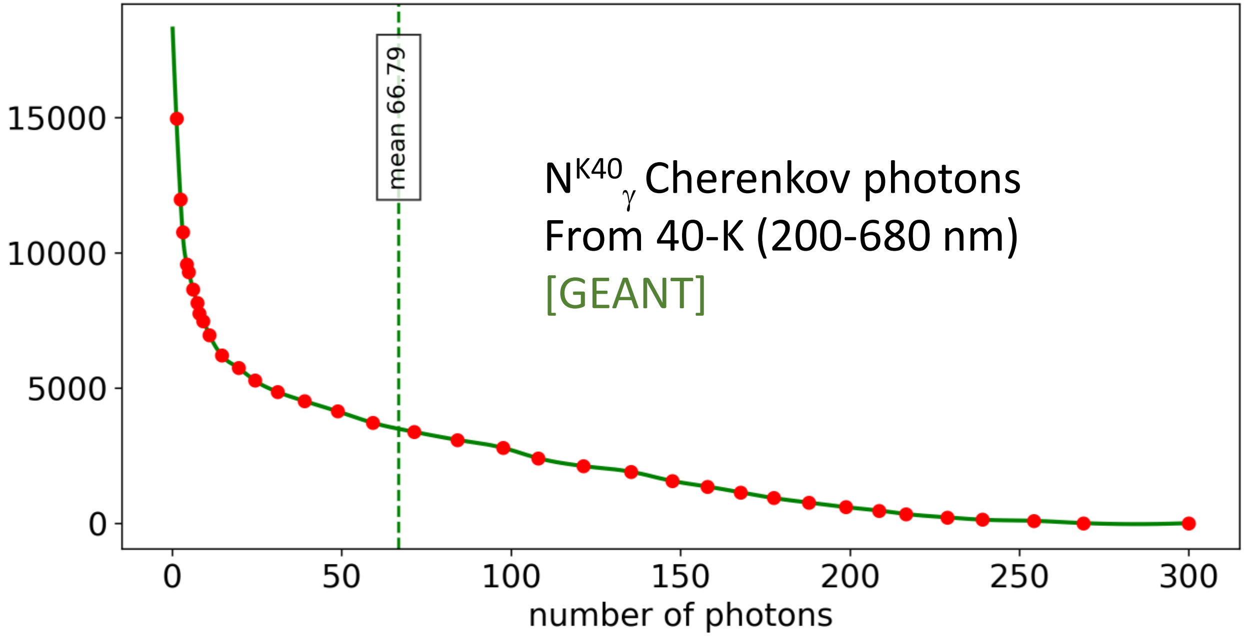
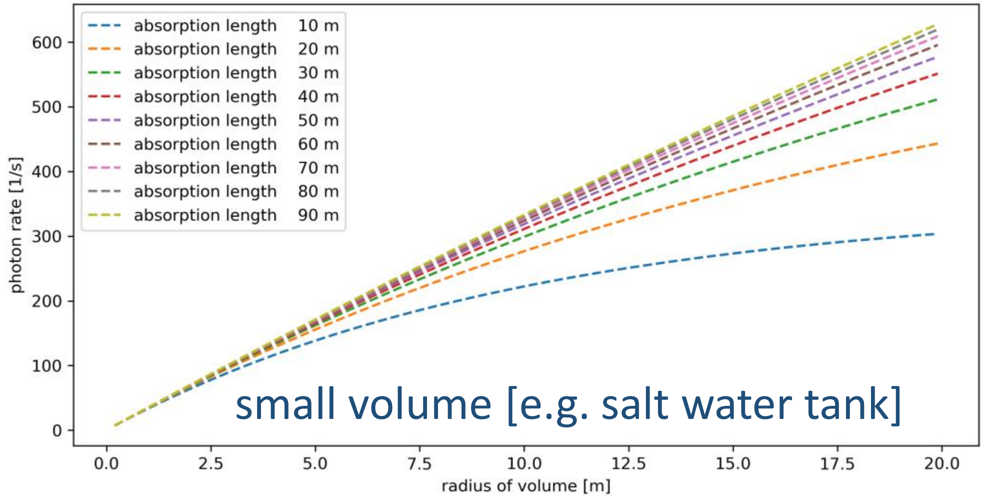
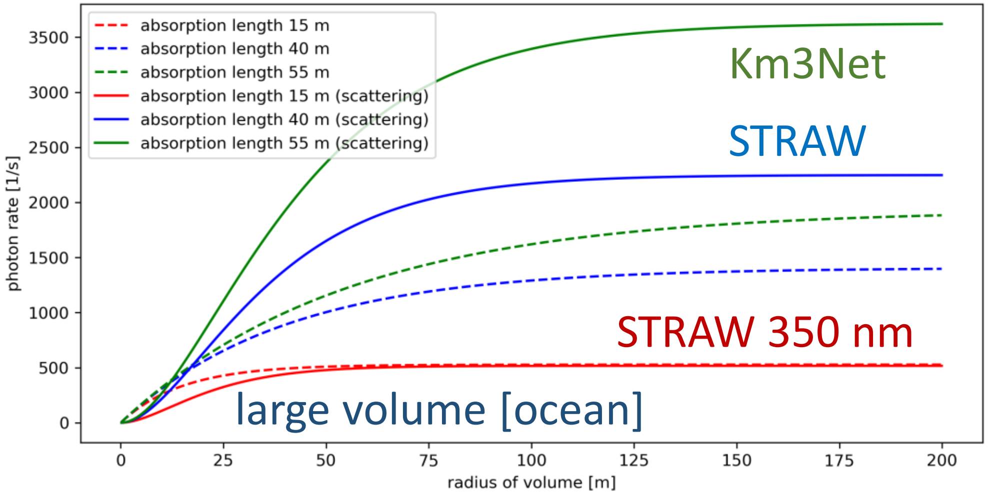


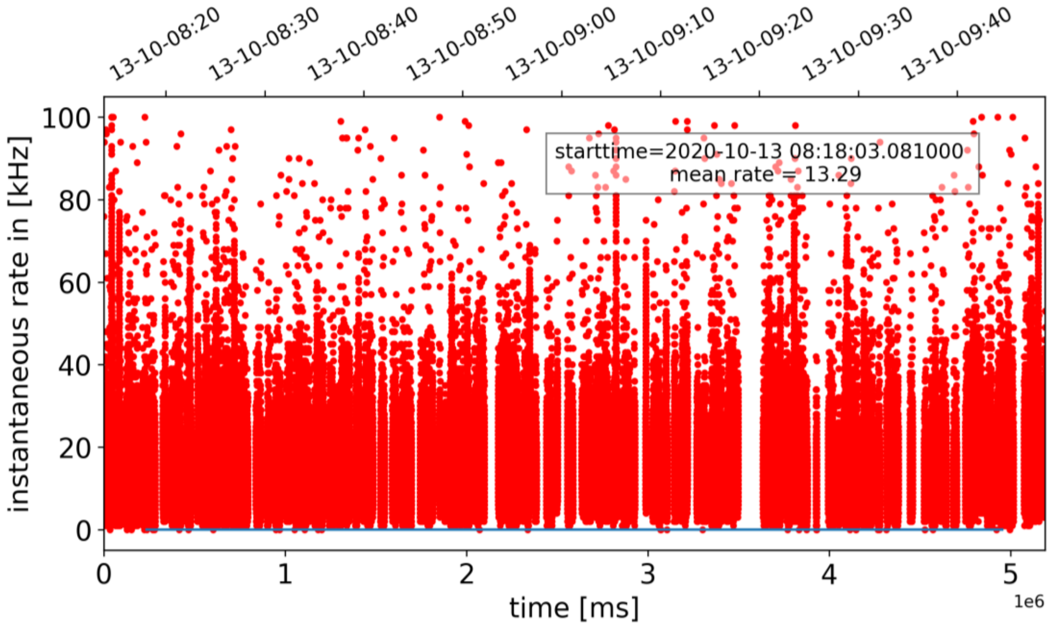
Expected rates for 3“ PMT 11 kBq/kg

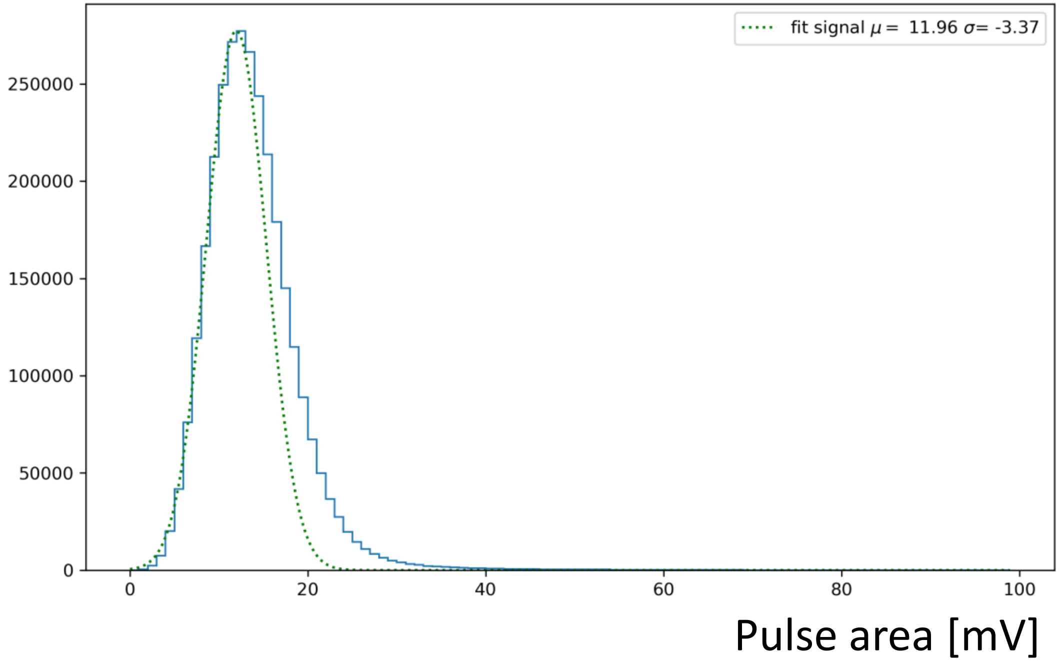


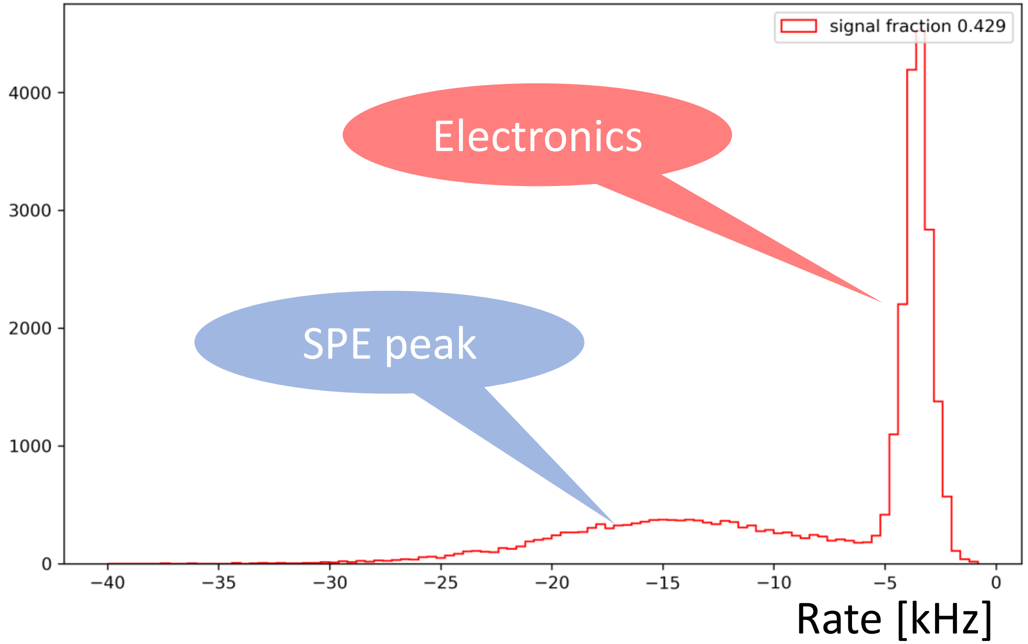


DETERMINE BASELINE

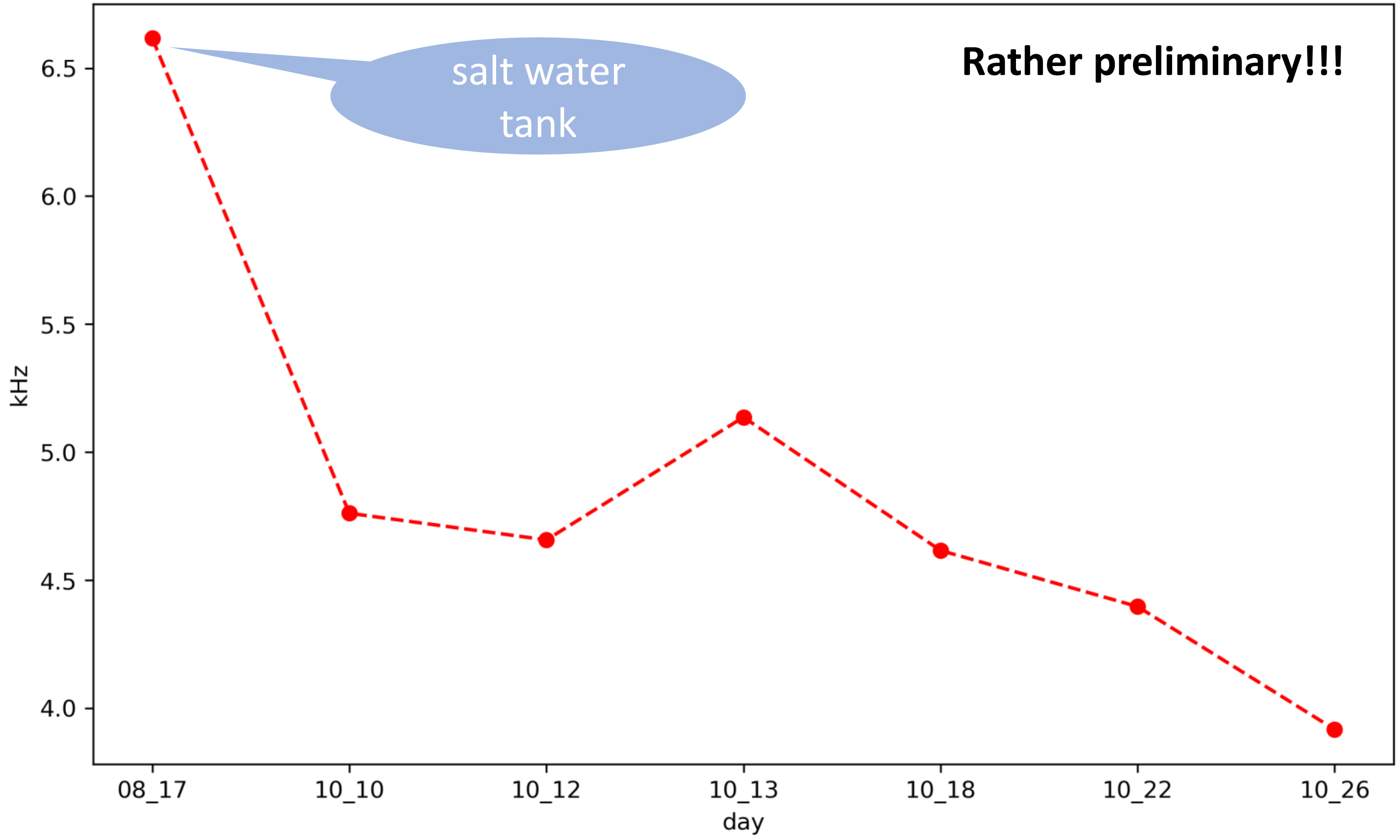
- Only investigate low bioluminescence runs
- De-select bioluminescence events
- Fit lower side of base rate with Gaussian
- Determine SPE fraction







40-K RATE + PMT-NOISE VERSUS TIME



where and what ….	K-40 [kHz]
Km3Net / 3“PMT [Geant]	4.12
STRAW / 3“ PMT [-1.25 kHz noise]	3.8#?
WOM [-0.4 kHz noise]	4.3

Many open questions:

- Why is WOM rate so low (direct light)?
- Noise due to glass correct?
- Was tank light tight?

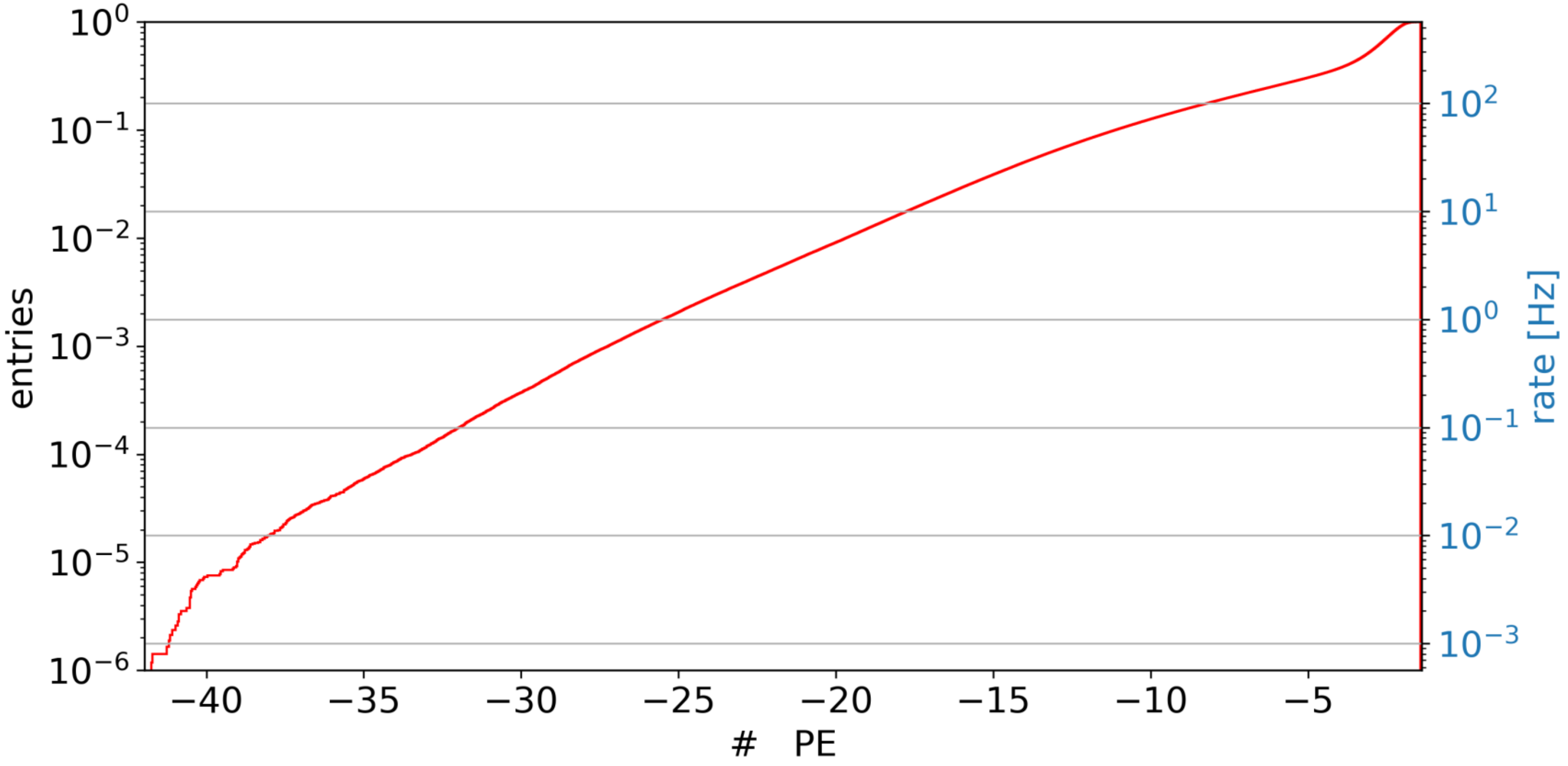
Maybe easier to study closeby 40-K decays via pulse height spectrum …. (see next slide)

see talk by Immacolata this morning

SPECIAL DATA SETS

PULSE HEIGHT DISTRIBUTION (CUT @ 2 PE)

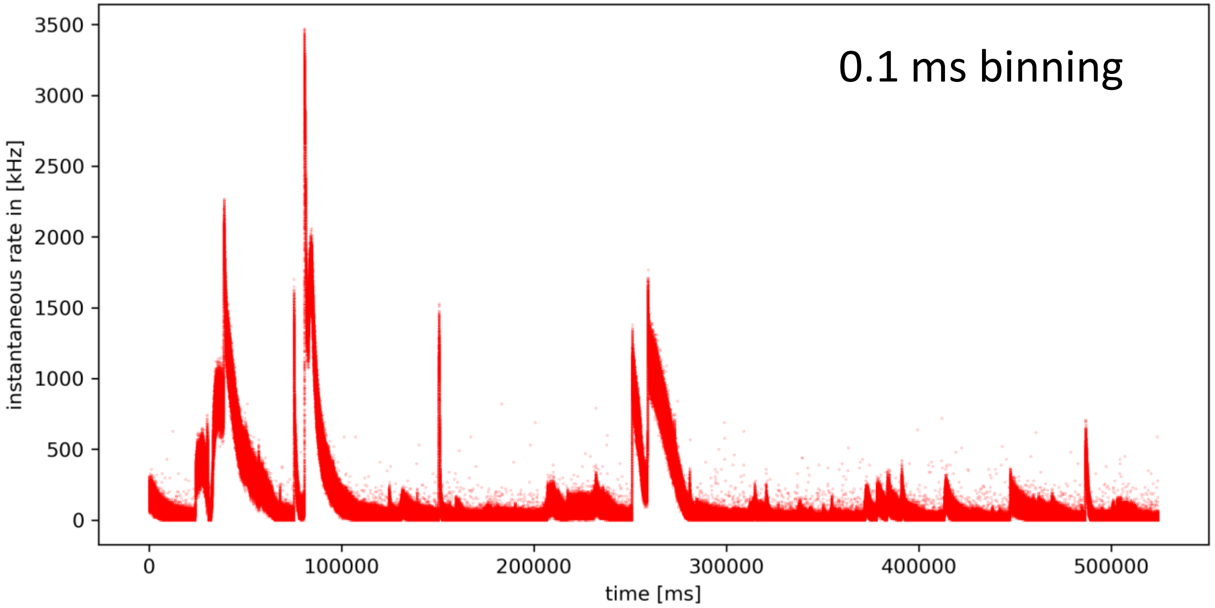
- 5400 s of data taken with cut at 2 PE
- Compare this to 40-K Monte Carlo? (Bioluminescence mainly 1 PE)

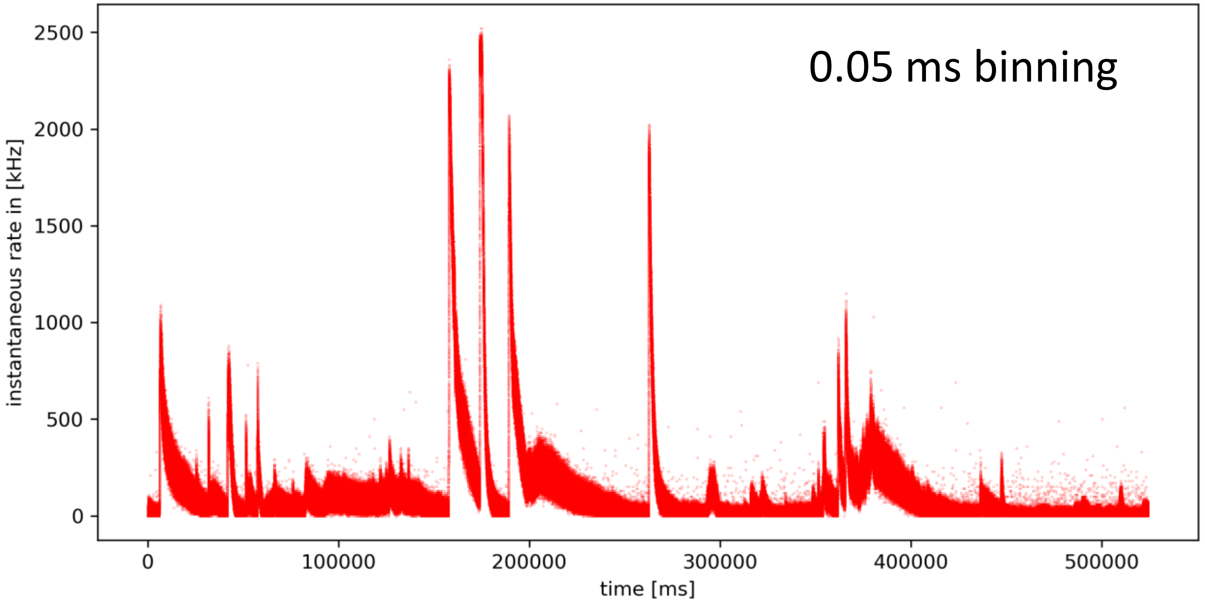


FINER RATE BINNINGS

Available runs: 4 x 5400 s (1 ms resolution), 2x400s (0.1 ms), 1x250s (0.05 ms), 3x90s (0.001 ms)

Examples for rate as function of time:



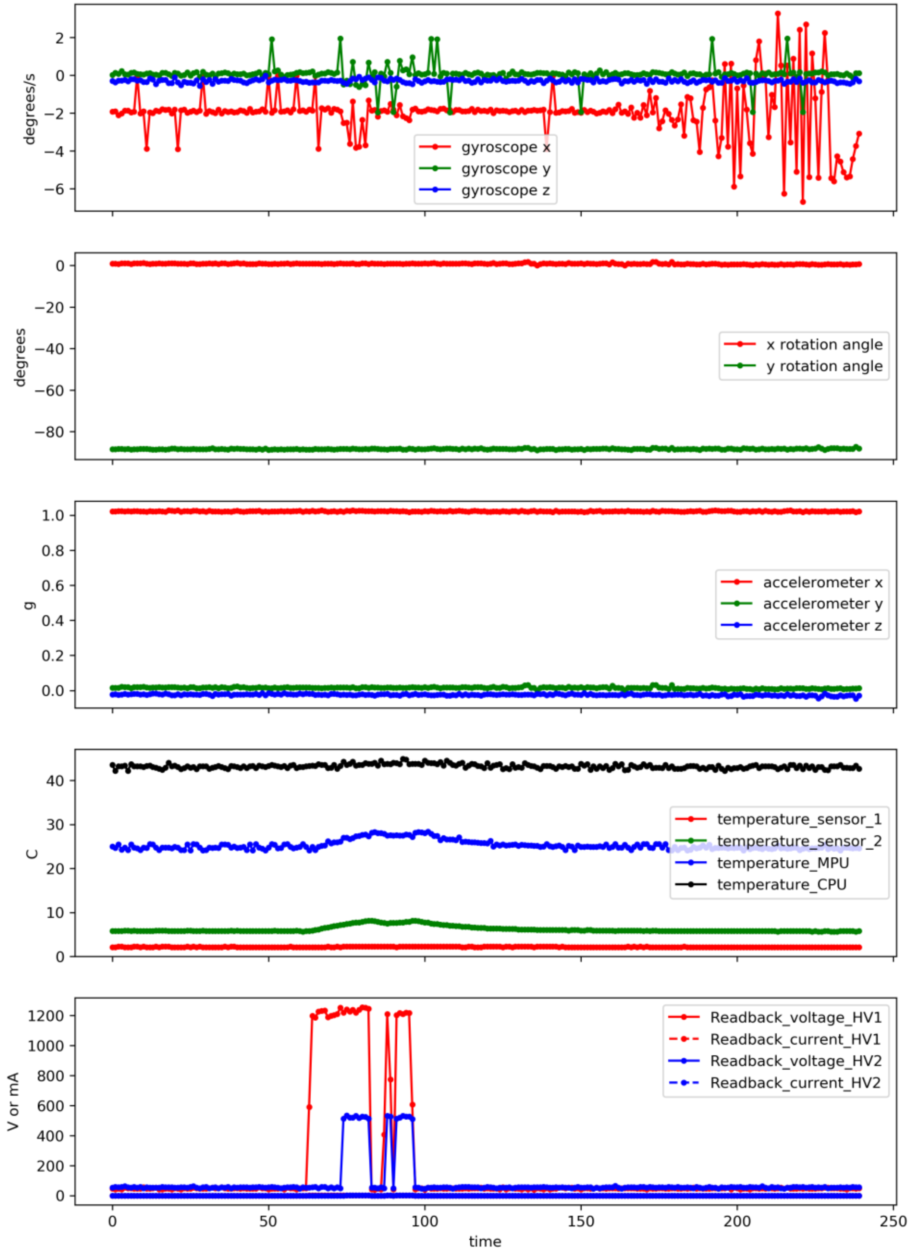


Spurious high rates in single bins are deadtime artifact of DAQ….

ENVIRONMENTAL SENSORS

- 24 days of data in ocean
- 19 sensors read out every minute
- Gyro, magnetometer, acceleration, temperature (4), HV
- Data not in Oceans 2.0 Plotting Utility (but stored in Mainz)

- Not studied in detail yet
- No comparison to other ONC information and WOM rate yet
- Work is under way



SUMMARY

- WOM deployment successful, but connectivity unfortunately lost
- Continuous data taking with 1 ms rate resolution for 18 days
- Many special runs and environmental sensor readings
- First results on bioluminescence based on 18 days

  → frequency space (inertial frequency low?)

  → rise and fall times (how to interprete these results?)
- First ideas on effective area determination in-situ (40-K)

  →K-40 rates too low ?

many open questions !!!

APPENDIX

K-40 FOR ABSOLUTE CALIBRATION?

Implications of optical properties of ocean, lake, and ice for ultrahigh-energy neutrino detection

P. Buford Price

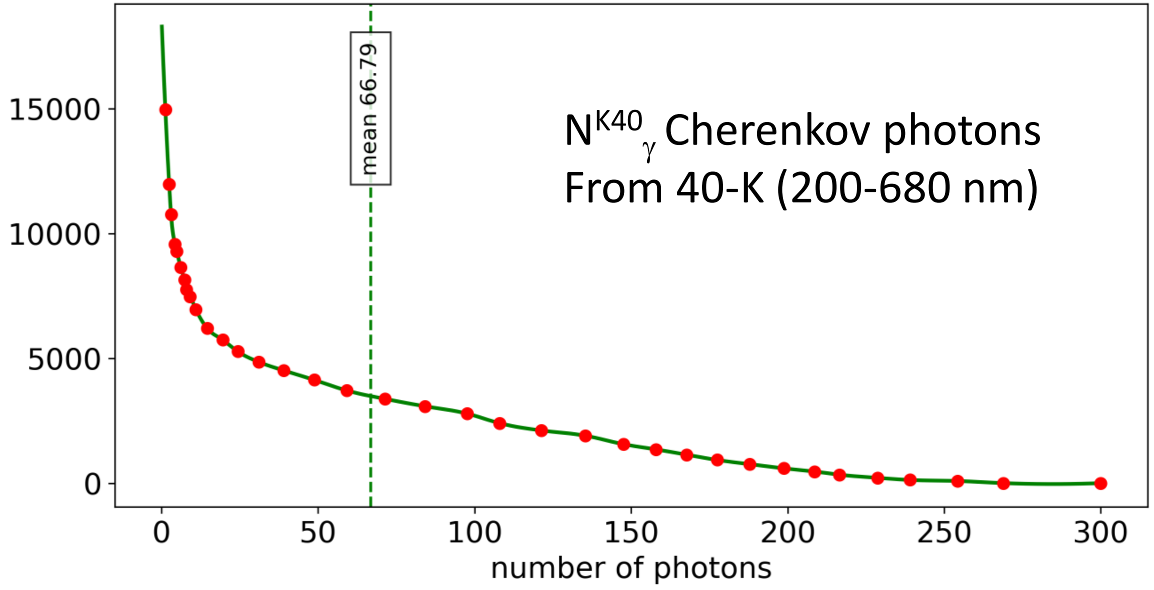
Single emitter:

Absorption dominated

$$N_\gamma^{PMT} = L(E_e)\frac{1}{\pi}\int T(\lambda)\eta(\lambda)2\pi\alpha_e(1-1/\beta^2m^2) \times \frac{A_{PMT}}{4\pi d^2\lambda^2}\exp[-a(\lambda)d]d\lambda,$$

diffusion regime:

$$N_\gamma^{PMT} = L(E_e)\frac{1}{\pi}\int T(\lambda)\eta(\lambda)6\pi\alpha_e(1-\beta^{-2}m^{-2}) \times \frac{A_{PMT}\Sigma[b_i(1-\tau_i)]}{16\pi d\lambda^2}\exp[-\alpha(\lambda)d]d\lambda.$$



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$\mathbf{R_\gamma} = N^{K40}_\gamma\, \rho\, A_{eff} /\pi/\mathbf{a(\lambda)}$ x (1-exp(-a(λ)*d_{max}))

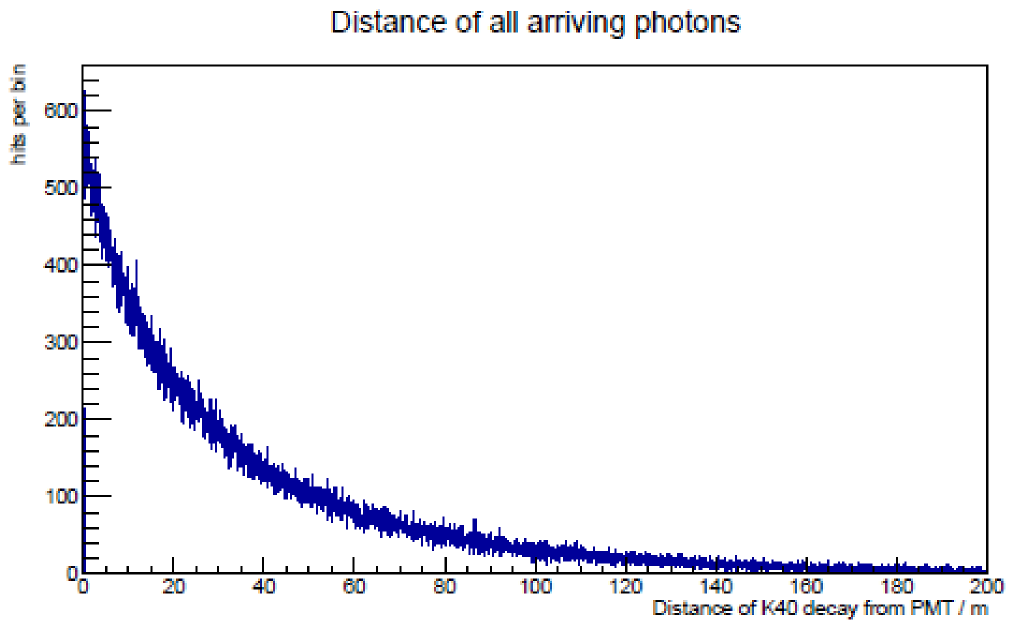
diffuse case accordingly ….

KM3NET

Björn Herold, Simulation and measurement of optical background in the deep sea using a multi-PMT optical module, dissertation 2017:

Assume 13 kBq per m^3, 11250 photons per KM3Net PMT hitting cathode surface (before QE and DAQ!)
Expect **128.2 kHz** for full KM3Net Module with 31 PMTs of 76 mm cathode diameter (measurements higher)

4.13 kHz per 3“ PMT



Detect photons from far away:
→ Rate depends on absorption!

Look at coincidences or pulse height spectrum instead (sensitive to close 40-K decays!)

Can‘t do coincidences in straw-b, but maybe pulse height?

Salinity @ Cascadia Basin: 34.83 g /kg
in Mediterranian probably around 38 g/kg; 40-K rate lower in Canada

JG|U

EXPECTED FREQUENCIES IN PERIODIGRAM

Latitude ODP 1027C: 47.7567º

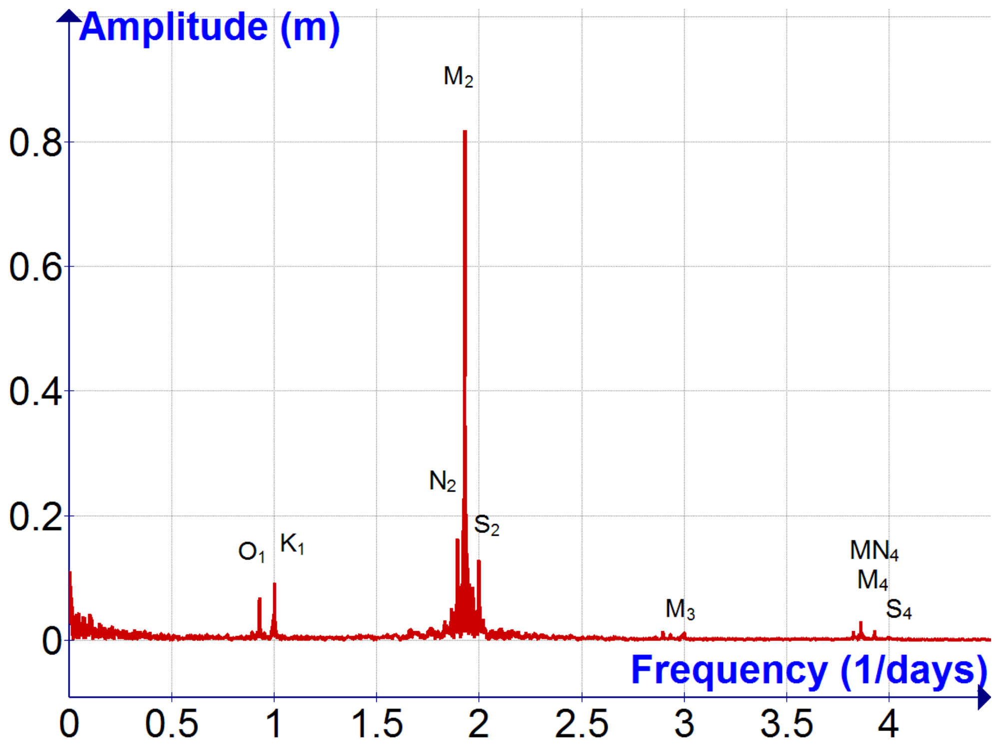
Dominant frequencies:

semidiurnal lunar tide M2 12.4206012 h

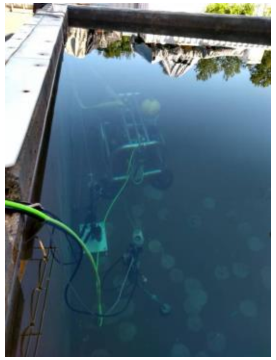
Inertial cycle 12h/sin(latitude)=16.21 h

https://en.wikipedia.org/wiki/Theory_of_tides

			Amplitudes Kodiak	SF
Principal lunar semidiurnal	M_2	12.4206012	97.3	58.0
Principal solar semidiurnal	S_2	12	32.5	13.7
Larger lunar elliptic semidiurnal	N_2	12.65834751	20.1	12.3
Lunar diurnal	K_1	23.93447213	39.8	36.8
Lunar diurnal	O_1	25.81933871	25.9	23.0



SALT WATER TANK



Water temperature between 4-6 degrees; however, sensor temperature rising to 30 degrees, when running