Technische Universität München

SFB 1258 Neutrinos Dark Matter Messengers

STRAW – STRings for Absorption length in Water

Christian Fruck

for the STRAW team

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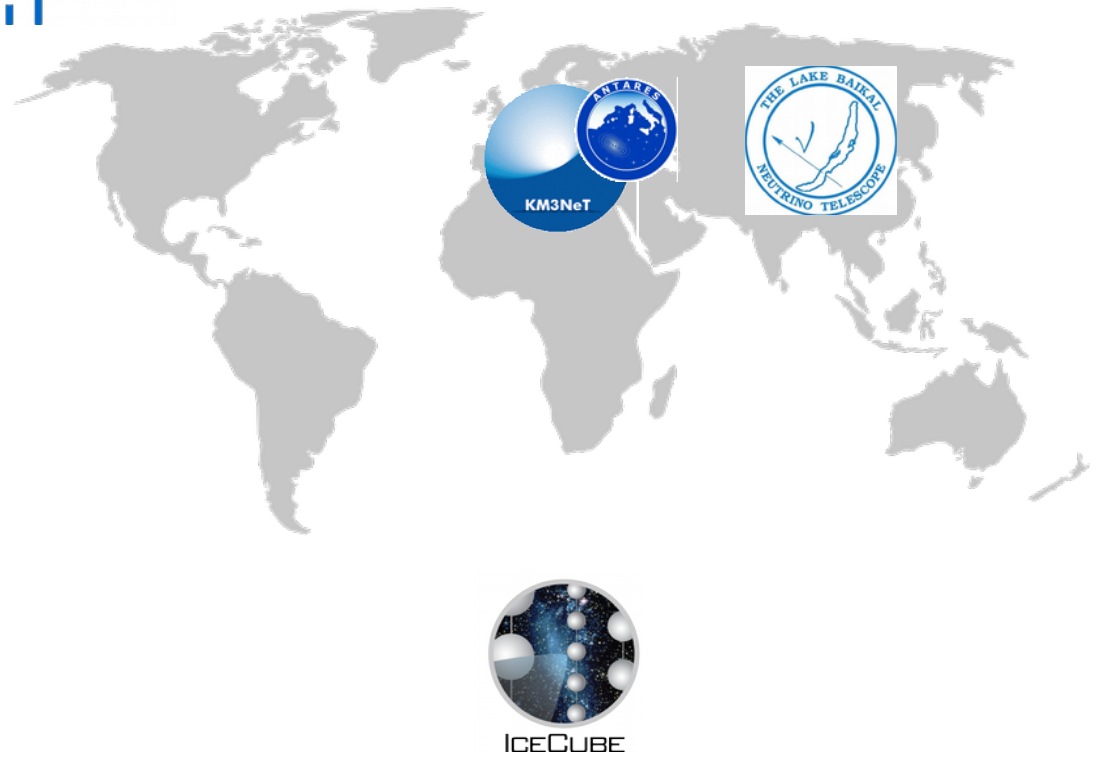
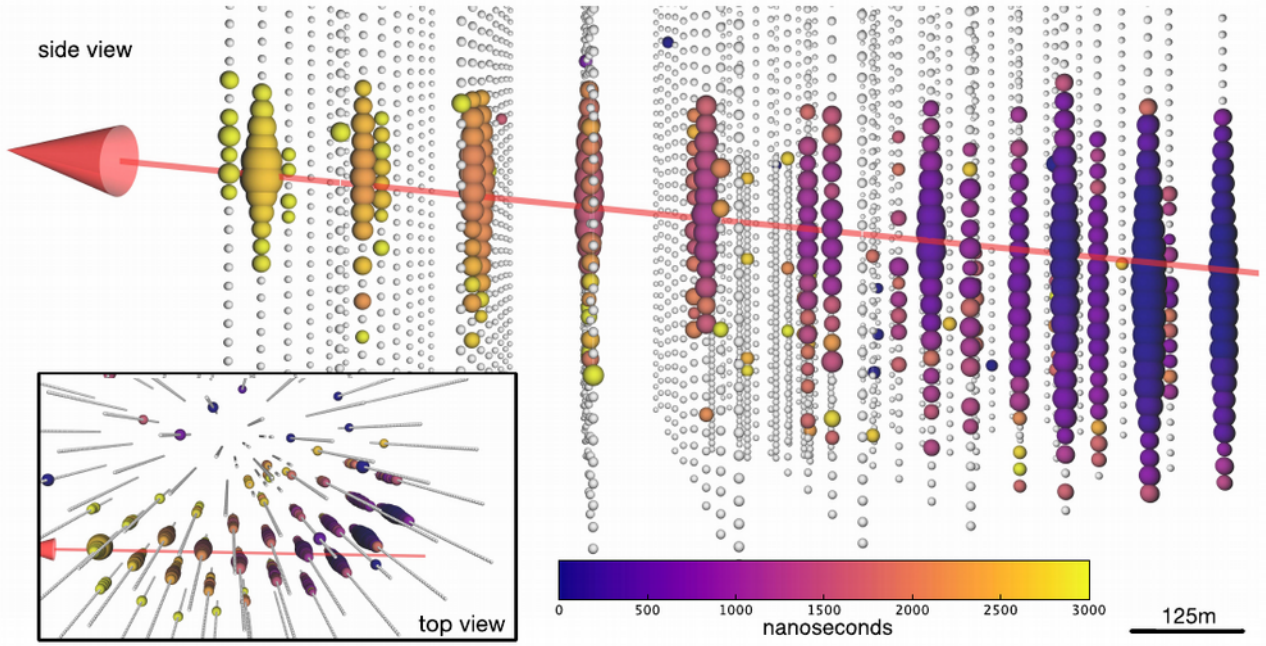
with support of Ocean Networks Canada

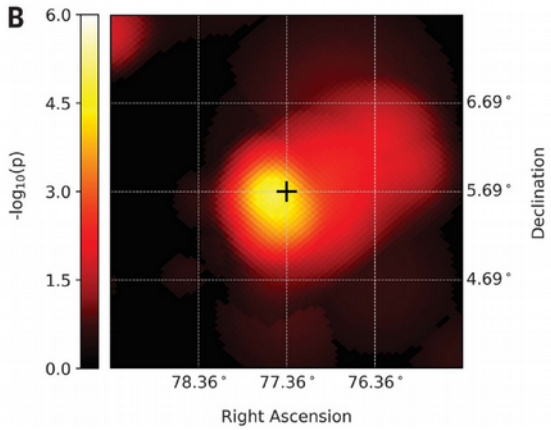
Neutrino Astronomy today: we need larger detectors!



The IceCube Collaboration et al., Science 361, 146 (2018)



IceCube Collaboration, Science 361, 147–151 (2018)

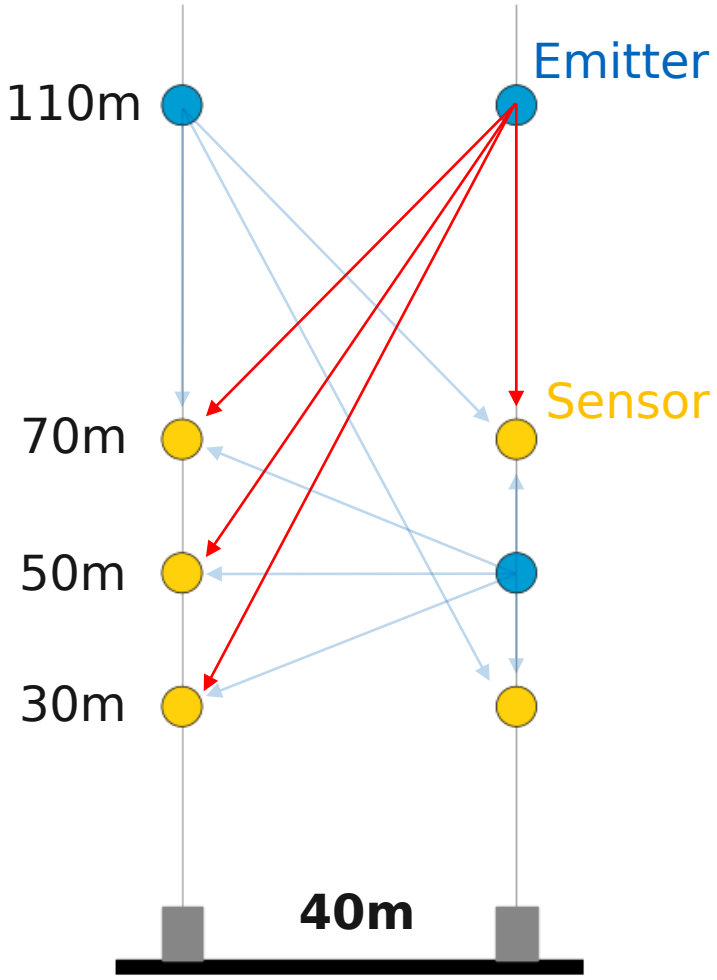


- A single astrophysical object (IceCube-170922A) associated with neutrino emission so far
- MWL observations triggered by a single event
- Even stronger evidence for association after adding archival IceCube data
- Detector volume needs to increase by ~2 orders of magnitude for real astronomical observations like in Gamma-ray astronomy

Possible solution: extend and connect

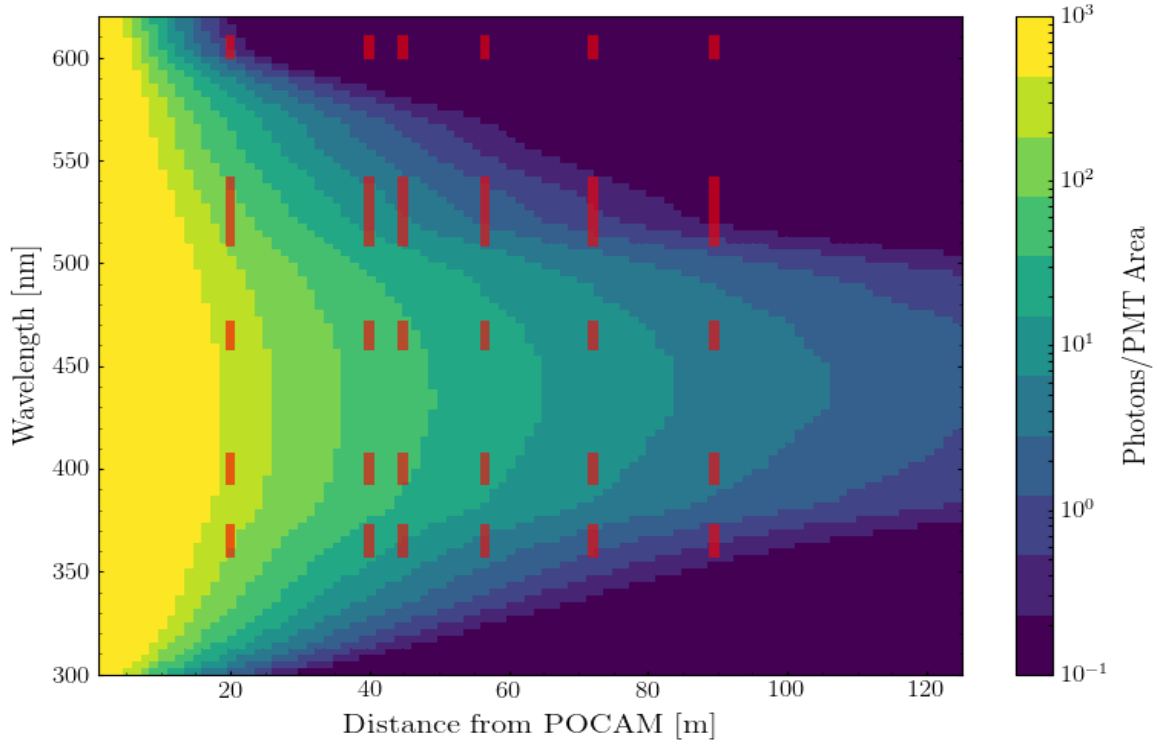
- Complete existing installations (GVD, KM3NeT)
- Upgrade existing instruments (IceCube Gen2)
- Explore new sites and build new instruments
  - ➔ Aim for large volumes
  - ➔ Use simple and proven technologies
  - ➔ Collaborate with experienced partners
- ➔ Cascadia Basin
  - Ocean Networks Canada (ONC)
  - ~10 y of experience with deep sea deployments/operation
  - Site is already “wired” with large electrical/optical sub-sea infrastructure
  - Deployment/connection is possible with minimal delay/overhead (as we will show)
  - One question remains: how good are the optical properties down there?

STRAW – STRings for Absorption length in Water

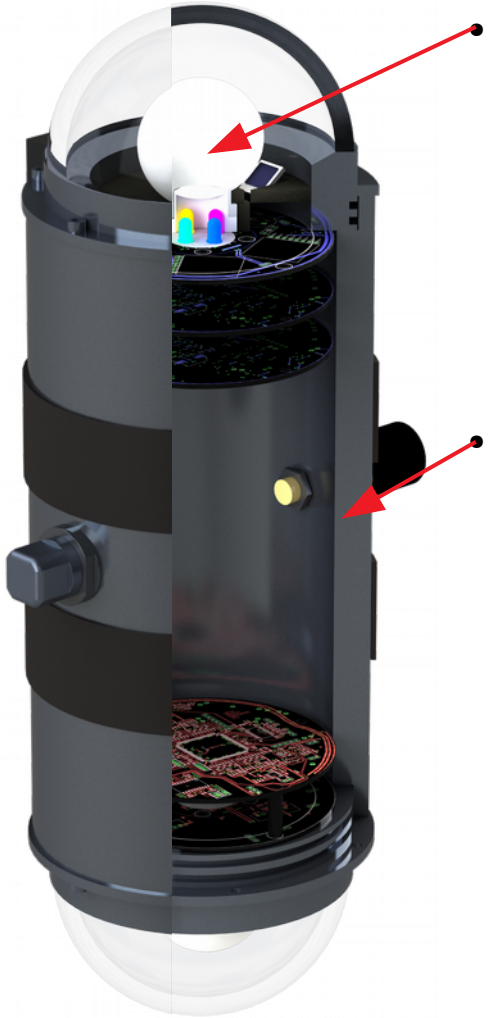


- Two-string detector with eight instruments
  - **Emitter:** Precision Optical Calibration Module (POCAM)
  - **Sensor:** STRAW Digital Optical Module (sDOM)
- Design based on expected optical properties (pure seawater)

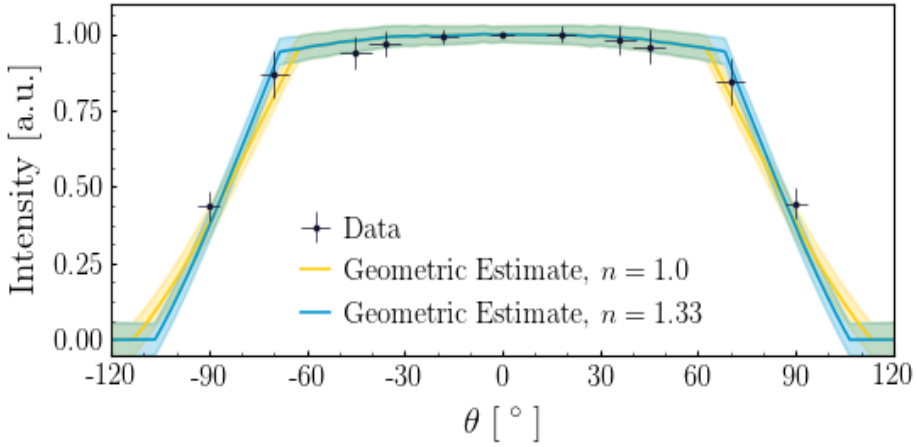
Smith, R. C. & Baker, K. S. Appl. Opt. 20, 177–184 (Jan. 1981).

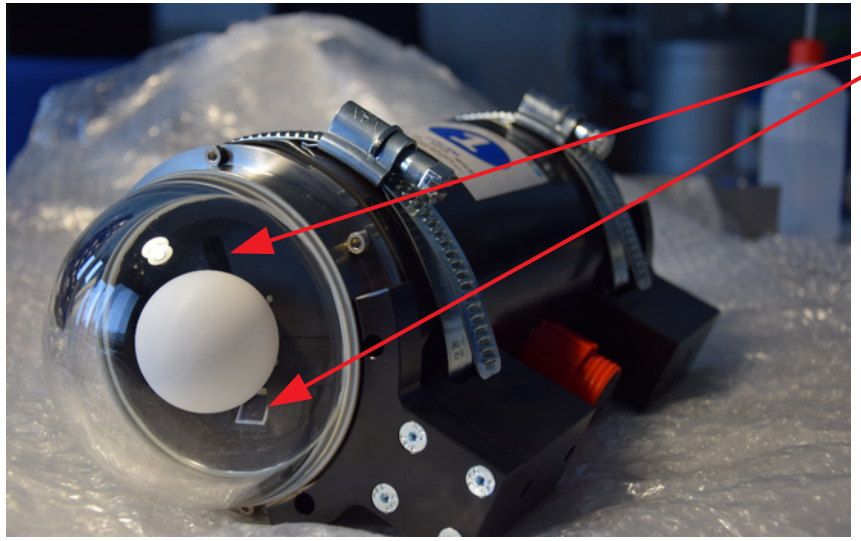


The POCAM flasher – calibration unit for IceCube Gen2



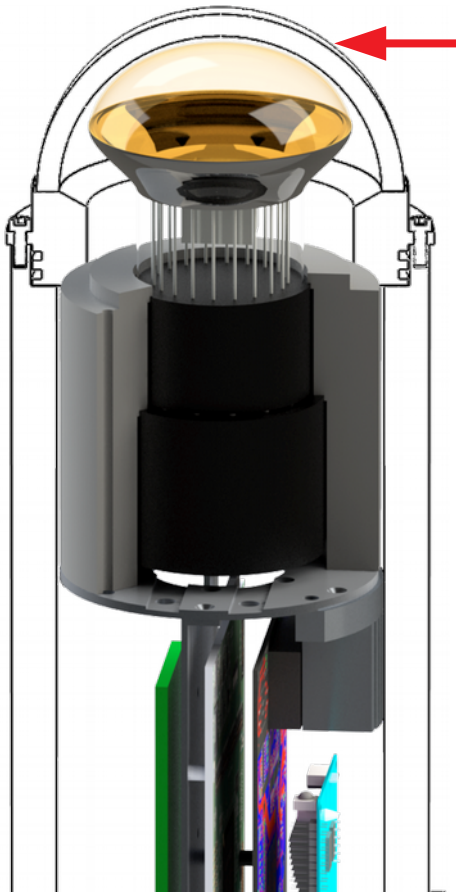
- Precision Optical Calibration Module
- Create isotropic light flash using a PTFE integrating sphere
  - Intensity adjustable over at least 2 orders of magnitude
  - PTFE is Lambertian reflector
  - High reflection across broad wavelength range
  - Spherical integration isotropy
- Titanium housing designed for 1400 bar

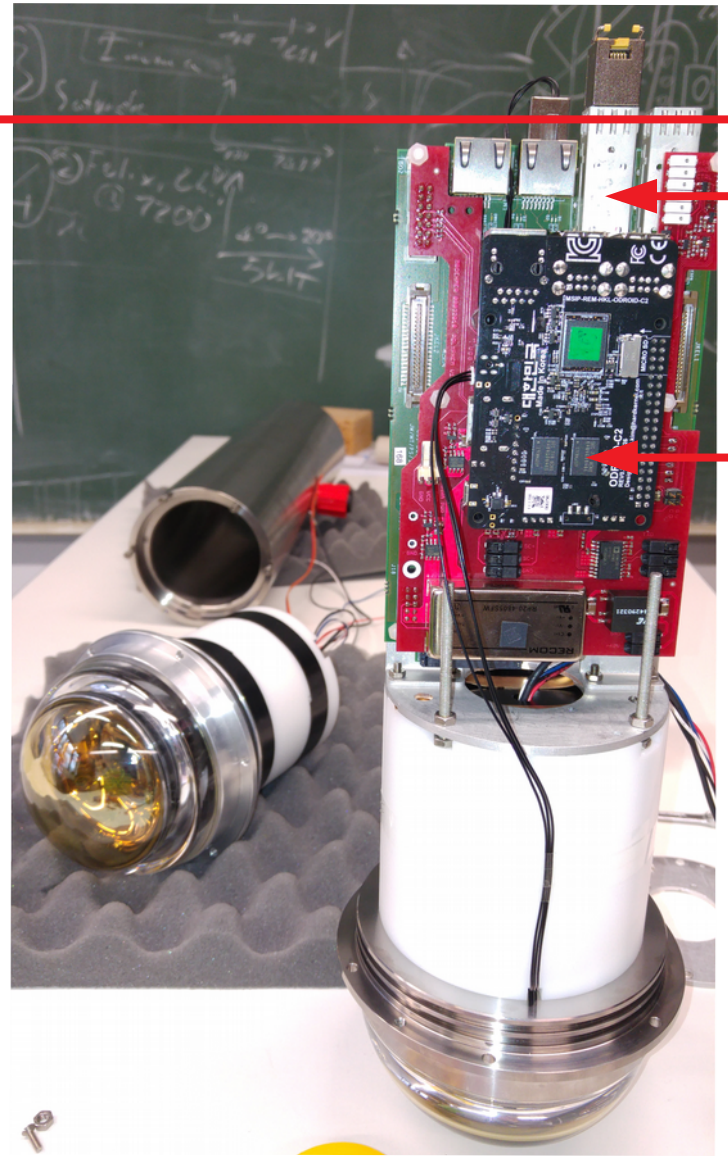




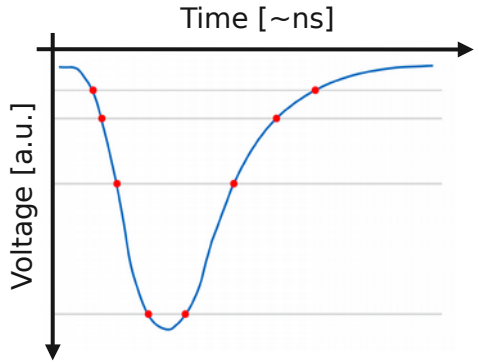
- Use internal photosensors for self-calibration
  - SiPM and Photodiode for high dynamic range
  - Multi-wavelength emission for spectral studies
    - 365, 405, 465, 525, 605nm

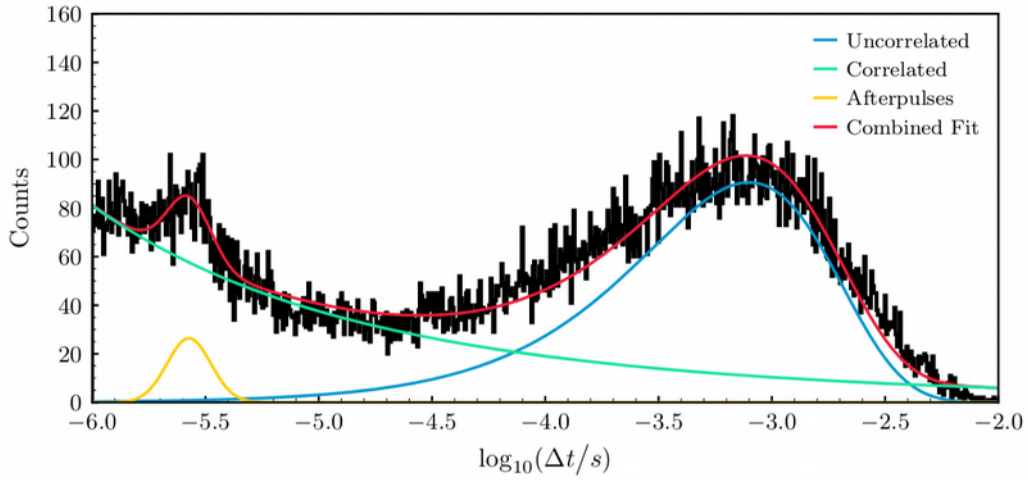
sDOM – the STRAW digital optical module



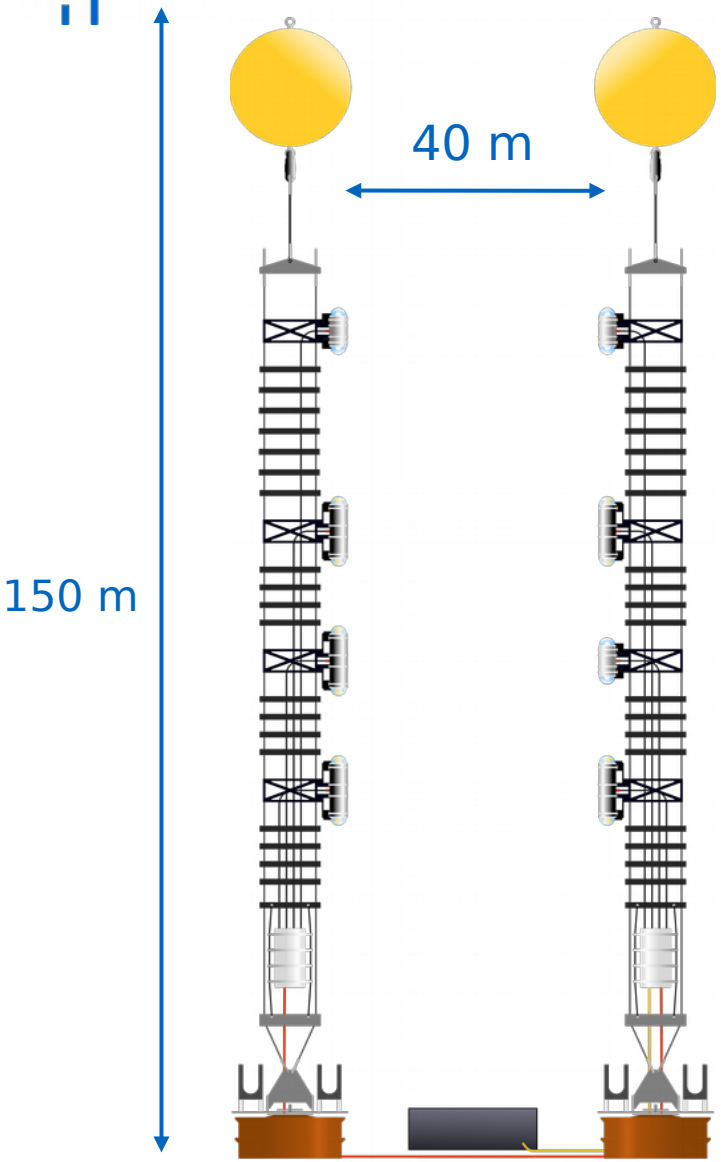


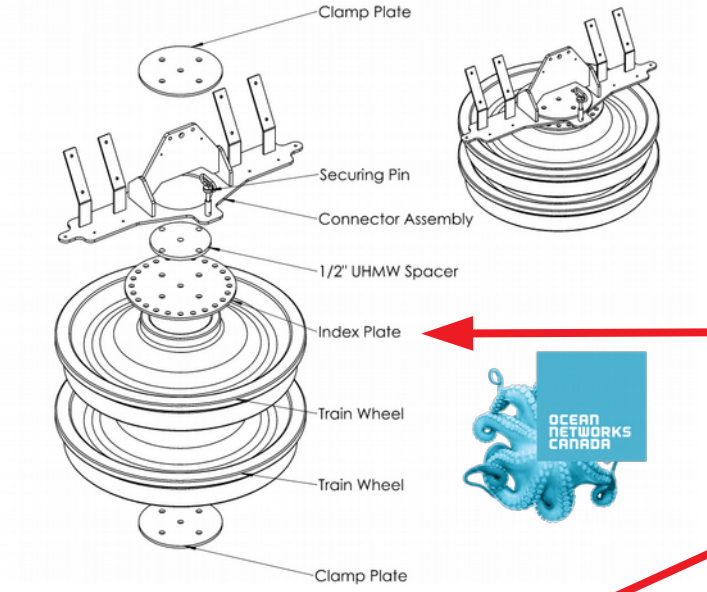
- Mechanics based on POCAM design
- Two 3“ PMTs (Hamamatsu R12199)
- Readout with TRB3 and PaDiWa (TDC designed by GSI) http://trb.gsi.de/
- 4 channels per PMT
- Control via Ethernet and single board computer Odroid C2



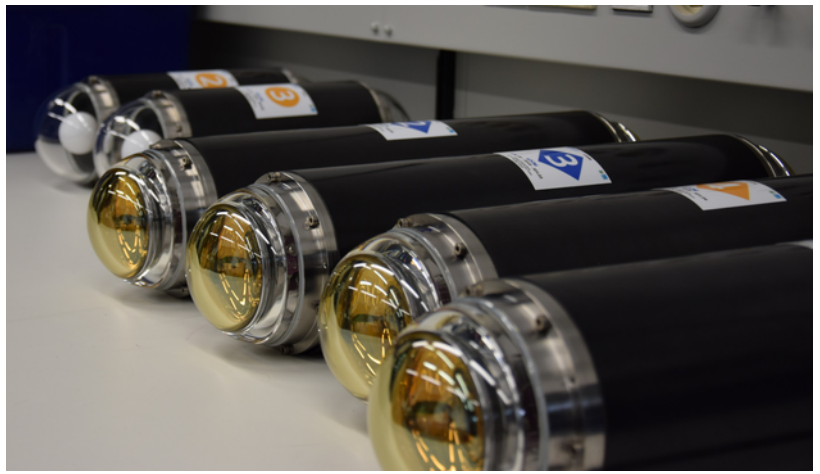


String design and deployment mechanism



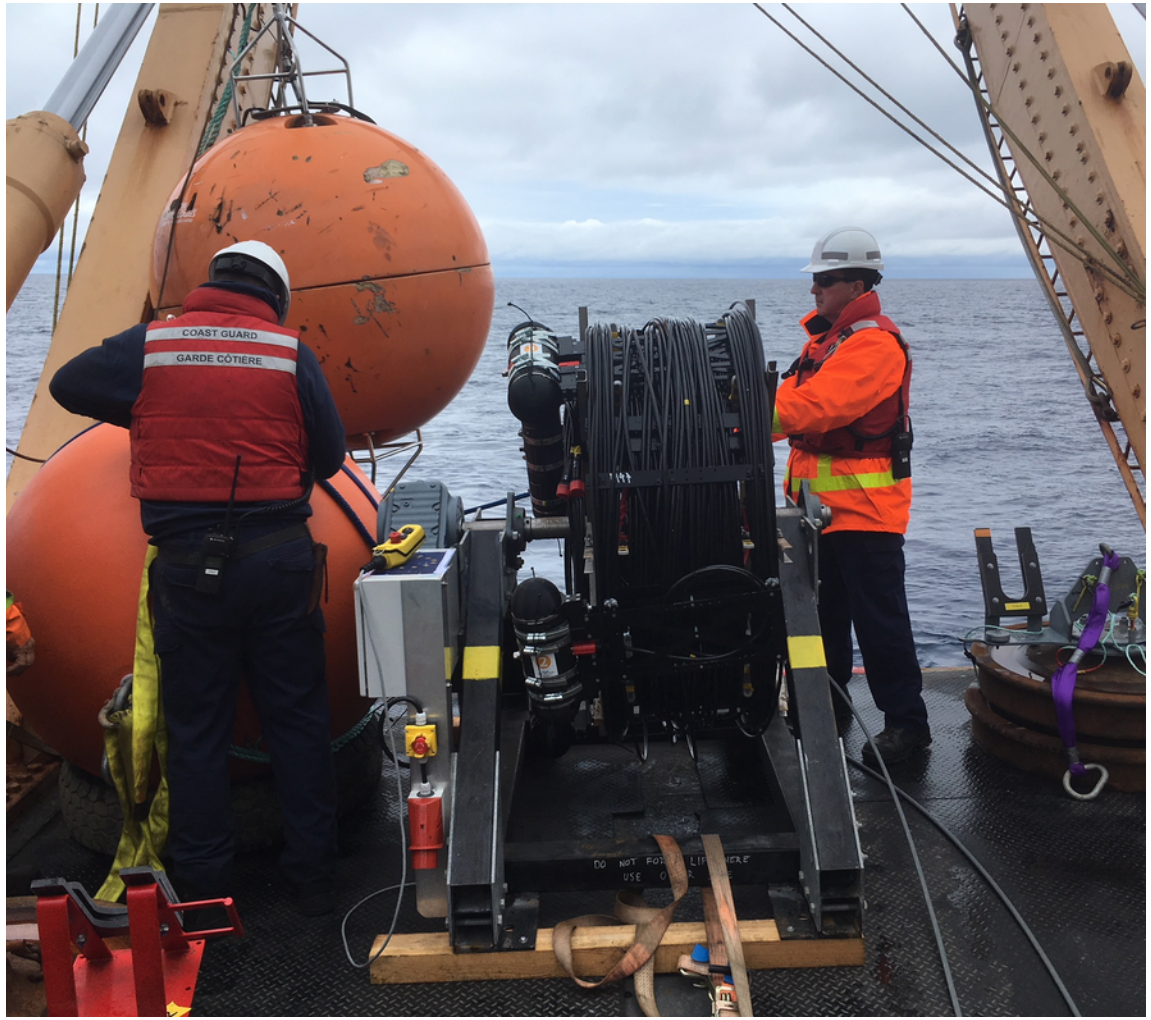


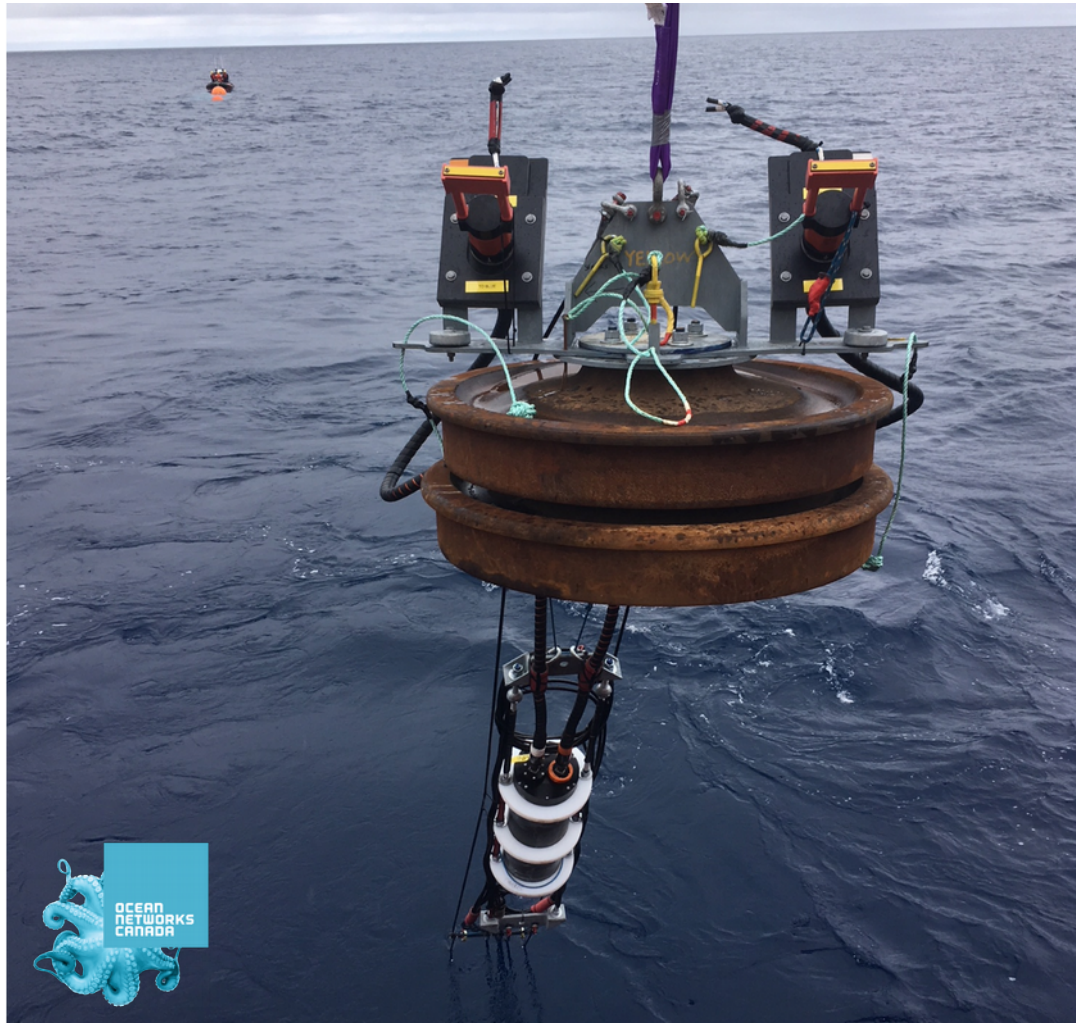
- Mechanical design minimizes bending and rotation in currents
  - Two-line strings
  - Strong up-lift float
- Rotational anchor for ROV alignment of the strings
  - Post-deployment rotation
- Motorized spooling system for shipment and deployment



Deployment (24/25.06.2018)

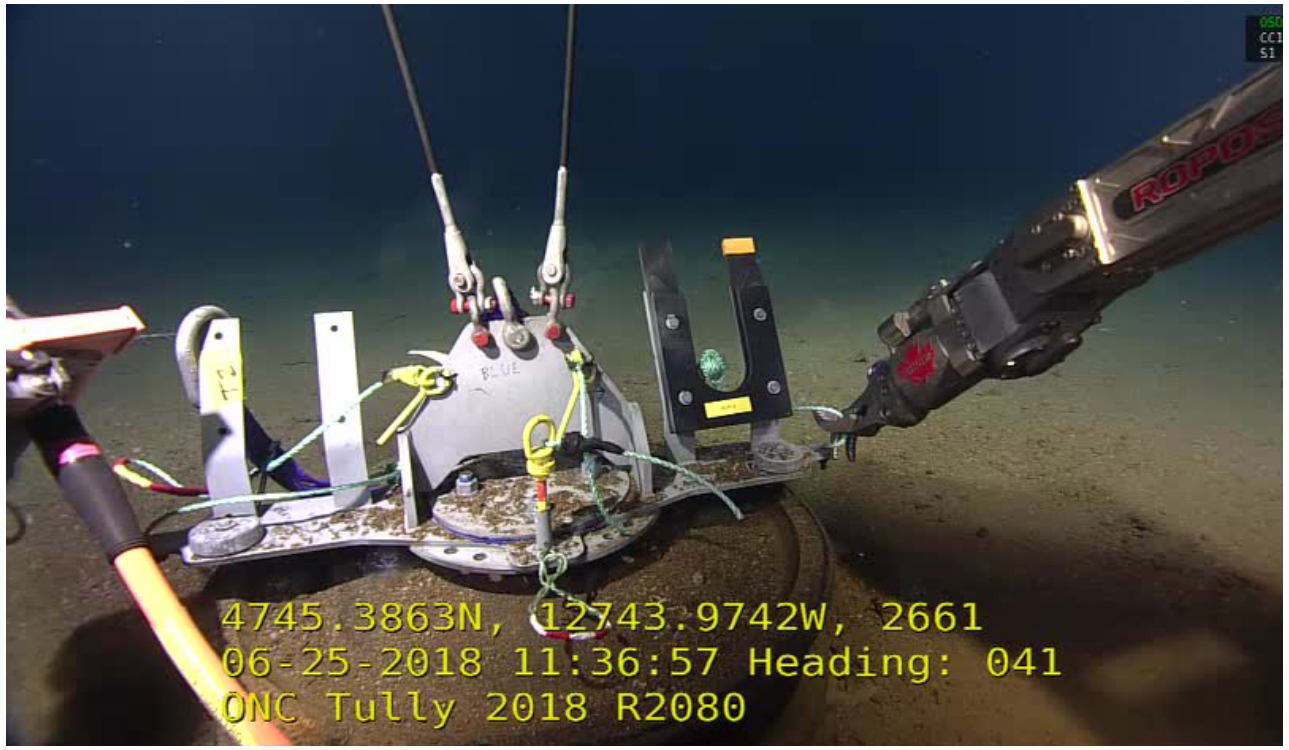
All deadlines met, STRAW arrives in Canada on time and is deployed on June 24th

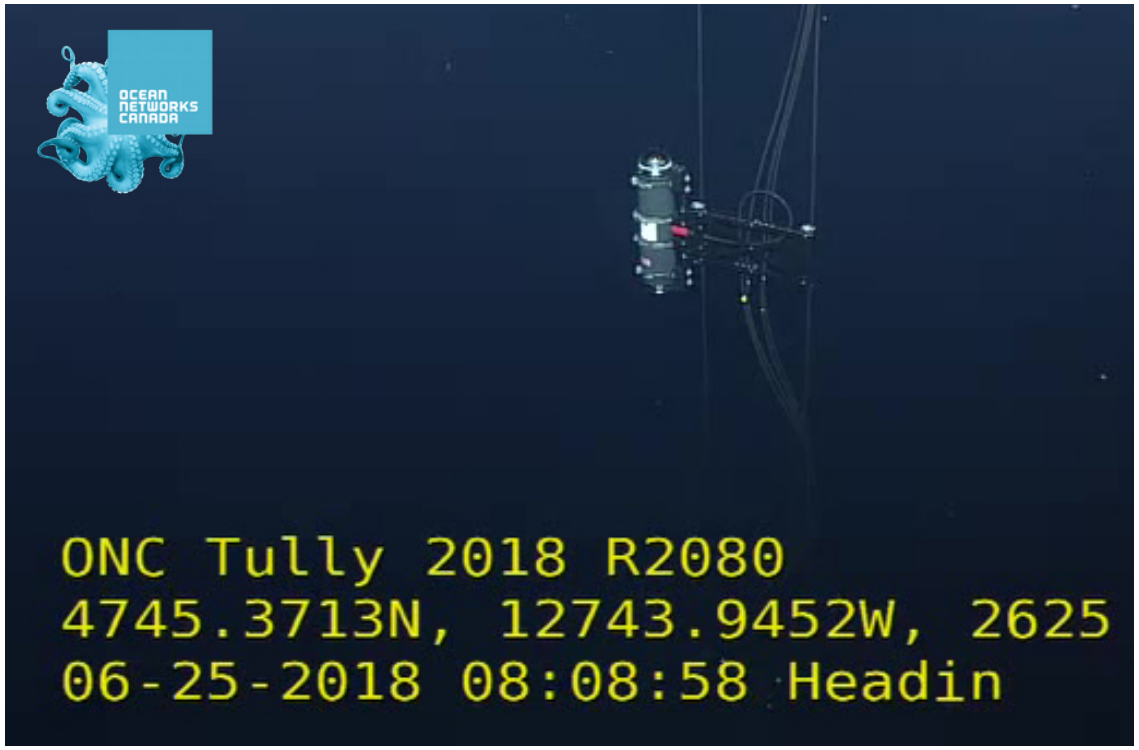




Deployment (24/25.06.2018)

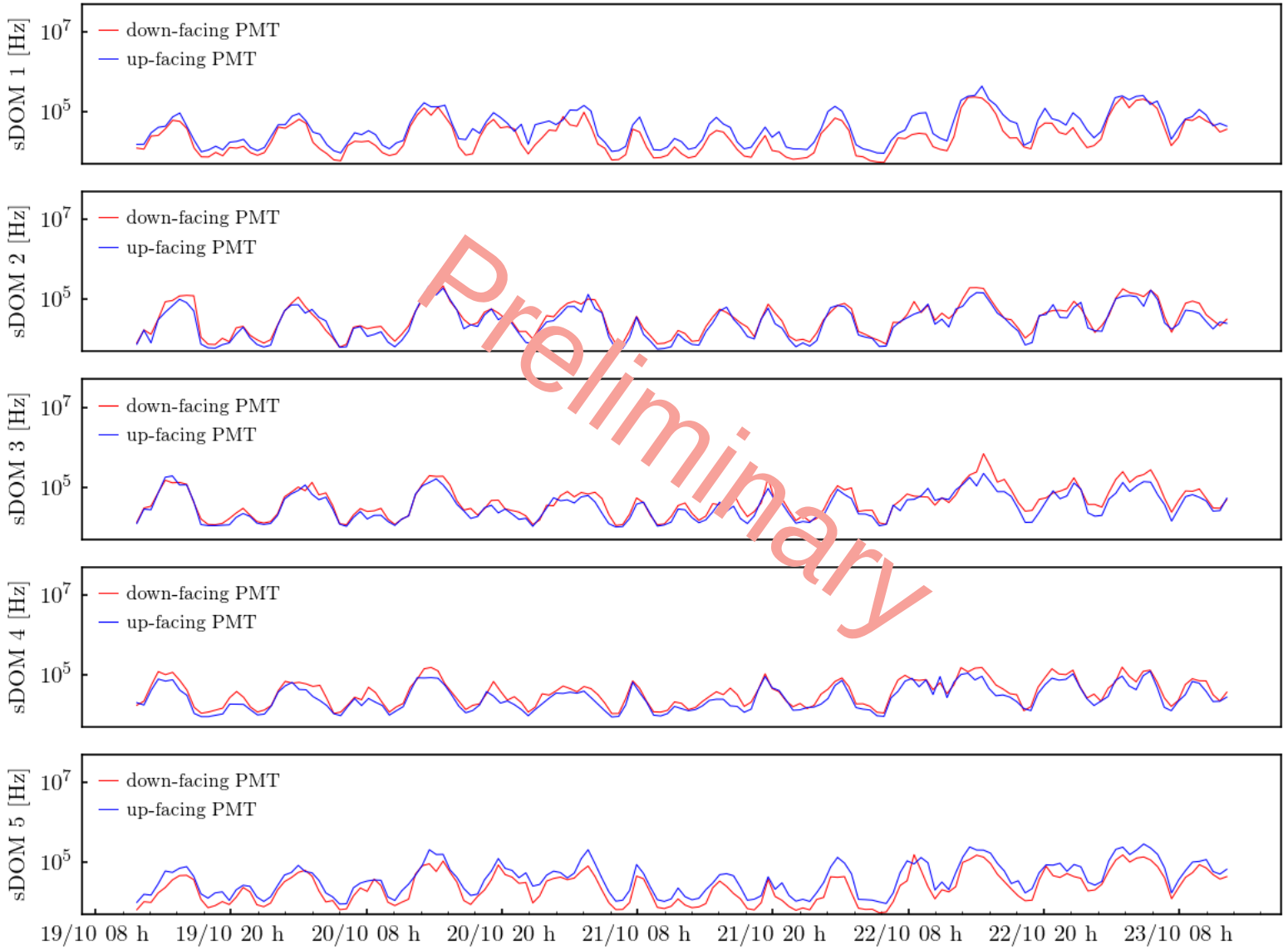
After lowering the strings to the seafloor, an ROV is used for alignment, inspection and connection to the ONC power/data infrastructure





First data and results

- All instruments alive and working according to specifications!
- sDOMs measure rates between 10 kHz and a few MHz
- Hourly median rates reveal structure on a time scale of several hours



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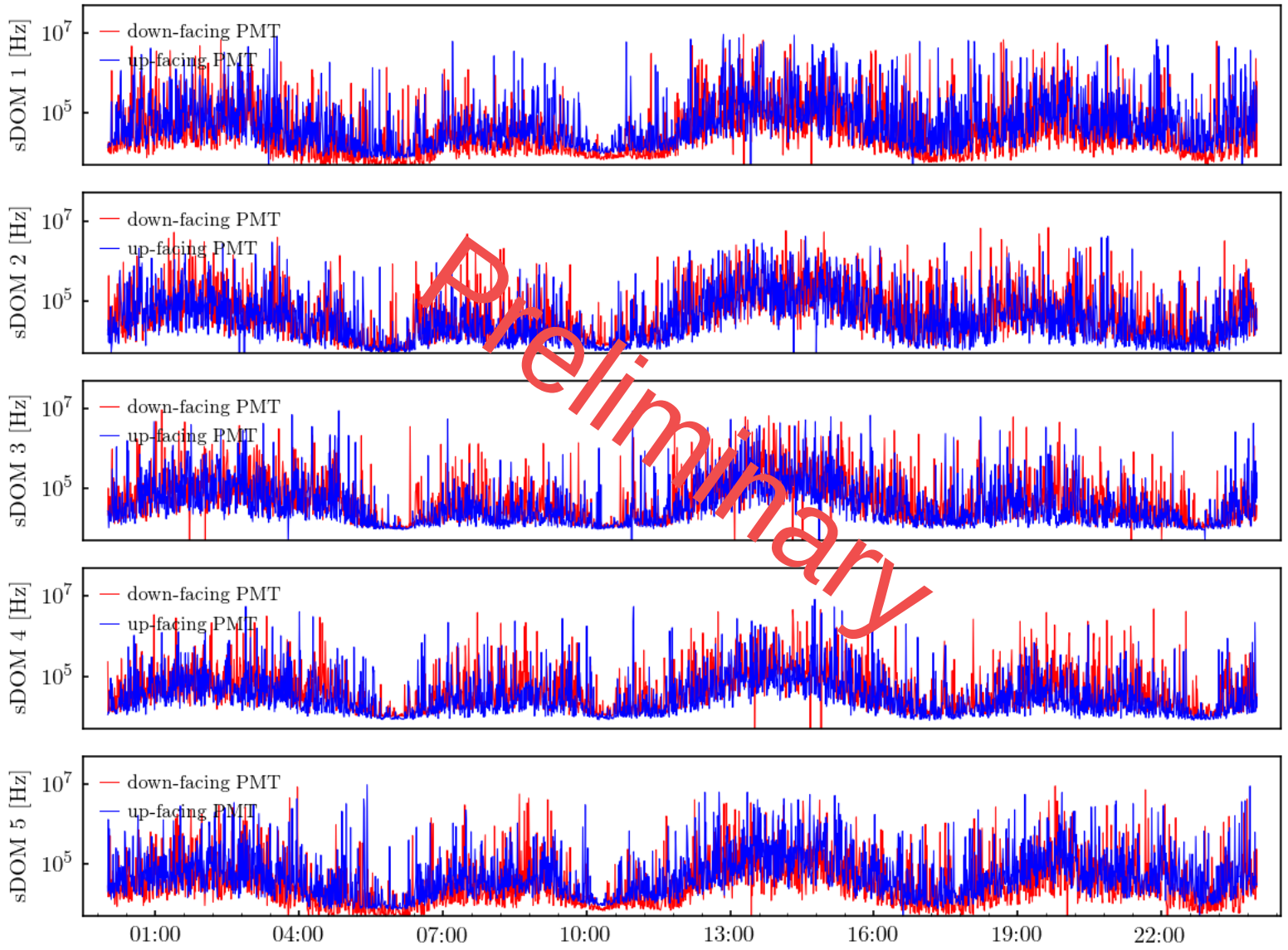
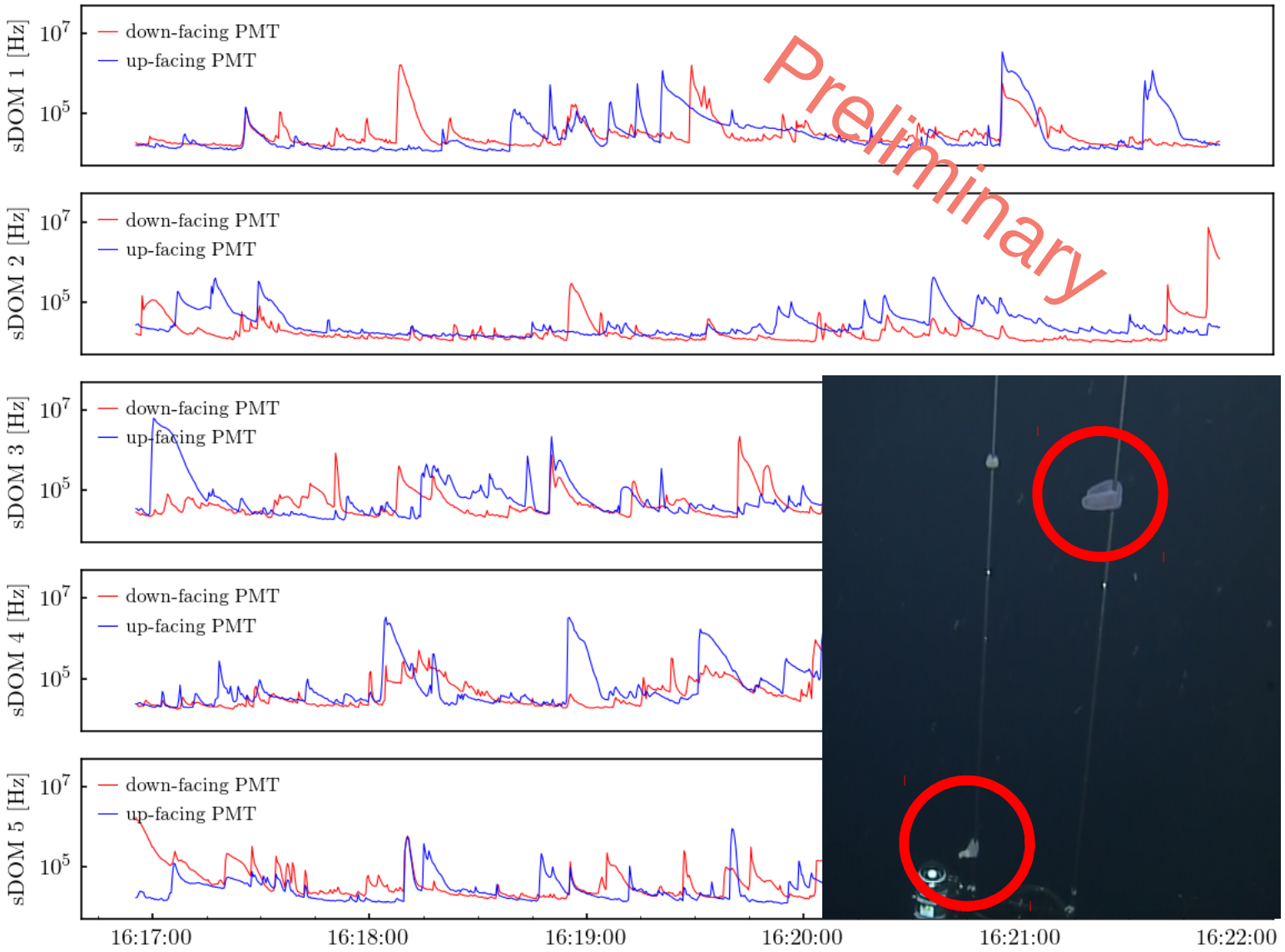
- A finer binning indicates the presence of much shorter timescale flashes (24h are shown)



First data and results

- All instruments alive and working according to specifications!
- sDOMs measure rates between 10 kHz and a few MHz
- Hourly median rates reveal structure on a time scale of several hours
- A finer binning indicates the presence of much shorter timescale flashes
- At even shorter timescales (5 min shown here):
  - Rising edge on the order of one second or less
  - Decay over several seconds
  - Origin: bioluminescence from animals and microorganisms

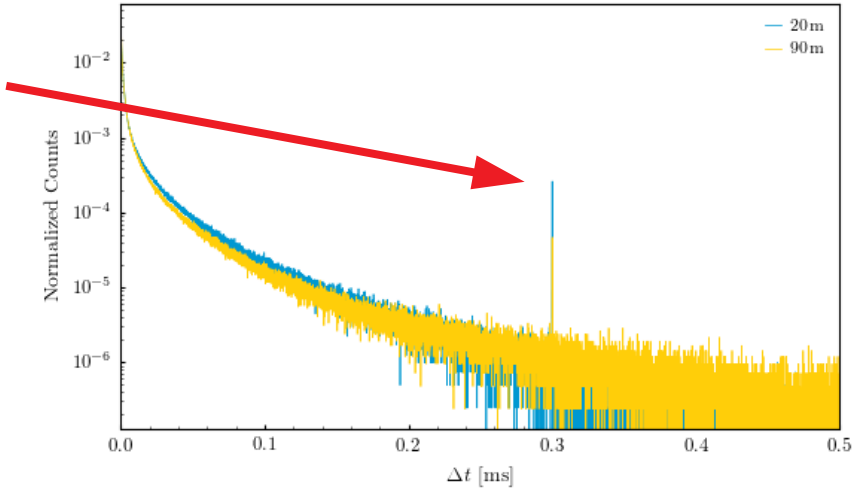


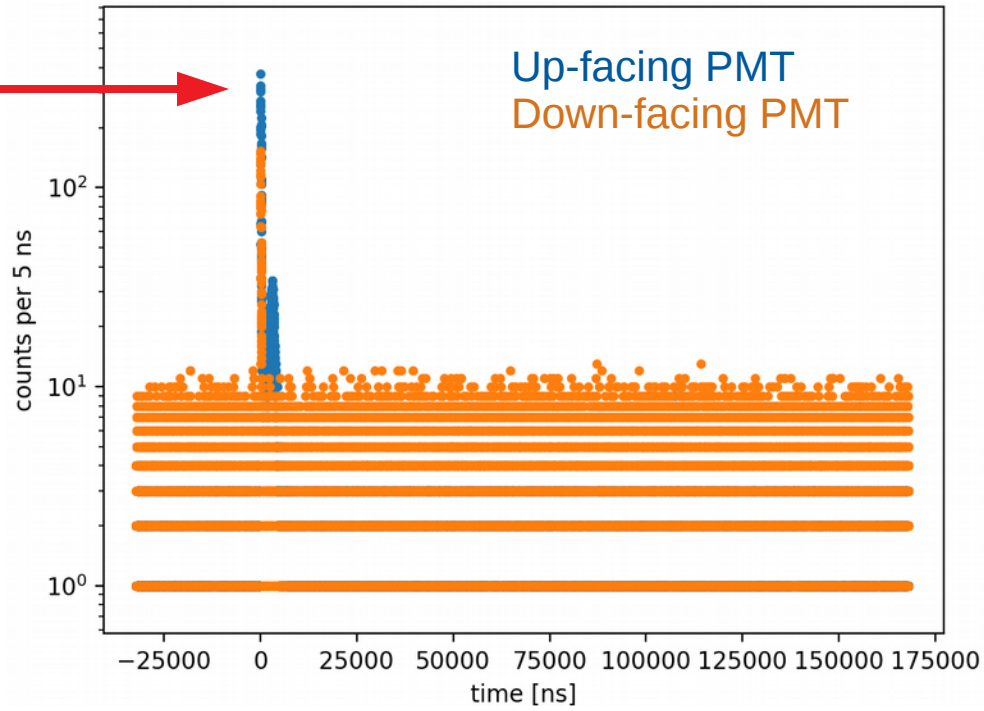
POCAM flashes and absorption measurement

- Δt histogram immediately reveals POCAM pulses at expected frequency
- High dark rate causes large fraction of shorter Δt values
- sDOMs are synchronized, but POCAMs are not integrated
- Reconstruction of collected PMT charge from ToT data is possible but rater complex

➔ Using simplest approach for the first analysis:

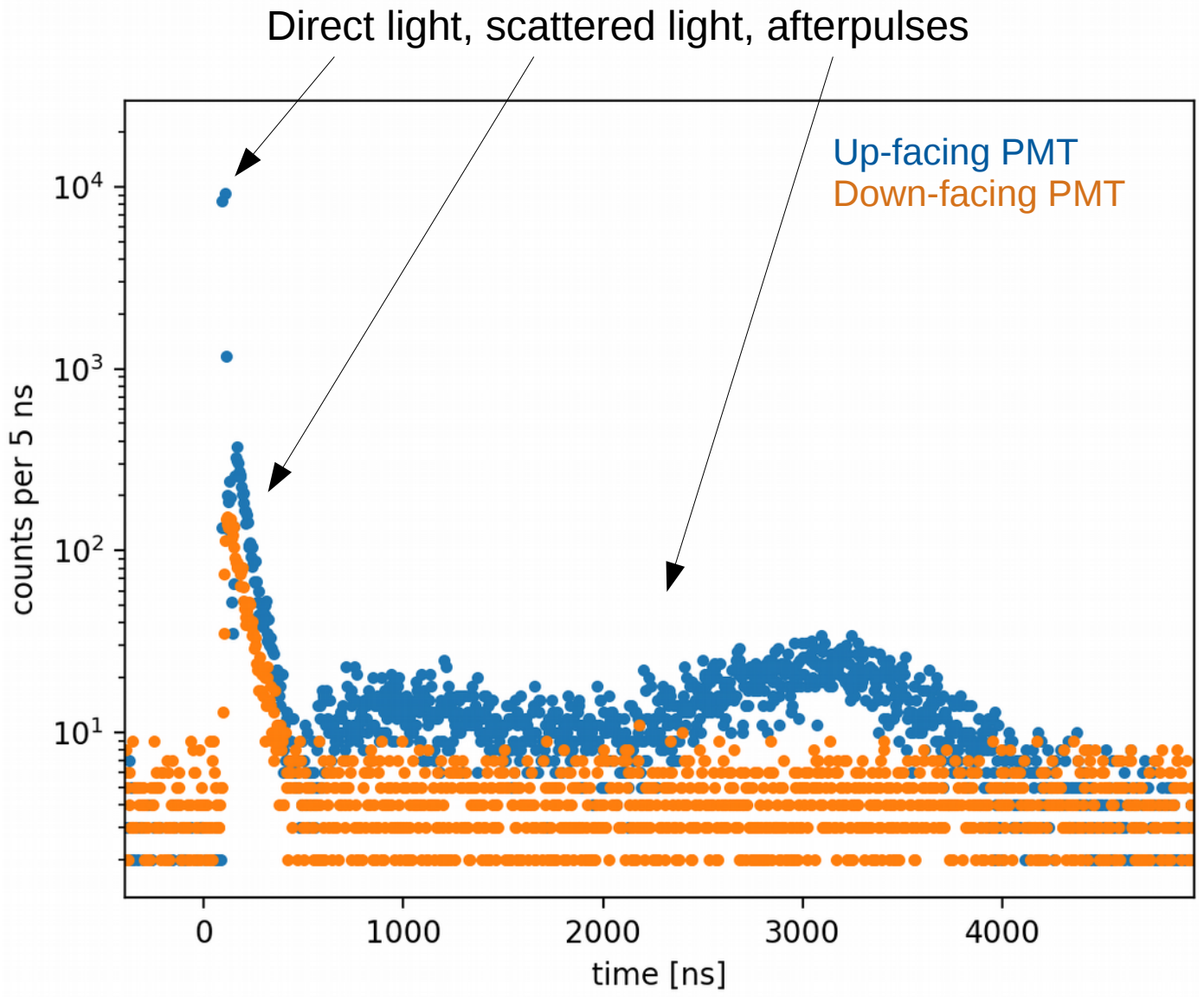
- Detected fraction of light only via ‘hit-fraction’
- POCAM flashes identified via periodicity search (frequency fit)
- After background subtraction → number of detected flashes
- POCAM needs to be adjusted to suitable intensity where on average only a fraction of the flashes lead to a detected photon
- Model the whole instrument
- Fit to data
- **Absorption length!**





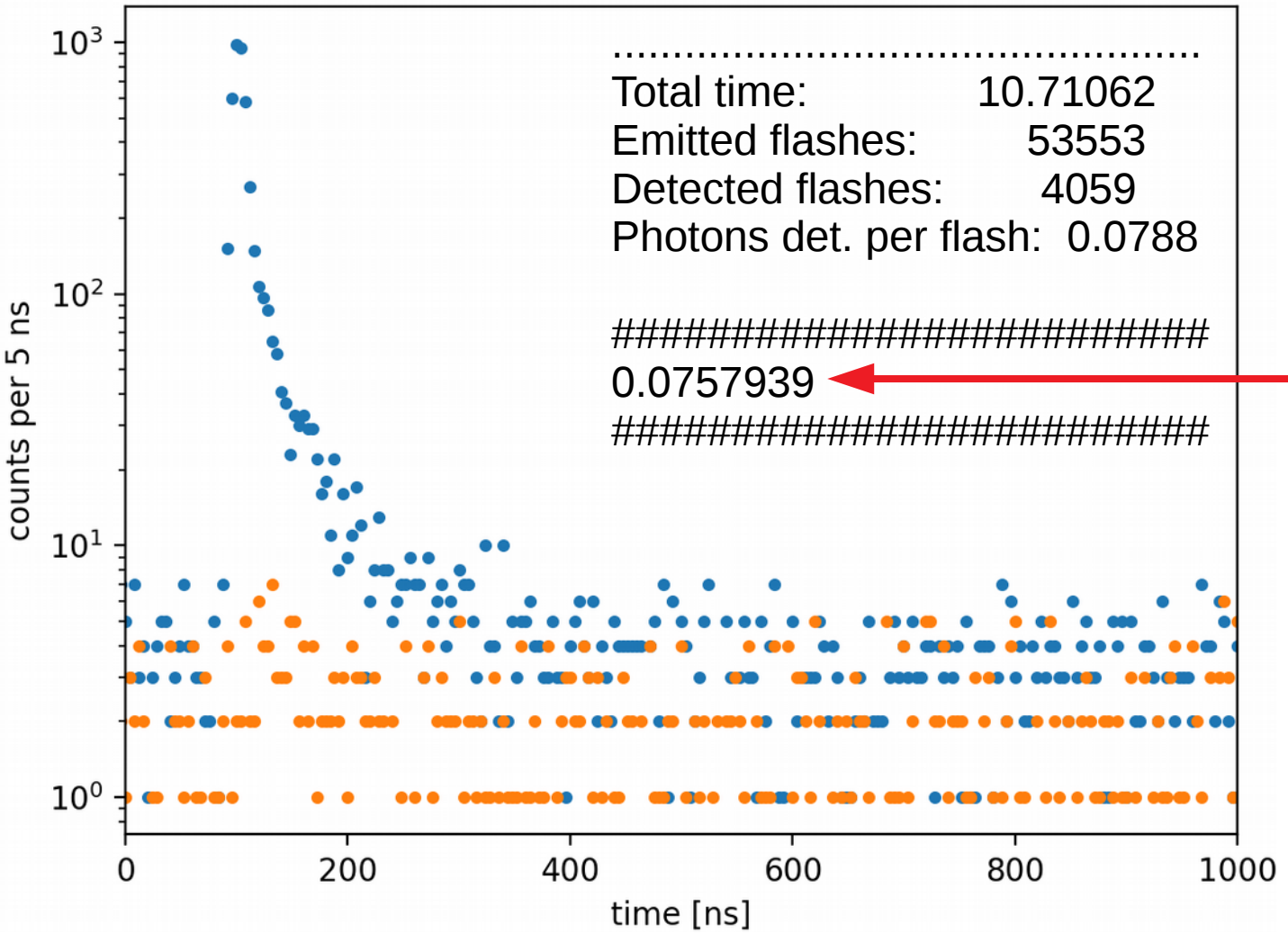
POCAM flashes and absorption measurement

- Information that can be extracted from this simple scheme presenting the data:
  - ➔ Scattering information, also from the away-facing PMT
  - ➔ Afterpulsing time structure
- Only 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 5 kHz



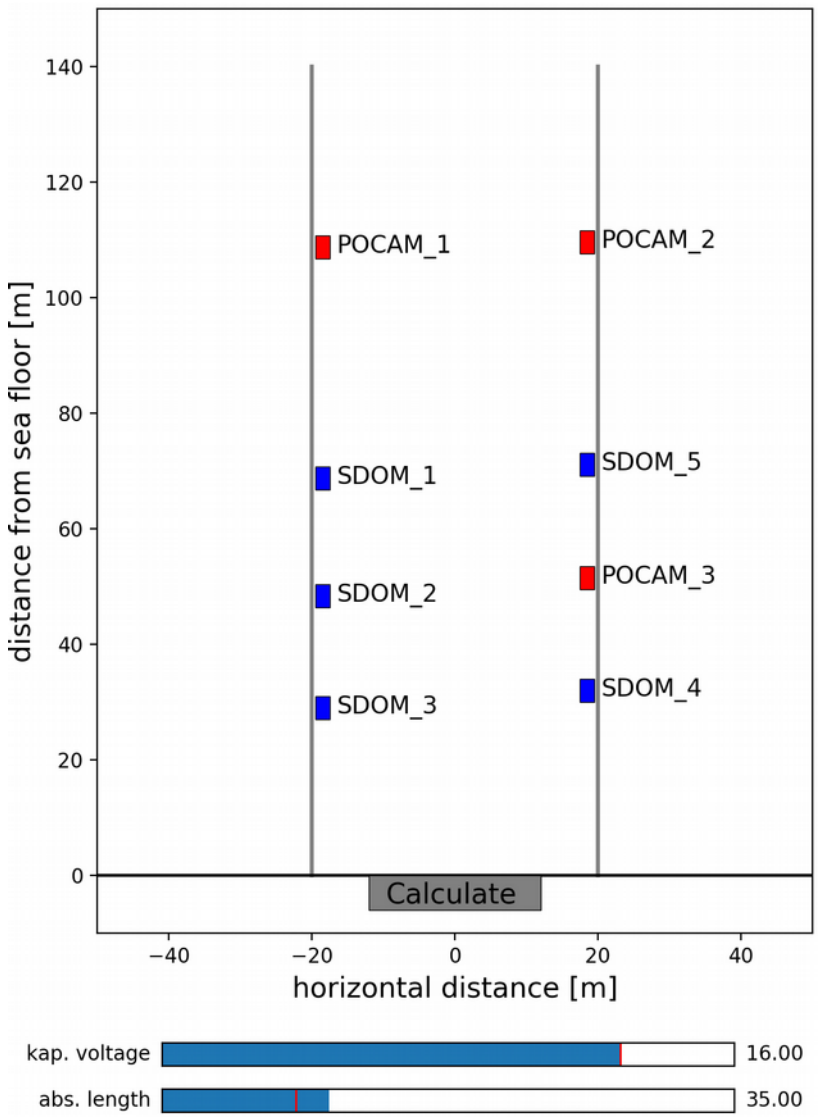
Signal extraction

Searching for signal periodicity
200100.30816036806



"hit fraction"

Preliminary attenuation length results



Model has the following parameters:

POCAM:
→ Calibration error 1x per POCAM (+/- 10%)
→ Global calibration error due to temperature (15%)

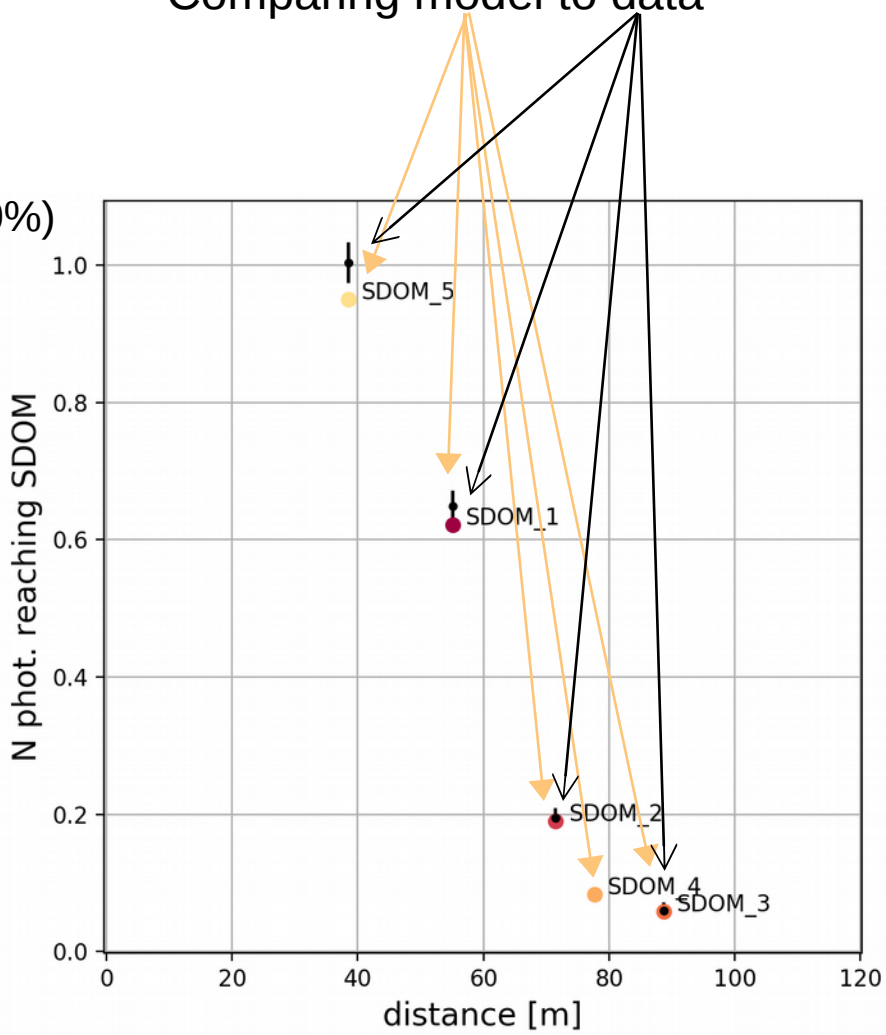
sDOM:
→ QE/PDE error per 1x per sDOM (+/- 20%)
→ QE global (~25%)
→ Threshold efficiency (~45%)

STRAW:
→ **attenuation length**
→ y offset (+- 2m)

Fit 400 nm and 465 nm simultaneously

→ **MCMC sampling using emcee**
http://dfm.io/emcee/current/

Comparing model to data



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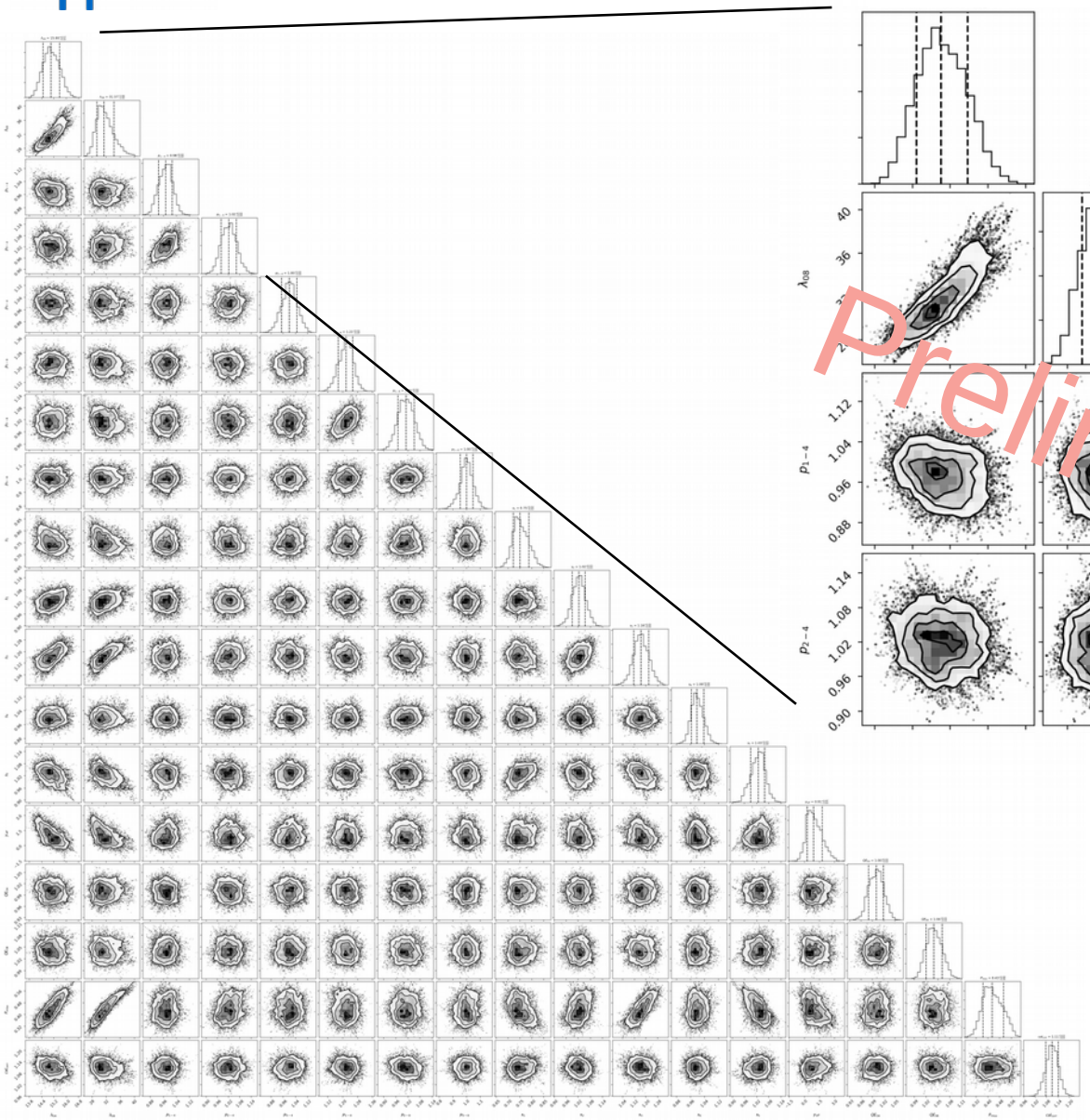
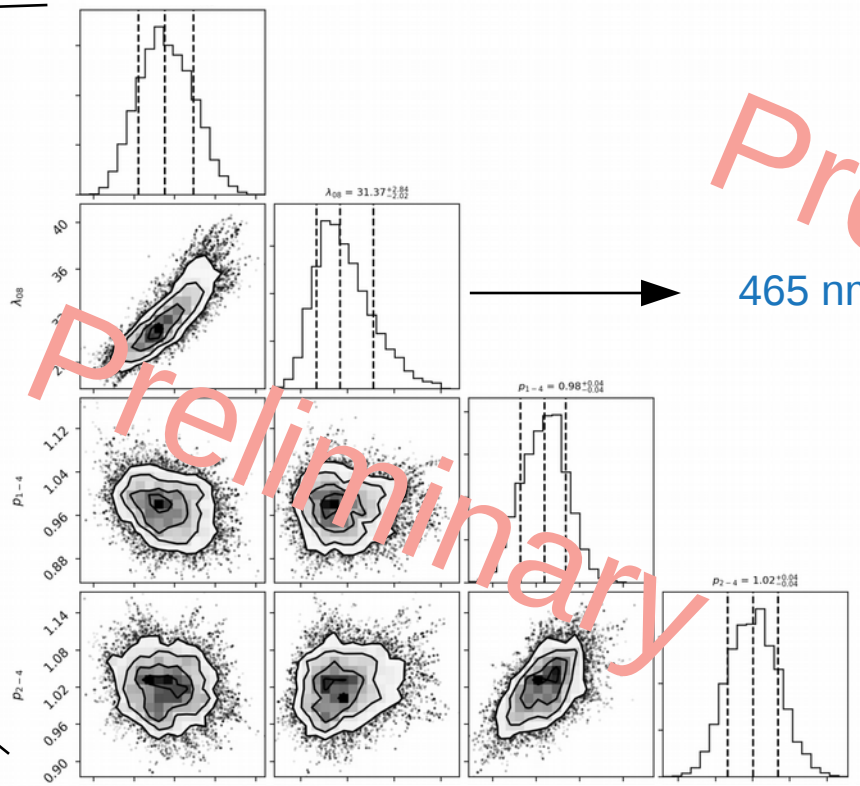




465 nm: **31.4** m +/- **3.0** m (stat.) +/- **5.0** m (sys.)

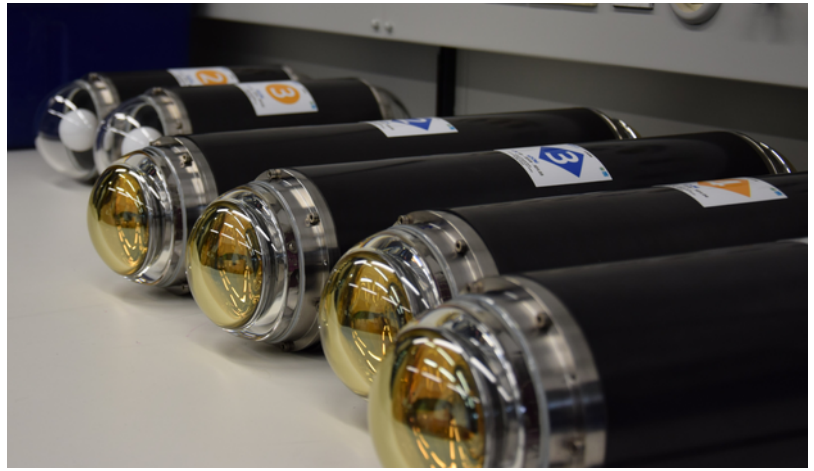
First results look promising!

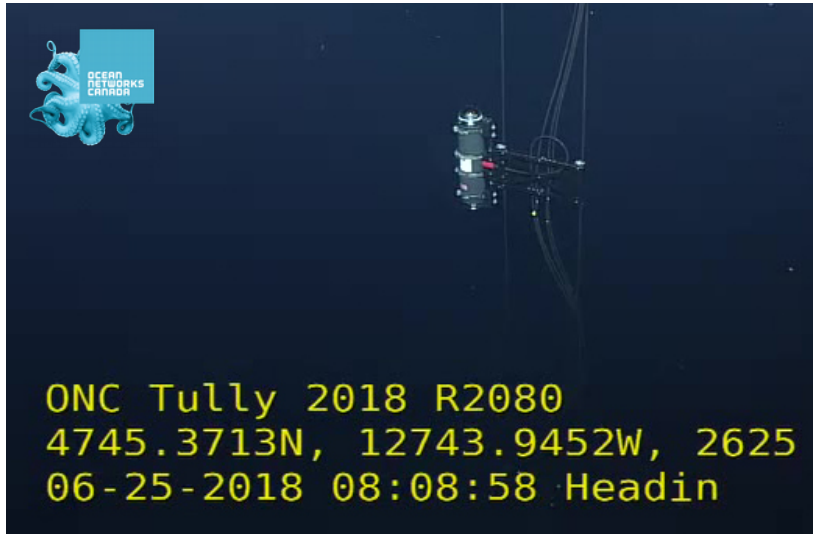
Waiting for confirmation by AC9 measurements

Conclusions and outlook

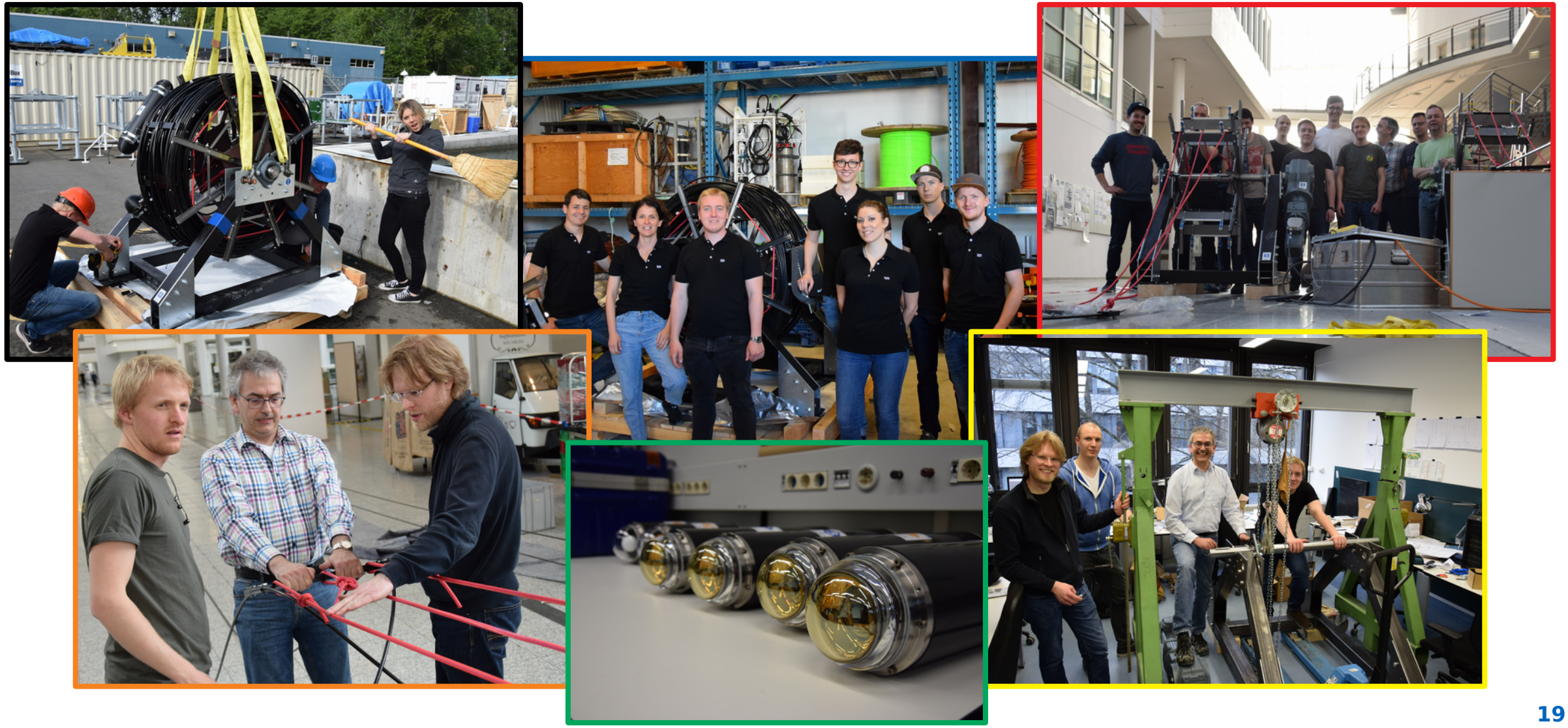
- Designed, built and deployed a pathfinder instrument (STRAW) for exploring the Cascadia Basin site as possible location of a next generation large scale neutrino telescope within less than a year
- Deployment was a 100% success, all instruments are alive and taking data
- Hardware paper draft just uploaded:
  STRAW (STRings for Absorption length in Water): pathfinder for a neutrino telescope in the deep Pacific Ocean (arXiv:1810.13265)
- First preliminary results from data analysis available
- Absorption length at 465 nm and backgrond light look promising
- Next step (STRAW-b) already in preparation

  ➔ Stay tuned



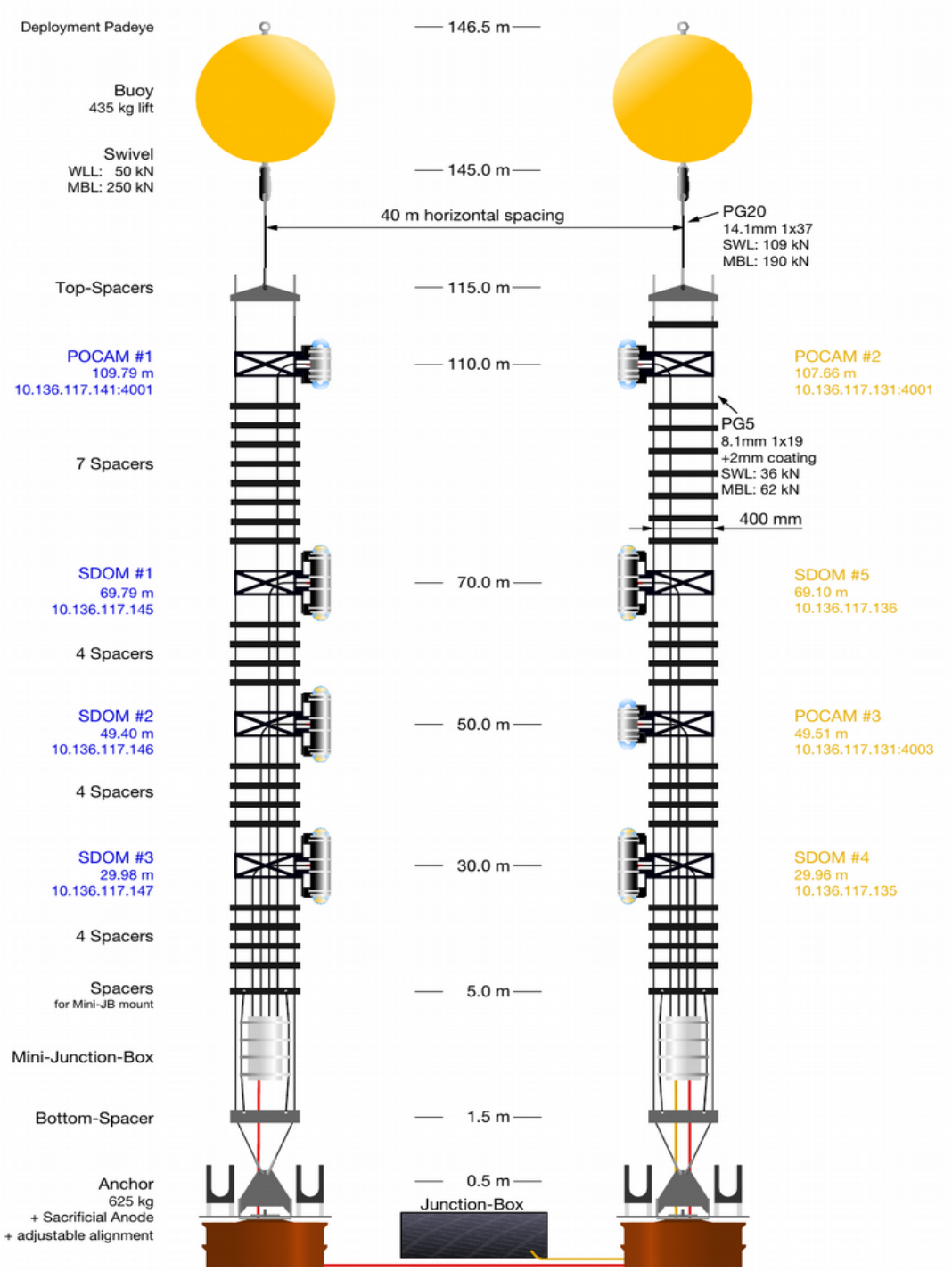


Thank you!

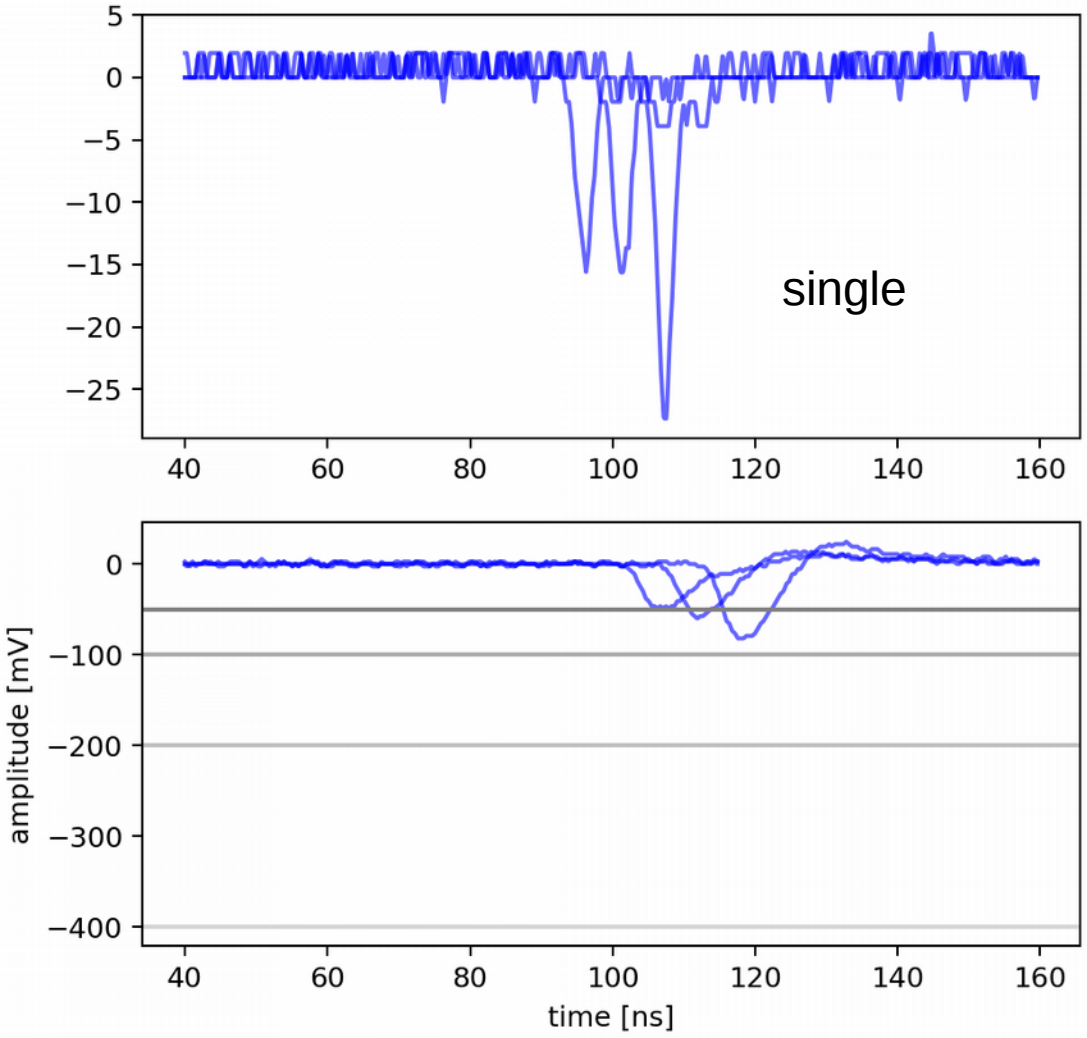


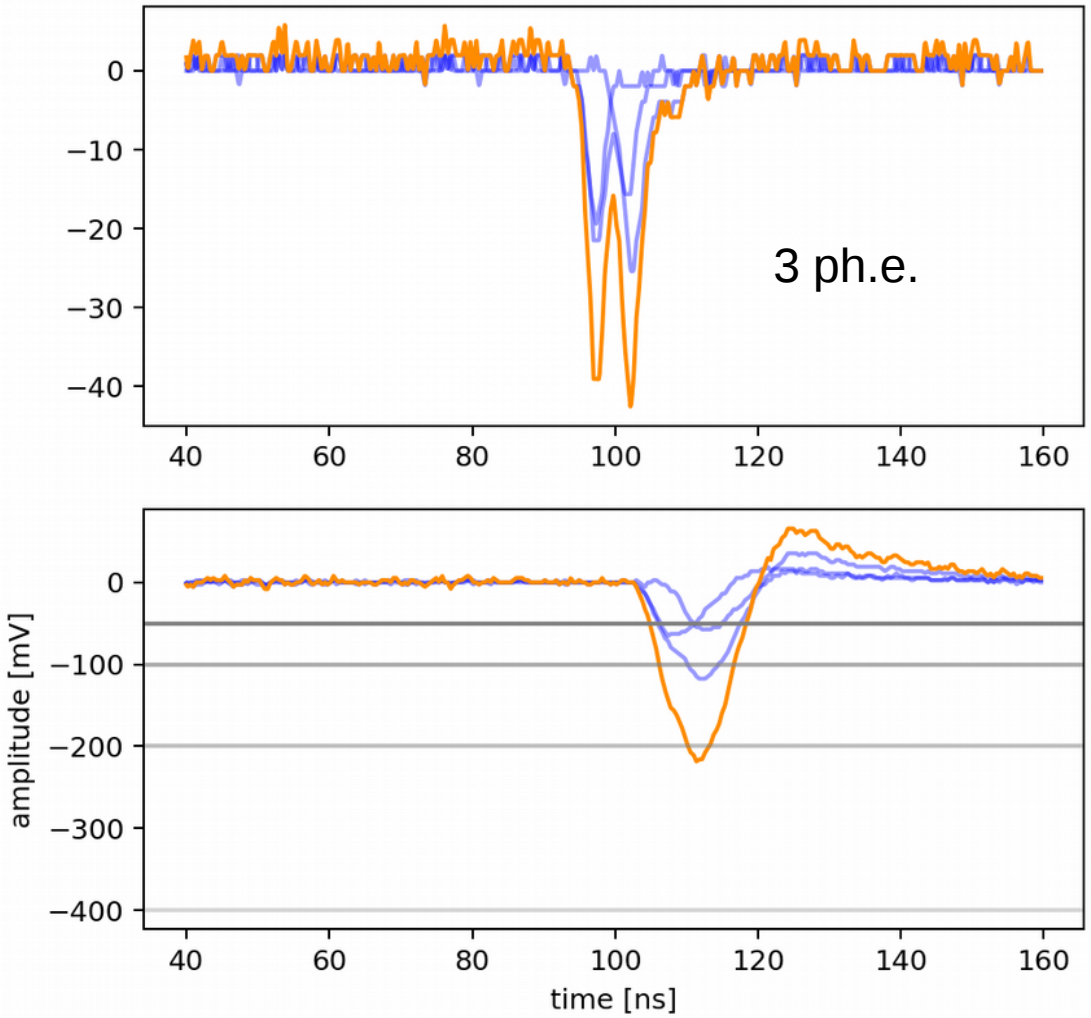
Backup

20

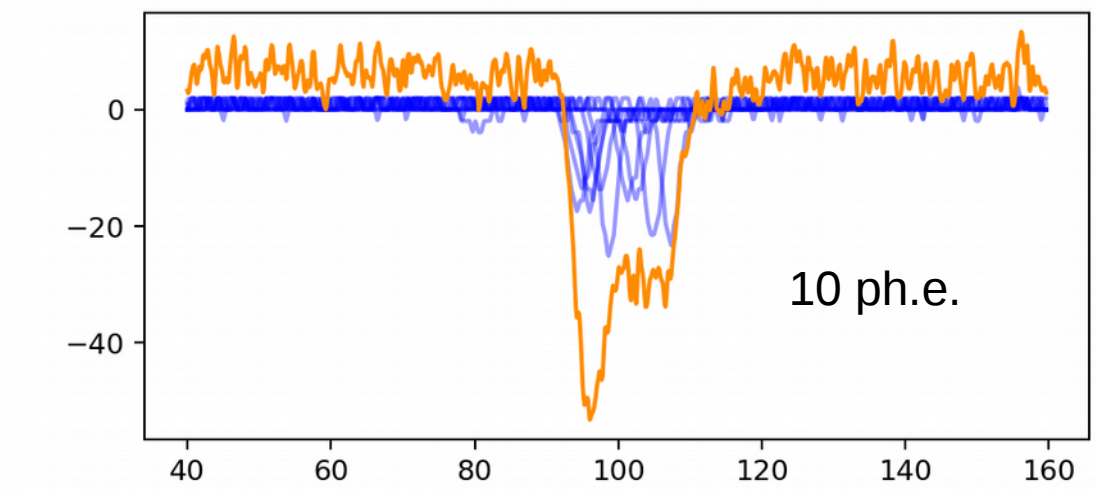

Deployment Padeye
146.5 m
Buoy
435 kg lift
Swivel
WLL: 50 kN
MBL: 250 kN
145.0 m
40 m horizontal spacing
PG20
14.1mm 1x37
SWL: 109 kN
MBL: 190 kN
Top-Spacers
115.0 m
POCAM #1
109.79 m
10.136.117.141:4001
110.0 m
POCAM #2
107.66 m
10.136.117.131:4001
PG5
8.1mm 1x19
+2mm coating
SWL: 36 kN
MBL: 62 kN
7 Spacers
400 mm
SDOM #1
69.79 m
10.136.117.145
70.0 m
SDOM #5
69.10 m
10.136.117.136
4 Spacers
SDOM #2
49.40 m
10.136.117.146
50.0 m
POCAM #3
49.51 m
10.136.117.131:4003
4 Spacers
SDOM #3
29.98 m
10.136.117.147
30.0 m
SDOM #4
29.96 m
10.136.117.135
4 Spacers
Spacers
for Mini-JB mount
5.0 m
Mini-Junction-Box
Bottom-Spacer
1.5 m
Anchor
625 kg
+ Sacrificial Anode
+ adjustable alignment
0.5 m
Junction-Box

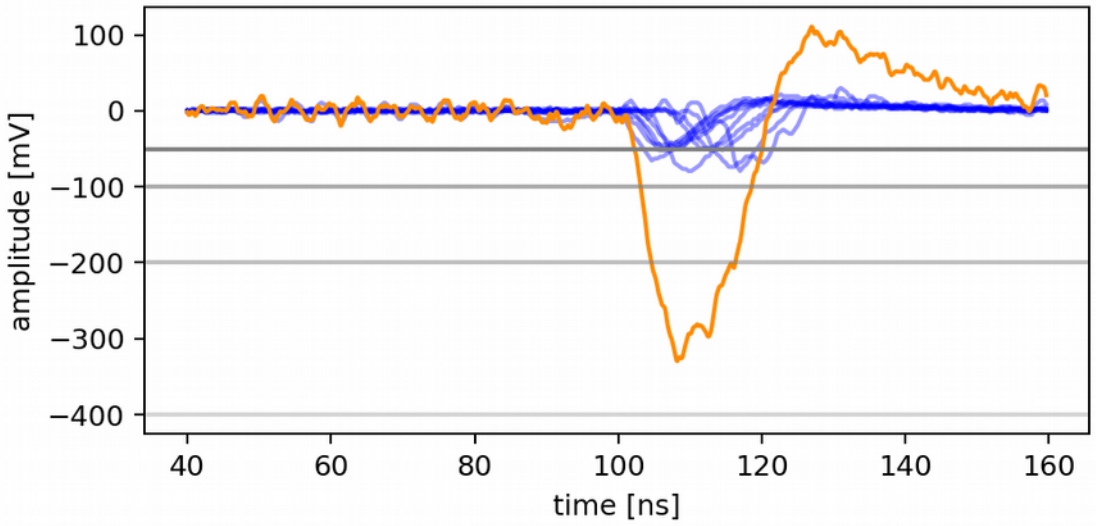
The Signal

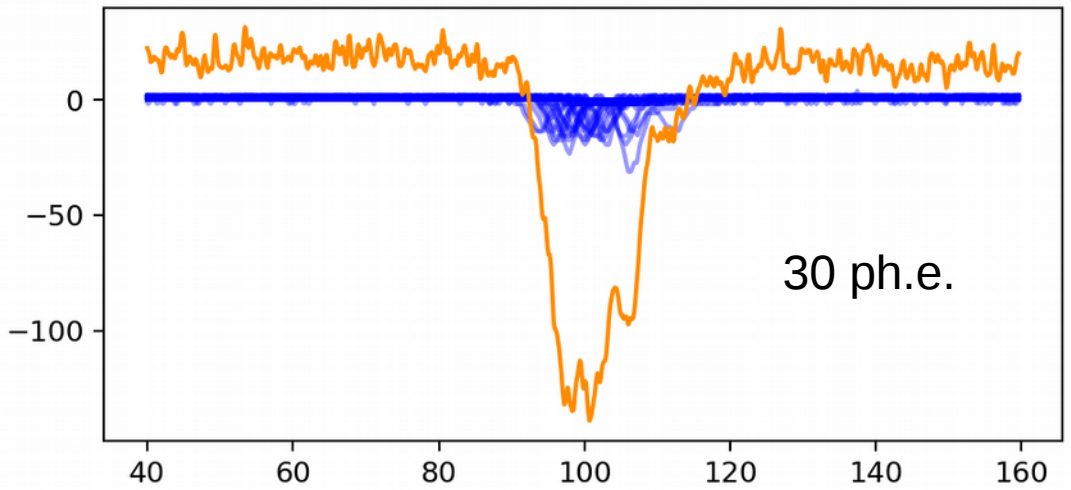


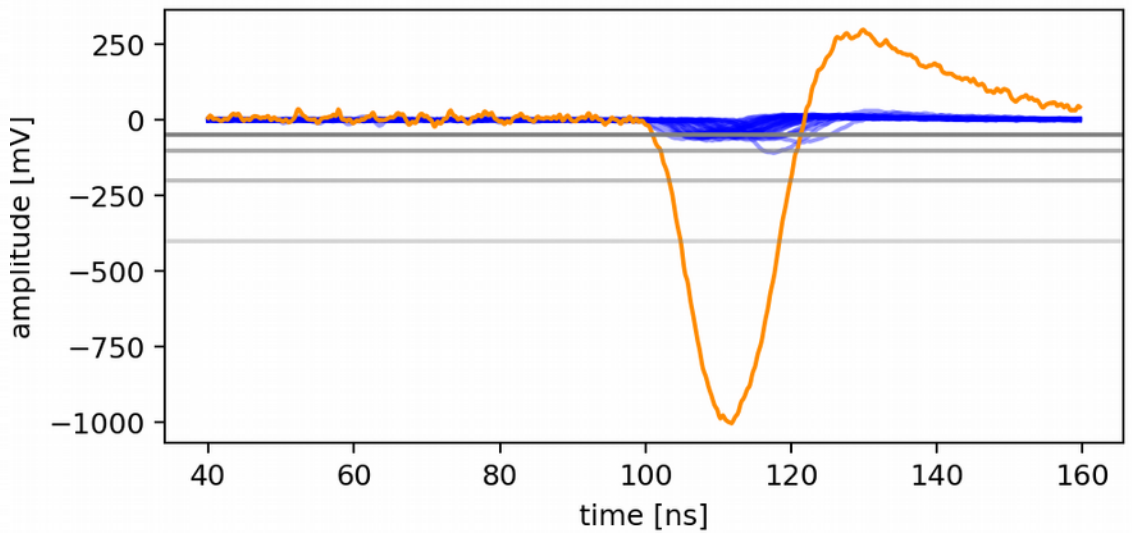


The Signal


0
−20
−40
40
60
80
100
120
140
160
10 ph.e.


amplitude [mV]
100
0
−100
−200
−300
−400
40
60
80
100
120
140
160
time [ns]


0
−50
−100
40
60
80
100
120
140
160
30 ph.e.


amplitude [mV]
250
0
−250
−500
−750
−1000
40
60
80
100
120
140
160
time [ns]

The Data

Readout every 100000 ns

Rising in ch0 defines timestamp

rising falling

```
000001 -50697.25000 21249302.75000 0.00000 3.54297 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000002 -37134.71094 21262865.28906 0.00000 8.96094 1.98438 10.03125 0.00000 0.00000 0.00000 0.00000
000001 -73273.73438 21426726.26562 0.00000 2.89062 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -79894.06250 21620105.93750 0.00000 3.01562 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000002 -37678.07812 21662321.92188 0.00000 1.61328 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000003 -27682.33203 21672317.66797 0.00000 2.42969 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -44738.92578 21855261.07422 0.00000 2.60156 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000002 -34588.05469 21865411.94531 0.00000 9.31250 1.65625 10.75781 3.08984 8.35547 0.00000 0.00000
000001 -33898.14062 21966101.85938 0.00000 2.72266 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -37477.92188 22062522.07812 0.00000 2.90625 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -37374.67578 22262625.32422 0.00000 4.55469 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -52912.94141 22447087.05859 0.00000 2.21875 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000002 -31309.13281 22468690.86719 0.00000 0.93555 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
000001 -90971.11719 22609028.88281 0.00000 10.81250 1.66406 12.51562 2.50000 11.82812 0.00000 0.00000
```

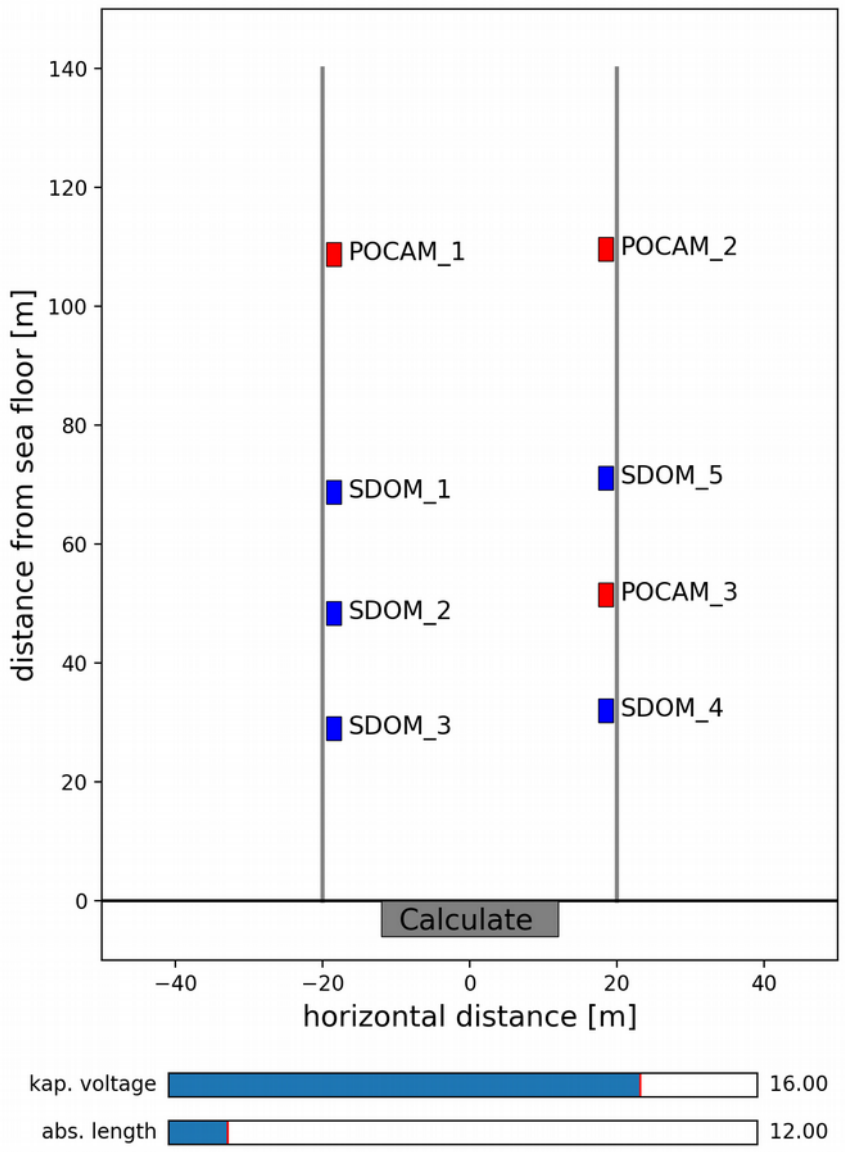
Absolute timestamp

The Simulation

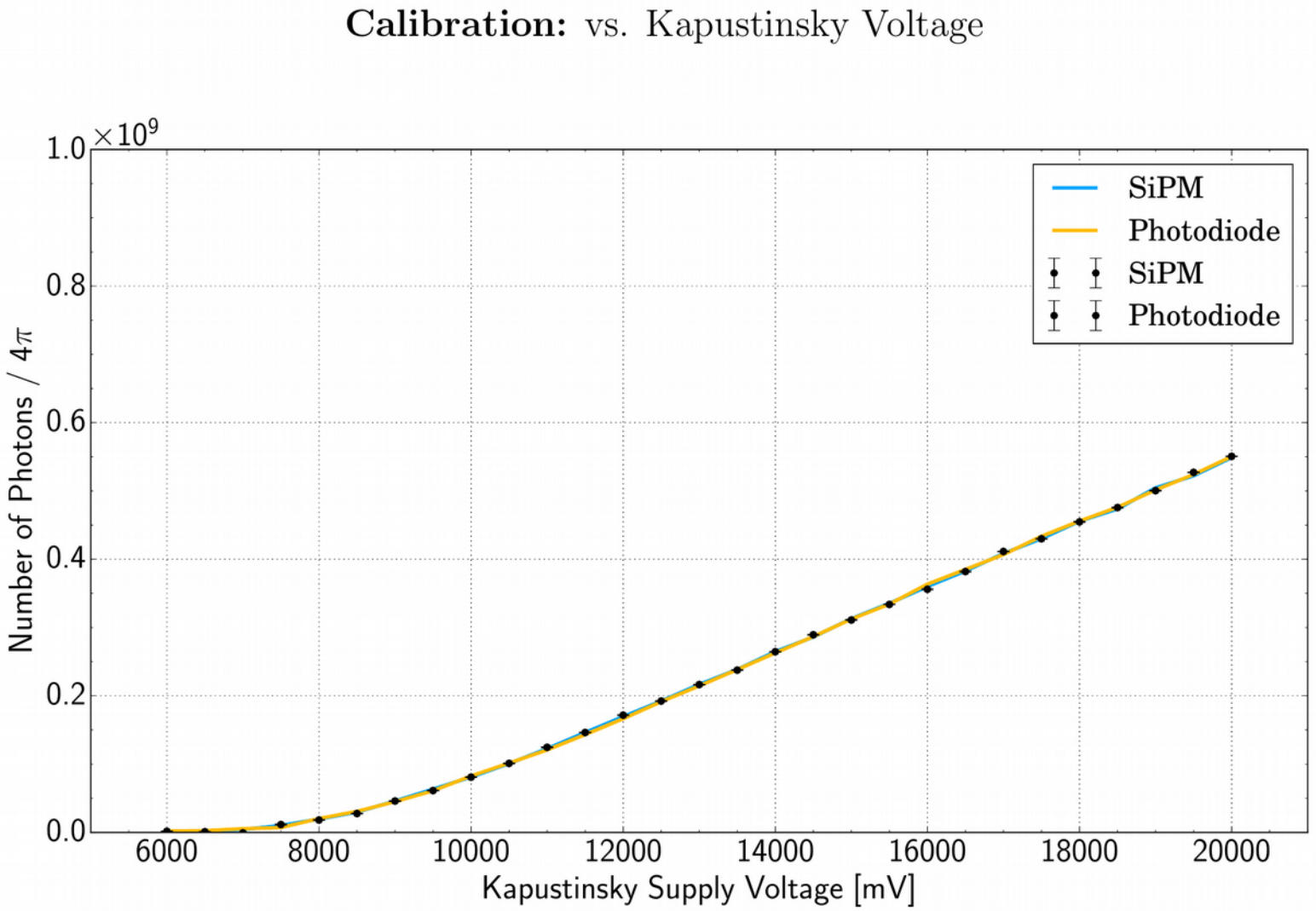
POCAM:
→ $N_{photons}(V_{kap})$ from calibration file
→ angular calibration as analytic approx.

sDOM:
→ QE/PDE form data sheet
→ angular calibration as analytic approx.
→ main predicted quantity: “hit fraction”
“hit fraction” **$1\text{-}P_{0,\mu}$** (from Poisson stats.) corresponds to measured quantiy

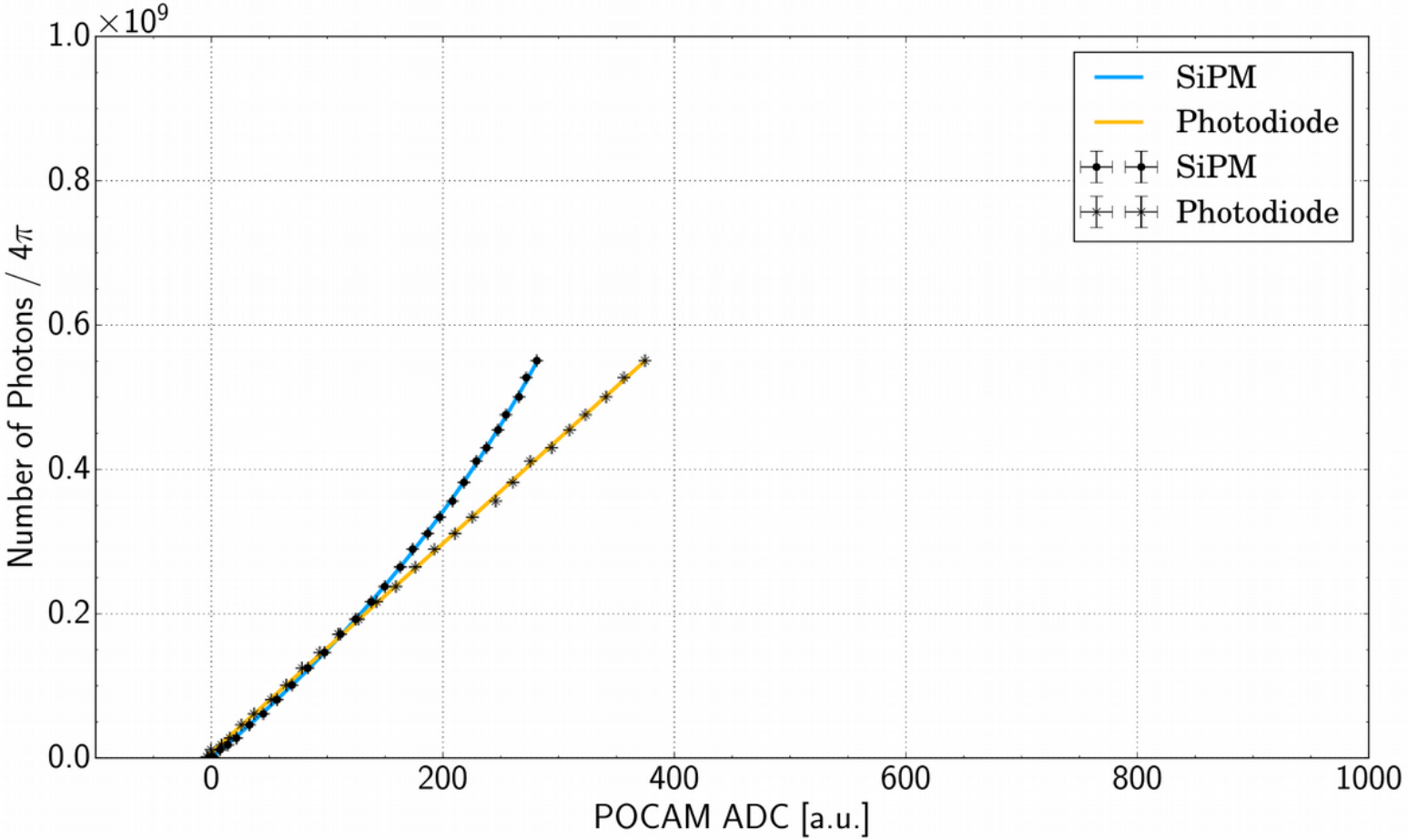
STRAW:
→ **attenuation length**
→ distances
→ relativ string height (depth difference)



POCAM calibration



POCAM calibration



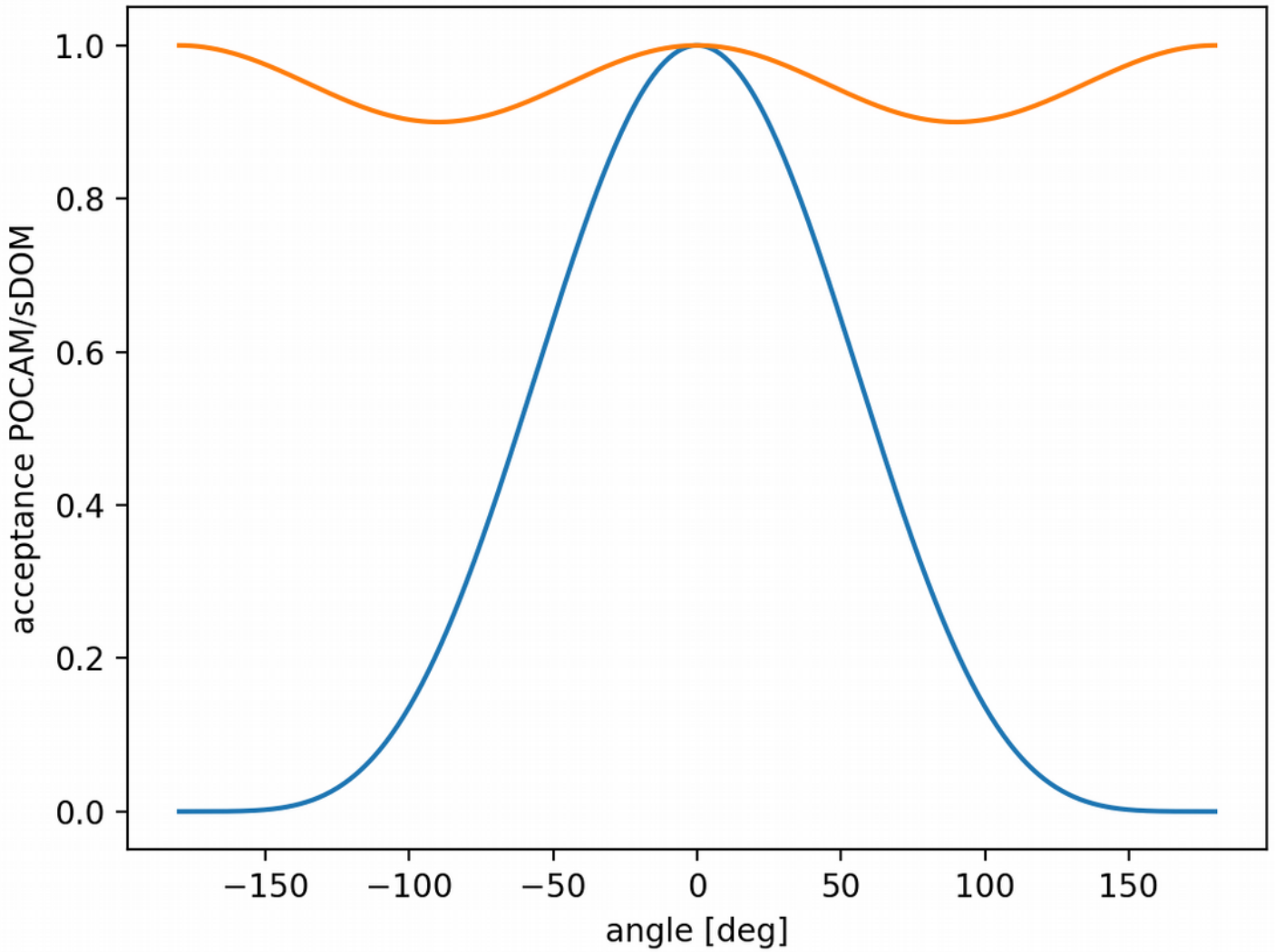
Calibration SiPM (fit): $N_{\text{phot,tot}} = -\frac{N_{\text{pix}}}{P_1} \cdot \log\left(1 - \frac{ADC_{\text{val}}}{P_2 \cdot N_{\text{pix}}}\right)$

$N_{\text{pix}} = 38800, P_1 = 5.61e-05, \mathrm{P}_2 = 1.32e-02$

Calibration Photodiode (fit): $N_{\text{phot,tot}} = ADC_{\text{val}} \cdot P_1 + P_2$

$P_1 = 1.45e+06, \mathrm{P}_2 = 7.47e+06$

POCAM/sDOM angular calibration (analytic approx.)



The Fit to data (MCMC sampling)

http://dfm.io/emcee/current/

emcee is an extensible, pure-Python implementation of Goodman & Weare's Affine Invariant Markov chain Monte Carlo (MCMC) Ensemble sampler. It's designed for Bayesian parameter estimation and it's really sweet!

Feedback

emcee

Seriously Kick-Ass MCMC

`emcee` is an MIT licensed pure-Python implementation of Goodman & Weare's Affine Invariant Markov chain Monte Carlo (MCMC) Ensemble sampler and these pages will show you how to use it.

This documentation won't teach you too much about MCMC but there are a lot of resources available for that (try this one). We also published a paper explaining the `emcee` algorithm and implementation in detail.

emcee has been used in quite a few projects in the astrophysical literature and it is being actively developed on GitHub.