Technische Universität München

UNIVERSITY OF ALBERTA

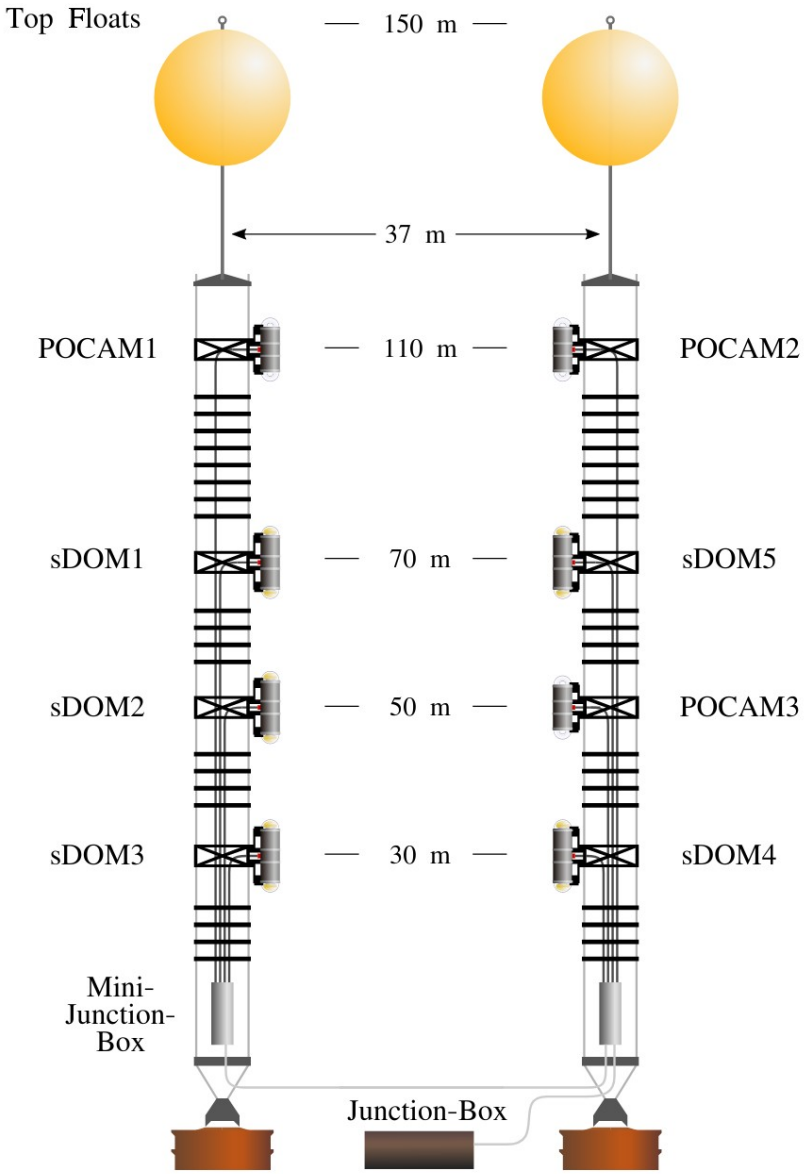
STRAW – Status of the STRAW attenuation absorption/scattering analyses

Christian Fruck & Andreas Gärtner

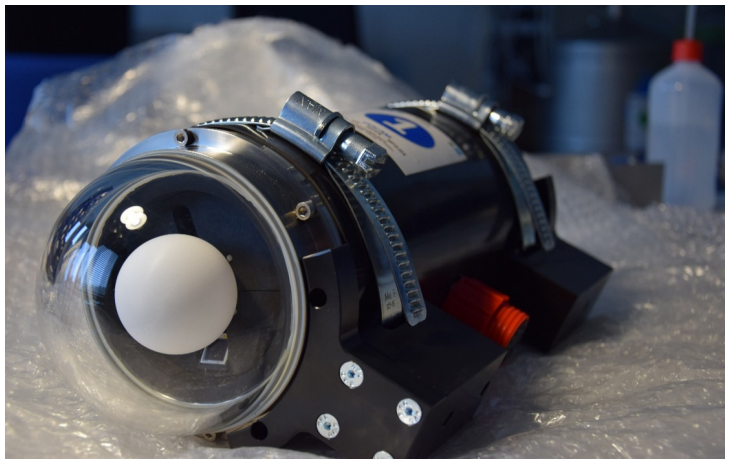
2020-12-14

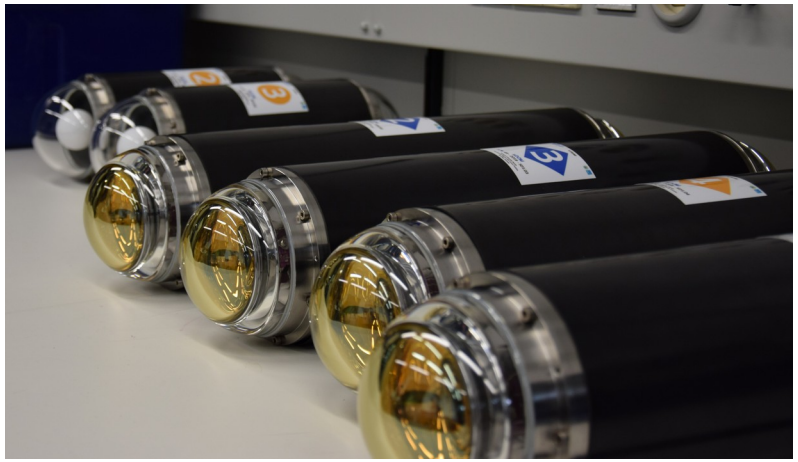
PONE-Meeting

STRAW – quick recap



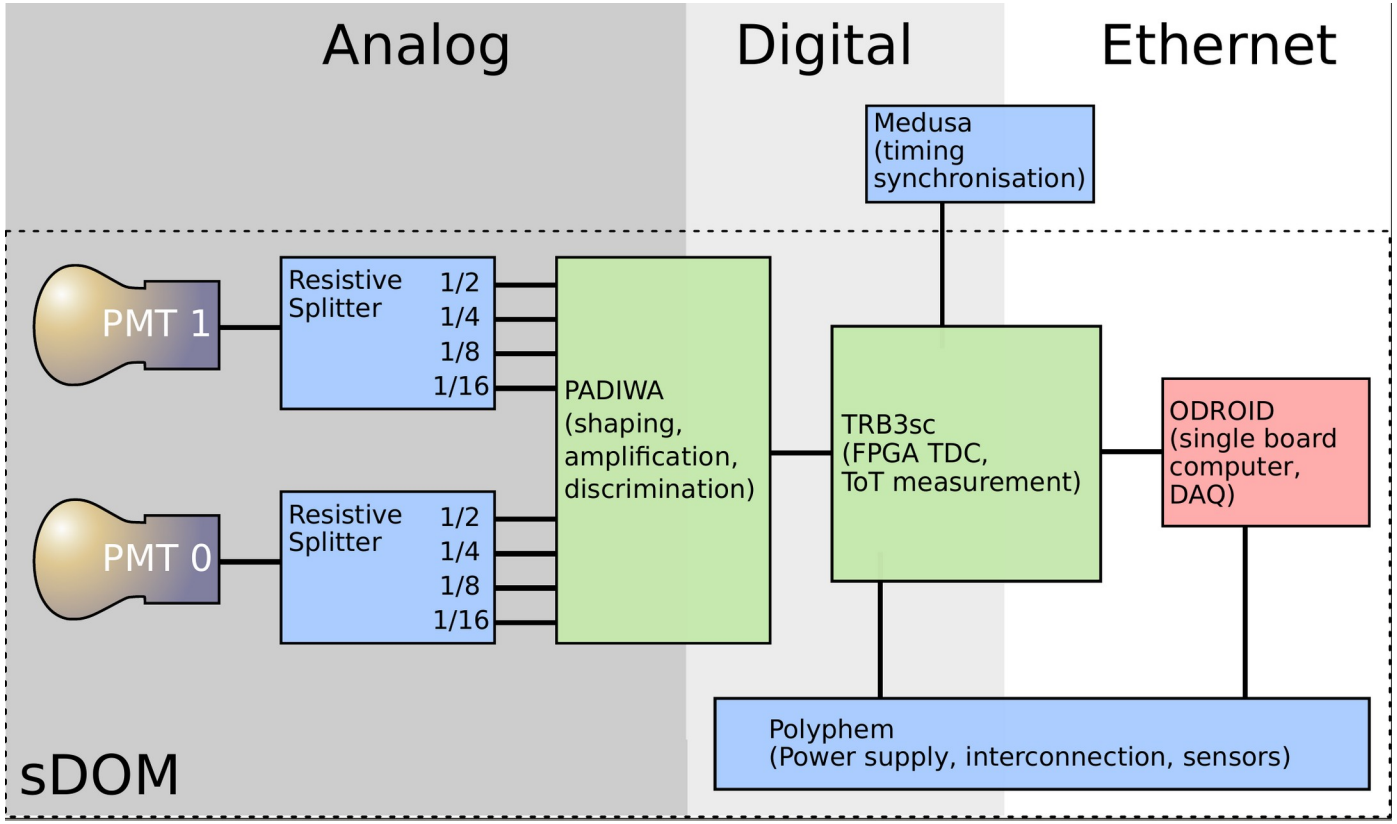
- Two-string detector with eight instruments
  - **Emitter:** Precision Optical Calibration Module (POCAM)
  - **Sensor:** STRAW Digital Optical Module (sDOM)
- Different baselines for attenuation/absorption/scattering measurements
- Different wavelengths: 365 nm, 405 nm, 465 nm and 605 nm



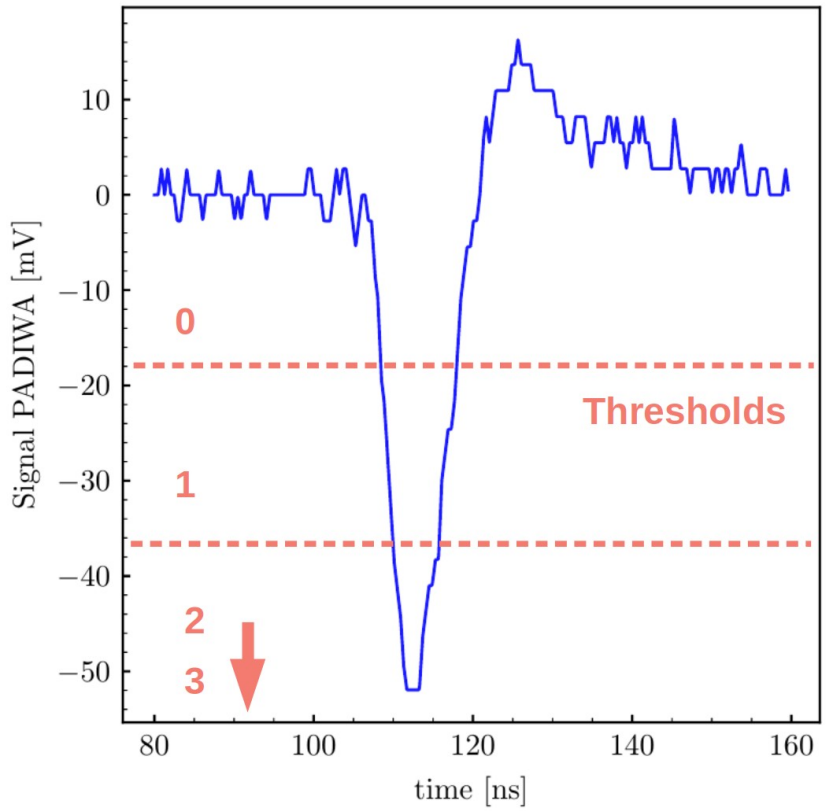


The signal of a single photoelectron (reminder)

- ToT measurement of PMT signal
- Despite four thresholds, charge reconstruction difficult
  → Intensity measurements via Poisson statistics

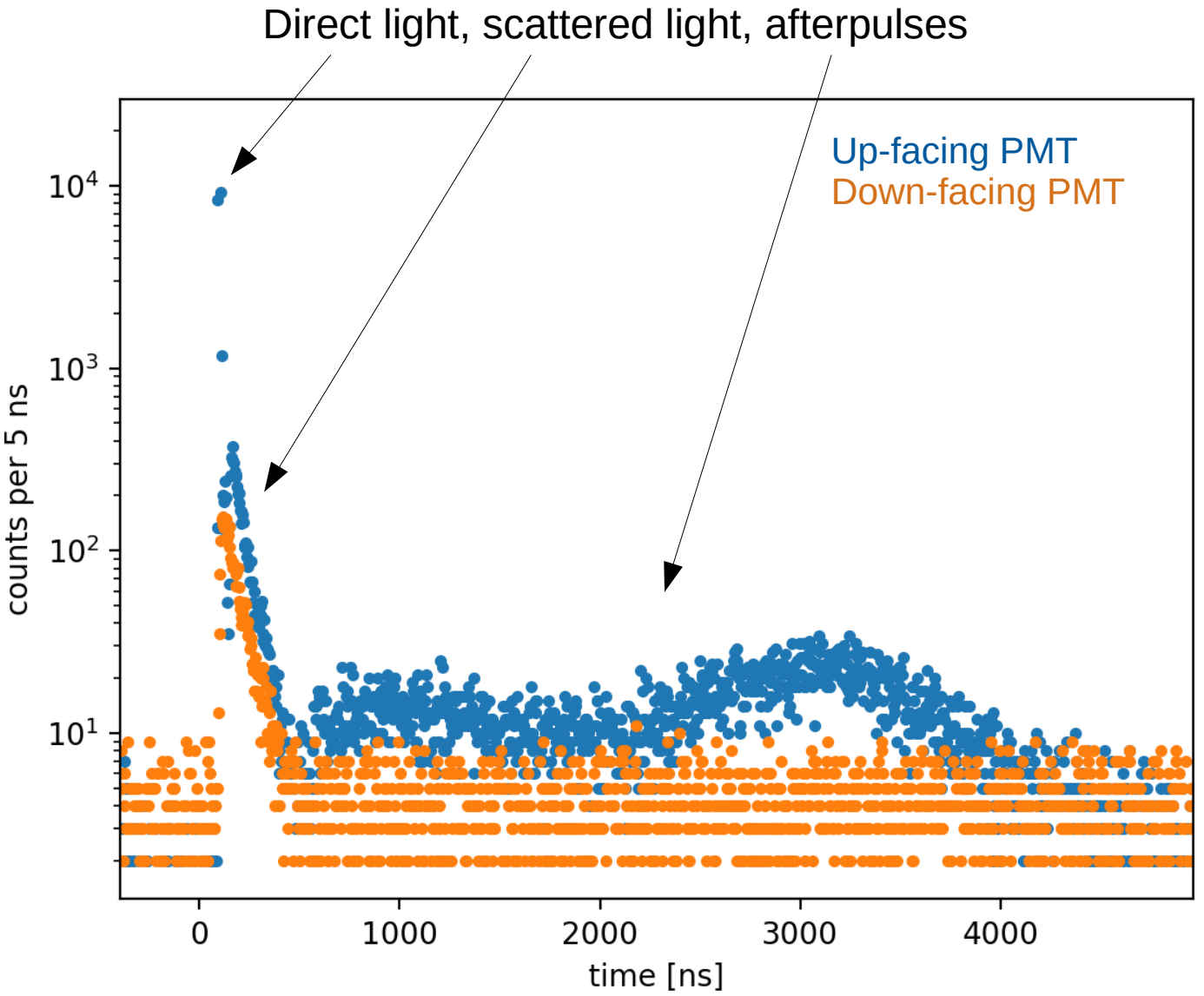


single ph.e.



POCAM phasogram

- 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 2.5 kHz



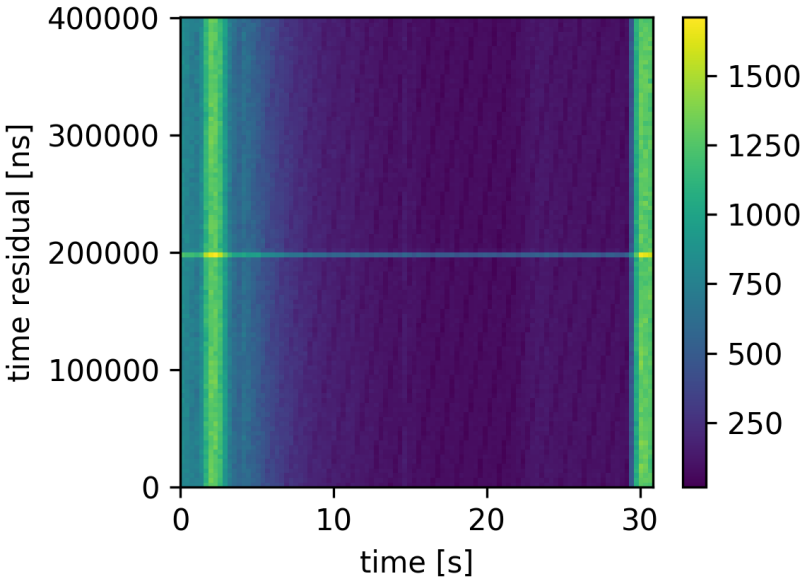
Absorption and scattering from MC simulation + fit

(Andreas)

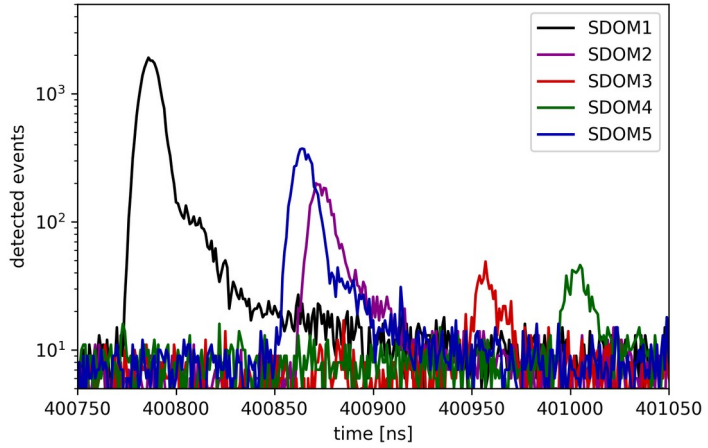
Signal extraction

- POCAM flashes at fixed period T, background flashes randomly
- Look at histograms of t%T shows a clear POCAM signal for close sDOMs
- Take certain region around maximum as signal, everything else as background
- All analysis is performed at lowest PMT threshold (single-photon level)

Histogram of t and t%T for one SDOM



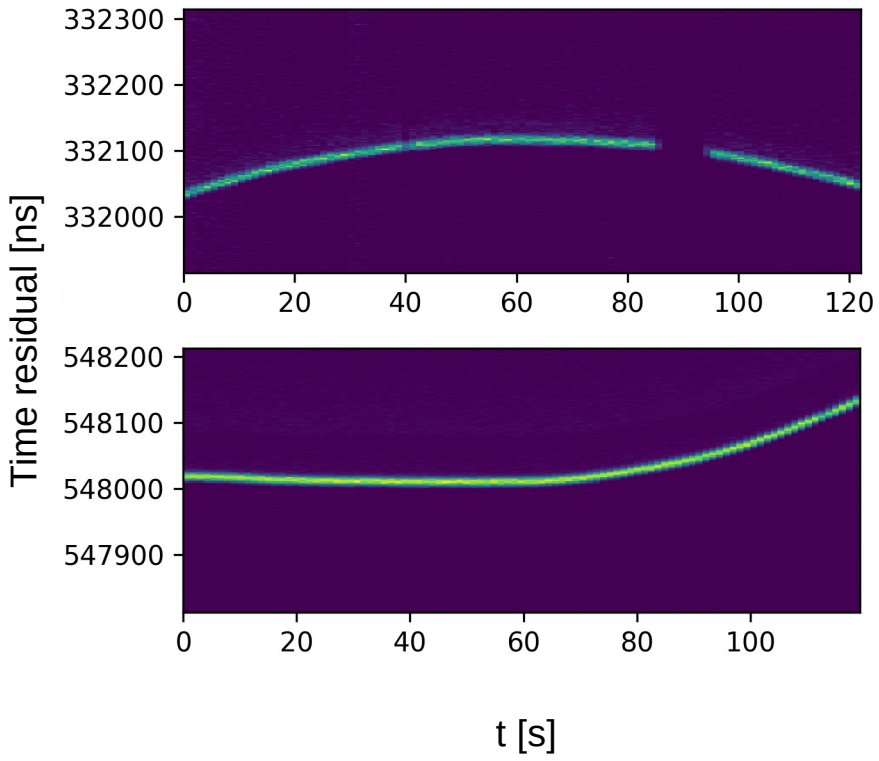
POCAM pulse as seen in all five SDOM detectors



Signal extraction

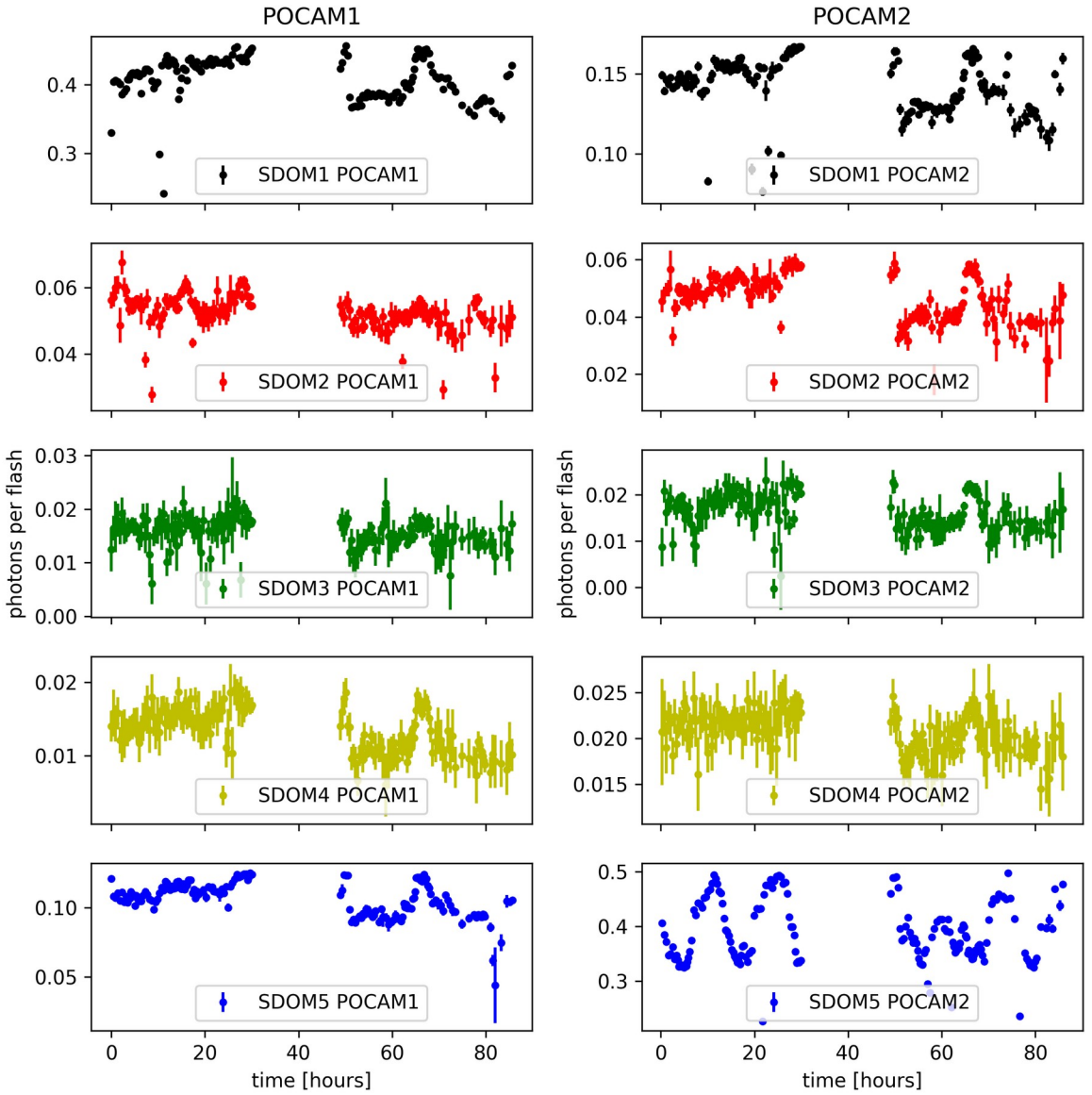
- Detailed view on histogram shows slight clock drift and gaps in the data
  - Make period T a second order function of time
  - Use TRB-overflow bit to remove gaps caused by DAQ
  - Remove single-PMT gaps by statistical analysis
- Weak signals can not be detected over background
  - Use stronger signal from different sDOM as timing reference

Histogram of t and t%T for two data files showing clock drift and gaps



Signal stability

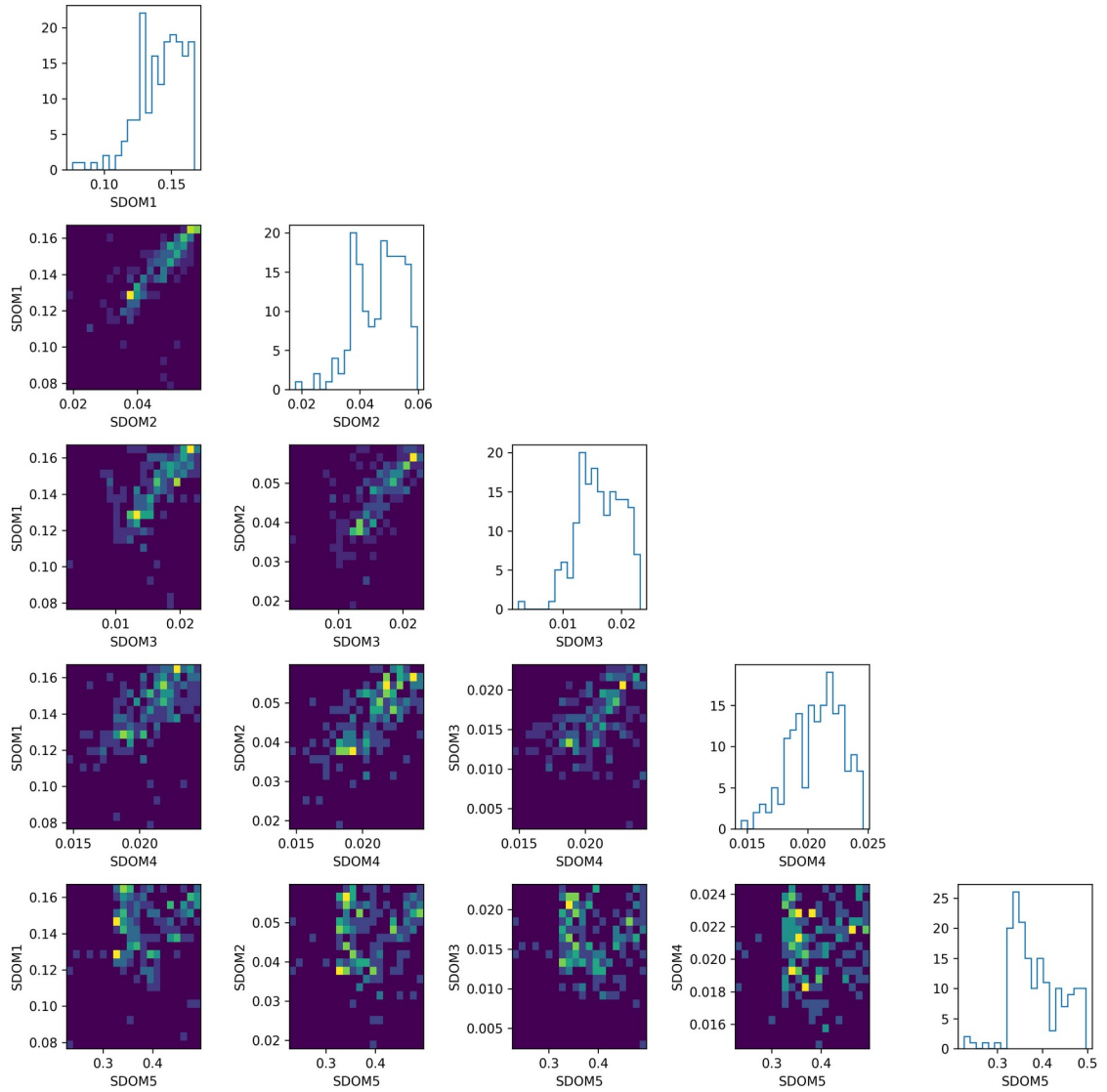
- Repeatedly flashing POCAM at fixed settings should yield constant signal in each sDOM
  - Data shows that this is not the case
  - Strong variations for sDOM5-POCAM2
  - Small variations for all other sDOM-POCAM combinations



Signal stability

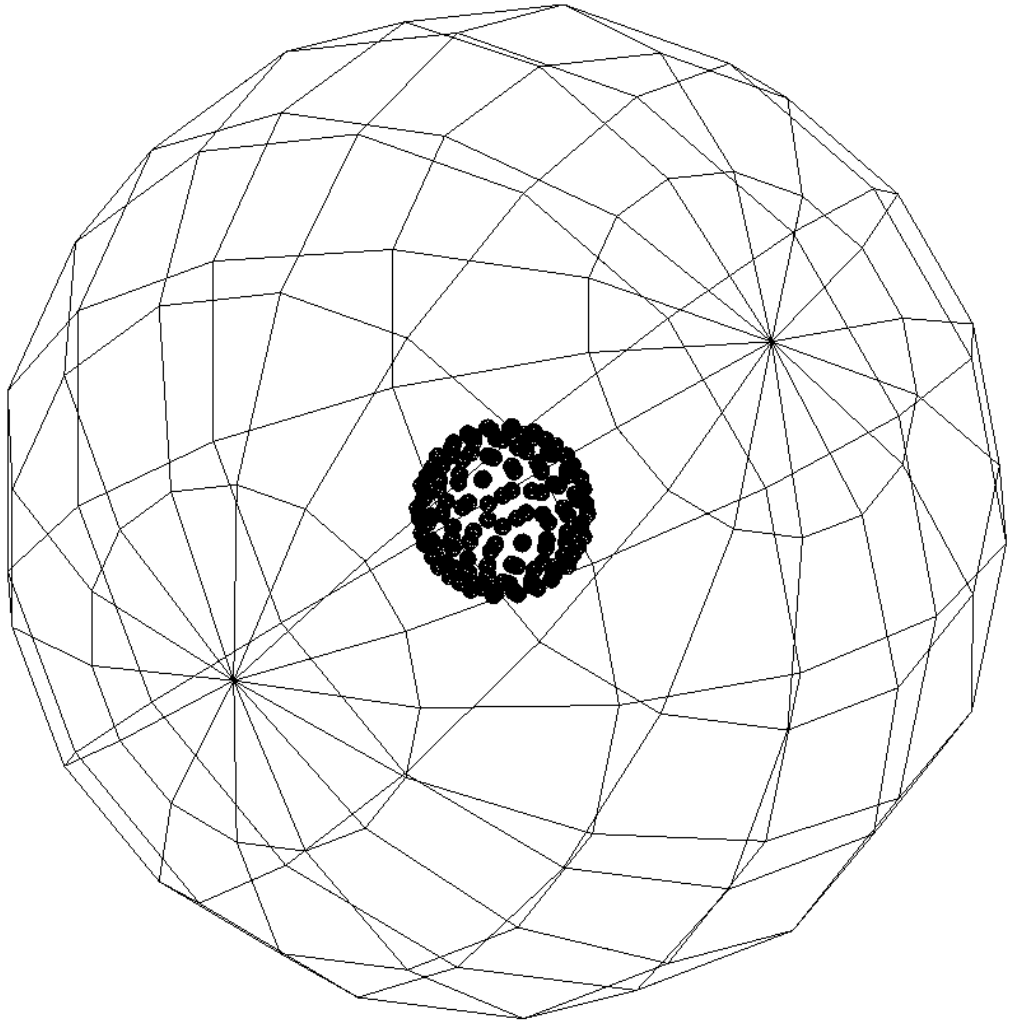
- Repeatedly flashing POCAM at fixed settings should yield constant signal in each sDOM
  - Data shows that this is not the case
  - Strong variations for sDOM5-POCAM2
    - No correlation with other sDOMs
  - Small variations for all other sDOM-POCAM combinations
    - Small variations are correlated across SDOMs

➔ Remove sDOM5-POCAM2 for analysis



Simulation

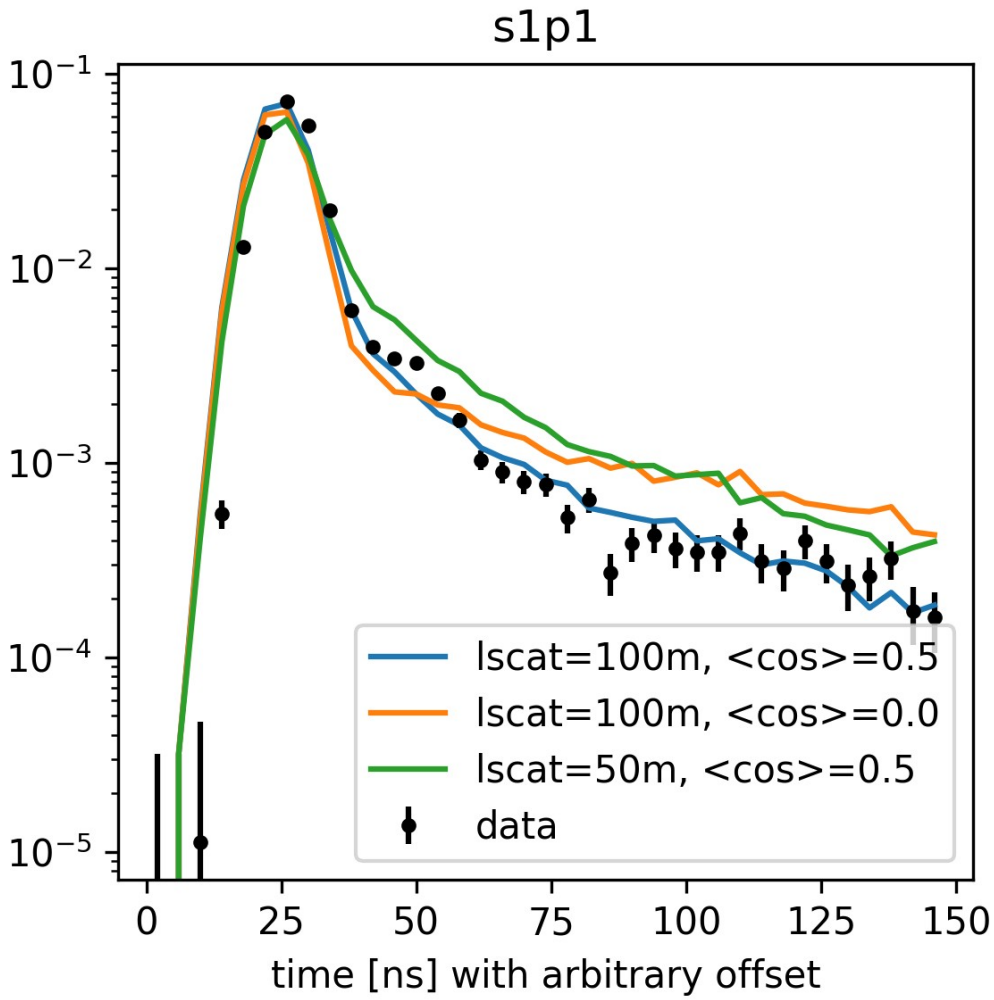
- Geant4 simulation using
  - Absorption length
  - Scattering length
  - Average cosine of scattering angle
- Scattering is implemented using Henyey-Greenstein approximation
- SDOMs and POCAMs are idealized as sphere and point source, measured angular profile is applied by re-weighting data



Simulation

- Geant4 simulation yields time profile that can be compared to data
- Re-weighting takes care of POCAM intensity (scaling), angular profiles, quantum efficiencies, dead time

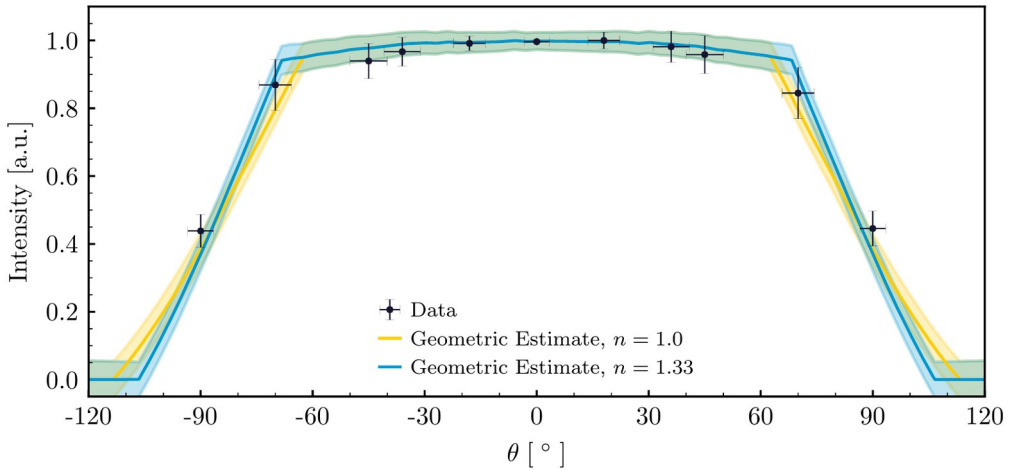
➔ Scattering properties can be extracted in addition to absorption length



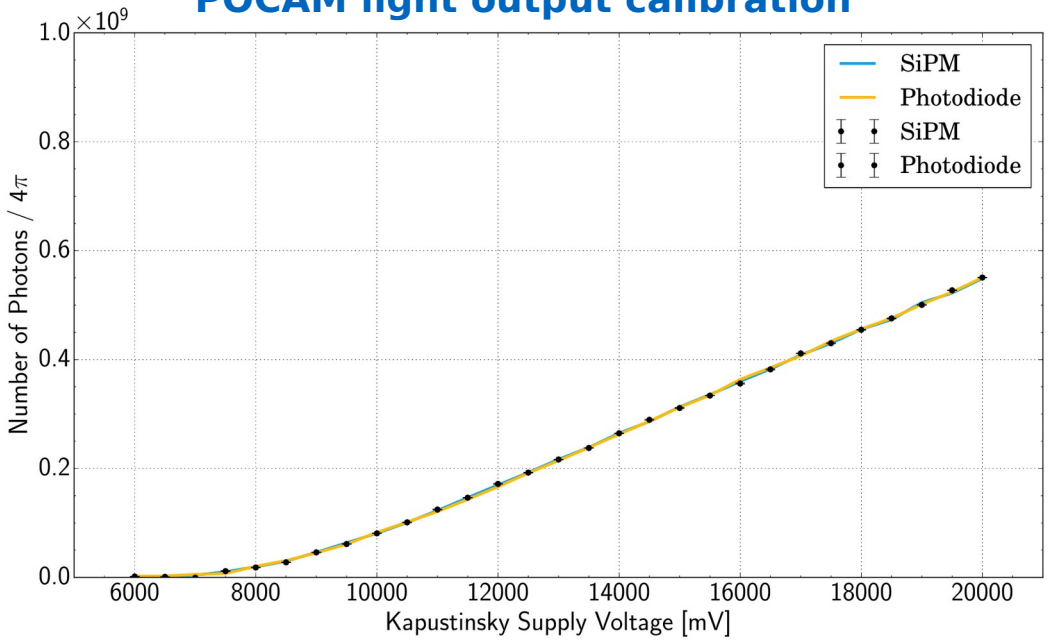
Attenuation length from LLH fit
(Christian)

Modeling and fitting to STRAW data

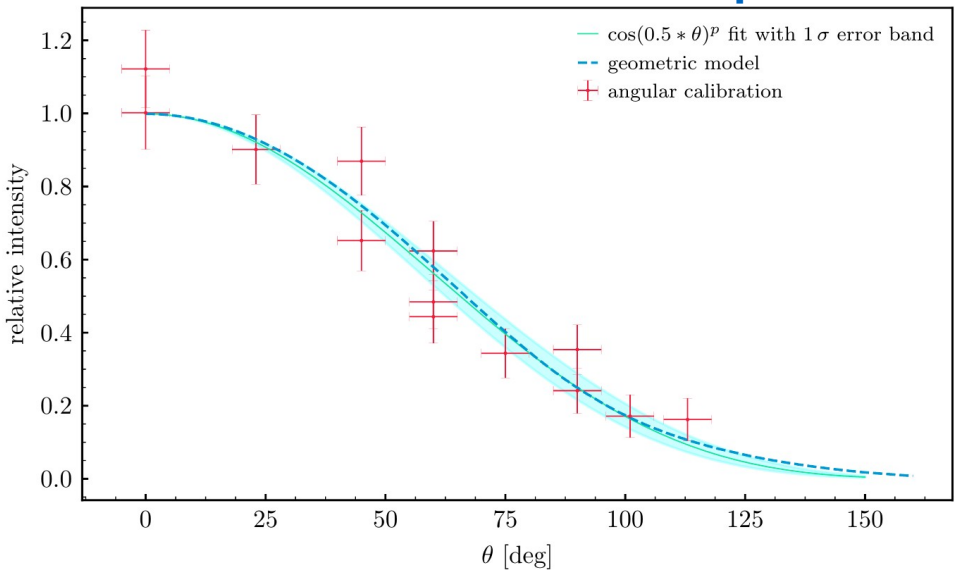
POCAM angular calibration



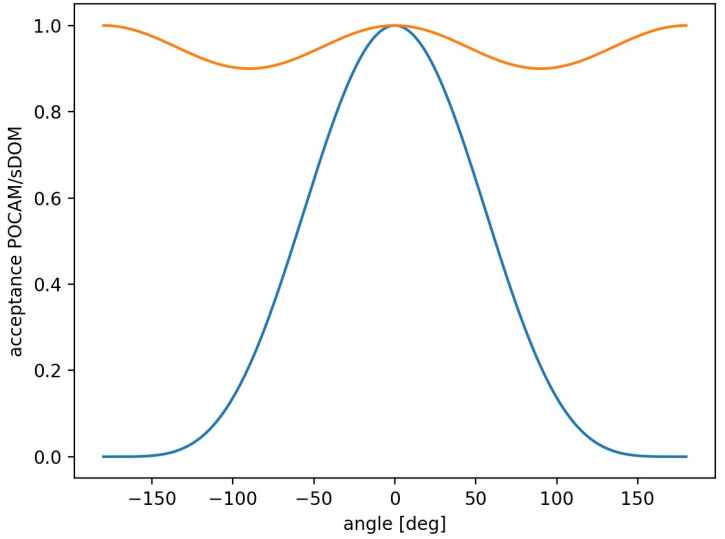
POCAM light output calibration



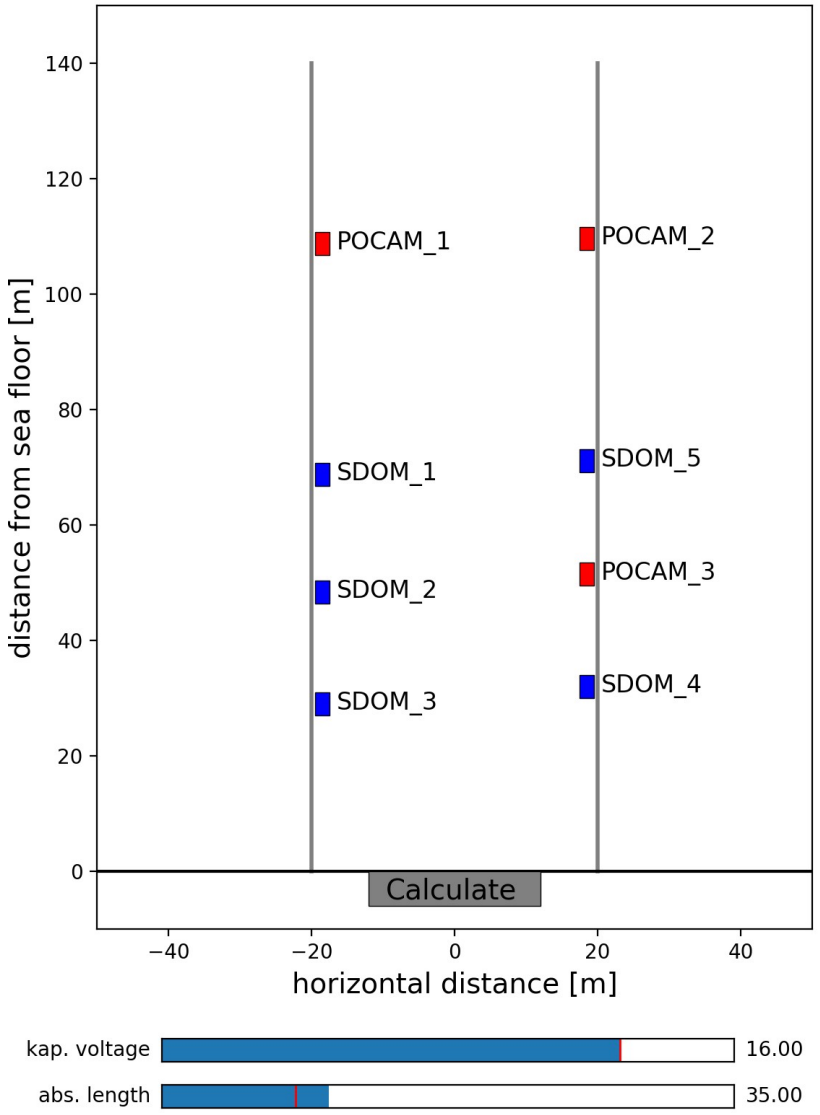
Measurement of sDOM acceptance



POCAM/sDOM angular calibration (analytic approx.)



“Munich Method”



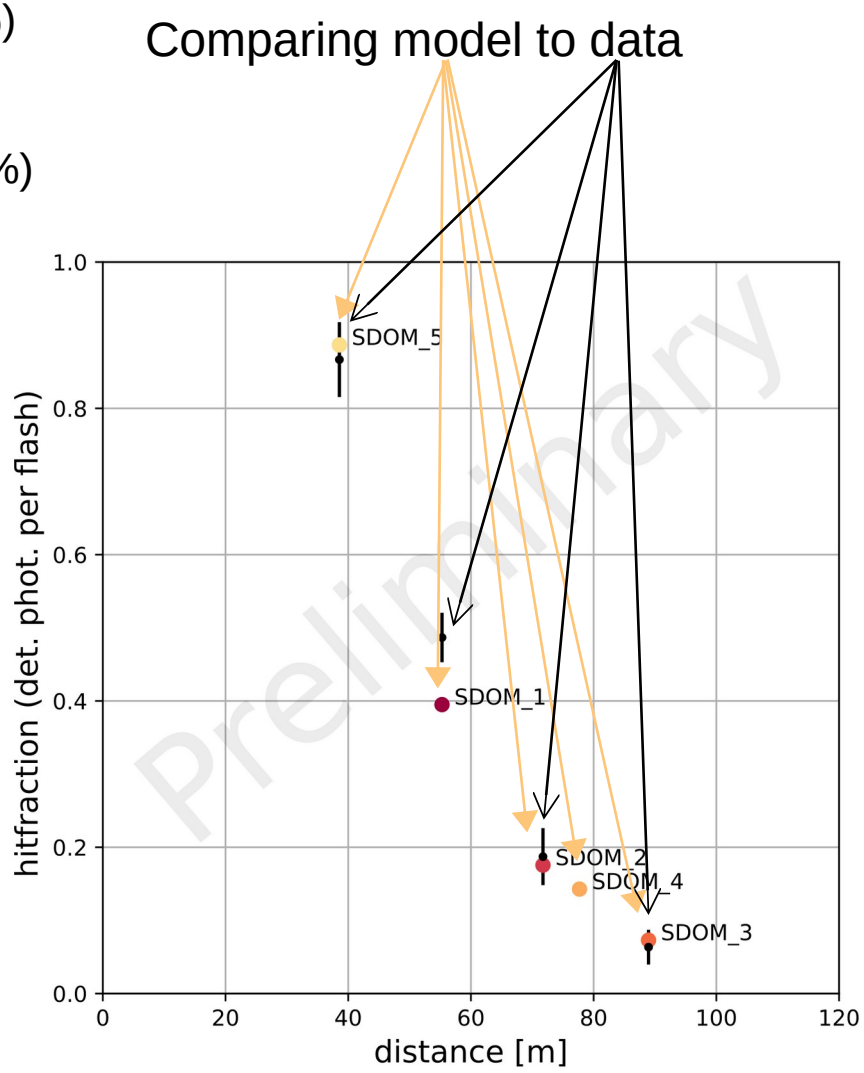
Model has the following parameters:

POCAM:
→ Calibration error 1x per POCAM (+/- 5%)

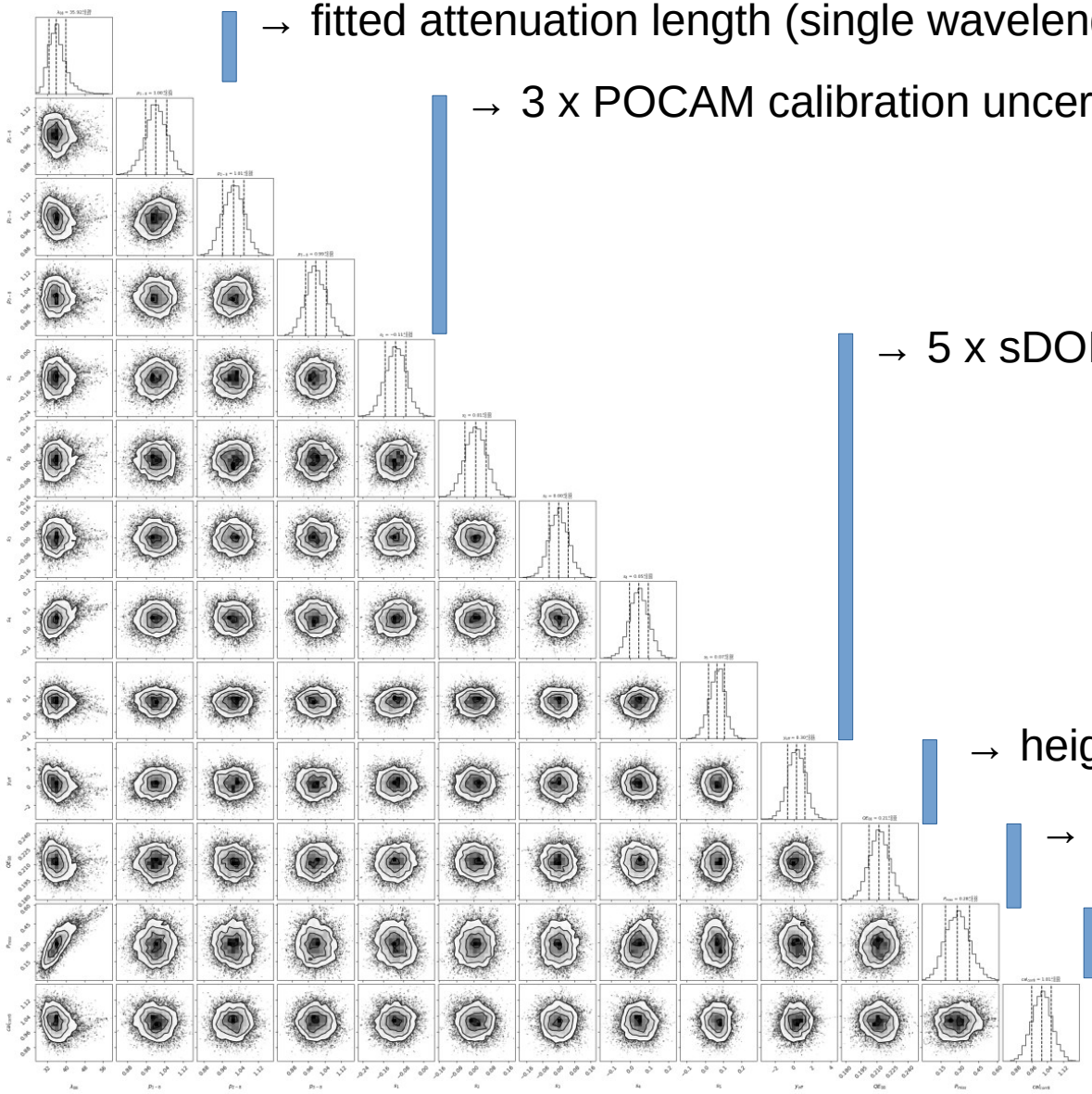
sDOM:
→ QE/PDE error per 1x per sDOM (+/- 10%)
→ QE global (~22% +/- 2%)
→ Threshold efficiency (~75%)

STRAW:
→ **attenuation length**
→ sDOM acceptance (+/- 0.5)
→ y offset (+- 1m)

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



“Munich Method”



→ fitted attenuation length (single wavelength, no prior)

→ 3 x POCAM calibration uncertainty prior (+- 5%, gaussian prior)

→ 5 x sDOM calibration uncertainty prior (+- 10%, gaussian prior)

→ height offset between the strings offset (+- 1m, gaussian)

→ PMT QE (+- 2% absolute, gaussian)

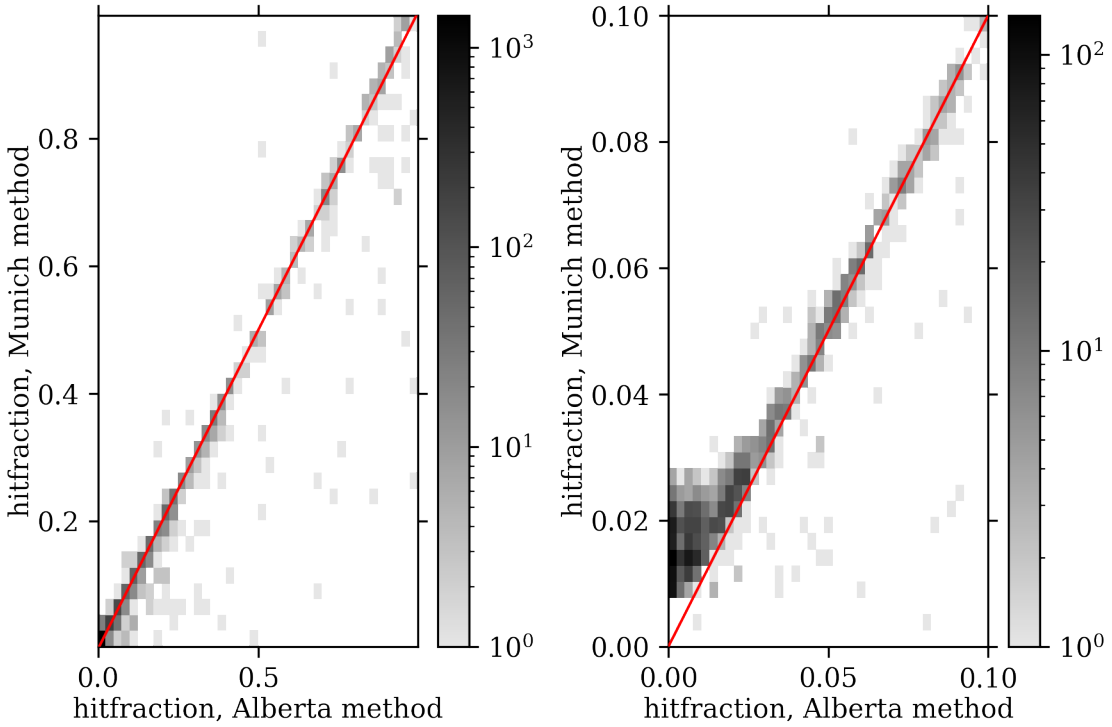
→ threshold/trigger probability (+- 10% abs., gaussian)

→ angular accept. func corr. (+- 0.5 in exponent, gaussian)

Comparing Methods
(Andreas)

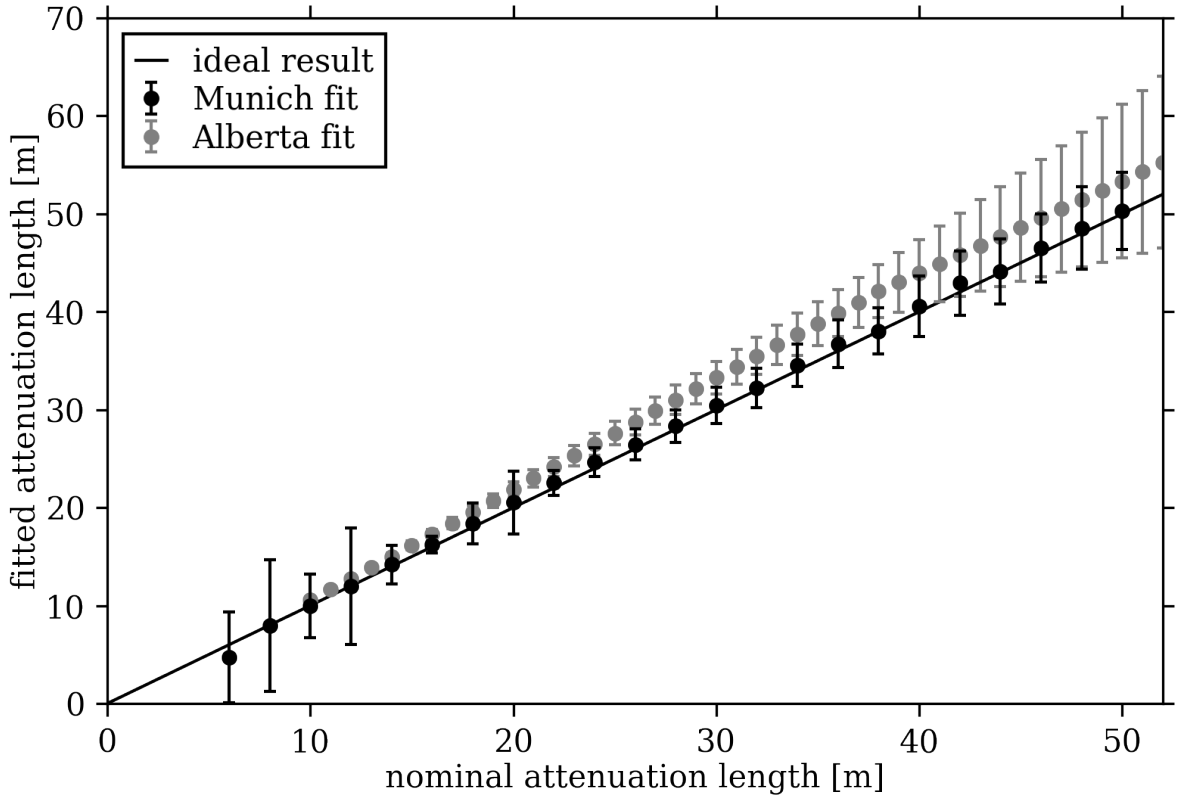
Comparing methods – signal extraction

- Munich and Alberta method for extracting POCAM signal were compared over 3000 data files
- Hit fraction: Photons seen per POCAM flash
- Good agreement for large hit fractions (>0.05)
- Slight deviation for small hit fractions (<0.05)
  - Munich method has slight bias to detect a signal even if no signal is present



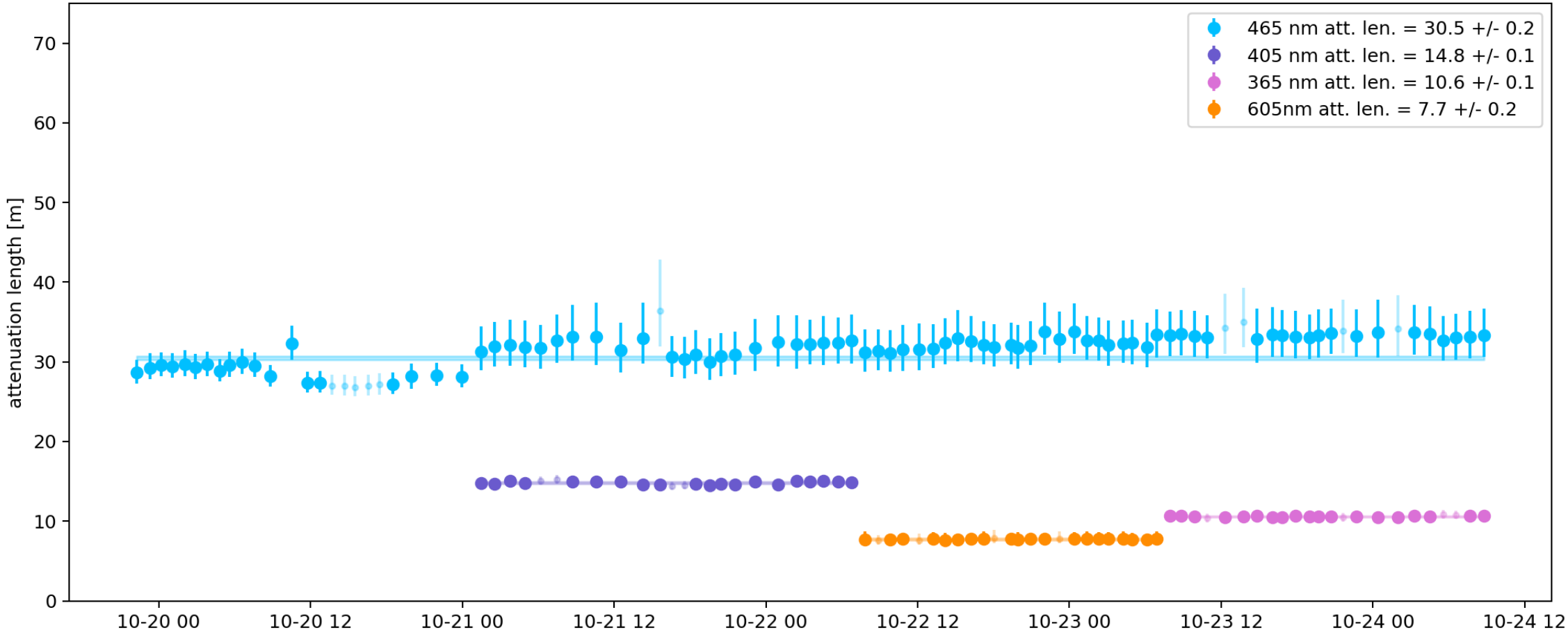
Comparing methods – fitting attenuation length

- Munich and Alberta method for fitting the absorption length were tested using analytically created data points
  - No real data, estimated numbers based on lab measurements
  - Actual attenuation length was know
- Munich fit is always spot on
- Alberta fit slightly overestimates within uncertainties
  - Reason: Alberta fit did not take different POCAM intensities into account



Results
(Christian)

Individual fits to Oct. 2020 data



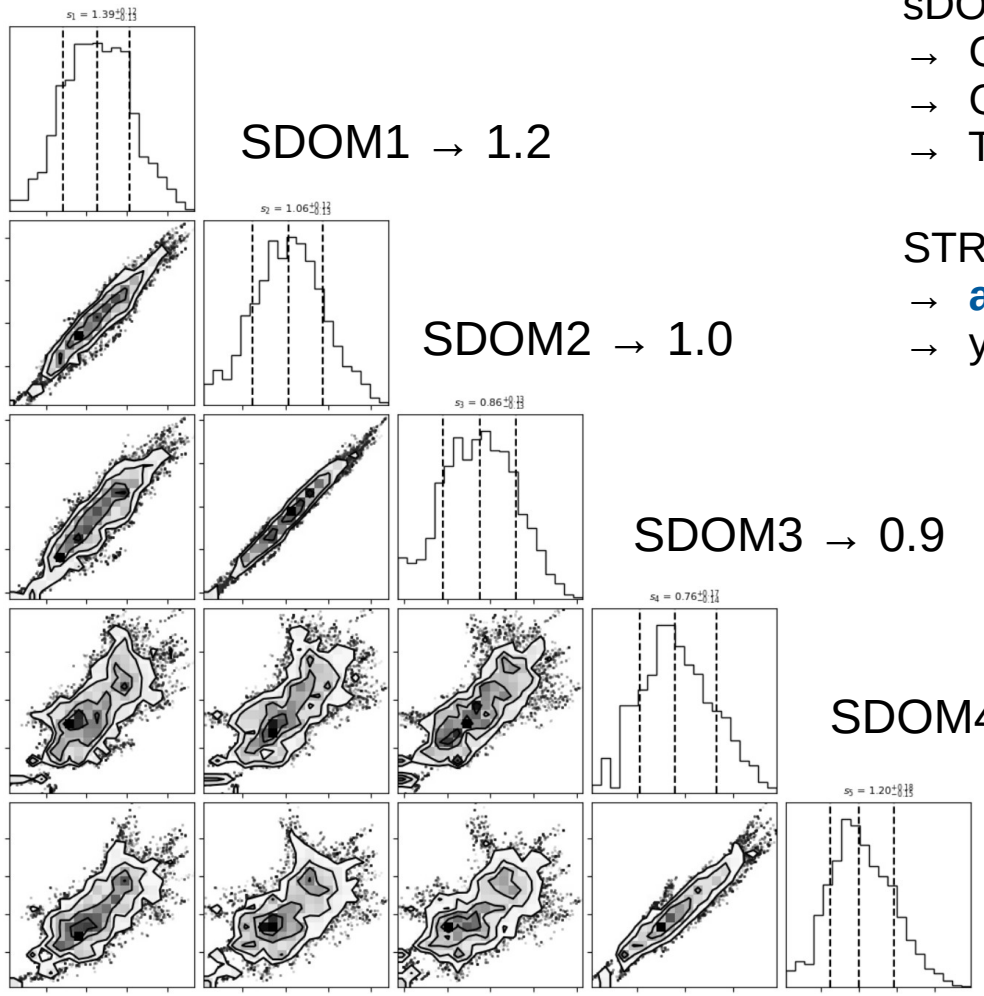
- Discrepancy between low and high intensity flashes at 465 nm
- Low intensity flashes: S1 and S5 dominate
- Difference in detection efficiency? Sedimentation?

Simultaneously fitting all Oct. 2020 data

POCAM:
→ Calibration error 1x per POCAM (+/- 5%)

sDOM:
→ QE/PDE error per 1x per sDOM (+/- **50%**)
→ QE global (~20% +/- 2%)
→ Threshold efficiency (~75%)

STRAW:
→ **attenuation length**
→ y offset (+- **5m**)



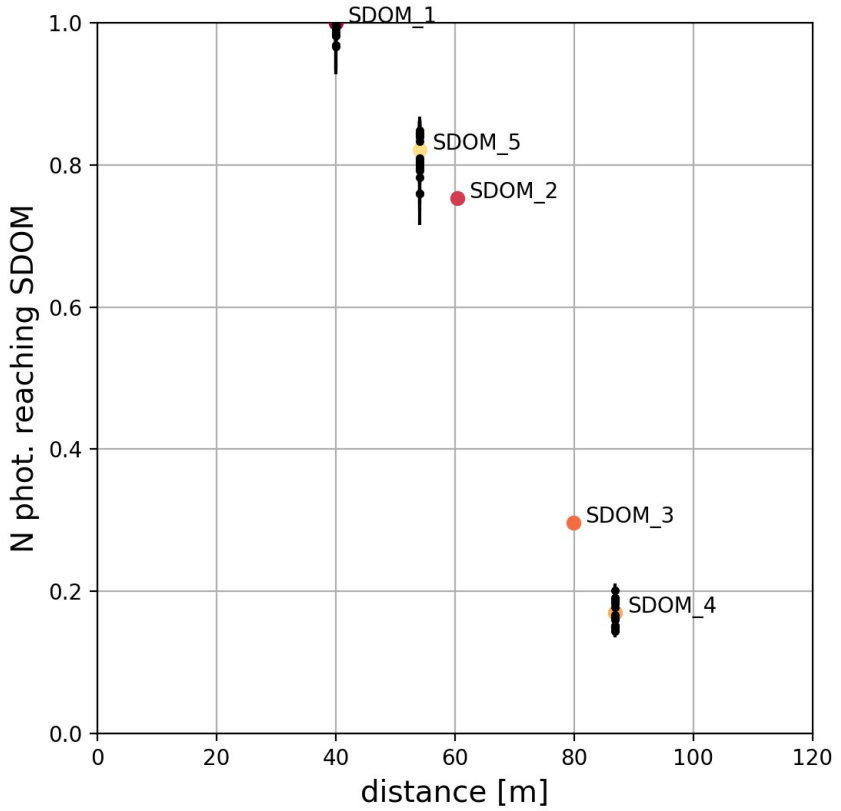
SDOM1 → 1.2

SDOM2 → 1.0

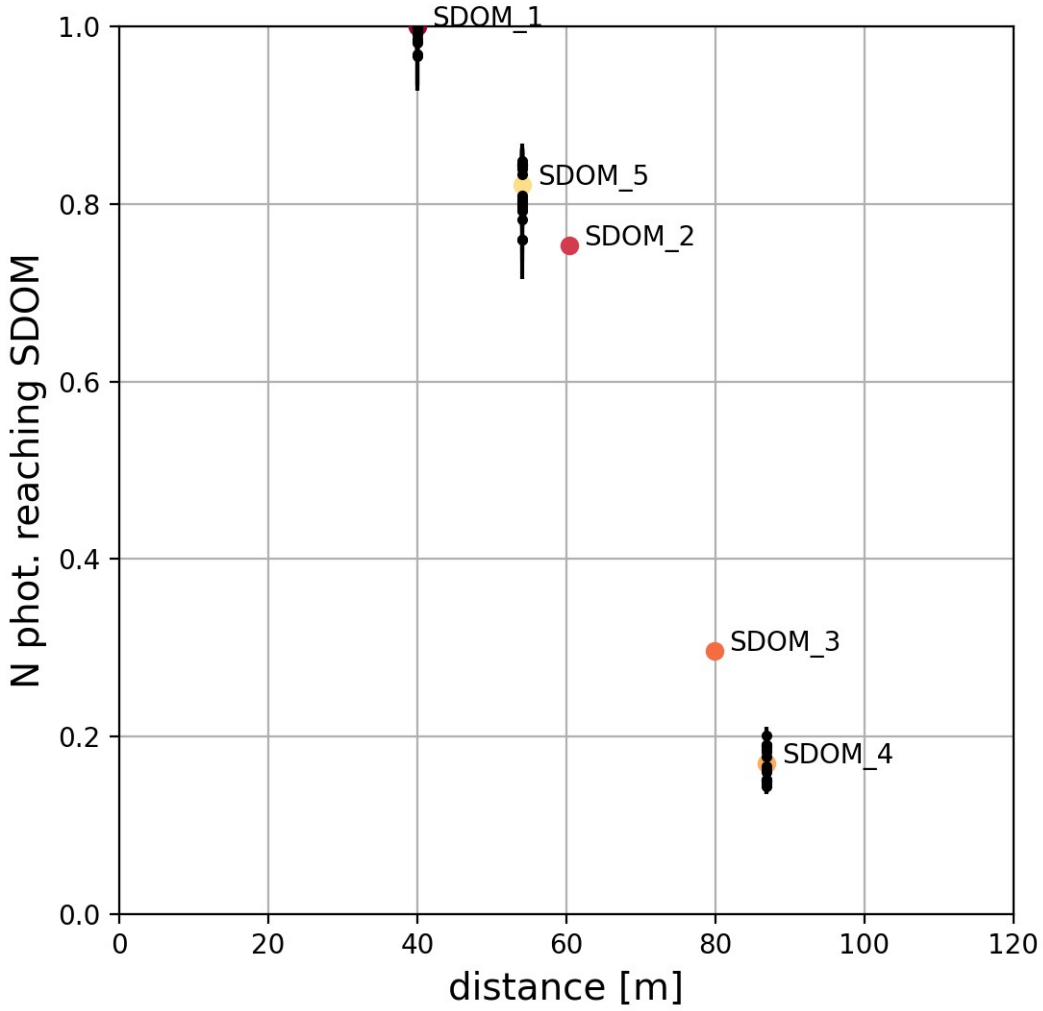
SDOM3 → 0.9

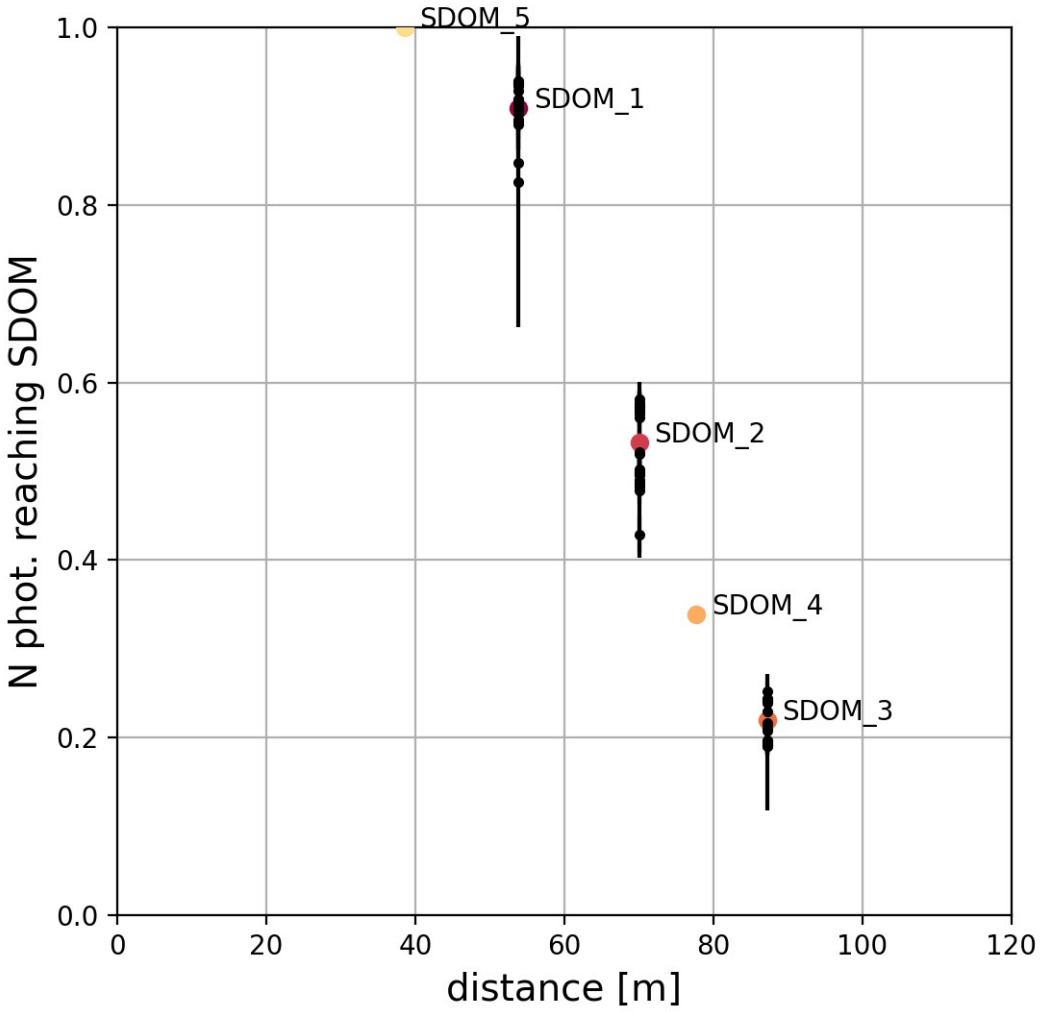
SDOM4 → 0.8

SDOM5 → 1.1

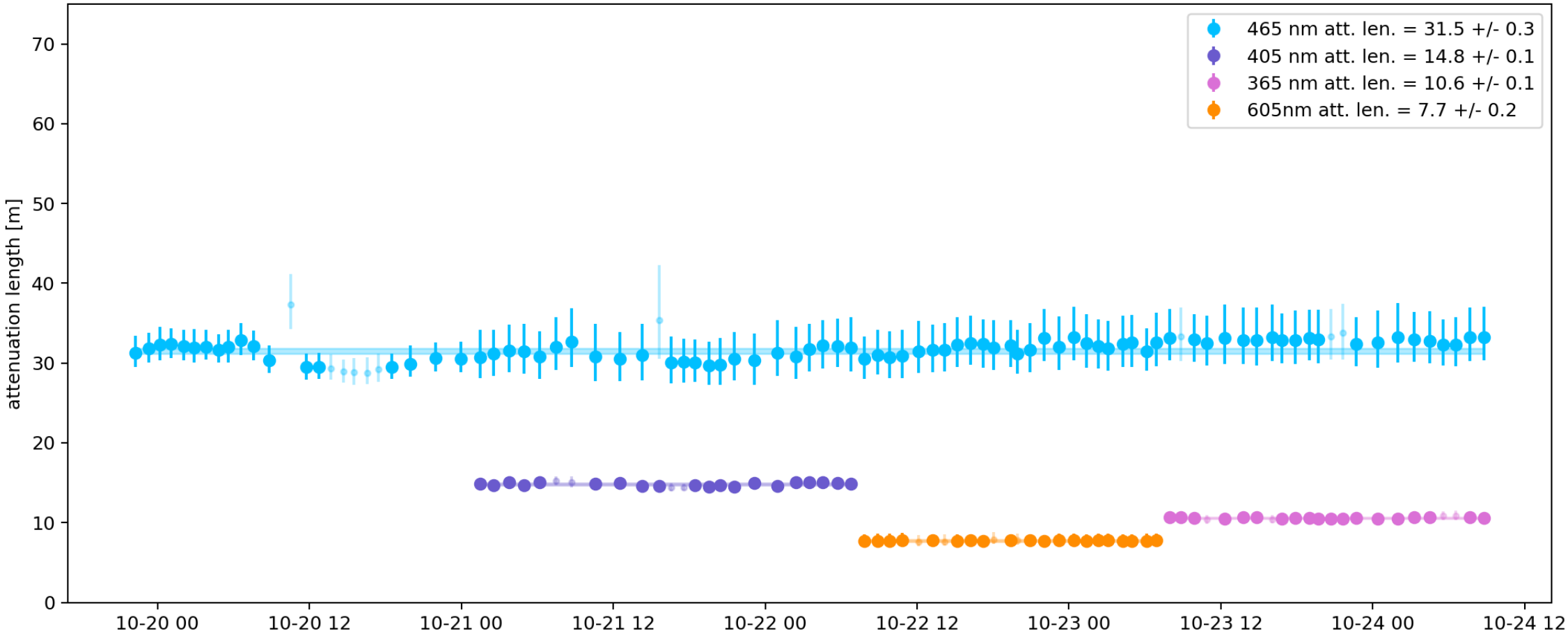


Simultaneously fitting all Oct. 2020 data





Final result with adjusted sDOM efficiencies



- Better match for 465 nm between low and high intensity flashes
- No dramatic change for attenuation lengths!

Summary

Two Year Optical Site Characterization for P-ONE in the Cascadia Basin

Matteo Agostini, Michael Böhmer, Christian Fruck, Roman Gernhäuser, Kai Krings, Klaus Leismüller, Stephan Meighen-Berger, Laszlo Papp, Immacolata Carmen Rea, Elisa Resconi, Christian Spannfellner, Michael Traxler, and Andrea Turcati
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Jeff Bosma, Reyna Jenkyns, Paul Macoun, Mike Morley, Benoît Pirenne, Chuantao Qiu, Adrian Round, and Albert Ruskey
Ocean Networks Canada, University of Victoria, Victoria, British Columbia, Canada

K. Clark
Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, Ontario, Canada

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Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada

A. Gärtner, C. B. Krauss, Roger Moore, and Juan Pablo Yañez
Department of Physics, University of Alberta, Edmonton, Alberta, Canada

D. Grant and C. Kopper
Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA

Felix Henningsen
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Kilian Holzapfel and Matthias Huber
Department of Physics, Technical University of Munich, Garching, Germany

S. Leys
Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada

Jan Michel
Institut für Kernphysik, Goethe Universität, Frankfurt, Germany

Paolo Padovani
European Southern Observatory, Garching, Germany
(P-ONE Collaboration)
(Dated: December 13, 2020)

The STrings for Absorption length in Water (STRAW) experiment is the first of a series of pathfinder missions towards the Pacific Ocean Neutrino Explorer P-ONE, the first stage of a large scale neutrino telescope in the Pacific ocean.
Over the course of one year of successful operation we could monitor the attenuation length and light background in the deep ocean ...

I. INTRODUCTION

II. INSTRUMENT

STRAW consists of two 150 m long deep-sea mooring lines at a distance of 37 m. Along each mooring line, four optical modules are mounted at 30, 50, 70 and 110 m above the seafloor. Three of these modules - called POCAMs (Precise Optical CAlibration Modules) - act as light emitters, five - called sDOMs (STRAW Digital Optical Modules) - act optical receivers. Thees modules are symmetric along the Z-axis with emitters/receivers at both, the bottom and top.

The POCAMs use LEDs and a circuit suggested by Kapustinsky *et al.* [1] behind an integrating sphere in order to produce nearly isotropic (if adding the two hemispheres) light flashes of a few nanoseconds in length. Four different wavelengths are available for those flashes: 365 nm, 405 nm, 465 nm and 605 nm. The flasher intensity can be adjusted via the supply voltage in order to achieve a suitable level of illumination on the sensors.

The sDOMs house two PMTs behind glass hemispheres, one at the top and one at the bottom of the otherwise cylindrical module.

A very detailed description of the STRAW hardware has been compiled by Boehmer *et al.* [2].

events were registered in each readout channel. The data produced in this mode is of particular interest for the long-term monitoring of bioluminescence. In high-precision mode, STRAW records the time-over-threshold of each event in all readout channels with sub-nanosecond precision. This data is used for the analysis of the optical parameters of the water. High-precision data is taken approximately once per month, when we iterate over a number of POCAM configurations, flashing each POCAM at various colours and voltages. At each setting we record high-precision data from the SDOMs for one minute.

IV. OPTICAL PARAMETERS

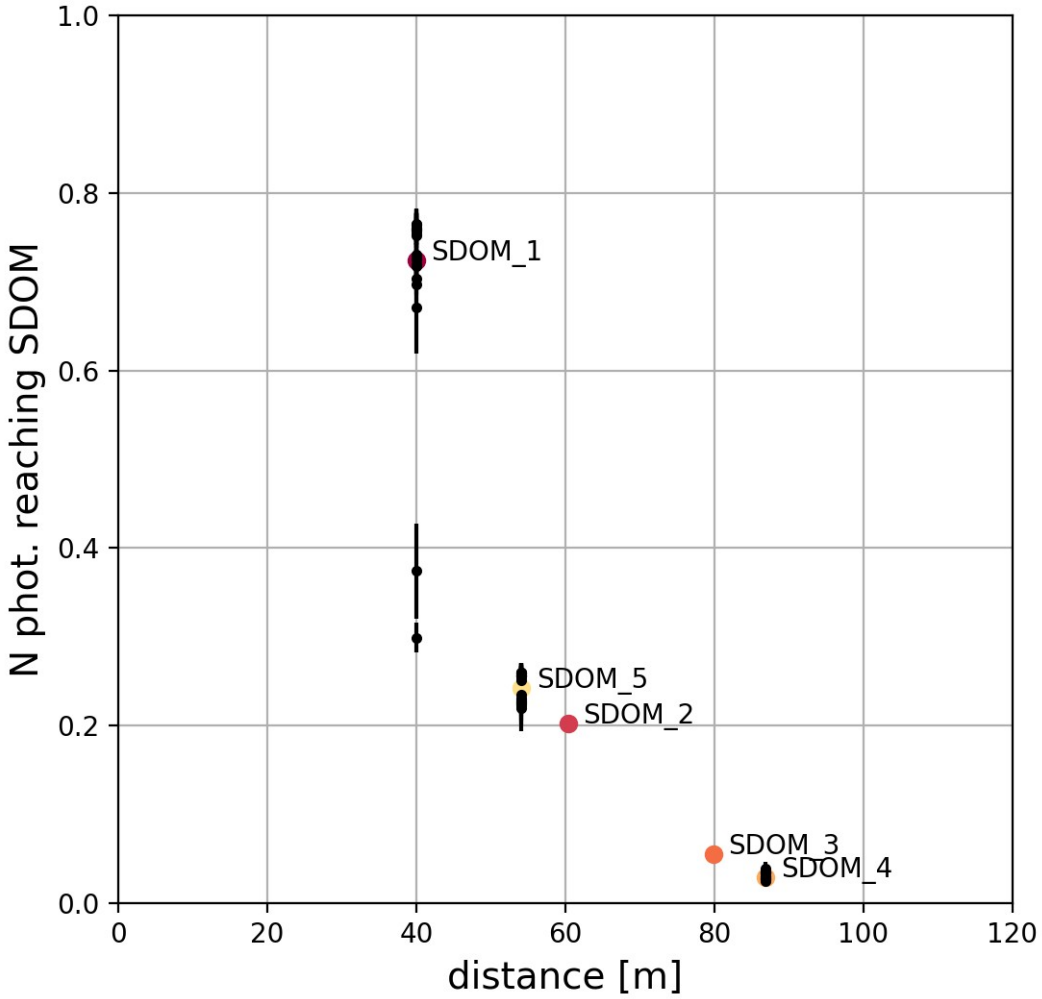
For the scope of this paper, to optical phenomena a relevant: absorption and scattering. Absorption is characterised by the absorption length l_{abs}. A photon that has traveled l_{abs} is absorbed with a probability of $1/e$. In the absence of scattering the intensity of a collimated beam I_{coll} can therefore be described as a function of distance x

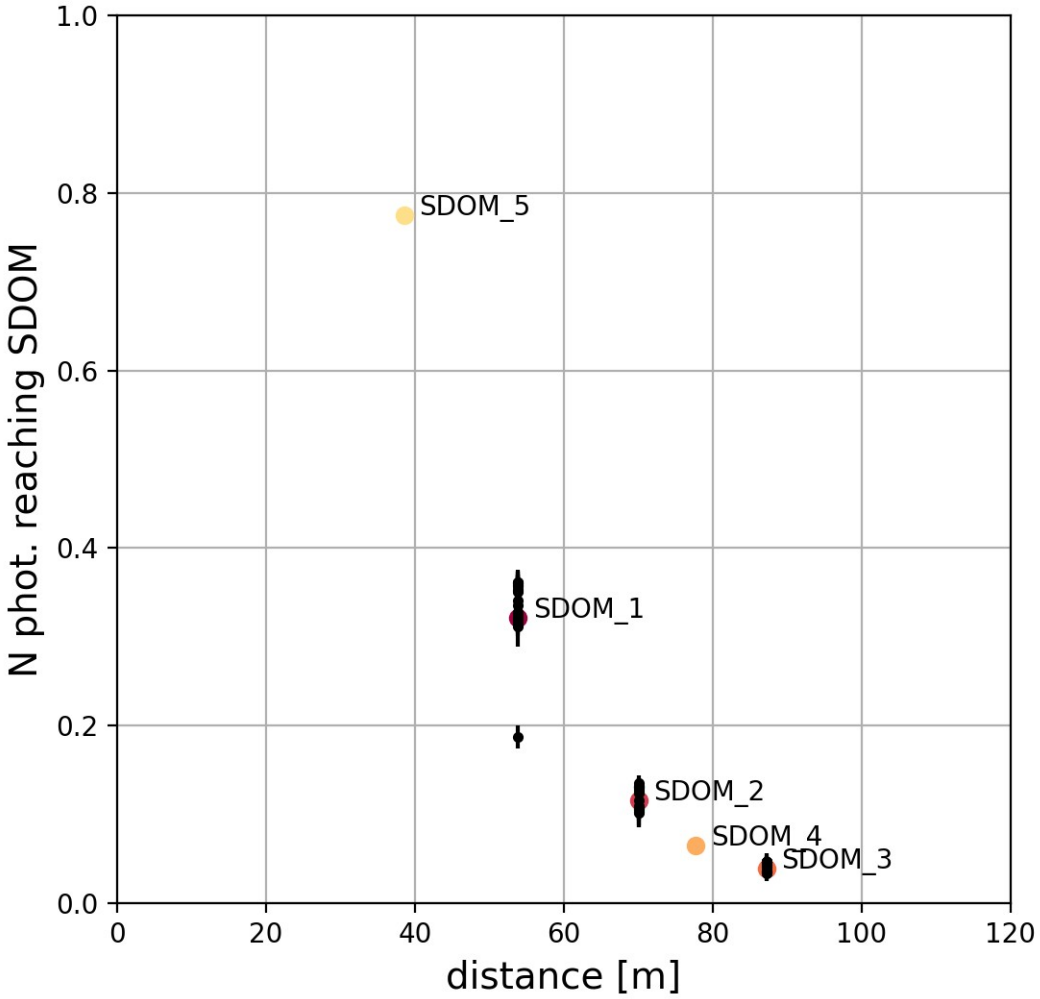
- Data taking concluded for site characterization paper
- Data analysis nearly finished too. Currently finalizing study on systematic errors
- Paper writing has finally started
- In the paper we want to present both methods
  - LLH fit of model to measured “hit fractions”
    → “direct” measurement of attenuation
  - absorption and scattering lengths from simulation
    → “indirect” measurement of attenuation length

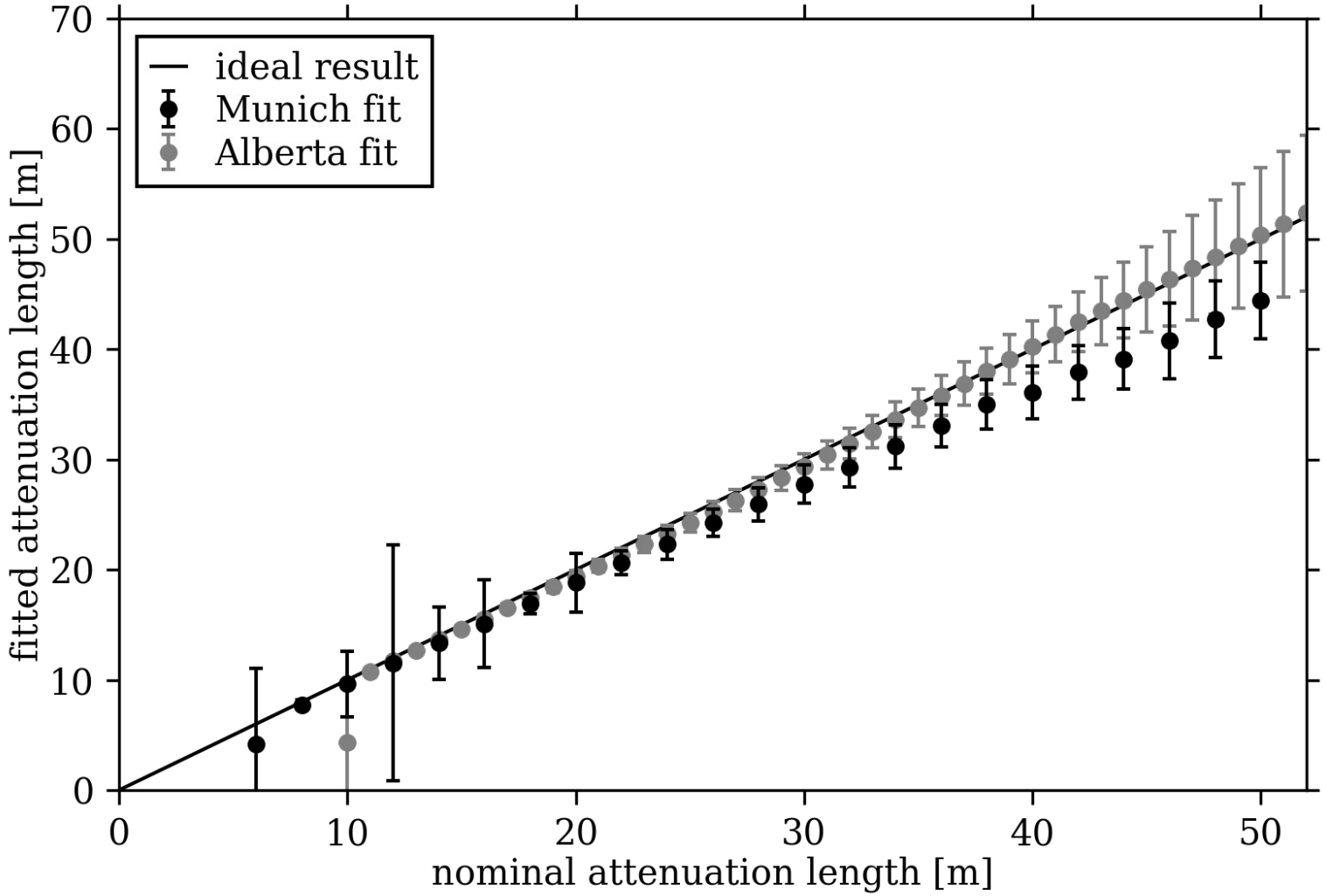
Thanks for your attention!

Backup

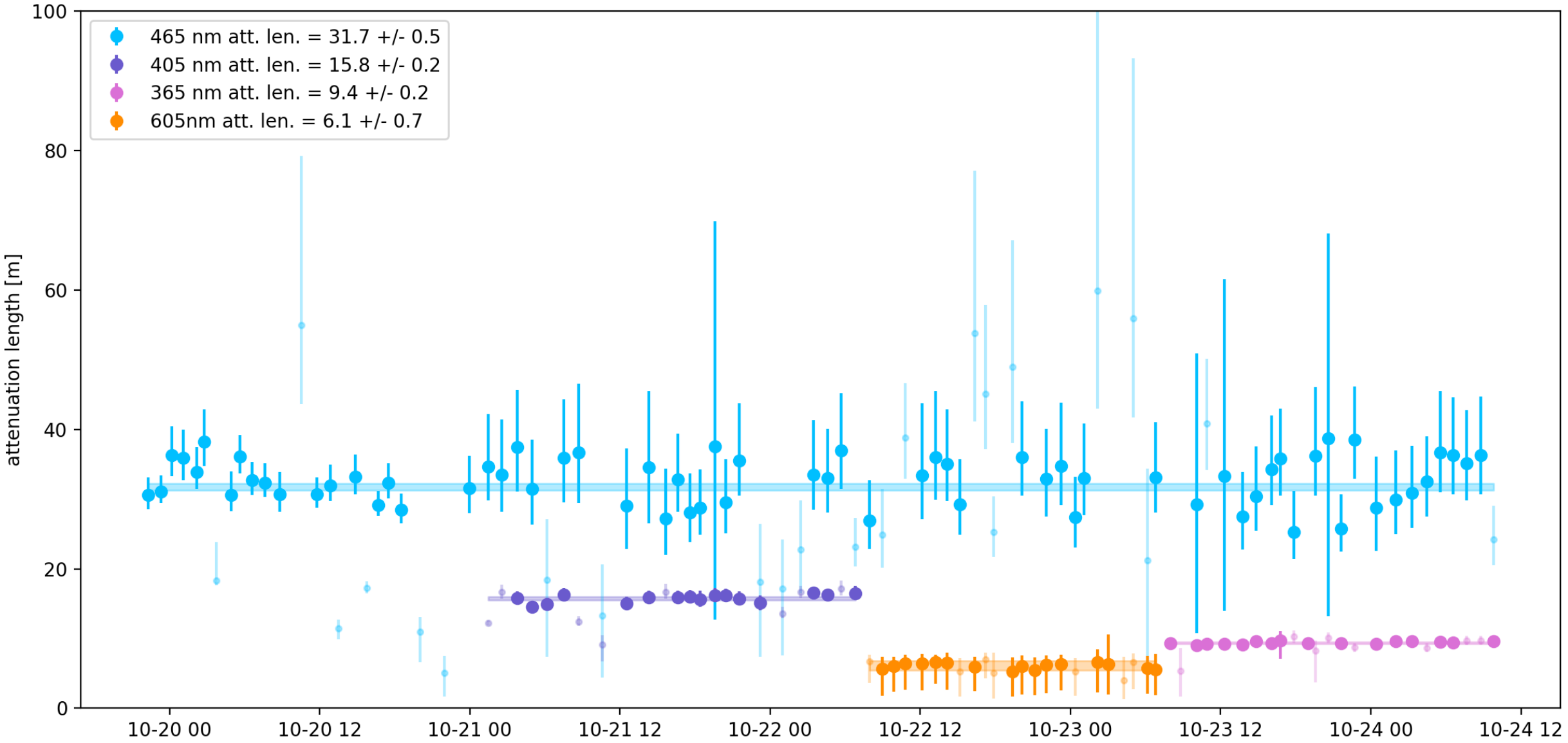
Latest results from the LLH fit (SNAPE runs)



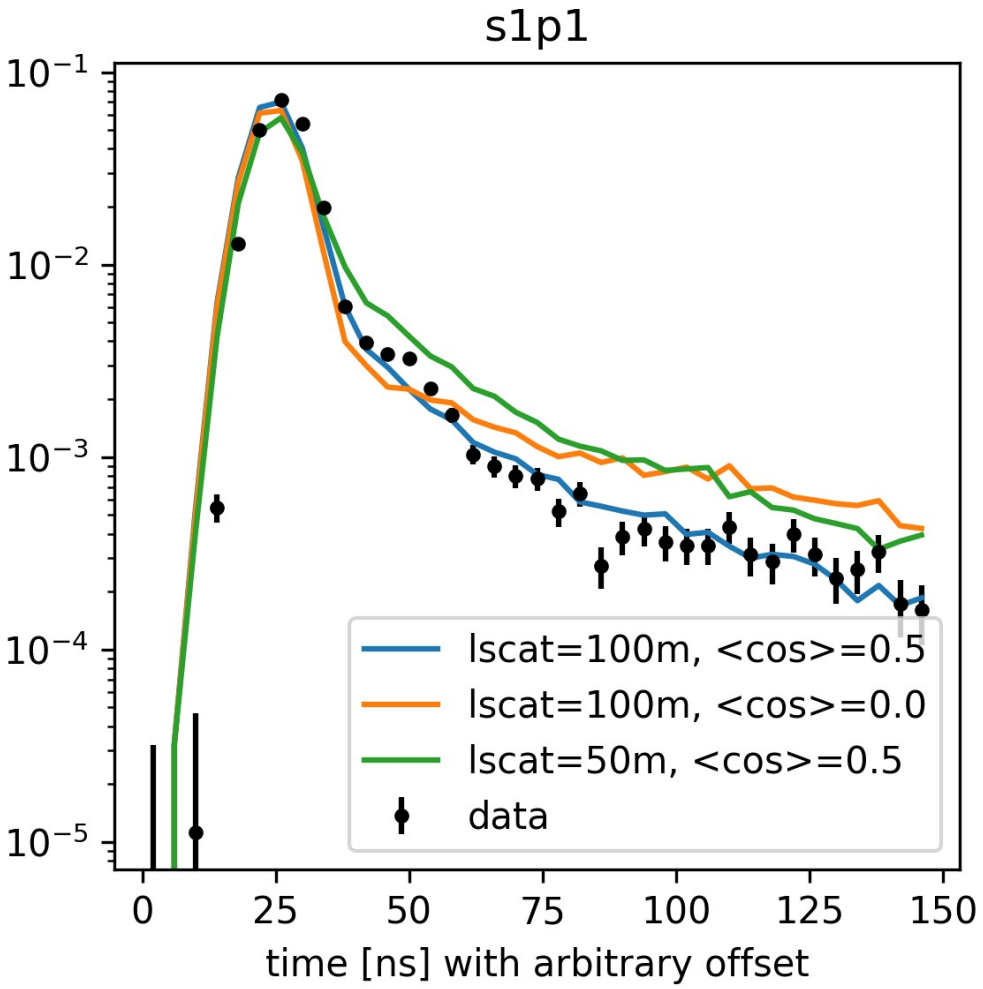



ideal result
Munich fit
Alberta fit
fitted attenuation length [m]
nominal attenuation length [m]
0
10
20
30
40
50
60
70

Latest results from the LLH fit (SNAPE runs)

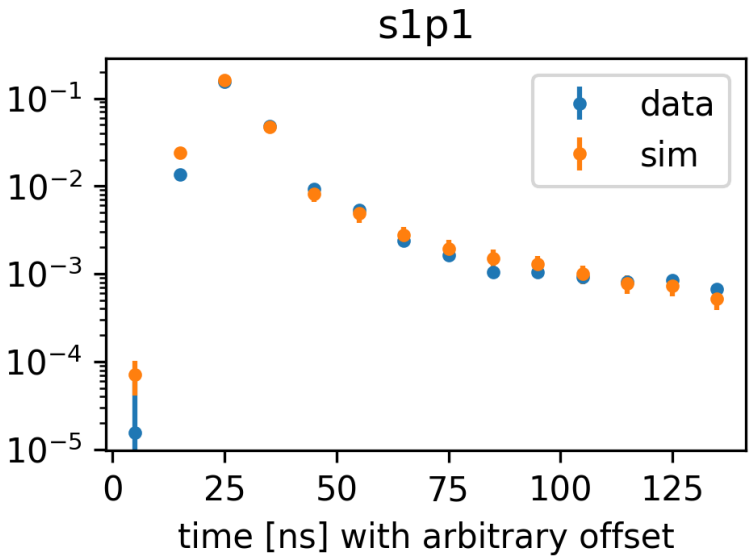


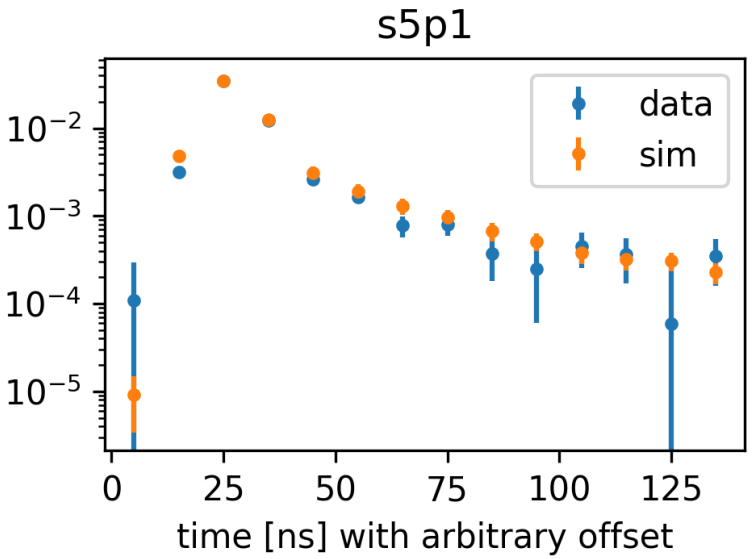
Latest results from Geant4 simulation + fit

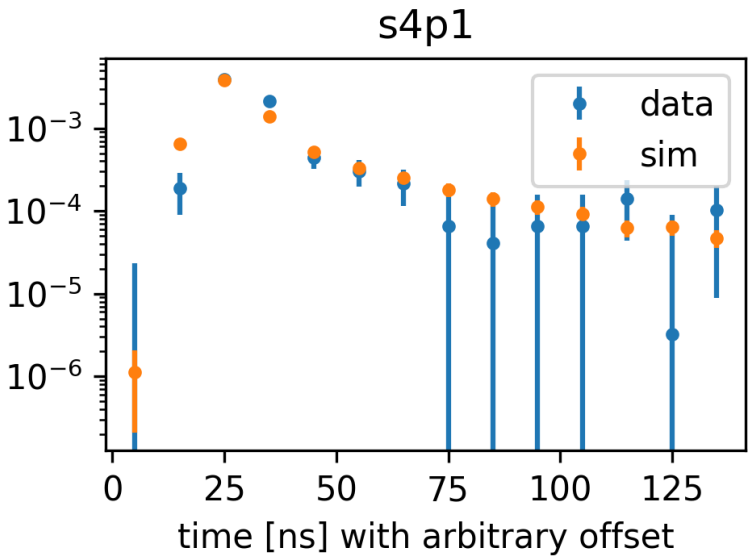


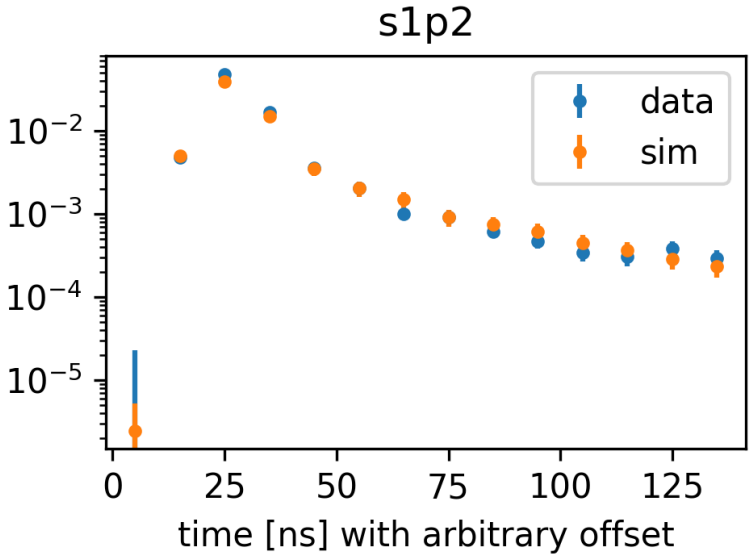
- currently mixing discrete simulation sets (scattering length and <cos>) with continuous parameter fit (absorption length), work on minimizer ongoing
- uncertainties in fit parameters strongly depend on systematics, main contribution: angular sensitivity of SDOMs

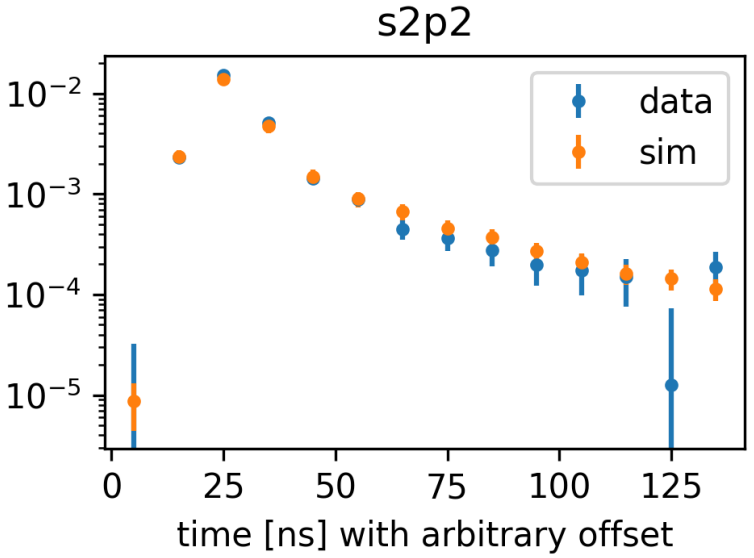
Latest results from Geant4 simulation + fit (by eye)

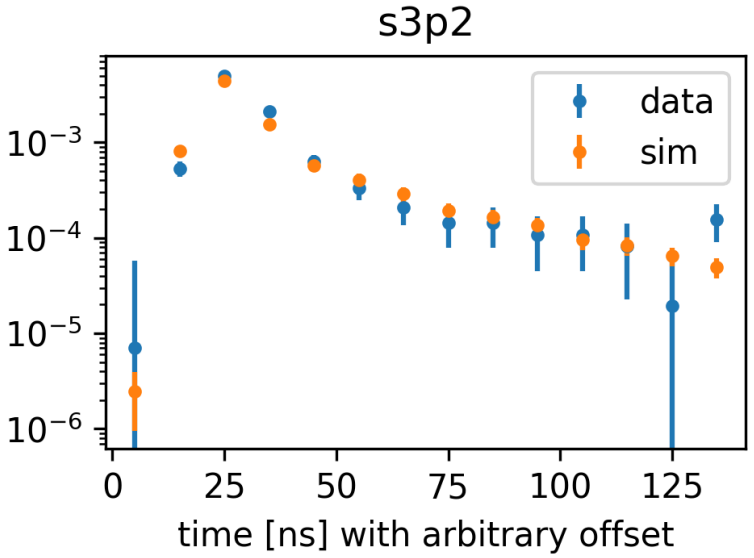












Remaining 2019/20 data set

- Currently being re-processed with the latest SW version
- Nearly completed, only final MCMC missing/running currently
- Next step: describe method and present data in paper draft