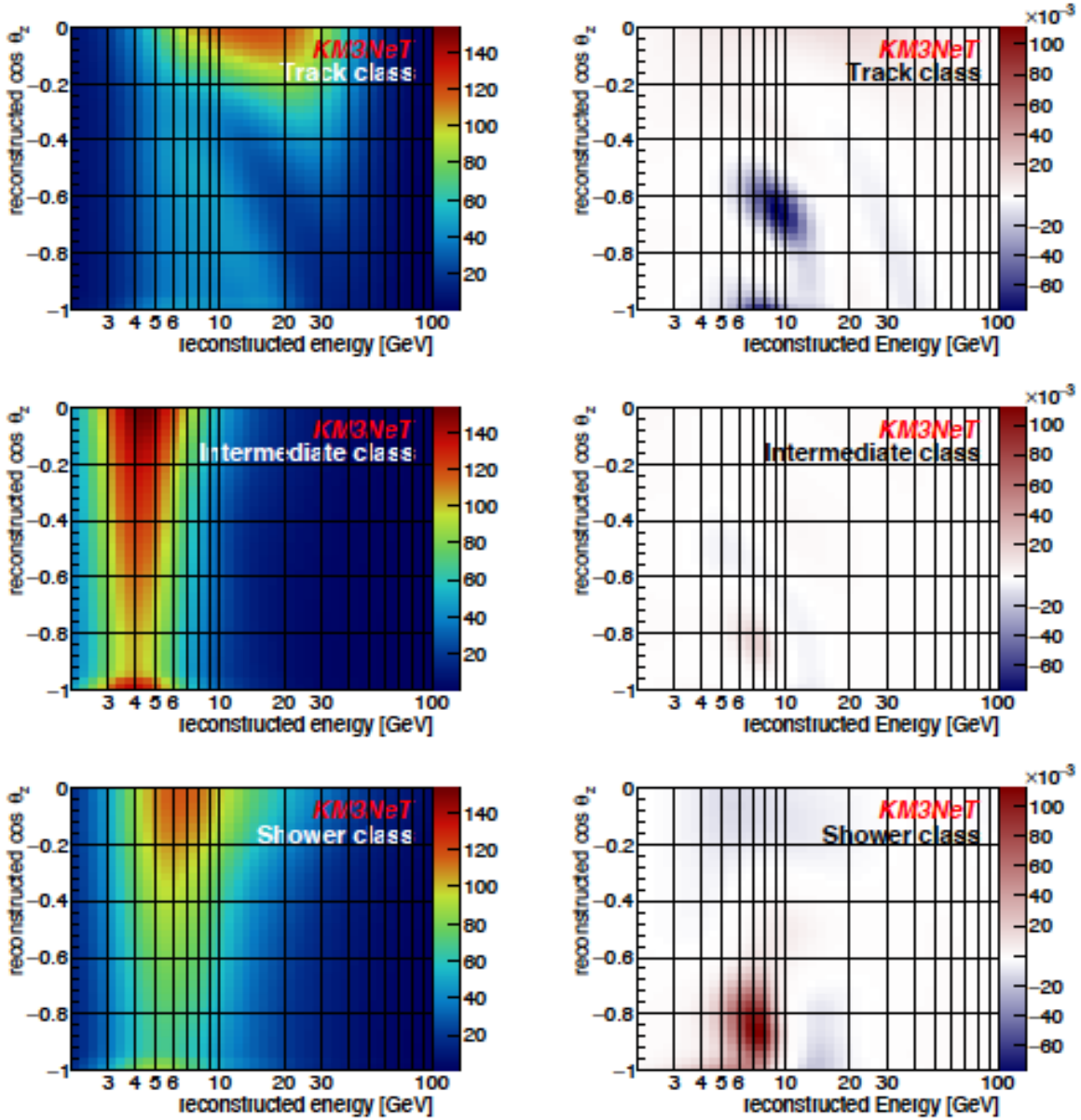
Precision energy calibration

Why?

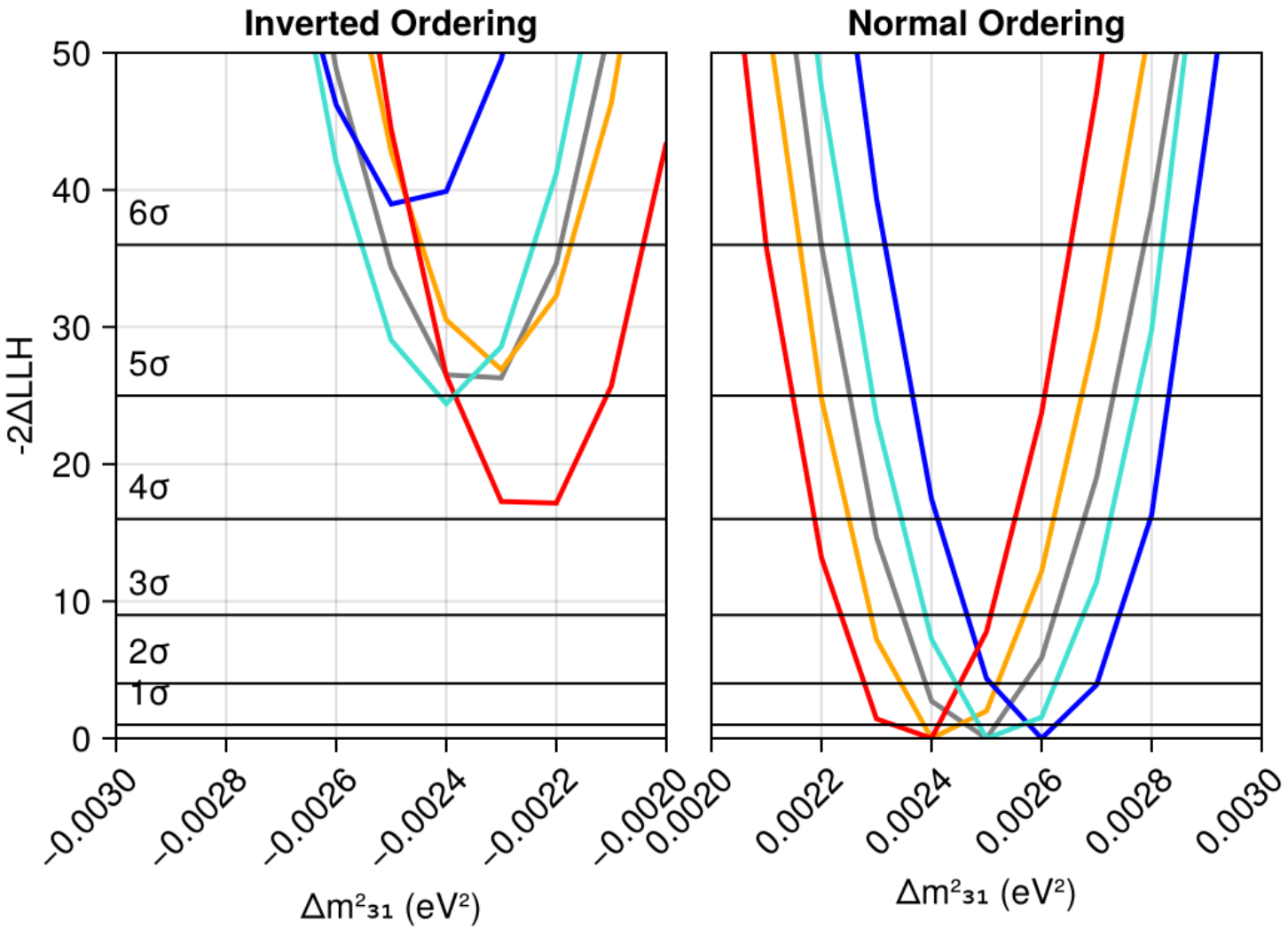
Neutrino mass ordering predictions for (full) ORCA – 3 years



In evaluations energy scale and hadronic energy scale with priors of ±6% and ±5% priors

Determining the neutrino mass ordering and oscillation parameters with KM3NeT/ORCA
European Physics C, 82, 26, (2022)

Neutrino Mass Ordering evaluations with shifted energy scales (combination IceCube & ORCA)



Credit: **Philipp Eller**
Technische Universität München

IceCube Upgrade + ORCA

- nominal
- energy scales: Icecube↑ ORCA↓
- energy scales: Icecube↓ ORCA↓
- energy scales: Icecube↑ ORCA↑
- energy scales: Icecube↓ ORCA↑

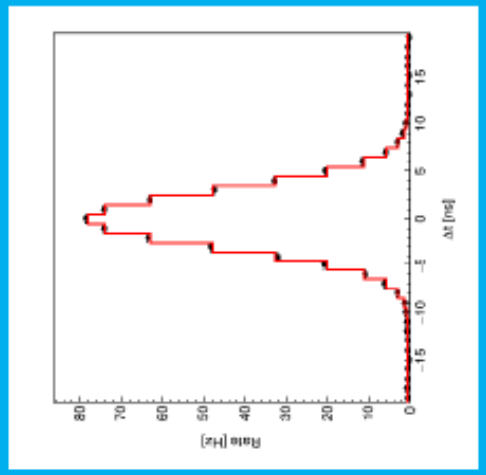
- energy scale degenerate with Δm^2_{31}
- for IO: detection significance changes

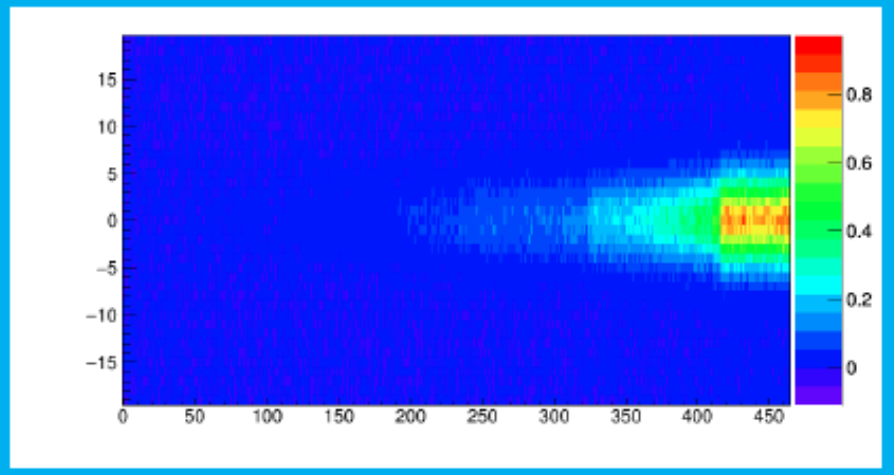
Efficiency calibration from correlated PMT pair rates (origin: K40 decays)

Model fit to data (simulation)

PMT

1. t_0
2. (relative) QE
3. TTS (σ)



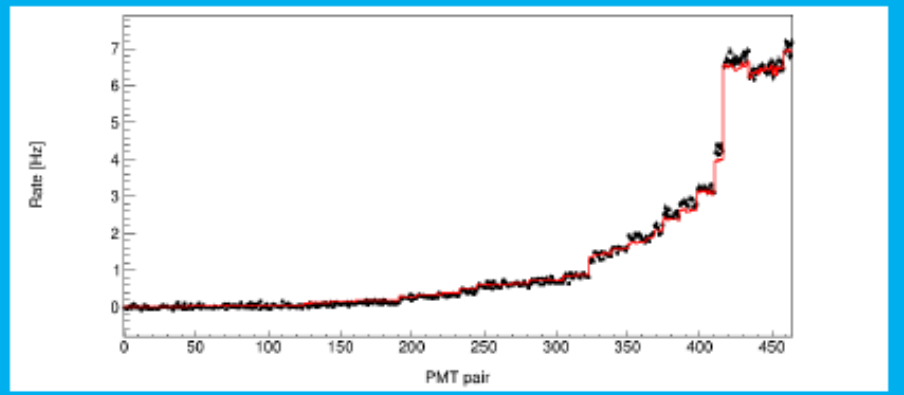


Fit

3 × 31 = 93 parameters

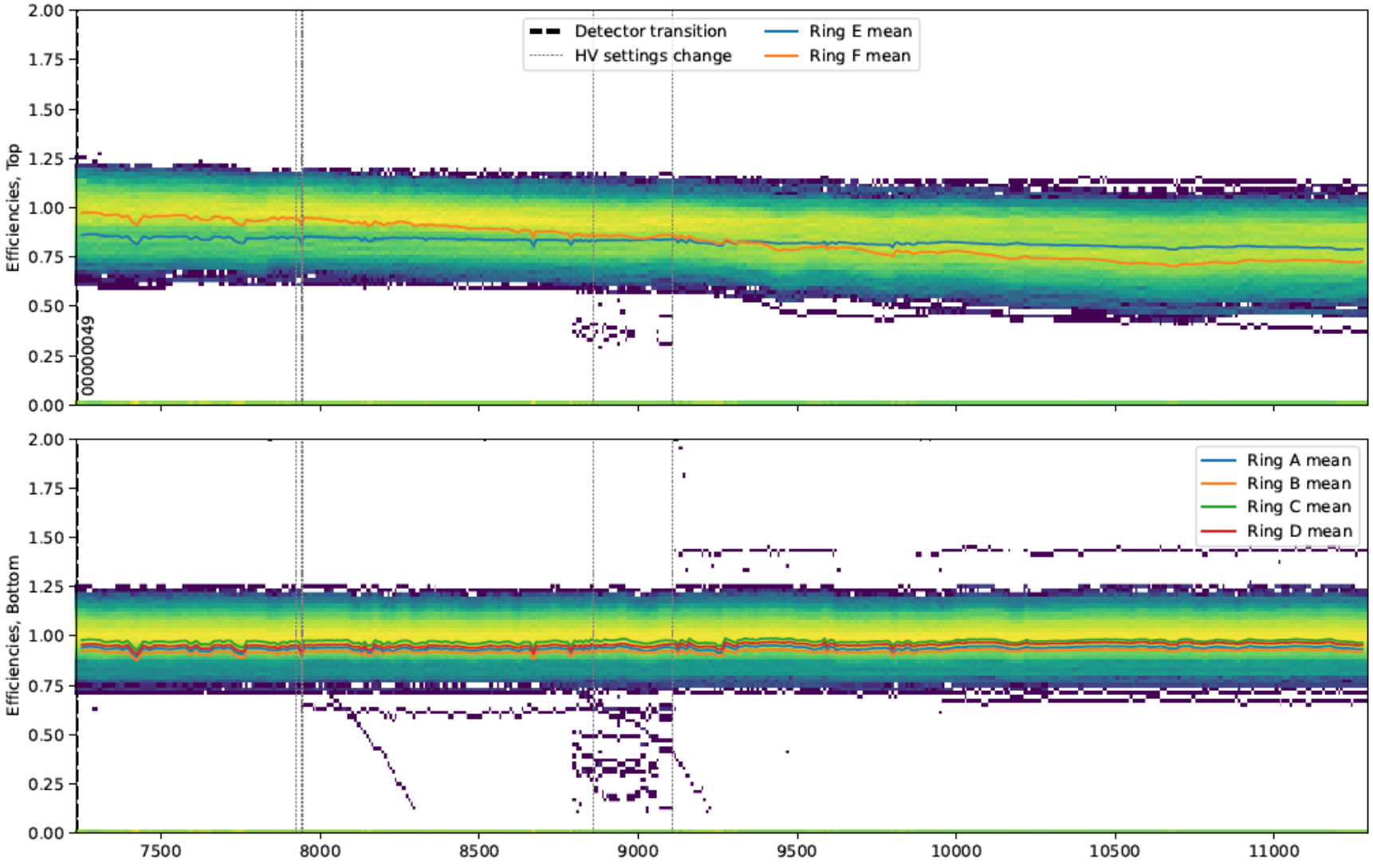
465 × 40 = 18,600 data points

Elapsed time ~0.5 seconds / module

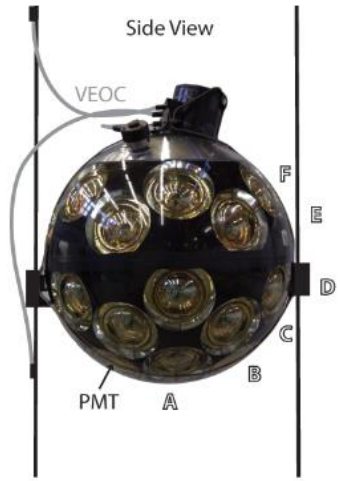


Maarten de Jong, neutrino group outing January 2024

Efficiency as determined from K40 for ORCA-6 (2 years)

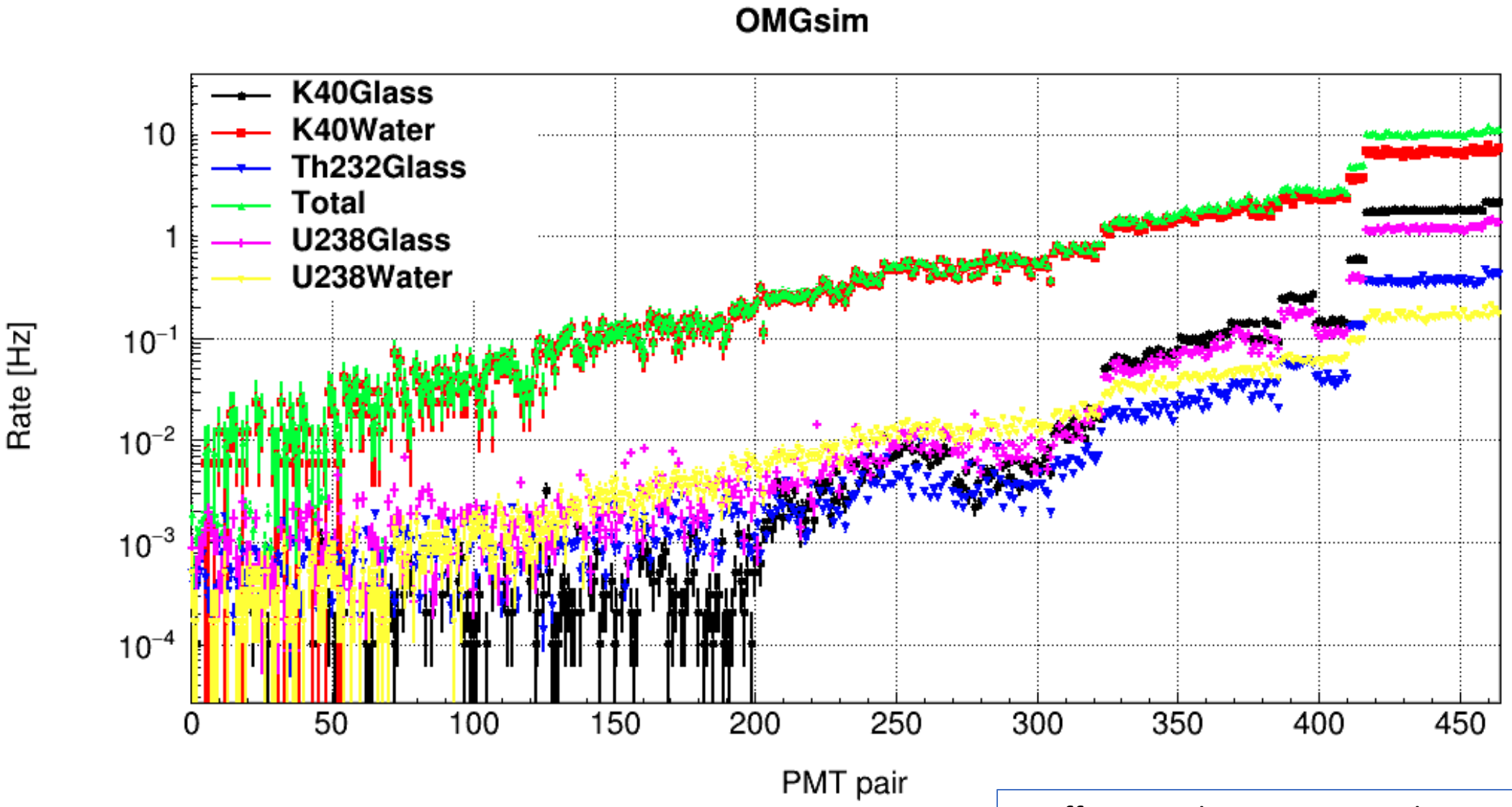


PMT ring numbering



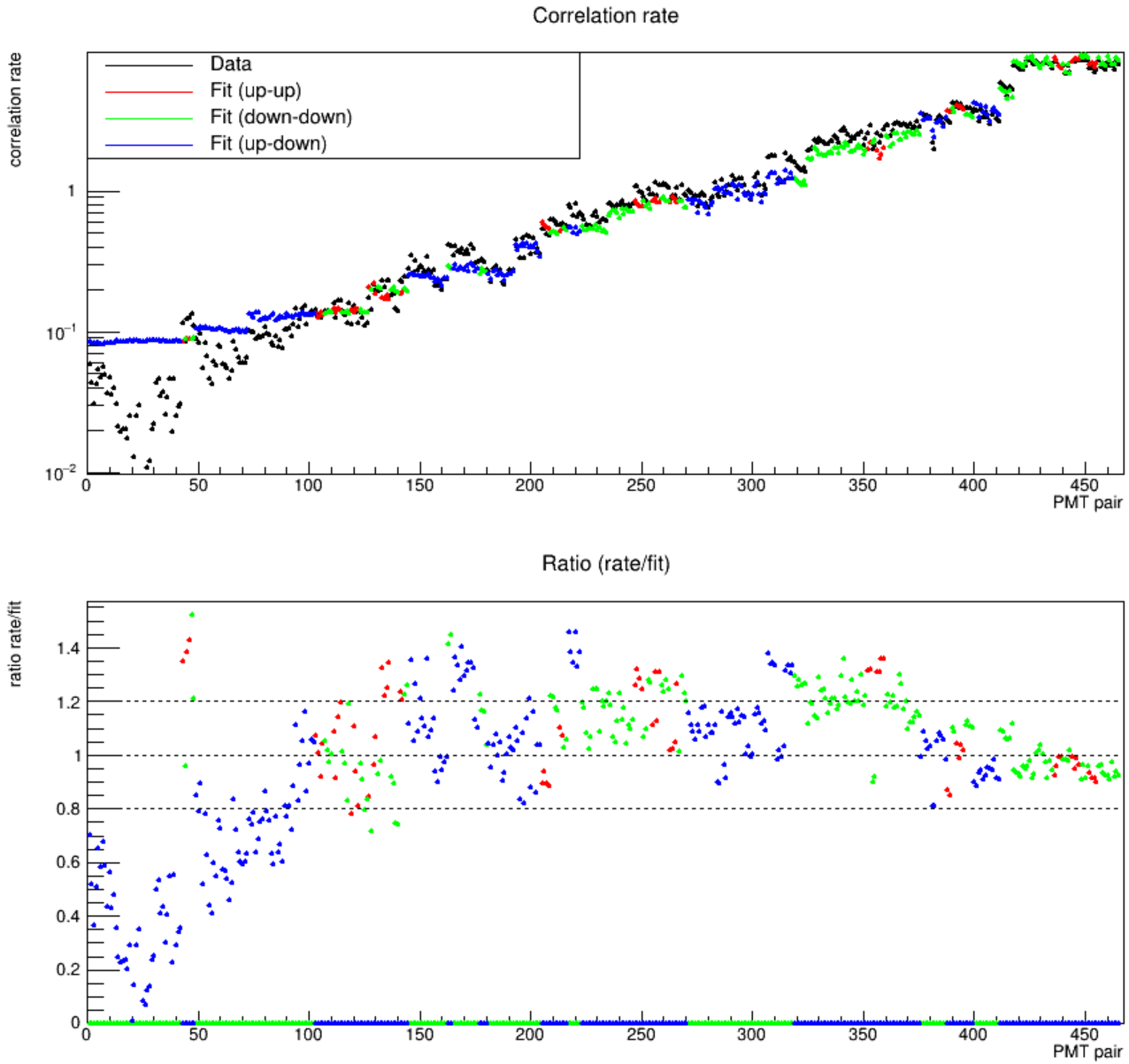
- E-ring efficiency lower than other rings (shadowing of titanium belt)
- F-ring efficiency decreasing with time
  -> sedimentation
  in periods of strong movements sometimes sedimentation sometimes falls off again
  (not visible here)

Correlated K40 and radioactivity rate in PMT pairs in simulation



In efficiency determination glass radioactivity not yet included

Comparison with real data (ARCA)



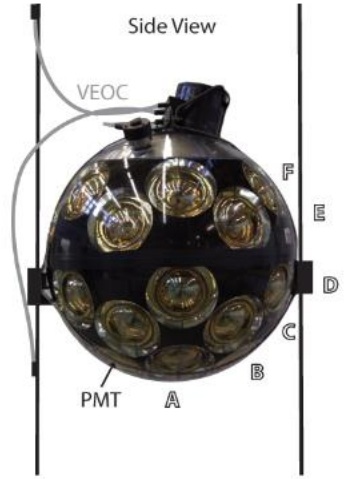
https://elog.km3net.de/Analysis/522 (2019)

Rate impacted by
- PMT-acceptance
- Non-isotropic PMT acceptance, e.g. shadowing by titanium belt, equator tape

- Efficiency fit assumes for every PMT a direction-independent efficiency:
- Determines average efficiency towards the directions of other PMTs (most weight is with the directly neighboured PMTs)
- Could lead to biasses in the case of non-isotropic acceptance (e.g. sedimentation)

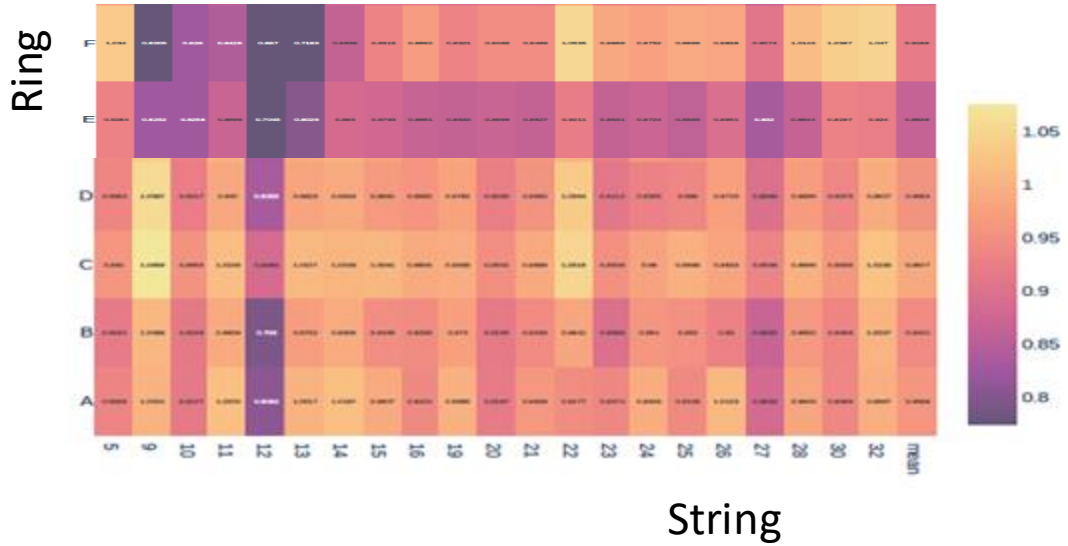
Comparison of atmospheric muon hits in data/MC in ARCA-21

PMT ring numbering

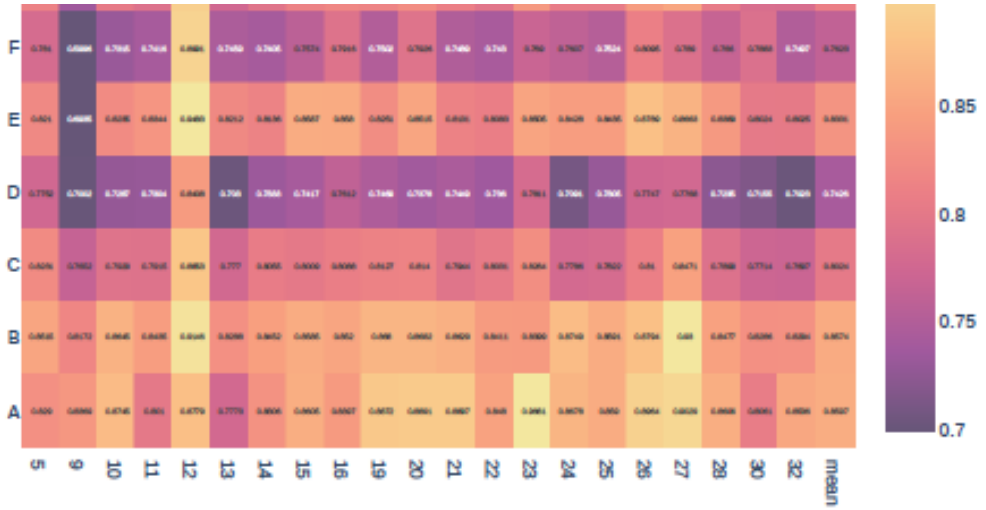


Possible origins of data/MC variations:
- ‘gel issue’ (wavelength-dependent transparency shift (https://elog.km3net.de/Calibration/365, 2021)
- non-isotropic PMT efficiency (assumption in efficiency average is isotropy)
- …

Efficiencies



Ratio data/MC
(counting direct muon hits within 20ns)



Bachelor thesis **Mike Wang**, 2023

Precision Optical Calibration Module
POCAM

for KM3NeT

POCAM @ Technische Universität München (TUM)

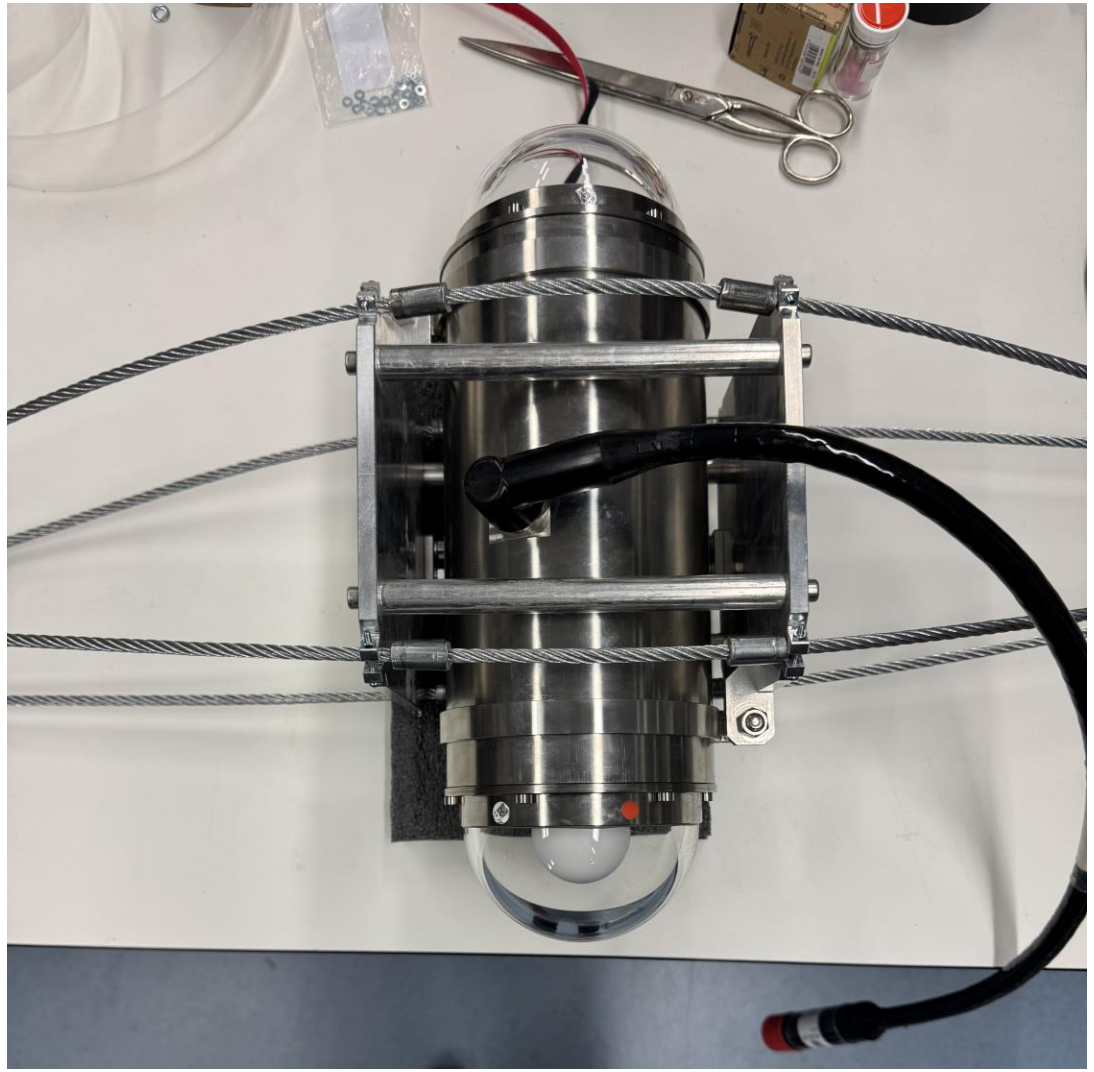
Goal:
- determine absolute energy scale
- energy resolution at percent level

Development since 2014
2017 First prototype used in GVD Baikal
2018 Upgraded version in STRAW (Pacific site)
2021++ Further refinement in

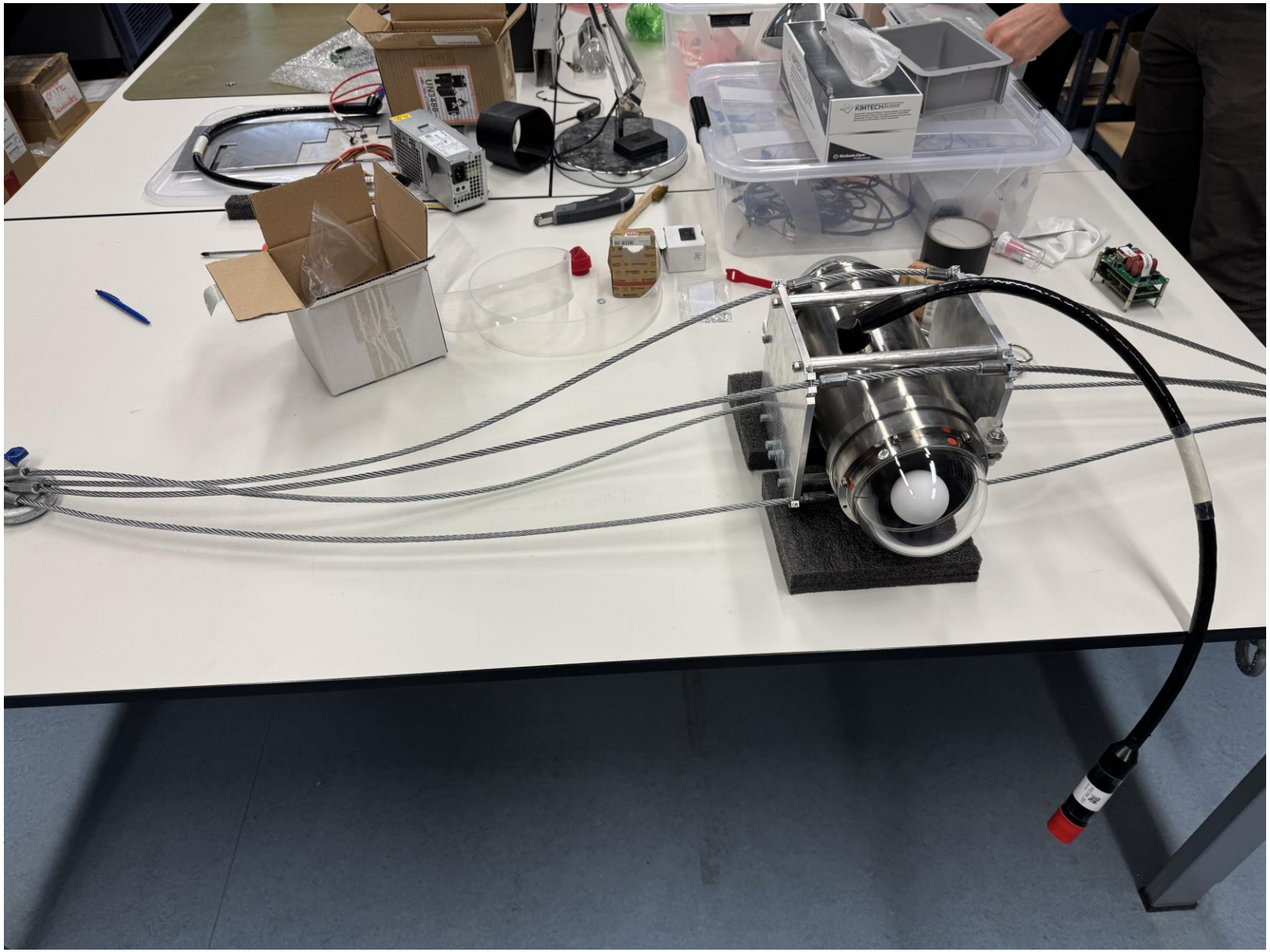
6 light emitters

3 LEDs: 365nm, 405nm, 465nm

3 LDs: 405nm, 455nm, 520nm

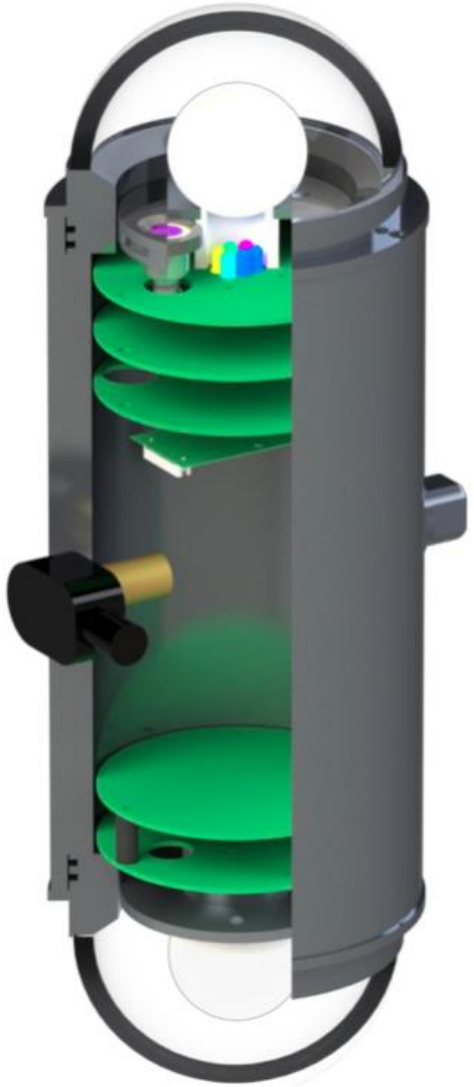


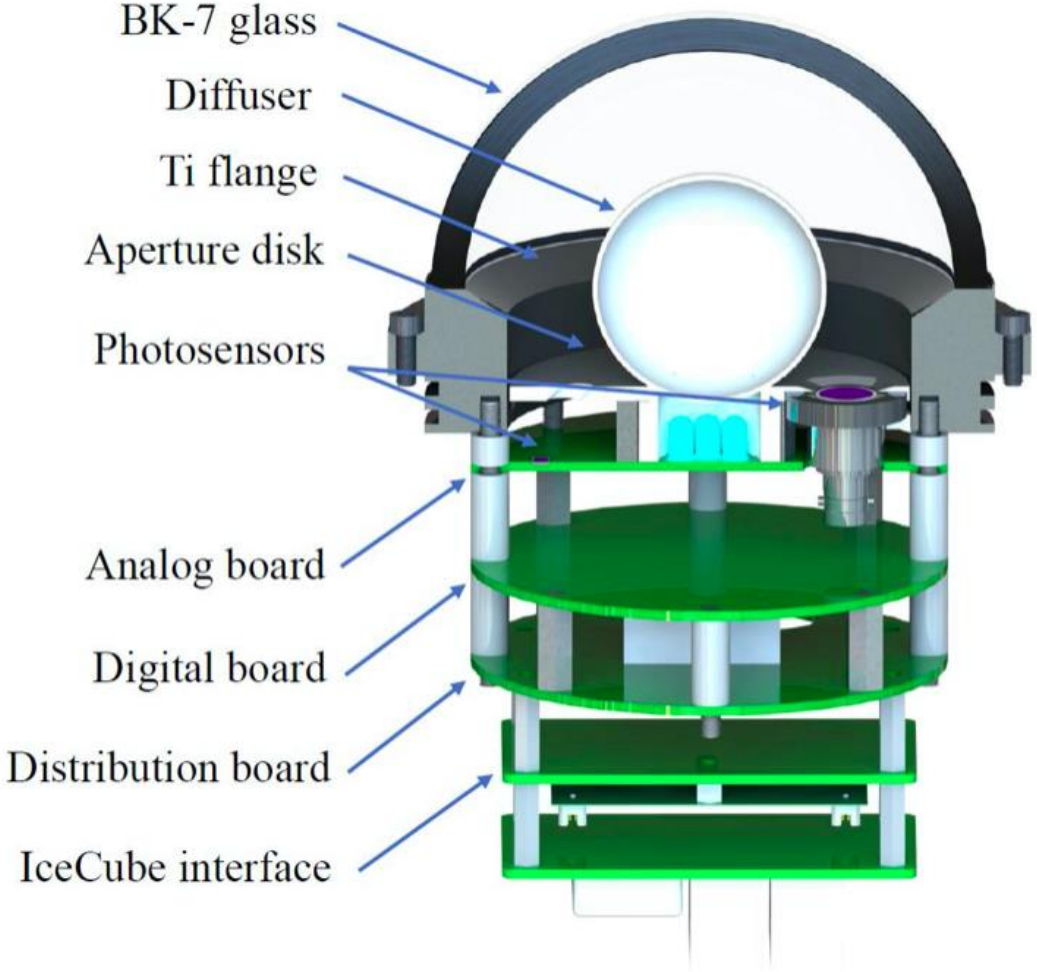
POCAM @ Technische Universität München (TUM)



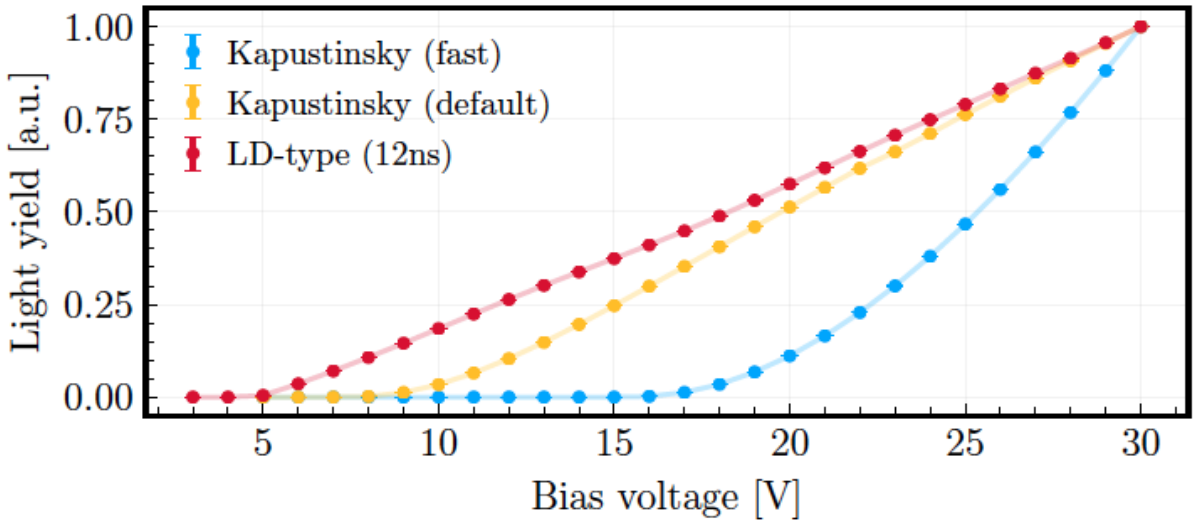
POCAM

Precision Optical Calibration Module

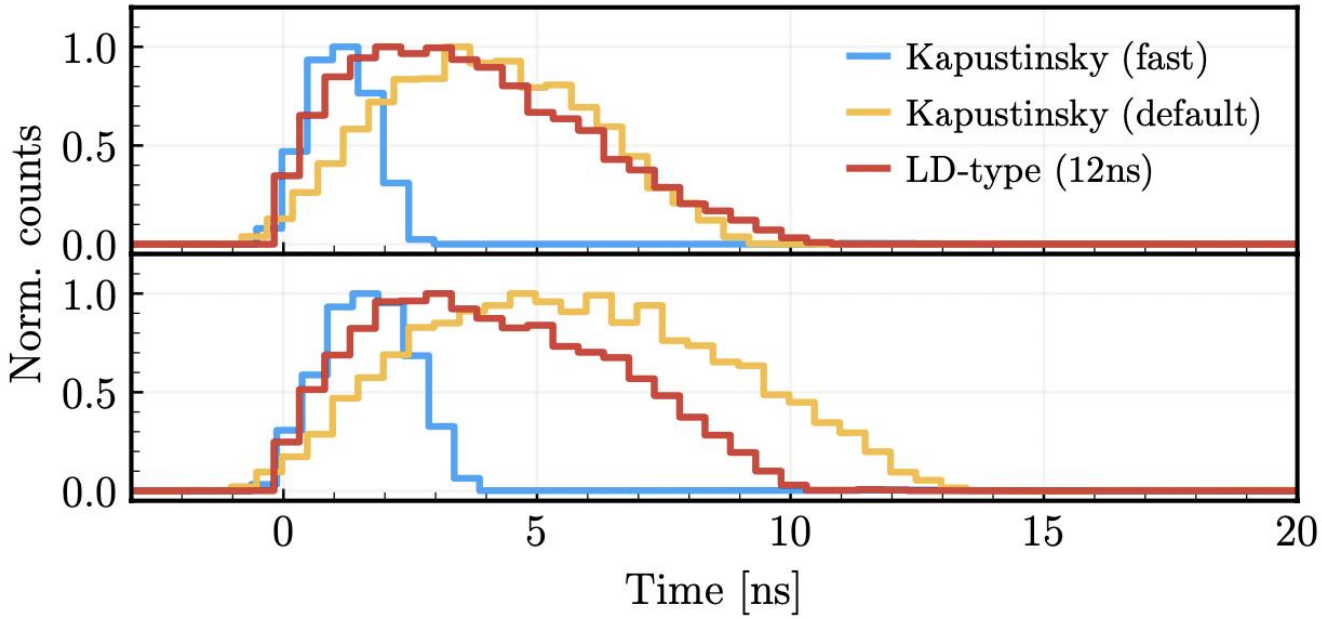




Intensity (@405nm)



Time profile (@405nm)



Minimal bias voltage

Maximal bias voltage

Two independent photo detectors embedded

SiPM
- low intensity regime
- FPGA discriminator
- TDC => ToT

Photodiode
- high intensity regime
- amplifiers => voltage amplitude proportional to charge

Relative and absolute calibration setup

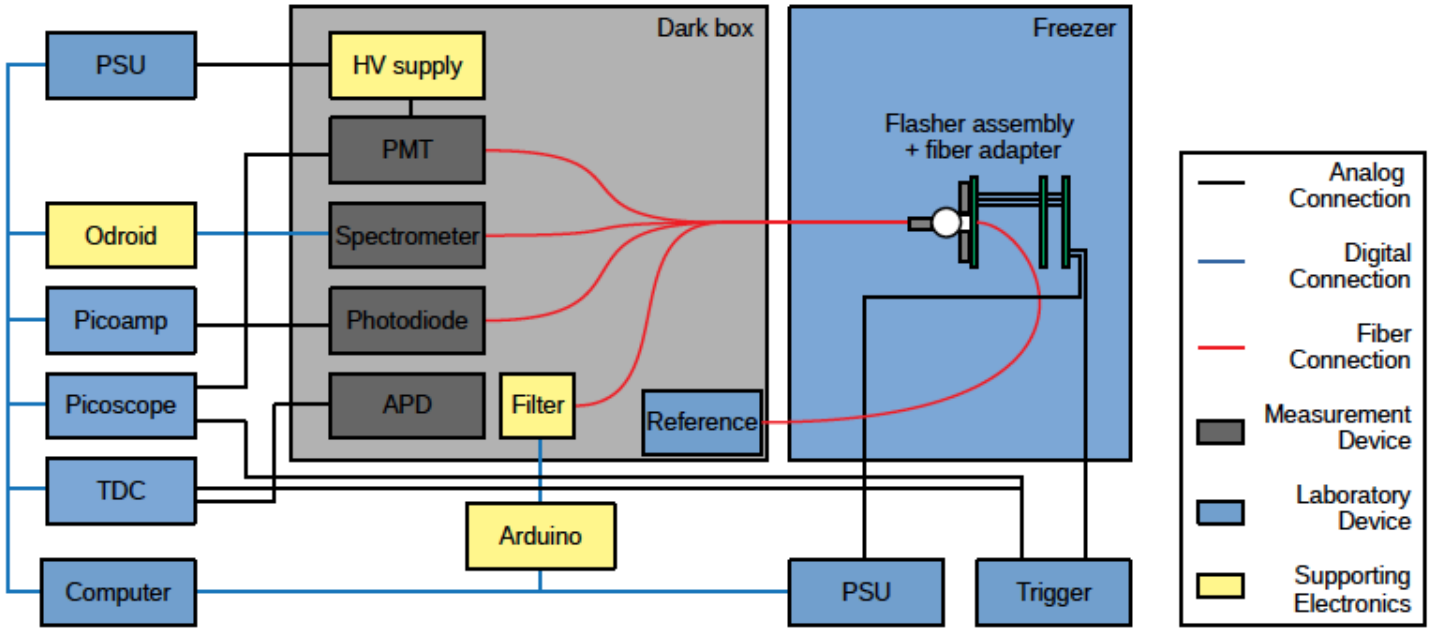
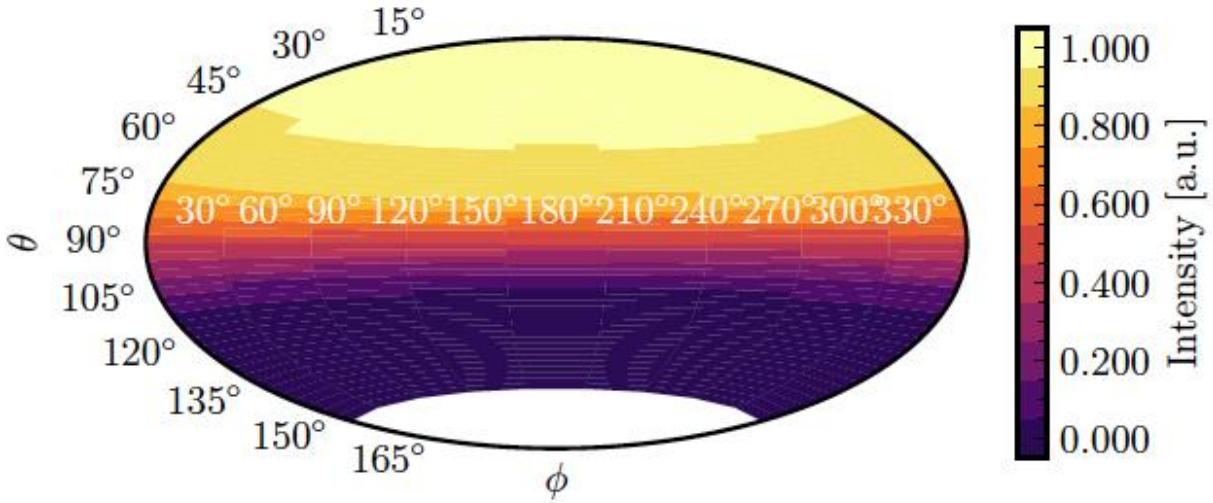


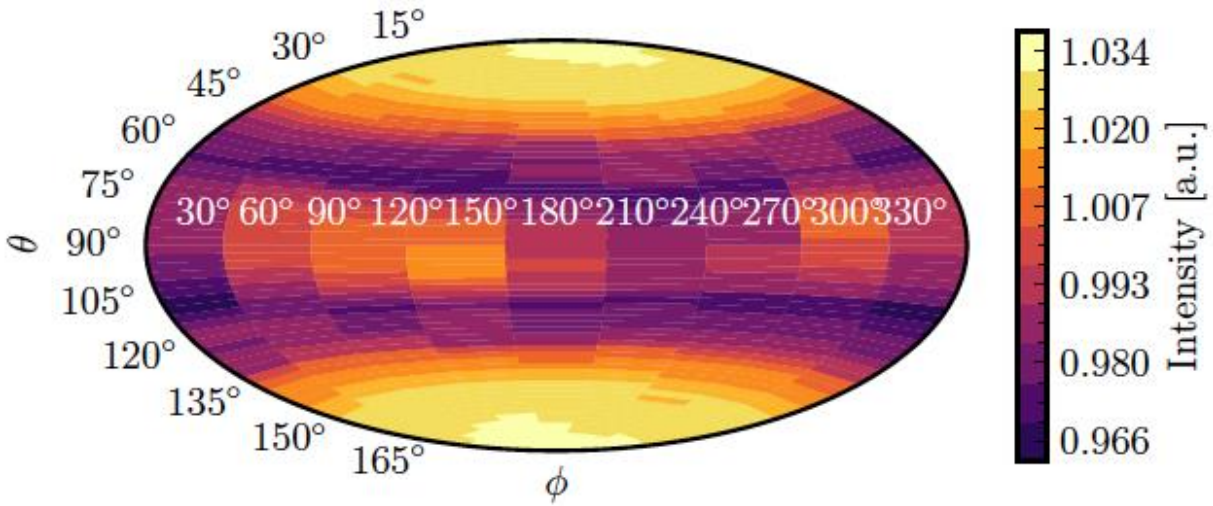
Figure 15. Schematical workflow diagram of the light pulser calibration station. For details on the sub-components and their functions, refer to the text.

Emission isotropy



(a) Single hemisphere prototype emission

Measured (one half POCAM)



(b) Virtual dual-hemisphere emission

Virtual addition of both halves)