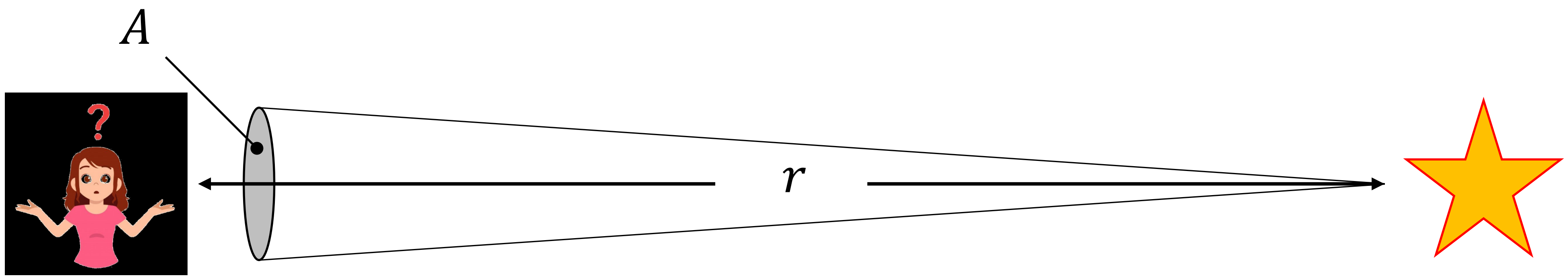
K40NeT = K40 in KM3NeT

Maarten de Jong

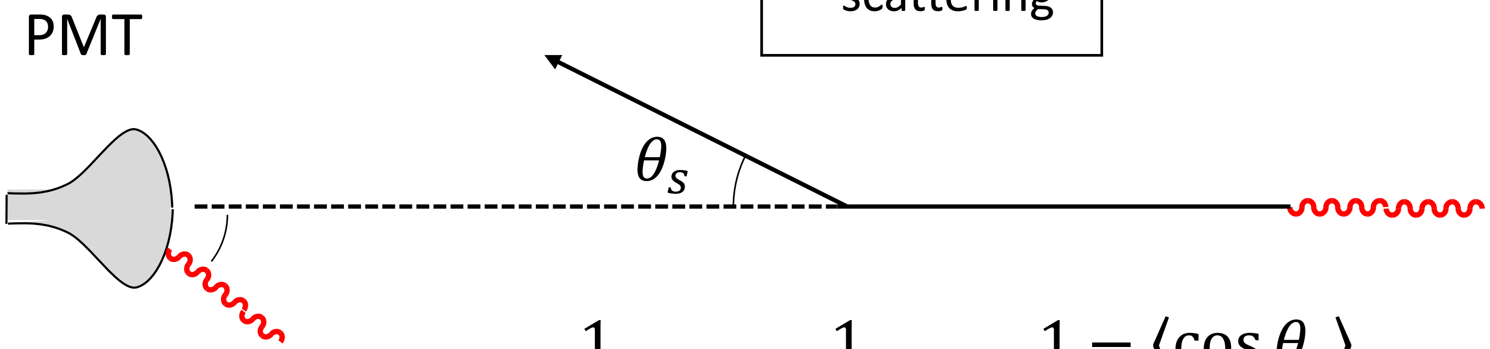
What has K40 to do with the night sky?



$$\Omega = \frac{A}{r^2}$$

$$L = \int_0^\infty dr\, \frac{\Omega}{4\pi} \times \rho\, L_* \times 4\pi r^2$$

- absorption
- scattering



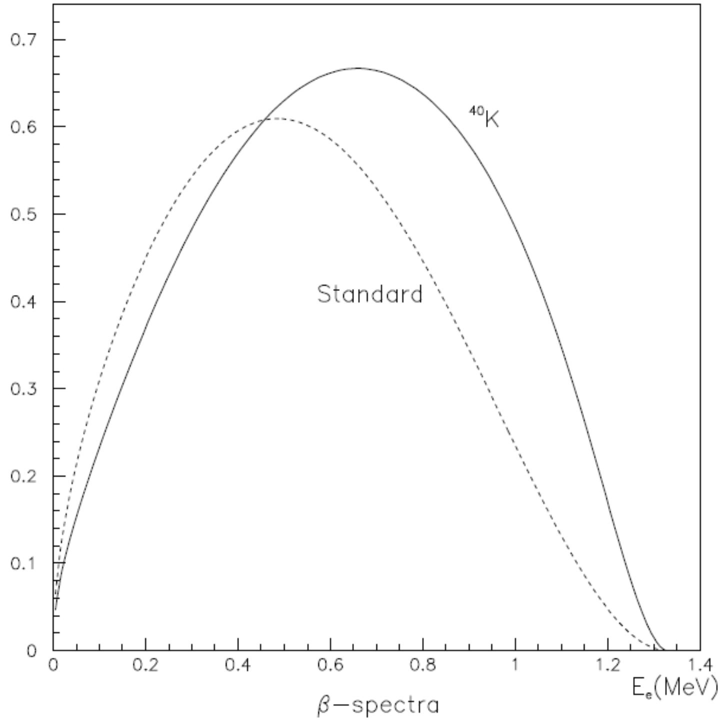
$$^{40}K \rightarrow {}^{40}Ca + e^-$$

$$\frac{1}{\lambda_{att}} = \frac{1}{\lambda_{abs}} + \frac{1 - \langle \cos\theta_s \rangle}{\lambda_s}$$

- quantum efficiency
- photo-cathode area¶

- radioactivity
- β-spectrum
- number of photons
- electron propagation(!)

¶ Angular acceptance factors out.



Isotope	A	r_m	r_I	τ (years)	Bq per m^3	Q (MeV)
^{40}K	39.1	$4.27 \cdot 10^{-4}$	$1.170 \cdot 10^{-4}$	$1.277 \cdot 10^{9}$	13,750	1.33
^{238}U	238.0	$3.30 \cdot 10^{-9}$	$0.993 \cdot 10^{0}$	$4.468 \cdot 10^{9}$	40 ($\times$6)	many *
^{87}Rb	85.5	$1.20 \cdot 10^{-7}$	$0.278 \cdot 10^{0}$	$4.750 \cdot 10^{10}$	110	0.28
^{235}U	238.0	$3.30 \cdot 10^{-9}$	$0.720 \cdot 10^{-2}$	$7.038 \cdot 10^{8}$	1.9 ($\times$4)	many *
^{187}Re	186.2	$1.00 \cdot 10^{-12}$	$0.626 \cdot 10^{0}$	$4.350 \cdot 10^{10}$	$1.0 \cdot 10^{-3}$	0.003
^{232}Th	232.0	$4.00 \cdot 10^{-14}$	$1.000 \cdot 10^{0}$	$1.405 \cdot 10^{10}$	$1.6 \cdot 10^{-4}$($\times$4)	many *
^{176}Lu	175.0	$1.50 \cdot 10^{-13}$	$2.590 \cdot 10^{-2}$	$4.000 \cdot 10^{10}$	$7.3 \cdot 10^{-6}$	1.19
^{138}La	138.9	$3.40 \cdot 10^{-12}$	$0.900 \cdot 10^{-3}$	$1.050 \cdot 10^{11}$	$2.8 \cdot 10^{-6}$	1.74
^{113}Cd	112.4	$5.00 \cdot 10^{-11}$	$0.122 \cdot 10^{0}$	$7.700 \cdot 10^{15}$	$9.3 \cdot 10^{-8}$	0.32
^{115}In	114.8	$1.00 \cdot 10^{-13}$	$0.957 \cdot 10^{0}$	$4.410 \cdot 10^{14}$	$2.5 \cdot 10^{-8}$	0.49
^{50}V	50.9	$1.50 \cdot 10^{-9}$	$2.500 \cdot 10^{-3}$	$1.400 \cdot 10^{17}$	$7.0 \cdot 10^{-9}$	2.21
^{180m}Ta	180.9	$2.00 \cdot 10^{-12}$	$1.200 \cdot 10^{-4}$	$1.200 \cdot 10^{15}$	$1.5 \cdot 10^{-11}$	0.85

¶ ANTARES-SITE-1999-002, J. Brunner.

$$R \propto \int d\lambda \;\, \lambda_{att} \times \Phi(\lambda) \times \mathrm{QE}(\lambda)$$

Φ number of photons due to radioactive decays per unit volume, solid angle, time and wavelength

$$R \propto \int d\lambda \ \lambda_{att} \times \Phi(\lambda) \times \mathrm{QE}(\lambda)$$

Φ should also contain contribution of photons that scattered inside volume δV but were produced outside

Gauss divergence theorem

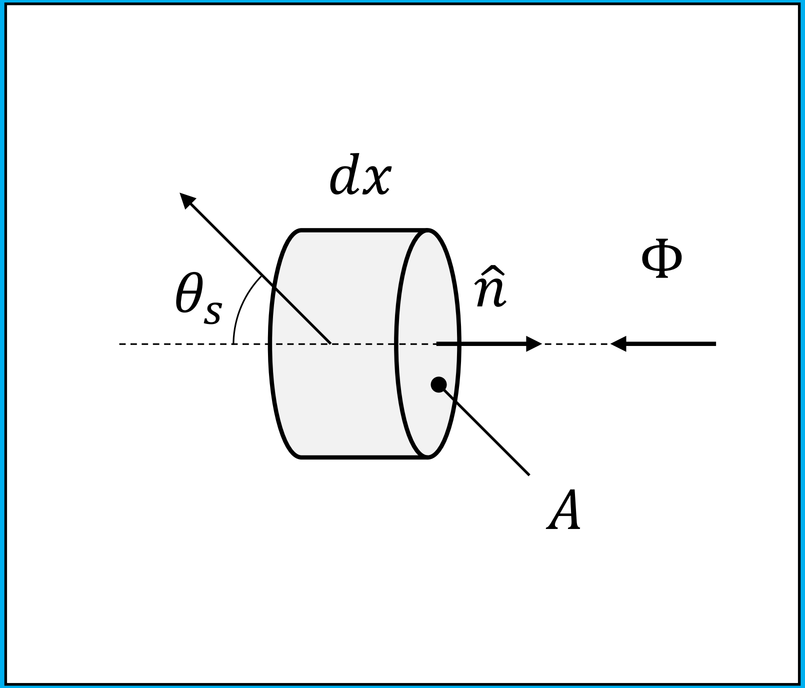
$$N(\delta V) = \int d\cos\theta \, d\phi \, dr \;\; r^2 \, e^{-\frac{r}{\lambda_{att}}} \, \frac{1}{r^2} \int dS \, \Phi \cdot \hat{n}$$

$$= \int dr \;\; e^{-\frac{r}{\lambda_{att}}} \int d\cos\theta \, d\phi \;\; \int dV \, \nabla \cdot \Phi$$

$$= \lambda_{att} \;\; \delta V \;\; \Phi \, \frac{1 - \langle \cos\theta_s \rangle}{\lambda_s}$$

$$\Downarrow$$

$$\frac{dN}{dV} = \lambda_{att} \; \frac{1 - \langle \cos\theta_s \rangle}{\lambda_s} \; \Phi$$



Recursively!

$$\Phi' = \Phi\left(1 + \frac{\lambda_{att}}{\lambda'_s}\left(1 + \frac{\lambda_{att}}{\lambda'_s}\left(1 + \frac{\lambda_{att}}{\lambda'_s}\ldots\right)\right)\right)$$

$$= \Phi\left(1 - \frac{\lambda_{att}}{\lambda'_s}\right)^{-1}$$

$$= \Phi\,\frac{\lambda_{abs}+\lambda'_s}{\lambda'_s}$$

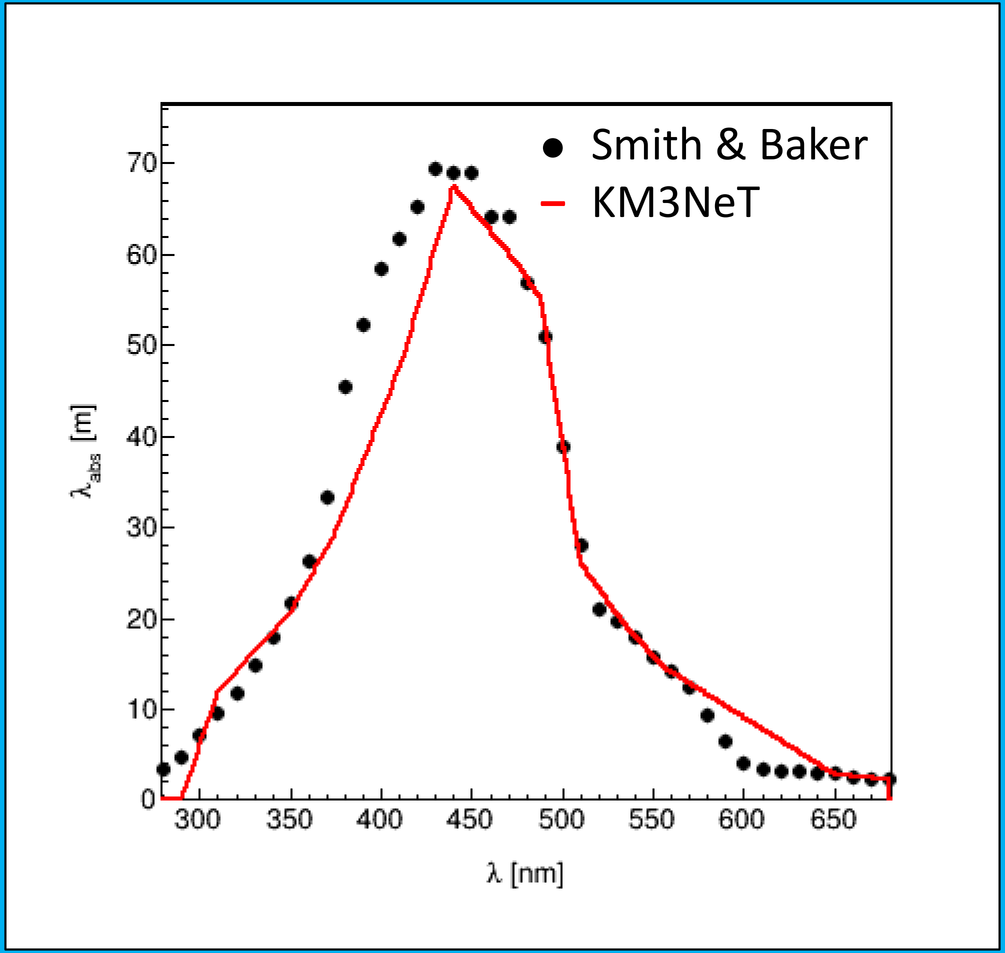
$$\lambda'_s \equiv \frac{\lambda_s}{1 - \langle\cos\theta_s\rangle}$$

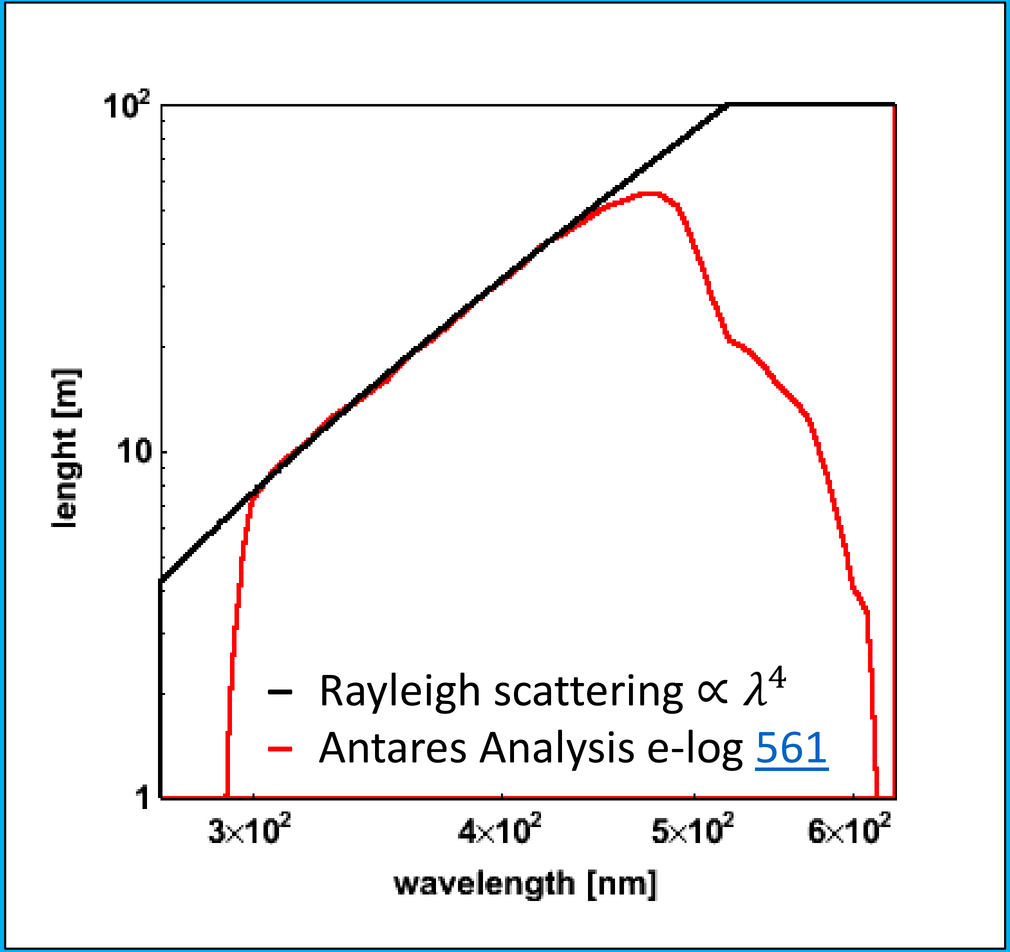
$$R \propto \int d\lambda \; \lambda_{att} \frac{\lambda_{abs} + \lambda_s'}{\lambda_s'} \Phi \, \mathrm{QE}$$

$$= \int d\lambda \; \lambda_{abs} \, \Phi \, \mathrm{QE}$$

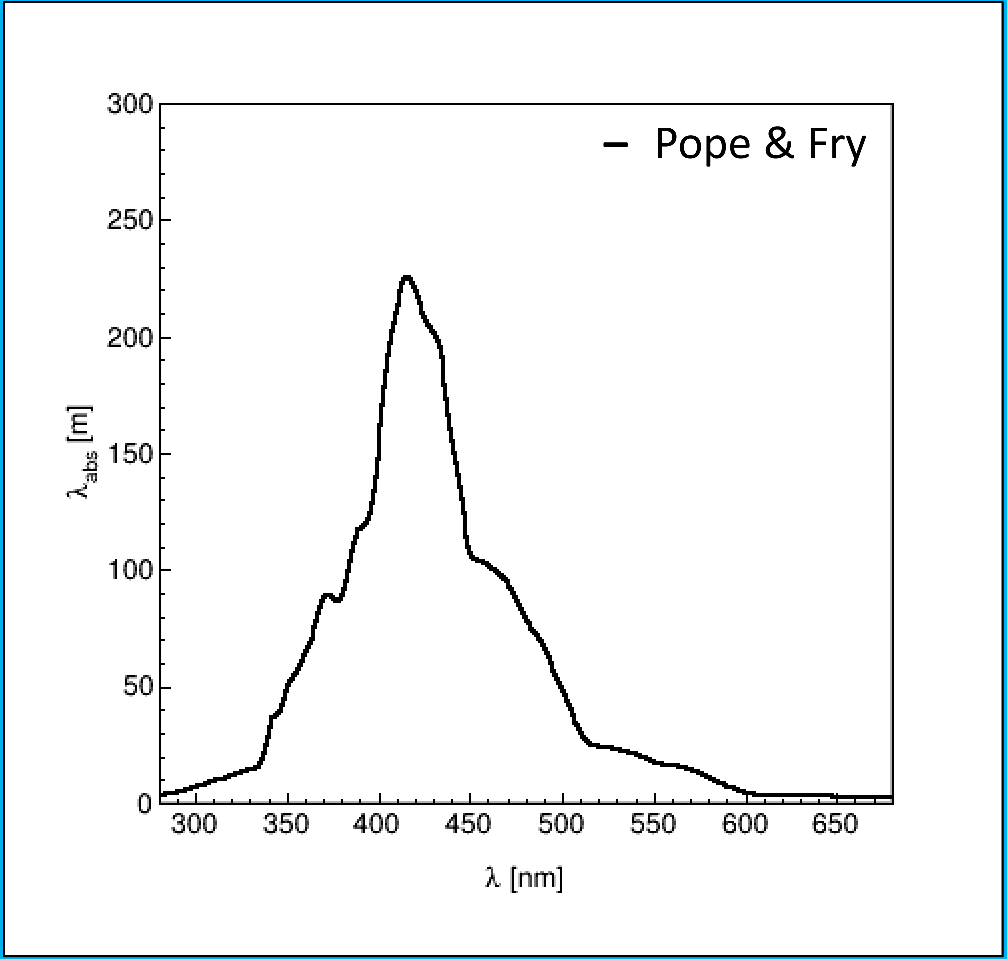
Rate is proportional to absorption length

Measurement of deep-sea water





Measurement of pure water



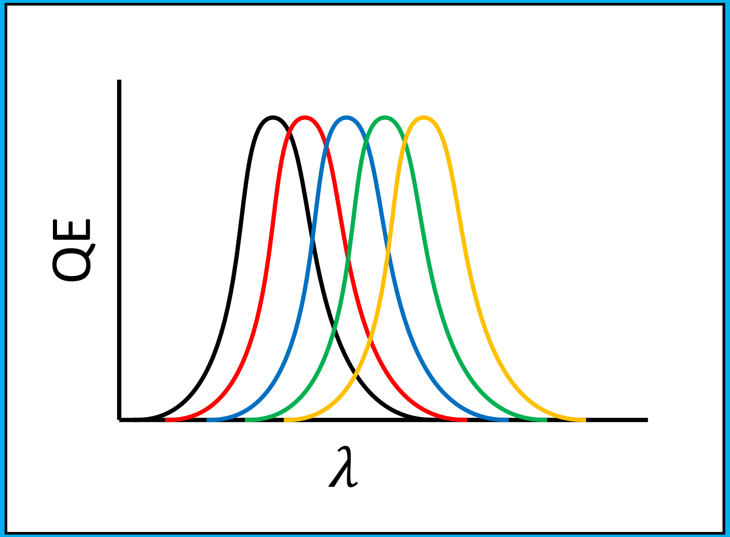
Pope & Fry:

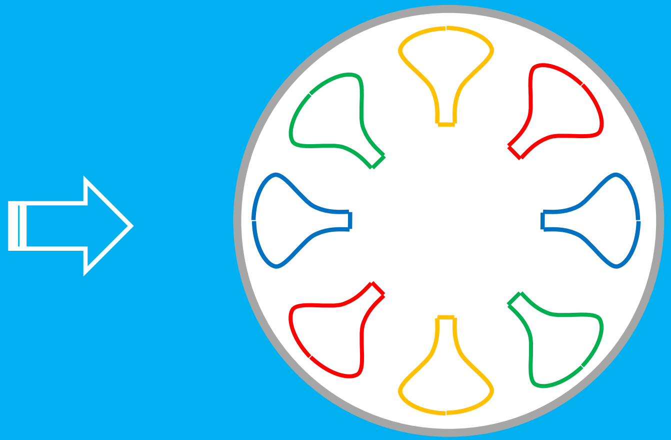
"In the case of the Smith and Baker data, there is significant disagreement below 490 nm. This disagreement is most likely due to a combination of
(1) our more effective water purification and maintenance,
(2) the absence of scattering effects in the ICAM, and
(3) the greater sensitivity of the ICAM."

Idea

- Singles rate = proportional to absorption length
  - “coloured modules” = measure singles rates using PTMs with tailored QE(λ)

  ⇒ measure absorption length as function of wavelength

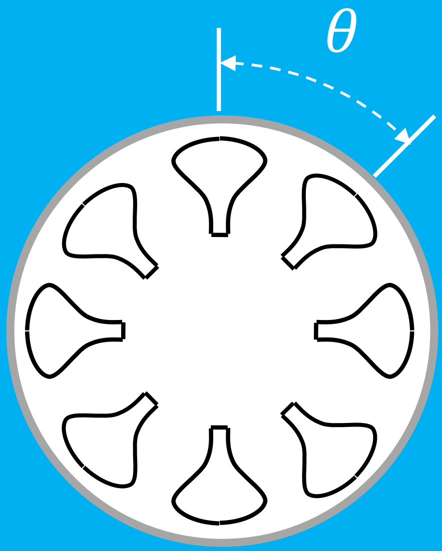


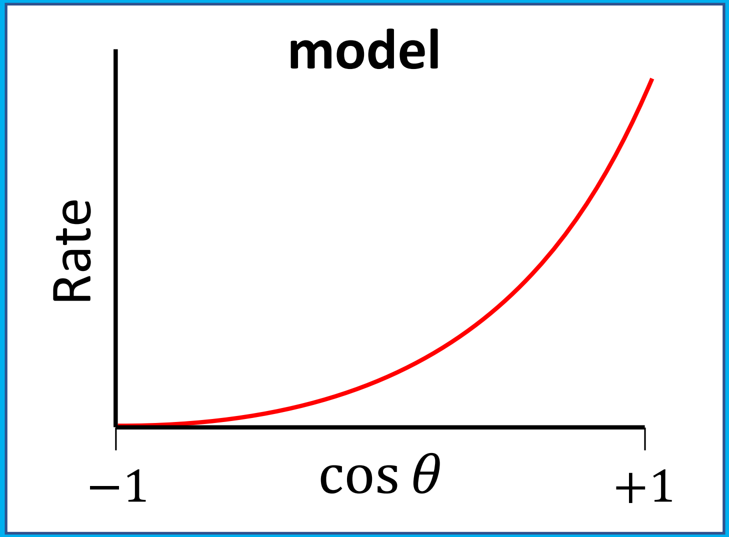


Can we calibrate detector with K40?

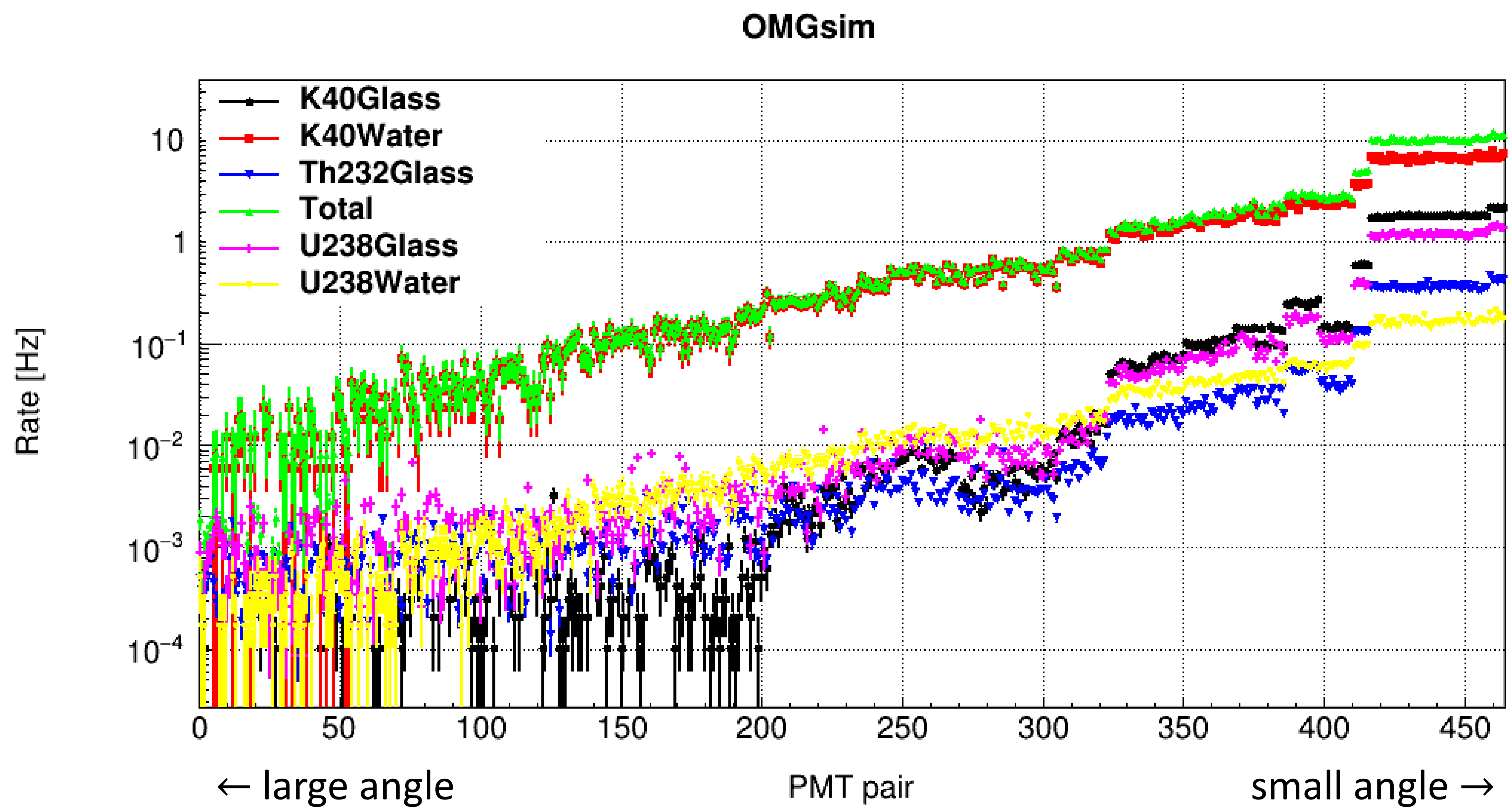
Coincidence rates

- GEANT → OMGsim → model → calibration





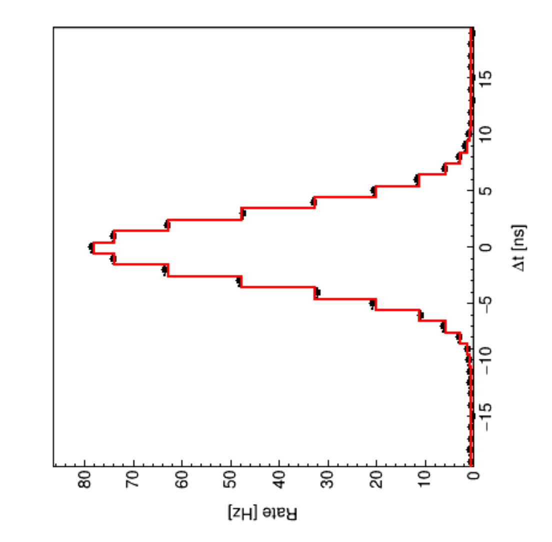
$\binom{31}{2}$ = 465 pairs

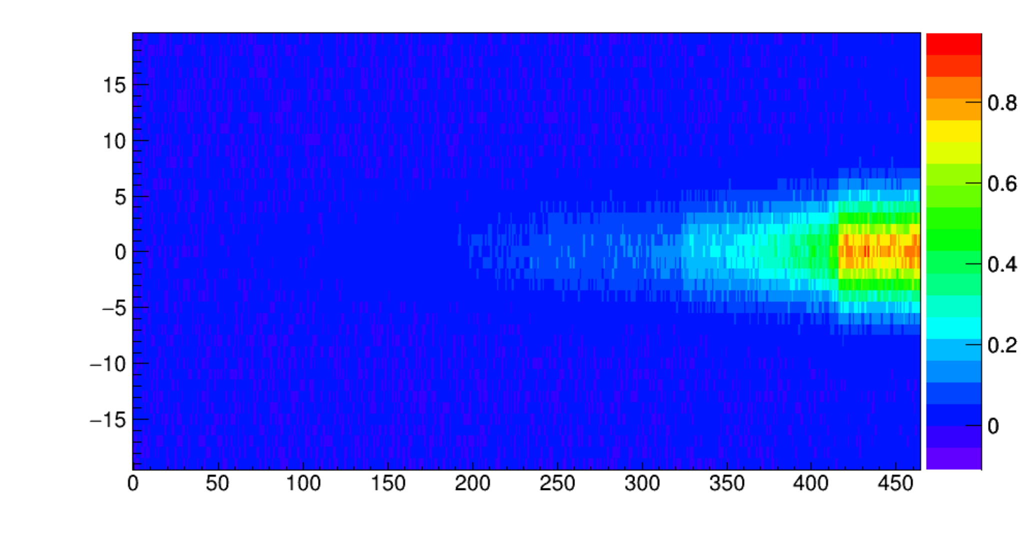

OMGsim
K40Glass
K40Water
Th232Glass
Total
U238Glass
U238Water
Rate [Hz]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
350
400
450
PMT pair
← large angle
small angle →

Model fit to data (simulation)

PMT

1. t_0
2. (relative) QE
3. TTS (σ)



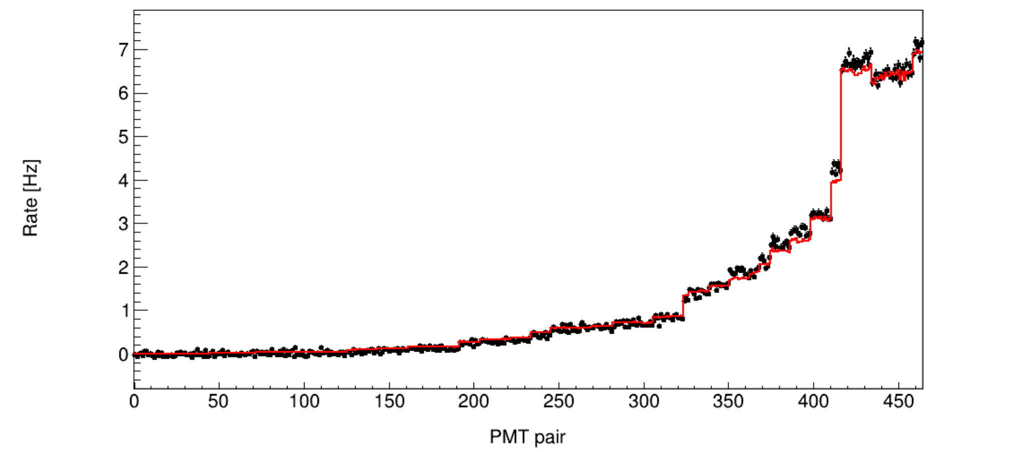


Fit

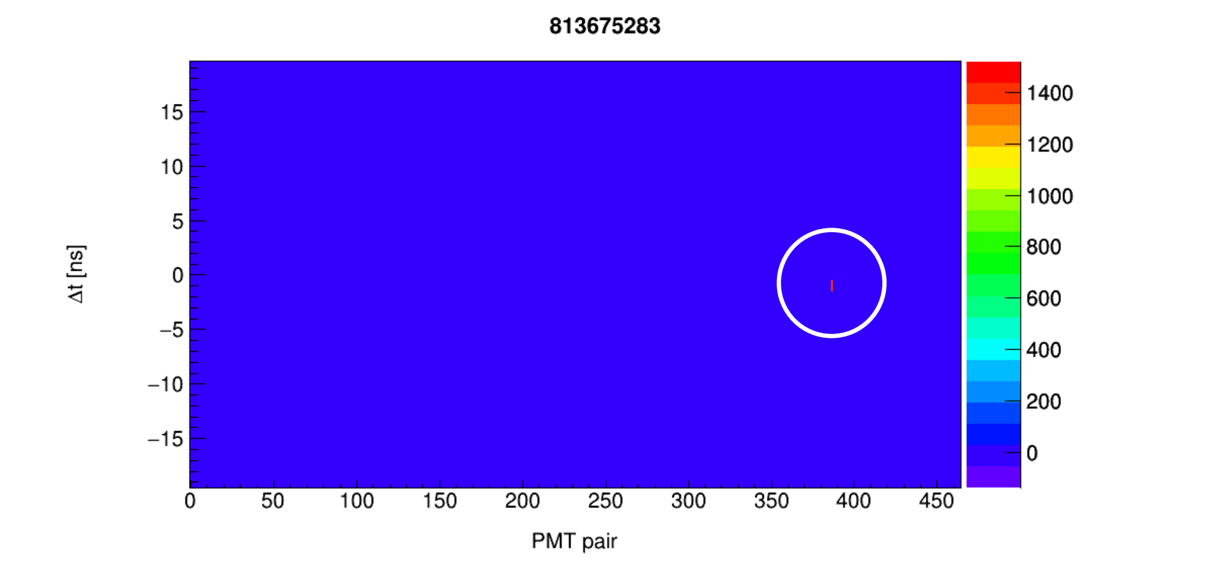
$3 \times 31 = 93$ parameters

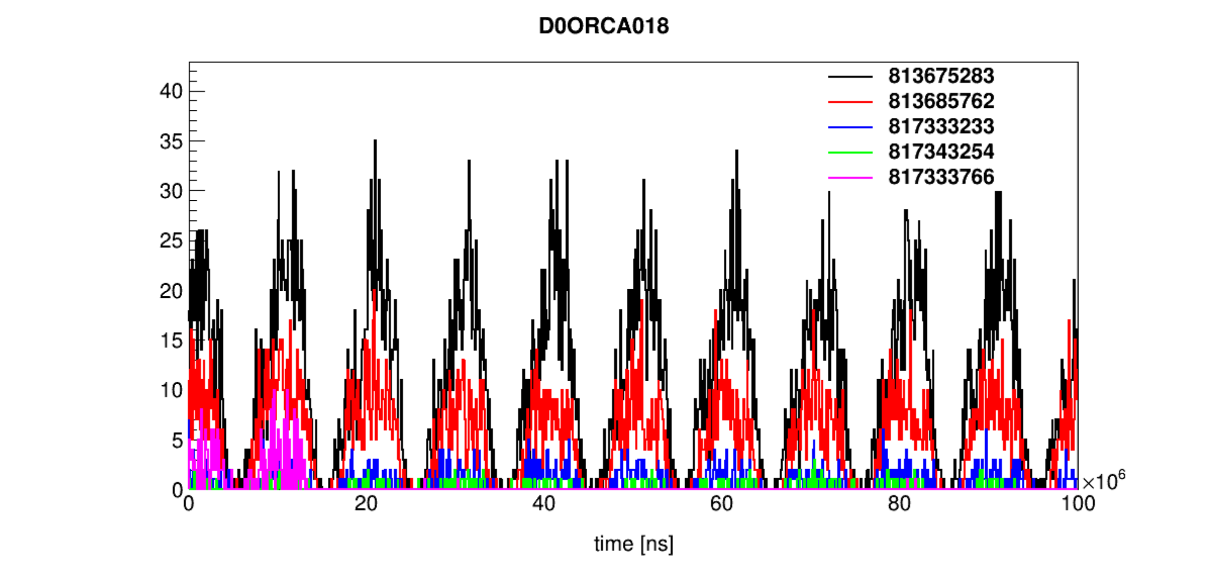
$465 \times 40 = 18{,}600$ data points

Elapsed time ~0.5 seconds / module



Real live… (1/)

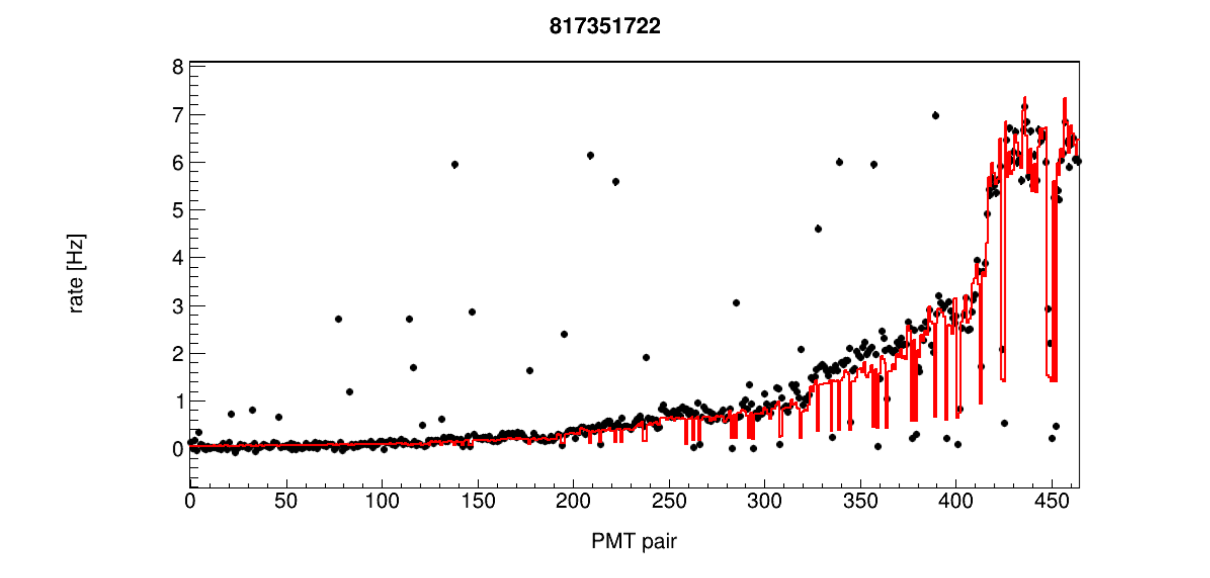


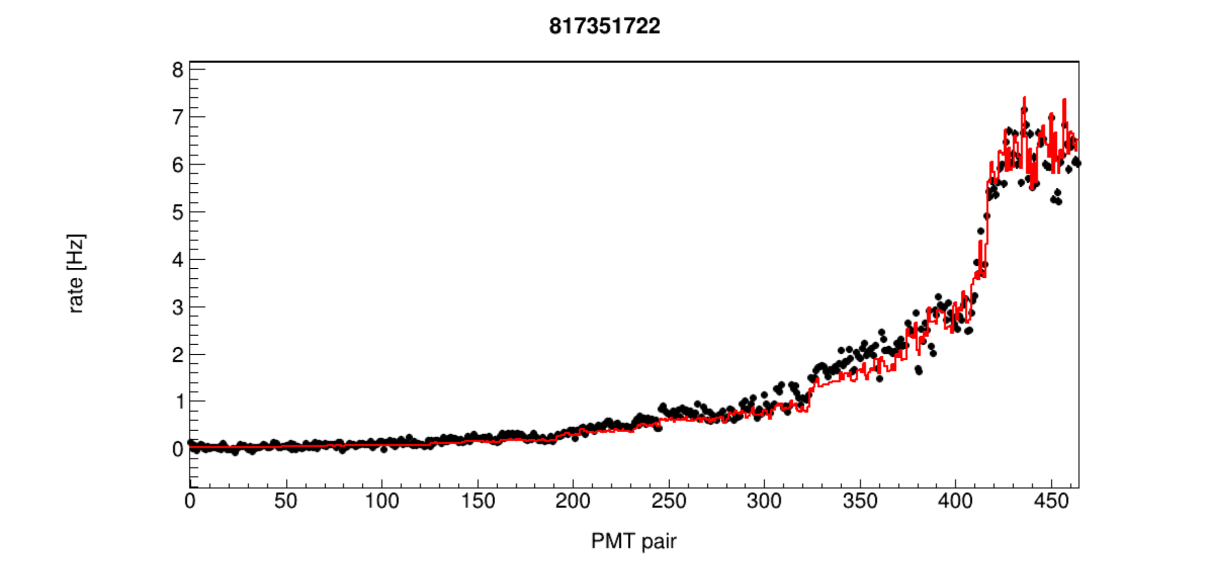


Fake coincidences by pairs of hits with time-over-threshold of $4\ ns$ and $\Delta t = 0\ ns$

Solution: Two-fold time-over-threshold cut any hit $\geq 4\ ns$ and (at least) one hit $\geq 7\ ns$

Real live… (2/)

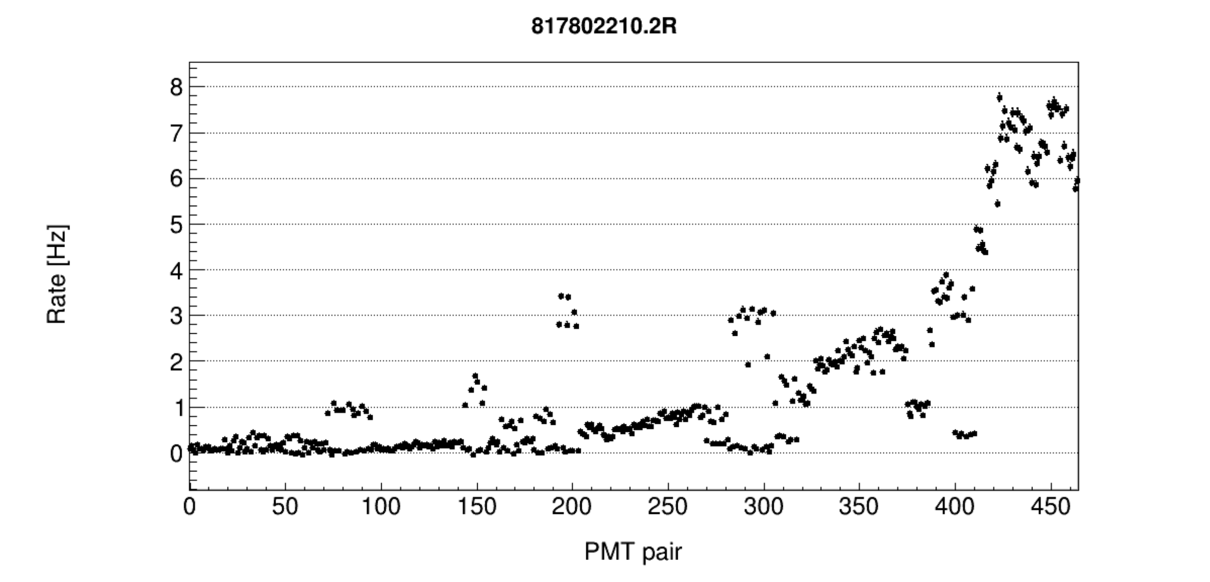


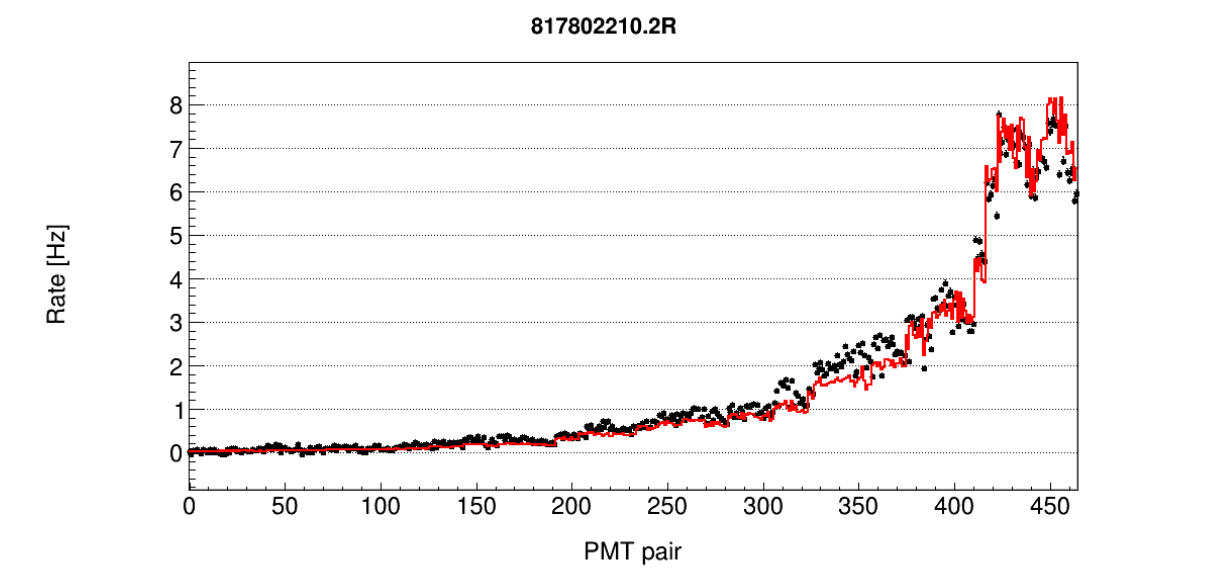


<u>Solution</u>:

```
JEditDetector \
    -a  detector.datx              \
    -M  "817351722 swap 15 17"     \
    -o  detector.datx
```

Real live... (3/)

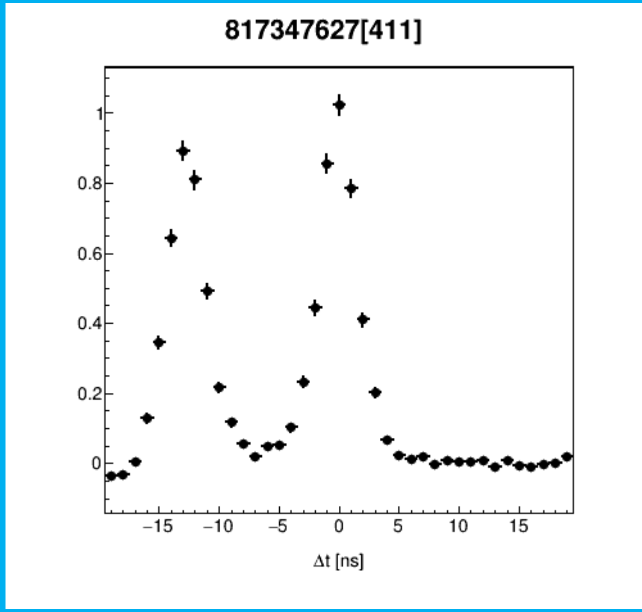


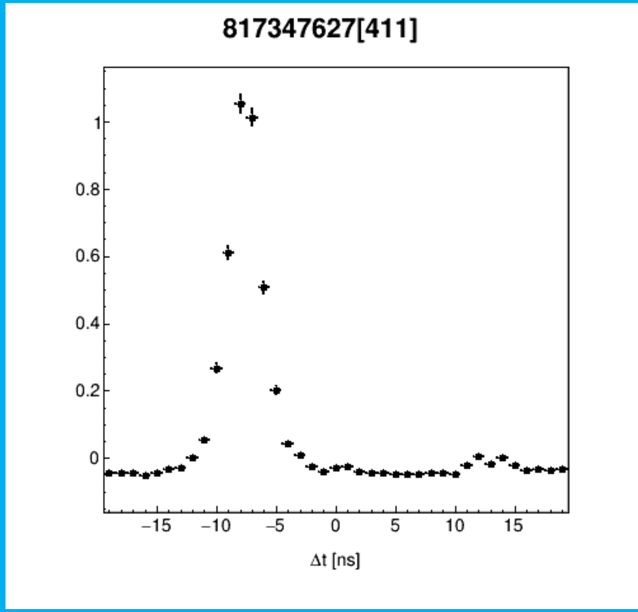


Solution:

```
JEditDetector \
    -a  detector.datx                                  \
    -M  "817802210 lower $((-60.0 * $PI / 180.0 ))"    \
    -o  detector.datx
```

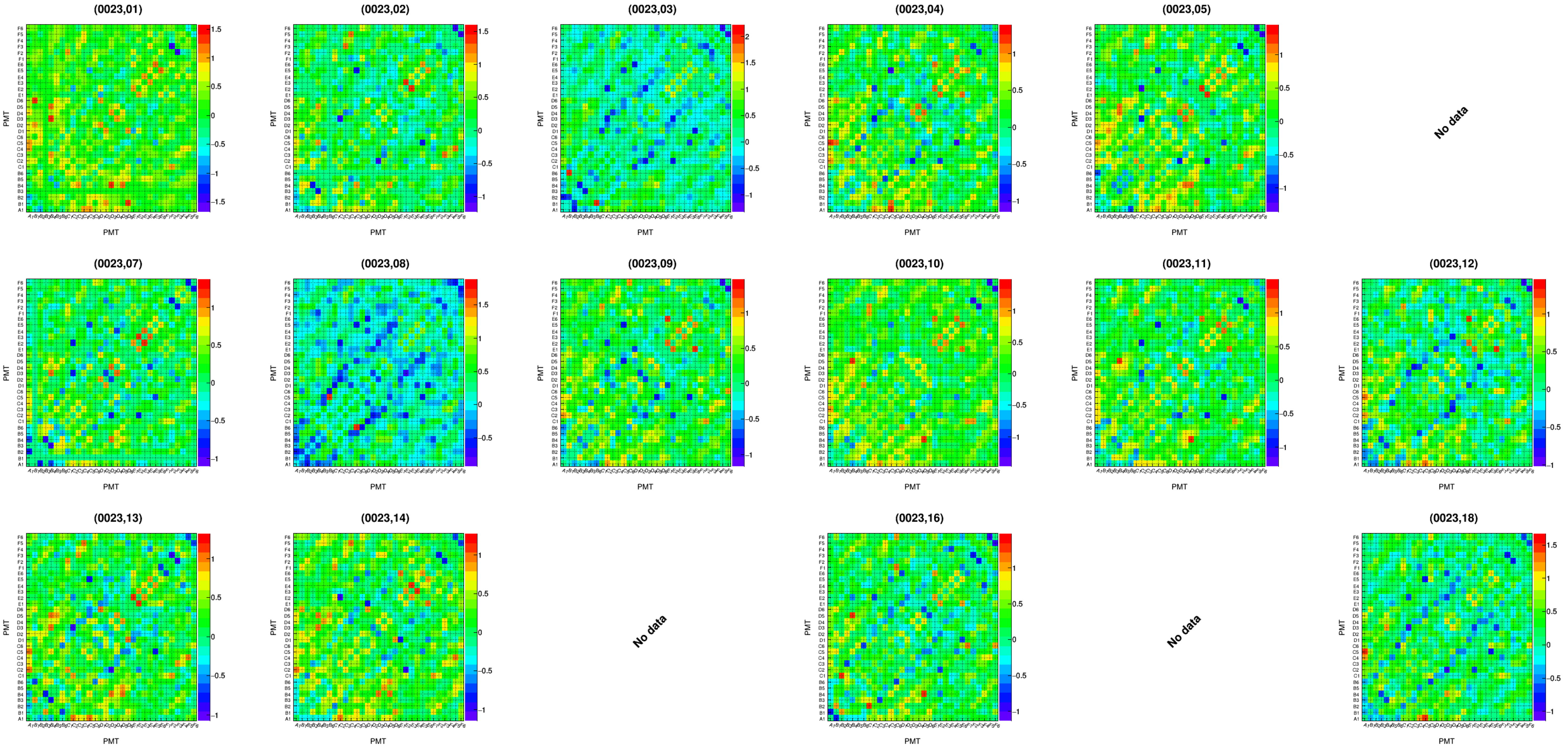
Real live… (4/)





Solution:

- filter // remove pending hits
- join // as filter but add time-over-thresholds
- remove // as filter but also remove first hit


(0023,01)
(0023,02)
(0023,03)
(0023,04)
(0023,05)
No data
(0023,07)
(0023,08)
(0023,09)
(0023,10)
(0023,11)
(0023,12)
(0023,13)
(0023,14)
No data
(0023,16)
No data
(0023,18)
PMT
PMT

Summary & outlook (1/2)

- K40 data can be used to measure optical properties of deep sea water
  - disentangle absorption and scattering of light (at last)
- K40 data can be used for calibration of PMTs inside optical module
  - time offset, QE and TTS (input to simulations but what about reconstruction?)
- K40 data can be used to debug hardware
  - PMT cable swaps, fake coincidences and rotation of glass hemisphere

Summary & outlook (2/2)

- K40 data can be used to check GEANT
  - default step size of electron too large for Cherenkov light generation
    ⇒ overestimation of coincidence rate
- K40 data can be used to measure gain and gain spread of each PMT (and tune HV)
  - read Bouke’s thesis;)

PDFs revisited (from last outing)