L1 time difference calibration

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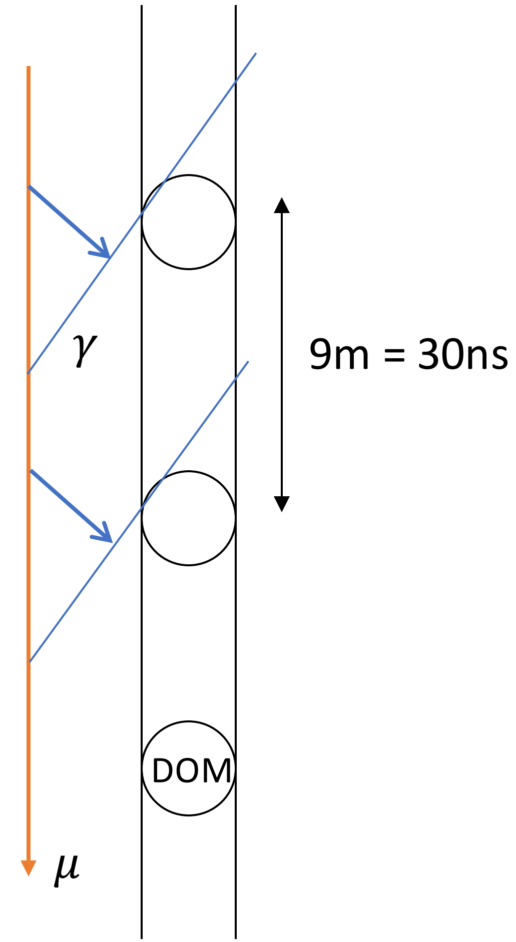
Outlook

- L1 hit time difference
  - Method
- Inter-DOM distance
  - Method
  - Results
- Time calibration
  - Method
  - Results

Method

- Cherenkov cone induces L1 hits
- Light arrival time measured
- Look at L1 coincidences in neighbouring DOMs in time window
- Arrival time difference per DOM pair
- Time depends on incoming angle
- Trigger level, no assumptions from reconstruction



Hit selection

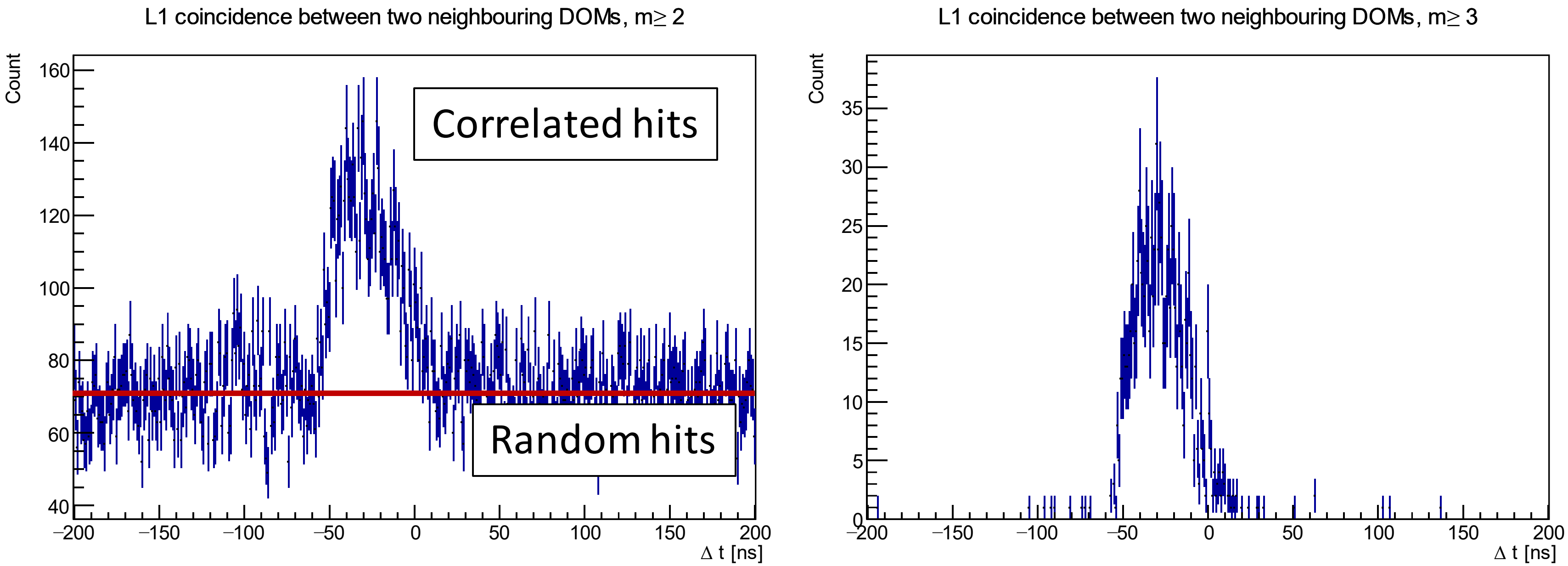
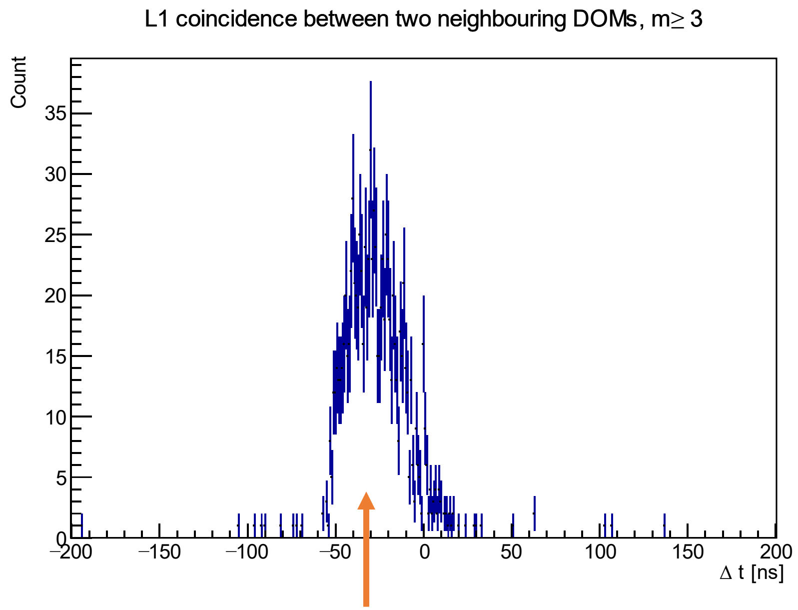


Figure: Arrival time difference of L1 hits between two DOMs in ORCA4 DU3.
Left: multiplicity 2, right multiplicity 3

- Using multiplicity 3 suppresses a lot of background:

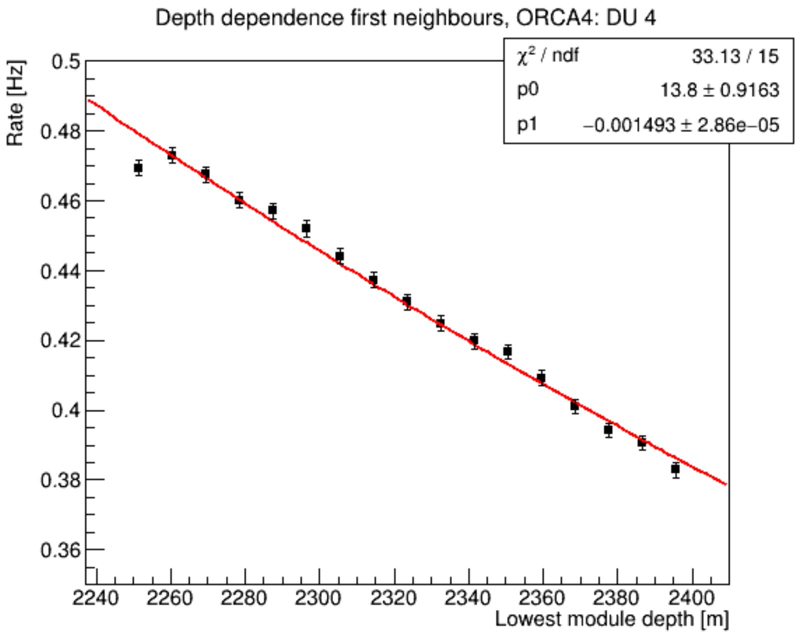
$$P(m = 3 \text{ on DOM i} | \, m = 3 \text{ on DOM i} + 1)$$

Depth dependence: L1 time difference



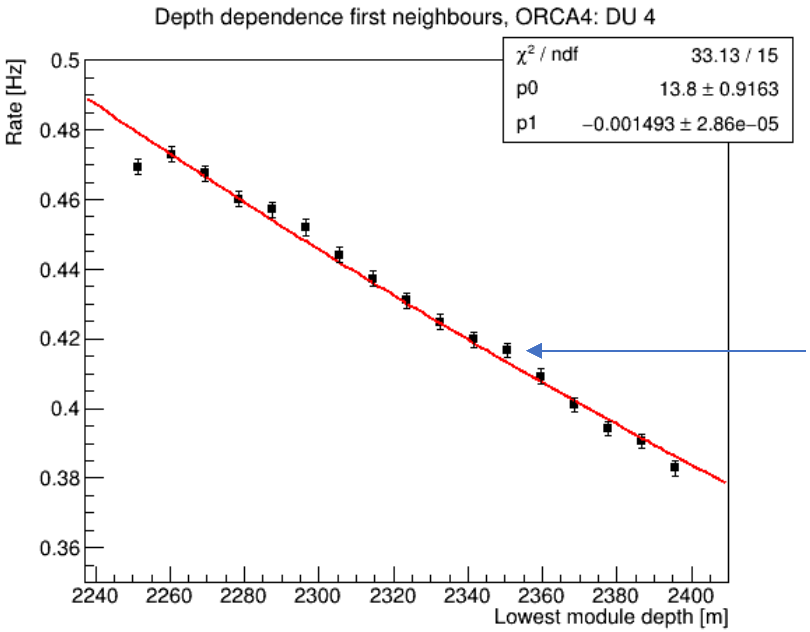
Area = correlated hit count.
Hits that are on both DOM i and DOM j

$$rate = \frac{count_{i,j}}{runtime}$$



Rates for one DU:
Depth dependence of correlated rate between neighboring DOMs

Inter-DOM distance calibration



d(model, data) is a measure for the inter-DOM distance

$$d = \frac{-1}{\lambda} \log\left(\frac{R}{A}\right)$$

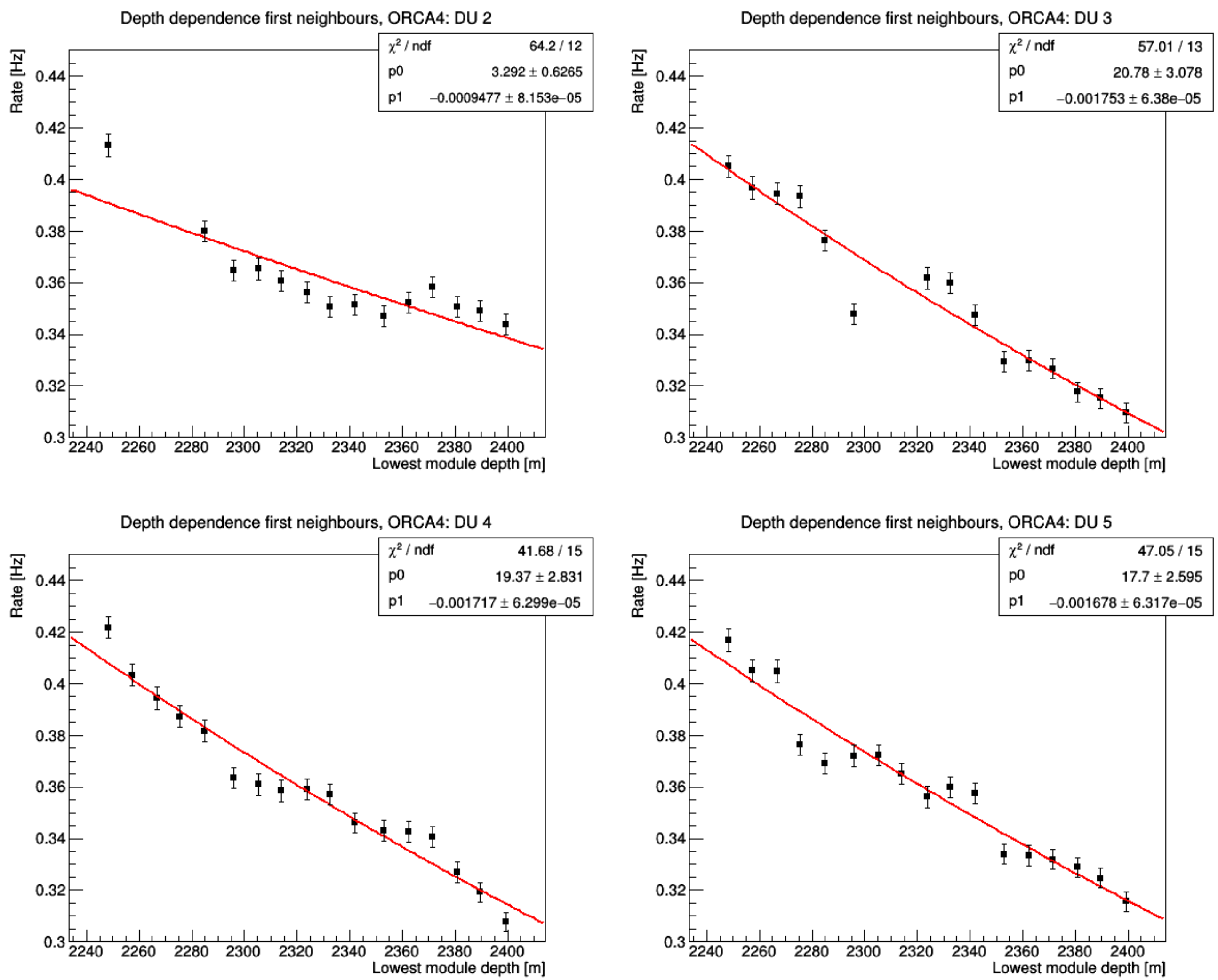
Model the rate as function of depth:

$$R = Ae^{-\lambda d}$$

Inter-DOM distance

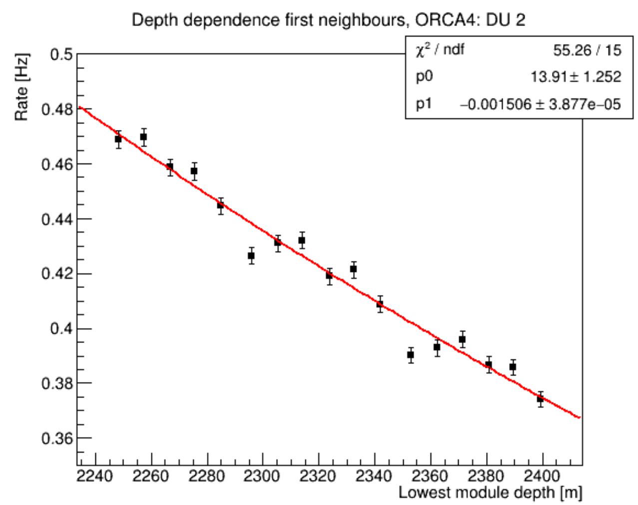
Depth dependence of L1 correlations

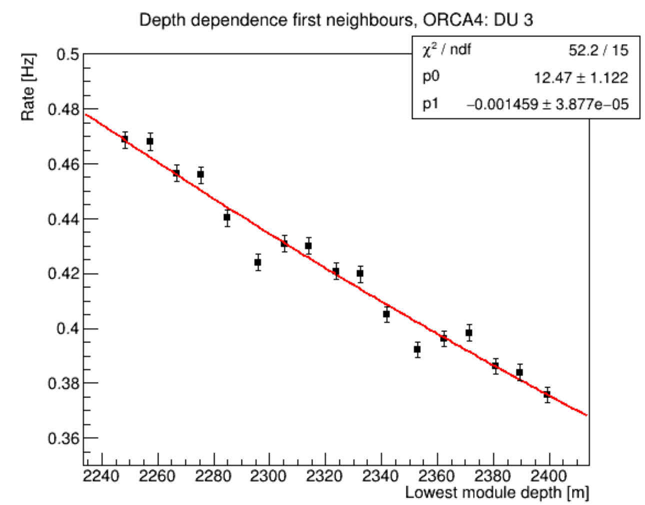
Runs 5900-5930
(4 days, downscale=20)
Multiplicity 3
Applied corrections:
Dead PMT channels,
High rate veto,
(Effective) PMT efficiency

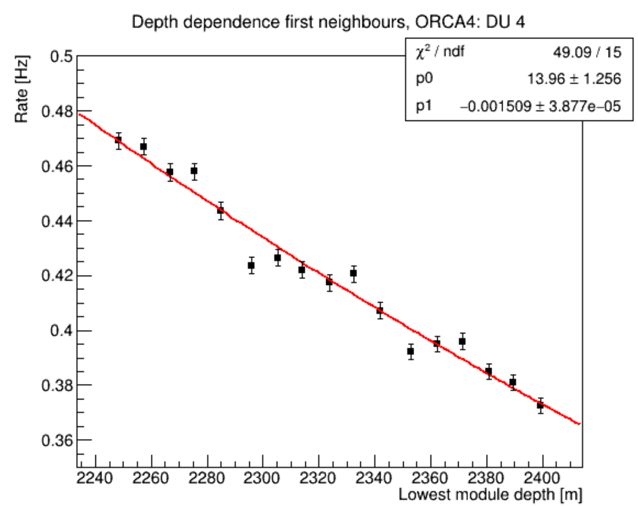


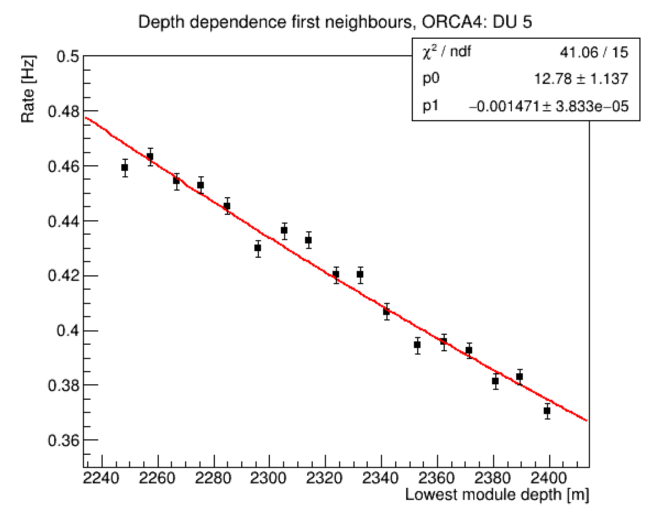
Depth dependence: nominal PMTs

Detector geometry: from DB
Multiplicity 3
Nominal PMTs:
Light scale = 2
Q = 0.5
25M muons (16 hrs)



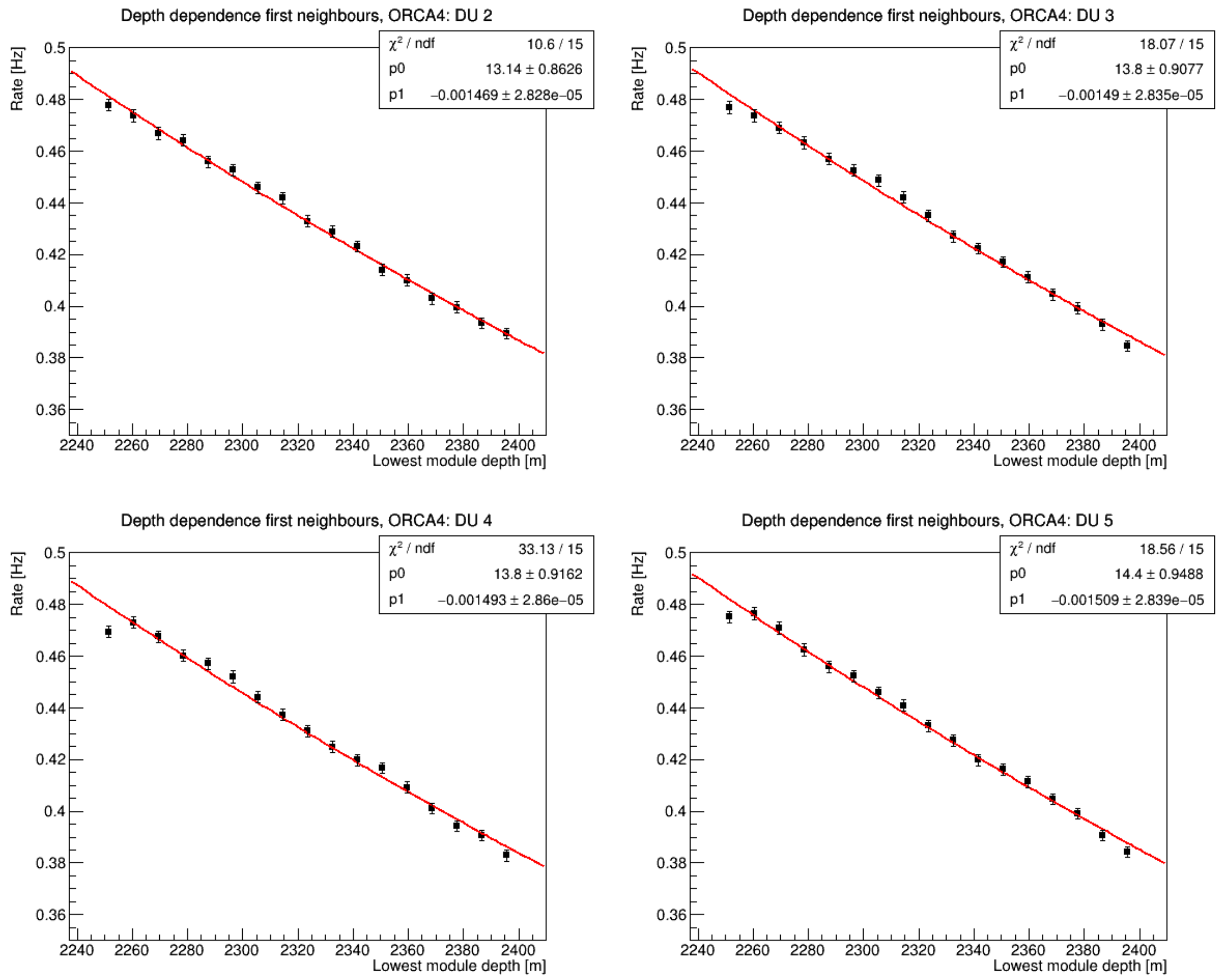






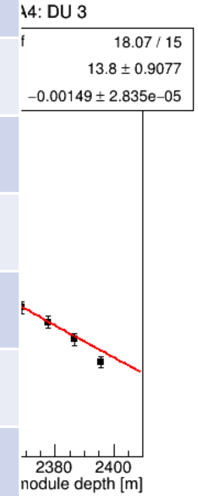
Depth dependence: perfect detector:

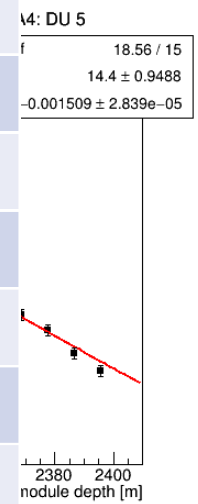
JDetector:
5 lines, 9x20m spacing
Multiplicity 3
Nominal PMTs:
Light scale = 2
Q = 0.5
50M muon (32 hrs)



Calculated Depth (DU4) [m]	Difference [m]	Depth [m]	Difference [m]	Simple error [m]	Propagated error [m]
2401.56		2400.04		3.56	62.95
2390.9	10.65	2391.04	9	3.53	62.80
2376.71	14.19	2382.04	9	3.49	62.61
2367.21	9.49	2373.04	9	3.47	62.48
2356.46	10.74	2364.04	9	3.44	62.33
2348.81	7.65	2355.04	9	3.42	62.23
2343.13	5.68	2346.04	9	3.40	62.15
2331.13	11.99	2337.04	9	3.37	61.99
2322.43	8.7005	2328.04	9	3.35	61.87
2310.57	11.859	2319.04	9	3.32	61.72
2302.96	7.61055	2310.04	9	3.30	61.61
2293.7	9.26429	2301.04	9	3.28	61.49
2288.46	5.23863	2292.04	9	3.27	61.42
2278.96	9.50059	2283.04	9	3.24	61.29
2266.93	12.0309	2274.04	9	3.21	61.13
2259.19	7.73423	2265.04	9	3.20	61.03

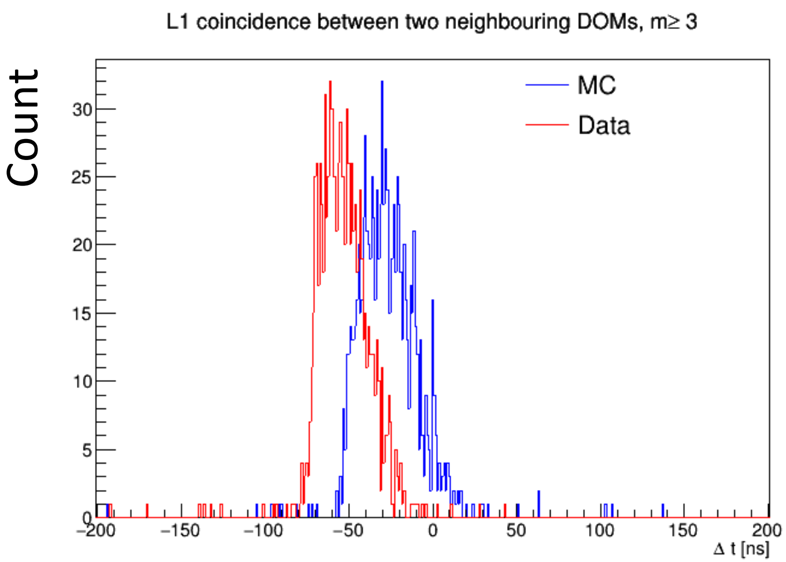
JDetect
5 lines,
Multipl
Nomina
Light sc
Q = 0.5
25M mu





Time calibration

Time calibration: 1 DOM

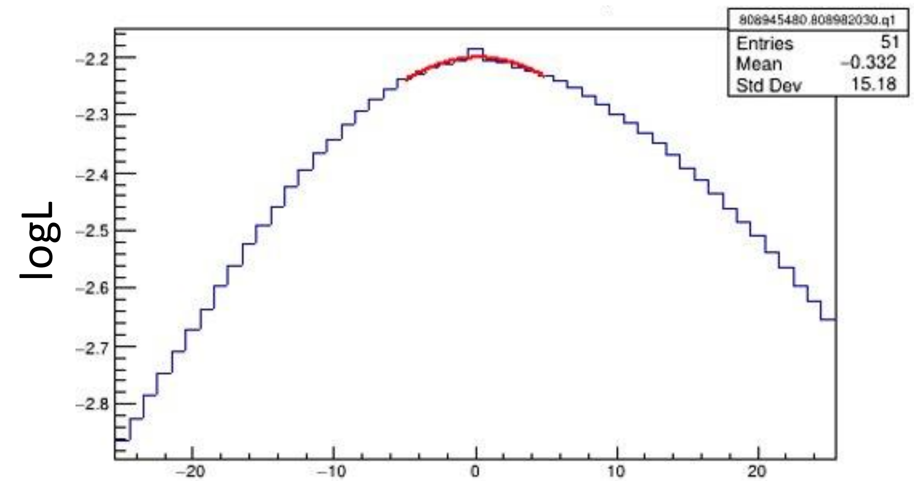


Shift the time-offset j of the data for one DOM-DOM pair to optimize a likelihood:

$$L_{ij} = \prod_{N_{bins}} P(N_k^{data}|N_k^{MC}) = \prod_{N_{bins}} \frac{m_k^{d_k} e^{-m_k}}{d_k!}$$

$$\text{Time offset } l\text{: } L_{ij}^l = \prod_{N_{bins}} P(N_{k+l}^{data}|N_k^{MC})$$

Likelihood time-offset between DOMs



Fit polynomial to the log-likelihood to find the optimal t0: LL works on bin-by-bin basis, it has 1 ns accuracy

$$\log(L) \approx A_{i,j}(t_{0i,j} - B_{i,j})^2 + C_{i,j}$$

Time calibration: more DOMs

- Optimizing the time-offset for a set of DOMs i,j simultaneously:

$$Q_{i,j} = \prod_{i \neq j} L_{ij} \rightarrow \log Q_{i,j} = \sum_{i \neq k} \log L_{i,j}$$

$$\frac{\partial}{\partial t_k^0} \left(\sum_{i \neq j} \log L_{ij}(t_i^0 - t_j^0) \right) = 0$$

- Depending on selection criteria (first neighbor, one DU, entire detector) solve a linear equation of the shape:

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \end{bmatrix} = 4 \cdot \begin{bmatrix} \sum_{i \neq 0} [A_{0,i}] & -A_{0,1} & -A_{0,2} & \cdots \\ -A_{1,0} & \sum_{i \neq 1} [A_{1,i}] & -A_{1,2} & \cdots \\ -A_{2,0} & -A_{2,1} & \sum_{i \neq 2} [A_{2,i}] & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \cdot \begin{bmatrix} t0_0 \\ t0_1 \\ t0_2 \\ \vdots \end{bmatrix} - 4 \cdot \begin{bmatrix} \sum_{i \neq 0} [A_{0,i} \cdot B_{0,i}] \\ \sum_{i \neq 1} [A_{1,i} \cdot B_{1,i}] \\ \sum_{i \neq 2} [A_{2,i} \cdot B_{2,i}] \\ \vdots \end{bmatrix}$$

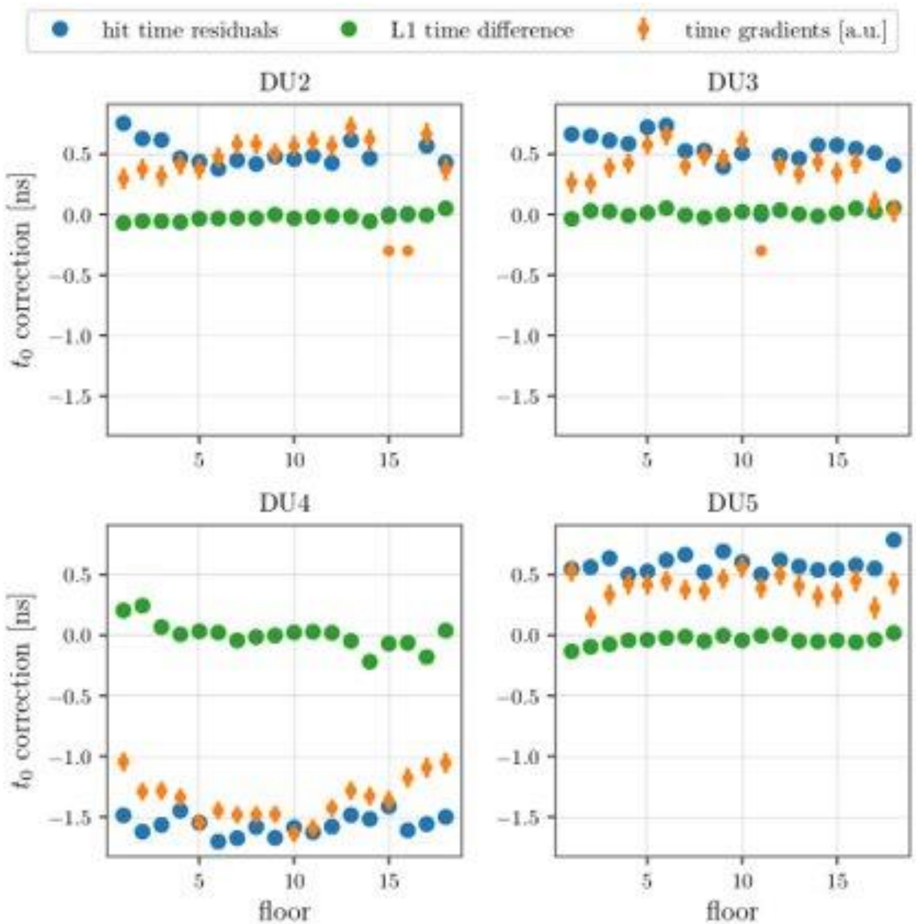
Blind study

- Daniel Guderian uses 2 methods:
  - Hit time residuals
  - Time gradients
- Both time intensive but exhaustive! (time, rotations, distances, etc)

- Lodewijk Nauta uses:
  - L1 hit time difference
- Very fast but only fits time offsets

- Colleague of Daniel created 3 detx files with different adjustments

Hit time calibration vs L1dt calibration: modification a



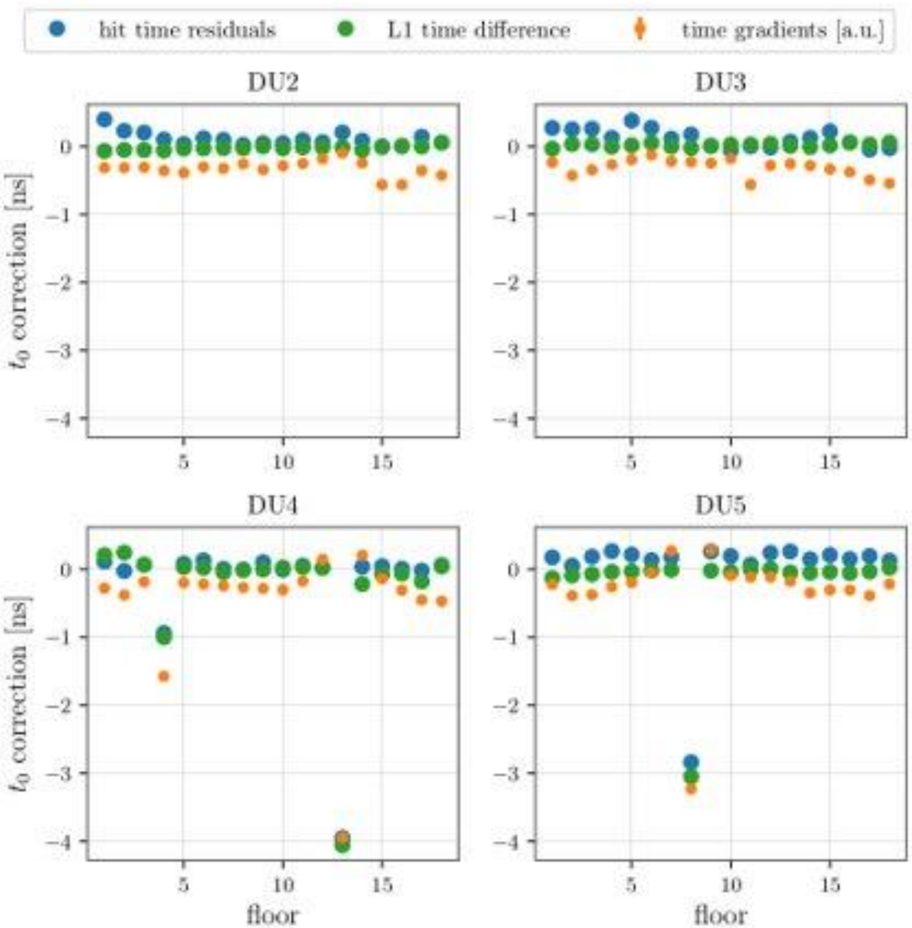
Adjustment:
DU4 had 2ns offset

mod a: -S “4 add 2”

Hit time calibration vs L1dt calibration: modification b

Adjustment:
DU4DOM4 +1ns
DU4DOM13 +4ns
DU5DOM8 +3ns

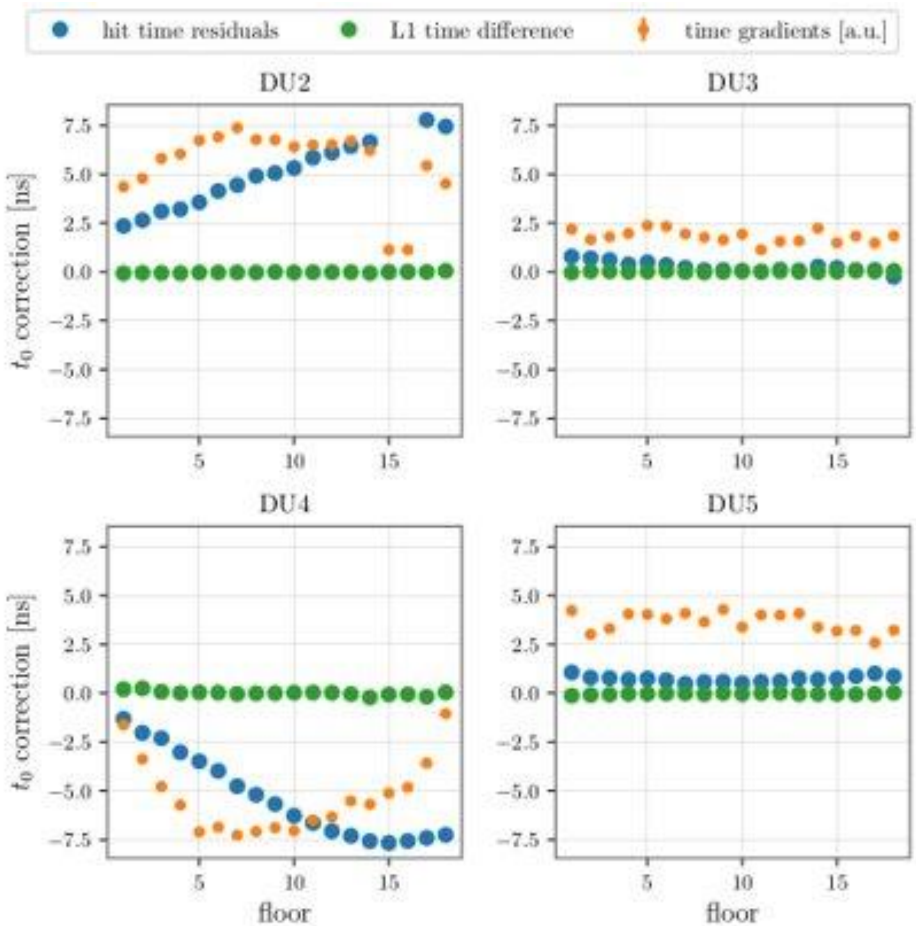
mod b:
-M “808981510 add 1” -M “808972593 add 4” -M “808981864 add 3”



Hit time calibration vs L1dt calibration: modification c

Adjustment:
Shrinking to DU2
Stretching to DU4

mod c:
-S “2 mul -0.02” -S “4 mul 0.02”



Next

- Error on Inter-DOM distance is too large
- Lower the error → more data?

- Does work for outliers
- Time calibration (seems to) contain a degree of freedom
- Remove degree by adding constraints (inter-DU)