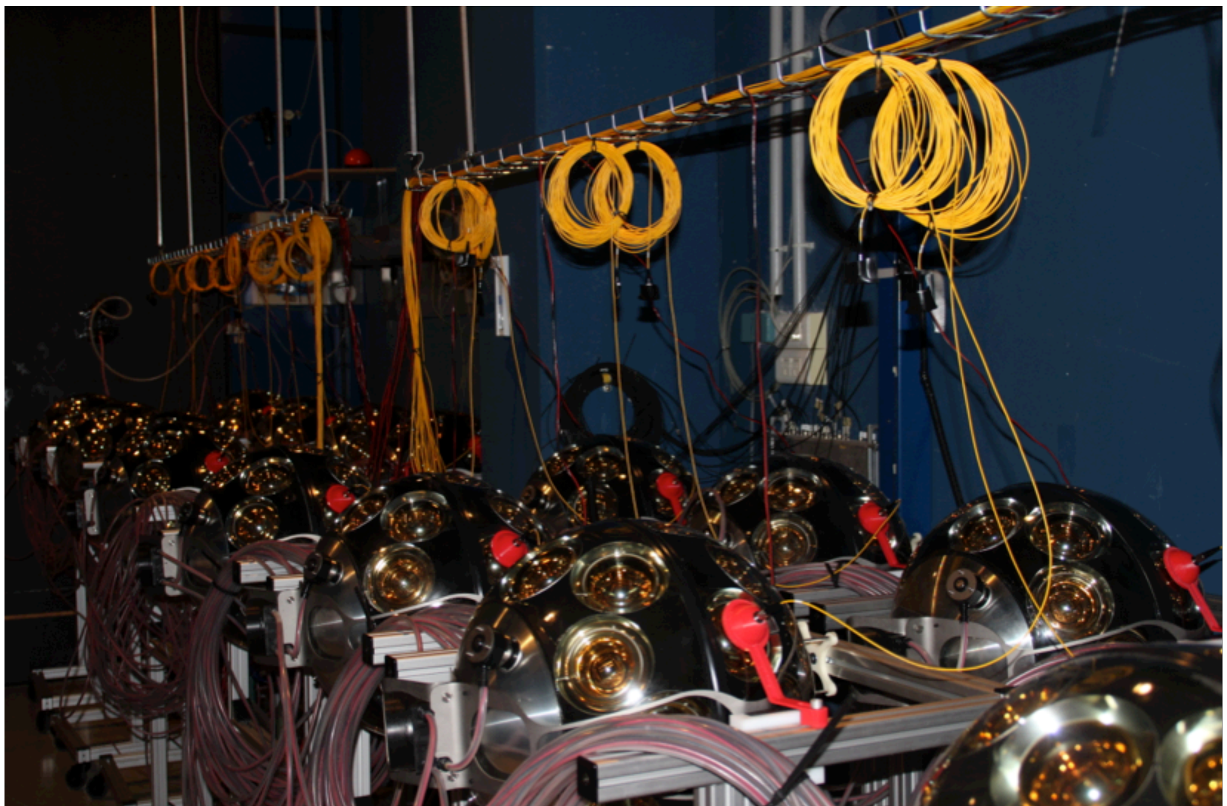
Time calibration of the KM3NeT detector in the laboratory with cosmic ray showers

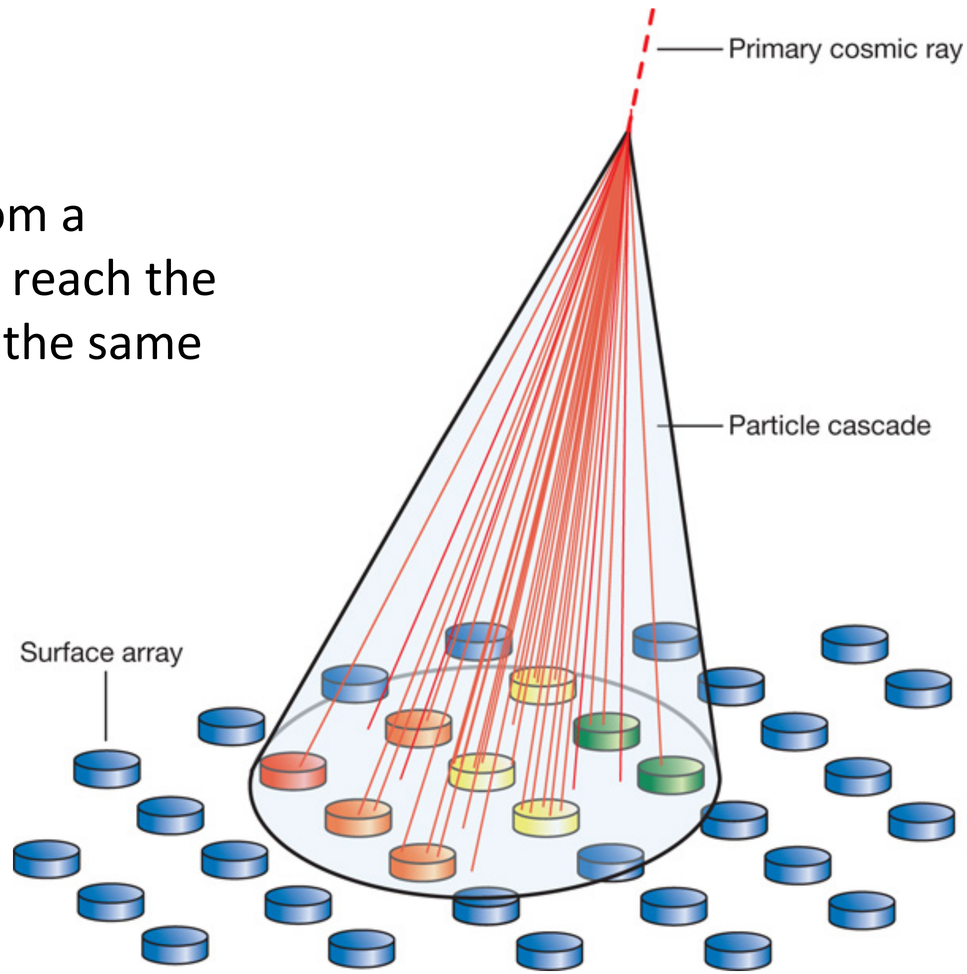
Calibration of DOMs

- Now done by laser in darkroom Marseille



Idea: use cosmic radiation

Different particles from a single cosmic shower reach the detectors at virtually the same time.



Goal

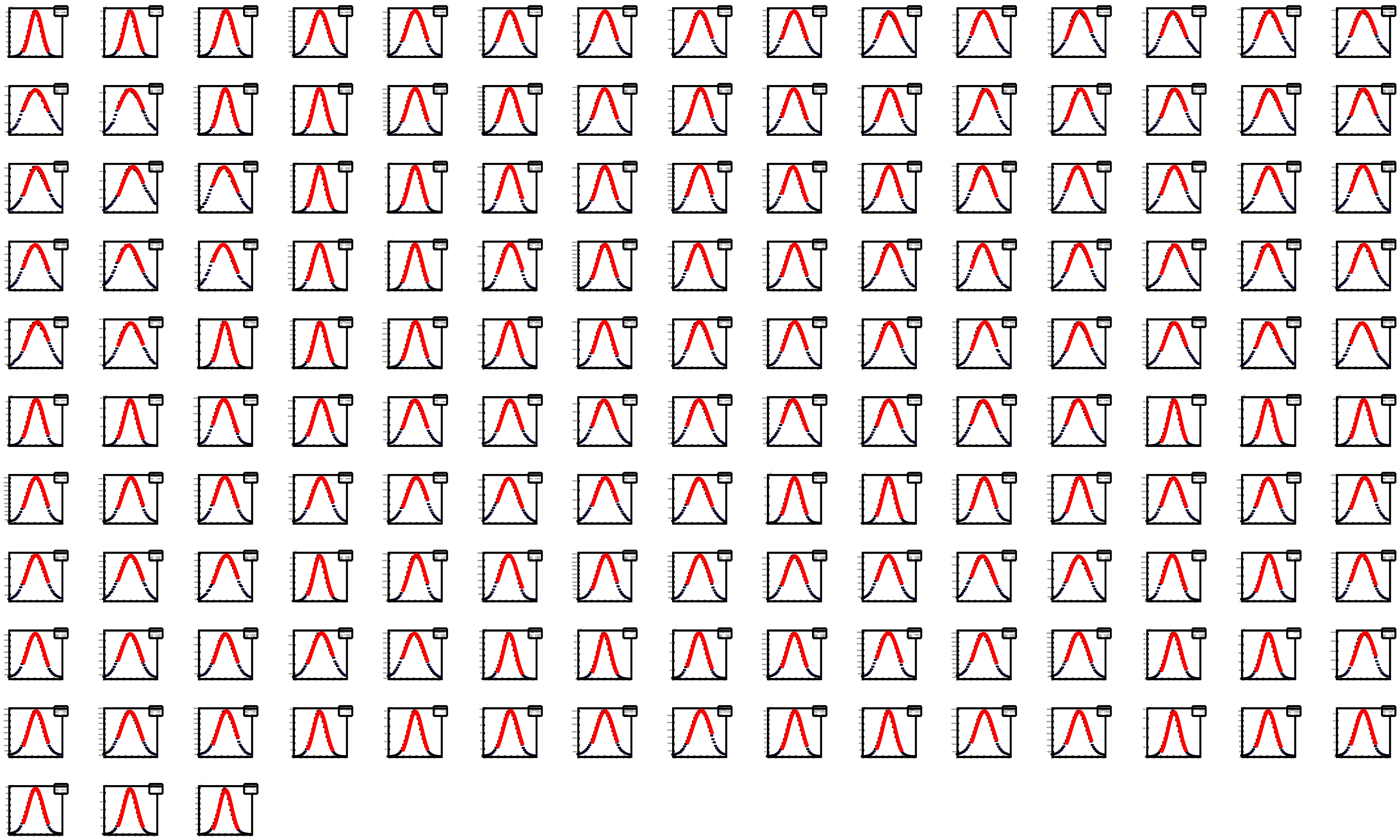
- Reproduce results achieved by laser
- Develop calibration procedure

Data collection

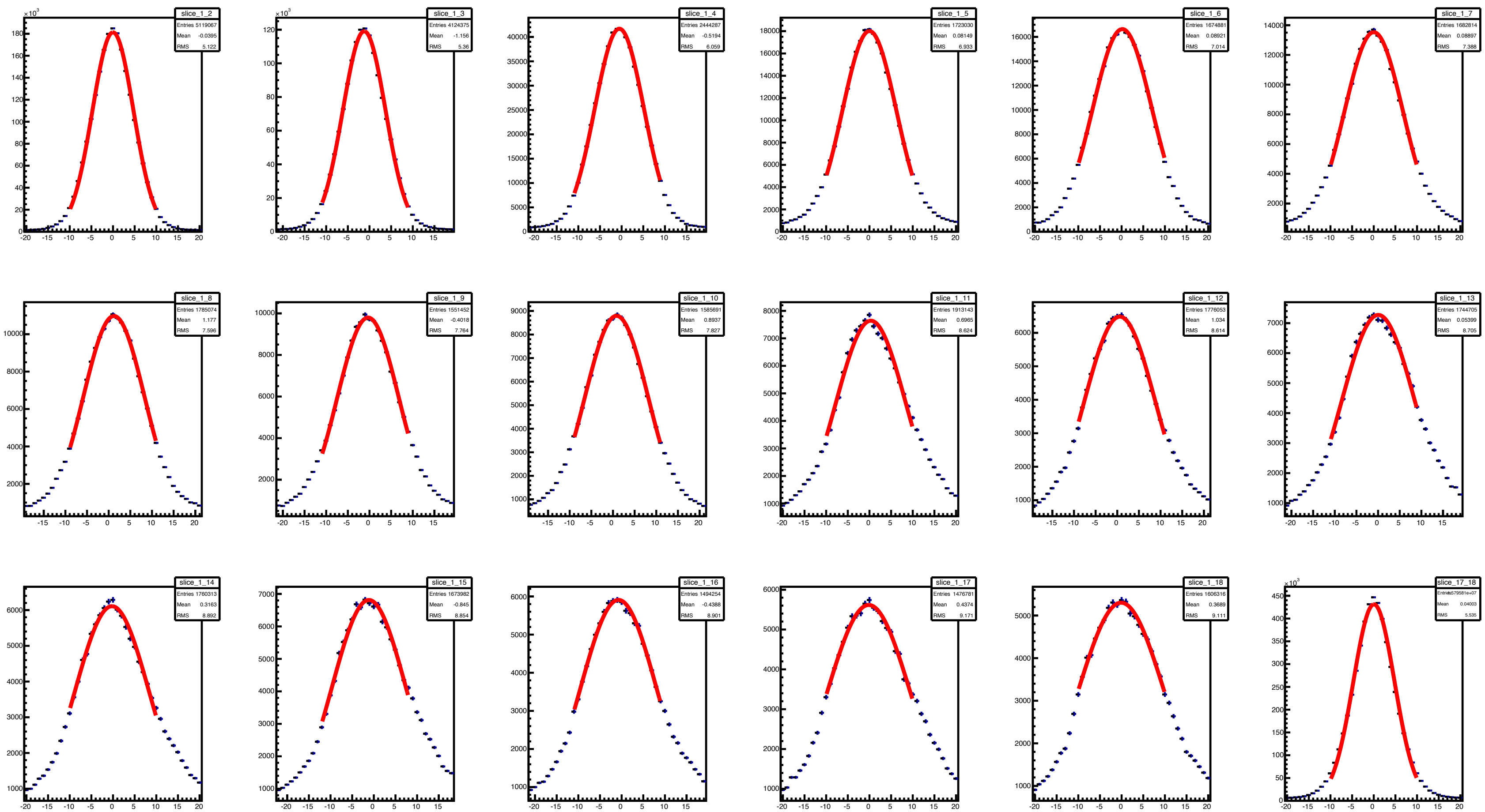
- Time difference between L1-hits of 2 DOMs are collected in a histogram.
- 18 DOMs -> ½ N(N-1) = 153 correlation histograms
- Fit histogram to Normal Distribution:

$$f(x) = \frac{A}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

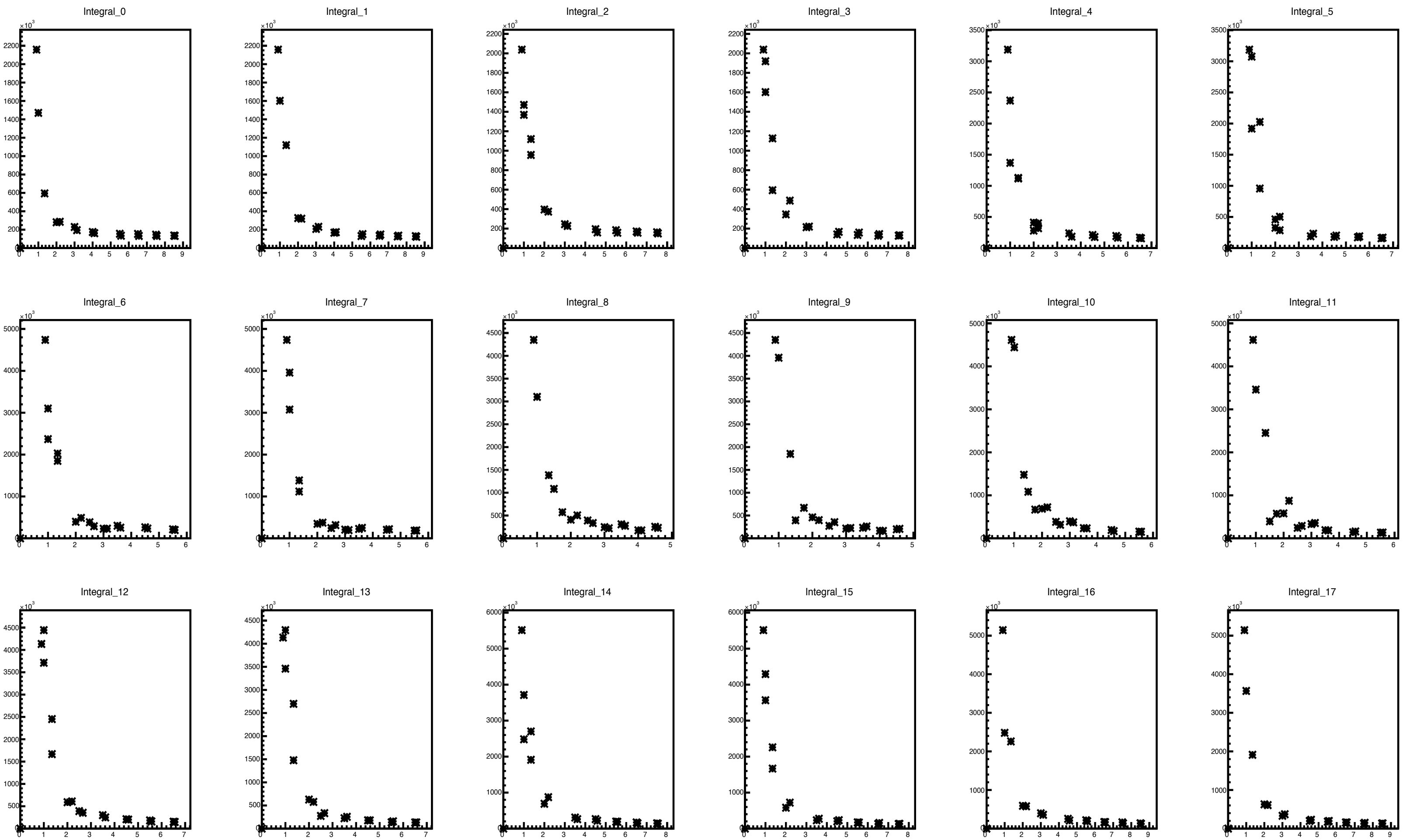
Data provided by darkroom in Marseille



Correlations DOM1 to other DOMs



Distance vs Integral



Method

- Need to find offsets of the DOMs: t_1, t_2,…,t_{18}
- Difference determined by fit: $t_i – t_j = \mu_{ij}$
- 153 equations: solve with Least Squares Approximation

- In matrix form:

$$\begin{bmatrix} 1 & -1 & 0 & . \\ 1 & 0 & -1 & . \\ . & . & . & . \\ 0 & 1 & -1 & . \\ . & . & . & . \\ 0 & . & 1 & -1 \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ . \\ t_{18} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ . \\ \mu 18 \\ . \\ \mu_{153} \end{bmatrix}$$

Or : $A.t = \mu$

Then: $t = (A^TA)^{-1} A^T\mu$

With variance matrix: $C = \mathrm{diag}(1/\sigma^2)$

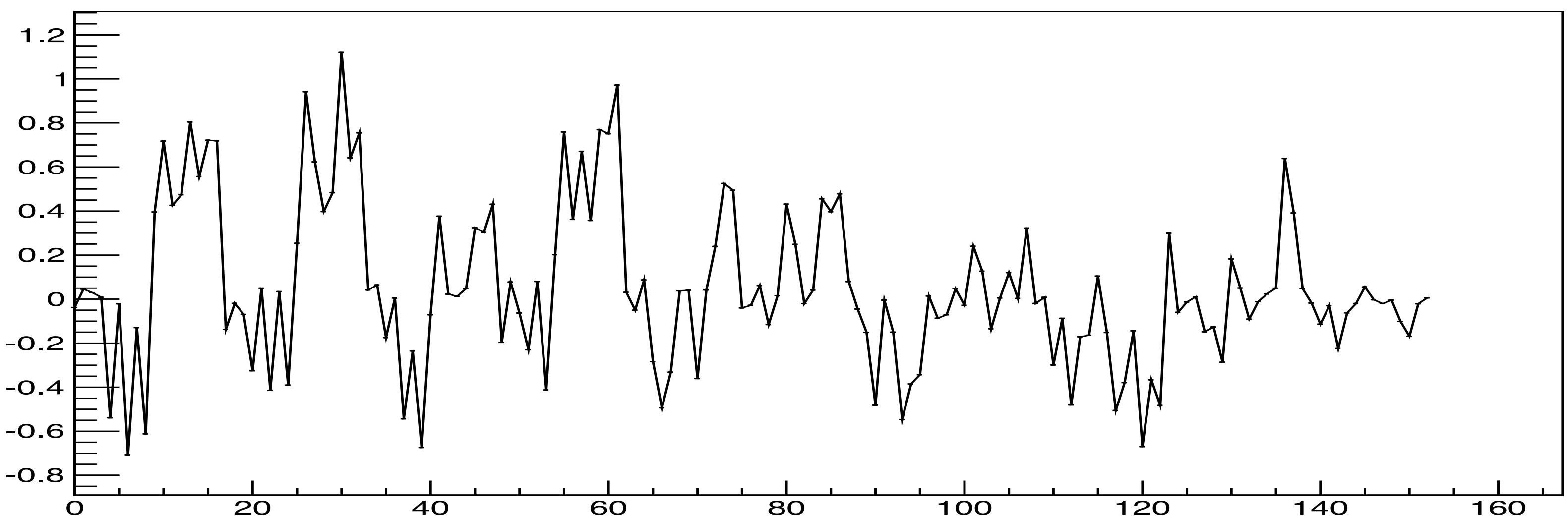
$$t = (A^TCA)^{-1} A^TC\mu$$

Absolute difference laser- and shower calibration

1	-0.01556	± 2.67e-07
2	1.32752	± 3.305e-07
3	0.43312	± 3.674e-07
4	0.15060	± 4.234e-07
5	0.37332	± 4.269e-07
6	0.29005	± 4.478e-07
7	-0.48400	± 4.494e-07
8	0.65829	± 4.627e-07
9	-0.07985	± 4.614e-07
10	-0.56297	± 5.127e-07
11	-1.0447	± 5.161e-07
12	-0.21689	± 5.198e-07
13	-0.11049	± 5.235e-07
14	0.53656	± 5.280e-07
15	0.46197	± 5.304e-07
16	-0.14841	± 5.410e-07
17	-0.22814	± 5.413e-07

Residues

With found values for offsets: determine residues of Least Square Approximation $t_i - t_j = \mu_{ij}$



Calibration is optimized by minimizing Chi-squared of residues and errorbars:

$$\chi^2 = \sum_{i,j} \frac{((t_i - t_j) - \mu_{ij})^2}{\sigma^2}$$

Advantage Muon-shower Calibration

- Redundancy of laser
- Improve results of laser
- Not dependent of functioning of single PMT