An overview of data calibration algorithms of NeuLAND in the R^{3}B setup

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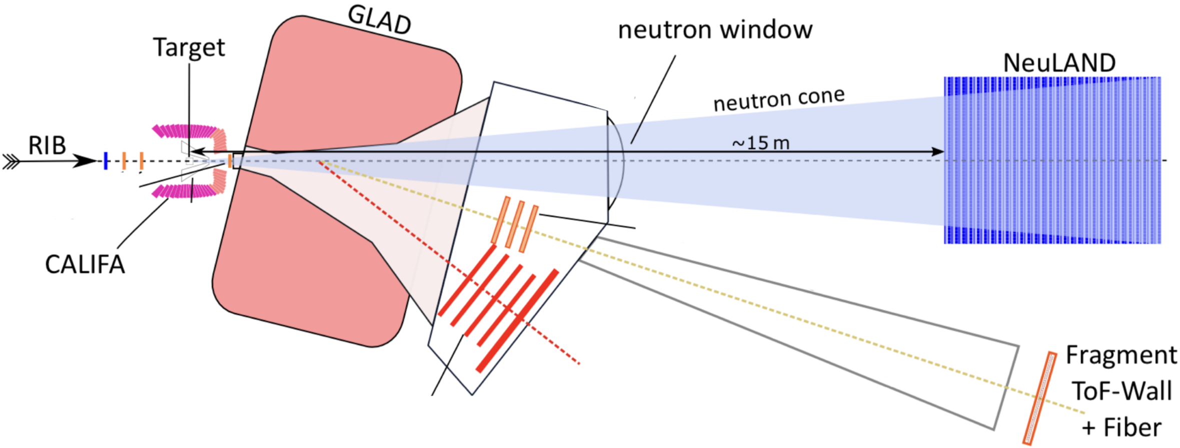
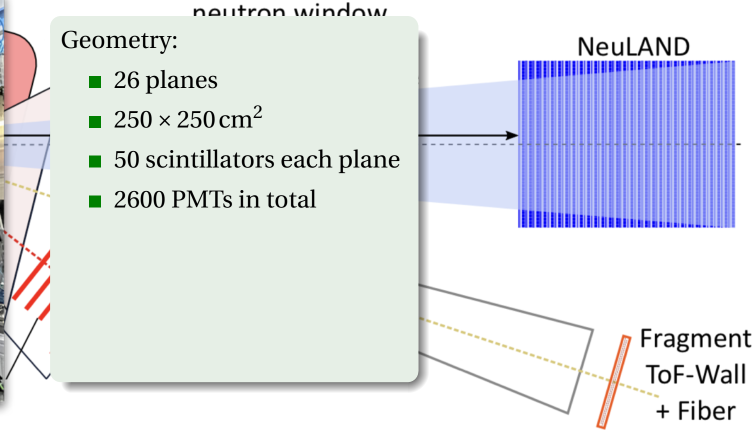


[1] K. Boretzky *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **1014**, 165701 (2021).

NeuLAND setup in R^3B[1]



Geometry:

- 26 planes
- $250 \times 250\,\mathrm{cm}^2$
- 50 scintillators each plane
- 2600 PMTs in total

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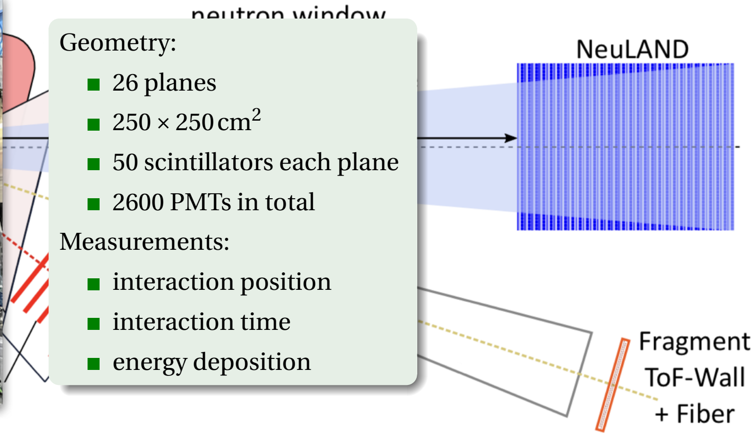
Measurements:

- interaction position
- interaction time
- energy deposition



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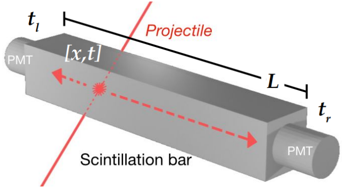
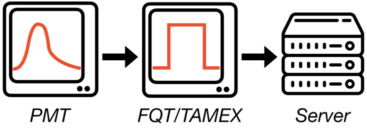
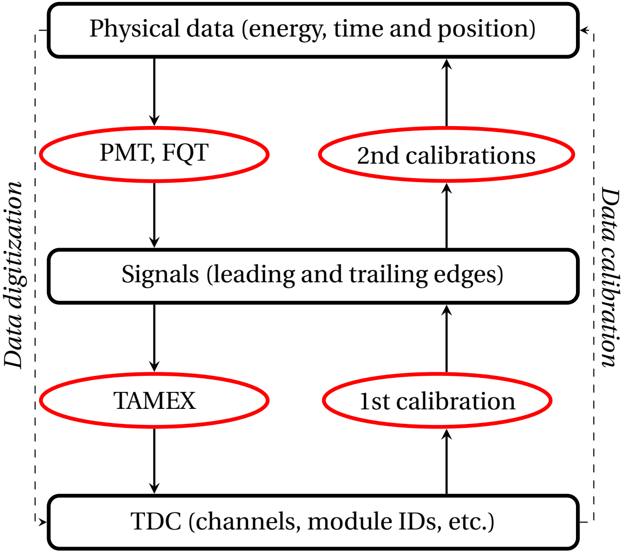
Processes of digitization

***Physical interactions*:**

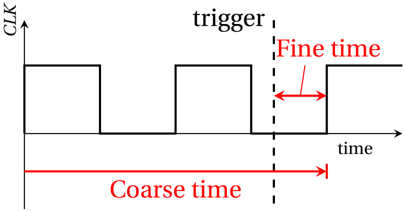


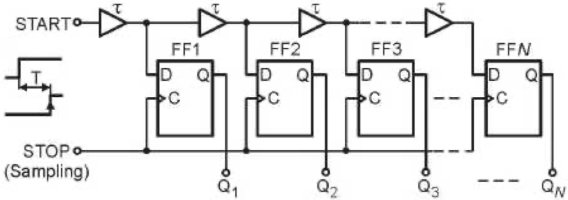
***Digitization of PMT signals*:**





Time measurement with clocks:





Tapped Delay Line (TDL)[1]

Real time calculation:

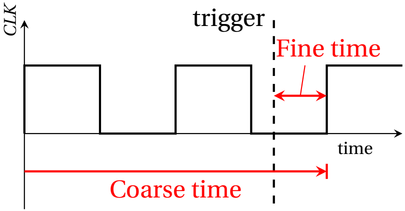
$$T_{\text{real}} = T_{\text{coarse}} - T_{\text{fine}}$$

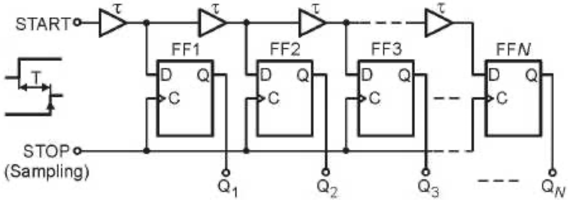
- T_{real}: Time value relative to START detector
- T_{coarse}: Clock cycles with a frequency of 200 MHz
- T_{fine}: Fine channel numbers (TDL)

[1] J. Kalisz, Metrologia **41**, 17 (2003).

Time measurement and TDC calibration

Time measurement with clocks:





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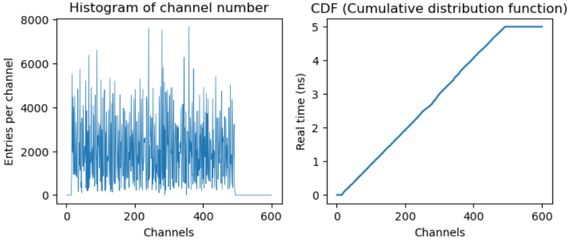
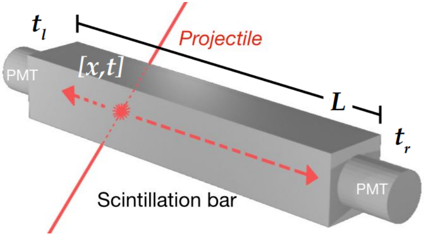


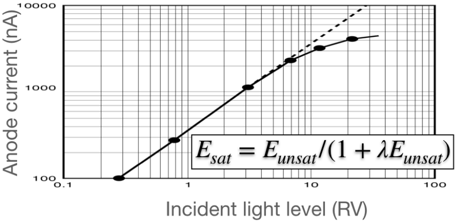
TDC Calibration (Time resolution ~ 10 ps)

[1] J. Kalisz, Metrologia **41**, 17 (2003).

Position, time and energy calibration parameters



PMT saturation effect[1] *:*



Position-Time calibration:

Interaction time:

$$t = \frac{t_r + t_l}{2} - \frac{L}{2 \cdot C_e} + t_{\text{sync}}$$

Interaction position:

$$x = \frac{C_e}{2}\left(t_r - t_l + t_{\text{offset}}\right)$$

[1] *Photomultiplier tubes: basics and applications*, 3a, Hamamatsu (Nov. 2007), p. 197.

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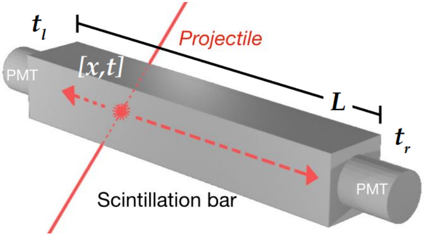

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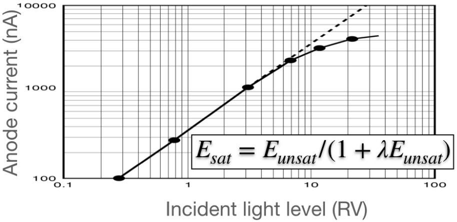

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Energy calibration relations:

Light attenuation effect:

$$I_{\text{PMT}} = E_{\text{dep}} \cdot \exp(-\alpha \cdot l)$$

PMT saturation:

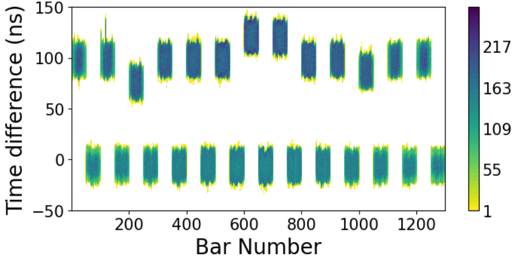
$$I_{\text{sat}} = I_{\text{PMT}} \cdot / \, (1 + \lambda \cdot I_{\text{PMT}})$$

PMT gain:

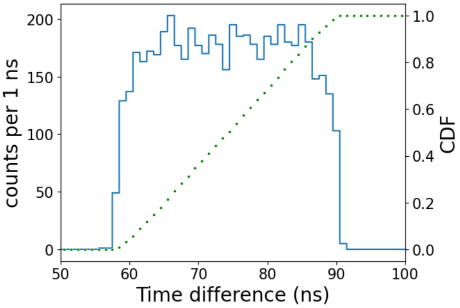
$$W = \mathscr{G} \cdot I_{\text{sat}} + W_0$$

New position calibration

Time differences of adjacent PMTs:



Parameter fitting:



Calibration steps:

1. Collect time differences of adjacent PMT signals
2. Normalize the distribution and convert to the CDF for each bar
3. Linear fitting of the CDF within its quantiles of 0.05 to 0.95

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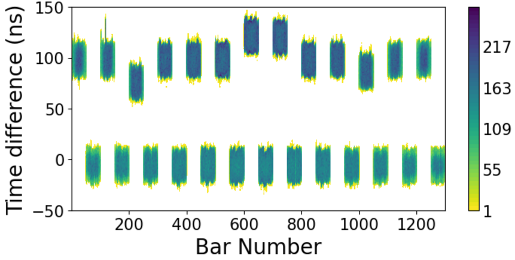

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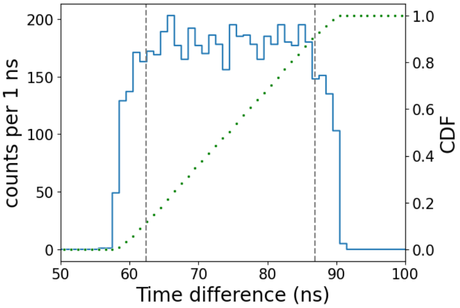

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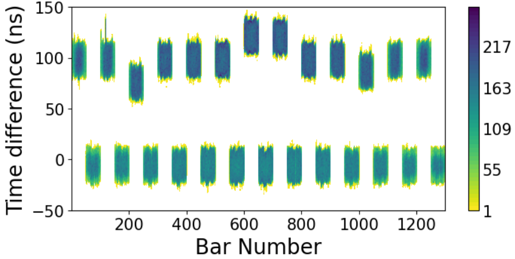

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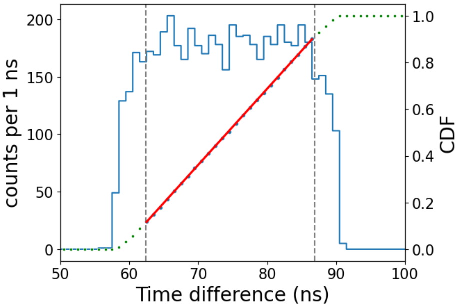

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Fitting function:

$$y = a \cdot x + 0.5 - a \cdot b$$

Calculation of parameters:

$$C_e = 2 \cdot a \cdot \text{bar length}$$

$$t_{\text{offset}} = b$$

Current energy calibration method (WIP)

Energy calibration relations

Light attenuation effect for both PMTs:

$$I_{\mathrm{PMT}} = E_{\mathrm{dep}} \cdot \exp(-\alpha \cdot l) \tag{1}$$

PMT saturation:

$$I_{\mathrm{sat}} = I_{\mathrm{PMT}} \Big/ (1 + \lambda \cdot I_{\mathrm{PMT}}) \tag{2}$$

PMT gain:

$$W = \mathcal{G} \cdot I_{\mathrm{sat}} + W_0 \tag{3}$$

Assumptions

- PMT saturation factor differs from gain factor by a constant value:

$$\lambda = 0.00175 \times \mathcal{G}$$

- Cosmic muon's stopping power is $1.73\,\mathrm{MeV\,cm^{-1}}$
- Adjacent PMTs have the same gain factor

Calculation of parameters:

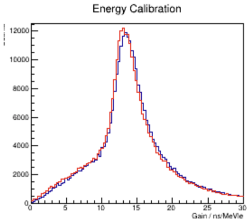
- PMT baseline W_0 is determined by the minimum cut on signal widths (i.e. trailing time – leading time).
- Calculation of attenuation factor:

$$\alpha = \ln\big((W_r - W_0)/(W_l - W_0)\big)\big/(2 \cdot x)$$

- Calculation of gain factor:

$$\mathcal{G} = \frac{W - W_0}{I_{\mathrm{PMT}}\,(1 - 0.00175(W - W_0))}$$

PMT gains from each event:



Parameter fine tuning with Millepede-II

Residual minimization

$$\partial \sum_{j=0}^{n} \sum_{i} \frac{(\mathcal{Z}_i^j(g_1, \ldots, g_m, p_1^j, \ldots, p_l^j))^2}{2(\sigma_i^j)^2} = 0$$

$g_{1\ldots m}$: *m global parameters*

$p^j_{1\ldots l}$: *l local parameters* for the jth μ track

n : the total number of μ tracks

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Features

- Simultaneous fitting of all parameters
- Separation to global and local parameters
- Computation complexity independent of local parameter size
- No muon track reconstruction
- Calibration relation **must be linear**

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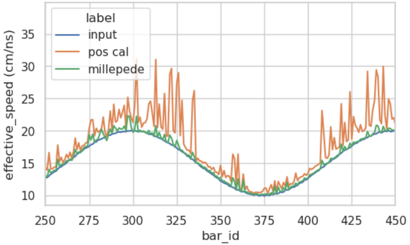
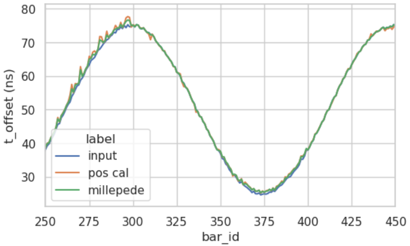
Fine tuning on C_e:



Fine tuning on t_{offset}:



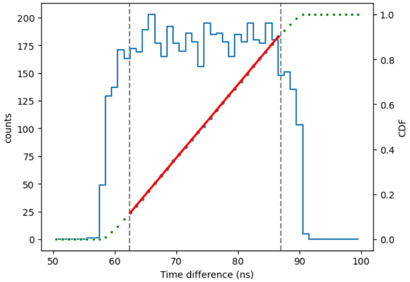
Summary and outlook

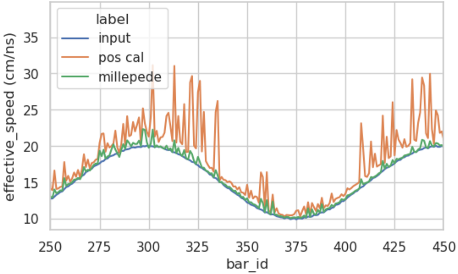
Summary

- Principle of digitization processes
- Calibration with TDC for time values
- Calibration with time values for physical values
- Fine tuning with the Millepede-II algorithm

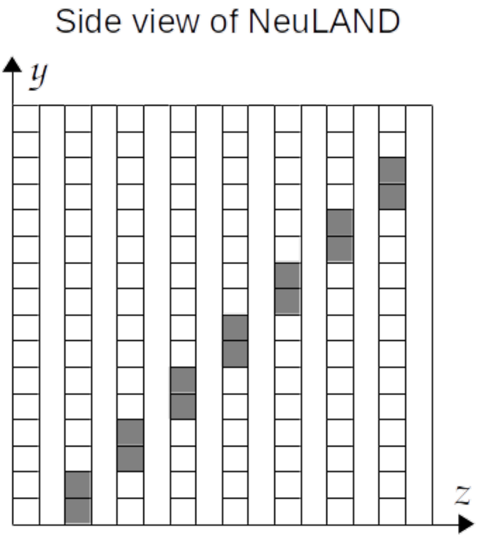
Outlook

- Improve energy calibration
- Apply Millepede-II algorithm on energy-related parameters
- Verify energy parameters via simulation





Current position calibration



Procedures

1. Obtain the positions of bars with signals
2. Reconstruct the muon track from the bar positions
3. Calculate the positions of the interaction points of the muon
4. Calculate the calibration parameters via data fitting

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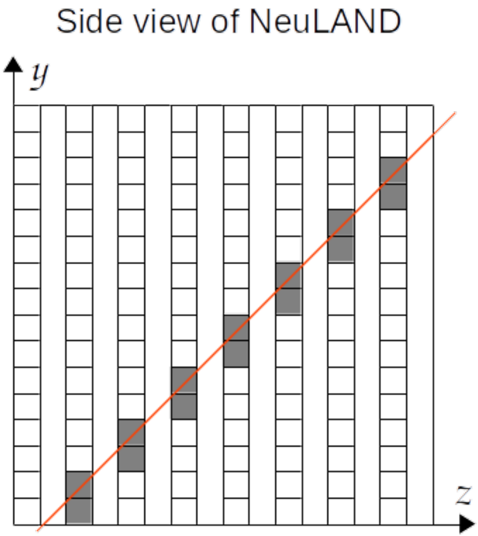

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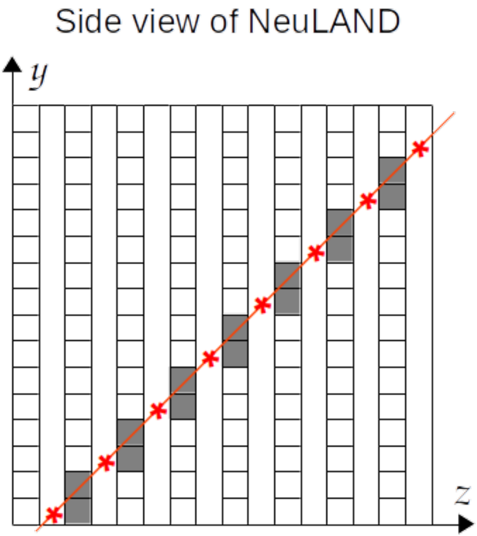

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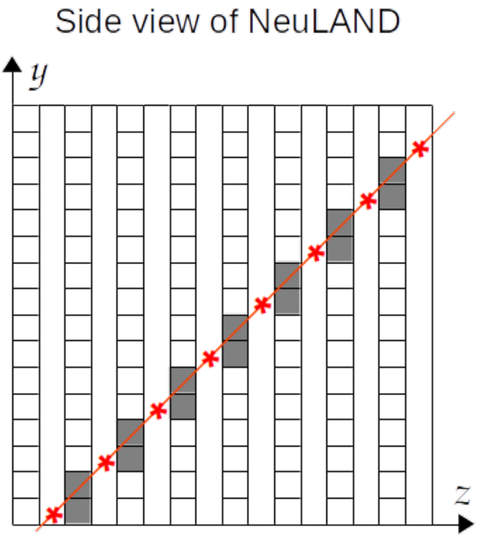

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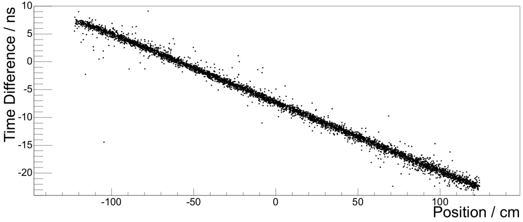

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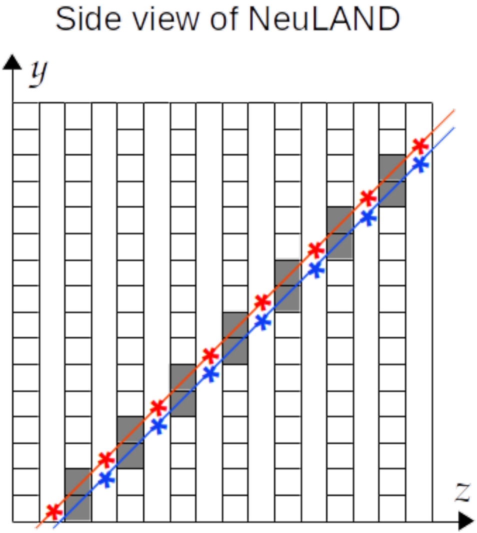

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