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

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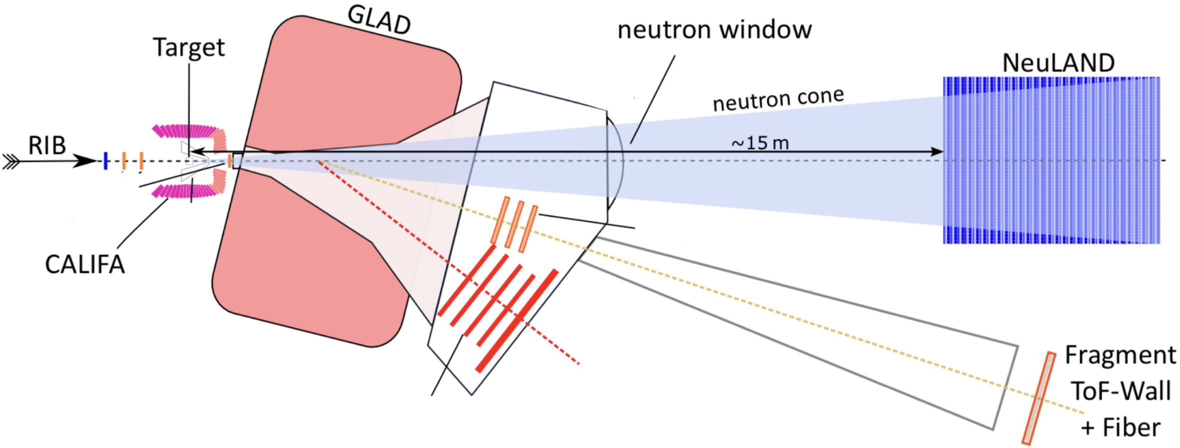
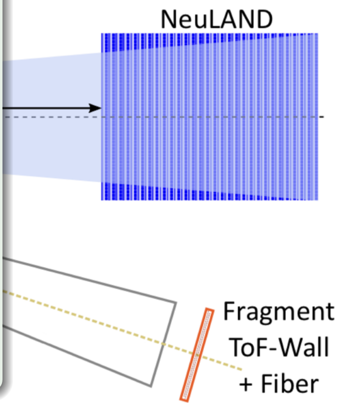
NeuLAND setup in R^{3}B



K. Boretzky *et al.*, Nucl. Instrum. Methods. Phys. Res. B **1014**, 165701 (2021)

Geometry:

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



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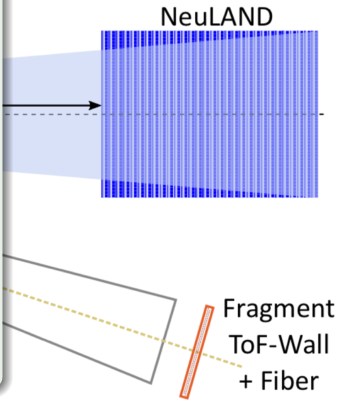
NeuLAND setup in R^3B

Geometry:

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

Measurements:

- interaction position
- interaction time
- energy deposition



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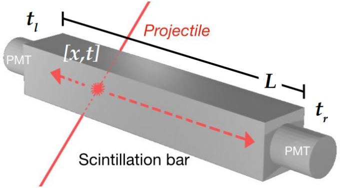
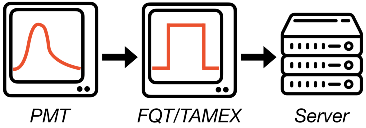
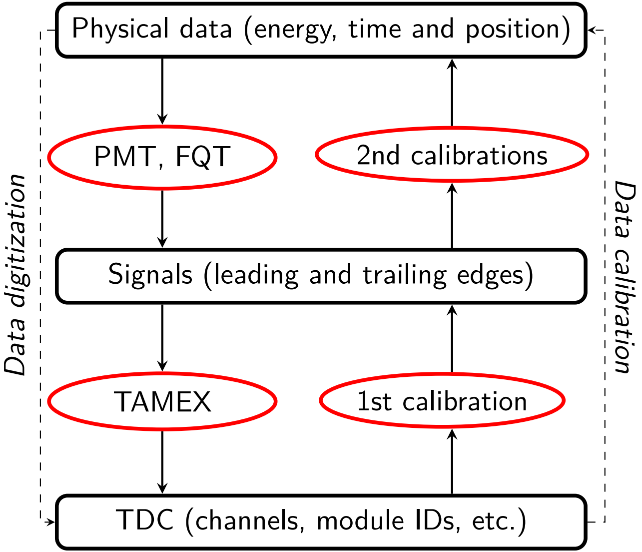
Processes of digitization

Physical interactions:



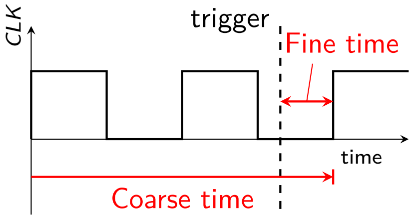
Digitization of PMT signals:

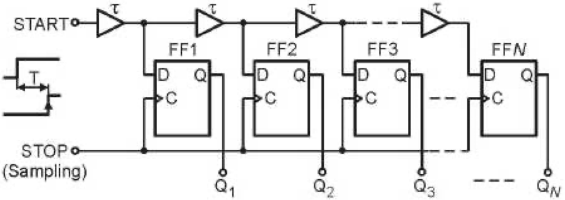




Time measurement and TDC calibration

Time measurement with clocks:





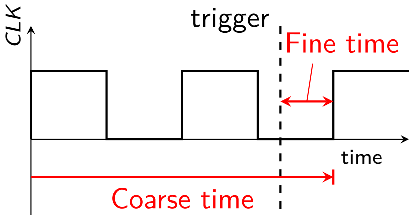
Tapped Delay Line (TDL)[1]

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)

Time measurement with clocks:



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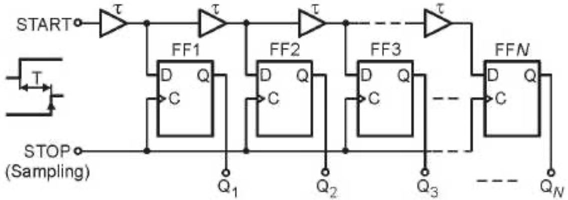

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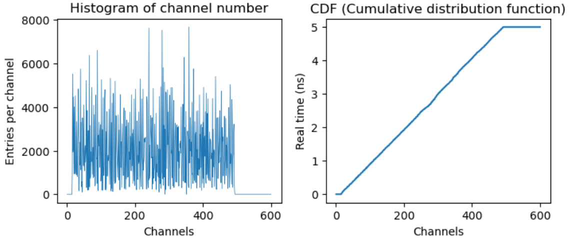
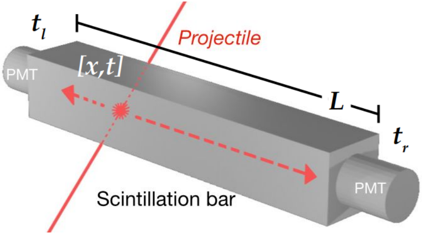


TDC Calibration (Time resolution $\sim 10\,\text{ps}$)

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

Position, time and energy calibration parameters



Position-Time calibration:

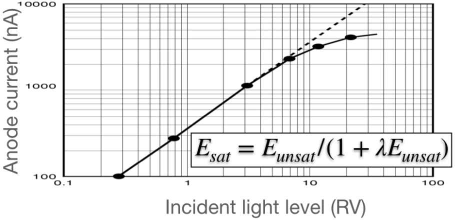
Interaction time:

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

Interaction position:

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

PMT saturation effect[2]*:*



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

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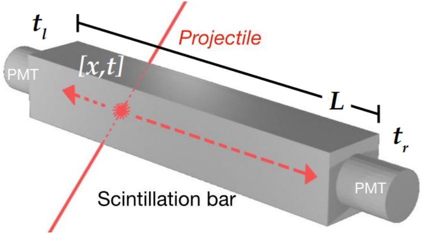

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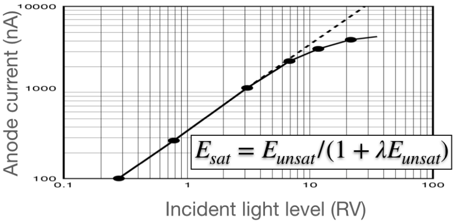

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Energy calibration relations:

Light attenuation effect:

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

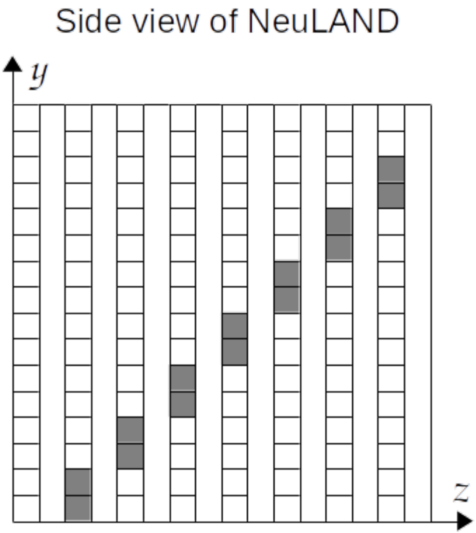
PMT saturation:

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

PMT gain:

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

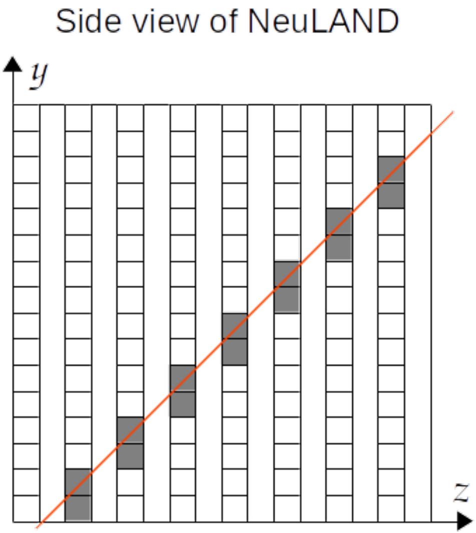
Current position calibration



Procedures

1. Obtain the positions of bars with signals

Current position calibration



Procedures

1. Obtain the positions of bars with signals
2. Reconstruct the muon track from the bar positions

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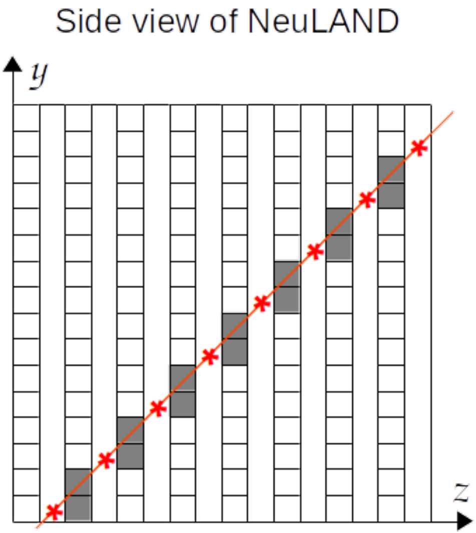
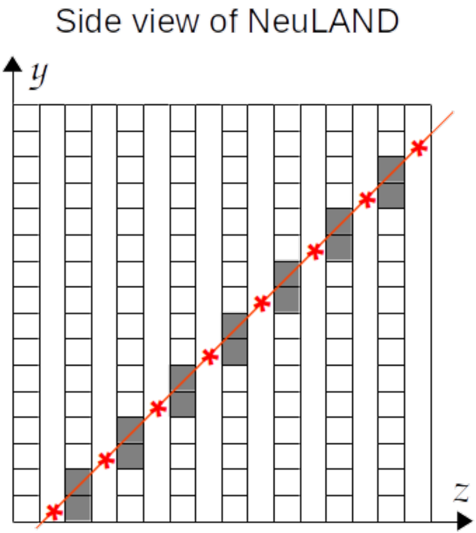


Procedures

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



Procedures

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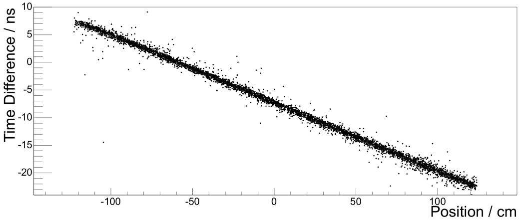
4. Calculate the calibration parameters via data fitting

Data fitting in the position calibration:



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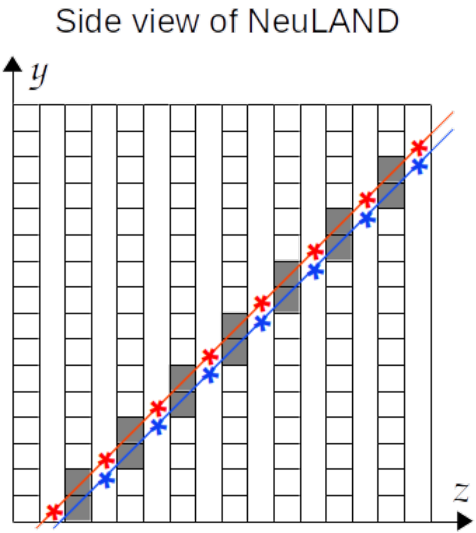

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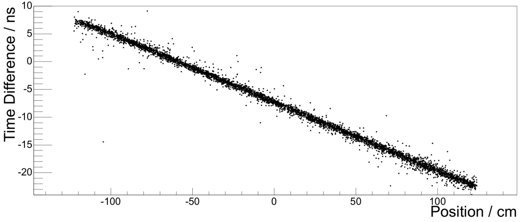
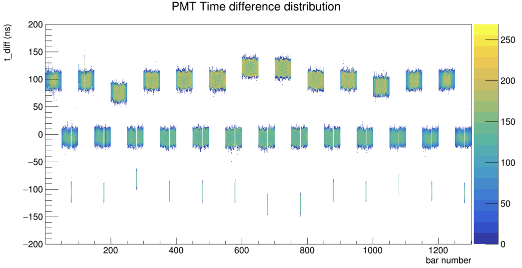


New position calibration

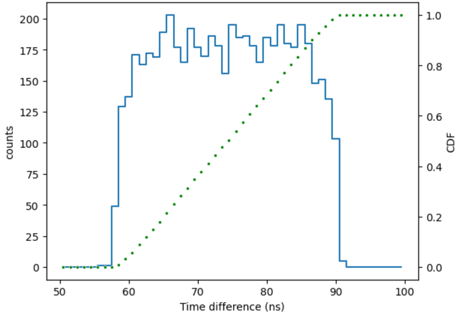
Time differences of adjacent PMTs:



Calibration steps:

1. Collect time differences of adjacent PMT signals

Parameter fitting:



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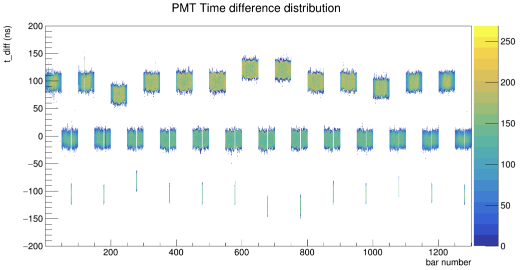

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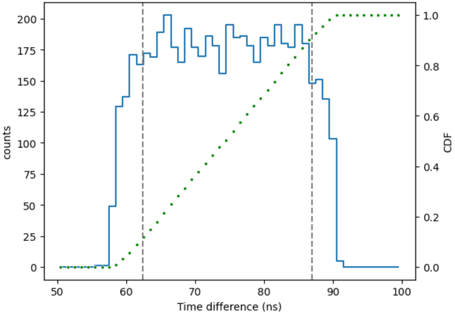
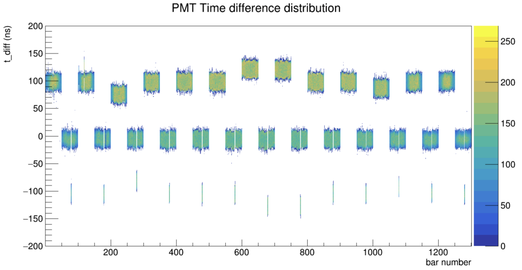


Calibration steps:

1. Collect time differences of adjacent PMT signals
2. Normalize the distribution and convert to the CDF for each bar

New position calibration

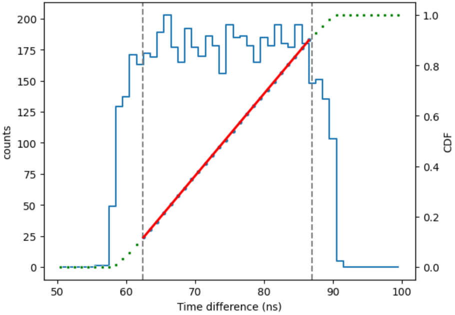
Time differences of adjacent PMTs:



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

Parameter fitting:



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:

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

PMT saturation:

$$I_{\text{sat}} = I_{\text{PMT}} \cdot / \left(1 + \lambda \cdot I_{\text{PMT}}\right) \quad (2)$$

PMT gain:

$$W = \mathcal{G} \cdot I_{\text{sat}} + W_0 \quad (3)$$

Assumptions

1. PMT saturation factor differs from gain factor by a constant value:
$$\lambda = 0.00175 \times \mathcal{G}$$
2. Cosmic muon's stopping power: $1.73\,\mathrm{MeV\,cm^{-1}}$
3. Adjacent PMTs have the same gain factor

Calculation of parameters:

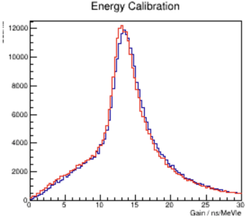
- PMT baseline W_0 is determined by the minimum cut on signal widths (i.e. trailing time − leading time).
- Calculation of attenuation factor:

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

- Calculation of gain factor:

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

PMT gains from each event:



Parameter fine tuning with Millepede-II

Residual minimization

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

$g_{1...m}$: m *global parameters*

$p^j_{1...l}$: 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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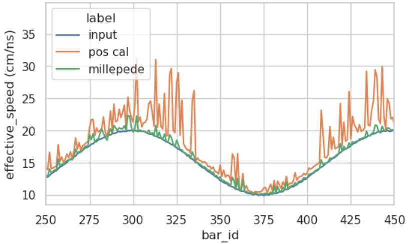
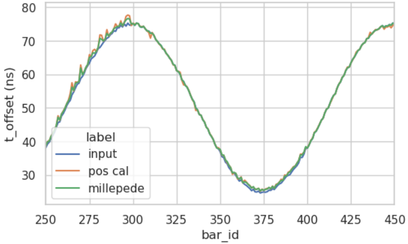
Fine tuning on C_e:



Fine tuning on t_{offset}:



Summary and outlook

Summary

1. Principle of digitization processes
2. Calibration with TDC for time values
3. Calibration with time values for physical values
4. Fine tuning with the Millepede-II algorithm

Outlook

1. Improve energy calibration
2. Apply Millepede-II algorithm on energy-related parameters
3. Verify energy parameters via simulation