Experimenting on a new method for the NeuLAND position calibration and fine tuning with the Millepede algorithm

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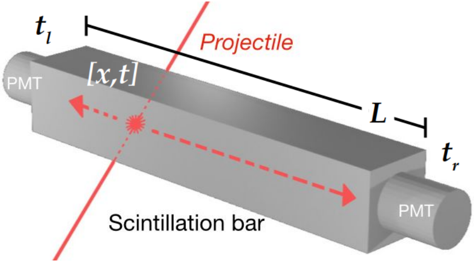
Time and position calibration parameters



Symbols:

x : position of the interaction

t : time of the interaction

L : length of the scintillator

t_l : time of the left PMT signal

t_r : time of the right PMT signal

C_e : effective speed of light

Time relation:

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

Position relation:

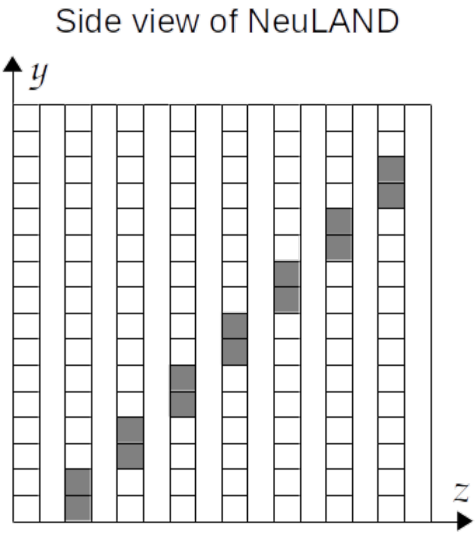
$$x = \frac{C_e}{2}\left(t_r - t_l + t_{\text{offset}}\right)$$

Additional calibration parameters:

- t_{sync} : time synchronization among scintillators
- t_{offset} : time offset between adjacent PMTs

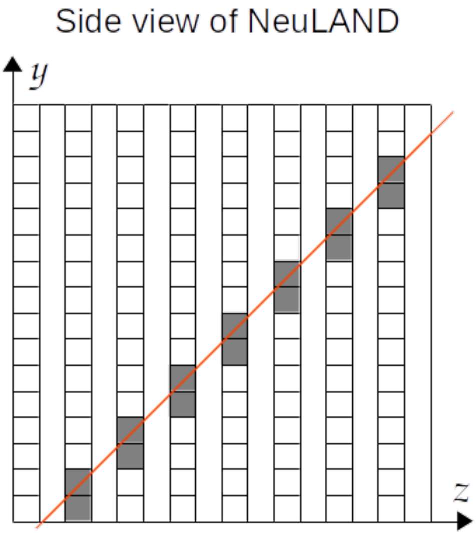
Total number of calibration parameters:
3900

Current calibration method



Procedures

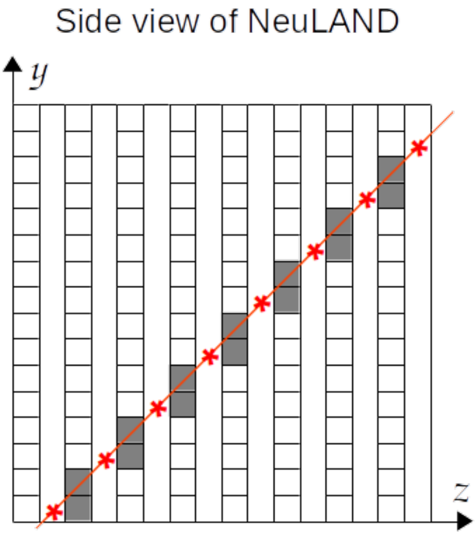
1. Obtain the positions of bars with signals



Procedures

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

Current calibration method



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2. Reconstruct the muon track from the bar positions
3. Calculate the positions of the interaction points of the muon

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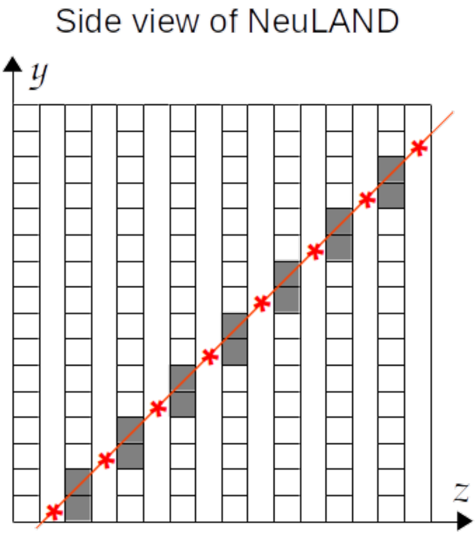

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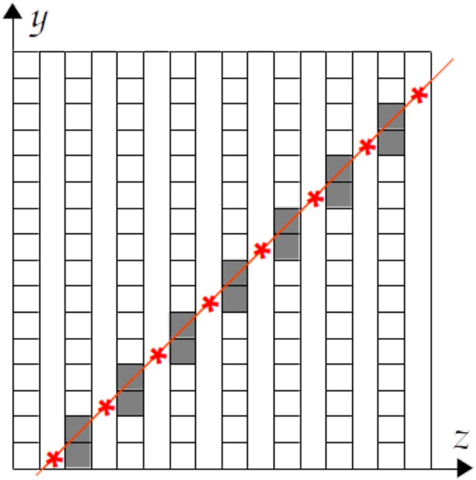
4. Calculate the calibration parameters via data fitting

Current calibration method

Side view of NeuLAND



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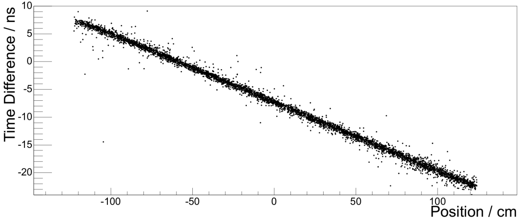
Data fitting in the position calibration:



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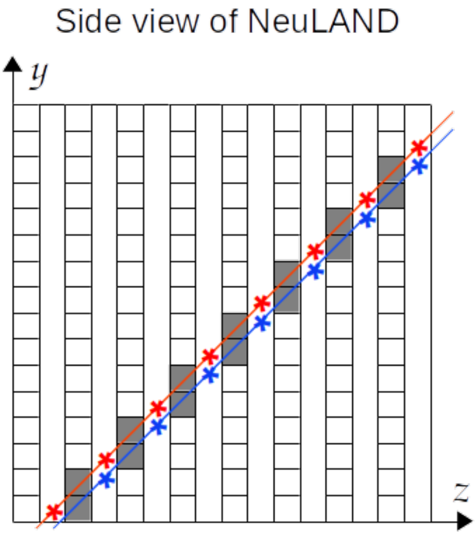

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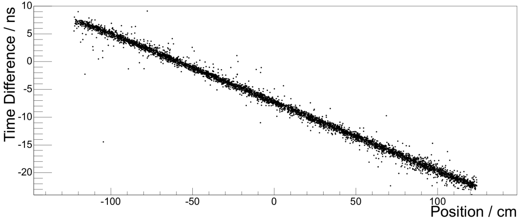

Simultaneous fitting using the Millepede algorithm

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Calibration with muon tracks:

$$\text{pos} = C_e \cdot (t_r - t_l + t_{\text{offset}})/2 \tag{1}$$

$$t = (t_r + t_l)/2 - L/(2 \cdot C_e) + t_{\text{sync}} \tag{2}$$

$$\vec{x}_\mu = \vec{a}^{\,i} \cdot z_\mu + \vec{b}^{\,i} \tag{3}$$

where $\vec{a} = (a_x, a_y, a_t)$, $\vec{b} = (b_x, b_y, b_t)$

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For time offsets of horizontal bars:

$$b_x^i - g_{ct}^i/2 + g_c^i \cdot \Delta t^i/2 + a_x^i z_\mu = 0$$

For time offsets of vertical bars:

$$b_y^i - g_{ct}^i/2 + g_c^i \cdot \Delta t^i/2 + a_y^i \cdot z_\mu = 0$$

For time sync:

$$b_t^i + g_s^i + L/(2 \cdot g_c^i) - t_{\text{sum}}/2 + a_t^i z_\mu = 0$$

with $g_c^i = C_e$, $g_{ct}^i = C_e \cdot t_{\text{offset}}$ and $g_s^i = t_{\text{sync}}$

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Millepede input:

(1) $\partial f/\partial q_j$: 1st order derivative of local parameters

(2) $\partial f/\partial p_l$: 1st order derivative of global parameters

(3) z : "measurements" (**constant values**)

σ : measurement errors

Simultaneous fitting using the Millepede algorithm

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Solutions to the rank deficit error

- Reduce global or local parameters
- Applying additional constraints

Introducing local constraints:

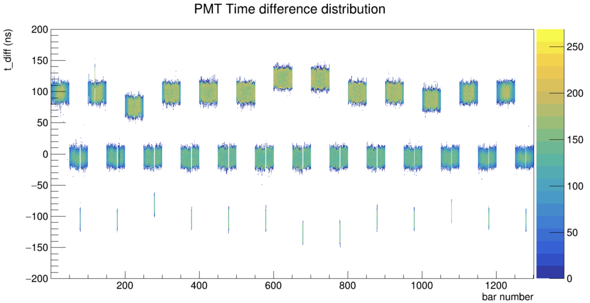
Horizontal bars : $b_y^i - Y_{bar}^i + a_y^i \cdot z_\mu = 0$

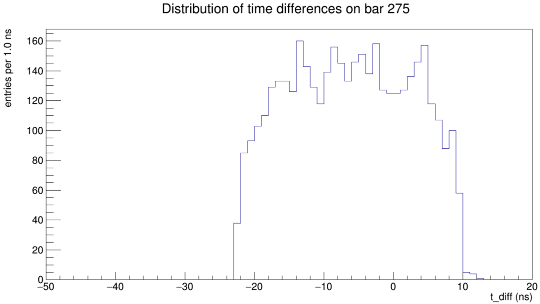
Vertical bars : $b_x^i - X_{bar}^i + a_x^i \cdot z_\mu = 0$

Purposes of predetermination

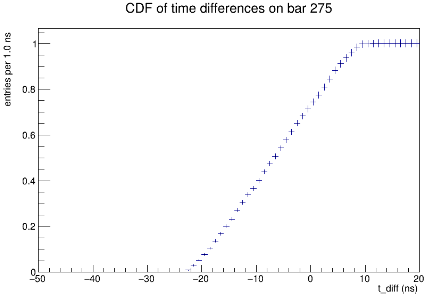
- Use good initial values from a crude calibration method to reduce rejected entries ($< 33.3\%$)
- Select one bar from the plane when a muon crosses multiple bars of the same plane
- Remove outliners caused by background γ rays

Step 1: Collect time differences of adjacent PMT signals





Step 2: Normalize the distribution and convert to a CDF for each bar



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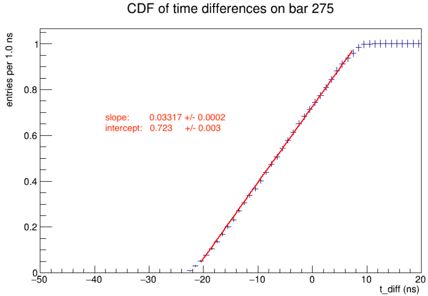

Step 3: Linear fitting from 0.05 to 0.95

Calculation of parameters:

$$C_e = 2 \cdot \text{BarLength} \cdot \text{slope}$$

$$t_{\text{offset}} = (0.5 - \text{intercept})/\text{slope}$$

Predetermination on position parameters

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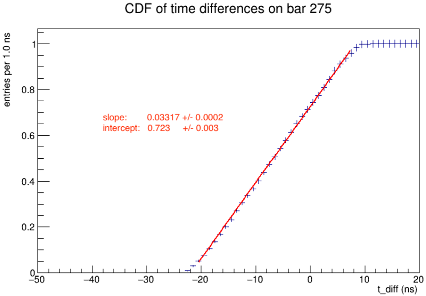

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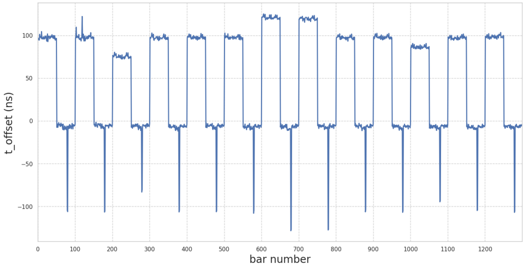
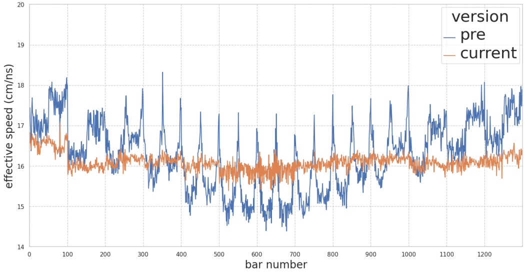
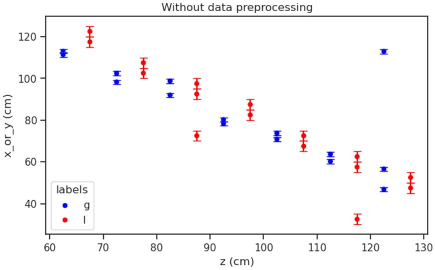
Evaluation results:

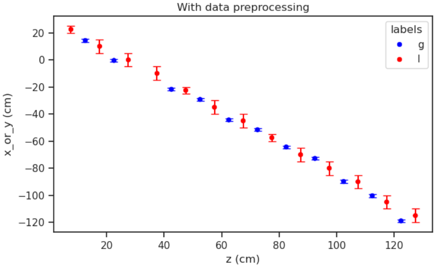




Data preprocessing

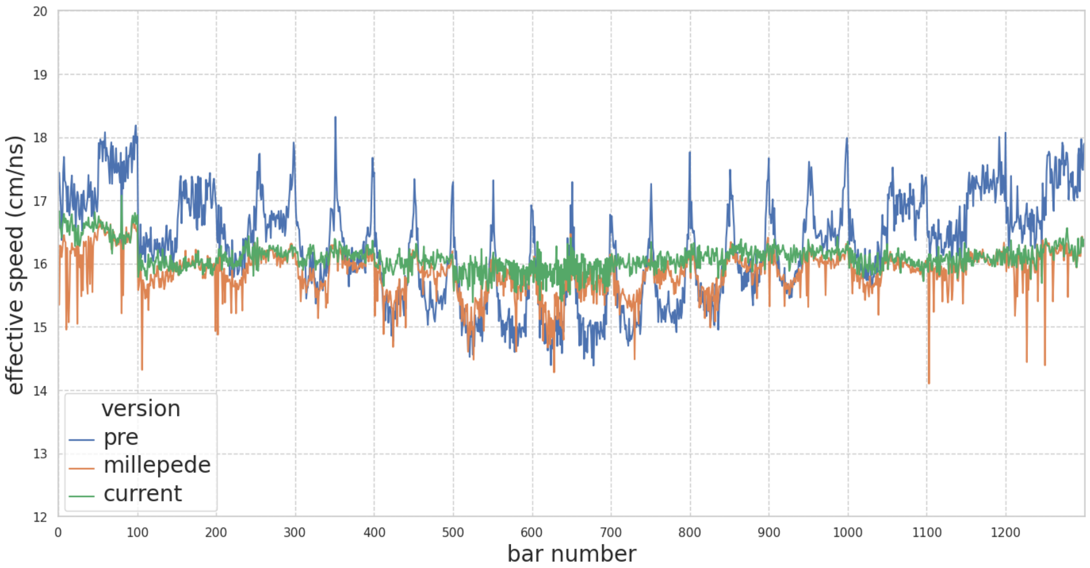
1. Scale the time/position values ($\times 10^{-1}$)
2. Select bars with only one signal per event
3. Remove the isolated bars of each plane
4. Average bar positions for local constraints
5. Linear fit with $z-x$ and $z-y$ functions on bar positions
6. Choose the bar closest to the linear function for each plane
7. Remove bars with large residuals





Comparison of time offset parameters

Comparison of effective speed parameters



Summary and outlook

Summary

- Simultaneous fitting using the Millepede algorithm
- Predetermination of the position-related calibration parameters
- Good consistency between the results from the Millepede algorithm and the current method

Outlook

- Adding time synchronization parameters
- Applying the Millepede algorithm to the energy calibration
- Further comparison between the Millepede algorithm and current method with the simulated data