Muon Scintillator Time Calibration Study - Plan -

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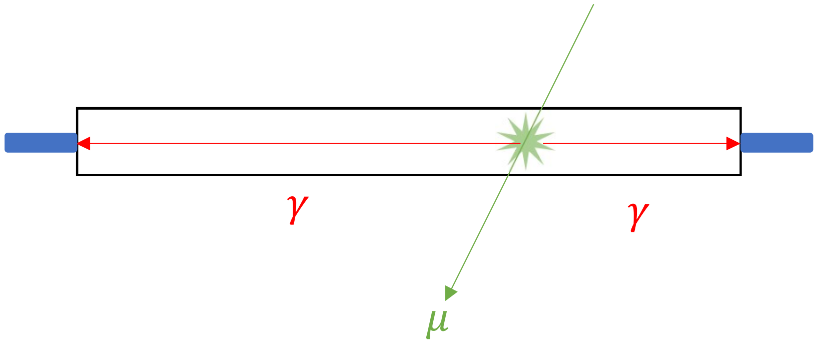
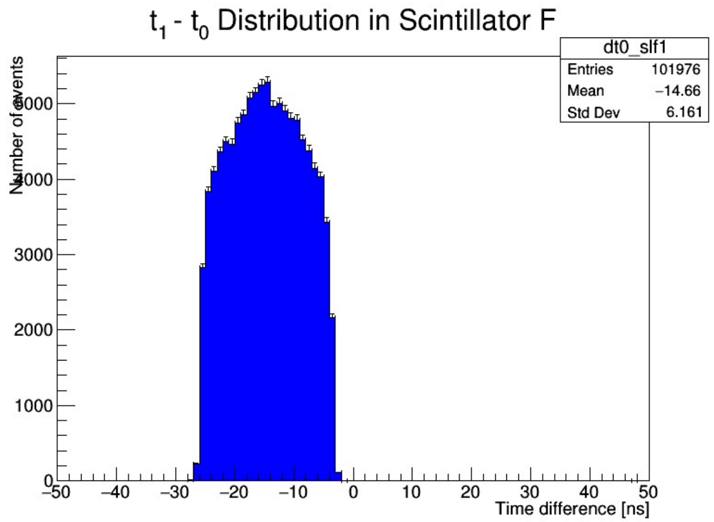
Time Calibration Study – Motivation

- Our μ-scintillator records the event information, including event occurring time.
- The event occurring time, however, is not accurate in $\mathcal{O}(2\ \mathrm{ns})$.
- The error may come from
  i) Flight time from the scintillation to PMTs
  ii) Delay in PMTs
  iii) Delay in DAQ system.





Time Calibration Study – Motivation

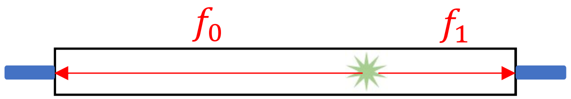
- It is easy to make a time calibration here (SNU) with various experimental setup, like crossing bars, shuffling bars, etc.
- The main point is time calibration at CERN.
- Many number of scintillation bars will be installed on the wall, so time calibration method which requires no additional experimental setup would be preferred.
- For this, we need some STUDY!

Time Calibration Study – Instincts

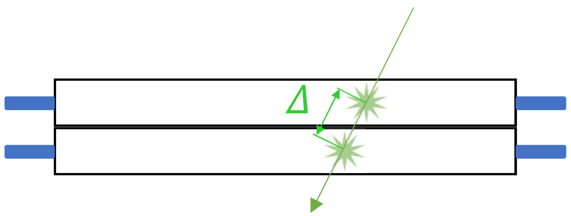
- If we have enough knowledge, time calibration is so easy.
- We need to know 2 things

i) $f_1 - f_0$: Distribution of signal flight time difference to both sides in a scintillator.

f_0 is the signal flight time from the event to the PMT 0,
f_1 is that to the PMT 1.



ii) Δ : Event occurring time difference between two adjoining scintillators.

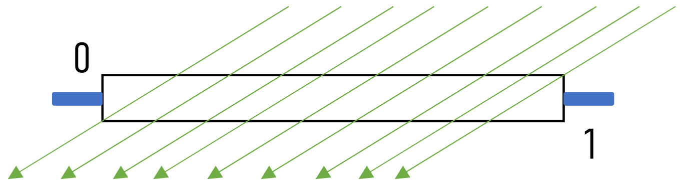


Time Calibration Study – Instincts

- We believe that $\langle f_1 - f_0 \rangle = 0$ and $\Delta = \frac{L}{c}$, where is the thickness of the scintillator.
- I want to check above two instincts.

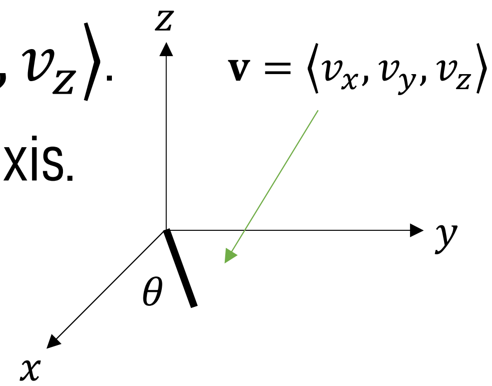
$\langle f_1 - f_0 \rangle$ Study

- We believe $\langle f_1 - f_0 \rangle = 0$ because most muons come vertically.
- But if muon incident angle is tilted, it can be asymmetric.



$\langle f_1 - f_0 \rangle > 0$

- Let the incident velocity of muon in the lab frame, $\mathbf{v} = \langle v_x, v_y, v_z \rangle$.
- And let our scintillator is on xy-plane, having angle θ with x-axis.



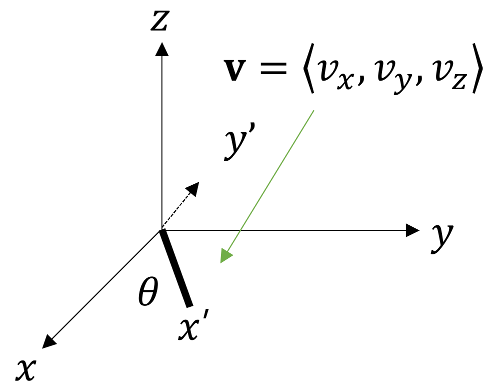
$\langle f_1 - f_0 \rangle$ Study

- In scintillator's frame, the incident angle is $\mathbf{v} = (v_x \cos\theta + v_y \sin\theta)\widehat{x'} + v_z \hat{z}$.
- Thus the incident angle ϕ with scintillator direction θ is

$$\phi(\theta) = \tan^{-1}\left(\frac{v_x \cos\theta + v_y \sin\theta}{v_z}\right).$$

- Especially, $\phi(0) = \tan^{-1}\left(\frac{v_x}{v_z}\right) = -\phi(\pi)$

$$\phi\left(\frac{\pi}{2}\right) = \tan^{-1}\left(\frac{v_y}{v_z}\right) = -\phi\left(\frac{\pi}{2}\right).$$



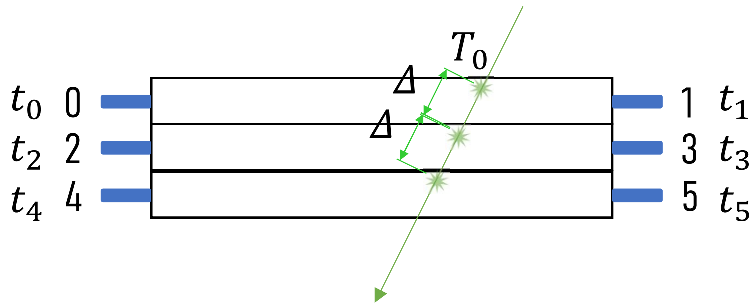
$\langle f_1 - f_0 \rangle$ Study

- Let's measure $\langle t_1 - t_0 \rangle$ in two directions.

- If two $\langle t_1 - t_0 \rangle$ measurements show no difference, it means we can use our instinct $\langle f_1 - f_0 \rangle = 0$ in practice.

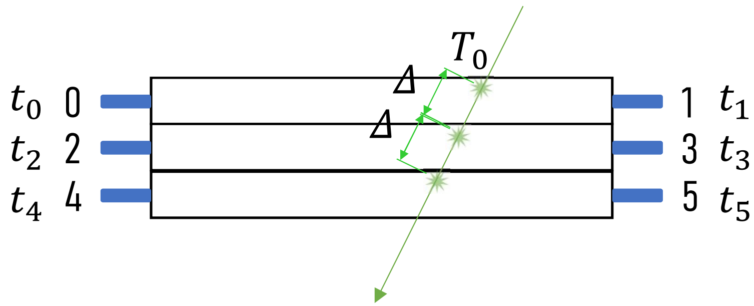
Δ Study

- Let's try time calibration with 3 scintillation bars.
- Let t_i is the time measured from PMT i, T_0 is the first event occurring time.
- Then $t_i = T_0 + \left[\frac{i}{2}\right] \times \Delta + f_i + d_i$, where d_i is intrinsic time delay in PMT i.



Δ Study

- First, use $\langle f_1 - f_0 \rangle = 0 \rightarrow \langle t_1 - t_0 \rangle = \langle d_1 - d_0 \rangle$.
- It should be zero, so we can add appropriate constant to t_1.
- Same procedure to t_3 and t_5.
- Now t_{2n+1} is consistent with t_{2n}.



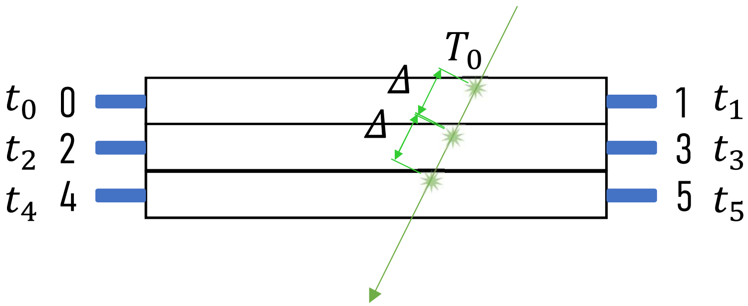
$$t_i = T_0 + \left[\frac{i}{2}\right] \times \Delta + f_i + d_i$$

Δ Study

- Next, we demand $\langle t_2 - t_0 \rangle = \langle t_4 - t_2 \rangle = \Delta$.
- From the measurement, we have

$$d_2 - d_0 + \Delta = \langle t_2 - t_0 \rangle_1$$
$$d_4 - d_2 + \Delta = \langle t_4 - t_2 \rangle_1$$
$$\rightarrow \; d_4 - d_0 + 2\Delta = \langle t_4 - t_0 \rangle_1.$$

Subscript 1 indicates the first experiment result.



$$t_i = T_0 + \left\lceil \frac{i}{2} \right\rceil \times \Delta + f_i + d_i$$

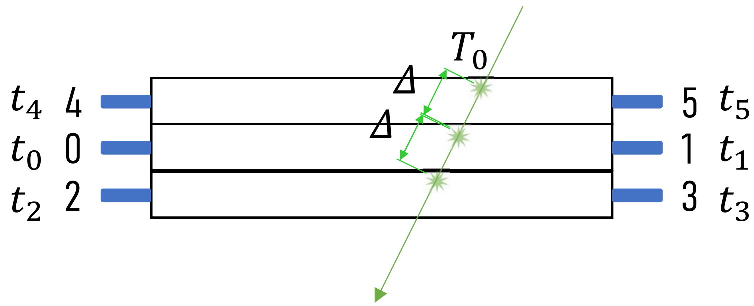
Δ Study

- One more experiment with different scintillator setup.
- This time, we get

$$d_0 - d_4 + \Delta = \langle t_0 - t_4 \rangle_2.$$

Subscript 2 indicates the second experiment result.

- Previously, we had $d_4 - d_0 + 2\Delta = \langle t_4 - t_0 \rangle_1$.



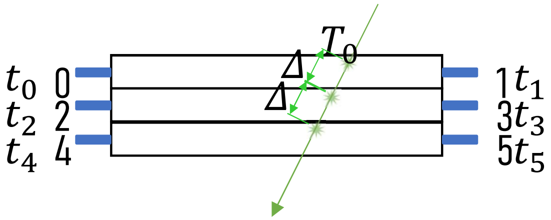
$$t_i = T_0 + \left[\frac{i}{2}\right] \times \Delta + f_i + d_i$$

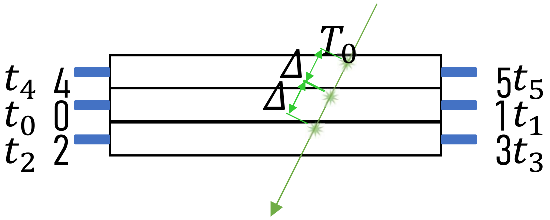
Δ Study

- Thus we have

$$3\Delta = \langle t_4 - t_0 \rangle_1 + \langle t_0 - t_4 \rangle_2.$$

- Now we can get Δ!





$$t_i = T_0 + \left[\frac{i}{2}\right] \times \Delta + f_i + d_i$$