Development of the TOF detector for the GBAR experiment

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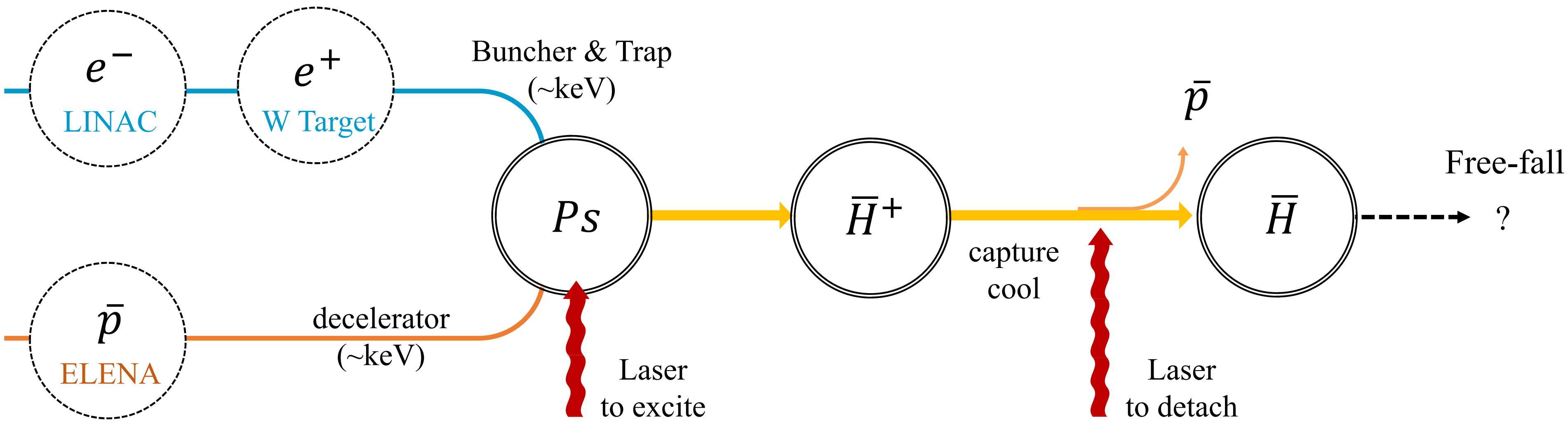
1. Introduction
2. Prototype TOF detector
    a. Set-up
    b. Analysis methods
    c. Results
3. Summary

1. Introduction

Introduction

GBAR : Gravitational Behavior of Antihydrogen at Rest
to measure the gravity of antimatter and test Weak Equivalence Principle



Introduction

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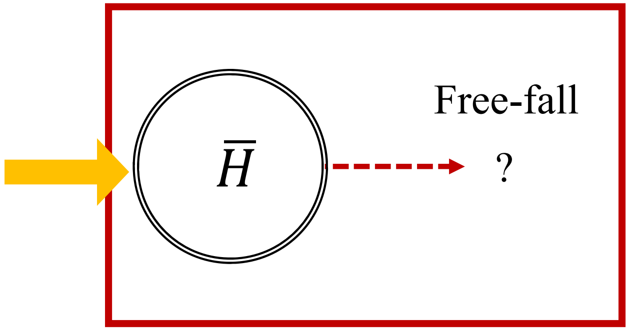


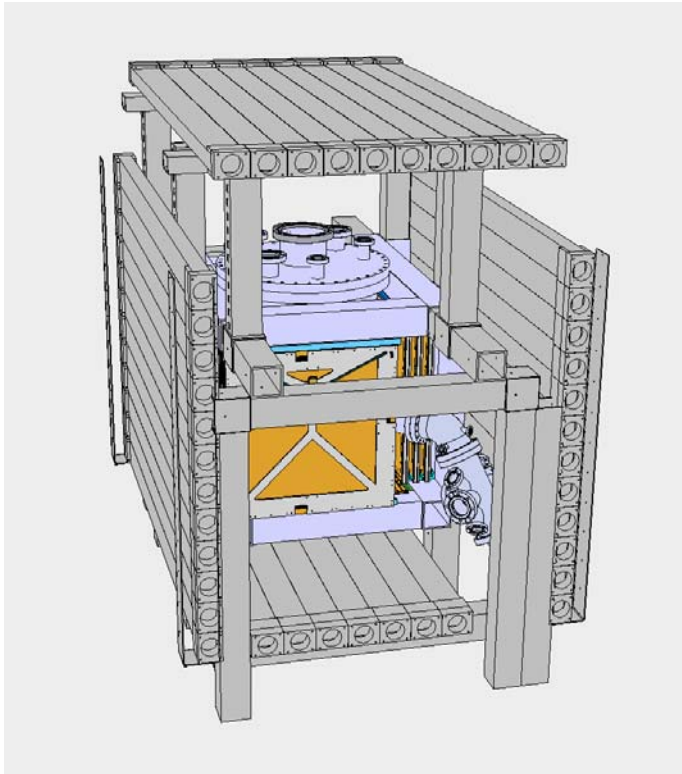
To calculate the gravitational acceleration, g, need to measure **time** and **position**.

How long it takes

where the annihilation is happened.

Introduction

GBAR : Gravitational Behavior of Antihydrogen at Rest
TOF detector : Time-of-Flight detector



An array of plastic scintillator bars

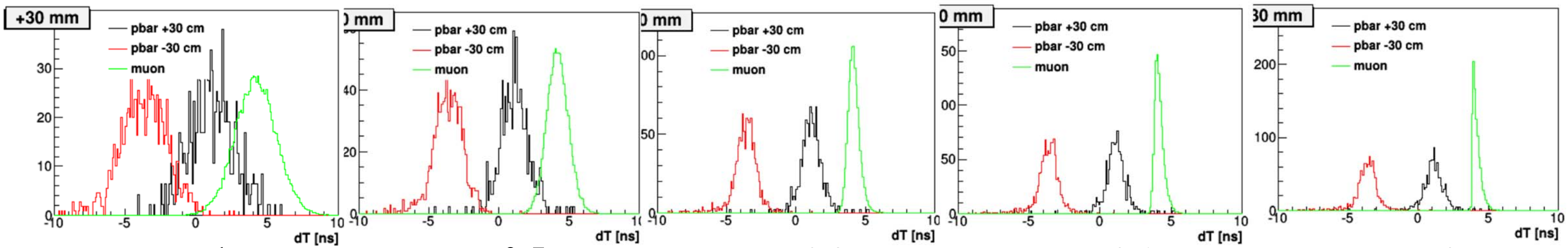
plastic : $10 \times 5 \times 170\ cm^3$

four walls – top, bottom, left, right

covered by about 40 bars

Introduction

GBAR : Gravitational Behavior of Antihydrogen at Rest
TOF detector : Time-of-Flight detector



σ = 1　　σ = 0.5　　σ = 0.2　　σ = 0.1　　σ = 0

To distinguish top & bottom and cosmic ray signal,
the time resolution(σ) should be smaller than 0.2 [ns]

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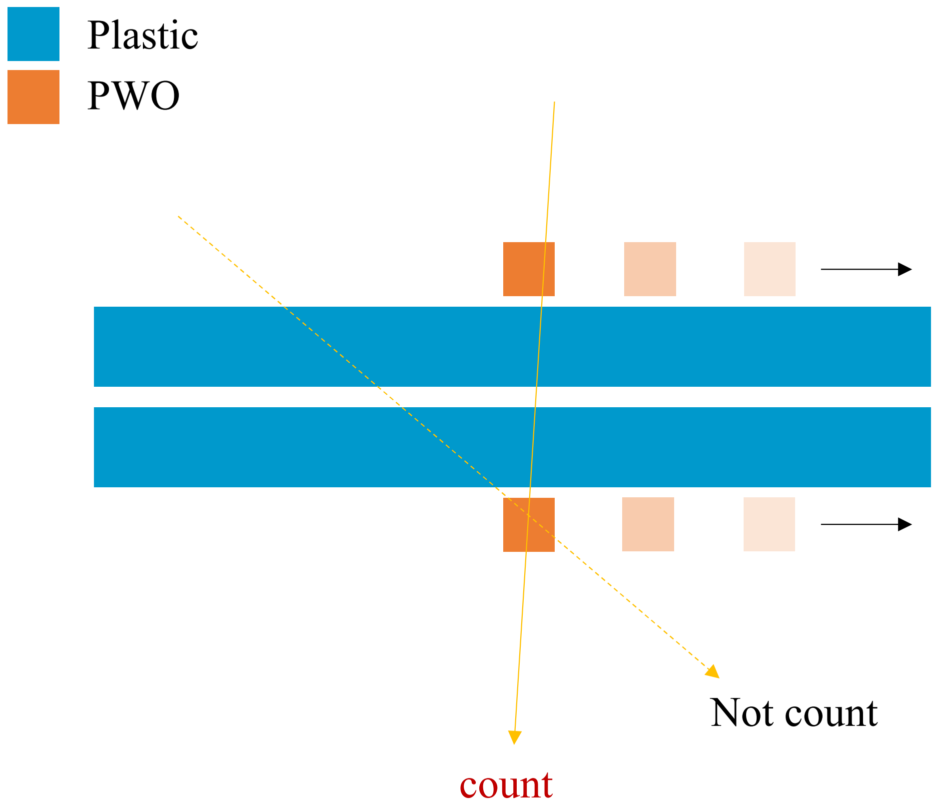
Prototype TOF detector : set-up

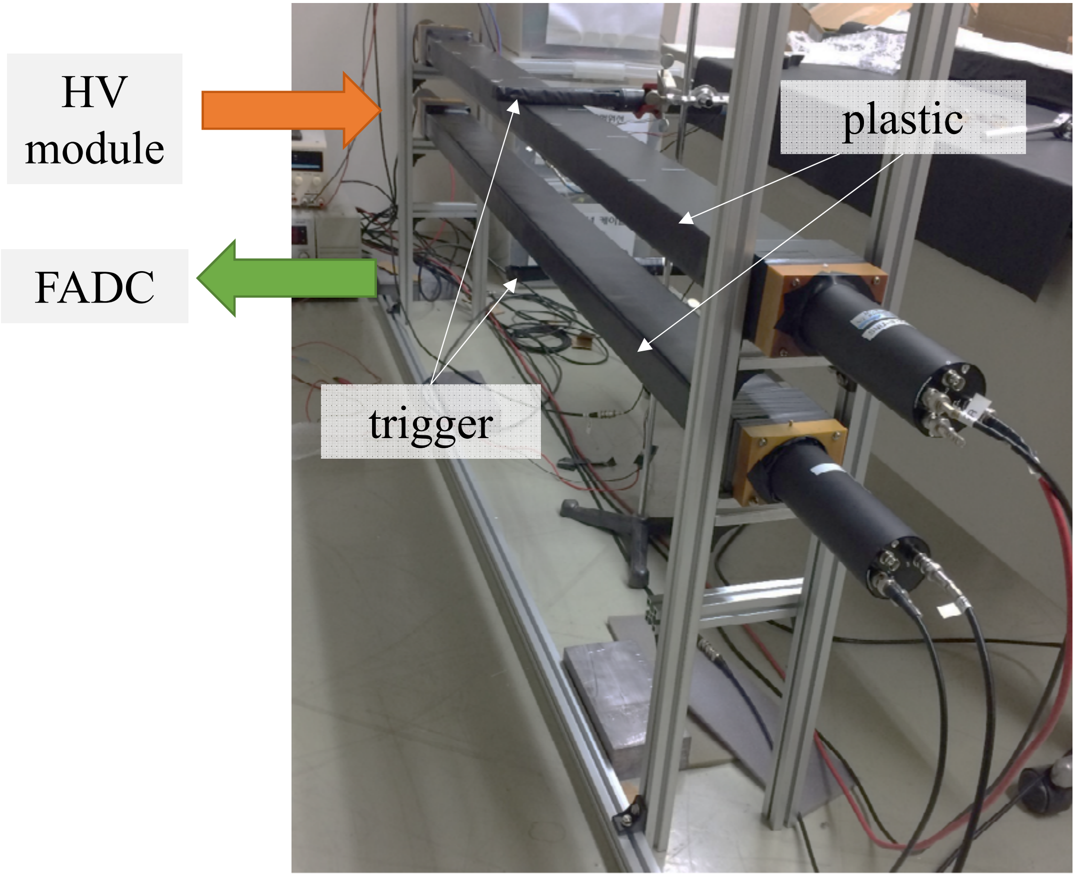


Without any source,
Cosmic rays go through scintillators and make signals.

Triggers are situated at center(0cm), 20cm, 40cm, 60cm, 77cm from center.

Only takes coincidence data of 4 PMTs,
then we can measure the time resolutions
and find time – position conversion factor.

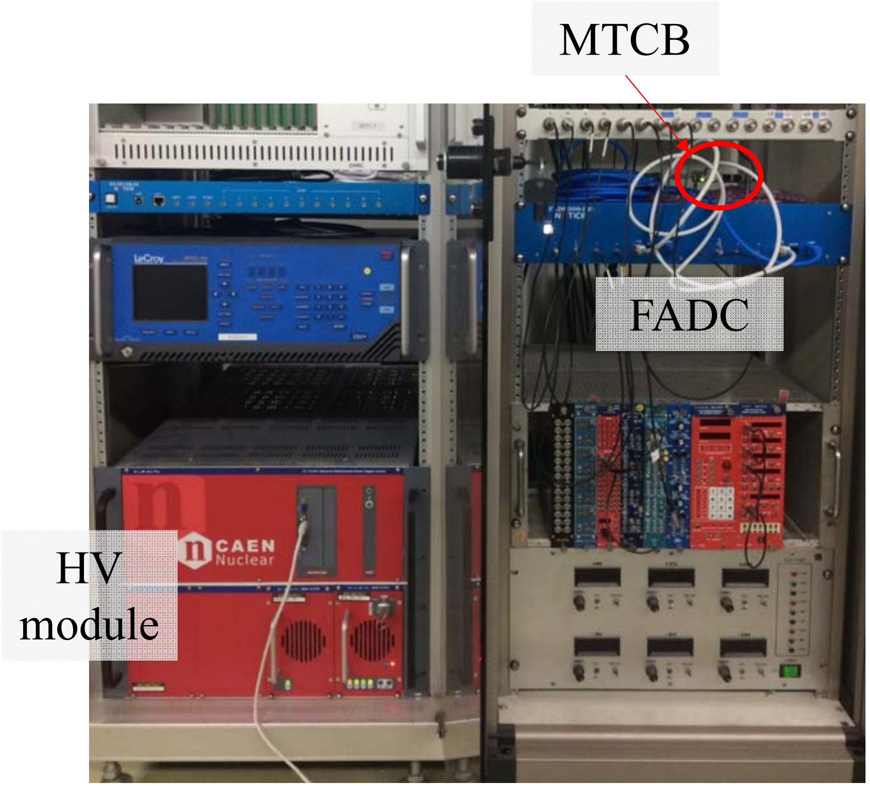
Prototype TOF detector : set-up



2 plastic bars + 2 PWO triggers
sustained by aluminum profiles and clamps

Cosmic ray data from PMTs, taken by FADC

Prototype TOF detector : set-up



FADC (NOTICE, 500-IBS)

- ✓ 2V /4000 ch = about 0.5mV / ch
- ✓ 500mHz = 2 ns / event
- ✓ USB 3.0 Hub

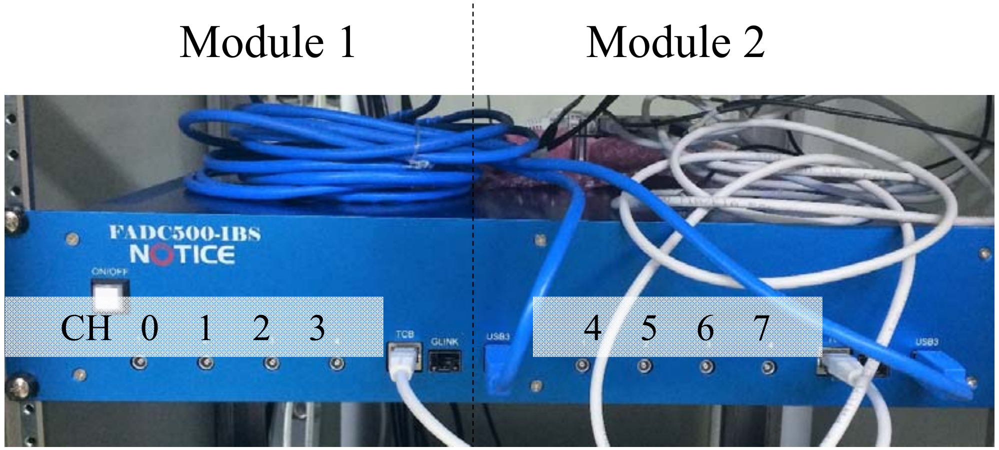
MTCB – sync board

- ✓ to synchronize two modules in FADC
- ✓ USB 3.0 Hub

HV supplier(CAEN, SY1527LC)

- ✓ 12 ch * 4 boards
- ✓ 4kV – 3mA
- ✓ power requirement : ~ 3,4000W

Prototype TOF detector : set-up



Top plastic scintillator – ch 0,1
Bottom plastic scintillator – ch 2,3

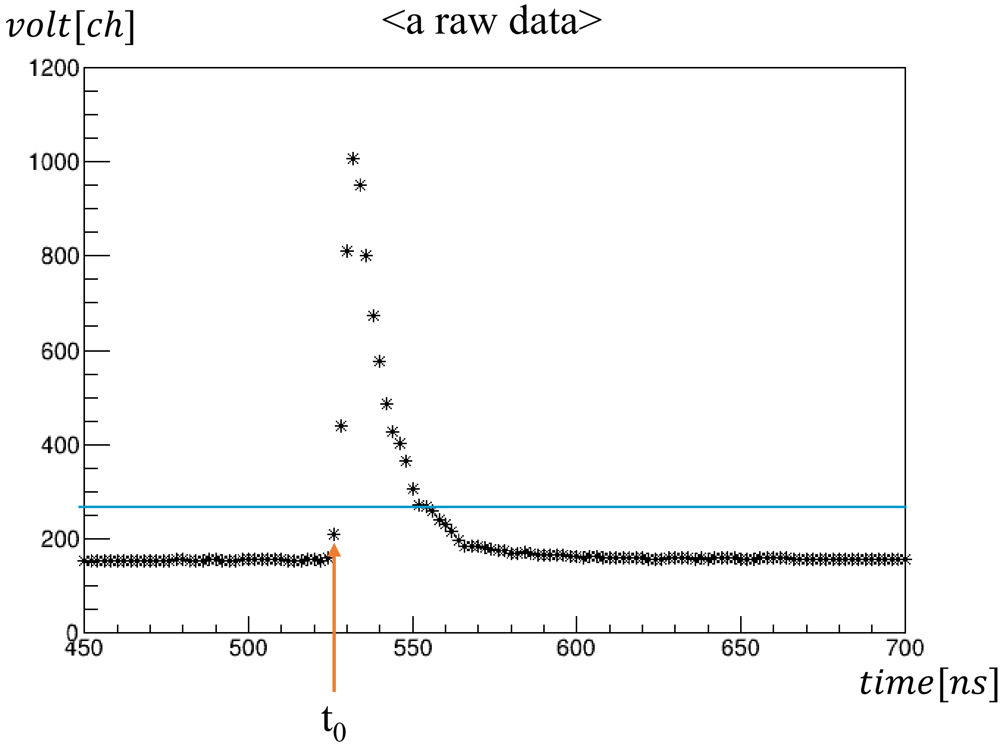
Trigger – ch4(up), ch5(down)

Prototype TOF detector : analysis method

1) How to find the rising time, t_r

→ Inverse interpolation is used to find t_r

<a raw data>



1. Find the voltage(height) at the peak
2. Find t_0, which is a time of the nearest point from the line indicating 10% peak

Prototype TOF detector : analysis method

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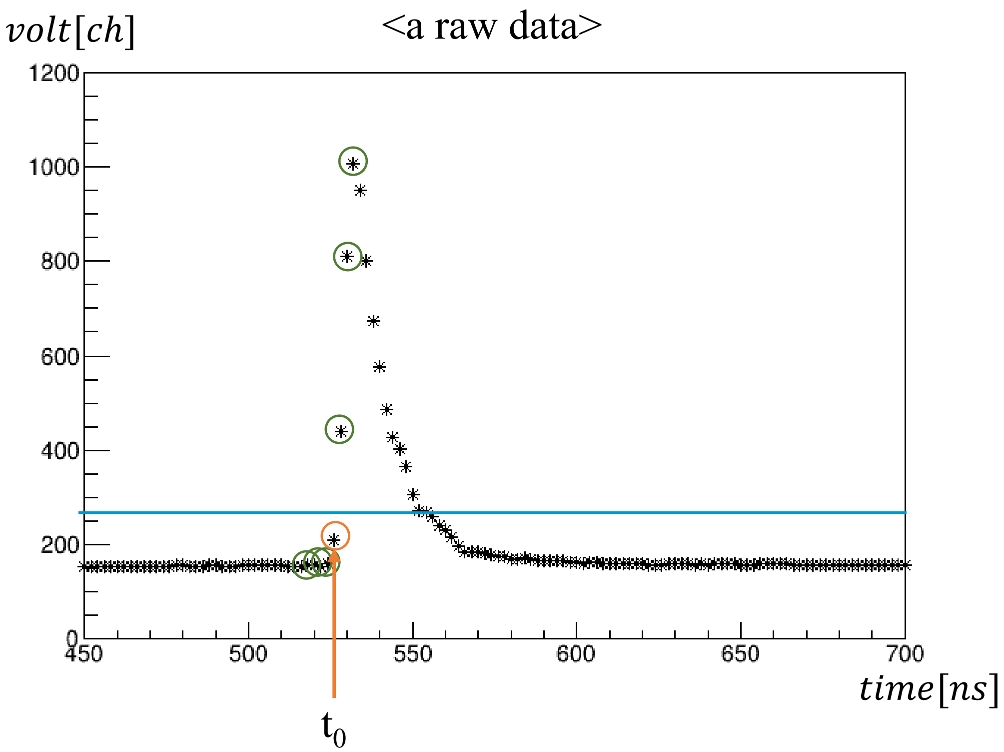

1. Find the voltage(height) at the peak
2. Find t_0, which is a time of the nearest point from the line indicating 10% peak
3. Select 3 points before t_0, and after t_0

Prototype TOF detector : analysis method

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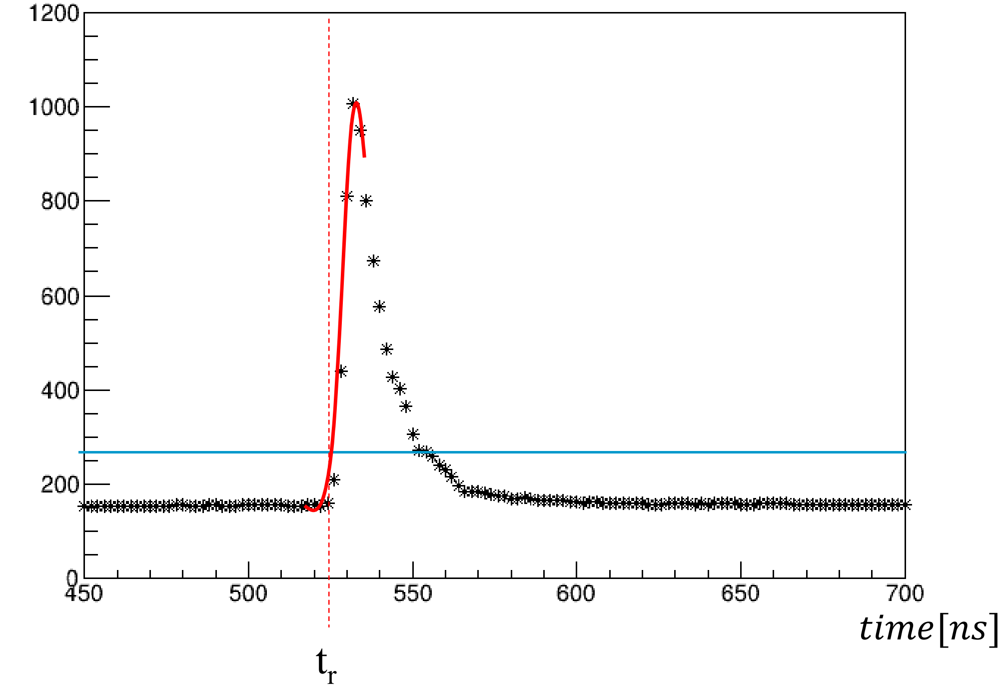


1. Find the voltage(height) at the peak
2. Find t_0, which is a time of the nearest point from the line indicating 10% peak
3. Select 3 points before t_0, and after t_0
4. With 7 points near t_0,
   use inverse interpolation and find t_r, where
   $$f(t_r) = 0.1 * (peak\ height)$$

Computational Methods in Physics and Engineering, S.M.Wong

Prototype TOF detector : analysis method

2) How to define the time difference

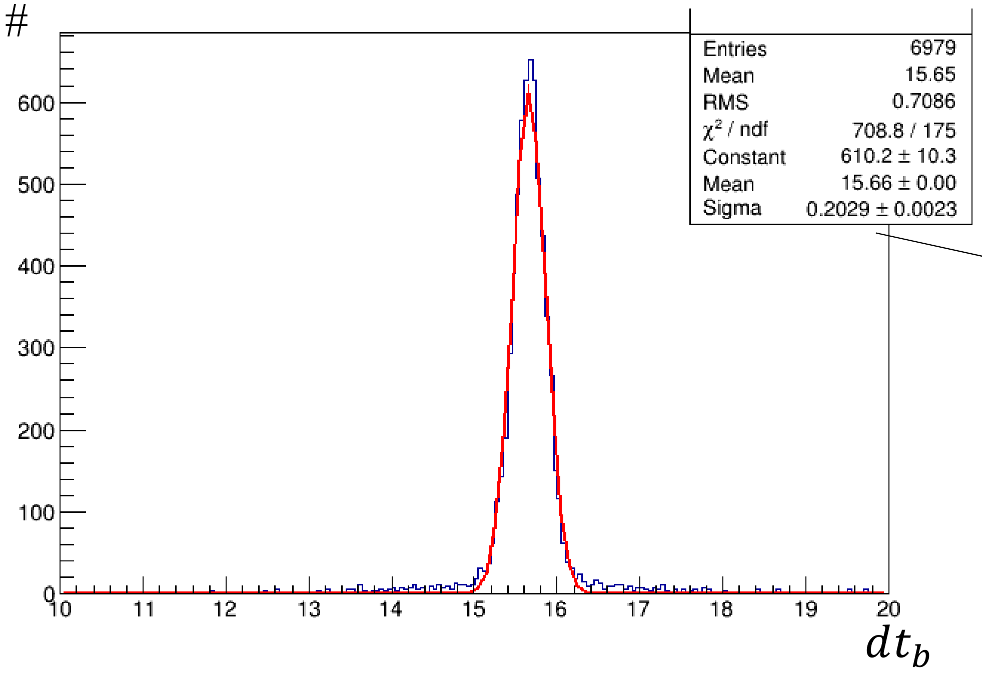
Using $t_{r,0} \sim t_{r,3}$,

1. $dt_b = t_{r,0} - t_{r,1}$, $dt_t = t_{r,2} - t_{r,3}$
2. dtmean = (tmean_b) – (tmean_t)
   tmean_b = $\frac{t_{r,0}+t_{r,1}}{2}$
   tmean_t = $\frac{t_{r,2}+t_{r,3}}{2}$
3. dtfast = (tfast_b) – (tfast_t)
   tfast_b = faster time btw $t_{r,0}$~$t_{r,1}$
   tfast_t = faster time btw $t_{r,2}$~$t_{r,3}$

Prototype TOF detector : analysis method

2) How to define the time difference

Draw the histogram of 1~3, and fit with Gaussian distribution.
Then can find mean, sigma values.



The resolution of histogram,

$$\sigma = 0.2029\ [ns]$$

The resolution of dt_b,

$$\sigma = \frac{0.2029}{\sqrt{2}}[ns] = 0.1434\ [ns]$$

Prototype TOF detector : results

① time resolution (at center)

	mean [ns]	sigma [ns]
dt_b	15.66	0.1434
dt_t	-1.794	0.1551
dtmean	7.718	0.1119
dtfast	0.7901	0.1335

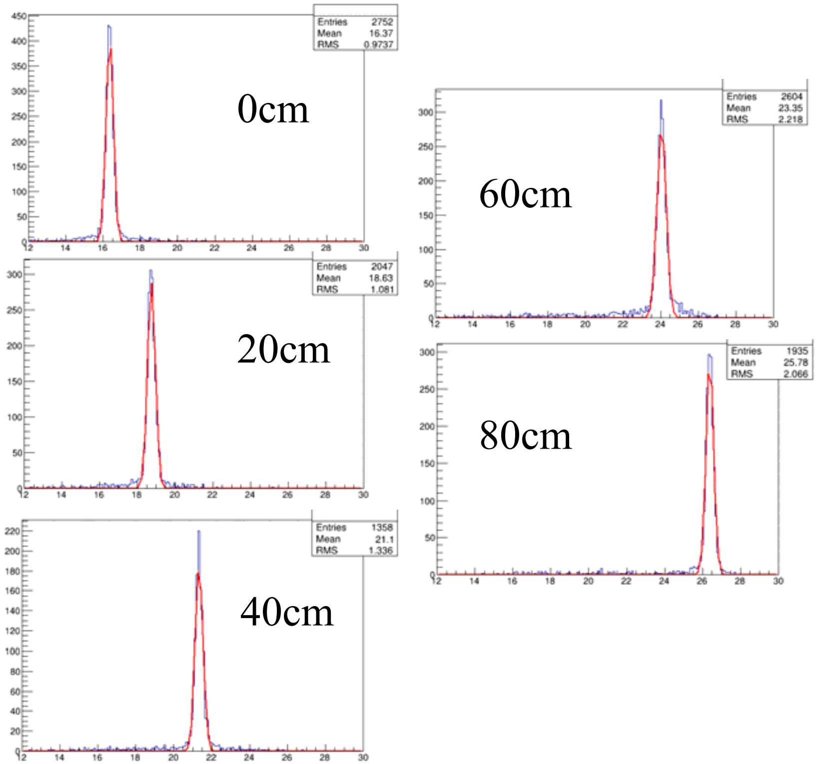
< 0.2 ns

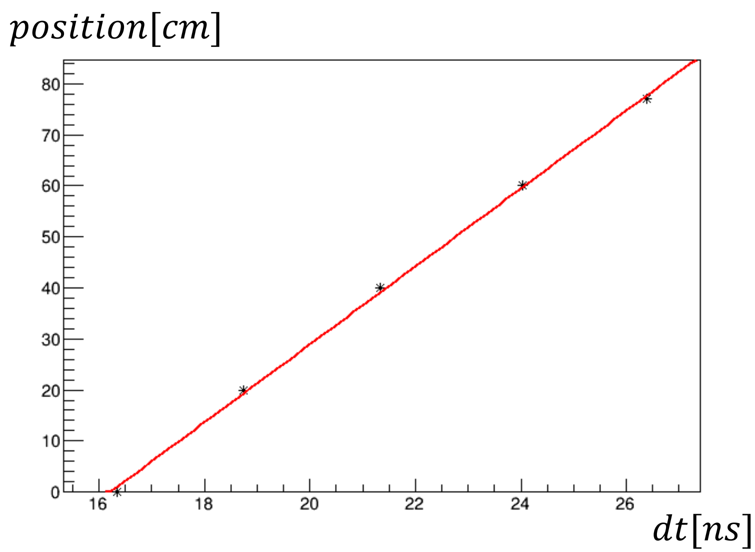
It varies depending on what methods we used to obtain time difference.
But, all of them is about 110~150ps.

→ **Enough to distinguish top & bottom and cosmic ray annihilation!**

Prototype TOF detector : results

② time – position conversion factor (bottom scintillator)

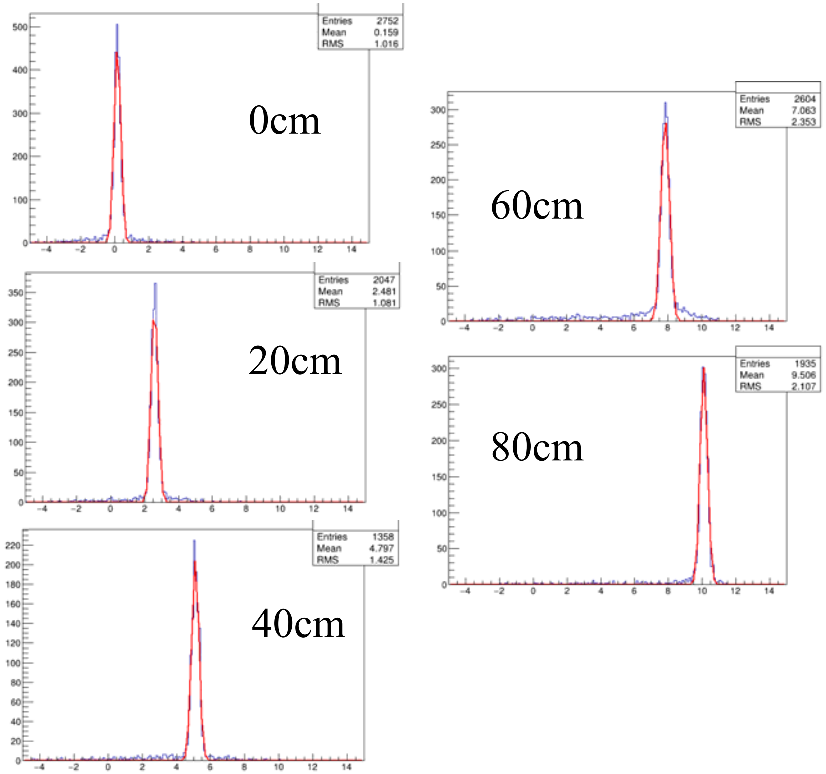


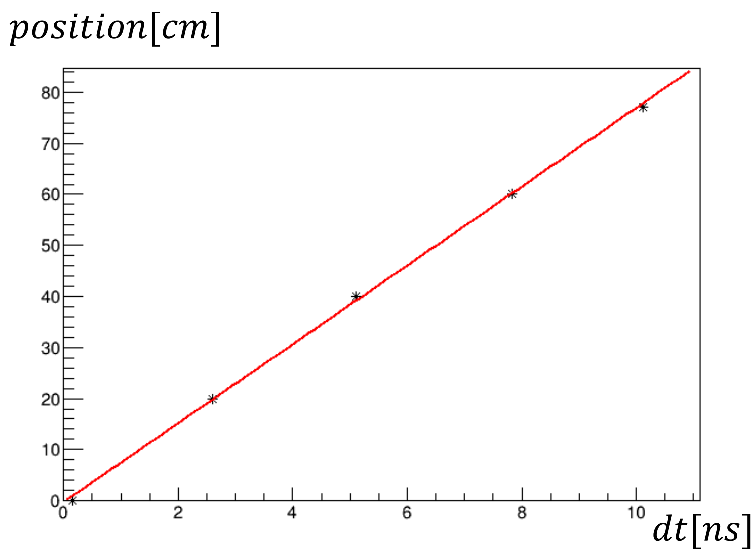


$$y[cm] = 7.6368\,x[ns] - 123.798$$

Prototype TOF detector : results

② time – position conversion factor (top scintillator)



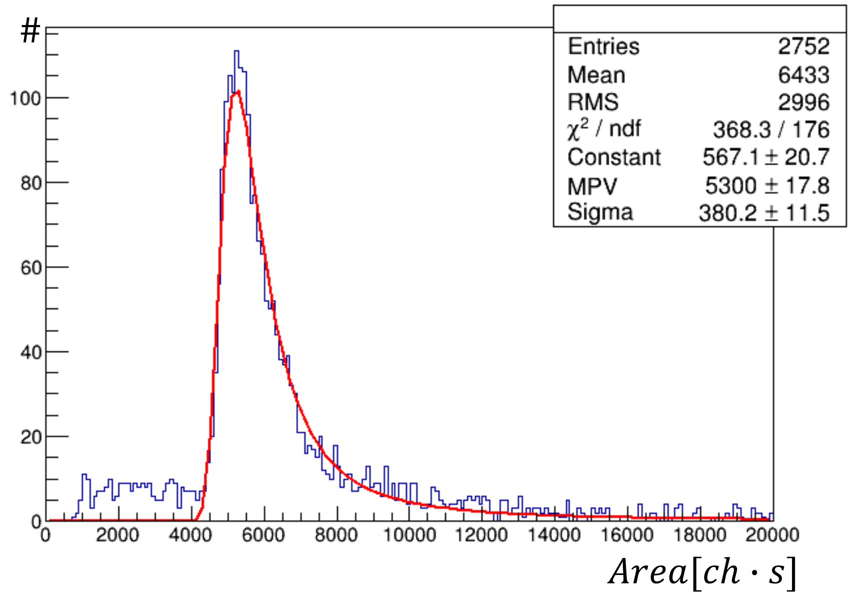


$$y[cm] = 7.7241\,x[ns] - 0.24933$$

Prototype TOF detector : results

③ Energy calibration

< Area distribution, ch0 >



$$\begin{pmatrix} Most \\ Probable \\ Value \end{pmatrix} = C * \ muon\ energy, \qquad C = const.$$

$$C = \frac{MPV}{38.5[MeV]} = \frac{5300[ch \cdot s]}{38.5[MeV]} = \frac{2650[mV \cdot s]}{38.5[MeV]}$$

$$\therefore C = 0.068\ [Vs \cdot MeV^{-1}]$$

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Summary

- the GBAR experiment is going to measure the gravity of antihydrogen.
- One of the most important steps in GBAR is the measurement of Time of Flight(TOF). As a TOF detector, we designed an array of plastic scintillator bars.
- According to simulation results, the resolution higher than 0.2ns is required, to distinguish if the signal came from top, bottom chamber or cosmic rays.
- We have developed a prototype TOF detector, with FADC DAQ system. By testing the prototype with cosmic ray signal, we confirmed that the resolution is much better than 0.2ns.
- Also, we calculated time – position conversion factor and calibrated its energy scale.