20171020
STATUS REPORT
(2017 Fall KPS presentation)

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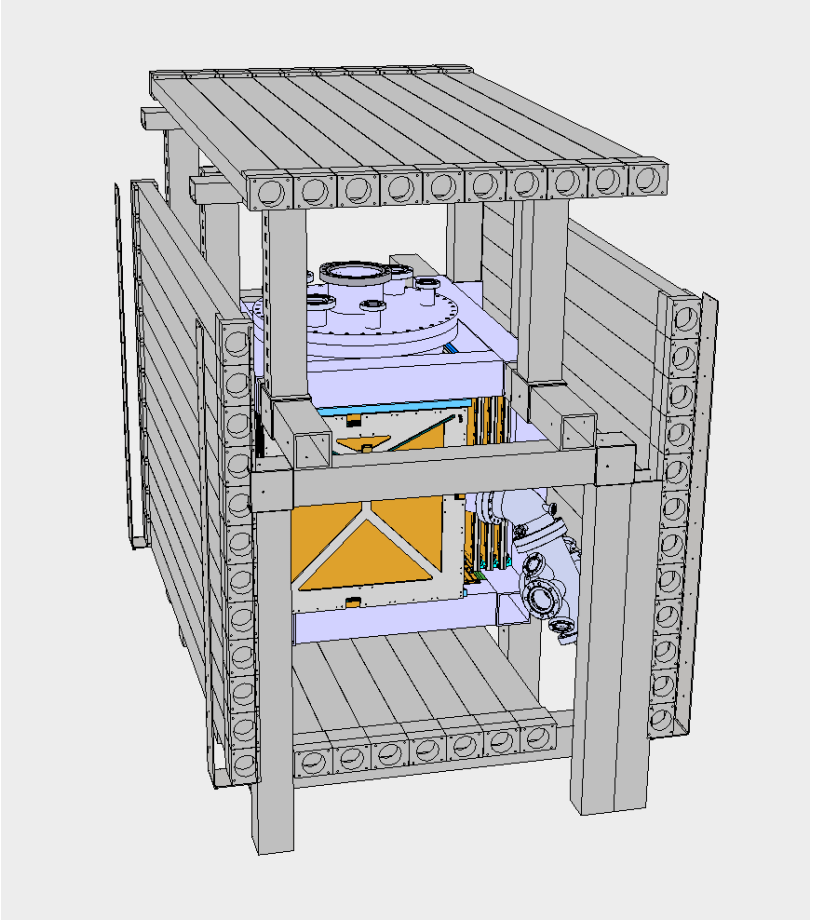
TOF description
Geometry

An array of plastic scintillation counters.

One bar = 10*5*170 cm^3
One counter = (PMT) – (plastic bar) – (PMT)
One wall (left/right) = 12 counters
(top/bottom) = 10 counters
* It is changeable, depending on FFC

Totally, 44bars and 88PMTs



TOF description

Purpose

From the fastest one among signals from the annihilation,
Free-fall time is obtained.

From the time difference between top & bottom hits,
top annihilation, bottom annihilation,
and cosmic ray hit are distinguished.

$dT < 0$ for chamber-bottom-annihilation
$0 < dT < 2$ top
$2 < dT$ for cosmic-ray signal

T_1 = time to bottom of TOF
T_2 = time to top of TOF
$\mathrm{dT} = \mathrm{T}_1 - T_2$

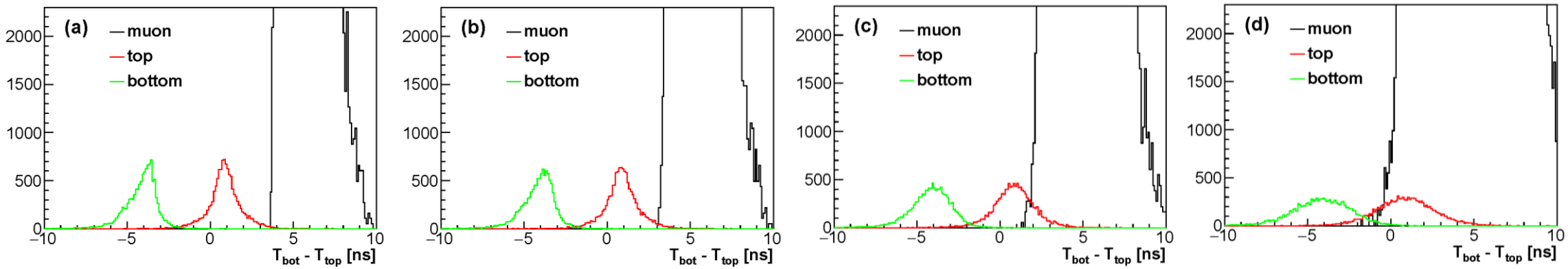
TOF description

Requirement

To cosmic ray rejection, the time resolution should be smaller than 0.2ns.

3-pi decay events, 825mm height, 4 different t-resolution

(normalized pion:muon = 1:5500)



(a) 0.1 ns (b) 0.2 ns (c) 0.5 ns (d) 1.0 ns

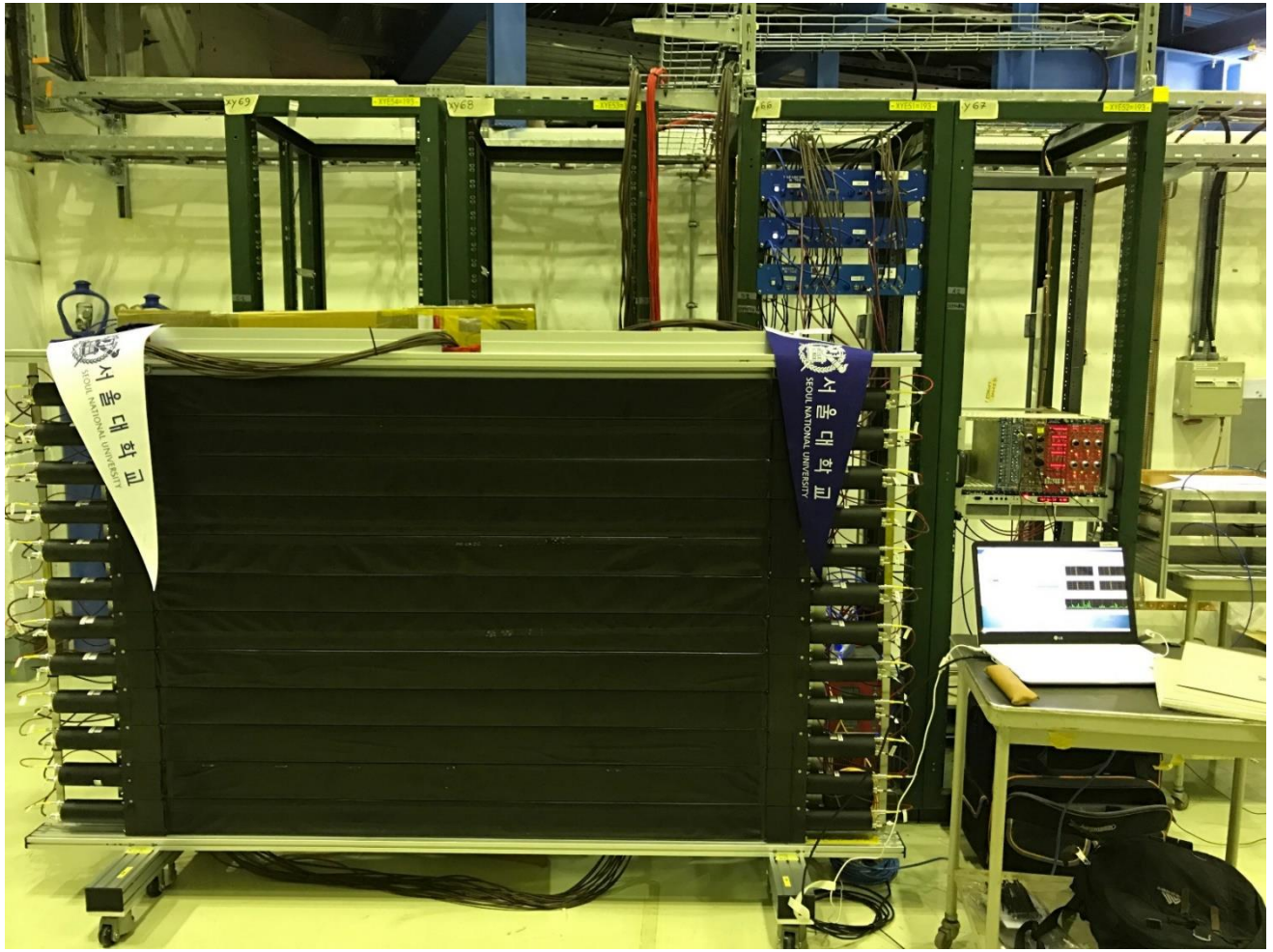
Distinguishable !

Chamber-top-annihilation signal is not distinguishable from cosmic ray signal

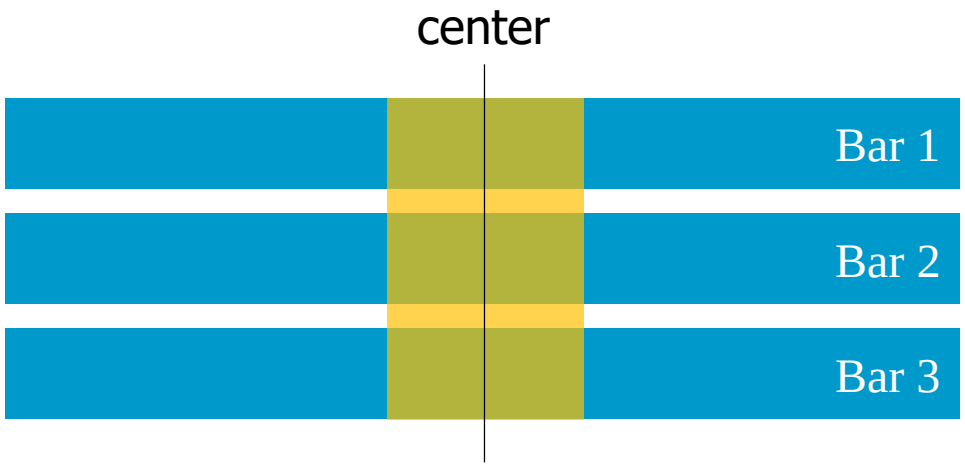
Performance
Cosmic muon test : settings

A wall of TOF has been installed
in AD hall, CERN, during this summer.

To check DAQ program,
and to see its performances as a wall,
Cosmic muon test has been proceeded.



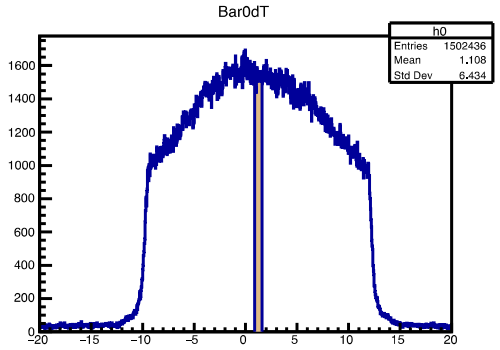
Performance
Time-resolution test

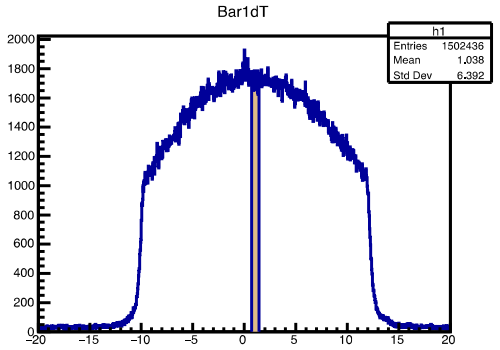


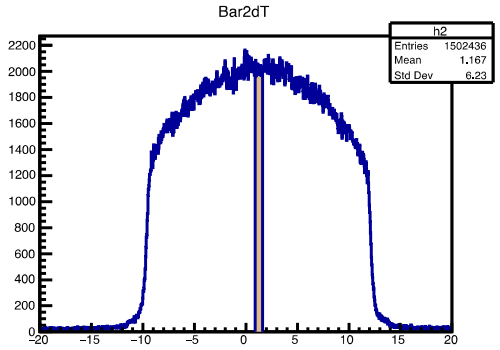
The event that cosmic ray hits any 6 bars among 12 bars, is saved.

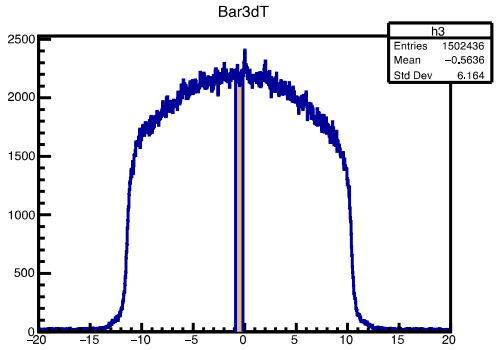
Group three bars into a group.

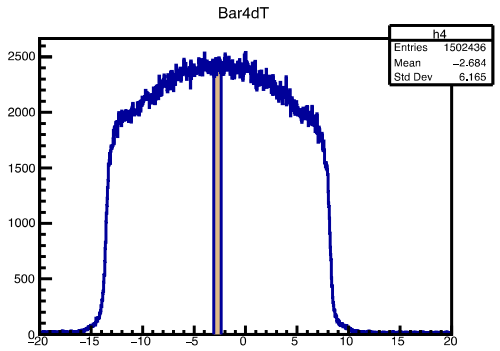
In a group,
select the events that passing through within +-5cm from their center(0cm).

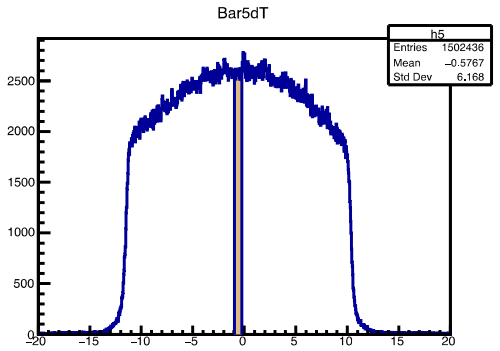

Bar0dT
h0
Entries 1502436
Mean 1.108
Std Dev 6.434

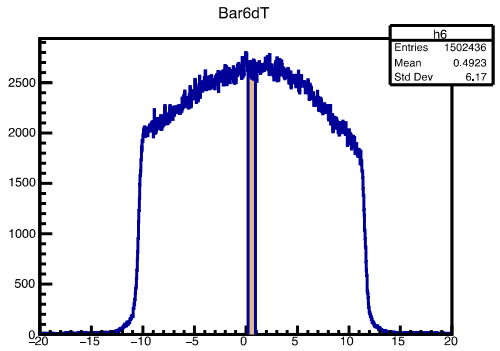

Bar1dT
h1
Entries 1502436
Mean 1.038
Std Dev 6.392

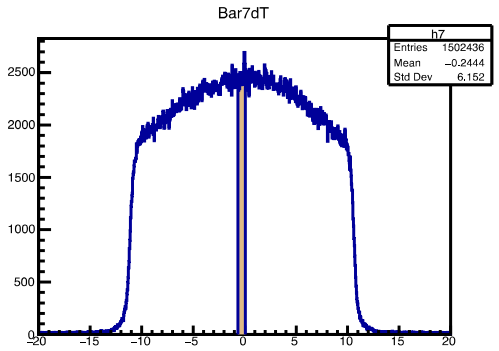

Bar2dT
h2
Entries 1502436
Mean 1.167
Std Dev 6.23

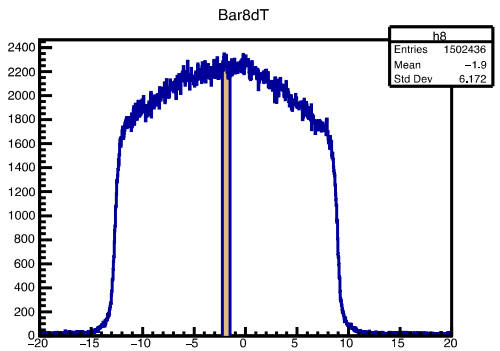

Bar3dT
h3
Entries 1502436
Mean −0.5636
Std Dev 6.164

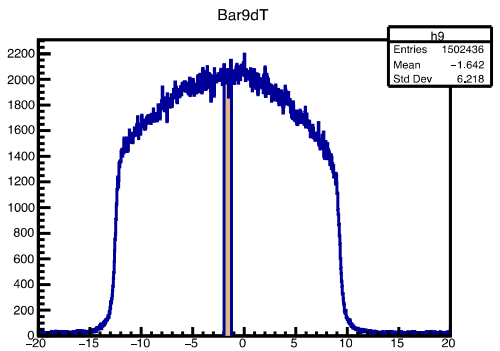

Bar4dT
h4
Entries 1502436
Mean −2.684
Std Dev 6.165

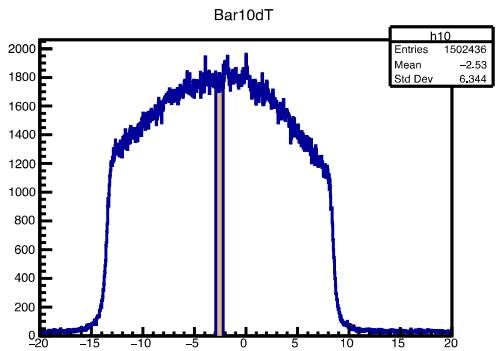

Bar5dT
h5
Entries 1502436
Mean −0.5767
Std Dev 6.168

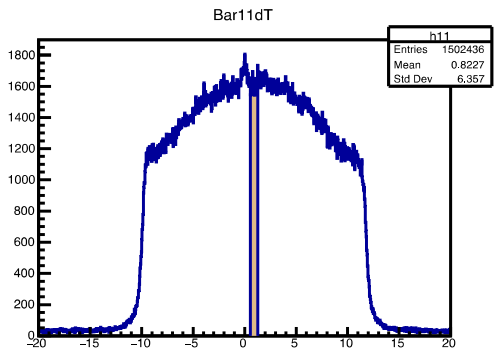

Bar6dT
h6
Entries 1502436
Mean 0.4923
Std Dev 6.17


Bar7dT
h7
Entries 1502436
Mean −0.2444
Std Dev 6.152


Bar8dT
h8
Entries 1502436
Mean −1.9
Std Dev 6.172


Bar9dT
h9
Entries 1502436
Mean −1.642
Std Dev 6.218

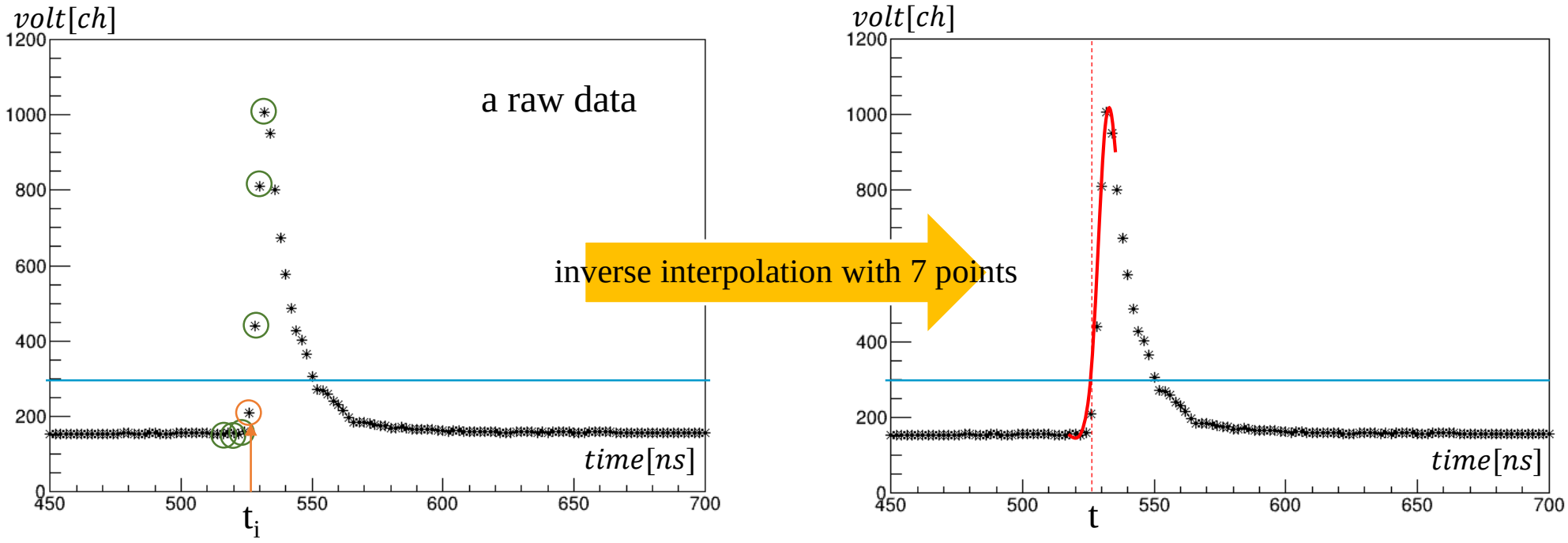

Bar10dT
h10
Entries 1502436
Mean −2.53
Std Dev 6.344


Bar11dT
h11
Entries 1502436
Mean 0.8227
Std Dev 6.357

Performance

Time-resolution test

The event time of signal is determined by inverse interpolation method.



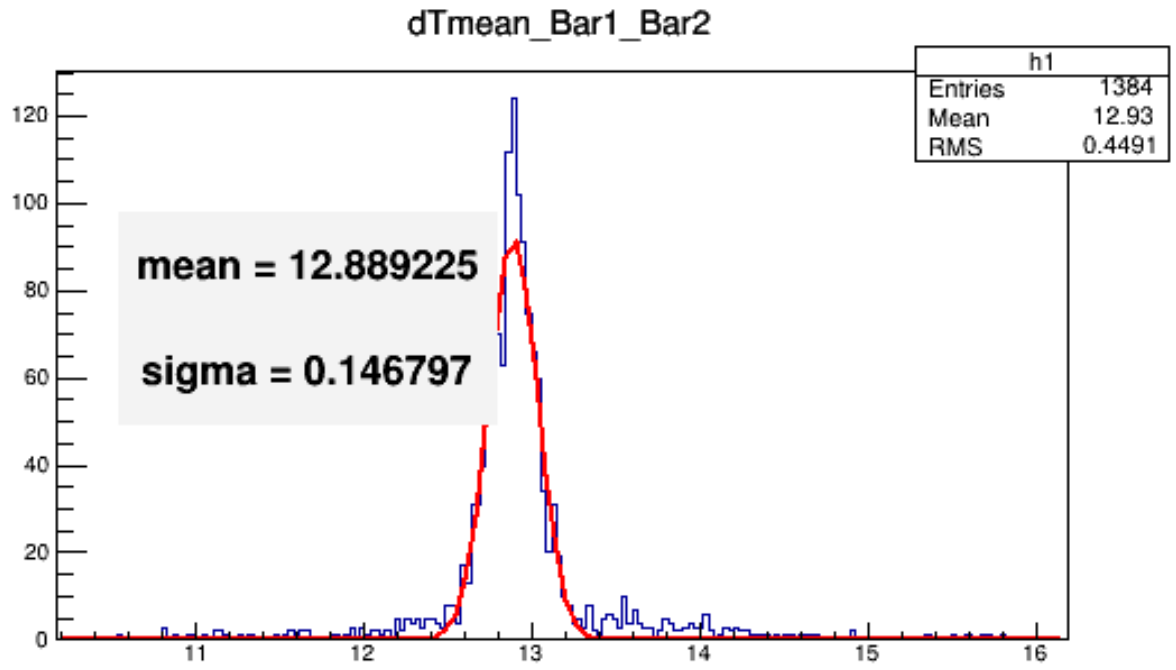
t_i = the nearest point from 10% line

$$f(\mathrm{t}) = 0.1 * (peak\ height)$$

Performance

Time-resolution test

From the distribution of the event time difference between bars,
Time resolution of one bar can be calculated.



dtmean = (tmean_1) – (tmean_2)

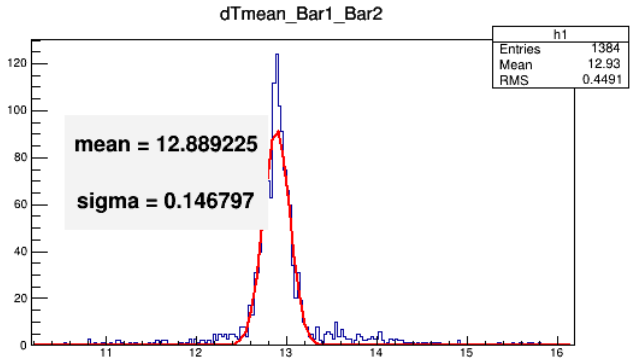
tmean_1 = $(t_1+t_2)/2$

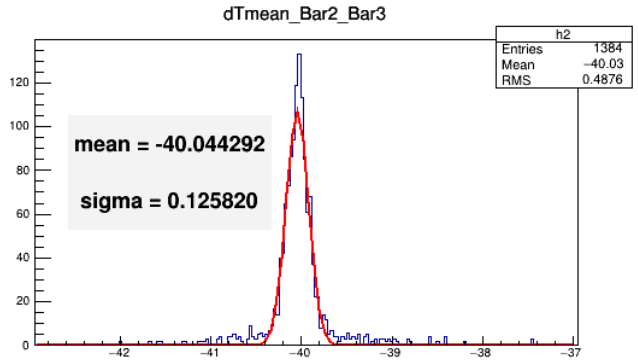
tmean_2 = $(t_3+t_4)/2$

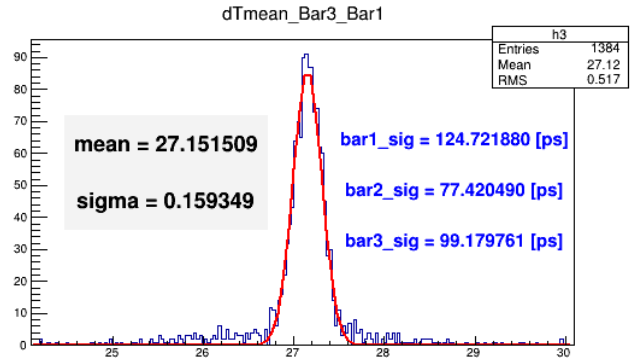
Performance

Time-resolution test

From the distribution of the event time difference between bars,
Time resolution of one bar can be calculated.

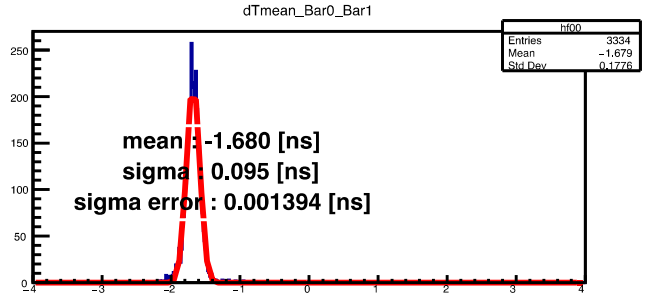


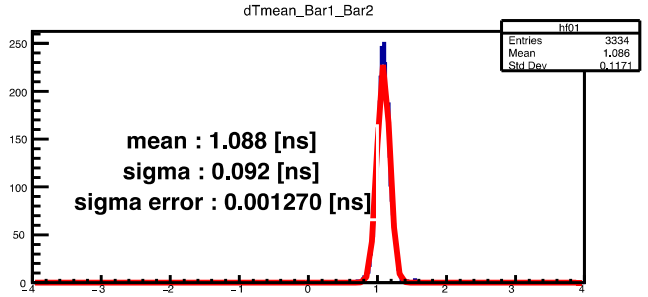


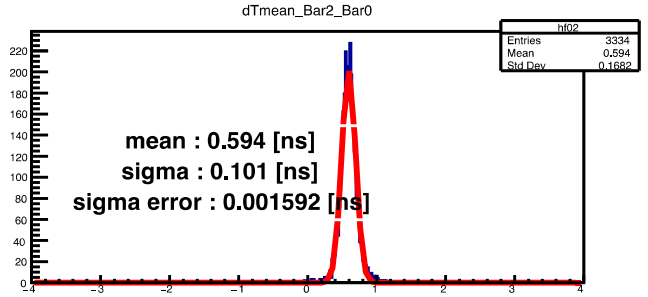


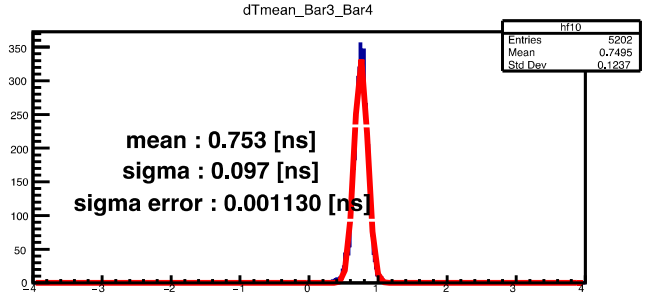
$$(\sigma_{h1})^2 = \sigma_1^2 + \sigma_2^2, \qquad (\sigma_{h2})^2 = \sigma_2^2 + \sigma_3^2, \qquad (\sigma_{h3})^2 = \sigma_3^2 + \sigma_1^2$$

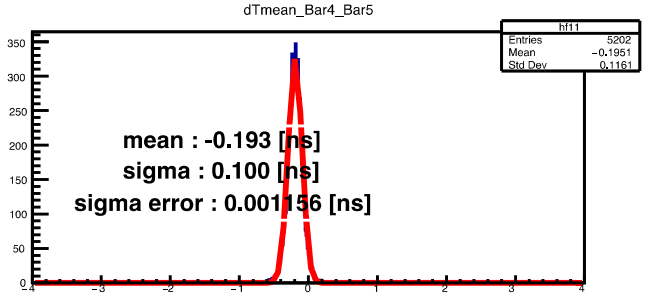
$$\longrightarrow \quad \sigma_1 = \sqrt{\frac{(\sigma_{h1})^2 - (\sigma_{h2})^2 + (\sigma_{h3})^2}{2}}, \qquad \sigma_2 = \sqrt{\frac{(\sigma_{h1})^2 + (\sigma_{h2})^2 - (\sigma_{h3})^2}{2}}, \qquad \sigma_3 = \sqrt{\frac{-(\sigma_{h1})^2 + (\sigma_{h2})^2 + (\sigma_{h3})^2}{2}}$$

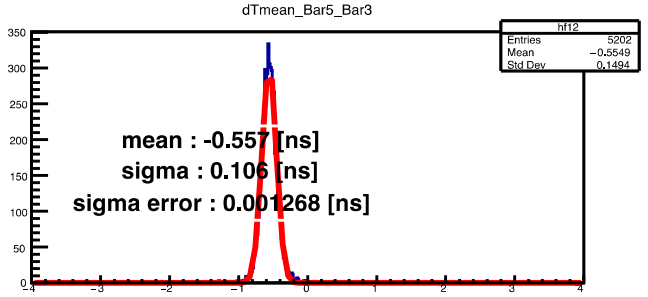

dTmean_Bar0_Bar1
hf00
Entries 3334
Mean −1.679
Std Dev 0.1776
mean : -1.680 [ns]
sigma : 0.095 [ns]
sigma error : 0.001394 [ns]

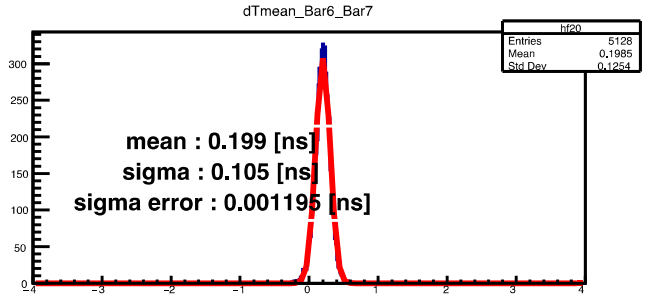

dTmean_Bar1_Bar2
hf01
Entries 3334
Mean 1.086
Std Dev 0.1171
mean : 1.088 [ns]
sigma : 0.092 [ns]
sigma error : 0.001270 [ns]

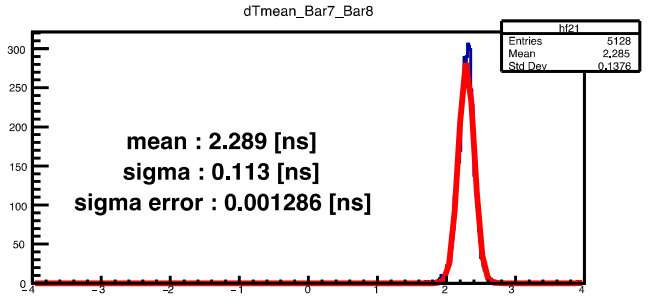

dTmean_Bar2_Bar0
hf02
Entries 3334
Mean 0.594
Std Dev 0.1682
mean : 0.594 [ns]
sigma : 0.101 [ns]
sigma error : 0.001592 [ns]

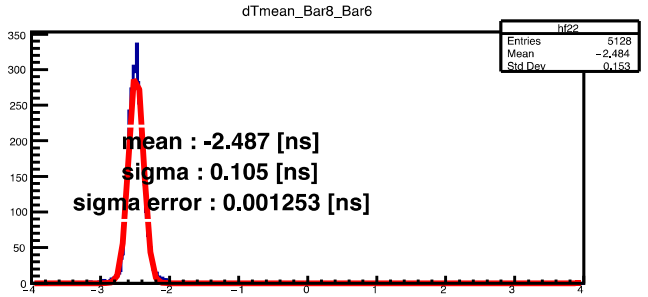

dTmean_Bar3_Bar4
hf10
Entries 5202
Mean 0.7495
Std Dev 0.1237
mean : 0.753 [ns]
sigma : 0.097 [ns]
sigma error : 0.001130 [ns]

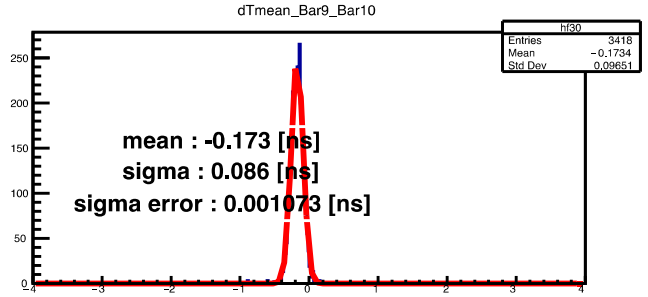

dTmean_Bar4_Bar5
hf11
Entries 5202
Mean −0.1951
Std Dev 0.1161
mean : -0.193 [ns]
sigma : 0.100 [ns]
sigma error : 0.001156 [ns]

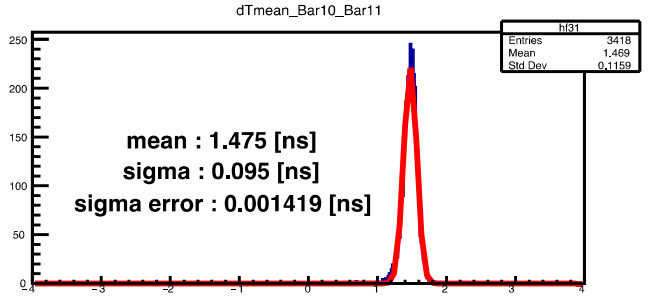

dTmean_Bar5_Bar3
hf12
Entries 5202
Mean −0.5549
Std Dev 0.1494
mean : -0.557 [ns]
sigma : 0.106 [ns]
sigma error : 0.001268 [ns]

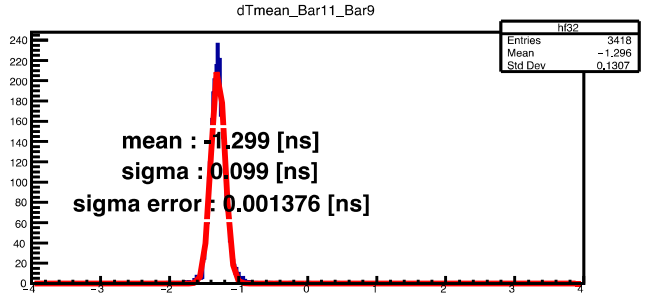

dTmean_Bar6_Bar7
hf20
Entries 5128
Mean 0.1985
Std Dev 0.1254
mean : 0.199 [ns]
sigma : 0.105 [ns]
sigma error : 0.001195 [ns]


dTmean_Bar7_Bar8
hf21
Entries 5128
Mean 2.285
Std Dev 0.1376
mean : 2.289 [ns]
sigma : 0.113 [ns]
sigma error : 0.001286 [ns]


dTmean_Bar8_Bar6
hf22
Entries 5128
Mean −2.484
Std Dev 0.153
mean : -2.487 [ns]
sigma : 0.105 [ns]
sigma error : 0.001253 [ns]


dTmean_Bar9_Bar10
hf30
Entries 3418
Mean −0.1734
Std Dev 0.09651
mean : -0.173 [ns]
sigma : 0.086 [ns]
sigma error : 0.001473 [ns]


dTmean_Bar10_Bar11
hf31
Entries 3418
Mean 1.469
Std Dev 0.1159
mean : 1.475 [ns]
sigma : 0.095 [ns]
sigma error : 0.001419 [ns]


dTmean_Bar11_Bar9
hf32
Entries 3418
Mean −1.296
Std Dev 0.1307
mean : -1.299 [ns]
sigma : 0.099 [ns]
sigma error : 0.001376 [ns]

Performance

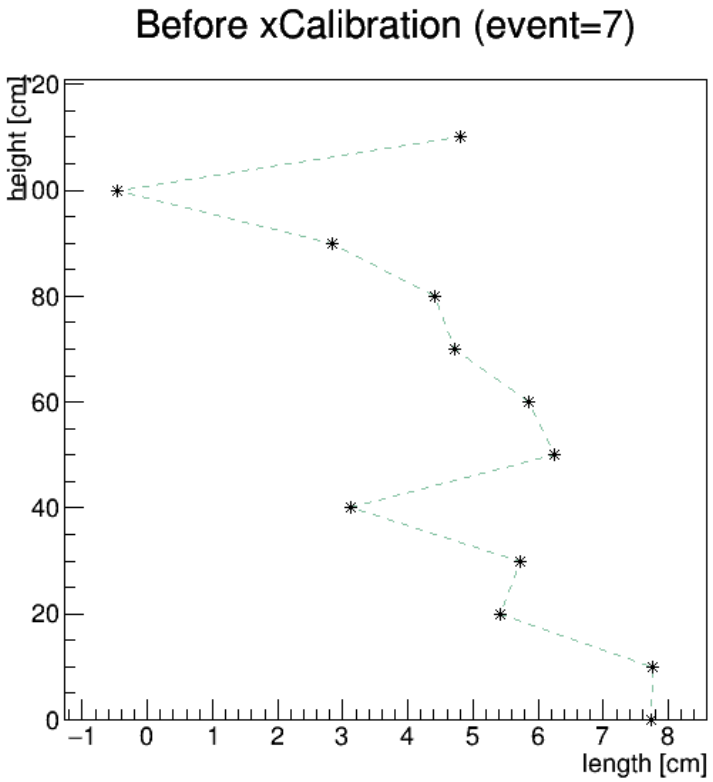
Time-resolution test : results

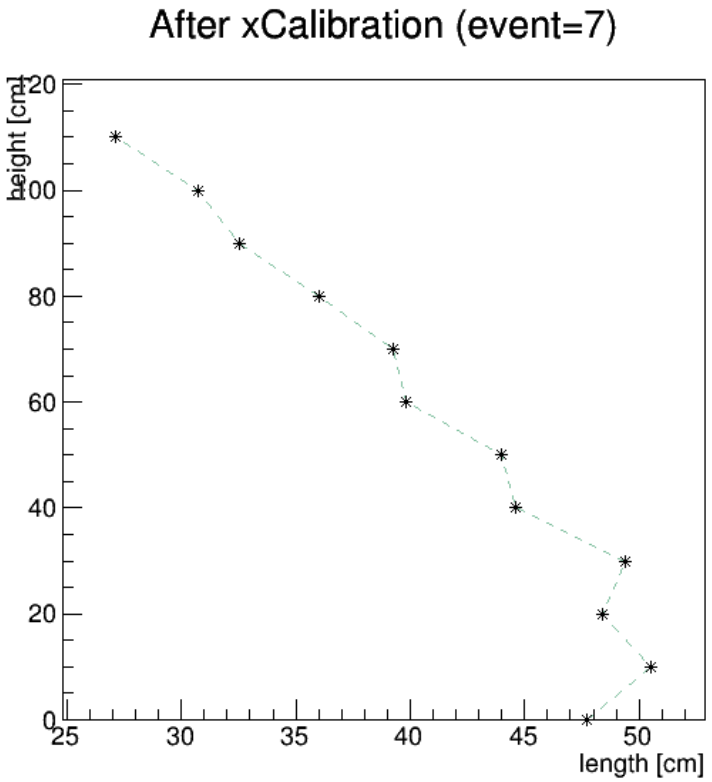
bar#	Resolution[ps]		bar#	Resolution[ps]	
	prototype	A wall		prototype	A wall
1	96	73	7	78	68
2	87	60	8	98	79
3	124	69	9	96	80
4	77	73	10	83	63
5	99	64	11	83	58
6	100	77	12	81	76

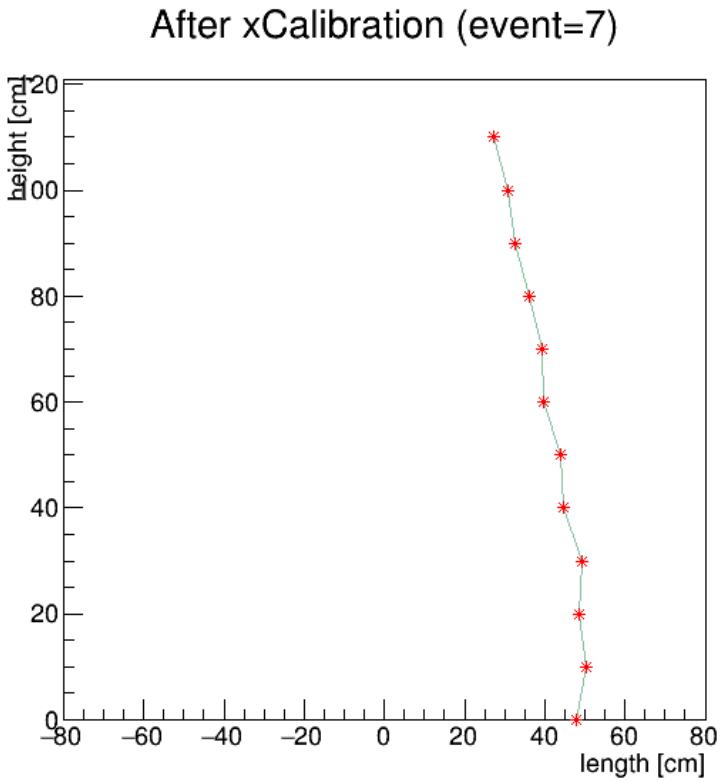
$$\sigma_{time} < 0.2\ ns,$$

→ Enough to distinguish top, bottom annihilations and cosmic ray signal

Performance
2D trajectory reconstruction



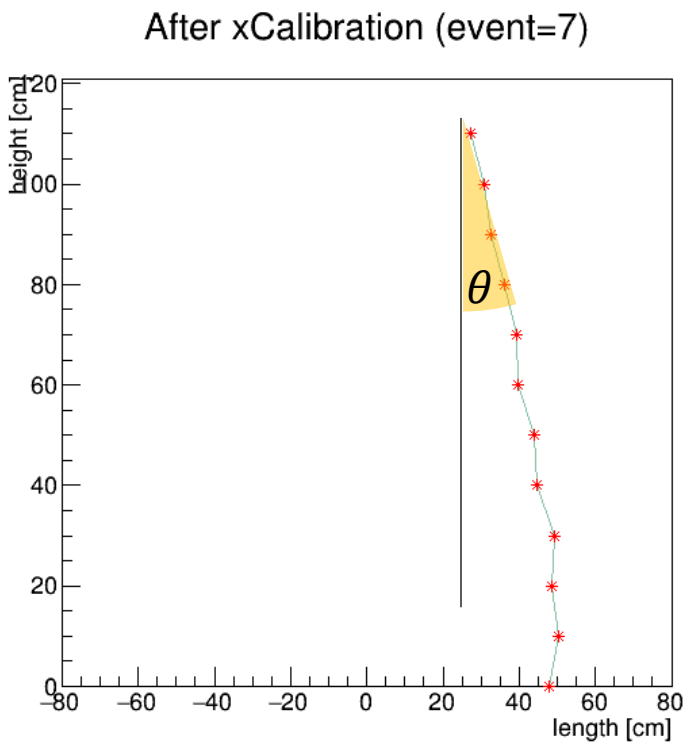


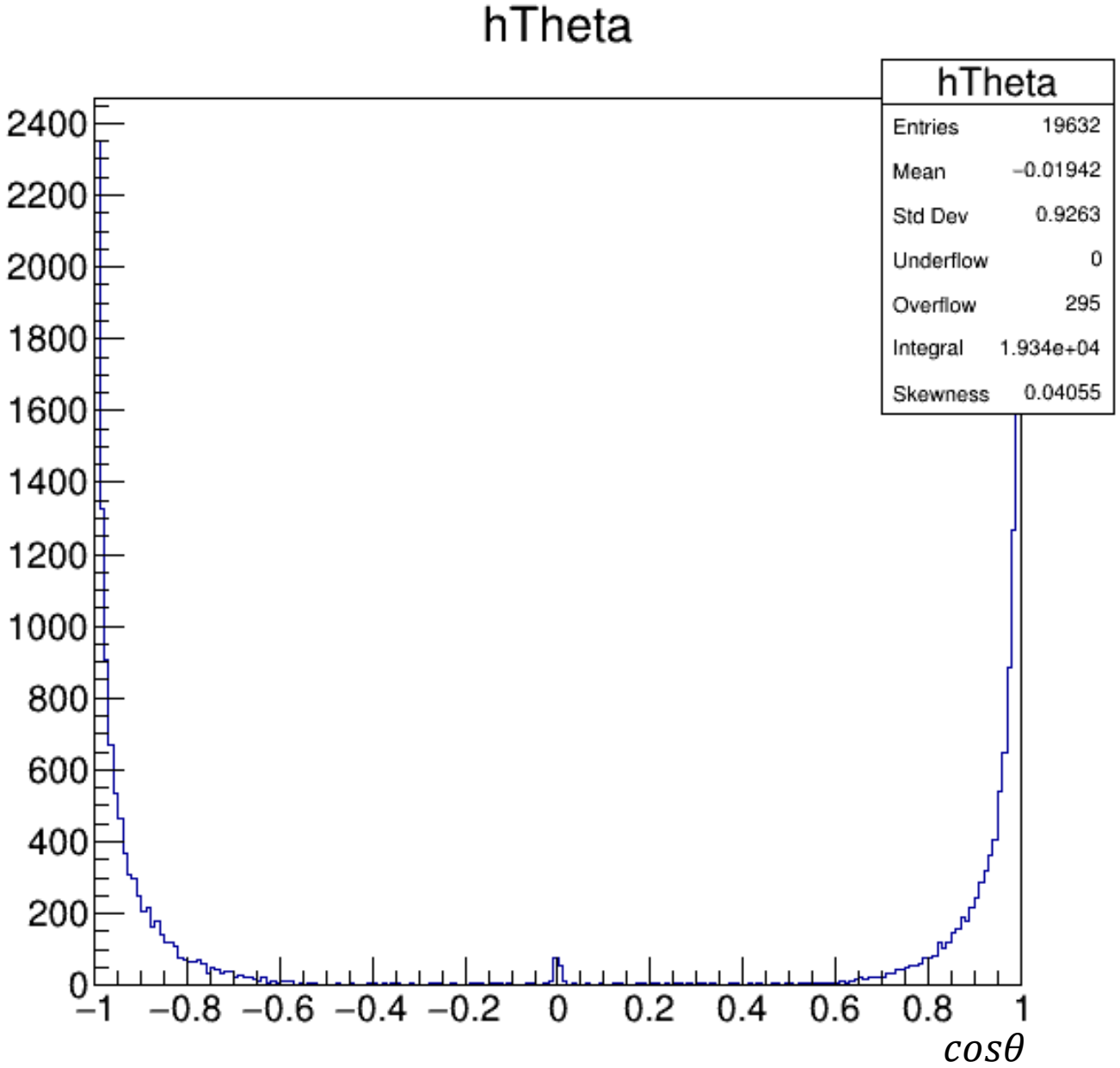


Performance

2D trajectory reconstruction

Angle distribution





Simulation

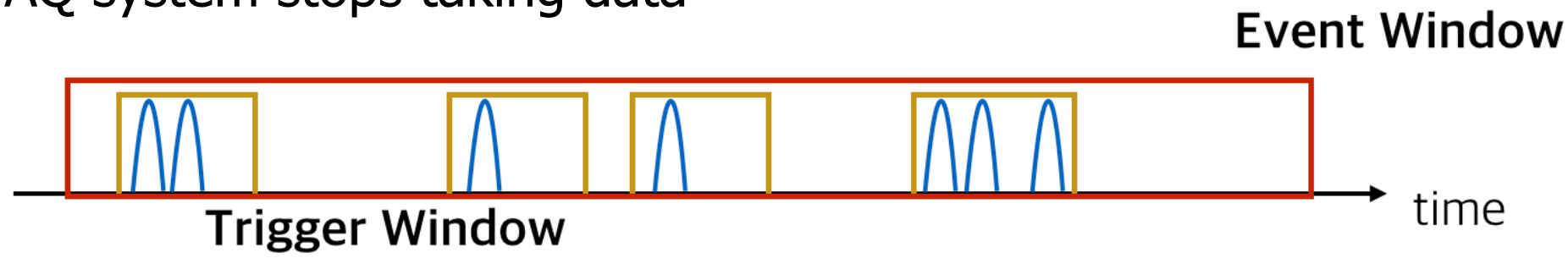
Experimental procedure : Data taking

In the experiment, data will be taken in the following sequence.

① Data acquisition starts, by positron detachment laser(PDL) trigger, when an anti-hydrogen begins to fall

② If any signal hit(from annihilation or cosmic ray), data is taken with time stamp, which trigger window is about 1μs

③ After the certain time of the event window(500ms), the DAQ system stops taking data



Simulation

Experimental procedure : Data analysis

For the single event,

① Clustering : merge hits of adjacent bars induced by a single track

② Cosmic-ray rejection : using the number of hits, hit pattern, and dT, determine if the trigger was caused by a cosmic ray or annihilation.

After that, the only real annihilation trigger should remain.

If so, we reconstruct the TOF, the annihilation vertex, and etc…

If not, the event may not be used

Good Events = **Only one** trigger selected

Successful Events = **Real annihilation events** in Good events

Cosmic-ray rejection

3 algorithms

(1) Select the triggers having Top-Bottom hits(with two or more hits).
Compare **the earliest** top hit and **earliest** bottom hit.
And reject the trigger with $dT = T_1 - T_2 > 2$

T_1 = time to bottom of TOF, T_2 = time to top of TOF

(2) Select the triggers having Top-Bottom hits(with two or more hits).
But compare **all the time differences** of top and bottom hit.
At least one combination of $dT > 2$ found, the event rejected.

(3) Select the triggers having Top-Bottom-hits, **more than two hits**.
But compare **all the time differences** of top and bottom hit.
At least one combination of $dT > 2$ found, the event rejected.

Cosmic-ray rejection

Simulation results

Threshold : 0.3MeV, Event window : 500ms

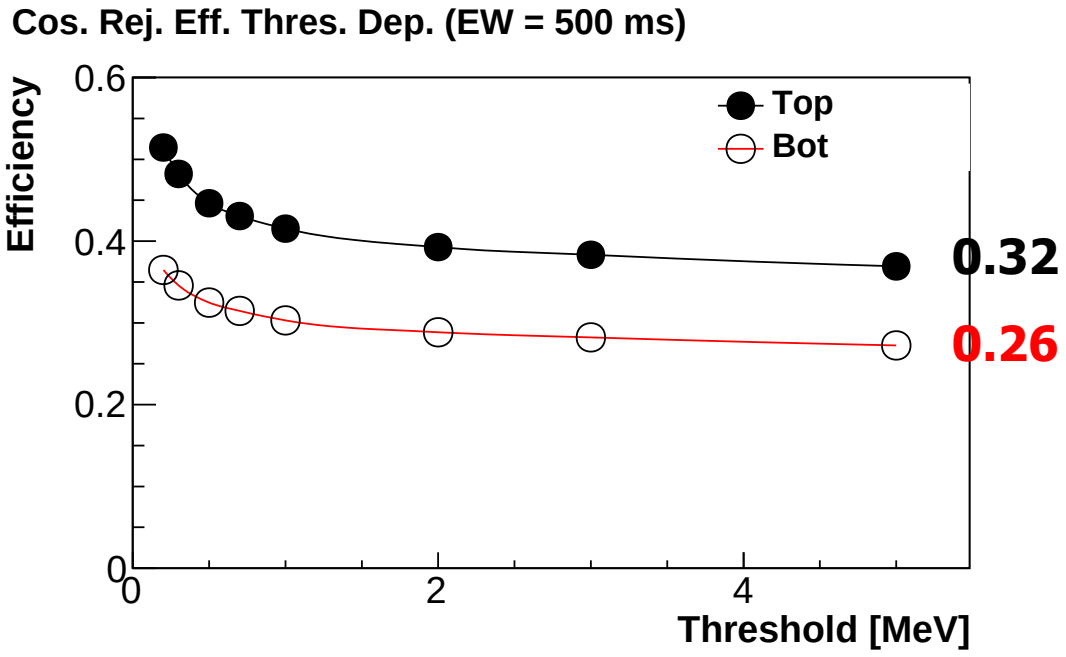
	Algorithm 1	Algorithm 2	Algorithm 3
Selection Efficiency (Top / Bot. ann.)	0.4822 / 0.3458	0.4335 / 0.3389	**0.4211 / 0.3342**
Background Fraction (Top / Bot. ann.)	0.0212 / 0.0363	0.0242 / 0.0355	**0.0152 / 0.0219**

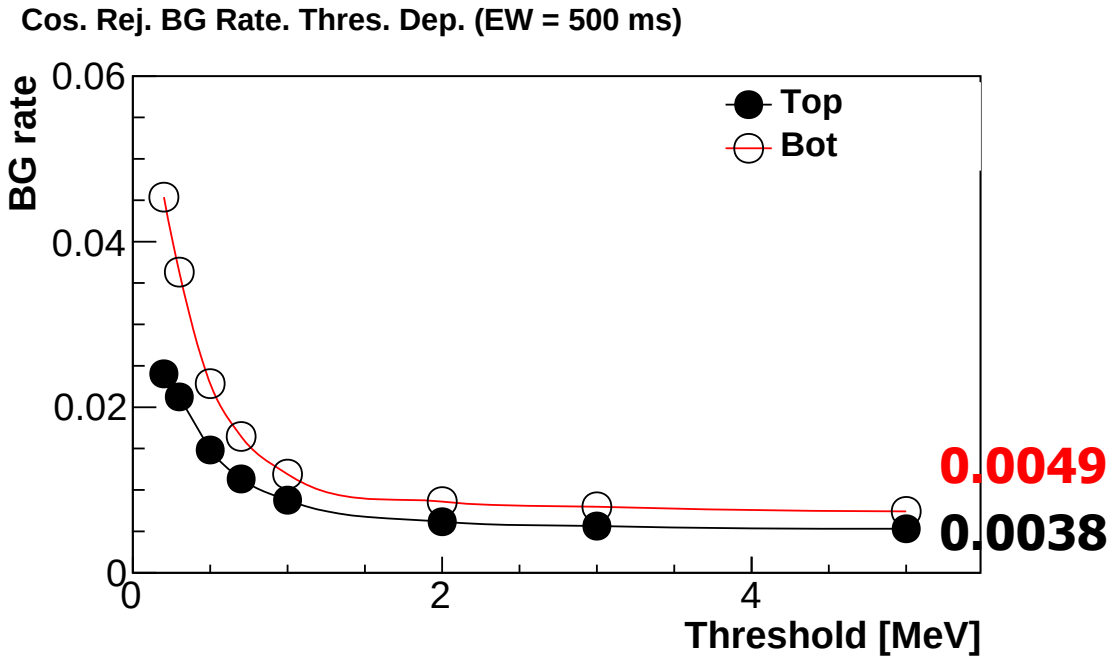
Selection efficiency = (the number of Good events) / (total events)
Selection accuracy = (the number of Successful events) / (Good events)
Background fraction = 1 – (Selection accuracy)

Cosmic-ray rejection

Simulation results – Algorithm 3

Threshold dependence (event window=500ms)

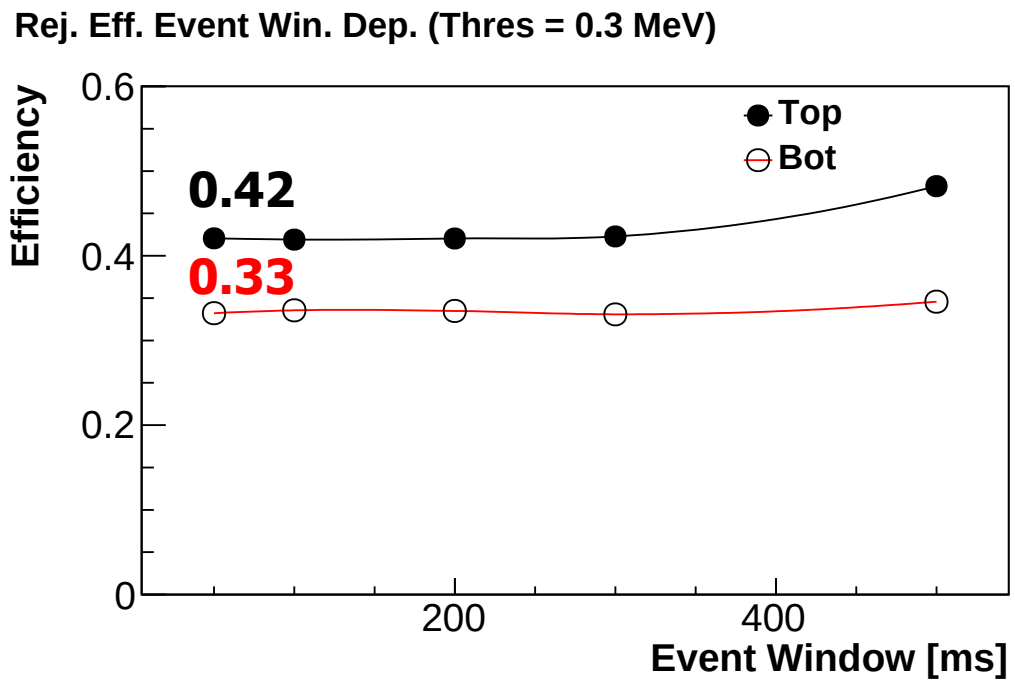


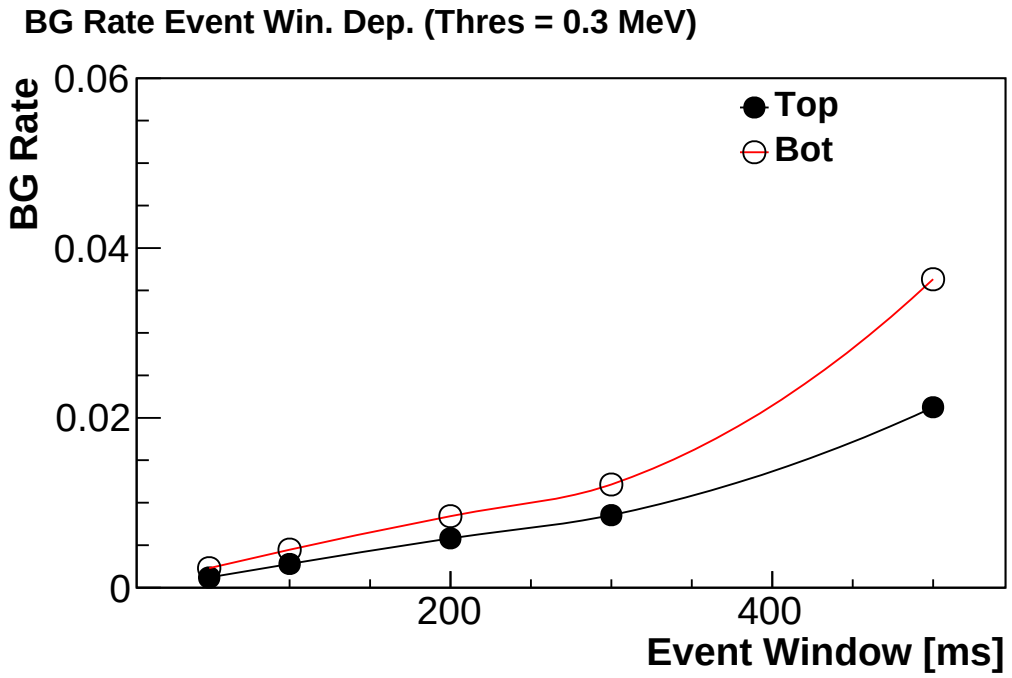


Cosmic-ray rejection

Simulation results – Algorithm 3

Event window dependence (th=0.3MeV)

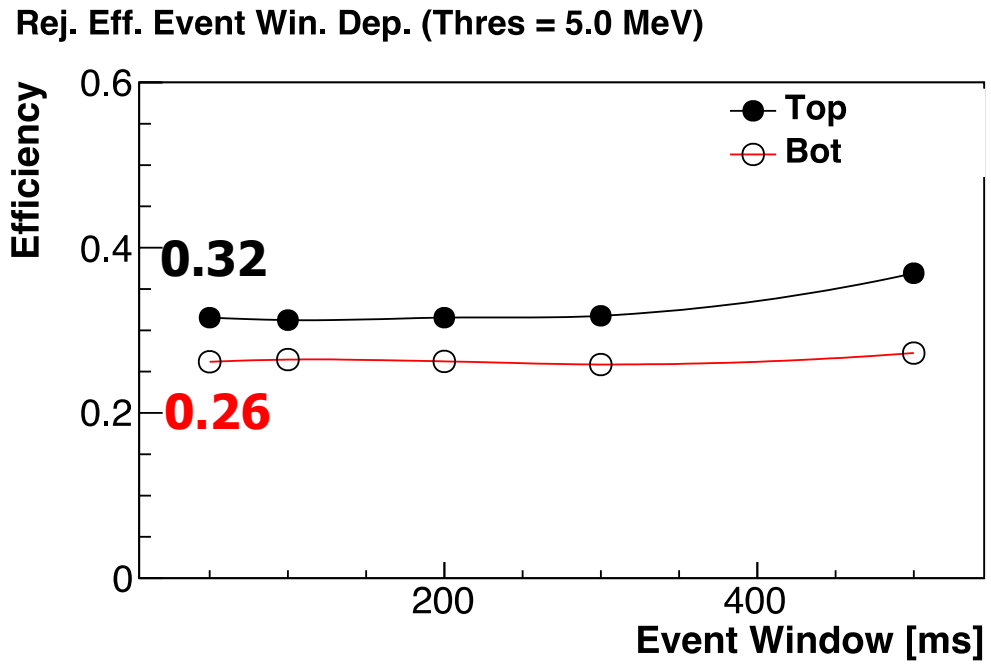


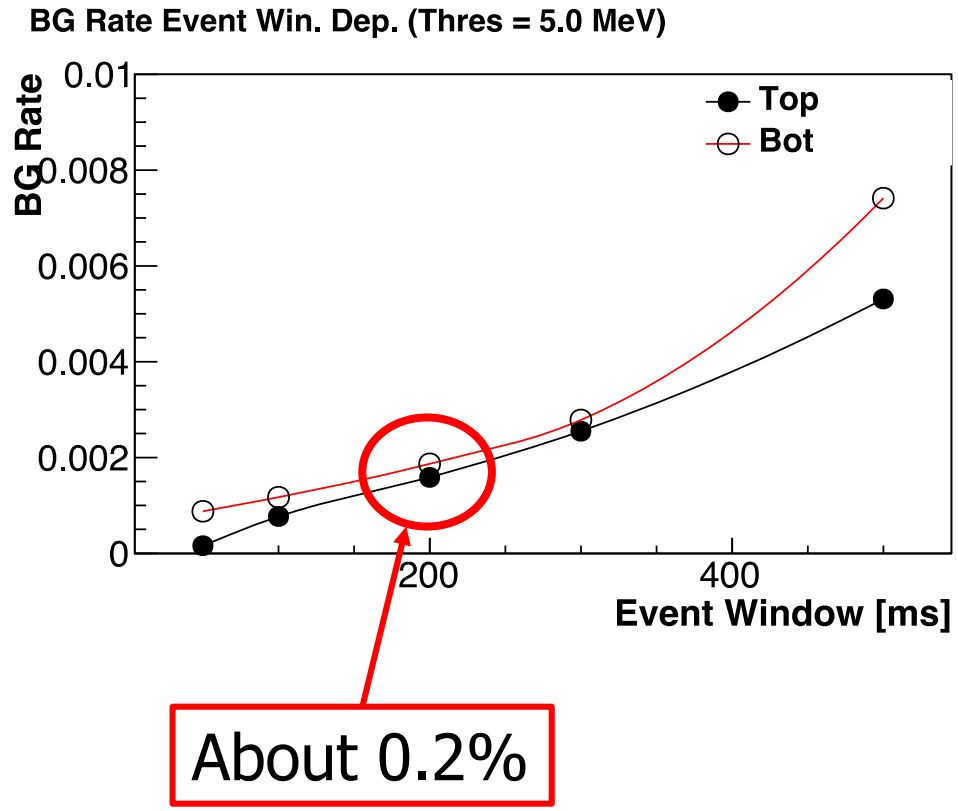


Cosmic-ray rejection

Simulation results – Algorithm 3

Event window dependence (th=5.0 MeV)





Summary

TOF will provide comic-ray rejection and free-fall time measurement.

Time resolution better than 0.2ns has been achieved, which is required for effective cosmic ray rejection and top/bottom annihilation separation.

With GEANT4 simulation, we checked performance of cosmic-ray rejection.
Efficiency and cosmic-ray background fraction for various cases has been studied
With high threshold and narrow event window, we can reduce background fraction below 0.2%

Material information of MMC, FFC and other needs to be added in the simulation.
* Note : Thicknesses of flange are 6mm(bottom, side) and 30mm(top)