Status of para-positronium lifetime measurement by utilizing magnetic field

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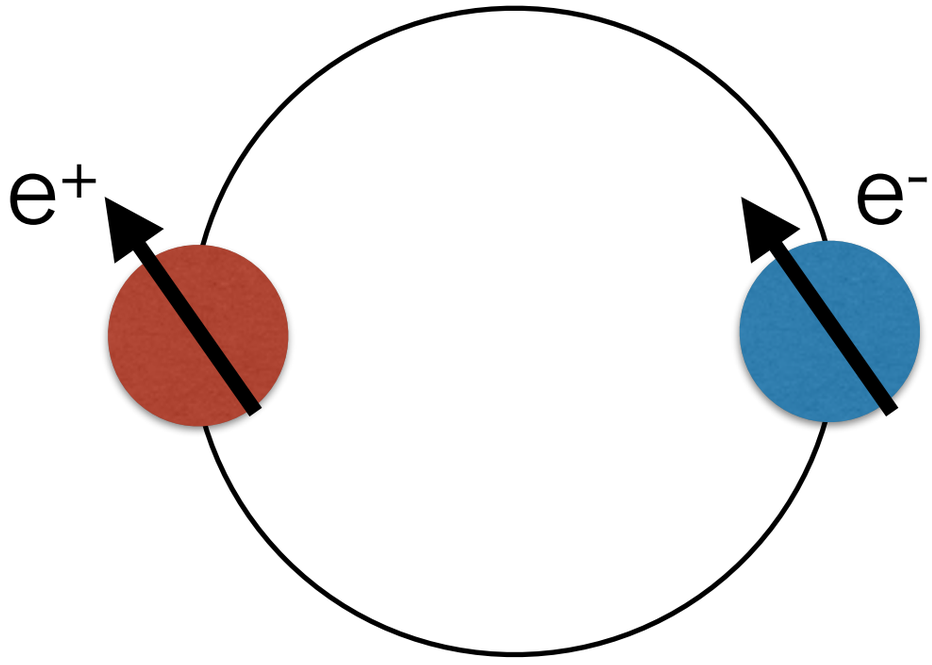
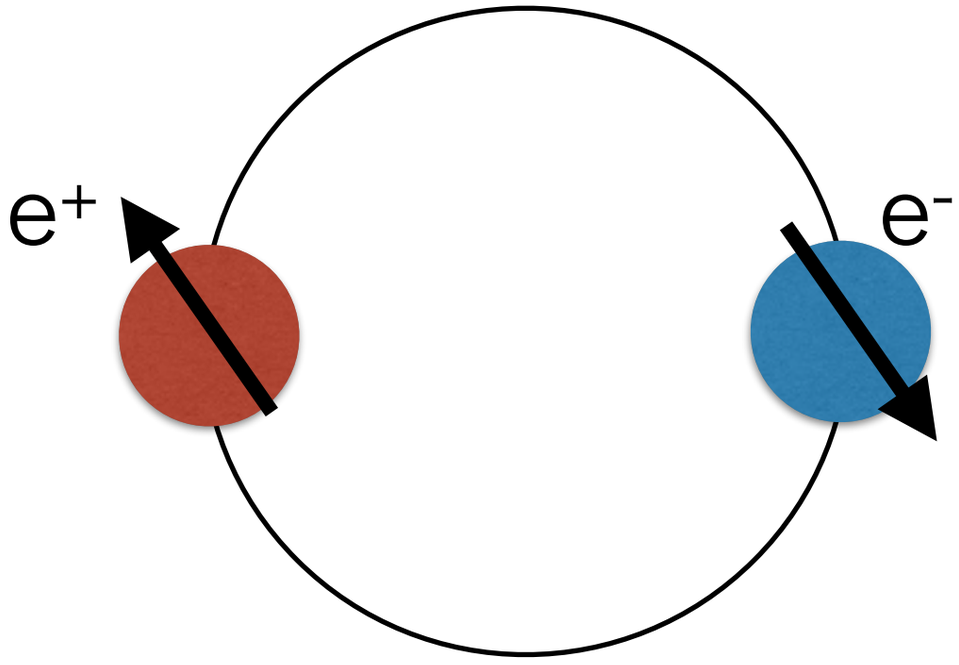
Outline

- What is para-positronium
- How to measure p-Ps lifetime
- Measurement of ortho-positronium lifetime
- Future prospect

What's para-positronium

positronium(Ps): bound state of electron and positron

	Ortho-positronium	Para-positronium
		
Decay	3 γ	2 γ
Lifetime	140ns	125ps

How to measure p-Ps lifetime

Ps has 2 types of Hamiltonian eigenstates

$|o-Ps\rangle$

$|p-Ps\rangle$

B

$|+\rangle$

$|-\rangle$

Magnetic field

mixes 2 types of eigenstates

How to measure p-Ps lifetime

2 types of new eigenstates

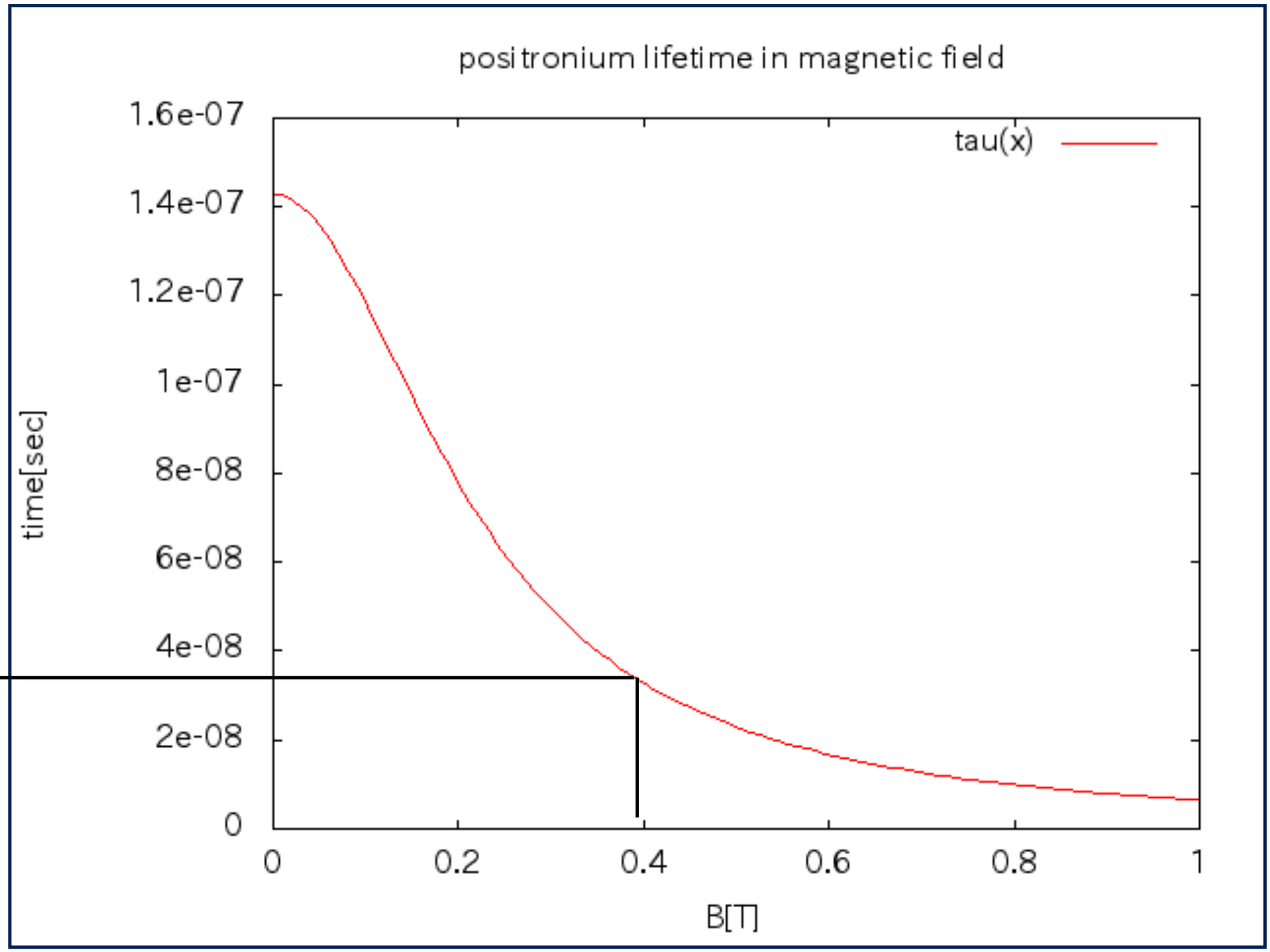
$|+\rangle$ $|-\rangle$

$\frac{1}{\sqrt{1+|\varepsilon|^2}}(|o-Ps\rangle+\varepsilon\,|p-Ps\rangle)$ $\frac{1}{\sqrt{1+|\varepsilon|^2}}(-\varepsilon\,|o-Ps\rangle+|p-Ps\rangle)$

ε : mixing parameter ← depends on magnetic field

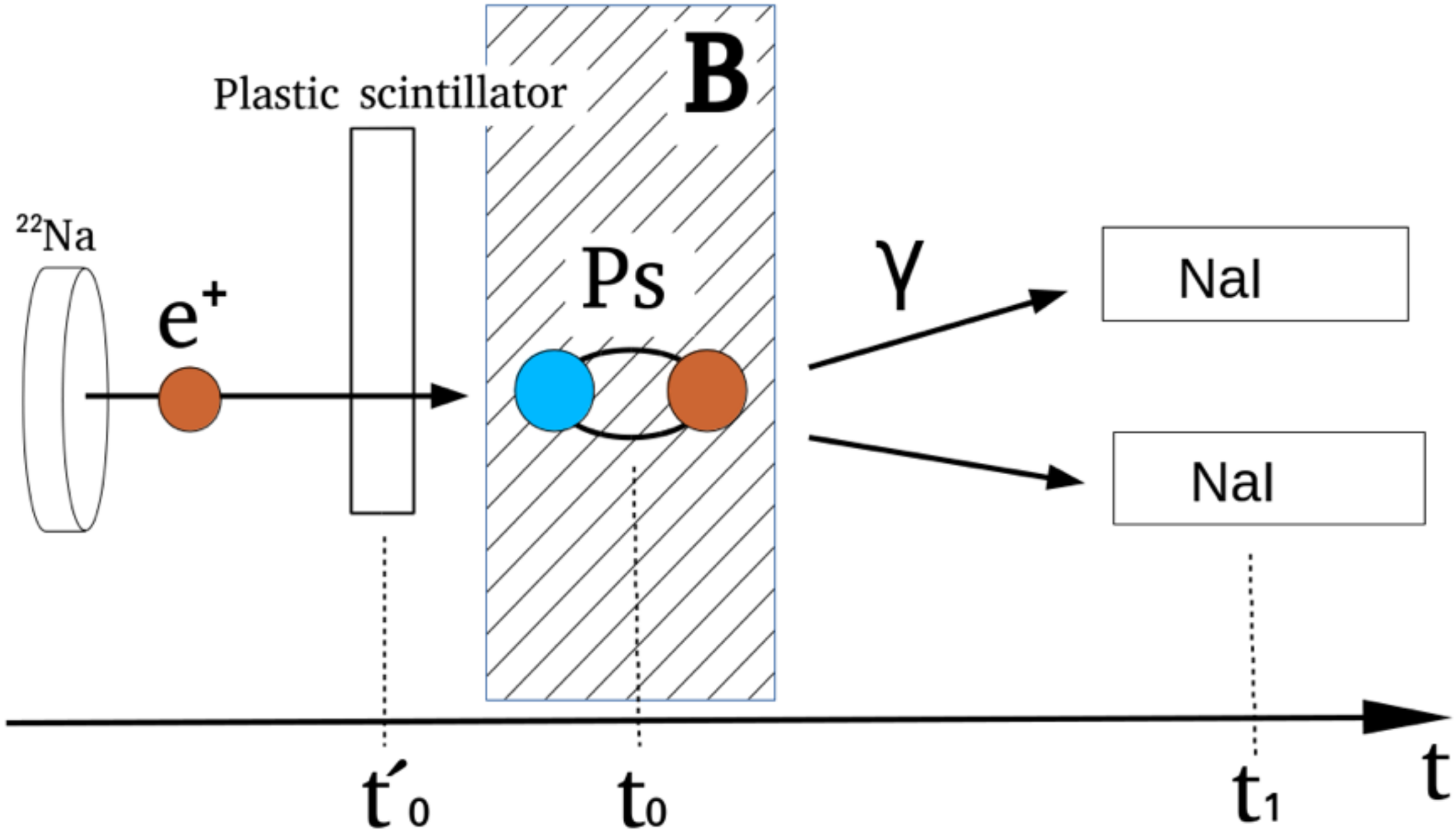
How to measure p-Ps lifetime

$|+\rangle$



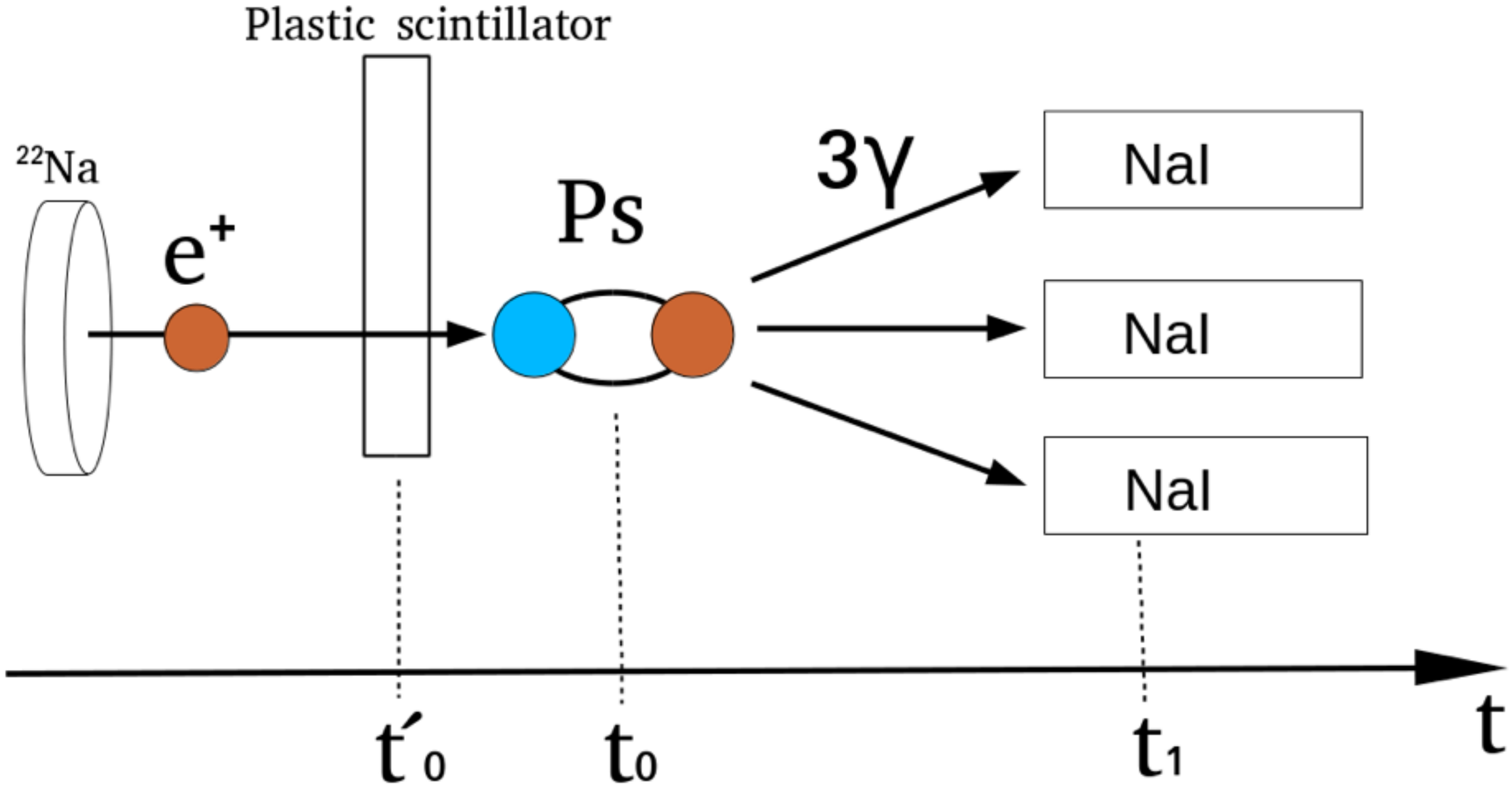
33 ns

Measurement of p-Ps lifetime



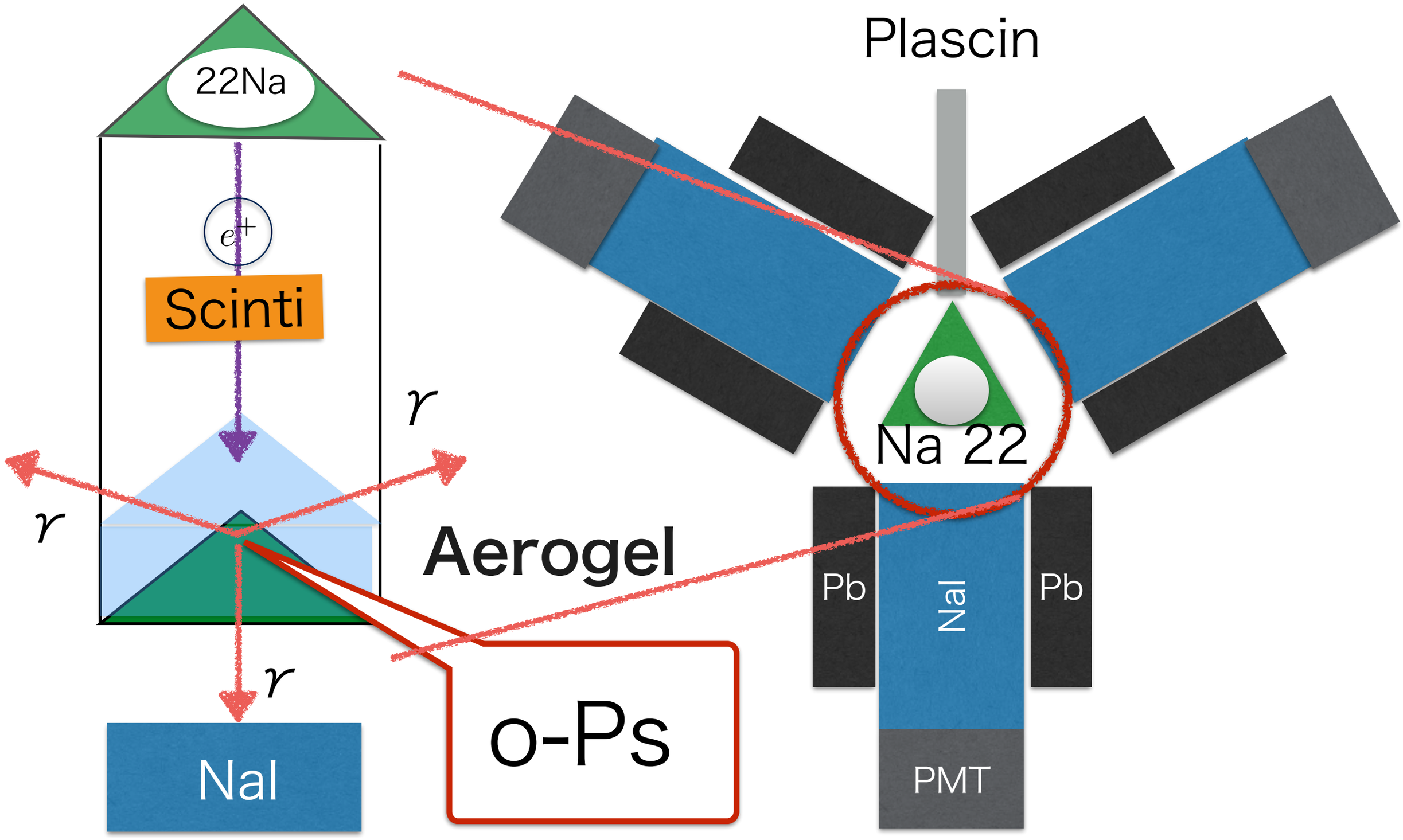
Measurement of oltho-positronium lifetime

Measurement of o-PS lifetime

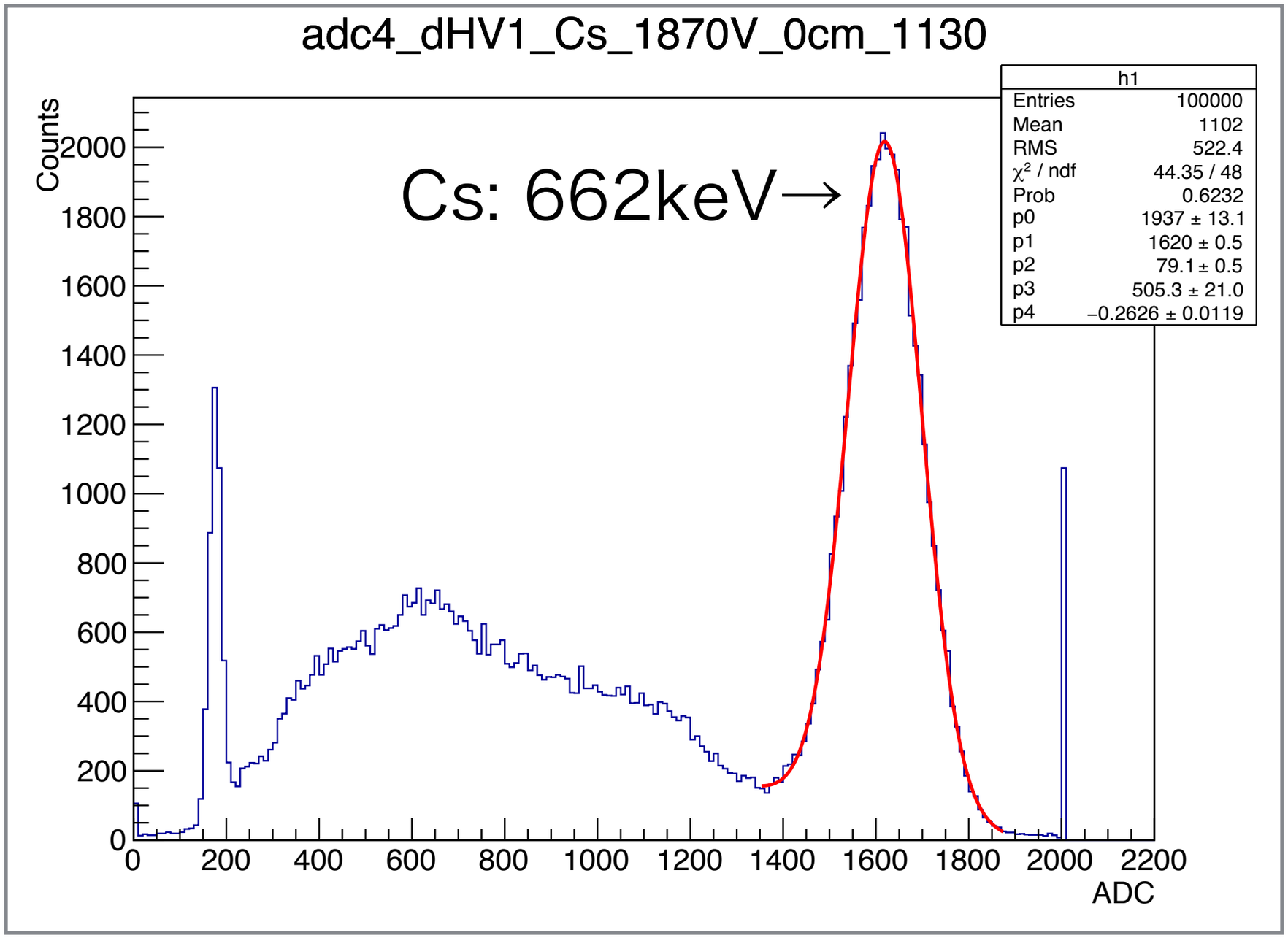


coincidence of 3 NaI

Setup

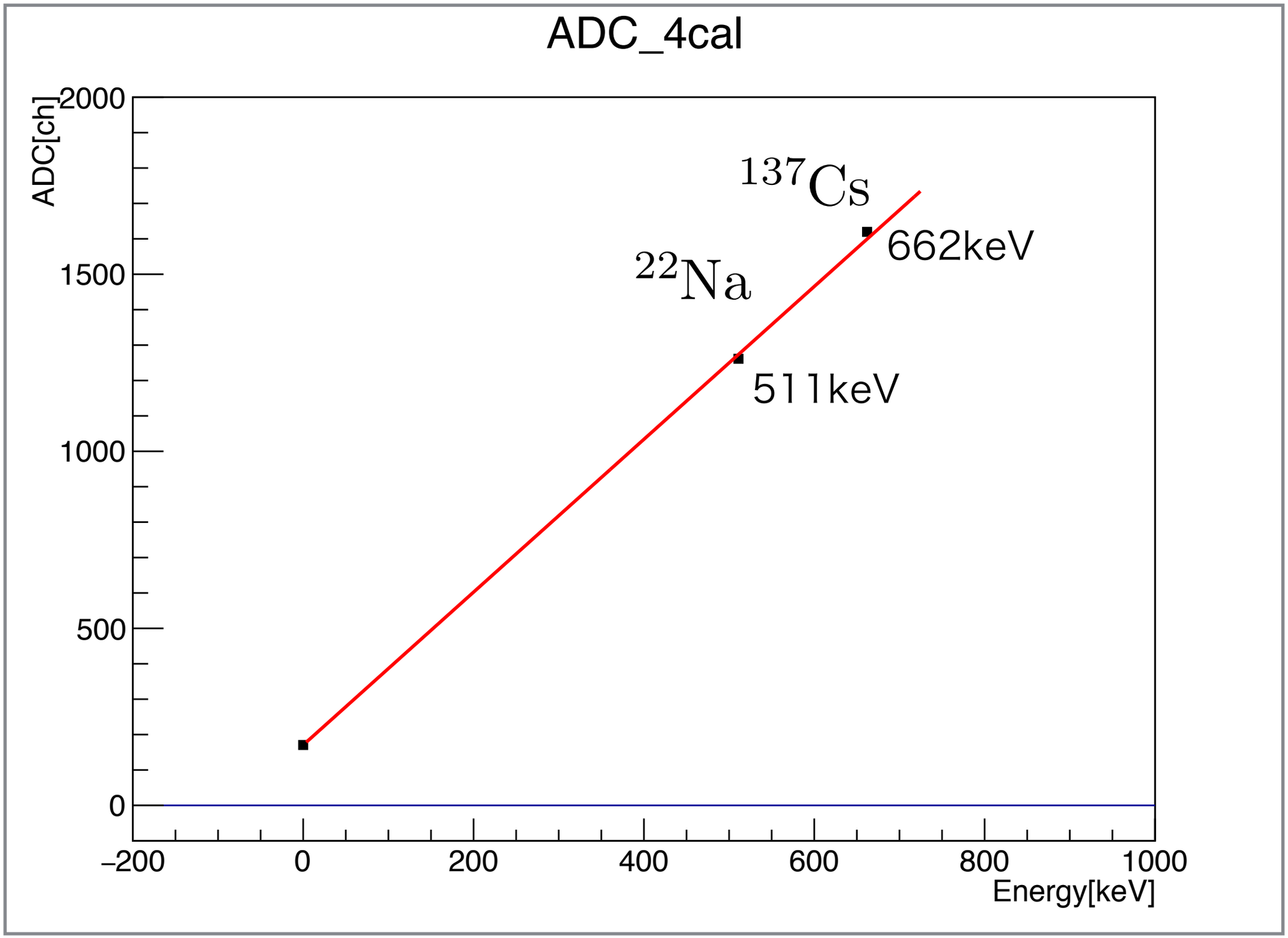


ADC Calibration

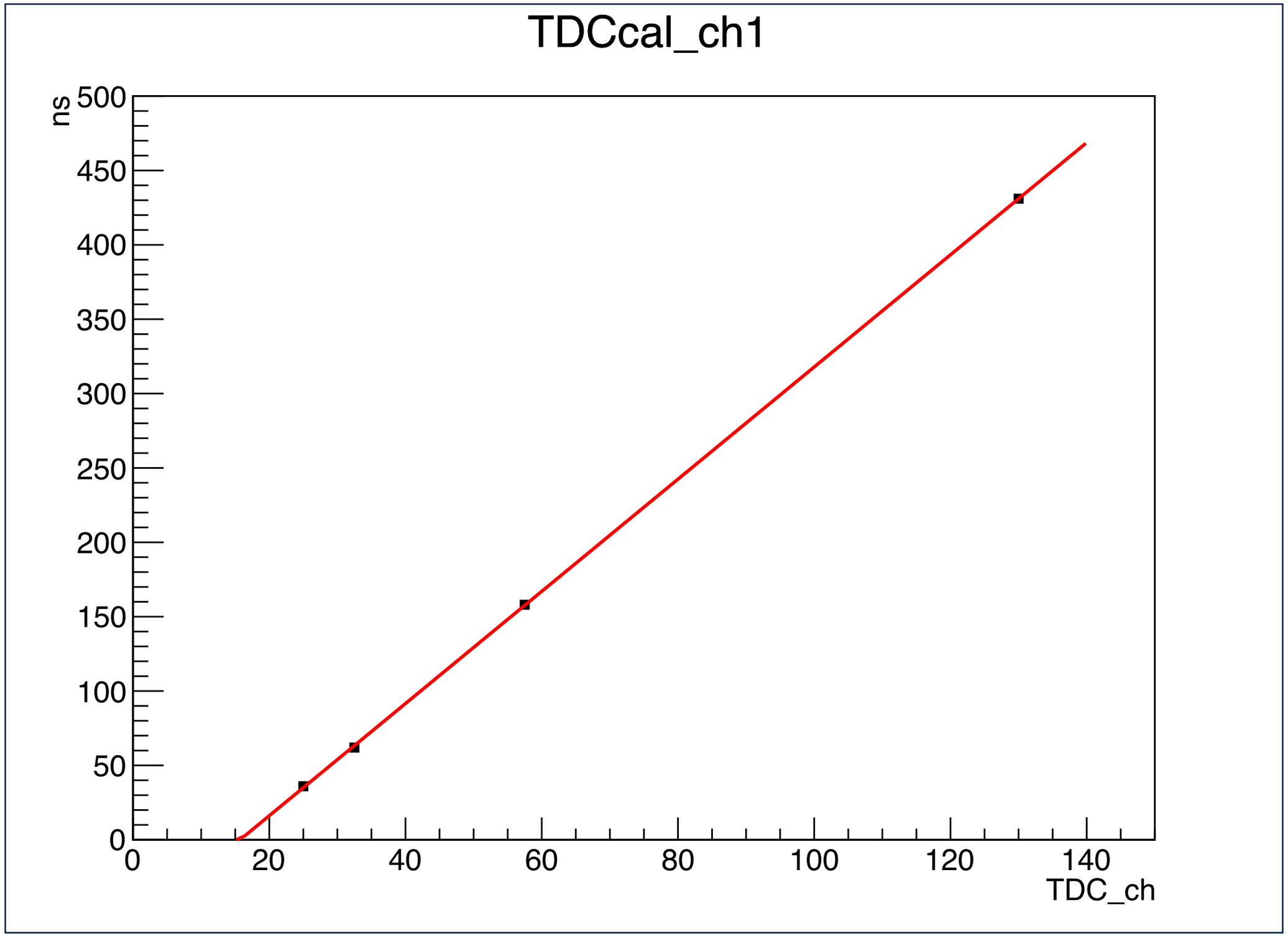


Energy resolution@662keV: 6%

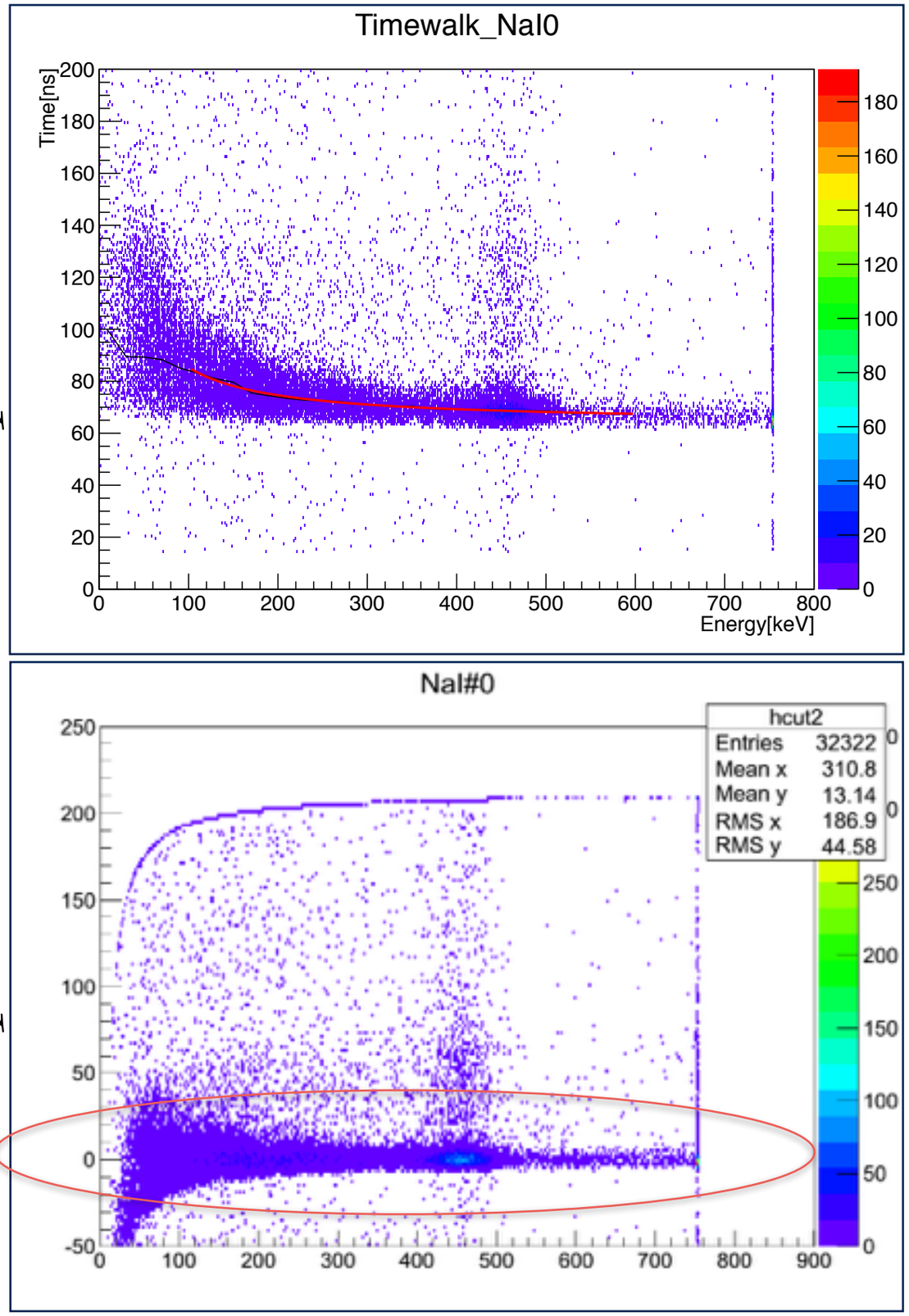
ADC Calibration



TDC Calibration

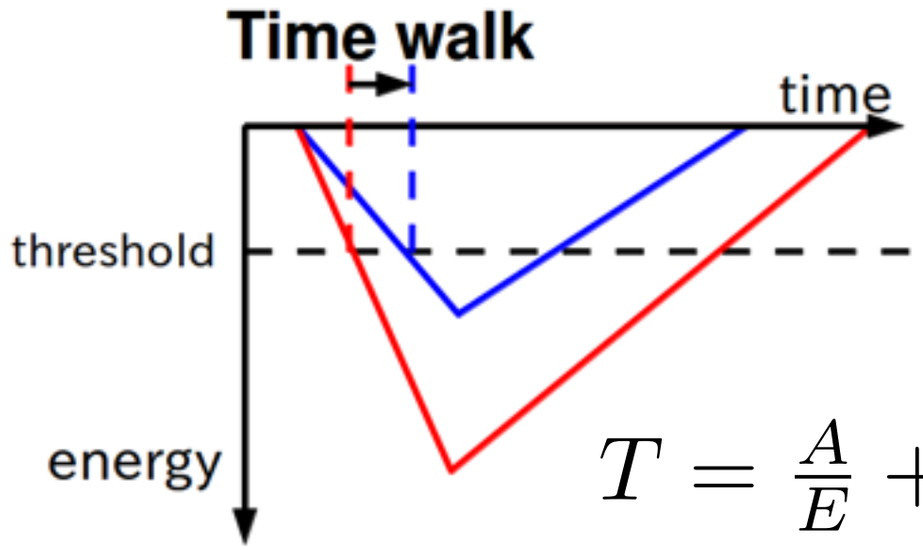


Time-walk correction



Measurement without aerogel

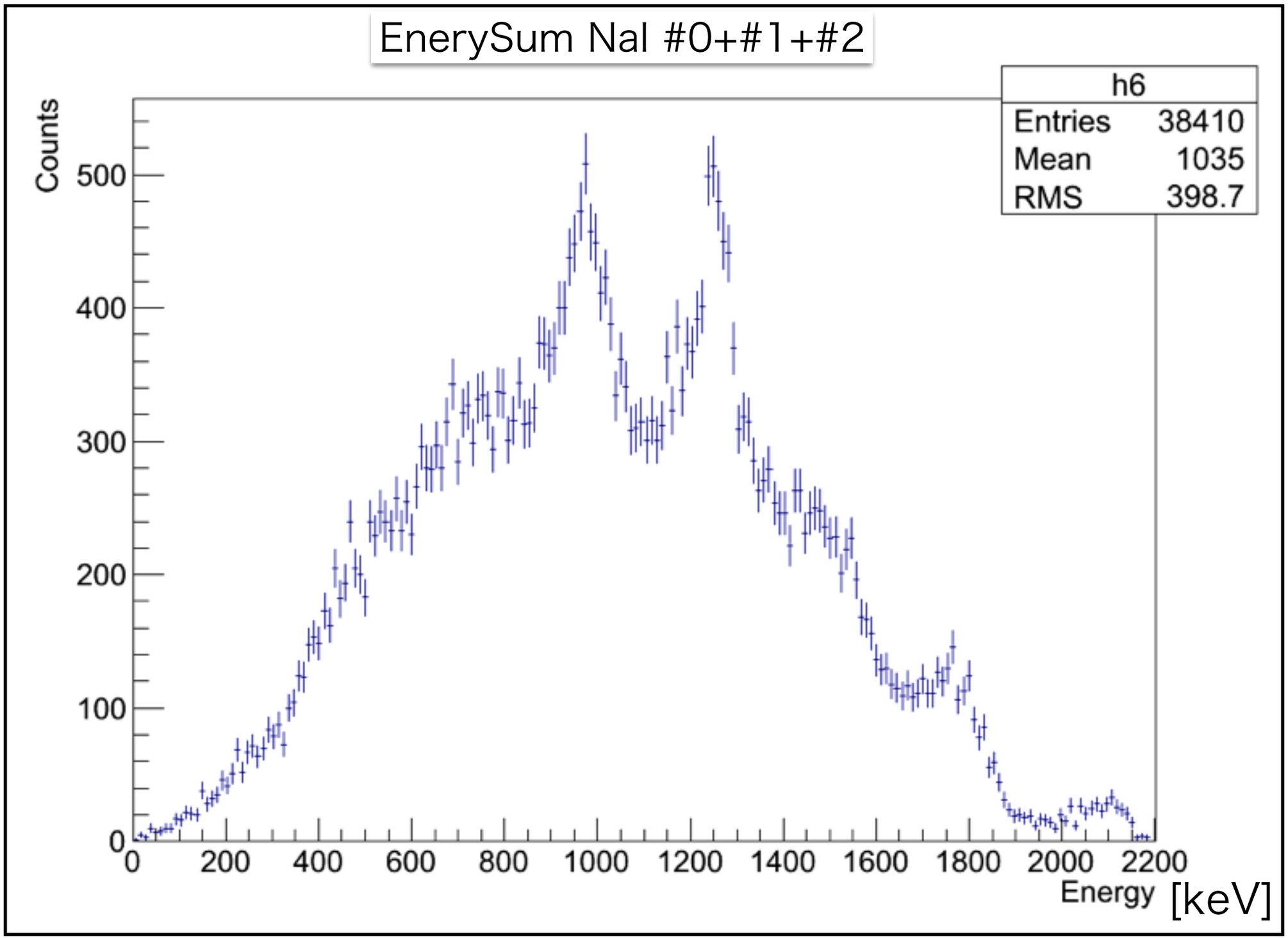
→pair annihilation



$$T = \frac{A}{E} + B$$

←After time-walk Correction

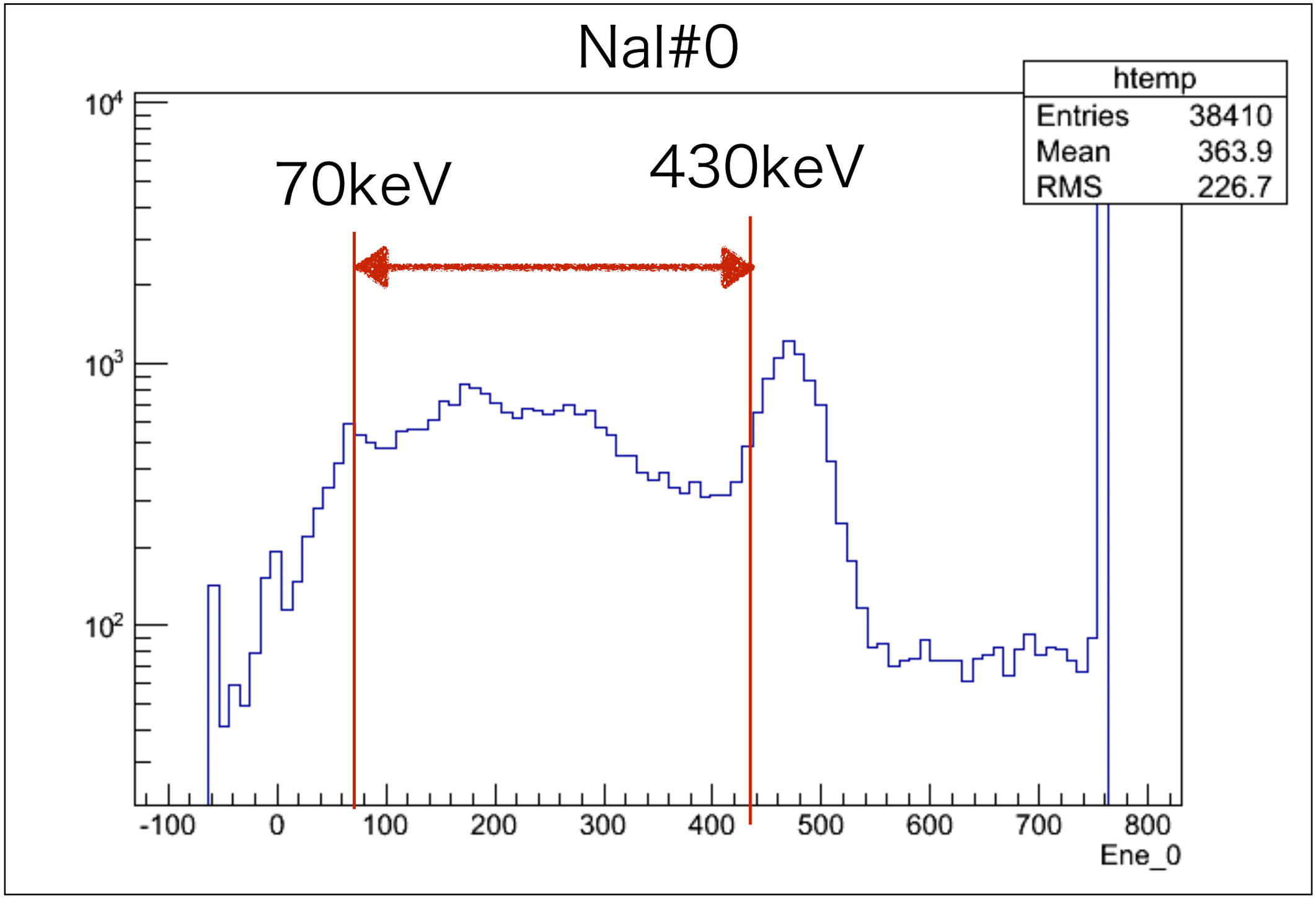
total energy of 3NaIs



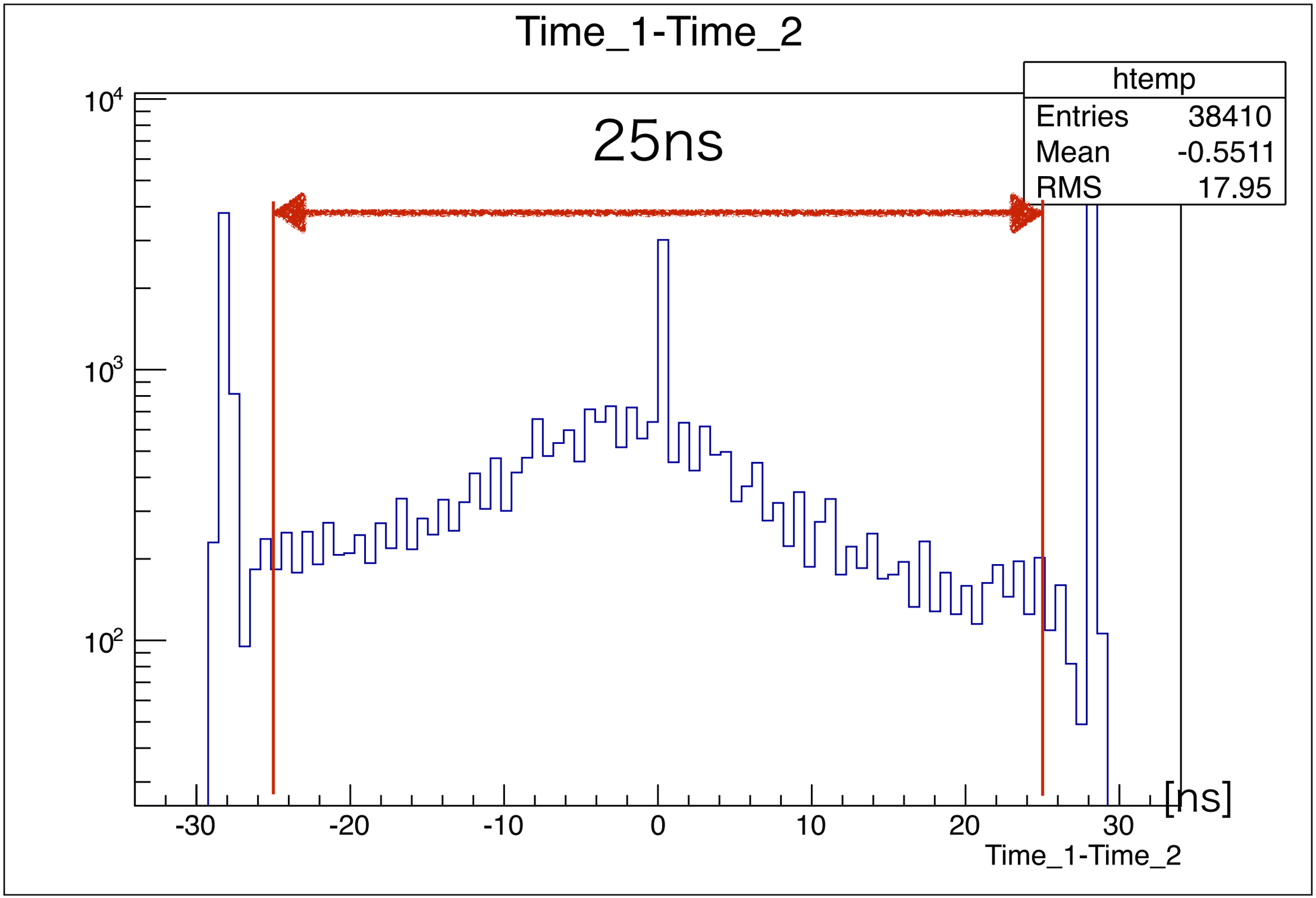
Selection of o-Ps

- each γ energy
- simultaneously $3\,\gamma$ detection

Energy cut of NaI

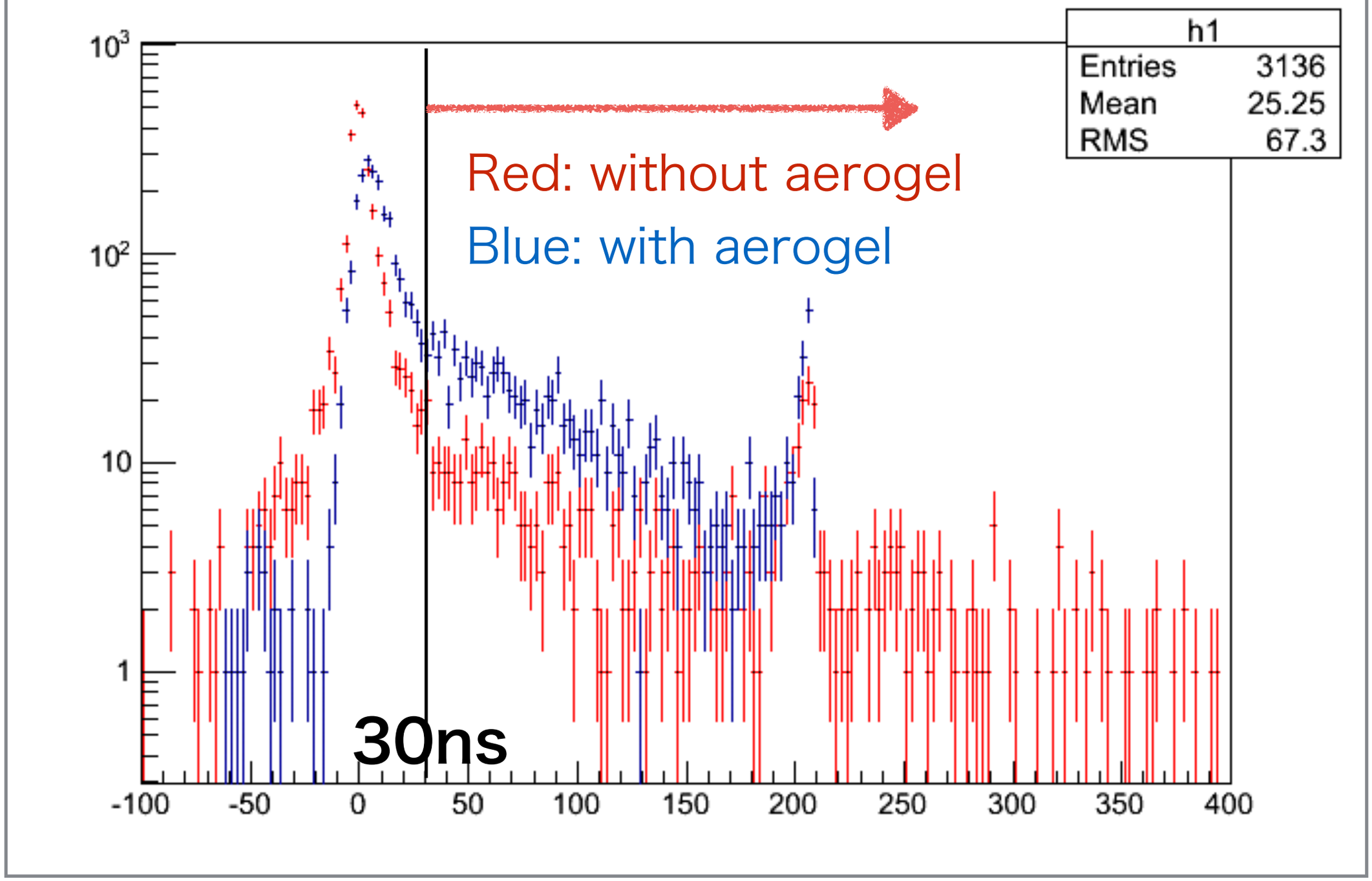


check simultaneously

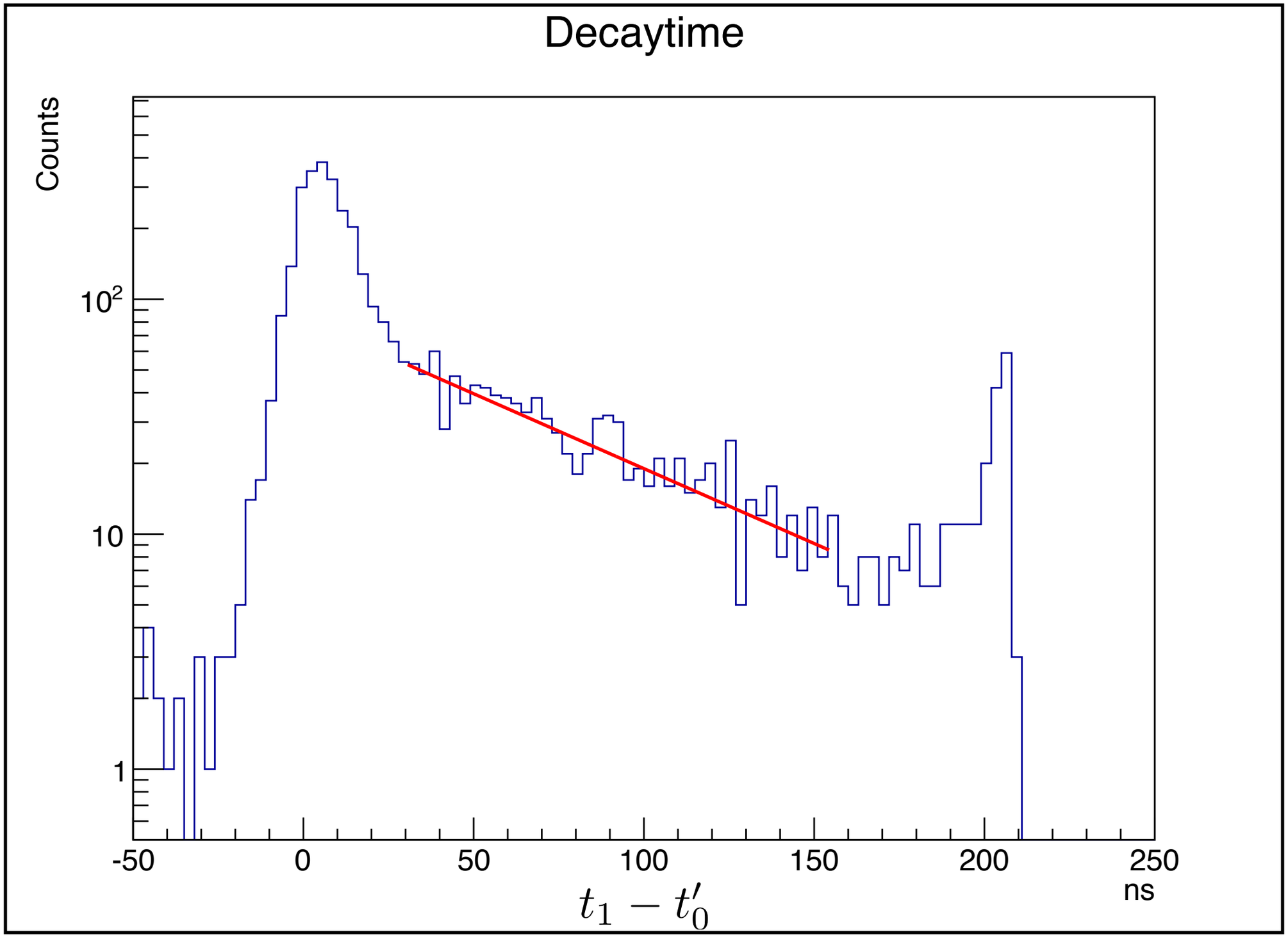


Time of Plasticscinti

(Aerogel ON/OFF)



Decay time of o-Ps



Result

Lifetime of ortho-positronium in the air

$\tau = 68.1 \pm 4.4$ [ns]

consistent

Last year $\tau = 70.6 \pm 1.9$ [ns]

Future prospect

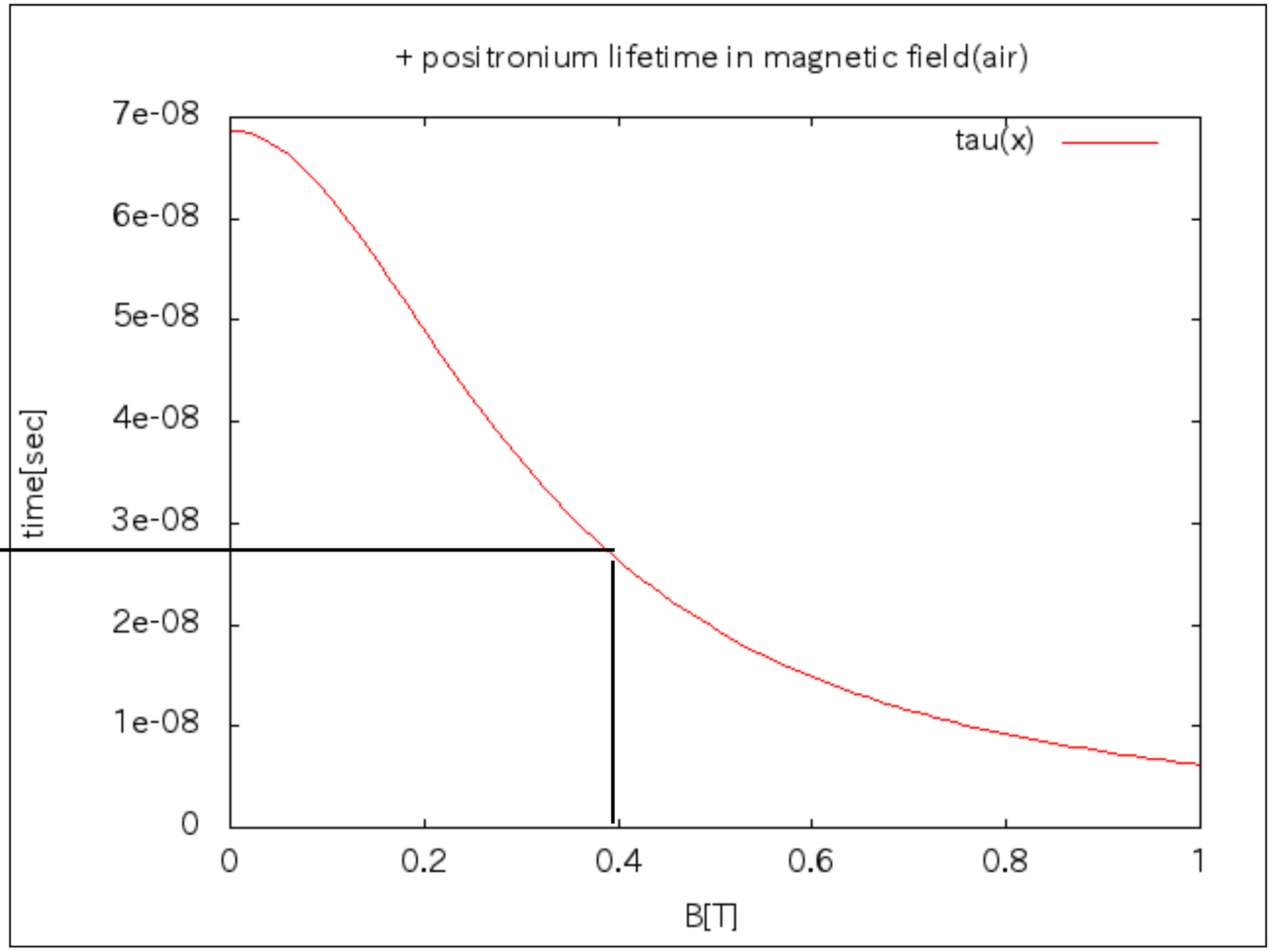
- Increase the number of o-Ps data
- Study more about physics of Ps in magnetic field
- Use magnetic field and measure $|+\rangle$ lifetime

  →p-Ps lifetime

Future prospect

$|+\rangle$ lifetime in the air

28 ns



Backup

2 types of positronium

positronium: mixture of electron and positron

$$|Ps\rangle = |e^+\rangle\,|e^-\rangle$$

$$|p-Ps\rangle = \tfrac{1}{\sqrt{2}}\,|\tfrac{1}{2},\tfrac{1}{2}\rangle_{e^-}\,|\tfrac{1}{2},-\tfrac{1}{2}\rangle_{e^+} - |\tfrac{1}{2},-\tfrac{1}{2}\rangle_{e^-}\,|\tfrac{1}{2},\tfrac{1}{2}\rangle_{e^+})$$

$$|o-Ps\rangle = \begin{cases} |1,1\rangle = |\frac{1}{2},\frac{1}{2}\rangle_{e^-}\,|\frac{1}{2},\frac{1}{2}\rangle_{e^+} \\ |1,0\rangle = \frac{1}{\sqrt{2}}(|\frac{1}{2},\frac{1}{2}\rangle_{e^-}\,|\frac{1}{2},-\frac{1}{2}\rangle_{e^+} + |\frac{1}{2},-\frac{1}{2}\rangle_{e^-}\,|\frac{1}{2},\frac{1}{2}\rangle_{e^+}) \\ |1,-1\rangle = |\frac{1}{2},-\frac{1}{2}\rangle_{e^-}\,|\frac{1}{2},-\frac{1}{2}\rangle_{e^+} \end{cases}$$

Decay of positronium

Conservation of charge conjugation number

$$(-1)^{l+s} = (-1)^{n}$$

positronium　　photon

l: orbit anglar momentum

s: spin

n; number of photon

- o-Ps[s=1,l=0(ground state)]

$$-1 = (-1)^{n} \rightarrow 3\gamma$$

lifetime: 140ns

- p-Ps[s=0,l=0]

$$1 = (-1)^{n} \rightarrow 2\gamma$$

125ps

Lifetime of positronium

Lifetime of particle

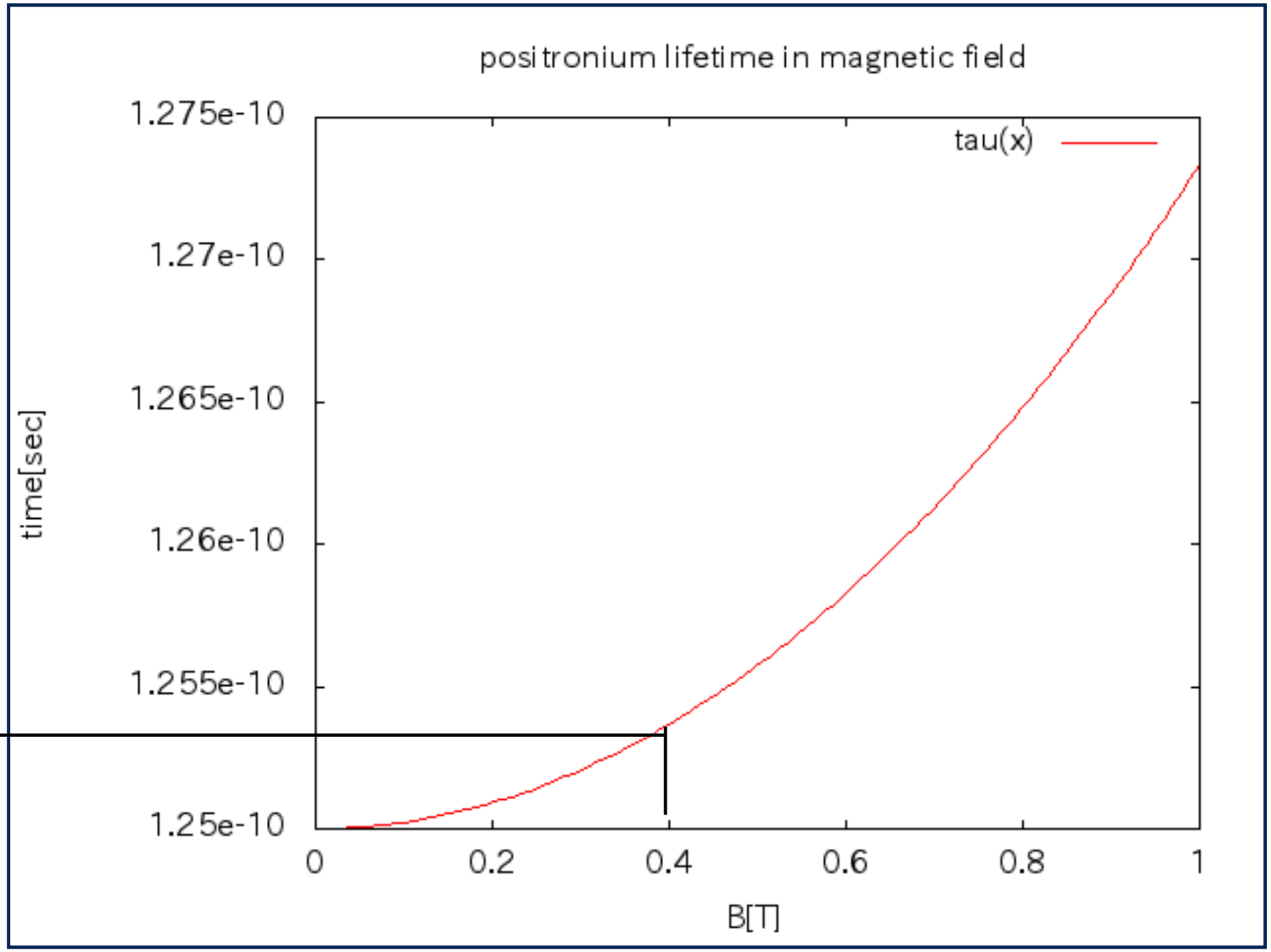
$dN = -\Gamma N(t)dt$

$\rightarrow N(t) = N(0)\exp(-\Gamma t)$

$\tau = 1/\Gamma$ ←lifetime

How to measure p-Ps lifetime

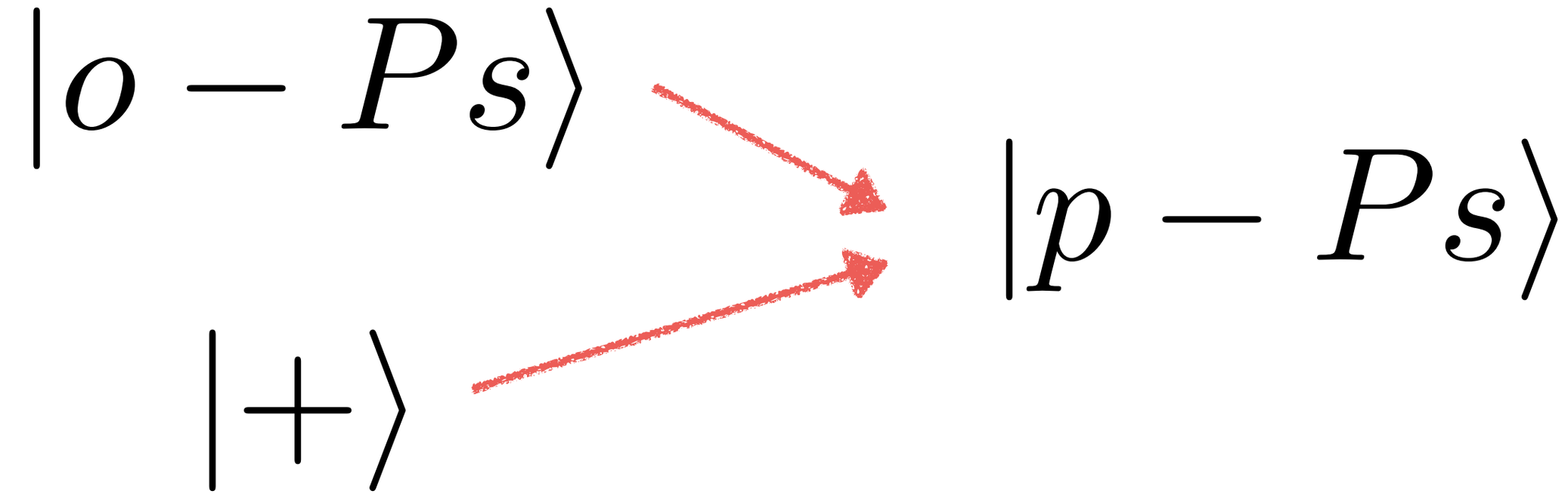
$|-\rangle$



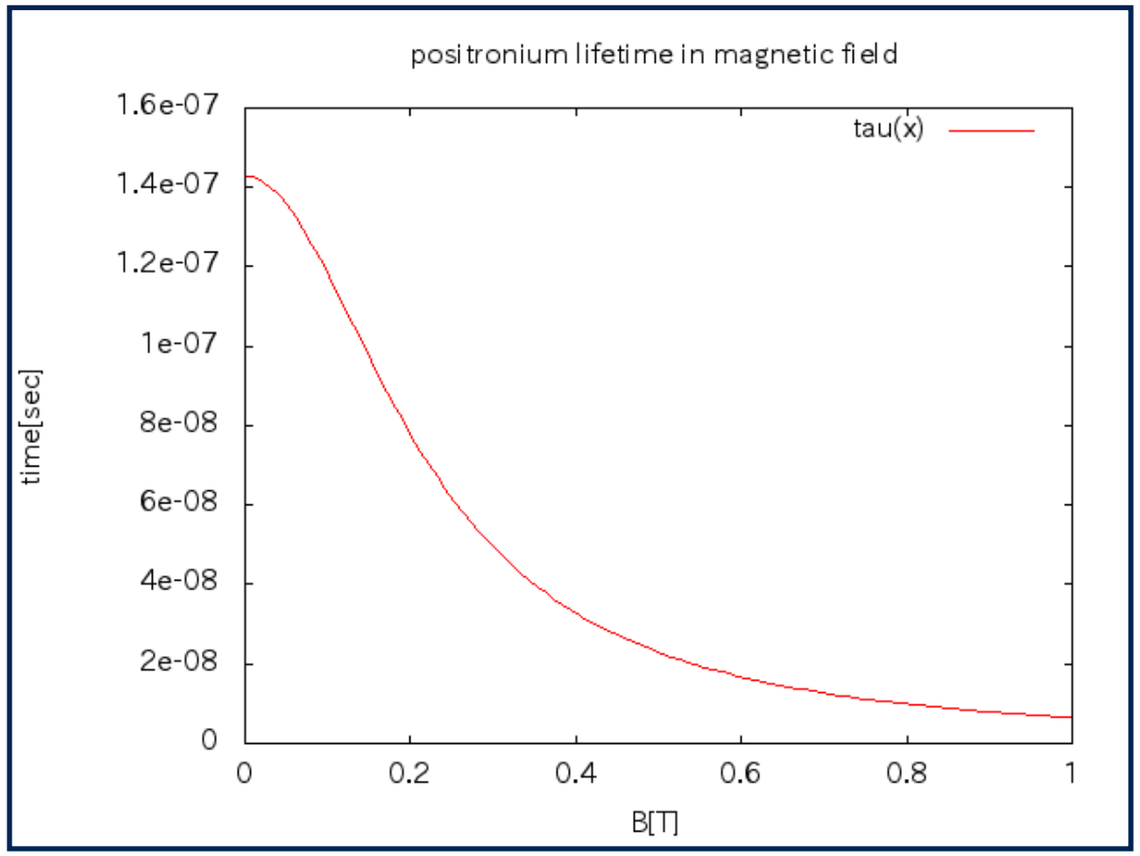
125.4 ps

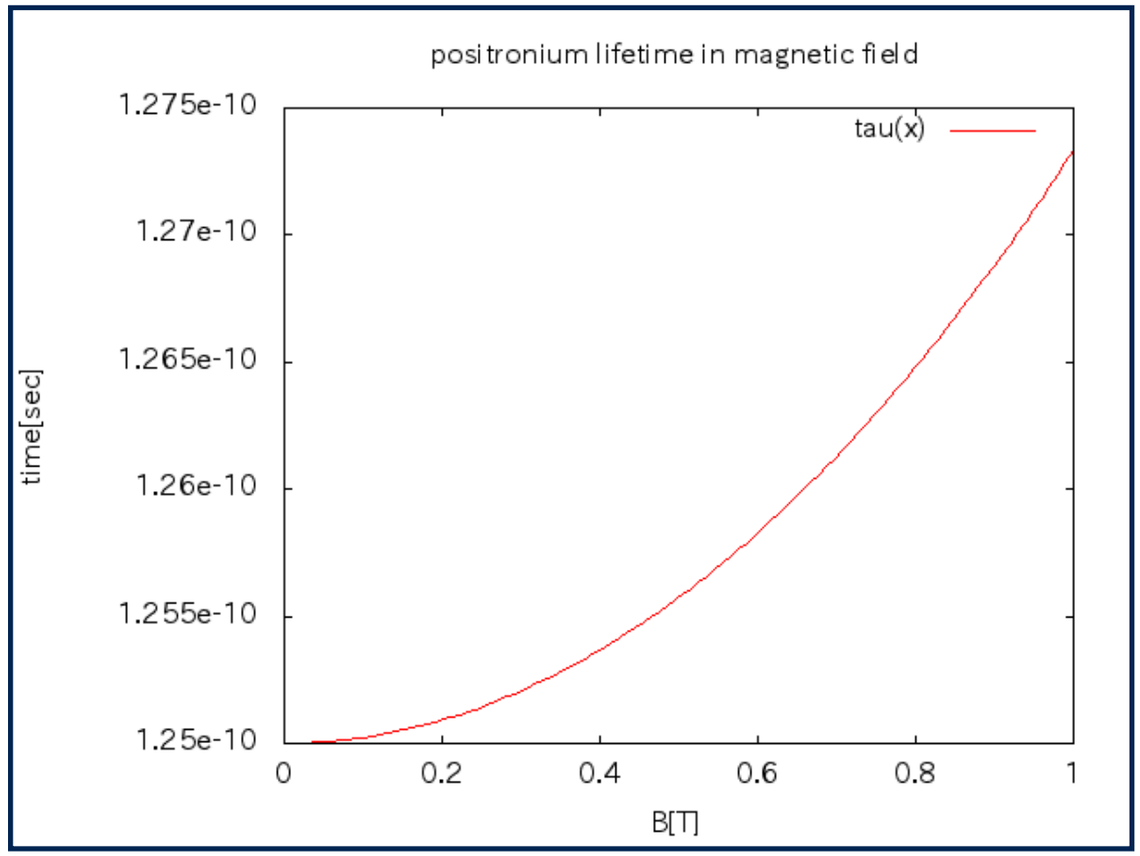
How to measure p-Ps lifetime

$$|+\rangle : \frac{1}{\sqrt{1+|\varepsilon|^2}}(|o-Ps\rangle + \varepsilon\,|p-Ps\rangle)$$



New eigenstate lifetime

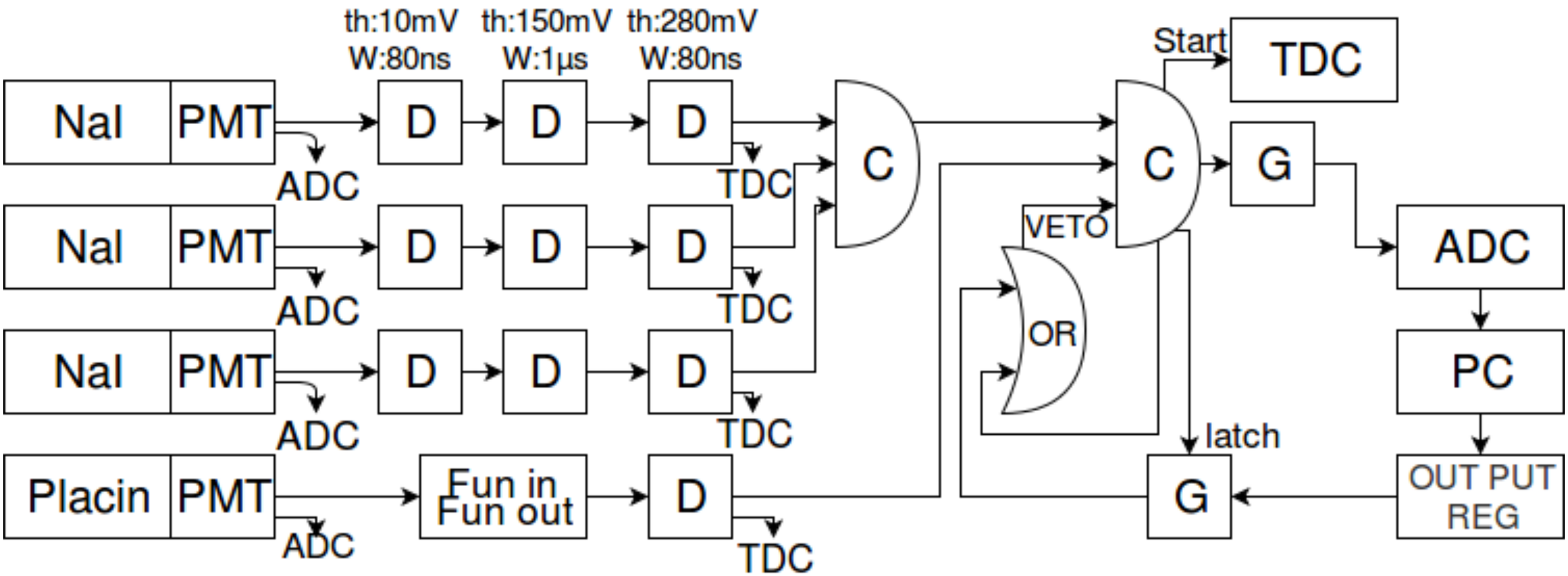




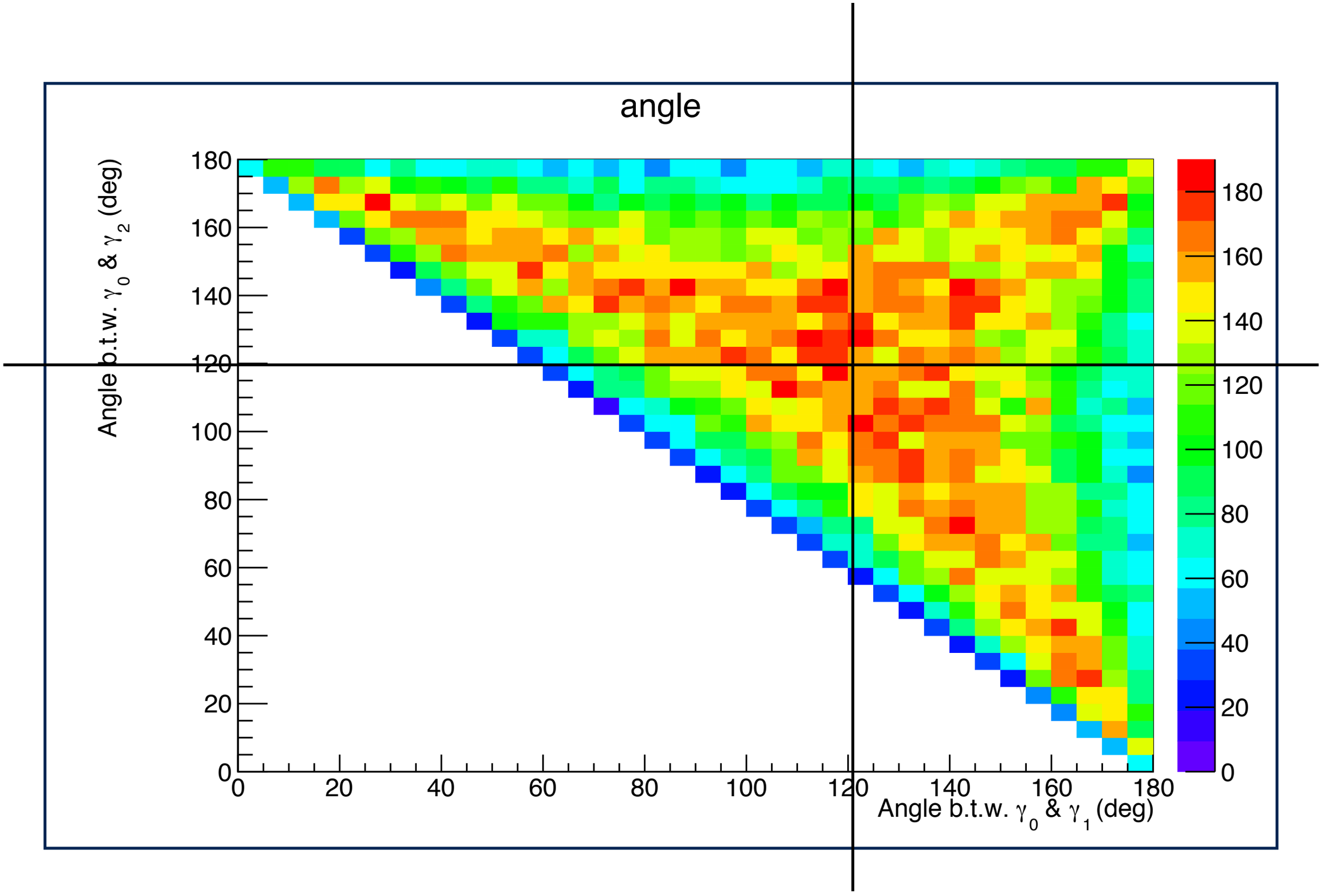
$|+\rangle$

$|-\rangle$

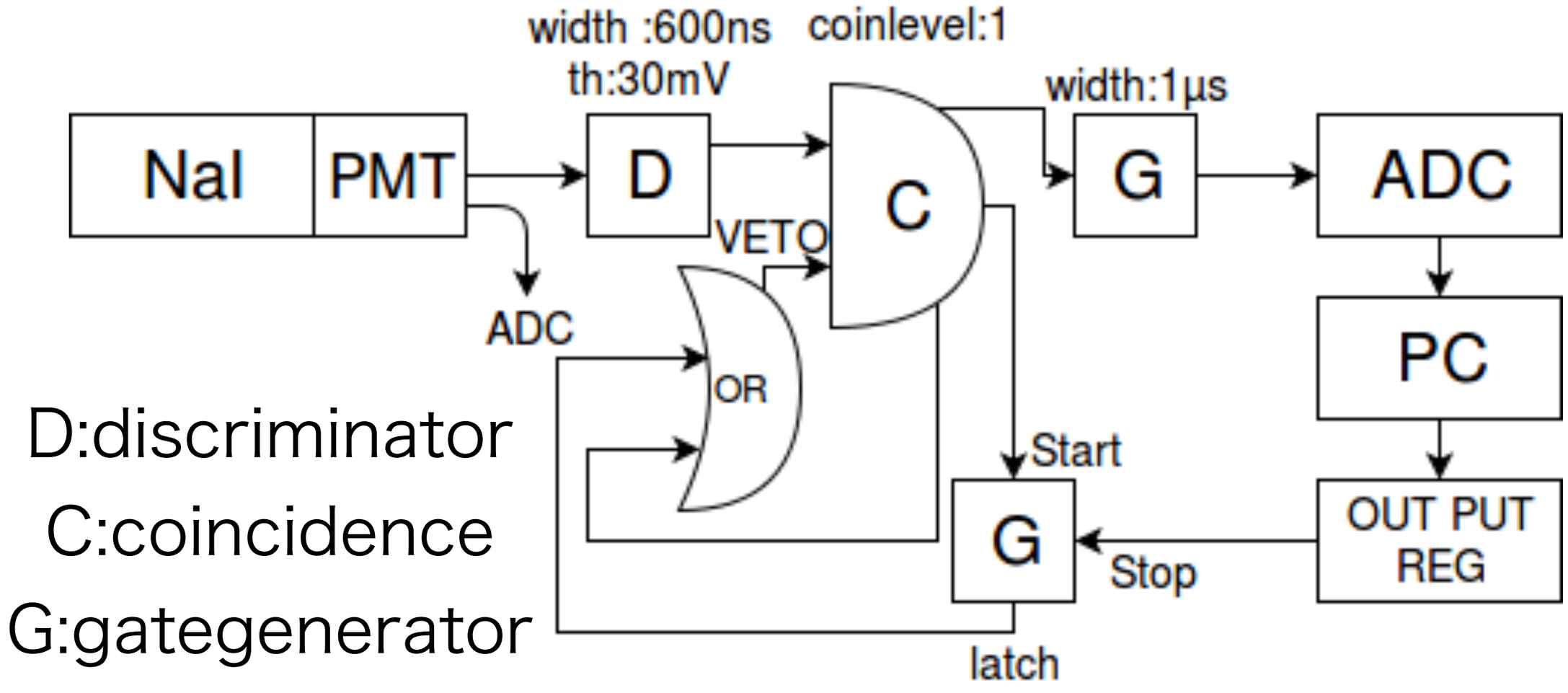
Setup


th:10mV
W:80ns
th:150mV
W:1μs
th:280mV
W:80ns
NaI
PMT
D
D
D
ADC
TDC
C
Start
TDC
C
G
VETO
ADC
OR
PC
latch
G
OUT PUT
REG
Placin
Fun in
Fun out

NaI angle


angle
Angle b.t.w. γ_0 & γ_2 (deg)
Angle b.t.w. γ_0 & γ_1 (deg)
0
20
40
60
80
100
120
140
160
180

ADC Calibration

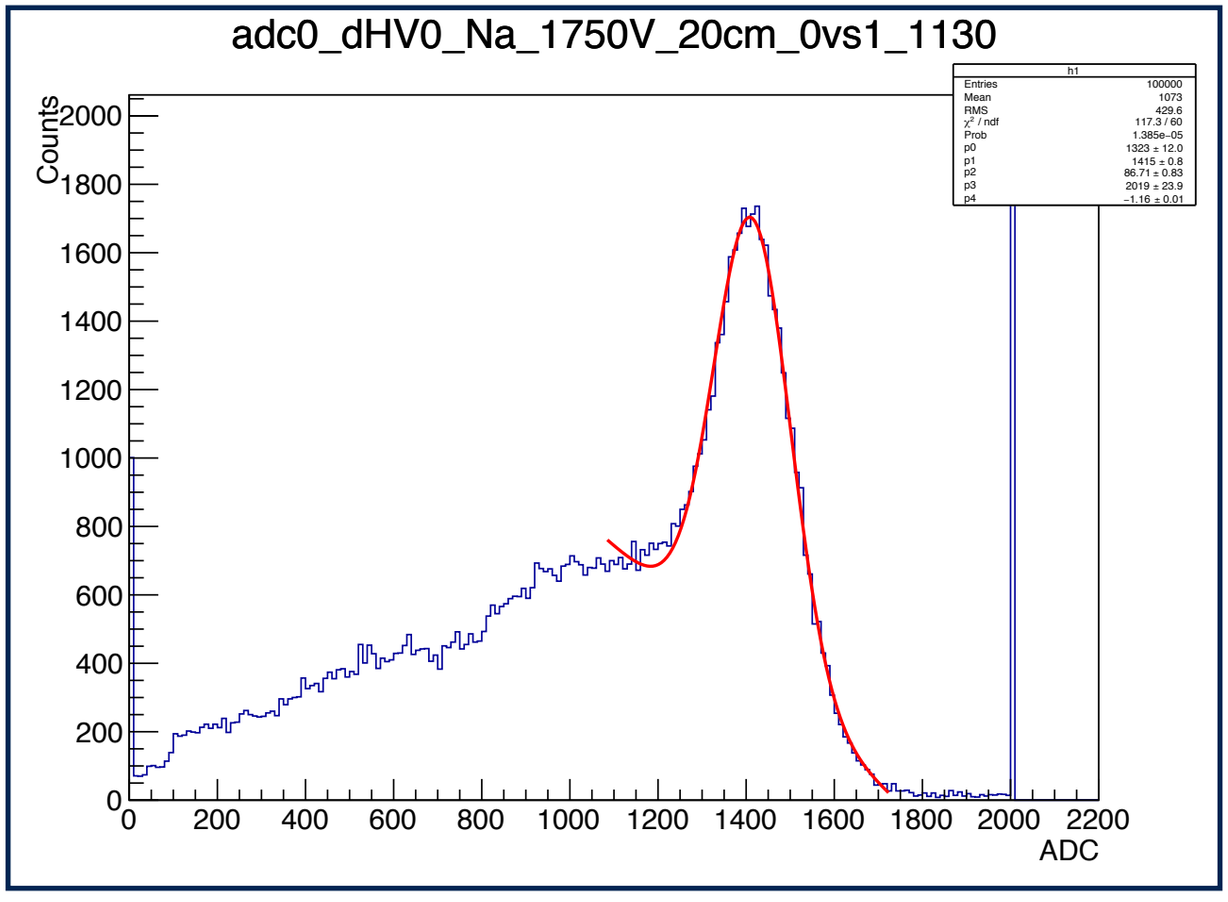


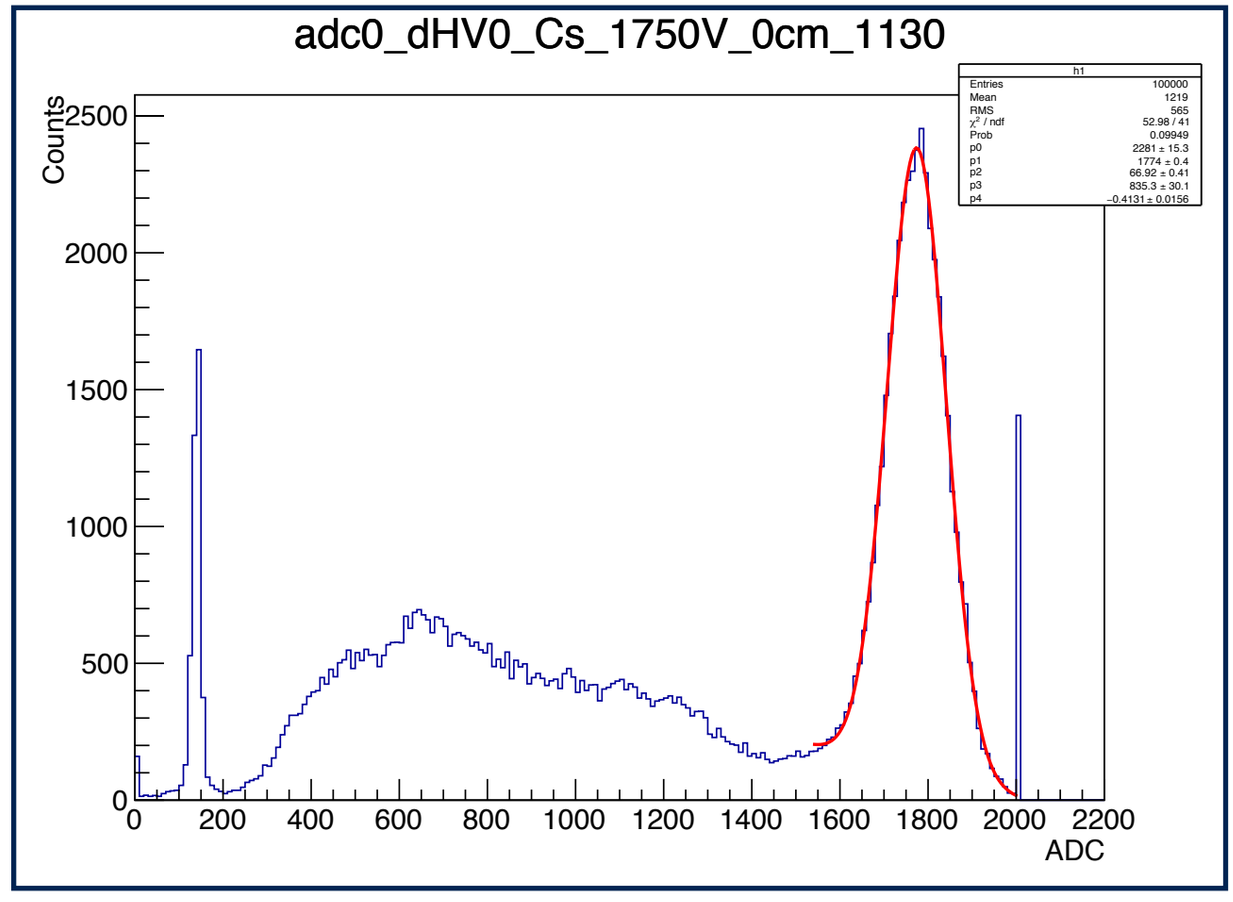
D:discriminator

C:coincidence

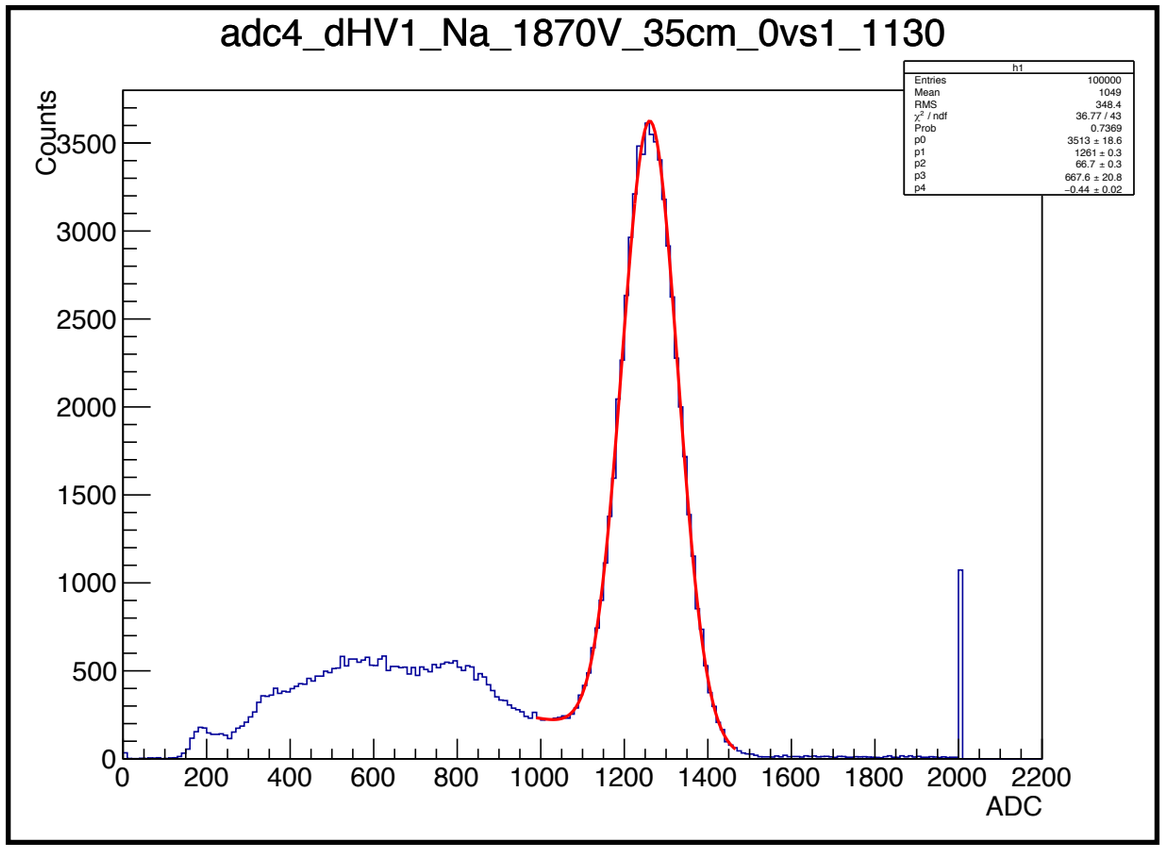
G:gategenerator

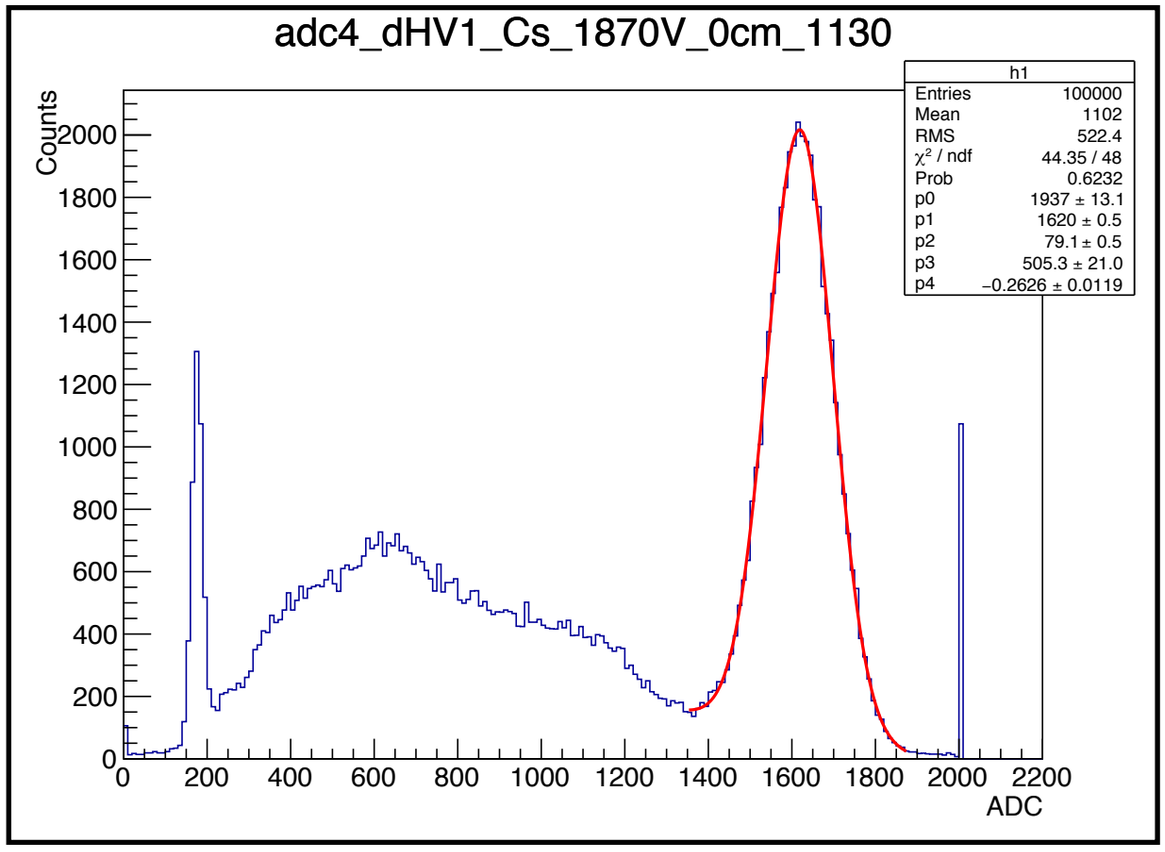
ADC Calibration NaI#0



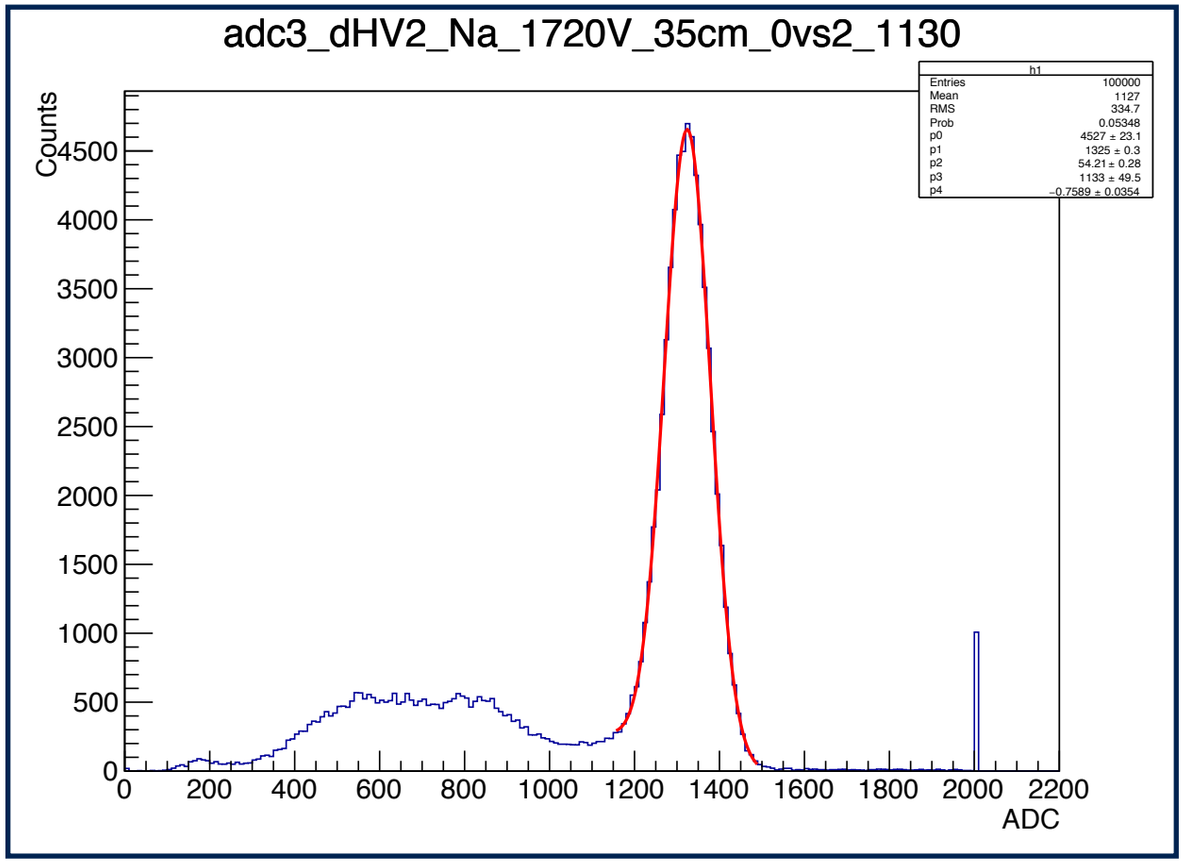


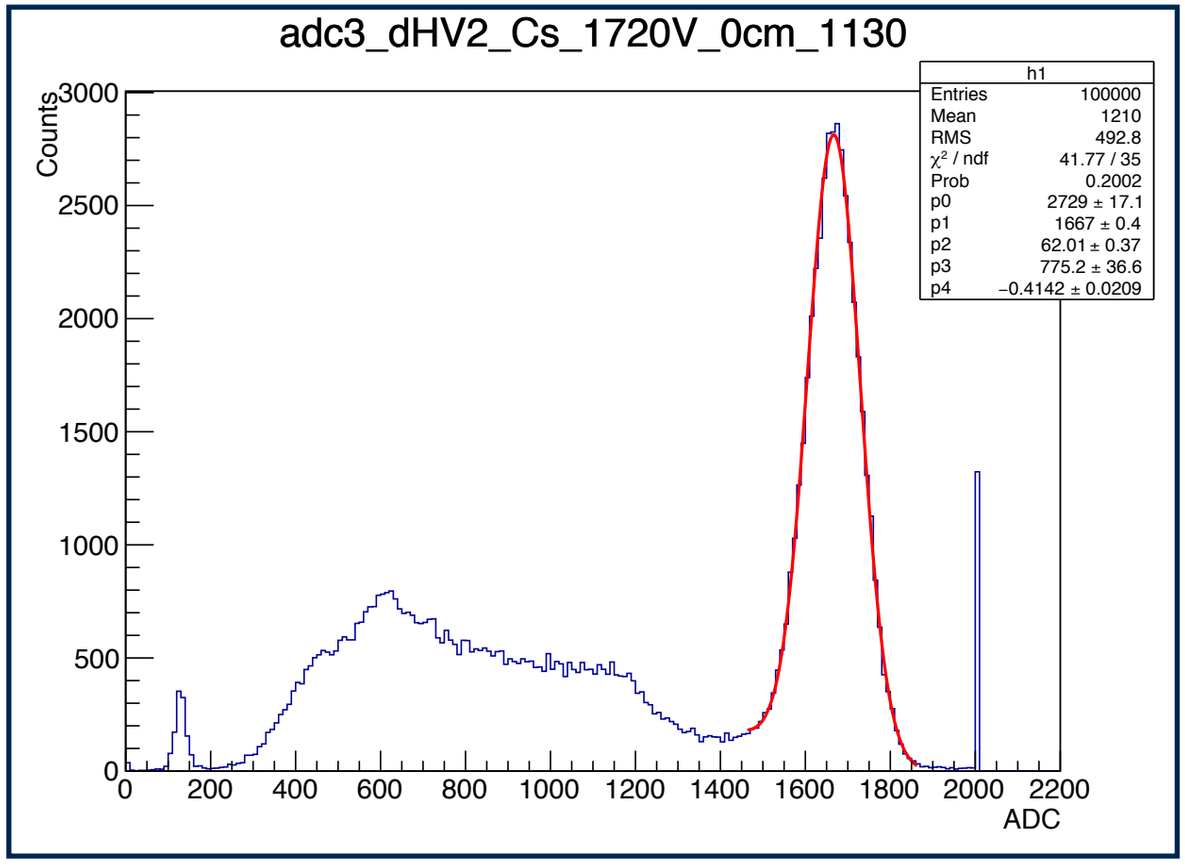
ADC Calibration NaI#1





ADC Calibration NaI#2

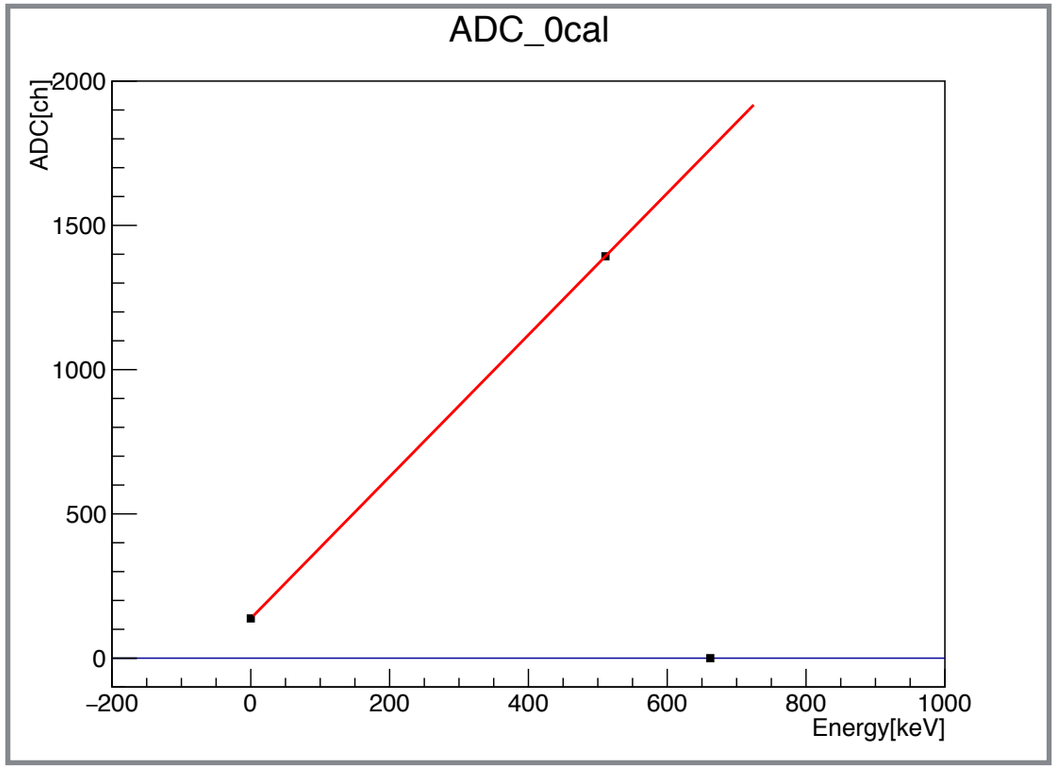


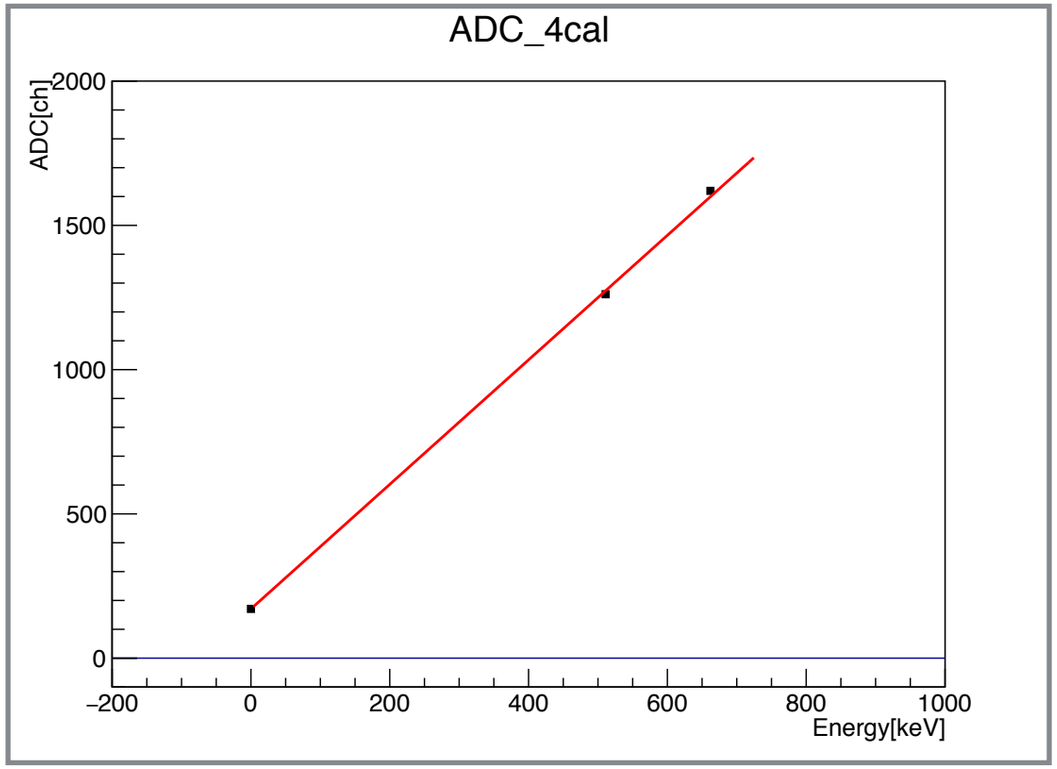


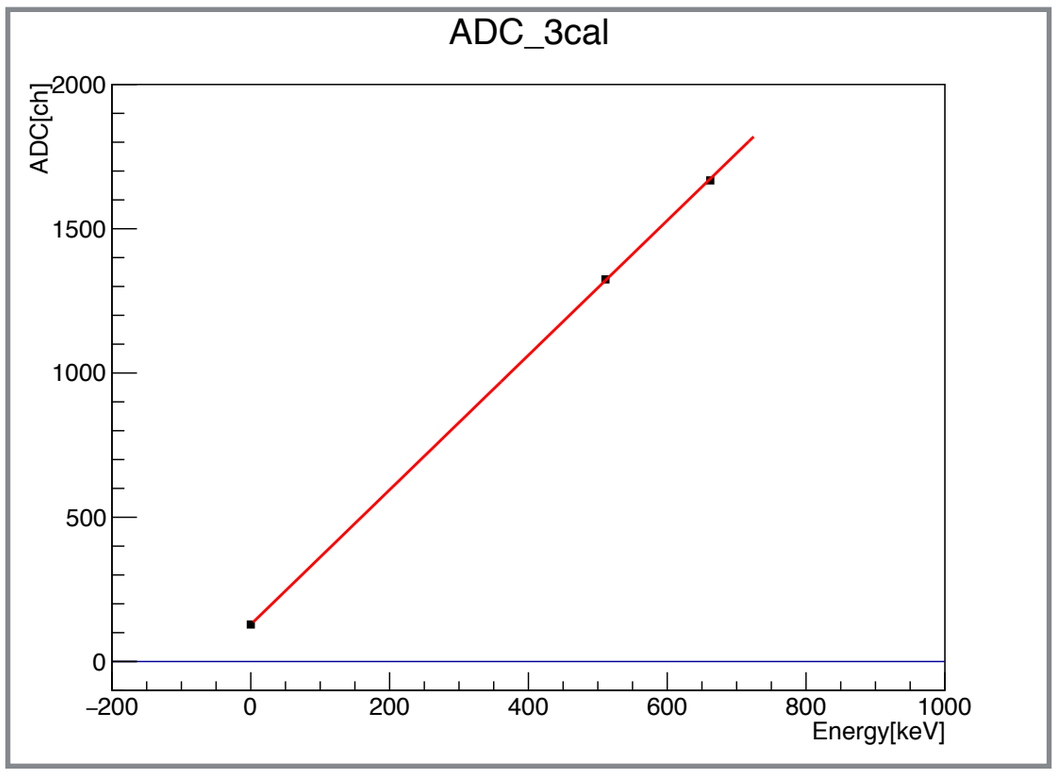
Energy resolution

	Na	Cs
NaI#0	4.6%	4.1%
NaI#1	6.0%	5.5%
NaI#2	4.6%	4.0%

ADC Calibration







ADC Calibration

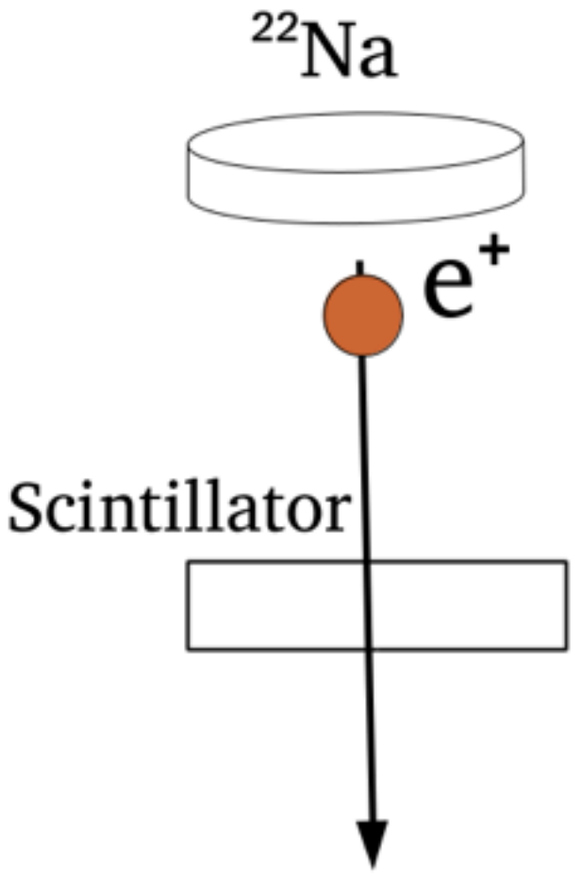
E	NaI#0	NaI#1	NaI#2
0	140.3±0.1	169.4±0.3	131.7±0.3
511.0	1393±58	1261±67	1325±54
661.7	1774±67	1620±79	1667±62

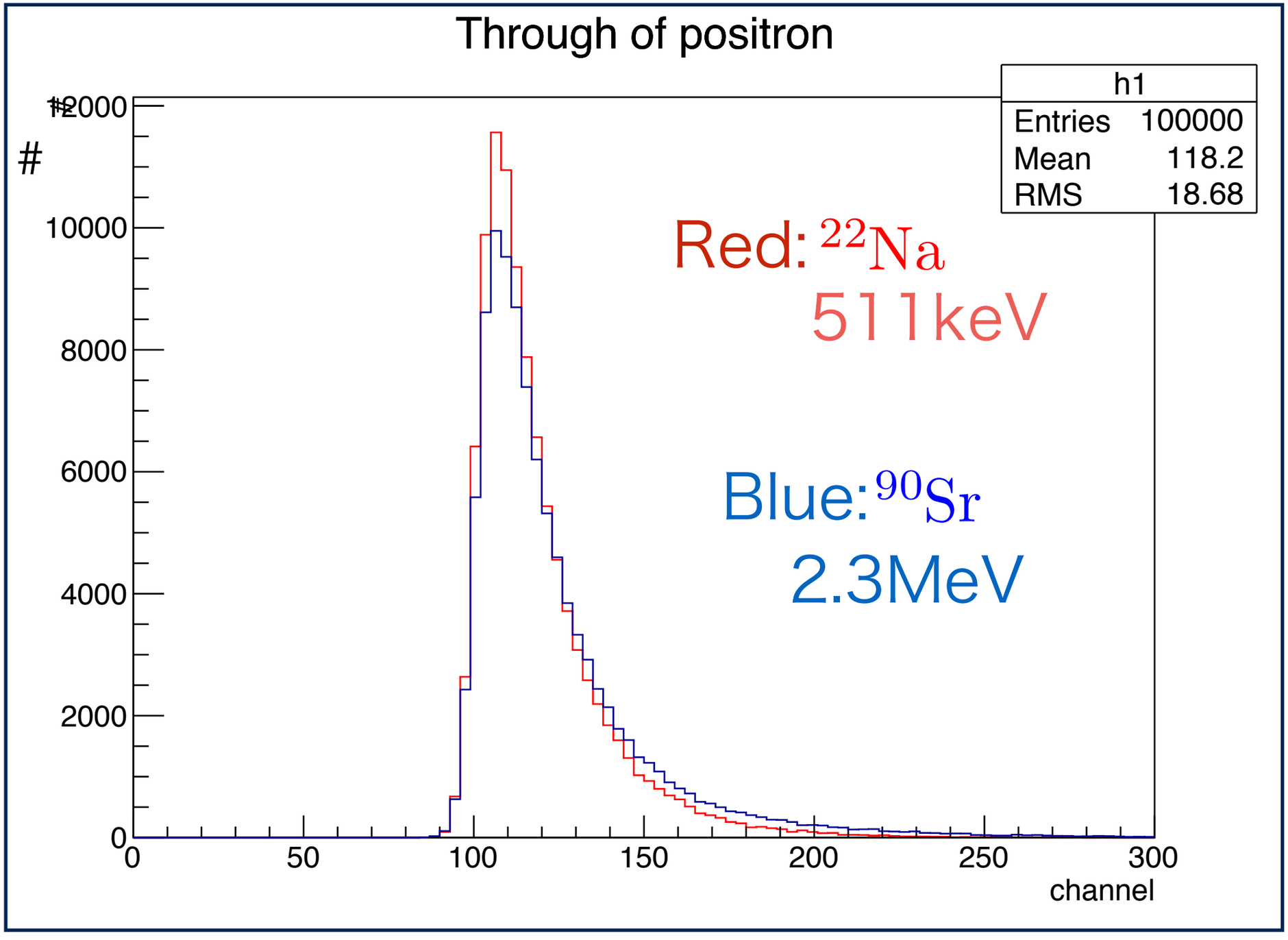
NaI#0:E[keV]=(0.41±0.01)×ADC[ch]-57±2

NaI#1:E[keV]=(0.46±0.02)×ADC[ch]-78±3

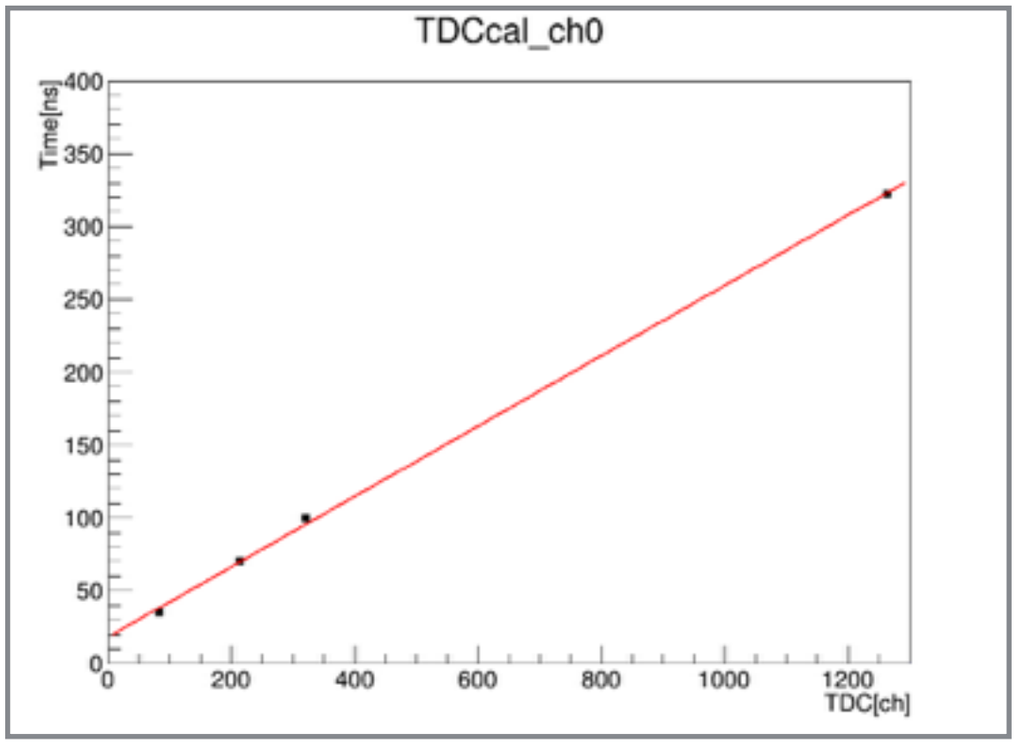
NaI#0:E[keV]=(0.43±0.01)×ADC[ch]-57±2

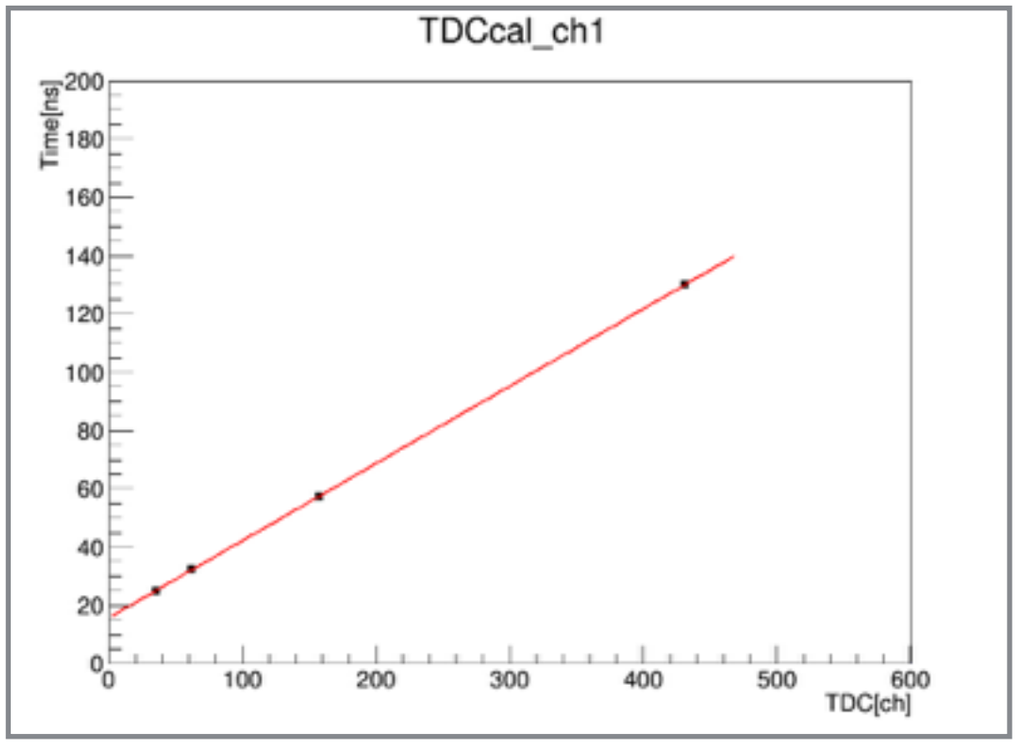
Through of positron

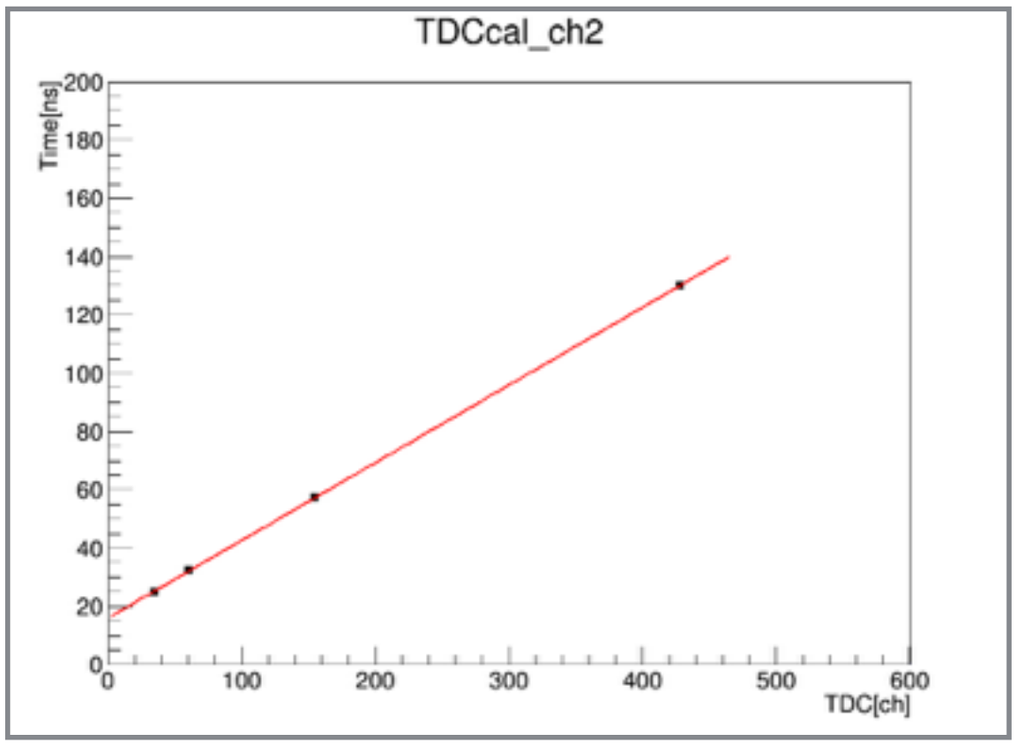


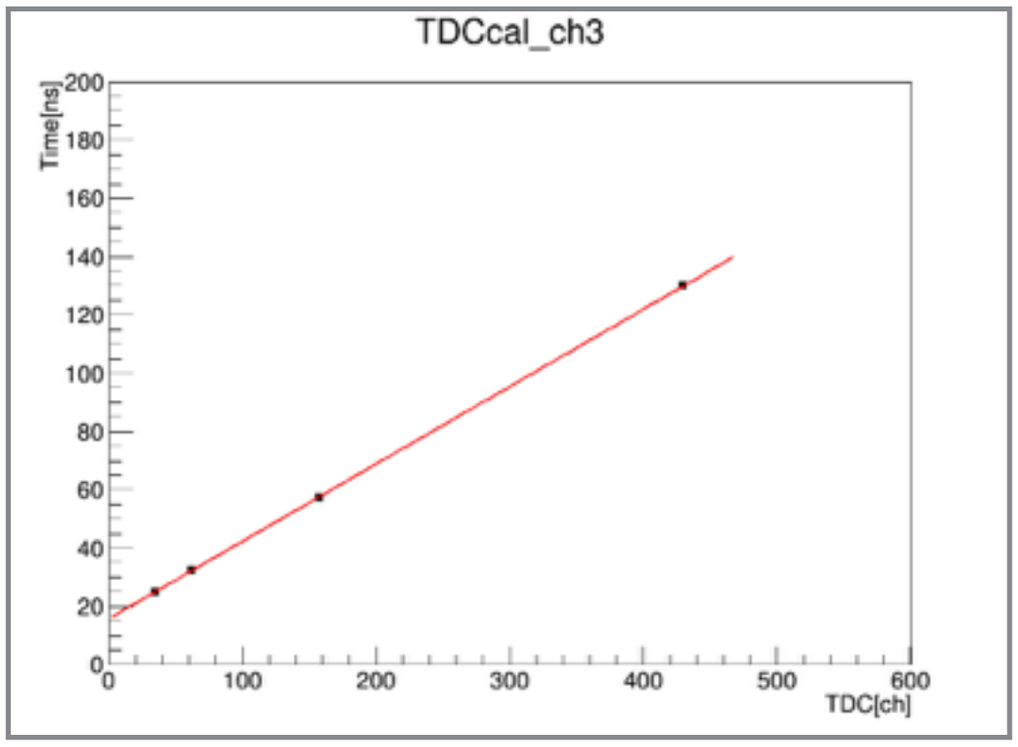


TDC Calibration

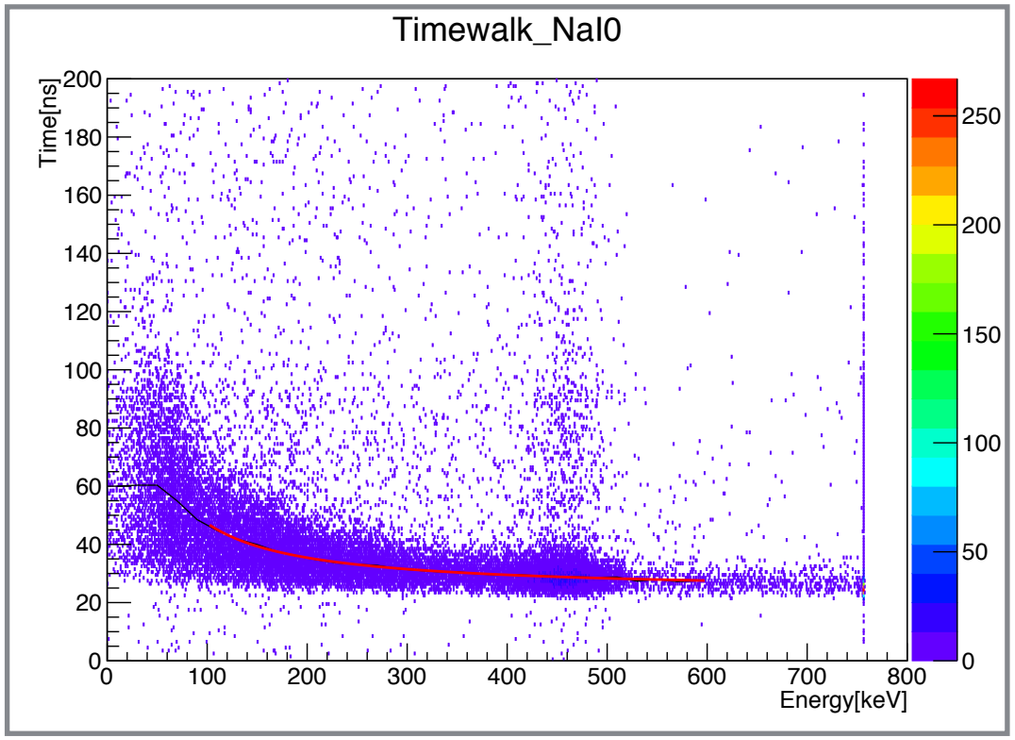


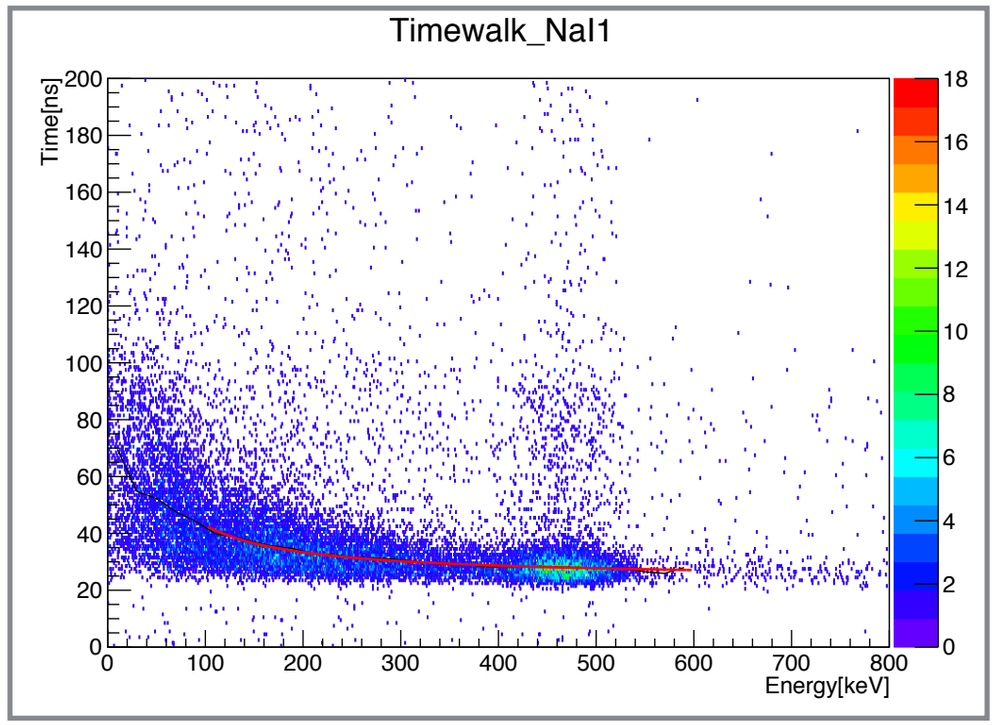


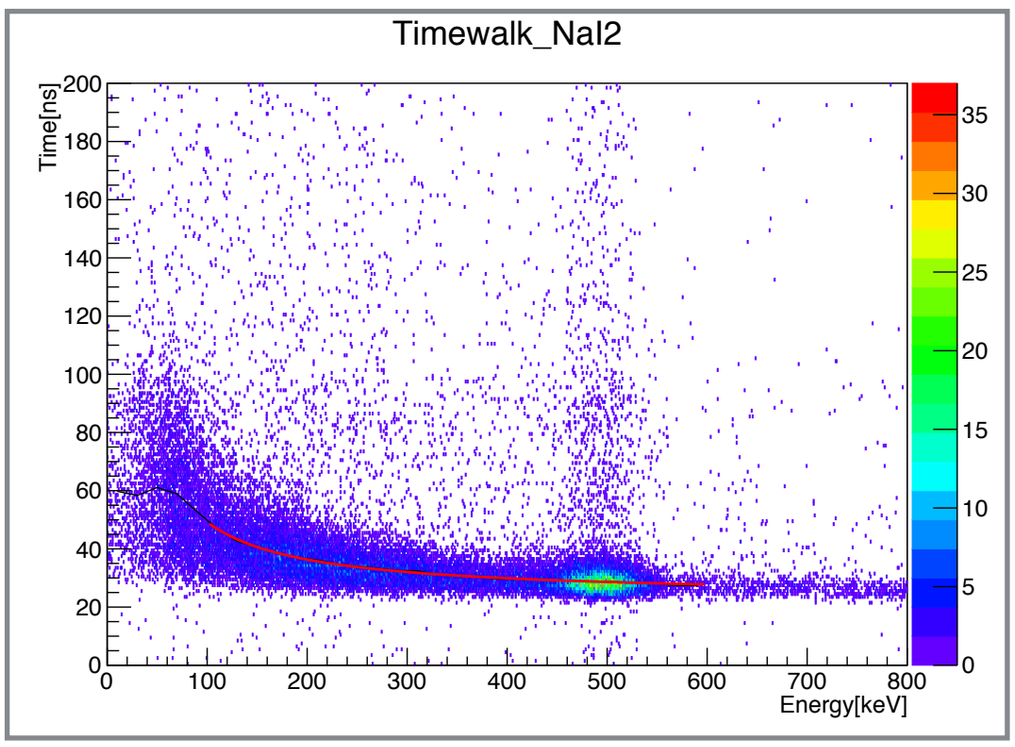




Time-walk correction



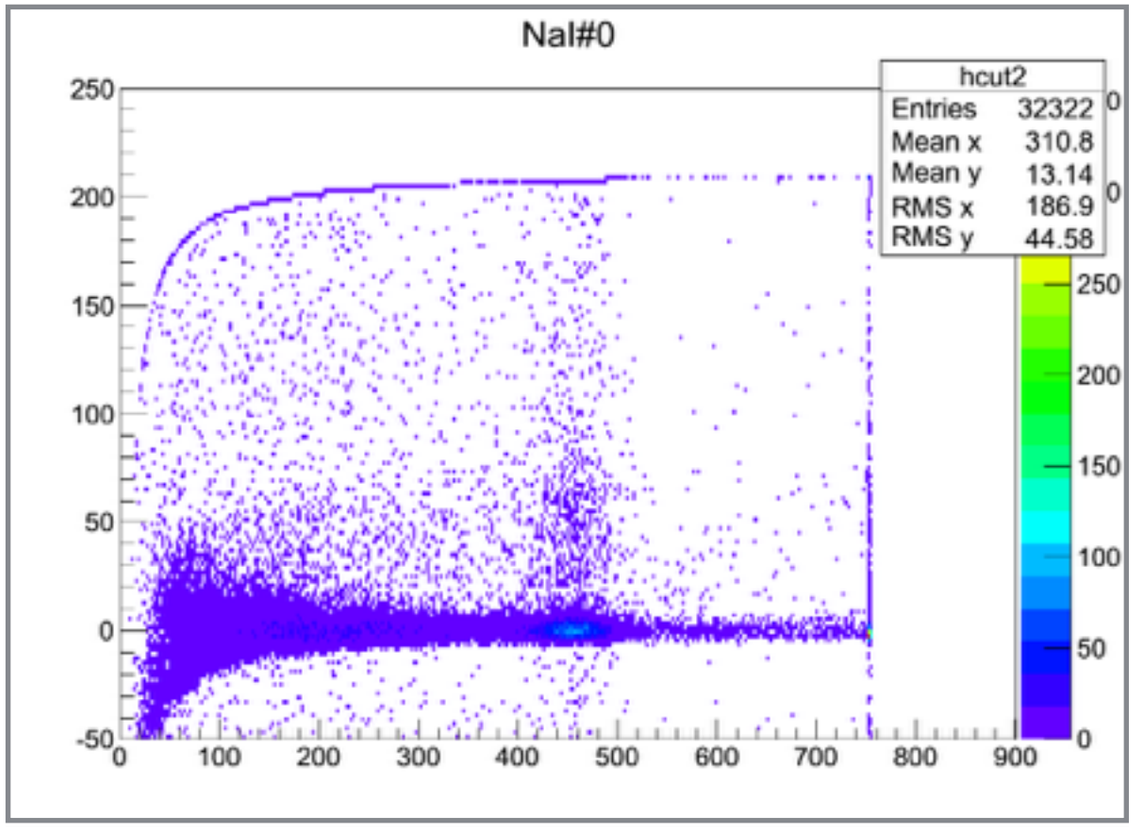


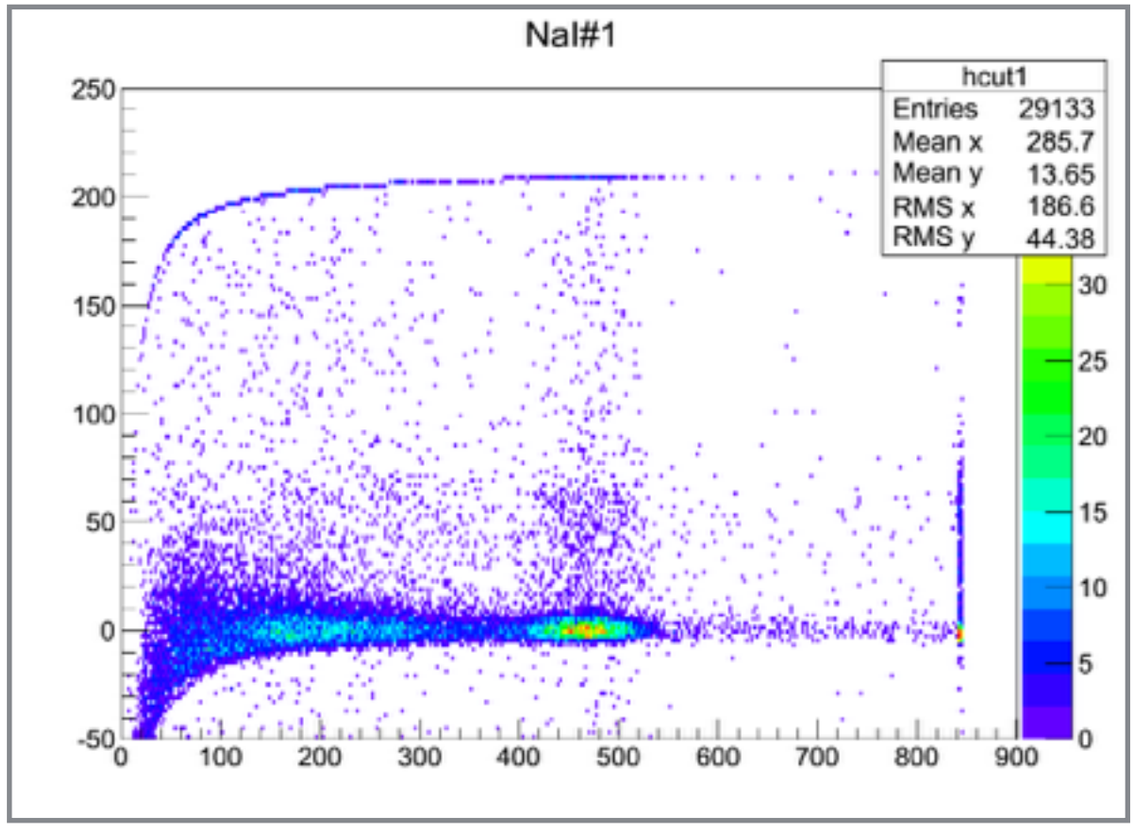


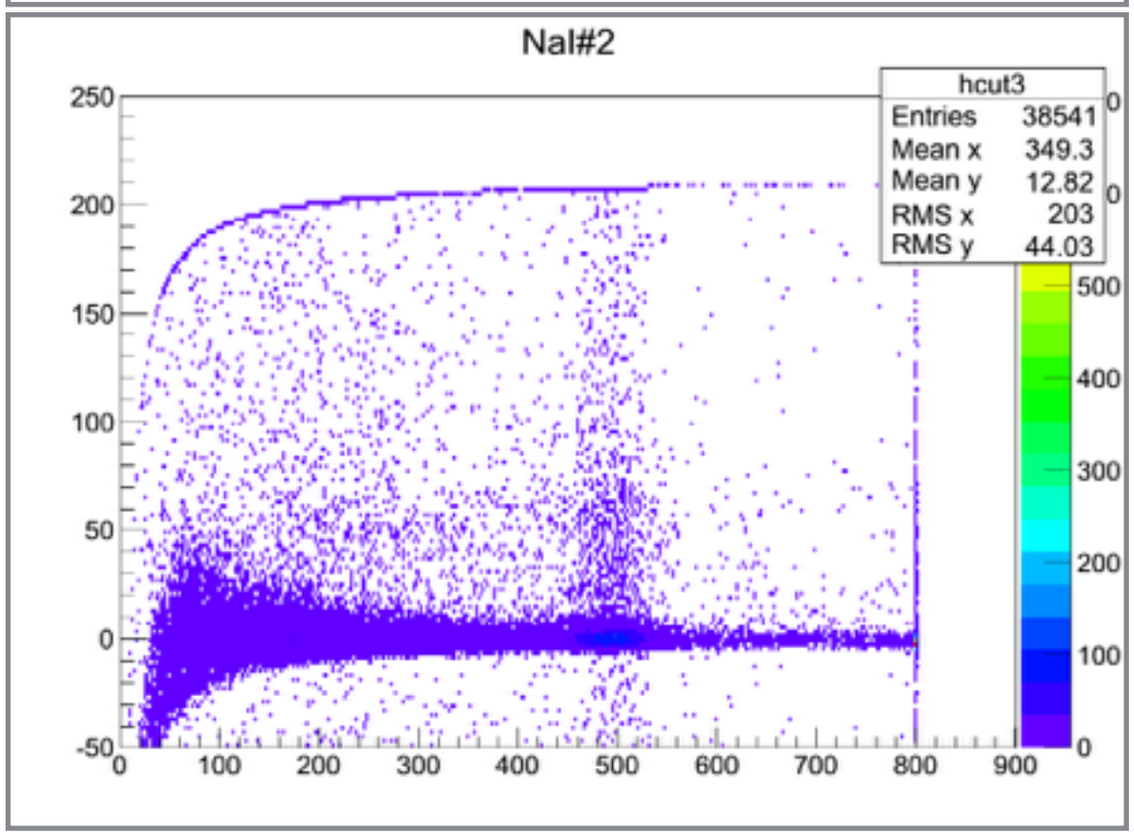
Measurement without aerogel

→pair annihilation

Time-walk correction

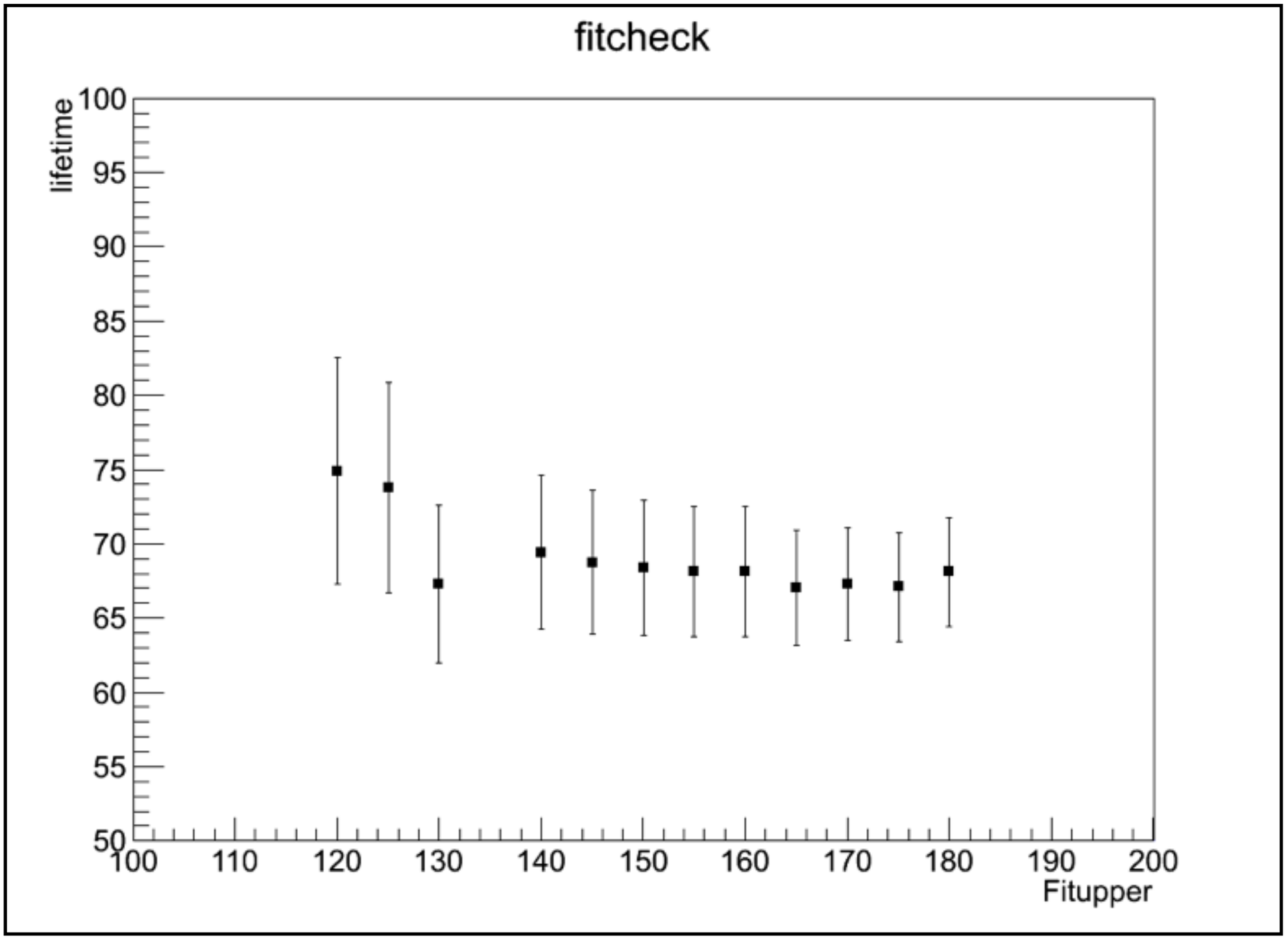




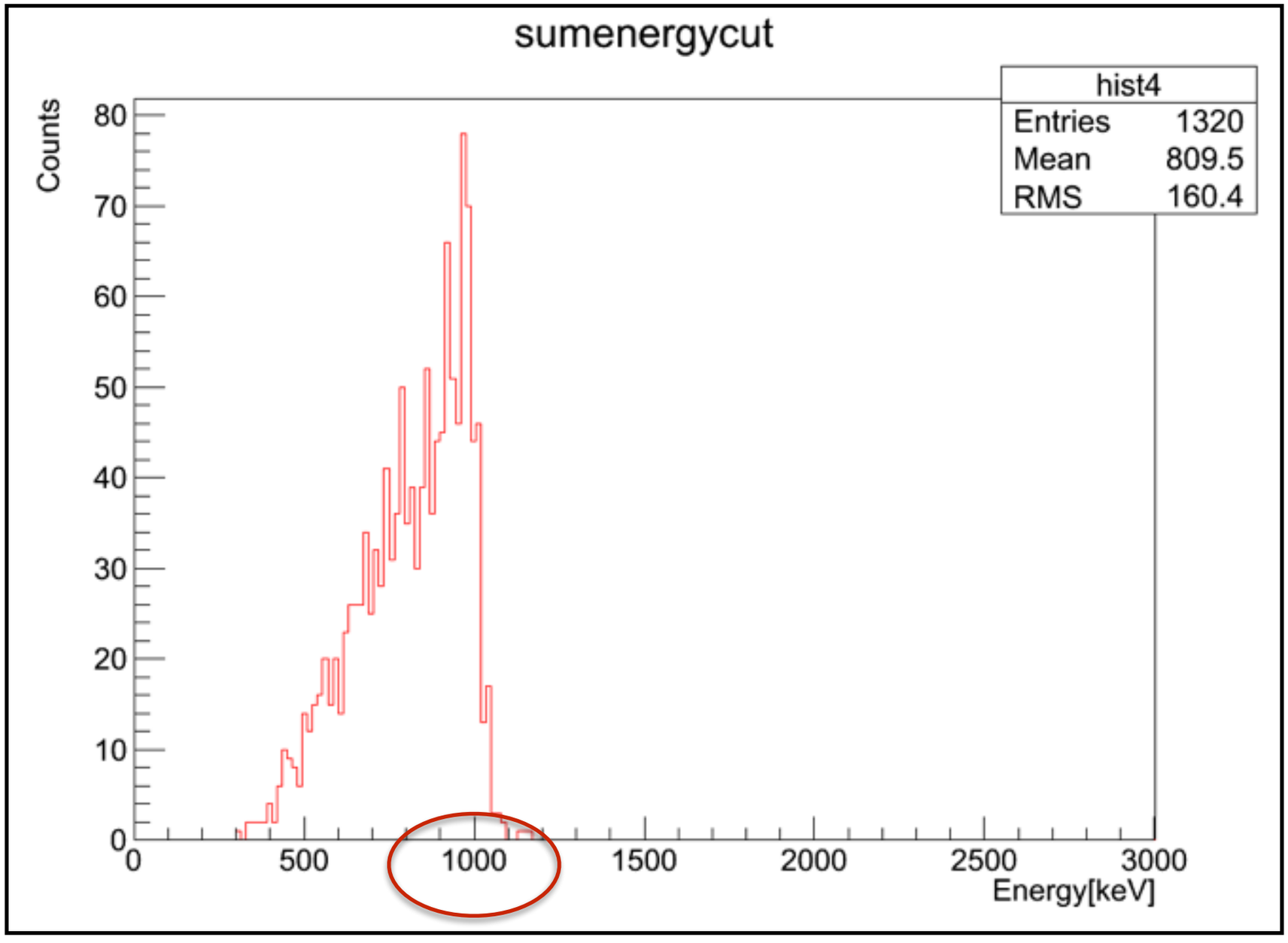


After time-walk Correction

Fitting range



Total energy with the cuts



cut E:70keV-430keV

$| T_i - T_j | < 25ns(NaI)$

$T_{plascin} > 30ns$