R&D of neutron detector

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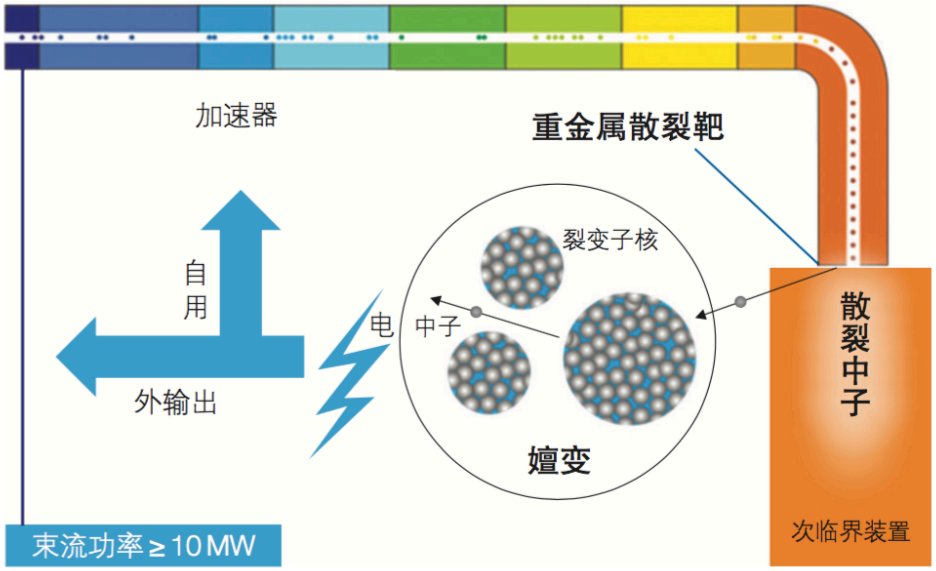
Outline

- Introduction
- Nuclear reaction
  - Neutron source of AmBe.
  - Thermal neutron and B10.
- Simulation of neutron experiment from Geant4
  - TOF and energy distribution of gamma
  - TOF and energy distribution of thermal neutron
- Neutron experiment
  - Time of Flight (TOF) method
    - Experimental setup 1
    - Experimental setup 2
  - Result of experiment
    - TOF distribution
    - Energy distribution
    - Calculation of signal events about thermal neutron
- Summary

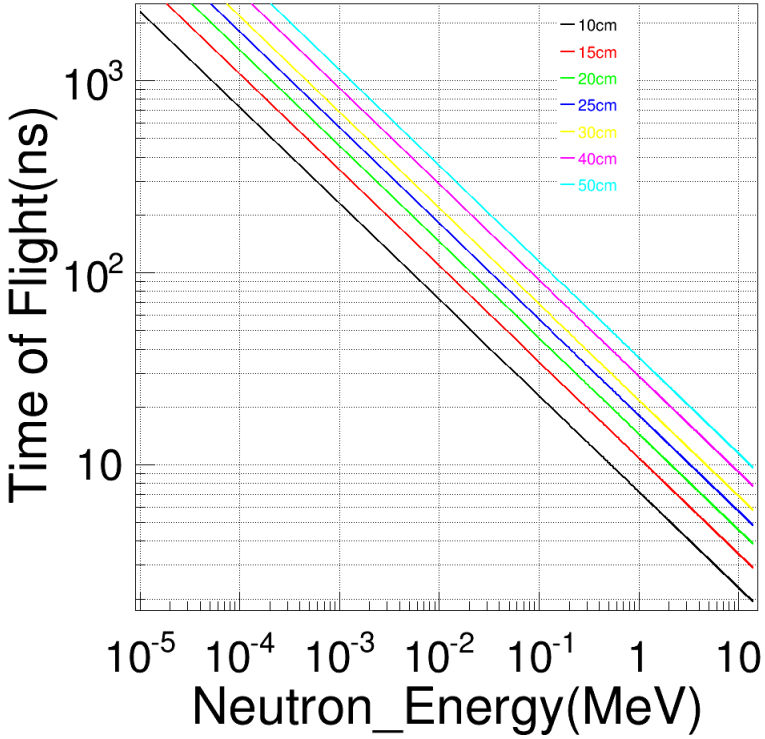
Introduction

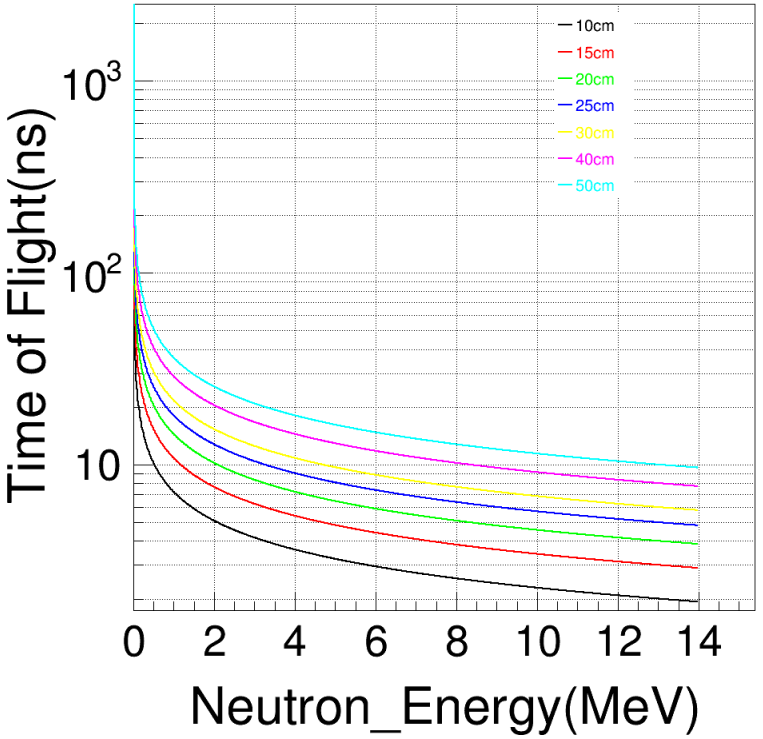
- The China Accelerator Driven subcritical System (C-ADS)
  - ✓ aim to solve the nuclear waste problem and the resource for nuclear power plants in China



Introduction

TOF Method





Time of Flight about Neutron

Introduction

PSD Method

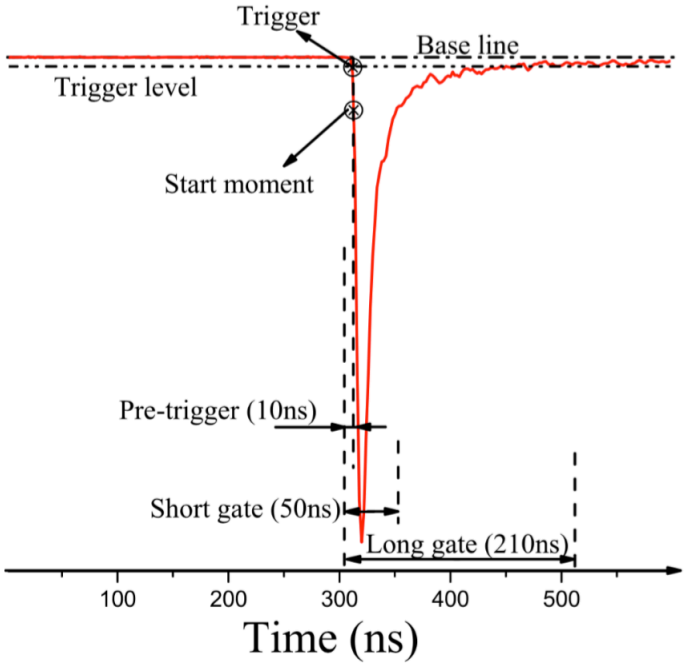


Fig. 2. The anode signal of the EJ309 liquid scintillator.

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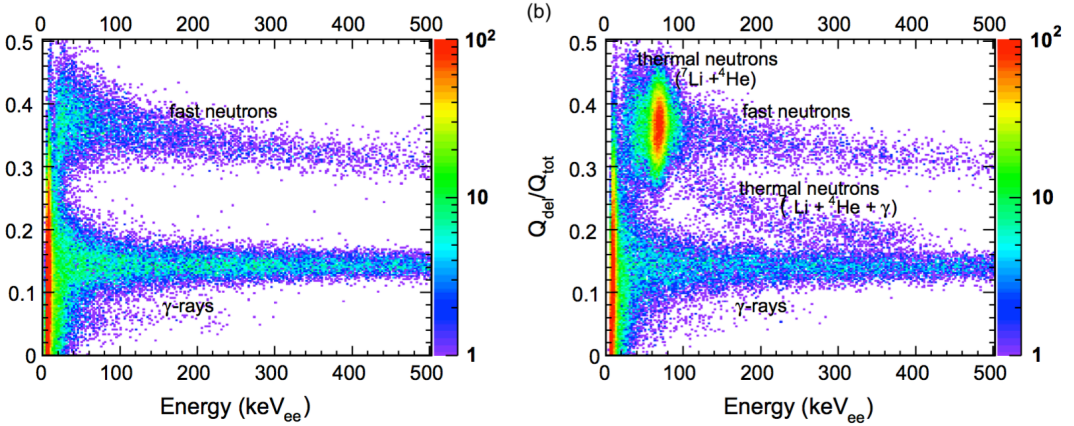

Pulse shape discrimination(PSD)

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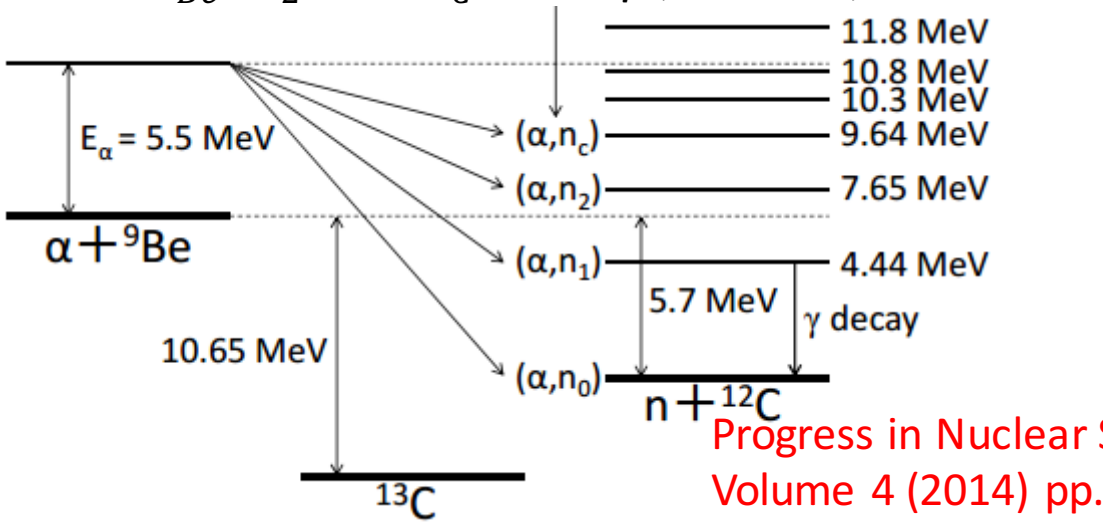
Nuclear reaction

- Energy level scheme of C12

$$9_{Be} + {}^{4}_{2}\alpha \rightarrow 12_{C} + n + \gamma(4.44MeV) + 5.7\ MeV$$



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- Capture reaction of B10

$$^{10}\mathrm{B} + \mathrm{n} = \begin{cases} ^{7}\mathrm{Li} + ^{4}\mathrm{He}, & Q = 2.792\ \mathrm{MeV}, \quad 6\% \\ ^{7}\mathrm{Li} + ^{4}\mathrm{He} + \gamma(480\ \mathrm{keV}), & Q = 2.310\ \mathrm{MeV}, \quad 94\%. \end{cases}$$

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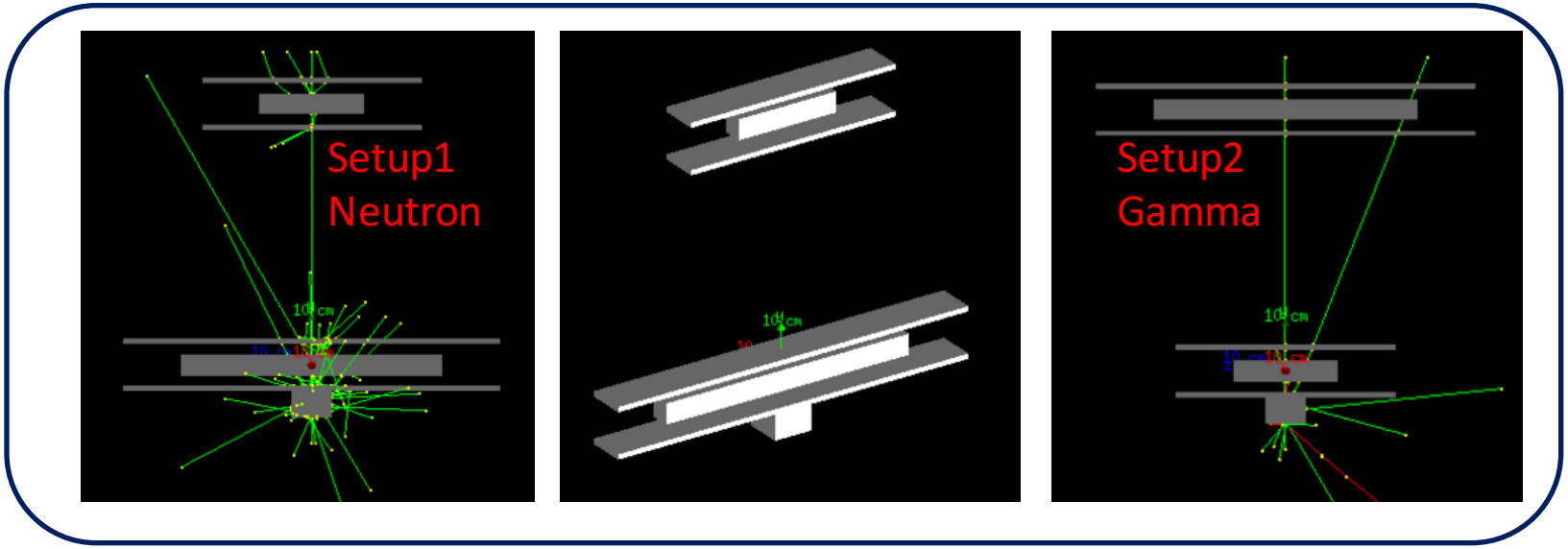
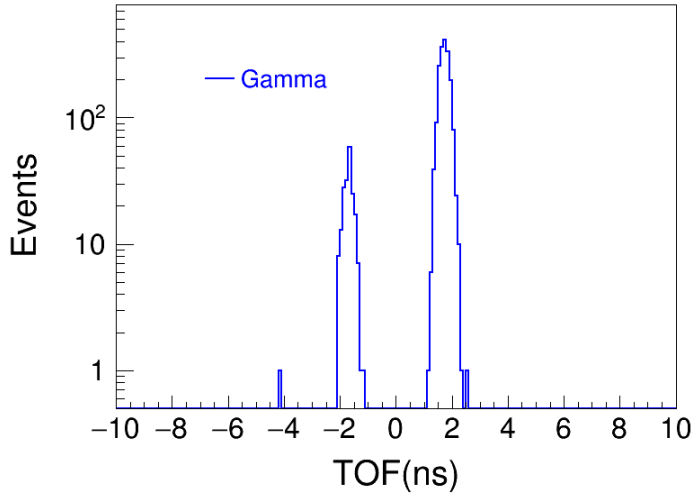
Simulation of experiment

- **Simulation of neutron experiment from Geant4**
  - Physics List
    - QGSP_BIC_HP

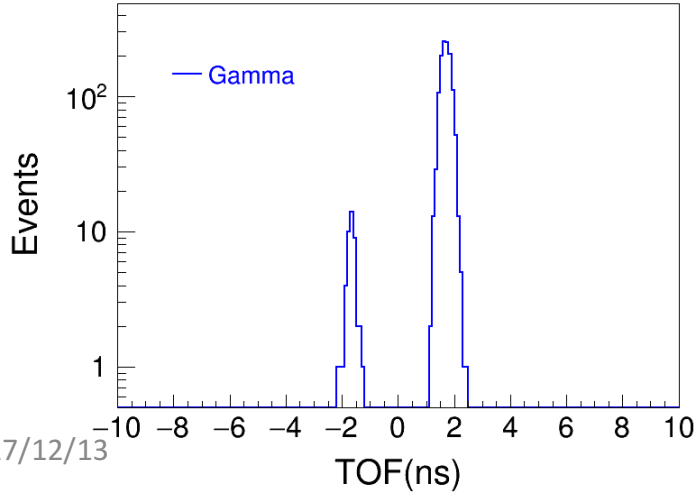


Simulation of experiment

➢ TOF distribution of gamma(Setup2)



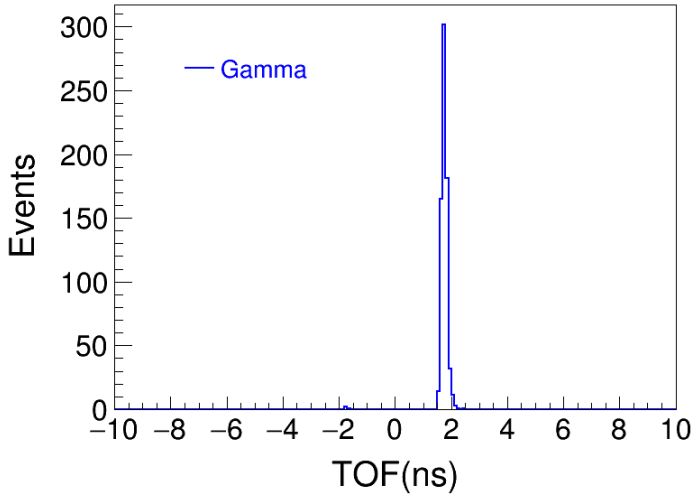
- Energy of gamma
  - 0.487MeV
- Number of Event
  - 10,0000
- Smear(105ps)



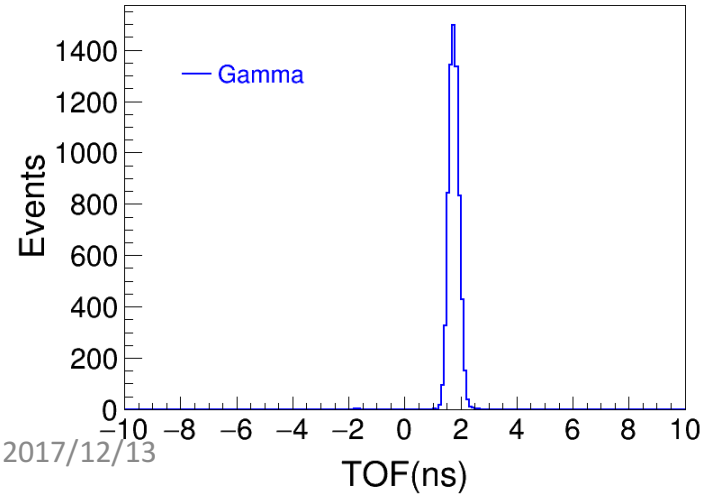
- Energy of gamma
  - 4.43MeV
- Number of Event
  - 100,0000
- Smear(105ns)

Simulation of experiment

➢ TOF distribution of thermal neutron(Setup2)



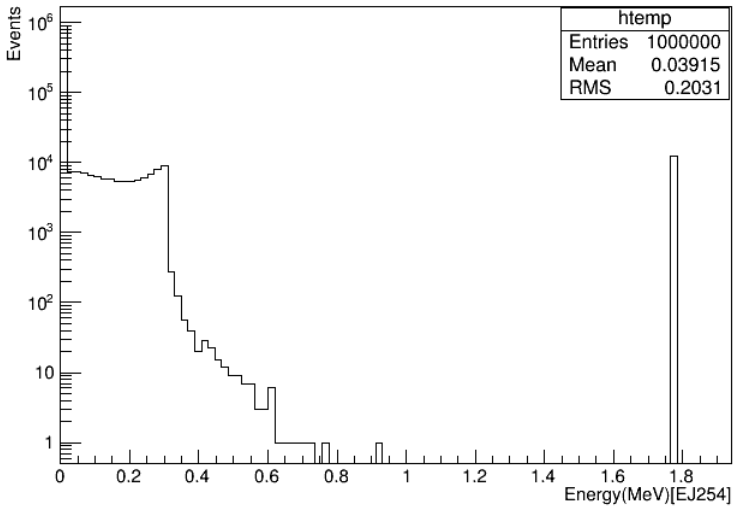
- Energy of thermal neutron
  - 0.0253eV
- Number of Event
  - 1,000,000

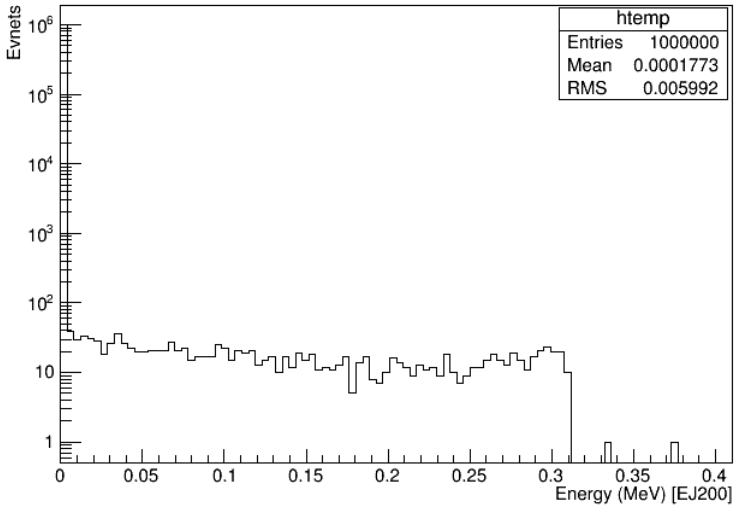


- Energy of thermal neutron
  - 0.0253eV
- Number of Event
  - 10,000,000
- Smear(105ps)

Simulation of experiment

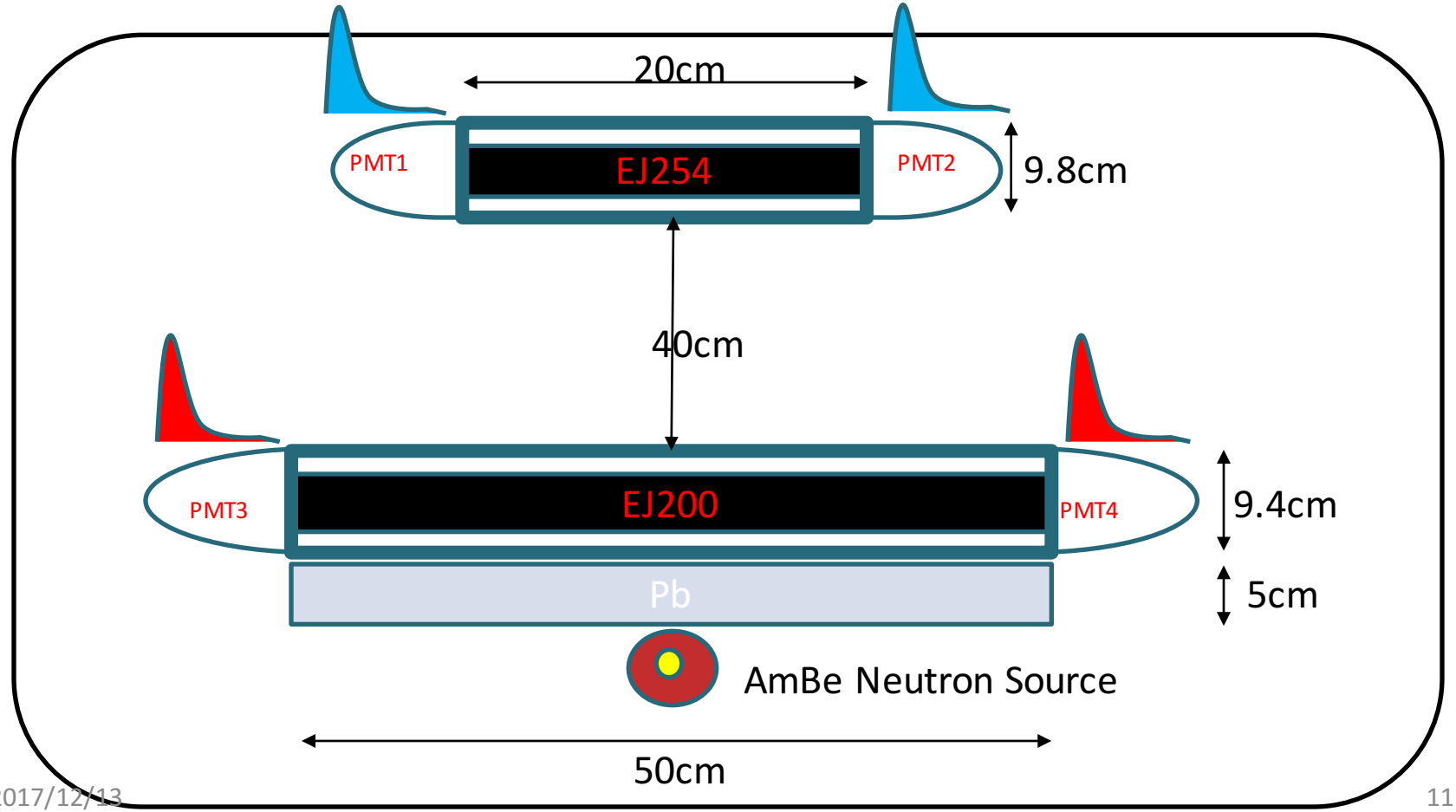
- Energy distribution of thermal neutron(Setup2)
  - Energy distribution from EJ254 and EJ200





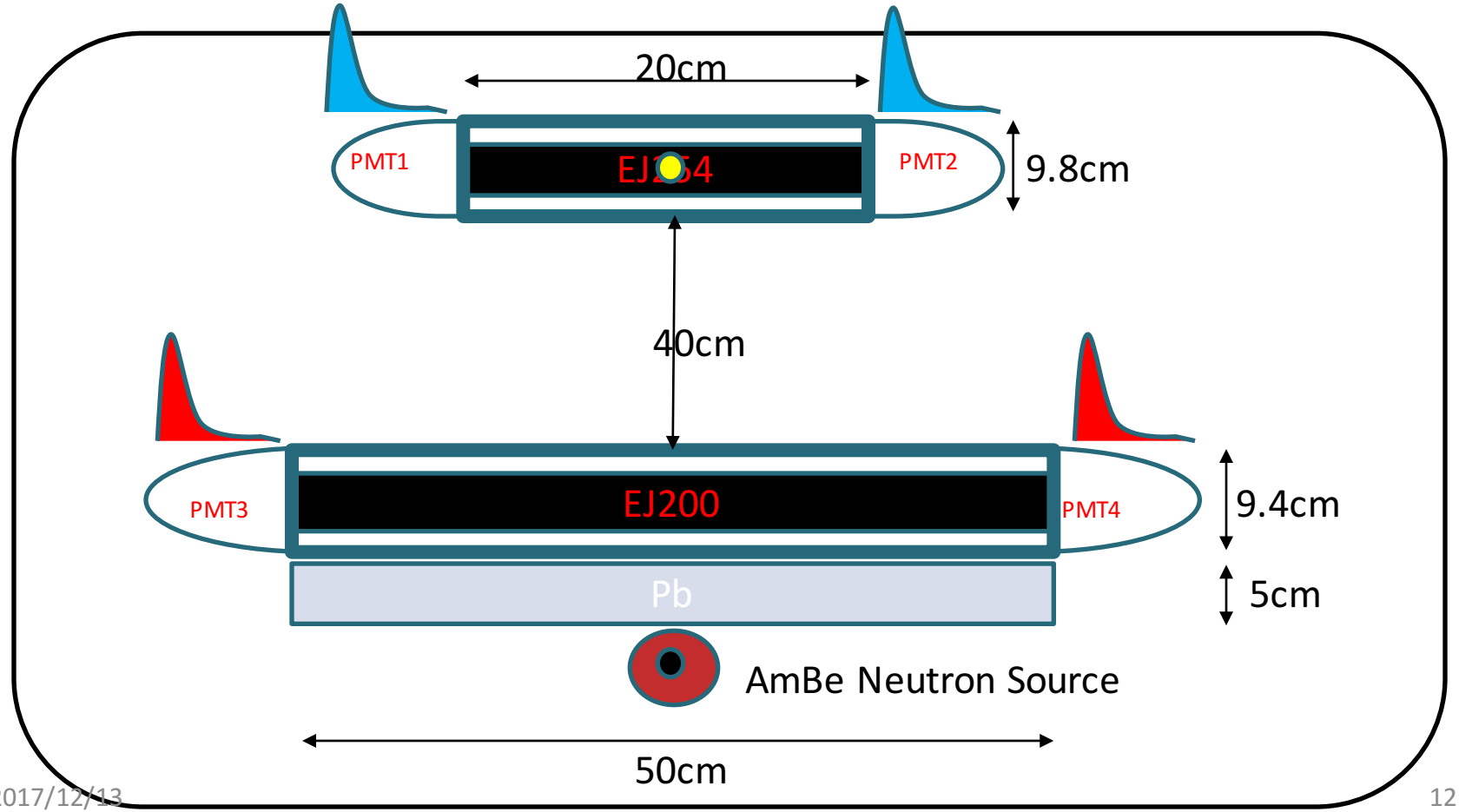
Neutron experiment

- Time of Flight (TOF) method
  - Experimental setup 1



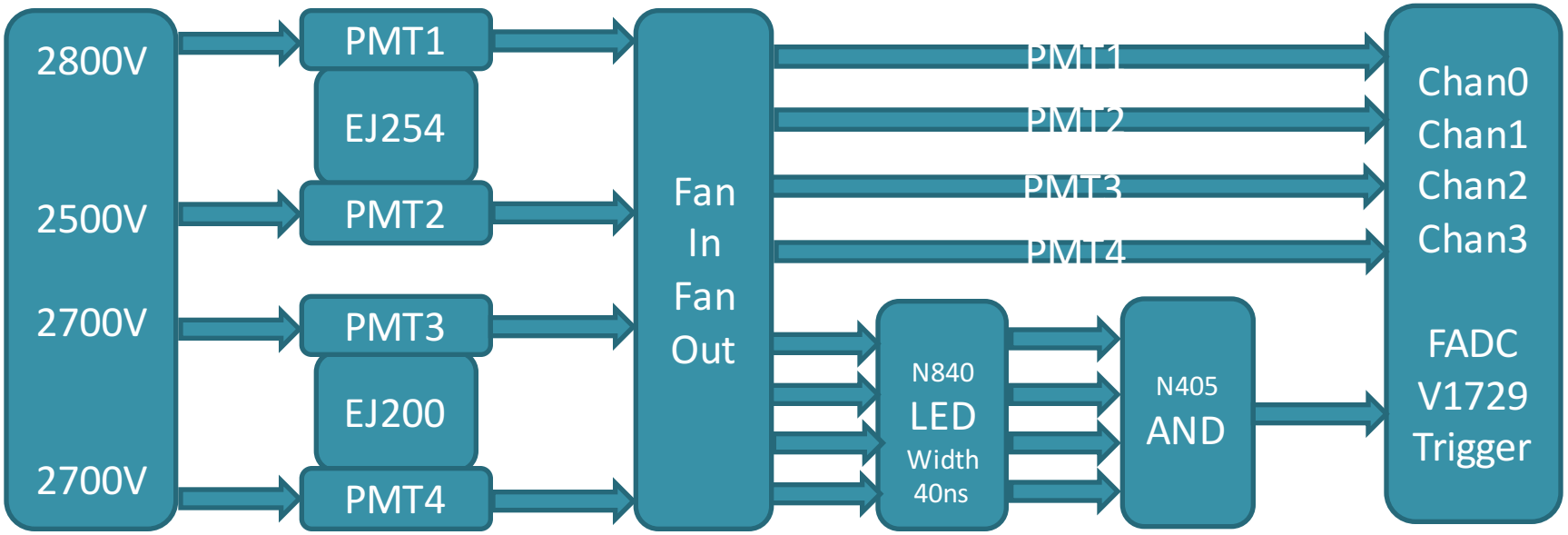
Neutron experiment

- Time of Flight (TOF) method
  - Experimental setup 1



Neutron experiment

- Time of Flight (TOF) method
  - Experimental setup 1



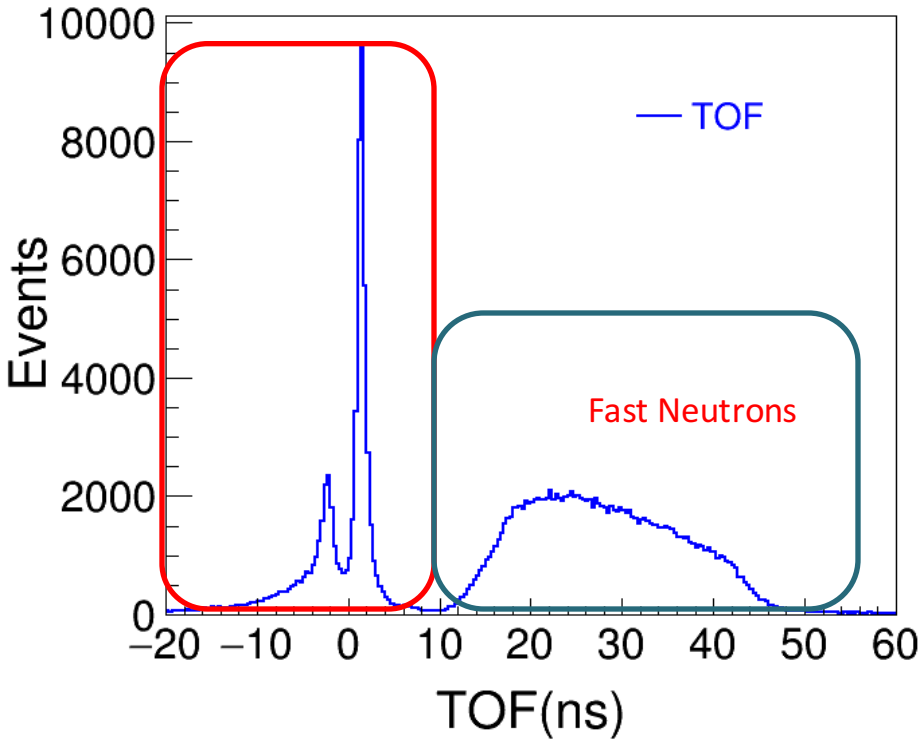
- Data Sets(Events=267000)

Date_Time: 2016-03-31-21:30 to 2016-04-01-14:22
Run_Number: run1_AmBe_V1729A_Threshold7F0_Events_267000/

Neutron experiment

➢ Result of experimental setup 1

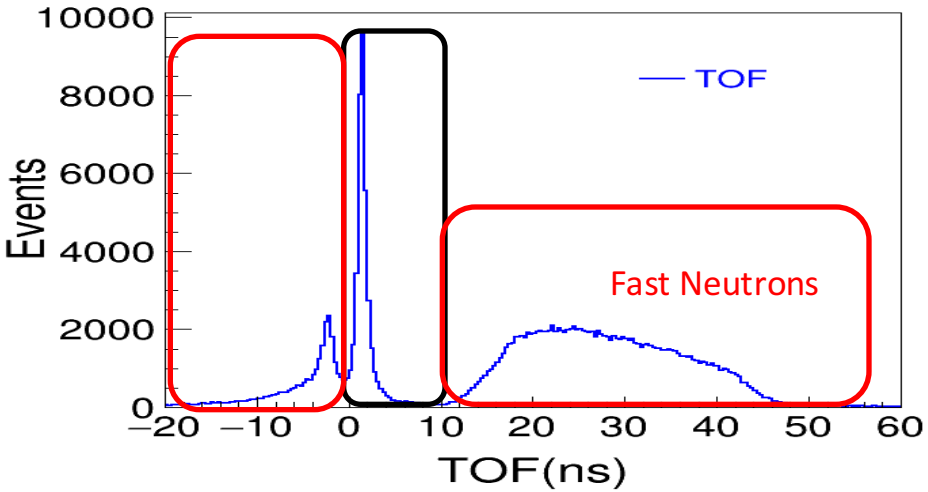
☐ TOF distribution

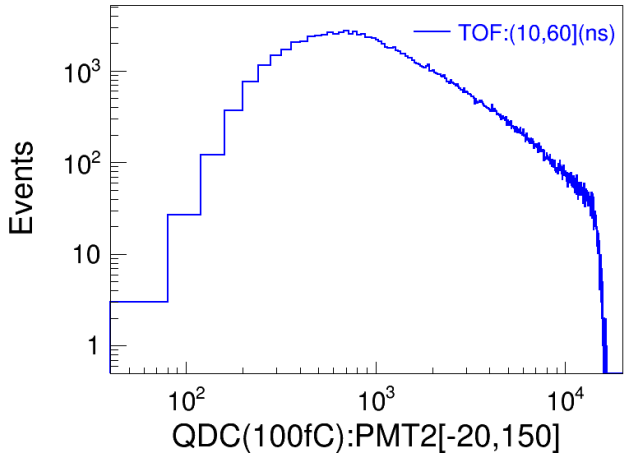


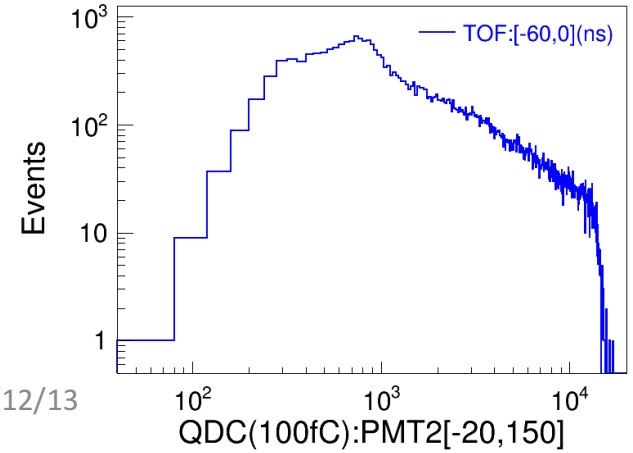
Delay time of four channels is same after time calibration.
Coincidence width is 40ns from the discriminator (Mod.N840)

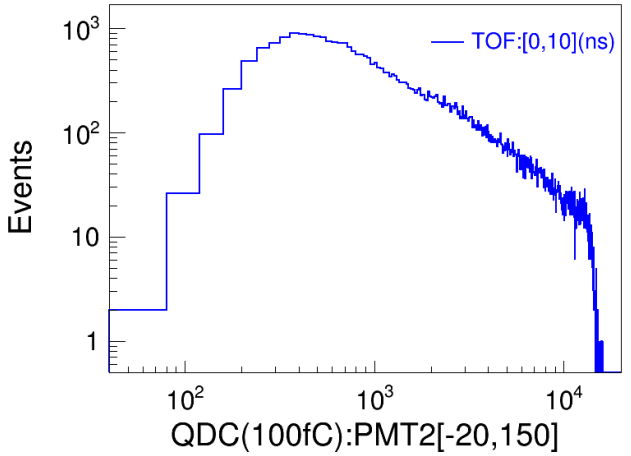
Neutron experiment

- **Result of experimental setup 1**
  - **Energy distribution of PMT2(EJ254)**



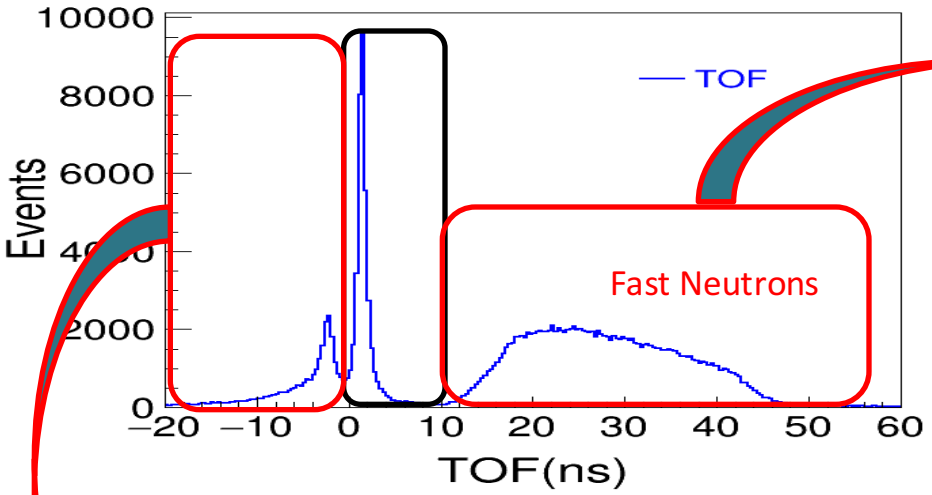


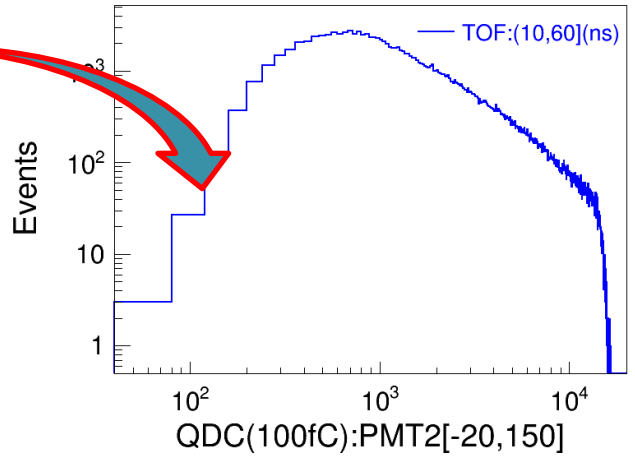


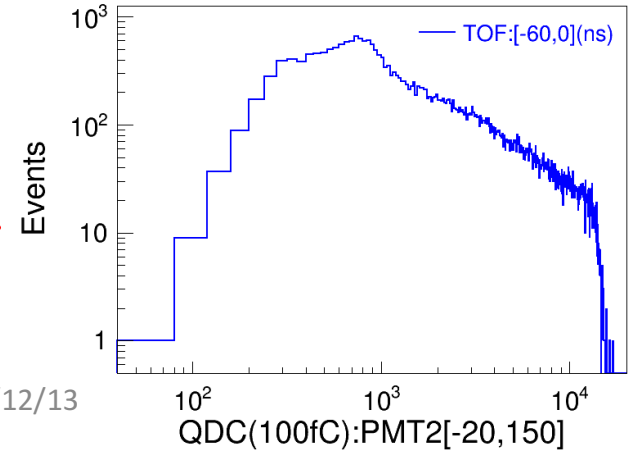


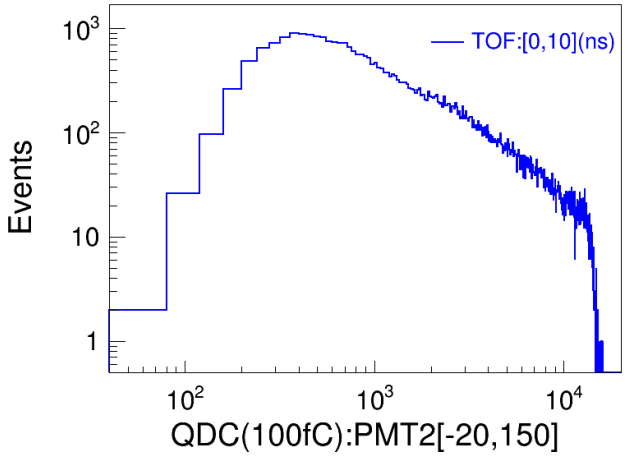
Neutron experiment

- **Result of experimental setup 1**
  - **Energy distribution of PMT2(EJ254)**



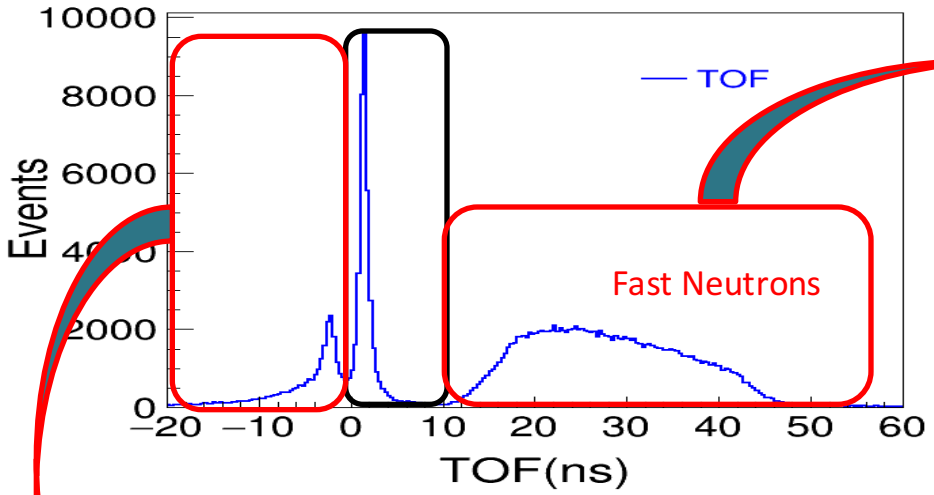


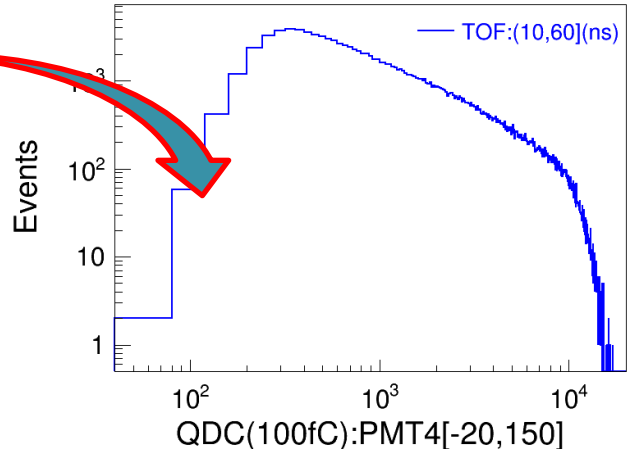


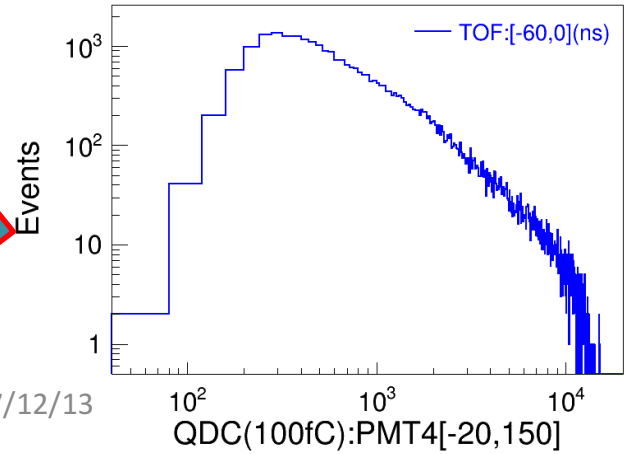


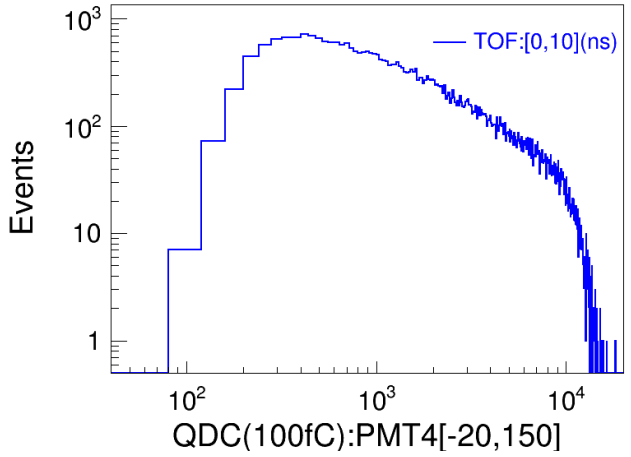
Neutron experiment

- Result of experimental setup 1
  - Energy distribution of PMT4(EJ200)



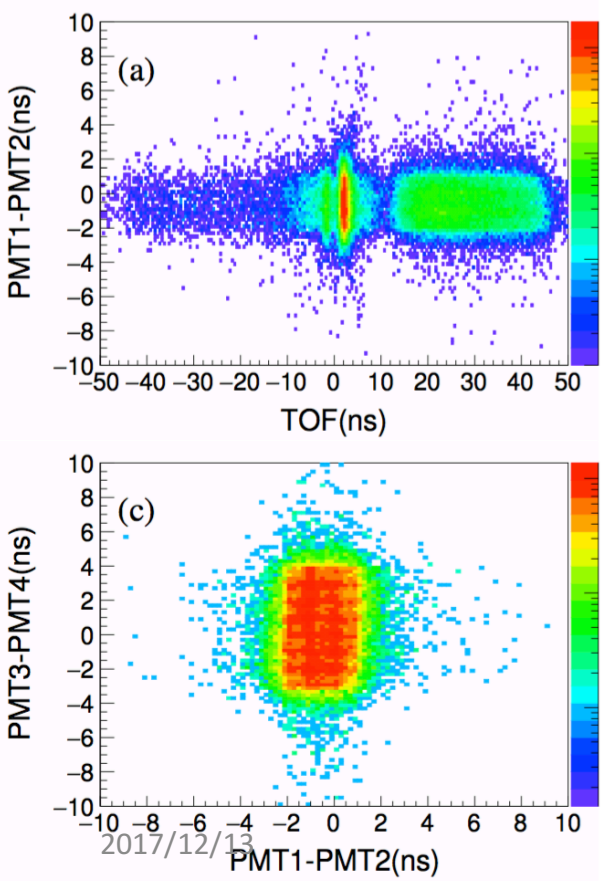


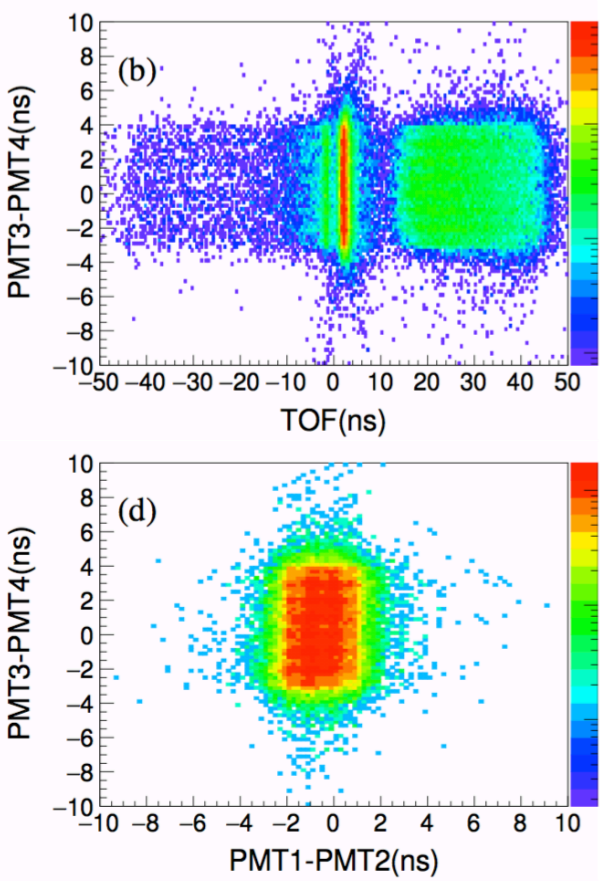


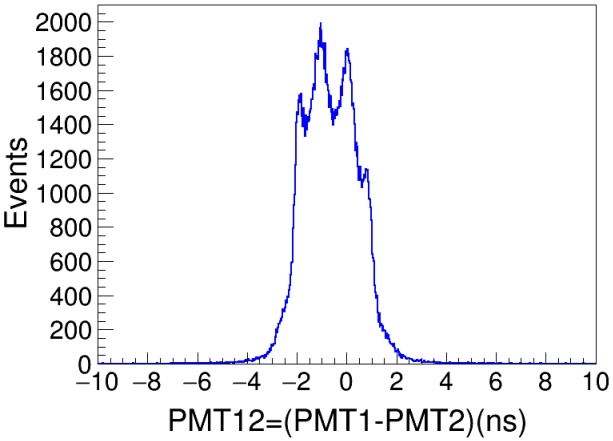


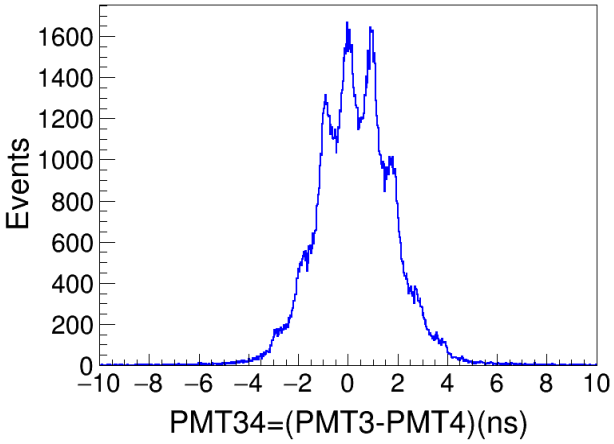
Neutron experiment

- Result of experimental setup 1
  - Position distribution





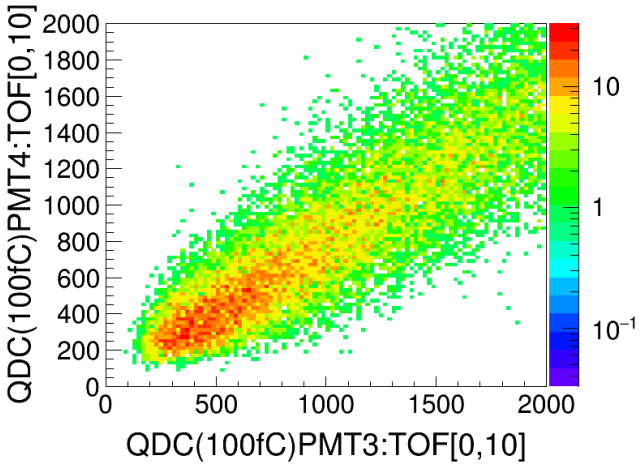


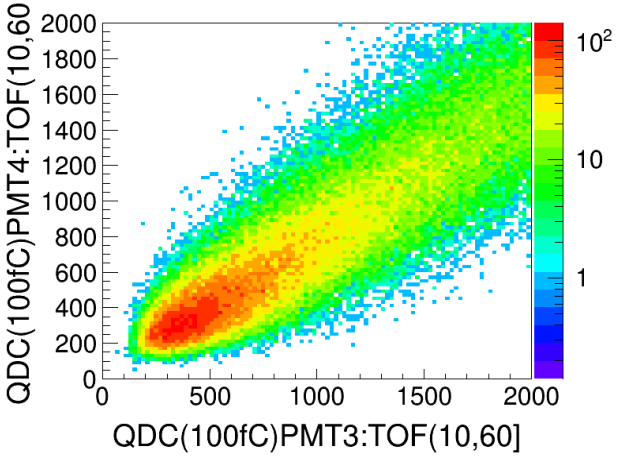


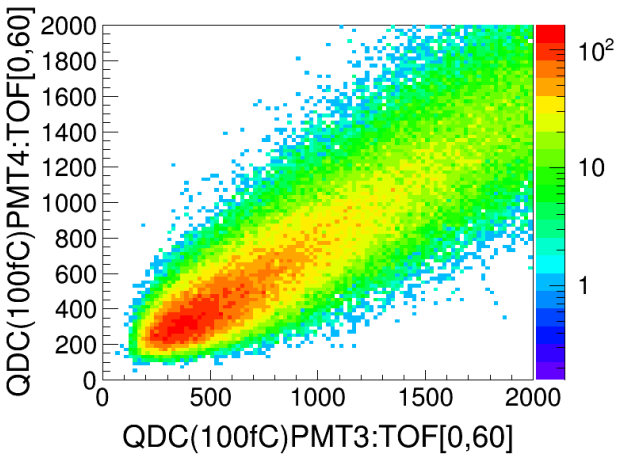
Neutron experiment

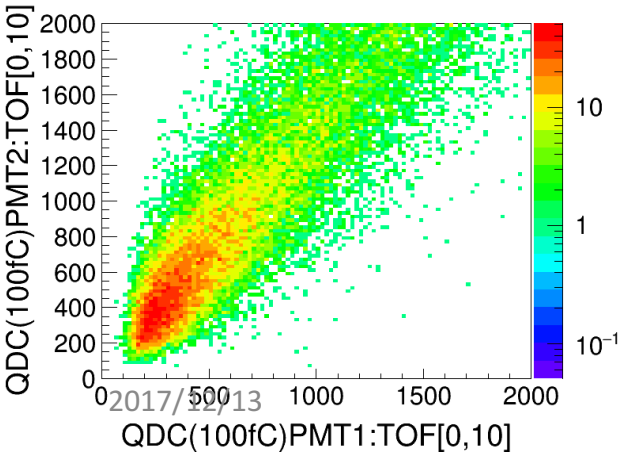
➢ Result of experimental setup 1

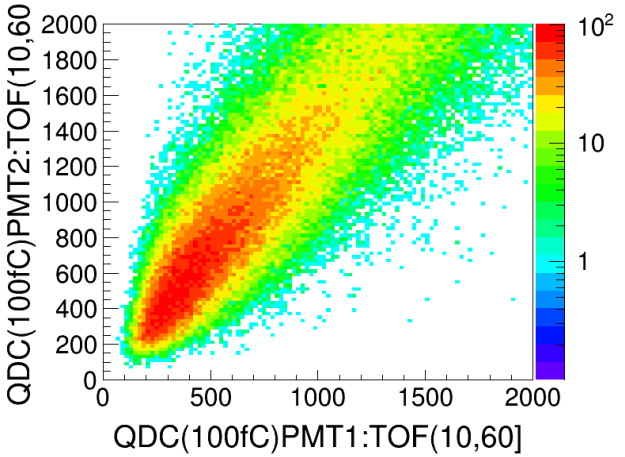
☐ QDC distribution

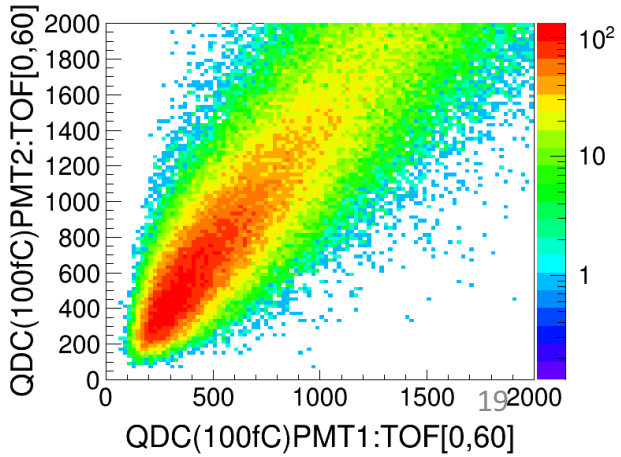






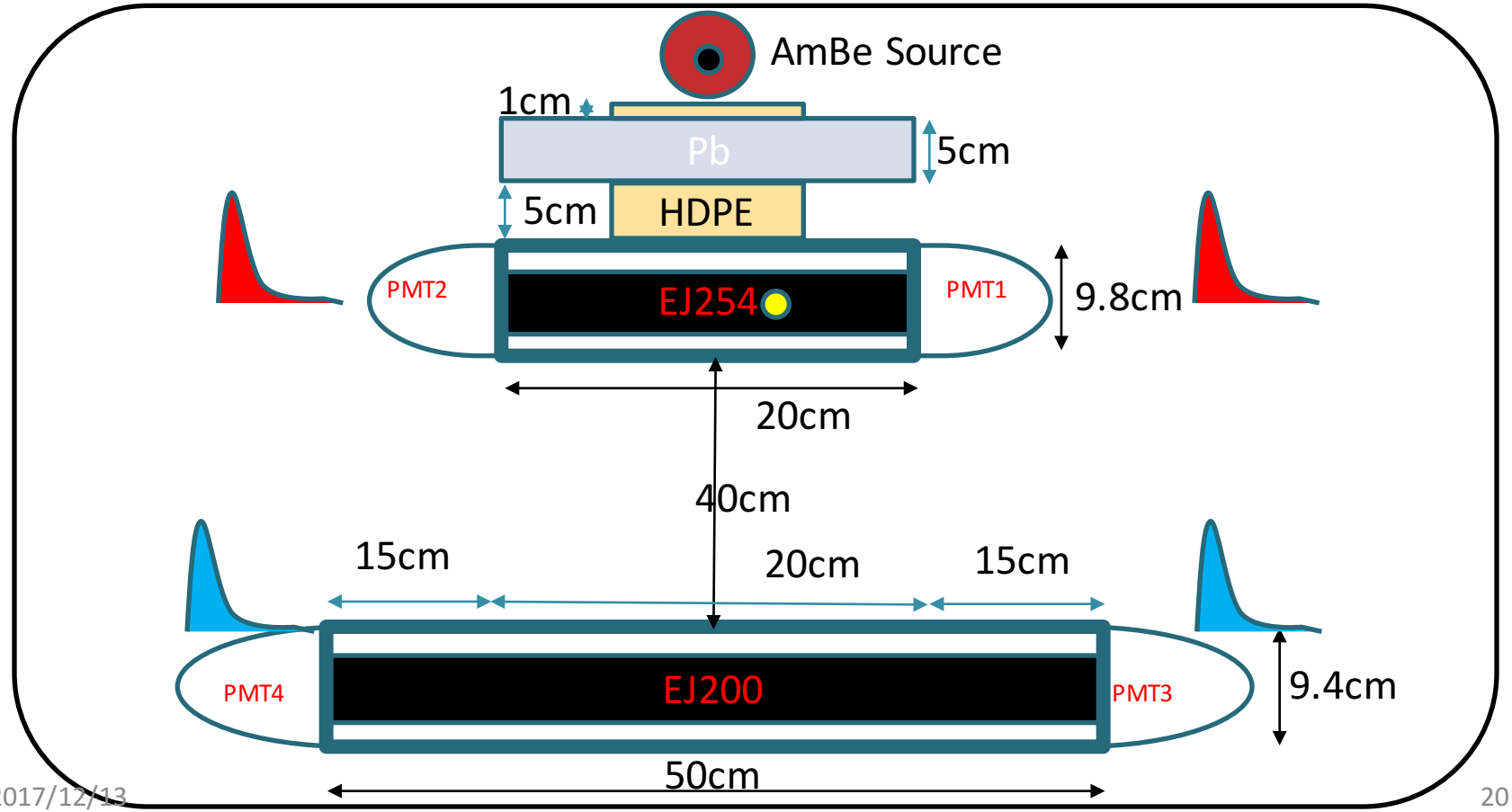






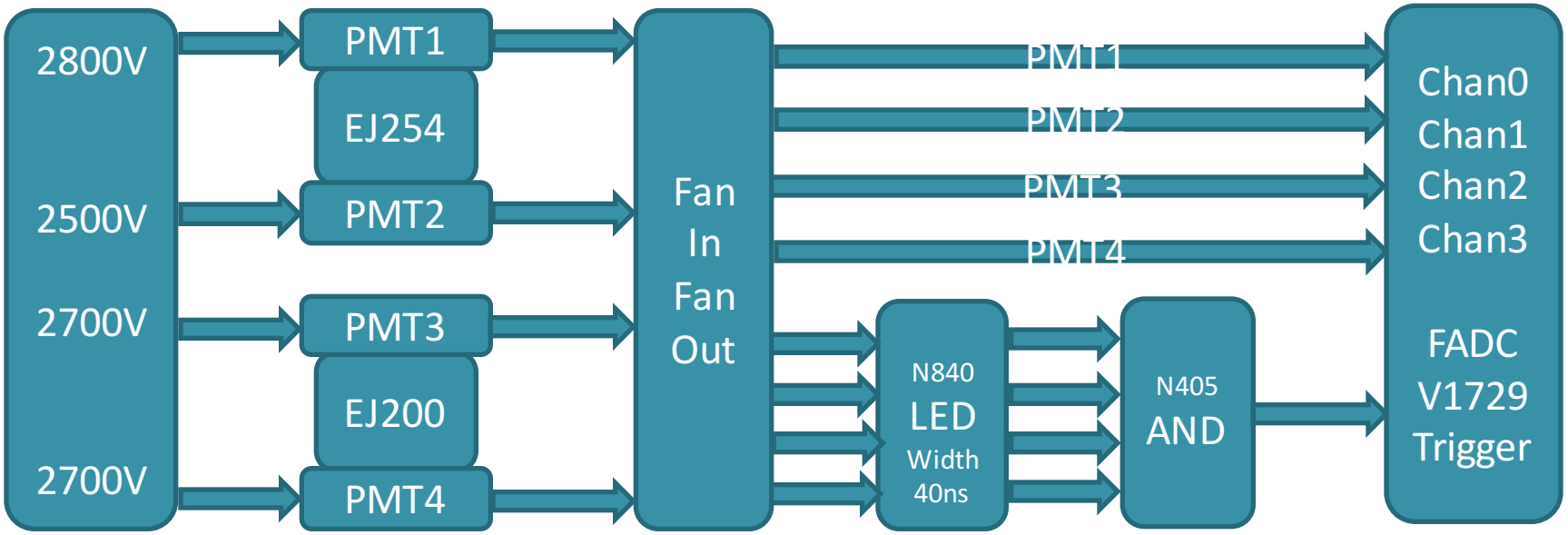
Neutron experiment

- Time of Flight (TOF) method
  - Experimental setup 2



Neutron experiment

- Time of Flight (TOF) method
  - Experimental setup 2

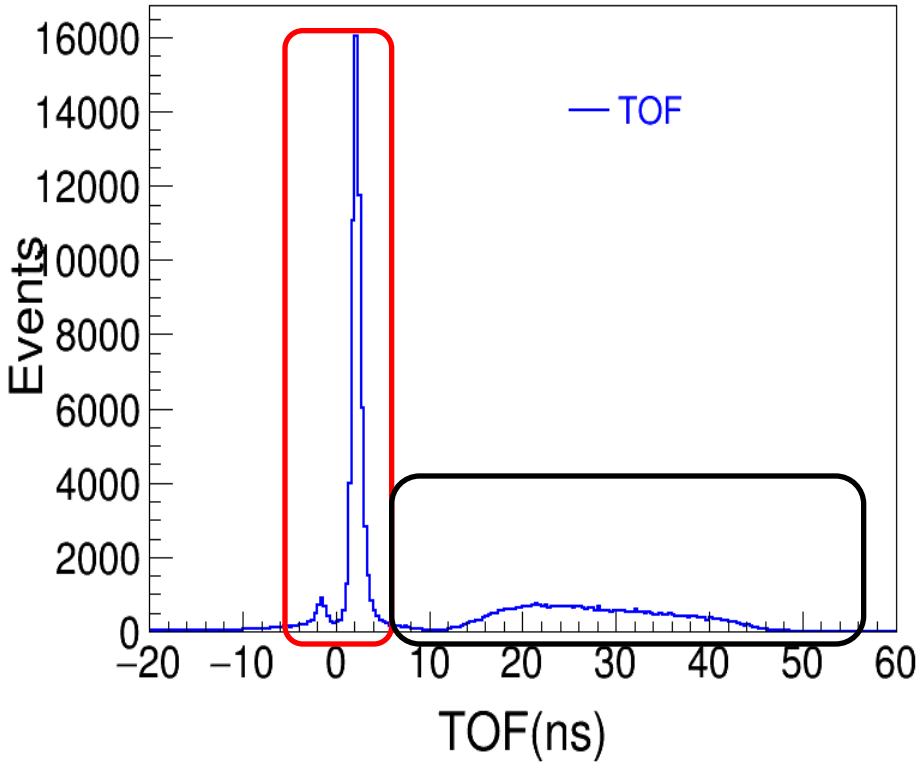


- Data Sets(Events=141000)

Date_Time: 2016-04-05-01:16 to 2016-04-05-12:15
Run_Number: run1_AmBe_0dB_Threshold_10mv_Width_40ns_Events_141000

Neutron experiment

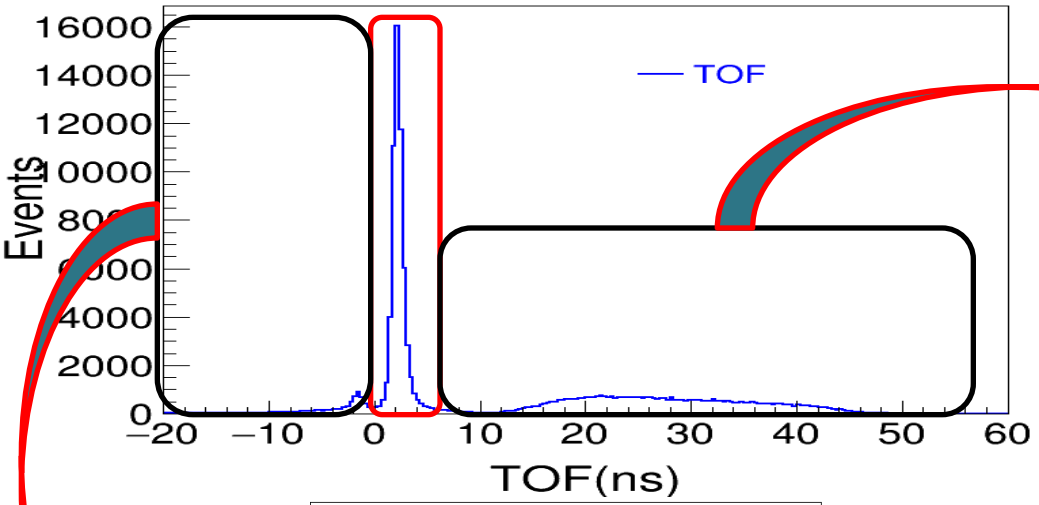
- Result of experimental setup 2
  - TOF distribution

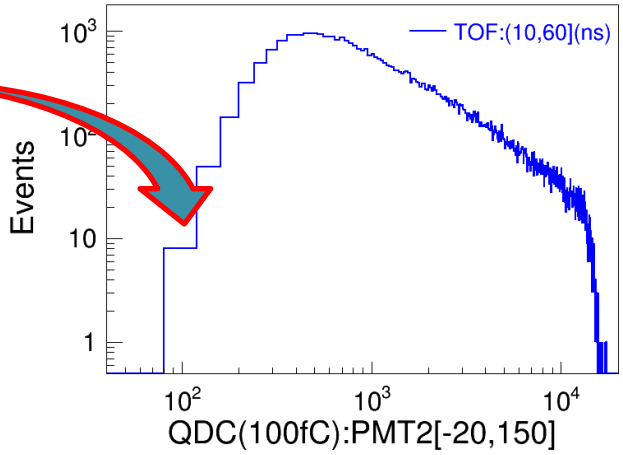


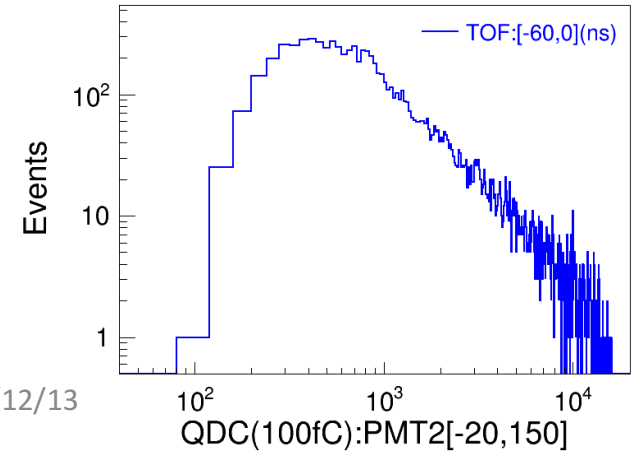
Delay time of four channels is same after time calibration.
Coincidence width is 40ns from the discriminator (Mod.N840)

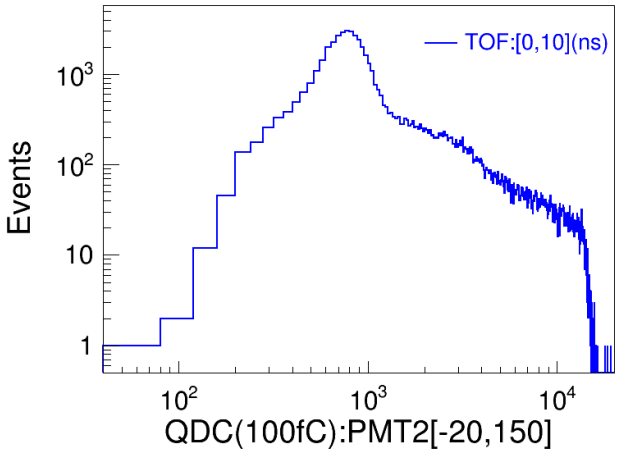
Neutron experiment

- Result of experimental setup 2
  - Energy distribution of PMT2(EJ254)



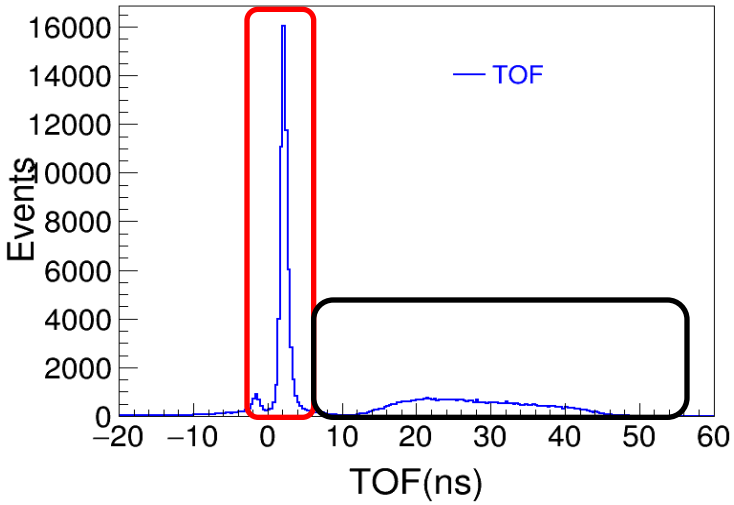


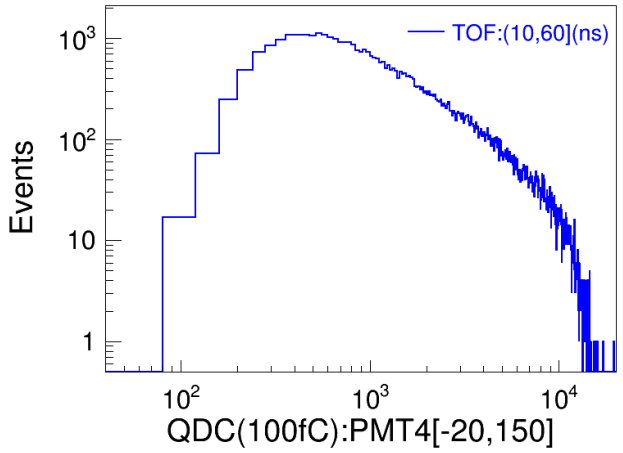


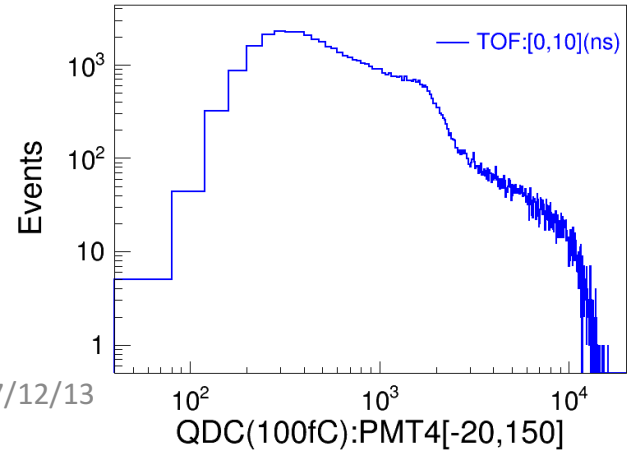


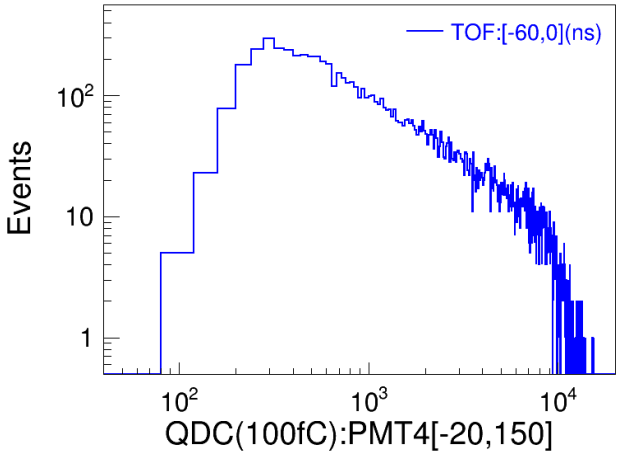
Neutron experiment

- **Result of experimental setup 2**
  - **Energy distribution of PMT4(EJ200)**



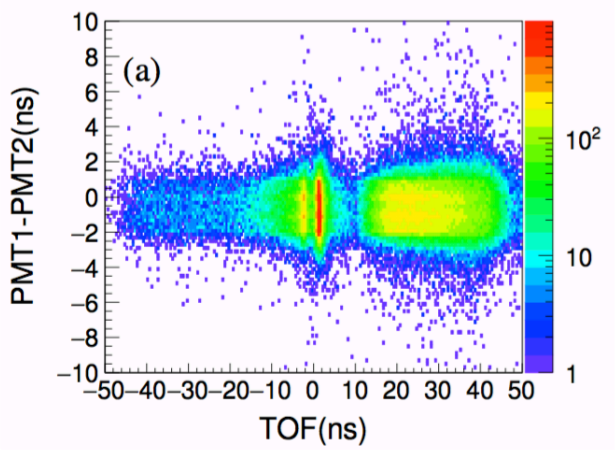


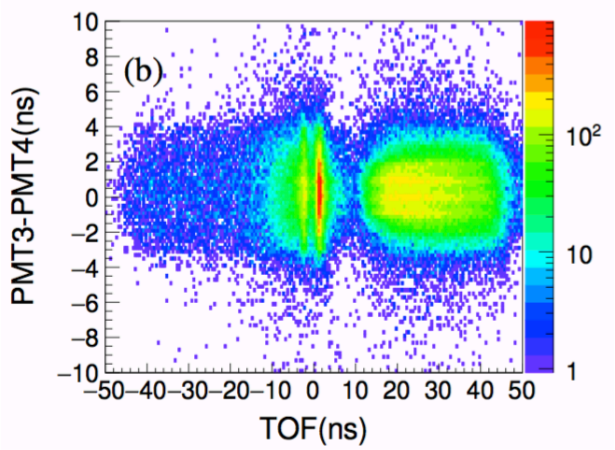


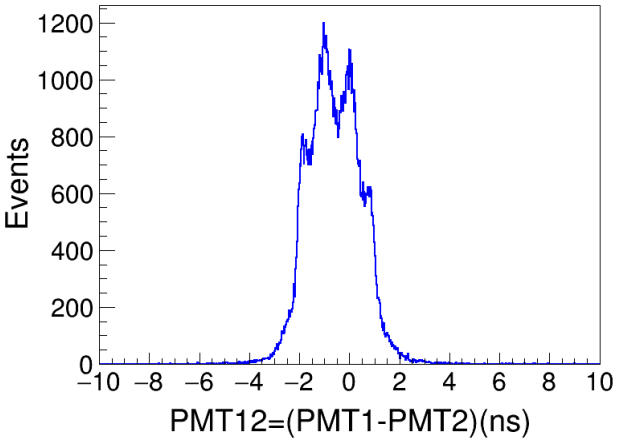


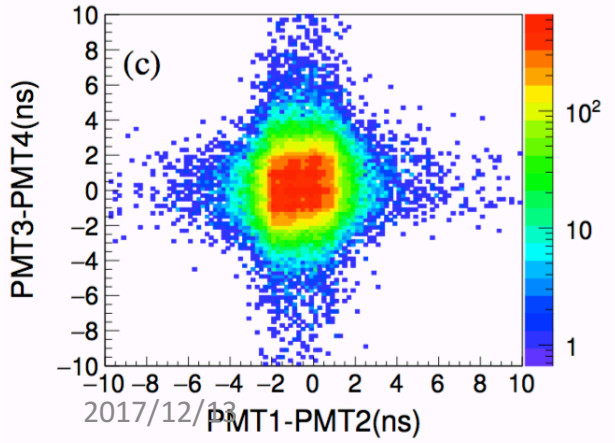
Neutron experiment

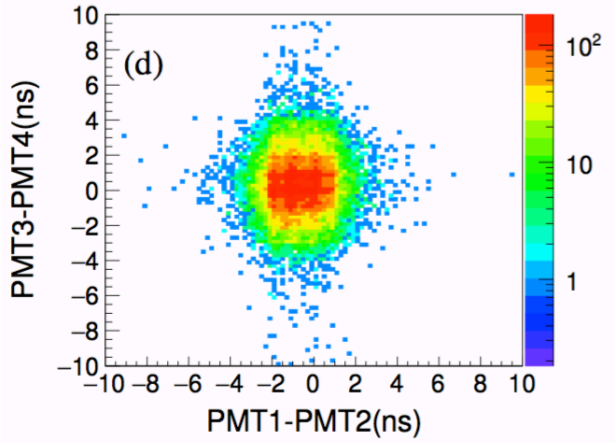
- Result of experimental setup 2
  - Position distribution

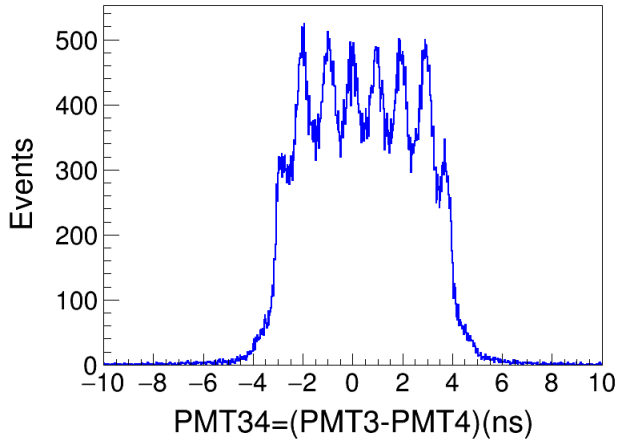






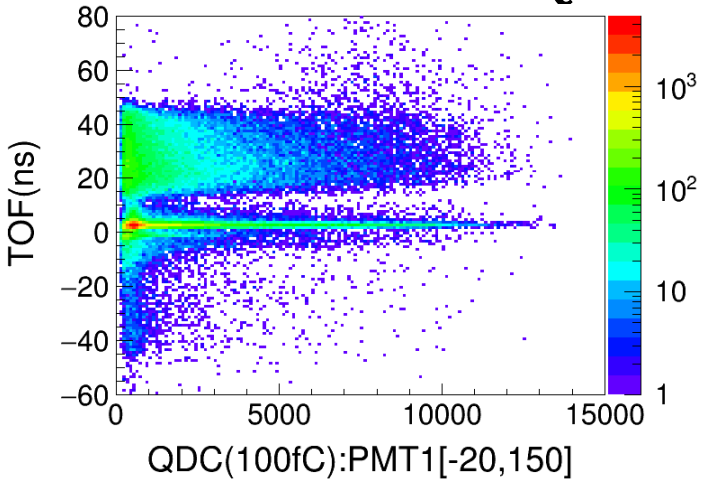


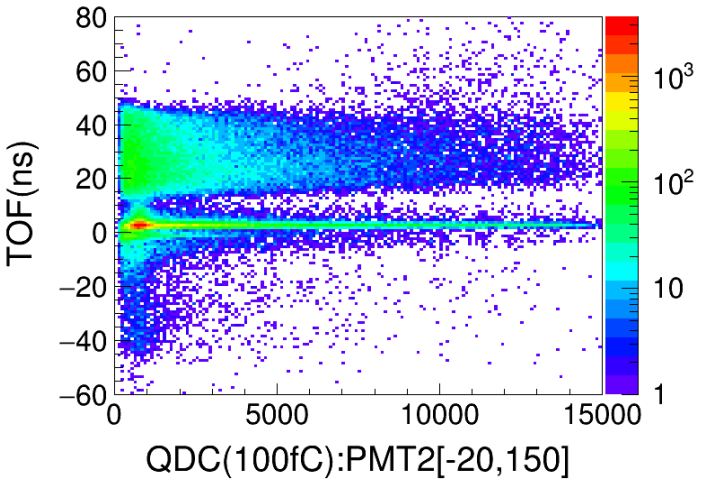


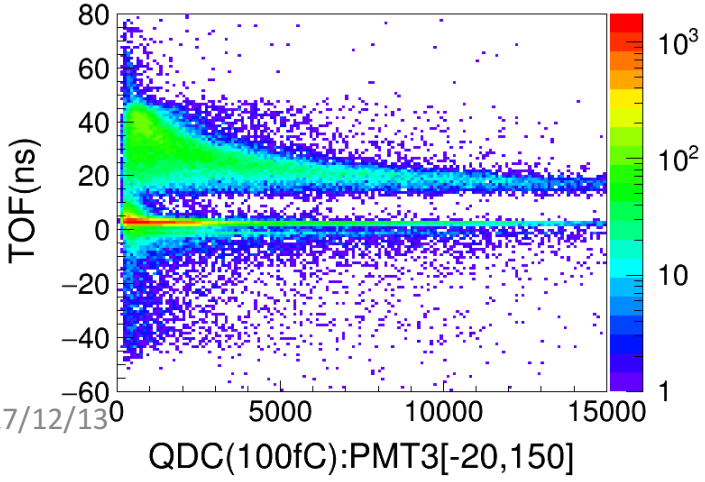


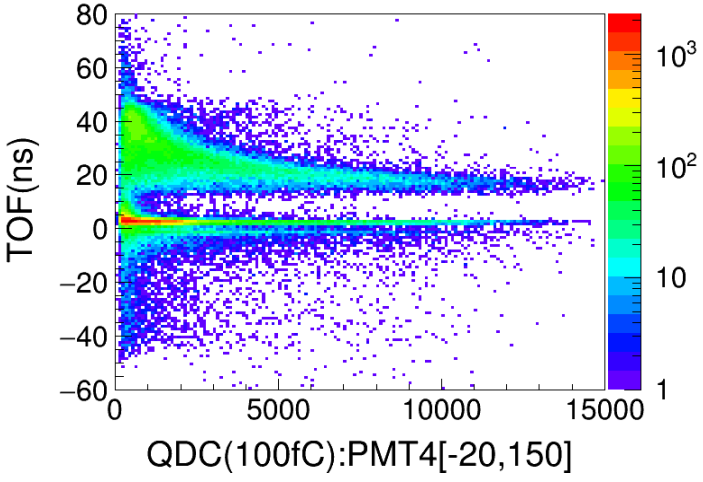
Neutron experiment

- Result of experimental setup 2
  - Distribution of QDC and TOF



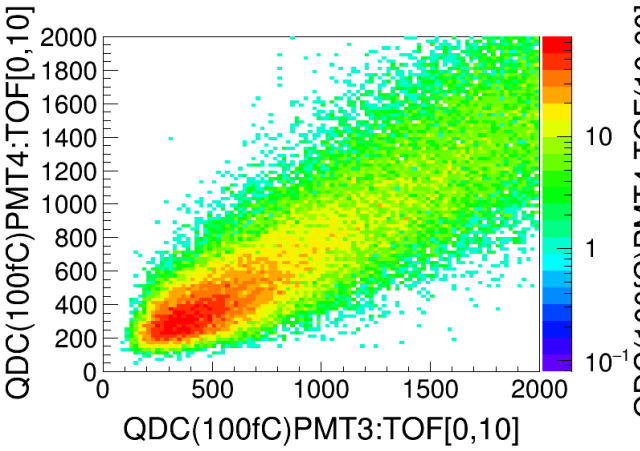


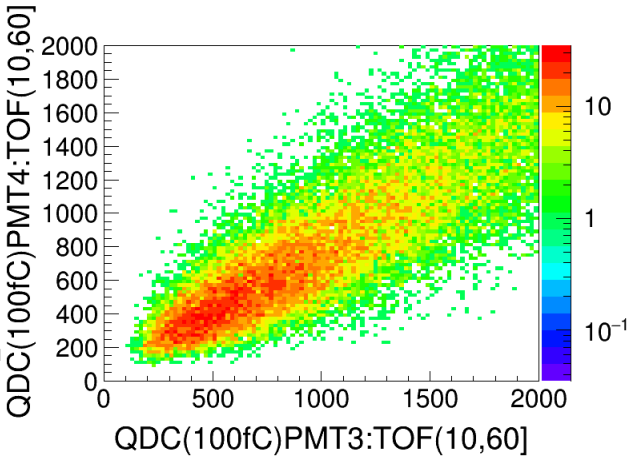


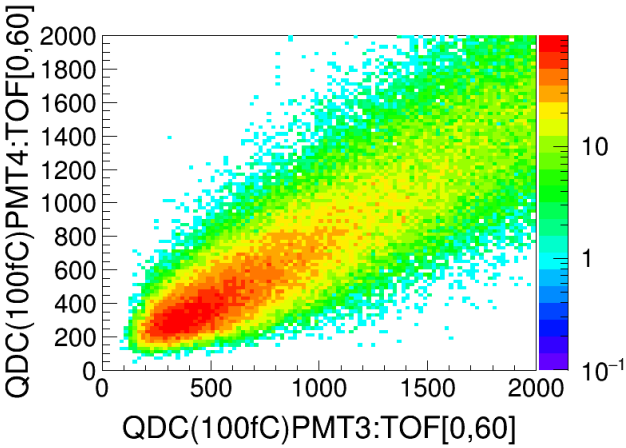


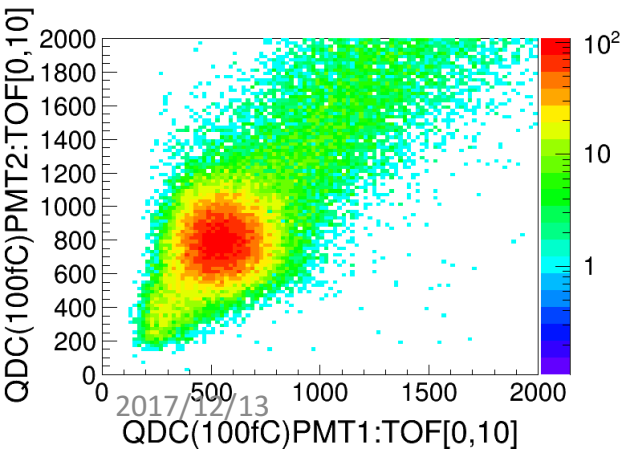
Neutron experiment

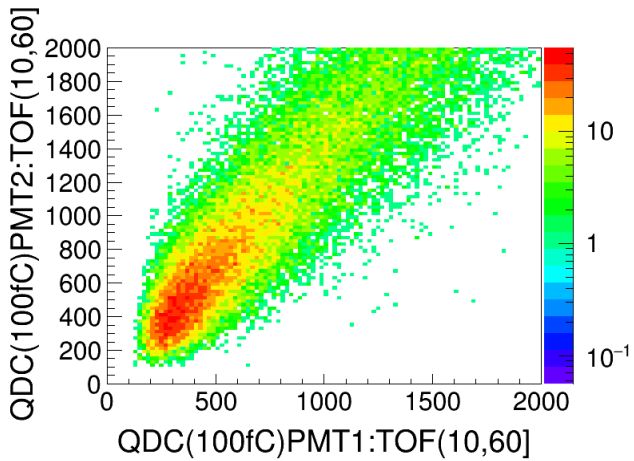
- Result of experimental setup 2
  - QDC distribution

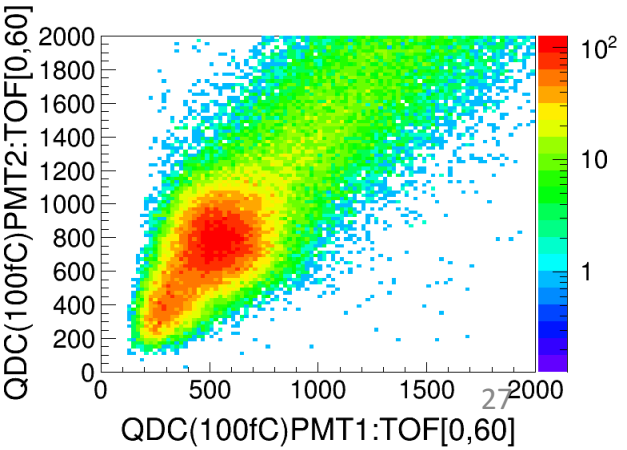






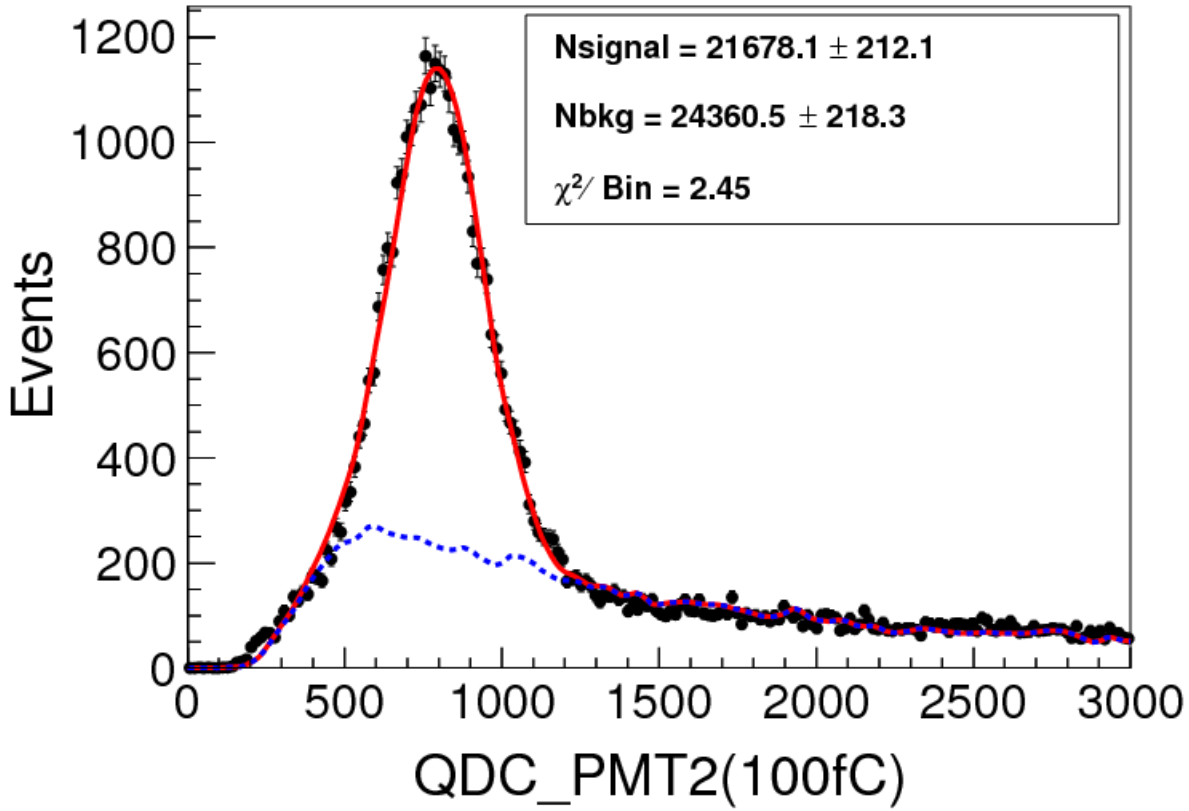




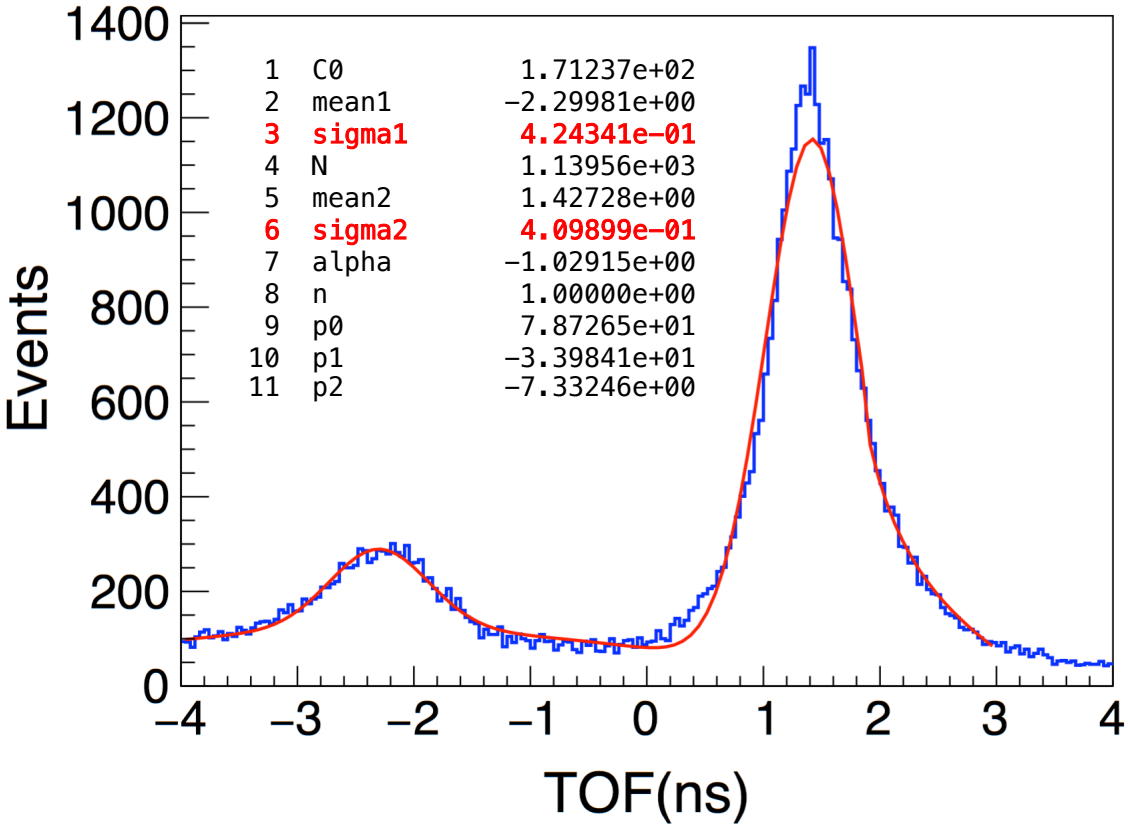


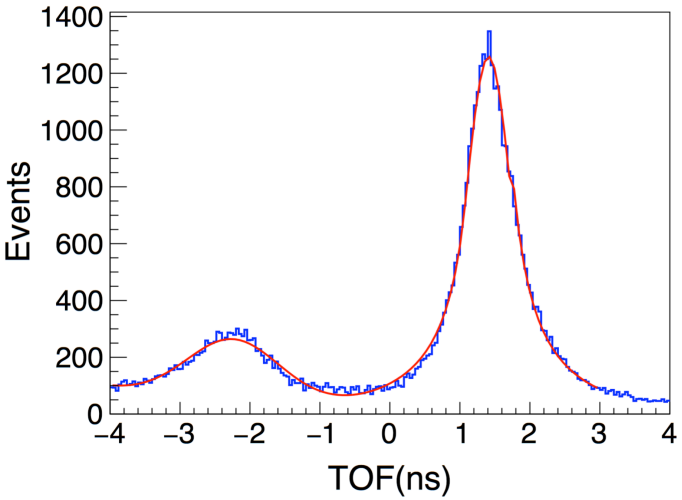
Neutron experiment

- Result of experiment
  - Calculation of signal events about thermal neutron



Unfold to TOF of fast neutron

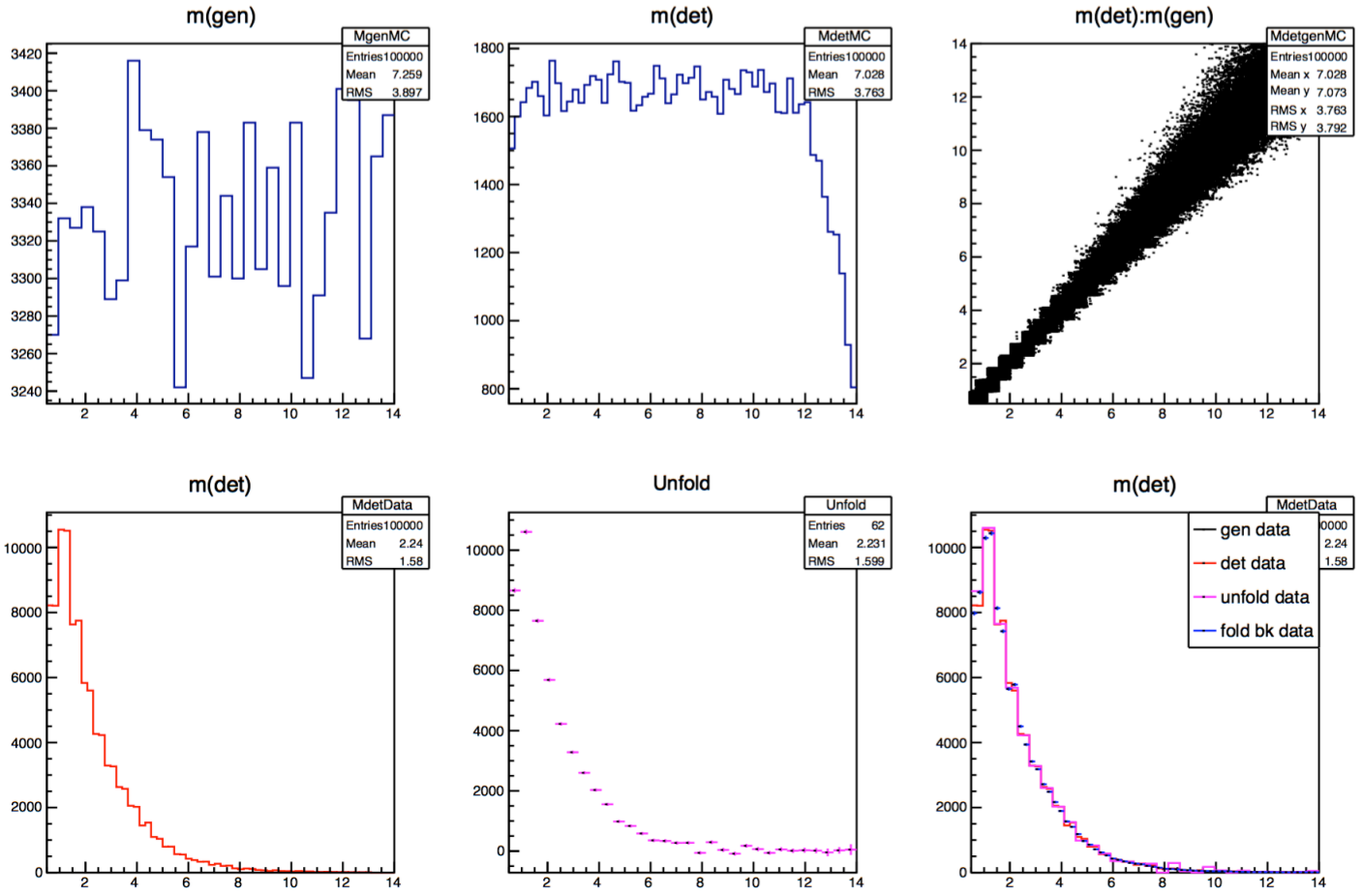




Fit function:

Gaussian +CrystallBall+Poly

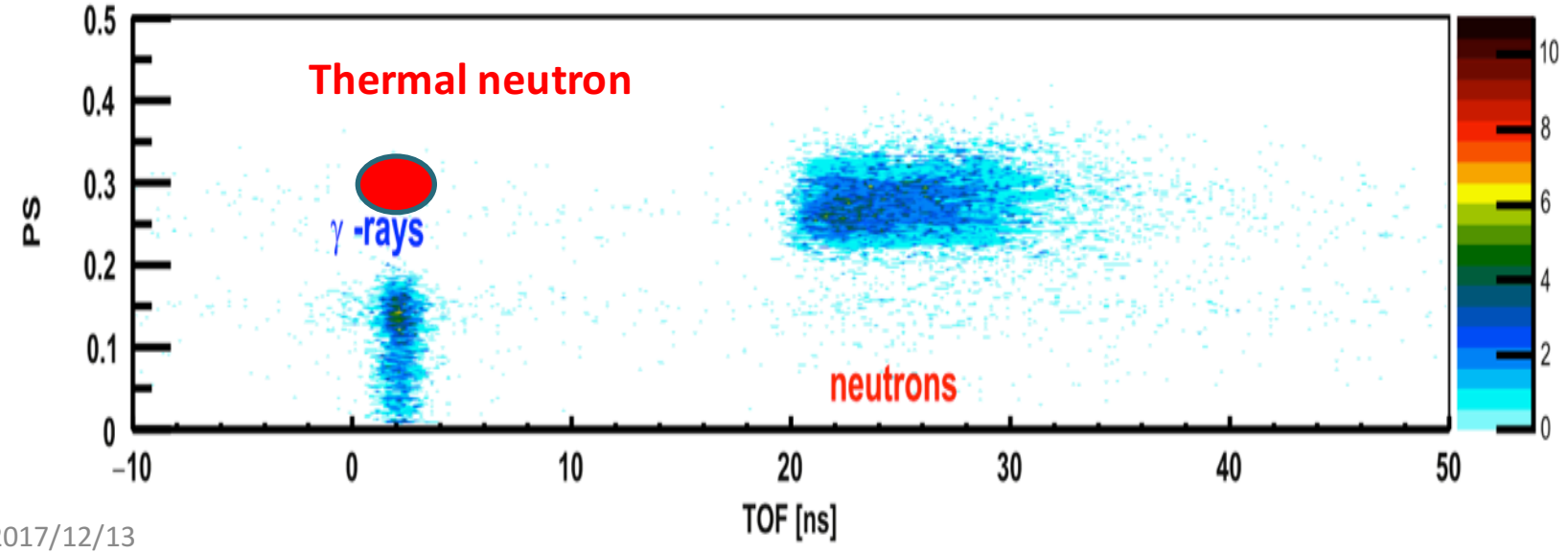
Unfold to TOF of fast neutron



Summary

- take advantage of characteristic gamma (480 keV) from thermal neutron capture reaction on 10B and develop a new TOF method to identify fast neutron, thermal neutron and gamma.

- combining PSD with TOF method that use EJ276 plastic scintillator to replace EJ200 in our experiment, it will make up for the shortcomings of PSD method and identify them completely.



Back up

Experimental Setup

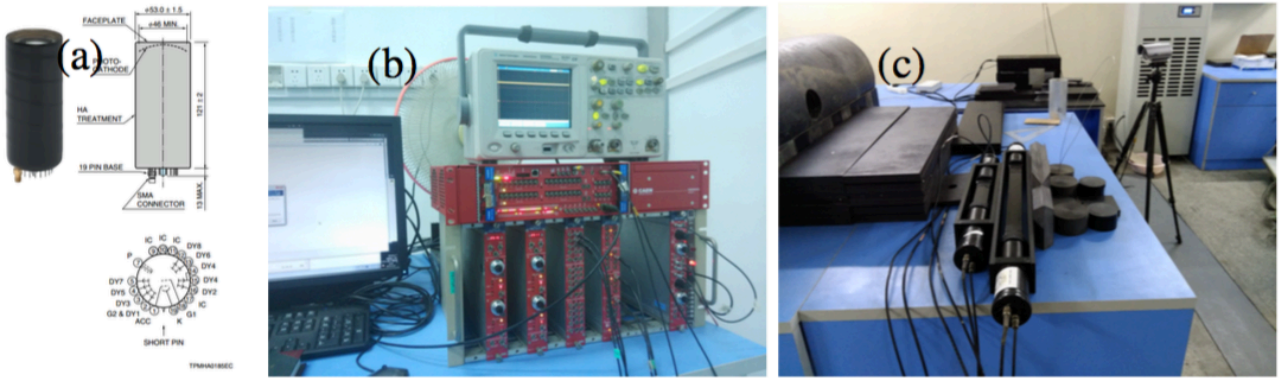
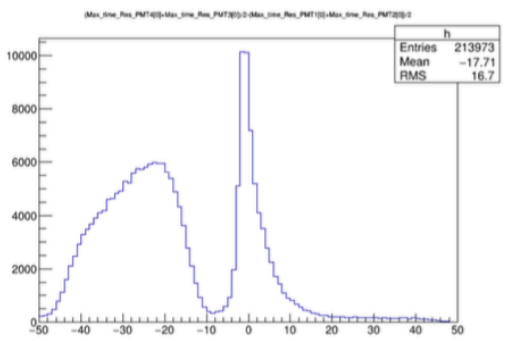
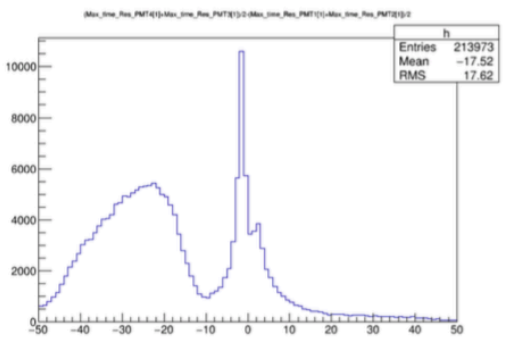
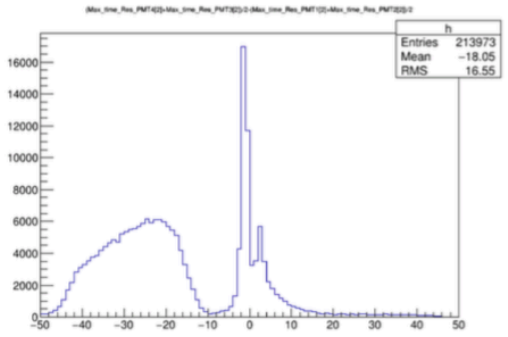


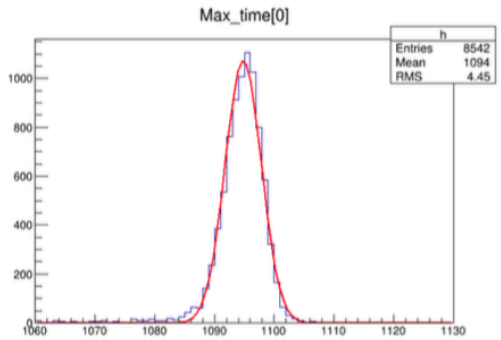
Figure 3: Experimental instruments: (a) PMT(Photomultiplier tubes, R2083,H2431-50, Hamamatsu). (b) Data Acquisition(DAQ). (c) Plastic scintillator detector.

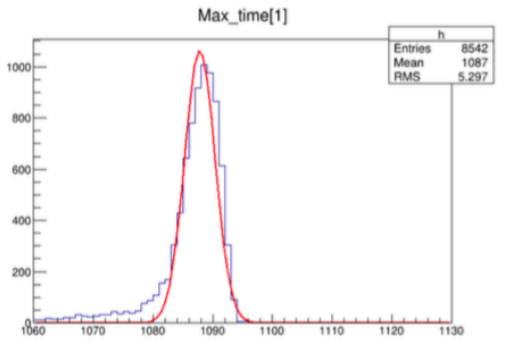
Timing methods

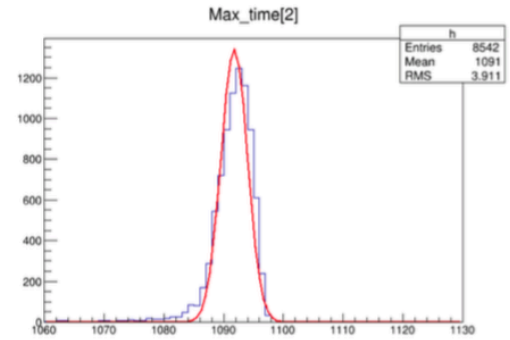












2 Mean 1.09483e+03
3 Sigma 3.03471e+00

Time-Mas_Pulse

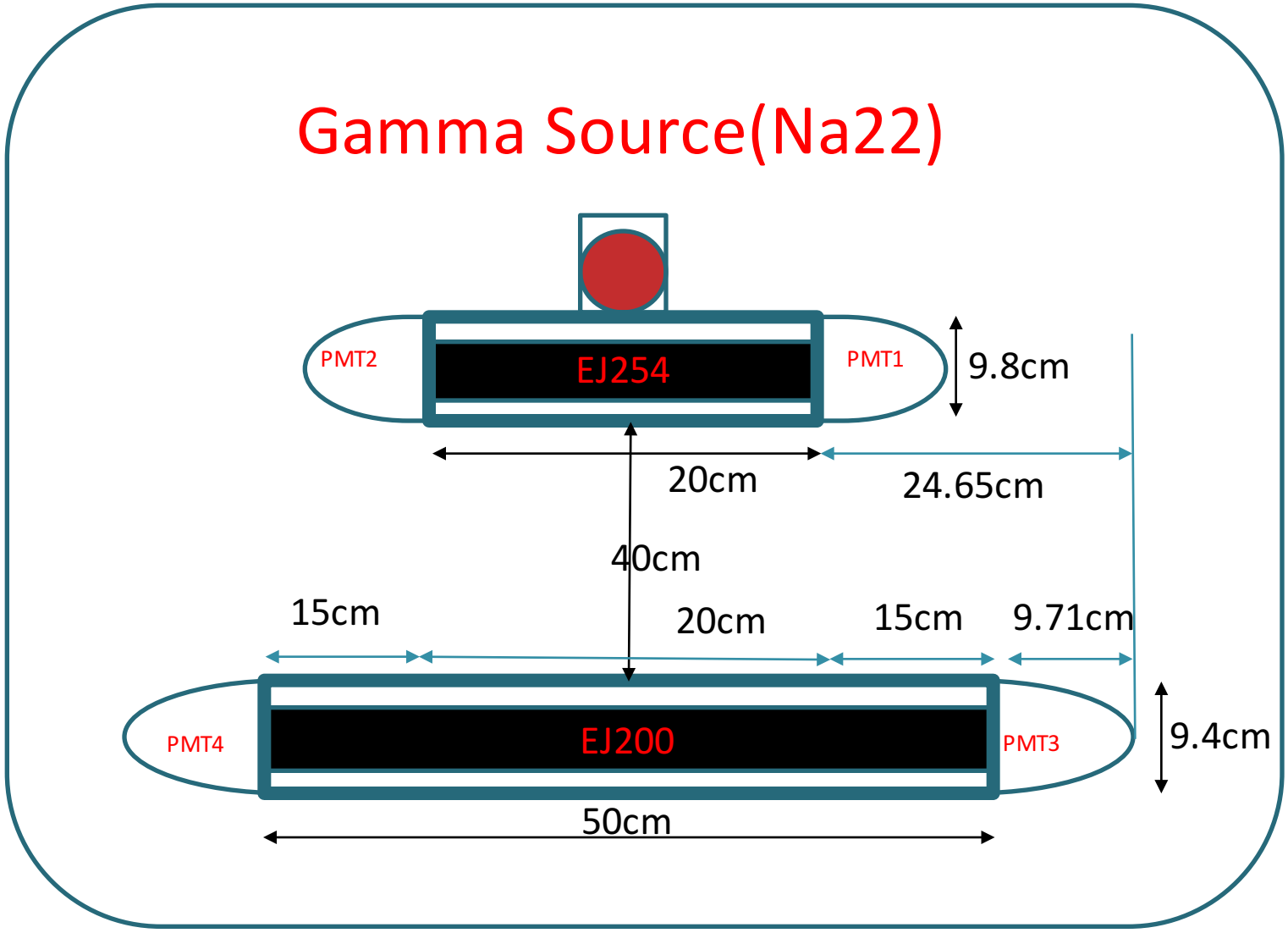
2 Mean 1.08783e+03
3 Sigma 2.55595e+00

Time-Fitting

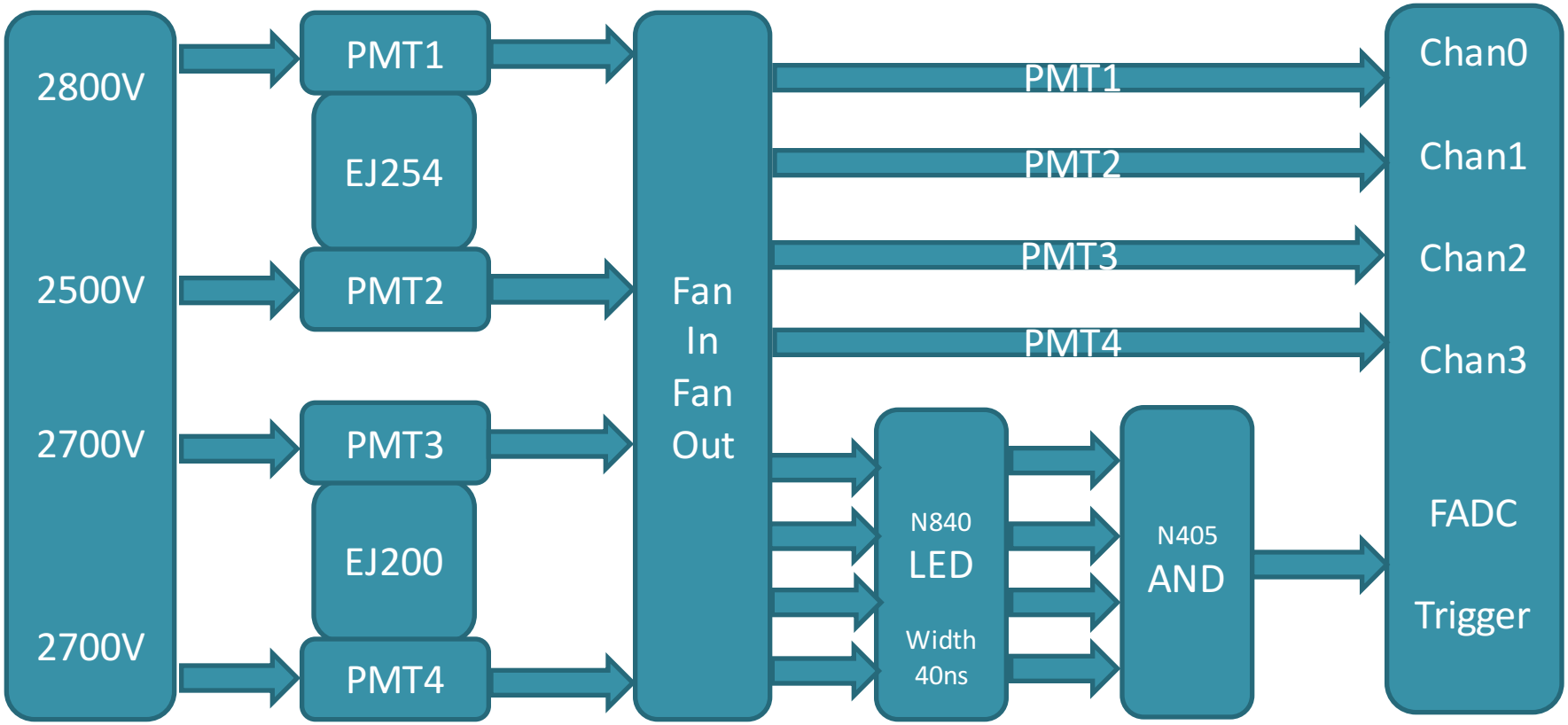
2 Mean 1.09177e+03
3 Sigma 2.22157e+00

Time-Half_Pulse

Experiment Setup(6)



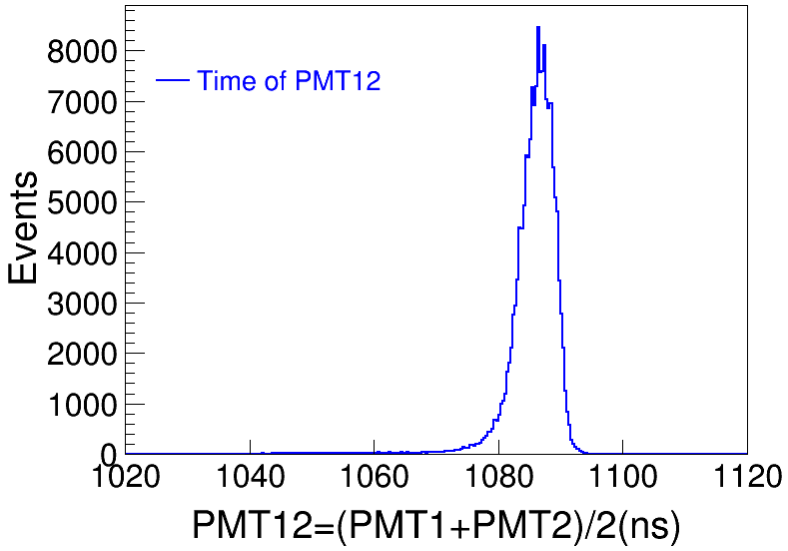
Data Flow and Data Sets

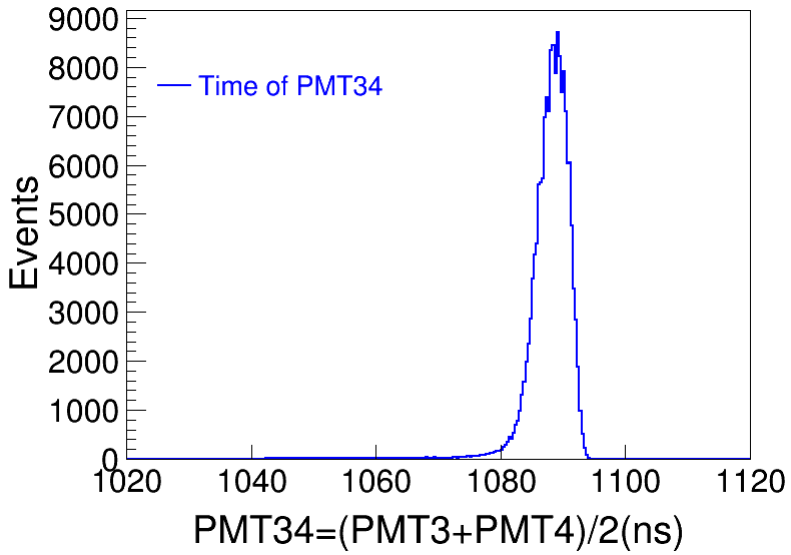


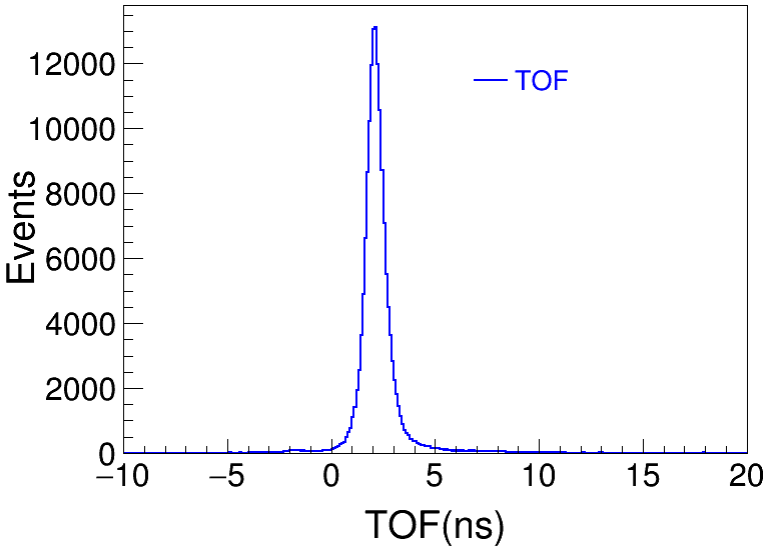
2、Data Sets(Events=174000)

Data_Path: /data2/sunming/FLASHADC/Neutron_experiments/2016-04-12/
Date_Time: 2016-04-12-01:26 to 2016-04-12-08:58
Run_Number: run1_Na22_Threshold_10mv_Width_40ns_Events174000_PMT1+PMT2+PMT3+PMT4

Time of Flight (T0 = Time_Fitting)

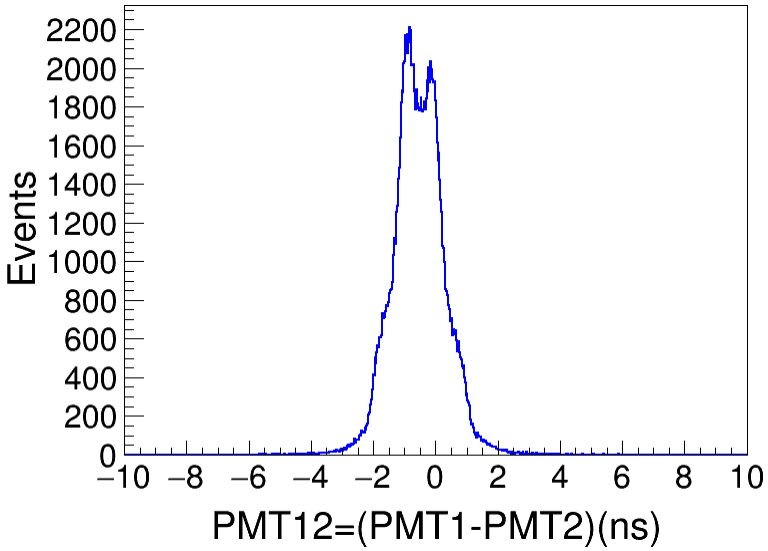


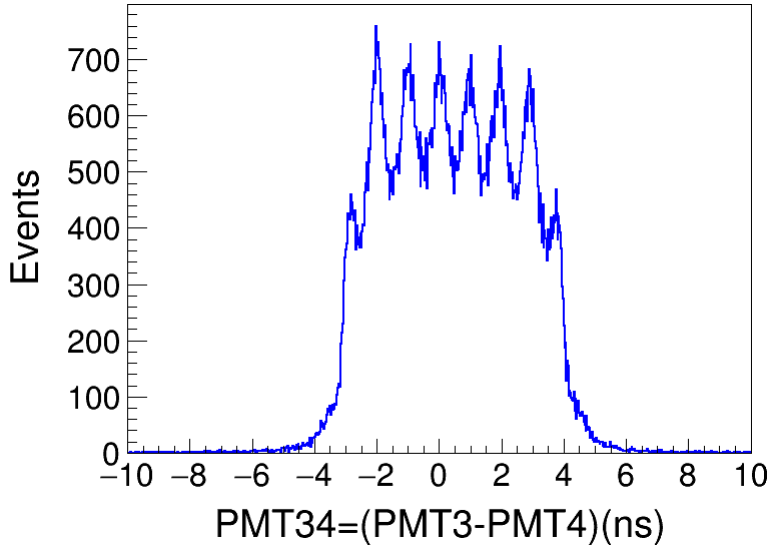




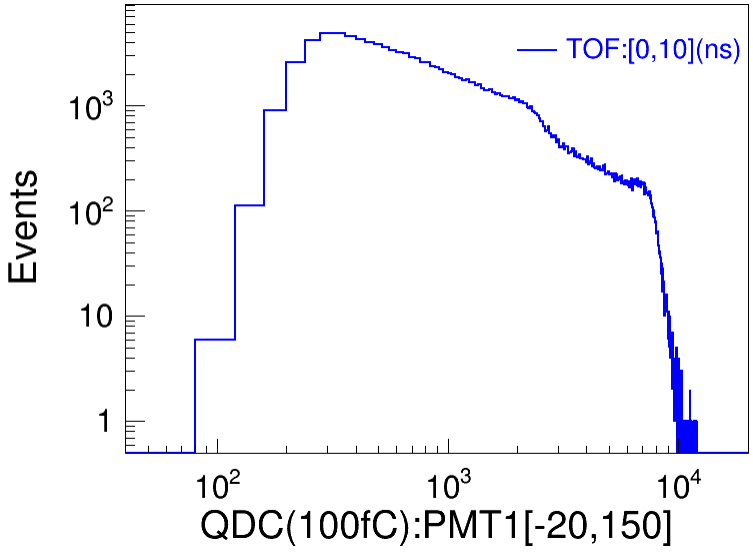
Delay time of four channels is same after time calibration.
Coincidence width is 40ns from the discriminator (Mod.N840)

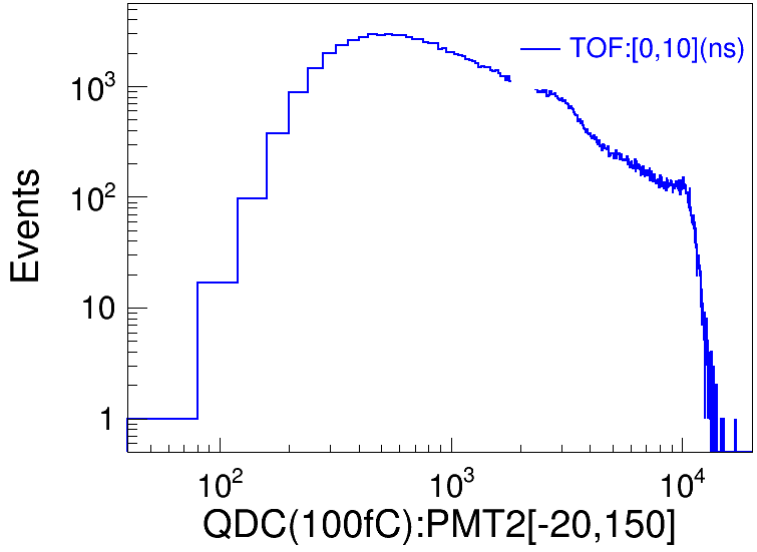
Position of hits(T0_fitting)

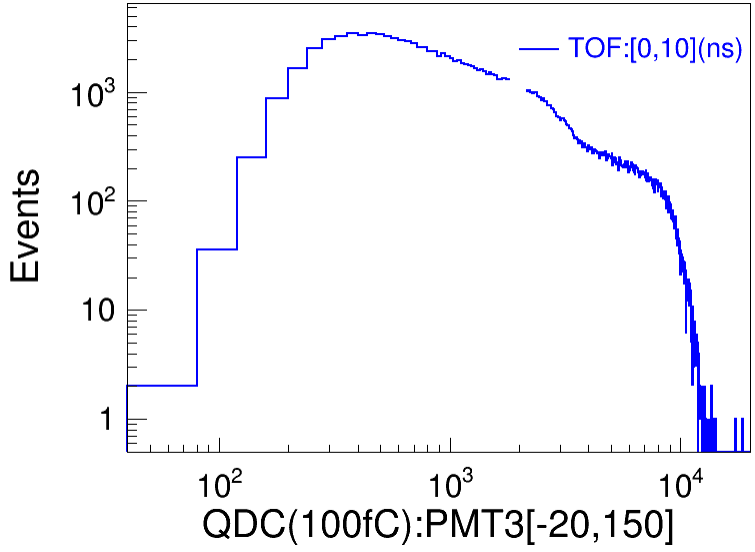


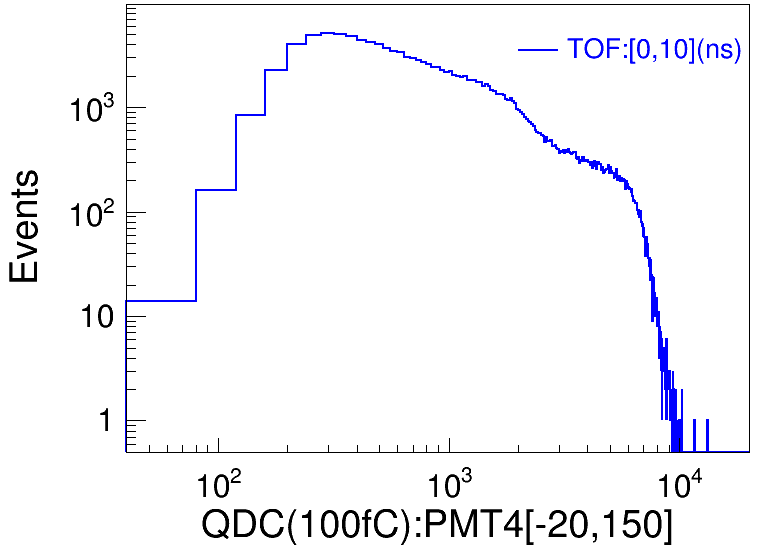


QDC


TOF:[0,10](ns)
Events
10^3
10^2
10
1
10^2
10^3
10^4
QDC(100fC):PMT1[-20,150]

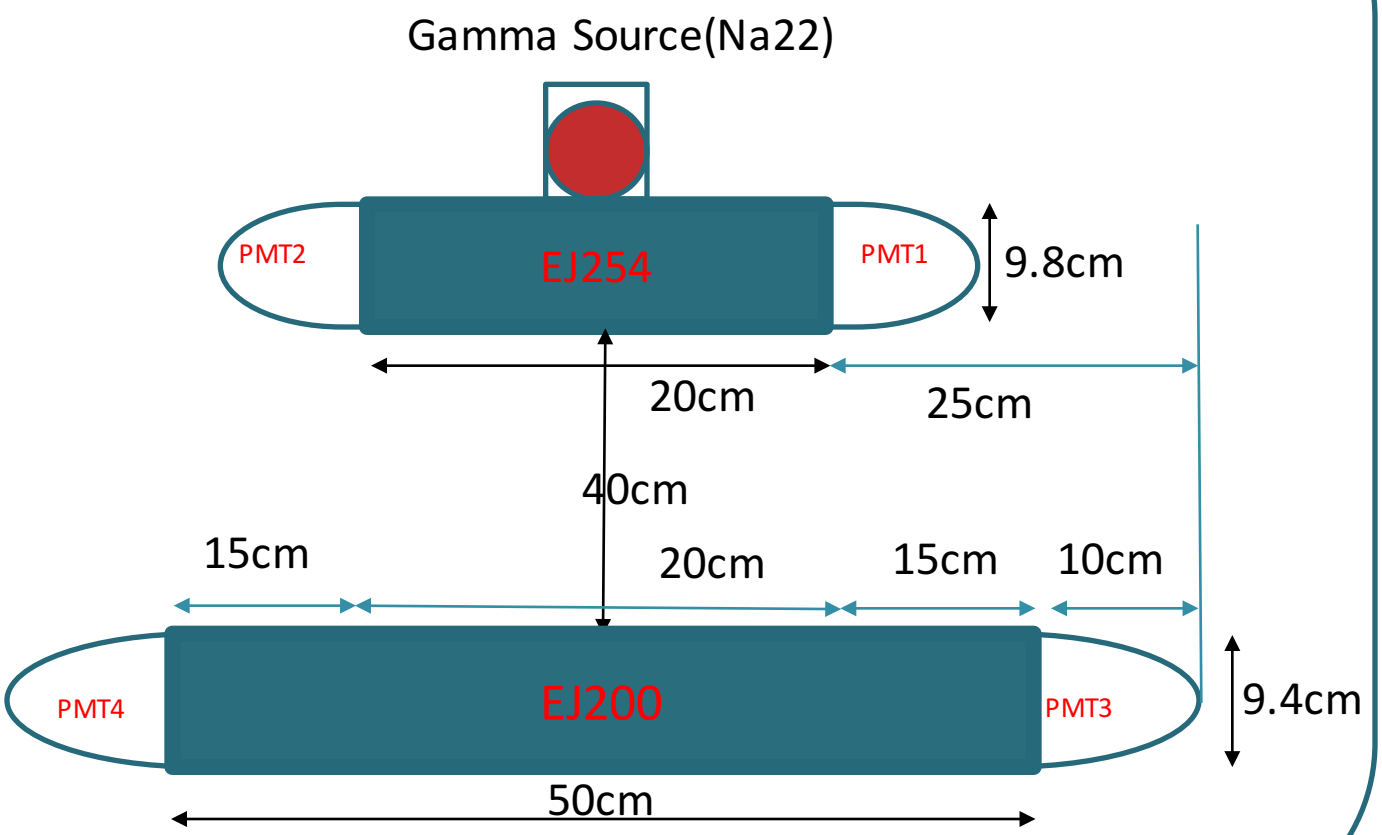

TOF:[0,10](ns)
Events
10^3
10^2
10
1
10^2
10^3
10^4
QDC(100fC):PMT2[-20,150]


TOF:[0,10](ns)
Events
10^3
10^2
10
1
10^2
10^3
10^4
QDC(100fC):PMT3[-20,150]

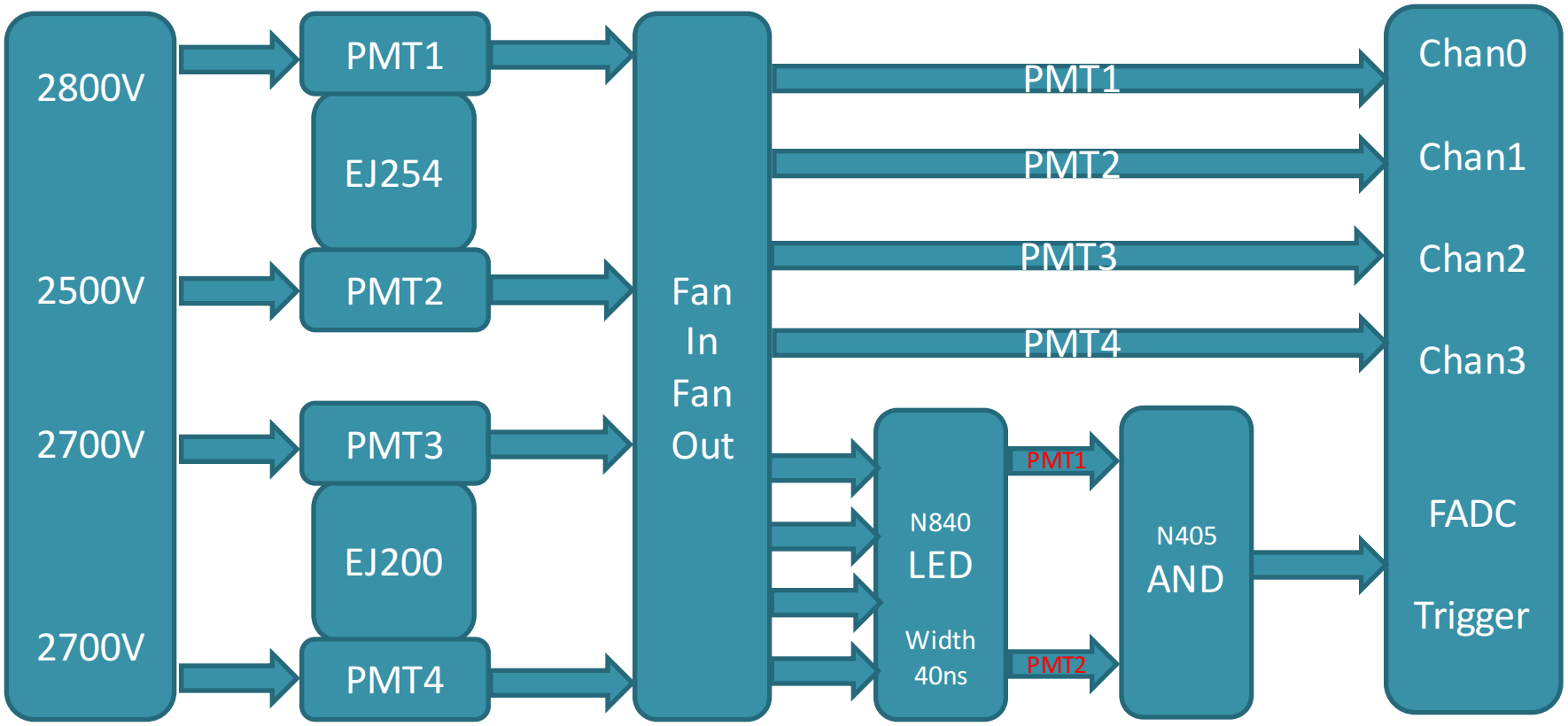

TOF:[0,10](ns)
Events
10^3
10^2
10
1
10^2
10^3
10^4
QDC(100fC):PMT4[-20,150]

Experiment Setup(7)

Gamma ray does not cross aluminium plate .



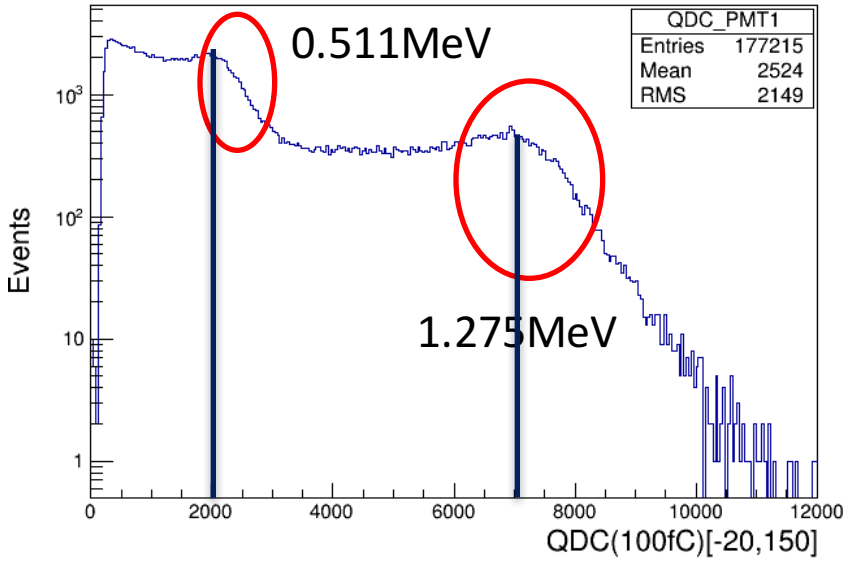
Data Flow and Data Sets

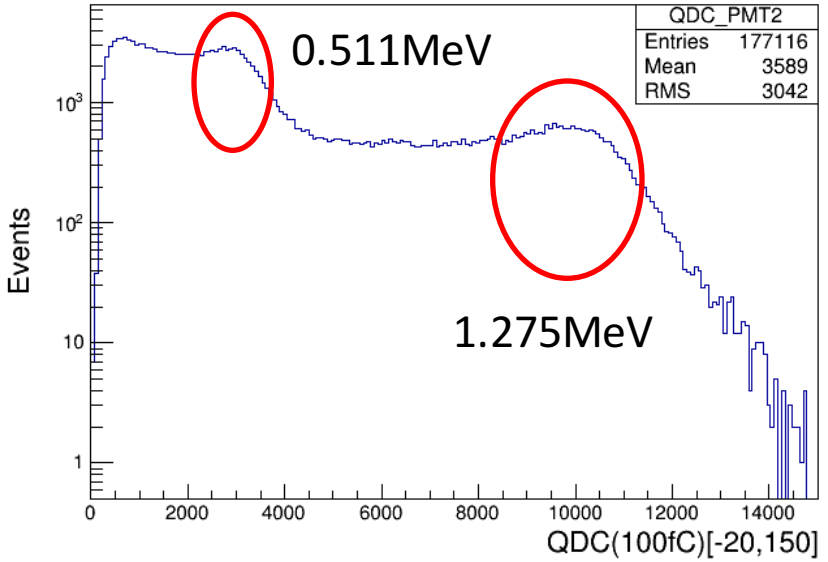


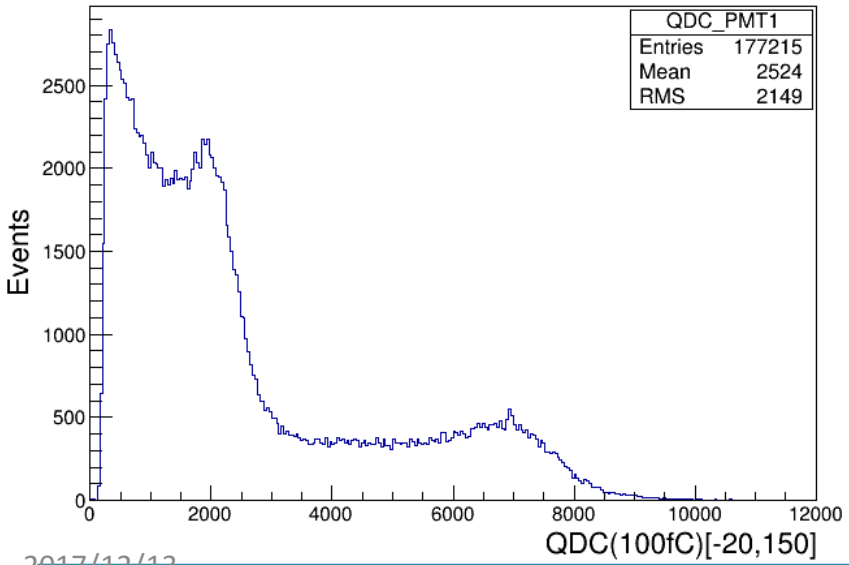
2、Data Sets(Events=180000)

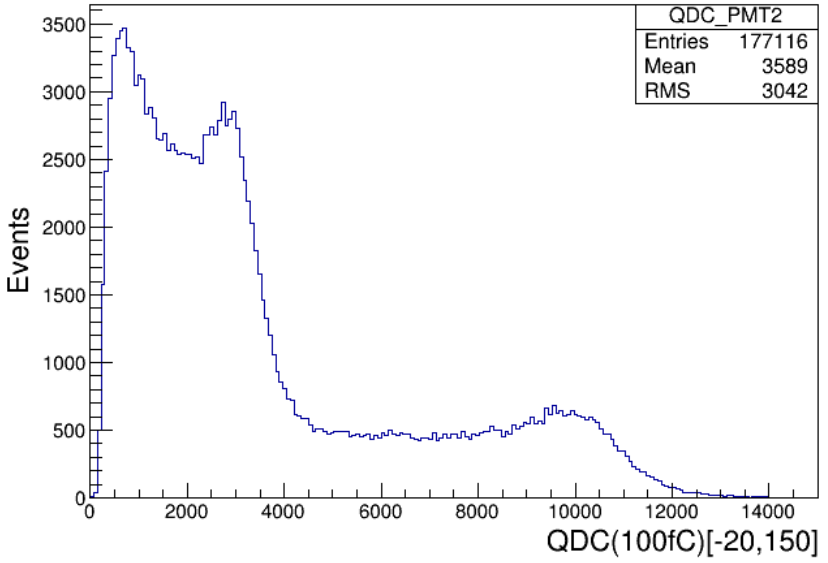
Data_Path: /data2/sunming/FLASHADC/Neutron_experiments/2016-04-13/
Date_Time: 2016-04-13-01:53 to 2016-04-13-08:58
Run_Number: /data2/sunming/FLASHADC/Neutron_experiments/2016-04-13/run1_Na22_Threshold_10mv_Width_40ns_PMT1+PMT2+PMT3+PMT4_Events180000

QDC_PMT12(Na22)

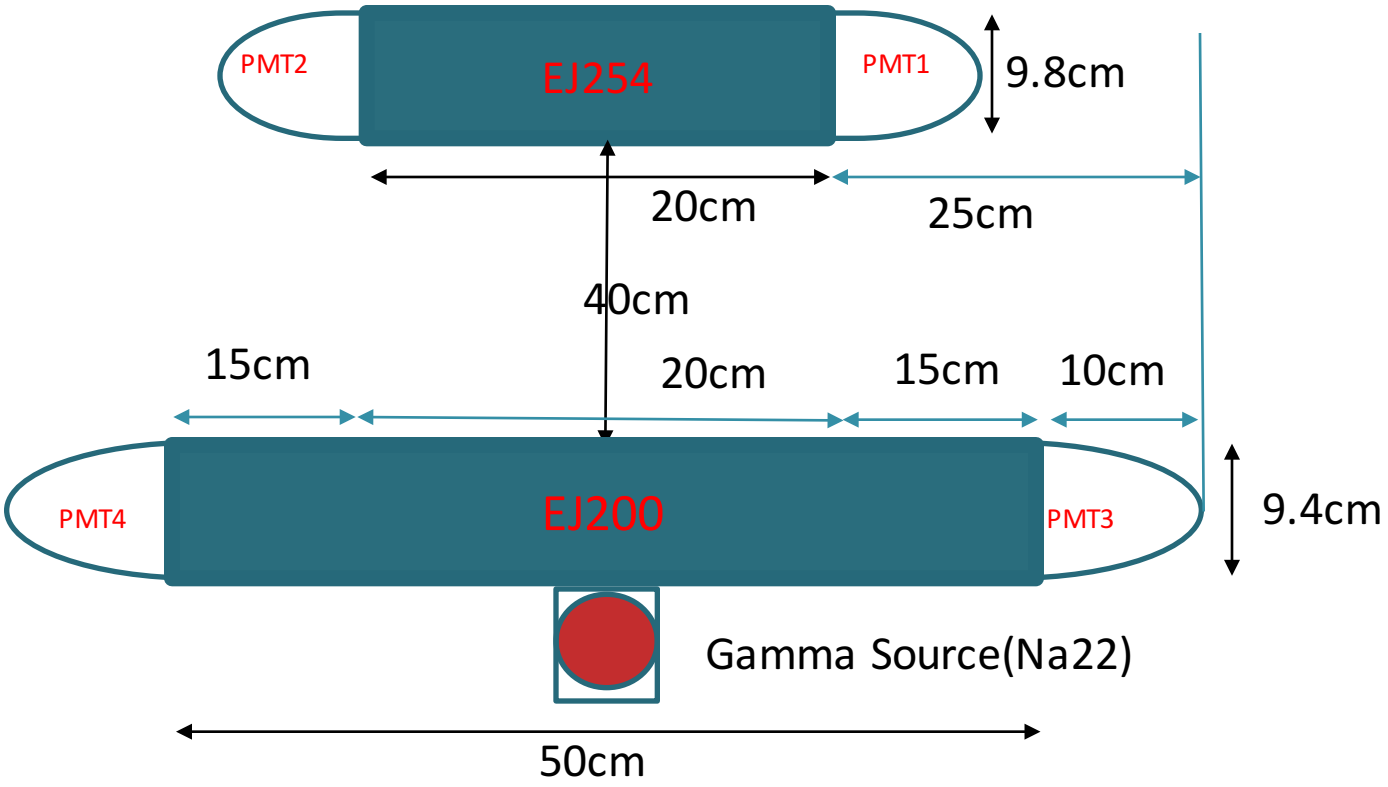






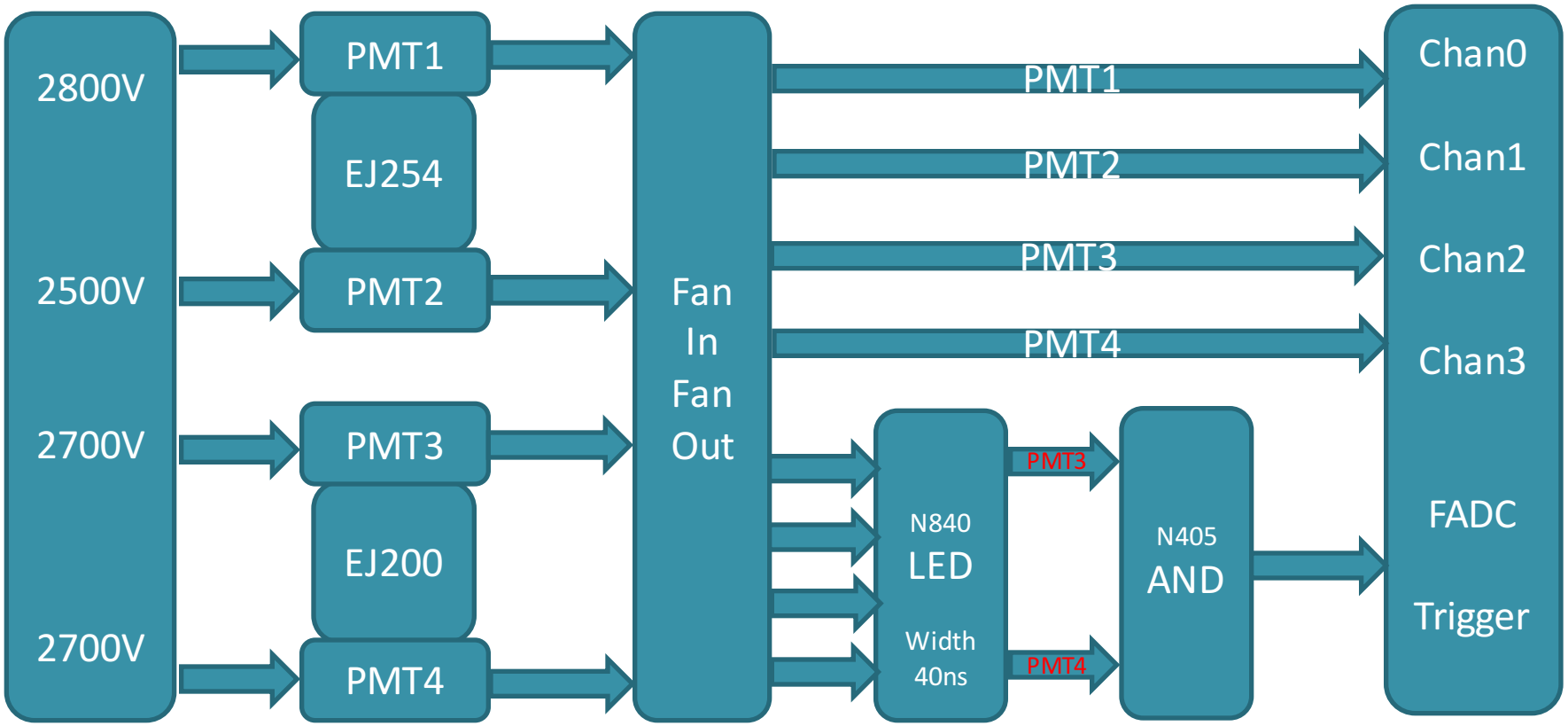


Experiment Setup(8)



Gamma ray does not cross aluminium plate .

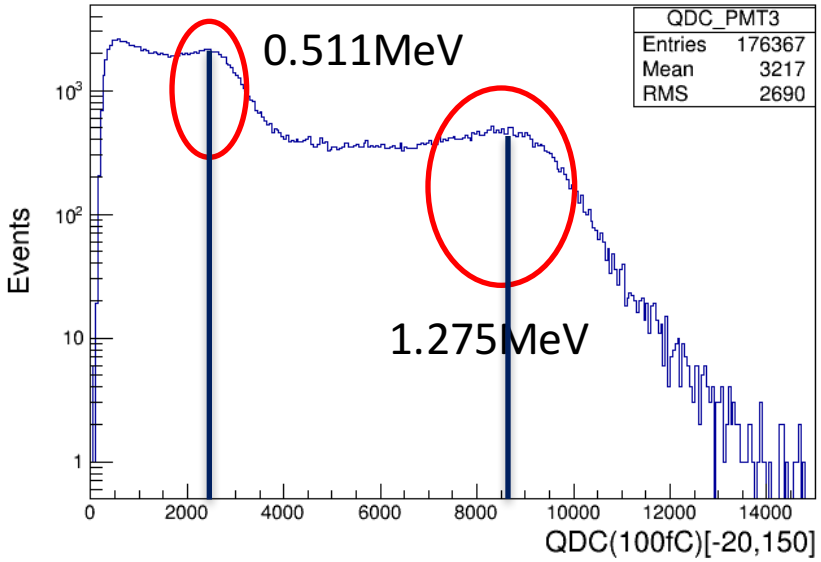
Data Flow and Data Sets

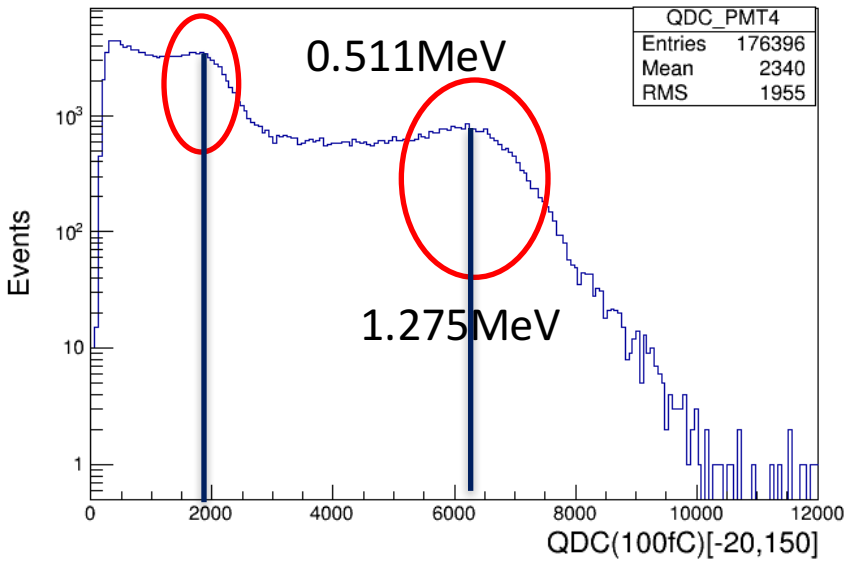


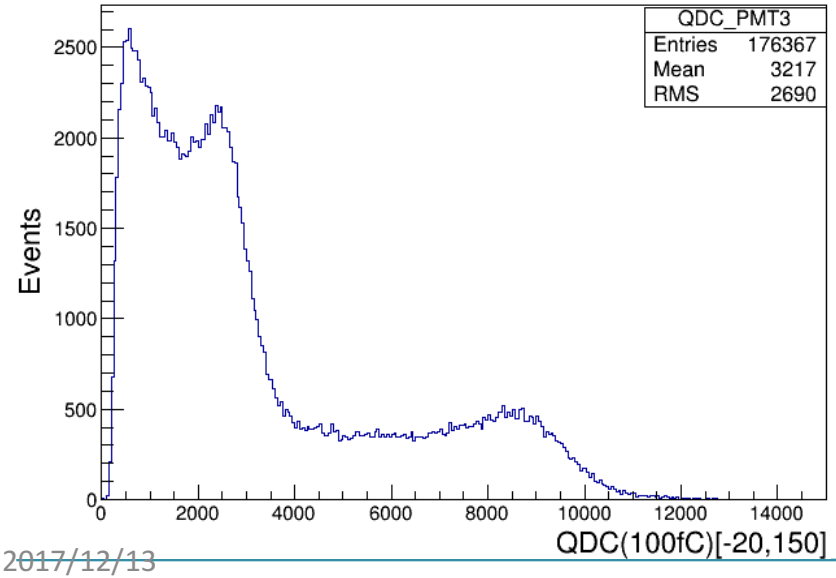
2、Data Sets(Events=180000)

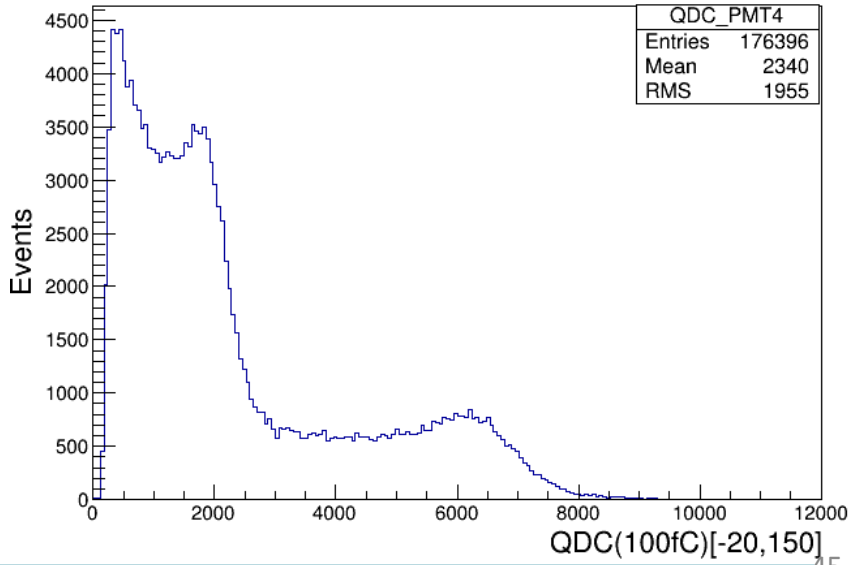
Data_Path: /data2/sunming/FLASHADC/Neutron_experiments/2016-04-14/
Date_Time: 2016-04-14-01:07 to 2016-04-14-08:26
Run_Number: /data2/sunming/FLASHADC/Neutron_experiments/2016-04-14/run1_Na22_0dB_Threshold_10mv_Width_40ns_PMT3+PMT4_Events_180000

QDC_PMT34(Na22)









QDC_PMT(Calibration)

$E_\gamma(MeV)$	$\alpha = \frac{E_\gamma}{m_e c^2}$	$E_e = \frac{2\alpha E_\gamma}{1+2\alpha}$	Channels (PMT3)	Channels (PMT4)
0.511	1.000	0.341	2500	1700
0.480	0.939	0.313	2294	1560
1.275	2.495	1.062	7785	5294

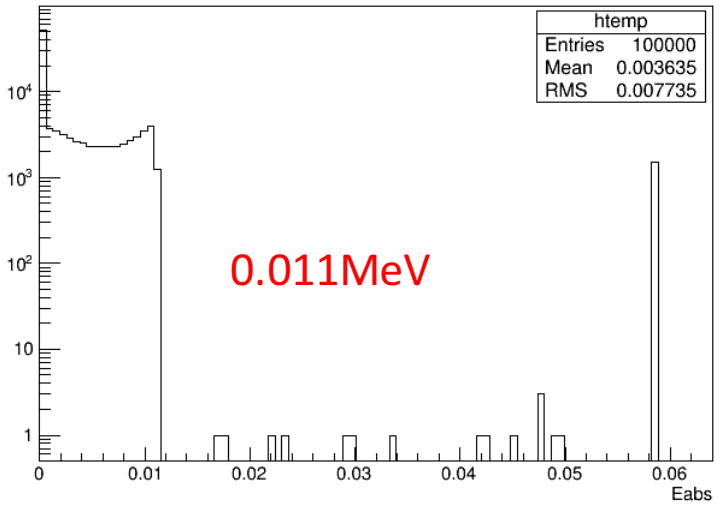
$E_\gamma(MeV)$	$\alpha = \frac{E_\gamma}{m_e c^2}$	$E_e = \frac{2\alpha E_\gamma}{1+2\alpha}$	Channels (PMT3)	Channels (PMT4)
59.5			390	290
0.511	1.000	0.341	2235	1662
0.480	0.939	0.313	2051	1525
1.275	2.495	1.062	6961	5176

- Neutron interactions in organic scintillators produce scattered protons through elastic scattering; protons have a short range and generate a high concentration of triplet states, which decay by delayed fluorescence.

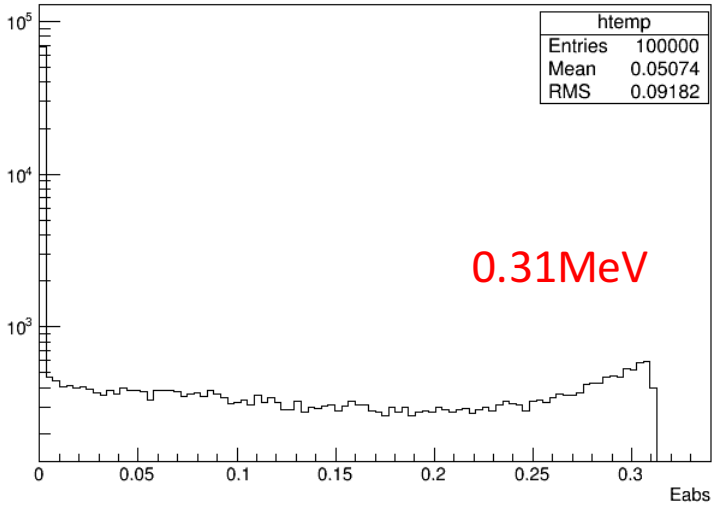
- Gamma ray interactions in organic scintillators produce scattered electrons. Electrons have a longer range than protons and generate a lower concentration of triplet states (electrons are more likely to produce excited singlet states, which decay by prompt fluorescence) .

- The difference in the pulse shape of the signal as a result of the ratio of prompt to delayed fluorescence produced by different types of radiation makes PSD a popular method of high-energy neutron detection in an environment where gamma rays are present.

Simulation of Energy deposition

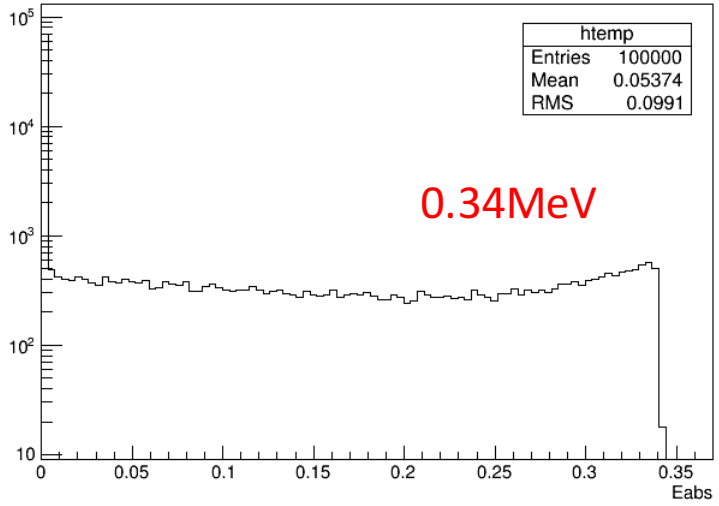


- Energy of gamma
  - 59keV
- Number of Event
  - 100,000

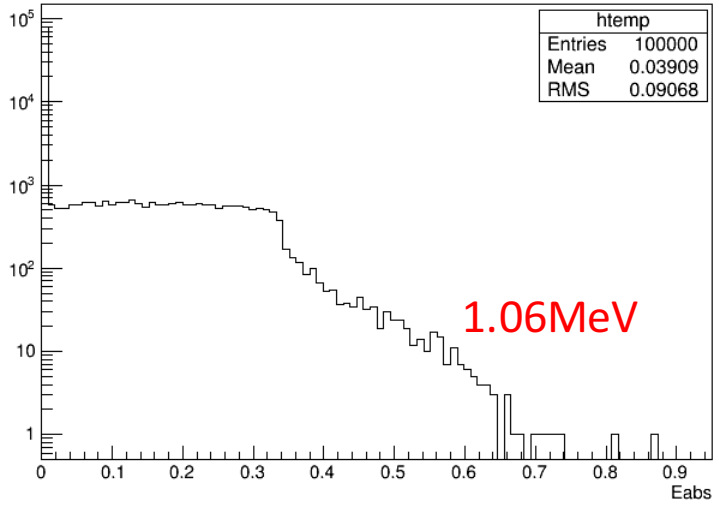


- Energy of gamma
  - 478keV
- Number of Event
  - 100,000

Simulation of Energy deposition

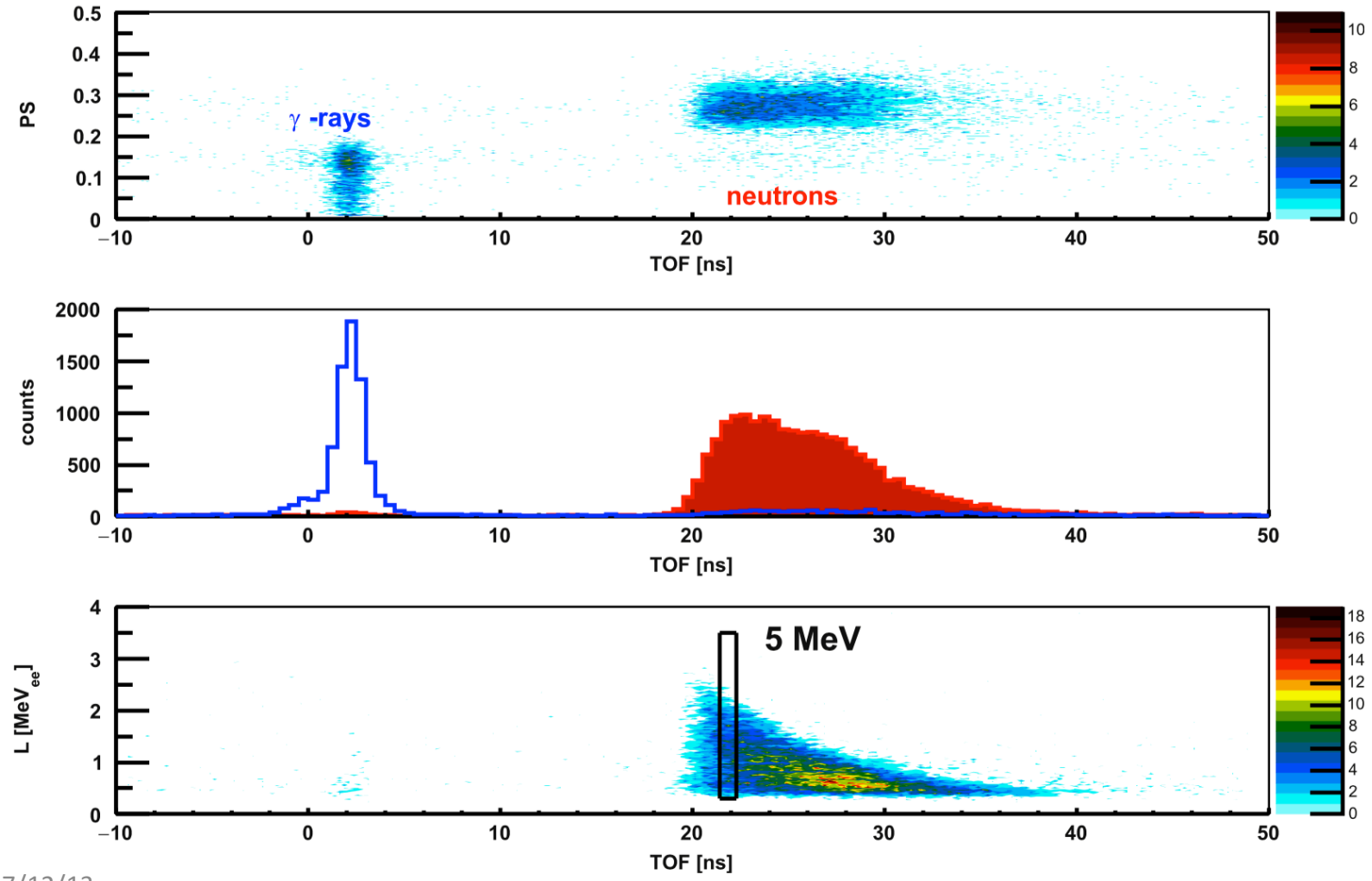


- Energy of gamma
  - 511keV
- Number of Event
  - 100,000



- Energy of gamma
  - 1.275MeV
- Number of Event
  - 100,000

PSD&&TOF



PSD Method

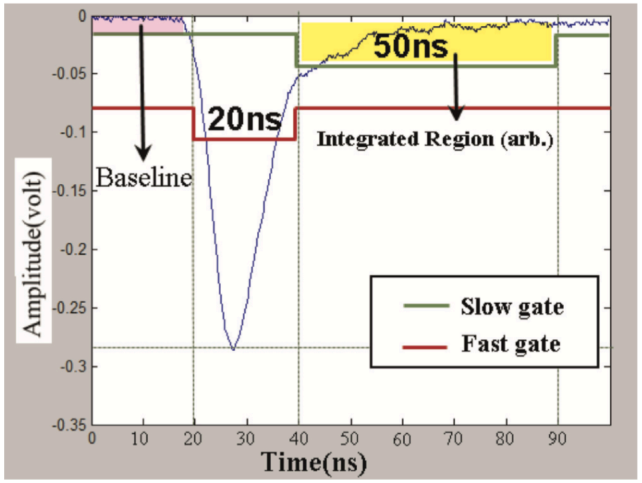


Fig. 3. A time gate used for sampling from anode pulses with pulse-heights reaching to 10% of maximum amplitudes.

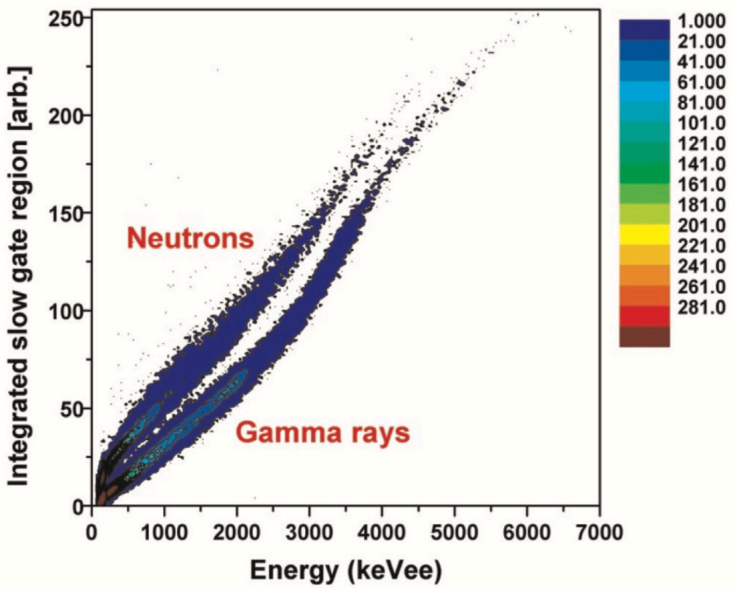


Fig. 6. A three-dimensional representation of the NGD performed with an NE213 scintillator exposed to ^{241}Am–Be source.

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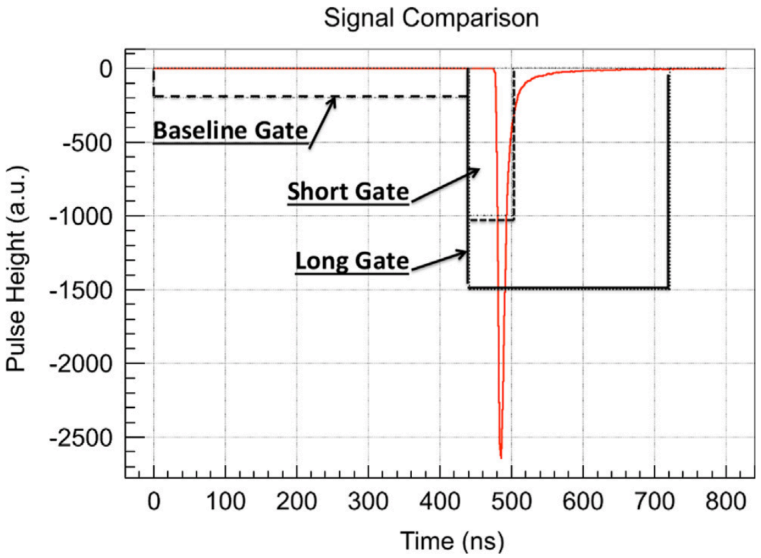
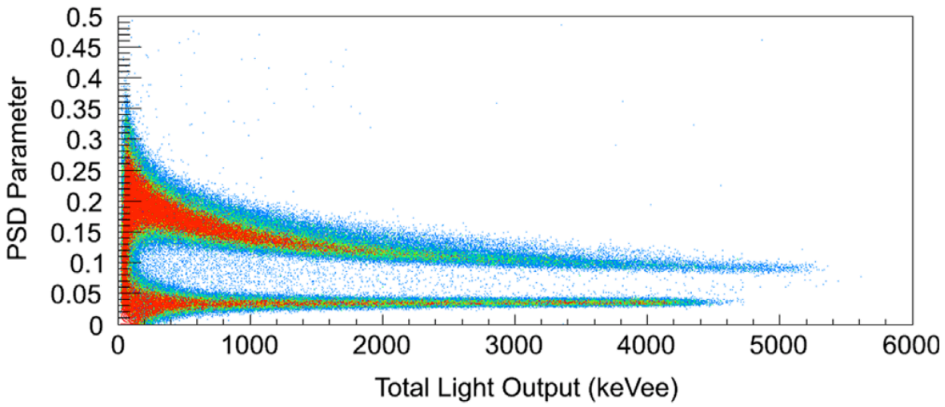
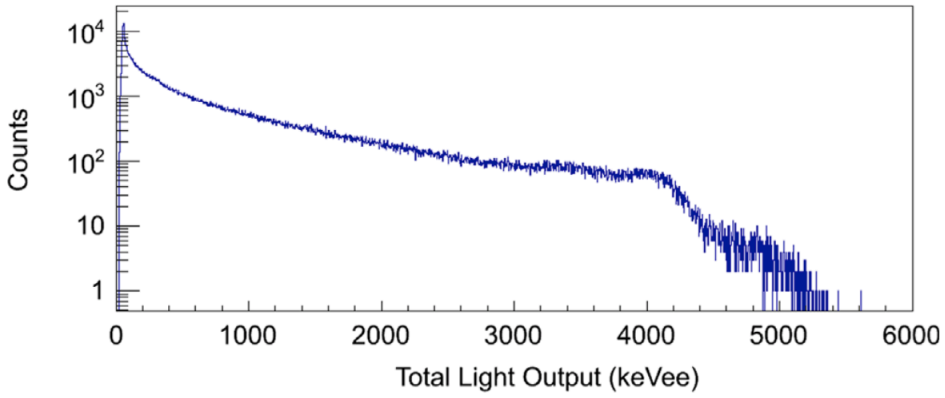
PSD Method



PSD versus total light output for Am/Be





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PSD Method

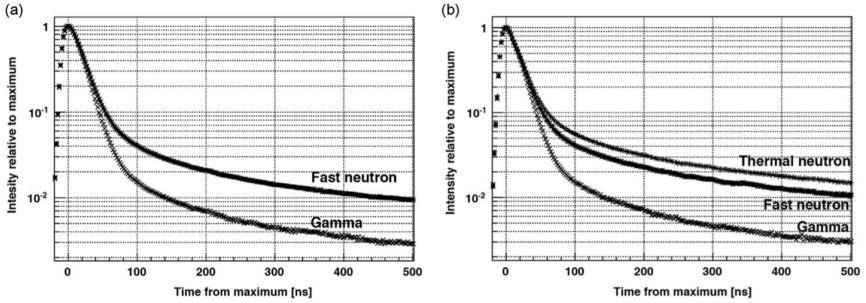

Fig. 2. Average ^{252}Cf waveforms corresponding to the normalized scintillation pulses recorded in the electron-equivalent energy range of 351–492 KeVee with (a) unloaded polystyrene-based PSD plastic containing 30% of PPO and 0.2% DPA, and (b) plastic of the same composition loaded with 5% of ^{6}Li-3-PSA.

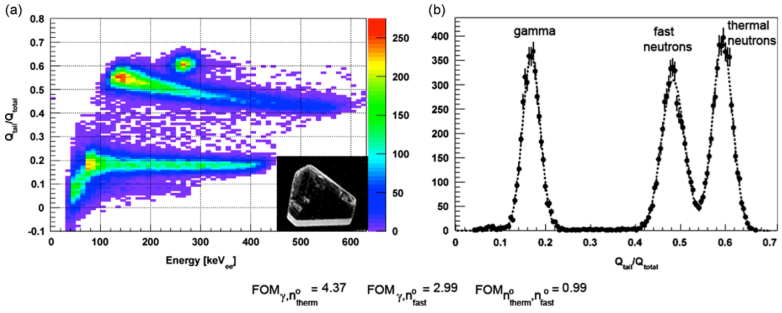

Fig. 8. (a) ^{252}Cf PSD measured in a Li-3-PSA single crystal with 9 mm HDPE moderation; inset shows a picture of the ~3 cm size crystal used for the measurements; (b) "triple" PSD patterns calculated for the near-thermal-neutron-spot energy range. Results were obtained with natural abundance Li that can be easily replaced by ^{6}Li isotope in the future crystals.

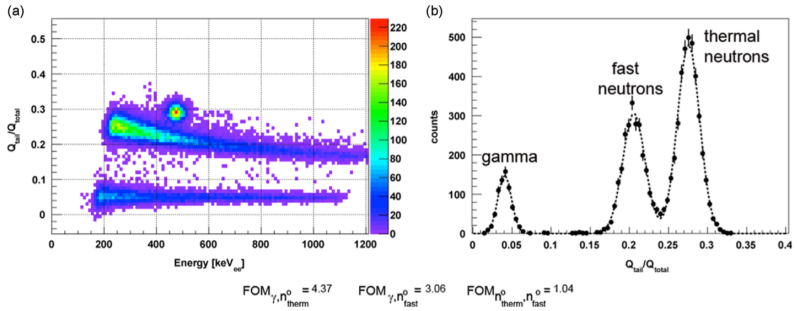

Fig. 6. (a) Energy-calibrated ^{252}Cf PSD measured in a liquid scintillator prepared as a mixture of 1% DPA in xylene loaded with 5% ^{Nat}Li-3-PSA; (b) corresponding PSD profile in the near-thermal-neutron-spot energy range showing the high degree of separation between three types of radiation.

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