PMT Waveform Timing Analysis Using Machine Learning Method

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Outline

- **I. Background**
- **II. Timing of a TOF system**
- **III. CNN model and Timing results**
- **IV. Summary**

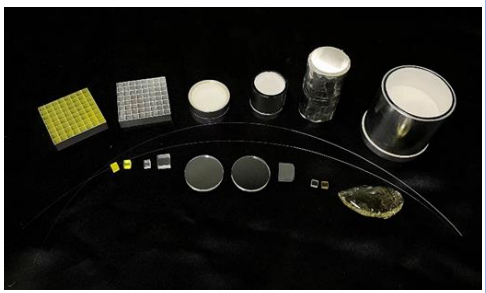
1.1 Background

Time of Flight System→ Fast Time & Real Time

Source → **Detector** → **Acquisition** → **algorithm**

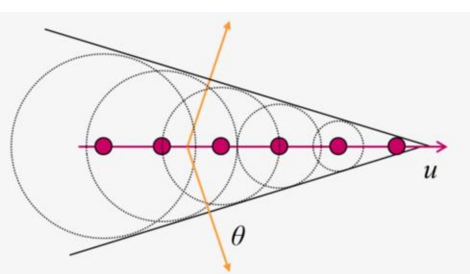
Scintillators

- Strong Light Yield
- Slow Time Performance



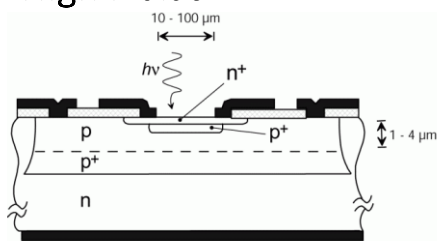
Cherenkov Radiator

- Fast!
- Low Light Yield



SiPM

- High QE & Cheap
- Temperature Dependance
- High Noise



MCP-PMT

- Fast!
- Low QE & Expensive

TDC

- Early time acquisition plugin
- Support CFD & LED

FADC

- Newly Developed acquisition device
- Whole waveform stored for analysis.

LED

- Constant Threshold leading Edge Discrimination

CFD

- Constant Fraction leading edge Discrimination

Template Fitting

- Reduce time jitter caused by noise

CNN

- Time correction by features extracting

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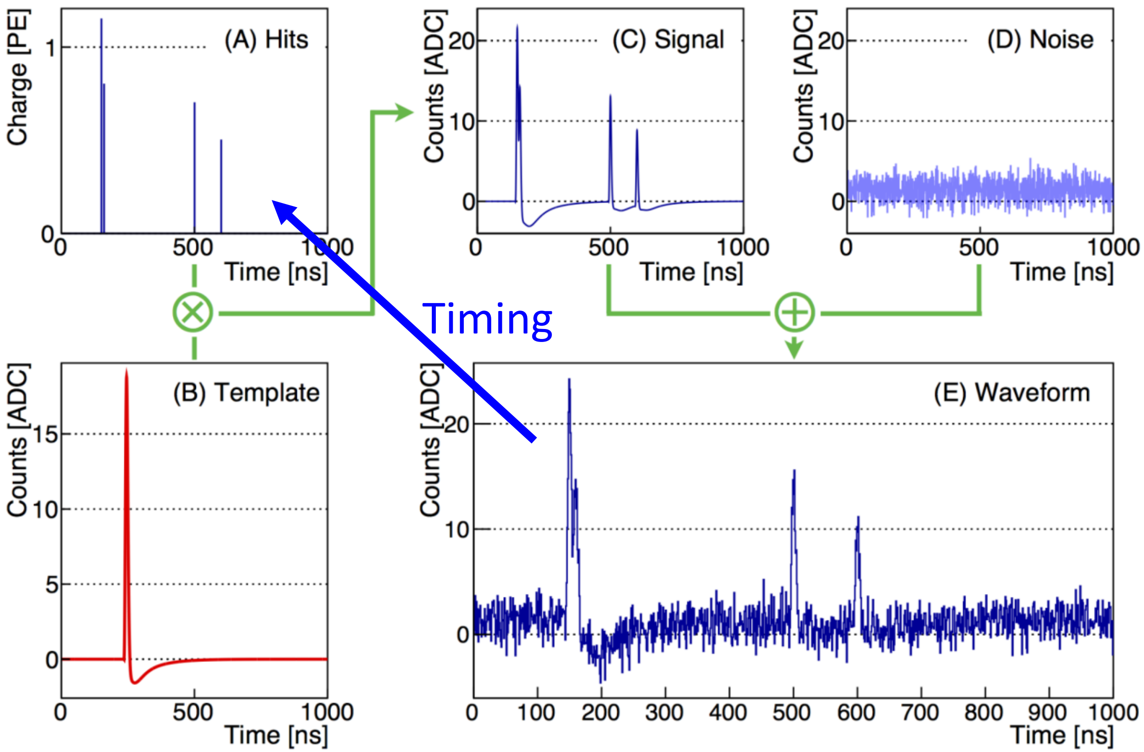
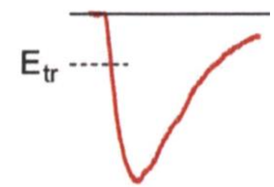
2.1 Different Timing Methods

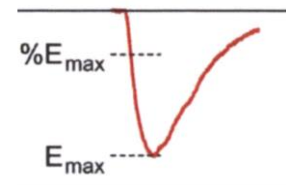


PMT waveform Formation Process [1]

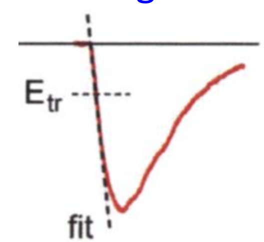
Leading Edge Discrimination (LED)



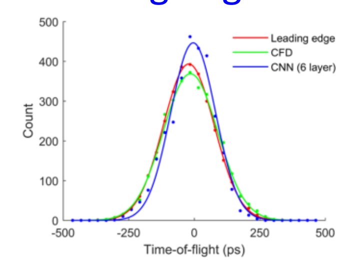
Constant Fraction Discrimination (CFD)



Template Fitting Before timing



CNN Timing Regression[2]



Locating the original time point from the waveform.

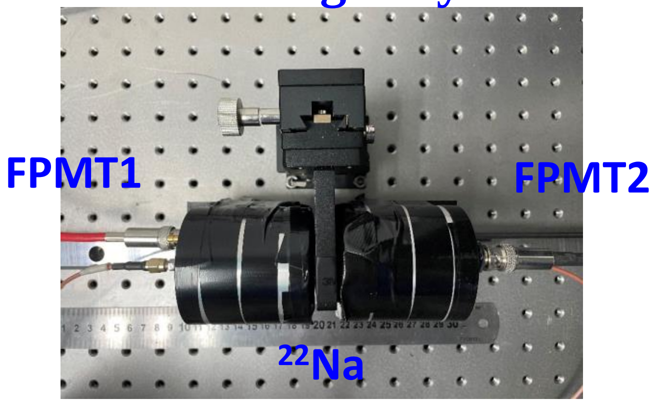
Amplitude fluctuation-Noise-PMT instinct jitter

Ref 1. BRIGATTI A, GRASSI M, et al. Charge reconstruction in large-area photomultipliers. Journal of Instrumentation, 2018, 13(2)
Ref 2. Eric Berg and Simon R Cherry, Using convolutional neural networks to estimate time-of-flight from PET detector waveforms, 2018 Phys. Med. Biol. 63 02LT01

2.2 Time of Flight System

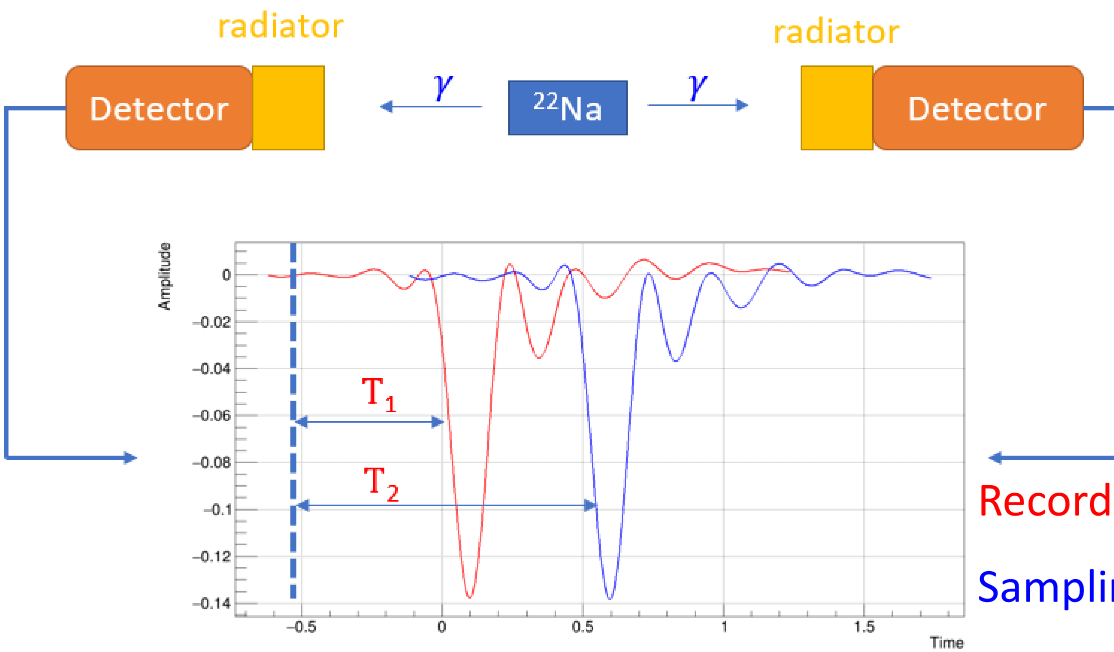
Cherenkov radiation detection

Time of Flight System



Detected by Fast time MCP-PMTs (FPMT)

	Gain	RT	TTS
FPMT1	1.9E6	104	46
FPMT2	2.9E6	96	44

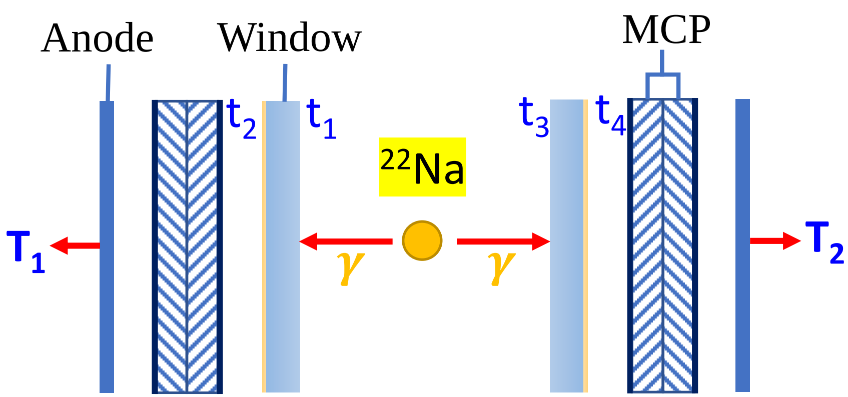


Recorded by oscilloscope

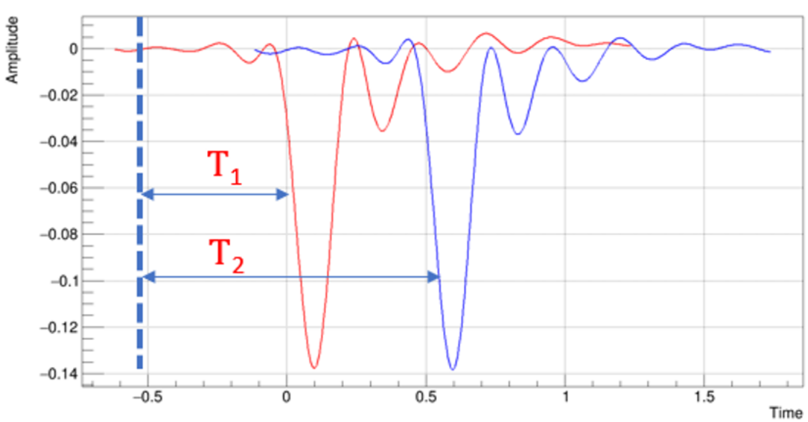
Sampling Rate: 20GSa/s

BandWidth:4G

2.3 Timing of Flight System



Time Difference = $T_1 - T_2$



Two Ways for FPMTs to interact with ϒ

- Cherenkov radiation in the window (t_1&t_3)
- Ionization in the lead glass MCPs (t_2&t_4)

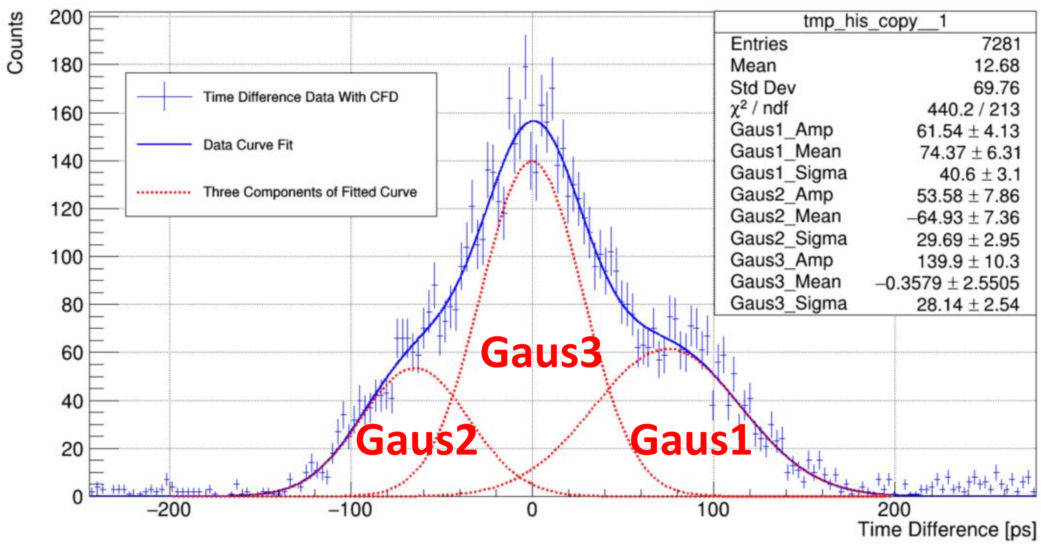
The Cherenkov process does not necessarily occur in a coincidence instance.

The leading edge of the waveform is used for timing.

Four components in Time Difference

- Time Difference = $(t_1 || t_2) - (t_3 || t_4)$

2.4 Time of Flight System



Time Difference distribution obtained with CFD

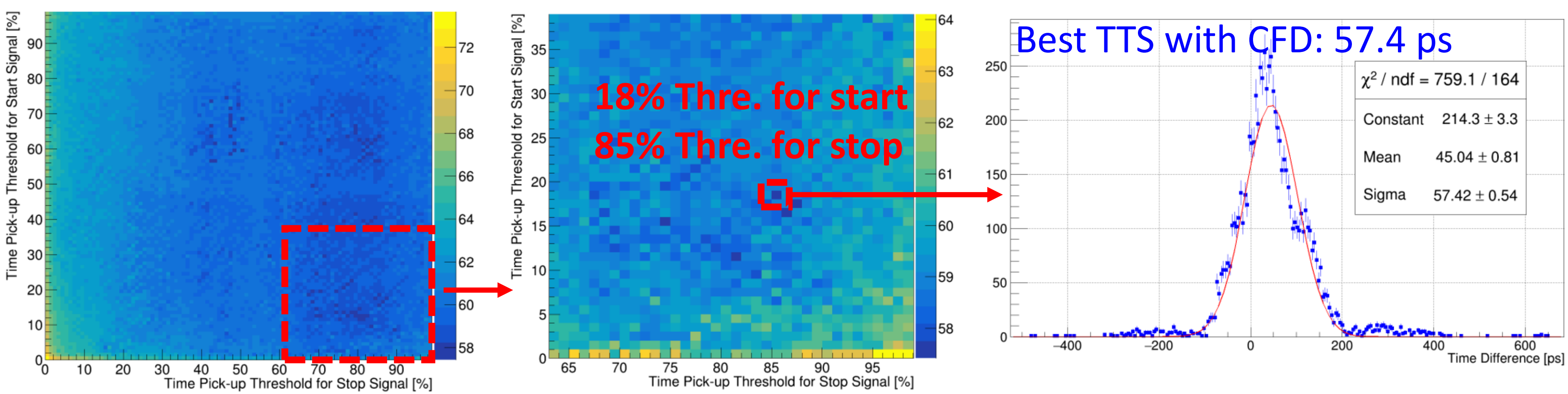
Gaus1: t_2 - t_3 Sigma = 41 ps

Gaus2: t_1 - t_4 Sigma = 30 ps

Gaus3: t_1-t_3 & t_2-t_4 Sigma = 28 ps

Global Std Dev = 70 ps

Time resolution is greatly deteriorated when different parts of PMT contribute at the same time.



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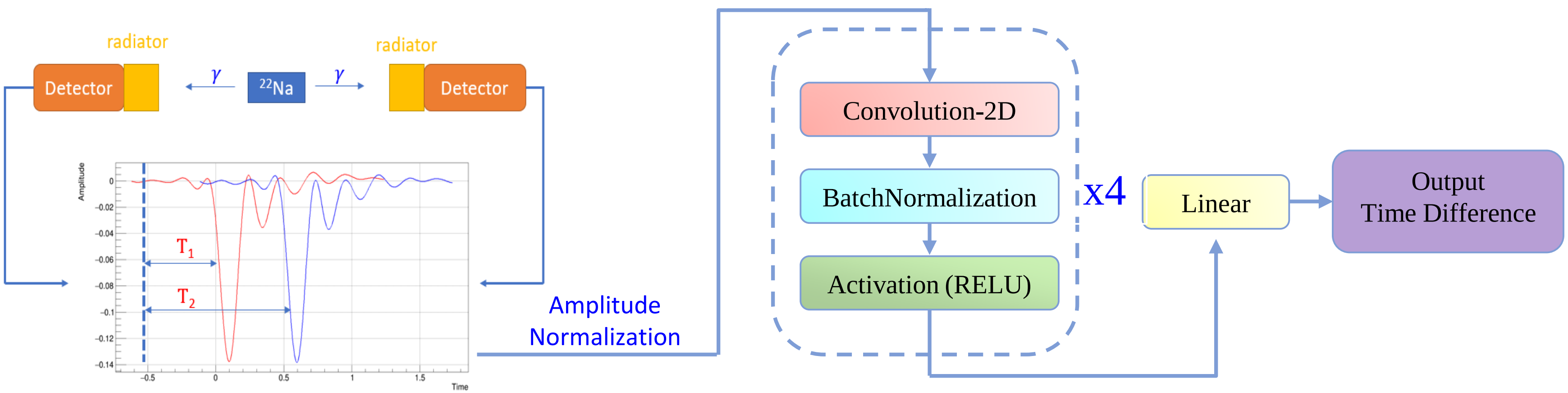
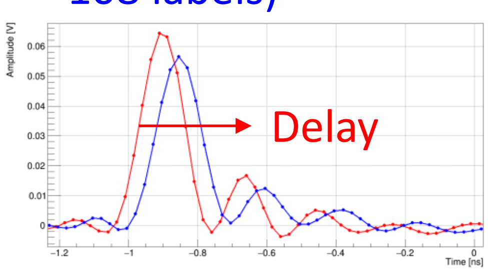
3.1 CNN structure and Data Preparation



The structure of timing CNN-based model

Training Dataset

- 6000 paired waveforms (ΔT = 0 ps)
- Delay the first waveform from -480 ps to 590 ps at 10ps intervals. (ΔT = -480 :10 :590 ps 108 labels)

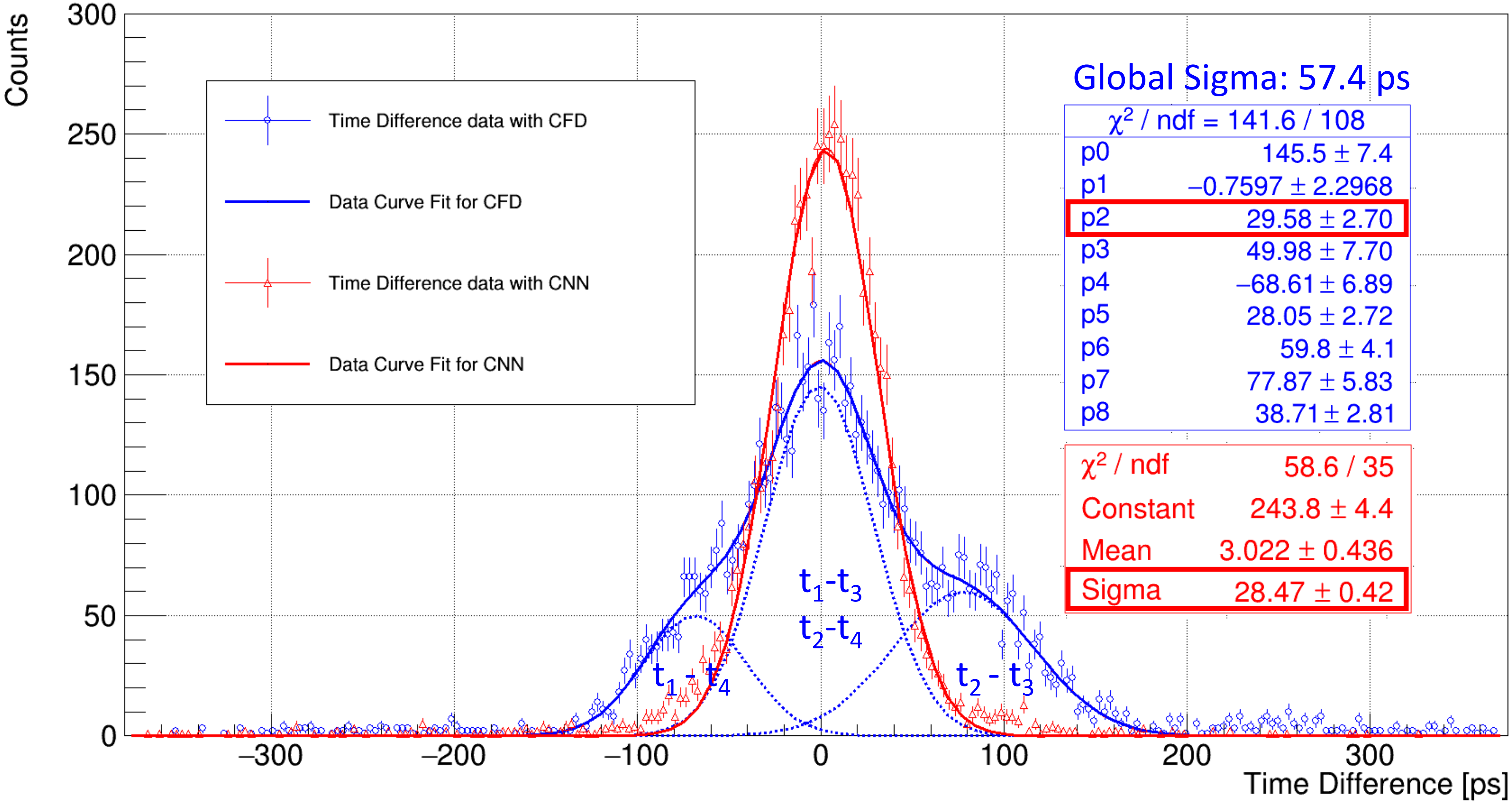


The delaying is feasible here because the shape of the waveform does not change with the ΔT.

CNN Paramaters

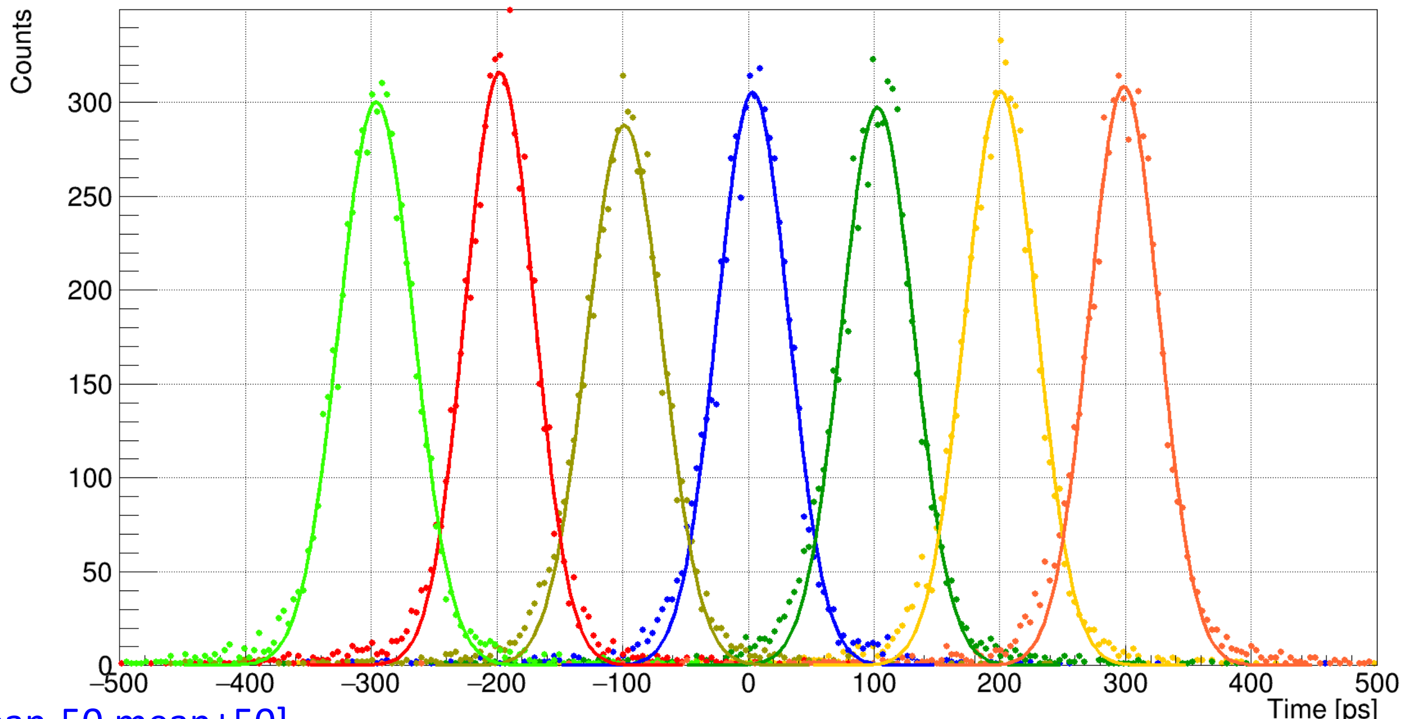
- LR: 0.0001
- EOPCH: 461
- Batch Size: 36
- Lose Function： MSE
- Optimizer： Adam
- GPU NVIDIA Quadro T1000

3.2 CNN timing results



- For the Global Std Dev, the CNN has 50% improved compared with the optimized CFD.
- The results show that the CNN successfully corrects the side peaks to the middle and furtherly improve the time resolution.

3.3 CNN timing among trained labels

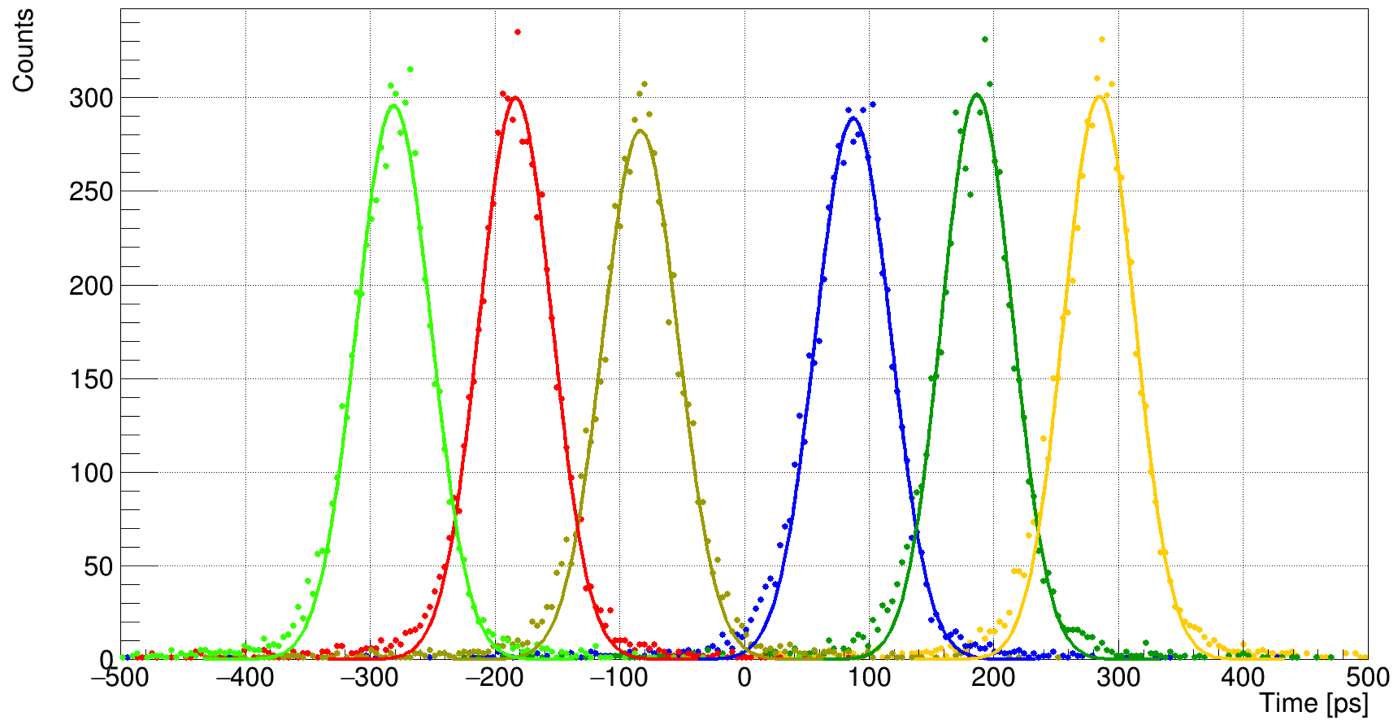


Fit Range [mean-50,mean+50]

Real Time	-300	-200	-100	0	100	200	300
Mean	-295.9	-197.7	-98.5	3.6	102.8	200.8	298.9
Sigma	29.7	27.4	29.9	28.5	28.8	28.6	29.9

- For the six groups whose labels are among the trained labels, the CNN shows uniform, precise and accurate time resolution.

3.4 CNN timing beyond trained labels



Fit Range [mean-50,mean+50]

Real Time	-285	-185	-85	85	185	285
Mean	-281.2	-183.4	-83.3	87.3	186.6	284.7
Sigma	29.8	29.1	30.0	30.0	28.5	28.5

- For the six groups whose labels are beyond the trained labels, the CNN also shows uniform, precise and accurate time resolution. (No overfit in the model)

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4 Summary

- The CNN method shows excellent ability in the PMT waveform feature extraction and make improvements on the time information correspondingly.
- The fasting timing MCP-PMT is being developed and improvement in our laboratory.   In order to furtherly realized the real-time timing analysis with the CNN method, more efforts are to be done in the electronics to write CNN into FPGA.