

Photon Response Model of MCP-PMT

- based on the onsite PMT testing data

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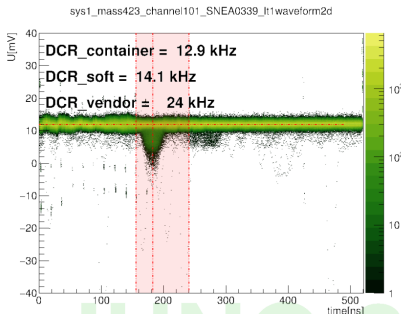


Outline

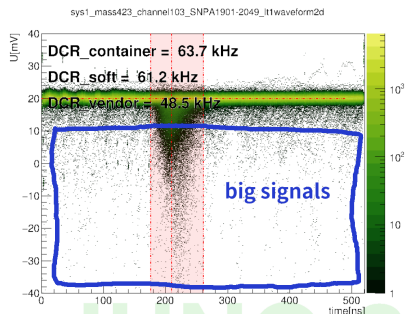
- ① Brief Introduction
- ② traing and test of CNN
- ③ Summary

the "big signals" of MCP PMT

The typical waveforms ¹ of MCP PMT, compared with dynode PMT.



: waveforms of HAMAMATSU PMT



: waveforms of MCP PMT

¹gain = $1\text{E}7, \mu \simeq 0.1$

the "big signals" of MCP PMT

The "long tail" in charge spectrum² of MCP PMT, compared with dynode PMT.

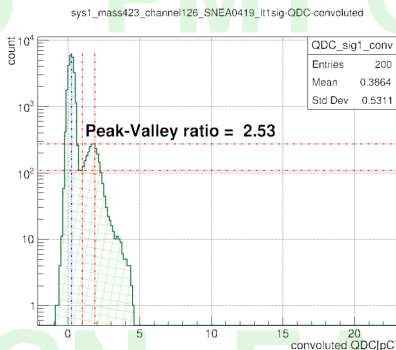


图: SPE of HAMAMATSU PMT

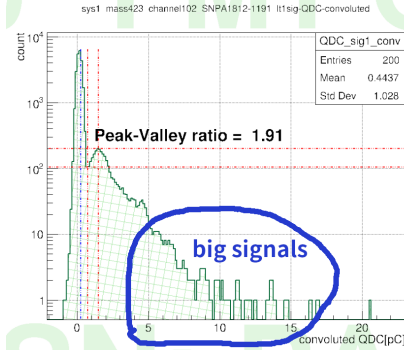


图: SPE of MCP PMT

$$^2_{\text{gain}} = 1\text{E}7, \mu \simeq 0.1$$

photon response characters of MCP PMT

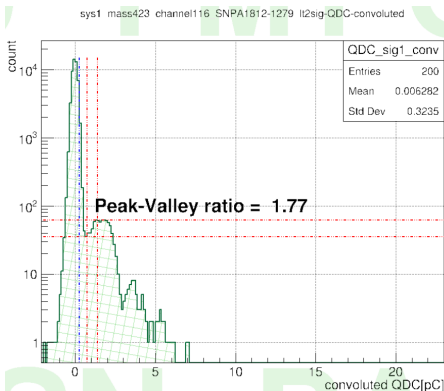
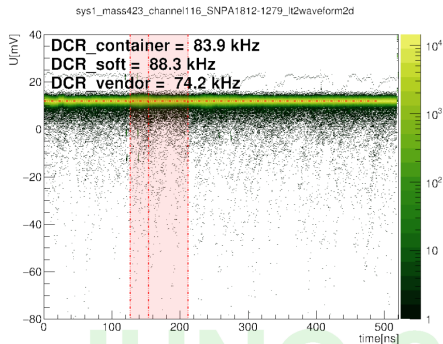
Based on the container testing data, we can acquire waveforms of the MCP PMT in 5 different illumination levels:

- 1 dark noise mode [no light incident]
- 2 non-trigger window @1 p.e
- 3 $\mu \simeq 0.1$ p.e
- 4 $\mu \simeq 1$ p.e
- 5 $\mu = \text{multi-p.e}$ [by laser]

photon response characters of MCP PMT

case 1:[dark noise]

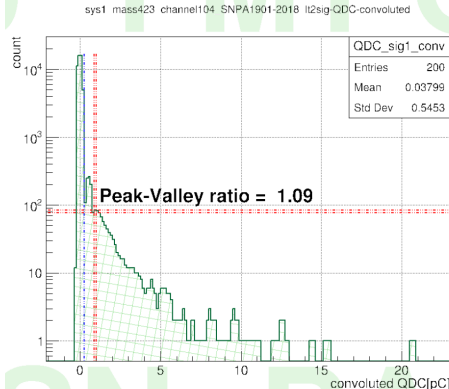
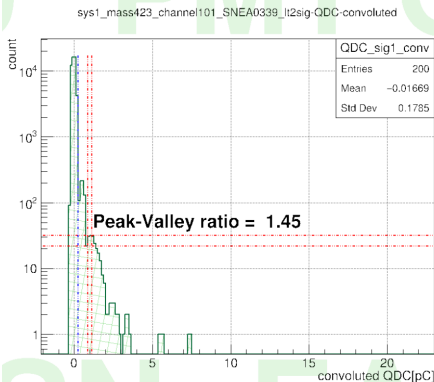
The typical waveform and charge spectrum of MCP PMT@gain = 10^7 .
If we suppose all the dark counts is caused by single thermal electron,
then those fake multi-p.e events are caused by the magnification of MCP.



photon response characters of MCP PMT

case 1:[dark noise]

The typical charge spectrum of HAMAMATSU and MCP PMT@gain = 10^7 , with time window 521ns.



photon response characters of MCP PMT

select the time interval before "trigger window", we can see similar QDC spectrum with dark noise case.

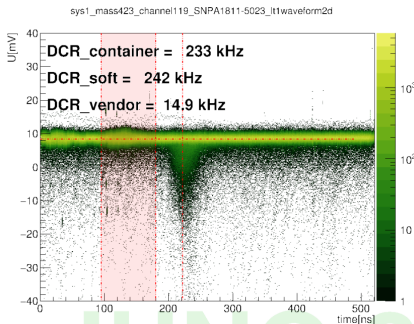


图: select non-trigger ROI

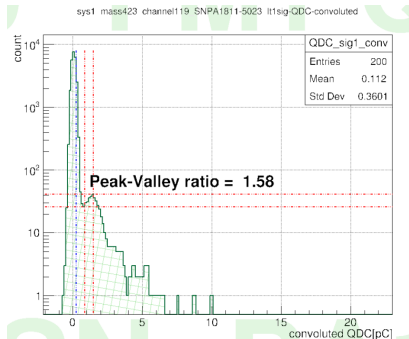


图: QDC of non-trigger ROI

photon response characters of MCP PMT @ $\mu \simeq 0.1$

case 3: $\mu \simeq 0.1$

In the trigger window, we can still see those "big signals" with charge $> 3\text{p.e.}$

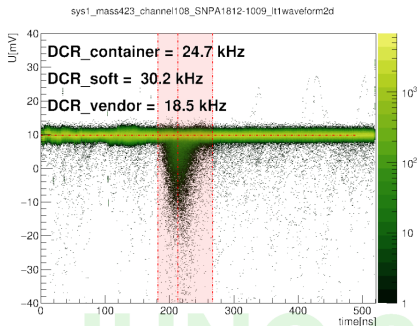


图: waveforms @ $\mu \simeq 0.1$

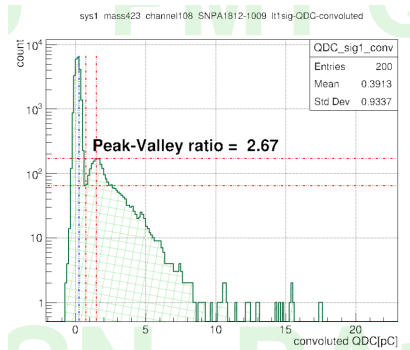
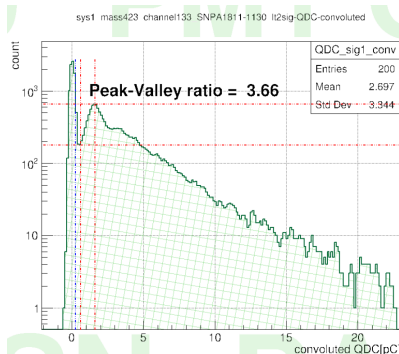
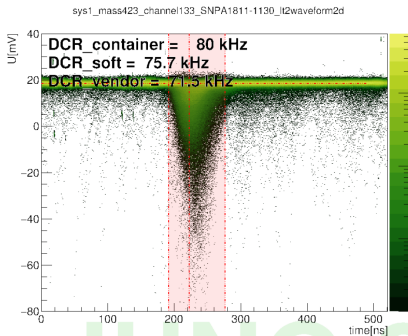


图: QDC @ $\mu \simeq 0.1$

photon response characters of MCP PMT @ $\mu \simeq 1$

case 4: $\mu \simeq 1$

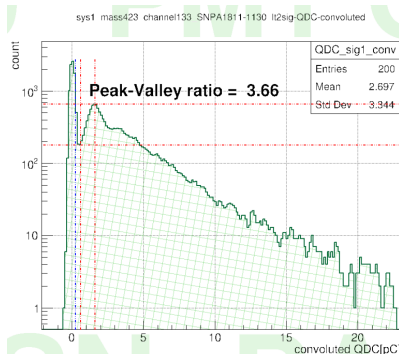
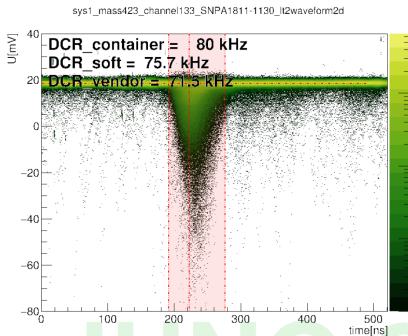
When the light intensity increase to $\mu \simeq 1$ we can see a continuous "long tail" with charge >5p.e; this is a clear clue that MCP will magnify little part of electrons with abnormal large gain.



photon response characters of MCP PMT @ $\mu > 2$

case 5: $\mu > 2p.e.$

When the light intensity increase to $\mu \simeq 1$ we can see a continuous "long tail" with charge $> 5p.e.$; this is a clear clue that MCP will magnify little part of electrons with abnormal large gain.



number

To conclude the above information, we find:

- The Gain of MCP-PMT is not stable enough, It has small probability to magnify single p.e to unreasonable large charge.

the expected photon number

If we do a "cut" is the charge spectrum@0.25 spe, the averager photon number μ can be acquired by³

$$\mu = -\ln\left(\frac{N_0}{N}\right) \quad (1)$$

where N_0 is the number of pedestal(0 p.e) events, N is the total event number.

However, if we know explicitly the photon number of specific event, the μ value is :

$$\mu = 1 \times n_1 + 2 \times n_2 + \cdots + N \times n_N \quad (2)$$

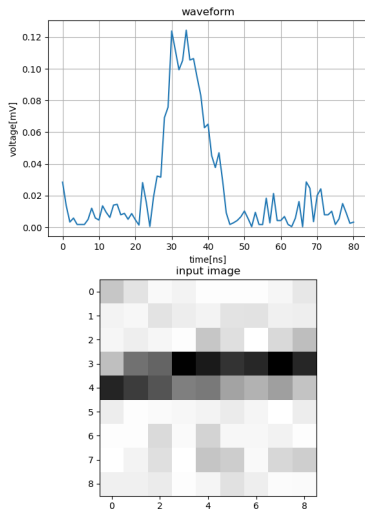
where n_N is the number of N p.e events.

³E. H. Bellamy et al /Nucl. Instr. and Meth. in Phys. Res. A 339 (1994) 468-476

input of CNN

training data selection and pre-process:

- random selection from different PMTs
- $1.5 < QDC < 1.7$ for 1p.e
- $3.1 < QDC < 3.3$ for 2p.e
- $4.7 < QDC < 4.9$ for 3p.e
- 81ns ROI $\rightarrow 9 \times 9$ 2D image
- normalization



CNN parameters

- 30k training waveform samples
- 2 convolution layers
- 4 output tags
- accuracy $\simeq 0.95$

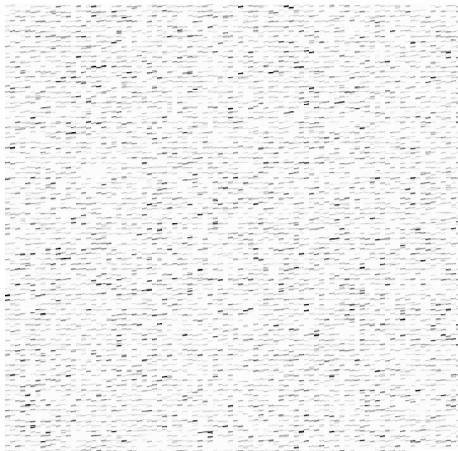
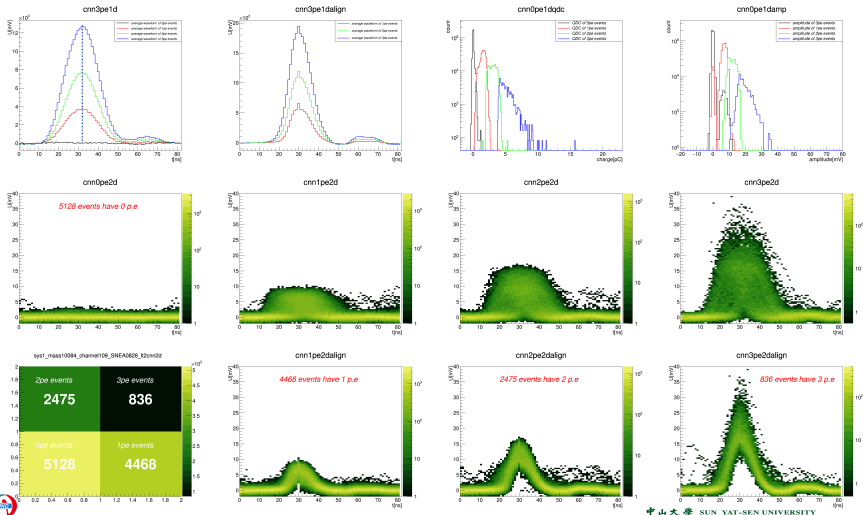


图: input data

results of cnn



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图: HAMAMATSU PMT

Figure 1 displays the results of event detection and classification for four different CNN models: **cnn3pe1d**, **cnn3pe1dalign**, **cnn0pe1dqdc**, and **cnn0pe1damp**.

The top row shows the **amplitude of the events** (Y-axis, 10^0 to 10^2) versus **time** (X-axis, 0 to 80 ms). The plots show the distribution of event amplitudes for each model, with the **cnn3pe1d** model showing a clear peak around 30 ms.

The bottom row shows the **count** of events (Y-axis, 0 to 40) versus **time** (X-axis, 0 to 80 ms) and **frequency** (Z-axis, 0 to 80 Hz). The plots show the distribution of event counts for each model, with the **cnn0pe1dqdc** model showing a clear peak around 30 ms.

The **cnn0pe1dqdc** model shows a clear peak around 30 ms, indicating a high detection rate for events with 0 p.e. The **cnn0pe1damp** model shows a clear peak around 30 ms, indicating a high detection rate for events with 3 p.e. The **cnn3pe1d** and **cnn3pe1dalign** models show a clear peak around 30 ms, indicating a high detection rate for events with 2 p.e.

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图: NNVT PMT

summary

- PSD by CNN provide a new option for PDE evaluation.
- can achieve *sim*0.95 accuracy with the traditional method using simple NN.
- much faster than traditional methods in PDE evaluation.
- CNN can extract more information from waveforms.

to list:

- refine the training samples and network structure.
- compare the accuracy in more details, for example using the reference tubes in container system.
- improve the input data quality.

THANKS

BACK-UP