

Photon Response Model of MCP-PMT

– based on the onsite PMT testing data

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Outline

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② new response model of MCP

③ Summary

the "big signals" of MCP PMT

The typical waveforms¹ of MCP PMT, compared with dynode PMT.

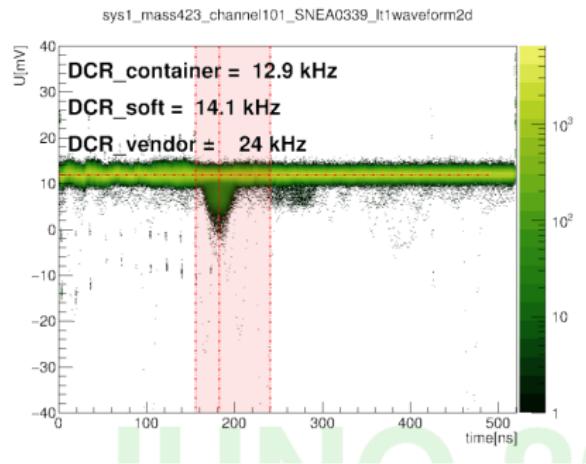


图: waveforms of HAMAMATSU PMT

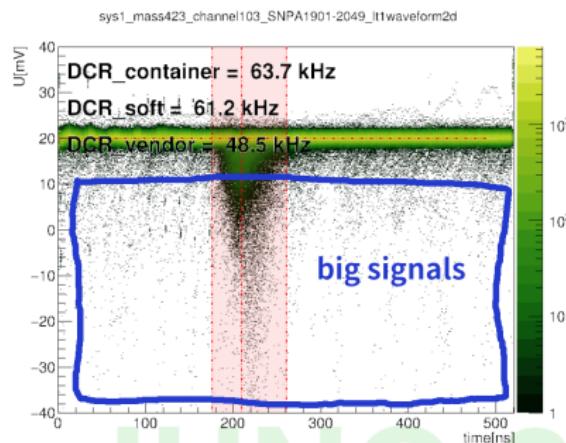


图: waveforms of MCP PMT

¹gain= 1E7, $\mu \approx 0.1$

the "big signals" of MCP PMT

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

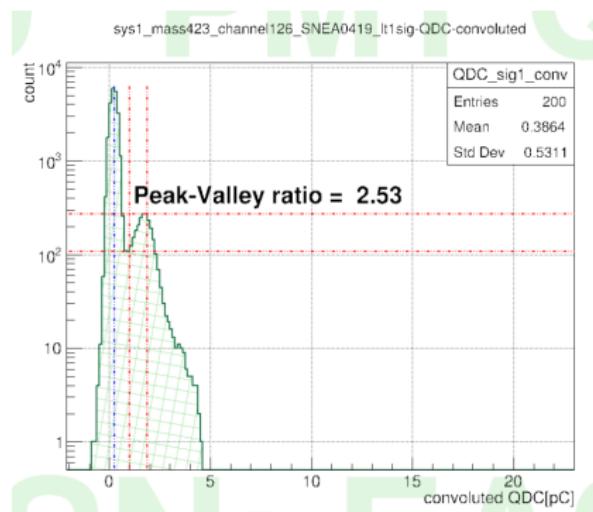


图: SPE of HAMAMATSU PMT

$$^2\text{gain} = 1E7, \mu \simeq 0.1$$

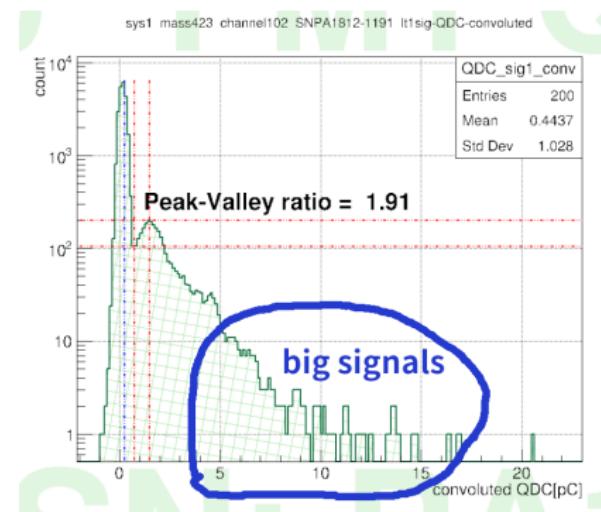


图: SPE of MCP PMT

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:

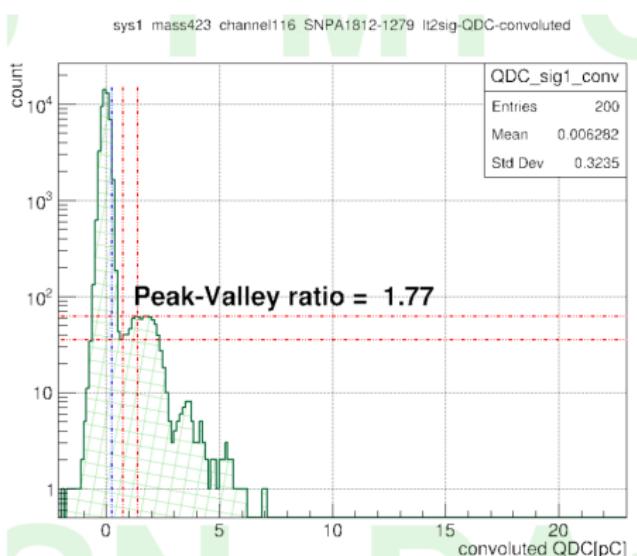
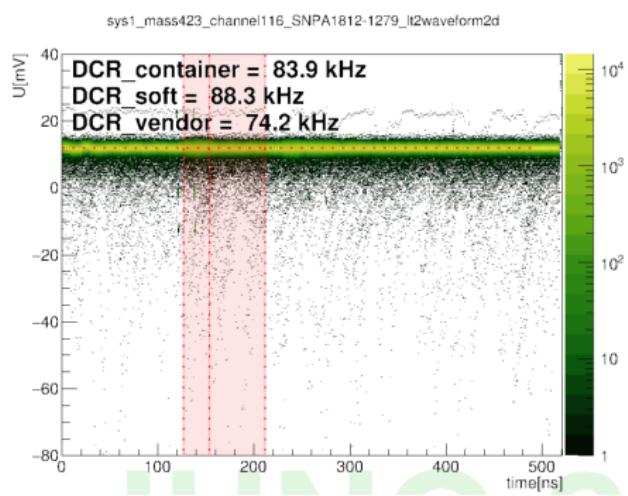
- ① dark noise mode [no light incident]
- ② non-trigger window @1 p.e
- ③ $\mu \simeq 0.1$ p.e
- ④ $\mu \simeq 1$ p.e
- ⑤ $\mu = \text{multi-p.e}$ [by laser]

photon response characters of MCP PMT

case 1:[dark noise]

The typical waveform and charge spectrum of MCP PMT@gain = 10^7 .

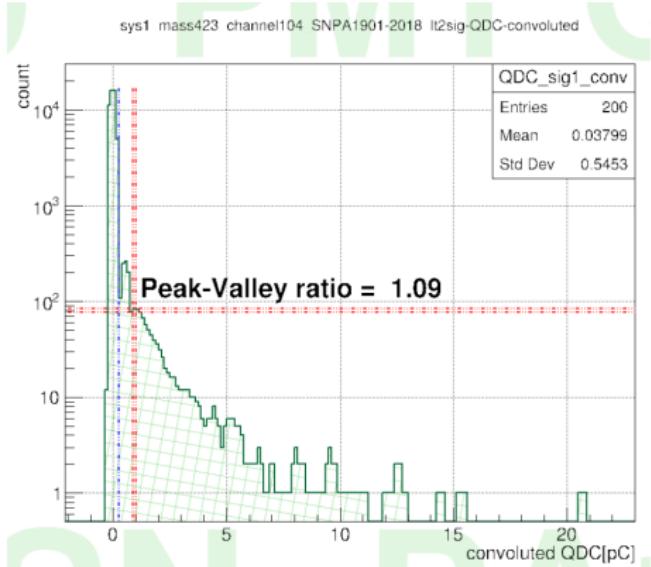
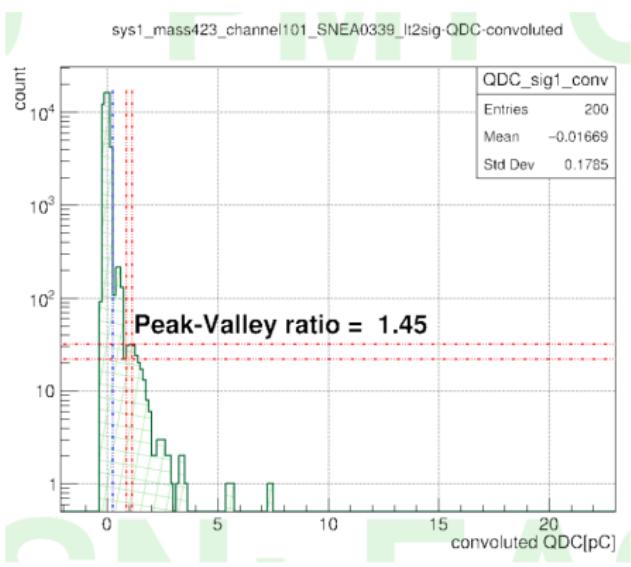
If we suppose all the dark counts is caused by single thermal electron, then those fake multi-p.e events are caused by the magnification of MCP.



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.

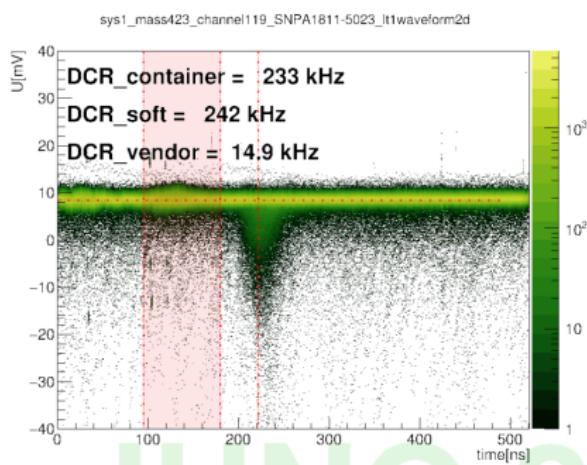


图: select non-trigger ROI

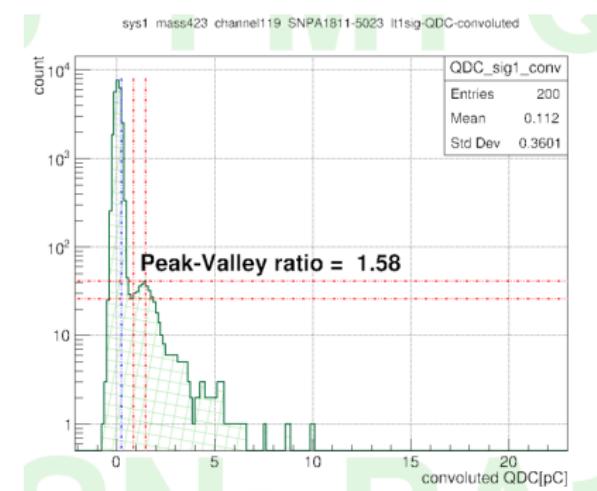


图: QDC of non-trigger ROI

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 >3p.e.

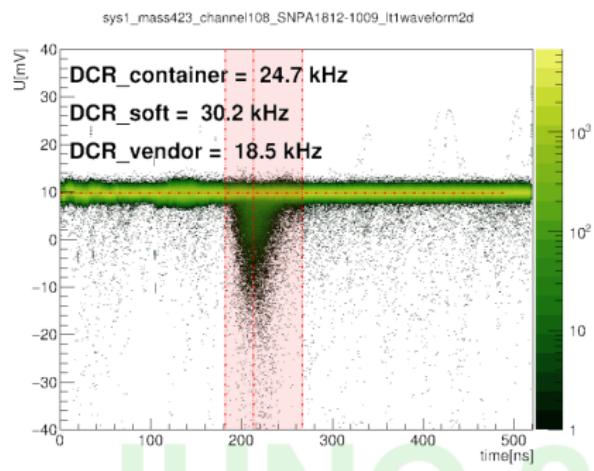


图: waeforms @ $\mu \simeq 0.1$

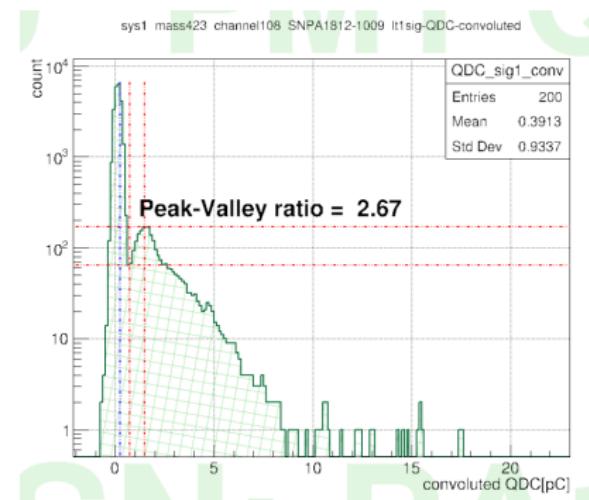
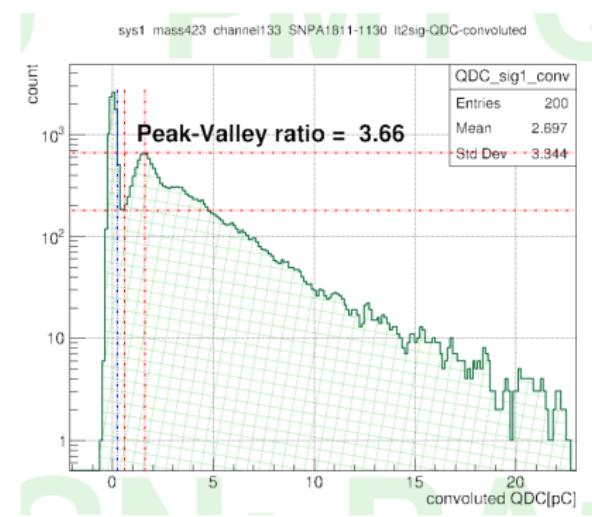
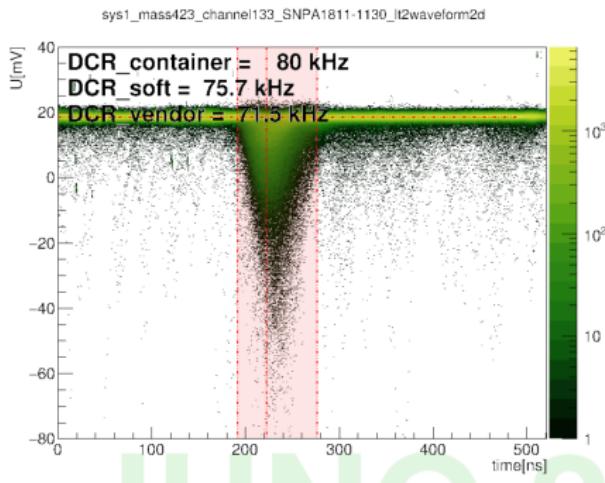


图: QDC @ $\mu \simeq 0.1$

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: $\mu > 2p.e.$

with $\mu = 3.48$, we can get signals with almost $> 15p.e.$

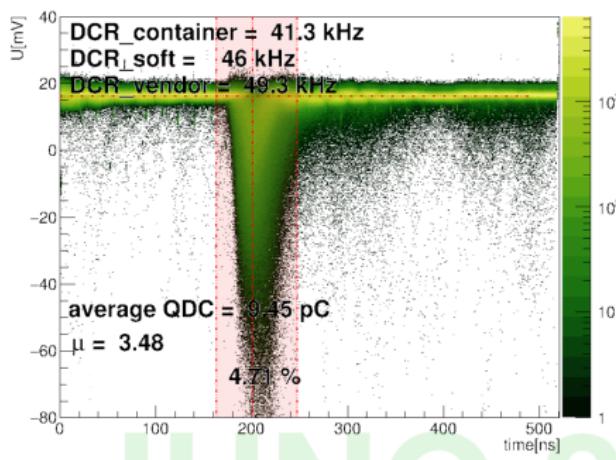


图: waforms @ $\mu \simeq 1$

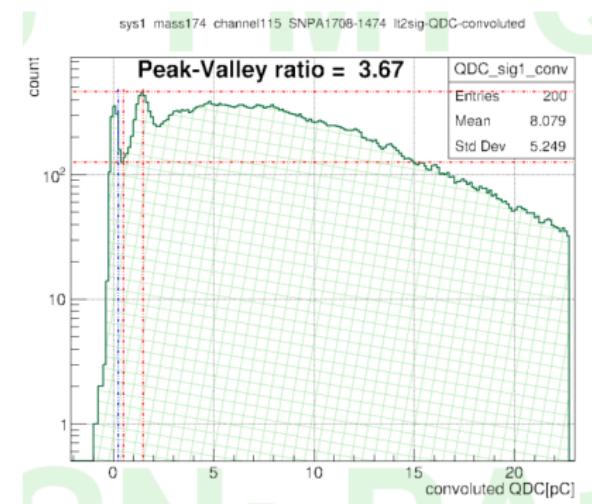


图: waforms @ $\mu \simeq 1$

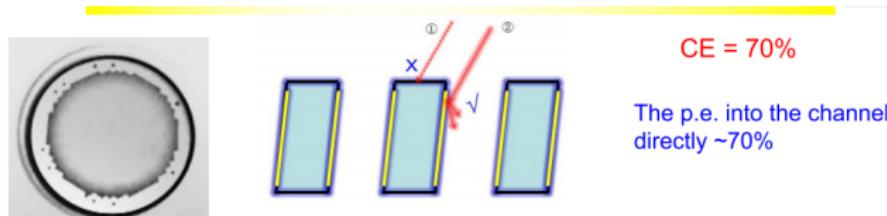
what we found

To conclude the above information, we find:

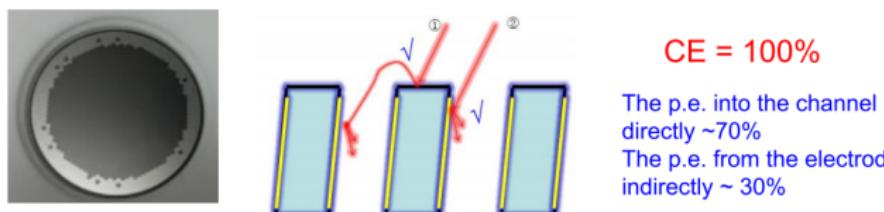
- The Gain of MCP-PMT is not stable enough, It has small probability to magnify single p.e to unreasonable large charge.
- the charge of "big signals" is proportional to incident light. the more incident photons, the more "big signals". So, the charge of "big signals" is closely related to the light intensity rather than a fixed charge sum.
- The "big signals" are slightly delayed (about several ns) in time.

possible reason:cross talk of MCP

From:JUNO-doc-4232-v2: If the second electrons from surface film hit more than one micro-channel, It may generate cross-talk signal.



The Diameter of the MCP: 33mm; 50mm;
 The Diameter of the Hole: 6um; 8um; 10um; 12um;
 The Inclined Angle: 0°; 8°; 12°;
 The Open Area Ratio: 60%; 77%;
 The Special Film by ALD for the same SEE material



new response model with cross-talk effect

Based on the above features, we try to adapt the traditional PMT respond model, which is

$$\begin{aligned} S_{\text{ideal}}(x) &= P(n; \mu) \otimes G_n(x) \\ &= \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \frac{1}{\sigma_1 \sqrt{2\pi n}} \exp\left(-\frac{(x - nQ_1)^2}{2n\sigma_1^2}\right) \end{aligned} \quad (1)$$

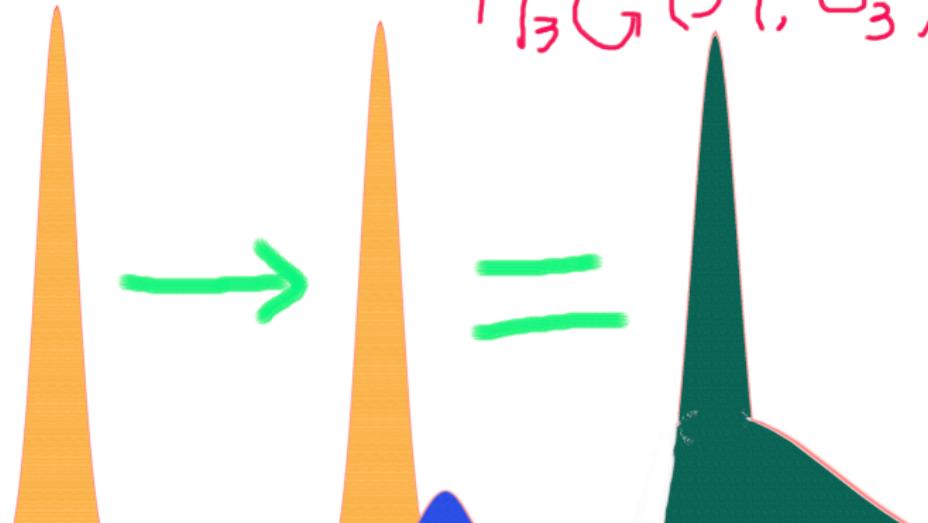
A simple cross-talk model: Suppose for a single p.e it could be magnified with gain = g_1 , $2 \times g_1$, $3 \times g_1$, the corresponding possibility are p_1, p_2, p_3 , we could modify the above signal model to:

$$\begin{aligned} S_{\text{ideal}} &= P(n; \mu) \otimes G_n(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \left[\frac{1}{\sigma_1 \sqrt{2\pi n}} \exp\left(-\frac{(x - nQ_1)^2}{2n\sigma_1^2}\right) \right. \\ &\quad \left. + p_2 * \frac{1}{\sigma_2 \sqrt{2\pi n}} \exp\left(-\frac{(x - 2nQ_1)^2}{2n\sigma_2^2}\right) + p_3 * \frac{1}{\sigma_3 \sqrt{2\pi n}} \exp\left(-\frac{(x - 3nQ_1)^2}{2n\sigma_3^2}\right) \right] \end{aligned} \quad (2)$$

the expected photon number

$$G(q_1, \sigma_1)$$

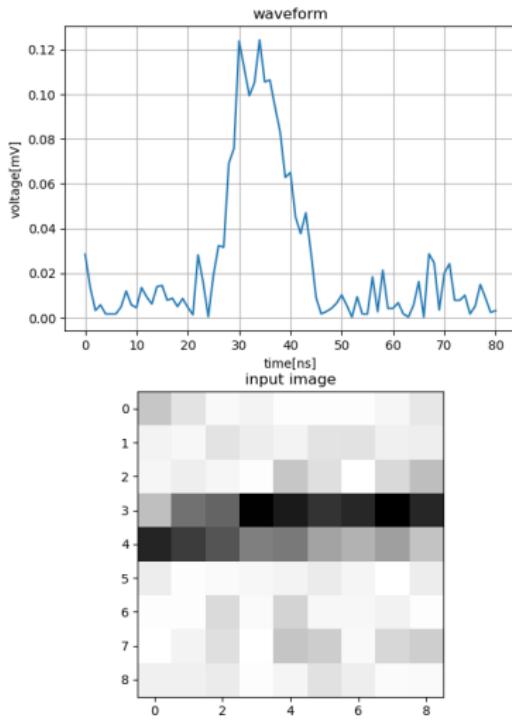
$$G(q_1, \sigma_1) + P_2 G(2q_1, \sigma_2) \\ + P_3 G(3q_1, \sigma_3)$$



input of CNN

training data selection and pre-process:

- random selection from different PMTs
- $1.5 < \text{QDC} < 1.7$ for 1p.e
- $3.1 < \text{QDC} < 3.3$ for 2p.e
- $4.7 < \text{QDC} < 4.9$ 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 \approx 0.95

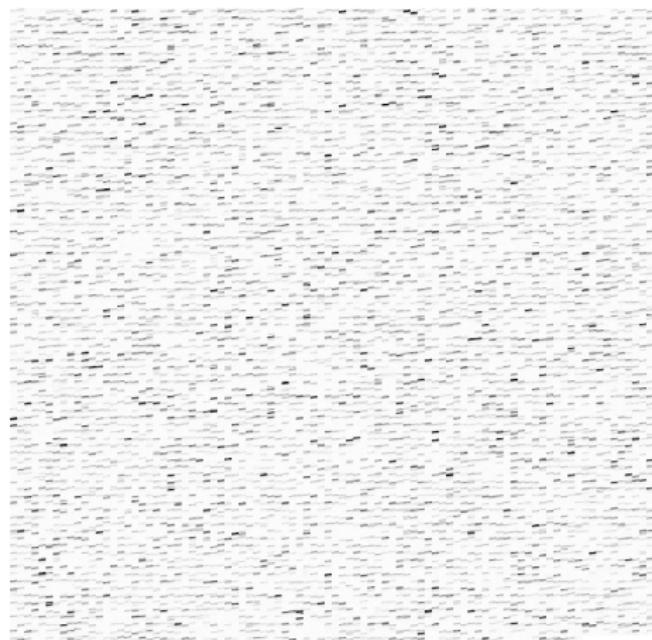
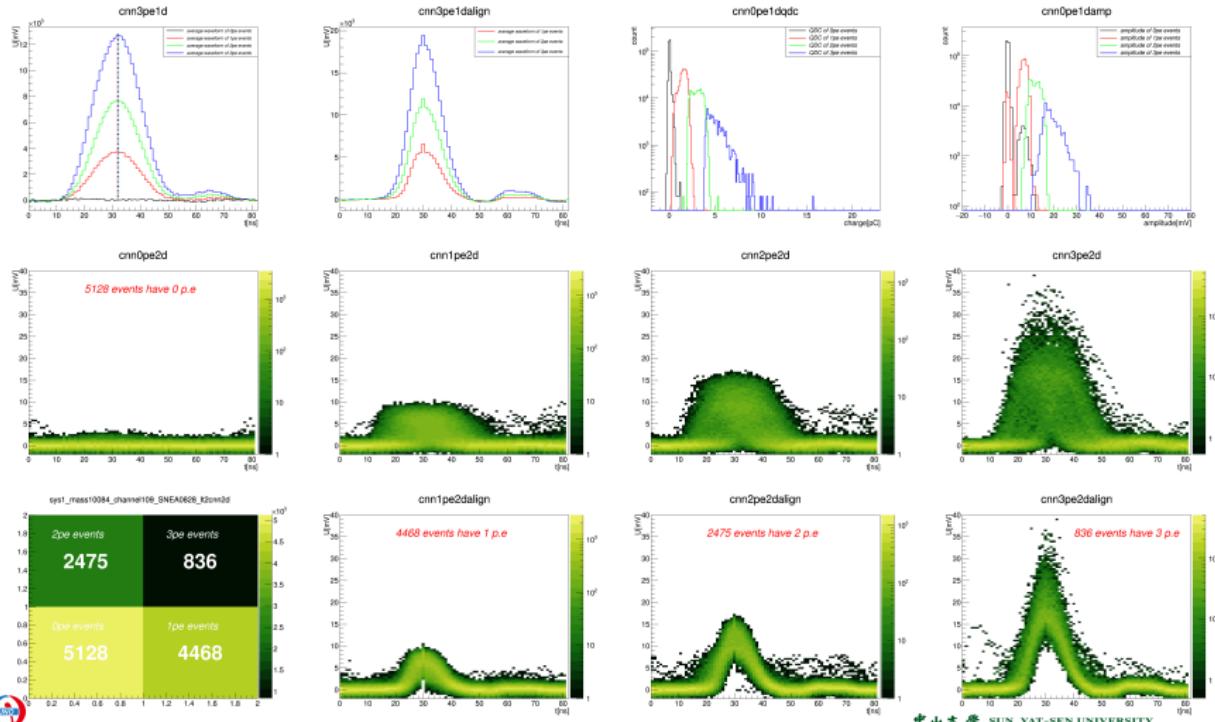


图: input data

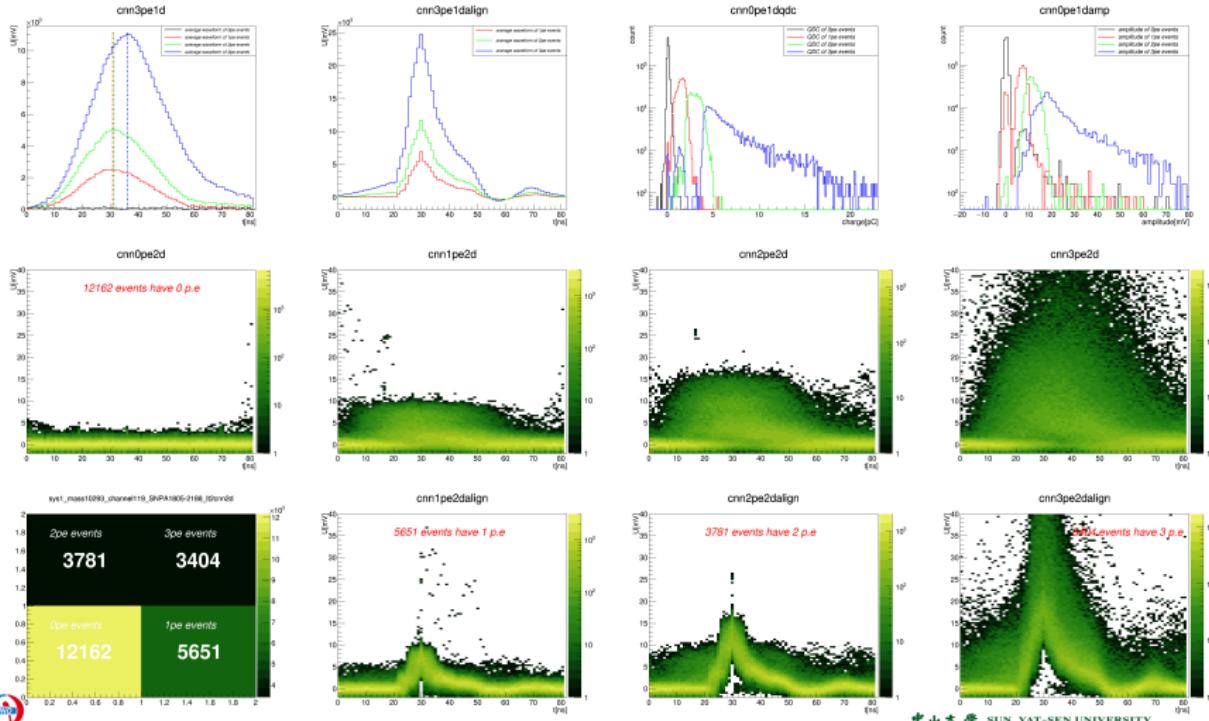
results of cnn



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HAMAMATSU PMT

results of cnn



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NNVT PMT

summary

- PSD by CNN provide a new option for PDE evaluation.
- can achieve sim0.95 acuuarcy with the traditional method using simple NN.
- much faster than traditionl methods in PDE evaluation.
- CNN can ectract more infromation 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