Photon Response Model of MCP-PMT

– based on the onsite PMT testing data

Email： zhaor25@mail2.sysu.edu.cn

School of Physics

SUN YAT-SEN UNIVERSITY

Outline

the "big signals" of MCP PMT

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

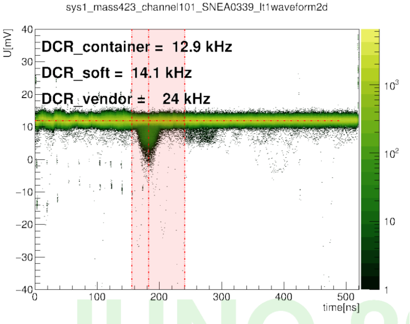


图: waveforms of HAMAMATSU PMT

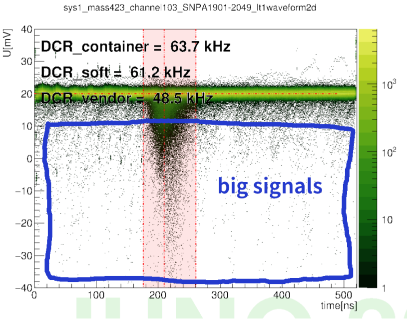


图: waveforms of MCP PMT

[1] gain= 1E7, $\mu \simeq 0.1$

the ”big signals” of MCP PMT

The ”long tail” in charge spectrum[2] of MCP PMT,compared with dynode PMT.

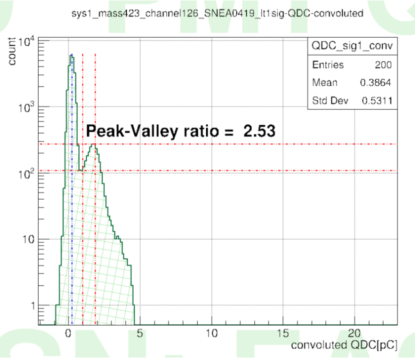


图: SPE of HAMAMATSU PMT

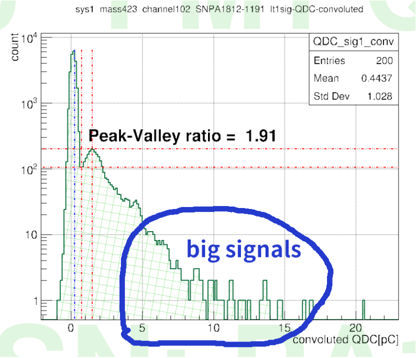


图: SPE of MCP PMT

[2] gain= 1E7, $\mu \simeq 0.1$

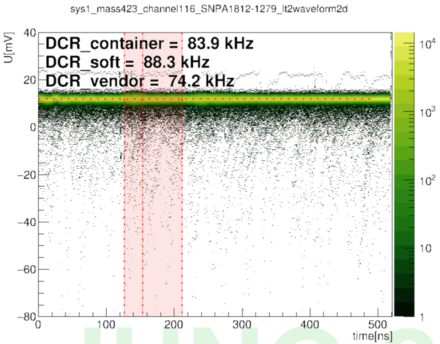
photon response characters of MCP PMT

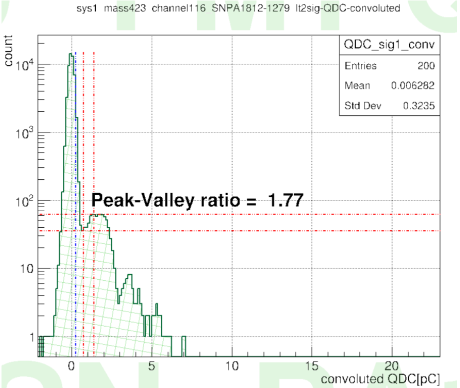
Based on the container testing data, we can acquire wavefroms of the MCP PMT in 5 different illumination levels:

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

photon response characters of MCP PMT

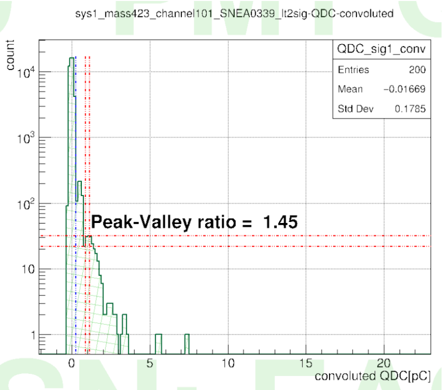
case 1:[dark noise]
The typical waveform and charge spectrum of MCP PMT@gain $=10^7$.
If we suppose all the dark counts is caused by single thermal electron, then those fake multi-p.e events are caused by the magnification of MCP.

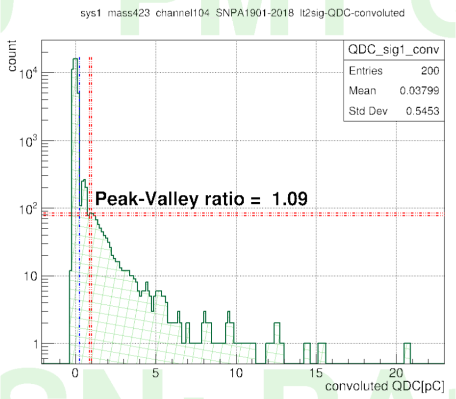




photon response characters of MCP PMT

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.

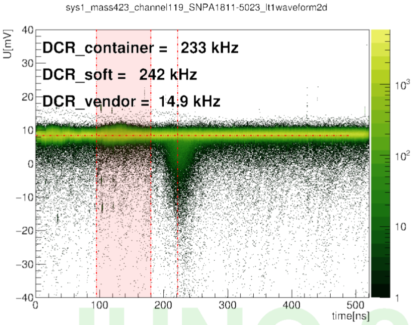


图: slect non-trigger ROI

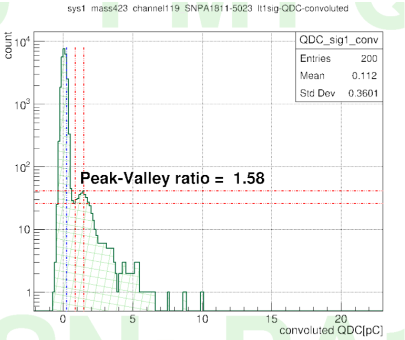


图: QDC of non-trigger ROI

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.

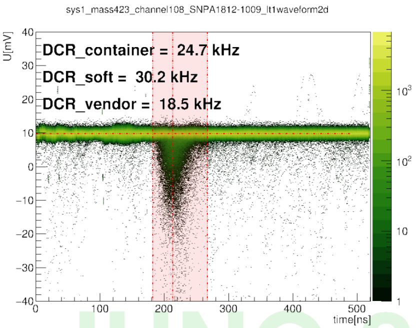


图: waeforms @ $\mu \simeq 0.1$

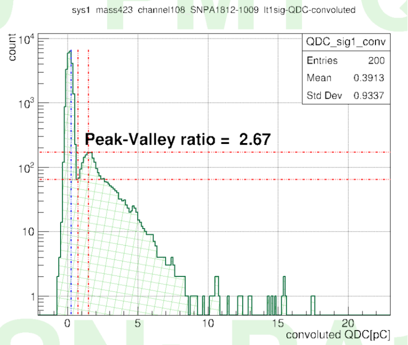
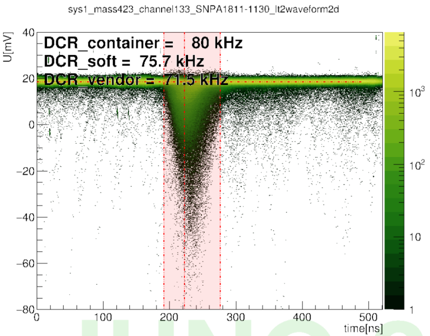
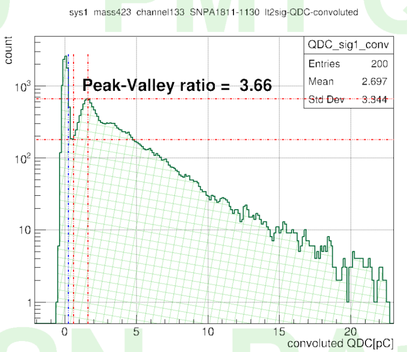


图: QDC @ $\mu \simeq 0.1$

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 abnornal large gain.





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

case 5: $\mu > 2$*p.e.*
with $\mu = 3.48$, we can get signals with almost > 15p.e.

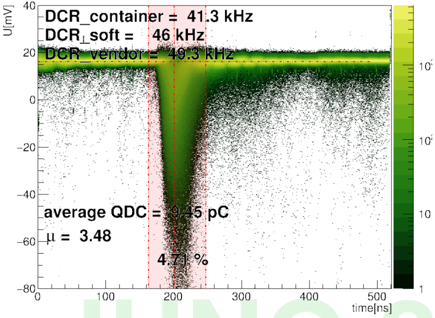


图: waeforms @$\mu \simeq 1$

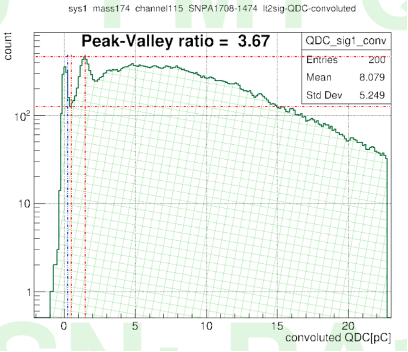


图: waeforms @$\mu \simeq 1$

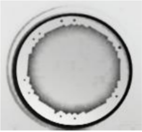
what we found

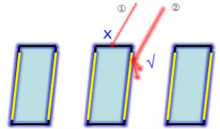
To conclude the above information, we find:

- The Gain of MCP-PMT is not stable enough, It has small propobilty to magnify single p.e to unreasonable large charge.
- the charge of ”big signals” is proportional to incident light.the more incident phtons, the more ”bgi signals”. So, the charge of ”bigsignals” is closely related to the light intensty rather and a fix 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.



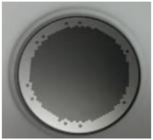


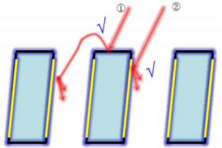
CE = 70%

The p.e. into the channel directly ~70%

change

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 ......





CE = 100%

The p.e. into the channel directly ~70%
The p.e. from the electrod indirectly ~ 30%

new response moddel with cross-talk effect

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

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

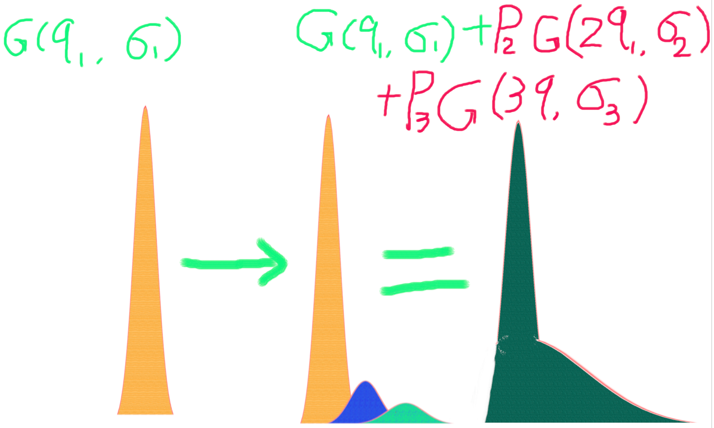
A simple cross-talk model: Suppose for a single p.e it could be magnified with gain=$g_1, 2\times g_1, 3\times g_1$, the corresponding possibility are p1,p2,p3,we could modify the above singnal model to:

$$
S_{idel} = P(n;\mu) \otimes G_n(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} [\frac{1}{\sigma_1\sqrt{2\pi n}} exp(-\frac{(x-nQ_1)^2}{2n\sigma_1^2})
$$

$$
+p2 * \frac{1}{\sigma_2\sqrt{2\pi n}} exp(-\frac{(x-2nQ_1)^2}{2n\sigma_2^2}) + p3 * \frac{1}{\sigma_3\sqrt{2\pi n}} exp(-\frac{(x-3nQ_1)^2}{2n\sigma_1^3})] \tag{2}
$$

the expected photon number

P_2 is the propobility of "2p.e." cross-talk event,P_3 is the propobility of "3p.e." cross-talk event.



fit example

Using the same model to fit charge spectrum of two types of PMTs, we can see the difference clearly.

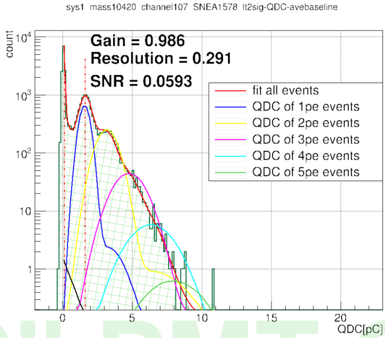


图: HAMAMATSU PMT

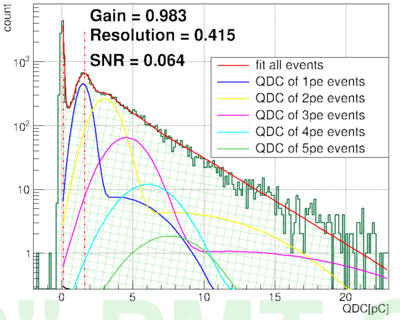


图: MCP PMT

fitting results

distribution of parameter P_2, P_3

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

图: input data

results of cnn

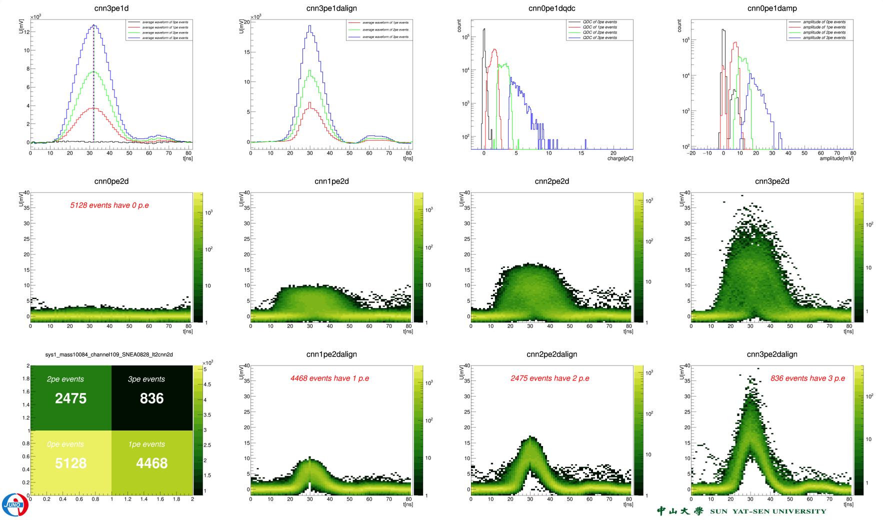


图: HAMAMATSU PMT

results of cnn

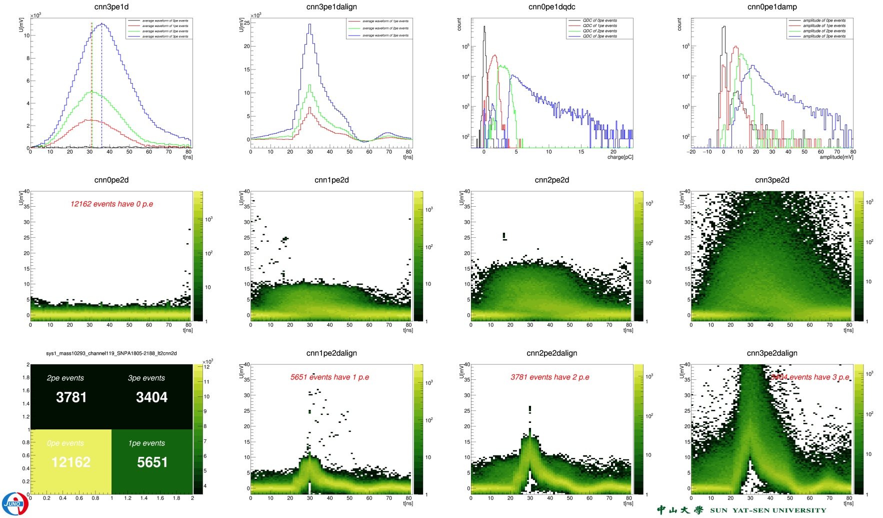


图: NNVT PMT

summary

- PSD by CNN provide a new option for PDE evaluation.
- can achieve *sim*0.95 acuuracy 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