

# Afterpulse Results Update

Email: zhaor25@mail2.sysu.edu.cn

School of Physics



中山大學  
SUN YAT-SEN UNIVERSITY



# Outline

① Brief Introduction

② new response model of MCP

③ Performance of the model

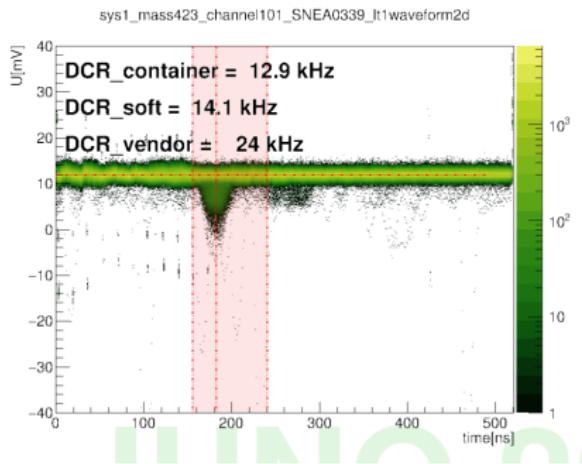
④ Summary

# 20 inch PMT

0. current state and strategies for AP test ,file size
1. two sections: HAM and MCP
2. 2D hist; time interval , rise time position distribution
3. DCR spectrum, DCR reduction
4. consistent with different light intensity?
5. details about the AP analysis.

## the "big signals" of MCP PMT

The typical waveforms<sup>1</sup> of MCP PMT, compared with dynode PMT.



## 图: waveforms of HAMAMATSU PMT

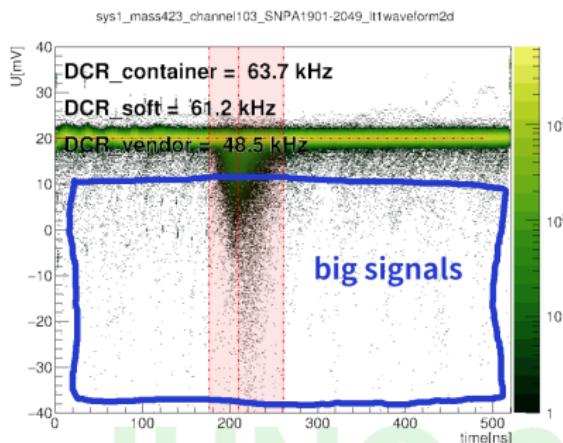


图: waveforms of MCP PMT

<sup>1</sup>gain= 1E7,  $\mu \simeq 0.1$

# the "big signals" of MCP PMT

The "long tail" in charge spectrum<sup>2</sup> of MCP PMT, compared with dynode PMT.

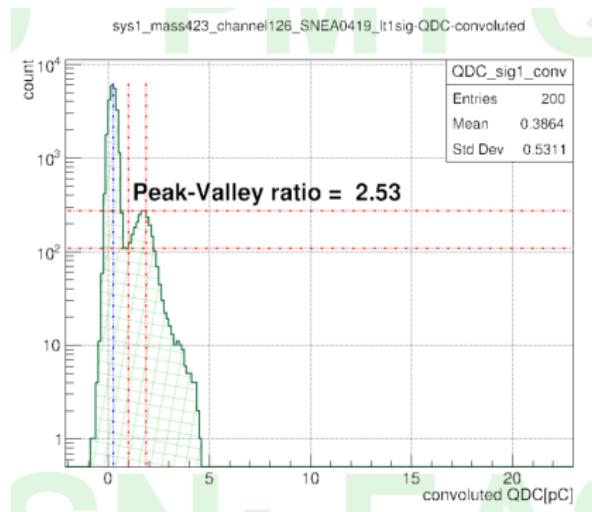


图: SPE of HAMAMATSU PMT

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

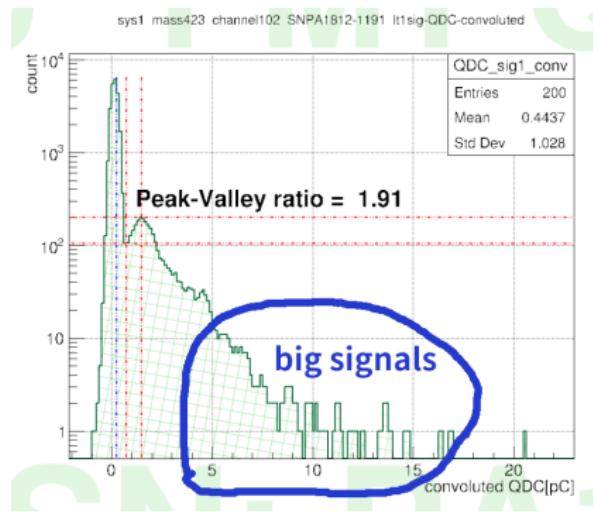


图: SPE of MCP PMT

# 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:

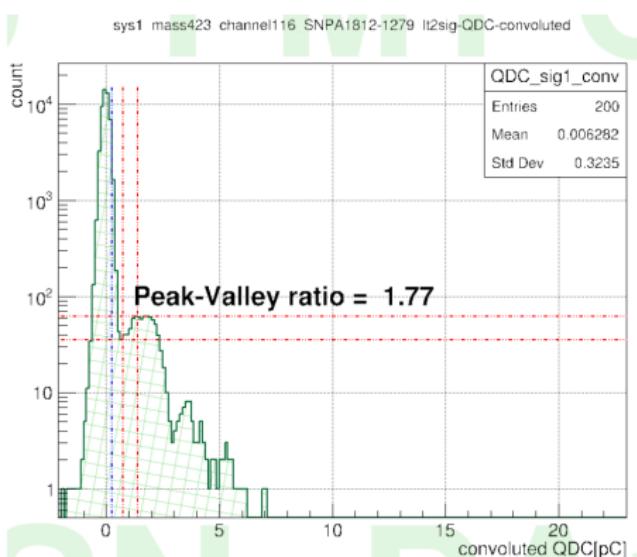
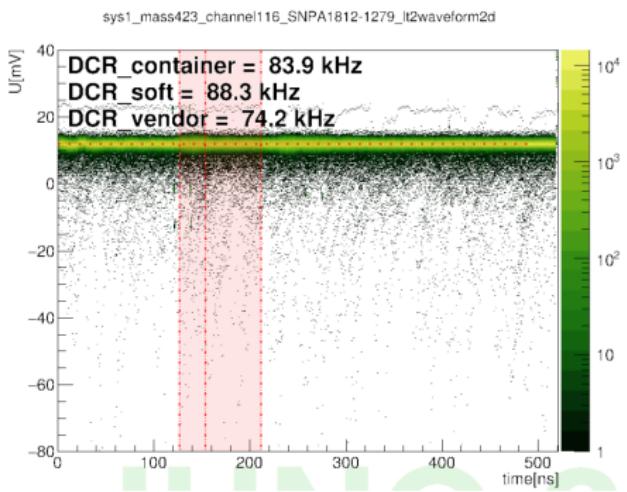
- ① dark noise mode [no light incident]
- ② non-trigger window @1 p.e
- ③  $\mu \simeq 0.1$  p.e
- ④  $\mu \simeq 1$  p.e
- ⑤  $\mu = \text{multi-p.e}$  [by laser]

# photon response characters of MCP PMT

case 1:[dark noise]

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

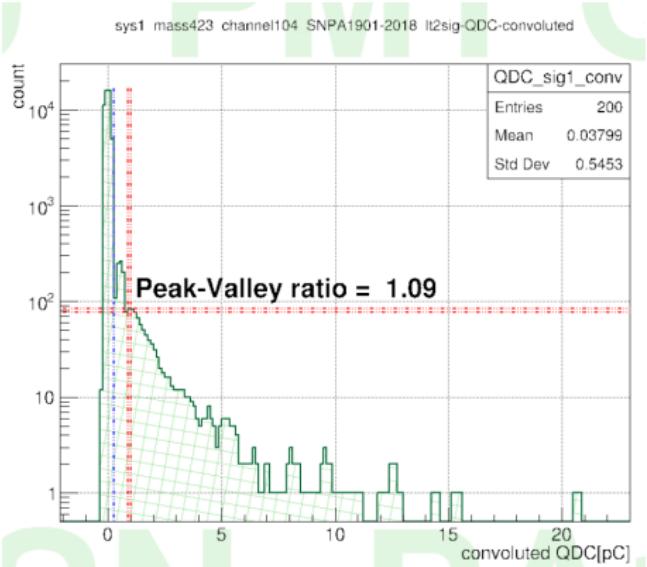
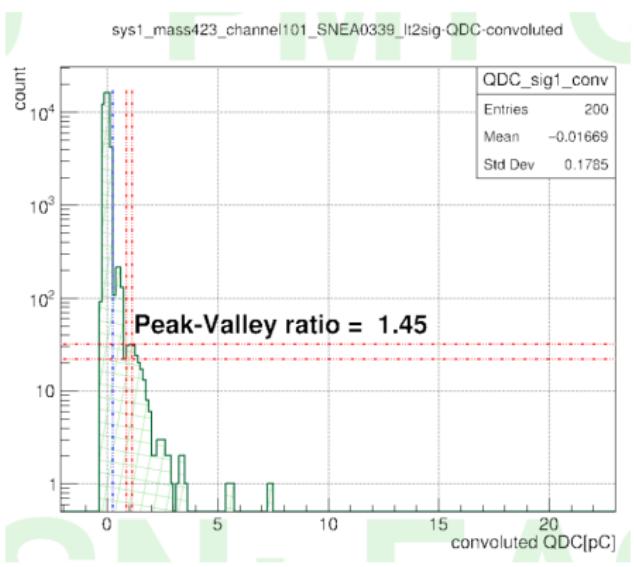
If we suppose all the dark counts is caused by single thermal electron, then those fake multi-p.e events are caused by the magnification of MCP.



# 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.

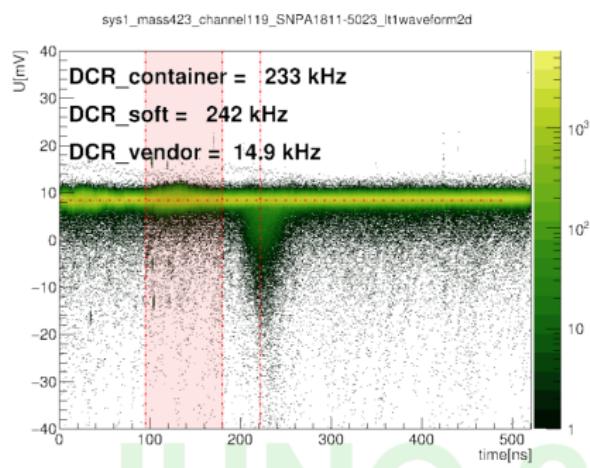


图: select non-trigger ROI

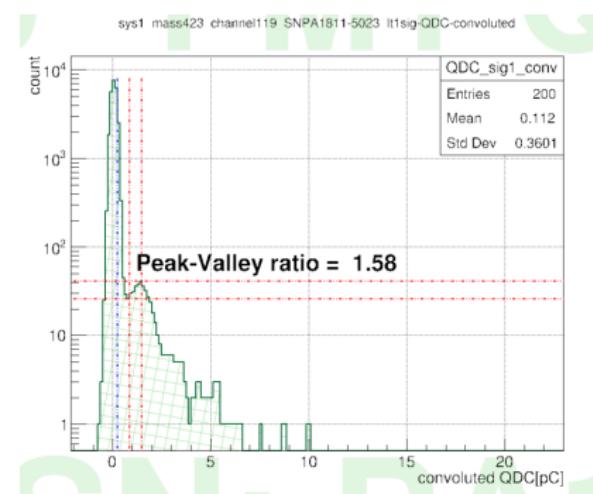


图: QDC of non-trigger ROI

# 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.

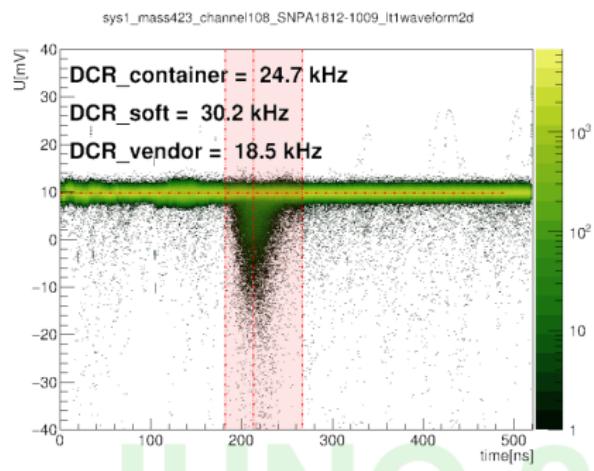


图: waeforms @  $\mu \simeq 0.1$

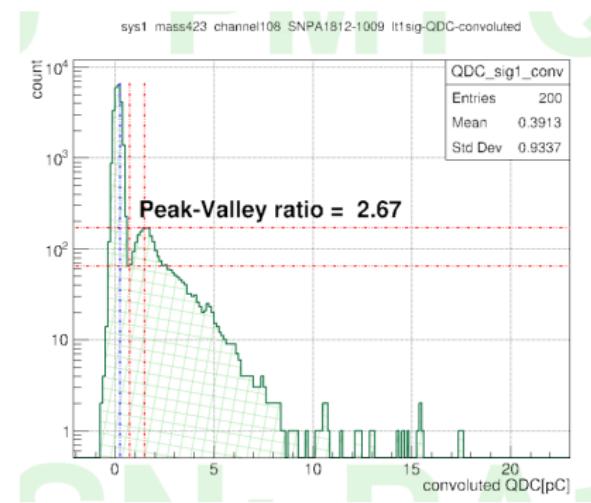
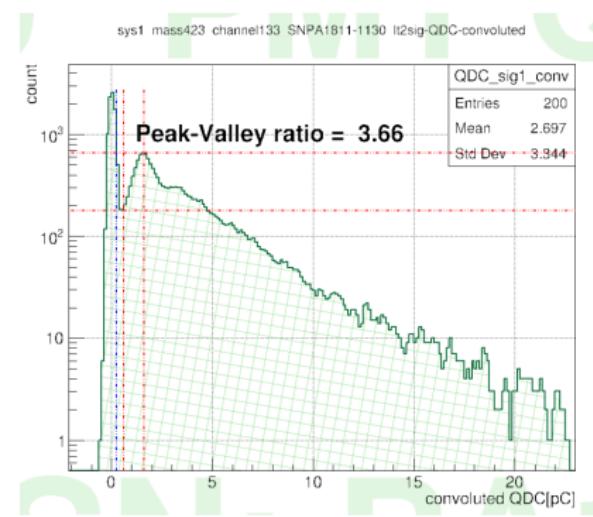
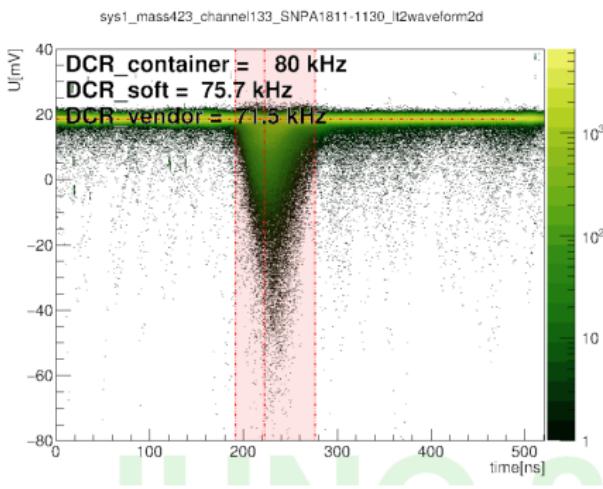


图: QDC @  $\mu \simeq 0.1$

# 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  $> 15p.e.$

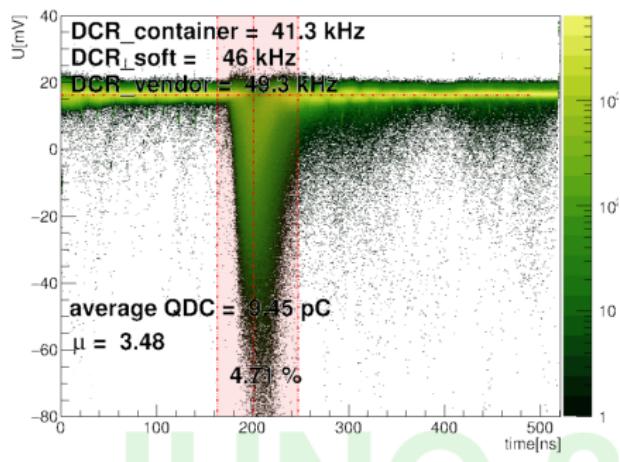


图: waforms @  $\mu \simeq 1$

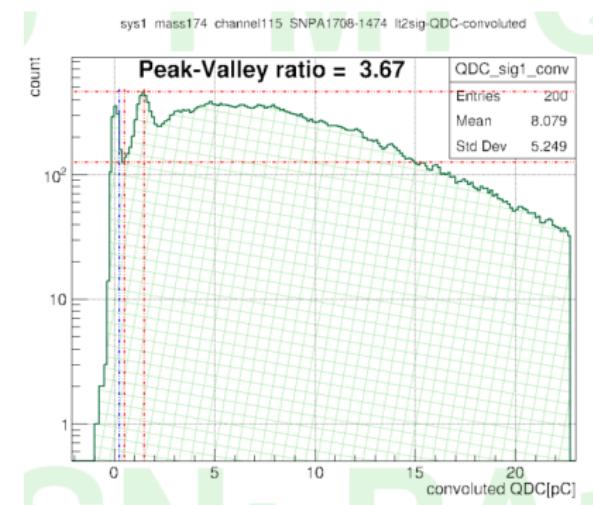


图: waforms @  $\mu \simeq 1$

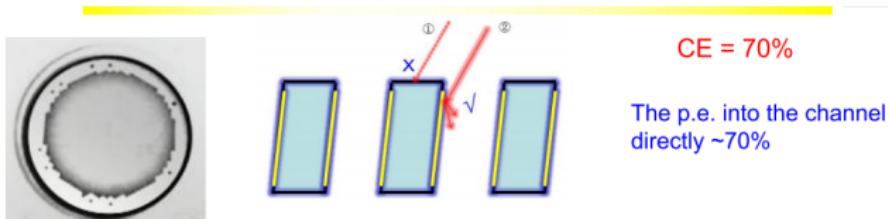
# what we found

To conclude the above information, we find:

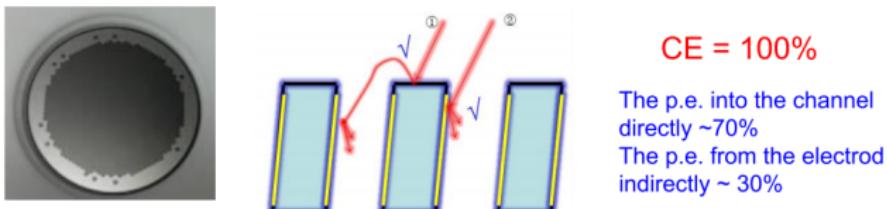
- The Gain of MCP-PMT is not stable enough, It has small probability to magnify single p.e to unreasonable large charge.
- the charge of "big signals" is proportional to incident light. the more incident photons, the more "big signals". So, the charge of "big signals" is closely related to the light intensity rather than a fixed charge sum.
- The "big signals" are slightly delayed(about several ns) in time.
- Compared with HAMAMATSU PMT, the "big signal" of MCP PMT have no obvious physical meaning and need to be handled carefully.

# 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:

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

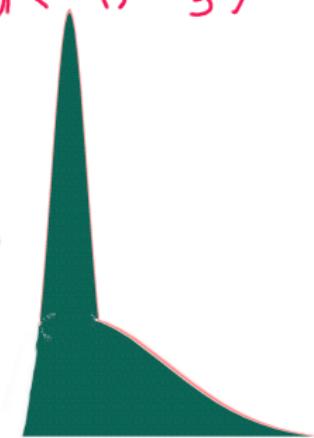
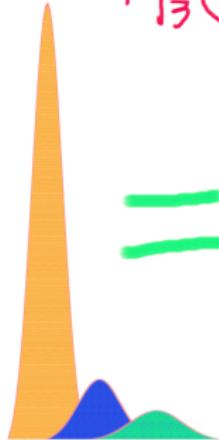
# the expected photon number

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

$$G(q_1, \sigma_1)$$



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



# fit example

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

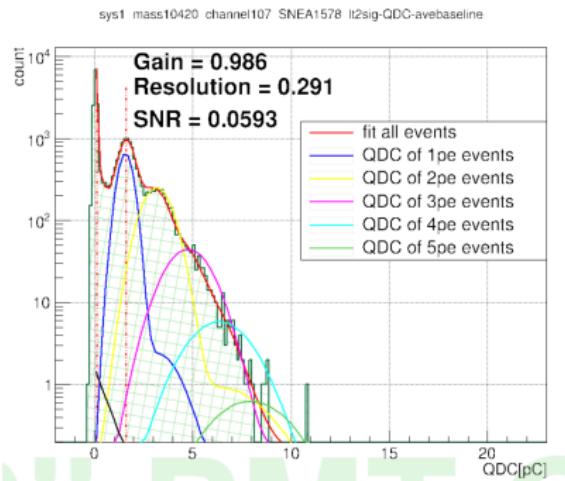


图: HAMAMATSU PMT

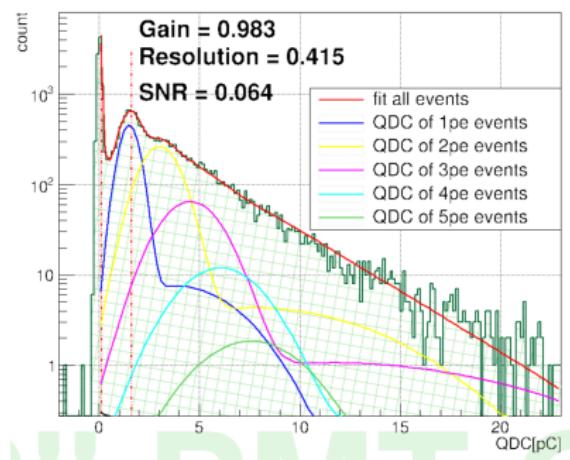


图: MCP PMT

# fitting results

distribution of parameter  $P_2, P_3$

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

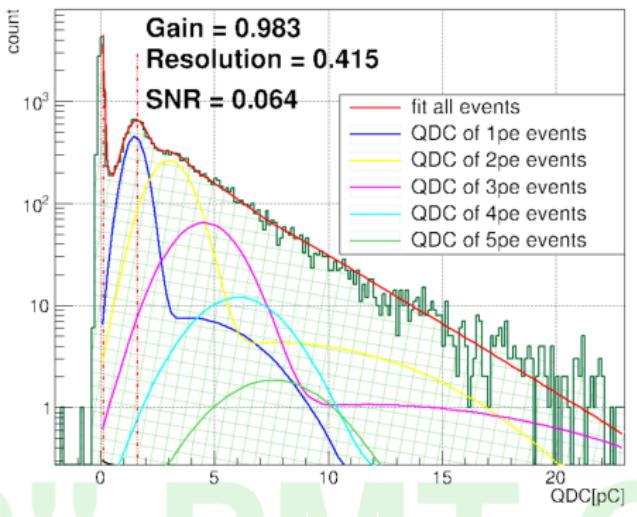


图: input data

# "cross-talk" coefficient

If one photon was magnified with two or times of the normal gain, the output signal can not be distinguished with the two photons event; this is really a bad news to PMT.

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we define a parameter  $\delta$  to describe the proportion of "cross-talk" signal as:

$$\begin{aligned}\delta &= \frac{\alpha}{1 + \alpha} \\ &= \frac{2 \times P_2 + 3 \times P_3}{1 + 2 \times P_2 + 3 \times P_3}\end{aligned}\tag{3}$$

where  $\alpha = 2 \times P_2 + 3 \times P_3$  is the total number of unreasonable events.

# distribution of $\delta$

## summary

- the cross-talk signal proportion of MCP PMT is about....
- can achieve *sim0.95* accuracy 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