

## Performance of CNN in PMT PDE Evaluation

– based on the onsite PMT testing data

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## Outline

## ① Brief Introduction

## ② Waveform and Charge Spectrum

### ③ Statistical Sesults of Parameters

## ④ Summary

# traditional methods of PDE evaluation

Calculate the expected p.e by "cut" or "fitting" of charge spectrum.

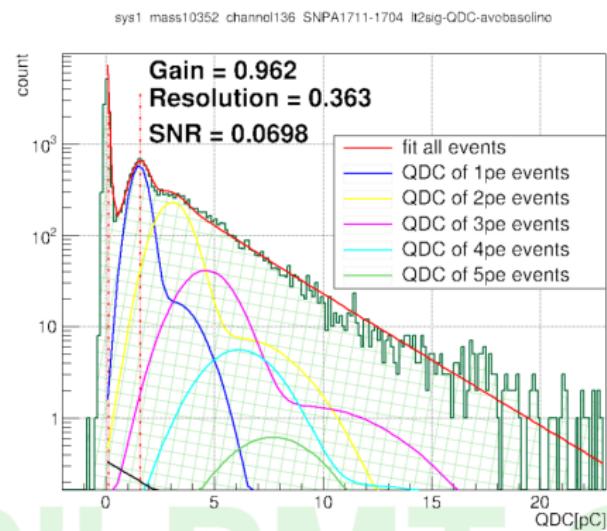
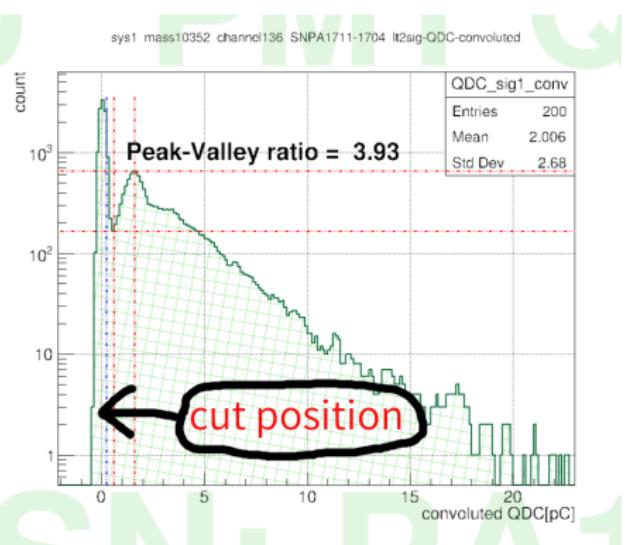


图: "cut" the charge spectrum to count pedestal events

图: fit using a PMT photon response model

## waveform classification using CNN

CNN can perform a powerful PSD and classify the waveforms, then we could get explicit p.e during one test.

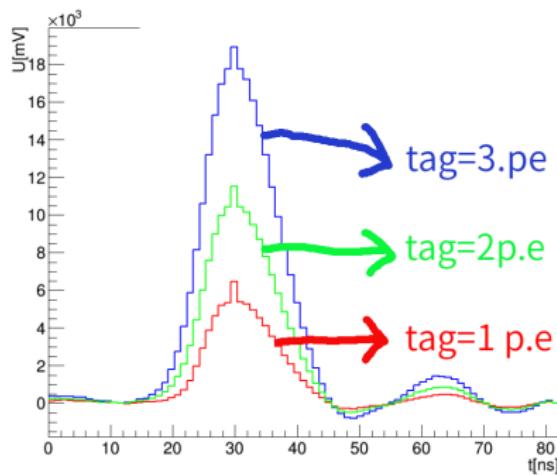
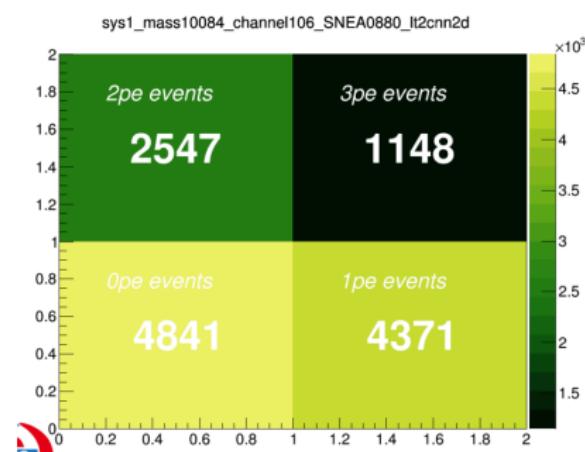


图: tags of typical waveform from CNN



## 图: classification of events in one test

# the expected photon number

If we do a "cut" is the charge spectrum@0.25 spe, the averager photon number  $\mu$  can be acquired by<sup>1</sup>

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

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

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However, if we know explicitly the photon number of specific event, the  $\mu$  value is :

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

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<sup>1</sup>E. H. Bellamy et al /Nucl. Instr. and Meth. m Phys . Res. A 339 (1994) 468-476

PMT testing report-pass

We have generated testing report for each qualified PMT.

QUALIFICATION TEST REPORT OF 20 INCH PMT								
Test Information:								
Test Date	Container#	Mass#	Drawer#	Mu	HV vendor	HV container	Gain	Sheet #
20171010	1	25	111	0.88	1670	1670	1.01	0
Parameters of Performance:								
Par	Value	Tag	Par	Value	Tag			
PDE[%]	27.27	√	Ristime[ns]	7.63	√			
DCR[kHz]	10.25	√	Falltime[ns]	10.50	√			
PV	3.23	√	FWHM[ns]	9.29	√			
TTS[ns]			SNR	0.06	√			
AP[%]			Resolution	0.28	√			
Test History and Notes:								
<b>This PMT was retested due to PDE problem , and then passed the test.</b>								
zhaor25@mail2.sysu.edu.cn								
Final Qualification Tag								
PASS								

# Output waveforms of PMT @Gain = $10^7$

The 2-D waveform histogram contains all the recorded waveforms, we can clearly see the "delayed signals" of HAMMATSU PMT and "big signals" of NNVT PMTs.

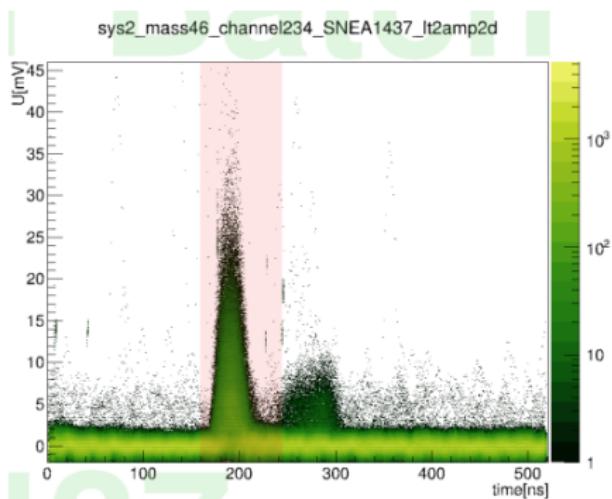


图: all frames of HAMAMATSU PMT

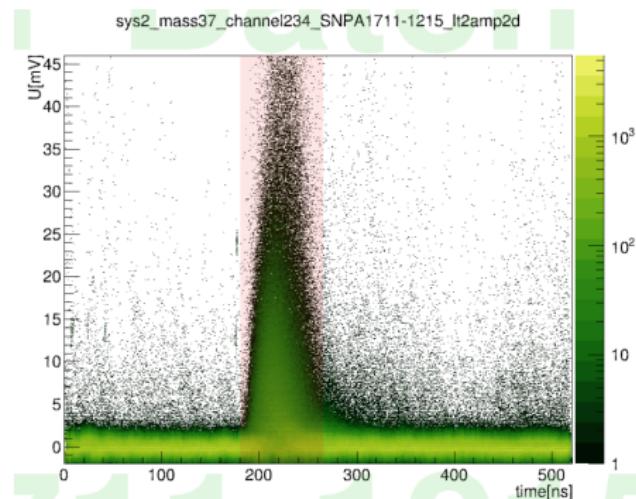
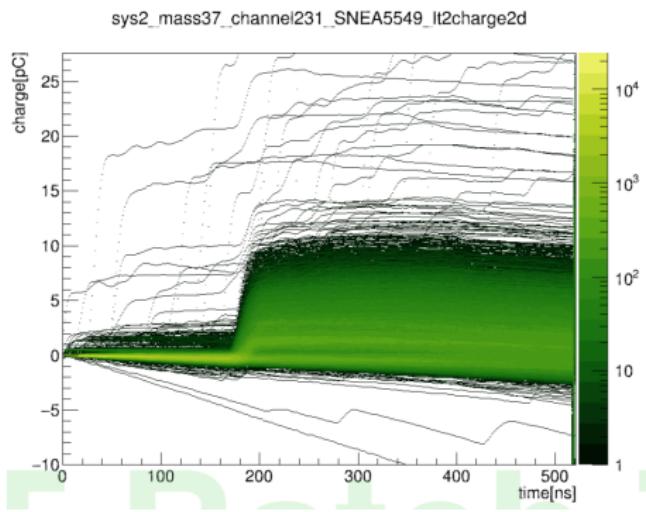


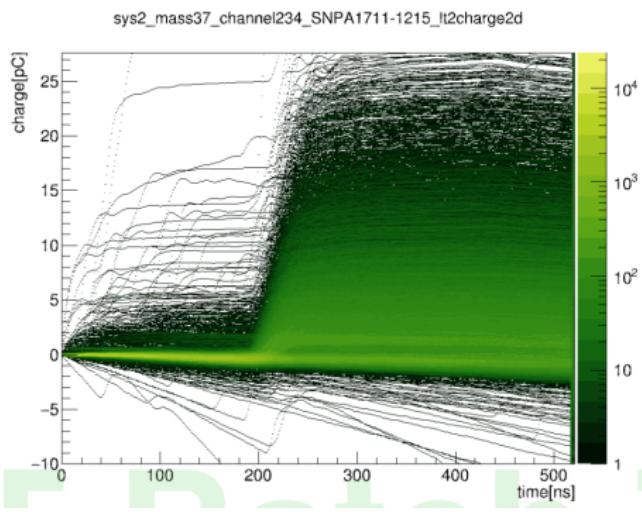
图: all frames of NNVT PMT

## Output integrated waveforms of PMT(@ $gain = 10^7$ )

From the waveform integral histogram we acquire more information.



 integrated waveforms of HAMAMATSU PMT



## 图: integrated waveforms of NNVT PMT

# Amplitude spectrum (@ $gain = 10^7$ & $\mu \simeq 1.3$ )

Signal amplitude stability of NNVT PMT is worse than HAMAMATSU PMT.

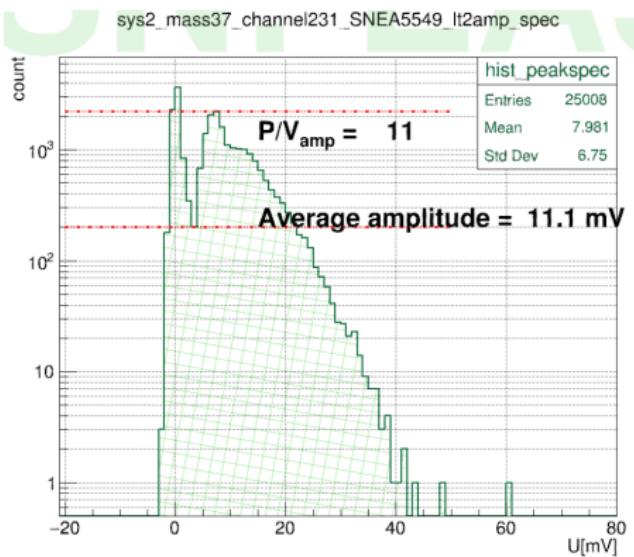


图: Amplitude spectrum of HAMAMATSU PMT

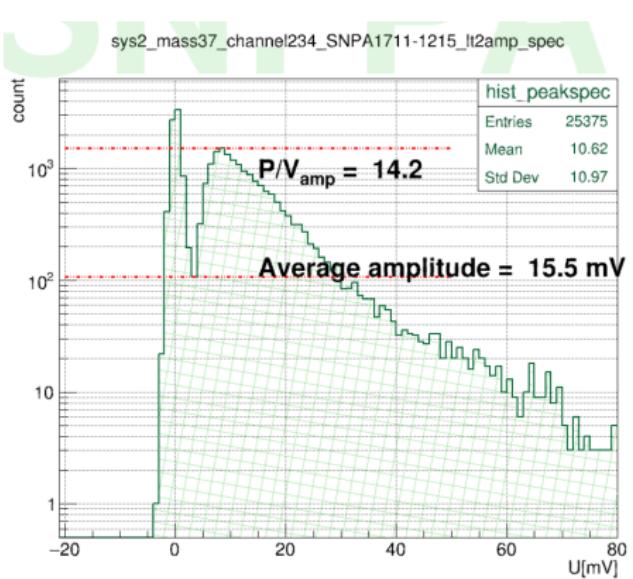
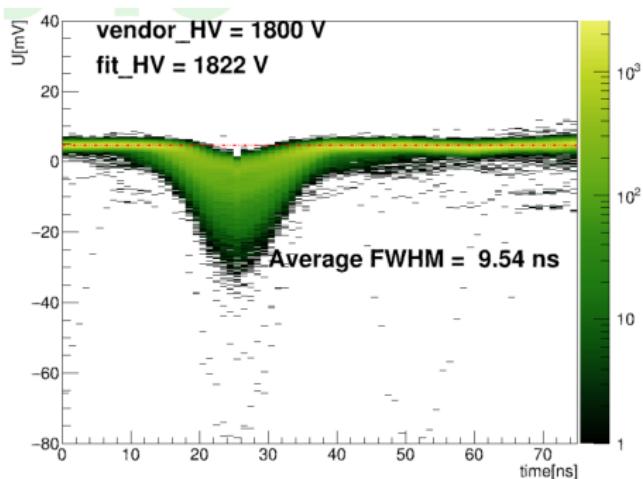


图: Amplitude spectrum of NNVT PMT

## Aligned waveforms (@ $gain = 10^7$ & $\mu \approx 1.3$ )

Aligning all signals according to their maximum: signal profile of HAMAMATSU PMT have better symmetry.



## 图: Aligned frames of HAMAMATSU PMT

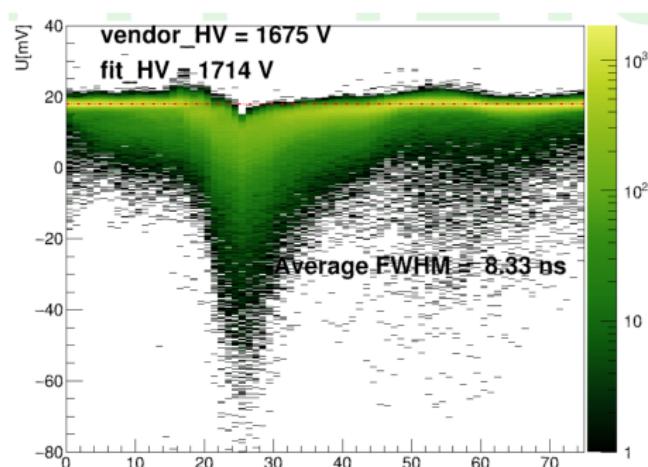


图: Aligned frames of NNVT PMT

# Average waveform (@gain = $10^7$ & $\mu \simeq 1.3$ )

The average waveform of NNVT PMT has faster rising edge and lower falling edge.

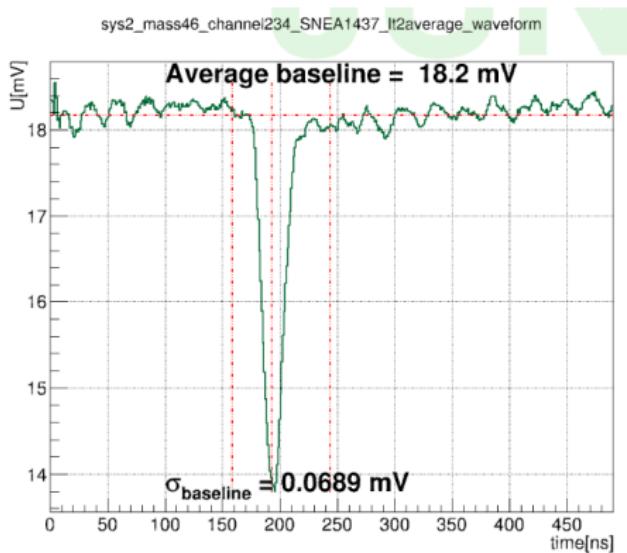


图: average waveform of HAMAMATSU PMT

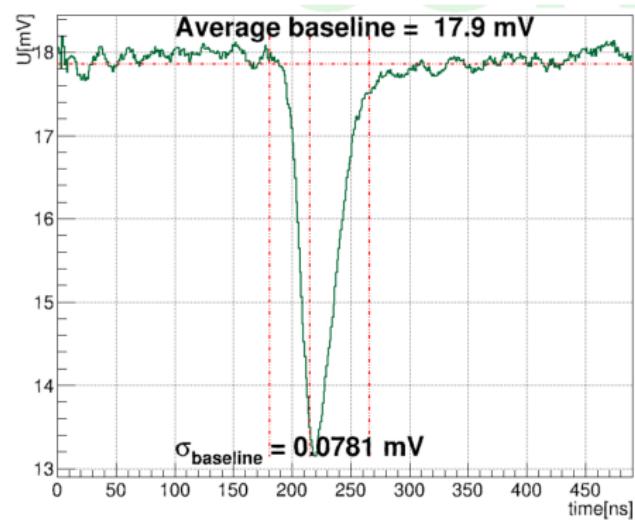


图: average waveform of NNVT PMT

# Signal hit time distribution

The hittime response of NNVT PMT is about 20ns slower than the HAMAMATSU PMT.

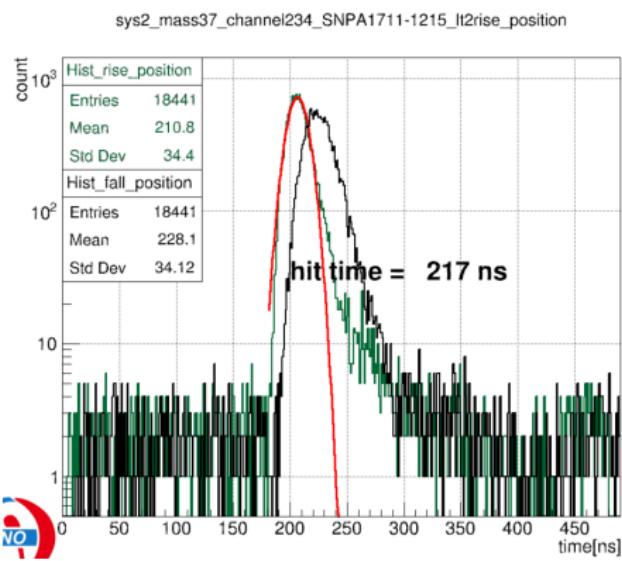
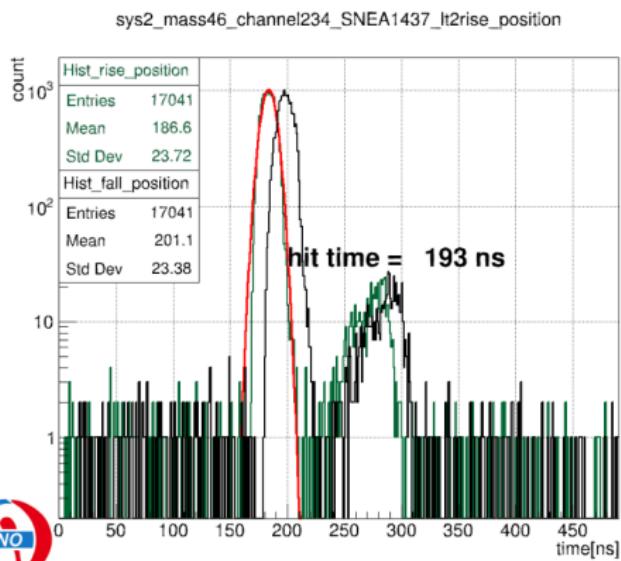


图: hit time of HAMAMATSU PMT

图: hit time of NNVT PMT

# charge and amplitude (@ $gain = 10^7$ & $\mu \simeq 1.3$ )

amplitudes and charge intergrals of NNVT PMT is not as stable as HAMAMATSU PMT.

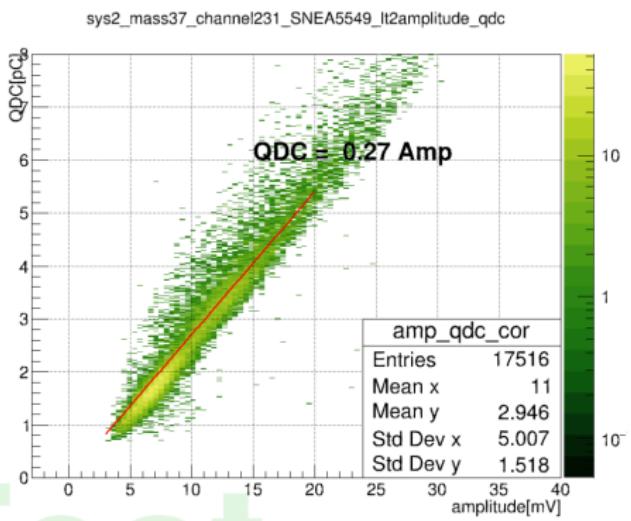


图: charge and amplitude correlation of HAMAMATSU PMT

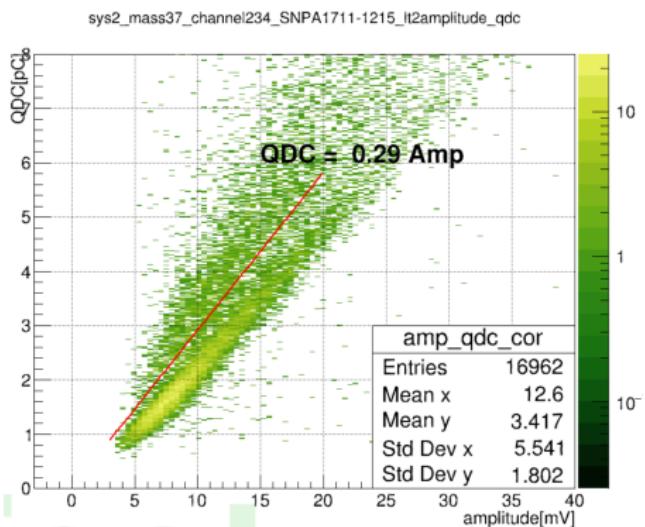


图: charge and amplitude correlation of NNVT PMT

# rise-time and fall-time (@gain = $10^7$ & $\mu \simeq 1.3$ )

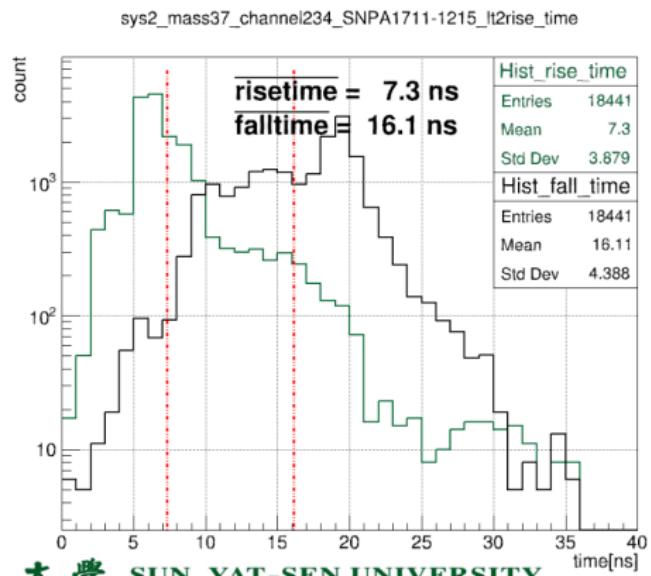
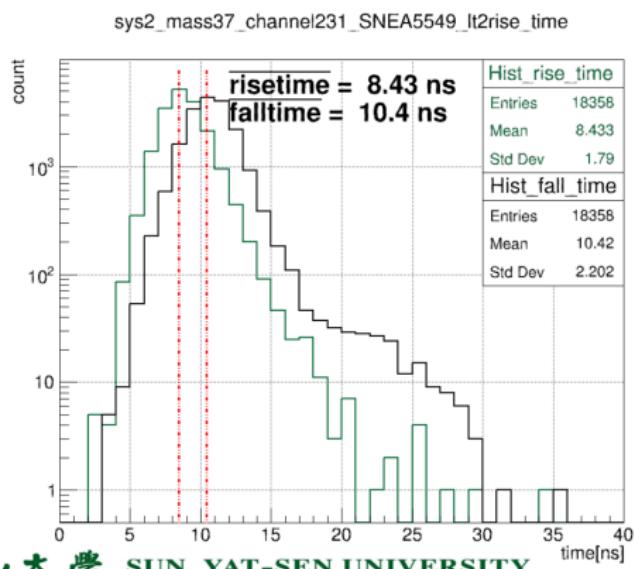
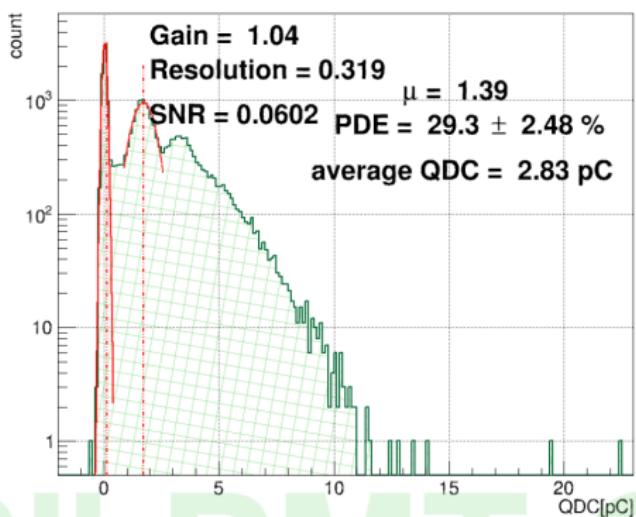


图: rise-time and fall-time of HAMAMATSU PMT

图: rise-time and fall-time of NNTV PMT

# Signal charge spectrum(@ $gain = 10^7 \& \mu \simeq 1.3$ )

sys2\_mass20037\_channel231\_SNPA5549\_lt2sig-QDC-avebaseline



sys2\_mass20037\_channel234\_SNPA1711-1215\_lt2sig-QDC-avebaseline

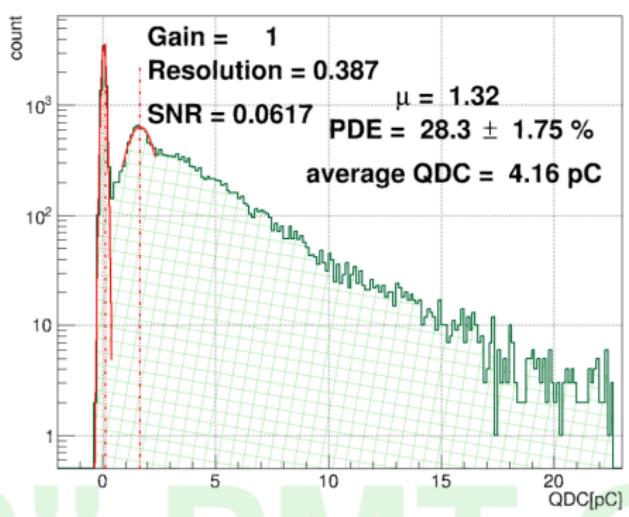


图: signal charge spectrum of HAMAMATSU PMT

图: rise-time and fall-time of NNVT PMT

# calculation of parameters

## signal waveform

- $\text{rise time} = t_{.9r\text{Maximum}} - t_{.1r\text{Maximum}}$
- $\text{fall time} = t_{.1f\text{Maximum}} - t_{.9f\text{Maximum}}$
- $\text{FWHM} = t_{+1/2\text{Maximum}} - t_{-1/2\text{Maximum}}$

## charge spectrum

- $\text{Gain} = \frac{Q_{1pe} - Q_{0pe}}{Q_e}$
- $\text{PV} = \frac{\text{Peak}_{spe}}{\text{Valley}_{spe}}$
- $S/N = \frac{\sigma_{0pe}}{Q_{1pe} - Q_{0pe}}$
- $\text{Resolution} = \frac{\sigma_{1pe}}{Q_{1pe} - Q_{0pe}}$

# calculation of drawer<sub>factor</sub>

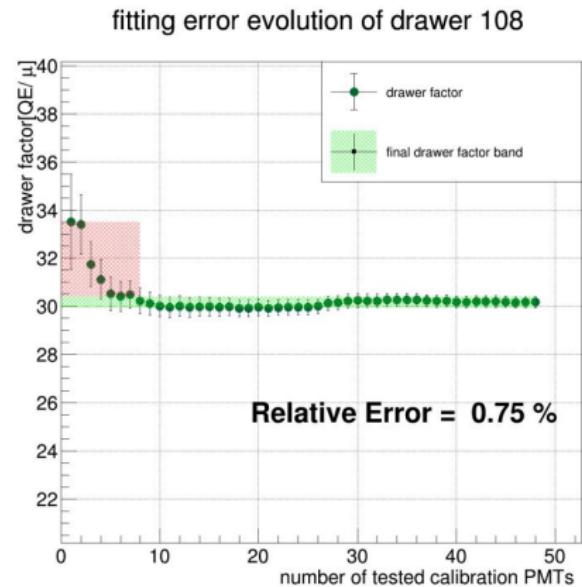
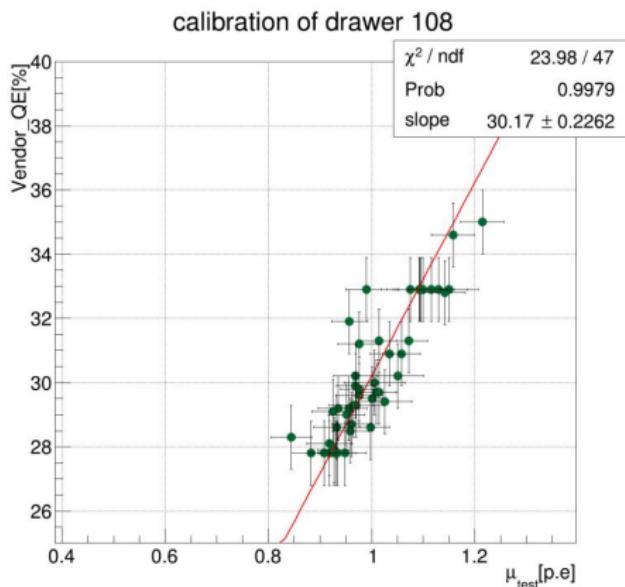


图: fitting the drawer factor in one drawer

## calculation of PDE

we can obtain the average photon number  $\mu_{test}$  from charge spectrum, along with the  $drawer_{factor}^2$ , the PDE result from container system is:

$$PDE_c = \mu_{test} \times drawer_{factor} \quad (3)$$

Then we map the PDE from container to the final PDE value with the help of container  $f_{cs}^3$ :

$$PDE = PDE_c \cdot f_{cs} + constant \quad (4)$$

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<sup>2</sup>Calibrate the drawer factor using PMT tested in the drawer which has vendor QE value.

<sup>3</sup>linear correlation factor

# statistical results

Mean value of parameters for HAMAMATSU-PMT and NNVT-PMT<sup>4</sup>:

parameters (mean)	HAMAMATSU	NNVT
DCR(kHz)	15.38	41.24
rise time(ns)	7.4	3.2
fall time(ns)	10.36	15.9
PV	3.39	3.19
resolution	0.28	0.35
HV@1E7(V)	1861	1783
FWHM(ns)	9.08	5.8

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<sup>4</sup>For the parameter TTS, we need to test the internal time resolution firstly, since we found the TTS results is highly drawer related.

# current PDE statistical results

For NNVT PMT, the new version High-QE tubes have higher PDE with mean value about 30.5%.

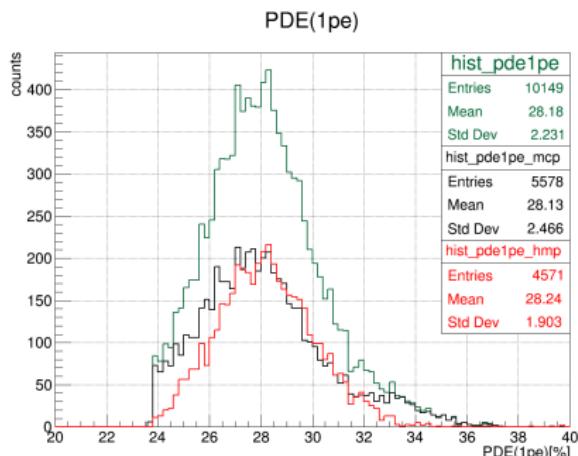


图: PDE of tested PMT

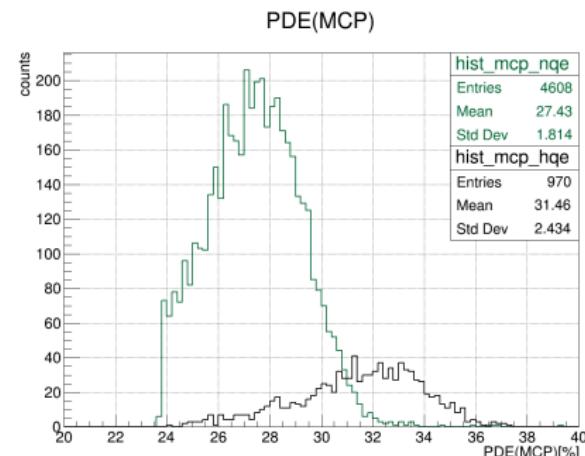


图: PDE of tested NNVT PMT

# predicted PDE statistical results

CD will use  $\sim 13k$  NNVT<sup>5</sup> PMT, and 5k HAMAMATSU PMT, we can predict the final PDE and DCR distribution based on the current data:

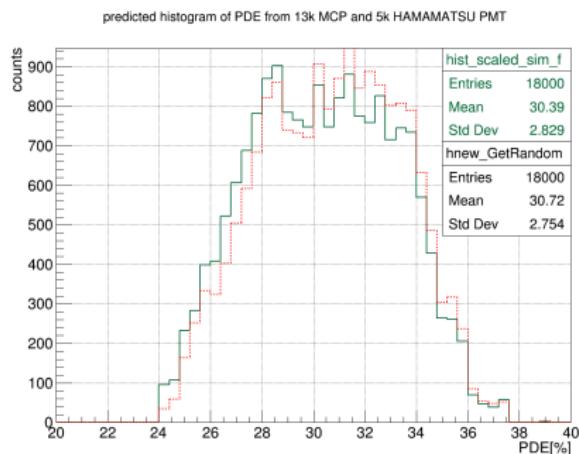


图: predicted PDE in CD

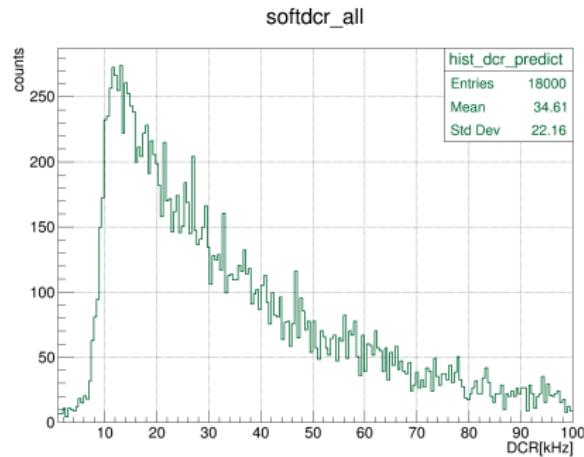


图: predicted DCR in CD

<sup>5</sup>with  $\sim 11k$  high QE PMT and 2k low QE PMT

# summary

- the charge and amplitude stability of HAMAMATSU PMT is better.
- ~6k NNVT PMTs and 5k HAMAMATSU PMTs has been tested in container system, test results and test reports are available from PMTDataBase<sup>6</sup>.
- we reject or accept one PMT according to its perfomance test results from container and scanning station.
- we need to study the "delay signal" of HAMAMATSU PMT and "big signal" of NNVT PMT<sup>7</sup> in detail<sup>8</sup>.
- the expected mean PDE value is 30.4% and mean DCR value is ~34kHz<sup>9</sup> in CD.

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<sup>6</sup>pmtdb.juno.ihep.ac.cn

<sup>7</sup>especially when PMT working in the multi-photon case

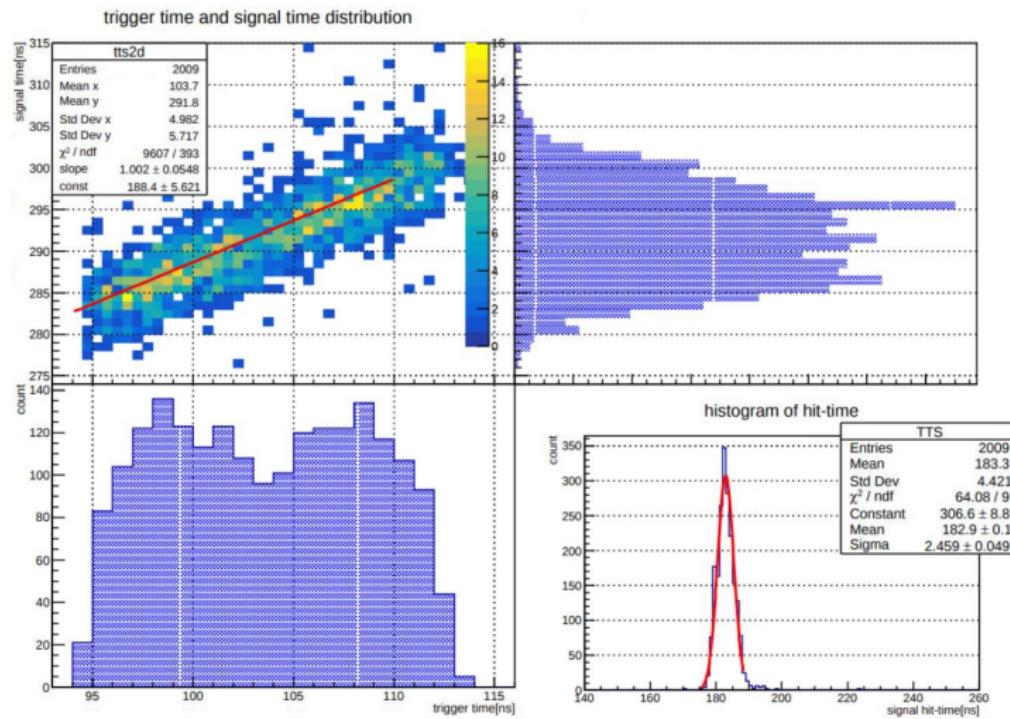
<sup>8</sup>one option is to transport several PMTs to SYSU for detailed study

<sup>9</sup>will decrease after installation

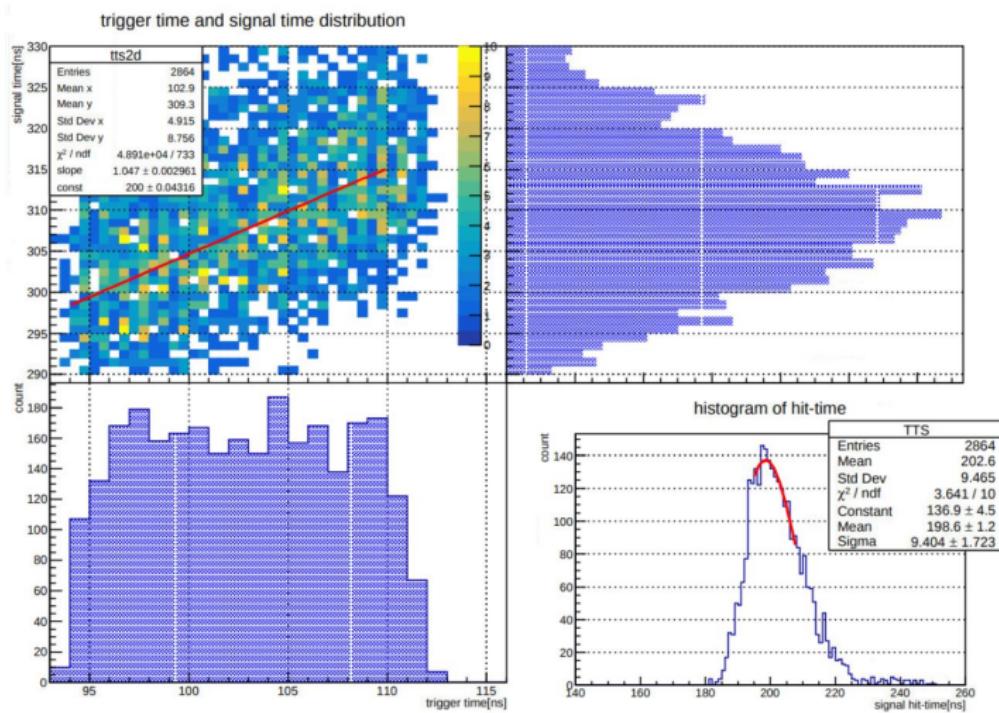
# THANKS

# BACK-UP

# TTS of HAMAMATSU PMT



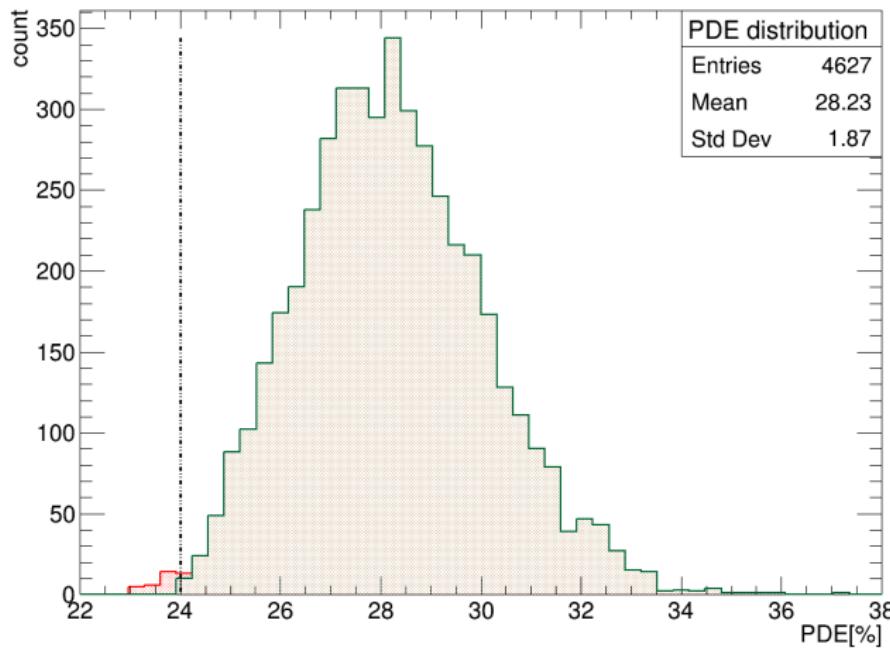
## TTS calculation of NNVT PMT



#### 图· hittime and trigger time

## 各个参数的统计结果-PDE

PDE Histogram of Qualified R12860 PMTs



# PDE 计算结果的初步对比

对所有测试的 PMT 的 PDE 和测试现场的分析结果进行对比，发现存在少数 PMT 差别较大，需要进一步查找原因。

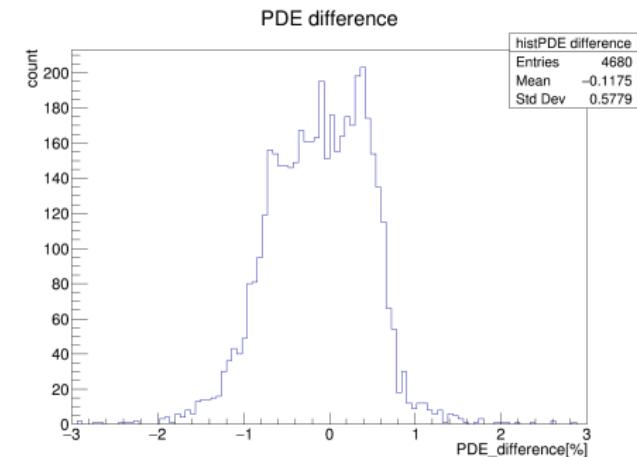
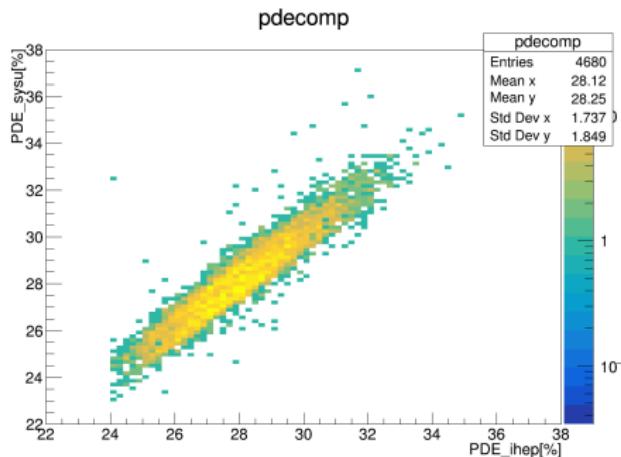
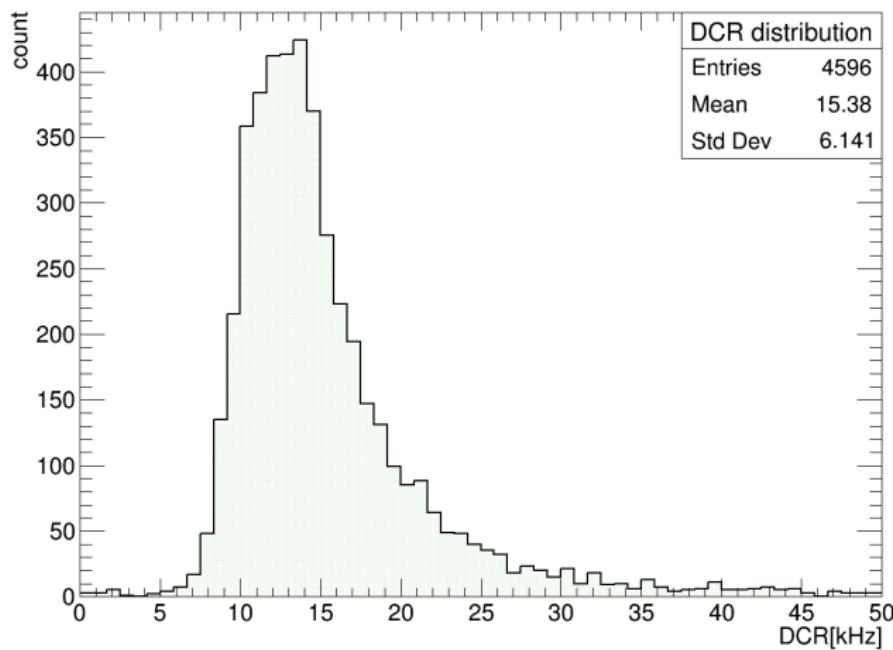


图: PDE 结果的关联对比

图: 两种分析的差值分布

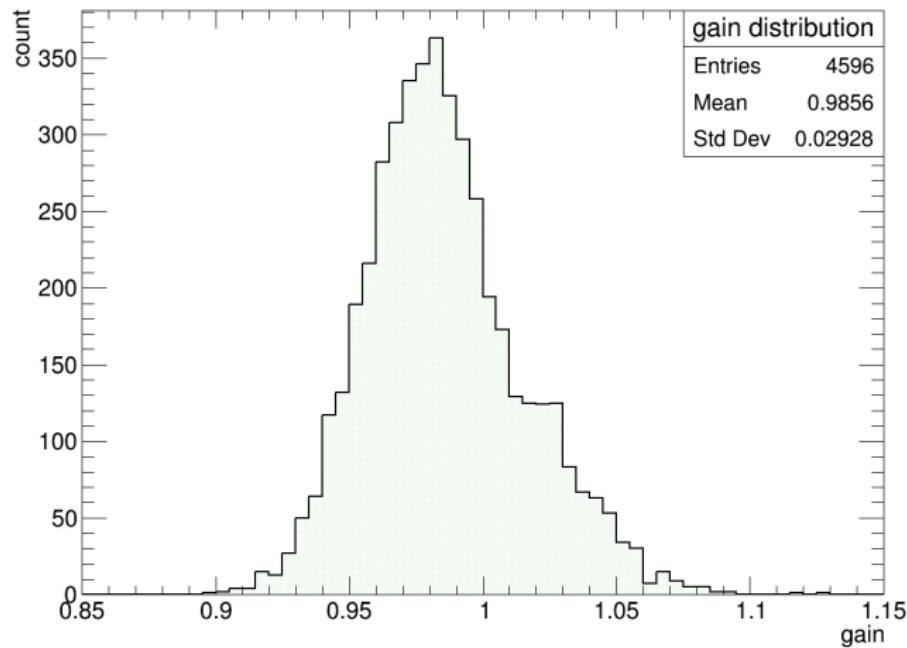
# 各个参数的统计结果-DCR

DCR Histogram of Qualified R12860 PMTs



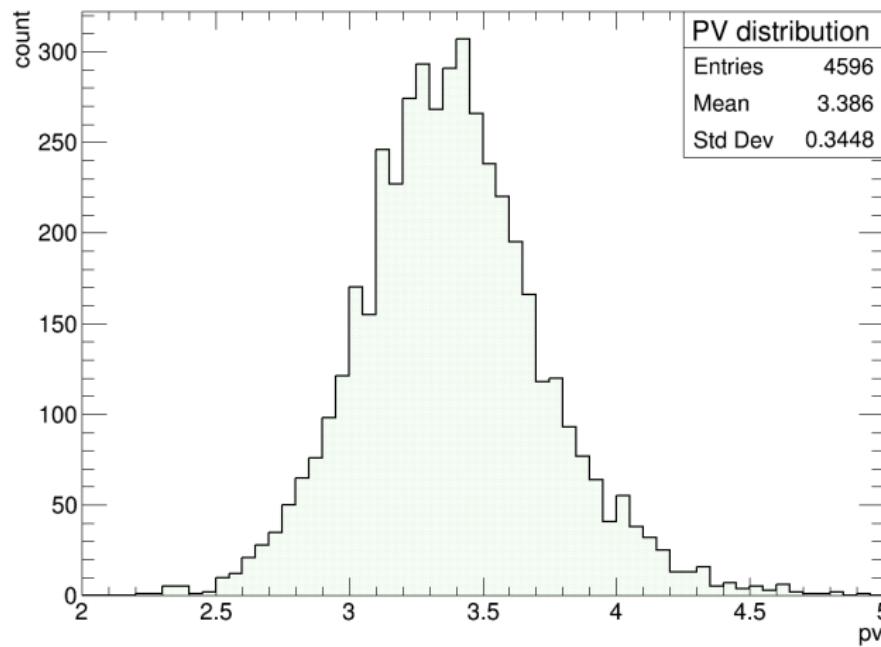
# 各个参数的统计结果-Gain

Gain Histogram of Qualified R12860 PMTs



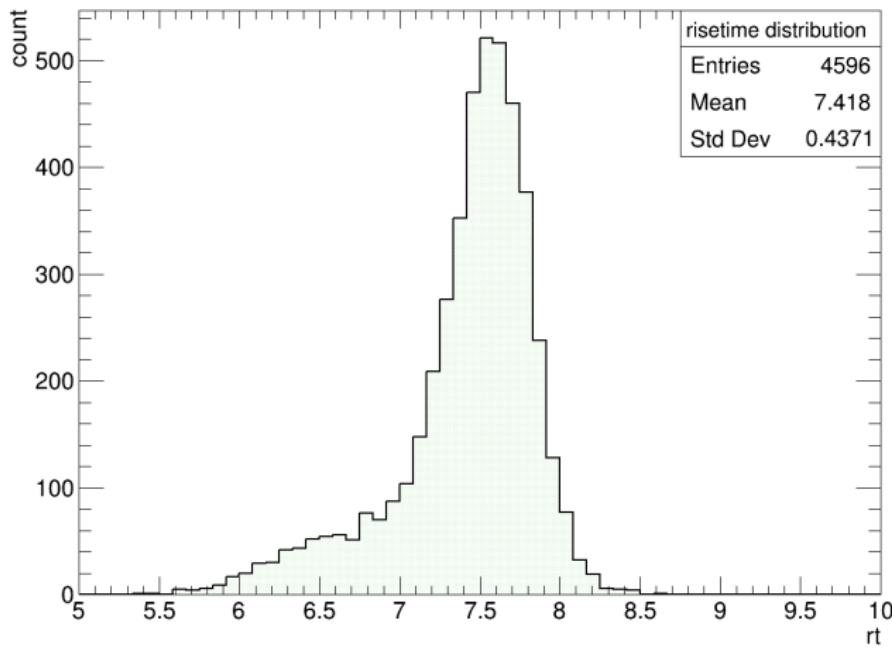
# 各个参数的统计结果-P/V

PV ratio Histogram of Qualified R12860 PMTs



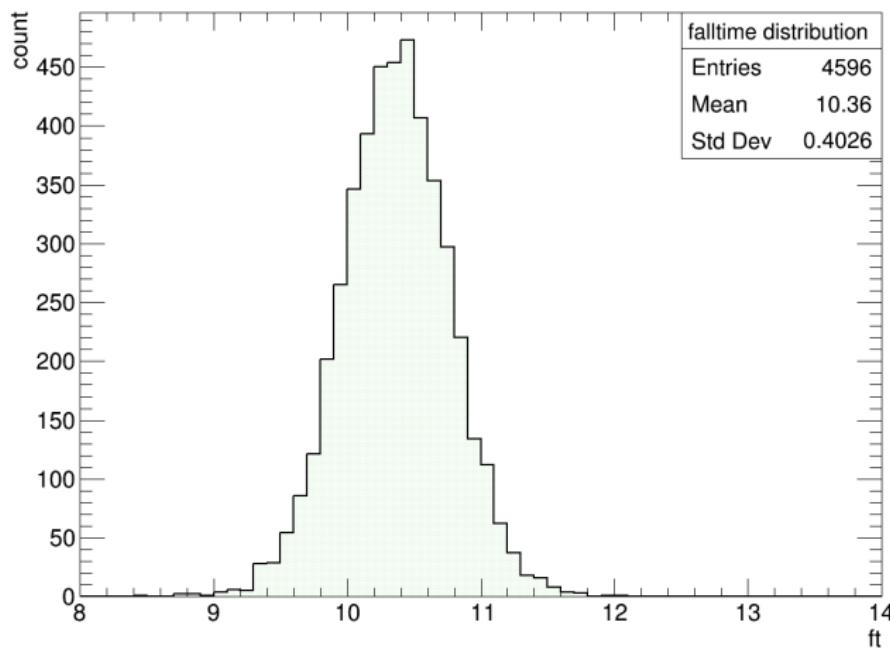
# 各个参数的统计结果-rise time

Risetime Histogram of Qualified R12860 PMTs



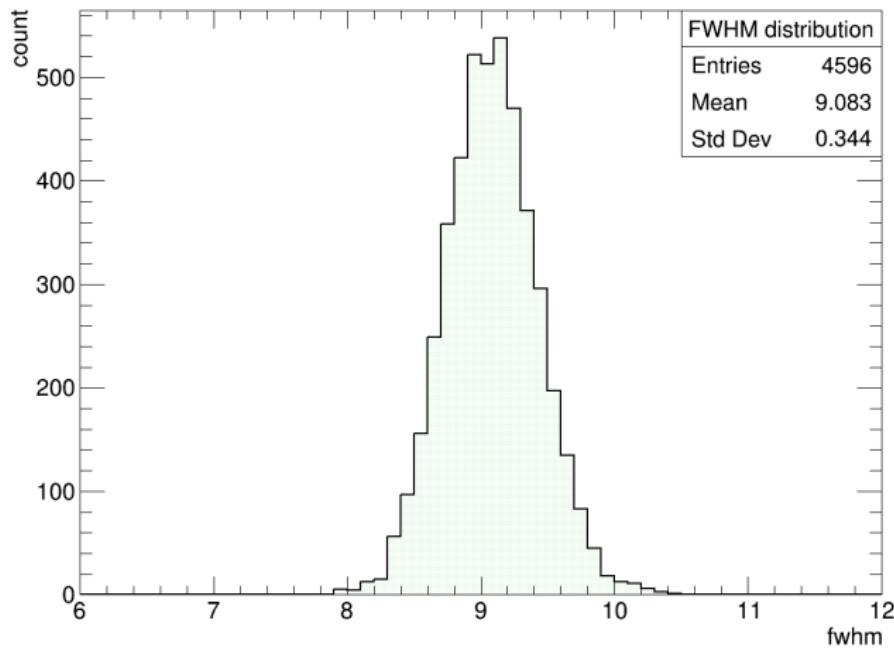
# 各个参数的统计结果-fall time

Falltime Histogram of Qualified R12860 PMTs



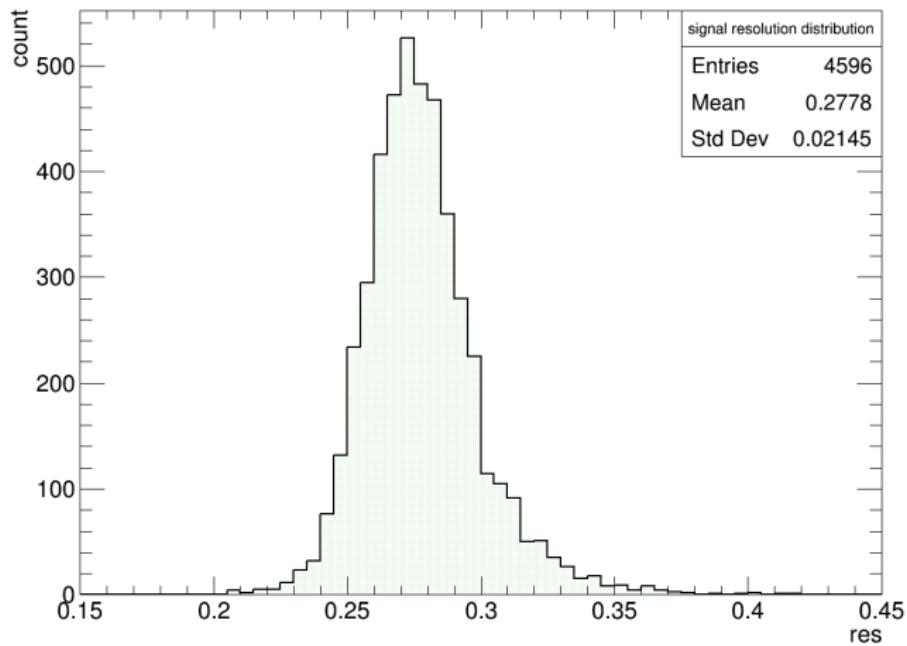
# 各个参数的统计结果-FWHM

FWHM Histogram of Qualified R12860 PMTs



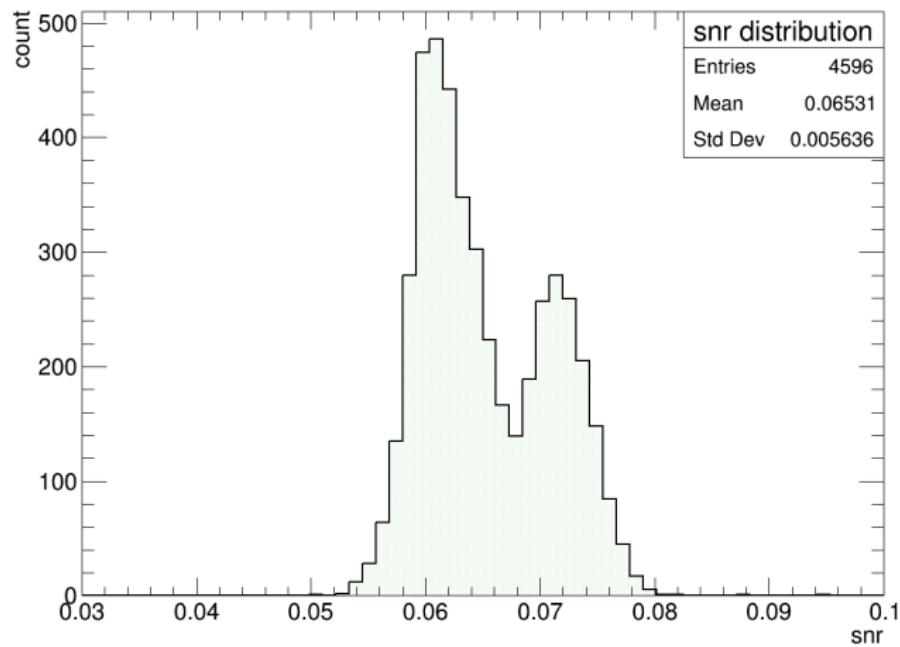
# 各个参数的统计结果-Resolution

Signal Resolution Histogram of Qualified R12860 PMTs



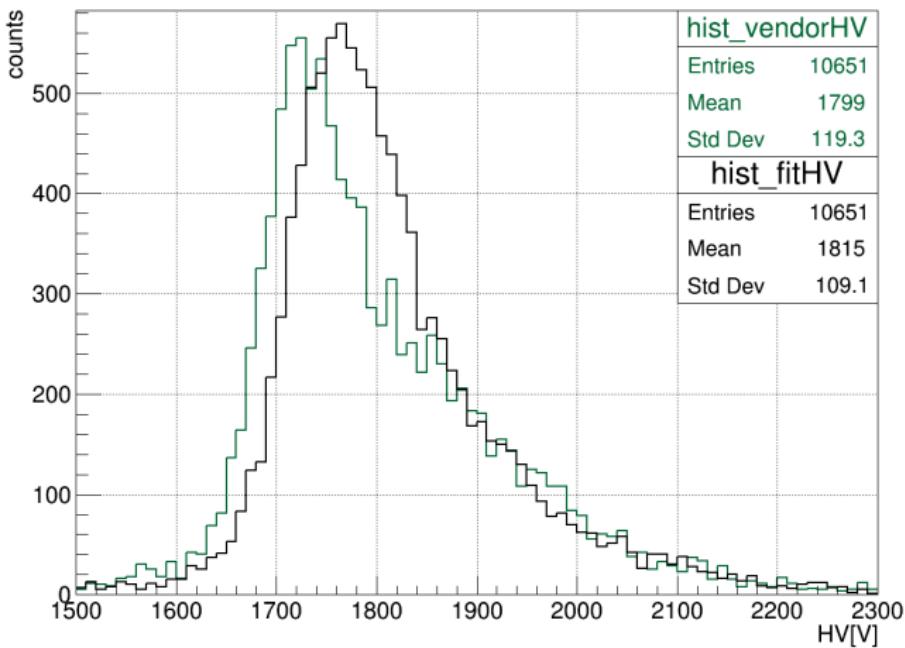
## 各个参数的统计结果-S/N

## SNR Histogram of Qualified R12860 PMTs



## 各个参数的统计结果-HV

vendor and fit HV of all PMT



# 抽屉因子的比较

factor\_1 是我的结果， factor\_2 是张海琼的结果。 $y = 1.148x + 0.998$

图：抽屉因子和现场使用值的对比

# 参考管稳定性

# 参考管电压稳定性

新DAQ对系统的性能产生了影响，高压平均值发生了变化：

# 暗计数

# 上升时间和下降时间分布