Check on the features of potted 20-inch PMTs with 1F3 electronics prototype at Pan-Asia

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IHEP

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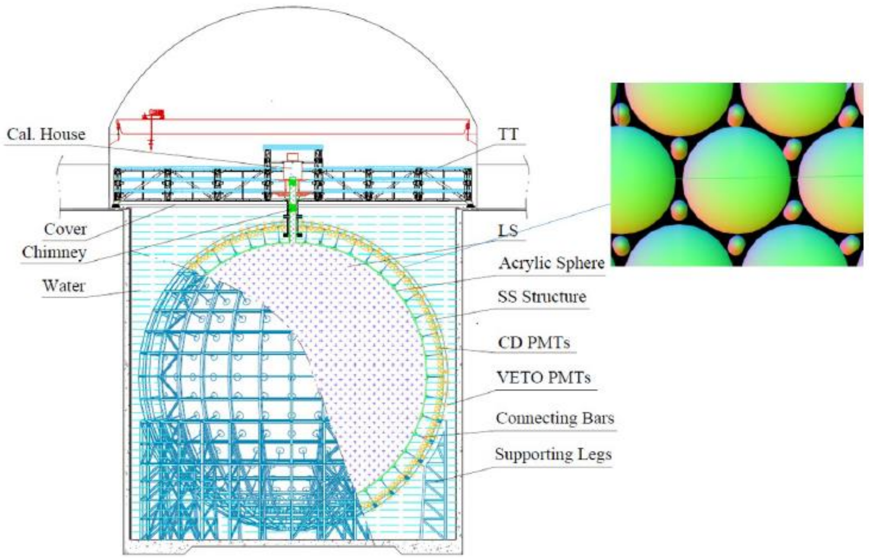
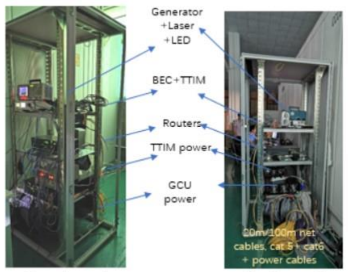
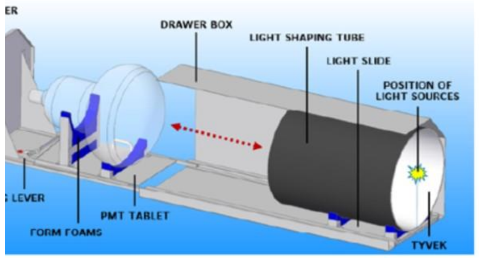
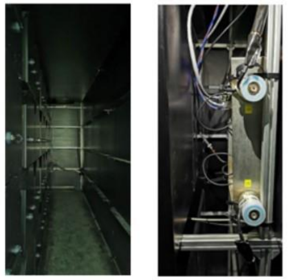
JUNO 20-inch PMT测试系统：集装箱D介绍





Front end　　Back end



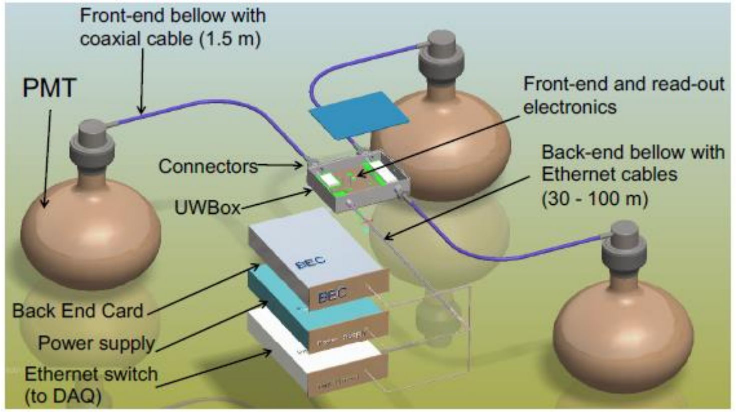


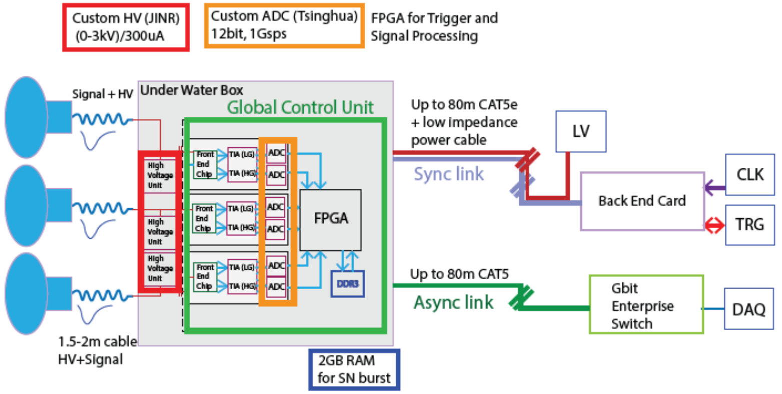
JUNO 计划使用大约20012支20-inch PMT，其中包括5000支日本滨松打拿极光电倍增管（dynode PMT）和15012支国内北方夜视（NNVT）生产的微通道板型光电倍增管（MCP PMT）；

集装箱系统：

集装箱A、B：配有商业电子学，用于PMT验收测试；

集装箱D：配有JUNO 1F3电子学(UWBox)做20-inch PMT与1F3电子学的联合测试；

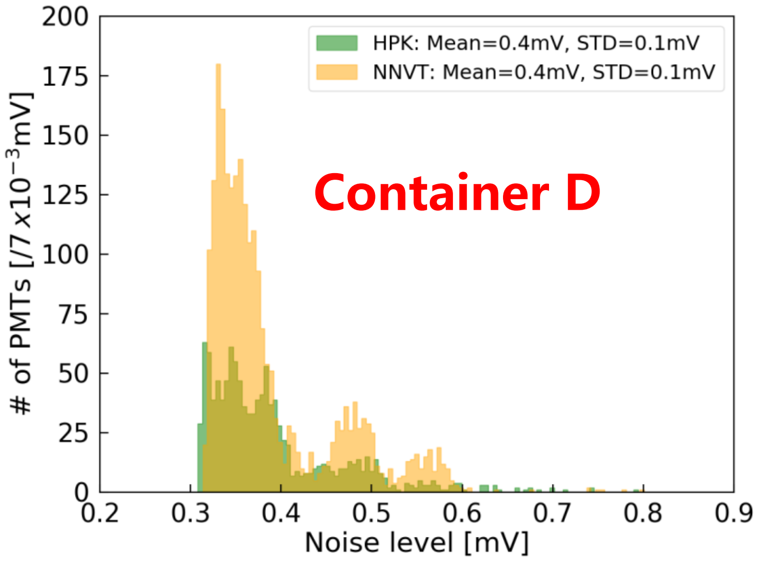


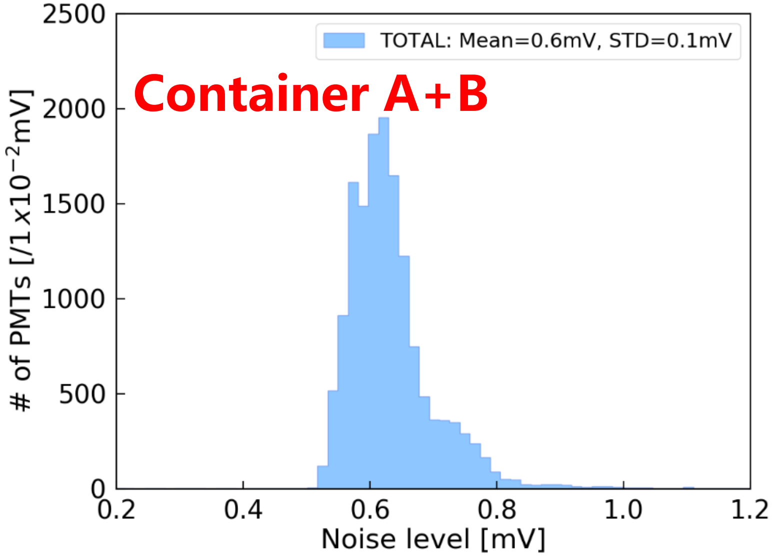


1F3电子学:可以同时连接三个PMT测试，动态范围广，线性响应良好（< 10% for 1000p.e.），对LS中的高分辨率重建能量十分有利。

因此，理解20-inch PMT与1F3电子学联合使用的性能十分重要。

● 1F3电子学与商业电子学的噪声水平

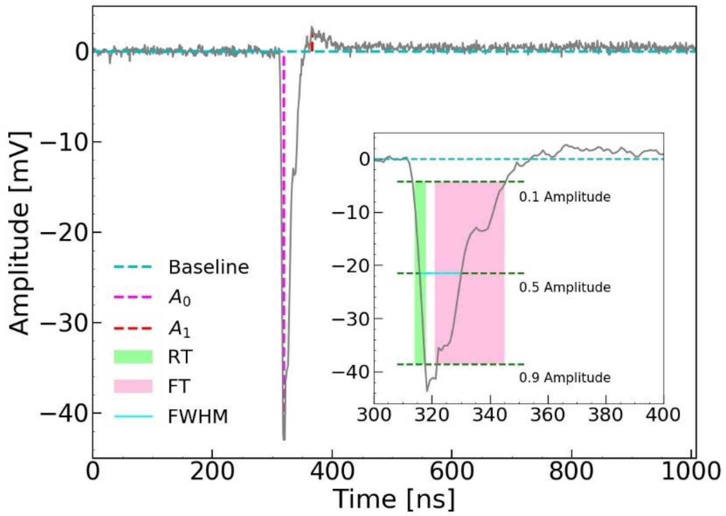




Container	A+B	D
Noise level	0.6mV	0.4mV

考虑系统噪声水平、PMT增益，PMT 暗噪声（DCR）测试的阈值设为1.8mV左右（~0.25pe）。

● Contaienr#D 基本性能参数分析

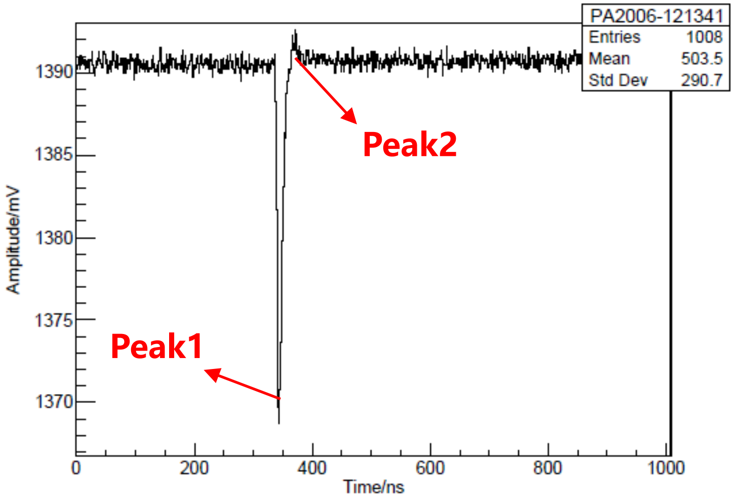


PMT	Number
ALL PMT	1969
Dynode PMT	738
MCP PMT	1231
H-QE MCP PMT	655
L-QE MCP PMT	576

Parameters	ALL PMT	Dynode PMT	MCP PMT	High-QE PMT	Low-QE PMT
HV /V	1799	1929	1722	1701	1745
Gain /10^6	10.0	9.9	10.0	9.9	10.1
PDE /%	27.4	27.7	27.2	29.0	25.1
DCR /kHz	26.5	16.6	32.4	31.0	33.9
Resolution /%	30.5	28.0	32.0	32.7	31.2
P/V	3.8	3.6	3.9	3.9	3.9
FWHM /ns	10.5	10.8	10.3	10.4	10.1
S/N	14.3	14.2	14.3	14.2	14.4
Rise Time /ns	4.8	6.4	3.9	4.0	3.9
Fall Time /ns	11.9	8.9	13.6	14.1	13.1
Hit Time /ns	314.0	285.4	331.1	331.8	330.2
Relative TTS /ns	8.8	6.2	10.3	10.3	10.4
Amplitude /mV	8.1	7.9	8.1	7.9	8.4

PMT波形脉冲过冲特征分析

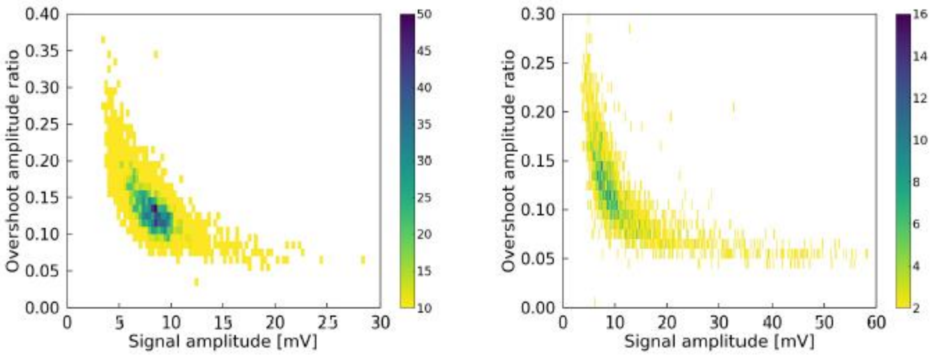
总数: 766 HPK, 1119 NNVT



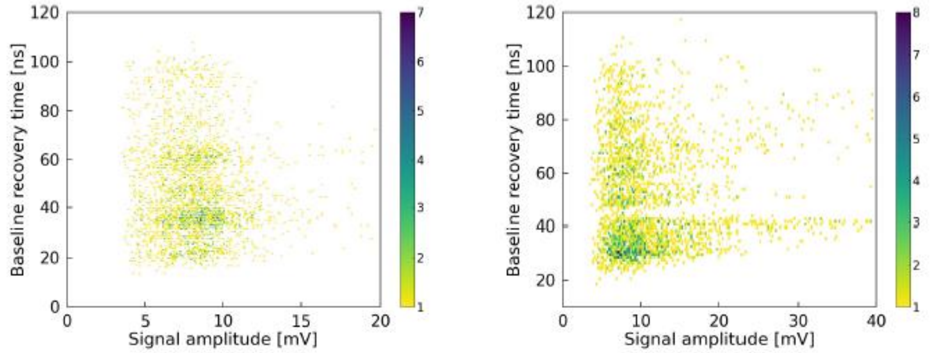
阈值: 3mV; 宽度：5ns
Peak1: A_0, T_0
Peak2: A_1, T_1
过冲振幅比: A_1/A_0
基线恢复时间：T_2

Types	A_0 /mV	A_1 /mV	T_1- T_0 /ns	T_2-T_0 /ns	A_1/A_0
Dynode PMT	8.4	1.2	43.6	49.0	0.15
MCP PMT	9.9	1.3	43.5	50.9	0.12

- 过冲峰值发生在主脉冲后约43ns，基线恢复约在50ns
- 过冲幅度比约为13%（SPE信号水平）
  - 过冲振幅比A_1/A_0随信号幅度增大明显减小
    - 噪声主导
- 基线恢复时间与A_0的关系还不甚明显



(a) A_1/A_0 vs. A_0 for HPK (b) A_1/A_0 vs. A_0 for NNVT.



(c) $T_2 - T_0$ vs. A_0 for HPK. (d) $T_2 - T_0$ vs. A_0 for NNVT.

Figure 7: Exemplary of a single PMT on the overshoot features versus the amplitude of primary pulse. Top left: amplitude ratio of overshoot versus primary pulse amplitude for HPK; top right: amplitude ratio of overshoot versus primary pulse amplitude for NNVT; bottom left: baseline recovery time after overshoot versus primary pulse amplitude for HPK; bottom right: baseline recovery time after overshoot versus primary pulse amplitude for NNVT.

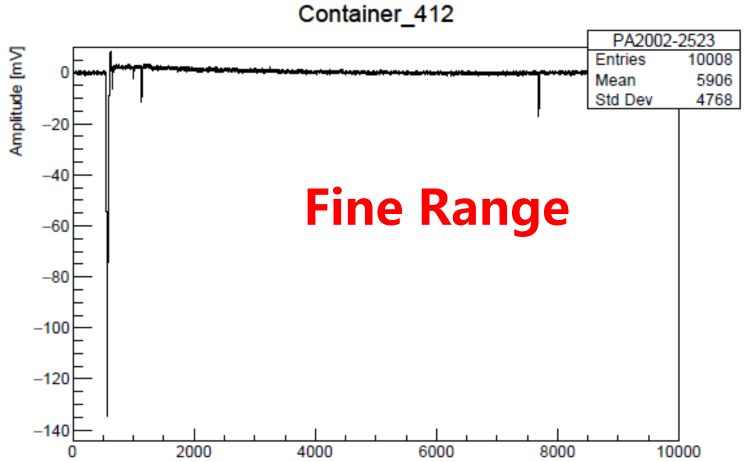
PMT大信号分析

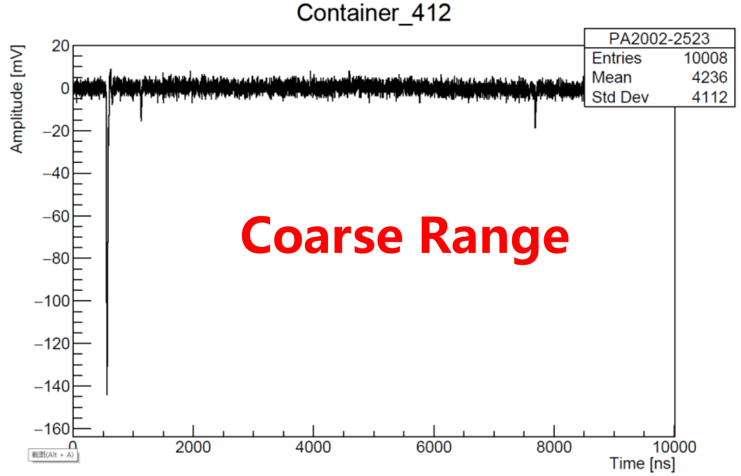
https://arxiv.org/abs/2206.07456

- 1F3电子学的两个量程:
  - **Fine Range**(range1, High Gian)： 1ADC=0.12mV 0-128 pe
  - **Coarse Range**(range0, Low Gain)： 1ADC= 0.83mV 0-1000 pe

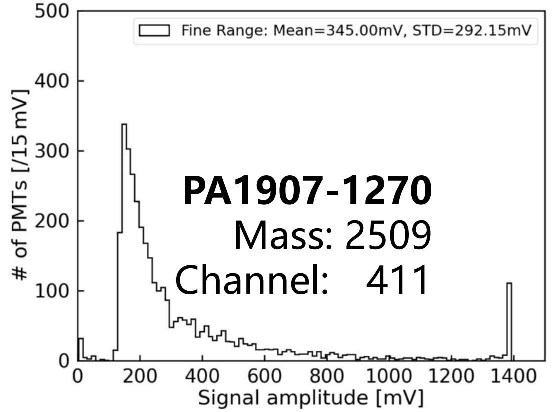
Range	Noise level /mV	Threshold /mV
Fine Range	**0.4**	**2**
Coarse Range	**2.1**	**6.3**

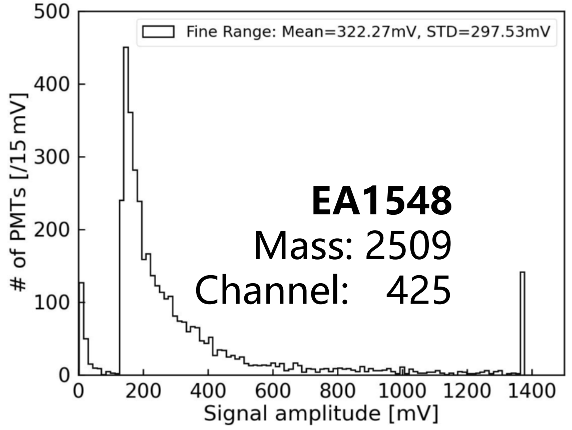
- 波形示例

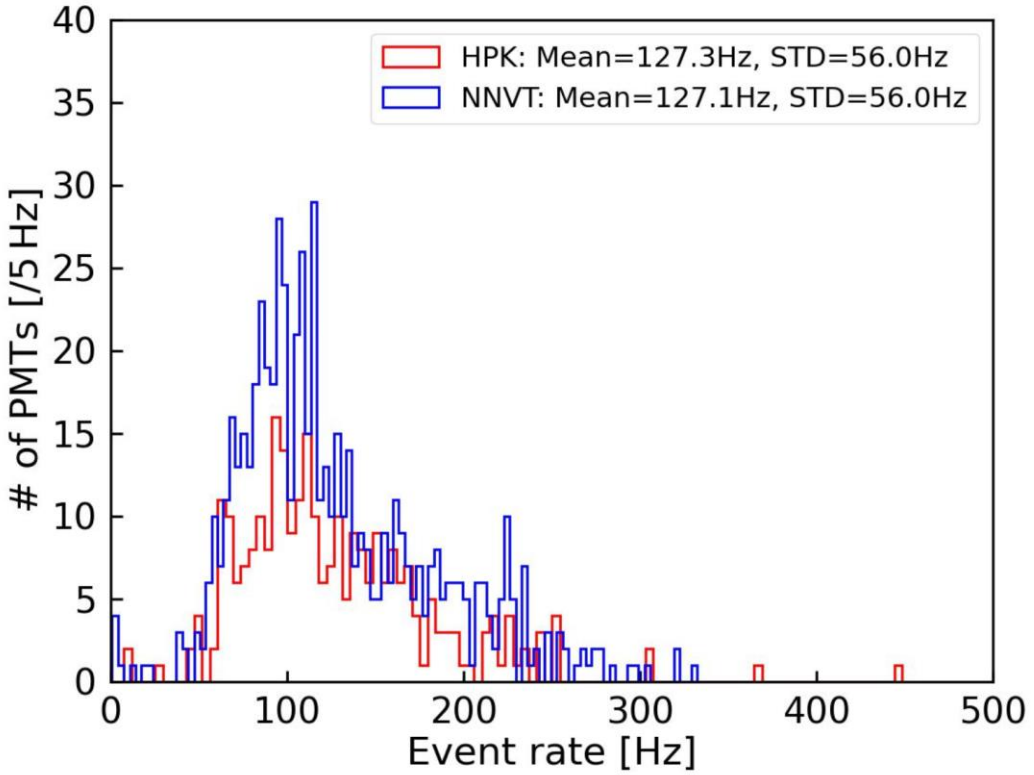




PMT自触发大信号







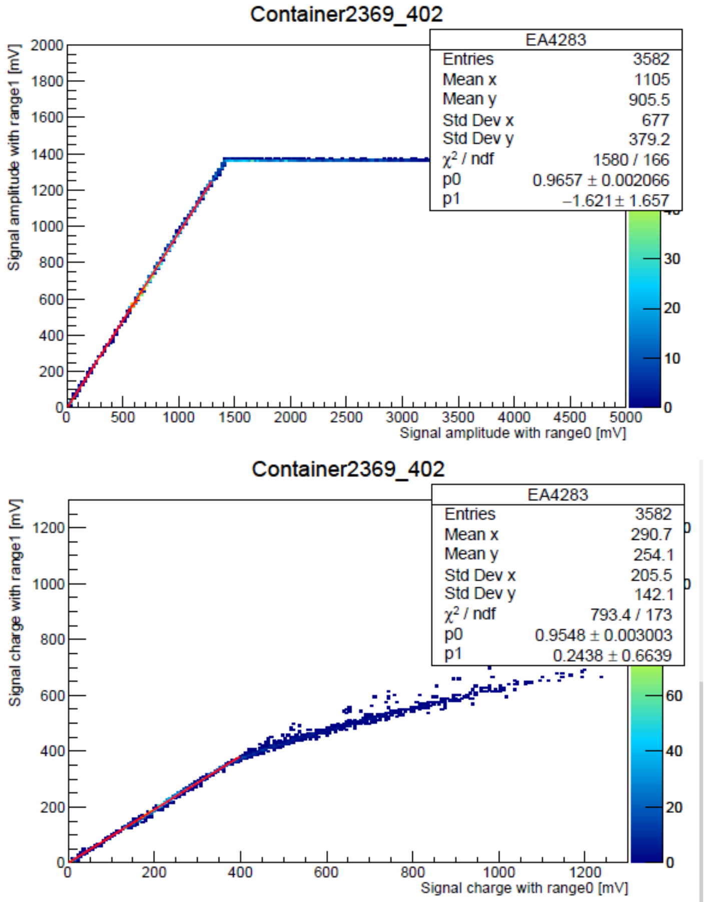
超过预设阈值100mV的大信号的平均事例数大约为127Hz。

(与在高能所中做实验的结果相符)

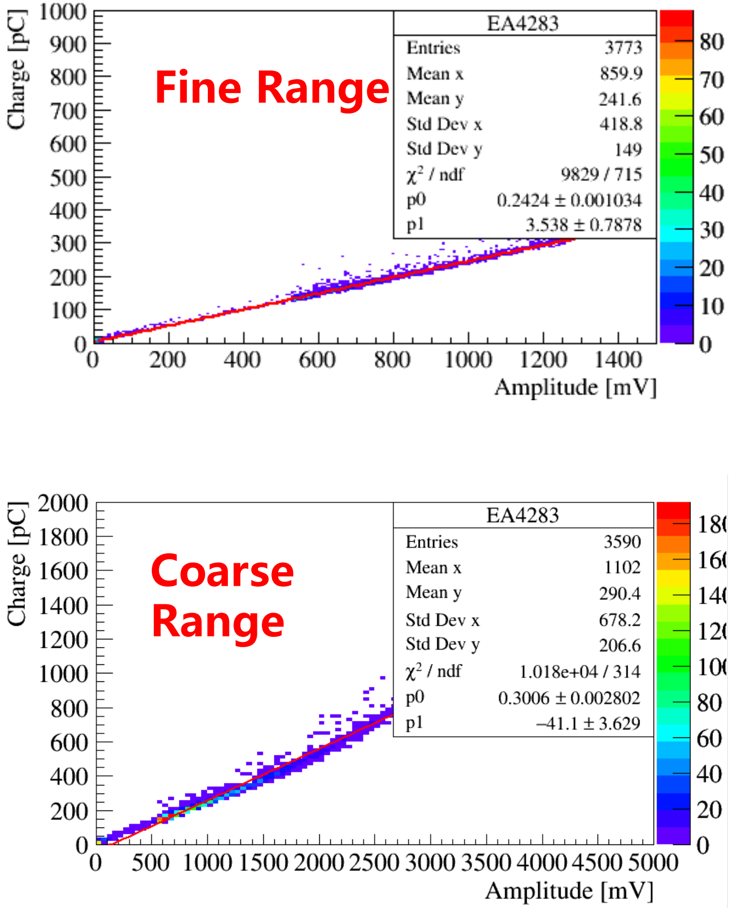
1F3电子学两个量程对比分析

280HPK, 621NNVT

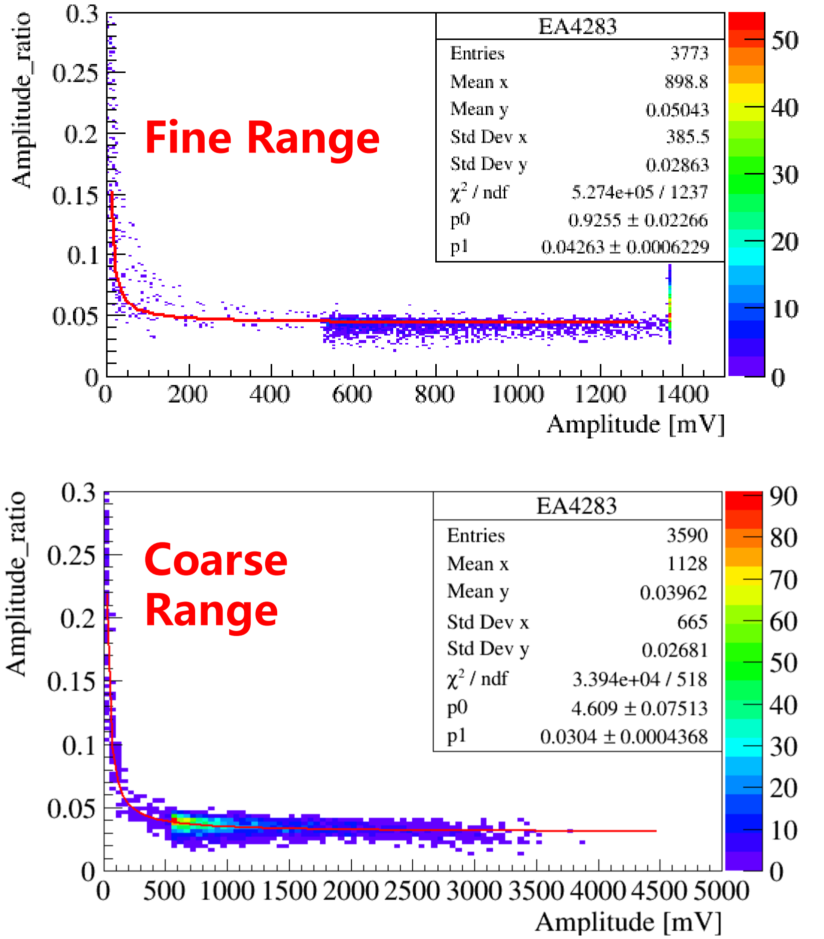
Fine vs. Coarse range



幅度与电荷



过冲幅度比



在Fine range的测量范围内，1F3电子学的两个量程的幅度与电荷具有良好的一致性。

总结

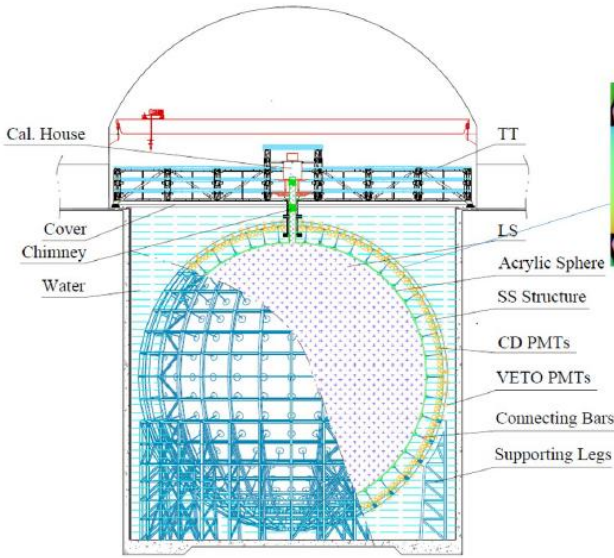
- **20-inch PMT与1F3电子学联合测试分析---外部LED触发**
  - 20英寸PMT与1F3电子学联合测试的SPE幅度大约为8mV；
  - Dynode PMT的DCR为16.6kHz, MCP PMT的DCR更大，为32.4kHz；
  - PMT与1F3电子学和商业电子学测试的大部分性能参数在误差范围内是基本一致的，但前者的过冲幅度比为8%，稍大于后者的6%；

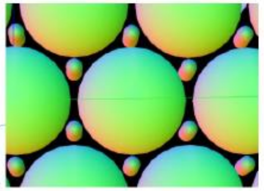
- **20-inch PMT与1F3电子学联合测试分析---PMT自触发**
  - 超过预设阈值的大信号的平均事例数大约为127Hz；
  - Fine range与coarse range的平均噪声水平大约是 0.4mV与2.1mV；
  - 在Fine range的测量范围内，1F3电子学的两个量程的幅度与电荷具有良好的一致性。
  - 随着幅度的增大，dynode PMT比MCP PMT更快地出现幅度与电荷的非线性。
  - Fine range与coarse range的平均过冲幅度比大约为6.4%与5.1%；
  - 两个量程之间存在时间差且并不固定。

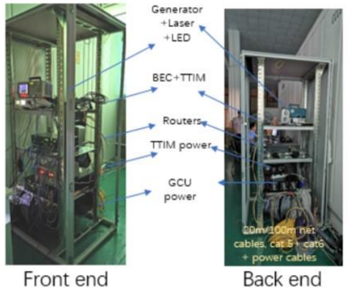
谢谢

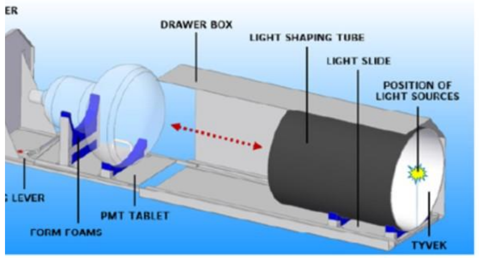
Backup

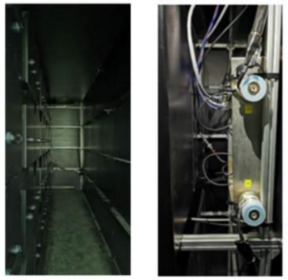
JUNO 20-inch PMT测试系统：集装箱D介绍











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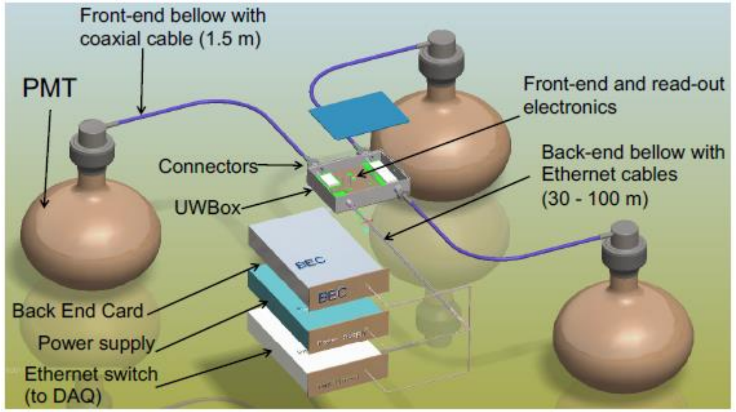

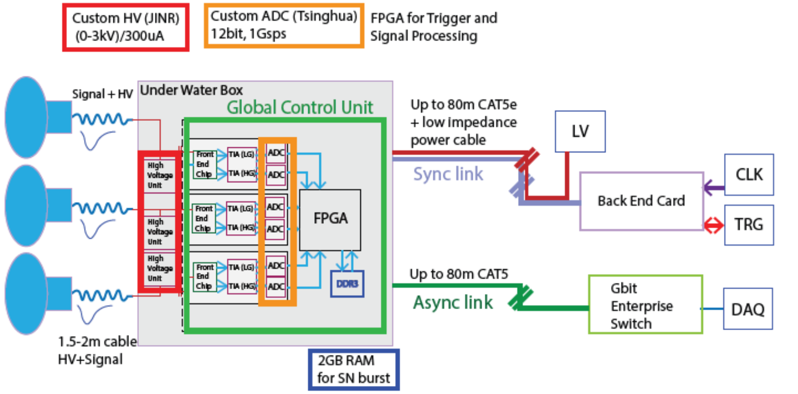

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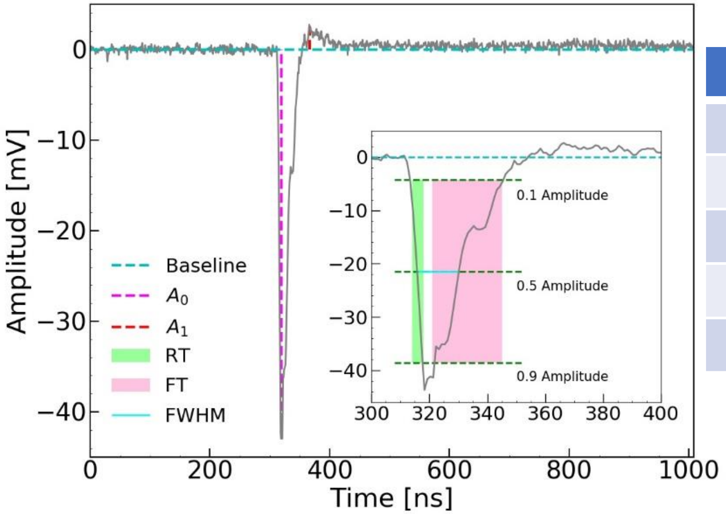
基本性能参数分析



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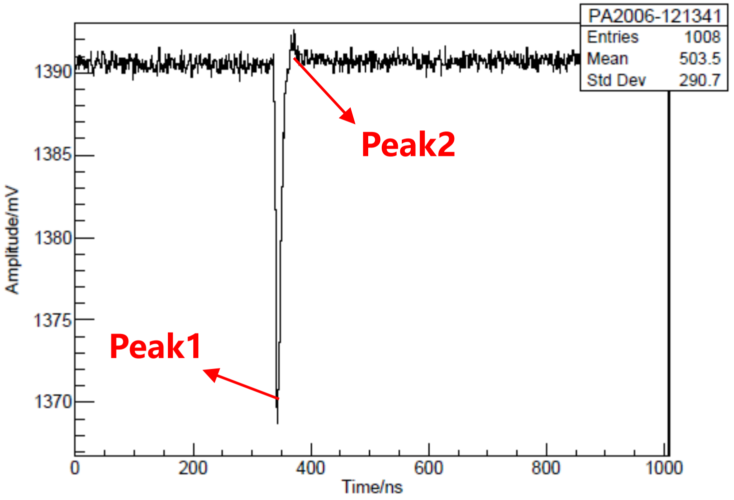
Dynode PMT	738
MCP PMT	1231
H-QE MCP PMT	655
L-QE MCP PMT	576

Parameters	ALL PMT	Dynode PMT	MCP PMT	High-QE PMT	Low-QE PMT
HV /V	1799	1929	1722	1701	1745
Gain /10^6	10.0	9.9	10.0	9.9	10.1
PDE /%	27.4	27.7	27.2	29.0	25.1
DCR /kHz	26.5	16.6	32.4	31.0	33.9
Resolution /%	30.5	28.0	32.0	32.7	31.2
P/V	3.8	3.6	3.9	3.9	3.9
FWHM /ns	10.5	10.8	10.3	10.4	10.1
S/N	14.3	14.2	14.3	14.2	14.4
Rise Time /ns	4.8	6.4	3.9	4.0	3.9
Fall Time /ns	11.9	8.9	13.6	14.1	13.1
Hit Time /ns	314.0	285.4	331.1	331.8	330.2
Relative TTS /ns	8.8	6.2	10.3	10.3	10.4
Amplitude /mV	8.1	7.9	8.1	7.9	8.4

- S/N的大于10，满足集装箱的10%的S/N要求；
- SPE幅度大约为8mV, PDE超过27%；
- Dynode PMT的DCR为16.6kHz，MCP PMT的DCR更大，为32.4kHz；
- 相对TTS较大主要是由于LED光源的发光时间晃动引起的；

过冲特征分析

总数: 766 HPK, 1119 NNVT



阈值: 3mV; 宽度：5ns

Peak1: A_0, T_0

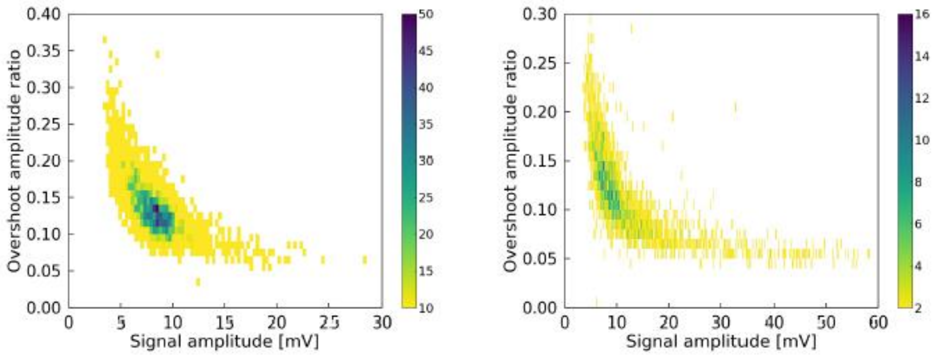
Peak2: A_1, T_1

过冲振幅比: A_1/A_0

基线恢复时间：T_2

Types	A_0 /mV	A_1 /mV	T_1- T_0 /ns	T_2-T_0 /ns	A_1/A_0
Dynode PMT	8.4	1.2	43.6	49.0	0.15
MCP PMT	9.9	1.3	43.5	50.9	0.12

- 过冲峰值发生在主脉冲后约43ns，基线恢复约在50ns
- 过冲幅度比约为13% （SPE信号水平）
  - 过冲振幅比A_1/A_0随信号幅度增大明显减小
    - 噪声主导
- 基线恢复时间与A_0的关系还不甚明显



(a) A_1/A_0 vs. A_0 for HPK (b) A_1/A_0 vs. A_0 for NNVT.

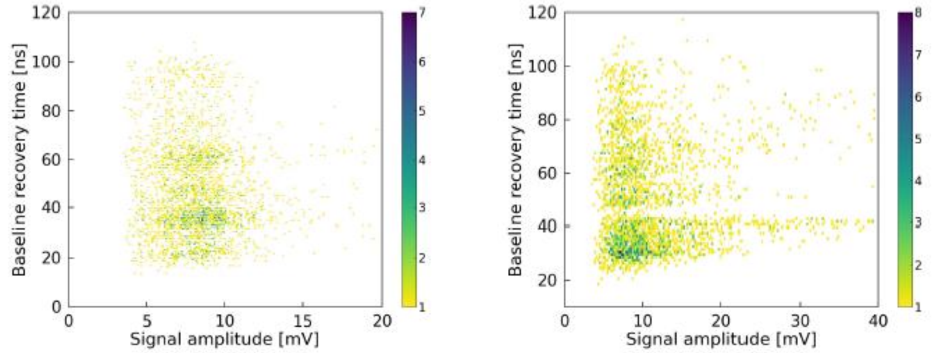


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Figure 7: Exemplary of a single PMT on the overshoot features versus the amplitude of primary pulse. Top left: amplitude ratio of overshoot versus primary pulse amplitude for HPK; top right: amplitude ratio of overshoot versus primary pulse amplitude for NNVT; bottom left: baseline recovery time after overshoot versus primary pulse amplitude for HPK; bottom right: baseline recovery time after overshoot versus primary pulse amplitude for NNVT.

与商业电子学的对比------参数对比及一致性检查 （参考管检查）

Container	Reference LPMT				
Container A	EA0339	EA1578	EA0419	PA1704-731	PA1705-117
Container B	EA0586	EA0574	EA1437	PA1704-108	PA1705-12
Container D	EA6751	PA1911-2625			

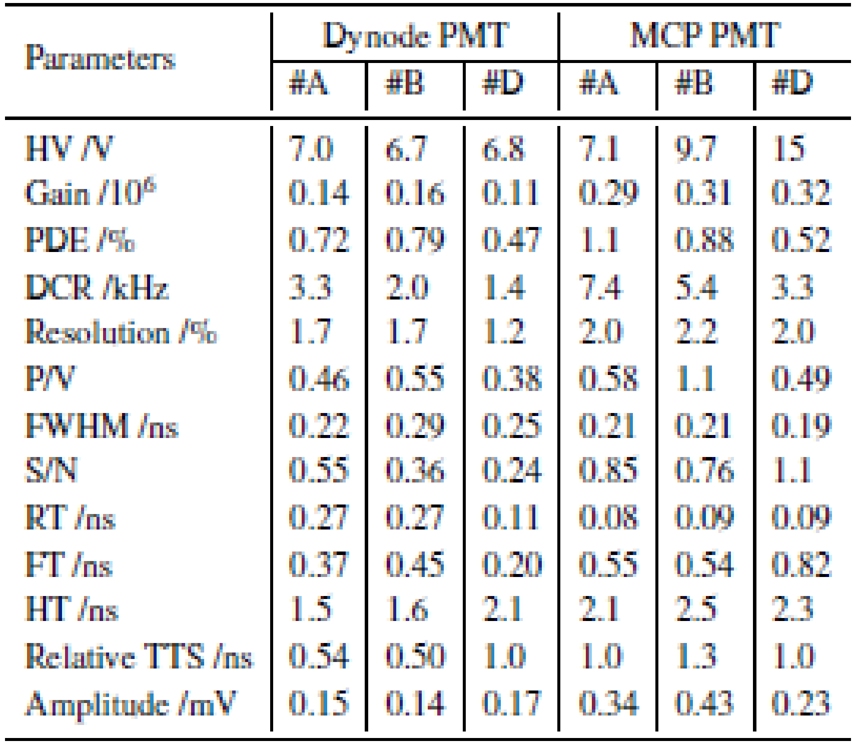
各集装箱内参考管多次测量性能参数分布，分布宽度σ作为对应测量误差。

集装箱测量相对差别R及误差Δ_R定义

$$R = \frac{P_D - \bar{P}}{\bar{P}} \quad \text{where } \bar{P} = \frac{P_D + P_{A/B}}{2}$$

$$\Delta_R = \frac{1}{2\bar{P}^2}\sqrt{(P_{A/B}\sigma_D)^2 + (P_D\sigma_{A/B})^2}$$

各集装箱的测量误差σ



Parameters	Dynode PMT			MCP PMT		
	#A	#B	#D	#A	#B	#D
HV /V	7.0	6.7	6.8	7.1	9.7	15
Gain /10^6	0.14	0.16	0.11	0.29	0.31	0.32
PDE /%	0.72	0.79	0.47	1.1	0.88	0.52
DCR /kHz	3.3	2.0	1.4	7.4	5.4	3.3
Resolution /%	1.7	1.7	1.2	2.0	2.2	2.0
P/V	0.46	0.55	0.38	0.58	1.1	0.49
FWHM /ns	0.22	0.29	0.25	0.21	0.21	0.19
S/N	0.55	0.36	0.24	0.85	0.76	1.1
RT /ns	0.27	0.27	0.11	0.08	0.09	0.09
FT /ns	0.37	0.45	0.20	0.55	0.54	0.82
HT /ns	1.5	1.6	2.1	2.1	2.5	2.3
Relative TTS /ns	0.54	0.50	1.0	1.0	1.3	1.0
Amplitude /mV	0.15	0.14	0.17	0.34	0.43	0.23

两种PMT测试给出的R±Δ_R

Parameters	Dynode PMT	MCP PMT
HV	0.007±0.004	0.002±0.005
Gain	-0.002±0.009	-0.009±0.022
PDE	0.006±0.016	0.008±0.020
DCR	0.03±0.11	-0.04±0.13
Resolution	-0.005±0.037	-0.007±0.045
P/V	-0.03±0.09	-0.02±0.13
FWHM	0.05±0.02	0.04±0.01
S/N	0.05±0.02	0.04±0.05
Rise Time	0.004±0.023	0.05±0.17
Fall Time	-0.05±0.02	-0.05±0.04
Hit Time	0.21±0.005	0.190±0.006
Relative TTS	-0.006±0.091	0.02±0.08
Amplitude	0.10±0.02	0.07±0.03

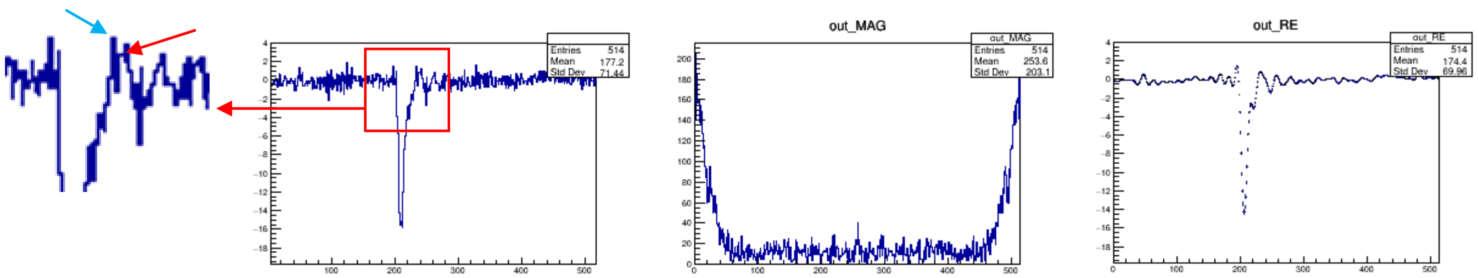
PMT	Number
ALL PMT	582
Dynode PMT	384
MCP PMT	198

1F3电子学和商业电子学的测试部分参数存在一定的差别，但主体在误差范围内是基本一致的。

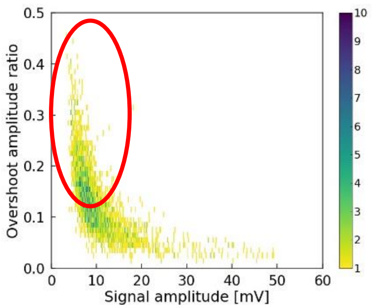
与商业电子学的------过冲对比

总数: 498 HPK, 2803 NNVT

由于A/B箱的噪声较大，在获取过冲特征时影响过大，这里采用FFT滤波的方式减小噪声影响。

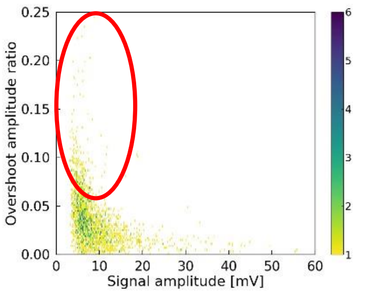


原始数据



NNVT

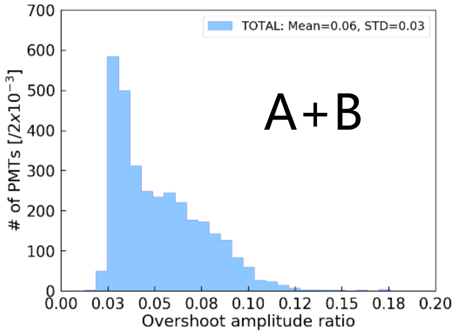
FFT滤波后

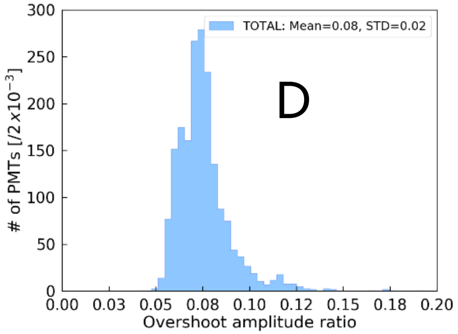


Container A+B	TATOL	Bare PMT	Potted PMT	HPK	NNVT
A_1 /mV	0.47	0.60	0.27	0.31	0.50
A_0 /mV	9.35	9.91	8.47	6.73	9.81
A_1/A_0	0.06	0.06	0.04	0.05	0.06

- 集装箱A/B从整体上来说过冲幅度比为6% （SPE信号幅度范围）
  - 其中裸管的过冲比比potting管略大，
  - 夜视与滨松的相差无几。
- 集装箱D滤波后，振幅比从13%下降到8%，比集装箱A/B的稍大。

Container D	TATOL	HPK	NNVT
A_1 /mV	0.72	0.64	0.78
A_0 /mV	8.74	7.96	9.28
A_1/A_0	0.08	0.08	0.07





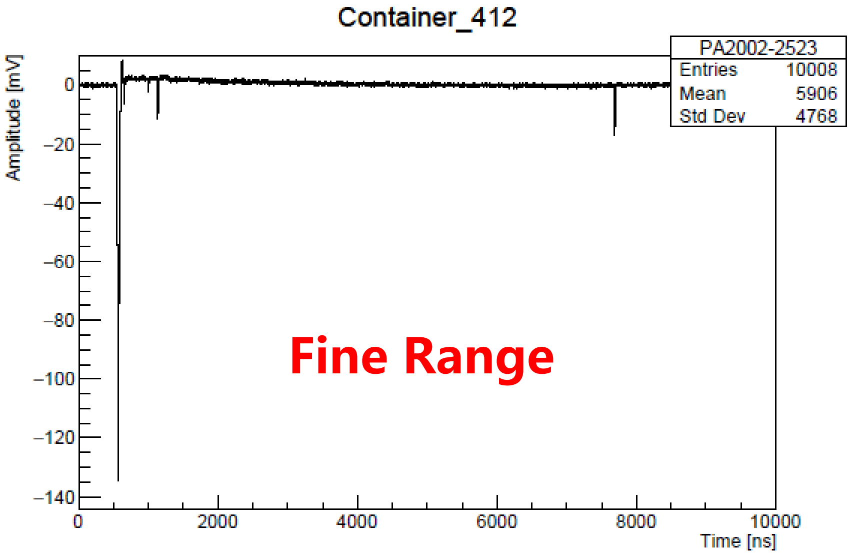
- 过冲=》电荷非线性=》能量非线性=》影响能谱

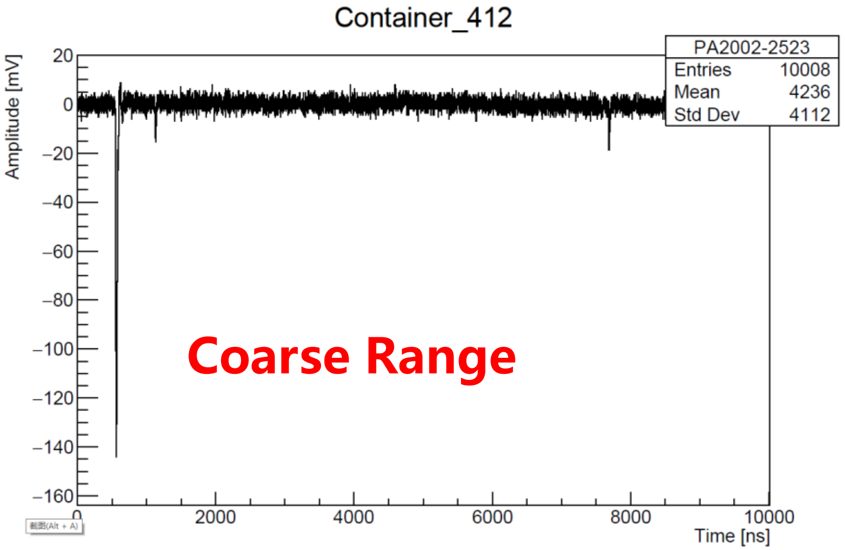
20-inch PMT与1F3电子学联合测试分析---PMT自触发

- 大信号的数据获取模式
- 大信号的事例率
- 1F3电子学的两个量程的特性
    - 噪声水平
    - 幅度、电荷的一致性
    - 幅度与电荷的关系
    - 过冲幅度比
    - 击中时间差

大信号的数据获取模式

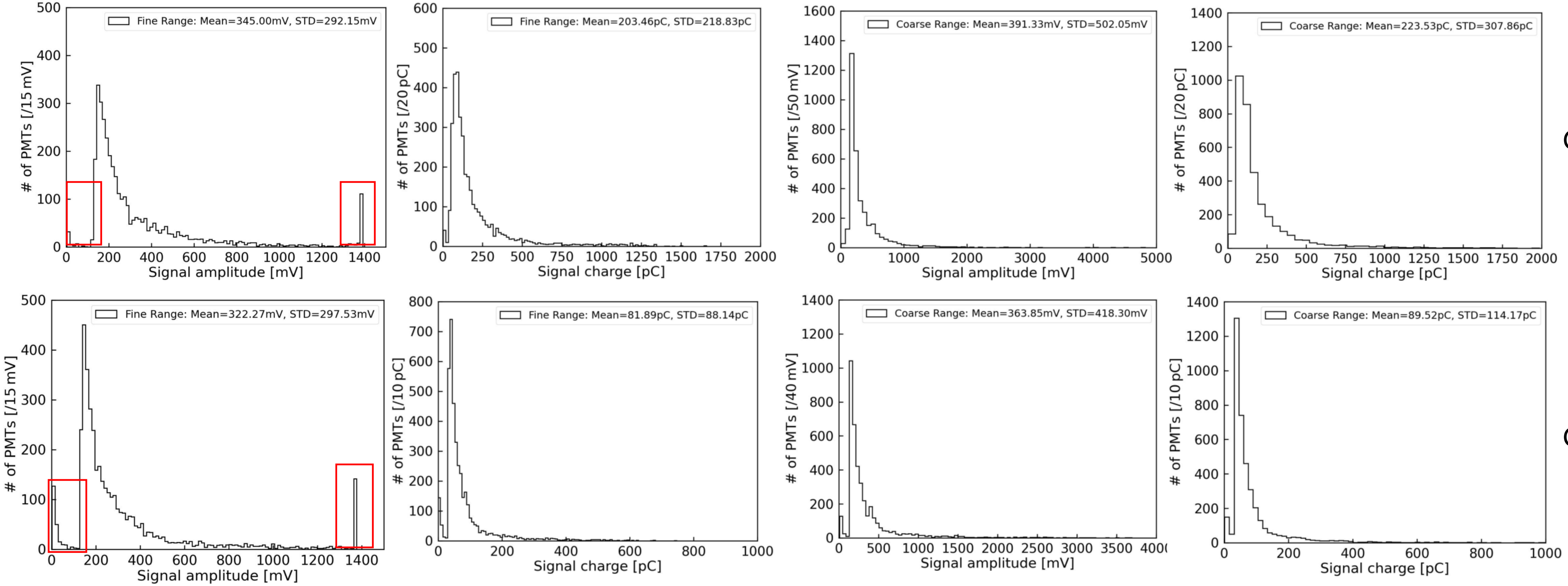
- PMT 自触发
- 高阈值: 1000ADC and 4000ADC for fine range
- 时间窗口：10us
- 每次运行10000次触发
- 1F3电子学的两个量程:
  - **Fine Range**(range1, High Gian)：1ADC=0.12mV 0-128 pe
  - **Coarse Range**(range0, Low Gain)：1ADC= 0.83mV 0-1000 pe
- 波形示例





大信号的幅度谱与电荷谱

Fine Range **Coarse Range**



PA1907-1270
Mass: 2509
Channel: 411

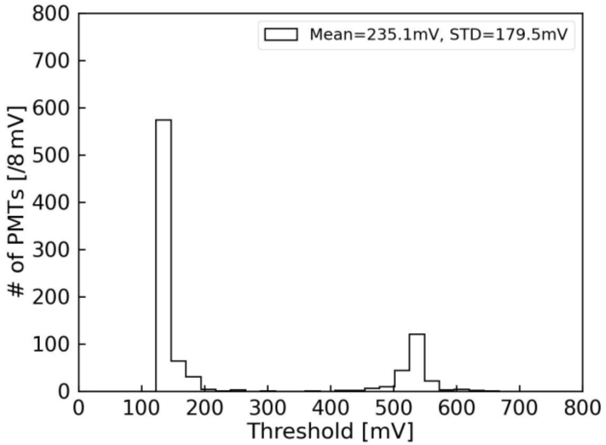
EA1548
Mass: 2509
Channel: 425

- 低于阈值的波形会被记录是因为来自同属于一个GCU的其他PMT通道的触发。
- fine range 的幅度测量上限大约为1380mV。

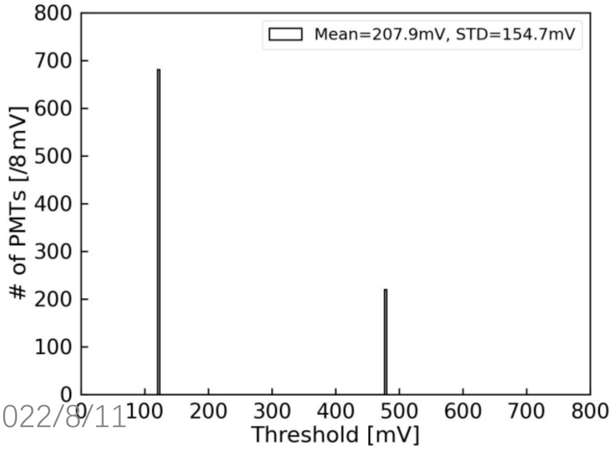
大信号的阈值检查

280HPK, 621NNVT

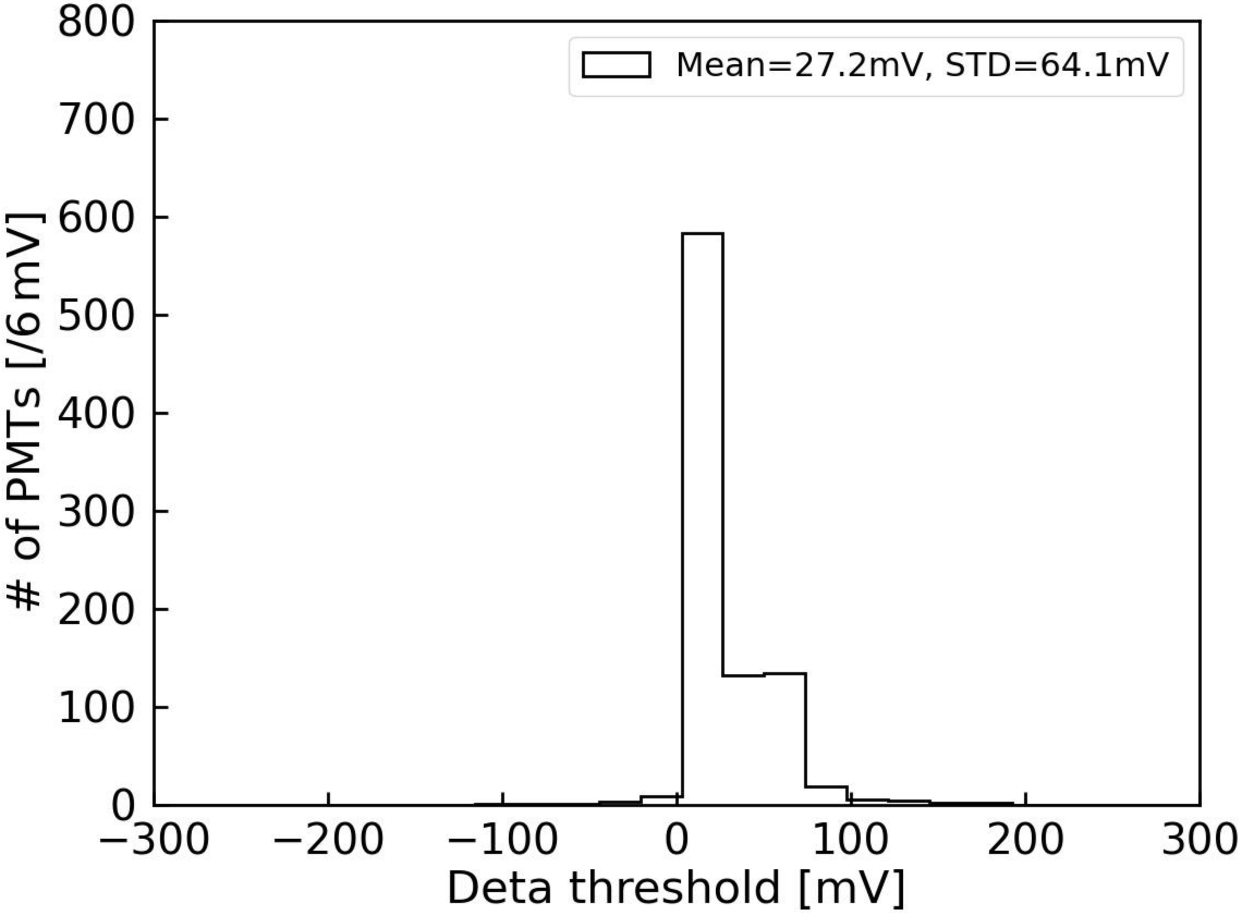
Threshold-1: 幅度谱0.5倍峰值处对应的阈值；



Threshold-2: 测试时fine range预设的阈值。



Threshold1- Threshold2



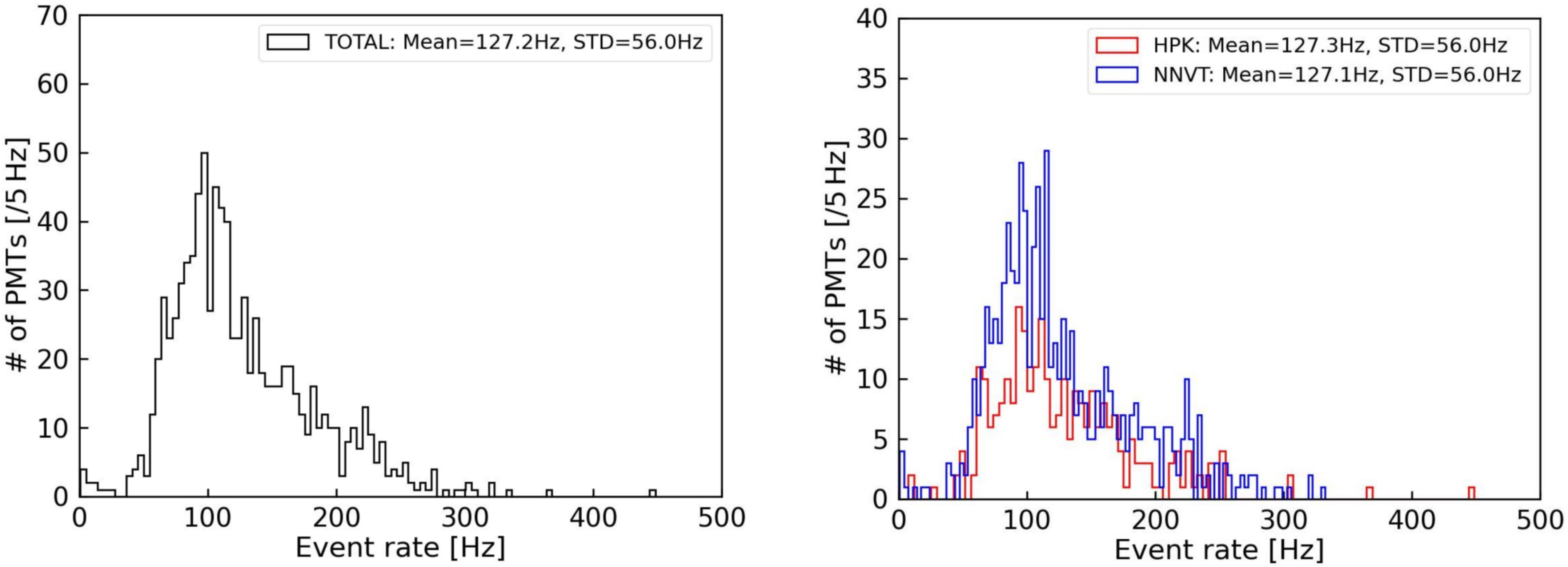
大信号的事例率

280HPK, 621NNVT

定义:

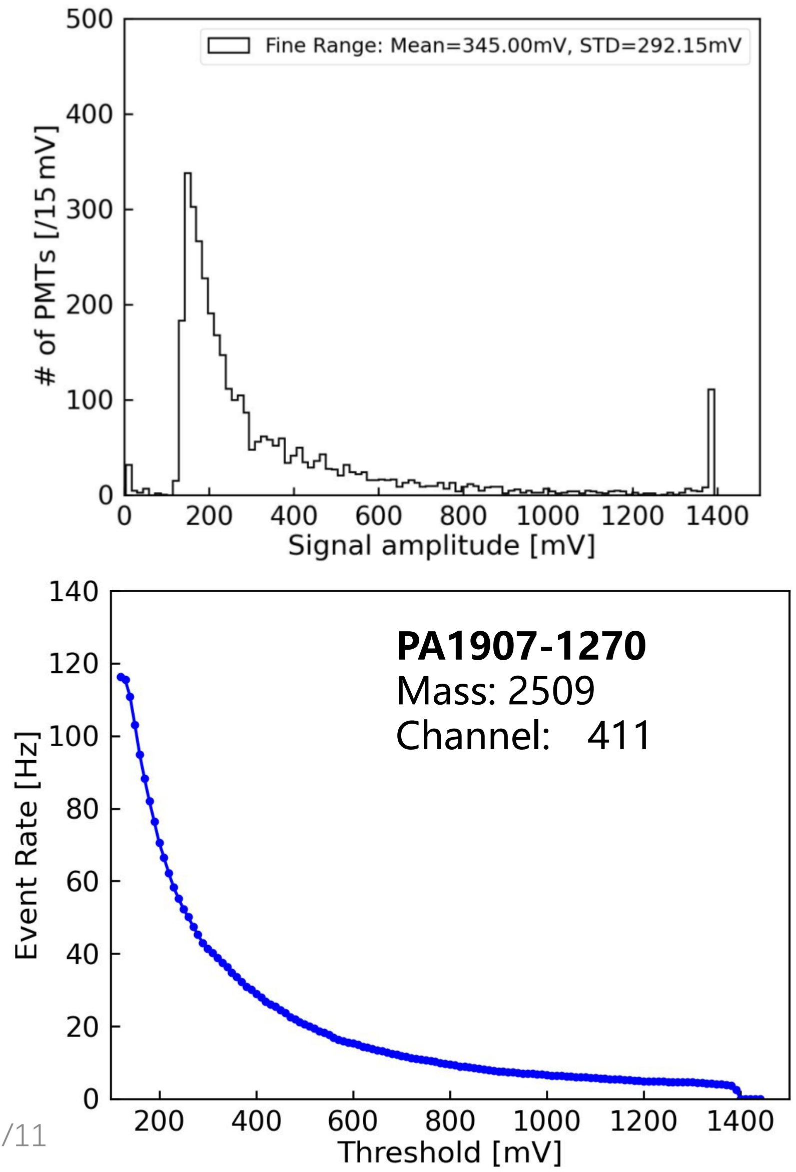
$$Event\ rate = \frac{Event\ number}{Event\ time}$$

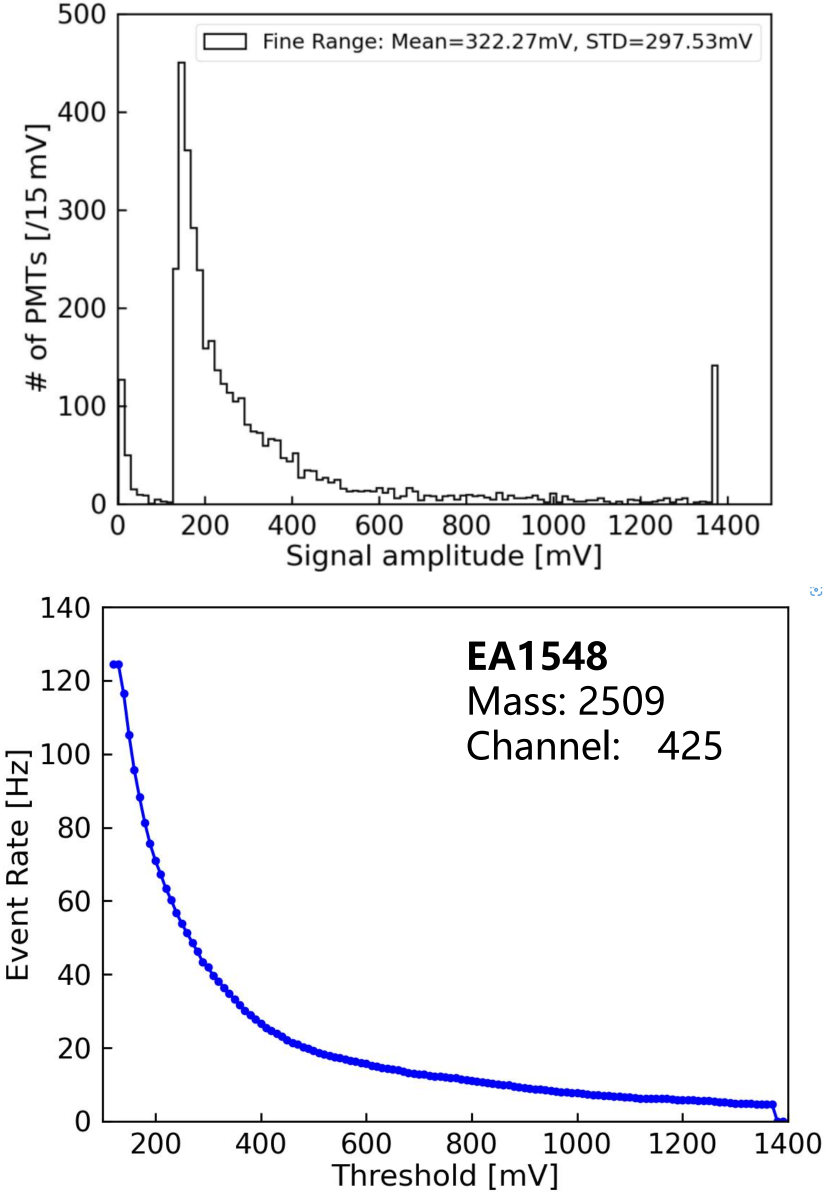
Event time: 第一个触发与最后一个触发之间的时间段；
Event number: 在Event time中，幅度超过预设阈值的事例数。



超过预设阈值的大信号的平均事例数大约为127Hz。
(与在高能所中做实验的结果相符)

大信号的事例率

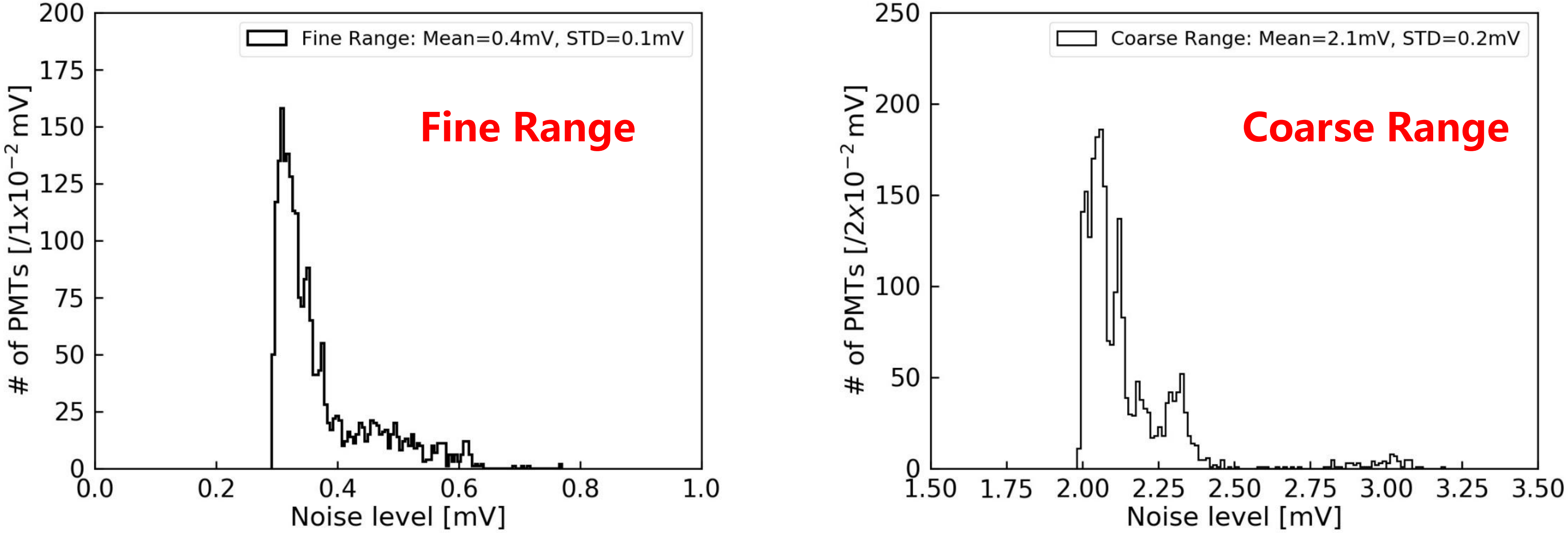

Fine Range: Mean=345.00mV, STD=292.15mV
# of PMTs [/15 mV]
Signal amplitude [mV]
0
100
200
300
400
500
0
200
400
600
800
1000
1200
1400
PA1907-1270
Mass: 2509
Channel: 411
Event Rate [Hz]
Threshold [mV]
0
20
40
60
80
100
120
140
200
400
600
800
1000
1200
1400


Fine Range: Mean=322.27mV, STD=297.53mV
# of PMTs [/15 mV]
Signal amplitude [mV]
0
100
200
300
400
500
0
200
400
600
800
1000
1200
1400
EA1548
Mass: 2509
Channel: 425
Event Rate [Hz]
Threshold [mV]
0
20
40
60
80
100
120
140
200
400
600
800
1000
1200
1400

1F3电子学的两个量程的噪声水平

591HPK + 1712NNVT

Fine Range(range1, High Gian)： 1ADC=0.12mV 0-1000 pe
Coarse Range(range0, Low Gain)： 1ADC= 0.83mV 0-128 pe



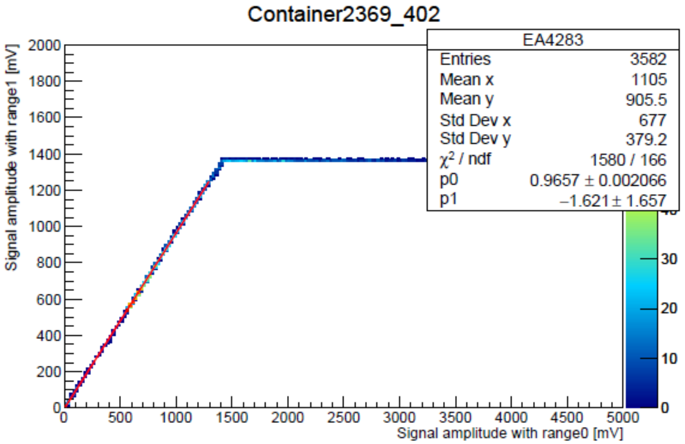
Range	Noise level /mV	Threshold /mV
Fine Range	0.4	2
Coarse Range	2.1	6.3

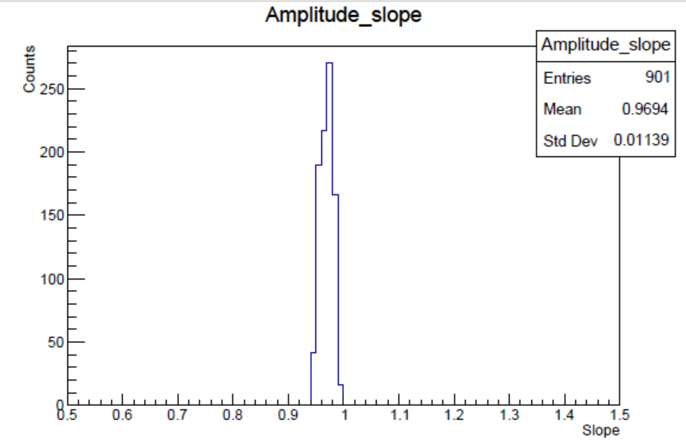
1F3电子学两个量程的幅度、电荷的一致性

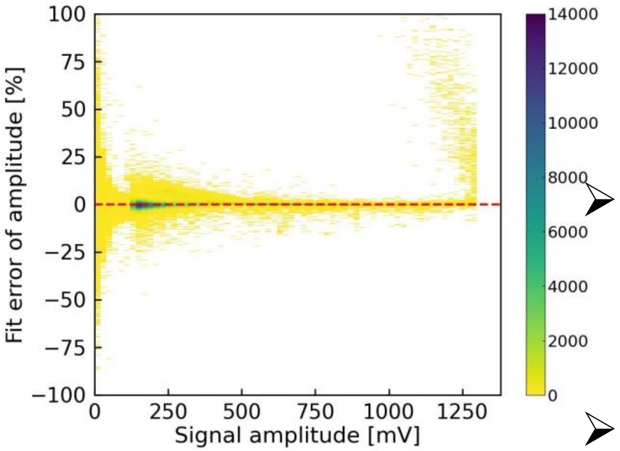
280HPK, 621NNVT

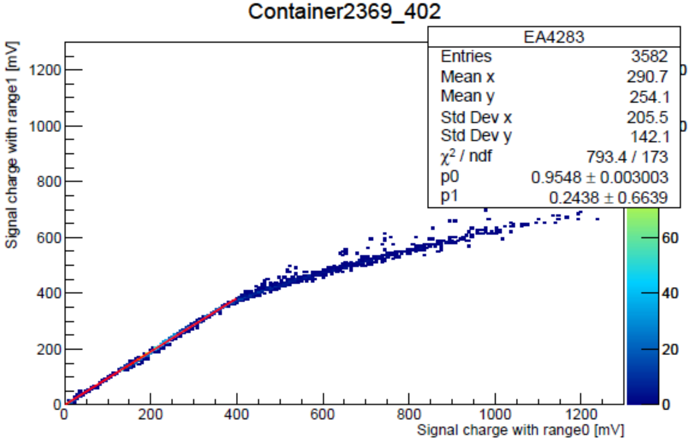
Fit function: Y = A*X + B

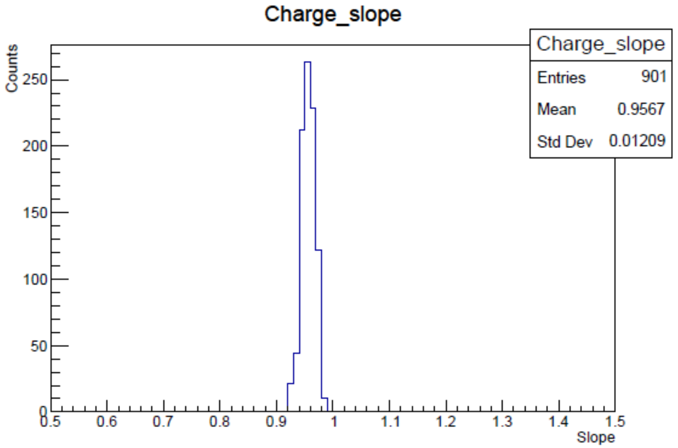
Fit error: $((Date_{fit}-Date_{test})/Date_{test})*100$

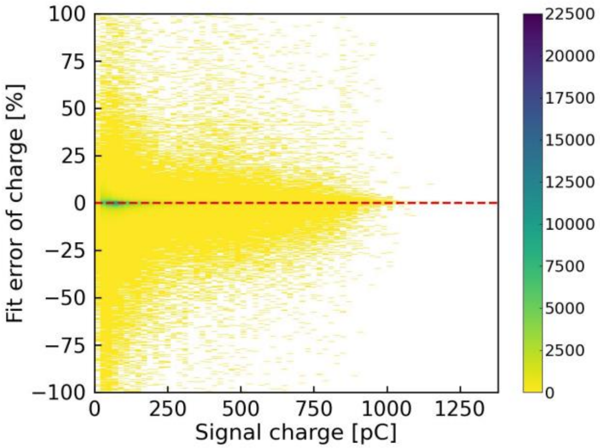












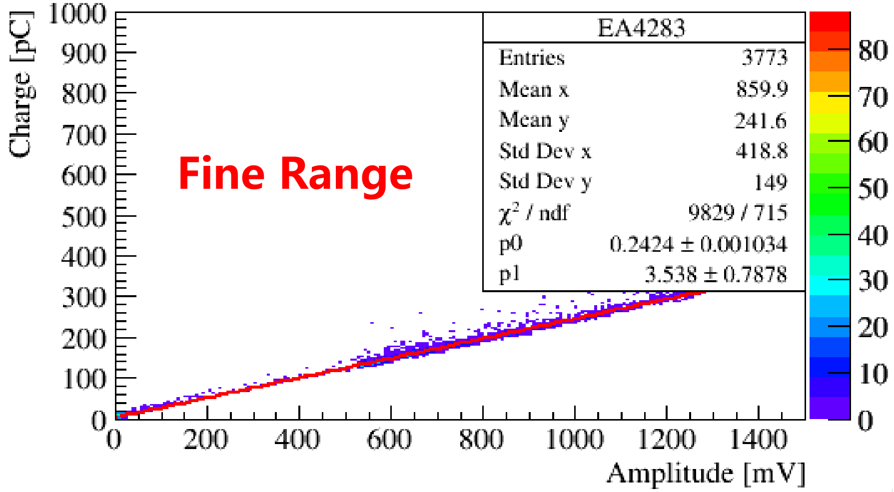
- ➢ 幅度与电荷的平均拟合斜率为0.97和0.96;
- ➢ 拟合误差都接近于0。

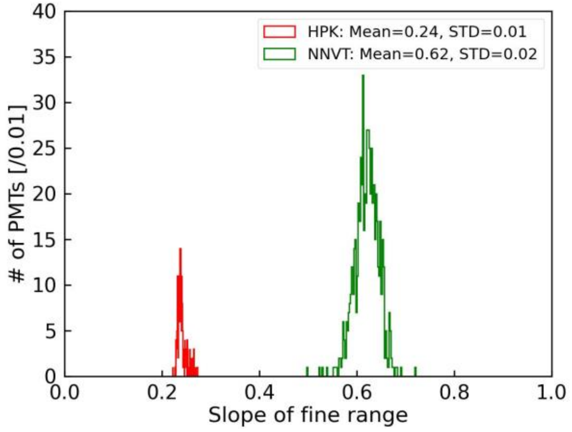
在Fine range的测量范围内，1F3电子学的两个量程的幅度与电荷具有良好的一致性。

1F3电子学两个量程各自的幅度与电荷的关系

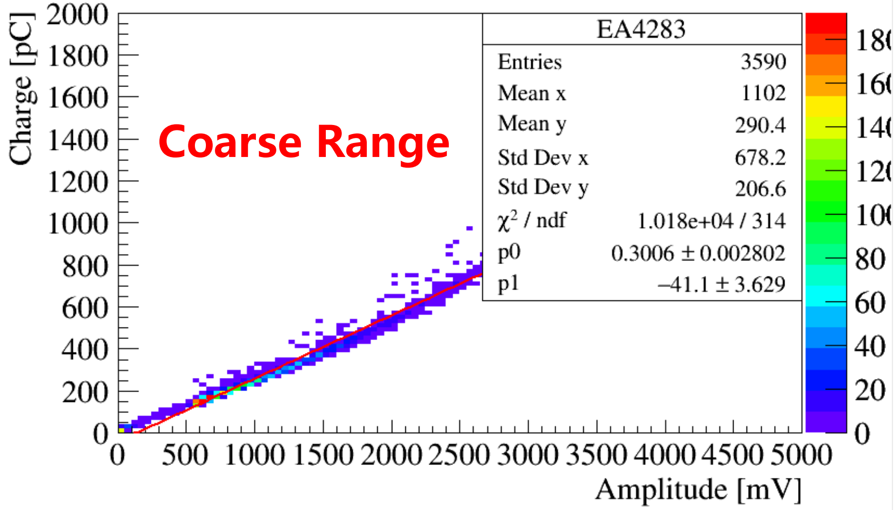
280HPK, 621NNVT

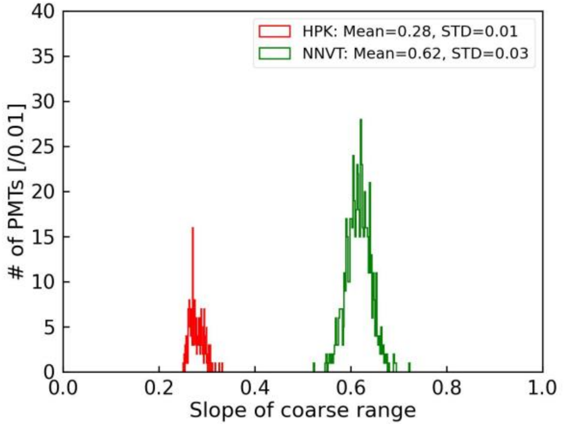
Fit function: Y = A*X + B

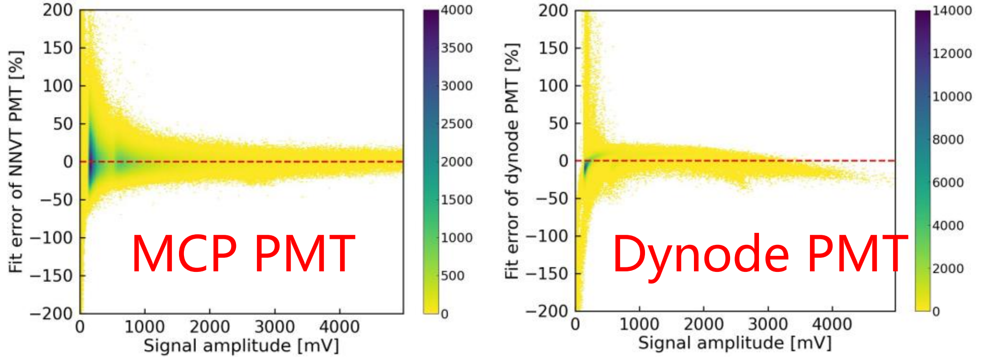




- MCP PMT和dynode PMT的平均拟合斜率大约是0.26与0.62； MCP PMT比dynode PMT具有更好的幅度与电荷的线性关系。
- 随着幅度的增大，dynode PMT比MCP PMT更快地出现幅度与电荷的非线性。





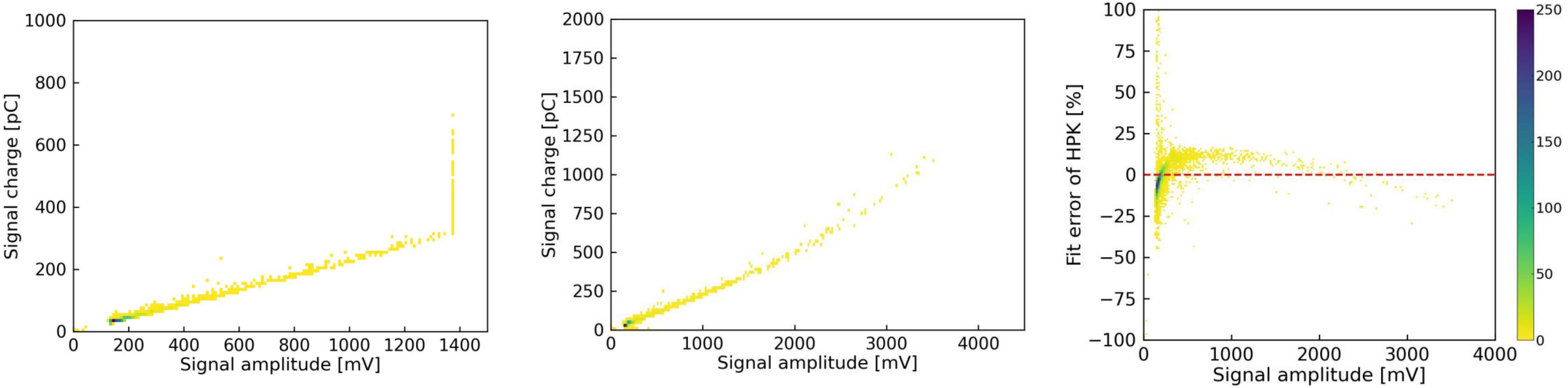


Coarse Range

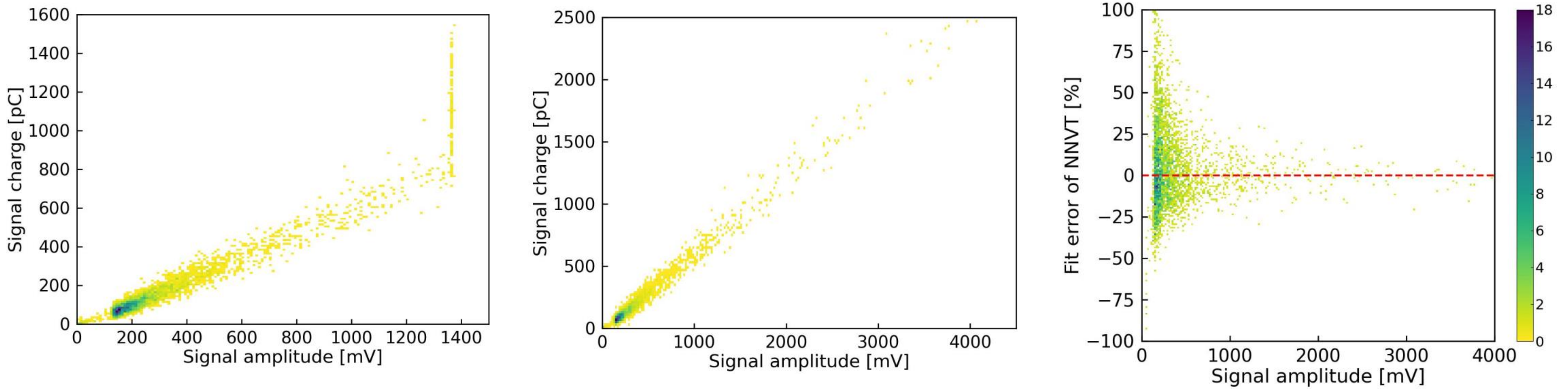
Fine Range

Coarse Range

EA1362
2563
408

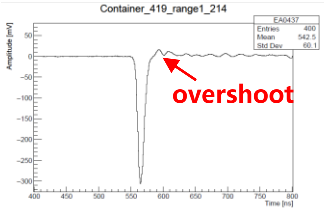


PA1711-1632
2563
409

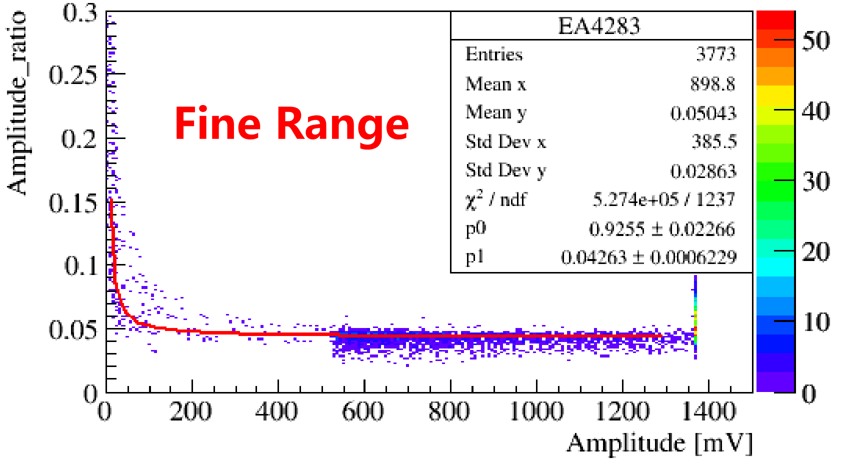


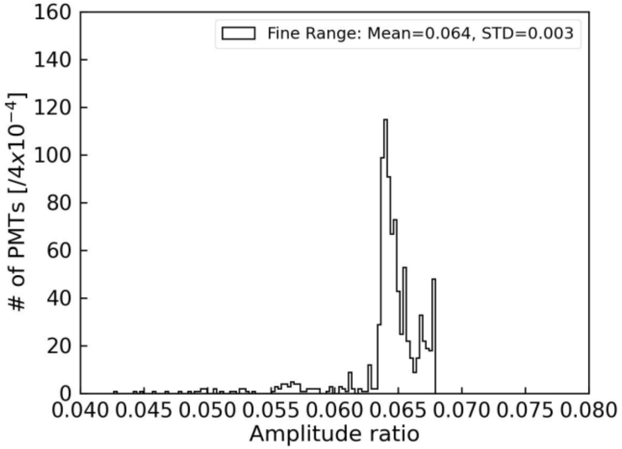
1F3电子学两个量程的过冲幅度比

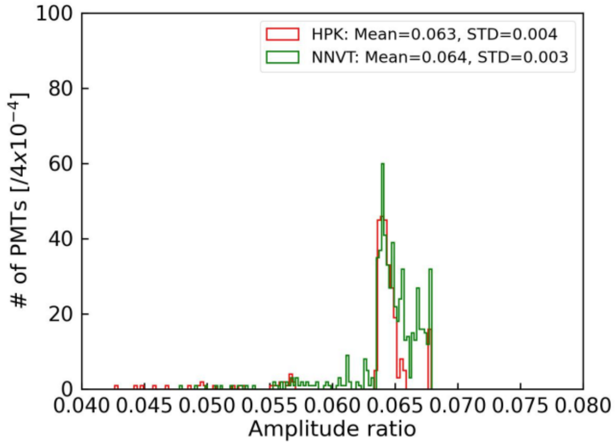
280HPK, 621NNVT

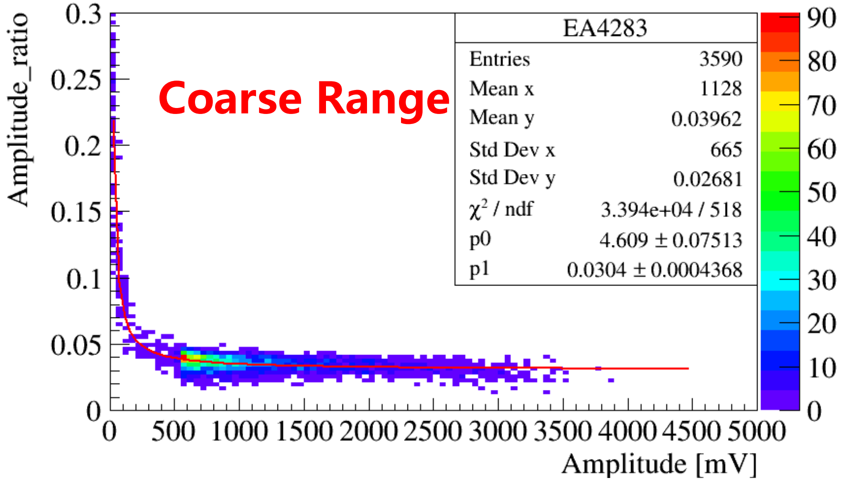


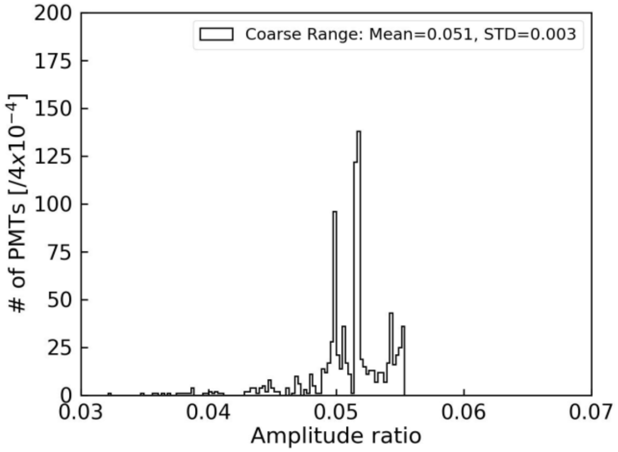
Fit function: Y = A/X + B

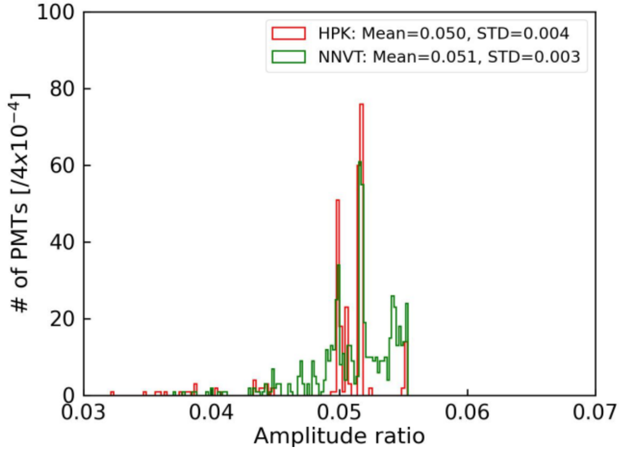








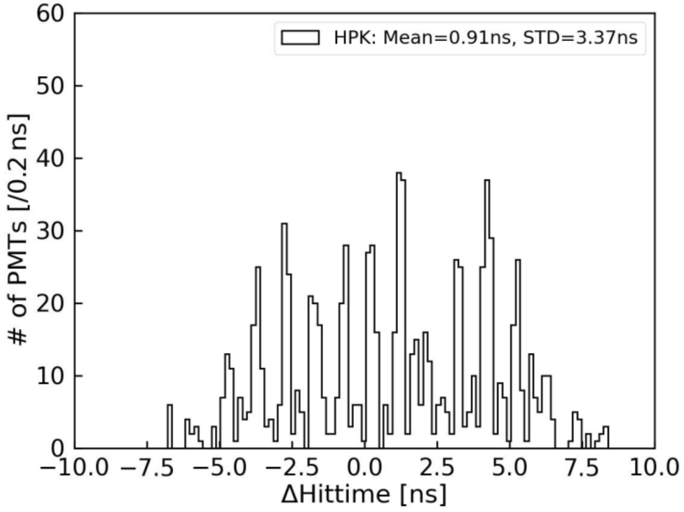


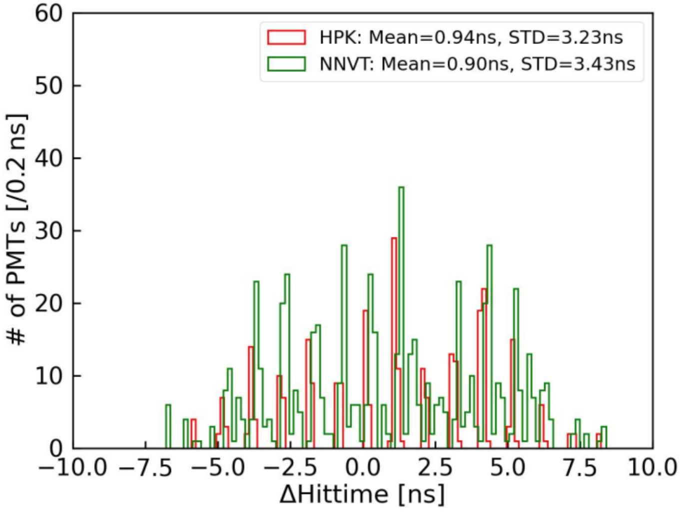


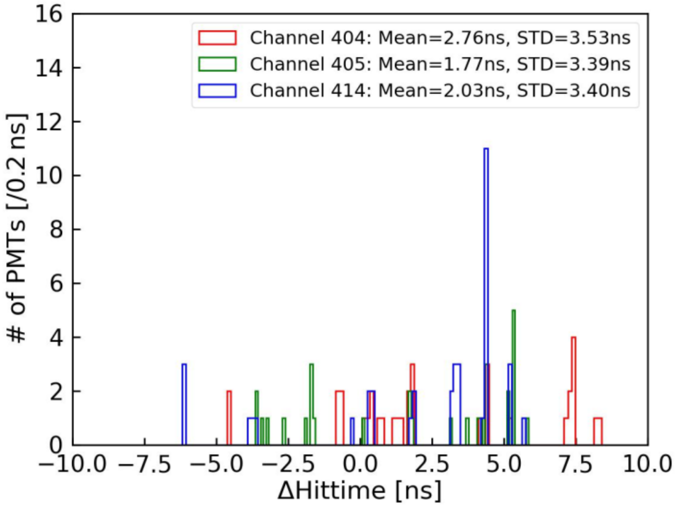
Fine range与coarse range的平均过冲幅度比大约为6.4%与5.1%，其中dynode PMT与MCP PMT的结果基本相同。

1F3电子学两个量程的击中时间差--- ΔHittime

280HPK, 621NNVT







- ➢ 两个量程之间并非严格同步，存在时间差；
- ➢ 同属于同一GCU的三个通道的时间差并不固定；
- ➢ 同一通道的时间差也不固定。

总结

- **20-inch PMT与1F3电子学联合测试分析---外部LED触发**
  - 20英寸PMT与1F3电子学联合测试的SPE幅度大约为8mV；
  - Dynode PMT的DCR为16.6kHz, MCP PMT的DCR更大，为32.4kHz；
  - PMT与1F3电子学和商业电子学测试的大部分性能参数在误差范围内是基本一致的，但前者的过冲幅度比为8%，稍大于后者的6%；

- **20-inch PMT与1F3电子学联合测试分析---PMT自触发**
  - 超过预设阈值的大信号的平均事例数大约为127Hz；
  - Fine range与coarse range的平均噪声水平大约是 0.4mV与2.1mV；
  - 在Fine range的测量范围内，1F3电子学的两个量程的幅度与电荷具有良好的一致性。
  - 随着幅度的增大，dynode PMT比MCP PMT更快地出现幅度与电荷的非线性。
  - Fine range与coarse range的平均过冲幅度比大约为6.4%与5.1%；
  - 两个量程之间存在时间差且并不固定；