



塑料闪烁体反应堆中微子探测器

鹿培志、江涛、罗光等

贺远强 王为

中山大学物理学院·哲生堂公共科研平台

中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会·大连

2022.08.10

目录

- 建设目标
- 建设状况
- 光电倍增管性能测试
- 基于塑料闪烁体的中子伽马波形甄别
- 总结与展望



一. 建设目标

反应堆中微子探测器建设目标

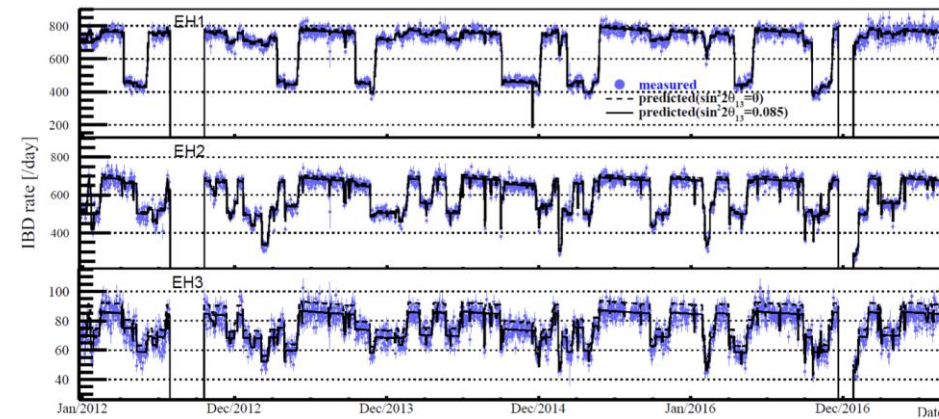
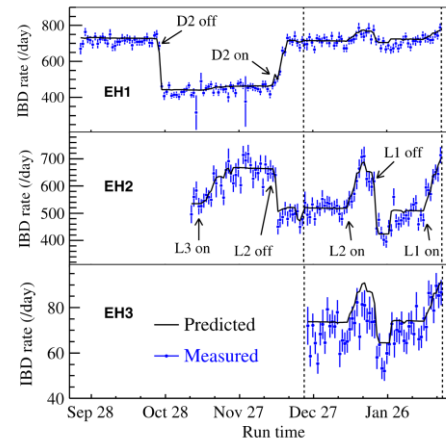
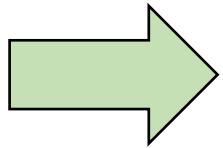
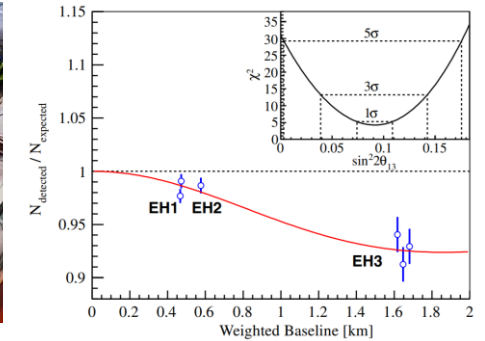
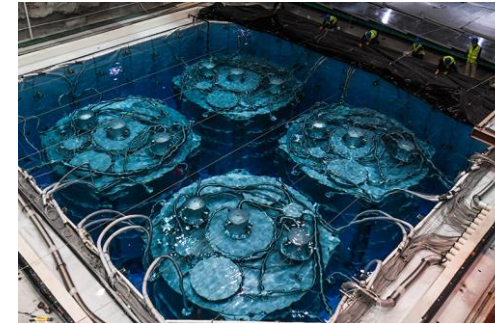
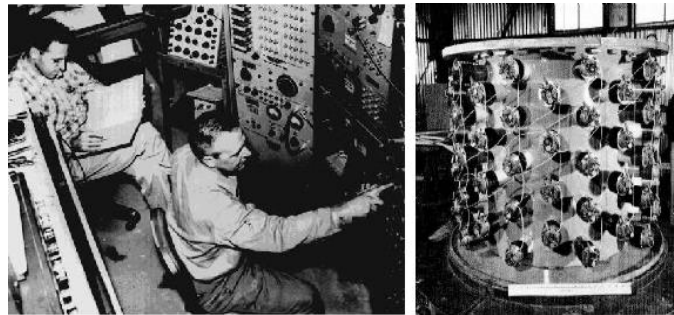


● 反应堆中微子

1930年泡利提出中微子假说

1956年莱因斯和柯温首次发现反应堆中微子

2012年中国的大亚湾中微子实验



中微子流强&反应堆功率

Phys. Rev. Lett. 108, 171803 (2012)

反应堆中微子探测器建设目标



● 中微子探测器建设科学目标

- 反应堆中微子的能谱
- 得到裂变元素的谱分解

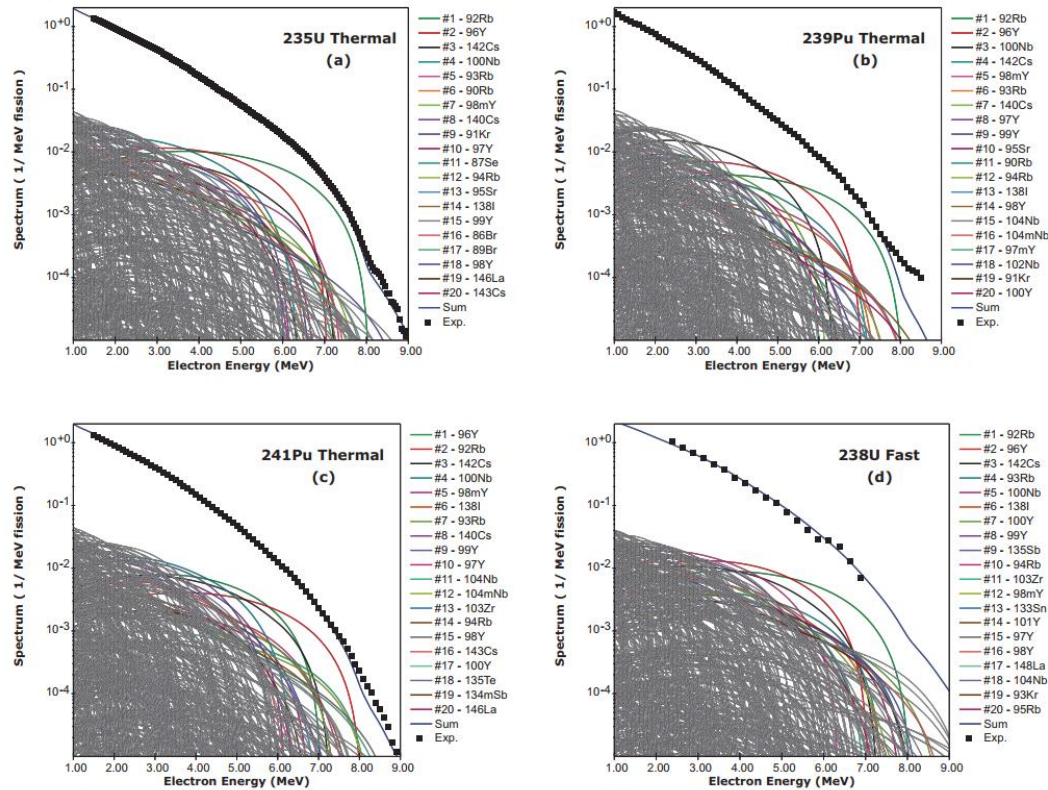
● 中微子探测器建设应用目标

- 反应堆监控

判断反应堆的运行状态...

- 研发新型闪烁体

可用于中子探测



PHYSICAL REVIEW C 91, 011301(R) (2015)



二. 建设状况

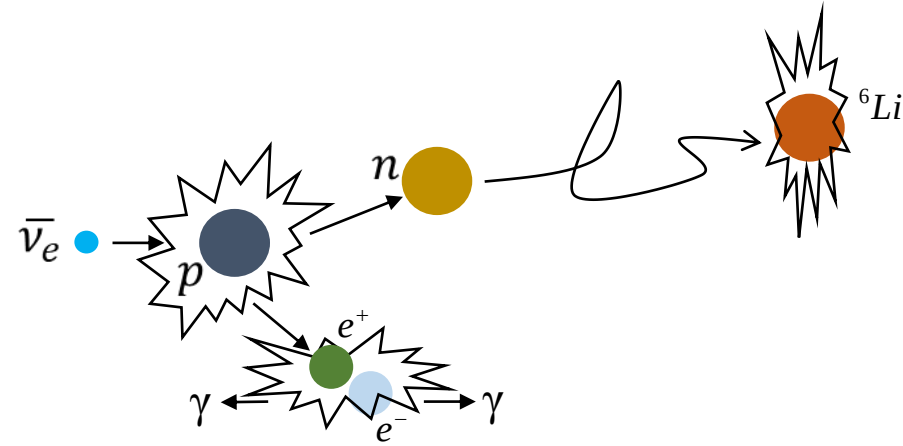
反应堆中微子探测器建设状况



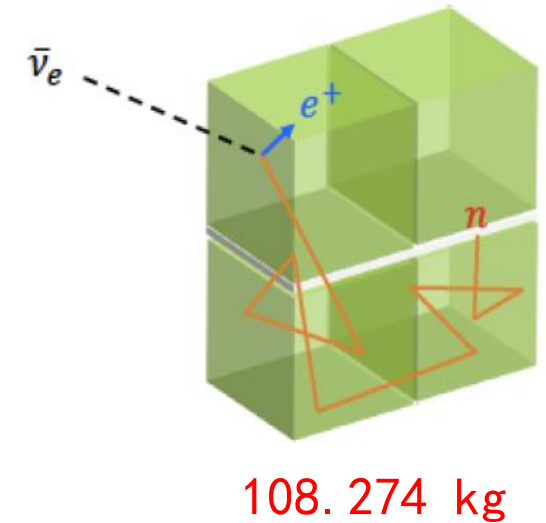
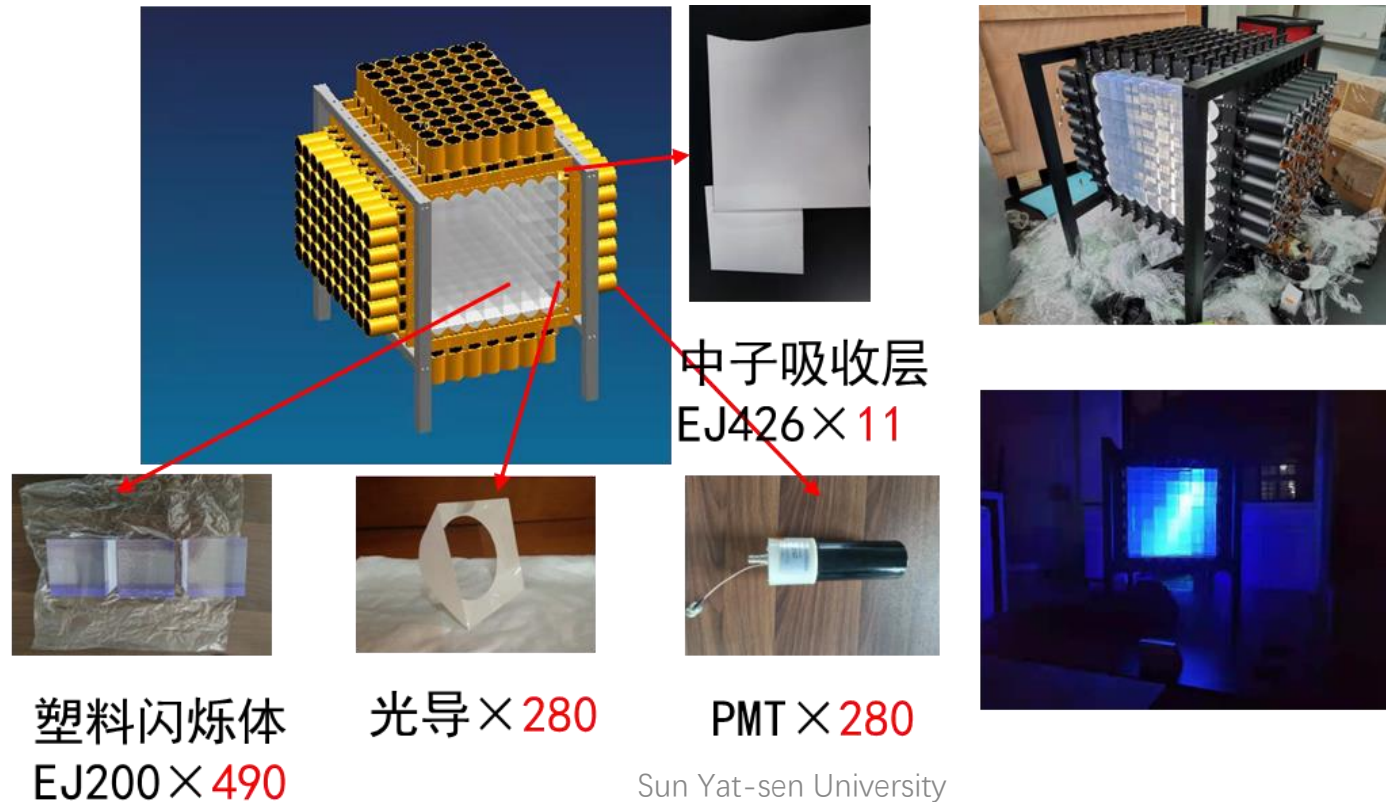
● 探测器反应原理

反 β 衰变:

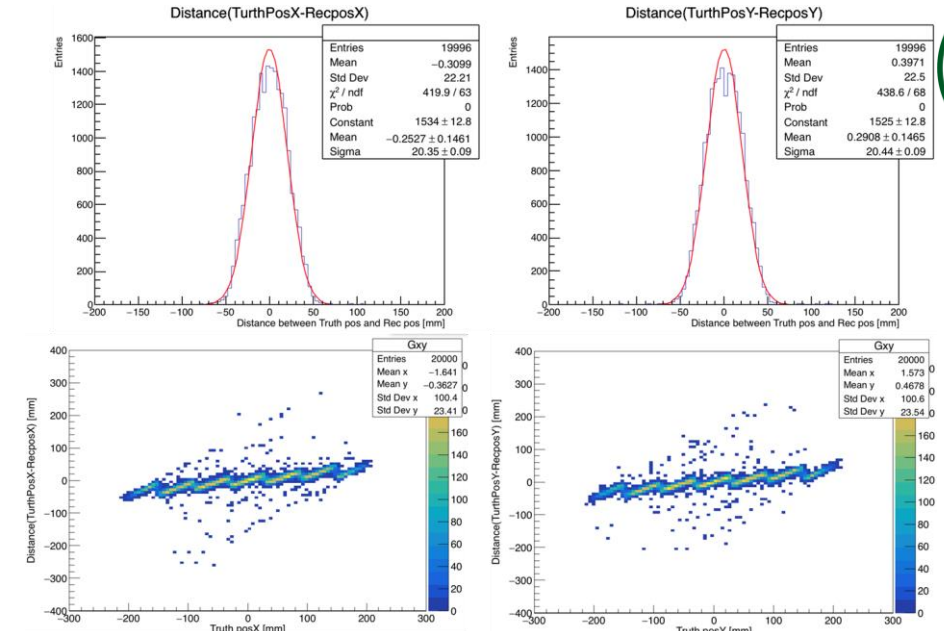
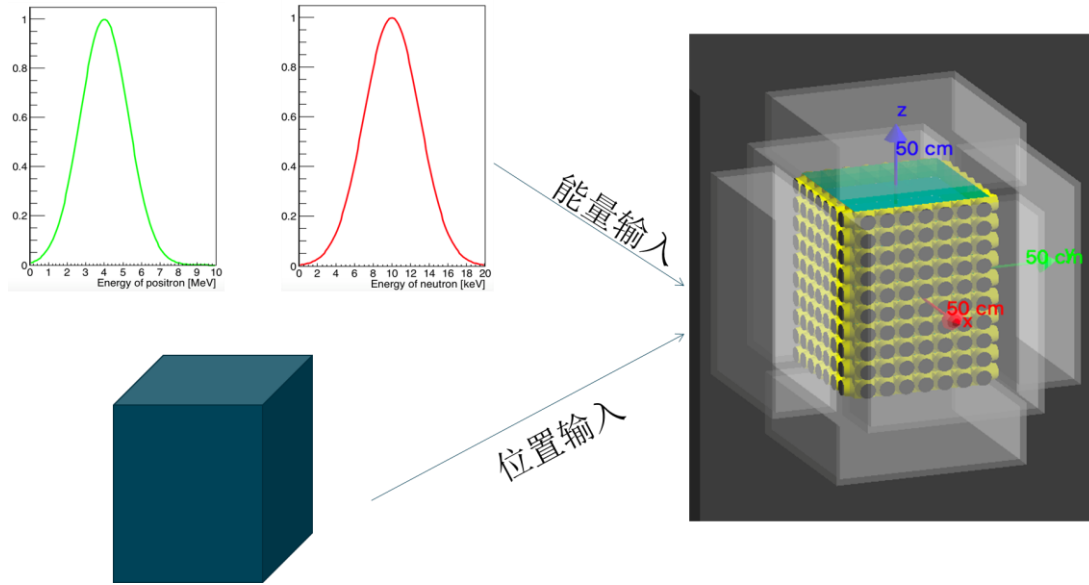
$$\bar{\nu}_e + p \rightarrow n + e^+$$



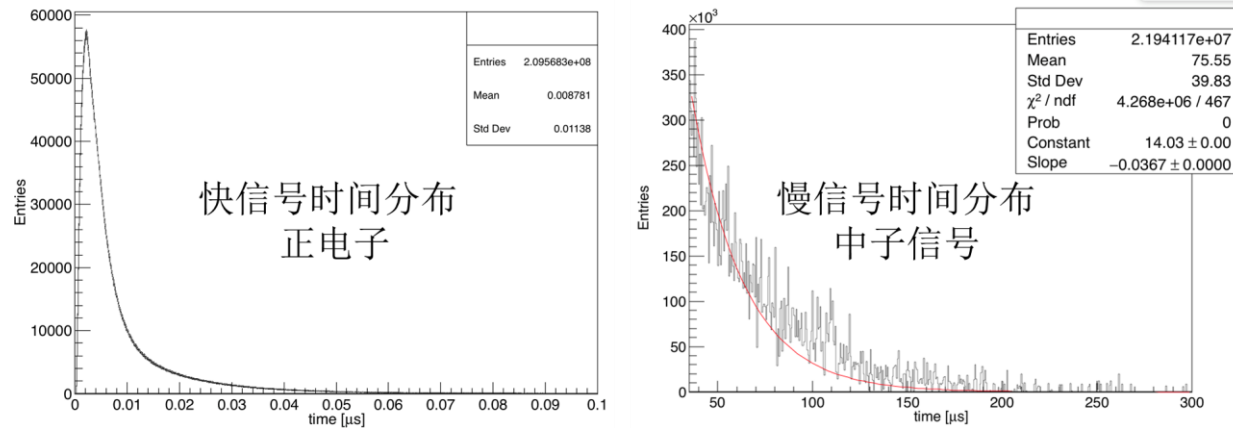
● 探测器结构



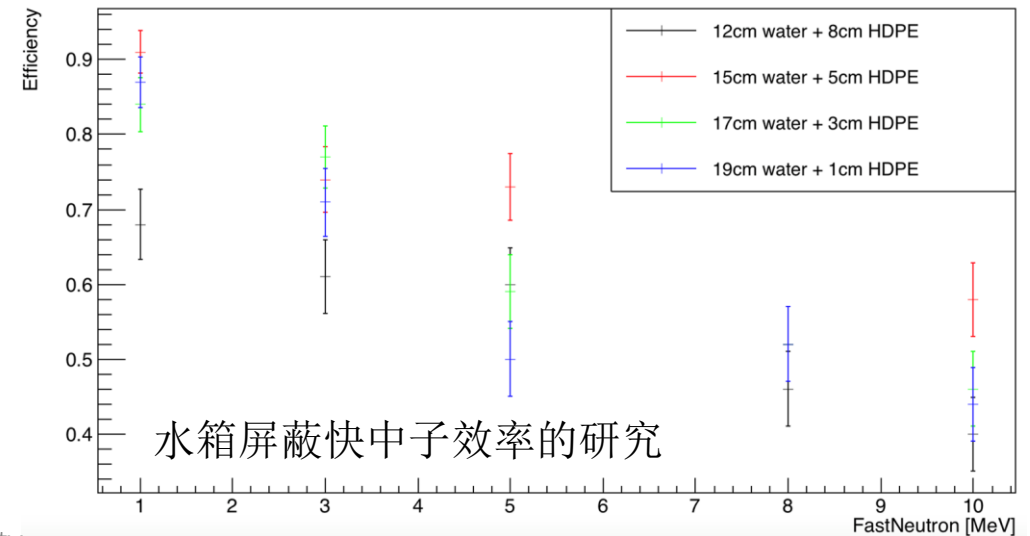
反应堆中微子探测器建设状况



两端PMT得到的光子数为权重重建位置



中间有30微秒时间



水箱屏蔽快中子效率的研究



三. 光电倍增管性能测试

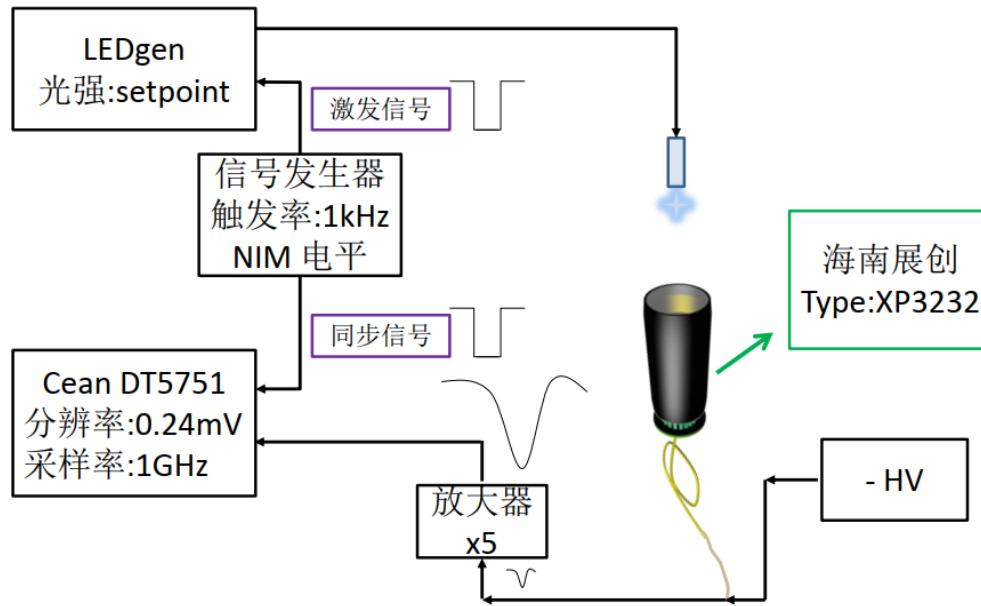
光电倍增管性质测试



●增益刻度

- 单光电子谱

Schematic Diagram



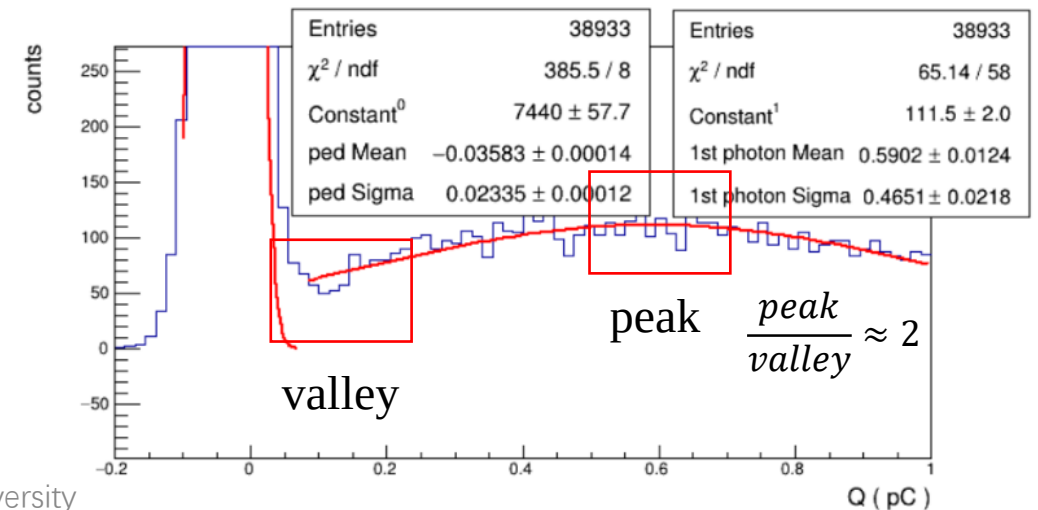
$$\text{电荷积分: } Q = \frac{\int_{t_2}^{t_3} U_{total} dt - \frac{\int_{t_0}^{t_1} U_{baseline} dt}{t_1 - t_0}}{R}$$



暗室中的PMT图



实验仪器图



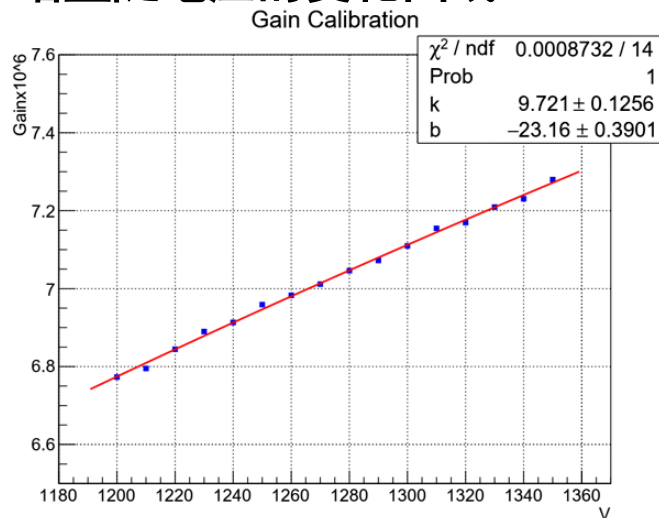
●增益刻度

在找出单光子峰以后，利用公式：

$$G = \frac{\int U dt}{R \cdot e}$$

其中 G 为增益， e 为单位电荷

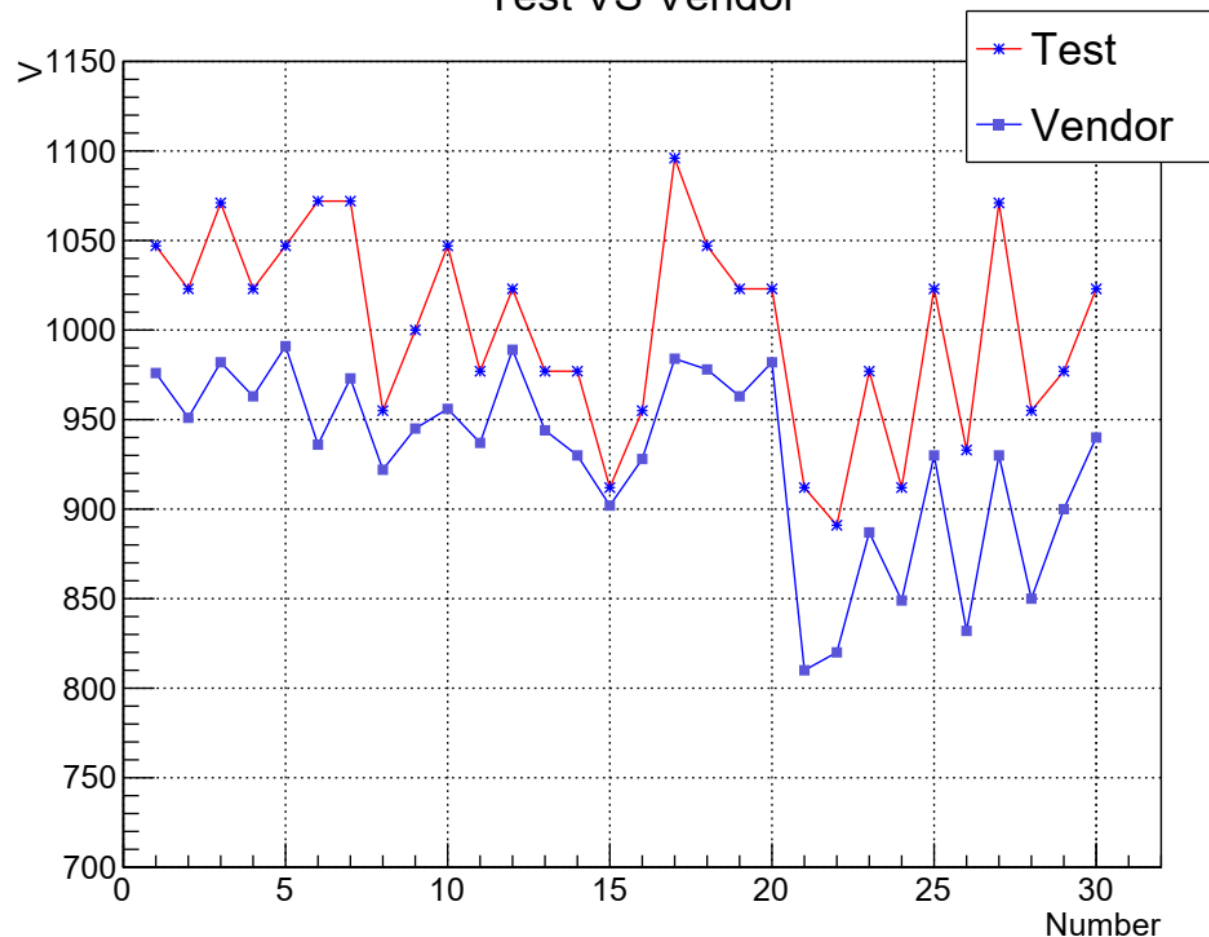
增益随电压的变化曲线



$$\lg(\text{Gain}) = 9.721 \lg(\text{HV}) - 23.16$$

2022/8/8

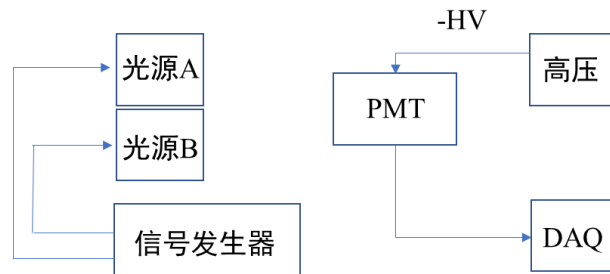
Test VS Vendor



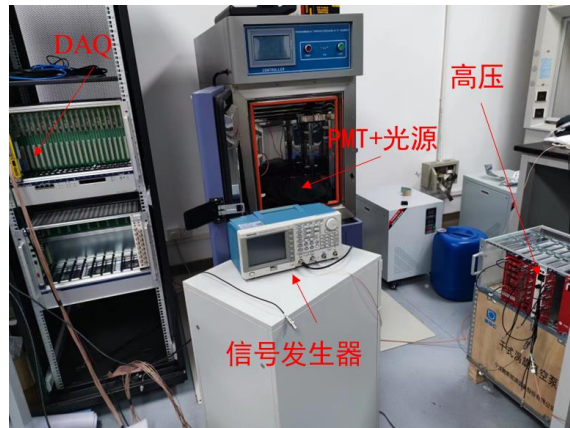
实验测试的30只PMT增益 (@Gain70e4) 并与厂家数据进行比较

● 阳极非线性测试

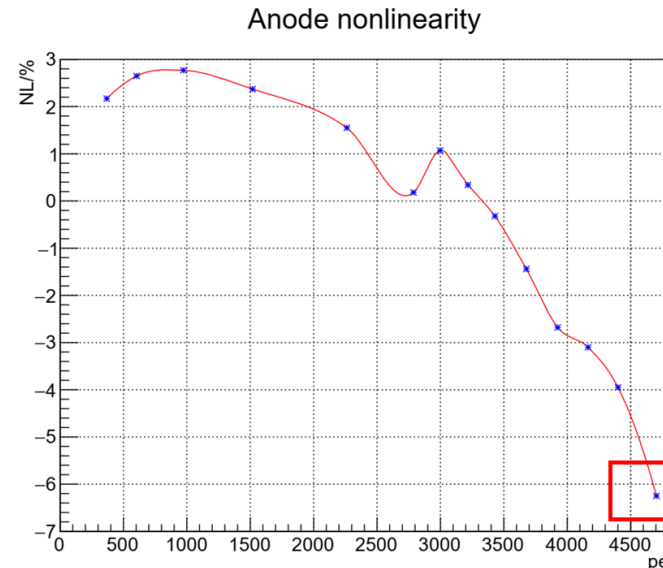
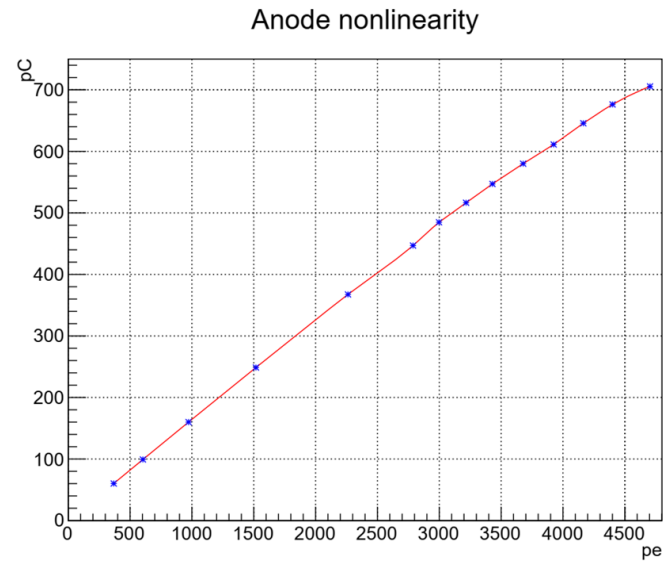
方法：利用“A-B”法测量。
用信号发生器提供脉冲信号（10kHz，25ns）



非线性测试示意图



非线性测试实验图



$$NL = \frac{Q_{AB} - (Q_A + Q_B)}{Q_A + Q_B} \times 100\%$$

4704, -6.25%



四. 基于塑料闪烁体的中子伽马波形甄别

基于塑料闪烁体的中子伽马波形甄别



● 实验原理

快中子和伽马在塑闪里面产生的次级粒子激发塑闪退激后发光分快慢两种信号

● 实验物品及装置

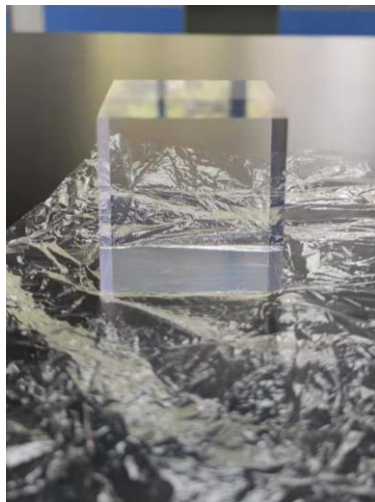


AmBe中子源

2022/8/8



EJ276塑闪



EJ200塑闪



EJ426薄片

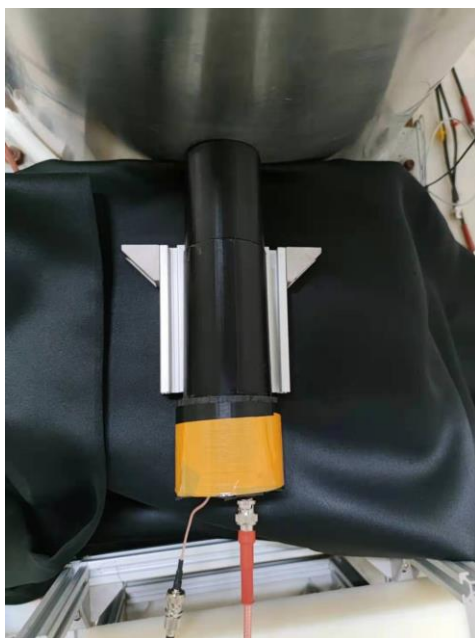
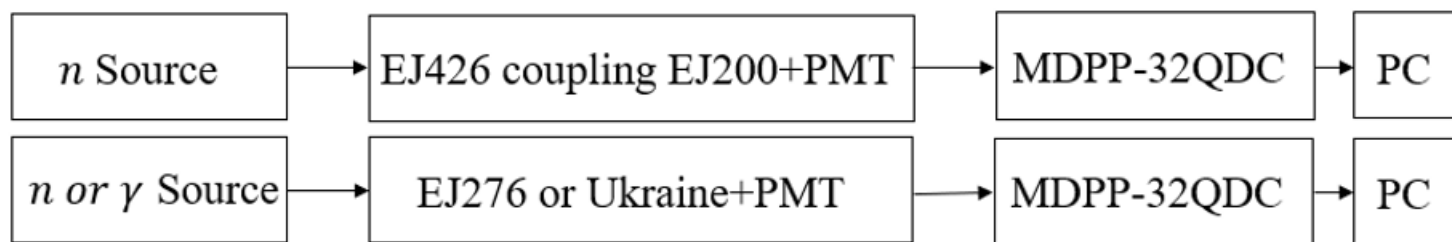


封装模具

基于塑料闪烁体的中子伽马波形甄别



● 实验过程



实验测试图1

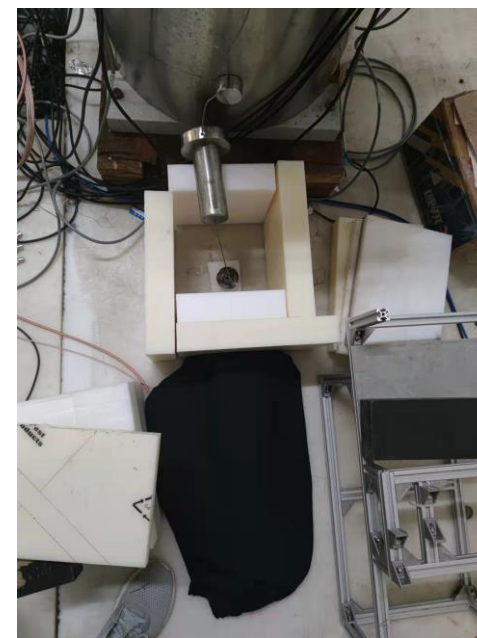
2022/8/8



实验测试图2



实验测试图3



实验测试图4

基于塑料闪烁体的中子伽马波形甄别



● 实验结果

• 能量刻度

对采集器进行能量刻度选择的是Cs137和Na22

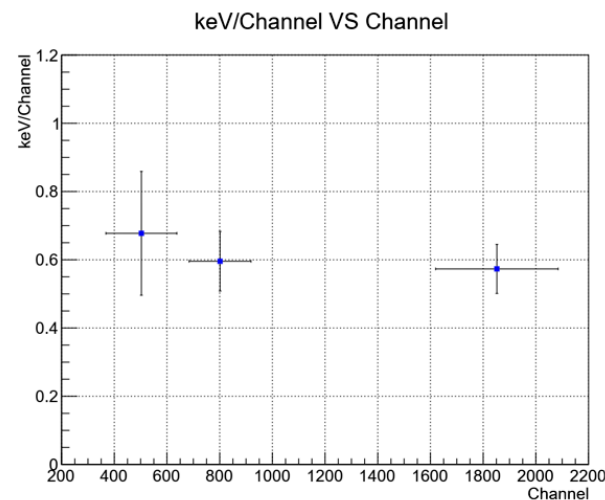
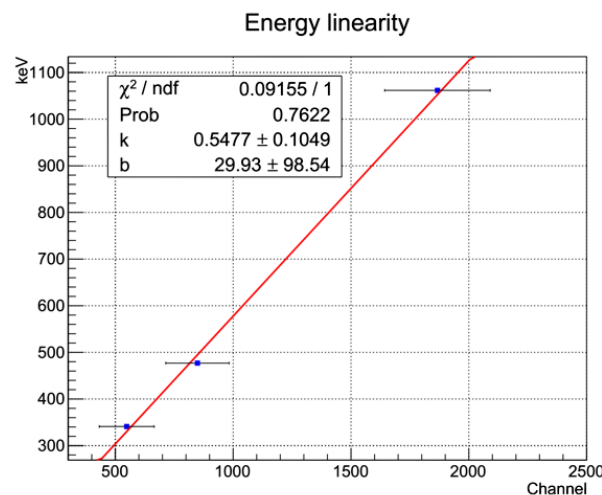
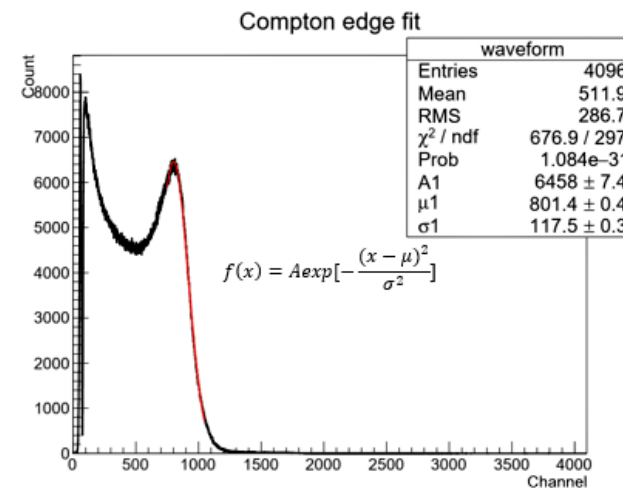
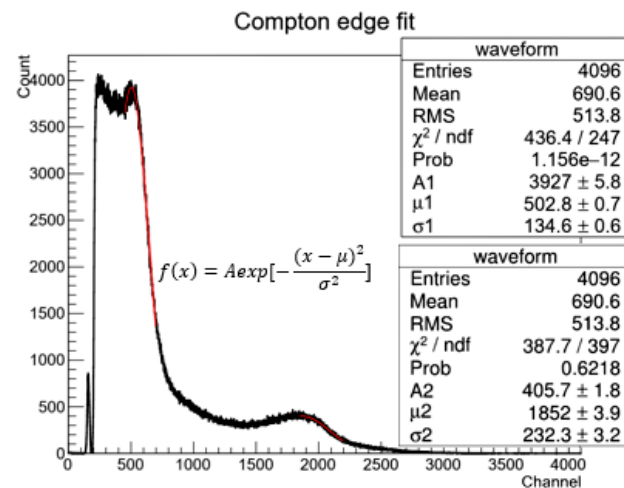


Cs137



Na22

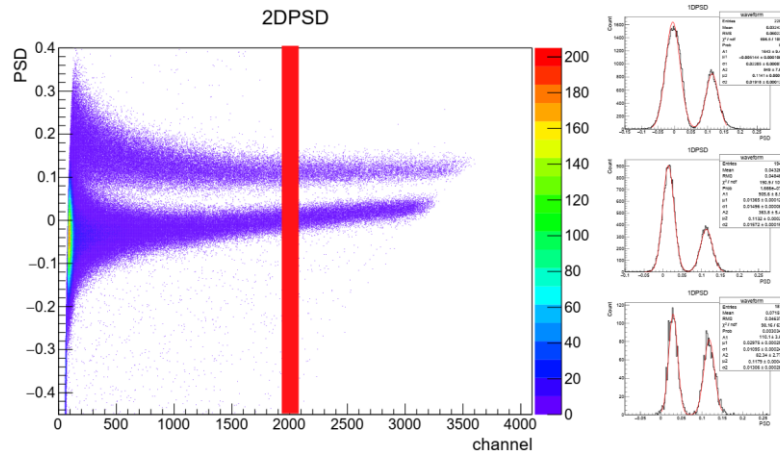
EJ276



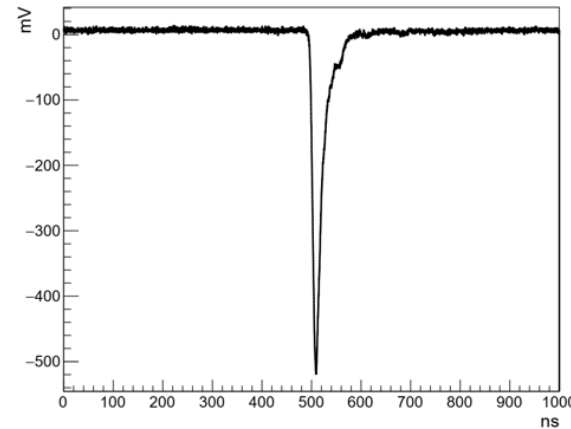
基于塑料闪烁体的中子伽马波形甄别



- 两种快中子伽马波形甄别(PSD)塑闪结果



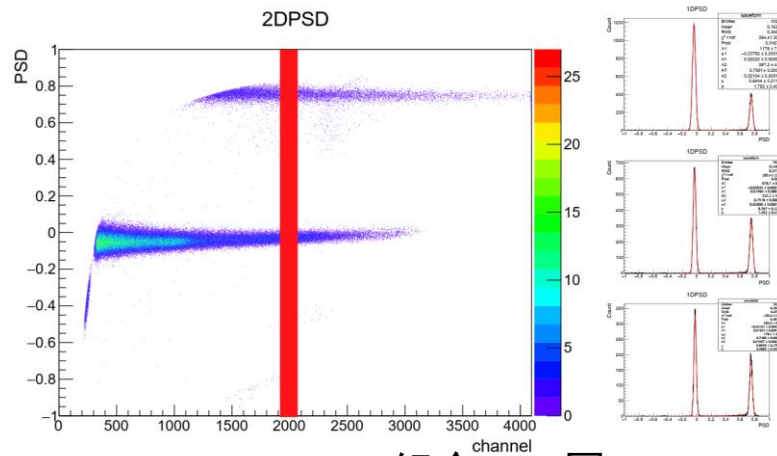
EJ276 PSD图



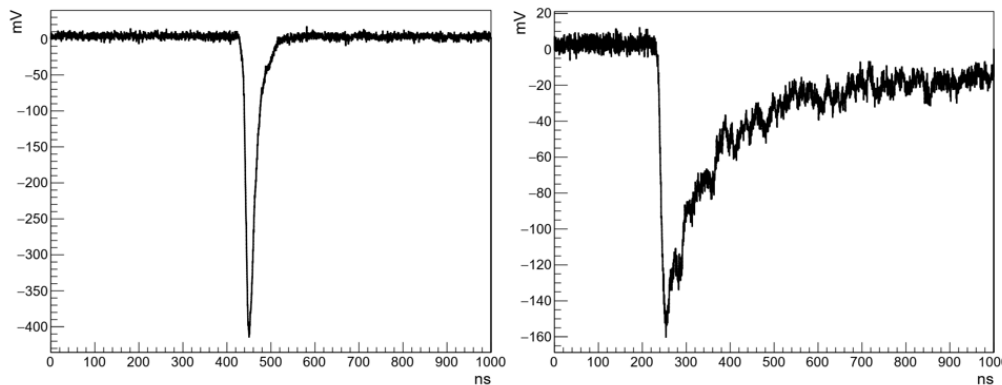
EJ276 波形图

选取1MeV的能量阈值

$$FOM = \frac{S_n - S_\gamma}{FWHM_n + FWHM_\gamma} = 1.35 \pm 0.01$$



EJ200EJ426组合 PSD图



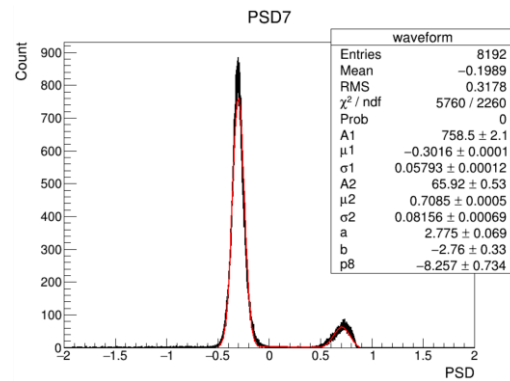
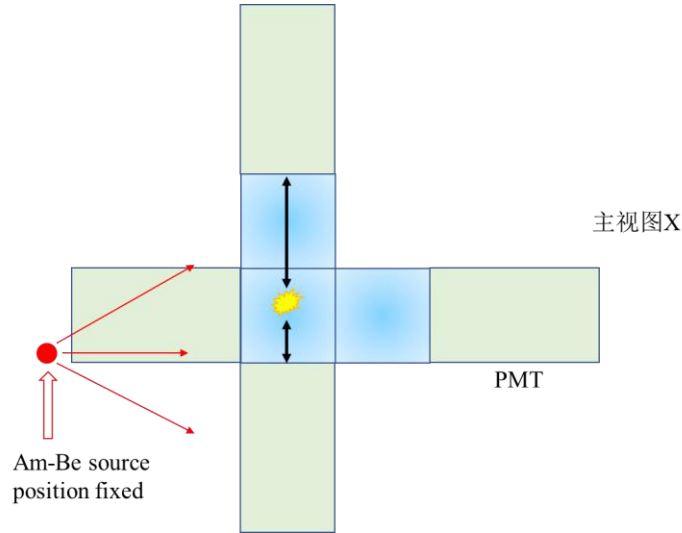
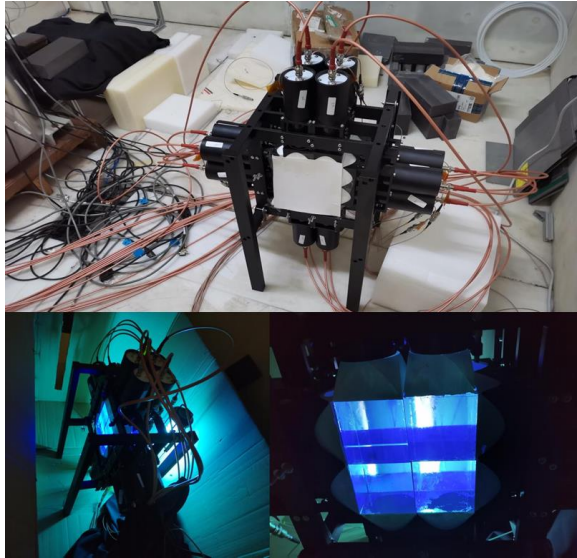
EJ200 (左) 和 EJ426 (右) 波形图

$$FOM = \frac{S_n - S_\gamma}{FWHM_n + FWHM_\gamma} = 6.61 \pm 0.01$$

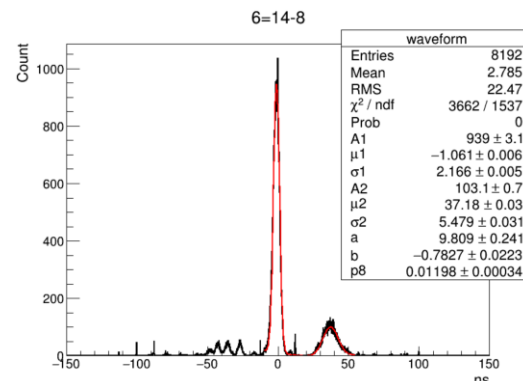
基于塑料闪烁体的中子伽马波形甄别



2×2×2阵列



FOM=3.08 ± 0.01



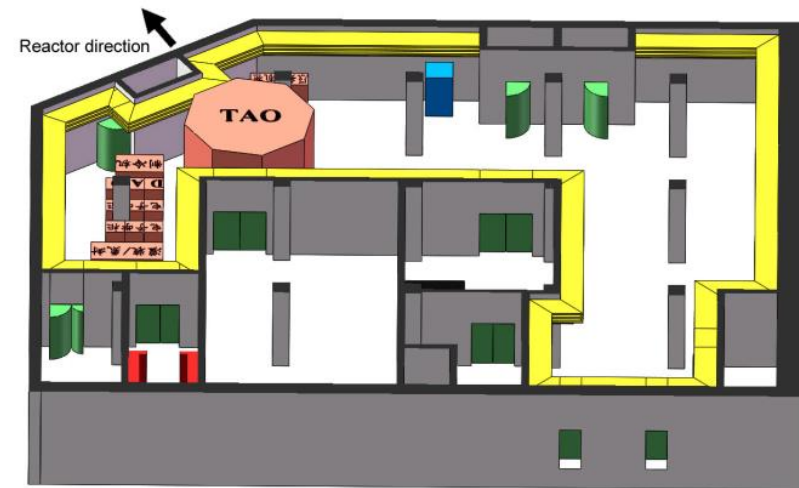
到达时间

核电站周边

200IBD/year/ton/GW@1km
2×4.6GW, 30m, 560IBD/day

9.6m

Muon rate	70 Hz/m ²
Singles from radioactivity	< 100 Hz
Fast neutron background after veto	< 200 events/day
Accidental background rate	< 190 events/day
⁸ He/ ⁹ Li background rate	~ 54 events/day



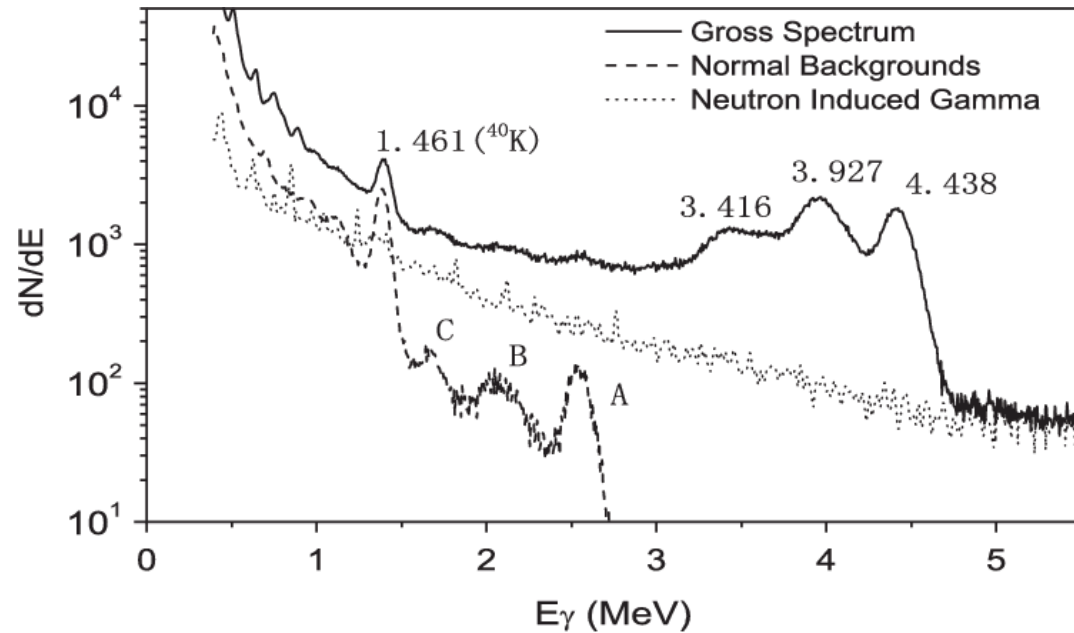
arXiv-prints, art. arXiv:2005.08745, May 2020.



- 中山大学团队正在开发应用性反应堆中微子测器
- 通过对PMT增益的刻度，保证了探测器增益的一致性，而对PMT阳极非线性的测试，可以更加明确增益的选择
- 通过比较两种塑闪对于中子伽马的甄别能力，选择了可以提高探测器空间分辨率和更有效的测量中微子事例的EJ200和EJ426组合方式作为探测器标靶系统
- 下一步计划把探测器安装在反应堆30米距离进行数据采集

谢 谢 !

Back up



A: 2.615 MeV (^{208}Tl from ^{232}Th series)
B: 2.204 MeV, C: 1.764 MeV (^{214}Bi from ^{226}Ra series)

[Backgrounds and Am-Be source g-rays spectrum. | Download Scientific Diagram researchgate.net](#)

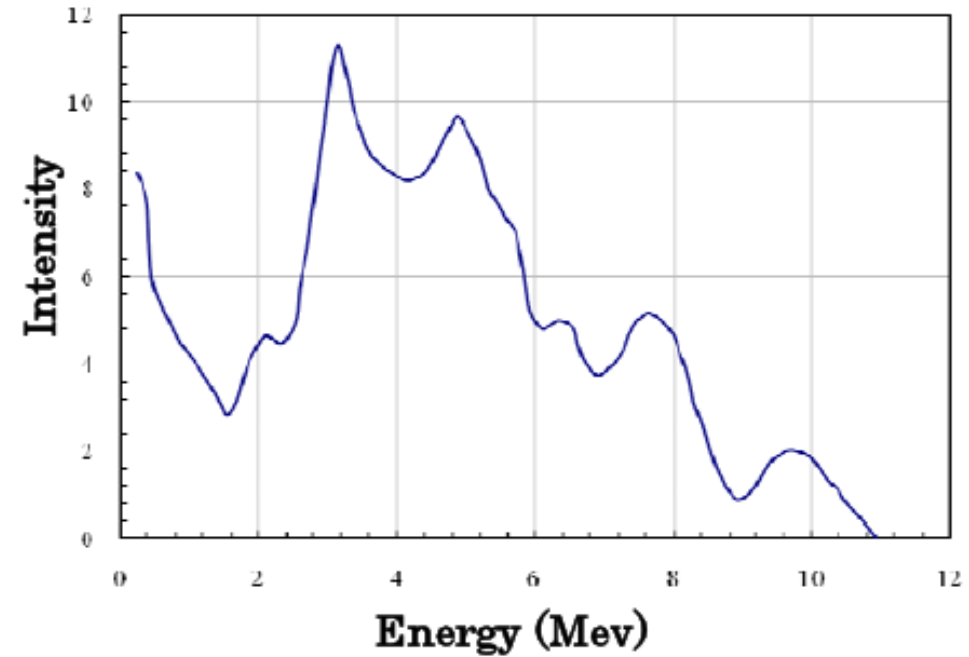


Figure 1. The neutron energy spectrum of Am-Be source.

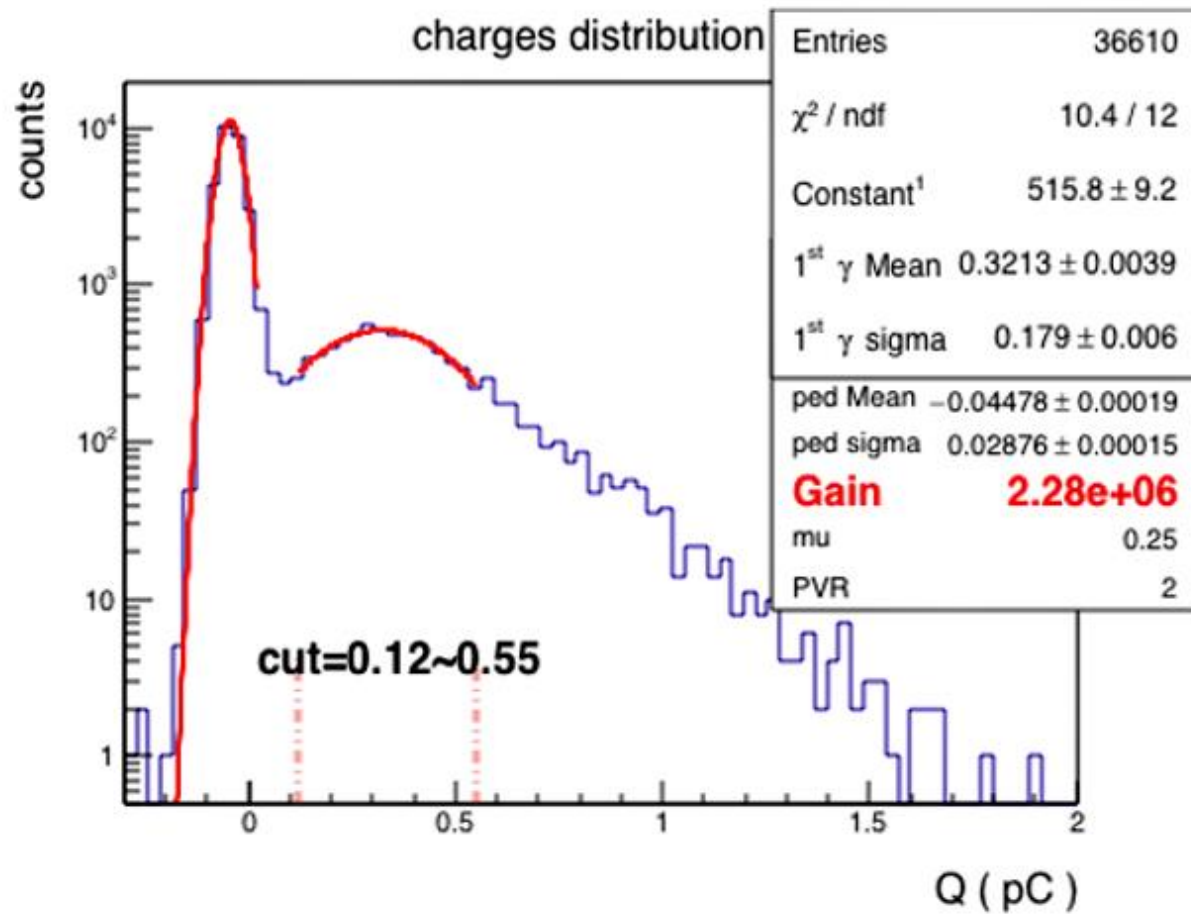
[The neutron energy spectrum of Am-Be source. | Download Scientific Diagram researchgate.net](#)

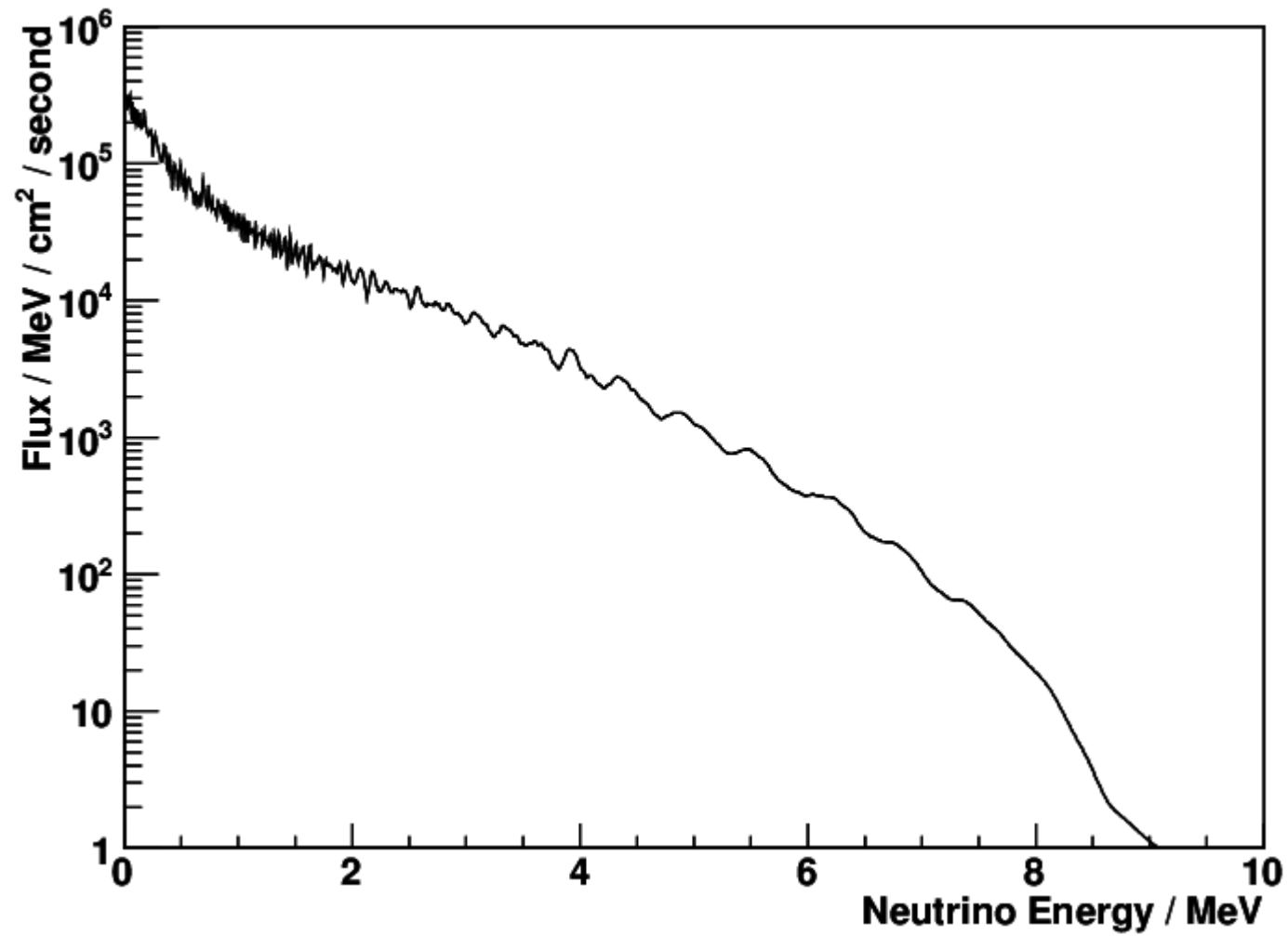
Photocathode characteristics

Spectral range :			290-650	nm
Maximum sensitivity at :			420	nm
Sensitivity ① :	Luminous :		80	μA/lm
†	Blue :	min.: 9	typ.: 11.5	μA/lmF
	Radiant, at 420 nm :		typ.: 80	mA/W

Characteristics with voltage divider A

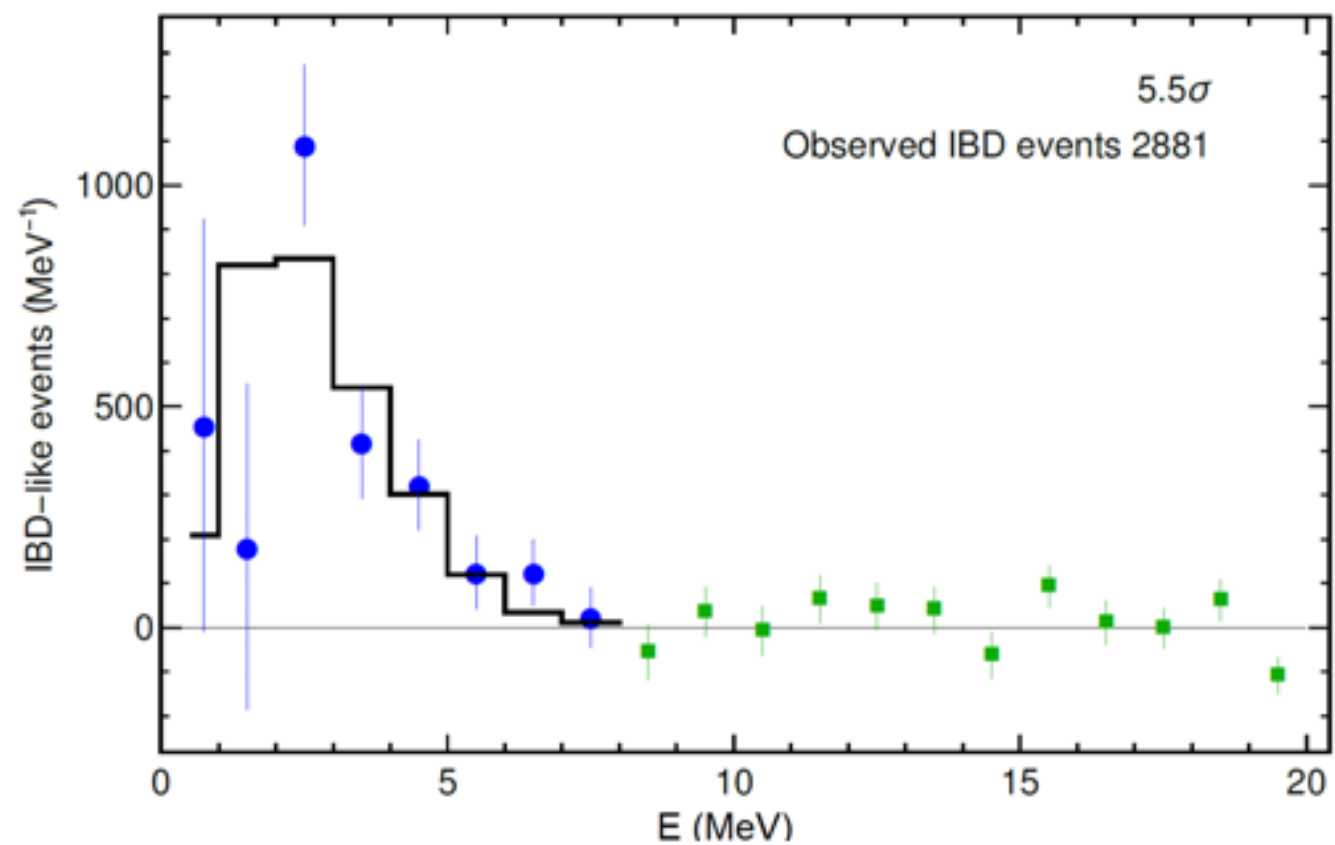
Gain slope (vs supp. volt., log/log) :			7.5	
For an anode blue sensitivity of :			7.5	A/lmF
† Supply voltage :	max.:1100 min.: 800	typ.: 950		V
Gain		typ.: 7x10 ⁵		
† Anode dark current ② :	max.: 10	typ.: 1		nA
Pulse height resolution ¹³⁷ Cs ③ :		typ.: 7.5		%
† Pulse height resolution ⁵⁷ Co ④ :	max.: 9.3	typ.: 8.8		%
Single electron spectrum Peak to Valley ratio		typ.: 2.0		
Mean anode sensitivity deviation ⑤ :				
	long term (16 h) :		1	%
	after change of count rate :		1	%
	vs temperature between 0 and +40°C at 420 nm :		- 0.3	%/K
For a supply voltage of :			1200	V
	Linearity (2%) of anode current up to :		20	mA
	Anode pulse rise time ⑥ :		5	ns
	Anode pulse duration at half height :		12	ns
	Signal transit time :		48	ns
Capacitance	anode to all		5	pF





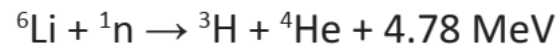
Beacom J F, Chen S, Cheng J, et al. Letter of intent: Jinping neutrino experiment[J]. arXiv preprint arXiv:1602.01733, 2016.

CHANDLER (美国)



EJ-426 is an efficient detector for thermal neutrons with low sensitivity to gamma radiation. The detector has the form of a flat, white, thin sheet consisting of a homogeneous matrix of fine particles of lithium-6-fluoride (^6LiF) and zinc sulfide phosphor (ZnS:Ag) compactly dispersed in a colorless binder. The lithium is enriched in ^6Li to a minimum of 95 atom percent.

The neutron detection process employs the nuclear reaction $^6\text{Li} (n, \alpha) ^3\text{H}$:



with a cross section of 941 barns for 0.025 eV neutrons. The resulting triton and alpha particle are detected by ZnS:Ag phosphor with the broad blue fluorescent spectrum shown below. The decay time of the prompt scintillation component is 200 ns.

