



中国科学院高能物理研究所

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基于纯 CsI 的中微子相干探测在 40K 低温下的 SiPM 特性表征

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- CEvNS: 中微子相干弹性散射
- 理论预测大约在50年前, 2017年得到证实

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Coherent effects of a weak neutral current

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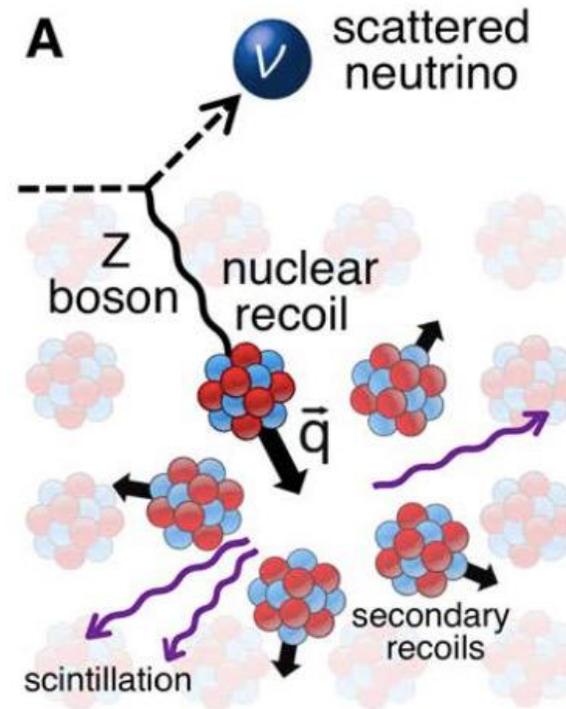
Science

REPORTS

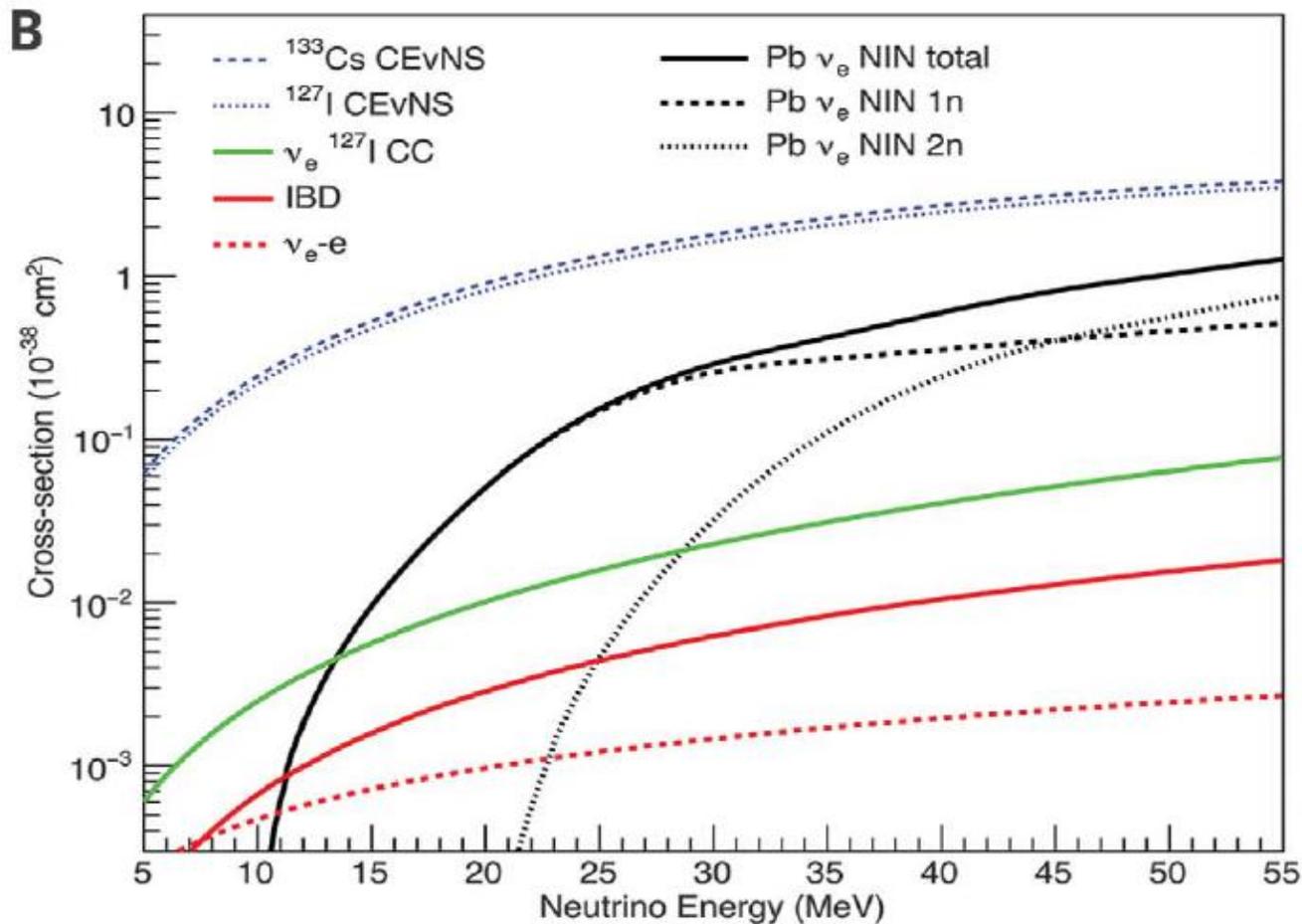
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Observation of coherent elastic neutrino-nucleus scattering

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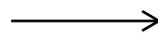


- 大截面
- 中微子探测器尺寸小型化

Science 357, 1123–1126 (2017)

硅光电倍增管(SiPM)作为低温纯 CsI 中微子相干探测的核心光电传感器，其工作性能直接决定闪烁体光产额的测量精度。我们前期的研究在液氮温度下使用纯 CsI 闪烁体和 SiPM 读出，光产额是常温下的 3 倍，预计它在 40K 温度下的性能会更好。然而在 40K 温区的性能特征仍有待探索。

- 自主搭建了一套 30K 至 293K 可调温控系统，以研究 SiPM 在不同温度下的关键性能参数。
- 重点考察了 40K 温区下 SiPM 的关键性能参数，以评估其在该温区用于光产额测量的可行性。



DCR 在低温下大幅度下降，获得了3款SiPM (Broadcom, Hamamatsu, NDL) 在不同温度下的参数变化趋势以及最佳工作条件。

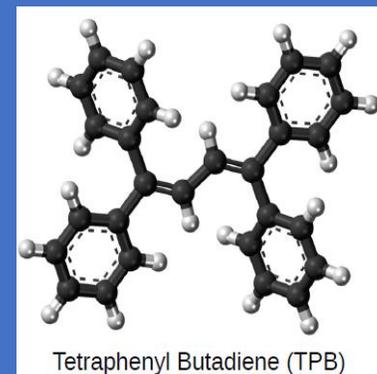
Cryogenic CsI+SiPM+TPB



CsI

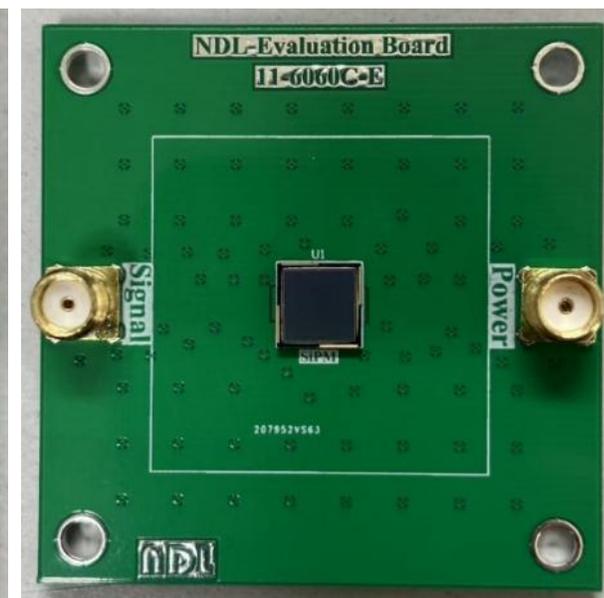
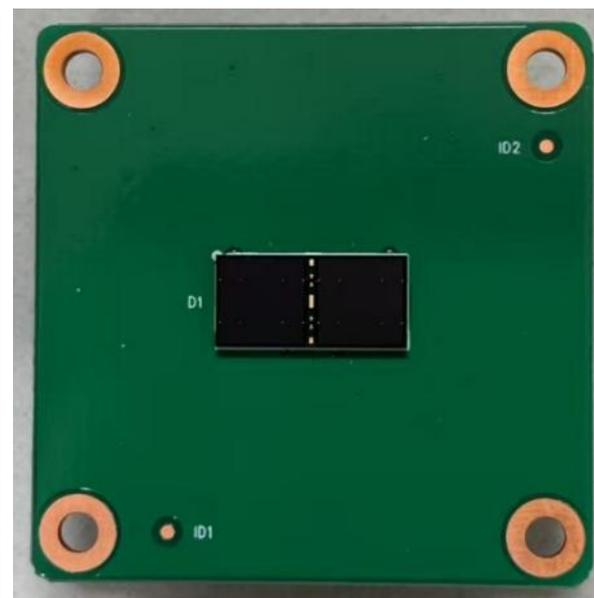
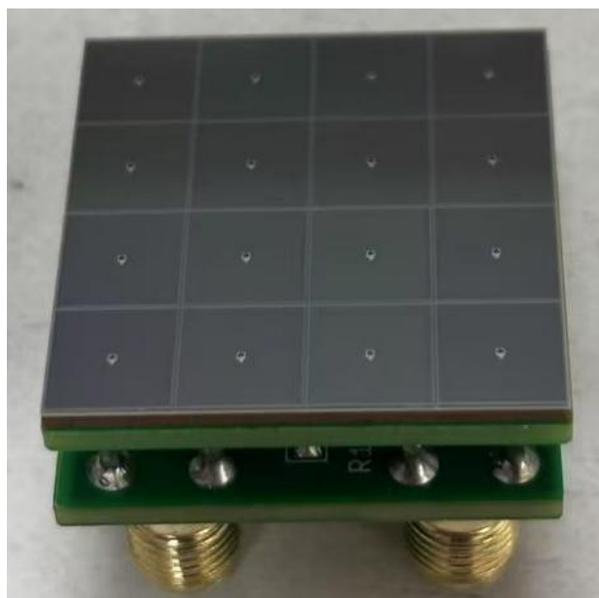
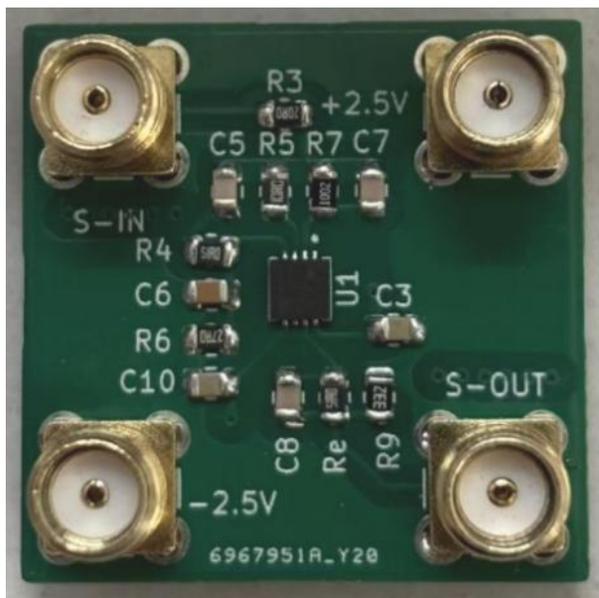


SiPM



TPB (WLS)

Low temperature (20~40K)

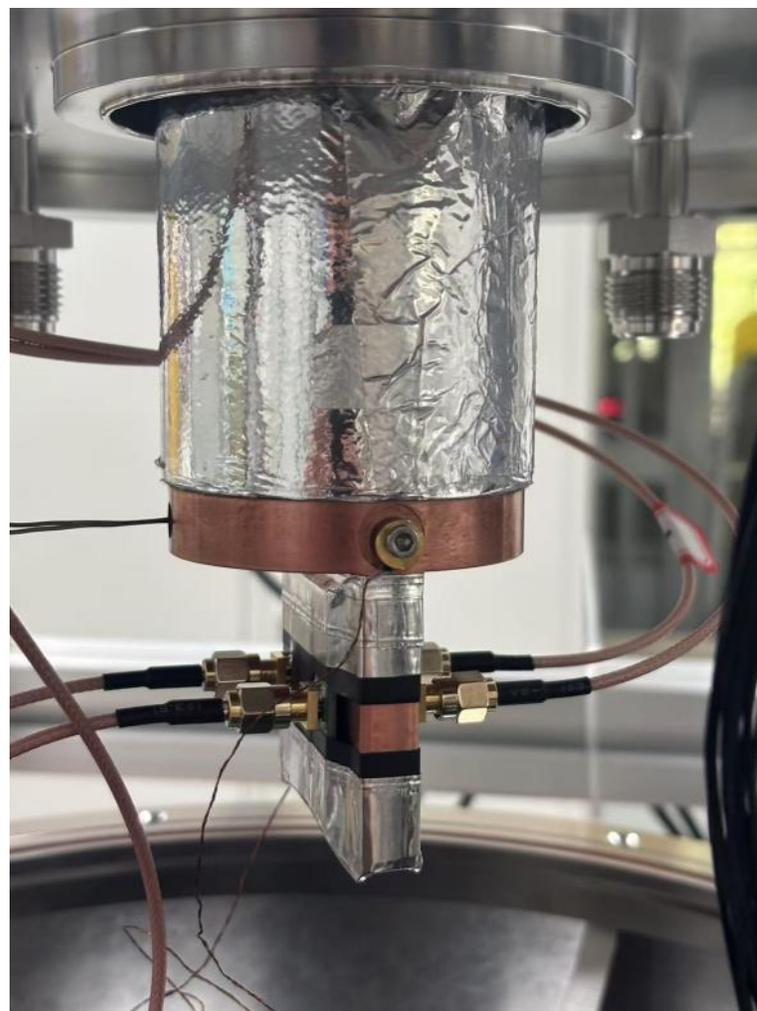


3款 SiPM

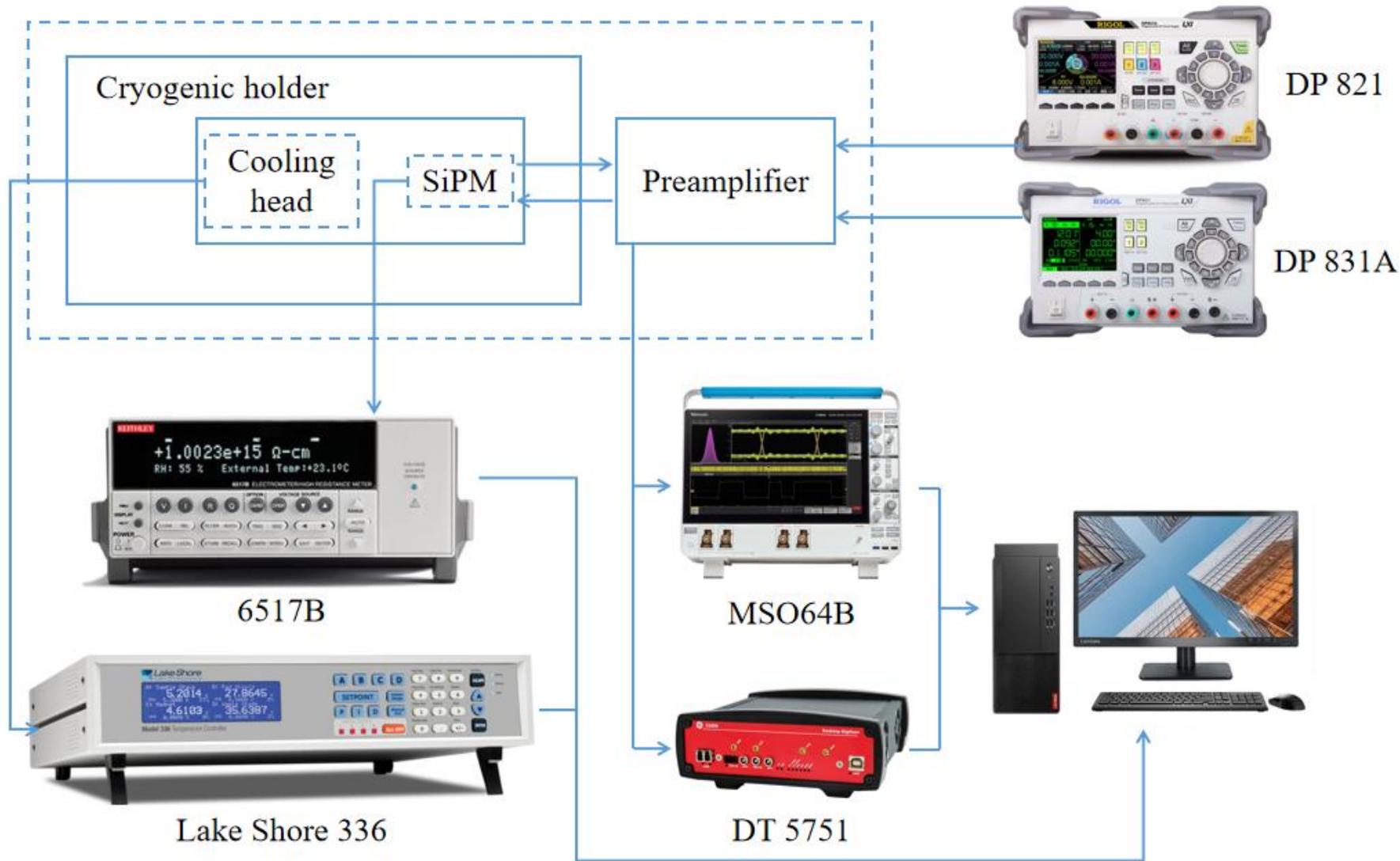
Hamamatsu S14161-6050HS-04

Broadcom AFBR-S4N66P024M 2×1

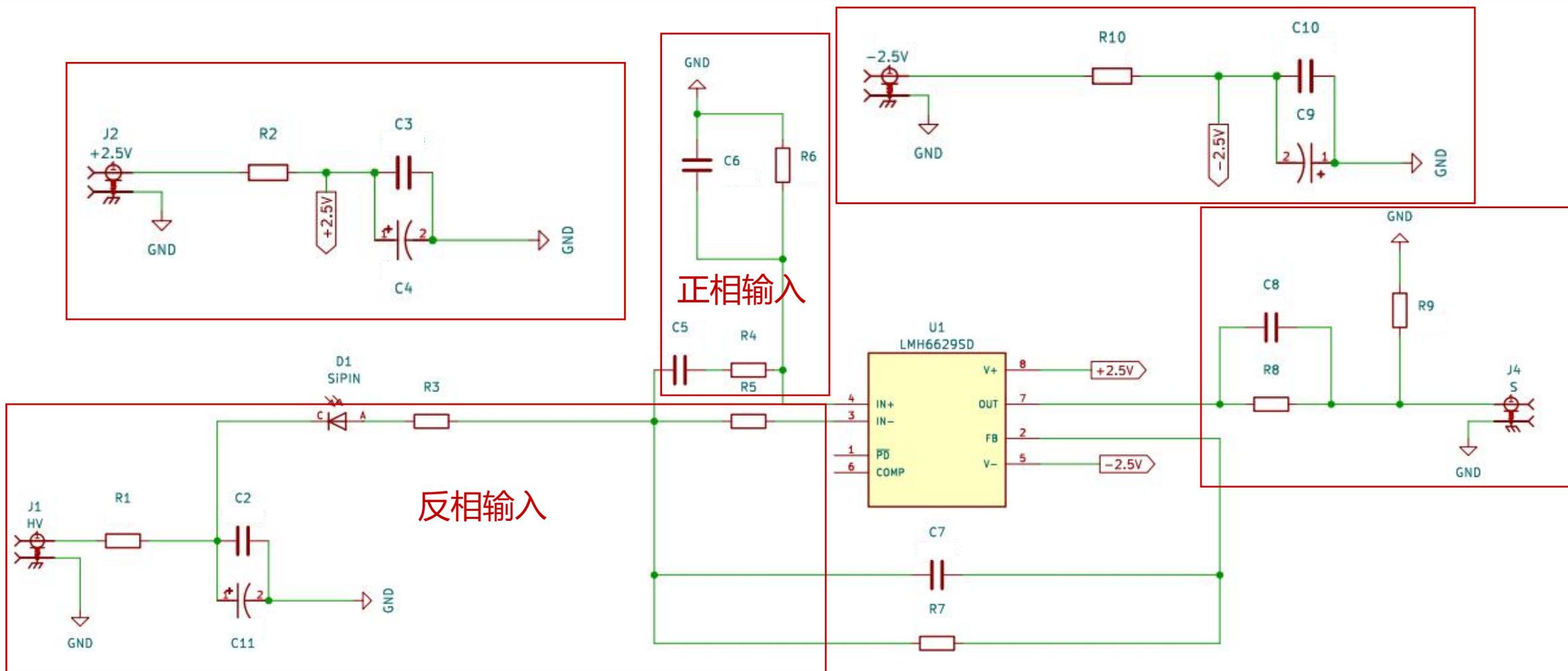
NDL EOR20 11-6060-E-P



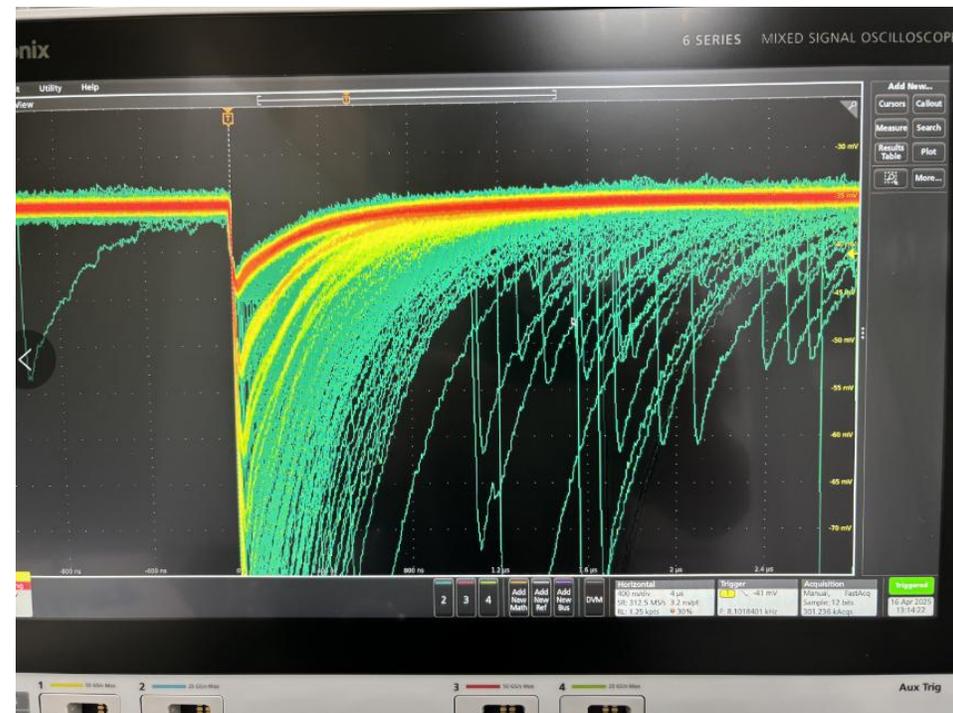
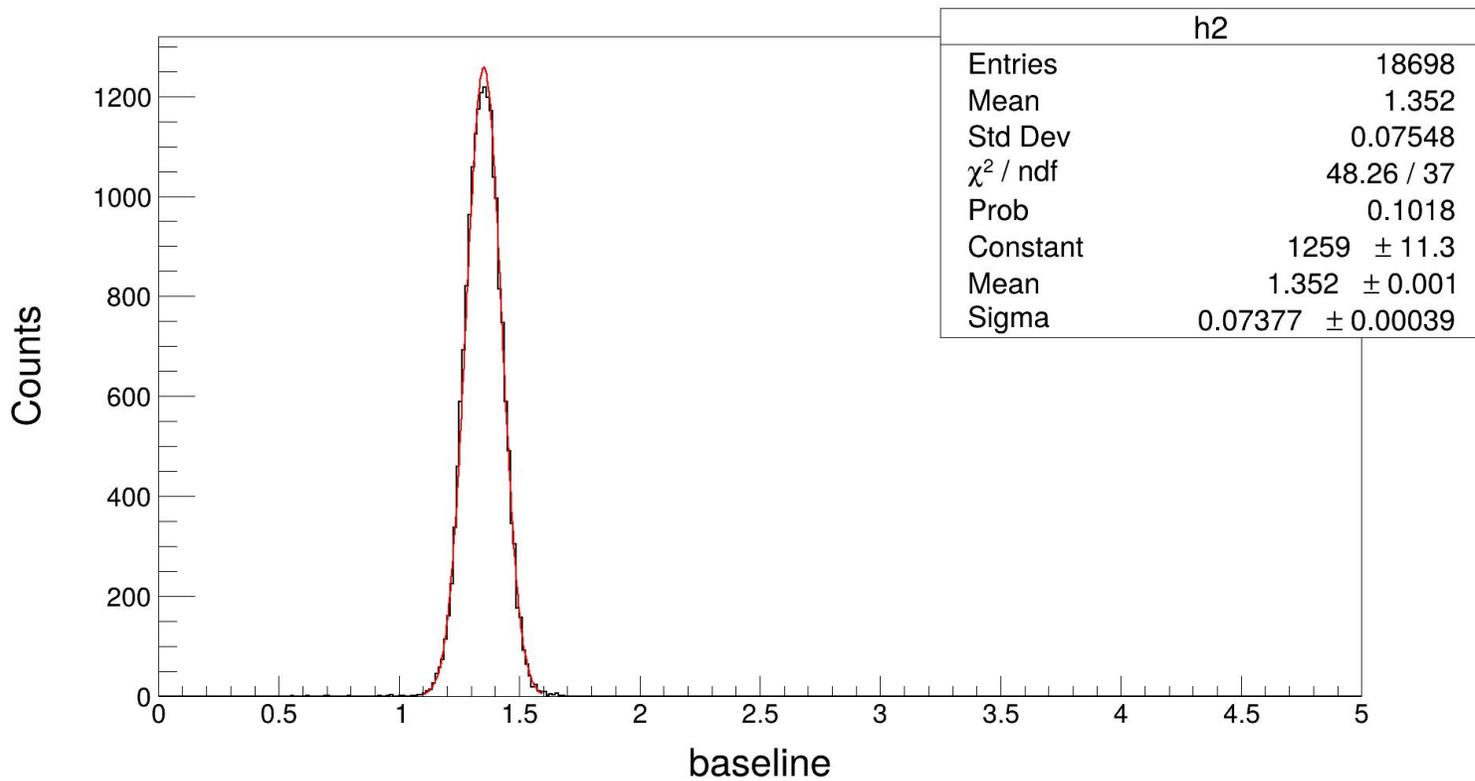
- 将同型号 SiPM 对称安装于冷盘两侧。
- 通过双通道数据比对，降低单点测量误差，提升实验结果的准确性。



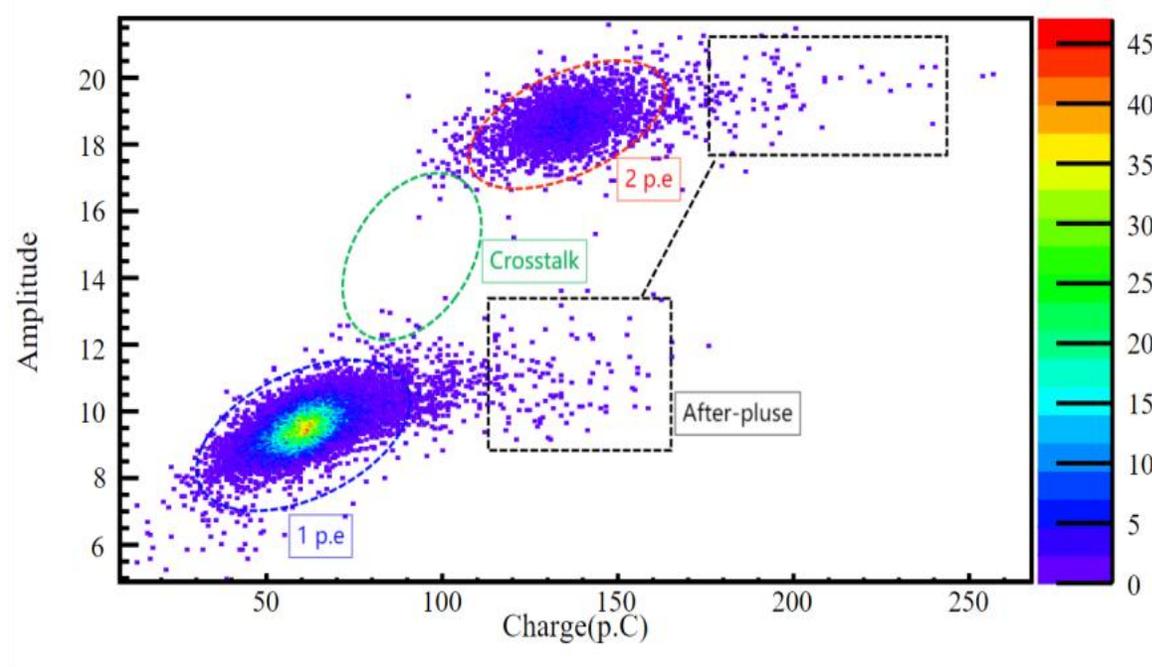
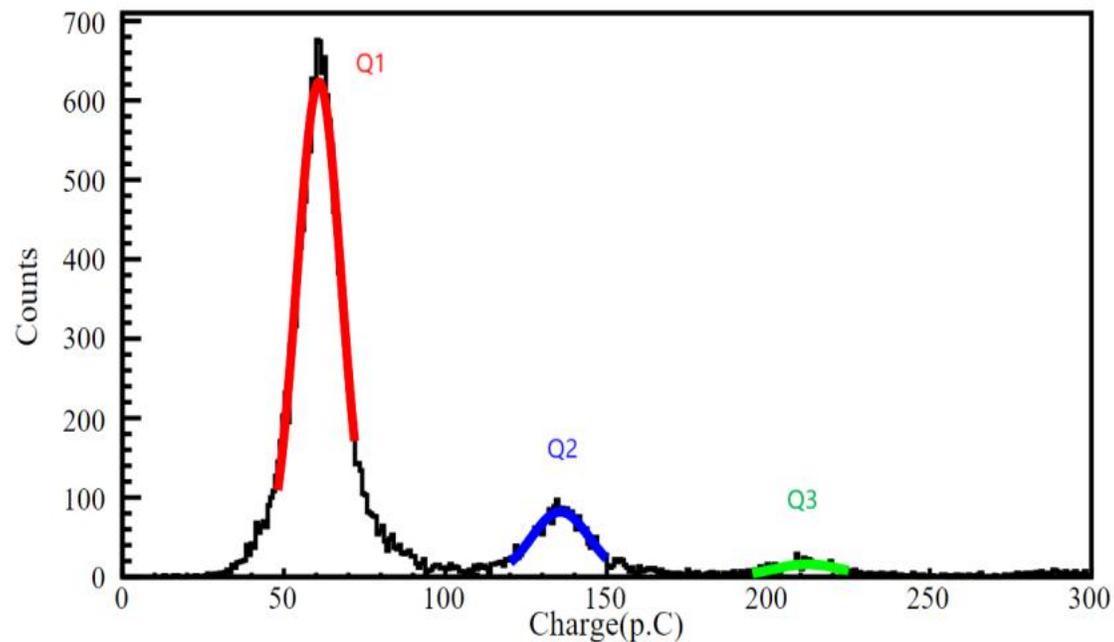
测试系统



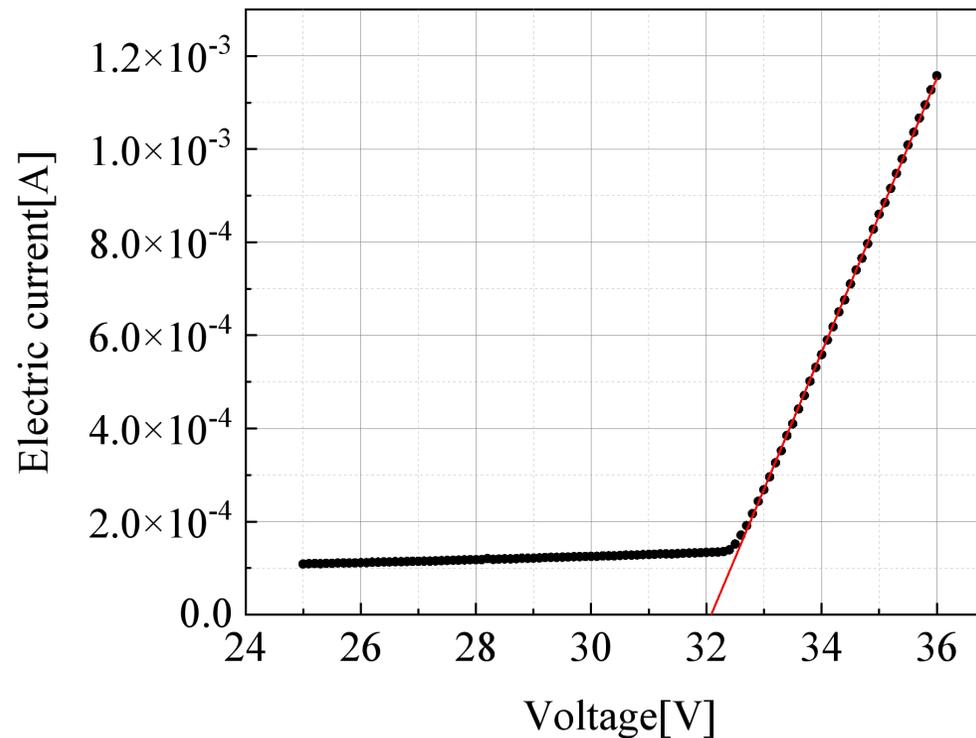
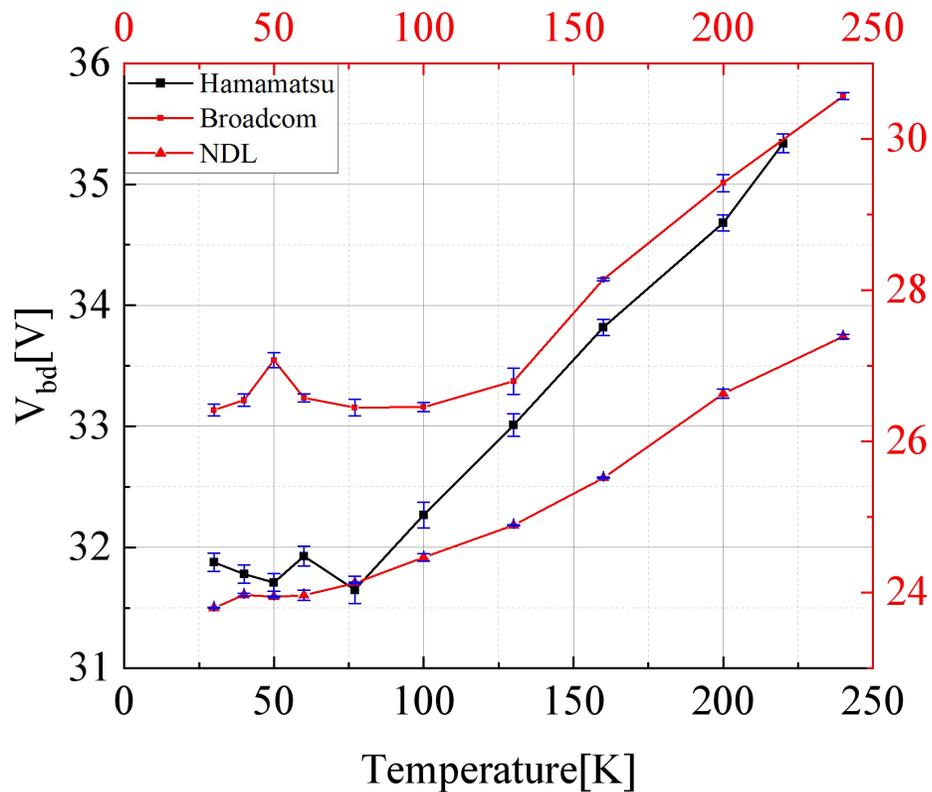
- 前置放大器的原理图
- 通过调节 R7 控制放大倍数



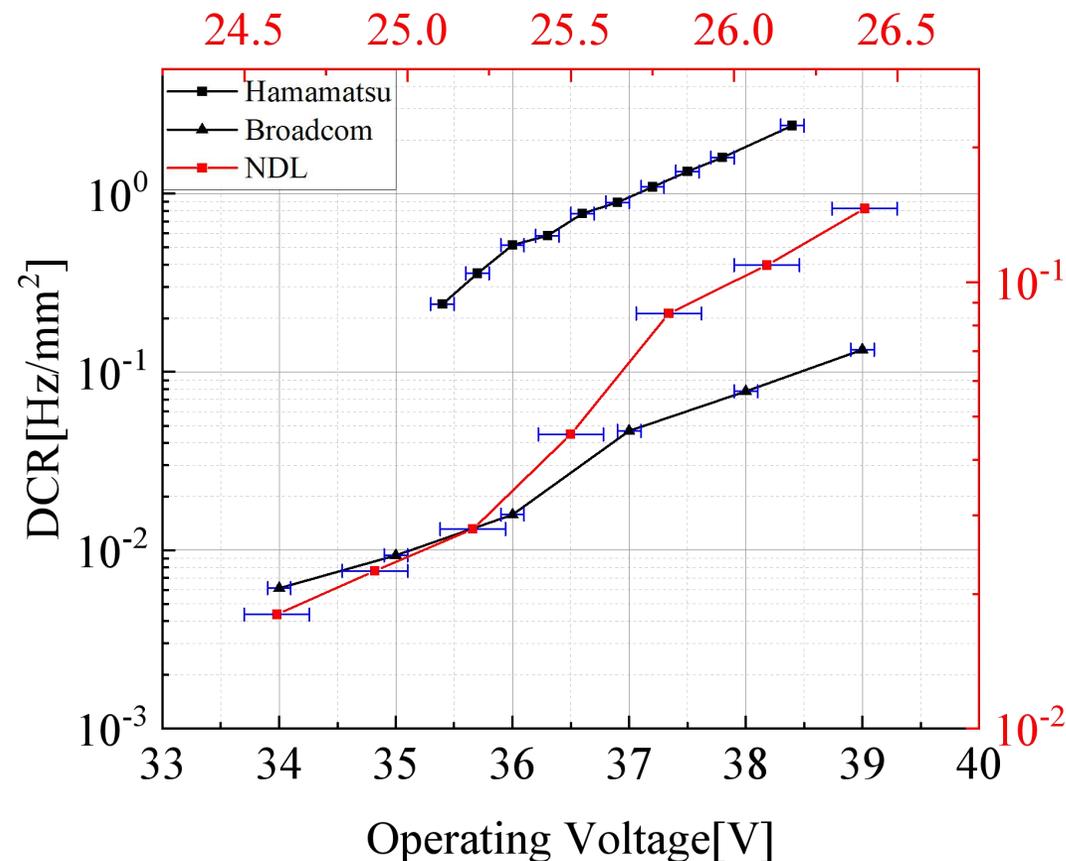
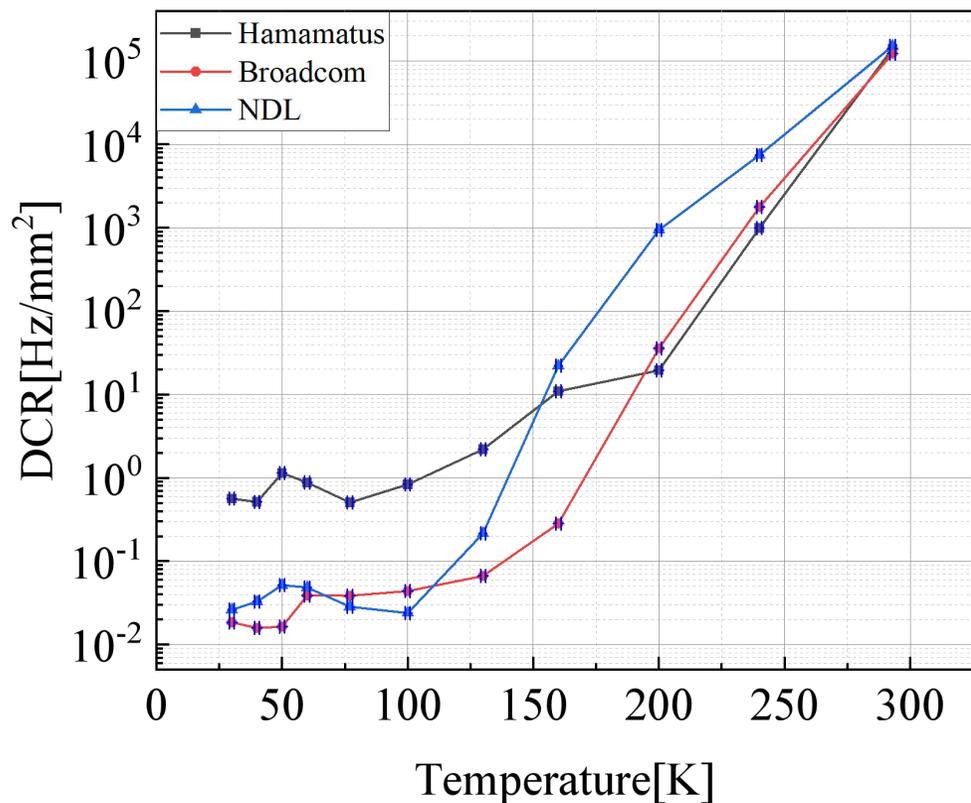
基线稳定 幅度小



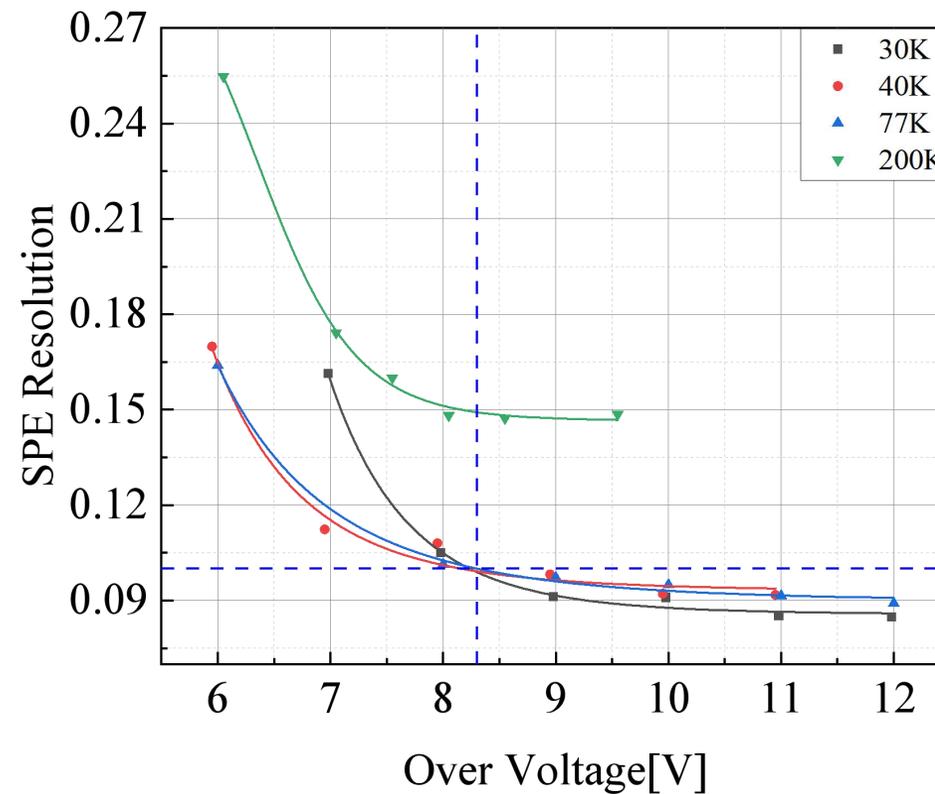
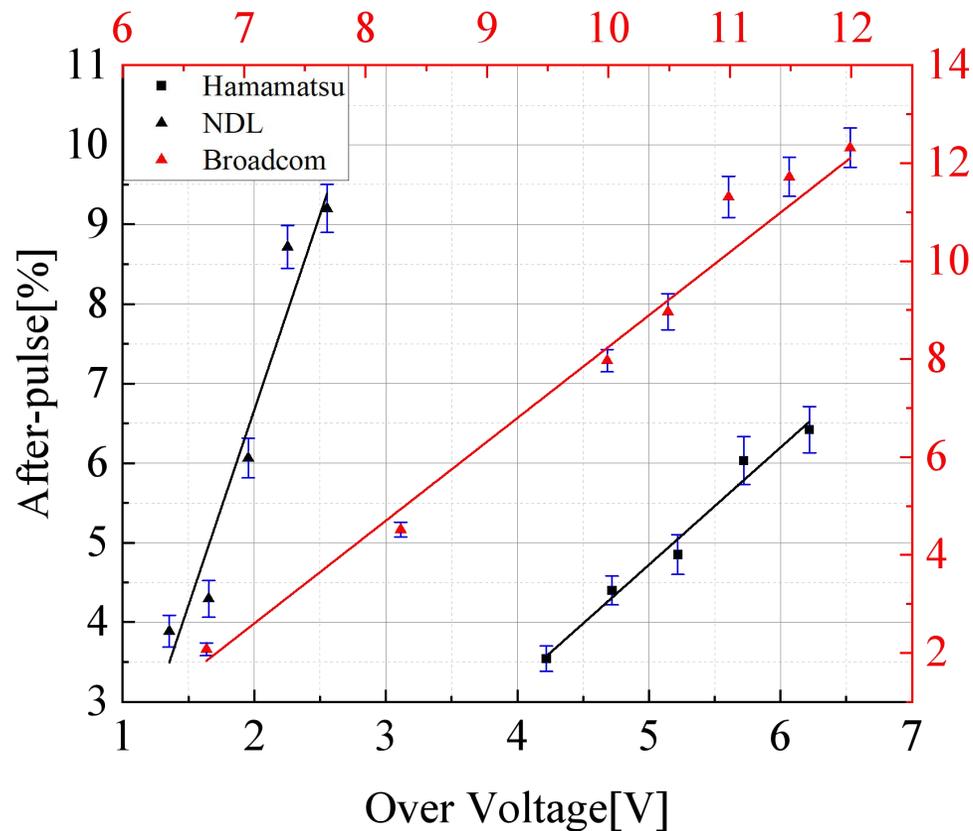
- SiPM 光电子能谱
- SiPM 的电荷-幅度散点分布



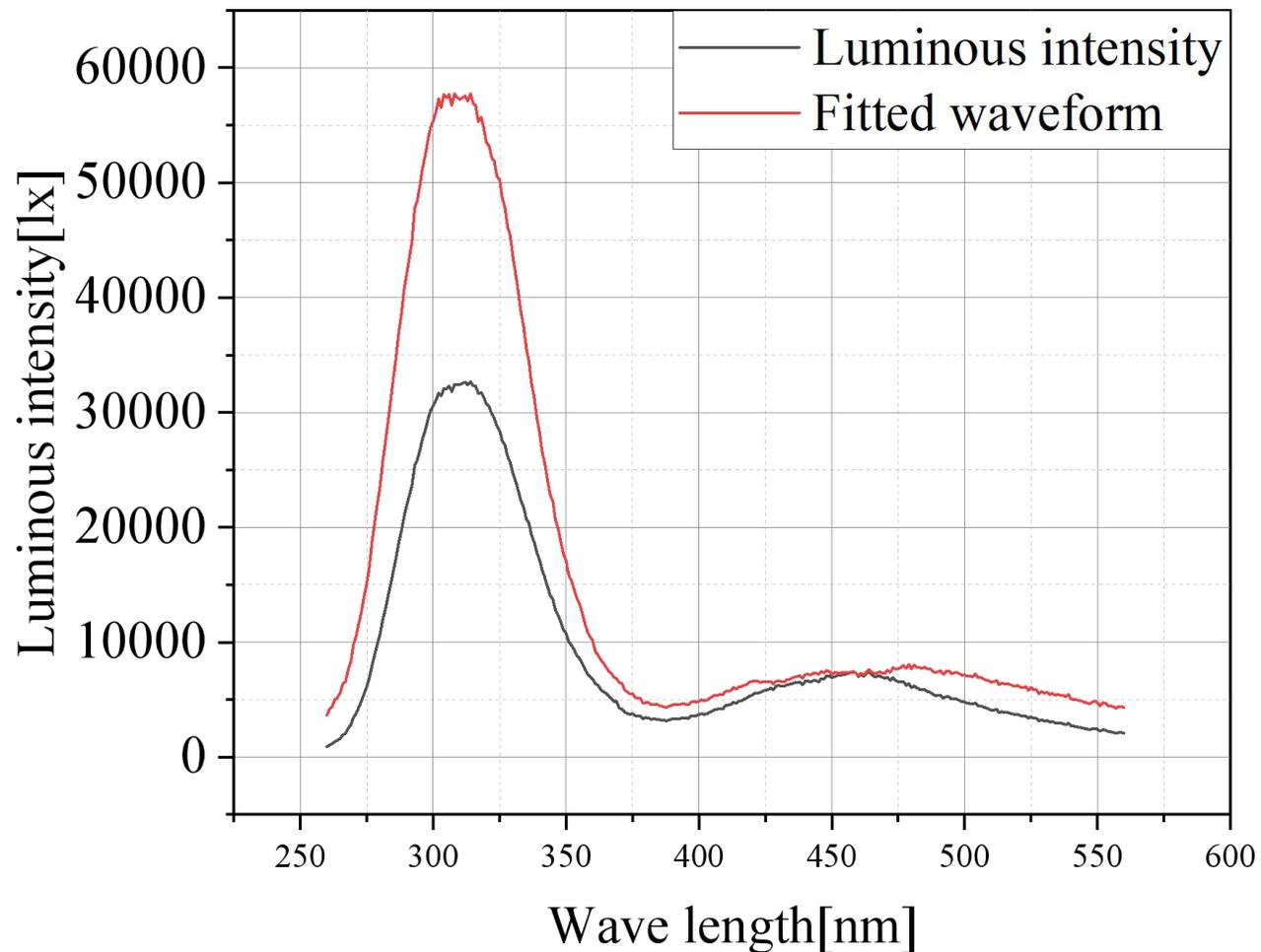
- 击穿电压随温度的变化 Gain 拟合
- \sqrt{I} -V 曲线拟合击穿电压



- DCR 随温度的变化曲线 (同一款 SiPM 保持同一过电压)
- 40K 下 DCR 随过电压的变化

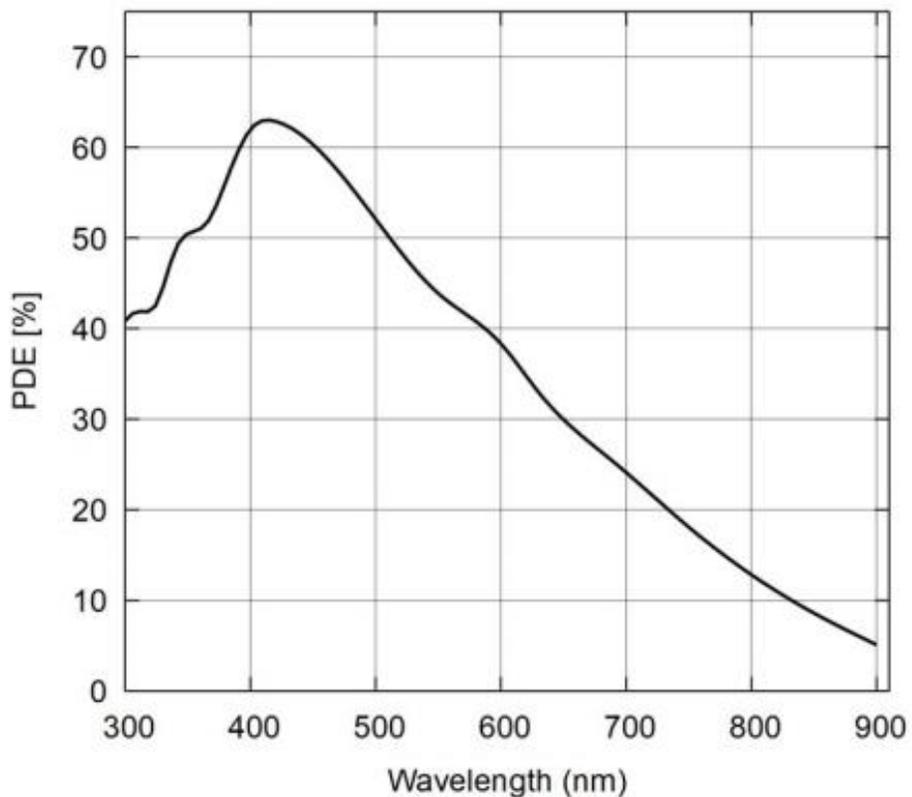


- 40K 下后脉冲概率随过电压的变化
- SiPM 单光子分辨率 (SPE)

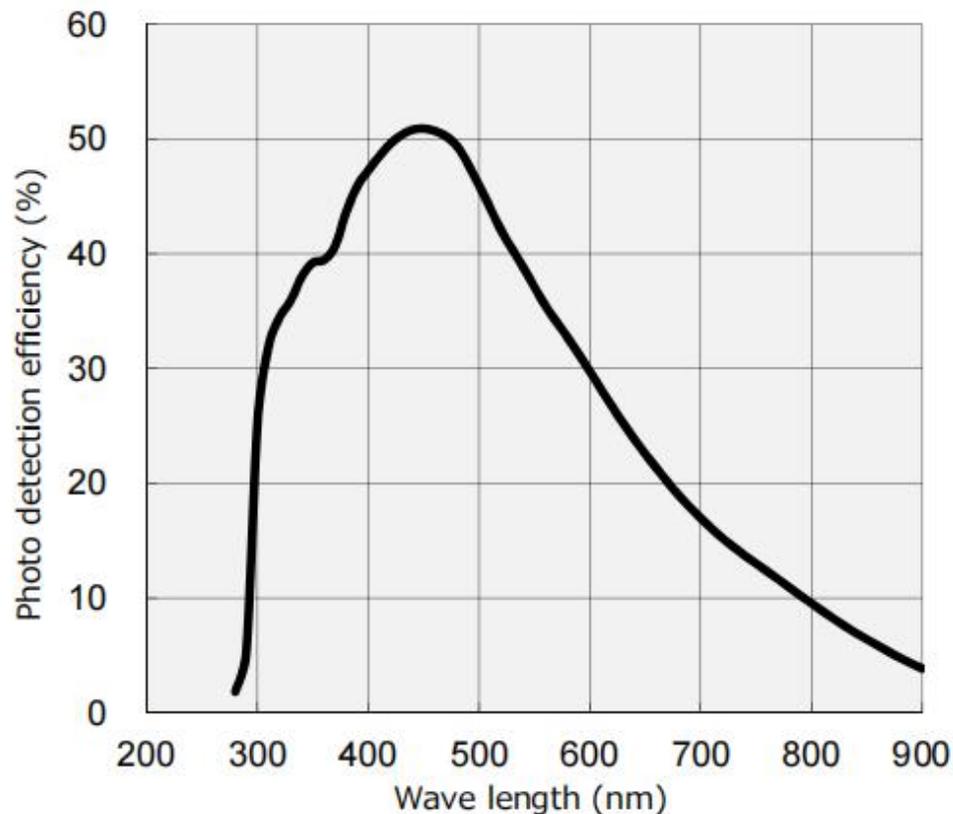


- 纯 CsI 晶体产生的典型光子波长在室温下峰值是 310nm;
- 液氮是 340nm。

- 将波长位移材料 TPB(1,1,4,4-四苯基-1,3-丁二烯)涂覆在 SiPM 表面;
- 可将 340nm 光子转化为 420nm, 150 $\mu\text{g}/\text{cm}^2$, 30.1 P.E/kev。



Broadcom SiPM (室温42%)



Hamamatsu SiPM (室温25%)

- SiPM 在低温下都能正常工作，NDL SiPM 在 40K 下工作电压范围较小，易发生二次击穿；
- 得到了 SiPM 在不同温度下的参数变化趋势，以及 40K 下的最佳工作条件；
- Broadcom SiPM 有更高的 PDE，用 2-inch 阵列 (8×8) 测试纯 CsI 在 40K 下的光产额；
- 通过 TPB 镀膜 (340nm→420nm)，对应 SiPM 最高的 PDE，提高纯 CsI 晶体的光产额。

谢谢各位专家!