Development of High-Density Silicon Photomultipliers at NDL

Hongmin Liu, Kun Liang, Baicheng Li, Lei Dai, Ru Yang and Dejun Han
NDL (Novel Device Laboratory, Beijing)

April 29, 2019

Outline

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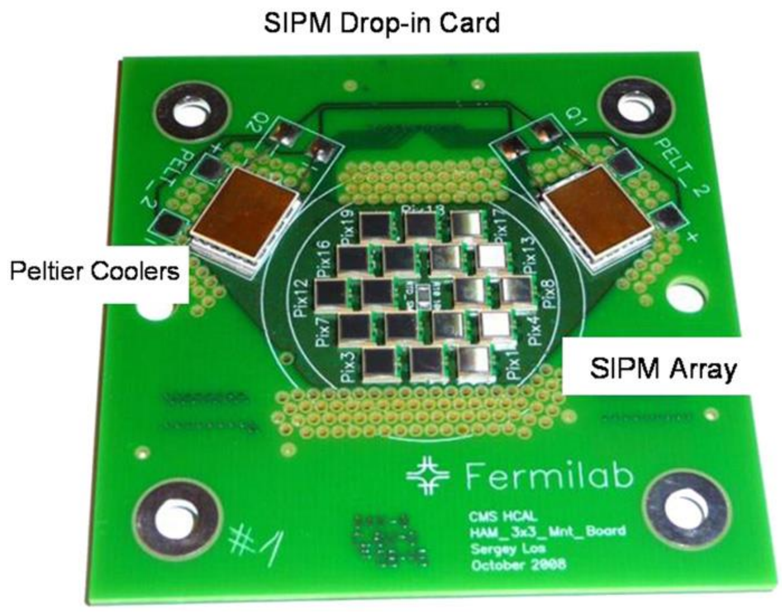
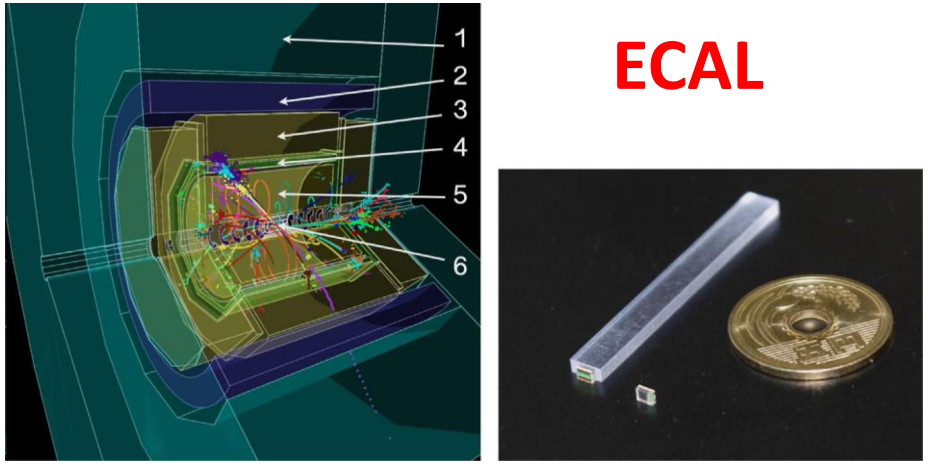
- Features of NDL SiPM Technology
- Results
- Road Map of NDL SiPMs for CEPC
- Summary

Motivation

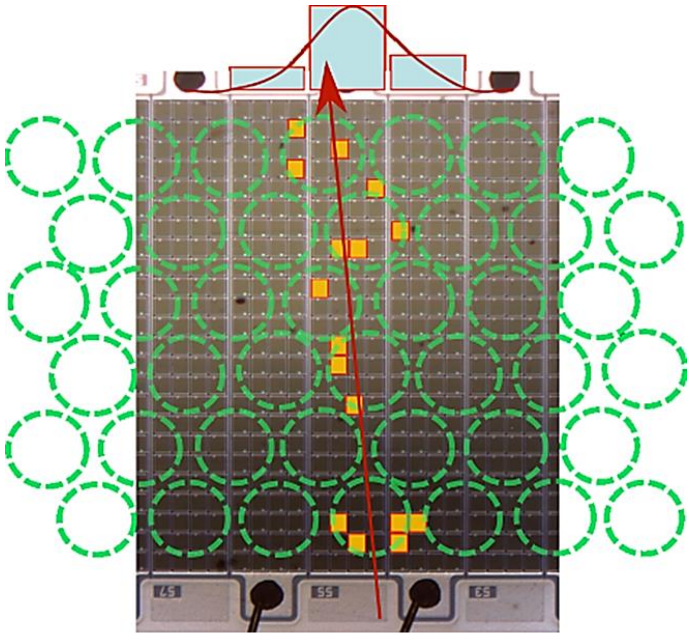
- Scientific Researches, such as hadronic calorimeter (HCAL), electromagnetic calorimeter (ECAL), or SciFi tracker in high energy physics, need huge amount of SiPMs with large dynamic range, , or highly resolved imaging with fewer readout channels



SiPMs for CMS **HCAL**

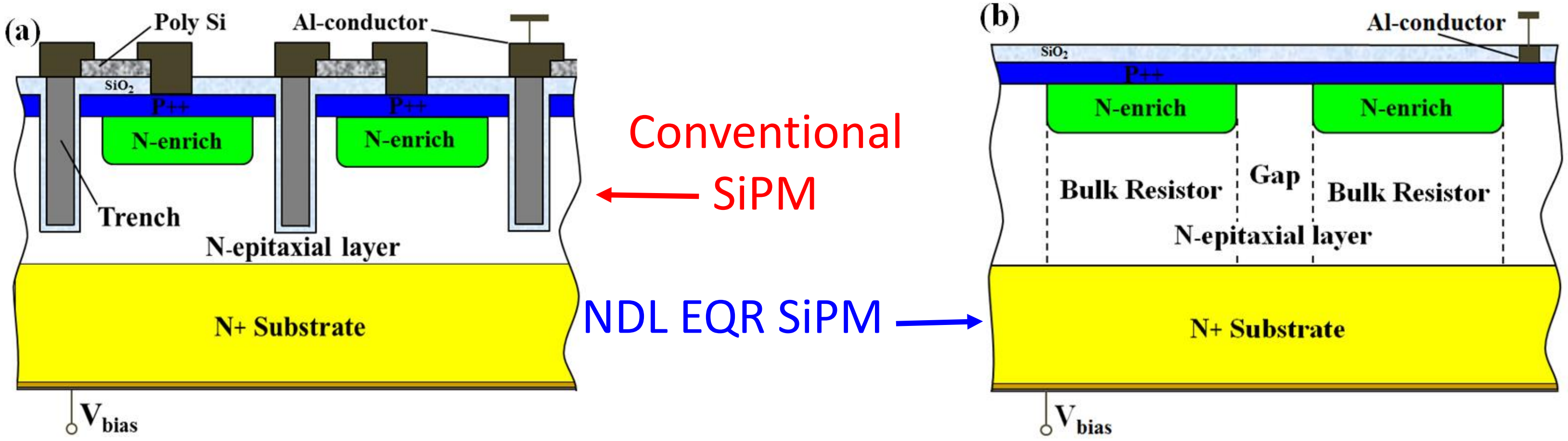


NIM A789 (2015) 158 – 164



LHCb **SciFi tracker** with 1-D pixel SiPM array [NIM A, 2017]

Features of NDL SiPMs



Features

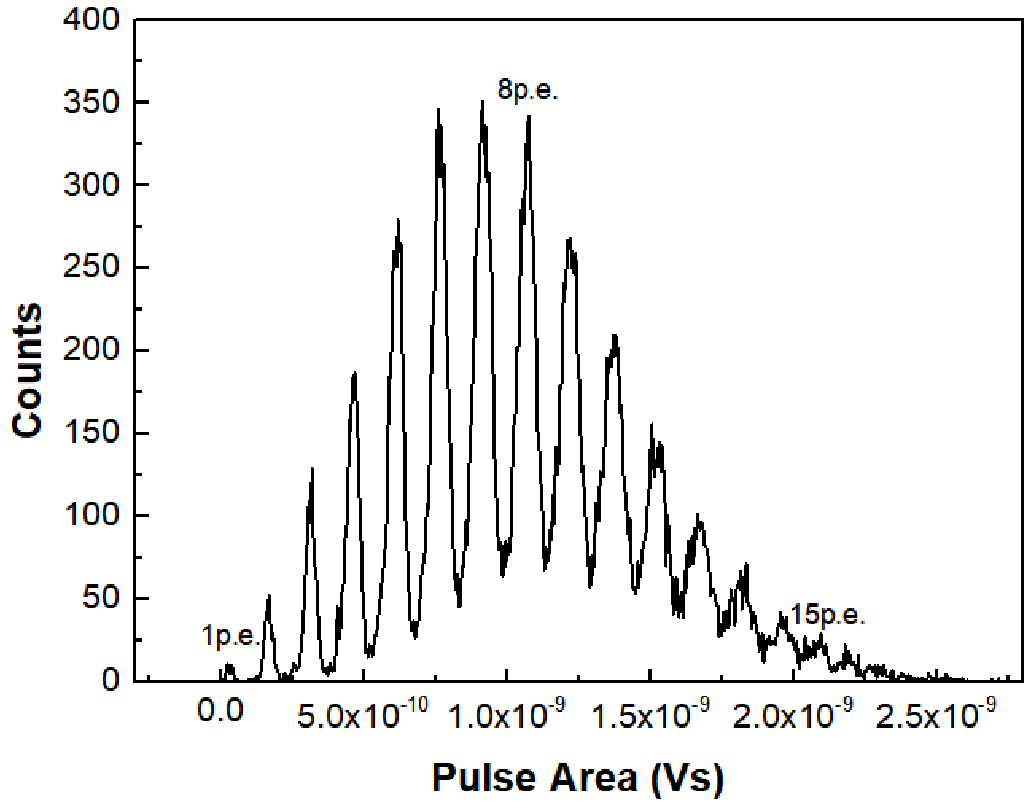
- In contrast to conventional SiPMs that quenching resistors are fabricated at device surface, the bulk resistor under each APD cell in the epitaxial layer is used as the quenching resistors

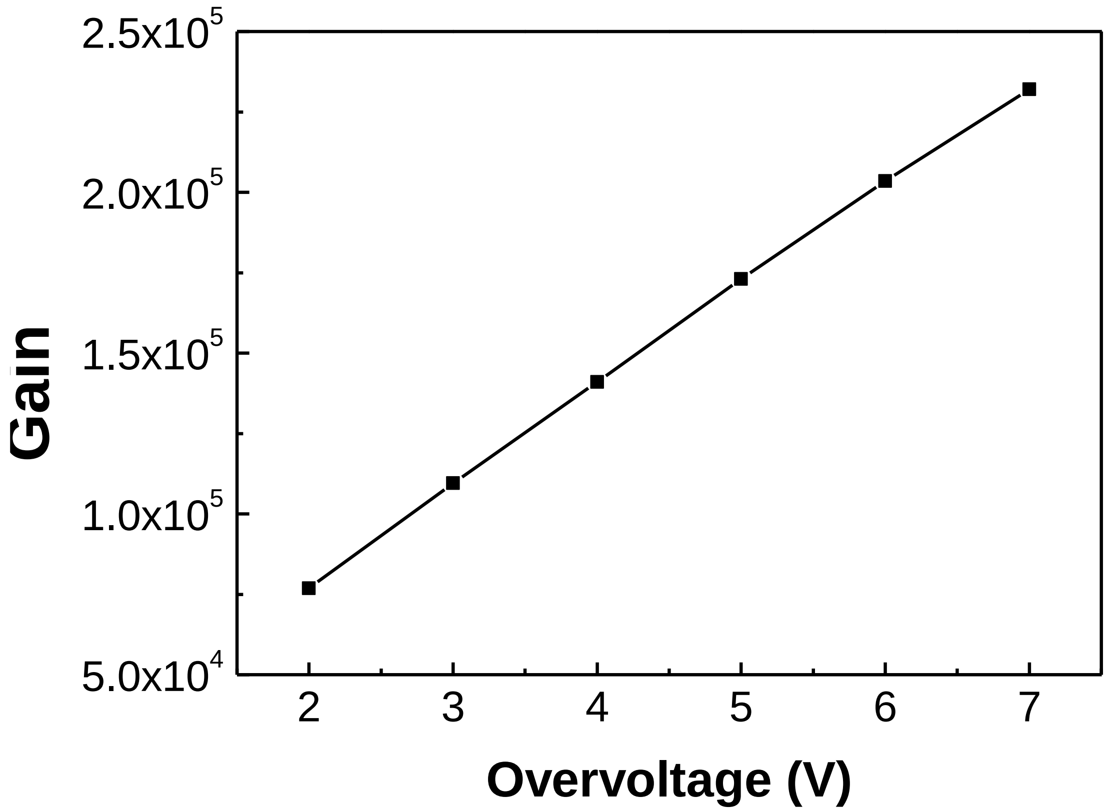
Advantages

- Small micro cell, high micro cell density (thus large dynamic range) while retaining high fill factor and photon detection efficiency (PDE)
- No extra fabrication processes for quenching resistors are needed, thus simple fabrication technology and cost effective.

Results--Pulse Area spectrum and Gain

1×1 mm^2 EQR SiPM with pitch of 10 μm

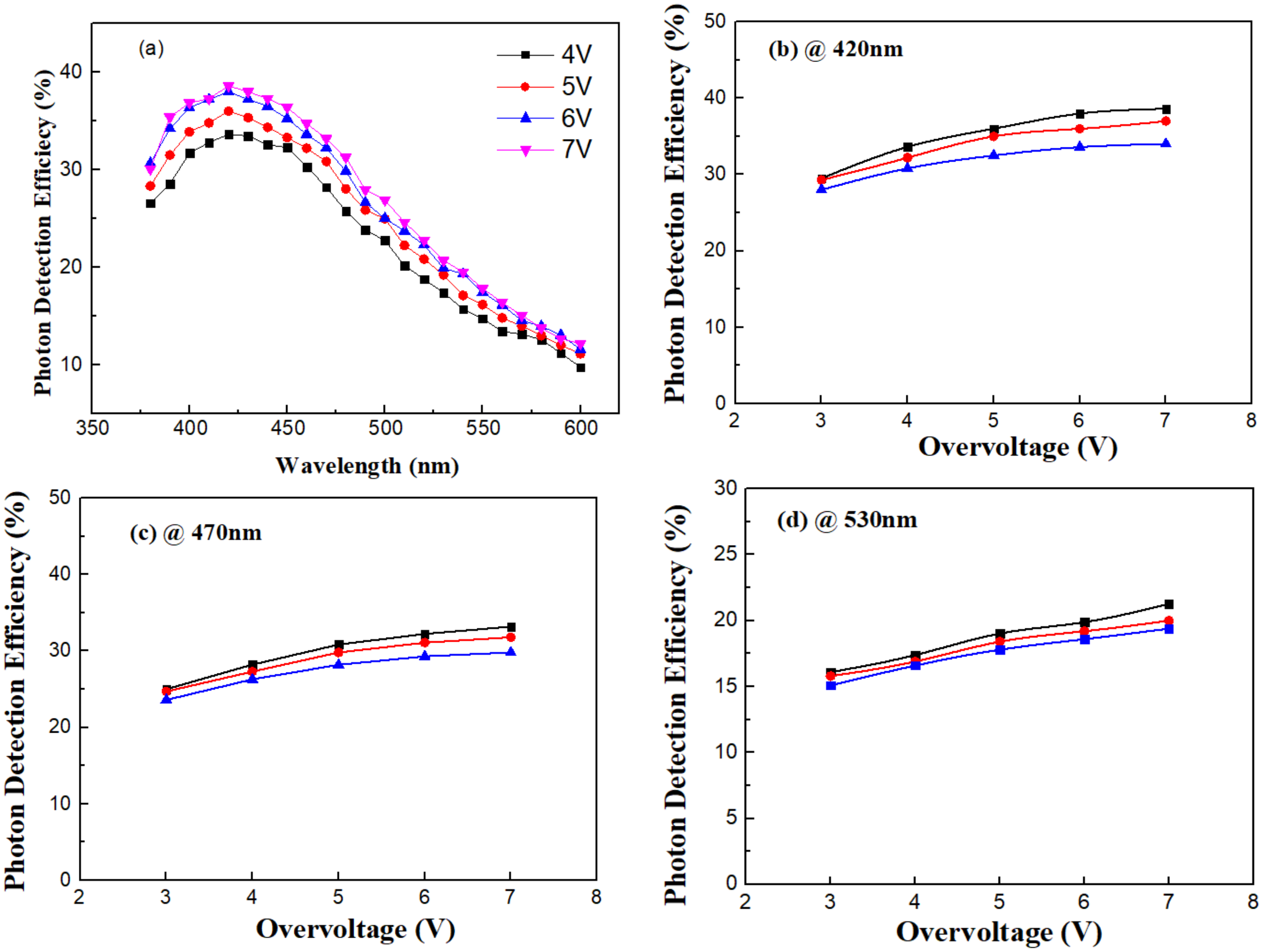




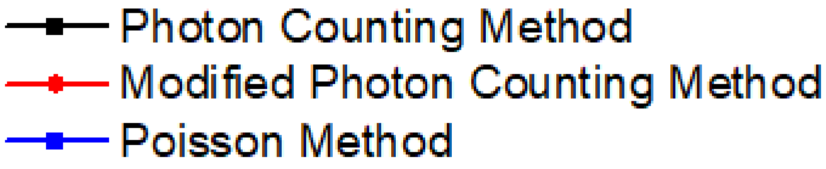
It can distinguish at least **15p.e.** under overvoltage close to 5V at 20^{o}C.

Gain at 6V overvoltage is about **2.1×10^5**.

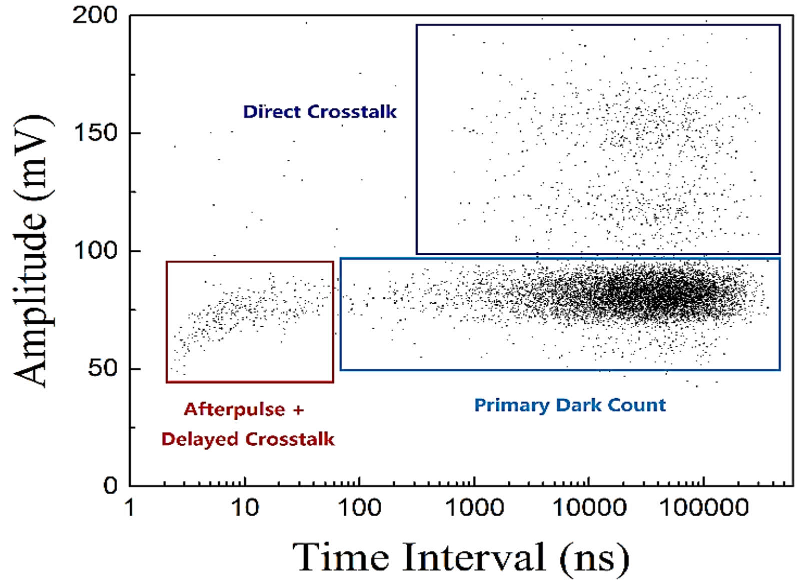
Results—PDE

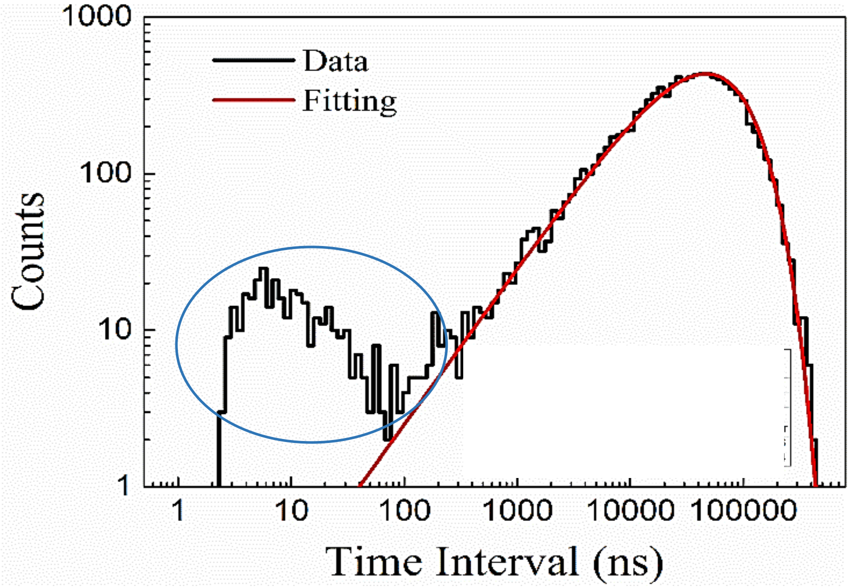


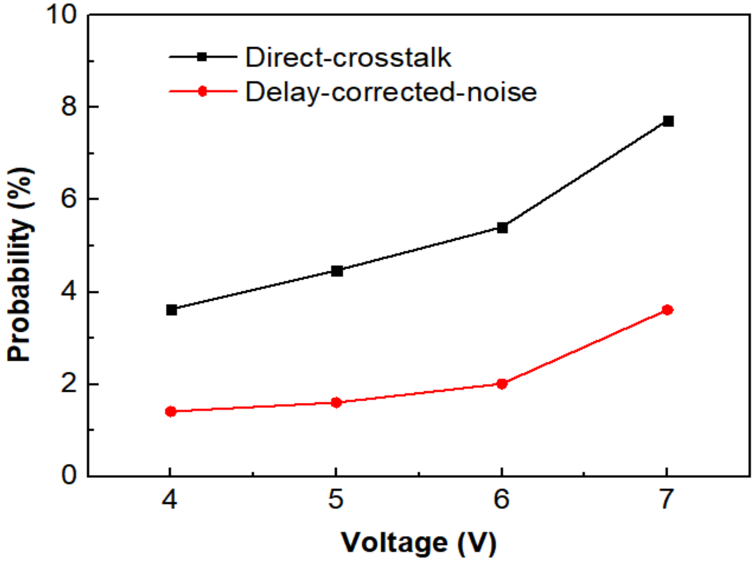
- 1×1 mm² NDL SiPM with pitch of 10 μm under 7V overvoltage at 20ºC.
  - ➢ (a) Measured PDE as a function of waveform by photon counting method at different overvoltage.
  - ➢ (b), (c) and (d) is measured by three methods at 420nm,470nm and 530nm.



Results--Correlated Noise

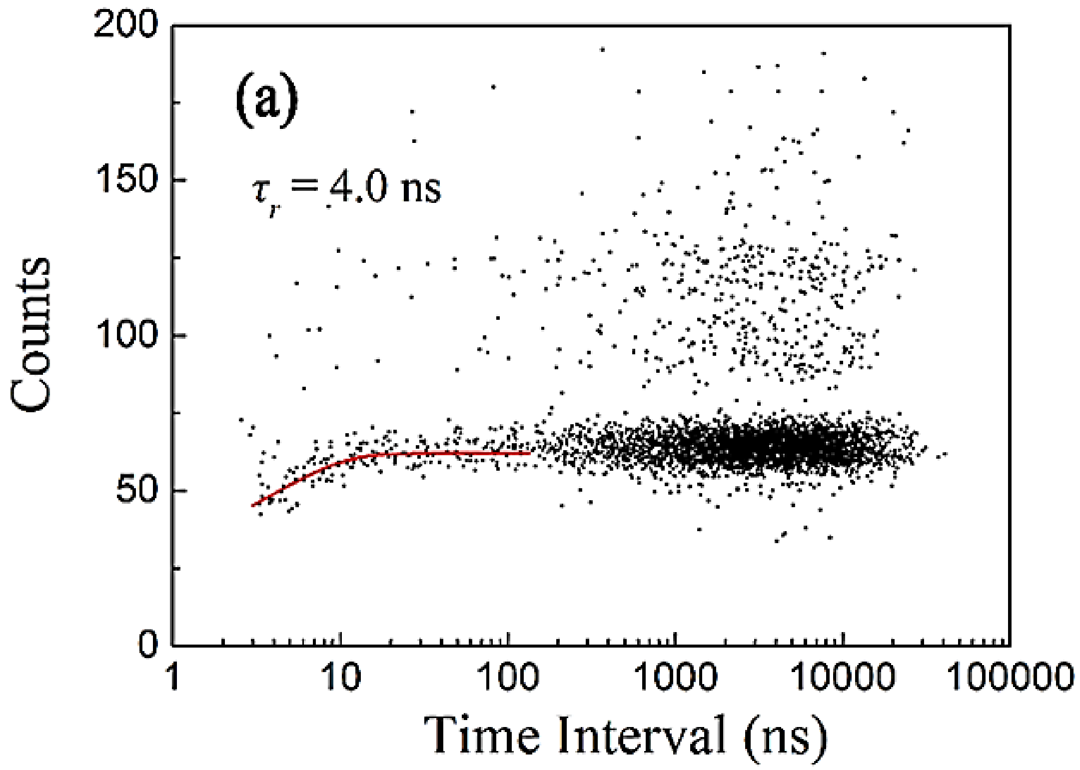


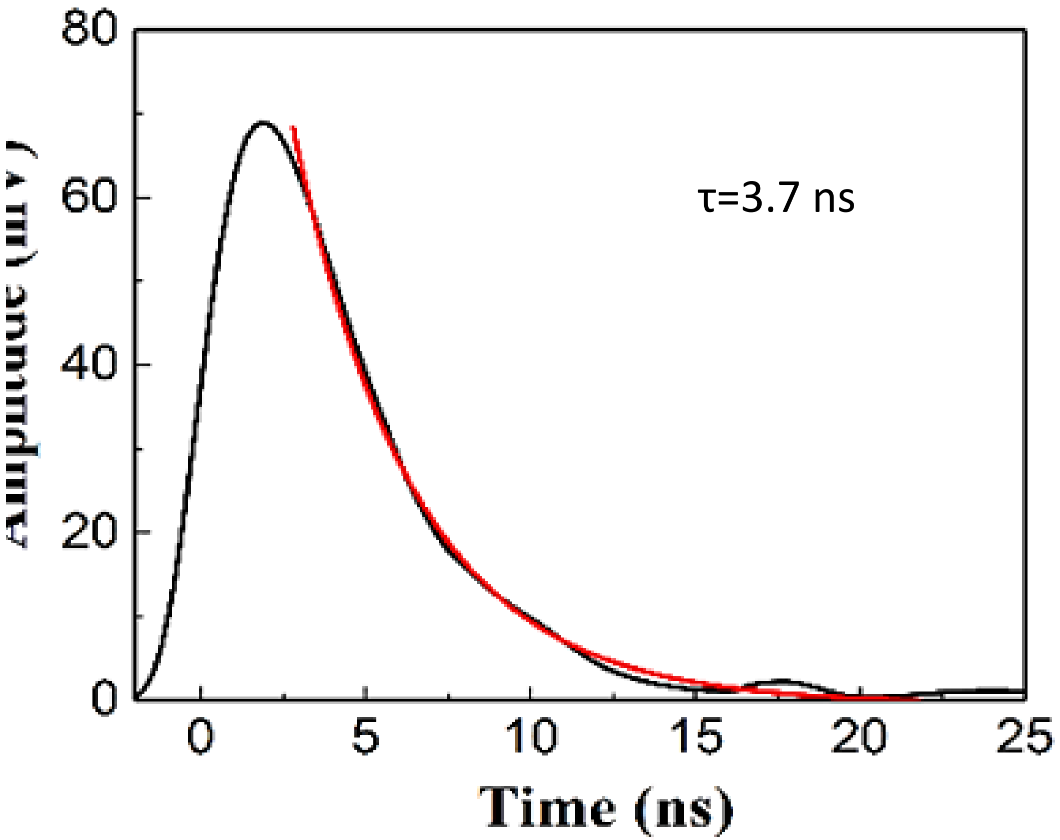




- The scatter plot analysis and the histogram distribution versus the time interval for dark pulses of 1×1 mm^2 NDL SiPM with pitch of 10 μm under 7 V overvoltage at -30°C.
- The direct crosstalk probability and the delayed-correlated-noise probability was **7.6%** and **3.0%** respectively.

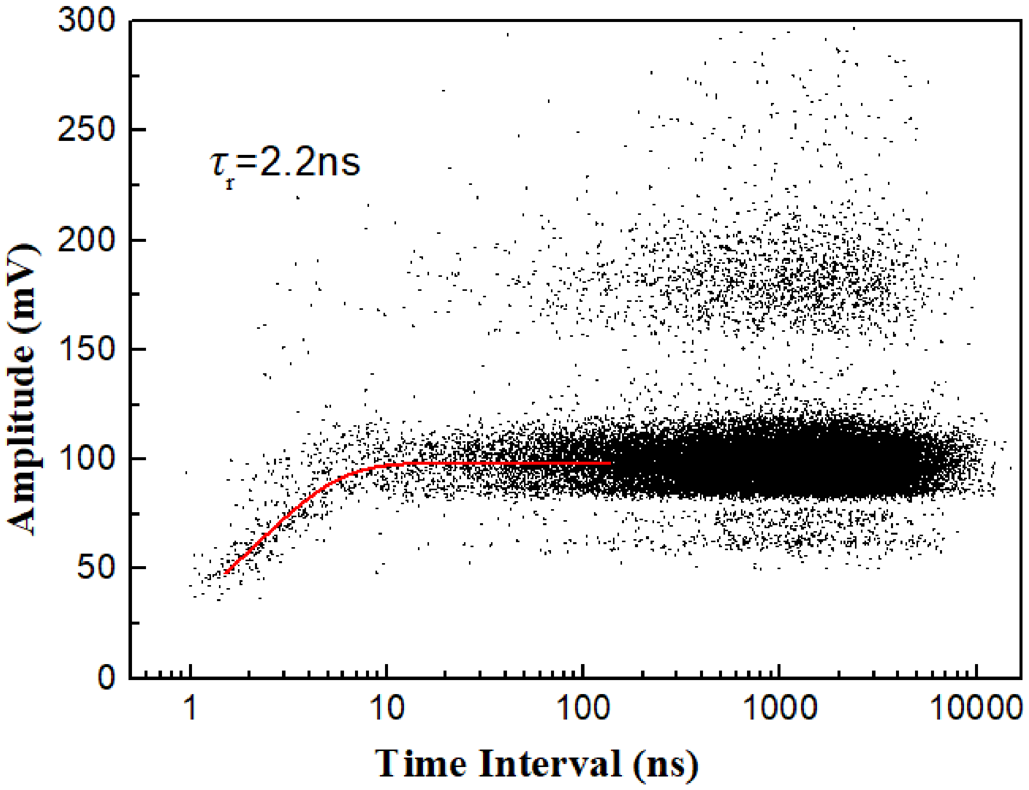
Results-- recovery time

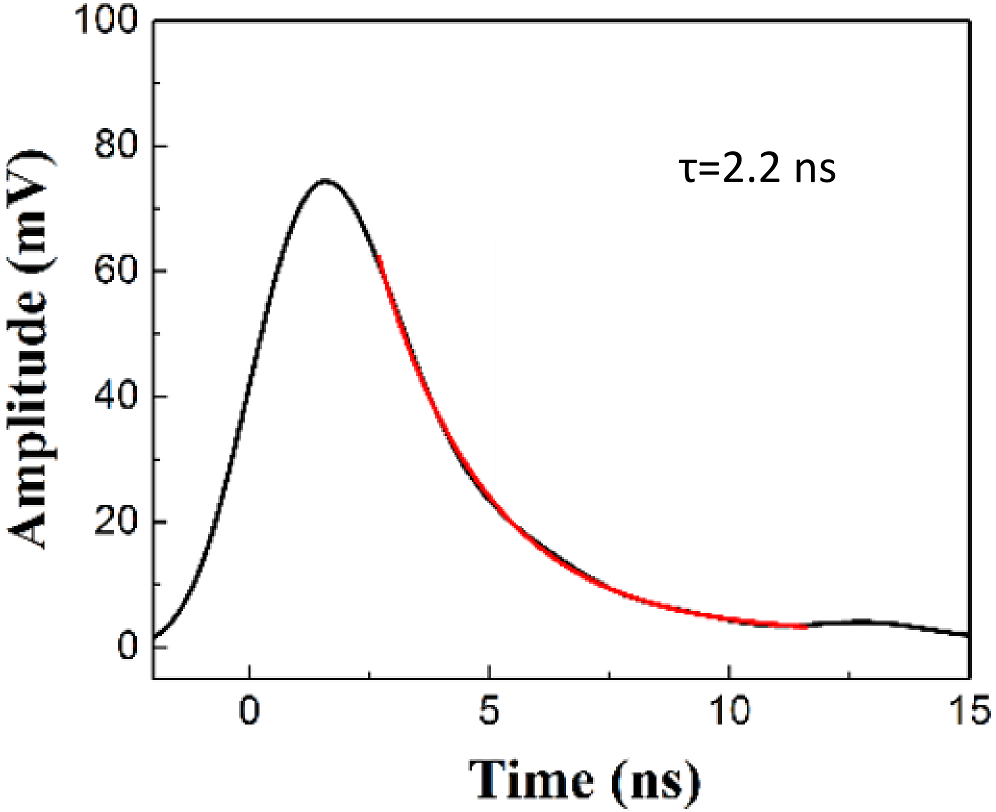




The recovery time of 3×3 mm^2 NDL EQR SiPM with pitch of 10 μm obtained by performing the noise scatter plot analysis (left) and the fitting for pulse falling edge (right) is **4.0 ns and 3.7 ns** respectively.

Results-- recovery time

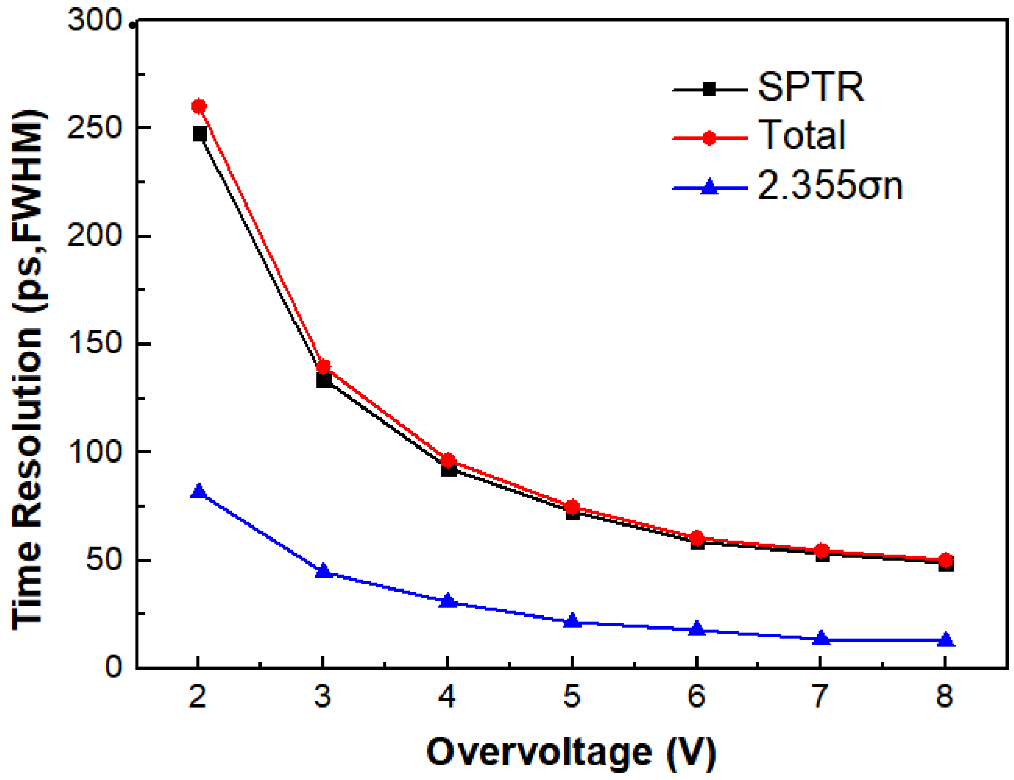




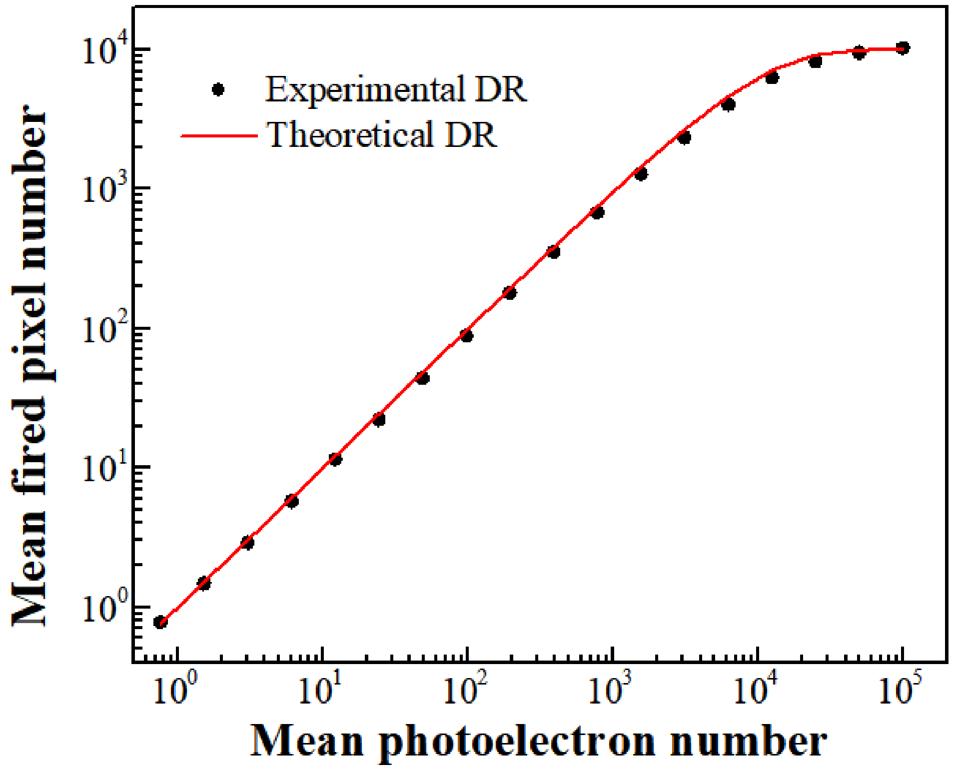
The recovery time of 1×1 mm^2 NDL SiPM with pitch of 10 μm obtained by performing the noise scatter plot analysis (left) and the fitting for pulse falling edge (right) is **2.2 ns**.

Results— SPTR and Dynamic Range

The EQR SiPM has a size of 1×1 mm^2 with pitch of 10 μm.

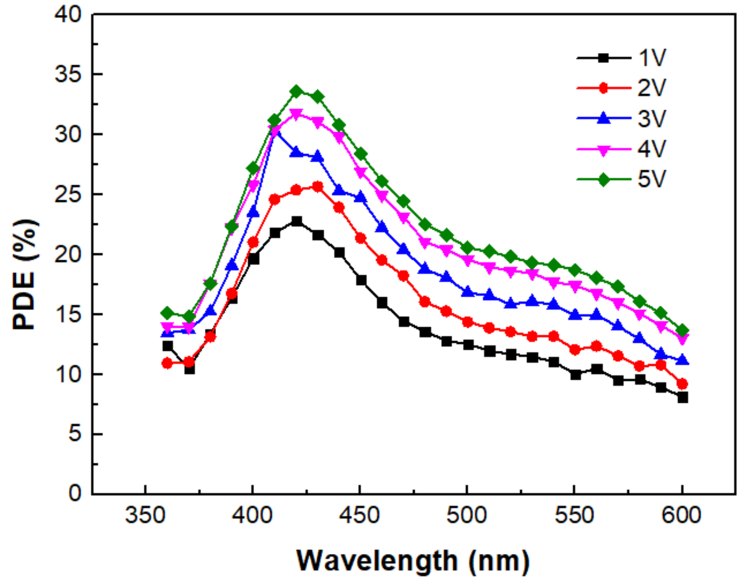


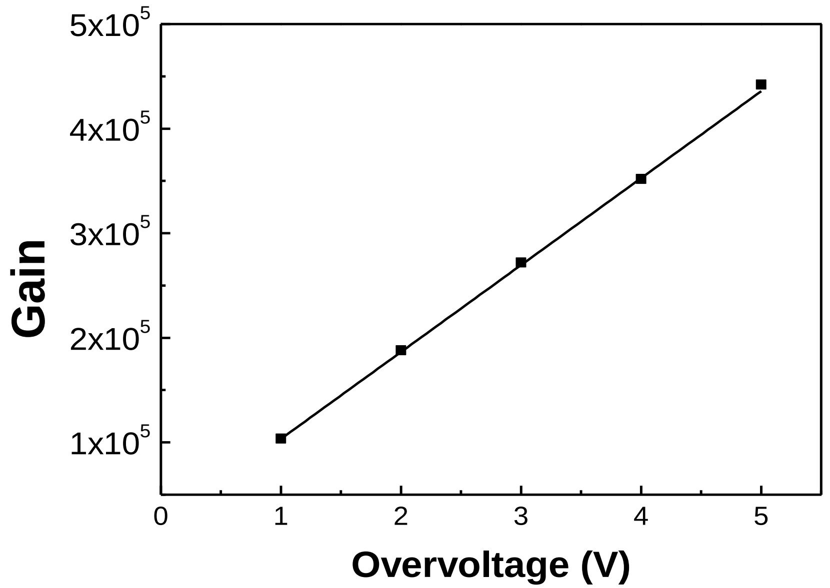
The time resolution of EQR SiPM is approximately **60 ps** at 6 V overvoltage.

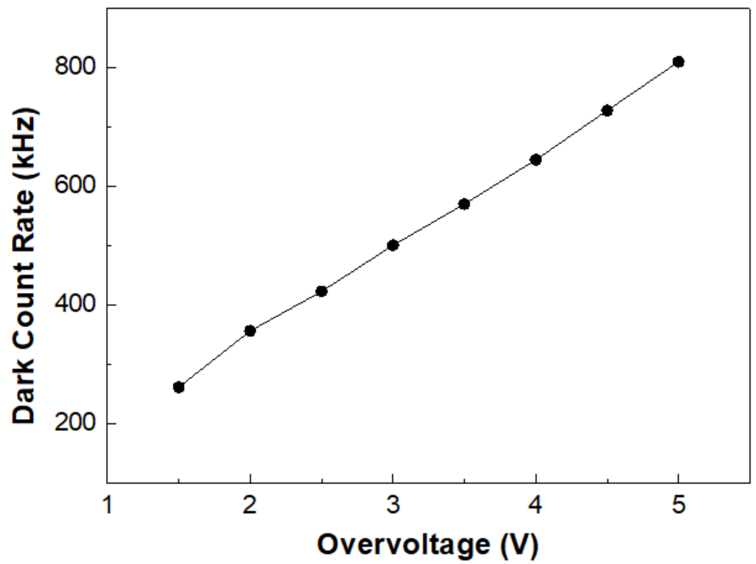


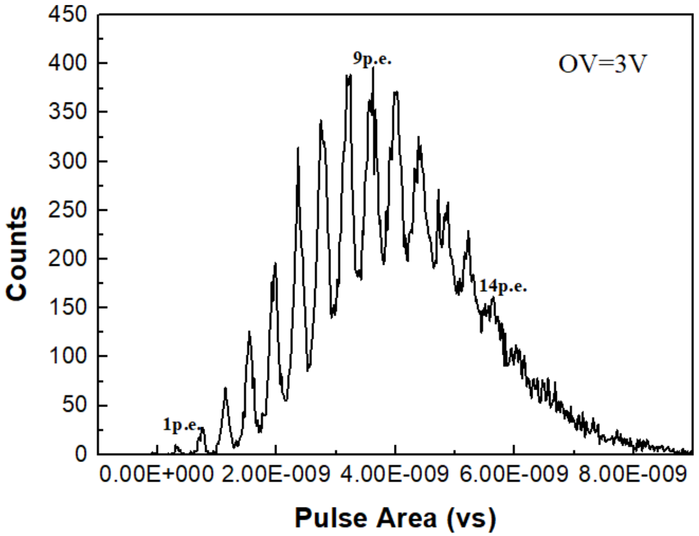
The dynamic range reaches about **10^4**.

Results— NDL SiPM with other geometrical parameter





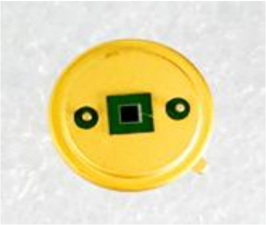




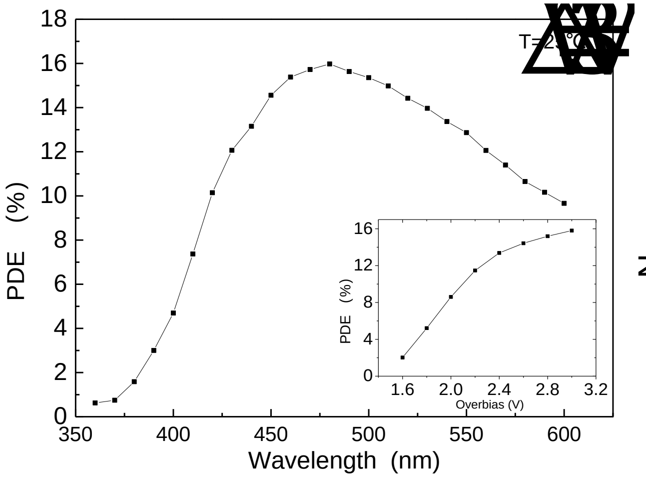
1×1 mm² NDL SiPM with pitch of 12.5 μm

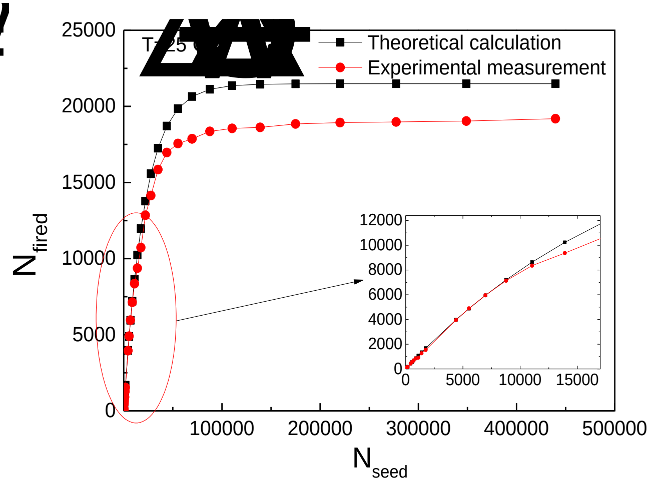
- PDE is 33% under 5V overvoltage at 420nm.
- Gain is about 4.5×10^5 at overvoltage 5V.
- DCR is about 800KHz at 20°C.

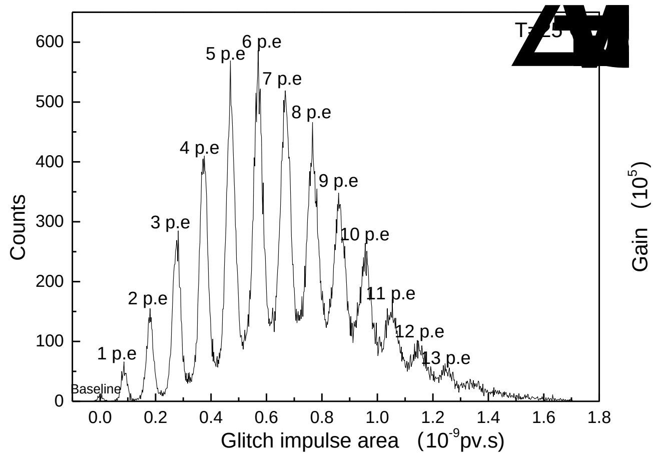
Results— NDL SiPM with other geometrical parameter

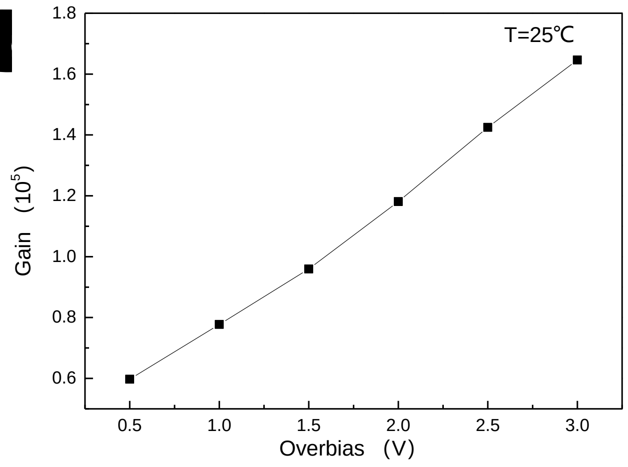


1mm×1mm N-ON-P type Test Sample， Cell diameter 5μm with gap 2 μm, Total 21488 micro cells





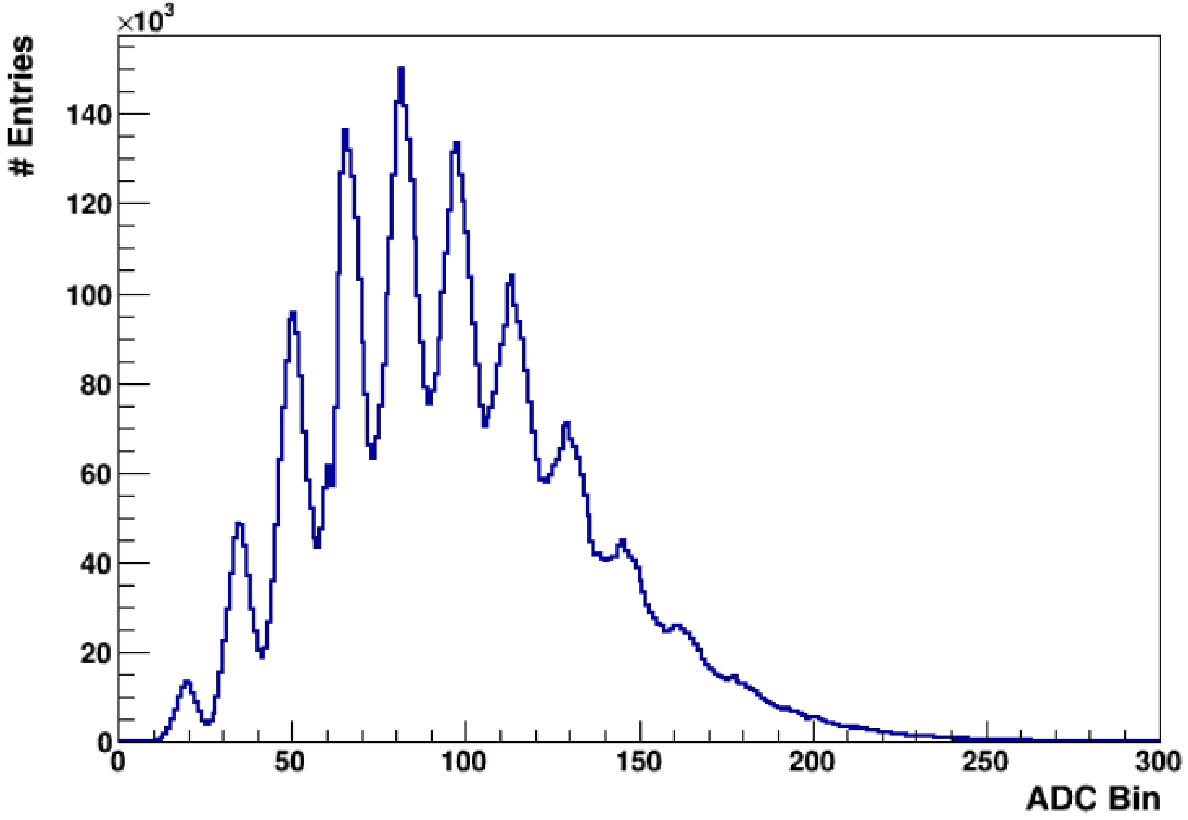


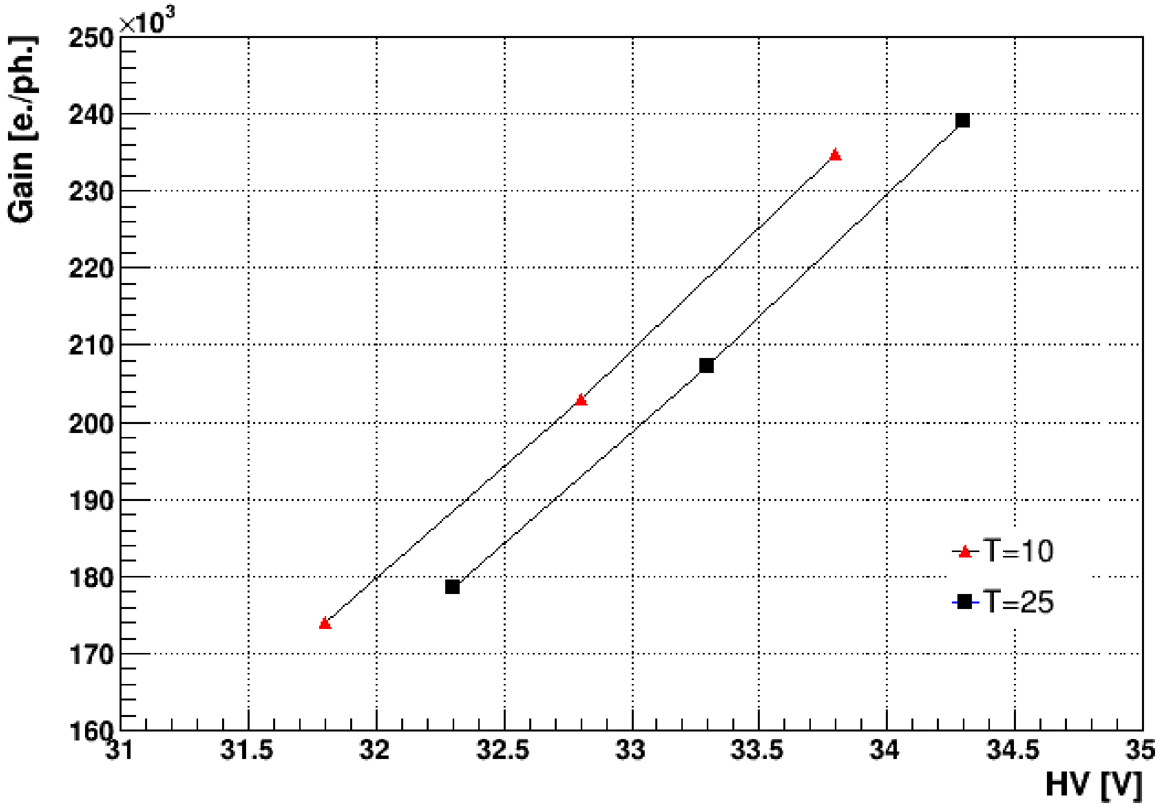


High Density SiPM: SensL, Hamamatsu VS NDL

	NDL SiPM		SensL SiPM		Hamamatsu MPPC	
Effective Active Area	11-3030 C-S/T	11-1010 C-S/T	C-30020-SMT	C-10010-SMT	S12572-010-C/P	S12571-010-C/P
	3.0×3.0 mm^2	1.0×1.0 mm^2	3.0×3.0 mm^2	1.0×1.0 mm^2	3.0×3.0 mm^2	1.0×1.0 mm^2
Effective Pitch	10 μm	10 μm	28 μm	18 μm	10 μm	10 μm
Micro-cell Number	90000	10000	10998	2880	90000	10000
Fill Factor	40%	40%	48%	28%	33%	33%
Breakdown Voltage (V_b)	27.5±0.4V	27.5±0.4V	24.2-24.7	24.2-24.7	65±10V	65±10V
Measurement Overvoltage (V)	5	5	2.5	2.5	4.5	4.5
Peak PDE	31%@420nm	31%@420nm	24%@420nm	14%@420nm	10%@470nm	10%@470nm
Max. Dark Count (kcps)	~6000	~500	860	96	2000	200
Gain	2×10^5	2×10^5	1×10^6	2×10^5	1.35×10^5	1.35×10^5
Temp. Coef. For V_b	25mV/℃	25mV/℃	21.5mV/℃	21.5mV/℃	60mV/℃	60mV/℃

NDL-11-1010C SiPM Readout by KlauS ASIC





Provided by the KIP, Heidelberg University

KlauS5: A 36-channel low power silicon photomultiplier charge readout ASIC

Road Map of NDL SiPMs for CEPC HCAL & ECAL

	Expected NDL SiPM for ECAL	Existed NDL SiPM		Expected NDL SiPM for HCAL
Effective Pitch	6 μm	10 μm	12.5 μm	14 μm
Micro-cell Number/mm²	27650	10000	6400	5040
Fill Factor	34%	40%	52%	56%
Breakdown Voltage (V_b)	24.0±0.1V	27.5±0.4V	27.5±0.4V	24.0±0.1V
Peak PDE	26%@420nm	31%@420nm	~31%@420nm[a]	43%@420nm
Dark Count (kcps/mm²)	<500	~500	~500	<500
Gain	6.0×10^4	2.0×10^5@6V	4.5×10^5@5V	6.0×10^5
Temp. Coef. For V_b	25mV/℃	25mV/℃	25mV/℃	25mV/℃

[a] anti-reflection coating was not optimized for 420 nm, so it was not expected as 40%

Summary

- NDL has been developing an unusual SiPM technology, epitaxial quenching resistor (EQR) type SiPM. It features:

➢ Small micro cell, high micro cell density (thus large dynamic range) while retaining high fill factor and photon detection efficiency (PDE) → alleviate the contradiction between dynamic range and PDE encountered by a usual SiPM

➢ No extra quenching resistors fabrication steps, thus simple fabrication technology and cost effective.

- It is very suitable for applications such as scientific researches (e.g., HCAL & ECAL)， safety & security, preclinical PET and small animal PET etc.

Thank You for Your Attentions!

We strongly hope to join CEPC so that we can understand its exact needs promptly and serve it whole-heartedly.

NDL (Novel Device Laboratory, Beijing Normal University)

Email： info@ndl-sipm.net

http://www.ndl-sipm.net/device.html