Silicon Photomultipliers for the CEPC Forward Aerogel RICH: Survey and Test System

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1 Introduction

- CEPC will produce unprecedented samples of Z and Higgs bosons; flavour physics benefits from identifying kaons among far more abundant pions [1].
- In the forward region, time of flight separates K/π only below **~3 GeV/c**, and TPC dN/dx degrades on shorter track paths [2].
- A proximity-focusing **aerogel RICH** (n ≈ 1.008) measures the Cherenkov angle, $\cos\theta_c = 1/(n\beta)$, targeting **3σ K/π up to 20 GeV/c** [3].
- A few tens of photons per track in 3 T: the sensor needs high PDE, mm pixels, low DCR and radiation tolerance — **SiPM is the baseline**.

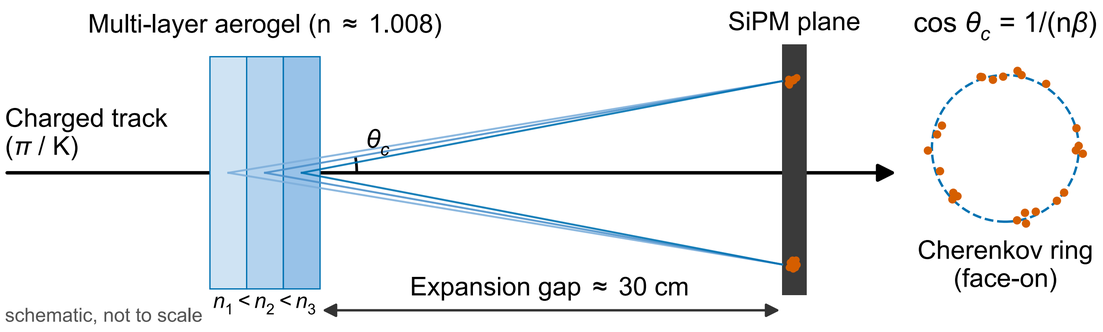


Fig. 1 Proximity-focusing multi-layer aerogel RICH (schematic): n rises layer by layer.

2 SiPM Survey

Requirements

Parameter	Requirement
Spectral range	> 300 nm
Peak PDE	~50 %
Pixel size	1 mm (or 3–6 mm with charge sharing)
Spatial resolution	~300 μm
Time resolution	100–200 ps
Dark count rate	100–200 kHz/mm² at room temperature
Crosstalk	1–5 %
Radiation tolerance	10^{12}–10^{13} n_{eq}/cm²
Total area	~1.6 m²

Preliminary specification [4]

Six vendors, 43 datasheets

Vendor	Peak PDE	Pixel	DCR (kHz/mm²)	Crosstalk	SPTR [12,13]
Hamamatsu (JP) [5]	48–50 %	1–6 mm	**41–167**	**3–10 %**	~117ps*
Broadcom (US) [6]	**63 %**	2–4 mm	111–270	9–34 %	~66 ps*
onsemi (US) [7]	41–50 %	1–6 mm	**30–150**	7–25 %	n.p.
NDL (CN) [8]	45–48 %	1–6 mm	150–650	n.p.	n.p.
Joinbon (CN) [9]	32–35 %	1–3 mm	88–288	3–3.5 %	n.p.
FBK (IT) [10,11]	**60–63 %**	1–2 mm	**~100**	15–20 %	**< 50 ps***

Typical room-temperature datasheet values; orange = favourable values; * literature or measurement; n.p. = not published; FBK devices are custom-made.

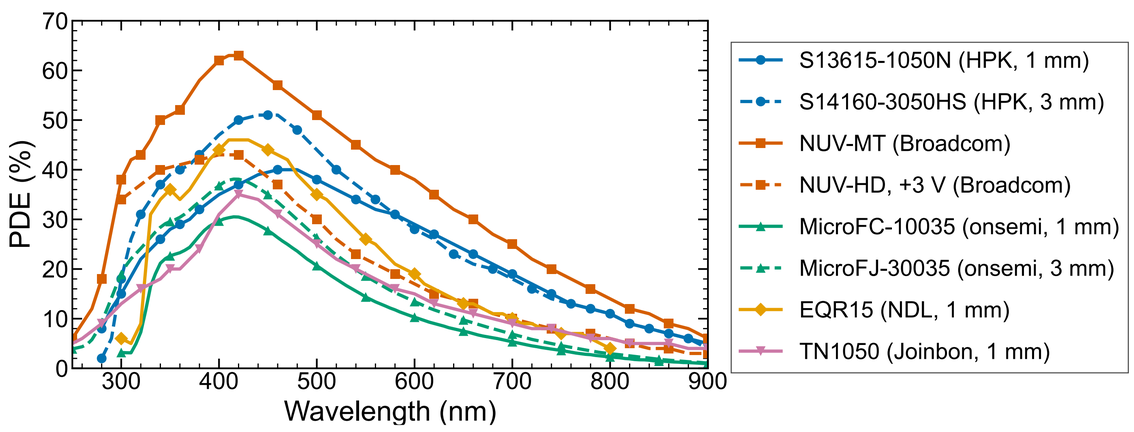


Fig. 2 PDE spectra of representative devices, digitized from vendor datasheets.

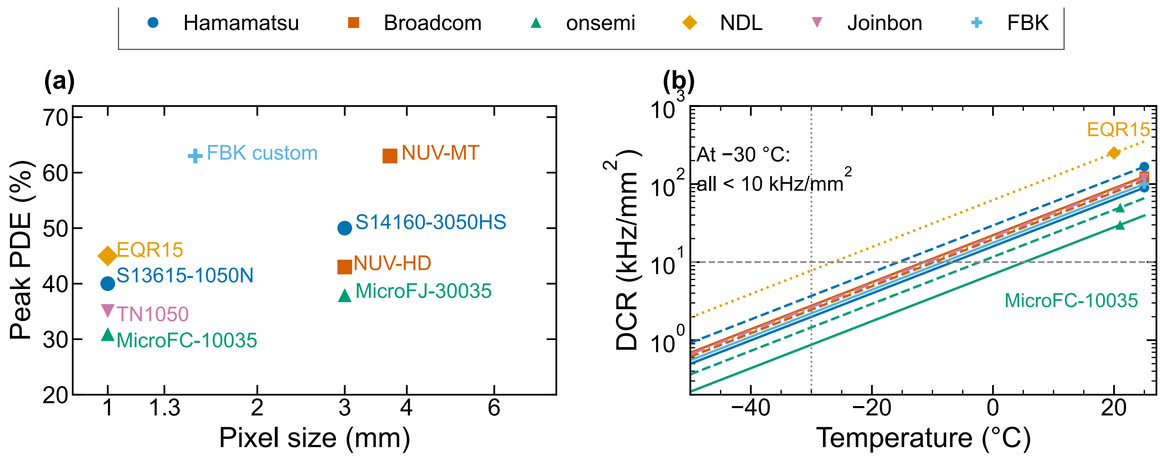


Fig. 3 (a) Peak PDE vs pixel size (b) Dark count rate vs temperature

Survey key findings

- Highest PDE: **Broadcom NUV-MT and FBK (60–63 % at 420 nm)**; lowest DCR: **onsemi (30 kHz/mm²)**.
- onsemi, NDL and Joinbon publish no timing data; **no vendor publishes radiation tolerance**.
- Cooling helps: DCR **halves every ~10 °C**; at −30 °C all devices in Fig. 3b are **below 10 kHz/mm²**.
- Irradiation hurts: DCR grows linearly with fluence [14–16], **so cooling is essential.**

Three candidate devices

Device	Pixel	PDE	DCR	Crosstalk	Why selected
Hamamatsu S14161-3050HS	3 mm	50 %	~167†	7 %	Best PDE–crosstalk balance; best-documented irradiation data
onsemi MicroFJ-30035	3 mm	38 %	50	8 %	Low DCR at low voltage; reference for cooling studies
NDL EQR15 11-1010D-S	1 mm	45 %	250	n.p.	Highest PDE among 1 mm devices; domestic supply

Datasheet values at room temperature and the vendor-recommended overvoltage (onsemi: +2.5 V). PDE at peak wavelength (450 nm for Hamamatsu, 420 nm otherwise); DCR in kHz/mm²; † estimated from dark current, not an official specification; n.p. = not published. S14161-3050HS is the TSV array of the S14160-3050HS chip shown in Figs. 2–3.

3 SiPM Test System at IHEP

- Readout: **CAEN A5202** [17] (64 ch, Citiroc-1A) controlled by Janus software over Ethernet.
- Sensor: **Hamamatsu S16088** from JUNO-TAO — 4 × 8 chips of 12 × 6 mm², paired into 16 channels of 12 × 12 mm².
- Light & cooling: pulsed LED with optical filter in a dark box; climate chamber at **~5 °C**.
- The large channel area (12 × 12 mm², two chips in parallel) brings high dark noise, which makes the photoelectron peaks less clear.

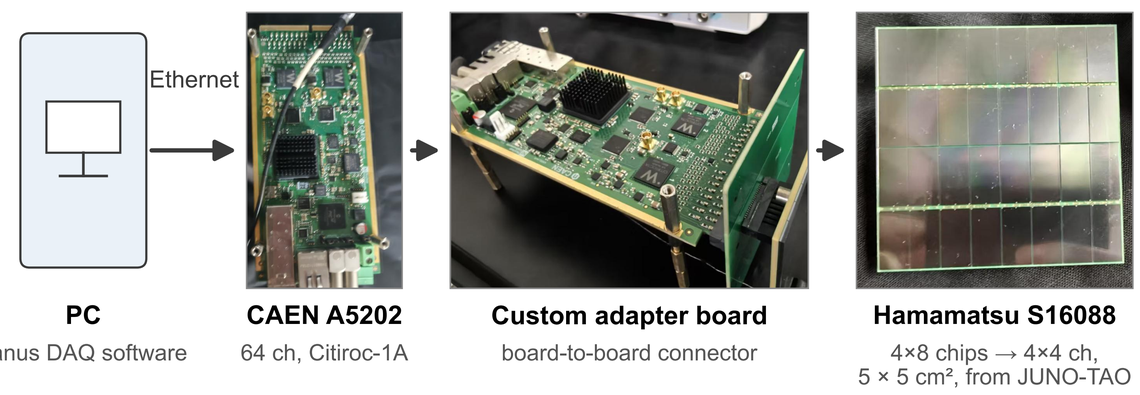


Fig. 4 Readout chain of the IHEP SiPM test system.

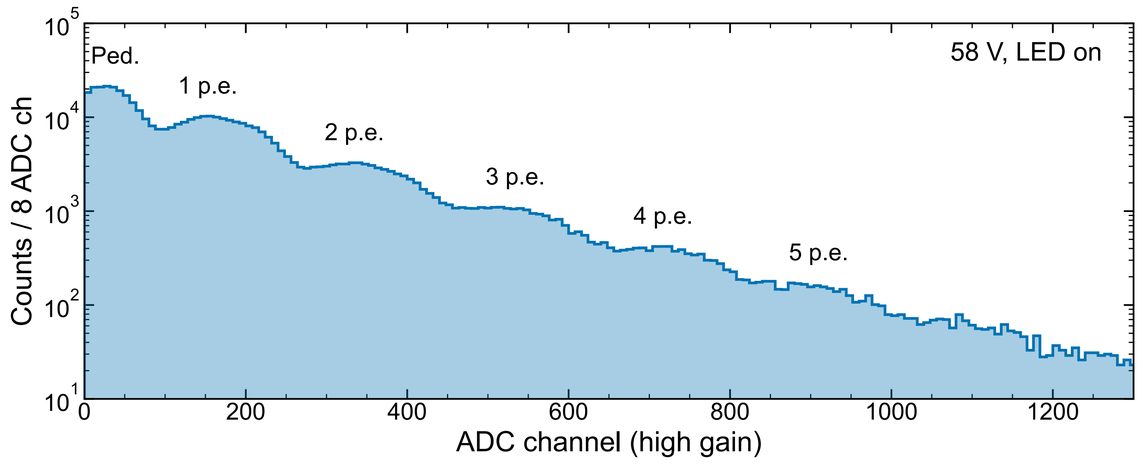


Fig. 5 LED charge spectrum of one S16088 channel at 58 V and ~5 °C: pedestal and 1–5 p.e. peaks are resolved.

4 Summary

- Six SiPM vendors compared against the forward-RICH requirements using **43 datasheets**; **three candidate devices** selected.
- Market gap: **no 1 mm pixel with PDE > 50 %**, and no published radiation tolerance.
- Irradiation-driven dark counts require operation at **−30 °C or below**.
- An SiPM test system is **running at IHEP**; S16088 LED spectra resolve **photoelectron peaks up to 5 p.e.**
- Next: colder operation, breakdown-voltage measurement, then gain, DCR, PDE and timing of candidate SiPMs.

References: [1] CEPC Study Group, CEPC Technical Design Report – Reference Detector, arXiv:2510.05260 (2025). [2] D. Yu, H. Ding et al., arXiv:2507.18164 (2025). [3] A.Yu. Barnyakov et al., arXiv:2604.08962 (2026). [4] Z. Qin, Investigation of an Endcap Cherenkov Detector for CEPC, Guangzhou, 15 July 2026. [5] Hamamatsu datasheets: S13615, S14160/S14161, S16088 (K30-I50549). [6] Broadcom datasheets: AFBR-S4N44P164M, AFBR-S4N22P014M (NUV-MT); NUV-HD. [7] onsemi datasheets: C-Series, J-Series. [8] NDL datasheets: EQR15, EQR20, PSS. [9] Joinbon datasheets: TN1000 and TN3000 Series, JARY-TN1050-8×8C. [10] A. Gola et al., Sensors 19 (2019) 308. [11] A. Gola, CERN Detector Seminar, 21 April 2023. [12] S. Gundacker et al., Phys. Med. Biol. 65 (2020) 025001. [13] S. Gundacker, SiPM single photon timing resolution, 2nd DRD4 Collaboration Meeting, CERN, 23 Oct. 2024. [14] E. Garutti, Yu. Musienko, Nucl. Instrum. Meth. A 926 (2019) 69. [15] S. Merzi et al., Sensors 24 (2024) 4990. [16] M. Calvi et al., Nucl. Instrum. Meth. A 922 (2019) 243. [17] CAEN, A5202/DT5202 User Manual, UM7945 (2023).