SiPM needs for CEPC sub-detectors
(a brief review and discussions)

Yuekun Heng (IHEP), Hengne Li (SCNU), Yong Liu (IHEP),
Zhonghua Qin (IHEP), Xiaolong Wang (FDU), Haijun Yang (SJTU)

CEPC Day (Jan. 28, 2026)

Disclaimer: slides prepared based on the input collected from ECAL, HCAL, Muon and RICH.
SiPM requirements for RICH are still preliminary and need further studies.

Outline

- Briefly go through SiPM candidates listed in CEPC Ref-TDR
  - For ECAL, HCAL and Muon Detector
- Summarise/highlight common needs and identify issues to be addressed
- SiPM requirements for Cherenkov Detector
  - New with respect to CEPC Ref-TDR: *still in development*

- Backup slides: information on SiPM development
  - Collaboration with industry: NDL-SiPM news
  - International collaboration within DRD4 (Photodetectors and PID techniques)

SiPM candidates in CEPC Ref-TDR: ECAL

- Key requirement: a large dynamic range
  - Dynamic range: 0.1 – 3000 MIPs
  - $1-2 \times 10^5$ pixels in the sensitive area of $3 \times 3\ \text{mm}^2$
  - Pixel pitch: $6-10\ \mu\text{m}$ (with a typical gain of 10^5)
- Desirable features: low inter-pixel crosstalk, peak PDE compatible with BGO/BSO (480nm)

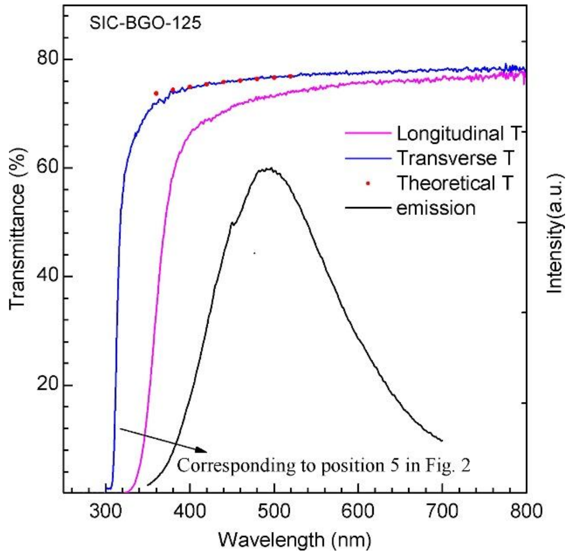
SiPMs for ECAL

- Quantity: 571,000 pcs
- Total area: 5.14 m^2

Table 7.2: Parameters of SiPM candidates selected for the crystal ECAL

SiPM Type	NDL EQR06	NDL EQR10	HPK S14160-3010PS
Pixel Pitch µm	6	10	10
Pixel Quantity in $3 \times 3\ \text{mm}^2$	244,719	90,000	89,984
Pixel Gain	8×10^4	1.7×10^5	1.8×10^5
Typical peak PDE	30 % (at 420 nm)	36 % (at 420 nm)	18 % (at 460 nm)
Typical DCR (20 °C)	2.5 MHz	3.6 MHz	700 kHz
Inter-pixel Crosstalk	12 %	N/A	< 1 %
Terminal Capacitance (pF)	45.9 pF	31.5 pF	530 pF

60cm BGO from SIC (paper)



SiPM candidates in CEPC Ref-TDR: HCAL

- Key requirement: balance of signal-to-noise ratio and dynamic range
  - Dynamic range: 0.1 – 100 MIPs
  - $\sim 10^4$ pixels in $3 \times 3\ \mathrm{mm}^2$
  - Pixel pitch: $15 - 20\ \mu\mathrm{m}$ (with a typical gain of 10^6)

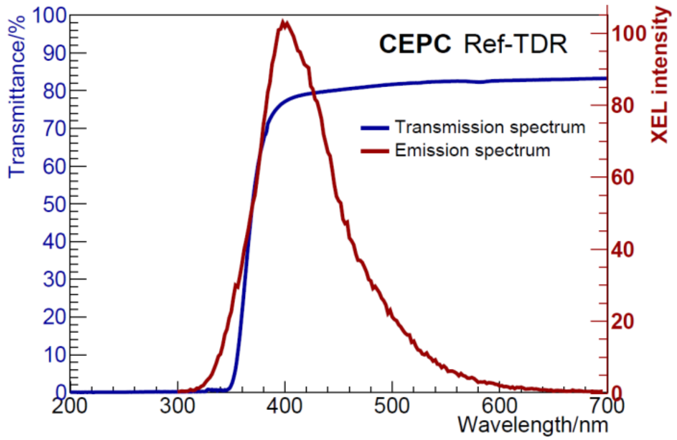
SiPMs for HCAL

- Quantity: 5.2 M pcs
- Total area: 46.8 m^2

- Desirable features: low inter-pixel crosstalk, peak PDE compatible with glass (GFO 400 nm)

Table 8.4: The parameters of some typical commercial SiPMs.

Supplier	HPK		NDL	JBT
Type	S14160-3015PS	S14160-3050HS	EQR20-11-3030-S	JSP-TP3050-SMT
Pitch [μm]	15	50	20	50
Number of pixels	39984	3531	22500	3364
Terminal capacitance [pF]	530	500	157.5	170 (fF)
Breakdown voltage (V_B) [V]	38 ± 3	38 ± 3	27.2 ± 1	24.6 ± 0.2
Recommended operation voltage [V]	$V_B + 3$	$V_B + 2.7$	$V_B + 5$	$V_B + 2$
Peak sensitive wavelength [nm]	450	450	420	420
Peak PDE at PSW [%]	32	50	47.8	35
PDE at 400 nm [%]	27	47	45	33
Gain	3.6×10^5	2.5×10^6	8.0×10^5	2.1×10^6
DCR [kHz/mm^2]	700–2100	10–100	150–450	120–270



SiPM candidates in CEPC Ref-TDR: Muon Detector

- Key requirement: a high signal-to-noise ratio
  - SiPM candidates: HPK S14160-3050, NDL EQR20-11-3030
  - Pixel pitch: $20 - 50\ \mu\text{m}$ (with a typical gain of 10^6)
  - Sensitive area: $3 \times 3\ \text{mm}^2$
  - A low inter-pixel crosstalk: a few percent

SiPMs for Muon Detector

- Quantity: 43,000 pcs
- Total area: 0.4 m^2

HPK MPPC Data Sheet

Electrical and optical characteristics (Typ. Ta=25 °C, Vover=2.7 V, unless otherwise noted)

Parameter		Symbol	S14160/S14161 -3050HS-04, -08	S14160/S14161 -4050HS-06	S14160/S14161 -6050HS-04	unit
Spectral response range		λ	270 to 900			nm
Peak sensitivity wavelength		λp	450			nm
Photon detection efficiency at λp*3		PDE	50			%
Breakdown voltage		VBR	38			V
Recommended operating voltage*4		Vop	VBR + 2.7			V
Vop variation between channels in one product*5	Typ.	-	0.1			V
	Max.		0.2			
Dark current	Typ.	ID	0.6	1.1	2.5	μA
	Max.		1.8	3.3	7.5	
Crosstalk probability		-	7			%
Terminal capacitance		Ct	500	900	2000	pF
Gain		M	2.5×10^6			-
Temperature coefficient of recommended reverse voltage		ΔTVop	34			mV/°C

NDL-SiPM Data Sheet

Type		EQR20 11-3030D-S	EQR20 11-6060D-S
Effective Pitch		20 μm	
Element Number		1×1	
Active Area		$3.0 \times 3.0\ \text{mm}^2$	$6.24 \times 6.24\ \text{mm}^2$
Micro-cell Number		22500	97344
Terminal Capacitance [1]		57.5 pF	397
Breakdown Voltage (V_B)		27.2V±1 V	
Maximum operation voltage(V_m)		34.7±1.6 V	
Recommended Operation Voltage [2]		V_B + 5 V	
Temperature Coefficient for V_B		24.8 mV/℃	
Peak PDE @ 420nm		47.8	
Gain		8.0×10^5	
Dark Count Rate (DCR)	typical	150 kHz / mm^2	
	maximum	450 kHz / mm^2	

SiPM common needs (scintillator readout)

- Two SiPM types identified: sensitive area of $3 \times 3\ \mathrm{mm}^2$
  - High Dynamic Range for ECAL: $6 - 10\ \mu\mathrm{m}$ pixel pitch
  - High Signal-to-Noise Ratio for HCAL/Muon: $\sim 20\ \mu\mathrm{m}$ pixel pitch

SiPMs for ECAL, HCAL and Muon
- Quantity: 5.81M pcs
- Total area: 52.3 m^2

- Low inter-pixel crosstalk
  - State-of-art level: < 1% *

*Using trenches implemented in pixels: limited PDE in HDR-SiPM for ECAL; not feasible for EQR-SiPM from NDL

- Peak PDE compatible with crystal/glass **To be addressed**
  - (Not an issue for Muon Detector: perfect peak PDE matching with plastic scintillator)
  - BGO/BSO peak emission at 480 nm; GFO glass peak emission at 400 nm
  - Existing SiPM candidates: peak PDE at 450/460 nm (HPK) or 420 nm (NDL)
- Radiation hardness: in endcap/forward regions **To be addressed**
  - Crystal ECAL studies in Ref-TDR: NIEL up to $1 \times 10^{10} \mathrm{n_{eq}}(1\mathrm{MeV})\ \mathrm{cm}^{-2}$ at 20°C (paper)
  - CMS HGCAL SiPM-on-Tile modules: fluence up to $4 \times 10^{13} \mathrm{n_{eq}}(1\mathrm{MeV})\ \mathrm{cm}^{-2}$ at -35°C
- Towards the final detector: production yield, QA/QC and cost **To be addressed**

SiPM needs for Cherenkov Detector

- Key requirements
  - High PDE and low noise
  - Radiation tolerance
  - Single photon detection capability

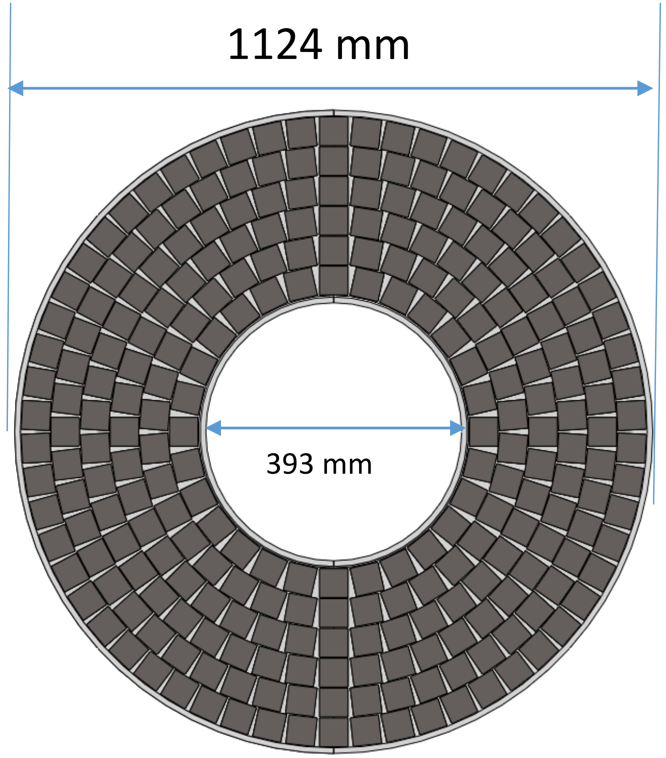
SiPMs for RICH

- Total area: 1.6 m^2

- Preliminary parameters

Parameters	Requirement (preliminary)
Photon Detection Efficiency	> 50% (420nm)
Sensitive Area (two SiPM types identified)	Type 1: $1 \times 1\ \mathrm{mm}^2$ (conventional); Type 2: $3 \times 3\ \mathrm{mm}^2$ (position sensitive)
Dark noise rate	< ~10 kHz/mm^2 (to be further studied)
Spatial resolution	~280 μm
Radiation tolerance	< 10^{13} $N_{eq.}$ /cm^2 (to be further studied)

RICH conceptual design



Photon detector:

- 258 modules in 6 layers
- Each module of 5 cm x 5 cm

- SiPM radiation hardness: talk in RICH2025
- VUV-sensitive SiPM: nEXO paper (2022)
- SiPM-Based RICH: Particles 2025, 8(4), 94

Backup slides

Information on SiPM development

Information: SiPM development in collaboration with industry

- NDL for custom-made SiPM prototypes
  - Multi-Project Wafer (MPW) service, starting in Q1 2026
  - 6-inch wafers
  - Two SiPM types: Epitaxial Quenching Resistor (EQR), Position Sensitive (PSS)
- NDL MPW schedule in 2026
  - Submission deadlines: March 13, July 3 and October 30

MPW Process

The active area, microcell pitch, and array size of customized devices are as follows:

Devices	Microcell Pitch	Active Area of EQR SiPM/PSS SiPM/APD/PIN						
		(0.5-9.5)-9.5 mm^2	6×6 mm^2	3×3 mm^2	1×1 mm^2	0.75×0.5 mm^2	0.5×0.5 mm^2	0.25×0.25 mm^2
EQR/PSS SiPM	20 μm	1×1-12×1	NA*	NA*	3×3 1×16	1×32	4×32	8×64
	15 μm	1×1-12×1	1×1	NA*	3×3 1×16	1×32	4×32	8×64
	10 μm	NA	NA	1×1	3×3 1×16	1×32	4×32	8×64
APD/PIN	/	1×1-12×1	1×1	1×1	1×16	1×32	NA	NA

*Standard devices available in stock from Capital Photonics Co., Ltd.

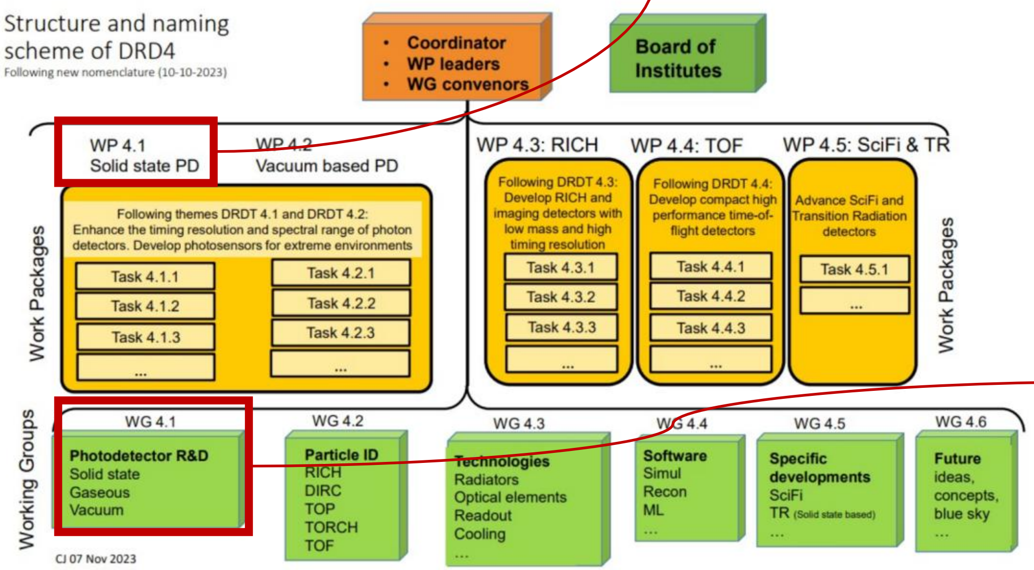
EQR-SiPM: candidate for most sub-detectors

PSS-SiPM: potentially interesting for RICH

Information: SiPM development in DRD4 collaboration

Working Package 1

DRD4 structure (from the Proposal)



Working Group 1

- DRD4 status report: photon detectors and PID (Corfu2025 talk)
- The DRD4 Collaboration for research and development on photon detectors and particle identification techniques (RICH2025 talk)

WP1: Solid-State Photodetectors

- Task 1 - SSPD with new configurations and modes
  - Development of back-side illuminated SiPM (potential for better PDE and radiation tolerance); development of ultra-granular SiPM that integrates with the electronics by using 2.5D or 3D interconnection techniques; development of CMOS-SPAD light monolithic sensors for HEP; study of new materials for light detection
- Task 2 - Fast radiation hard SiPMs
  - Standardize procedures for quantification of radiation effects; irradiated SiPMs characterization in wide temperatures range (down to -200 °C); study of annealing; study and quantify other measures enabling the use of SiPM in highly irradiated areas (e.g. smaller SiPMs, macro- and micro-light collectors)
- Task 3 - Timing of SSPD, including readout electronics
  - Study and improve the timing of SiPMs; co-design of a multi-ch. readout ASIC exploiting the timing potential; integration and packaging with integrated cooling; vertical integration of SiPM arrays to FEE (better timing via reduction of interconnections' parasitic inductances and capacitances)

WG1: Photon Detectors

- Scientific forum for studies and development of novel photodetectors with focus on PID for future experiments
- Topics (selection):
  - Radiation hardness; timing resolution; high-rate capabilities; longevity
  - Extreme conditions: e.g., cryogenic and high magnetic field
  - Large-area (e.g. SiPMs arrays, LAPPDs, etc.); hybrid detectors
  - Fine granularity detectors for future high-rate experiments
  - New technologies: CMOS-SPADs, new SiPM structures, BSI SiPMs
  - New photocathode structures and materials
  - Novel materials for photon detection: e.g., Ge-on-Si APDs;
  - Read-out electronics for extreme environments, fast timing and high channel density; optimal sensors and R/O electronics integration
  - Simulations of photo-detector response
- Standardization of procedures for photodetectors characterization