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The nEXO Program

- Search for $0\nu\beta\beta$ decays of ^{136}Xe using 5 tonnes of LXe TPC
- Half-life sensitivity: 1.35×10^{28} yr (90% CL), 10 years of data^[1]
- A monolithic LXe TPC detector -- 90% enriched ^{136}Xe
 - Charge collection: a pad like charge readout tile
 - Light collection: $\sim 4.6 \text{ m}^2$ VUV sensitive SiPMs
 - Cold electronics both for charge and light readout
- Energy resolution: $< 1\%$ @Q-value
- A "background-free" experiment: 7×10^{-5} cts/(FWHM kg yr)

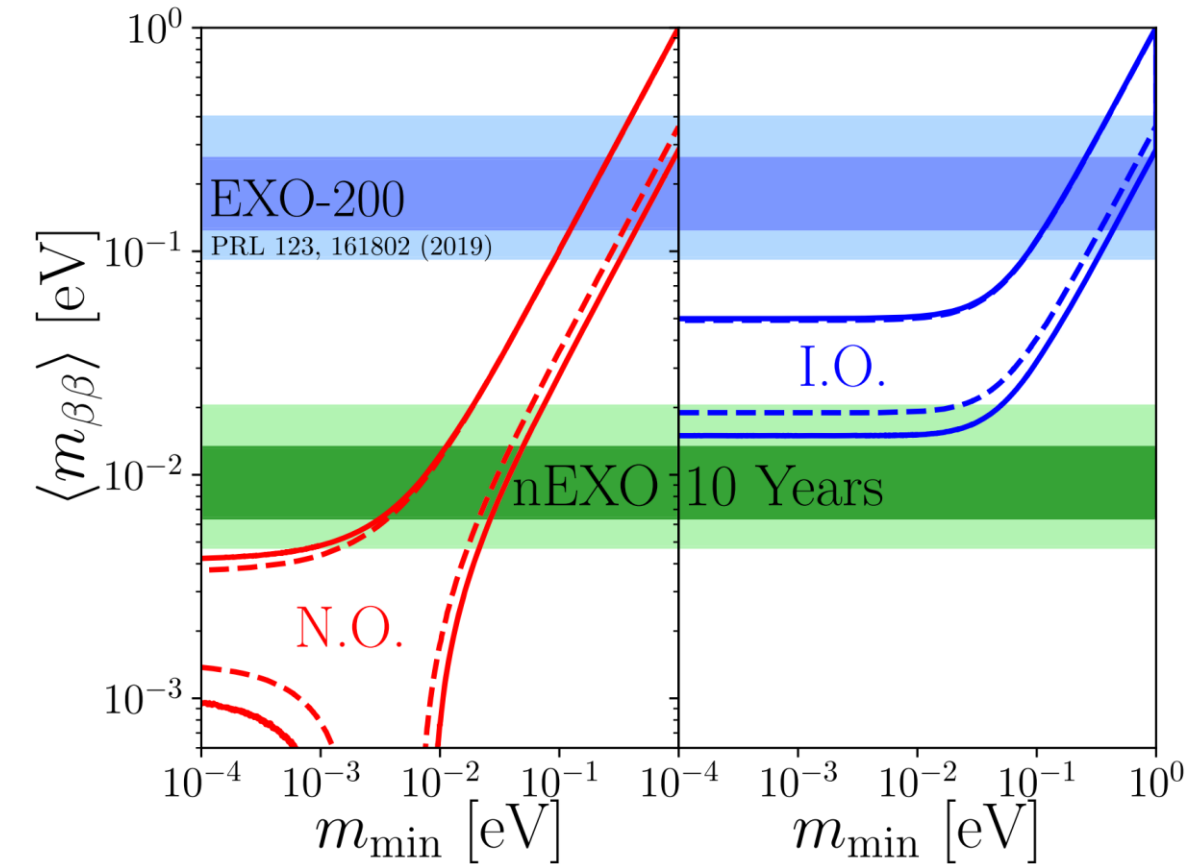
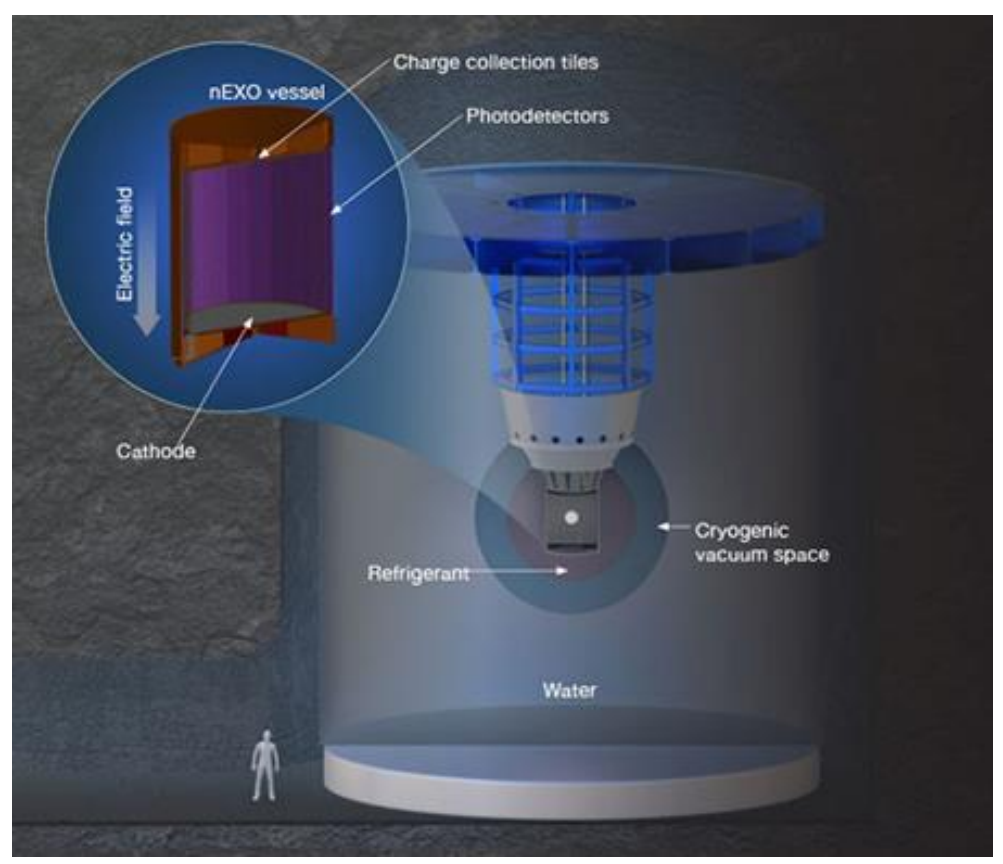
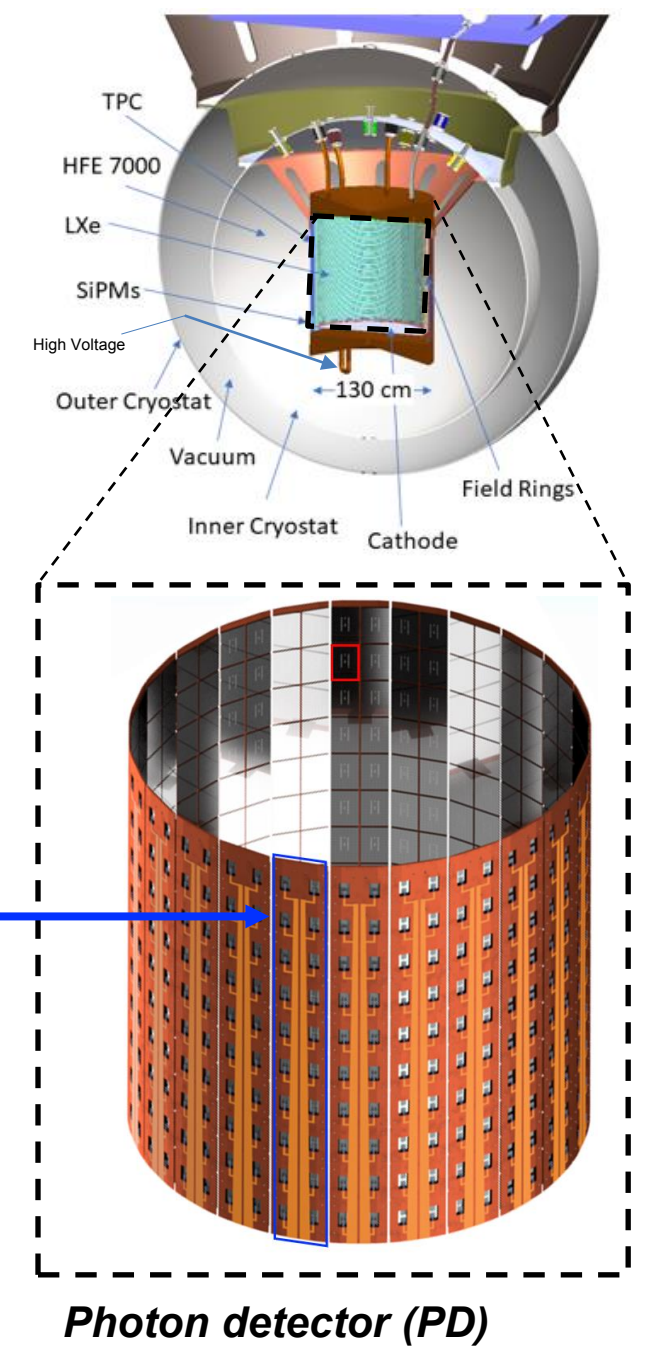
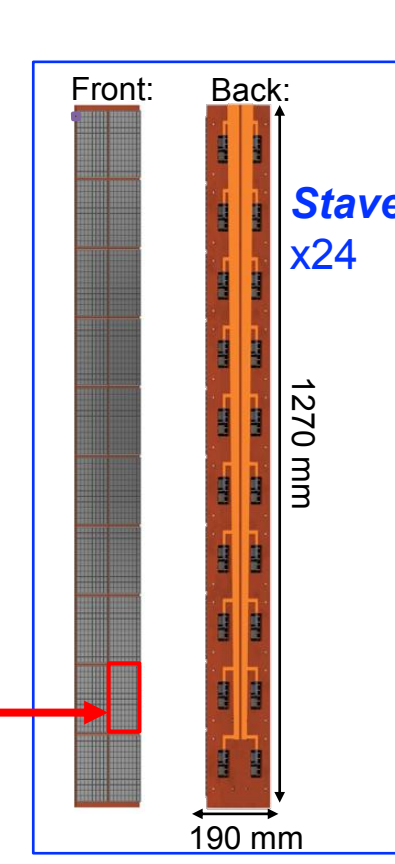
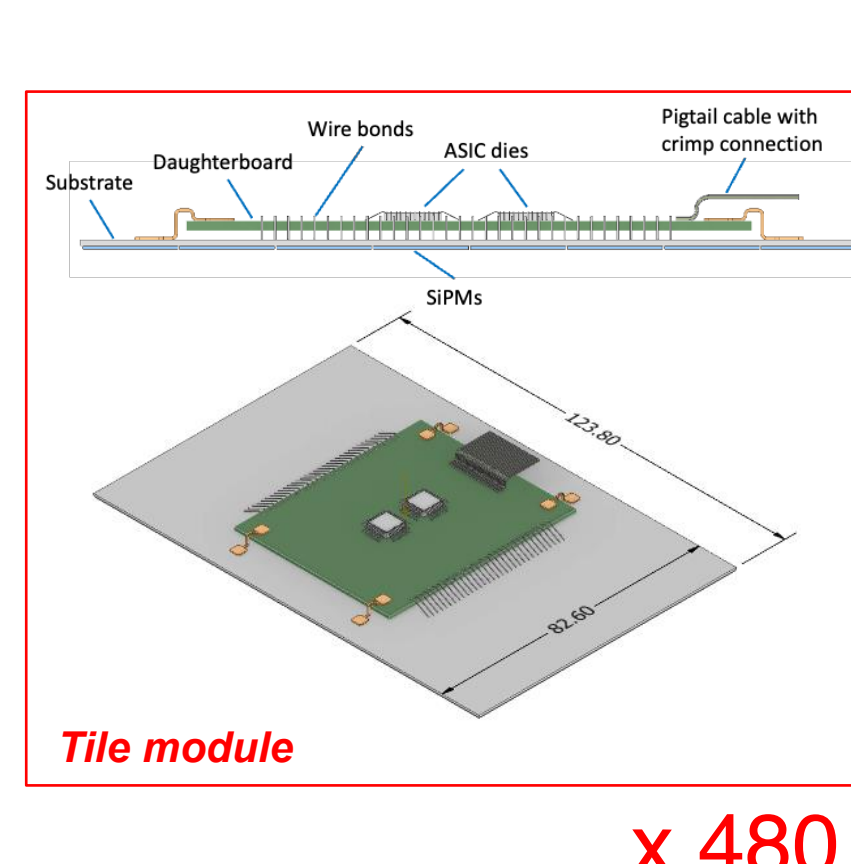
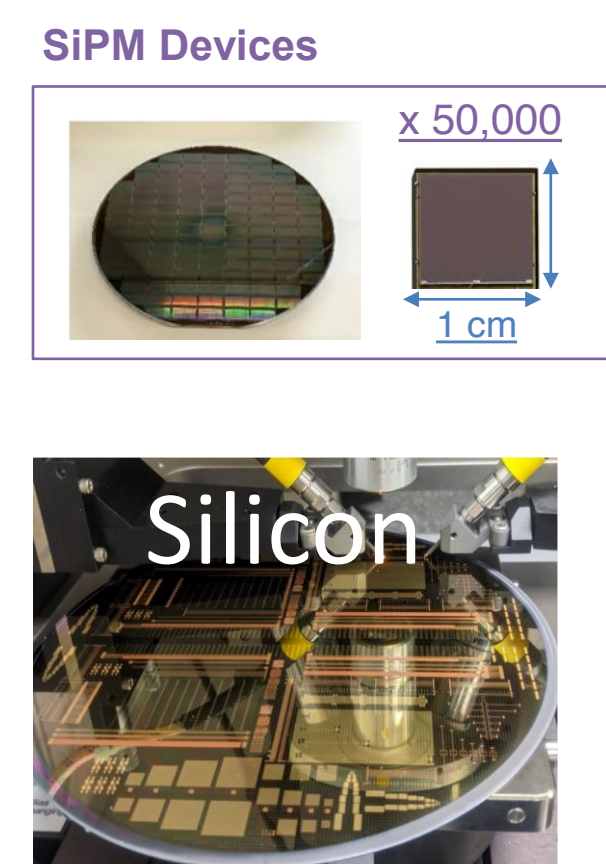
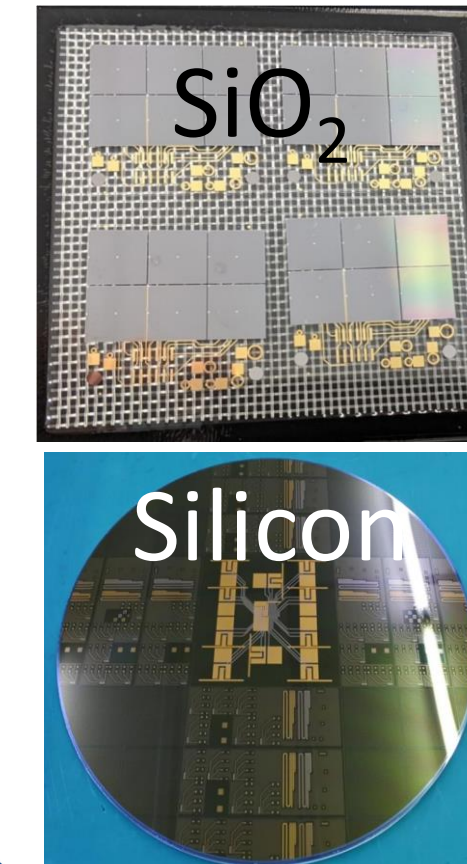
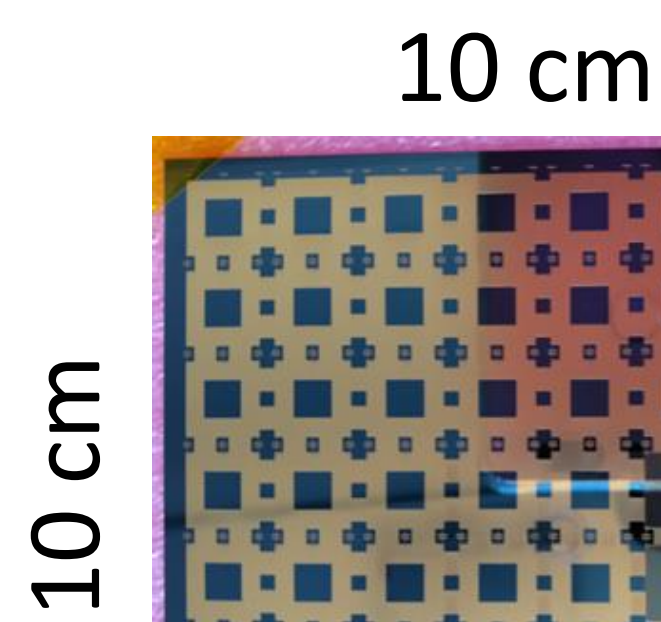


Photo-detector System

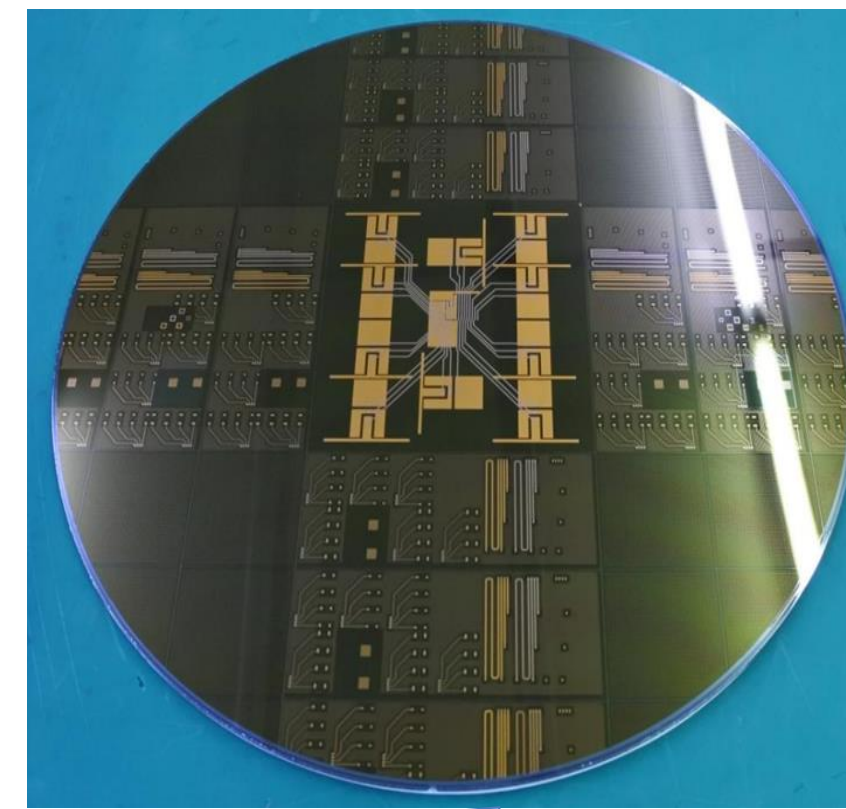
- 4.6 m^2 large area VUV-sensitive SiPMs in the barrel of TPC
 - $\sim 46,000$ $1 \text{ cm} \times 1 \text{ cm}$ SiPMs \rightarrow grouped into 7680 6 cm^2 readout channels
- 24 staves and each contains 20 tiles, and each tile has 16 readout channels
- Interposer provides supporting and connections of SiPM and readout chips
 - Ultra-low radioactivity is a must
 - Two solutions are under development, at the $\sim 100 \text{ cm}^2$ level
 - Fused silica substrate (BNL)
 - Silicon substrate (IHEP-IME, Sherbrooke-TRIUMF-IZM)



Roadmap of Silicon Interposer Development at IHEP/IME



- Thickness: 320 μm , 3 RDLs
- Number of channels: 64
- Trace length: 95 mm
- Trace width: 50 μm
- Trace thickness: 3.5 μm
- Large trace resistance: 14~30 Ω
- $\sim 1.5\%$ open nets
- Poor insulation: tens of M Ω



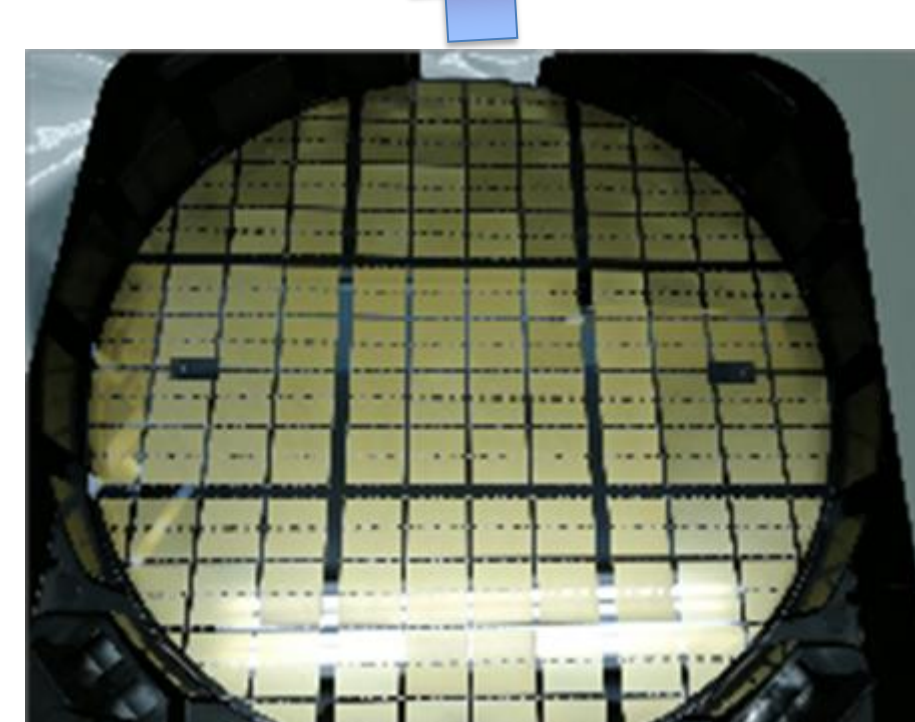
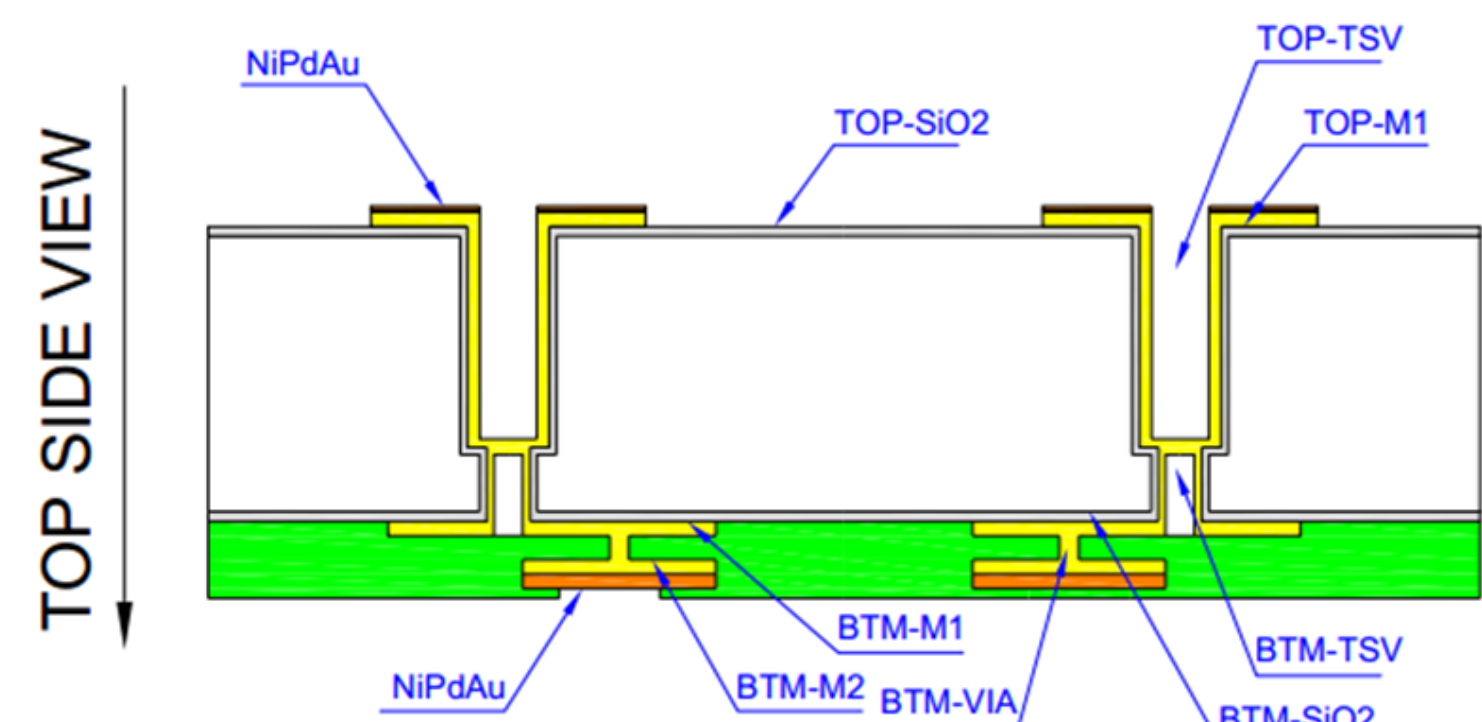
- Thickness: 320 μm , 3 RDLs
- Number of channels: 11
- Trace: 50 mm (L), 400 μm (W), and 3.5 μm (T)
- Trace resistance: $< 2 \Omega$
- No open nets
- Insulation: $> 1 \text{ T}\Omega$

2018 Prototype

2021 Run-I

2023 Run-II

2023 Run-III



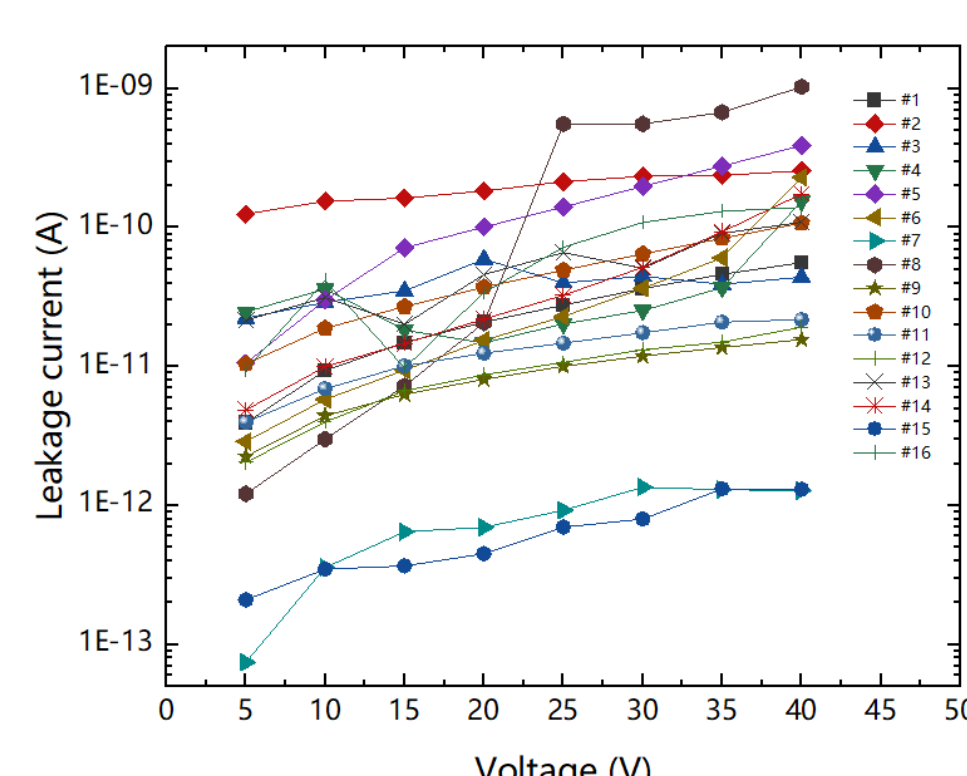
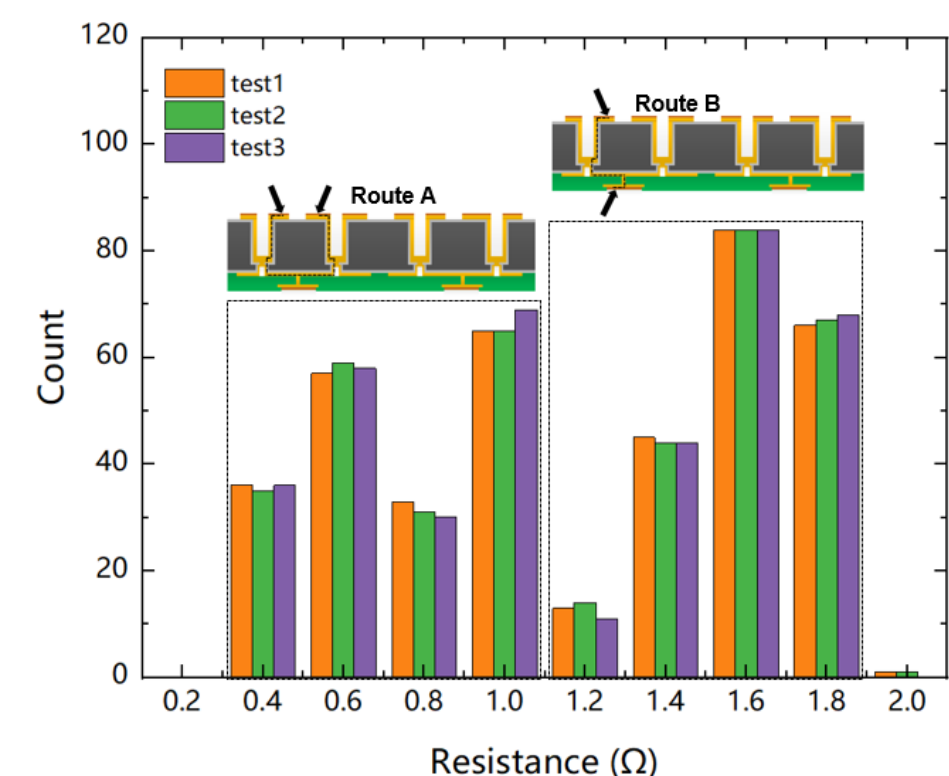
- Thickness: 320 μm , 3 RDLs
- Number of channels: 16
- Trace: 50 mm (L), 400 μm (W), and 3.5 μm (T)
- Trace resistance: $< 2 \Omega$
- No open nets
- Insulation: $> 100 \text{ G}\Omega$



- Thickness: 320 μm , 3 RDLs
- Number of channels: 16
- Trace: 50 mm (L), 400 μm (W), and 3.5 μm (T)
- Under fabrication

The Performance of the Si-Interposer from Run-I^[2]

- The resistance on traces is less than 2 Ω , meets the requirement of $< 2 \Omega$
- The insulation performance is varying among different nets with the minimum of $\sim 120 \text{ G}\Omega$ (the requirement is $> 1 \text{ T}\Omega$)
- No breakdown is observed with voltages up to 100 V



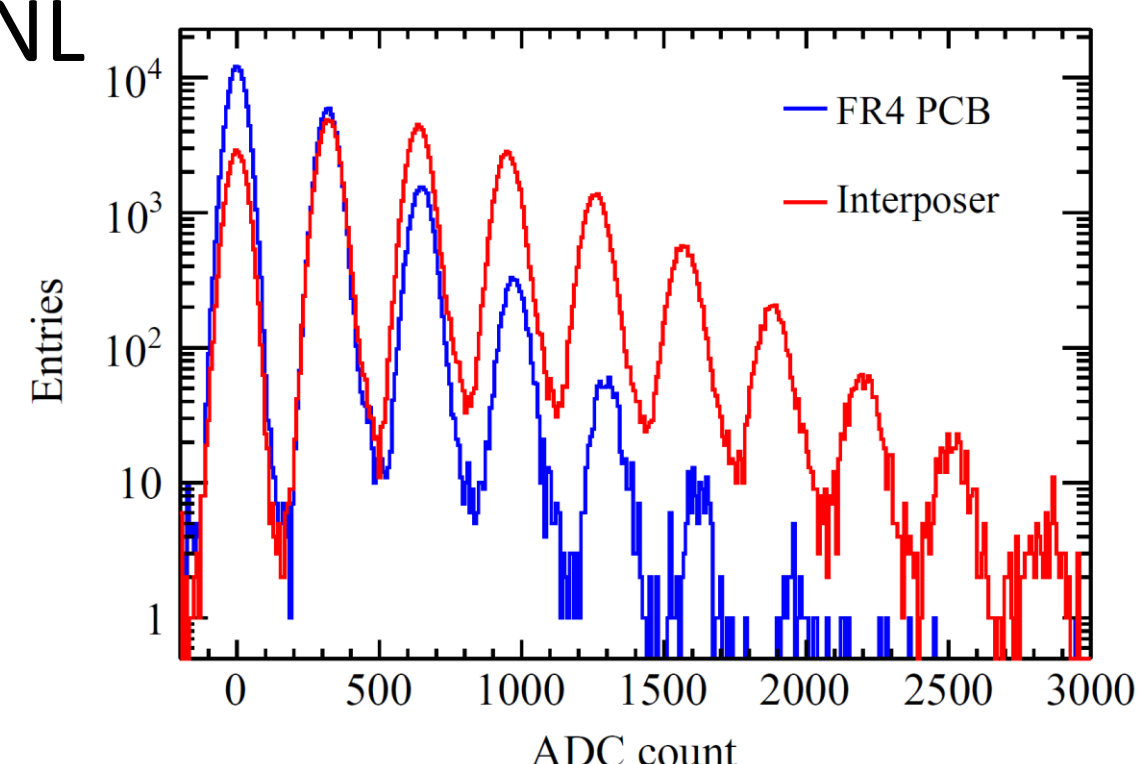
Block ID	R (G Ω)	Block ID	R (G Ω)
1	861	9	2500
2	125	10	475
3	644	11	1670
4	965	12	2260
5	161	13	482
6	924	14	647
7	26500	15	35900
8	537	16	548

- The single photon signal can be clearly observed by mounting SiPMs on the interposer and tested at LXe temperature

- The radiopurity is measured by ICP-MS at PNNL

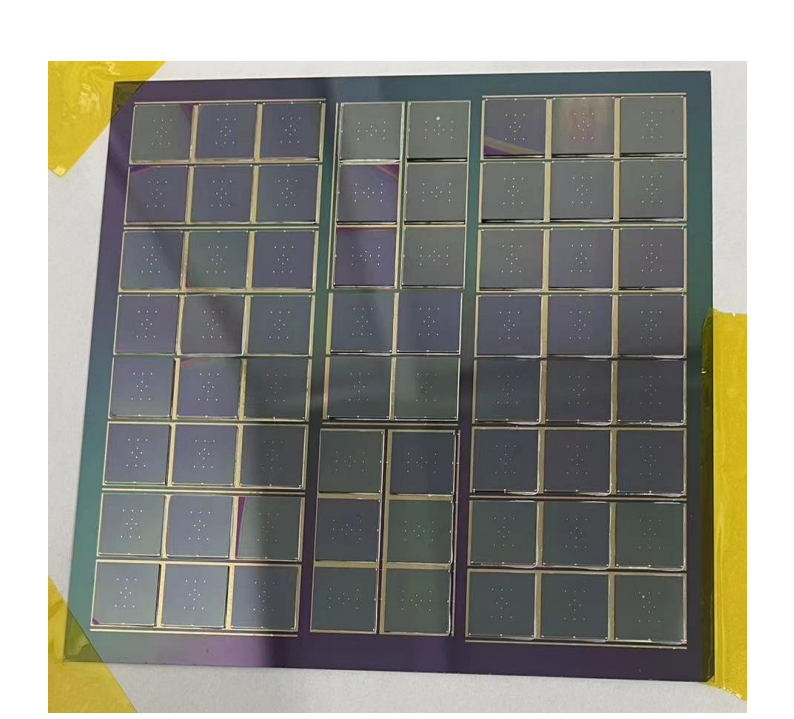
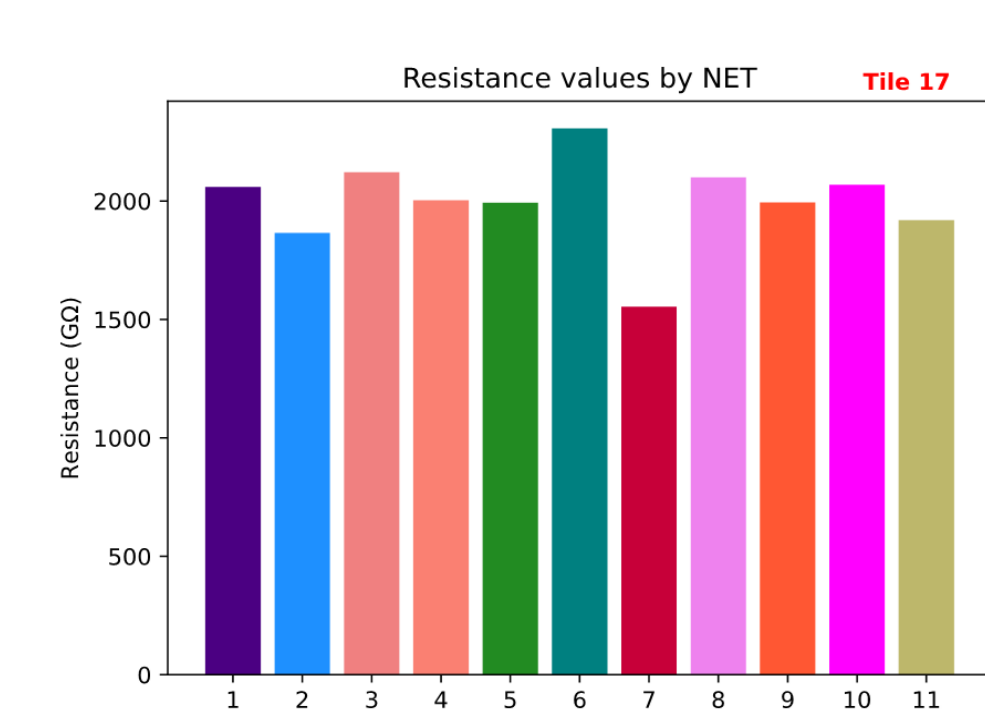
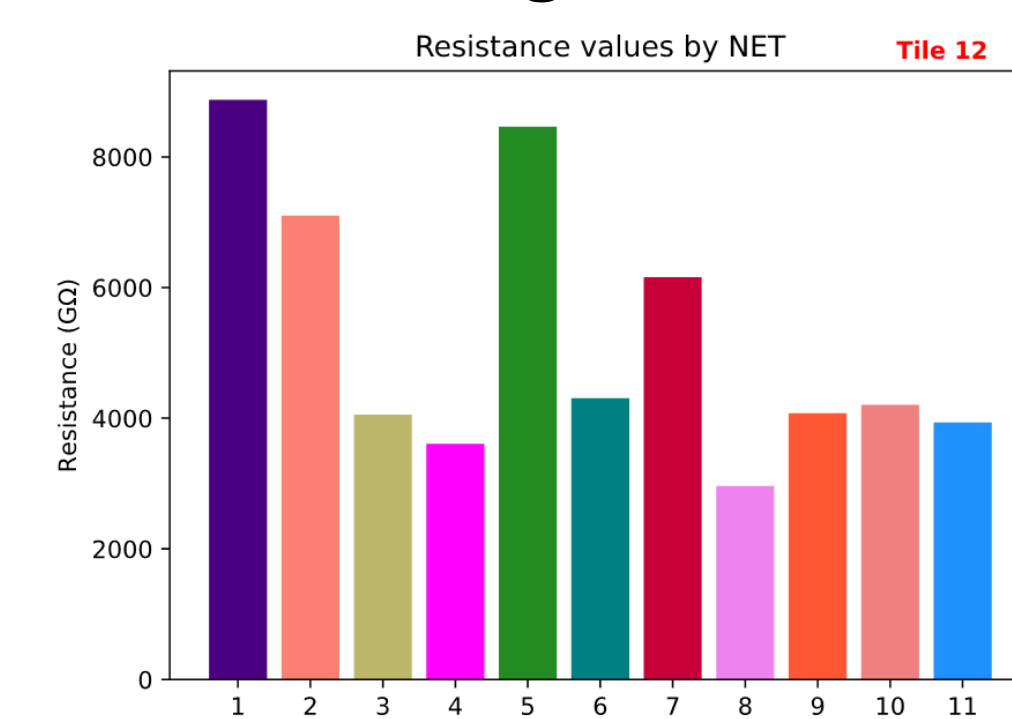
^{238}U : 4.6 ppt, ^{232}Th : 2.3 ppt, we are satisfied

Materials	Total mass (mg)	Mass fraction (%)
Silicon	7448.2	90.45
Copper	471.6	5.73
Nickel	177.6	2.16
Polyamide	177.6	0.84
Silicon dioxide	25.4	0.31
Palladium	24	0.29
Titanium	15	0.18
Gold	3.9	0.05



Status of Run-II and Run-III

- The Si-interposers from Run-II (for FBK SiPMs) have been fabricated in 2023, and the Run-III (for HPK SiPMs) is under fabrication.
- Excellent insulation performance achieved on the overall interposer, $> 1 \text{ T}\Omega$
- FBK SiPMs fully assembled on the interposer, and no mechanical issues were found during several rounds of temperature cycling tests, up to $0.4 \text{ }^\circ\text{C}/\text{min}$
- More testing results will come soon



Summary and References

- Si-interposer provides a solution for building a SiPM-based ultra-low radioactivity photo-detector.
- Si-interposer development at IHEP/IME is in good shape and the performance is quite promising.

[1] J. Phys. G: Nucl. Part. Phys. 49 (2022) 015104 [2] IEEE TNS 70 (2), 129-138 2023