LoLX phase 2

SiPM testing, assembly and operation

CAP congress

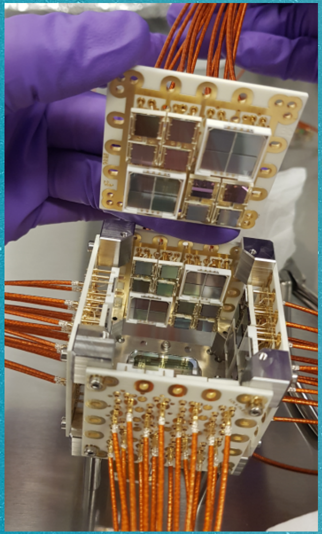
18-23 June 2023 Fredericton

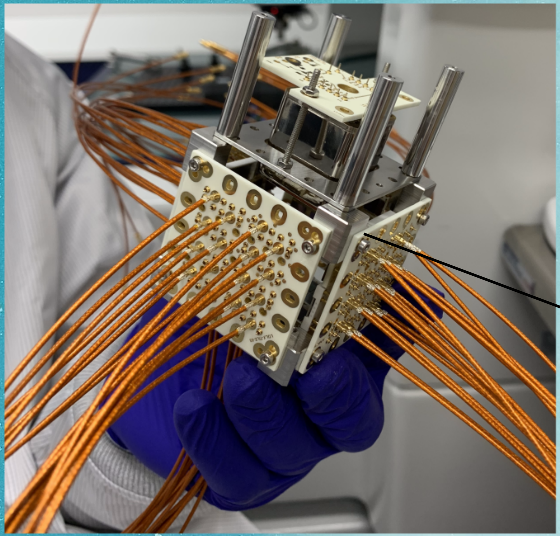
Stéphanie Bron
for the LoLX collaboration

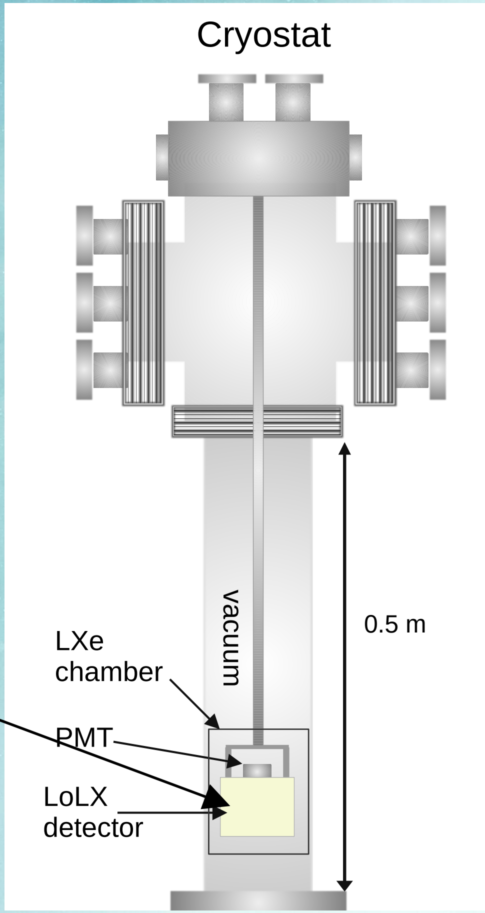
TRIUMF

LoLX: Light-only Liquid Xenon experiment

- Small cube instrumented with photosensors
- Cube immersed in liquid xenon (LXe)
- Placed in a cryostat → xenon at 160K (-110C)

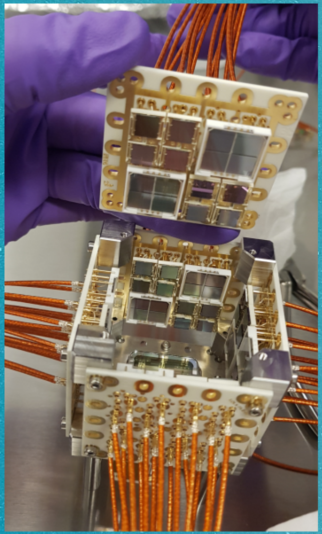


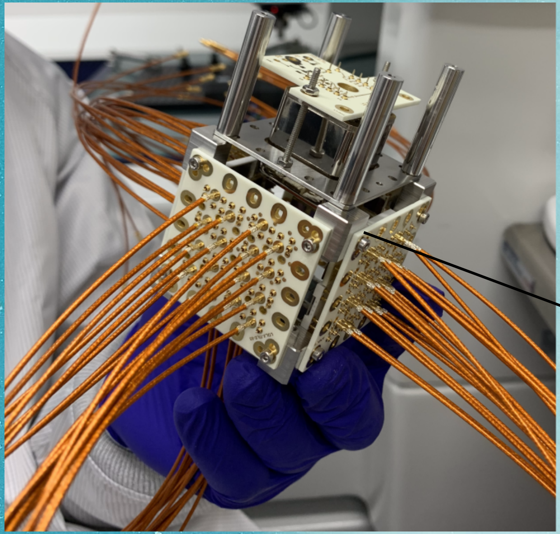


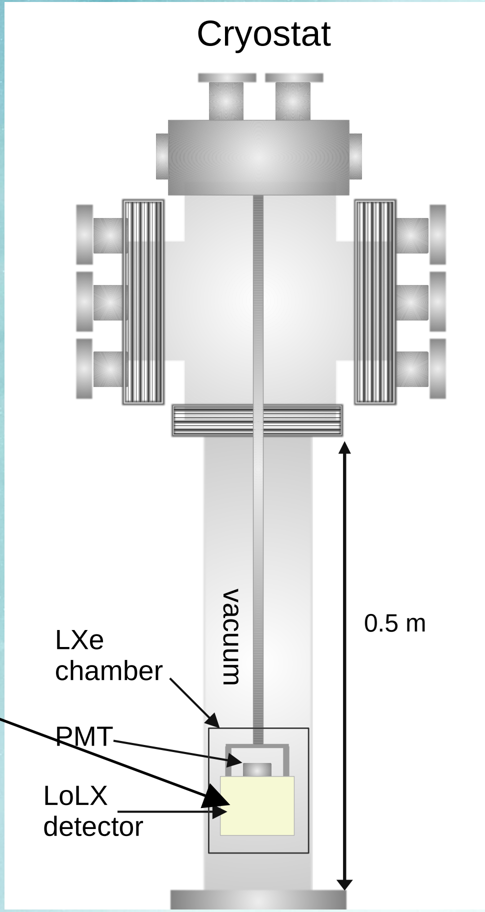


LoLX: Light-only Liquid Xenon experiment

- Setup at McGill
- TRIUMF: design, development of LoLX detectors, data collection and analysis







Physics goals

1) Study **light in liquid Xenon** and **validate simulations**

Physics goals

1) Study **light in liquid Xenon** and **validate simulations**
2) Photosensor **R&D**: silicon photomultipliers (SiPMs), new sensor technologies, etc.

Physics goals

1) Study **light in liquid Xenon** and **validate simulations**

2) Photosensor **R&D**: silicon photomultipliers (SiPMs), new sensor technologies, etc.

3) Gain experience in **operating SiPMs** over long time periods – impact on devices?

Physics goals

1) Study **light in liquid Xenon** and **validate simulations**

2) Photosensor **R&D**: silicon photomultipliers (SiPMs), new sensor technologies, etc.

3) Gain experience in **operating SiPMs** over long time periods – impact on devices?

Inform **future rare-decay experiments** (neutrinoless double beta decay, lepton flavor universality)

	LoLX	nEXO	PIONEER
LXe	4-5 kg	5 tons	7 tons
E field	no	yes	no
Energy	$\sim 0.2 - 2$ MeV	$\sim$2.5 MeV	0-70 MeV
nSiPMs	80	50'000	N/A

PIONEER: talk from Kate Pachal and from Thomas Brunner
nEXO: talk from Samin Majdi and Soud Al Kharusi

Light in liquid xenon

Energy deposit in LXe: Xe ionization/excitation → **scintillation ~175nm**

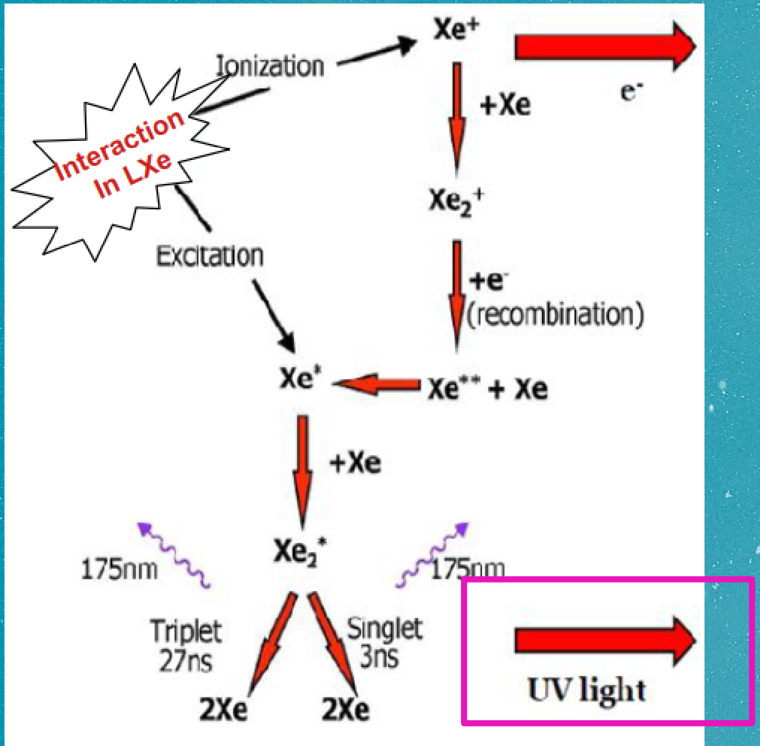


Fig. from N. Larsen (2012) Thesis Prospectus, Yale University

Light in liquid xenon

Radioactive source (^{90}Sr) → beta decay → **Cherenkov** light

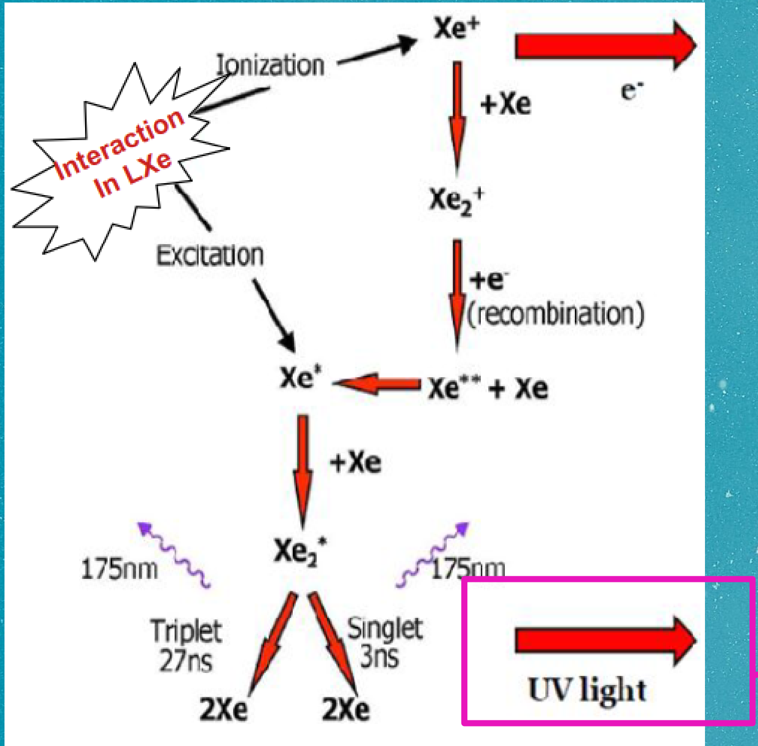
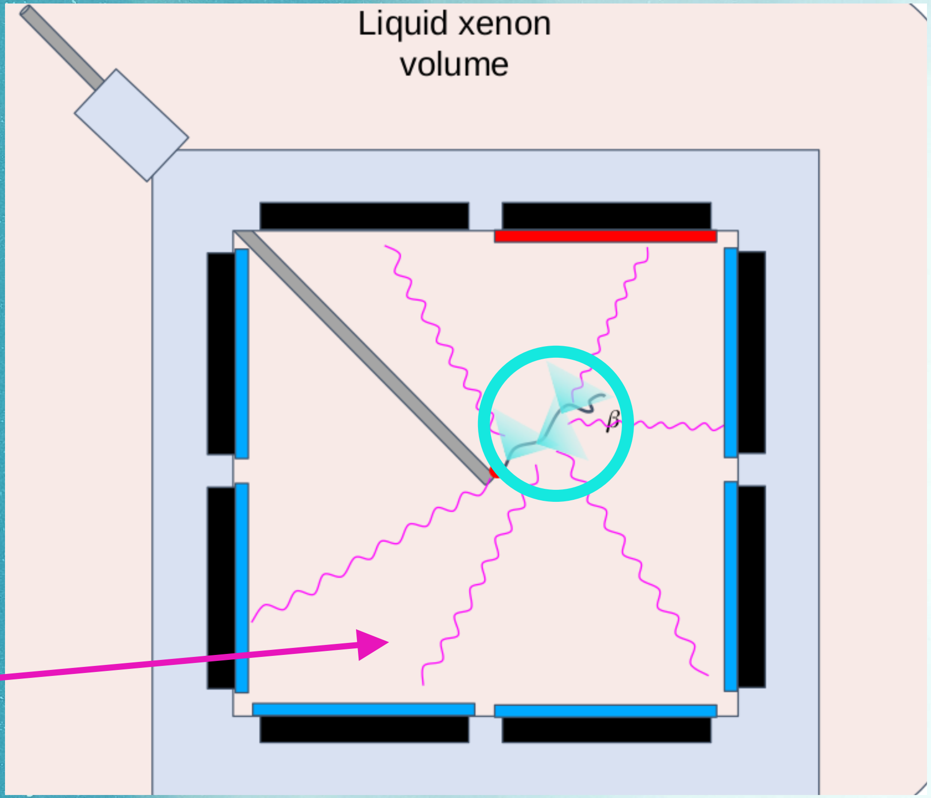
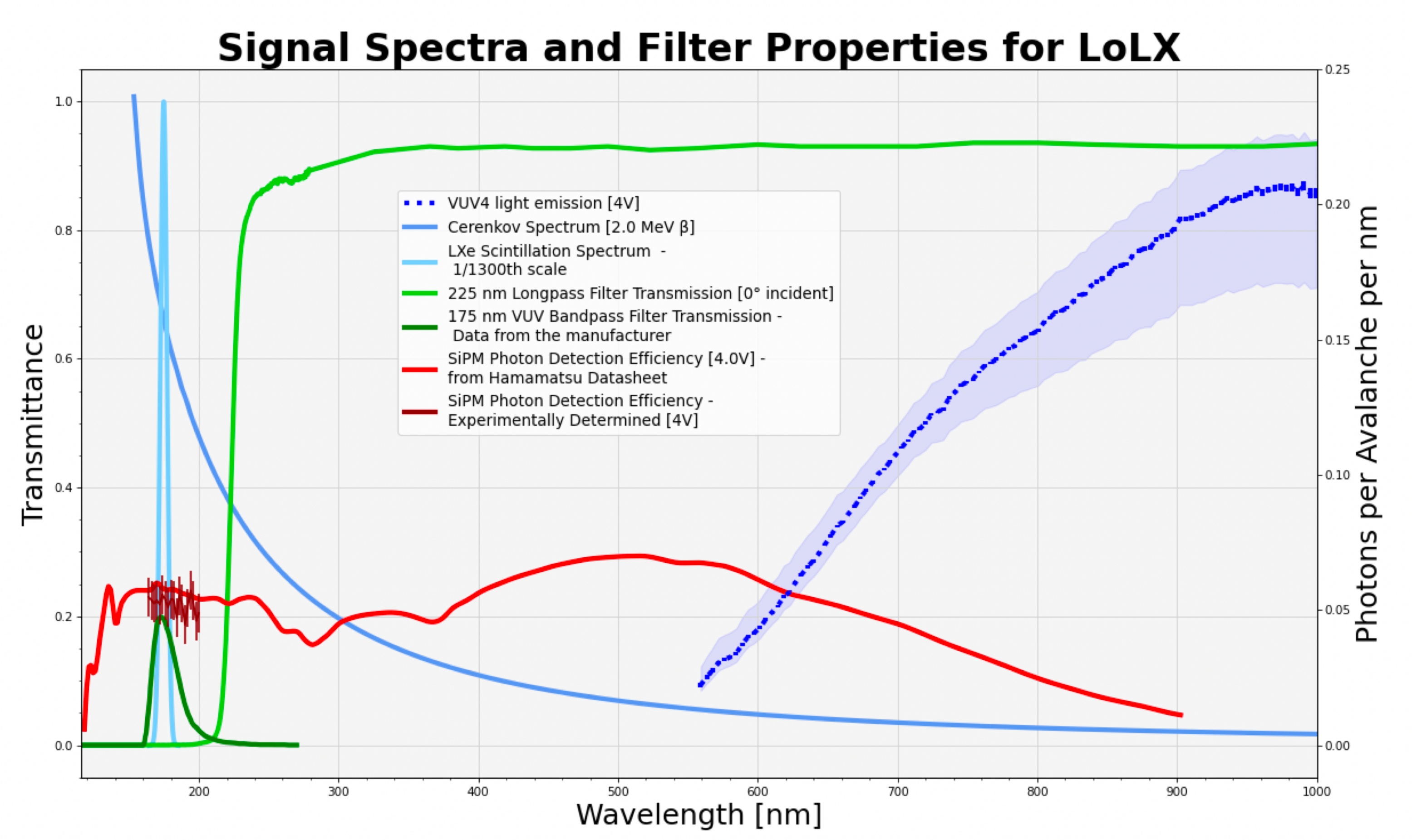


Fig. from N. Larsen (2012) Thesis Prospectus, Yale University

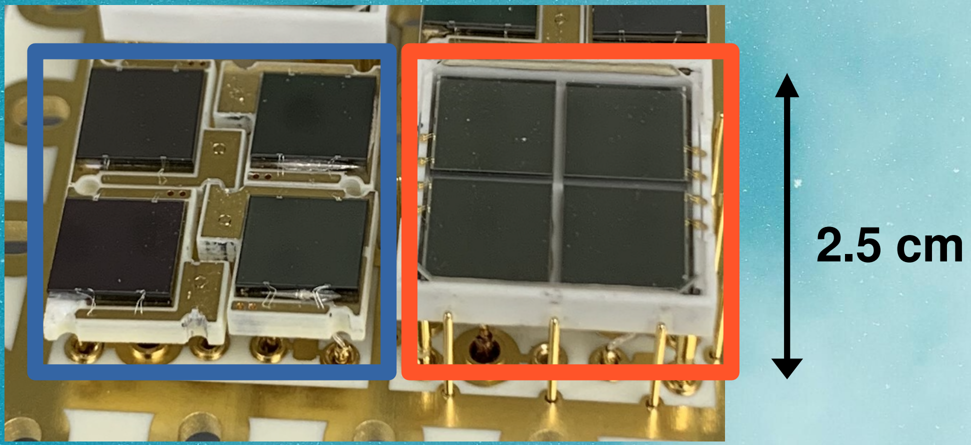


Light in liquid xenon

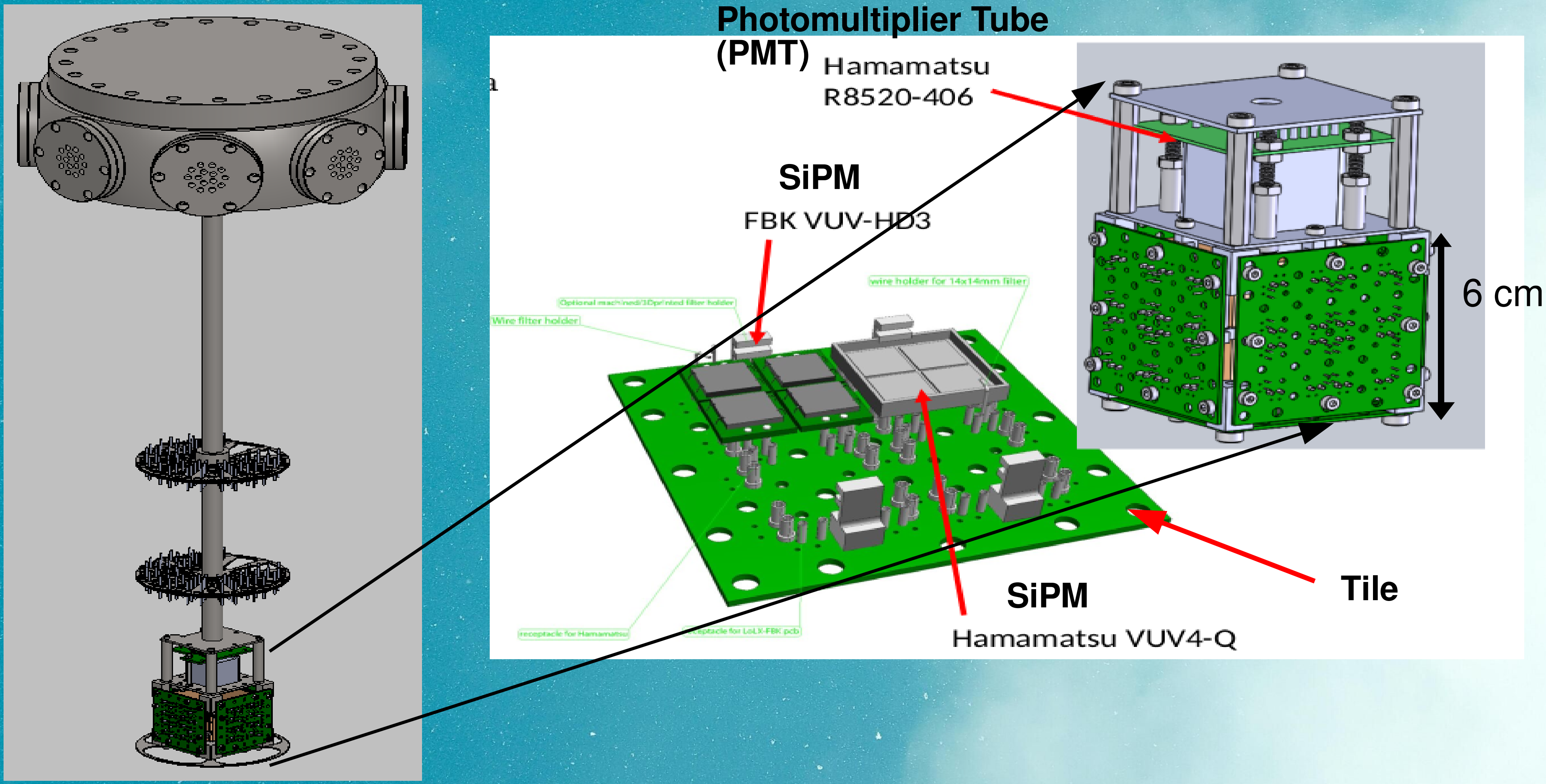


Silicon PhotoMultipliers: SiPMs

- Arrays of single-photon avalanche diodes (SPADs)
- Radiopure, very good single photon separation
- Custom vacuum ultraviolet (VUV) SiPMs: **Hamamatsu** and **FBK** (Fundazione Bruno Kessler)

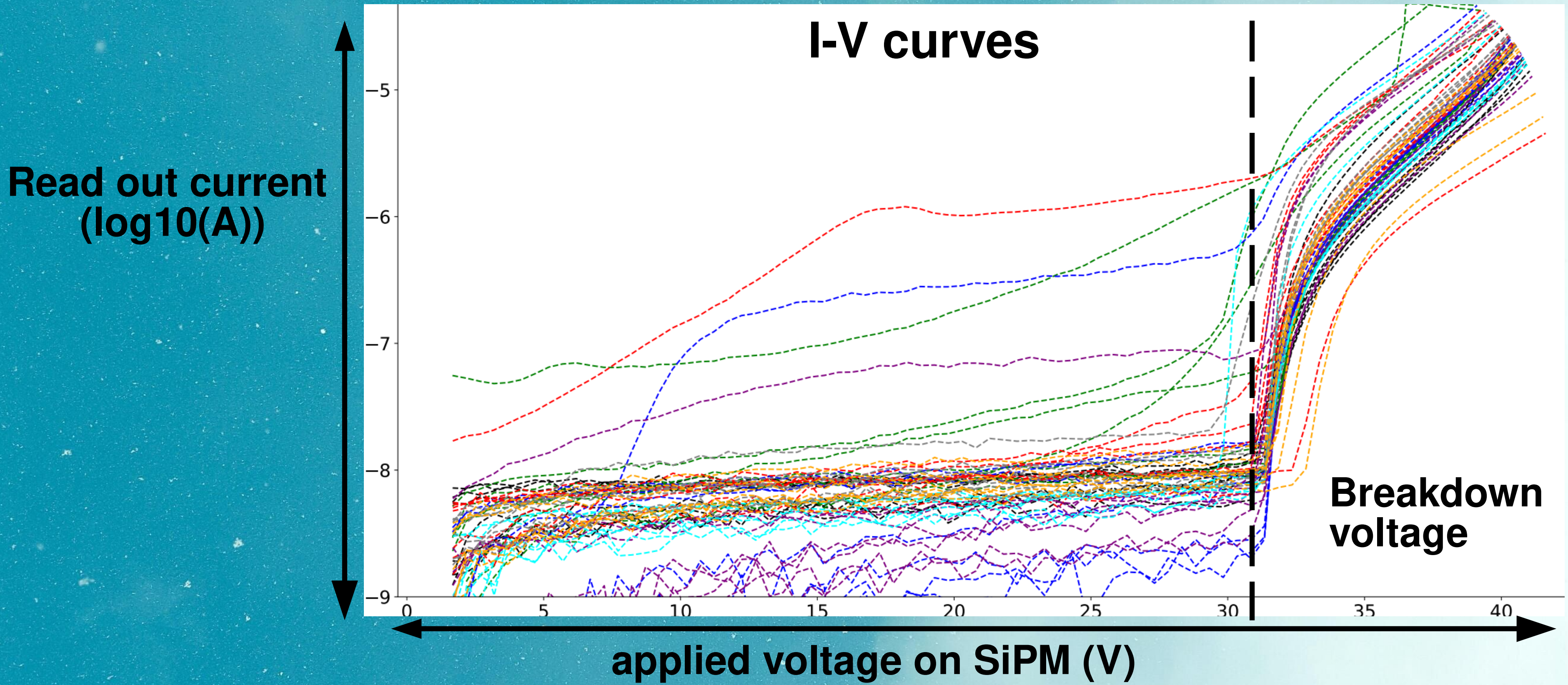


LoLX phase 2: design



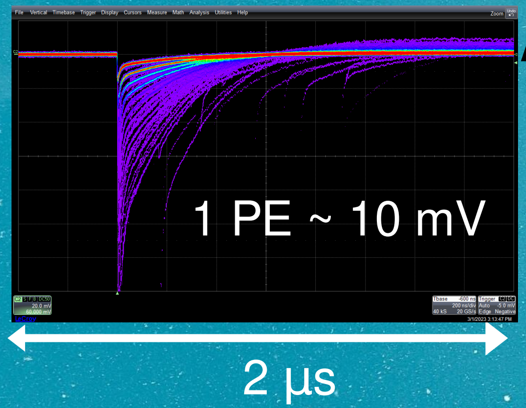
FBK SiPM testing before installation

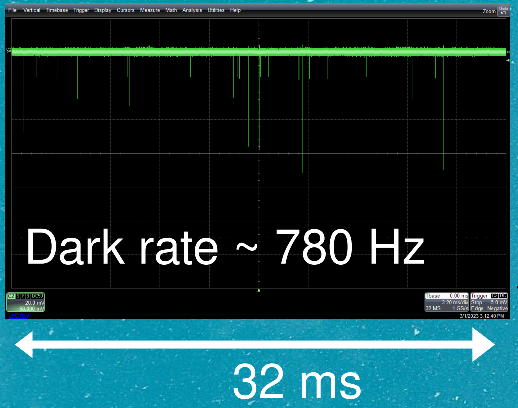
- 64 FBK SiPMs tested

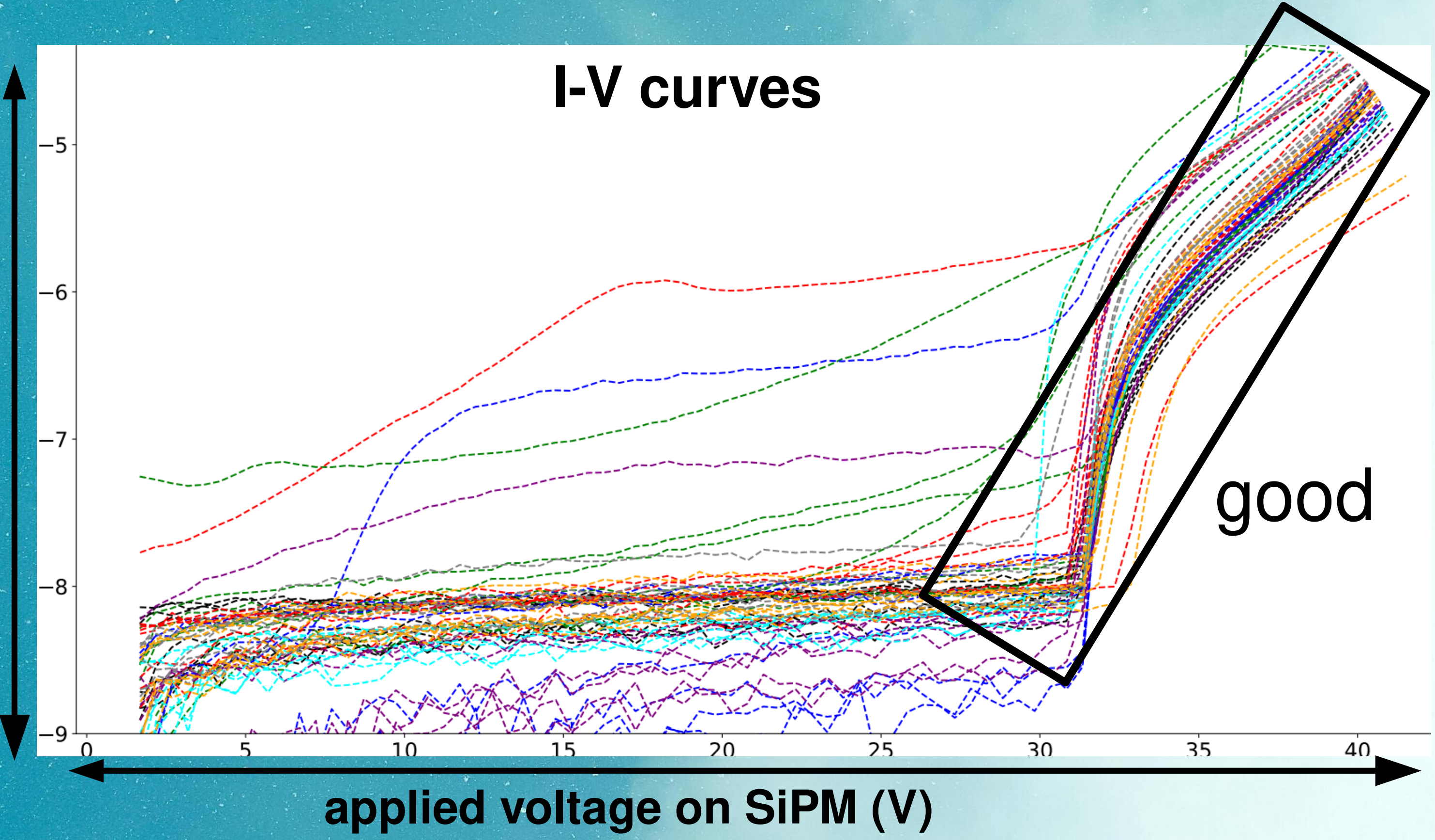


FBK SiPM testing before installation

- 64 FBK SiPMs tested: 40 SiPMs selected for LoLX

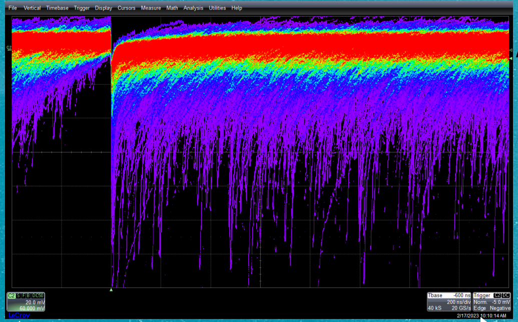




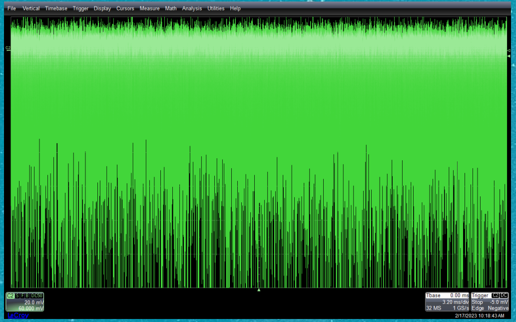


FBK SiPM testing before installation

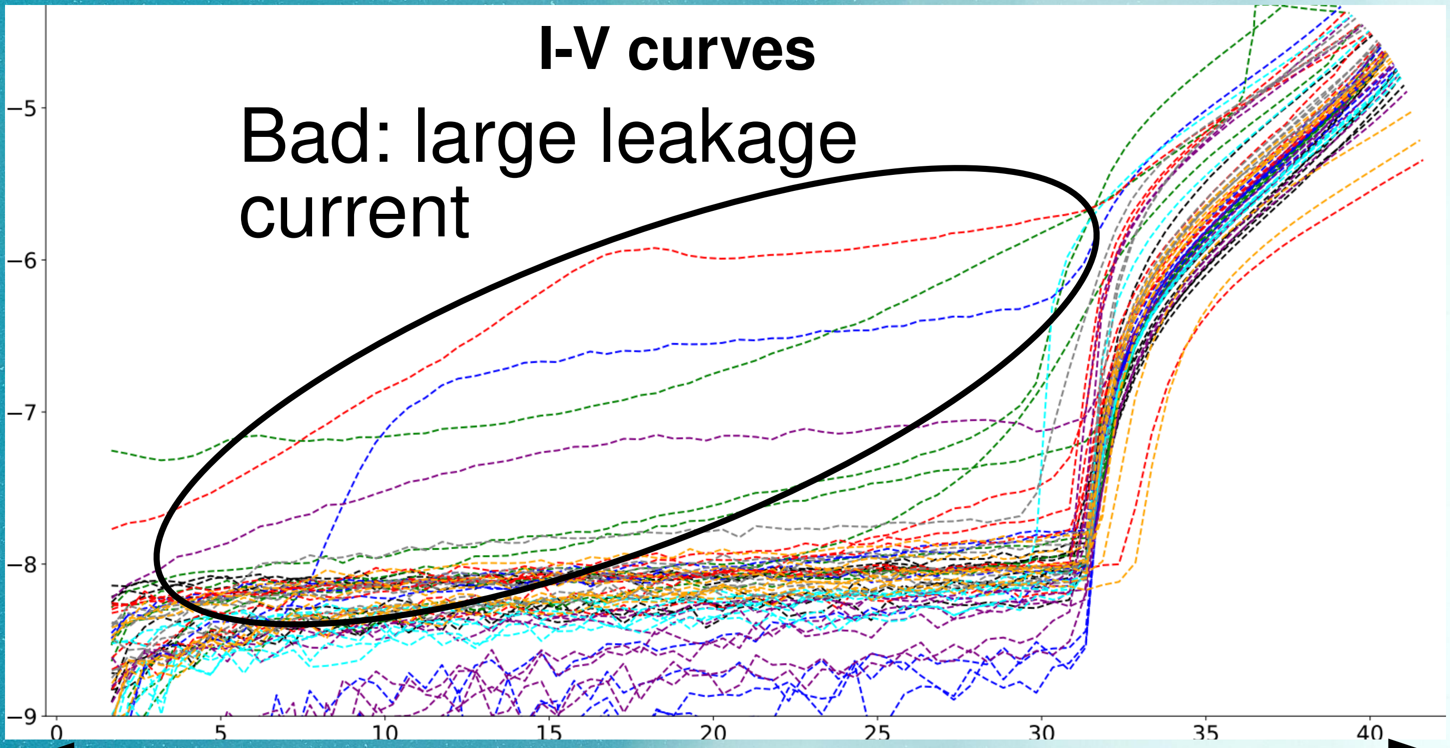
- 64 FBK SiPMs tested: 40 SiPMs selected for LoLX



2 µs



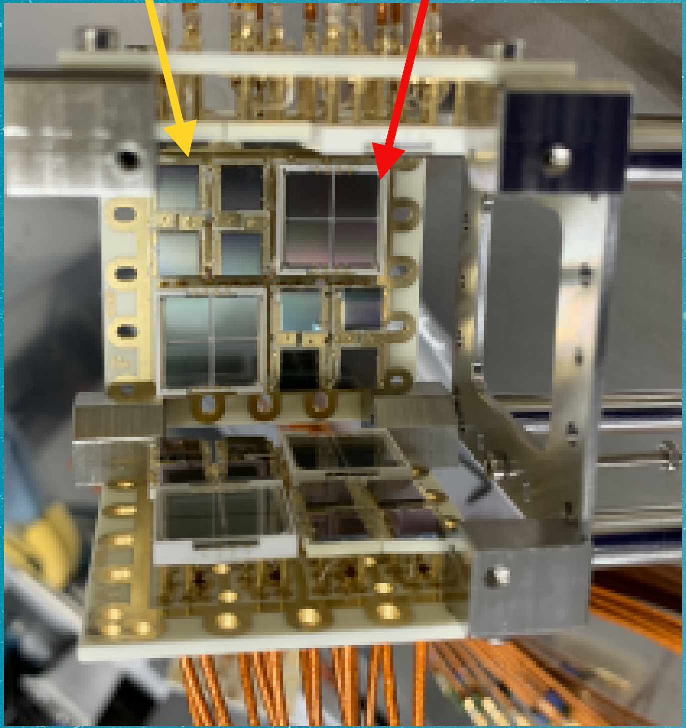
32 ms

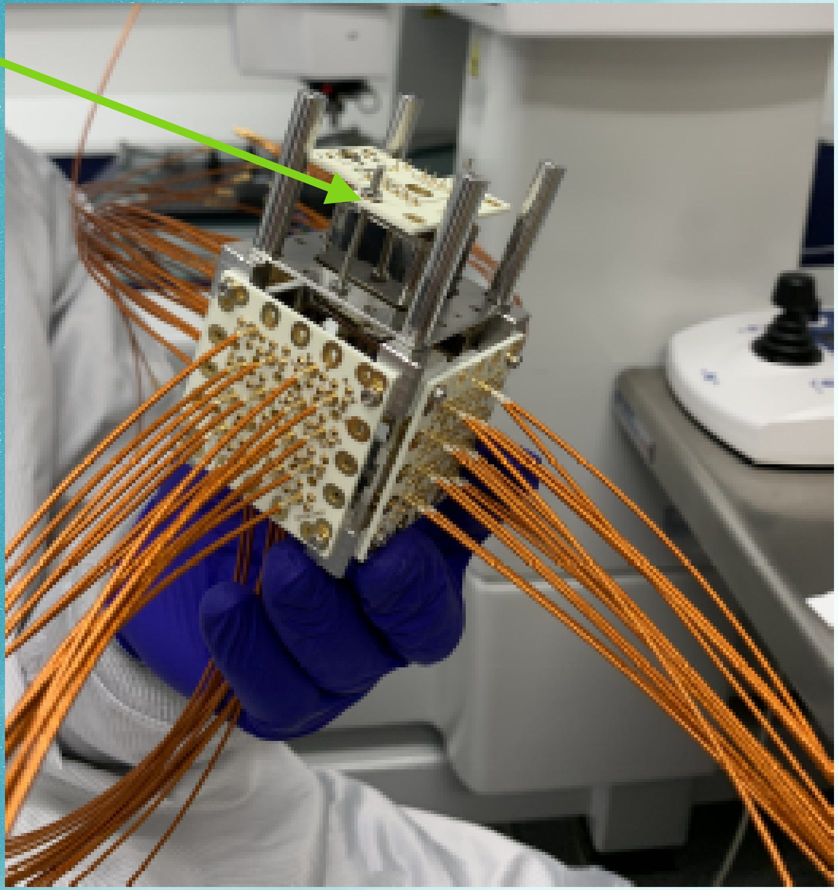


applied voltage on SiPM (V)

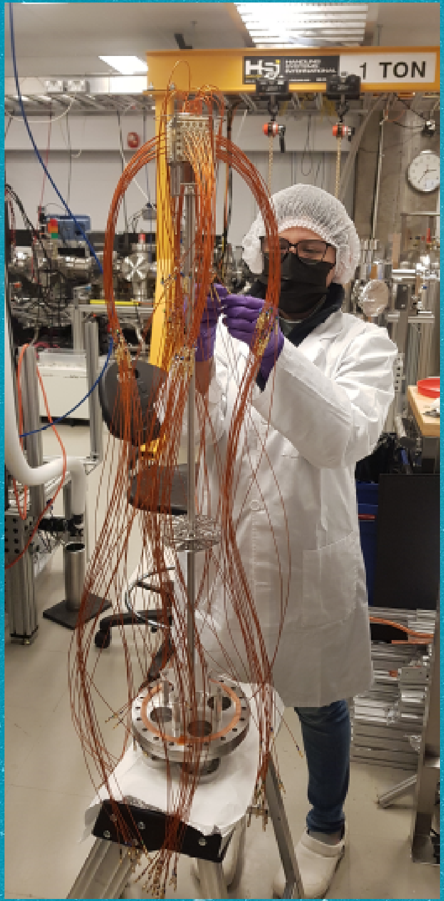
Cube assembly at McGill

- PMT on top of cube
- 5 tiles with SiPMs
- 8 FBK + 8 HPK /tile





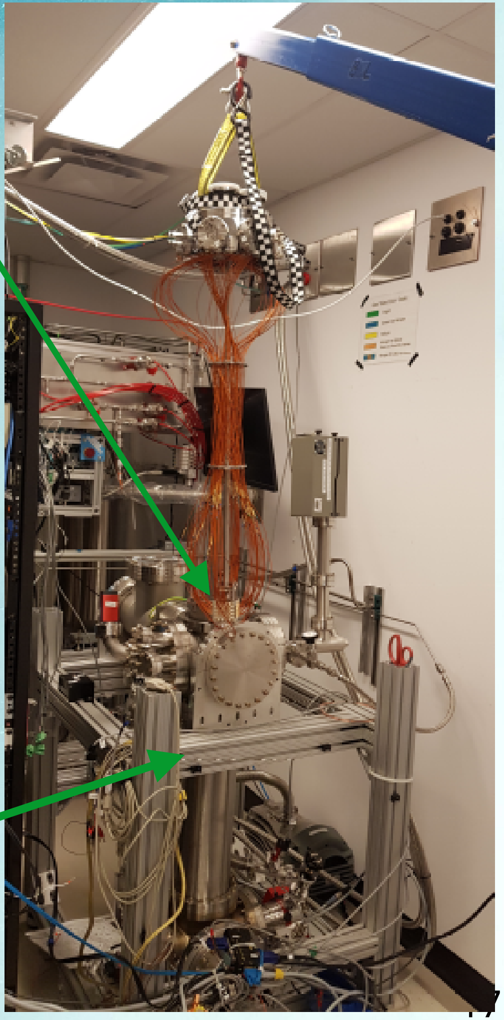
Cabling and insertion in cryostat at McGill



cabling

feedtrough

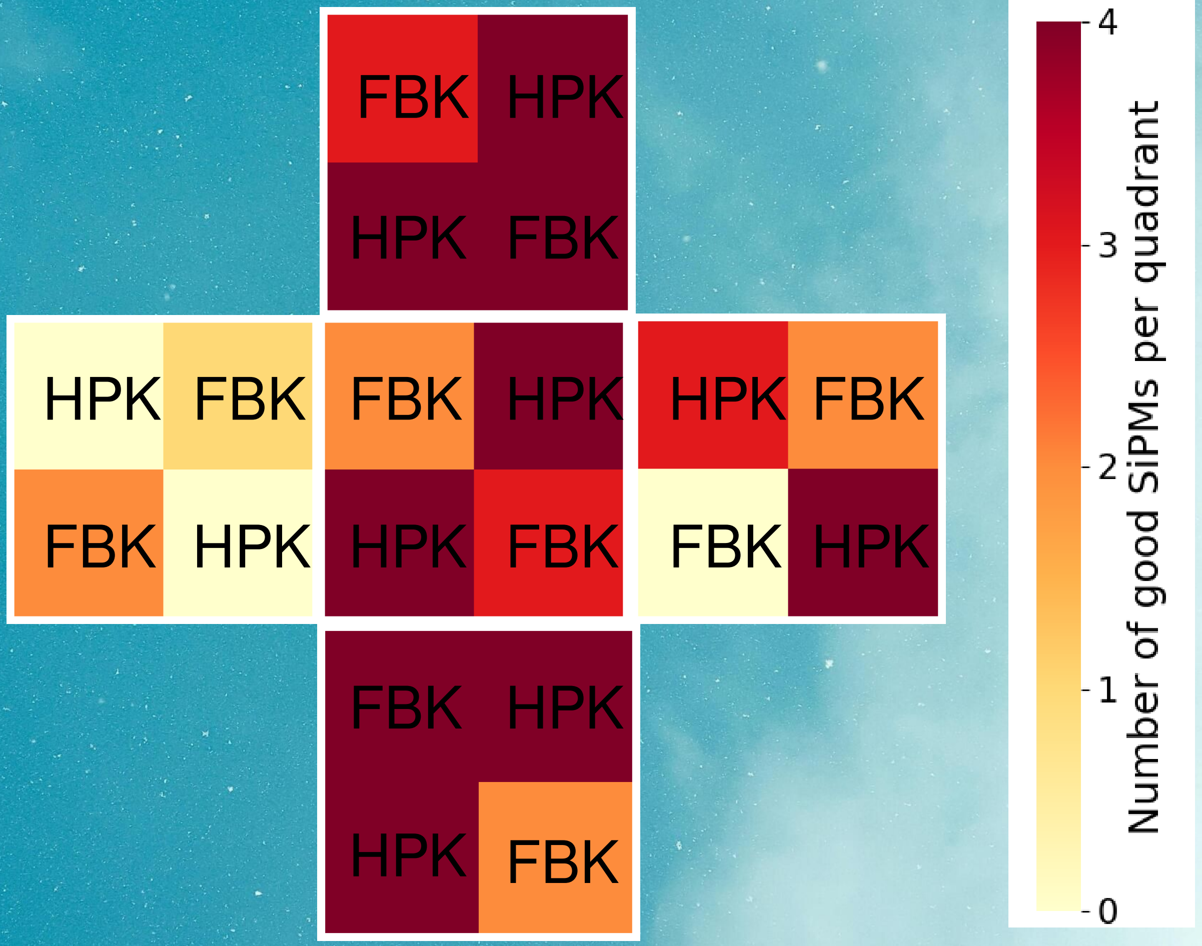
LoLX
cube



cryostat

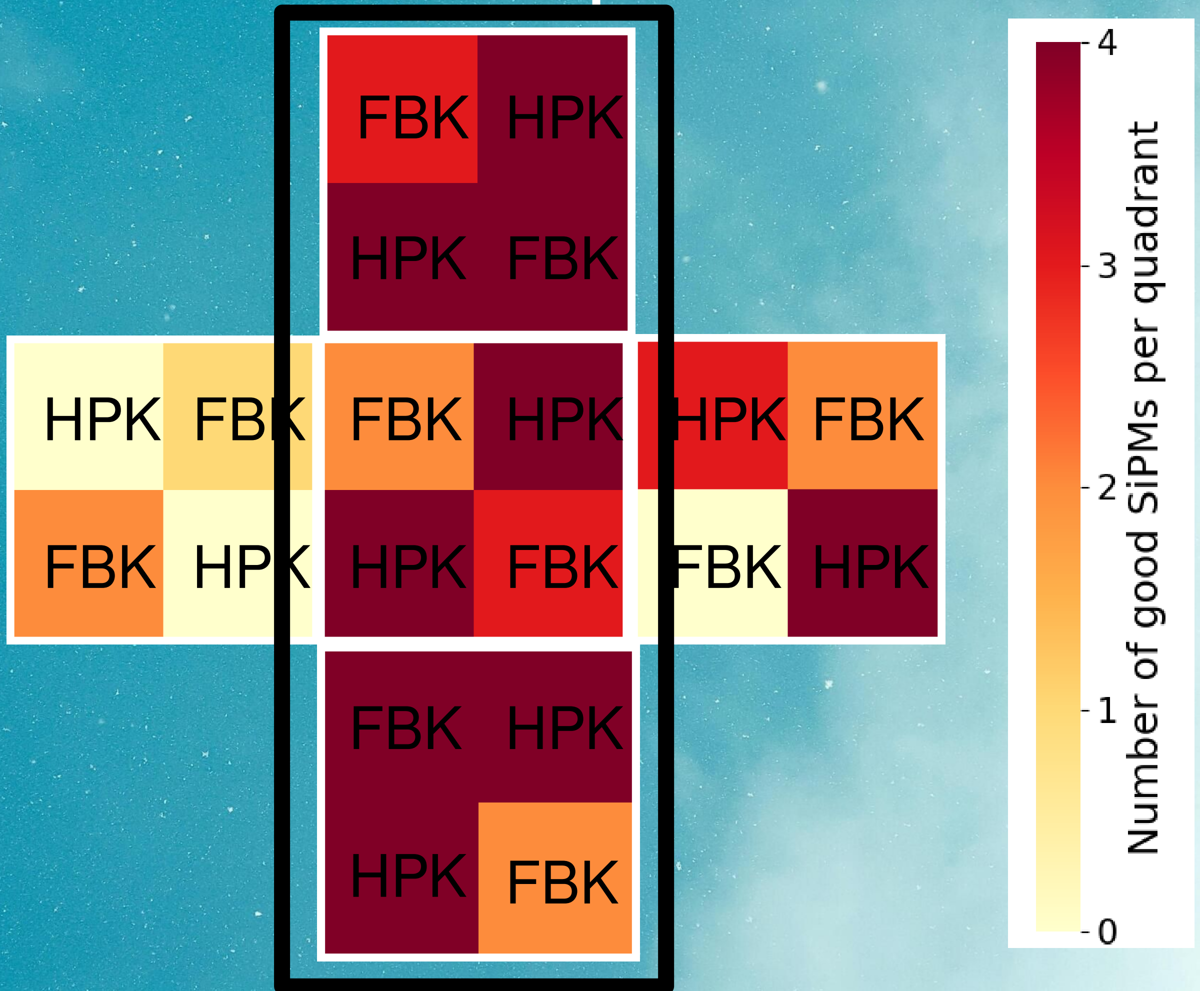
Results: heatmap of the cube

80 SiPMs



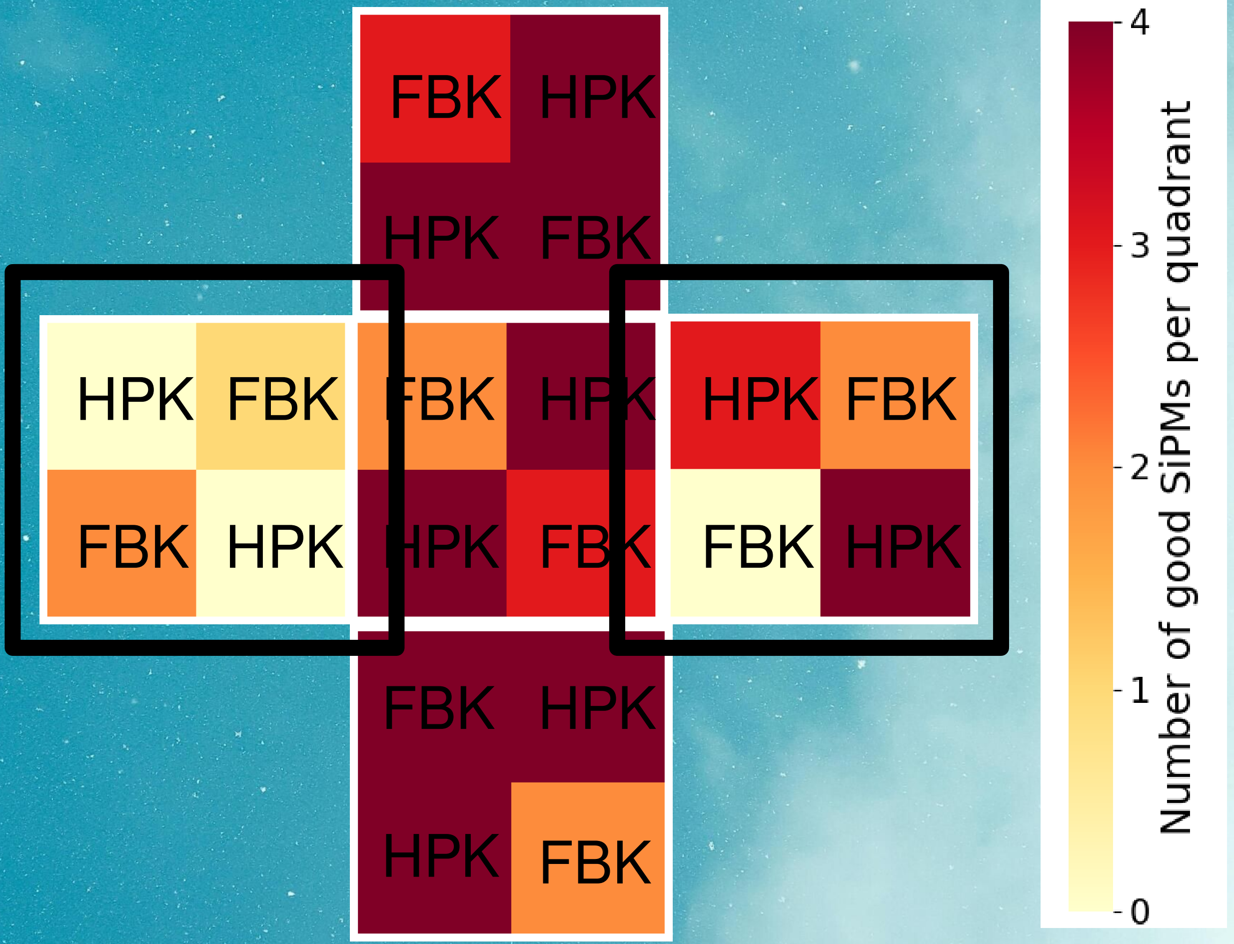
Results: heatmap of the cube

88% good SiPMs



Results: heatmap of the cube

38% good SiPMs

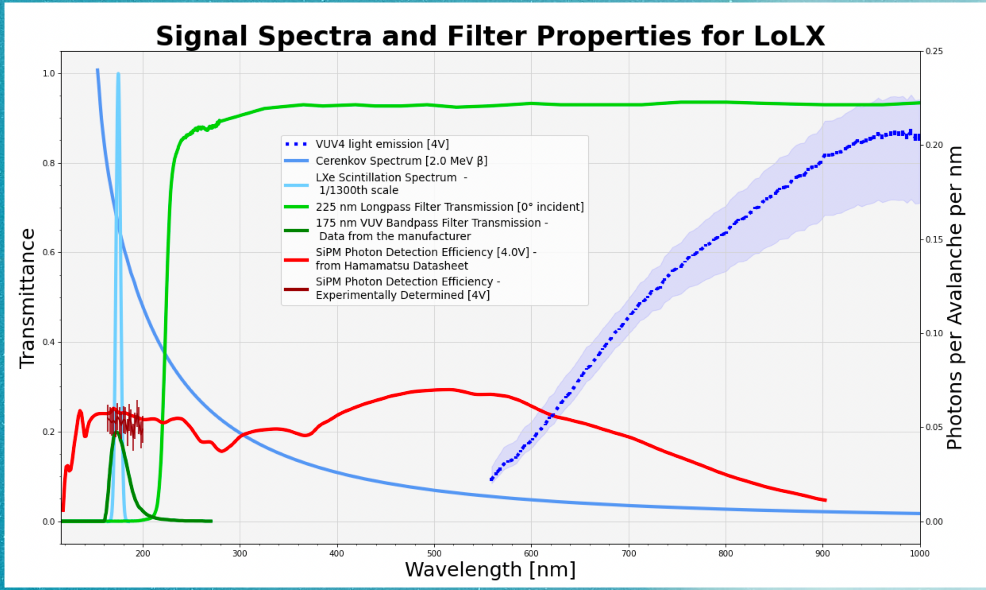


Foreseen measurements with LoLX 2

- **Photon yield** and relative **photodetection efficiency** of FBK and Hamamatsu SiPMs, and PMT

Foreseen measurements with LoLX 2

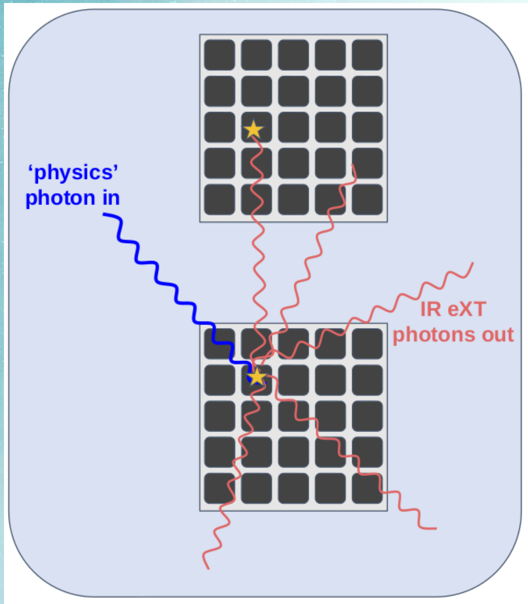
- **Photon yield** and relative **photodetection efficiency** of FBK and Hamamatsu SiPMs, and PMT
- **Cherenkov** light measurement with optical filters/timing



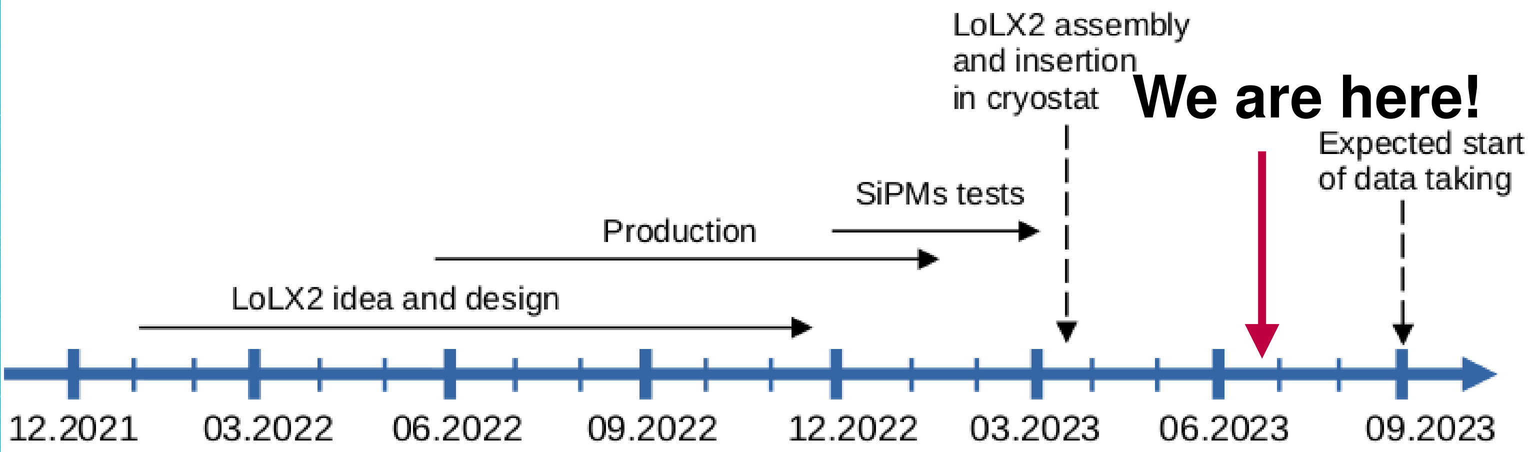
Foreseen measurements with LoLX 2

- **Photon yield** and relative **photodetection efficiency** of FBK and Hamamatsu SiPMs, and PMT
- **Cherenkov** light measurement with optical filters/timing
- **External cross talk** (eXT) measurement

  (see talk from David Gallacher)



Summary



- **Modular** facility – R&D
- **Light in LXe**, simulations
- Experience with **SiPMs in LXe**
- Inform **future LXe** large-scale **experiments**

Thank you for your attention

LoLX Collaboration: Canada-US-Italy

TRIUMF

Fabrice Retière
Chloé Malbrunot
Austin de St. Croix
Colin Hempel
Zach Charlesworth
Peter Margetak
Alex Sorokin
Pietro Giampa
Stéphanie Bron

McGill

Thomas Brunner
David Gallacher
Soud Al Kharusi
Eamon Egan
Lisa Rudolph

Carleton University

Simon Viel
Bindiya Chana

Université de Sherbrooke

Marc-André Tétraut
Alaa al Marsi

INFN

Luca Galli
Marco Francesconi

Rensselaer Polytechnic Institute

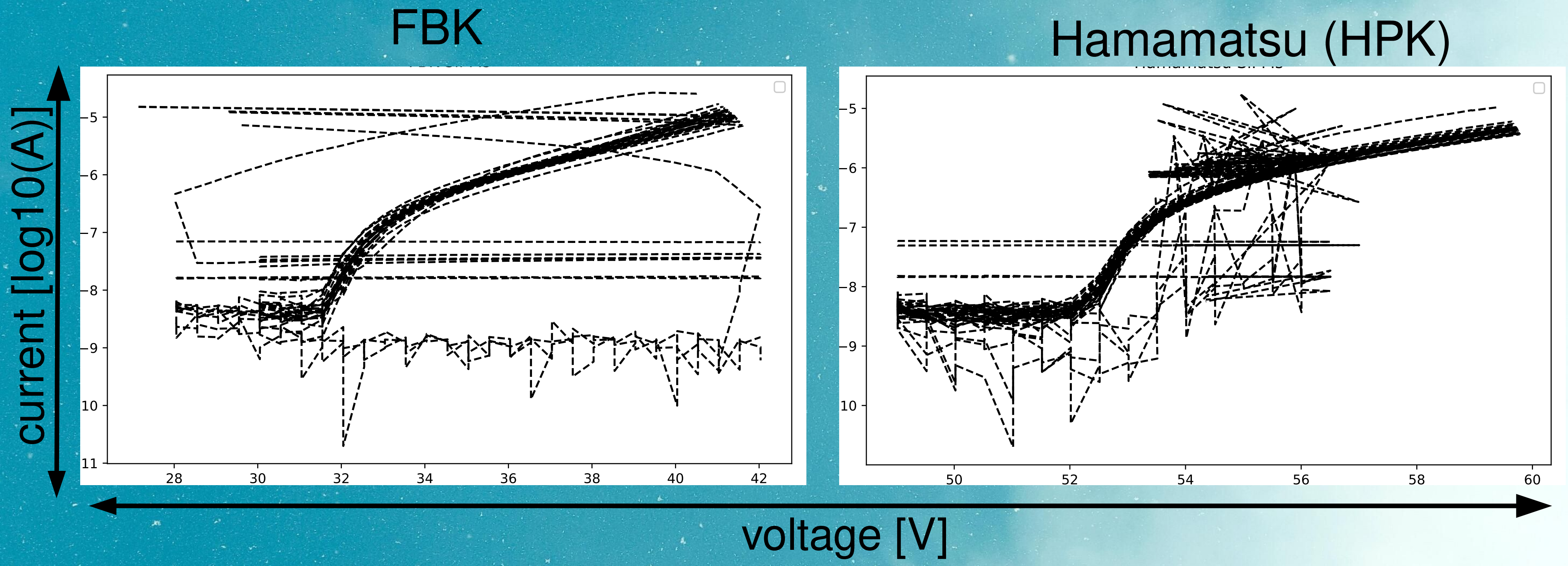
Ethan Brown
Kirsten McMichael

Additional slides

LoLX 1 vs LoLX 2

	Gen1	**Gen2**
design	octogonal	cubic
material	3D printed plastic (problem: fluorescence)	hydrocarbon ceramic
photosensors	96 Hamamatsu VUV4 SiPMs	40 Hamamatsu VUV4 SiPMS 40 FBK VUV3 SiPMs 1 PMT Hamamatsu R8520-406
cooling system	cryostat cooled with liquid N_2	cryostat with compressor
data acquisition system	CAEN v1740 62.5 MHz sampling rate $\rightarrow$ 16 ns resolution	WaveDREAM up to 5GHz sampling rate $\rightarrow$ $<$ns resolution

Results: IV curves after installation McGill



- Installation slightly challenging
- 63% of SiPM channels working

2D and 3D SPADS

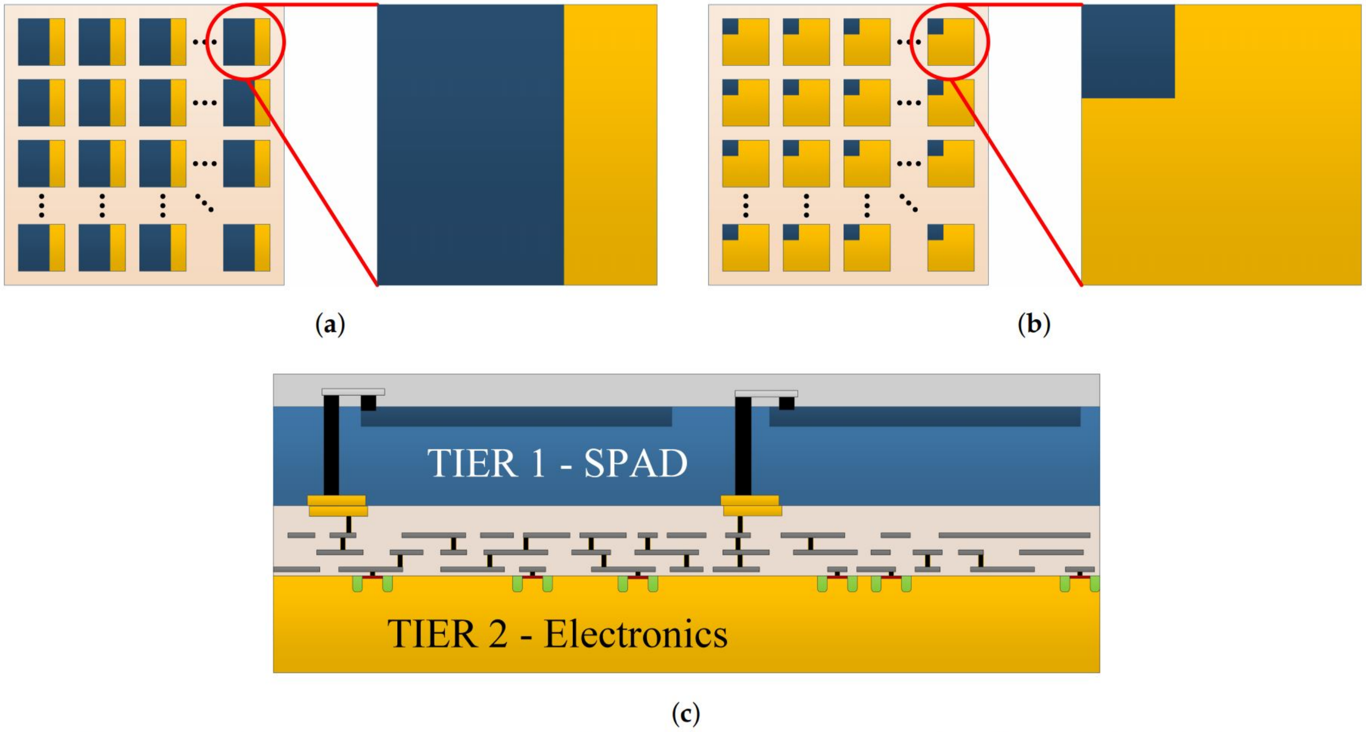
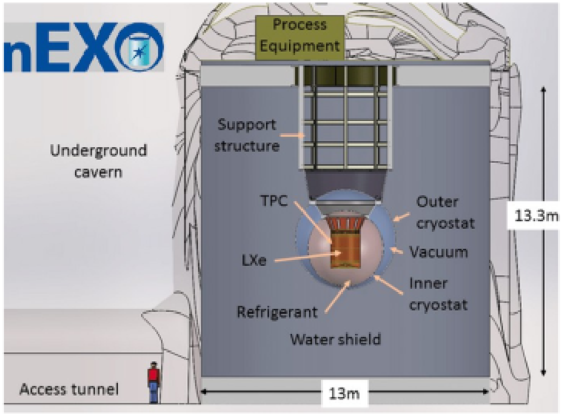


Figure 4. Illustration of the trade-off between the SPAD and the electronic functionality for 2D PDCs sharing the same technology node compared to a 3D PDC. In (**a**), a 2D PDC with large SPAD (blue), but limited in-pixel electronics functionalities (yellow). In (**b**), a 2D PDC with small SPAD (blue), but greater in-pixel electronic functionalities (yellow). In (**c**), a 3D PDC with large SPAD (blue) and large area for in-pixel electronic functionality (yellow).

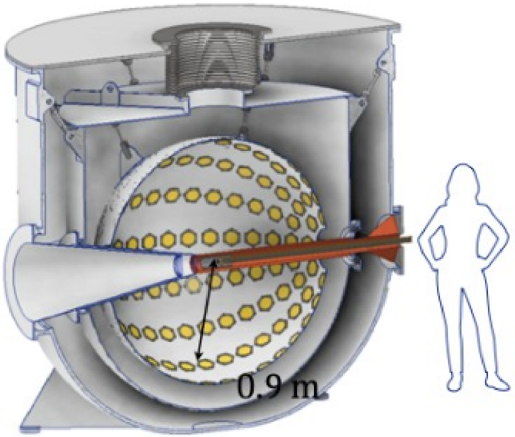
Future rare-decay experiments

nEXO



Is the neutrino the same particle as the antineutrino?
→ look for ***neutrino-less double beta-decay***

PIONEER



Is the ***lepton flavor universality*** violated?
→ measure branching ratio of pion decay to electron (rare) and muon

$$R_{e/\mu} = \Gamma(\pi^+ \to e^+\nu(\gamma))/\Gamma(\pi^+ \to \mu^+\nu(\gamma))$$

PDE

$$PDE(\lambda, V) = QE(\lambda) \cdot P_{Trigger}(V) \cdot \varepsilon$$

QE = ***Quantum Efficiency*** - efficiency of conversion process of a photon into an electron-hole pair in the active region of the SPAD

$P_{Trigger}$ = ***Geiger Efficiency*** - probability that the generated electron-hole pair triggers a Geiger breakdown in the SPAD

ε = ***Geometric Efficiency*** - ratio of total active region of the SPADs and SiPM "active area"

λ = ***Wavelength***

V = ***Voltage***

Table 1: PMT and SiPM Comparison

Characteristic	Photomultiplier Tube (PMT)	Silicon Photomultiplier (SiPM)
Sensitivity	Single photon	Single photon
Gain	To 10^7	To 10^6
Operation voltage	800V to 2000V	30V to 50V
Large area	Yes	Yes, scalable
High-density arrays	No	Yes
High granularity/ resolution	No	Yes
Dark noise	Low	Middle
Uniformity	Good	Excellent
Response time	Fast	Very Fast
Photon-counting resolution	Good	Excellent
Temperature sensitivity	Low	Medium
Immunity to ambient light	No	Yes
Immunity to magnetic fields	No	Yes
Compactness and light weight	No	Yes

Background discrimination

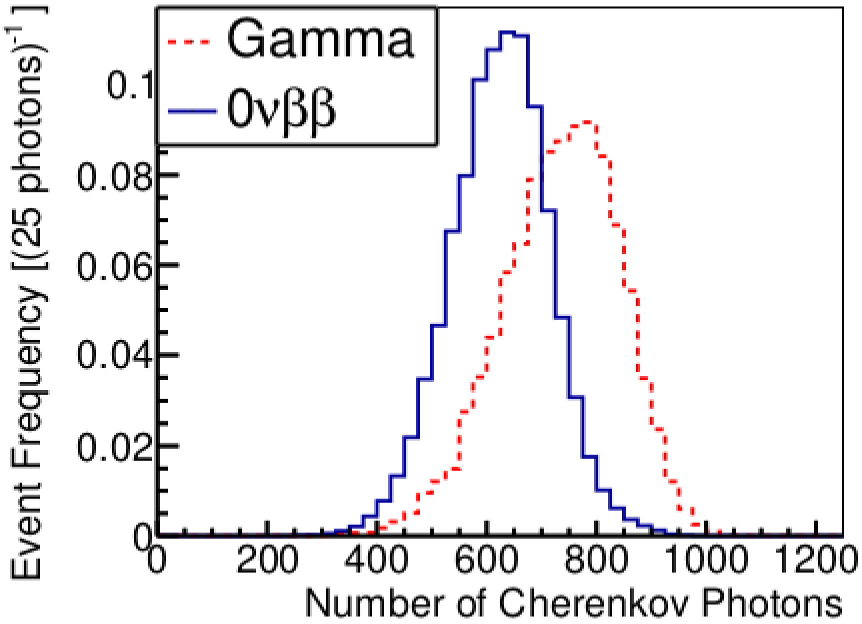


Figure 3: Cherenkov photon yield for ^{136}Xe $0\nu\beta\beta$ and photoelectric interactions of gammas of $Q_{\beta\beta}$ energy as obtained from the GEANT4 simulations used in this work.