Light-only Liquid Xenon

Bernadette Rebeiro

(For the LoLX Collaboration)

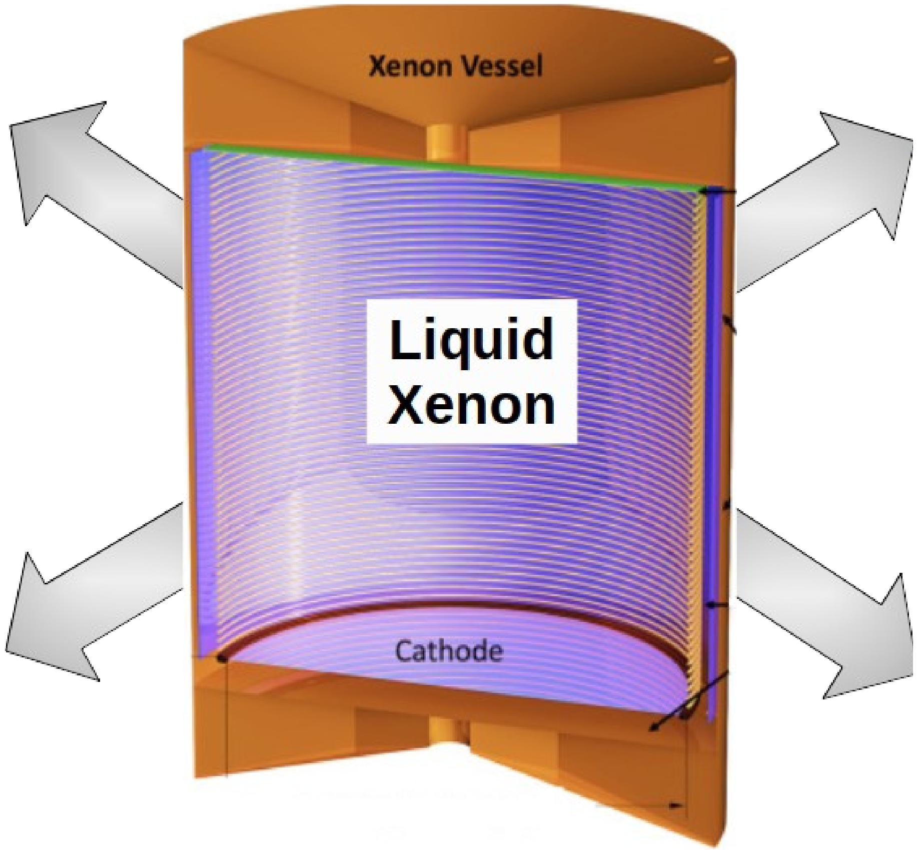
CAP Congress, 06 -11 June 2022

Liquid xenon as a detector

LoLX

- Liquid xenon as medium for radiation detection
  - First recognized in **1968** by Alvarez[1]

- Since used in various applications



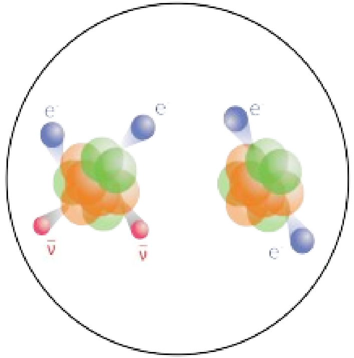
- High stopping power
  - ✔ Self shielding : *n*, *γ*
- High density
  - ✔ Compact detector
- High ionization & scintillation yield
- Scintillates at 175 nm
  - ✗ Wavelength shifter
- Fast time response

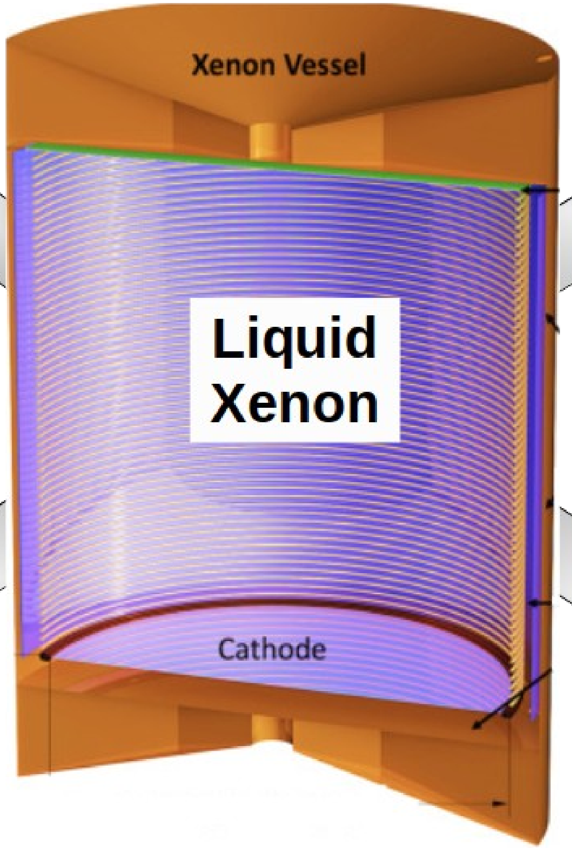
+ more …

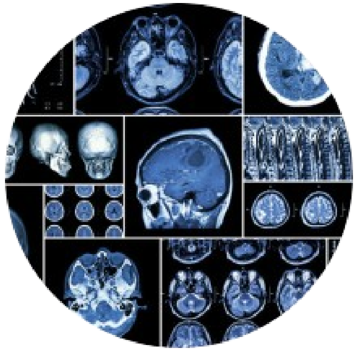
[1] Alvarez, L. W., 1968, Lawerence Radiation Laboratory, Physics Notes 672.

Liquid Xenon Detectors in Physics

Neutrinoless Double Beta Decay

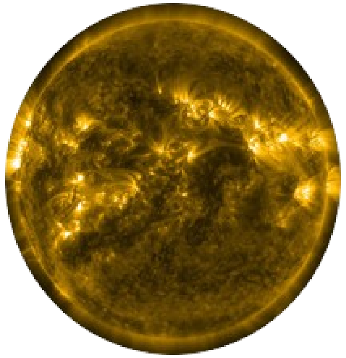






Medical Imaging

Astrophysical Studies



Direct Dark Matter Search

Interaction in LXe : How to detect?

Energy depositing event in liquid xenon (LXe)

- Ionization
- Excitation => scintillation (175 nm) [2]
- Cherenkov radiation => Broad band (> 150 nm)

nEXO

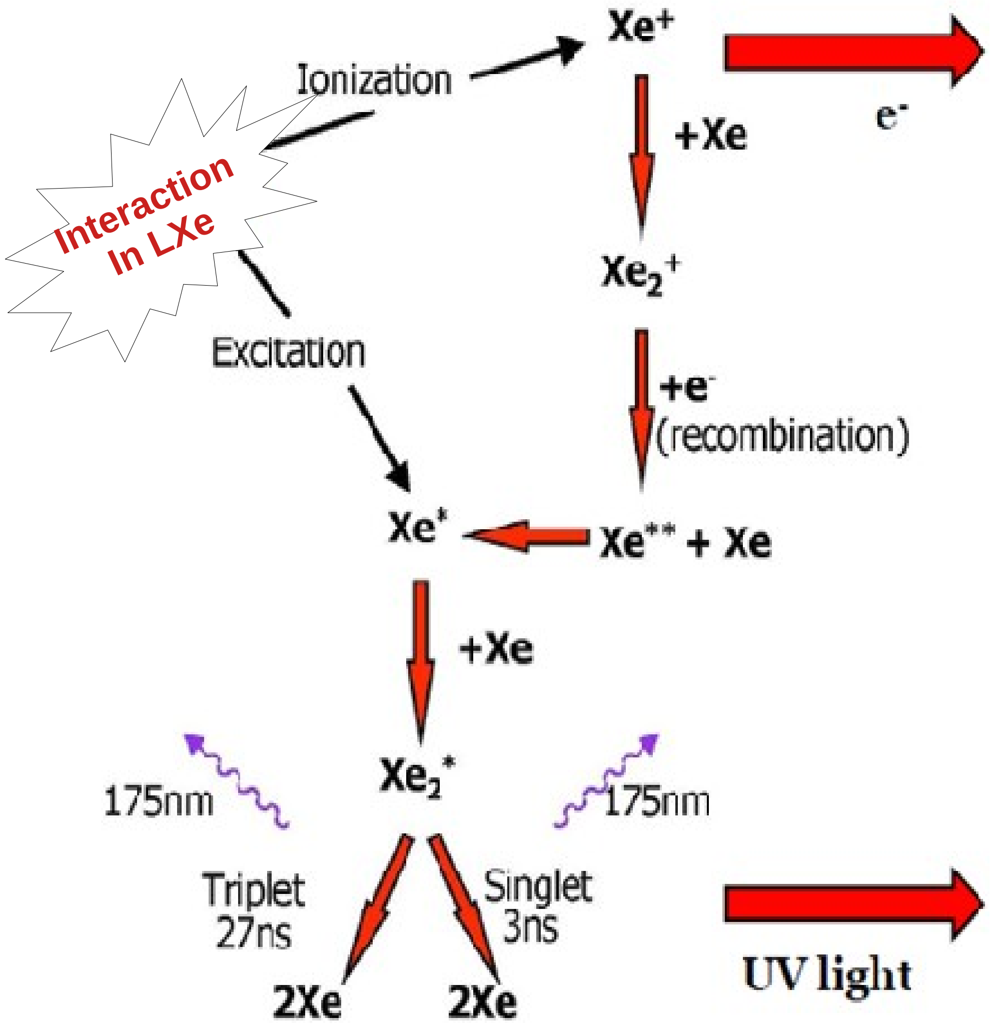


Fig. from N. Larsen (2012) Thesis Prospectus, Yale University

[2] M. Martin, J. Chem. Phys. 54, 3289 (1971)

Interaction in LXe : How to detect?

Energy depositing event in liquid xenon (LXe)

- Ionization
- Excitation => scintillation (175 nm) [2]
- Cherenkov radiation => Broad band (> 150 nm)

Silicon **P**hoto **M**ultipliers (SiPMs)

- fast, single photon counters
- Can be made radio-pure
- sensitive from UV to Visible

Ideal to study light emission properties of LXe

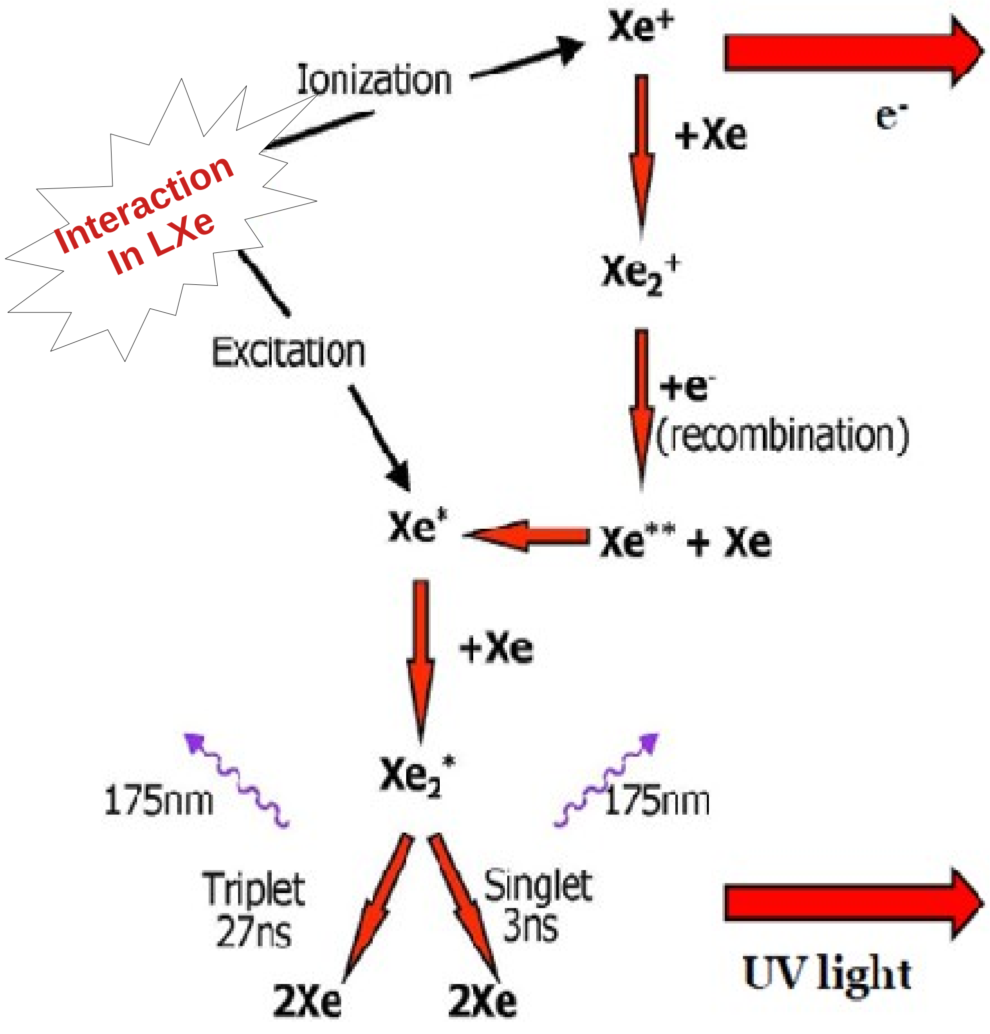


Fig. from N. Larsen (2012) Thesis Prospectus, Yale University

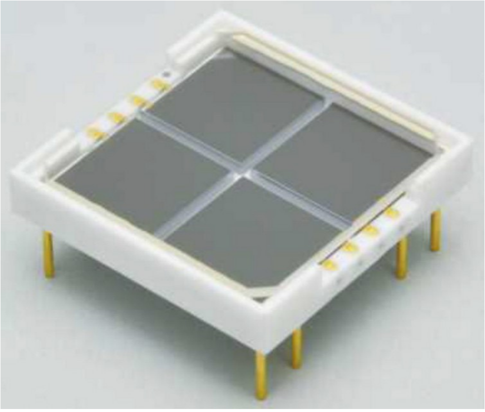
[2] M. Martin, J. Chem. Phys. 54, 3289 (1971)

Light-only Liquid Xenon Experiment

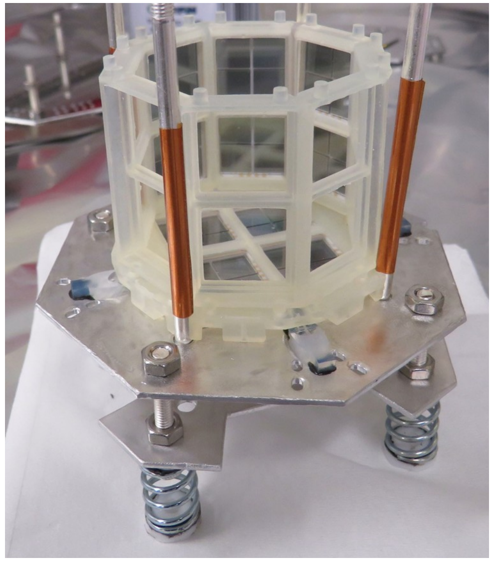
LoLX

Experiment to characterize and validate performance of multiple **Silicon Photo Multipliers** (SiPMs) in Liquid Xenon

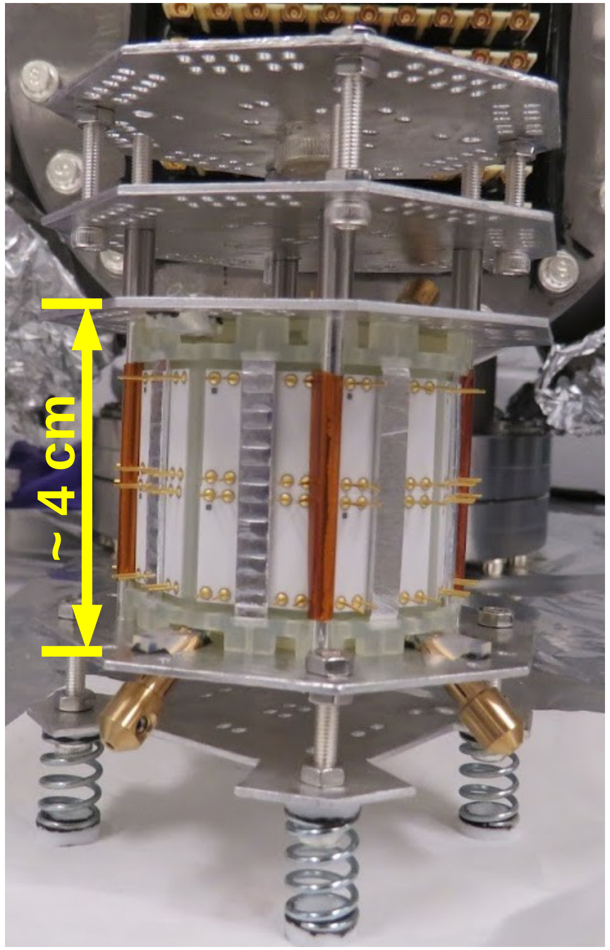
- Modular, light signal only detector
- SiPMs mounted on 3D printed cage
- Immersed in liquid xenon



1.5 x 1.5 cm SiPM module



3D printed cage for SiPM modules



LoLX detector body, aluminum plates for cable routing

Pictures : LoLX photo archive

Physics Goals

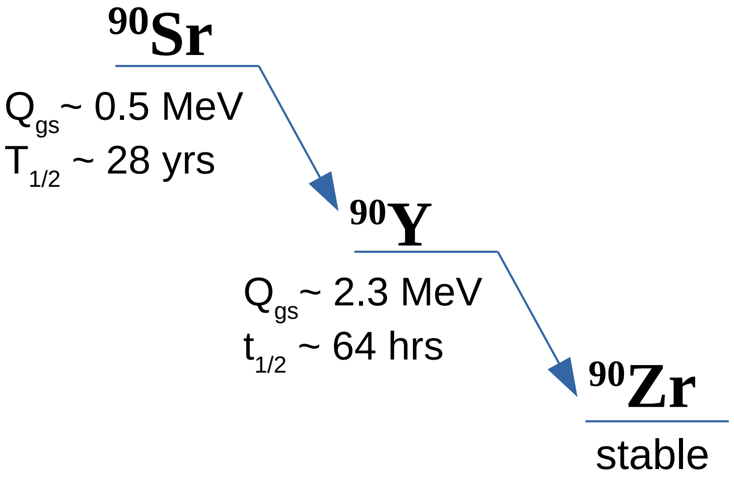
- Measure the Cherenkov and scintillation light yield in liquid xenon at zero electric field.

- Study behavior of multiple SiPMs in LXe and understand external cross-talk.

- Study the prompt light characteristics of LXe with fast electronics.

Detector Principle

- Beta source (on needle)



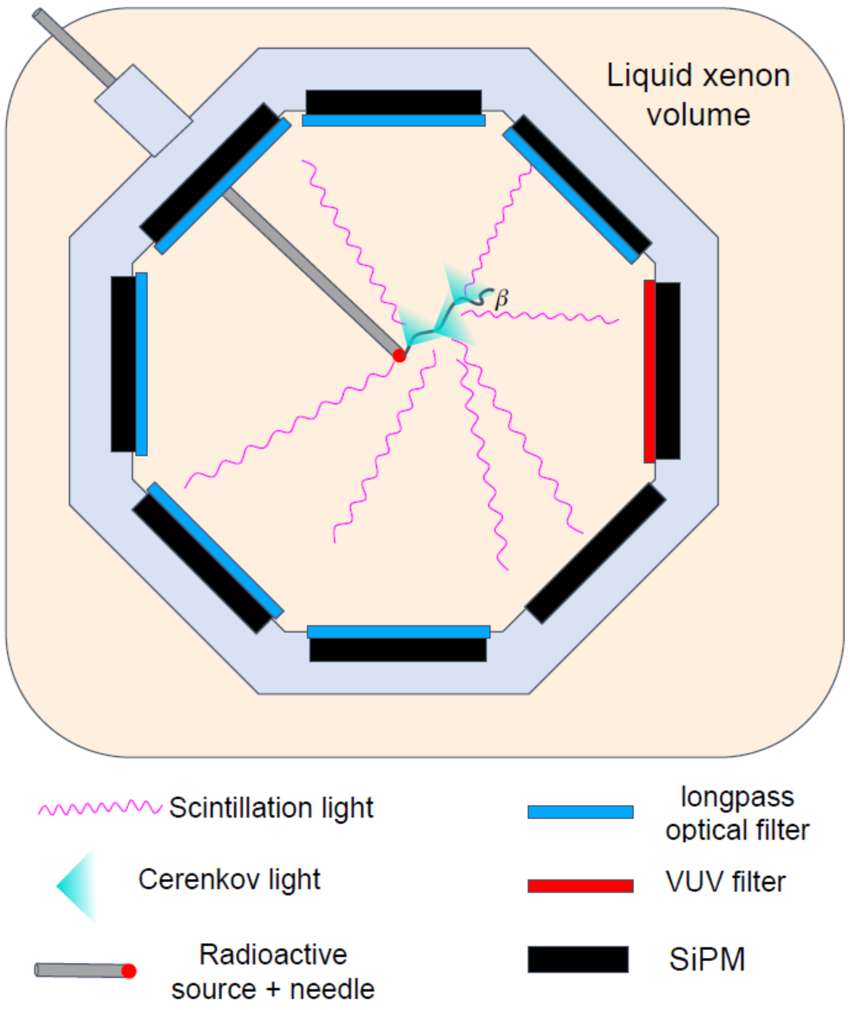
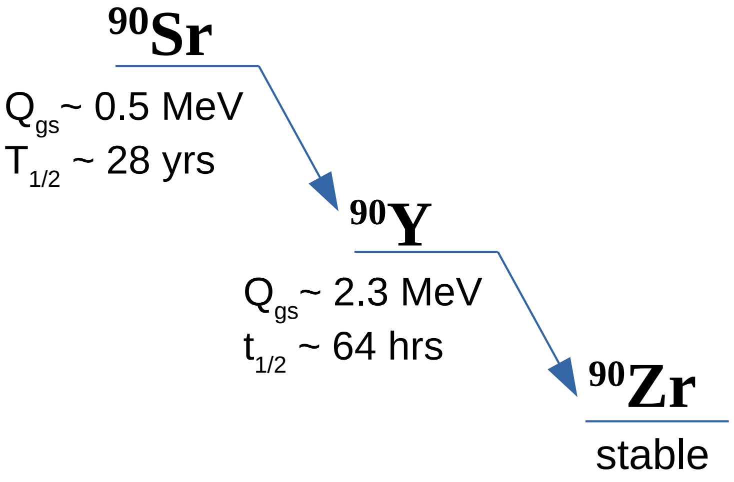
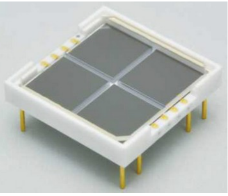


Figure by A. de St Croix

Detector Principle

➢Beta source (on needle)



 = 4 readout channels (except LP)

➢24 Hamamatsu[3] VUV4 SiPM modules (96 individual SiPM wafers)

- 22 modules with long-pass filter : Cherenkov (λ> 225 nm)
- 1 module with band-pass filter centered at 175 nm: Scintillation
- 1 module with no filter : everything

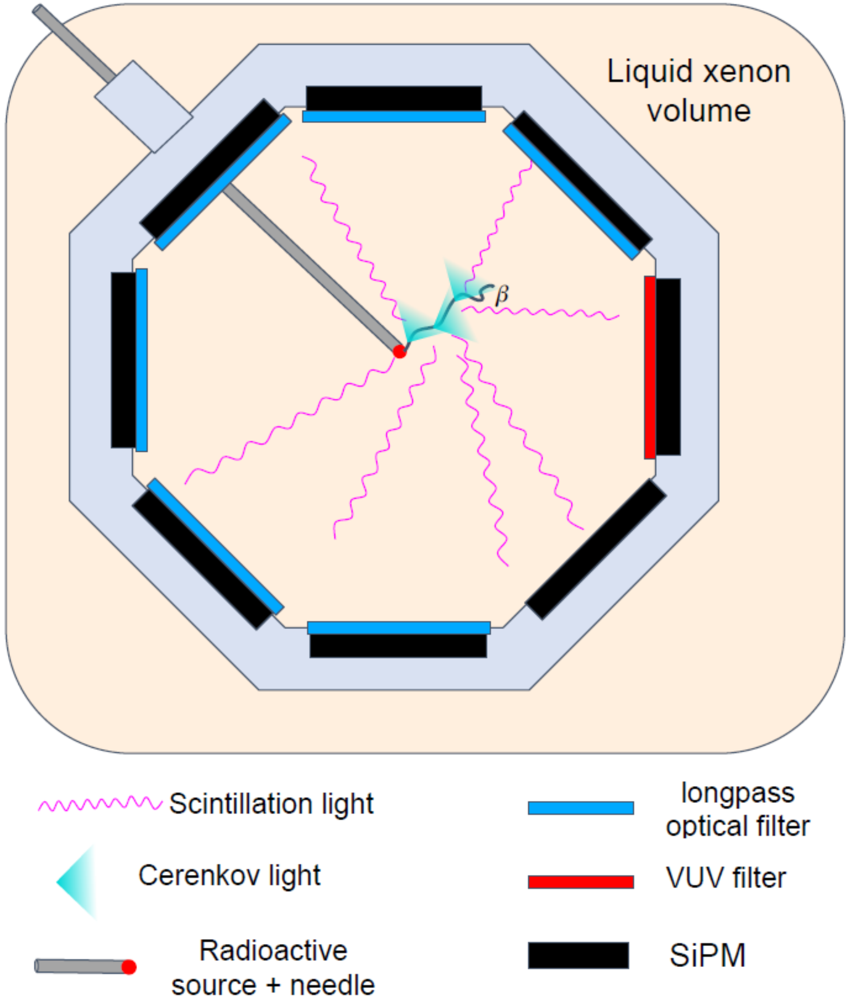
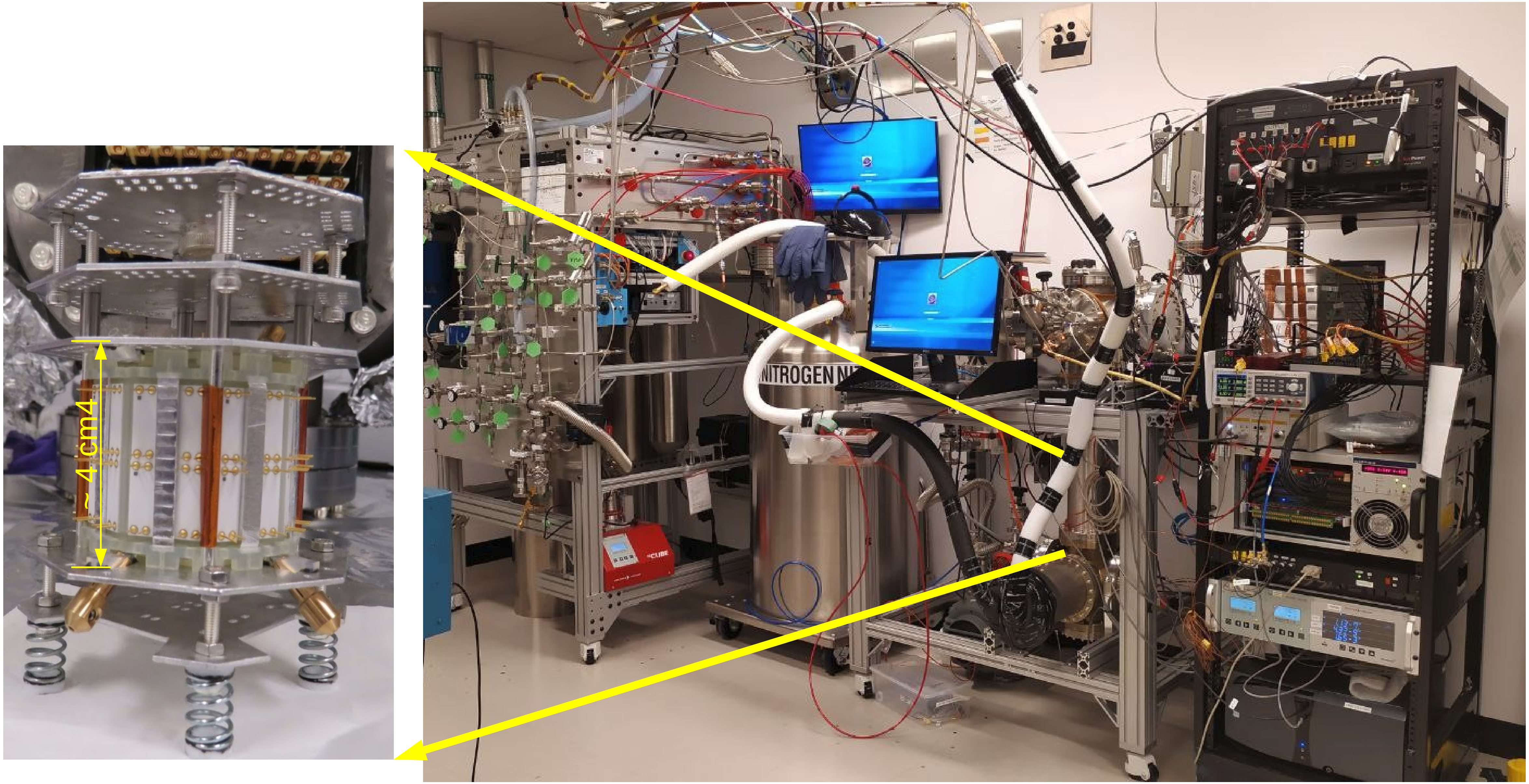


Figure by A. de St Croix

[3] Gallina *et al.*, NIM **940** (2019) 371-379

LoLX in BNL at McGill



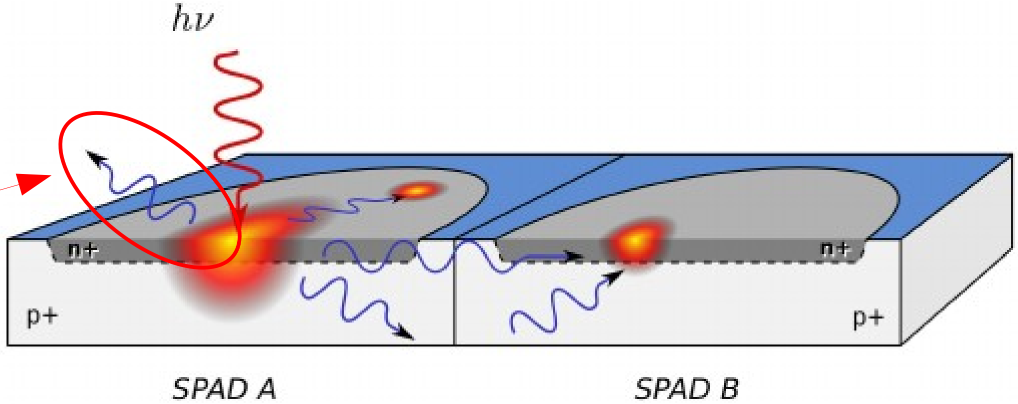
Physics Goals

LoLX

- Measure the Cherenkov and scintillation light yield in liquid xenon at zero electric field.
- Study behavior of multiple SiPMs in LXe and understand **external cross-talk.**
- Study the **prompt light characteristics** of LXe with fast electronics.

External Cross Talk

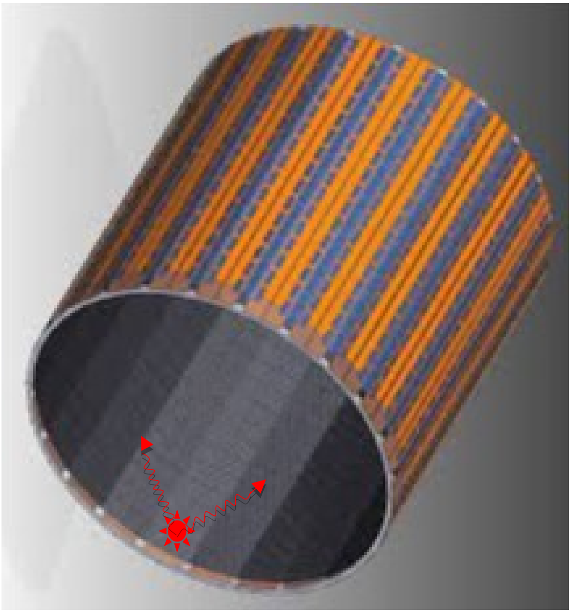
Could trigger an avalanche in neighboring SiPM aka **eXT**



Schematic representation of optical crosstalk between two SiPM SPADs. Figure from Rech *et al*. [3]

- Photon avalanche can create visible to infra-red photons that could potentially trigger other SiPMs → external cross talk (eXT)
- Depending on detector geometry, eXT could affect photon counting statistics and thus energy resolution

LoLX : study the probability of eXT and characterize it



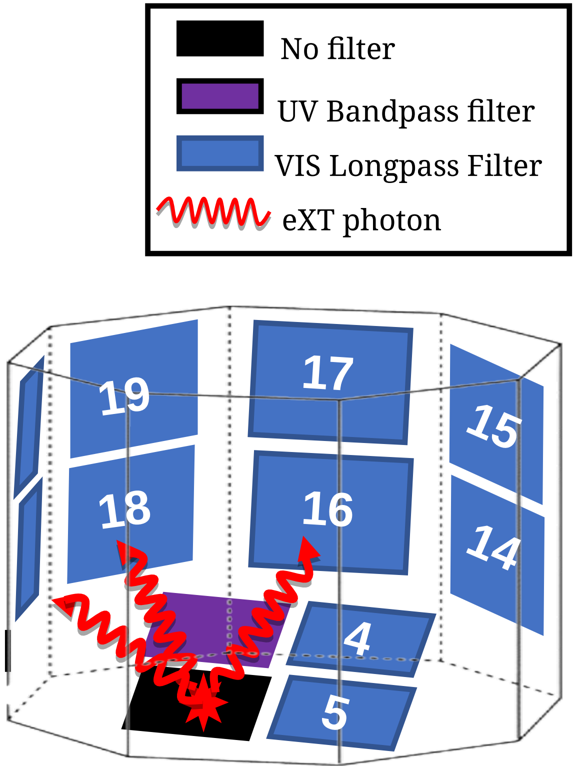
nEXO stave, conceptual design
arXiv:1806.02220 [physics.ins-det]

[3] I. Rech et al, (2008) https://doi.org/10.1364/OE.16.008381.

How do we look for external cross talk

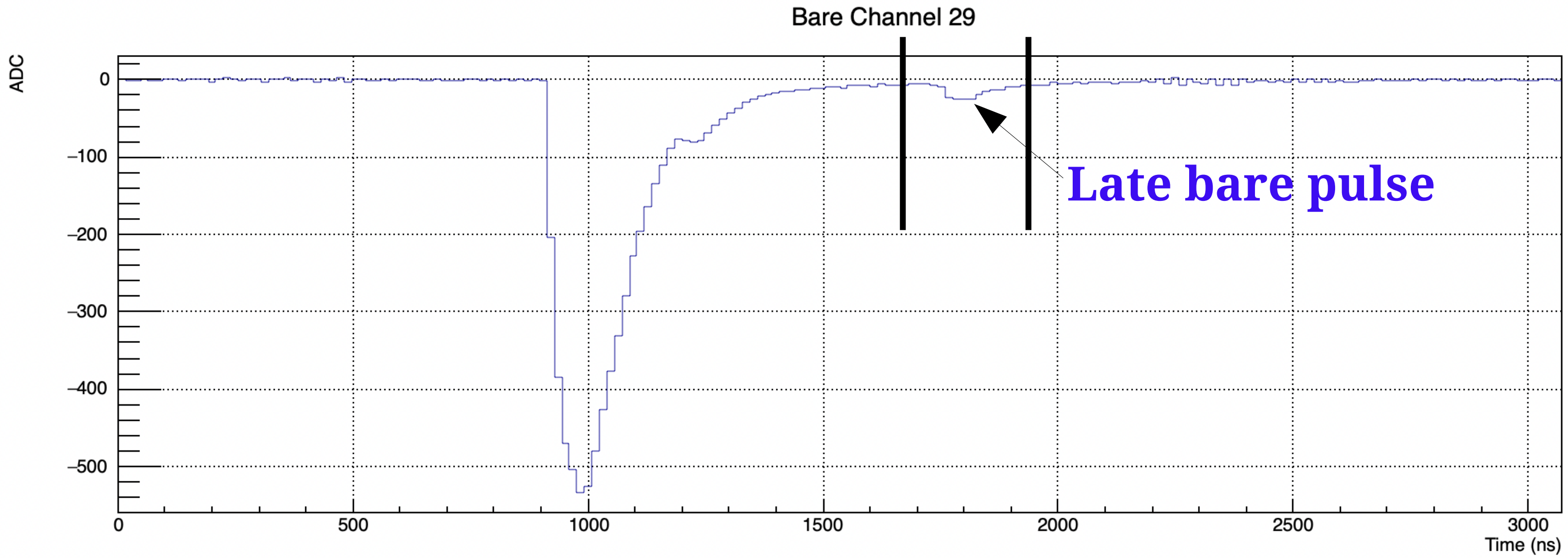
- Increase **over voltage** on bare SiPM
  - Set fixed over-voltage on other SiPMs

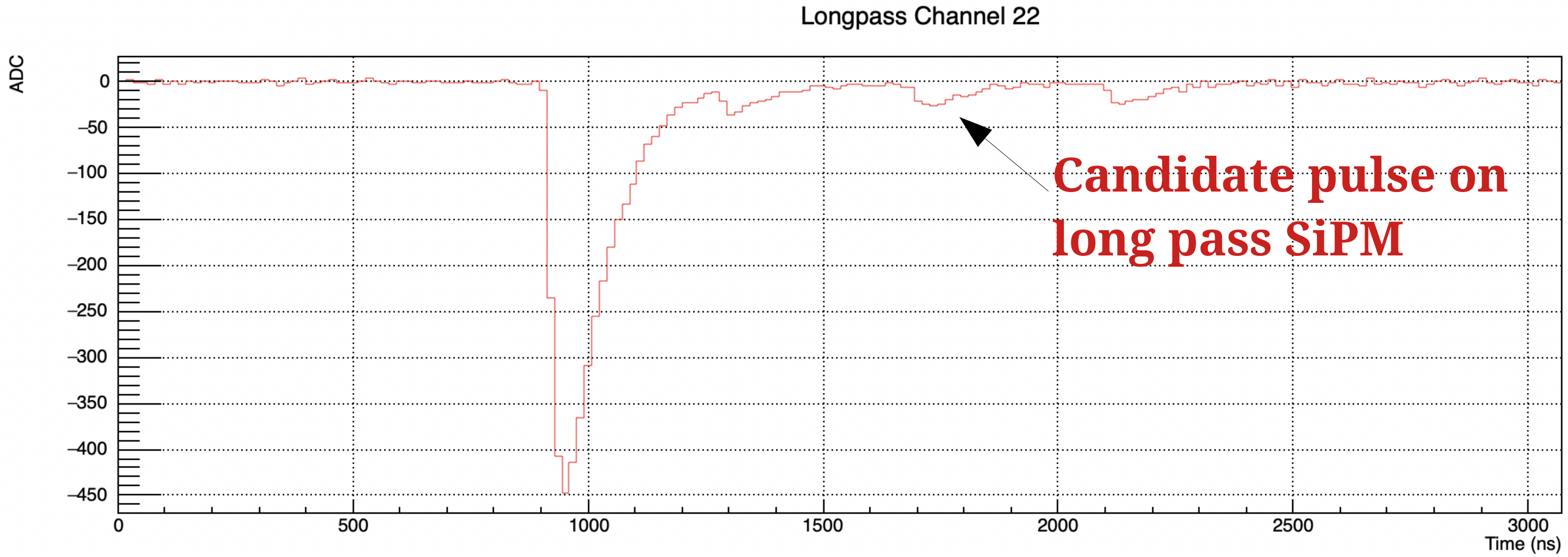
- Look for late pulses on a bare SiPM
  - Time distribution of subsequent pulses on long pass filtered SiPMS



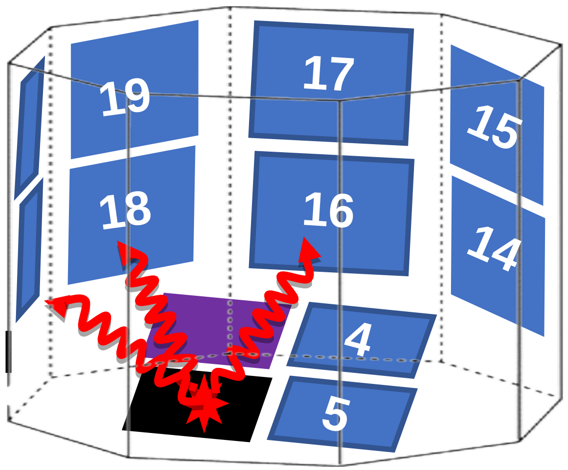
Schematic of LoLX cage. Figure by D. Gallacher

External Cross Talk

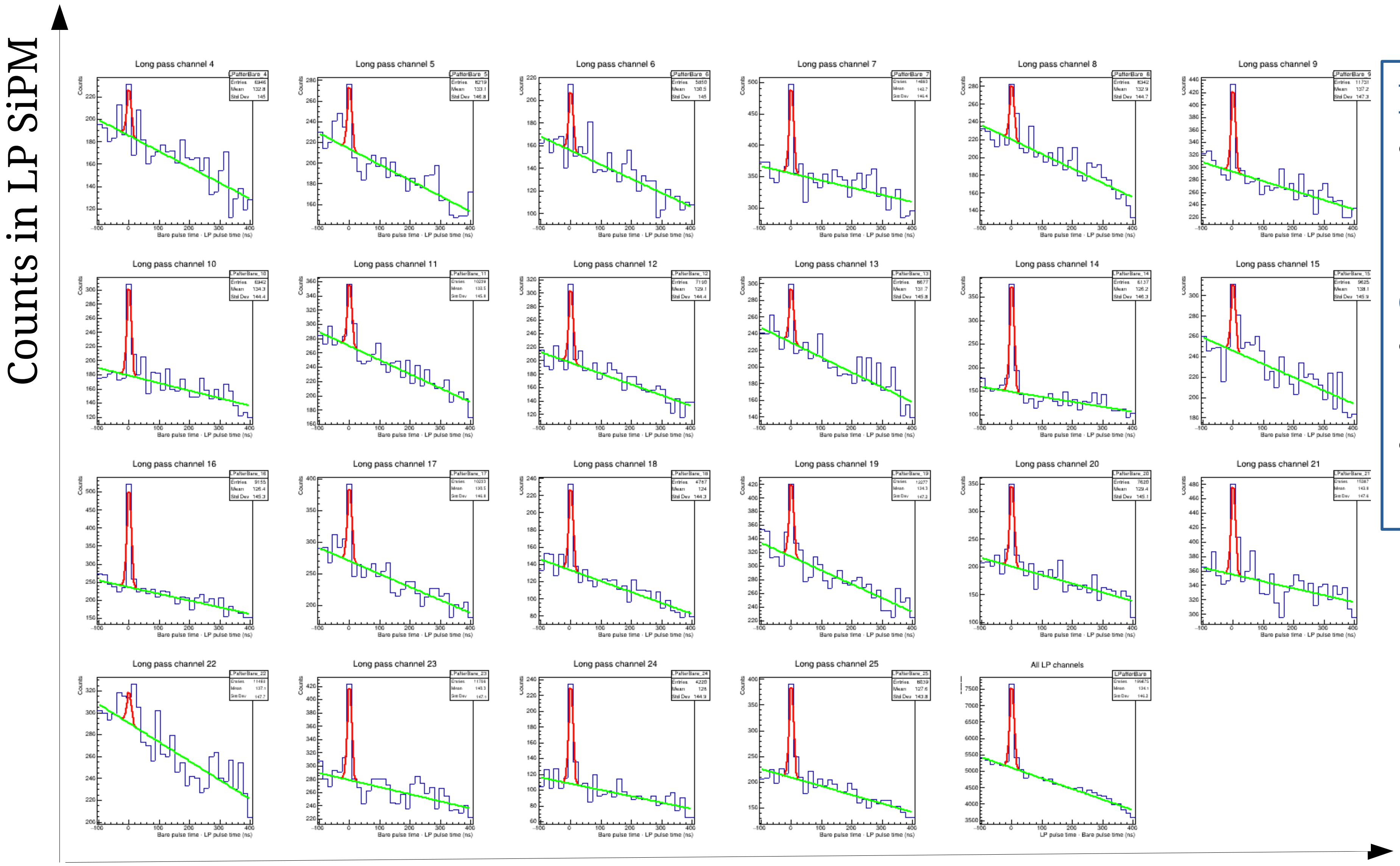




- Event threshold 2 photon avalanche (2PE) on bare SiPM
- Late bare pulse
  - 900-1500 ns after primary pulse
  - Threshold < 2PE



External Cross Talk



Pulse ΔT = ‘bare’ time – LP time

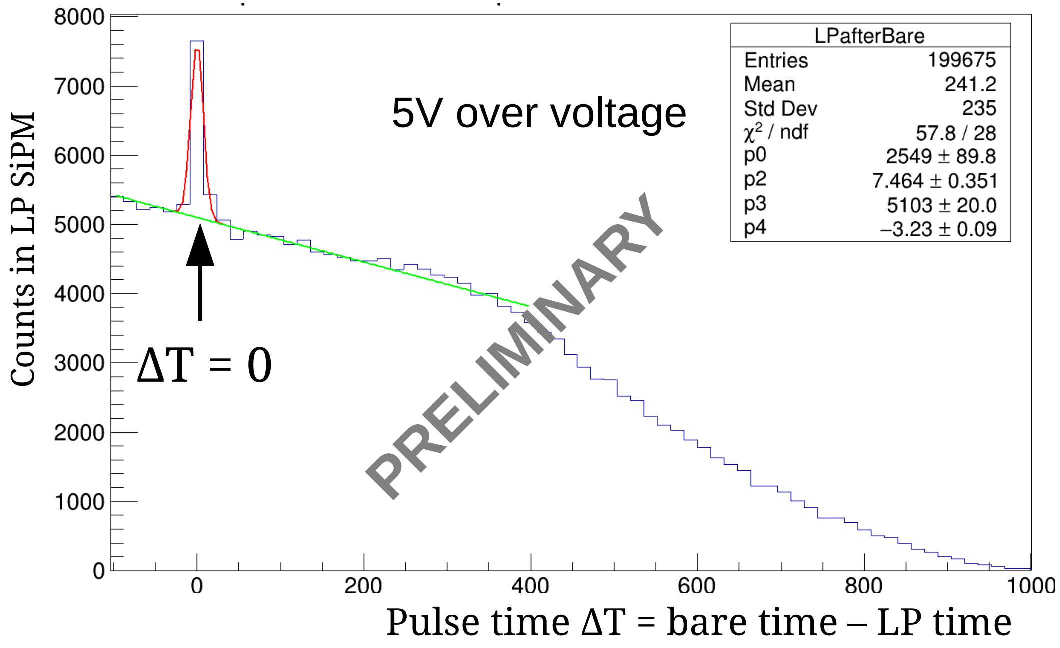
Fit function

- Gaussian + linear background

eXT signal : prompt

- CAEN V1740 timing resolution 16ns
- Mean of Gaussian fixed at zero

External Cross Talk

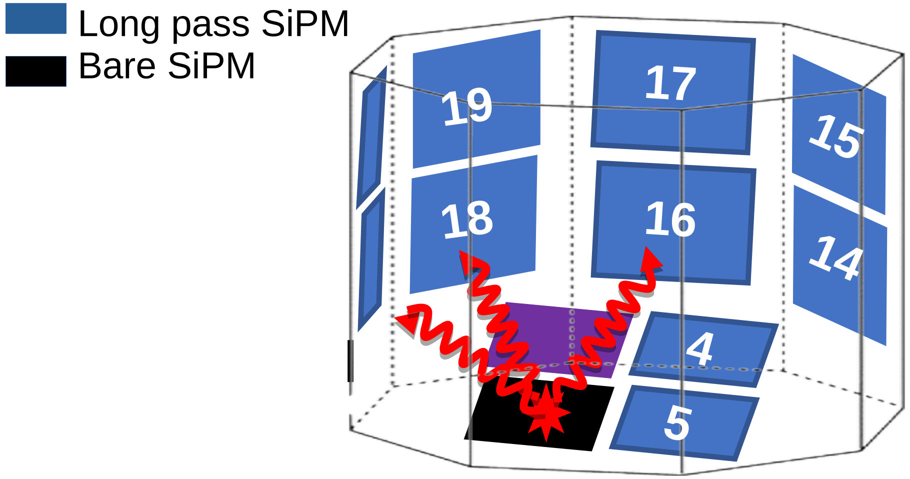


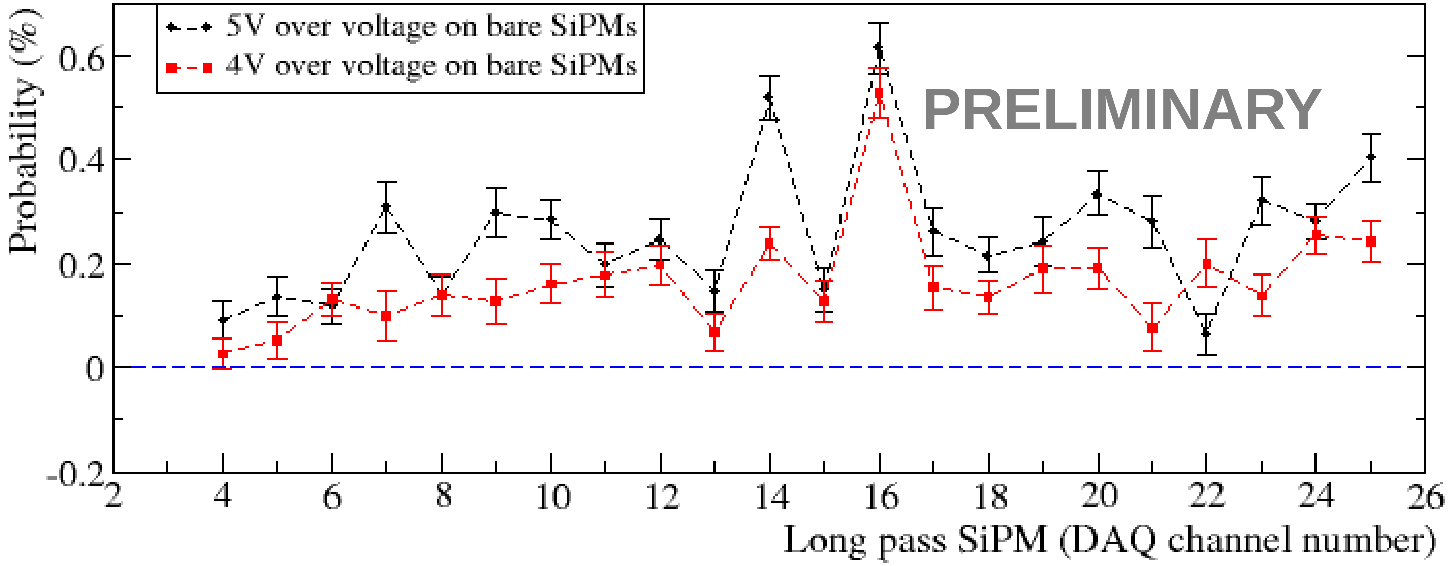
Probability of correlated hits on **summed** long pass channels

$$Prob = \frac{Total\ counts - background}{Counts\ \ bare\ \ SiPM}$$

- At **4V** OV : 3.4 ± 0.2* %
- At **5V** OV : 6.6 ± 0.3* %

PRELIMINARY





*Statistical uncertainties only

External Cross Talk

Next steps ...

- Repeat analysis for other over voltages : 2V, 7V
- Quantify the analysis further
  - Look for reverse correlations : Long pass (LP) -> Bare
  - Look for correlation in other channels : LP/LP, Bare/Band Pass (BP) , LP/BP, etc
- Investigate probability vs SiPM channel
  - Obtain eXT angular distribution
- Implement these results into LoLX simulations
- Manuscript coming up soon...

Physics Goals

LoLX

- Measure the Cherenkov and scintillation light yield in liquid xenon at zero electric field.

- Study behavior of multiple SiPMs in LXe and understand **external cross-talk.**

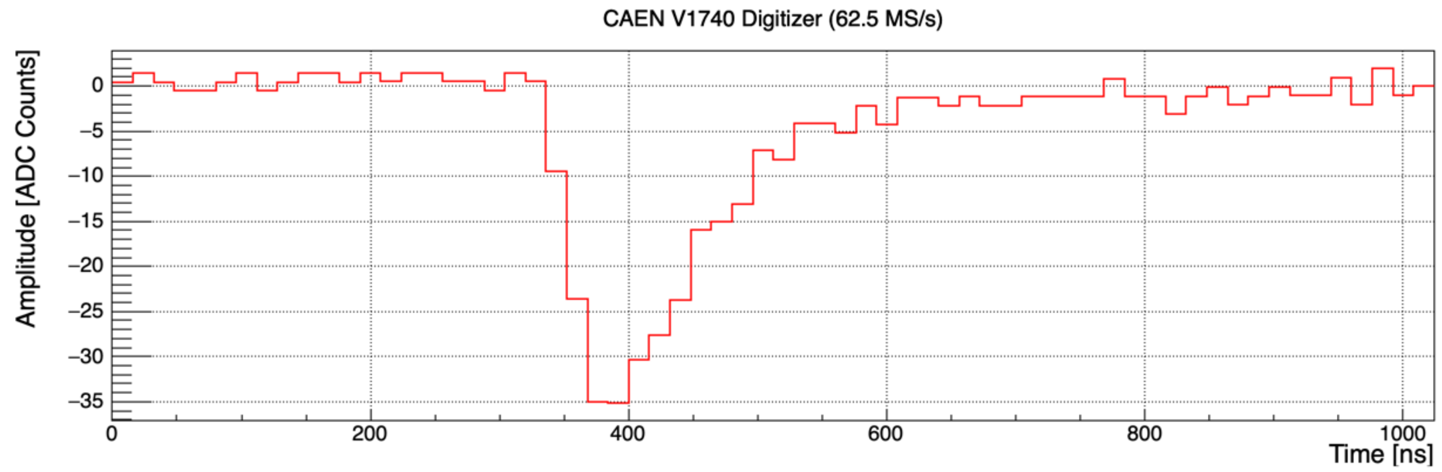
- Study the **prompt light characteristics** of LXe with fast electronics.

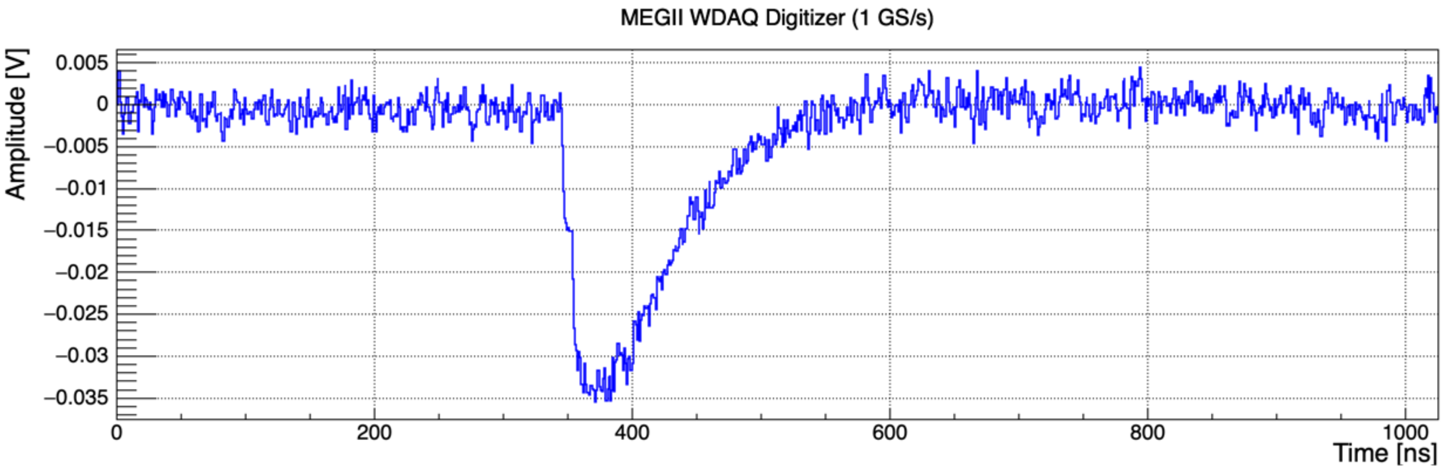
Why study prompt LXe light?

- Timing of MeV-scale deposits in LXe
  - inform LXe micro-physics models and **optical transport simulations**
- Identify Cherenkov vs scintillation photons using time differences
  - $0\nu\beta\beta$ background : γ with energy close to $Q_{\beta\beta}$
  - $\gamma \rightarrow$ PE $\rightarrow$ single site $0\nu\beta\beta$ like event
  - Ratio of cherenkov/scintillation yield $\rightarrow$ background rejection technique being explored for future nEXO upgrades
- LXe transparent to full Cherenkov spectrum
  - Short time scales (~ps) opens possibility for LXe based PET scanners using time of flight technique

    => medical imaging

Towards faster electronics





CAEN V1740 digitizer

- Sampling speed : 62.5 MHz
- Time resolution : 16 ns
- Cannot differentiate Cherenkov from scintillation

WaveDAQ[4] (from MEGII)

- Sampling speed : 1 GHz to 3 GHz (tuneable)
- Commissioned in Nov 2021 with GXe

WaveDAQ offers possibility to probe microphysics of interaction in LXe at the sub-nano second scale

[4] L. Galli *et al.*, https://doi.org/10.1016/j.nima.2018.07.067

Looking ahead …

- Upgrade LoLX cooling system with cryocooler [this summer]
  - Long-term SiPM stability studies in LXe.
- Source changes
  - No source : quantify background
  - Alpha source (^{210}Po or ^{148}Gd) : scintillation light only
- Upgrade cabling to make LoLX “plug-and-play”
  - Easy detector re-configuration
  - Operate with different SiPM combinations and configurations (FBK, Hamamatsu, nEXO tile proto-types)

Collaboration

LoLX

Thomas Brunner
Soud Al Kharusi, Christopher Chambers, Eamon Egan, Bernadette Rebeiro, Lisa Rudolph, David Gallacher

Marc-André Tétrault,
El Mehdi Rtimi
Alaa Al Masri

Luca Galli,
Marco Francesconi

Pietro Giampa

Simon Viel,
Bindiya Chana

Fabrice Retière,
Austin de St. Croix,
Juliette Martin,
Liang Xie, Mayur Patel,
Peter Margetak