A novel amorphous selenium based photosensor for liquid noble detectors

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on behalf of the Q-Pix Photondetector group

In collaboration with:

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Manchester 1824 The University of Manchester

University of California Santa Cruz

Oak Ridge National Laboratory

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Fundación BBVA

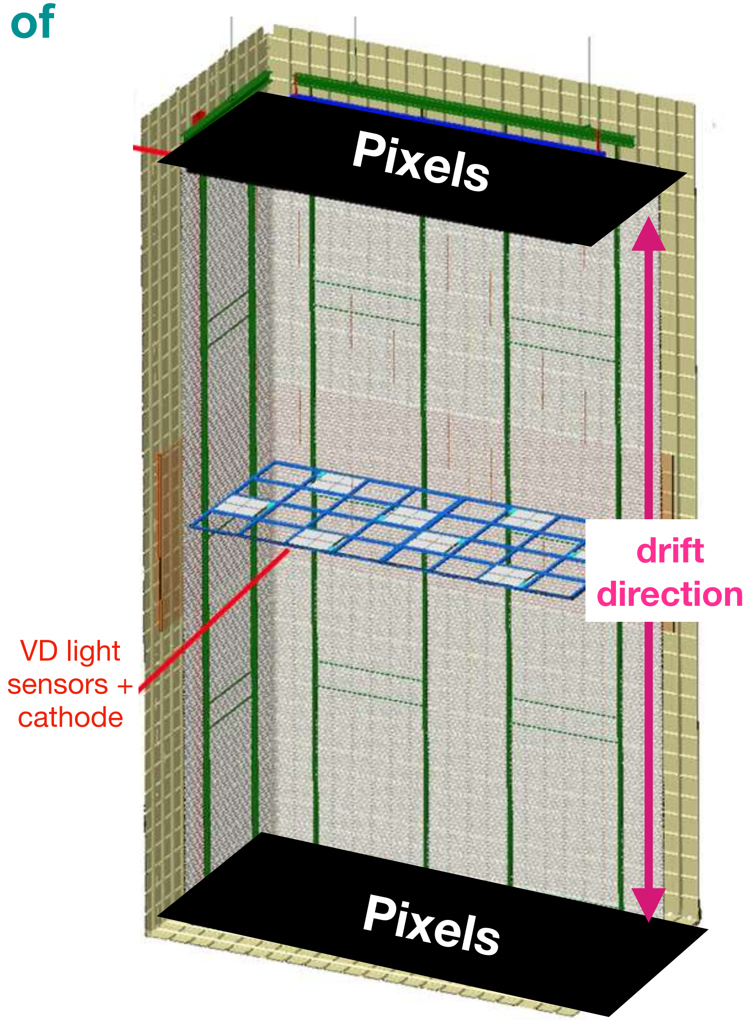
Pixels & Lights

Strength of noble liquid TPCs: anti-correlated emission (and detection) of ionisation charge and scintillation VUV light

Despite being successful, the traditional wire technology of LArTPC for charge readout is too expensive to be implemented in the DUNE modules of Phase-II

- The solution calls for a pixel-based charge readout
  - Robust, simple construction & lower electronic noise

- Problem: pixel boards are opaque and the photosensors should be inconveniently located
  - over the cathode (huge voltages ~300 kV)
  - behind the TPC walls (limited visibility)



DUNE vertical drift (VD) geometry

Pixels & Lights

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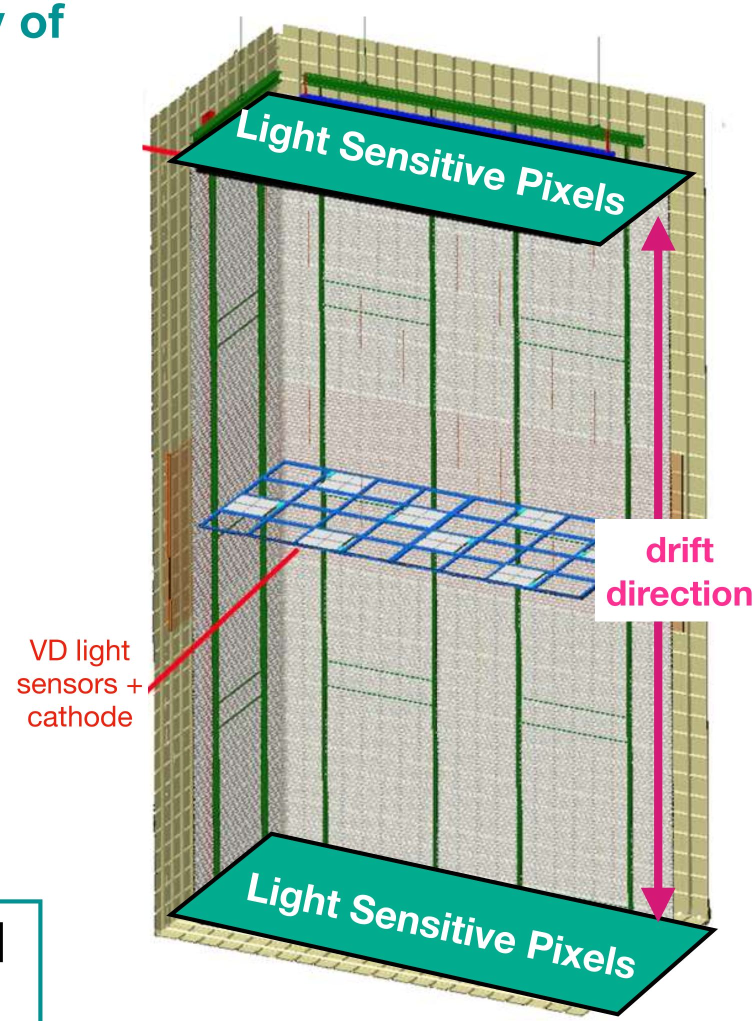
Our Proposal

A pixel sensitive to both scintillation VUV light and ionisation charge simultaneously (**Q+L sensor**)



DUNE-VD geometry

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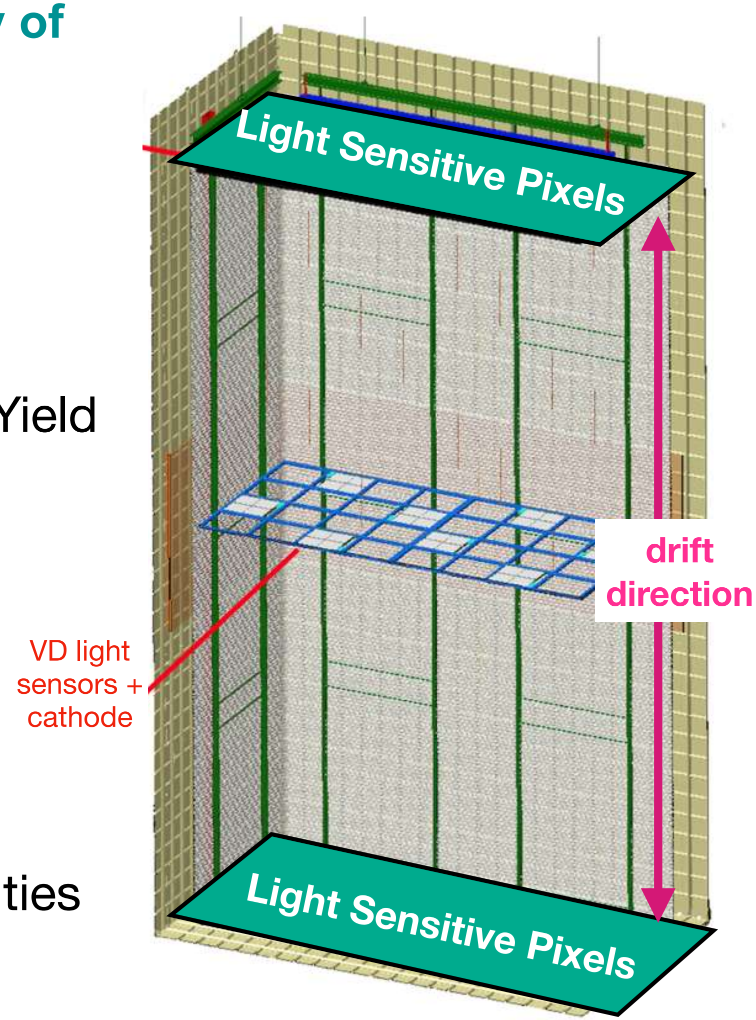
Benefits of this strategy:

1. **Enormous light sensitive area** —> Enormous Photon Yield
   - improved energy resolution

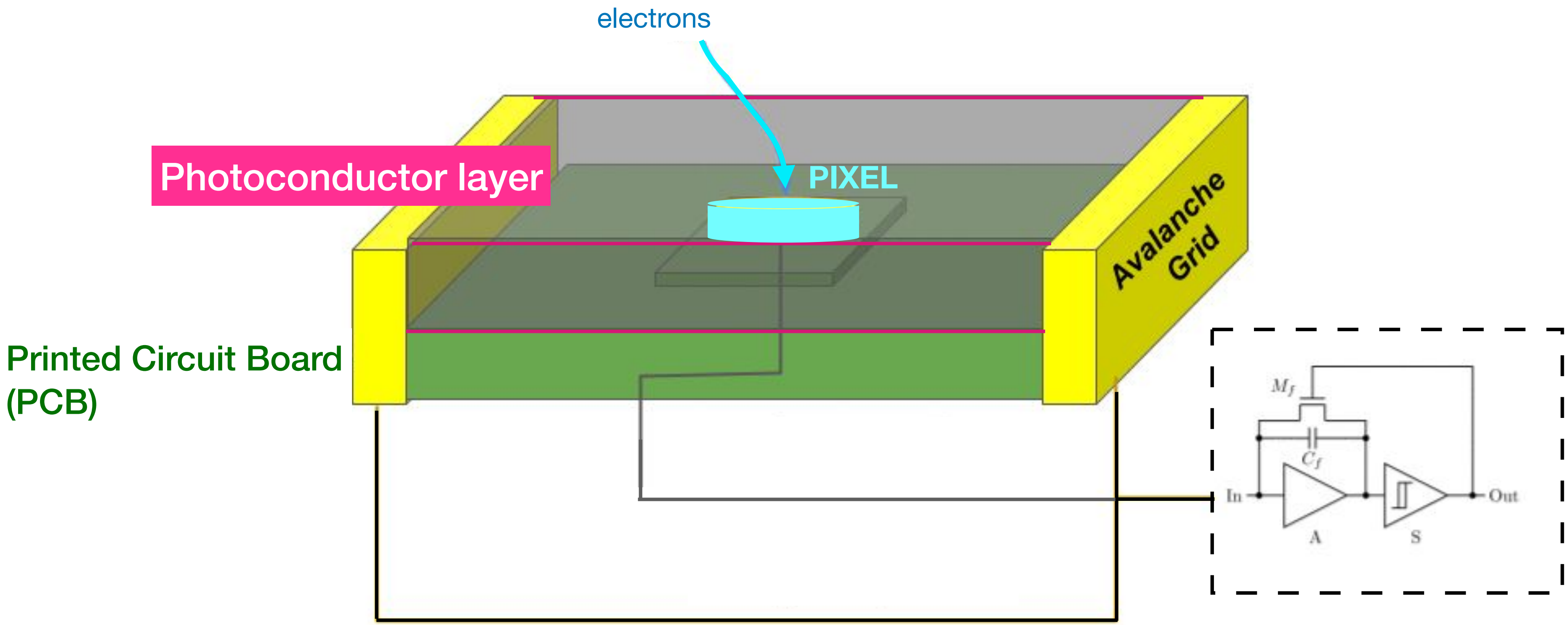
     Light + charge can boost the energy resolution up to 40% at low energies. *PRD 101 012010 (2020)*
   - light-enhanced particle identification
2. **Extremely light granularity** —> New detection capabilities
   - possible light imaging



DUNE-VD geometry

Sensor Concept: making a photosensitive pixel

A photoconductive substrate over the pixel plane would allow for the integration of charge and light in only one sensor



Q-Pix architecture for charge & light readout

Nygren & Mei
arxiv: 1809.10213

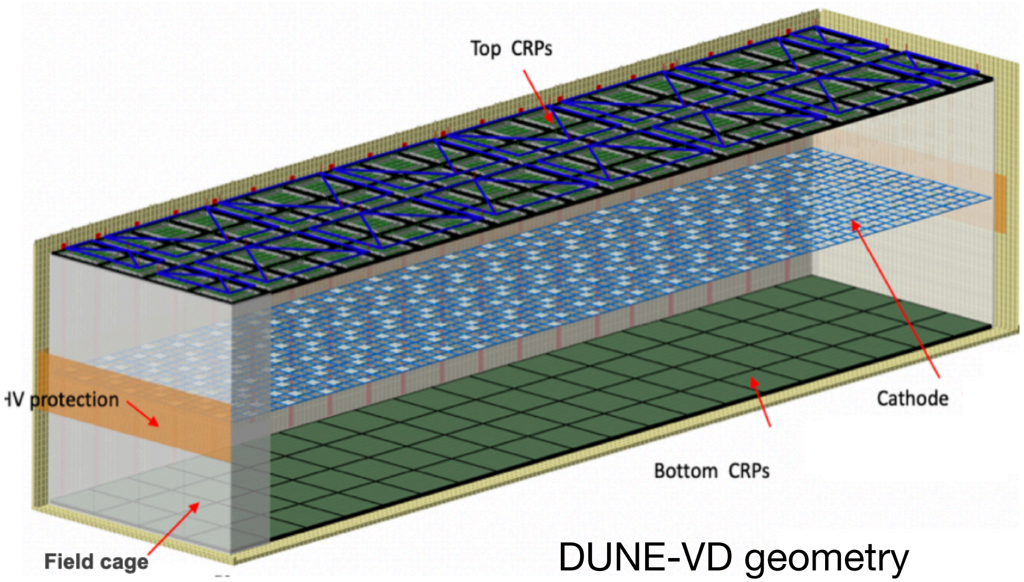
- Ideally the photoconductive material can be evaporated over the pixel plane
- Potential materials: *amorphous selenium, nanoplatelets, organic semiconductors ….*

Simulation of the Q+L sensor in a TPC

Developing a dedicated simulation tool to study the scientific impact of the Q+L sensor on the DUNE experiment

Questions to answer:

- Can we do light imaging, calorimetry and time discrimination with a Q+L sensor in a DUNE-VD geometry?
- Which physics channels can benefit from this technology?
  solar and supernova neutrinos, proton decay, …
- Which are the minimum requirements for this sensor?
  quantum efficiency, sensitive area, granularity…



DUNE-VD geometry

VD layout most likely for the DUNE PHASE-II modules

Simulation of the Q+L sensor in a TPC

Developing a dedicated simulation tool to study the scientific impact of the Q+L sensor on the DUNE experiment

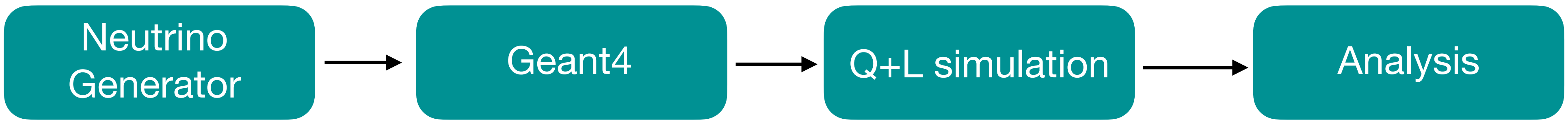
How ?

- Full Geant4 simulations (or photon libraries) are prohibitively slow (heavy) for DUNE-like geometries and the enormous amount of photons ✗

- We need to develop **fast optical methods** that allow the simulation of scintillation light

  - *Semi-Analytic Model* (EPJC 81 (2021) 4, 349) to predict the number of photons observed by the light sensors and the arrival times distributions (Isotropic emission + propagation effects)

  - Anticorrelation of charge and light taken into account in the simulations



Simulation of the Q+L sensor in a TPC

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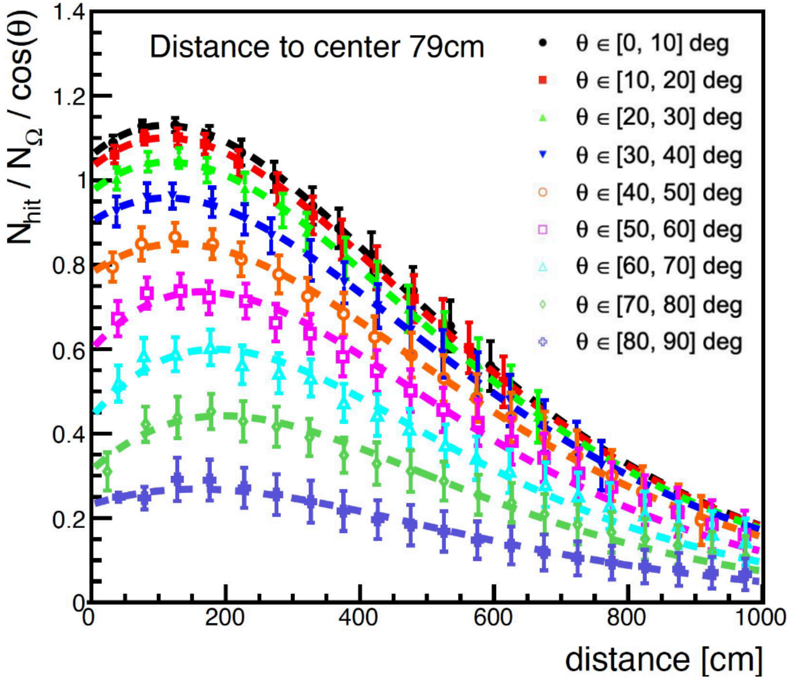
Prediction of the Number of Photons

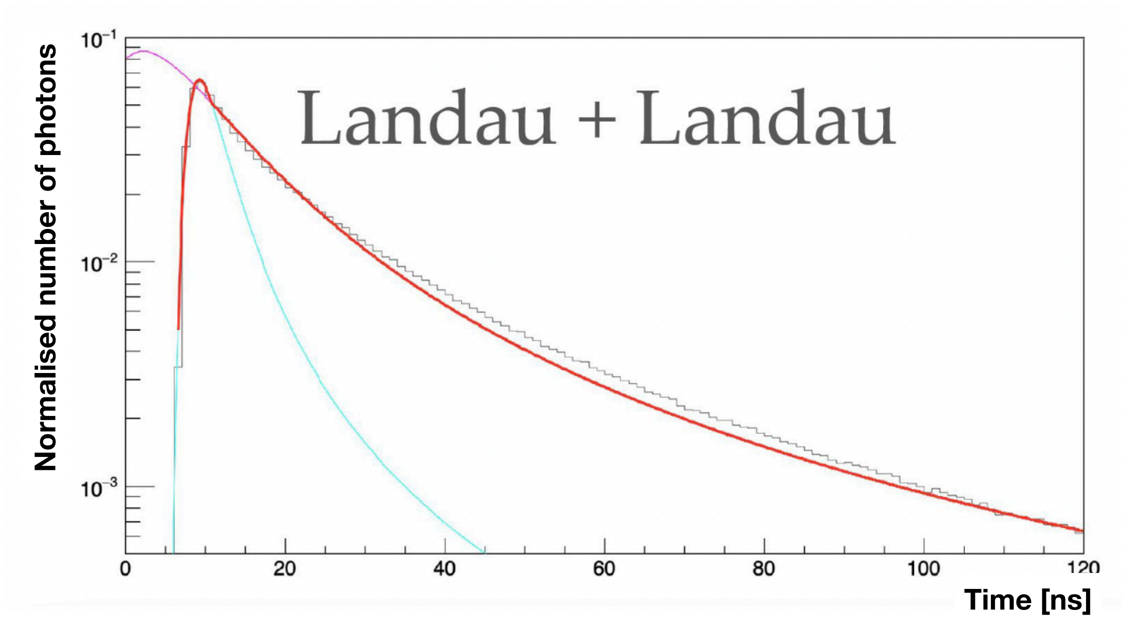


Propagation effects depend on the detector geometry

$$N_{\gamma} = N_{\Omega} \times GH'(d, \theta, d_T)/cos(\theta),$$

Dedicated calibration for a DUNE-VD geometry

Arrival Time Distributions



- Timing information not included in fast simulation methods
- Parameterization of the transport time distributions as a function of the distance

Amorphous Selenium (aSe)

Material commonly used in medicine for imaging diagnoses: X-Ray radiography at room temperature

- **Properties:**

1. High absorption coefficient for 128 nm photons

   -> Layer of 100 nm enough for 100% absorption

2. Favorable transport properties

   -> 1 photon produce 1.3 electron-hole pairs

3. Intrinsic gain: avalanche multiplication for high fields

   -> ~1000 electrons per photon for 80V/µm

Q-Pix design choice between 0.3 and 1.0 fC per reset time (1800 - 6000 electrons)

Q-Pix technology compatible!!

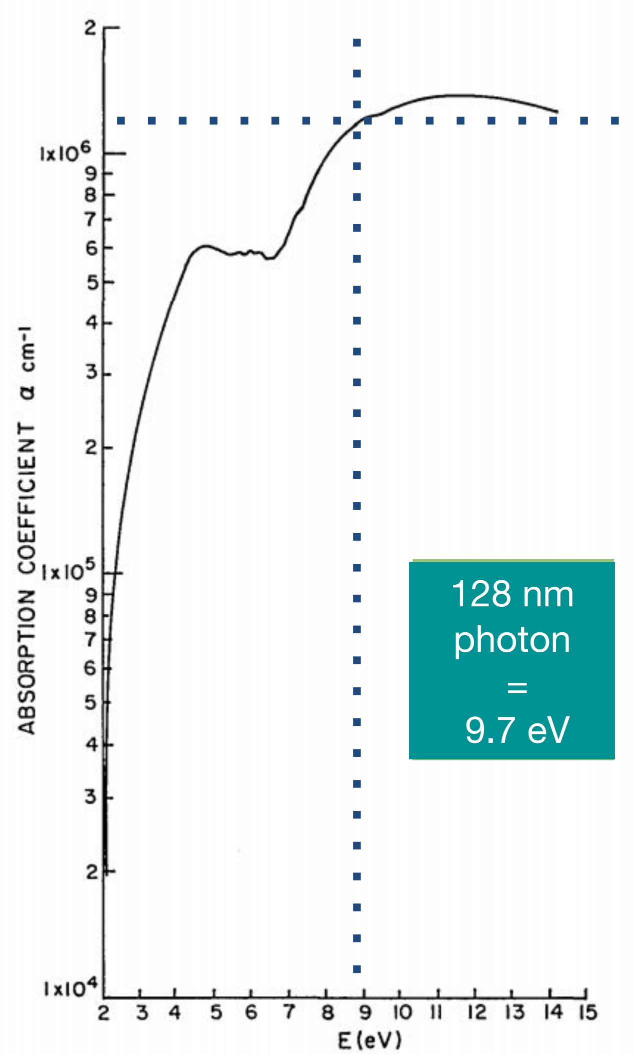


FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

Med Phys, 35(5):1978–1987, May 2008

Working Principle of the Q+L sensor

1. Scintillation VUV light is absorbed in the aSe substrate

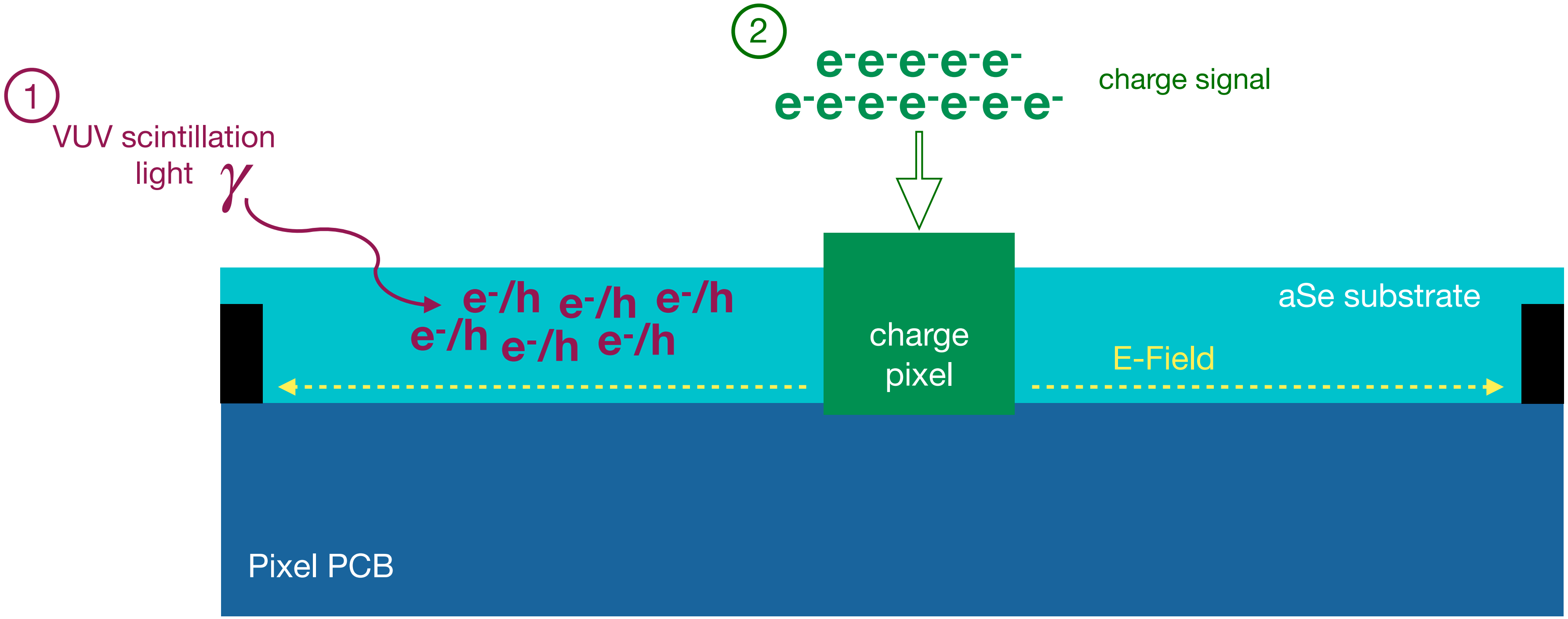
    -> Photons get to the sensor in ns

    -> Carriers start moving

    -> If E-field strong enough (80V/μm) avalanche multiplication

2. Charge is collected, after drifting, as in regular pixels

    -> Charge signal gets to the pixels after drifting times of ~ms



Working Principle of the Q+L sensor

1. Scintillation VUV light is absorbed in the aSe substrate
   - -> Photons get to the sensor in ns
   - -> Carriers start moving
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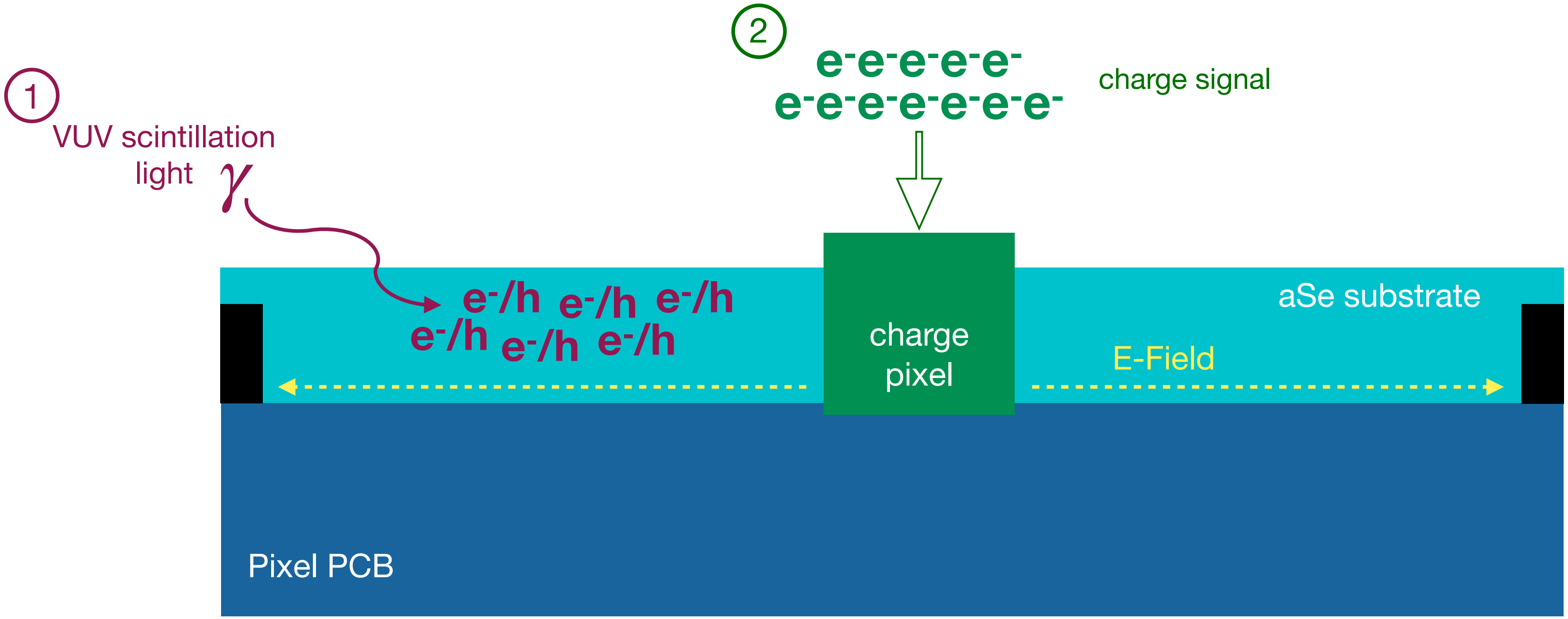
Main Challenge ??

Reach avalanche multiplication for cryogenic conditions

-> 80V/μm is a really high field

2. Charge is collected, after drifting, as in regular pixels
   - -> Charge signal gets to the pixels after drifting times of ~ms



Proof of Principle & First Prototype

MAIN GOAL:

Test a-Se coating in a PCB at cryogenic temperature and see light signal

PAPER

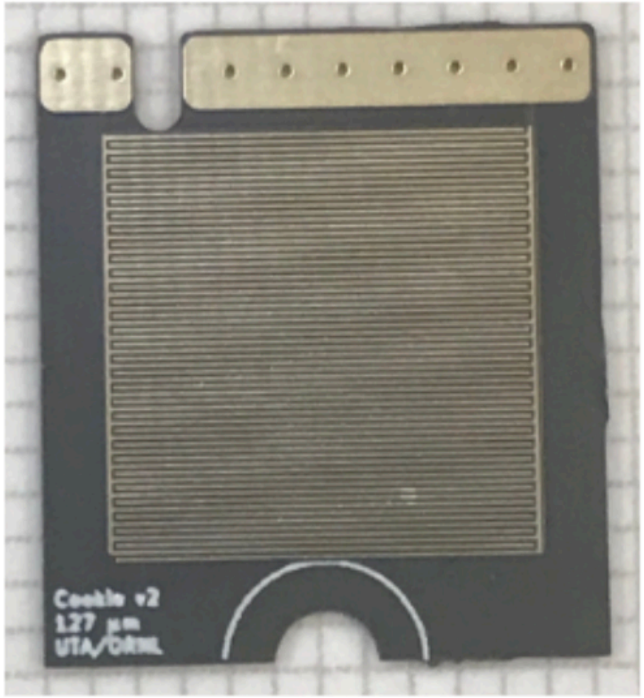
Development of a novel, windowless, amorphous selenium based photodetector for use in liquid noble detectors

M. Rooks[1], S. Abbaszadeh[2], J. Asaadi[1], M. Febbraro[3], R.W. Gladen[1], E. Gramellini[4], K. Hellier[2], F. Maria Blaszczyk[4] and A.D. McDonald[1]

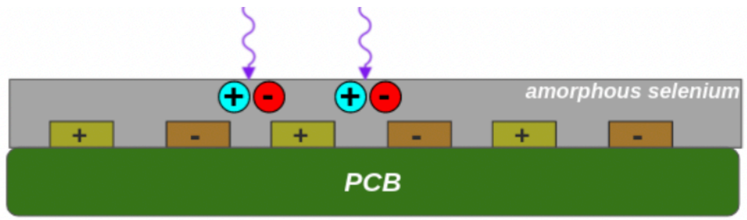
Published 25 January 2023 • © 2023 IOP Publishing Ltd and Sissa Medialab

Journal of Instrumentation, Volume 18, January 2023

JINST 18 P01029 (2023)



- PCB implemented with a commercial interdigitated board with 127 μm trace spacing and 35 μm trace thickness.
- > 99.999% a-Se was deposited by thermal evaporation
- Selenium layer of 1.2 μm



Horizontal Geometry

Experimental SetUp

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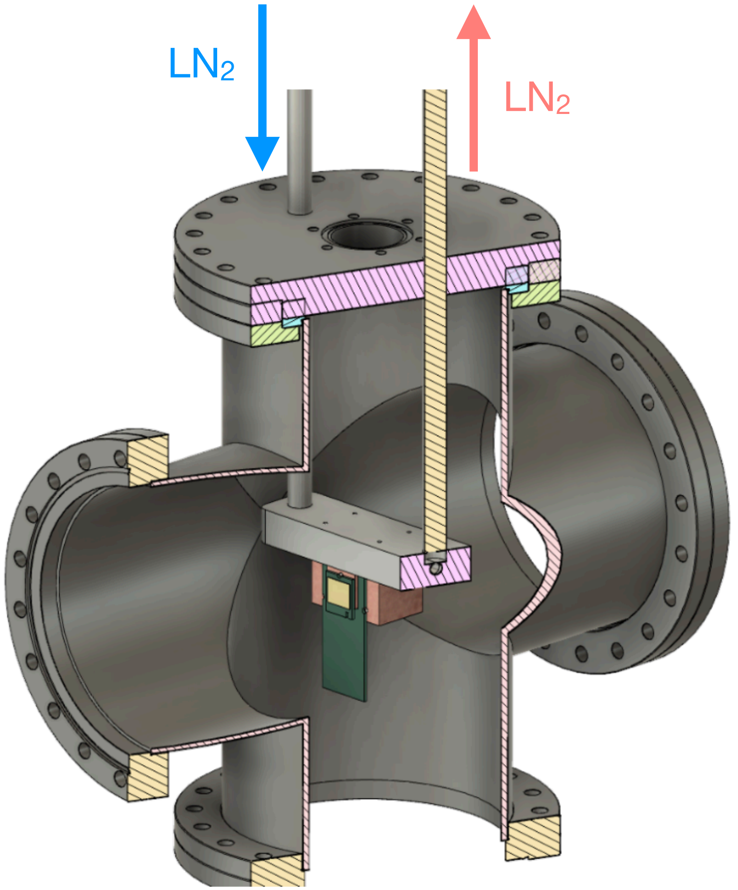
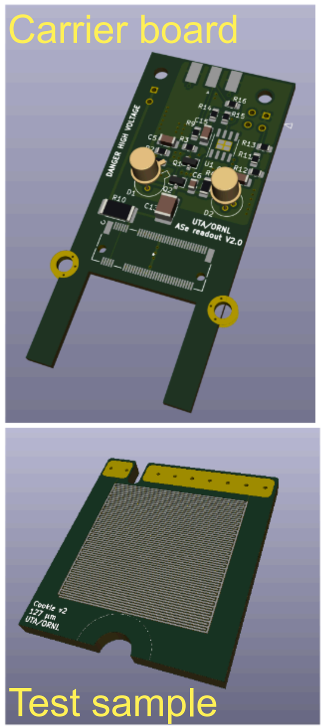
Custom made vacuum chamber with temperature control by flashing nitrogen





Detail of the SetUp:

- VUV light source: Xenon Flash Lamp
  - -> 5 Watt Hamamatsu L11316-11
- Custom HV/readout system
  - -> HV via a DC/DC converter (±750V)
  - -> 2 polarities
  - -> charge read via a decoupling capacitor
- Low noise charge sensitive amplifier
- Electric fields: 2.7 - 5.2 V/μm

The PCB is mounted on a copper block in contact with a heat exchanger

Cooling control: 1 kelvin/minute between 290K - 77K

Results (I): Waveforms at different temperatures

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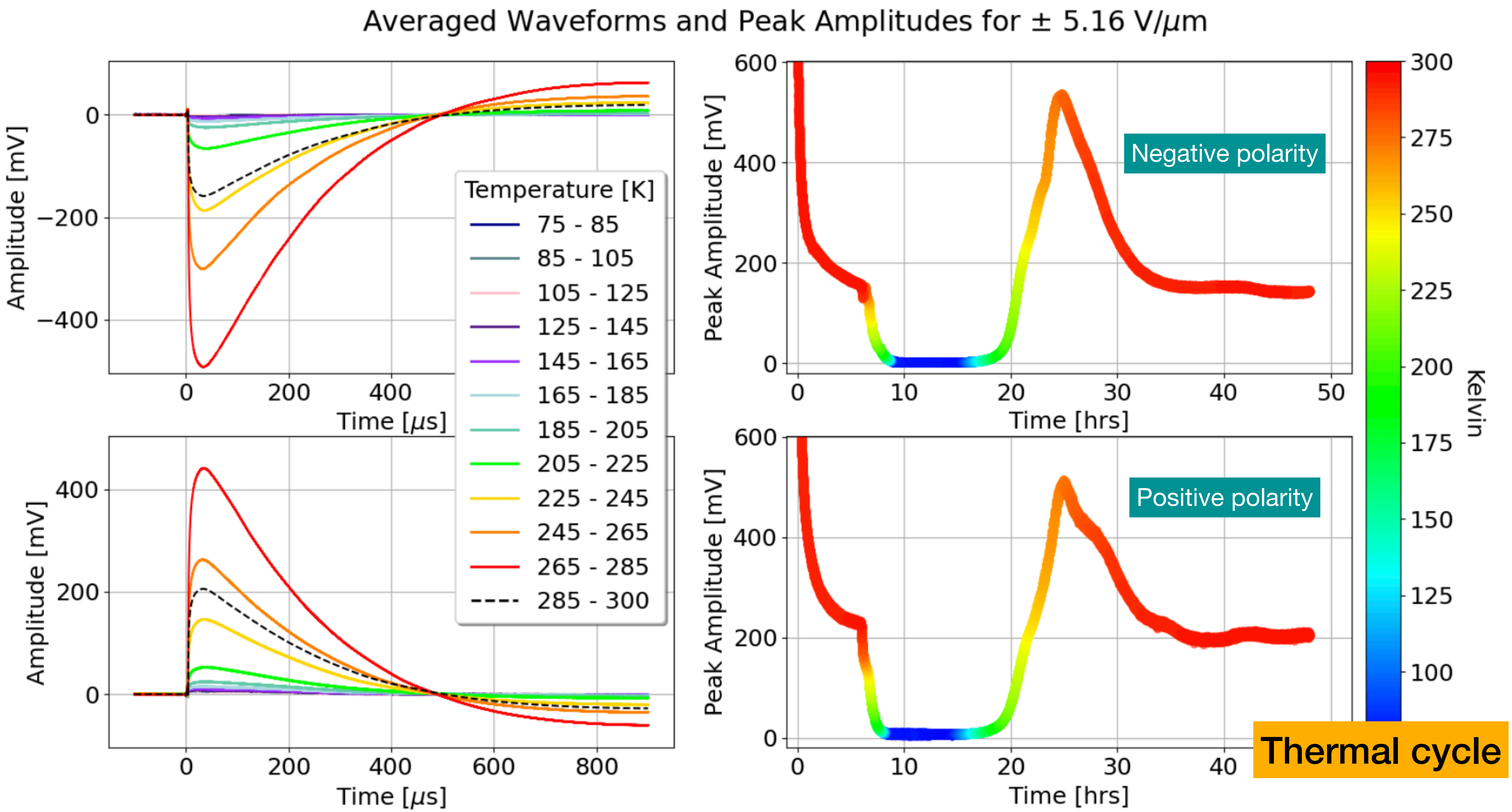

The peak amplitude clearly reduces at the lowest temperatures

Results (I): Some light at cryogenic temperatures

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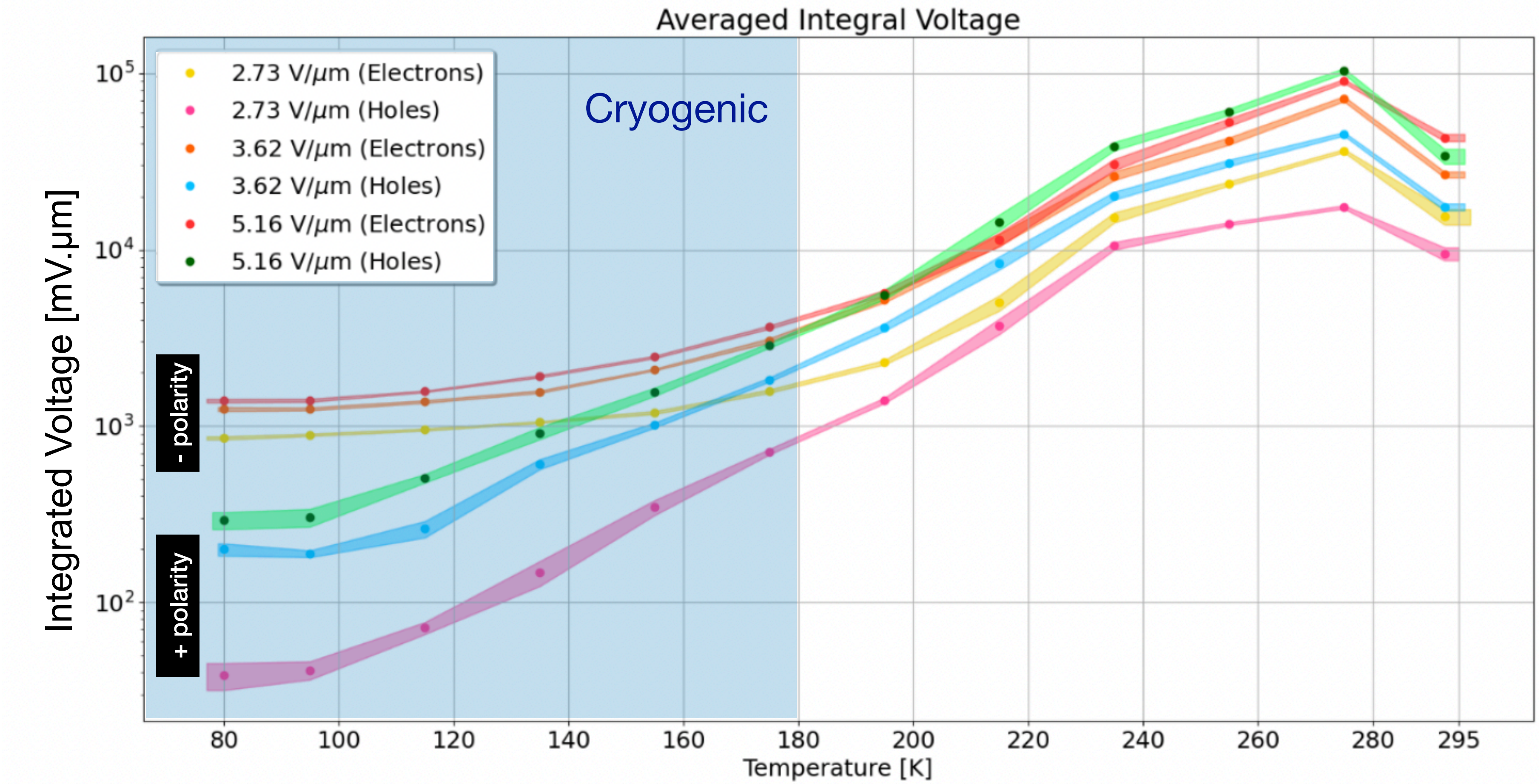


- Integral of the peaks is definitively non-zero
- Pulse shape consistent with a response due to a signal from the flash lamp
- At lowest temperatures, the peak amplitude is higher when collecting electrons

Conclusions

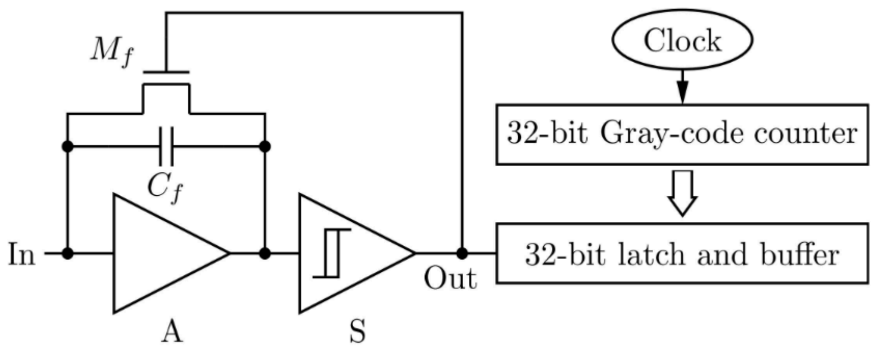
- Future LArTPCs will move to a pixelated solution for charge readout
- This will require new light systems against the traditional ones
- We propose a novel solution: light sensitive pixels (Q+L sensor)
- A reliable simulation tool is in place to evaluate the enhancement of this technology in the physics reach of DUNE
- A potential photosensitive material is the amorphous selenium
- The first prototype has shown the proof-of-principle of the device, robustness at cryogenic conditions and response to VUV light

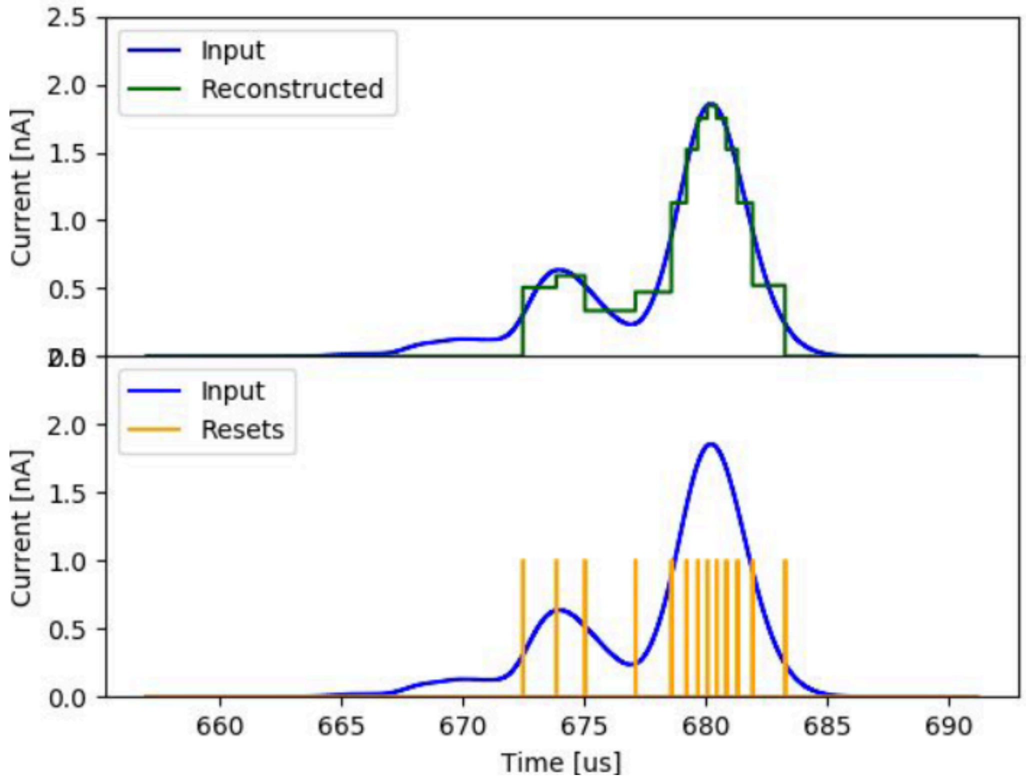
Proyecto realizado con la Beca Leonardo a Investigadores en Física 2023 de la Fundación BBVA

Back Up

Q-Pix

Nygren & Mei
arXiv: 1809.10213





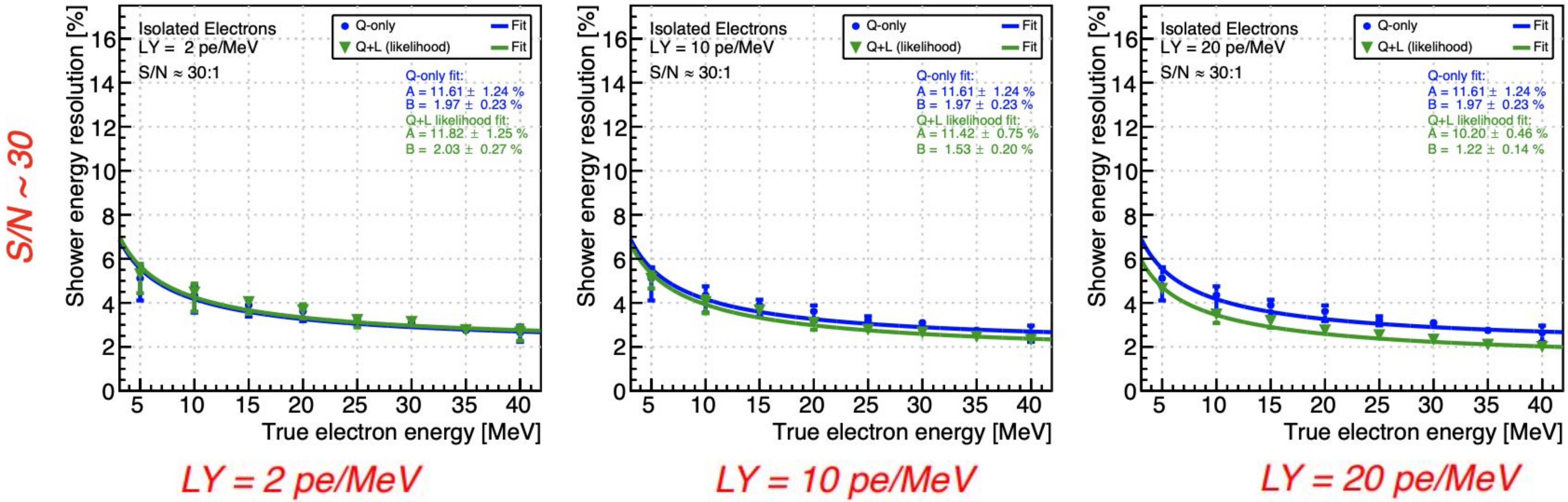
Better Energy Resolution

Combining light and charge information has been proven to boos energy resolution in a LArTPC, especially at low energies *LArIAT, PRD 101 012010 (2020)*

Q+L improves energy resolution for electros < 40 MeV by:

- 10% for 10 pe/MeV light yield
- 20% for 20 pe/MeV light yield
- 40% for 100 pe/MeV light yield

compared to Q-only reconstruction



Schematic of the setup

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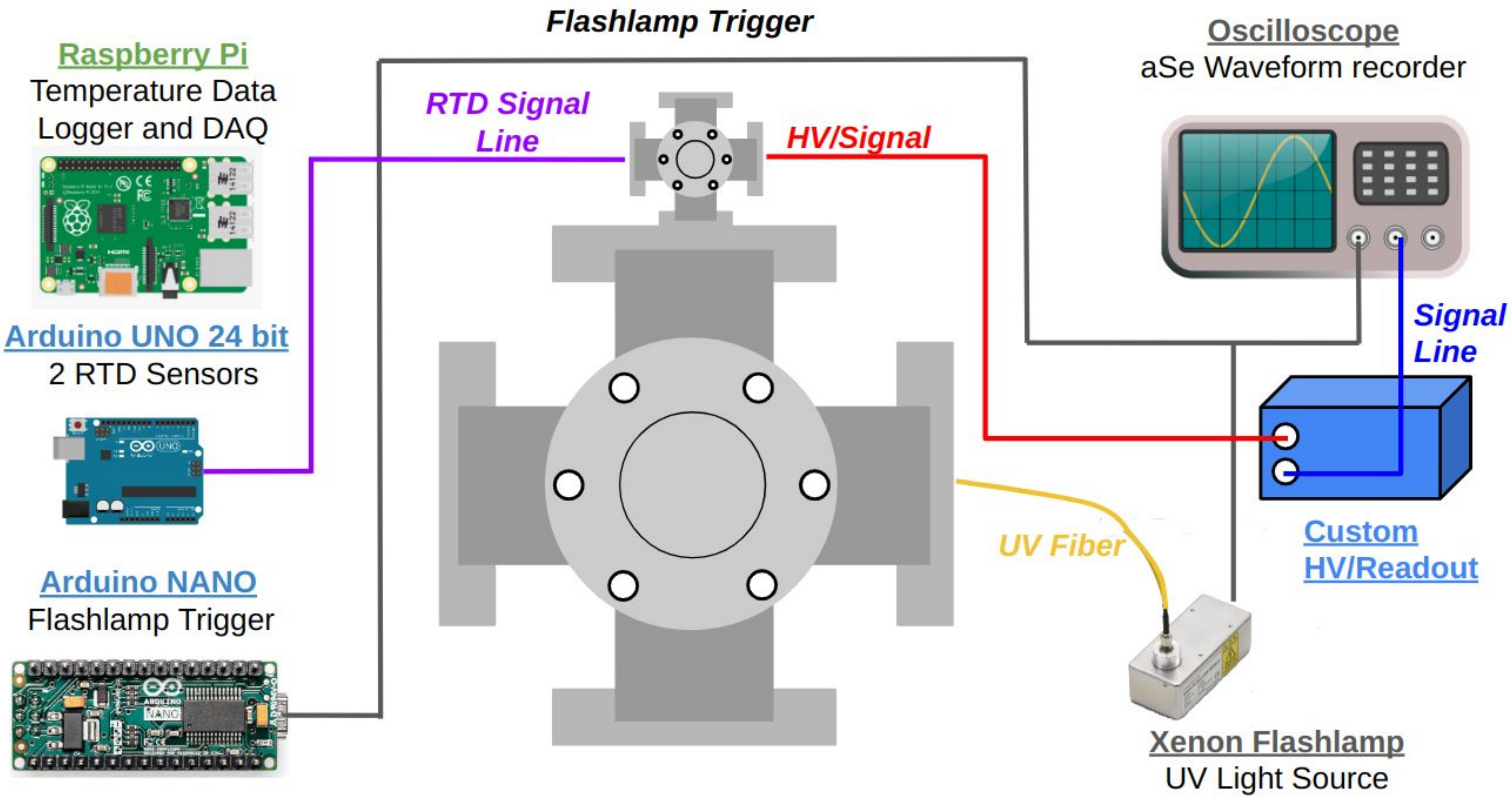

Preservation of Argon Purity

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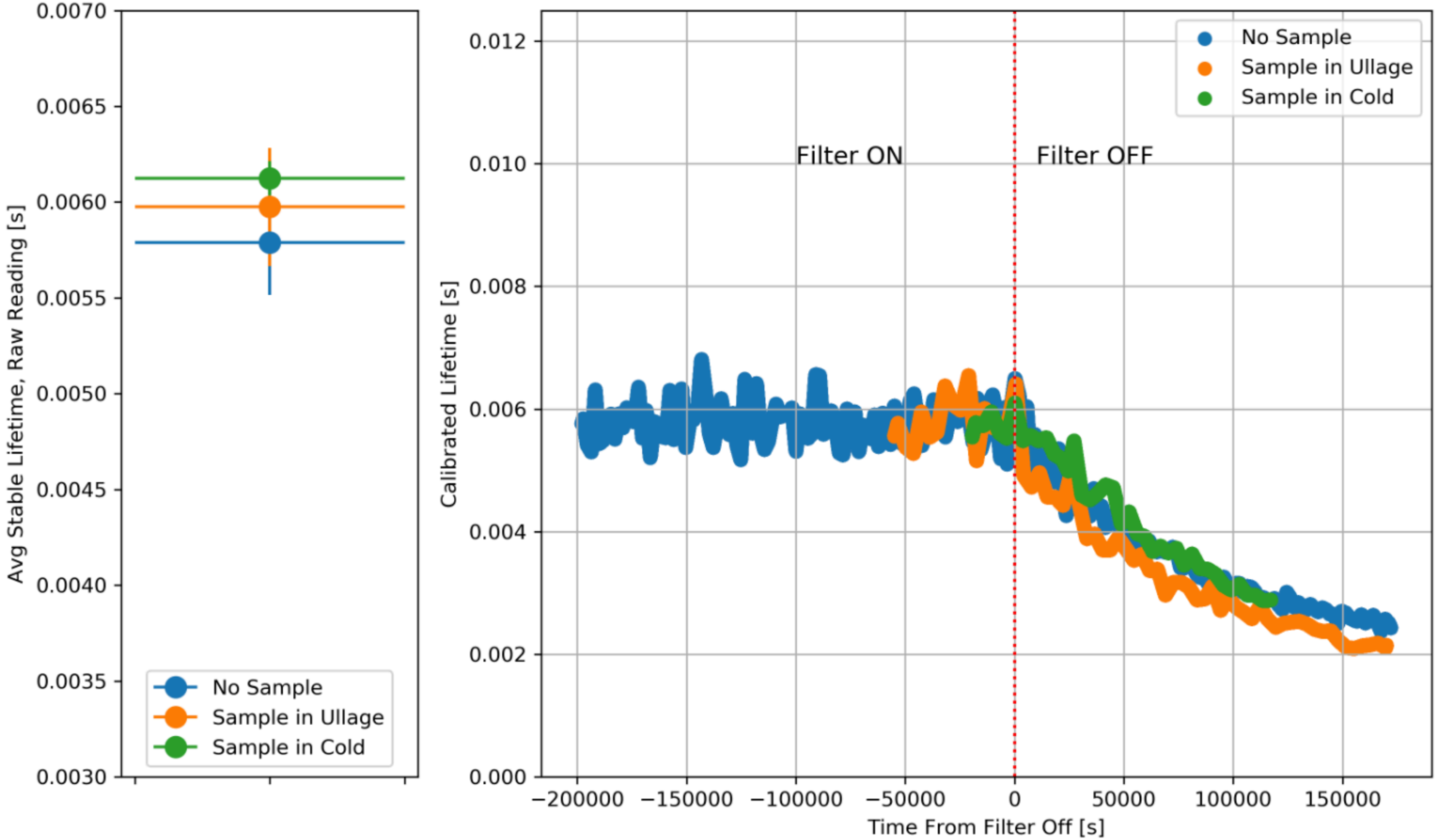

Time evolution of the peak amplitude

[JINST 18 P01029 (2023)](#)