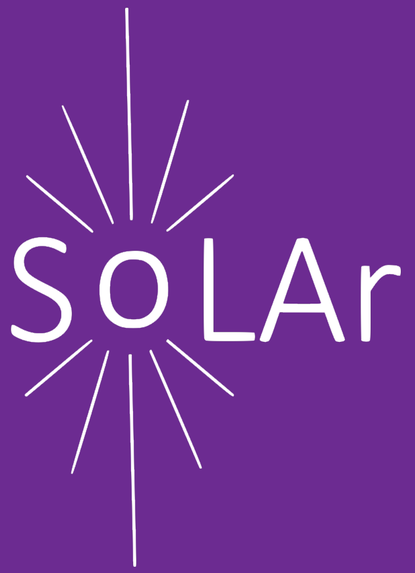
Update on SoLAr and Pixel R&D

Anyssa Navrer-Agasson



AIDA Innova Annual Meeting - 20 March 2024

SoLAr neutrinos in LAr

✳ Large Liquid Argon Time Projection Chambers (**LArTPCs**) have **significant potential** for low energy neutrino physics

- 10 kt module with 5 MeV threshold

✳ **Solar neutrinos**

✳ **Supernova neutrino** bursts

✳ **Diffuse supernova neutrino background**

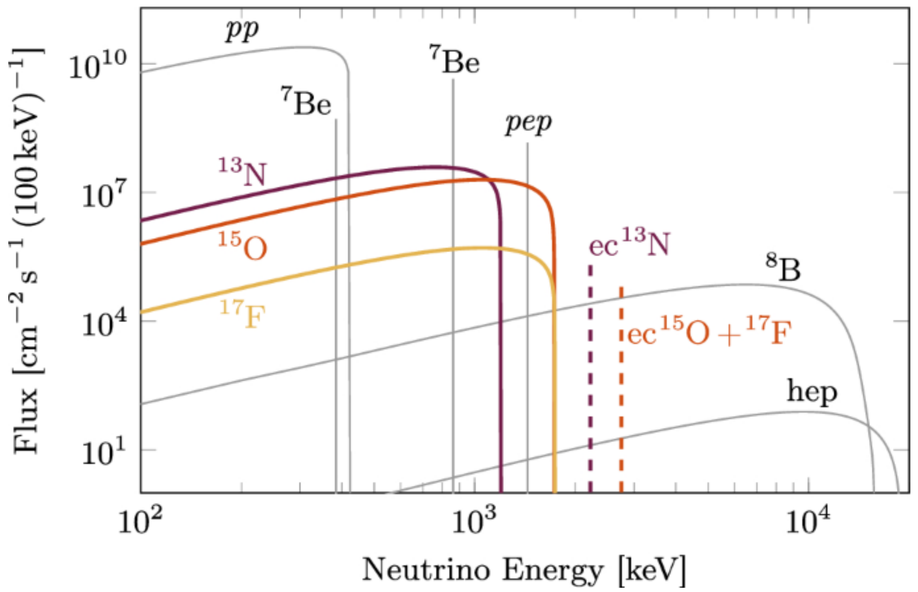
Challenges

- **Materials** not optimised for searches requiring low backgrounds
- Limited low energy **resolution**
- Difficult **reconstruction** of low energy events

Charged Current (**CC**) interaction: ν_e + **^{40}Ar** → **e$^-$ + ^{40}K***

Elastic scattering (**ES**): ν_x + **e$^-$** → ν_x + **e$^-$**

Agostini et al, Eur. Phys. J. C 80, 1091 (2020)



The SoLAr concept

Integrated charge & light readout tile for low energy neutrino physics in LAr

Integrate developing technologies

- Next generation VUV SiPMs
- Novel pixel readouts

Combine light and charge

✴ Improve triggering and energy resolution

✴ 7% energy resolution target

Improve background rejection

- Pulse Shape Discrimination
- Directionality

arXiv:2203.07501 [hep-ex]
August 25, 2022

SoLAr: Solar Neutrinos in Liquid Argon

Saba Parsa, Michele Weber, *University of Bern, Switzerland*

Clara Cuesta, Inés Gil-Botella, Sergio Manthey, *CIEMAT, Spain*

Andrzej M. Szelc, *University of Edinburgh, United Kingdom*

Shirley Weishi Li, *Fermi National Accelerator Laboratory, Batavia, Illinois, USA*

Marco Pallavicini, *Univ. of Genova and INFN Genova*

Justin Evans, Roxanne Guenette, David Marsden, Nicola McConkey, Anyssa Navrer-Agasson, Guilherme Ruiz, Stefan Söldner-Rembold [1], *University of Manchester, United Kingdom*

Esteban Cristaldo, Andrea Falcone, Maritza Delgado Gonzales, Claudio Gotti, Daniele Guffanti, Gianluigi Pessina, Francesco Terranova, Marta Torti, *University of Milano-Bicocca and INFN, Italy*

Francesco Di Capua, Giuliana Fiorillo, *University of Naples "Federico II" and INFN Napoli*

John F. Beacom, *Ohio State University, Columbus, OHio, USA*

Francesco Capozzi, *Instituto de Fisica Corpuscular, Universidad de Valencia & CSIC, Spain*

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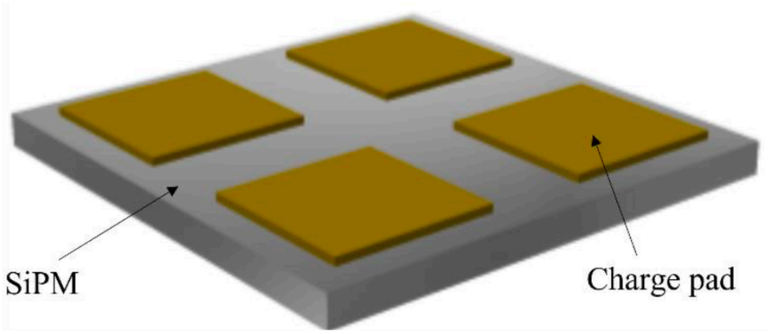
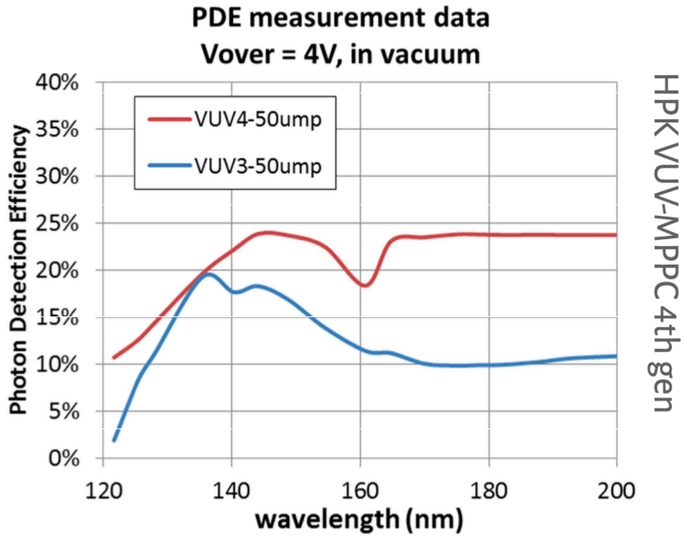


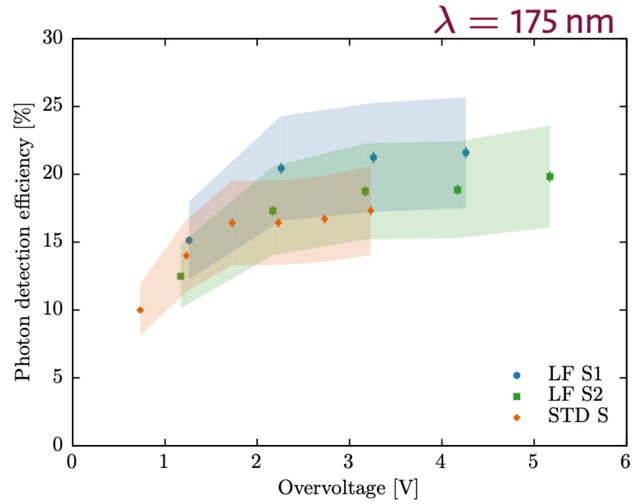
Francesco Capozzi, *Instituto de Fisica Corpuscular, Universidad de Valencia & CSIC, Spain*

Photon detection system

- **New generation SiPMs**:
  - **High photon detection efficiency** at LAr scintillation wavelength
  - Hamamatsu 4th generation MPPC
  - FBK VUV-HD technology



HPK VUV-MPPC 4th gen



Jamil et al. (nEXO Coll) IEEE Trans.Nucl.Sci. 65 (2018) 11

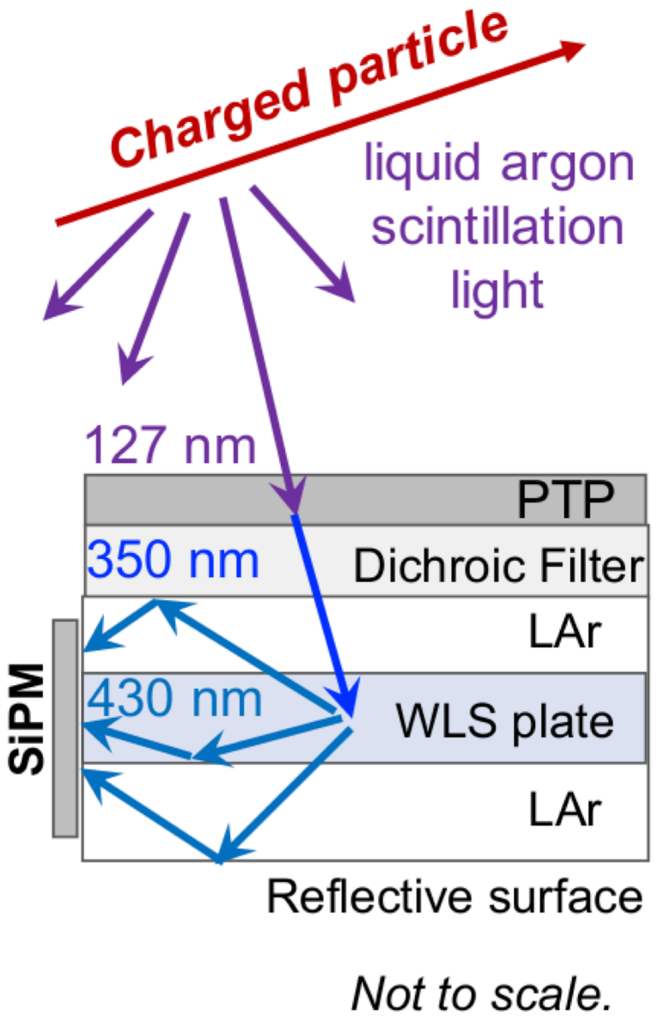
Photon detection system

✴ **New generation SiPMs**:

- **High photon detection efficiency** at LAr scintillation wavelength
- Hamamatsu 4th generation MPPC
- FBK VUV-HD technology

✴ Can be combined with **light traps**

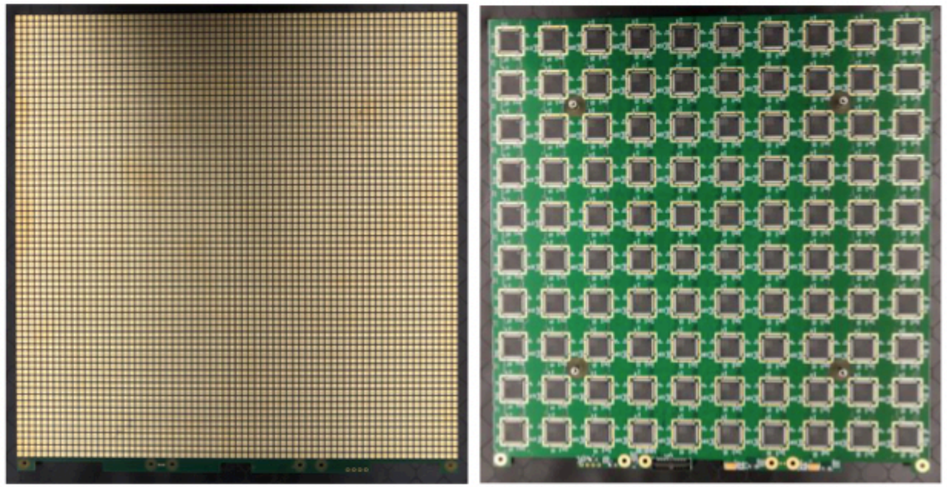
- Improve photodetector **coverage**
- Consider DUNE X-ARAPUCA design



Charge readout

LArPix

- Self triggered digitisation and readout
- Technology **demonstrated in ArgonCube**
- **Available now**
  - **Used for first prototypes**



32 cm by 32 cm anode PCB tile

Q-Pix

- Developed to **solve the data rate issue** of pixellated readouts
- **Electronic principle of least action**
- Saves time stamps instead of full waveforms

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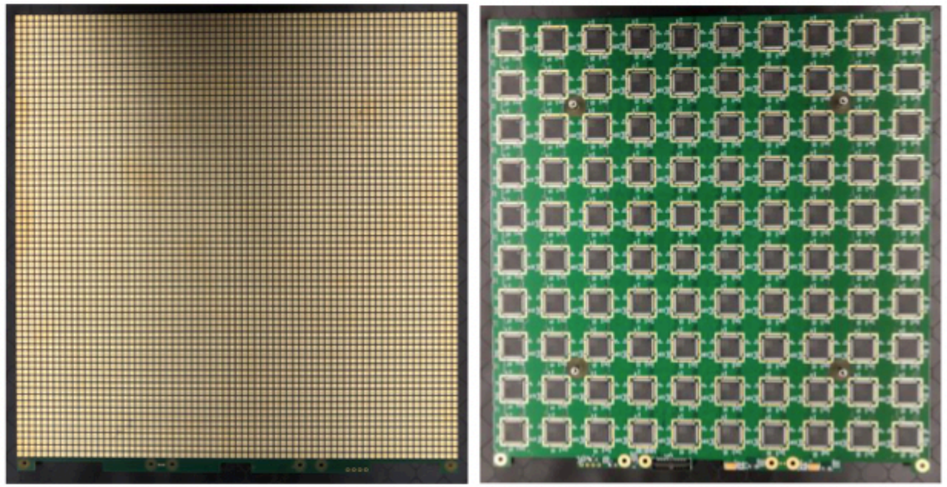

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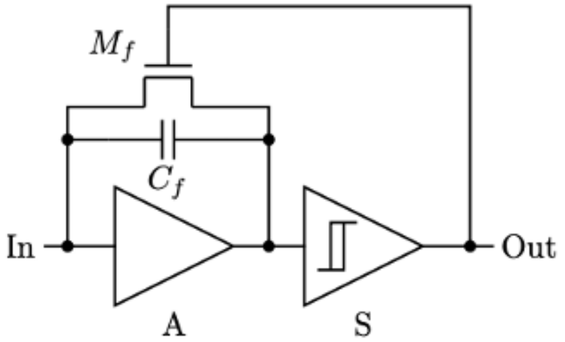

- Each channel integrates Charge Integrate Reset circuit
- Resets when charge > $\Delta Q/C_f$
- Measure reset times with embedded clock

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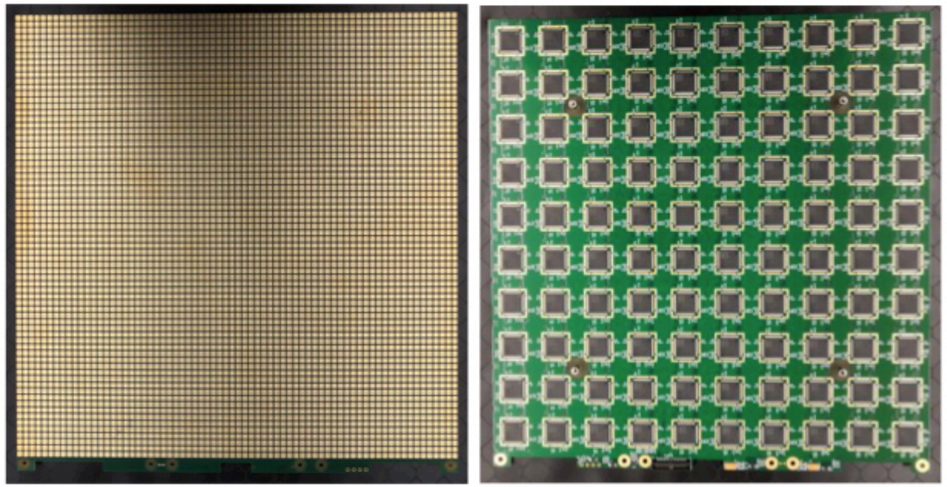

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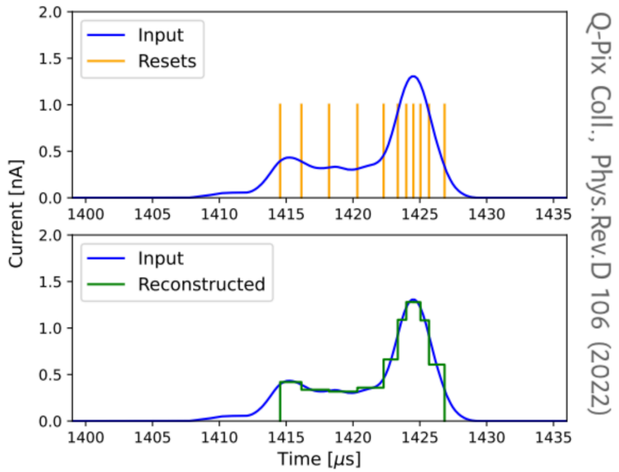

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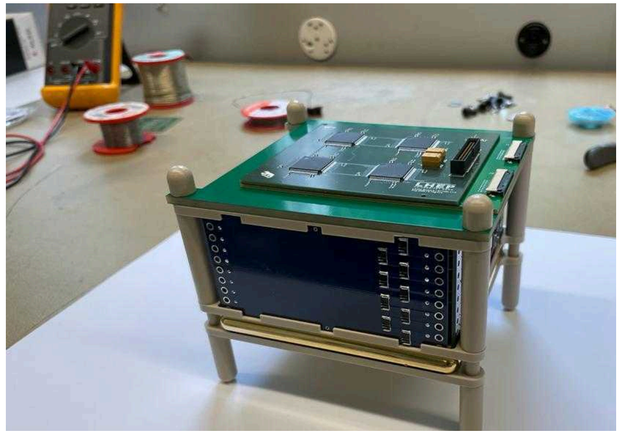
SoLAr development stages

Down, and down we go...

Small scale tests at LHEP Bern



2022-2025

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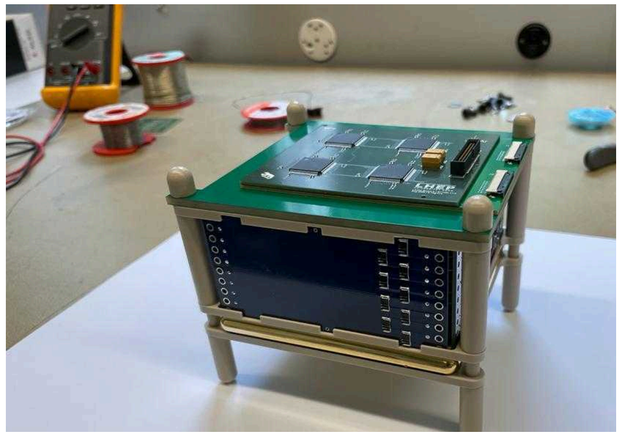
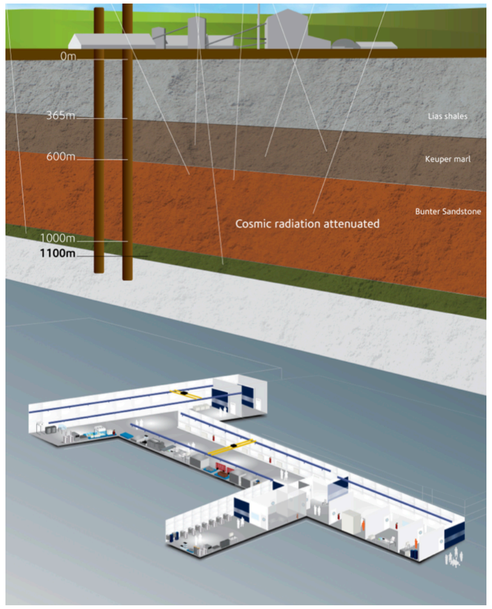


2022-2025

Medium scale demonstrator



~2025-2030

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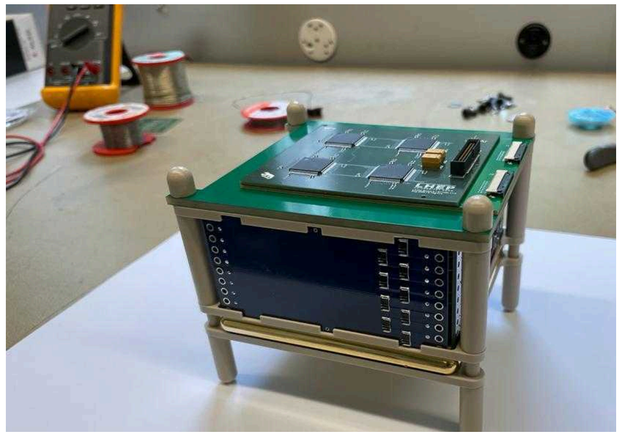

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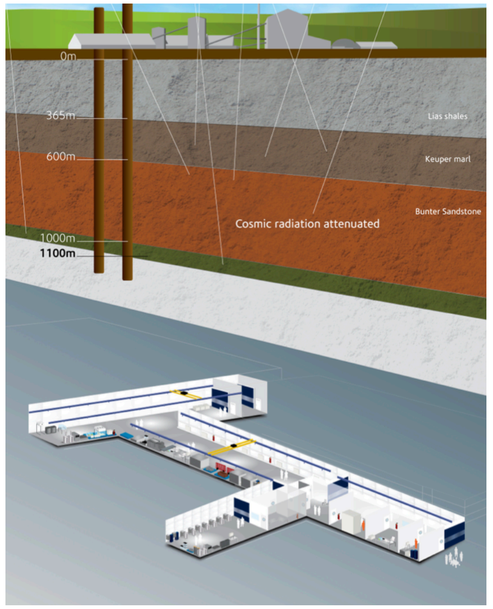
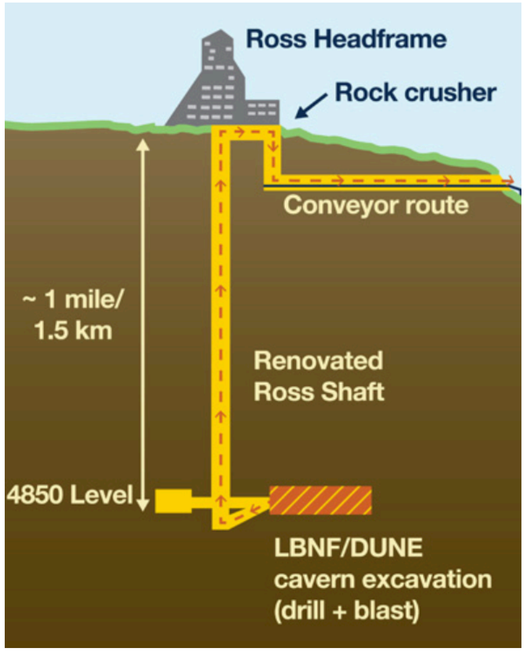


~2025-2030

2030 -

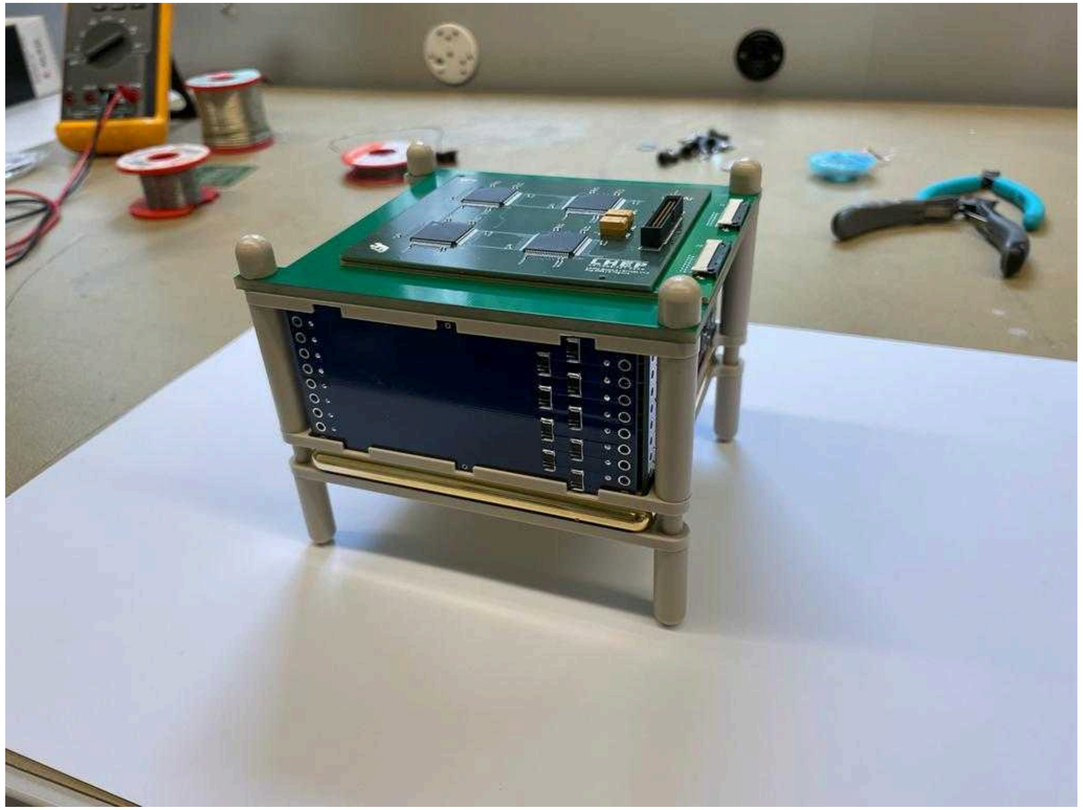


DUNE Module of Opportunity?

Small scale prototypes

Goals

- Operate an **integrated charge & light readout tile** for the first time
- Investigate **detector effects**:
  - Cross-talk, charge accumulation on SiPMs
- Observe cosmic muons tracks

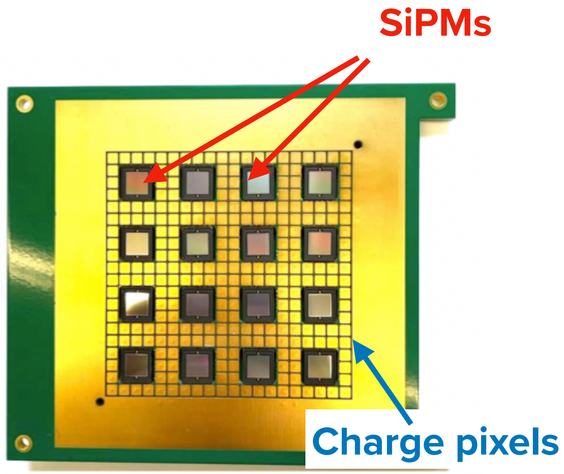


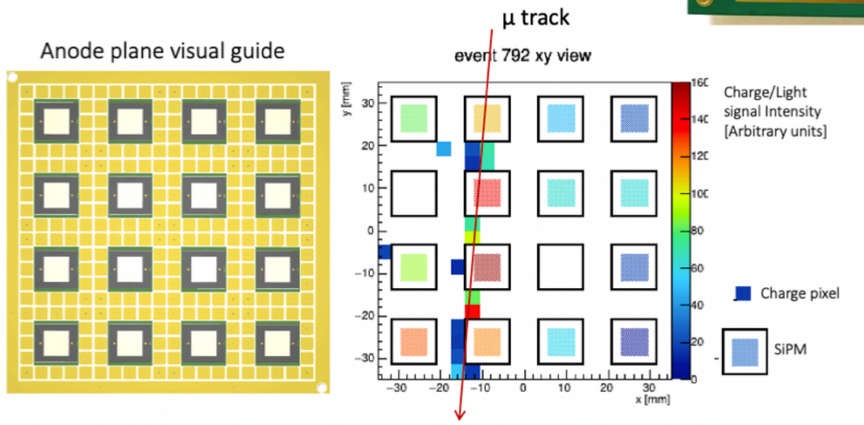
V1 prototype (October 2022)

Bern SoLAr prototypes

Prototype v1

- Run in LAr in **October 2022**
- 7 x 7 cm^2 readout tile
- ~5 cm drift distance
- 16 VUV SiPMs
- 4 LArPix chips





First tracks with integrated charge + light readout!

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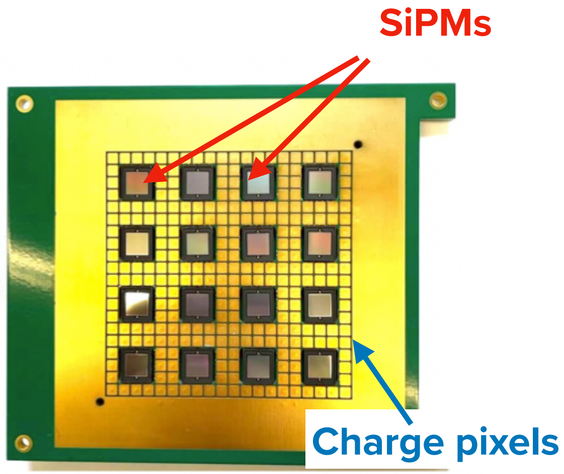
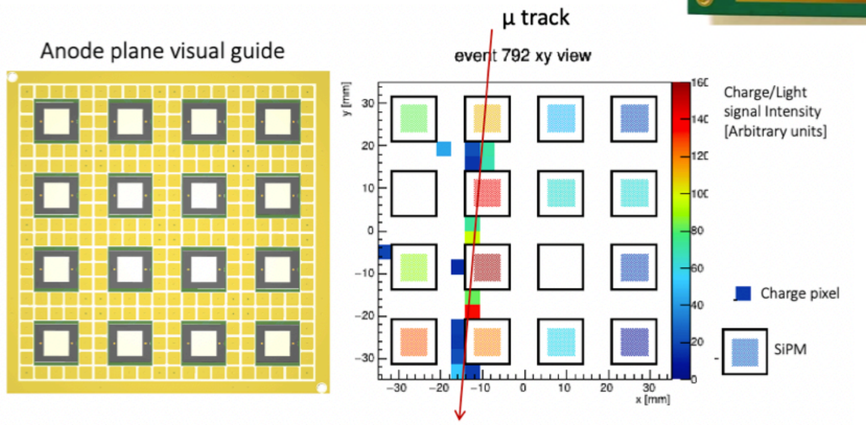
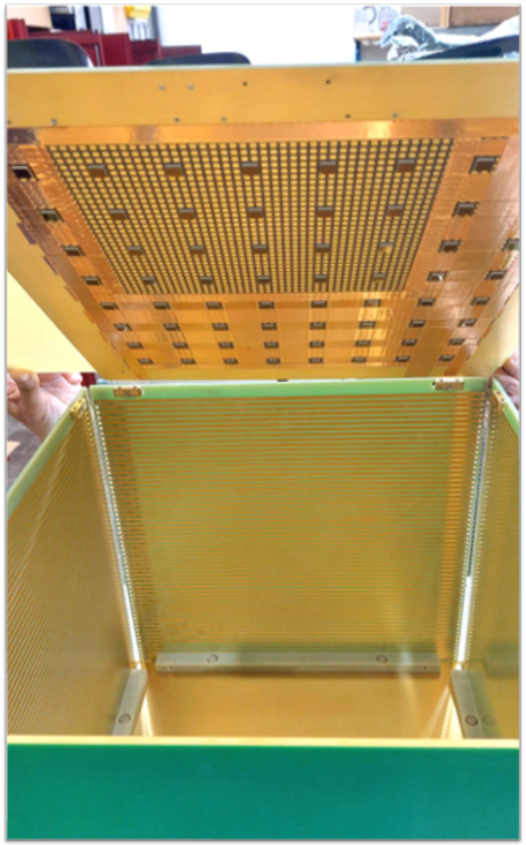




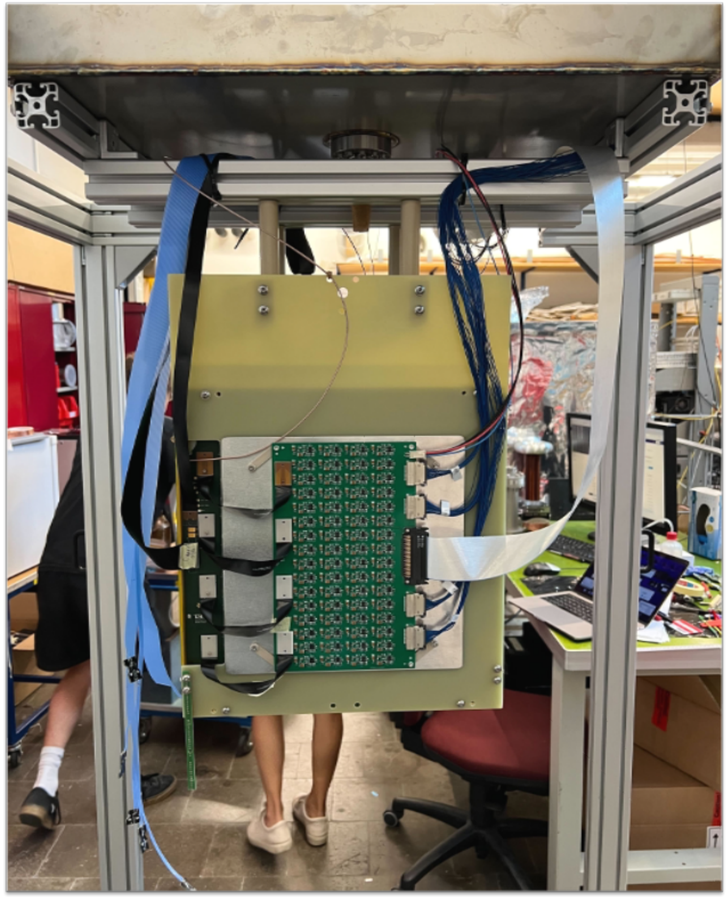
First tracks with integrated charge + light readout!

Prototype v2

- Run in LAr in **July 2023**
- 30 x 30 cm^2 readout tile
- 30 cm drift distance
- 20 LArPix chips
- 64 Hamamatsu VUV SiPMs

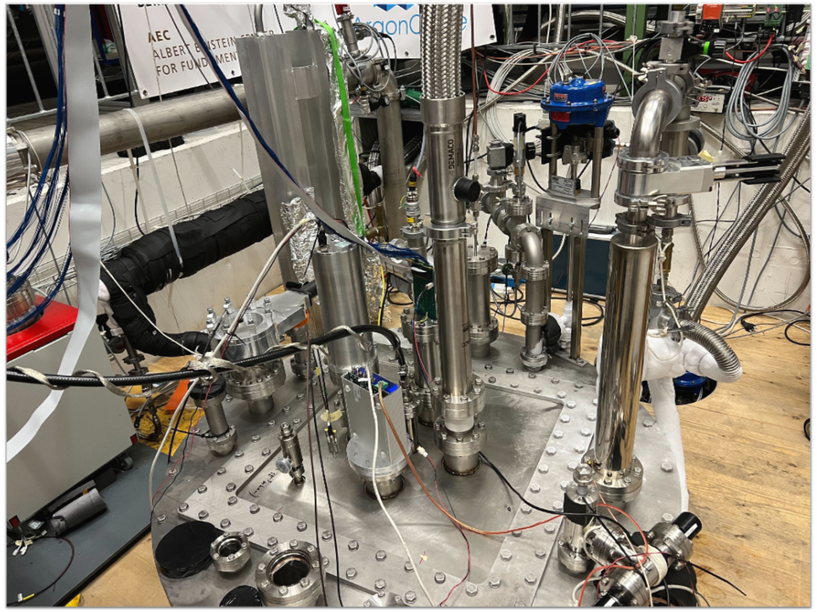


SoLAr V2 prototype run

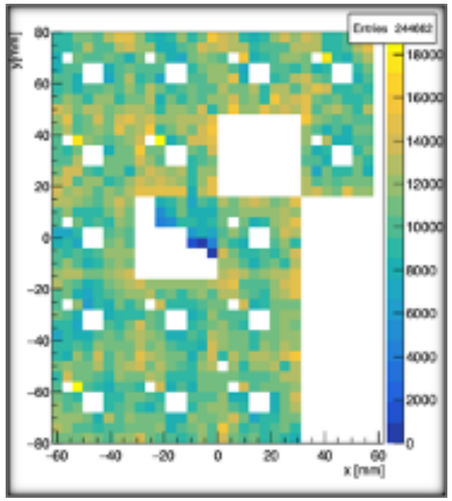


SoLAr prototype V2 TPC

ArgonCube cryostat



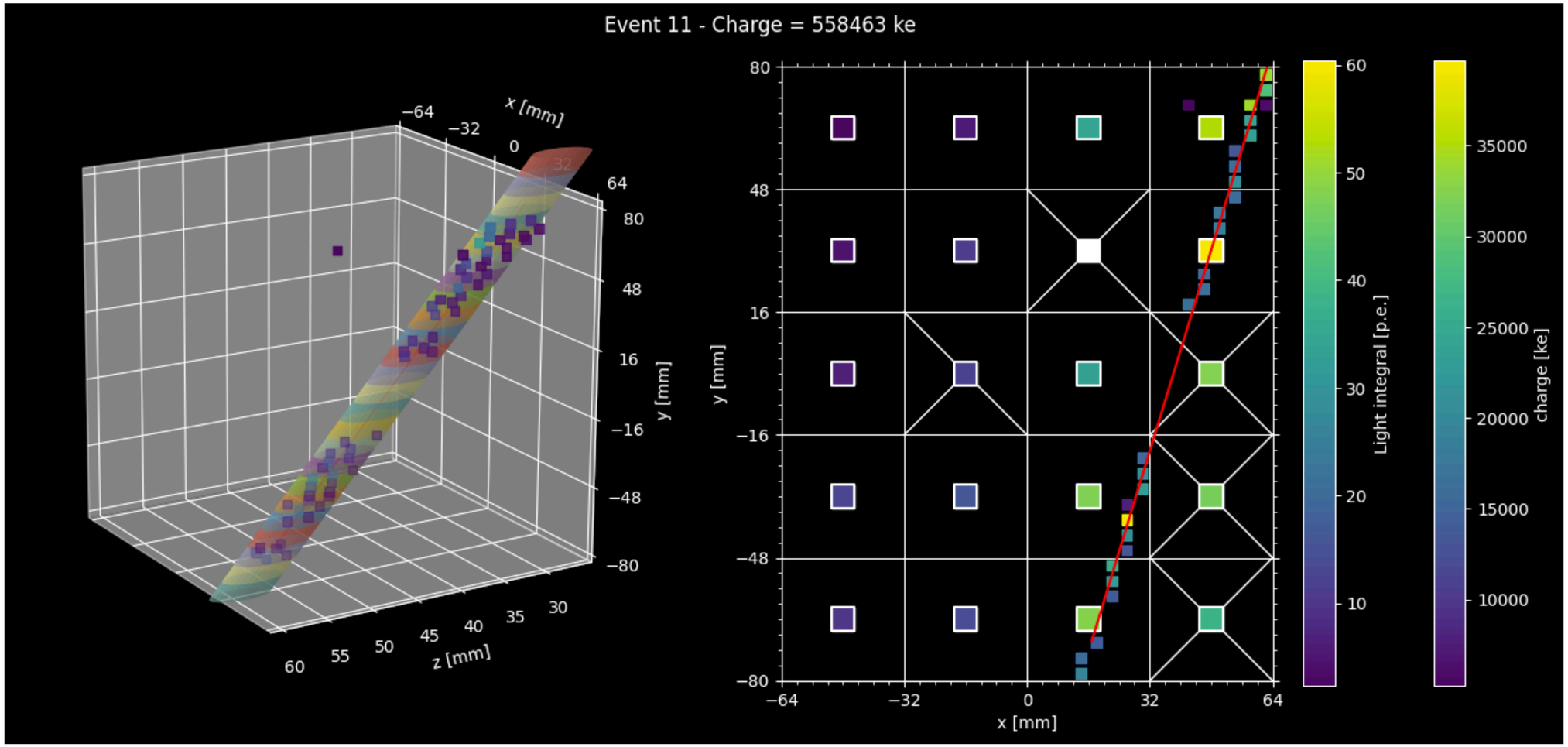
- Took data for **10 days**
- Sources:
  - **Cosmic rays**
  - **^{60}Co**
- Partially instrumented pixel tile



Hit map shows location of disabled pixels

SoLAr V2 prototype run

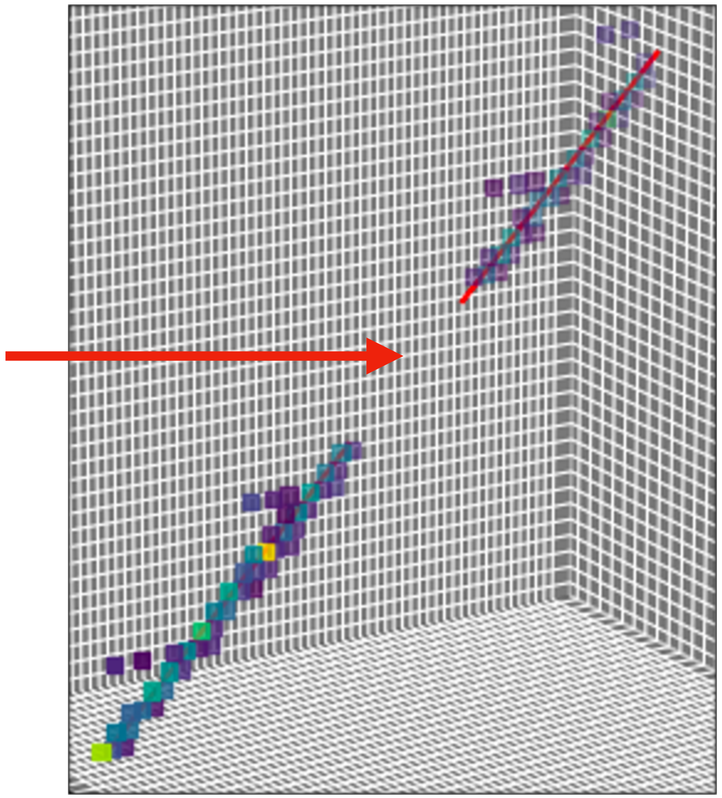
Charge & light event display!



Track fitting

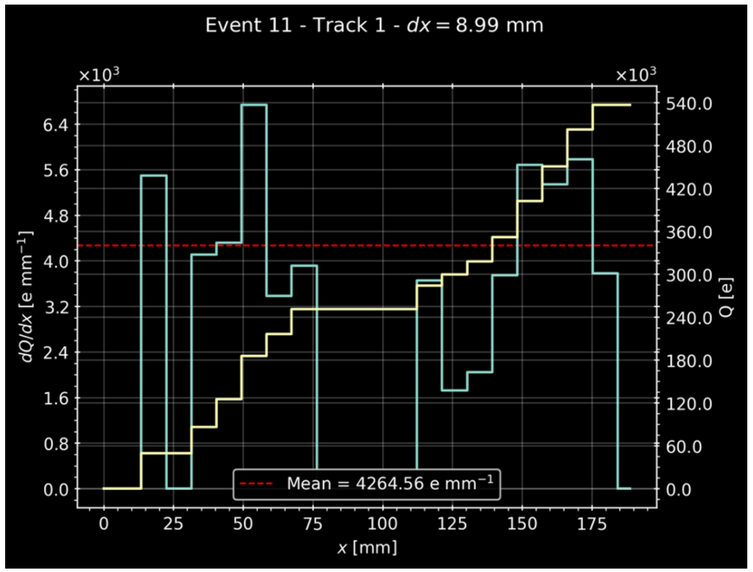
A. Clustering

1. Cluster hits in the xy-plane with DBSCAN
2. Determine the intervals in z between clusters
3. Generate fake data filling dead areas within the z intervals
4. Cluster hits + fake data in the xy-plane
5. Cluster hit labels from first stage with hit z-coordinates
6. Remove fake data



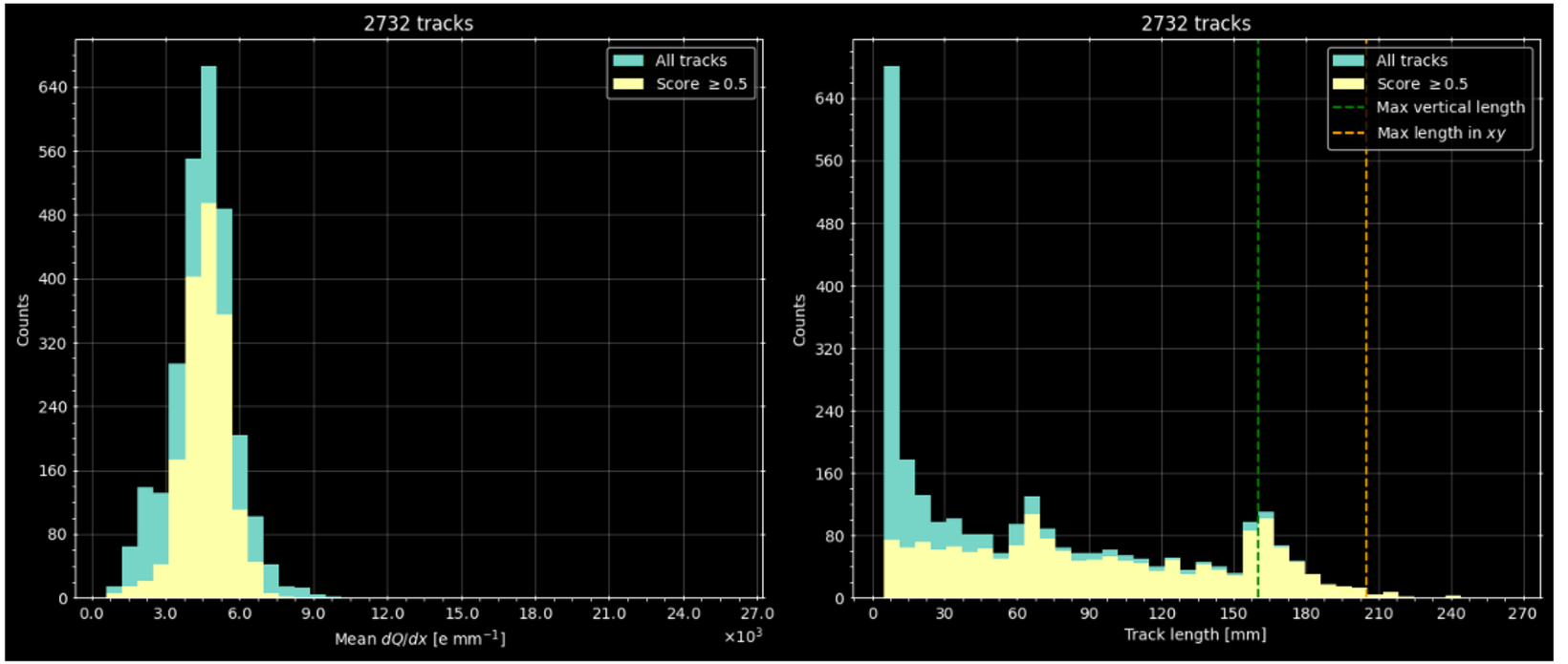
B. Fitting

8. Fit line to clustered hits
9. Use hit charge as weight for line fit
10. Optionally re-cluster and fit outliers to secondary tracks



Track fitting

- Extracted mean dQ/dx for a subset of events
- Shorter track fits show lower fitting score



Score indicates “goodness of fit”

Track fitting with light?

1. Select top 5 SiPMs with largest light signal

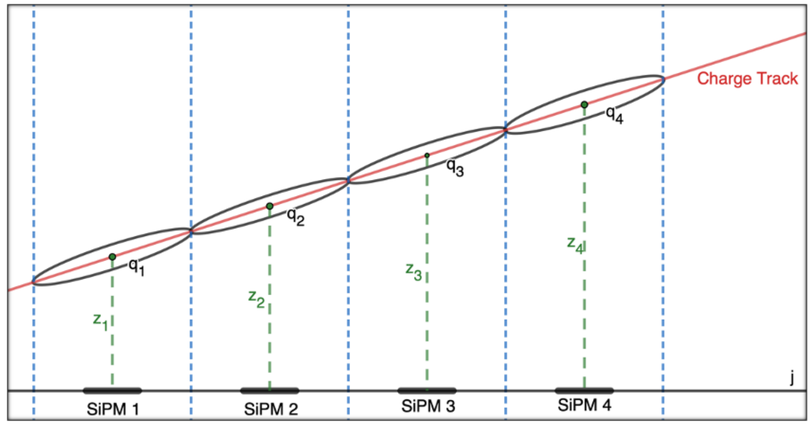
- Must be non-zero
- Minimum of 3 SiPMs
- x and y are determined by SiPM coordinates

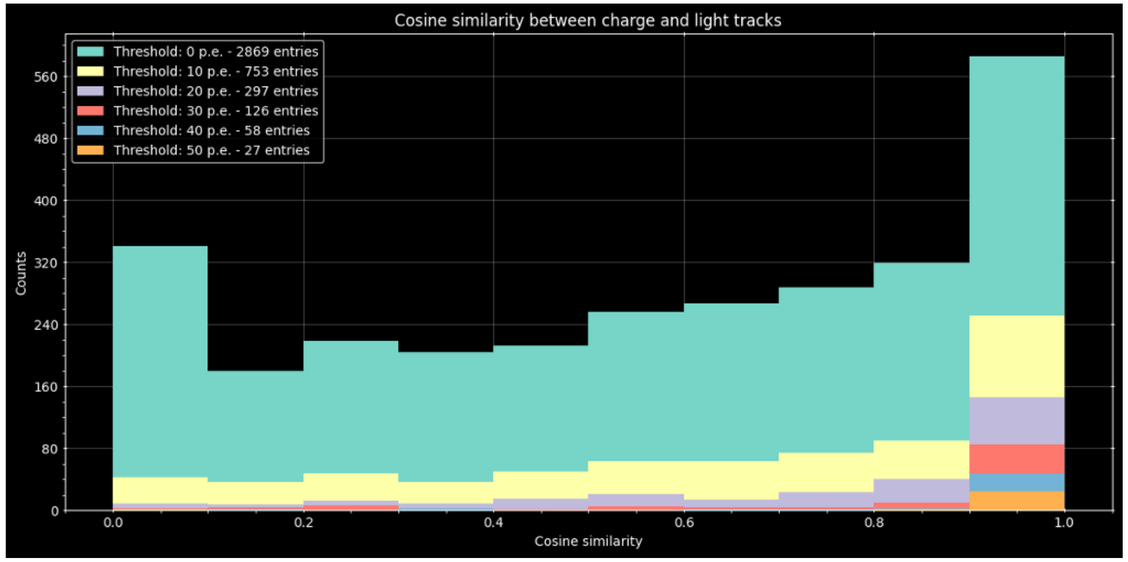
2. Estimate light signal z-coordinate

- Average the z-coordinate of the charge hits within the SiPM's quadrant
- Average is weighted by hits charge

3. Apply RANSAC regression to resulting points

- Fit quality depends strongly on the track angle of incidence to anode

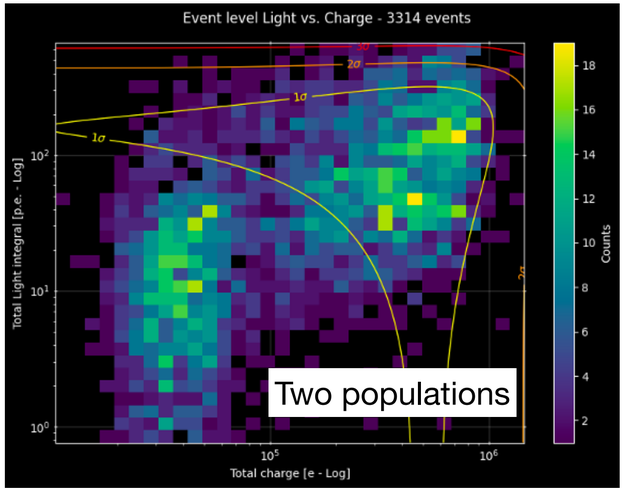


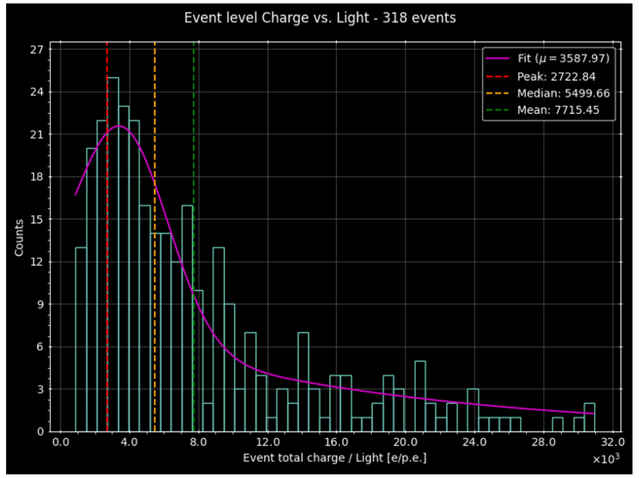


Light fit performs well with a strong enough signal and *z*-coordinate obtained from charge

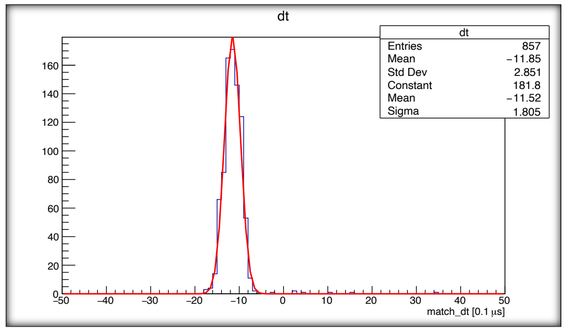
Light & charge correlation

- First look at correlation between charge and light signals
- 85.7% of the charge events found a corresponding light event match within a 10 µs search window

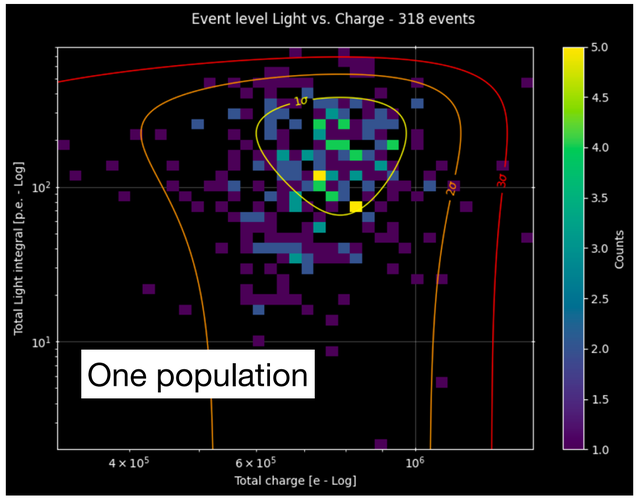


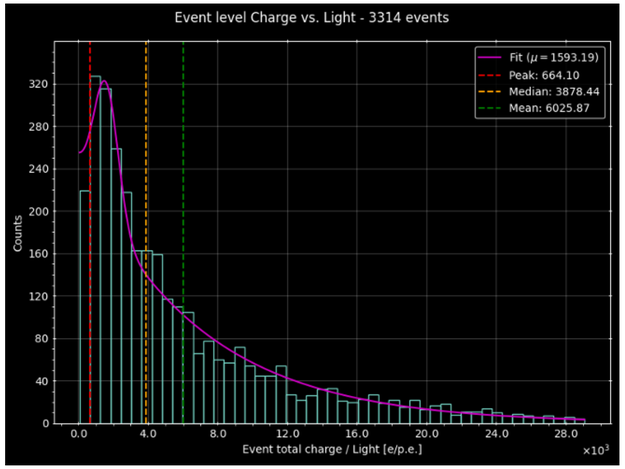


Select single track events

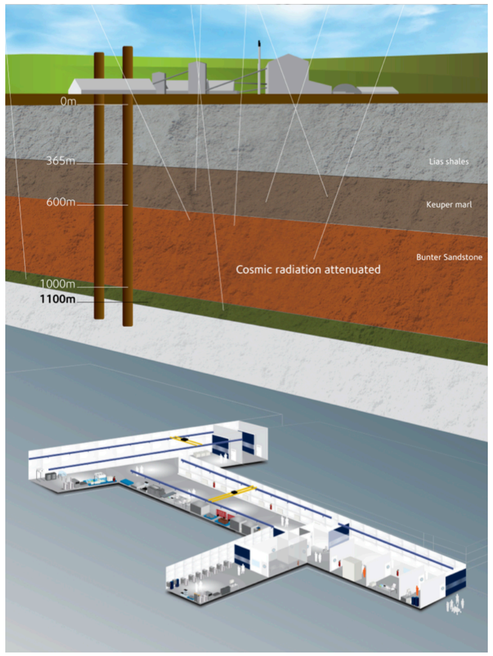


dt = charge timestamp - light timestamp





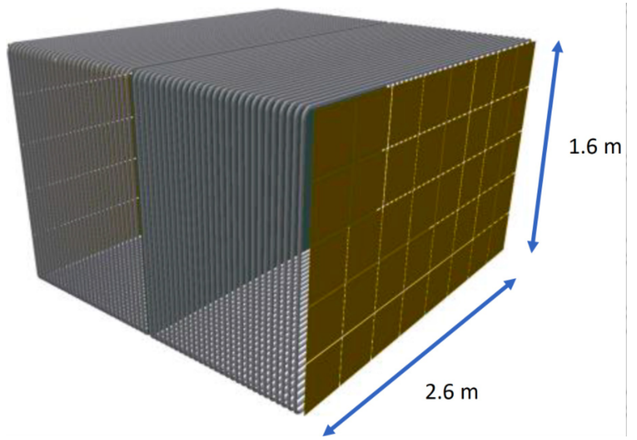
Medium-scale demonstrator



Science goals

- **Validate** SoLAr performance
- **Observe** ^{8}B flux with > 5 σ significance
- **Estimate** sensitivity to solar neutrinos for Module of Opportunity

- Planned in **Boulby Underground Laboratory (UK)**
  - 1 100 m rock overburden
- Proposal in preparation in synergy with dark matter (SOLAIRE)



- 1.6 x 2.6 x 2 m^3 (1 m drift length)
- 31 x 31 cm^2 tiles
- Light traps on 4 sides of the TPC

Summary

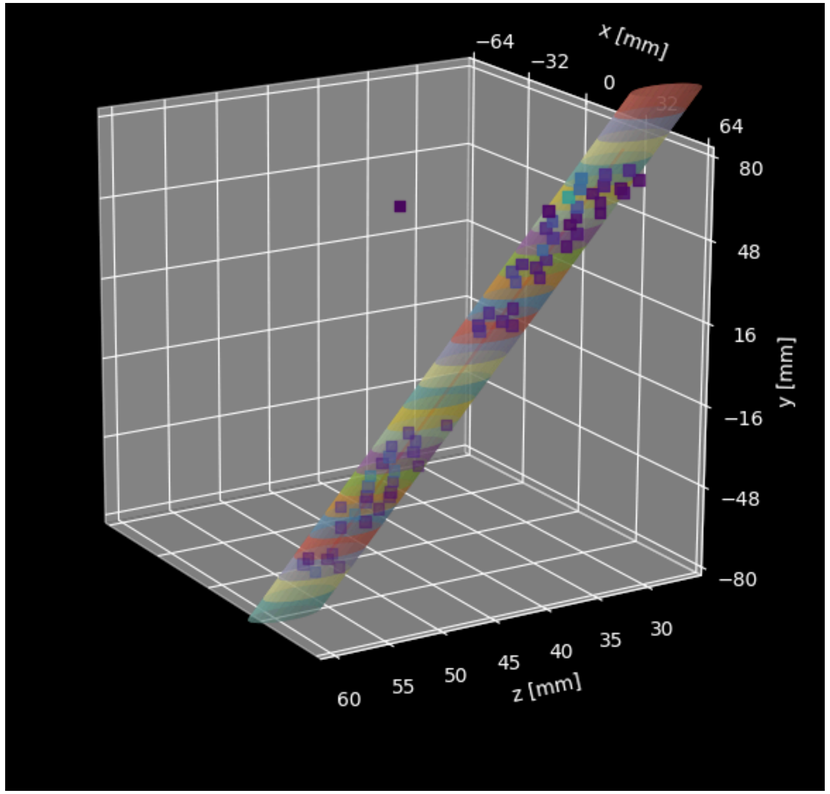
✳ SoLAr aims to extend the physics LArTPCs in the **MeV-scale range**

  ✳ New anode tile with **integrated charge & light readout**

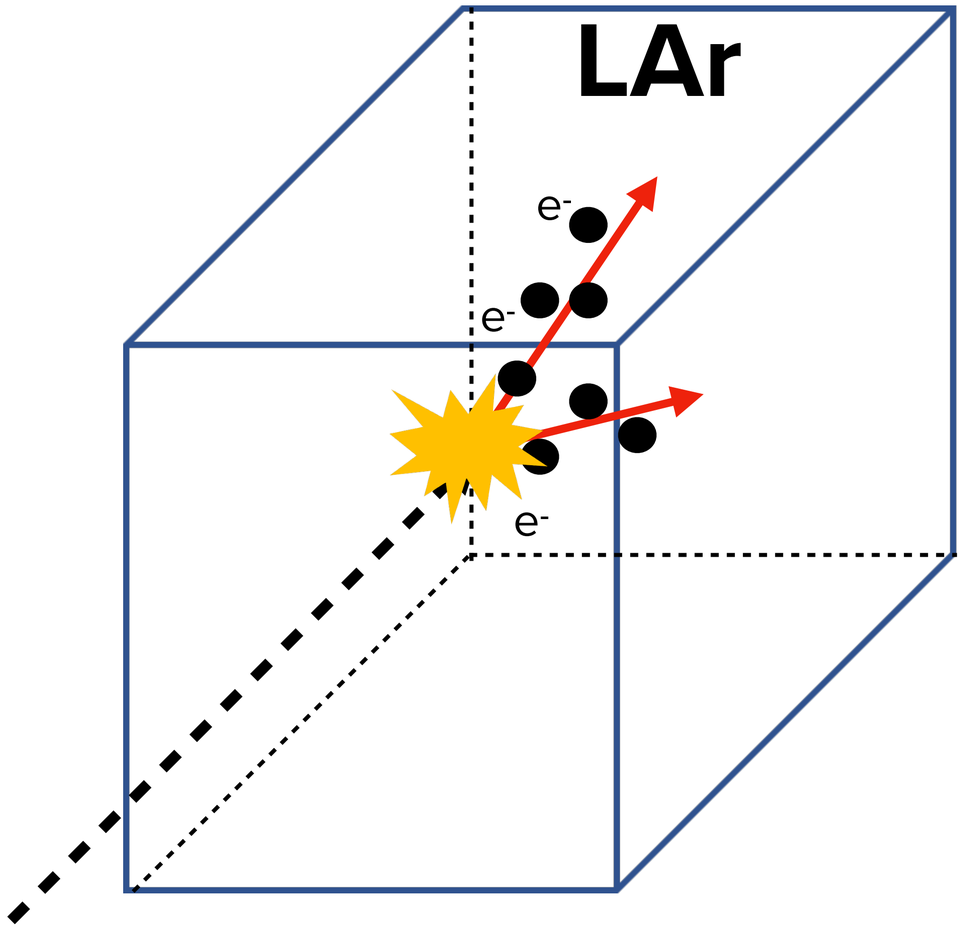
✳ **Staged R&D approach:**

- **Second run of prototype** integrated charge & light readout sensors
  - Cosmic ray and ^{60}Co source
  - Data analysis ongoing
- **Near-term goal:** design and operate a **medium scale 10 ton demonstrator in Boulby (UK)**
  - Synergy with dark matter (SOLAIRE)

- Ongoing performance studies for a **10 kton module**



Backup



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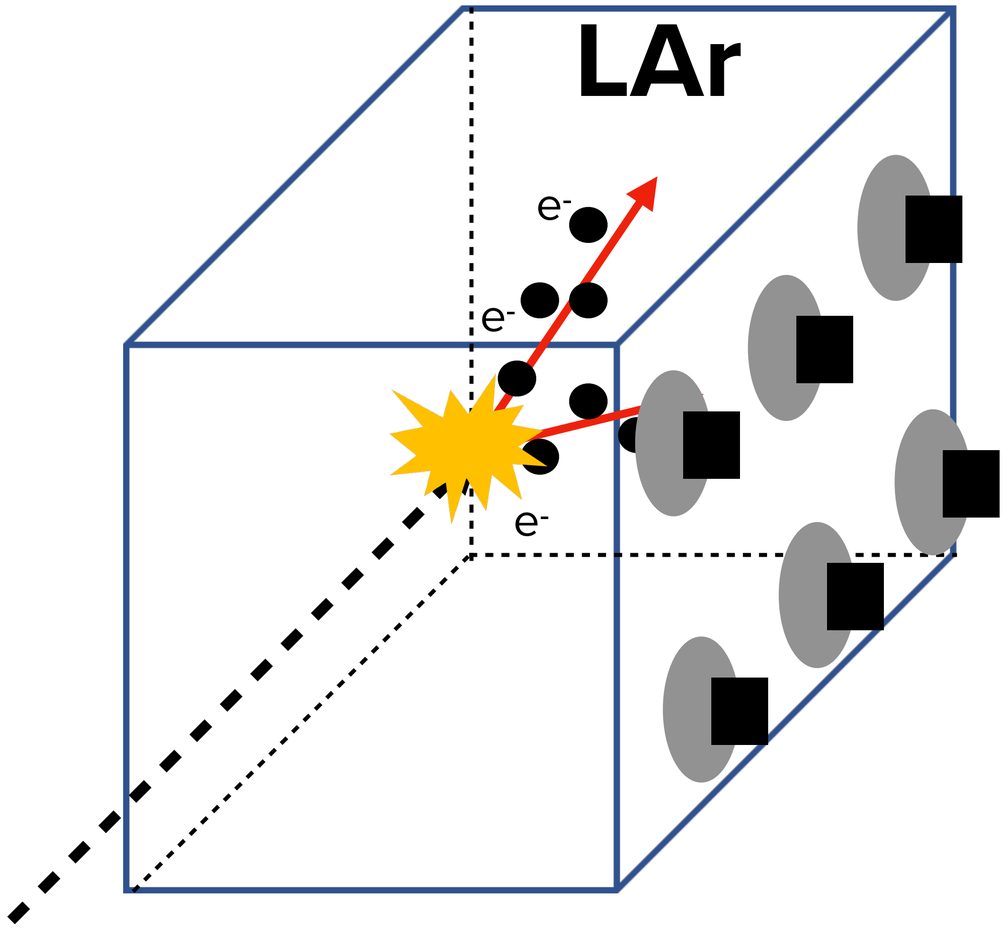
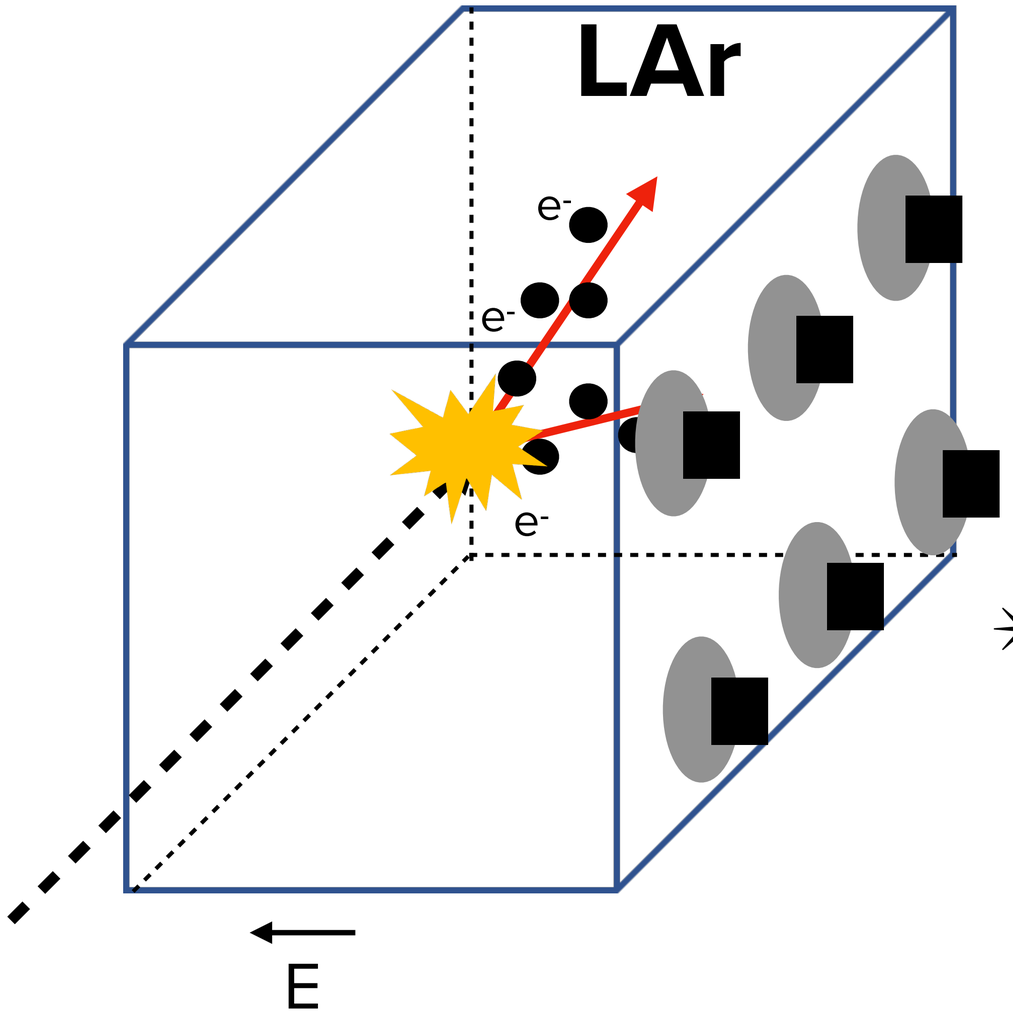
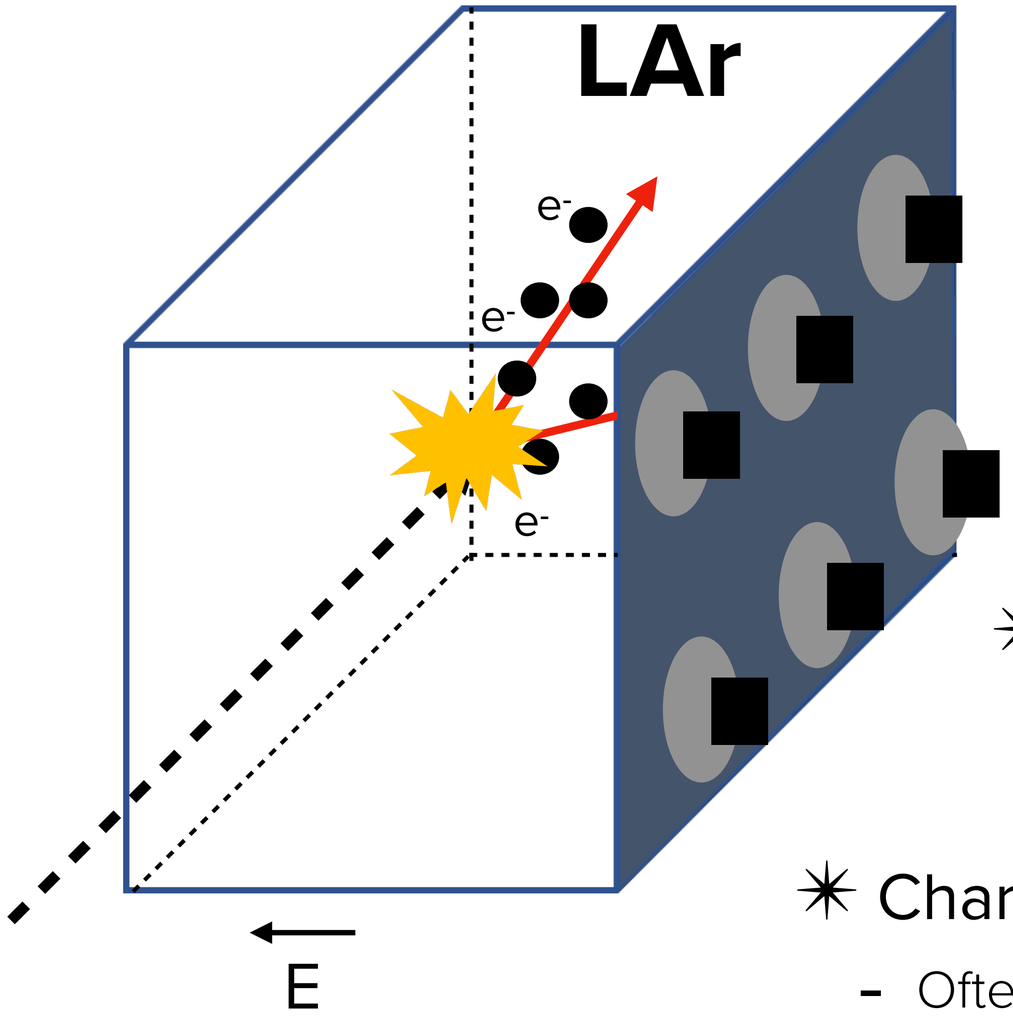
- Particle crosses the LAr volume
- Creates ionisation and scintillation



- (Large) volume of liquid argon (**LAr**)
  - Particle crosses the LAr volume
  - Creates ionisation and scintillation
- Light readout
  - Provide interaction timing



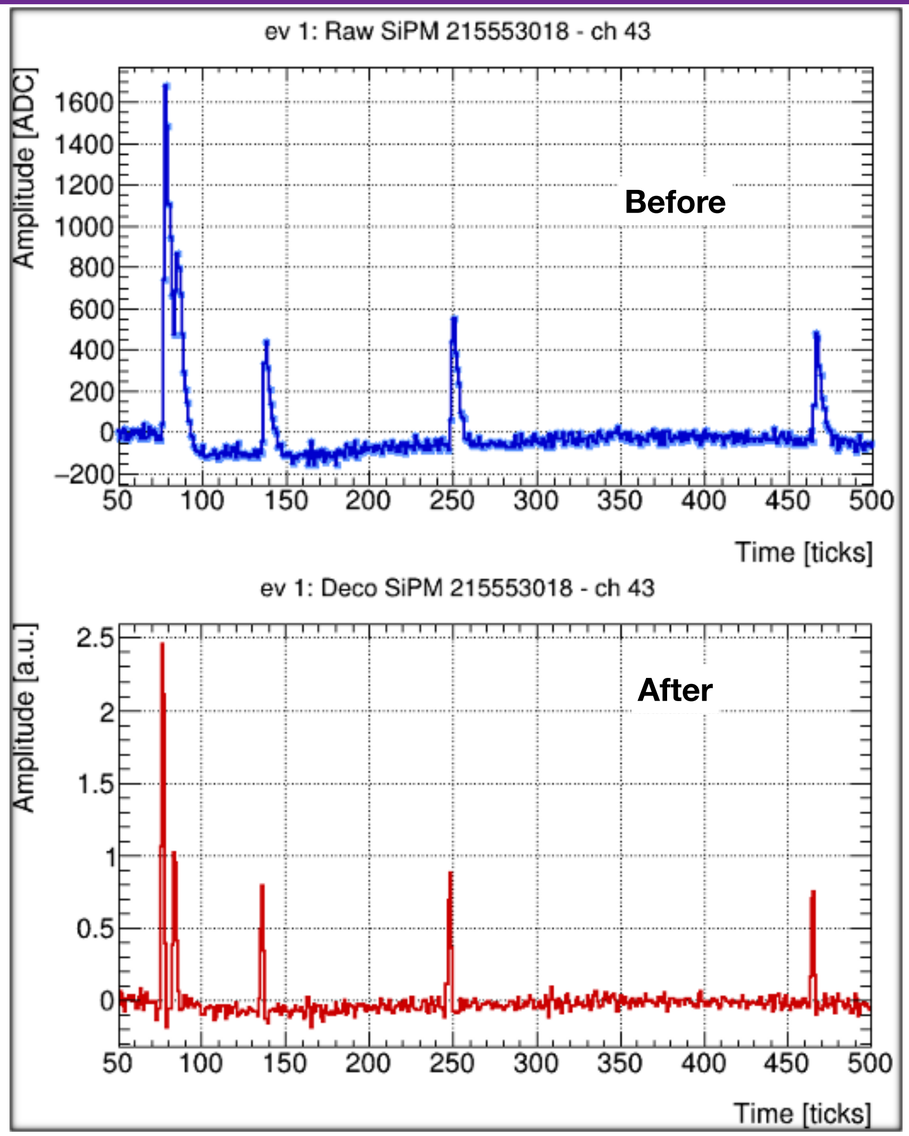
- (Large) volume of liquid argon (**LAr**)
  - Particle crosses the LAr volume
  - Creates ionisation and scintillation
- Light readout
  - Provide interaction timing
- Electric field
  - Electrons drift to the anode



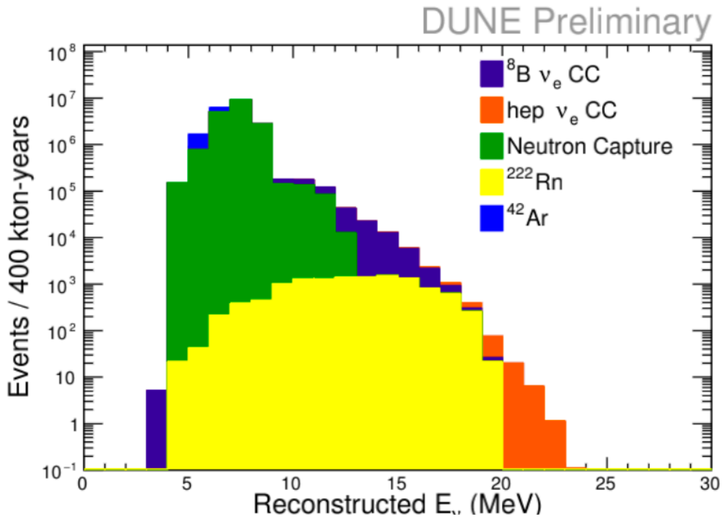
- (Large) volume of liquid argon (**LAr**)
  - Particle crosses the LAr volume
  - Creates ionisation and scintillation
- Light readout
  - Provide interaction timing
- Electric field
  - Electrons drift to the anode
- Charge readout at the anode
  - Often wire planes

Light signal deconvolution

1. **Fast analysis**
   - Identify pulses
   - Evaluate pulse-height
2. **Spectra**
   - Select pulse candidates
   - Fit single PE peaks
3. **Build template**
4. **Deconvolved waveforms**

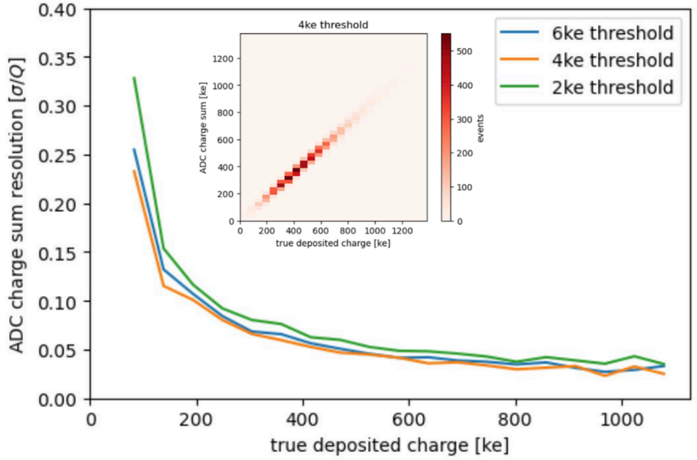


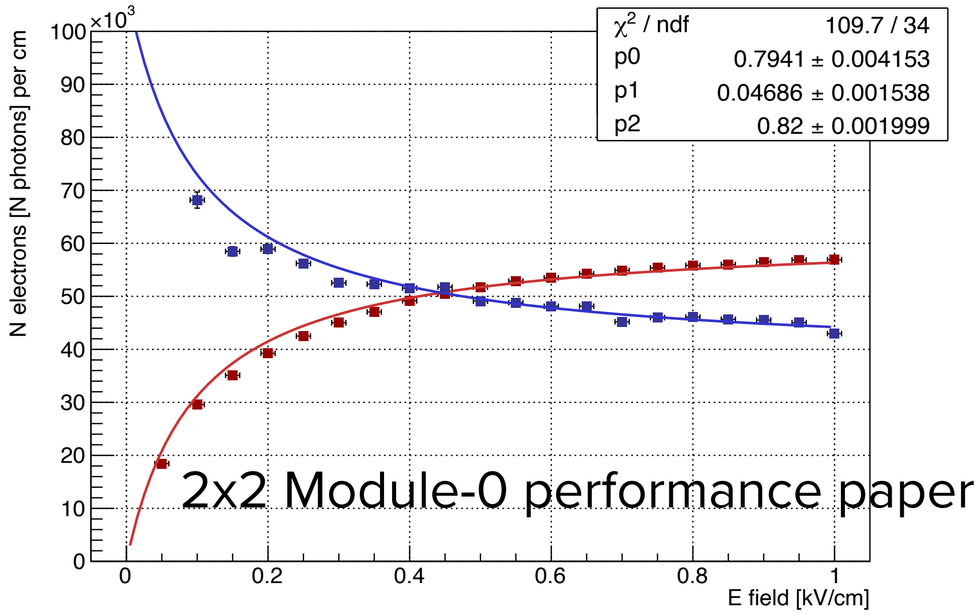
Energy reconstruction improvements



- Need few % resolution at 20 MeV to resolve the hep flux
  - Pixellated charge readout resolution $\frac{\sigma_q}{Q} \approx 5\%$
  - Gets better with combination with light
  - All in place to achieve the required resolution!

LArPix charge sum resolution





2x2 Module-0 performance paper