A novel technology for solar neutrino detection

SoLAr

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The University of Manchester

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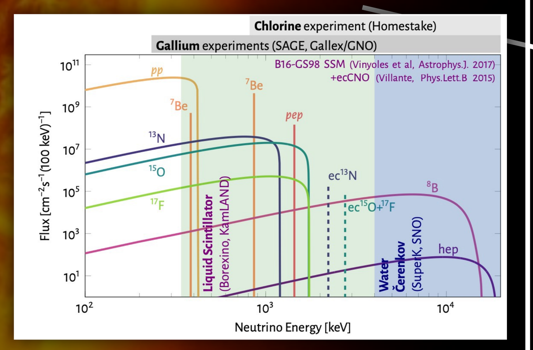
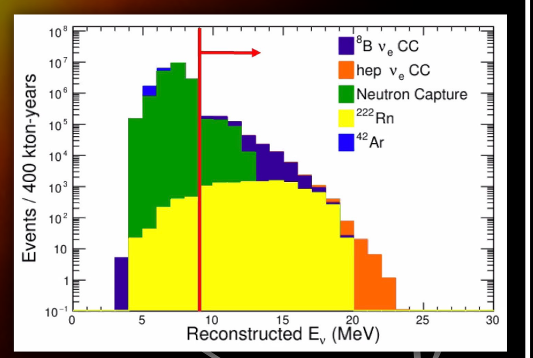
Solar Neutrinos in Liquid Argon

Concept
- Pixelated charge readout providing true 3D reconstruction
- Array of Very Ultra-Violet (VUV) Silicon Photon Multipliers (SiPMs) integrated on the charge readout plane allowing for reconstruction through light
- Easily scalable for a kiloton-scale LAr-TPC
- Online localized triggering for dealing with high data rates
- Identify MeV-scale events online in space and time

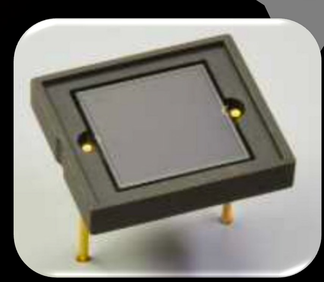
Motivation
- Detecting the Solar ^{8}B and hep neutrino fluxes via both Charged Current (CC) and Elastic Scattering (ES) reactions
- Detecting other low energy processes at the MeV region
- Detecting Supernova neutrino bursts

Challenges
- Achieve an excellent energy resolution
- Develop an efficient low-energy background mitigation strategy
- Tag Neutrino flavours
- Identify neutrino direction (angular resolution)
- Good calibration at MeV energies across the detector volume
- An efficient event reconstruction for online triggering


Solar neutrino fluxes.



Signal and background event rates expected in DUNE.


Hamamatsu S13370-6050CN VUV SiPM

Prototyping Road Map

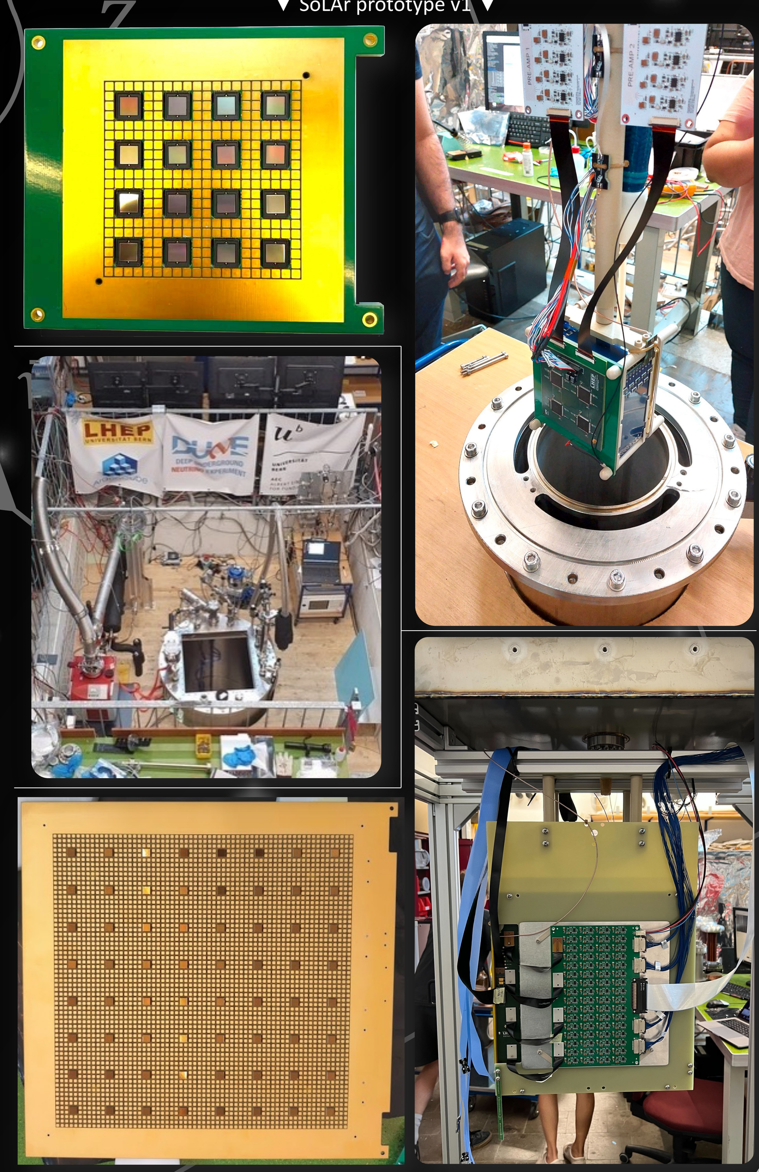
1) Small scale prototype v1
✓ successful test October 2022 @ The University of Bern
- $7x7\ cm^2$ anode plane - 3 stacked PCBs
- 16 ceramic packaged VUV SiPMs with and connector pins
- 4 LArPix v2a chips
- Observed cosmic muon tracks

2) Small scale prototype v2 → *This poster's data*
✓ successful test July 2023 @ The University of Bern
- $30\ x\ 30\ cm^2$ anode plane - single PCB
- 64 SMD packaged VUV SiPMs
- 20 LArPix v2b chips – slots for 64 chips
- Observed cosmic muon tracks and ^{60}Co gamma source

3) Small scale prototype with bespoke SiPMs
(charge pads on top of SiPM cell)
- Test of alternative readout chips LightPix and Q-Pix when available

4) Mid scale Demonstrator
2025-2028 prospect @ Boulby Underground Laboratory*
- Few-ton scale LAr detector underground (1100m overburden)
- $30cm^2$ readout anode tiles (≈ 6400 pixels per tile)
- First measurement of flavor tagged solar neutrinos in LAr

* Proposal submitted to funding agencies

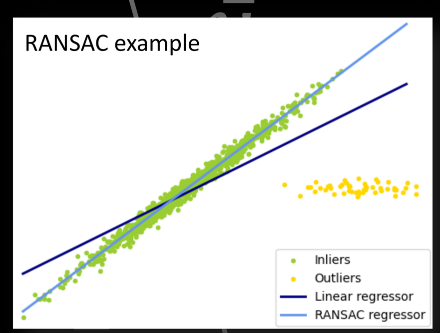
▼ SoLAr prototype v1 ▼

▲ SoLAr prototype v2 ▲

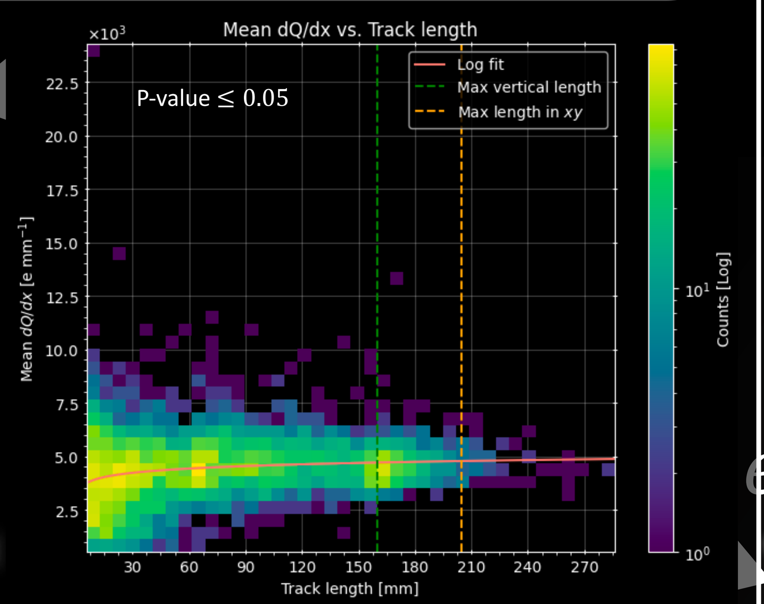
Track Reconstruction from Charge

DBSCAN clustering
1. Generate fake data filling dead areas
2. Cluster hits + fake data in stages: first x and y, then z coordinates
3. Remove fake data

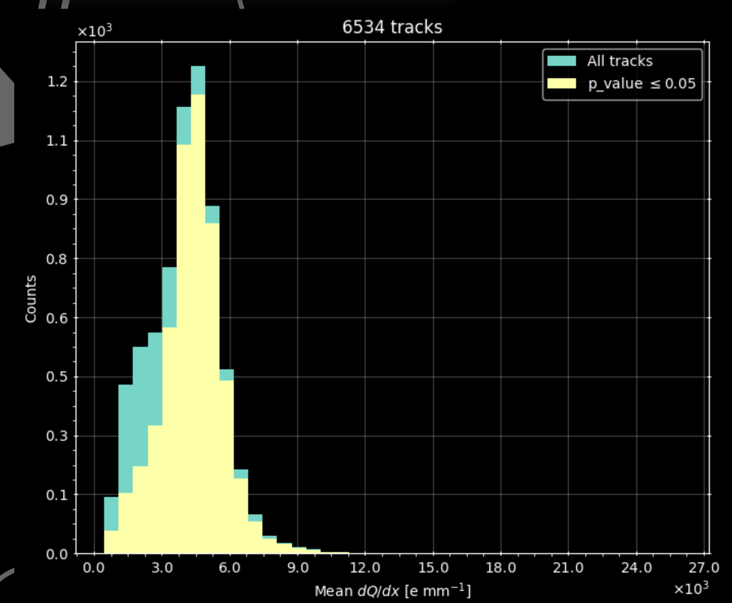
RANSAC regression
- Use hit charge as weight for fit
- Optionally re-cluster and fit outlier hits to find secondary tracks
- P-value quantifies fit quality

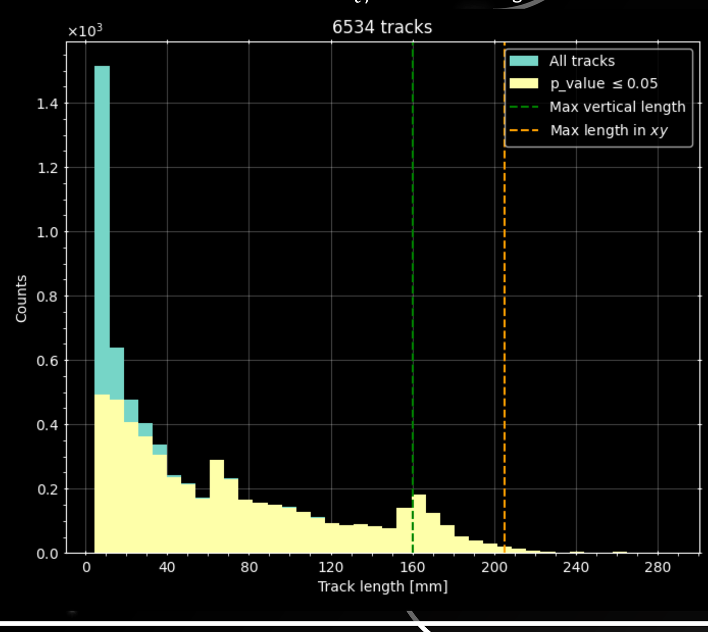
dQ/dx calculation
1. Stack cylinders around fitted line
2. Sum charge within each cylinder to define dQ
3. Cylinder height defines dx





▲ Mean dQ/dx vs. track length – shorter tracks are worse reconstructed ▲





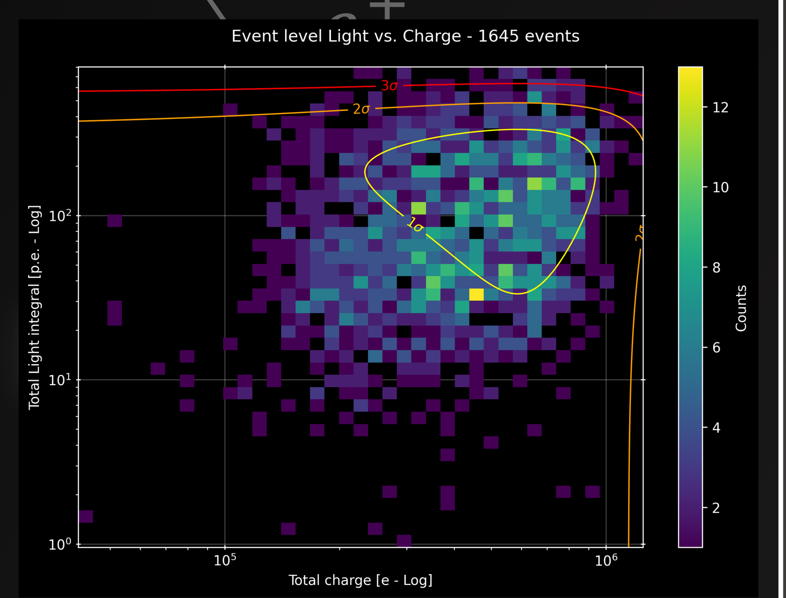
- Track fitting works quite well
- Bad fits are limited to short tracks $< 4cm$
- Obtained dQ/dx agrees with literature ($\sim 5\ ke/mm$)
- Dead areas are challenging but manageable

Track Reconstruction from Light

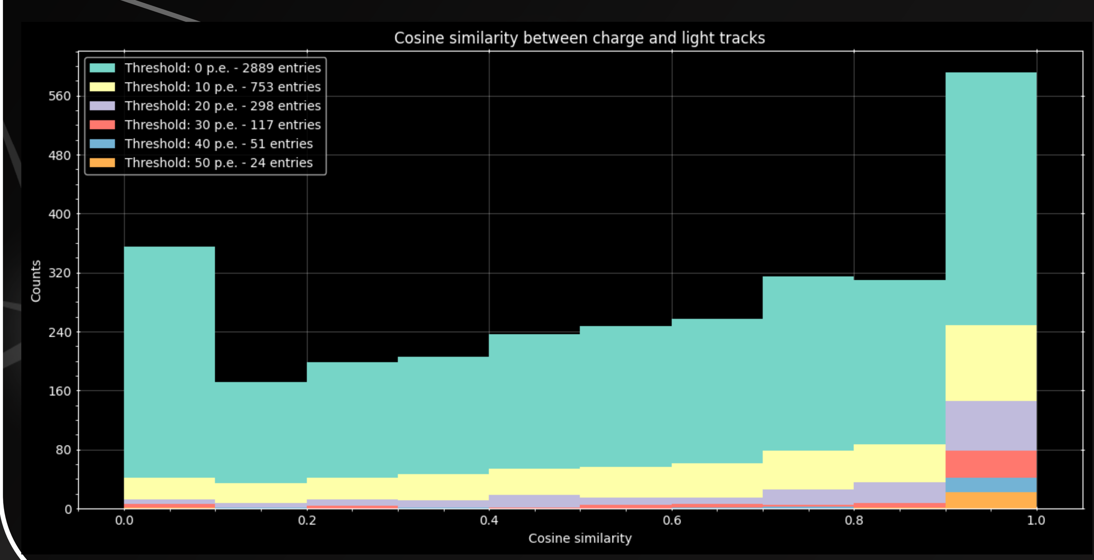
Select top 5 SiPMs with largest light signal
- Must be non-zero
- Minimum of 3 SiPMs
- x and y are determined by SiPM coordinates

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

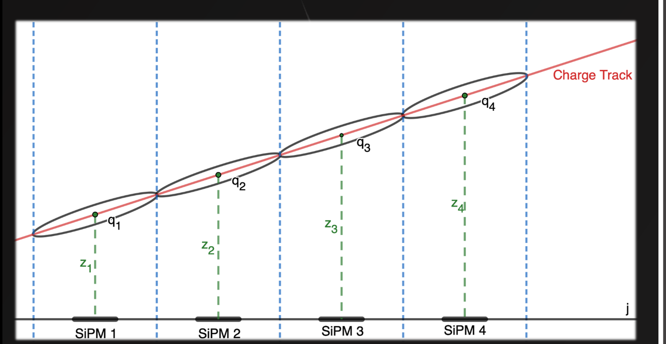
Apply RANSAC regression to resulting points
- Fit quality depends strongly on the track angle of incidence to anode



▲ Event by event total charge versus total light detected in Log scale ▲



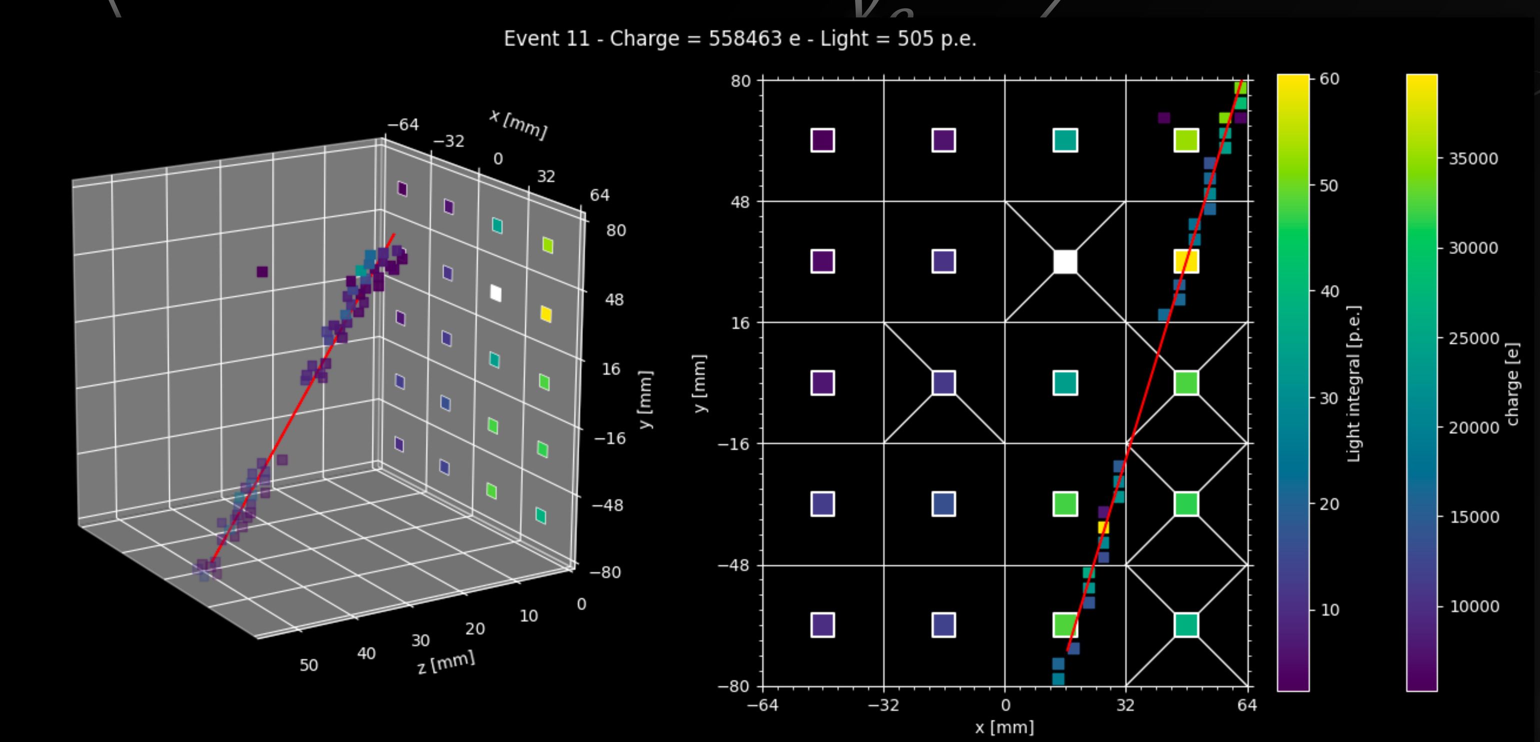
▲ Cosine similarity between track reconstructed from charge and track reconstructed from light ▲



▲ Determination of coordinates for each SiPM quadrant ▲

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

Integrated Light and Charge Event Display

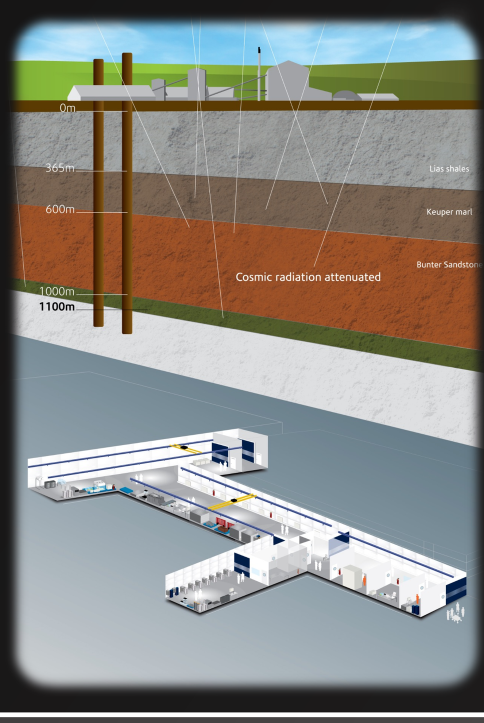


Summary

- Two SoLAr prototypes with integrated light and charge on the same anode plane have been successfully tested
- Reconstructing events required refined methods due to the large areas without charge pixel coverage
- Track reconstruction is performing remarkably well by combining DBSCAN with RANSAC algorithms
- There is a visible correlation between track position and the light detected, but more studies still needed
- Light "tracks" are in reasonable agreement with their respective charge counterparts

Next Steps

- R&D and prototyping program to benchmark new technology
  - **Deliver** a SoLAr cell with charge pads implemented on the surface of a VUV SiPM device
  - R&D in collaboration with Hamamatsu
- **Test** LightPix and Q-Pix chips as alternative readout technologies once they are available
- Simulation efforts to better understand background sources
  - **Develop** mitigation strategies
  - **Quantify** the sensitivity to solar neutrinos
- Medium scale demonstrator @ Boulby Underground Laboratory ⟶
  - **Achieve** the required tracking and calorimetric resolutions for low neutrino energy physics.
  - **Observe** neutrinos from the ^{8}B flux
  - **Estimate** sensitivity to solar neutrinos for Module of Opportunity
- **Integrate** the SoLAr design concept in the DUNE Module of Opportunity



Resources

- S. Parsa et al., SoLAr: Solar Neutrinos in Liquid Argon, 2022 https://arxiv.org/abs/2203.07501
- Hamamatsu S13370 data sheet https://hamamatsu.su/files/uploads/pdf/3_mppc/s13370_vuv4-mppc_b_(1).pdf
- Boulby Underground Laboratory https://www.ukri.org/about-us/stfc/locations/boulby-underground-laboratory
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- I. Gil-Botella et al., Decoupling supernova and neutrino oscillation physics with LAr TPC detectors Journal of Cosmology and Astroparticle Physics 2004 (2004) 001
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- D.A. Dwyer et al., LArPix: Demonstration of low-power 3D pixelated charge readout for liquid argon time projection chambers JINST 13 (2018) P10007 [1808.02969]
- V. Shebalin et al., The Q-Pix pixelated readout concept for future Liquid Argon Time Projection Chambers: status and prospects. J.Phys.Conf.Ser. 2374 (2022) 1, 012078

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