Progress in SoLAr Towards Reconstructing MeV-scale Neutrinos

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Solar neutrinos in Liquid Argon

- The SoLAr concept combines state-of-the-art **LArTPC** technology optimised to reach low energy thresholds. [1]
- For detecting **solar hep neutrinos** and potential supernova neutrino bursts, a threshold in the **MeV scale** is needed.
- Effective reduction and reconstruction of background processes are vital for achieving these goals

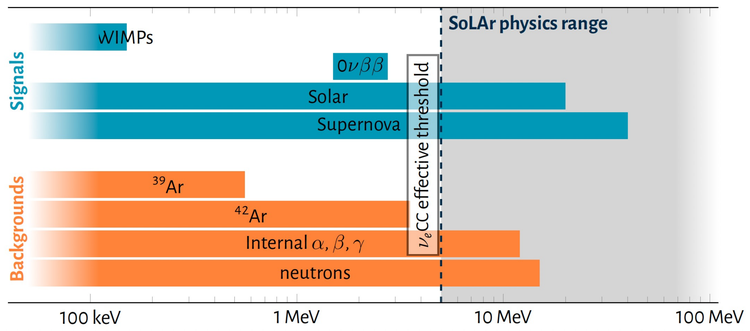

Fig. 1: Physics target of SoLAr. Adapted from [2].

Detector Technology and Prototyping

- **Integrated charge and light readout** on the same anode plane
- ASIC-based **pixelated charge readout** to achieve native 3D reconstruction
- Direct application of **VUV-sensitive** Silicon Photo-Multipliers (**SiPMs**). Additional light traps can be placed on top and bottom of the TPC

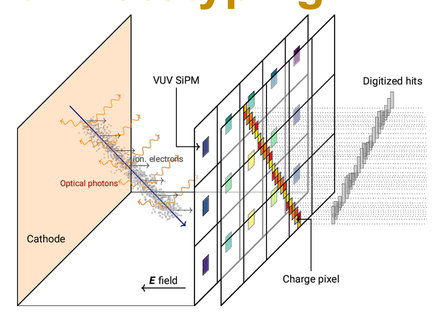

Fig. 2: SoLAr detection principle

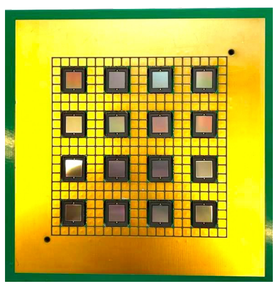

Fig. 3: Prototype V1 with VUV SiPMs integrated on a LArPix-based pixel readout [3].

- The first prototype (V1) with an active volume of 7 x 7 x 5 cm^3 and a 4x4 array of Hamamatsu S13370 SiPMs [4] was tested in Oct 2022 at Bern.
- For the **second prototype** (V2) an **8 x 8 surface-mount-SiPM array** was placed on a 30x30cm^2 tile. The detector with **1200 charge pixels** was successfully operated in July 2023.
- A **mid-scale demonstrator** of about 12 tons of active liquid argon is planned to be placed in the **Boulby Underground Laboratory**.

Light Reconstruction

- A **high-performance light reconstruction** is essential to reach a good energy resolution at low energy using a **combined charge and light calorimetry** (Target: ΔE/E ≈ 7%)
- The position of low-energy depositions can be reconstructed based on the array of SiPMs on the anode plane. This can be used for **3D voxelated triggering or background rejection**.
- Fig. 5 shows an ML-based reconstruction using a Convolutional Neural Network (CNN) to predict the light emission point in 3D.
- Pulse shape discrimination can be used to do further background rejection (see Fig. 4).

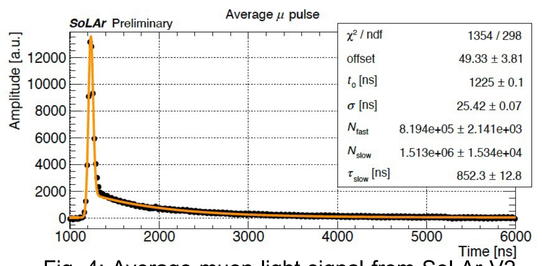

Fig. 4: Average muon light signal from SoLAr V2 protoype run

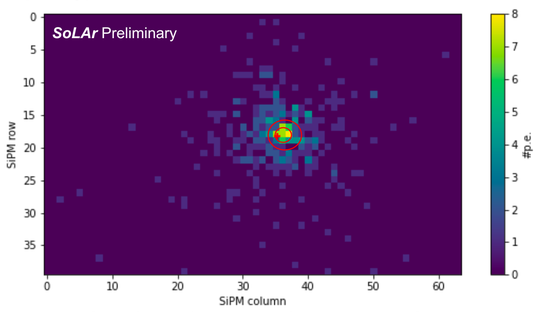

Fig. 5: Simulated light signals on anode SiPM array with true (red cross) reconstructed emission point (red circle) for 6.2 MeV energy deposit in a 2.5 x 1.6 x 1.0 m^3 TPC

Charge Reconstruction

- The pixelated charge readout enables **unambiguous 3D positional reconstruction of energy deposits**. The more traditional wire-based readout is susceptible to track-dependent inhomogeneous responses and ambiguities.
- From the spatial arrangement of the charge pixels, a native 2D projection of the collected charge is given. Adding the information from the time domain 3D hits can be directly constructed.

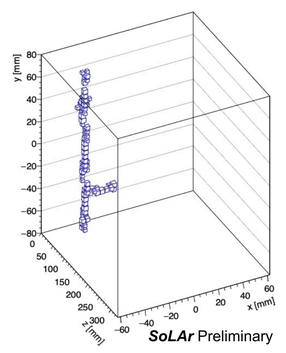

Fig. 6: Native 3D hit data from the V2 prototype.

- **Low-energy deposits** (1.17 MeV / 1.33MeV) from a Co-60 source could successfully be recorded and **matched with light data** on the SoLAr V2 prototype.

Future Plans

- R&D in collaboration with Hamamatsu to implement **charge pads on the surface of the VUV SiPMs** and therefore increase the charge readout efficiency and coverage
- Improve background simulations and develop mitigation strategies (e.g. shielding)
- SoLAr aims to use the design concept to build an **11.5 tonne** liquid argon detector with an active volume of about 1.6 m x 2 m x 2.6 m **at Boulby Underground (UK).**
- The SoLAr detector concept could also be adapted into an **alternative far detector module for DUNE.**

Combined Reconstruction

- **Combined event displays** show good agreement between light and charge data for the two existing proto-types.
- Alternative readout technologies that allow **combined data acquisition of charge and light signals** are under investigation (e.g. LightPix, Q-Pix).

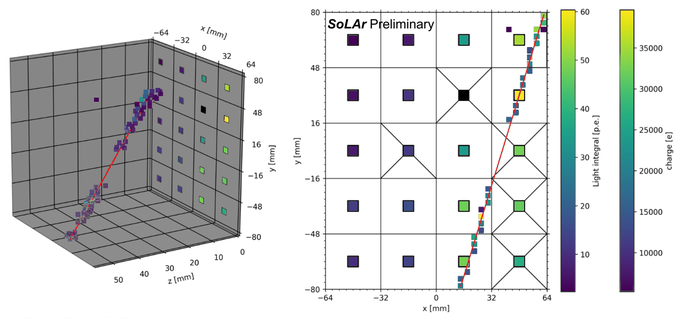

Fig. 7: V2 Prototype charge and light combined event display.

References

[1]: S. Parsa et al.: *SoLAr: Solar Neutrinos in Liquid Argon,* arXiv preprint arXiv:2203.07501 (2022).
[2]: T. Bezerra et al.: *Large low background kTon-scale liquid argon time projection chambers*, J.Phys.G 50 (2023) 6
[3]: D. A. Dwyer et al., LArPix: *Demonstration of low-power 3D pixelated charge readout for liquid argon time projection chambers*, JINST 13 (2018) P10007.
[4]: Hamamatsu S13370 datasheet, hamamatsu.com

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