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on behalf of the **SoLAr collaboration**

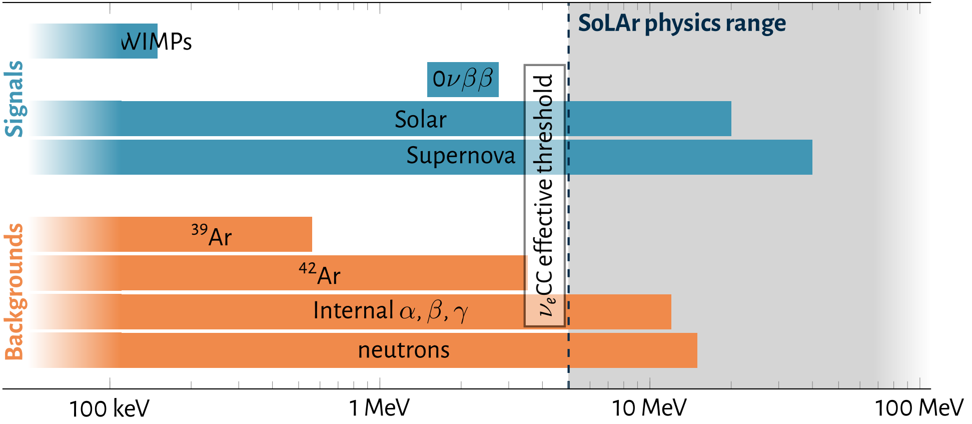
SoLAr: a novel approach to multipurpose LArTPCs for neutrino physics

May 14, 2024
Conference on Science at the Sanford Underground Research Facility

Physics opportunities and challenges at low-energy in LAr

Outstanding progress of LArTPC made it technology of choice for the next generation of LBL neutrino physics

What happens at low-energy?



Adapted from T. Bezerra et al (SLoMo), J.Phys.G 50 (2023) 6 e-Print: 2301.11878 [hep-ex]

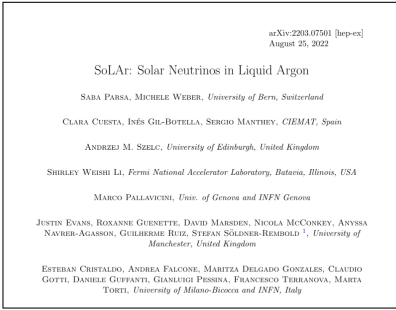
The SoLAr project: widening the low-energy window

Leverage **state of the art LArTPC** technology to design a detector **optimized for low-energy** studies while retaining good performance for high energy events

GOAL: develop and demonstrate a new technology to expand DUNE physics reach in the MeV scale.

- Lower threshold to solar neutrino measurement
- Supernova neutrino burst
- DSNB(?)

Integrate the SoLAr design in the DUNE **Module of Opportunity** one full DUNE volume



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

SoLAr: Solar Neutrinos in Liquid Argon

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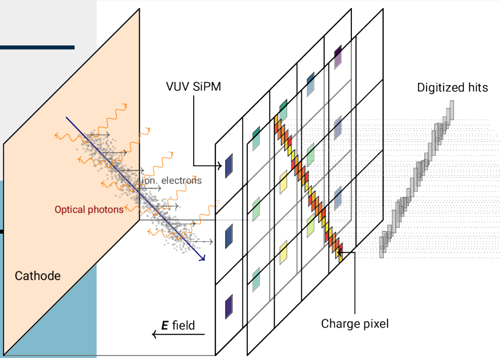
Key concepts for the SoLAr challenge

Pixelated readout:

Pixel readout plane will enhance event reconstruction, while replacing TPC wires is expected to simplify construction and installation

Improved light sensors:

Arapuca-style modules + **VUV SiPMs integrated on the anode**
Exploit the light signal in LAr to perform **combined Q + L calorimetry**: Target $\Delta E/E \approx 7\%$



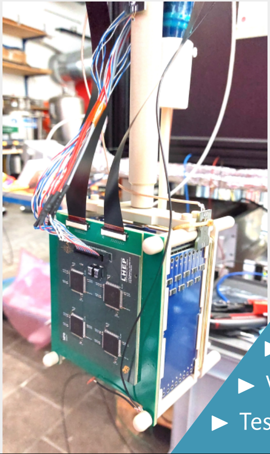
Improved background suppression

More accurate material selection, passive shielding, **pulse-shape** discrimination, event topology

Roadmap

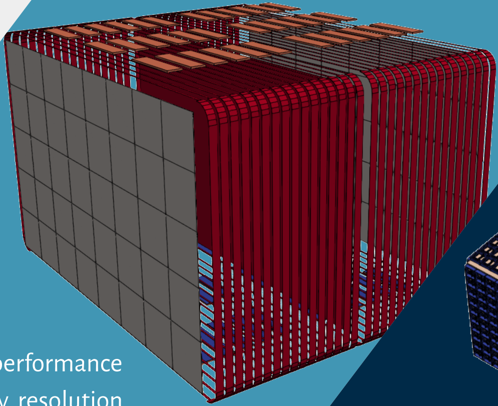
Phase I: Prototyping

Development of integrated charge+light readout

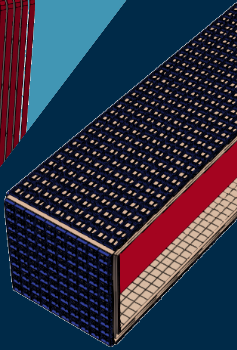


Phase II: Medium Scale Experiment

First detection of solar neutrinos in LAr



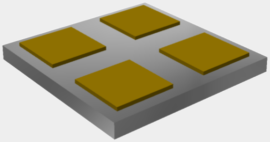
- Prove low-energy performance
- Validate target energy resolution
- Test background suppression methods

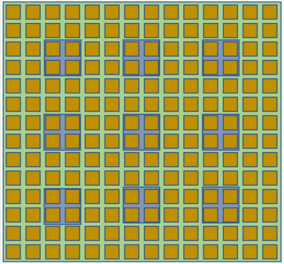


Phase III: DUNE MoO

SoLAr tile R&D Status

The SoLAr Readout Unit



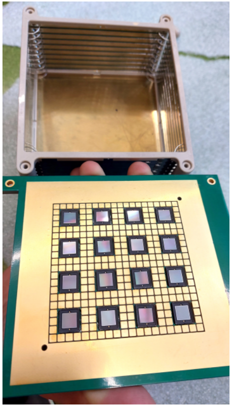


- One MPPC readout channel
- 4 charge readout channels
- 50% light readout coverage for SRU

Pixel readout options

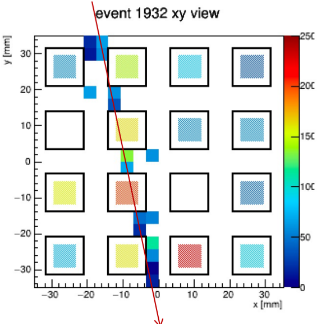
- **LArPix**
  Tested in ArgonCube
  Acceptable data-rate
- **QPix**
  Very low data-rate

2022: First Integration of a **light+charge module**



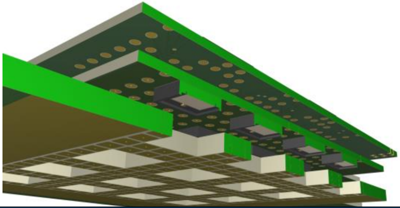
S. Parsa, MoO workshop, Valencia 2022

SoLAr tile V1 - LHEP Bern
Tested in a $12 \times 10 \times 5\,\text{cm}^3$ TPC
(area $7 \times 7\,\text{cm}^2$, 5 cm drift)



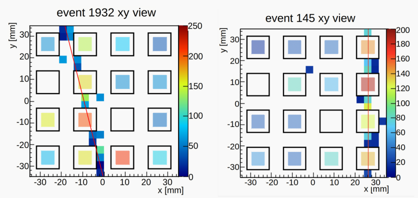
Prototyping: SoLAr v1

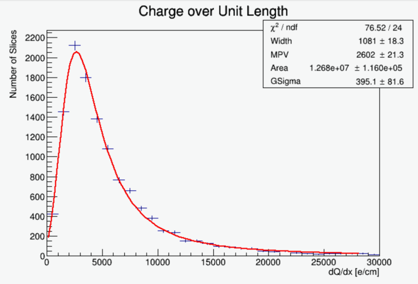
- **Charge readout:**
  256, $3 \times 3\,\mathrm{mm}^2$ pads, readout by 4 LArPix v2a ASIC + PACMAN
- **Light readout:**
  16 Hamamatsu S13370-6050CN ($6 \times 6\,\mathrm{mm}^2$) + Cold pre-amp + Warm amp + 62.5 MS/s digitizer
- **Anode assembly:**
  Three stacked PCB layers to accommodate SiPMs packaging
  SiPM floating bias to enhance charge collection



Test outcome

- combined operation of charge+light sensors
- calorimetric response ok

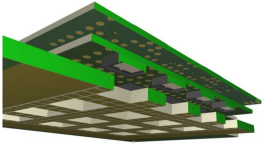




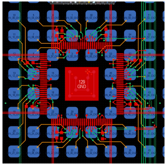
Prototyping: SoLAr v2

- Tile dimension: $32 \times 32\ \text{cm}^2$ (active area $25.6 \times 25.6\ \text{cm}^2$)
- Divided into 8×8 regions ($64 - 4$ pixel, 1 SiPM)
- 20 LArPix (room for 64)
- 64 Hamamatsu VUV MPPC with independent readout
- Complete re-design of the PCB

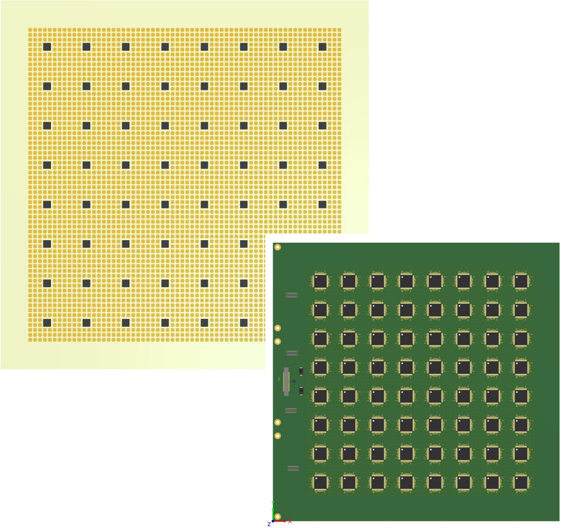
SoLAr tile V1 $\rightarrow$ SoLAr tile V2



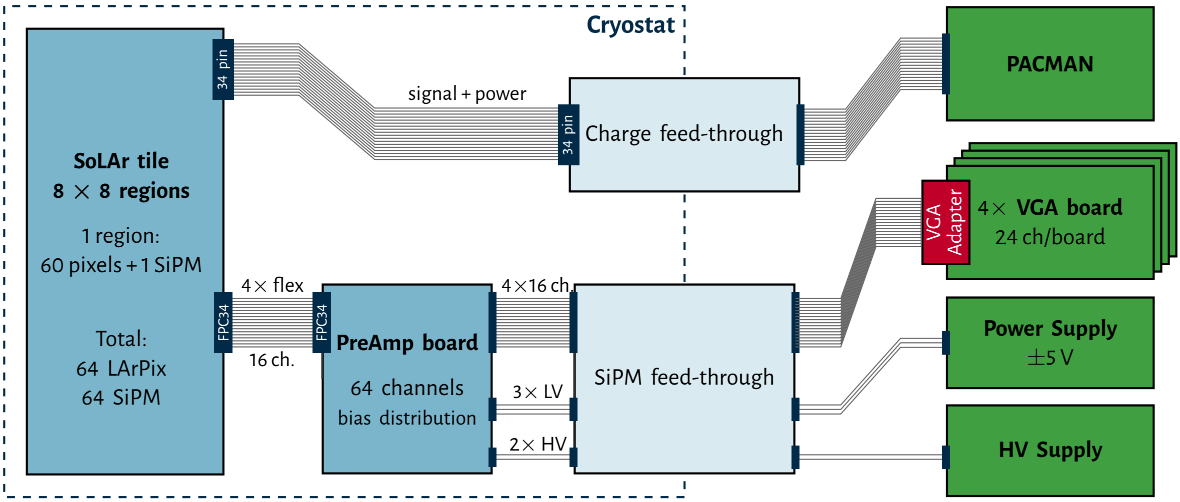
Three PCB stacked



Single multilayer PCB

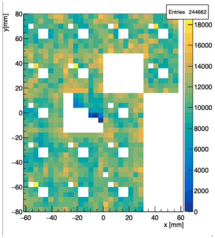


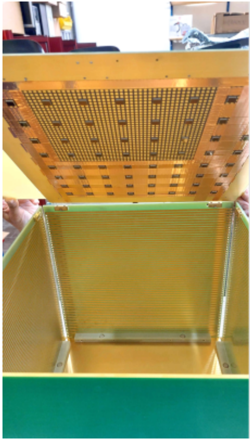
SoLAr V2: Electronics and DAQ

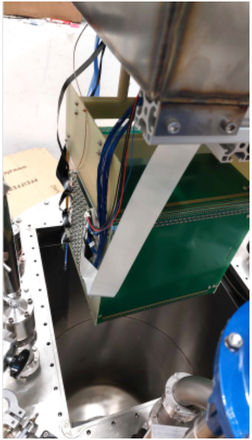


SoLAr v2: Operations

- 30 cm drift length
- Un-routed pads grounded with copper tape
- 2 days of cosmic data taking with nominal HV 15 kV
  + special runs at 7.5 and 3.75 kV
- Additional run with ^{60}Co source
- Good LAr purity
- Low charge hit threshold $\approx 3.8\,ke$
- few dead areas on the anode



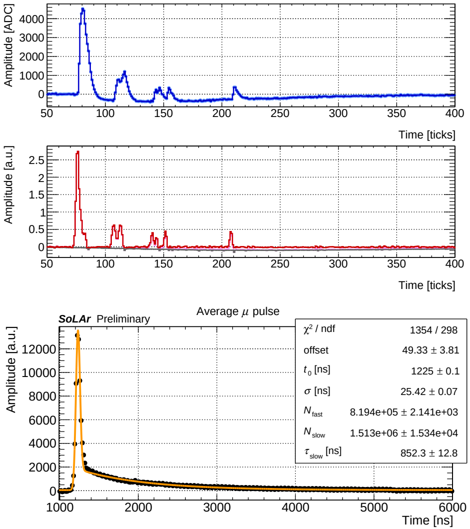




SoLAr v2: Preliminary results

SiPM waveform analysis

- SiPM waveform show a characteristic undershoot due to electronics coupling
- SiPM impulse response studies with dedicated LED runs
- Various waveform filtering strategies (Wiener filter, ...)
- Residual baseline modulation corrected applying a SNIP algorithm



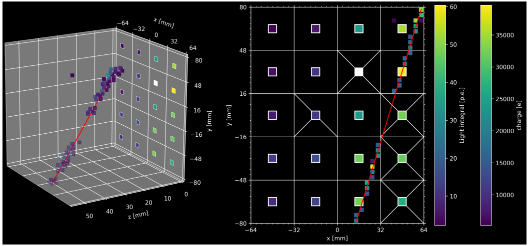
Preliminary results

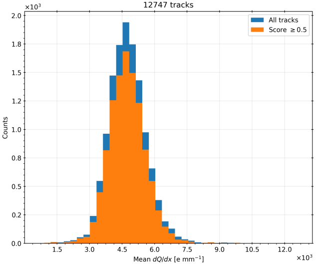
- Scintillation time profile obtained averaging filtered waveforms from ≈ 80 min cosmic run
- Slow time constant and relative weight of fast/slow component show a small discrepancy with expected values

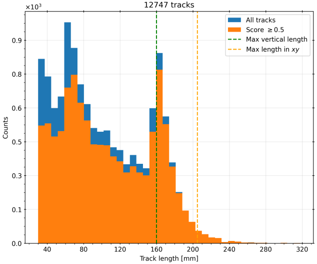
SoLAr v2: Preliminary results

Charge hit analysis

- **Clustering**
  Solving ambiguities due to dead areas using simulated data
- **Track fit**
  Identify outliers and secondary tracks





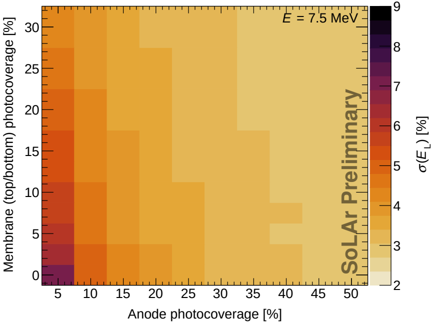


Preliminary results

- Track length distribution influenced by dead areas on the anode tile
- dQ/dx distribution compatible with similar experiments

Simulation studies

- How can we push the detector **energy resolution** with an optimized PDS?
  What is the **optical coverage** we need? What are the other constraints?
- How can we **suppress the radiological background**?



Preliminary light collection study

- Semi-analytical model of light propagation in LAr
  [D. Garcia-Gamez, P. Green, A.M. Szelc, Eur.Phys.J.C 81 (2021) 4, 349]
- Energy estimate from scintillation signal accounting for light propagation effects
- Study of energy resolution as a function of the coverage of the anode and membrane
- Conservatively, 10% anode + 15% membrane coverage should meet our requirements

Background simulation

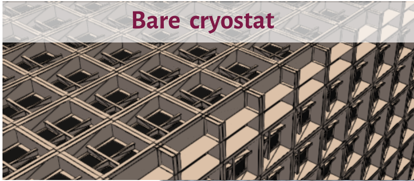
- Neutrons and neutron-induced γ's are among the most prominent backgrounds for low-energy searches in DUNE-like detectors
- Internal production in (α, n) reactions in LAr
- External neutron flux from cavern walls and cryostat materials $\to$ Design of **passive shielding**

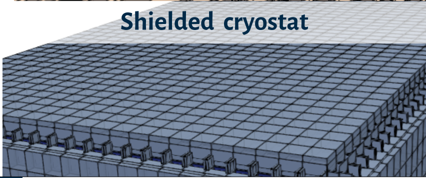
Shielding studies

Study of cryostat shielding from cavern neutrons comparing baseline DUNE-like cryostat to a shielded version

- external shielding: 50 cm water
- internal shielding: 10 cm Borated-Polyethylene (5%)

(as expected) neutrons flux @ LAr suppressed by 10^3–10^4 Impact of γ from n-capture to be assessed





Conclusions and outlooks

SoLAr R&D progress

SoLAr v1: first successful demonstration of integrated charge+light readout

SoLAr v2: larger and more complex device
Data analysis in progress, encouraging preliminary results

...Medium scale demonstrator?
aim to build a medium scale demonstrator underground (Boulby) to prove the technology for the search of low-energy neutrino events

Progress in sensitivity studies

Simulation and analysis studies to asses the potential and requirements of SoLAr are progressing.

Focus on **backgrounds**:
Full simulation pipeline for neutron shielding studies is crucial for cryostat design