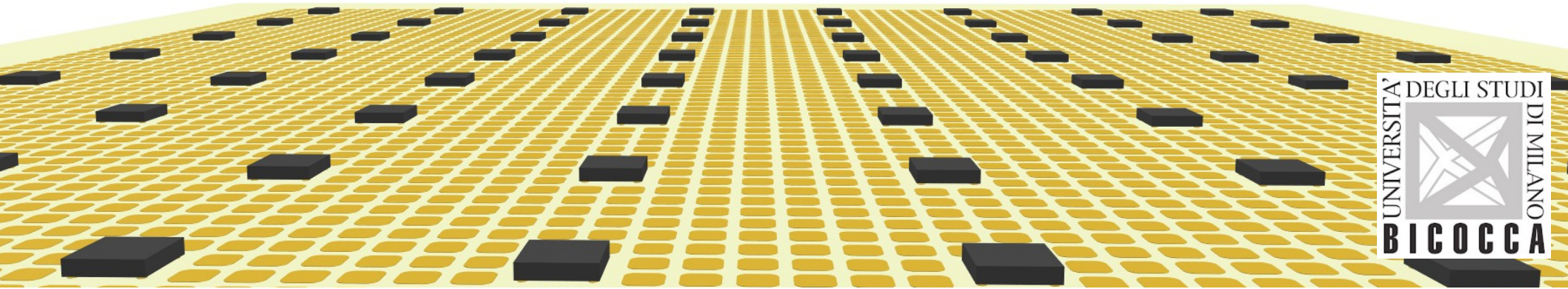
Prototyping the SoLAr dual readout LAr TPC



Anja Gauch for the SoLAr Collaboration

XX International Workshop on Neutrino Telescopes

October 23-27 2023

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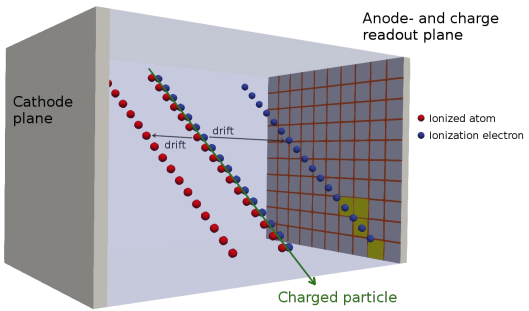
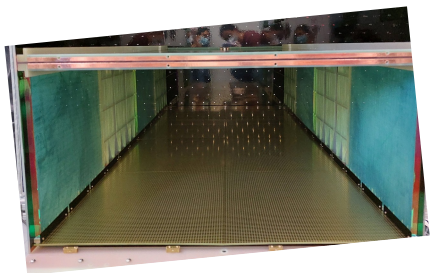
From current LAr TPCs to the SoLAr TPC

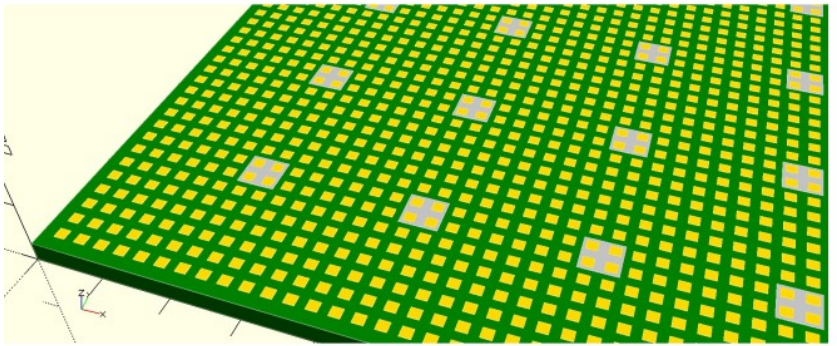
- LAr is ionized when a charge particle is passing through.
- An electric field drifts electrons to the anode plane.
- The drifting electrons are reconstructed by a charge readout system on the anode plane, wire readout or pixelated readout.
- The light detectors measure the scintillation light with which the drift time of the electrons are determined (distance of track to anode plane).





1 TPC of one DUNE prototype (2x2) module

- SoLAr is proposing a pixelated anode plane with distributed array of VUV SiPMs to improve the reconstruction of low energy events.



SoLAr cell schematic

https://argoncube.org/LArTPCs.html

Novel detector concept

- An array of **VUV** (Vacuum Ultra Violet) SiPMs (Silicon Photon Multiplier) **on the same anode plane** is capable to do position reconstruction in the same view and improve the light/charge matching of low energy deposits.
- Ability to **identify ”MeV-scale” events** in space and time online (not possible in current LAr TPCs)
- The combination of the two readout systems will be able to do online localized triggering to **deal with the high data rates**.
- The detector concept can be used for a large LAr TPC.
- The goal is to develop and demonstrate a new technology.

Physics motivation and main challenges

Physics motivation:

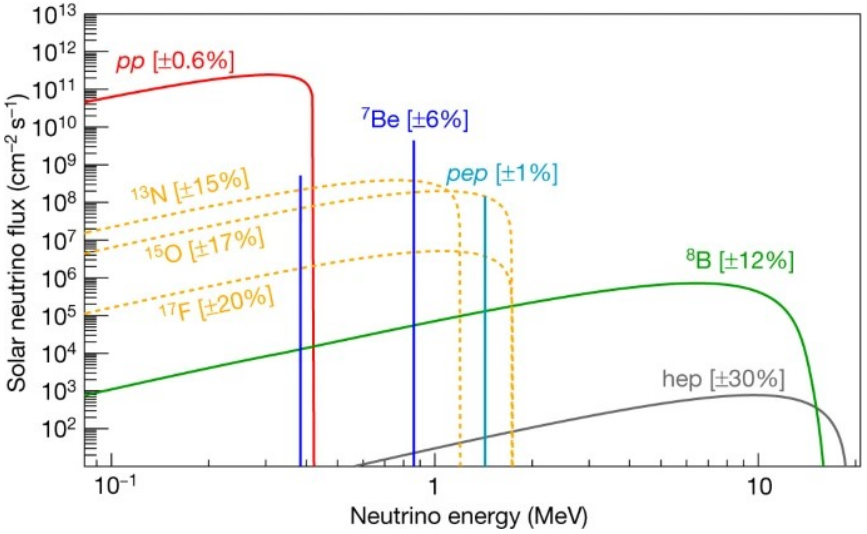
- The detection of the solar hep neutrinos and other low MeV energy scale particles.

$$^{3}\mathrm{He} + p \rightarrow ^{4}\mathrm{He} + e^{+} + \nu_{e}$$

- Supernova neutrino bursts will be detectable.

Main challenges:

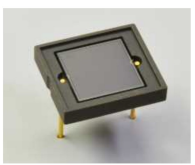
- The low-energy background needs to be identified efficiently.
- Neutrino flavors have to be tagged.
- Neutrino directions should be reconstructed.
- An excellent energy resolution and a good MeV energy calibration are essential for the full detector size.



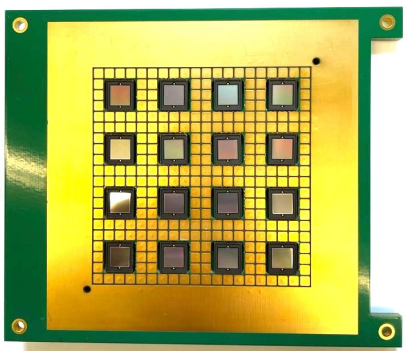
The Borexino Collaboration. Comprehensive measuremen t of pp-chain solar neutrinos. Nature 562, 505–510 (2018).

SoLAr prototype-v1

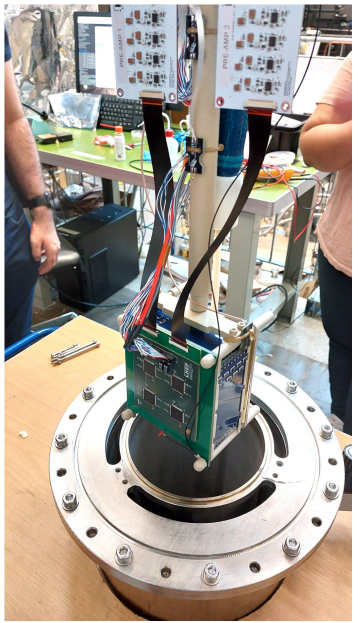
- **Successful test in October 2022**
- A small scale LAr TPC with an anode plane that collects the charge on pixels and the light in VUV pin SiPMs directly.
- The set-up allowed to put the SiPMs on a floating voltage level.
- The test set-up is used to
  - Investigate charge accumulation on SiPMs.
  - Check for cross talks between the readouts.
  - Observe cosmic muon tracks.



SiPM type: Hamamatsu S13370-6050CN
Ceramic packaged with pins
15 % PDE for 128 nm, VUV
link to the product flyer



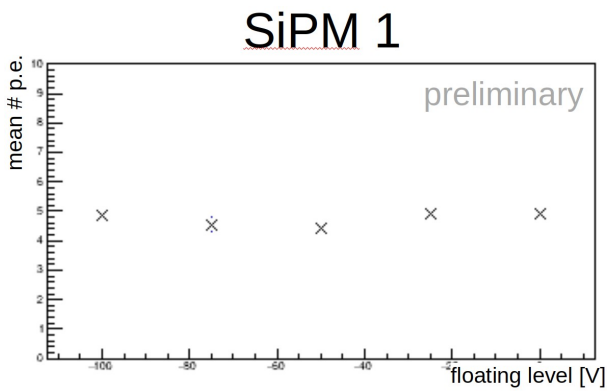
- 7 cm x 7 cm anode plane (3 stacked PCB)
- 16 VUV SiPMs with ceramic package and pins
- 4 LArPix-v2a chips

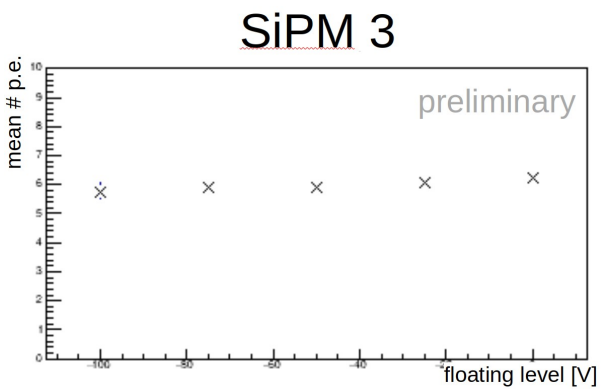


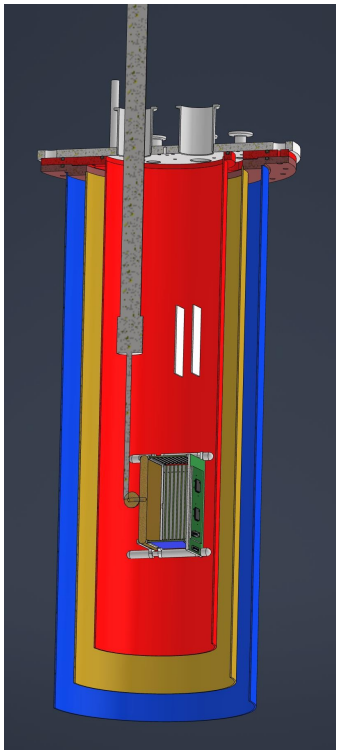
Insertion into cryostat

SoLAr prototype-v1 results

- The TPC took continuous cosmic rays measurements in Bern from 24th to 26th October 2022, operating for ~24 hours.
- The data taking is split into runs of about 10 min.
- A few 10 min runs with different negative floating voltage levels for the SiPMs were performed (0 V, -25 V, -50 V, -75 V and -100 V compared to the ground of the anode plane).
  - different negative voltage level could deflect more electrons towards the charge pixels.
  - No significant changes in the light yield were observed.



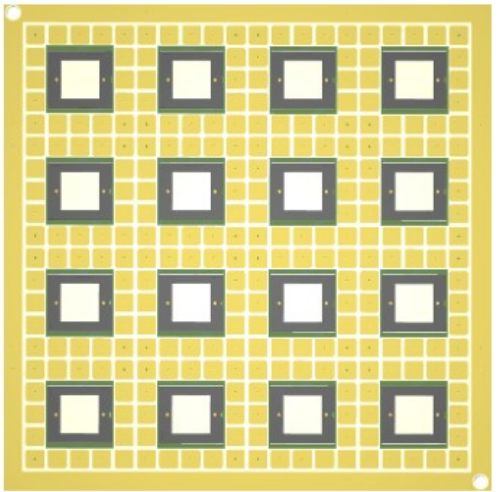


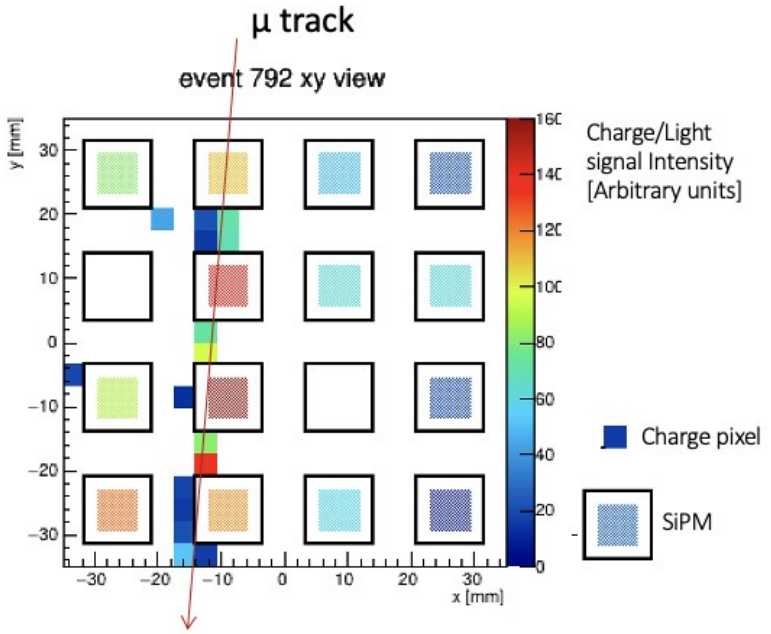


Drawing of a cut through the cryostat

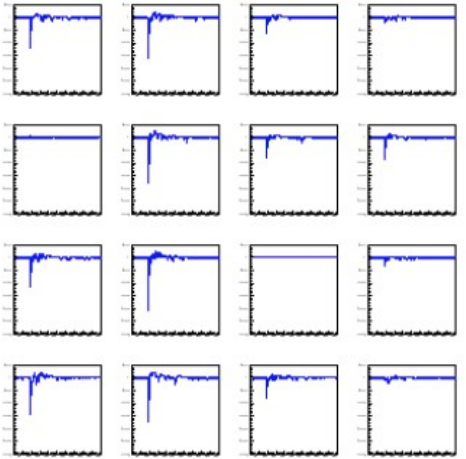
SoLAr v1 events from the cosmic run

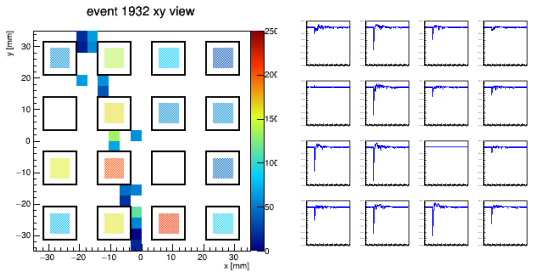
Anode plane visual guide

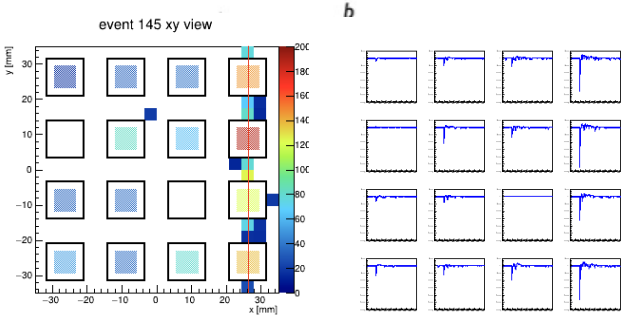




SiPM waveforms



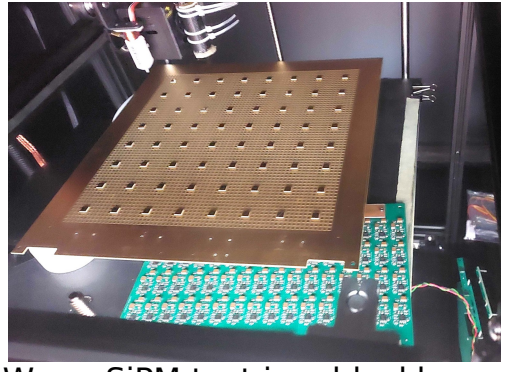




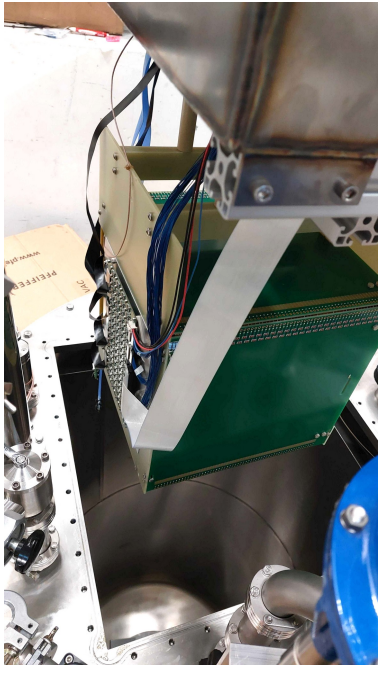
Anja Gauch

SoLAr prototype-v2

- **Successful test in July 2023.**
- The test set-up is used to:
  - Investigate charge accumulation on SMD SiPMs
  - Check for cross talks between the readout
  - Observe longer cosmic muon tracks
- The SoLAr prototype-v2 tile was assembled in a single cube setup and tested in the single module cryostat at Bern.



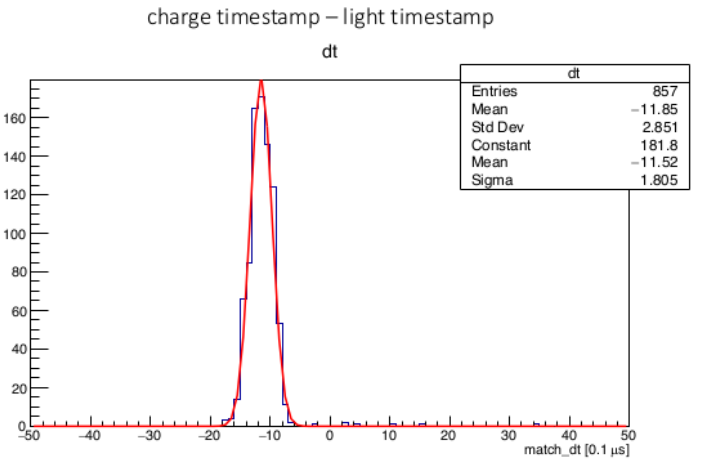
- Warm SiPM test in a blackbox
- 64 SMD Hamamatsu VUV SiPMs
- One single PCB with 20 LArPix and VUV SiPMs routed

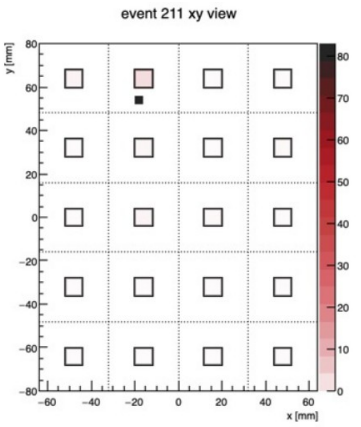


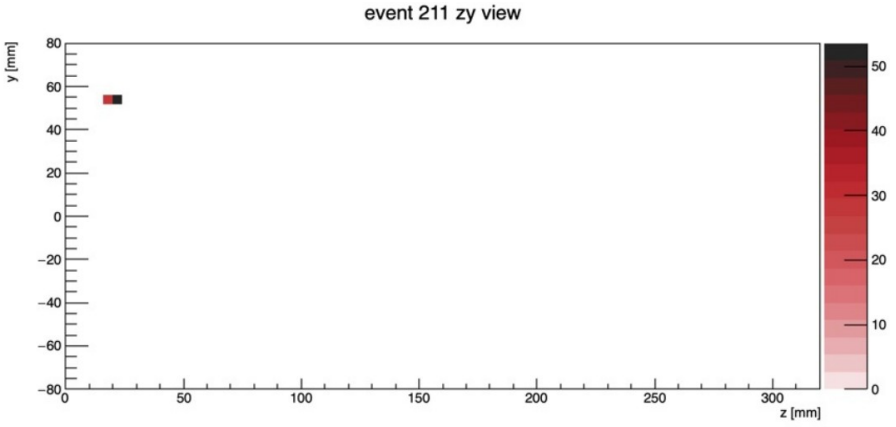
Insertion into cryostat

SoLAr prototype-v2 results

- Cosmic rays were tracked in Bern from 3. to 10. July 2023 with two days of cosmic run (nominal HV 15kV).
- 85.7% of the charge events have a corresponding light event match (search window of 10us).
- Special Cobalt-60 source run:
  - Isolated point like events with matched light.
  - Interesting samples to study energy resolution and position resolution.

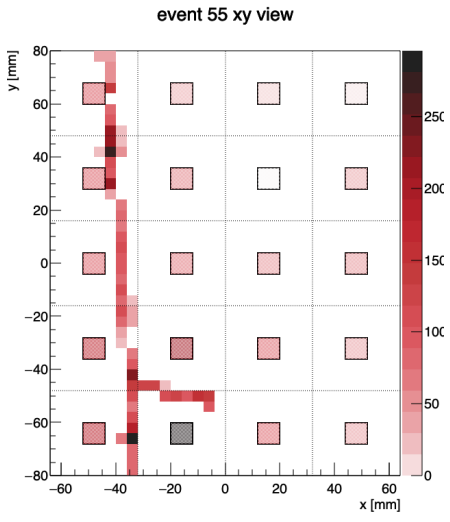


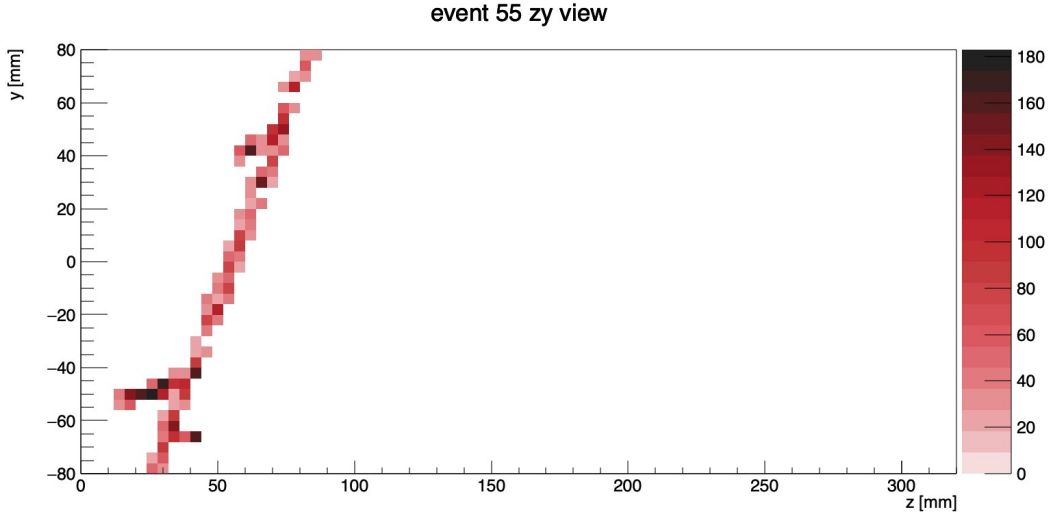


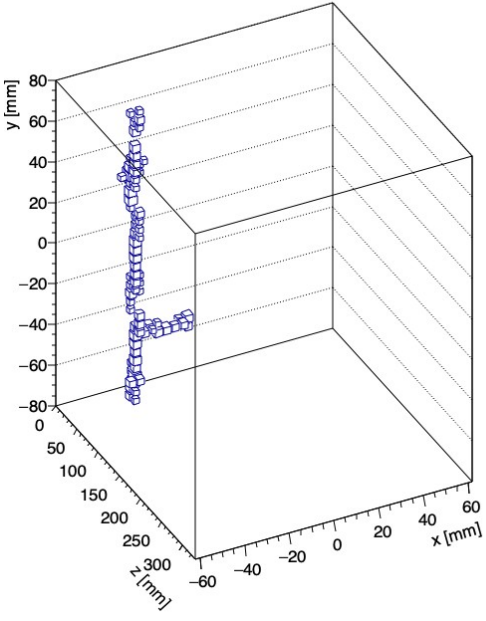


Events of SoLAr prototype-v2

- Anode plane is located at z=0.
- SiPMs are visualized as square boxes in the xy view.
- SiPMs relative light intensity is presented as fill color (arbitrary units).
- Light and charge combined 3D display of a cosmic muon track.

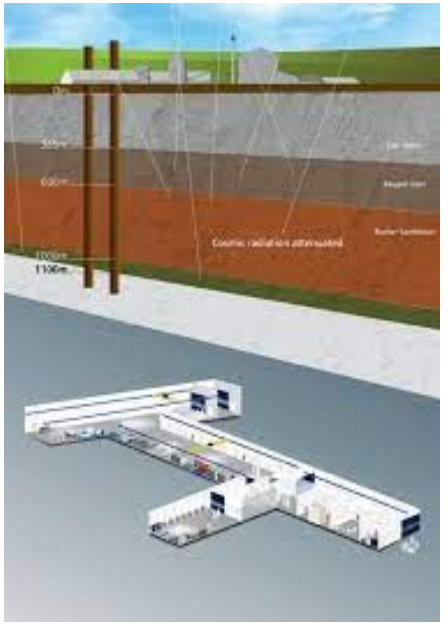




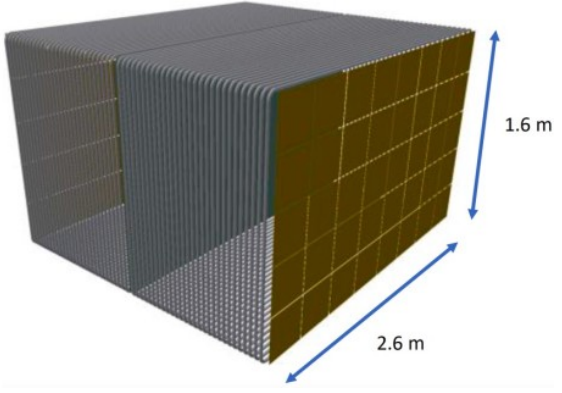


Future R&D

- Small scale prototype with improved SiPMs (charge pads on top)
  - R&D and collaboration with Hamamatsu and/or FBK
  - Test of alternative readout chips
- Mid scale, SoLAr Demonstrator @Boulby (2025-2028?)
  - aim to satisfy the requirement of tracking and calorimetric resolutions for low neutrino energy physics.
  - Few-ton scale LAr detector underground (Boulby, UK, 1100 m overburden)
  - 30 × 30 cm^2 readout anode tiles (≈ 6400 pixels/tile)
  - First measurement of flavor tagged solar neutrinos in LAr
- Integrate the SoLAr design concept in the DUNE Module of Opportunity.



Boulby

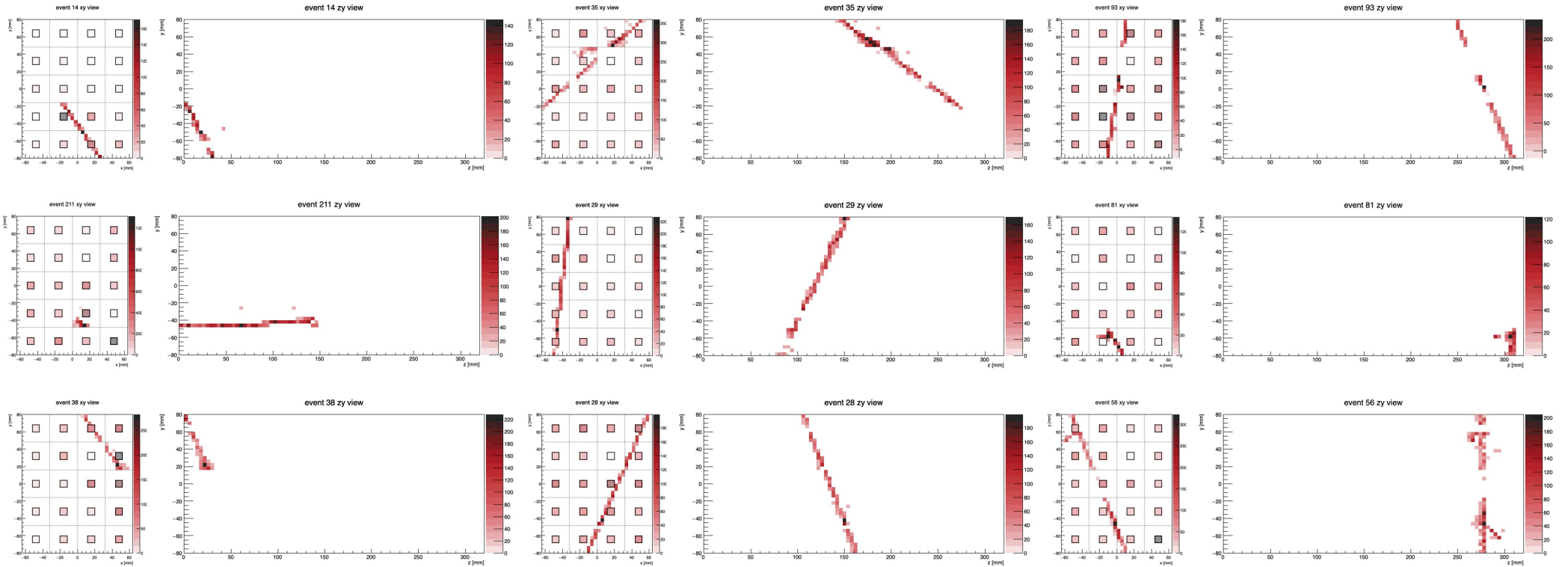


Conclusion

- First successful operation of the SoLAr prototype-v1 at small scale.
- There is no difference observed in the mean amount of collected photoelectrons for different SiPM bias-voltage floating-levels.
- Second SoLAr prototype-v2 took successfully cosmic data at small scale. Data analysis is ongoing.
- Simulation efforts in progress (understanding background sources, developing mitigation strategies, quantifying the sensitivity to solar neutrinos > 5 MeV).

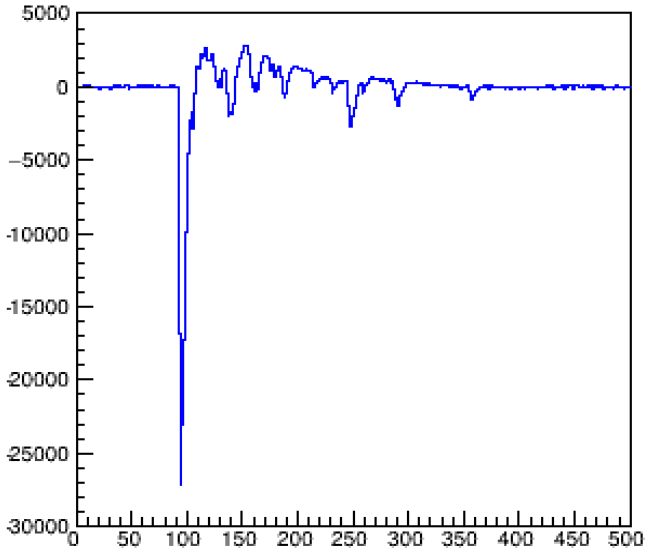
Laboratory in Bern

Thank you!

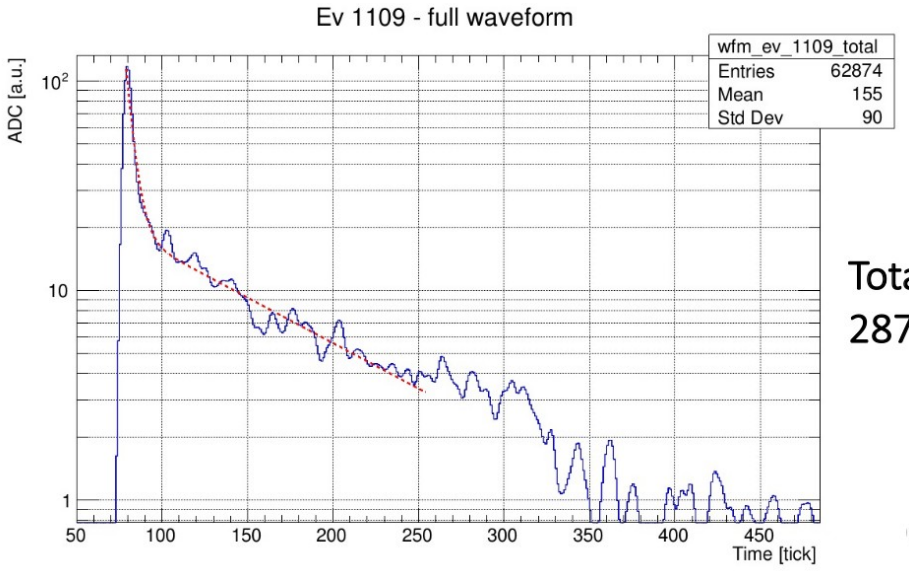

event 14 xy view
event 14 zy view
event 35 xy view
event 35 zy view
event 93 xy view
event 93 zy view
event 211 xy view
event 211 zy view
event 29 xy view
event 29 zy view
event 81 xy view
event 81 zy view
event 38 xy view
event 38 zy view
event 28 xy view
event 28 zy view
event 56 xy view
event 56 zy view

Back up

A single light wafeform



Timestamp [16 ns]

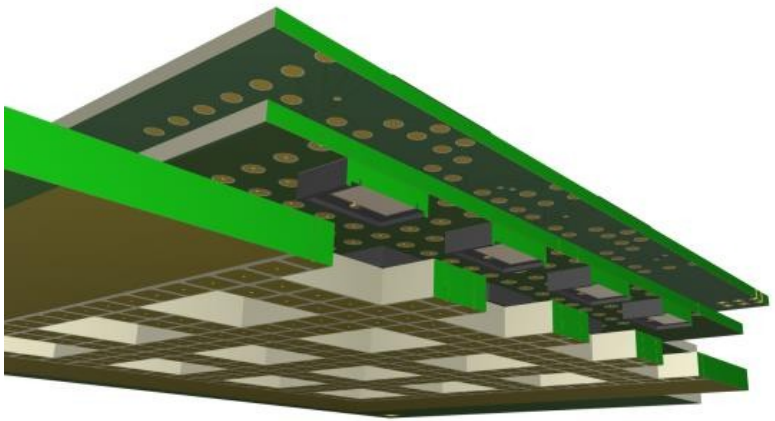


Total event light yield
2876.47 [p.e]

etector, S. Parsa, TAU

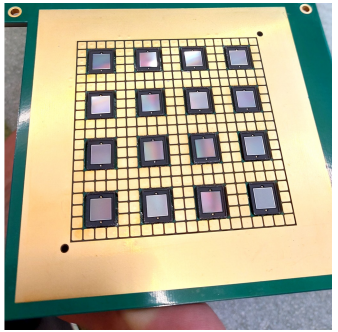
3 PCBs for v1

- On a single PCB the pins would interfere with the LArPix ground pads
- A stackup of 3 different PCBs that are soldered together solves the problem



C. Tognina (University of Bern)

SoLAr prototype-v1 and v2 anode plane design

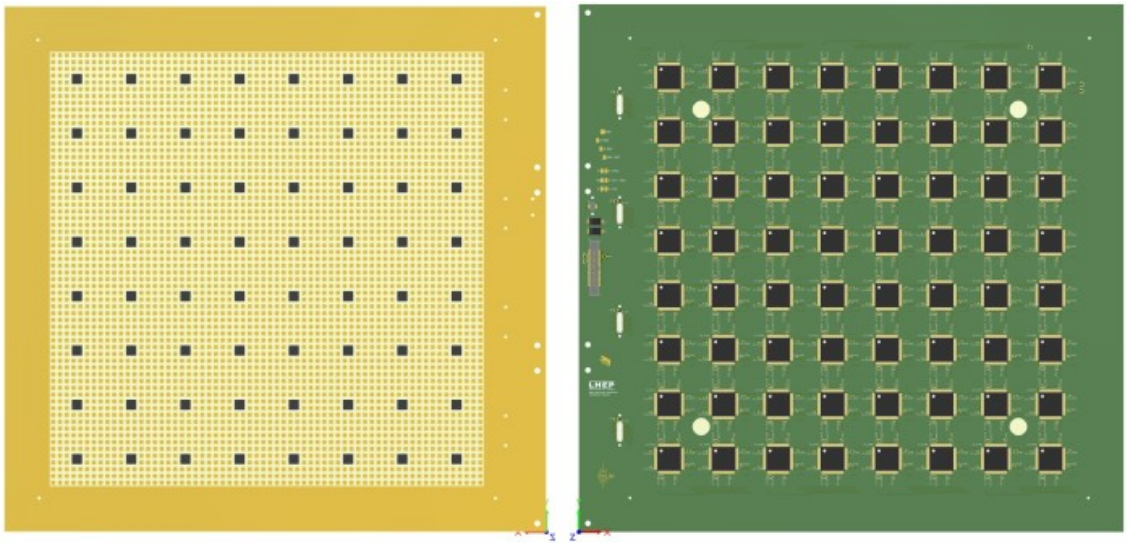


v1:

- charge pixel pads: 3mm
- pixel pitch: 3.5mm
- SiPM sensitive area 6mmx6mm
- SiPM pitch: 17.5mm
- Readout area: 70mmx70mm

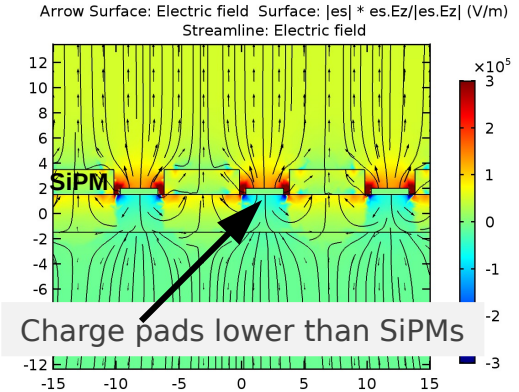
v2:

- Tile dimenstions: 31cm x 32cm
- Divided into 8x8 regions (60pixels +1SiPM)
- Pixel pitch 4mm
- 64 LarPix
- 64 Hamamatsu VUV SiPMs (SiPM pitch: 32mm)

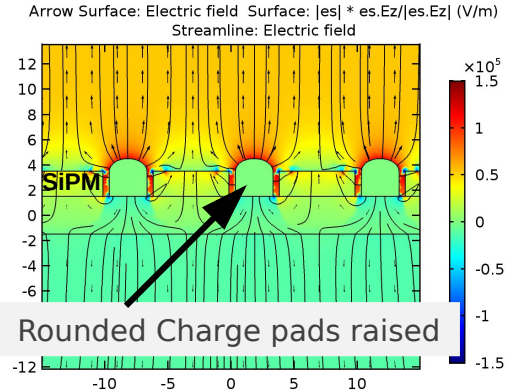


Electric field simulation around SiPMs

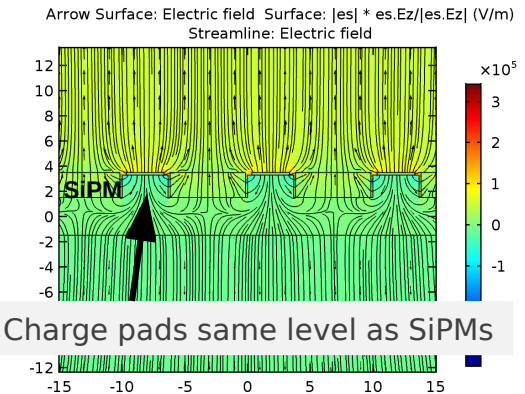
- Simulations of the electric field performed with Comsol for different heights of charge pixels.
- A homogeneous electric field can be realized even with SiPMs on the anode plane.
- To float the SiPMs on a different negative voltage level could deflect more electrons towards the charge pixels.



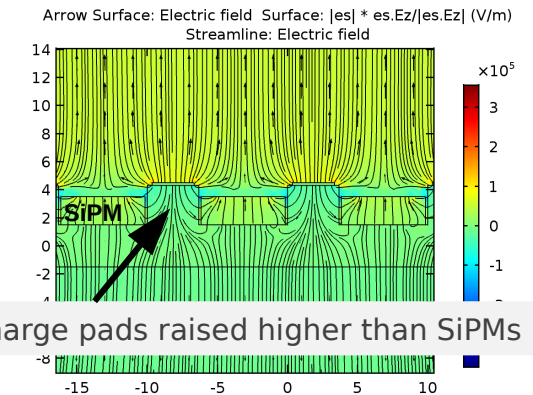
Charge pads lower than SiPMs



Rounded Charge pads raised



Charge pads same level as SiPMs



Charge pads raised higher than SiPMs