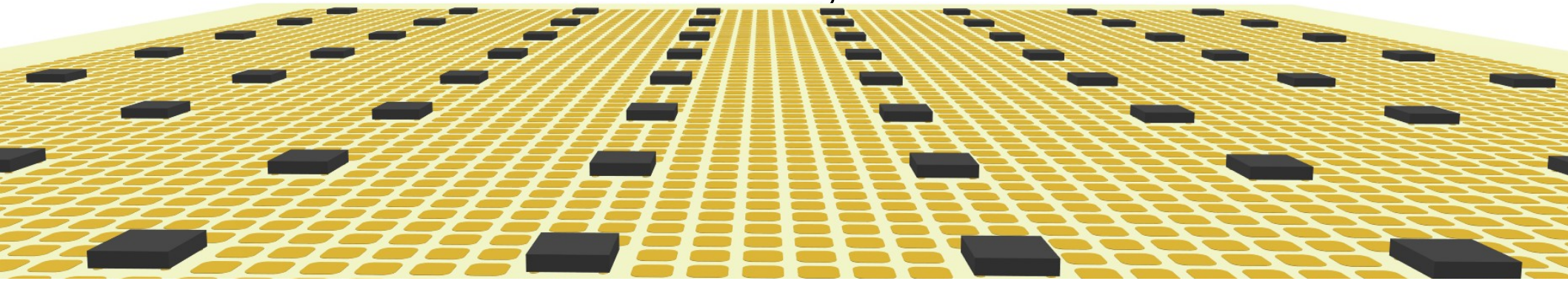
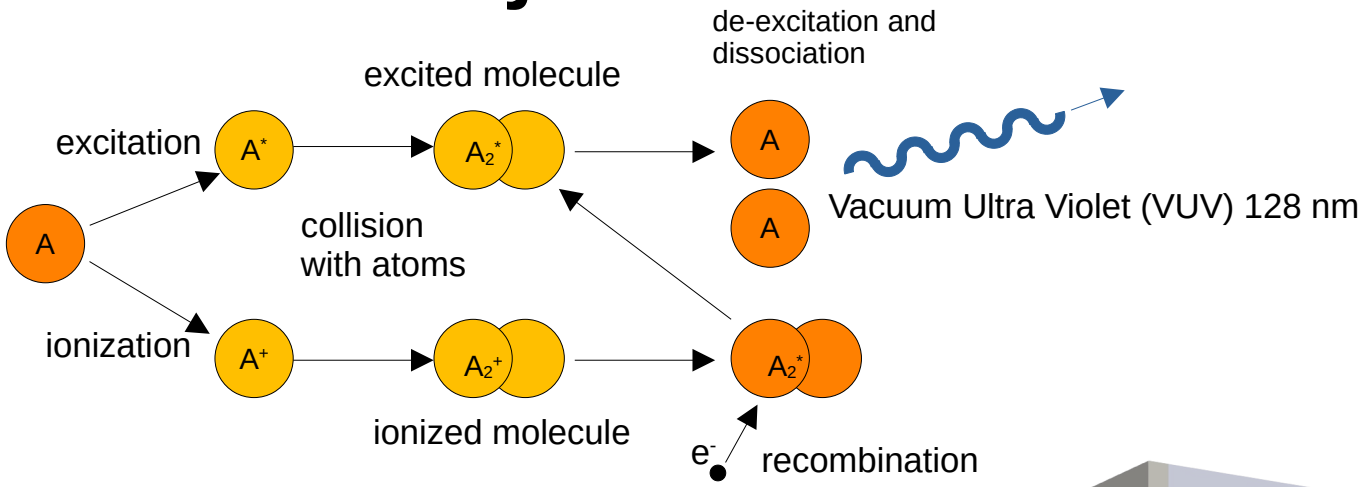
SoLAr: A future LAr TPC to detect MeV-scale neutrinos

Jan Kunzmann, on behalf of SoLAr collaboration
jan.kunzmann@unibe.ch

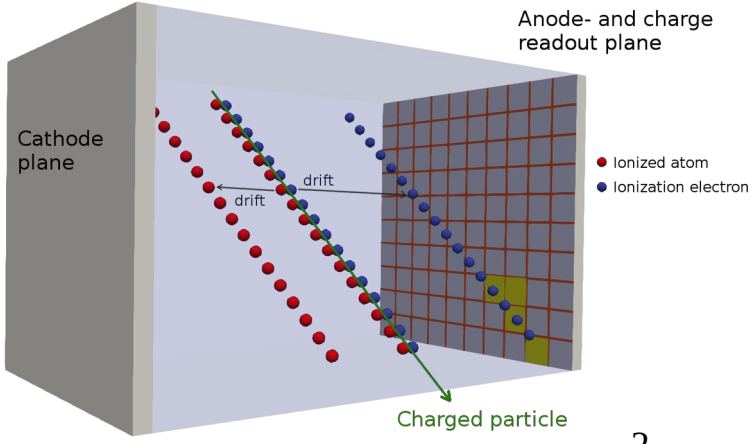
University of Bern
LHEP
IPRD 2023, Siena



Time Projection Chamber



- An electrical field drifts the electrons to the anode plane.
- On the anode plane is an electrical 2D readout.
- The scintillation light is used to measure drift time of the electrons.
- This gives the distance of the track to anode plane.
- A TPC is able to do 3D track reconstruction.



https://argoncube.org/LArTPCs.html

Solar neutrinos in Liquid Argon

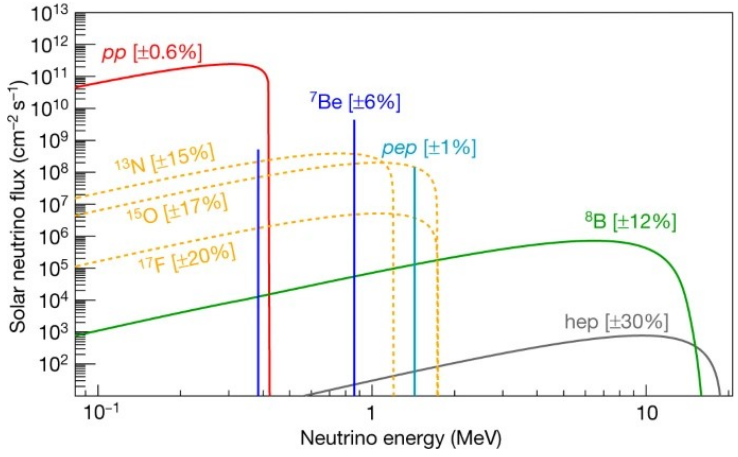
Novel detector concept:

- MeV-scale events are online detectable in space and time.
- The detector concept can be used for a large LAr-TPC.
- A true 3D reconstruction is possible with a pixelated charge readout anode plane.
- An array of VUV (Vacuum Ultra Violet) SiPMs (Silicon Photon Multiplier) on the same anode plane is capable to do 3D reconstruction from light.
- The combination of the two readout systems will be able to do online localized triggering to deal with the high data rates.

S. Parsa et al., SoLAr: Solar Neutrinos in Liquid Argon. arXiv:2203.07501. August 25, 2022

Physics motivation:

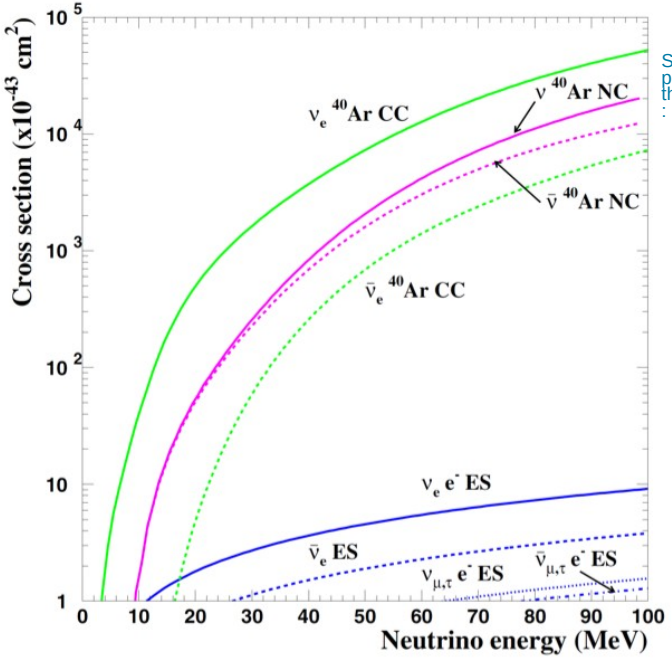
- The detection of the Solar hep neutrinos and other low MeV energy scale particles.
- Supernova neutrino bursts will be detectable.



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

Main challenges for MeV energy scale physics

- An excellent energy resolution is essential.
- For the full detector size a good MeV energy calibration is needed.
- The low-energy background needs to be identified efficently.
- Neutrino flavors have to be tagged.
- Neutrino directions should be reconstructed.
- An efficient event reconstruction is needed for the online triggering.

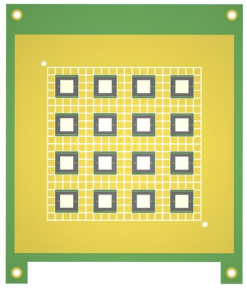


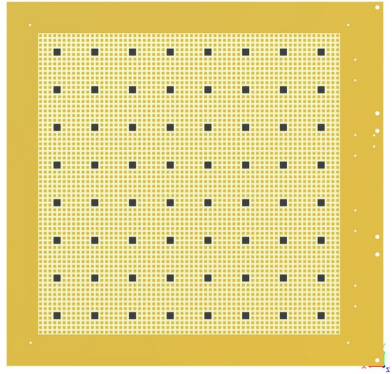
Supernova Neutrinos at the DUNE Ex periment, Amanda Weinstein and for theDUNE Collaboration 2020 J. Phys. : Conf. Ser. 1342 012052

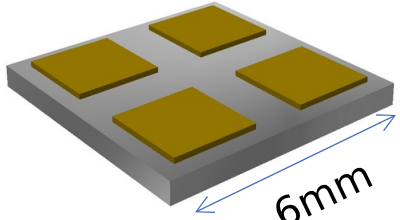
For low energy the cross section of neutrinos with liquid argon decreases. A good detection and identification is needed.

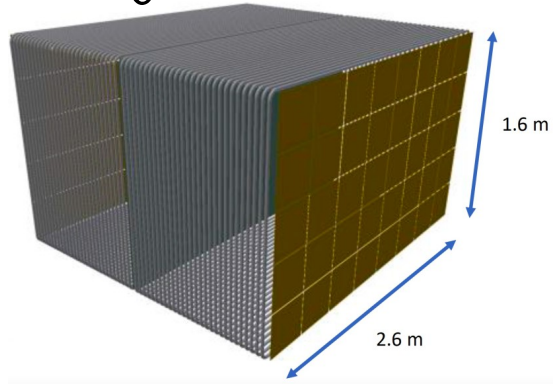
Road map of SoLAr

- Small scale SoLAr prototype-v1 @Bern **(successful test in October 2022)**
  - 7 cm x 7 cm anode plane (3 stacked PCB)
  - 16 VUV SiPMs with ceramic package and pins
  - 4 LArPix-v2a chips
- Small scale SoLAr prototype-v2 @Bern **(successful test in July 2023)**
  - 30 cm x 30 cm (1 PCB)
  - 64 SMD packaged VUV SiPMs
  - 20 LArPix-v2b chips (space for 64 chips)
- 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?)
  - 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



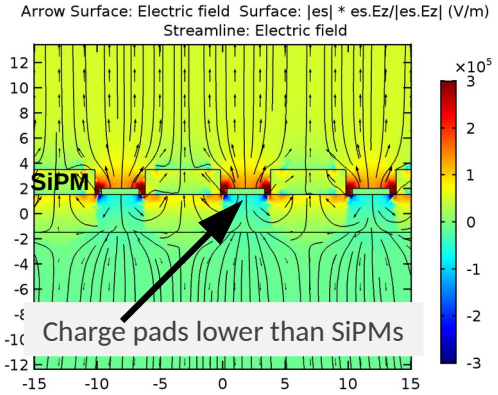


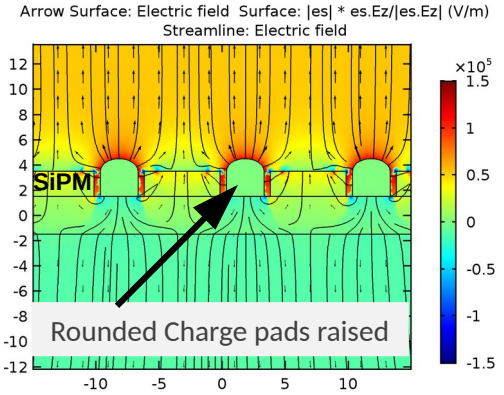


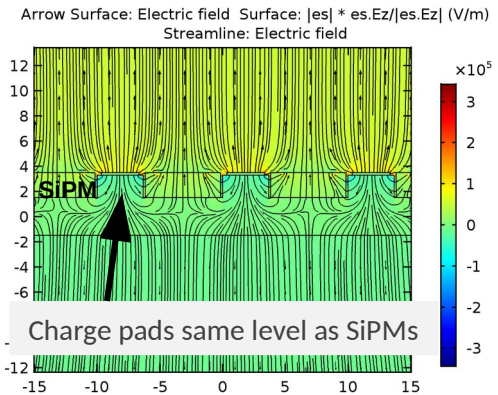


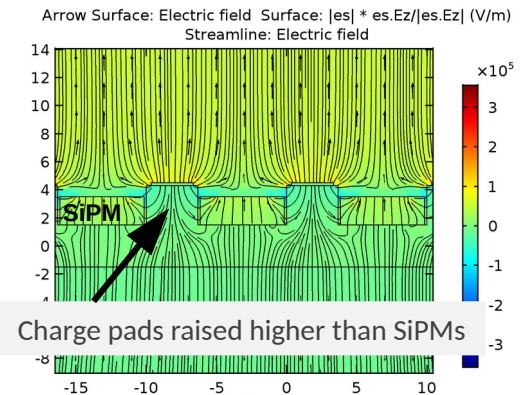
Electric field simulation around SiPMs

- 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.







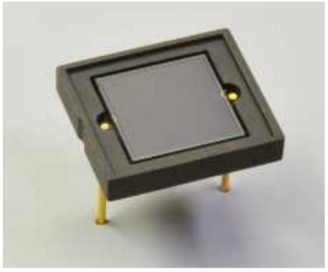


by Nikola McConkey and
Guilherme Ruiz Ferreira

SoLAr prototype-v1

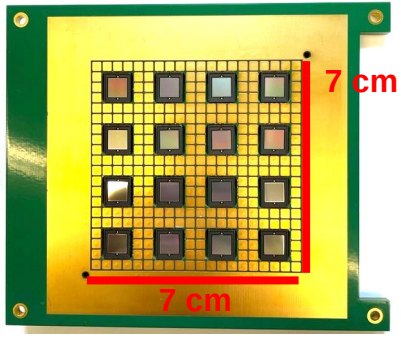
- A small scale LAr TPC with an anode plane that collects the charge on pixels and the light in VUV pin SiPMs directly.
- The set-up allowed to put the SiPMs on a floating voltage level.
- The test set-up is used to
  - Investigate charge accumulation on SiPMs.
  - Check for crosstalks between the readouts.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

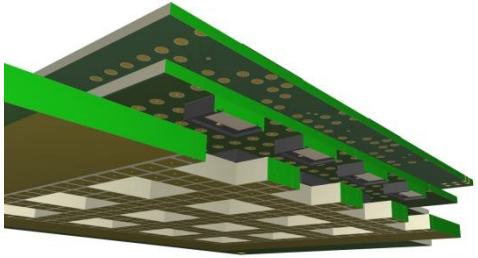
- SiPM type: Hamamatsu S13370-6050CN
- Ceramic packaged with pins
- 15 % PDE for 128 nm, VUV



link to the product flyer

- 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

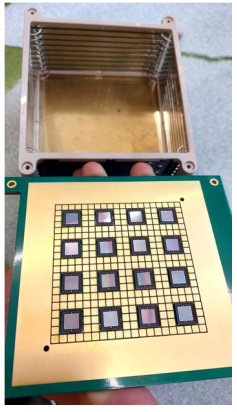




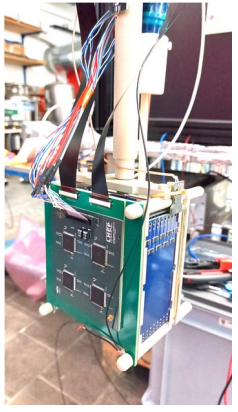
C. Tognina (University of Bern)

Final design of the SoLAr prototype-v1

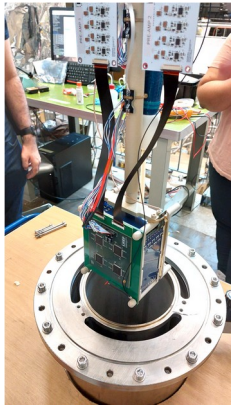
- The TPC took cosmic rays measurement in Bern from 24.-26. October 2022 (~24 h operation).
- Continuous measurements are performed.
- The data taking is split into runs of about 10 min.
- A few 10 min runs with different floating voltage levels for the SiPMs were performed.



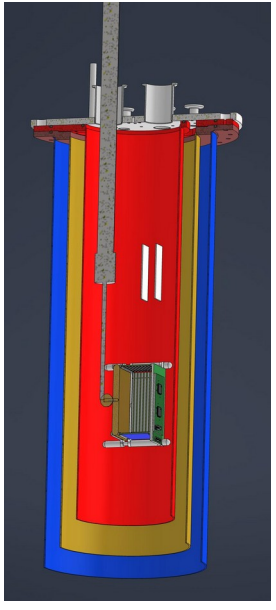
Inside the TPC



SoLAr-v1 TPC



Insertion into cryostat

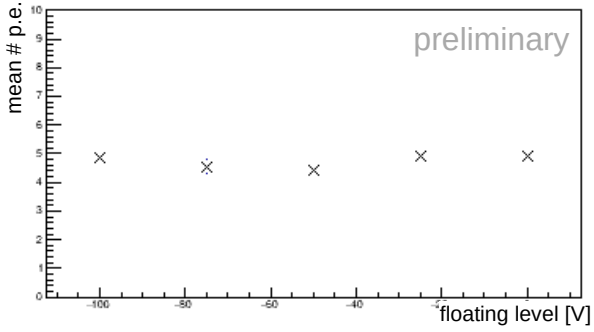


Drawing of a cut through the cryostat

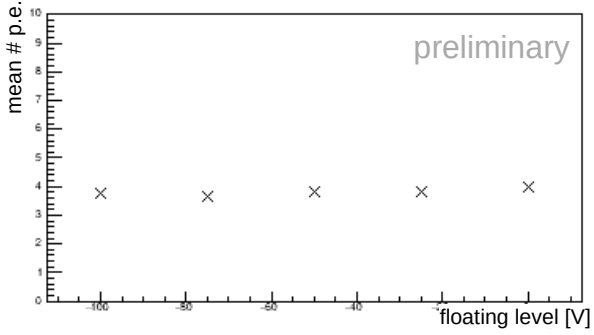
First results of the SoLAr prototype-v1 cosmic run

- The SiPM's bias voltage ground were put on different negative floating levels in comparison to the ground of the pixelated anode plane.
- The levels were set to 0 V, -25 V, -50 V, -75 V and -100 V.
- Comparing the means of the amount of collected light for 3 SiPMs for the different floating levels show no significant change.

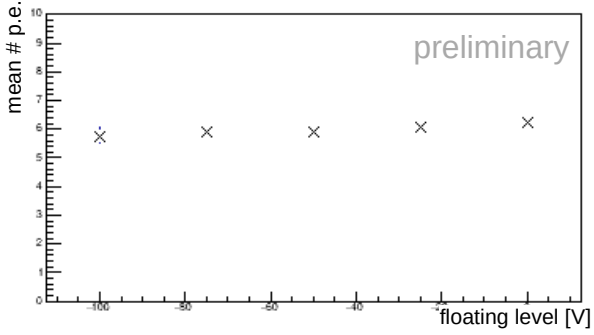
SiPM 1



SiPM 2

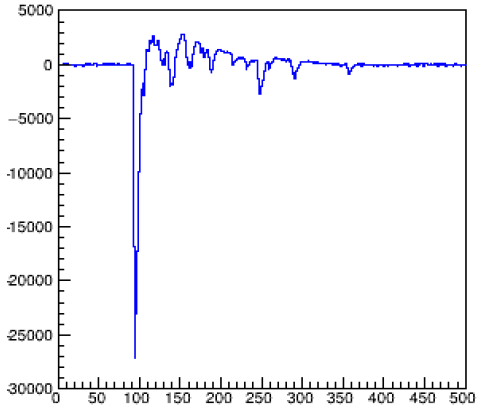


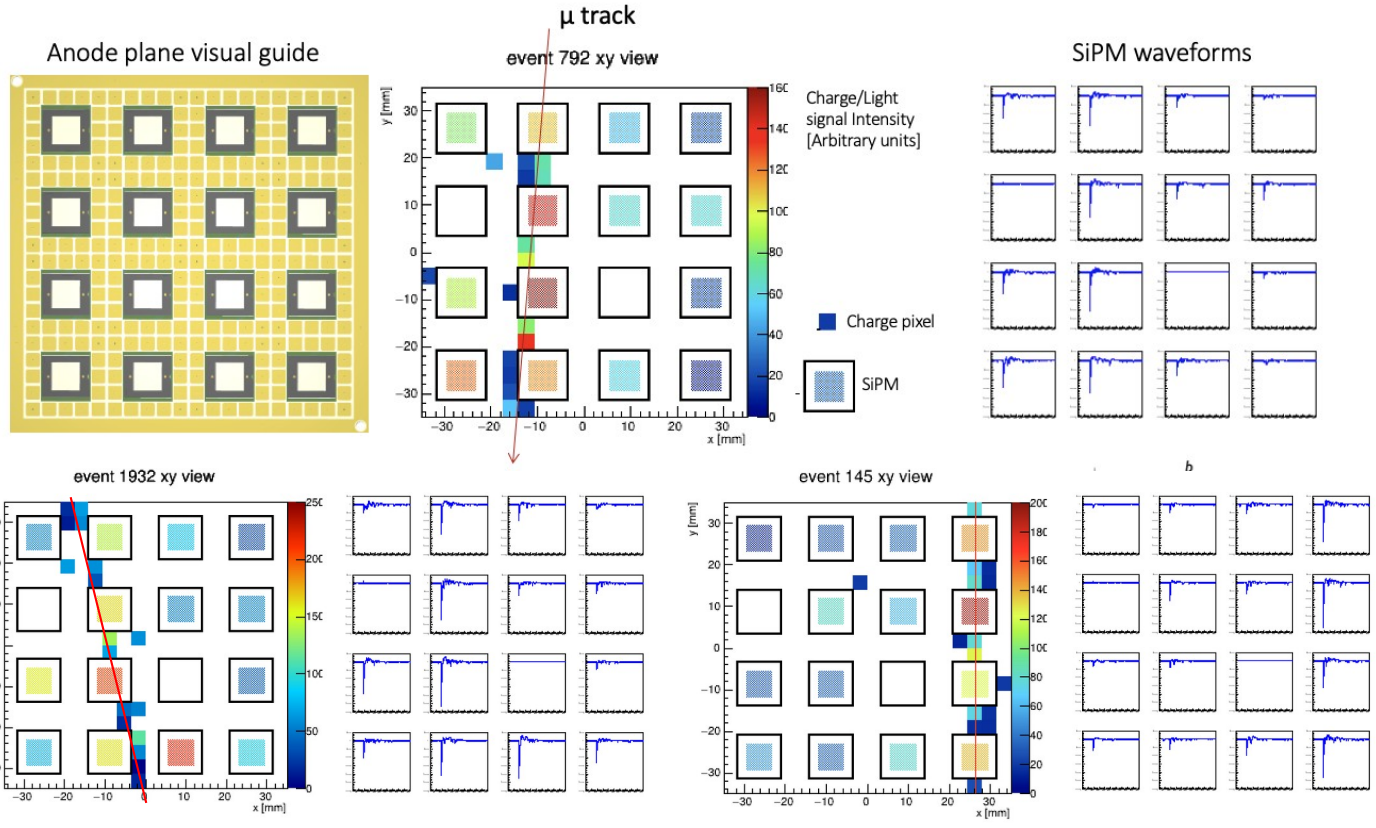
SiPM 3



First results of the SoLAr prototype-v1 cosmic run

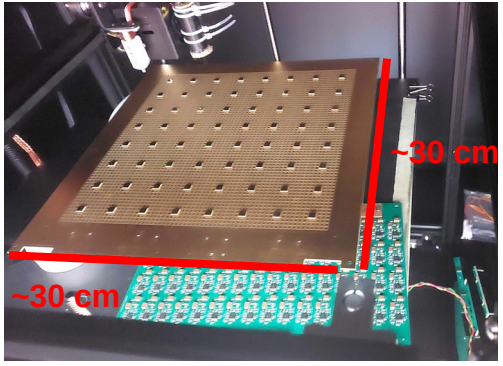
A single light waveform



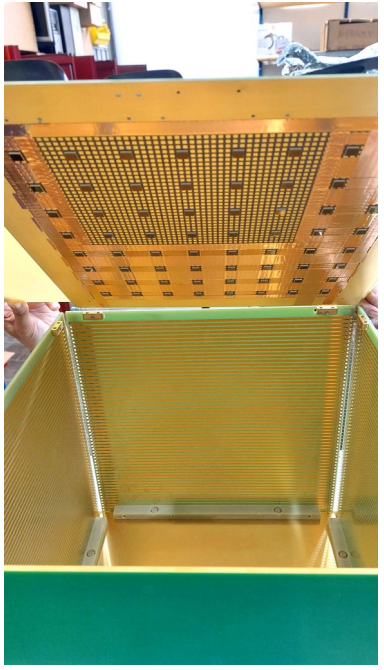


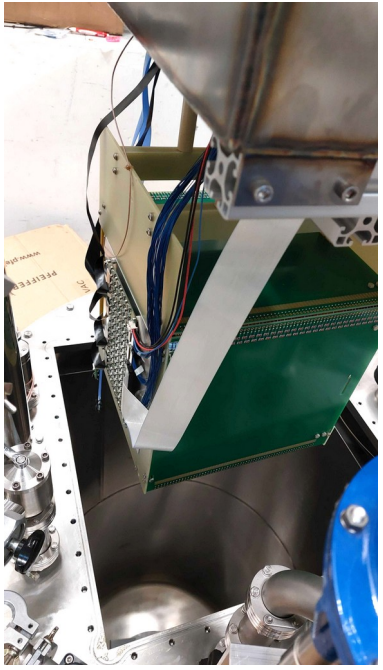
Final design of the SoLAr prototype-v2

- One single PCB with LArPix and VUV SiPMs routed.
- 64 SMD Hamamatsu VUV SiPMs
- The test set-up is used to
  - Investigate charge accumulation on SMD SiPMs
  - Check for crosstalks between the readout
  - Observe longer cosmic muon tracks



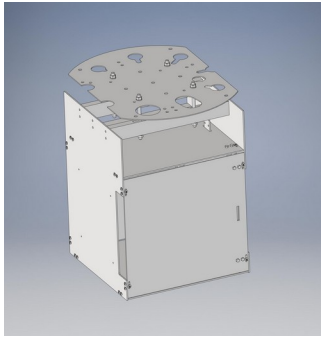
Warm SiPM test in a blackbox


Inner view of the TPC


Insertion into cryostat

Final design of the SoLAr prototype-v2

- Cosmic rays were tracked in Bern from 3. to 10. July 2023.
- The SoLAr prototype-v2 tile was assembled in a single cube setup.
- The test was performed in the single module cryostat at Bern.



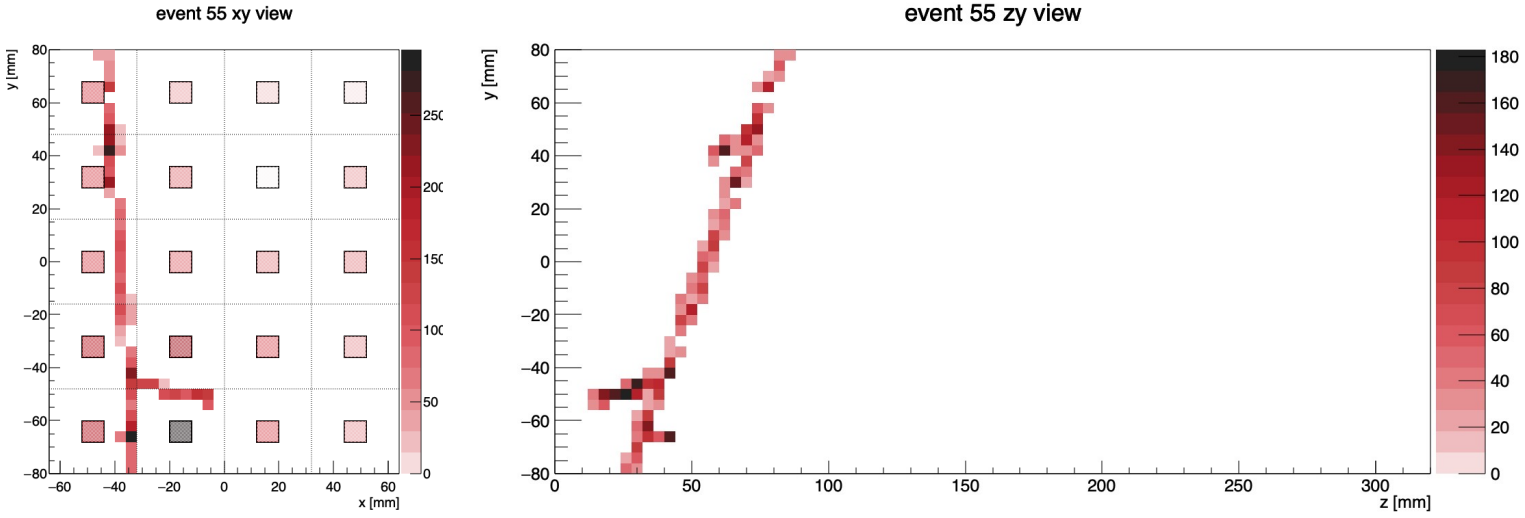
CAD drawing of the cube TPC

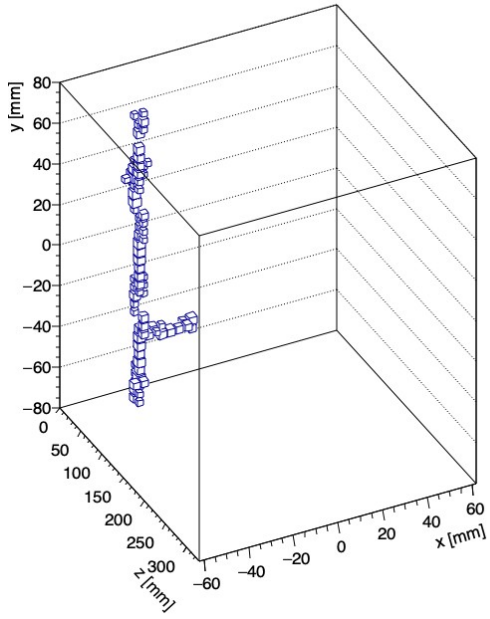
The cube TPC assembled and hanging on the top flange

The laboratory at University of Bern with the LAr cryostat

Light and charge combined 3D display of a cosmic muon track

- 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)





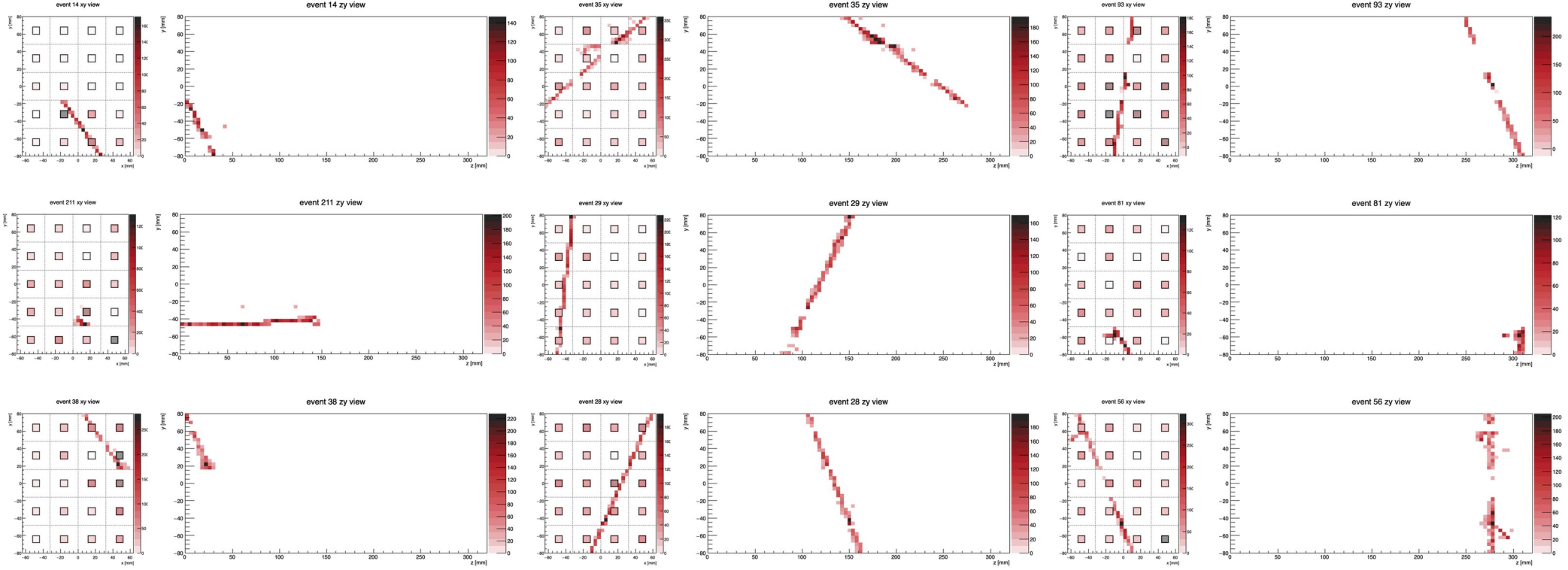
Outlook

- Future R&D and prototyping program aims to benchmark new technology and delivers a SoLAr cell unit with charge pads implemented on the surface of a VUV SiPM device.
- Simulation efforts in progress (understanding background sources, developing mitigation strategies, quantifying the sensitivity to solar neutrinos > 5 MeV).
- A medium scale demonstrator @Boulby would aim to satisfy the requirement of tracking and calorimetric resolutions for low neutrino energy physics.
- Integrate the SoLAr design concept in the DUNE Module of Opportunity.

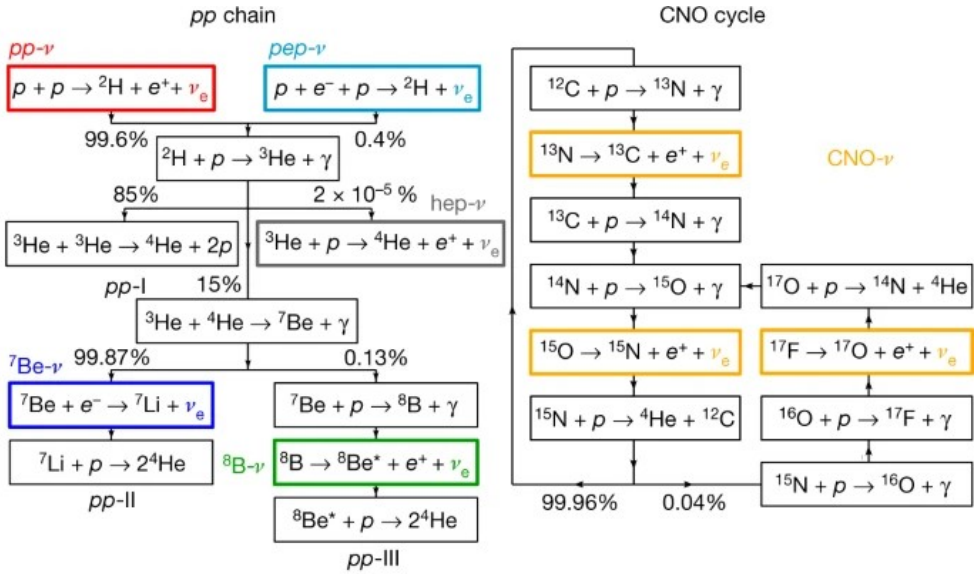
Conclusion

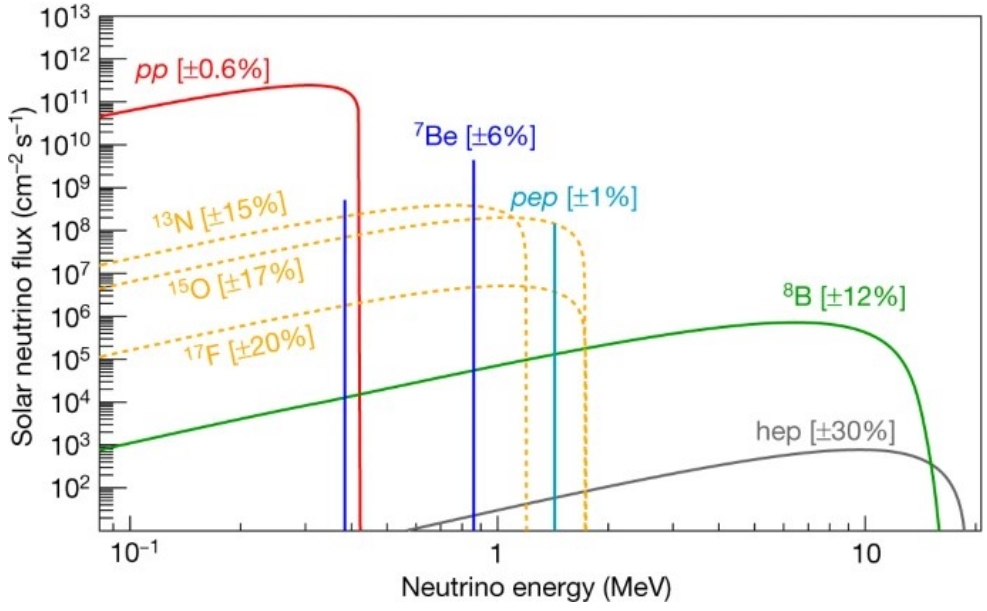
- First successful operation of the SoLAr prototype-v1 at small scale.
- There is no difference observed in the mean amount of collected photoelectrons for different SiPM bias-voltage floating-levels.
- Second SoLAr prototype-v2 took successfully cosmic data at small scale. Data analysis is ongoing.

More cosmic tracks from SoLAr prototype-v2



hep neutrinos





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