SoLAr: Solar Neutrinos in Liquid Argon

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on behalf of the SoLAr Collaboration

MANCHESTER 1824
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Introducing: SoLAr

- New collaboration!
- **Goal:** Use a **combined light and charge readout plane** to probe **MeV-scale** physics in a LAr TPC
- Collaborators from 5 countries
- Snowmass whitepaper: arXiv:2203.07501

arXiv
March 16, 2022

SoLAr: Solar Neutrinos in Liquid Argon

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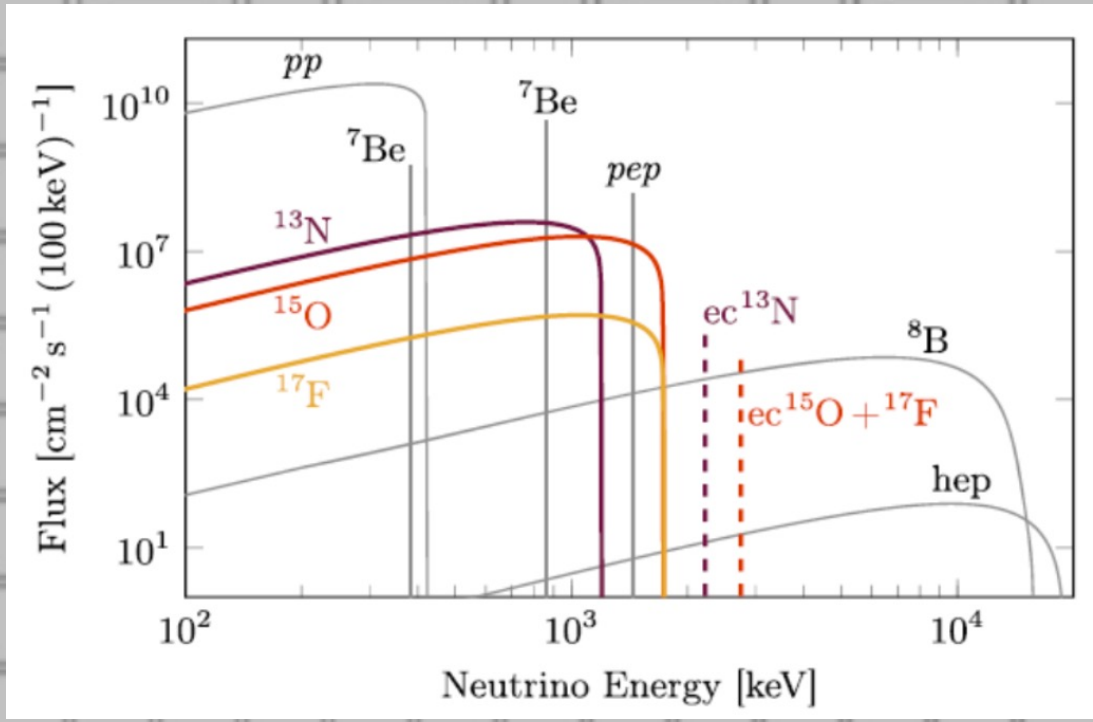
Physics motivations

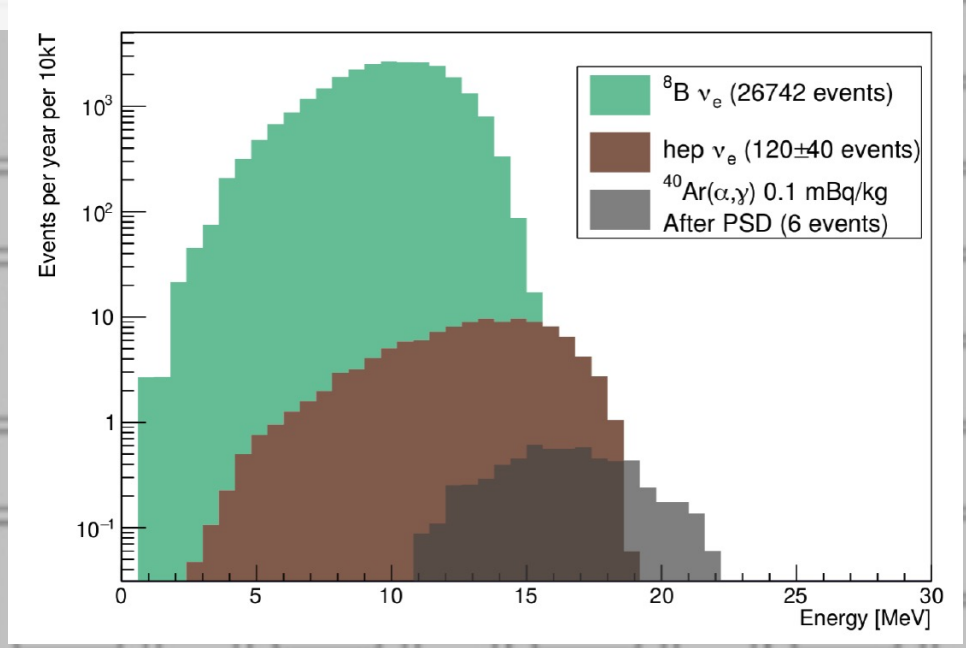
- Detection of low energy events with LAr TPC
  - Expand the neutrino physics capabilities at low energy (~MeV) range in LAr TPCs
- Leverage the combination of charge transport and optical properties of LAr as a detector medium
- Pull together developing readout technologies
  - VUV sensitive SiPMs
  - Charge readout pixels



Low energy neutrino physics

- Solar neutrinos
  - Improve the precision on the solar neutrino oscillation parameters
  - Aim for observation of the hep solar neutrino flux
- Supernova neutrinos
- Diffuse Supernova Neutrino Background

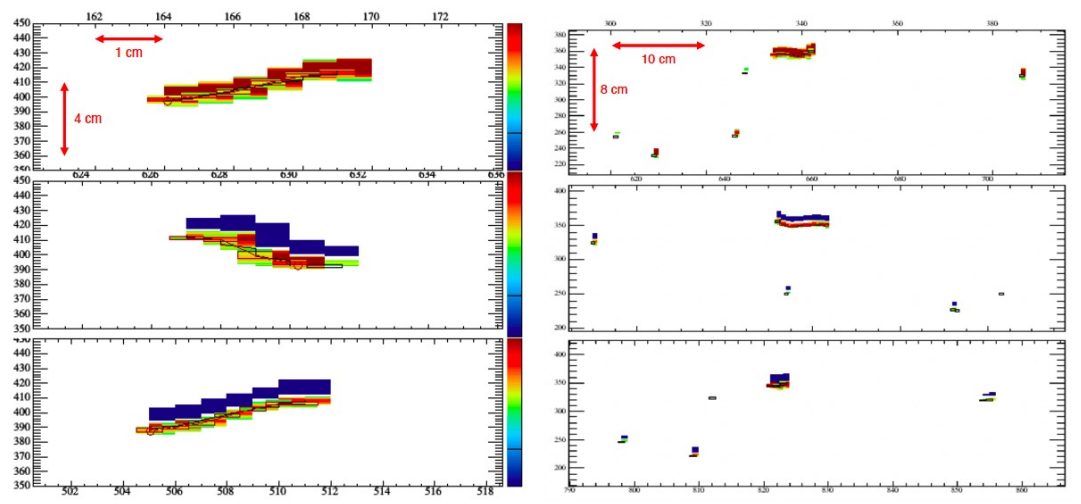
- DUNE has the potential to record an enormous amount of solar neutrinos
- For an energy threshold of 5 MeV in a 10 kt FD:
  - ~10,000 CC evts/year
  - ~2000 ν-e scattering evts/year
- Above 14 MeV, pure hep neutrino sample
  - Up to 50 evts/year



Challenges for MeV scale physics

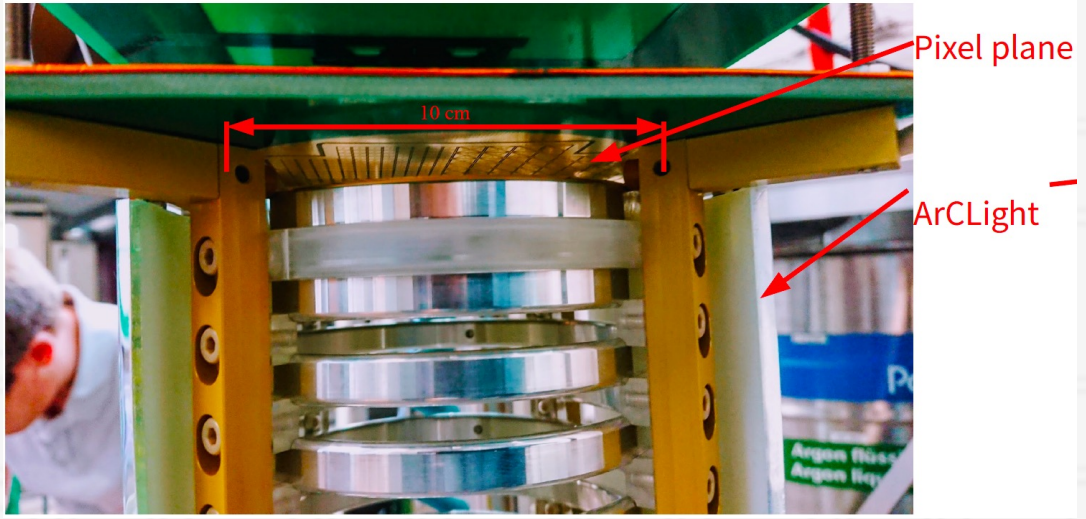
- Rare event selection from all MeV signals
  - SoLAr benefits from pixellated readout and direct combination with light
  - True 3D detector -- Voxellization of entire detector
- Efficient continuous readout of low energy signals necessary
  - ASICs to collect and digitize charge and light signals, giving hit data
  - Zero suppression at digitization step and at physics signal collection point
- Energy resolution crucial to distinguish radioactive backgrounds from signal
  - Combined light and charge readout will enhance the energy resolution

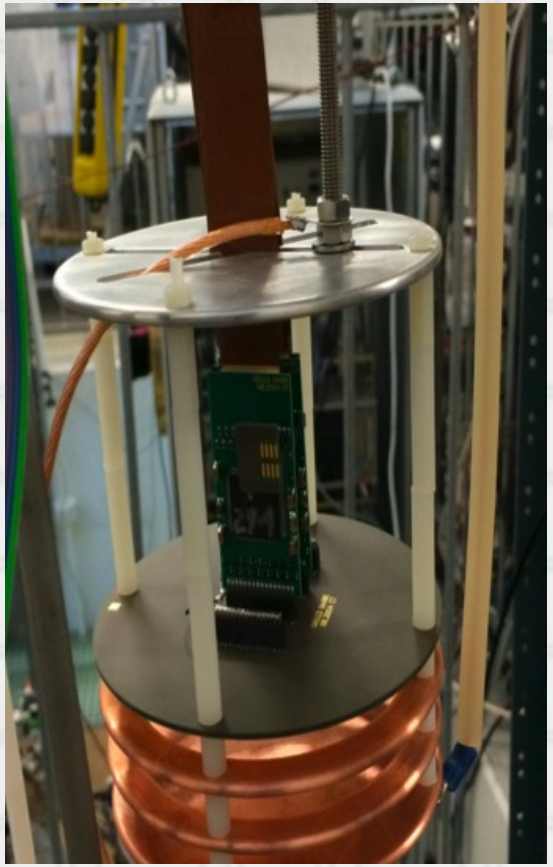
- LAr TPC advantages:
  - Excellent position granularity in **both** charge and light
  - Measure directionality for very short tracks
    - Mitigation tool against some radioactive backgrounds
  - Pulse shape discrimination



Current status: Pixel readout in LAr

- Technology development for charge collection pixels in LAr
  - Bern has well established laboratory
- Pixel readout is under development for DUNE ND (LAr) and future FD pixel applications
  - LArPix
  - Qpix

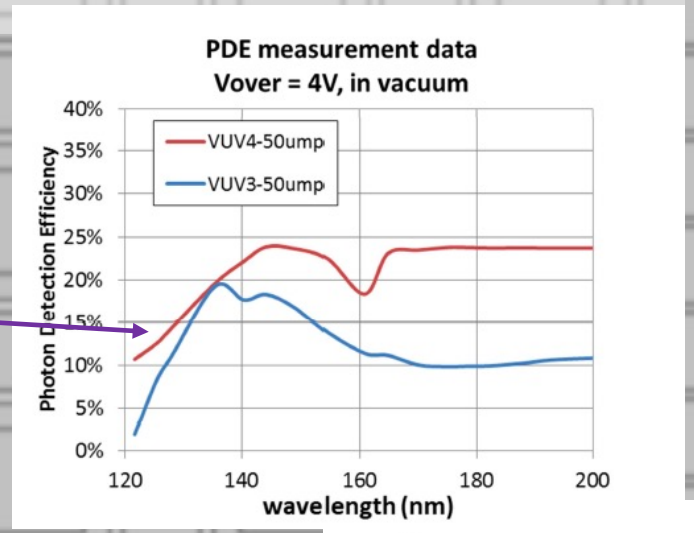


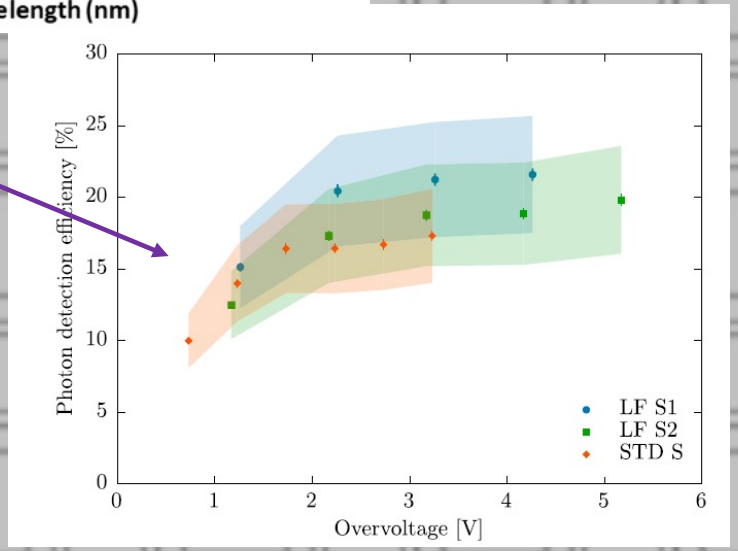


LArPix:
JINST 13 (2018) 10

Current status: Light readout in LAr

- Technology for VUV SiPMs has made significant advances over the past decade
  - Hamamatsu VUV SiPM (gen 4): 15%
  - FBK VUV-HD technology
- Mature enough for direct light detection without wavelength shifting
- SoLAr takes a staged approach
  - Working with existing devices with a view to forthcoming upgrades





Plans going forward

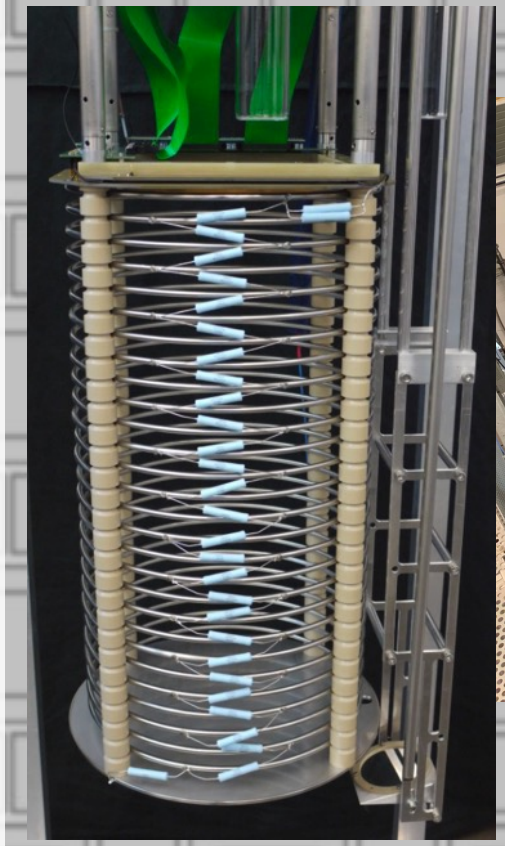
Small-scale benchtop prototype

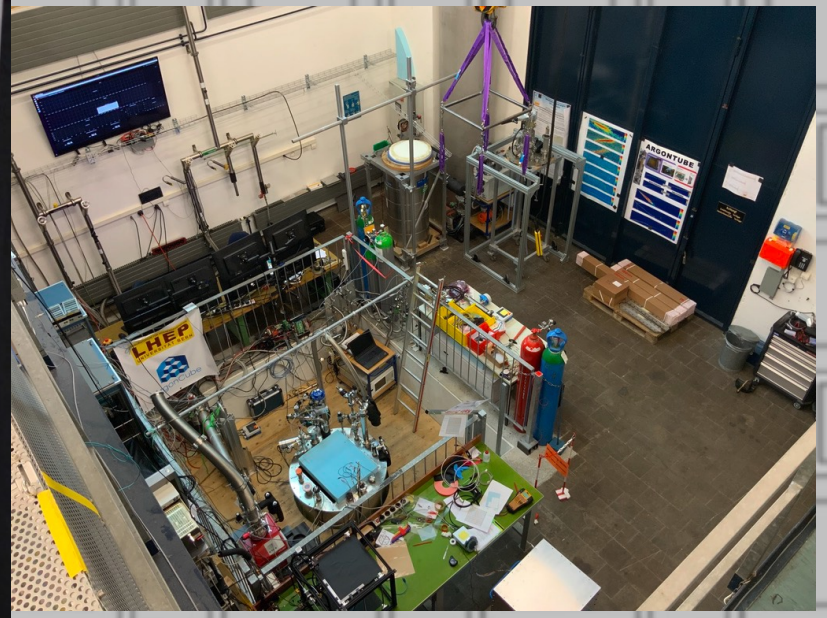
Medium scale prototype at Boulby

DUNE Module of Opportunity (?)

Benchtop prototype

- Proof of concept detector
  - Summer 2022 at Bern
  - Using currently available technologies
    - 6mm x 6mm Hammamatsu VUV SiPMs
    - LArPix readout (for both charge and light collection
- 100mm x 100mm readout plane
- 100mm drift distance

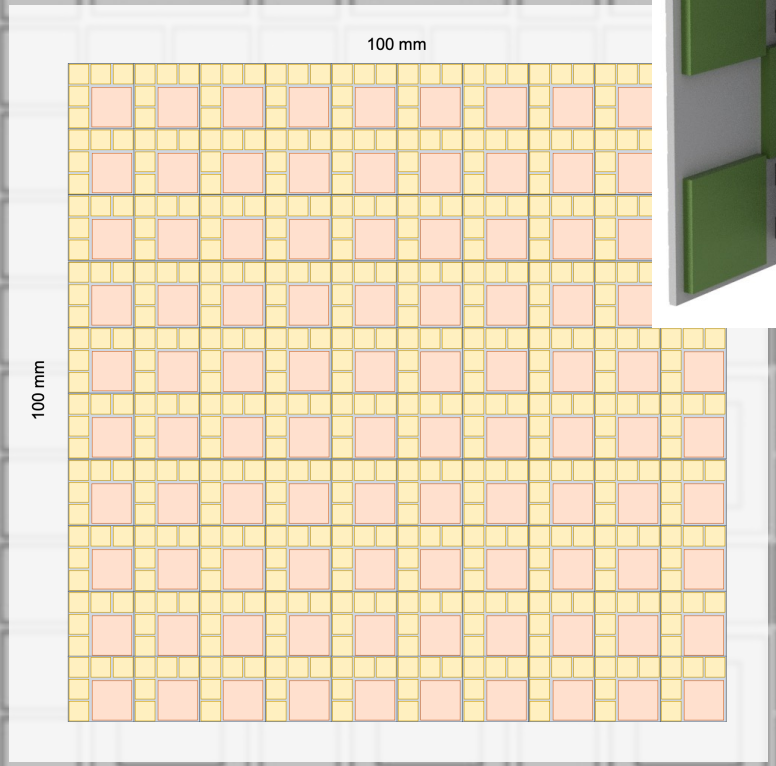


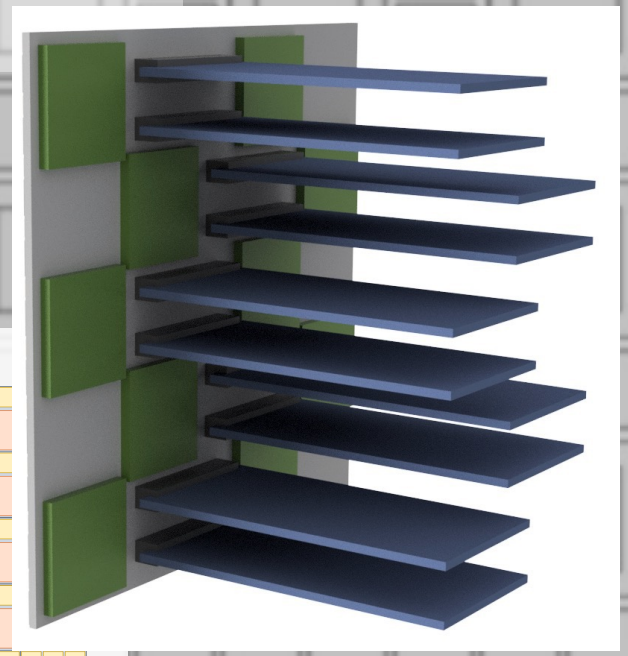


Baseline SoLAr design – Combined pixel plane

- Plane combining SiPMs and charge readout pads
- Prototype tile design
  - 100mm x 100mm
  - 100 SiPMs
  - 500 x 3x3mm pixels
- Initial plan to use existing electronics used in DUNE ND neutrino prototype modules

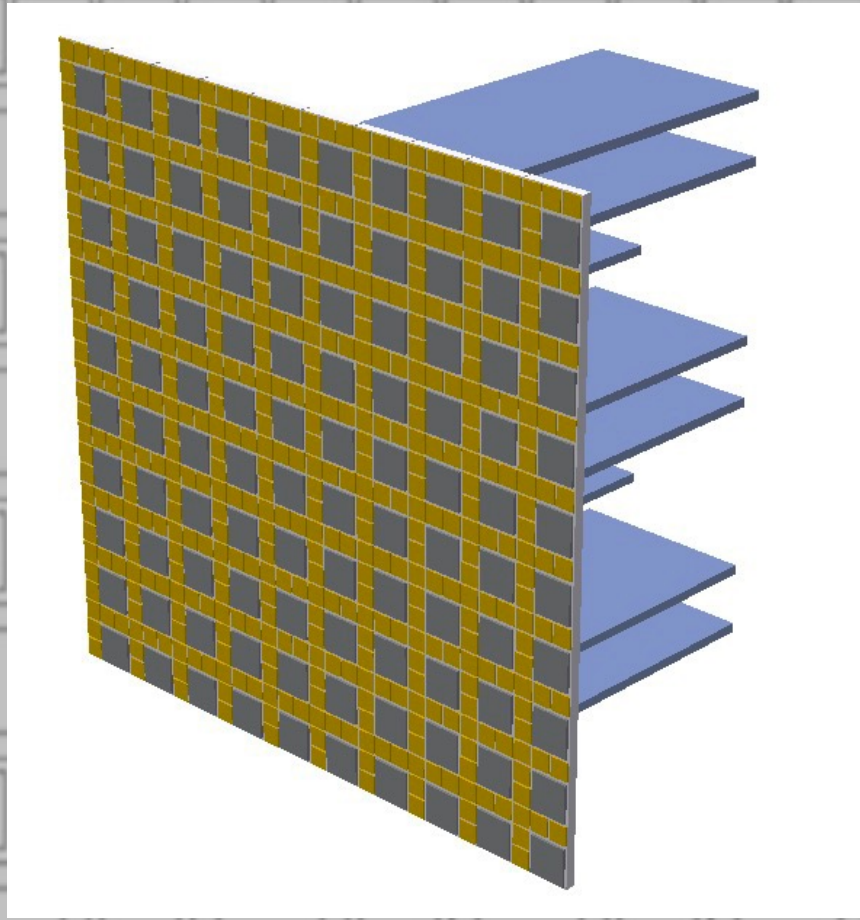
  (2x2 ArgonCube)
  - 10 LArPix chips + PACMAN controller
  - 10 preamplifier cards (light readout)





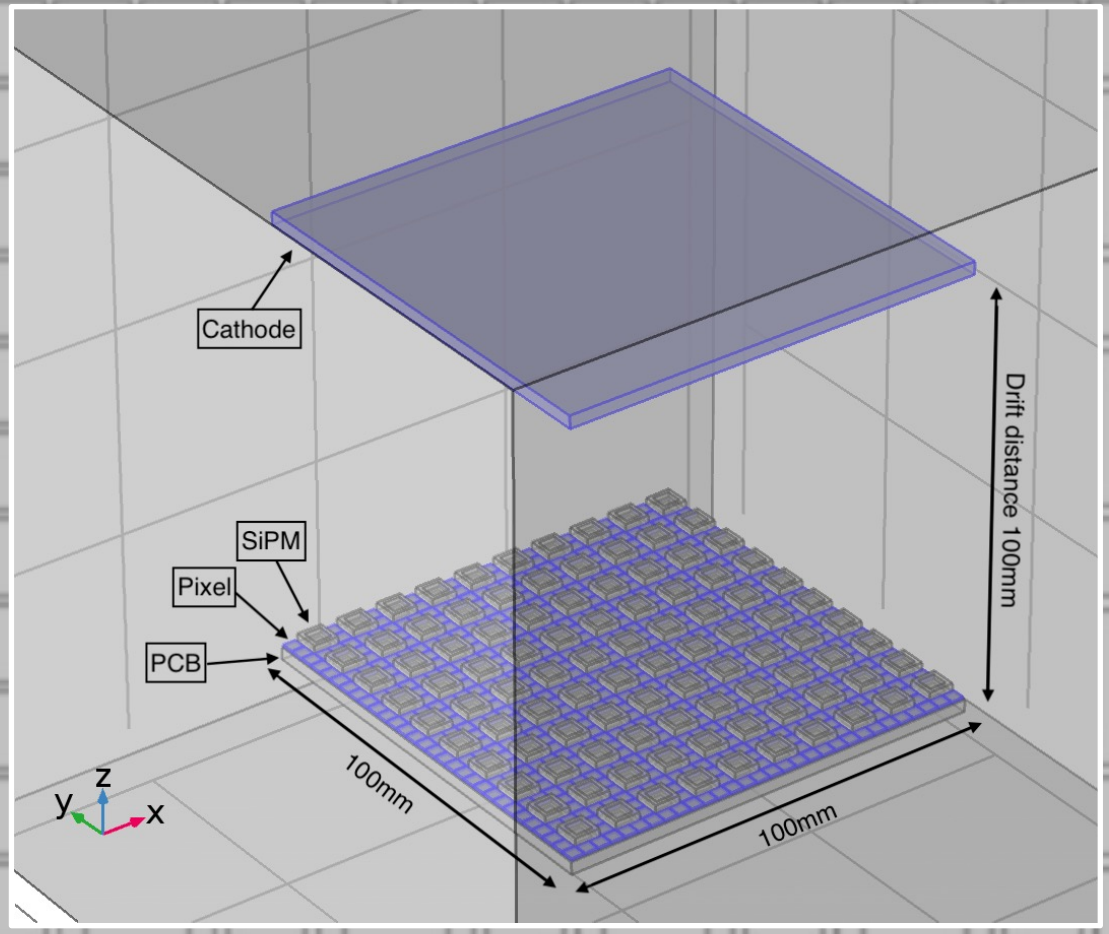
Baseline SoLAr design – initial goals

- **First readout of light and charge signals in the same plane in a LArTPC**
- Combining light and charge on the same PCB is new:
- Initial goals are to study signal integrity, crosstalk, electrical noise between the two technologies
- Next prototyping step:
  - Use LightPix/Qpix chip for light readout



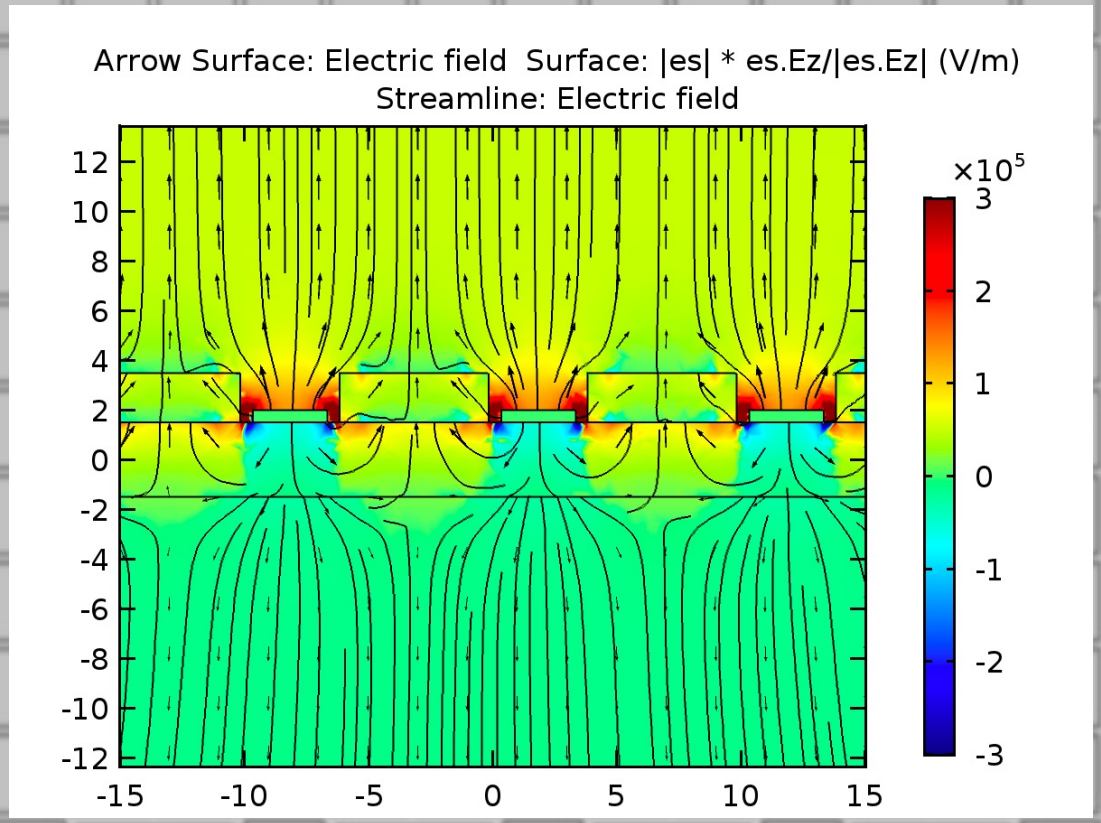
First simulations

- Modelling electric fields in a basic TPC with combined readout anode
  - COMSOL finite element modelling of electrostatics
  - 3D model
- Efficacy of charge collection calculated for different pixel geometries



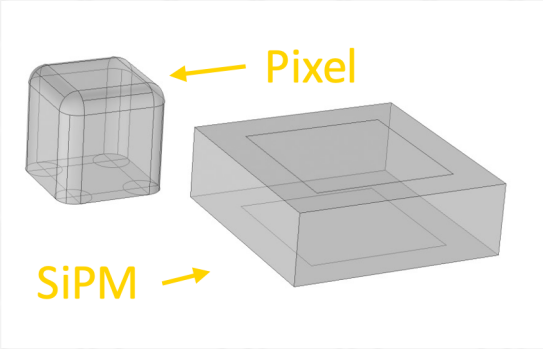
Field simulations – starting point

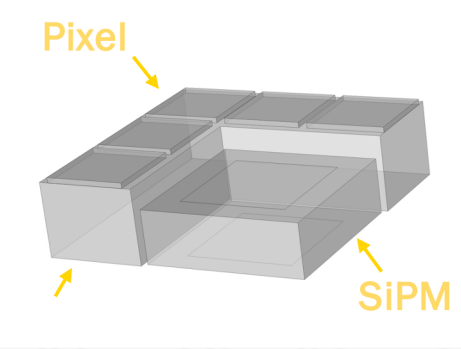
- Simple pixel geometry with SiPMs on PCB
- Pixels biased at 0V
- Nominal bias of SiPMs is +57V
  - Surface area of SiPMs is large and higher than pixels
- Necessary to float SiPM at -300V (247V at base) to achieve reasonable charge collection at pixels
- Motivated alternative geometry investigations

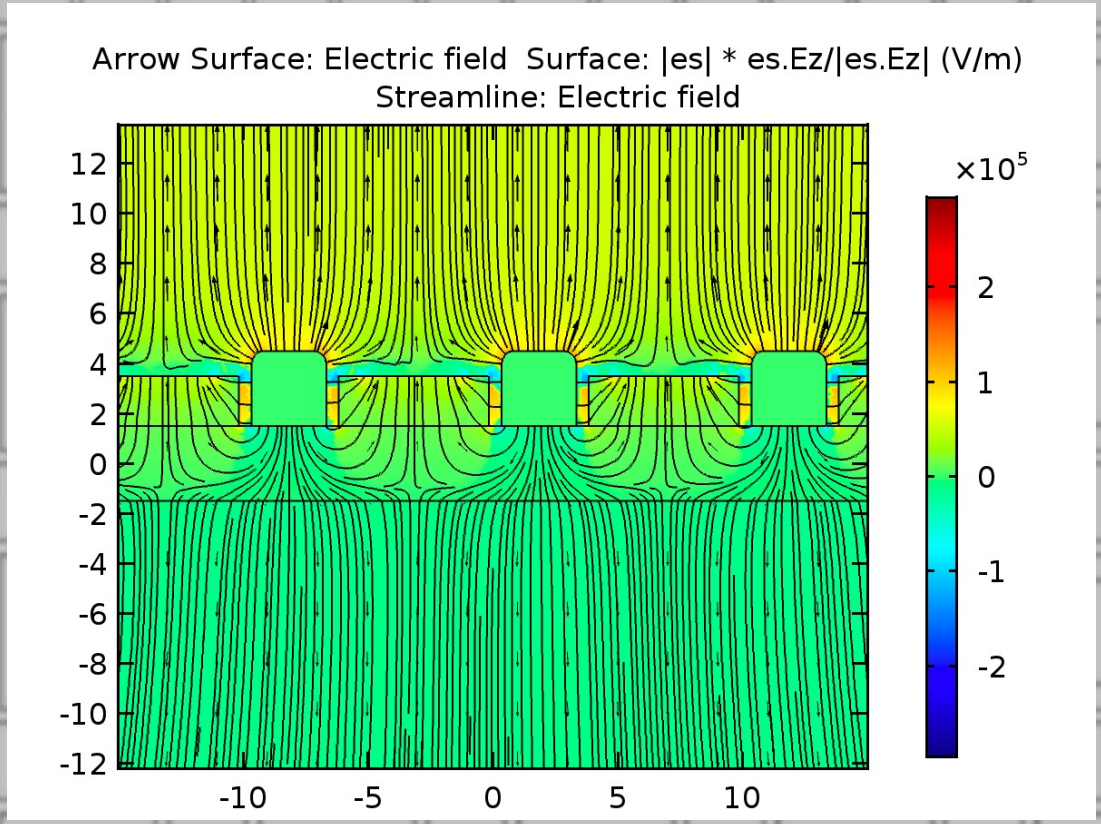


Field simulations – raised pixels

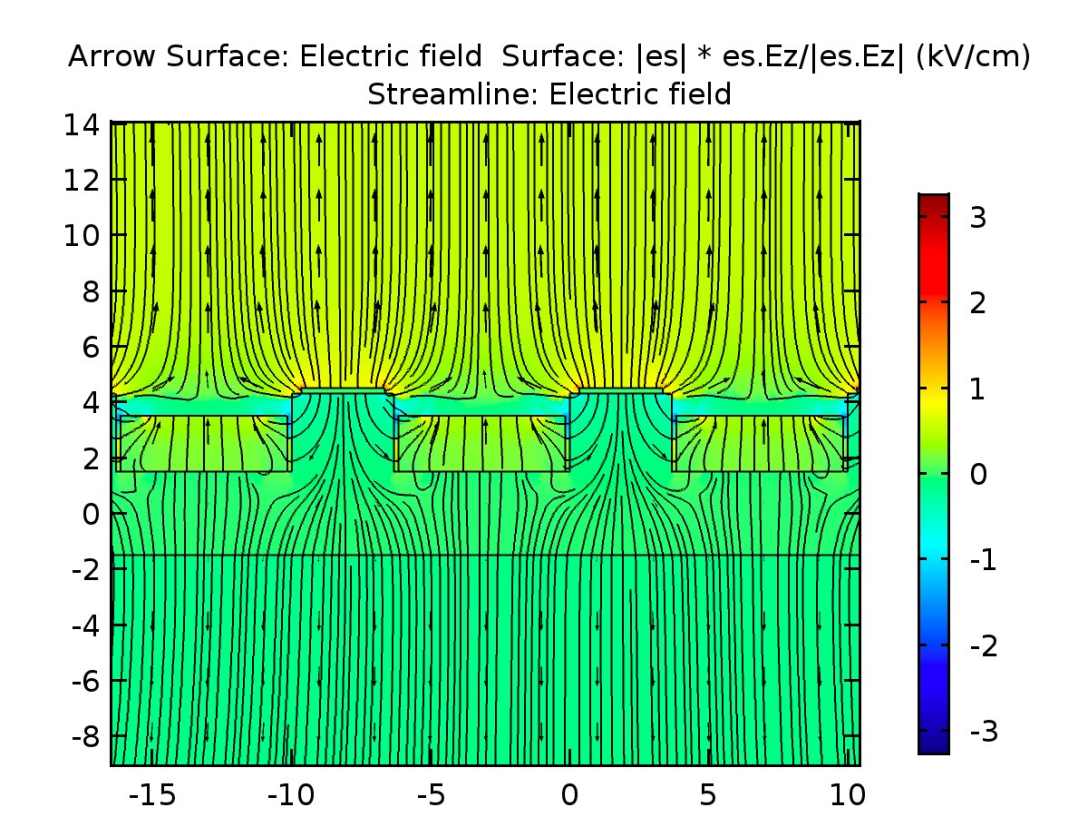
- Two options modelled for raising pixels
  - Tall pixels
  - Raised PCB
- Both necessitate reverse biasing SiPM and floating at -100V







Field simulations – conclusions



- Using electric field lines as a metric for charge collection efficacy:
  - Baseline flat pixels with floating SiPM bias of -300V: ***83%***
  - Both raised pixel geometries with floating SiPM bias of -100V: ***99%***
- Raising the pixel pads to be level with the SiPM allows good charge collection on a combined readout plane
- Pixel plane **fabrication studies** will determine the future direction

Plans going forward

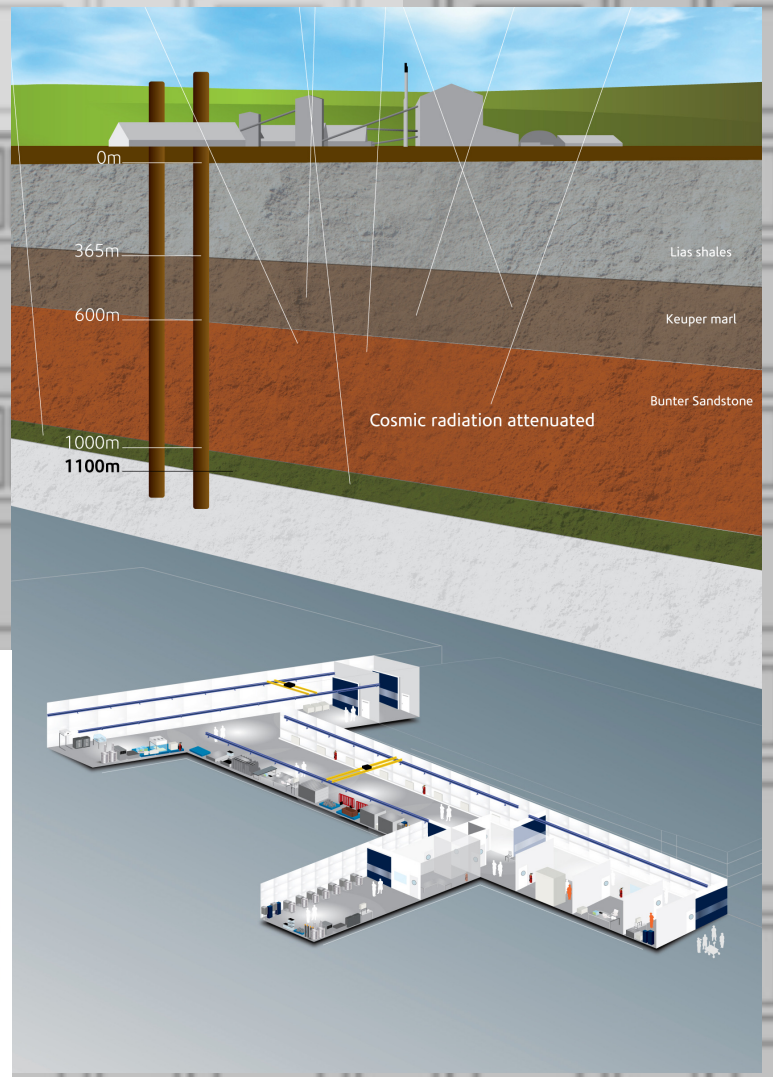
Small-scale benchtop prototype

Medium scale prototype at Boulby

DUNE Module of Opportunity (?)

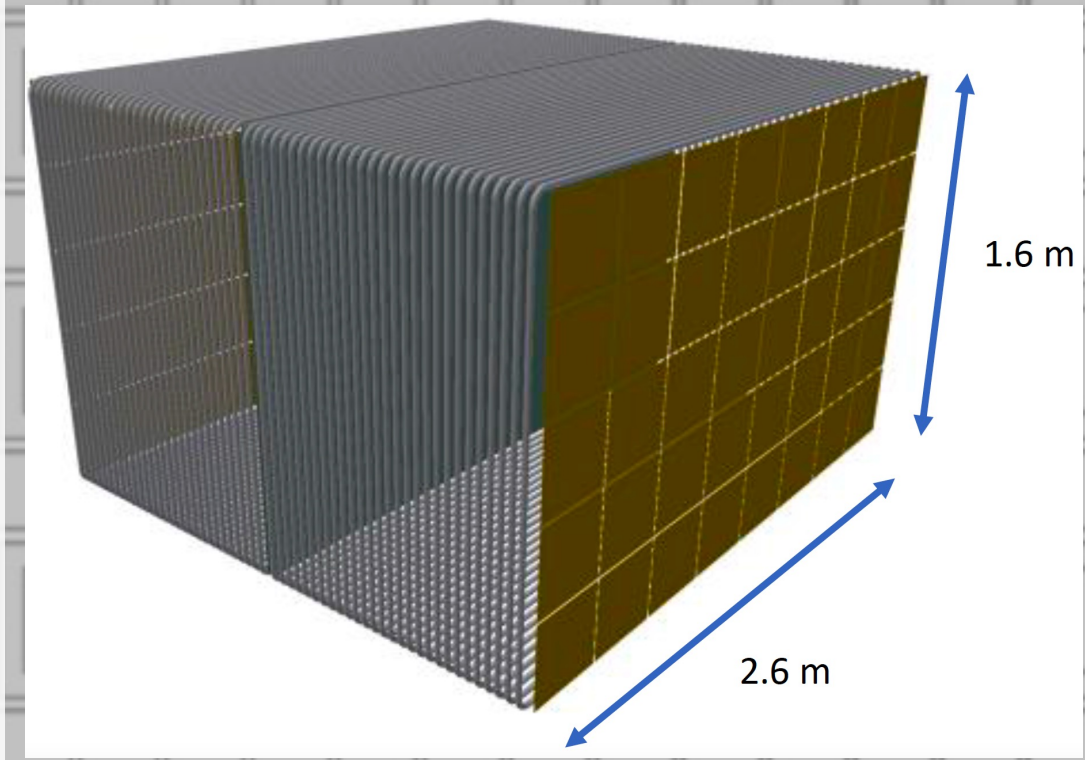
Prototype detector at Boulby

- Boulby Underground Laboratory (UK)
  - Working potash, polyhalite and rock-salt mine since 1968
  - Underground science lab since 1990s
    - Dark matter, material screening
  - 1,100m of rock overburden



Prototype detector at Boulby

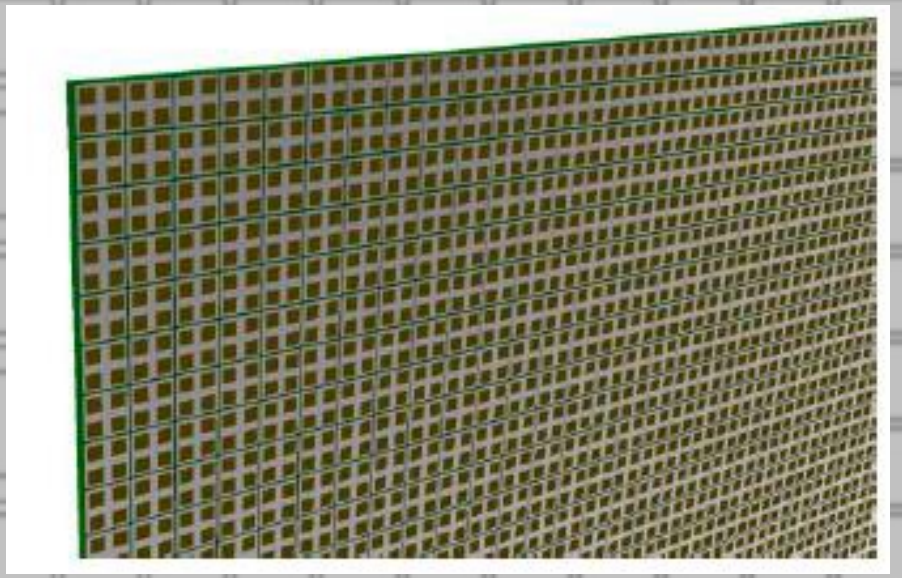
- Tests of intermediate size detector
- Detector physics measurements:
  - Light yield
  - Charge collection + readout
  - Background vs solar neutrinos
    - Developing software + hardware to reduce backgrounds
- Design, prototyping, construction:
  - 2023 – 2027
- Integration, operation:
  - 2027– 2028



DUNE module of Opportunity

- Three areas developing in parallel:

- Technology development in pixel readout
- Technology development in VUV SiPMs
- SoLAr prototype – integration test!



Future large scale detector monolithic light/charge pixel detector

Summary and Conclusions

- SoLAr is a new collaboration with aims to extend the physics reach of LAr detectors to the ~MeV range
  - Sensitivity to solar neutrinos, supernova neutrinos
- Pulling together charge and light readout technologies in liquid argon to achieve this goal
- Staged approach to become a feasible contender for DUNE Module of Opportunity
- Stay tuned for future results!

Backup

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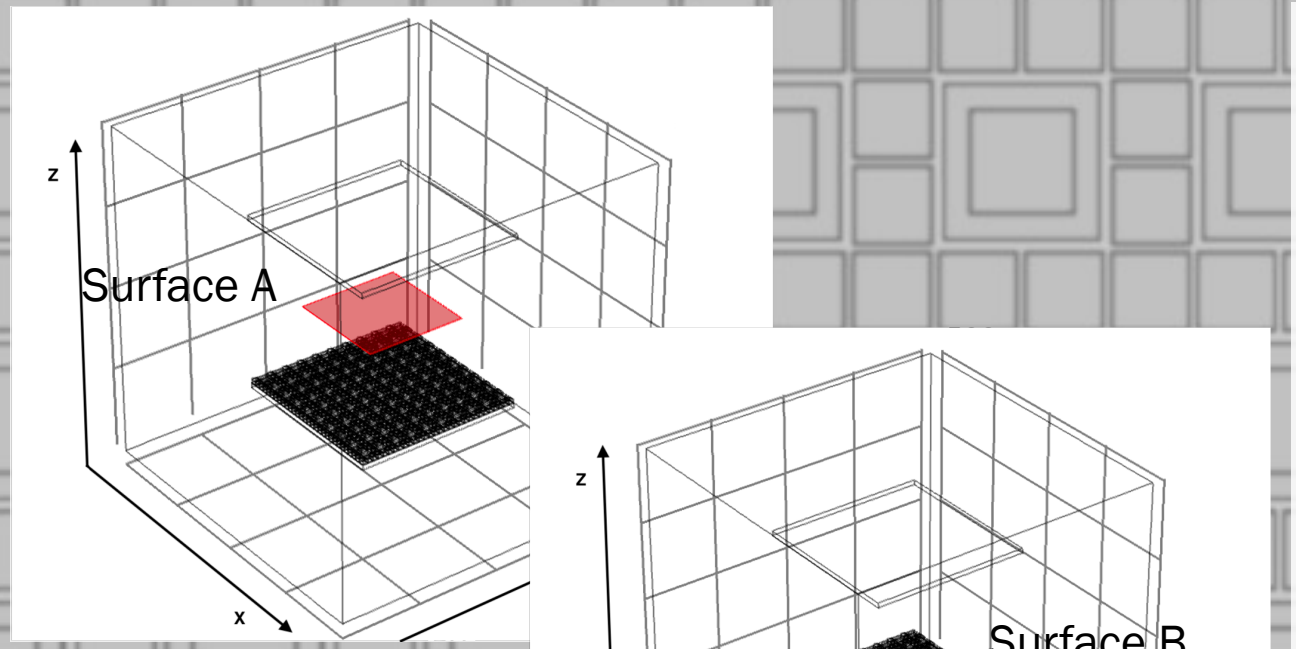
Charge collection efficacy calculations



- Integrating the Z-component of the electric field where $z \geq 0$ over each surface gives a metric for the number of electric field lines and hence drifting electrons which are passing through each surface, propagating towards the collection plane.
- Calculating the ratio of Surface B / Surface A, we obtain the fraction of the electric field lines ending in the SiPM surface.
- This represents the space where electrons are not captured by the charge pixels.
- Subtracting this from unity gives the charge collection efficacy.

Low energy neutrino signal in LAr

I.Gil-Botella & A.Rubbia
hep-ph/0307222
JCAP 10 (2003) 009
JCAP 08 (2004) 001

- Elastic scattering (ES) on electrons

$$\nu + e^- \rightarrow \nu + e^-$$

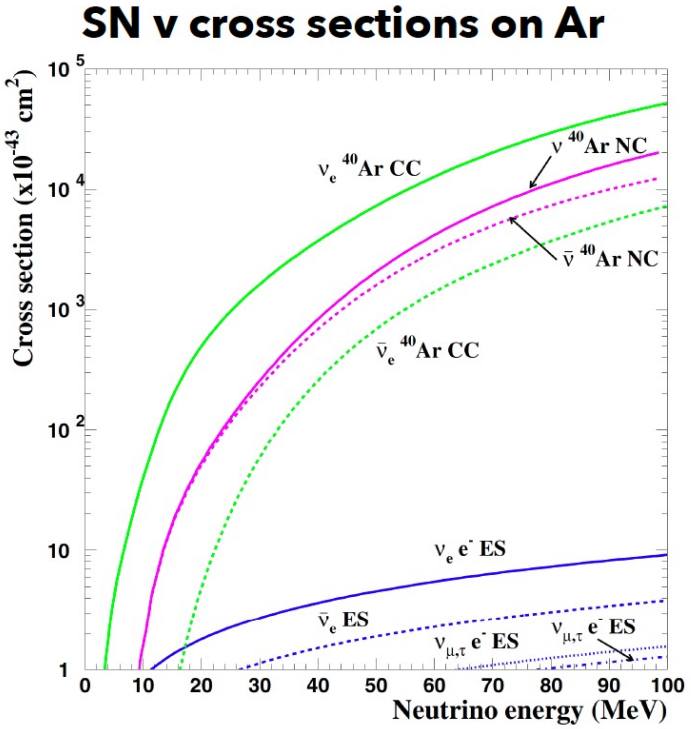
- Charged-current (CC) interactions on Ar

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^- \qquad E\nu_e > 1.5 \text{ MeV}$$

$$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+ \qquad E\bar{\nu}_e > 7.48 \text{ MeV}$$

- Neutral current (NC) interactions on Ar

$$\nu + {}^{40}Ar \rightarrow \nu + {}^{40}Ar^* \qquad E\nu > 1.46 \text{ MeV}$$



Possibility to separate the different channels by a classification of the associated photons from the K, Cl or Ar de-excitation (specific spectral lines for CC and NC) or by the absence of photons (ES)

Current status of DSNB

- Guaranteed source of SN neutrinos (averaged neutrino flux from all supernovae)
- Not detected yet
  - Best limit by SK: (Phys. Rev. D 85, 052007 (2012))

    $\Phi(\bar{\nu}_e) < 2.8\text{-}3.1\ cm^{-2}\ s^{-1}$ for $E_\nu > 17.3$ MeV
- WC and LSc experiments detecting antineutrinos while DUNE will uniquely constrain the neutrino flux
- Main backgrounds for ν_e channel: solar and atmospheric neutrinos
- Look for an energy window where signal dominates over backgrounds
- **DUNE**, in 10 years, n.h. (from DUNE Physics TDR)
  - $N_{DSNB} = 46 \pm 10$ (16 MeV $\leq E_e \leq$ 40 MeV)

SNR flux prediction based on Strigari et al., JCAP03 (2004) 007