LArCADe | L iquid Argon Charge Amplification Devices

Tiny Tips, Big Signals: Toward Low-Threshold CEνNS Imaging in Argon

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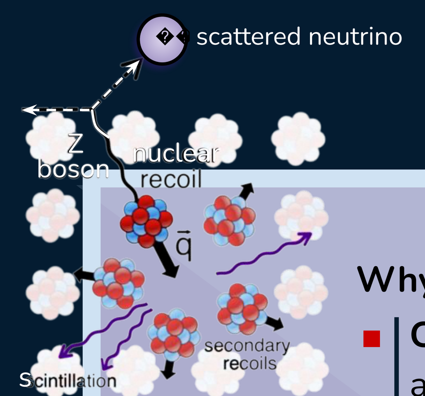
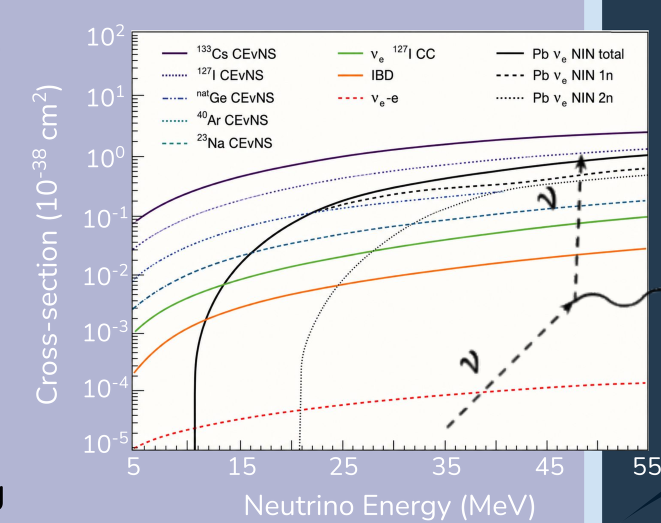


THE PHYSICS CASE[1]

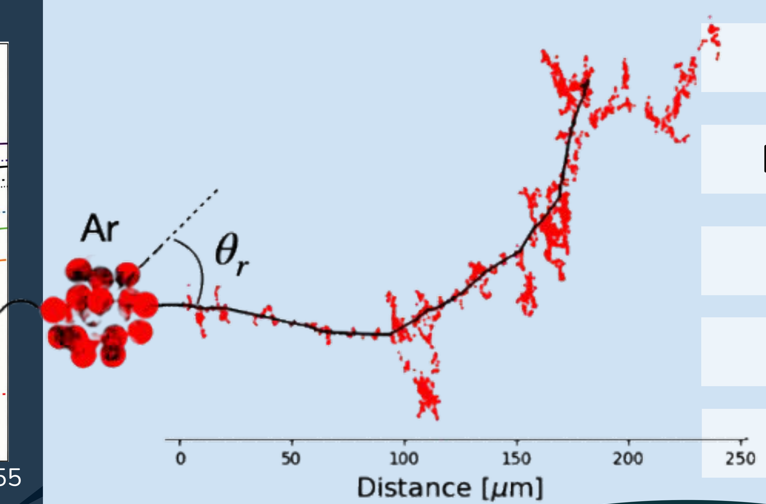
Why CEνNS in LAr?

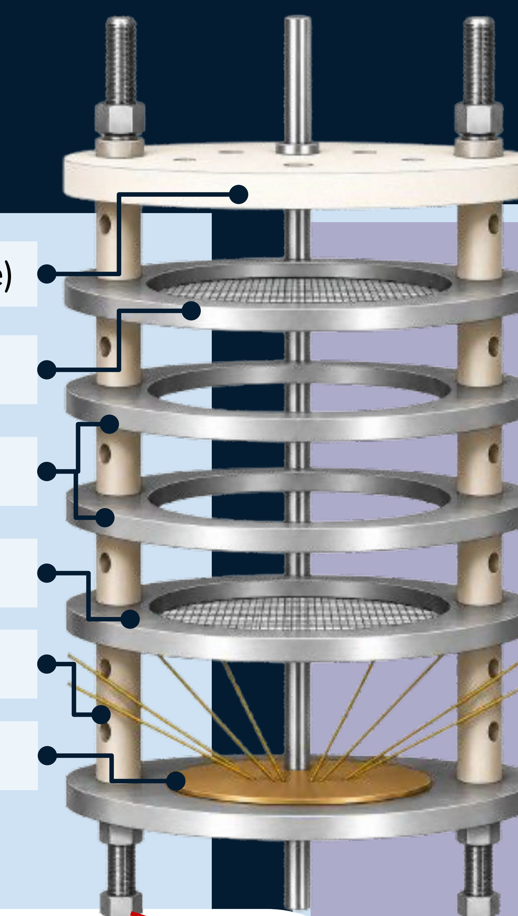
- **CEνNS is a clean neutral-current probe** of neutrino and BSM physics
- To fully exploit it we need the **recoil energy and direction**
- In argon, CEνNS recoils are **short and weakly ionising**, producing only O(10s–100) e⁻
- This pushes signals toward current LArTPC electronics-noise limits O(100s-1k)
- **LArCADe goal:** stable, proportional charge amplification to enable low-threshold recoil imaging



Expand reach of large-scale single-phase LArTPCs to be sensitive to nuclear recoil ionisation signatures

AIM

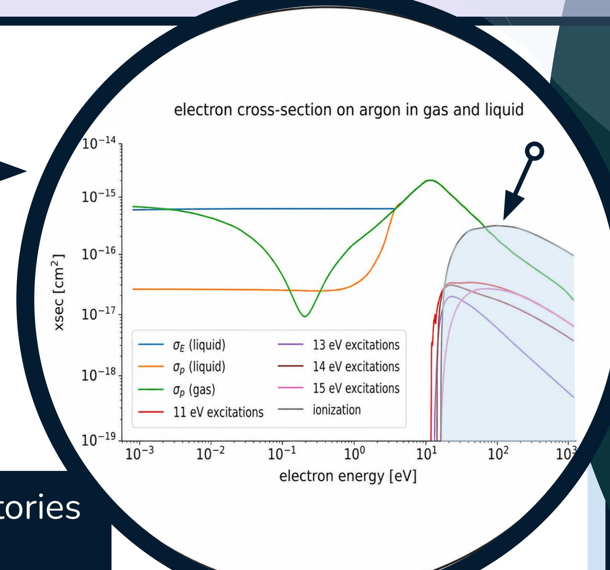




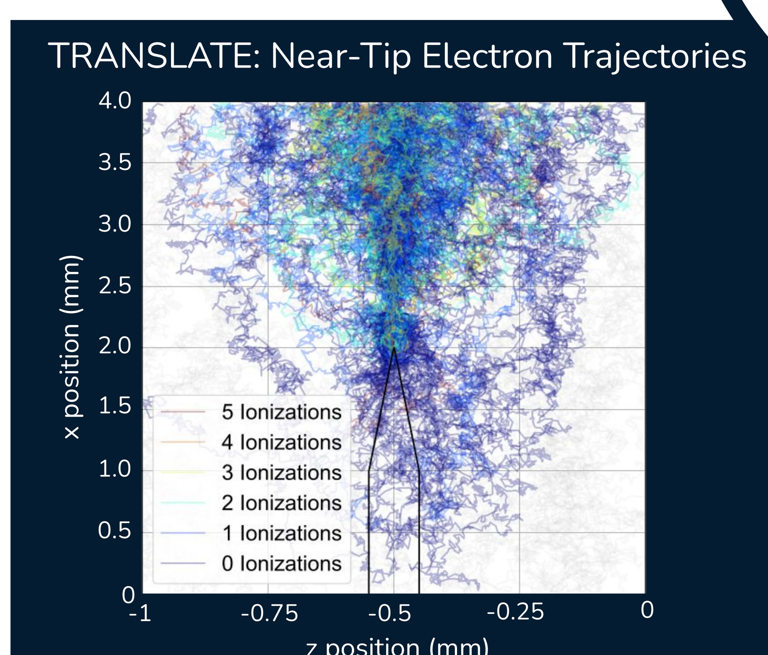
TRANSLATE[2]

A custom first-principles micro-physics MC simulation of charge propagation, amplification & recombination in Argon.

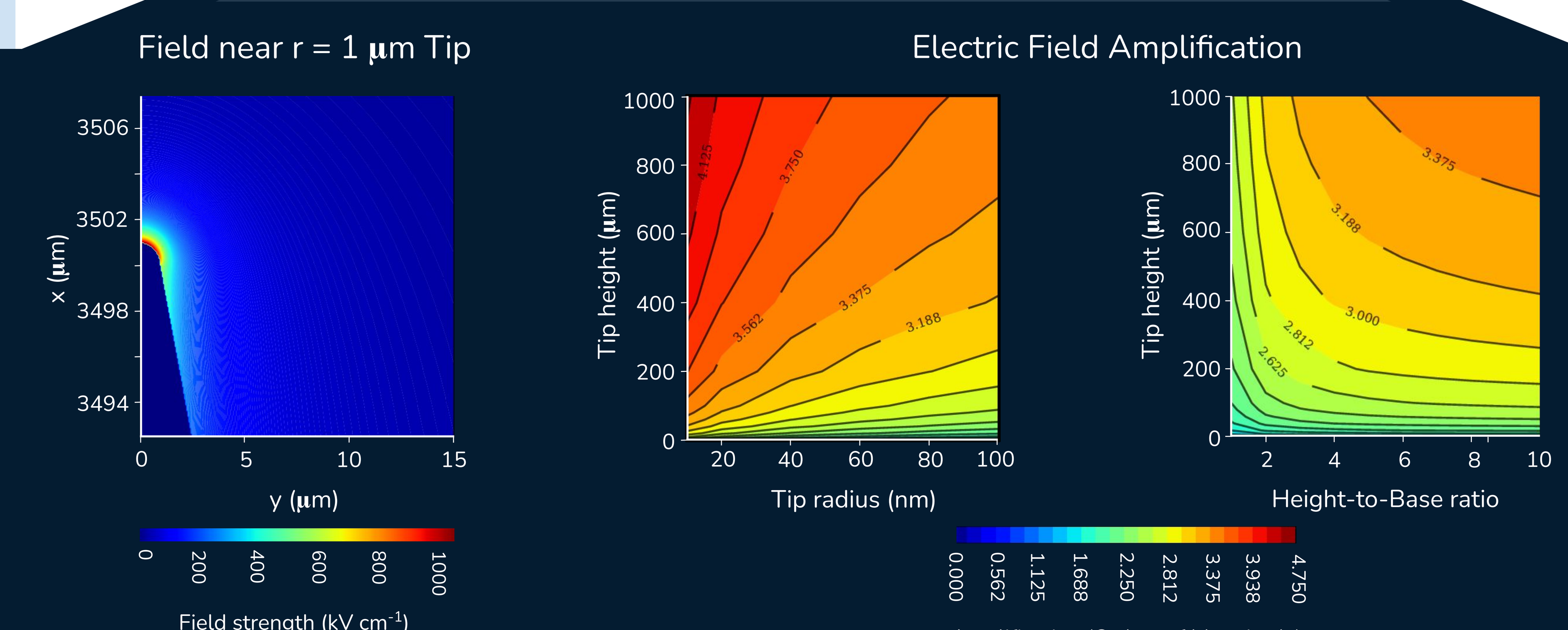
- Electrons must reach **O(10 eV)** to ionise Ar and produce avalanche multiplication
- Dense LAr scattering competes with electron energy gain
- TRANSLATE models electron transport, scattering, excitation, and ionisation in non-uniform E-fields



- **Benchmarked to data** | GAr swarm parameters from LxCAT/Biagi databases, LAr mobility/diffusion from BNL/ ICARUS/ MicroBooNE.



- Simulation guides:
  - **tip radius**, **height**, **pitch**, and **operating field**



The Challenge

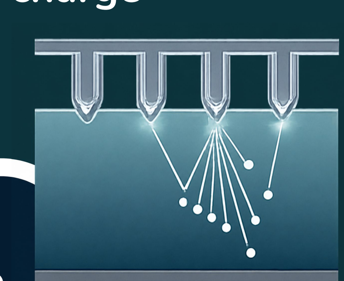
CEνNS nuclear recoils in LAr produce only **O(10s–100) free electrons**, near/below the noise scale of current LArTPC charge readout.

Toward CEνNS Imaging

Local amplification can lift few-electron charge deposits above electronics noise while preserving spatial information.

The Solution

Sharp anode tips create intense local electric fields, aiming for **stable, proportional charge amplification** in Ar.

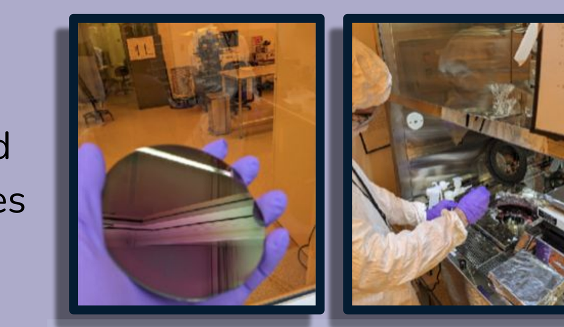


Big Signals, Localised Collection

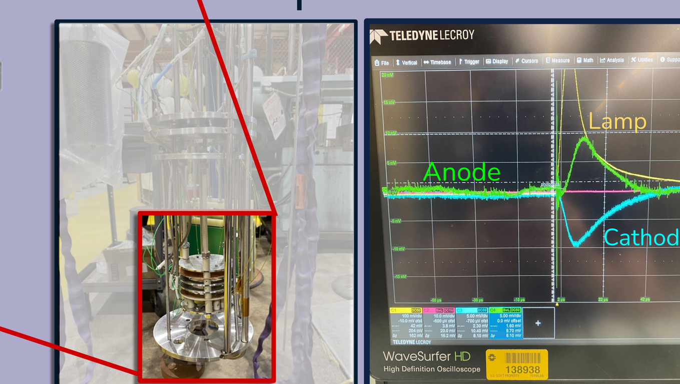
LArCADe targets low-threshold, **O(100 μm)** charge reconstruction for spatially resolved nuclear-recoil measurements.

CURRENT STATUS

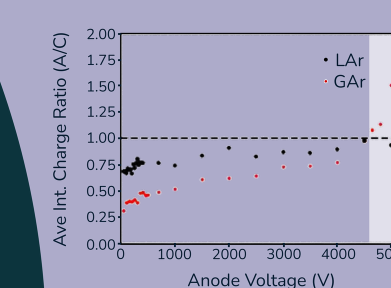
- Using **conventional microfabrication workflow**
- These **structures** were used in initial amplification studies
- Established the first **hardware platform** for testing charge amplification concepts in LAr:

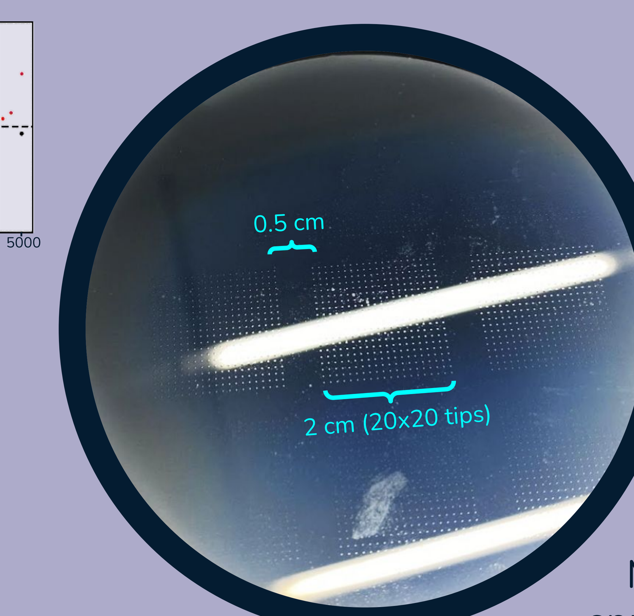

Photolithography

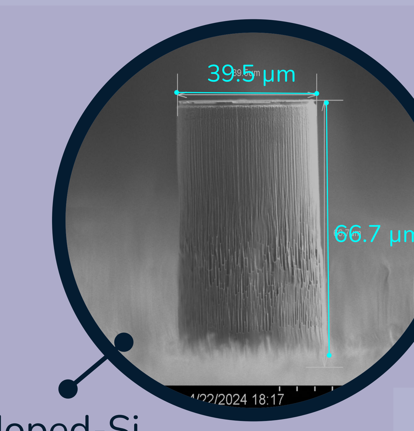

Mask Alignment & Deposition



Doped Si alone can produce clean, stable, reproducible photoelectron signals in vacuum!

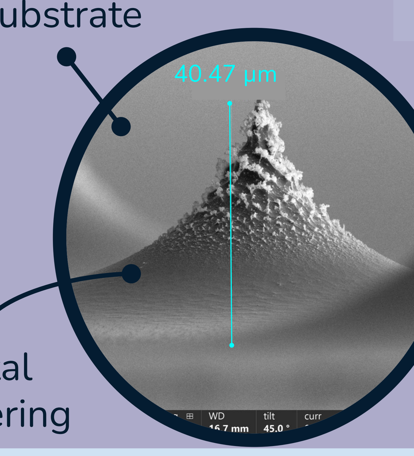






doped-Si substrate

Etching & Sputtering



Metal sputtering

TAKEAWAYS

Achievements

- Established LArCADe test bed for anode/tip R&D
- Benchmarked **TRANSLATE** electron-transport and amplification simulations
- Demonstrated stable GAr amplification with metal-sputtered Si tips
- Showed doped Si can produce stable signals without sputtering - characterisation of resistive anodes started as a parallel dedicated effort **(MOSAIC)**

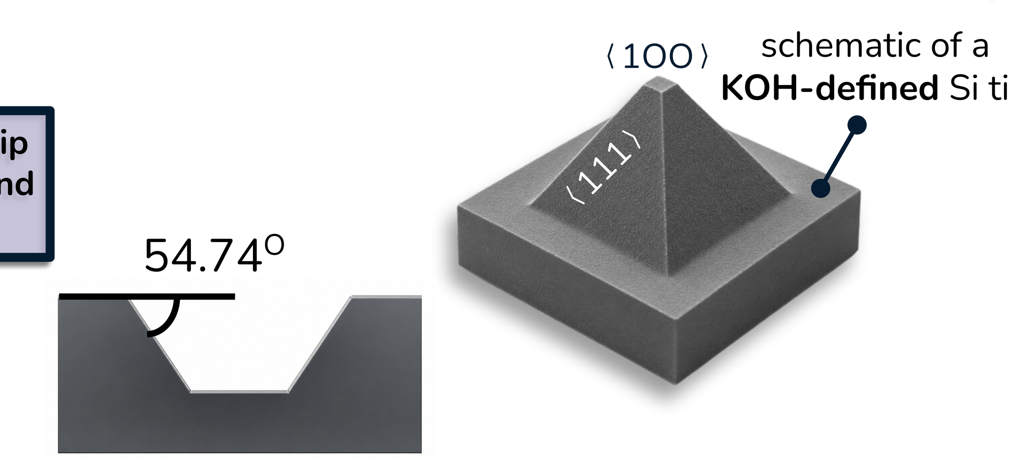
Next Steps

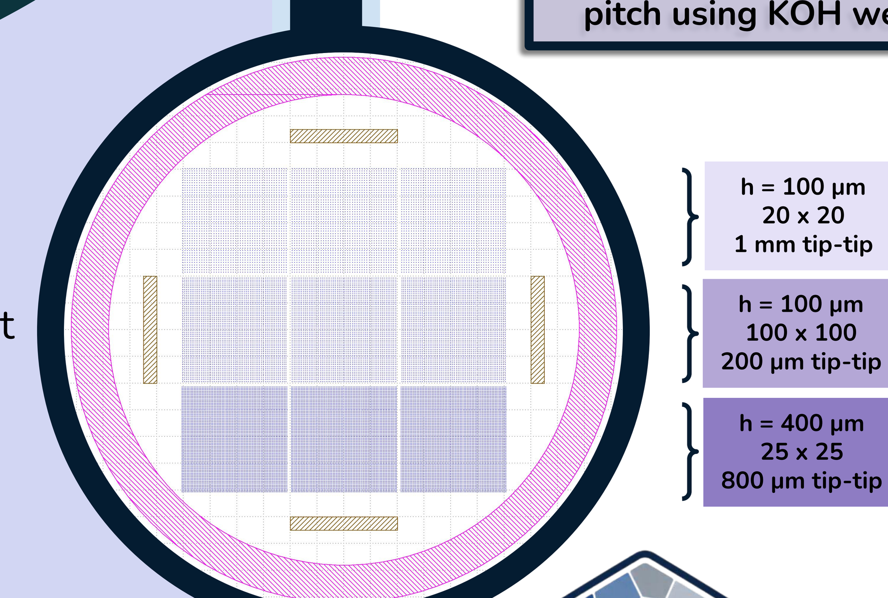
- Fabricate KOH-defined Si nanotip arrays at UCSB
- Validate simulated gain predictions in GAr and LAr

NEW DIRECTIONS

NEW!

Doped-Si truncated-pyramidal tip structures with tunable height and pitch using KOH wet-etching[3]





MOSAIC
Material-Oriented Signal Architecture in Cryogenic Detectors

- **Closed simulation-to-hardware loop:** TRANSLATE outputs set mask geometry
- Doped-Si **simplifies fabrication** by eliminating sputtering while providing **tunable conductivity**
- KOH etching[3] of ⟨100⟩ Si forms sloped **{111} facets** set by crystal geometry
- **Square cap masks protect the apex**, leaving doped-Si tip structures after etching (10 μm square tip)
- **100–400 μm tip heights** and variable pitch/spacing tune field amplification
- **CAD-generated 3×3 layouts** enable wafer-scale tip-array fabrication

References

[1] Marinho et al., JINST **17**, C07009 (2022).
[2] Beever et al., Comput. Phys. Commun. **297**, 109056 (2024).
[3] Yun et al., J. Vac. Sci. Technol. B 16, 2844 (1998).

Acknowledgements

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