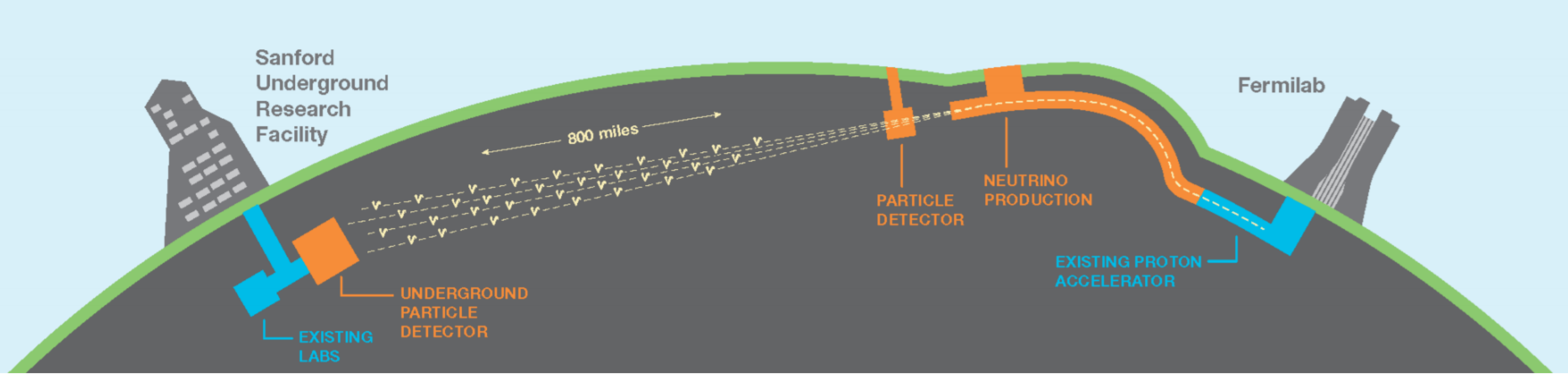
DUNE prospect for DSNB

Dan Pershey – Florida State University

Towards the detection of diffuse supernova neutrinos

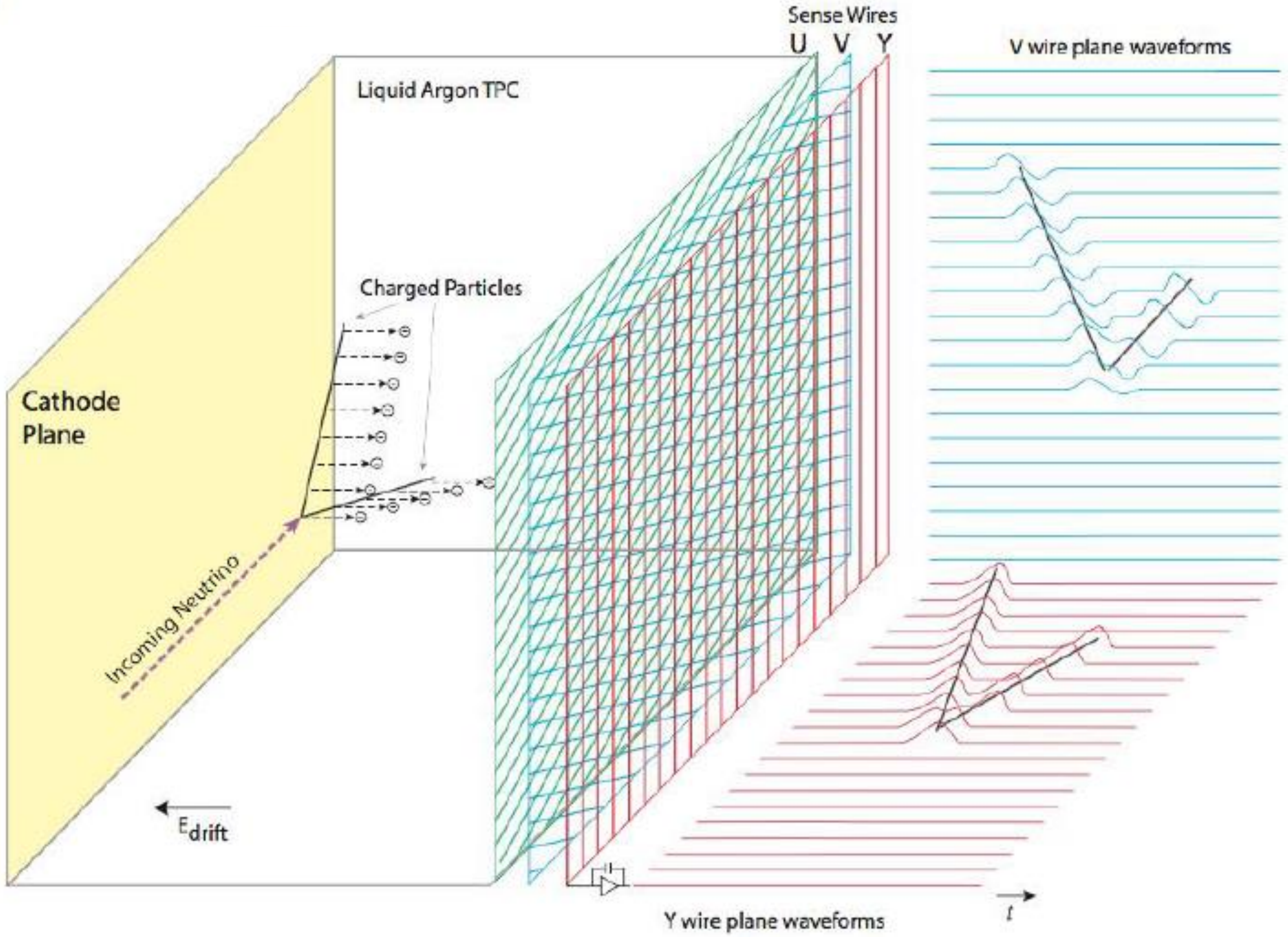
Johannes Guttenberg University Mainz // Sep 16, 2024

The DUNE experiment



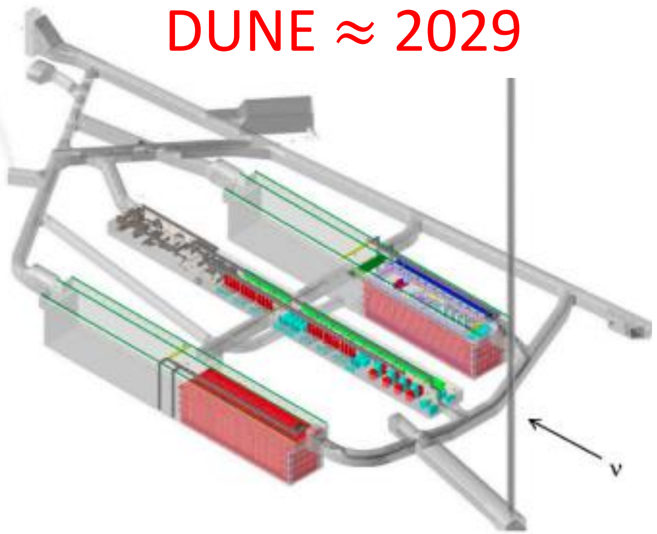
- 4 x 10 kton (fiducial) mass LArTPC detectors with 4300 mwe overburden -> ideal for searching for rare astro-neutrinos with precision reconstruction
  - Assume in this talk a DUNE with four liquid argon TPC modules
- DUNE will further constrain neutrino oscillation parameters including the CP-violating phase angle
  - Measured using a high-purity $\nu_\mu/\bar{\nu}_\mu$ beam produced at Fermilab

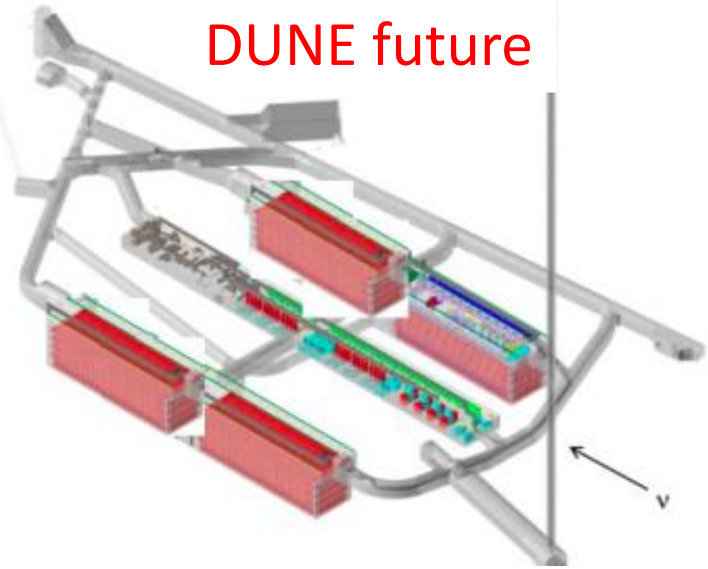
LArTPC technology



- Noble liquids have no chemistry – ionized charge stable in medium for >> ms
- Charge drifts along electric field to a detection plane
  - Economy of scale, number of channels $\propto \sqrt[3]{M}$
- Detectors are slow, *exploit high argon scintillation yield* for t_0 determination

The far detector complex





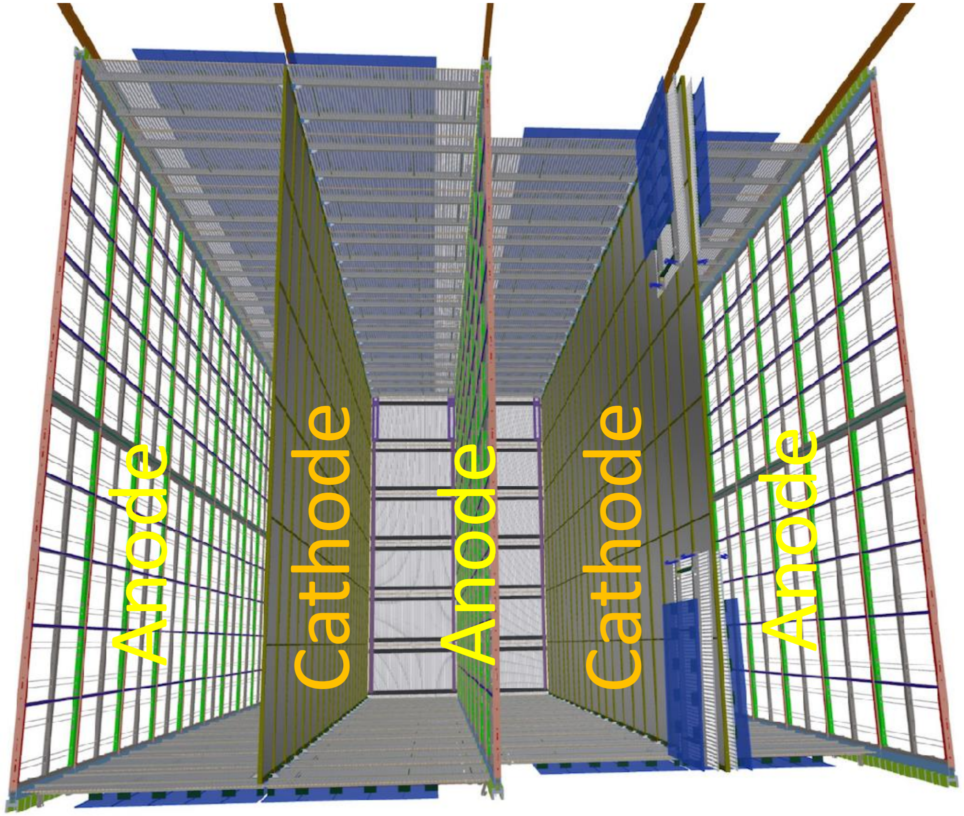
- New caverns excavated off the Ross shaft at Sanford Underground Research Facility (SURF)
- Construction of the enormous and modular experiment will occur over two phases
  - Phase I: construction of first two far detectors, FD1 + FD2 (≈ 2029), along with new beamline and first generation near detector (≈ 2031)
  - Phase II: construction of FD3 + FD4 along with beam and near detector upgrades (future)
- US Particle Physics Project Prioritization Panel <u>prioritizes early construction of FD3 with expanded low energy program</u> and later FD4

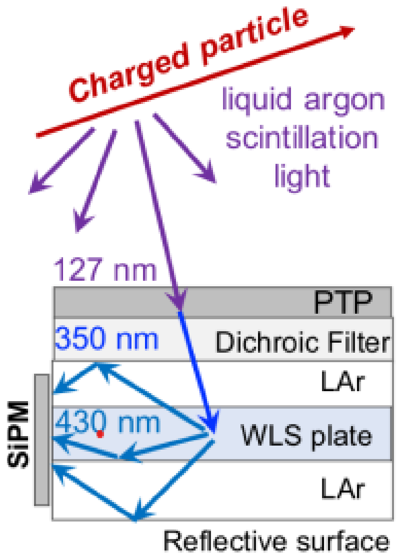
Cavern excavation complete!

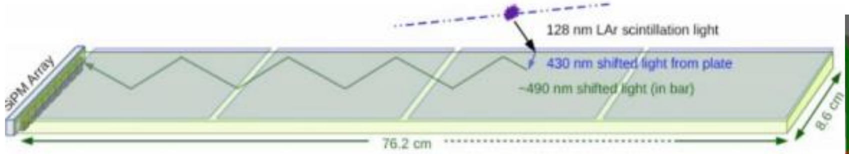
- Underground excavation has completed as of May 2024
  - Support for four 14x12x60 m^3 detector modules and associated utilities (LAr cryogenics and filtration)
- Construction of detector components already underway with first data in 2028-2029

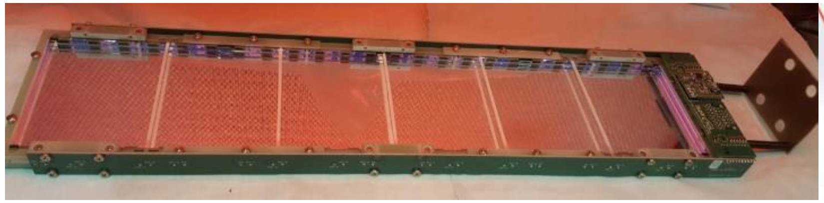
https://www.nytimes.com/2024/08/30/science/astrophysics-dune-neutrinos.html

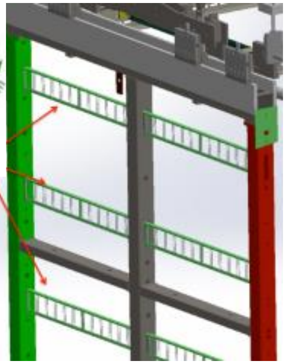
FD1 – the "horizontal drift" module





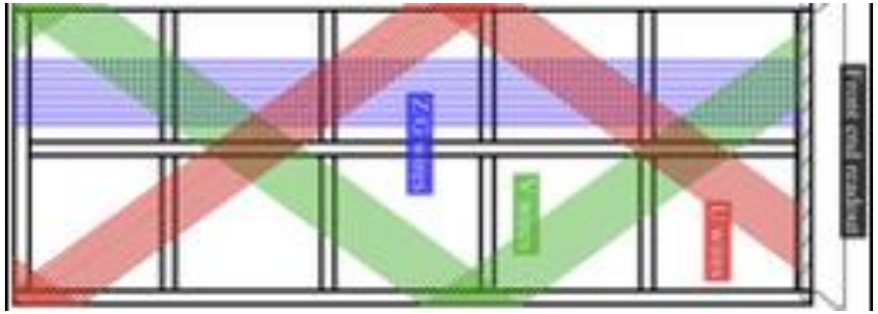






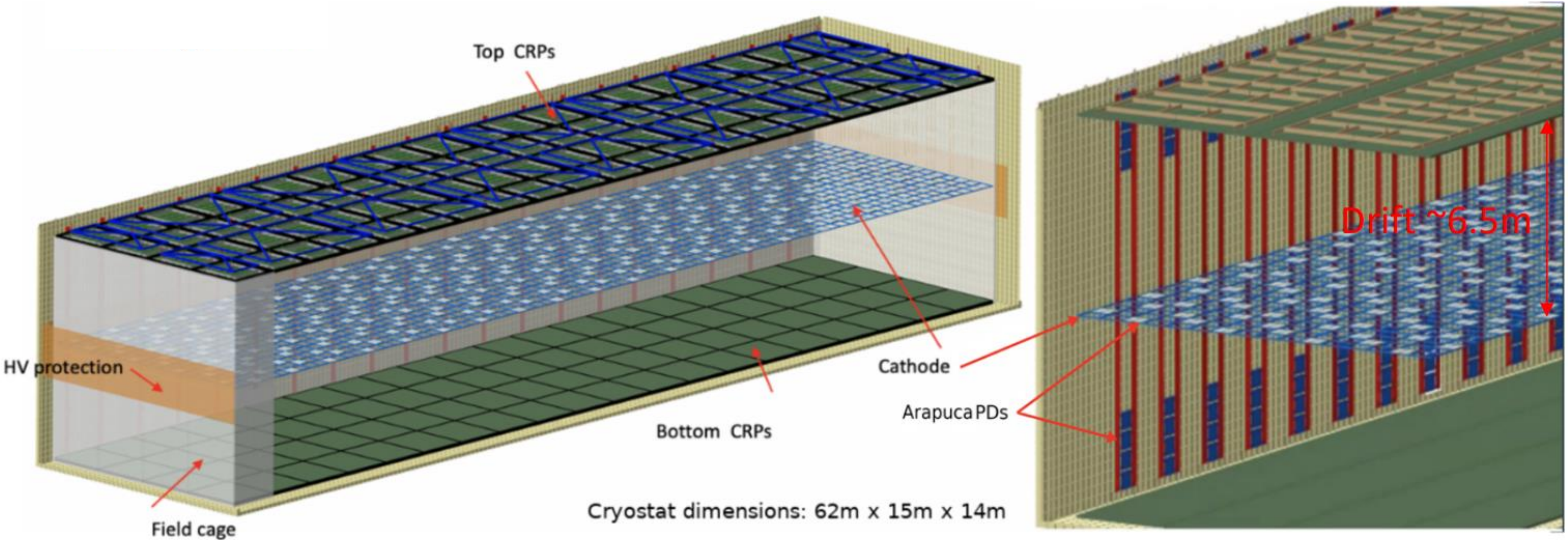
- Light collection – 10 ARAPUCA light guide bars affixed to each APA

ARAPUCA collaboration, arXiv:2405.12014 (2024)



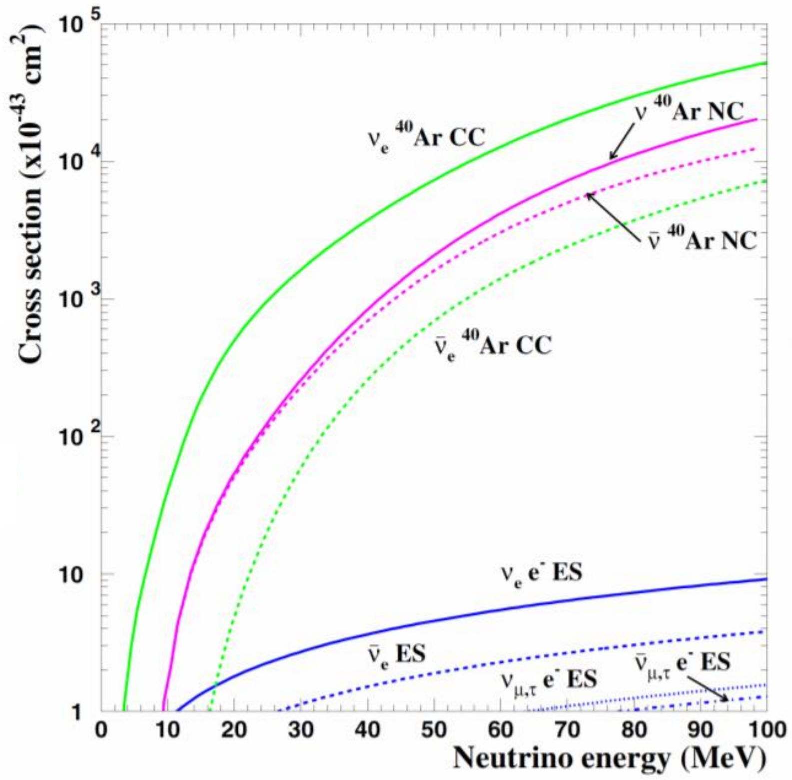
- Charge collection – anode plane assemblies with 480 collection + angled induction planes at 4.8 mm pitch

FD2 – the “vertical drift” module



- Two drift volumes with charge collection on top and bottom charge-readout planes (CRP) made of perforated PCB
- Light detectors along central cathode and four walls of detector

Low-energy interaction channels in argon



- Charged current (CC) interactions on Ar

$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$

$\bar{\nu}_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$

- Neutral current interactions on Ar

$\nu_x + {}^{40}Ar \rightarrow \nu_x + {}^{40}Ar^*$

$\bar{\nu}_x + {}^{40}Ar \rightarrow \bar{\nu}_x + {}^{40}Ar^*$

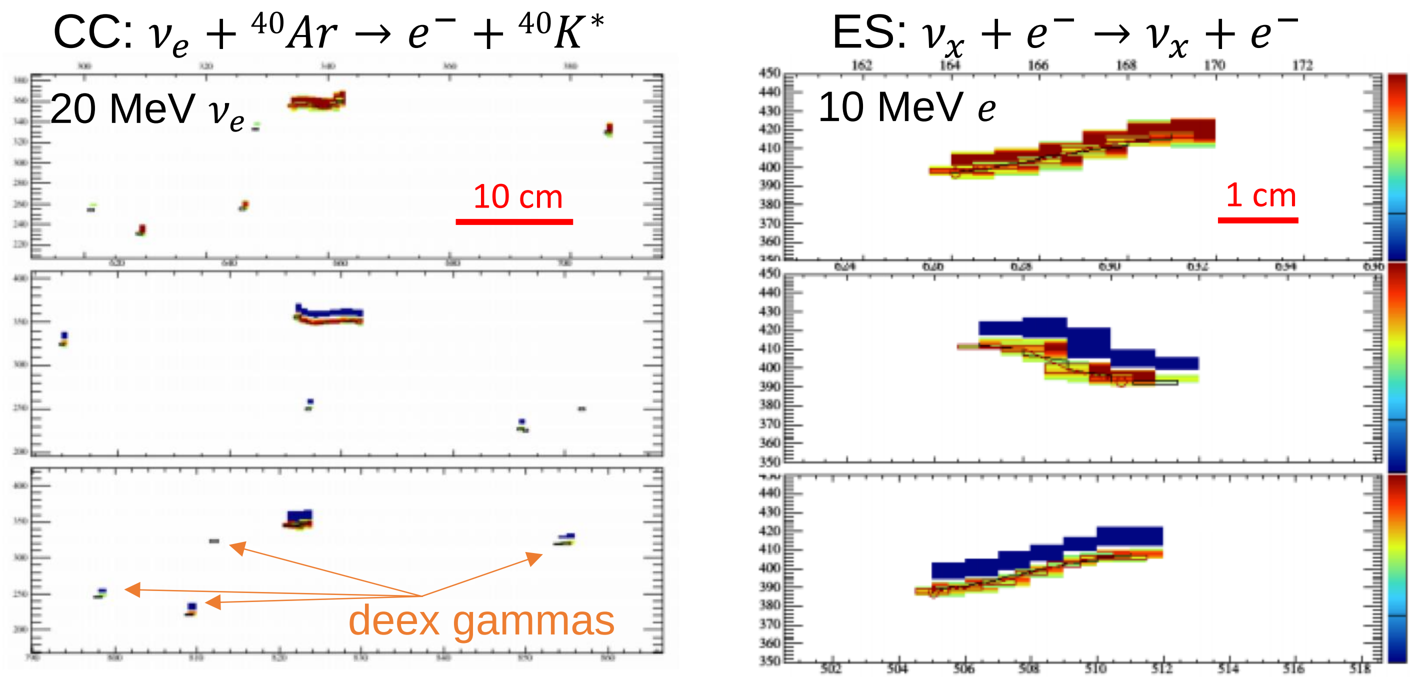
- Neutrino scattering off electrons (ES)

$\nu_x + e^- \rightarrow \nu_x + e^-$

$\bar{\nu}_x + e^- \rightarrow \bar{\nu}_x + e^-$

- ν_e CC interaction dominates low-energy astroparticle sensitivity with sub-dominant processes important for solar / supernova physics

Precision channel tagging with LArTPC technology

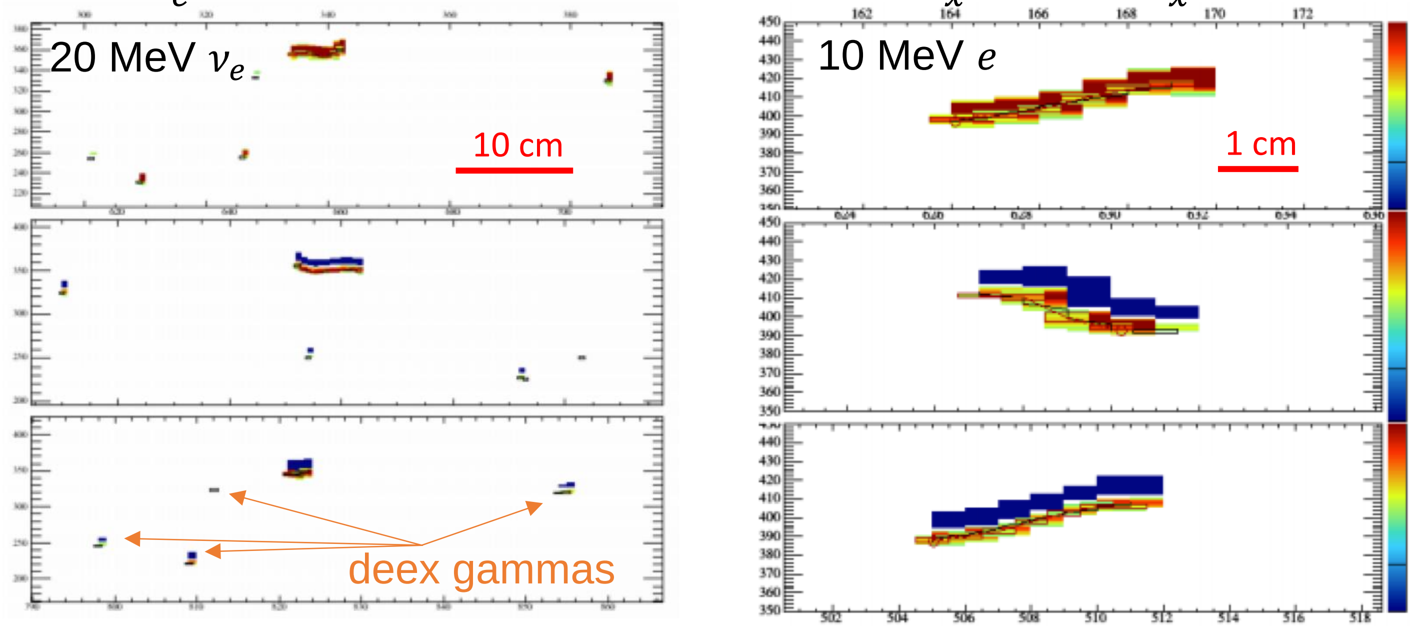


- ❑Tracking detector with sub-cm resolution reveals distinctive signal topologies
- ❑Wealth of information to discriminate various low-energy signals + backgrounds

Precision channel tagging with LArTPC technology

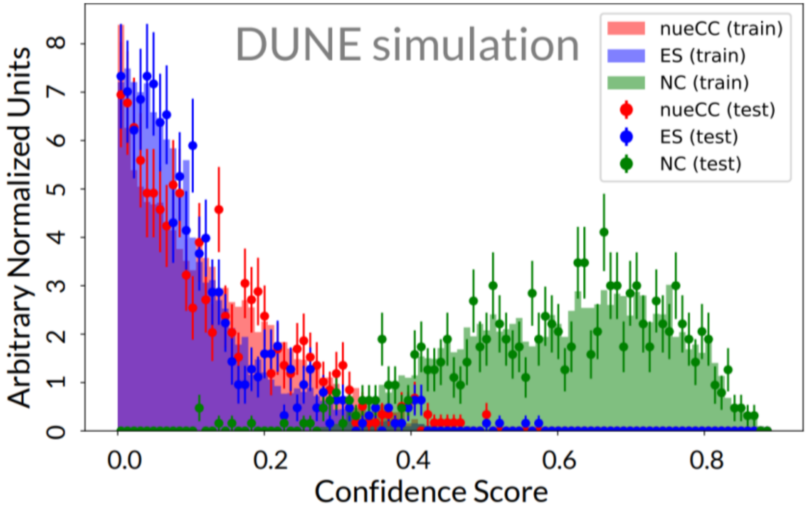
CC: $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$

ES: $\nu_x + e^- \rightarrow \nu_x + e^-$

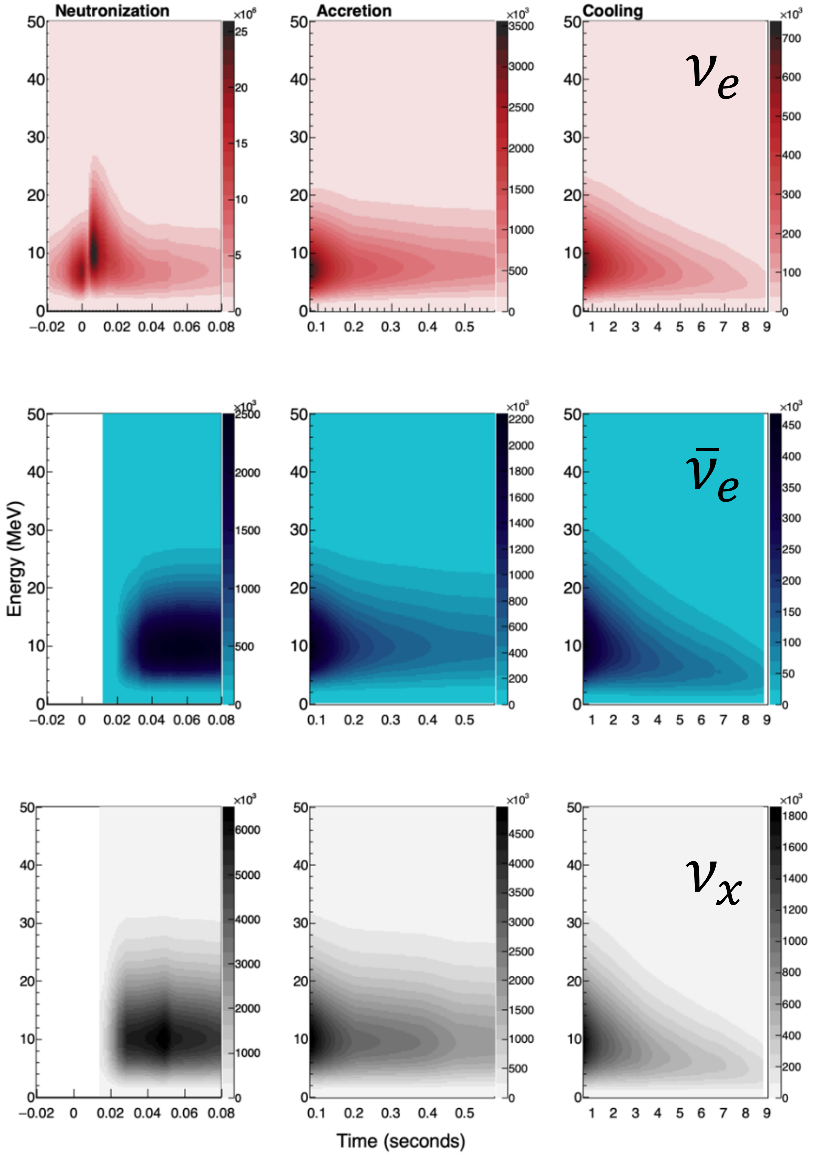


- Tracking detector with sub-cm resolution reveals distinctive signal topologies
- Wealth of information to discriminate various low-energy signals + backgrounds
- Conventional MVA + deep learning applied to channel selection
- Active area of study!

Machine learning to tag channels



Detection of core-collapse supernova in DUNE



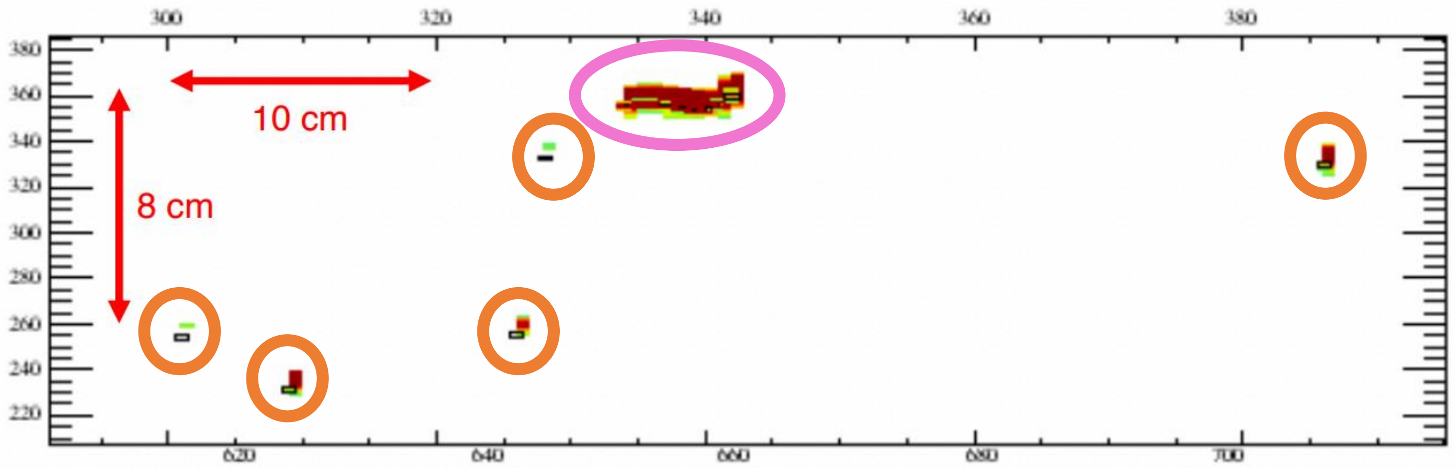
- ❑Measure differential neutrino flux as a component of multi-messenger study of core-collapse supernova
- ❑Beyond precise reconstruction of kinematics, we must probe all flavors to fully understand the core collapse

DUNE uniquely sensitive to ν_e component!

	ν_e	$\bar{\nu}_e$	ν_x
DUNE	89%	4%	7%
SK[1]	10%	87%	3%
JUNO[2]	1%	72%	27%

[1]Super-Kamiokande, *Astropart. Phys.* **81** 39-48 (2016)
[2]Lu, Li, and Zhou, *Phys Rev. D* **94** 023006 (2016)

Reconstructing solar neutrinos



- Largest labeled primary cluster is electron candidate
- Gammas tagged as adjacent clusters

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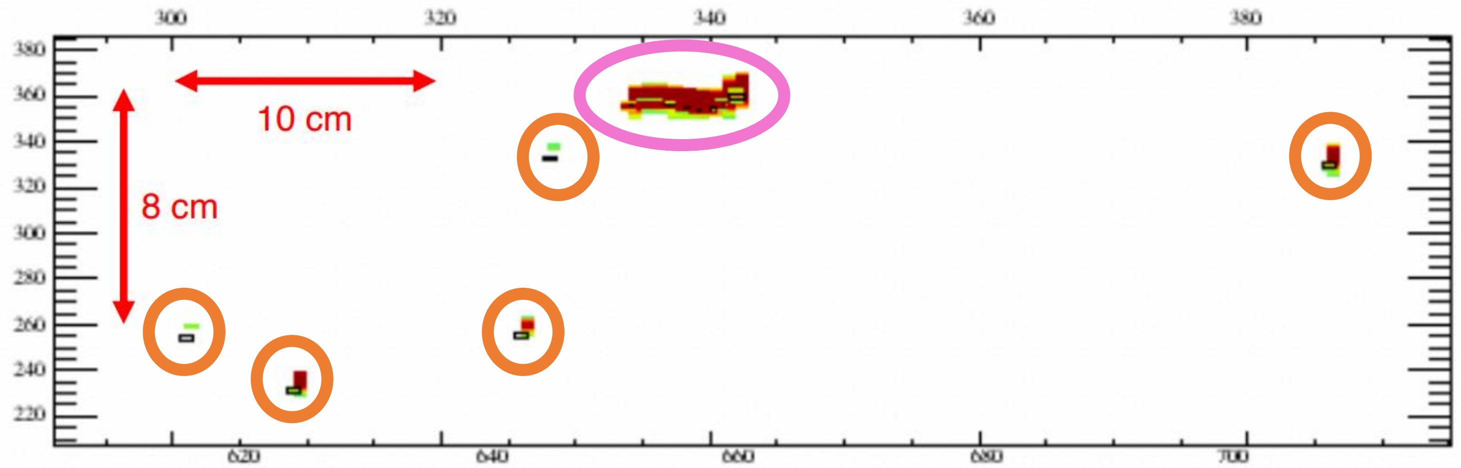

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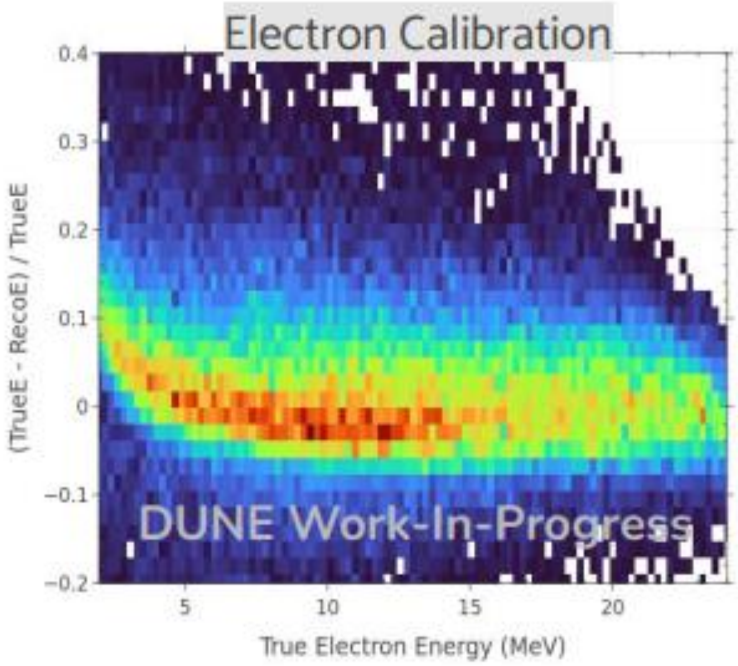
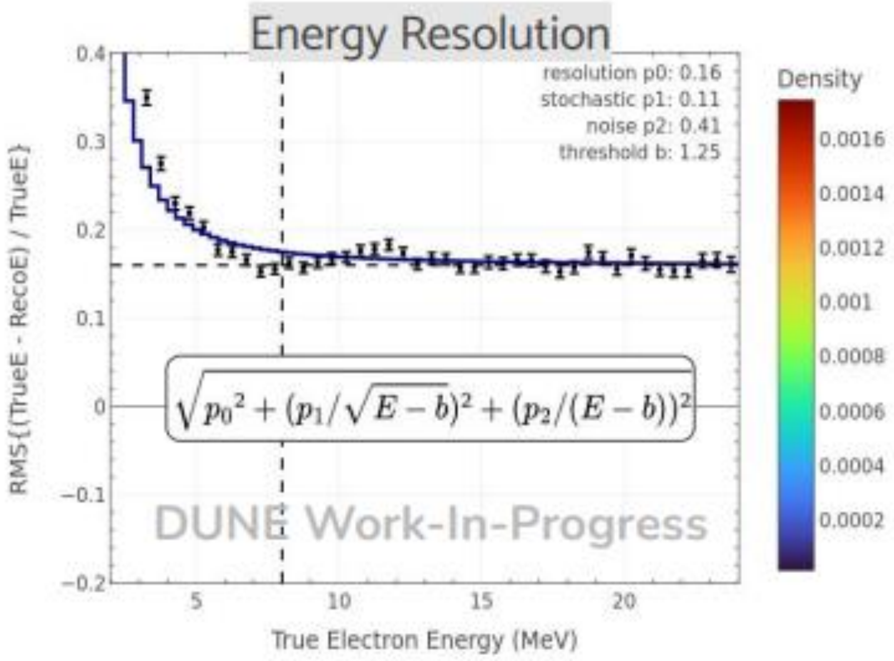
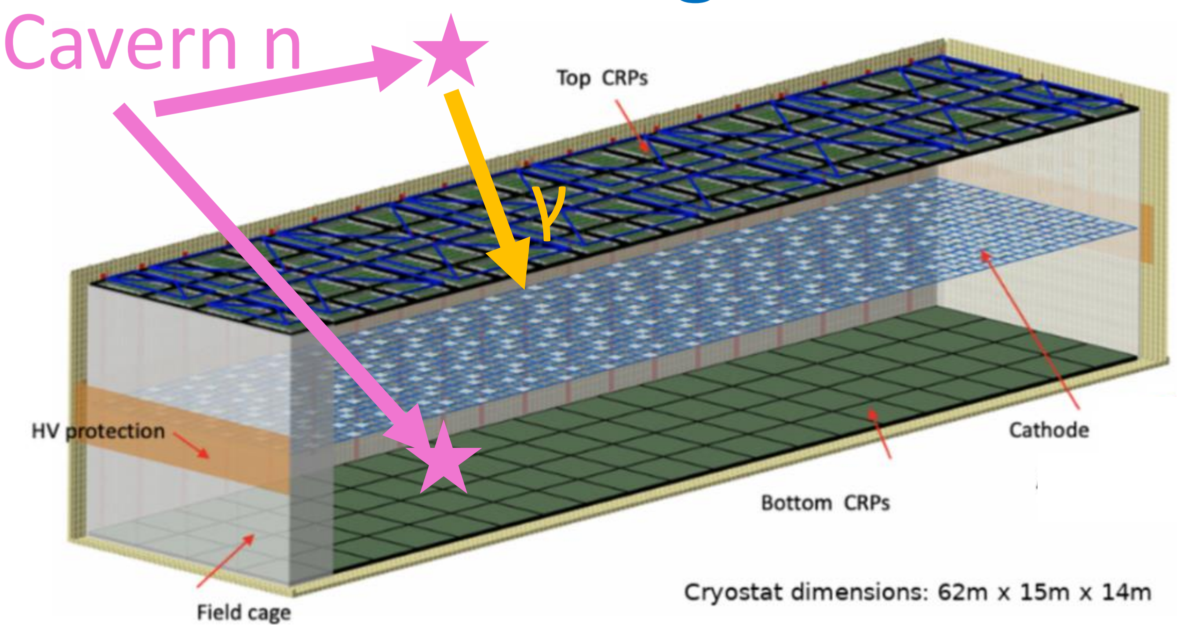
- Constant ≈ 16% resolution with current phase I reco
- Scintillation drives resolution for phase II





Dominant backgrounds for DUNE



- External backgrounds limit physics (at least for phase I)
  - n capture on ^{40}Ar(6.1 MeV) ~ Hz and ^{36}Ar(8.7 MeV) ~ mHz
  - External gammas from n capture in heavy nuclei in rock/cryostat
- ^{40}Ar(α,γ) 15 MeV, low rate

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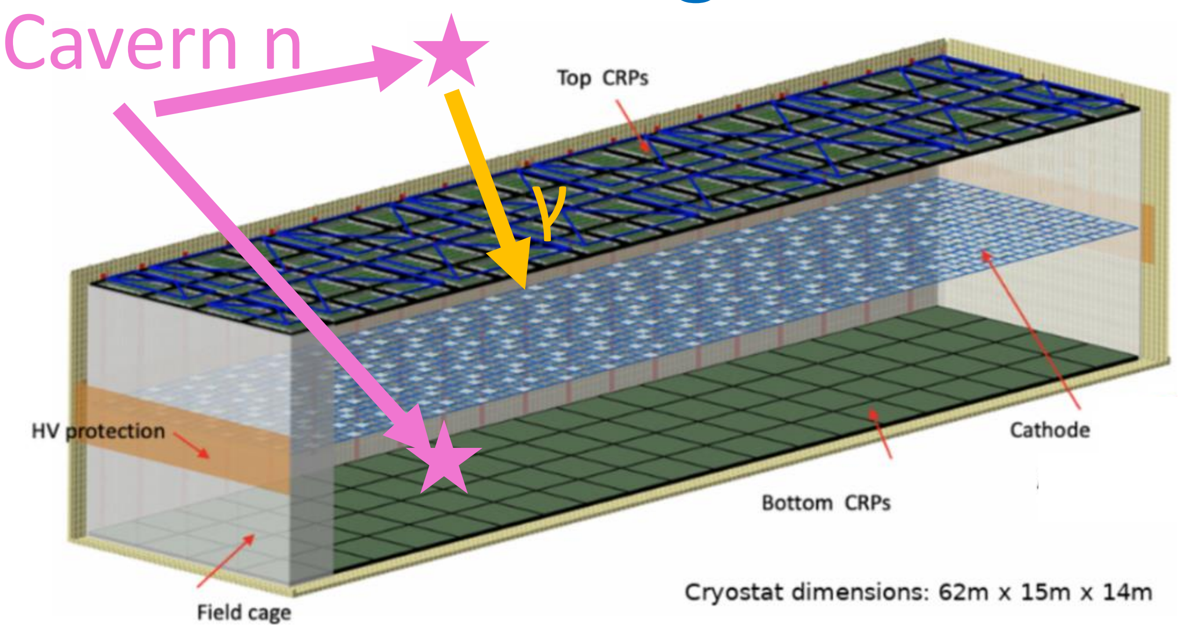

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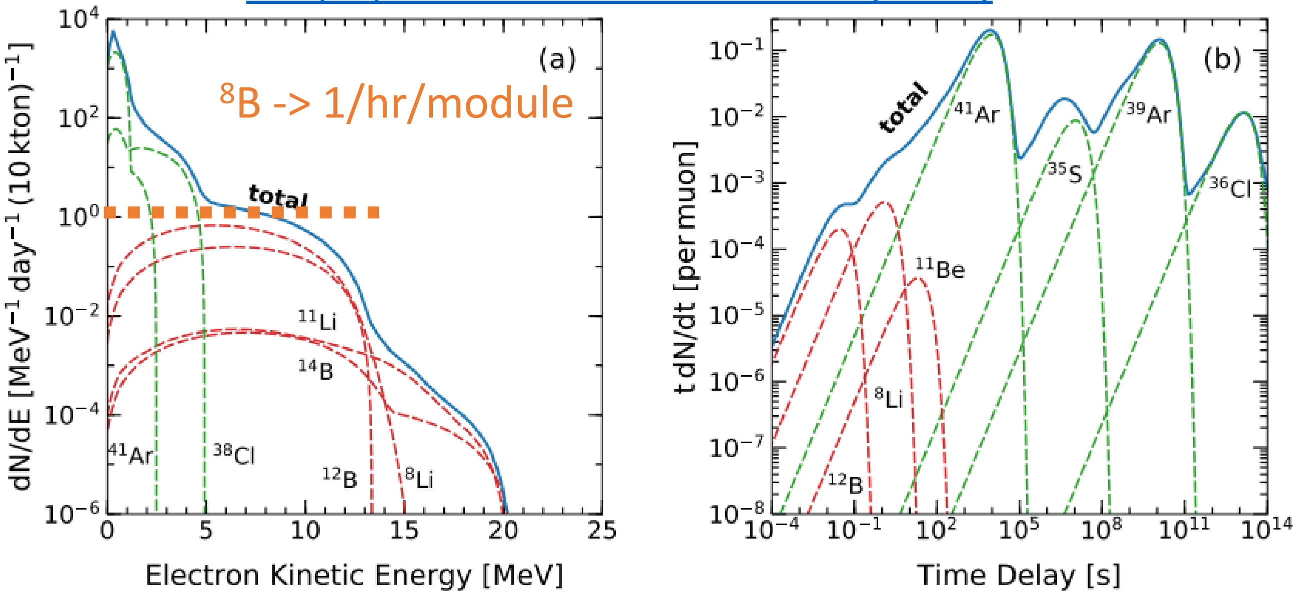
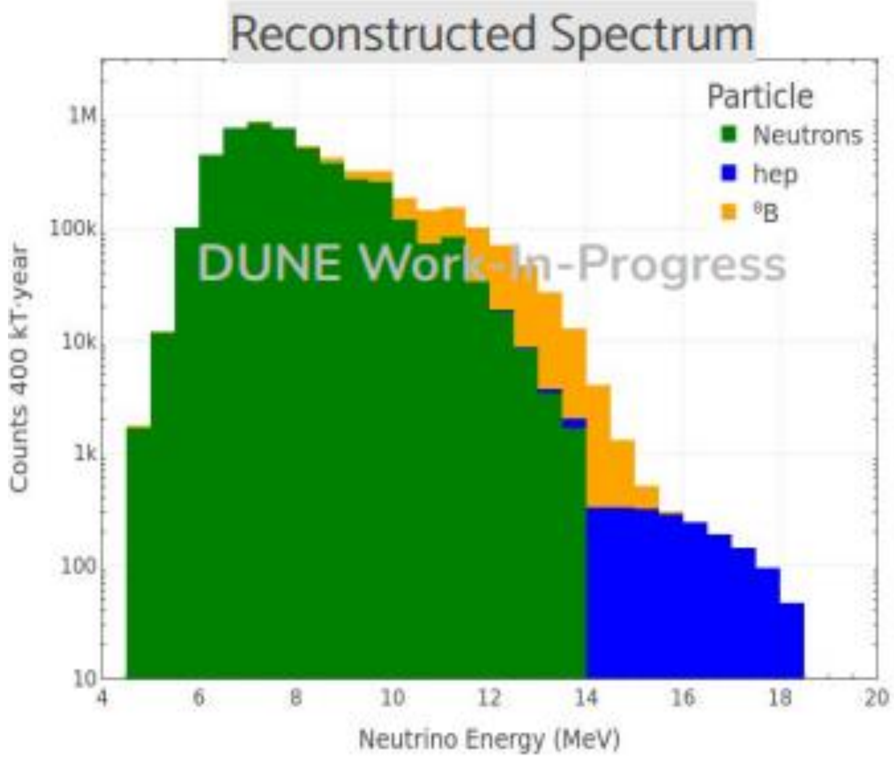
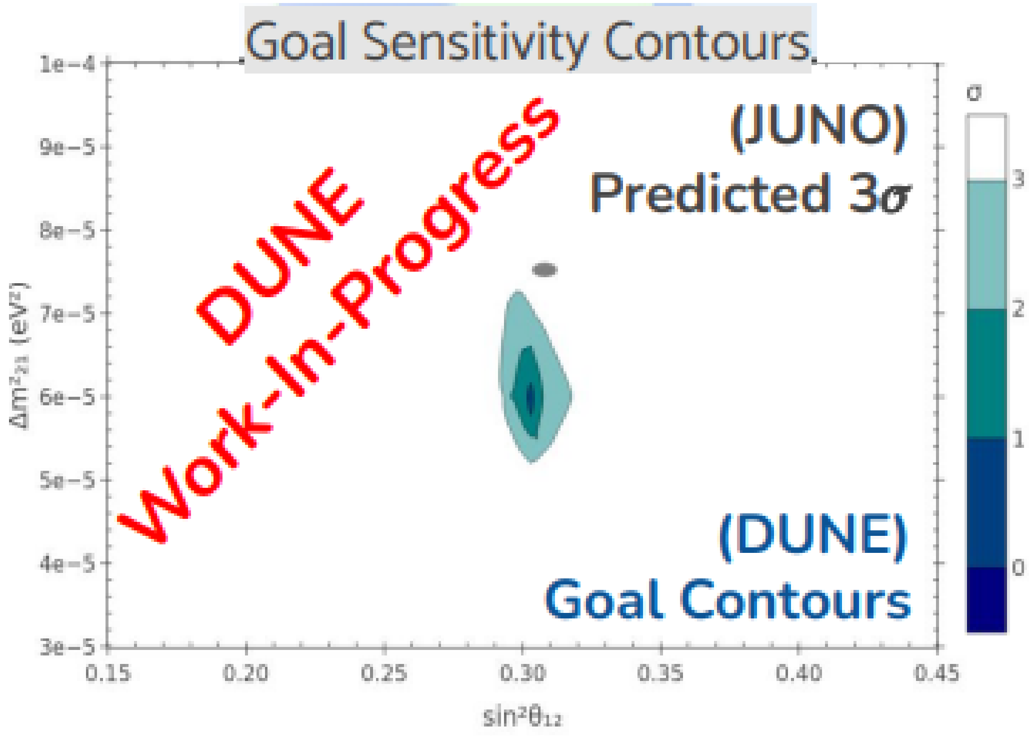
- With perfect neutron rejection, Ee < 5 MeV limited by spallation
- High Q-value, short-lifetime nuclei vetoed with μ coincidence

Zhu, Li, Beacom *PRC* **99** 055810 (2019)



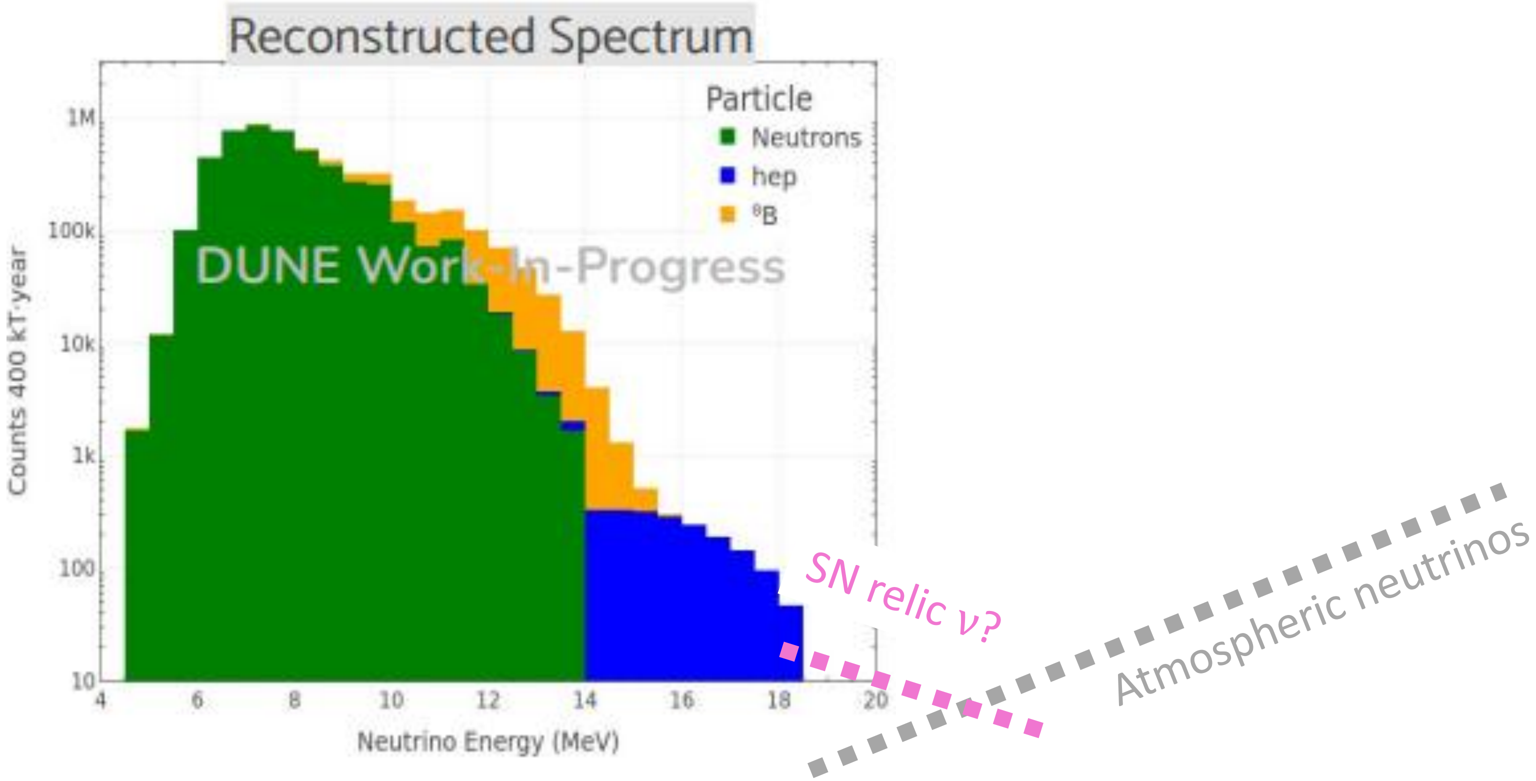
Solar neutrino analysis





- Oscillation analysis possible using ^{8}B and hep neutrinos
  - ^{40}Ar(n,γ) dominates radiological background, does not extend to hep ROI
  - All solar neutrinos reconstruct < 19 MeV – defines low end of DSNB ROI
- DUNE will improve Δm^2_{21} measurement with solar neutrinos

DUNE strategies for DSNB

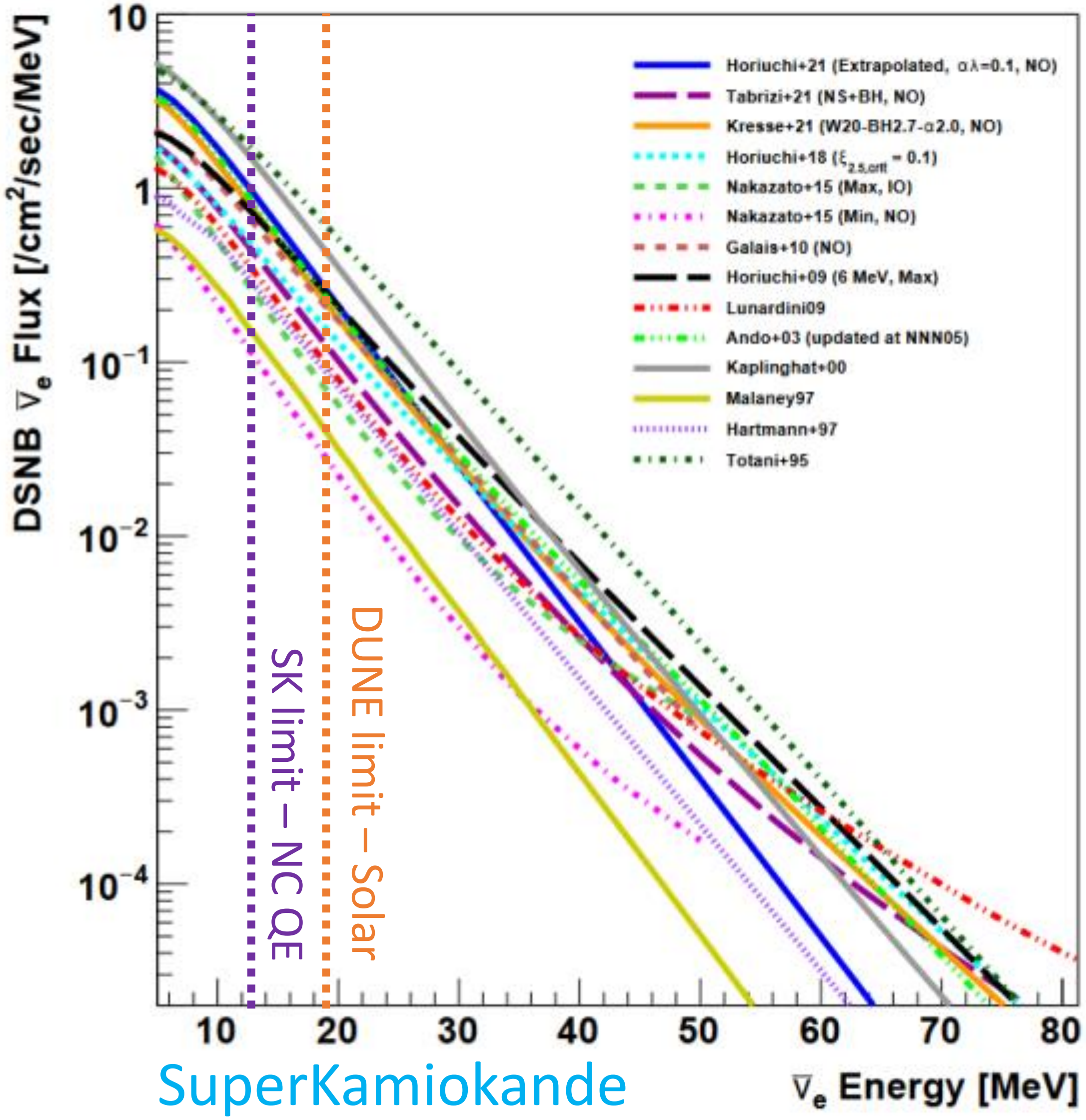


DUNE has unique ν_e sensitivity, strong desire to include in global DSNB results

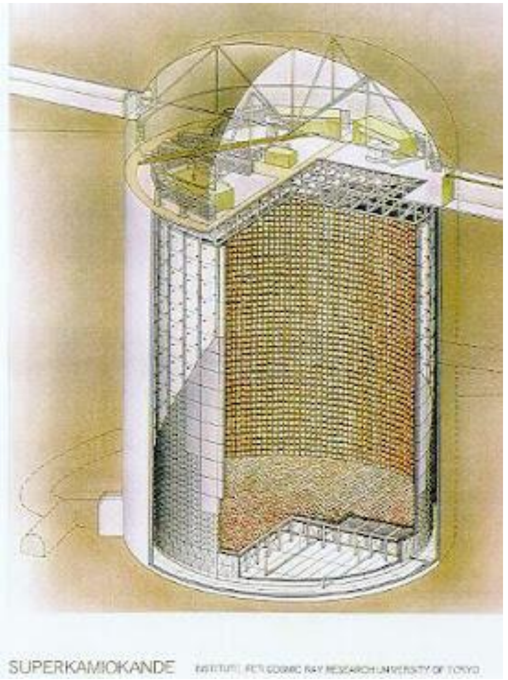
Issue to overcome 1: searching at high energies

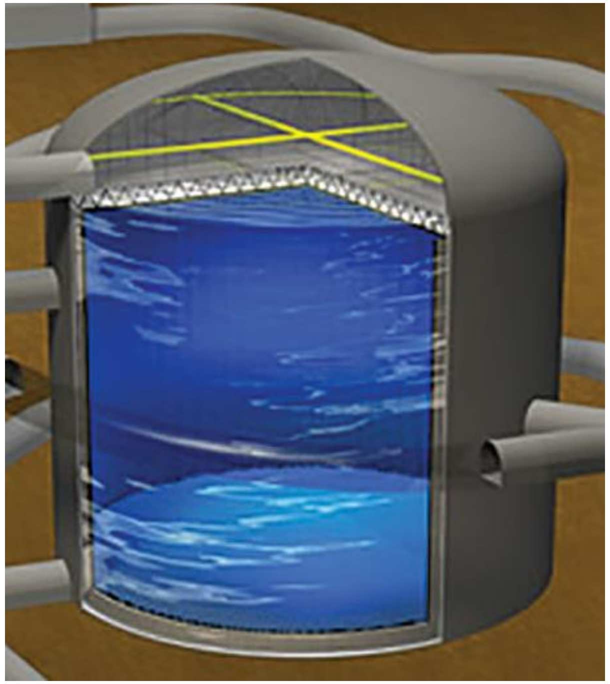
- Various DSNB calculations follow an approximately exponential shape
  - Solar He+p ν_e CC are an irreducible background extending to 19 MeV
  - DUNE will have more limited region-of-interest than SK-Gd and JUNO

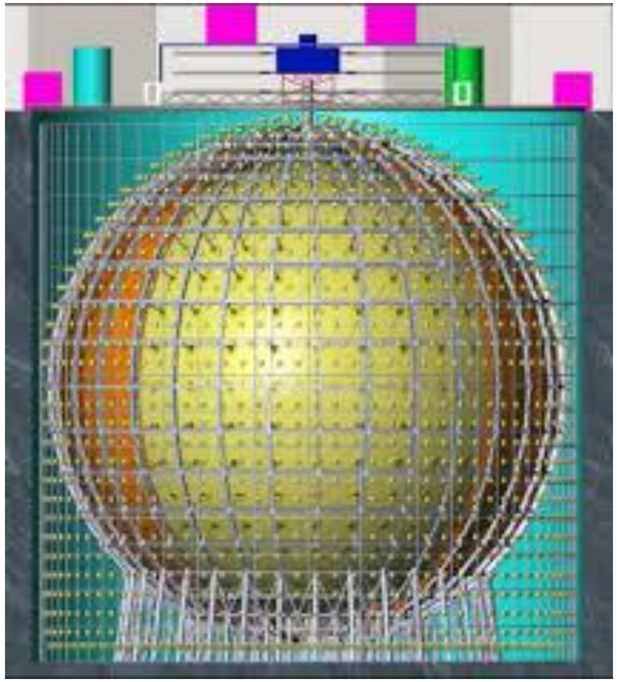
- Silver lining:
  - DUNE sensitivity driven by high-energy flux -> sensitivity to f_{BH}

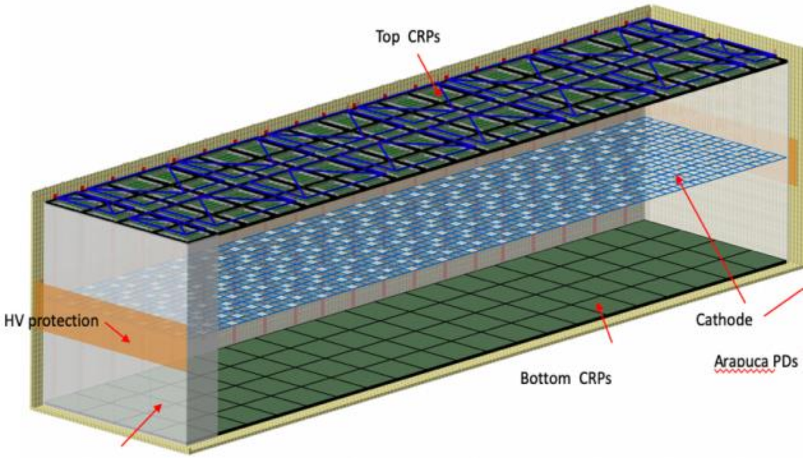


Issue to overcome 2: detecting DSNB with no veto









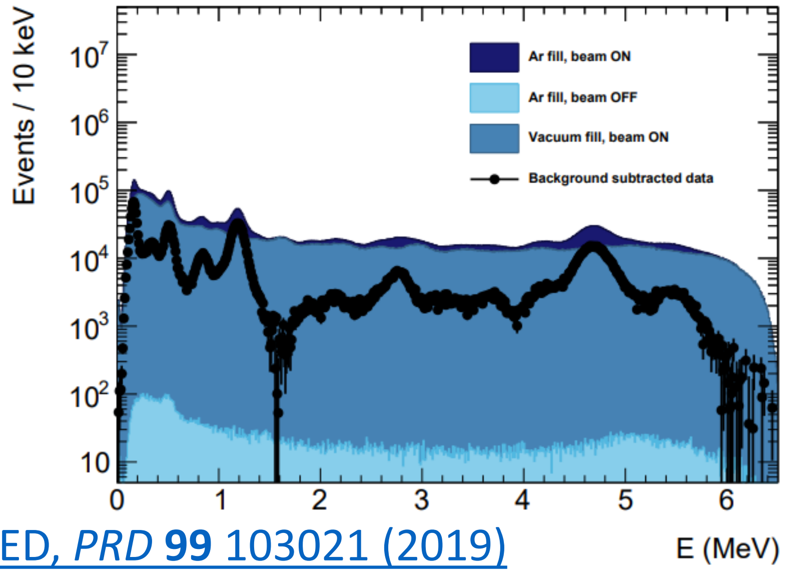
SK – 22.5 kt of water Cherenkov with outer veto

HK – 190 kt of water Cherenkov with outer veto

JUNO – 20 kt of liquid scintillator with outer water veto

DUNE – 40 kt LArTPC, no outer veto

Self-vetoing with LArTPC technology

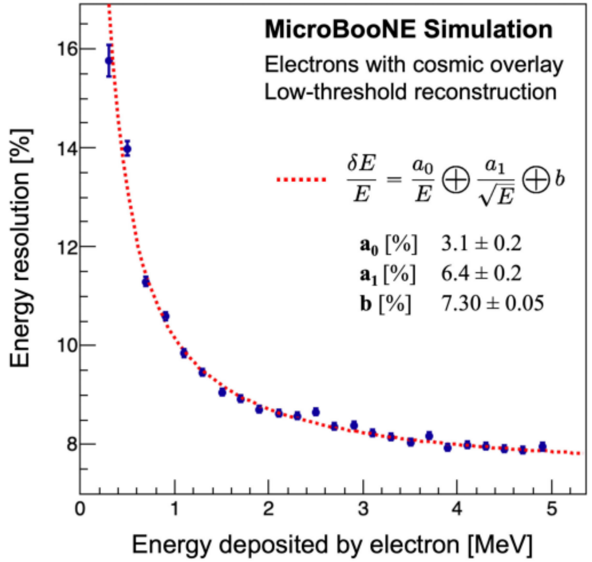


[ACED, *PRD* **99** 103021 (2019)]

- Initial results from ML show promise for bkg rejection
- CNN trained on 4.7 MeV γ (I≈50%) from n capture

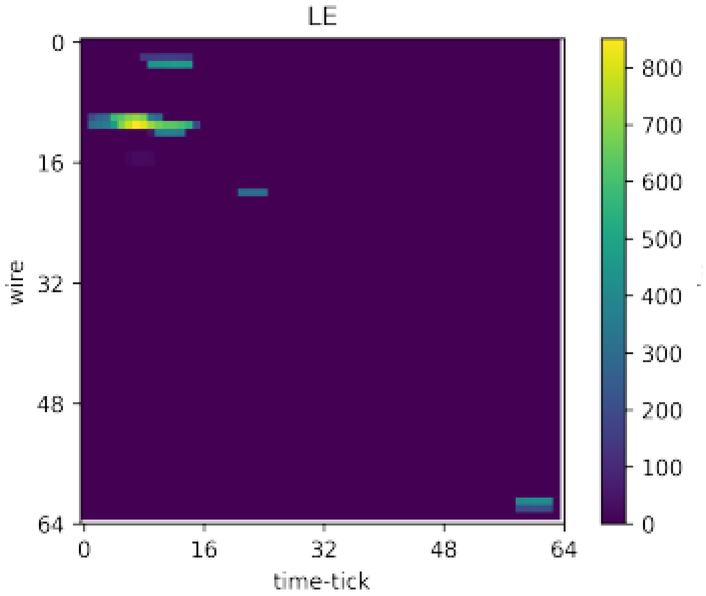
[MicroBooNE, *PRD* **109** 052007]

- ≈ 8% resolution from MicroBooNE for 4.7 MeV
- Separable for $E_e > 5$ MeV



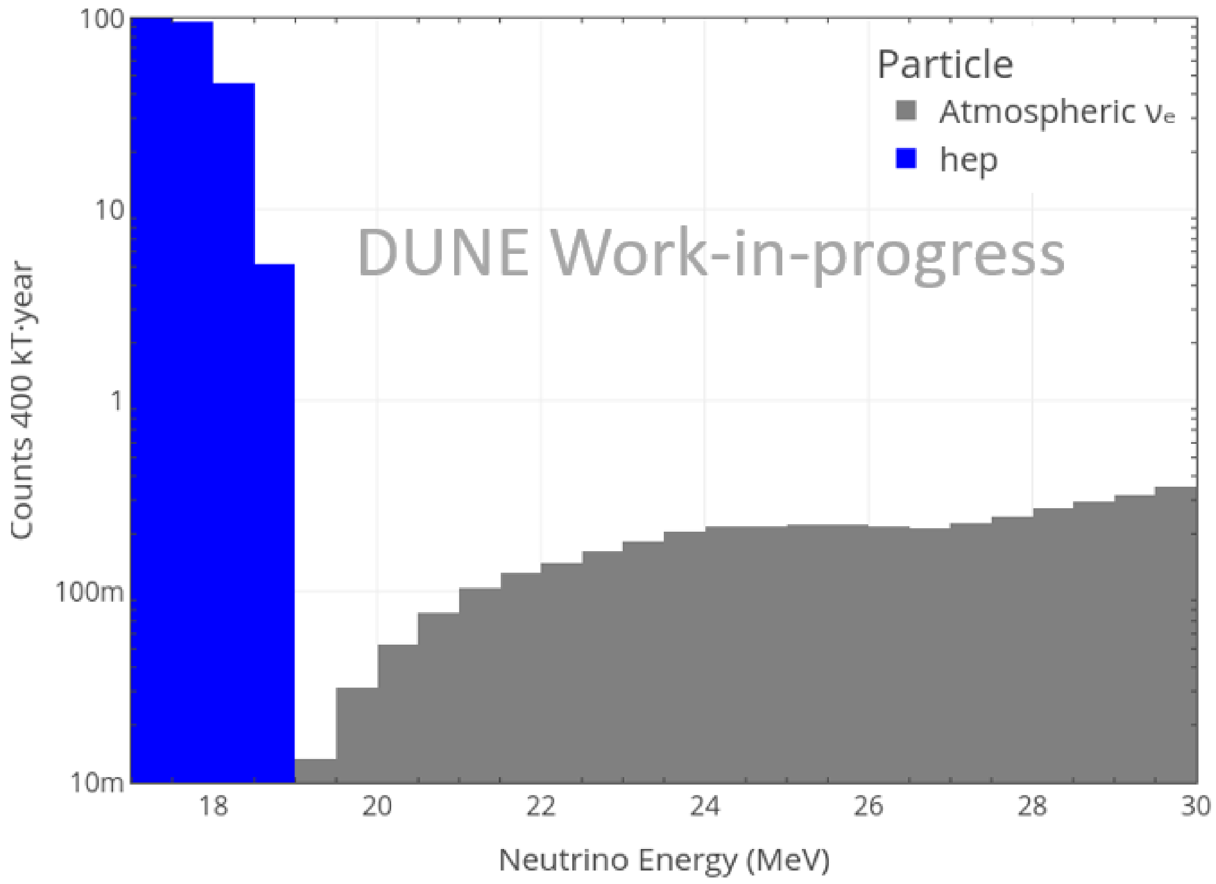
[Jwa et al., *FRAI* **2022** 855184]

- Bkg rejection online with CNN
- Trained with old bkg model and without light info



High-energy low-energy neutrinos

- Radiological and cosmogenic backgrounds below DSNB ROI
- Solar He+p flux dominates, restricts ROI to > 19 MeV
- Recent calculation of atmospheric neutrino flux
  - [Zhuang, Strigari, Lang (2022)]
  - Agrees with HKKM @ Kamioka
  - ≈ 2x higher at SURF



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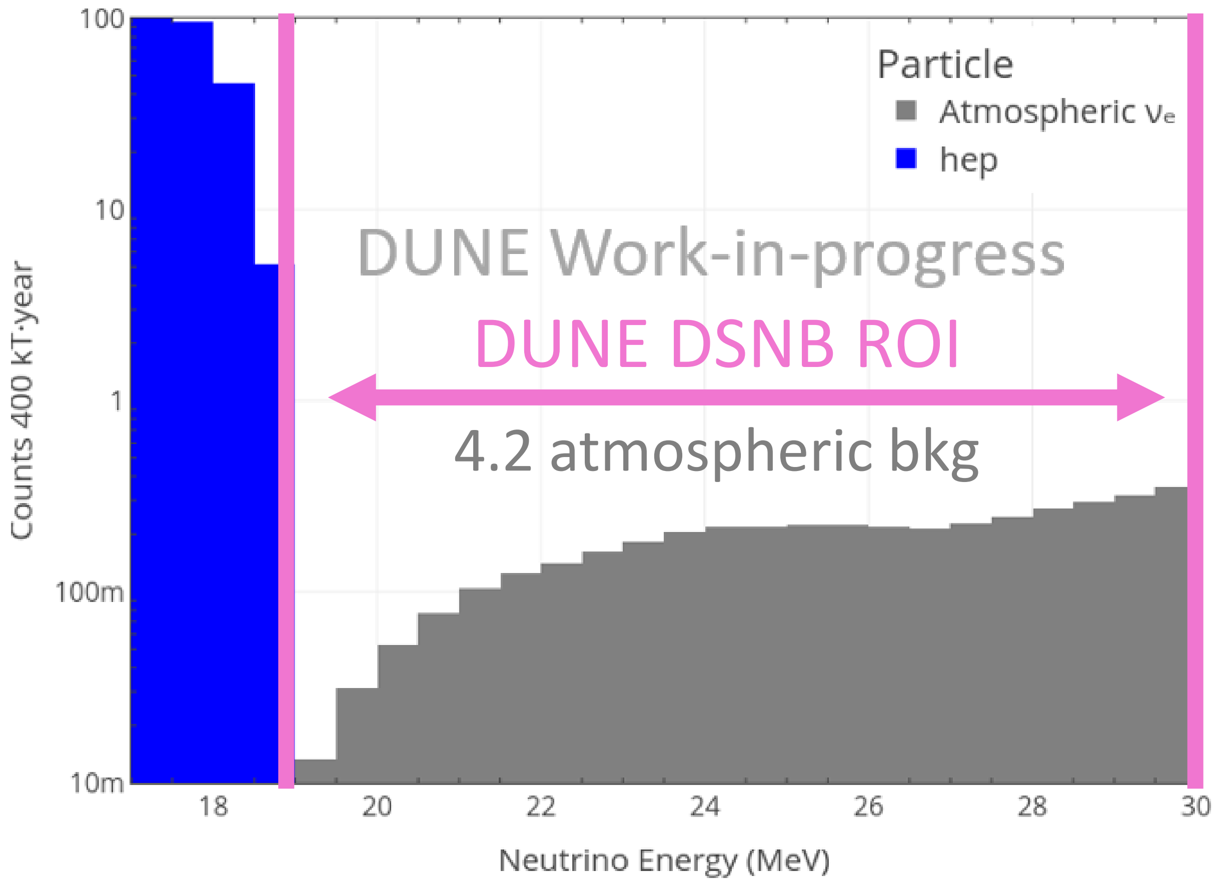

DUNE FD1 simulation

Reminder – investigation of Q+L matching and fiducial mass underway

Summary

- DUNE excavation complete. Construction of detector ongoing with transfer of materials underground to commence soon
- LArTPC's are a new, developing technology for low-energy physics -> promising initial data from sub-kt prototypes with improvements still expected
- First publicly available prediction for DUNE atmospheric background rates will facilitate upcoming sensitivity calculations