SNeND Measurements: "Supernova Neutrino constrained by Neutrino Data" for DUNE

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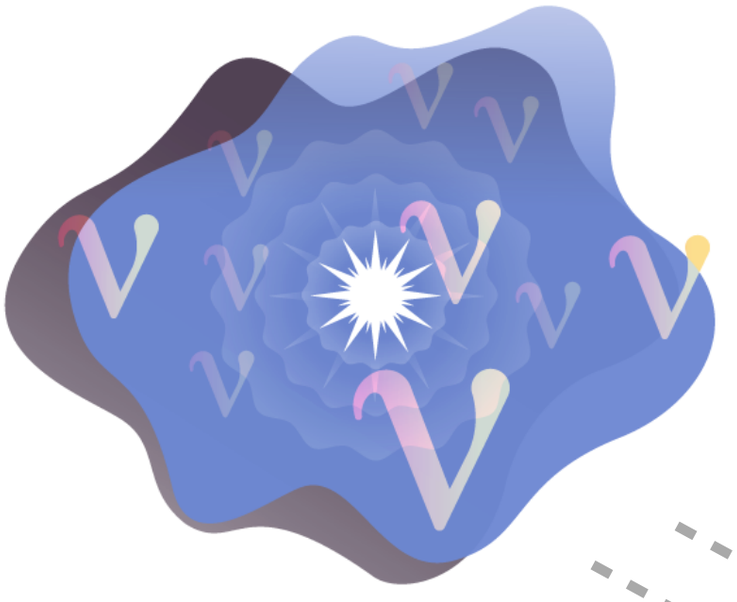
PoU IF Brainstorming@SLAC

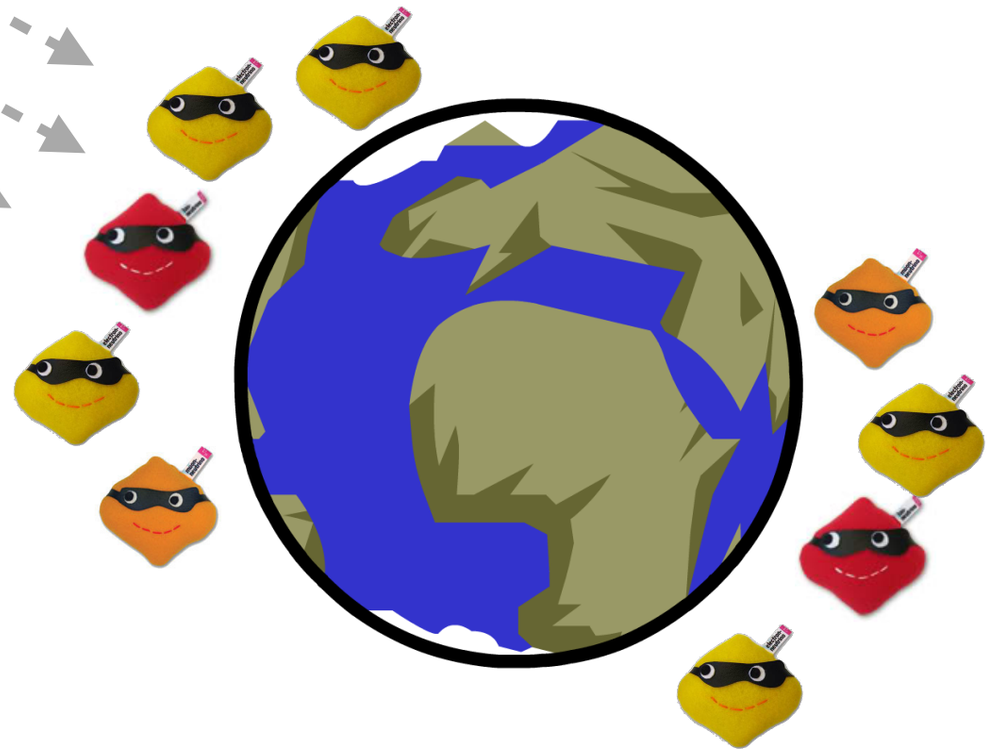
September 26th 2025

Supernova Neutrino



Core-collapse supernova neutrino energy:
O(1-10) MeV

DUNE has unique sensitivity to ν_e via charged-current (CC) ν_e-Ar interactions



Supernova Neutrino Flux

Pinched-thermal form: to fit simulated flux

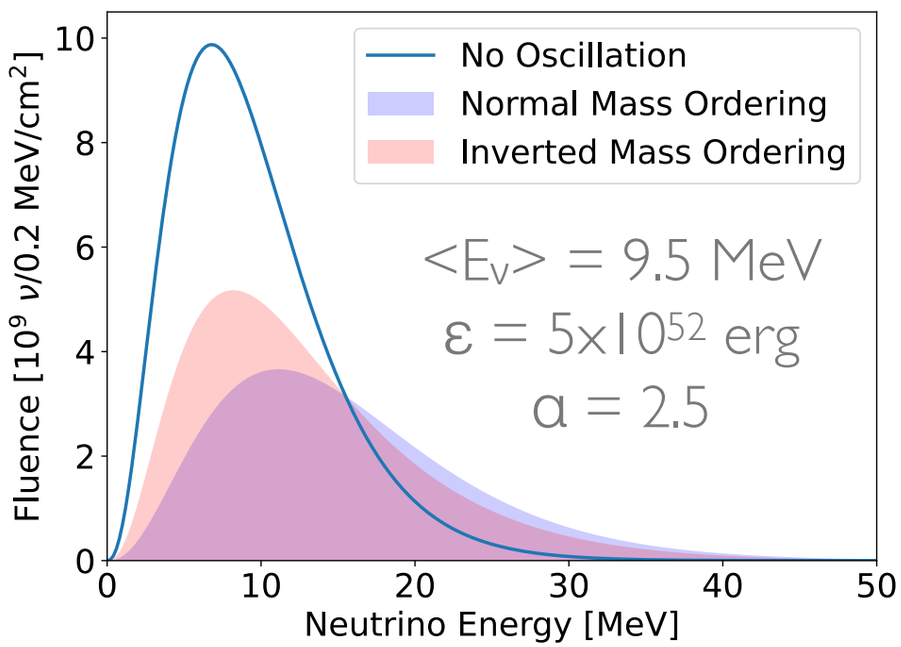
$$\phi(E_\nu) = \mathcal{N}\left(\frac{E_\nu}{< E_\nu >}\right)^{\alpha} \exp\left[-(\alpha+1)\frac{E_\nu}{< E_\nu >}\right]$$

E_ν: neutrino energy

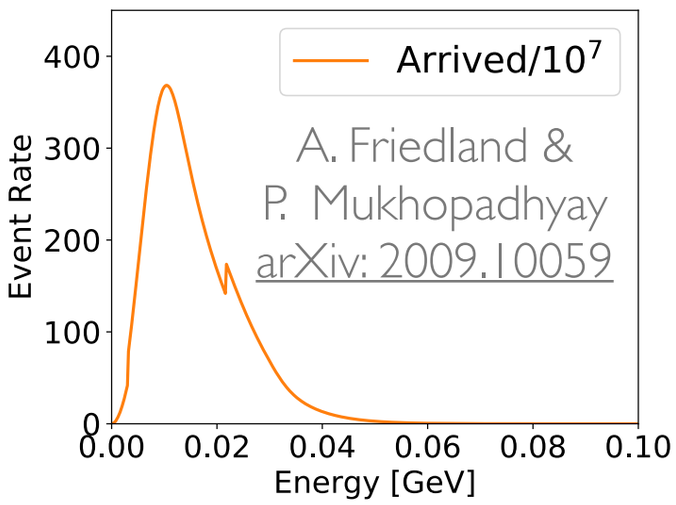
$<E_\nu>$: average E_ν

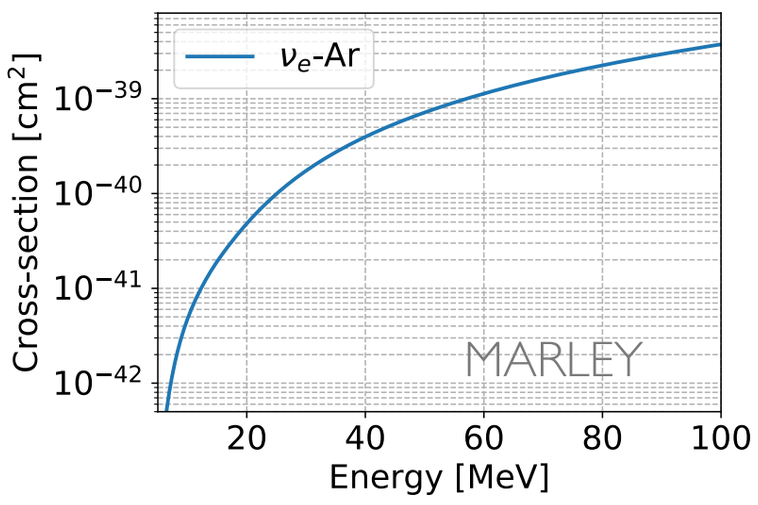
$N \propto \nu$ luminosity, ε

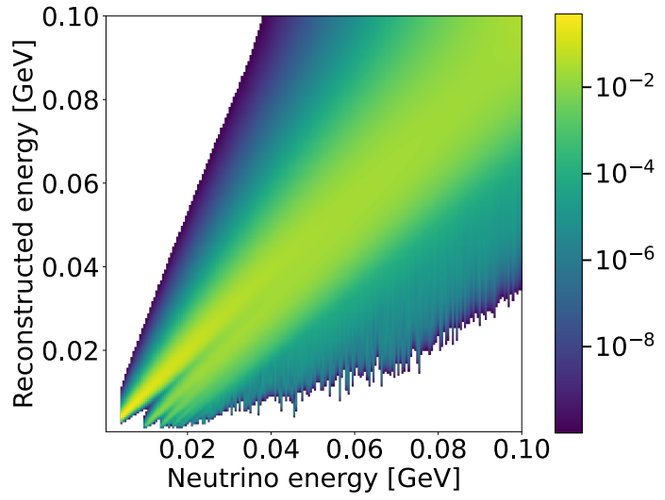
α: pinching parameter

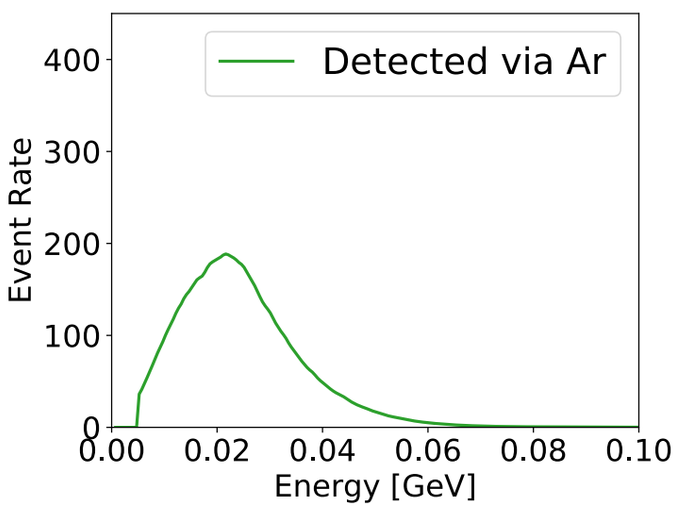


SN Neutrino Detection





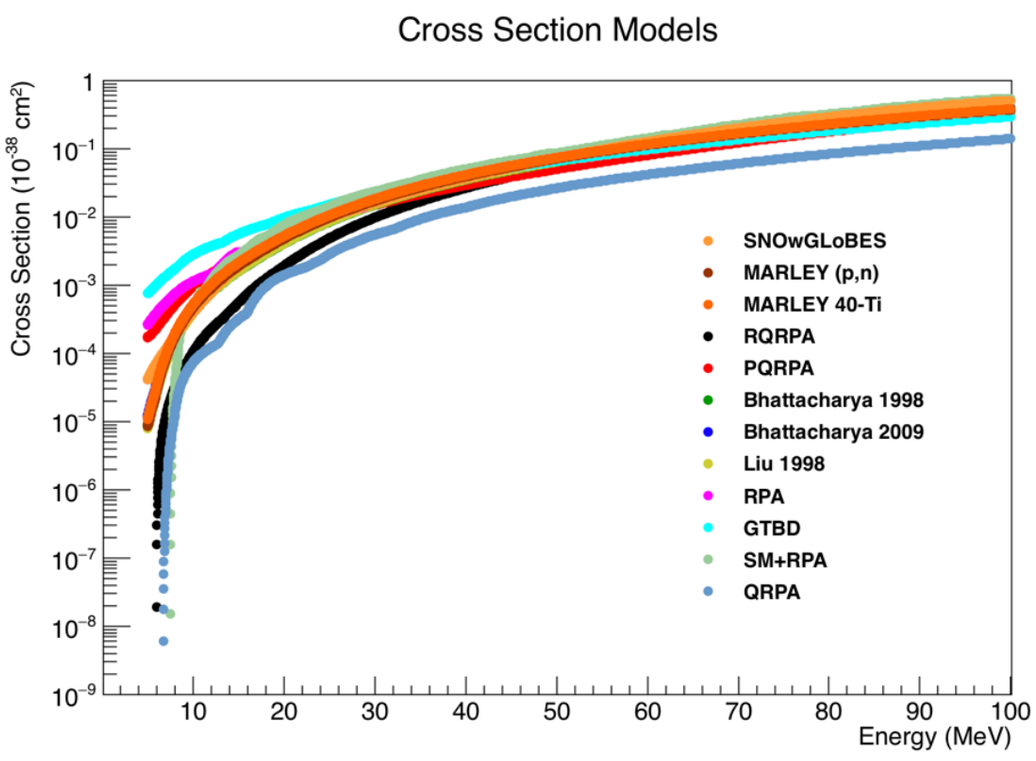


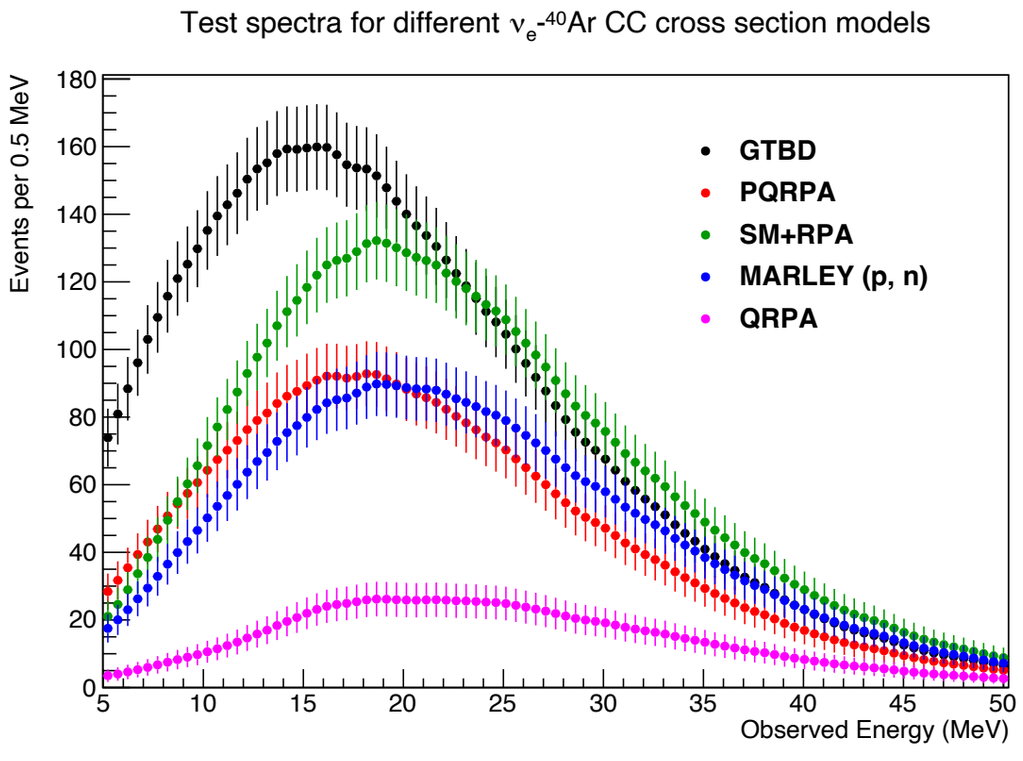


- Detect convolved ν flux and interaction cross sections
- Disentangled ν fluxes are desired
- These ν_e-Ar CC cross sections have never been measured
  - Uncertainties from cross section models are relevant

Impact from ν_e-Ar σ

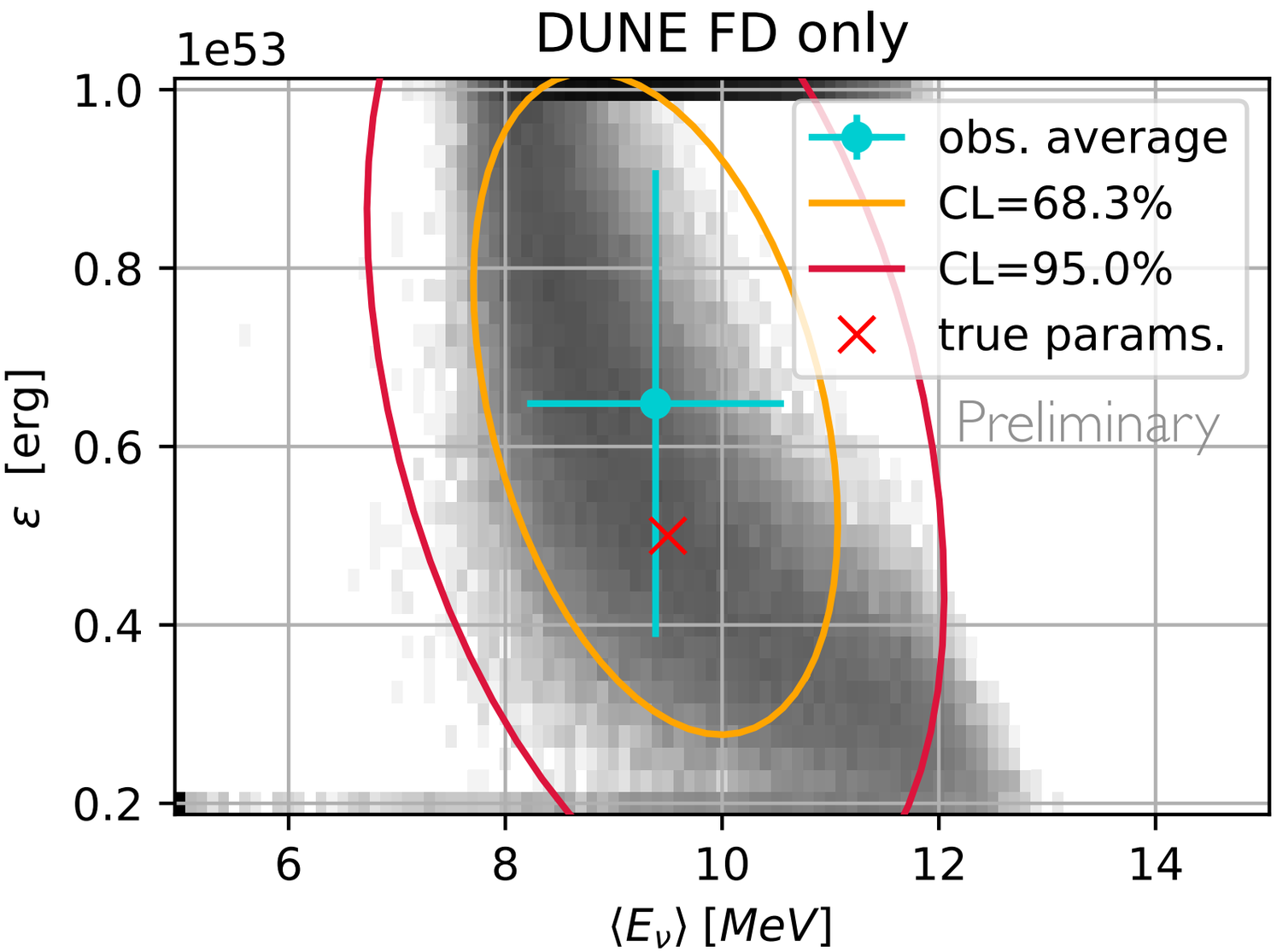
- ν_e-Ar charged-current (CC) interaction cross section with E_ν<100 MeV has never been measured
  - Theoretical models vary > O(10%)
- Highly significant impacts on DUNE SN ν measurements, particularly on ε, biased from -94% to +1400% in extreme scenarios (PRD 107, 112012 (2023))





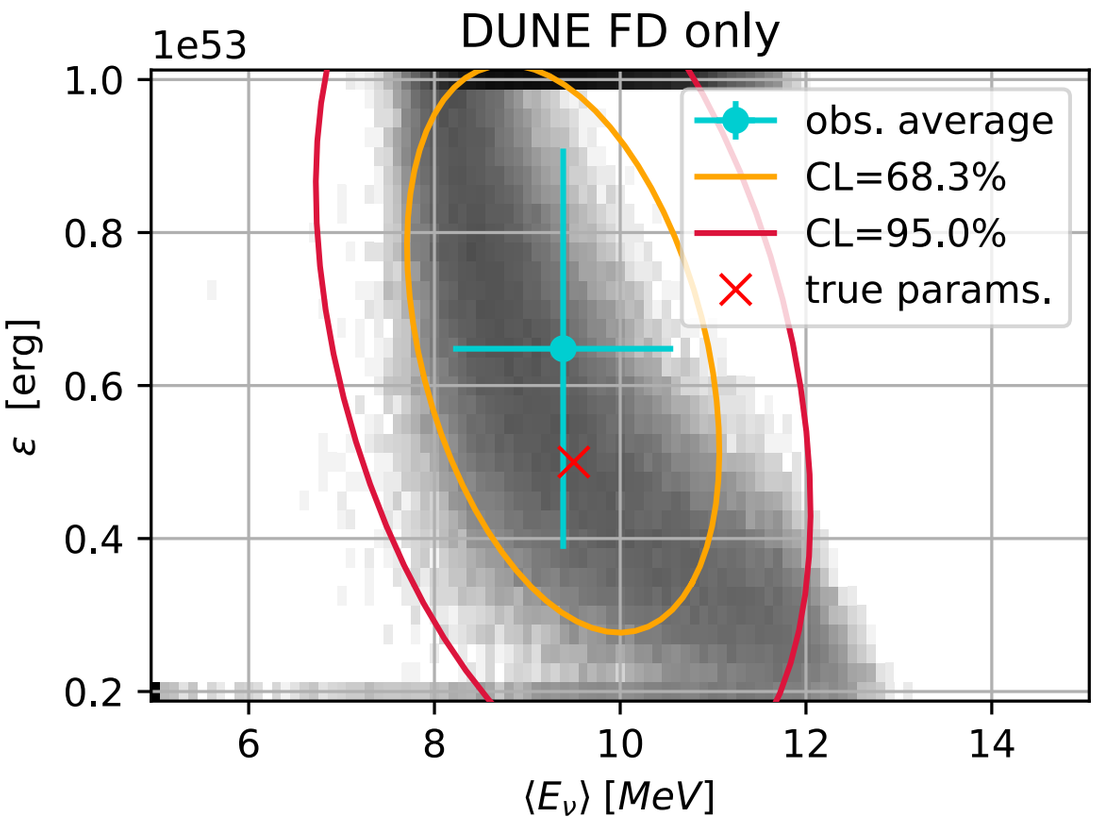
Measure ν_e-Ar CC σ

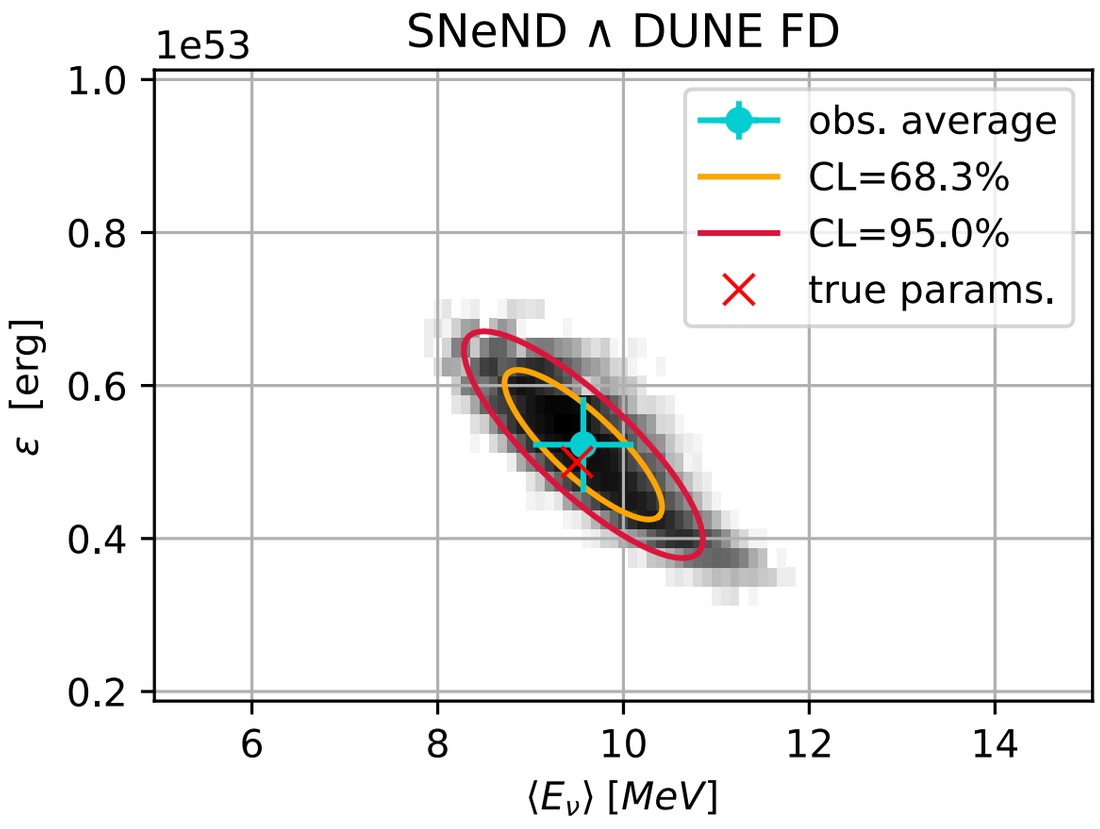
If we know the total σ and σ(45 MeV) at the precision of 20%, as suggested by PRD 107, 112012 (2023)



SNeND Constraints

…and with the "neutrino data" constraints, SNeND,





Preliminary result. In collaboration with Gianluca Petrillo (SLAC), Yen-Hsun Lin (NCTS)

Proposing a LArTPC detector near a human-made neutrino source to collect neutrino data for SNeND measurements

Proposing a LArTPC detector near a human-made neutrino source to collect neutrino data for SNeND measurements

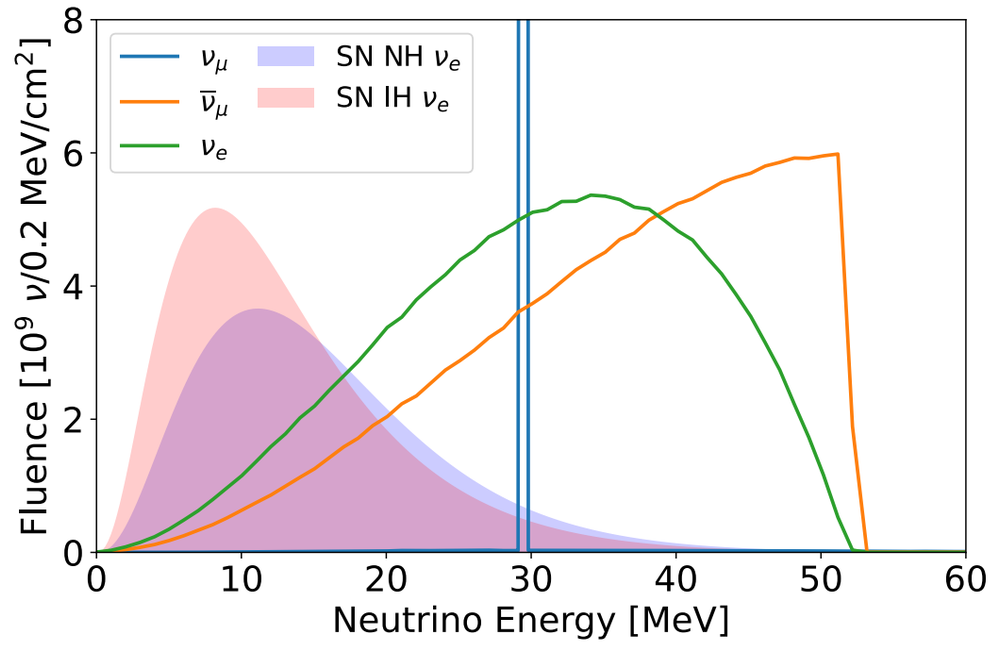
$$\rho(E_{\nu,j}) = \frac{\sum_k \phi_{\mathrm{SN}}(E_{\nu,k}) \times \sigma(E_{\nu,k}) \times R_{j,\mathrm{DUNE}}(E_{\nu,k})}{\sum_k \cancel{\phi_{\mathrm{SNeND}}}(E_{\nu,k}) \times \sigma(E_{\nu,k}) \times \cancel{R_{j,\mathrm{SNeND}}}(E_{\nu,k})}$$

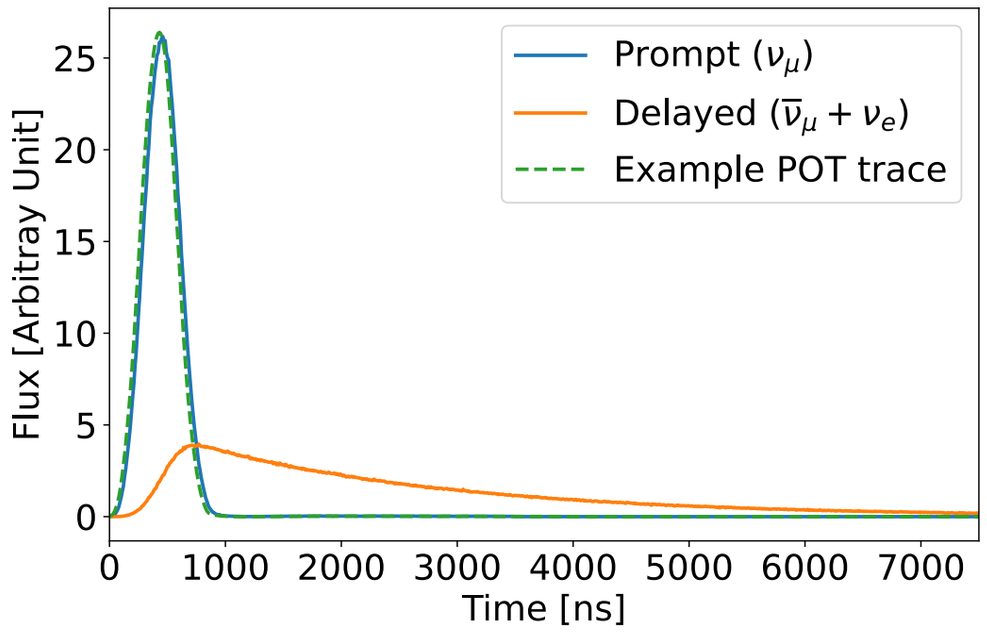
ϕ_{SNS} at 2-3% precision

COHERENT-LArTPC

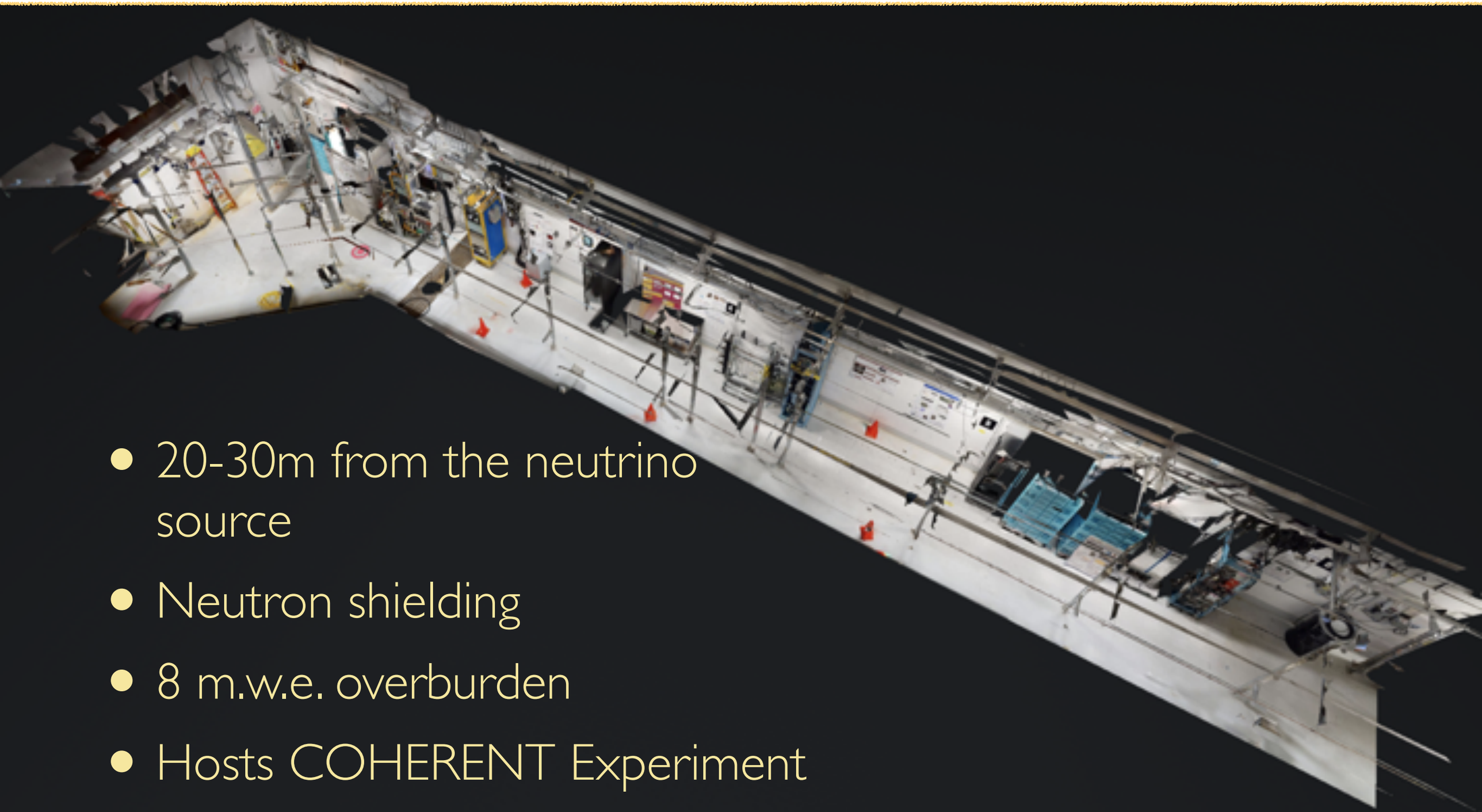
Measure ν_e-Ar CC σ@SNS

- Neutrinos produced from π^+ decay at rest, $E_\nu \sim O(10MeV)$
  $\pi^+ \rightarrow \mu^+\nu_\mu \rightarrow (e^+\nu_e\bar{\nu}_\mu)\nu_\mu$
- H- LINAC: 1GeV @1.4MW, 60 Hz; mostly pions
  - Will be upgraded 2024!
- Liquid mercury target
  - Minimize pions decay-in-flight
- Operate ~5000 hours/year
- $2.81\times10^{14}\nu/cm^2/flavor/year$ @ 20m



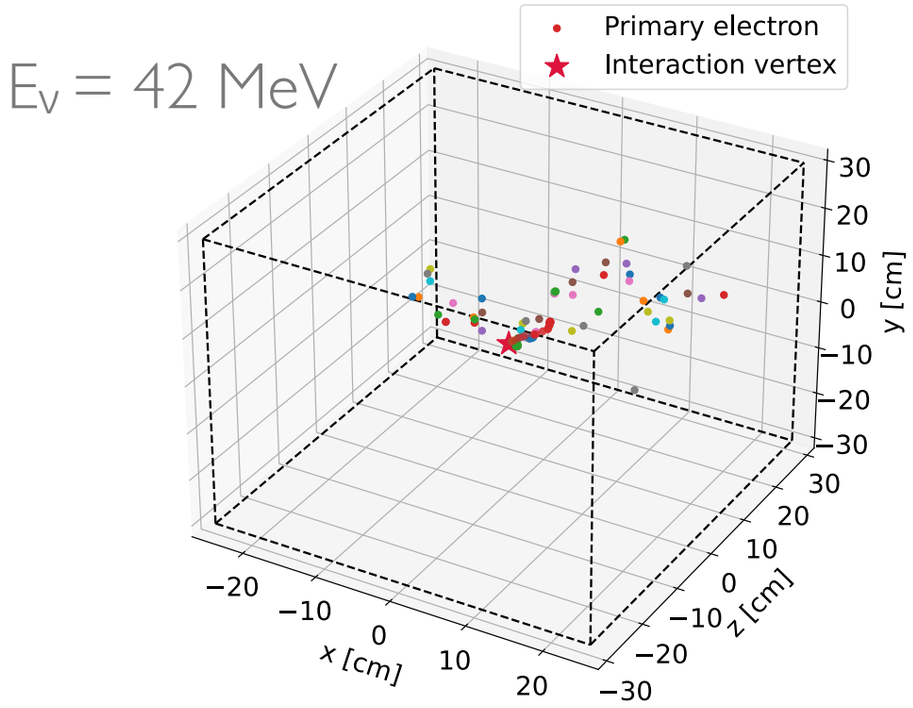


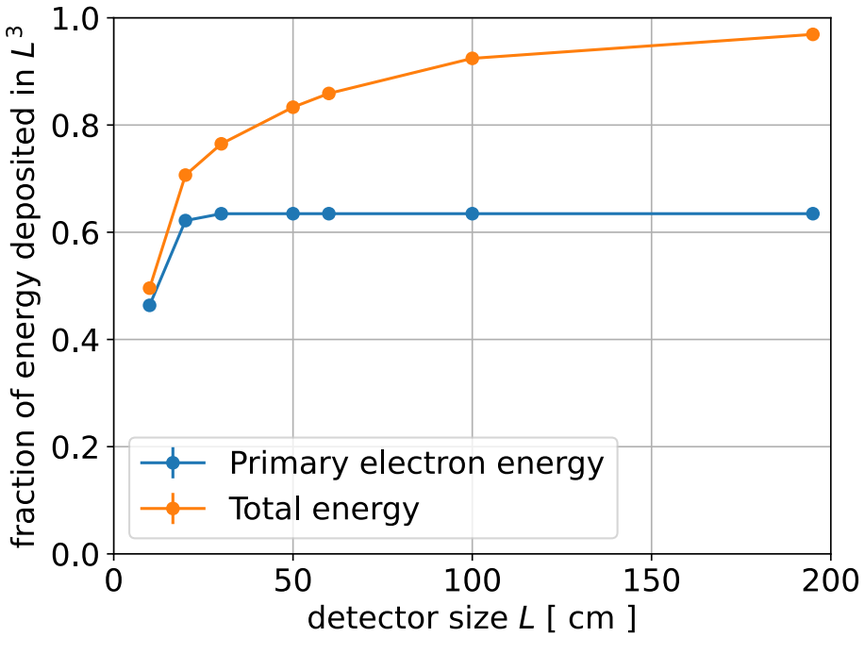
First Target Station



- 20-30m from the neutrino source
- Neutron shielding
- 8 m.w.e. overburden
- Hosts COHERENT Experiment

Proposed LArTPC



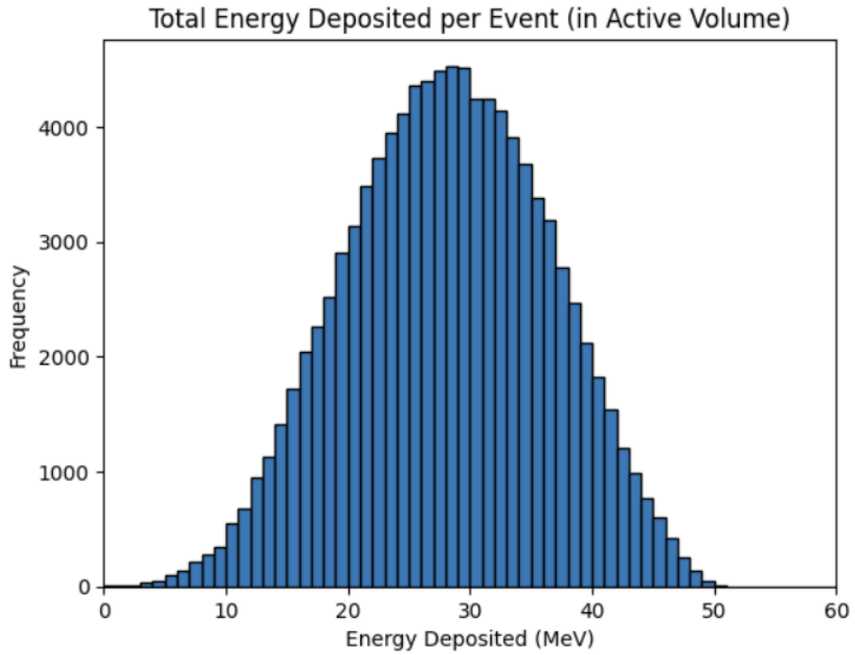


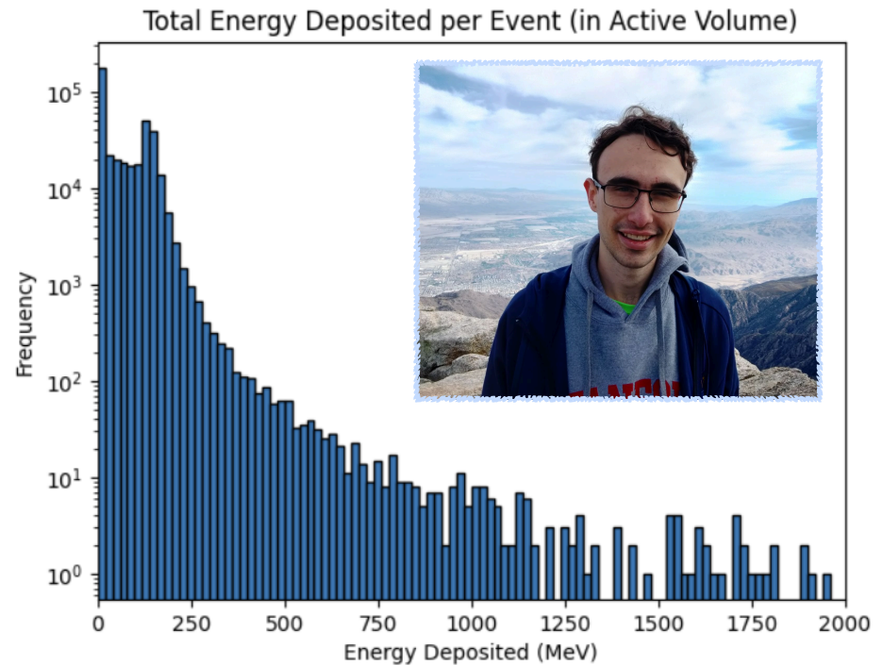
- 50x60x60cm^3, 250 kg LAr in the active volume
- Pixelated charge readout
- 30cm drift distance: 2 TPCs
- Expected signal: ~150/year
- Expected background
  - Cosmic rays (main)
  - Beam related neutrons
  - ν interactions outside
  - Hot-off gas (radiological waste)

ν_e-Ar CC Sensitivity

GEANT4-level study by John Vaccaro (Stanford)

	Location 1	Location 2
Signal	176.4	86.9
Cosmics	27	27
Beam related neutrons	0.1	3.82
ν outside	44.5	21.9
Likelihood to observe 3 S.D. in 1 year	100%	93.3%
Likelihood to observe 3 S.D. in 3 year	100%	97.5%





Opportunities & Synergy

- Synergy in the MeV-scale physics LArTPC R&D, e.g. GAMPix, and DUNE ND-LAr, and theorist efforts at SLAC
- Collaborators from Hawaii, Napoli (Italy), Campinas (Brazil), Alabama, UT Arlington, Wellesley, NYCU (Taiwan) expressed interests
- Future opportunities
  - 10-ton-scale for differential cross section measurements (ASTAE-scale)
  - The Second Target Station at Oak Ridge and European Spallation Source

Backup

20% Uncertainty on σ