LArTPC Technology

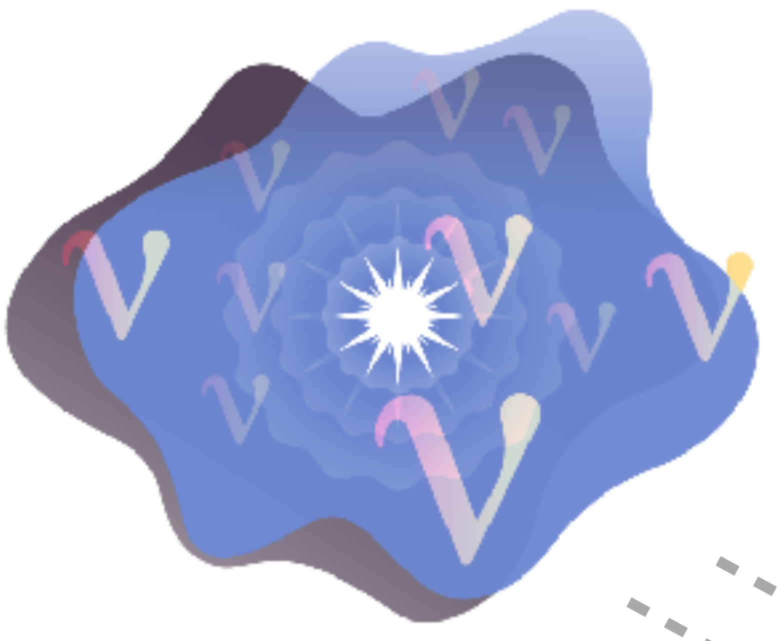
SLAC NATIONAL ACCELERATOR LABORATORY

Yun-Tse Tsai (SLAC)

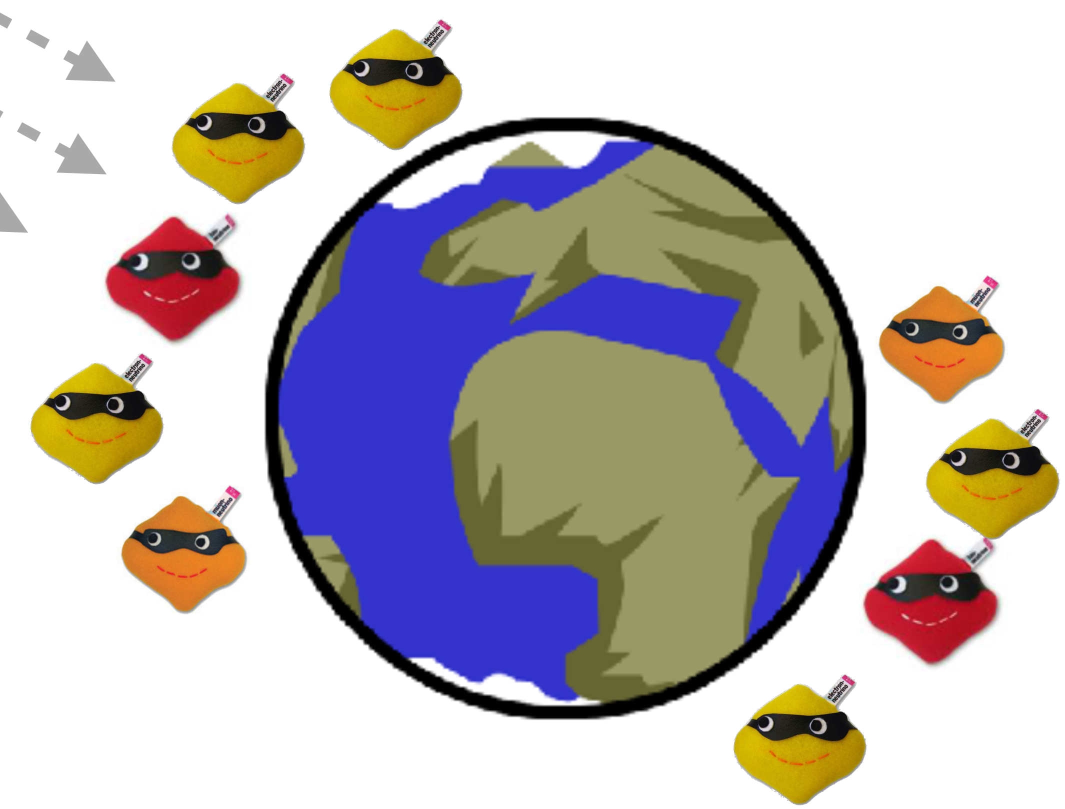
Beam Dump in PIP-II Workshop

May 11th 2023

Supernova Neutrino

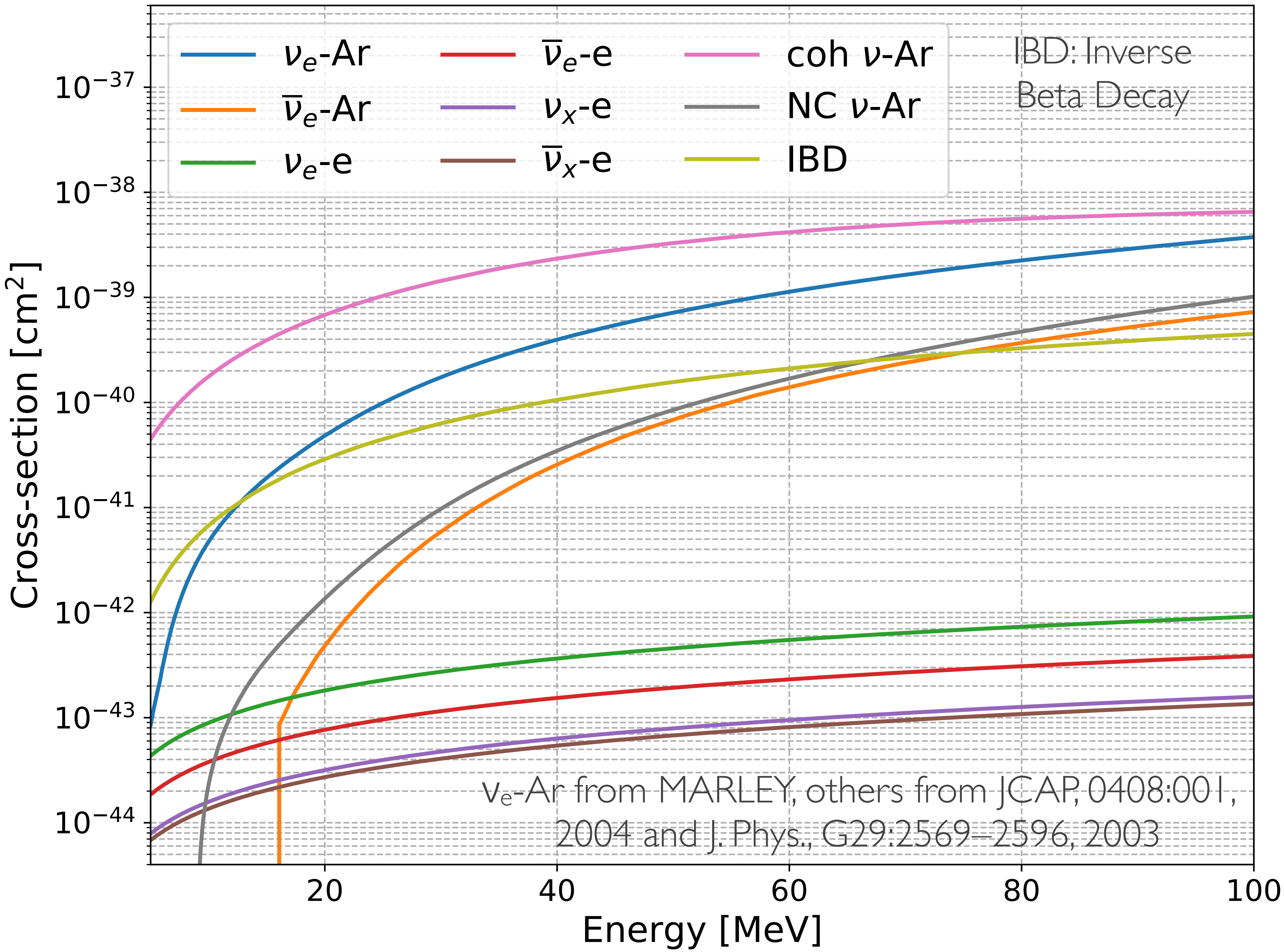


Core-collapse supernova neutrino energy: O(1-10) MeV

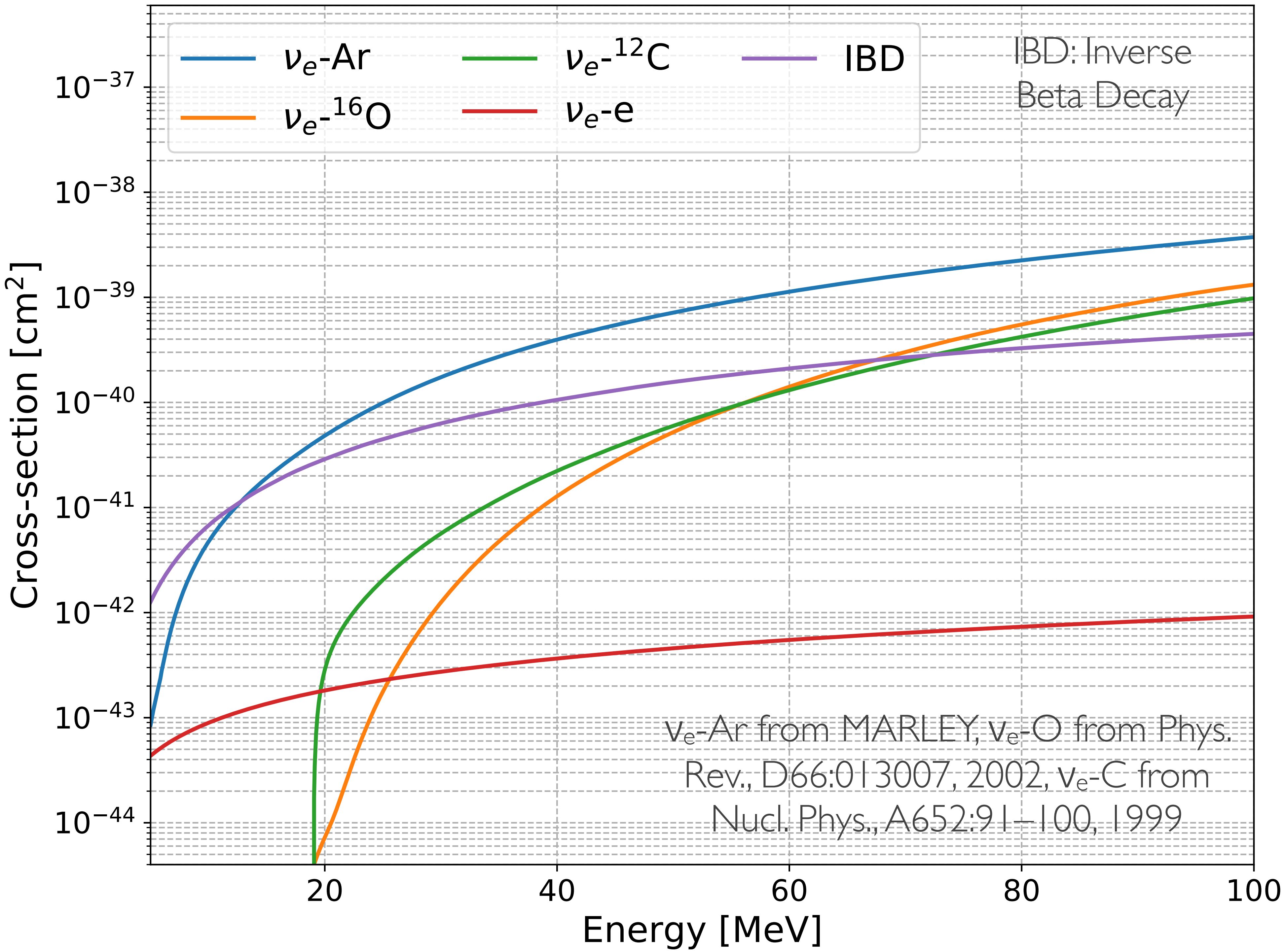


DUNE has unique sensitivity to ν_e via charged-current (CC) ν_e-Ar interactions

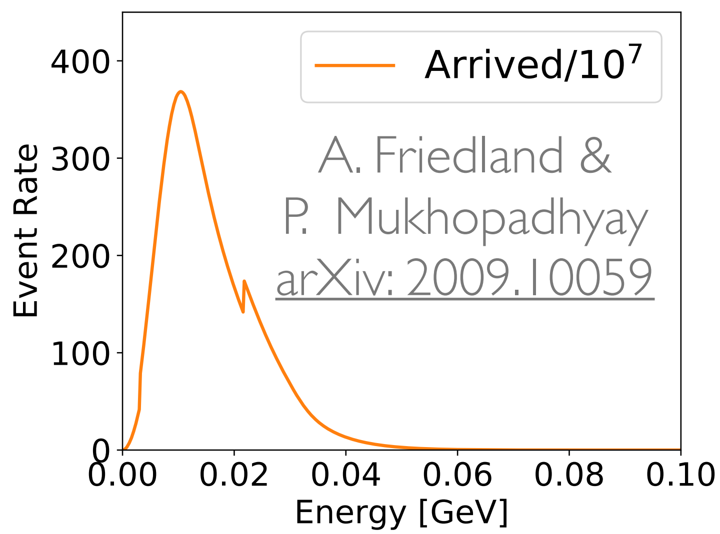
ν_e-Ar Cross Sections



ν_e Cross Sections



SN Neutrino Detection



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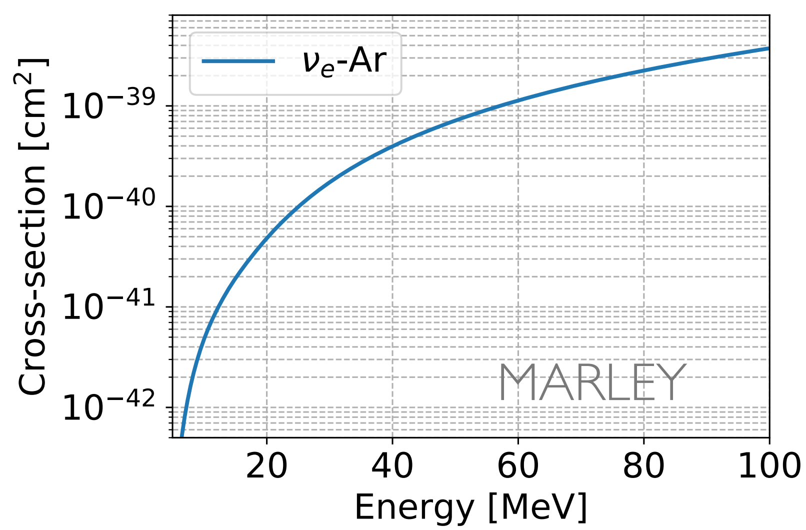

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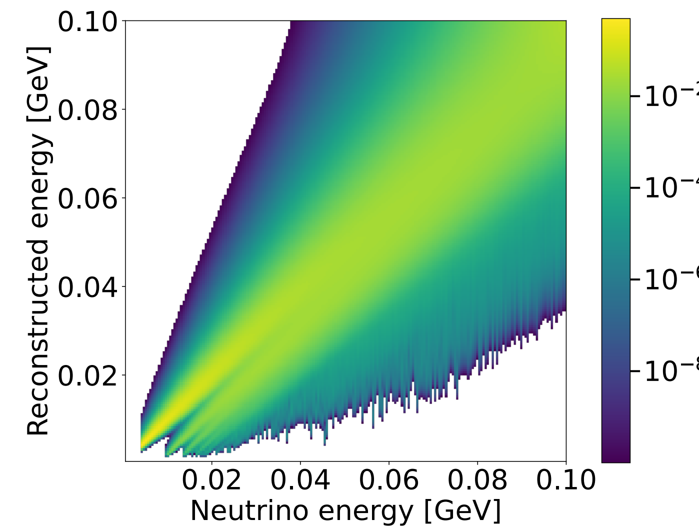
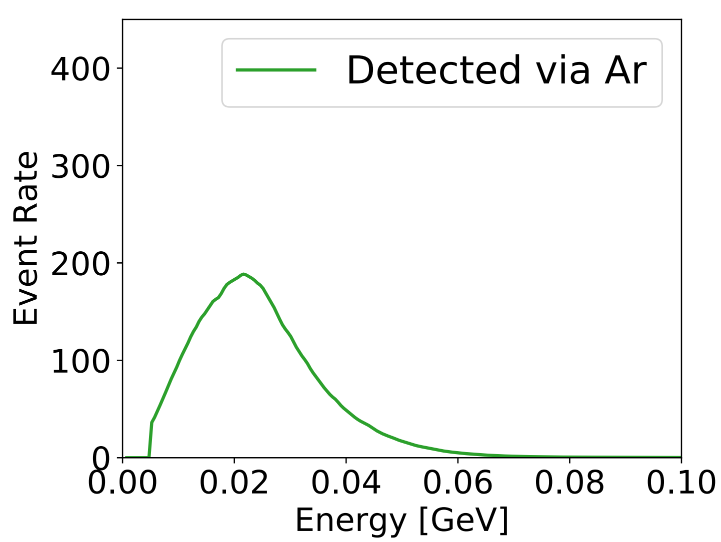
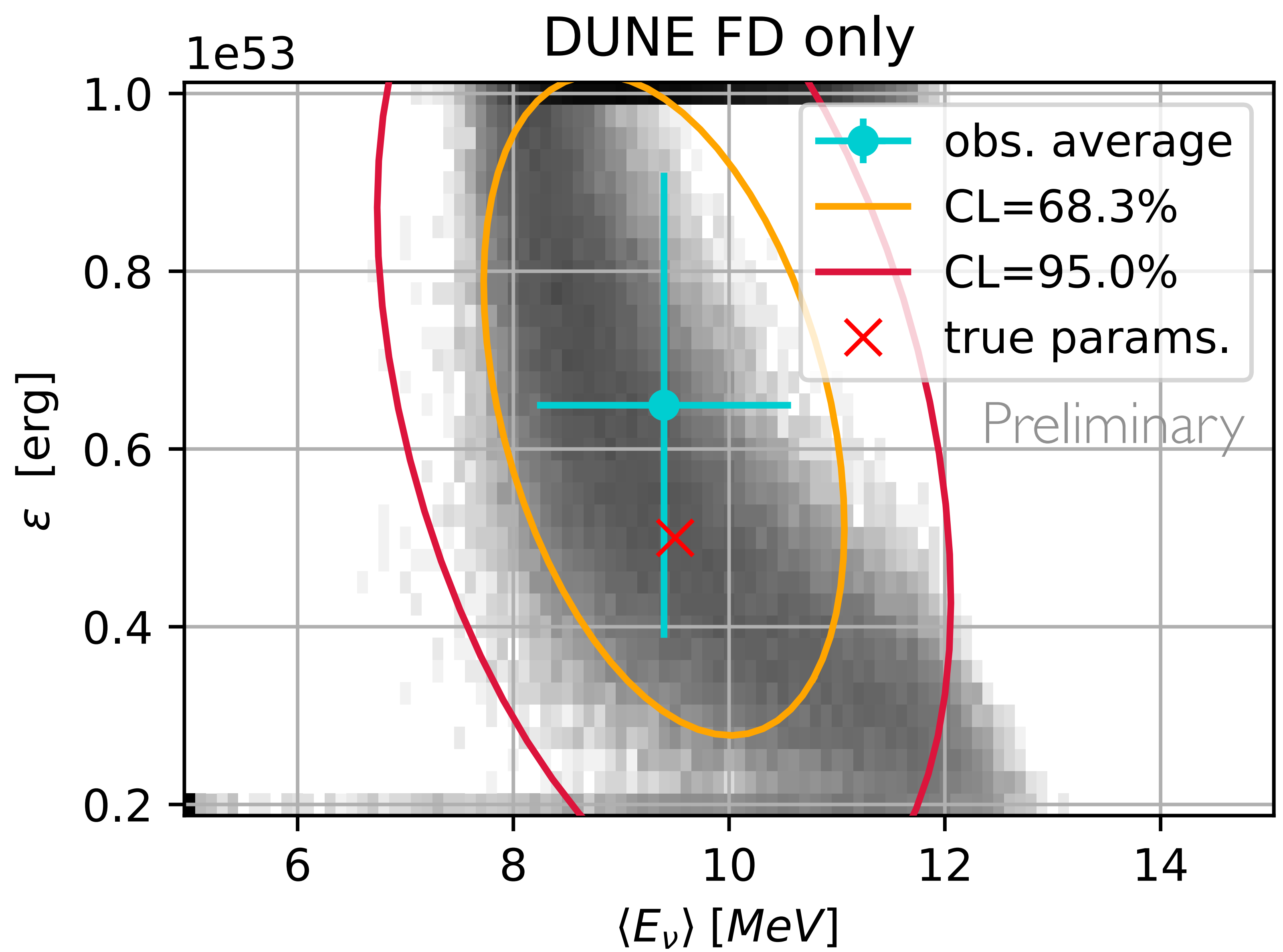




- Detect convolved ν flux and interaction cross sections
- Disentangled ν fluxes are desired
- These ν_e-Ar CC cross sections have never been measured
  - Uncertainties from cross section models are relevant

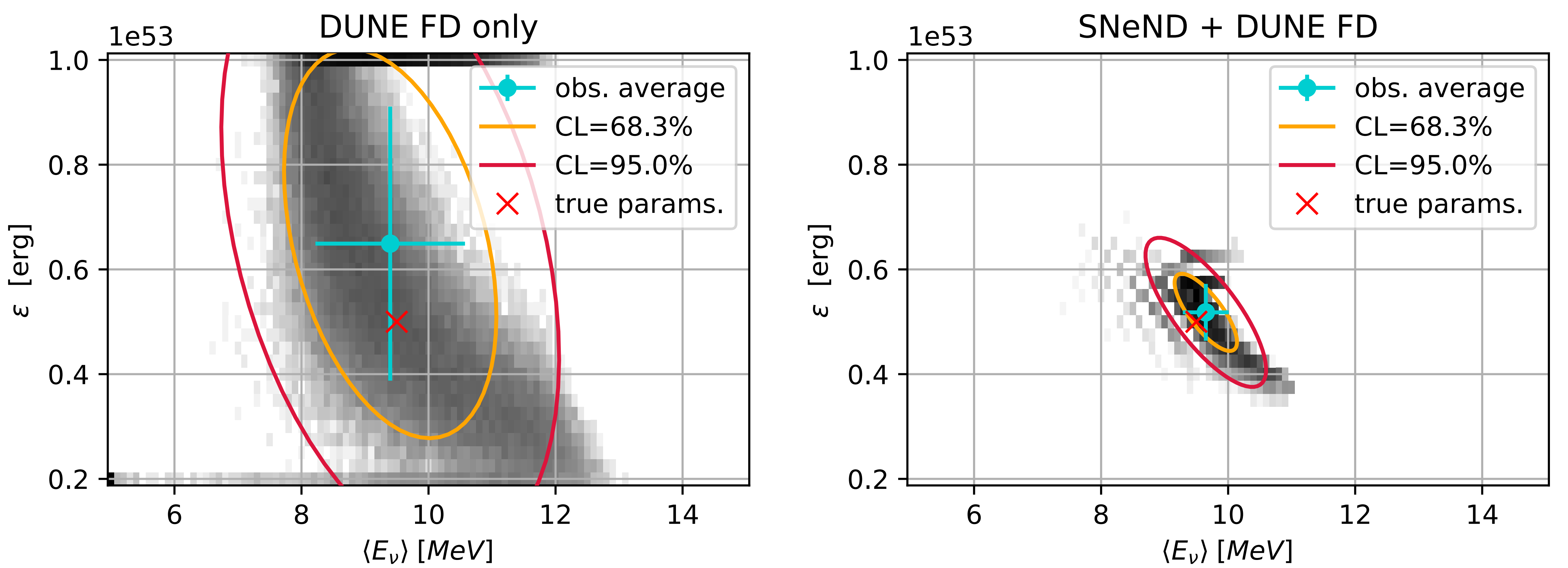
Measure ν_e-Ar CC σ

If we measure the total σ and σ(45 MeV) at the precision of 20%, as suggested by arXiv:2303.17007



SNeND Constraints

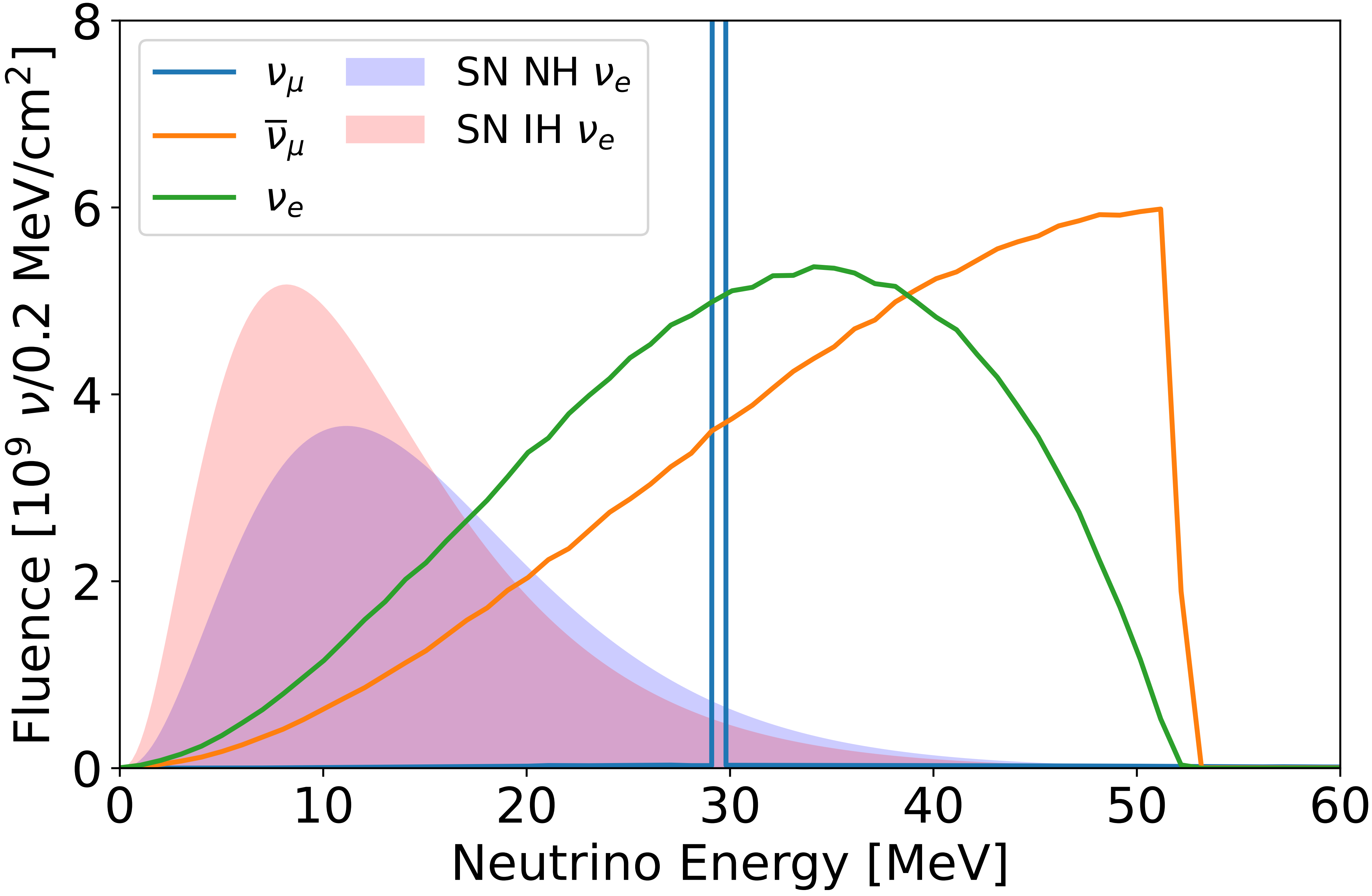
If we measure the cross section with a well-controlled neutrino source and a functional equivalent detector.



Statistical uncertainties not included yet

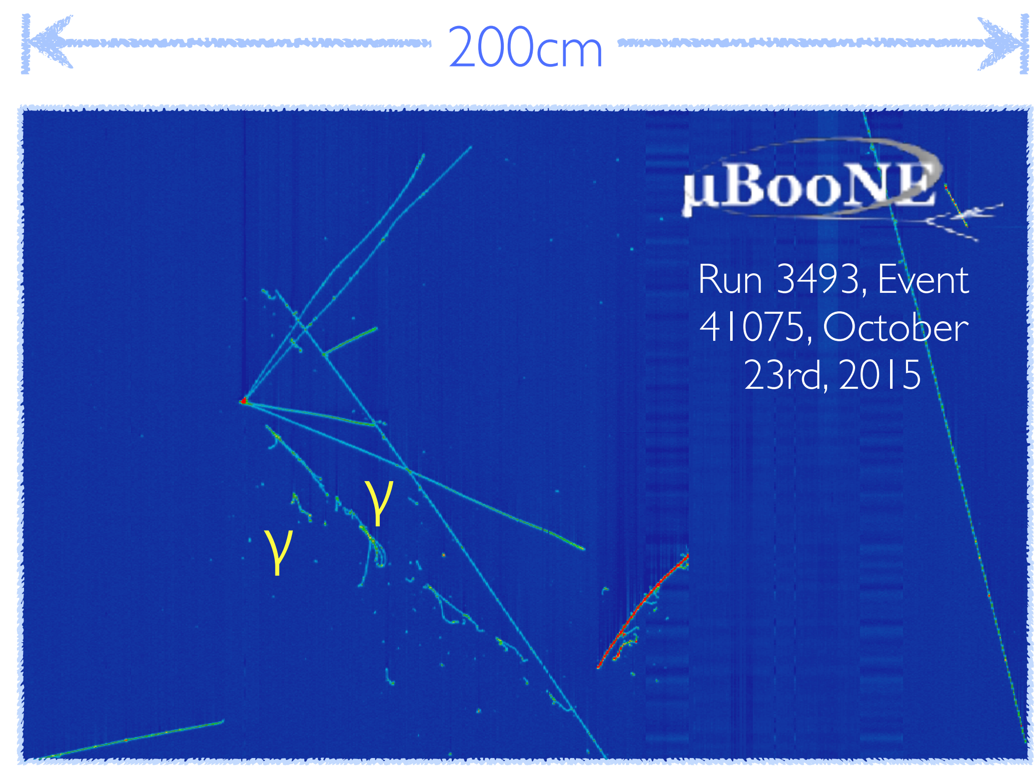
Preliminary result. Paper in preparation.
In collaboration with Gianluca Petrillo (SLAC), Yen-Hsun Lin (NCTS)

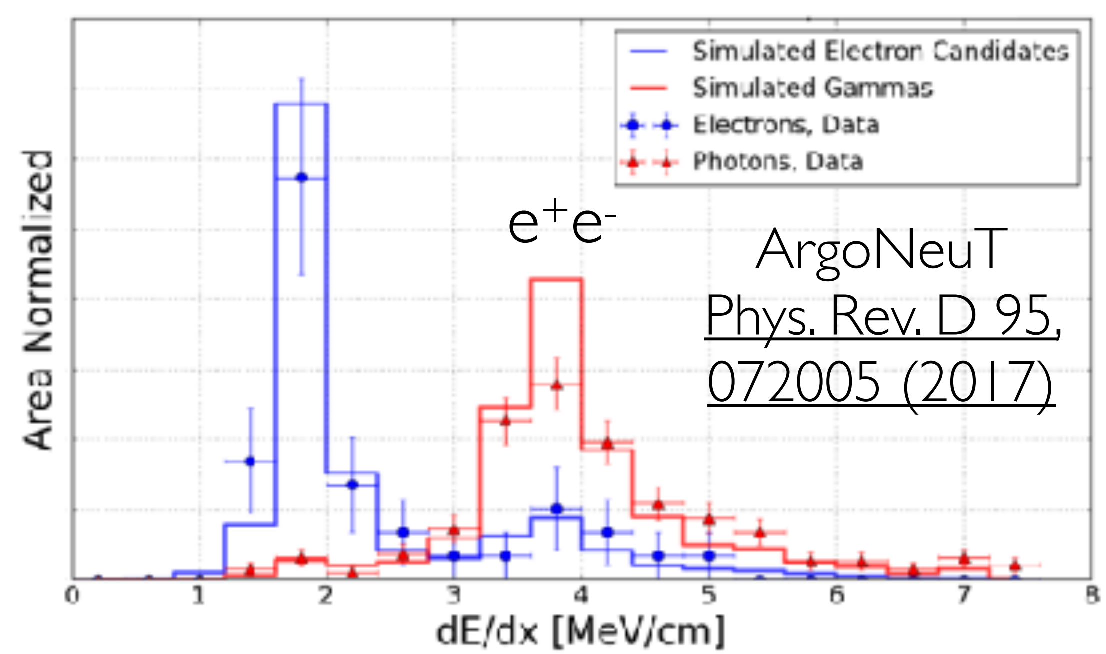
ν from π Decay-At-Rest



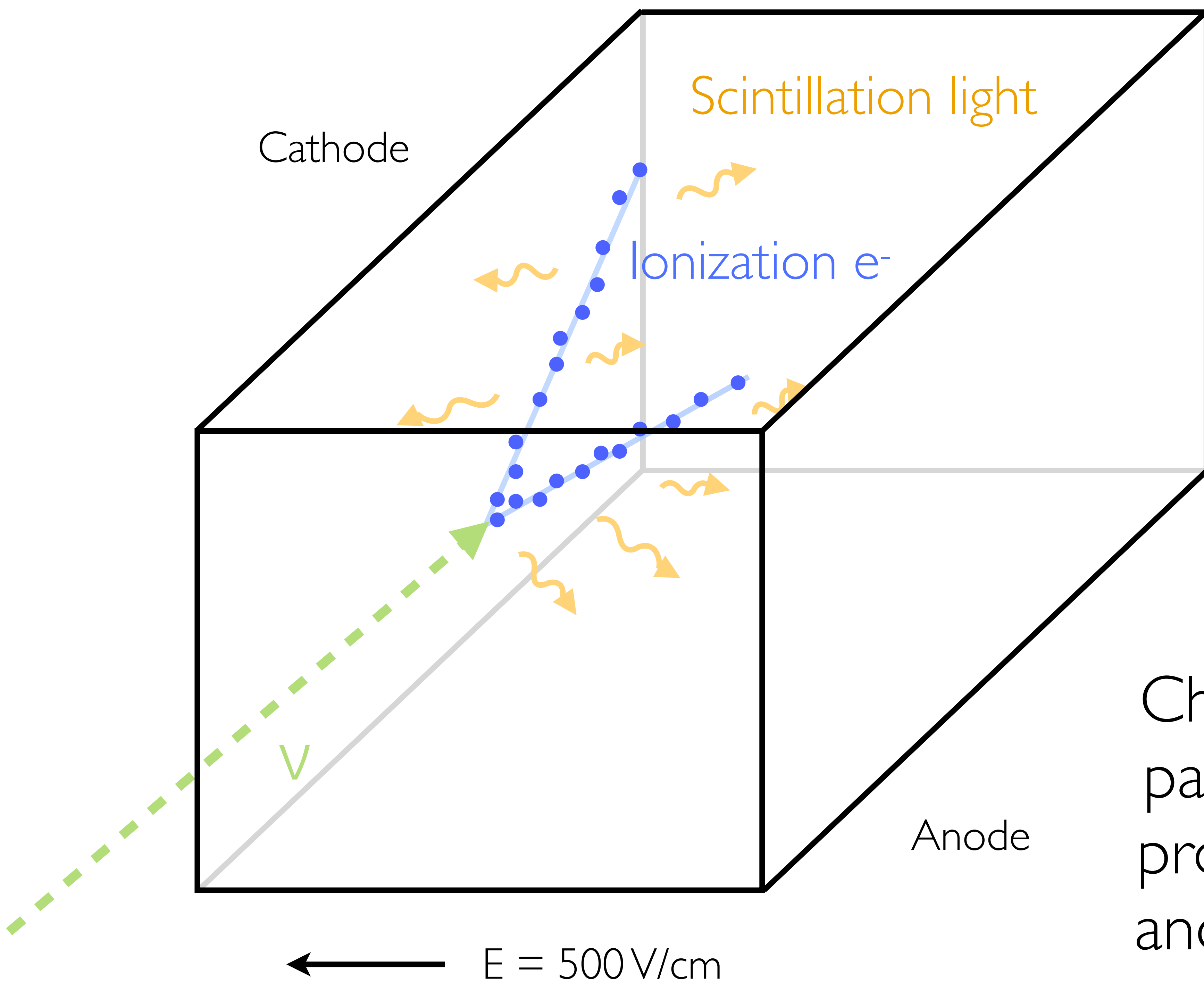
Why LArTPC?

- Liquid-Argon Time-Projection Chamber
- LAr: large interaction rate
- Modular and scalable
- Millimeter resolution
- Calorimetric measurement
  - e/γ separation
- Supernova ν_e (E~10 MeV)
- Low detection threshold
- Technology used for DUNE





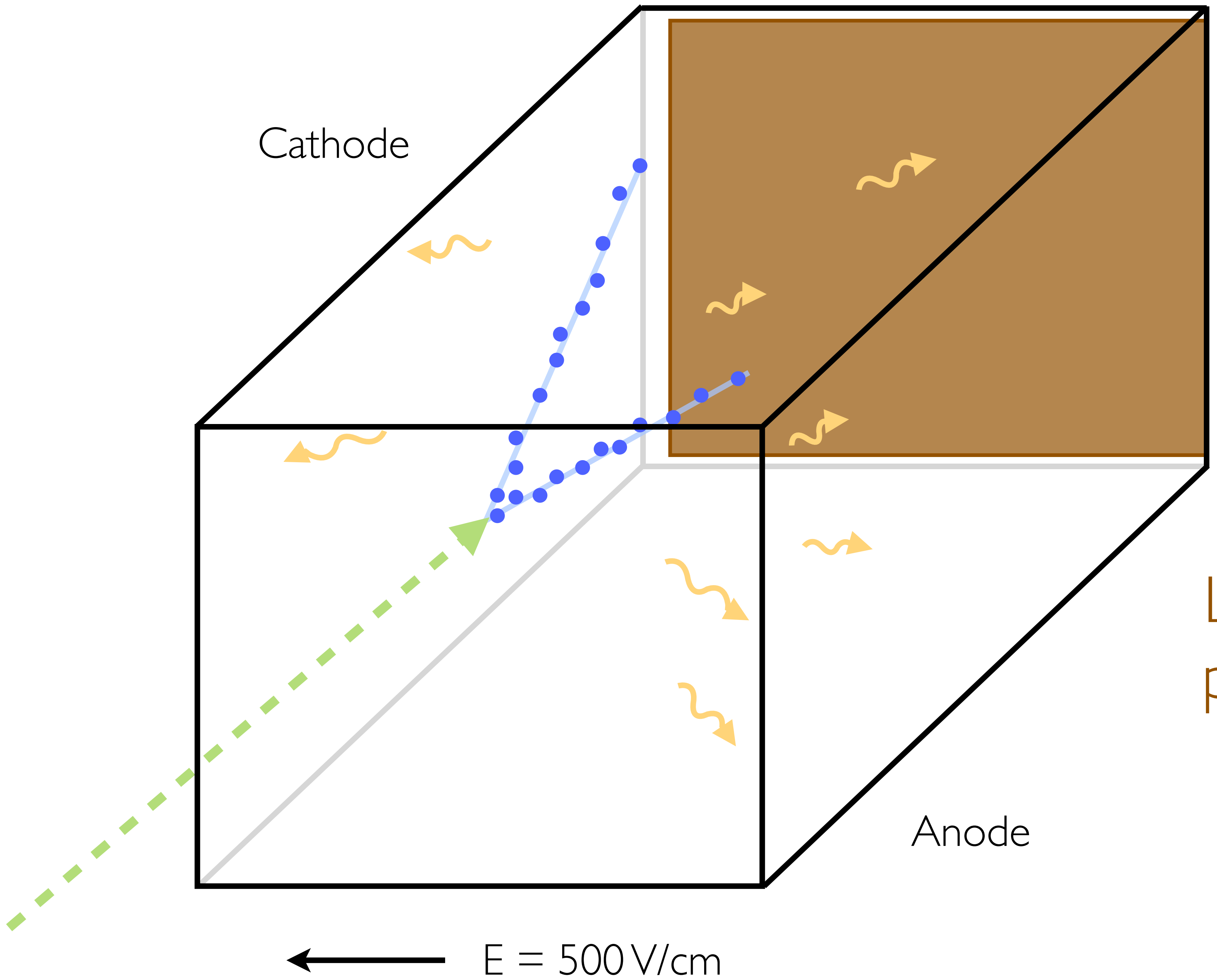
LArTPC



Incoming neutrino interacting with LAr

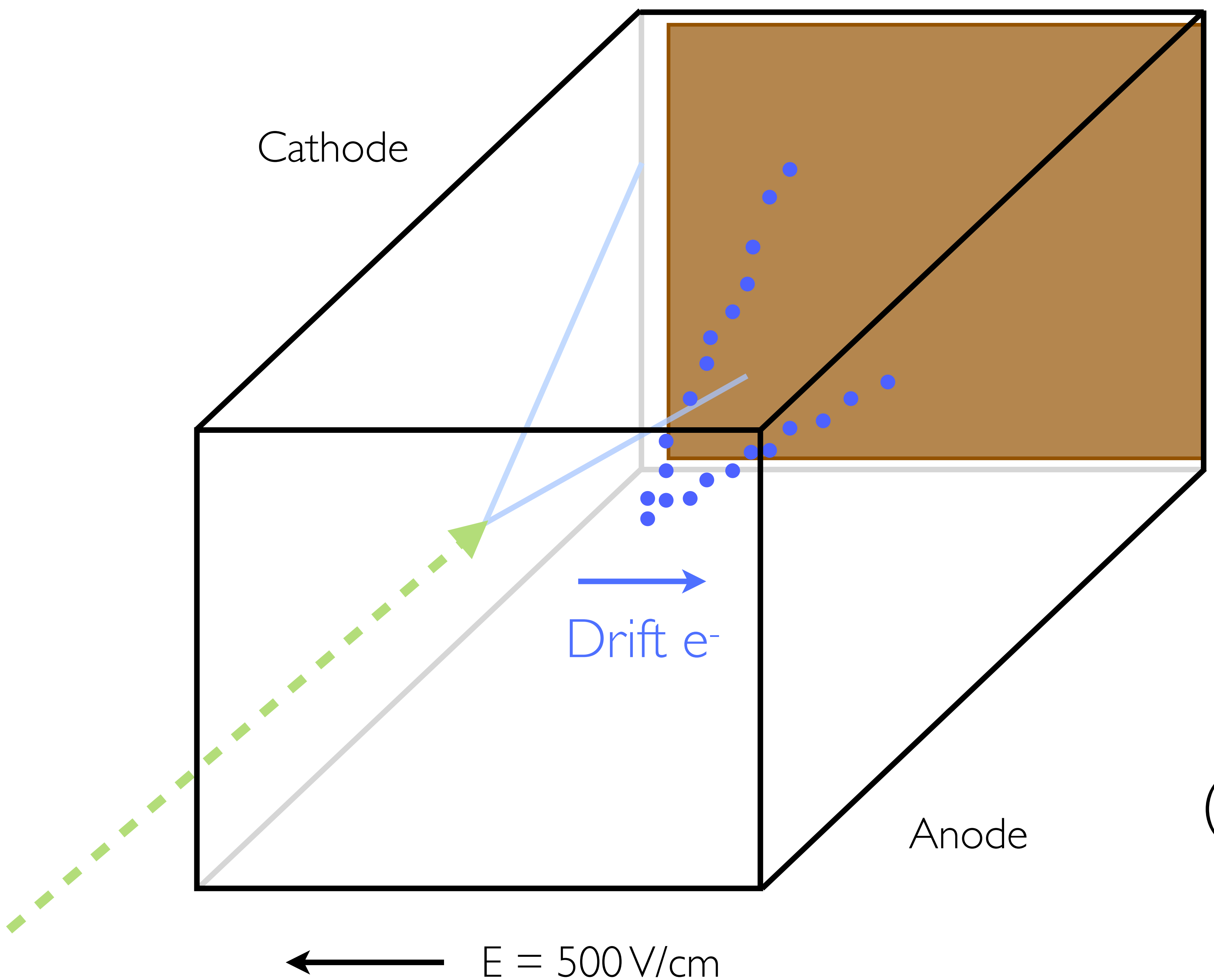
Charged secondary particles ionize LAr, producing electrons and scintillation light

LArTPC



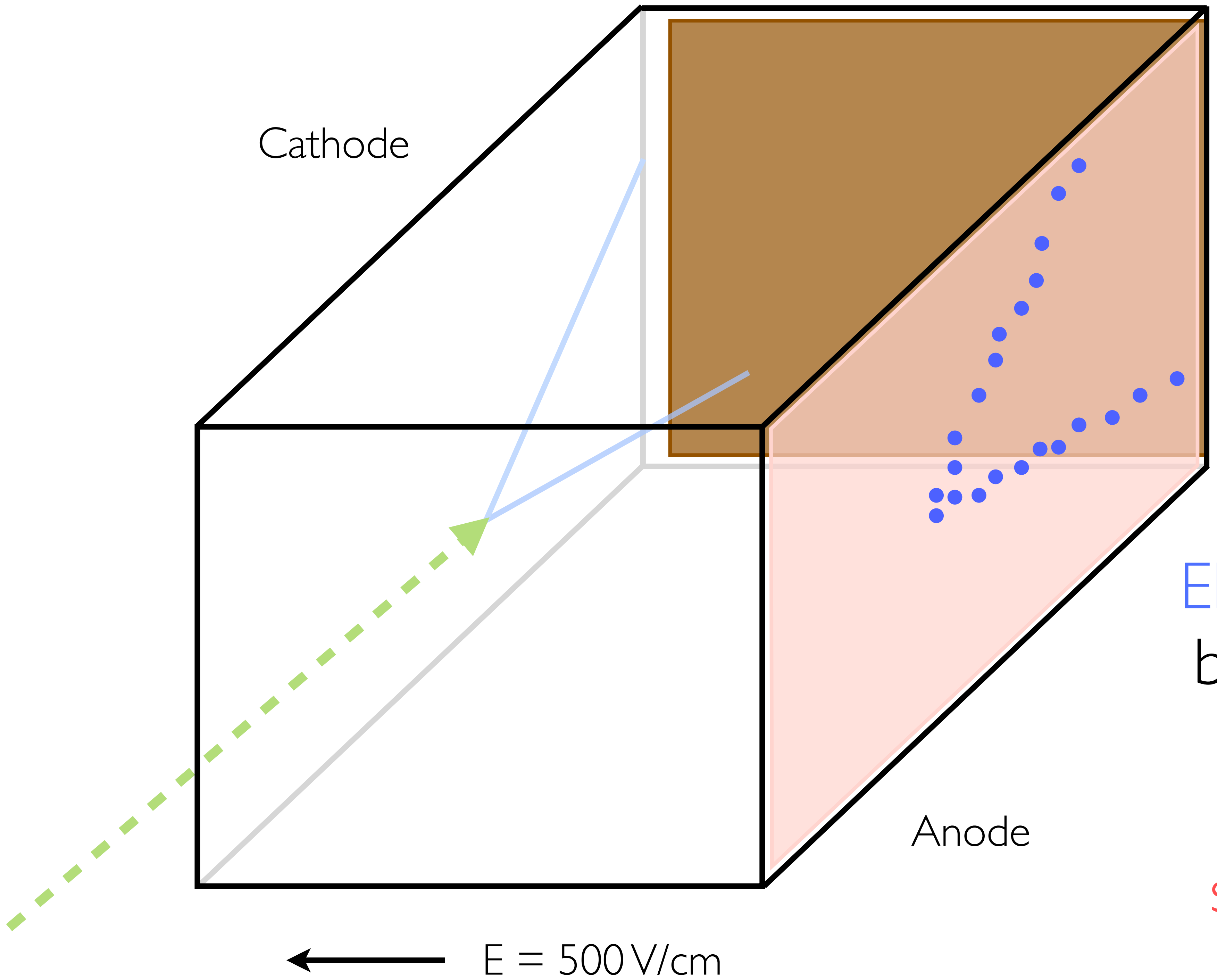
Light collected by photon detectors (10-100ns), determining event time t_0

LArTPC



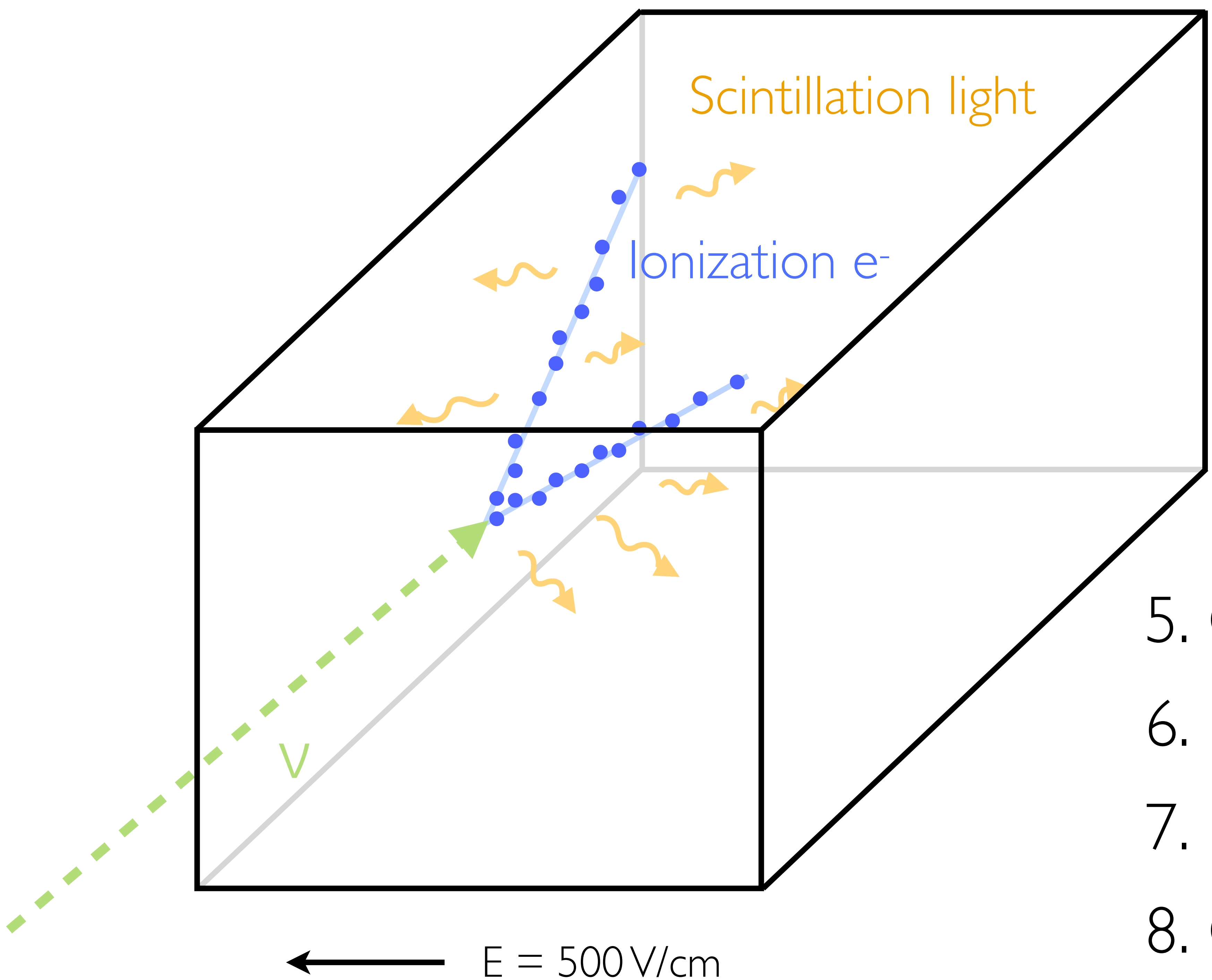
Electrons drift towards anode (drift time at ms scale)

LArTPC



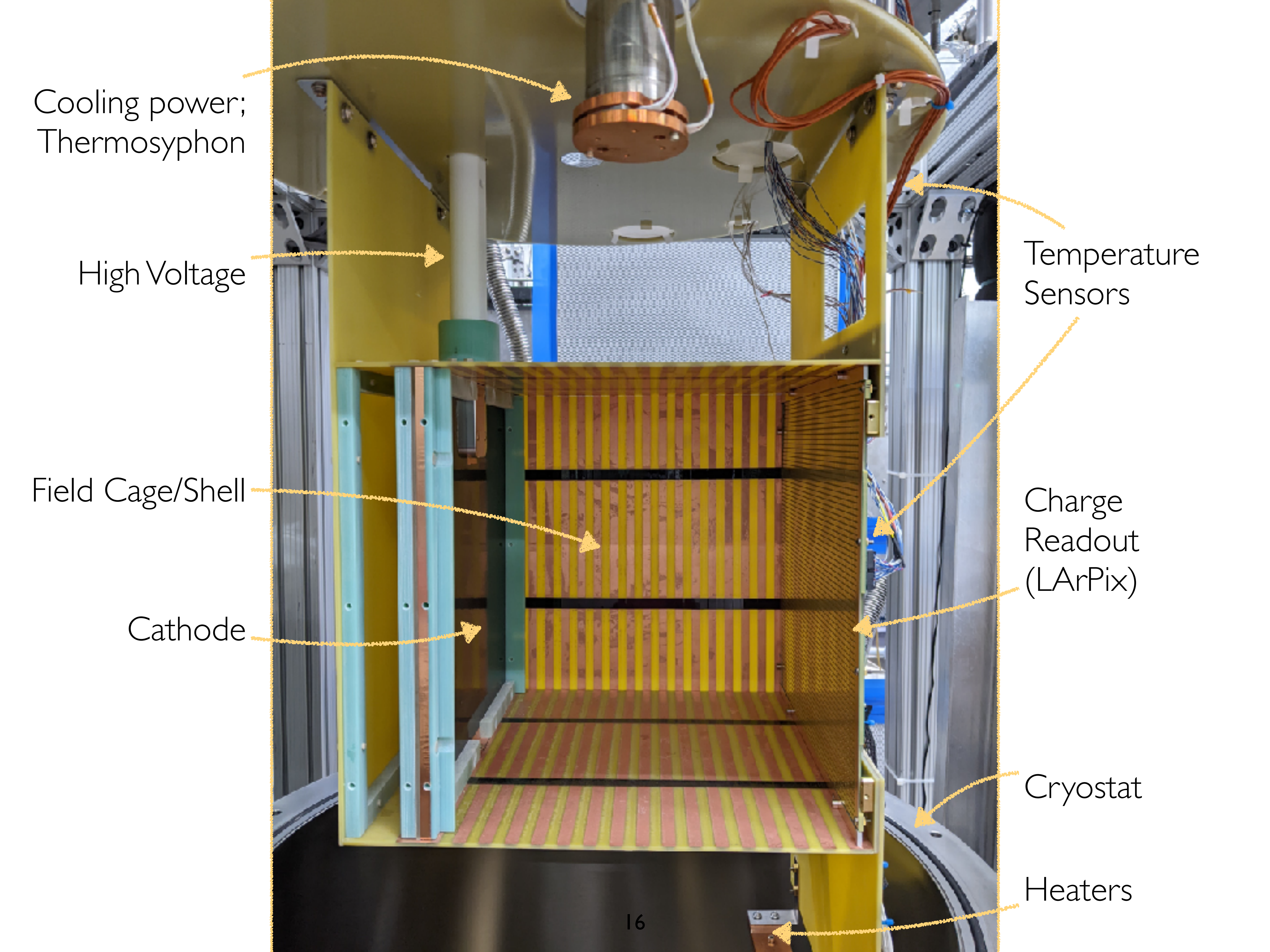
Electrons detected by the pixel plane at anode, providing the spatial, kinematic information.

LArTPC



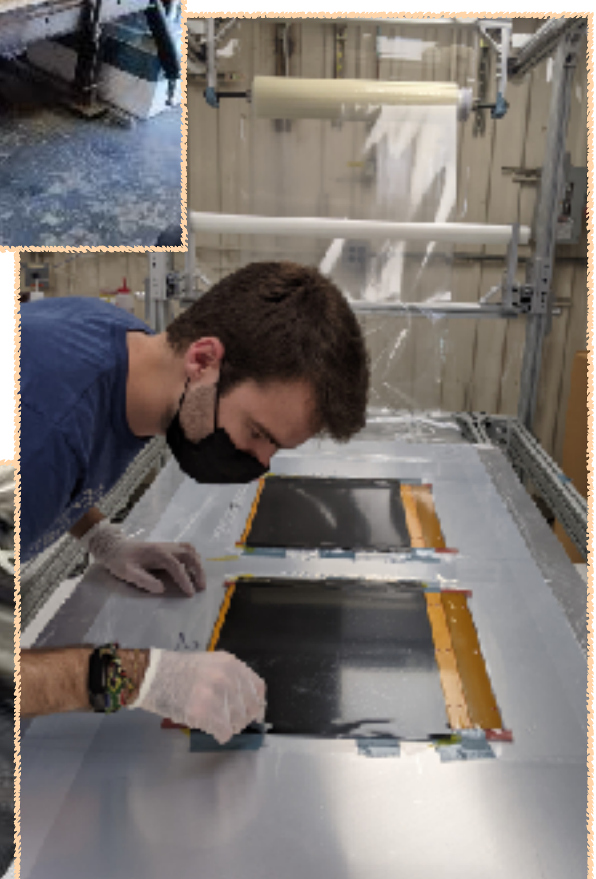
1. Cryogenic system
2. Detector control
3. High voltage
4. Field shell
5. Charge detector
6. Light detector
7. Pure LAr
8. Calibration

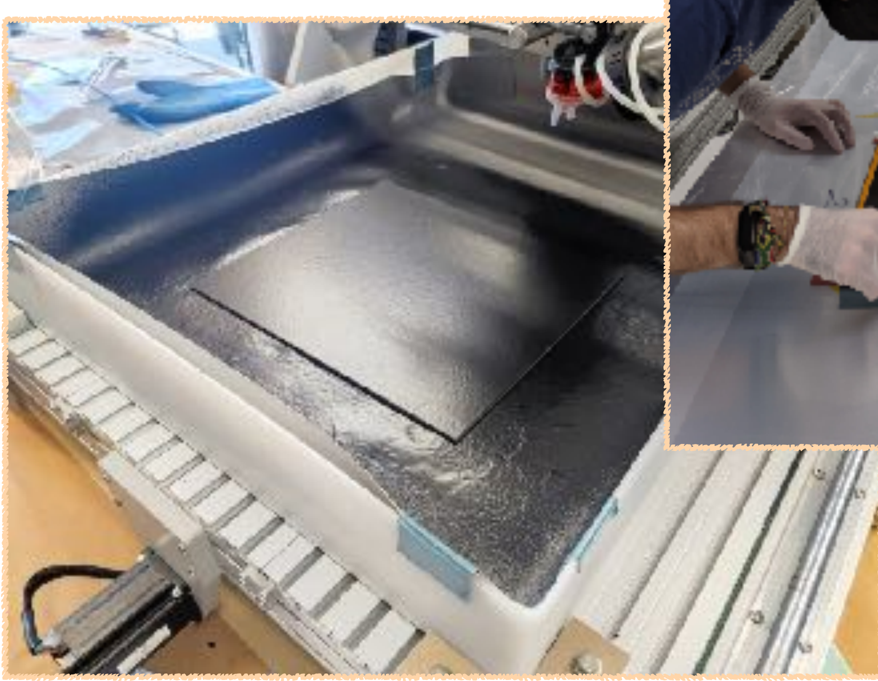
DUNE
ND-LAr
Concept



Cooling power;
Thermosyphon
High Voltage
Field Cage/Shell
Cathode
Temperature
Sensors
Charge
Readout
(LArPix)
Cryostat
Heaters

Field Shell





- Time projection requires uniform electric field
- Maximize the active volume in a modular TPC
  → thin panels
- Keep the electric potential linear and smooth
  → resistive materials
- Operate at 500V/cm
- Heat local density
  $< 100\ mW/cm^2$

➡ Dupont Kapton sheets or carbon coated panels

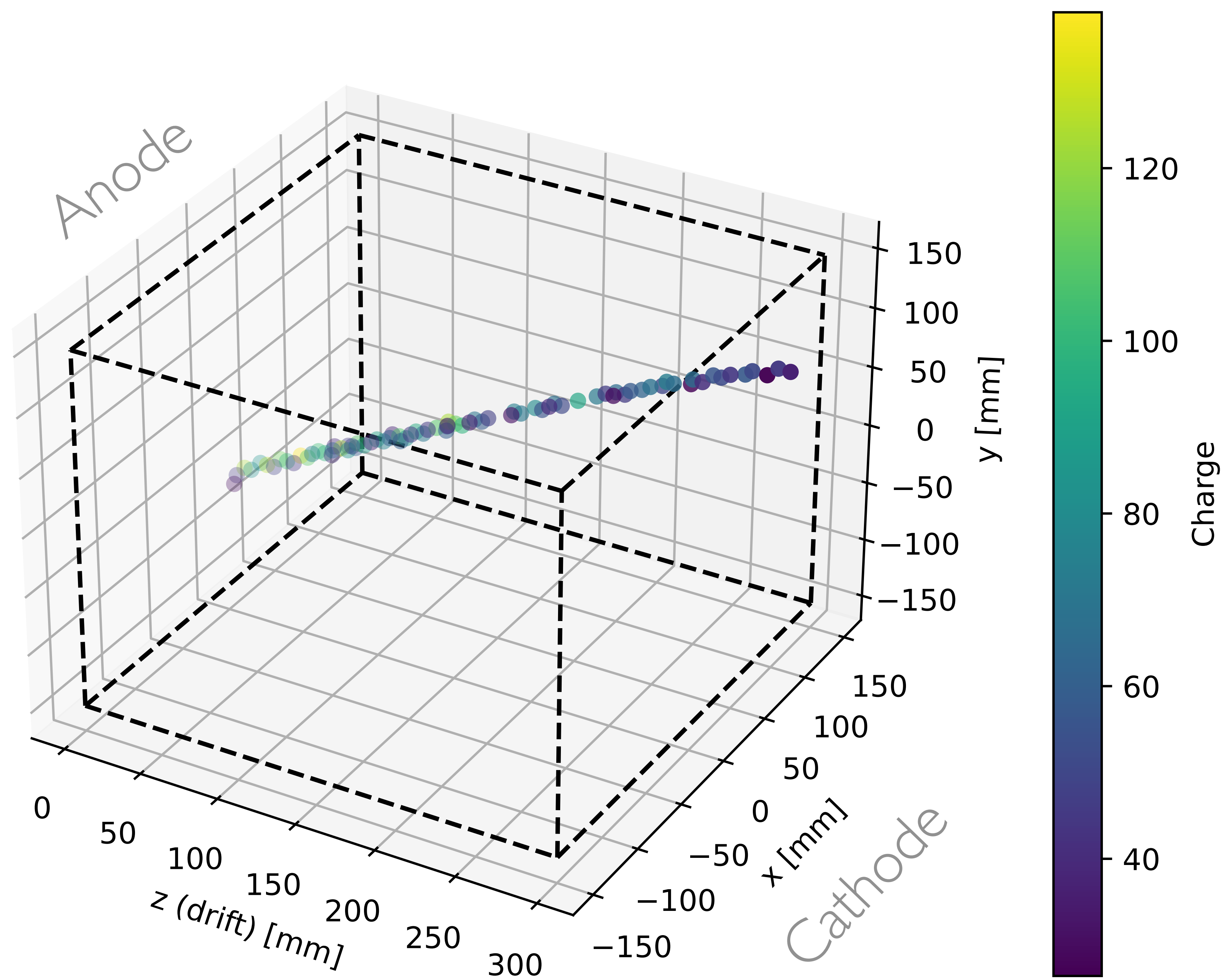
Cosmic Muon Track

E = 500 V/cm

Electron lifetime (LAr purity) ~ 225 µs

Data taken on July 31st (P. Tsang)

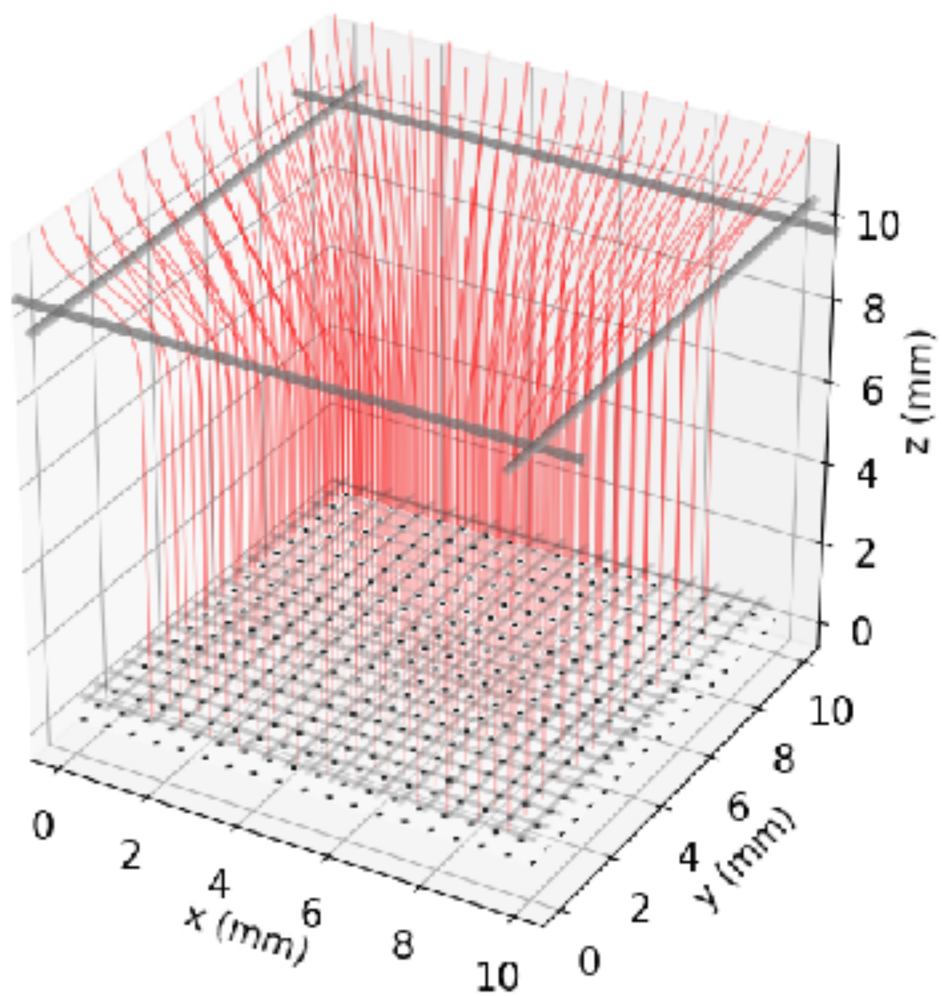
~1 cosmic ray track every 2 minutes



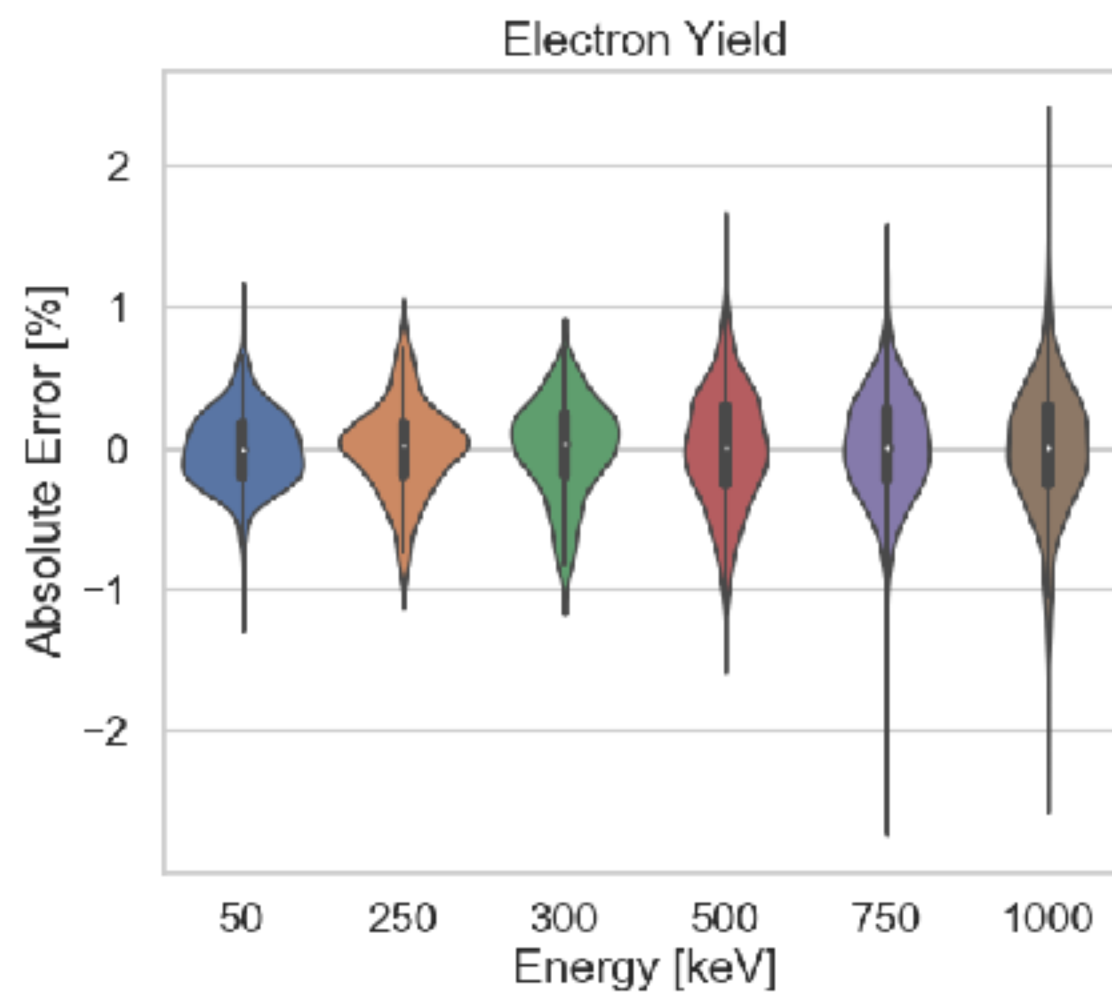
GAMPix

500µm-pixels triggered by mm scale wire readout. Low noise level (50e-) for MeV γ detection

Combine the signals on wires and pixels to obtain fine tracking, calorimetry, drift distance, etc.

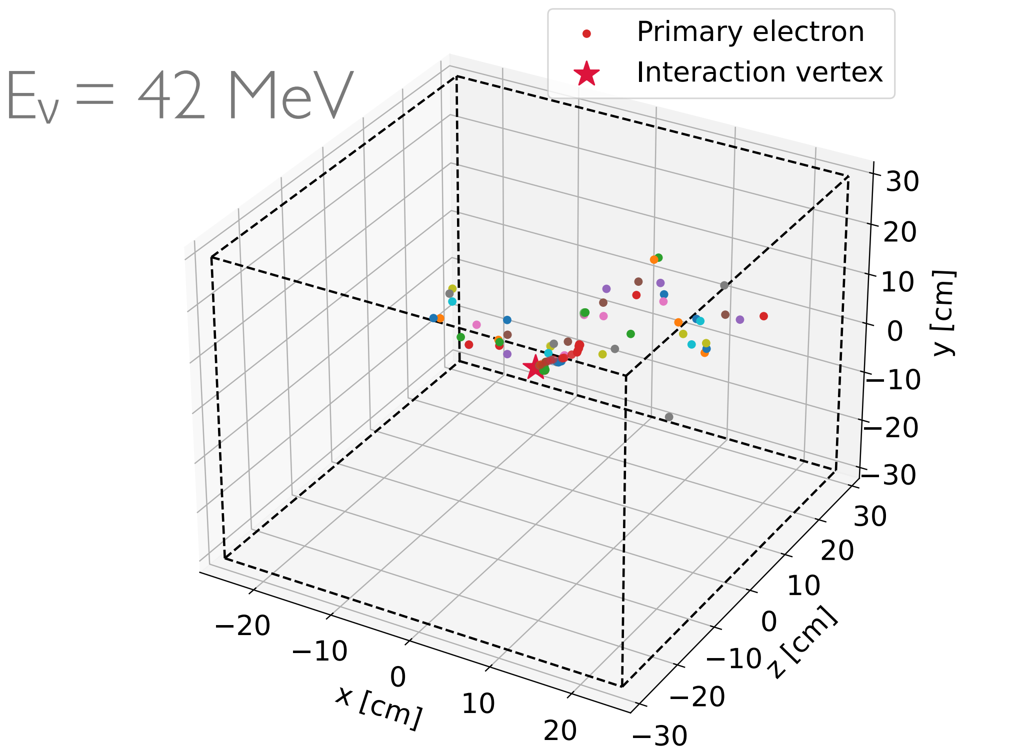


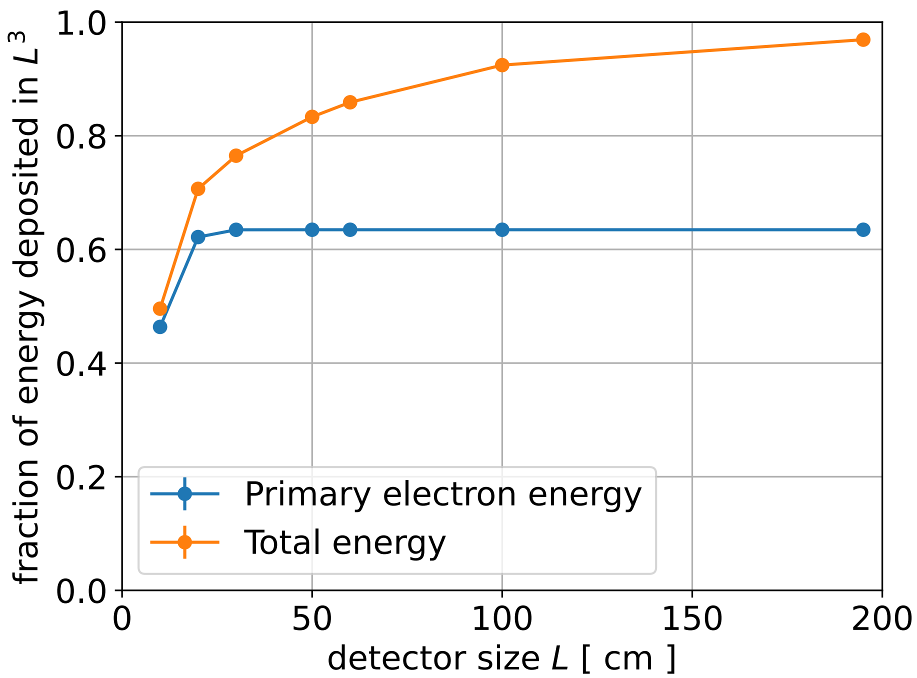
R&D underway at SLAC



Plots by B. Trbalic (SLAC/Stanford)

Potential LArTPC





- Optimal detector dimension depends on the neutrino intensity, distance from the target, background rates, etc.
- Tracking capabilities enable BSM opportunities, e.g. axion-like particles
- Slow detectors (milliseconds): requiring shielding and veto systems
  - Beam-related neutrons, etc.
  - Cosmic rays
  - Environmental, radiological

LArTPC Dimension

- Assume proton beams 1.3 GeV at 2 MW, operating 5000 hours per year (SNS upgrade configuration)
- 50x60x60cm^3, 250 kg LAr in the active volume, 27.5m from the Hg target
- Cross section calculation from MARLEY

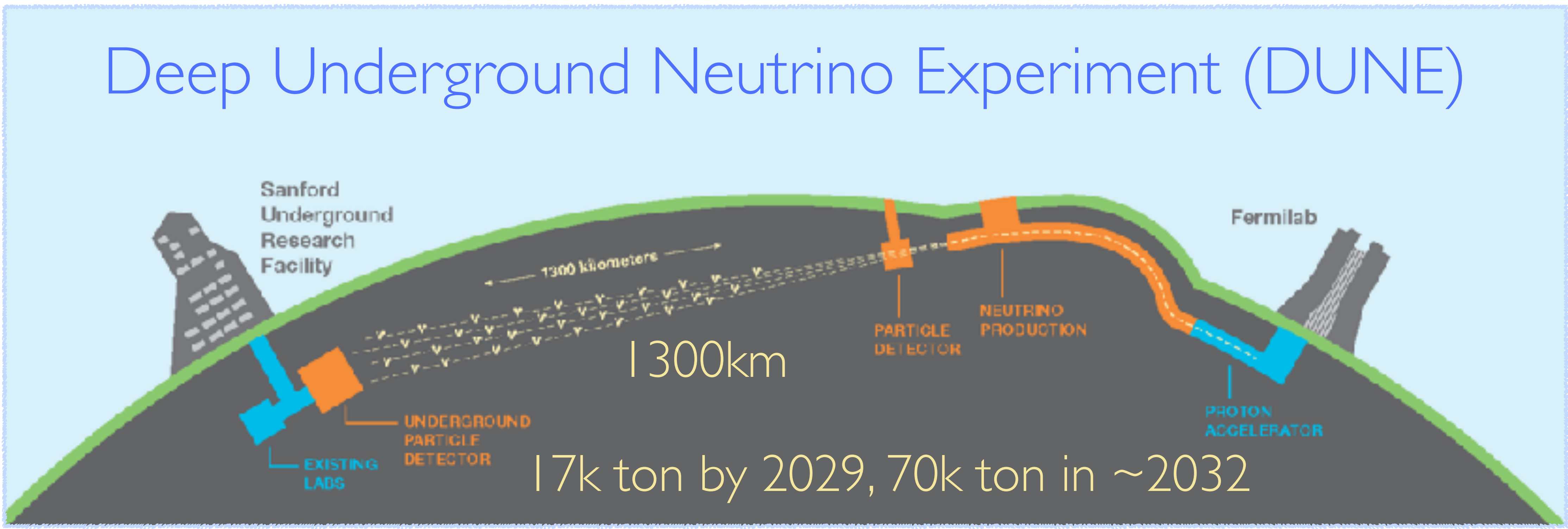
	Dimension (cm)	Ar Mass (kg)	Est. ν_e-Ar CC per year
Fiducial	30x40x40	66.72	55.9
Partly Contained	40x50x50 -30x40x40	72.28	60.6

Summary & Remark

- Supernova neutrino measurements: one of the primary physics goals in DUNE
  - ν_e-Ar CC σ measurements in LArTPCs with well-controlled ν, will reduce the bias
- MeV-scale detection in LArTPCs not largely explored; a number of R&Ds underway
- Tracking capabilities enable BSM opportunities
- Slow feature (milliseconds) requires appropriate shielding and veto systems
- Density of LAr might be more sensitive for search for BSM via interactions than via decays

Backup

Long Baseline Experiment



- Aim to measure:
  - CP violation in lepton sector
  - neutrino mass ordering
  - neutrinos from supernovae, proton decays, etc.
- ν_μ from Fermilab accelerator, detected by LArTPC

Supernova Neutrino Flux

Pinched-thermal form: to fit simulated flux

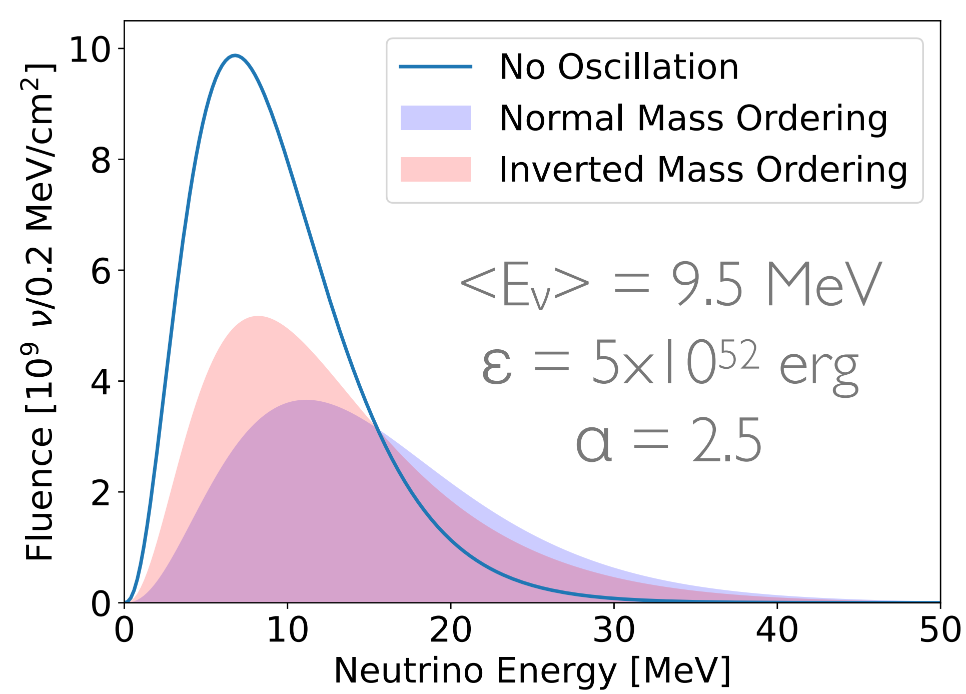
$$\phi(E_\nu) = \mathcal{N}\left(\frac{E_\nu}{< E_\nu >}\right)^{\alpha} \exp\left[-(\alpha+1)\frac{E_\nu}{< E_\nu >}\right]$$

E_ν: neutrino energy

$< E_\nu >$: average E_ν

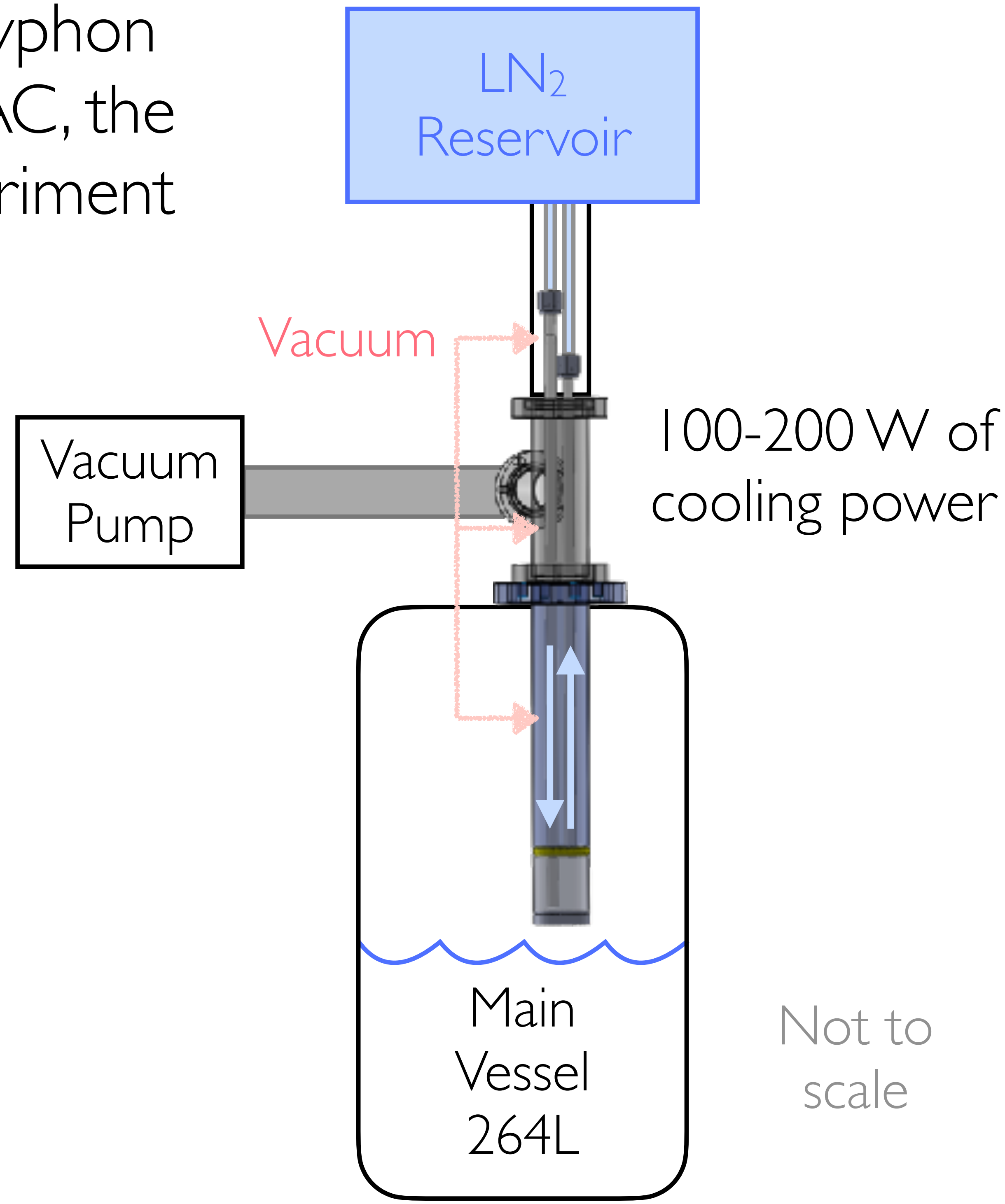
$N \propto \nu$ luminosity, ε

α: pinching parameter



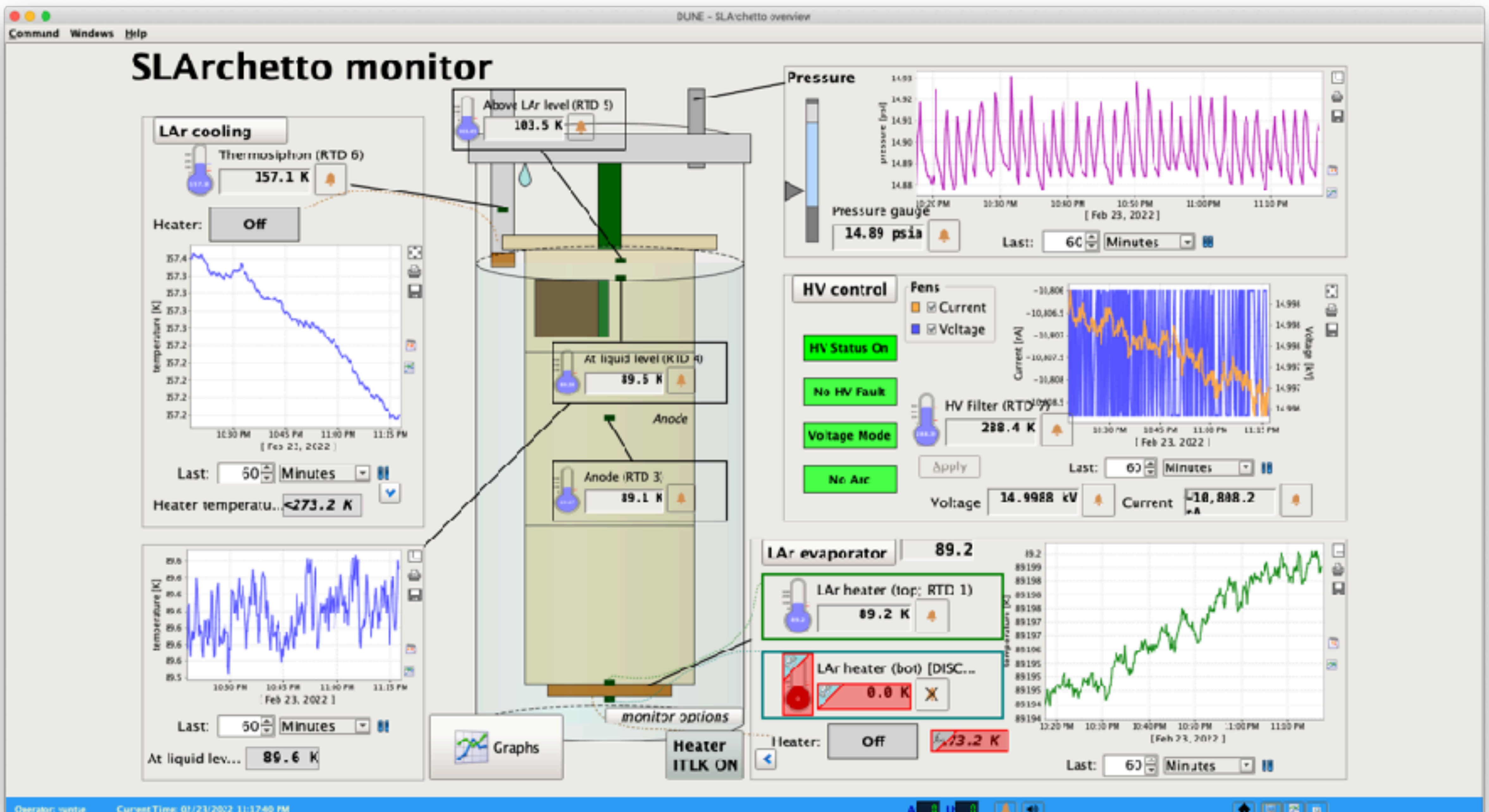
Cooling Power

Cooling power from the thermosyphon at Liquid Noble Test Facility at SLAC, the same technology used in LZ experiment



Detector Control

Based on Ignition: industrial detector control & monitoring, programmable in python

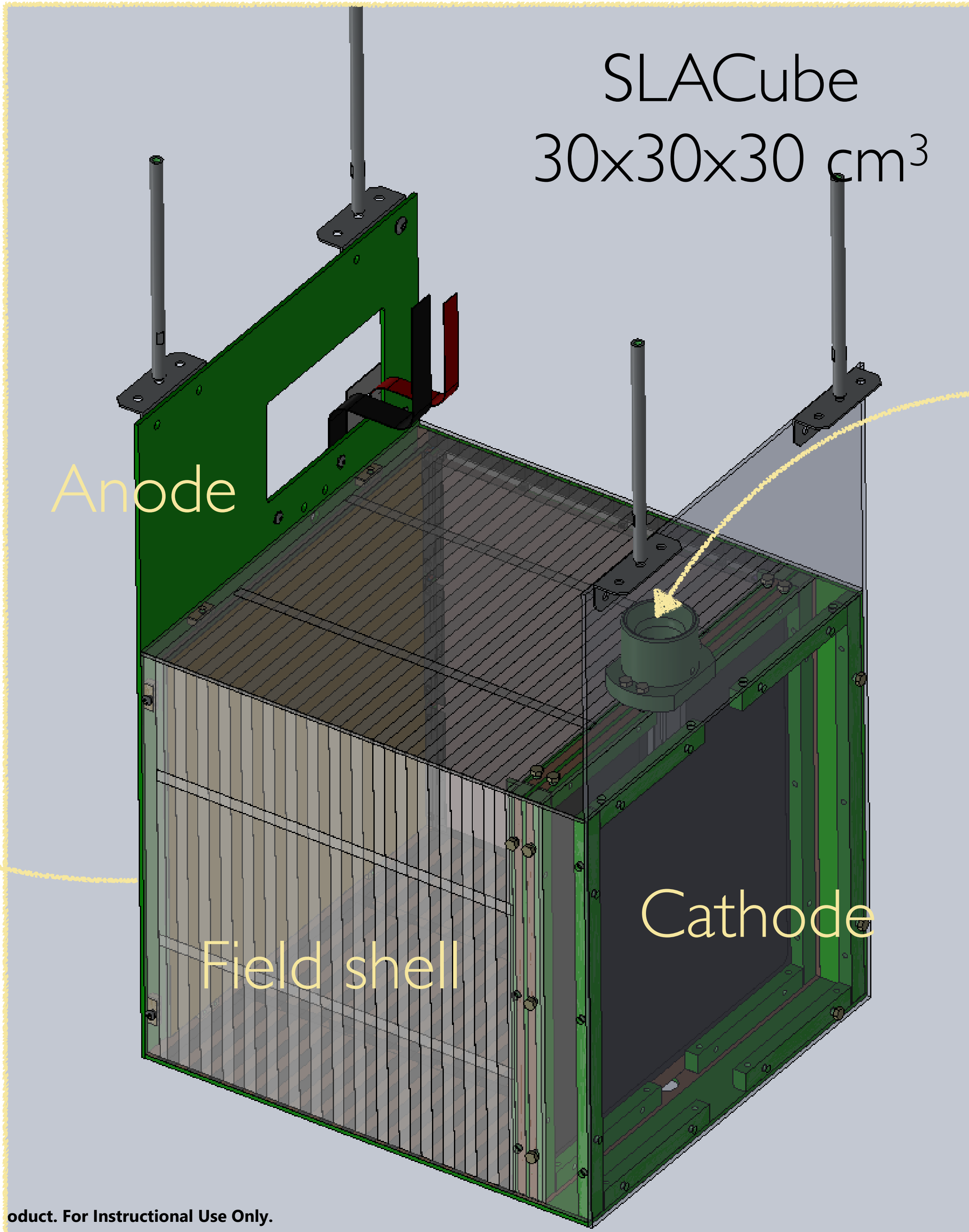


Time-Projection Chamber

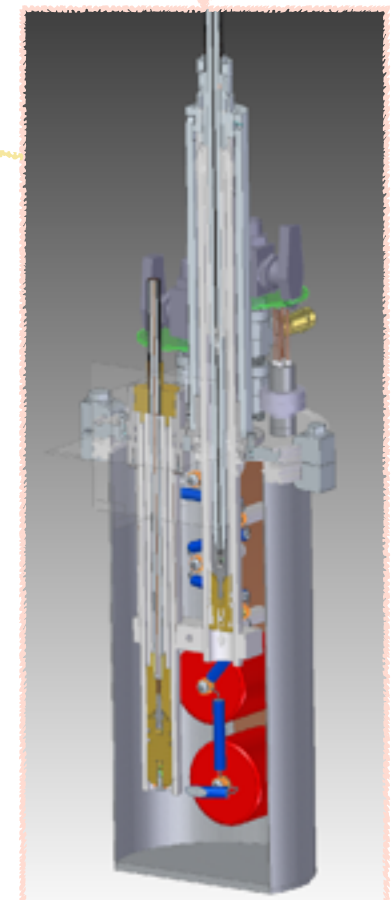
High voltage (HV) power supply ground = building ground

PicoAmmeter (Current measurement)

Nominal field:
500 V/cm
(15 kV total)



HV power supply



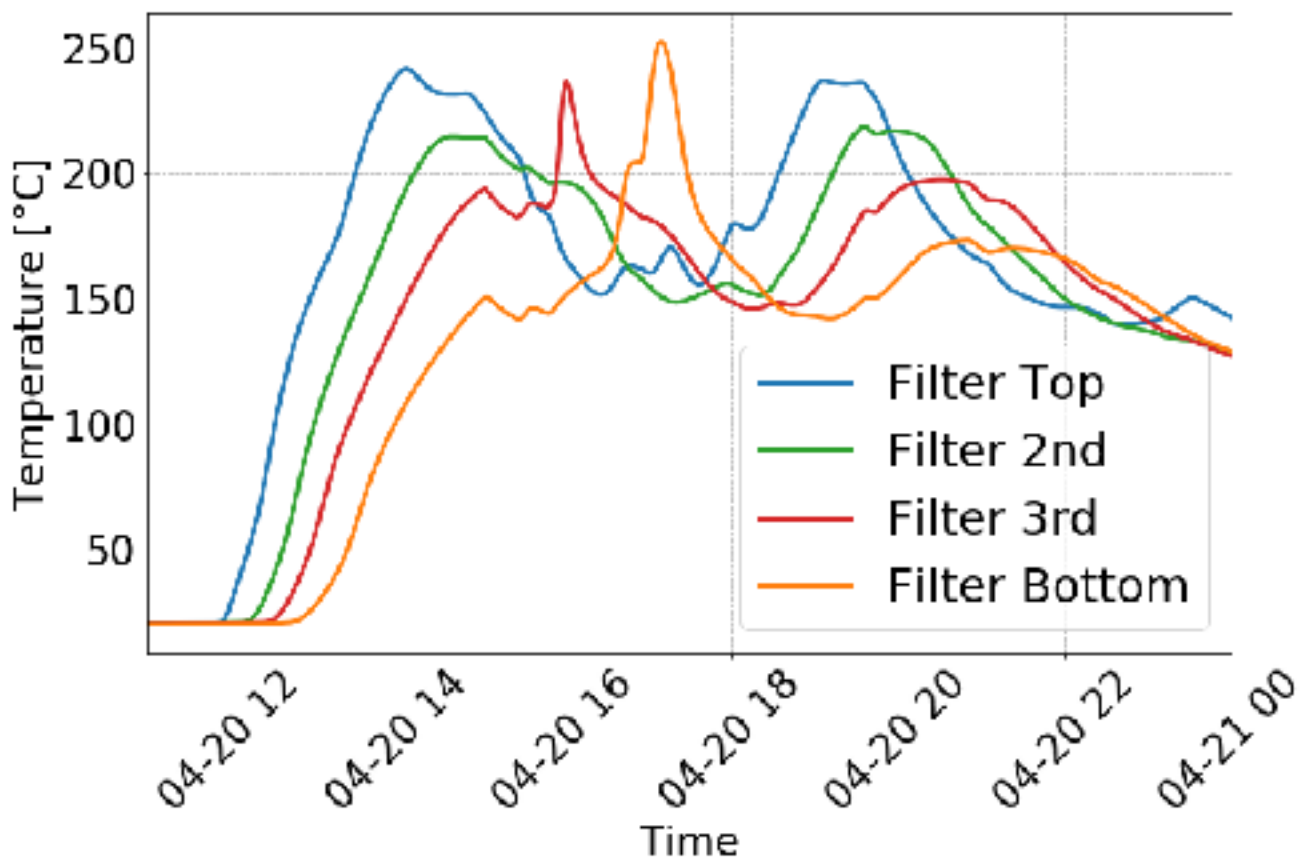
HV filter (low pass)


ARGON


HV cable
Charge readout
HV filter
LAr cryostat+ LArTPC
Detector monitoring
DAQ server
LAr HV teststand
LAr purifier
LAr supply

LAr Purifier

- Single pass purifier, ~180L of LAr
- Top: 4.6 kg molecular sieves (water)
- Bottom: 5.2 kg copper sieves (oxygen)
- Ar and 2% H_2+Ar gas to regenerate the molecular and copper sieves



- 15 L/min gas flow/kg
- ~200°C
- H+O→H_2O exothermal reaction