Calibrating the DUNE LArTPC Detectors for Precision Physics

Viktor Pěč (University of Sheffield)
for the DUNE Collaboration

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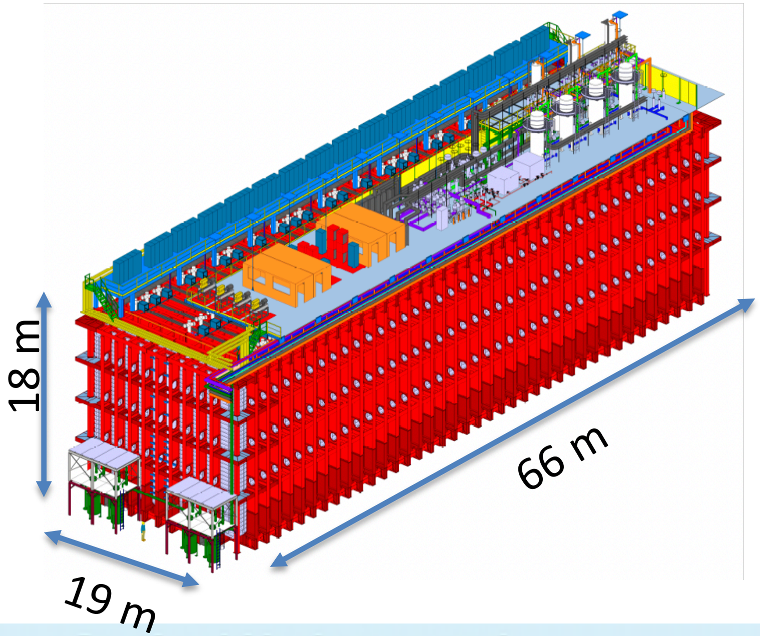
The University Of Sheffield.

DUNE - Deep Underground Neutrino Experiment



P.Dunne, talk 271

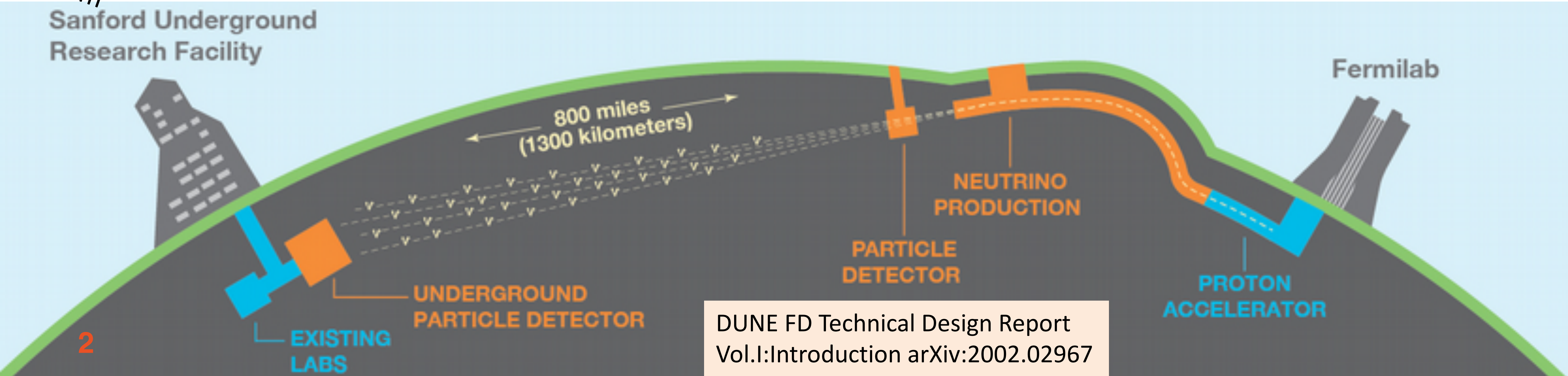
Far detector (FD):

- **LArTPC**
- **1.5 km** underground
- **4 × 17-kt modules (10 kt fiducial)**

Near detector (ND)

- 3 components:
- **LArTPC**, GArTPC, non-TPC

Movable off-axis (PRISM)



DUNE FD Technical Design Report Vol.I:Introduction arXiv:2002.02967

Physics Requirements

Performance drivers

- Oscillation physics: **CP-violation and neutrino mass ordering**
  - Energies O(GeV)
  - Uncertainty on energy scale < 2% (5%) for leptons (hadrons)
- **Supernova neutrino burst**
  - Energies O(MeV)
  - Energy resolution 20-30%

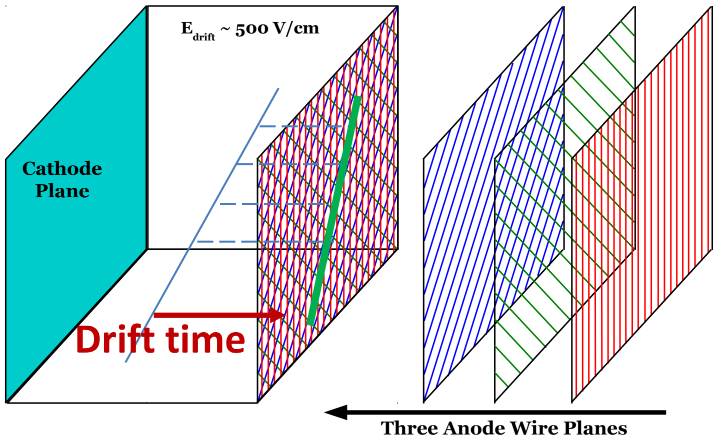
Other considerations under study

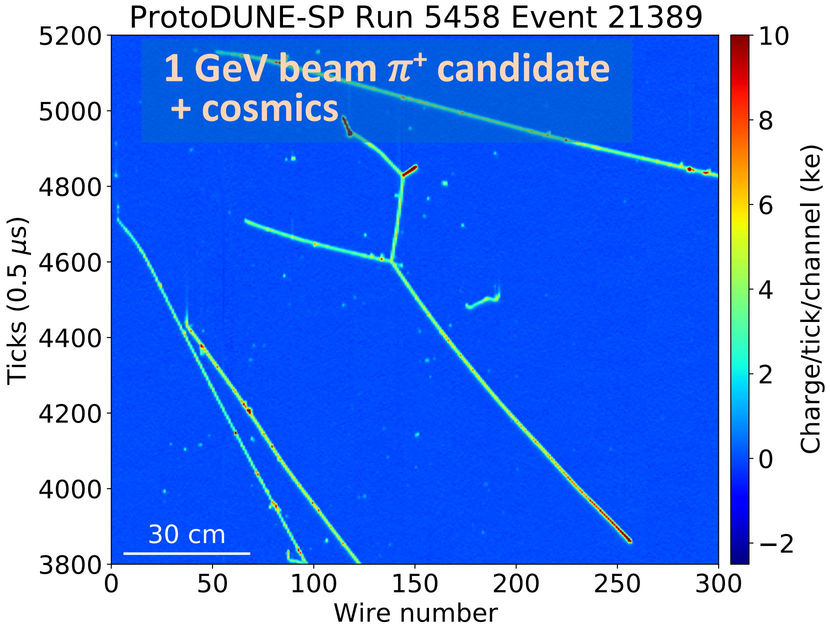
- Baryon number violation and other BSM
- Atmospheric neutrinos
- …

DUNE experiment physics, S.Jones, talk 262

DUNE FD Technical Design Report Vol.II:Physics arXiv:2002.03005

LArTPC - Liquid Argon Time Projection Chamber





Major inputs on detector response for TPC calibration	
Recombination	Electron-ion recombine after ionisation
Drift velocity/E-field	Essential for drift coordinate
Electron lifetime	Attachment on impurities
Electron diffusion	Affects signal shape and distribution across wires
Electronics gain	Important for absolute energy scale

DUNE FD Technical Design Report Vol.IV:Single-phase arXiv:2002.03010

Strategy

- Establish **connection** between **physics measurement sensitivities** and **calibration requirements**
- Develop procedures to:
  - Determine **detector parameters**
    - Drift velocity, electron lifetime, ... (previous slide)
  - Measure detector **response to “standard candles”**
    - Stopping power of through-going muons
    - Stopping muons
    - Michel electrons
    - Delta-ray electrons
    - π^0 decay
    - Neutron capture
    - Natural radioactivity

Sources for Calibration

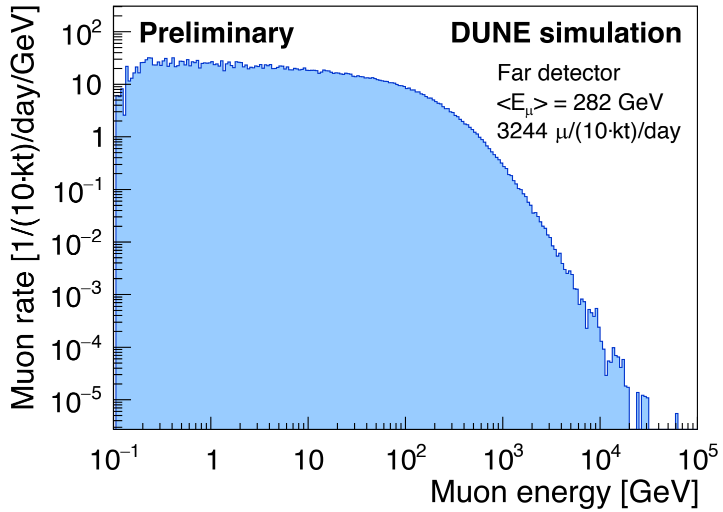
Cosmogenic/-beam/intrinsic sources

- Cosmic muons
- Beam neutrino events
- Atmospheric neutrinos
- Intrinsic radioactive isotopes

Dedicated calibration devices

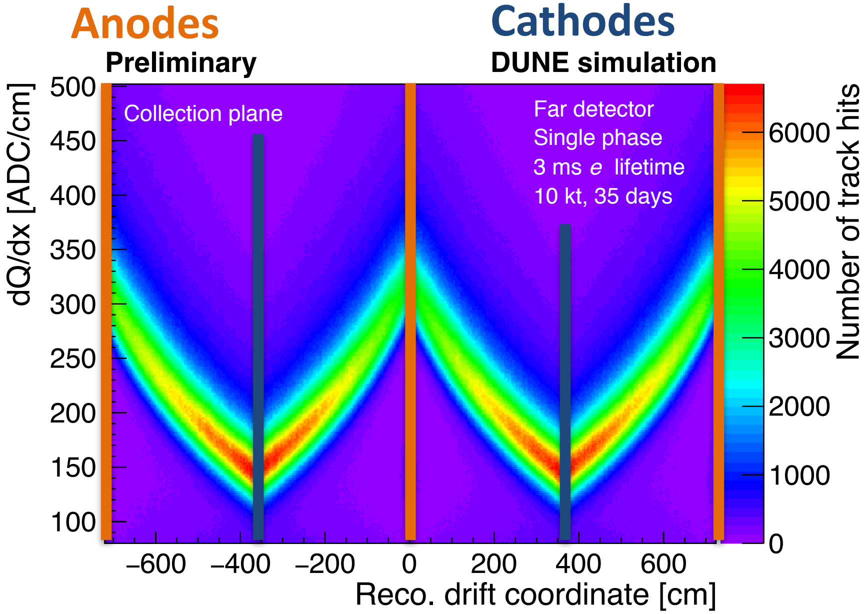
- Ionisation laser system
- Pulsed neutron source
- Cf/Ni source (9 MeV γ) under consideration

Cosmic Muons



From MC Simulations at FD:

- **~4700 muons** in single 17-kt module per day
- Only ~**90 a day stopping** inside TPC



Advantages	Challenges
• Rich source - *e* lifetime - Recombination - Alignment - δ-rays - Michel electrons - Stopping muons: - MIP + Bragg peak	• Low statistics

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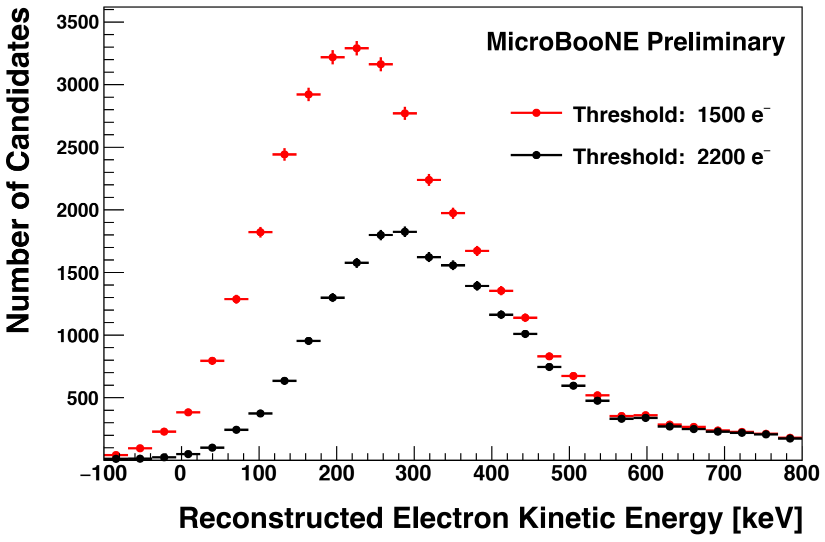
^{39}Ar

- Naturally present ~1 Bq/kg
- β-decay with Q = 565 keV
- well defined spectrum = “standard candle”

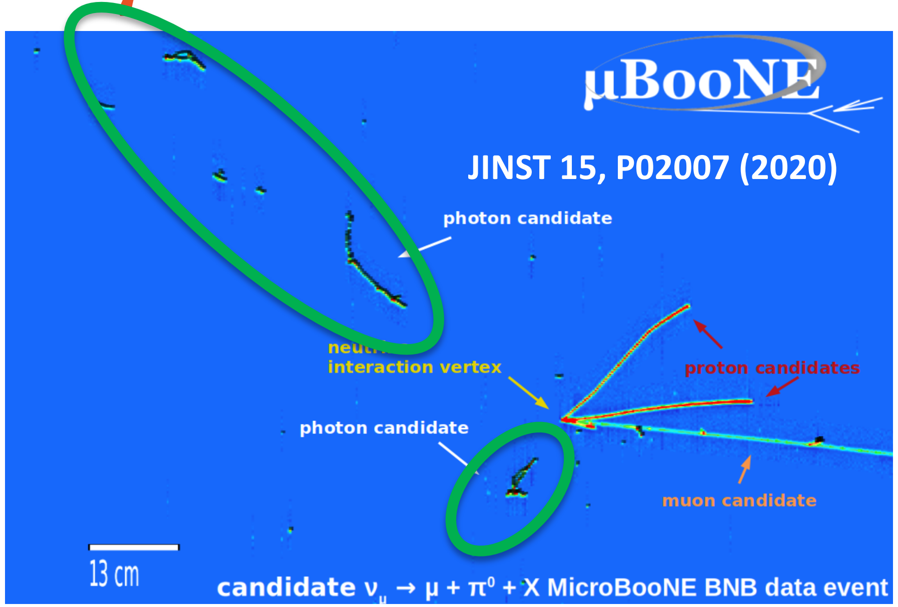
MICROBOONE-NOTE-1050-PUB

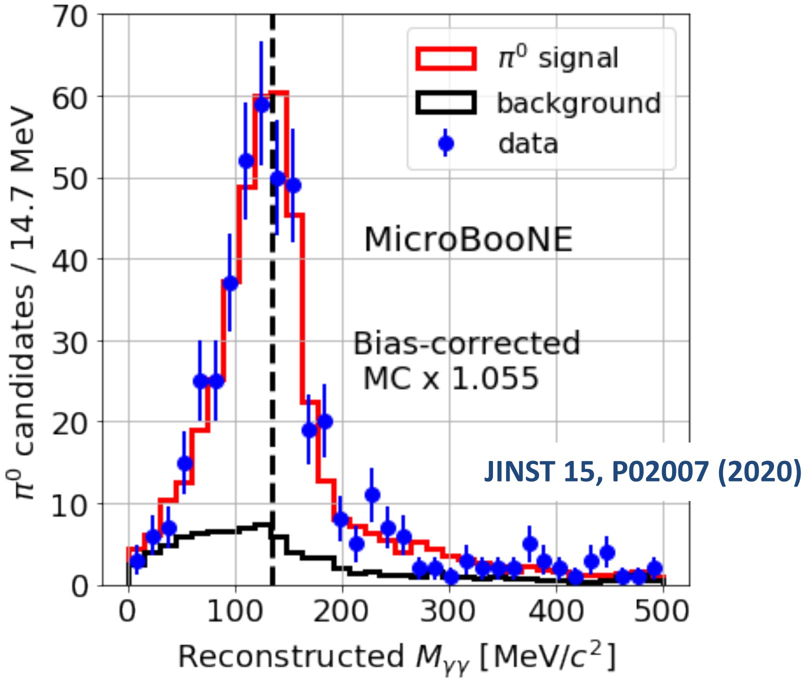


Advantages	Challenges
• High statistics • Uniform • Sensitive to: - *e* lifetime - Recombination - Electronics noise	• Low energy only • Unknown position in drift direction • Triggering/DAQ

- $^{42}Ar/^{42}K$ also under consideration

$\pi^0 \rightarrow 2\gamma$



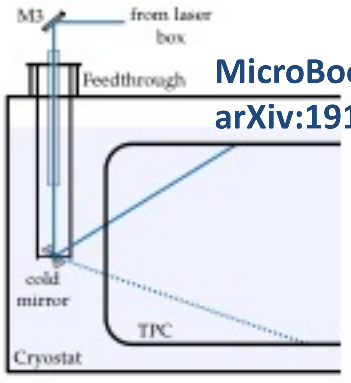


Advantages	Challenges
• Beam neutrino interactions • Cosmic muon interactions • 2γ invariant mass = “standard candle” • Electromagnetic energy scale	• Difficult selection • Low statistics

Ionisation Laser System

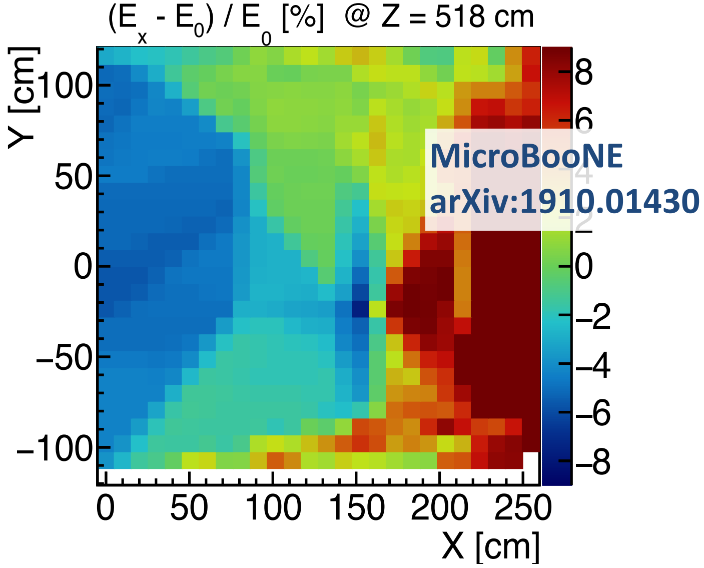
- Multiple periscopes → coverage
- Aperture in field cage considered
- Test in ProtoDUNE Run 2 end of next year

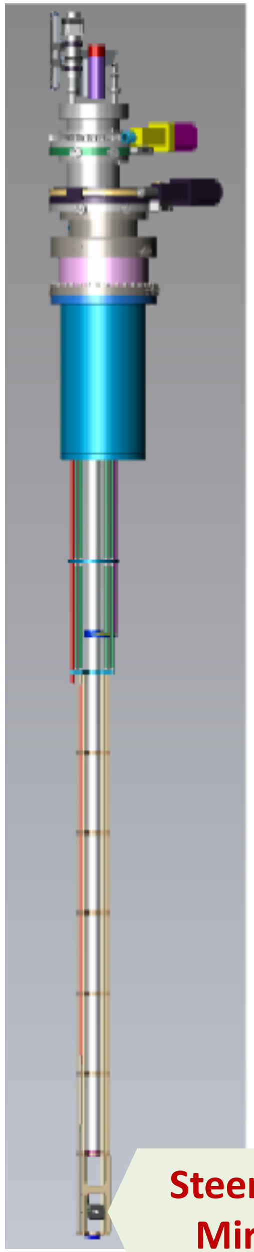
Advantages	Challenges
• High statistics • Well defined tracks - E-field - Alignment - *e* lifetime (being investigated)	• Limited coverage depending on design



MicroBooNE
arXiv:1910.01430

E-field distortions





Pulsed Neutron Source

Candidate DD generator

- Neutron anti-resonance at 57 keV → LAr nearly transparent → travel far
- Neutron capture: n + ^{40}Ar → ^{41}Ar + 6.1-MeV γ's
- Dedicated measurements at Los Alamos
  - ACED – n-capture gamma spectrum
  - ARTIE – neutron elastic scattering anti-resonance

Advantages	Challenges
• Triggered • High statistics - Neutron capture - γ energy scale + resolution - *e* lifetime (to be investigated)	• Non-uniform coverage • Difficulties in associating scintillation light with individual interactions

ProtoDUNE and SBN Programme

ProtoDUNE on test beam at CERN

- 2 prototype modules: Single-/Dual-phase

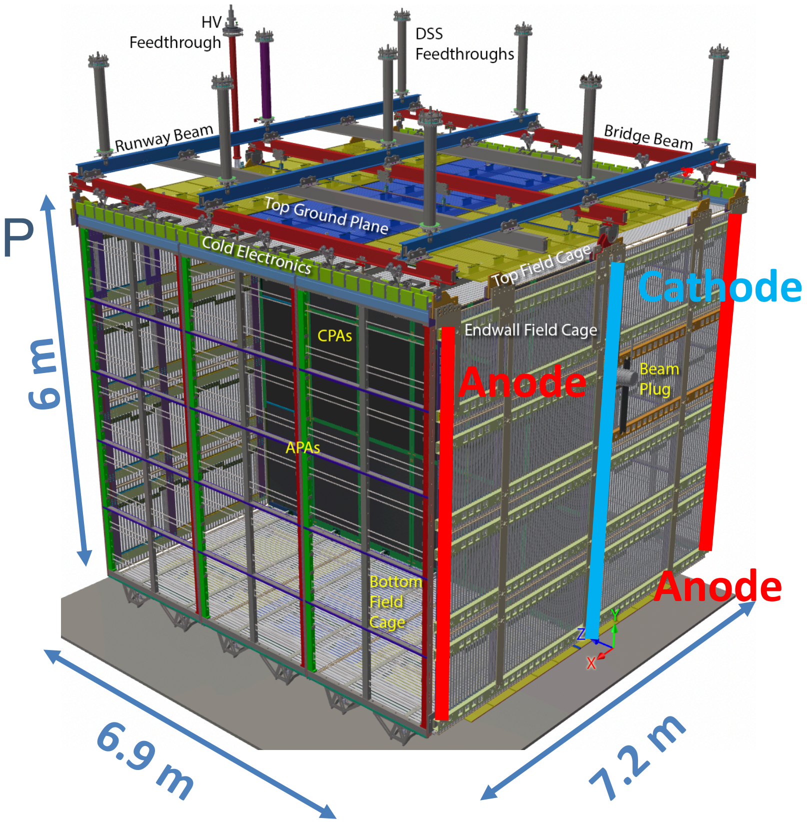
+ Development of techniques to be used in ND and FD
  - DUNE FD calibrations already being informed by ProtoDUNE SP
+ Measure LAr properties at same E-field & drift distance

- Space charge build-up due to cosmics (no problem for ND and FD) see M. Mooney, talk 275

SBN at Fermilab

- LArTPCs: SBND, MicroBooNE, ICARUS
- Benefit of development of calibration techniques before DUNE starts

ProtoDUNE Single-phase



Also see R.Diurba: talk 276, poster 530

Summary

- Requirements on performance driven by ν **oscillation physics** and **low-energy astrophysical neutrino physics**
- Outlined strategy to develop calibration techniques
- Combined use of intrinsic sources and dedicated devices
- DUNE will benefit from robust LArTPC calibration programme

Measurement	**Tools**
Alignment	Cosmics, **Laser**
E-field	Cosmics**, Laser**
e lifetime	**Cosmics**, **^{39}Ar**, Laser, PNS
Recombination	**Cosmics,** ^{39}Ar, Beam
Energy scale	**Cosmics, Beam, PNS**, ^{39}Ar

* PNS – Pulsed Neutron Source