DUNE

Jennifer Raaf

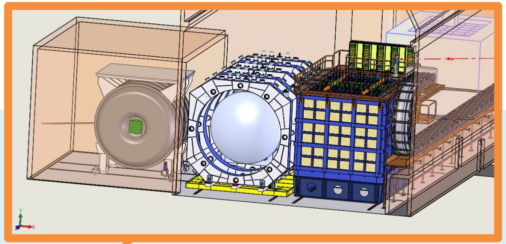
Neutrinos at Fermilab | Briefing to DOE OHEP

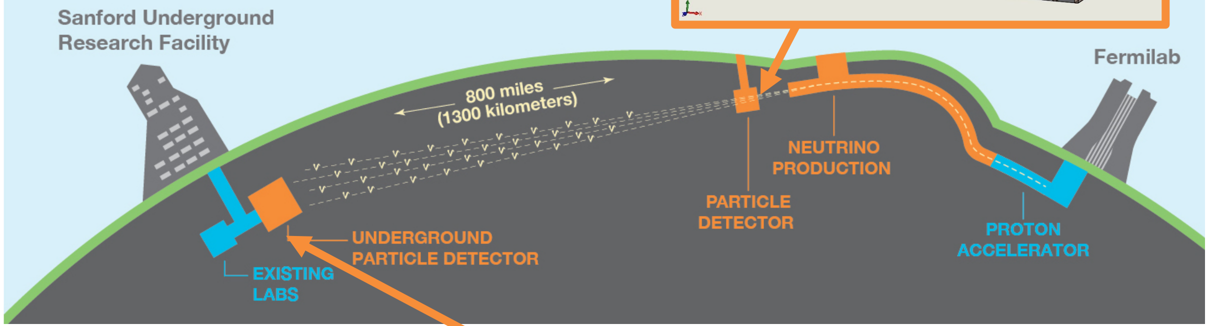
Tues 12 Jan 2021

Personal Bio

- **PhD 2005, University of Cincinnati**
  – "A Measurement of the Neutrino Neutral Current π^0 Cross Section at MiniBooNE"
- **[2005—2011] Postdoctoral Researcher, Boston University**
  – Super-Kamiokande & T2K
- **[2011—present] Scientist, Fermilab**
  – **MicroBooNE**
    - L2 Manager detector assembly and installation (2011—2014)
    - On-call expert, TPC and HV systems (ongoing)
    - Editorial Board analysis reviewer (cross sections, oscillations, nucleon decay) (ongoing)
  – **LArIAT**
    - Co-spokesperson (2012—present)
  – **DUNE**
    - Technical Board member (2015—2017)
    - Nucleon Decay Working Group co-convener (2015—2017)
    - ND-GAr High-Pressure Gaseous TPC group leader (2017—present)
  – **2016 DOE Early Career Award (High-Pressure Gas TPC for the DUNE Near Detector)**

Deep Underground Neutrino Experiment





DUNE's primary science goals:

- Measure CP phase
- Supernova & proton decay
- Precision PMNS measurements

High intensity wide-band 1.2 MW LBNF neutrino beam, upgradeable to 2.4 MW

- Neutrinos will travel 1300 km from the near detector at FNAL to the far detector at SURF

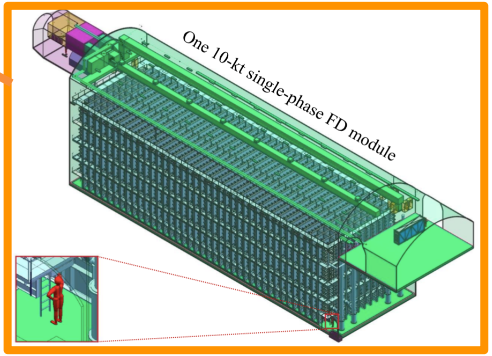
Near Detector

- Suite of 3 highly capable detectors with complementary approaches

Far Detector

- 4 LArTPCs, each 10 ktons fiducial mass

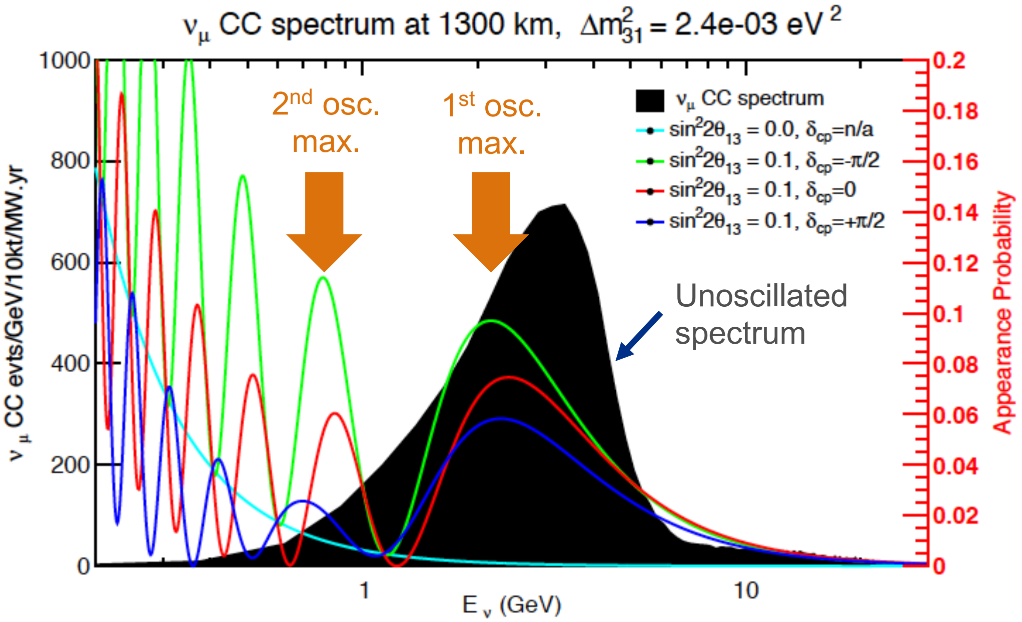
4x

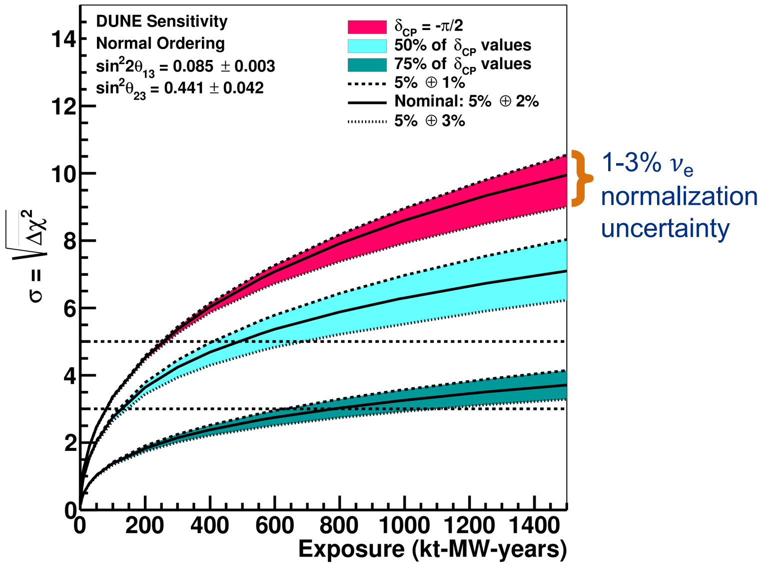


Fermilab

DUNE Oscillation Physics

Note: sensitivities depend strongly on the true values in Nature.





The DUNE Far Detector site will be on-axis of the broad energy spectrum neutrino beam

- Measure CP violation by 2 methods (ν vs anti-ν, relative heights of 1st and 2nd oscillation maxima)

Capable of 5-sigma measurement of δ_{CP} for 50% of all values in 500 kt-MW-years (3-sigma measurement for 75% of all values in ~800 kt-MW-years)

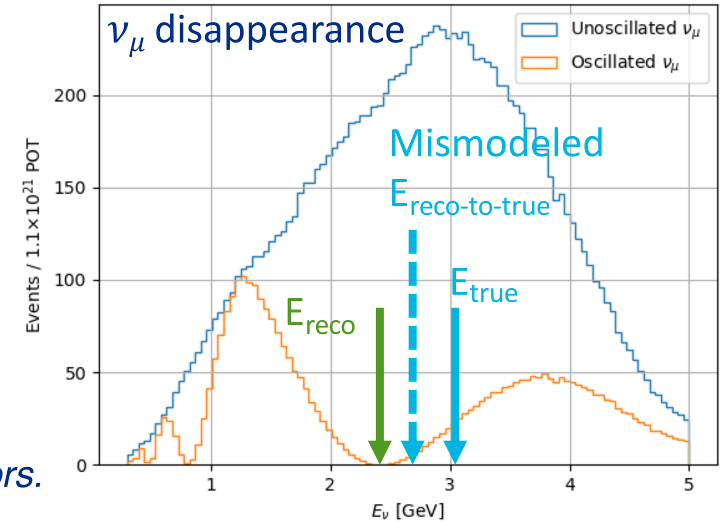
- Benefit from increased detector mass, higher beam power, or reduced uncertainty

The Importance of Near Detectors

$$\frac{dN_{\nu}^{\rm det}}{dE_{\rm rec}} = \int \underbrace{\phi_{\nu}^{\rm det}(E_{\nu})}_{\text{Flux}} \cdot \underbrace{\sigma_{\nu}^{\rm target}(E_{\nu})}_{\text{Cross section}} \cdot \underbrace{T_{\nu_\mu}^{\rm det}(E_{\nu}, E_{\rm rec})}_{\text{Detector response}} dE_{\nu}$$

Detectors measure flux times cross section, with smearing, biases, and inefficiencies due to detector effects

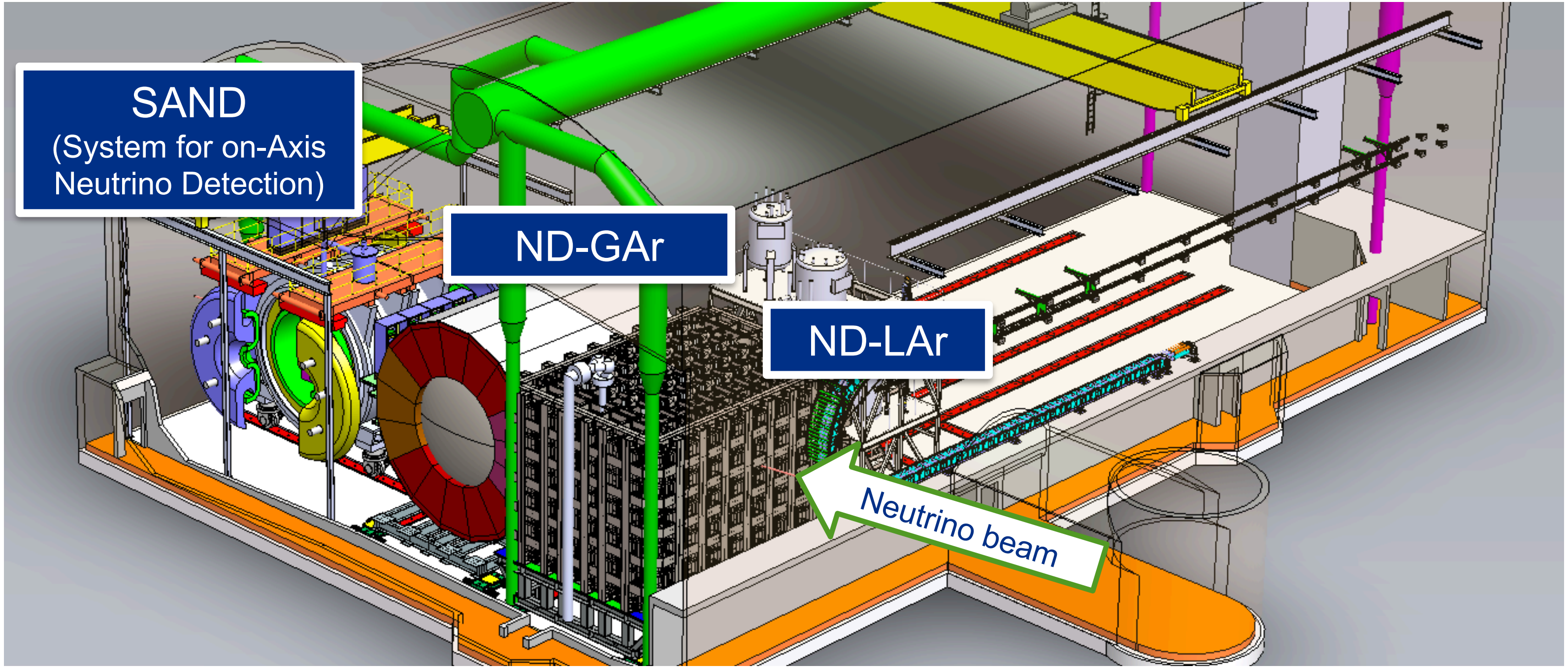
- In reality, we cannot factorize flux, cross section, and detector response – there are no simple cancellations
- Fluxes at near and far detectors differ
- Relationship of $E_{reco} \rightarrow E_{true}$ depends on poorly understood neutrino interaction models and on detector response
    - Reconstructed energies can feed down into oscillation dip, biasing measured oscillation parameters



Requires something better than functionally identical near detectors.

DUNE: multi-pronged approach with complementarity among subdetectors

DUNE Near Detector Suite



Three main detector components, working together:

1. Liquid argon detector (ND-LAr)
2. Magnetized downstream tracker with gaseous argon target (ND-GAr)
3. On-axis flux monitor with neutron detection capability (SAND)

} LAr and GAr systems can move to off-axis fluxes (PRISM)

Fermilab DUNE Activities

Fermilab is the largest group on DUNE

- **52 FTEs, funded by several B&Rs**
- **We are active in all main areas of the collaboration (in orange)**

Within each area, we concentrate our efforts where we can maximize input based on the expertise we have built through work in other experiments (NOvA, MicroBooNE, etc.) and on our existing facilities

Spokespeople
Stefan Soldner-Rembold
Ed Blucher

Joint Project Office
Michael Andrews, Linda Bagby, Ami Dave, Mohammed Elrafih, Kevin Fahey, Justin Freitag, Ladia Jakubec, Eric James, Regina Rameika, Teresa Shaw, Patrick Weber, Sam Zeller

Technical Coordination
Eric James
Steve Kettell

Resource Coordinator
Regina Rameika

Beam Coordinator
Zarko Pavlovic

ProtoDUNE-SP
Flavio Cavanna
Regina Rameika

ICEBERG
Shekhar Mishra

Far Detector Consortia
David Christian, Michael Kirby, Alberto Marchionni, Marco Verzocchi

HV Test Stand
Sarah Lockwitz

Light Collection R&D
Flavio Cavanna, Carlos Escobar, Alex Himmel

Near Detector
Alan Bross
Alfons Weber

ND-LAr 2x2 Demonstrator
Ting Miao

ND-GAr Test Stand
Jennifer Raaf

Computing Coordination
Michael Kirby
Heidi Schellman

Physics
Ryan Patterson
Elizabeth Worcester

Fermilab DUNE Department

We have organized the DUNE Department to focus on our 7 areas of expertise:

- DUNE Management
- DUNE Beam
- DUNE Electronics, APAs, & Light Collection
- DUNE Slow Controls, HV, & Cryo
- DUNE Near Detector
- DUNE Computing
- DUNE Simulation & Reconstruction

Spokespeople
Stefan Soldner-Rembold
Ed Blucher

Joint Project Office
Michael Andrews, Linda Bagby, Ami Dave, Mohammed Elrafih, Kevin Fahey, Justin Freitag, Ladia Jakubec, Eric James, Regina Rameika, Teresa Shaw, Patrick Weber, Sam Zeller

Technical Coordination
Eric James
Steve Kettell

Resource Coordinator
Regina Rameika

Beam Coordinator
Zarko Pavlovic

ProtoDUNE-SP
Flavio Cavanna
Regina Rameika

ICEBERG
Shekhar Mishra

Far Detector Consortia
David Christian, Michael Kirby, Alberto Marchionni, Marco Verzocchi

HV Test Stand
Sarah Lockwitz

Light Collection R&D
Flavio Cavanna, Carlos Escobar, Alex Himmel

Near Detector
Alan Bross
Alfons Weber

ND-LAr 2x2 Demonstrator
Ting Miao

ND-GAr Test Stand
Jennifer Raaf

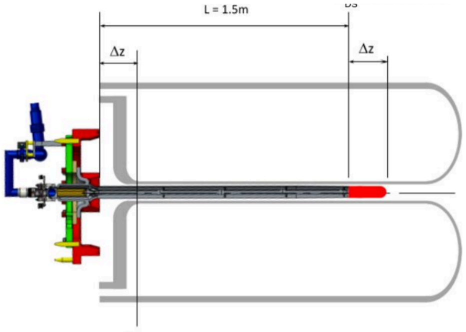
Computing Coordination
Michael Kirby
Heidi Schellman

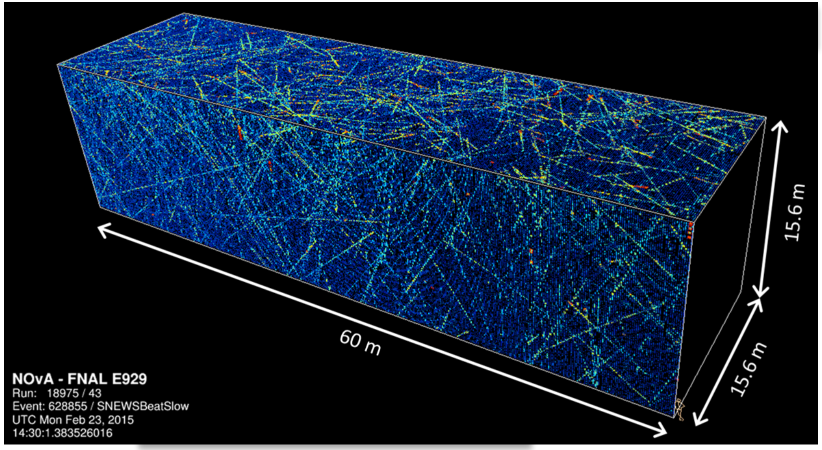
Physics
Ryan Patterson
Elizabeth Worcester

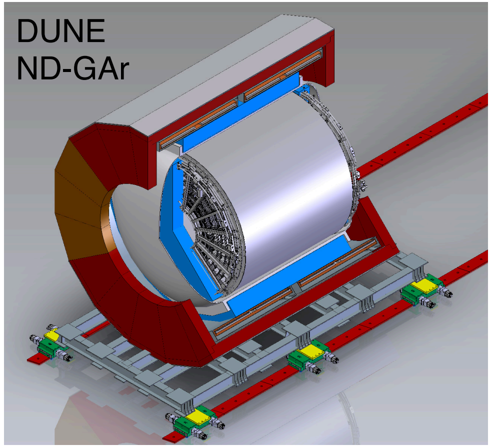
DUNE Department: Beam and Near Detector Groups

L. Fields, J. Hylen, J. Paley, Z. Pavlovic, R. Zwaska

- **Long history of FNAL leadership in beamline design**
  - Recent development of new techniques for beam optimization
    - Genetic algorithm scans many different horn and target geometries and evaluates impact on oscillation sensitivity (metric: 75% coverage of δ_{CP} phase space)
- **Long history (MINOS, MINERvA, NOvA, MicroBooNE, …) of building and operating neutrino detectors, studying neutrino interactions, and performing oscillation analyses**







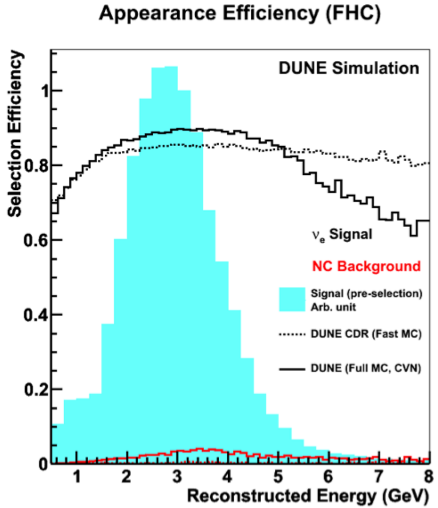
A. Bross, L. Bellantoni, T. Junk, T. Mohayai, J. Raaf

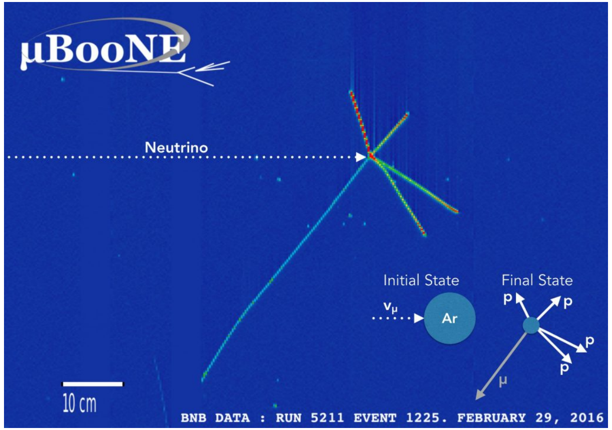
Collider detector expertise has also benefited DUNE ND design process.

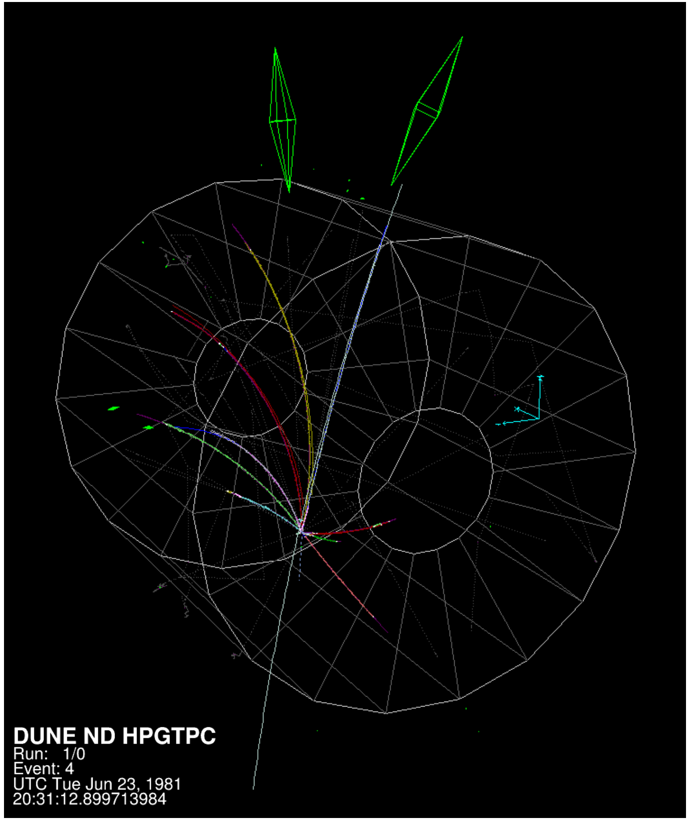
DUNE Department: Computing and Sim/Reco

A. Himmel, T. Junk,
M. Kirby, T. Yang

- Key roles in computing coordination
- Machine learning, calibration, and reconstruction development expertise built in NOvA and MicroBooNE enables leadership in DUNE near and far detector sim/reco efforts







DUNE Department: Slow Controls, HV, & Cryo + Electronics, APAs & Light Collection

R. Acciarri, B. Ramson, F. Cavanna, A. Himmel, S. Lockwitz, S. Pordes, R. Rameika, T. Yang

ProtoDUNE-SP

Completed (Phase I):

- DAQ development & testing
- Cold electronics testing
- Xenon doping tests
- Neutron source

Next up (Phase II):

- Full characterization of DUNE FD "Module 0"s (improved APAs, cold electronics, photon detectors)
- Develop, implement, demonstrate new calibration techniques, incl. laser calib system and pulsed neutron source

D. Christian, S. Mishra, M. Verzocchi

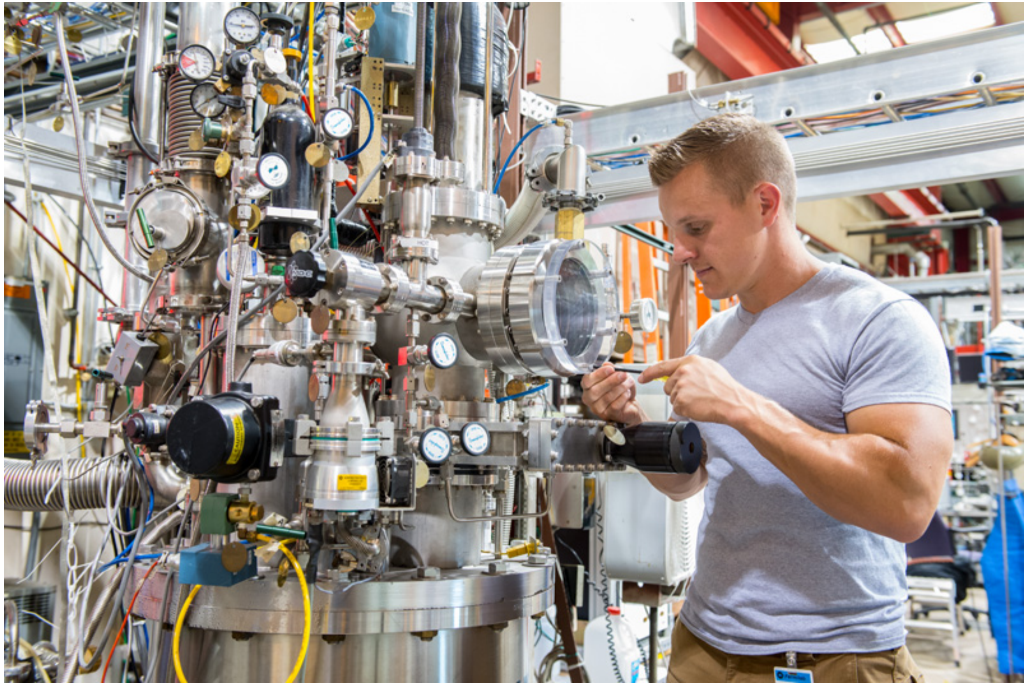
ICEBERG

- A micro-DUNE (two 1x1x0.3 m drift volumes, 1280 channels of cold electronics with DUNE-style APA)
- Takes advantage of existing FNAL LAr infrastructure

DUNE Department: Slow Controls, HV, & Cryo + Electronics, APAs & Light Collection

F. Blaszczyk, G. Cancelo, C. Escobar, A. Hahn, A. Himmel,
S. Lockwitz, T. Mohayai, W. Mu, A. Para, J. Raaf, B. Ramson

Noble Liquid Detector R&D Facility



Extensive infrastructure supporting LAr and GAr tests

Host to many additional test stands that are also critical to DUNE's success

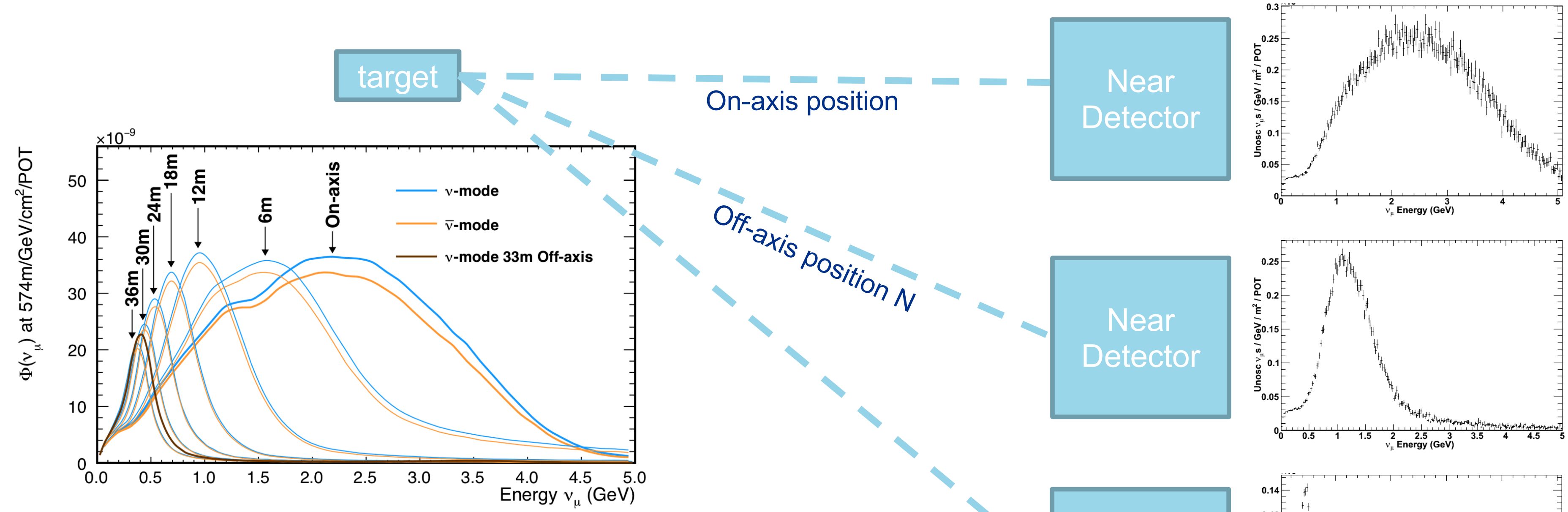
Materials/LAr purity
High voltage
Xe-doping
Light collection
High-pressure gaseous argon

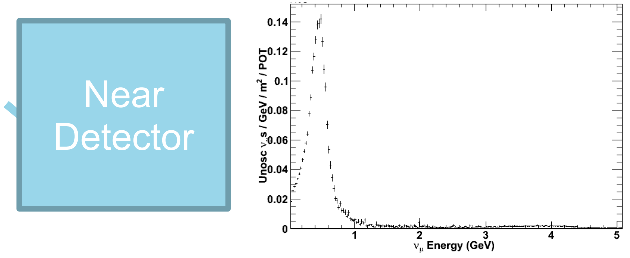
Summary

The Fermilab DUNE group is the largest in the collaboration

- Strong contributions in all major areas of DUNE and LBNF
- We concentrate our efforts in the areas that allow us to maximize our impact based on existing expertise and facilities

PRISM (Precision Reaction Independent Spectrum Measurement)





New technique: PRISM

- **Use near detector data collected at several off-axis angles**
  - Narrow energy bands allow experimental determination of the relationship between true and reconstructed energy (and other observables)
  - Data-driven predictions of far detector event rates with minimal cross section model dependence

Fermilab