



# NOvA

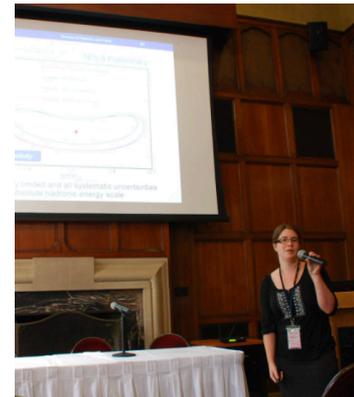
Louise Suter

Neutrinos at Fermilab | Briefing to DOE OHEP

Tues 12 Jan 2021

# Personal Bio

- **PhD 2013** - University of Manchester, with Prof. Söldner-Rembold
- **[2013-2016]** - Postdoctoral Researcher ANL
- **[2016 - present]** - Wilson Fellow, Scientist
  - Thesis joint advisor (Siva Prasad Kasetti)
  - Post Doc advisor (Anne Norrick)



## • Scientific interests

- Neutrino oscillations physics - three flavor oscillations, searches for sterile neutrinos, and BSM processes

## • What I do

- NOvA Co-Convener of 3-flavor Oscillation Group (since 2019)
- NOvA Operations Manager (since 2017)
- Neutrino Physics Center Coordinator (since 2017)
- Snowmass Public Policy and Gov. Eng. Convener (since 2020)

## • Past roles

- NOvA Sterile Neutrino Physics Group Convener (2016-2019)
- NOvA Near Detector Manager and Commissioner (2014-present)
- NOvA Data-Quality Convener (2014-2016)
- Scientist Advisory Council Chair (elected 2018-2020)
- NOvA Executive Committee (elected since 2017)
- APS DPF Executive Committee (Early Career Member, 2015-16)
- Fermilab UEC, Government Relations Chair (2015-2017)

# NOvA – Overview

2013–2020: NOvA

13 physics publications

6 short author list technical/algorithm publications

40 PhDs on NOvA data

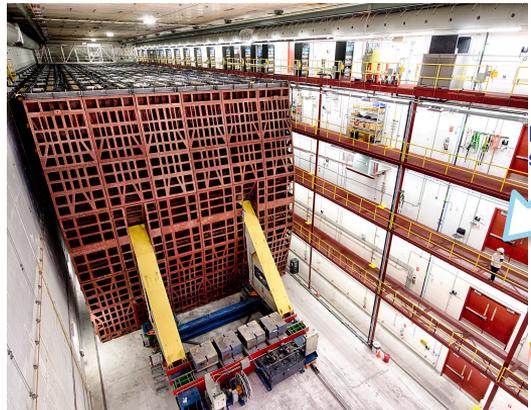
- NOvA can probe many of the questions called out in the P5
  - What is the origin of neutrino mass?
  - **How are the masses ordered?**  
*NOvA can measure the mass hierarchy*
  - What are the masses?
  - **Do neutrinos and antineutrinos violate CP symmetry?**  
*NOvA can probe the CP phase*
  - **Are there additional neutrino types or interactions?**  
*NOvA can search for sterile neutrinos and NSI*
  - Are neutrinos their own antiparticles?
- Fermilab group is contributing leadership and developing expertise in areas critical to success of DUNE:
  - Long-baseline neutrino oscillations, neutrino interactions, neutrino beam design & operations, neutrino flux modeling, long-distance operations



NOvA Far Detector under construction

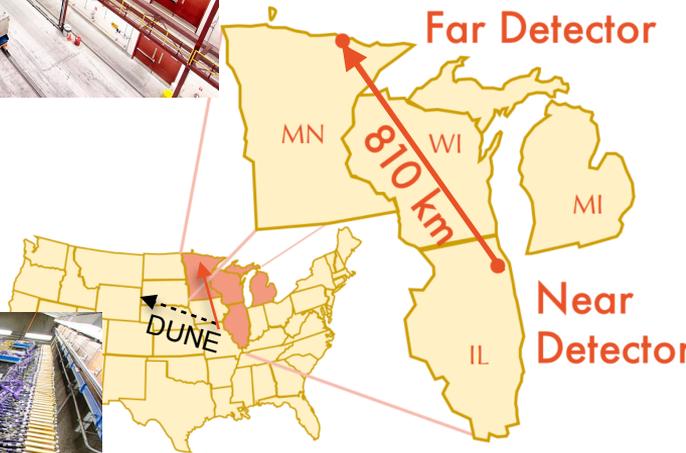
# The NOvA Experiment

- Currently running long-baseline neutrino oscillation experiment, between Fermilab and Ash River, IL MN
- Measures  $\nu_\mu$  beam with near detector before oscillation and again 810km later, after oscillation, looking for  $\nu_e$  appearance
- Fermilab scientists hold a variety of key leadership roles and contribute to all aspects of the experiment
  - Spokesperson - **Shanahan** (since 2015), Analysis Coordinator - **Himmel** (since 2018), Operations Manager - **Suter** (since 2017) + 6 other current convenerships
- 11 scientists on IF Research, 4 current RAs
  - Aliaga (RA), Himmel, Hatcher, Norman, Norrick (RA), Paley, Ramson (RA), Rebel (joint-appointment), Shanahan, Suter, Mu (RA).
  - Plus another 10 scientists who contributed to the design & construction continue to take shifts and review results



Far detector in Ash River MN  
14 kton, on surface

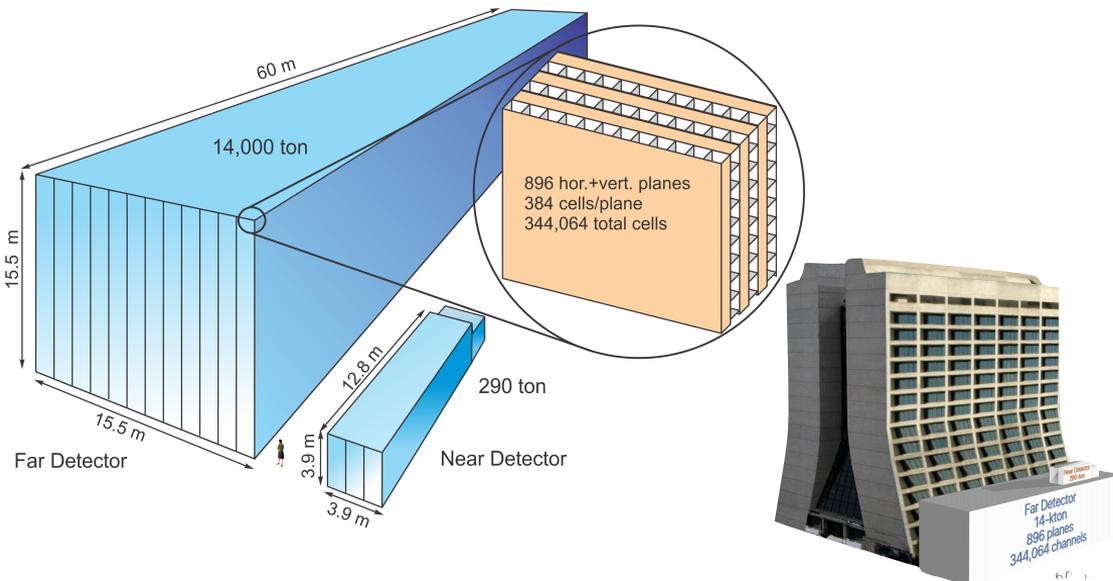
Person for scale



Near Detector at Fermilab,  
300 ton, 100 meters underground

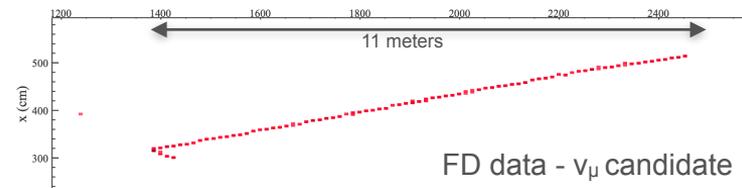
# The NOvA Detector design and Operations

- Huge liquid scintillator tracking calorimeter designed to maximize  $\nu_e$  selection efficiency
- 15.5 meter PVC cells contain a wavelength shifting fiber read out by an avalanche photodiode
- The detectors have been running excellently since reaching CD4 in 2013
  - Greater than > 99% uptime enabled with strong Fermilab team



- Leadership in detector operations
  - Operations Managers, **Suter, Plunkett**,
  - Run Coordinators **Mu, Norrick, Niner, Suter, Paley**
- DAQ leadership and expertise
  - Leads **Shanahan, Norman and Ding**
  - **Niner, Suter, Norman, Shanahan, Ding, Aliaga, Paley**, served as DAQ or detector experts.

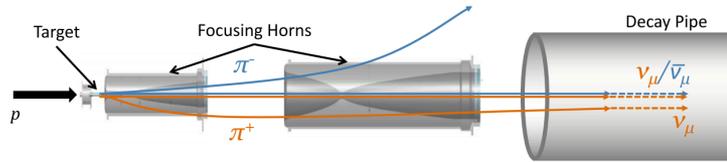
\*bold = current



Long baseline operations expertise and experience will enable successful DUNE operations

# Neutrino Beam

- Use beam produced from 120 GeV protons produced in the Main Injector.
- Beam has been running excellently, regularly exceeding 700 kW designed power



900+ kW capable target

900+ kW capable horn

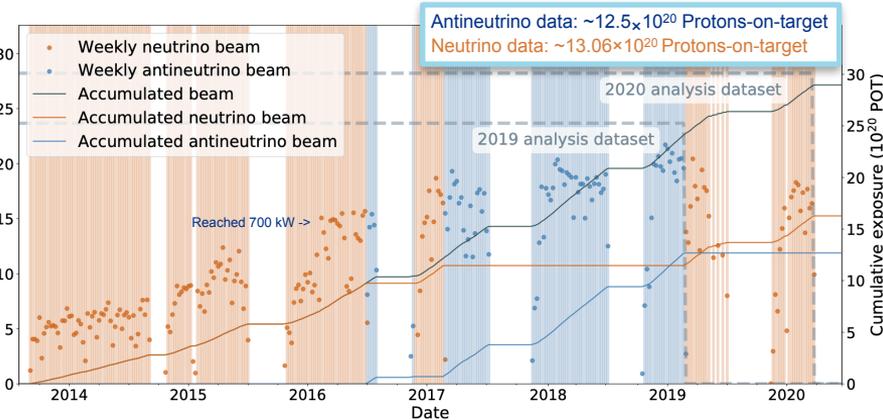
*Fermilab PAC Recommendation: Prioritize the proposed PIP-1+ activities and their execution in order to deliver the maximum number of POT.*

## Beam construction and design

- **Team of beam experts** have enabled a strong beam performance and are working on future improvements  
**Adamson, Hylen, Schlabach, Zwaska**
- Plan to enable up to 900+ kW running, 30% increase in current beam power.

## Beam simulation

- **Fermilab has strong presence** in improving beam simulation. Co-led by **Zwaska** and currently **Aliaga**
- **Aliaga** implemented improved flux modeling, reducing uncertainties at Near Detector from 22% to 9%. **Formed group to work in collaboration with DUNE**
- **Paley** - designed experiment EMPHATIC aimed to **reduce dominant flux uncertainties for both NuMI and LBNF**

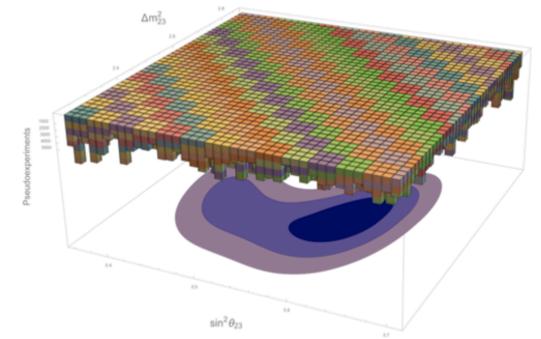
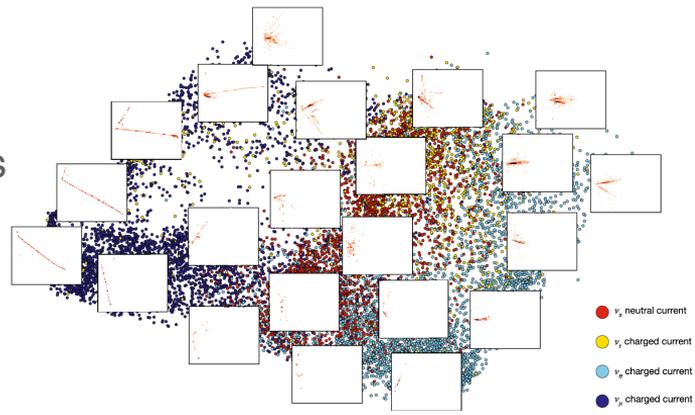


Expertise and skills learned have already informed the LBNF design

# Pioneers in ML and HPC in Neutrino Physics

Fermilab scientists have also made significant contributions in multiple parts of the analysis chain and have pushed the bounds on ML and HPC use in neutrino physics.

- Leaders in ML efforts in reconstruction. Reconstruction group, co-led by **Shanahan** and later **Niner**
- **Niner** and **Himmel** were part of small group that pioneered **machine learning efforts in neutrino physics**, **JINST (2016)**, **Phys.Rev.D (2019)**. **Himmel**, co-author of ML **Nature Review (2018)**
  - Led to **30% increase** in signal  $\nu_e$  selection efficiency
- High Performance Computing on NERSC
  - **Ding, Norman, Himmel, Mu**, with Cincinnati and Colorado collaborators, pioneered a **High Performance Computing** effort, as part of SciDAC4 award, reducing running time for producing results from weeks to days
  - Further tests on running whole analyses on HPC currently ongoing



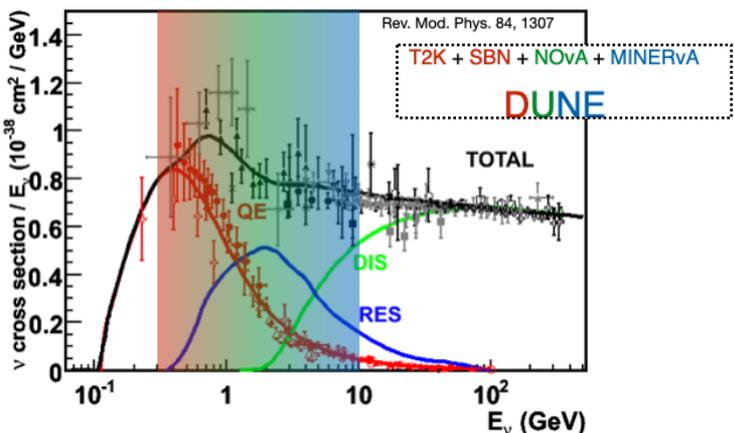
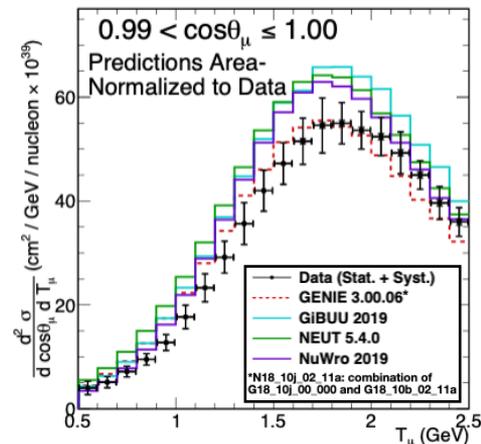
**Tools developed by Fermilab Scientists on NOvA data have been transitioned for use on DUNE and in the wider community.**

# Cross Section Physics Program

$\nu_\mu$  Inclusive results presented JETP Seminar 2020

- NOvA is beginning to significantly contribute to the global neutrino scattering effort, with its first publication and two major results in 2020
- Fermilab group has big presence in these efforts, convened by **Paley** and **Aliaga**. Fermilab RAs and scientists are lead analyzers
- NOvA's beam energies overlap with all other current and planned accelerator-based experiments. NOvA's beam sits at the cross-roads of QE, RES, 2p2h and DIS scattering
- **Results are contributing to an improved understanding of neutrino interactions for the era of precision neutrino physics with DUNE**

NOvA Preliminary



Fermilab group very active in the Near Detector physics measurements  
Conveners, **Paley**, and **Aliaga**

**Results presented at Neutrino2020 and FNAL JETP Seminar**

- $\nu_\mu$  Inclusive, lead analyzers, **Paley, Aliaga, Niner**
- $\nu_e$  Inclusive, **Paley, Aliaga, Ding**
- In progress, lead by Fermilab RAs**
- NC  $\pi 0$ , **Ramson**
- Double-differential low-hadronic-energy xsec measurement, **Aliaga**

# 3-flavor Oscillation Flagship Measurement

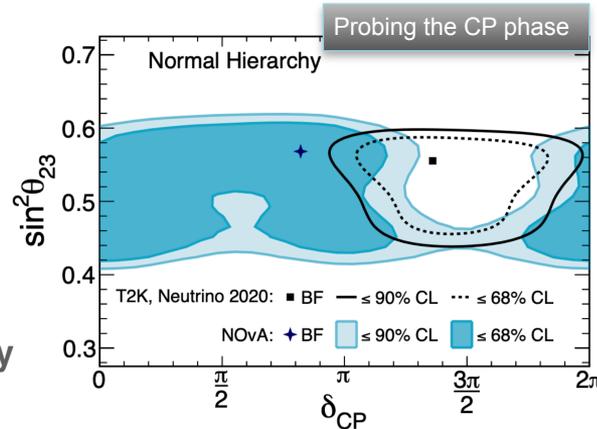
- Fermilab scientists have had key roles in NOvA's oscillation program throughout its development
- Flagship analysis which measures  $\nu_e$  appearance through oscillation. Enables:
  - Precision measurements of the atmospheric neutrino mixing parameters
  - Determining mass ordering
  - Probing the CP phase
- Skills learned on these analyses will directly translate to DUNE

2020 3-flavor oscillation results:

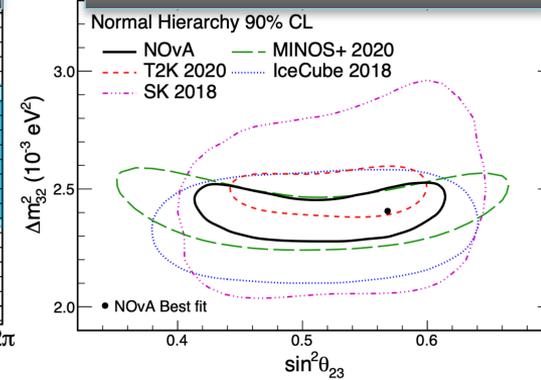
$$\Delta m_{32}^2 = (2.41 \pm 0.07) \times 10^{-3} \text{ eV}^2$$

$$\sin^2 \theta_{23} = 0.57^{+0.04}_{-0.03}$$

exclude IH,  $\delta = \pi/2$  at  $> 3\sigma$ ,  
disfavor NH,  $\delta = 3\pi/2$  at  $\sim 2\sigma$



Atmospheric neutrino mixing parameters



- Neutrino analyses: PRL (2019), PRD (2018), PRL (2017), PRL (2017), PRL (2016), PRD (2016)
- 2020 analysis presented at NEUTRINO2020 conference showed interesting potential tension with T2K, co-led by Suter
- NOvAs first joint neutrino and anti-neutrino analysis showed first evidence ( $4\sigma$ ) for electron anti-neutrino appearance, was presented NEUTRINO2018, co-led by Himmel
- Conveners of oscillation groups, Suter (current),  $\nu_e$  Himmel (2017 - 2018),  $\nu_\mu$  Paley (2015),
- Fermilab RA's have been lead analyzers, reviewers and authors of these analyses

