



# The NOvA Test Beam Program

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on behalf of the NOvA collaboration

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# **NOvA Physics**

- Study  $v_{\mu} \rightarrow v_e, \overline{v}_{\mu} \rightarrow \overline{v}_e$  oscillations to:
  - resolve the neutrino mass ordering (is  $v_3$  the heaviest mass state?)
  - measure the octant of  $\theta_{23}$  (is there an • underlying  $v_{\mu}/v_{\tau}$  symmetry?)
  - search for CP symmetry violation in leptons (constrain differences between *v* and  $\overline{v}$ oscillations)
- Measure neutrino cross-sections at the Near Detector.
- Search for sterile neutrinos via non-standard oscillations.
- Other exotics and more!





# **Oscillation Analyses**

- Measure energy spectrum of  $v_{\mu}$ ,  $v_e$ ,  $\overline{v}_{\mu}$ ,  $\overline{v}_e$  selected events and fit to oscillation models.
- As more data are collected, statistical uncertainties will decrease and systematic uncertainties will become more limiting.
- Some of the largest uncertainties can be addressed directly using a Test Beam experiment:
  - validate and improve detector calibration procedures;
  - characterize detector response;
  - collect single particle libraries for use in improving the simulation and reconstruction tools.





# The NOvA Test Beam Program

- The NOvA Test Beam Program uses a scaleddown 30-ton NOvA detector with identical technologies to the other NOvA detectors.
- It analyzes tagged charged particles from a tertiary beamline consisting of protons, pions, muons, electrons and kaons in the
  0.2 2.0 GeV/c momentum range relevant to NOvA's neutrino interactions.



- Timeline:
  - Deployed at the Fermilab Test Beam Facility in from Summer 2018 Spring 2019.
  - Commissioning May July 2019.
  - Data taking December 2019 March 2020.



## **MCenter Beam**

- NOvA Test Beam is located on the MCenter beamline;
  - Downstream of the the area previously used by LArIAT.
- Protons accelerated up to 120 GeV by the Main Injector are extracted in a continuous 4.2 s spill once a minute.
- A secondary beam containing
  8 80 GeV protons and pions is created by impinging the primary protons on a Cu target.
- A second Cu target is used to produce a tertiary beam containing the particles of interest for NOvA Test Beam.

Fermilab Accelerator Complex





**Tertiary beamline instrumentation** provides **trigger**, **particle identification** and precise a **momentum measurement** for tertiary beam particles of interest before interactions in the **NOvA Detector**.







**Analyzer magnet** is used to select the tertiary beam momentum and charge of interest with a field up to 1.8 T.



**Time-of-Flight** with 13.2 m lever arm provides identification of heavier particles (protons and kaons).



Four **wire chambers**, each with two 5.5"x5.5" planes and 1 mm wire pitch, provide particle tracking and are used to reconstruct the particle momentum with 1-3% resolution.



**Threshold Cherenkov Counter** containing 1 atm CO<sub>2</sub> for tagging electrons in the tertiary beam via Cherenkov light.



# **NOvA Detector Technology**

- Detectors are constructed from **planes of cells**, alternately oriented vertical and horizontally perpendicular to the beam direction.
- Filled with **liquid scintillator** and instrumented with **wavelength-shifting fibers**.
- Scintillation light is read out by **photodiodes**.
  - Different front-end electronics are used at the Far Detector and Near Detector.
  - Test Beam detector uses both types.



# Preliminary Results

- Particle identification using fully automated reconstruction of beamline data.
- Data shown taken between January 7 and March 20, 2020; 5178 selected events.





- Data collected at two magnetic fields:
  - $\sim 0.8 \text{ T} \rightarrow \sim 1 \text{ GeV/c};$
  - $\sim 0.4 \text{ T} \rightarrow \sim 500 \text{ MeV/c.}$

# **Preliminary Results**

- Proton candidate matched to event in NOvA detector.
  - Reconstructed **Time**-**of-Flight: 55.7 ns**.
  - Reconstructed momentum: 1.0 GeV/c.
  - No signal from Cherenkov counter.





# **Preliminary Results**

- Electron candidate matched to event in NOvA detector.
  - Reconstructed **Time**of-Flight: 42.7 ns.
  - Reconstructed momentum: 1.3 GeV/c.
  - **Signal** detected from Cherenkov counter.





# **Summary & Future Plans**

- New tertiary beamline and NOvA detector installed and commissioned at Fermilab Test Beam Facility.
- Collected ~6 months of data between May 2019 and March 2020, corresponding to a commissioning phase and a subsequent initial data run.
- Full detector calibration with cosmics nearing completion.
- Beginning the process of analyzing the data collected with a view to improving understanding of the NOvA detectors and incorporating improvements into the calibration, reconstruction and analyses.
- Working to optimize the beam and running conditions using analysis of commissioning data and simulations over the current accelerator shut-down.
- Planning further operations to collect more data between ~November 2020 and Summer 2021.

# **Thanks!**









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# **Preliminary Simulation**

- True momentum and Time-of-Flight from simulation at -0.97 T magnetic field strength (984 events).
- Calculation from kinematics:

$$\mathbf{ToF} = L\sqrt{\left(\frac{m}{p}\right)^2 + \frac{1}{c^2}}$$

where *L* is the baseline (13.2 m).



#### **NOvA Simulation**

# **Cosmic Ray Event**



# **Cosmic Ray Event**



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