Design and Operation of a Charged Particle Beamline for the NOvA Test Beam Experiment

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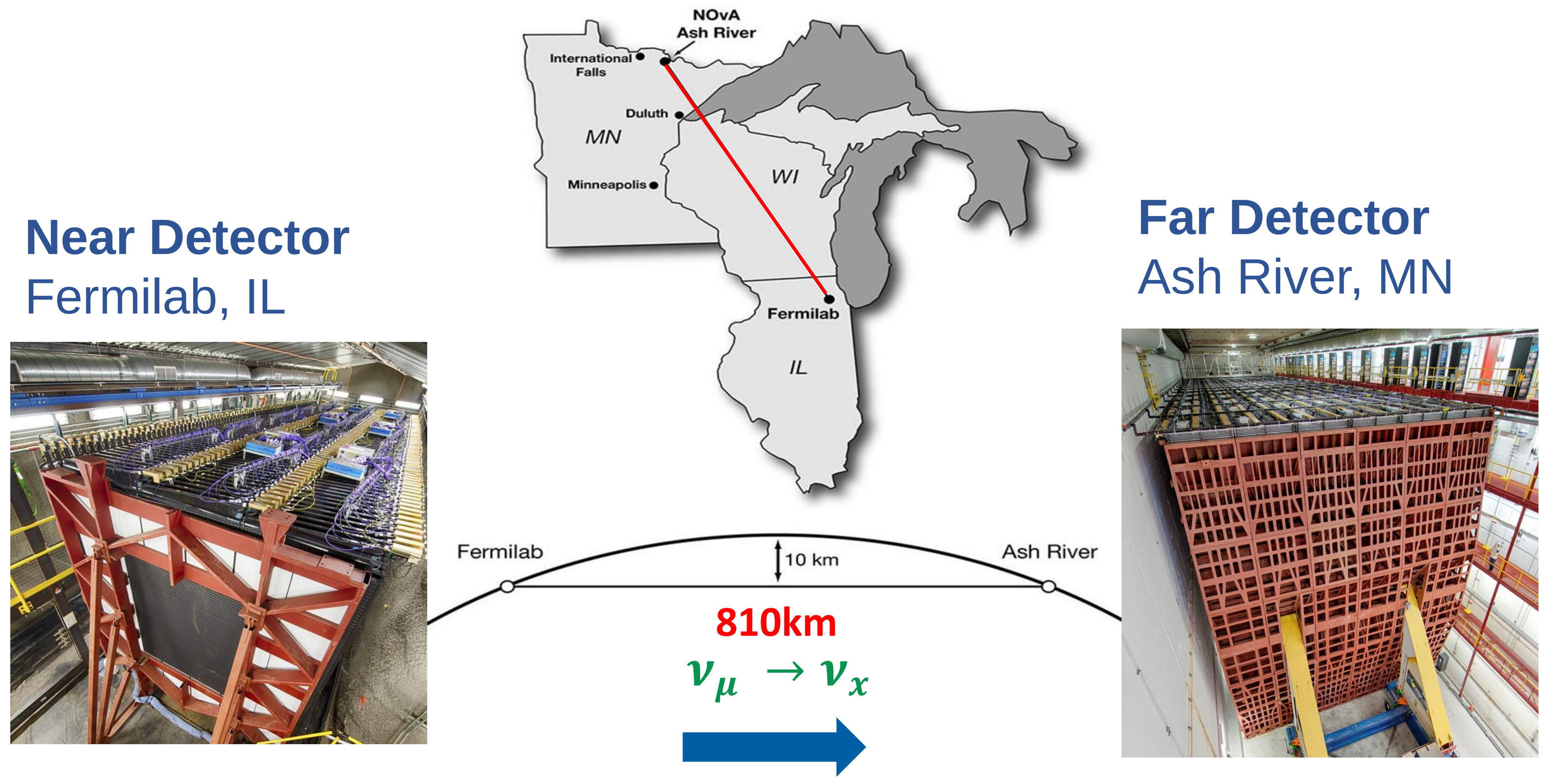
The NOvA Experiment

- **NOvA** (**NuMI Off-Axis ν_e Appearance**) is a long-baseline neutrino oscillation experiment using Fermilab's NuMI beam.
- Neutrinos detected by two detectors, after 1 km and 810 km, 14.6 mrad off-axis.
- The neutrino spectrum is sharply peaked at 2 GeV, with a width of 0.4 GeV.

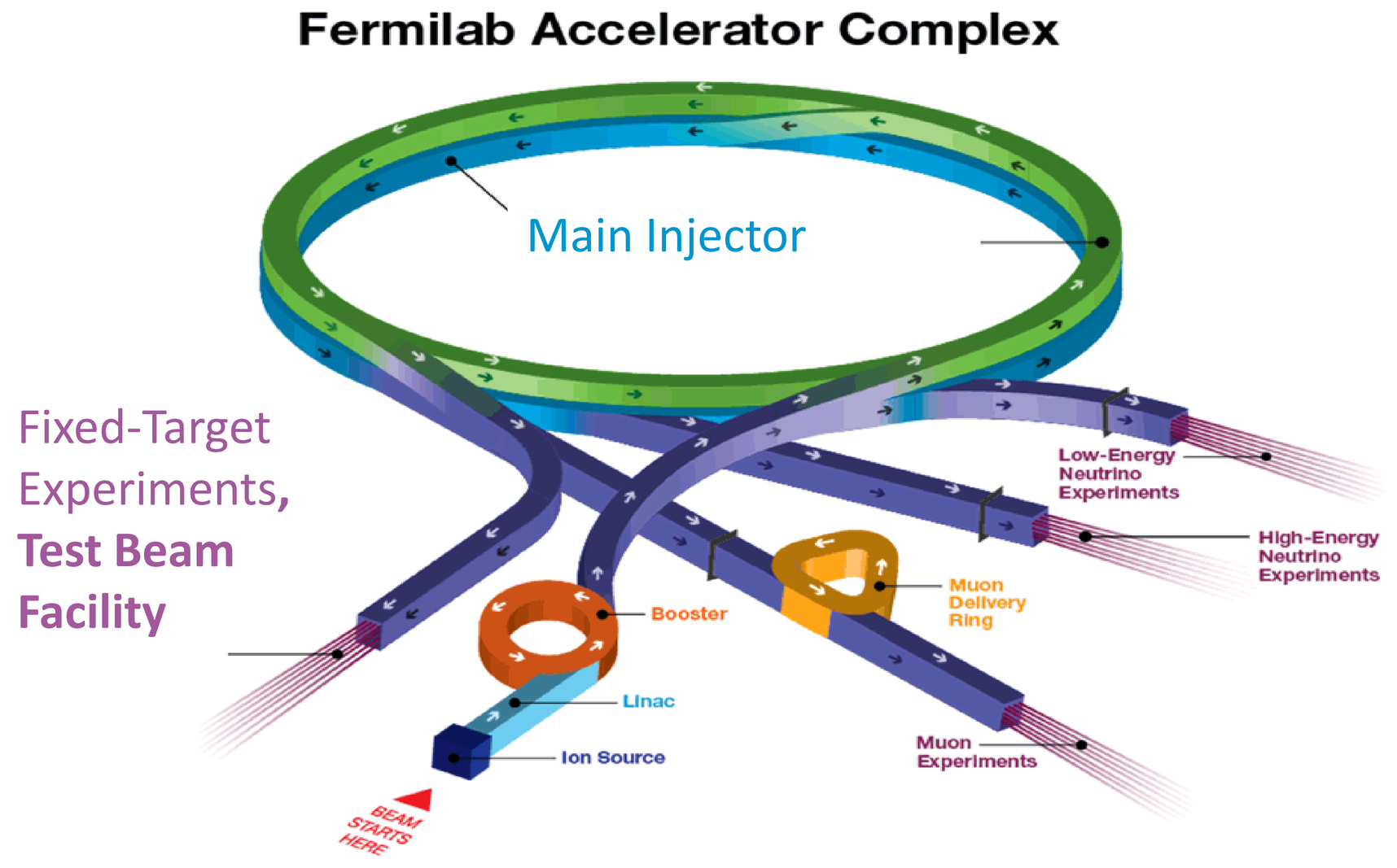


- NOvA is making precision measurements of the parameters governing neutrino oscillations, searching for evidence of CP violation in the lepton sector and aiming to resolve the mass hierarchy.
- The NOvA Test Beam uses a scaled-down NOvA detector to improve understanding of detector response, simulation and calibration, in order to reduce the experimental uncertainties and improve event reconstruction and analysis.

Fermilab Accelerator Complex

- **The Fermilab Accelerator Complex** provides a high energy proton beam to several locations, including **NOvA** and the **Fermilab Test Beam Facility (FTBF).**
- **FTBF** receives **120GeV/c** protons from the **Main Injector** for a 4.2 s continuous spill every minute.
- Typically accumulate between 1x10^9 and 1x10^{10} protons each spill.

Fermilab Accelerator Complex

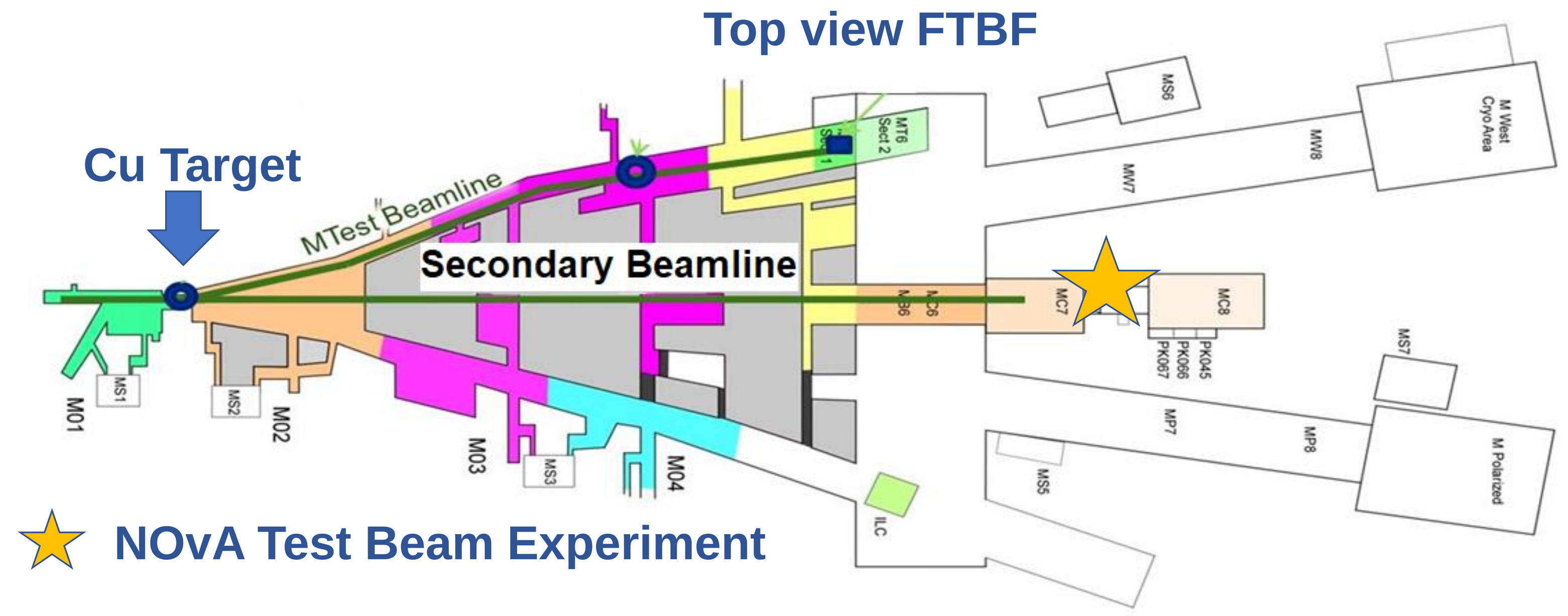


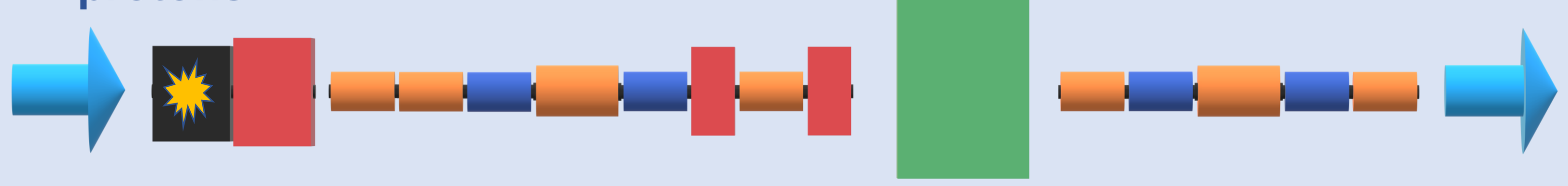
FTBF

- The primary proton beam interacts with a primary cooper target in the facility creating a **secondary beam**.
- A **tertiary beam** is then produced through interactions of the secondary beam particles with a second copper target.

https://www.fnal.gov/pub/science/particle-accelerators/images/accel-complex-animation.gif

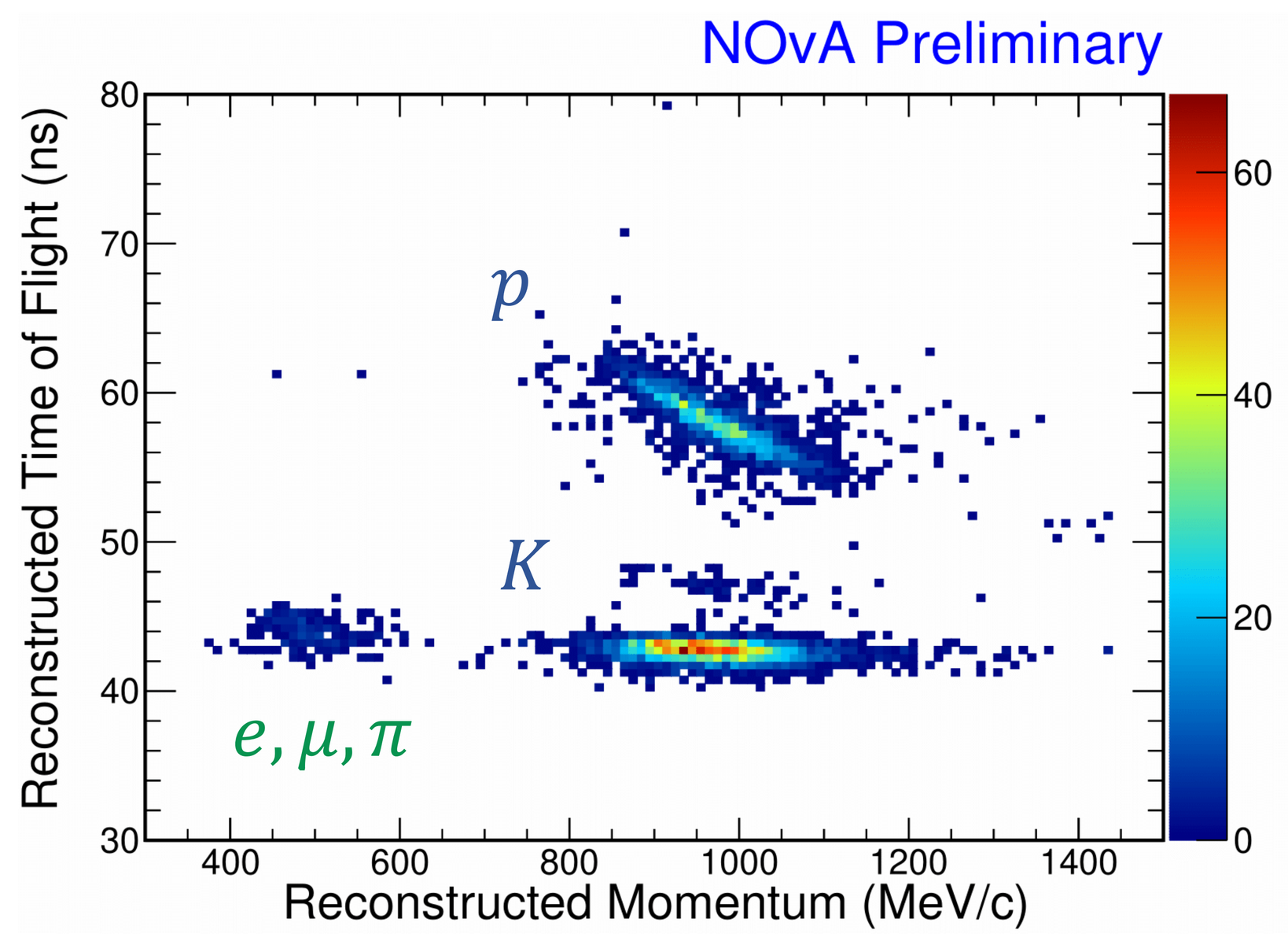
Secondary Beamline



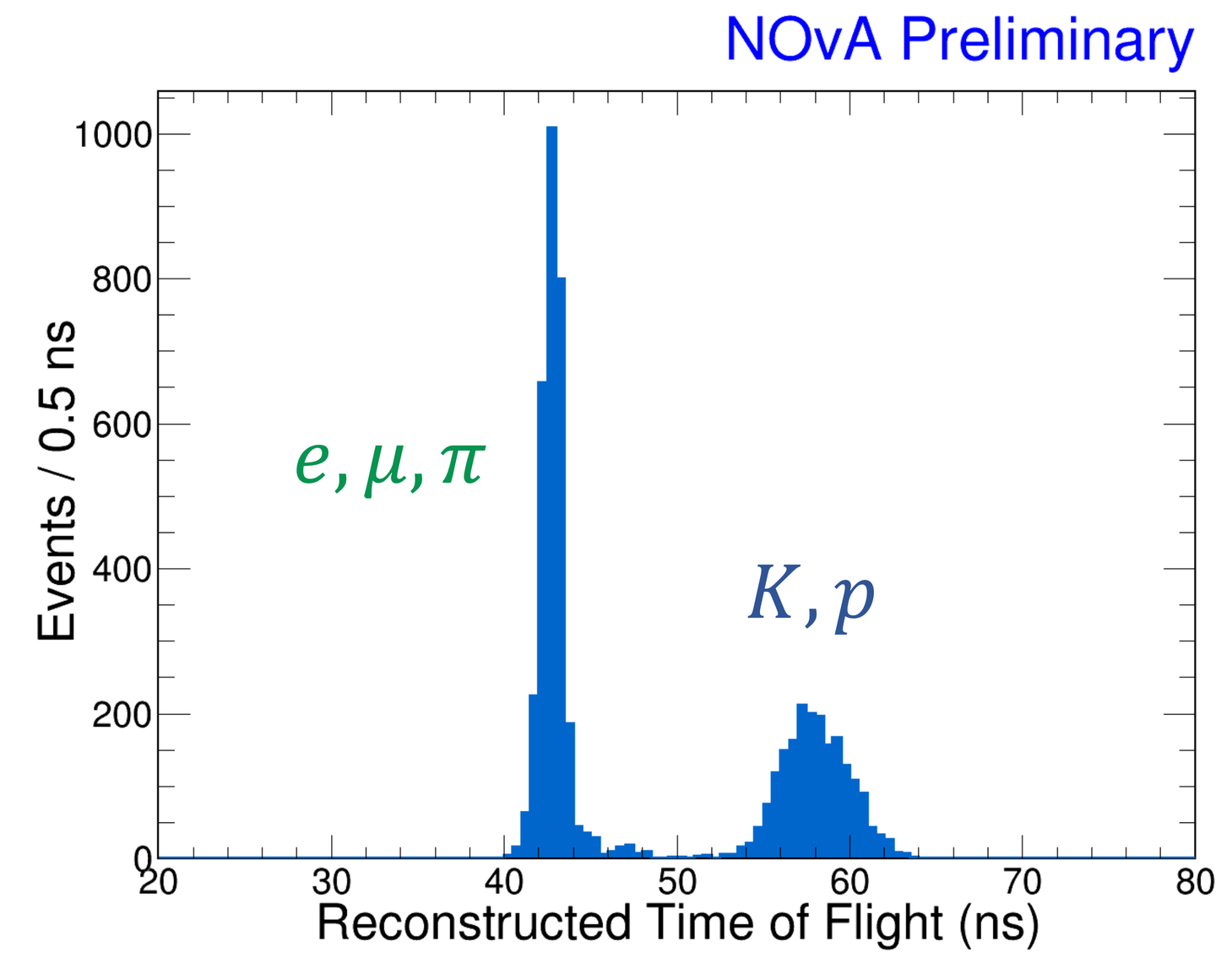


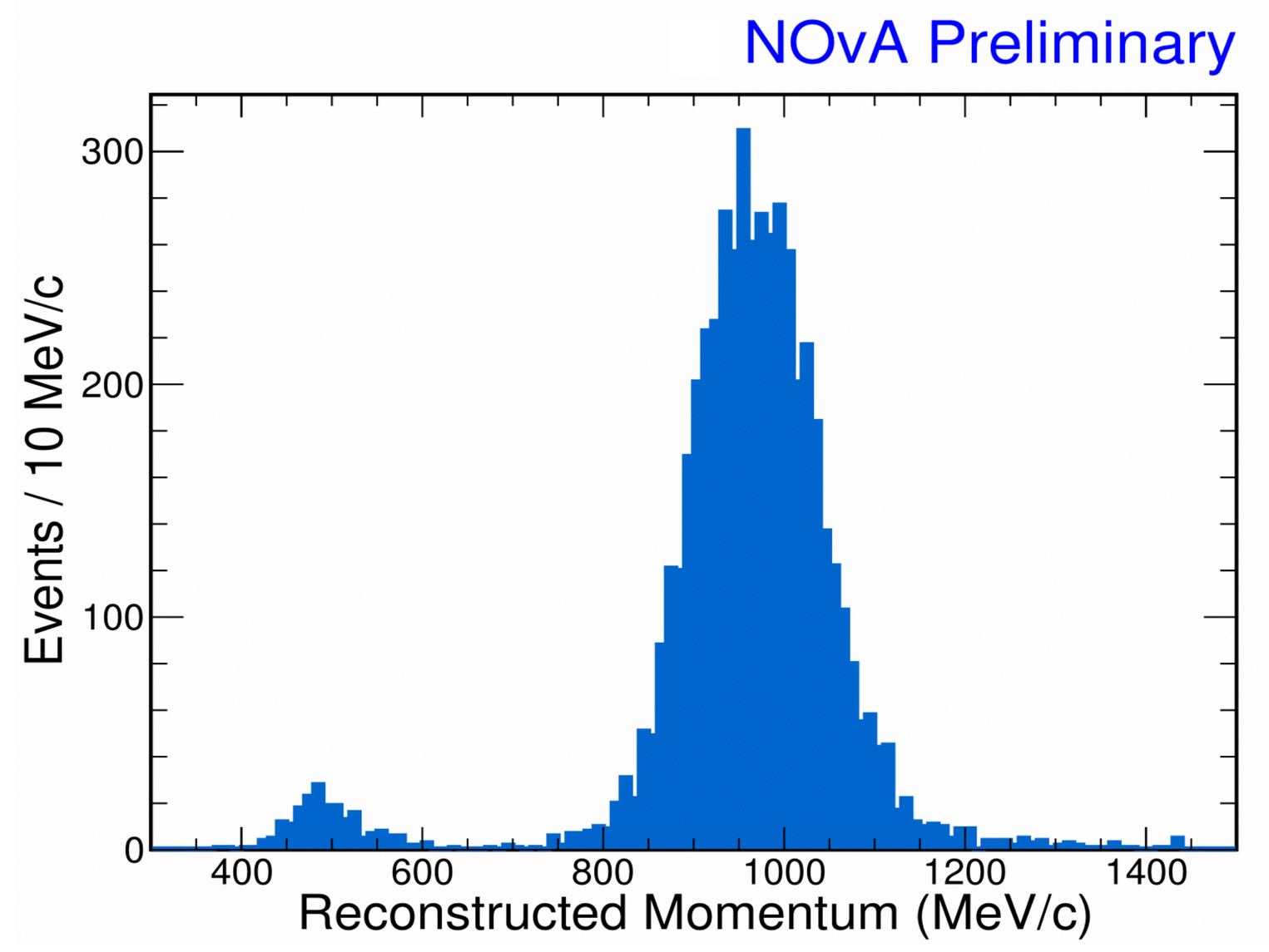
- **Primary Cu Target: 120 GeV/c** protons interact on the target to produce a secondary beam of mainly protons and pions.
- **Shielding Blocks and Collimators:** Remove off-axis and off-momentum particles.
- **Quadrupole Magnets:** Focus charged particles along the secondary beamline.
- **Dipole Magnets:** Used to select the momentum from 1 to 80 GeV/c by deflecting the particles. **The Nova Test Beam Experiment** has chosen 64 GeV/c to give the optimal tertiary production
- **Momentum selecting Collimator:** With variable aperture, selects particles of the correct momentum and control the momentum bite of the beamline.

Preliminary Results



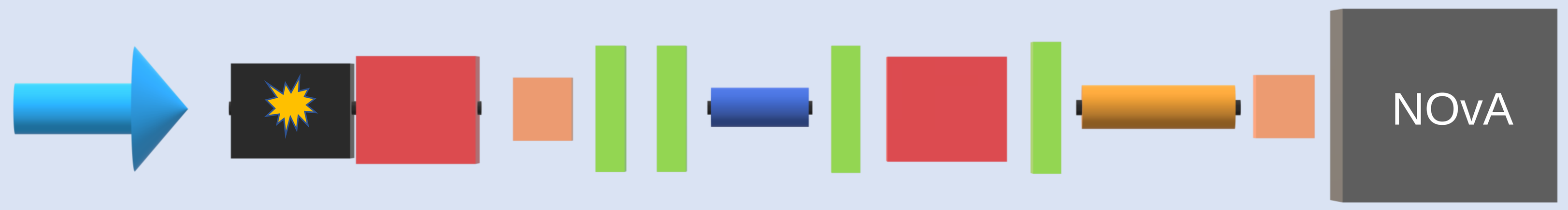
- Tertiary beamline data collected from January 7 to March 20, 2020: 5178 events selected.
- Two Different **Dipole Magnet** current configurations.
  - 500 A ➡ ~ 500 MeV/c particles.
  - 1000 A ➡ ~ 1000 MeV/c particles.
- Particles (e, μ, π) traversing the beamline detectors close to the speed of light.
- Heavy particles (K, p) traversing the beamline detectors.





Tertiary Beamline

- **The NOvA Test Beam Experiment** analyzes particles with properties of interest to understanding the neutrino interactions in NOvA; charged particles with energies 0.2-2 GeV.
- In order to produce these particles, a tertiary beam is created from the 64 GeV/c secondary beam particles.
- The tertiary beamline includes multiple detectors to characterize the particles before interaction in the NOvA detector and provide an external trigger for the readout systems.



- Beamline components tag and select **protons, pions, kaons, muons and electrons** in the momentum range of 0.2 to 2 GeV/c.
- **Secondary Cu Target : The secondary beam particles** interact on the target to produce lower energy particles.
- **Time Of Flight (TOF)** : Two scintillator paddles located at the upstream **(US)** and downstream **(DS)** ends of beamline to provide precise timing information and assist in particle identification.
- **Dipole Magnet:** Selects the momentum and charge of tertiary particles through their deflections in the field.
- **Wire Chambers (WC) (4):** Provide precise tracking of the particles through the beamline.
- **Cherenkov Detector**: Tags electrons in the beam using Cherenkov light. The detector contains CO_2 at 1atm pressure.
- **NOvA Test Beam Detector** : Tracking calorimeter filled with liquid scintillator equipped with both Near Detector and Far Detector technologies.

Conclusions

- **The NOvA Test Beam Experiment** has in place a fully instrumented **tertiary beamline** at Fermilab.
- Data taking operations from December 6, 2019 to March 20, 2020. Currently considering the possibility of collecting more data next year.
- Preliminary results show the capability of the tertiary beamline in identifying and characterizing charged particles.
- Beginning to understand and analyze the data with a view to incorporating improvements into NOvA calibration, reconstruction and analyses.

Fermilab

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