The NOvA Test Beam Program

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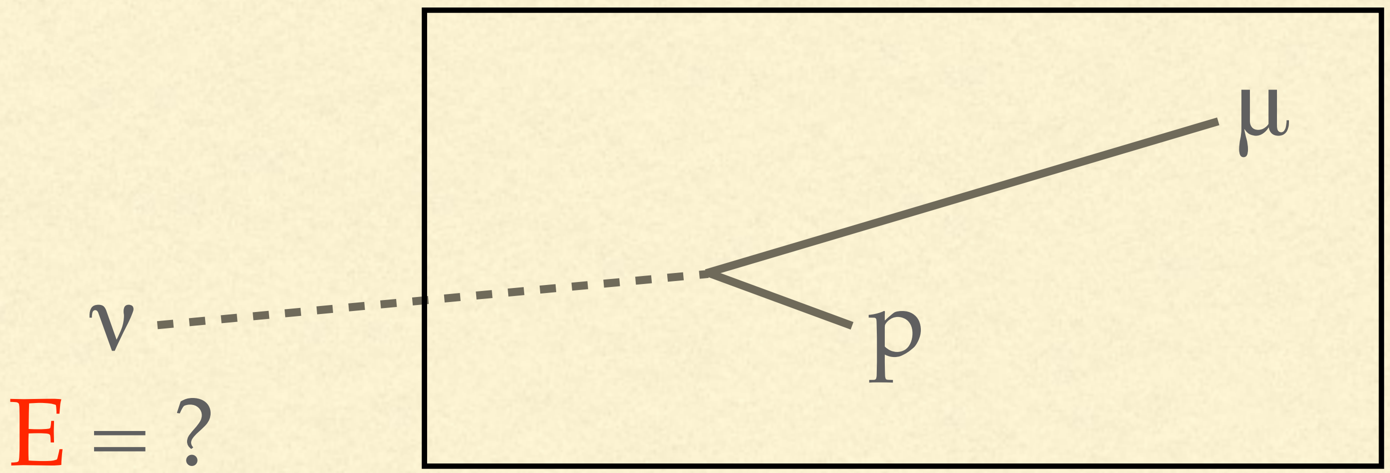
- Neutrino oscillation probabilities depend on the energy of the neutrino:

$$P\left(\nu_\mu \rightarrow \nu_\mu\right) \approx 1 - \sin^2(2\theta_{23})\sin^2\left(\Delta m^2_{32}\frac{L}{4E}\right)$$

$$P\left(\nu_\mu \rightarrow \nu_e\right) \approx \sin^2(2\theta_{13})\sin^2(\theta_{23})\sin^2\left(\Delta m^2_{31}\frac{L}{4E}\right) + f\left(\mathrm{sign}\left(\Delta m^2_{31}\right)\right) + f(\delta_{CP})$$

- Neutrino experiments differ from other high energy particle physics experiments in that we do not know the incoming energy of our particle. We have to determine this energy by studying the final state particles of neutrino interactions.

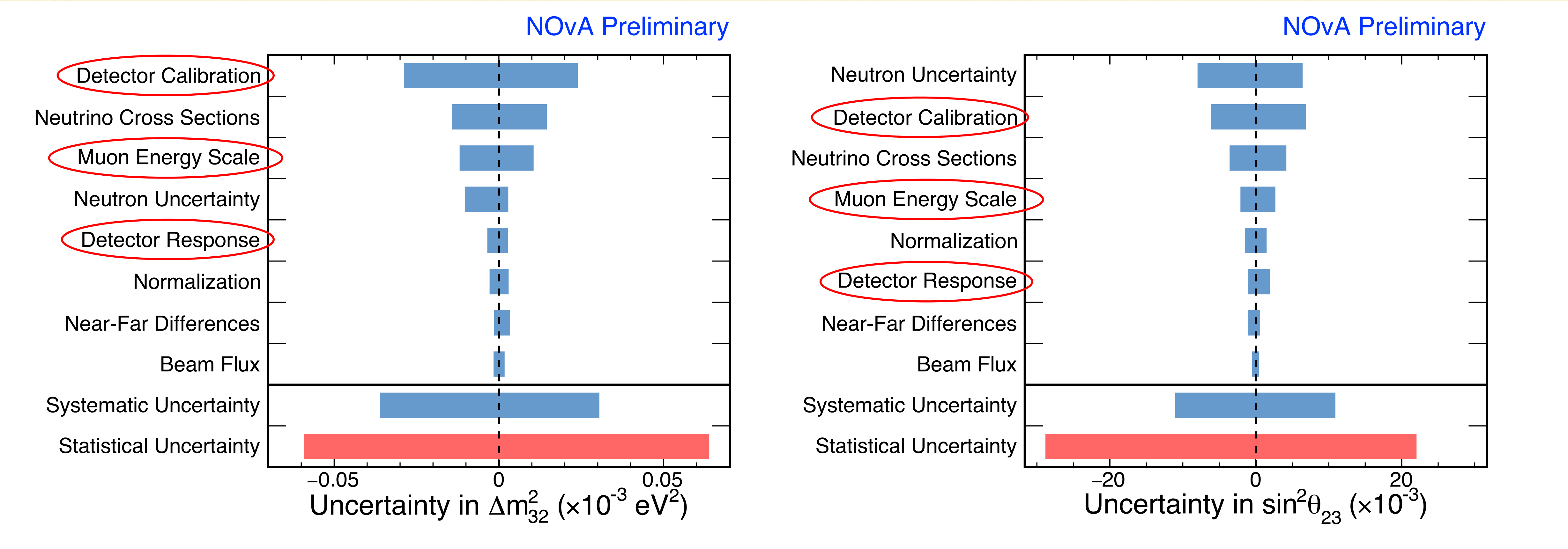


- It is important that we understand how our detectors respond to energy

Why Test Beam?

NOvA has been taking data since 2013, so why do a Test Beam experiment now?

- Want to understand more about how our detectors behave.
- NOvA plans to run until 2026. As we continue taking data, we will reach the point where our statistical errors will be comparable to our systematic errors. Test Beam can help to shrink these systematic errors as we gain more understanding about how our detectors respond to energy deposits.

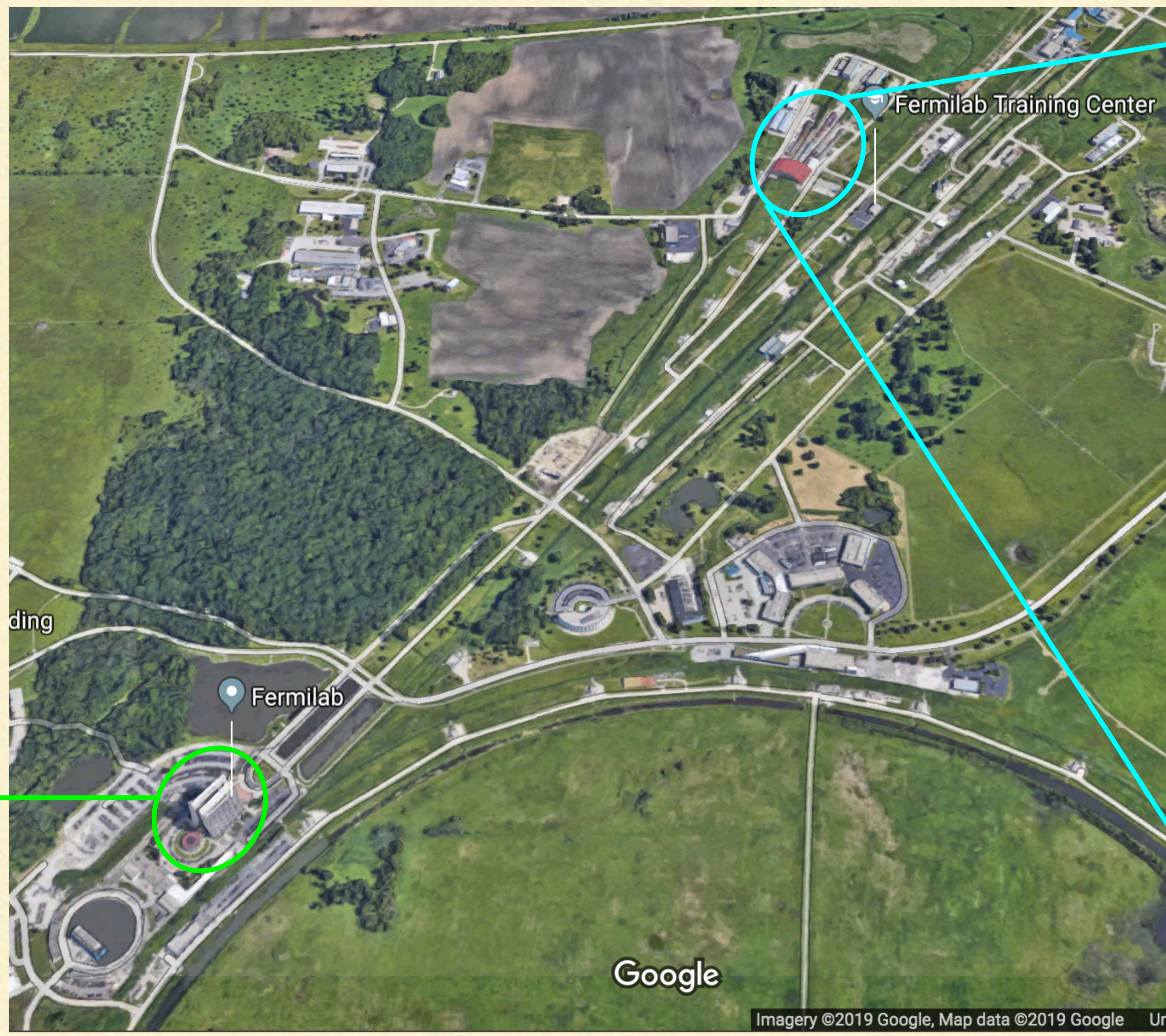


- Opportunity to collect a library of events for training reconstruction and particle identification algorithms.

What does a Test Beam experiment entail?

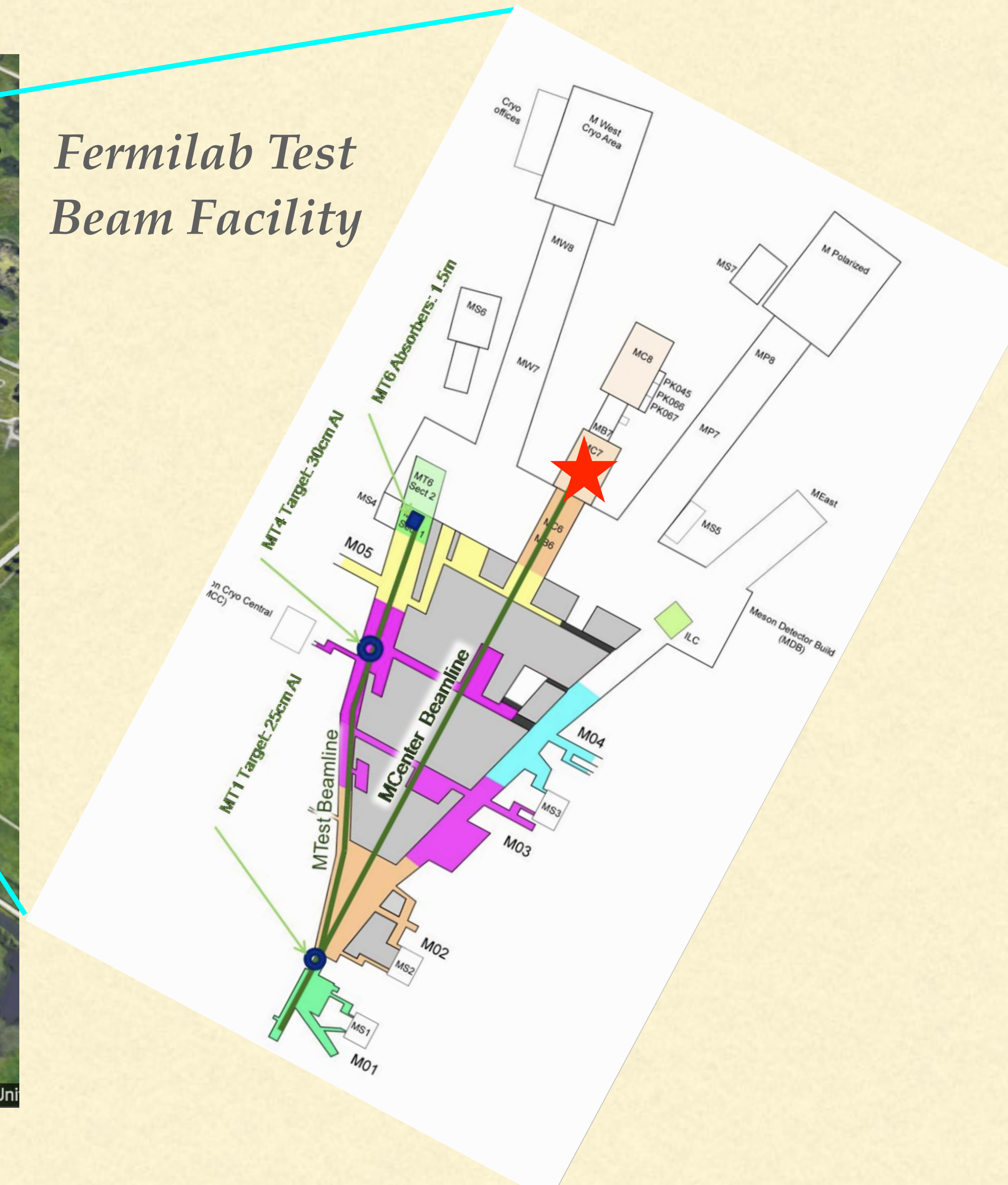
- The experiment consists of two main parts:
    1. Beamline detectors for particle ID and momentum measurements

       - Tertiary beamline in the MCenter beamline onsite at the Fermilab Test Beam Facility (FTBF), delivering 0.3 - 2.0 GeV/c protons, pions, electrons, and kaons to (2)
    2. Mini NOvA detector downstream of beamline



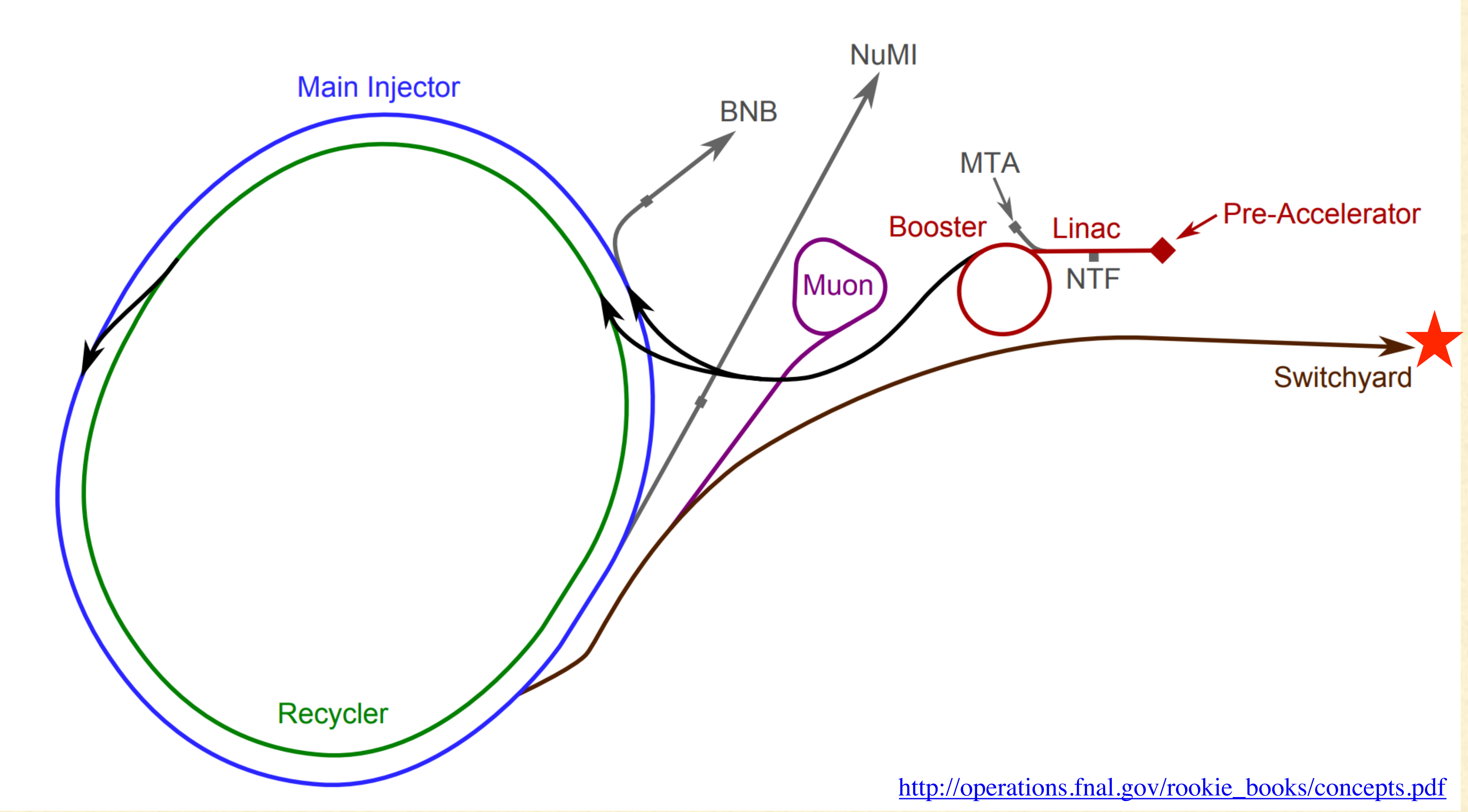
You are here (Wilson Hall)

Fermilab Test Beam Facility

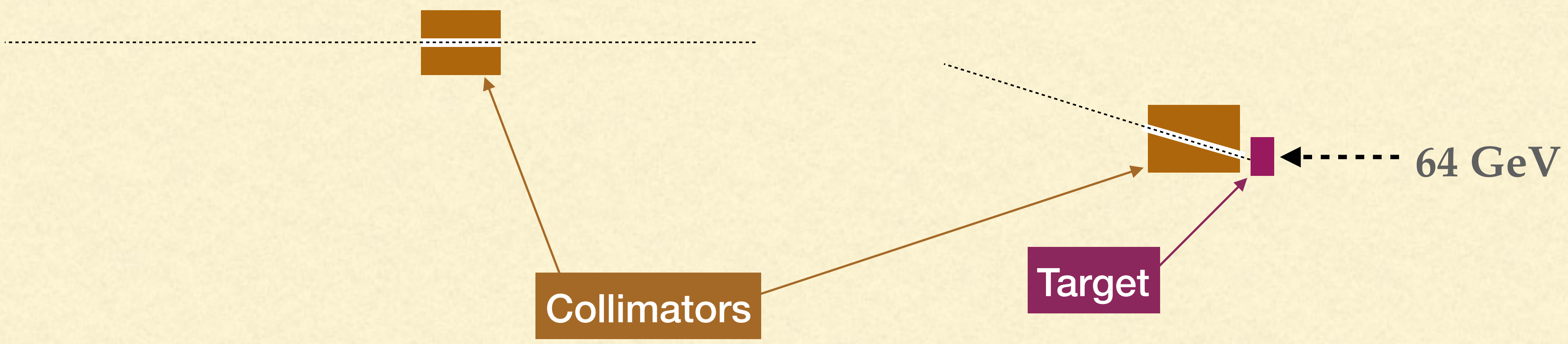


Beam details

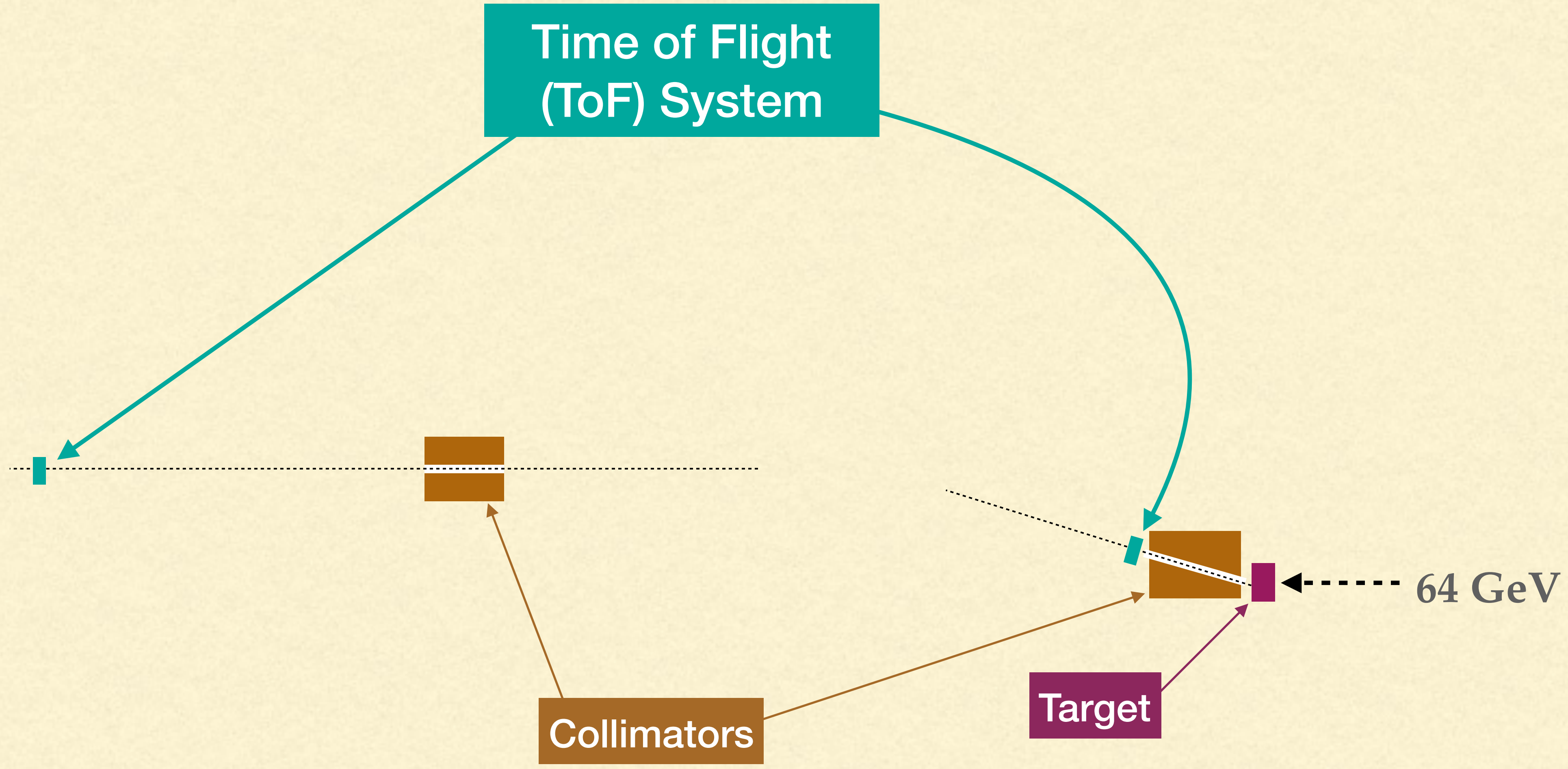
- Extract 120 GeV protons from the Main Injector and send it to Switchyard.
- Secondary beam of 64 GeV protons along the MCenter beamline.



- Receive one 4.2 s beam spill once a minute.



- 64 GeV protons hit a copper **target**, producing protons, pions, electrons, and kaons



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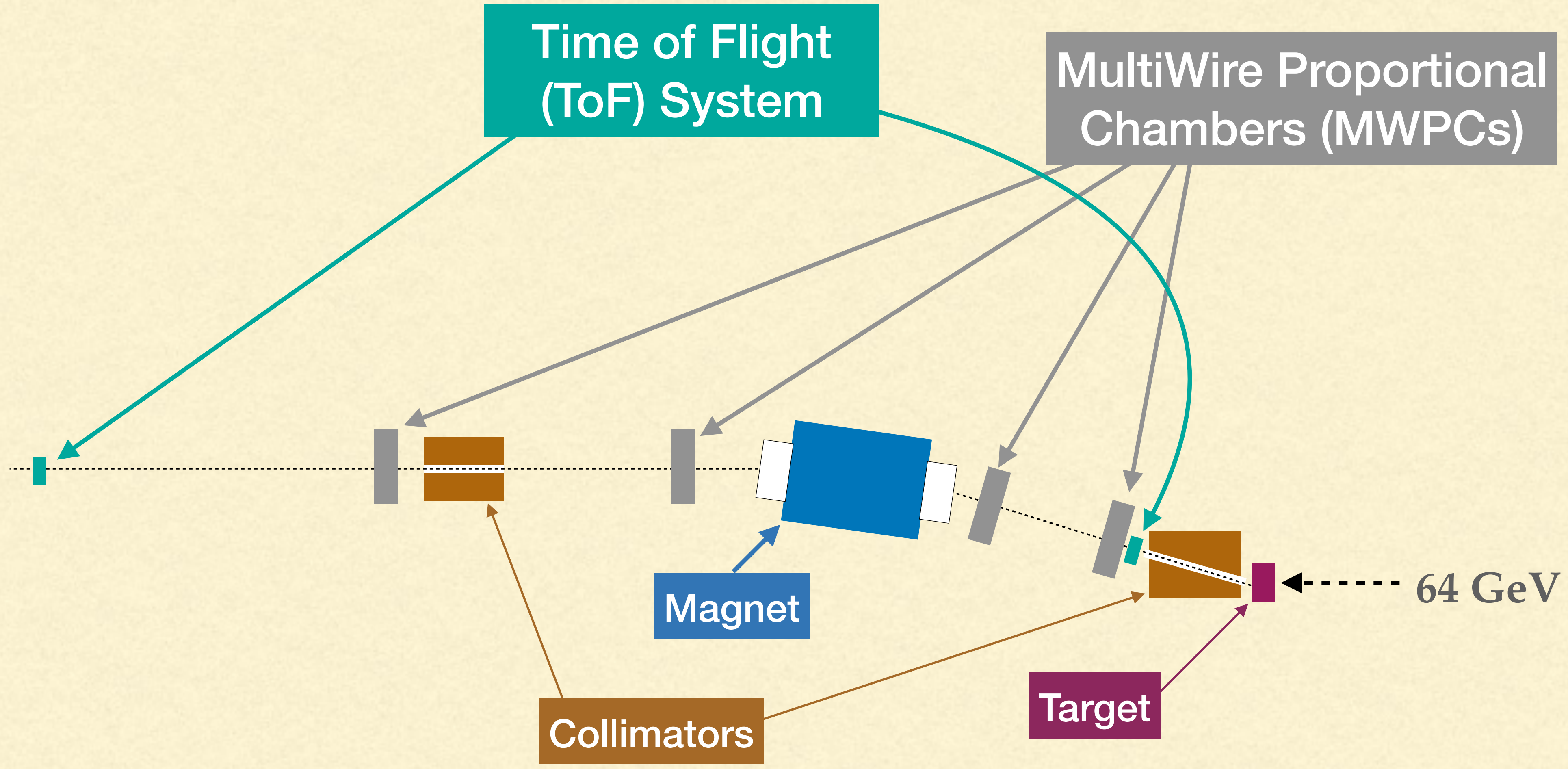
- Measure particles' **time-of-flight** using scintillator paddles for particle identification

The Beamline:



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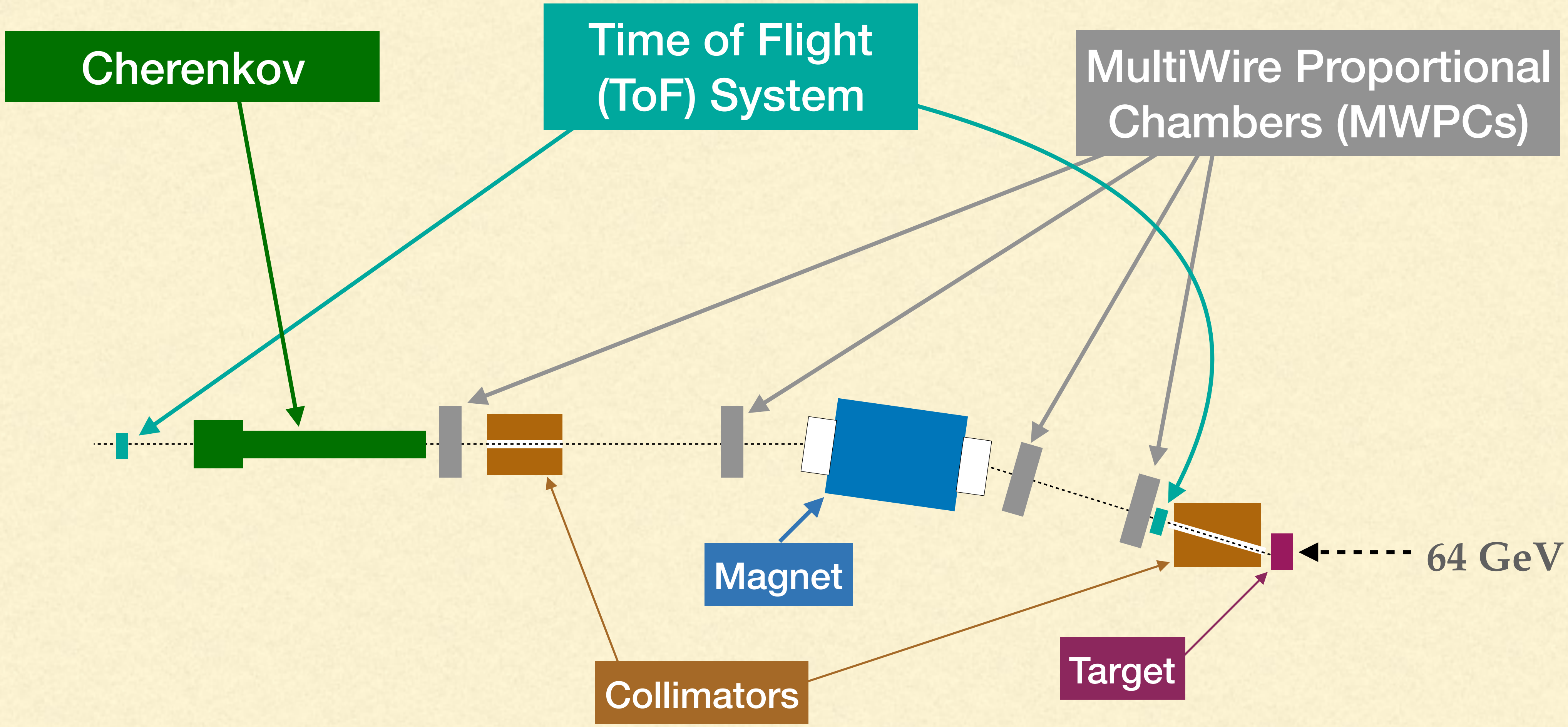

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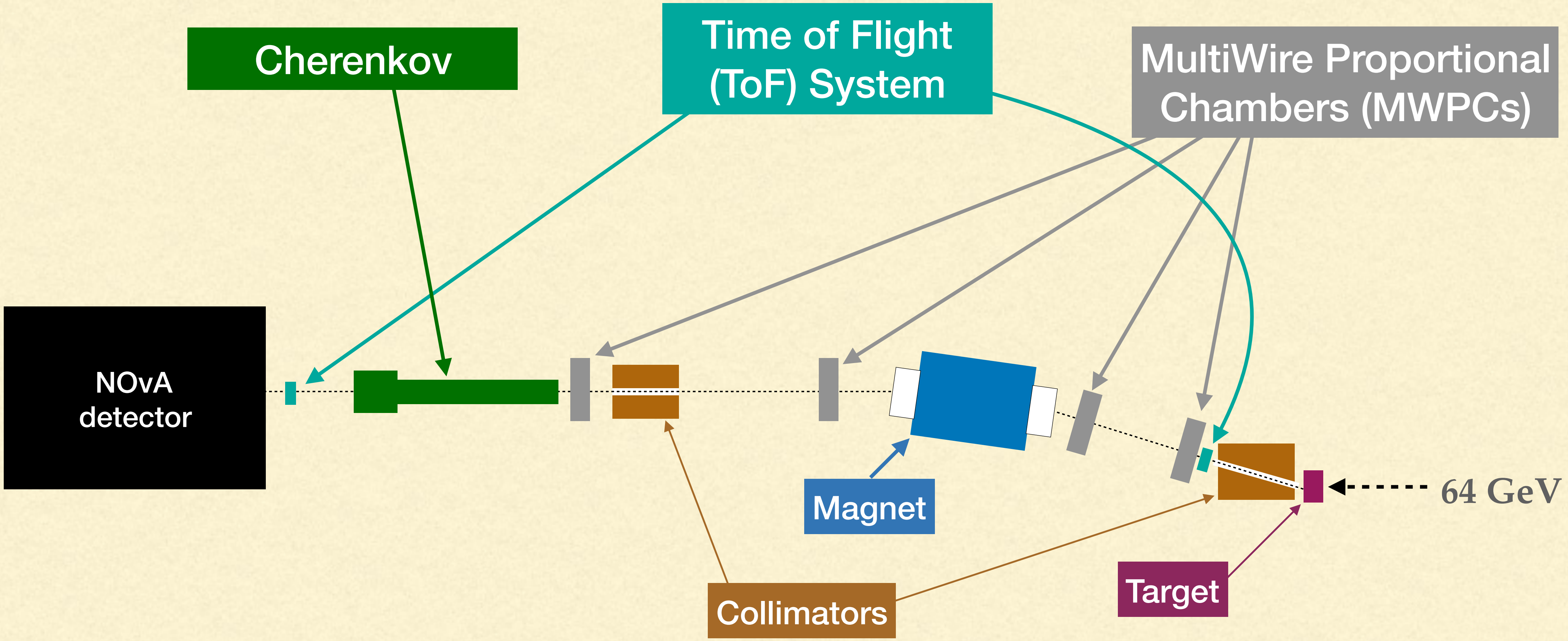

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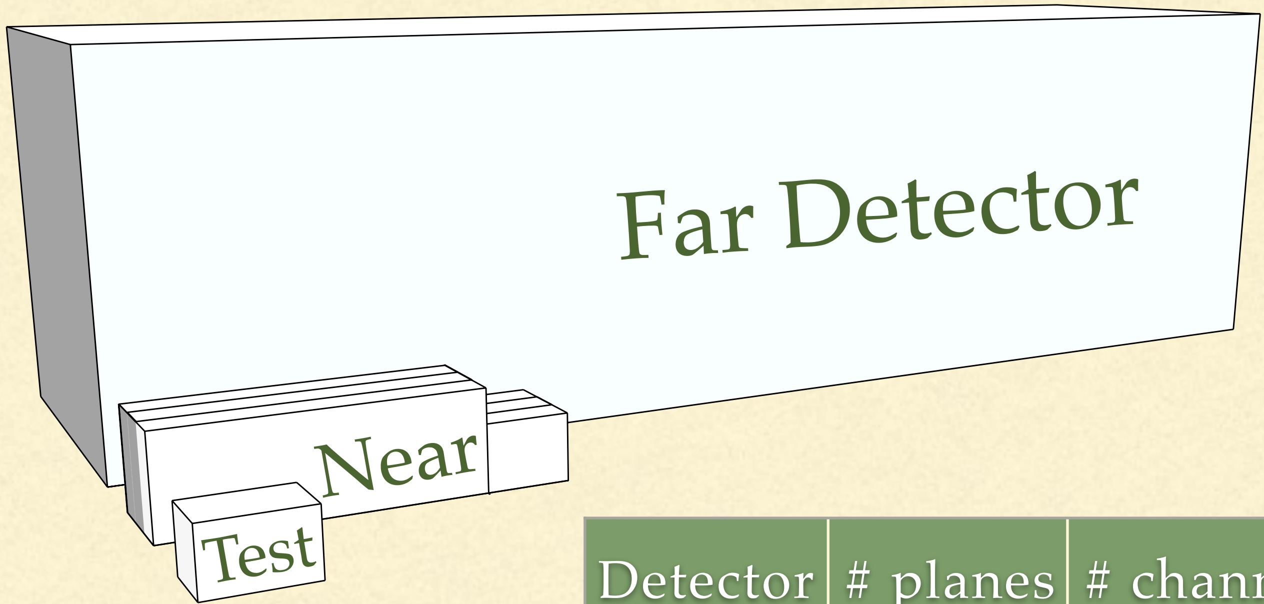
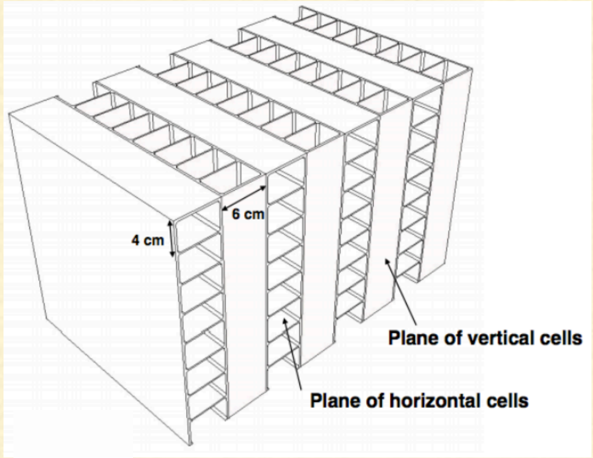
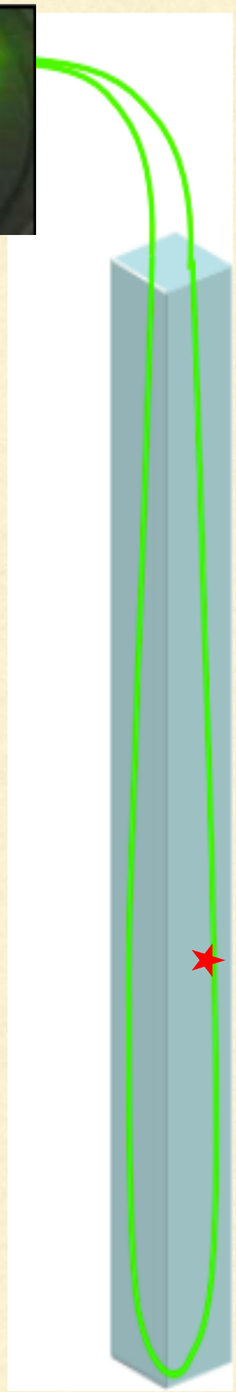
- Further discrimination of electrons provided by **Cherenkov** detector
- Measure response to particle in **NOvA detector**

The Detector:







Detector	# planes	# channels
Far	896	343,968
Near	214	20,192
Test	63	4,032

- Detectors composed of alternating horizontal and vertical planes of extruded PVC cells, filled with liquid scintillator and wavelength shifting fibers.
- In order to study potential differences between electronics used at our Far and Near Detectors, the Test Beam detector will be composed of mostly Far Detector electronics, with a handful of Near Detector electronics interspersed.

Commissioning

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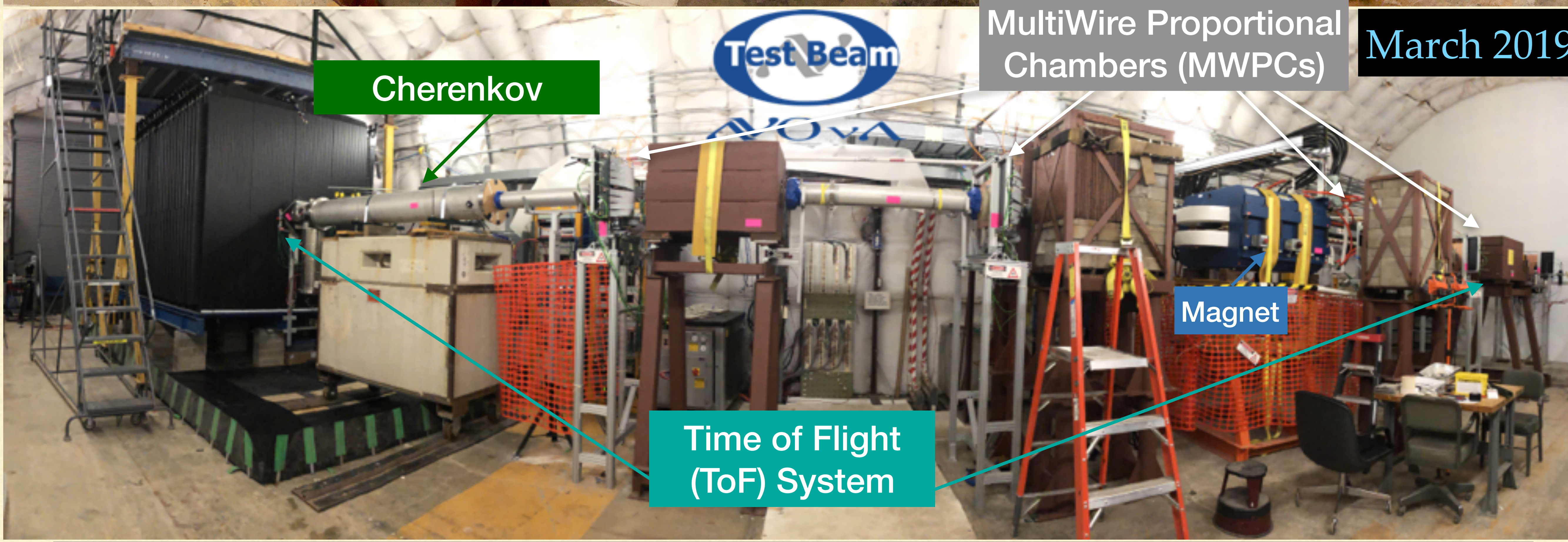
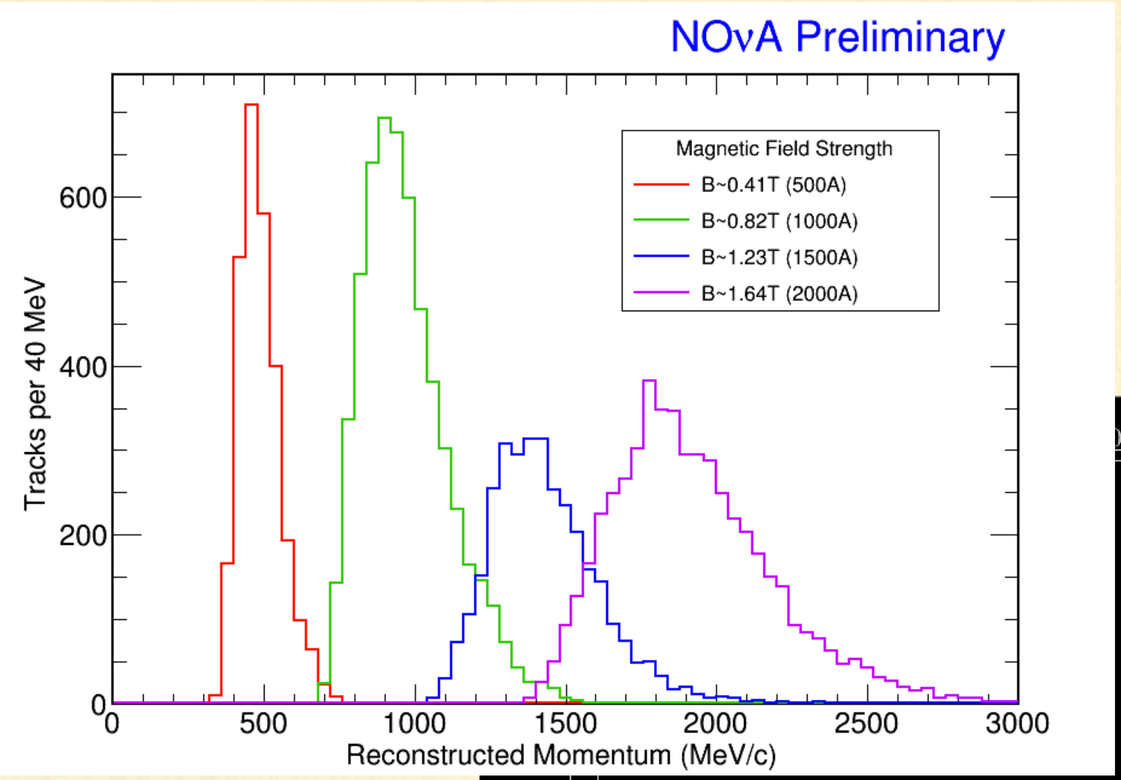


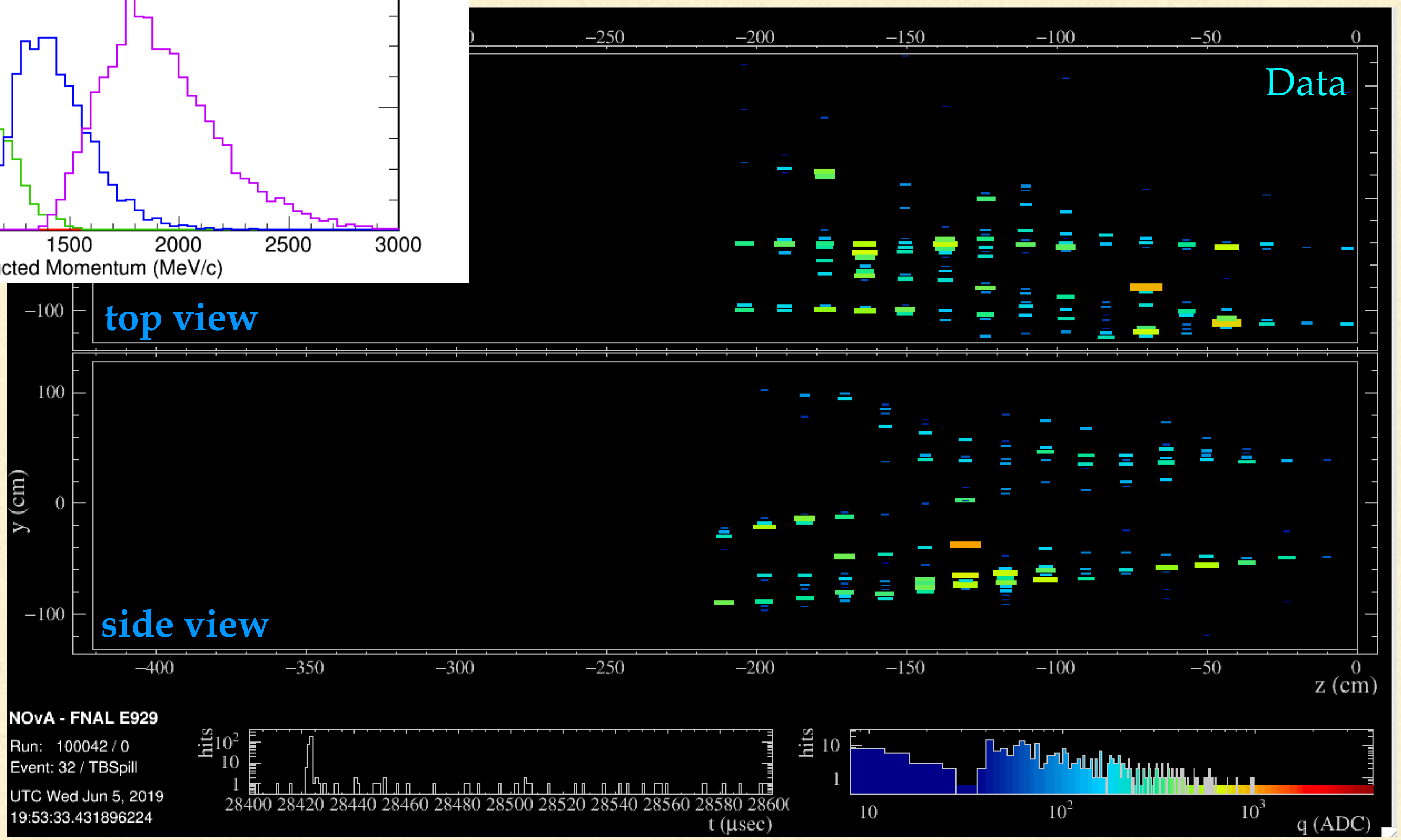
The NOvA Test Beam Detector

- 63 planes - 32 vertical, 31 horizontal
- First half filled with liquid scintillator and instrumented.
- Will fill and instrument remainder of detector during shutdown.
- Cooled detector for the first time May 24th (APDs operate cold).

Current Status

- We have been taking shifts since May, recording beam data before shutdown.
- Tuning beam and ensuring our DAQ is stable.
- Recorded cosmics in our detector for the first time May 24th, beam June 3rd!



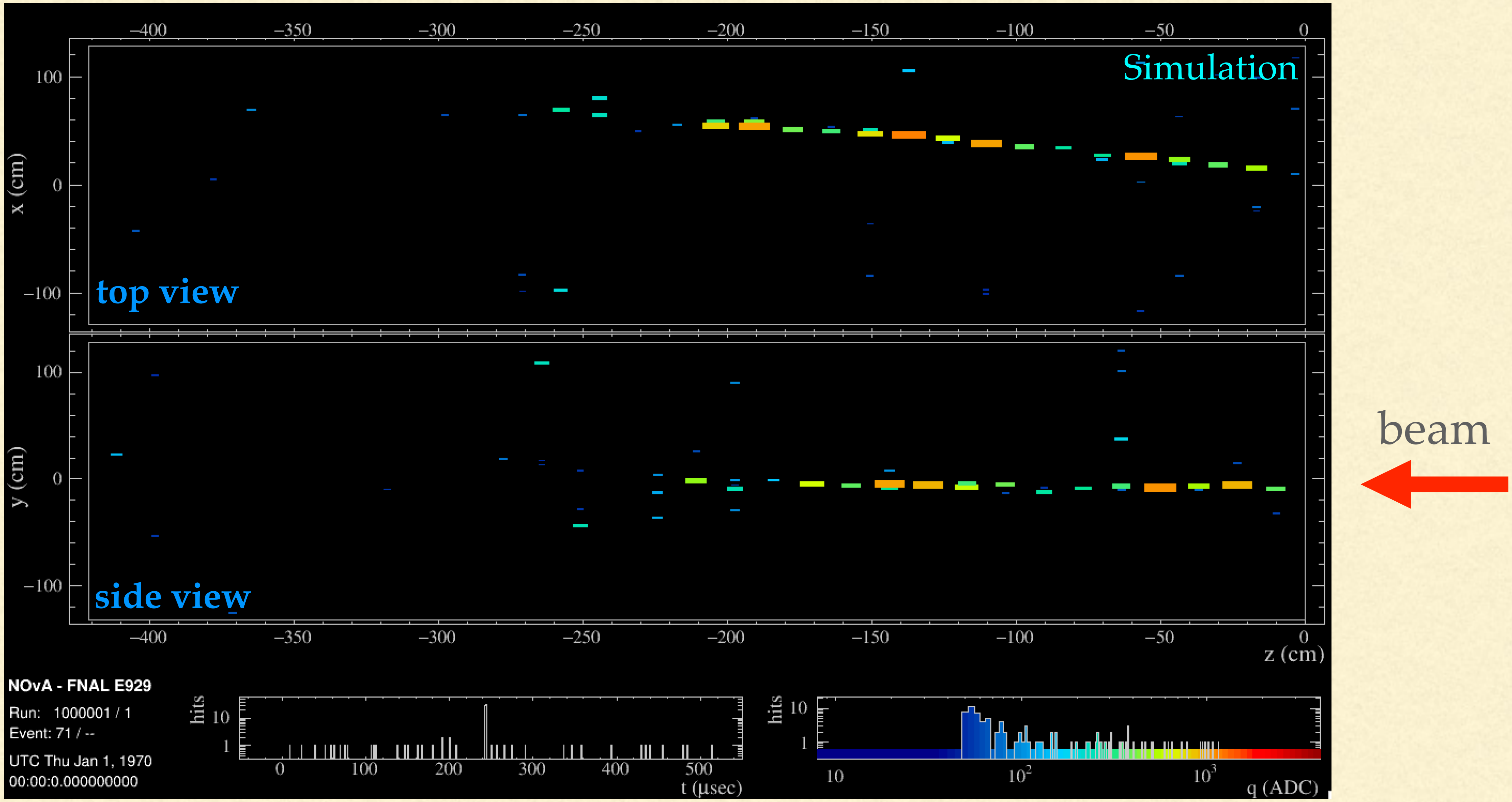


beam

Possible studies

- We can take the output of a g4beamline simulation of our beamline and use it as an input for our detector simulation.
- By reconstructing particles we identify as protons, pions, and electrons using information from the beamline detectors, we can study the hadronic and electromagnetic response of our detector.

eg. How much energy do we say a 1 GeV electron deposits in our detector?



Example (simulated) 1 GeV electron in Test Beam detector.

Conclusion

- Beamline detectors in place and taking data.
- Mini NOvA detector half filled with scintillator and instrumented
  - *Will fill and instrument remainder of detector during beam shutdown this summer.*
- Once we come back from shutdown, we will take data at various magnetic fields to collect various particles of various momenta.
- The NOvA Test Beam program will give us the opportunity to better understand how our detector works, along with testing our calibration and reconstruction techniques.
- Will additionally provide us samples of single particle events for training reconstruction and particle identification algorithms.

11 undergrads, 11 graduate students, and 7 post-docs contributing to NOvA TestBeam