The NOvA Test Beam Program

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On behalf of the NOvA collaboration

IOP APP & HEP Annual Conference

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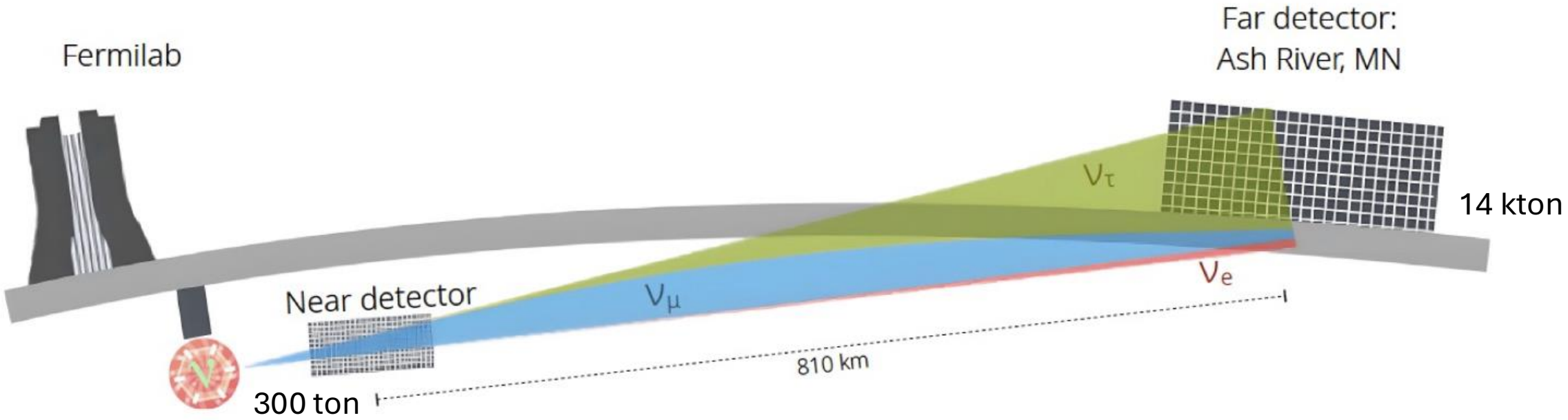
Overview

- Brief overview of the NOvA experiment.
- The motivation for NOvA's Test Beam program.
- An overview of the experiment, including the beamline instrumentation used.
- The measurement potential from the Test Beam data.

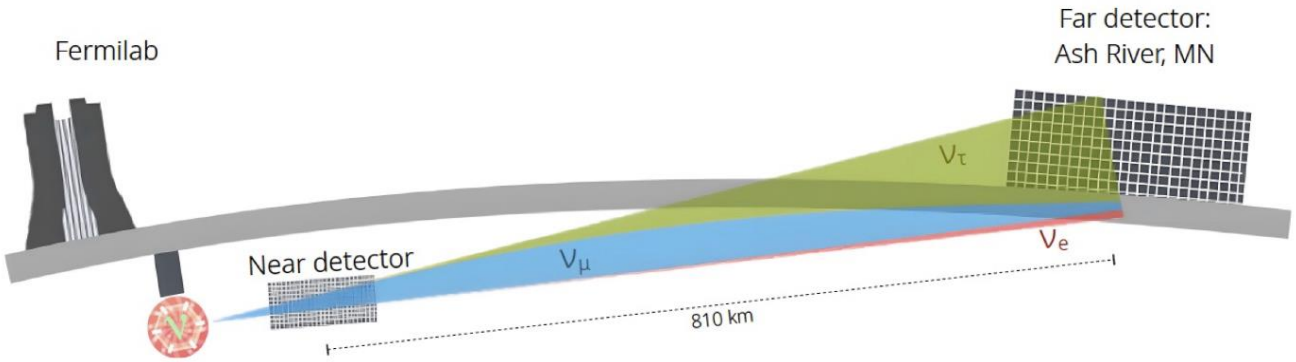
The NOvA Experiment

NuMI Off-Axis ν_e Appearance Experiment

- Long-baseline neutrino oscillations

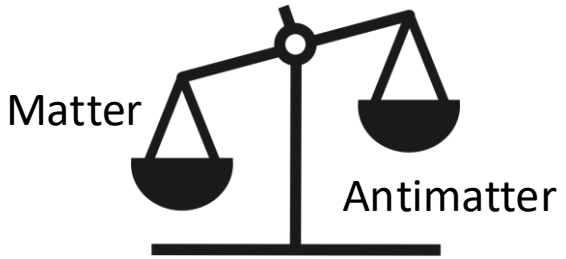


The NOvA Experiment

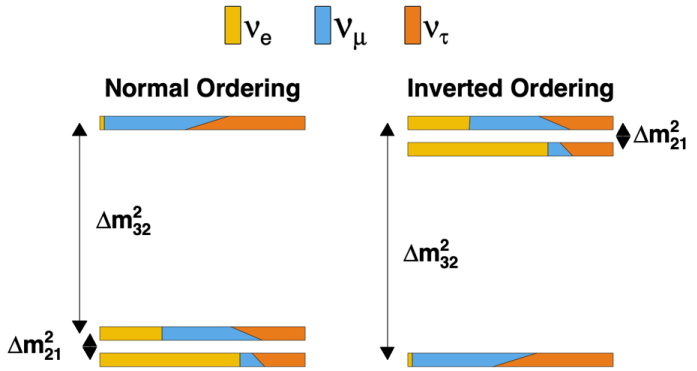


Observe:
- ν_μ disappearance.
- ν_e appearance.

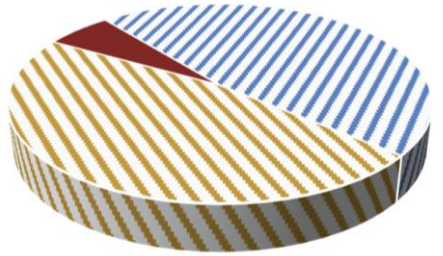
δ_{CP}: Do neutrinos violate CP?



Neutrino mass hierarchy:
Inverted or normal ordering?



Is θ_{23} maximal?

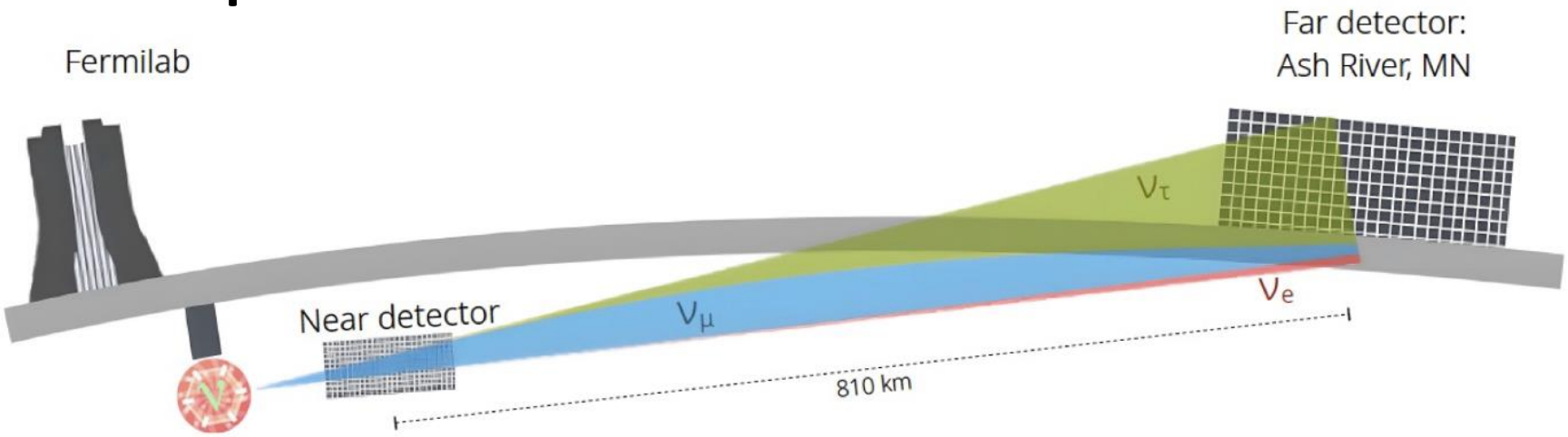


$\nu_\mu = \nu_\tau$ in ν_3?

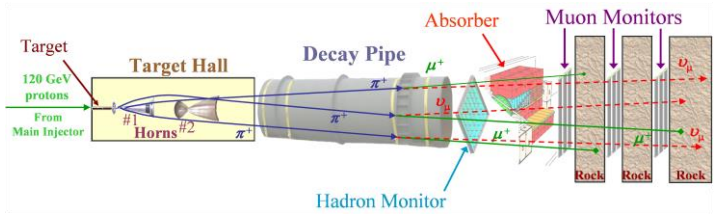
More analyses:
- Sterile neutrino search.

- Neutrino cross-sections.
- Exotics, …

The NOvA Experiment



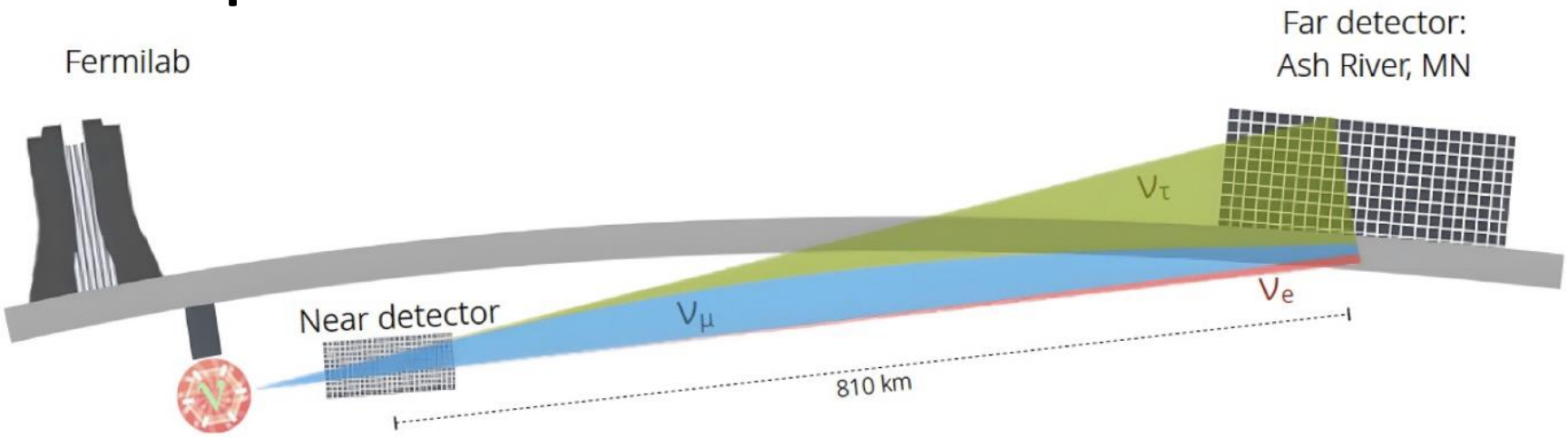
1. Produce a beam of muon (anti)neutrinos.



2. Select samples of ν_μ and ν_e at the near and far detectors.

3. Fit neutrino energy spectra.

The NOvA Experiment



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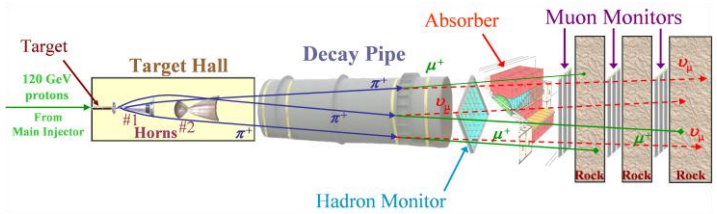

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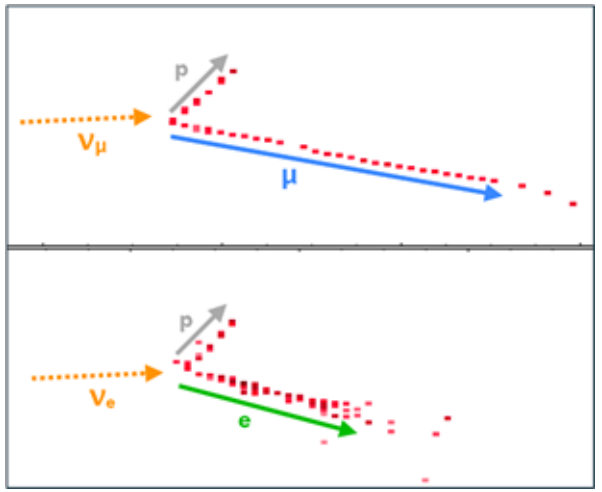

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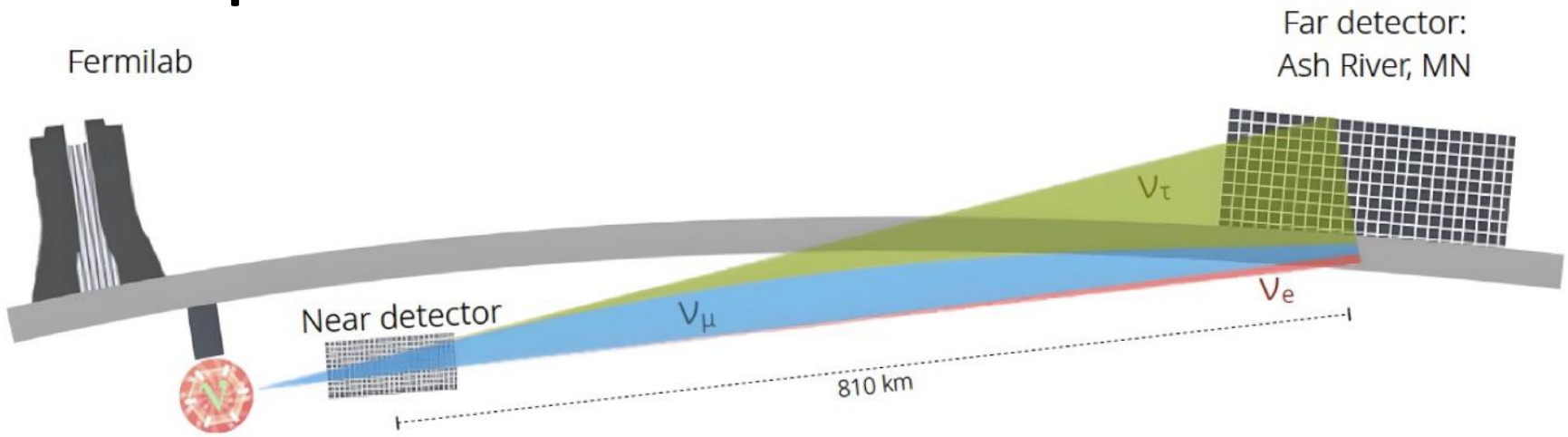
The NOvA Experiment



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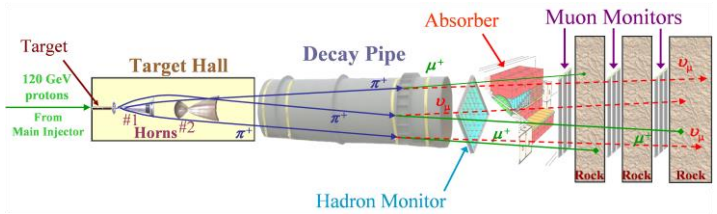

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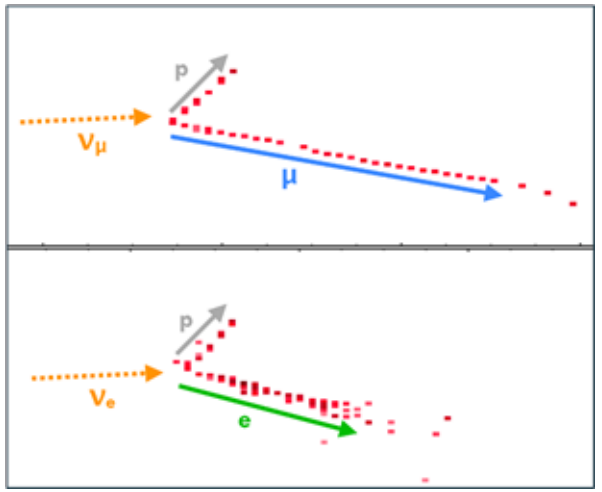

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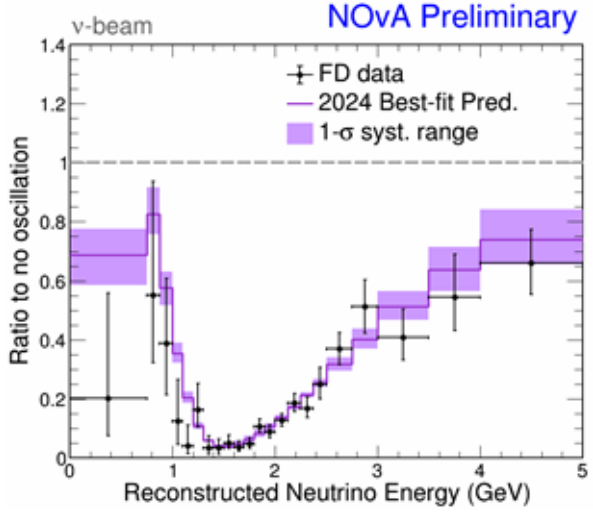
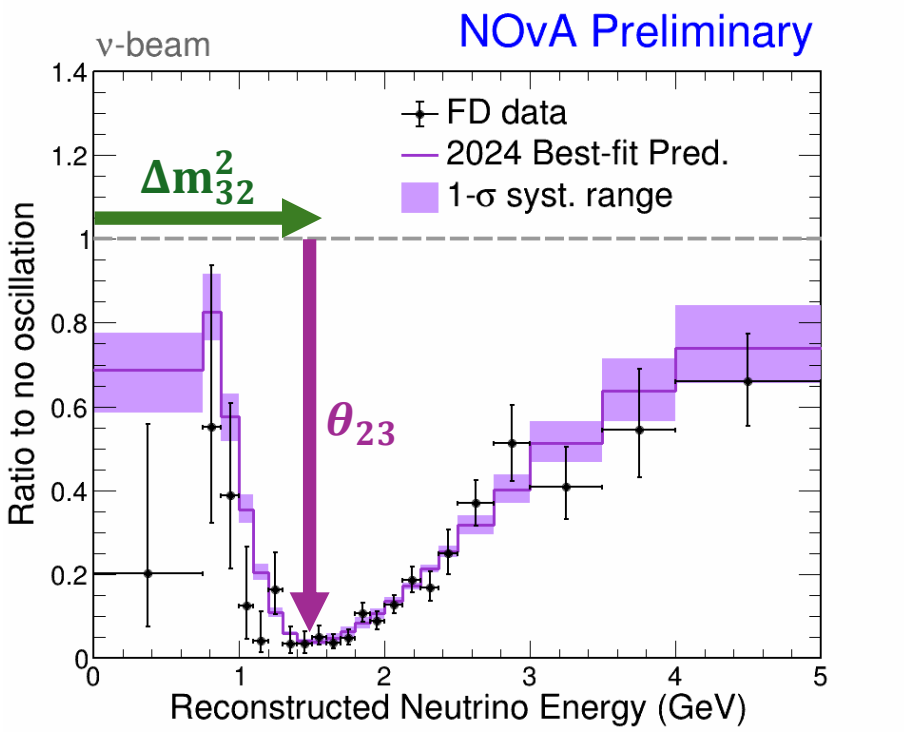
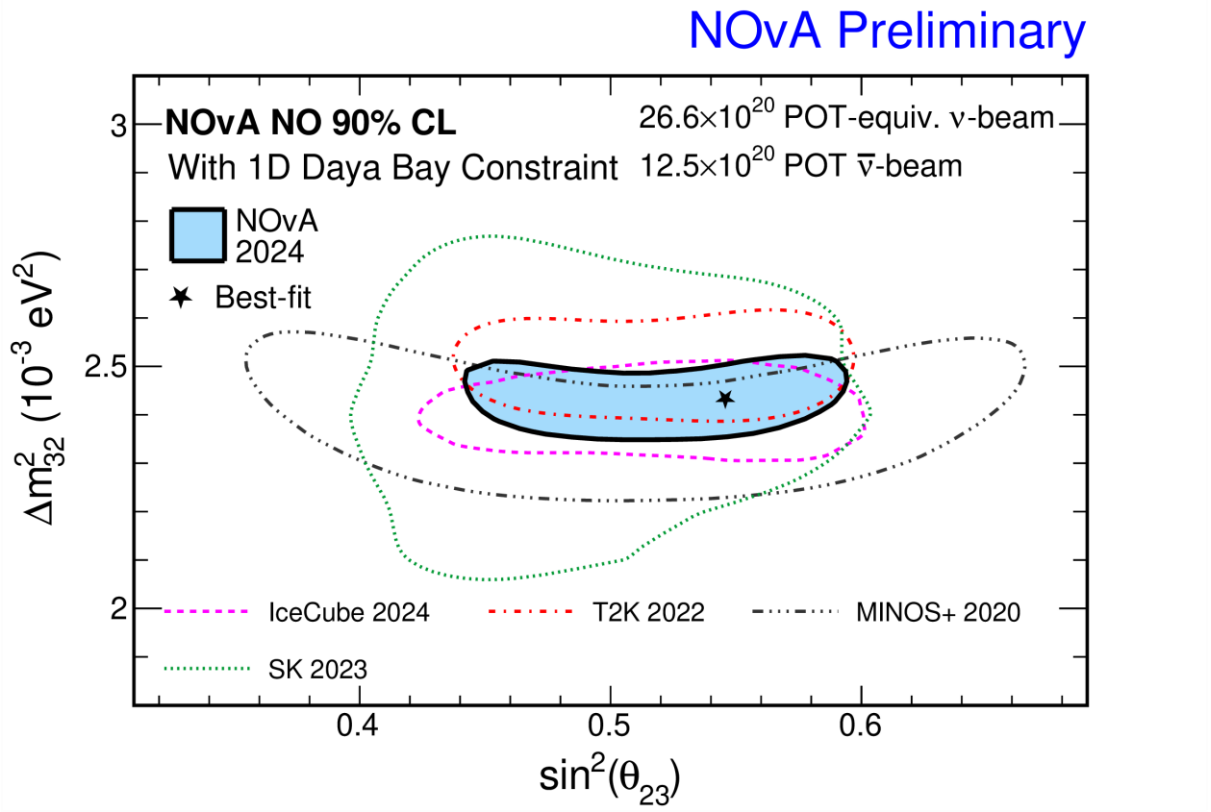


The NOvA Test Beam Program: Motivation

Reduce our systematics





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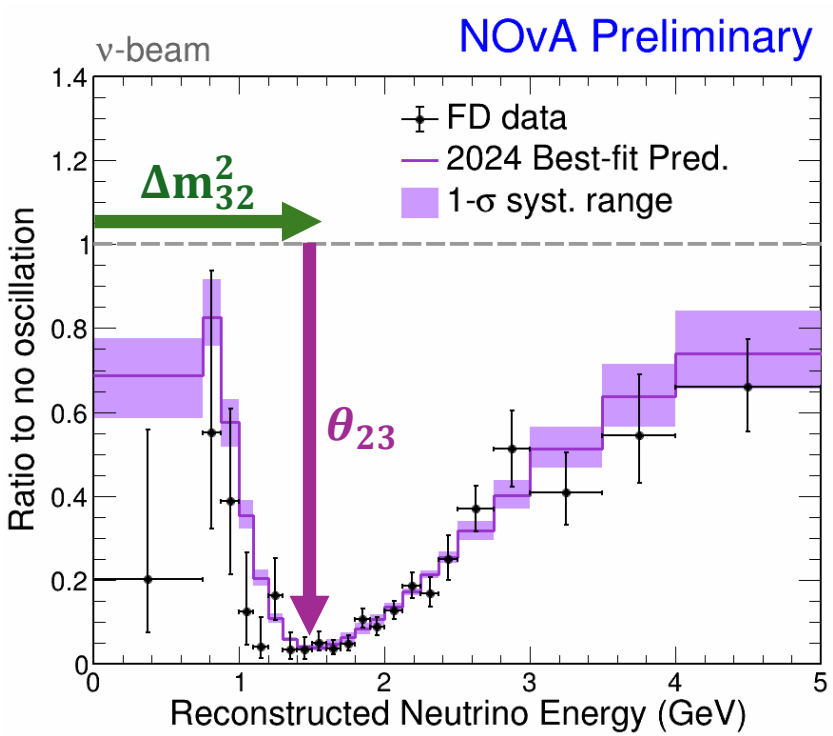

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{23}) \sin^2\left(\frac{\Delta m^2_{32}}{4}\frac{L}{E}\right)$$

Fixed L: Distance between near and far detectors.
Need to reconstruct E.

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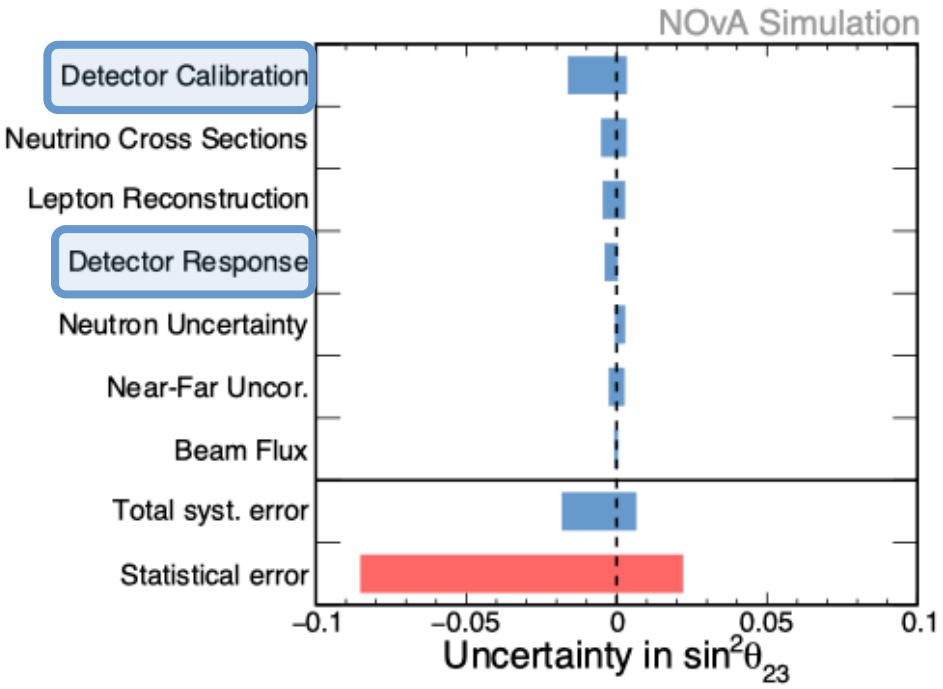
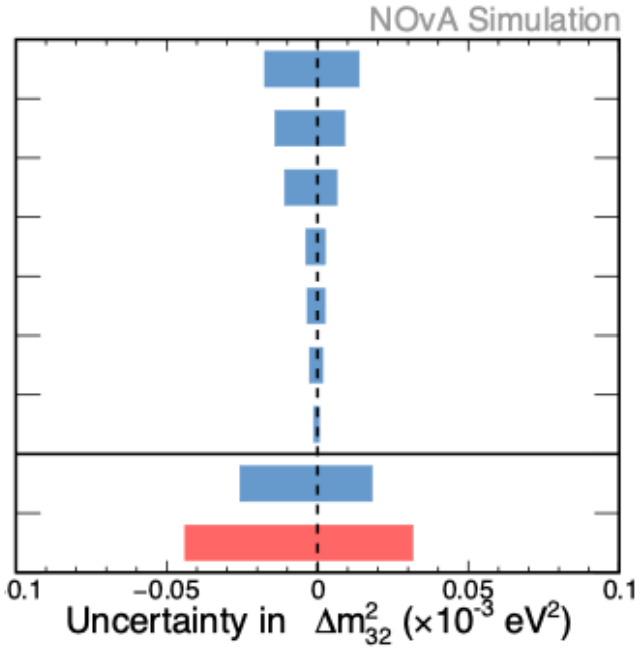
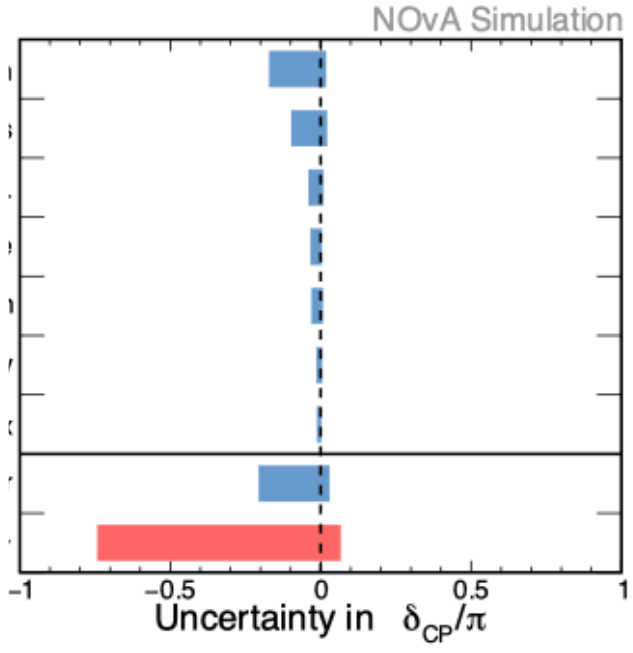






The Test Beam Program can reduce the largest **systematic uncertainty** on NOvA measurements.

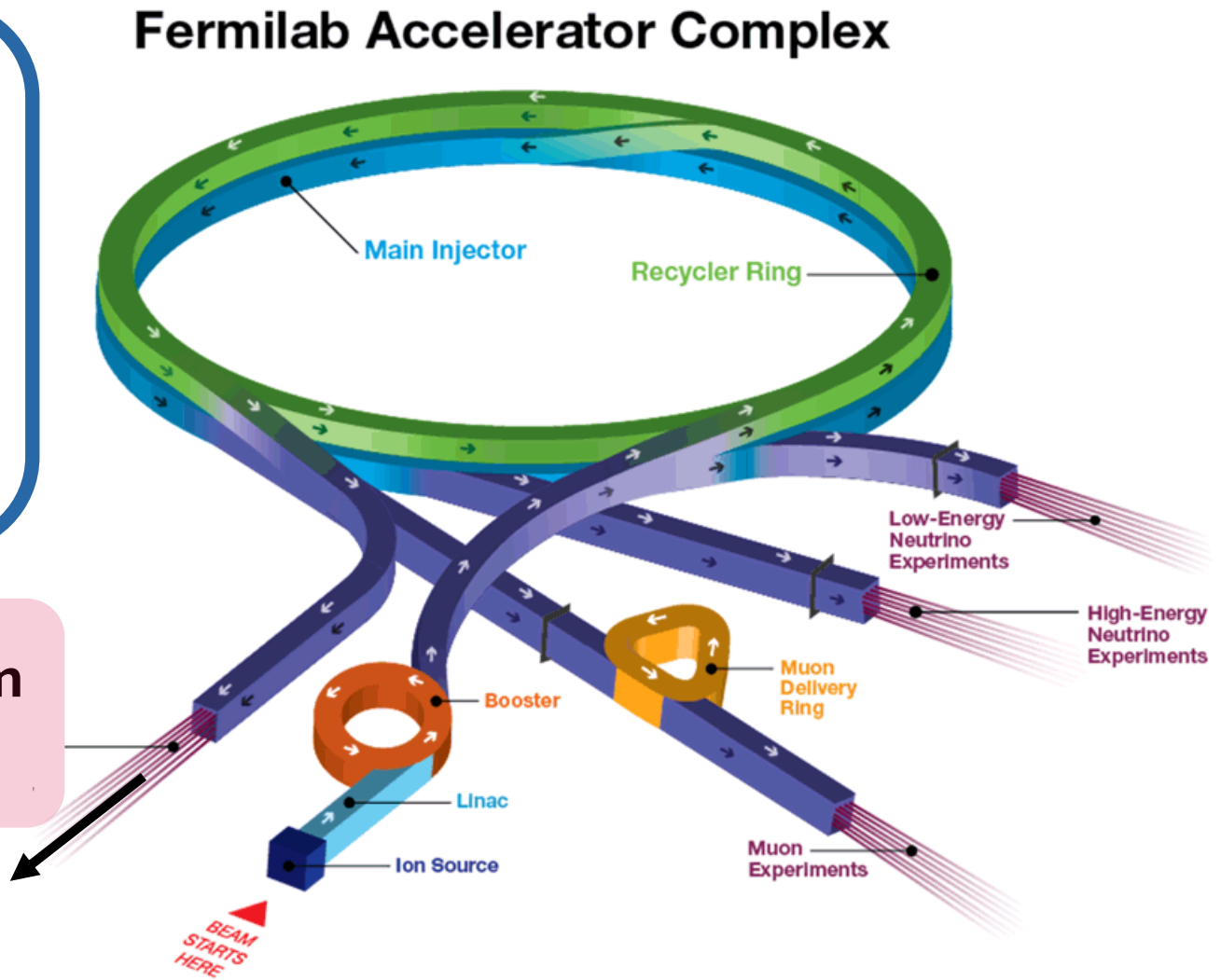
Goals:

- Improve NOvA detector calibration.
- Improve detector response and energy reconstruction.

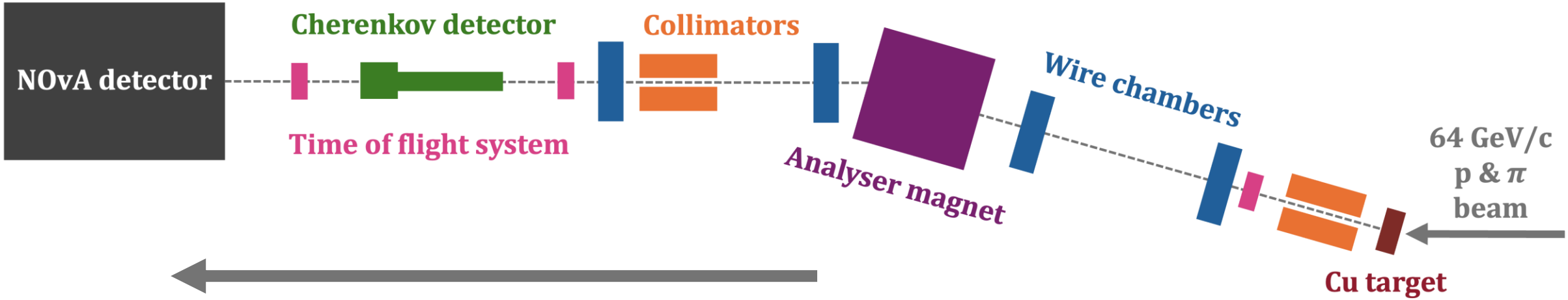
Producing the beam

1. 120 GeV/c protons from the Main Injector interact with a target.
2. Produces a secondary beam of 64 GeV/c protons and pions.
3. Hit a second copper target.
4. Produces a beam of e, μ, π, K, p.

Test beam facility

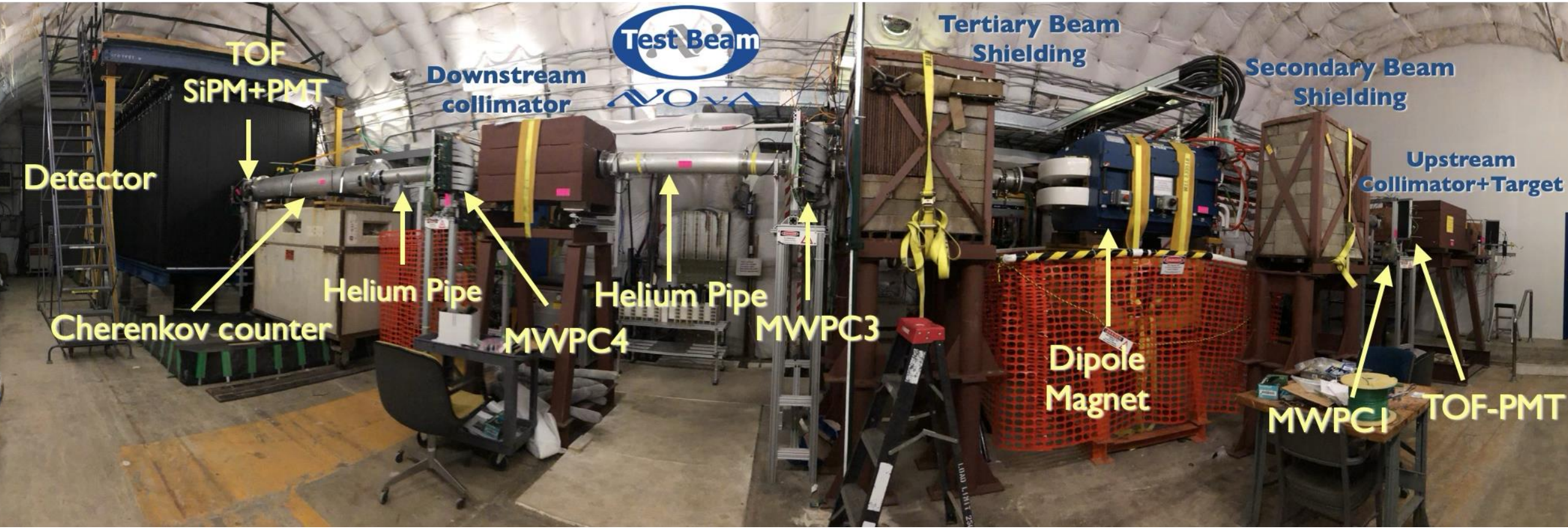


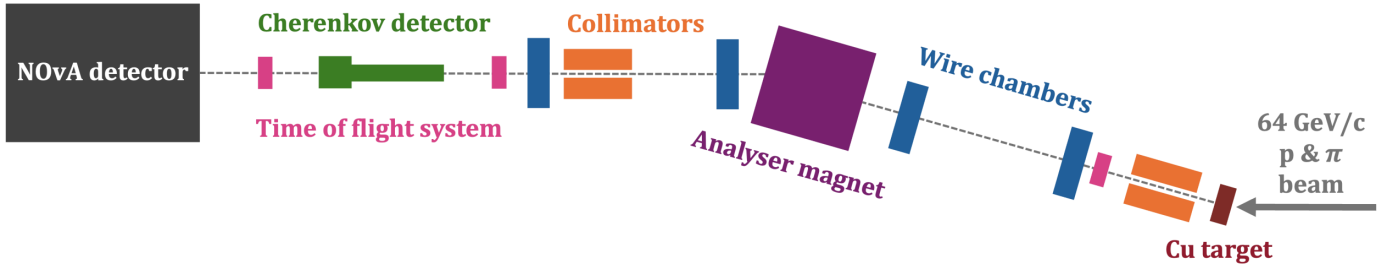
Instrumentation



Beam of 0.4 – 1.5 GeV/c $e^{\pm}$, $\mu^{\pm}$,$\pi^{\pm}$ $p^{\pm}$, $K^{\pm}$ from the target, through the beamline instrumentation, toward the scaled-down NOvA detector.

Instrumentation





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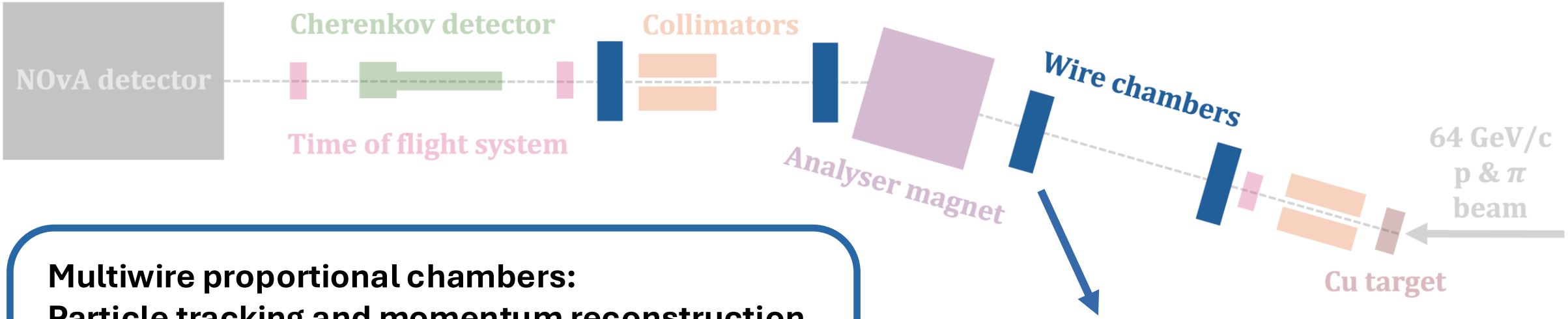
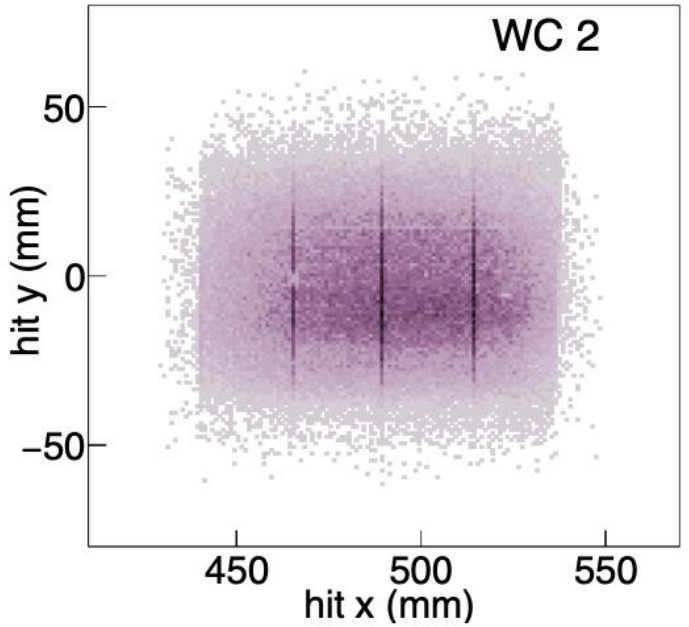


Multiwire proportional chambers:
Particle tracking and momentum reconstruction.

- Measure x,y position in each chamber.
- Use the change in track angle across magnet to reconstruct momentum.



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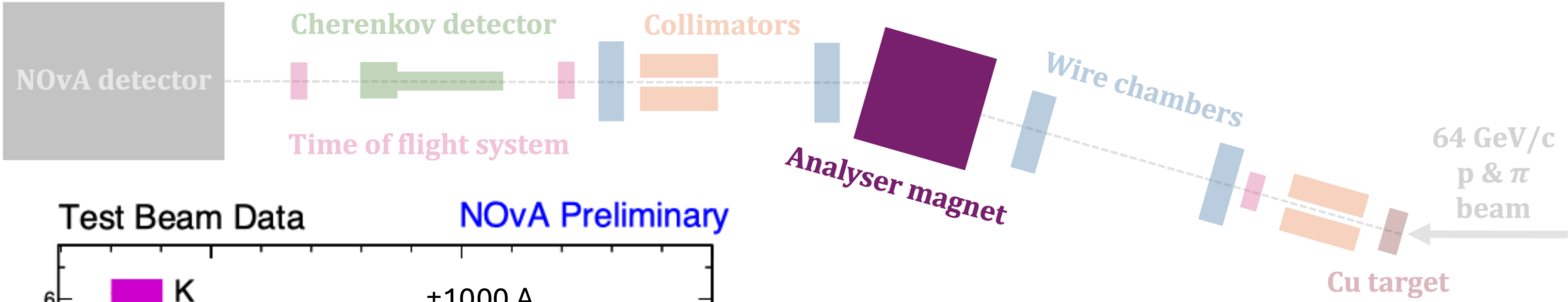
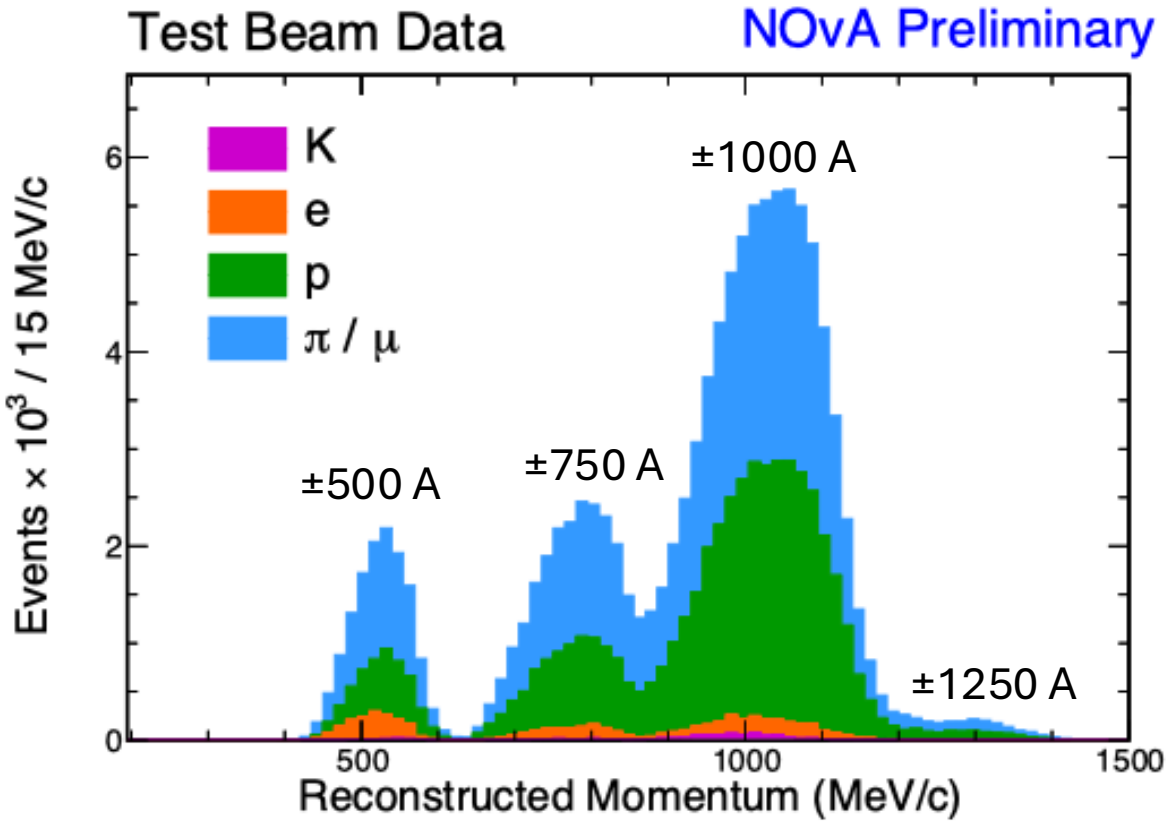
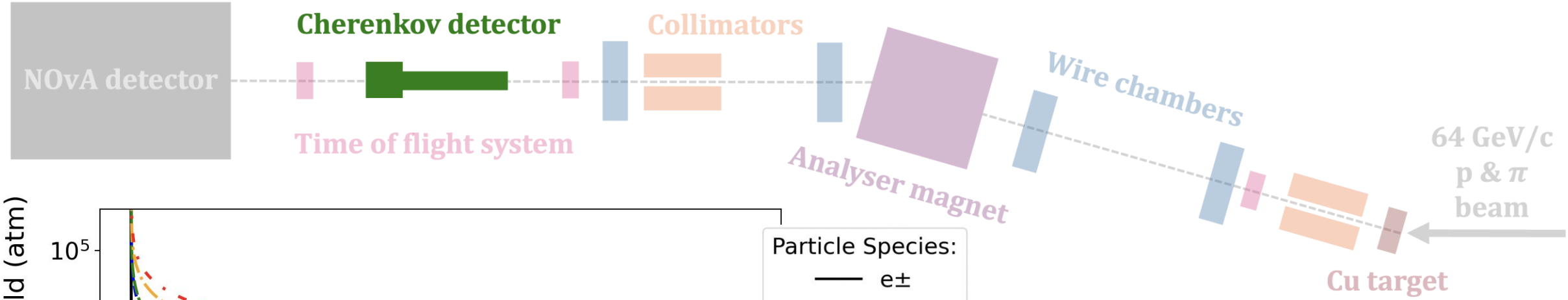


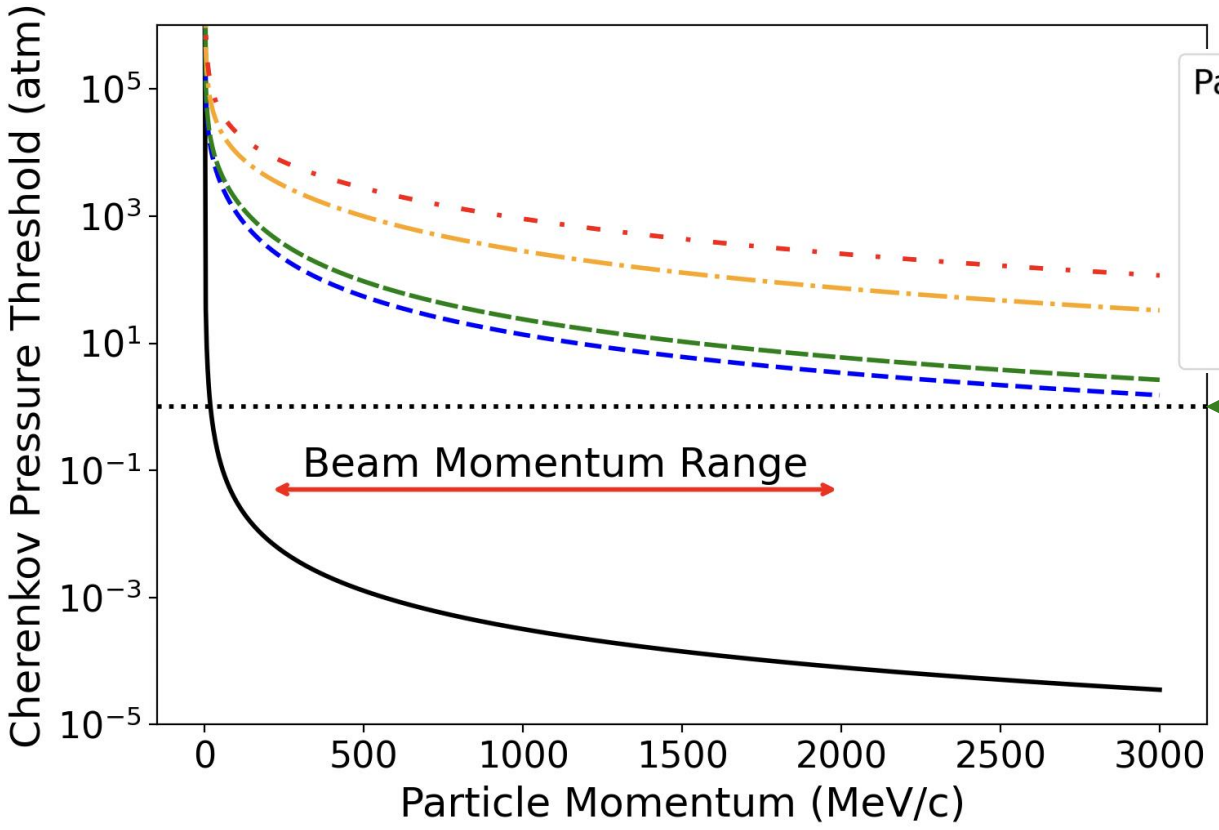


Analyser magnet: To select the particle momentum and charge of interest.

- 0.4 – 1.5 GeV/c

Instrumentation



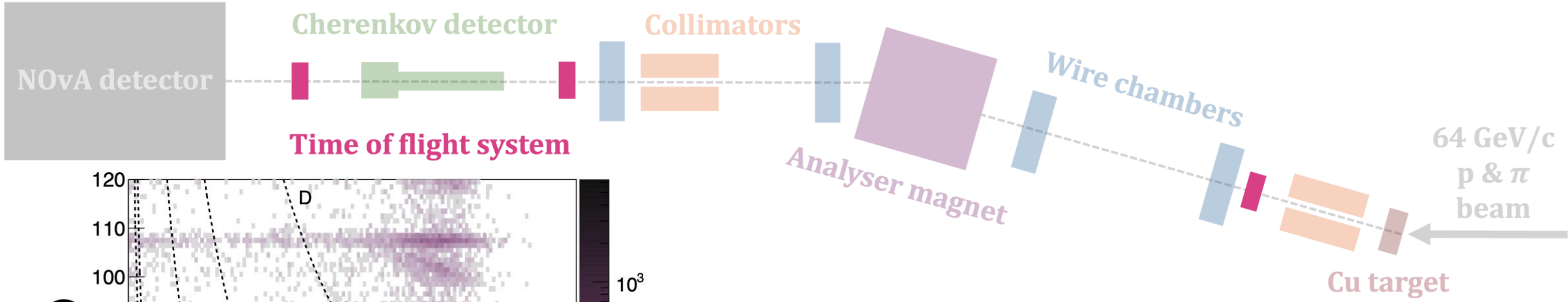


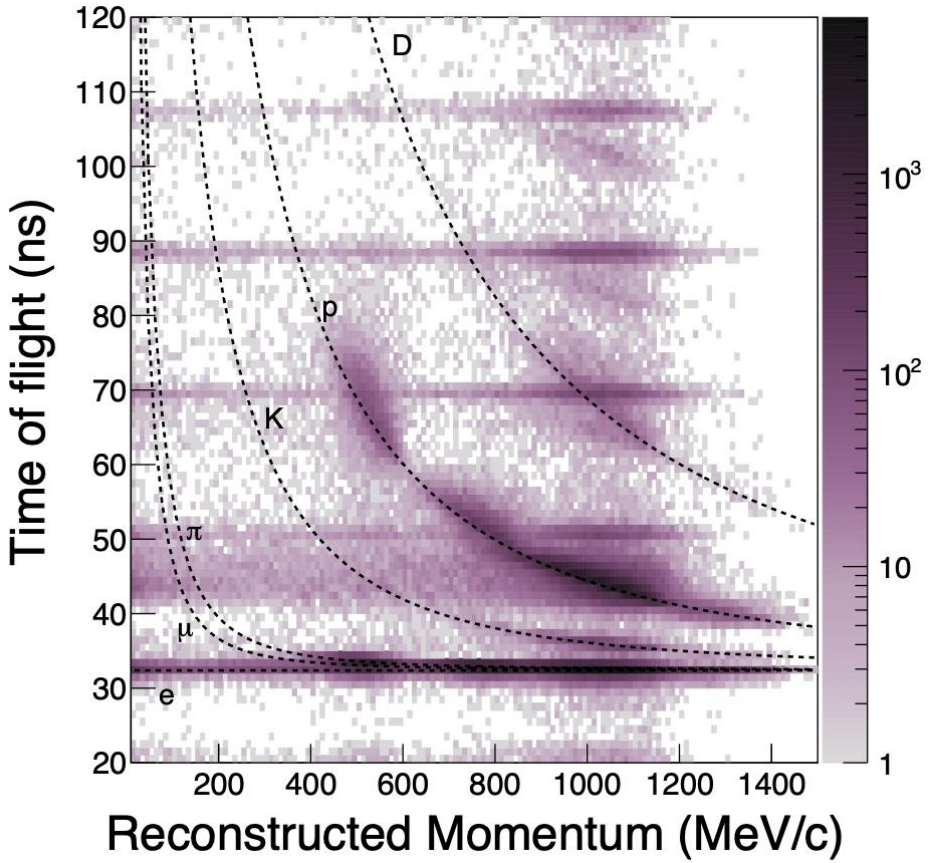
Operating pressure (1 atm)

Cherenkov detector: electron tagging.

- Cherenkov signal = particle is $e^{\pm}$.
- Separating e from π

Instrumentation



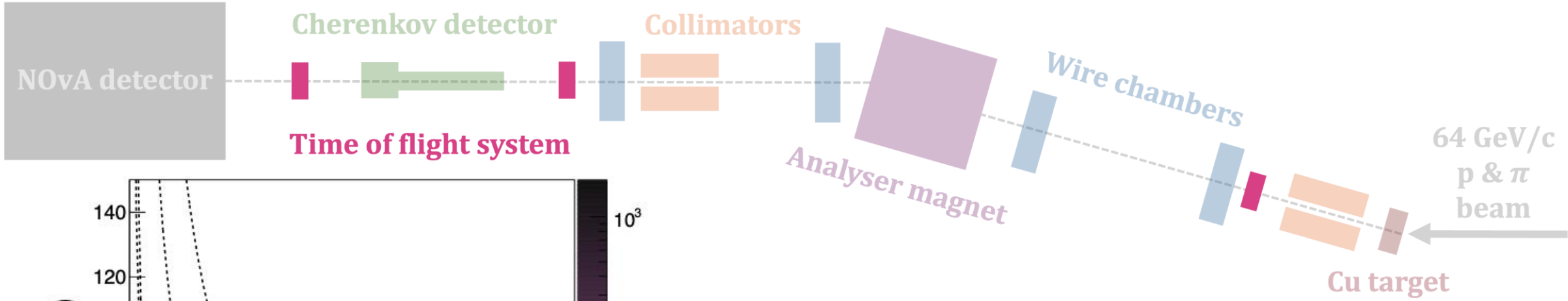


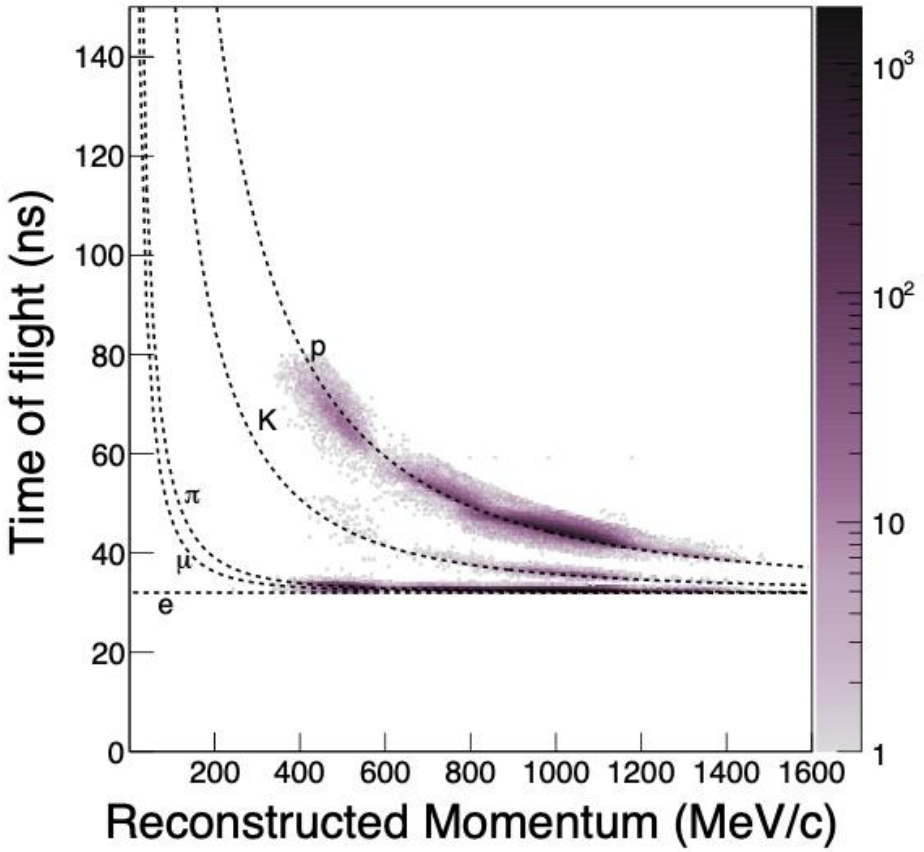
Time of flight system: Identification of heavier particles (protons and kaons).

- Detectors: plastic scintillator with PMTs or SiPMs.

← **Before** data quality and selection requirements.

Instrumentation





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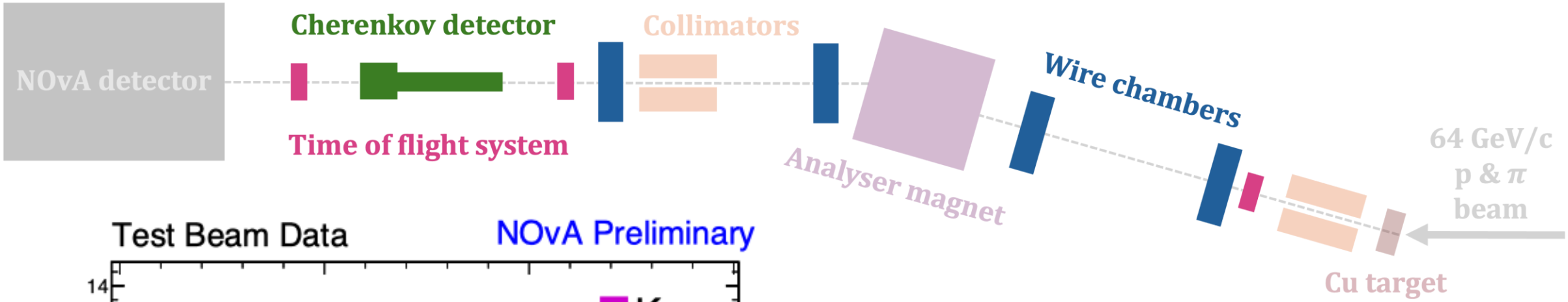
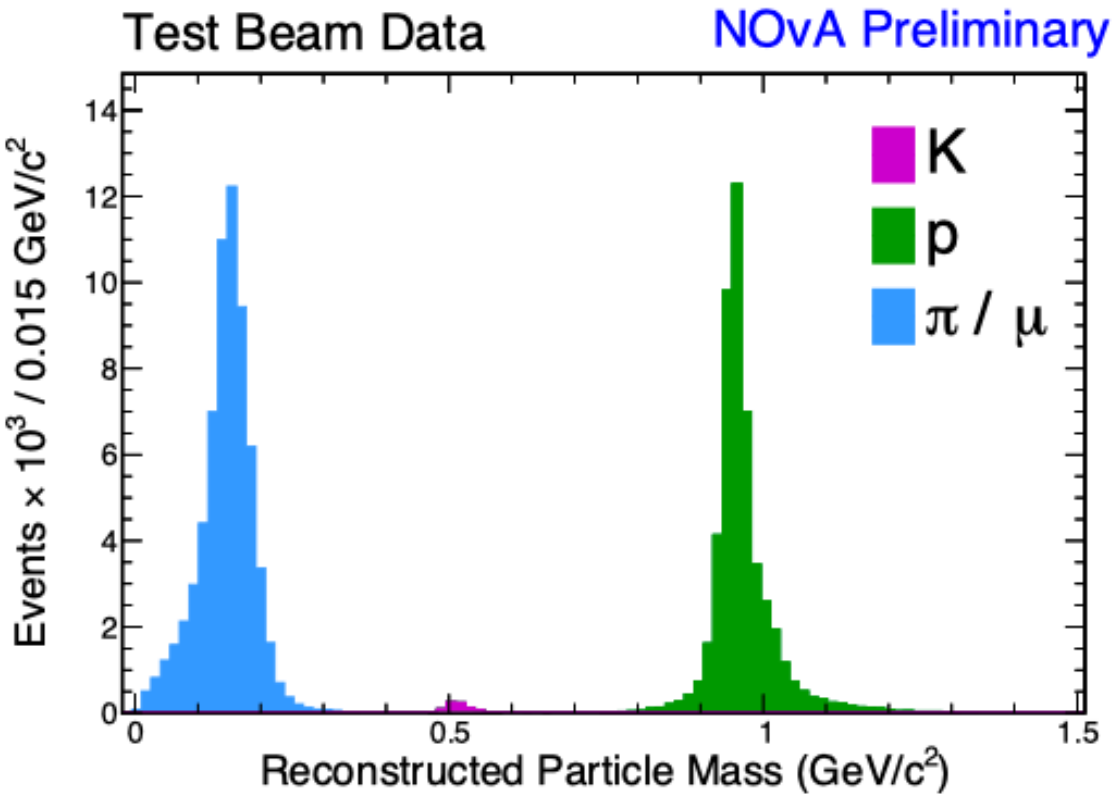




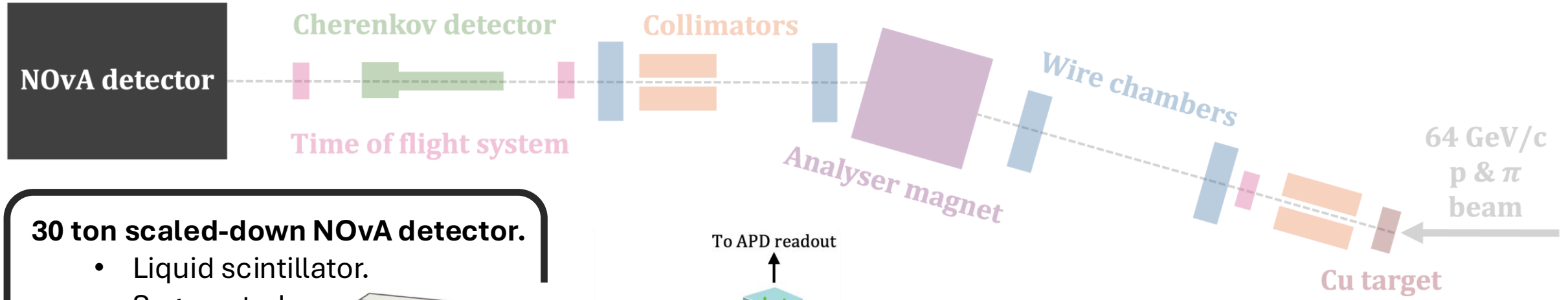
Reconstructed momentum and time of flight.

↓

Reconstructed mass of particles.

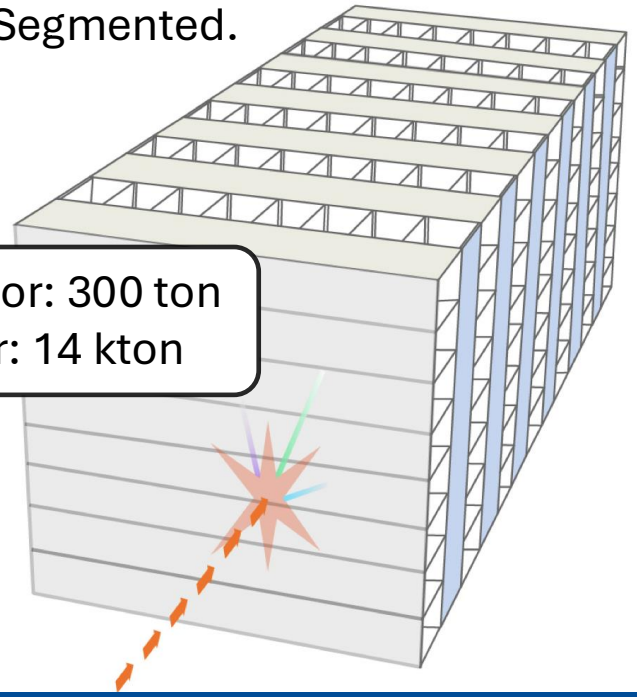
- Used to ID protons and kaons.
- Sets upper bound for pions.
- Electrons separated by Cherenkov detector.

Instrumentation

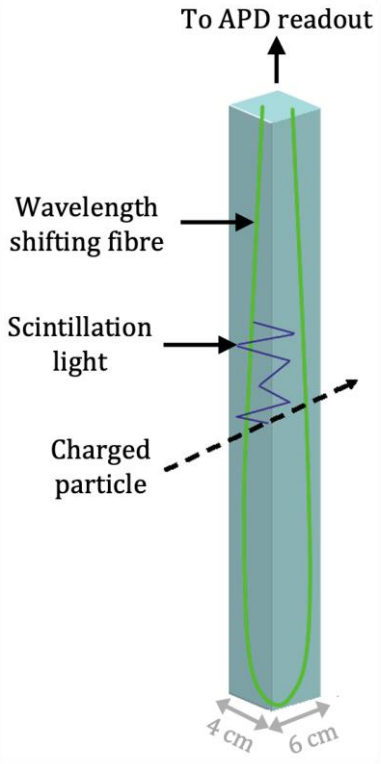


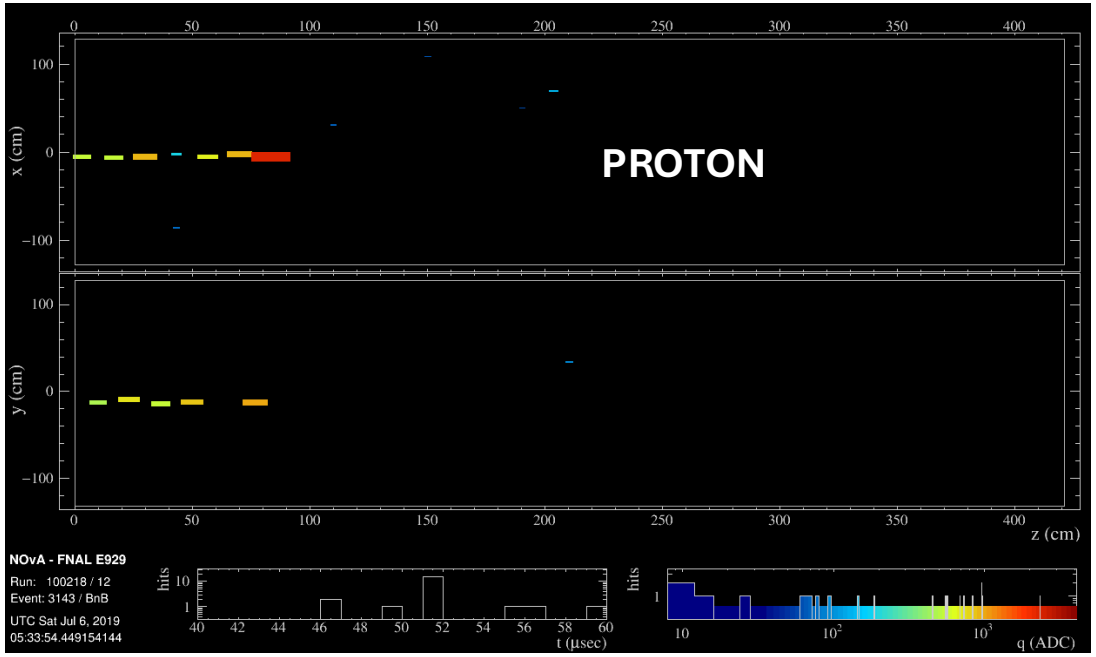
30 ton scaled-down NOvA detector.

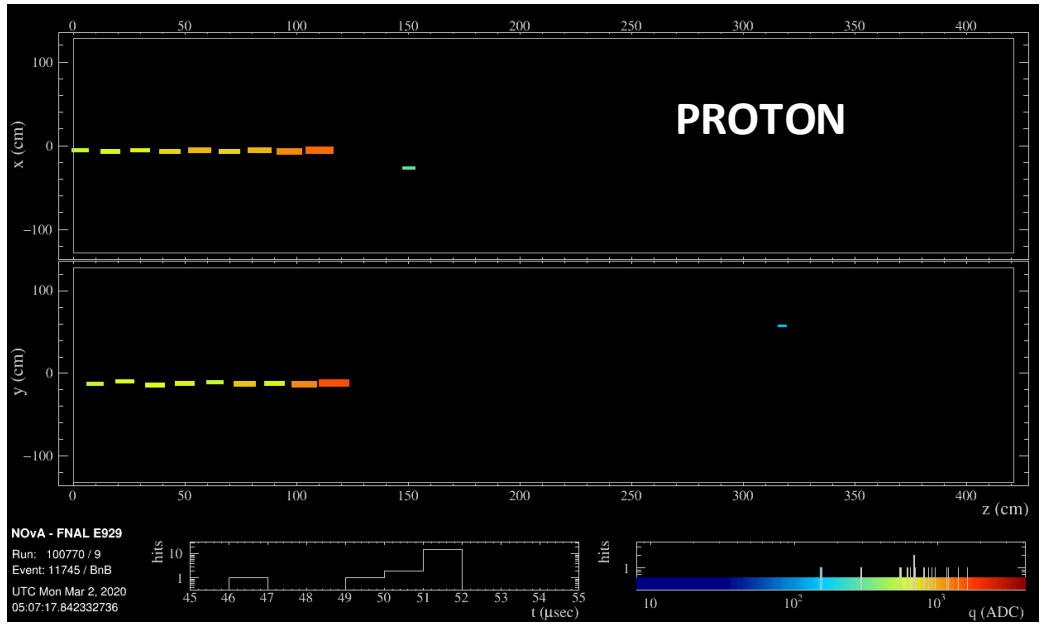
- Liquid scintillator.
- Segmented.

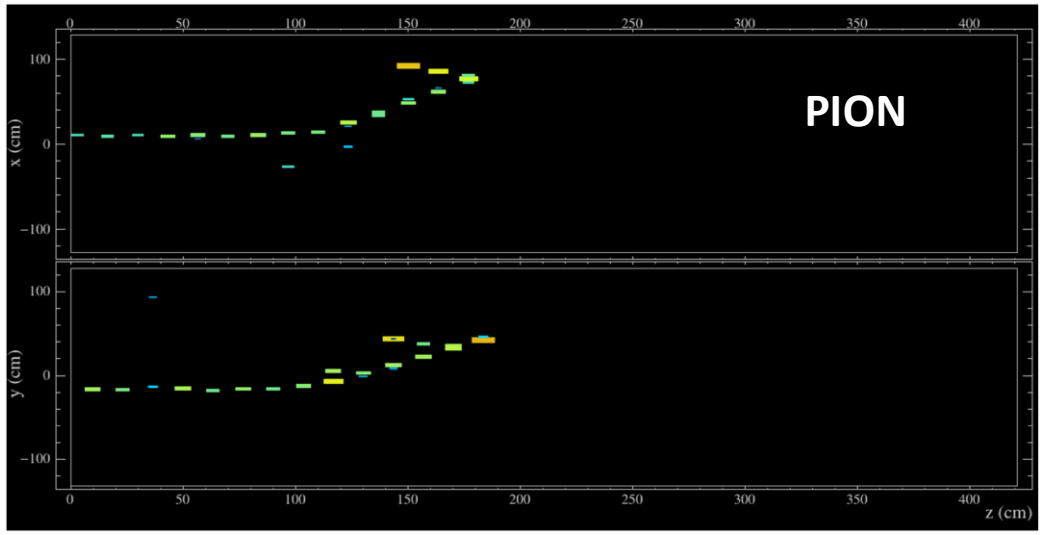


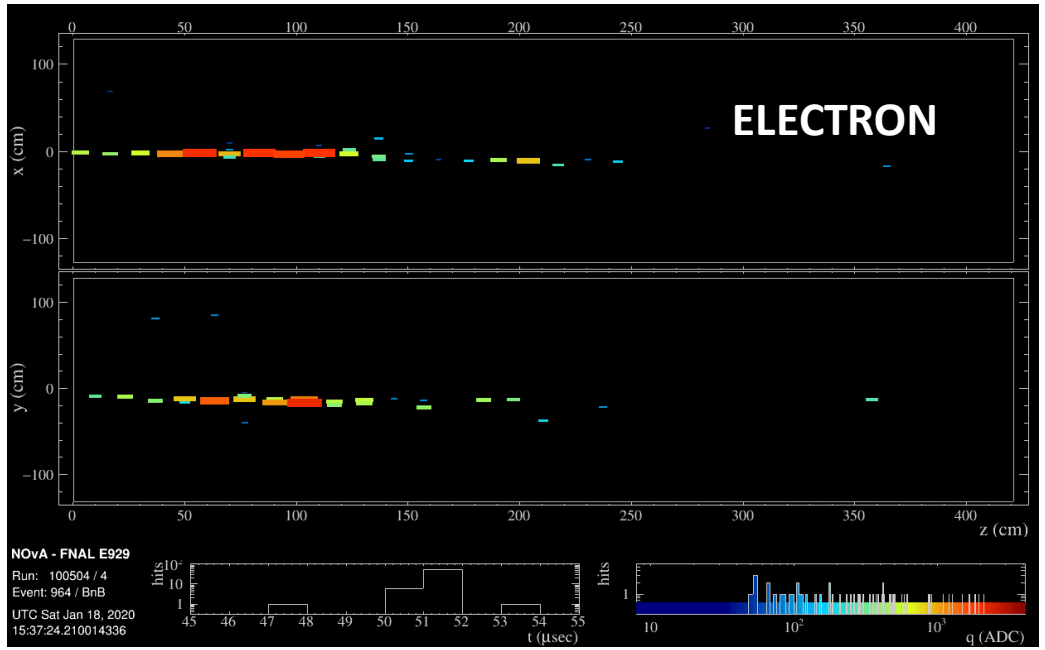
Near detector: 300 ton
Far detector: 14 kton











- NOvA's Test Beam data will provide particle-dependent energy scales for electrons, pions, and protons.
- This will improve our understanding of systematic uncertainties on NOvA's neutrino oscillation measurements.

Summary and Outlook

- NOvA's Test Beam Program: To reduce NOvA's detector calibration and detector response systematic uncertainties.
- Instrumentation for particle momentum and time of flight reconstruction → particle mass reconstruction → particle ID.

Summary and Outlook

- NOvA's Test Beam Program: To reduce NOvA's detector calibration and detector response systematic uncertainties.
- Instrumentation for particle momentum and time of flight reconstruction → particle mass reconstruction → particle ID.

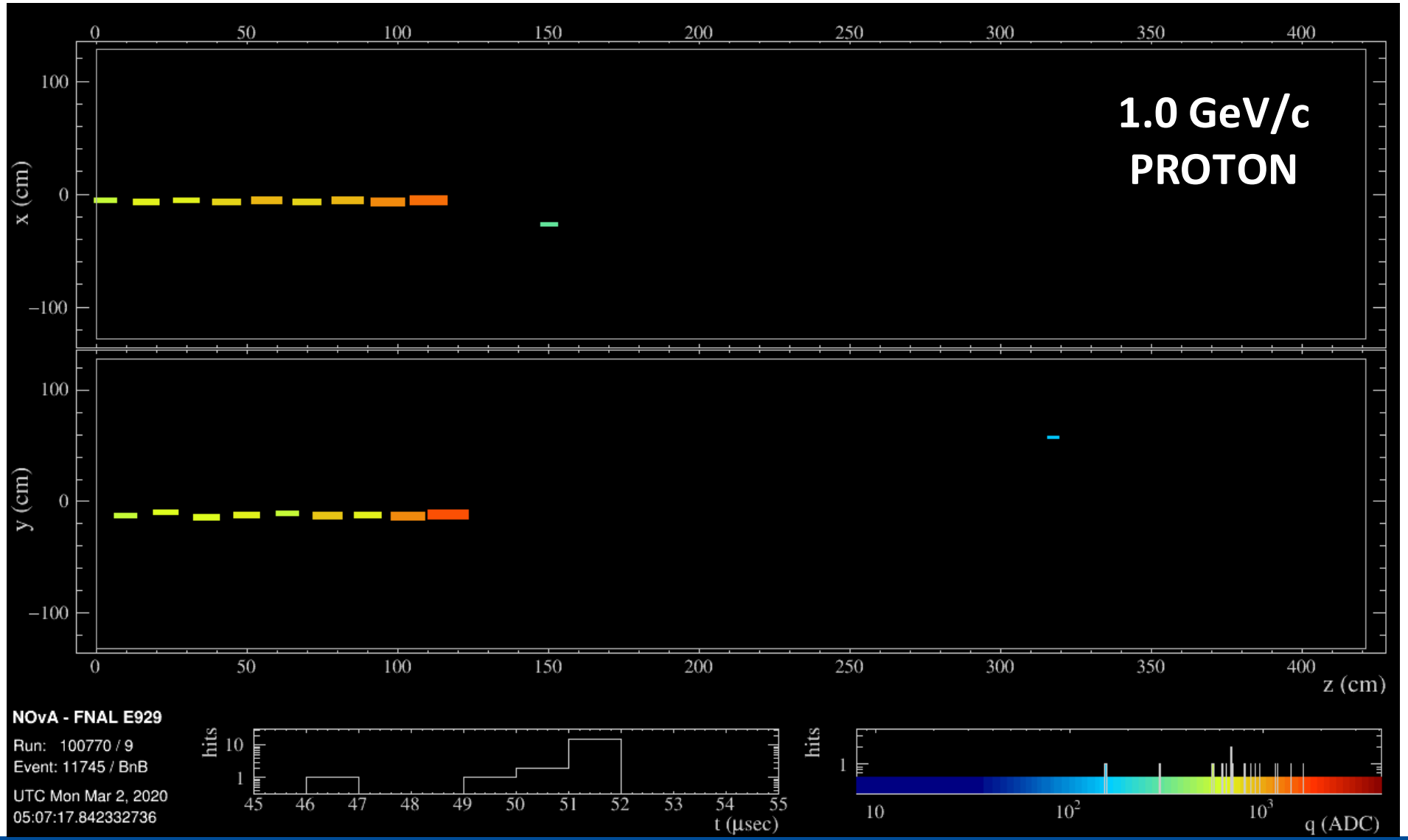
Coming soon:

- The NOvA Test Beam Detector and Beamline paper.
- Incorporating particle-based energy uncertainties into analyses.
- Measurements of the $\pi^{\pm}$, electron, and proton energy responses.

Thank you!

Backup

Event Displays



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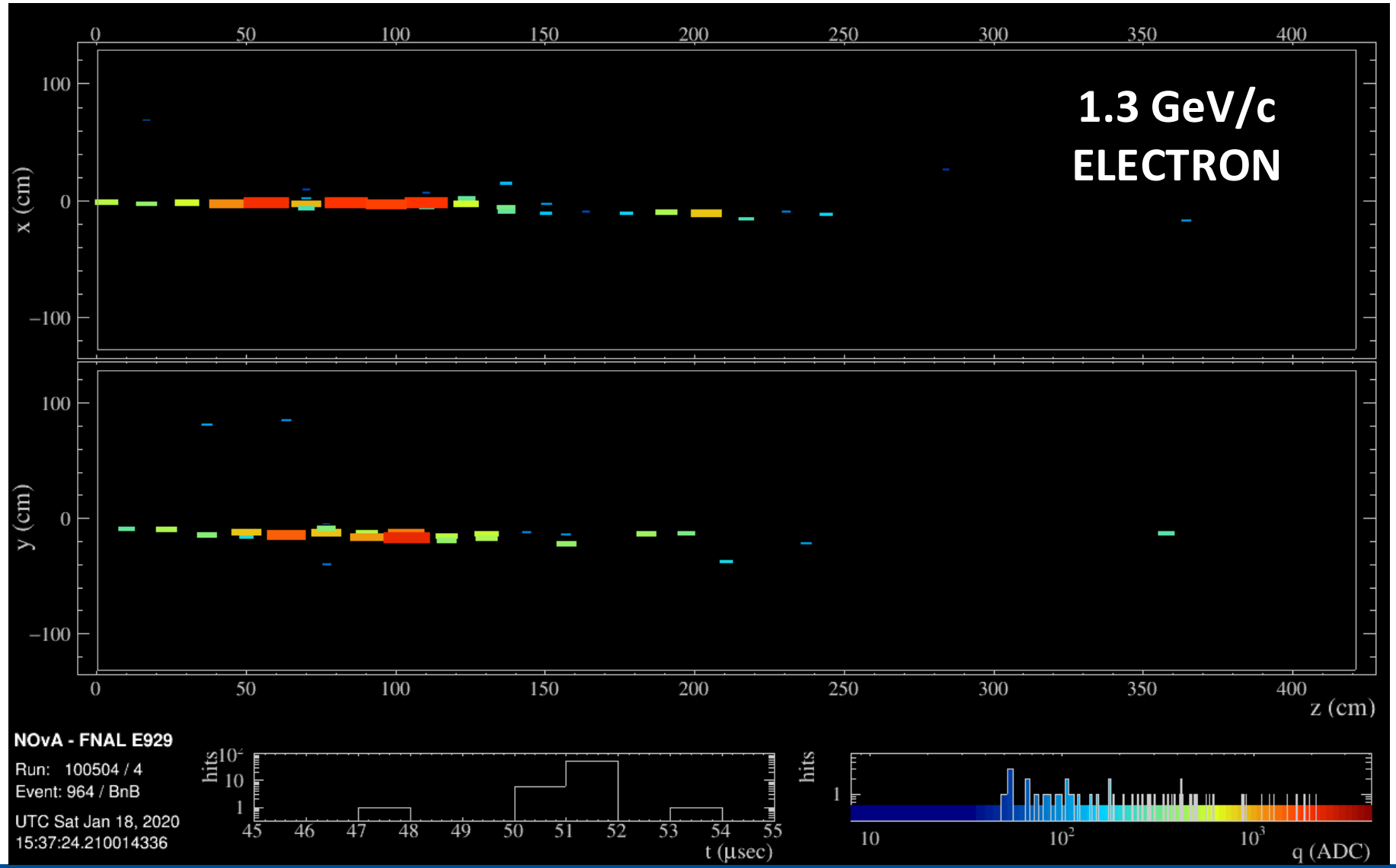
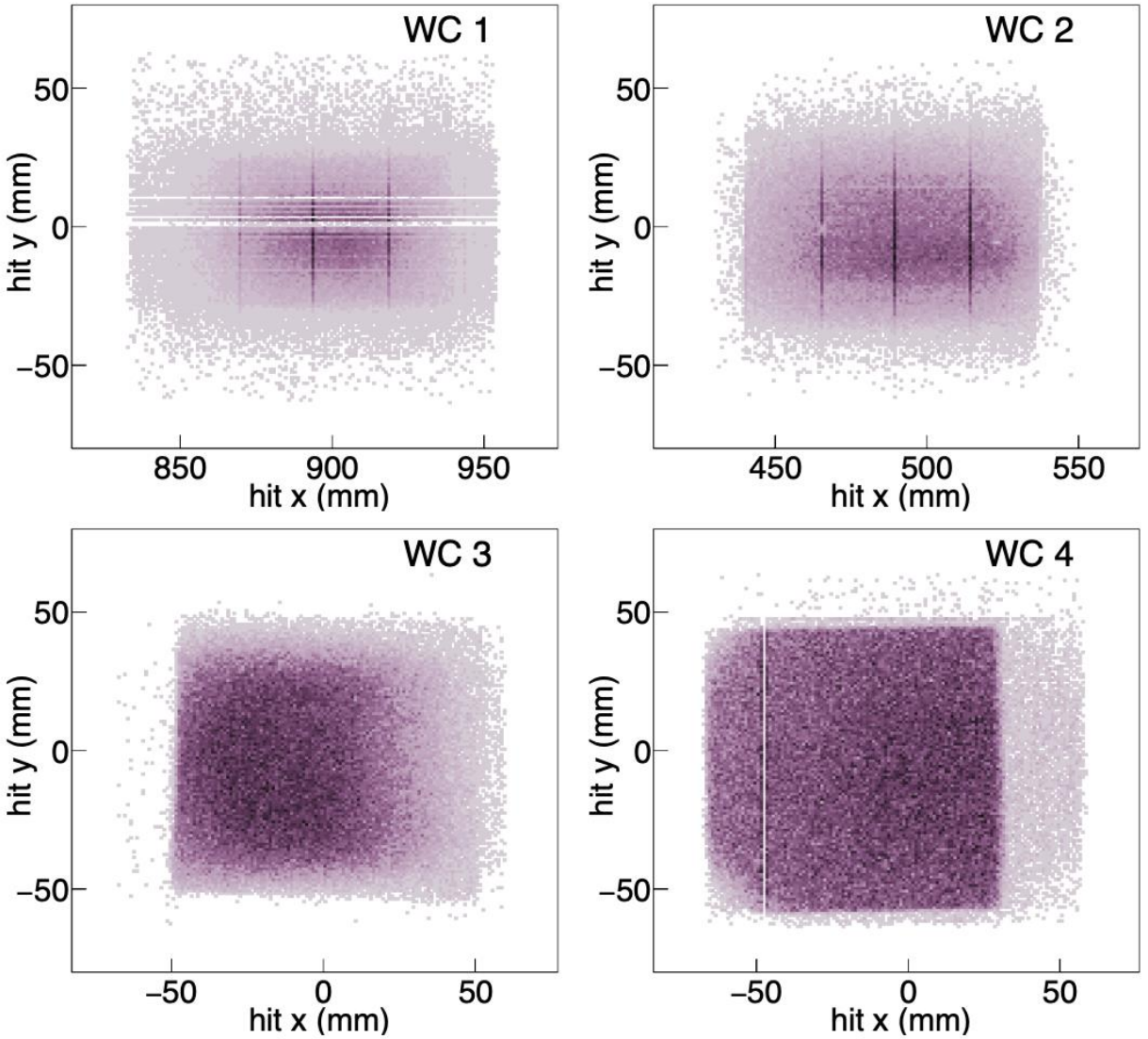


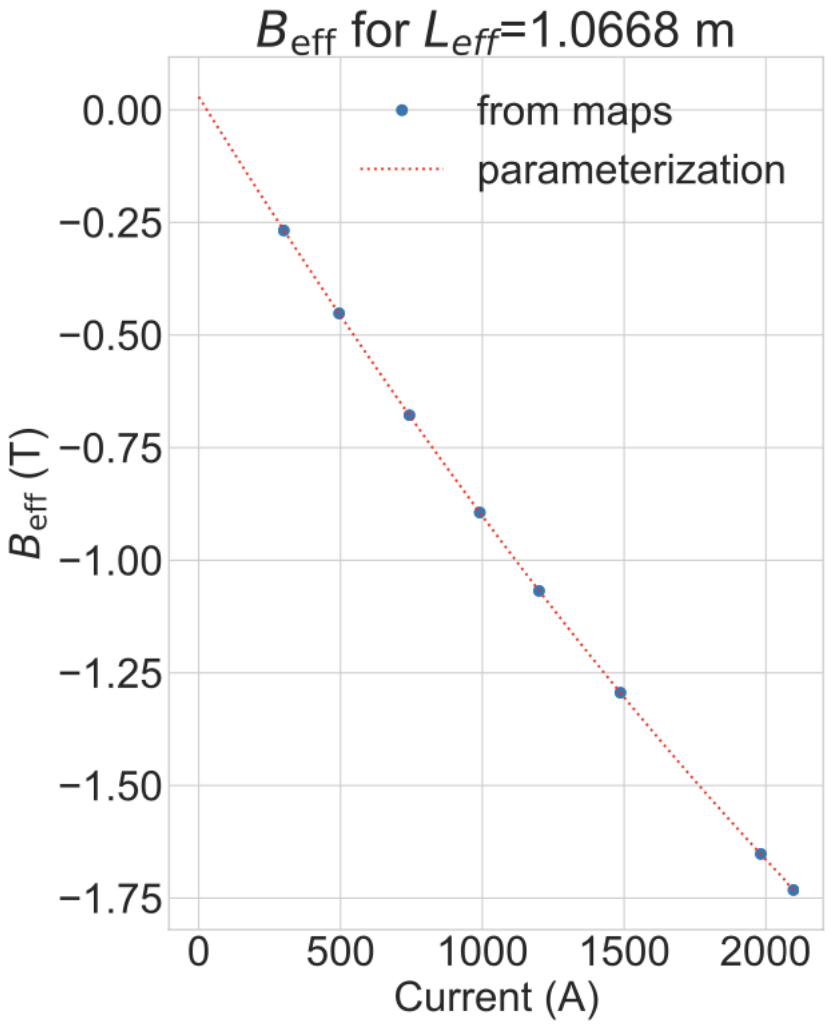
MWPC

- 4 multiwire proportional chambers, from LArIAT experiment.
- 1 x-plane, 1 y-plane, each with 128 gold-tungsten wires.
  - Diameter: 10 μm
  - Spacing: 1 mm
- Ionisation from a charged particle causes hits on multiple wires



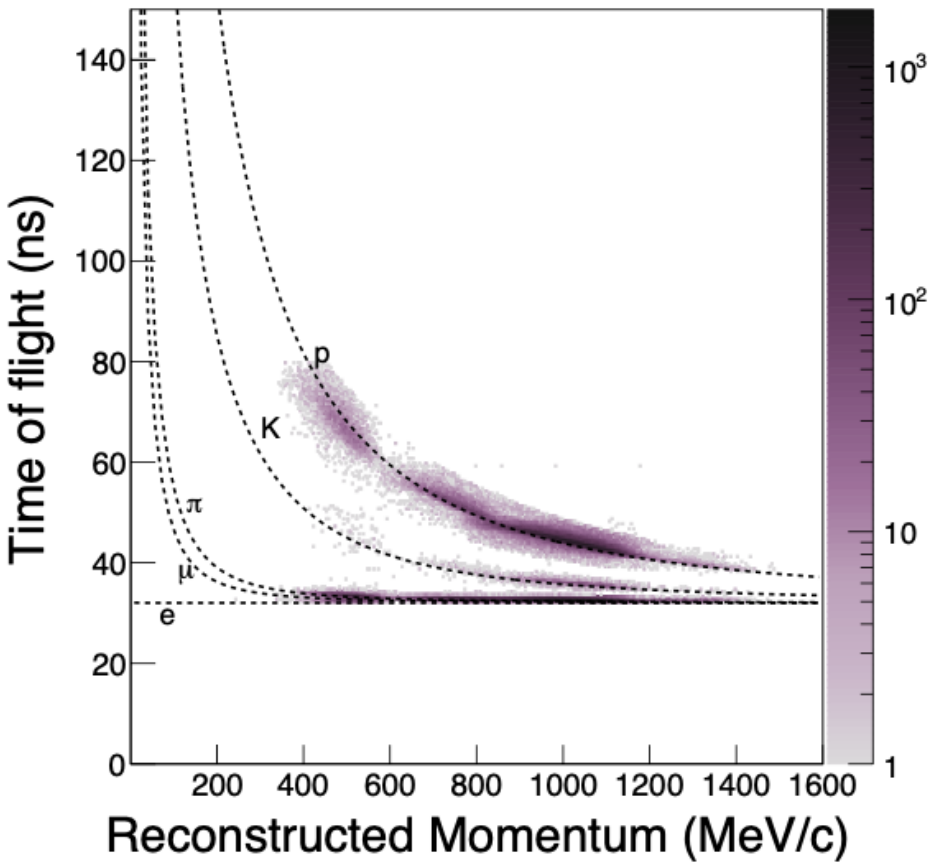
Magnet

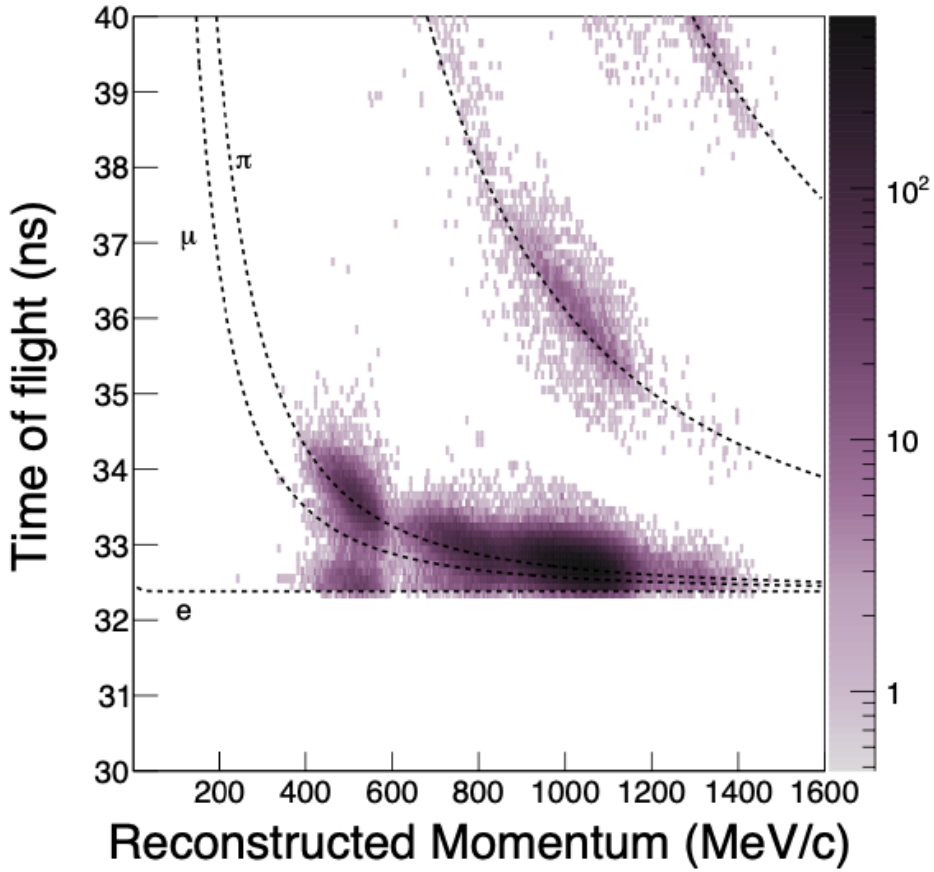
$$B_{\text{eff}} = -0.0294 + \frac{|I|}{985.3} - \left(\frac{|I|}{3451.2}\right)^2$$



Time of Flight (ToF)

- **Identification of heavier particles (protons and kaons).**
  - Cherenkov detector needed to separate electrons from muons and pions.





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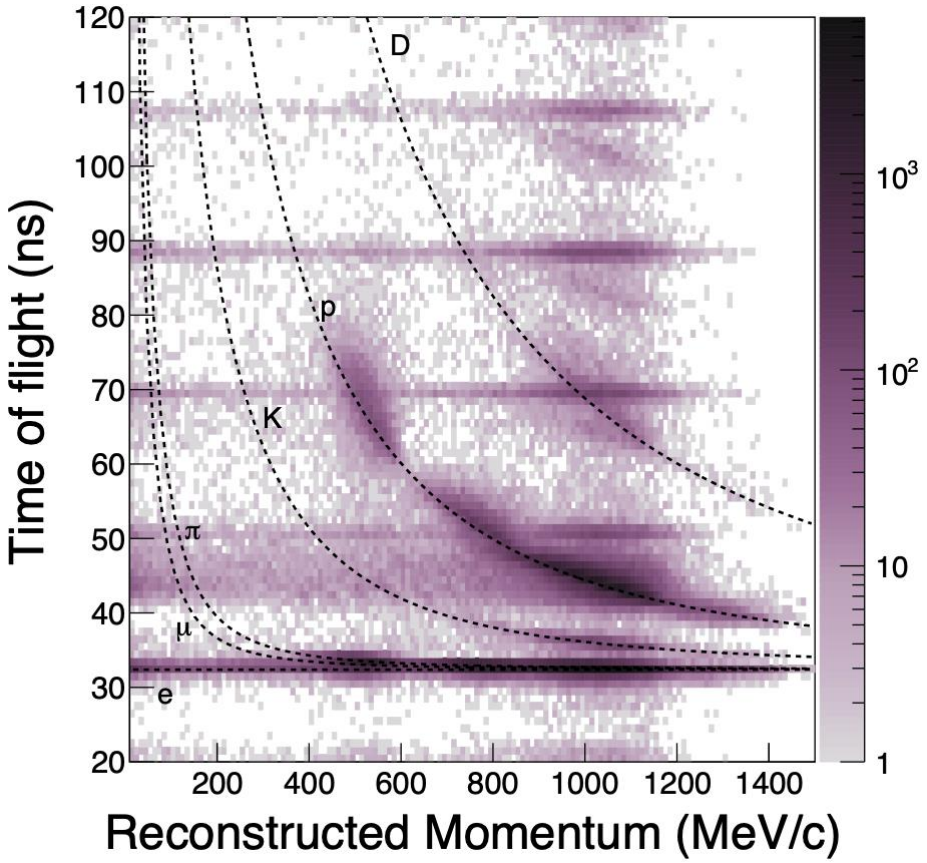


- **Identification of heavier particles (protons and kaons).**
  - Basic preselection requirements, combined with data quality requirements.

Selection	p	π/μ	e
m (GeV)	$750-1126$	<300	N/A
t (ns)	$37-80$	$30-40$	$30-36$
ckov	0	0	1
l (cm)	<250	<380	N/A
$nhit$	≥ 5	≥ 5	≥ 5

- Horizontal structures: time-of-flight signal pairs from light particles from different main injector bunches.
- Repeating sloped structures (at ~1000 MeV/c): protons from different main injector bunches.
- Diffuse structures (at ~21-42 ns): thought to be one light particle and one proton from different main injector bunches.

Electrons

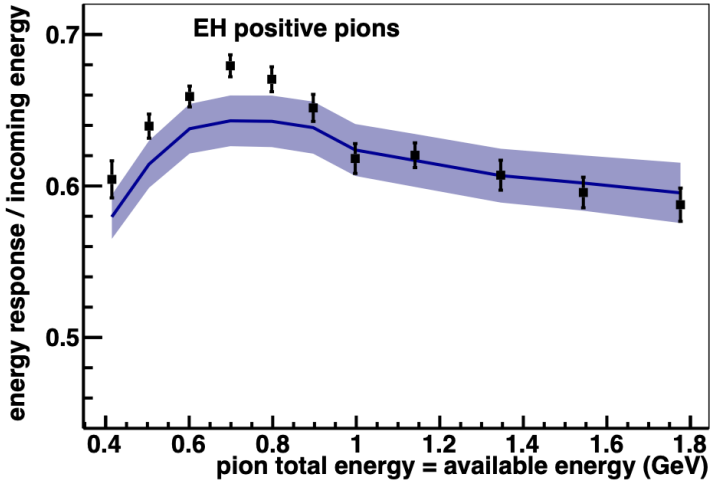
- ML to increase number of candidates
- High energy loss through beamline
- Energy response

Protons

- Energy response
- Measuring the Birks quenching parameter for protons

Pions

- Energy response for π^+ and π^-



MINERvA
https://arxiv.org/abs/1501.06431

Table 2: The composition of the NOvA scintillator blends, showing mass fractions.

Component	Purpose	Mass fraction (%)	
		Blends 1-2	Blends 3-25
Mineral oil	Solvent	94.91	94.63
Pseudocumene	Scintillant	4.98	5.23
PPO	Waveshifter	0.11	0.14
Bis-MSB	Waveshifter	0.0016	0.0016
Stadis-425	Antistatic	0.001	0.001
Vitamin E	Antioxidant	0.001	0.001

The NOvA Test Beam Program: Motivation

Detector Calibration

- Calibrate to ensure uniform energy reconstructed across the detector, for a given energy deposition.
- NOvA calibration uses cosmic ray muons to correct for:
  - Attenuation of light along the fibres.
  - Differences in response between individual detector cells.

Test Beam:

- **Smaller detector** → reduces the effects of APD thresholds, self-shadowing, and attenuation of light along the detector cells.
- **Variety of readout electronics (near and far detector)** → test the detector response and the calibration procedure in various scenarios.

The NOvA Test Beam Program: Motivation

Detector Response

- Primary goal of the NOvA Test Beam program:
  To reduce the detector-based systematic uncertainties on the measurements of neutrino oscillation parameters.
  - By measuring the energy response of the detector to identified particles over a range of momenta.