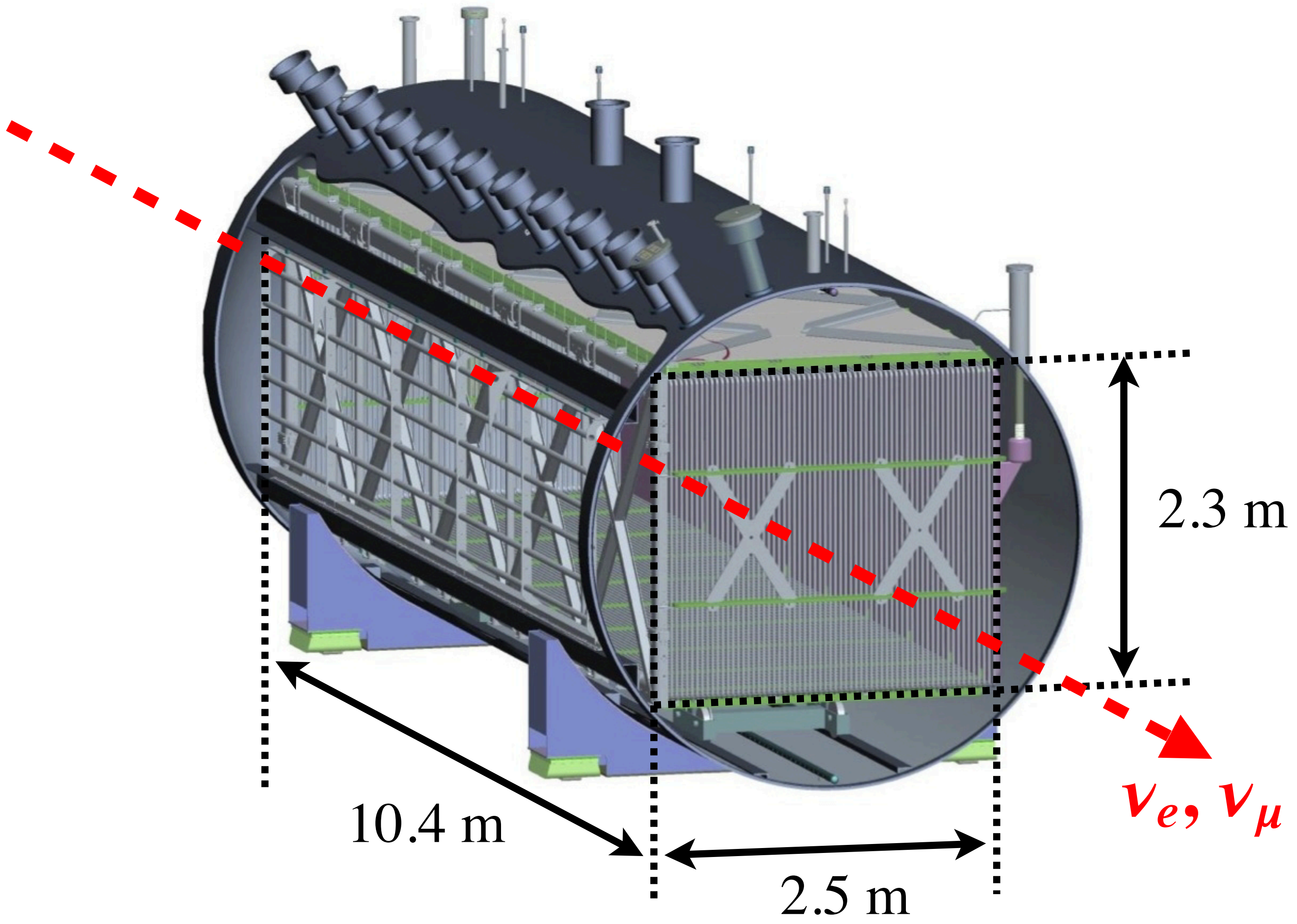
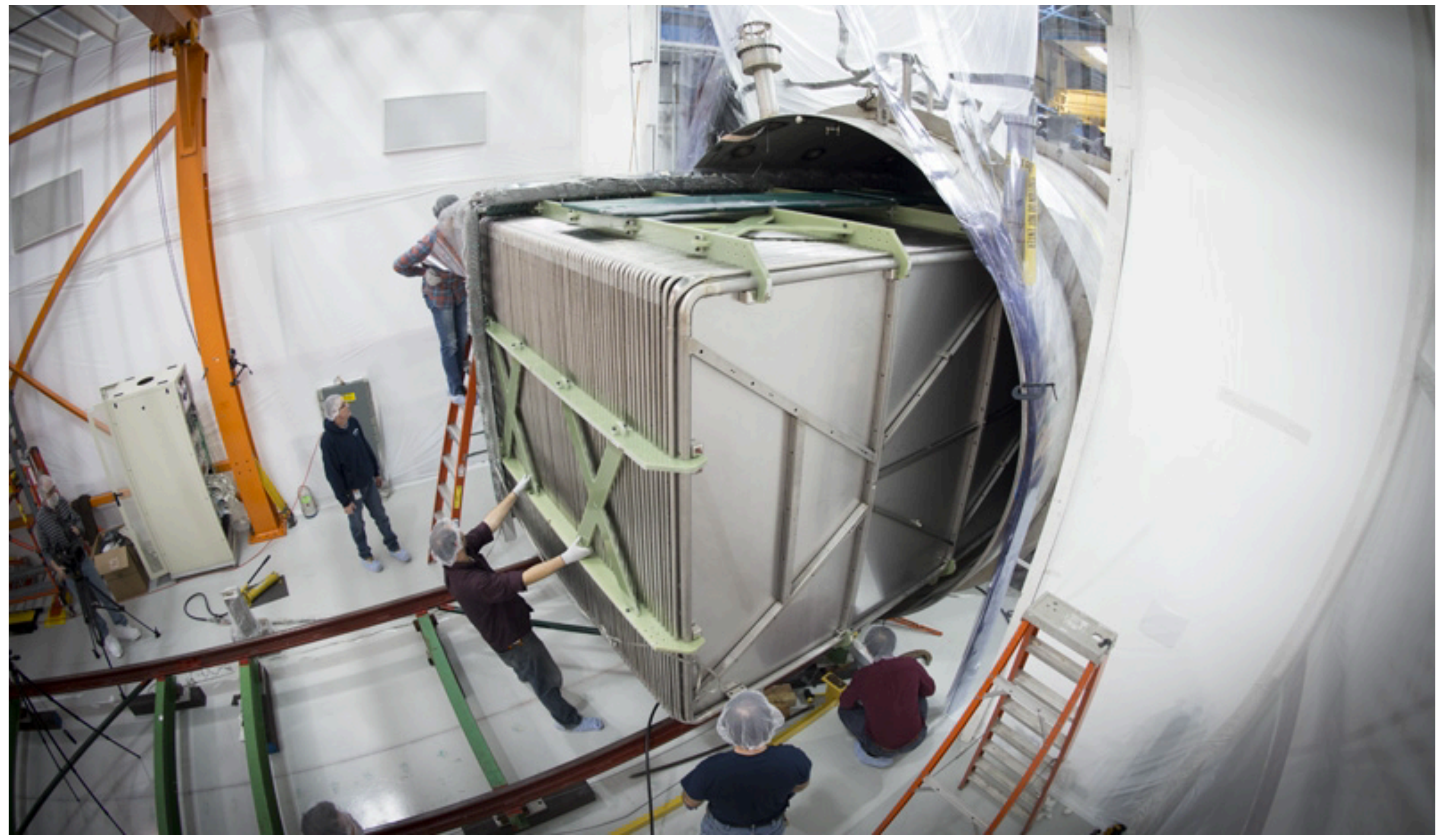
MicroBooNE:
Recent Results and a Focus on the Future

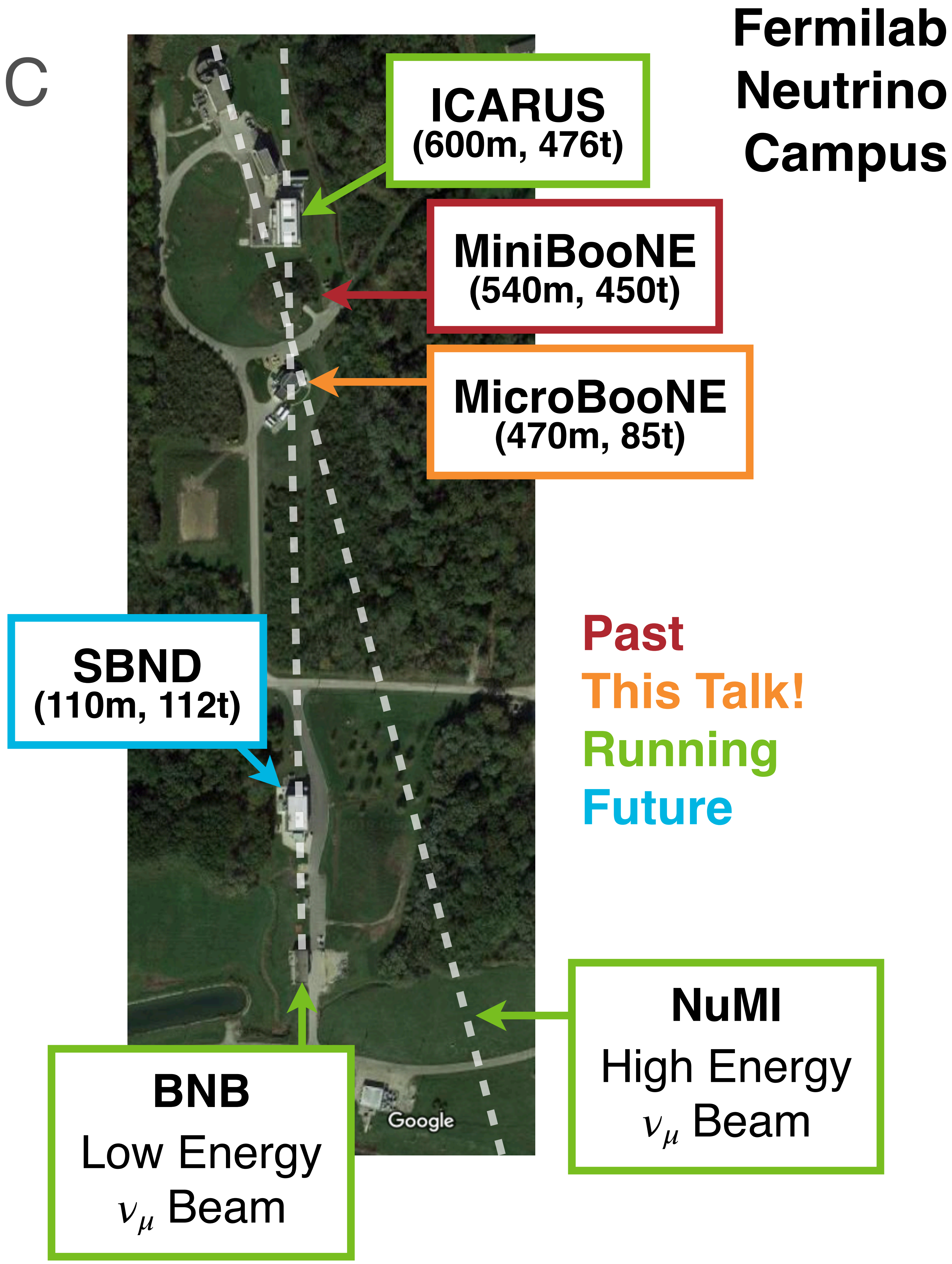
Lauren Yates (Fermilab) on behalf of the MicroBooNE Collaboration
55th Annual Fermilab Users Meeting
June 16, 2022

MicroBooNE Experiment at a Glance

- MicroBooNE observes neutrino interactions using a LArTPC
  - BNB: on-axis, flux peaks at ~600 MeV
  - NuMI: off-axis by ~8°, flux peaks low but goes out to a few GeV
- Completed five years of beam physics data-taking, collected largest neutrino–argon interaction dataset
- Also completed several post-operations R&D studies







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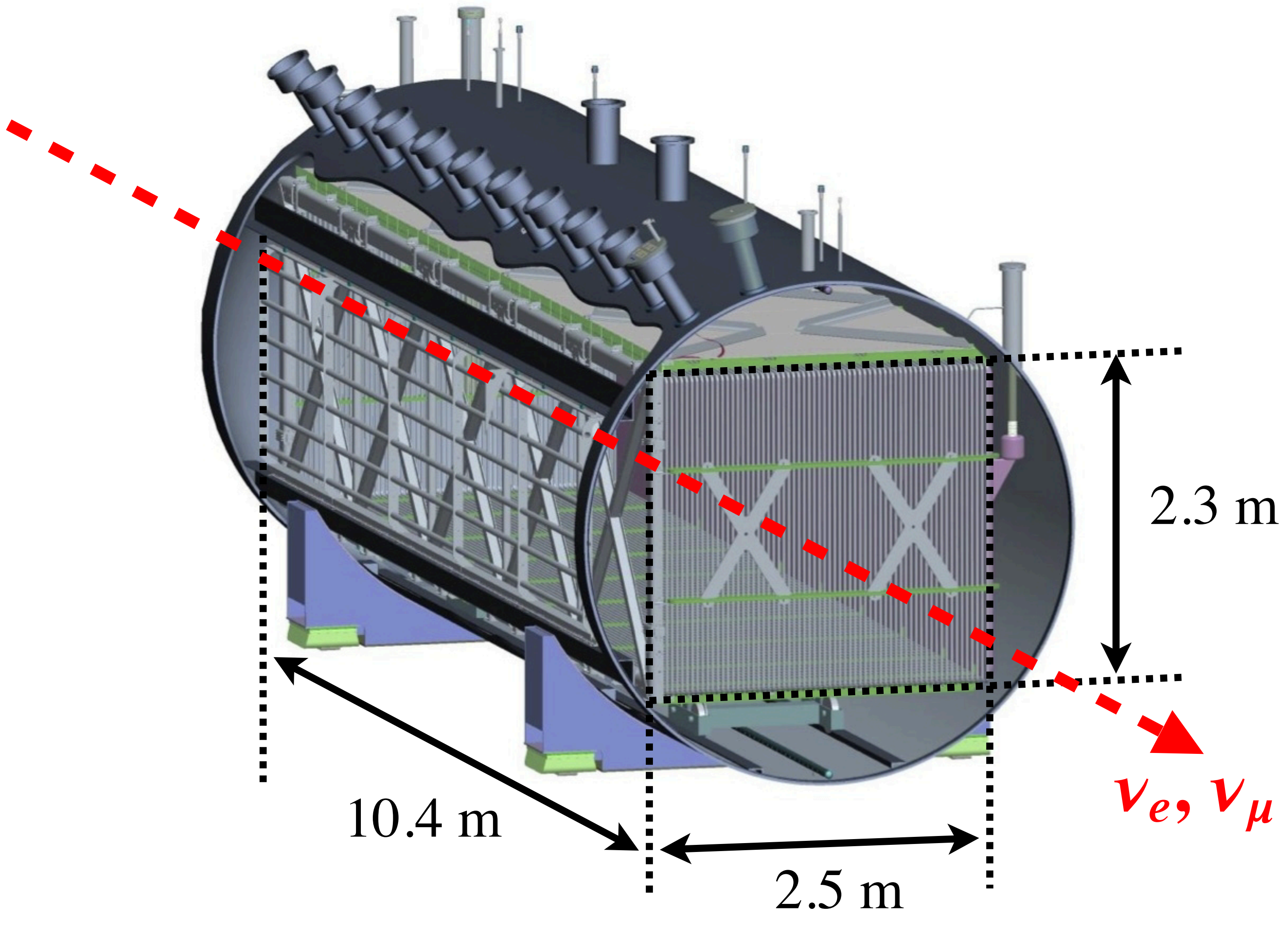
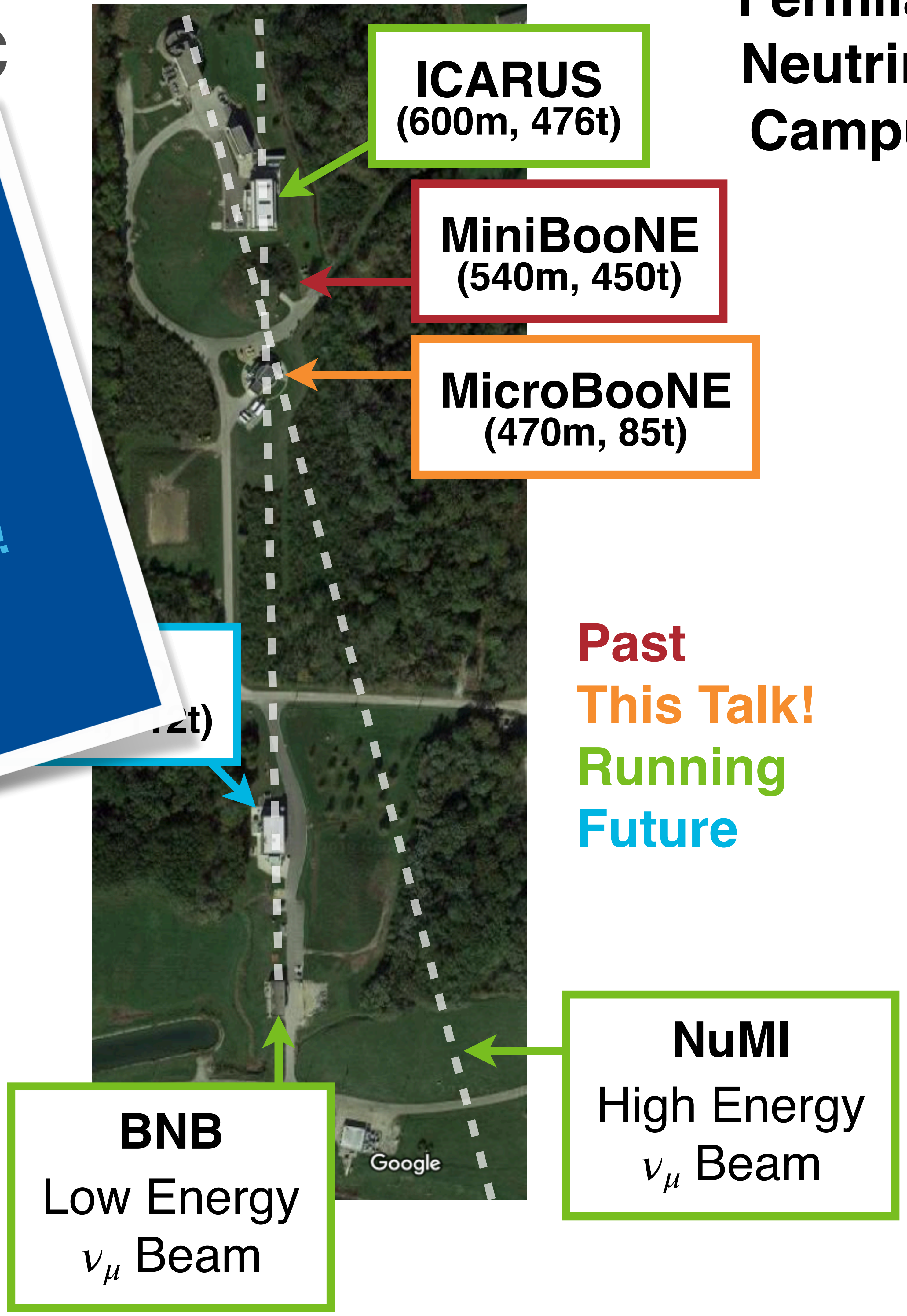
Thank you to Fermilab for excellent support of neutrino beams, operations, and data processing!



Fermilab Neutrino Campus

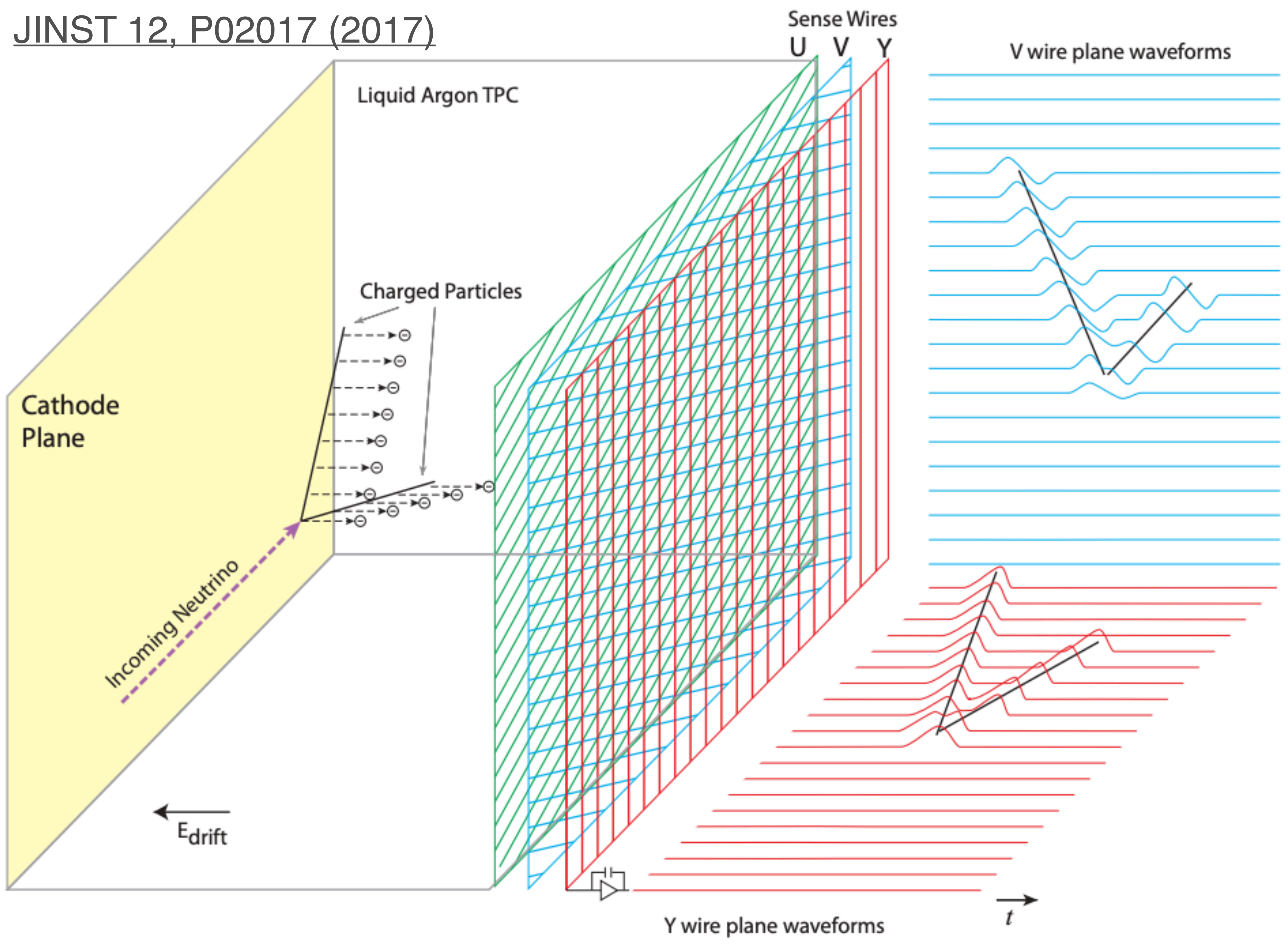


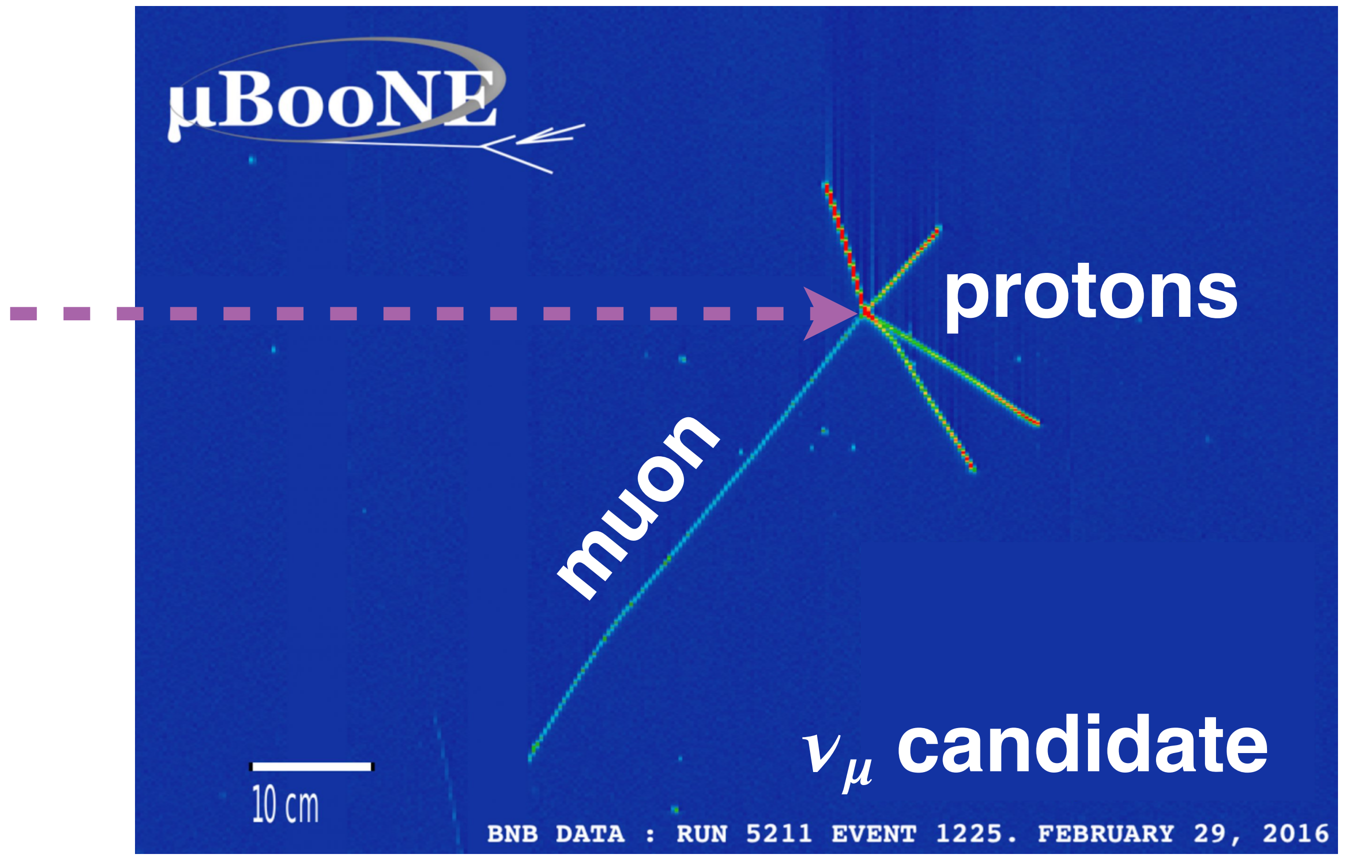
Past
This Talk!
Running
Future

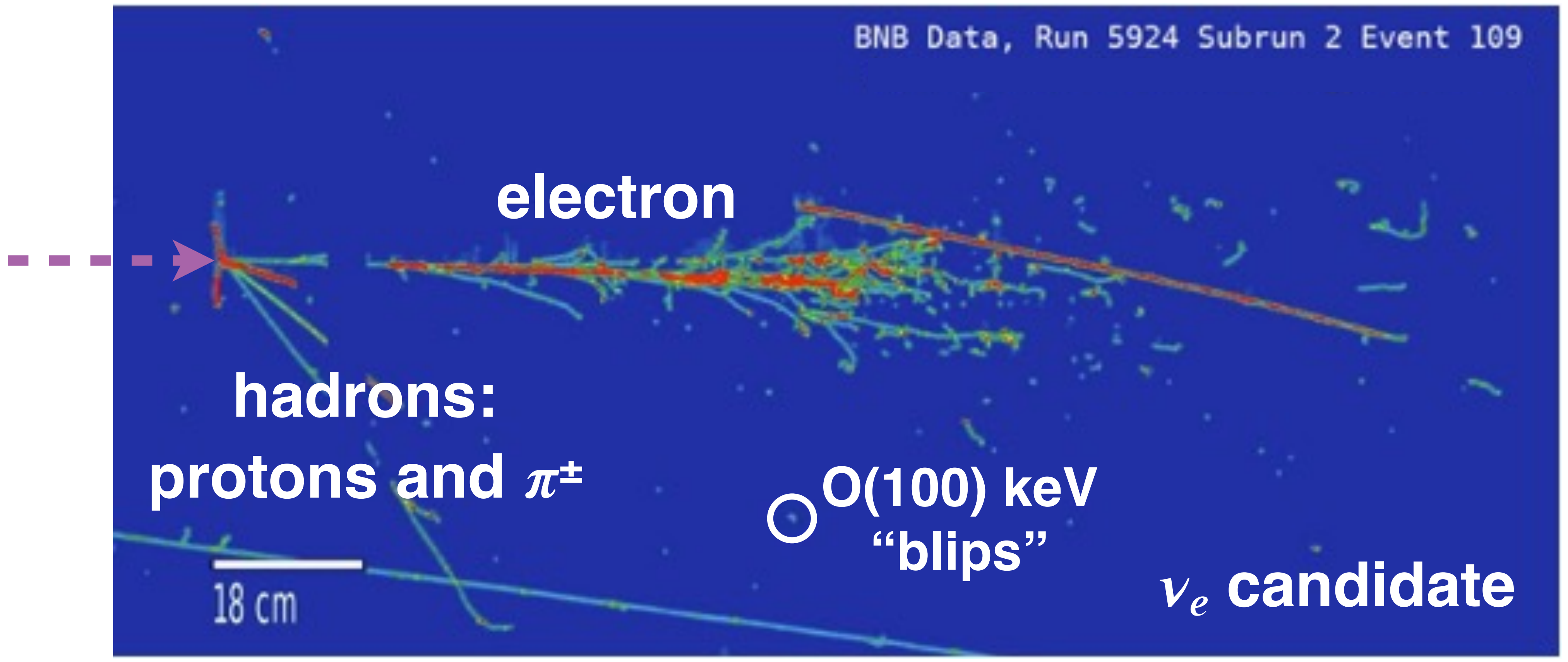
MicroBooNE Detector: A Liquid Argon Time Projection Chamber

- LArTPCs are highly-capable, fully-active tracking calorimeters
- Detailed images of interactions with ~3 mm spatial resolution enable low thresholds and excellent particle identification

JINST 12, P02017 (2017)







MicroBooNE’s Scientific and Technical Accomplishments

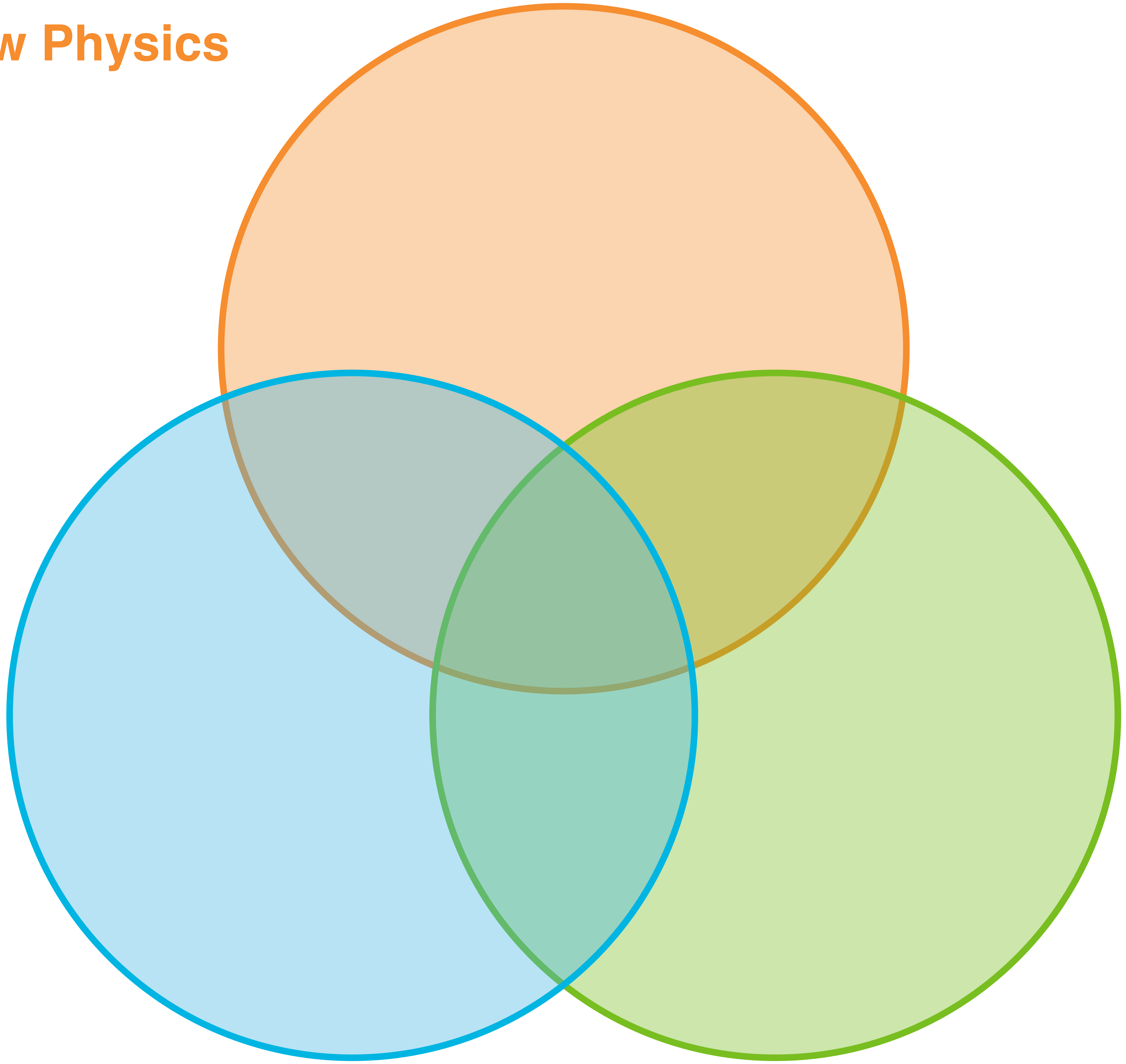
More than 45 publications written by MicroBooNE in the past 5 years

More than 75 public notes sharing progress with community as we go

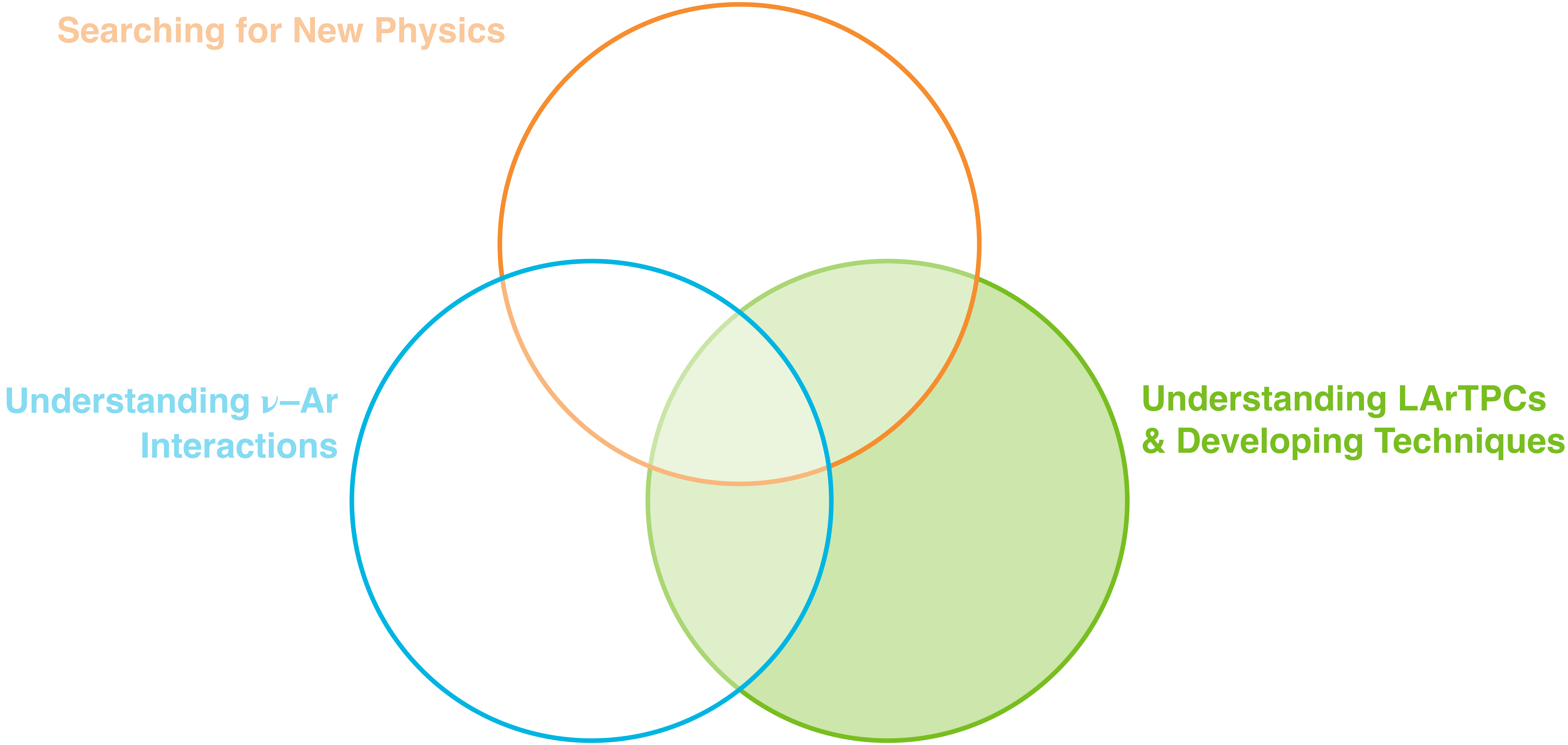
Searching for New Physics

Understanding ν–Ar Interactions

Understanding LArTPCs & Developing Techniques



Understanding LArTPCs & Developing Techniques



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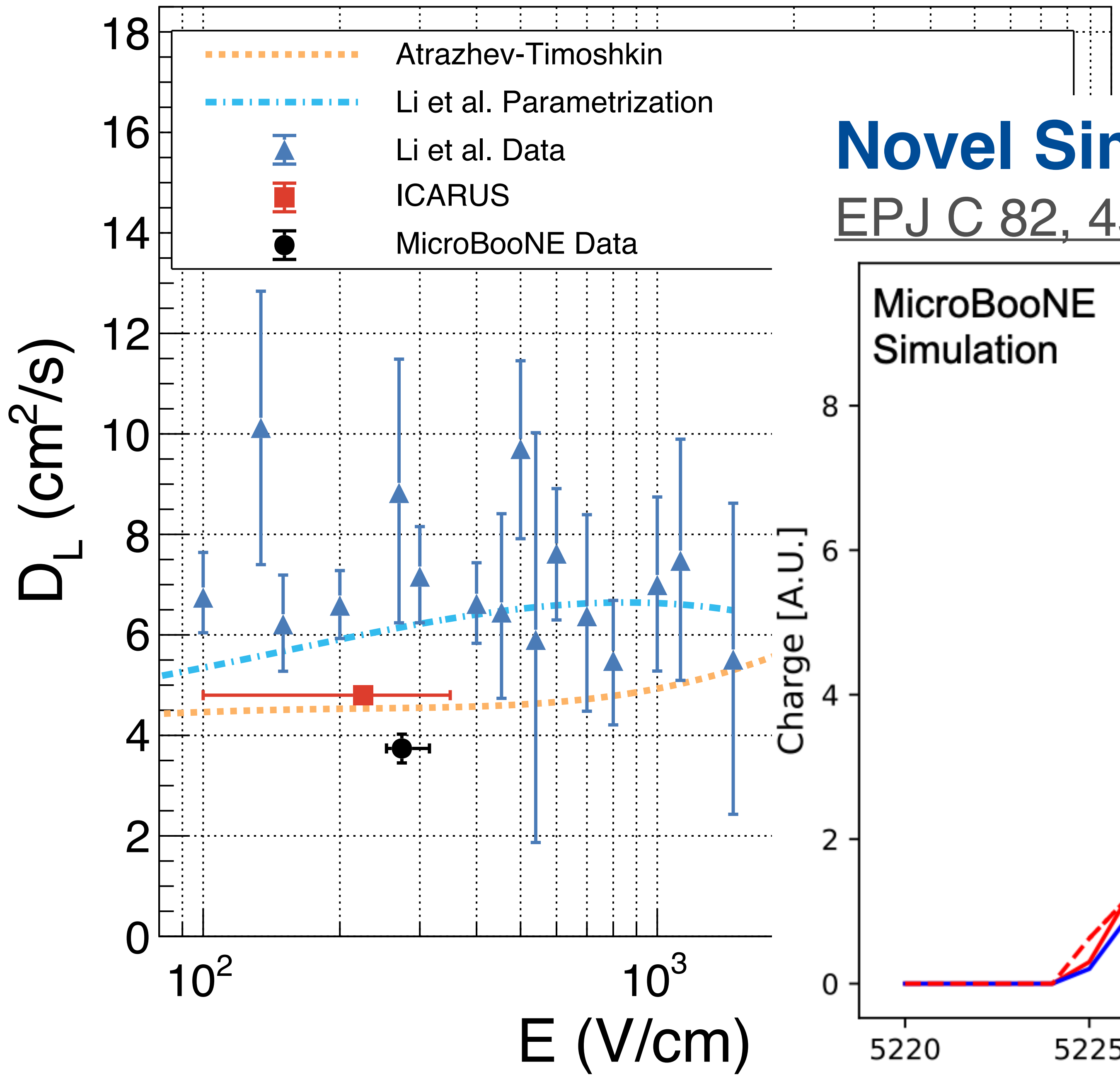
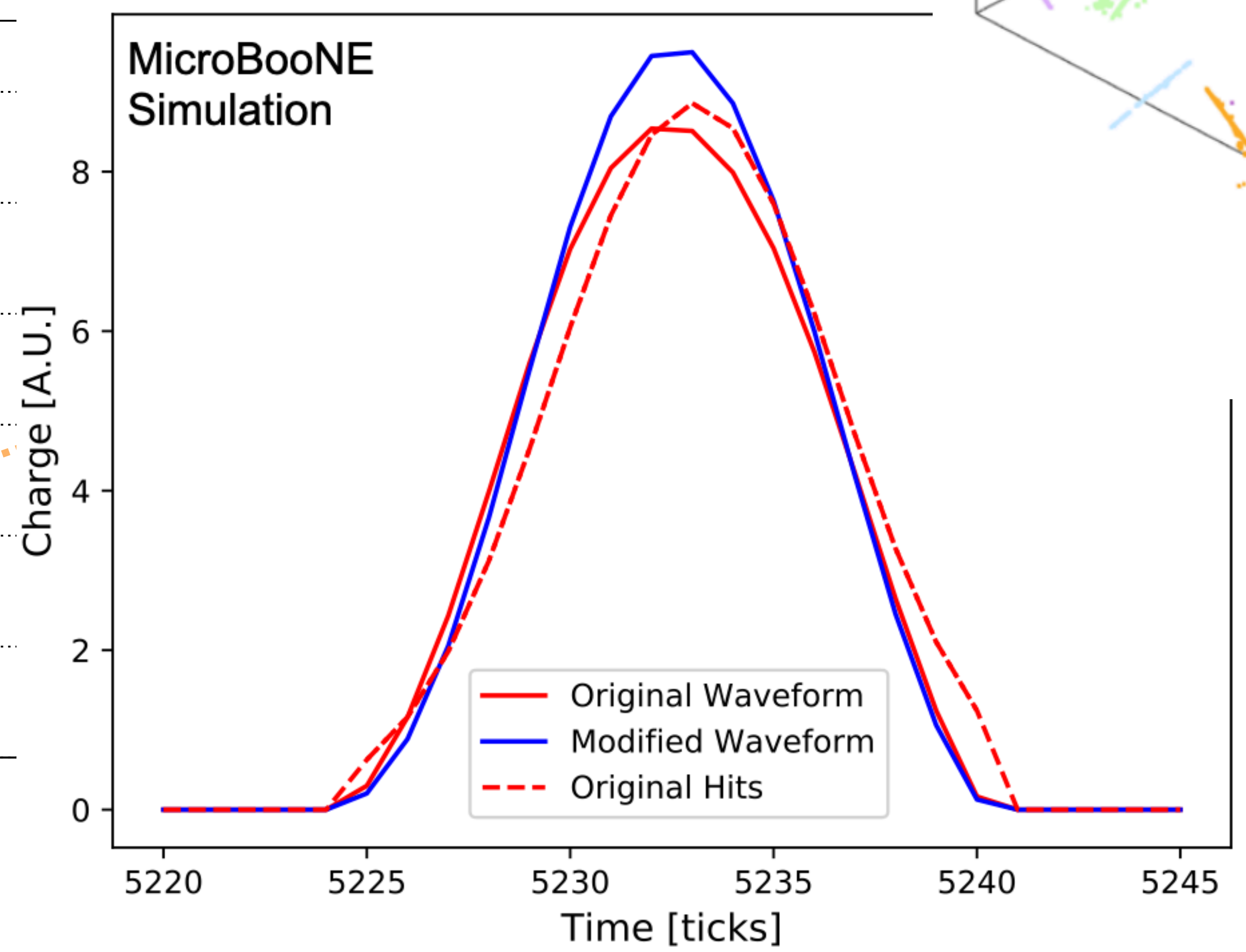
Understanding LArTPCs & Developing Techniques

- MicroBooNE has contributed to significant advances in LArTPC detector physics, modeling, and reconstruction
- Post-operations R&D studies are just beginning to bear fruit

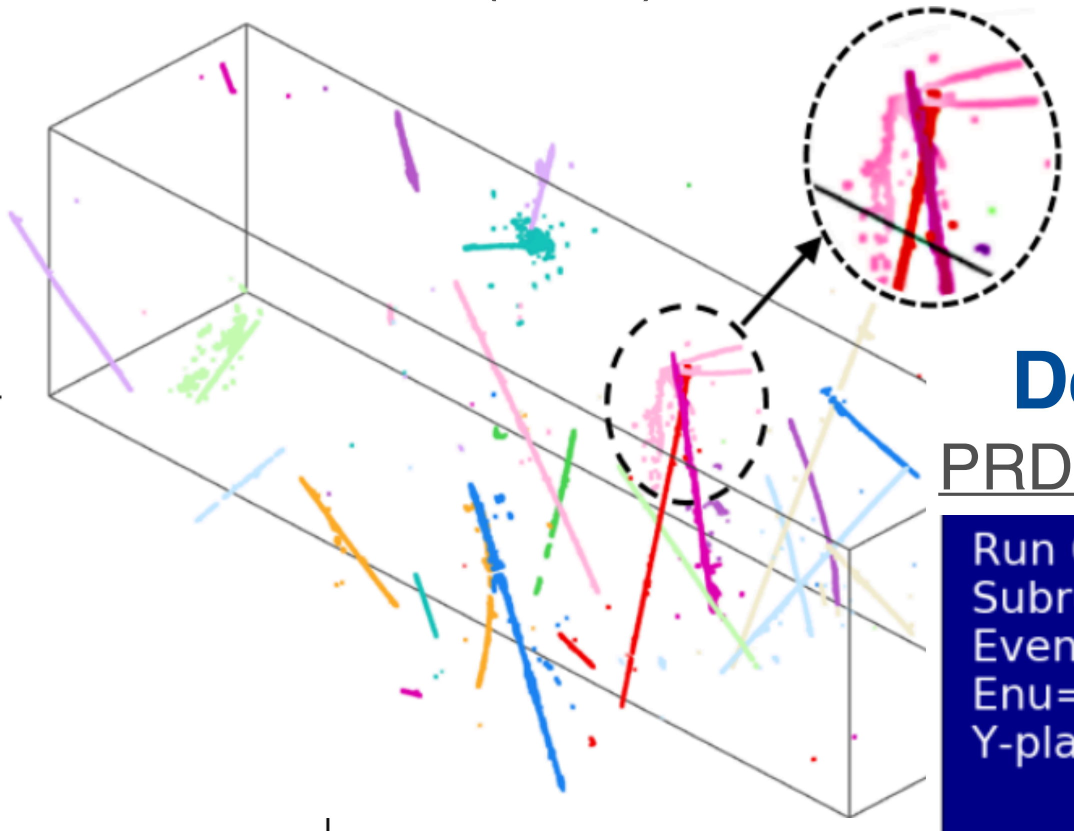
Electron Diffusion Measurement
JINST 16, P09025 (2021)



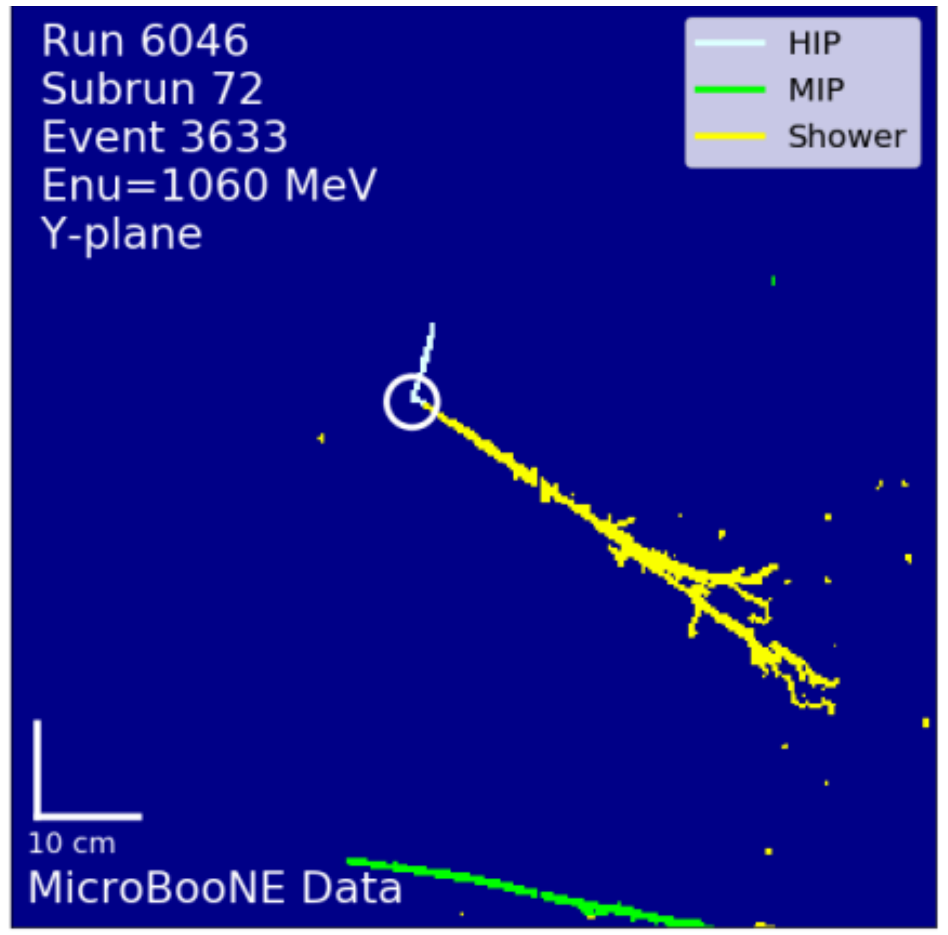
Novel Sim. Modification
EPJ C 82, 454 (2022)



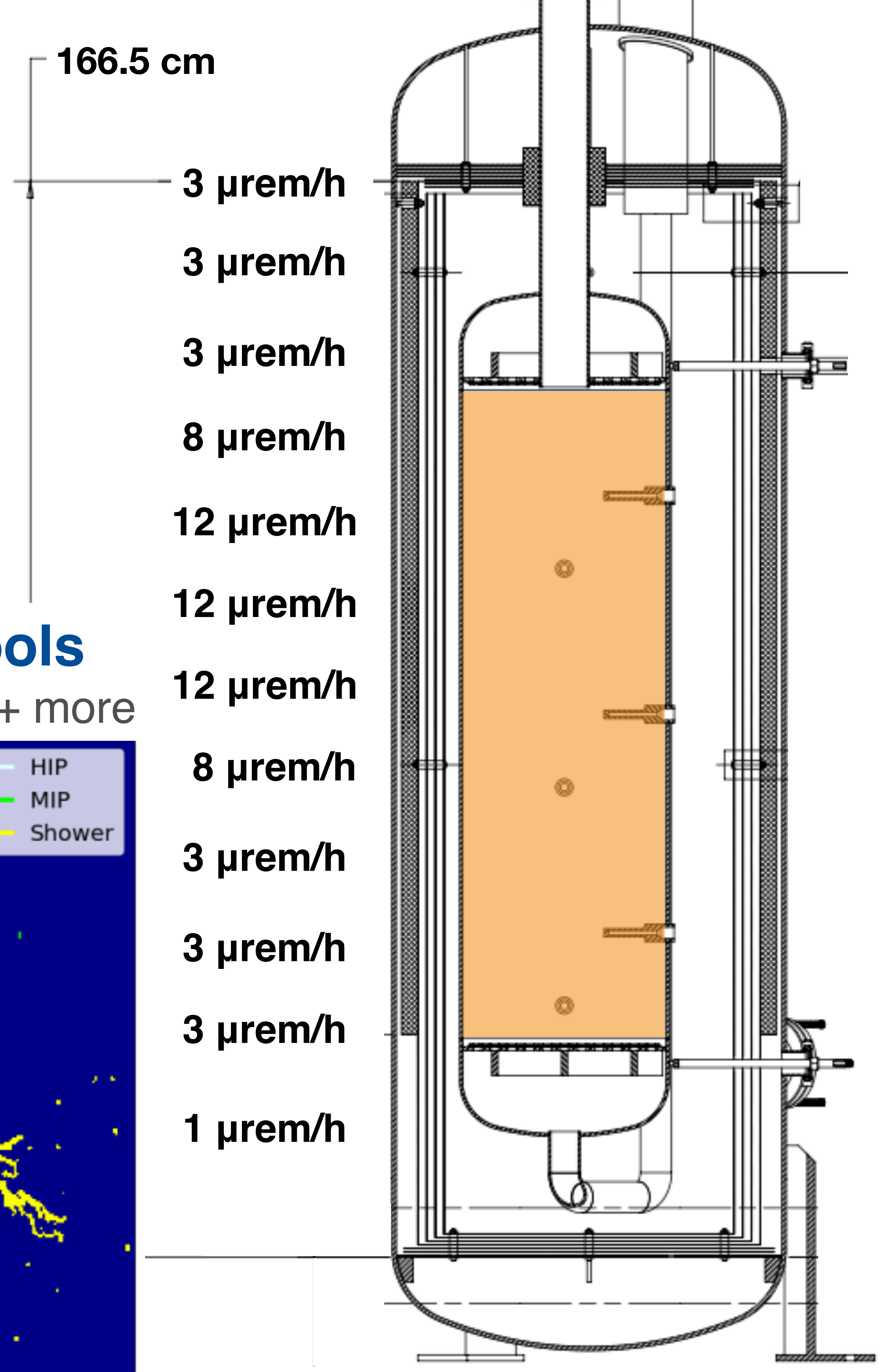
Wire-Cell Reconstruction Tools
JINST 16, P06043 (2021) + more



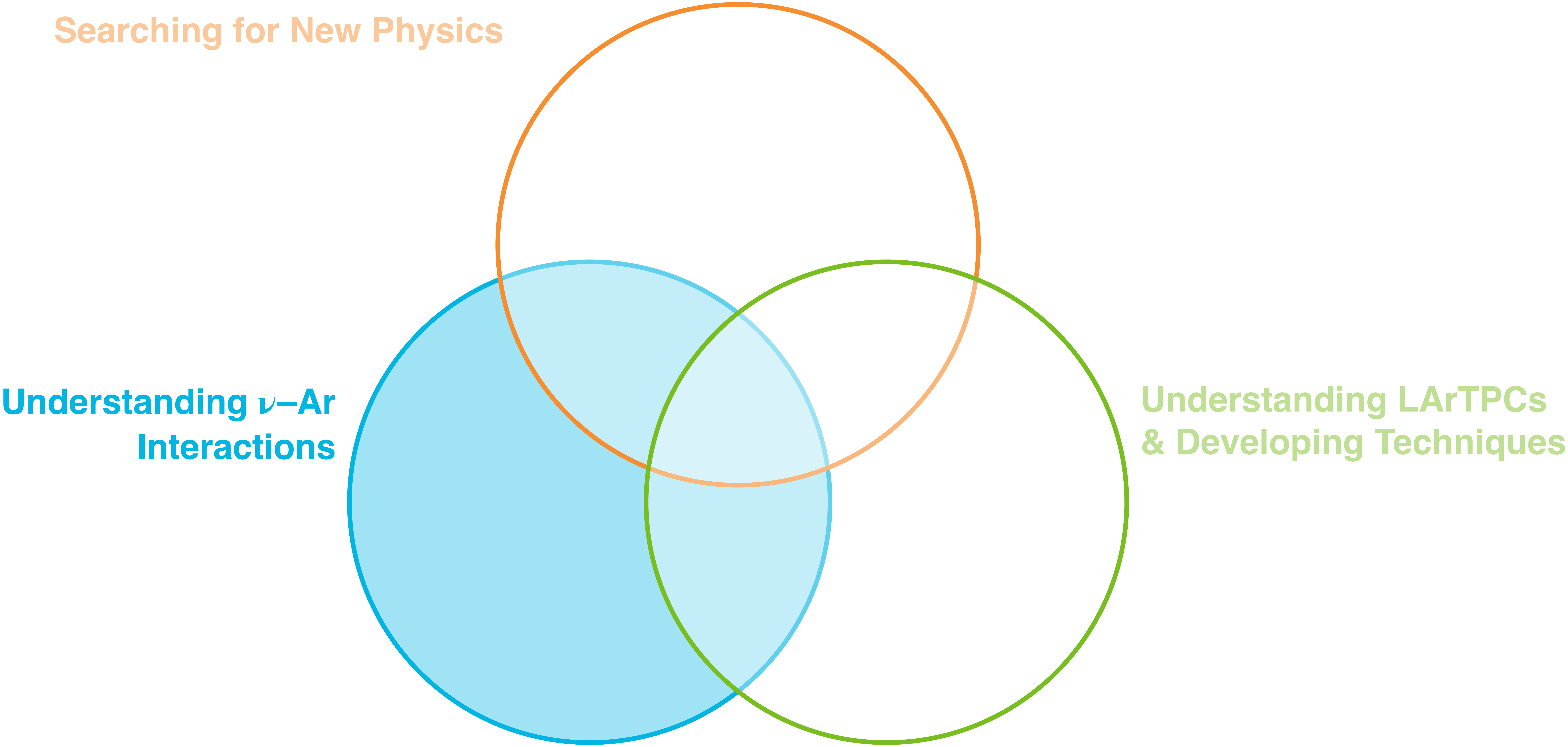
Deep Learning Tools
PRD 103, 052012 (2021) + more



Radon Mitigation R&D Study
arXiv:2203.10147

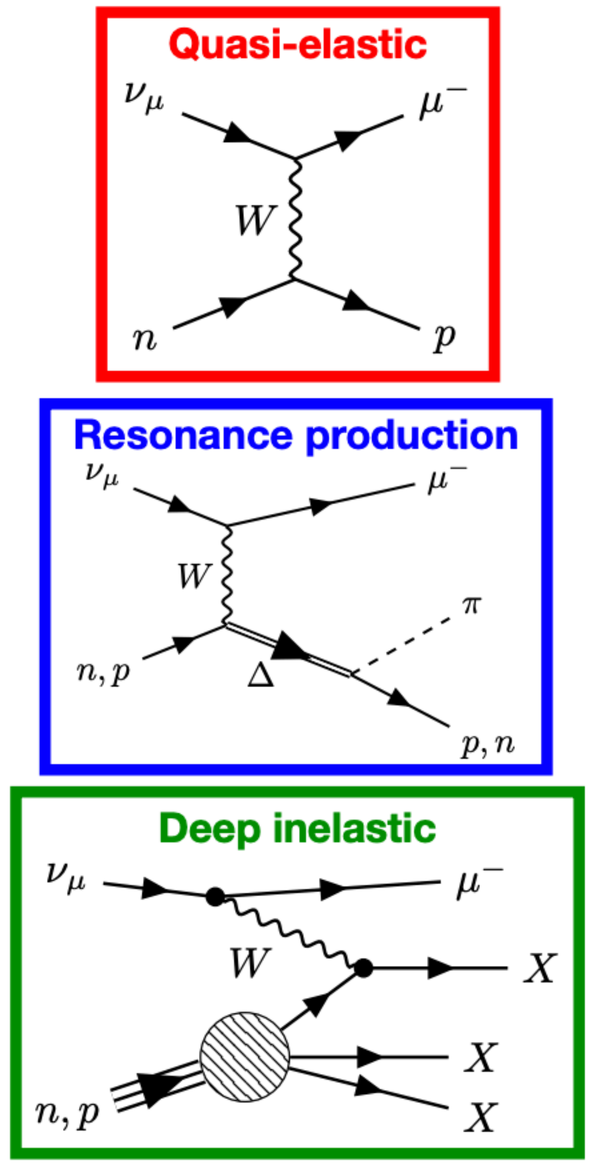


Understanding Neutrino–Argon Interactions

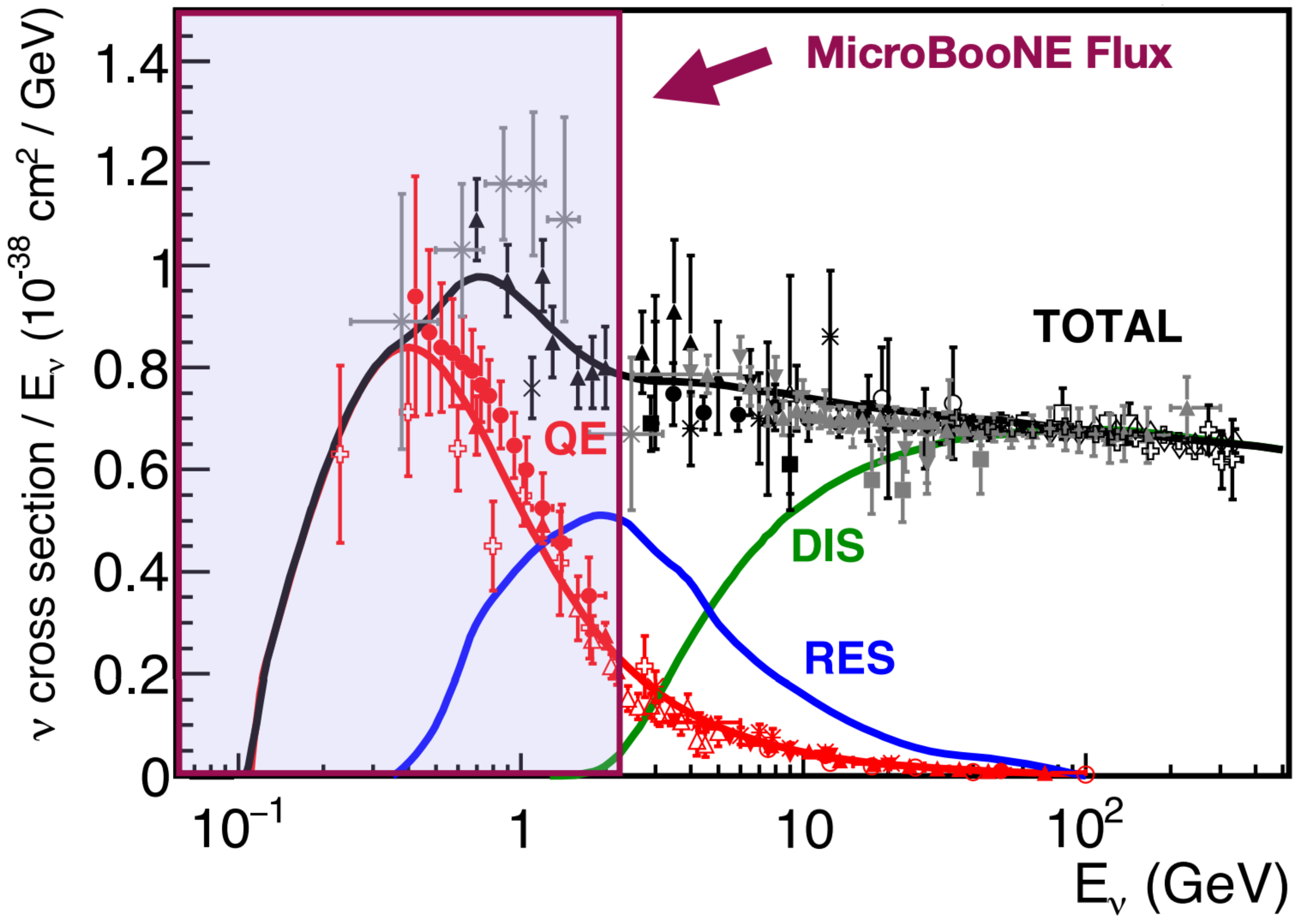


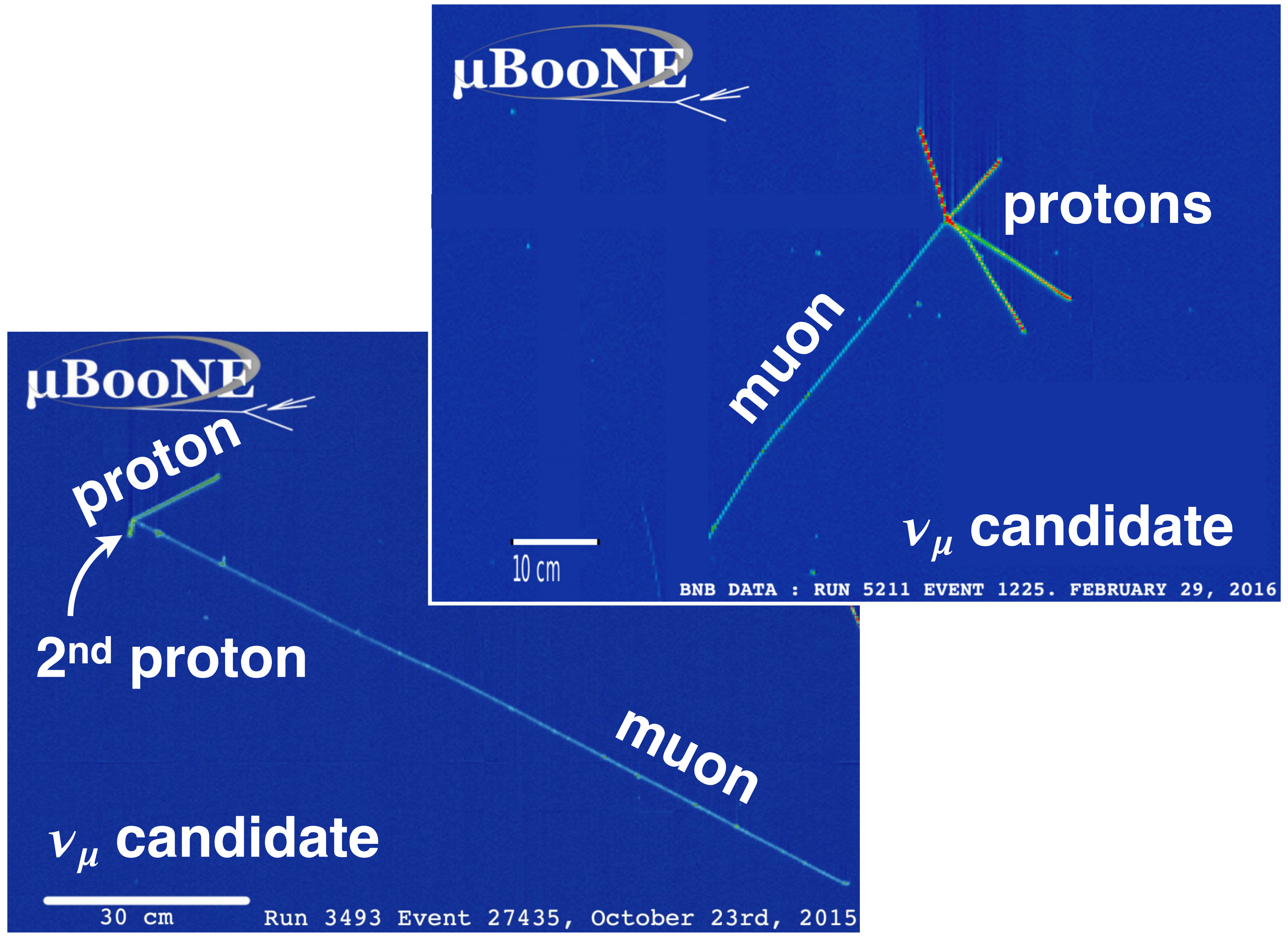
Neutrino Interactions

- Discovery science with neutrinos requires understanding and modeling interactions
  - Essential for interpreting final state particle content and kinematics to extract neutrino properties
- Theory is complex due to multiple channels, nuclear effects, final-state interactions
- Cross-section measurements are key to benchmarking models and improving them



Rev. Mod. Phys. 84, 1307 (2012)

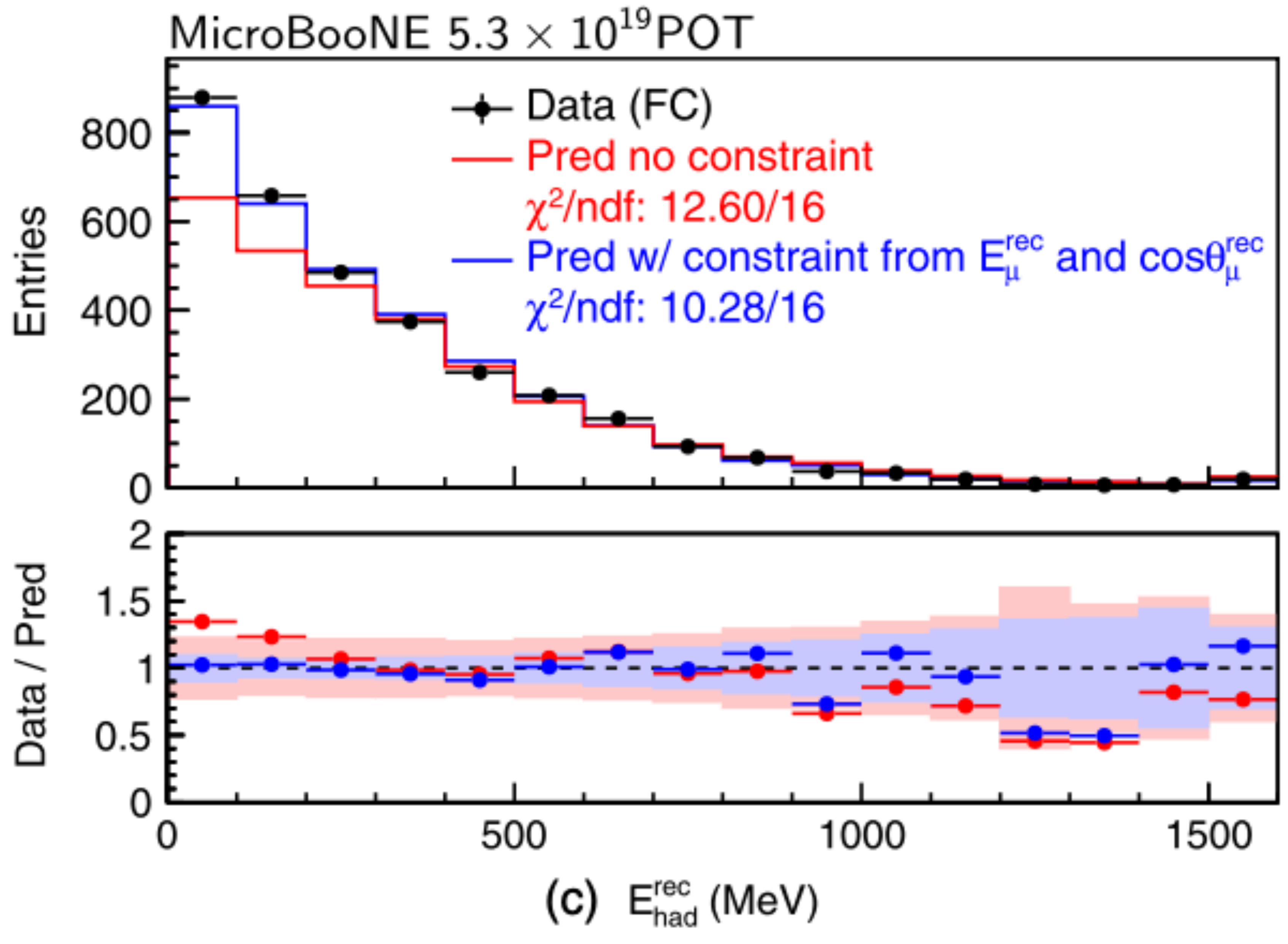


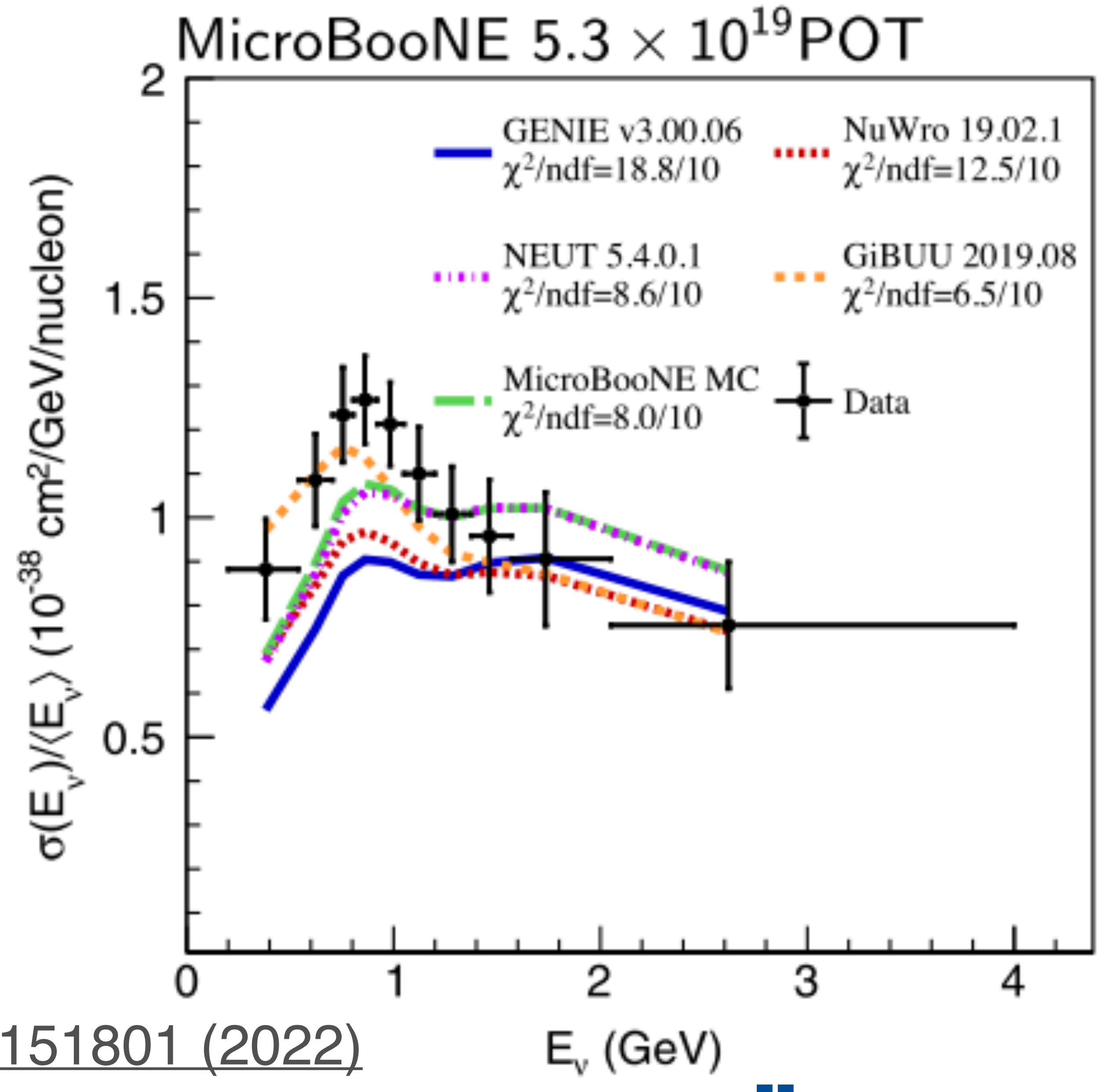


ν_μ CC Inclusive: Probing Hadronic Energy

- Recent MicroBooNE ν_μ charged-current inclusive measurement focuses on hadronic energy
  - Critical for estimating the neutrino energy, which in turn is necessary for neutrino oscillation measurements
- Probes the physics of the final-state hadronic system
- Model validated using novel constraint procedure
- More on this at the JETP Seminar tomorrow!
- And more to come: higher statistics, multi-differential

MICROBOONE-NOTE-1110-PUB

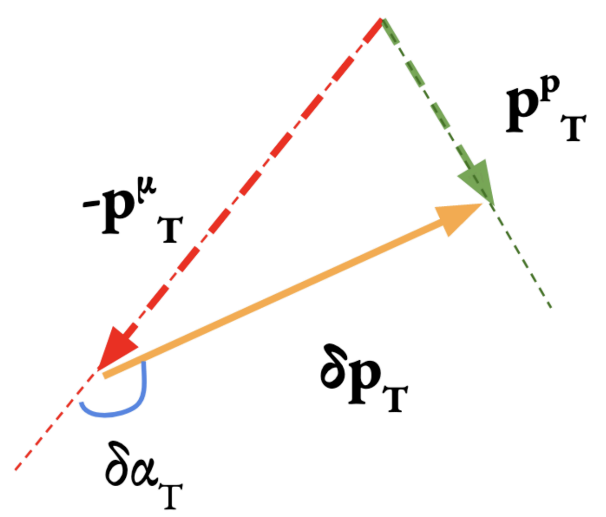


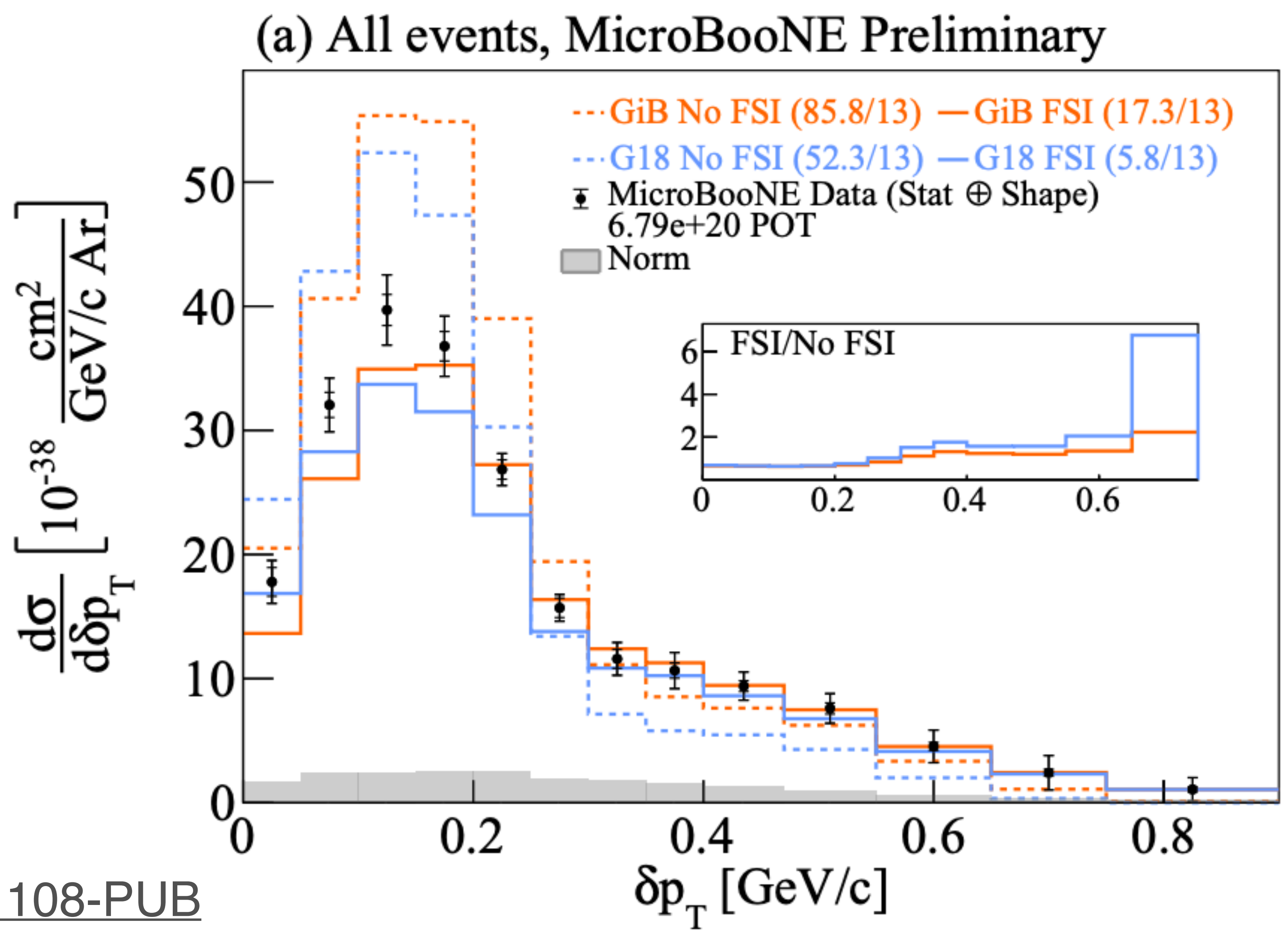


PRL 128, 151801 (2022)

ν_μ CC Exclusive Measurements: Probing Nuclear Physics

- Additionally, exclusive measurements of ν_μ charged-current interactions on argon probe specific aspects of nuclear physics modeling with unprecedented detail
- Targeting $1\mu 1p 0\pi$ topology and using transverse kinematic imbalance (TKI) variables to investigate nuclear effects in argon — initial nucleon motion, final state interactions
- Targeting $1\mu 2p 0\pi$ topology to study meson exchange currents (MEC)





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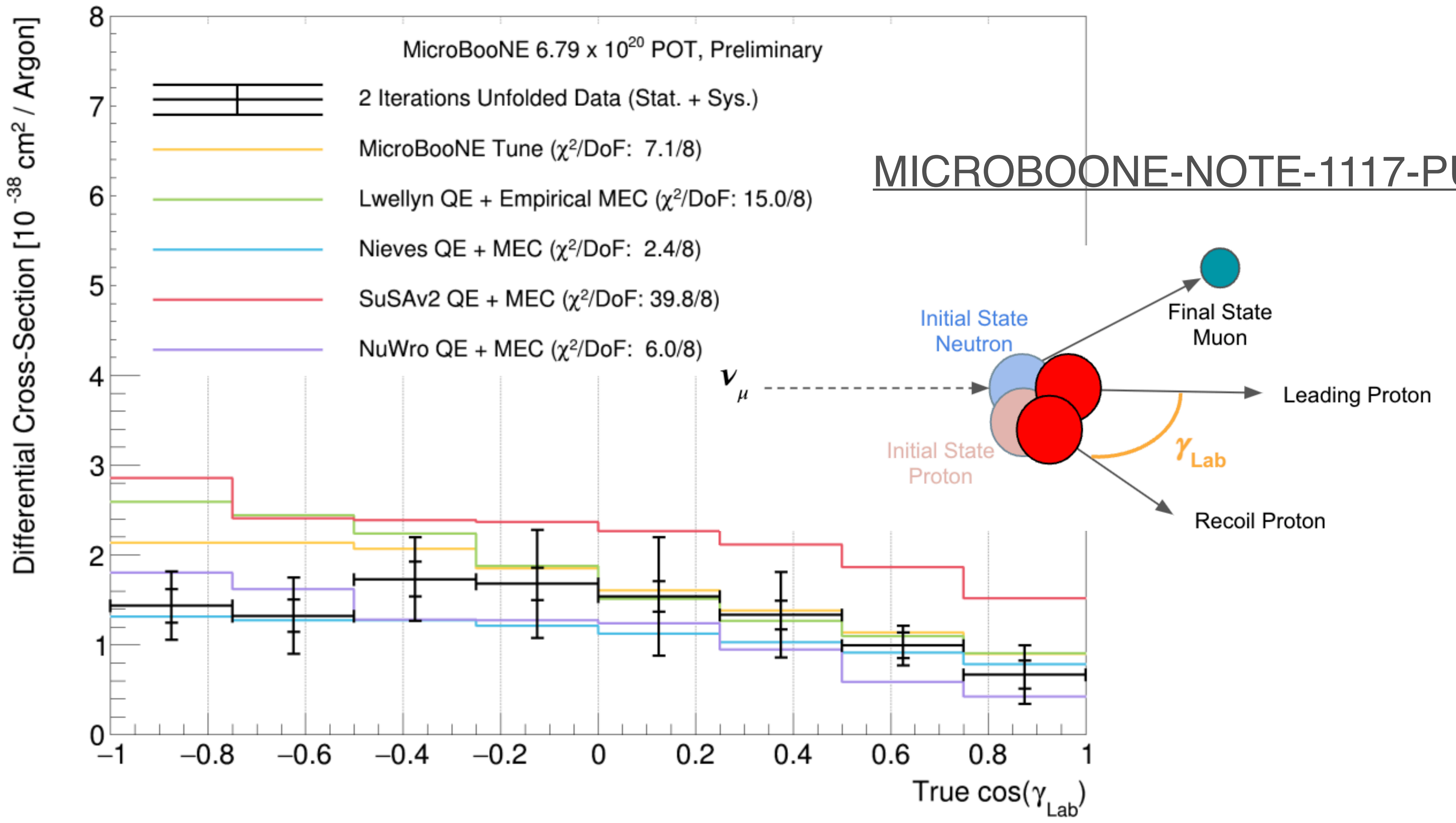

MICROBOONE-NOTE-1117-PUB

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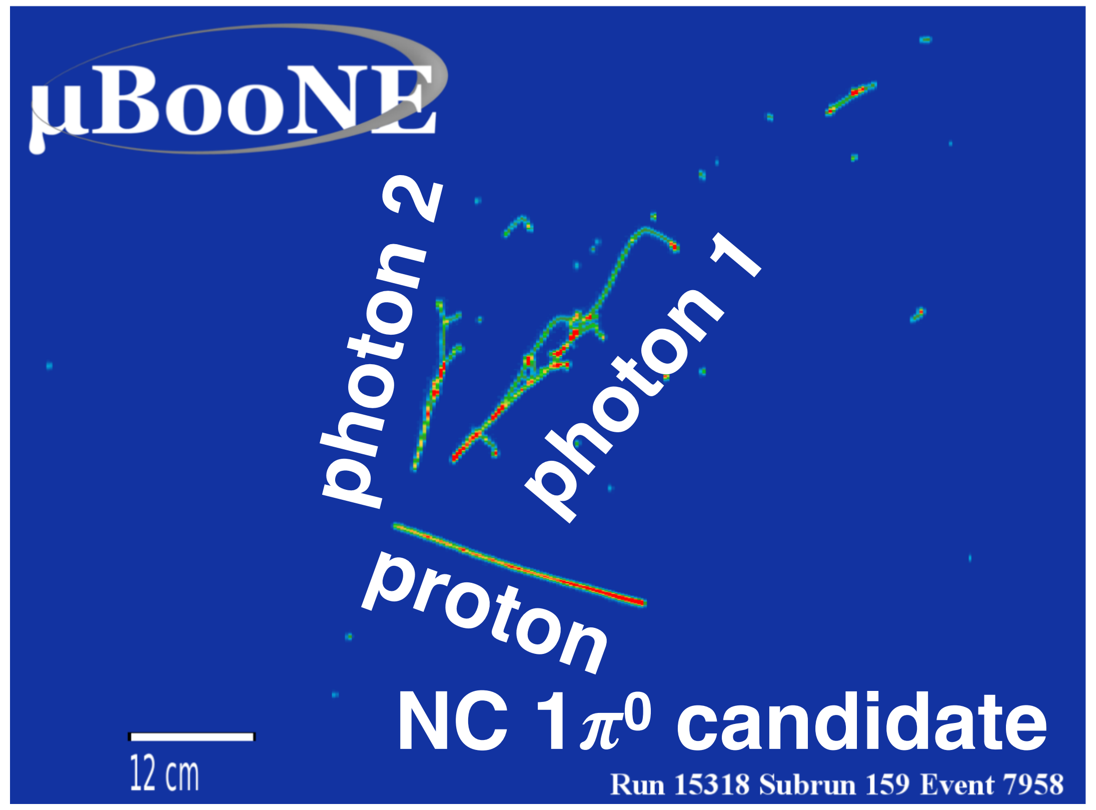
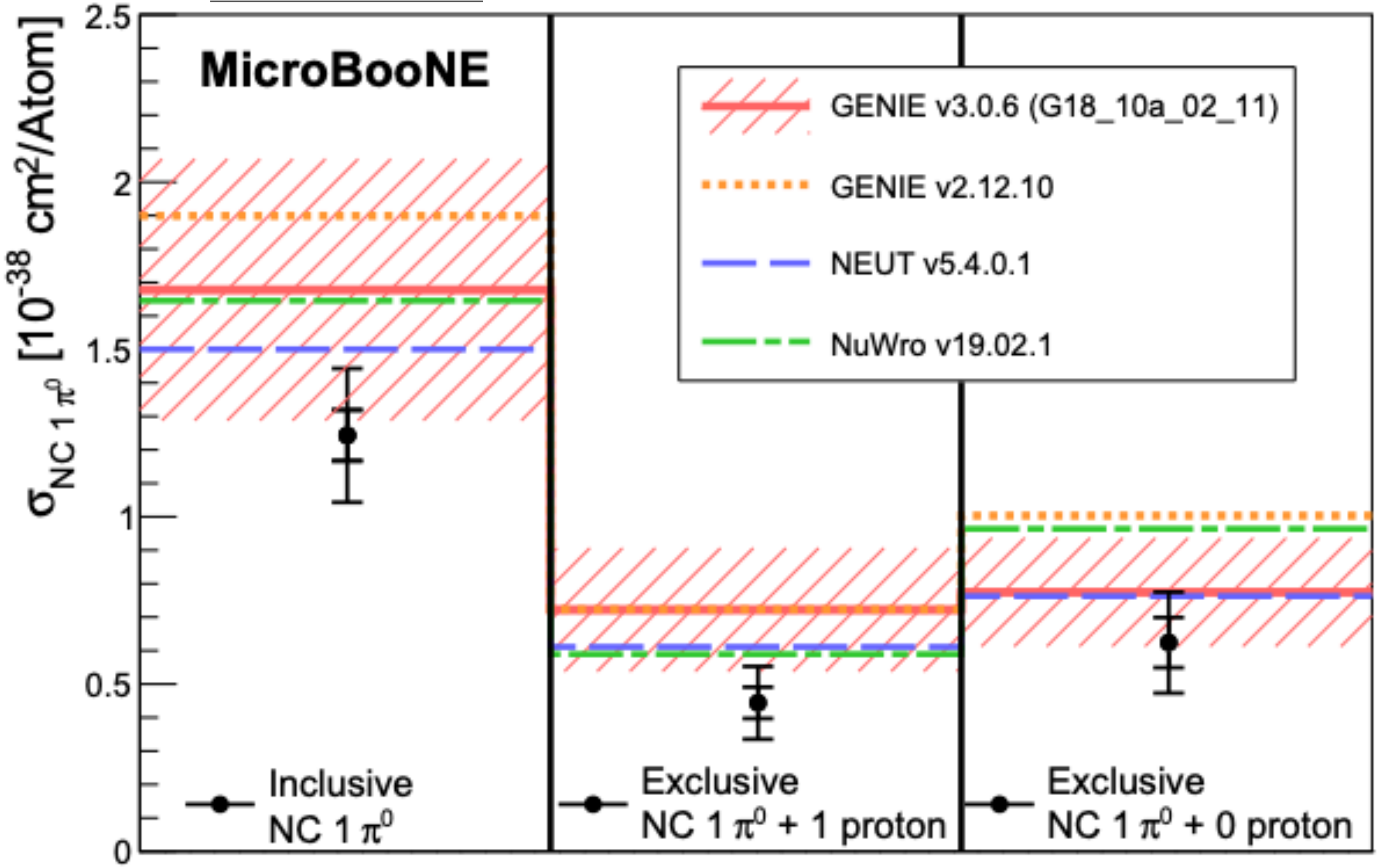
π^0 Final States: Probing Pion Production

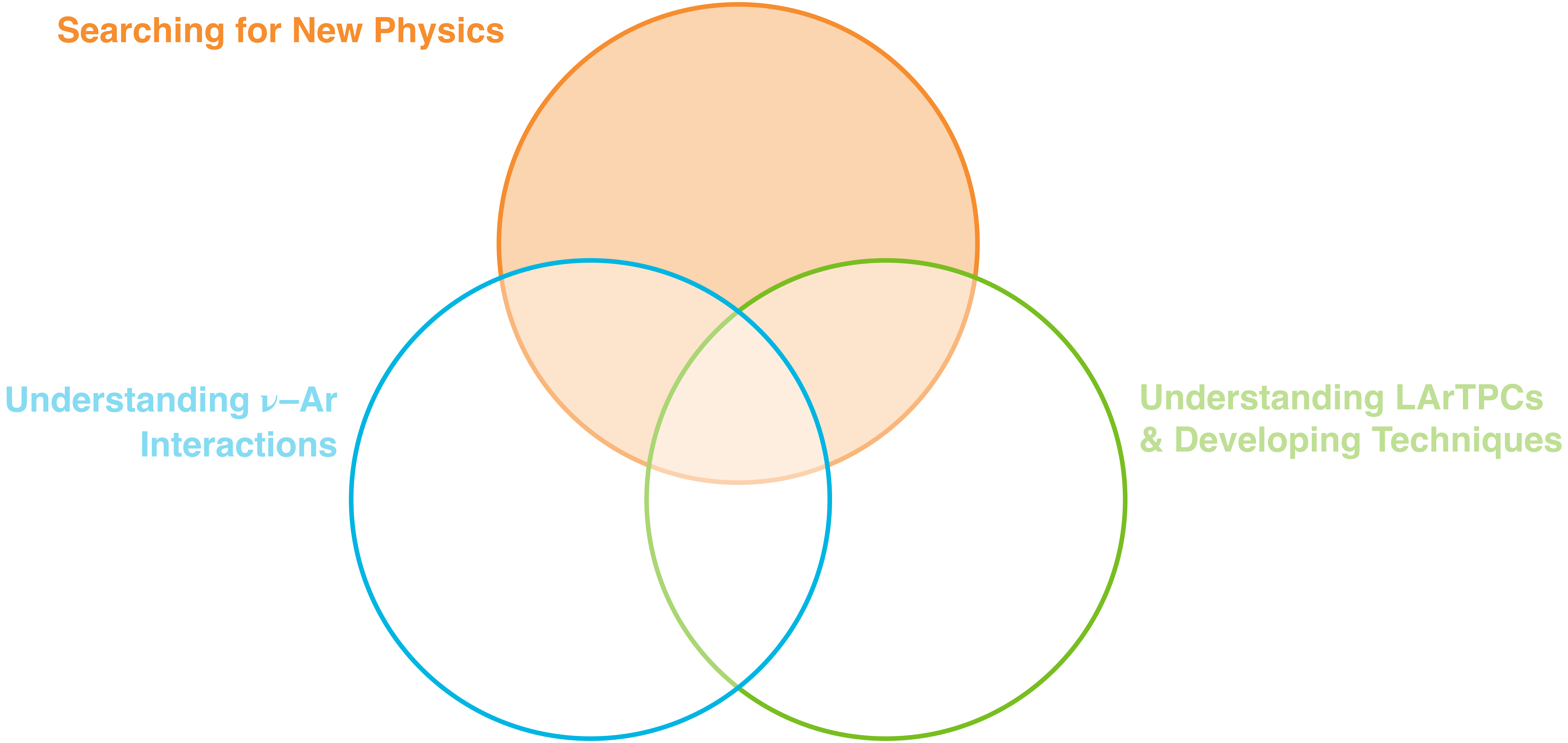
- Recently published a measurement of NC 1π^0 cross section on argon
- Also first exclusive measurements of NC 1π^0 cross sections on argon
- Measure a smaller cross section than predicted by all of the models studied
  - Result is ~1σ (sys+stat) from GENIE v3
- More to come:
  - Differential ν_μ CC 1π^0 measurement
    MICROBOONE-NOTE-1107-PUB
  - Differential NC ≥1π^0 measurement
    MICROBOONE-NOTE-1111-PUB



arXiv:2205.07943

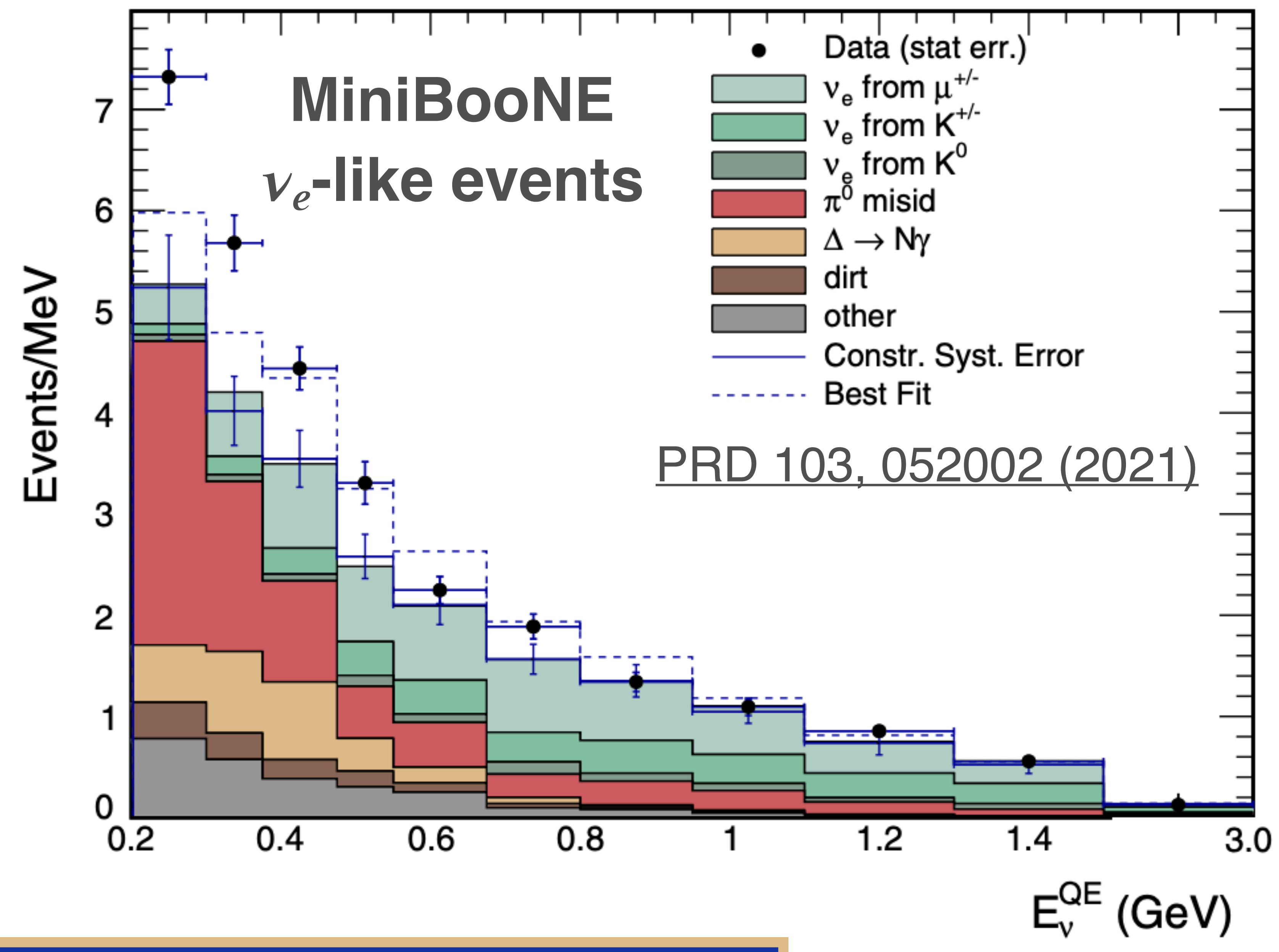


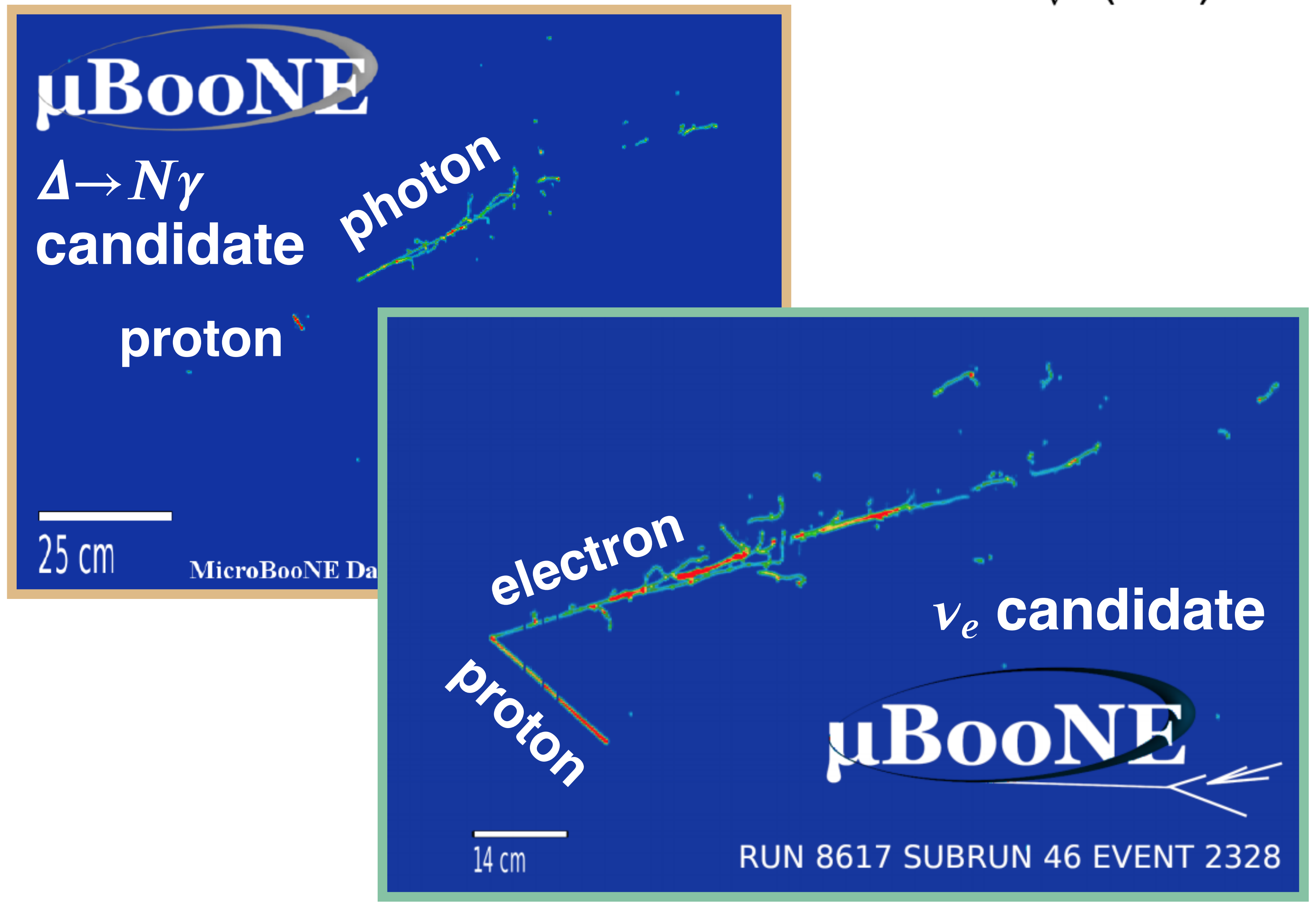
Searching for New Physics



The MiniBooNE LEE Anomaly

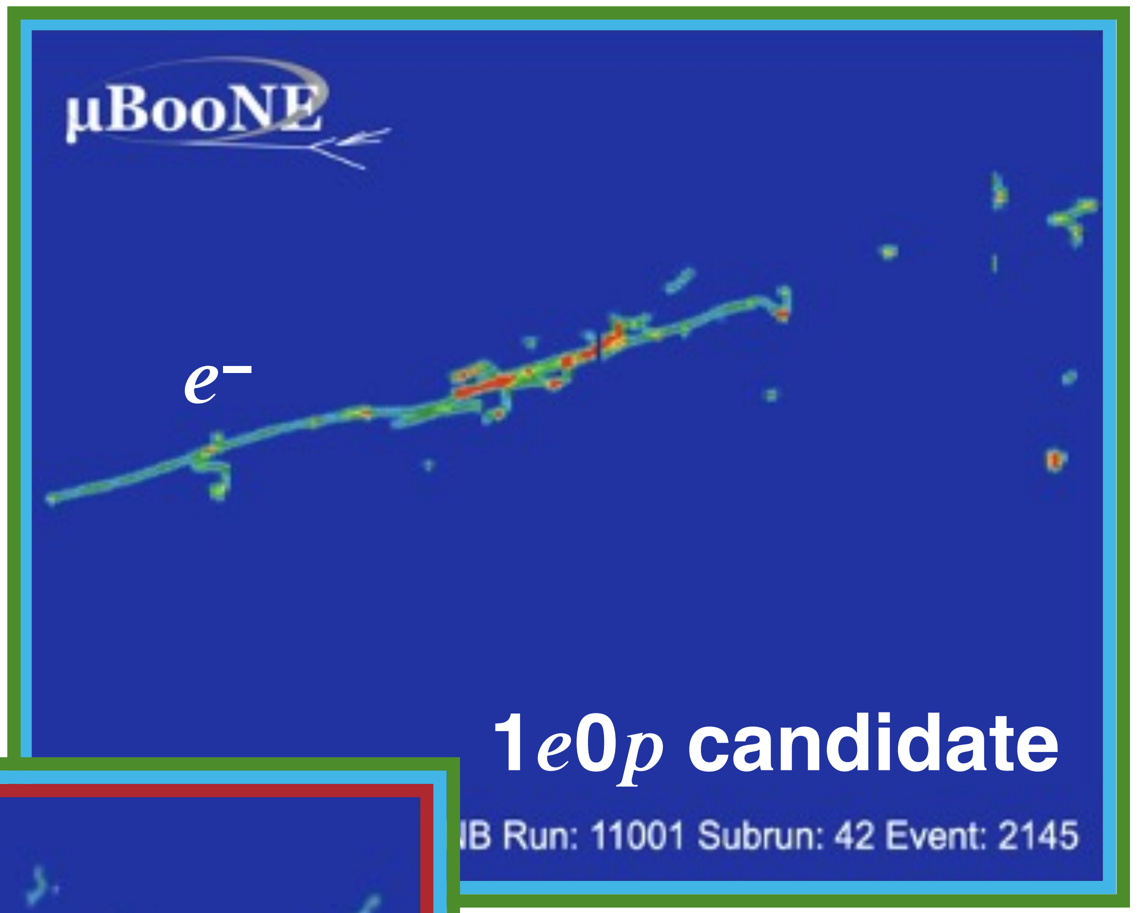
- MiniBooNE studied $\nu_\mu \rightarrow \nu_e$ appearance using the BNB beam and a mineral oil Cherenkov detector
- MiniBooNE's final results show a 4.8σ excess of ν_e-like events, called the low-energy excess (LEE)
- MicroBooNE's first searches addressing the LEE anomaly pursue two main hypotheses:
  – Electrons from charged-current ν_e interactions (greens)
  – Single photons from neutral-current Delta resonance radiative decays, NC $\Delta \rightarrow N\gamma$ (yellow)

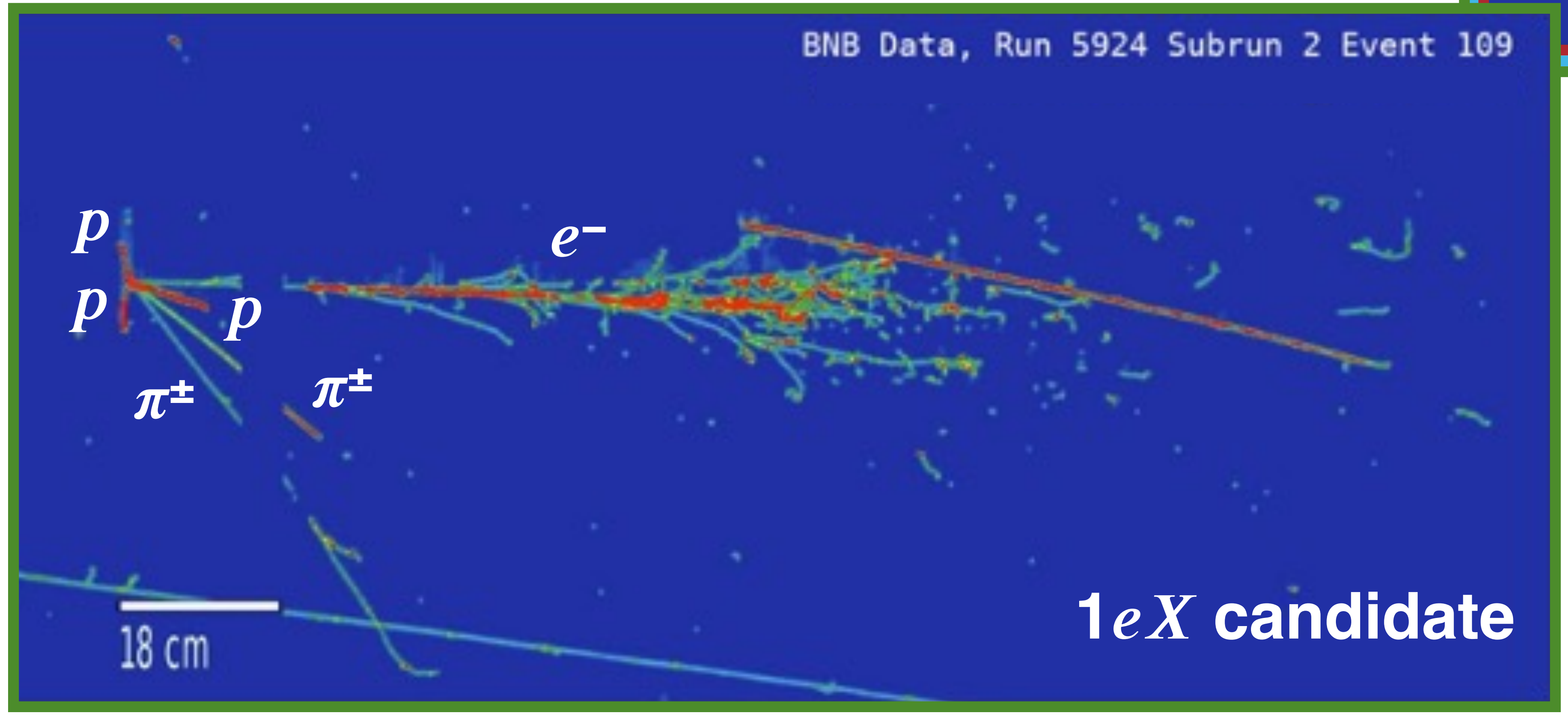


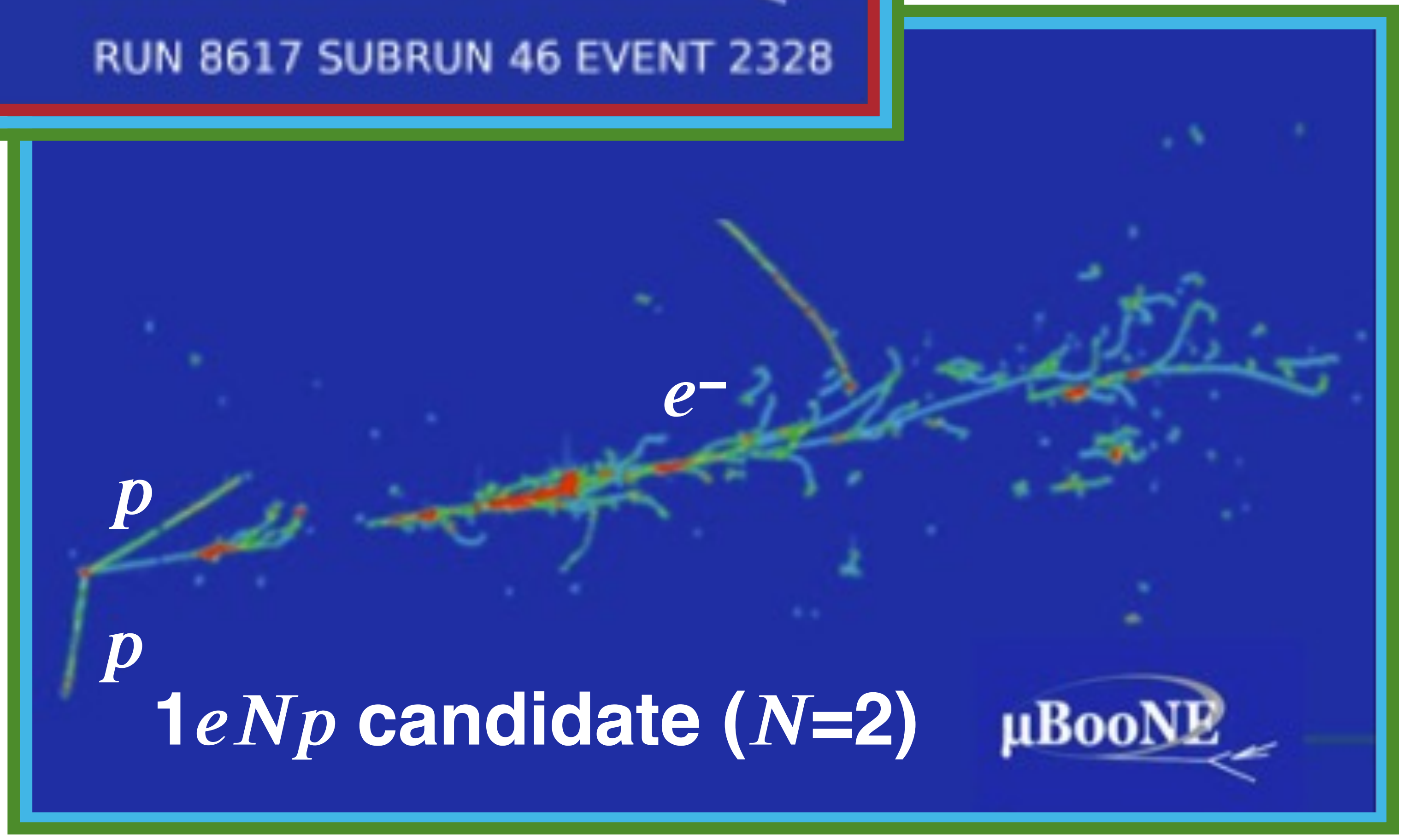


MicroBooNE's First LEE Results: Electrons

- Three MicroBooNE analyses searched for an enhanced rate of low-energy ν_e interactions
  - **$1e1p$ CCQE**: events with $1e1p$ topology and kinematics consistent with two-body scattering
    PRD 105, 112003 (2022)
  - **$1eNp$ + $1e0p$**: events with no pions in the final state
    PRD 105, 112004 (2022)
  - **$1eX$**: events with any hadronic final state
    PRD 105, 112005 (2022)







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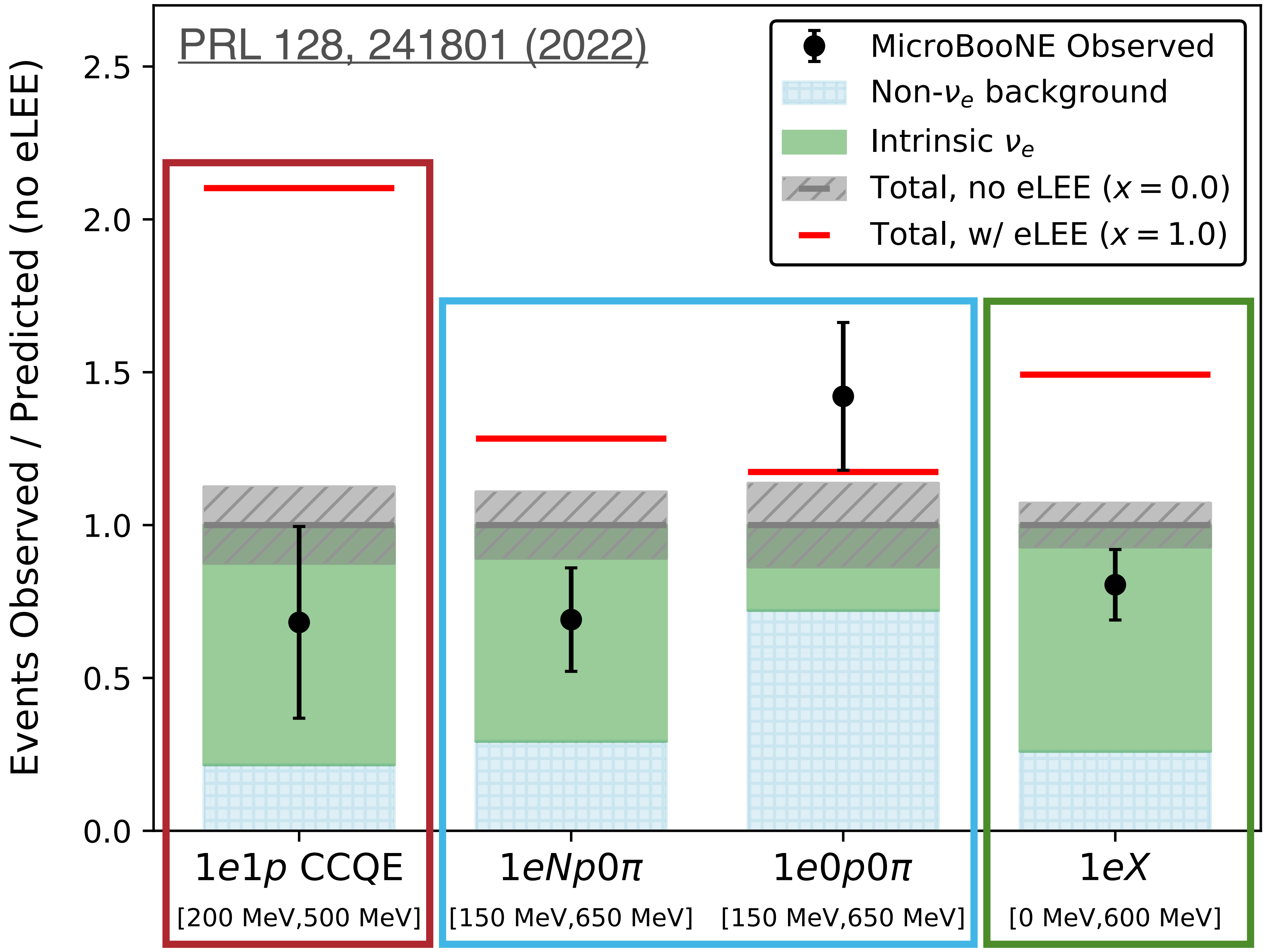
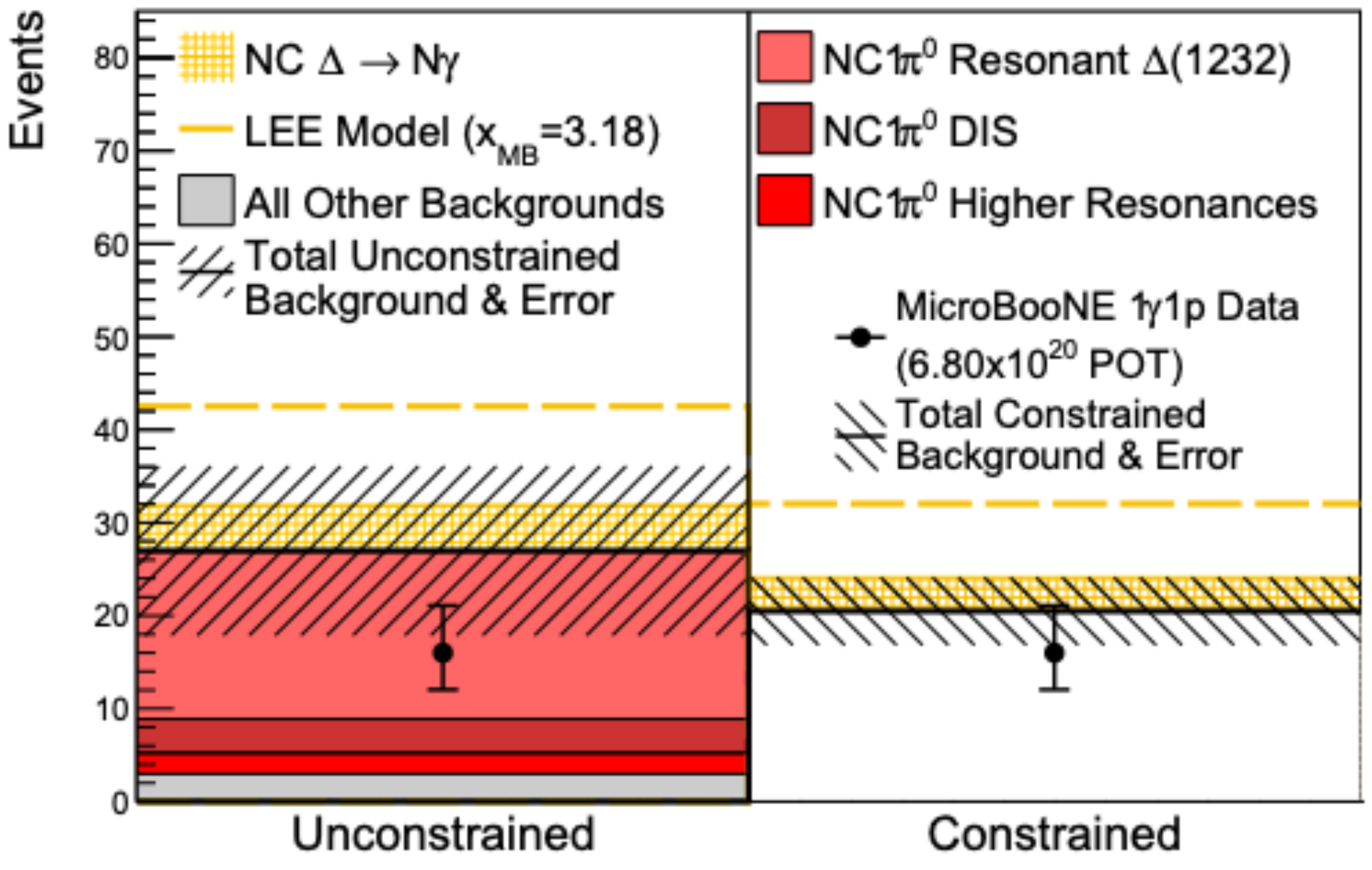
    PRD 105, 112004 (2022)
  - **$1eX$**: events with any hadronic final state
    PRD 105, 112005 (2022)
- Observations in low-energy region consistent with intrinsic ν_e rate expected from the BNB
  - No evidence for an excess of low-energy ν_e

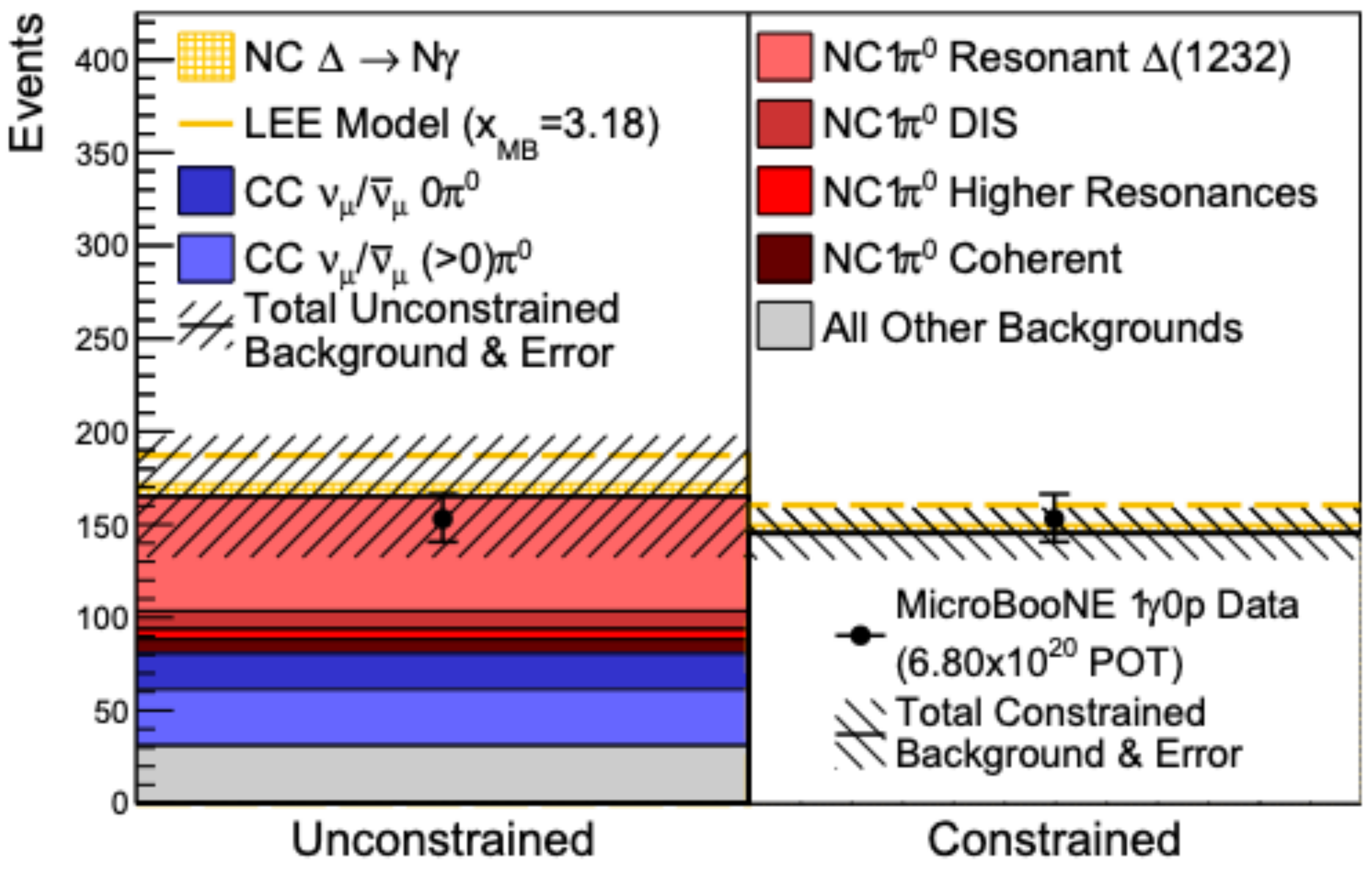


MicroBooNE's First LEE Results: Single Photons

PRL 128, 111801 (2022)

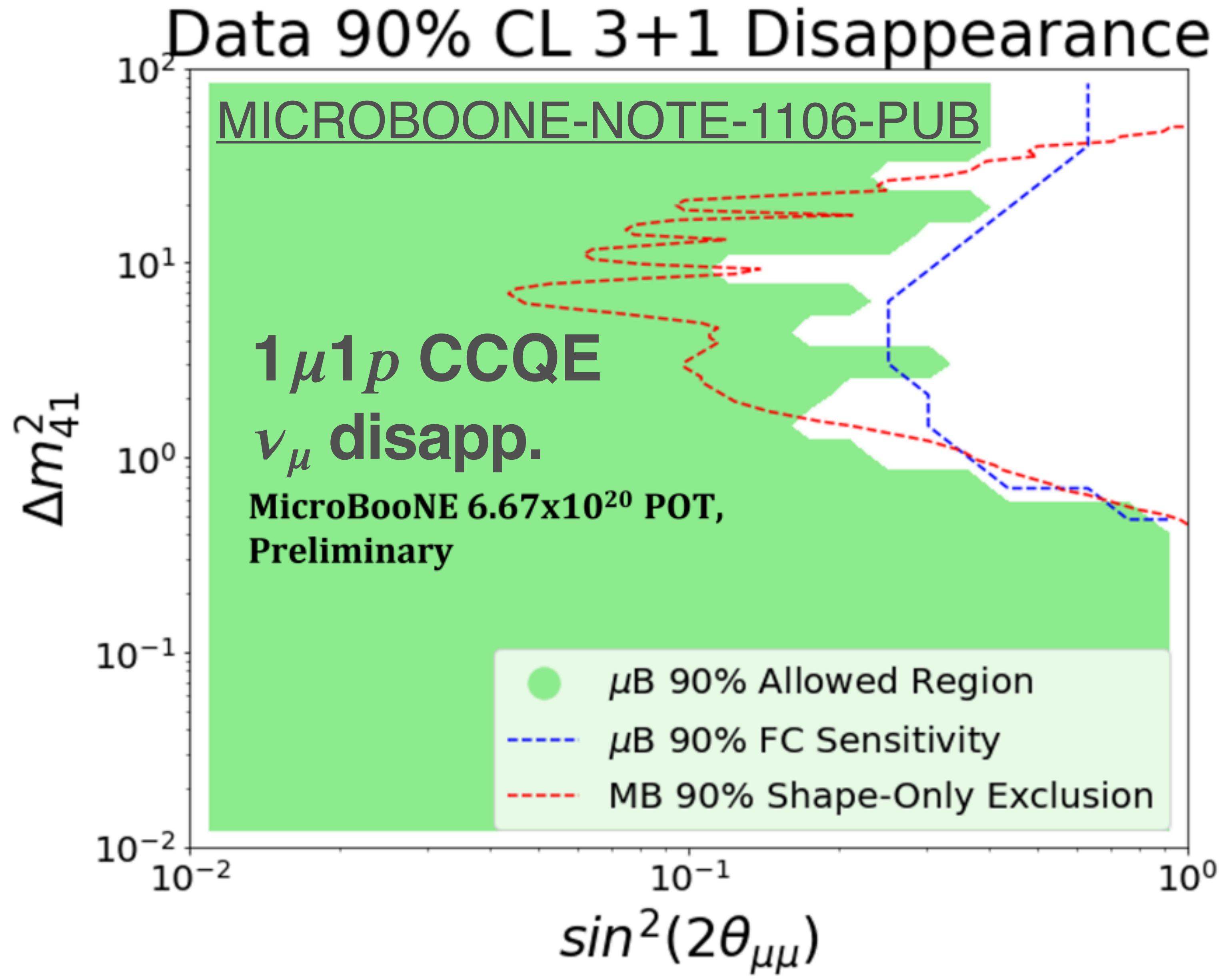
- MicroBooNE's single photon search studied two topologies: $1\gamma1p$ and $1\gamma0p$
- Main background to this search is NC π^0 events, which were constrained by side-band samples identified using parallel analysis tools
- No excess consistent with an enhancement of NC $\Delta \rightarrow N\gamma$ is observed, and sets a limit on the effective branching ratio for this decay that is 50× better than previous

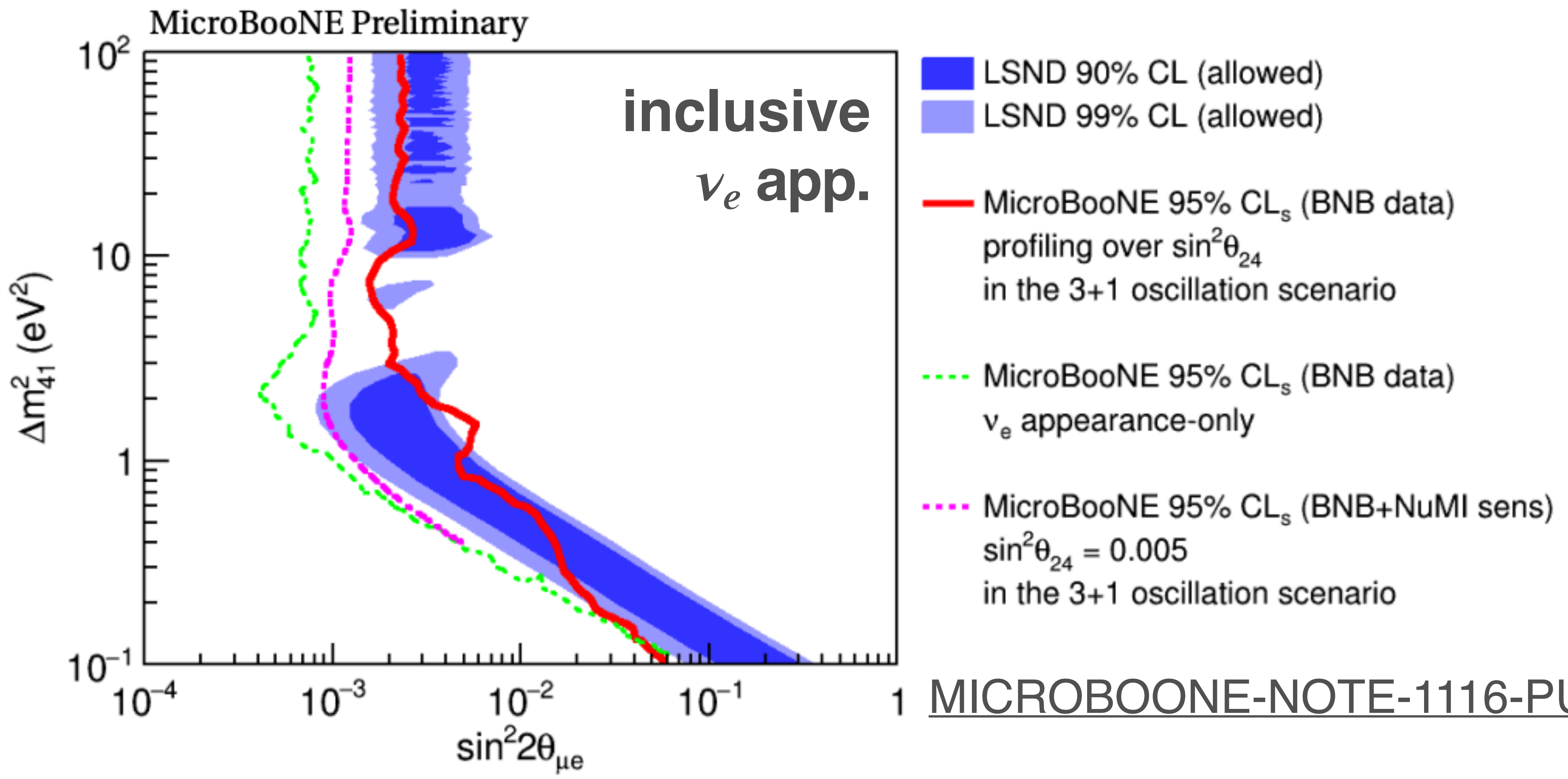




Searches for Sterile Neutrinos

- Building on first LEE results, now pursuing searches for sterile neutrinos within the 3+1 oscillation framework
- A $1\mu1p$ CCQE selection used in the $1e1p$ analysis has been used to study ν_μ disappearance in the BNB
- Selections used in the fully inclusive $1eX$ analysis have been used to study general 3+1 oscillations in BNB
- Results so far consistent with three neutrinos
- More coming soon:
  - Joint $1e1p$+$1\mu1p$ analysis in the BNB
    MICROBOONE-NOTE-1105-PUB
  - Inclusive analysis combining BNB and NuMI
    MICROBOONE-NOTE-1116-PUB
  - Future analyses addressing other sterile models

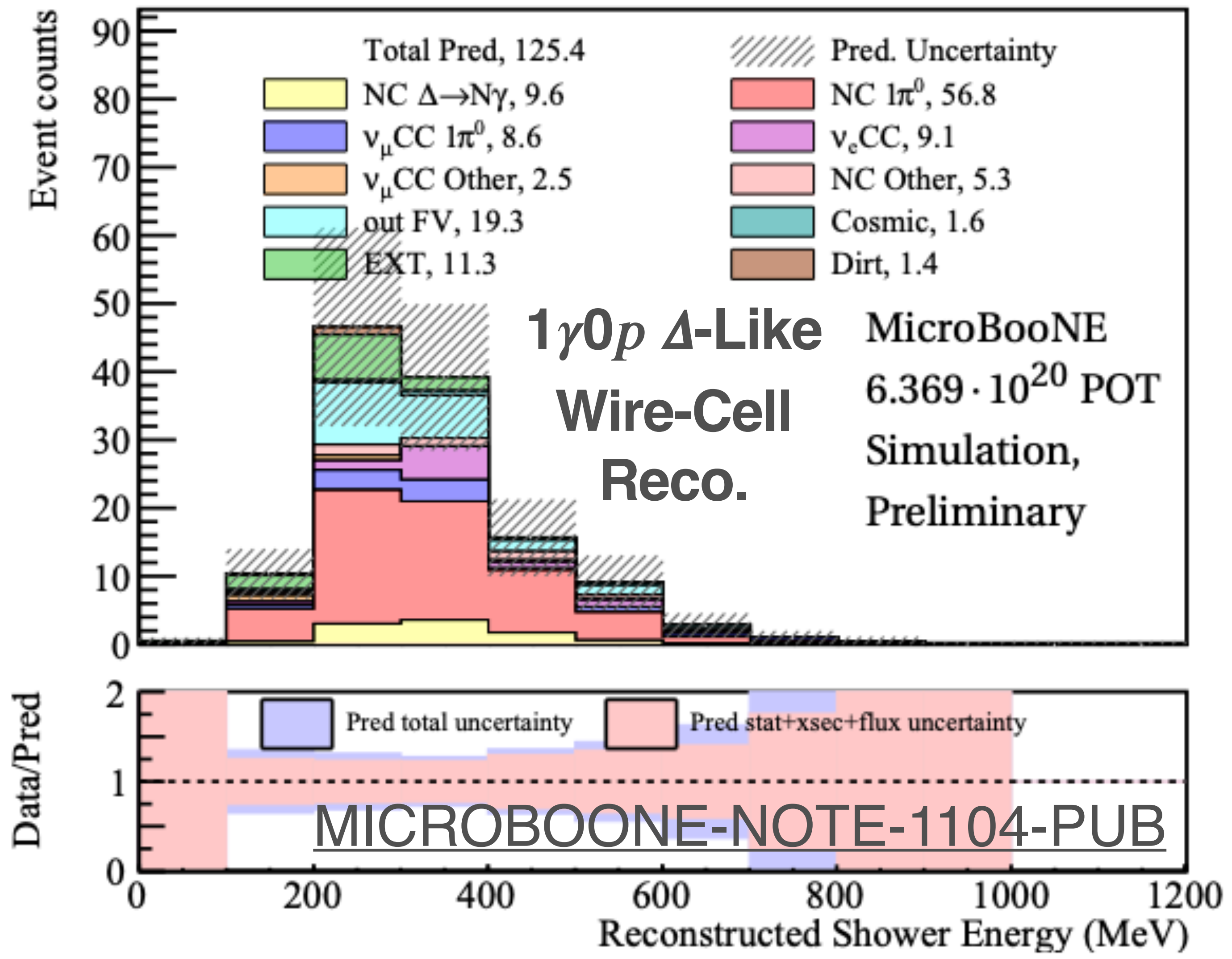


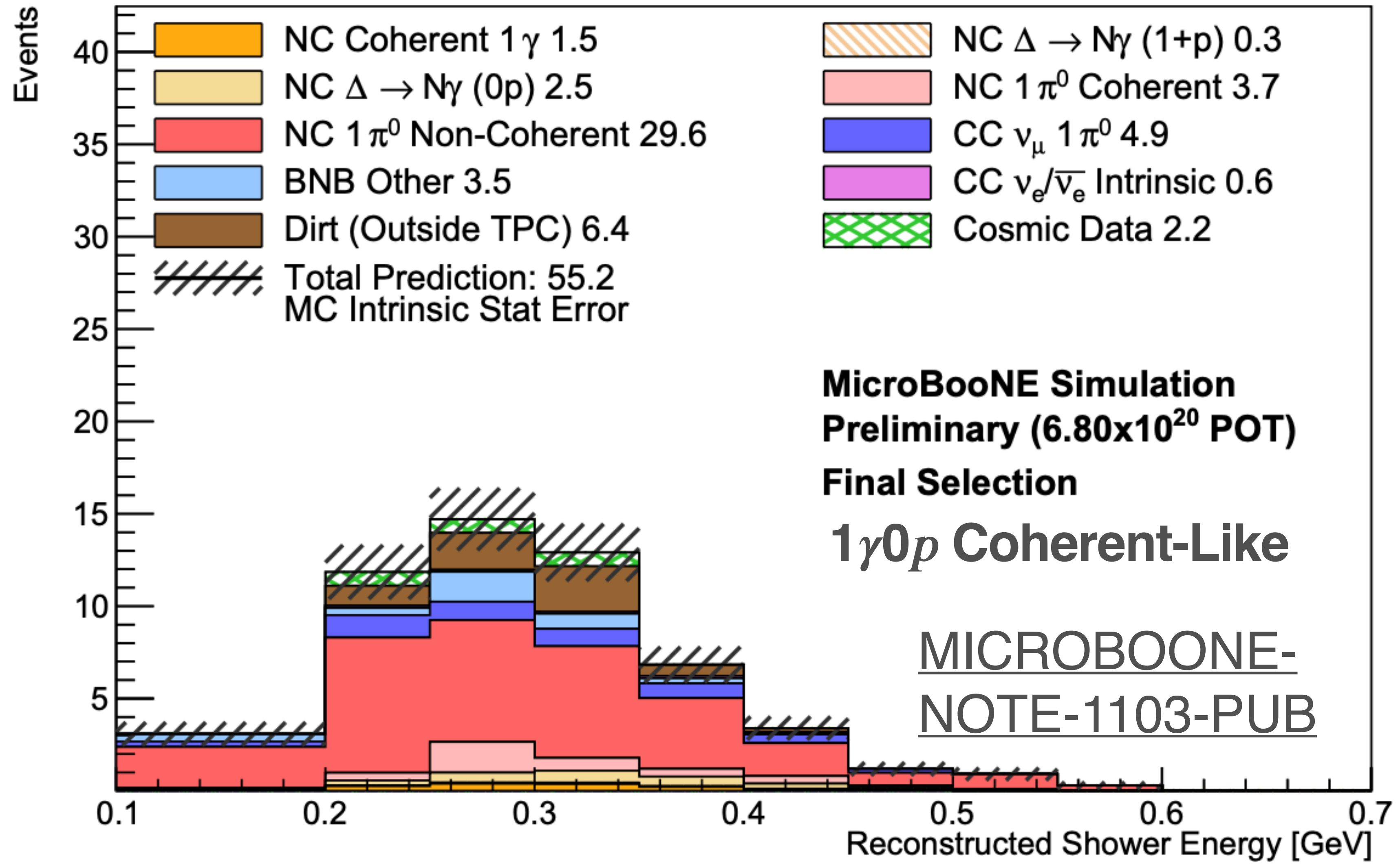


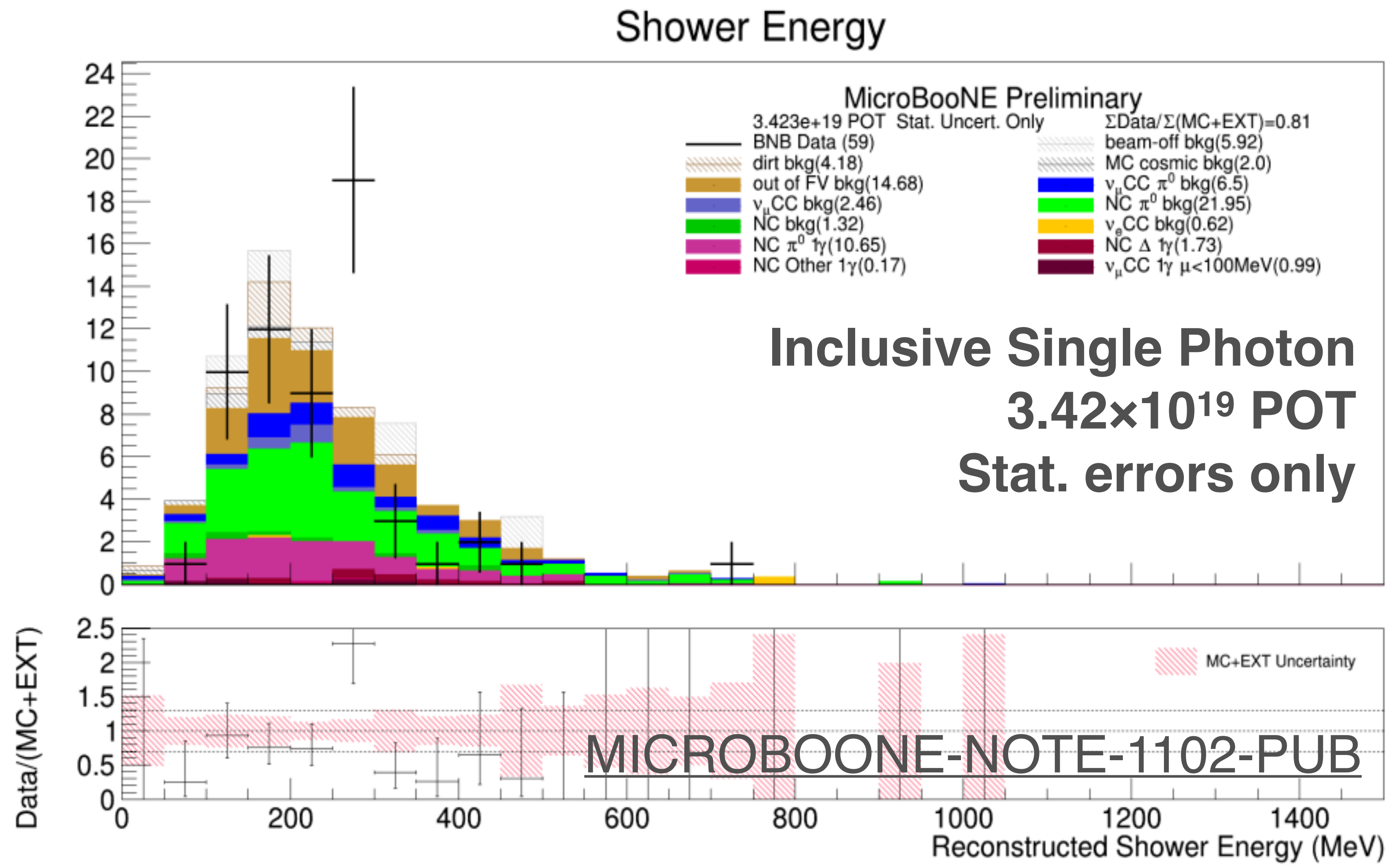
MICROBOONE-NOTE-1116-PUB

Investigating Other LEE Models

- Theory landscape related to the LEE anomaly continues to evolve — many new models involving photons or e^+e^- pairs in the final state
- Currently expanding investigations of photon-like and e^+e^- pair channels
  - Some preliminary results are shown below, and even more is on the way
- MicroBooNE will continue to test many LEE-motivated models of new physics, leveraging the excellent performance of our LArTPC detector and multiple reconstruction paradigms



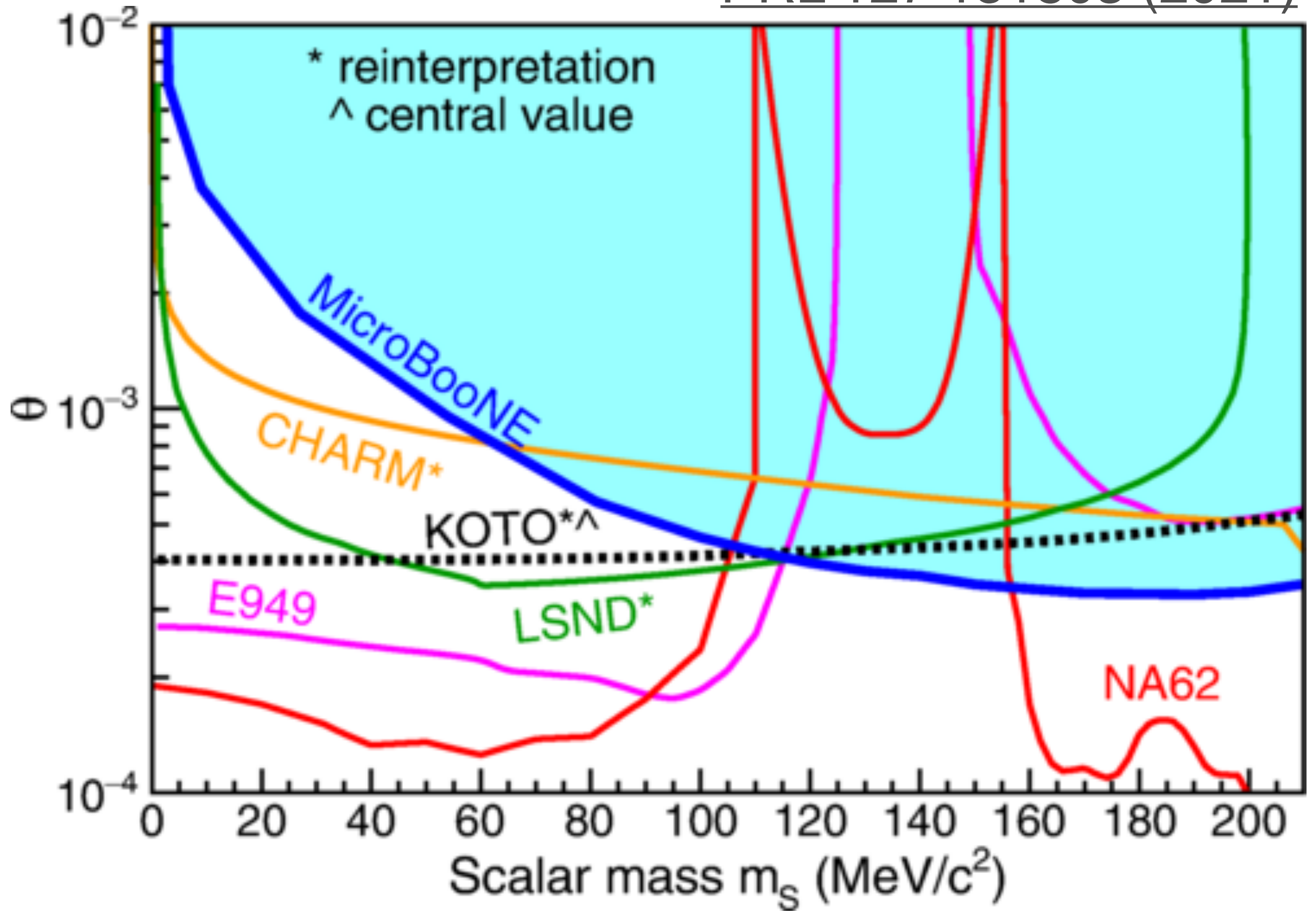


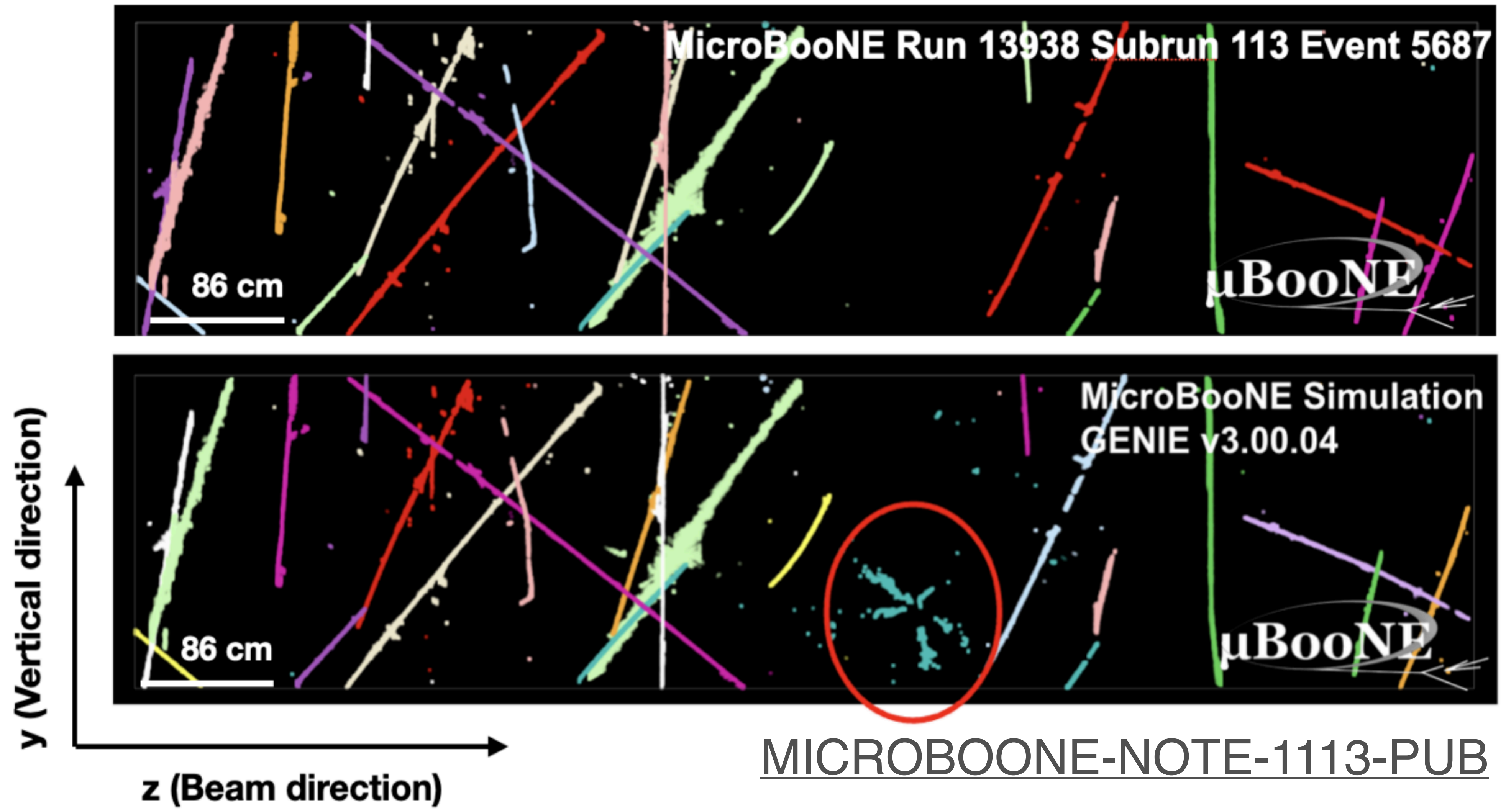


Searching for Other New Physics Signatures

- MicroBooNE is also capable of searching for many other new physics signatures
- Searched heavy neutral leptons from BNB decaying to $\mu\pi$ pairs PRD 101 052001 (2020)
- Searched for Higgs portal scalar bosons from NuMI decaying to e^+e^- pairs
- Searching for neutron-antineutron oscillations from neutrons bound in detector's argon nuclei
- More coming soon:
  - Updated heavy neutral lepton search
  - Updated Higgs portal scalar boson search
  - Search for dark trident interactions
  - Search for millicharged particles

PRL 127 151803 (2021)





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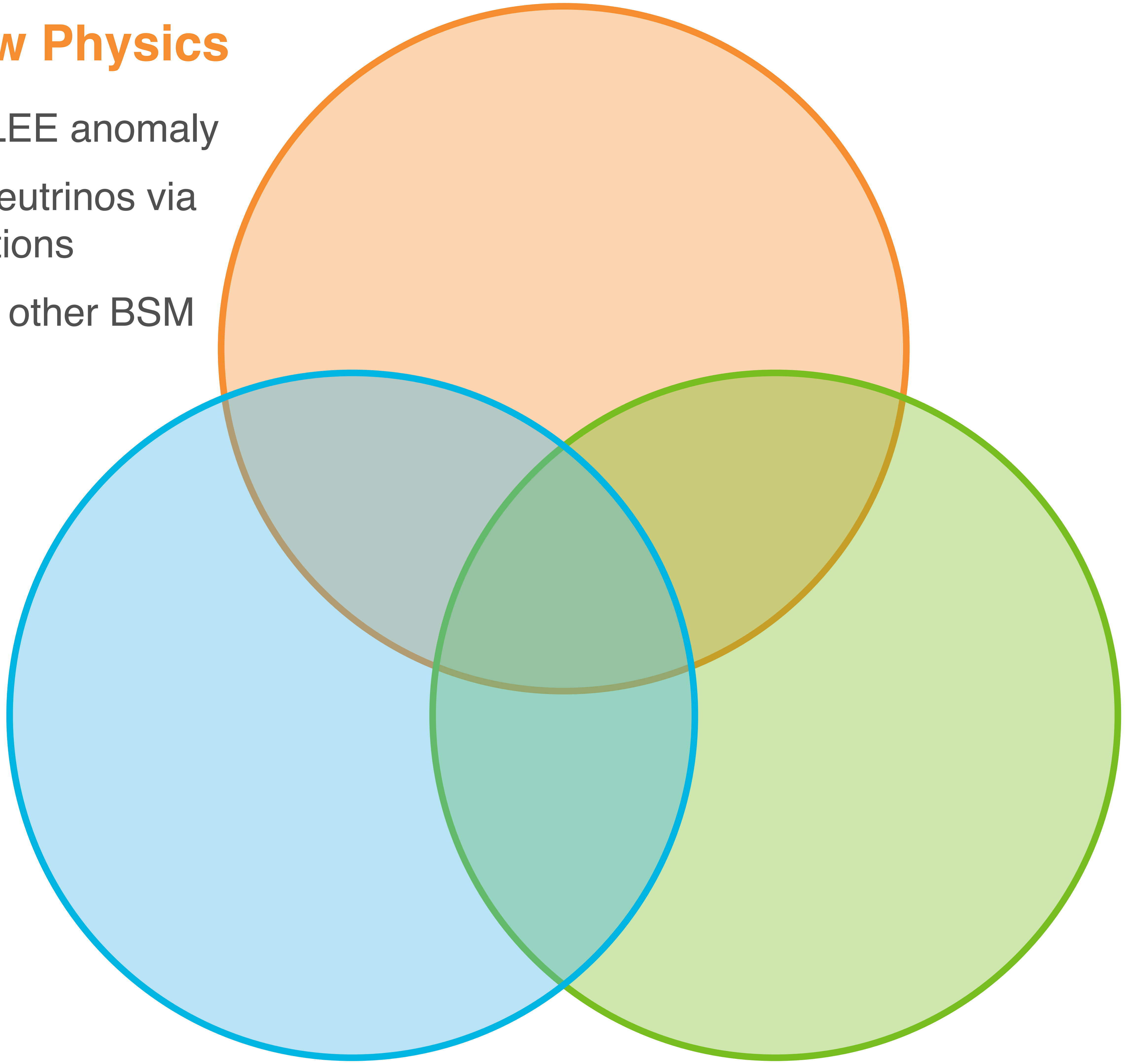
MicroBooNE's Scientific and Technical Accomplishments

Searching for New Physics

- Addressing origin of LEE anomaly
- Investigating sterile neutrinos via short baseline oscillations
- Searching for several other BSM physics signatures



Understanding ν–Ar Interactions

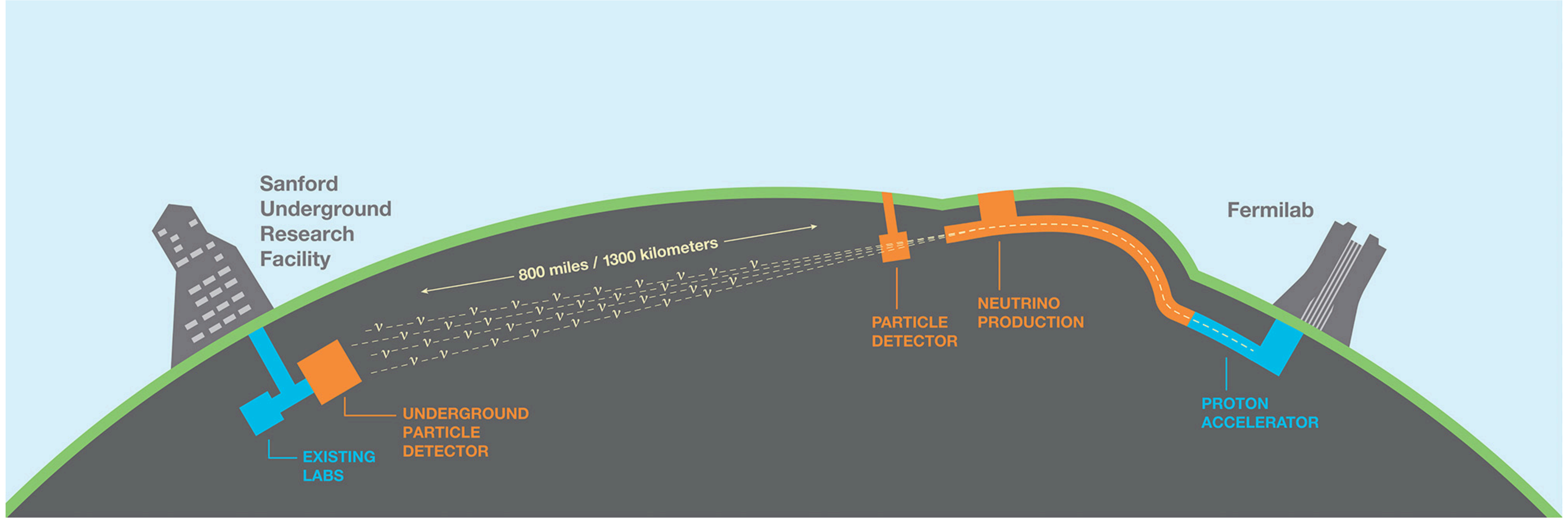
- Measuring a variety of inclusive and exclusive cross-sections
- Performing key tests of models
- Leveraging powerful detector, largest ν–Ar interaction dataset

Understanding LArTPCs & Developing Techniques

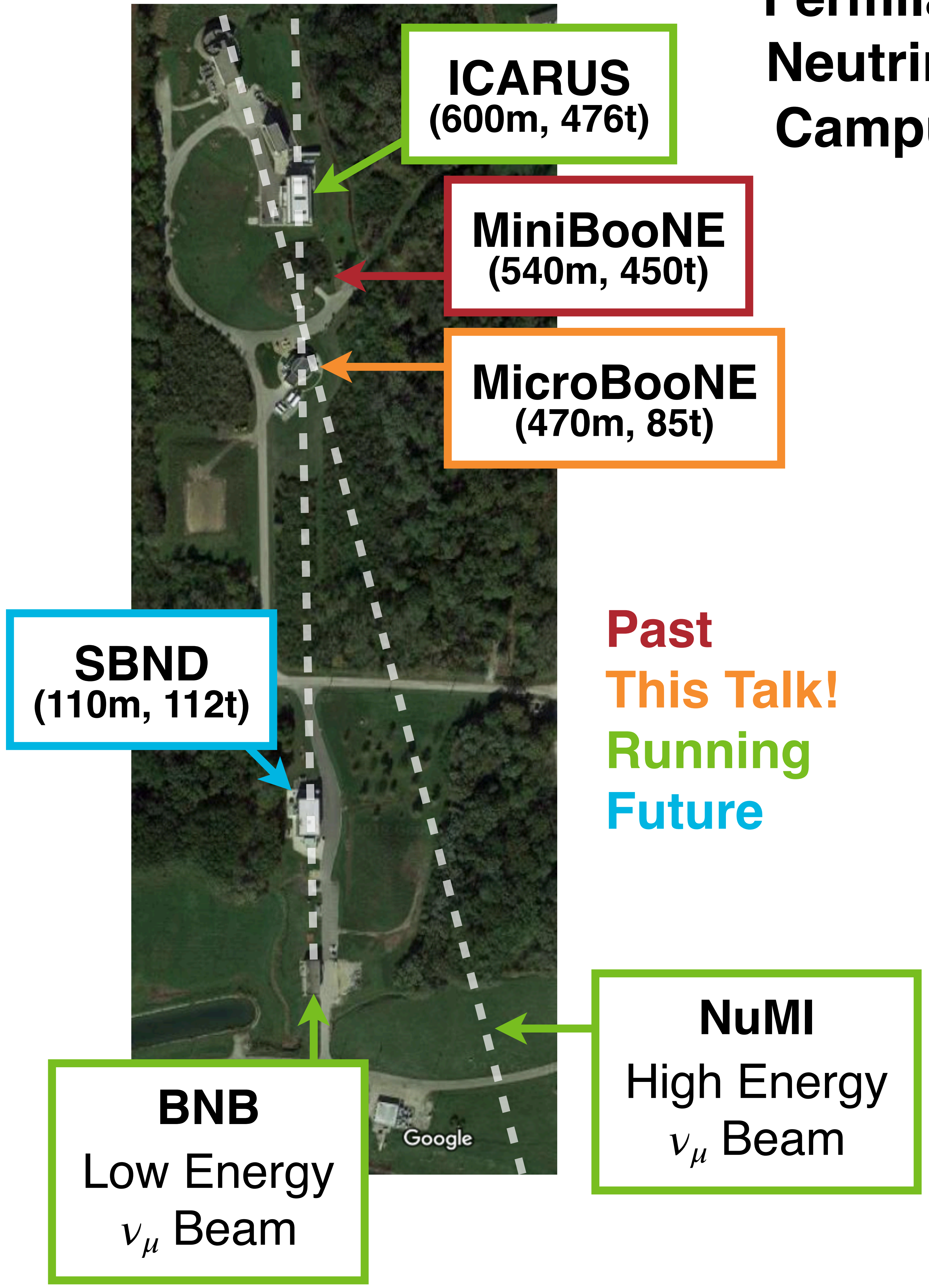
- Advances in detector physics, modeling, signal processing, and calibration
- Developed multiple novel reconstruction techniques
- Post-operation R&D studies

A Focus on the Future

- The full Short Baseline Neutrino (SBN) program, which includes ICARUS and SBND, has much more exciting physics yet to come
- SBN is critical to building LArTPC expertise leading up to the DUNE long-baseline oscillation experiment
- Will hear more about SBND, ICARUS, and DUNE in the next few talks!



Fermilab Neutrino Campus



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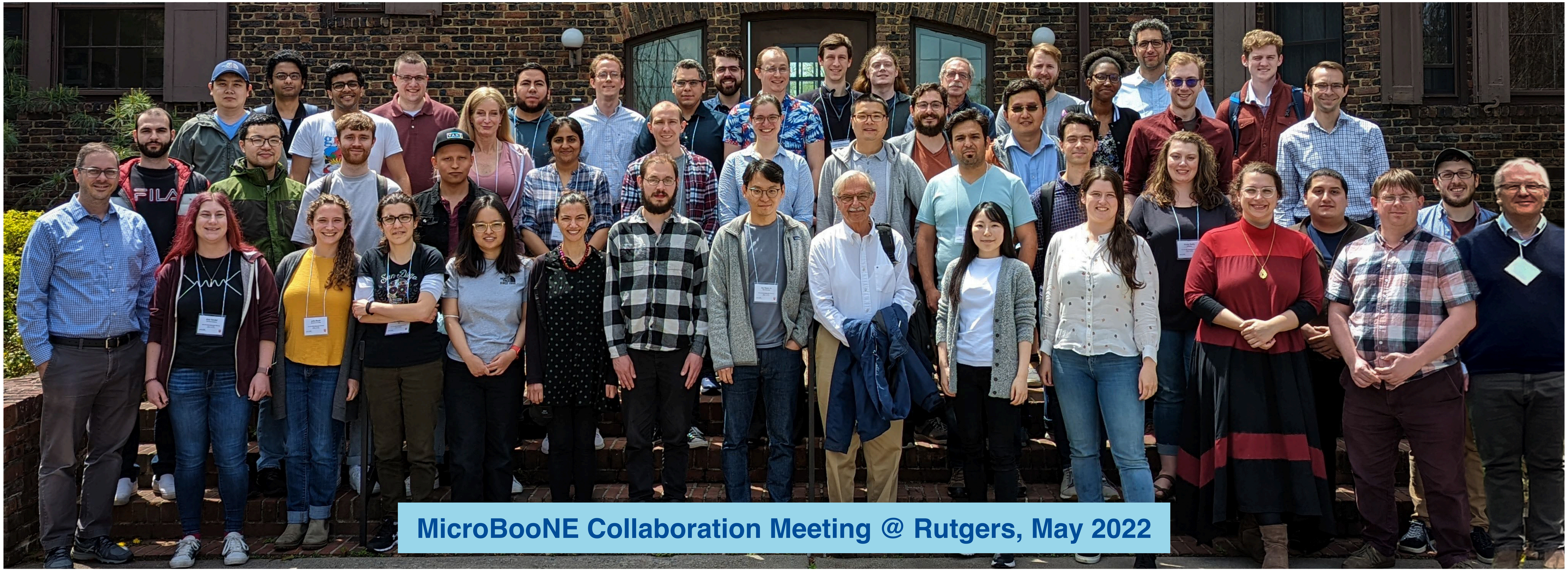
Fermilab

Thank you!



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Horizon 2020
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