

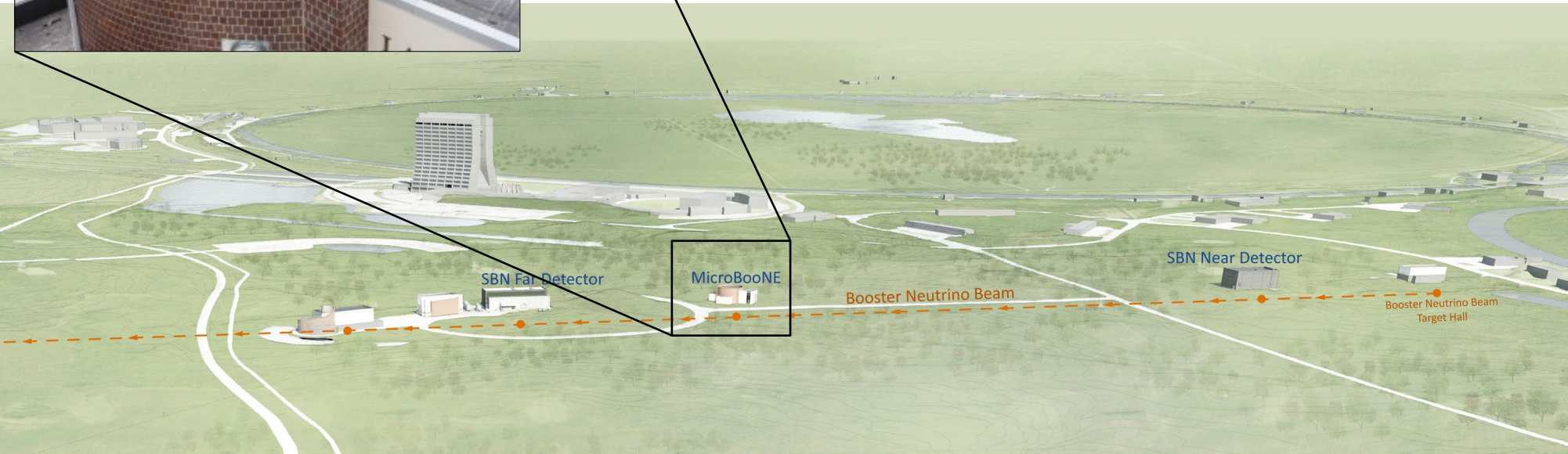
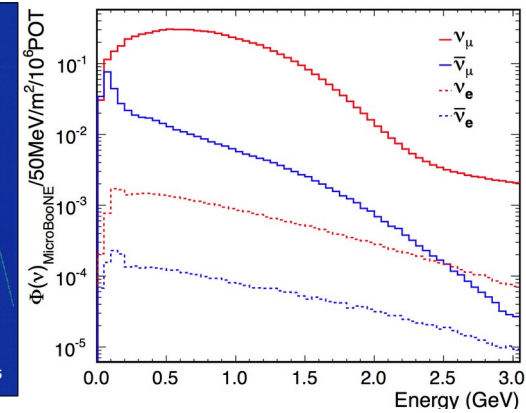
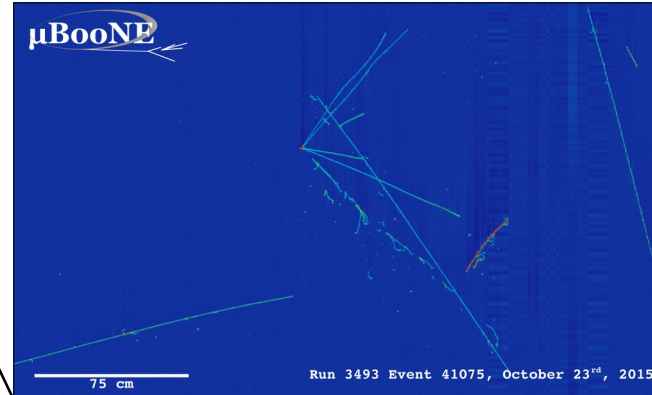
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# MicroBooNE: New Ideas for the Future

Andrew Furmanski  
Fermilab Users Meeting  
28<sup>th</sup> June 2023



# The MicroBooNE experiment



# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



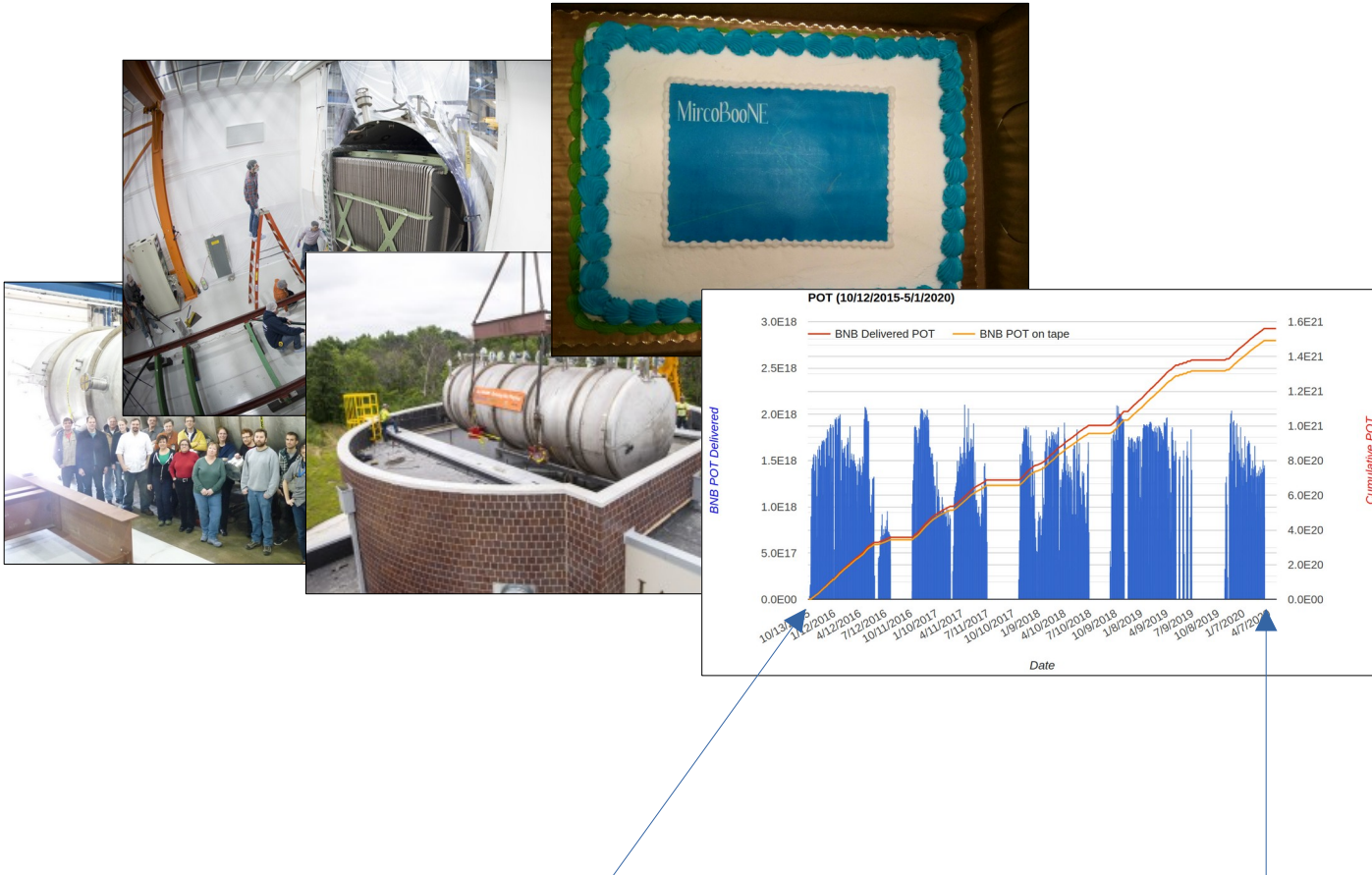
# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



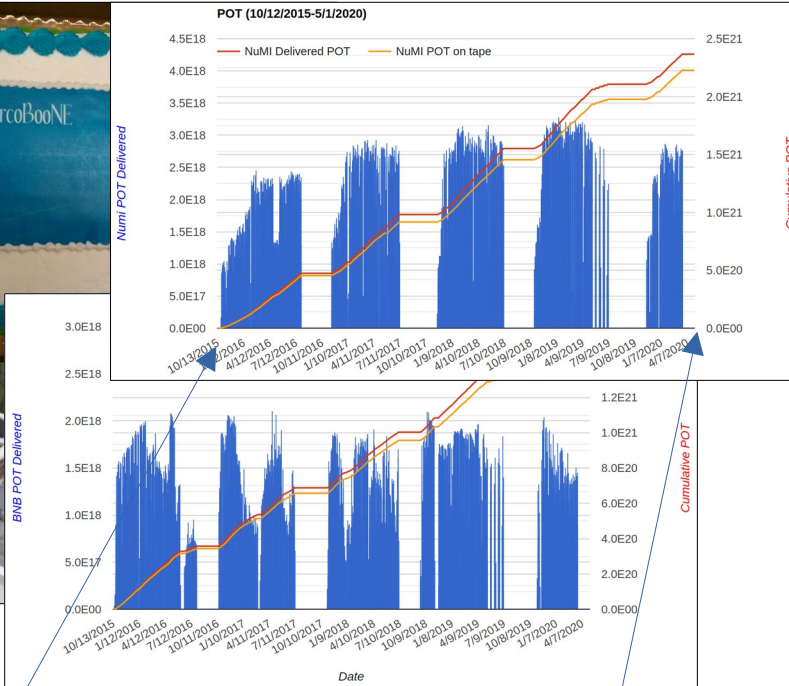
# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



# MicroBooNE Timeline

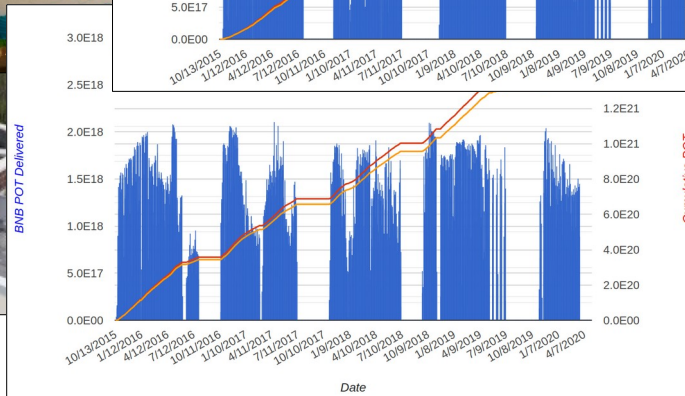
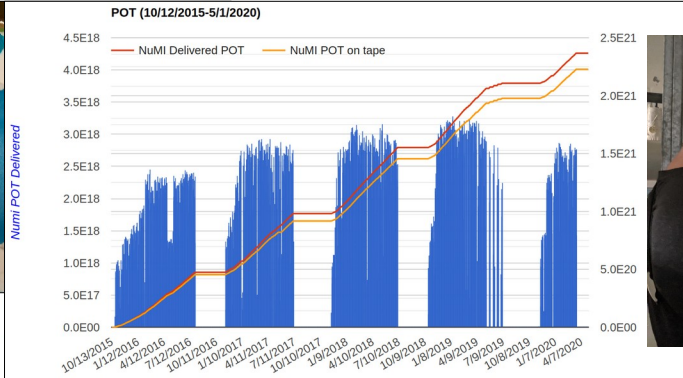


2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...





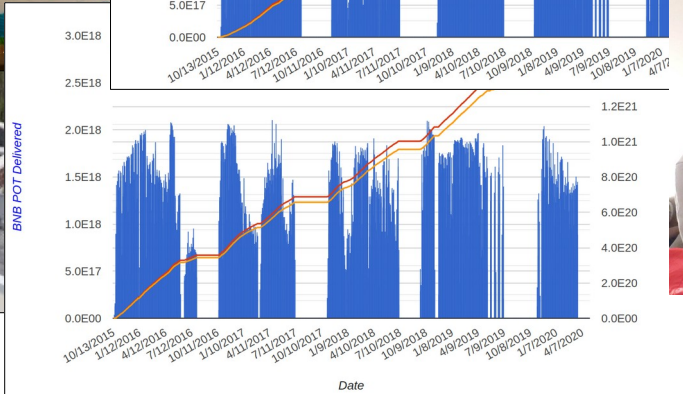
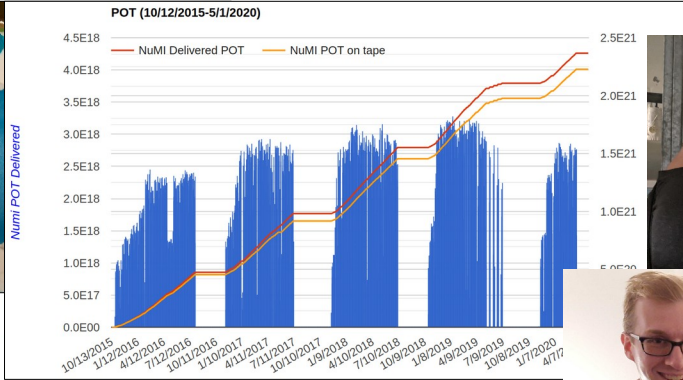
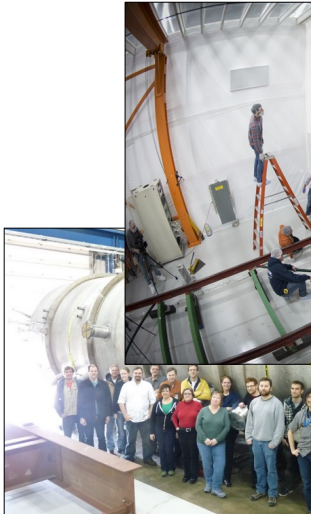
# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



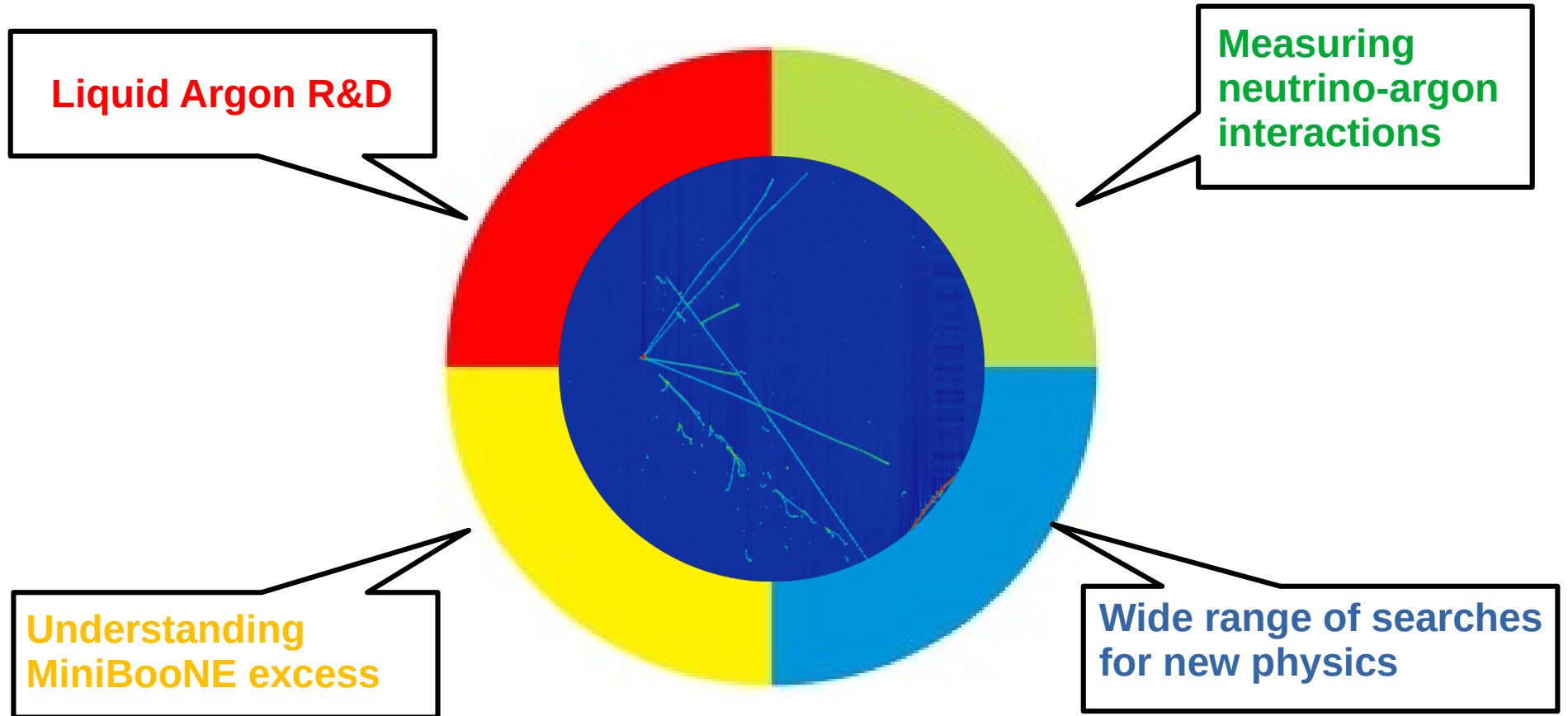
# MicroBooNE Timeline



2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 ...



# MicroBooNE physics goals



# MicroBooNE physics goals

Liquid Argon R&D

Measuring  
neutrino-argon  
interactions

Today: A non-exhaustive list of our achievements in all these categories, and our new ideas for the future!

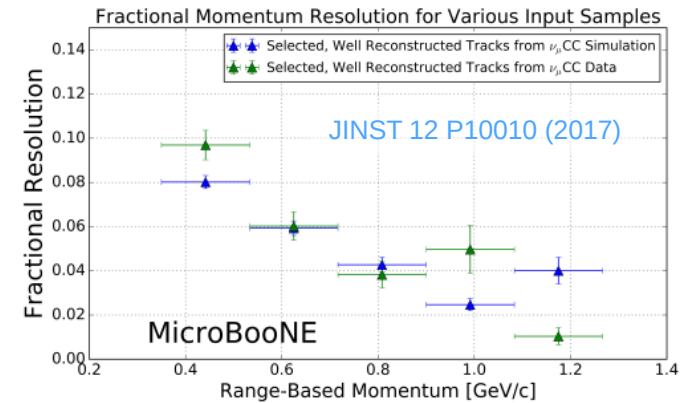
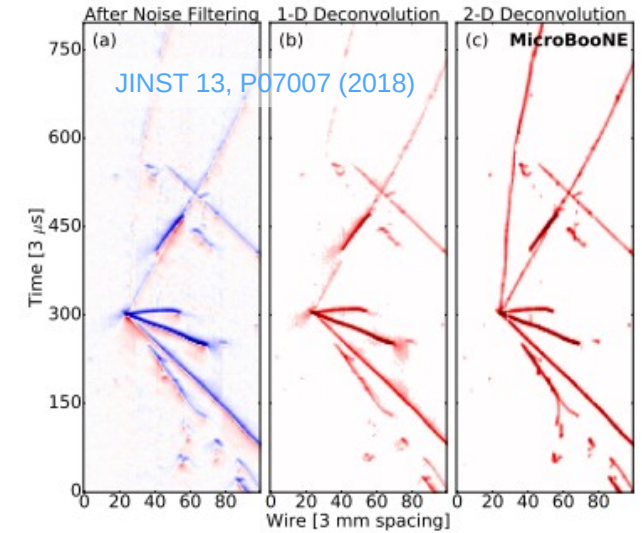
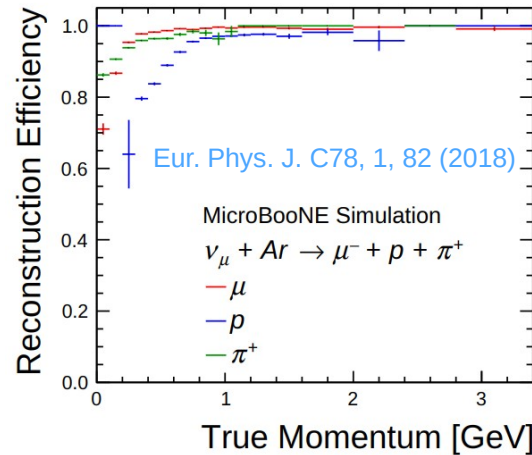
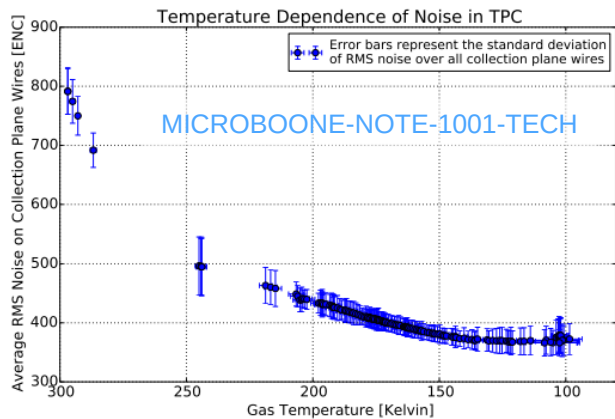
Understanding  
MiniBooNE excess

Wide range of searches  
for new physics



# Detector R&D - past

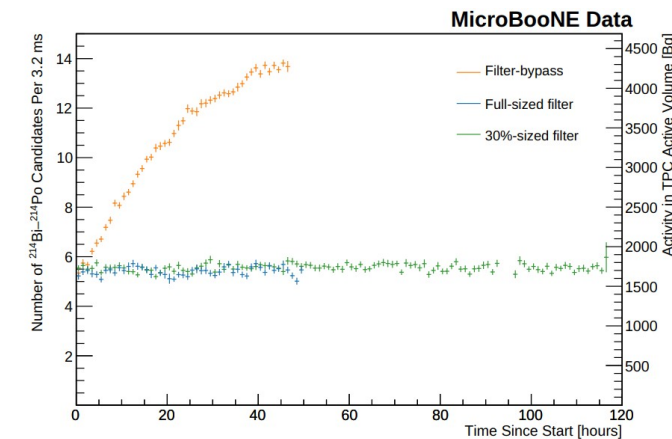
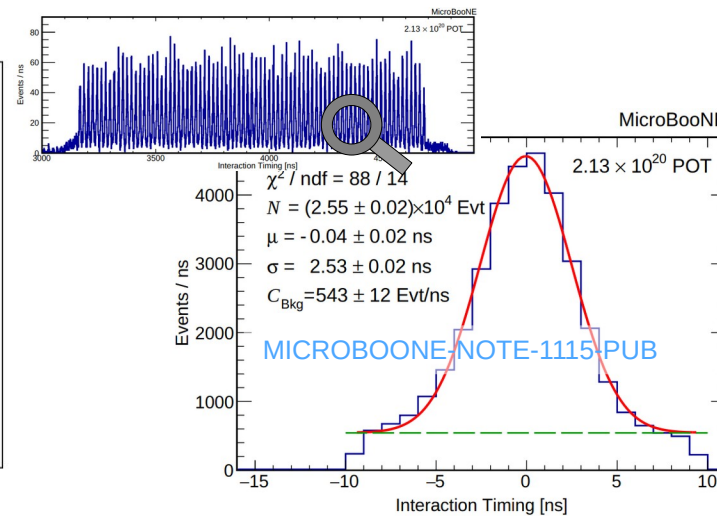
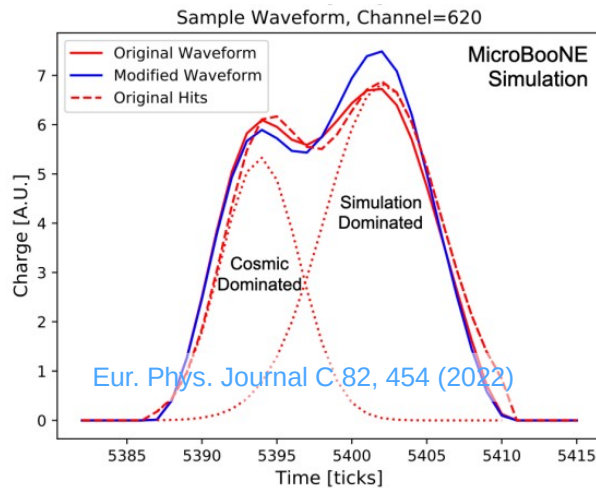
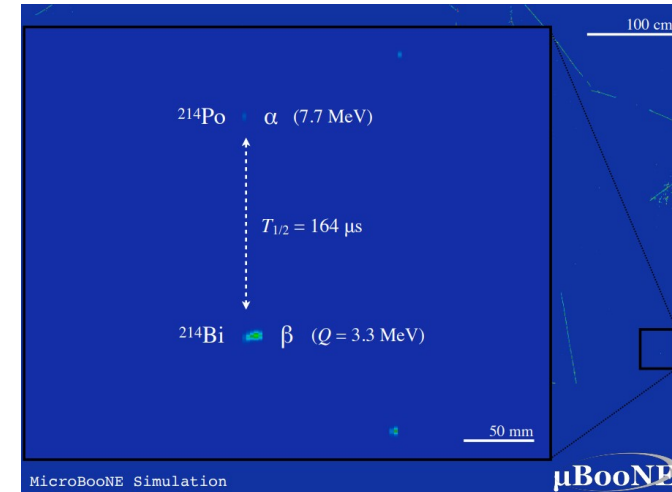
- MicroBooNE demonstrated liquid argon TPC technology at scale:
  - Argon purity
  - Cold, low-noise electronics
  - Laser calibration system
- Overhaul of signal simulation/processing
- Developed automated reconstruction tools



# Detector R&D - present

2022 JINST 17 P11022

- Unique assessment of detector response uncertainties
- Demonstration of ns-timing to identify beam bunch structure
  - Implications for BSM searches
- R&D run demonstrated sensitivity to low-energy radioactivity contaminants
  - And that our filter removes them!



# Detector R&D - future

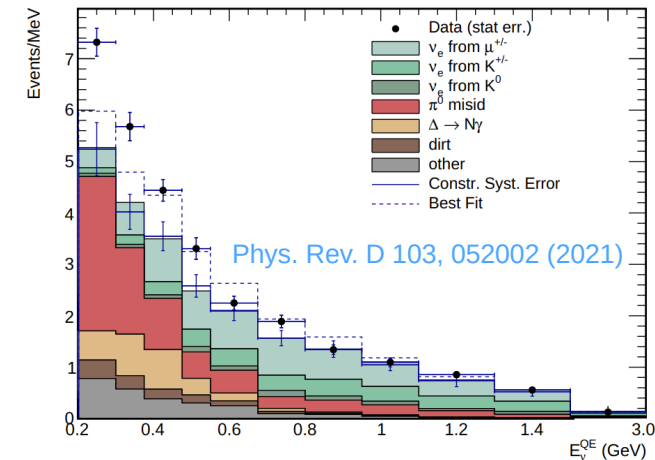
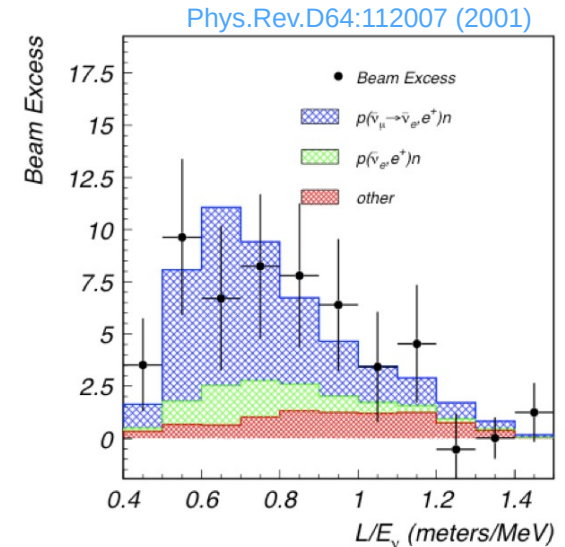
- Argon is being vented from the cryostat
  - We are monitoring resistances as the LAr boils off
- After venting, we will find out what 8 years of cryogenic operation does to a LArTPC
- We are continuing to analyse the data from our R&D run
- Demonstration of TPC-based trigger, and more!





# MiniBooNE/LSND – the past

- LSND indication of neutrino oscillations at  $\Delta m^2 \sim 1 \text{ eV}^2/\text{km}$
- MiniBooNE excess of low-energy electron-like events
  - We call this the “low-energy excess” or LEE
  - One interpretation is also oscillations from eV-scale sterile neutrinos

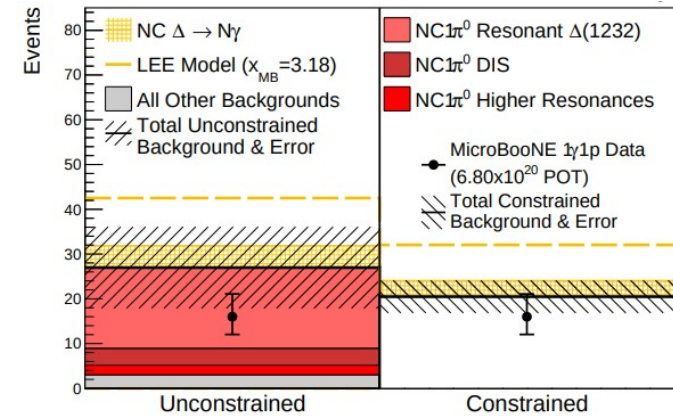


# Testing MiniBooNE's Excess

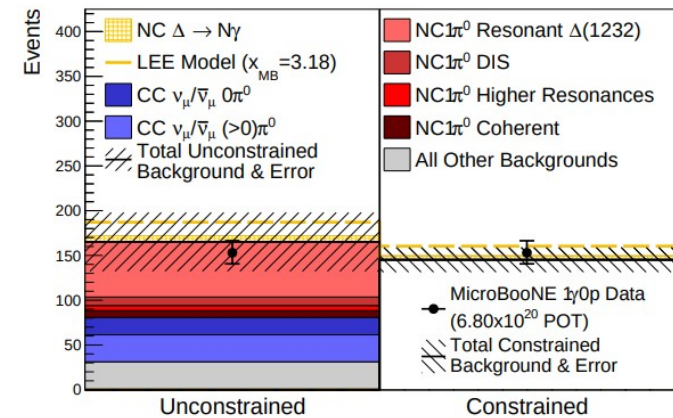
- Four electron neutrino channels
- Two photon channels
- No evidence for an excess!

Phys. Rev. Lett. 128, 241801 (2022)

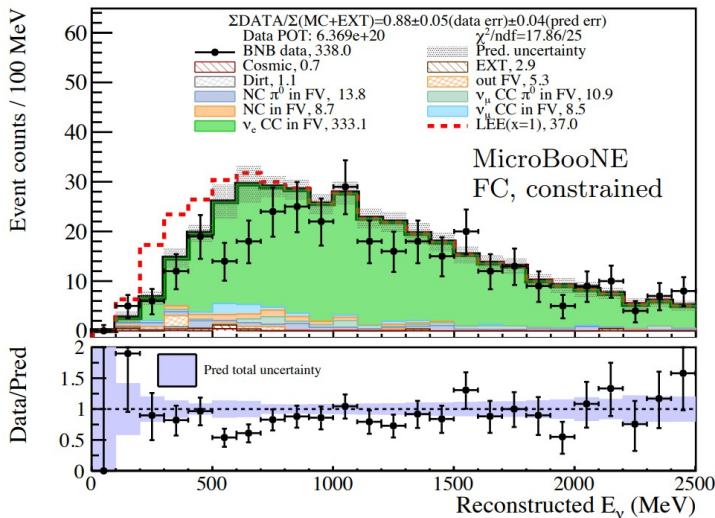
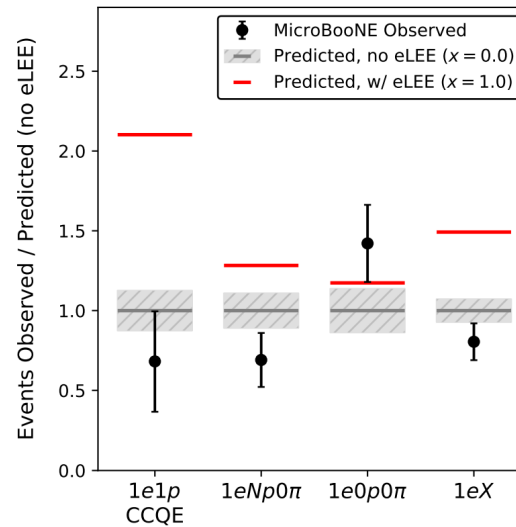
Phys. Rev. Lett. 128, 111801 (2022)



(a)

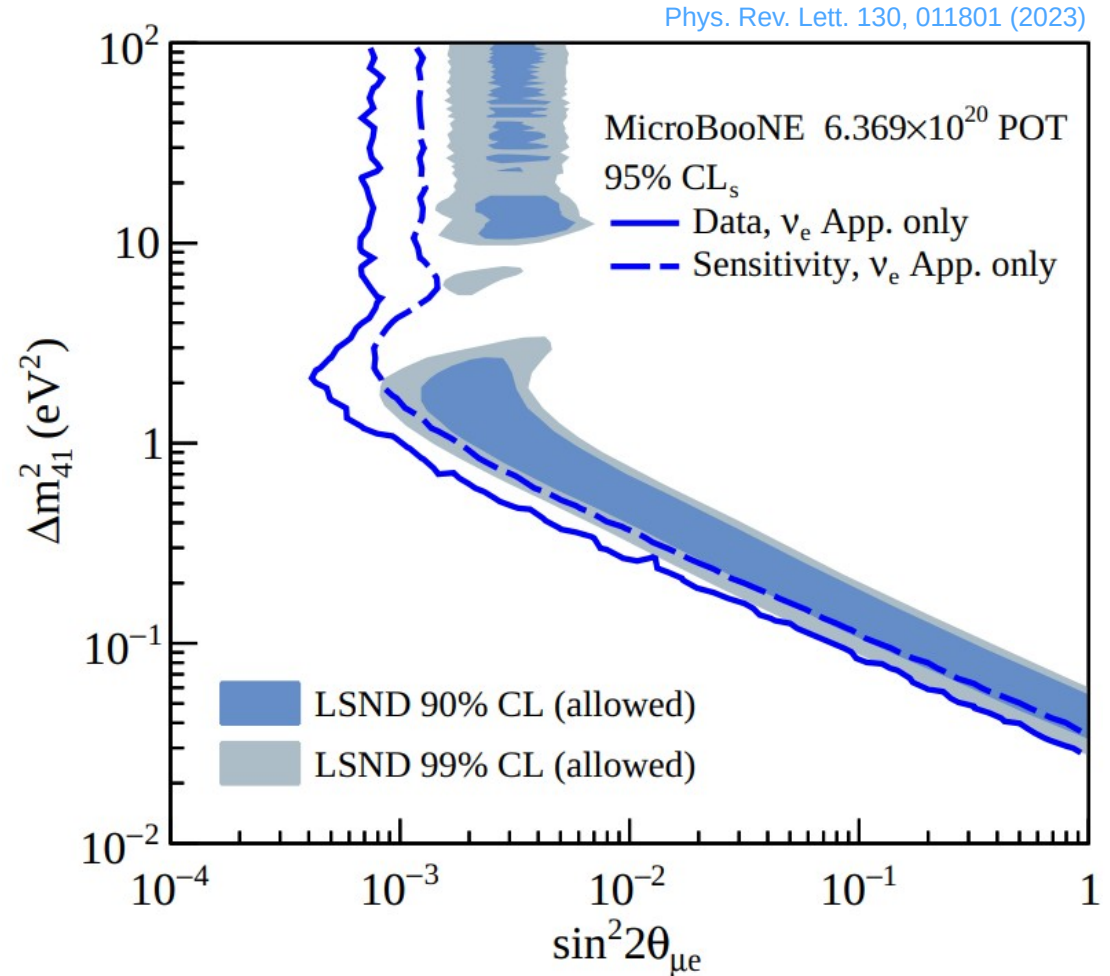


(b)



# Testing the oscillation hypothesis

- Considering a 2-flavour oscillation of  $\nu_\mu \rightarrow \nu_e$
- Data rules out LSND allowed region
- But what if that's not the only thing happening?

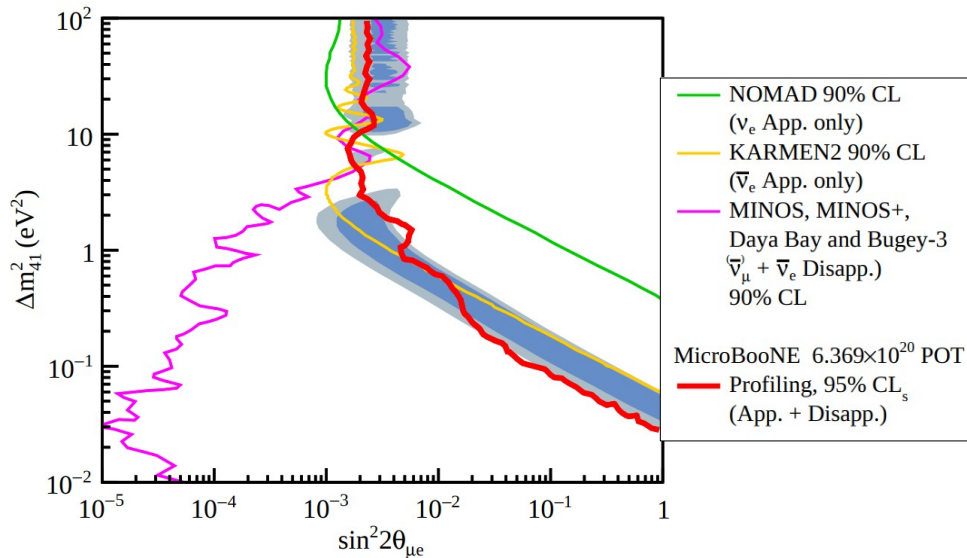
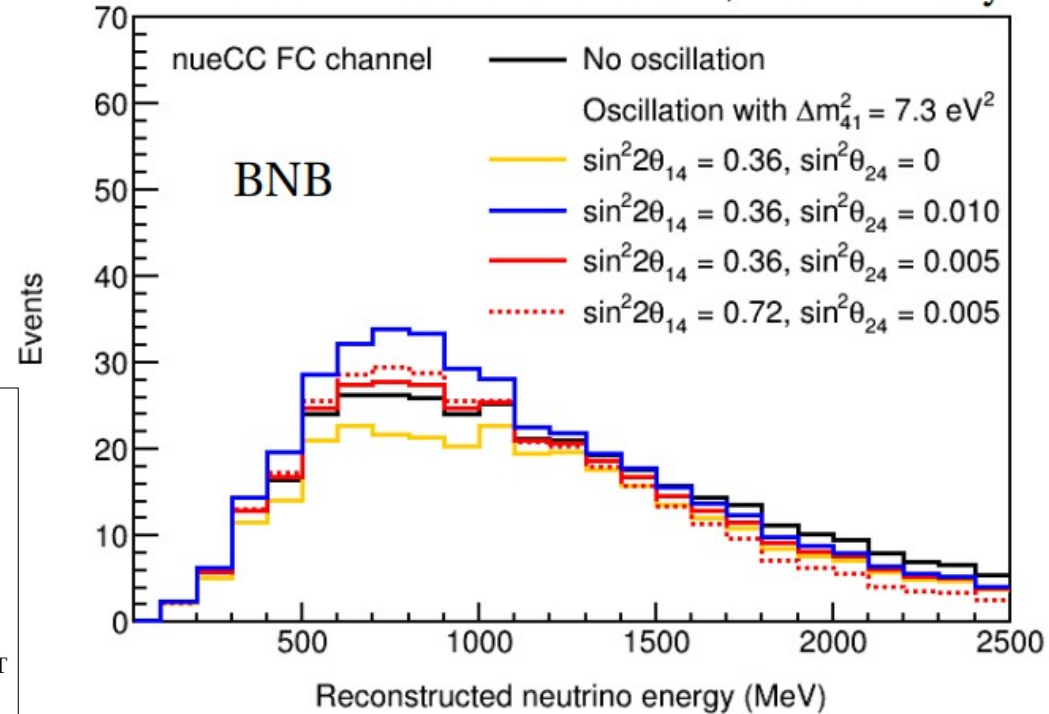


# Testing the oscillation hypothesis

- Profiling over all parameters, allowing for electron neutrino disappearance too
- Problem – electron neutrino disappearance can perfectly cancel an appearance signature!

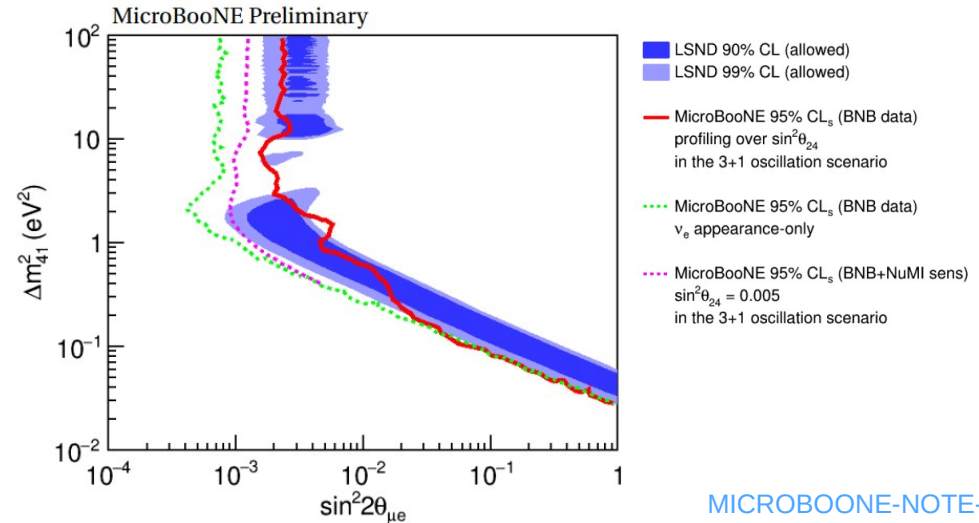
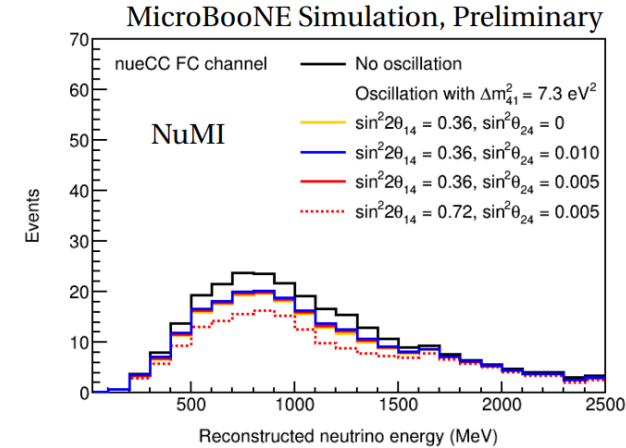
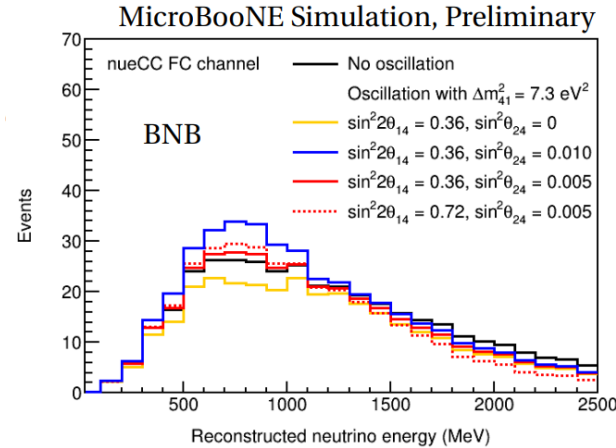
MICROBOONE-NOTE-1116-PUB

## MicroBooNE Simulation, Preliminary



# Oscillations - future

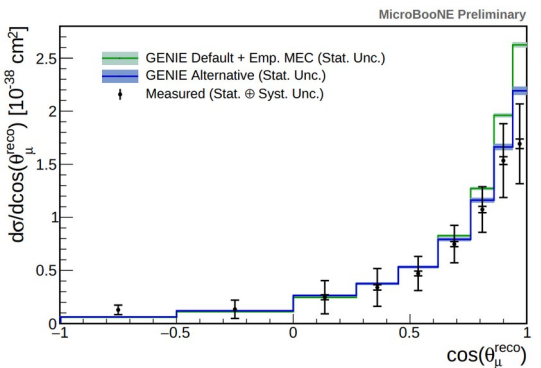
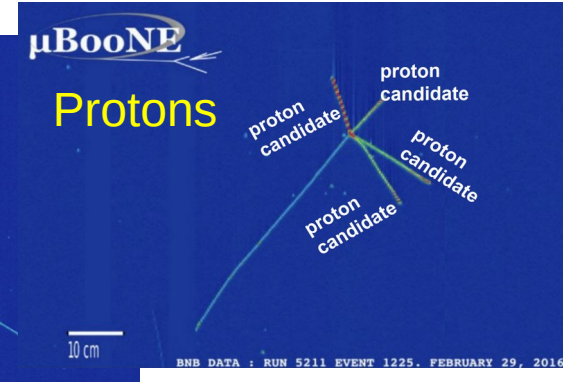
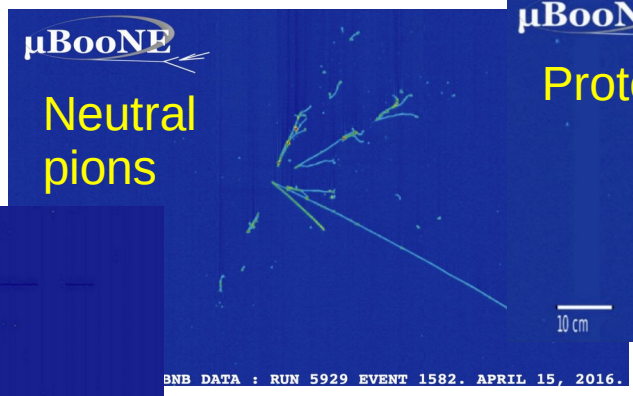
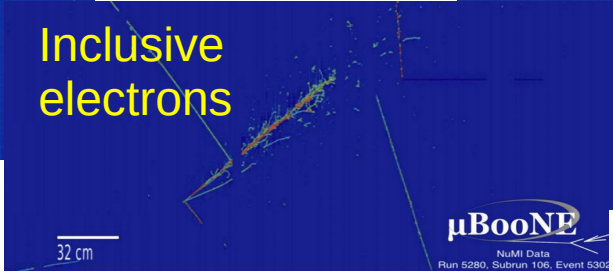
- Change the  $\nu_\mu/\nu_e$  ratio in the beam!
- Or, use a different beam
- NuMI data will break this degeneracy – analysis in progress!



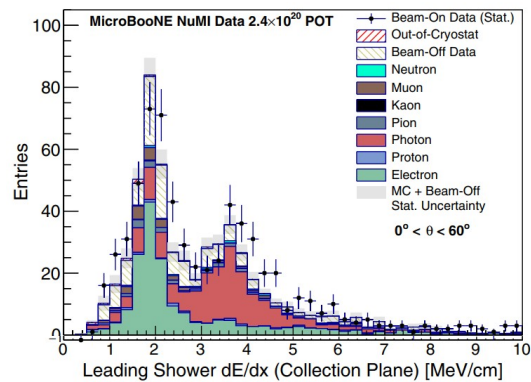
MICROBOONE-NOTE-1116-PUB



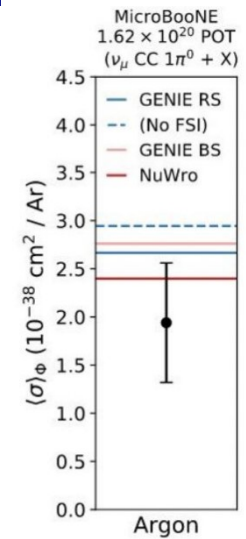
# Neutrino interactions - past



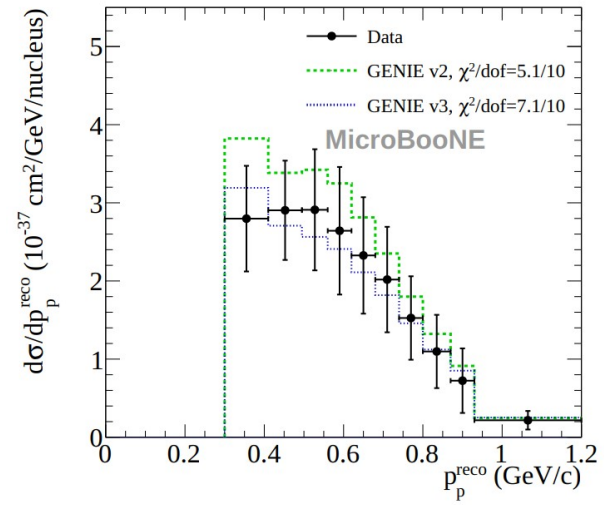
Phys. Rev. Lett. 123, 131801 (2019)



Phys. Rev. D104, 052002 (2021)



Phys. Rev. D99, 091102(R) (2019)



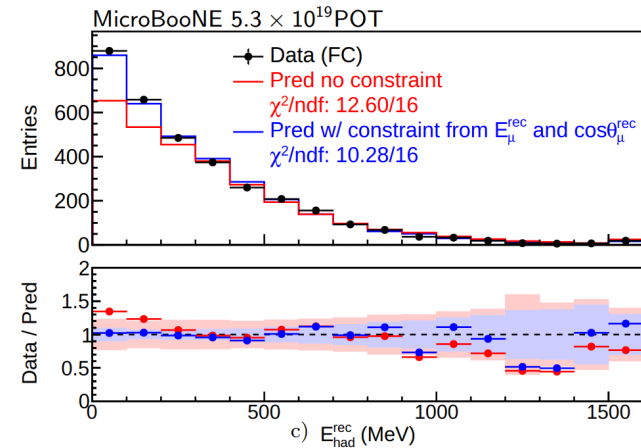
Phys. Rev. D102, 112013 (2020)



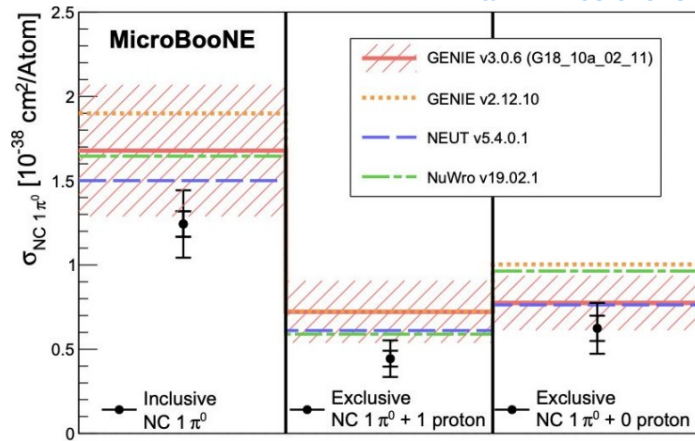
# Neutrino interactions - present

- Detailed tests of interaction models
- More exclusive final states
  - Proton counting
  - First ever two-proton differential cross sections!

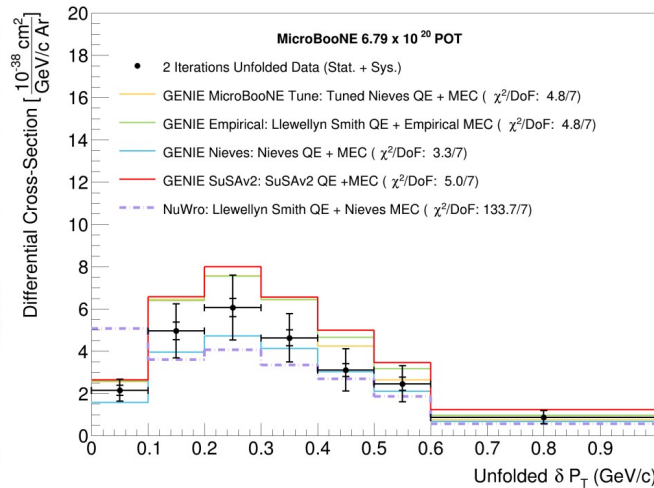
Phys. Rev. Lett. 128, 151801 (2022)



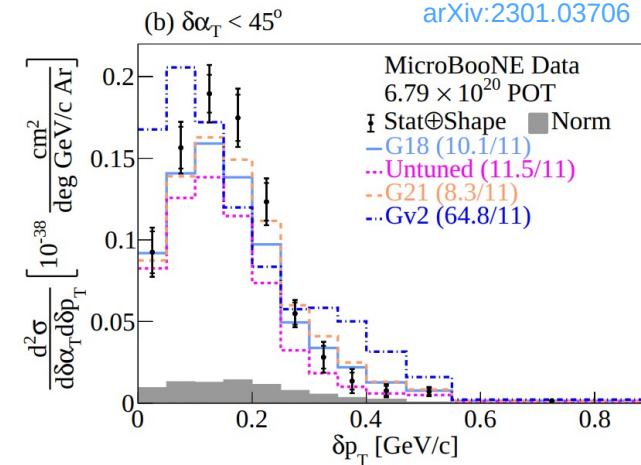
arXiv:2205.07943



arXiv:2211.03734



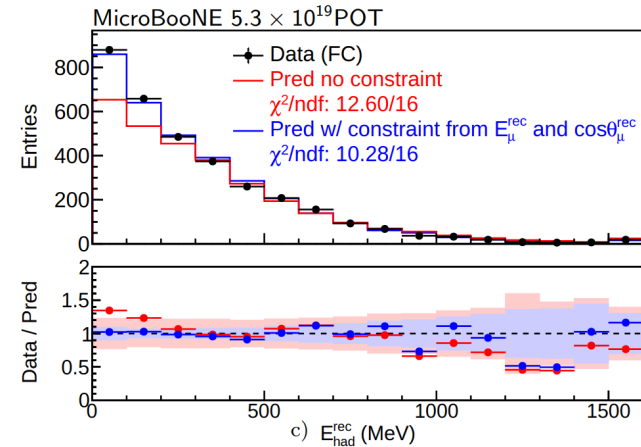
arXiv:2301.03706



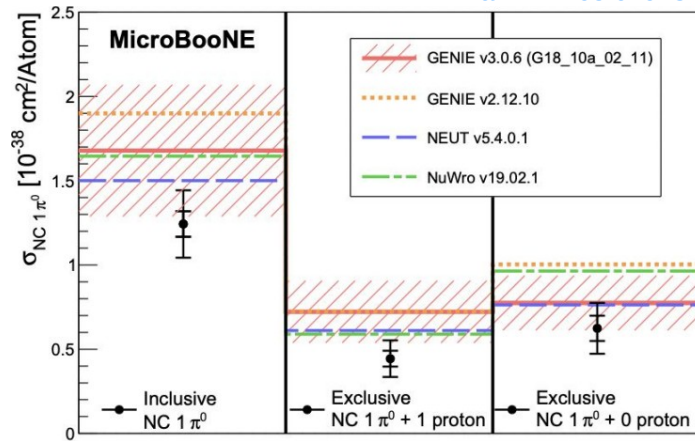
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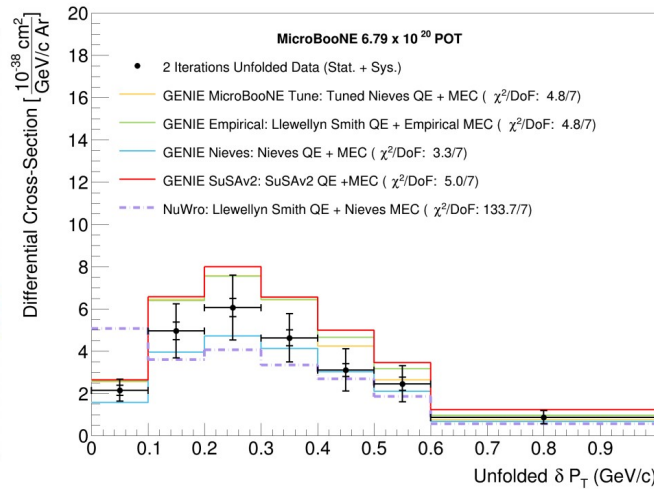
Phys. Rev. Lett. 128, 151801 (2022)



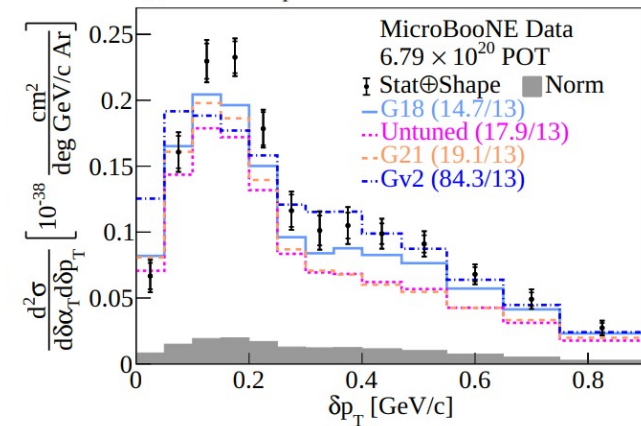
arXiv:2205.07943



arXiv:2211.03734



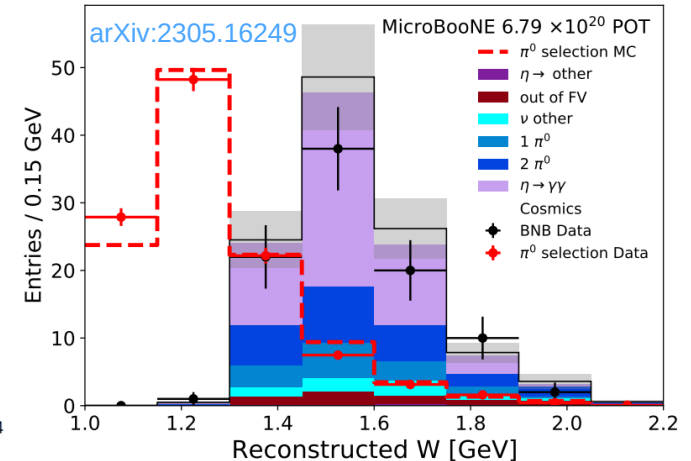
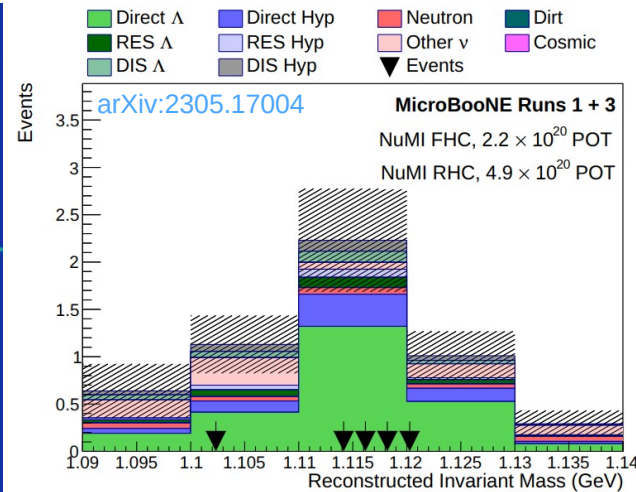
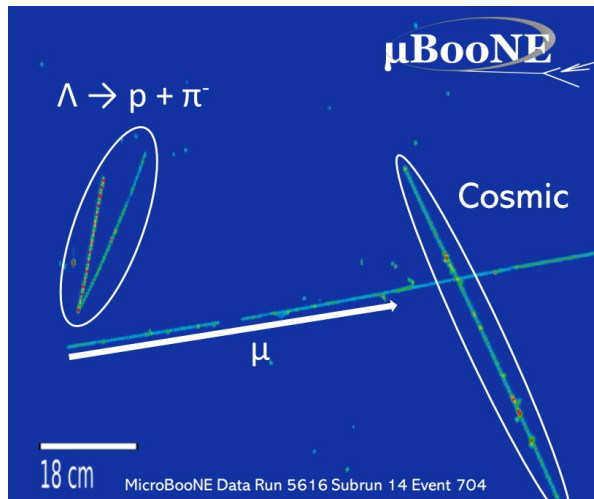
(e)  $135^\circ < \delta\alpha_T < 180^\circ$  arXiv:2301.03706





# Neutrino interactions - future

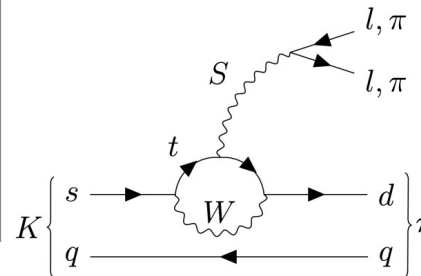
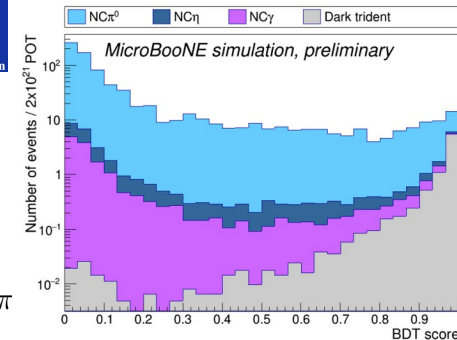
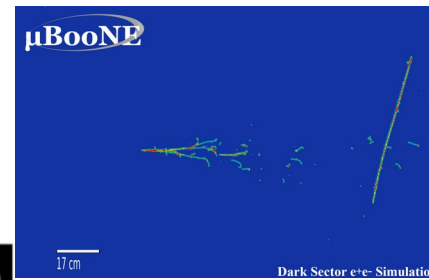
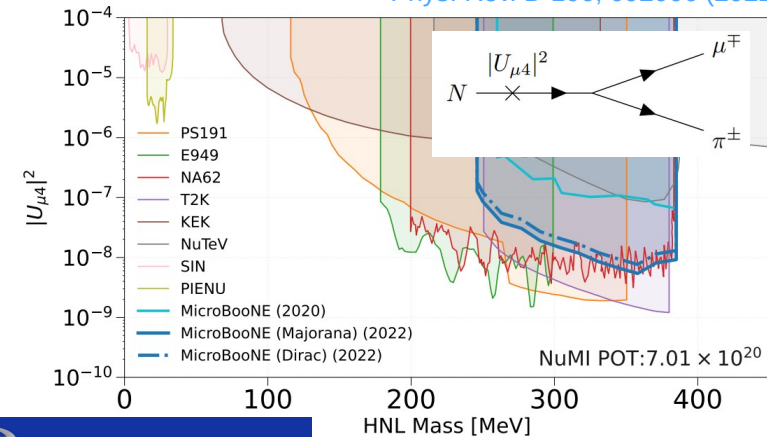
- Rare particle production – Lambda,  $\eta$
- Future analyses: harder final states
  - neutrons, de-excitation photons, and more
- More detailed tests of interaction model across multiple topologies and final states
  - **30+ ongoing analyses!**



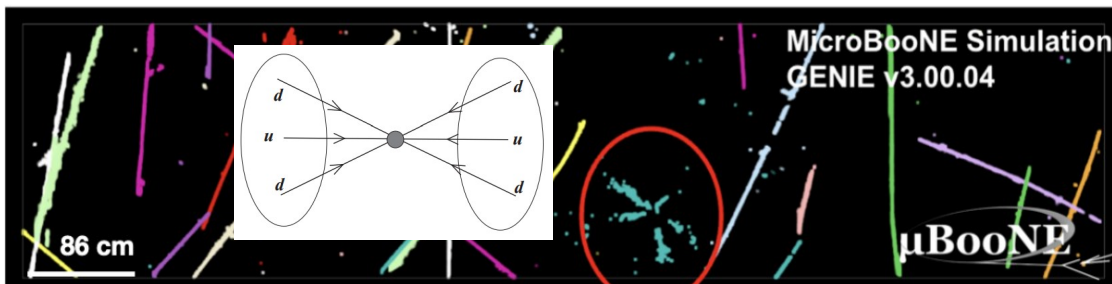
# Beyond the Standard Model

- Searches for long lived neutral particles
  - Heavy Neutral Leptons
  - Higgs Portal Scalar
- Coming soon – baryon number violation
  - Neutron-antineutron oscillation
- Future - dark tridents, Millicharged particles, and much more!
  - Some of these models will address the MiniBooNE excess from other directions!

Phys. Rev. D 106, 092006 (2022)



MICROBOONE-NOTE-1113-PUB



# Summary

- MicroBooNE detector is being decommissioned after over 8 years of cold operation!
  - And 56 publications to date
- But we still have lots of new ideas for the future!
  - Learning more about LArTPC technology through decommissioning measurements
  - Extending oscillation sensitivity using two beams
  - Novel BSM searches
  - A wealth of cross section measurements in the works
- A huge thank you to Fermilab Accelerator Division for the beam, cryo and technical staff, and administrative staff – we couldn't do it without you!



# Thank You!



Andrew Furmanski  
University of Minnesota

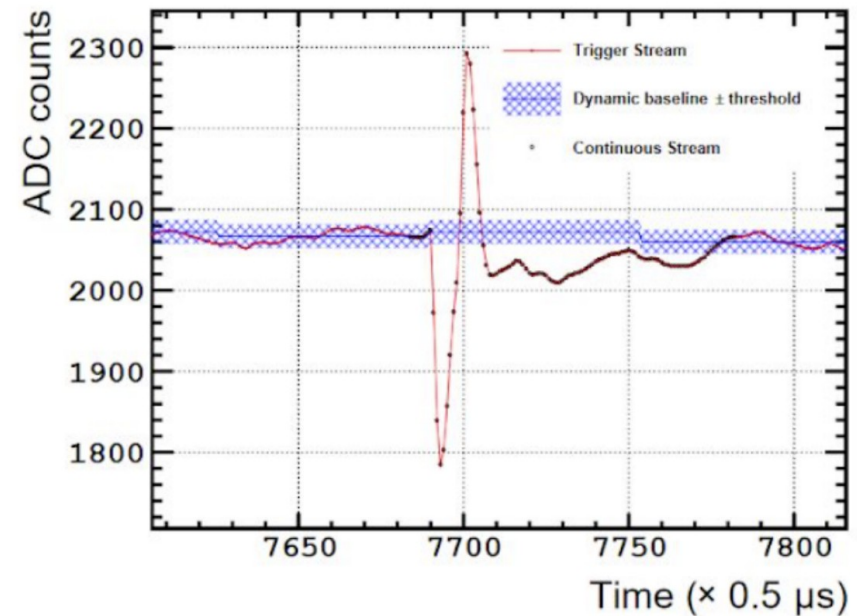


# Backup slides

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# TPC trigger



J.Phys.Conf.Ser. 2374 (2022) 1, 012163

