



MicroBooNE's tests of the MiniBooNE anomaly

Pawel Guzowski

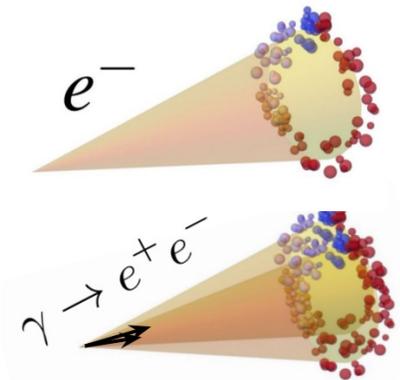
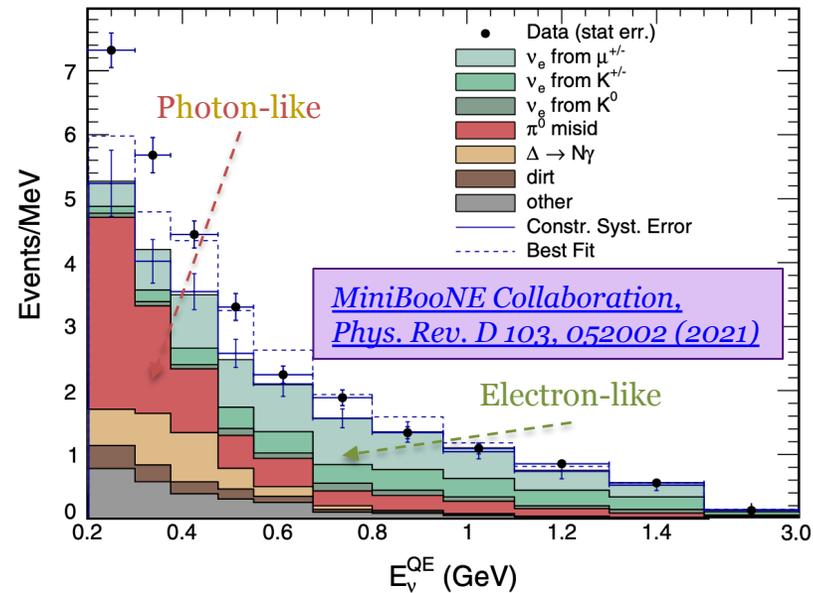
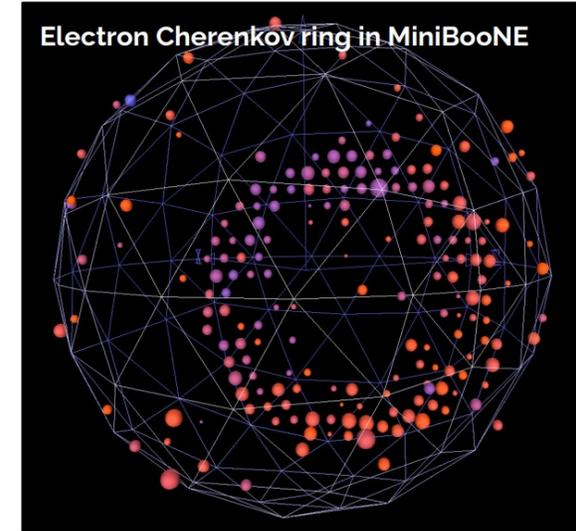
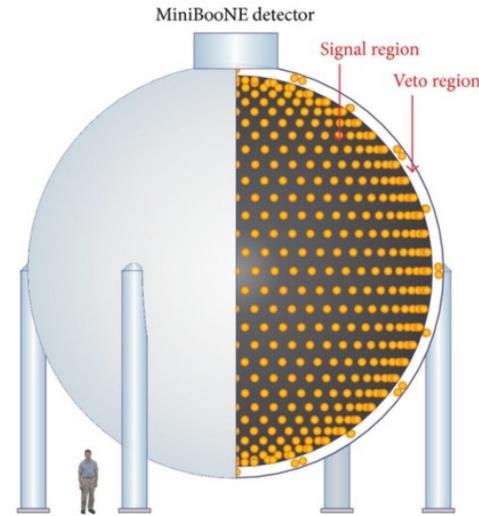
The University of Manchester

On behalf of the MicroBooNE Collaboration

IOP HEPP-APP 2023
KCL, London
3 Apr 2023

MiniBooNE anomaly

- Long-standing 4.7-sigma excess of electron-neutrino-like interactions in MiniBooNE
- Mineral oil Cherenkov detector
 - Cannot distinguish electrons from photons
- Is excess due to electron neutrinos appearing in the muon neutrino beam? Or photons? Or some other electromagnetic activity?

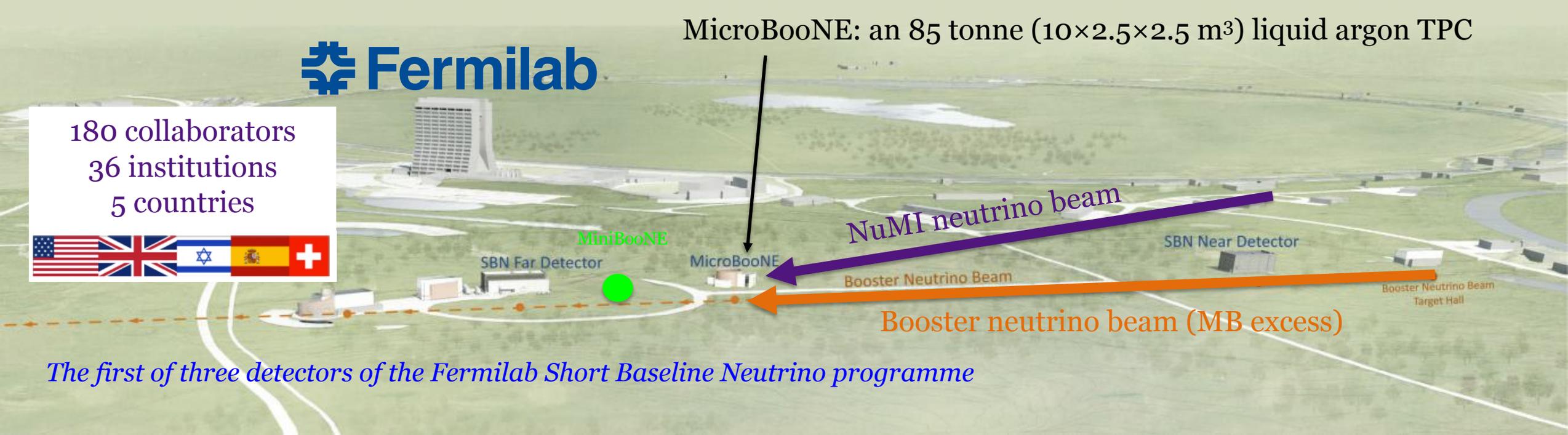


MicroBooNE



MicroBooNE: an 85 tonne ($10 \times 2.5 \times 2.5 \text{ m}^3$) liquid argon TPC

180 collaborators
36 institutions
5 countries



The first of three detectors of the Fermilab Short Baseline Neutrino programme

Experimental goals

- Investigate MiniBooNE excess
- Neutrino cross sections
- BSM searches
- LArTPC R&D

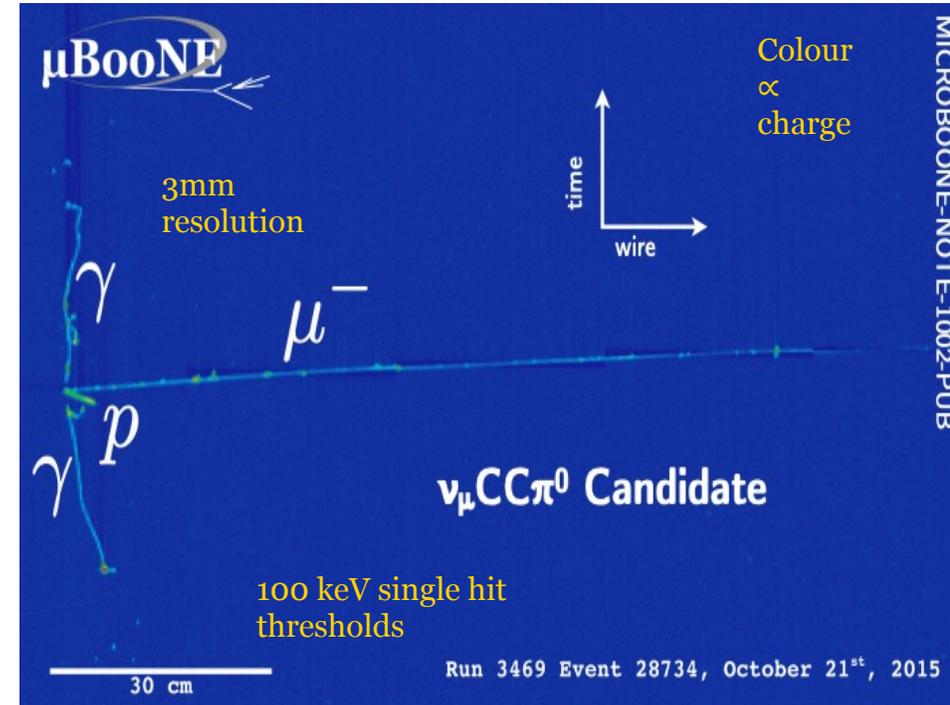
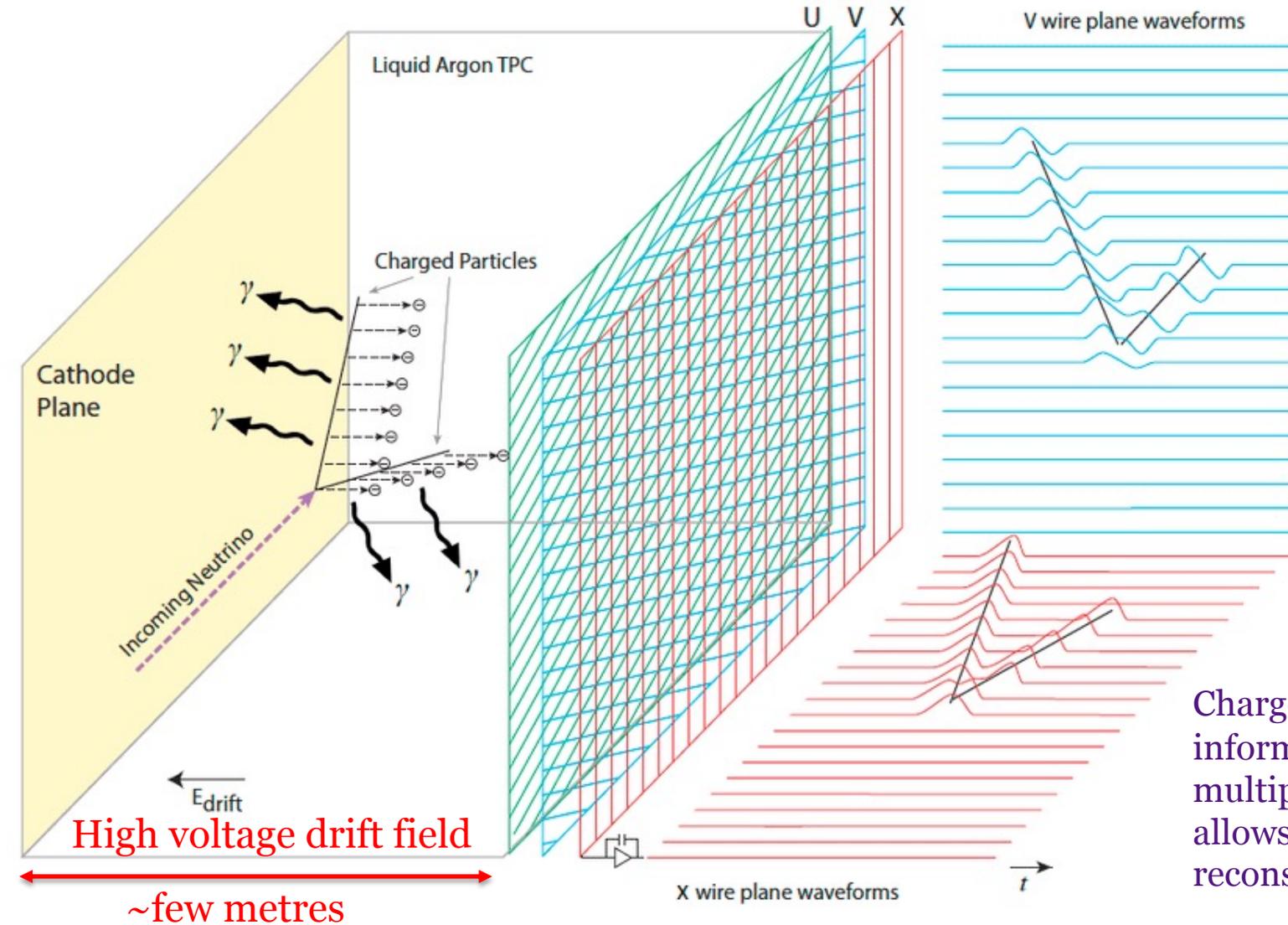
Outline of this talk

- LArTPCs, e/g separation
- Single photon search
- Single electron searches
- Oscillation fits
- BSM models

See also IOP talks and posters by:
David Marsden – heavy neutral leptons
Luis Mora – dark matter
Natsumi Taniuchi – kaon cross section

LArTPCs

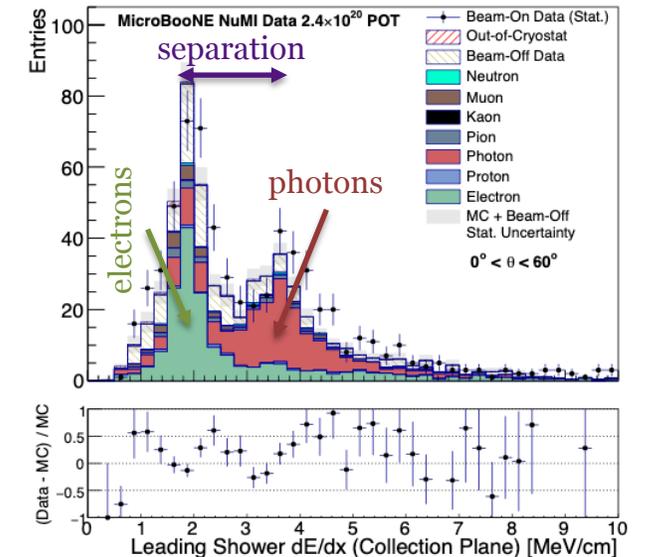
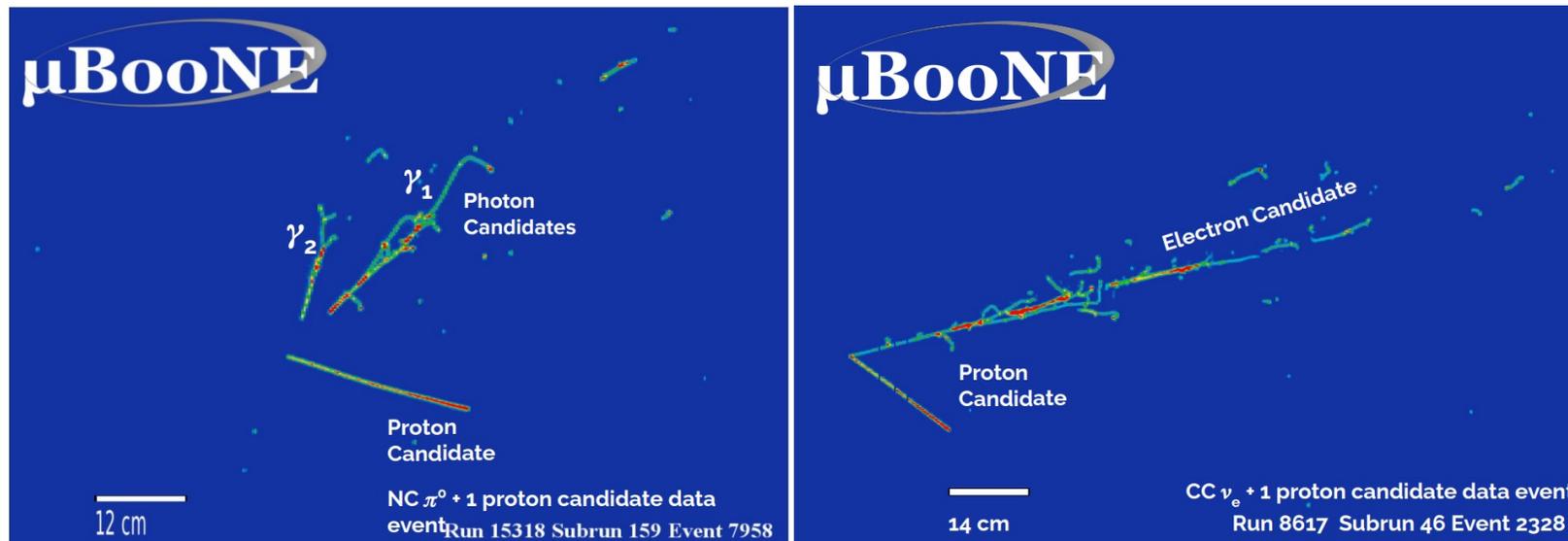
Multiple planes of readout sense wires



Charge vs time information on multiple planes allows for 3D reconstruction

e/ γ separation

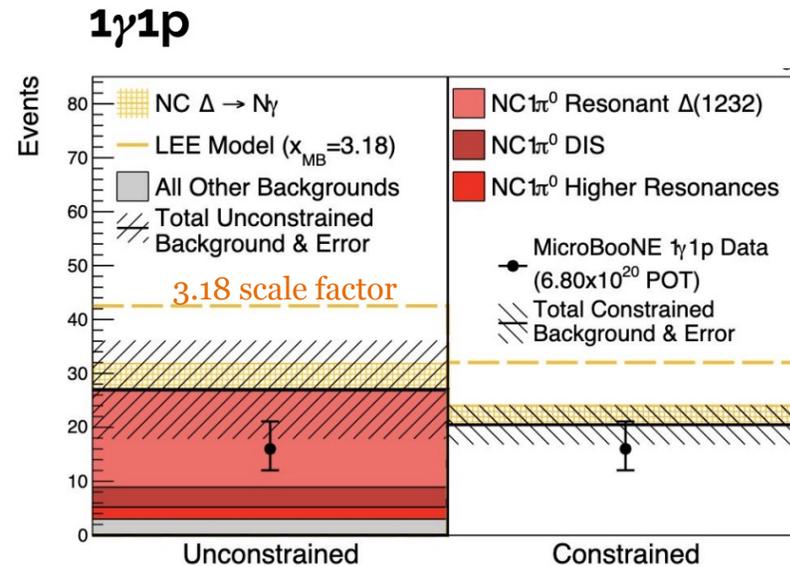
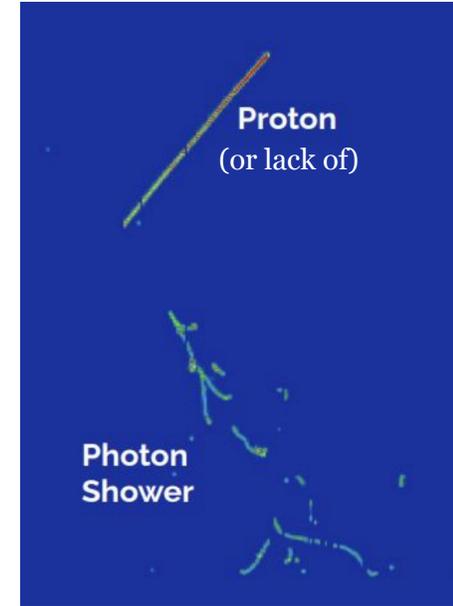
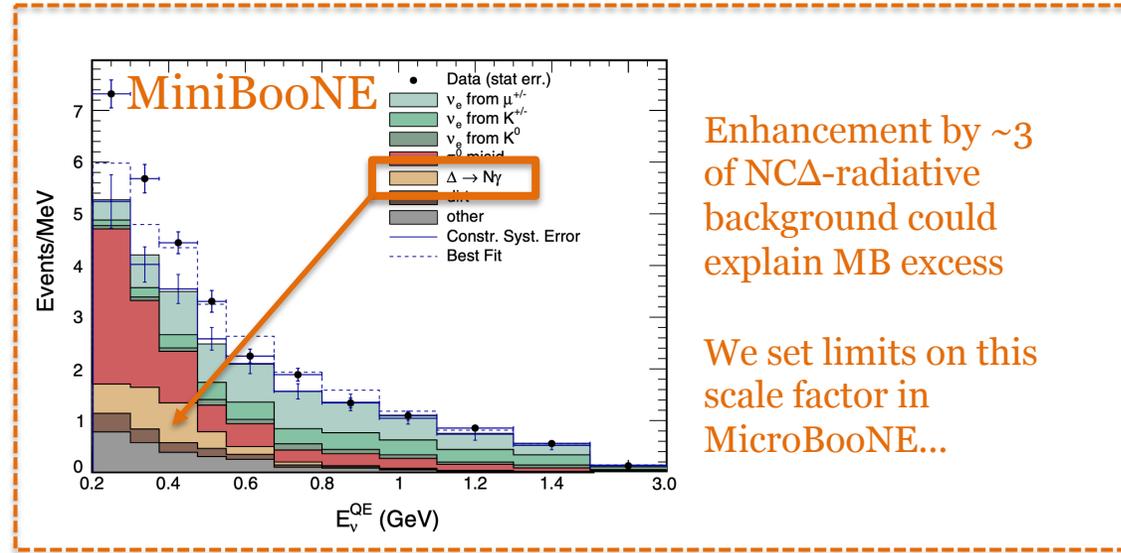
- Electron-photon separation is achieved with multiple handles
 - Electrons are attached to the interaction vertex
 - Photons convert some distance away from the vertex
 - Photon pair production induces twice as much charge at the beginning of the track relative to single electrons



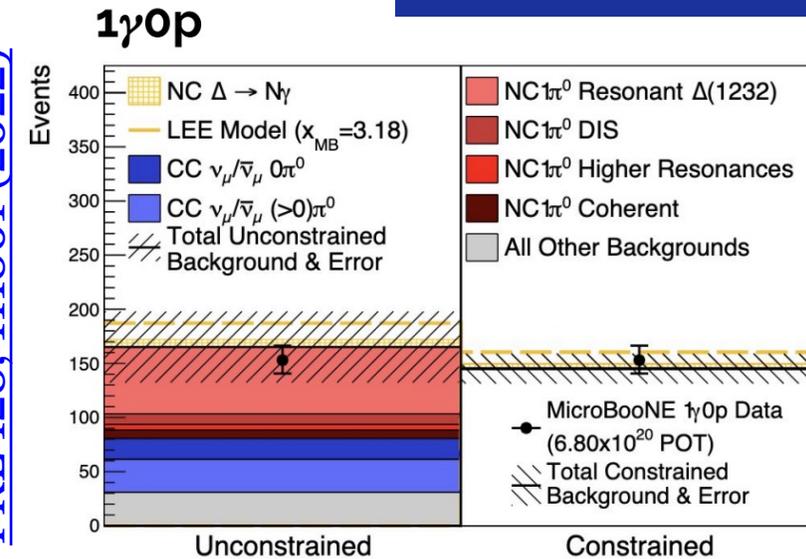
[PRD 104, 052002 \(2021\)](#)

Investigating single photon production

- We search for single photons from NC Δ radiative decays
- We set 90% CL limit on scale factor relative to nominal production rate at 2.3
- Exclude the 3.18 factor alone required for MB excess at 2-sigma



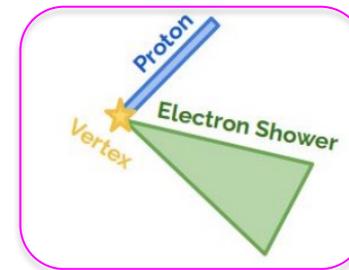
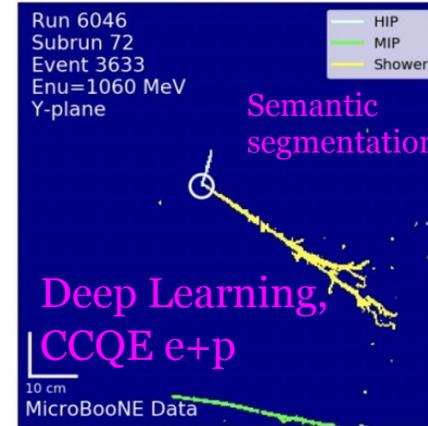
PRL 128, 111801 (2022)



Investigating single electron production

- Three independent analyses using different reconstruction paradigms and targetting different final states
 - **Deep Learning**, for 1 electron + 1 proton, CCQE kinematics
 - **Pandora***, for 1 electron and any number of protons
 - **WireCell***, for inclusive 1 electron final states

**names of reconstruction frameworks*

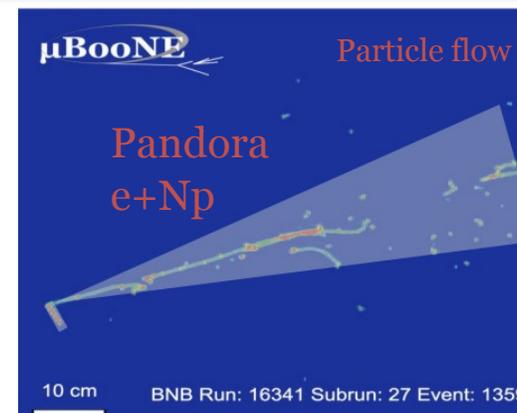
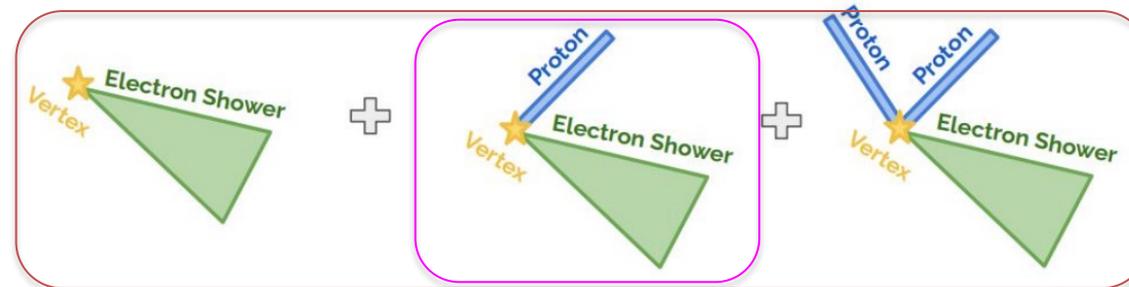
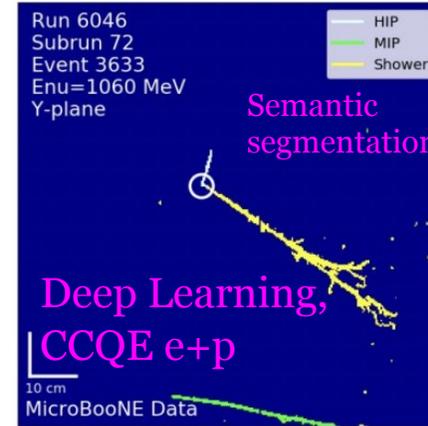


Deep Learning: [PRD 103, 052012 \(2021\)](#)
Pandora: [EPJC 75, 439 \(2015\)](#)
WireCell: [JINST 13, 05032 \(2018\)](#)

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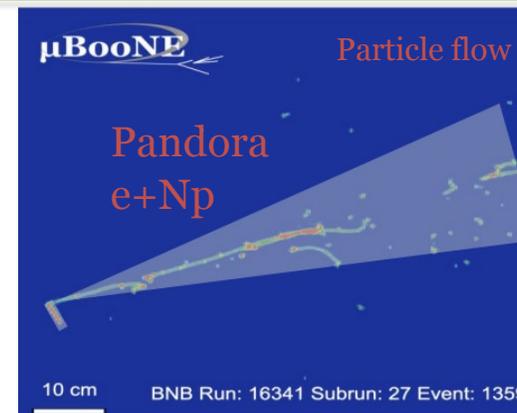
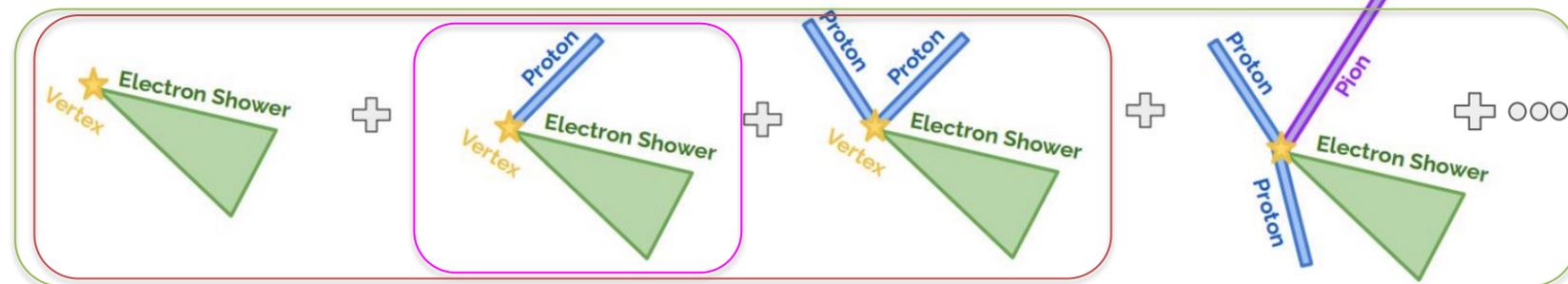
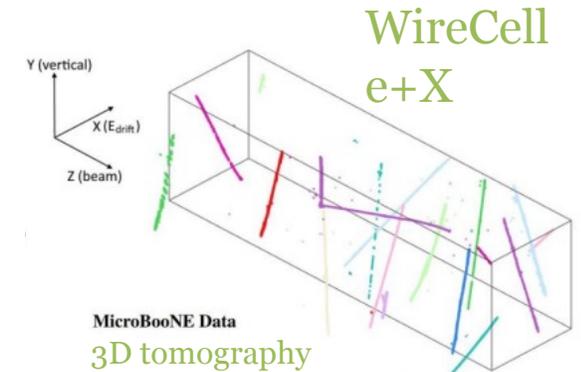
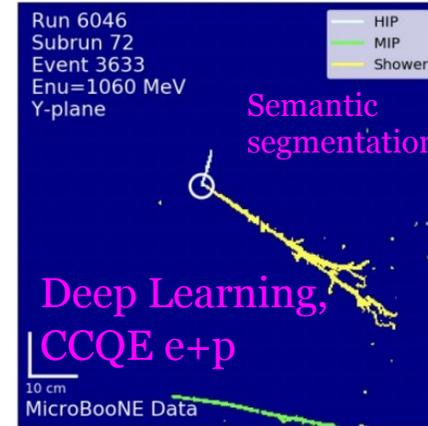


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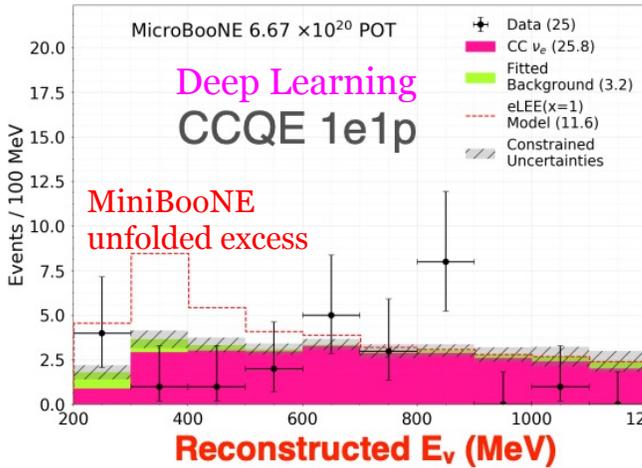
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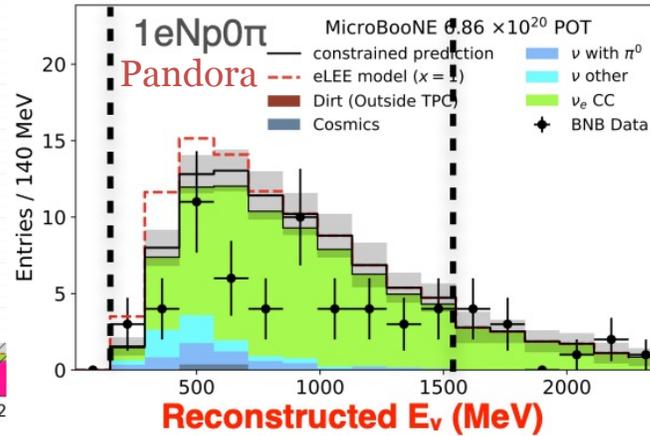
Deep Learning: [PRD 103, 052012 \(2021\)](#)
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WireCell: [JINST 13, 05032 \(2018\)](#)

Single electron results

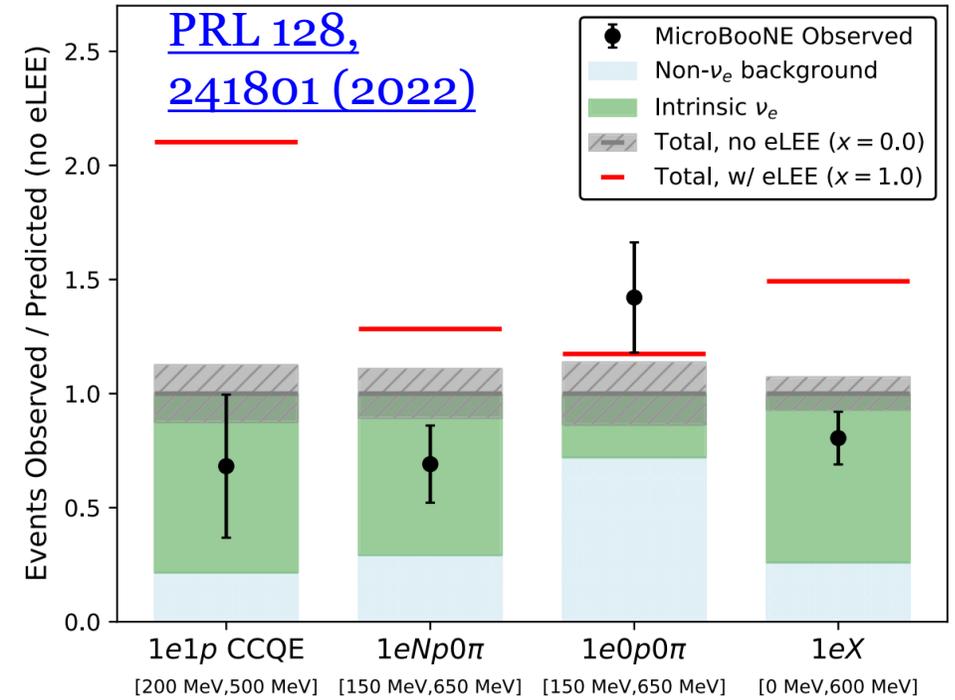
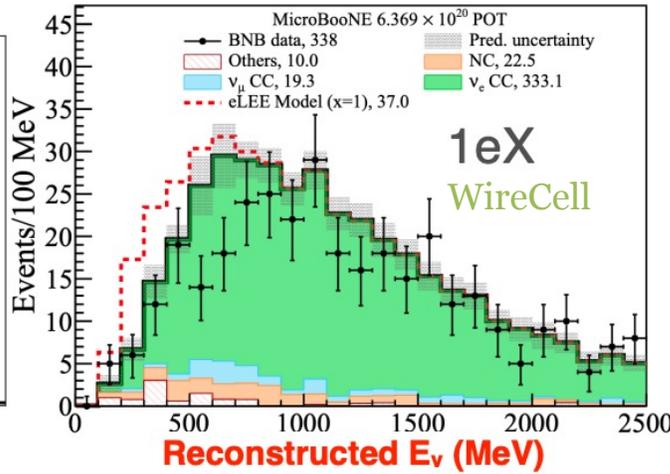
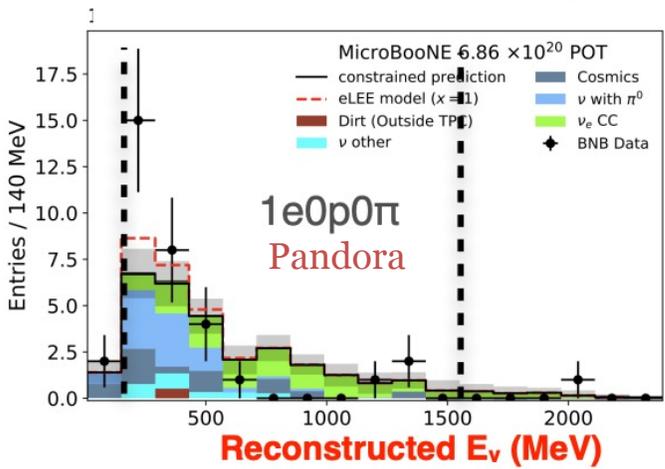
[PRD 105, 112003 \(2022\)](#)



[PRD 105, 112004 \(2022\)](#)



- No significant excess is observed
 - Some deficits, except for least sensitive, most background dominated channel
- Single-electron-alone explanation for MiniBooNE is ruled out at >97% CL



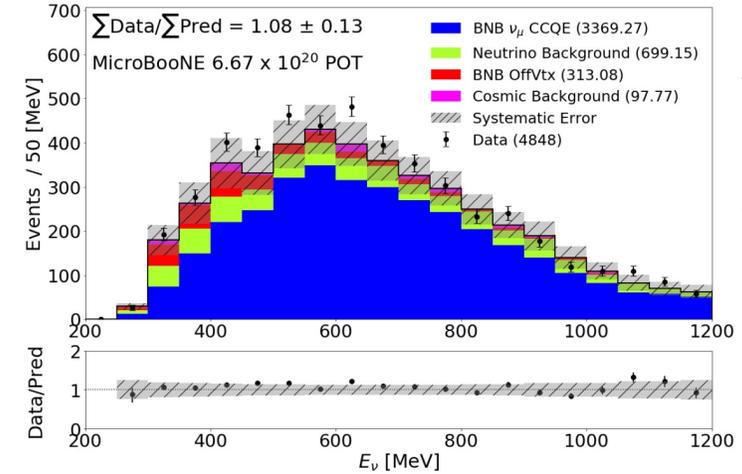
[PRD 105, 112004 \(2022\)](#)

[PRD 105, 112005 \(2022\)](#)

Oscillation fits – numu disappearance

- Using the Deep Learning CCQE analysis
- Muon neutrino spectrum data is consistent with prediction
 - No significant deviation is observed
- Dataset is used to produce exclusion contour for muon neutrino disappearance

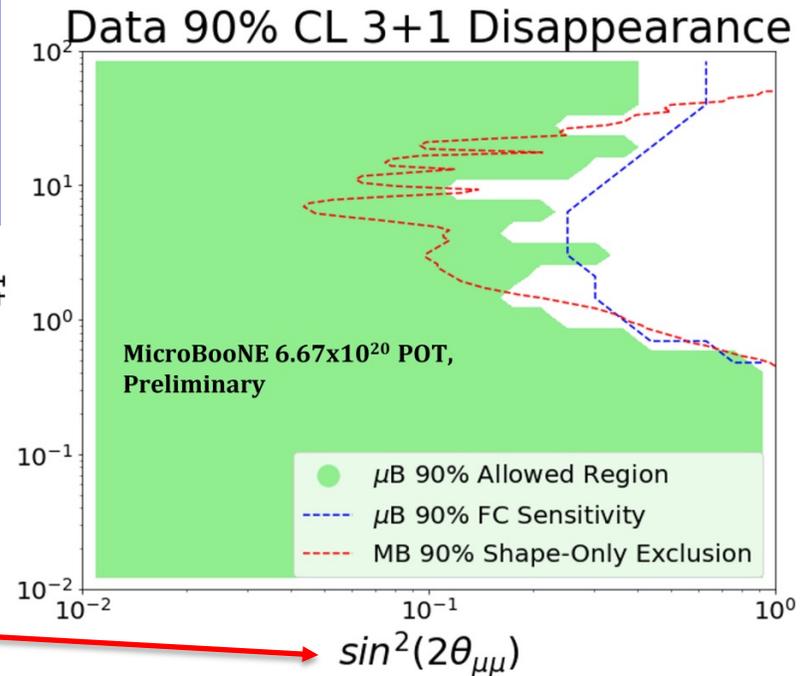
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Numu
CCQE
spectrum

Δm_{41}^2

Oscillation parameters*

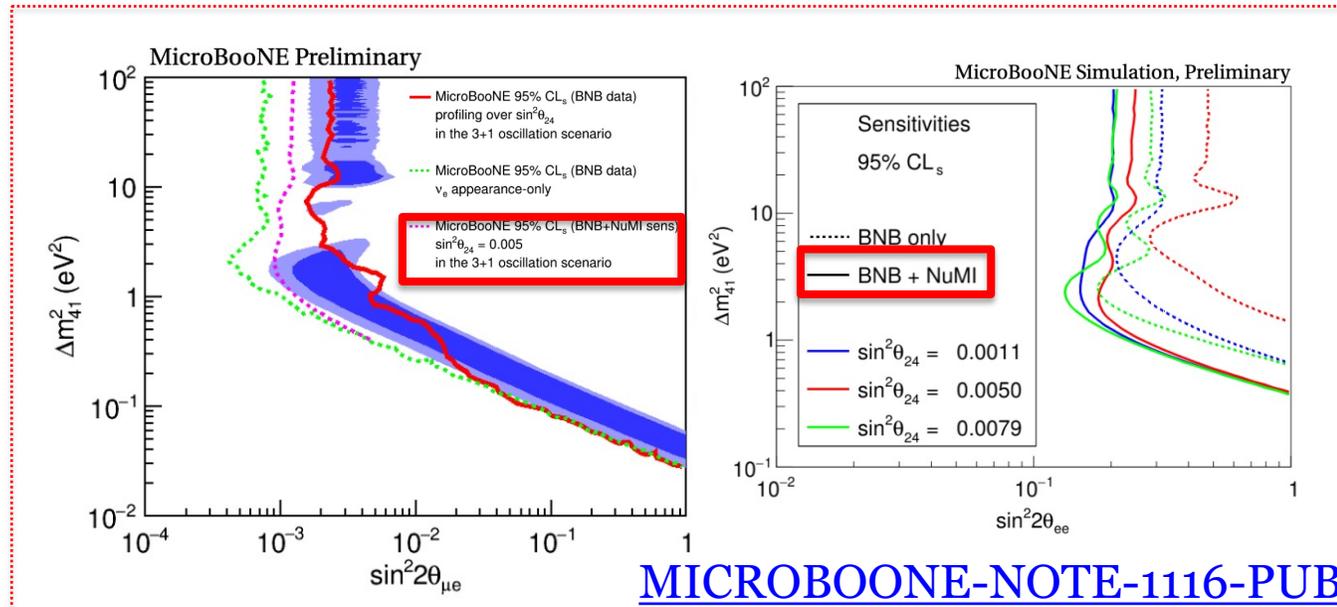
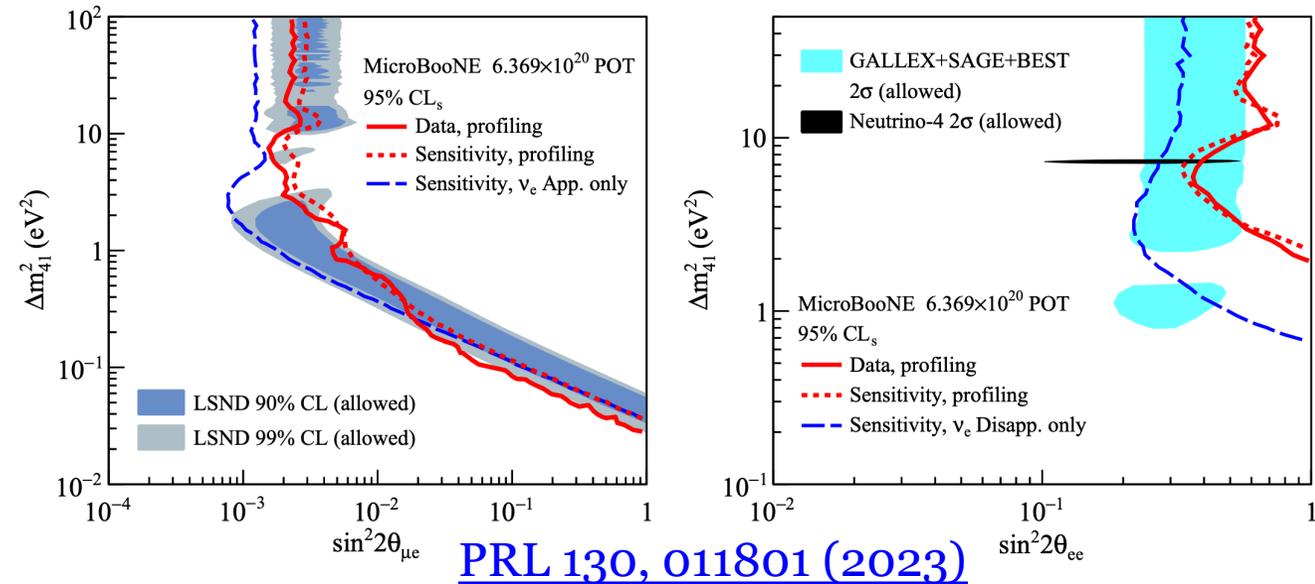


$\sin^2(2\theta_{\mu\mu})$

*Please see Elena Gramellini's talk for oscillation overview, parameter definitions etc

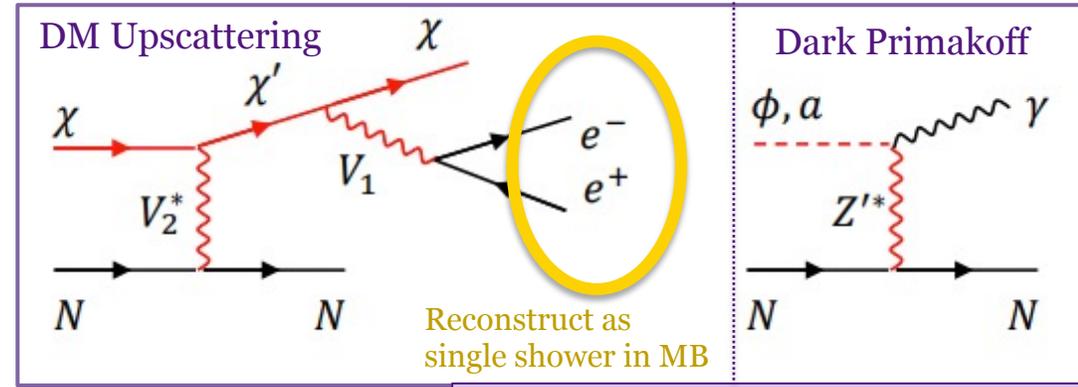
Oscillation fits – nue (dis)appearance

- For a 1+1, nue appearance only analysis, we are sensitive to the whole LSND/MB allowed region
- Extending to a 3+1 model, there is cancellation between nue appearance and intrinsic nue disappearance
- Degeneracy can be broken by using **NuMI data**
 - Different L/E
 - Larger intrinsic nue contribution

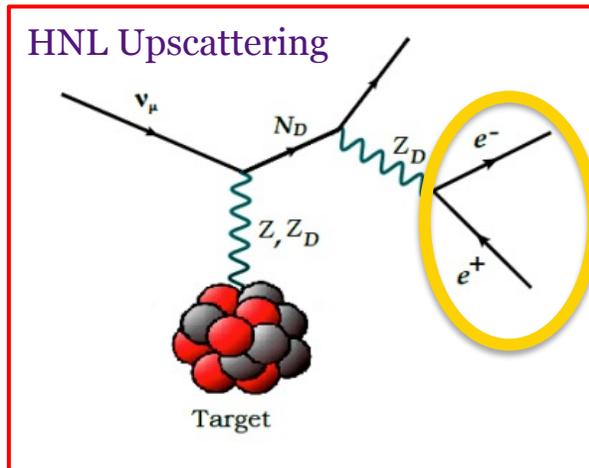


Newer BSM models

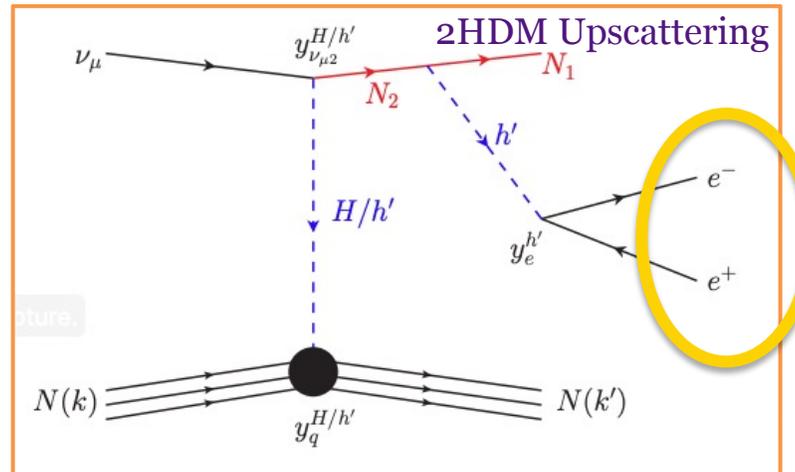
- Over past few years, theorists have been having new BSM ideas for explaining MiniBooNE beyond light sterile neutrinos
- Models involving **dark lepton sector & dark U(1) gauges**; **adding new scalars (2HDM etc)**; or even **dark-matter based solutions** unrelated to neutrinos (plus many others...)
- MicroBooNE will be probing these models, expect results soon...



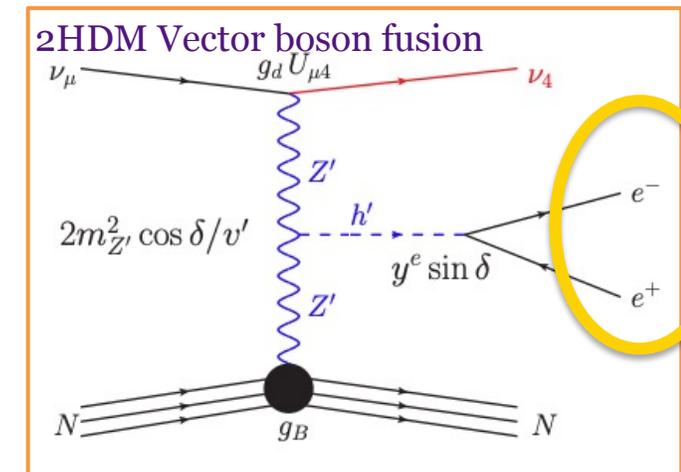
[Dutta et al, PRL 129, 111803 \(2022\)](#)



[Bertuzzo et al, PRL 121, 241801 \(2018\)](#)
[Ballett et al, PRD 99, 071701 \(2019\)](#)
[Abdullahi et al, PLB 820, 136531 \(2021\)](#)

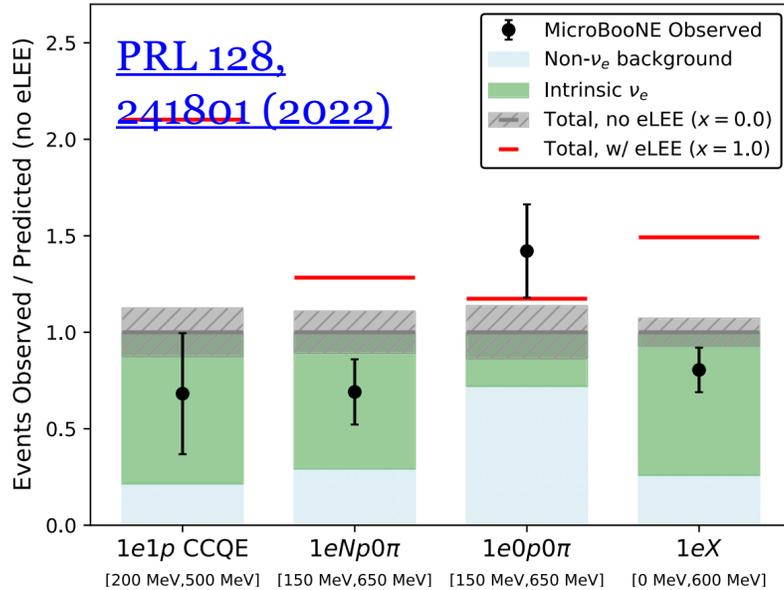


[Dutta et al, PRD 102, 055017 \(2020\)](#)
[Abdallah et al, PRD 104, 055028 \(2021\)](#)

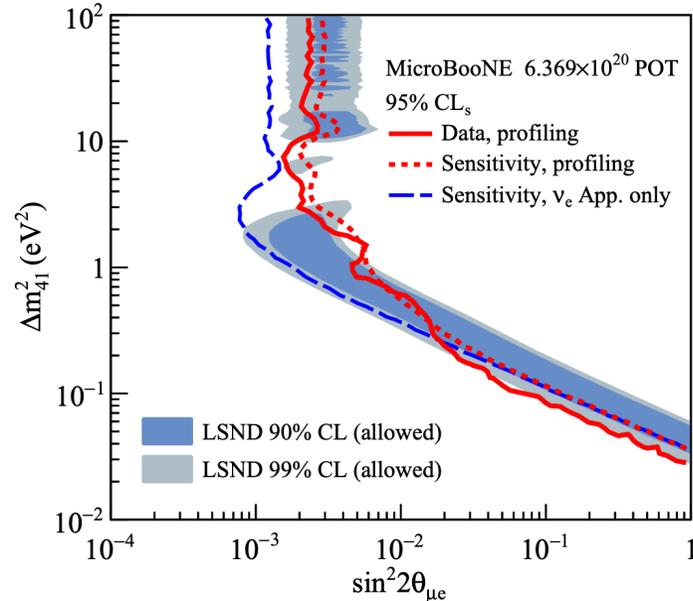


[Abdallah et al, JHEP 12, 188 \(2020\)](#)

Summary



[PRL 130, 011801 \(2023\)](#)

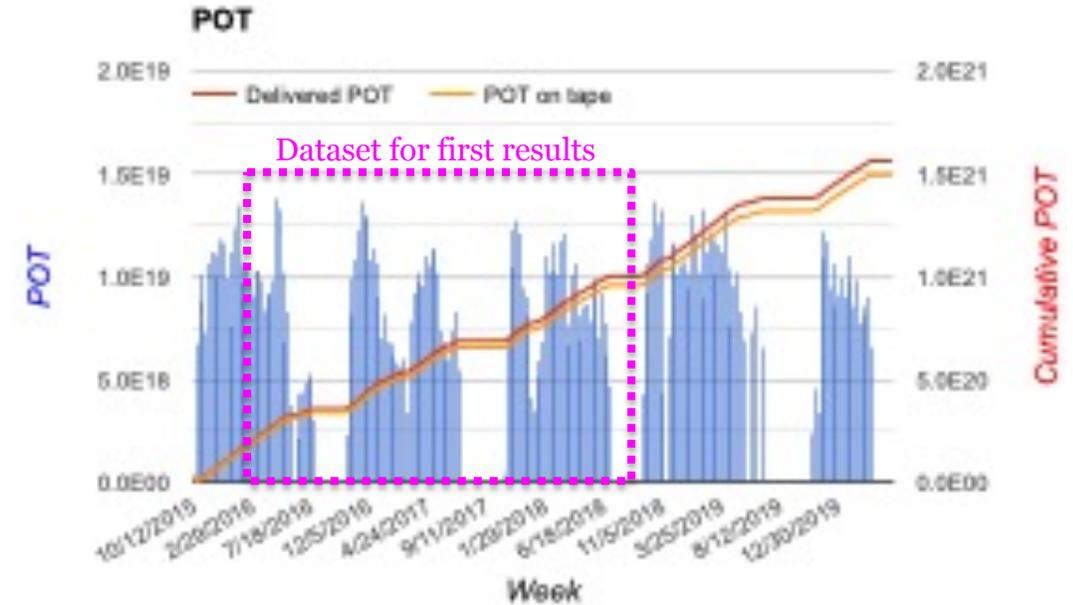


- MicroBooNE was designed to test the electromagnetic nature of the MiniBooNE anomalous excess
- So far, we do not see an excess of single photons or single electrons
- We can use our data to perform sterile neutrino oscillation fits
 - With a 3+1 fit, there exists some cancellation between $\nu_{\mu e}$ appearance and disappearance, reducing our sensitivity
 - Degeneracy can be broken with NuMI data
- We have begun to search for BSM models involving electron-positron pair production
 - First results expected very soon...

ADDITIONAL SLIDES

Prospects for the near future

- These first results are using $\sim 1/2$ of our final dataset
 - Full dataset results expected soon...
- Improvements to reconstruction
 - Improved efficiencies, background rejection
- Inclusive, coherent single photon analyses
 - NC- Δ search was fine tuned for Δ invariant mass
- e^+e^- models: kinematics, opening angles, invariant masses, if signal is observed



MICROBOONE-NOTE-1102-PUB

