Impact of MicroBooNE latest results on the SBN program

Pedro Machado

November, 2021

Outline

Why are MicroBooNE's Δ and LEE-electron results so important?
(regardless of the MiniBooNE anomaly)

Does MicroBooNE rule out the ν_e interpretation of the MiniBooNE anomaly?

Does MicroBooNE rule out the sterile neutrino interpretation of the MiniBooNE anomaly?

What did the Δ and LEE-electron analyses teach us and what else can we do with that?

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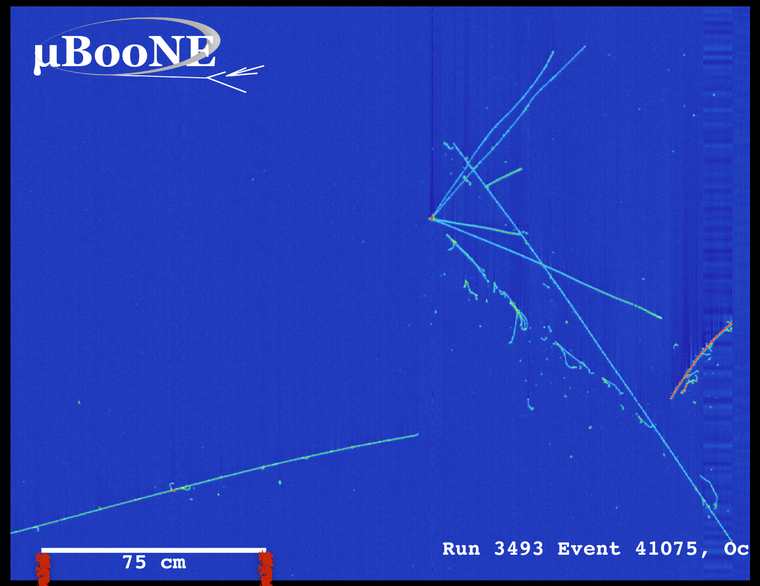
Why are MicroBooNE's Δ and LEE-electron results so important?



Both results are turning points in experimental (and by extension theoretical) neutrino physics

Why are MicroBooNE's Δ and LEE-electron results so important?

Take the Δ analysis as an example

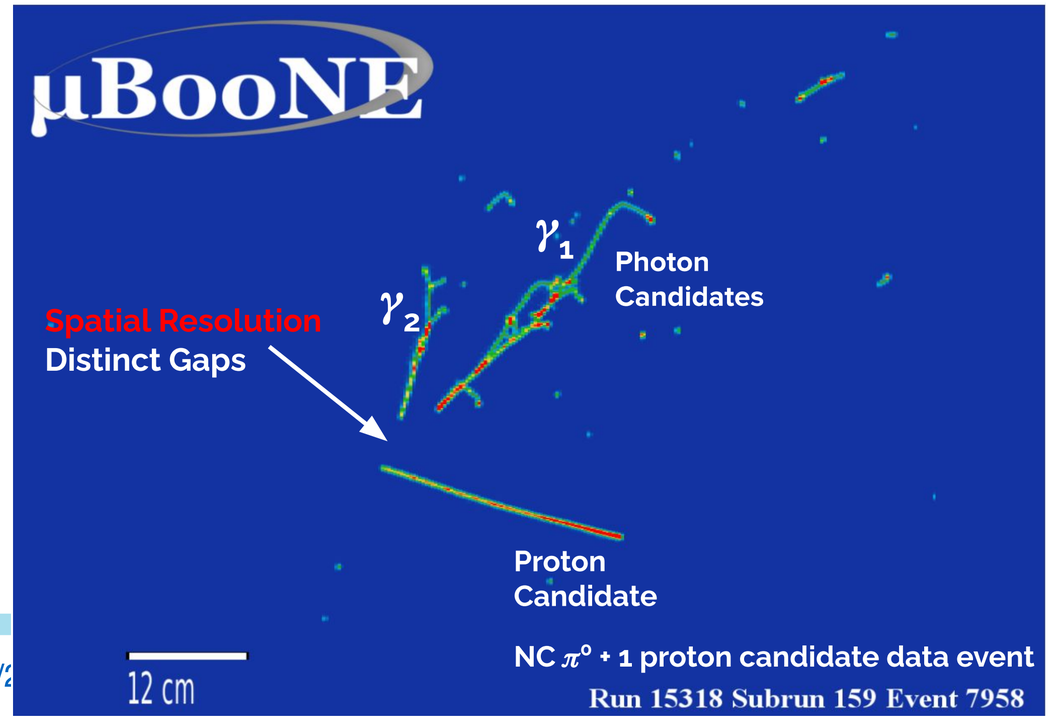
Topology: 1γ0p vs 1γ1p, number of pions, …

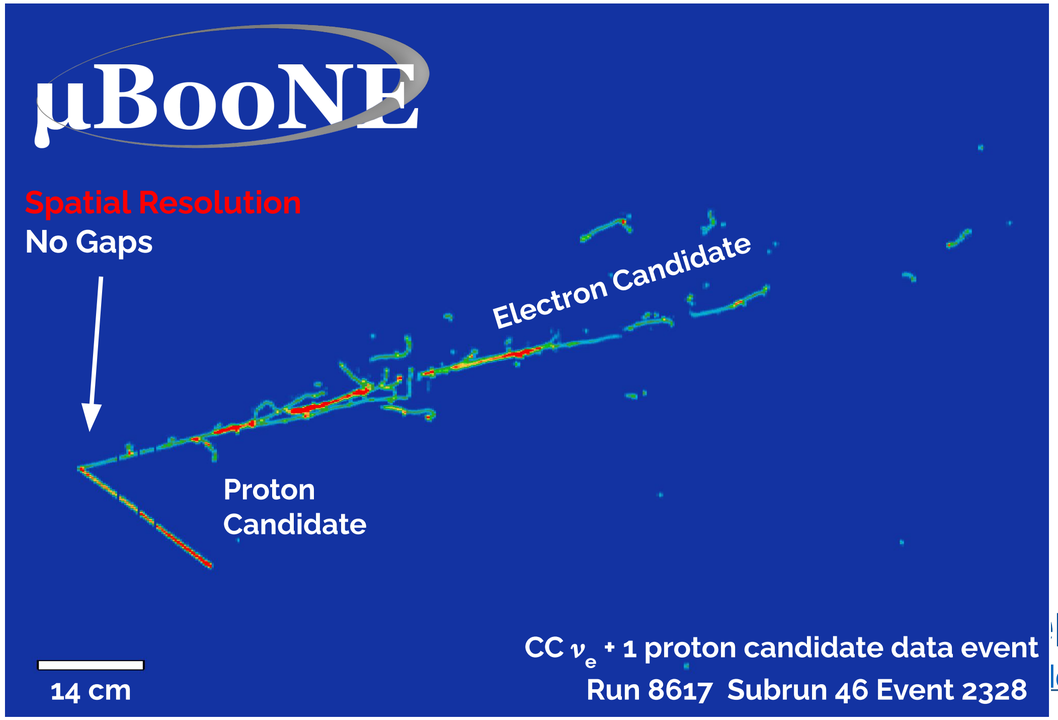
Topology: gap between EM shower and proton

Calorimetry: dE/dx

Reconstruction: individual particle reconstruction, Δ invariant mass cut in 1γ1p topology

Data-driven backgrounds: π^0 reconstruction for 2γ0p and 2γ1p





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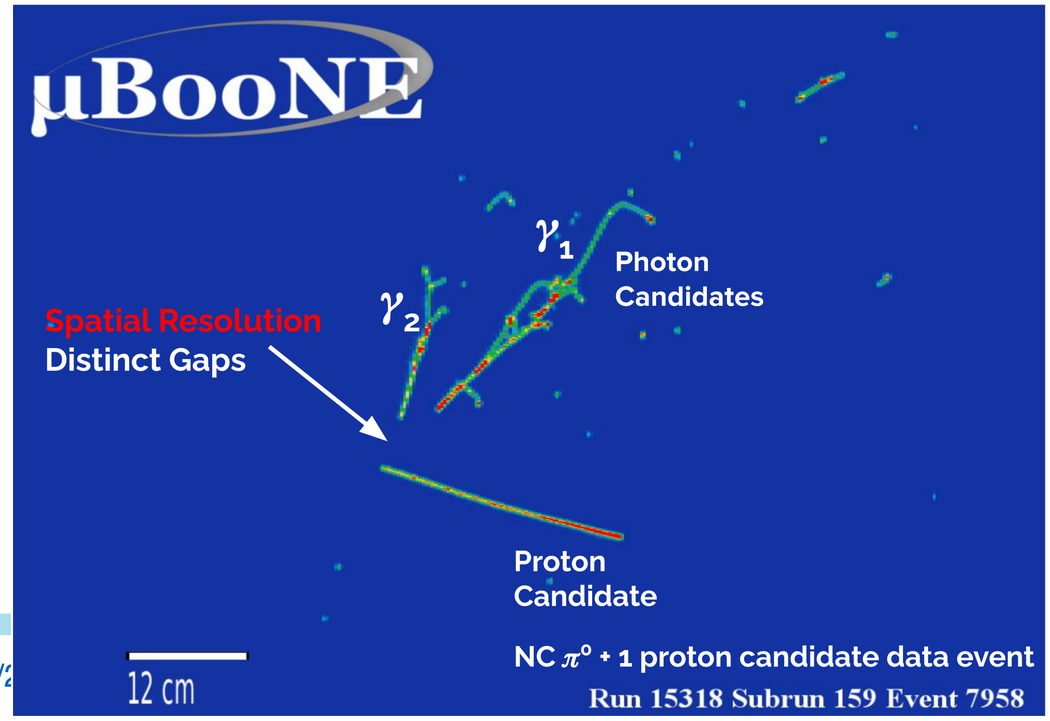
Why are MicroBooNE's Δ and LEE-electron results so important?

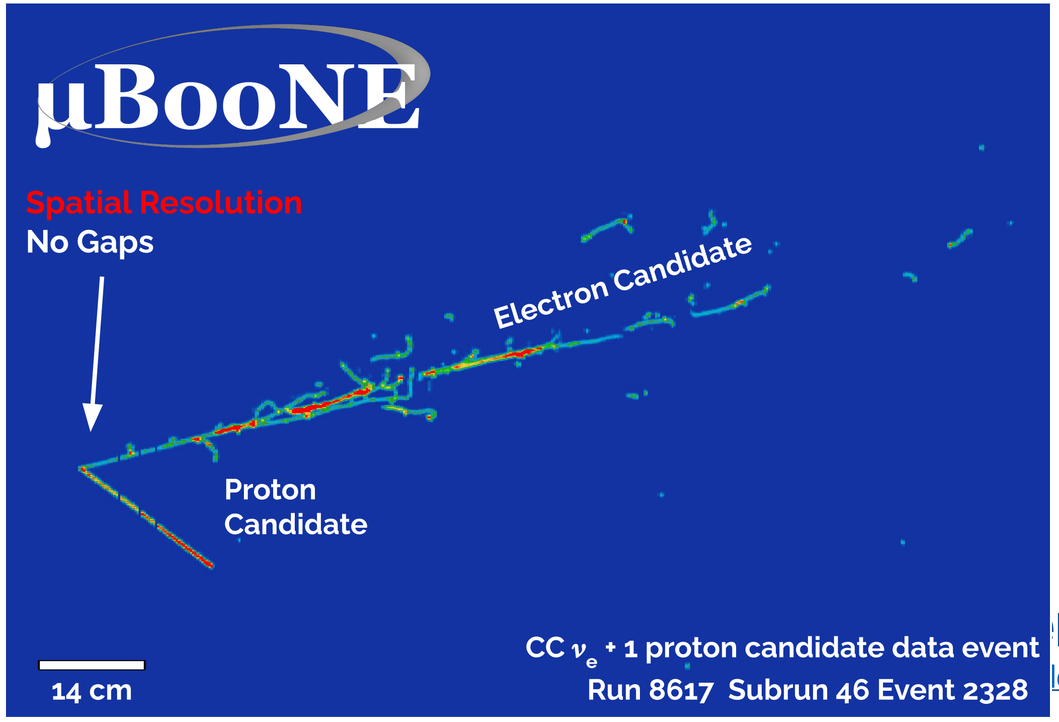
The sophistication of these analyses

and the amount of information they contain are remarkable

MicroBooNE has set a very high standard for future LArTPC analyses

at the SBN detectors and eventually at DUNE





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Does MicroBooNE rule out the ν_e interpretation of the MiniBooNE anomaly?

MicroBooNE does not see any evidence for a ν_e excess
compatible with MiniBooNE excess taken at face value

Does that mean MicroBooNE rule out a ν_e excess in a model independent way?

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Does MicroBooNE rule out the ν_e interpretation of the MiniBooNE anomaly?

MicroBooNE does not see any evidence for a ν_e excess
compatible with MiniBooNE excess taken at face value

Does that mean MicroBooNE rule out a ν_e excess in a model independent way?
No.

Let's make sure we do not mix the media coverage with the claims in the paper

MicroBooNE: "With differing signal topologies, statistics, backgrounds, reconstruction algorithms, and analysis approaches, […] no excess of ν_e events is observed."

BBC: "A major experiment has been used to search for an elusive sub-atomic particle: a key component of the matter that makes up our everyday lives. The search failed to find the particle, known as the sterile neutrino."

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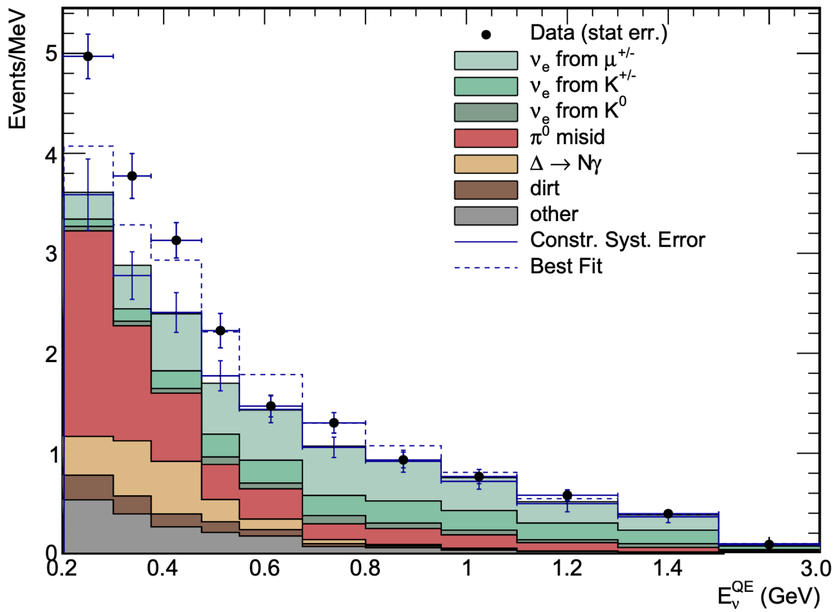

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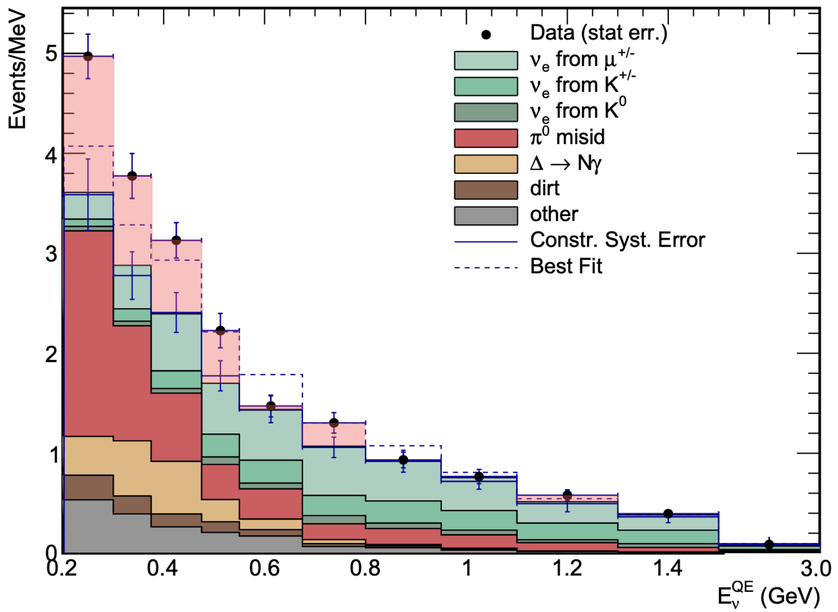

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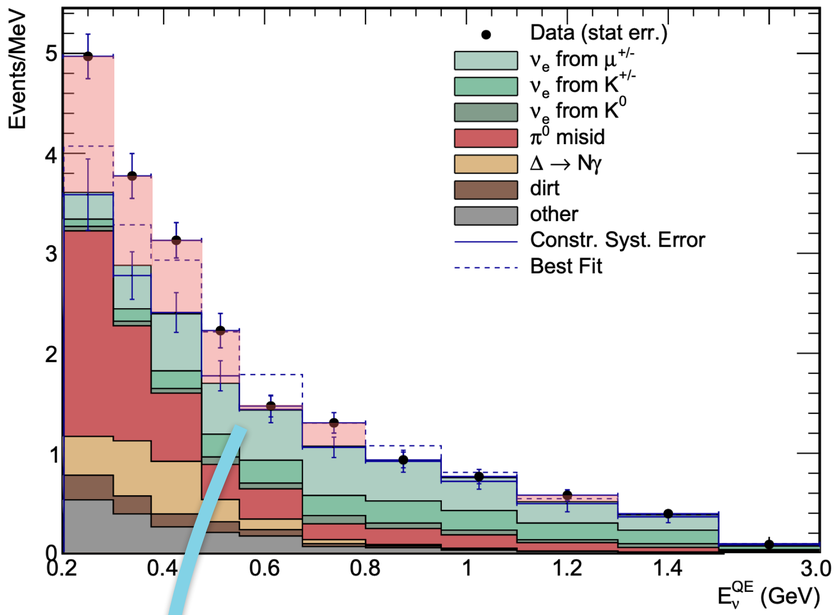
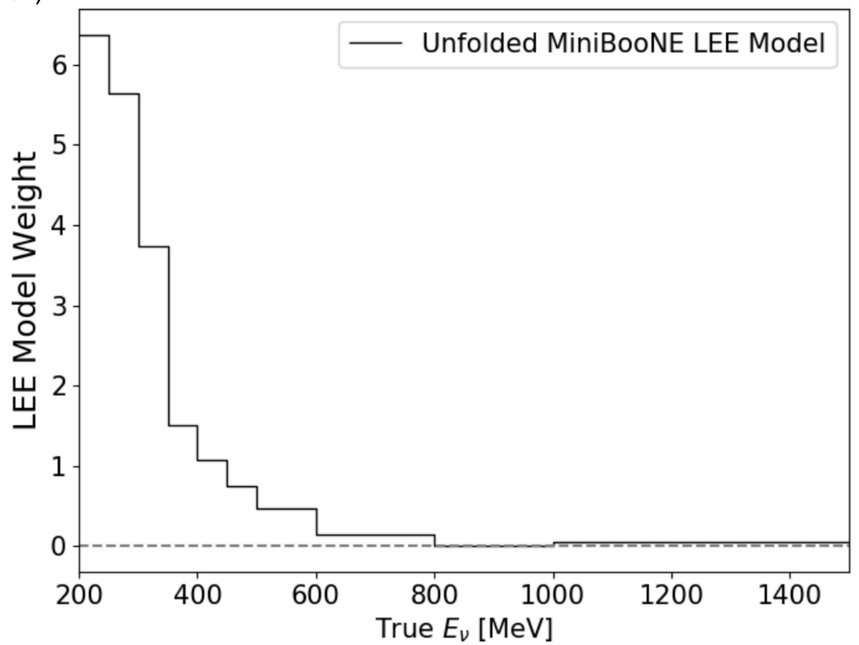


unfolding



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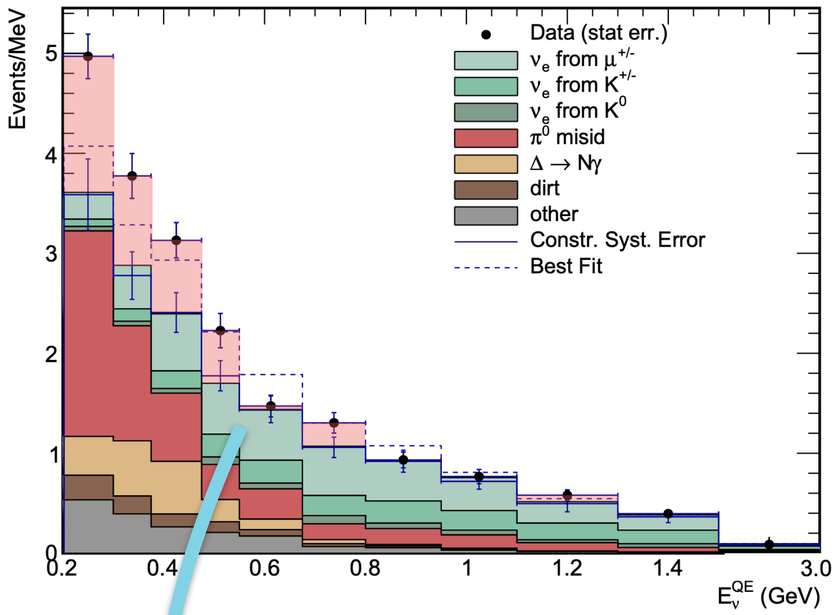

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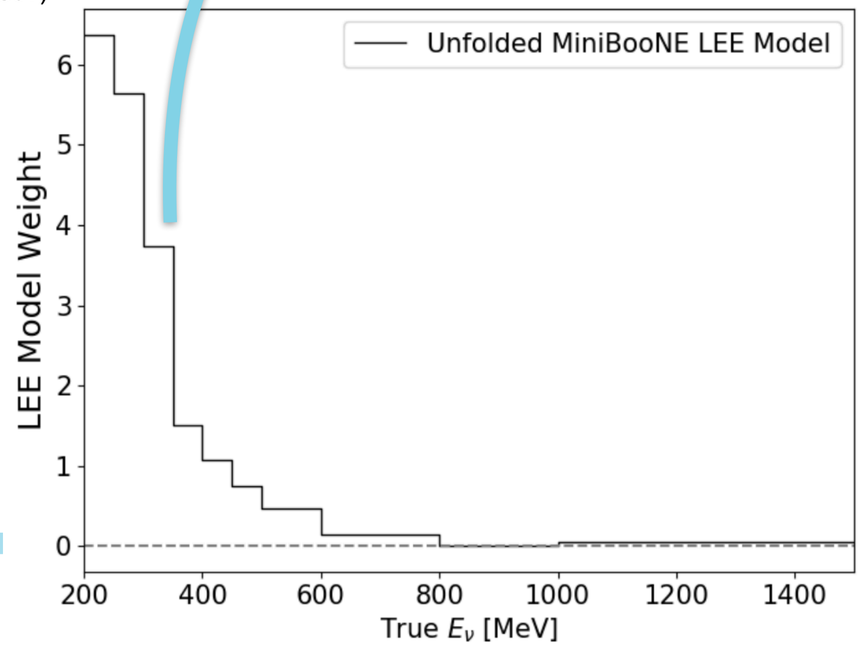

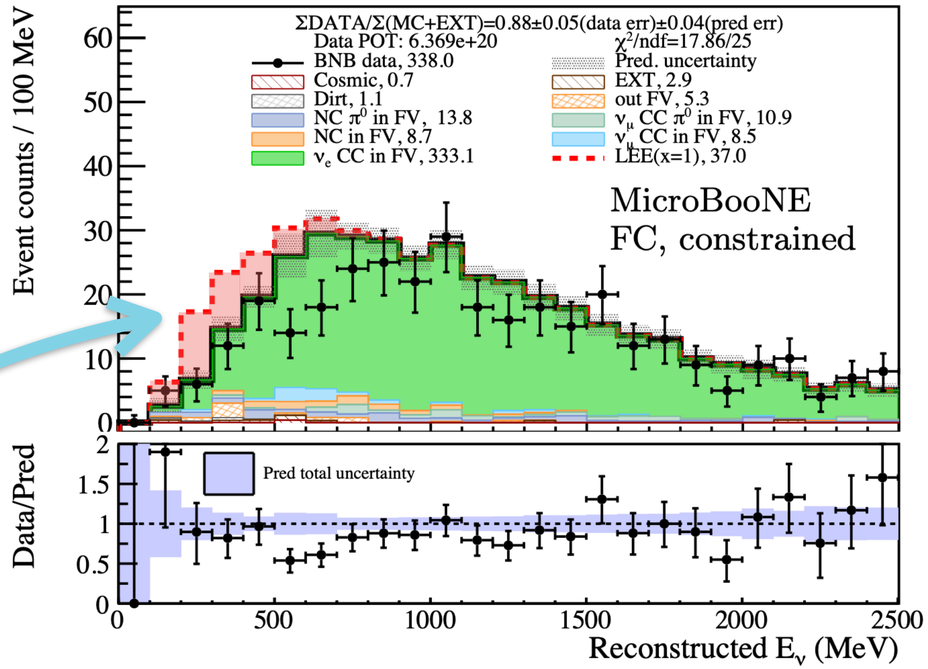

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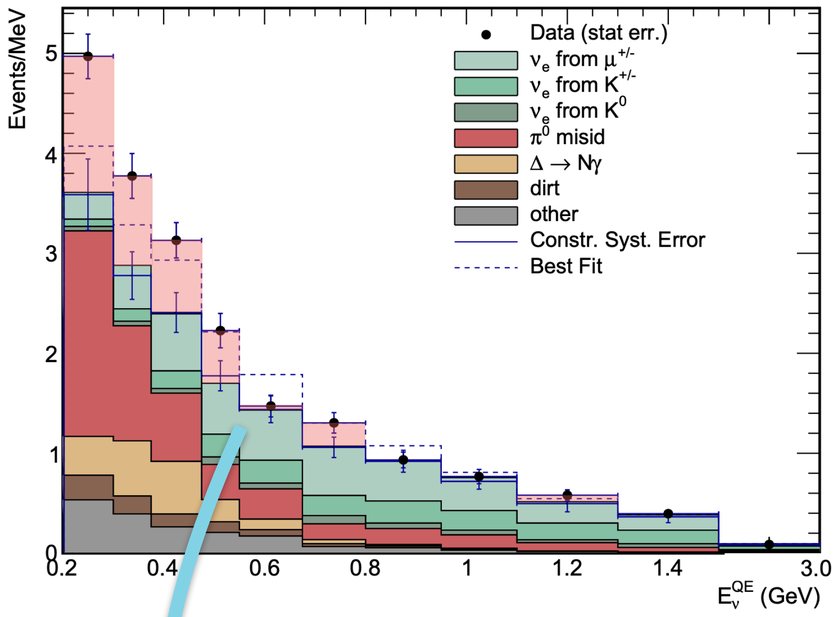

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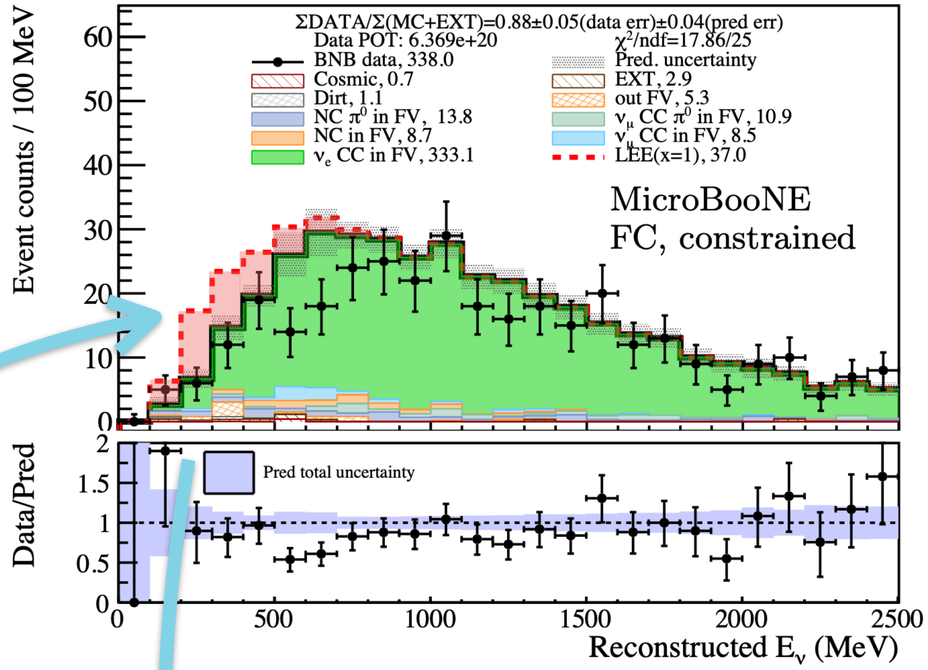

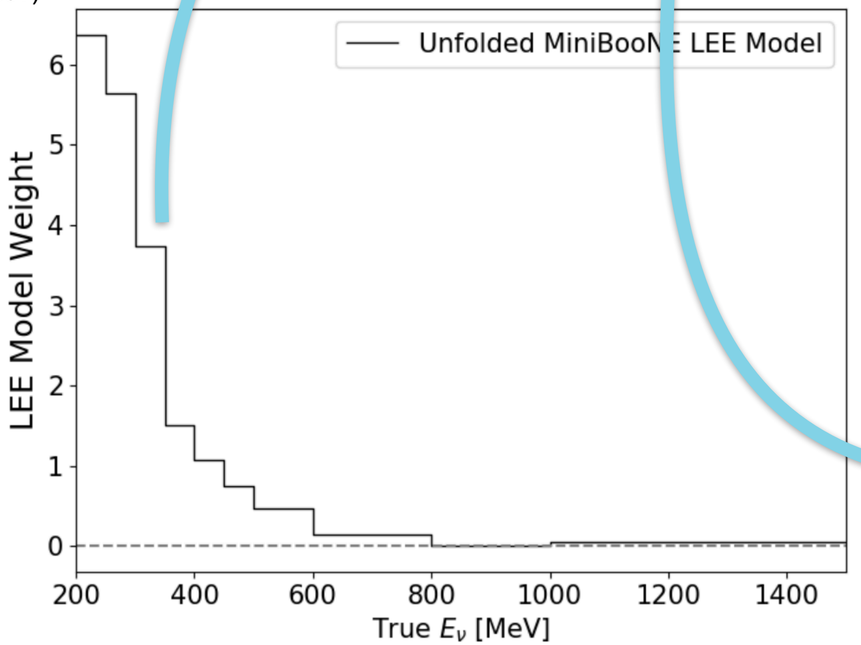

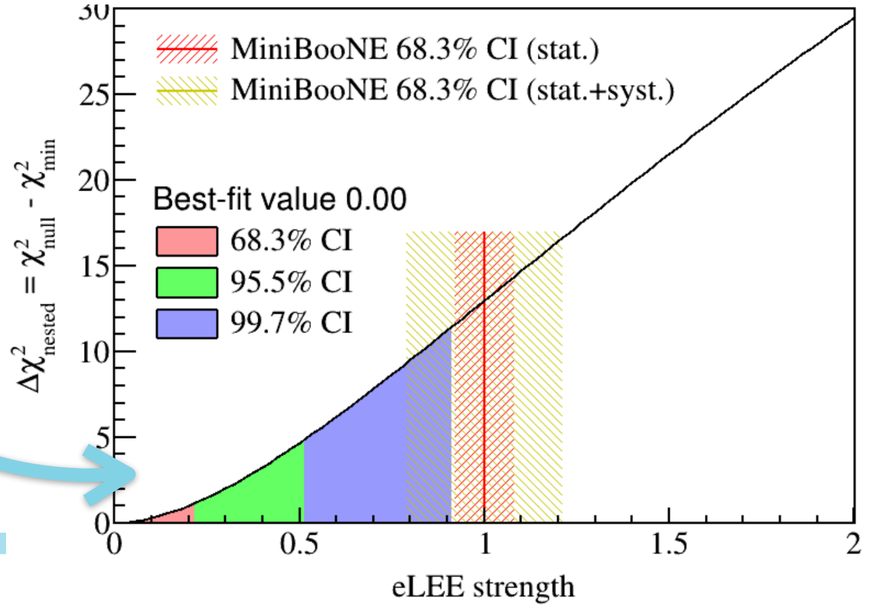

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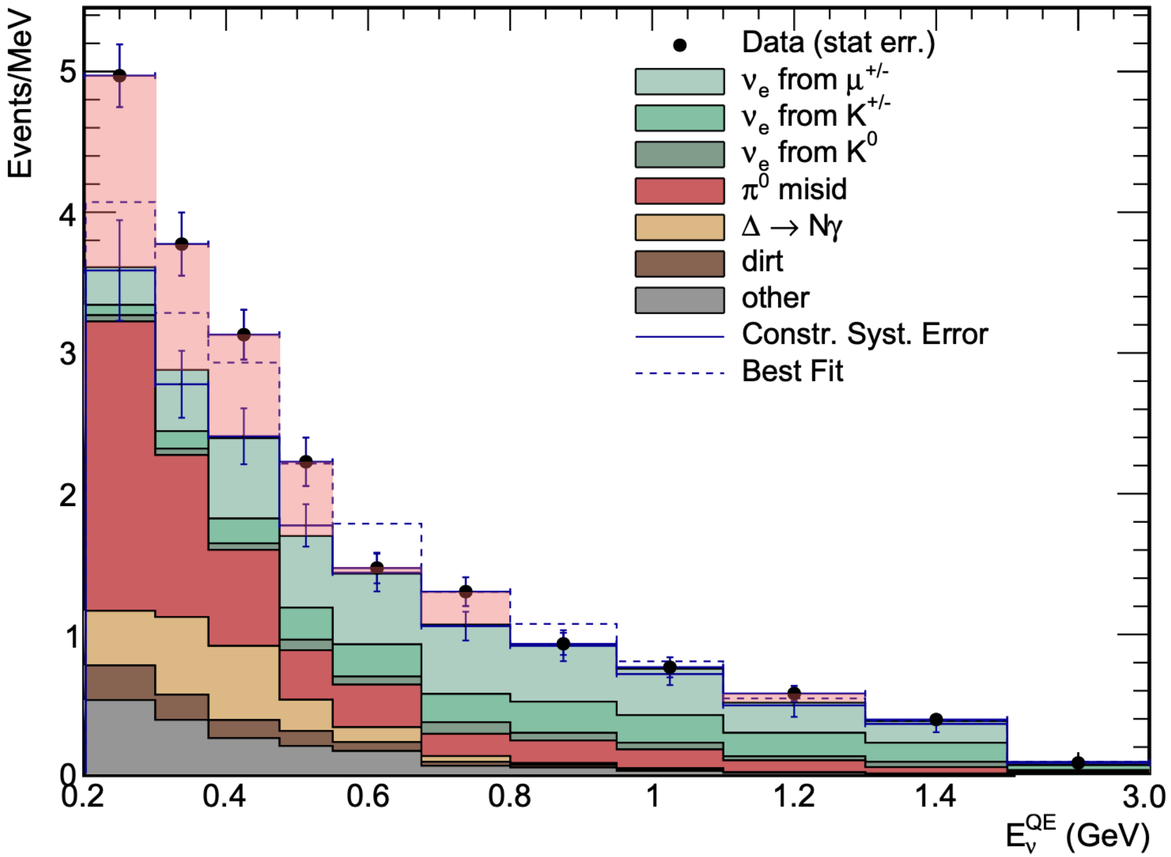
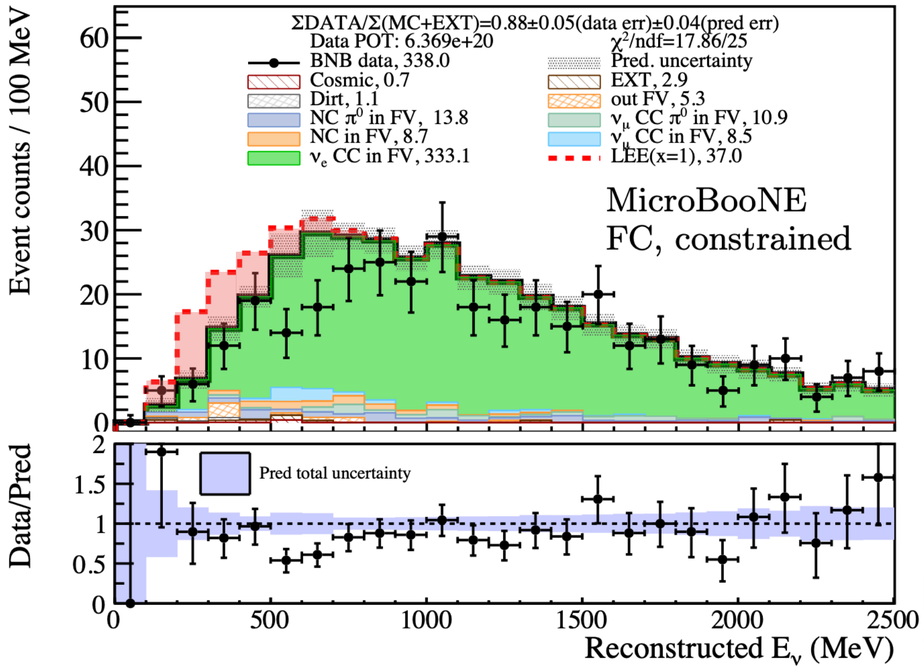


The statistical significance of MiniBooNE LEE is dominated by background uncertainties

MiniBooNE backgrounds peak at low energy

MicroBooNE backgrounds are low at low energies

What is the impact of MiniBooNE background uncertainties on MicroBooNE sensitivity?



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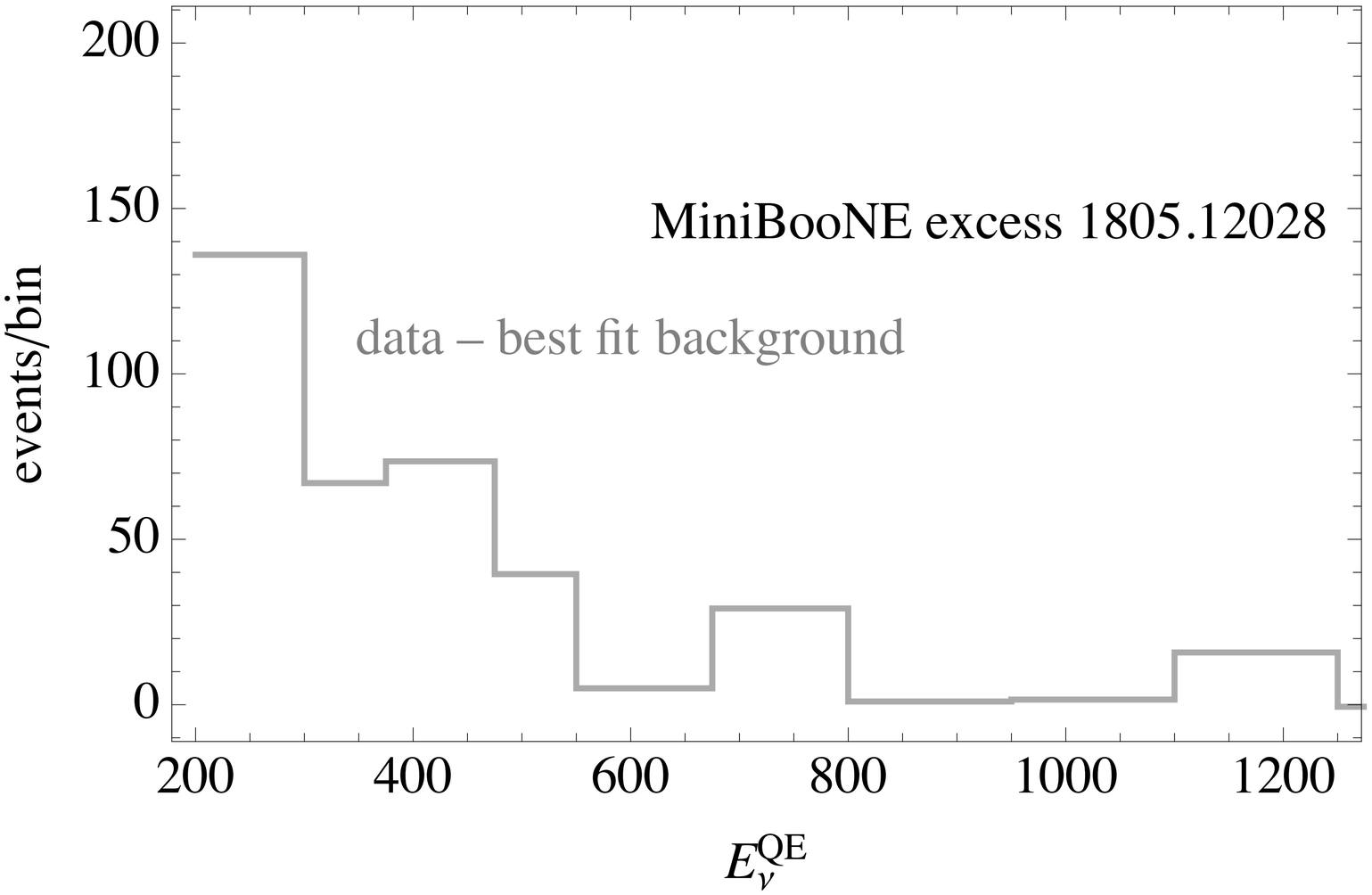

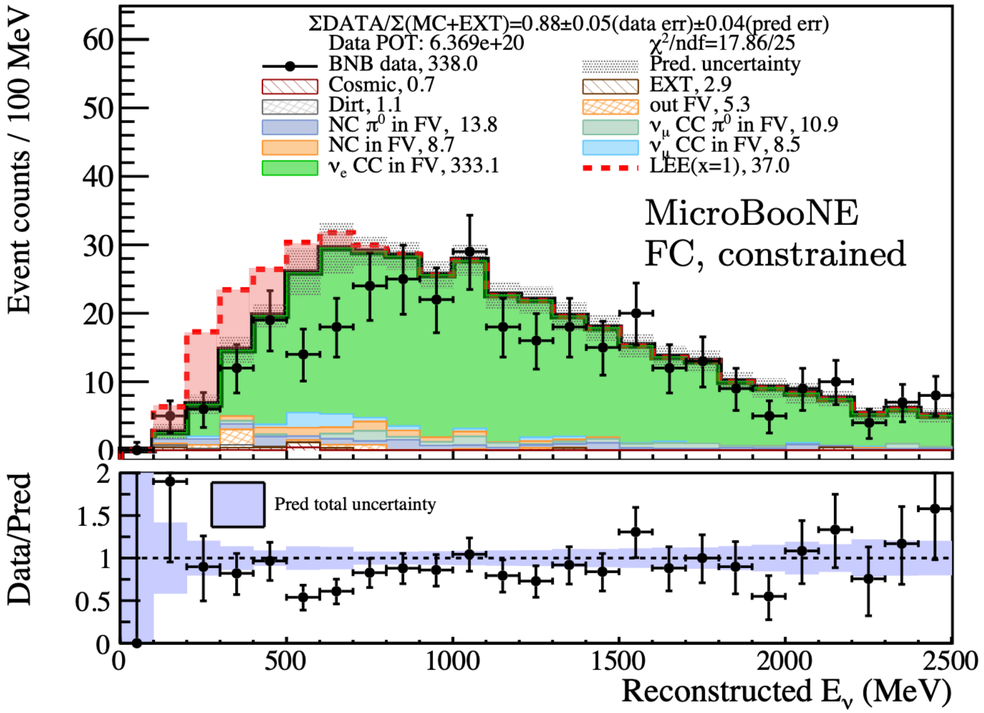

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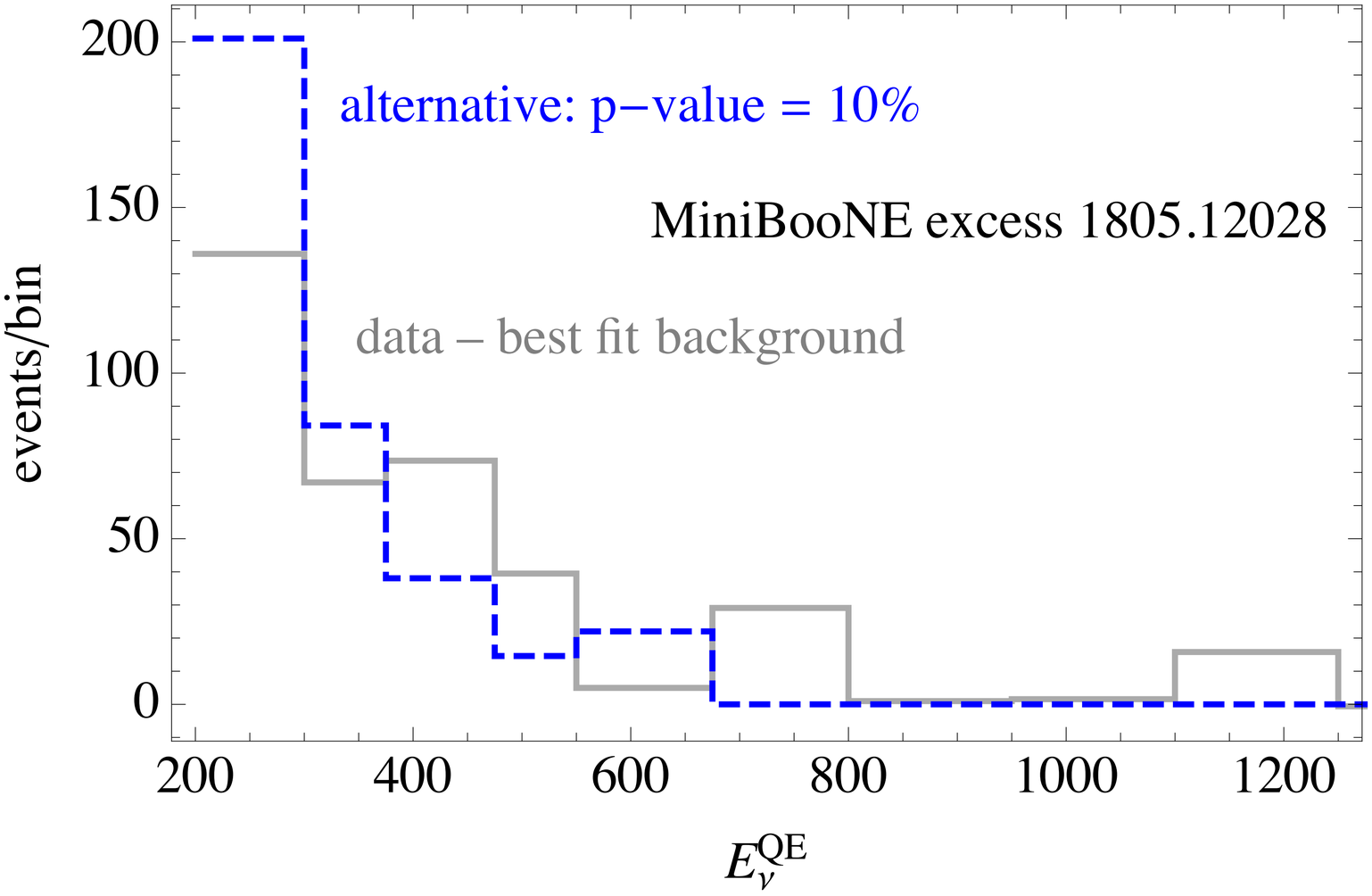

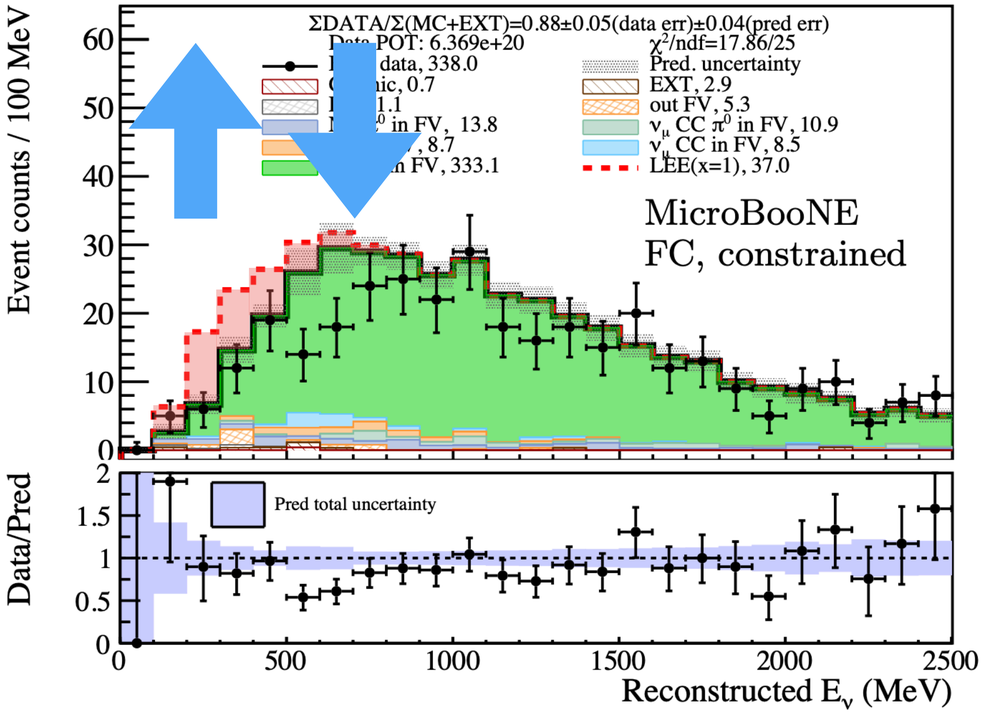

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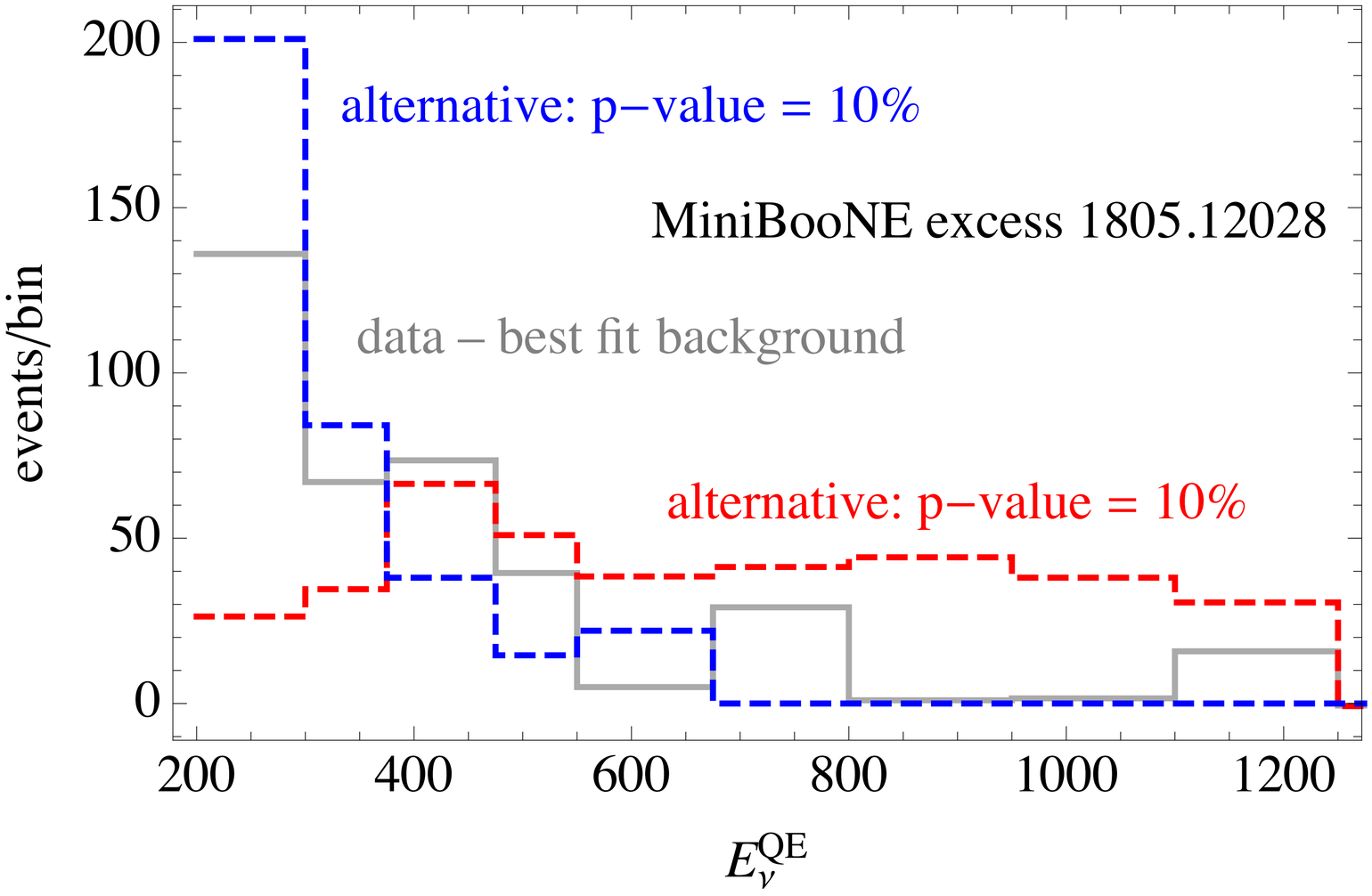

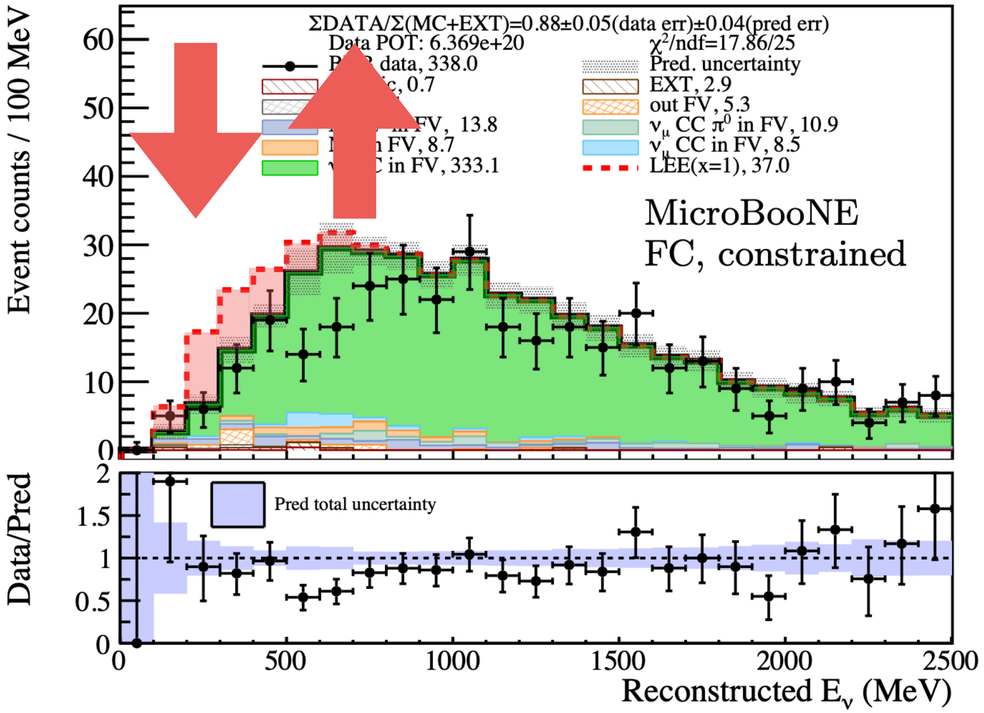

*Downward fluctuation of the data will boost sensitivity

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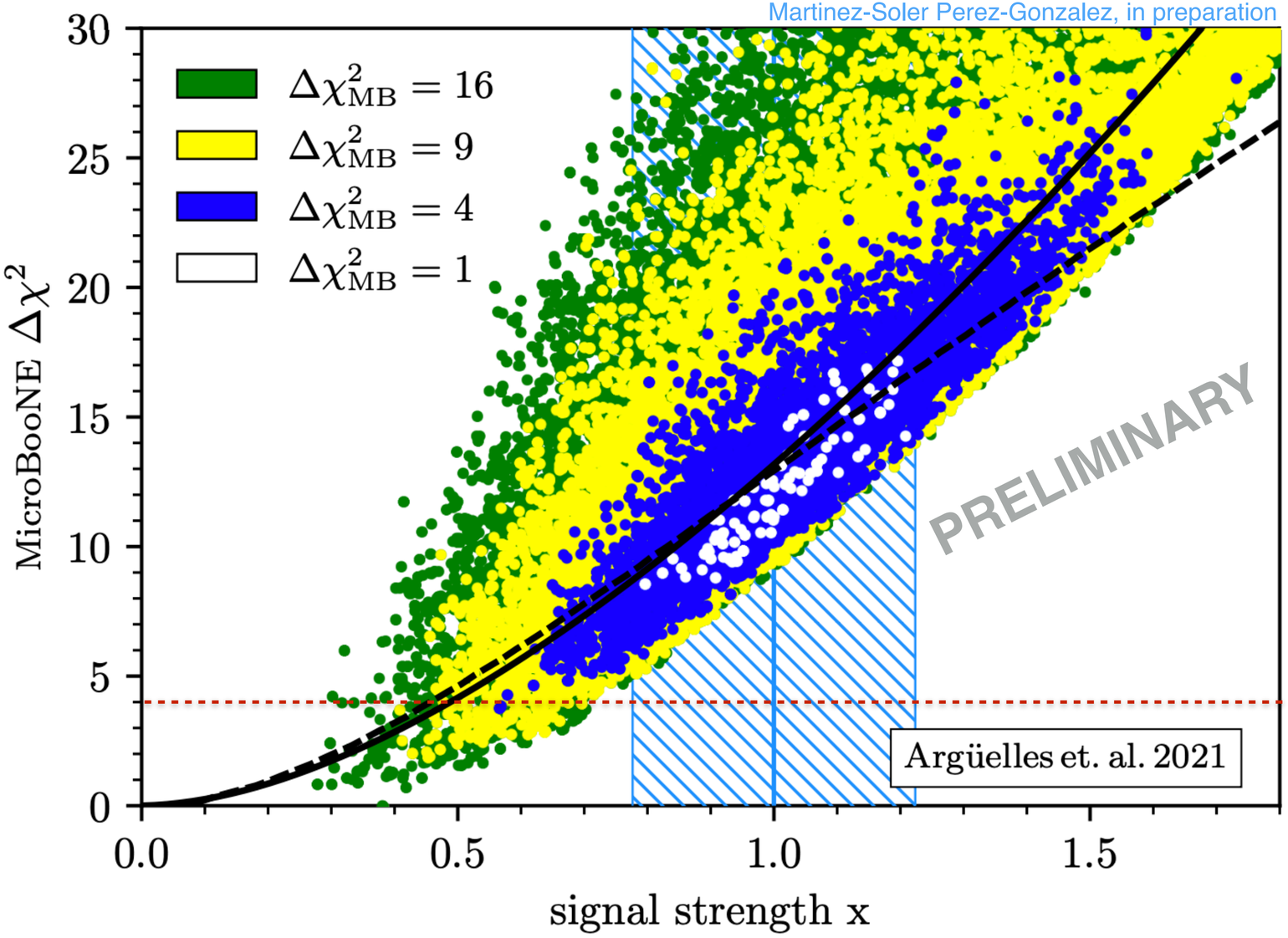
Does MicroBooNE rule out the ν_e interpretation of the MiniBooNE anomaly?

Arguelles Esteban Hostert Kelly Kopp Machado
Martinez-Soler Perez-Gonzalez, in preparation



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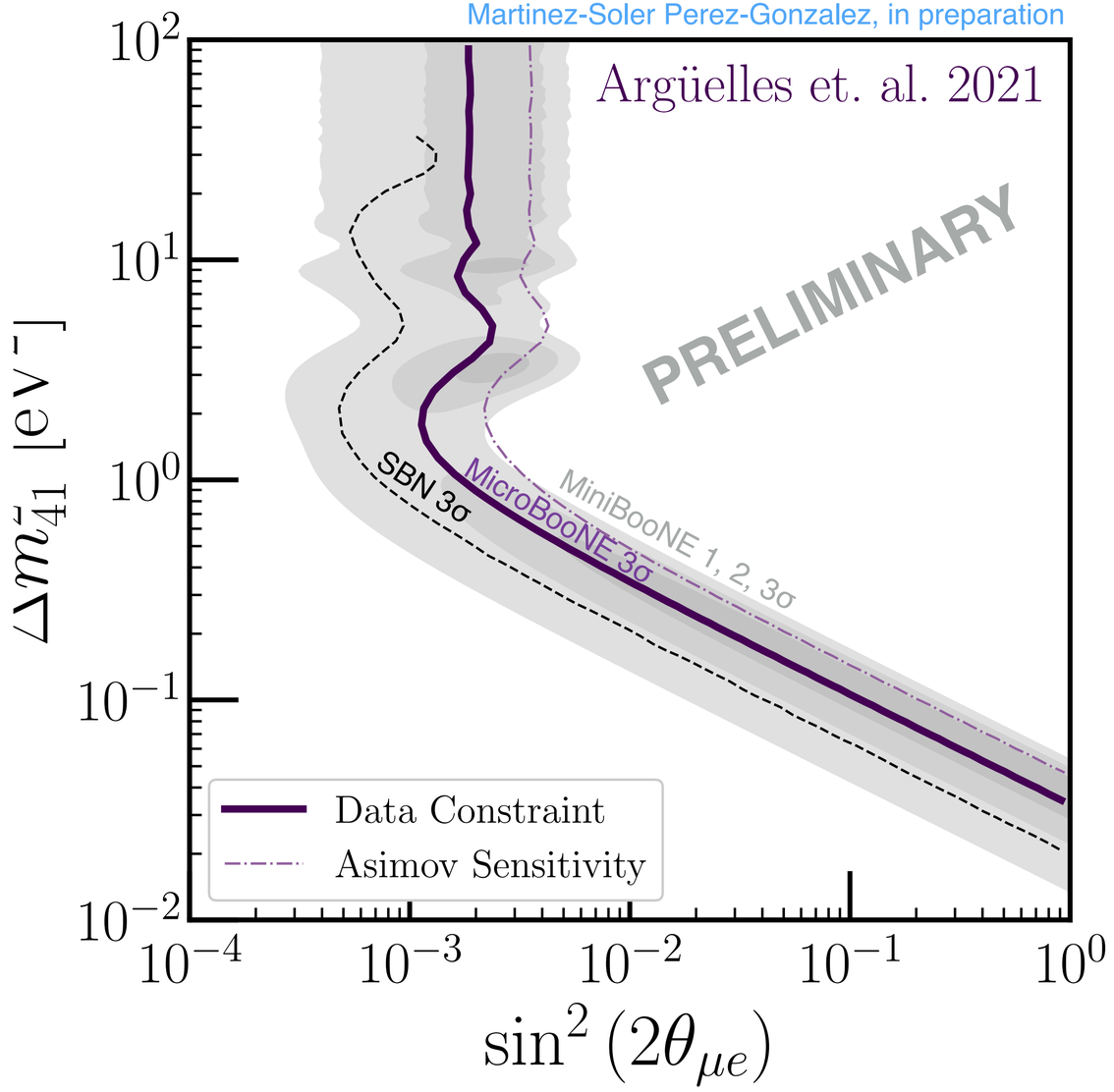
Does MicroBooNE rule out the sterile neutrino interpretation of the MiniBooNE anomaly?

L/E behavior is the smoking gun signature of sterile neutrinos or any model that relies on oscillations

SBND data will make the background estimates more robust

The combination SBND + MicroBooNE + ICARUS will be key to probe the sterile neutrino interpretation of MiniBooNE-LEE in a definitive way

Arguelles Esteban Hostert Kelly Kopp Machado Martinez-Soler Perez-Gonzalez, in preparation



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What did the Δ and LEE-electron analyses teach us and what else can we do with that?

The better is a detector, the more one can tailor analyses
to improve experimental sensitivities

But you only probe what you are searching for

Several alternative explanations of the MiniBooNE excess
and other BSM scenarios at large
would not show up in the Δ nor in the LEE-electron analyses

Here is an excursion through some these, their theoretical and
experimental motivations, and how to probe them in LArTPCs

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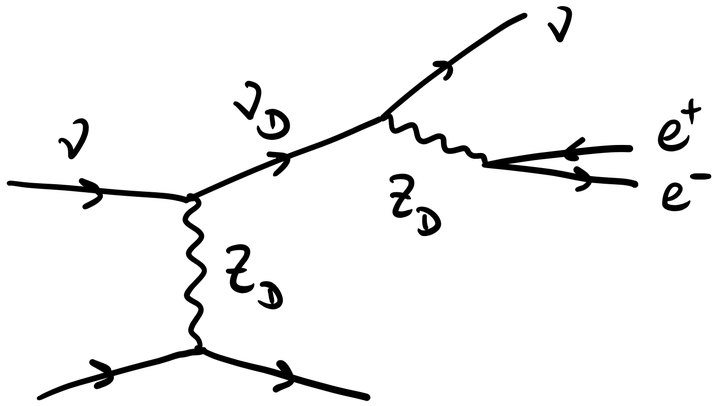
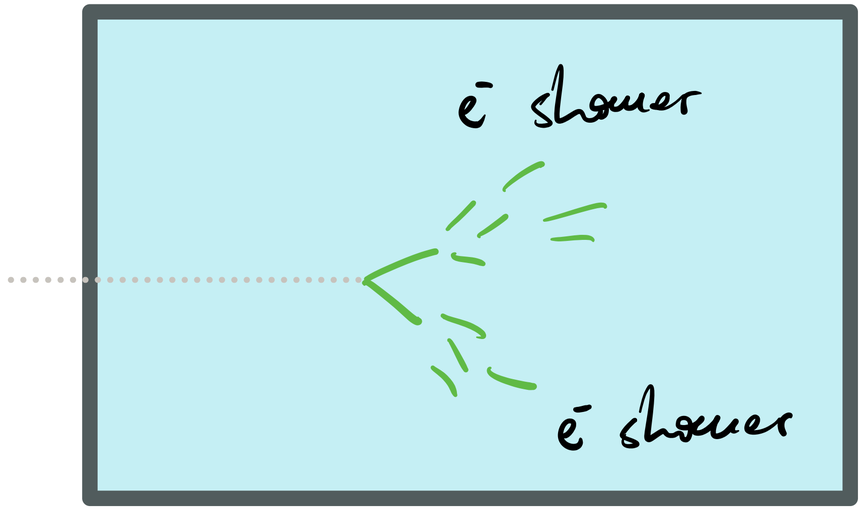
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Bertuzzo Jana Machado Zukanovich PRL 2018
Bertuzzo Jana Machado Zukanovich PLB 2019
Arguelles Hostert Tsai PRL 2019

Model in a nutshell

Dark neutrinos with light Z_D





Theoretical motivation

- Origin of neutrino masses
- Dark sector portal

Experimental motivation

- Excellent fit to MB energy spectrum
- Fair fit to MB angular spectrum

Experimental signature

- Somewhat collimated e^+e^- pair
- No hadronic activity
- Some missing transverse momentum
- Z_D invariant mass

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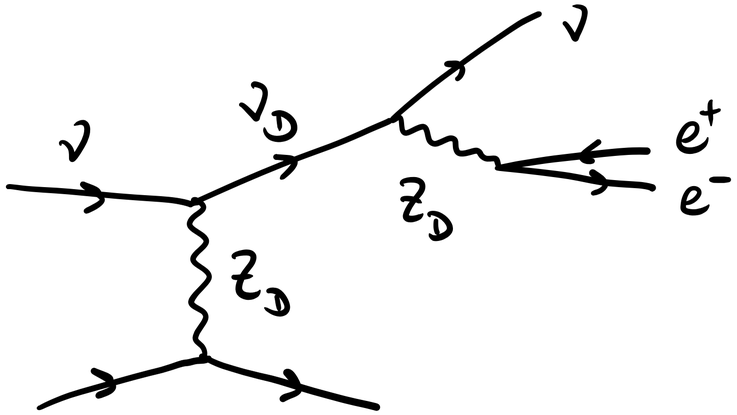
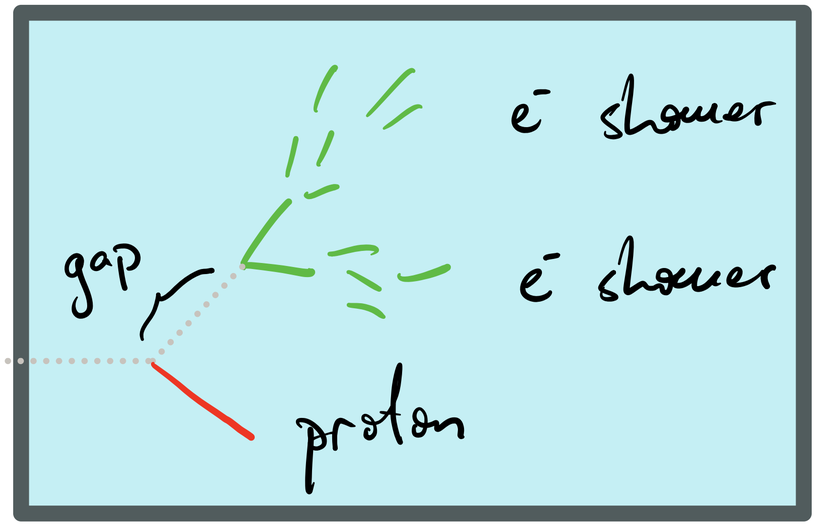
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Ballett Pascoli Ross-Lonergan PRD 2019
Ballett Hostert Pascoli PRD 2020

Model in a nutshell

Dark neutrinos with heavy Z_D





Theoretical motivation
- Origin of neutrino masses
- Dark sector portal

Experimental motivation
- Excellent fit to MB energy spectrum
- Excellent fit to MB angular spectrum

Experimental signature
- Less collimated, asymmetric e^+e^- pair
- Hadronic activity similar to CC events
- Z_D could be long lived: arbitrary gap

***Similar signature for scalar mediator**

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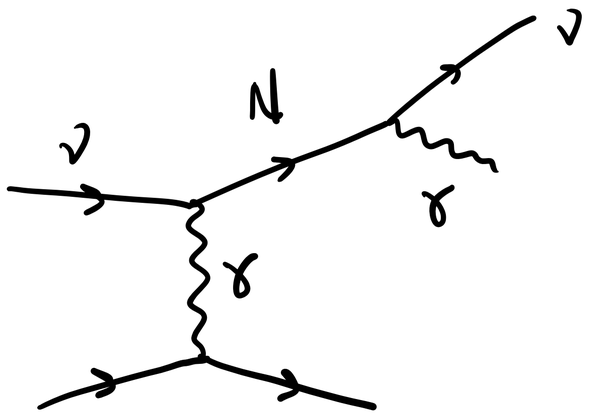
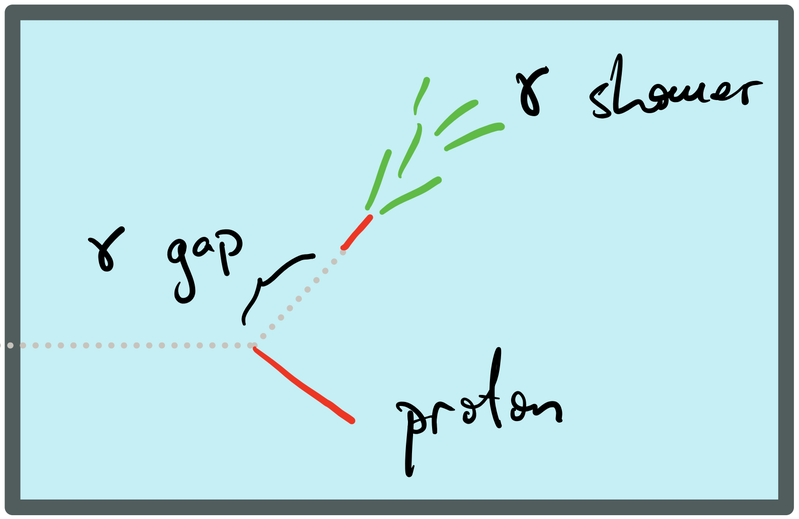
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Gninenko PRL 2009
Coloma Machado Soler Shoemaker PRL 2017
Atkinson et al 2021
Vergani et al 2021

Model in a nutshell

Transition magnetic moment





Theoretical motivation

- May be a consequence of the mechanism of neutrino masses

Experimental motivation

- Excellent fit to MB energy spectrum

Experimental signature

- Photon EM shower: dEdx and gap
- Some hadronic activity (1γ1p events)

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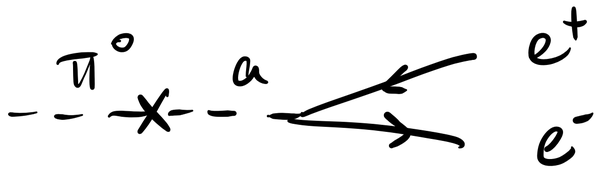
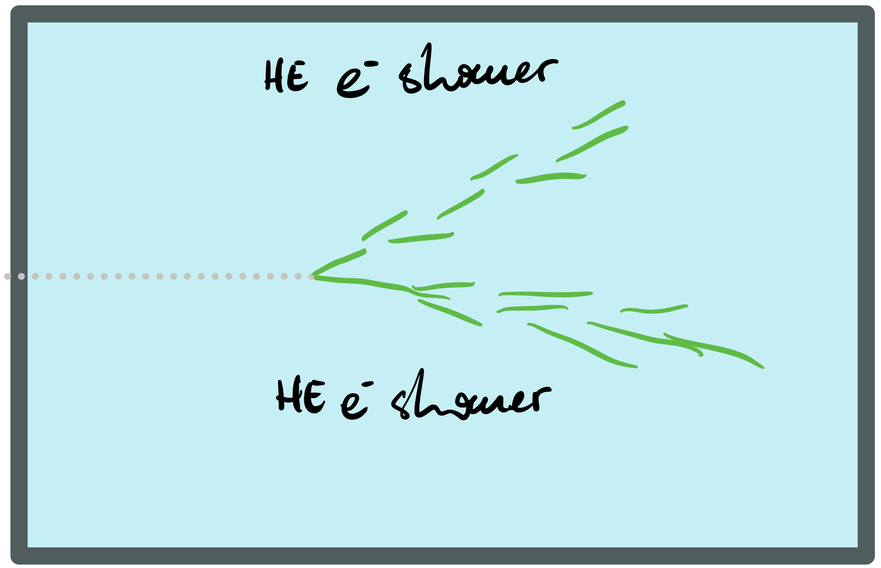
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Kelly Kumar Liu PRD 2021
Brdar et al PRL 2021

Model in a nutshell

Axion-like particles





Theoretical motivation

- Axions are well motivated, though this would not necessarily be related to the strong CP problem

Experimental motivation

- Relatively simple search

Experimental signature

- Two high energy electron-like EM showers
- No hadronic activity
- Invariant mass

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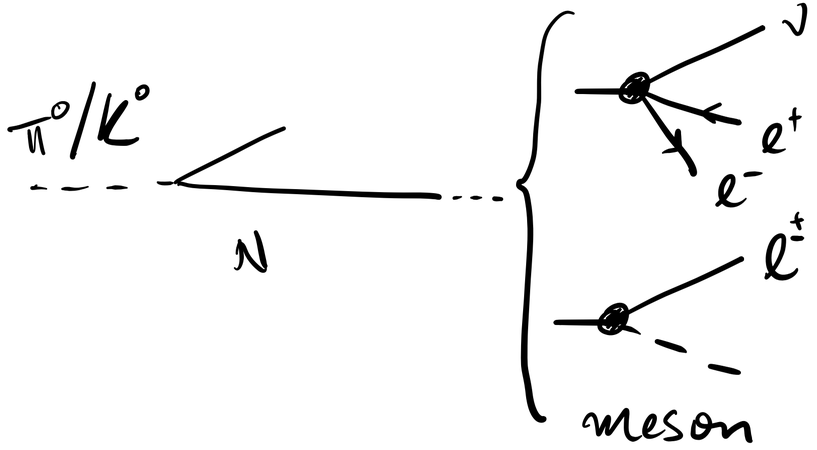
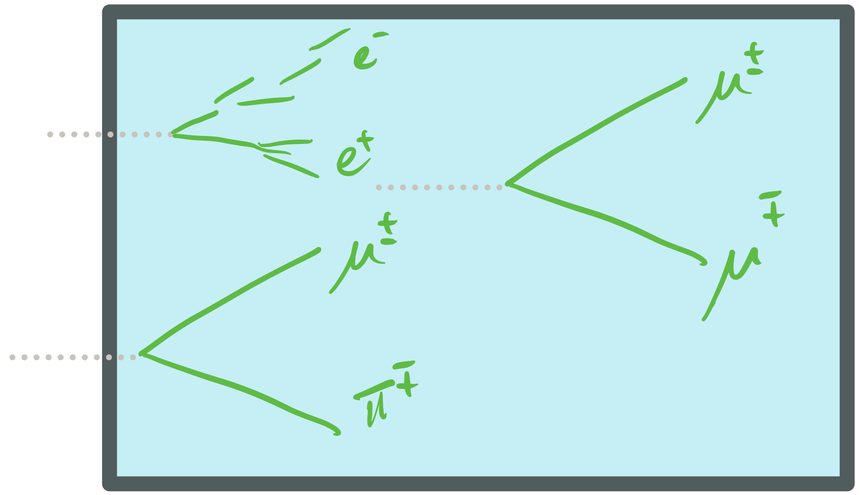
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Too many papers to list, but see
Ballett Pascoli Ross-Lonergan JHEP 2017
Kelly Machado PRD 2021

Model in a nutshell

Heavy neutral leptons





Theoretical motivation

- Possibly related to neutrino mass

Experimental motivation

- Dirac vs Majorana nature of HNLs can be probed, if discovered

Experimental signature

- No “soft” hadronic activity
- Possible invariant mass
- Several possibilities: e^+e^-, $\mu^+\mu^-$, $\mu\pi$, …
- Timing can help
- ICARUS off-axis NuMI could help

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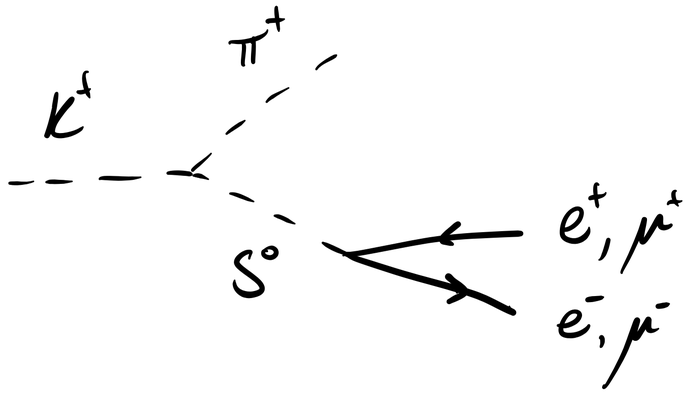
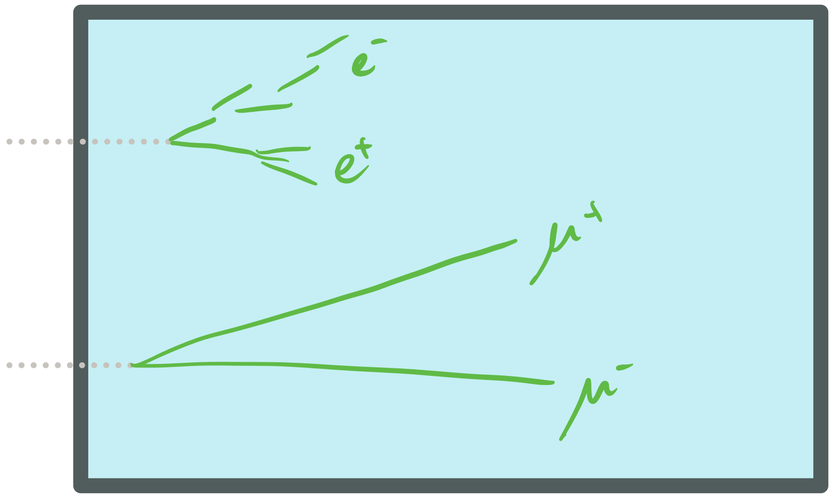
What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Pat Wilczek 2006
Batell Berger Ismail PRD 2019
MicroBooNE 2021

Model in a nutshell
Higgs portal scalars





Theoretical motivation
- Portal to dark sector
- Connection to Higgs sector

Experimental motivation
- Synergy with HNL search

Experimental signature
- No hadronic activity
- Invariant mass
- e^+e^-, $\mu^+\mu^-$
- Timing can help
- ICARUS off-axis NuMI could help
- NuMI absorbed can be a source too

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What did the Δ and LEE-electron analyses teach us and what else can we do with that?

Model	main signature	# protons	hadronic activity (≠ protons)	gap	dE/dx	invariant mass	opening angles	Highlight	motivation
Dark nu, light Z_D	e^+e^-	none	none	✗	crucial	Z_D	e^+e^- (small)	SBND	MB, M_ν, portal
Dark nu, heavy Z_D	e^+e^-	similar to σ_{CC}	similar to σ_{CC}	any	relevant	no	e^+e^- (small)	SBND	MB, M_ν, portal
Transition mag. mom.	γ	fewer than σ_{CC}*	less than σ_{CC}*	γ	crucial	no	γ-like	SBND	MB, consequence of M_ν
Axion-like particles	$\ell^+\ell^-$	none	none	✗	relevant	yes	large	SBND	Scalar sector
Heavy neutral leptons	$\ell^+\ell^-$, $\ell\,\pi$, …	none	none or hard	✗	relevant	yes if no MET	large	μB/ICARUS	M_ν
Higgs portal scalars	$\ell^+\ell^-$	none	none	✗	relevant	yes	large	μB/ICARUS	dark sector portal
Steriles+	e^-, L/E	similar to σ_{CC}	similar to σ_{CC}	no	relevant	no	✗	All SBN detectors	MB
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

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What did the Δ and LEE-electron analyses teach us and what else can we do with that?

All these BSM scenarios rely on properly estimating standard backgrounds,
so understanding neutrino-argon interactions is crucial

SBND will have a large, high-quality statistical sample

MicroBooNE and ICARUS will be able to leverage NuMI for nontrivial studies

We will organize a special, informal SBN-Theory mini-workshop
to address physics opportunities and synergies at SBN

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Conclusions

MicroBooNE results are a milestone on the field of neutrino physics
They set a very high standard for future LArTPC analyses

The electron neutrino interpretation of MiniBooNE LEE is still viable
Sterile neutrino parameter space is still open

Several BSM scenarios will leverage the three SBN detectors differently

The three detectors are crucial to have
a vibrant, multi-purpose neutrino physics program at Fermilab

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