MicroBooNE's Low Energy Excess Search: First Results and Future Prospects

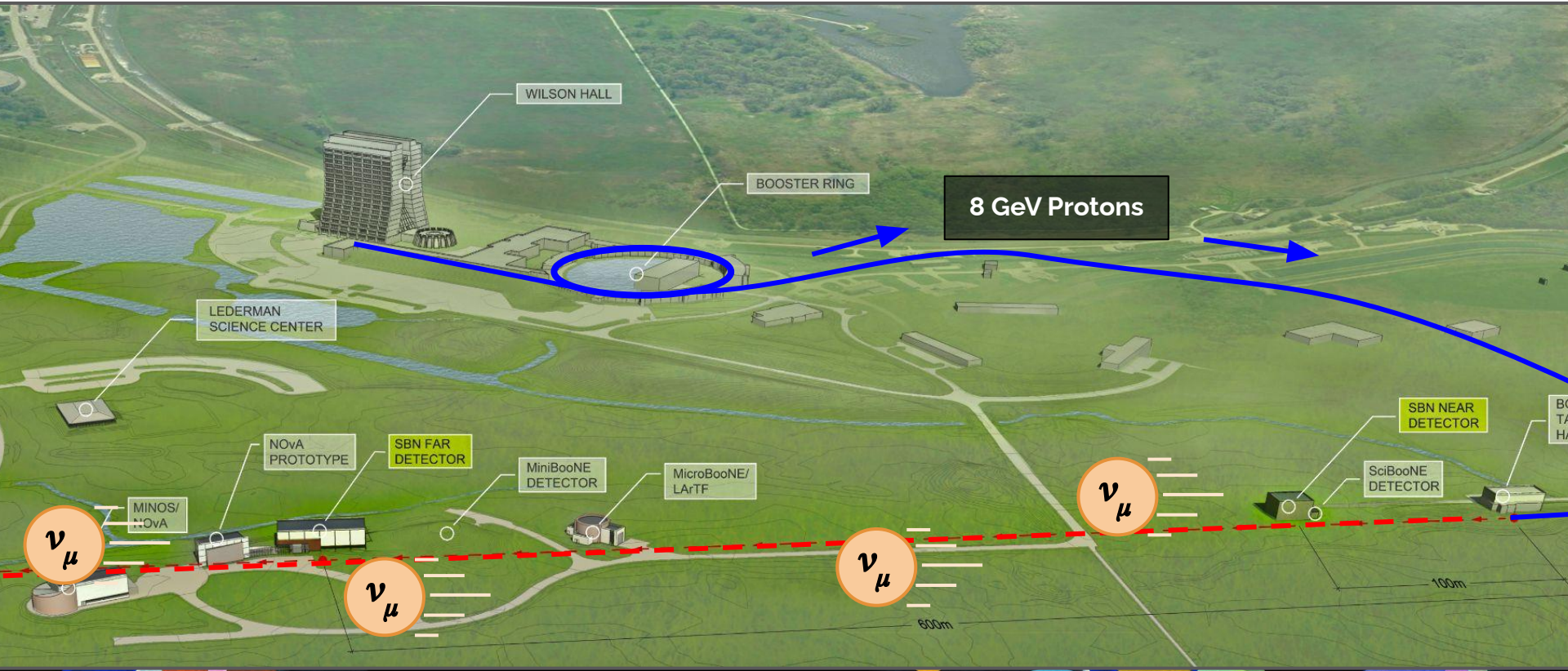
Mark Ross-Lonergan

on behalf of the ***MicroBooNE Collaboration***

Snowmass BSM@nu Workshop

February 11th 2022

Introduction to MicroBooNE and Booster Neutrino Beam (BNB) at Fermilab



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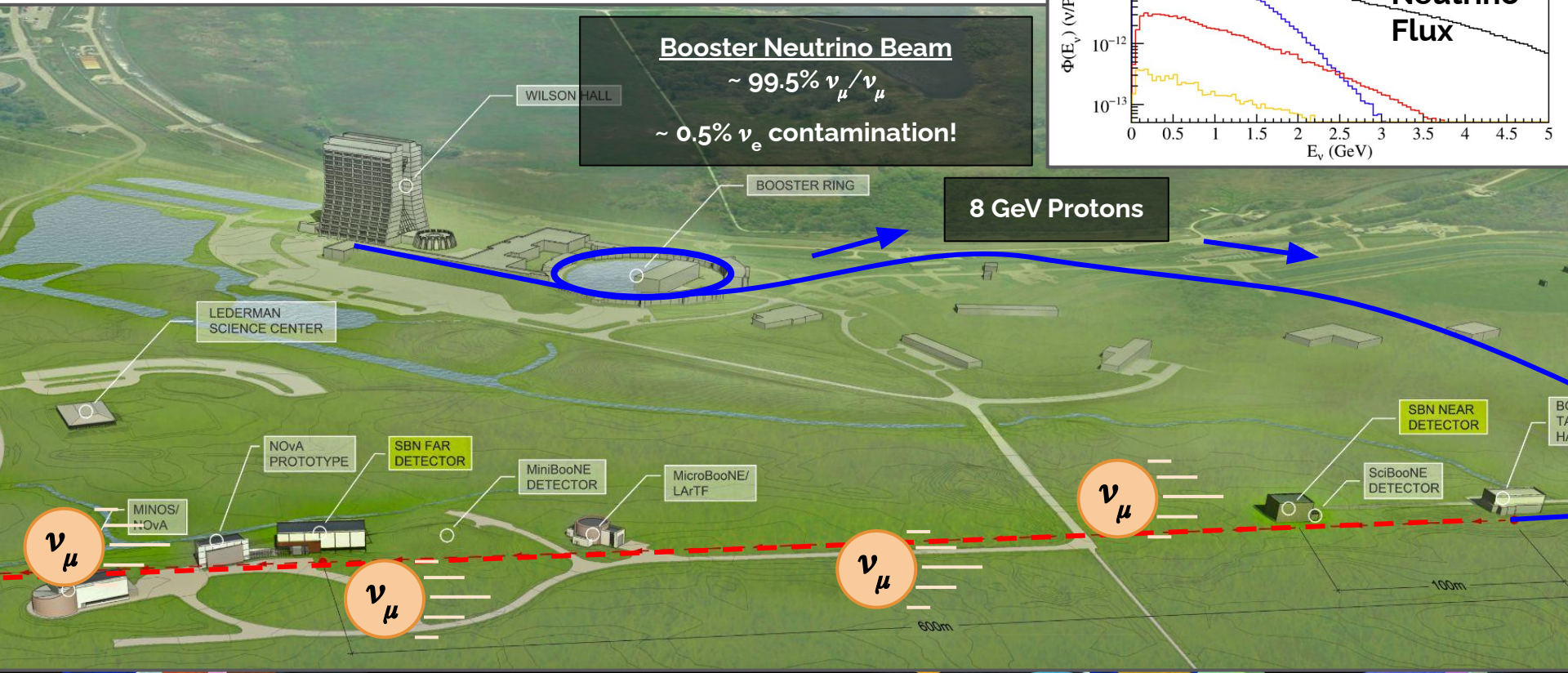
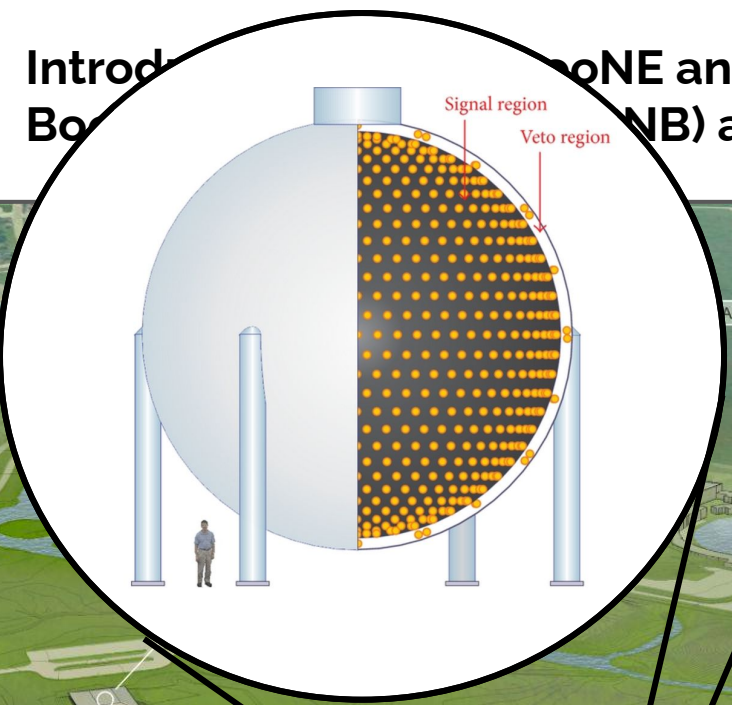


Introd…ooNE and Bo…NB) at Fermilab



BOOSTER

NOvA PROTOTYPE

SBN FAR DETECTOR

MiniBooNE DETECTOR

MicroBooNE/ LArTF

MINOS/ NOvA

SBN NEAR DETECTOR

SciBooNE DETECTOR

100m

MiniBooNE!

~70m

MicroBooNE!

~470m

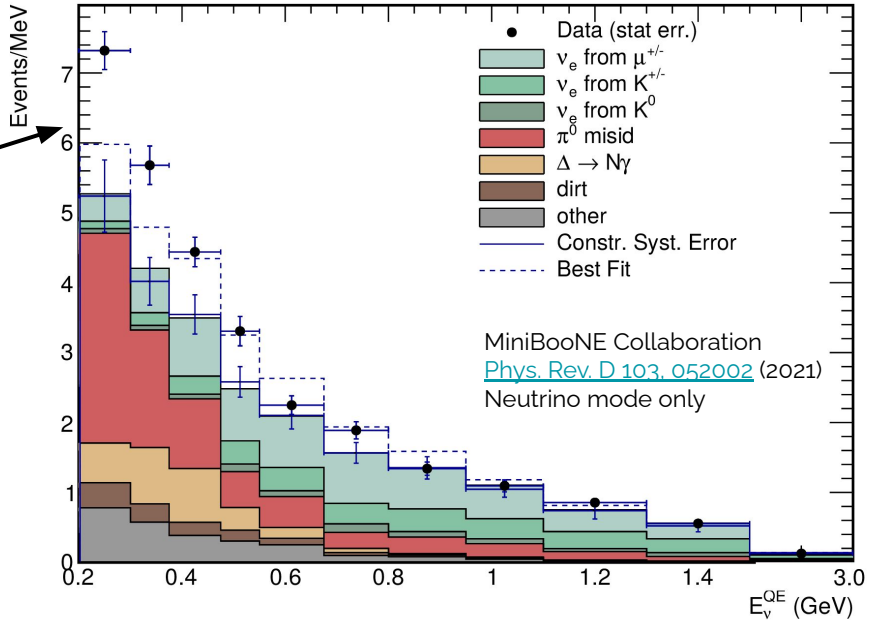
MiniBooNE Low-Energy Excess (LEE)

MiniBooNE was designed to look for

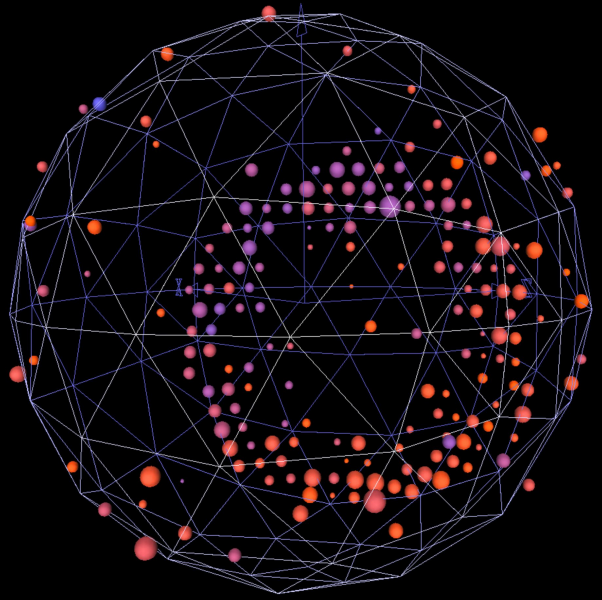
$\nu_\mu \rightarrow \nu_e$

MiniBooNE observed an excess of electron like-events

Its **significance** is now **4.8σ** (systematics limited) when combining all neutrino and antineutrino beam data.

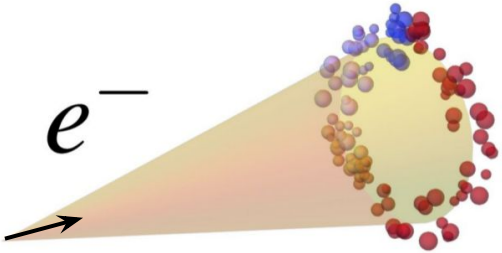


Electrons

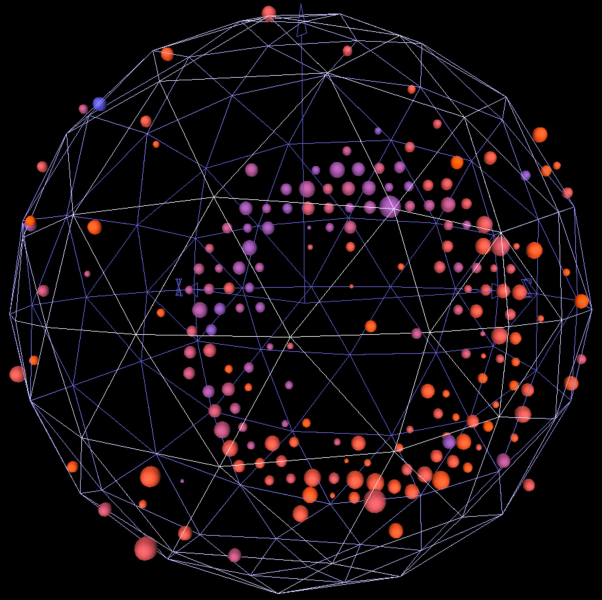


Electron Cherenkov ring event in MiniBooNE

Electrons produced in charged current (CC) ν_e interactions were detected by their Cherenkov ring



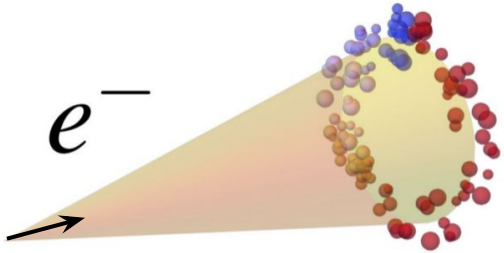
Electrons or Photons?



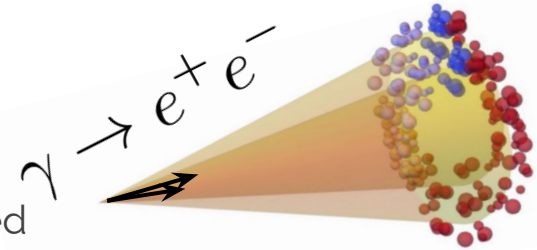
Electron Cherenkov ring event in MiniBooNE

MiniBooNE couldn't separate electrons from photons.

Electrons produced in charged current (CC) ν_e interactions were detected by their Cherenkov ring



However, **photons**, that pair produce extremely collimated electron/positron pairs produced an identical Cherenkov ring



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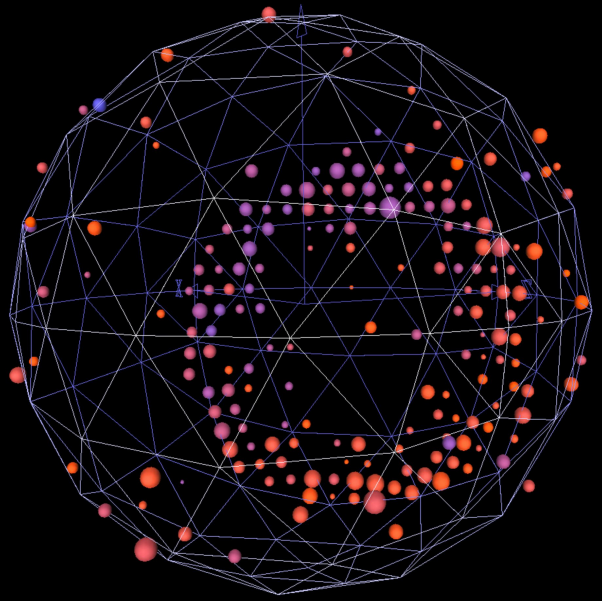

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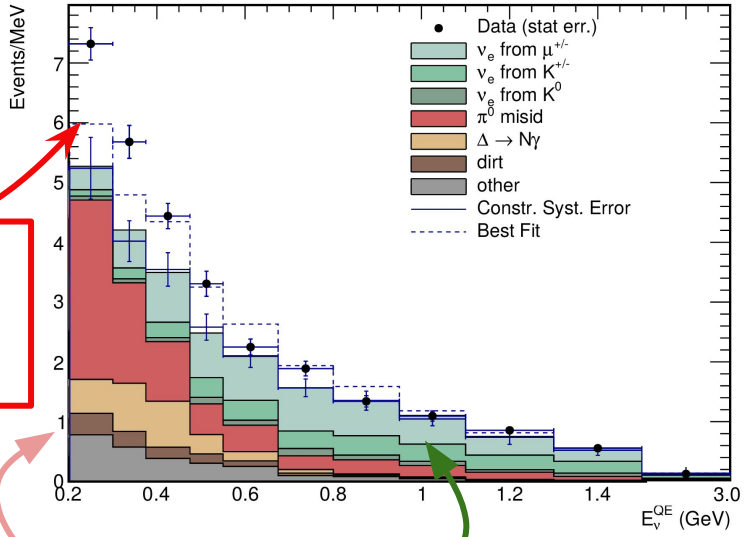
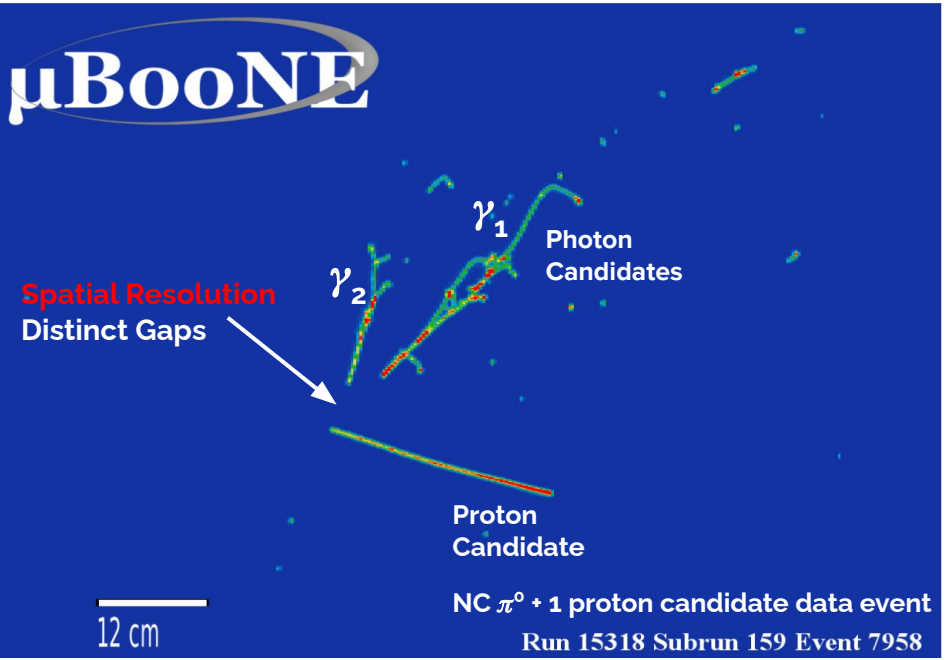


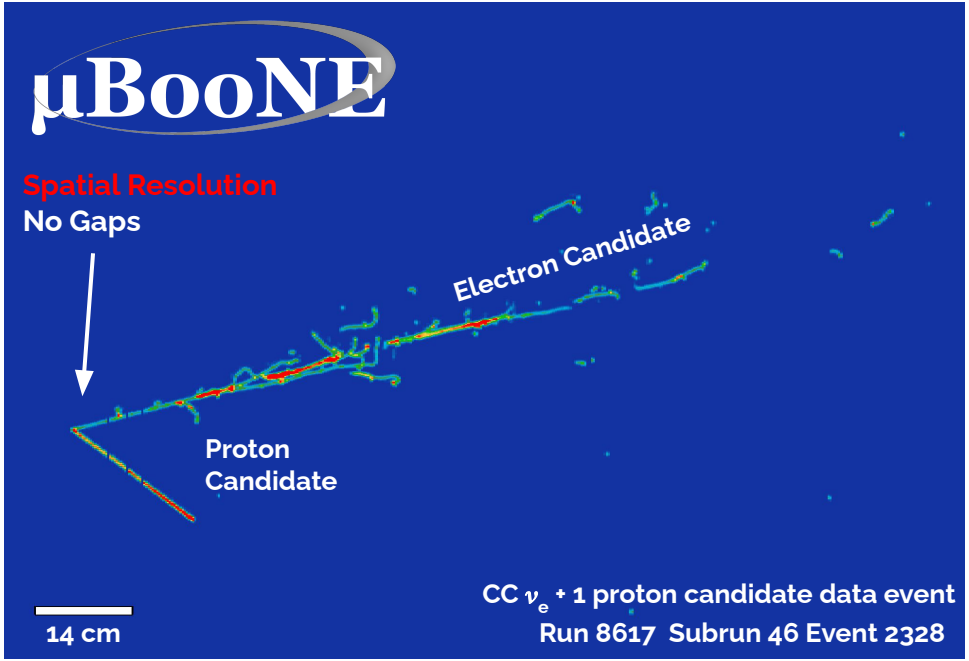
What really is happening in MiniBooNE?!

Photons or Electrons

Electron /Photon Separation in MicroBooNE

LArTPC's can separate **photons** from **electrons** due to **fine spatial resolution** and calorimetry





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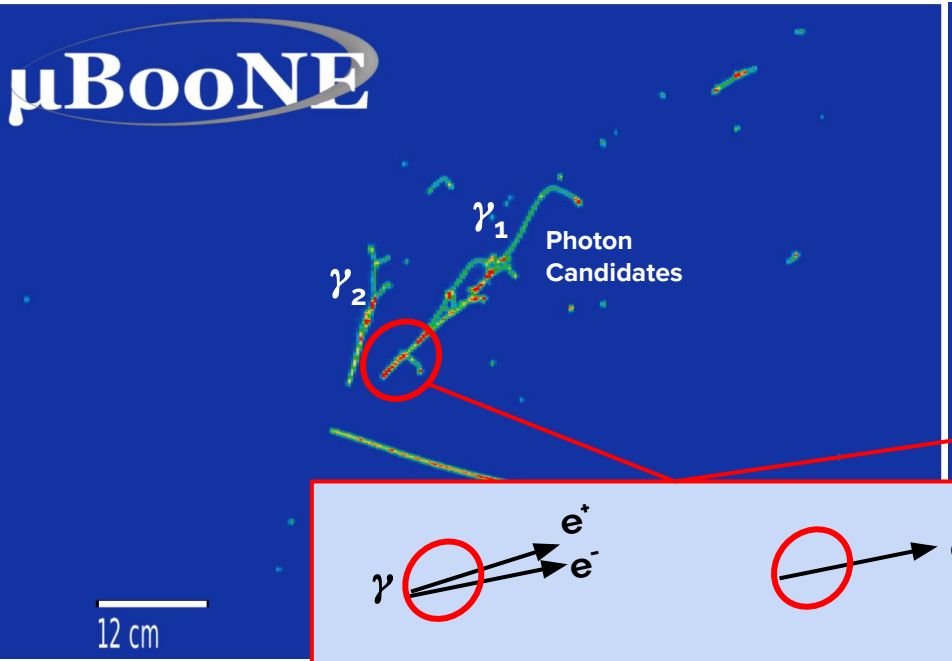
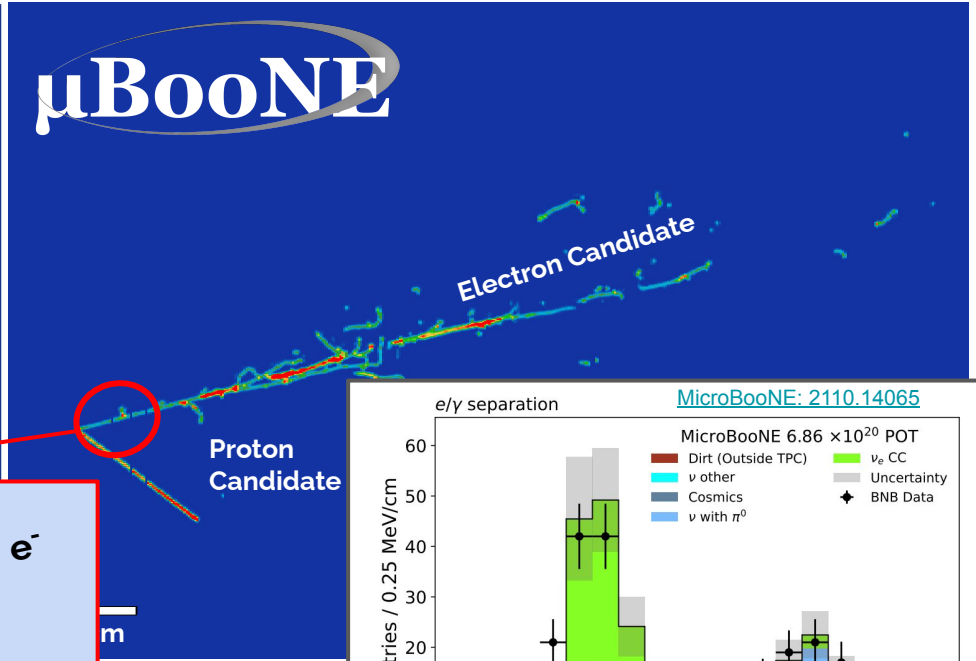
LArTPC's can separate **photons** from **electrons** due to fine spatial resolution and **calorimetry**





A pair producing photon quite literally has twice the number of minimally ionizing electrons, so has **twice the charge deposited at the start of the shower (dE/dx)**

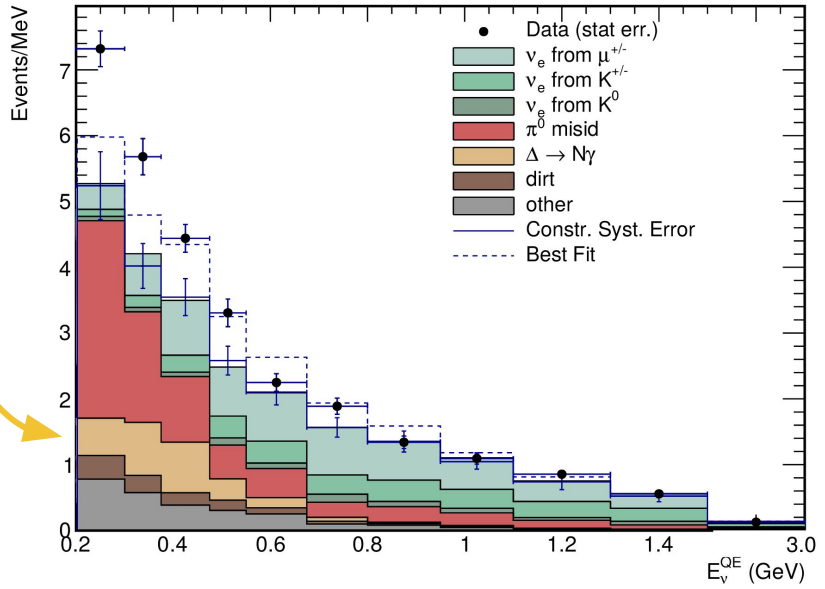

Searching for Photons

Neutral Current Δ Radiative Decay (NC Δ→Nγ)

First MicroBooNE photon search targeted Neutral Current Δ Radiative Decay (**NC Δ→Nγ**), a standard model source of lone photons that has **never been directly observed in the neutrino sector** before.

Shape of expected events very close to that of the MiniBooNE Low-Energy Excess.

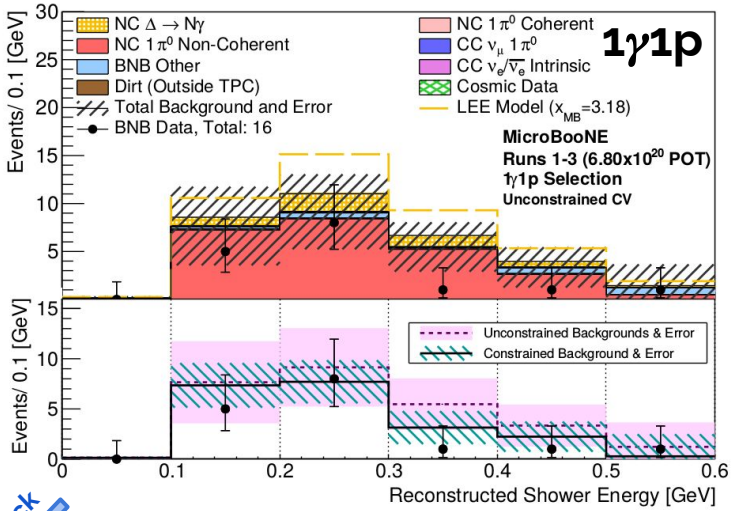
A x3.18 enhancement could explain the excess. (Phys. Rev. D 103, 052002 (2021))

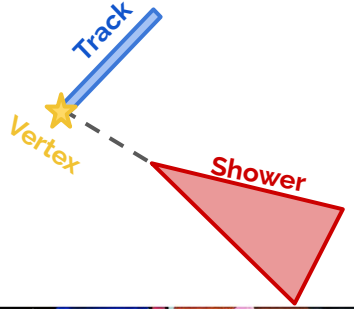


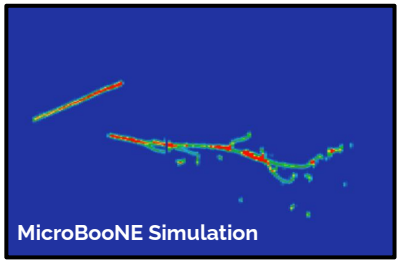
For more info See Single-Photon Paper, submitted to PRL: https://arxiv.org/abs/2110.14065

Target two distinct topologies

Developed analyses targeting two topologies containing a **single-photon like shower** and either **1 or 0 proton tracks**







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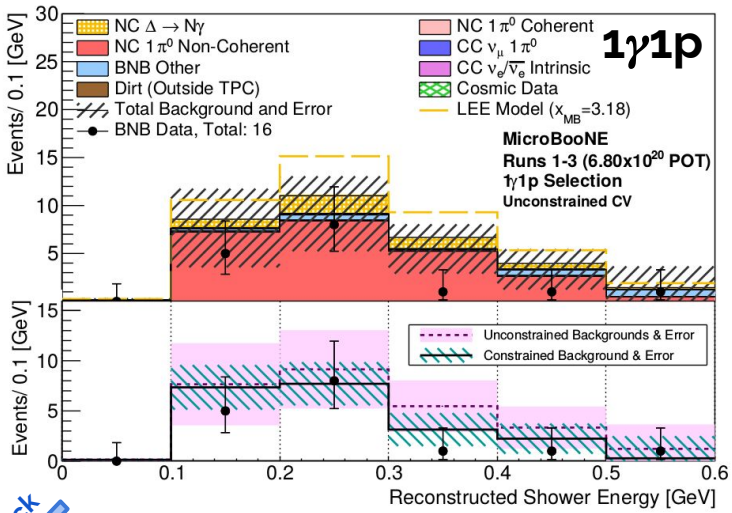
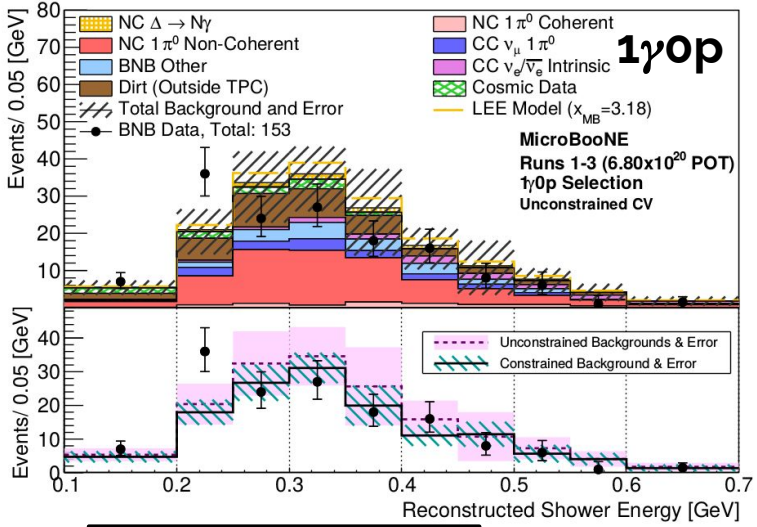
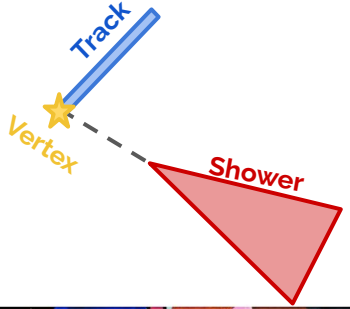
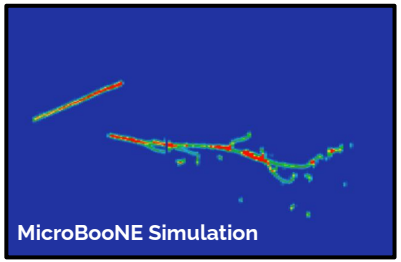
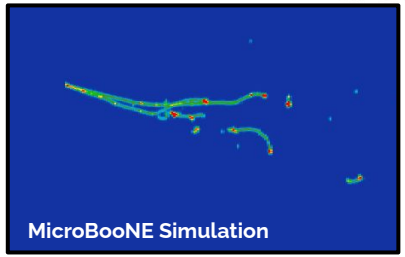
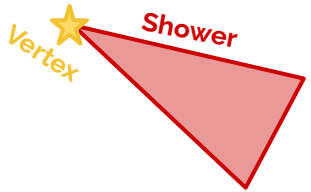




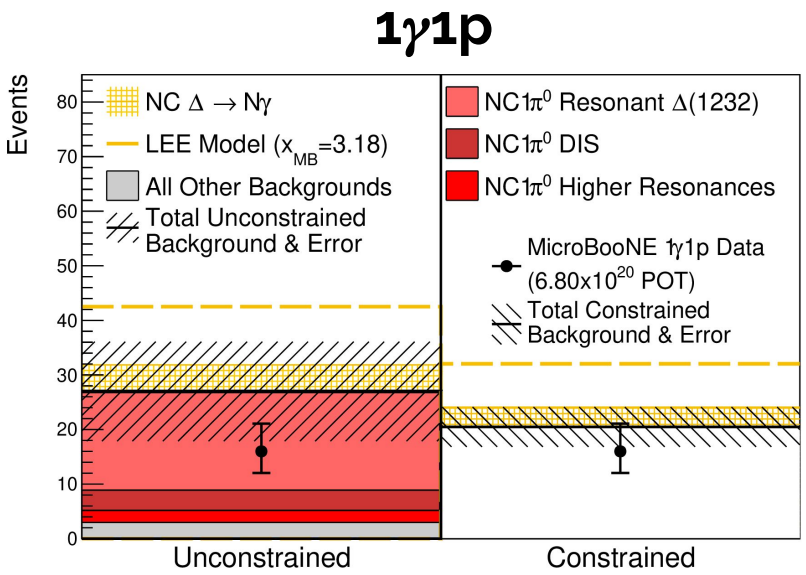








One-bin counting experiment



1γ1p

Unconstr. bkgd.	27.0 ± 8.1
Constr. bkgd.	20.5 ± 3.6
NC $\Delta \to N\gamma$	+ 4.88
LEE ($x_{\mathrm{MB}} = 3.18$)	+ 15.5

16 Data Events Observed

- We see **no evidence** for an enhanced rate of single-photons from **NC Δ→Nγ decay**, above nominal expectations
- Under a two-hypothesis test, the data disfavours the interpretation of the MiniBooNE anomalous excess as a factor of 3.18 enhancement to the rate NC Δ→Nγ, in favor of the nominal prediction at **94.8% CL**
- Majority of the sensitivity of this comes from the 1γ1p selection, 1γ0p less constrained


e-
νe
e-
Searching for Electrons
νe
νe
νe
e-
e-

MicroBooNE's First electron searches

MicroBooNE has recently released the results of **three separate analyses** that target looking for **electrons from ν_e** in the BNB

- Charged Current **Inclusive ν_e** measurement (hep-ex:2110.13978)
- Charged Current **Pion-less ν_e** measurement (hep-ex:2110.14065)
- Charged Current **Quasi Elastic ν_e** measurement (hep-ex:2110.14080)

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All three use different and complementary **LArTPC reconstruction techniques** and focus on different final states

Wire-Cell 3D tomography reconstruction (2110.13961)

Pandora pattern recognition reconstruction (2110.14065)

Imaged based **Deep-Learning** reconstruction (2110.14080)

MicroBooNE's First electron searches

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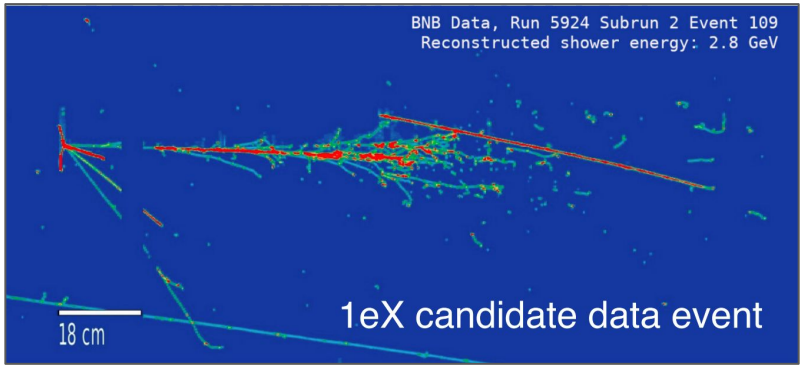
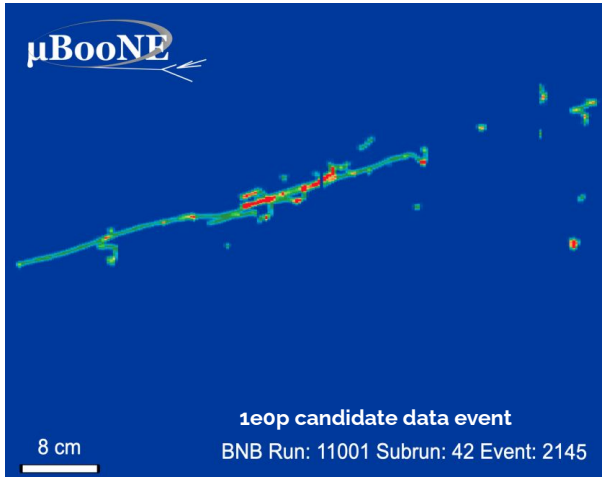
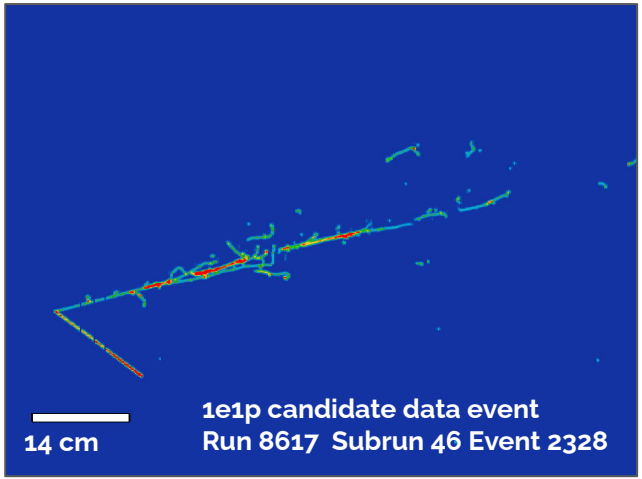


Topology agnostic
Just looking for electron-like showers, regardless of NY other mesons or hadrons.

High Efficiency,
High Statistics and
high purity selection





Inclusive ν_e Results

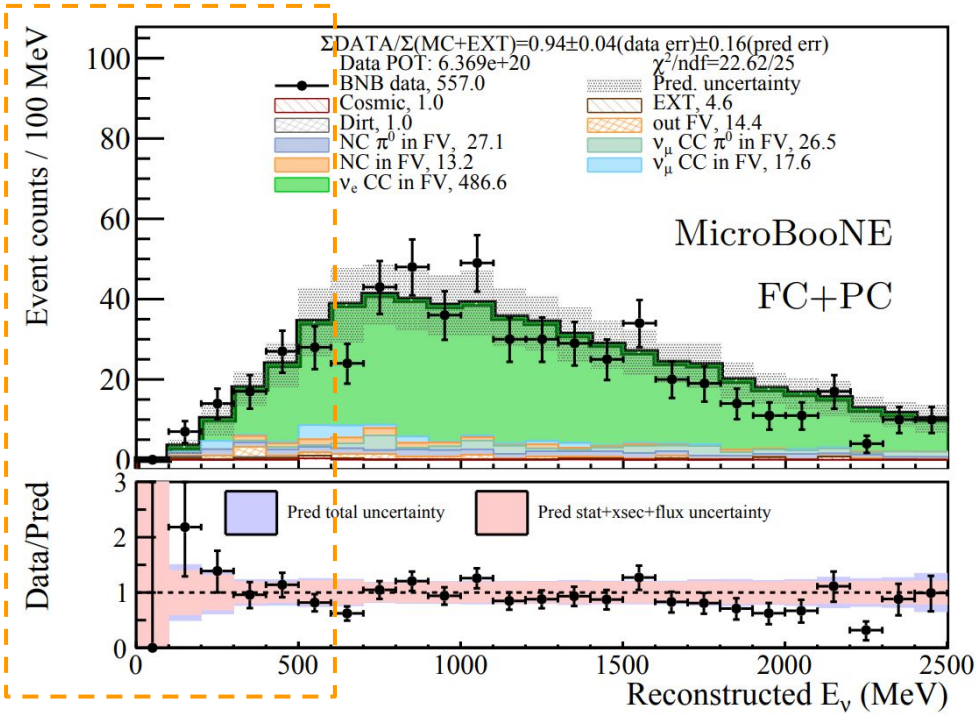
The **Signal region** is where we would expect to see the **Low-Energy Excess** if it were due to an increased rate of intrinsic-ν_e

Good agreement within assigned systematic uncertainties is observed across entire energy range with χ^2/ndof = 22.62/25

CC ν_e purity of **82%**

CC ν_e selection efficiency of **46%**

Signal region defined as reconstructed E_ν < 600 MeV



MicroBooNE hep-ex:2110.13978

Inclusive ν_e Results

Restrict ourselves to subset of well-reconstructed, **fully contained** events

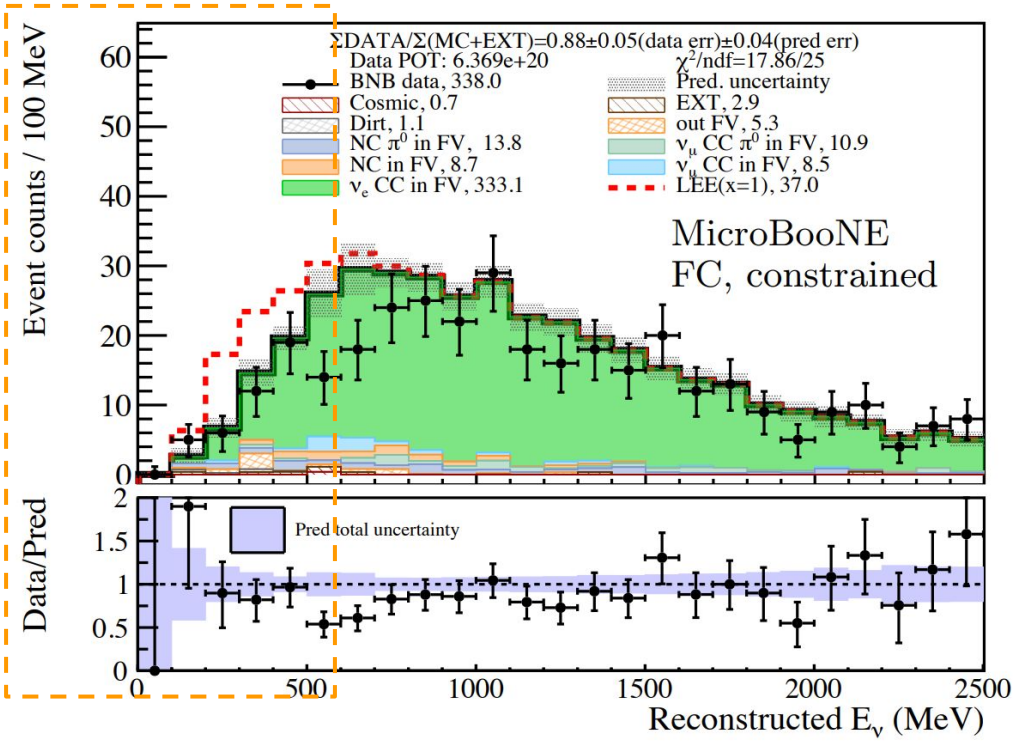
In the **Signal region** Observed **56** events

And predicted

- **69.6** ± 5.0 (sys) ± 8.0 (stat) events
  - (**No LEE hypothesis**)
- 103.8 ± 7.4 (sys) ± 9.0 (stat) events
  - (with a **simple LEE model**)

No excess of low energy ν_e candidates is observed

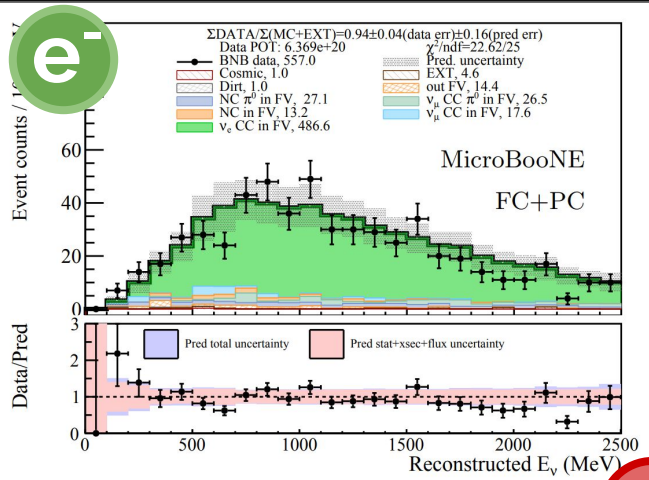
Signal region defined as reconstructed E_ν < 600 MeV

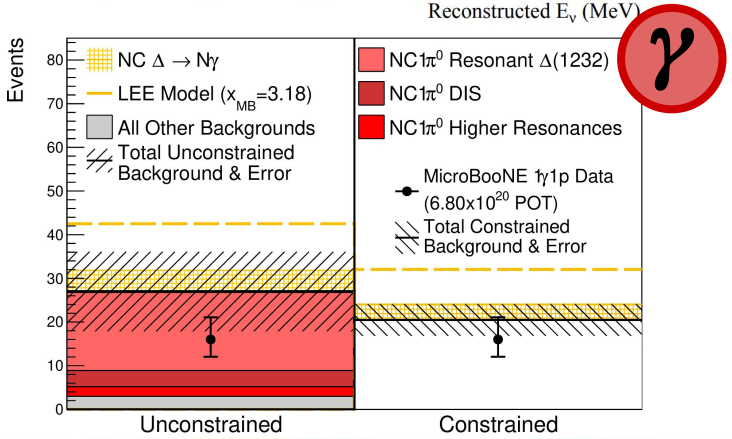


First Series of MicroBooNE Results

While these results **strongly disfavour** the possibility of the MiniBooNE low-energy excess being entirely due to an **increased ν_e rate** or enhanced **single-photons from NC $\Delta \rightarrow N\gamma$** decays they don't change the fact that **MiniBooNE saw an anomaly!**

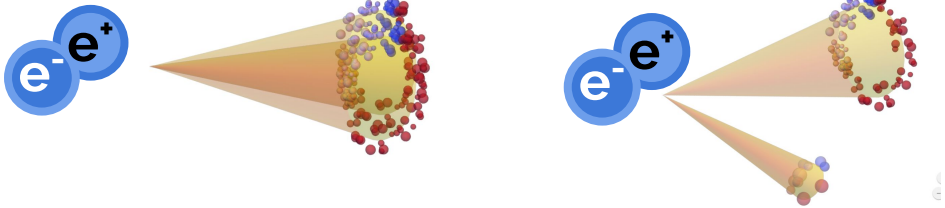
With these first tests, leveraging the power of **LArTPC neutrino detector** technology, we have begun to **eliminate avenues**, but plenty remain..



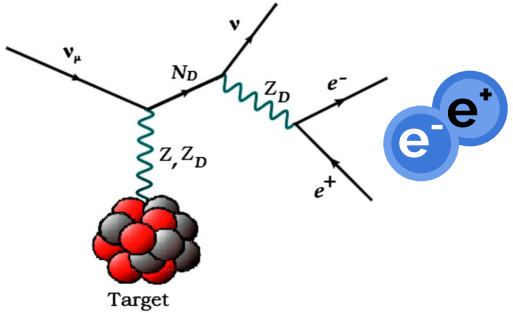



Future Prospects

Electrons or Photons? … or e^+e^- pairs?



Bertuzzo et al, PRL 121, 241801 (2018)



Rich phenomenology developing in recent years around the possibility of the MiniBooNE excess being due to **e^+e^- pairs from decays of new exotic particles** such as **dark-photons, axion-like particles or new scalars!**

If sufficiently overlapping these can mimic the MiniBooNE electron-like signal

Evolving Theory Landscape

- **Decay of O(keV) Sterile Neutrinos** to active neutrinos
  - *Dentler, Esteban, Kopp, Machado Phys. Rev. D 101, 115013 (2020)*
  - *de Gouvêa, Peres, Prakash, Stenico JHEP 07 (2020) 141*
- New **resonance matter effects**
  - *Asaadi, Church, Guenette, Jones, Szelc, PRD 97, 075021 (2018)*
- **Mixed** O(1eV) **sterile oscillations** and O(100 MeV) **sterile decay**
  - *Vergani, Kamp, Diaz, Arguelles, Conrad, Shaevitz, Uchida, arXiv:2105.06470*
- Decay of **heavy sterile neutrinos** produced in beam
  - *Gninenko, Phys.Rev.D83:015015,2011*
  - *Alvarez-Ruso, Saul-Sala, Phys. Rev. D 101, 075045 (2020)*
  - *Magill, Plestid, Pospelov, Tsai Phys. Rev. D 98, 115015 (2018)*
  - *Fischer, Hernandez-Cabezudo, Schwetz, PRD 101, 075045 (2020)*
- Decay of **upscattered heavy sterile** neutrinos or new scalars mediated by **Z' or more complex higgs sectors**
  - *Bertuzzo, Jana, Machado, Zukanovich Funchal, PRL 121, 241801 (2018)*
  - *Abdullahi, Hostert, Pascoli, Phys.Lett.B 820 (2021) 136531*
  - *Ballett, Pascoli, Ross-Lonergan, PRD 99, 071701 (2019)*
  - *Dutta, Ghosh, Li, PRD 102, 055017 (2020)*
  - *Abdallah, Gandhi, Roy,Phys. Rev. D 104, 055028 (2021)*
- Decay of **axion-like particles**
  - *Chang, Chen, Ho, Tseng, Phys. Rev. D 104, 015030 (2021)*

Produces True Electrons

Produces True Photons

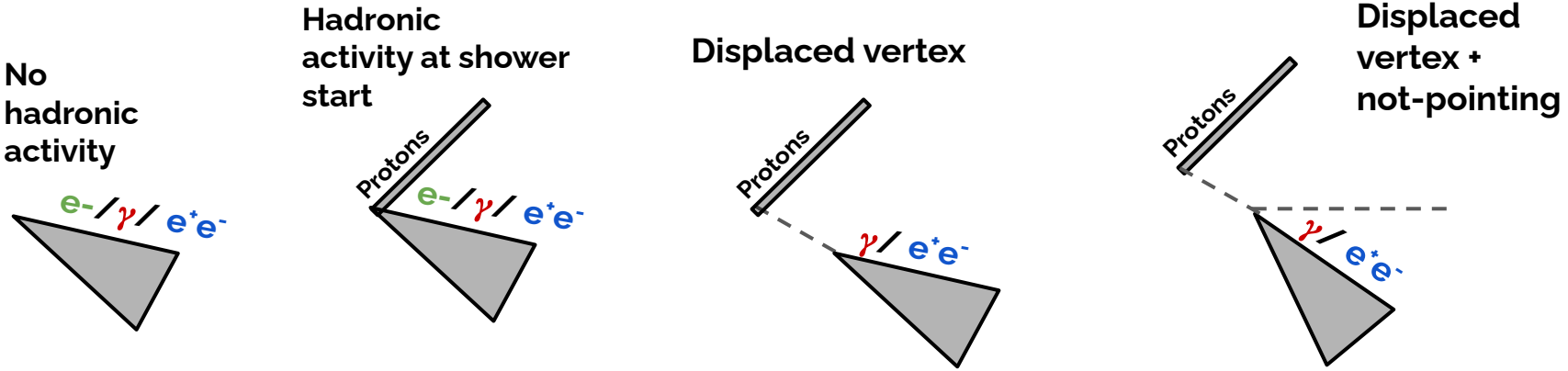
Produces e^+e^- pairs

(Caution: not an exhaustive list!)

The hadronic side of things

Many of these models predict widely varying **hadronic activity** alongside the e-, γ or e^+e^- needed to explain the anomaly.

To MiniBooNE all of these look identical, as they couldn't see **protons** below cherenkov threshold



The **hadronic final state topologies** can give us a handle to separate out these models!

Summary

MicroBooNE's first results have demonstrated that by leveraging LArTPC technology we can perform detailed measurements capable of both **separating electron from photons** and delving into the **hadronic reconstruction** opening the door for potentially distinguishing between a wide range of BSM theories.