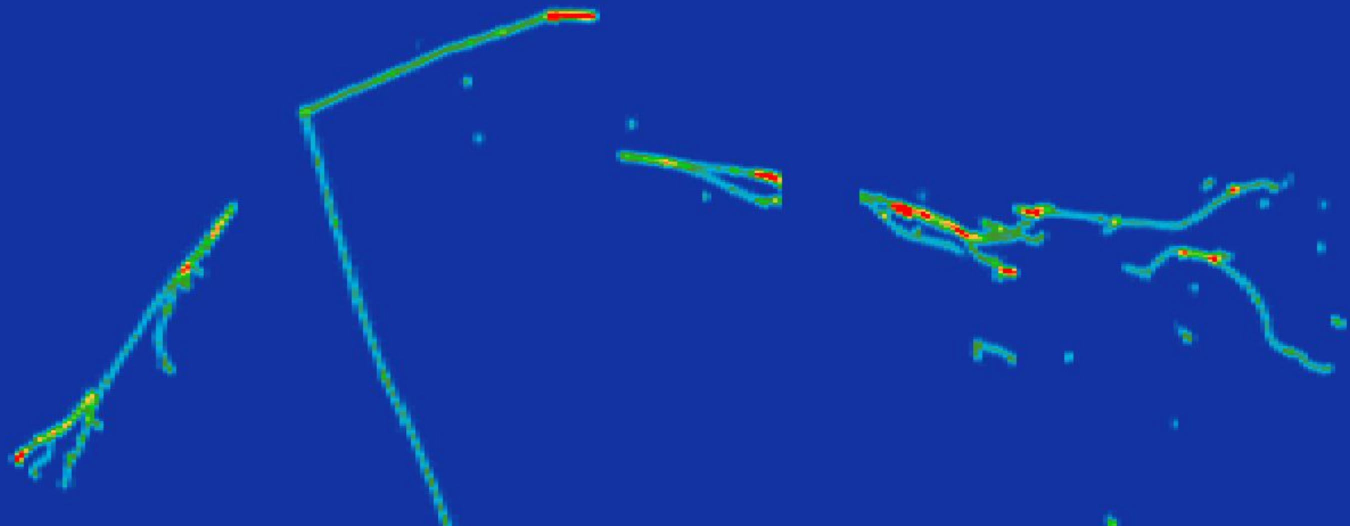
η production in neutrino interactions on argon with MicroBooNE

arxiv:2305.16249

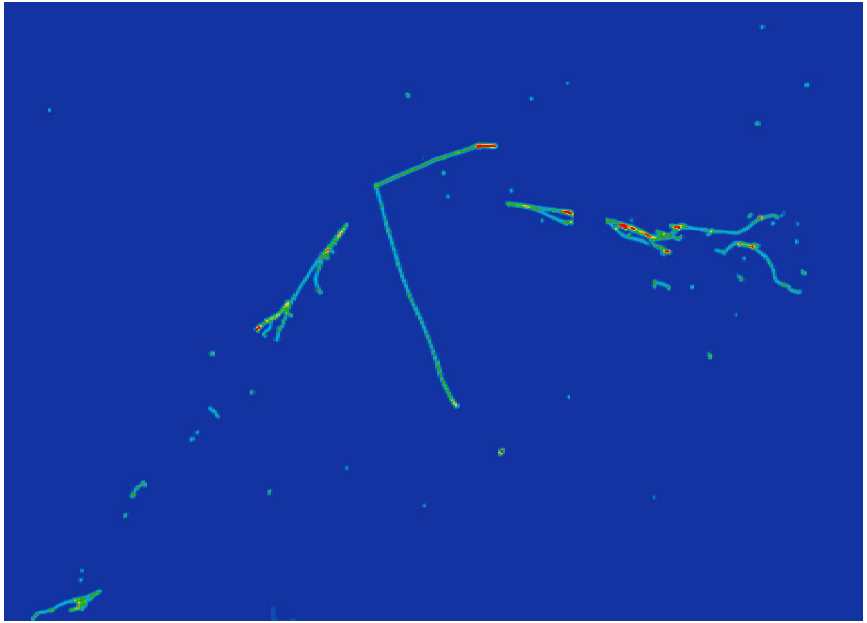


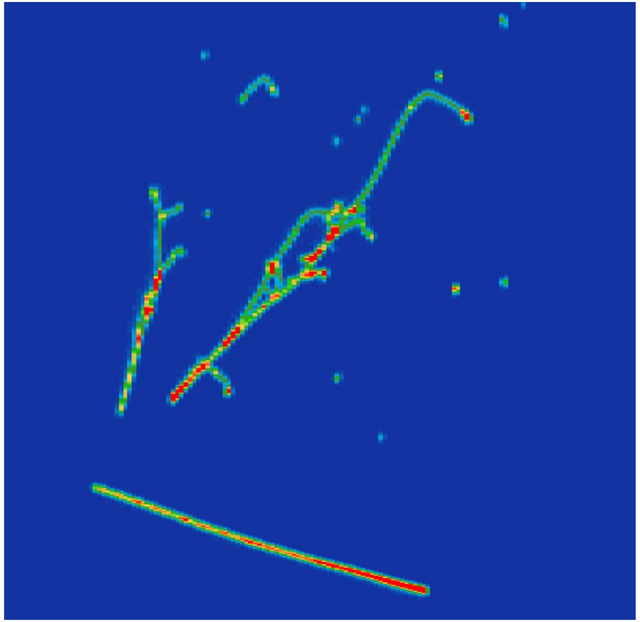
David Caratelli / UC Santa Barbara

August 25th 2023 / NuFact '23

On behalf of the MicroBooNE collaboration

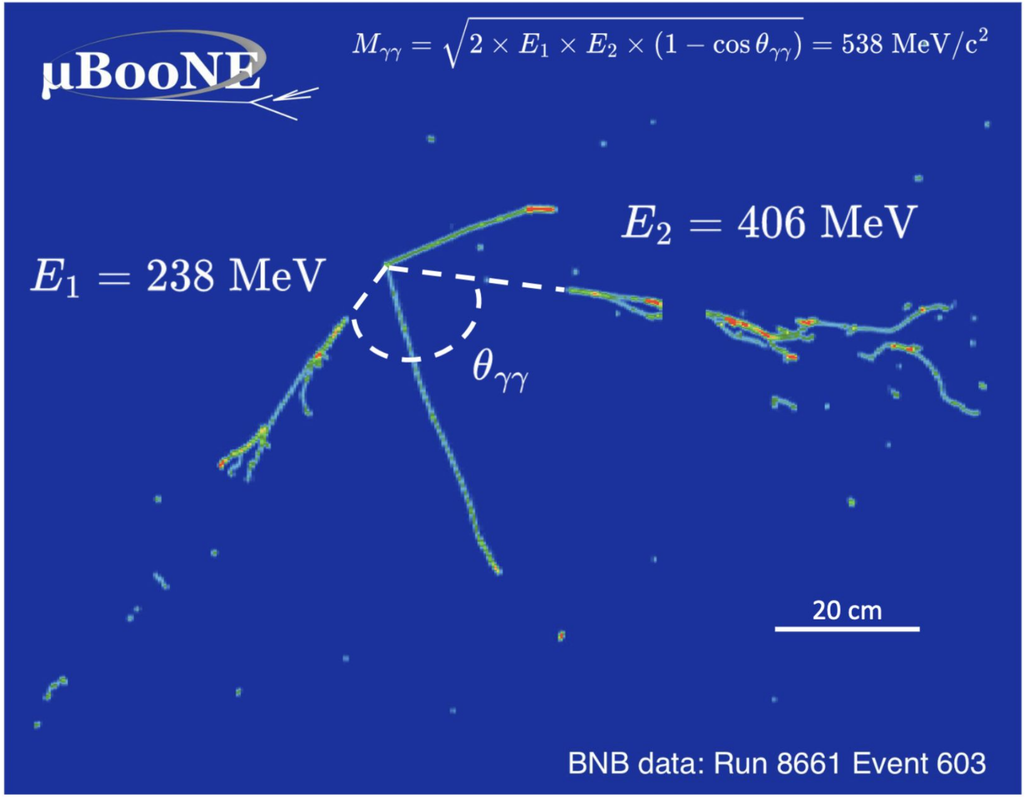
$\gamma\gamma$ event from data

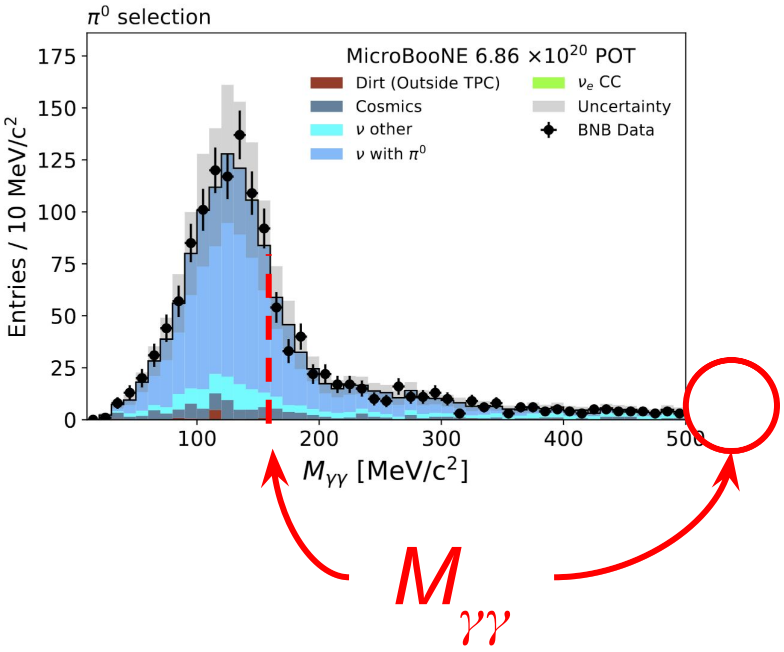




What’s the difference between these two MicroBooNE data events?

Selected η candidate from data

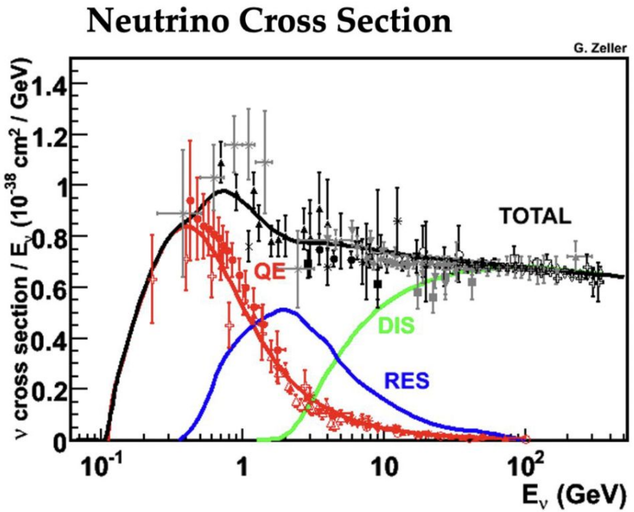




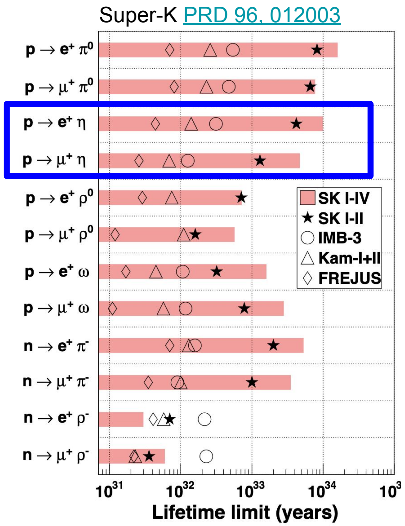
η: 1/√6 [u$\bar{u}$ + d$\bar{d}$ -2 s$\bar{s}$], M = 547 MeV

Motivation

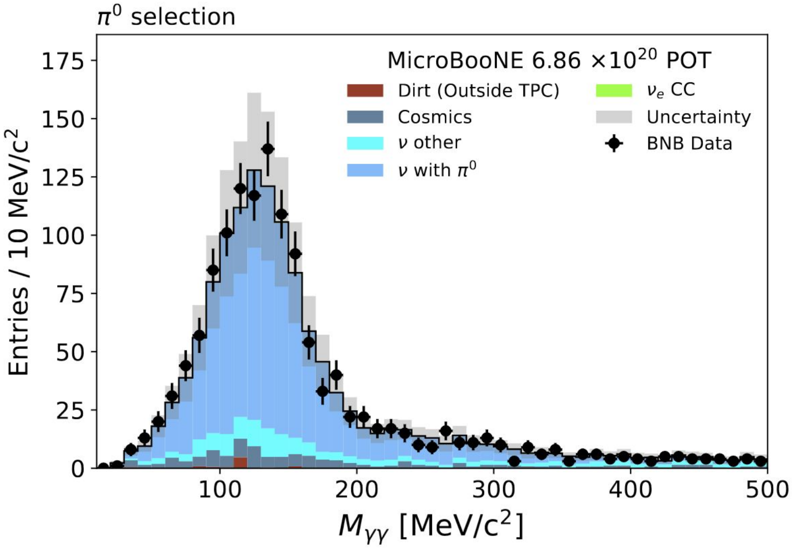
ν-Ar scattering



proton decay

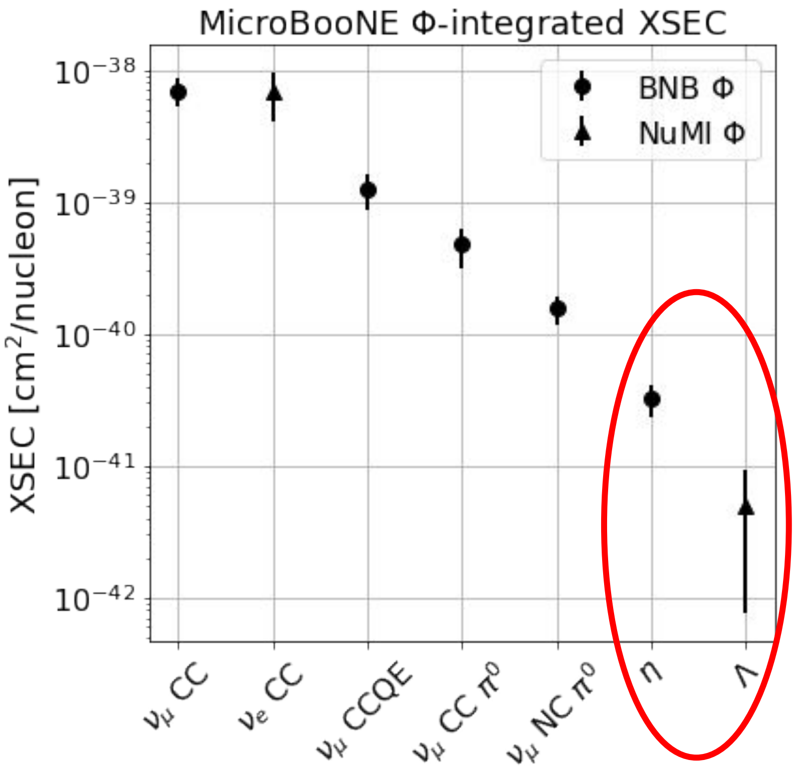


LArTPC EM calibrations



Will spend some time discussing impact on broader ν-Ar scattering program

MicroBooNE Rare Searches



more refined analysis tools + larger dataset

↓

probing exciting rare signatures!

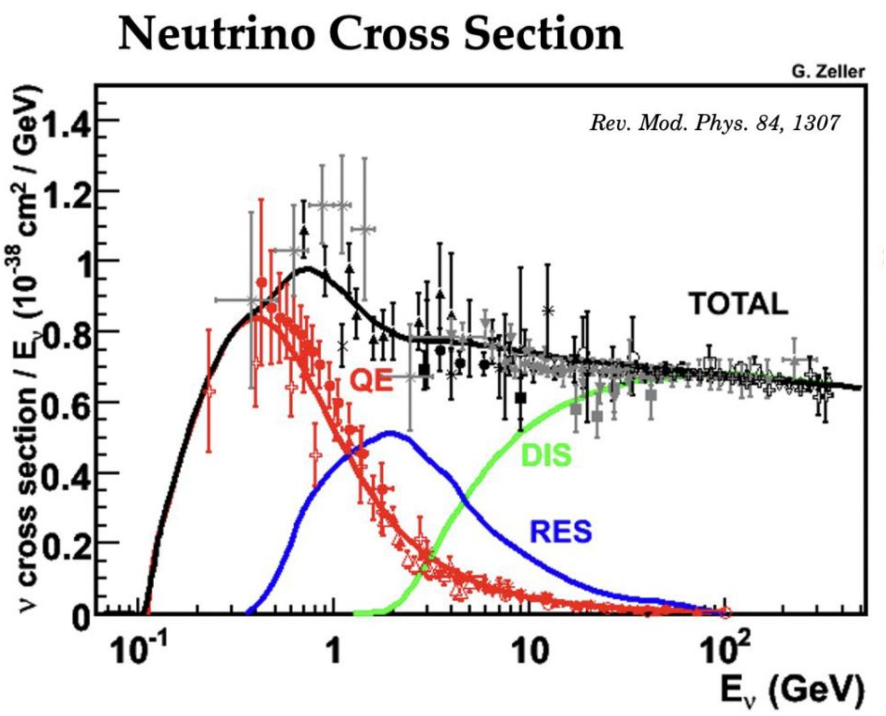
Expanding breadth of our cross-section program.

Other rare process recently published:

“First Measurement of Quasielastic Λ Baryon Production in Muon Antineutrino Interactions in the MicroBooNE Detector”
PRL 130 (2023) 23, 231802

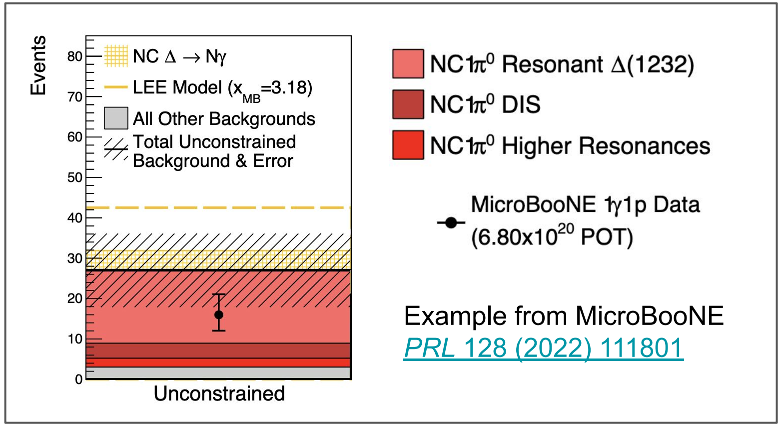
Subset of uB xsec results. References: *PRL 123 (2019) 13, 131801*, *PRD 104 (2021) 5, 052002*, *PRL 125 (2020) 20, 201803*, *PRD 99 (2019) 9, 091102*, *PRD 107 (2023) 1, 012004*,

Motivation: RES interactions



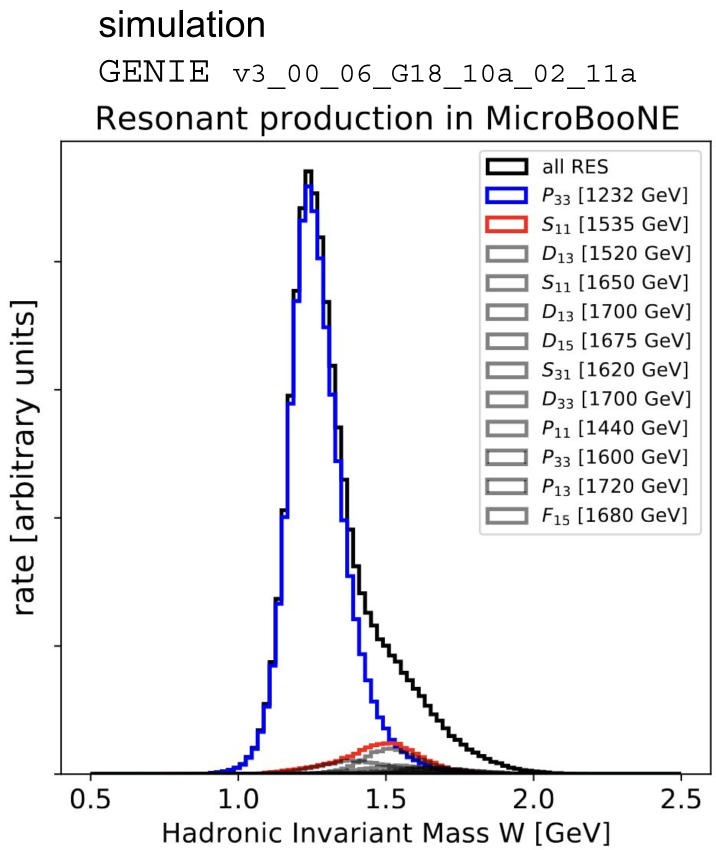
Resonant (RES) interactions play a critical role in GeV-scale accelerator neutrino physics program.

1. DUNE oscillations
2. γ from RES background to BSM searches



Example from MicroBooNE *PRL* 128 (2022) 111801

RES interactions

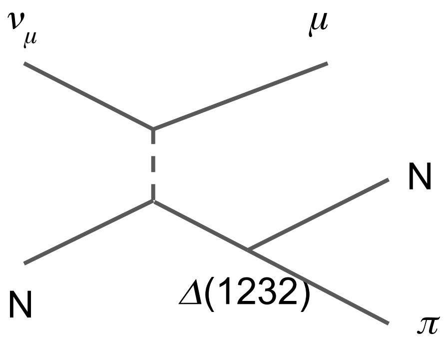


Resonant (RES) interactions play a critical role in GeV-scale accelerator neutrino physics program.

“RES” is a broad category…

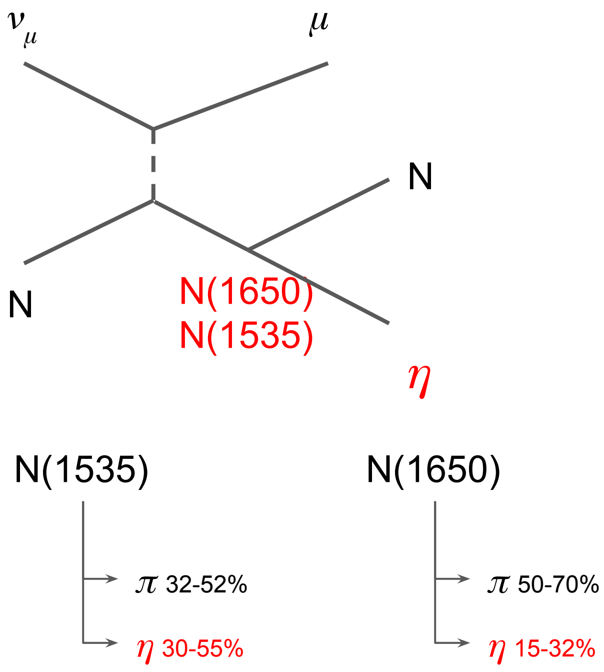
- $\Delta^{++} \rightarrow p + \pi^{+}$, $\Delta^{+} \rightarrow p + \pi^{0}$, ….
- Many resonances beyond the Δ(1232)
    - Hard to target. Poorly constrained
    - Experimental focus on $\pi \rightarrow \Delta$ “swamps” higher order resonances.

Resonant ν interactions



O(90%) of RES interactions in MicroBooNE excite Δ(1232) state which decays to pions.

η production

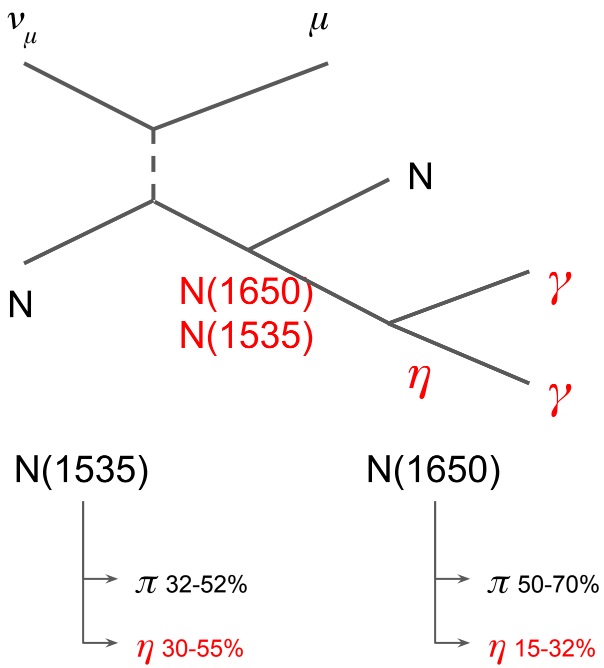


Δ(1232) is one of many resonances.

N(1535) and N(1650) have significant branching ratio to η.

N(1535) dominates η production over other channels.

$\eta \to \gamma\gamma$

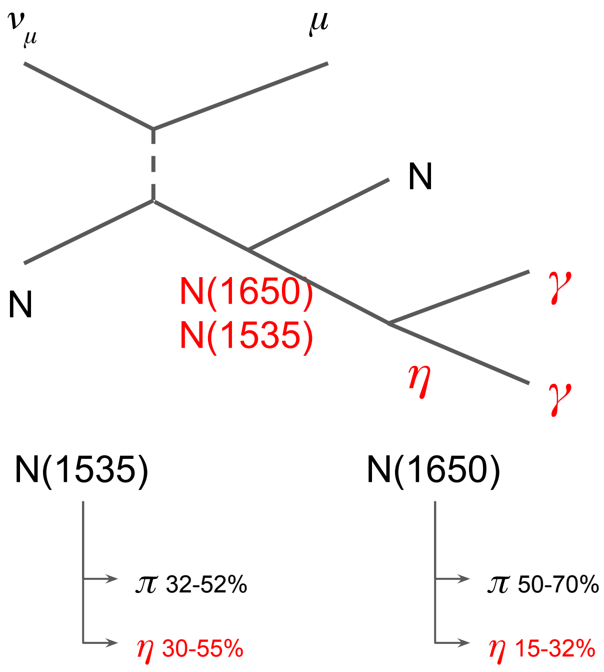


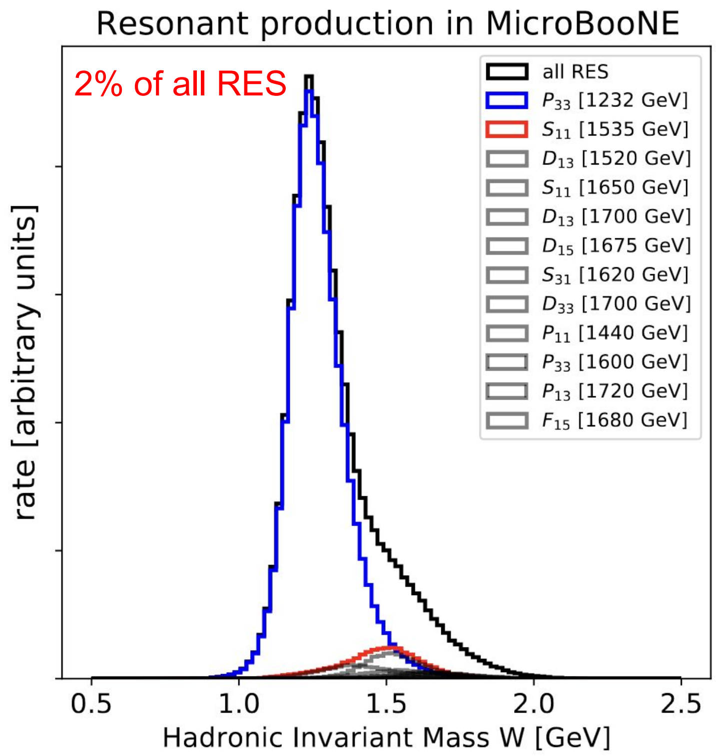
$\Delta(1232)$ is one of many resonances.

N(1535) and N(1650) have significant branching ratio to η.

$\eta \to \gamma\gamma$ cleanest signature. Branching ratio is 40%.

Resonant production





Motivation: ν interaction modeling

Typically measure inclusive RES interactions through final-state π.

η channel by its nature is “isolating” N(1535) resonance.

→ measurement of exclusive RES interactions beyond $\Delta(1232)$.
→ new orthogonal handle w.r.t. $\Delta(1232)$. Improved model constraints.

Overall, η measurements offer an exciting new way to characterize an important category of interactions which impacts DUNE / SBN ν oscillation & BSM programs.

Selection

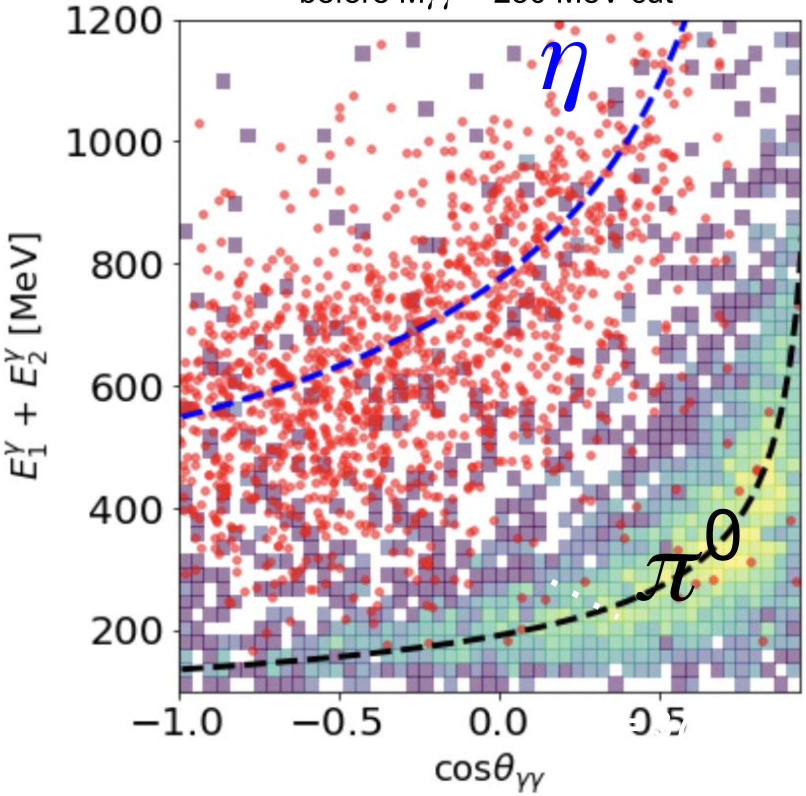
Pandora reconstruction [EPJC 78 (2018) 1, 82]
Tools from “LEE” analyses [PRD 105 (2022) 11, 112004]

“box-cut” selection: 2-shower topology.

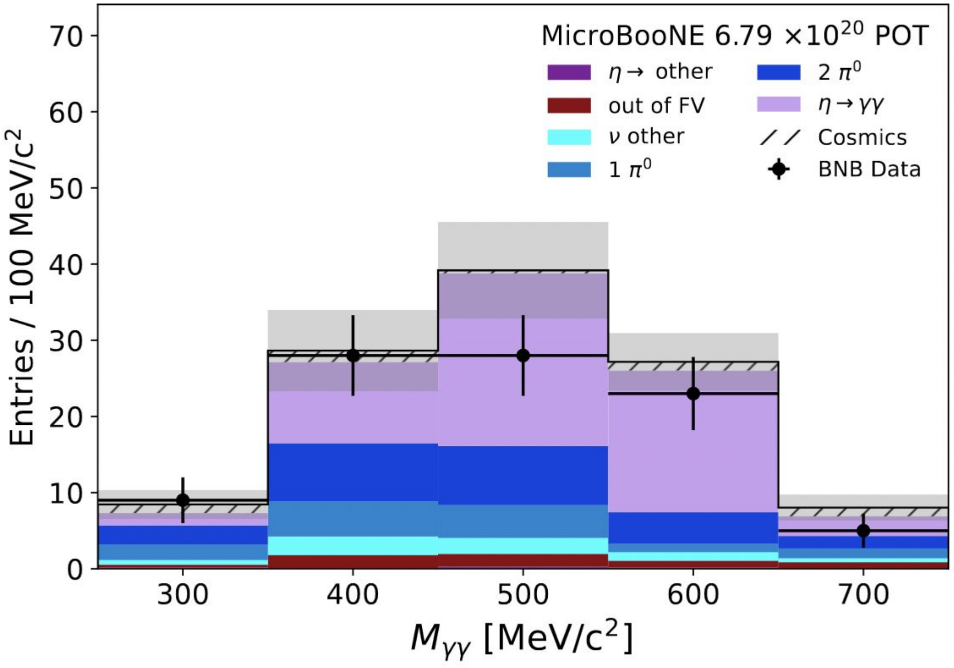
Leveraging $\eta \rightarrow \gamma\gamma$ decay kinematics is key:

- Less boosted $\gamma\gamma$ for equal energy
- Purity: 3.5% → 49.9%
- Efficiency: 19.5% → 13.6%

before $M_{\gamma\gamma}$ > 250 MeV cut



Selection



50% purity

Dominant backgrounds:

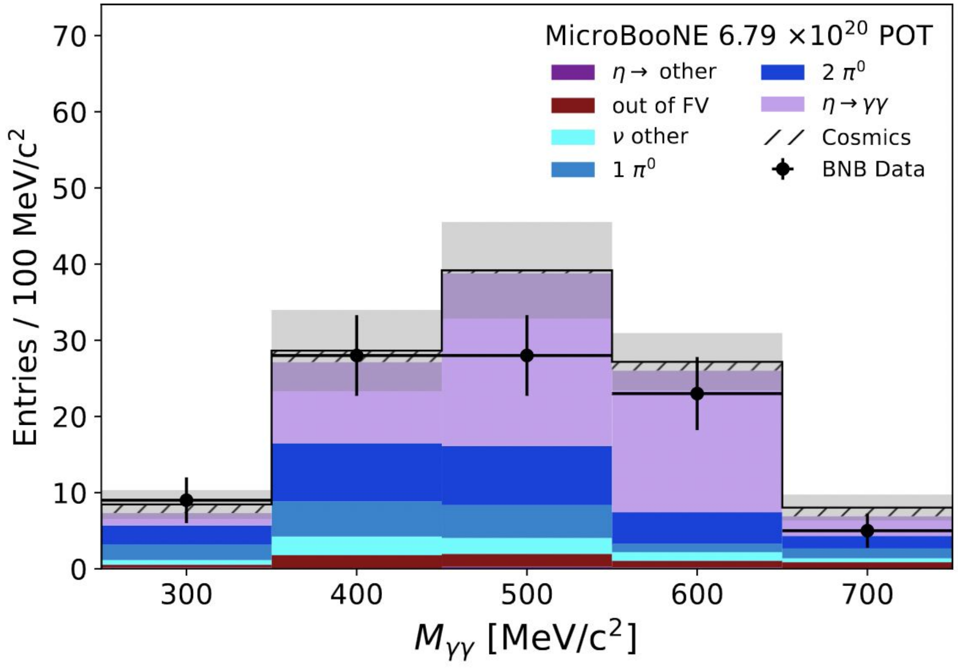
- $1\pi^0$ events
- multi-π^0 events

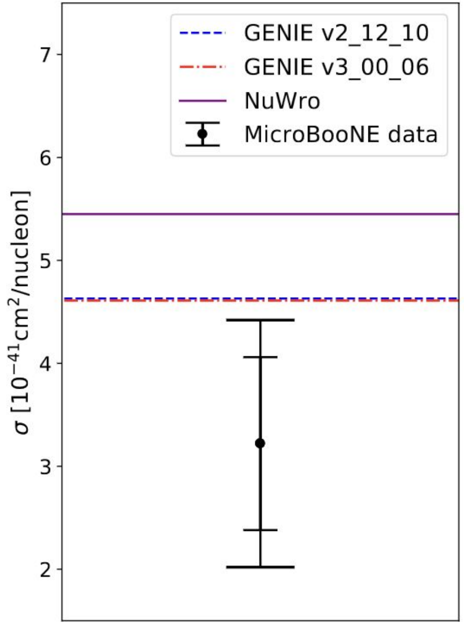
Constrain with targeted sidebands:

- $1\pi^0$: $M_{\gamma\gamma}$ < 250 MeV
- $2\pi^0$: 4 reconstructed showers

Systematic uncertainty: 40% → 26%
Statistical uncertainty on data: 26%

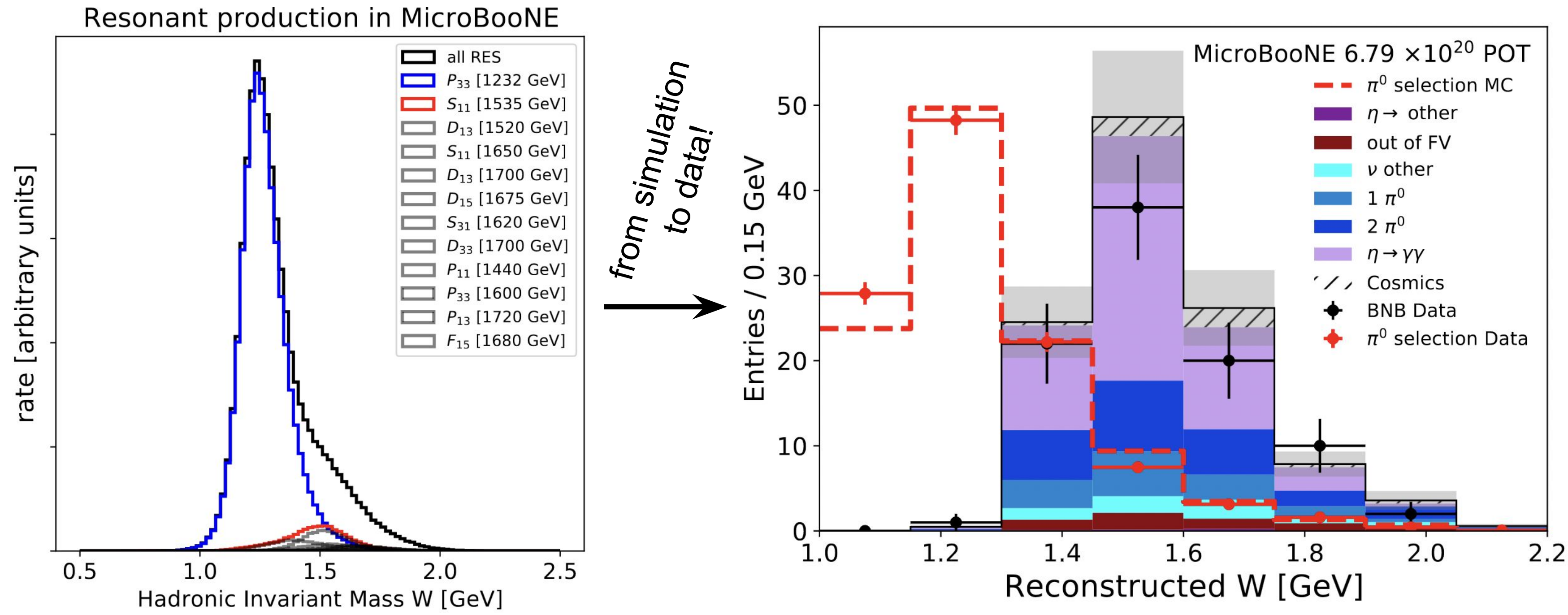
$\nu_x + \text{Ar} \rightarrow \eta + \text{x}$ cross-section





$$3.22 \pm 0.84 \ (\text{stat.}) \pm 0.86 \ (\text{syst.}) \ 10^{-41} \text{cm}^2/\text{nucleon}$$

Hadronic system: N(1535)



When reconstructing invariant mass of hadronic system see consistency with higher order resonances!

Theoretical Landscape

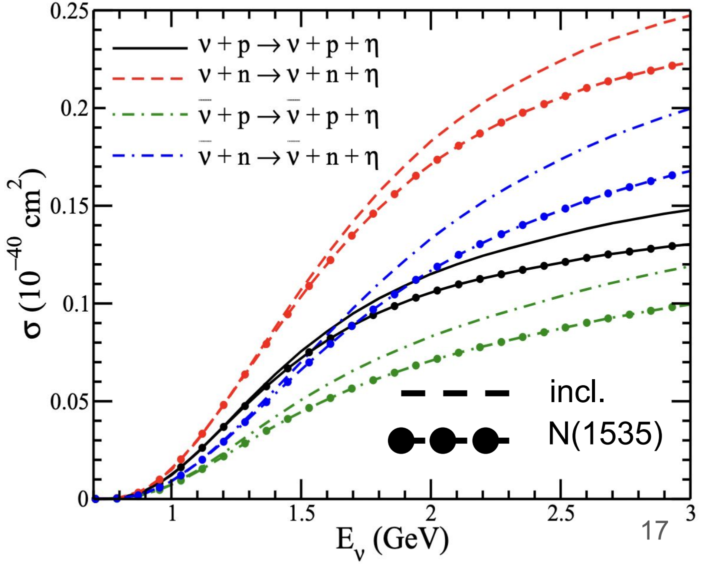
Several existing calculations for η production in neutrino interactions:

“*Charged current neutrino and antineutrino induced eta production off the nucleon*” . Fatima, M. Sajjad Athar, S. K. Singh, *Phys.Rev.D* 107 (2023) 3, 033002, arXiv:2211.08830

“*Dynamical coupled-channels model for neutrino-induced meson productions in resonance region*”, S. X. Nakamura, H. Kamano, T. Sato arXiv:1506.03403

And more recent calculations following MicroBooNE result!

“*Weak production of η mesons induced by $\nu_\mu(\bar{\nu}_\mu)$ at MicroBooNE energies*”, A. Fatima, M. Sajjad Athar, S. K. Singh arXiv:2307.12686



Looking forward to identifying how future measurements can best help support theoretical work and constrain models.

- CC and NC measurements
- Differential measurements

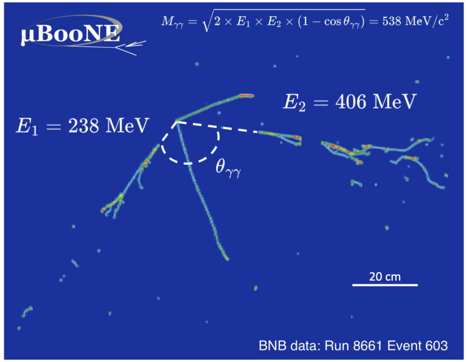
Outlook

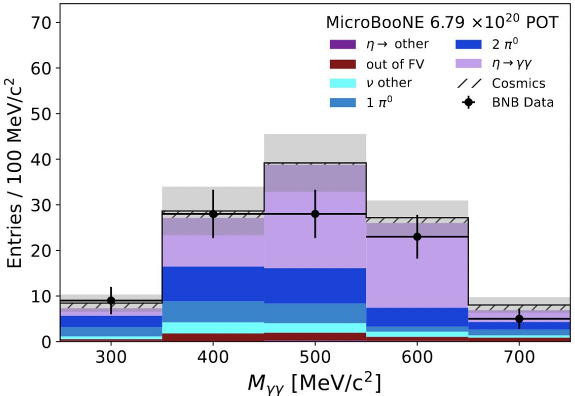
Presented first measurement of η production in MicroBooNE

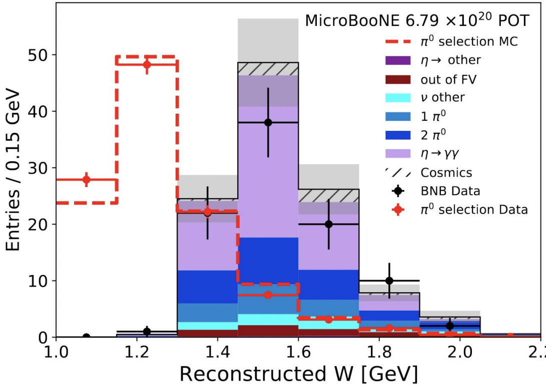
New tool to study RES interactions and unique probe for higher order resonances.

MicroBooNE has more to offer: full-dataset and NuMI beam!

SBND & DUNE-ND will offer additional opportunities for measurements of this process.



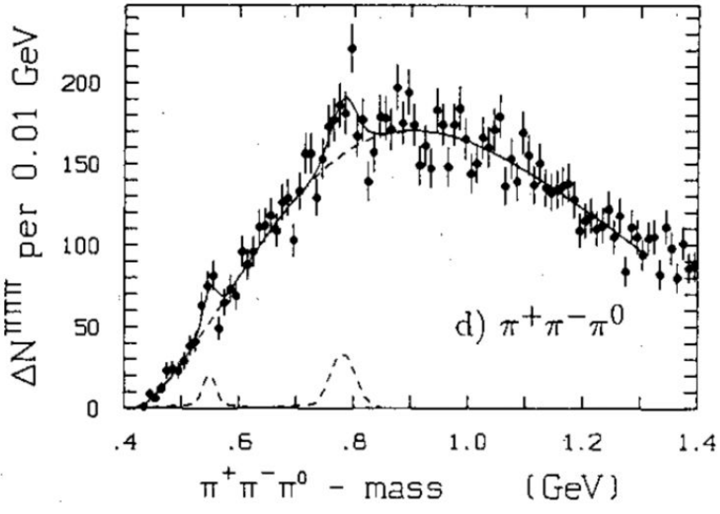




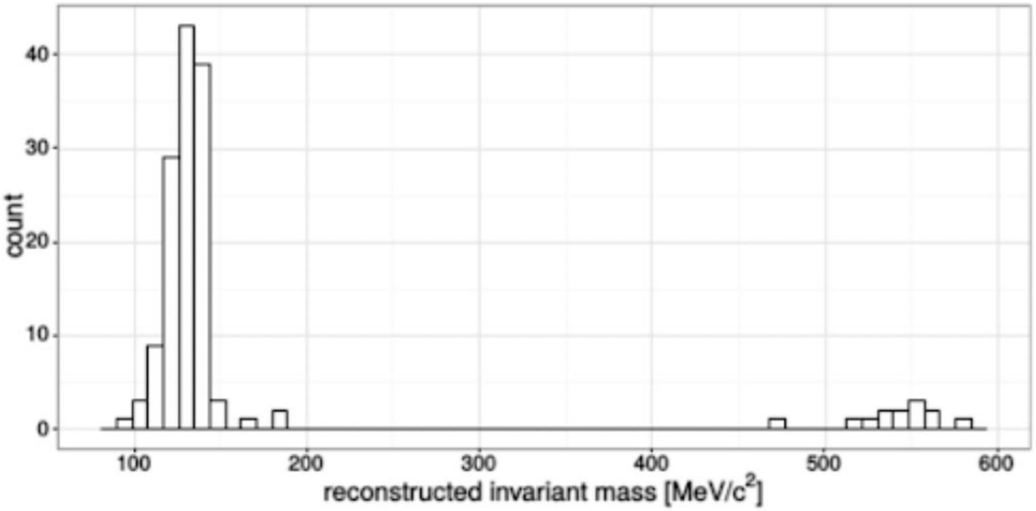
Backup

Past Measurements

Motivation: ν interaction modeling



(a) BEBC WA59 Collaboration



(b) ICARUS Collaboration

[7] W. Wittek *et al.* (BEBC WA59), Z. Phys. C **44**, 175 (1989).

[8] I. Kochanek, PhD, Silesia University, Katowice (2015).

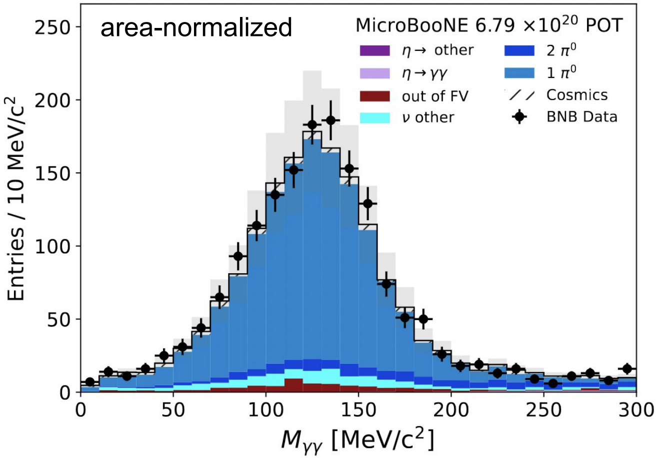
Background Constraint

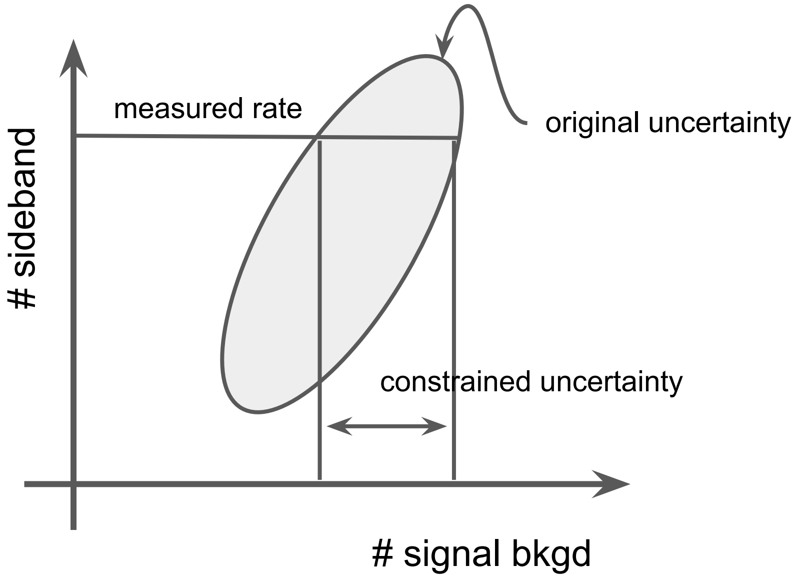
Background Constraint

Constraint carried out through conditional covariance / block matrices as a one-bin measurement.

$$N_{MC}^{S,constrained} = N_{MC}^{S} + \frac{\sigma^{corr}}{(\sigma^{B})^2} \times \left(N_{data}^{B} - N_{MC}^{B}\right),$$

$$\left(\sigma^{S,\ \mathrm{constrained}}\right)^2 = \left(\sigma^{S}\right)^2 - \frac{\left(\sigma^{corr}\right)^2}{\left(\sigma^{B}\right)^2}$$





Signal Region:

Systematic uncertainty: 40% → 26%
Statistical uncertainty on data: 26%

Modeling

Resonant production

η Branching Ratios in GENIE

resonance	branching ratio	PDG values	μB RES abundance [%]	μB η abundance [%]
1440	0.12	< 0.01	2.82	10.9
1535	0.40	0.40-0.55	6.75	86.5
1650	0.015	0.15-0.35	0.13	< 0.3
1675	0.01	< 0.01	0.35	< 0.3
1700	0.04	"seen"	0.26	0.3
1710	0.22	0.10-0.50	N.A.	N.A.
1720	0.035	0.01-0.05	1.32	1.6

Motivation

N(1535) branching

Typically measure inclusive RES interactions through final-state π.

η channel by its nature is isolating N(1535) resonance.

→ measurement of exclusive RES interactions beyond Δ(1232).
→ new orthogonal handle w.r.t. Δ(1232). Improved model constraints.

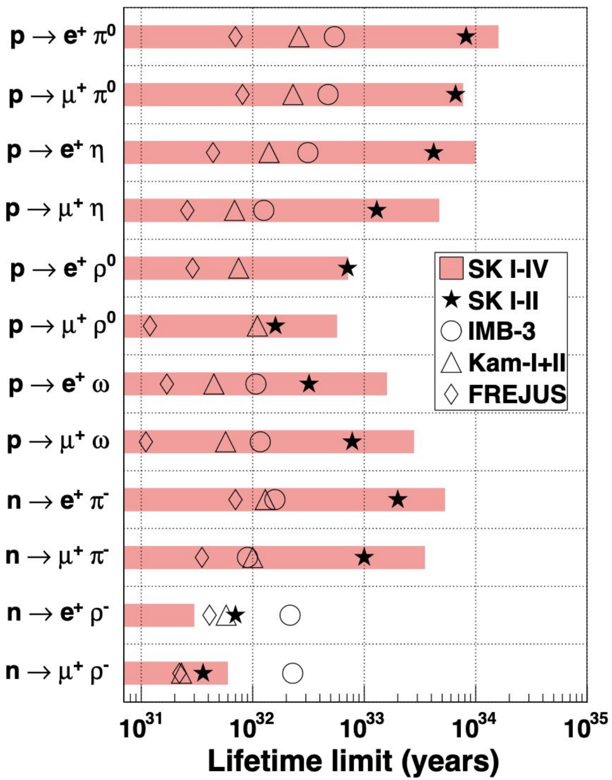
Overall, η measurements offer an exciting new way to characterize an important category of interactions which impacts DUNE / SBN ν oscillation & BSM programs.

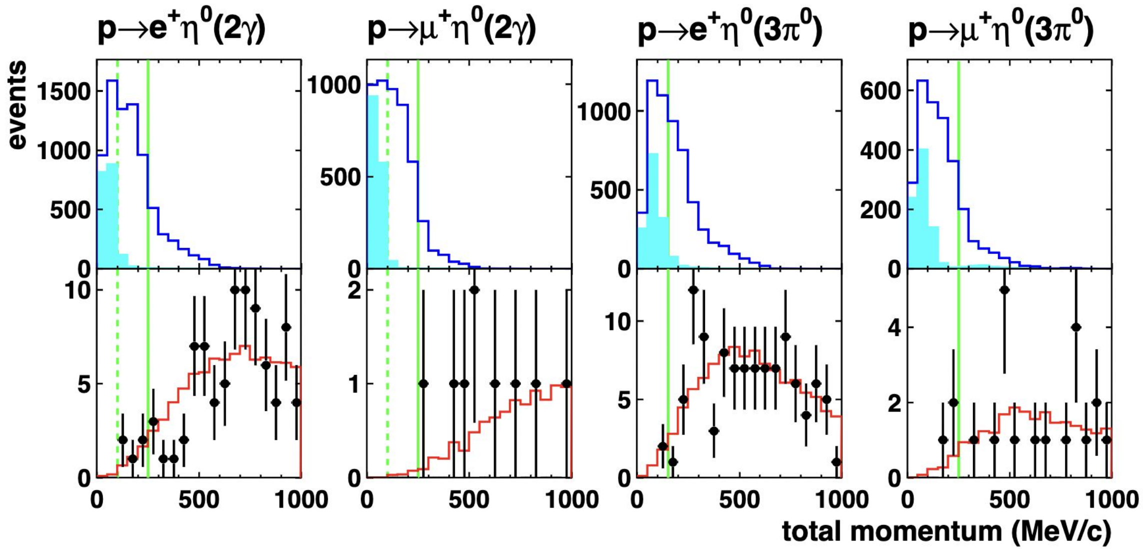
N(1535)
- → π 32-52%
- → η 30-55%

Bonus: N(1535) has a large uncertainty in branching ratio to η. 30-55% according to PDG. *Interested in exploring if high-statistics measurement can provide competitive constraint*.

Motivation: proton decay

plots from Super-K Phys. Rev. D 96, 012003

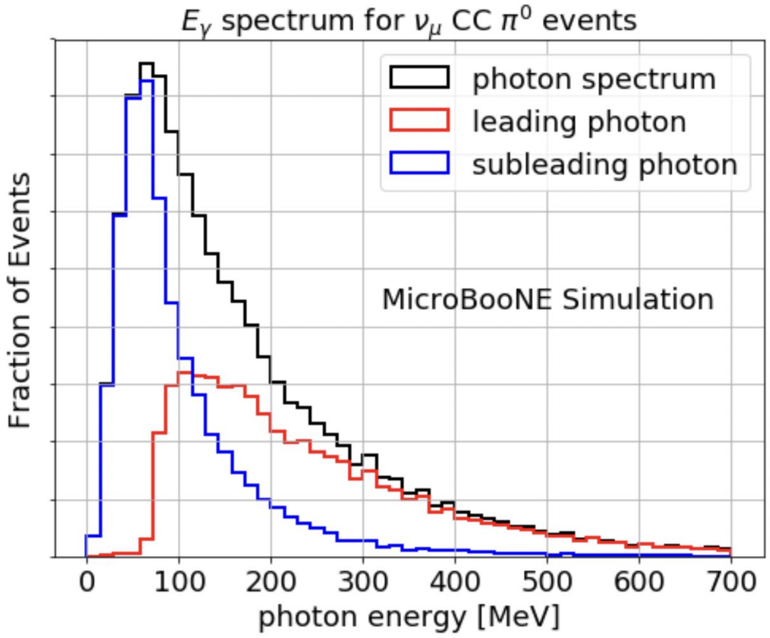


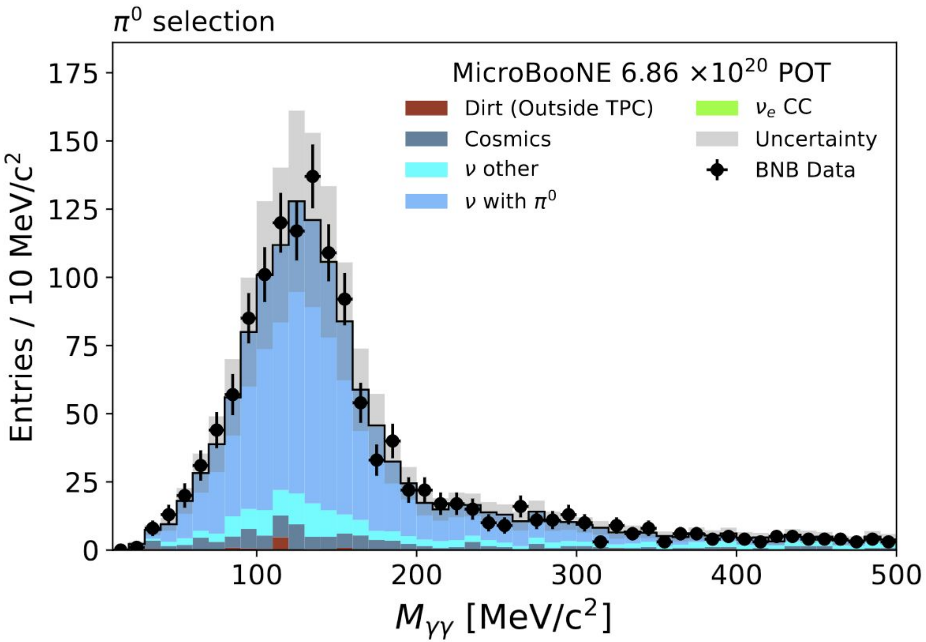


Proton decay branching ratio to η provides competitive channel for proton lifetime limits.

Investigating η production and reconstruction in LArTPC important for future DUNE p-decay searches

Motivation: EM Calibrations





MicroBooNE, JINST 15 (2020) 02, P02007
Reconstruction and Measurement of O(100) MeV Energy Electromagnetic Activity from π0 → γγ Decays in the MicroBooNE LArTPC

MicroBooNE, Phys.Rev.D 105 (2022) 11, 112004
Search for an anomalous excess of charged-current νe interactions without pions in the final state with the MicroBooNE experiment

Selection

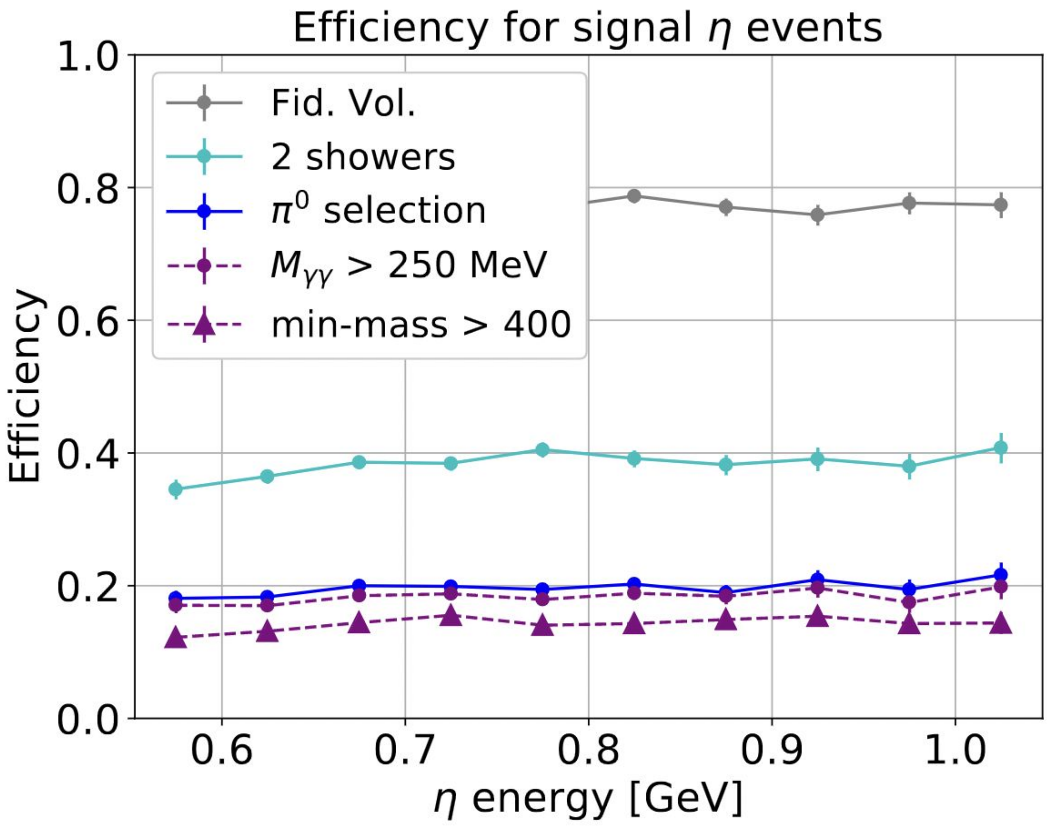
Selection

Cut-based selection:

1. Pandora ν Slide ID
2. Fiducial volume.
3. two-shower cut.
4. π^0 quality cuts.
5. $M\gamma\gamma$ > 250 MeV.
6. Kinematics cuts.

Purity: 49.9%

Efficiency: 13.6%



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