

Neutrino–Nucleus Interactions in the Standard Model and Beyond

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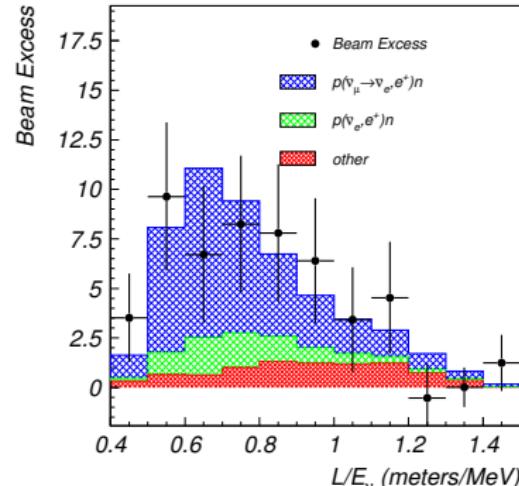
Northwestern
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MC Event Generators



Generator	Tune	Ref.	Comments
NUANCE	–	[40]	the generator used by MiniBooNE
GiBUU	–	[42]	theory-driven generator
NuWro	–	[41]	
GENIE	G18_01a_02_11a	[39, 44]	GENIE baseline tune; see [44] for naming conventions
	G18_01b_02_11a		different FSI implementation compared to G18_01a_02_11a
	G18_02a_02_11a		updated res./coh. scattering models compared to G18_01a_02_11a
	G18_02b_02_11a		updated res./coh. scattering models and different FSI
	G18_10a_02_11a		theory-driven configuration; similar to G18_02a
	G18_10b_02_11a		theory-driven configuration; similar to G18_02b

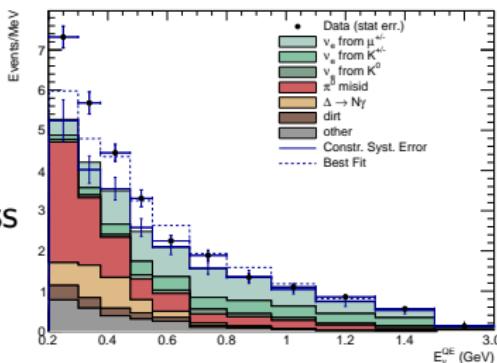
LSND and MiniBooNE



► LSND: $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam from stopped pion source ($> 3\sigma$) at $L/E \sim 1\text{km GeV}^{-1}$
 (arXiv:hep-ex/0104049)

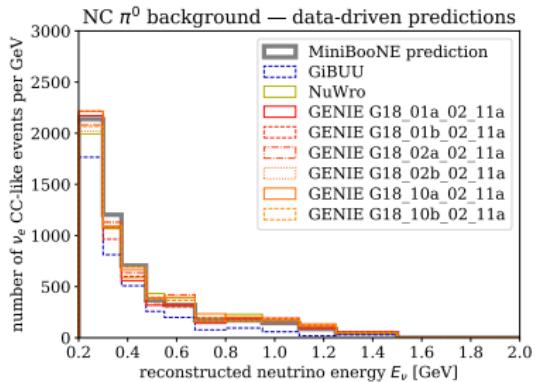
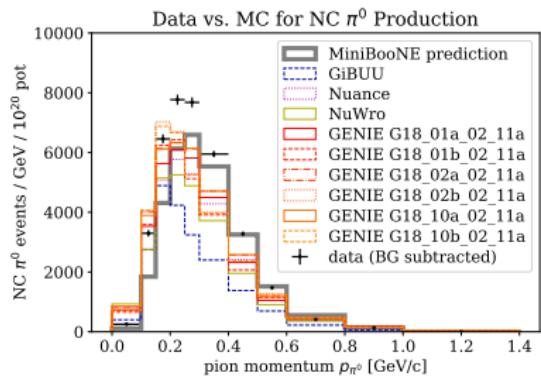
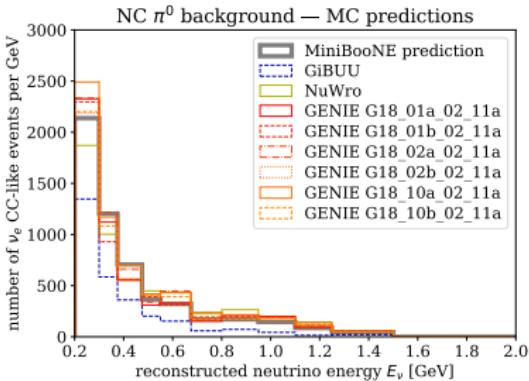
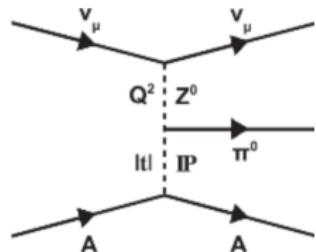
► MiniBooNE: reports electron-like event excess (4.8σ); in combination with LSND at 6.1σ
 (arXiv:0812.2243, 1805.12028, 2006.16883)

Process	Neutrino Mode	Antineutrino Mode
ν_μ & $\bar{\nu}_\mu$ CCQE	107.6 ± 28.2	12.9 ± 4.3
NC π^0	732.3 ± 95.5	112.3 ± 11.5
NC $\Delta \rightarrow N\gamma$	251.9 ± 35.2	34.7 ± 5.4
External Events	109.8 ± 15.9	15.3 ± 2.8
Other ν_μ & $\bar{\nu}_\mu$	130.8 ± 33.4	22.3 ± 3.5
ν_e & $\bar{\nu}_e$ from μ^\pm Decay	621.1 ± 146.3	91.4 ± 27.6
ν_e & $\bar{\nu}_e$ from K^\pm Decay	280.7 ± 61.2	51.2 ± 11.0
ν_e & $\bar{\nu}_e$ from K_L^0 Decay	79.6 ± 29.9	51.4 ± 18.0
Other ν_e & $\bar{\nu}_e$	8.8 ± 4.7	6.7 ± 6.0
Unconstrained Bkgd.	2322.6 ± 258.3	398.2 ± 49.7
Constrained Bkgd.	2309.4 ± 119.6	400.6 ± 28.5
Total Data	2870	478
Excess	560.6 ± 119.6	77.4 ± 28.5



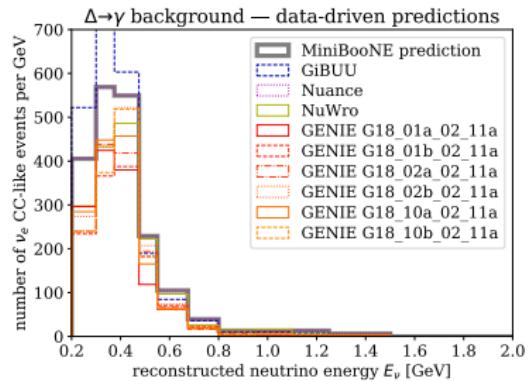
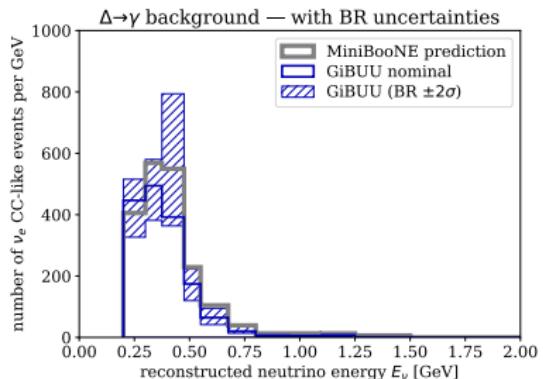
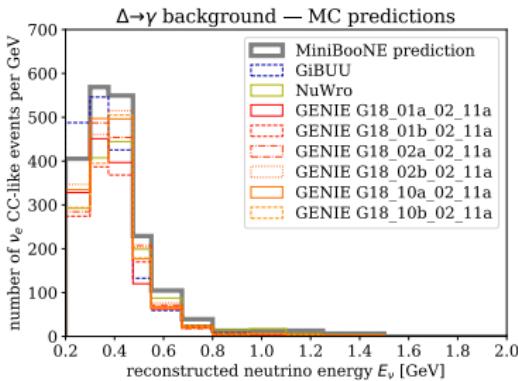
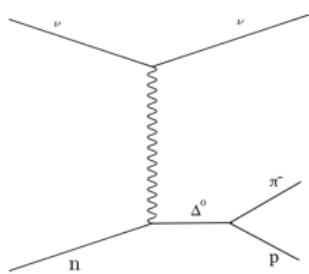
Neutral Current π^0 Production

$$\nu + N \rightarrow \nu + N + \pi^0(\gamma\gamma)$$

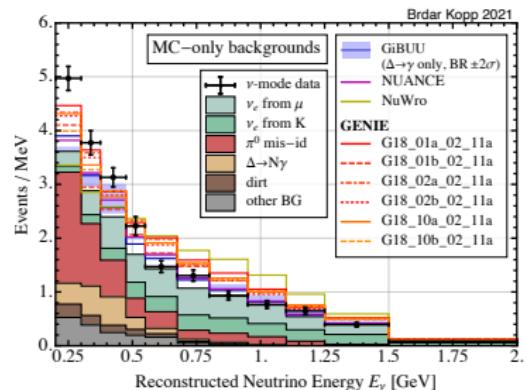
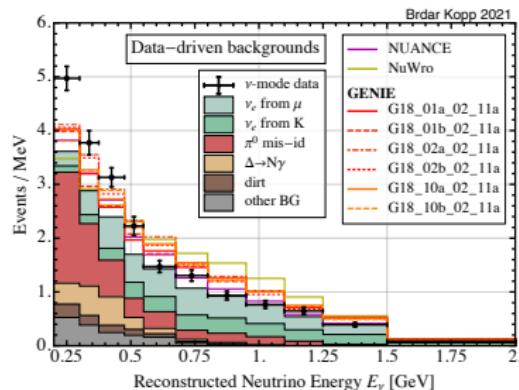


Neutral Current Single γ Production

$$\Delta \rightarrow N\gamma$$



3+1 model with eV-scale sterile neutrino

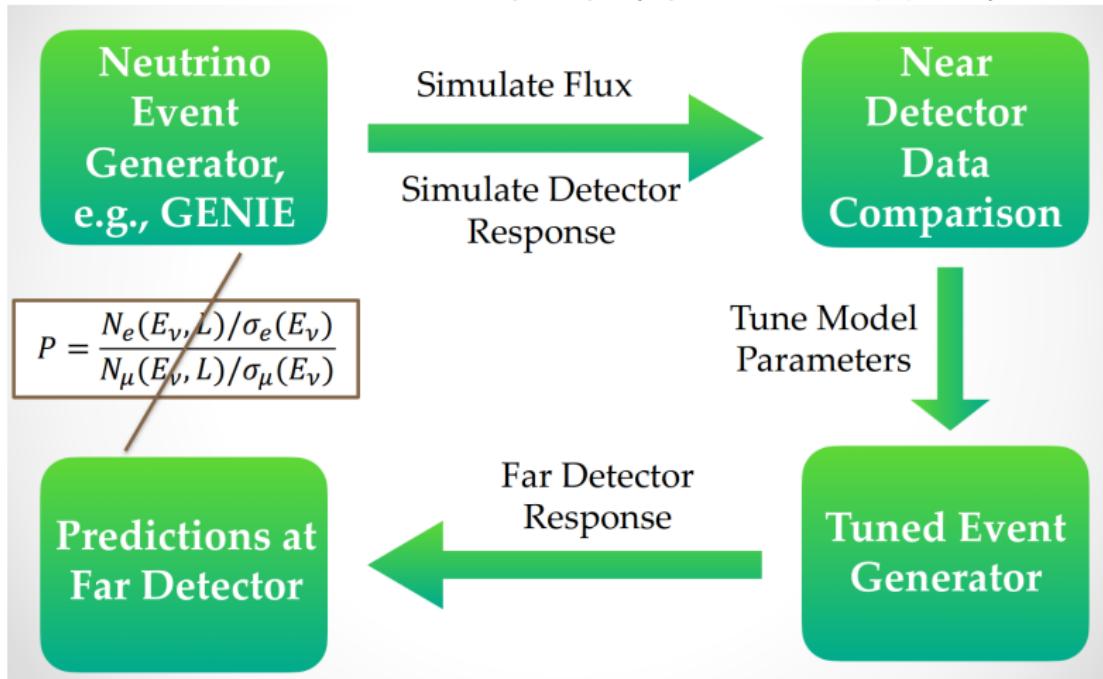


data-driven backgrounds

Generator	Tune	Δm_{41}^2	$\sin^2 2\theta_{\mu e}$	$ U_{\mu 4} ^2$	χ^2/dof	$\Delta\chi^2_{\text{no osc.}}$	Significance
MB official		0.25	0.01	0.062	12.0	19.1	4.0σ
NUANCE	-	0.32	0.0079	0.051	12.3	19.3	4.0σ
NuWro	-	3.2	0.0016	0.040	13.3	12.7	3.1σ
GENIE	G18_01a_02_11a	0.79	0.00020	0.14	12.2	23.3	4.4σ
	G18_01b_02_11a	0.79	0.0001	0.12	12.2	15.5	3.5σ
	G18_02a_02_11a	0.13	0.063	0.18	12.2	19.2	4.0σ
	G18_02b_02_11a	0.13	0.050	0.20	12.3	16.9	3.7σ
	G18_10a_02_11a	0.25	0.016	0.062	12.3	15.1	3.5σ
	G18_10b_02_11a	0.40	0.013	0.016	12.1	19.5	4.0σ

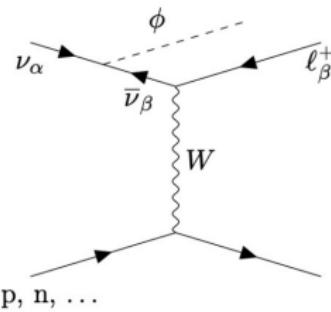
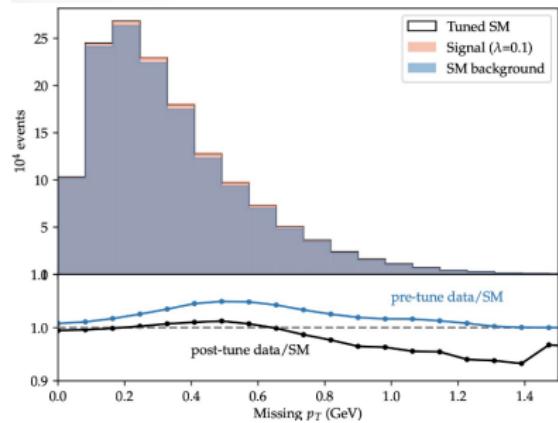
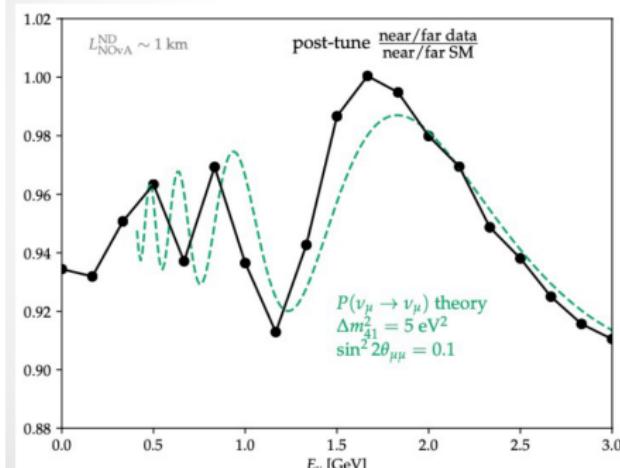
Near Detector Tuning and BSM

talk by Shirley Li (Coyle, Li, Machado, in preparation)

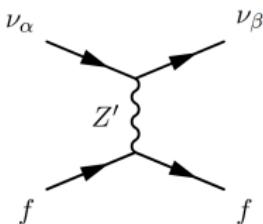


Near Detector Tuning and BSM

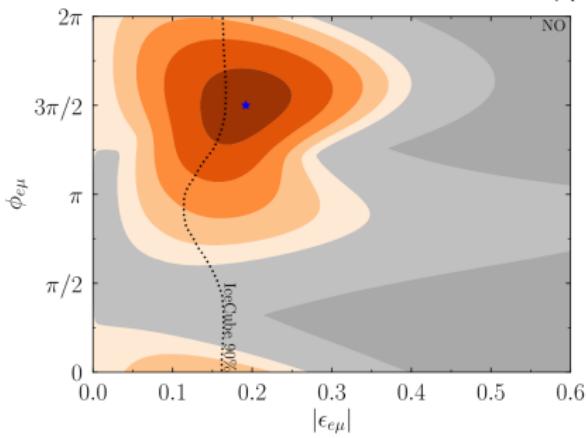
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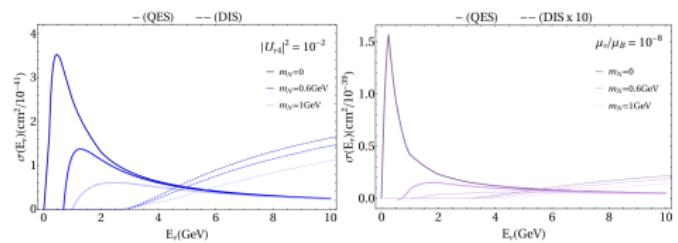
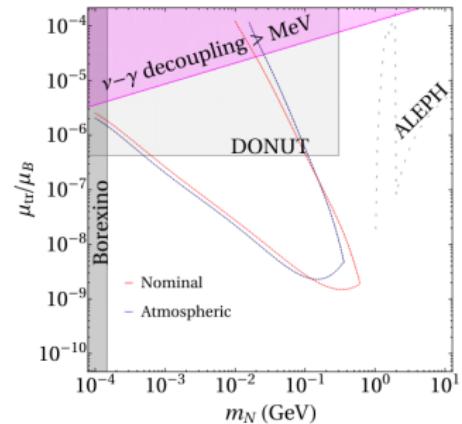
BSM at the far detector



Denton et al., (2020)



Atkinson et al., (2021)
DUNE



Further BSM Scenarios

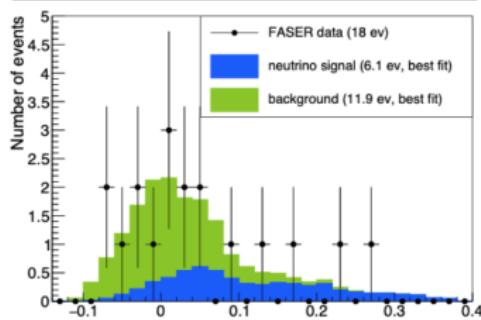
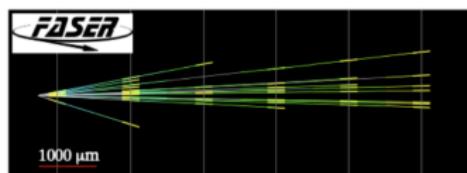
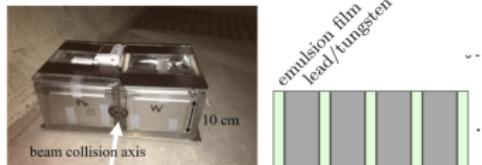
adopted from Jae Yu

Process	Signatures	Background
ALP	Scattering: $\gamma + e/\gamma + N(n)$ Decay in flight: $\gamma\gamma$	ν coherent, NC w/ π^0 , ν_e CC w/ π^0 , etc
LDM	$\chi e^- \rightarrow \chi e^-$, $\chi N \rightarrow N'n$	NC w/ π^0 , ν_e CC, QE, RES
mCP	Multiple e^- scatterings	ν_e CC w/ π^0
Dark Photon	$A \rightarrow e^-e^+, \mu^-\mu^+$	ν CC + mis-ID π , Accidental overlap of CC
HNL	$N \rightarrow \nu e^-e^+, \nu \mu^-\mu^+, \nu \bar{\mu}, \nu \pi^0, e\pi, \mu\pi$	ν CC + mis-ID π , ν_e CC w/ π^0
ν trident	$\nu \rightarrow \nu e^-e^+, \nu \mu^-\mu^+, \nu \bar{\mu}$	$\nu_\mu N \rightarrow \nu_\mu \pi N \square$ (ν CC)
BDM/ iBDM	$\chi N \rightarrow e N$	ν coherent, NC w/ π^0 , ν_e CC

FASER ν

adopted from Vishvas Pandey

FASER collaboration: [arXiv:2105.06197 \[hep-ex\]](https://arxiv.org/abs/2105.06197)



FASER ν Pilot Detector

Suitcase-size, 4 weeks
\$0 (recycled parts)

6 neutrino candidates

[2105.06197](https://arxiv.org/abs/2105.06197)



Not the 5σ discovery of collider neutrinos, but highlights the remarkable latent potential of far-forward physics

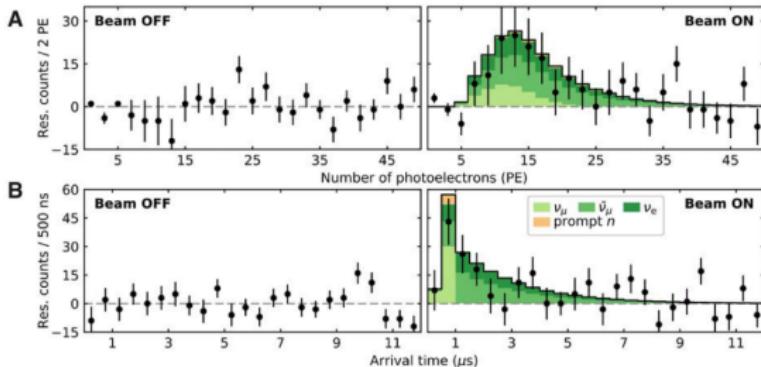


Building-size, decades
~\$10⁹

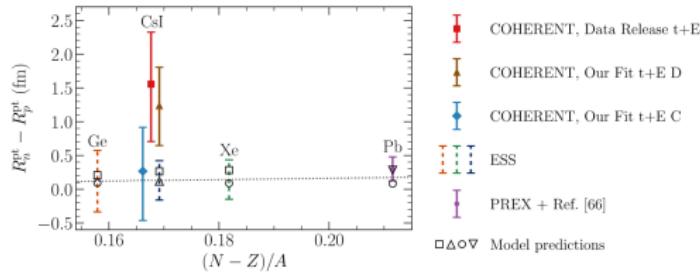
0 neutrino candidates

Slide by Jonathan Feng

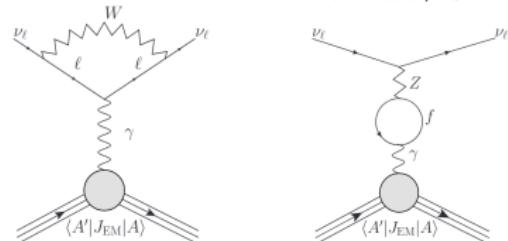
arXiv:1708.01294



Coloma et al, 2020



Tomalak et al, 2021



Neutrino capture for $C\nu B$ discovery

$$(A, Z) \rightarrow (A, Z + 1) + e^- + \bar{\nu}_e$$
$$\nu_e + (A, Z) \rightarrow (A, Z + 1) + e^-.$$

from A. Boyarsky, see also 2111.09292

