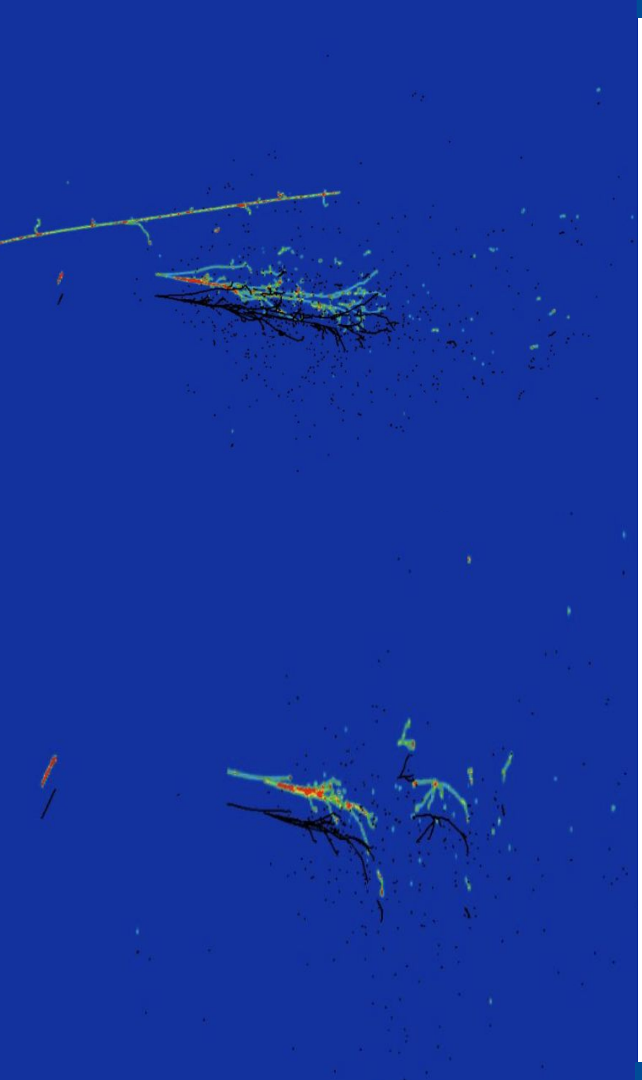


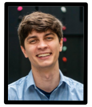
Exotic e^+e^- production at MicroBooNE

Asli M. Abdullahi*

FIPs 2022

* together with:


Jaime Hoefken Zink
Uni. of Bologna

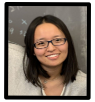

Matheus Hostert
Perimeter & UMN


Georgia Karagiorgi
Columbia Uni


Daniele Massaro
Uni. of Bologna


Silvia Pascoli
Uni. of Bologna


Mark
Ross-Lonergan
LANL

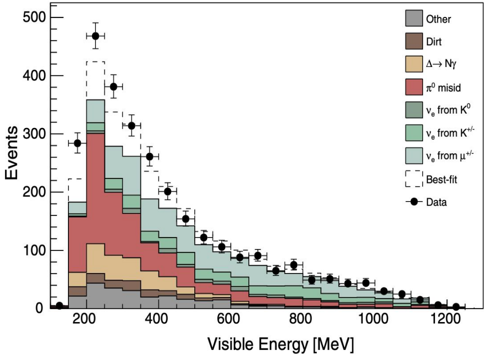

Guanqun Ge
Columbia Uni.

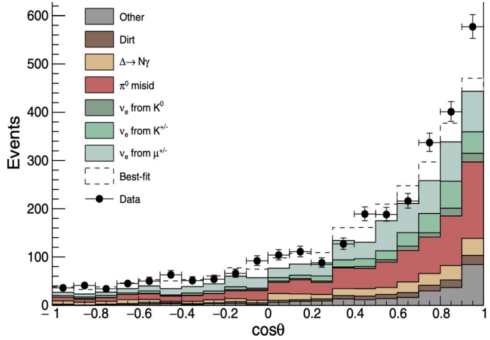
Fermilab

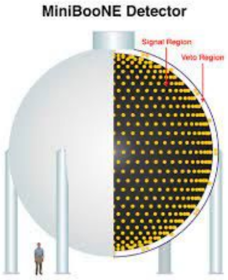
U.S. DEPARTMENT OF ENERGY | Office of Science

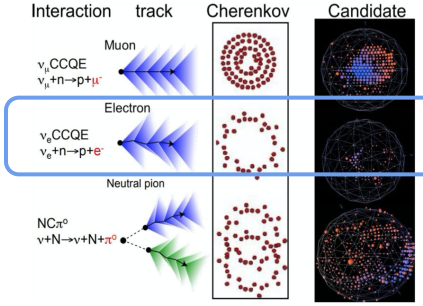
Motivations

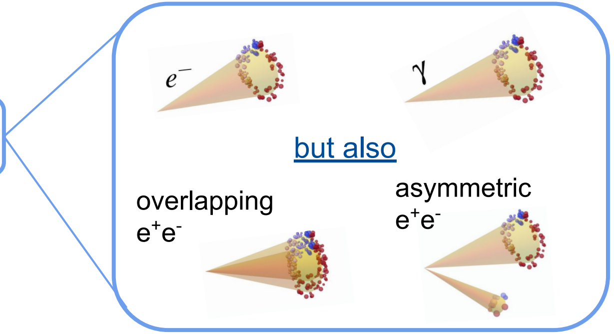
With Fermilab's SBN programme starting up, understanding the MiniBooNE anomaly is of particular interest









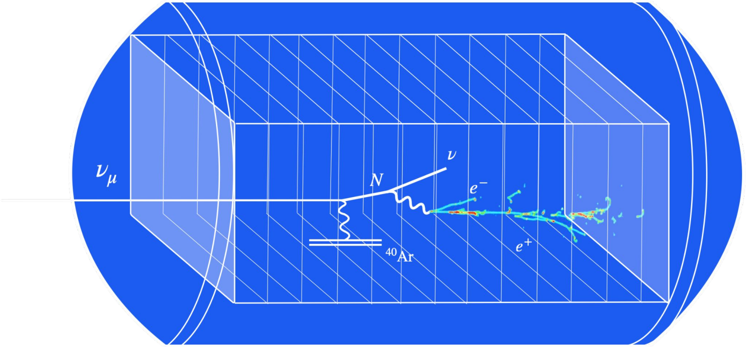


Although traditionally interpreted as an electron excess, **photon and e^+e^- final states are indistinguishable**

Motivations

MicroBooNE LAr TPC may be able to disentangle these final states with improved PID:

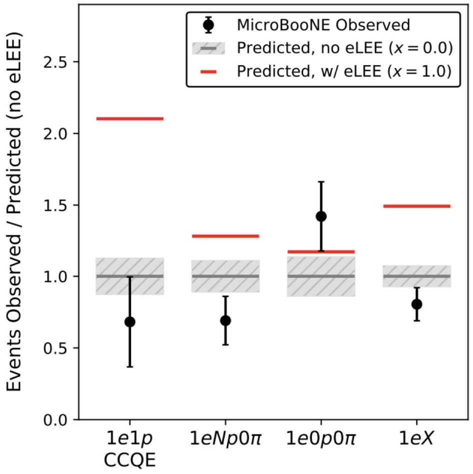
1. **Better hadronic vertex ID (go to lower proton energy, ~ 40 MeV)**
2. **Shower conversion length (displaced vertices for photons, where hadronic vertex is ID'd)**
3. **Shower dE/dx (photon dE/dx ~ 2 x MIP)**



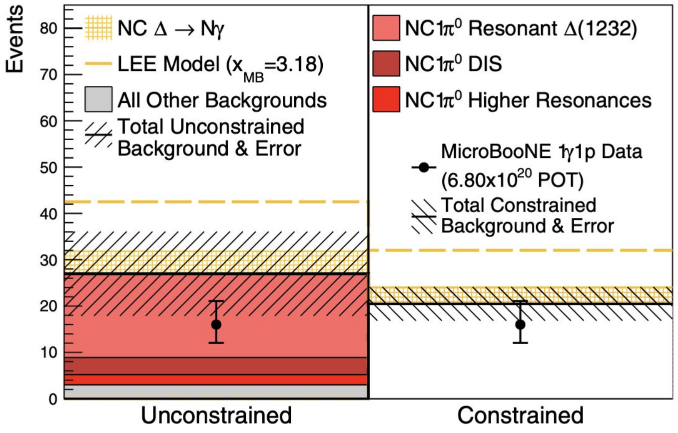
Motivations

MicroBooNE have already performed eLEE and gLEE searches:

Search for excess e⁻ (PRL 128, 241801 2022)



Search for SM NC $\Delta \rightarrow N\gamma$ (PRL 128, 111801 2022)

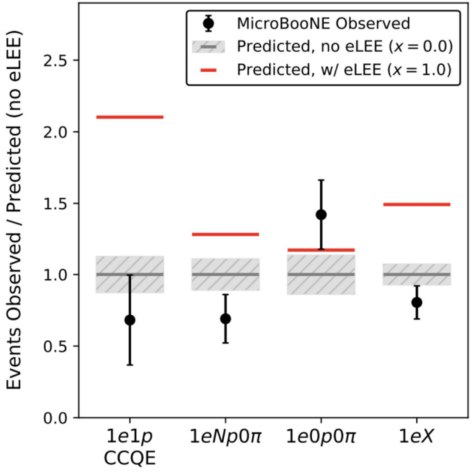


No electron or single photon excess observed compatible with MiniBooNE!

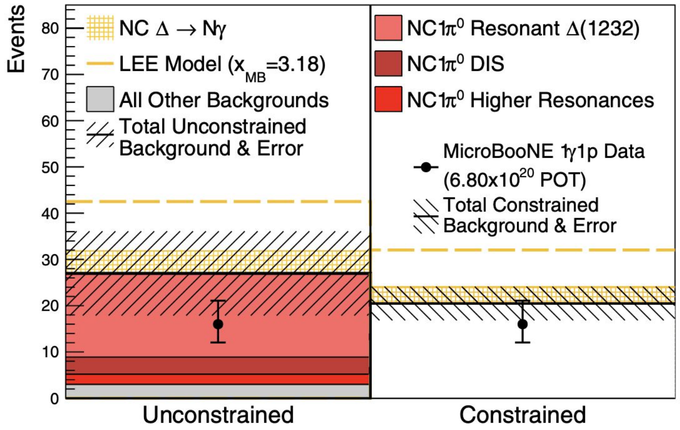
Motivations

MicroBooNE have already performed eLEE and gLEE searches:

Search for excess e^- (PRL 128, 241801 2022)



Search for SM NC $\Delta \to N\gamma$ (PRL 128, 111801 2022)



The e^+e^- explanation is, as of yet, unprobed → dedicated search is currently on the way

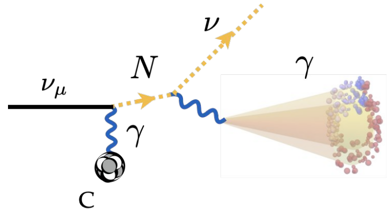
Motivations

<u>This talk:</u>

Can we already constrain models of BSM e^+e^- (and single photon) production using MicroBooNE public data?

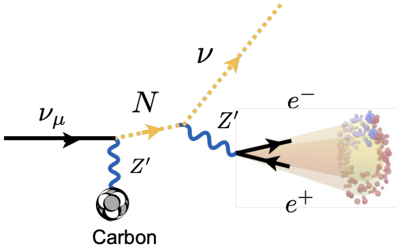
yes

New particle production at MicroBooNE



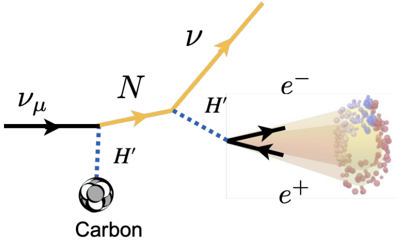
transition magnetic moment

$$F^{\mu\nu}\left(\frac{\mu_\nu^{\alpha j}}{2}\overline{\nu_\alpha}\sigma_{\mu\nu}N_j+\frac{\mu_\nu^{ij}}{2}\overline{N_i}\sigma_{\mu\nu}N_j\right)$$



dark photon

$$Z'_\mu\left(V^{\alpha j}\overline{\nu_\alpha}\gamma^\mu N_j+V^{ij}\overline{N_i}\gamma^\mu N_j+d_V^\ell\,\overline{\ell}\gamma^\mu\ell\right)$$



dark scalar

$$h'\left(S^{\alpha j}\overline{\nu_\alpha}N_j+S^{ij}\overline{N_i}N_j+d_S^\ell\overline{\ell}\ell\right)$$

	Vector	Scalar
Light mediator	A	B
Heavy mediator	C	D

Transition mag moment	TMM

* Model independent parameterization.

Signal Model – `DarkNews`

Signal events generated by DarkNews
(A. Abdullahi, J. Hoefken, M. Hostert, D. Massaro, S. Pascoli)

`DarkNews` is a light-weight Python generator for neutrino-nucleus upscattering to heavy neutrinos.

- Supports up to 3 (Dirac or Majorana) HNLs
- Scalar, vector, or transition magnetic moment contributions.
- Event output weighted (fast) or unweighted (slower).
- Pandas or numpy, as well as **HepEvt, HepMC2 and 3**.
- Simple detector geometry for MiniBooNE and **MicroBooNE**.
- Several neutrino fluxes implemented.

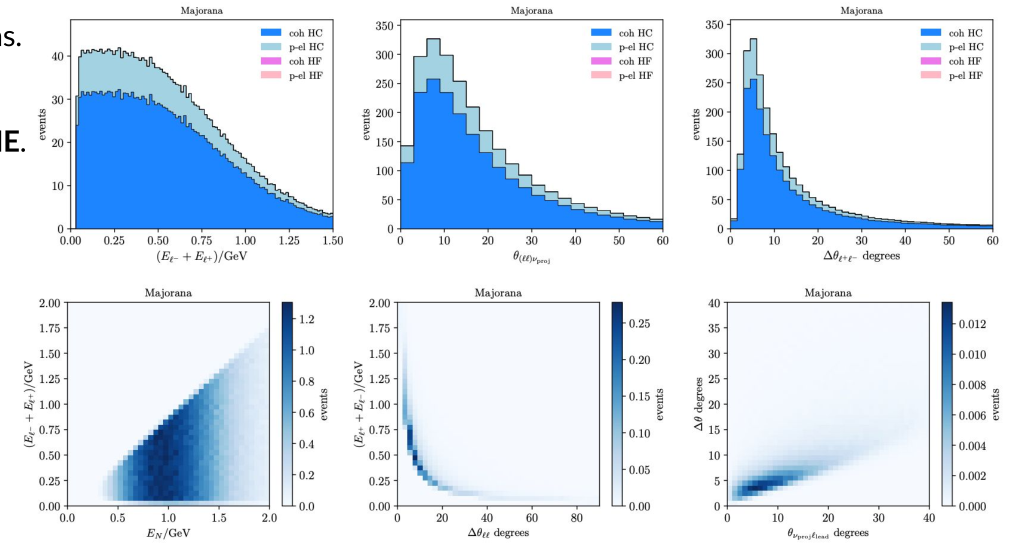
```
import DarkNews as dn
my_gen = dn.GenLauncher(mzprime=1.25, m4=0.140,
↪  neval=1000, noHF=True, HNLtype="dirac",
↪  experiment="microboone",
↪  nu_flavors=["nu_mu","nu_mu_bar"])
df = my_gen.run()
```

Public and documented

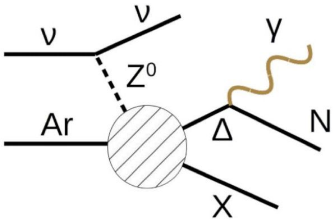
Paper: arxiv.org/abs/2207.04137
GitHub: github.com/mhostert/DarkNews-generator
PyPI: pypi.org/project/DarkNews/

`pip install DarkNews`

Example of e^+e^- kinematics at MiniBooNE (Majorana HNL)

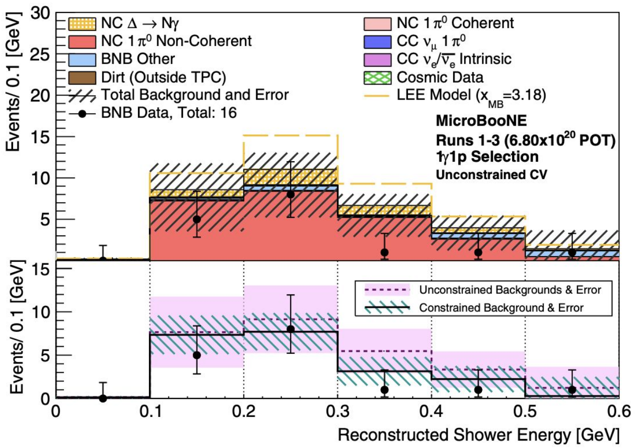


gLEE: NC $\Delta \rightarrow N\gamma$ search

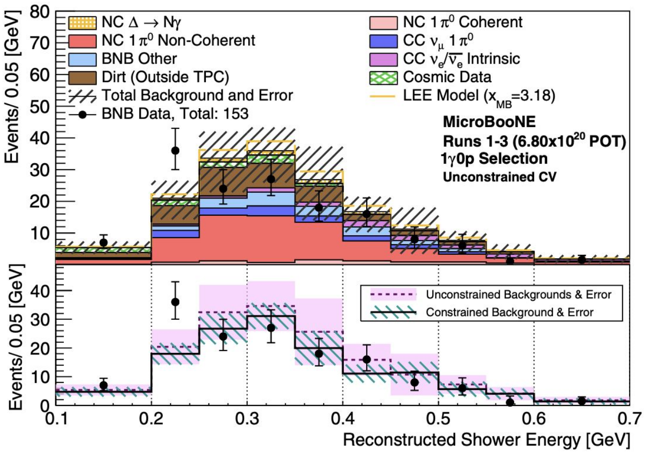


MicroBooNE constrain two topologies in the gLEE (γLEE) search:

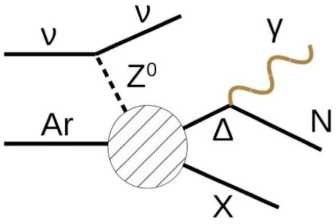
1. $\Delta^{+} \rightarrow p\,\gamma \;\rightarrow 1\gamma\, 1p$



2. $\Delta^{0} \rightarrow n\,\gamma \;\rightarrow 1\gamma\, 0p$

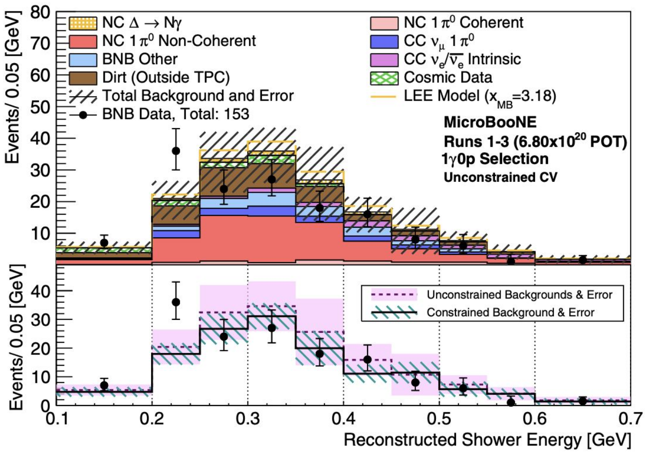


gLEE: NC Δ → Nγ search



MicroBooNE constrain two topologies in the gLEE (γLEE) search:

2. $\Delta^0 \rightarrow n\,\gamma \rightarrow 1\gamma\ 0p$



While our models do contribute to both topologies, we **consider only the 1γ 0p topology** to avoid issues with nuclear modelling

caveat: 1γ 0p selection has larger bkg, as proton kinematics cannot be leveraged for bkg rejection

Fermilab

gLEE 1γ 0p selection

Selection Stages
Topological cut
Pre-selection cuts
Cosmic BDT
BNB Other BDT
NC π^0 BDT

One reconstructed shower and no reconstructed tracks

Reconstructed shower energy

Shower start position from SCB

More involved set of cuts, e.g. second shower veto

Impossible to apply official MicroBooNE selection and so we make some educated guesses

gLEE 1γ 0p selection

Selection Stages
Topological cut
Pre-selection cuts
Cosmic BDT
BNB Other BDT
NC π^0 BDT

One reconstructed shower and no reconstructed tracks

Reconstructed shower energy

Shower start position from SCB

More involved set of cuts, e.g. second shower veto

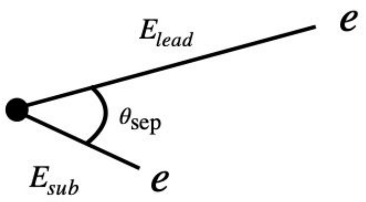
We can, however, apply our knowledge of e^+e^- reconstruction to make a *pseudo* topological cut

Information about the energy distribution of our events can also aid us

Detour: e^+e^- topological reconstruction at MicroBooNE

Topological reconstruction efficiency

Topological reconstruction of generic* e^+e^- pairs already studied!

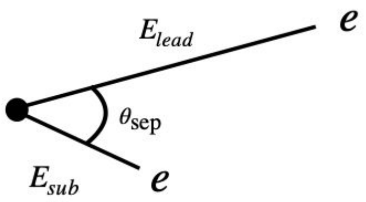


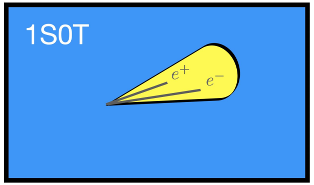
Pairs of uniformly distributed e^+e^- are passed through MicroBooNE reconstruction (*Pandora, as used in gLEE analysis*)

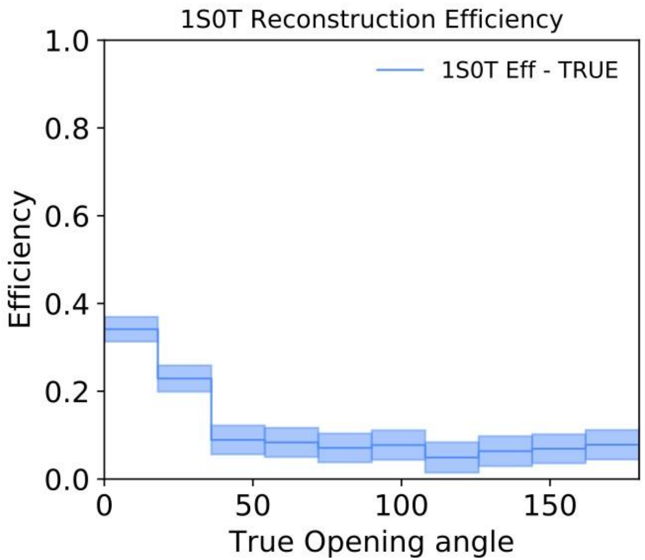
*Generic e+e- events generated with flat separation angle and energy asymmetry distributions: $0 \leq \theta_{sep} \leq 180°$, $E_{total} = 1$ GeV

Topological reconstruction efficiency

Topological reconstruction of generic* e^+e^- pairs already studied!



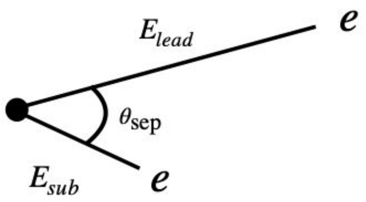


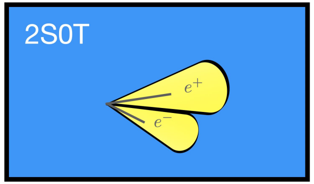


*Generic e+e- events generated with flat separation angle and energy asymmetry distributions: $0 \leq \theta_{sep} \leq 180°$, $E_{total} = 1$ GeV

Topological reconstruction efficiency

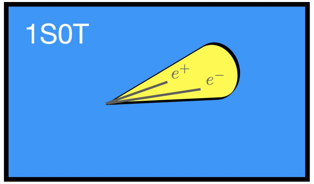
Topological reconstruction of generic* e^+e^- pairs already studied!

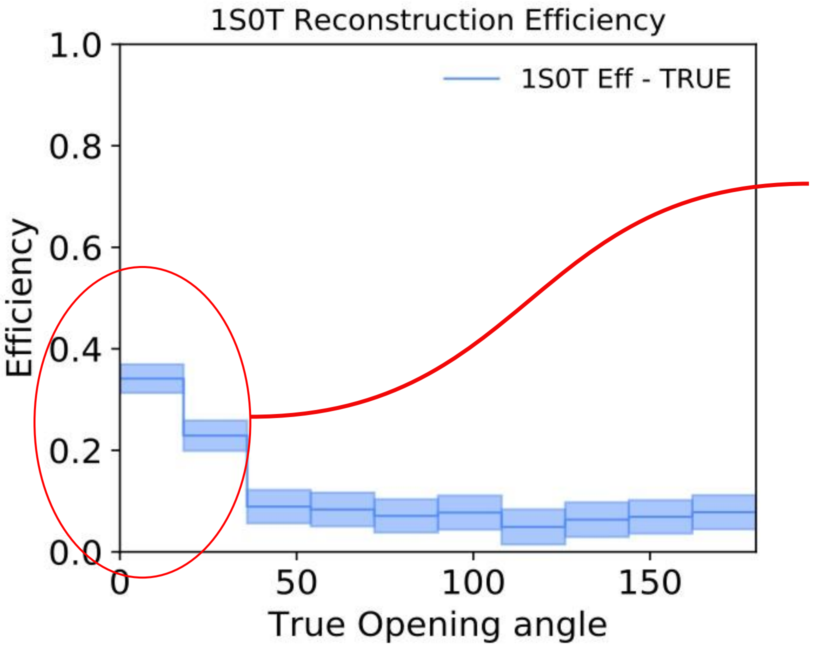




*Generic e+e- events generated with flat separation angle and energy asymmetry distributions: $0 \leq \theta_{sep} \leq 180°$, $E_{total} = 1$ GeV

Topological reconstruction efficiency





Efficiency highest to reconstruct a single shower for e^+e^- separation angle **< 35 deg.**

gLEE 1γ 0p *pseudo*-selection

Informed by our topology studies, we decide on the following selection

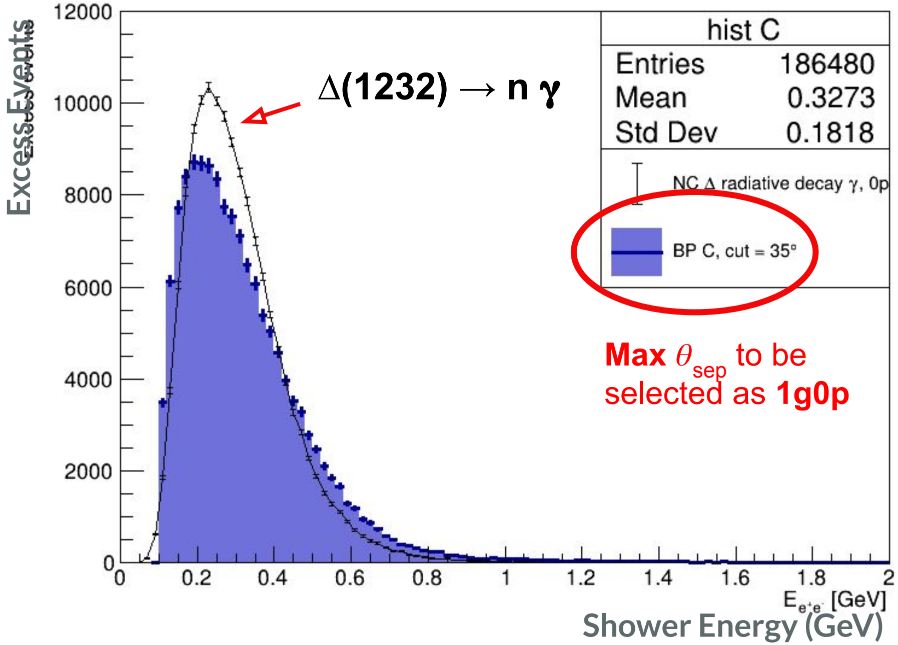
Pseudo-selection	
Topological cut	$\theta_{sep.}$ < 35 deg.
Energy	?

Assume that e^+e^- indistinguishable passing angular cut are indistinguishable from single photons

We also require the energy distribution is **sufficiently similar*** to that of single photons from NC Δ radiative decays!

NC Δ 1γ 0p truth energy distribution

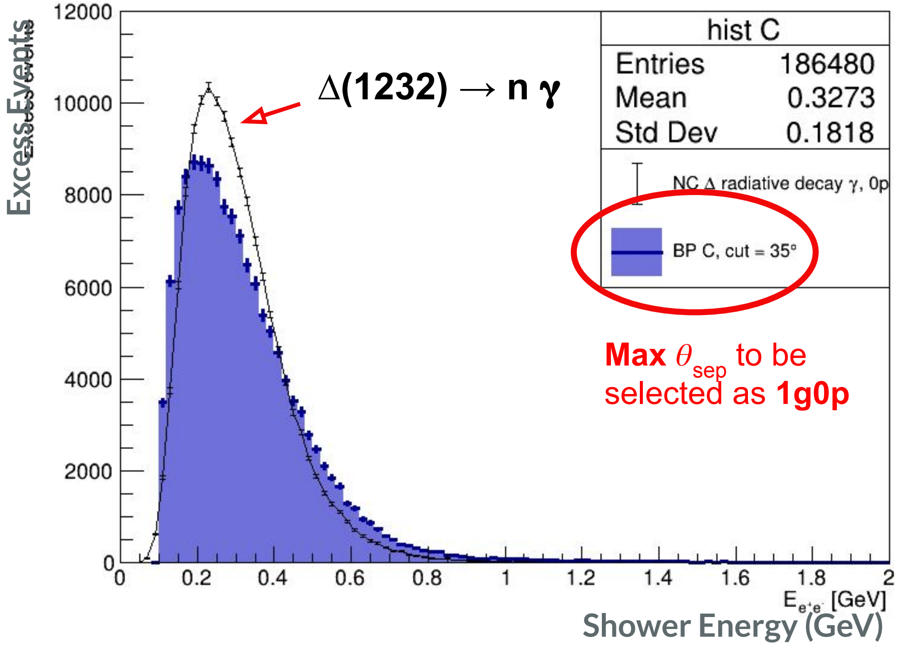
m_i=150 MeV, m_j=107 MeV, $m_{Z'}$ = 30 MeV



Taking light dark photon model as an example, we see that energy distribution of the e^+e^- approaches that of NC Δ photon **above 20 deg.**

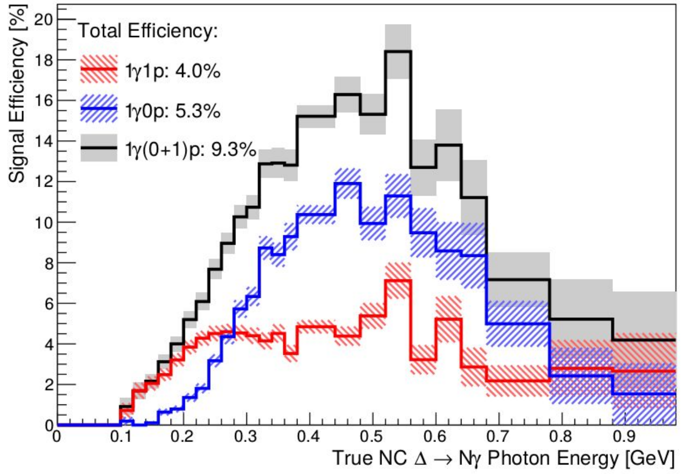
NC Δ 1γ 0p truth energy distribution

m_i=150 MeV, m_j=107 MeV, $m_{Z'}$ = 30 MeV



We can then apply 1g0p efficiency to our remaining events

Note: 5.3% is doubled to 10.6% as generated events contain only 0p events



Fermilab

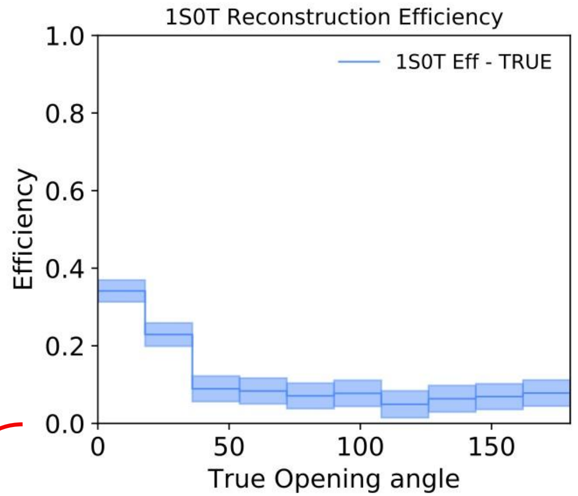
gLEE 1γ 0p *pseudo*-selection

Selection is fairly simplistic as based on limited public data!

Pseudo-selection	
Topological cut	$\theta_{sep.}$ < 35 deg.
Energy	binned efficiency applied (net 10.6%)

MicroBooNE can likely do much better than 35 deg. angular resolution

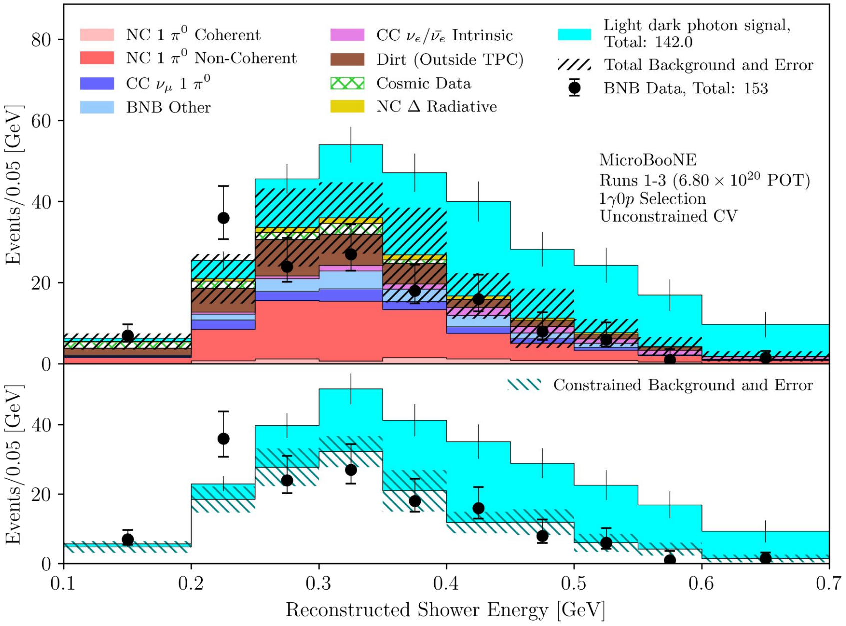
Limited by binning

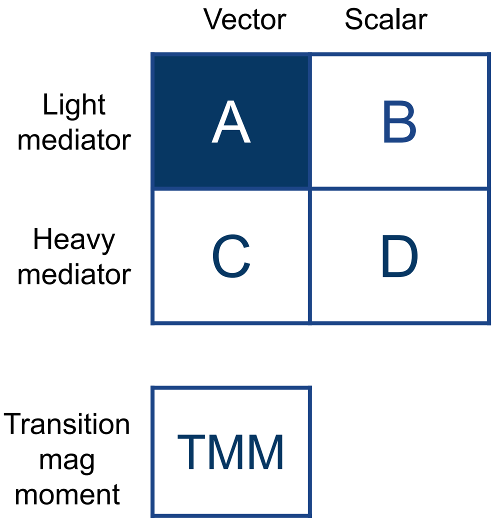


Preliminary results

Results: Light dark photon BP

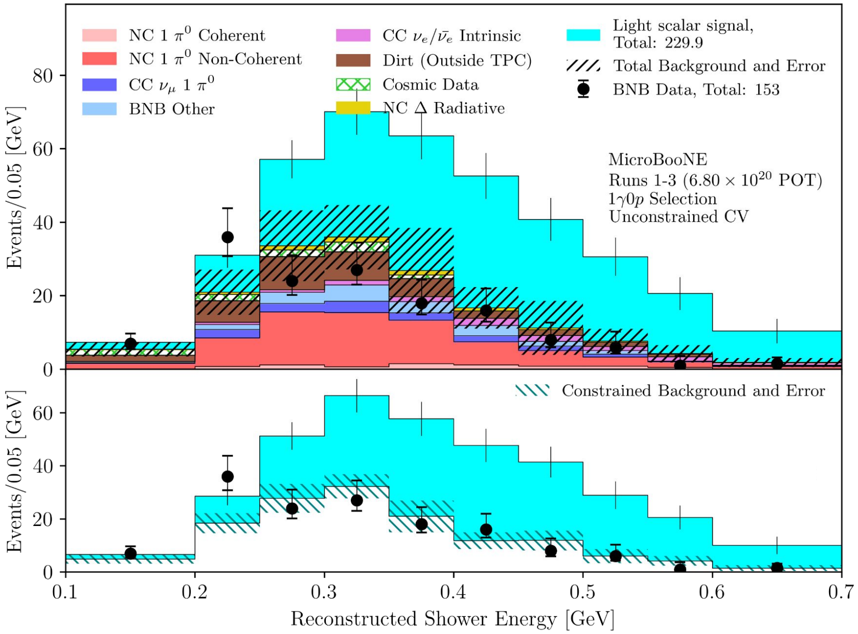
BP A – MiniBooNE p-val: 0.56

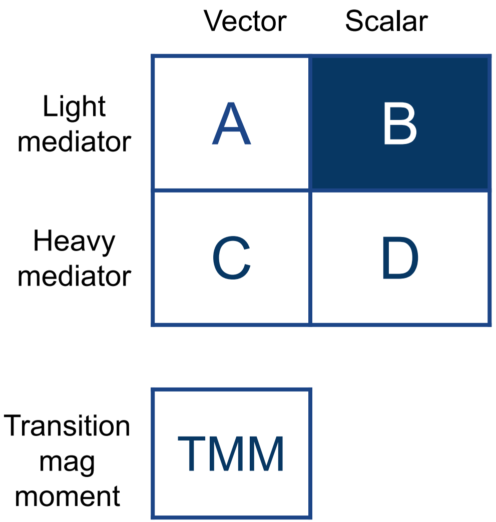




Results: Light scalar BP

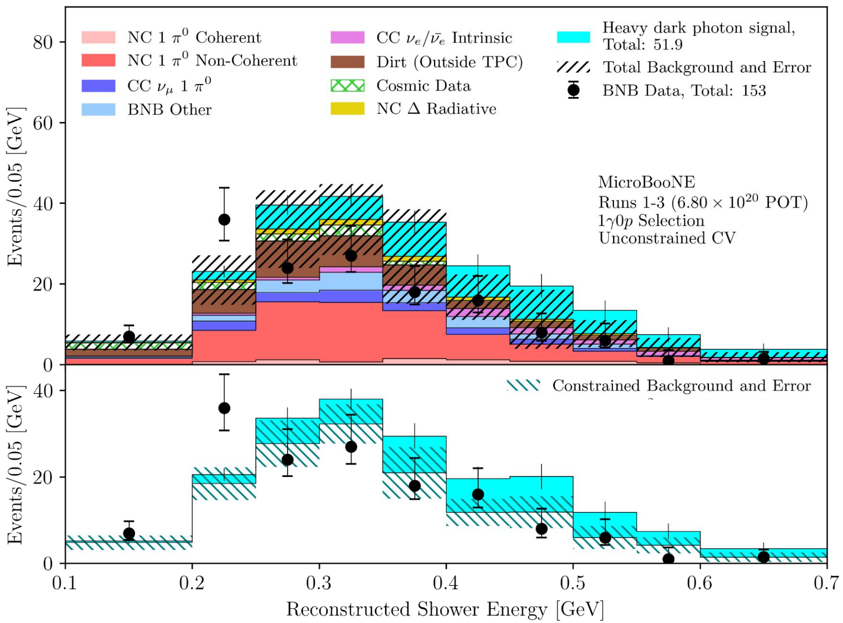
BP B – MiniBooNE p-val: 0.62

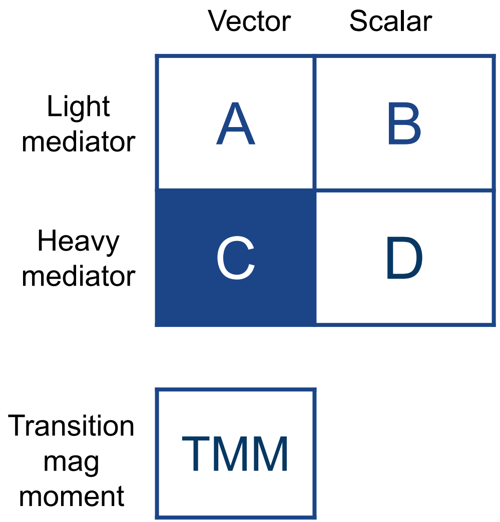




Results: heavy dark photon BP

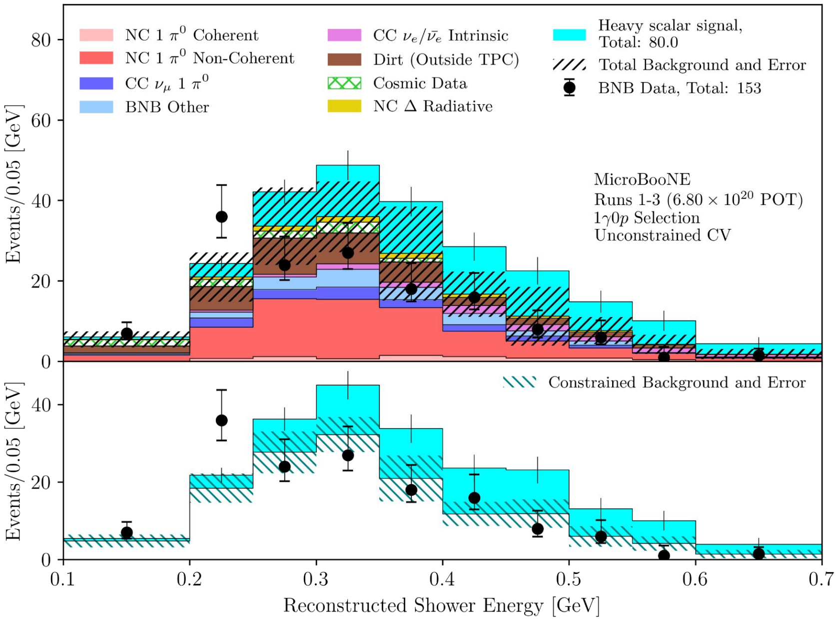
BP C – MiniBooNE p-val: 0.41





Results: heavy scalar BP

BP D – MiniBooNE p-val: 0.23

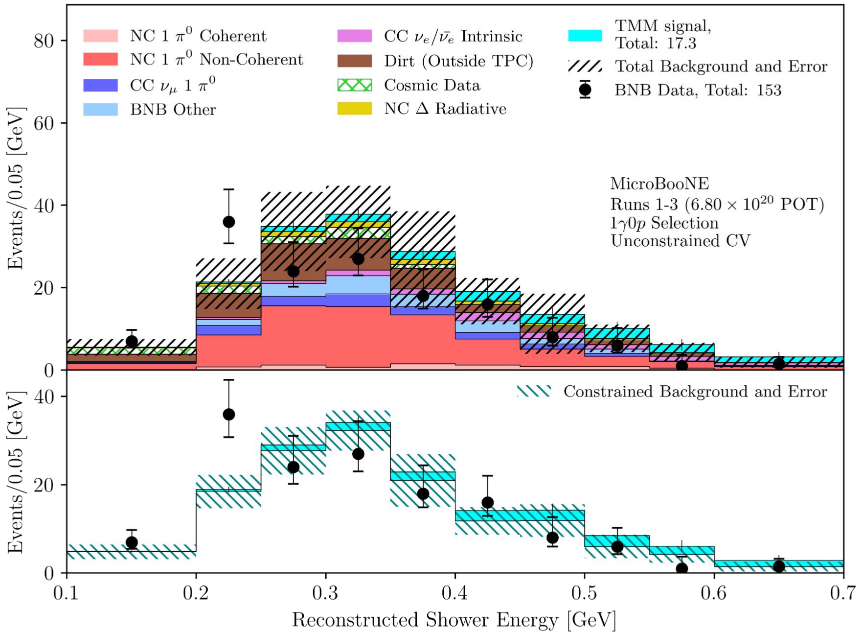


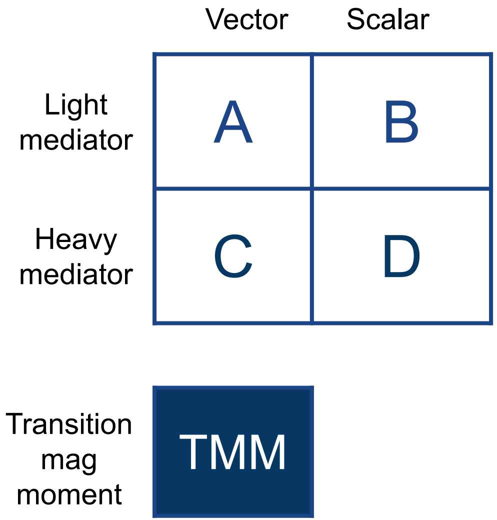
	Vector	Scalar
Light mediator	A	B
Heavy mediator	C	D

Transition mag moment	TMM

Results: TMM BP

TMM – MiniBooNE p-val: 0.42



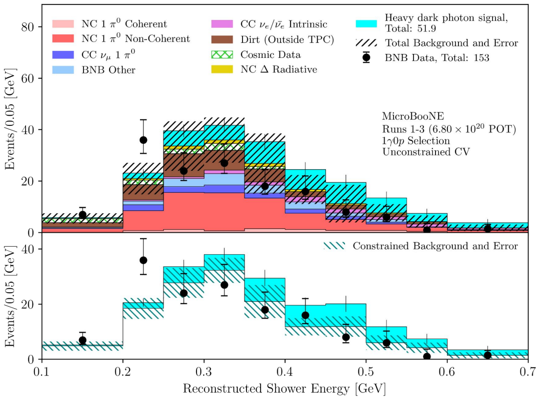


Impact of improved selection

Contribution to 1g0p selection seems very high (for some BPs) at MicroBooNE suggesting the search for **NC Δ radiative decays is highly constraining for our coherent-like benchmarks**

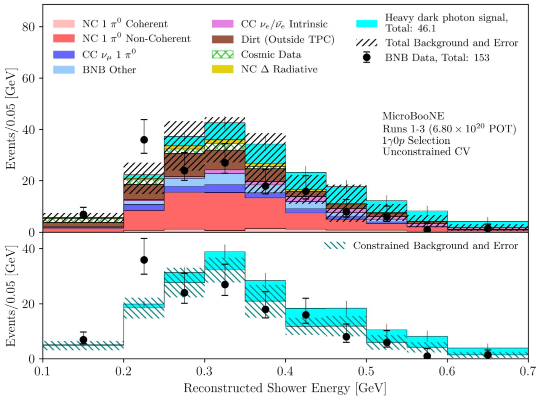
What is the impact of improved selection cuts? E.g. improved angular resolution for e^+e^-

$\theta_{sep.}$ < 35 deg.



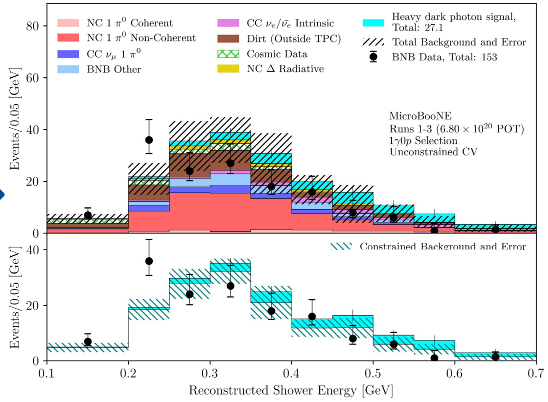
51.9 events

$\theta_{sep.}$ < 25 deg.



46.1 events

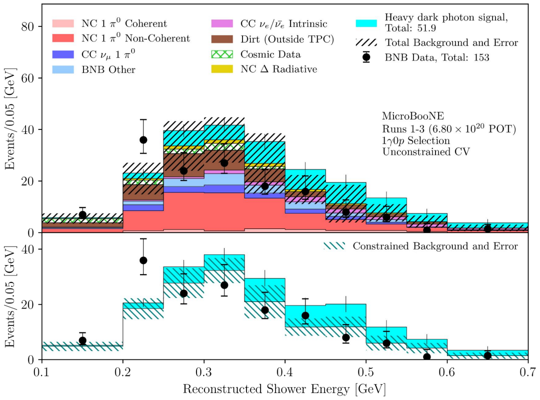
$\theta_{sep.}$ < 15 deg.



27.1 events

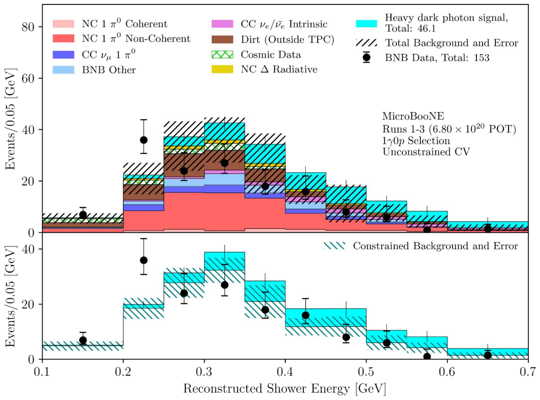
Impact of improved selection

$\theta_{sep.}$ < 35 deg.



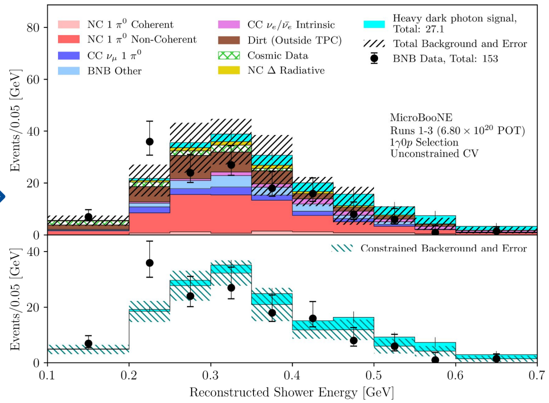
51.9 events

$\theta_{sep.}$ < 25 deg.



46.1 events

$\theta_{sep.}$ < 15 deg.



27.1 events

In a dedicated analysis, we are **no longer limited to a single shower selection** and can leverage the two shower topologies allowing us to more strongly constrain the models.

Main takeaways

The MiniBooNE anomaly is “alive and kicking” — MicroBooNE is providing new insights.

MicroBooNE still has not searched for e+e- interpretations of the excess.

But first constraints using the gLEE $\Delta(1232)$ search can already provide limits.

- Light mediators are much more strongly constrained thanks to the coherent scattering enhancement in Argon ($Z = 18$ at Micro vs $Z = 6$ at Mini).
- The public gLEE analysis not ruling out heavy mediators and large HNL masses, where coherent effects are less pronounced.

Dedicated searches for all topological final states should provide definitive tests.

Thank you