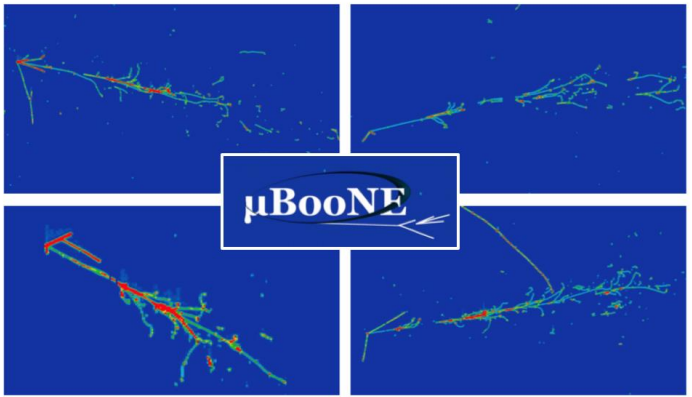
MicroBooNE's BSM physics programme



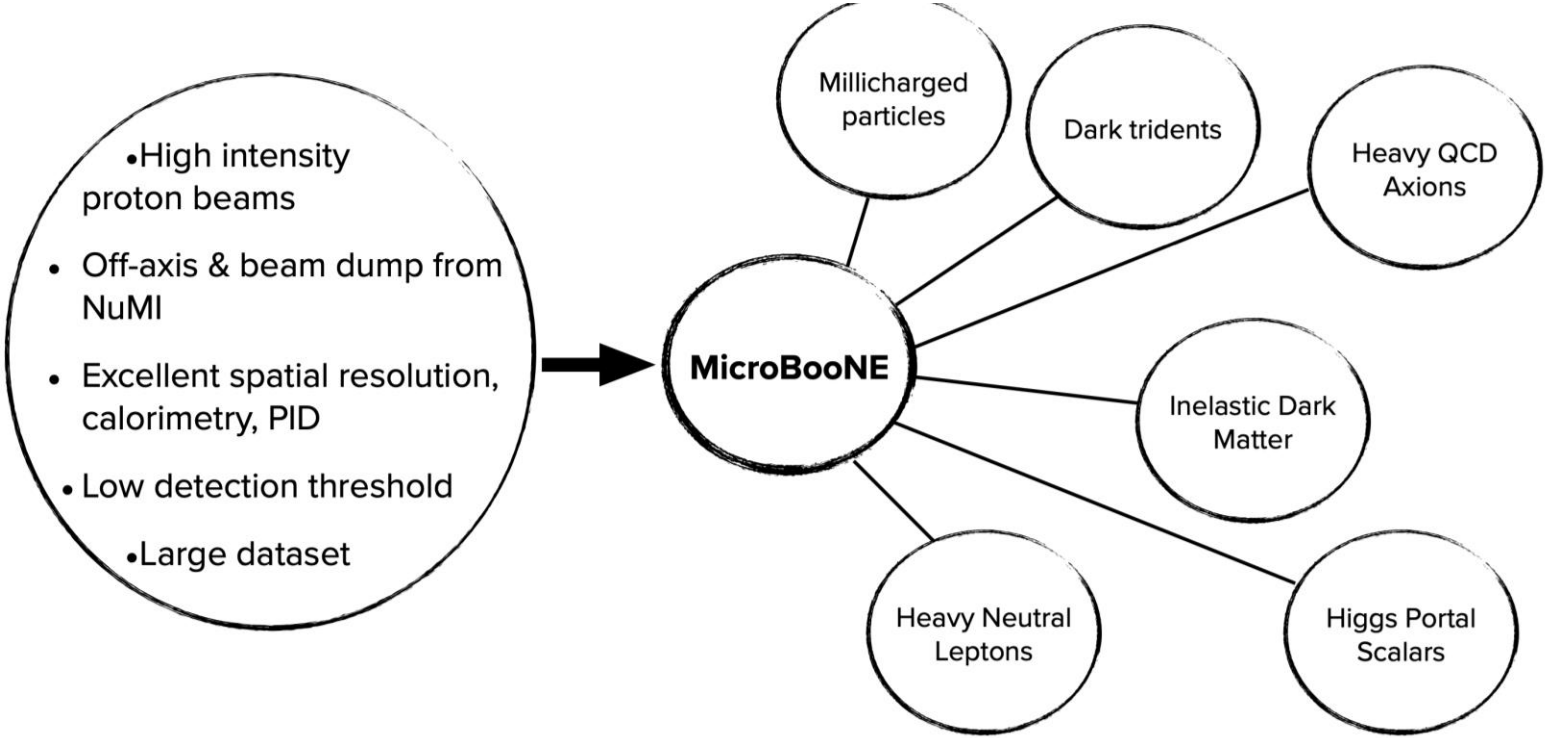
Justin Evans

University of Manchester

μBooNE

MANCHESTER 1824
The University of Manchester

BSM physics with MicroBooNE



BSM physics with MicroBooNE

Results shown in this talk:

arXiv:2312.13945

Phys. Rev. Lett. **132**, 041801 (2024)

arXiv:2308.03924

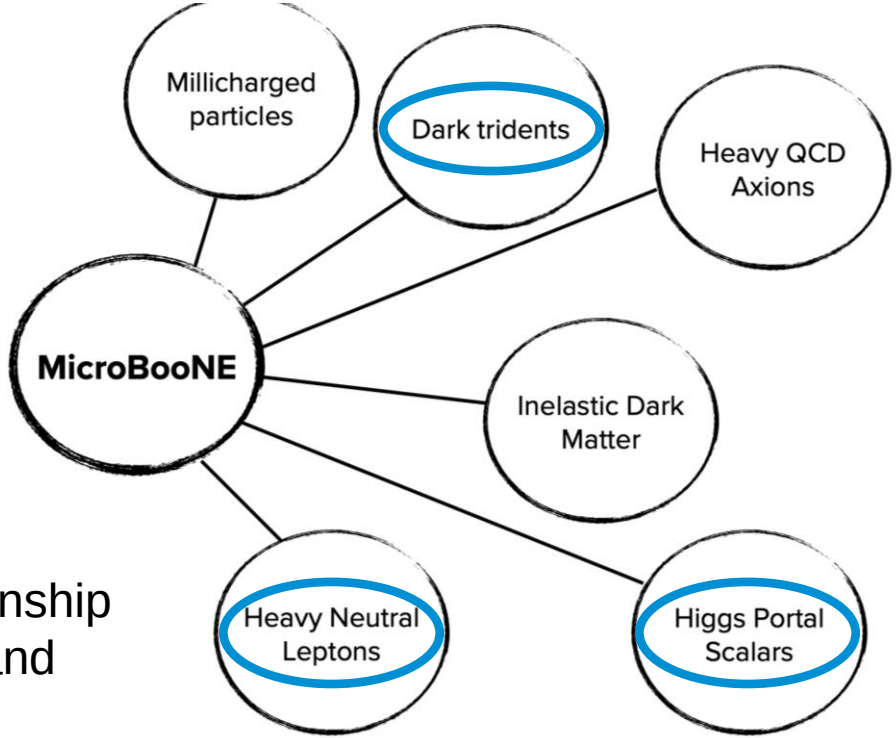
Phys. Rev. Lett. **130**, 011801 (2023)

Phys. Rev. D **106**, 092006 (2022)

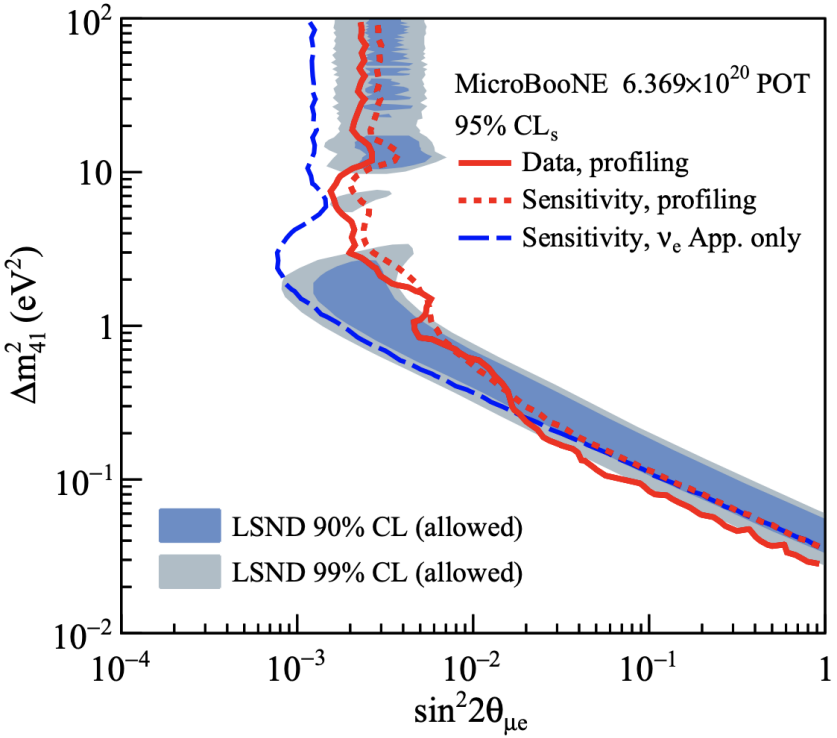
Phys. Rev. Lett. **127**, 151803 (2021)

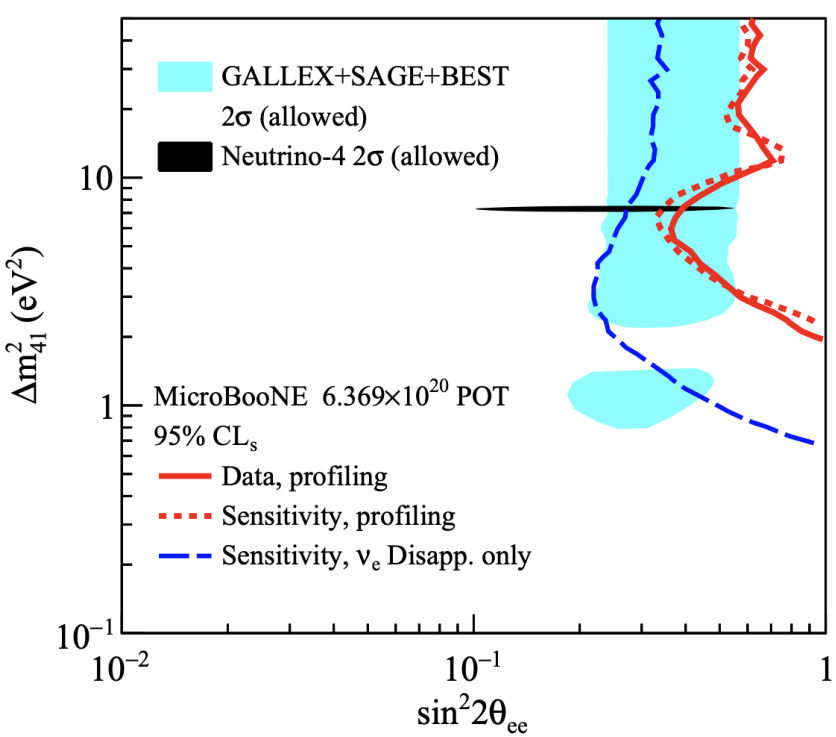
Phys. Rev. D **101**, 052001 (2020)

Made possible by a strong relationship with theorists, providing models and sensitivity estimates



Constraints on eV sterile neutrinos

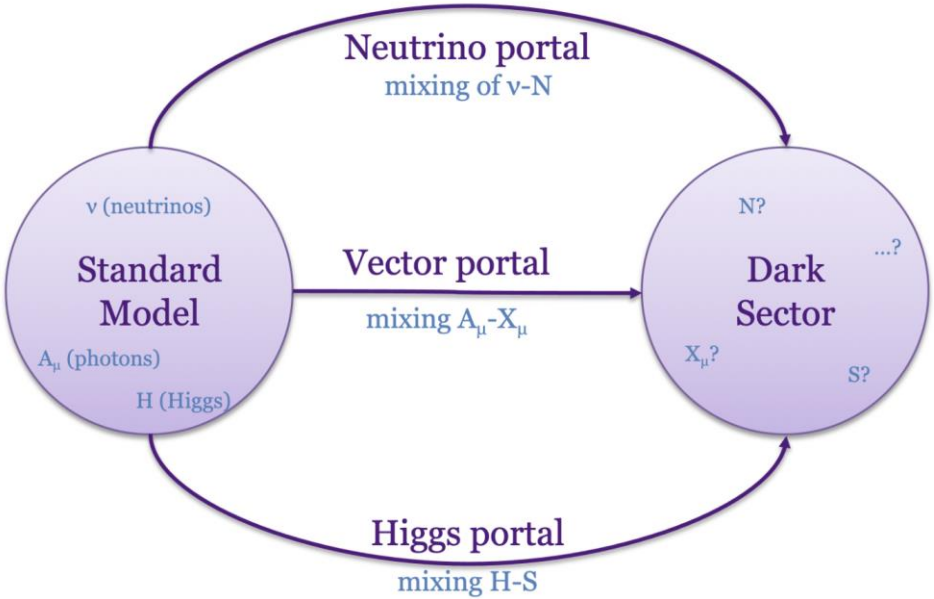




Erin Yandel's talk

Phys. Rev. Lett. **130**, 011801 (2023)

Portals to dark sectors

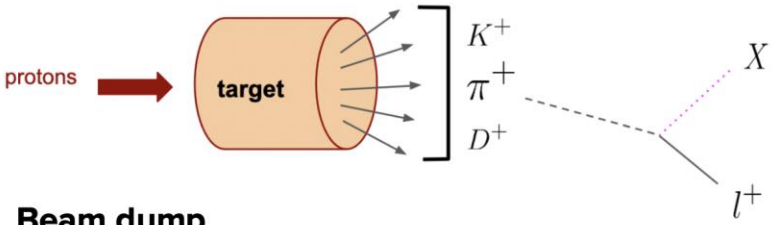


Portals to dark sectors

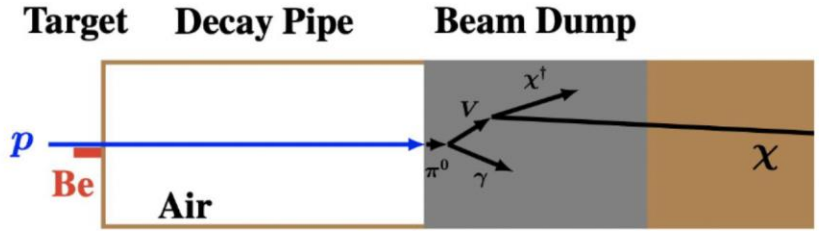
New particles can be produced from meson decays

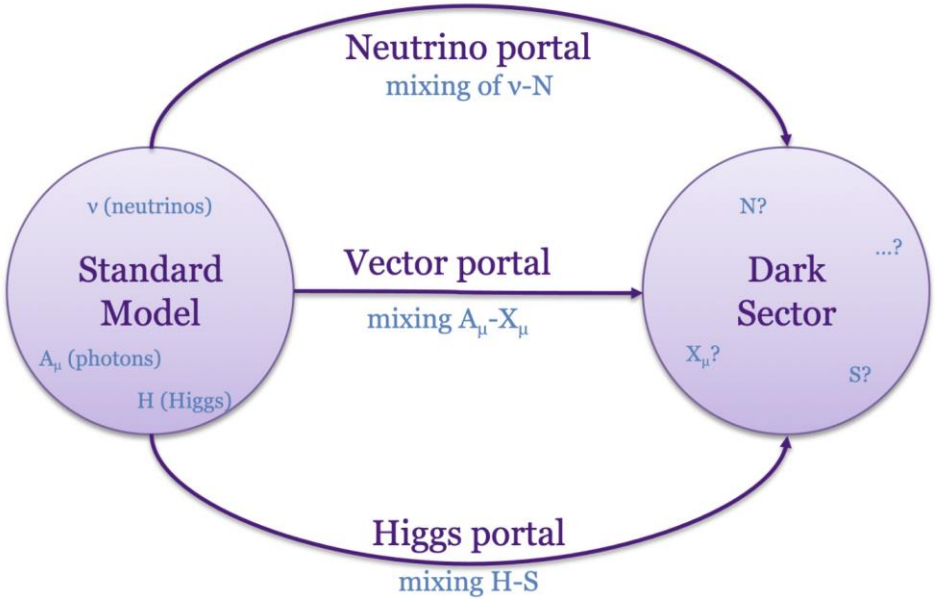
- Large flux of charged & neutral mesons from high intensity proton beams

Meson decay in flight

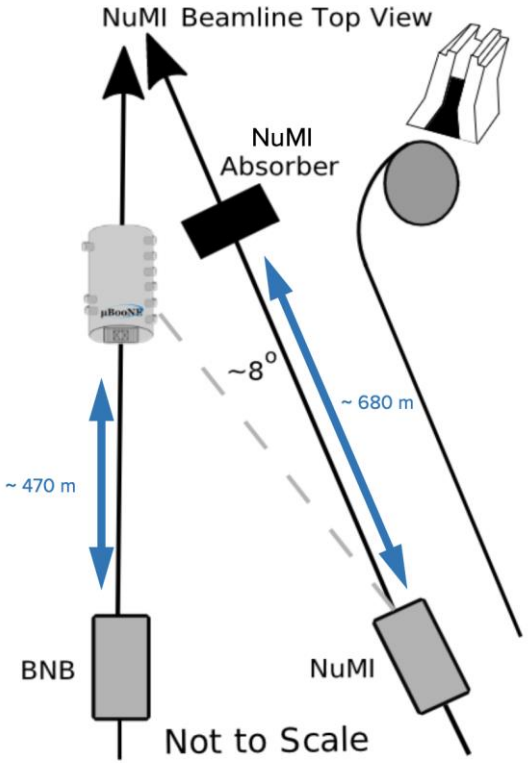


Beam dump





Two beamlines



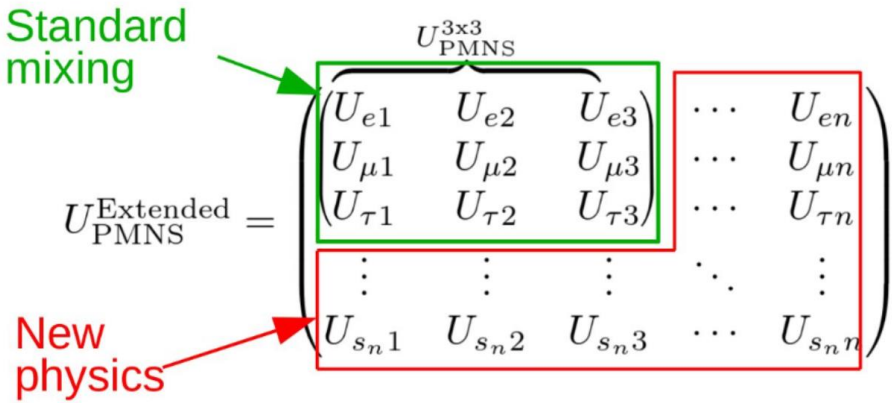
Booster Neutrino Beam

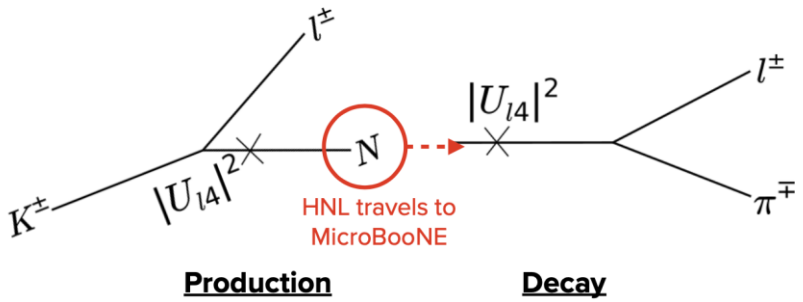
- 8 GeV protons
- 0.8 GeV mean neutrino energy
- On-axis

NuMI Beam

- 120 GeV protons
- 1.5 GeV mean neutrino energy
- ~8^{o} off-axis

Heavy neutral leptons (HNLs)





Incorporate a new right-handed singlet that mixes with the active neutrinos

Heavy neutral leptons produced in the beam

- Decay to Standard-Model particles in the detector

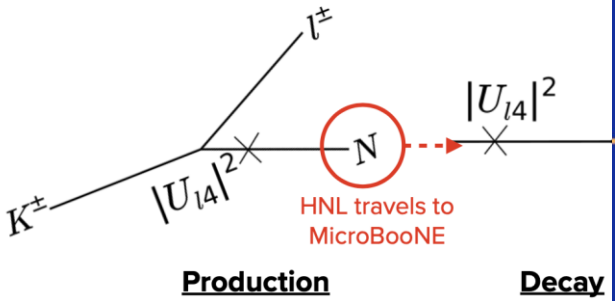
Heavy neutral leptons (HNLs)

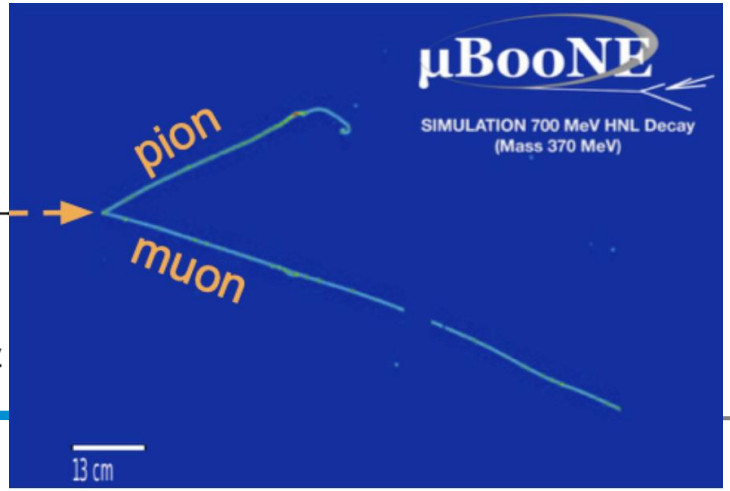
Standard mixing

New physics

$$U_{\text{PMNS}}^{\text{Extended}} = \begin{pmatrix} \overbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}}^{U_{\text{PMNS}}^{3\text{x}3}} & \cdots & U_{en} \\ & \cdots & U_{\mu n} \\ & \cdots & U_{\tau n} \\ \vdots & \vdots & \vdots \\ U_{s_n 1} & U_{s_n 2} & U_{s_n 3} \end{pmatrix} \quad \begin{matrix} \\ \\ \\ \ddots \\ \cdots \end{matrix} \quad \begin{matrix} \\ \\ \\ \vdots \\ U_{s_n n} \end{matrix}$$

- Production and decay rates both proportional to $|U_{l4}|^2$





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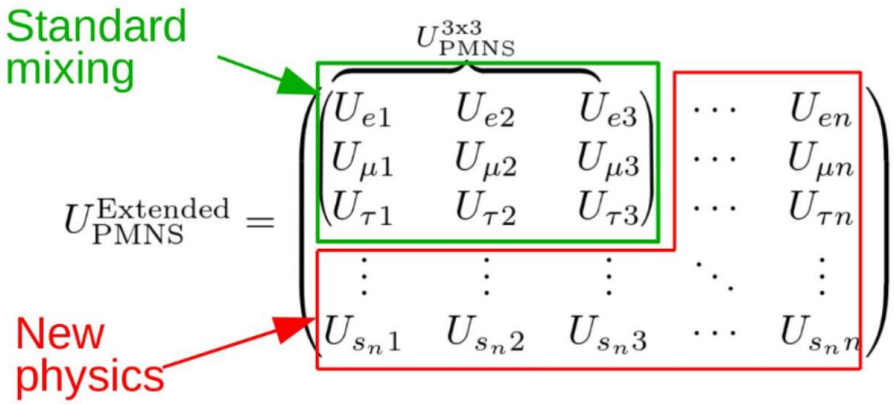
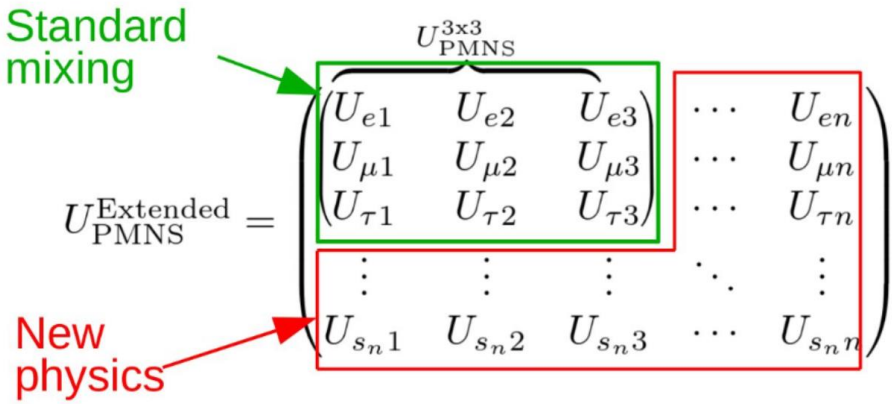
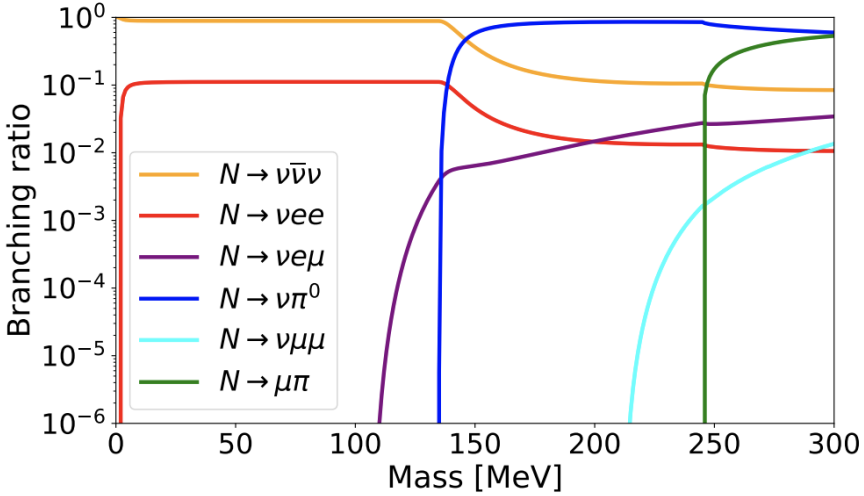
Heavy neutral leptons (HNLs)



- We assume $|U_{e4}| = |U_{\tau 4}| = 0$ and set limits on $|U_{\mu 4}|$
- We focus on production via $K \rightarrow \mu N$

Heavy neutral leptons (HNLs)

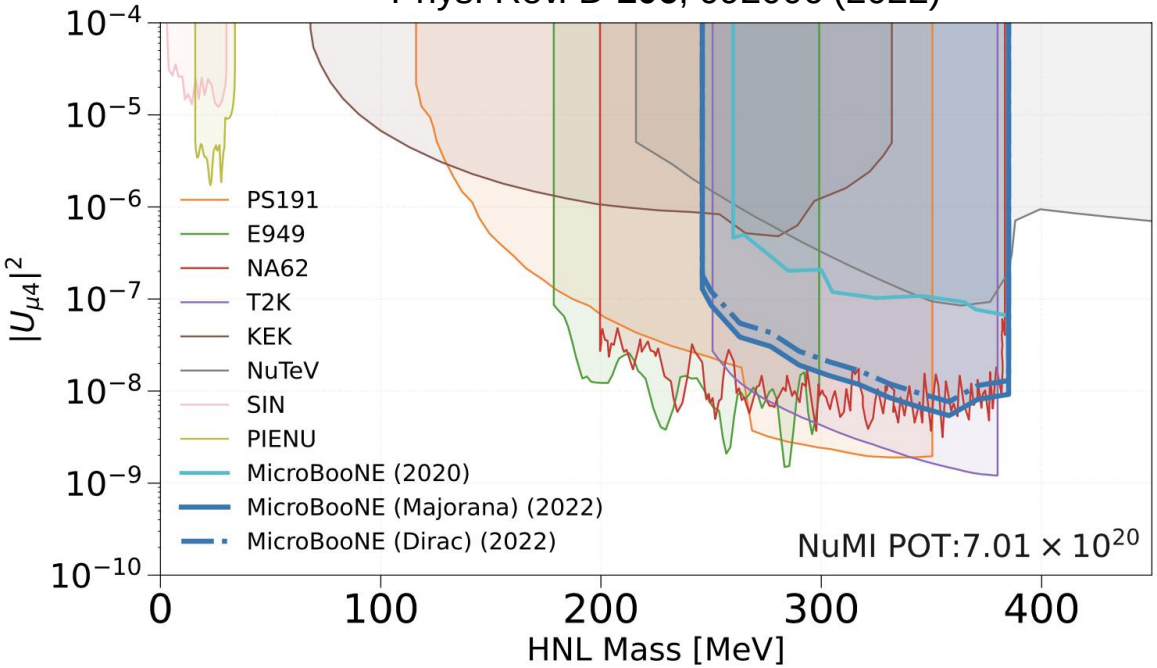




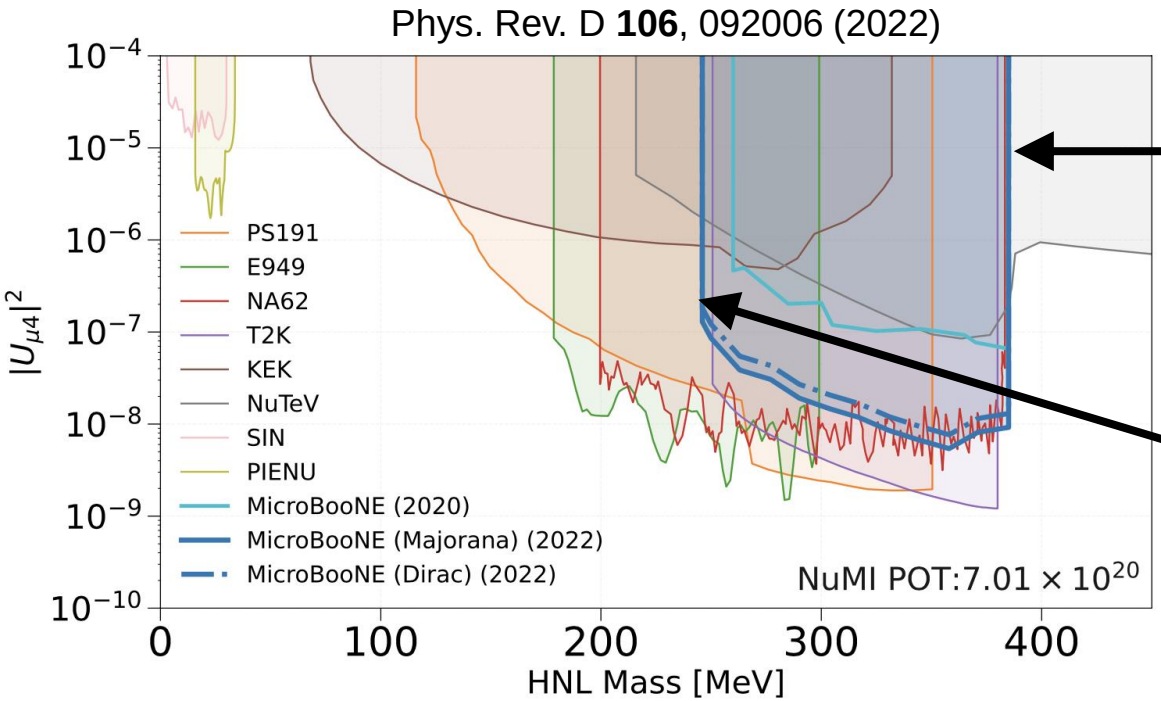
- We assume $|U_{e4}|= |U_{\tau4}|=0$ and set limits on $|U_{\mu4}|$
- We focus on production via $K \to \mu N$
- Most likely decay channel depends on m_N

Search for $N \rightarrow \mu^{\pm}\pi^{\mp}$

Phys. Rev. D **106**, 092006 (2022)



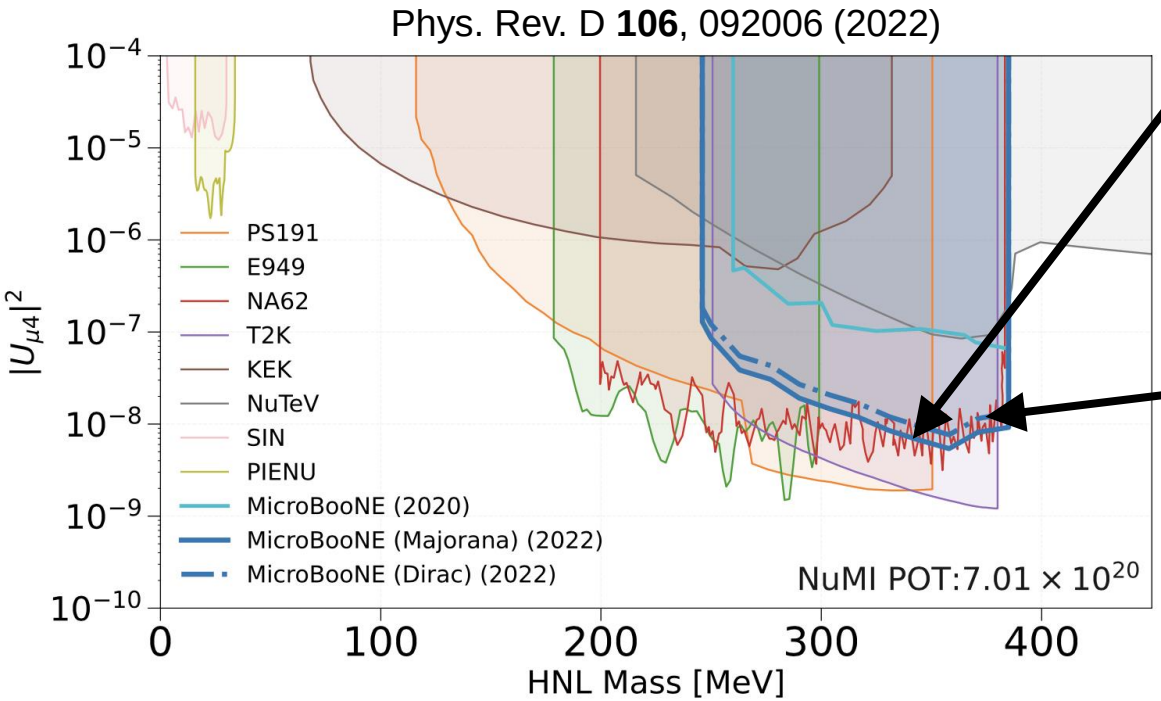
Search for $N \rightarrow \mu^{\pm}\pi^{\mp}$



Kinematic limit for $K \rightarrow \mu N$ production

Kinematic limit for $N \rightarrow \mu\pi$ decay

Search for $N \rightarrow \mu^{\pm}\pi^{\mp}$



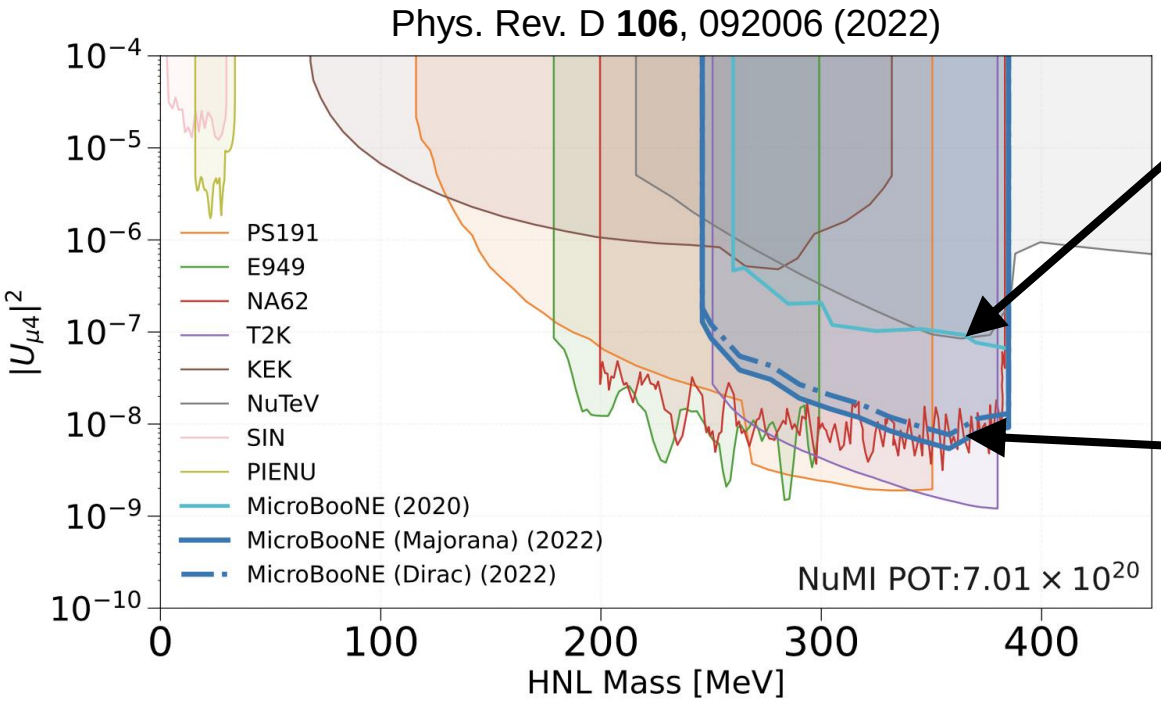
Majorana HNL

- $N \rightarrow \mu^{+}\pi^{-}$ and $N \rightarrow \mu^{-}\pi^{+}$
- Isotropic decays (summed over both channels)

Dirac HNL

- $N \rightarrow \mu^{-}\pi^{+}$ only: factor of two lower rate
- Non-isotropic decays (negligible effect)

Search for $N \rightarrow \mu^{\pm}\pi^{\mp}$

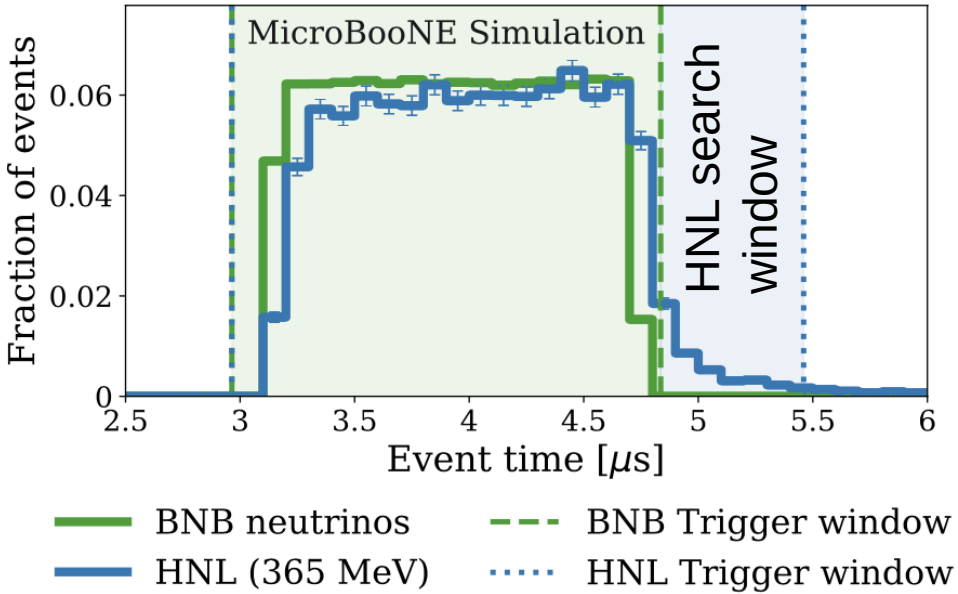


BNB search
Phys. Rev. D **101**, 052001 (2020)

NuMI search
Phys. Rev. D **106**, 092006 (2022)

μBooNE

BNB search: late-arrival trigger



Used the fact that heavy HNLs arrive later than light neutrinos

- Implemented a dedicated late-arrival trigger to eliminate regular neutrino interactions
- Uses a 0.6 μs window after the usual BNB trigger

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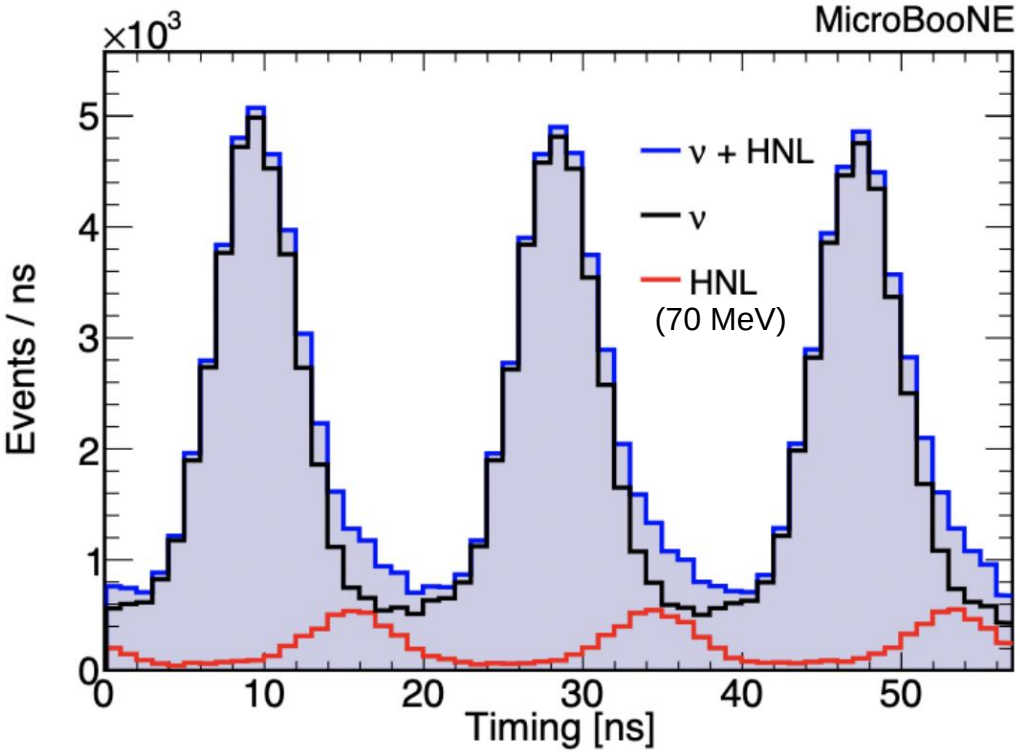
Phys. Rev. D **106**, 092006 (2022)

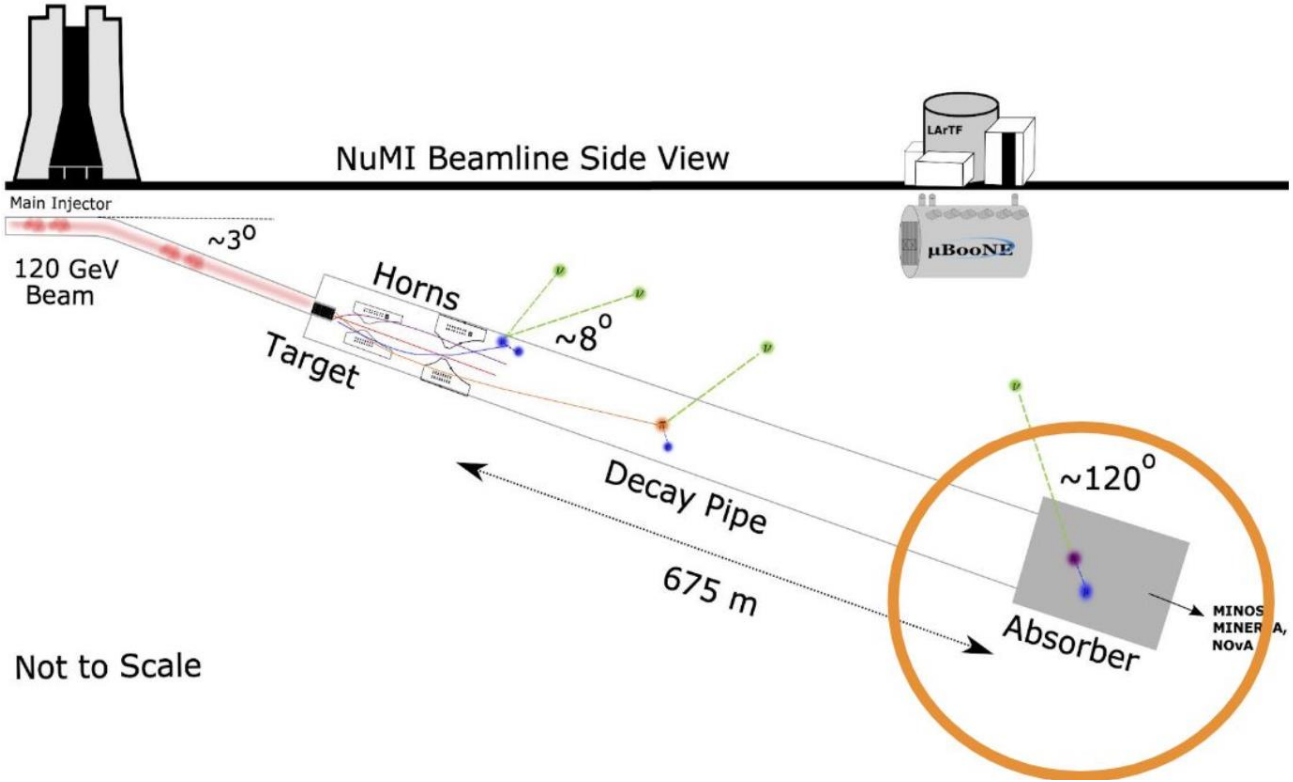
Potential upgrade with ns timing

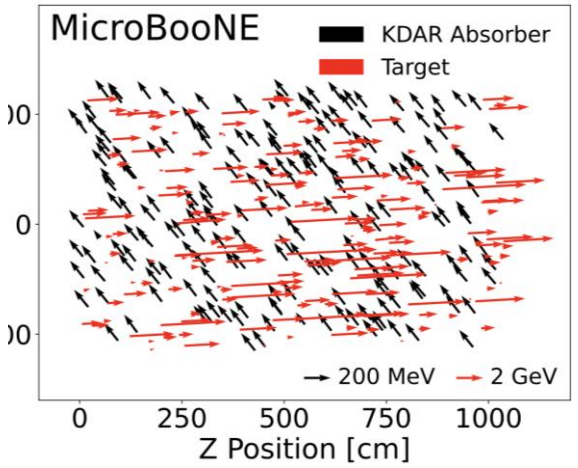


Phys. Rev. D **108**, 052010 (2023)

Dante Totani's talk

NuMI search: off-axis





Events from HNLs produced in the NuMI absorber have a specific directionality

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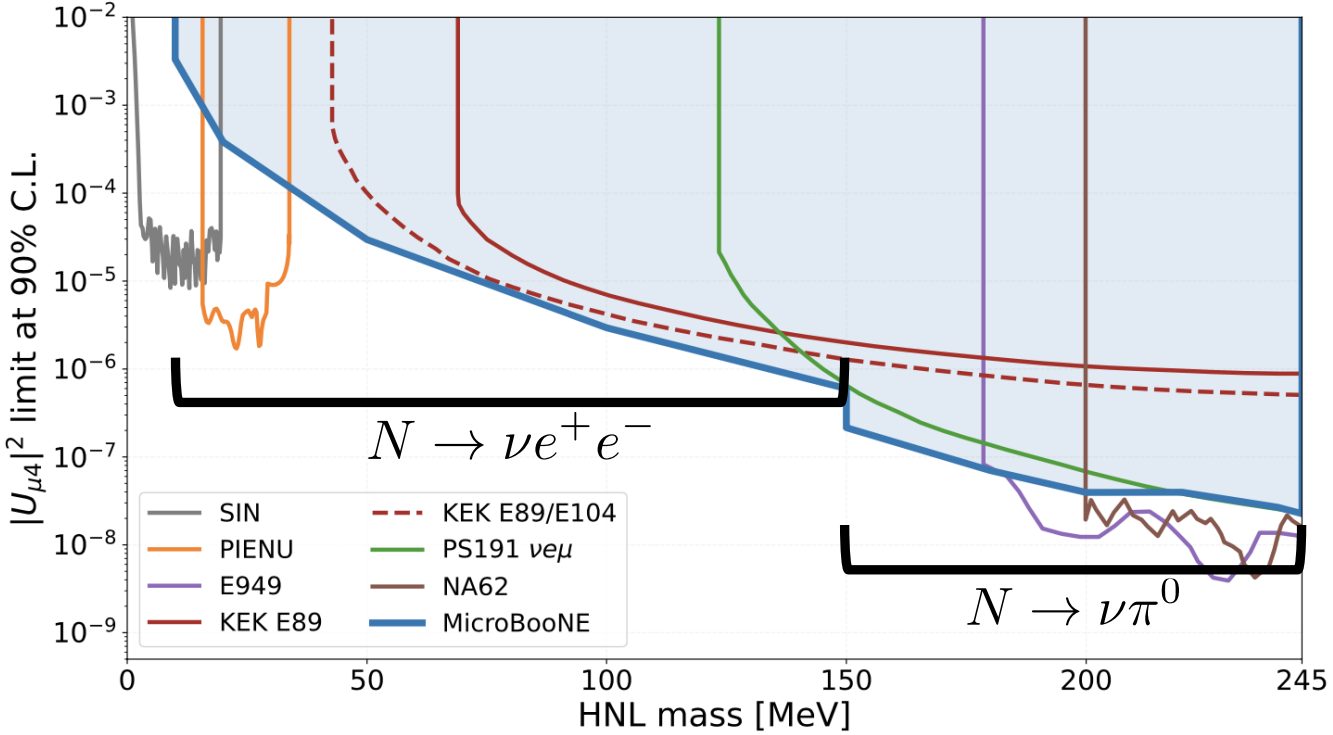
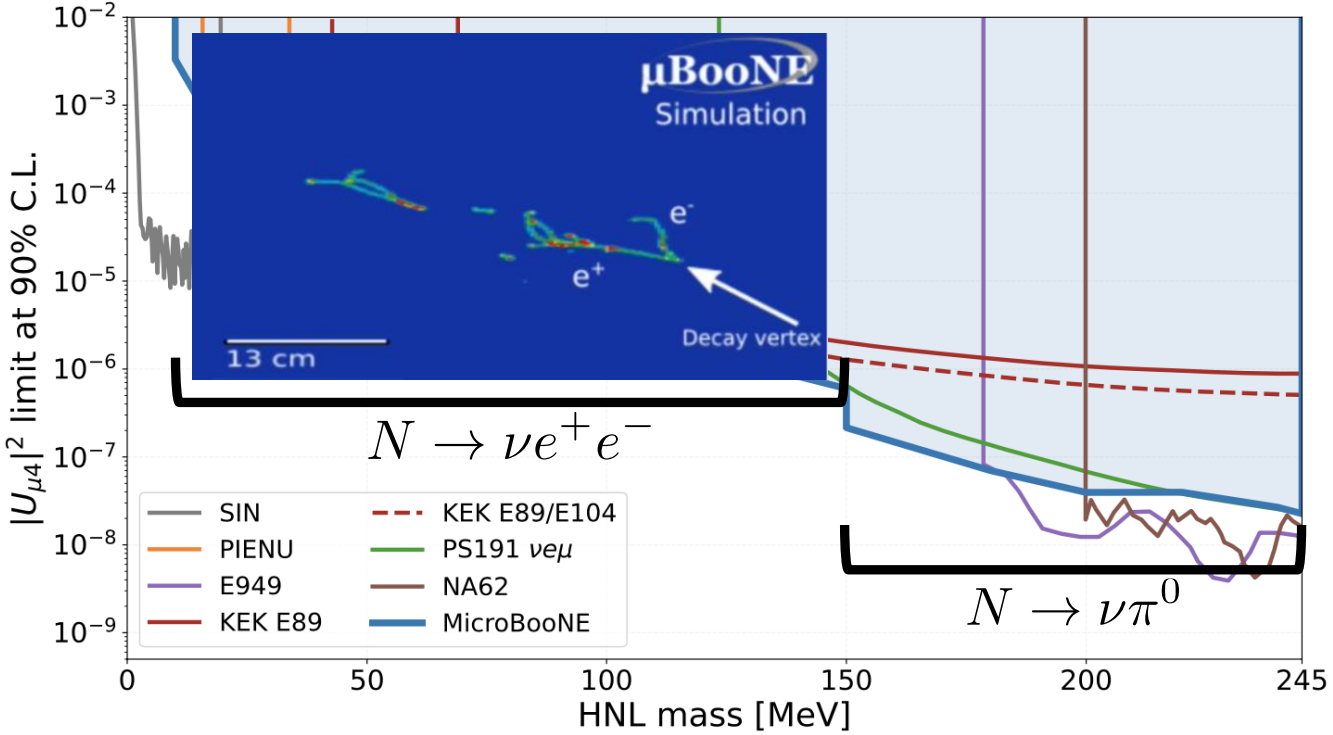
Phys. Rev. D **106**, 092006 (2022)

Lighter heavy neutral leptons



Phys. Rev. Lett. **132**, 041801 (2024)

Lighter heavy neutral leptons



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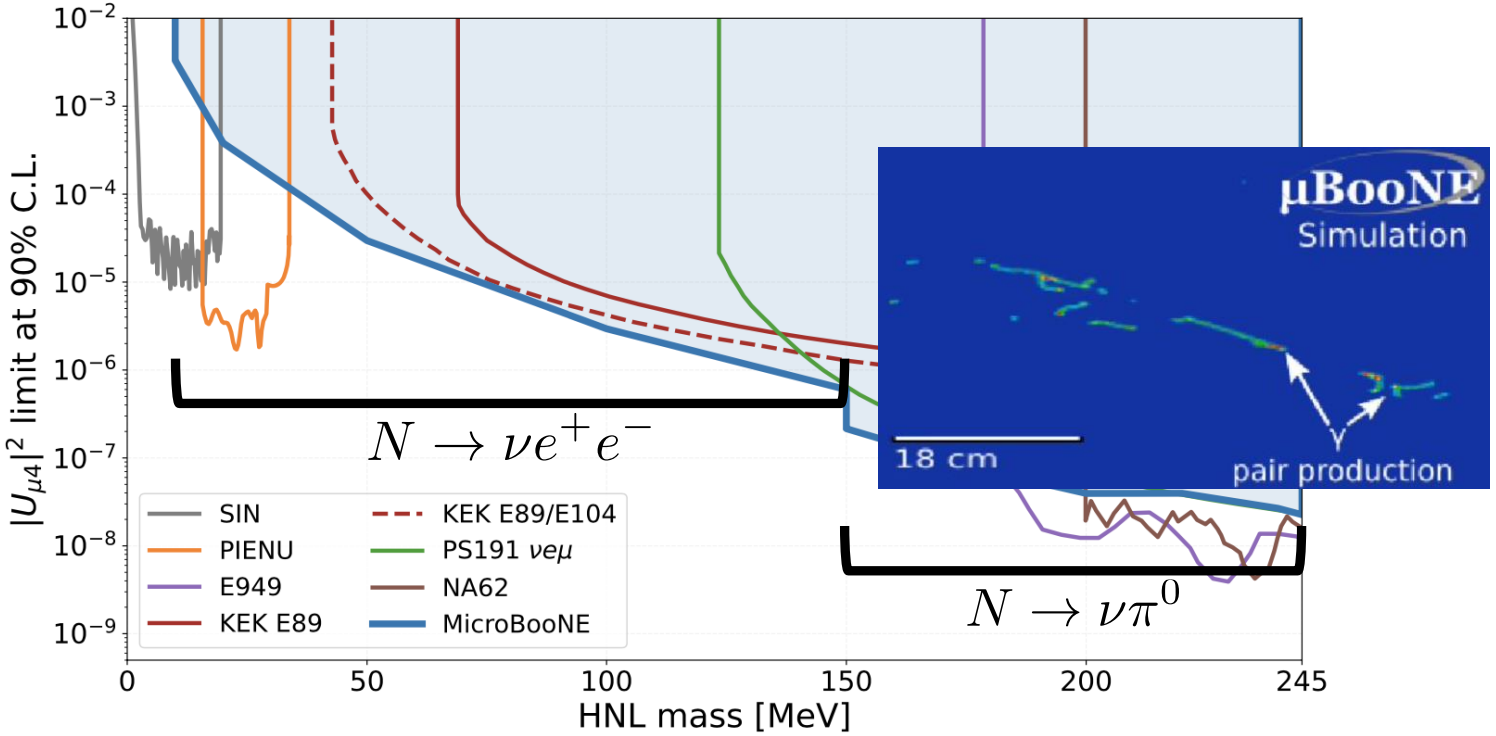
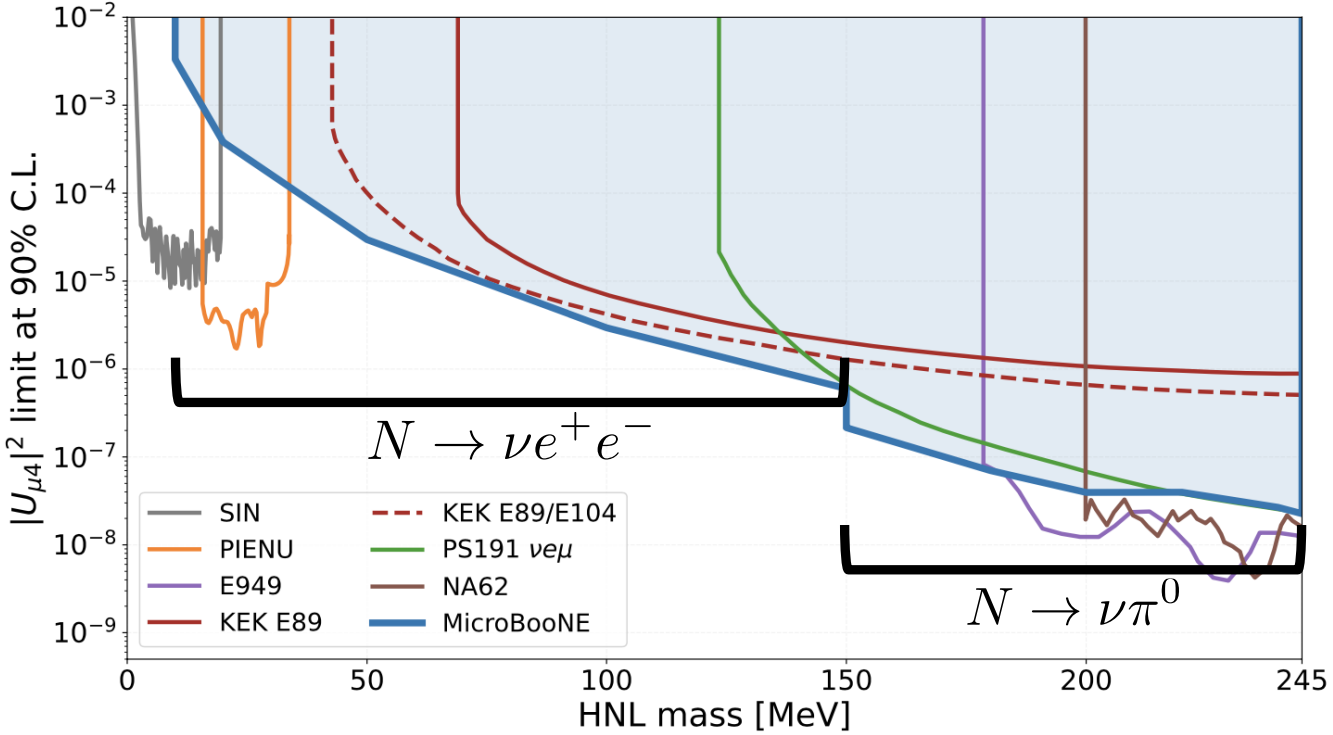
Phys. Rev. Lett. **132**, 041801 (2024)

Lighter heavy neutral leptons



Phys. Rev. Lett. **132**, 041801 (2024)

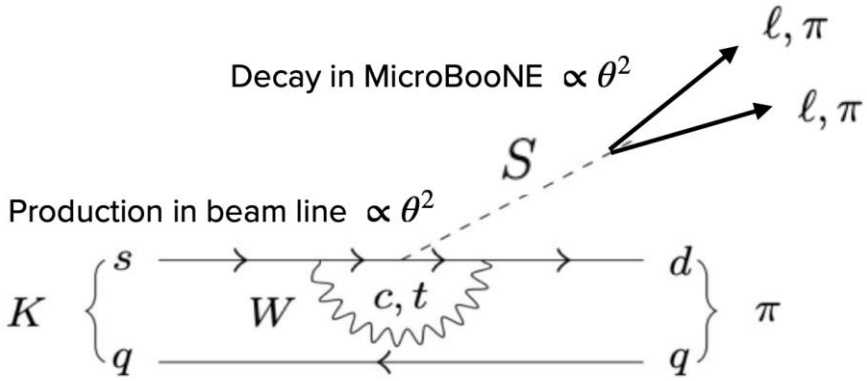
Lighter heavy neutral leptons

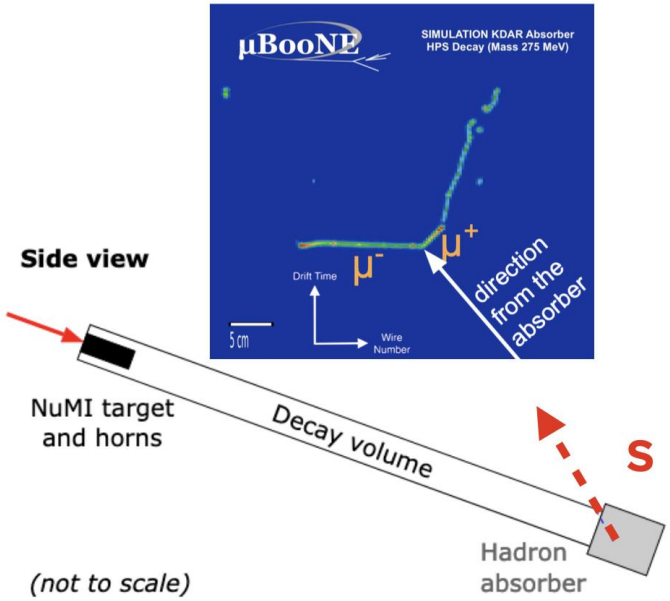


Phys. Rev. Lett. **132**, 041801 (2024)

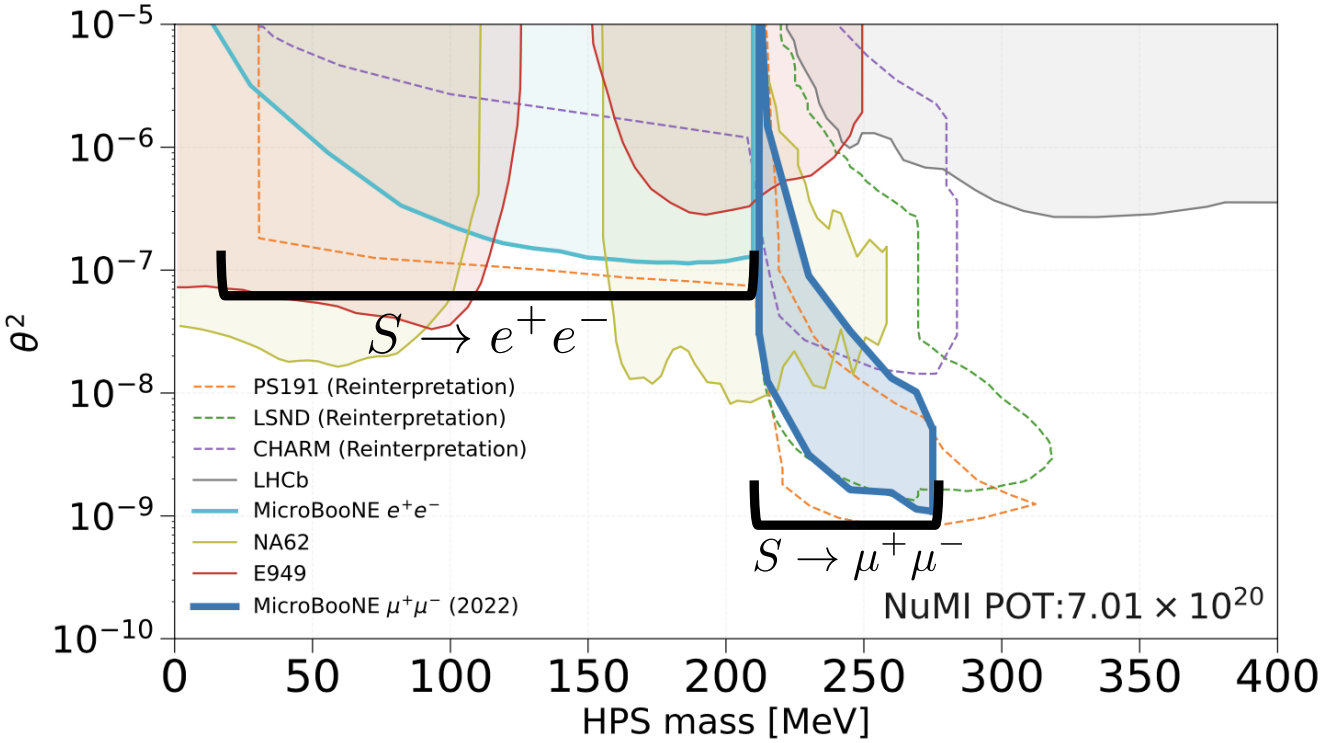
Higgs portal scalars

- Neutral singlet scalar, S
- Mixes with the Higgs, parameterized by an angle θ
- Produced in meson decays in the beam
- Decays into Standard-Model particles in the detector





Higgs portal scalars



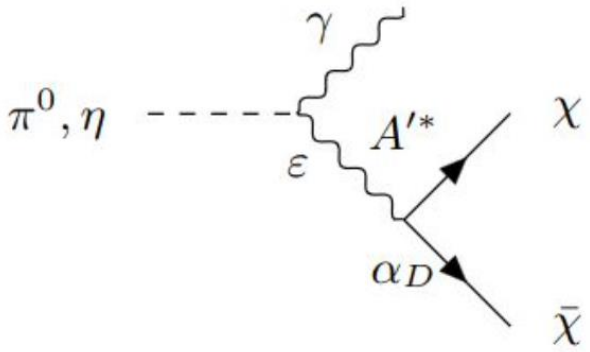
µBooNE

Phys. Rev. Lett. **127**, 151803 (2021), Phys. Rev. D **106**, 092006 (2022)

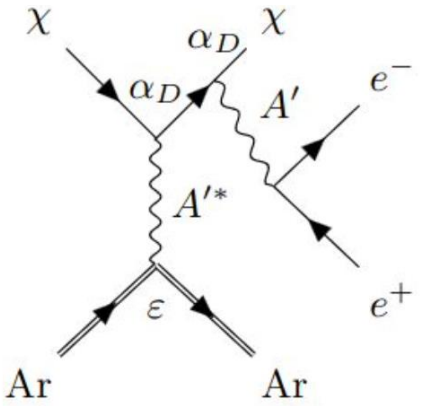
Dark tridents

arXiv:2312.13945

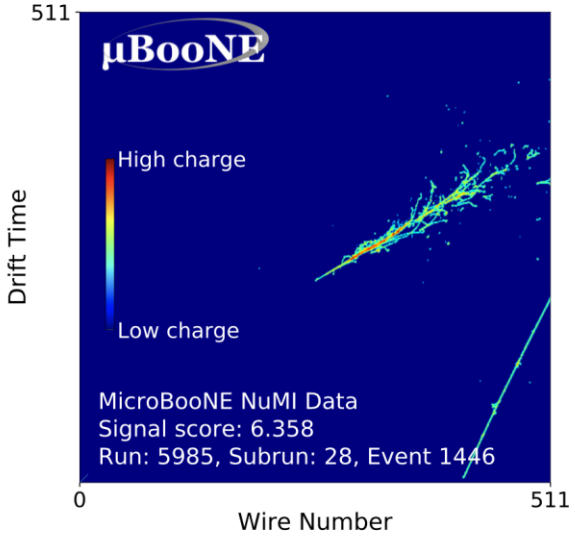
Production in the NuMI beam



Interaction in the detector



- Dark matter particles, χ, produced in decays of neutral mesons
- χ particles interact in the detector, mediated by a dark photon
- Free parameters are ε, α_D and M_χ/M_A

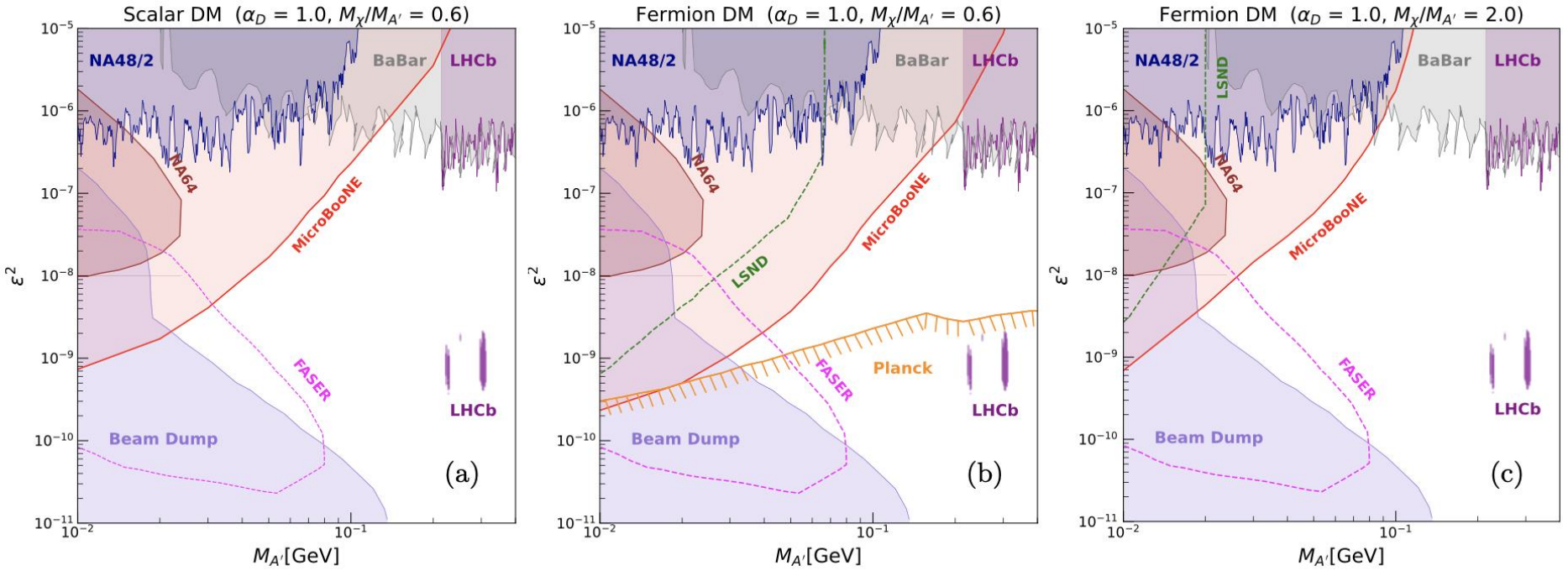


Uses pixel-based deep learning techniques

μBooNE

Dark tridents

arXiv:2312.13945



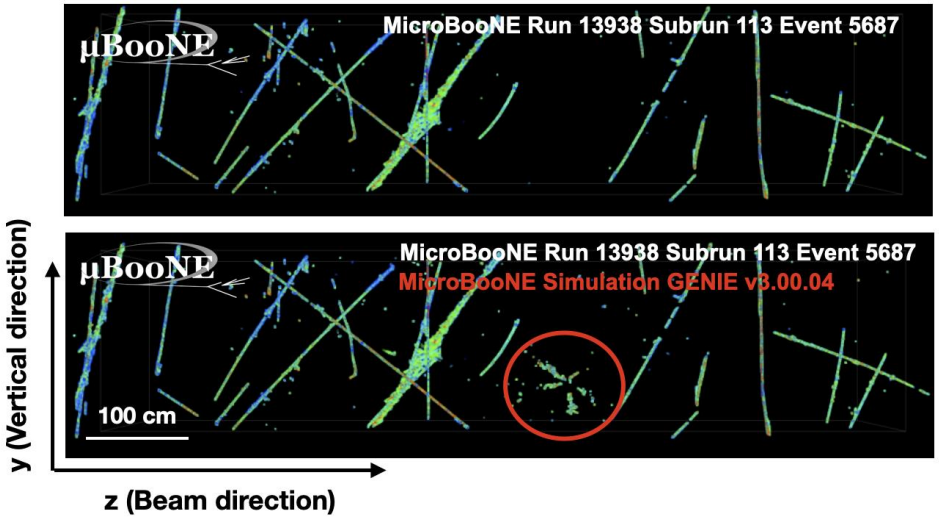
Neutron-antineutron oscillations

Neutron transforms into an antineutron

- Annihilates with a neighbouring neutron
- Produces a star-like topology of pions

We use pixel-based deep learning techniques to identify the topology

- Achieve 70% signal efficiency
- Our techniques can improve DUNE's published efficiency for neutron-antineutron searches by a factor of 7



arXiv:2308.03924

Summary

Searches for BSM particles have been an integral part of MicroBooNE's physics programme

- Heavy neutral leptons
- Higgs portal scalars
- Dark tridents
- Light sterile neutrinos

More analyses are in the pipeline

- e+e- production, axion-like particles, millicharged particles

The full SBN programme, and DUNE, will be able to expand on these searches

We're eager for more ideas of models we can test with our data!