Dark sector searches with the MicroBooNE Detector

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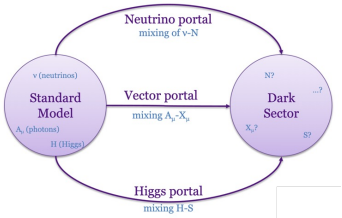
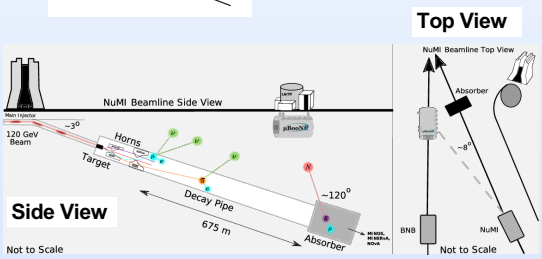
IMPERIAL

MicroBooNE can explore the different portals to the dark sector using its two neutrino beams:



- Heavy neutral leptons (HNLs) in e+e-, $\nu\pi^0$, $\mu\pi$ final states [1,2].
- Higgs portal scalars (HPS) in e+e-, μ+μ- final states [2,3].
- Search for dark-trident processes [4].



Production mechanisms:

- Higher energy NuMI beam used for the searches presented here.
- Kaons decaying at rest in the absorber could produce an HNL/HPS that reaches MicroBooNE.
- Dark-matter particles χ from the decays of π^0 or η mesons could be produced in the NuMI target.

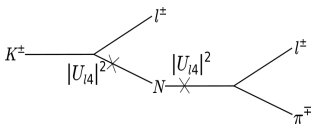
Data sets used:

- Run 1 (Forward Horn Current) 2.2 x 10^{20} POT
- Run 3 (Forward Horn Current) 5.0 x 10^{20} POT

Main backgrounds to the searches:

- Cosmic-ray triggers – modelled by "beam-off" data samples.
- "Out-of-cryostat" neutrino interactions with surrounding material (Monte Carlo).
- "In-cryostat" neutrino interactions in detector (Monte Carlo).

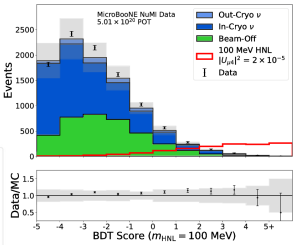
Heavy Neutral Leptons

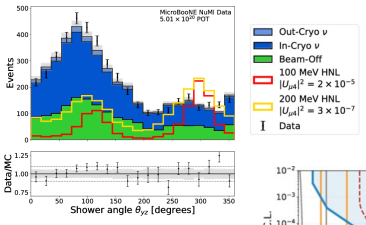


- One right-handed singlet state mixing through PMNS matrix.
- We assume only one $|U_{l4}|^2 > 0$.
- Rate proportional to $|U_{l4}|^2$.

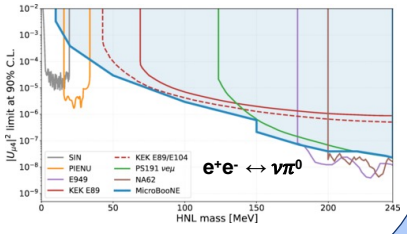
- Boosted Decision Tree (BDT) used for signal/background discrimination with 20 most sensitive variables as input.
- Angular variables most powerful as HNLs enter detector "backwards". Double peak due to ambiguity in shower direction.

BDT with 20 input variables

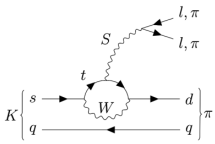




- Most stringent constraints on $|U_{\mu4}|^2$ in mass range 34-175 MeV.
- Combined with previous limits on $\mu\pi$ decays [2], MicroBooNE covers full mass range 10-385 MeV.

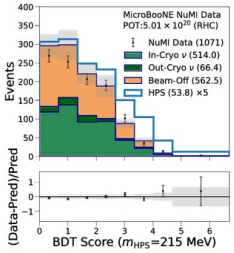


Higgs Portal Scalars

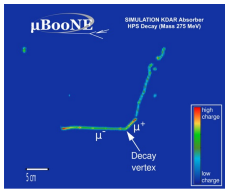


- Higgs portal: minimum extension of the standard model Higgs sector.
- Scalar mixing angle θ with the Higgs boson.
- Scalar S decays to lepton or pion pairs.

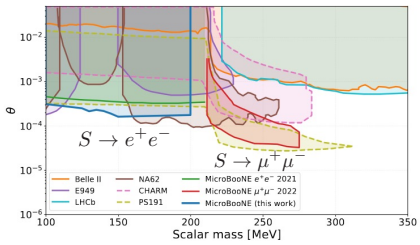
BDT with 21 input variables



Simulated signal event, originating from absorber.

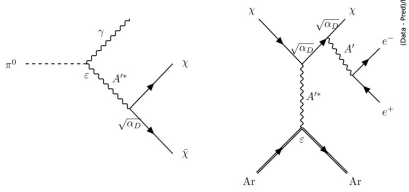


- Most stringent constraints in the HNL mass region 110-155 MeV.
- First results from a dedicated search in the mass range 212-279 MeV.

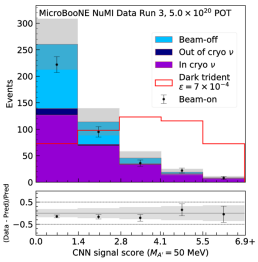


Dark Tridents

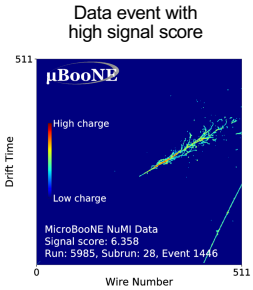
- Dark matter particles interacting through dark-photon portal.
- Dark matter particles χ produced from neutral meson decays in the beam via dark-photon mixing.
- NuMI *off-axis* search reduces background from neutrino interactions.



CNN signal score



Data event with high signal score

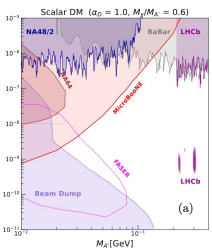


- Convolutional Neural Network (CNN) used for signal/background discrimination.
- Uses Region of Interest of 512 x 512 pixels around interaction vertex.

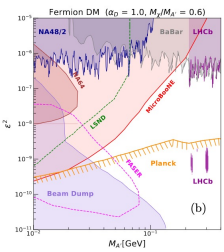
Model Parameters

- Masses of dark photon $M_{A'}$ and of dark fermion/scalar M_χ for M_χ/ $M_{A'}$ = 0.6 and 2.
- Dark- fine structure constant $0.1 \leq \alpha_D \leq 1$.
- Kinematic mixing parameter ε.

Scalar DM



Fermion DM



Constraining previously unexplored parameters space for fermion and scalar dark matter.

[1] Phys. Rev. Lett. 132 (2024) 4, 041801
[2] Phys. Rev. D 106 (2022) 9, 092006
[3] Phys. Rev. Lett. 127 (2021) 15, 151803
[4] Phys. Rev. Lett. 132, 241801

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