

**IMPERIAL**



# Physics Beyond the Standard Model at MicroBooNE

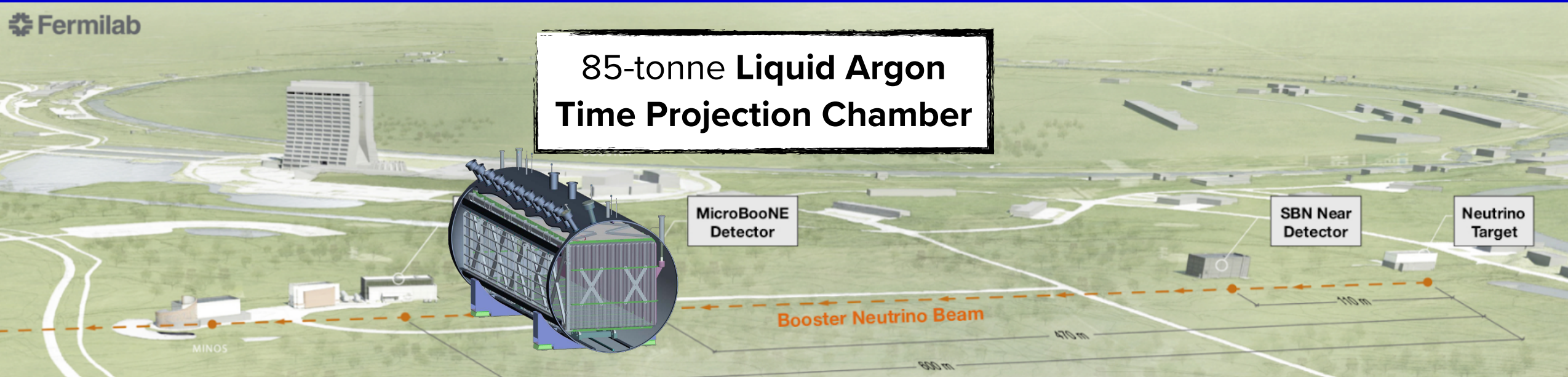
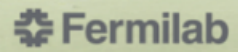
*Anyssa Navrer-Agasson,*

*On behalf of the MicroBooNE Collaboration*

[a.navrer-agasson@imperial.ac.uk](mailto:a.navrer-agasson@imperial.ac.uk)

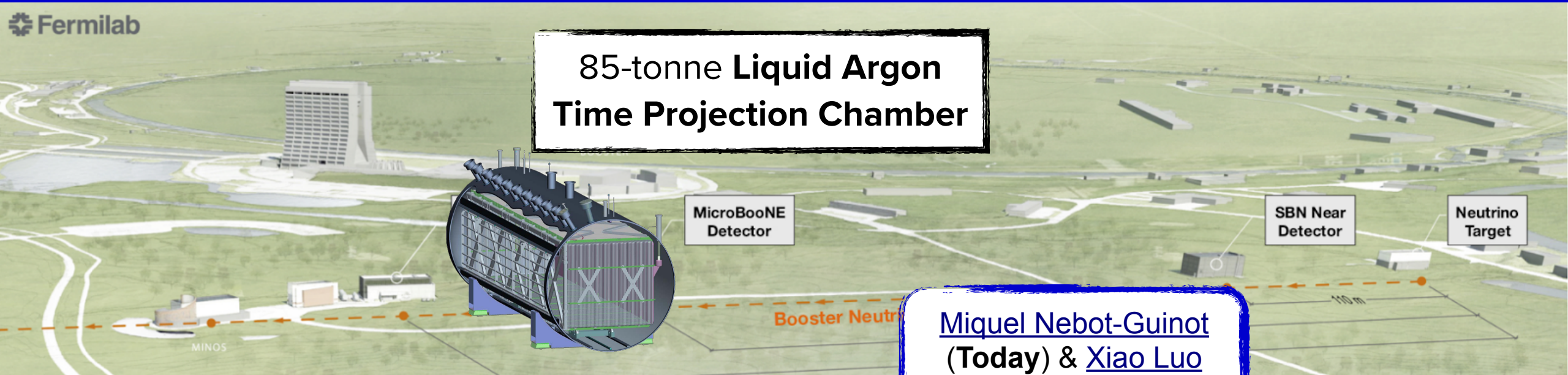
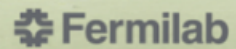
**International Conference on High Energy Physics  
Prague - 18- 24 July 2024**

# The MicroBooNE Detector



- Non-standard neutrino oscillations
- Neutrino cross-section measurements
- Detector physics, R&D, tool development
- Beyond Standard Model physics → **This talk!**

# The MicroBooNE Detector



85-tonne **Liquid Argon**  
**Time Projection Chamber**

MicroBooNE  
Detector

SBN Near  
Detector

Neutrino  
Target

Booster Neutrino

Miquel Nebot-Guinot  
(Today) & Xiao Luo  
(Saturday)

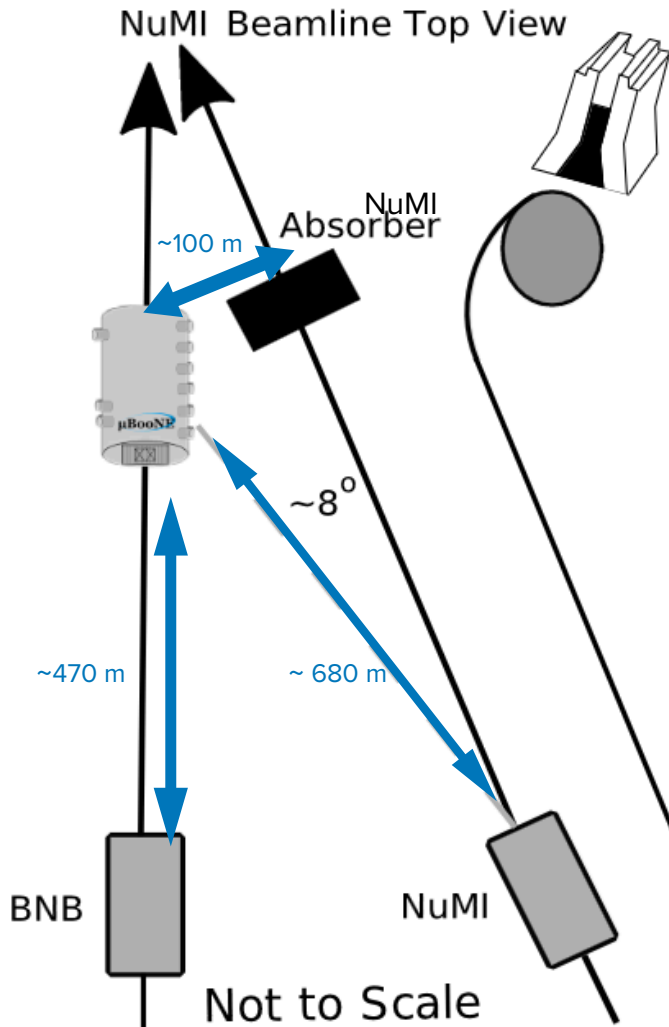
- Non-standard neutrino oscillations
- Neutrino cross-section measurements
- Detector physics, R&D, tool development
- Beyond Standard Model physics → **This talk!**

Today: Marina Reggiani-Guzzo,  
Richard Diurba, Michael Kirby

Friday: Vincent Basque,  
Maria Brigida Brunetti

# Beamlines @ MicroBooNE

MicroBooNE observes flux from two neutrino beams



## Booster Neutrino Beam (BNB)

- **8 GeV** protons
- Target **~470 m** from MicroBooNE
- **On-axis**

## Neutrino Main Injector (NuMI)

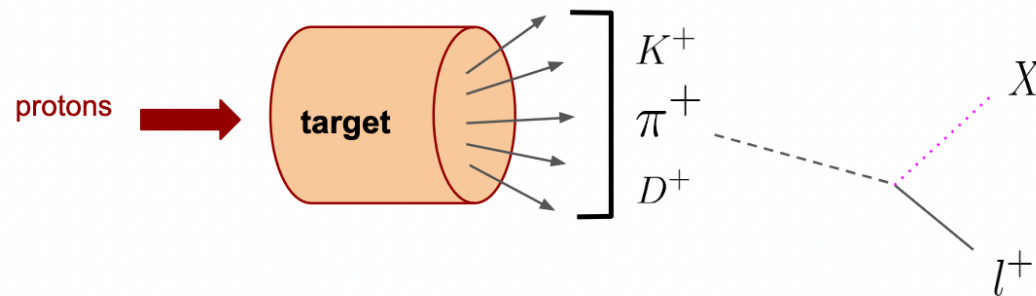
- **120 GeV** protons
- **~680 m** away from target
- **~8° off-axis**
- **Absorber ~100 m** from MicroBooNE



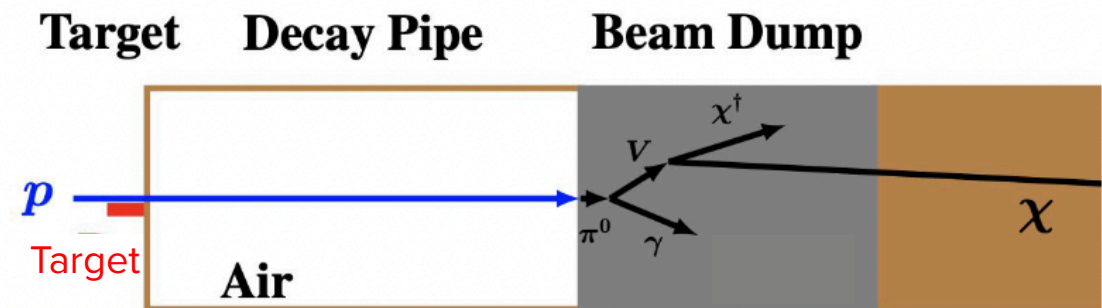
# BSM Physics @ MicroBooNE

- Large flux of **charged/neutral mesons** from **high intensity proton beams**
- New particles can be produced from **meson decays**
- **Proximity to the NuMI absorber** → particles survive long enough to reach MicroBooNE

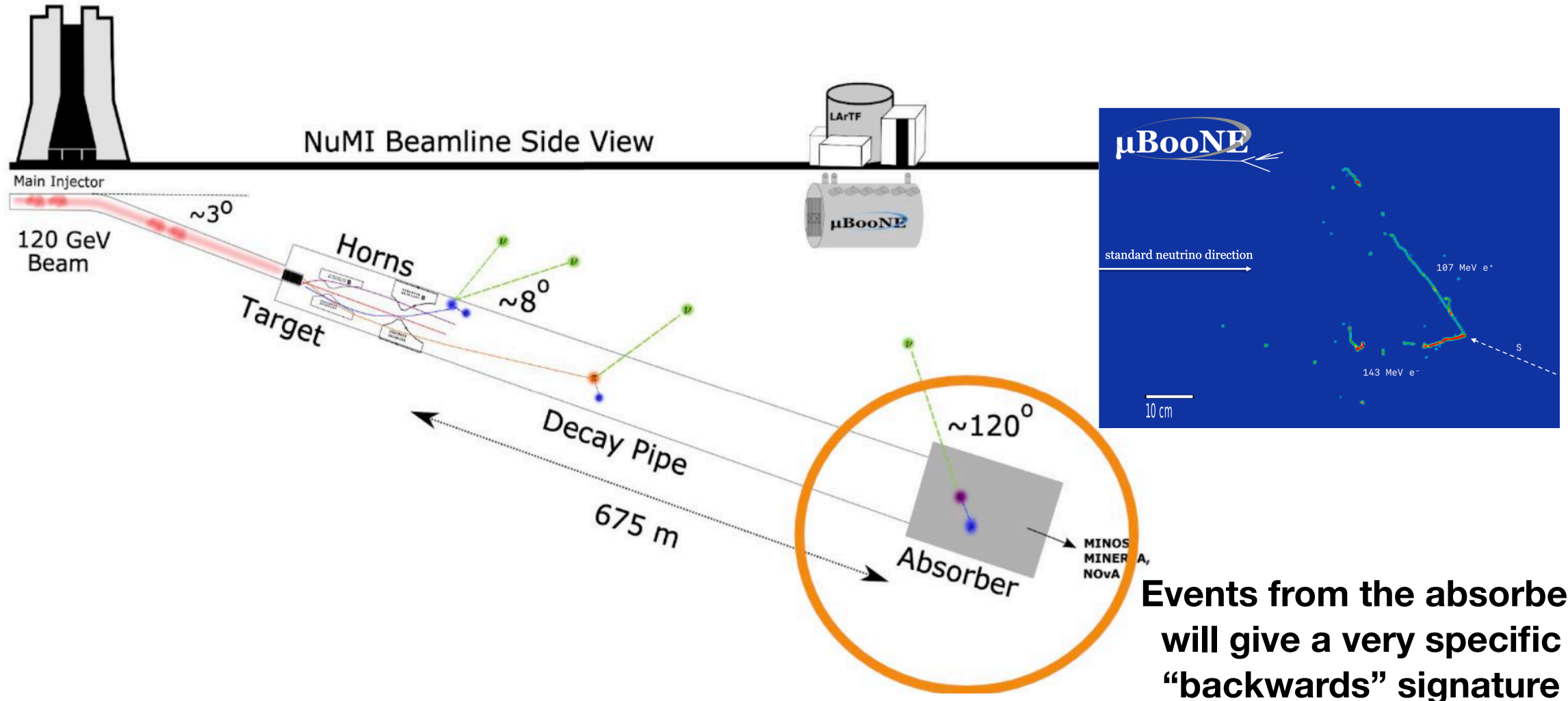
## Meson decay in flight



## Beam dump

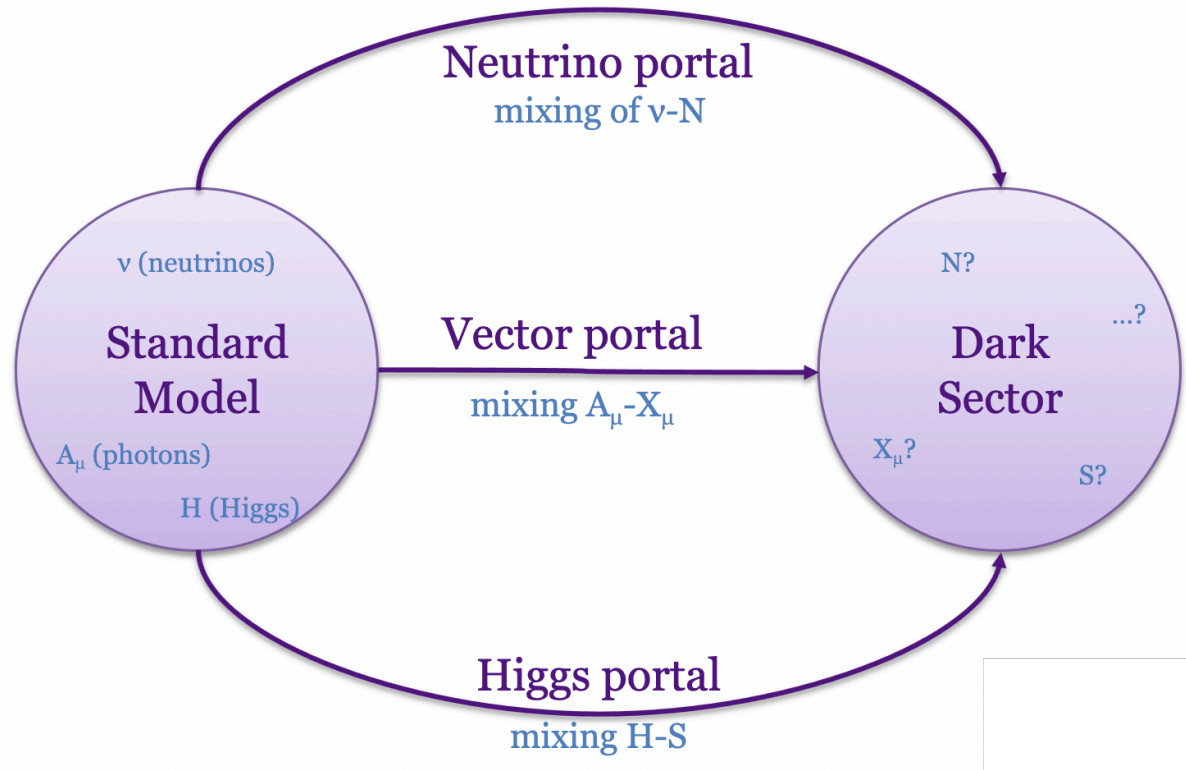


# The NuMI beam absorber



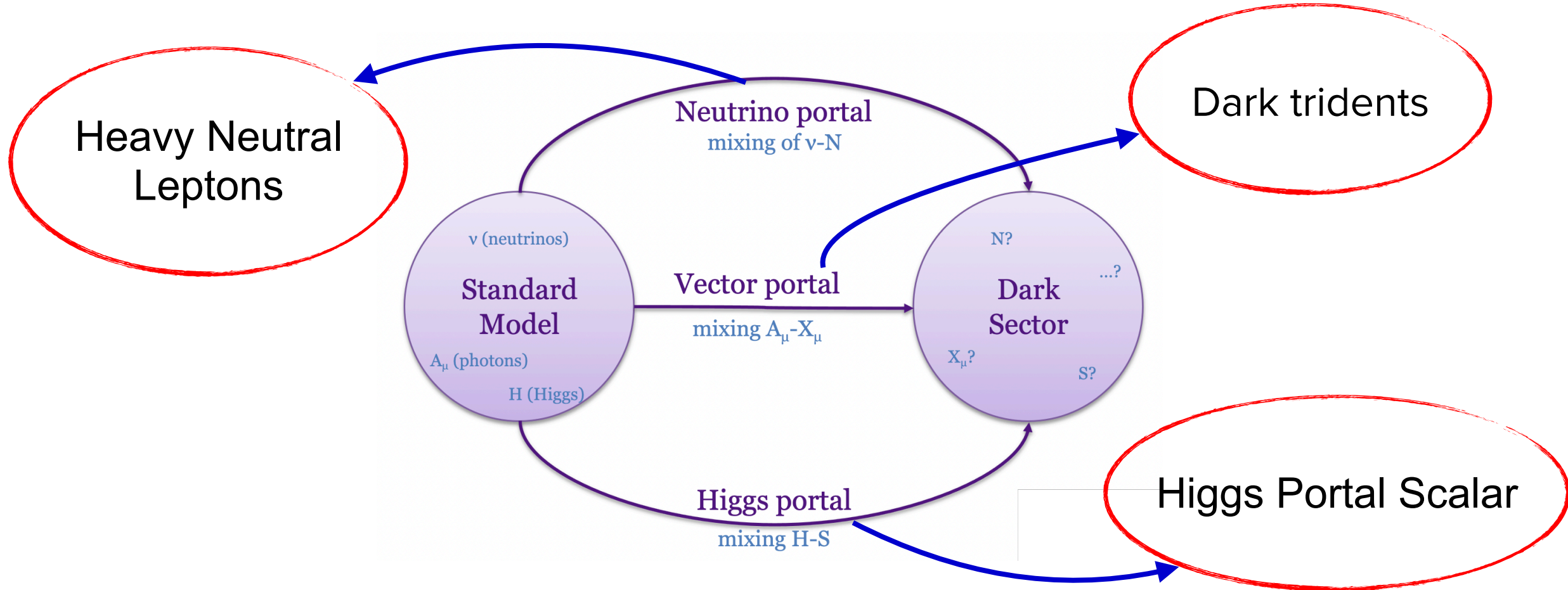
# In this talk

**Strategy: explore the different portals to the dark sector**



# In this talk

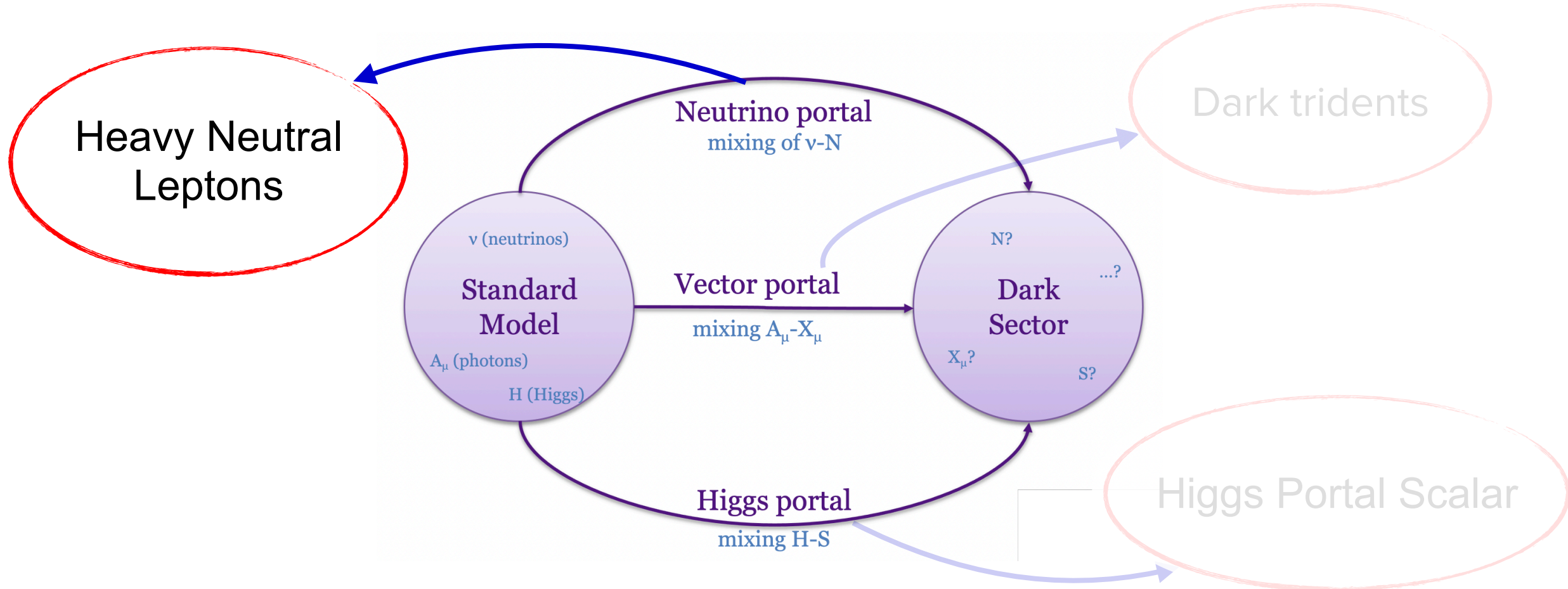
Strategy: explore the different portals to the dark sector





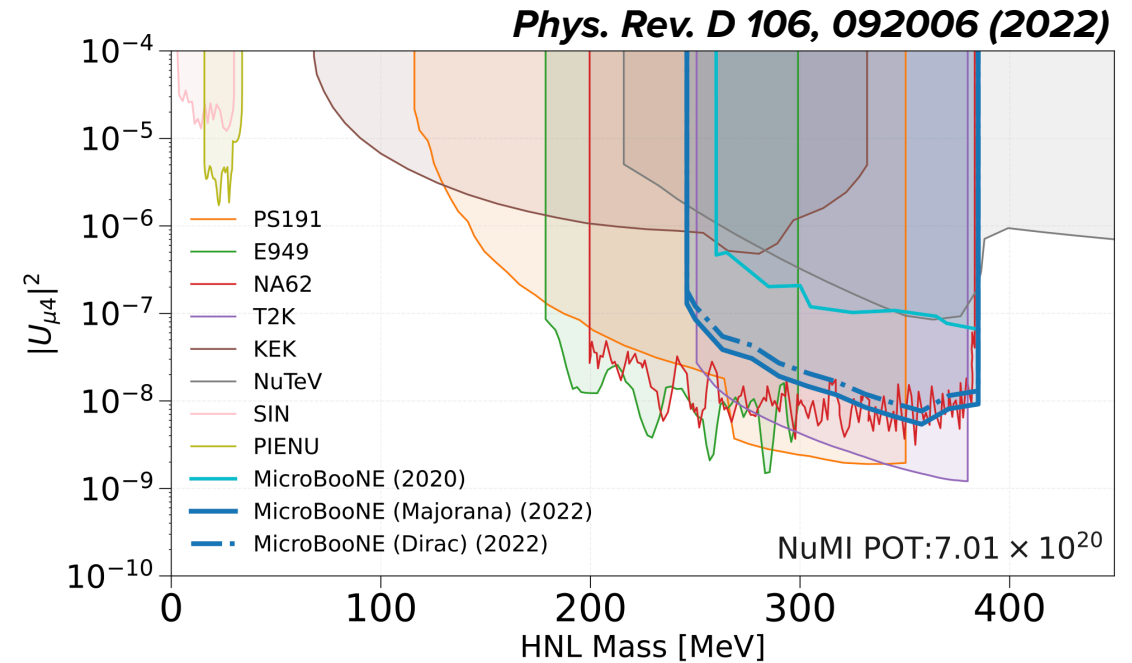
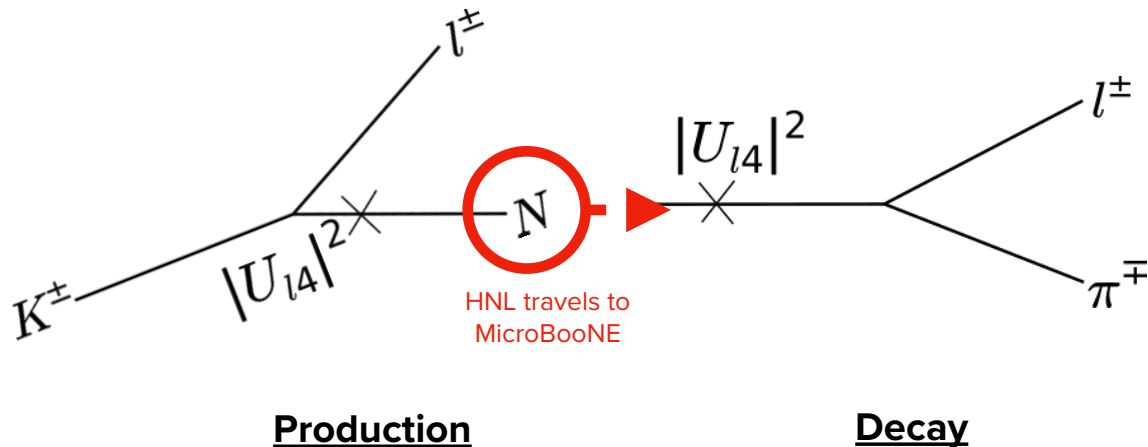
# In this talk

Strategy: explore the different portals to the dark sector



# Heavy Neutral Leptons in MicroBooNE

- One new right handed singlet state
- Mixing with active neutrinos via **extended PMNS matrix**
- HNLs can be produced in place of neutrinos when kinematically allowed



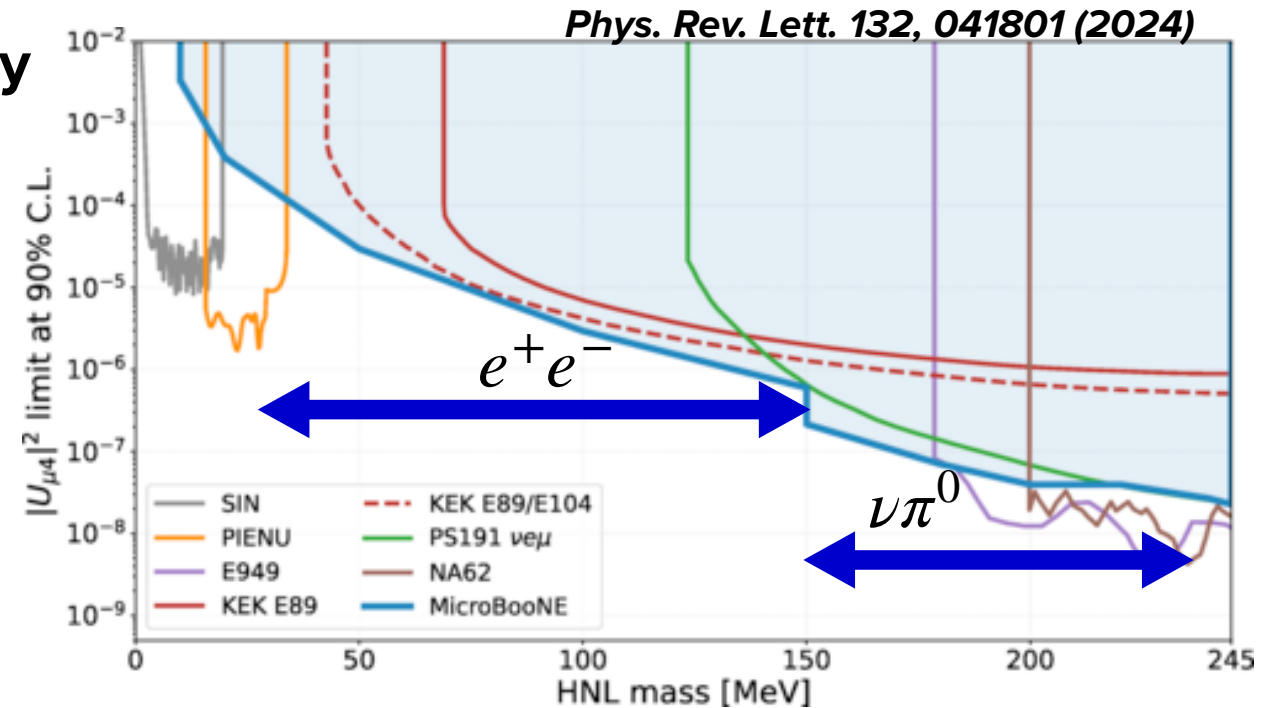
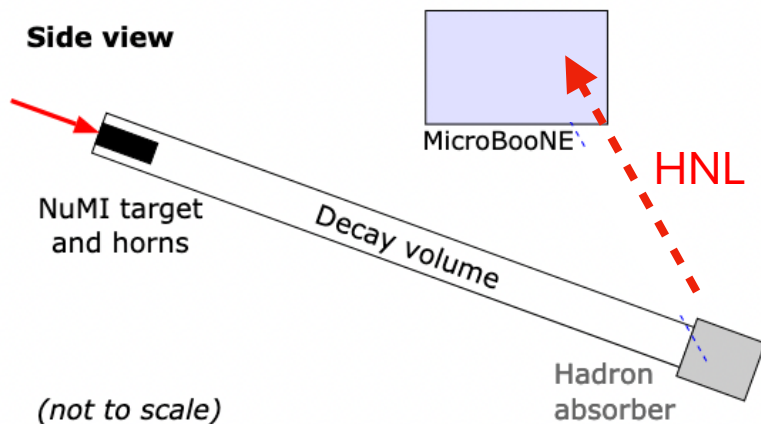
## Previous results:

- HNLs from the **BNB target** decaying to  $\mu\pi$   
*Phys. Rev. D 101, 052001 (2020)*
- HNLs from **NuMI absorber** decaying to  $\mu\pi$   
*Phys. Rev. D 106, 092006 (2022)*

# Heavy Neutral Leptons

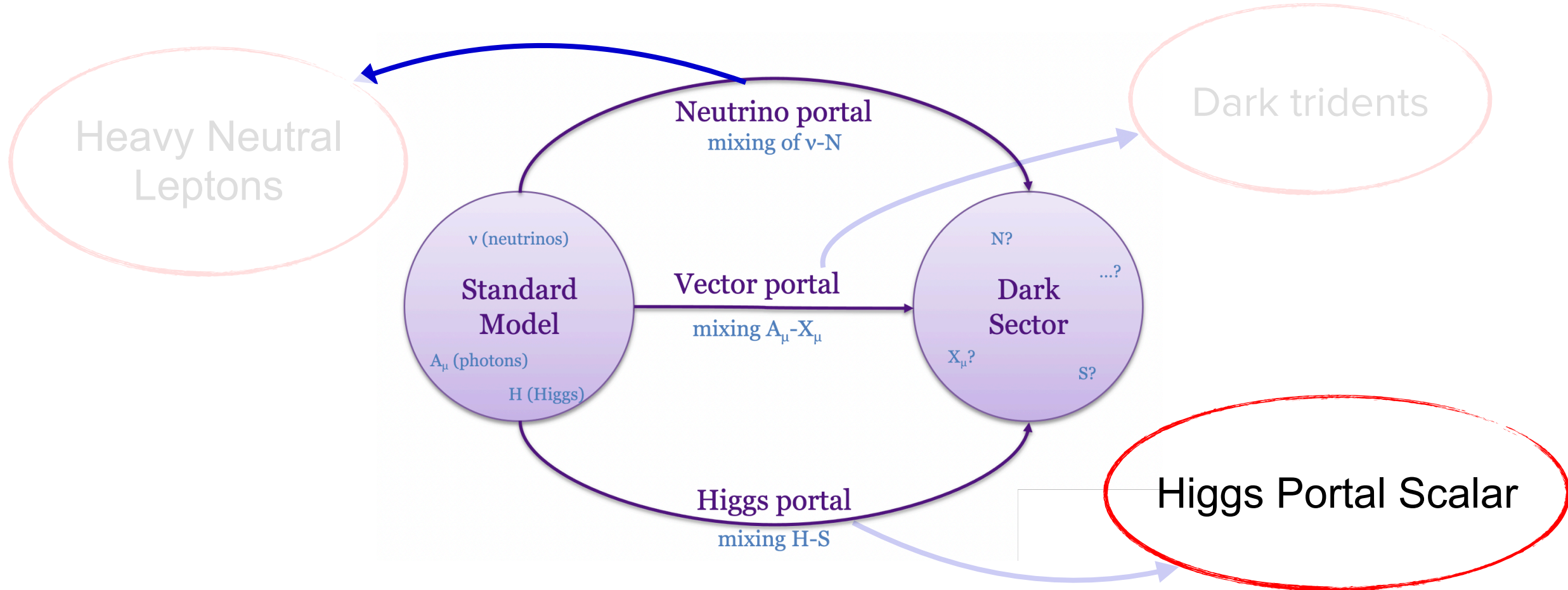
2024

- Consider **kaons decaying at rest in the NuMI absorber**
- Extend the HNL search to **two new decay channels**:  $N \rightarrow \nu e^+ e^-$  and  $N \rightarrow \nu \pi^0$
- **Probe lower HNL masses** ( $< 250$  MeV) compared to  $N \rightarrow \mu \pi$



# In this talk

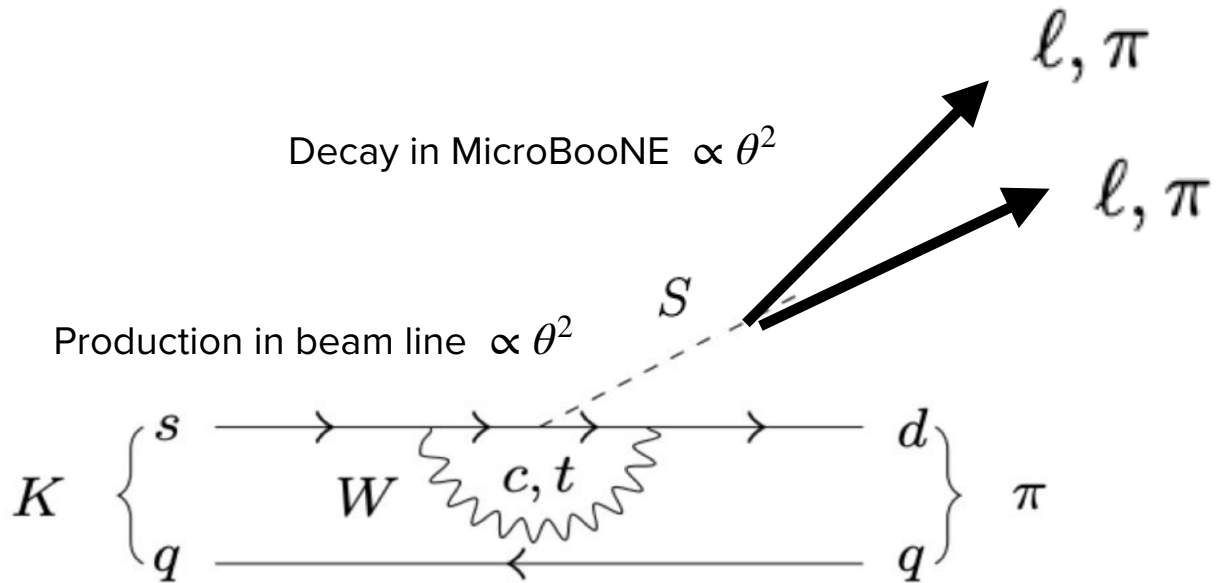
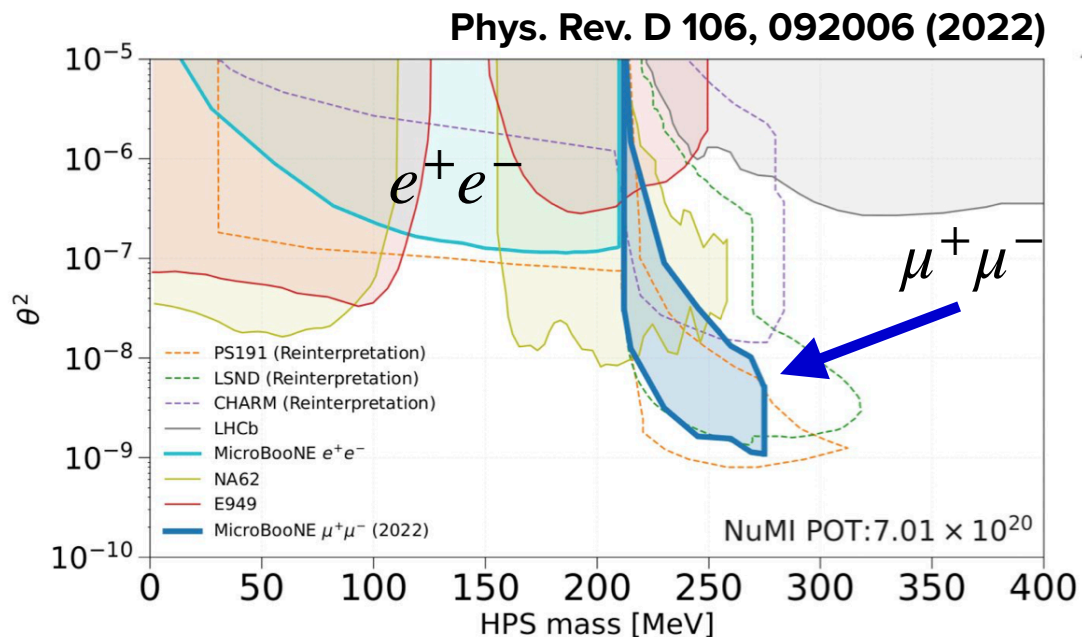
**Strategy: explore the different portals to the dark sector**





# Higgs Portal Scalars in MicroBooNE

- **Neutral scalar singlet  $S$** , mixing angle  $\theta$  with the Higgs boson
- Production from **charged kaon decays**
- **Decay to lepton or pion pairs**



## Previous results:

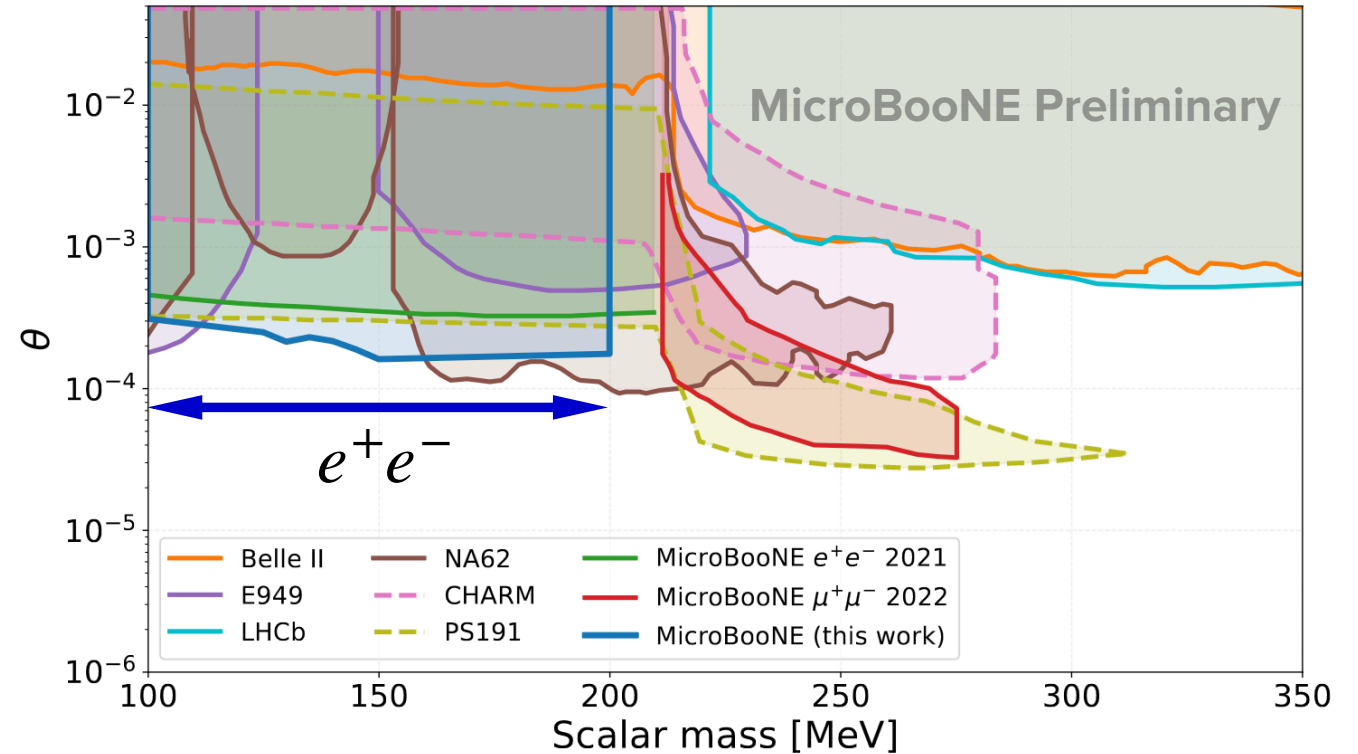
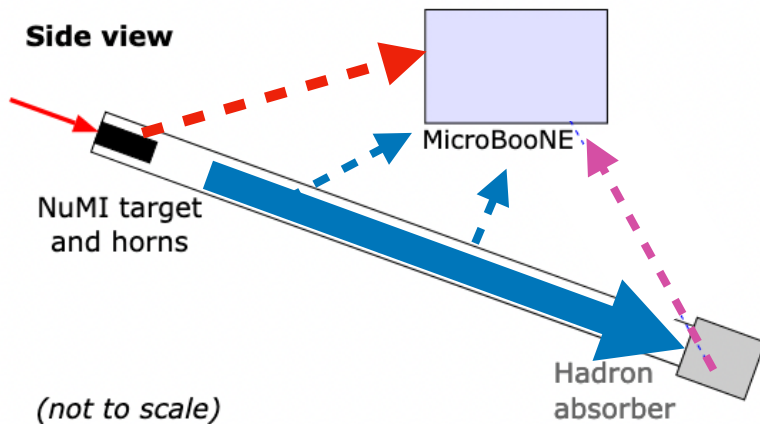
- Kaons decaying at rest in the NuMI absorber
- **Final states in MicroBooNE:**
  - $e^+e^-$  [Phys. Rev. Lett. 127, 151803 (2021)]
  - $\mu^+\mu^-$  [Phys. Rev. D 106, 092006 (2022)]

# Higgs Portal Scalars



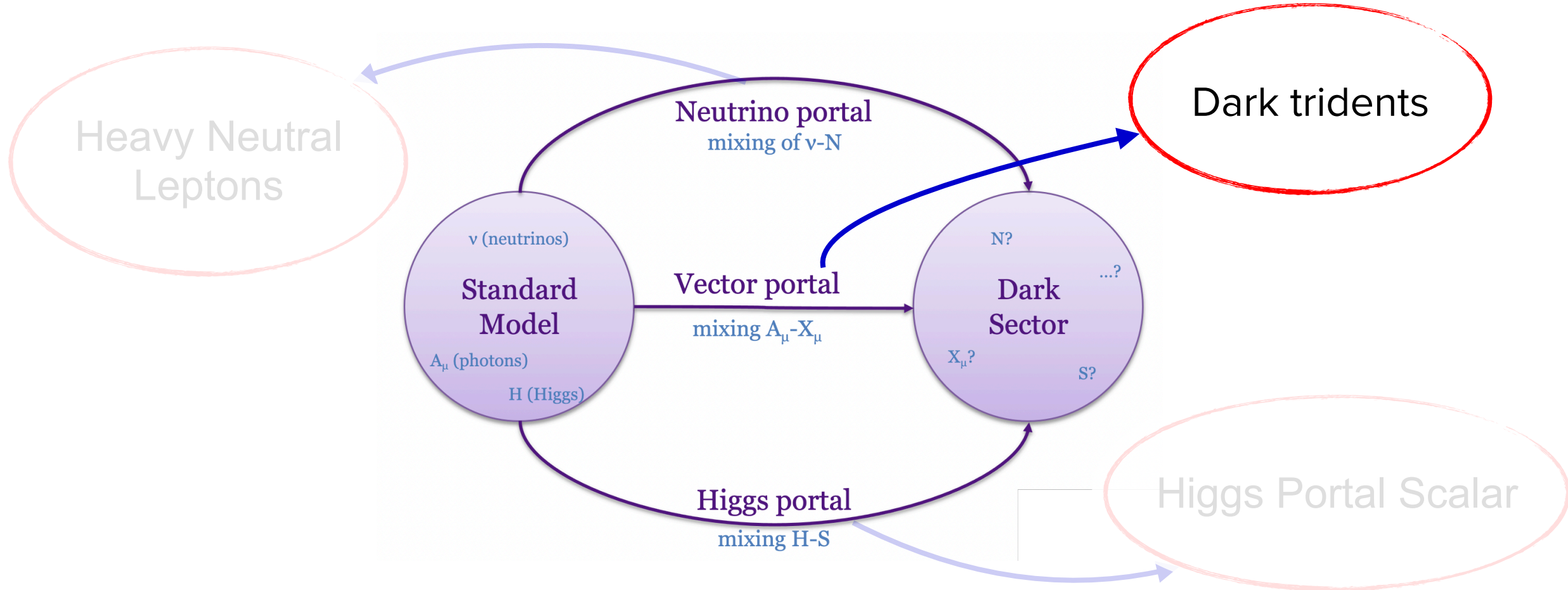
Kaons decaying

- at rest **in the NuMI target**
- at rest **in the NuMI absorber**
- **In flight**
- **Final state:**  $e^+e^-$



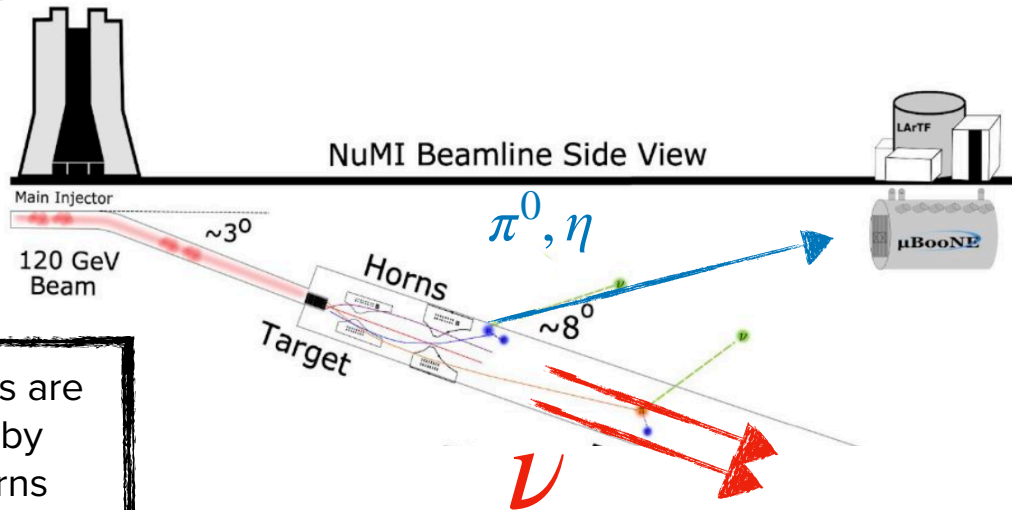
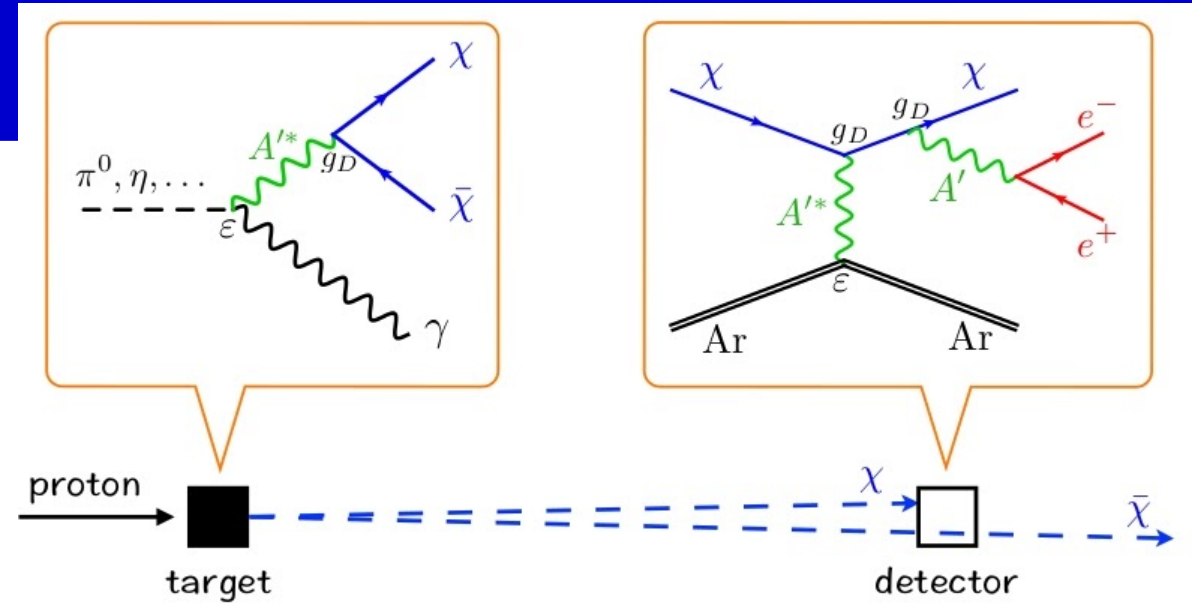
# In this talk

**Strategy: explore the different portals to the dark sector**

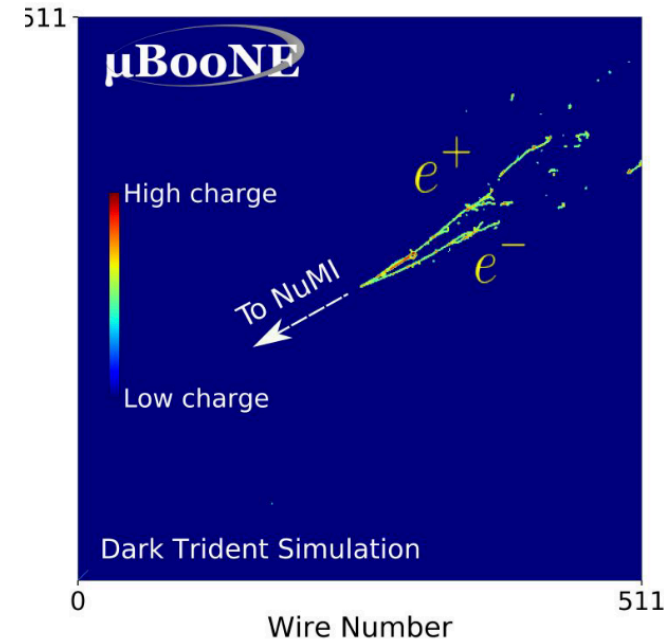


# Dark Tridents

- **Dark matter** produced in the beam via **dark photon mixing**
- **Scatter off argon nucleus**, accompanied by a dark photon radiation subsequently decaying to  $e^+e^-$
- **NuMI off-axis search**: neutrino background reduction



Neutral mesons are not focused by magnetic horns

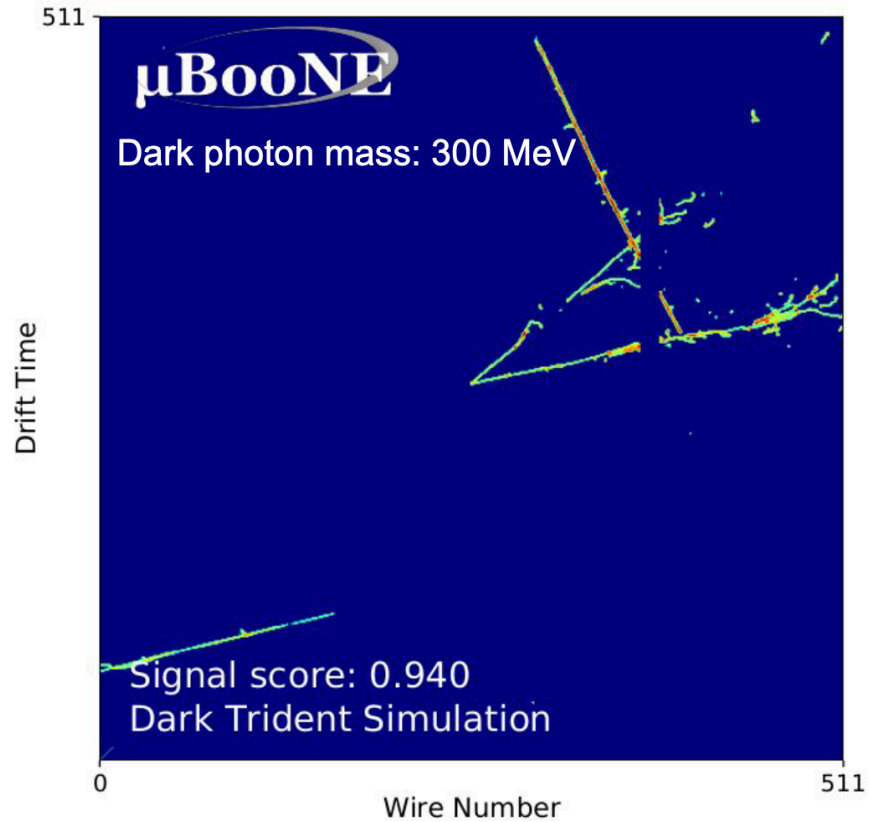




# Dark Tridents



## Deep learning-based analysis

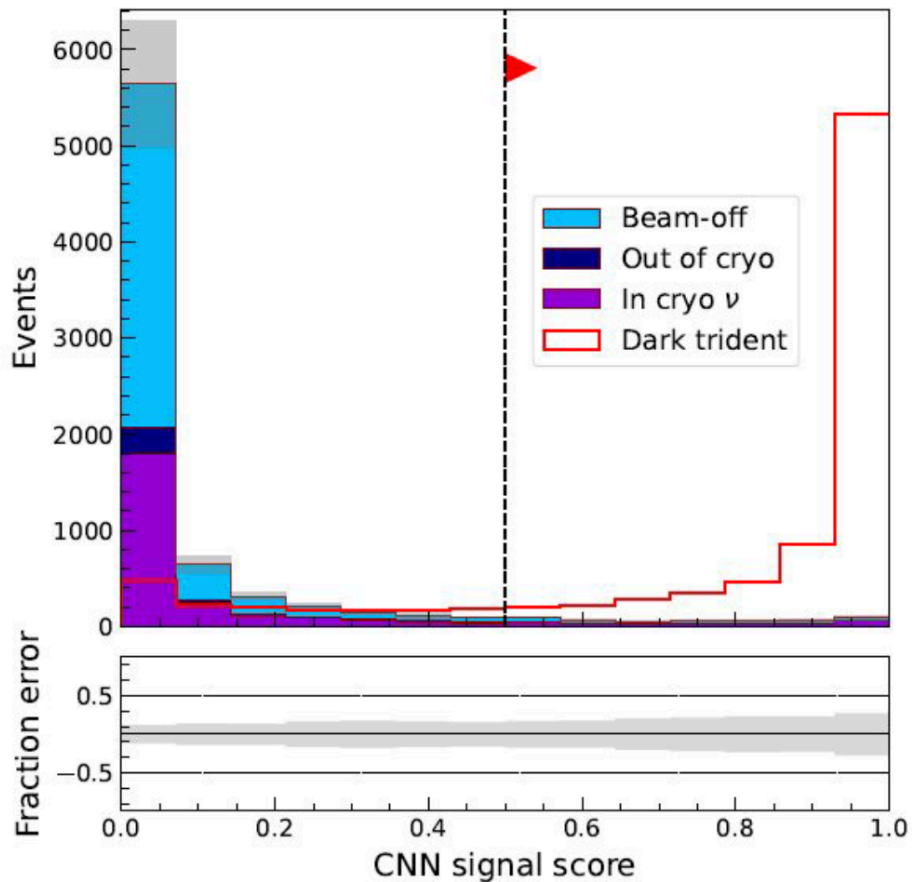


Phys. Rev. Lett. 132, 241801 (2024)

# Dark Tridents

2024

## Deep learning-based analysis

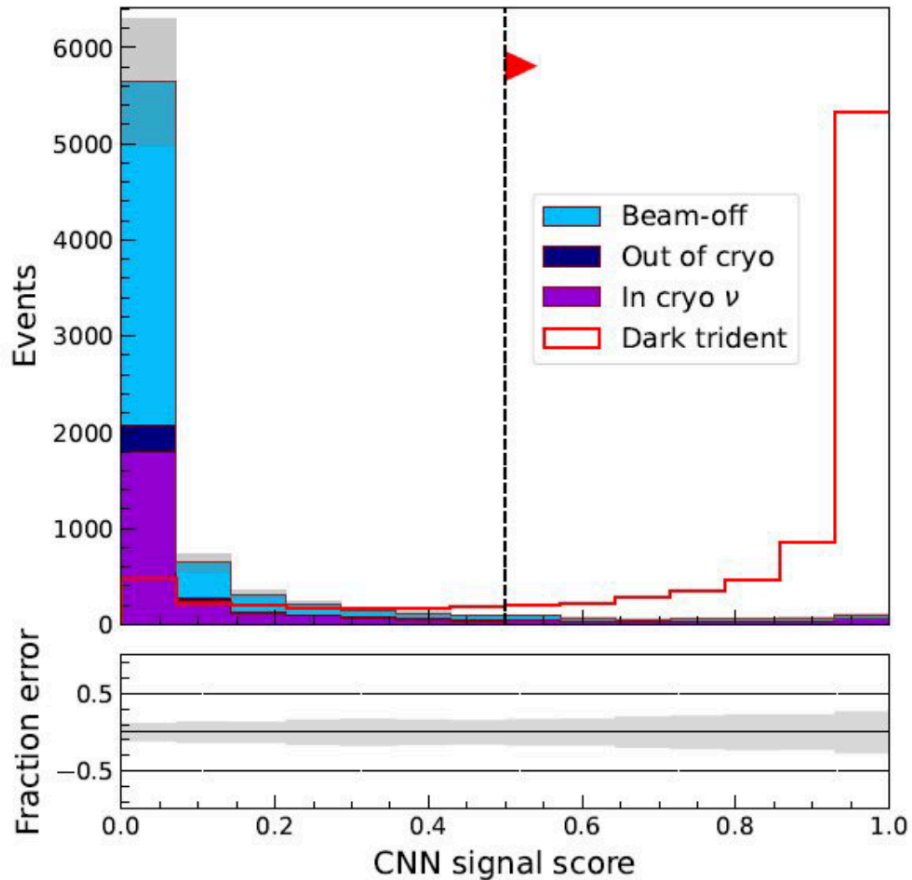


Phys. Rev. Lett. 132, 241801 (2024)

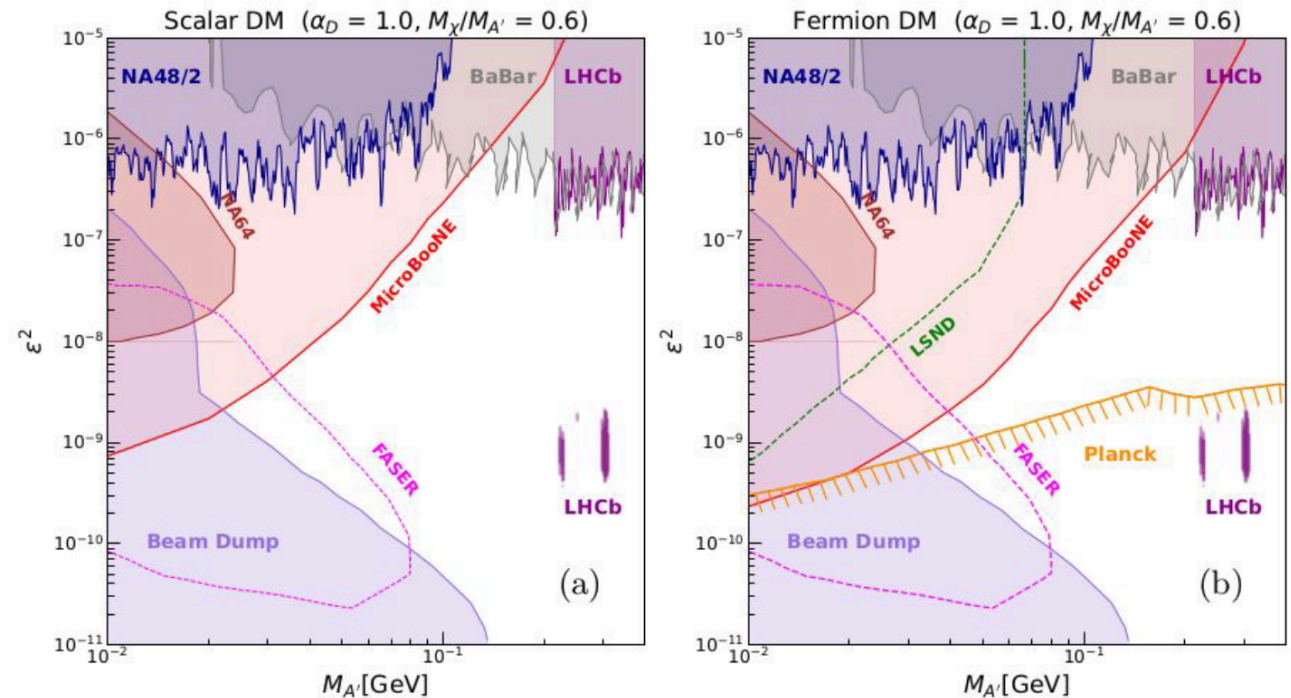
# Dark Tridents



## Deep learning-based analysis



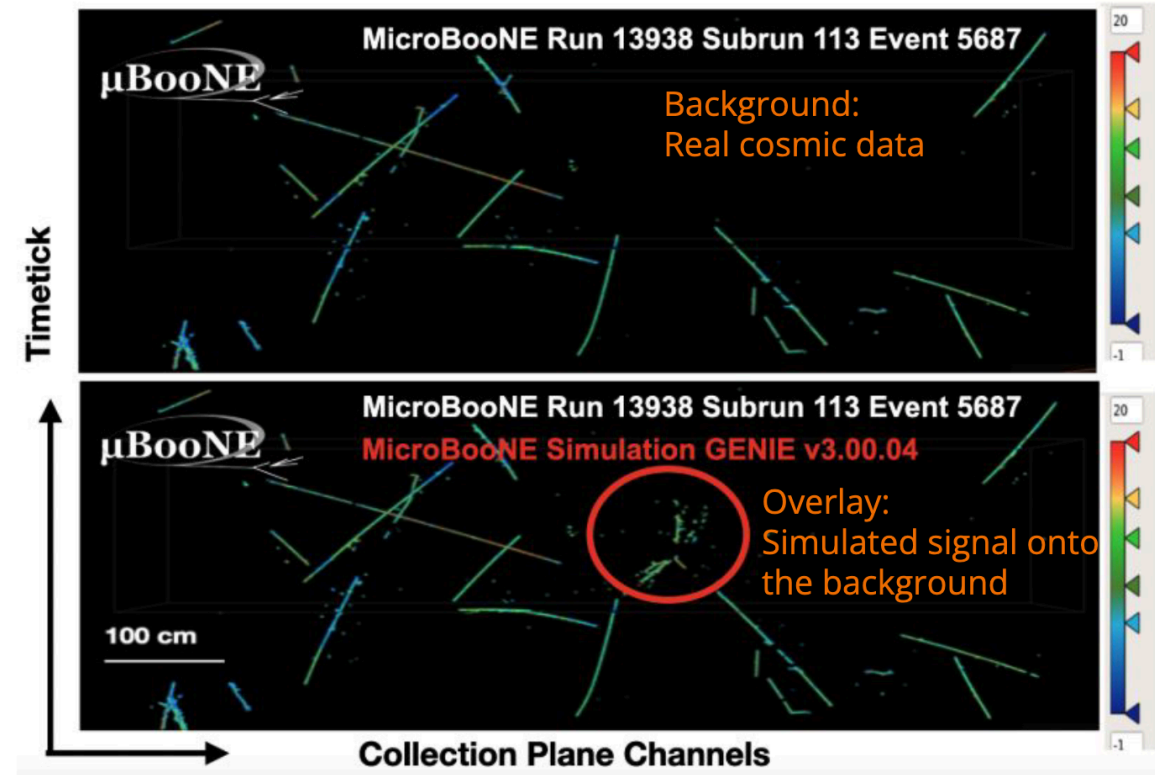
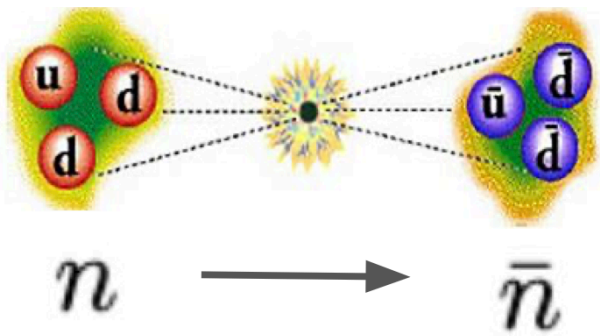
- Consider **both scalar and fermion** dark matter
- Several **couplings and mass ratios**



Phys. Rev. Lett. 132, 241801 (2024)

# Neutron - antineutron transition

- **Baryon number violating transition** allowed in some extensions of the Standard Model
- **Intranuclear transition**  $n \rightarrow \bar{n}$
- Resulting  $\bar{n}$  annihilates with a neighbouring nucleon
  - **Final states with multiple pions**
  - Striking “star”-like topology in MicroBooNE

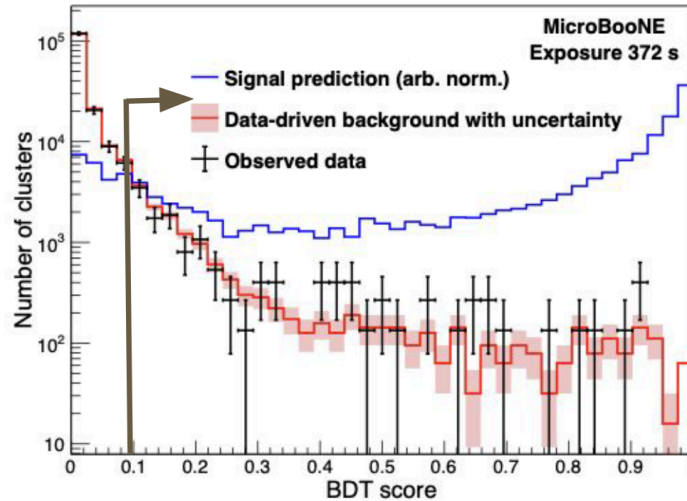




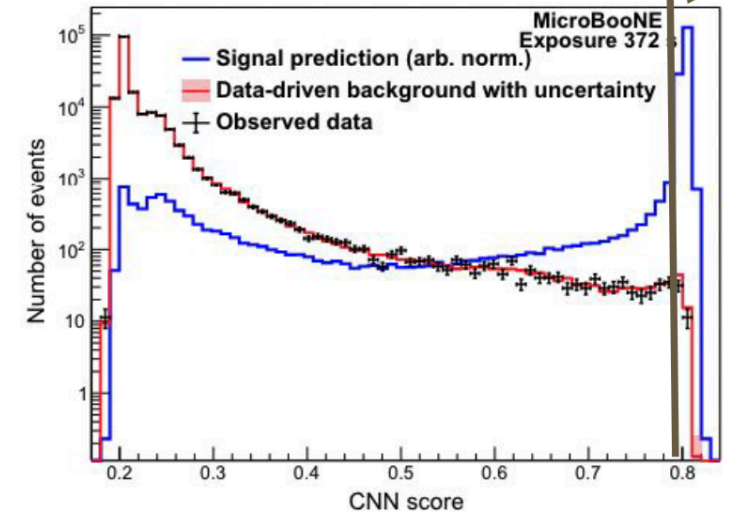
# Neutron - antineutron transition

- **Image-based selection**
  - Use of **machine learning and deep learning**
- **No excess of interactions** above the expected background

Step 1: Boosted Decision Tree



Step 2: Convolutional Neural Network



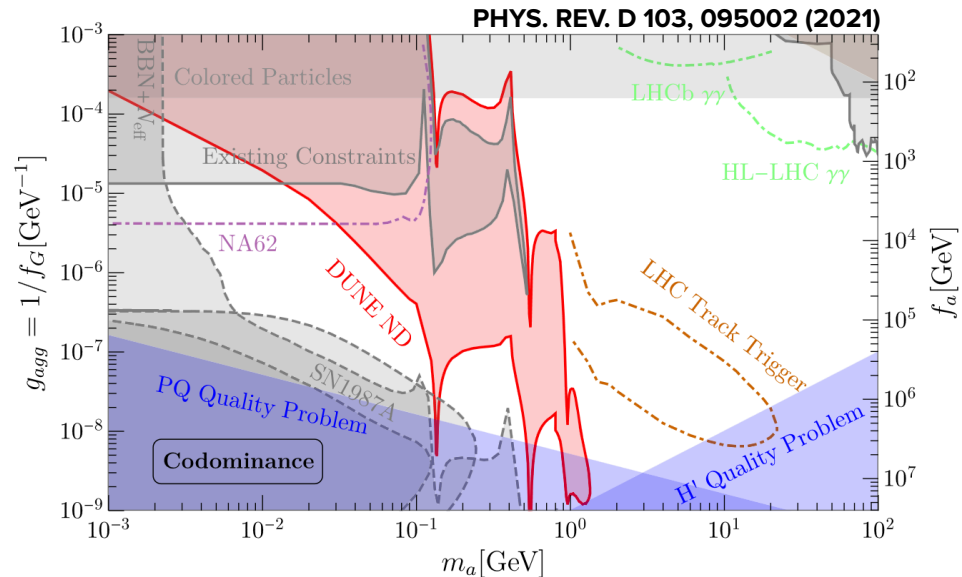
- **Proof-of-concept** for a future search in DUNE
  - Excellent signal selection efficiency (**70.2%**)
  - **x7 increase in sensitivity in DUNE**

	Exposure	Total interactions	Observed interactions	Expected background	Demonstrative limit 90%CL
<b>MicroBooNE</b>	<b>372s</b>	<b>168636</b>	<b>2</b>	<b>3.2</b>	<b><math>1.1 \times 10^{26}</math> years</b>

# More models to explore!

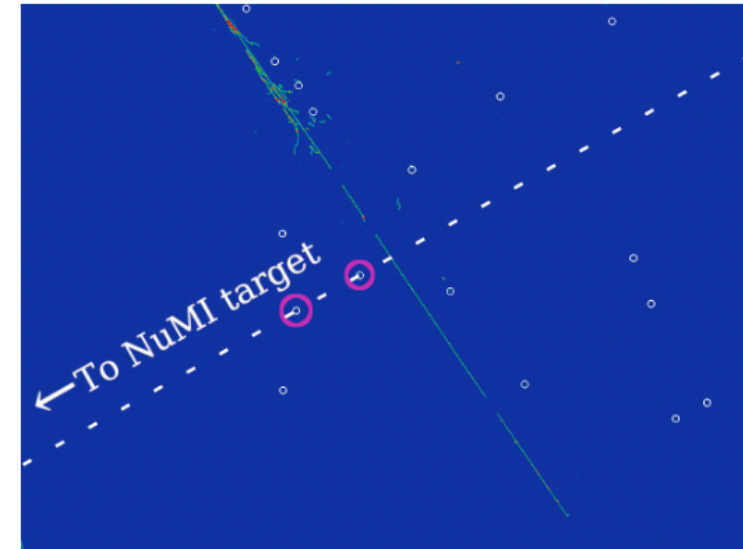
## Heavy Axions

- Axions produced via **mixing with neutral mesons**
- Decay to **di-photon pairs** in MicroBooNE



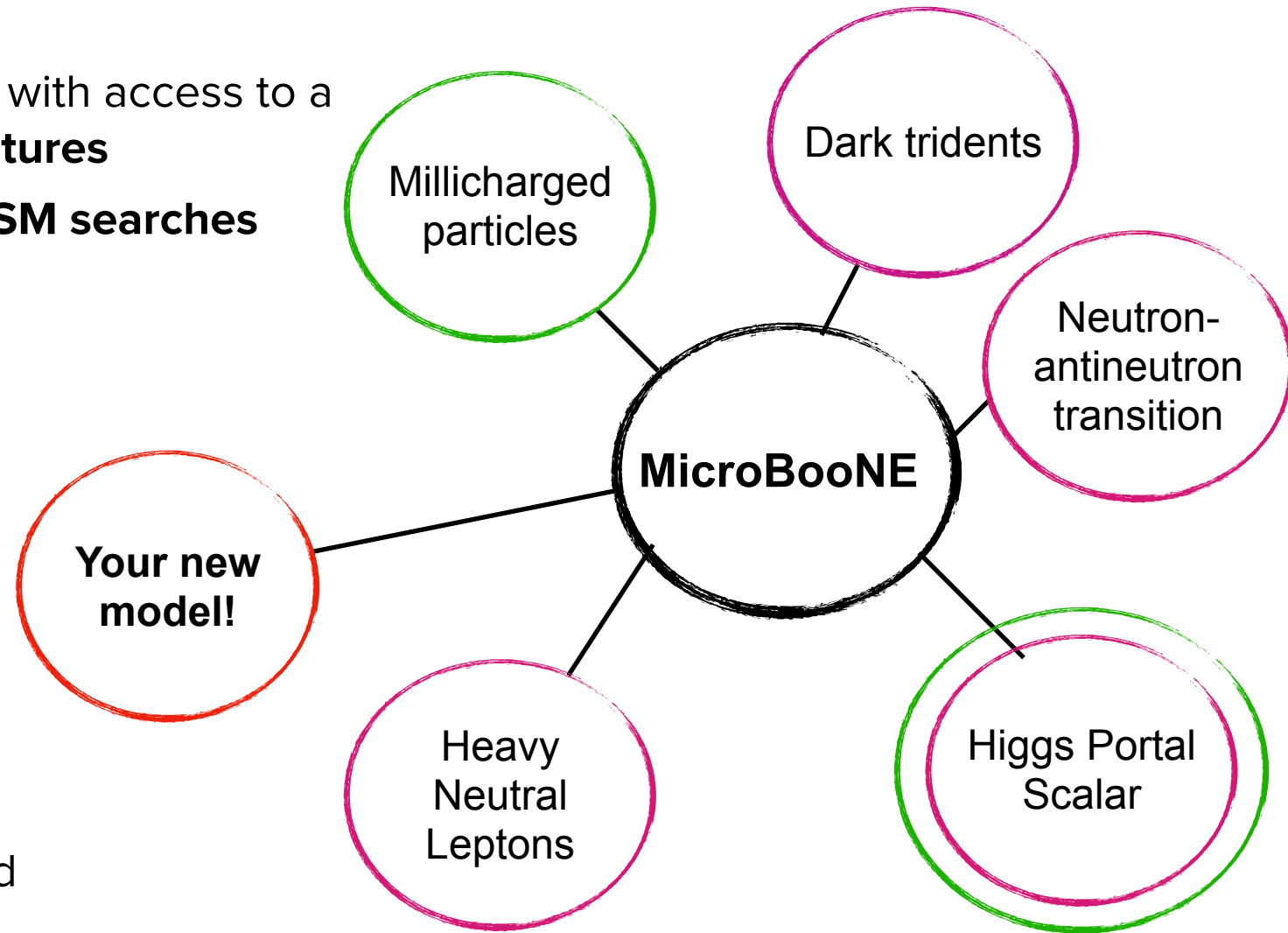
## Millicharged particles

- Particles with a **fraction of electric charge**
- **Scatter off atomic electrons** and cause “blips” of ionisation in LAr
- Novel **low energy reconstruction** techniques (see [Diego Andrade’s poster](#))



# Summary

- MicroBooNE is a multi-purpose detector with access to a **wide range of signal sources and signatures**
  - Excellent capabilities **in sub-GeV BSM searches**
- **Exciting results** published recently
- More searches **in the near future**:
  - New models/channels
  - More data
- **Pioneering techniques** to be used in future LArTPC experiments
- If you have an idea of a model we should consider, **please get in touch!**





# Thank you!

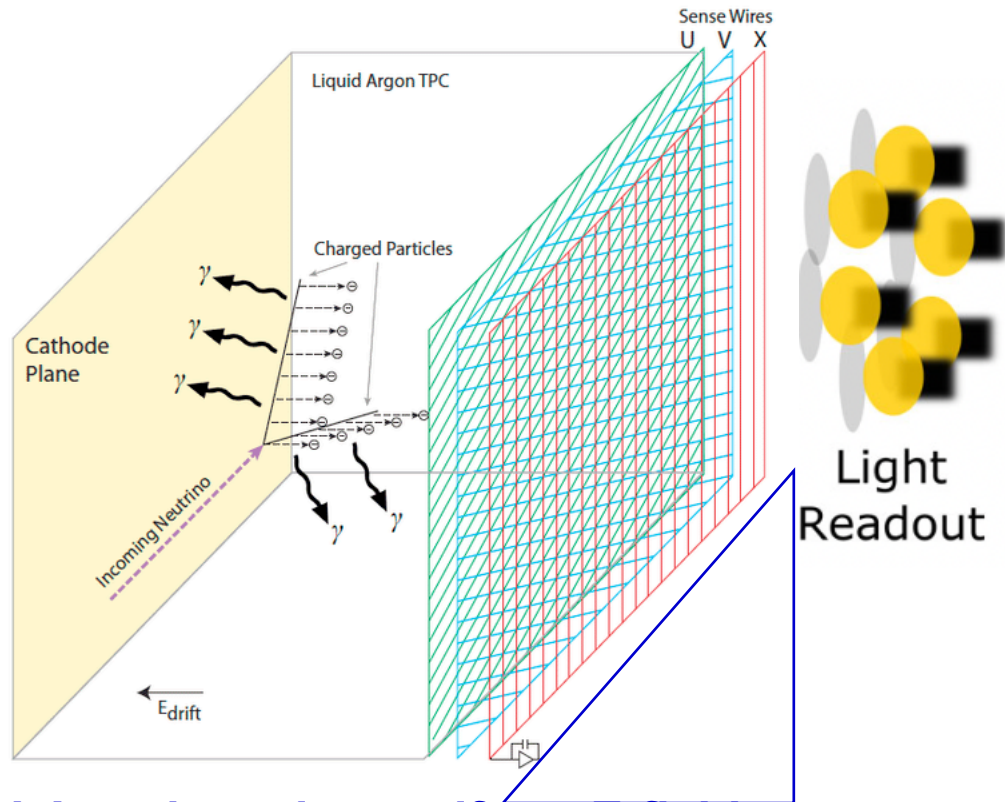




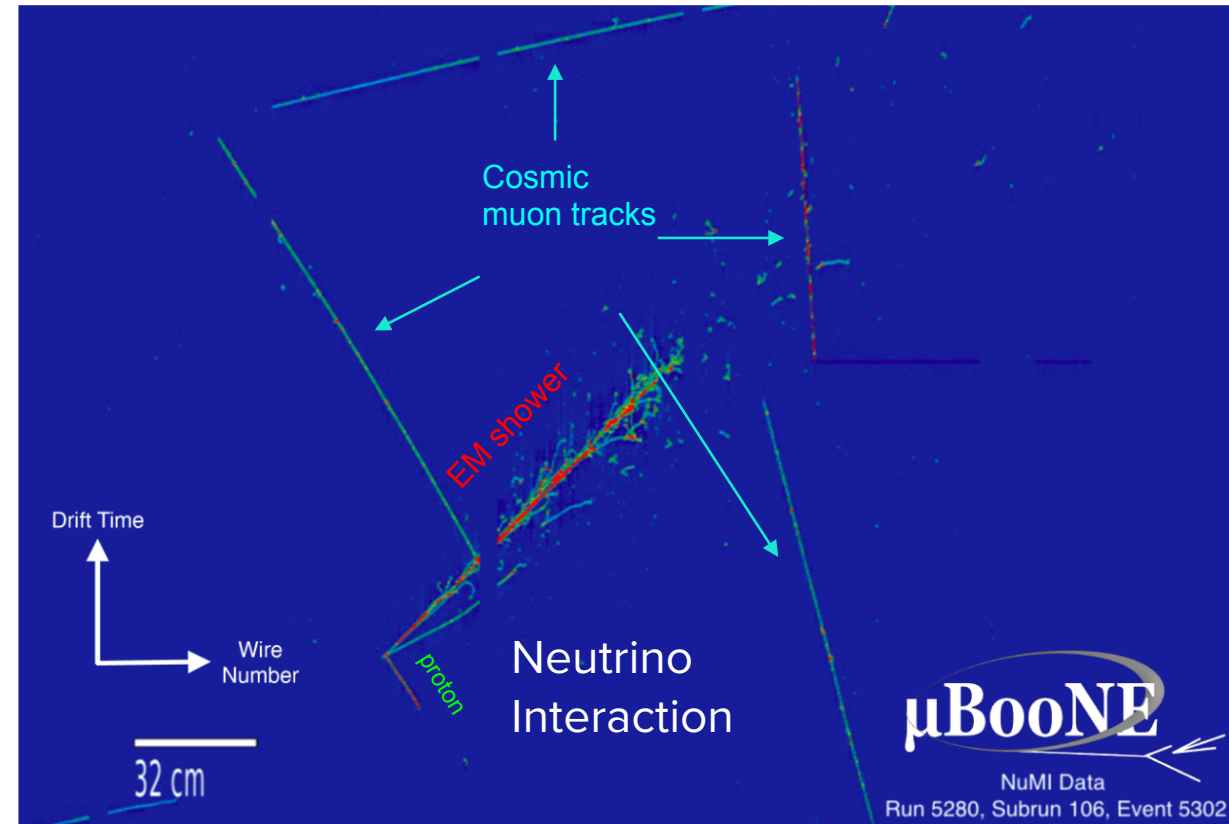
# Backup



# LArTPC essentials



- LAr volume in a uniform E-field
- Light readout (PMTs) records scintillation light
- Charge readout (wires planes) records ionisation charge



Excellent **spatial resolution**

- (3 mm wire pitch)

Powerful **particle identification**

**Low detection threshold**

# BSM searches workflow

- Develop a **custom event generator**
- Generate a range of **masses of the new particle**

Event Generation

Initial selection

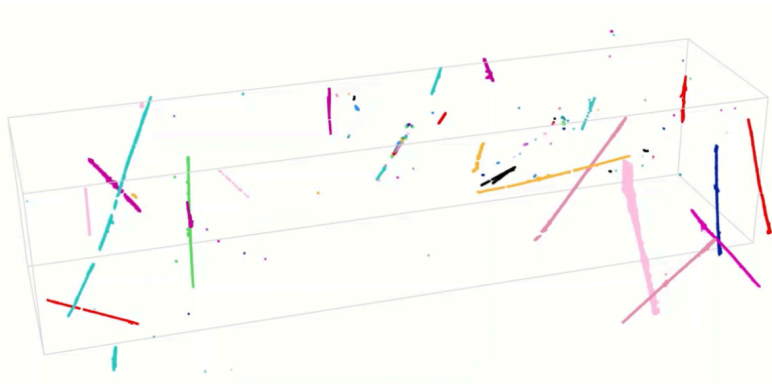
- Initial selection based on **event topology & kinematics**
- Targets:
  - **Cosmics**
  - **Neutrino interactions**

- **Boosted decision trees, deep learning, ...**
- Train algorithms on a **combination of masses or separate mass points**

Advanced selection

# BSM searches backgrounds

Beam neutrino interactions and cosmic rays form the background prediction

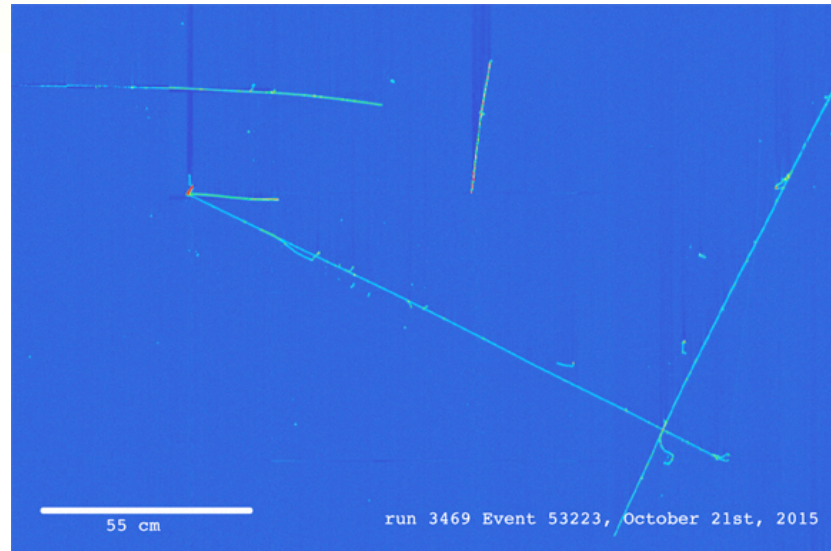


## In-cryostat neutrinos

Interactions of neutrinos with the argon inside the cryostat.

## Beam-off

Events collected with beam trigger but at times where no neutrino beam is present. Contains only cosmics.



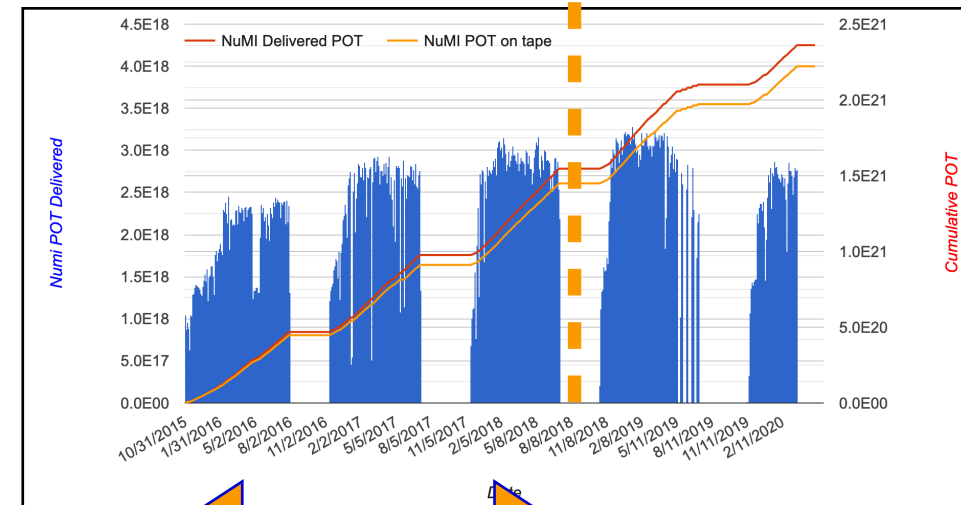
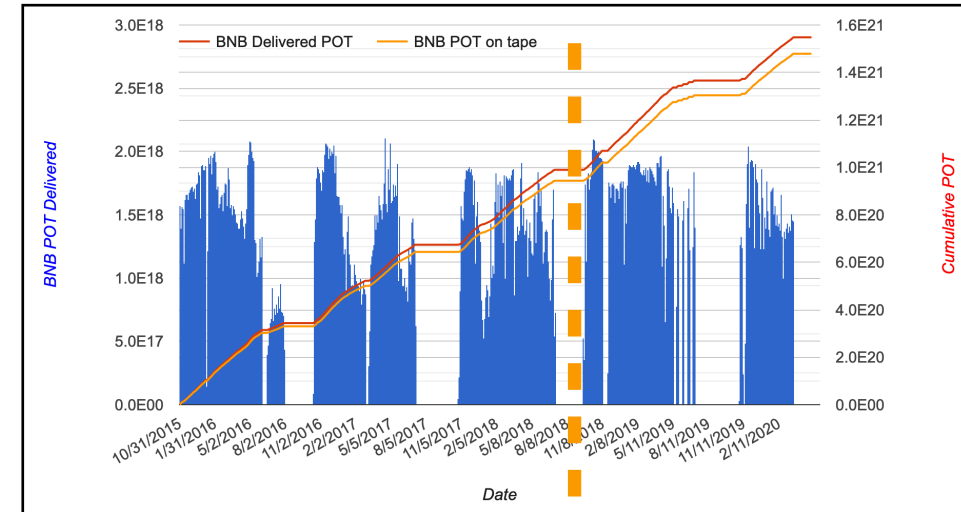
## Out-of-cryostat neutrinos

Neutrino interactions outside of the cryostat.

# Data collected by MicroBooNE

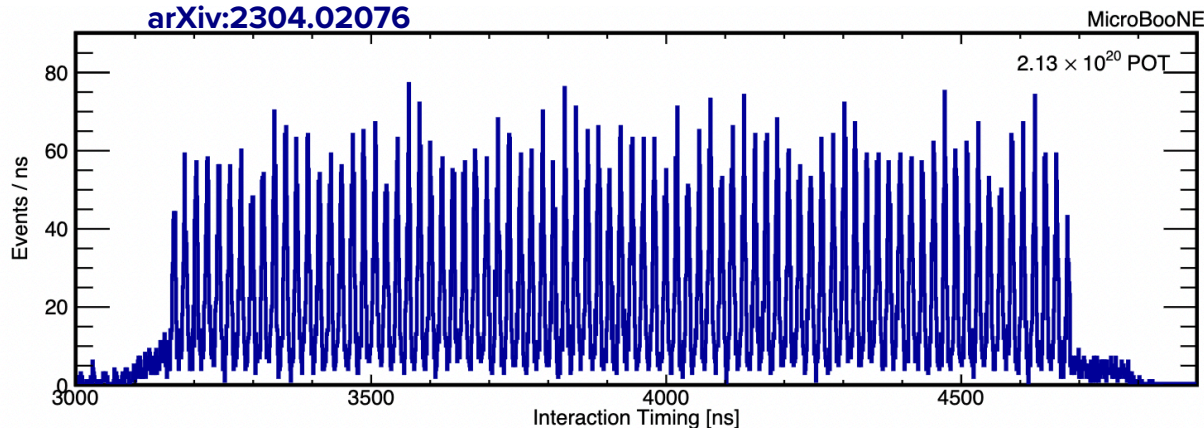
POT: Protons on Target

- MicroBooNE collected BNB and NuMI data between 2015 and 2020
- Also collected data without beam
- ~50% of the dataset used in first wave of results



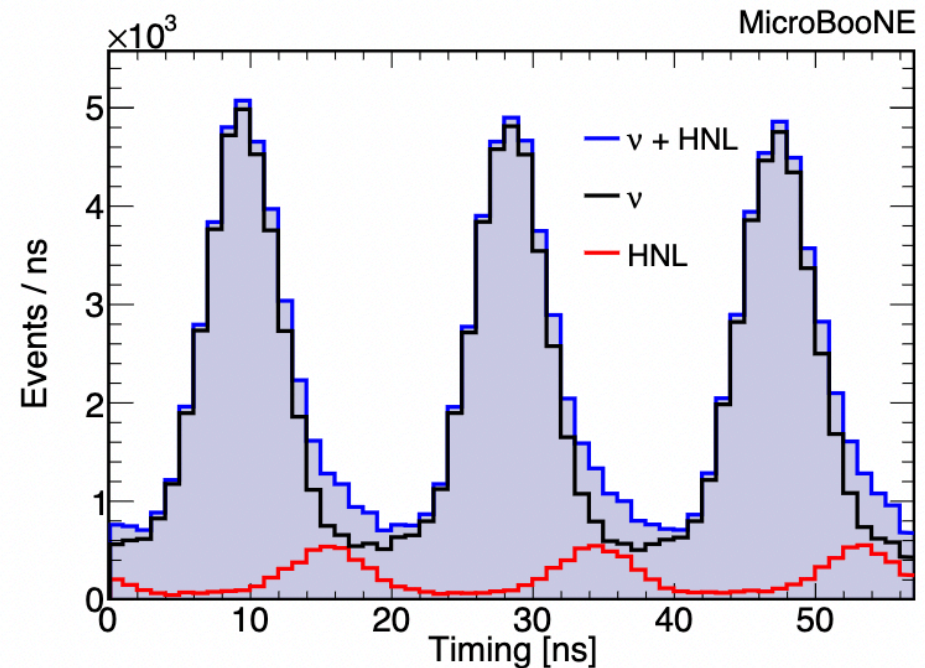
First results

# $\mathcal{O}(1 \text{ ns})$ timing resolution



- **Out-of-bunch** searches in BNB lead to a reduction of the neutrino background
- Ns timing in NuMI being studied

- MicroBooNE demonstrated **1.73 ± 0.05 ns resolution** on neutrino interaction time
- Allows to **probe the beam structure!**

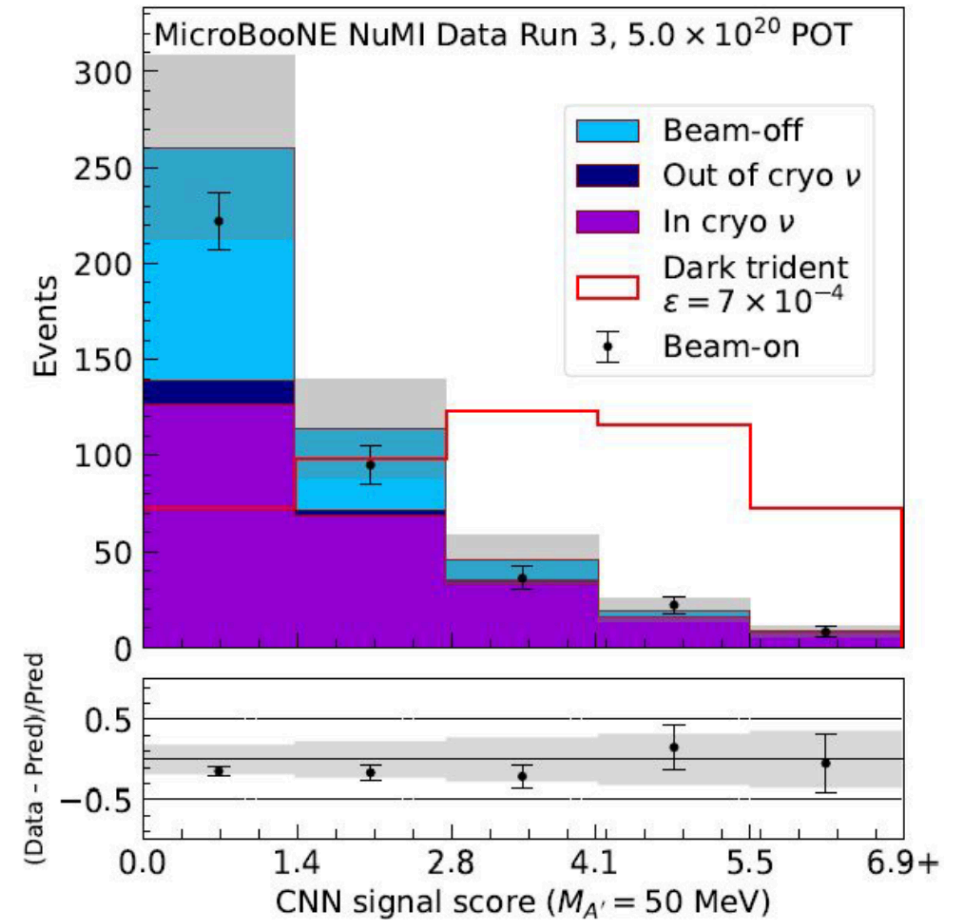




# Dark Tridents Analysis

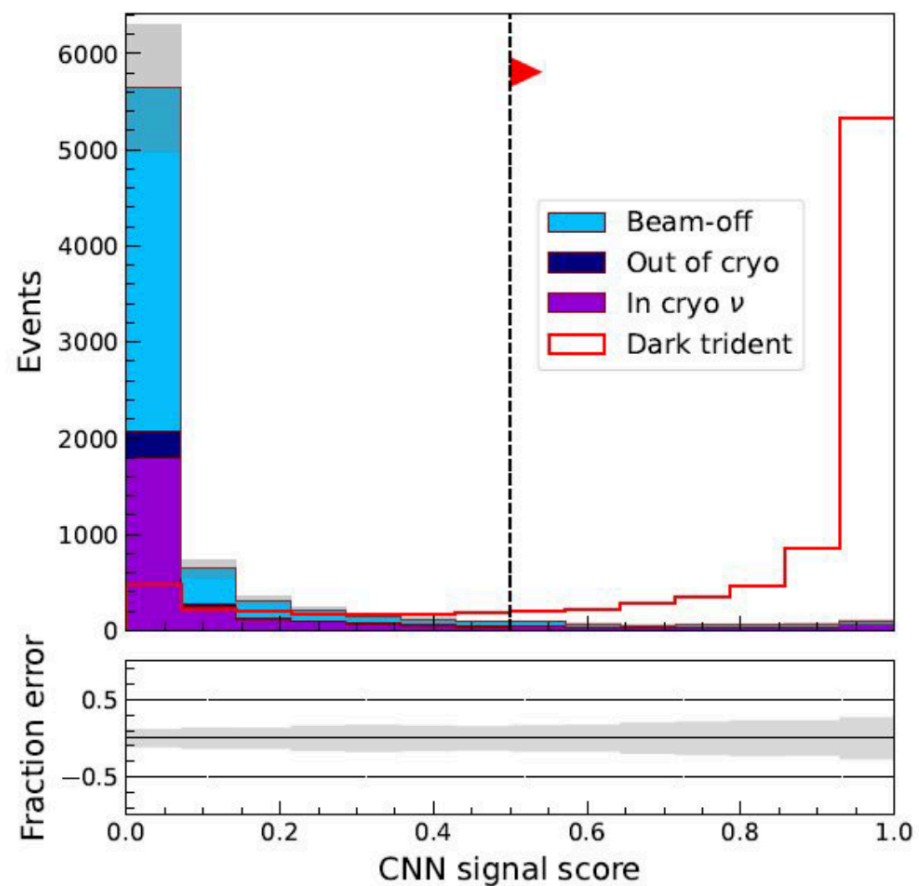
Convolutional Neural Network

Signal Region

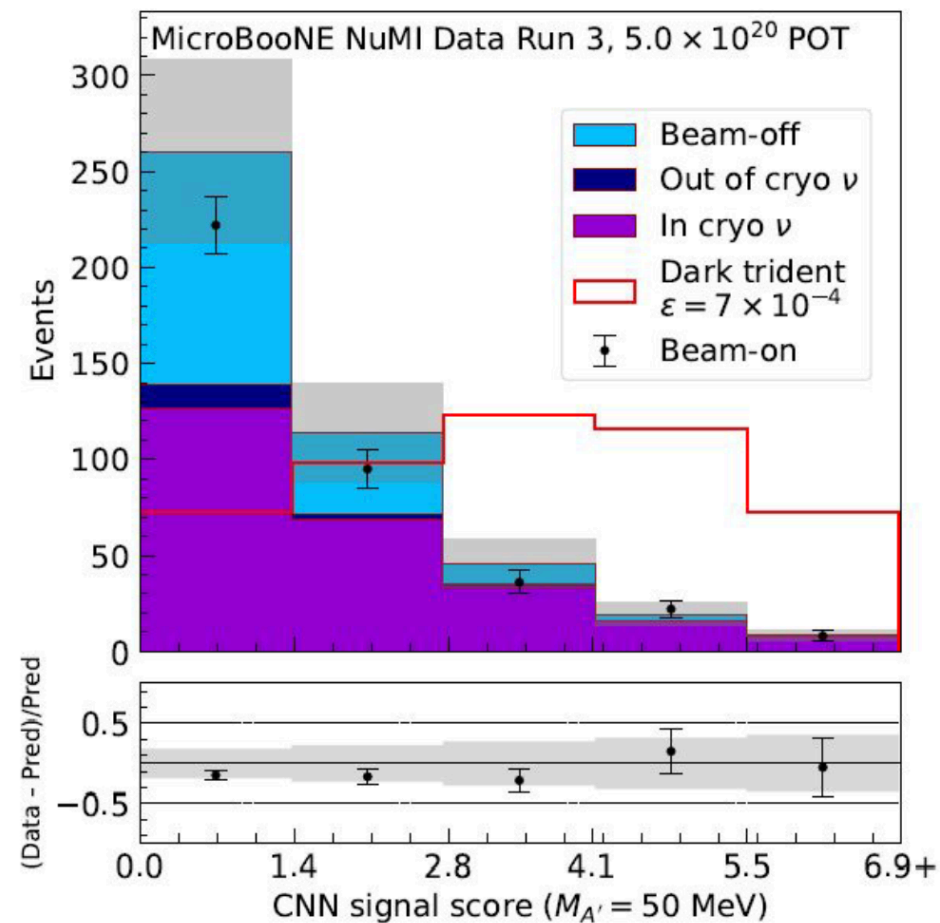


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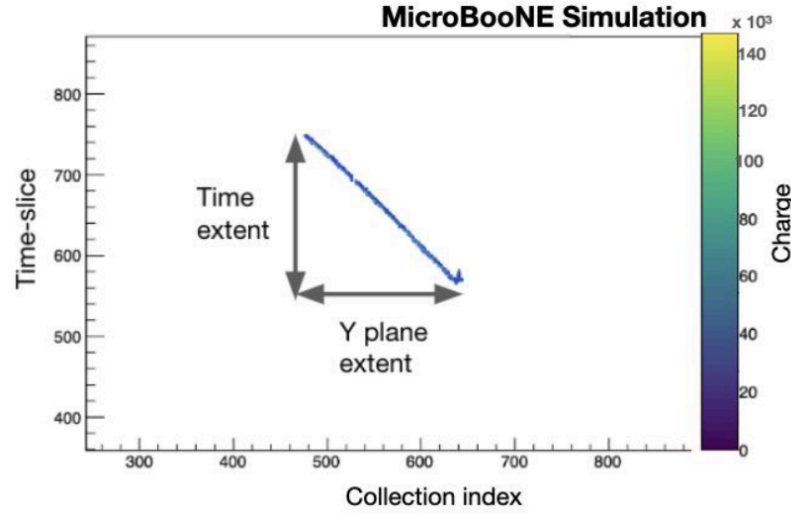
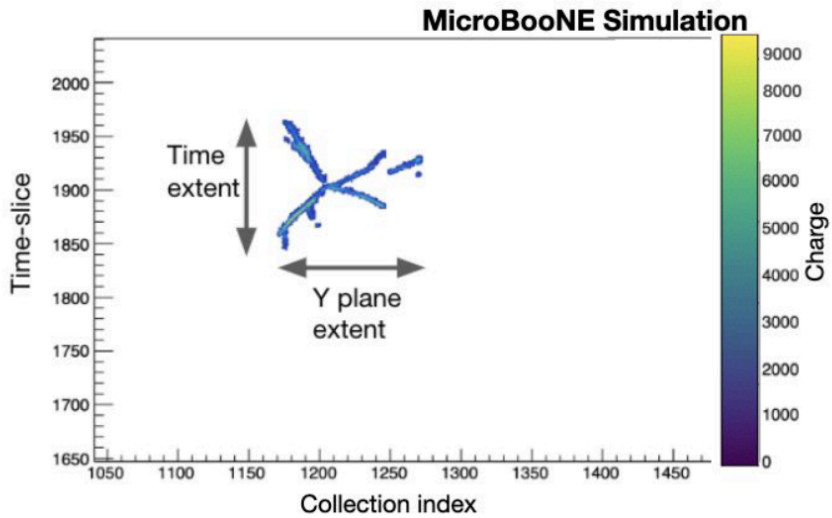
## Convolutional Neural Network



## Signal Region



# Neutron - Antineutron transition analysis



Convolutional Neural Network for further rejection

Boosted Decision Tree to reject cosmic events

