MANCHESTER 1874

BSM searches at the MicroBooNE cetector

TAUP - Vienna - August 30, 2023

Anyssa Navrer-Agasson, on behalf of the MicroBooNE Collaboration

anyssa.navrer-agasson@manchester.ac.uk



El Fermilab





What is MicroBooNE?



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

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



Booster Neutrino Bea

mas

07014

A. Navrer-Agasson - TAUP 2023 - August 30, 2023



SBN Near

Detector





What is MicroBooNE?



- Non-standard neutrino oscillations
- Neutrino cross-section measurements
- Detector physics, R&D

MANCHESTER

1824

Beyond Standard Model physics — This talk!

85-tonne Liquid **Argon Time Projection Chamber MicroBooNE** SBN Near Detector Detector **Booster Neutrino** 07014 mar



A. Navrer-Agasson - TAUP 2023 - August 30, 2023







LArTPC essentials



LAr volume in a uniform E-field

MANCHESTER

1824

- 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

- TAUP 2023 - August 30, 2023





Beamines @ MicroBooNE



- 8 GeV protons
- On-axis





MicroBooNE observes flux from two neutrino beams





A. Navrer-Agasson - TAUP - 30 August 2023





BSM physics with MicroBooNE

- New particles can be produced from meson decays
 - Large flux of charged/neutral mesons from high intensity proton beams











BSM physics with MicroBooNE

New particles can be produced from meson decays

MANCHESTER

1824

 Large flux of charged/neutral mesons from high intensity proton beams



eson decays Is from high intensity





BSM physics with MicroBooNE

A. Navrer-Agasson

New particles can be produced from meson decays

MANCHESTER

1824

Large flux of charged/neutral mesons from high intensity proton beams



- TAUP 2023 - August 30, 2023





Higgs Portal Scalars

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







A. Navrer-Agasson - TAUP 2023 - August 30, 2023

uBool





Higgs Portal Scalars

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







- Kaons decaying at rest in the NuMI absorber
- Scalars travel "backwards" to MicroBooNE
 - Very specific signature





Heavy Neutral Leptons

- Consider one new right handed singlet
- Mixing with active neutrinos via extended PMNS matrix
- HNLs can be produced in place of neutrinos from meson decays
- Decay to SM particles









µBooNE

A. Navrer-Agasson - TAUP 2023 - August 30, 2023



7

Heavy Neutral Leptons

- Consider one new right handed singlet
- Mixing with active neutrinos via extended PMNS matrix
- HNLs can be produced in place of neutrinos from meson decays
- Decay to SM particles

Consider production/decay $K \rightarrow N \rightarrow \mu \pi$





Expected signal(s)





Very similar signatures from Heavy Neutral Leptons and Higgs Portal Scalars!



µBooNE

A. Navrer-Agasson - TAUP 2023 - August 30, 2023



8

Expected signal(s)

Perfect setting for a joint search!

- Search for long-lived particles produced in the NuMI absorber
- Two signals:

MANCHESTER

1824

- Heavy Neutral Leptons: $246 \le m_{HNL} \le 385$ MeV, decay to $\mu\pi$
- Higgs Portal Scalars: $212 \le m_{HPS} \le 279$ MeV, decay to $\mu^+\mu^-$



Very similar signatures from Heavy Neutral Leptons and Higgs Portal Scalars!

A. Navrer-Agasson - TAUP 2023 - August 30, 2023





Joint long lived particles search



- Initial selection based on event topology & \bullet kinematics
- Targets:
 - Cosmics
 - **Neutrino interactions**
- Same selection applied for both models







A. Navrer-Agasson - TAUP 2023 - August 30, 2023



Phys. Rev. D 106, 092006 (2022)

Heavy Neutral Leptons





Higgs Portal Scalars







Phys. Rev. D 106, 092006 (2022)











Phys. Rev. D 106, 092006 (2022)

MANCHESTER

1824



One order of magnitude increase in sensitivity compared to previous MicroBooNE result.

First constraints from a dedicated experimental search for a range of parameters







Phys. Rev. D 106, 092006 (2022)

MANCHESTER

1824

Heavy Neutral Leptons



One order of magnitude increase in sensitivity compared to previous MicroBooNE result.

Higgs Portal Scalars



Both results are being updated to include more production/decay modes.

First constraints from a dedicated experimental search for a range of parameters









More models to explore!

Dark tridents

- Dark matter produced via dark photon mixing
- Meson decays in **NuMI beam**
- Use state-of-the art deep learning methods



MANCHESTER

1824





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







µBooNE

13

Neutron-antineutron transition

- Baryon number violating transition allowed in some extensions of the Standard Model
- Intranuclear transition $n \to \bar{n}$

MANCHESTER

1824

- Resulting \bar{n} annihilates with a neighbouring nucleon
 - Final states with multiple pions
 - Striking "star"-like topology in MicroBooNE







- Novel event selection combining BDTs and deep learning
- First ever **proof-of-principle** for future searches in LArTPCs



A. Navrer-Agasson - TAUP 2023 - August 30, 2023



New

14

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 something we should search for, get in touch!









Backup

Data collected by MicroBooNE

- 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





A. Navrer-Agasson - TAUP 2023 - August 30, 2023

3.0E18

2.5E18

BNB Delivered POT



1.6E21

1.4E21

1.2E21



BNB POT on tap





Majorana HNLs vs. Dirac HNLs

<u>Majorana HNL</u>

- $N \rightarrow \mu^+ \pi^-$ and $N \rightarrow \mu^- \pi^+$
- Isotropic decays (summing both channels)

Dirac HNL

- $N \rightarrow \mu^{-}\pi^{+}$ only
- Half the event rate of Majorana HNLs
- Asymmetric angular spectrum





A. Navrer-Agasson - TAUP 2023 - August 30, 2023



18

HNL late window trigger (BNB)

HNL time of flight depends on its mass and momentum







Some HNLs will arrive later than neutrinos in MicroBooNE!

"Late window" trigger specifically for this analysis

Effectively eliminates in-beam neutrino events



- TAUP 2023 - August 30, 2023





HNL Arrival Time (NuMI)





A. Navrer-Agasson - TAUP 2023 - August 30, 2023





20

Signal event generation



Custom generator developed for the first MicroBooNE HPS search Adapted to extend HPS mass range and include HNLs













Initial selection

- **1.** Slice identification
- 2. Vertex building

3. Preselection

- Object multiplicity
- Containment
- Kinematics
- Calorimetry
- Cosmic rejection

4. Final selection efficiency: (13 - 30)%



Total energy reconstructed



A. Navrer-Agasson - TAUP 2023 - August 30, 2023



Boosted decision trees



1824

- initial selection
- Gradient boosting algorithm **XGBoost** is used to train BDTs
- mass point
 - Reconstructed calorimetric and kinematic variables
- Trained BDTs applied to data & simulation
- Data well modelled by background prediction across runs
 - No excess observed in data
 - Set limits on mixing parameters



Use Boosted Decision Trees to discriminate candidates passing

Train separate BDTs for each LLP







Systematics evaluation

Sample re-simulation

- MC simulation with single modified parameter
- Modified simulation compared to central value to determine impact
- Used for detector uncertainties
 - uncertainty range
 - weights
 - Uncertainty is estimated the central value and sample variation(s)



Event re-weighting

- Produce altered distributions with one or more modified parameters
- Assign a weight to events based on the difference between central value and modified distribution

Multi-sim method: randomly sample multiple parameters within their

• Each iteration produces a new "universe", represented by a set of event





Coming soon: Updated HNL and HPS results

Heavy Neutral Leptons

- 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 $N \rightarrow \mu \pi$
- Search for kaons decaying at rest in the NuMI absorber

Higgs Portal Scalars

- General search for HPS from NuMI kaon decays: ullet
 - Both kaon decays in flight and at rest
 - From NuMI target and absorber
- HPS decay to e^+e^-





Coming soon: Dark Tridents

- in the beam via dark photon mixing
- radiation subsequently decaying to e^+e^-
- NuMI off-axis search: neutrino background reduction





A. Navrer-Agasson - TAUP 2023 - August 30, 2023





Coming soon: Dark Tridents

- in the beam via dark photon mixing
- radiation subsequently decaying to e^+e^-
- NuMI off-axis search: neutrino background reduction



A. Navrer-Agasson



- TAUP 2023 - August 30, 2023



JHEP01(2019)001



0(1 ns) timing resolution



- In-bunch neutrino searches:
 - Reduction of cosmic background
- Out-of-bunch BSM searches
 - Reduction of neutrino background



- Demonstrated **1.73** ± **0.05** ns resolution on neutrino interaction time
- Allows to probe beam structure! lacksquare







