Searching for rare processes in short-baseline neutrino experiments with liquid argon time projection chambers

Guanqun Ge[1] on behalf of MicroBooNE and SBND Collaborations
[1]Columbia University **gg2690@columbia.edu**

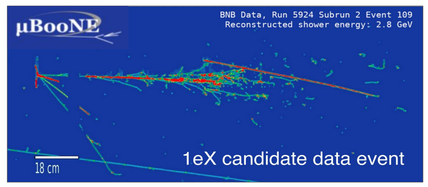
Nevis Laboratories
Columbia University

Liquid Argon Time Projection Chamber

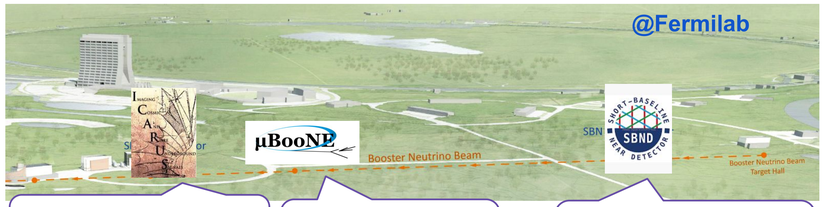
Liquid argon time projection chamber (LArTPC) [1] detector offers:

- Unprecedented spatial and calorimetric resolution
- Scalability and high cost-efficiency

The readout of LArTPC can be viewed as a 2D time-space image



The Short-Baseline Neutrino Program [2]



- 476 tonne active mass
- Started taking data in 2022

- 85 tonne active mass
- Physics run in 2015 - 2020

- 112 tonne active mass
- Physics commissioning in December 2023

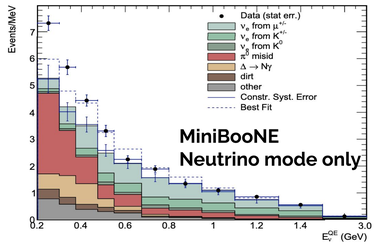
- Comprises three LArTPC detectors: **SBND** (near detector), **MicroBooNE** and **ICARUS** (far detector)
- Main Physics goal:
  - Search for light sterile neutrino oscillations
  - Measure neutrino-argon cross-sections
  - Beyond-Standard Model (BSM) physics searches

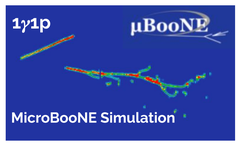
Searches for SM-predicted, rare neutrino scattering processes

Neutral Current Δ radiative decay search in MicroBooNE[3]

MicroBooNE investigated hypothesis of enhanced neutral current (NC) $\Delta \rightarrow N + \gamma$ as source of LEE seen by MiniBooNE [4]

- Never before measured process
- 3.18 enhancement could account for the MiniBooNE observed excess





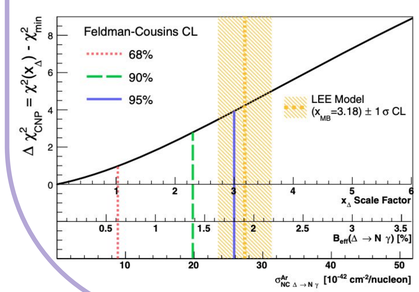
Two signal topologies:

- $1\gamma 1p$ ($\Delta \rightarrow p + \gamma$)
- $1\gamma 0p$ ($\Delta \rightarrow n + \gamma$)

Challenges

Very rare signal - **125** events expected for first three run periods ⇒ 5 tailored boosted decision trees (BDT's) to remove cosmic, charged current and NC π^0 background

Dominant π^0 background ⇒ Dedicated high-statistics NC π^0 sample to **constrain NC π^0 rate *in-situ***



- **No evidence** in MicroBooNE first 3-year data for an enhanced rate of single-photons from NC $\Delta \rightarrow N\gamma$ decay, above nominal SM expectations
- Being 4x closer to the target than MicroBooNE, SBND could reach same amount of data in less than 3 months; higher statistics data from SBND will allow first direct measurement of this process!

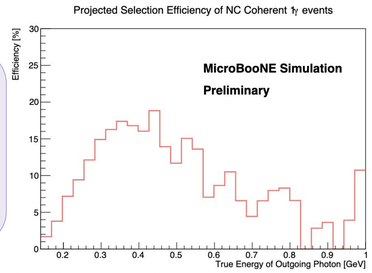
NC coherent single photon search in MicroBooNE[5]

Neutrino-induced NC coherent 1γ production is a rare, never before measured but SM predicted process [6]

- **O(10)** events expected in MicroBooNE for first three runs
- **No hadrons** exiting the nucleus in the final state but only one **photon**

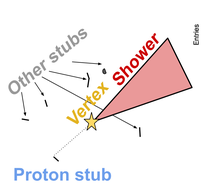
Signal topology: $1\gamma 0p$

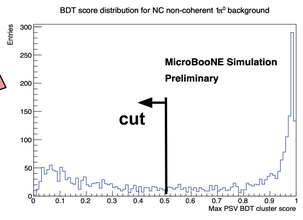
- Similar search as NC Δ single photon analysis
- Additionally exploit no hadronic activity and forwardness of outgoing photon relative to neutrino beam

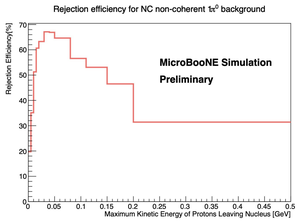


Further development to reject proton background

Use tailored proton stub veto (PSV) BDT to identify and veto candidate activity from proton



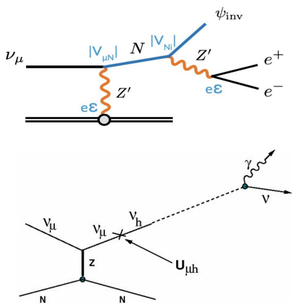




- Current MicroBooNE selection yields high background rejection efficiency and shows the excellent potential of proton-veto tool
- While MicroBooNE can only place limits to this SM process, SBND is in excellent position to measure it!

Searches for BSM single-photon-like processes

Ongoing searches in MicroBooNE and SBND that look for single-photon-like activity:



- **Exotic e^+e^- production** through light dark photon mediated neutrino scattering [7][8]
- Single photon production from heavy neutrino due to **transition magnetic moment** [9]
- Both searches are made possible by the DarkNews event generator[10]

Predicted e^+e^- signal for MicroBooNE [8] corresponding to e^+e^- model parameters which best fits MiniBooNE reconstructed visible energy: $m_{Z'}$= 1.25 GeV, m_N= 107.5 MeV, m_ψ = 72 MeV, ε = 0.01

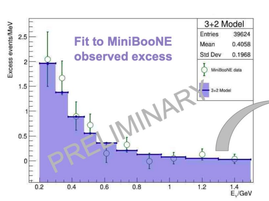
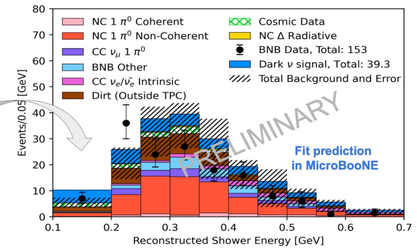


Fig. 3. a) Visible energy spectrum at MiniBooNE for best fit parameters [7].



- Current efforts are ongoing to evaluate the sensitivity of MicroBooNE and SBND to these models

[1] R. Acciarri *et al* 2017 *JINST* 12 P02017
[2]MicroBooNE and LAr1-ND and ICARUS-WA104 Collaborations, arXiv:1503.01520
[3] MicroBooNE Collaboration, Phys. Rev. Lett. 128, 111801 (2022)
[4] MiniBooNE Collaboration, Phys. Rev. D 103, 052002 (2021)
[5] MicroBooNE Collaboration, *MICROBOONE-NOTE-1103-PUB*
[6] E. Wang *et al*, Phys. Rev. C 89, 015503 (2014)
[7] A. Abdullahi *et al*, *Phys.Lett. B* 820 (2021) 136531
[8] A. Abdullahi , *Neutrino 2022 poster*
[9] S. N. Gninenko, Phys. Rev. Lett. 103, 241802 (2009)
[10] A. Abdullahi *et al*, arXiv:2207.04137

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