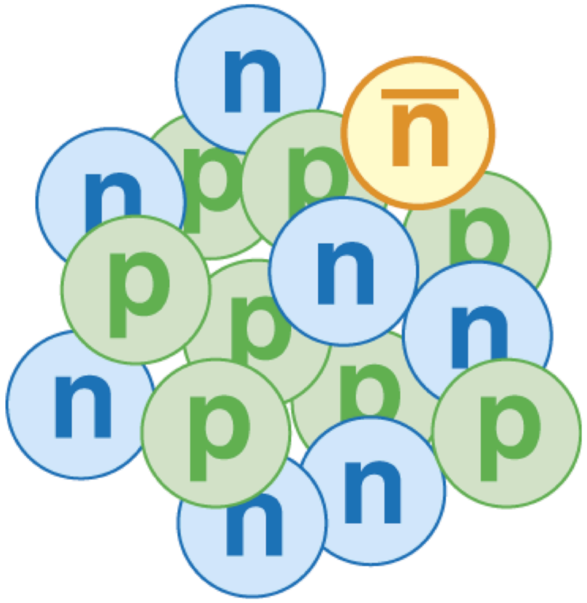
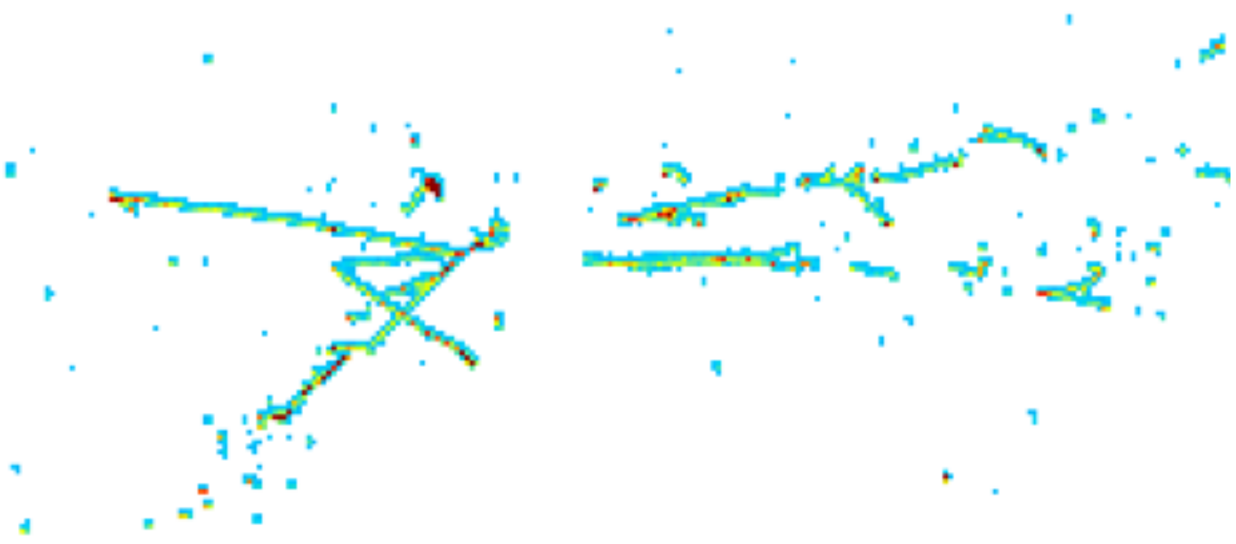
$n - \bar{n}$ oscillation in MicroBooNE and DUNE

Jeremy Hewes
The University of Manchester
New Perspectives 2015

Neutron-antineutron oscillation

- Several classes of Grand Unified Theories allow non-conservation of lepton and baryon number.
- In some such models, the spontaneous oscillation of a neutron into an antineutron is permitted.



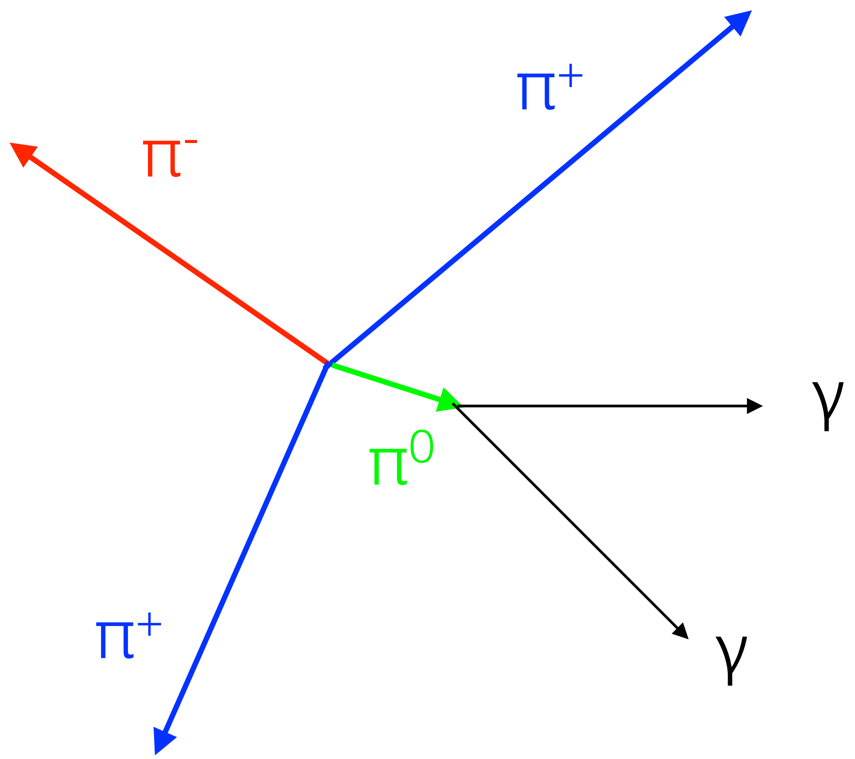


Simulated neutron-antineutron annihilation in a Liquid Argon time projection chamber

- For **bound** neutrons, signal is the annihilation of an oscillated antineutron with another nucleon.
- Rate is suppressed by a nuclear suppression factor R (~10^{23}) compared to free neutrons.

Bound antineutron-nucleon annihilation

- Final states are extrapolated from 1955 bubble chamber with antiprotons on deuterium & hydrogen targets.
- Star-shaped event topology:

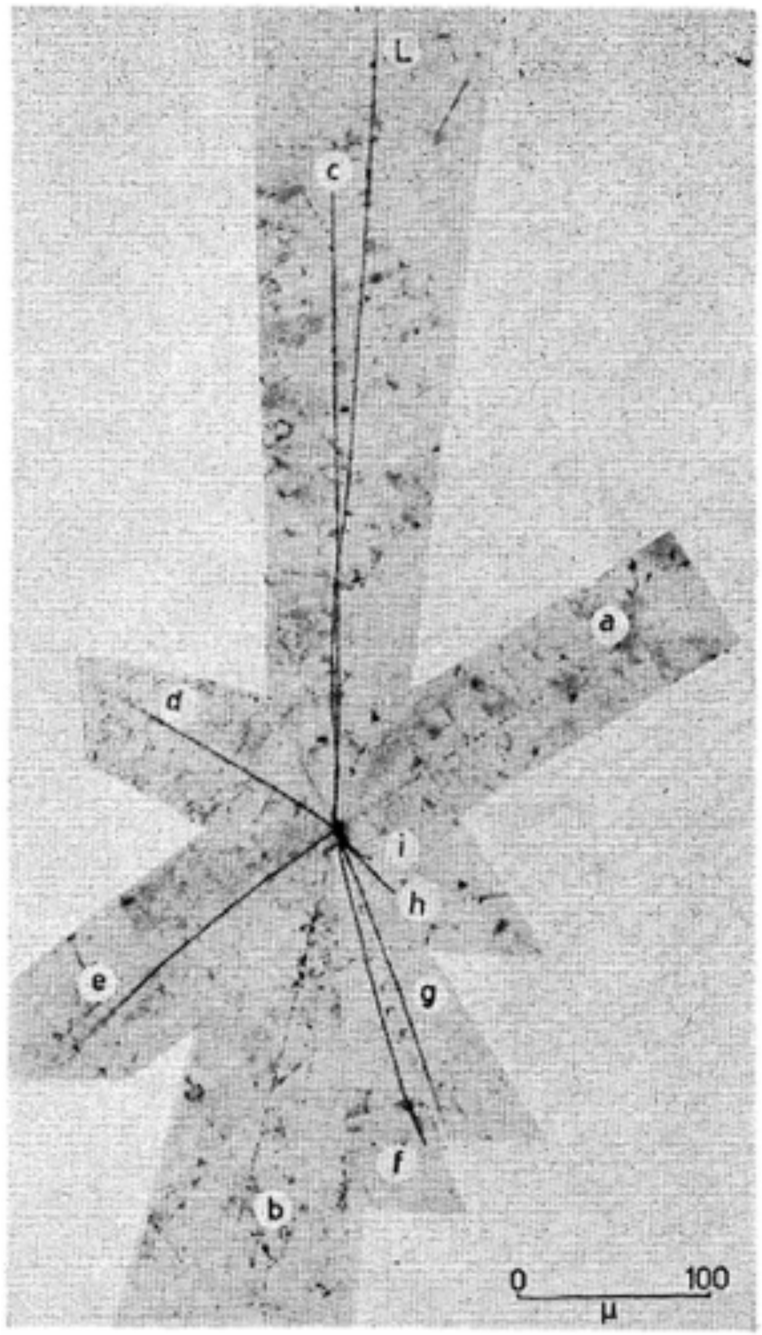


Final state: 2-6 πs

Total energy ≃ $2m_n$

Net momentum < p_F

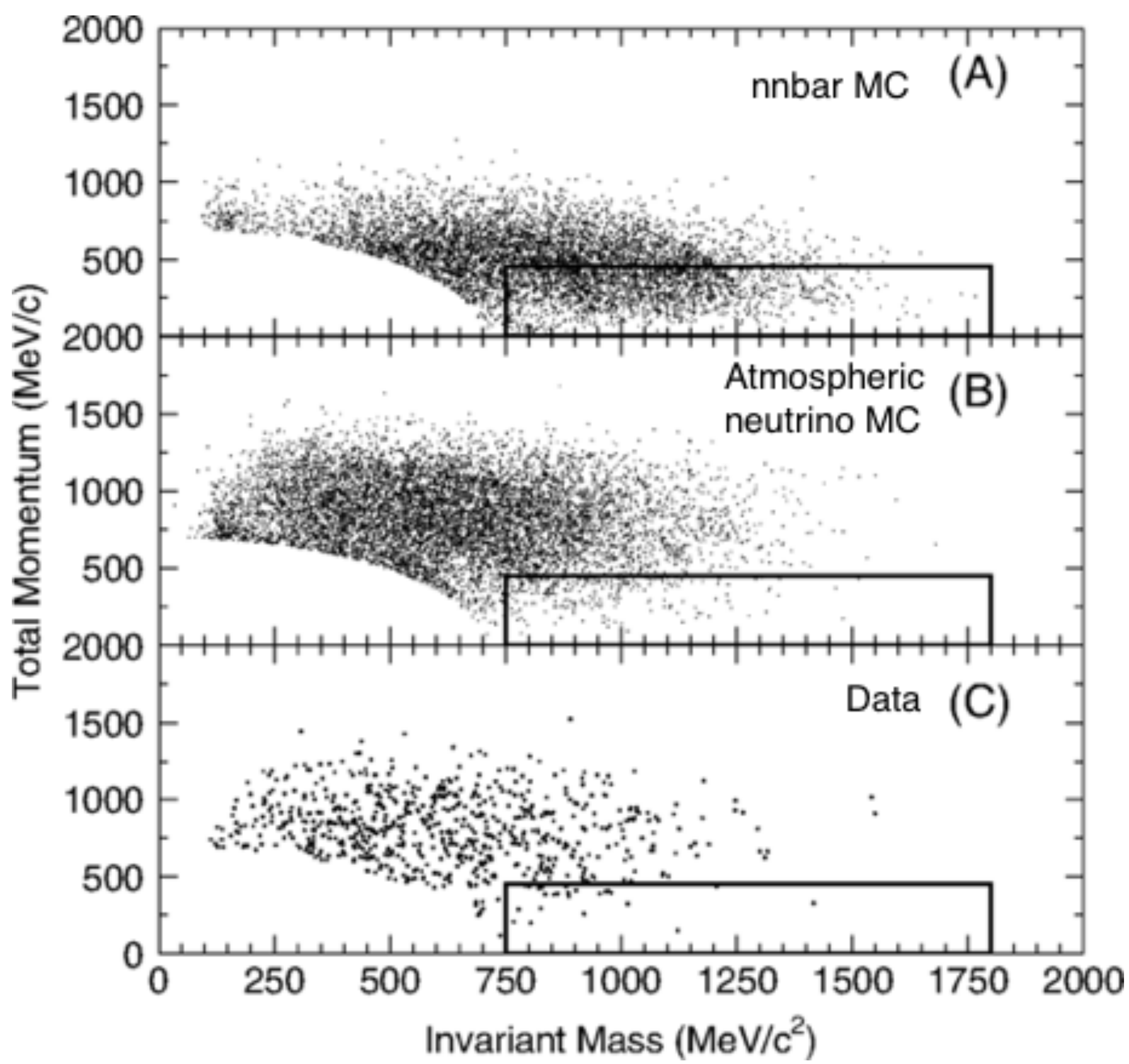
Antiproton annihilation event from 1955 data (Phys. Rev. 101.909)



$n - \bar{n}$ in Super-Kamiokande

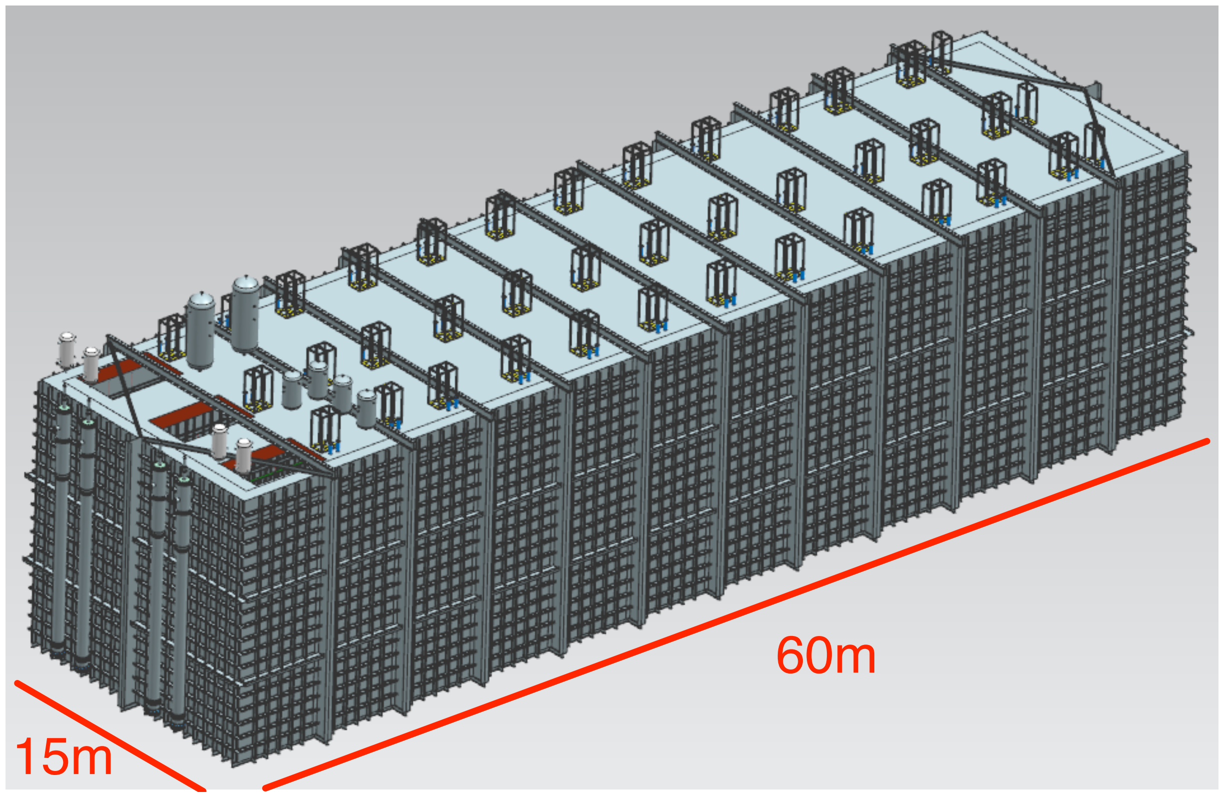
- Super-Kamiokande collaboration published nnbar analysis in April 2015 (Phys. Rev. D 91, 072006)
- 50kt water Cherenkov detector, ^{16}O target.
- Measured 24 candidate events, with a predicted background of 24.1 events
- Signal selection efficiency of 12.1%.
    - Cherenkov threshold means many final state particles are lost.
- Limit set at $\tau = 1.89 \times 10^{32}$ s (90% CL) for bound neutron.
- Equivalent to $\tau = 3.45 \times 10^{8}$ s for free neutron.

Cuts made by Super-K on total momentum & invariant mass



Deep Underground Neutrino Experiment

DUNE detector 10kt cryostat



- Liquid Argon TPC: low energy threshold, great resolution, tracking information.
- Expect to greatly improve over Super-K in selection efficiency & background rejection.

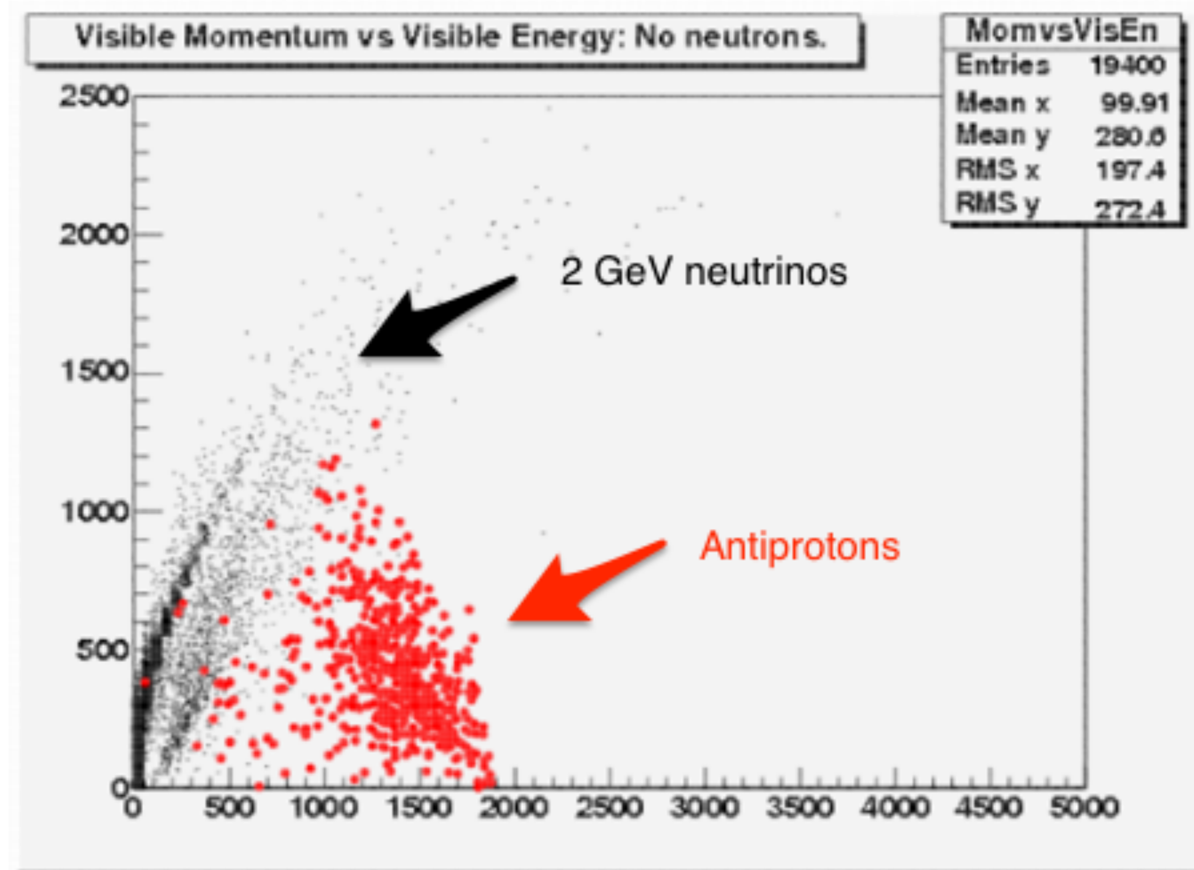
- Future neutrino oscillation experiment.
- 40kT Liquid Argon time projection chamber (LArTPC).
- Large-mass, inert, deep underground detector, ideal for nucleon decay searches.

Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \to K^+\overline{\nu}$	19%	4	97%	1
$p \to K^0\mu^+$	10%	8	47%	< 2
$p \to K^+\mu^-\pi^+$			97%	1
$n \to K^+e^-$	10%	3	96%	< 2
$n \to e^+\pi^-$	19%	2	44%	0.8

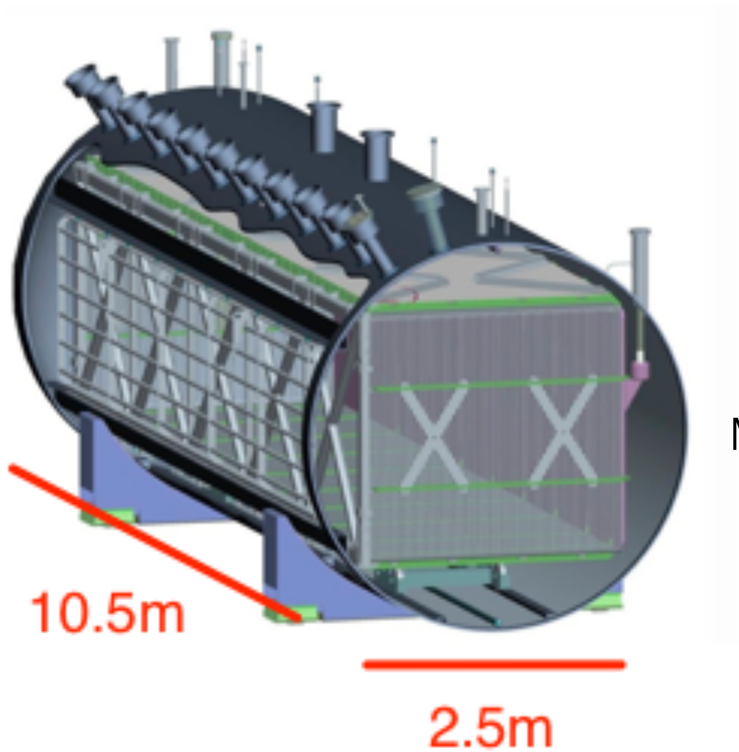
Comparison of some nucleon decay modes between Cherenkov and LArTPC (LBNE science document)

MicroBooNE

- 170 ton near-surface LArTPC, with data available in the near future!
- MicroBooNE fiducial mass is far too small to be sensitive to $n - \bar{n}$ oscillation.
- Presents an opportunity to measure potential background signals!



Comparison of simulated proton-antiproton annihilation and neutrino events at truth level (N. Ayoub, Columbia U.)



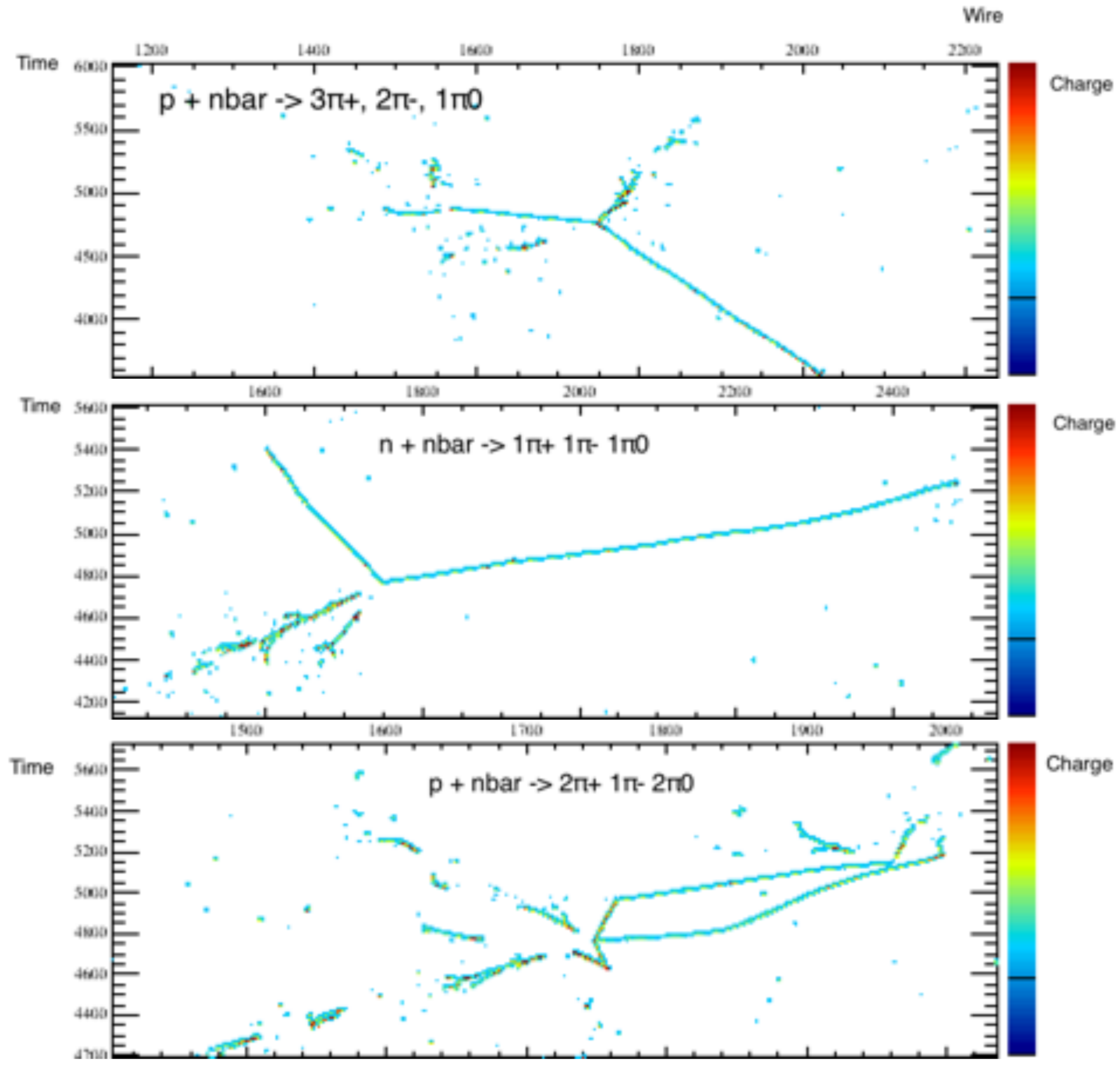
Schematic of the MicroBooNE detector cryostat

- Examples:
  - Cosmic primary & secondary particles.
  - NuMI off-axis flux.

Current status & future plans

- Existing antineutron-nucleon annihilation event generator (J. Dickinson, Columbia U.).
- Currently working to implement generator within existing neutrino event generator, in order to incorporate nuclear effects:
    - Fermi momentum & nuclear density of nucleons.
    - Simulation of Argon nuclear remnant.
    - Intranuclear final state interactions.
- Develop reconstruction, particle ID & event selection.
- Use simulated $n - \bar{n}$ events, cosmogenic backgrounds, high-energy neutrinos and in-situ data rates to test signal selection and background rejection.

Example events using $n - \bar{n}$ event generator with MicroBooNE simulation chain:



Summary

- Pushing the limits of $n - \bar{n}$ oscillation parameter space could lead to discovery of physics beyond the Standard Model.
- Opportunity to achieve this with DUNE while simultaneously broadening experiment's physics potential.
- Laying the groundwork for a future measurement by studying backgrounds and developing analysis tools in MicroBooNE.