

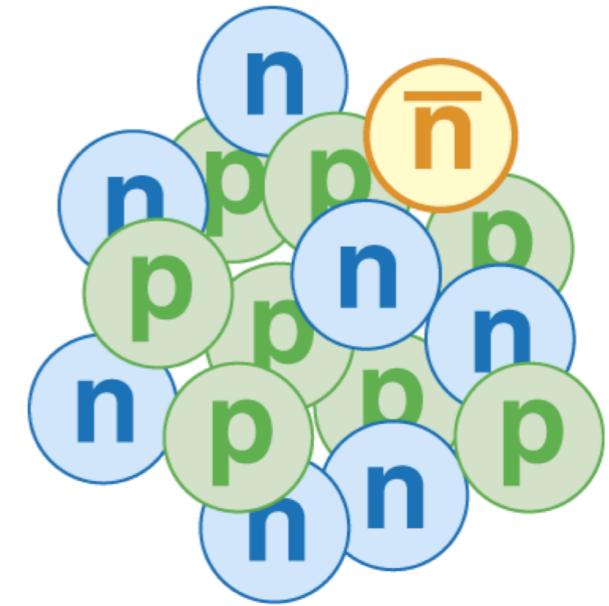
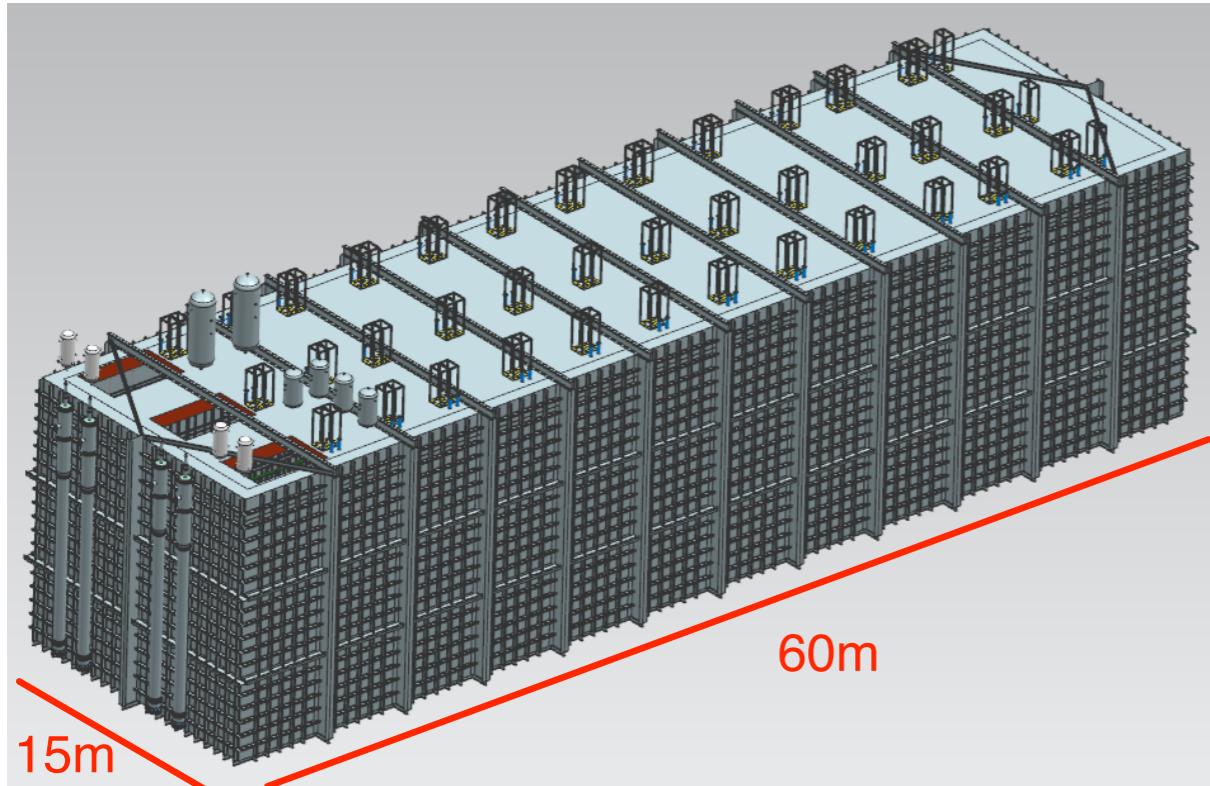
# Neutron-Antineutron Oscillation in DUNE

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DUNE Proton Decay & Atmospherics WG meeting  
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# Neutron-antineutron oscillation

- Baryon number violating process ( $\Delta B = 2$ ).
- Bound neutron oscillates into antineutron & annihilates.
- Current lifetime limit  $\tau = 1.89 \times 10^{32} \text{ s}$

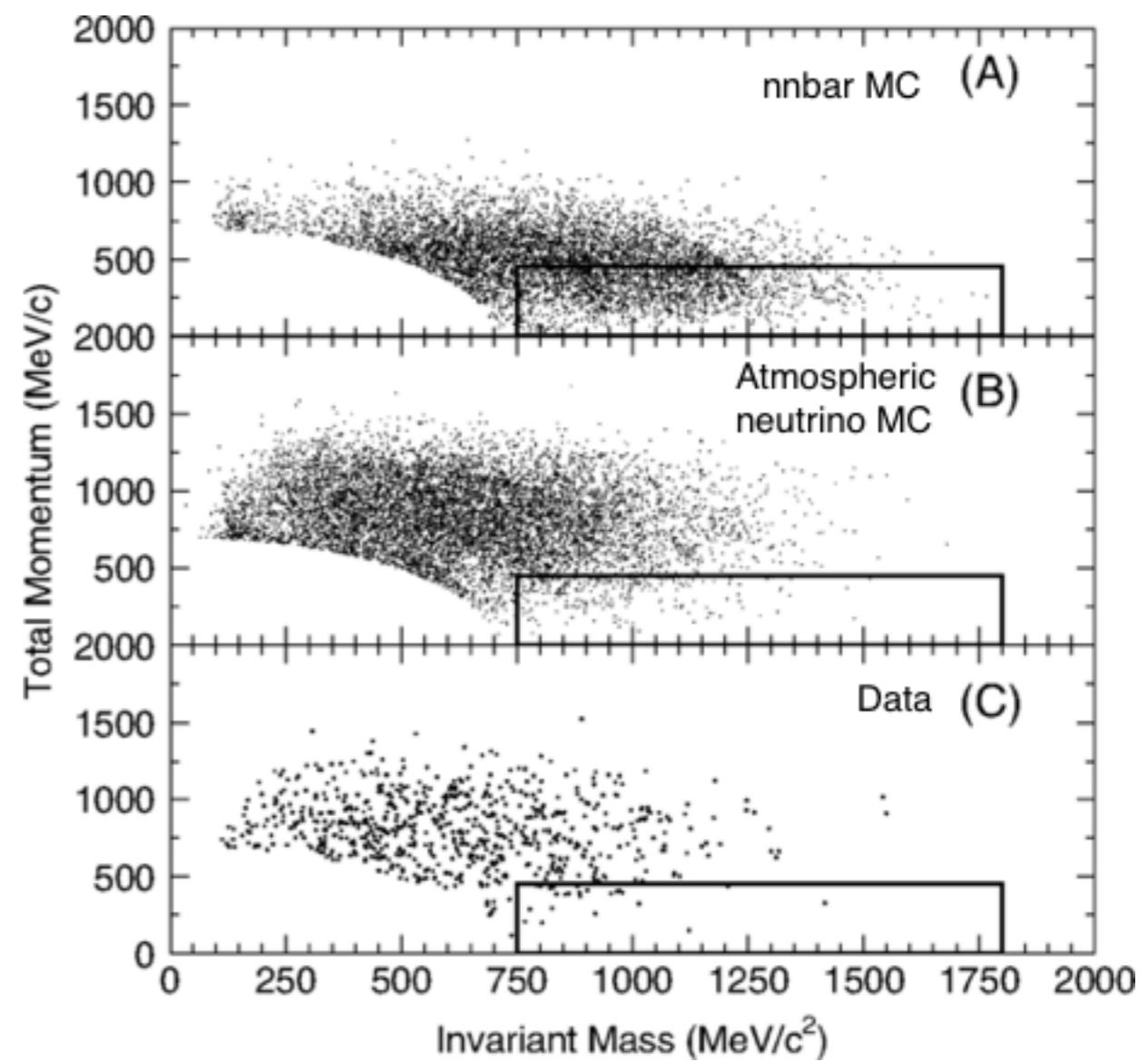


- DUNE:
  - 40kT Liquid Argon time projection chamber (LArTPC).
  - Large-mass, inert, deep underground detector, ideal for nucleon decay searches.

# Super-Kamiokande measurement

- Super-Kamiokande collaboration published neutron-antineutron oscillation analysis in April 2015 (Phys. Rev. D 91, 072006)
- 50kt water Cherenkov detector,  $^{16}\text{O}$  nucleus.
- 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  $\tau = 1.89 \times 10^{32} \text{ s}$  (90% CL) for bound neutron.
- Equivalent to  $\tau = 3.45 \times 10^8 \text{ s}$  for free neutron.

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



# Neutron-antineutron oscillation in DUNE

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- Super-Kamiokande evaluates lifetime using Bayesian distribution:

$$P(\Gamma|n_{\text{obs}}) = A \int \int \int \frac{e^{-(\Gamma\lambda\epsilon+b)} (\Gamma\lambda\epsilon + b)^{n_{\text{obs}}}}{n_{\text{obs}}!} \times P(\Gamma)P(\lambda)P(\epsilon)P(b)d\lambda d\epsilon db.$$

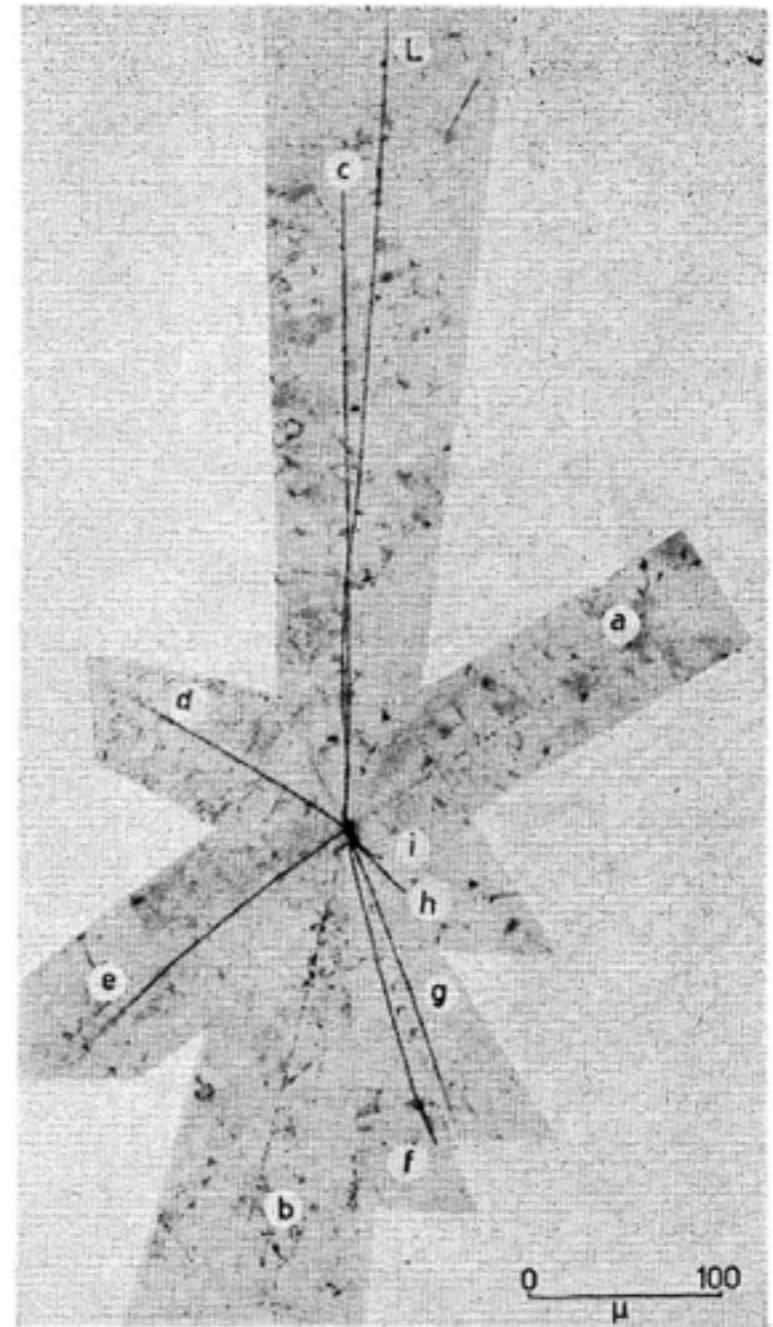
- Limit set using **value** and **uncertainty** of:

- **Exposure  $\lambda$**
- **Signal selection efficiency  $\epsilon$**
- **Background rate  $b$**

# Event reconstruction

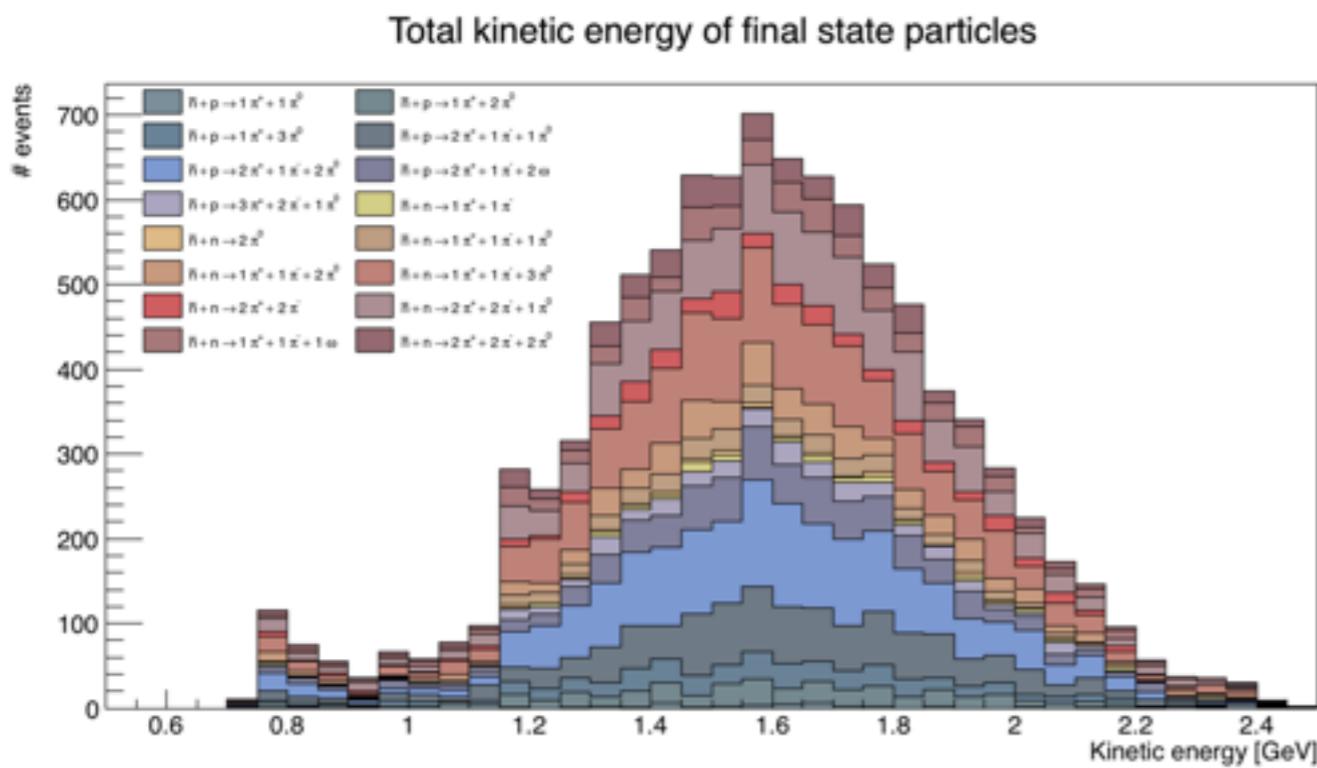
- Distinctive event topology:
  - 2-6  $\pi^{\pm,0}$  in final state.
  - Total KE  $\sim 2$  nucleon masses.
  - Total net momentum  $\sim p_F$ .
- Full event reconstruction requires good track/shower reco,  $\pi^0$  identification.
- Unique topology (spherical, high-energy) could allow identification from raw detector-level information.

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



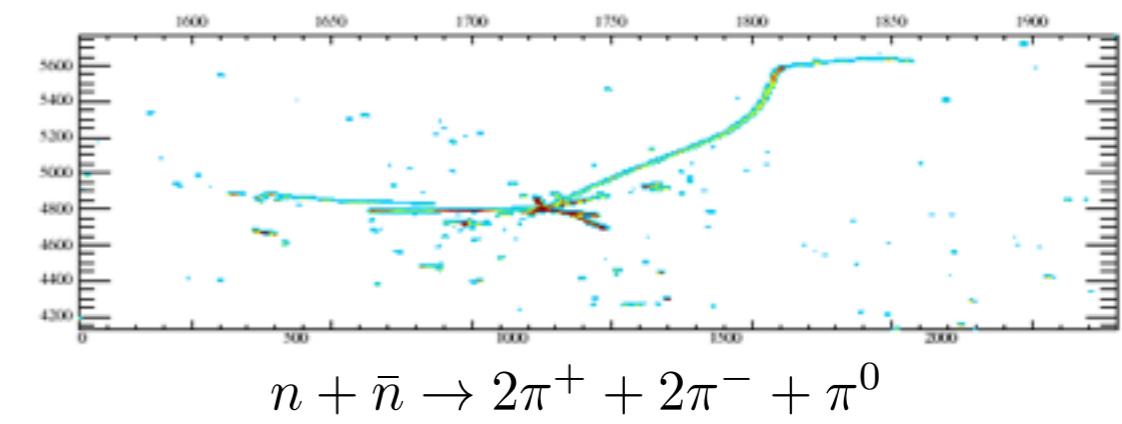
# Simulation

- Simulating process in Argon-40.
- Developed event generator module in GENIE.
  - Fermi momentum & binding energy.
  - Intranuclear cascade model.



	$\bar{n} + p$	$\bar{n} + n$	
$\pi^+ \pi^0$	1%	$\pi^+ \pi^-$	2%
$\pi^+ 2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+ 3\pi^0$	10%	$\pi^+ \pi^- \pi^0$	6.5%
$2\pi^+ \pi^- \pi^0$	22%	$\pi^+ \pi^- 2\pi^0$	11%
$2\pi^+ \pi^- 2\pi^0$	36%	$\pi^+ \pi^- 3\pi^0$	28%
$2\pi^+ \pi^- 2\omega$	16%	$2\pi^+ 2\pi^-$	7%
$3\pi^+ 2\pi^- \pi^0$	7%	$2\pi^+ 2\pi^- \pi^0$	24%
		$\pi^+ \pi^- \omega$	10%
		$2\pi^+ 2\pi^- 2\pi^0$	10%

Branching ratios for free annihilation



# Backgrounds

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- Identify background sources in on-surface MicroBooNE detector:
  - Cosmogenic antiprotons and antineutrons.
  - NuMI neutrinos.
  - Atmospheric neutrinos.
- Estimate background rate in underground DUNE detector:
  - Simulate atmospheric neutrinos.
  - Make an estimate of background rate for neutron-antineutron oscillation.

# Summary

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- Pushing the limits of neutron-antineutron oscillation parameter space could lead to discovery of physics beyond the Standard Model.
- Opportunity to make a landmark measurement using the DUNE detector.
- Laying the groundwork for a future measurement through:
  - Developing simulation tools & event selection.
  - Identifying background sources & rates.
- Final goal is to estimate sensitivity in DUNE.