Studies of Cosmogenic Background to Nucleon Decay in MicroBooNE

Elena Gramellini - Yale University
On behalf of the MicroBooNE collaboration

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Motivations for Nucleon Decay

Every interaction in the SM conserves baryon number.

Proton (or bound neutron) decay can occur only as a violation of baryon number and it’s predicted by almost every GUT.

The detection of even one nucleon decay event would be a direct evidence of physics BSM, opening a window on GUTs exploration.
Not Only Golden Modes

\[ p \rightarrow K^+ \bar{\nu} \]

\[ p \rightarrow e^+ \pi^0 \]

... plus many others!

The discovery of a particular decay mode would constrain GUT models.

Need of experimental handle on many different predicted modes.
Experimental Limits on $\tau_P$

\begin{itemize}
  \item $p \rightarrow e^+ \pi^0$
  \item $n \rightarrow e^+ \pi^-$
  \item $p \rightarrow \mu^+ \pi^0$
  \item $n \rightarrow \mu^+ \pi^-$
  \item $p \rightarrow \nu \pi^+$
  \item $n \rightarrow \nu \pi^0$
  \item $p \rightarrow e^+ \eta$
  \item $p \rightarrow \mu^+ \eta$
  \item $n \rightarrow \nu \eta$
  \item $p \rightarrow e^+ \rho^0$
  \item $n \rightarrow e^+ \rho^-$
  \item $p \rightarrow \mu^+ \rho^0$
  \item $n \rightarrow \mu^+ \rho^-$
  \item $p \rightarrow e^+ \omega$
  \item $p \rightarrow \mu^+ \omega$
  \item $n \rightarrow \nu \omega$
  \item $p \rightarrow e^+ K^0$
  \item $n \rightarrow e^+ K^+$
  \item $n \rightarrow e^+ K^-$
  \item $p \rightarrow \mu^+ K^0$
  \item $n \rightarrow \mu^+ K^+$
  \item $n \rightarrow \mu^+ K^-$
  \item $p \rightarrow \nu K^+$
  \item $n \rightarrow \nu K^0$
  \item $p \rightarrow e^+ K^{*(892)}_0$
  \item $p \rightarrow \nu K^{*(892)}^+_0$
  \item $n \rightarrow \nu K^{*(892)}^+_0$
\end{itemize}
A Tool for Many Modes: LArTPC

Working principles of a Liquid Argon Time Projection Chamber:

1. **Charged particles** interact in Ar
   - Produce scintillation light
   - Ionize electrons

2. Ionization $e^{-}$ drift to anode

3. **Wire planes** detect drift $e^{-}$
LArTPC Key Features for Nucleon Decay

Wire pitch at the millimeter scale.

U plane induction  V plane induction  Y plane collection

Drift time =

3D imaging
Millimetric Space Resolution

Calorimetry information

One of first MicroBooNE events
Ingredients for Nucleon Decay Detection

Lots of nucleons
Lots of time
Low background
[so low you need to go underground?]
Future and present LArTPCs…

DUNE: Increase Nucleon Decay sensitivity in multiple channels.
Future and present LArTPCs…

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40K ton active volume
Future and present LArTPCs…

DUNE: Increase Nucleon Decay sensitivity in multiple channels.

μBooNE Study Cosmogenic Backgrounds in a LArTPC.
MicroBooNE and Nucleon Decay

**GOAL**
Perform a topological search of events that mimic proton decay to estimate the mis-id rate from cosmogenic sources.

1. Study the decay topologies by exploiting the variety of information provided by a LArTPC.
Some example modes

- \( p \rightarrow e^+ \pi^0 \) Standard candle
- \( p \rightarrow \mu^+ \gamma \) High background channel
- \( p \rightarrow K^+ \bar{\nu} \) Golden channel in LAr
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Standard candle

\[ p \rightarrow \mu^+\gamma \]
High background channel

\[ p \rightarrow K^+\bar{\nu} \]
Golden channel in LAr
Some example modes

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Standard candle

\[ p \rightarrow \mu^+ \gamma \]
High background channel

\[ p \rightarrow K^+ \bar{\nu} \]
Golden channel in LAr
Simulated Event Display for $p \rightarrow e^+ \pi^0$
Simulated Event Display for $p \to e^{+} \pi^{0}$
Selection strategy

Geometry selection & PID
- $\pi^0$ and $e$ identification
- No additional vertex activity
- Proximity
- Planarity

Calorimetry selection
- Total energy deposited consistent with the proton rest mass
- Total net momentum consistent with Fermi Momentum
Selection strategy

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Selection strategy: Geometry & PID

We look for events that meet all the selection criteria: important background.

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- ✔ e identification
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- ✔ Proximity

**3D Planarity**

**Calorimetry selection**
- Total Energy deposited
- Total net momentum
Selection strategy: Calorimetry

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✓ $\pi^0$ identification
✓ e identification
✓ No additional vertex activity
✓ Proximity
3D Planarity

Calorimetry selection
✗ Total Energy deposited
✗ Total net momentum
Some example modes

- $p \rightarrow e^+ \pi^0$
  - Standard candle

- $p \rightarrow \mu^+ \gamma$
  - High bkg channel

- $p \rightarrow K^+ \bar{\nu}$
  - Golden channel in LAr
Simulated Event Display for $p \rightarrow \mu^+ \gamma$
Simulated Event Display for $p \rightarrow \mu^+ \gamma$ with cosmics data overlay
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Fiducialization
Selection strategy

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Selection strategy: geometry

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Selection strategy: geometry

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- ✗ γ identification
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- ✗ Proximity
- 3D Planarity

**Calorimetry selection**
- ✔ Total energy deposited
- ✗ Total net momentum

**Fiducialization**
Selection strategy: calorimetry

We look for events that meet all the selection criteria:
important background.

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Planarity

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Fiducialization
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3D Planarity

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- ✗ Total energy deposited
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**Fiducialization**
\[ p \rightarrow \mu^+ \gamma \] signature in 2D

We look for events that meet all the selection criteria:

important background.

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Calorimetry selection
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Calorimetry selection
✓ Total energy deposited
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Fiducialization
p → μ⁺γ signature in 2D

We look for events that meet all the selection criteria:
important background.

Geometry selection & PID
✓ μ/π identification
✓ γ identification
✓ No additional vtx activity
✓ Proximity
✓ 3D Planarity?

Calorimetry selection
✓ Total energy deposited
✓ Total net momentum
✓ Fiducialization?
The shower activity of the event is very close to the edge of the TPC: event rejected by planarity and fiducialization.
Selection strategy: fiducialization

Run 1593 Event 215. August 19th 2015

The shower activity of the event is very close to the edge of the TPC: event rejected by planarity and fiducialization.
Visual summary

In the first MicroBooNE events, we’ve seen…
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In the first MicroBooNE events, we’ve seen...

... and more to come!
Takeaways

Even in the initial MicroBooNE cosmics data, we are seeing for the first time topologies of interest for proton decay searches in a LAr.

This analysis is in progress. The goal is to produce full characterization and analysis of cosmogenic backgrounds mis-ID rates.

With MicroBooNE (a 100 ton scale experiment), we can measure backgrounds, as well as develop strategies and reconstruction tools critical for future LArTPCs proton decay searches.
Thanks for the attention!

... if you want to hear more about MicroBooNE, don’t forget to attend our run coordinator’s (Matt Toups) talk tomorrow!
Back up
Simulated Event Display for the $p \rightarrow K^+\nu^-$

Event display of a simulated $p \rightarrow K^+\nu$ proton decay mode.
MicroBooNE is a 170 ton LArTPC in the Booster Neutrino Beam at Fermilab. While the mass is not sufficient to explore $\tau_P$ not already excluded. Surface position and currently taking cosmic data: perfect venue to study

**Cosmogenic Backgrounds in a LArTPC.**

Test the potential of LArTPC in proton decay searches.