

The Necessity of DUNE Intranuclear $B - L$ -Violating Searches for a World- Leading, Complementary Physics Program

by [J. L. Barrow](#)

Snowmass Early Career Neutrino Frontier
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Please see the associated [Letter of Interest](#), and references therein



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Theoretical Points

Why $B - \mathcal{L}$ Violation?

How do we understand
baryogenesis?

SCIENCE AND TECHNOLOGY

Astrophysicists prove Big Bang
was result of gender reveal party
gone wrong

1 WEEK AGO by MARY GILLIS (@LIVING_MARBLE)



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Can $\Delta B = \Delta L$ Remedy the Baryon Asymmetry?

- Baryon (B) and lepton number (L) are violated *infinitesimally* in the SM due to anomalies
- The SM nonperturbatively conserves $B - L$ ([t'Hooft 1976](#))

$$\Rightarrow \Delta B = \Delta L$$

- It turns out that no theory that operates within the SM has produced a proper baryon abundance ***yet, fully and consistently—EWBG???***
 - **Topological tunneling** is completely ***inadequate***
 - The **sphaleron** mechanism still ***washes out*** any asymmetry we would see today ***if*** when they are generated they conserve $B - L$

[A. D. Dolgov, *Baryogenesis, 30 Years Later*](#)

M. E. Shaposhnikov et al [1993](#) and [1998](#)

Figure 1
corresp

The short answer?

NO!

Proceed by contradiction...

SHOULD

$B - L$

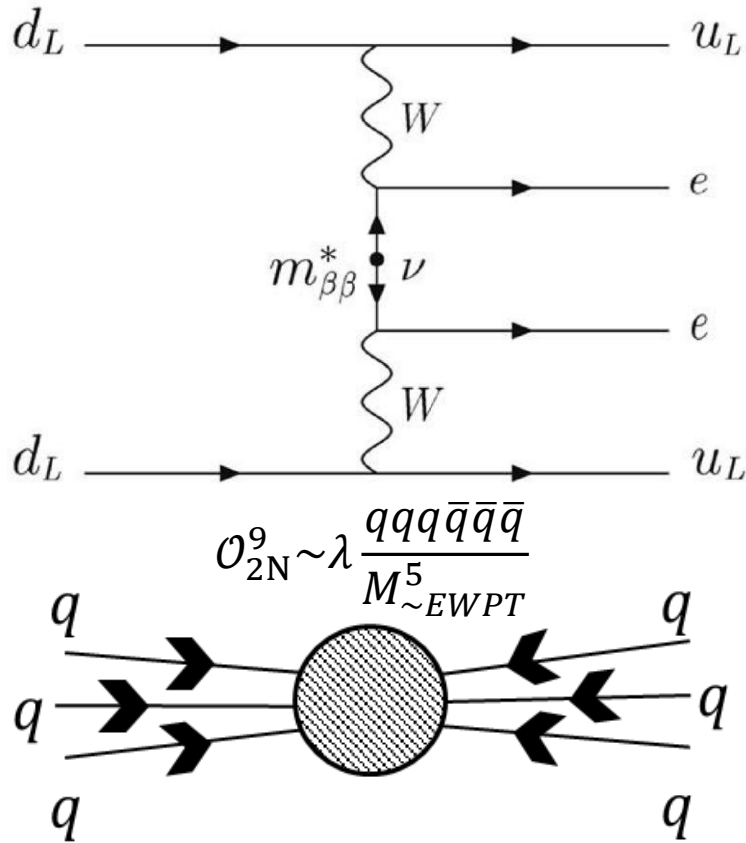
BE VIOLATED???

Maybe...

But let's be more *conservative*, and focus on observing processes with

$\Delta B \neq 0$

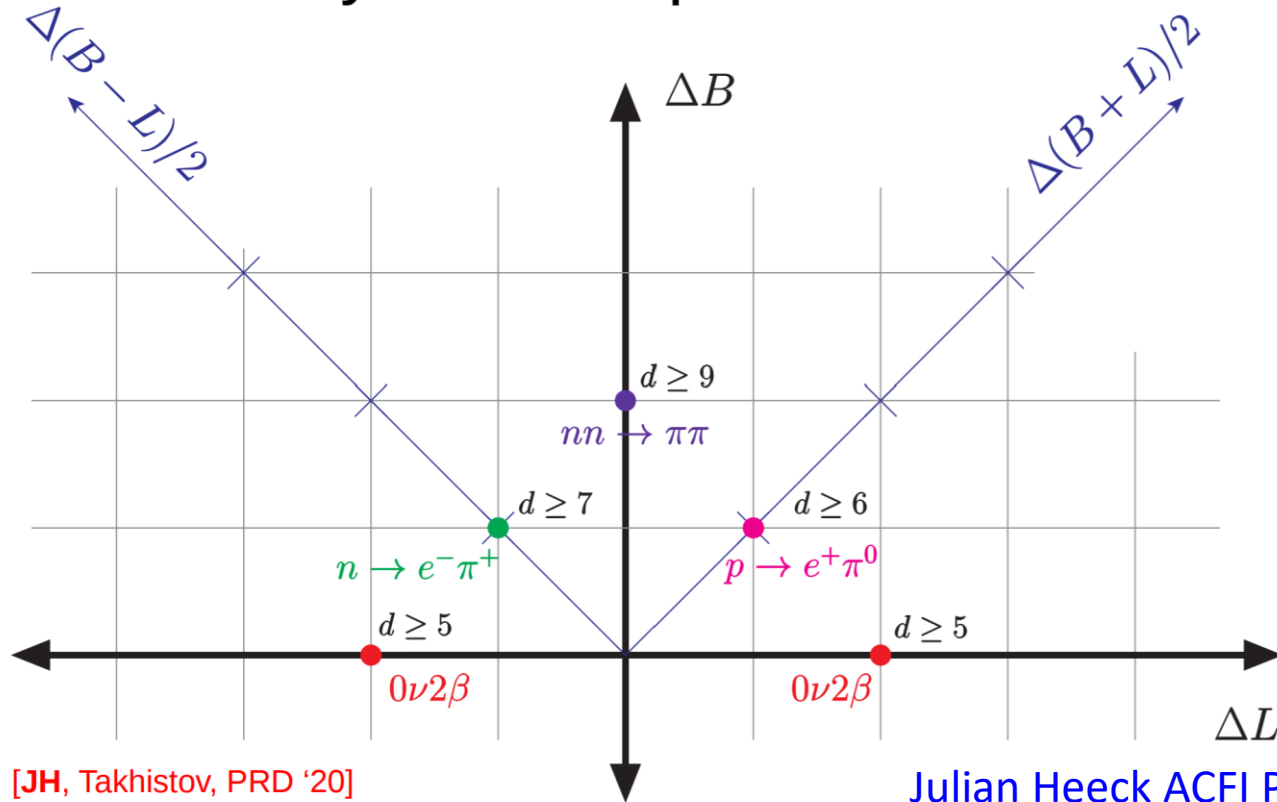
Going Beyond the Standard Model



What else do we need to add?

- Proton decay? $\propto qqql \Rightarrow B - L$ conserving
 - Important to some BSM GUT SUSY theories
 - No experimental evidence in large volume detectors
 - LHC has turned up no persistent signs of SUSY
- Some other kinds of $\Delta B \neq 0$ or $\Delta L \neq 0$?
 - $\Delta B = 2$ operators?
 - $\Delta L = 2 \Rightarrow$ leptogenesis?
- Why some over others?
 - Can they properly generate the baryon asymmetry of the universe?
 - At what energy scales can these theoretically produce the correct value?

Baryon and lepton number

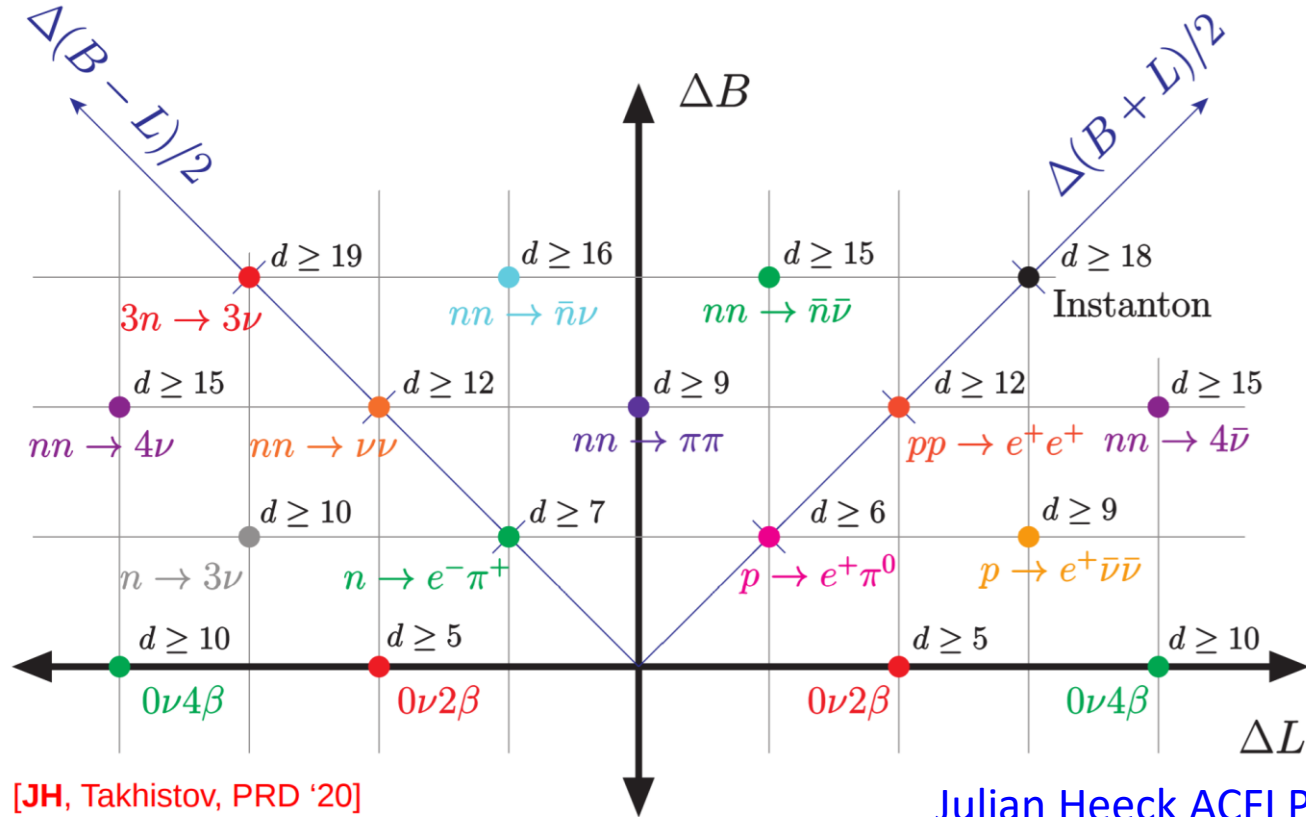


ACFI, 8/6/20

Julian Heeck

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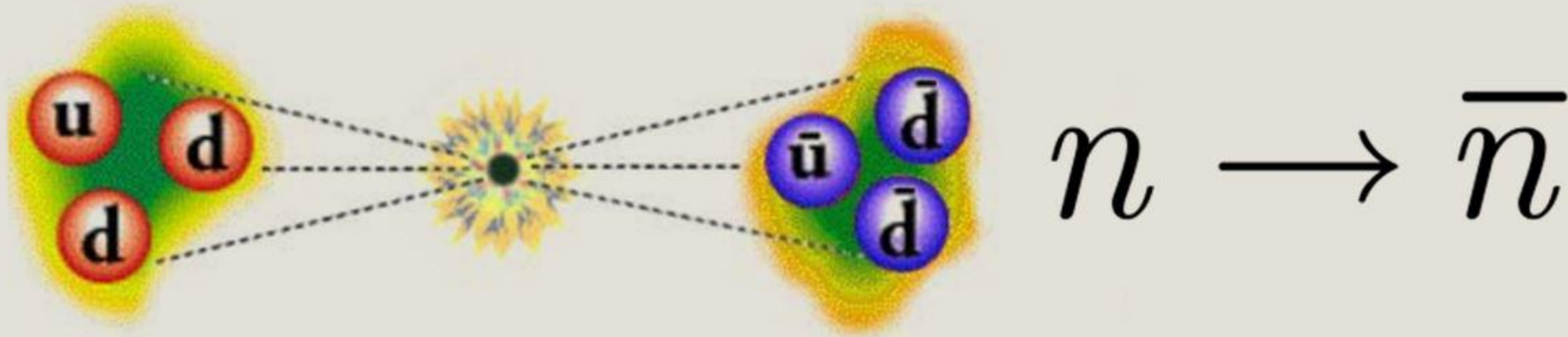
Exotic ΔB and ΔL



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A Few (MC Truth) Considerations

Toward the Future

Consider $\mathcal{B} - \mathcal{L}$ -violating $n \rightarrow \bar{n}$

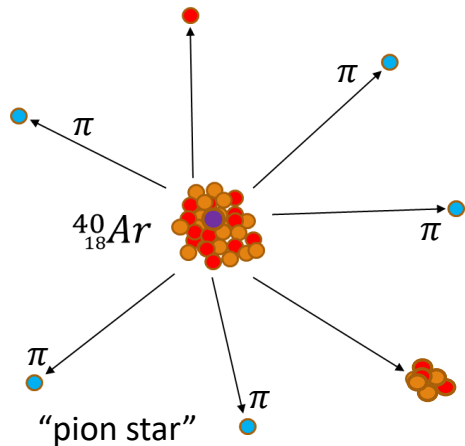
Understanding Modeling Systematics Beyond Previous Ad-hoc Assumptions

Signal Comparison

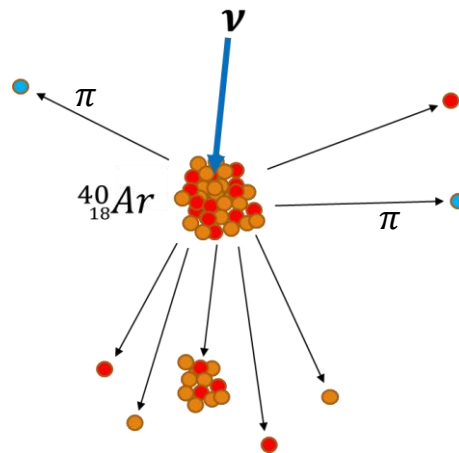
$n \rightarrow \bar{n}$ vs. Backgrounds (ex: Atmospheric Neutrino, ν)

- $n \rightarrow \bar{n}$ Annihilation and Knockouts

- Neutral Current Atmospheric ν



- ~Noncontinuous energy spectrum
- Generally a ~spherical topology
- ~Low momentum due only to Fermi motion



- Continuous energy spectrum
- Generally a ~correlated topology
- Large range of total momentum

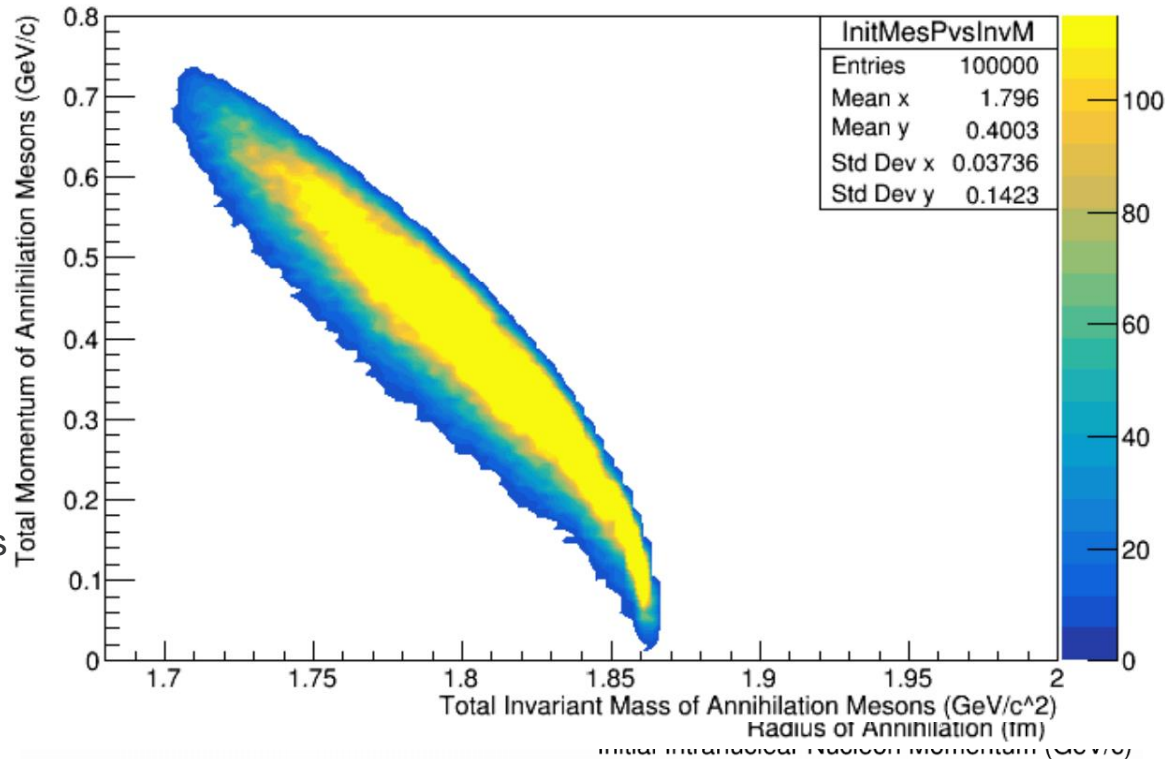
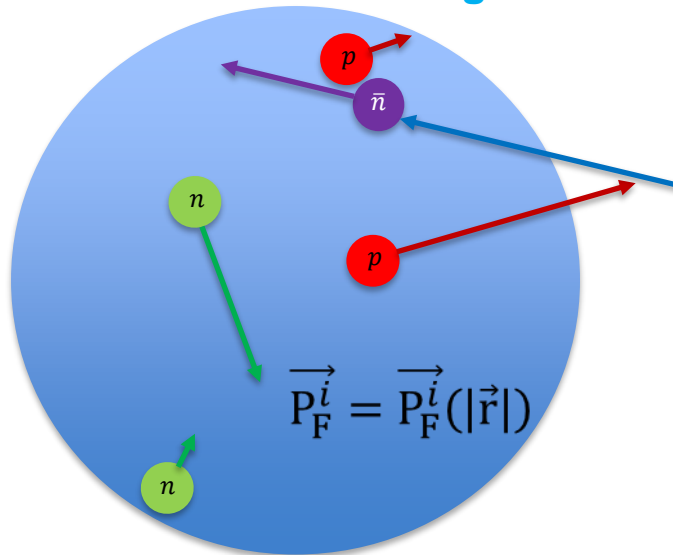
- - Antineutron
- - Neutron
- - Proton
- - Pion

Goals of Ongoing Studies

- Utilize realistic models of rare process signals and associated backgrounds
 - Integration of the newest *nuclear model configurations* available in GENIE [and other \$n \rightarrow \bar{n}\$ generators from Golubeva et al.](#) into full DUNE reconstruction chain underway
 - Fully oscillated atmospheric neutrino fluxes/spectra; expected counts complete
 - Proper ν_τ CC-interactions *and subsequent τ decays underway* (issues with GEANT)
- Approximate uncertainties in signal and background topologies
 - Iterate across many nuclear model configurations *and generators* as possible
- Automate analysis techniques to extract expected lower limits of many rare processes
 - *Generate many different samples for many different signals over many different nuclear model configurations, producing outputs from many individually trained CNN/BDTs*

The Importance of Some Initial Physical Correlations

Consider a local Fermi gas nuclear model of Fermi momentum (initial state)

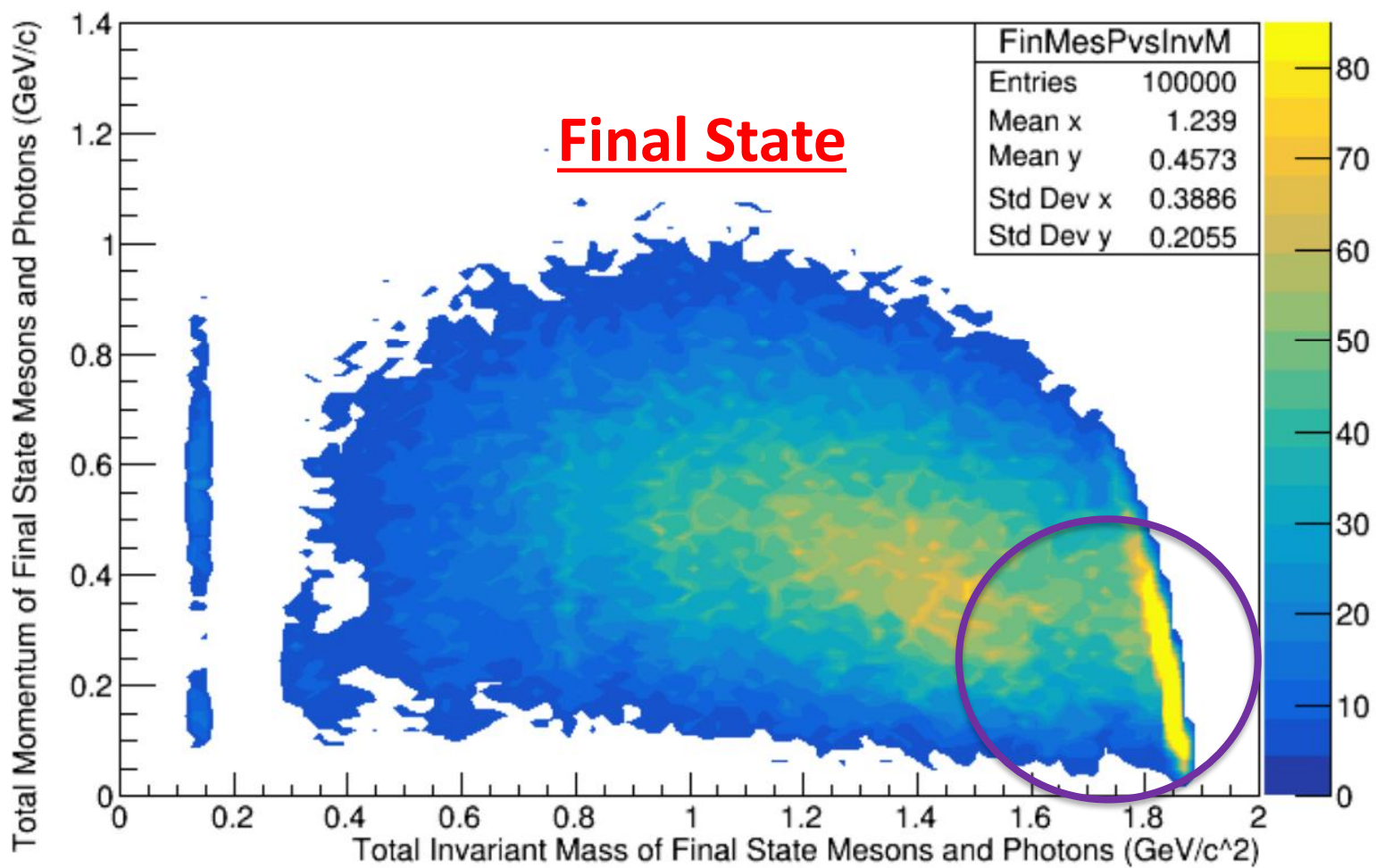


The correlation of radius and momentum has been previously ignored for *all* $n \rightarrow \bar{n}$ simulations in *all* experiments

High radii lead to...

- Fewer FSIs, more meson emission
- Lower total momentum (near *ideal* case)

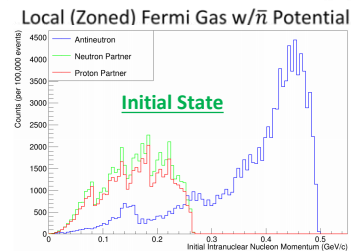
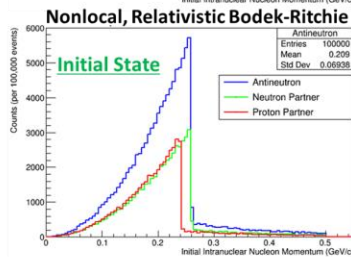
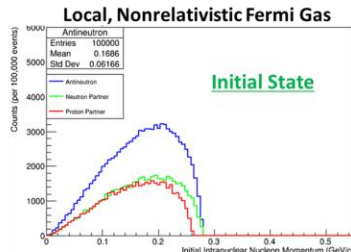
Paryev's [distribution](#)



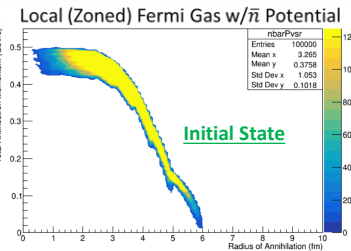
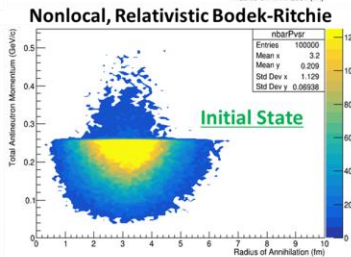
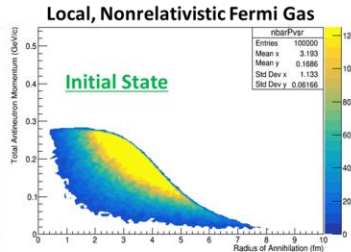
Model Dependencies in Final State Topologies are Being Investigated

First foray into this study detailed in [our recent PRD](#)

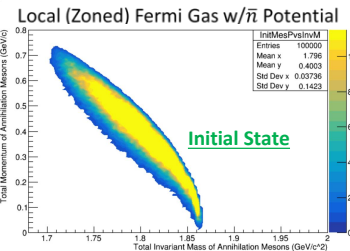
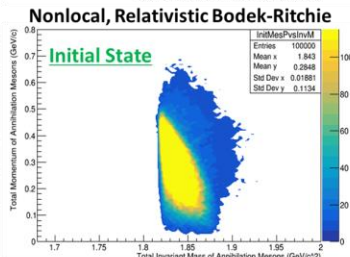
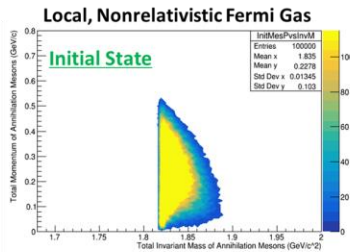
- Compares many GENIE models to our generator work with E. S. Golubeva



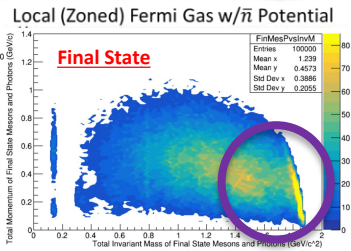
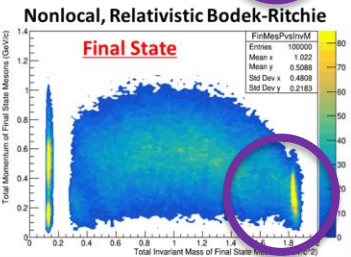
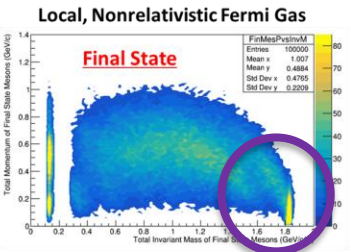
Example single nucleon (p, n, \bar{n}) Fermi motion momentum distributions are shown for GENIE & Golubeva. These serve as the starting conditions for all annihilation products.



Example \bar{n} momentum vs. radius distributions are shown for GENIE & Golubeva. Annihilation near the nuclear surface may lead to low momentum products with aspherical topologies.



Example initial annihilation product distributions are shown for GENIE & Golubeva. Different initial conditions, & preservation of radial correlations, may effect the final topology.

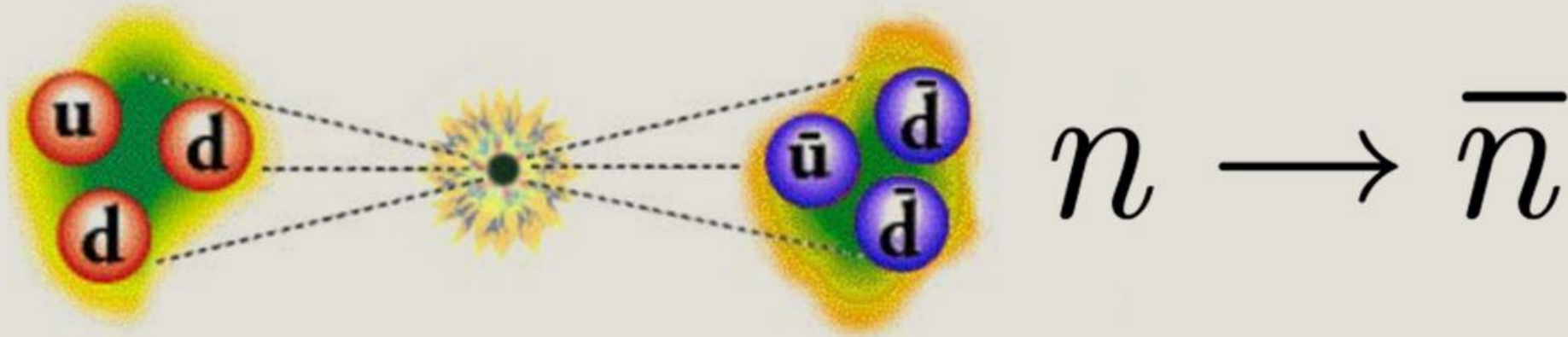


Example final pionic parameter spaces are shown for GENIE & Golubeva. Some localization of events might imply more complete signal to background separation in automated analyses.



Summary and Conclusions

- [DUNE shows potential to reach \$\tau_{n\bar{n}} \geq 5.58 \times 10^8 s\$ lower limit](#)
- Improvements are sought via...
 - Better reconstruction can hopefully lead to better ROI selection
 - BDT input of CNN PID for better cuts against background
- Iteration over nuclear model configurations underway
 - Will allow us to test stability of CNN/BDT response to various topological differences
 - Effectively determine model systematics
 - Will $S:B$ remain the same independent of the nuclear model configuration?



[Theoretical Innovations for Future Experiments Regarding Baryon Number Violation, Part 1](#)

ACFI WORKSHOP ON $\Delta\mathcal{B} = 2$

Associated Letter of Interest

[\$\Delta\mathcal{B} = 2\$: A state of the Field, and Looking Forward](#)

Associated Book of Abstracts (Short Proceedings)

[\$|\Delta\mathcal{B}| = 2\$: A State of the Field, and Looking Forward](#)

[A brief status report of theoretical and experimental physics opportunities](#)