Neutron Oscillations – overview

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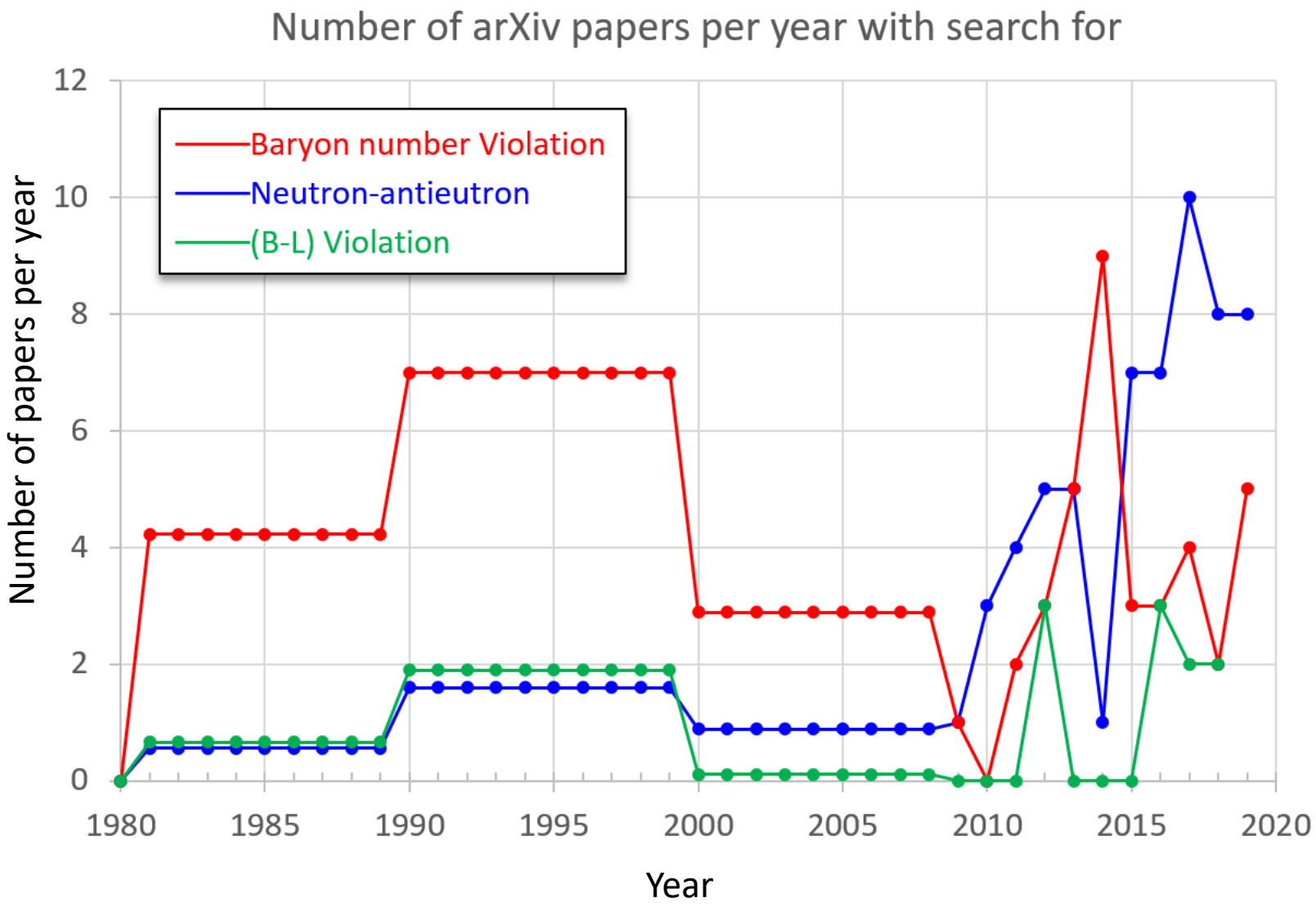
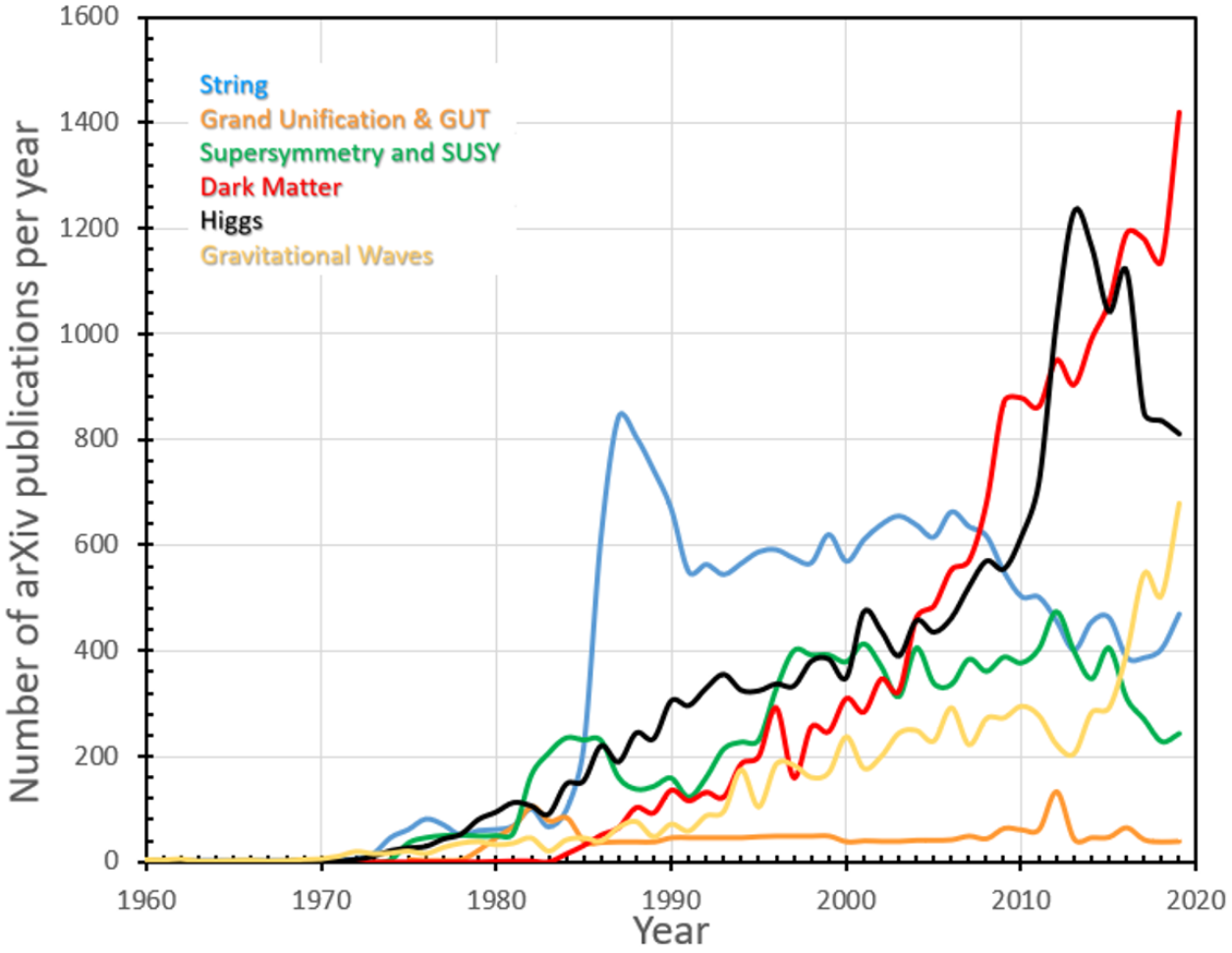
How often physics of n-bar is being discussed in the literature?



For comparison with other popular topics in HEP



Nevertheless, physics that we pursue addresses fundamental questions:

$n \to \bar{n}$ → baryogenesis (mechanism of matter-antimatter asymmetry)

$n \to n'$ → possible nature of Dark Matter

But remember the story of David and Goliath …

Recent significant events for $n \to \overline{n}$ and $n \to n'$ discussions

1. NT Workshop INT-17-69W: Neutron Oscillations: Appearance, Disappearance, and Baryogenesis October 23 - 27, 2017, INT, University of Washington, Seattle, http://www.int.washington.edu/PROGRAMS/17-69W/

2. "NORDITA" workshop at Stockholm University: Particle Physics with Neutrons at the ESS, 10-14 December 2018, https://agenda.albanova.se/conferenceDisplay.py?confId=6570

3. The 2019 International Workshop on Baryon and Lepton Number Violation (**BLV2019)** IFT, Madrid, October 21-24, 2019 https://indico.cern.ch/event/754031/timetable/#all.detailed

   My talk there: https://indico.cern.ch/event/754031/contributions/3217619/attachments/1929672/3195696/YK-BLV-2019.pdf
   Josh Barrow poster and talk: https://indico.cern.ch/event/754031/contributions/3586543/attachments/1930445/3197159/Presentation-JLBarrow_SPLIT_ForPosting.pdf

4. Nuclear physics neutron community workshops at ILL, PSI, Mainz, …

5. European Particle Physics Strategy Update 2018-2020
   https://council.web.cern.ch/en/content/european-strategy-particle-physics-update-2018-2020

6. Next BIG event is USA: Snowmass 2021 Planning process is starting now
   https://www.aps.org/units/dpf/snowmass-2021.cfm

   NNbar collaboration proposed conveners for neutron-oscillation topical group at Snowmass:
   Leah Broussard (ORNL), Giorgia Karagiorgi (Columbia University), Josh Barrow (University of Tennessee)

Menu of potentially observable processes in neutron oscillations for BLV

- $\Delta B = -2$ search known as $n \leftrightarrow \bar{n}$, it also violates $(B - L)$
  D.G. Phillips II et al., Phys. Rept. 612, 1 (2016).
- $n \leftrightarrow \bar{n}$ in the presence of $(B - L)$ massive field
  A. Addazi, Z. Berezhiani, YK, Eur. Phys. J.C. (2017) 77:301.
- Connection of n to Dark Mirror Matter: $n \to n'$
  Z. Berezhiani, L. Bento, PRL **96,** 081801 (2006) and after
- $\Delta B = -1$ search ($n \to n'$ disapperance and regeneration)
  Z. Berezhiani, M. Frost, Y. Kamyshkov, B. Rybolt, L. Varriano, Phys. Rev. D96 (2017) no.3, 035039
- Neutron Transition Mag. Moment
  Z. Berezhiani, R. Biondi, YK, L. Varriano, Physics 2019, Volume 1, Issue 2, 271-289
- $n \to \bar{n}$ through mirror transformation Z. Berezhiani (2018)
- Complementarity of intranuclear $n \to \bar{n}$ processes
  (Josh Barrow talk at BLV-2019 for DUNE experiment and references therein)

Possible NNbar/ESS Collaboration with ORNL

Effort to create collaboration between NNbar at ESS and Oak Ridge National Laboratory for preparation of big n-nbar experiment at ESS around 2030 and for participation in the measurements at ANNI beam in ~ 2023-2027.

- Meeting of **David Milstead** and **Gustaaf Brooijmans** with ORNL new Physics Division Head **Marcel Demarteau** on February 4-th, 2020.
  The idea is to have ORNL involved in Collaboration with NNbar ESS project with neutronic, engineering, and physics support for US group participating at ESS/NNbar.
  It is expected that ORNL group and University groups will be supported by DOE/HEP.

Group of US Universities around the ORNL
is preparing a proposal to DOE/HEP (due January 22, 2020) for
Development of Experimental Program to Search for Free $n \to \bar{n}$ Transformations
for 3 years 2020-2023

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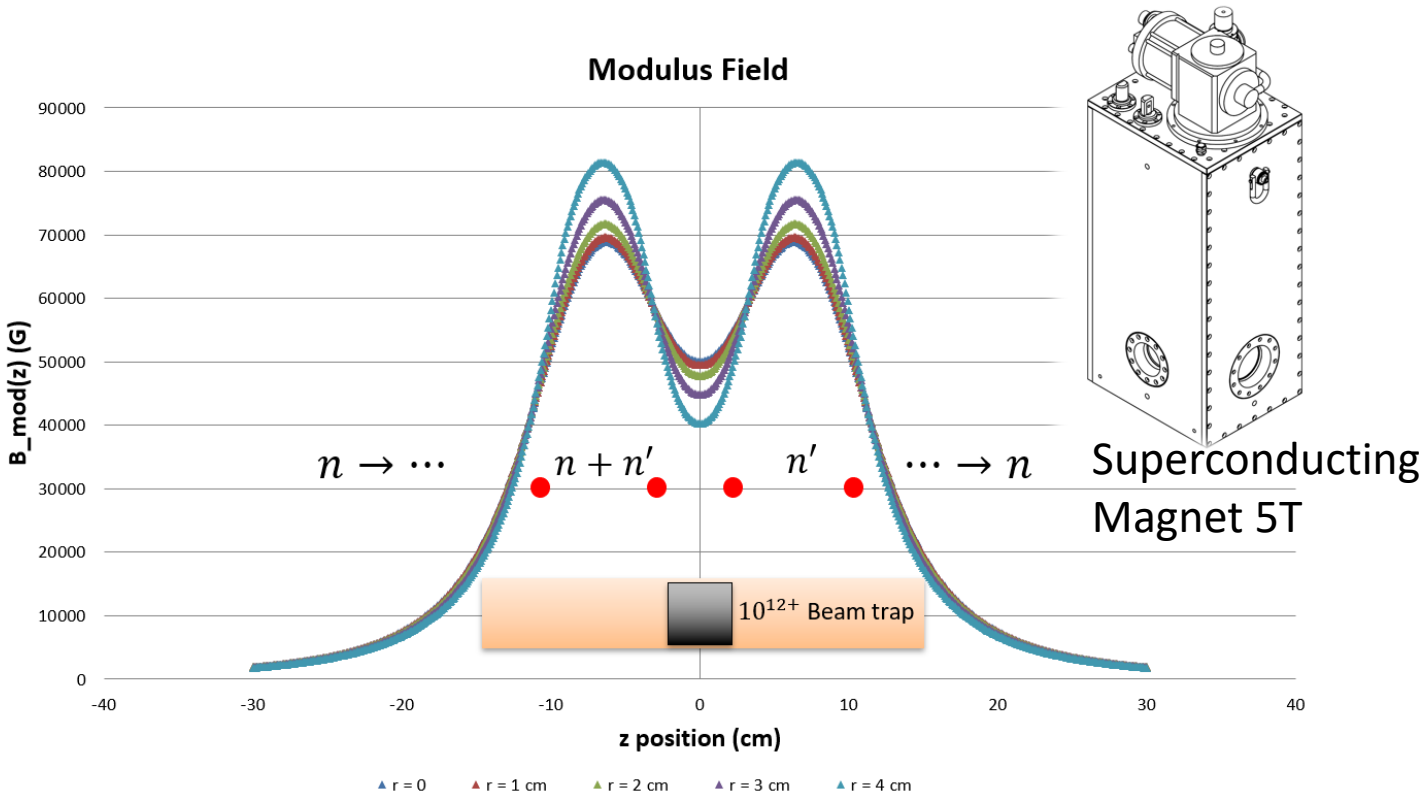
This proposed program will include work of the universities together with ORNL on the

- ORNL/NNbar Collaboration at ESS
- Evaluation of neutron sources available in US for nnbar search
- Development and evaluation of the experimental methods for $n \to n'$
- Performing $n \to n'$ disappearance search with sensitivity available at ORNL (HFIR GP-SANS). If at this level of sensitivity the $n \to n'$ disappearance will be detected, then perform search of $n \to Mirror\ states \to \bar{n}$ in a constant magnetic field $B = B'$
  [Similar search can be repeated later on with higher sensitivity at ESS/ANNI]

- Proposal will be submitted on January 22. We will know whether DOE will fund the program in several months, hopefully by July 1-st or later.

Small regeneration experiment was performed at SNS in August 2019 by ORNL-UT group to test the idea proposed in the Berezhiani paper https://link.springer.com/article/10.1140%2Fepjc%2Fs10052-019-6995-x where Mirror and Ordinary neutrons are slightly non degenerate by mass for the order of $\Delta m \sim 100\ nT$. Measurement took 24 hours of beam time. Results of the experiment are currently analyzed and will be published soon.



August 2019

Another proposal was submitted on December 3, 2019 to the
National Science Foundation (NSF) from 3 Universities:

Search for Hidden Sector Neutrons at High Flux Isotope Reactor

Indiana U	W. Mike Snow and Chen-Yu Liu
Kentucky U	Chris Crawford
U. of Tennessee	Mike Fitzsimmons, Lawrence Heilbronn, Yuri Kamyshkov

ORNL as national laboratory is not allowed to be funded by NSF

We proposed to perform at GP-SANS instrument at HFIR reactor as a user's facility for three years (2020-2023) three experiments:

Measurement using regeneration scheme the nTMM in the range $\eta = 10^{-5}\mu$
that is interesting for the explanation of neutron beam-trap lifetime difference
Z. Berezhiani, R. Biondi, YK, L. Varriano, Physics 2019, Volume 1, Issue 2, 271-289

A. With the method of Fermi potential compensation by magnetic field
B. With the method of gradient separation of oscillating components
and separately:
C. Search for $n \to n'$ disappearance with the magnetic path of 16 m at GP-SANS

GP-SANS Instrument at HFIR

3.5 m space

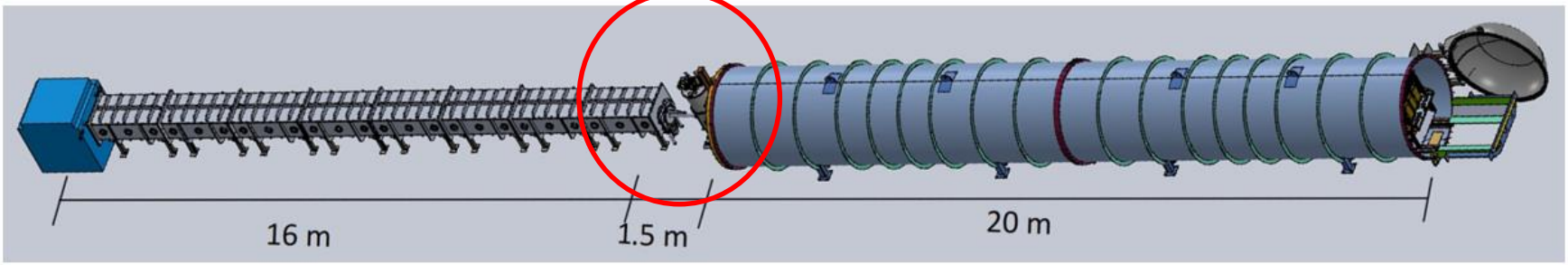


FIG. 4. Design model of the collimator system currently installed in GP-SANS beamline at HFIR. From left to right along the beam direction: inside the blue box beam shutter, velocity selector, and intensity monitor, followed by 16-m vacuum a collimation guide with 8 sections, 1.5-m instrumentation gap that can be flexibly extended to 3.5 m with replacing last 2-m section of the guide with instrumental table, and 20-m vacuum detector tank with shown open back door for detector services.

NSF Proposal Experiments A and B:

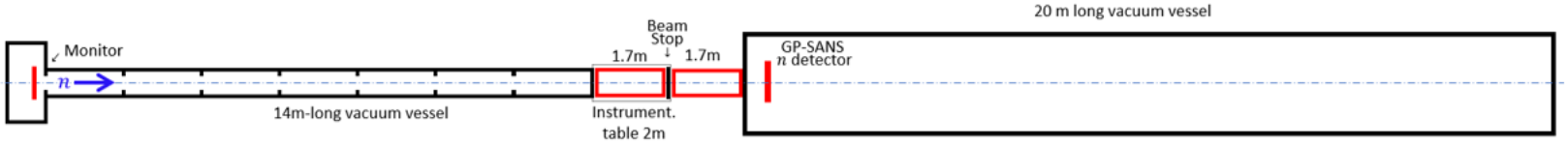


Figure 5. Configuration of Experiments "A" and "B" at GP-SANS

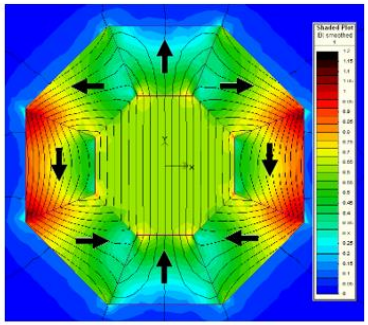


FIG. 6. Uniform field inside Halbach ring [34].

For several days of measurements with HFIR cold beam intensity $\sim 10^{10}\ n/s$ both methods A and B can provide limit on nTMM down to practically interesting value $\eta = 10^{-5}\mu$

If search of nTMM at HFIR will not detect the effect within $\eta = 10^{-5}\mu$, that can serve as an explanation for some UCN experiments, then further searches of nTMM at ESS or elsewhere might be not well motivated.

Disappearance $n \rightarrow n'$ search proposed for NSF

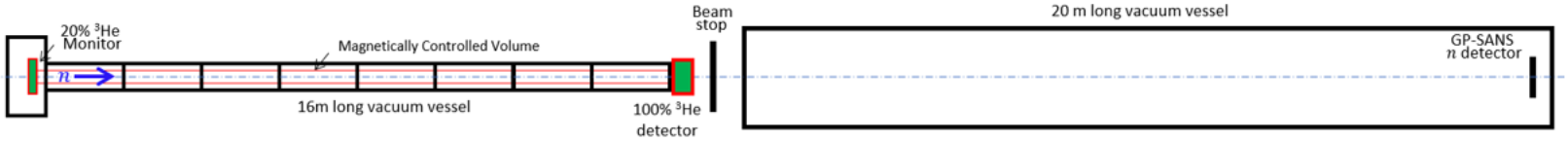


Figure 7. Configuration of Experiment "C" at GP-SANS

For magnetic field scan from -0.5G to +0.5 G with disappearance $n \rightarrow n'$ search oscillation time $\tau > 20$ s can be uniformly excluded for 10-20 days of beamtime.

At ANNI beam line with higher intensity (6.4/1.0)$\times 10^{10}$ n/s,
larger distance (54m/16m),
and more time for measurement (10 / 1)

Disappearance limit at ANNI can be pushed to $\tau > 400$ s

Our previous proposal that was sent to DOE/HEP Cosmic Frontier on May 30, 2010

Search for Dark Metter Particles in Neutron Transformations

Same suite of participants, but including ORNL

This proposal was NOT for doing experiments but only for development of the Technical Design Report for the next round of funding for the small experiments pursuing new methods in Dark Matter search. We proposed all possible variations of experiments that can be done using GP-SANS instrument at HFIR.

Proposal was declined in November as
“not having large chances for success” i.e. for discovering nature of Dark Matter