New Search for Mirror Neutrons at HFIR

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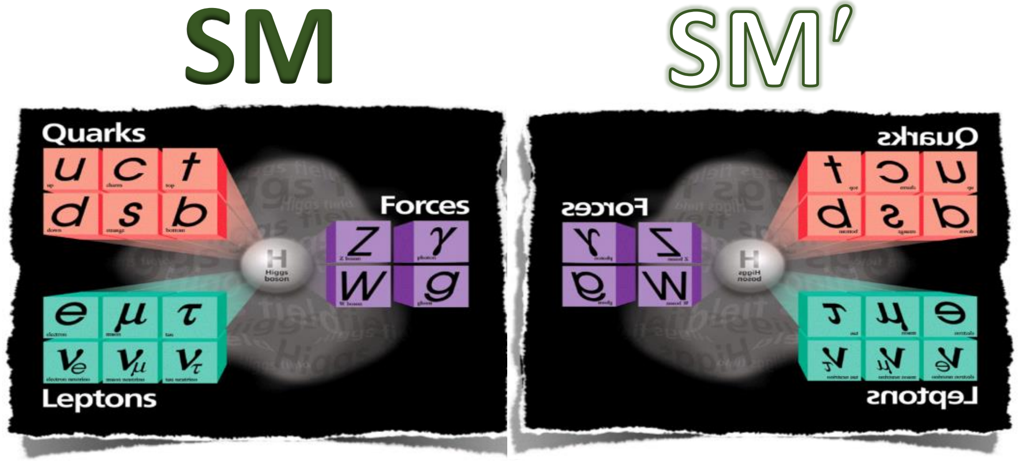
Mirror Matter



- Dark Matter candidate?
  - BBN/Cosmology requires T’/T ~ 0.2 → colder, He-dominated, smaller scale structure, faster star evolution[1,2]
  - DM halos?[3]
  - WIMPs/axions are well motivated, but time to consider other possibilities…
- Implications for Baryon Number Violation

[1] Z. Berezhiani, D. Comelli, F. L. Villante, PLB **503** (2001)
[2] R. Foot, Int. J. Mod. Phys. A **29** 1430013 (2014)
[3] J. Clarke and R. Foot, PLB **766** 29 (2017)

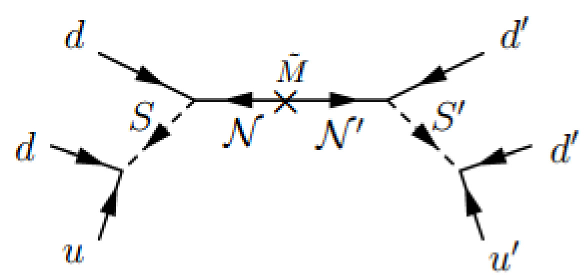
Neutron Oscillations

- Very testable prediction of neutral particle oscillations
  - Neutron: “turn on” oscillation with B field
- Weak experimental limits for fast neutron oscillation time!

$$\hat{H} = \begin{pmatrix} m - i\Gamma / 2 + \mu(\vec{B}\cdot\vec{\sigma}) & \varepsilon \\ \varepsilon & m' - i\Gamma' / 2 + \mu'(\vec{B}'\cdot\vec{\sigma}) \end{pmatrix}$$

$$\mathrm{P}(n \to n') = \frac{\sin^2[(\omega-\omega')t]}{[(\omega-\omega')]^2 2\tau^2} + \frac{\sin^2[(\omega+\omega')t]}{(\omega+\omega')^2 2\tau^2}$$
$$+ \cos\beta \left[\frac{\sin^2[(\omega-\omega')t]}{(\omega-\omega')^2 2\tau^2} - \frac{\sin^2[(\omega+\omega')t]}{(\omega+\omega')^2 2\tau^2}\right]$$

$\omega = \frac{1}{2}|\mu B|$, $\omega' = \frac{1}{2}|\mu' B'|$, $\mu = \mu'$ and $\tau = \frac{1}{\varepsilon}$

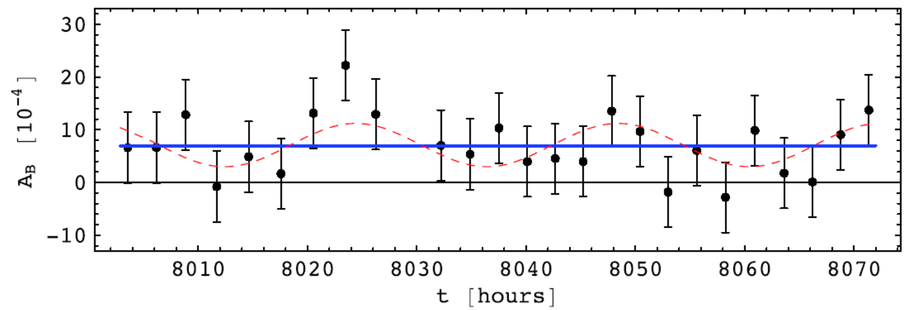


- Small B’ possible due to accumulated MM captured by earth

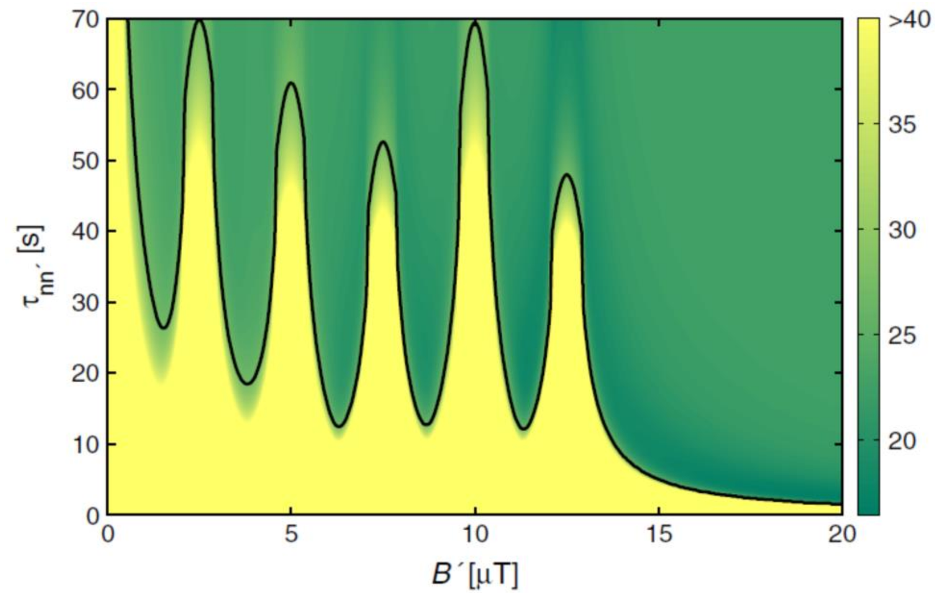
Berezhiani and Bento PRL **96** (2006) 081801

Prior n → n’ searches

- UltraCold Neutrons (UCN): search for very small fractional loss
- Fairly strong limits if B’=0 (τ > 448 s)[1]
  - Reanalysis found anomalous disappearance at B’ ~ 100 mG, τ ~ 10 s;
  - Systematic effect? Real signal?
- Second measurement: no signal < 12 s



Eur. Phys. J. C (2012) 72:1974

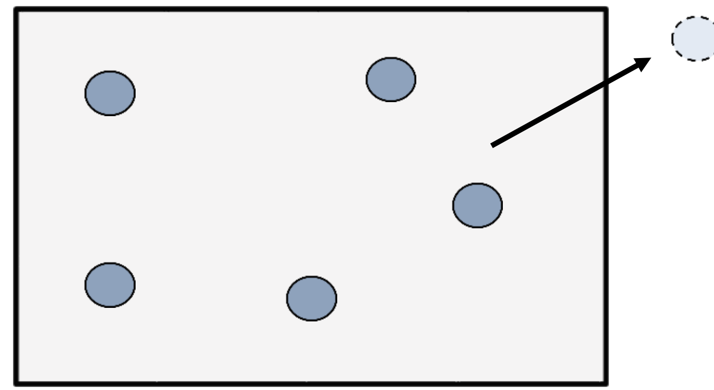


PHYSICAL REVIEW D **80,** 032003 (2009)

[1]A. P. Serebrov *et al*, *NIMA* **611** (2009) 137

Cold neutrons vs UCN

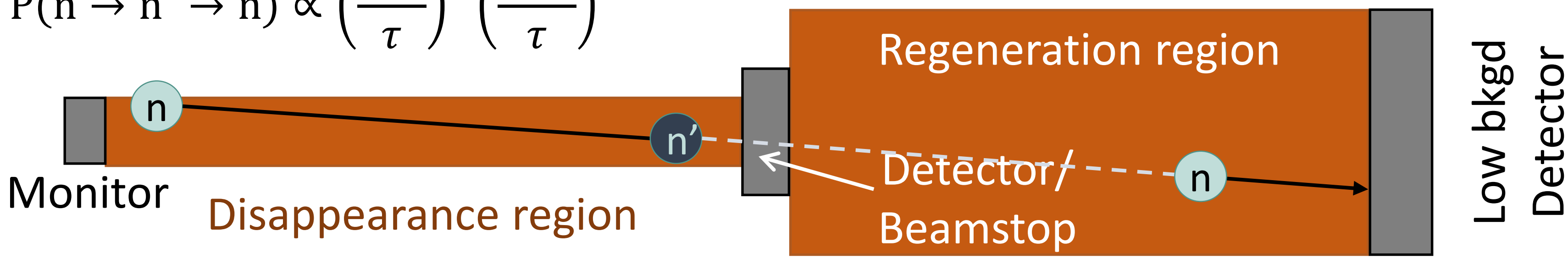
- Quick primer: CN "beam" (reflect at glancing angles) and UCN "bottles" (totally internal reflection)
- UCN sensitivity
  - Vary $\tau_{storage}$ vs $\vec{B}$
  - LOW statistics, uncertainty of normalization, loss mechanisms?
  - Can only search for disappearance n → n'



- CN sensitivity
  - Less compact, flux monitoring challenging
  - BUT: can search for unambiguous n → n' → n

Neutron Regeneration

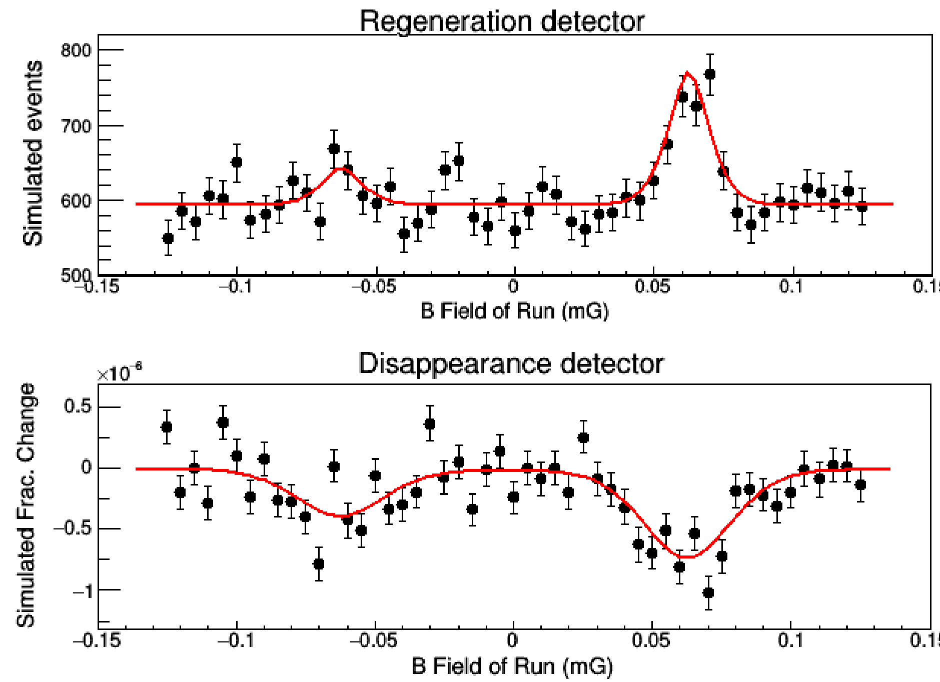
$$P(n \rightarrow n' \rightarrow n) \propto \left(\frac{t_{Dis}}{\tau}\right)^2 \left(\frac{t_{Reg}}{\tau}\right)^2$$



Wish List:

- High cold neutron flux + long, large area guides
- Disappearance: precise monitoring of changes in transmission
- Regeneration: large area, low background detector
- Magnetic field uniformity and control

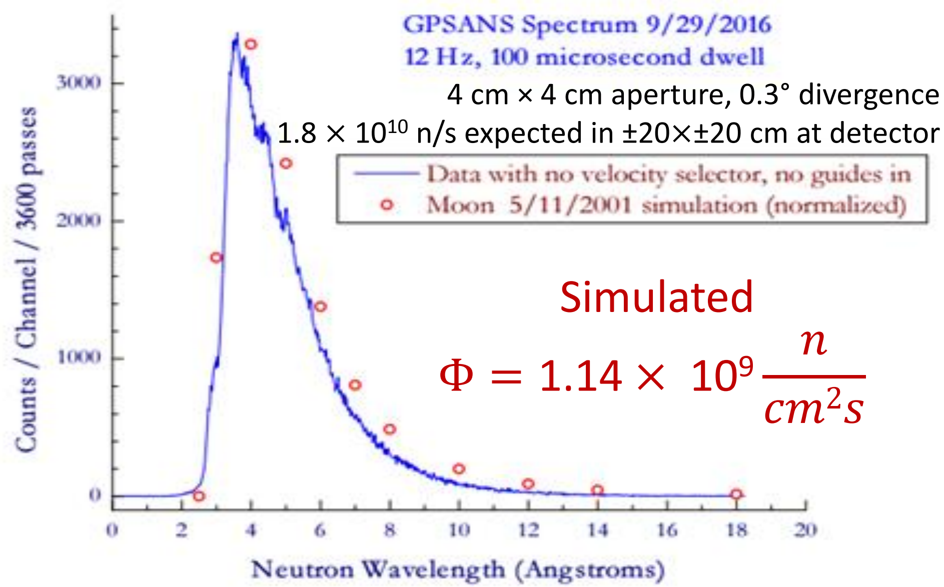
Simulated assuming τ = 14 s using HFIR flux/geometry



Z. Berezhiani *et al*, *arXiv:1703.06735*

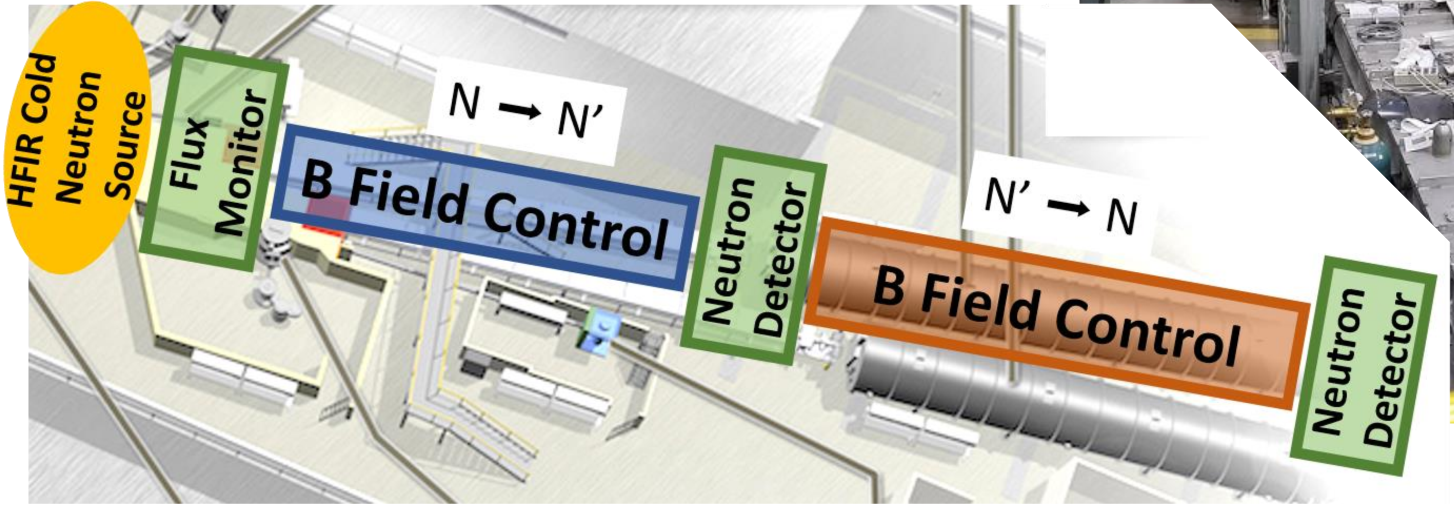
GP-SANS at HFIR

- High Flux Isotope Reactor at Oak Ridge Nat'l Lab
- 85 MW reactor: highest reactor based source of neutrons for research in US
- Also considering NIST, SNS
- GP-SANS beamline: 1.8×10^{10} n/s
- At τ = 15 s:
  10^4 n→n' per s
  0.05 n→n'→n per s



GP-SANS at HFIR

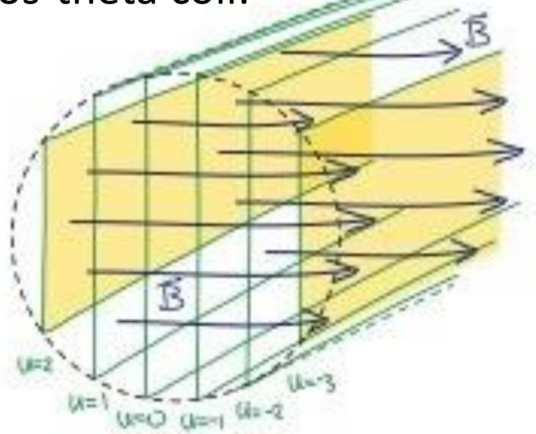
- Hostile takeover of existing instrument: General-Purpose Small Angle Neutron Scattering
- 14 m "Disappearance" and 20 m "Regeneration" beamlines
- Existing large area, low(ish) bkgd detector in shielded chamber
  - BONUS: movable!
- Room for B control coils, monitors

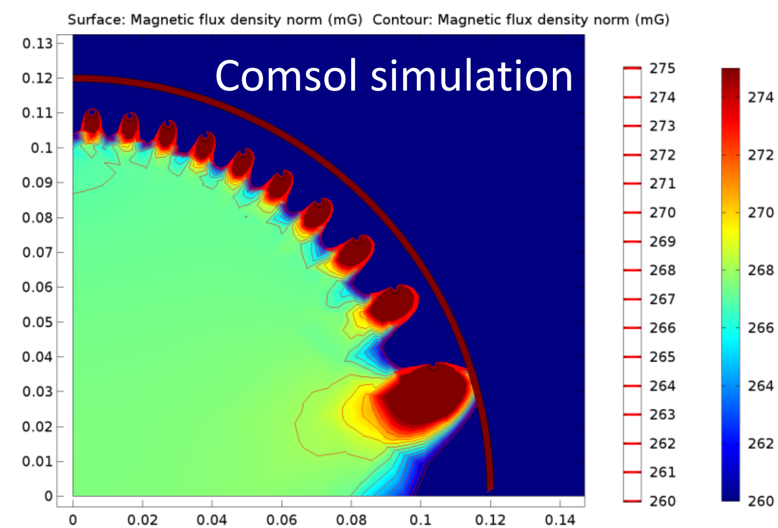


Magnetic field uniformity

- 20 mG spatial and temporal non-uniformity
  - Short duration 500 mG spikes
  - Some “hot spots” → beamline upgrade
- Design goal ~2 mG uniformity
  - solenoid (z) and Cos-theta coils (x-y)

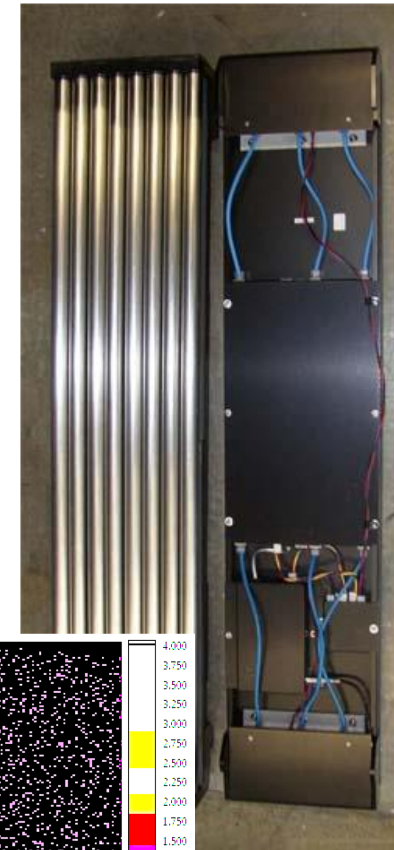
Cos-theta coil:

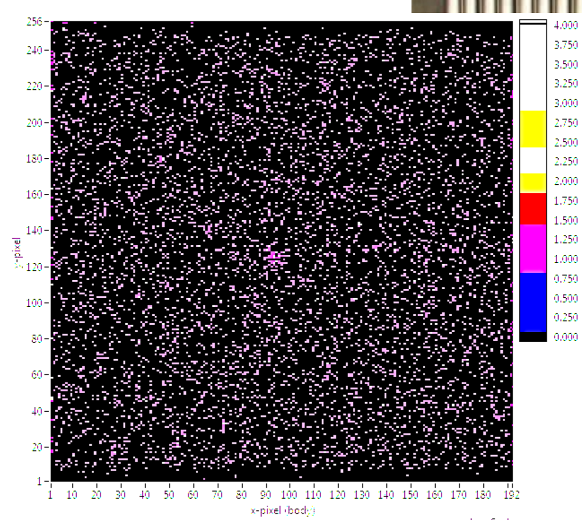




Regeneration detector

- Sensitivity depends on Signal to Background
- 1 m x 1 m ^{3}He, position-sensitive detector[1]
  - $n+{}^3He \rightarrow t+p$
  - Large signal, well defined amplitude, insensitive to gamma radiation
  - 5 mm x 5 mm position resolution
- 2 x 10^{-4} cps/cm^2 background
  - Primarily from cosmogenic neutrons, moderated by concrete floor
  - Rely on position cuts and additional shielding/veto
  - Goal: 0.05 cps total

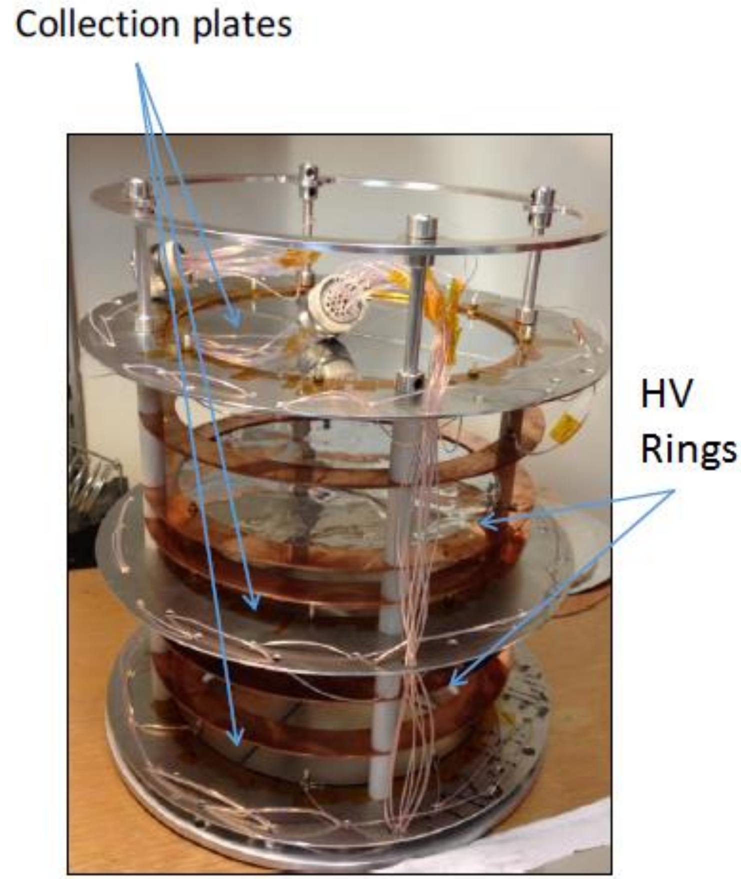




[1]K. D. Berry *et al*, *NIMA* **693** (2012) 179

Neutron flux monitoring

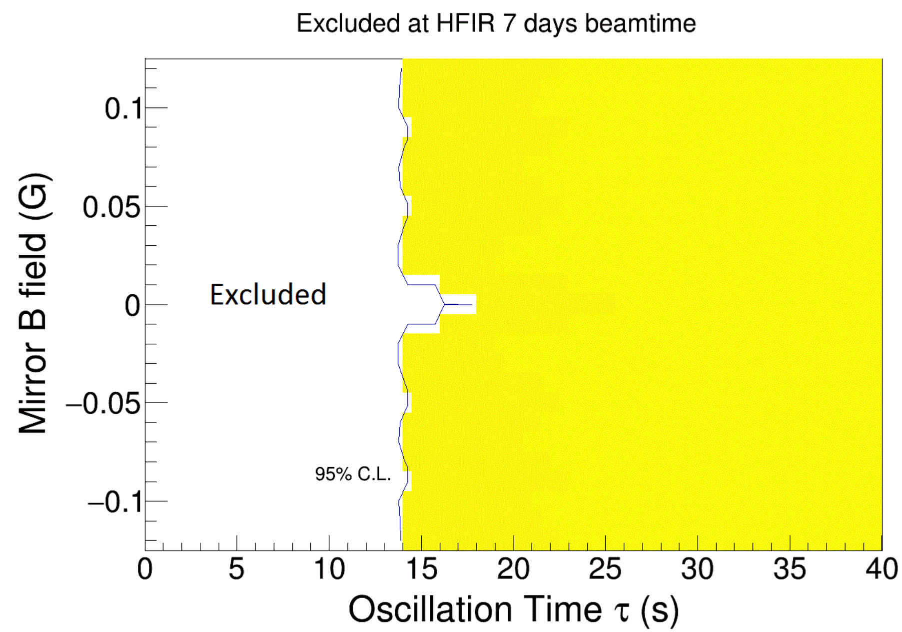
- Require 10^{-7} level monitoring of neutron flux (disappearance only)
- Detector designed for n-^{3}He spin rotation experiment (Indiana U.)
- Flux monitoring ~ $1.1\sqrt{N}$
    - Demonstrated for 10^{-8} level asymmetry measurements
- Segmentation suppresses systematic, 1/f beam noise cancellation
- Monitor sequence cancels linear, quadratic drift (+ - - + - + + -)



[1]S. D. Penn *et al*, *NIMA* **457** (2001) 332

Expected Sensitivity

- Assumptions:
  - Simulated HFIR flux/ beamline
  - Bkgd as measured
  - Statistics limited monitoring (50% monitor)



- Cover parameter space of UCN expts in 1 week beamtime
  - $\tau < 14$ s (95% C.L.)
  - Key: GP-SANS heavily subscribed

What's next?

- Demonstrate feasibility
  - Prototype short section of magnetic field control
  - Demonstrate flux monitoring for disappearance
- Phase 1: Disappearance
  - Collimation upgrade in 2018 or 2019 (eliminate magnetic materials)
  - Flux monitor characterizations (10^{-7} level)
  - Implement mG-level magnetic field control
- Phase 2: Regeneration
  - Implement mG-level magnetic field control (limited access to chamber)
  - Implement additional background detectors, shielding, active veto system
- Expect to achieve interesting limits with very modest costs!

n → n' Collaboration

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