Yuri Kamyshkov

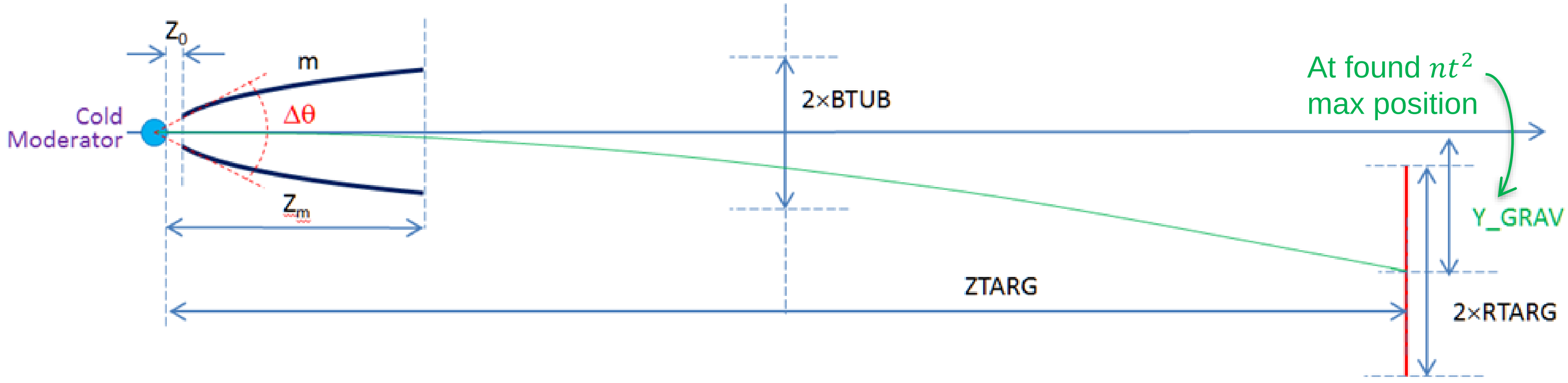
*Possibility for another experiment with MAGREF at SNS*

# Understanding the retaining of the oscillation phase in reflection from highly absorbing materials.

It is about $n \to \bar{n}$ rather than for $n \to n'$

# Large elliptical focusing reflector with m=6 was proposed for ESS $n \rightarrow \bar{n}$ experiment

$n \rightarrow \bar{n}$ Baseline Configuration for Simulation (2015)




- Elliptical Reflector Section
  - Minor Radius (BTUB) 2.00 m
  - Source-to-Target Distance (ZTARG) 200 m
  - Entrance/Exit Position ($Z_o$/ $Z_m$) 10/50 m
  - Reflectivity (m) m=6
  - RTARG (annihilation target radius) 1.00 m
  - *cold* source model variable

<u>Focusing idea:</u>
Neutrons emitted withing large $\pm 5°$ aperture by single reflection should be directed to annihilation target

In vacuum with B=0
($\mu_n = -\mu_{\bar{n}}$ from CPT)

$$P(n \rightarrow \bar{n}) = (\epsilon t)^2$$

! Challenges ≡ cost
! Will be difficult to assemble
+ 200m × dia 4m vacuum tank
+ magnetic compensation screen
+ large volume rad. shielding
+ building with floor and crane

According to classical paper S. Marsh and K.W. McVoy (1983) oscillation phase of mixed $n \to \bar{n}$ system is reset due to collapse of the wave function under collision to either to $n$ or to $\bar{n}$ interaction state.

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**Theory of neutron-antineutron oscillation using bottled ultracold neutrons**

S. Marsh and K. W. McVoy
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(Received 6 June 1983)

We contrast the quantum-mechanical treatment of neutron oscillations in a "bottle" with the usual free-space formalism. The quantum-mechanical corrections appear to reduce the figure of merit for the bottled-neutron experiments, and also place constraints on the experimental arrangement.

Therefore, one should not allow the number of collisions of the system to be > 1.
If # $\gg$ 1 there will be no quadratic time dependence, but rather only linear.

Recent conjecture of Valery Nesvizhevsky et al. (ILL, 2019) is that reset of the wave function occurs because the complex potential of interaction of $n$ and $\bar{n}$ with reflecting surface is very different, e. g. due to large annihilation (imaginary) potential of $\bar{n}$ interaction with the reflector.

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# Experimental Approach to Search for Free Neutron-Antineutron Oscillations Based on Coherent Neutron and Antineutron Mirror Reflection

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An observation of neutron-antineutron oscillations ($n-\bar{n}$), which violate both $B$ and $B-L$ conservation, would constitute a scientific discovery of fundamental importance to physics and cosmology. A stringent upper bound on its transition rate would make an important contribution to our understanding of the baryon asymmetry of the Universe by eliminating the postsphaleron baryogenesis scenario in the light quark sector. We show that one can design an experiment using slow neutrons that in principle can reach the required sensitivity of $\tau_{n-\bar{n}} \sim 10^{10}$ s in the oscillation time, an improvement of $\sim 10^4$ in the oscillation probability relative to the existing limit for free neutrons. The improved statistical accuracy needed to reach this sensitivity can be achieved by allowing both the neutron and antineutron components of the developing superposition state to coherently reflect from mirrors. We present a quantitative analysis of this scenario and show that, for sufficiently small transverse momenta of $n/\bar{n}$ and for certain choices of nuclei for the $n/\bar{n}$ guide material, the relative phase shift of the $n$ and $\bar{n}$ components upon reflection and the $\bar{n}$ annihilation rate can be small enough to maintain sufficient coherence to benefit from the greater phase space acceptance the mirror provides.

Their next conjectured points there:

- If $U_n = V_n - iW_n \equiv U_{\bar{n}} = V_{\bar{n}} - iW_{\bar{n}}$ there will be no osc. reset
- If potentials are about the same, then $(n\bar{n})$ system can be reflected from surfaces many times before decoherence will happen.

→ if coherence will be maintained under many collisions, then one can have a very long reflecting tube of a small diameter, e. g. 20 cm. Thus, it can cut the cost, and gain in sensitivity of $n\bar{n}$ search.

Most recent published paper on that is https://pos.sissa.it/380/428/pdf

**Implementations of neutron/antineutron ($n/\bar{n}$) guides in experiments searching for $n-\bar{n}$ oscillations**

Preferred example:
$nCu \Rightarrow V_n - iW_n = 168. - i \cdot 0.026\, neV$
$\bar{n}Cu \Rightarrow V_{\bar{n}} - iW_{\bar{n}} = 94 - i \cdot 27.0\ neV$
This is *m=1* reflection, super-mirrors are questionable

Even if it is correct, the fact of retaining the phase under reflection is not experimentally established.
How to test it? Obviously not with $n\bar{n}$, but with some other two-level mixed system.
**Other** two-level system can be polarized neutron beam precessing in the magnetic field.

Albert Young (with different motivation) several years ago proposed such measurement

Reflector should "detect" the polarization (like $n$ and $\bar{n}$)

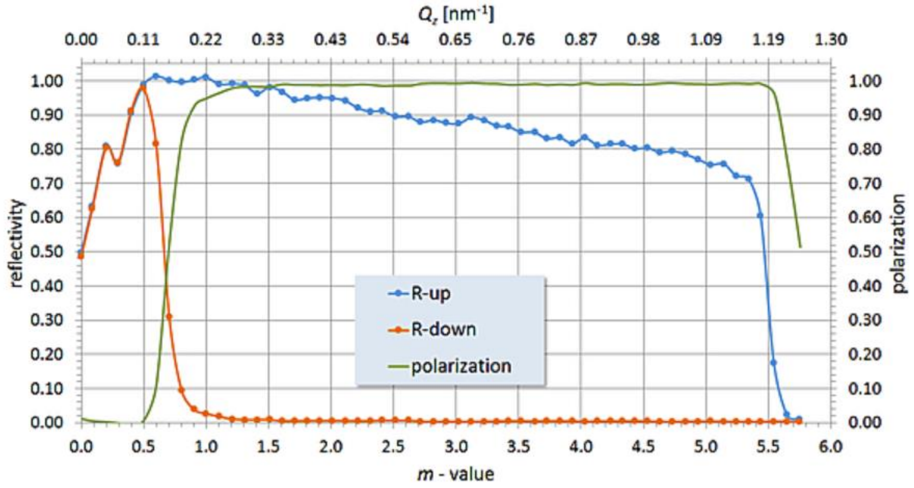
Two-state system $n = \begin{pmatrix} \uparrow \\ \downarrow \end{pmatrix}$ $\quad H = \mu \boldsymbol{\sigma} \cdot \boldsymbol{B} = \mu \begin{pmatrix} B_z & B_x + iB_y \\ B_x - iB_y & -B_z \end{pmatrix}$

$$E_{1,2} = \pm \mu B_{total}$$

- MAGREF can be used for reflection from sample with selected $U_n = V_n - iW_n$. Reflection is due to $V_n$ Fermi potential. Uniform mag. field ~ 1 Gauss is needed to set a controlled precession.

Fe / Si polarising supermirror

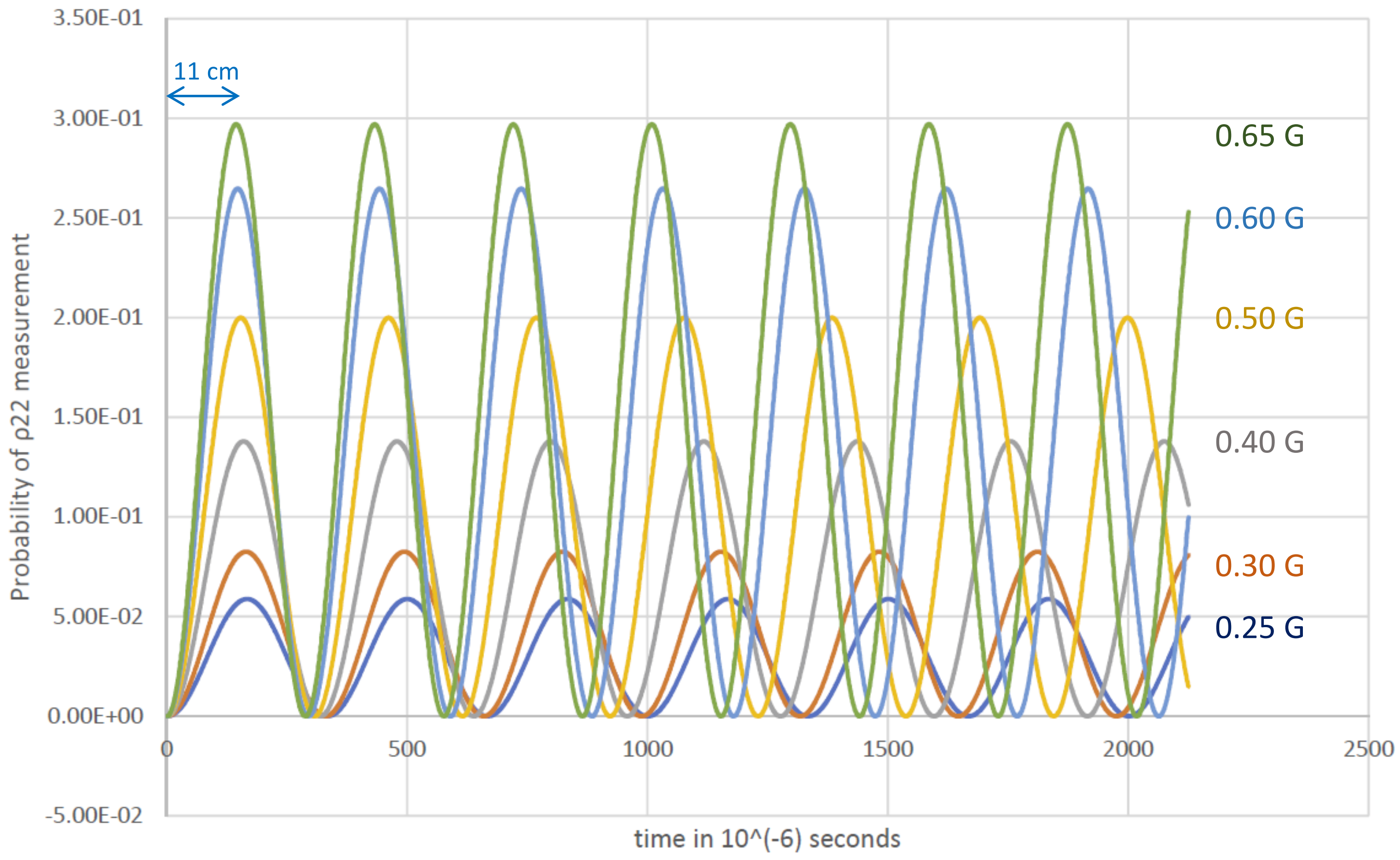
- Fe/Si polarizing supermirror? High-absorptive material (e. g. Gd) can be evaporated on the surface of reflector (?) If we create equal V and W on the surface of the reflector, will it be still spin sensitive?



Spin dependent reflectivity and polarization of a Fe/Si polarizing supermirror m = 5.5

- Alternatively, for polarized beam one can have a reflection surface with high V and W and use $^3$He analyzer of the spins after reflection.

# Spin precession in uniform field (Erich Bermel / UT / 2021)




Probability of ρ22 measurement
Initial state Polarzed ρ11 =1
Bz = 1 Gauss. Bx =.25 -.65 Gauss

Velocity 800 m/s

$$\omega = \mu B$$