Workshop “Hot Topics in Astroparticle Physics”
LNGS • 17 September 2015

On the Road to Experimental Observation of Baryon Number Violation

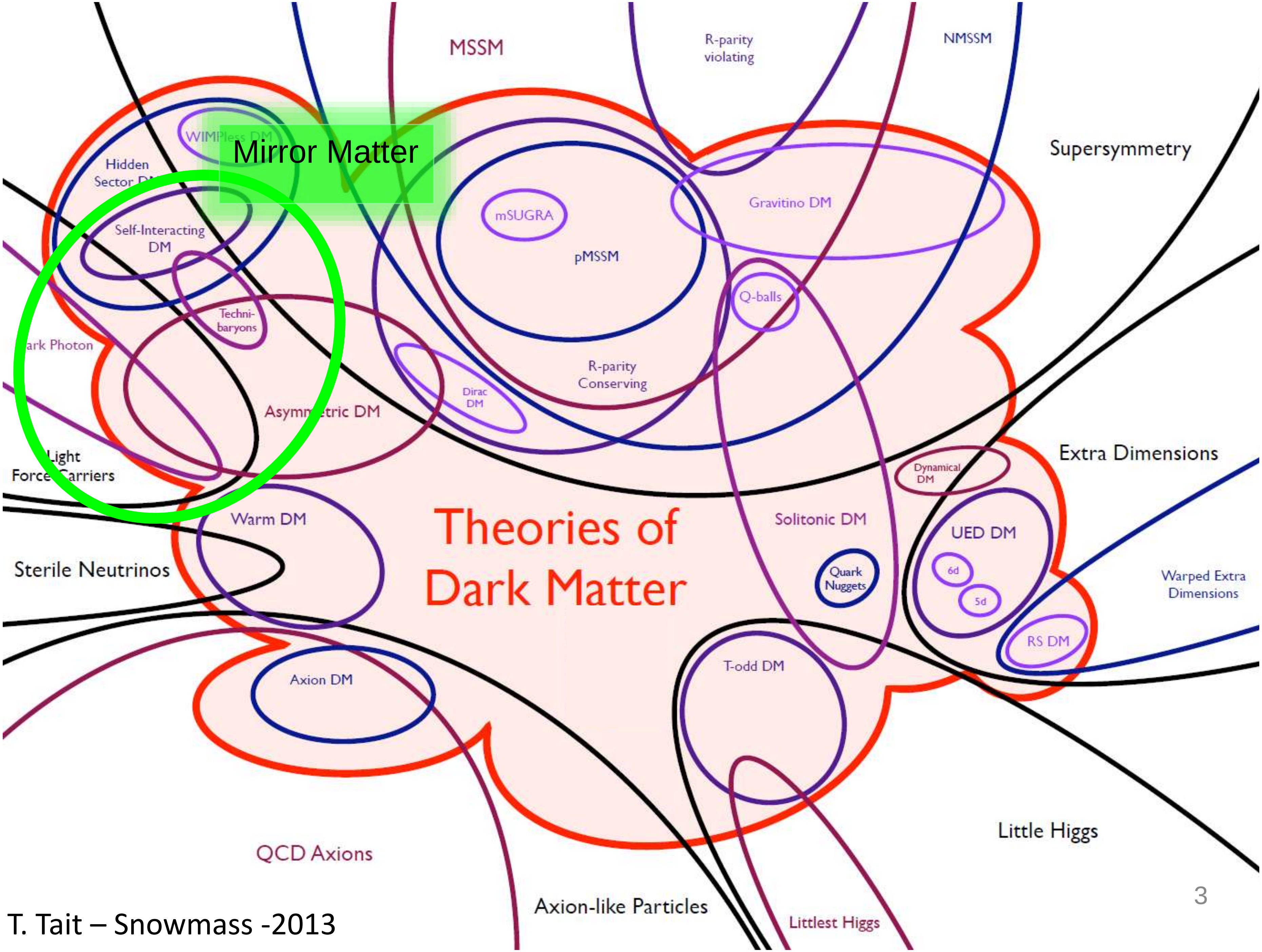
Part 2. MM = DM search

Yuri Kamyshkov/ University of Tennessee
email: kamyshkov@utk.edu

Outline

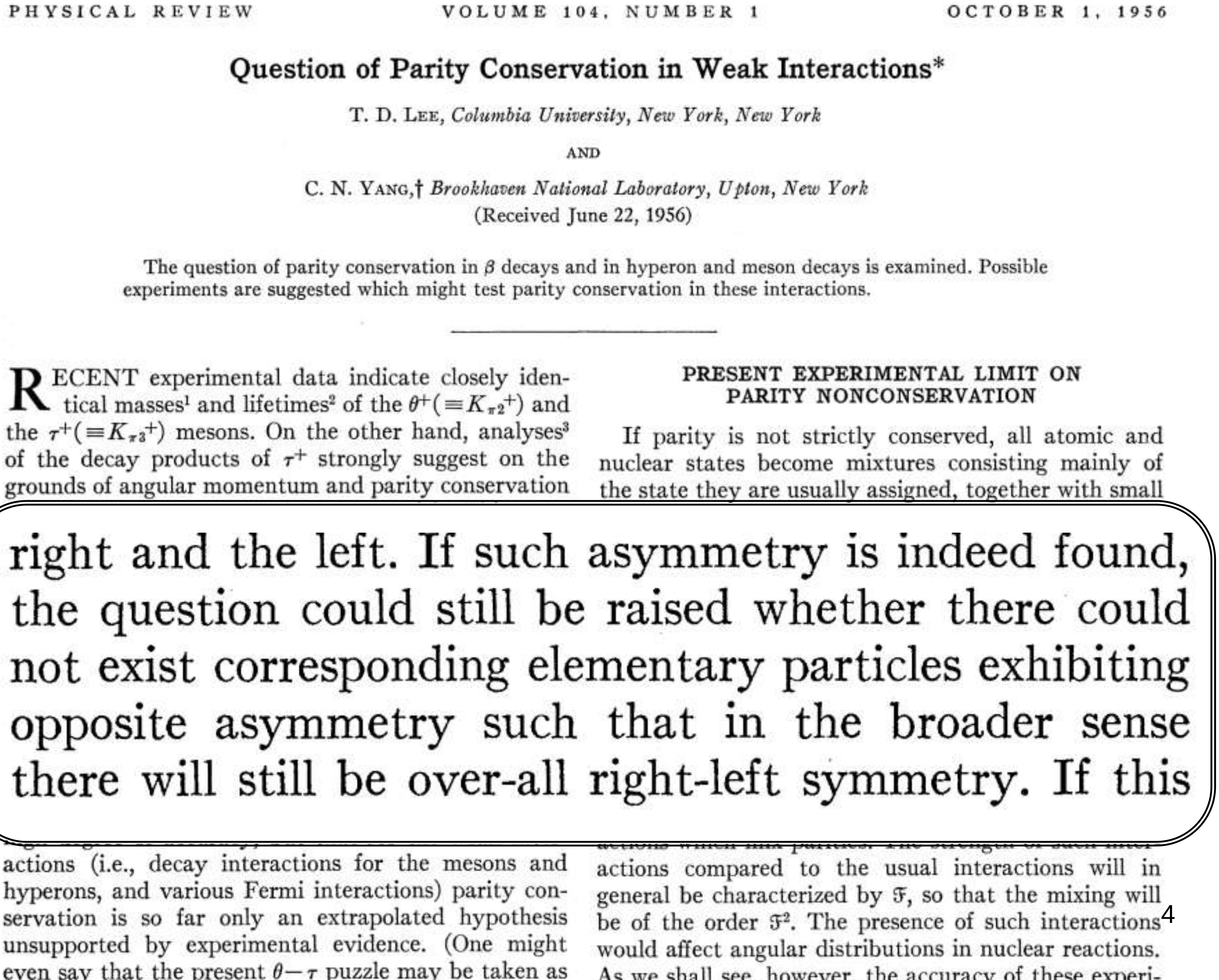
<u>2-nd hour</u>

- Short concept of mirror matter
- It can be related to BNV and n-nbar (n → n')
- (1) Search for mirror matter as n → n'
- (2) Can MM explain the difference in observed n lifetime?
- (3) New paradigm of direct search for DM as MM



Mirror Matter

T. Tait – Snowmass -2013



PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

T. D. LEE, *Columbia University, New York, New York*

AND

C. N. YANG,† *Brookhaven National Laboratory, Upton, New York*

(Received June 22, 1956)

The question of parity conservation in β decays and in hyperon and meson decays is examined. Possible experiments are suggested which might test parity conservation in these interactions.

RECENT experimental data indicate closely identical masses[1] and lifetimes[2] of the $\theta^+(\equiv K_{\pi 2}^+)$ and the $\tau^+(\equiv K_{\pi 3}^+)$ mesons. On the other hand, analyses[3] of the decay products of τ^+ strongly suggest on the grounds of angular momentum and parity conservation

actions (i.e., decay interactions for the mesons and hyperons, and various Fermi interactions) parity conservation is so far only an extrapolated hypothesis unsupported by experimental evidence. (One might even say that the present $\theta-\tau$ puzzle may be taken as

PRESENT EXPERIMENTAL LIMIT ON PARITY NONCONSERVATION

If parity is not strictly conserved, all atomic and nuclear states become mixtures consisting mainly of the state they are usually assigned, together with small

actions compared to the usual interactions will in general be characterized by $\mathfrak{F}$, so that the mixing will be of the order $\mathfrak{F}^2$. The presence of such interactions would affect angular distributions in nuclear reactions. As we shall see, however, the accuracy of these experi-

right and the left. If such asymmetry is indeed found, the question could still be raised whether there could not exist corresponding elementary particles exhibiting opposite asymmetry such that in the broader sense there will still be over-all right-left symmetry. If this

Ideas of Mirror Matter

- Left-Right symmetry can be restored in nature

  Lee&Yang (1956)

- Mirror fermions can not have common E-M, Weak and Strong Interactions but only common Gravity

  Kobzarev, Okun, Pomeranchuk (1966)

- Two Standard Models : SM (matter) and SM′ (mirror)

  Foot et al. (1991)

- Lepton number violation (ν) in ordinary and mirror matter

  Berezhiani, Mohapatra (1995)

- MM as a viable candidate for DM if $T'/T \ll 1$

  Berezhiani, Comelli, Vilante (2001)

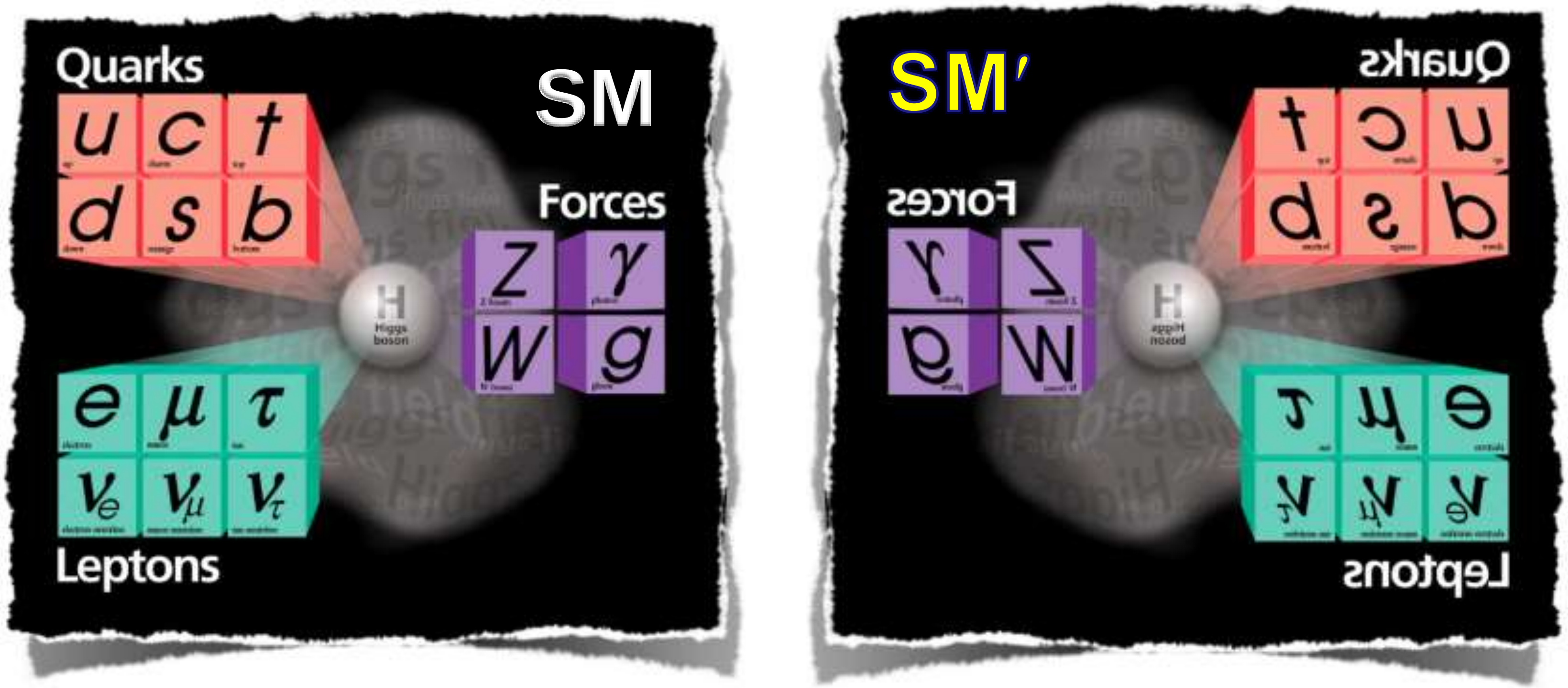
- Baryon number violation (n) in ordinary and mirror matter

  Berezhiani (2006-2015)

Review: “Mirror particles and mirror matter: 50 years of speculations and search.” by L.B. Okun, (Moscow, ITEP), 2006, http://arxiv.org/abs/hep-ph/0606202 (contains all references before 2006)

- The possibility that MM=DM should be explored.
- It is not clear to me for what reason it is not very popular in theoretical discussions and why it is not pursued in the direct DM search experiments?
- A mechanism of direct MM detection is not developed. It is different from that of WIMPs.
- Z. Berezhiani is developing MM theory and ideas of experiments at LNGS. I am collaborating with Zurab for the goal of developing a new paradigm and experiments for MM=DM detection.

Two coexisting worlds look theoretically very attractive



- Two identical gauge factors, $G \times G'$, with identical field contents and Lagrangians: $\mathcal{L}_{\rm tot} = \mathcal{L} + \mathcal{L}' + \mathcal{L}_{\rm mix}$ – $SU(5) \times SU(5)'$, *etc* .
- Can naturally emerge in string theory: O & M matter fields localized on two parallel branes with gravity propagating in bulk: e.g. $E_8 \times E_8'$
- Exact parity $G \leftrightarrow G'$: Mirror matter is dark (for us), but its particle physics we know exactly (on our skin) – no new parameters!

Where are the windows to the mirror world?

All neutrals:

(a) Neutrinos
(b) Neutrons
(c) Photons
+ Heavy neutral messenger particles

Observations that point to a new concepts

- No experimental indication for **heavy** DM from direct searches;
- Supersymmetric DM candidates so far haven't been seen at LHC;
- There are provoking indications for the sterile neutrinos (3+1, 3+2, 3+3 ?);
- 5σ indication for $n \to n'$ transformation from ILL UCN experiment;
- Direct DM detection experiments indicate that DM is light:

  (DAMA/LIBRA, CRESST, CoGeNT, CDMS-Si);
- Mirror Dark Matter models are totally compatible with CMB and LSS precision data if $T'/T \ll 1$ [Berezhiani et al., 2001];
- Observed $\Omega_{B'} / \Omega_B \sim 5$ naturally follows from MM [Berezhiani, Bento 2001];
- MACHOs can be invisible mirror stars;

  [Berezhiani et al, 1995; Silagadze, 1995]
- More …

Mirror Matter in the mirror sector is like OM

- It consists of mirror hydrogen, helium, and “metals”.
- Because of T′/T <<1 the abundance of He is higher than H.
- Mirror stars are older than ordinary stars; some populate the galaxy halo as MACHOs; many MM stars has exploded as Super Novae.
- Like for OM most of MM in the universe exists in the form of gas clouds rather than in the form of stars and planets.
- MM is self-interacting but become collisionless when form mirror stars and planets.
- MM clouds in our galaxy consists of interacting gas at different temperatures and density. Motion of MM gas in our galaxy relative to the solar system and Earth can be detected by the direct DM search experiments.

OM Cloud Types ~ MM Cloud Types

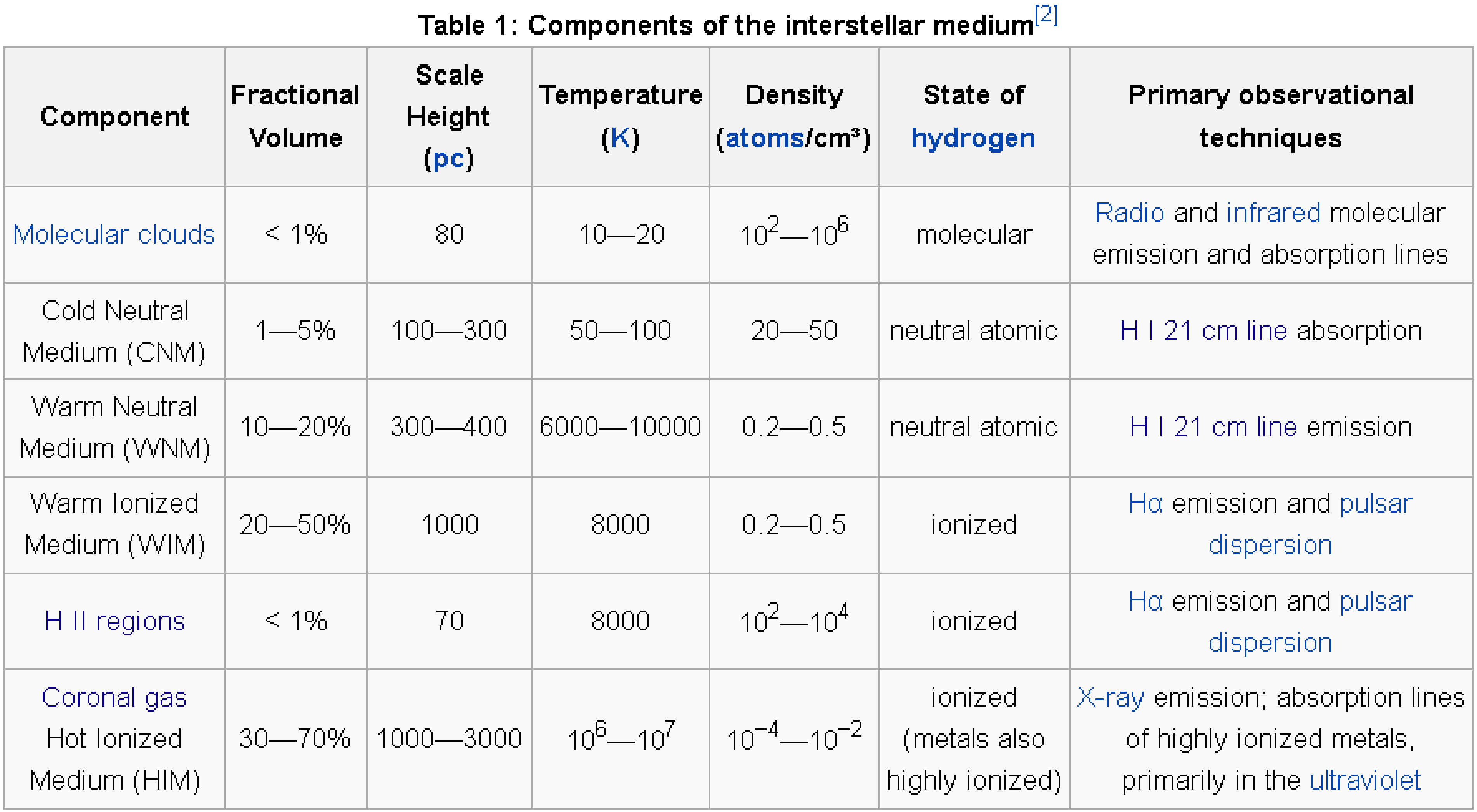


Table 1: Components of the interstellar medium[2]

Component	Fractional Volume	Scale Height (pc)	Temperature (K)	Density (atoms/cm^3)	State of hydrogen	Primary observational techniques
Molecular clouds	< 1%	80	10—20	10^2—10^6	molecular	Radio and infrared molecular emission and absorption lines
Cold Neutral Medium (CNM)	1—5%	100—300	50—100	20—50	neutral atomic	H I 21 cm line absorption
Warm Neutral Medium (WNM)	10—20%	300—400	6000—10000	0.2—0.5	neutral atomic	H I 21 cm line emission
Warm Ionized Medium (WIM)	20—50%	1000	8000	0.2—0.5	ionized	Hα emission and pulsar dispersion
H II regions	< 1%	70	8000	10^2—10^4	ionized	Hα emission and pulsar dispersion
Coronal gas Hot Ionized Medium (HIM)	30—70%	1000—3000	10^6—10^7	10^{-4}—10^{-2}	ionized (metals also highly ionized)	X-ray emission; absorption lines of highly ionized metals, primarily in the ultraviolet

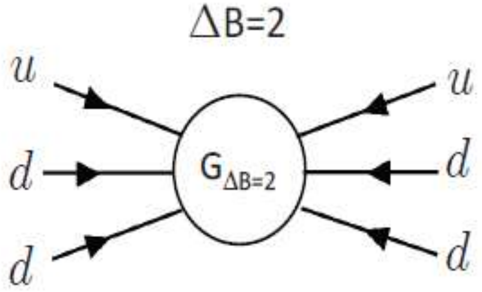
Wikipedia, “Interstellar Medium”
K. Ferriere

Accumulation of MM in Earth and Sun

Due to MM and OM clasteriztion the primodial MM chunks might not be abundant on Earth. MM particles from clouds falling on the Earth might be captures into the orbit; after multiple interactions for billion years they might be accumulated in Earth, picking the temperature of OM particles (300 K – 6000K); distribute this temperature in the gas atmosphere due to self-interactions; cooling down by emitting mirror photons from the Earth surface; building atmosphere of H, D, He around the Earth with barometric distribution, thus, on the Earth surface it is mostly mirror hydrogen (Zurab will argue for antihydrogen) that can create environmental conditions for interactions of e.g. neutrons due to oscillation to mirror neutrons.

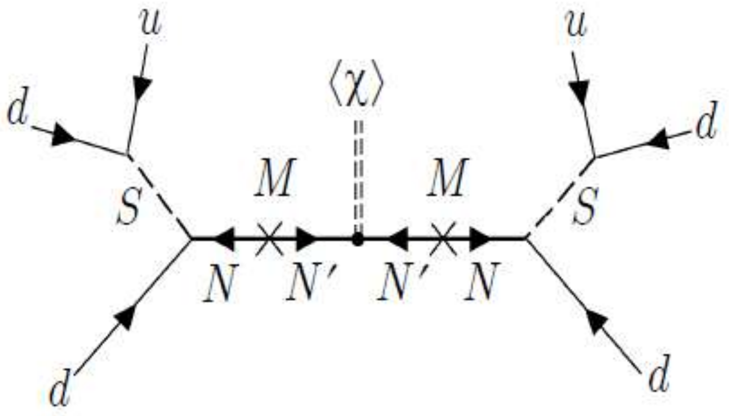
I understand that this seems to be much like a phantasy, but how one can avoid all that if we assume that MM self-interactions are the same as OM self-interaction and there is a mixing due to oscillations.

Connection of $n \to \bar{n}$ to Mirror = Dark Matter $n \to n'$ (Z. Berezhiani, 2015)

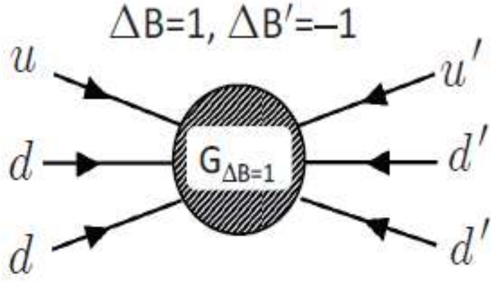


$$G_{\Delta B=2} = \frac{\langle\chi\rangle}{M_D}\frac{1}{M_D M_S^4}$$

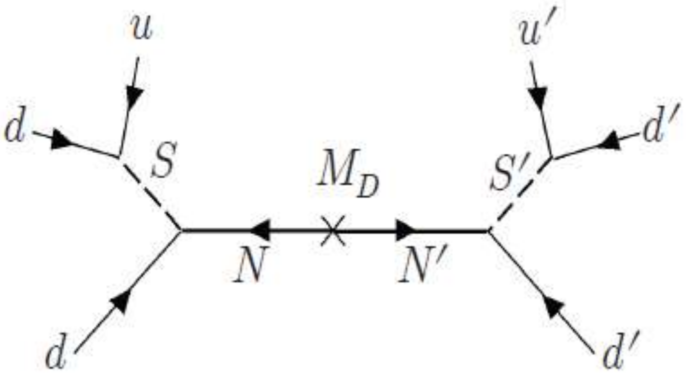
small



$\Delta B = -2$ violation



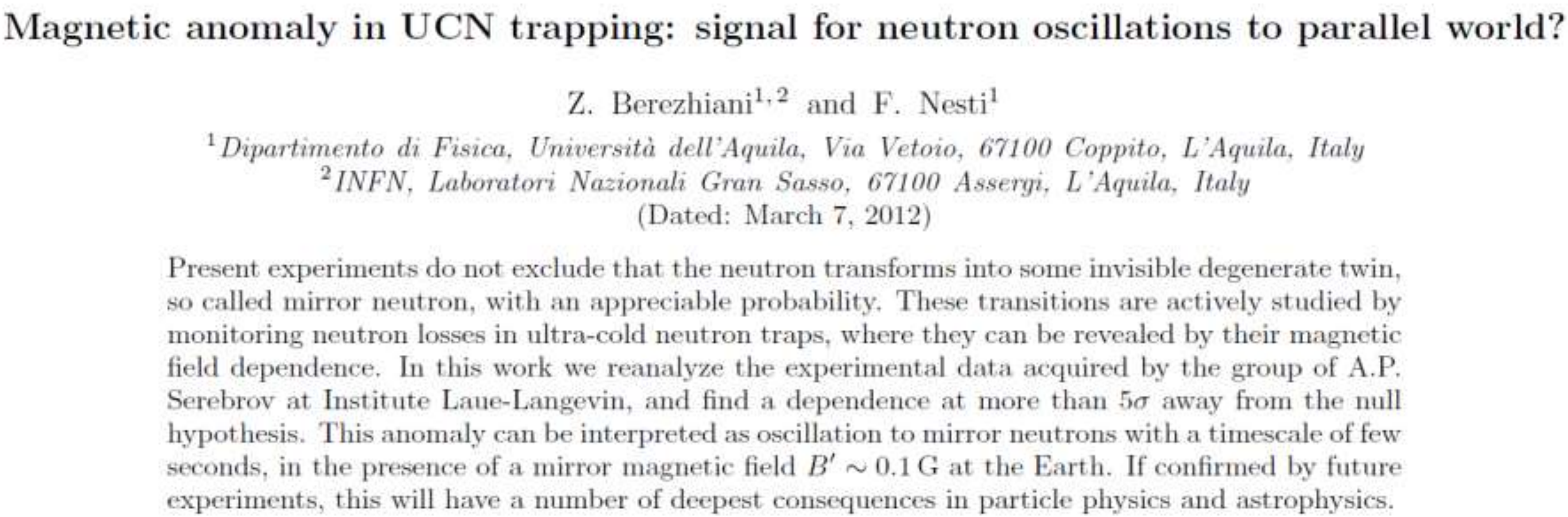
$$G_{\Delta B=1} = \frac{1}{M_D M_S^4}$$



$\overline{B} = B + B'$ conserved !

(1) $n \rightarrow n'$ disappearance

Eur.Phys.J. C72 (2012) 1974



Magnetic anomaly in UCN trapping: signal for neutron oscillations to parallel world?

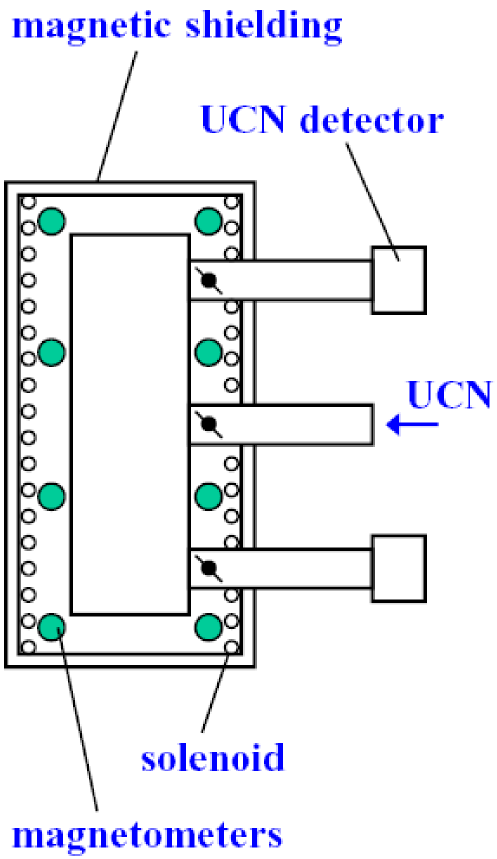
Z. Berezhiani[1,2] and F. Nesti[1]
[1] *Dipartimento di Fisica, Università dell'Aquila, Via Vetoio, 67100 Coppito, L'Aquila, Italy*
[2] *INFN, Laboratori Nazionali Gran Sasso, 67100 Assergi, L'Aquila, Italy*
(Dated: March 7, 2012)

Present experiments do not exclude that the neutron transforms into some invisible degenerate twin, so called mirror neutron, with an appreciable probability. These transitions are actively studied by monitoring neutron losses in ultra-cold neutron traps, where they can be revealed by their magnetic field dependence. In this work we reanalyze the experimental data acquired by the group of A.P. Serebrov at Institute Laue-Langevin, and find a dependence at more than 5σ away from the null hypothesis. This anomaly can be interpreted as oscillation to mirror neutrons with a timescale of few seconds, in the presence of a mirror magnetic field $B' \sim 0.1\,\mathrm{G}$ at the Earth. If confirmed by future experiments, this will have a number of deepest consequences in particle physics and astrophysics.

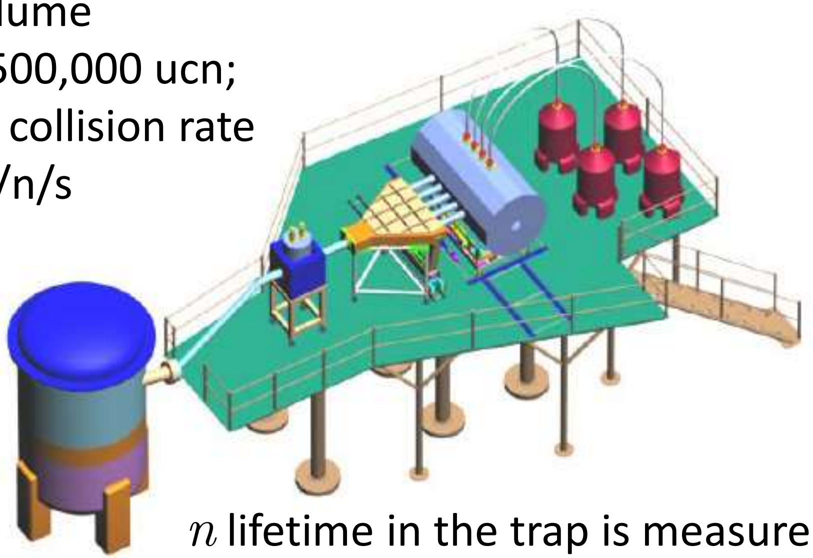
Physics Letters B 663 (2008) 181–185

A.P. Serebrov et al, Experimental search for neutron–mirror neutron oscillations using storage of ultra-cold neutrons (at ILL/Grenoble)

See also: Nuclear Instruments and Methods in Physics Research A 611 (2009) 137-140



190 L volume
stores ~ 500,000 ucn;
with wall collision rate
~ 10/n/s

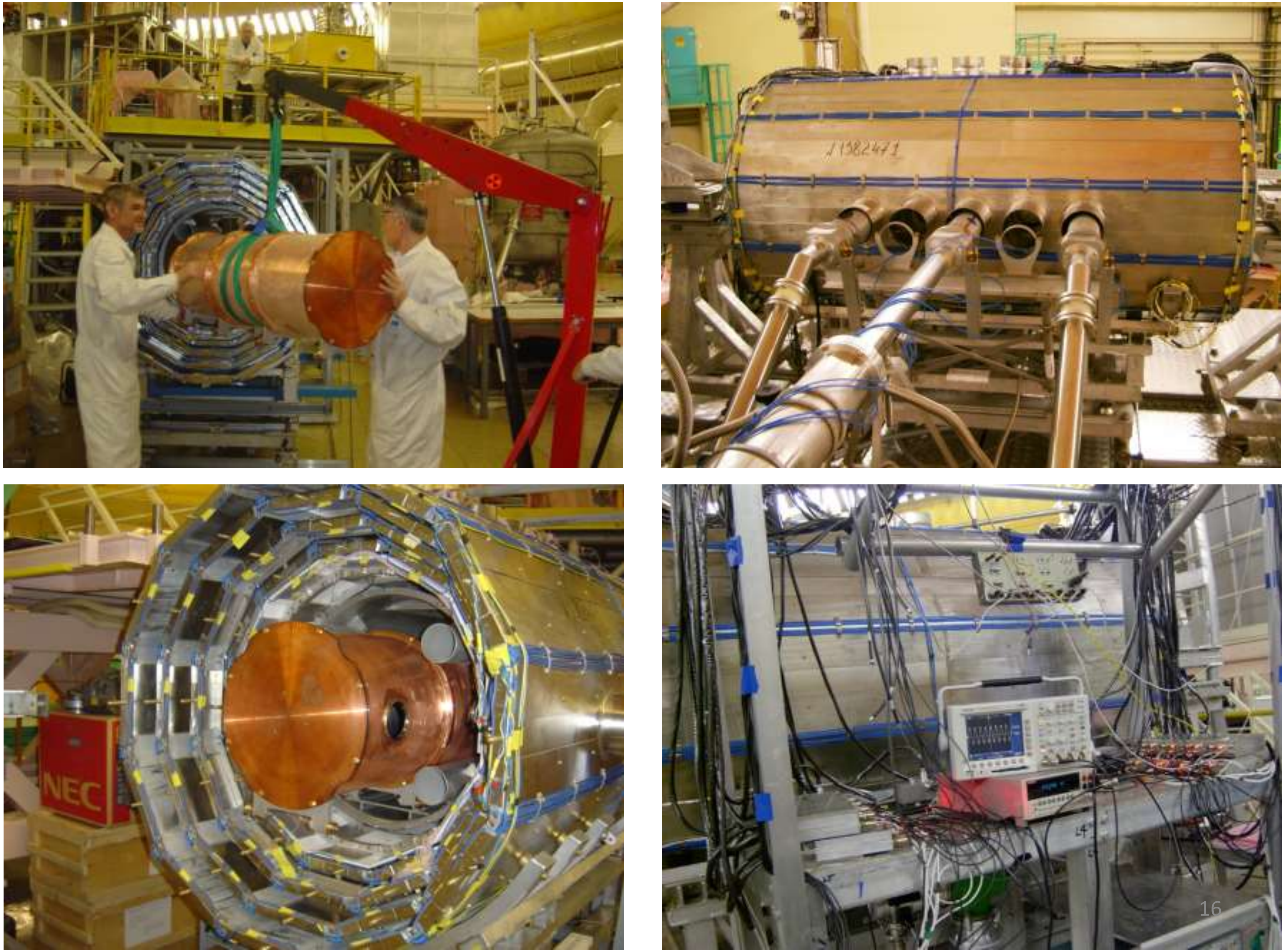


n lifetime in the trap is measured.
One measurement: 130 s filling;
300 s storage; 130 s counting n's

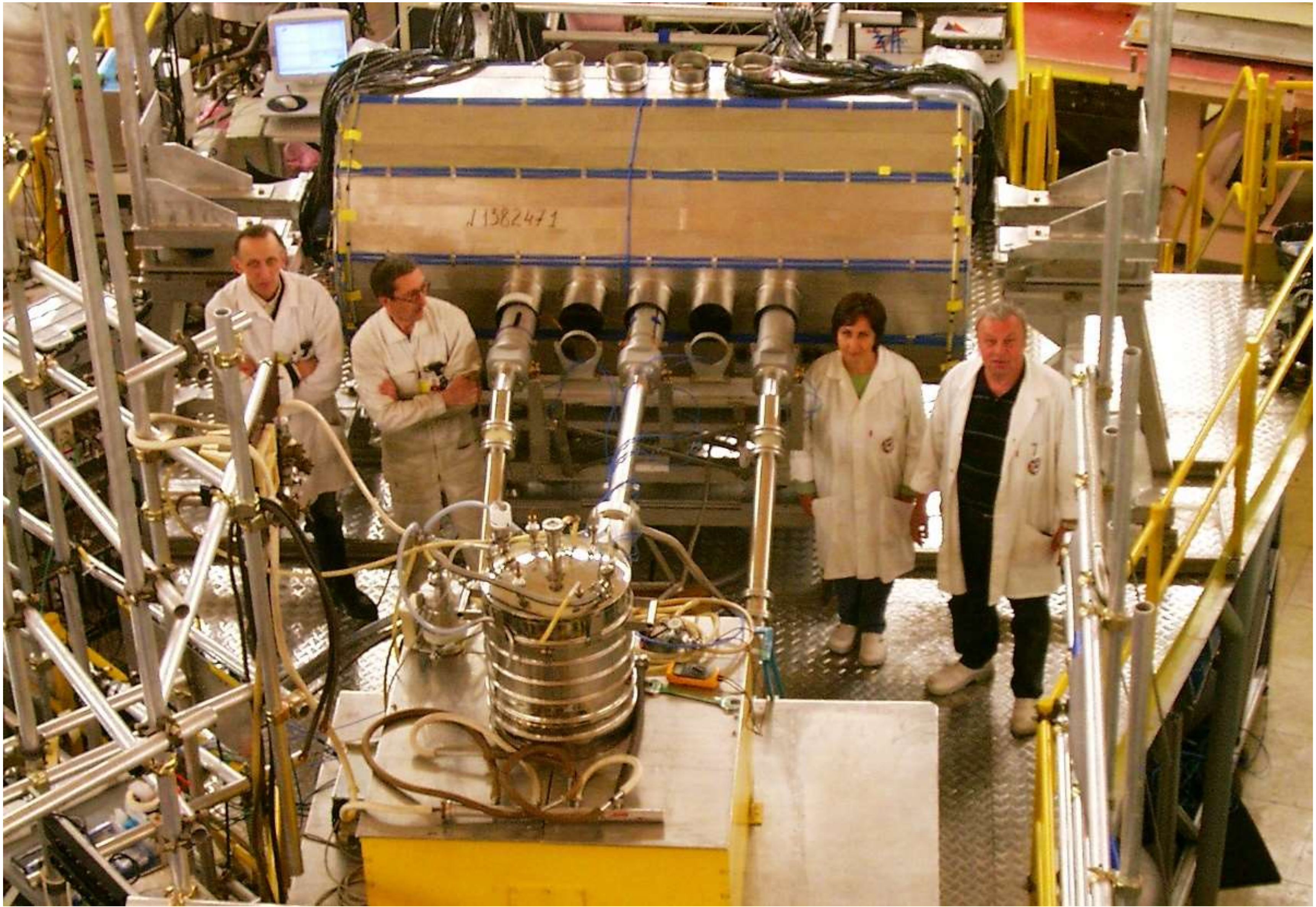
Magnetic field variation:
± 0.2 Gauss up/down

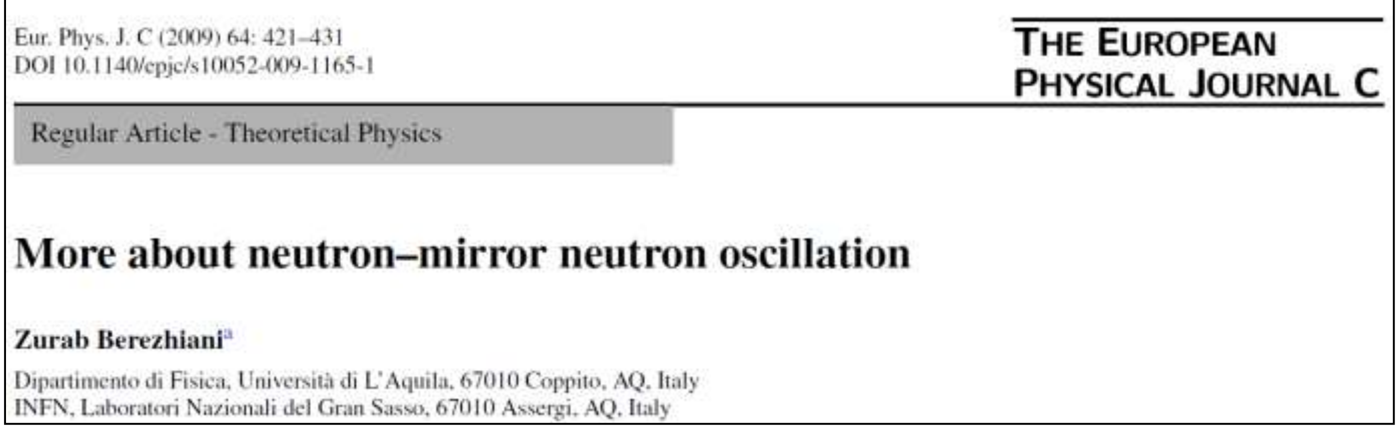
Assuming zero B' mirror magnetic field
$n \to n'$ oscillation time limit $\tau(90\%\text{CL}) > 414$ s

$n \rightarrow n'$ search at ILL / Grenoble



n-n′ oscillation search at ILL (2007)





Eur. Phys. J. C (2009) 64: 421–431
DOI 10.1140/epjc/s10052-009-1165-1

THE EUROPEAN
PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

More about neutron–mirror neutron oscillation

Zurab Berezhiani[a]
Dipartimento di Fisica, Università di L'Aquila, 67010 Coppito, AQ, Italy
INFN, Laboratori Nazionali del Gran Sasso, 67010 Assergi, AQ, Italy

Detailed QM treatment of $n \to n'$ transformation when $\vec{B}' \neq \vec{B} \neq 0$

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

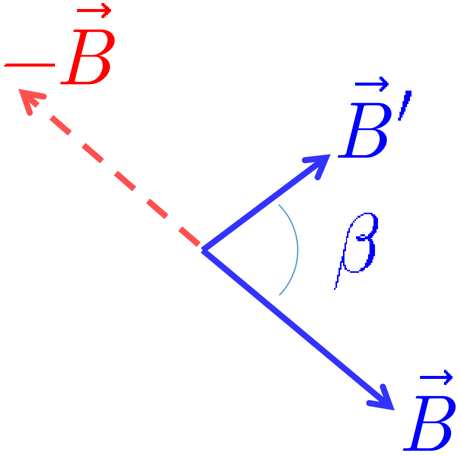
- $V'_{mag} = \vec{\mu}' \cdot \vec{B}', \quad \mu' = \mu$
- $\vec{B}'$ is not known. Presence of $V \neq V'$ suppresses $n \to n'$.
- By varying V_{mag} one can try to guess and compensate the unknown V'_{mag} → disappearance probability is a function of $\boldsymbol{B}$ (lab magnetic field) and its direction
- → Life time of UCN in the storage trap might be affected by external environmental parameters: mag. field ***B*, *B'*** and density of mirror matter in the trap.

Neutron disappearance in the presence of B'(Z. Berezhiani, 2009)

$$P_B(t) = p_B(t) + d_B(t) \cdot \cos\beta$$

$$p(t) = \frac{\sin^2\left[(\omega-\omega')t\right]}{2\tau^2(\omega-\omega')^2} + \frac{\sin^2\left[(\omega+\omega')t\right]}{2\tau^2(\omega+\omega')^2}$$

$$d(t) = \frac{\sin^2\left[(\omega-\omega')t\right]}{2\tau^2(\omega-\omega')^2} - \frac{\sin^2\left[(\omega+\omega')t\right]}{2\tau^2(\omega+\omega')^2}$$



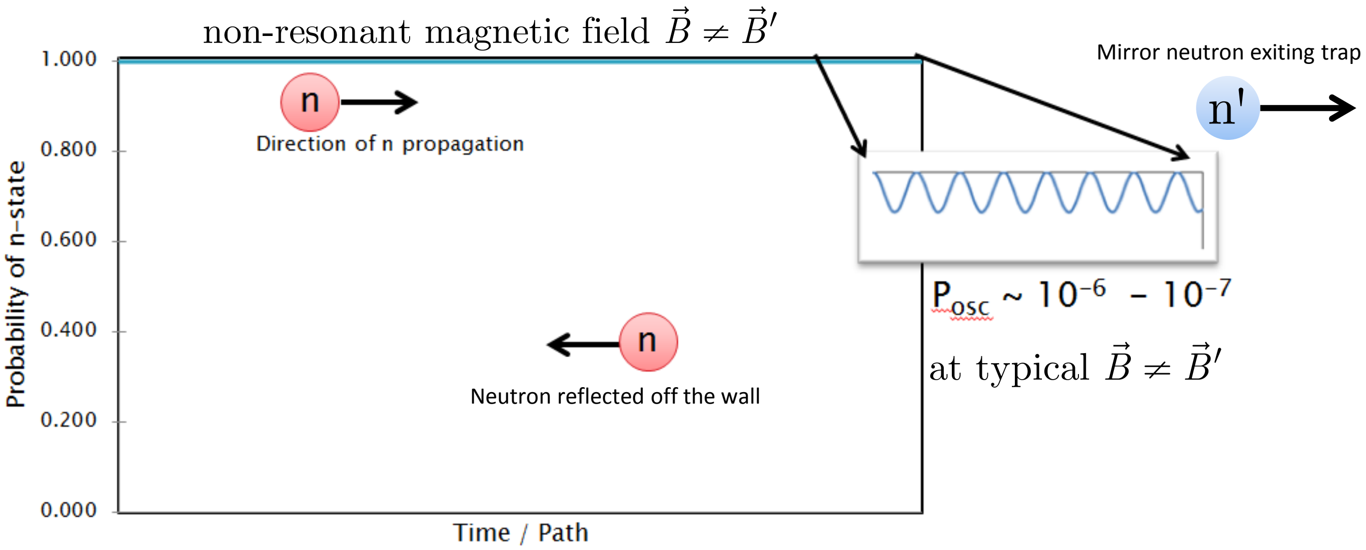
where $\omega = \frac{1}{2}\left|\mu B\right|$ **and** $\omega' = \frac{1}{2}\left|\mu B'\right|$ **;** τ **- oscillation time**

$$A_B^{\det}(t) = \frac{N_{-B}(t) - N_B(t)}{N_{-B}(t) + N_B(t)} = N_{collis} d_B(t) \cdot \cos\beta \leftarrow$$ **assymetry**

Reasonable exploration region
$\tau > 1s$; B' ~ similar to 0.5 G

Probability is related to
$n \to n'$ oscillation time τ
that can be ≥1 sec
(Z. Berezhiani et al, Phys.Rev.Lett.96:081801,2006)

Neutron oscillating into mirror neutron. The latter is going through the trap wall



$P_{osc} \sim 10^{-6} - 10^{-7}$

at typical $\vec{B} \neq \vec{B}'$

in case of successful guessing for $\vec{B} = \vec{B}'$ the resonance enhancement is expected: the oscillation frequency will be reduced to (1/few s) and oscillation amplitude increased by few orders of magnitude, ultimately to

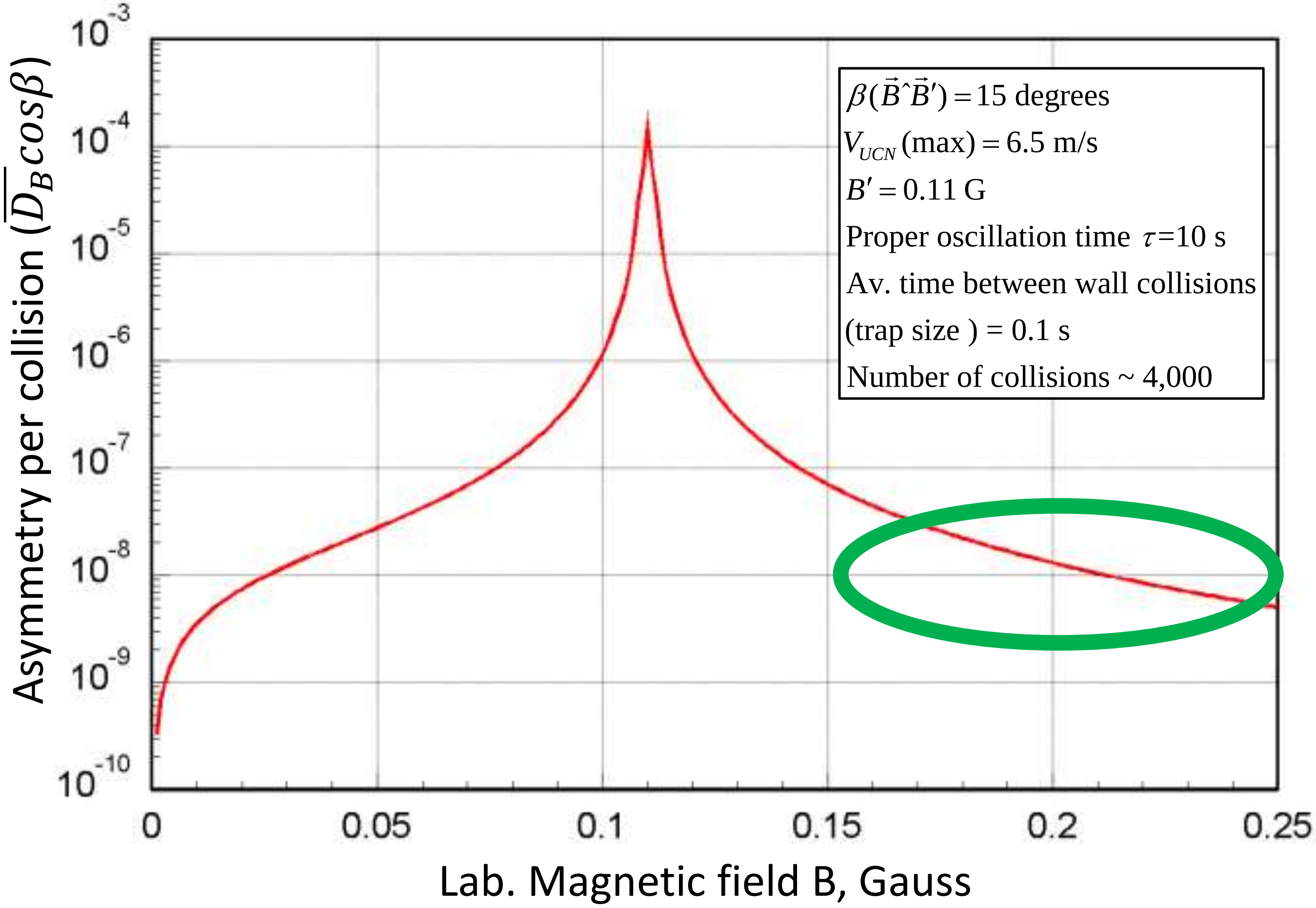
t – observation time

$$P_{nn'} = \left(\frac{t}{\tau_{nn'}} \right)^2$$

$\tau_{nn'}$ – oscillation time > 1 sec

Calculated asymmetry per collision with wall

to be multiplied by the number of collisions



$\beta(\vec{B}\hat{}\vec{B}') = 15$ degrees

$V_{UCN}(\max) = 6.5$ m/s

$B' = 0.11$ G

Proper oscillation time τ=10 s

Av. time between wall collisions

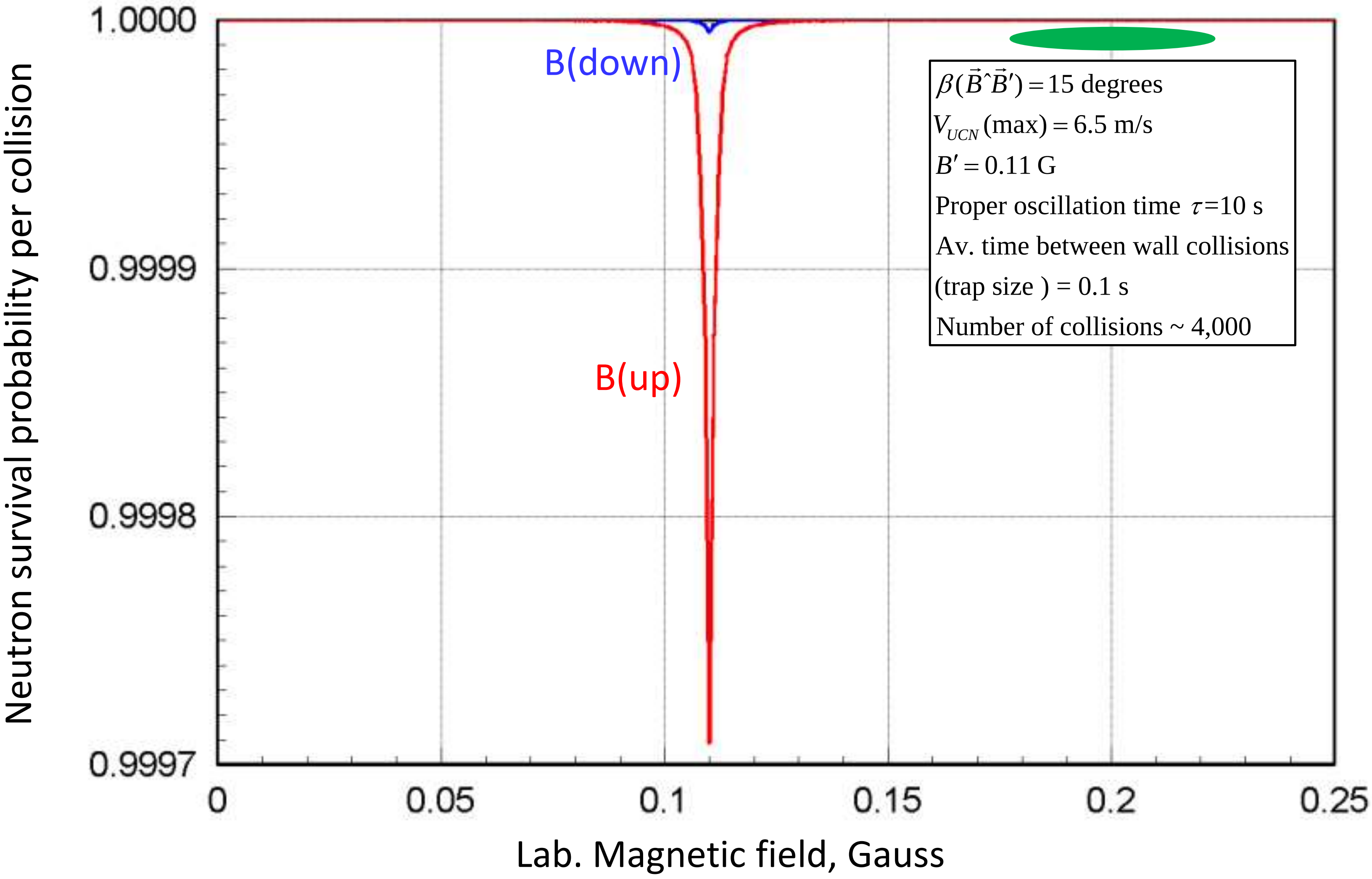
(trap size) = 0.1 s

Number of collisions ~ 4,000

Calculated survival probability

per wall collision vs lab magnetic field

averaged across time of flight and trap velocity distribution



$\beta(\vec{B}\,\hat{}\,\vec{B}') = 15$ degrees

$V_{UCN}(\text{max}) = 6.5$ m/s

$B' = 0.11$ G

Proper oscillation time τ=10 s

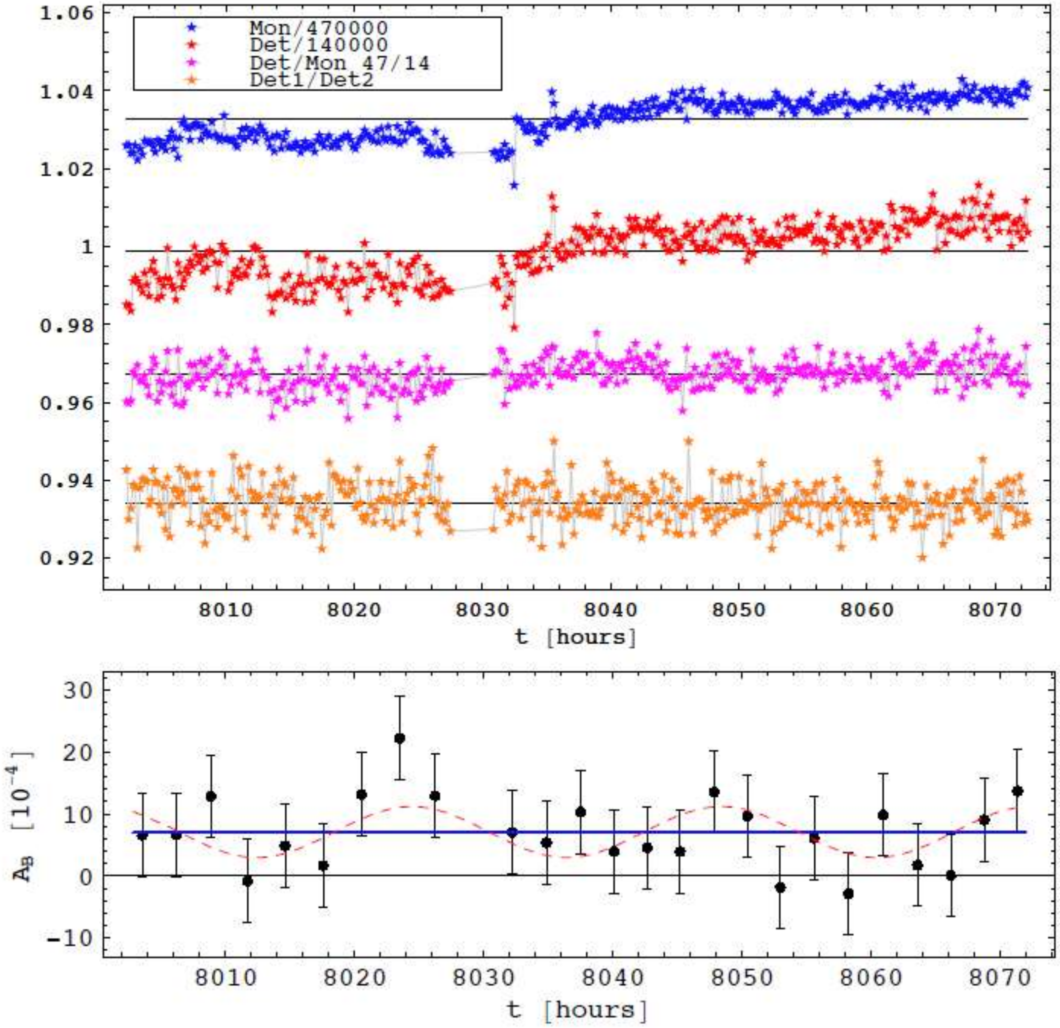
Av. time between wall collisions

(trap size) = 0.1 s

Number of collisions ~ 4,000

Magnetic anomaly in UCN trapping: signal for neutron oscillation to parallel world?

Z. Berezhiani and F. Nesti
Eur. Phys. J. C72 (2012) 1974;
also http://arxiv.org/abs/1203.1035

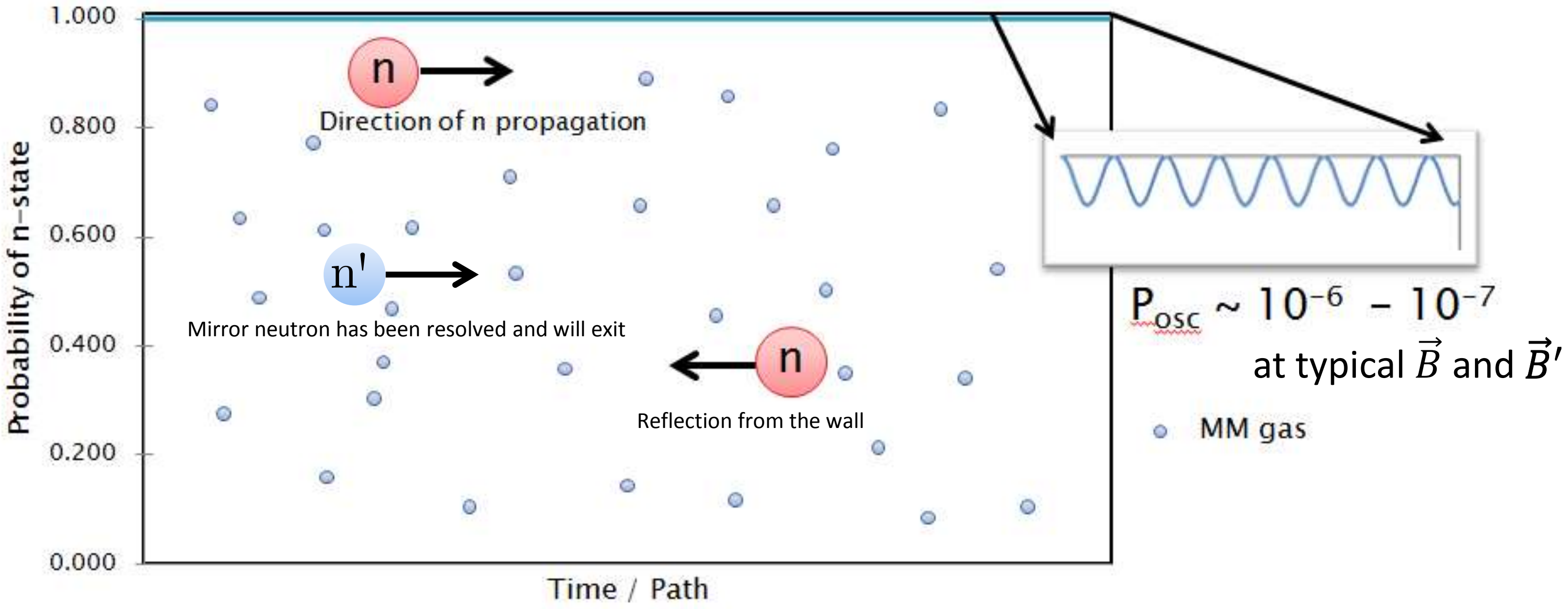


$$A_B^{\mathrm{det}}(t) = \frac{N_{-B}(t) - N_B(t)}{N_{-B}(t) + N_B(t)}$$

Measured asymmetry →
~ $(7\pm1.4)\times10^{-4}$ (~5σ)

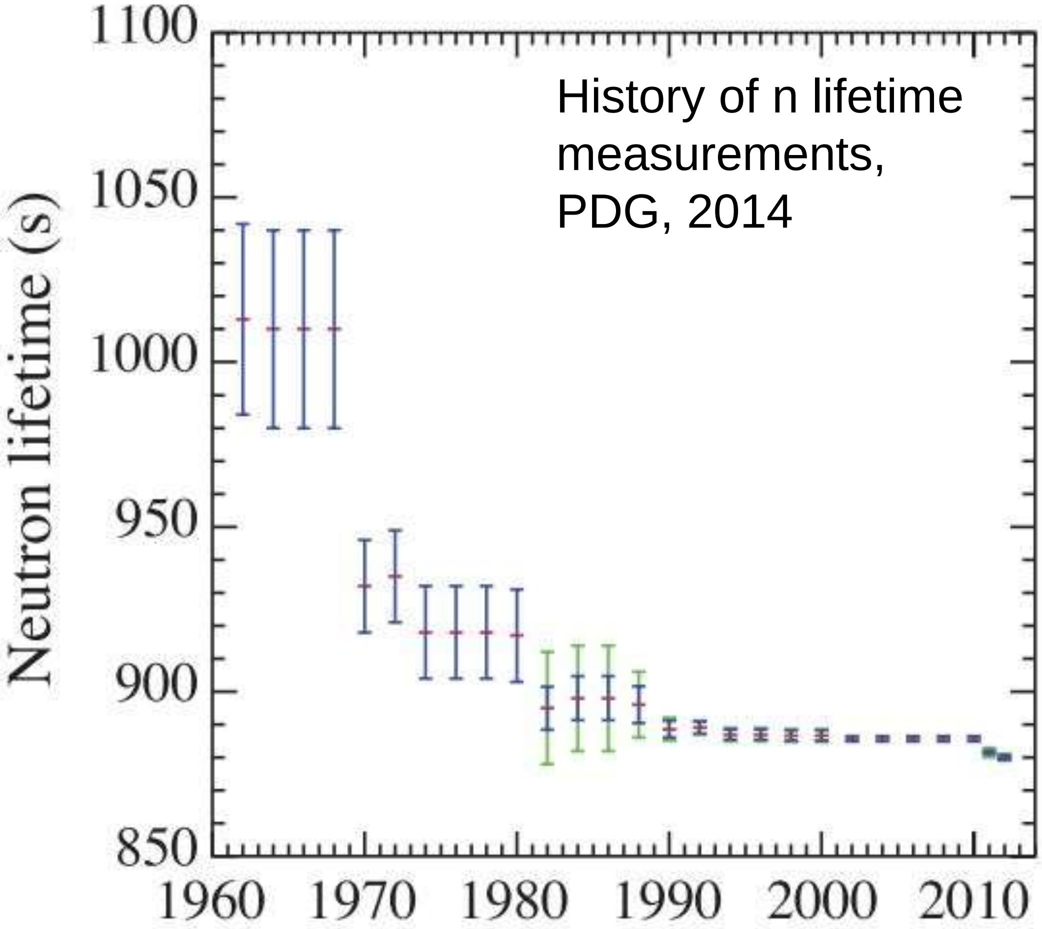
Fig. 1. Upper Panel: *from up to down, the monitor and detector counts in* $\{\boldsymbol{B}\}$ *series,* M *and* $N = N_1 + N_2$ *normalized respectively to 470000 and 140000; and the ratios* $N/M\,(\times 47/14)$ *and* N_1/N_2. Lower Panel: *results for* $A_{\mathrm{B}}^{\mathrm{det}}$ *binned by two* $\{\boldsymbol{B}\}$ *cycles (16 measurements), with the constant and periodic fits.*

Via Oscillations n→n’ Neutrons Can Interact with Mirror Particles



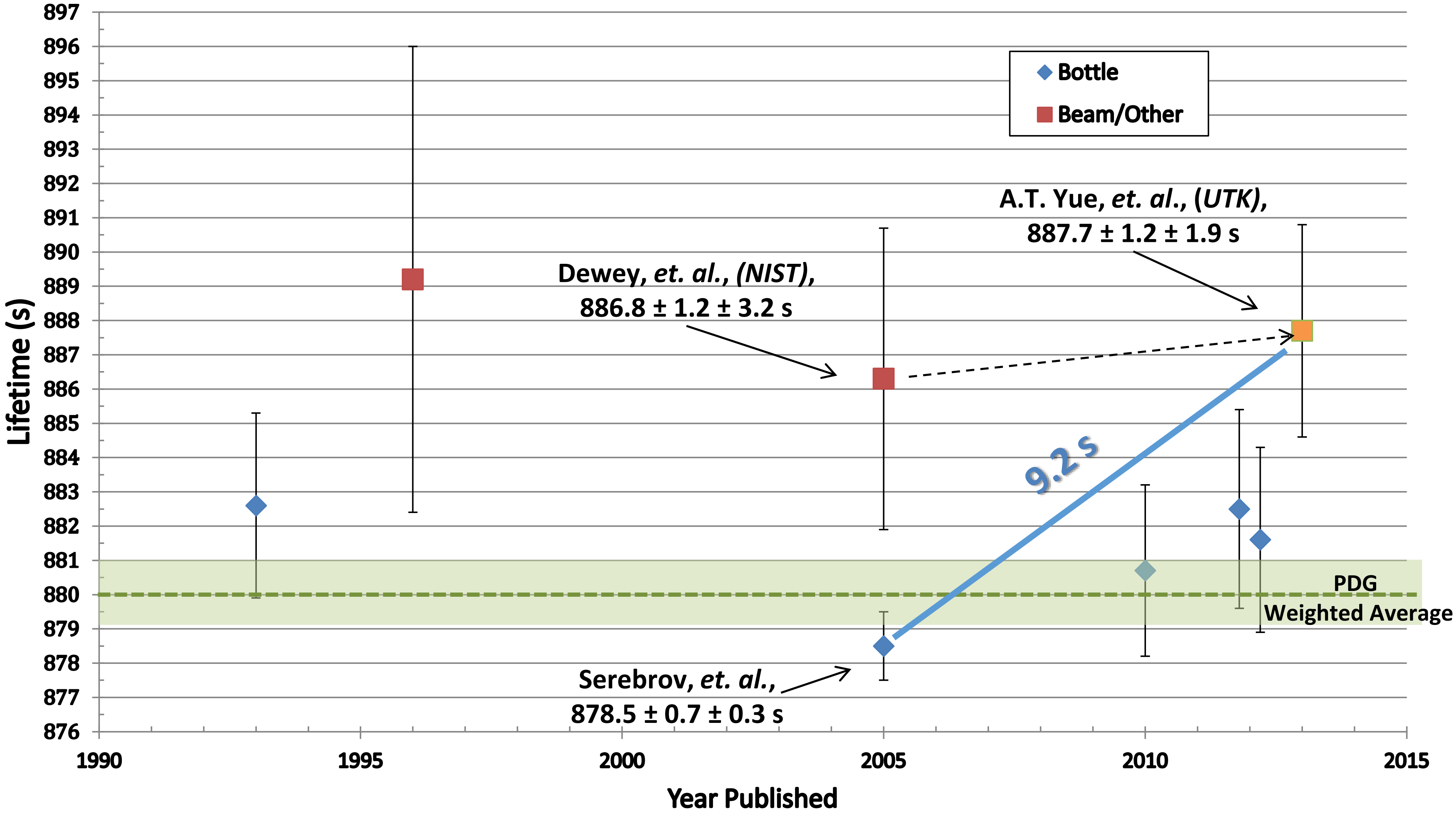
- Neutrons remain within the trap. Due to the oscillations between ordinary and mirror states, there is a small chance that the mirror neutron component will interact with an accumulated MM gas particle. (Z. Berezhiani, YK , B.Kerbikov, L. Varriano paper in preparation)

(2) Neutron Lifetime Measurements



History of n lifetime measurements, PDG, 2014

Measurements of the Neutron Lifetime



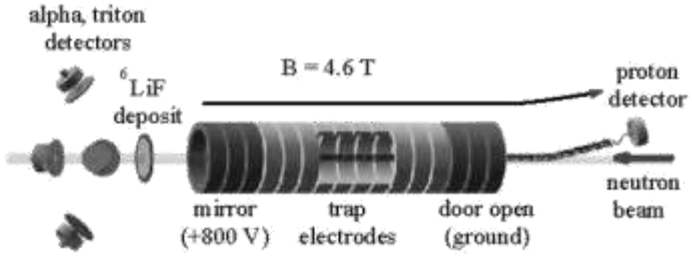
Particle Data Group (pdg.lbl.gov)

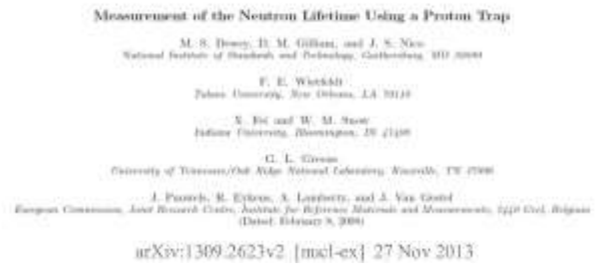
9.2 s => ~ 3 σ

or <1% probability of statistical fluctuation

Two Methods of Neutron Lifetime Measurement

Beam Measurement




Measurement of the Neutron Lifetime Using a Proton Trap

M. S. Dewey, D. M. Gilliam, and J. S. Nico

F. E. Wietfeldt

X. Fei and W. M. Snow

G. L. Greene

J. Pauwels, R. Eykens, A. Lamberty, and J. Van Gestel

arXiv:1309.2623v2 [nucl-ex] 27 Nov 2013

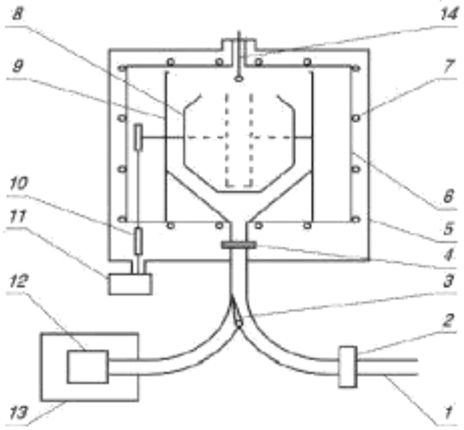
Proton appearance detected

4.6 T magnetic field

10 ms storage

Cold neutrons, ~0.025 eV

Bottle Measurement




PHYSICAL REVIEW C **78**, 035505 (2008)

Neutron lifetime measurements using gravitationally trapped ultracold neutrons

A. P. Serebrov,[1,*] V. E. Varlamov,[1] A. G. Kharitonov,[1] A. K. Fomin,[1] Yu. N. Pokotilovski,[2] P. Geltenbort,[3] I. A. Krasnoschekova,[1] M. S. Lasakov,[1] R. R. Taldaev,[1] A. V. Vassiljev,[1] and O. M. Zherebtsov[1]

[1] *Petersburg Nuclear Physics Institute, Russian Academy of Sciences, RU-188300 Gatchina, Leningrad District, Russia*
[2] *Joint Institute for Nuclear Research, RU-141980 Dubna, Moscow Region, Russia*
[3] *Institut Max von Laue Paul Langevin, Boite Postal 156, F-38042 Grenoble Cedex 9, France*

(Received 11 February 2008; published 23 September 2008)

Neutron disappearance detected

4 x 10^{-5} T magnetic field

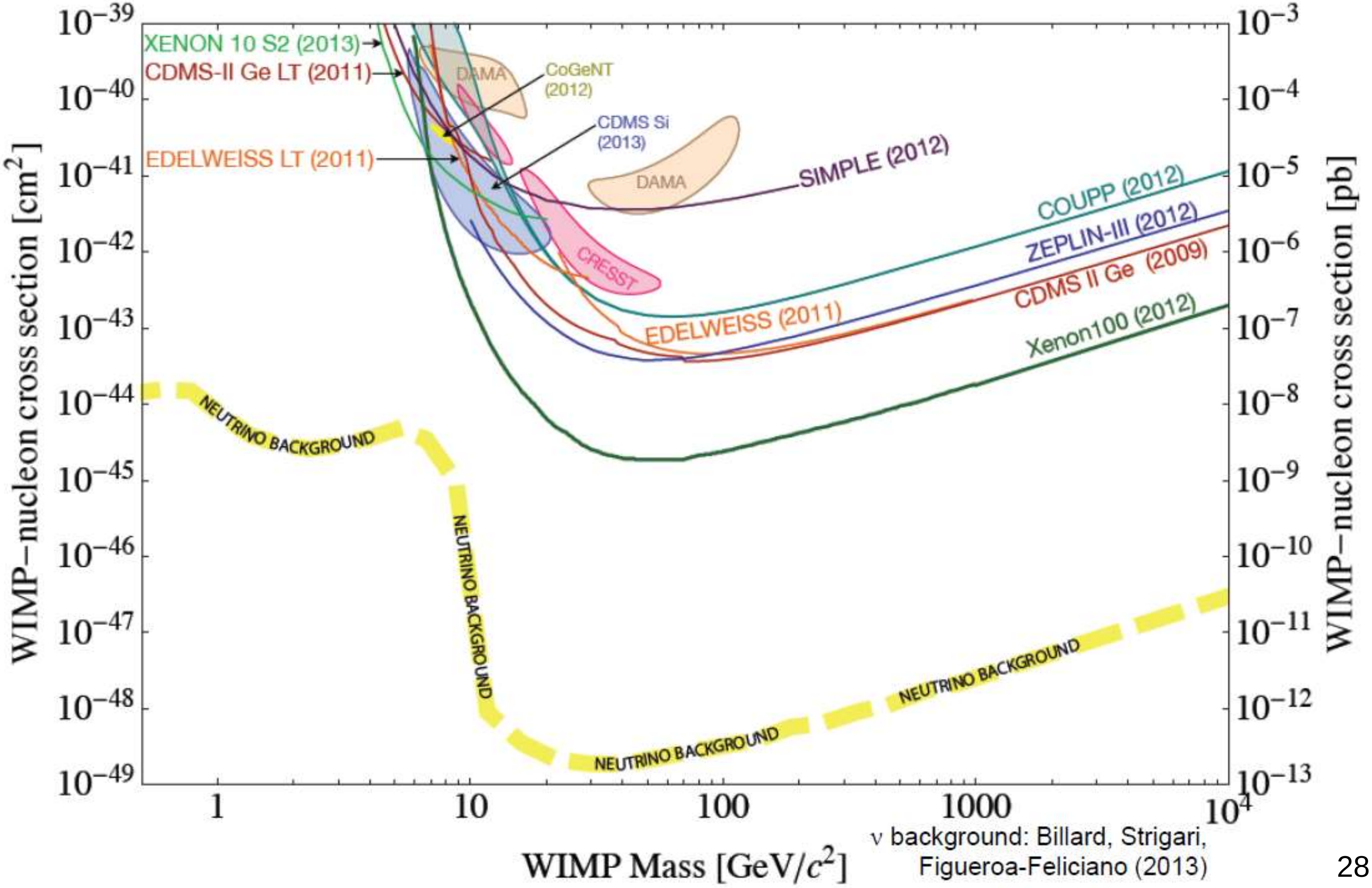
~700 s storage

Ultracold neutrons, ~ 62.3 neV

M. S. Dewey et al., Phys. Rev. Lett. 91, 152302 (2003);

A. P. Serebrov et al., Phys. Rev. C 78, 035505 (2008).

(3) Direct Detection of Mirror DM



ν background: Billard, Strigari, Figueroa-Feliciano (2013)

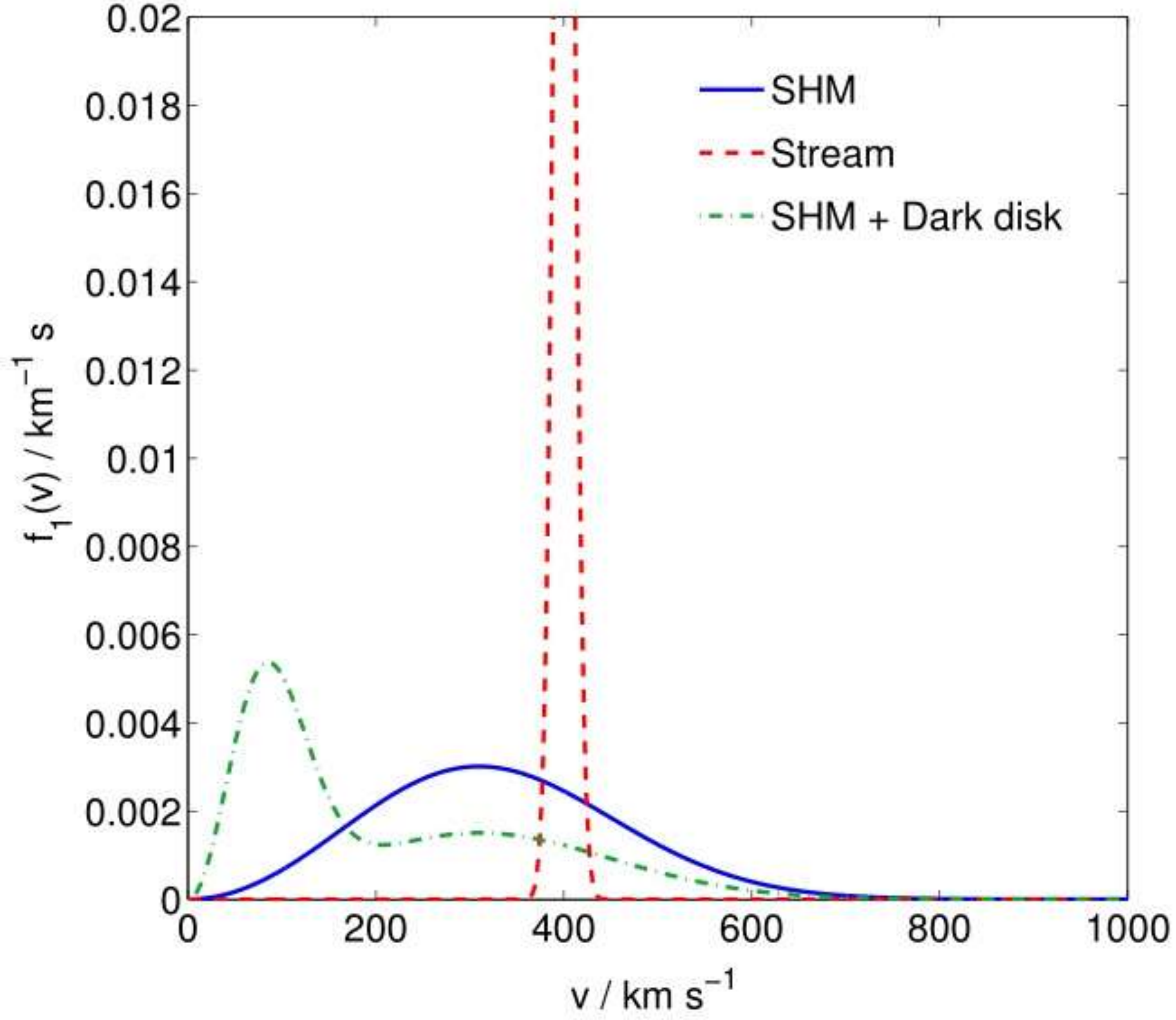
Observations

- No heavy masses observed as predicted by SUSY (also, no SUSY signal from LHC)

- Currently experiments have no detection sensitivity below $M_{WIMP} < 6$ GeV

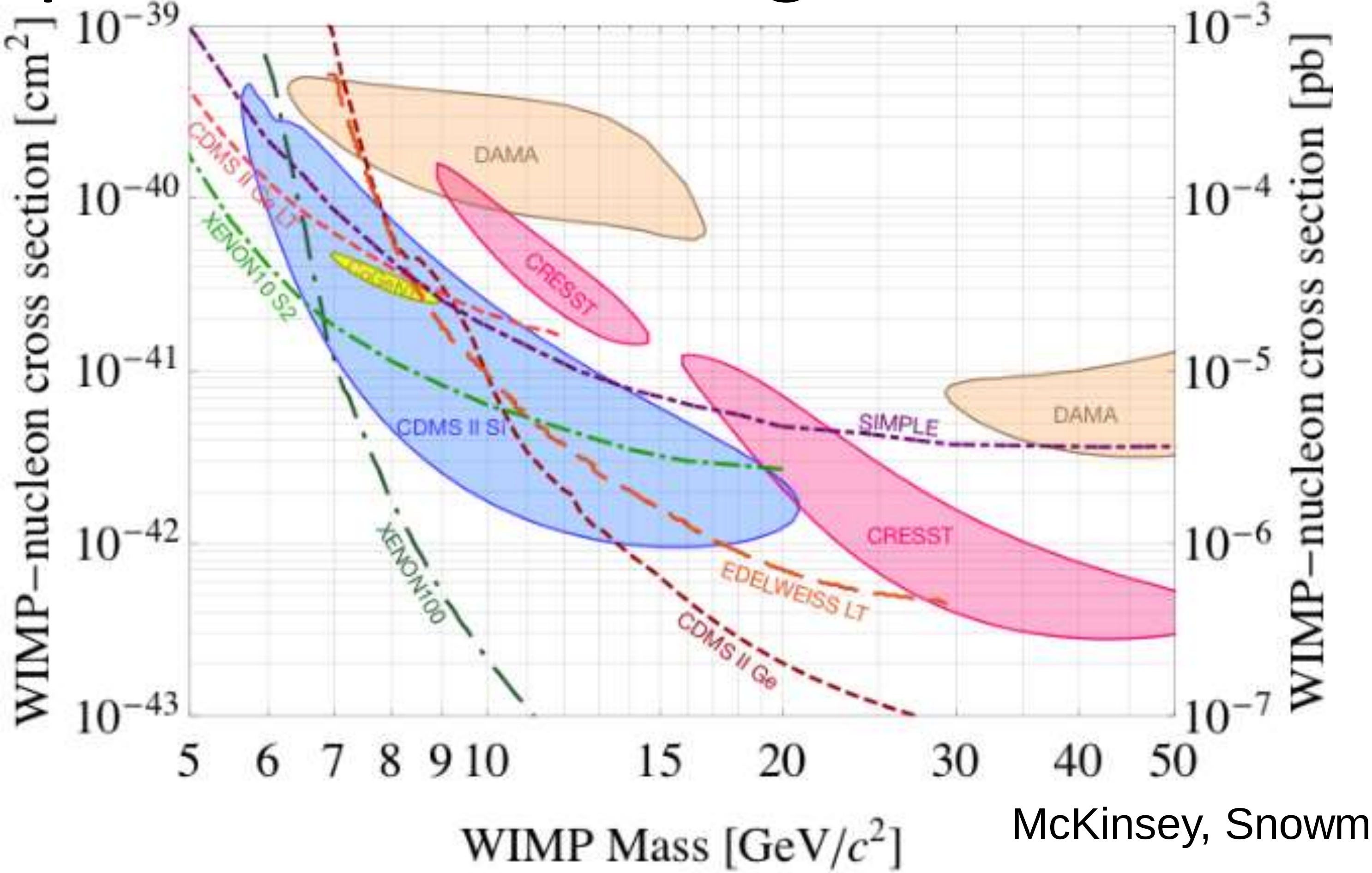
- For low M masses experiments are still using same WIMP paradigm.

Usual Velocity Distribution Models of DM



B. J. Kavanagh et al., arXiv:1308.6868v2

Experiments Claiming DM Detection



McKinsey, Snowmass 2013

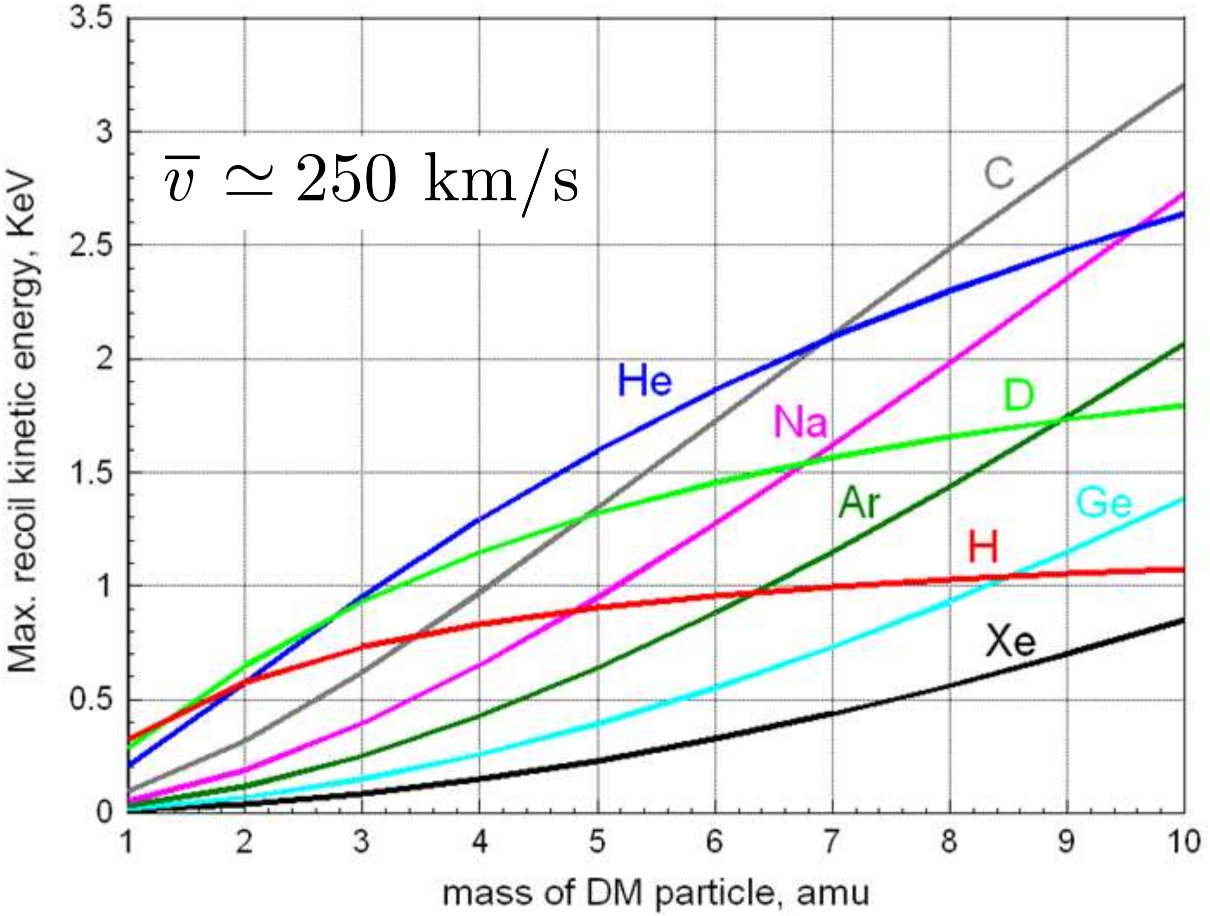
- In the low mass region the experiment might be detecting the small fraction of MM “metallic” part of DM clouds.
- These experiments have low mass target nuclei and/or low thresholds.

Why low masses are difficult to detect?

$$T_{recoil}(\max) = T_0 \frac{4m_{nuc}M_{DM}}{(m_{nuc}+M_{DM})^2}$$

CDMS-Si
7 keV

DAMA-Na
2 keV



Why low masses are difficult to detect?

- Energy transfer to the nucleus might not result into ionization or excitations of the target atom. After collision with DM atom can be moving as a whole neutral object. Quenching is difficult to calculate or determine experimentally.

- E.g. slow neutrons scattering signal used for recoil calibration might be not entirely equivalent due to Schwinger scattering of neutron magnetic moment on the on the bound electrons of the inner shells.

(1) Possible n→n’ experiments to be performed with UCN and CN

1. to repeat the ILL disappearance experiment with same magnetic field values, with better trap techniques and higher statistics to confirm independently the presence of the observed effect.

2. experiment can be repeated at different alternating values of magnetic field, with possible observation of enhancement of measured asymmetry. Scan with magnetic field magnitude and direction in order to find the effect enhancement. Unique signature!

3. Regeneration mode: neutrons are filled and contained in the sealed trap but mirror neutrons can pass through the trap wall into the next volume with same magnetic field B that is resonant for transformation. In this case appearance effect (regeneration) of neutrons from mirror state in the second “empty” volume can be observed.

4. Extended configuration: with found magnetic field enhancement the path of neutron flight can be increased e.g. to ~ 25 m for each of two chambers separated by total neutron absorber. This should be performed with a beam of cold (or even thermal) neutrons. Using parameters (B’ and τ) claimed in ILL experiment and with cold beam intensity 10^7 per sec the observed rate of regeneration can be 10-20 per hour. Such counting rate of cold neutrons will require robust shielding of the detectors which represent a challenging effort. Similar problems was successfully solved in the environment of SNS.

(2) Neutron lifetime difference

1. New experiments are due with beam and trap techniques. Should be more seriously considered if difference will remain with larger significance. Variation of external B during trap measurements might reveal a dependence.

2. Since Hamiltonian in general can have absorptive part for different components of n and n’ making in general 4x4 matrix non-unitary, new calculational tools need to be developed based of density matrix.

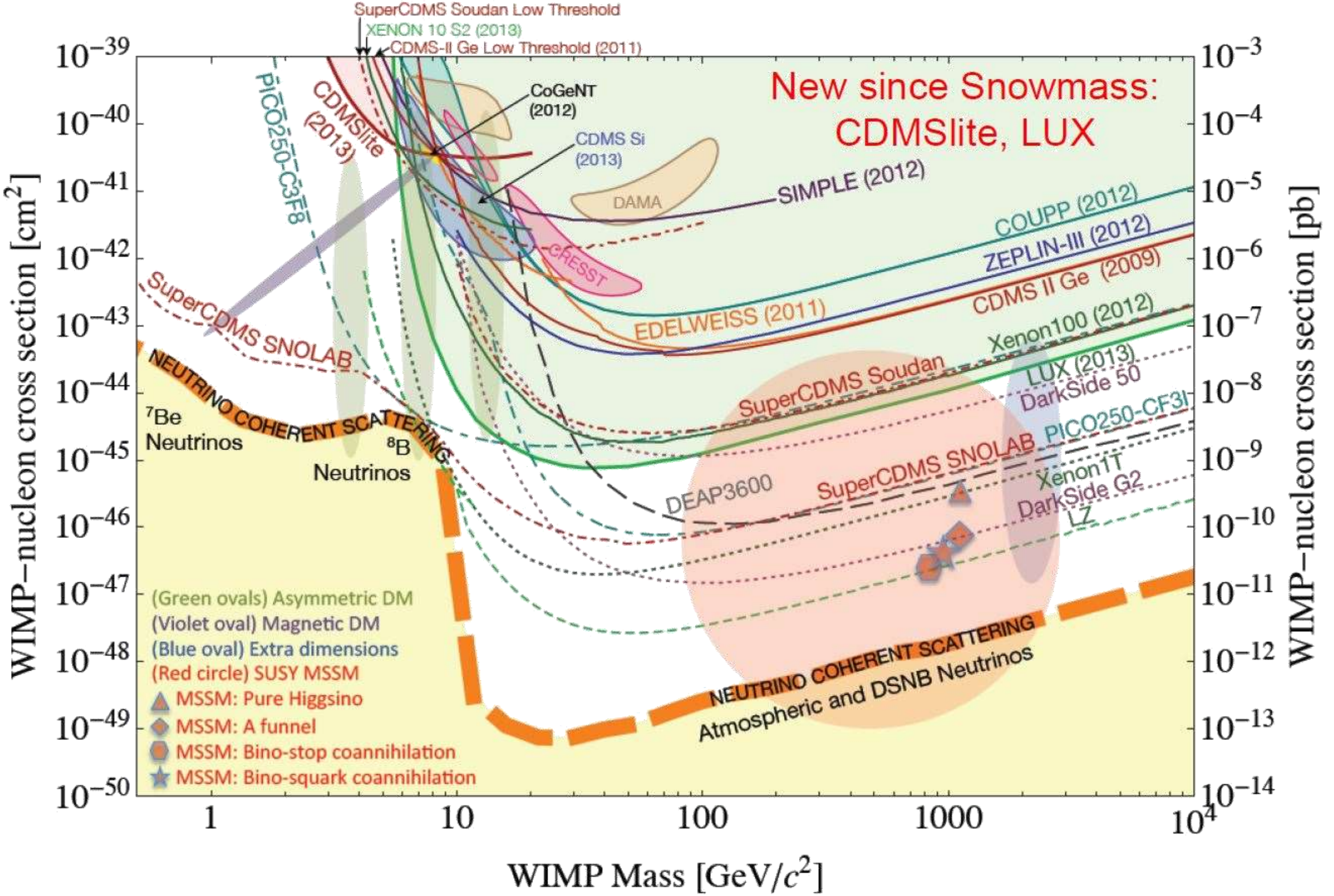
(3) Direct detection of DM

1. Develop a new paradigm of MM motion in the galaxy as gas clouds relative to Solar system. Several unknown parameters can be included as multi-dimensional space where all existing DM experiments can be re-analyzed. Allowed regions can be used for planning new direct dM detection experiments.

2. Develop detectors with light experimental target materials: H, D, He, C (e.g. CH4)

3. Ab initio QM calculation of ionization loss (seems it is possible for hydrogen gas)

Dark Matter Direct Detection: Current and Future



J. Feng and S. Ritz, "Snowmass Cosmic Frontier," (2 Nov. 2013), <http://hep.ps.uci.edu/~jlf/research/presentations/1311P5.pdf>

“Errors runs down an inclined plane, while truth has to laboriously climb its way up hill”

Old proverb
From The Secret Doctrine
By H. Blavatsky, Vol. 1