International Workshop “Search for Baryon and Lepton Number Violations”, LBLN Berkeley, September 20-22

Search for B-L violation with neutrons at

DUSEL

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Is (B–L) number conserved?

- ✧ In regular matter (B–L) = # protons + # neutrons – # electrons $\neq$ 0

(B–L) $\neq$ 0 ; Is it a smoking gun?

- ✧ In the Universe most of the leptons exist as, yet undetected, relict neutrino and antineutrino radiation (similar to CMBR) and the conservation of (B–L) on the scale of the whole Universe is still an open question

- ✧ Fast anomalous SM interactions (*sphalerons*) in early Universe require that (B–L) should be violated at > 10 TeV scale

V. Kuzmin, V. Rubakov, M. Shaposhnikov, 1985

"Proton decay is not a prediction of baryogenesis!" [Yanagida'02]

↑

with conservation of (B–L)

$\Delta(B-L)$: two possibilities

For transitions *fermion* $\rightarrow$ *fermion* the conservation of angular momentum requires that spin ½ of nucleon should be transferred to another fermion (lepton or baryon):

That leads to the selection rule:
$\Delta B = \pm \Delta L$ or $|\Delta(B-L)| = 0, 2$

- <u>In Standard Model, in SU(5), and many SUSY extensions:</u>

  $\Delta(B-L) = 0$ or $\Delta B = + \Delta L$ (e.g. nucleon $\rightarrow$ antilepton)

- Second possibility of $|\Delta(B-L)| = 2$ allows transitions with

  $\Delta B = - \Delta L$ (nucleon $\rightarrow$ lepton), or $|\Delta B| = 2$, or $|\Delta L| = 2$

Possible (B–L)V manifestations following from Δ(B–L)=2

$\Delta B = 0$; $\Delta L = 2$ $\nu \leftrightarrow \bar{\nu}$ *i.e.* Majorana neutrino, $2\beta 0\nu$ observable

$\boxed{\Delta L = 0 \; ; \; \Delta B = 2 \quad n \leftrightarrow \bar{n} \text{ oscillations}}$ most promising !

$\Delta B = -\Delta L$ e.g. $n \to \nu\nu\bar{\nu}$ or $p \to \nu\nu e^+$ (nucleon $\to$ lepton)

also e.g. $\tau^- \to n + \pi^-$ or $\Lambda^0 \to \mu^- + \pi^+$ (with heavy flavors involved)

Why neutrons? n_R is a singlet part of the SM and available for experiments while ν_R might be very heavy and difficult to detect

All observable Δ(B–L)=2 processes are topologically similar: operators of dim-9 for non-SUSY amplitude

$\to$ There must be a scale of (B–L) violation and physics

$n \leftrightarrow \bar{n}$ $\qquad$ $|\Delta B|=2$; $|\Delta(B-L)|=2$

- There are no laws of nature that would forbid the N $\leftrightarrow$ Nbar transitions except the conservation of "*baryon charge (number)*":

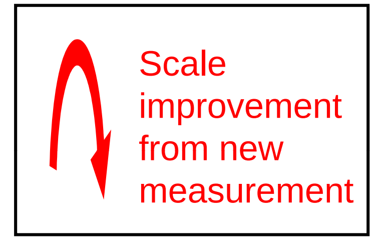
M. Gell-Mann and A. Pais, Phys. Rev. 97 (1955) 1387
L. Okun, Weak Interaction of Elementary Particles, Moscow, 1963

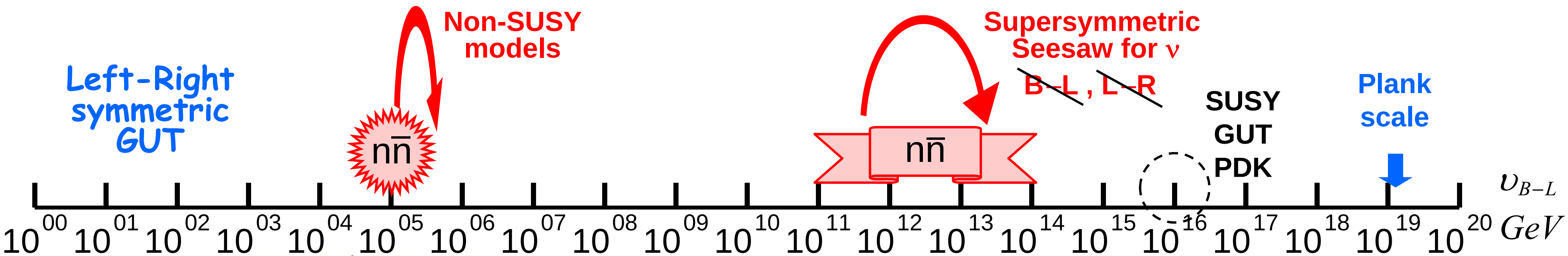
- N $\leftrightarrow$ Nbar was first suggested as a possible mechanism for explanation of Baryon Asymmetry of Universe *by V. Kuzmin, 1970*

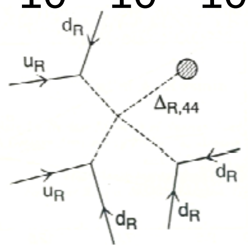
- N $\leftrightarrow$ Nbar works within GUT + SUSY ideas. First considered and developed within the framework of L/R symmetric Unification models

by R. Mohapatra and R. Marshak, 1979 ...

Scales of $n \to \bar{n}$

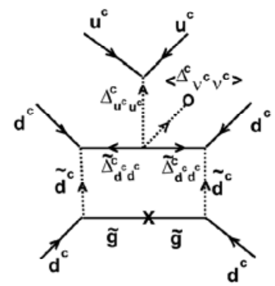






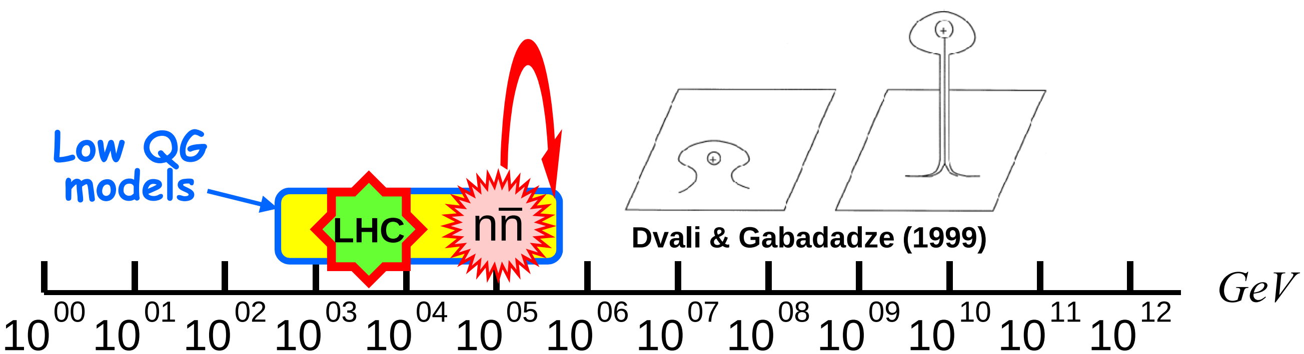
$$\propto \upsilon_{B-L}^{-5}$$

Mohapatra & Marshak (1980)



$$\propto \upsilon_{B-L}^{-2} \cdot \upsilon_{WK}^{-3}$$

Dutta-Mimura-Mohapatra (2005)



Dvali & Gabadadze (1999)

n→nbar transition probability

All beyond SM physics is here

α-mixing amplitude

$$\Psi = \begin{pmatrix} n \\ \bar{n} \end{pmatrix}$$ mixed n-nbar QM state

$$\mathrm{H} = \begin{pmatrix} E_n & \alpha \\ \alpha & E_{\bar{n}} \end{pmatrix}$$ Hamiltonian on the system

where E_n and $E_{\bar{n}}$ are non-relativistic energy operators:

$$E_n = m_n + \frac{p^2}{2m_n} + U_n \quad ; \quad E_{\bar{n}} = m_{\bar{n}} + \frac{p^2}{2m_{\bar{n}}} + U_{\bar{n}}$$

Important assumptions:

- $\alpha(n \to \bar{n}) \cong \alpha(\bar{n} \to n) = \alpha$ (i.e. T-invariance is hold)
- there is a reference frame where $p = 0$
- $m_n = m_{\bar{n}}$ (if CPT is not violated)
- gravipotential for n and $\bar{n}$ is the same: $\Delta U = U_n - U_{\bar{n}} = 0$
- magnetic moment $\mu(\bar{n}) = -\mu(n)$ as follows from CPT [BTW $\mu(\bar{n})$ not measured!]
- Earth mag. field can be screened down to accepatable few nT level

n→nbar transition probability (for given α)

For $H = \begin{pmatrix} m_n + V & \alpha \\ \alpha & m_{\bar{n}} - V \end{pmatrix}$

$$\boxed{P_{n\to\bar{n}}(t) = \frac{\alpha^2}{\alpha^2 + (V + \Delta m/2)^2} \times \sin^2\left[\frac{\sqrt{\alpha^2 + (V+\Delta m/2)^2}}{\hbar} t\right]}$$

where V is a potential different for neutron and anti-neutron
(e.g. due to non-compensated Earth mag. field; or part of gravipotential)
t is observation time in an experiment, and $\varDelta m = m_n - m_{\bar{n}}$

In an ideal situation of the "vacuum oscillations" $V = 0$ and $\varDelta m = 0$

$$\boxed{P_{n\to\bar{n}} = \left(\frac{\alpha}{\hbar} \times t\right)^2 = \left(\frac{t}{\tau_{n\bar{n}}}\right)^2}$$

$\tau_{n\bar{n}} = \dfrac{\hbar}{\alpha}$ is characteristic transition (oscillation) time $[\alpha < 10^{-23}\, eV]$

$$\boxed{\text{"}\mathit{Sensitivity}\text{"} \propto N_n \bullet < t^2 >}$$

(N_n number of neutrons used per sec, t^2 square of flight time)

PDG 2006:
Limits for both
free reactor neutrons and
neutrons bound inside nucleus

New SK result today ↘

Bound n: J. Chung et al., (Soudan II)
Phys. Rev. D 66 (2002) 032004 $> 7.2 \cdot 10^{31}$ years

Free n: M. Baldo-Ceolin et al., (ILL/Grenoble) *Z. Phys* **C63** (1994) 409
with $P = (t/\tau_{free})^2$

$$\tau_{bound} = R \cdot \tau_{free}^2$$
$$\text{where } R \sim 10^{23} s^{-1}$$

(talk of A. Gal)

LIMIT ON $n\bar{n}$ OSCILLATIONS

Mean Time for $n\bar{n}$ Transition in Vacuum

A test of ΔB=2 baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for $n\bar{n}$ oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for $n \rightarrow \bar{n}$ transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table.

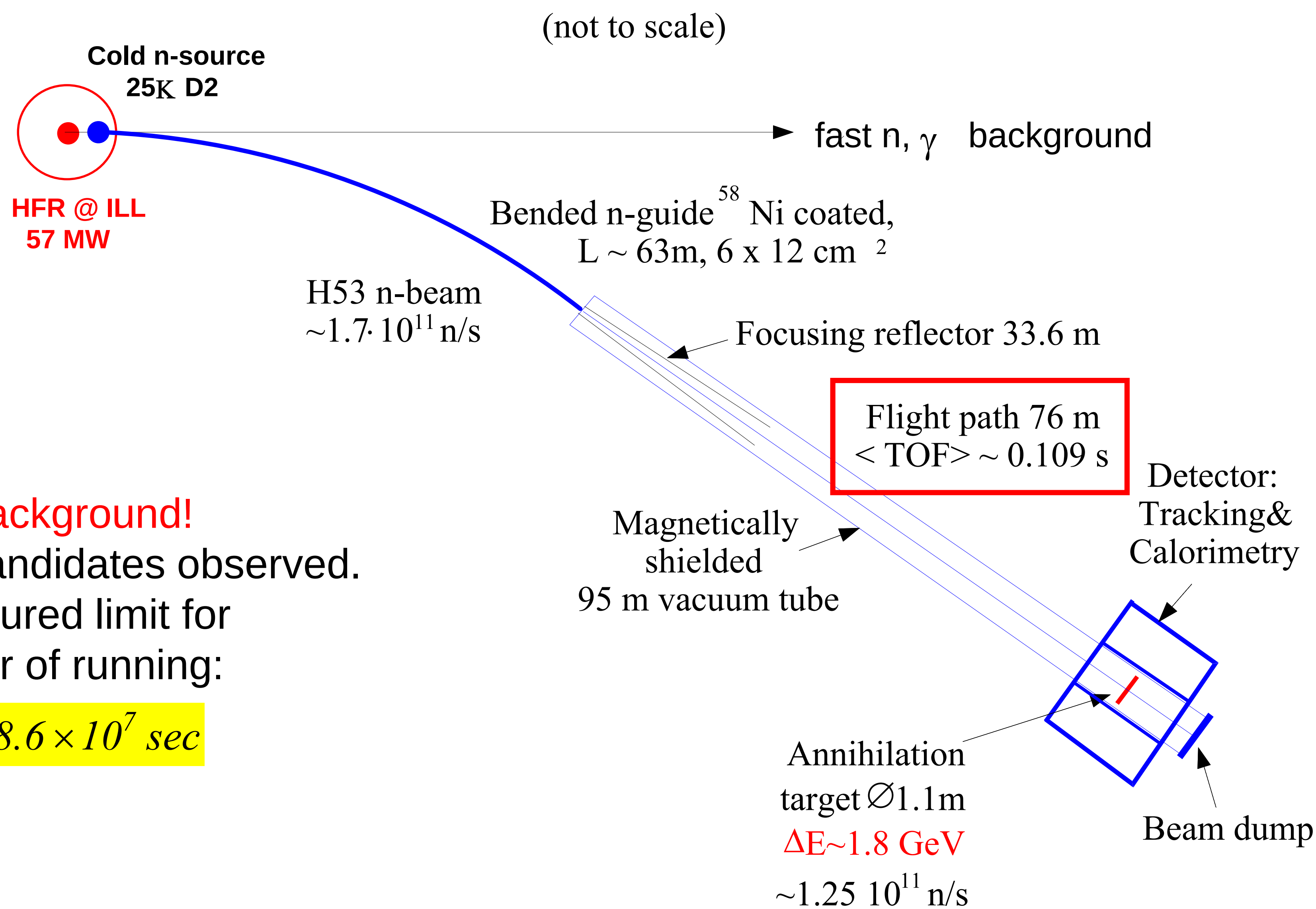
VALUE (s)	CL%	DOCUMENT ID		TECN	COMMENT
$>1.3 \times 10^8$	90	CHUNG	02B	SOU2	n bound in iron
$>8.6 \times 10^7$	90	BALDO-...	94	CNTR	Reactor (free) neutrons
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>1 \times 10^7$	90	BALDO-...	90	CNTR	See BALDO-CEOLIN 94
$>1.2 \times 10^8$	90	BERGER	90	FREJ	n bound in iron
$>4.9 \times 10^5$	90	BRESSI	90	CNTR	Reactor neutrons
$>4.7 \times 10^5$	90	BRESSI	89	CNTR	See BRESSI 90
$>1.2 \times 10^8$	90	TAKITA	86	CNTR	n bound in oxygen
$>1 \times 10^6$	90	FIDECARO	85	CNTR	Reactor neutrons
$>8.8 \times 10^7$	90	PARK	85B	CNTR	
$>3 \times 10^7$		BATTISTONI	84	NUSX	
$> 2.7 \times 10^7$–1.1×10^8		JONES	84	CNTR	
$>2 \times 10^7$		CHERRY	83	CNTR	

Search with free neutrons is square more advantageous but with suppressed intra-nuclear transitions the larger number of neutrons can be available although with background limitations

Previous N-Nbar search experiment with free neutrons

At ILL/Grenoble reactor in 89-91 by Heidelberg-ILL-Padova-Pavia Collaboration

M.Baldo-Ceolin M. et al., Z. Phys., C63 (1994) 409



No background!

No candidates observed.

Measured limit for

a year of running:

$$\tau_{n\bar{n}} \geq 8.6 \times 10^7 \ sec$$

How one can improve on such state-of-the-art experiment and achieve 3-4 orders of magnitude higher sensitivity?

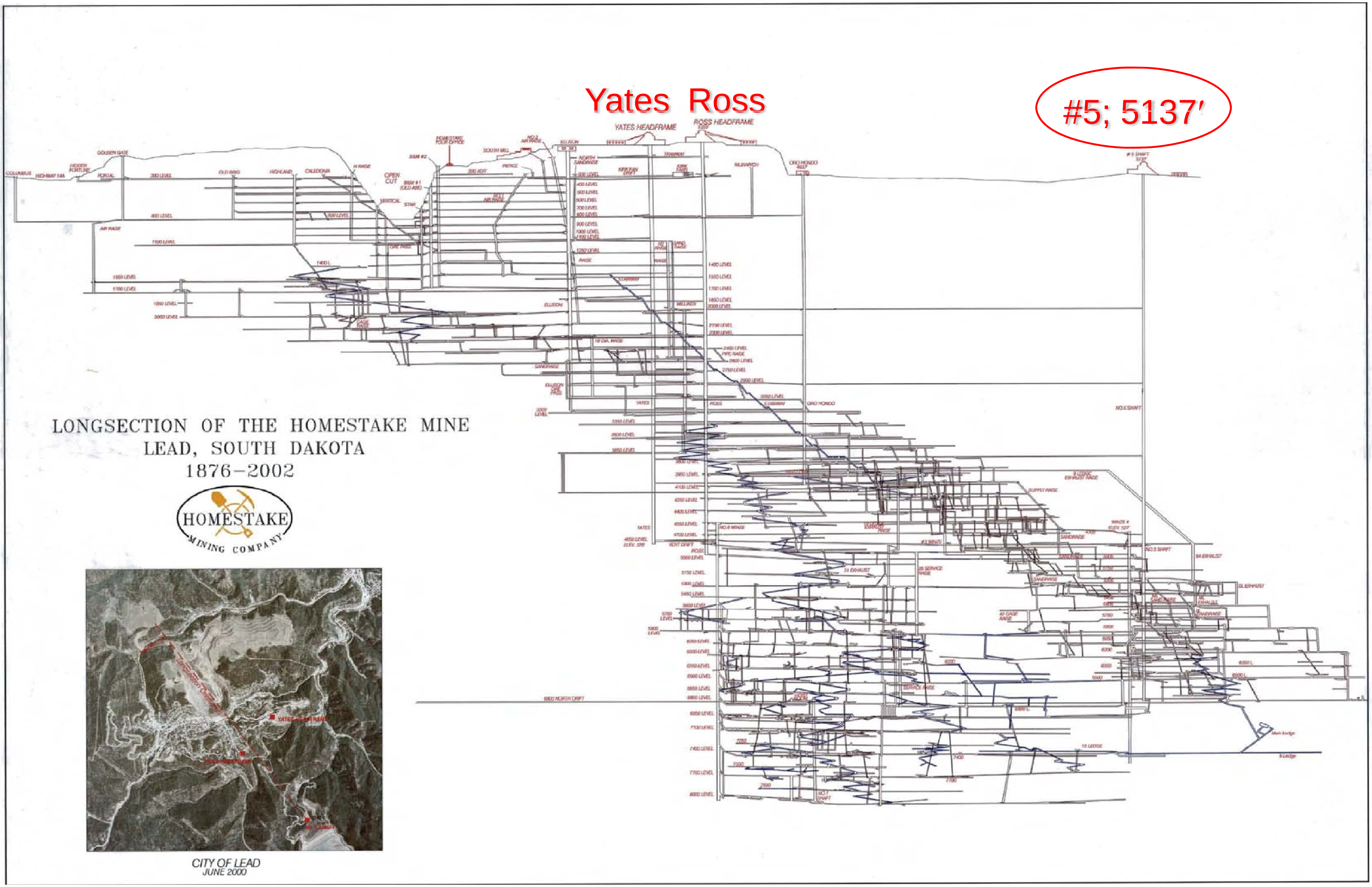
Two major possible improvements:

1. Focusing of neutrons: use of larger solid angle
   $\rightarrow$ longer neutron flight path $\geq$ 1 km

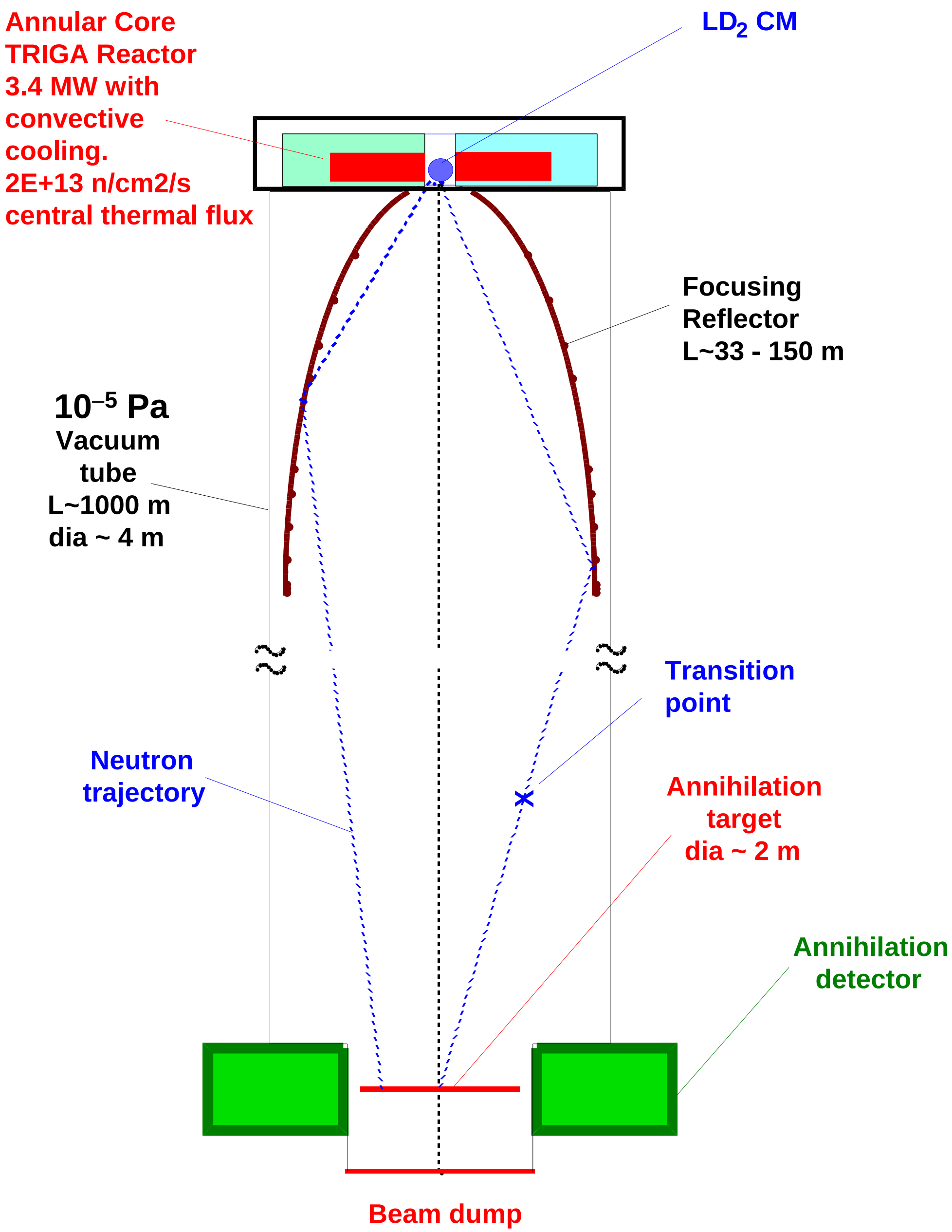
2. Vertical layout: compensating Earth gravity

Homestake shafts

HOMESTAKE DUSEL
Deep Underground Science and Engineering Laboratory



N-Nbar search experiment idea with vertical layout



Not to scale

Neutron source needed: commercial TRIGA type small power 3.4 MW reactor

HOMESTAKE DUSEL

Deep Underground Science and Engineering Laboratory

February 9, 2006, Lead, SD (LOI #7)

Search for neutron → antineutron transitions at DUSEL

N-Nbar proto-collaboration

D. Baxter[2], W. Bugg[8], Y. Efremenko[8], A. Fomin[7], T. Gabriel[8], K. Ganezer[1],
T. Handler[8], T. Ito[3], Y. Kamyshkov[8], A. Kharitonov[7], A. Kozlov[8], M. Leuschner[2],
C-Y. Li ... ev[7],
W. M. Snow[2], S. Spanier[8], A. Young[5], C. West[8], A. Young[5], B. Wehring[5], A. Zakharov[7]

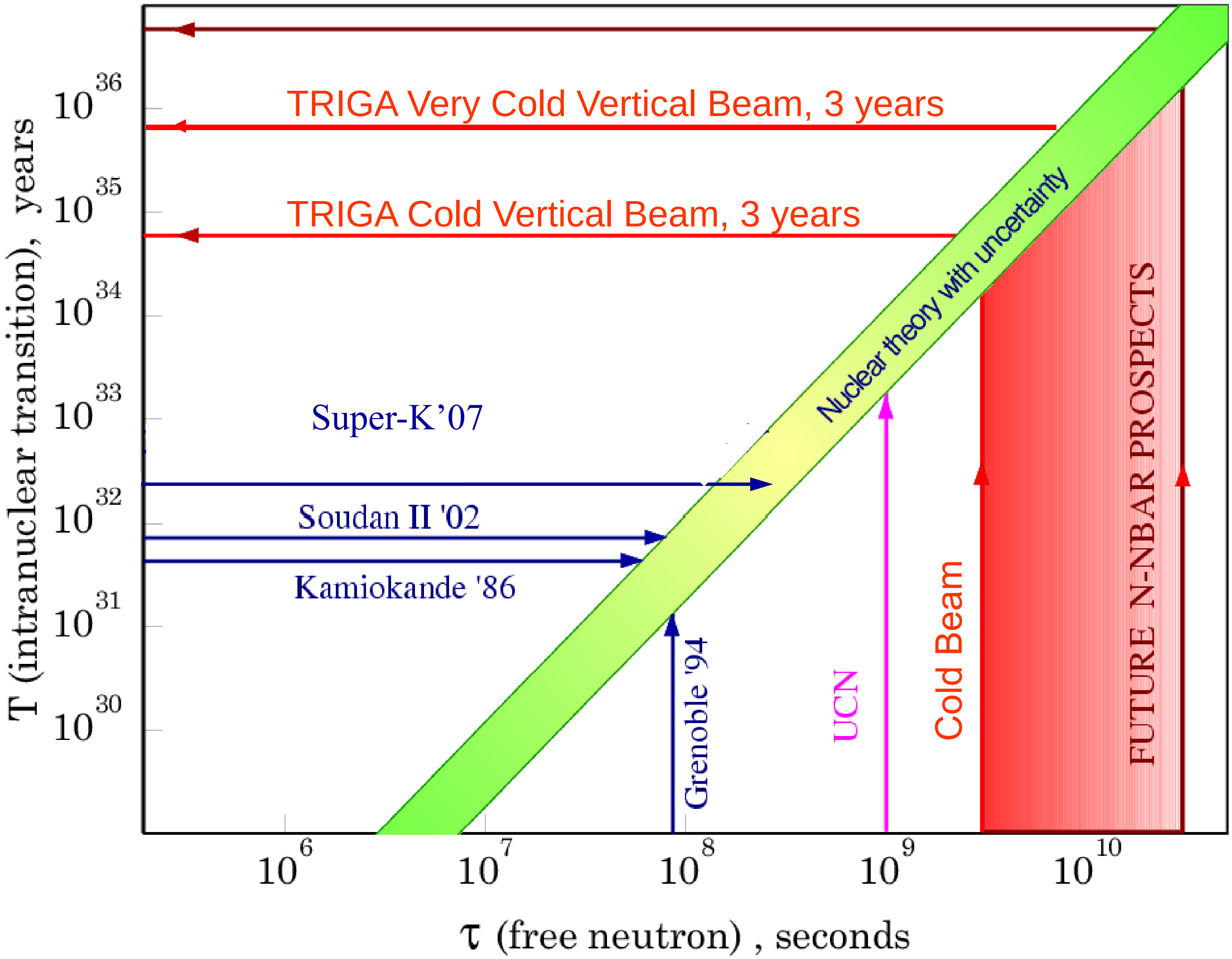
Goal is to build a vertical 1-km long experiment with zero background that would be factor of 1000 more sensitive than previous expt. at ILL/Grenoble

[1] California State University, Dominguez Hills
[2] Indiana University
[3] Los Alamos National Laboratory
[4] University of Maryland
[5] North Carolina State University
[6] NRC/NIST
[7] St. Petersburg Nuclear Physics Institute, Russia
[8] University of Tennessee

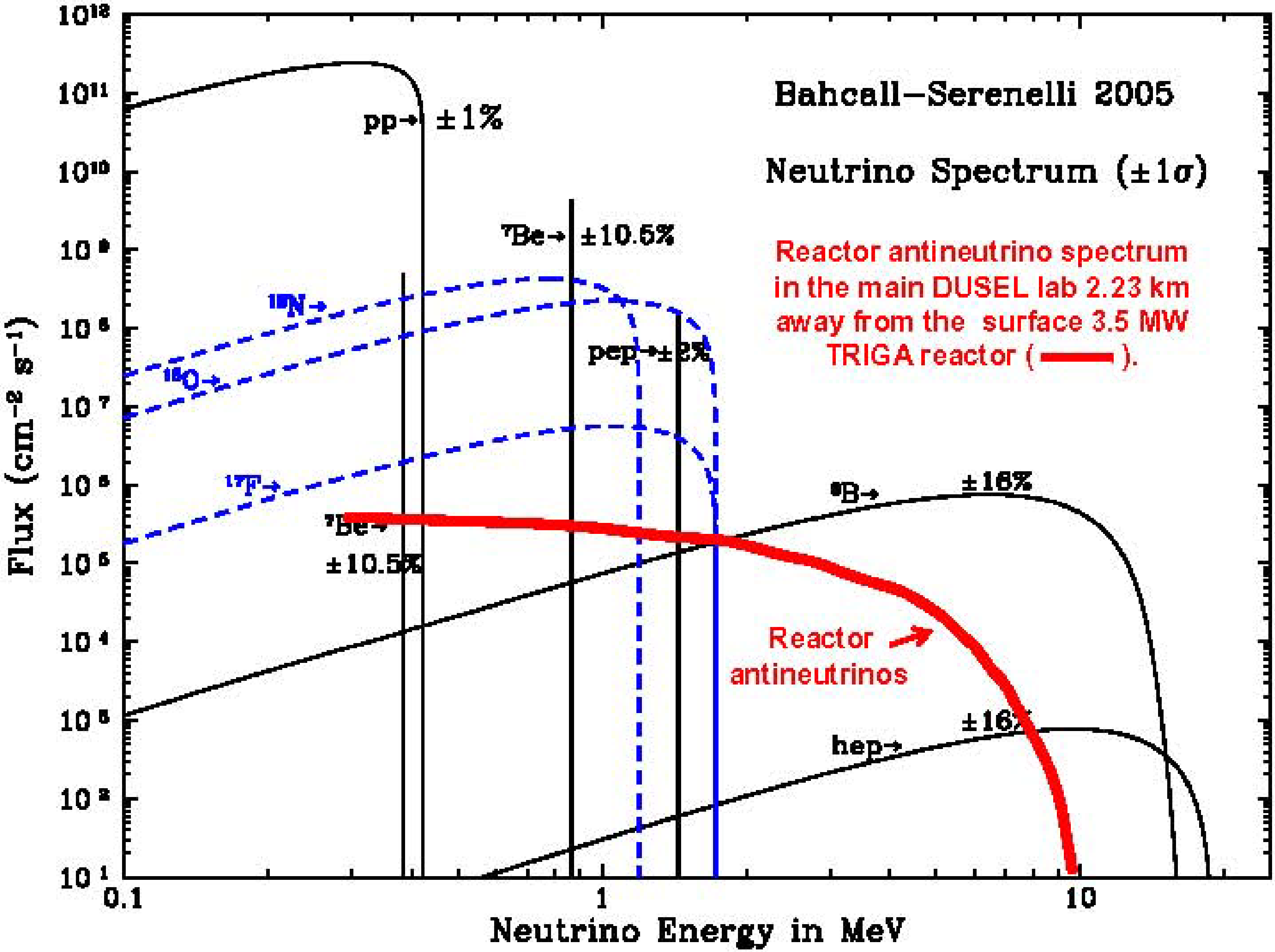
(Contact address: Yuri Kamyshkov <kamyshkov@utk.edu>)

Stability of matter from Neutron-Antineutron transition search

$T_A = R * (\tau_{free})^2$, where R is "nuclear suppression factor" in intranuclear transition



Spare slides



calculated by Ken Ganezer