Neutron-Antineutron Oscillations with UCN: the IU/UT/TUNL workshop @ Indiana

- Theoretical expectations: why look?
- Limits/limitations from underground detectors
- Cold neutron experiment?
- UCN experiment?
- What is to be done?

$n \leftrightarrow \bar{n}$ transitions — "too crazy"?

But neutral meson $|q\bar{q}\rangle$ states oscillate -

$K^0, B^0 \leftrightarrow$ [2^{nd} order weak interactions] $\leftrightarrow \bar{K}^0, \bar{B}^0$

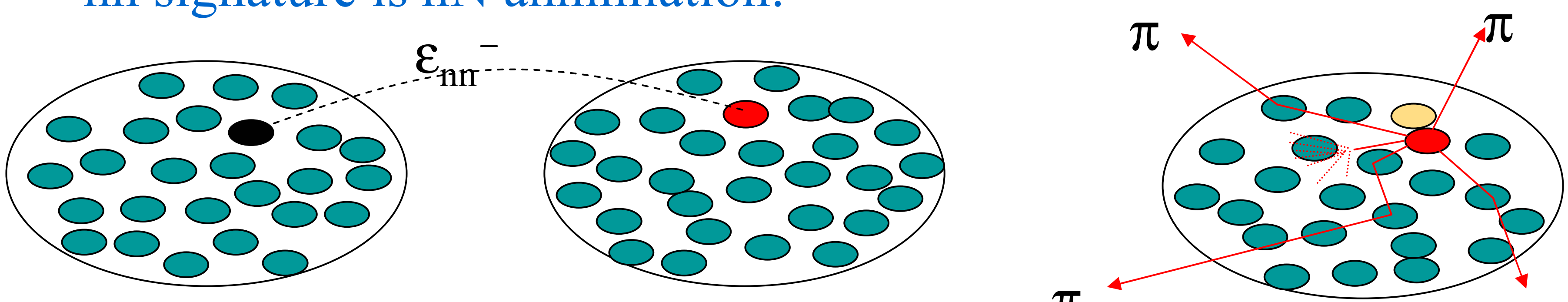
And neutral fermions can oscillate too -

$\nu_\mu \leftrightarrow$ [ΔL] $\leftrightarrow \nu_\tau$

So why not -

$n \leftrightarrow$ [$\Delta[B\text{-}L]$] $\leftrightarrow \bar{n}$?

$n\bar{n}$ signature is $\bar{n}N$ annihilation:



Nucleus $A \rightarrow A^* + \bar{n}$

$\bar{n}N \rightarrow$ pions

What motivates searches for baryon instability?

- Baryon asymmetry of the universe (BAU).
- *Sakharov (1967), Kuzmin (1970)*
- In Standard Model baryon number is not conserved
- (at the non-perturbative level) *'t Hooft (1976)* **...**
- Idea of Unification of particles and their interactions.
- *Pati & Salam (1973): quark– lepton unification, Left - Right symmetry, Georgi & Glashow (1974): SU(5) - unification of forces* **...**
- New low quantum gravity scale models: *N. Arkani-Hamed, S. Dimopoulos, G. Dvali (1998)* **...**

Conservation or violation of (B–L) is an essential issue

Conservation of angular momentum in N disappearance

->$\Delta B = \pm \Delta L$ or $|\Delta(B-L)| = 0, 2$

In Standard Model and in GUTS which lead to proton decay, $\Delta(B-L) = 0$

What about $|\Delta(B-L)| = 2$?

What Mass Scale is probed?

in the lowest order the n-nbar transition should involve a 6-quark operator with the amplitude suppressed by $\sim m^{-5}$:

- Observable transition rates would correspond to the mass scale m ~ **100** TeV
- Anything happening at this scale?

New Ideas for n-nbar Oscillations

- G. Dvali and G. Gabadadze, “Non-conservation of global charges in the brane universe and baryogenesis”, Physics Letters B 460 (1999) 47-57

- K. S. Babu and R. N. Mohapathra. “Observable neutron-antineutron oscillations in seesaw models of neutrino mass, Physics Letters B 518, (2001) 269-275

- S. Nussinov and R. Shrock, “N-nbar Oscillations in models with large extra dimensions” Phys. Rev. Lett. 88, (2002) 171601

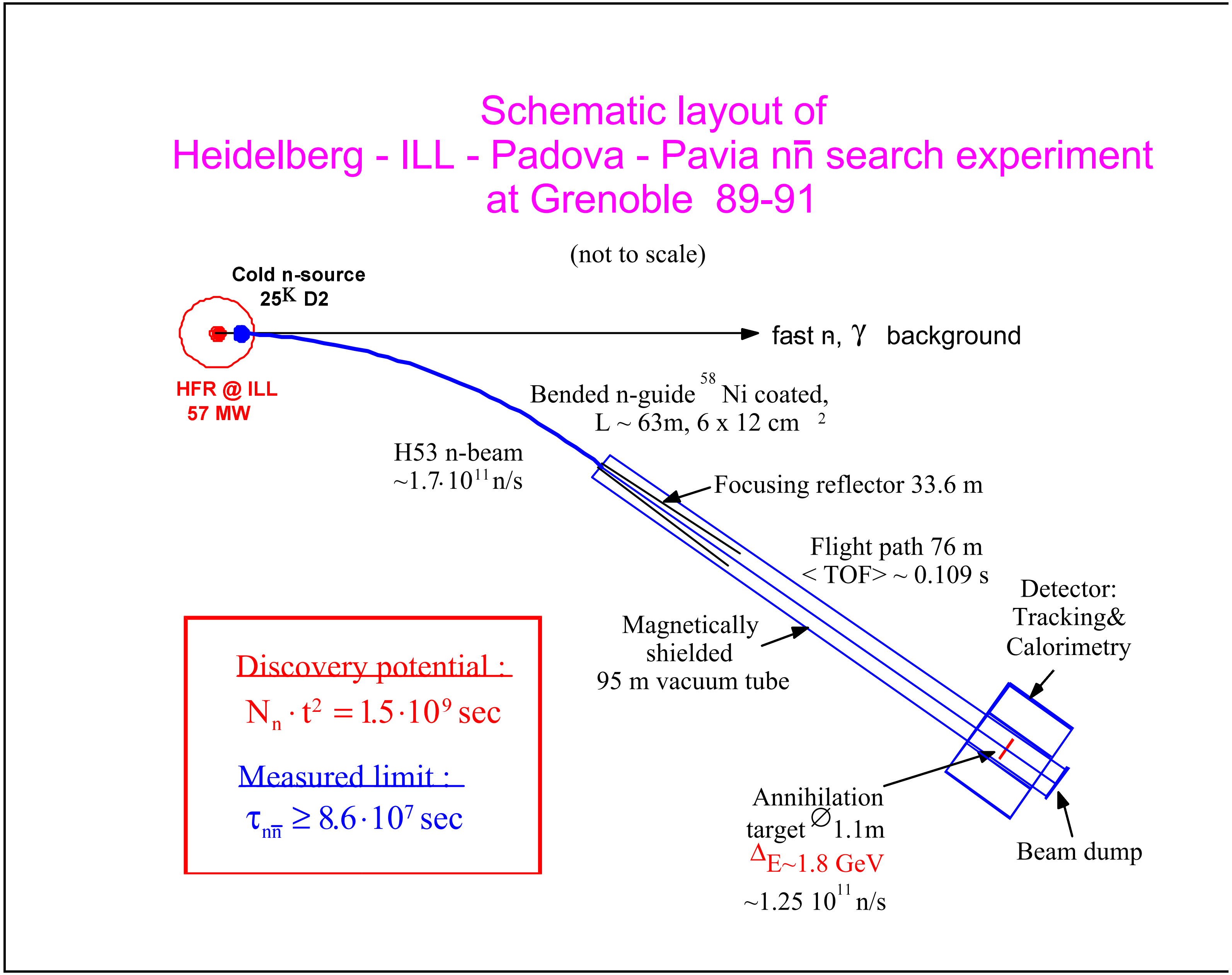
What About the Baryon Asymmetry?

Non-perturbative phenomana will wipe out BAU at electro-weak energy scale if BAU was generated at a scale > ~ TeV by (B–L) conserving processes such as GUT proton decay (*Kuzmin, Rubakov,Shaposhnikov 1985)*

If (B–L) is violated at the scale above 1 TeV, BAU will survive-> mechanisms are leptogenesis (popular) and ΔB=2 (n-nbar oscillations)

N-nbar oscillations are more relevant to BAU than GUT proton decay!

Last Experiment at ILL



Limits from Nucleon Decay Experiments

A 5.56 fiducial kty exposure of Soudan 2 has been used to set a new lower limit for $n\bar{n}$ oscillations in iron of:

$T_A(\text{Fe}) > 7.2 \times 10^{31}$ years - at 90% CL.

The corresponding limit for free neutrons, assuming $T_R = 1.4 \times 10^{23}$ s, is

$\tau_{n\bar{n}} \geq 1.3 \times 10^8$ seconds.

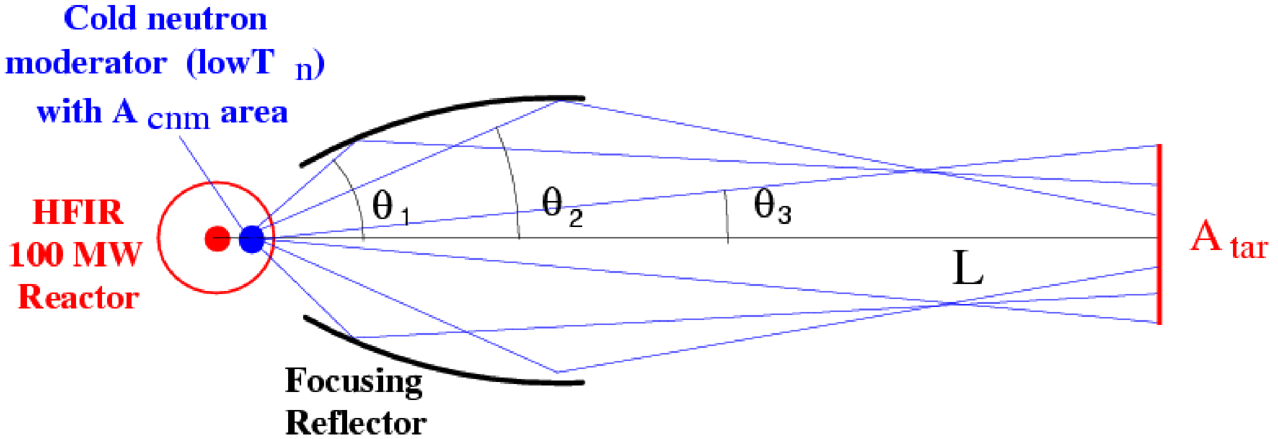
Background arising from multiprong interactions of atmospheric neutrinos is observed:~ 0.7 ν evts/kty.

Limit-setting to $\tau_{n\bar{n}} > (4 - 5) \times 10^8$ secs is achievableby SNO and SuperK.

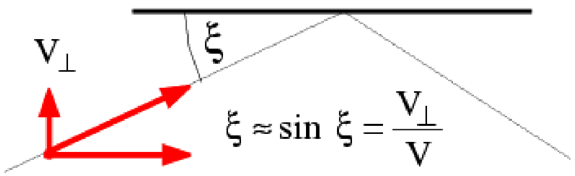
Extending search limit sensitivity to/beyond $\tau_{n\bar{n}} = 10^9$ secs requires a different approach. For $n\bar{n}$ exploration, the future lies with new free neutron experiments.

Schematic layout of a new experiment with focusing reflector

(not to scale)



Reflection :



$$\xi \approx \sin\xi = \frac{V_\perp}{V}$$

$$\Delta\Omega \sim \xi^2 \sim \frac{1}{V^2} \sim \frac{1}{T^{o}K}$$

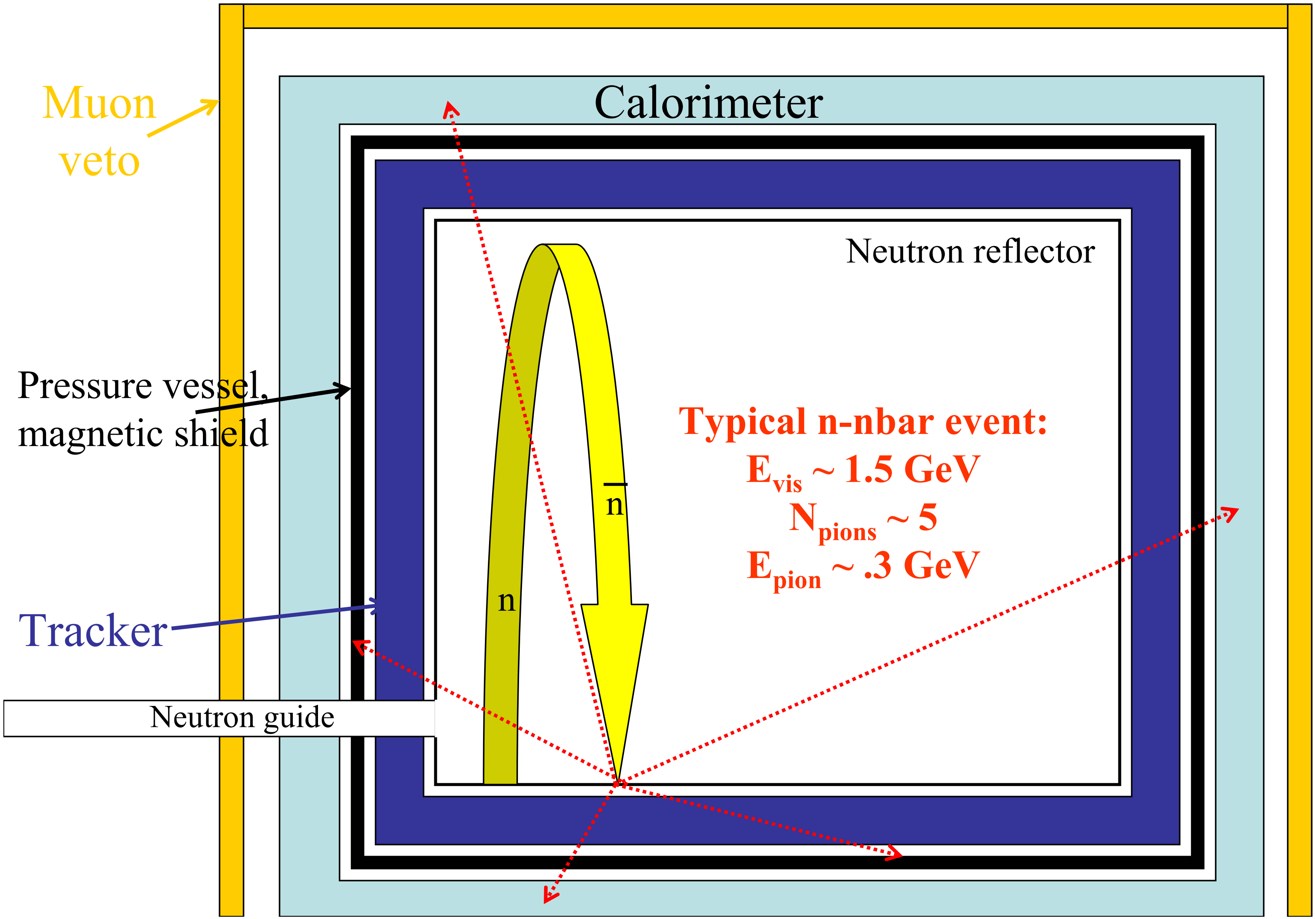
$$\theta_1 < \theta < \theta_2 \rightarrow \Delta\Omega; \quad \Delta\Omega \sim \left(\frac{1}{T_n}\right)$$

$$D.P. \sim N_{\bar{n}} \sim \Phi_n \cdot A_{cnm} \cdot \frac{\Delta\Omega}{4\pi} \cdot \left(\frac{L}{V_n}\right)^2; \quad \Phi_n \sim V_n$$

$$D.P. \sim N_{\bar{n}} \sim \frac{L^2}{T_n^{3/2}}$$ (if no gravity)

When focusing reflector is used, the large distance L and low neutron temperature T_n are most essential for discovery potential improvement

Typical detector for the "neutrons in the bottle experiment"



Possible Future UCN Sources

- **source/moderator/density/mode/fill rate/timing**
- **type (UCN/cc) (UCN/s)**
- PSI D2 1E+3 3s/600s 1E+7 >2006
- Munich D2 7E+4 CW <3E+7 >2006
- LANL D2 2E+2 1s/10s 2E+5 2003
- NSCU D2 2E+3 CW 1E+7 >2005
- KEK 4He 2E+5 CW 5E+7 >2008
- LENS D2 1E+2 CW <1E+6 ?

Method	Present limit	Possible future limit	Possible sensitivity increase
N-decay	$7.2 \cdot 10^{31}$ yr = 1u (Soudan II)	10^{33} yr (Super-K)	× 16 u
UCN trap	none	$\sim 5 \cdot 10^{8}$ s	× 30 u
Geo-chemical (ORNL)	none	$4 \cdot 10^{8} \div 1 \cdot 10^{9}$ s (Tc in Sn ore)	× 15-150 u
Cold beam	$8.6 \cdot 10^{7}$ s = 1u (ILL/Grenoble)	$3 \cdot 10^{9}$s (ORNL)	x1,000 u

(My) Conclusions from Workshop

Particle physics/cosmology developments favor $\Delta(B\text{-}L)=2$

Neutrino backgrounds->underground detectors are limited

Motivations to improve on nnbar oscillations are good! But how to do it?

UCN approach: need to make more UCN

Cold neutron approach: very large experiment, big mirrors, B shielding, maybe shoot the beam down a hole?

It's going to take some effort/R&D, let's get started…