Neutron-Antineutron Oscillations with Free Neutrons:Detector/Tracker Requirements

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Project X Workshop

Free neutron oscillations

Experimental requirements

Thanks for slides: Yuri Kamyshkov

Neutron-Antineutron Oscillations: Formalism

$\alpha \neq 0$ allows oscillations

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

$\mathrm{H} = \begin{pmatrix} E_n & \alpha \\ \alpha & E_{\bar{n}} \end{pmatrix}$ Hamiltonian of n-nbar system

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

Note :

- α real (assuming T)
- $m_n = m_{\bar{n}}$ (assuming CPT)
- $U_n \neq U_{\bar{n}}$ in matter and in external B [$\mu(\bar{n}) = -\mu(n)$ from CPT]

Neutron-Antineutron transition probability

For $H = \begin{pmatrix} E+V & \alpha \\ \alpha & E-V \end{pmatrix}$ $\quad P_{n\to\bar{n}}(t) = \frac{\alpha^2}{\alpha^2+V^2} \times \sin^2\left[\frac{\sqrt{\alpha^2+V^2}}{\hbar}t\right]$

where V is the potential difference for neutron and anti-neutron.

Present limit on $\alpha \le 10^{-23} eV$

Contributions to V:

<Vmatter>~100 neV, proportional to density

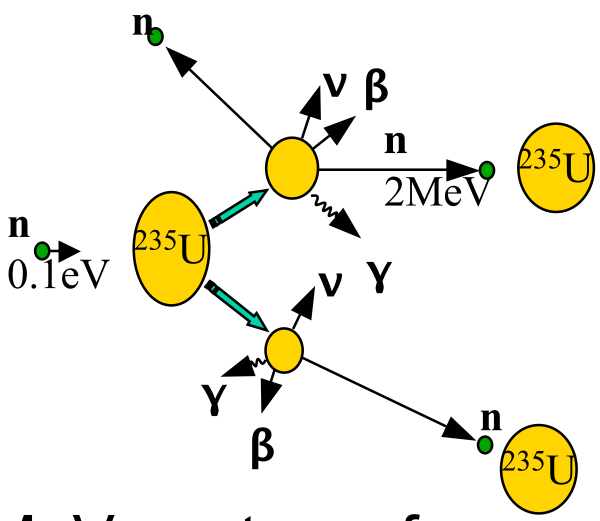
<Vmag>=μB, ~60 neV/Tesla; B~10nT-> Vmag~10^{-15} eV

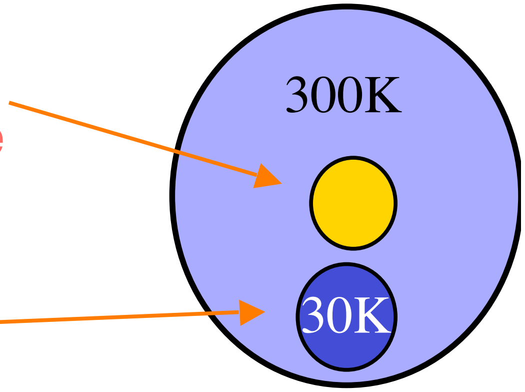
<Vmatter> , <Vmag> both >>α

For $\left[\frac{\sqrt{\alpha^2+V^2}}{\hbar}t\right]$<<1 ("quasifree condition") $\quad P_{n\to\bar{n}} = \left(\frac{\alpha}{\hbar}\times t\right)^2 = \left(\frac{t}{\tau_{n\bar{n}}}\right)^2$

Figure of merit= NT^2 N=#neutrons, T="quasifree" observation time

“Slow” Neutrons: MeV to neV



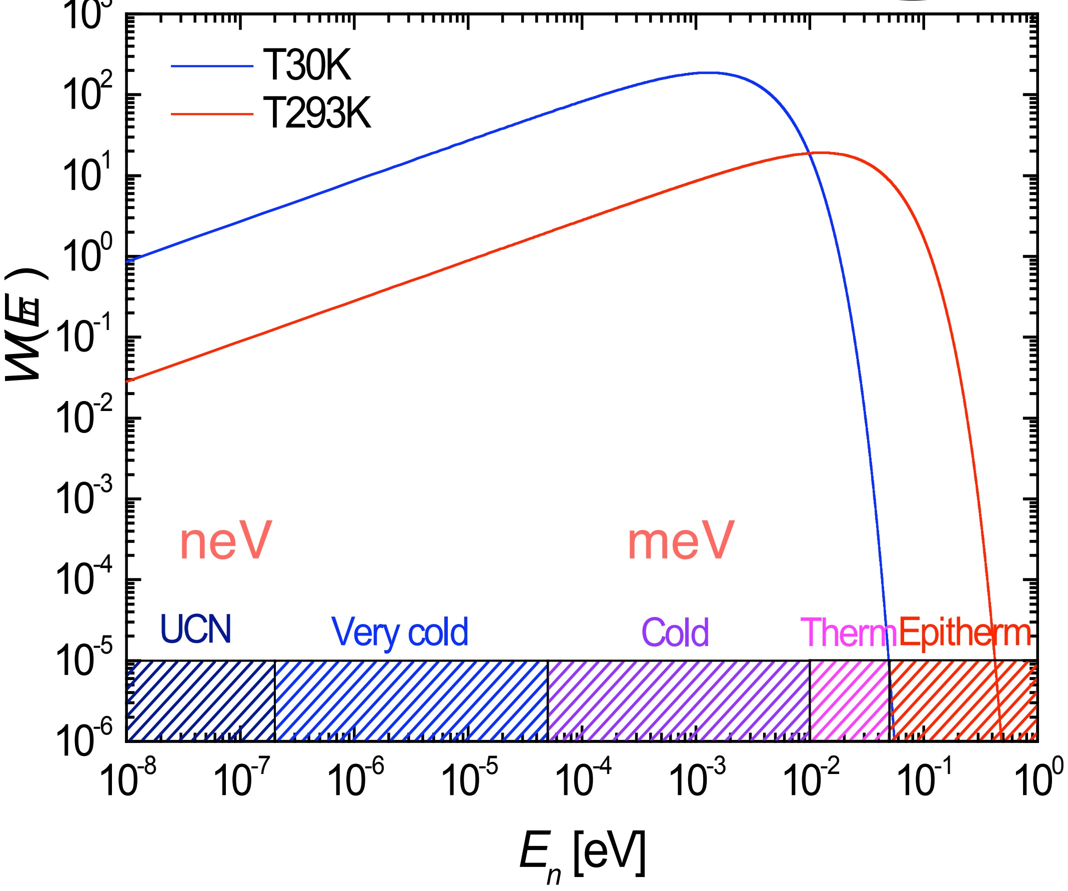


Nuclear reactor/ Spallation source

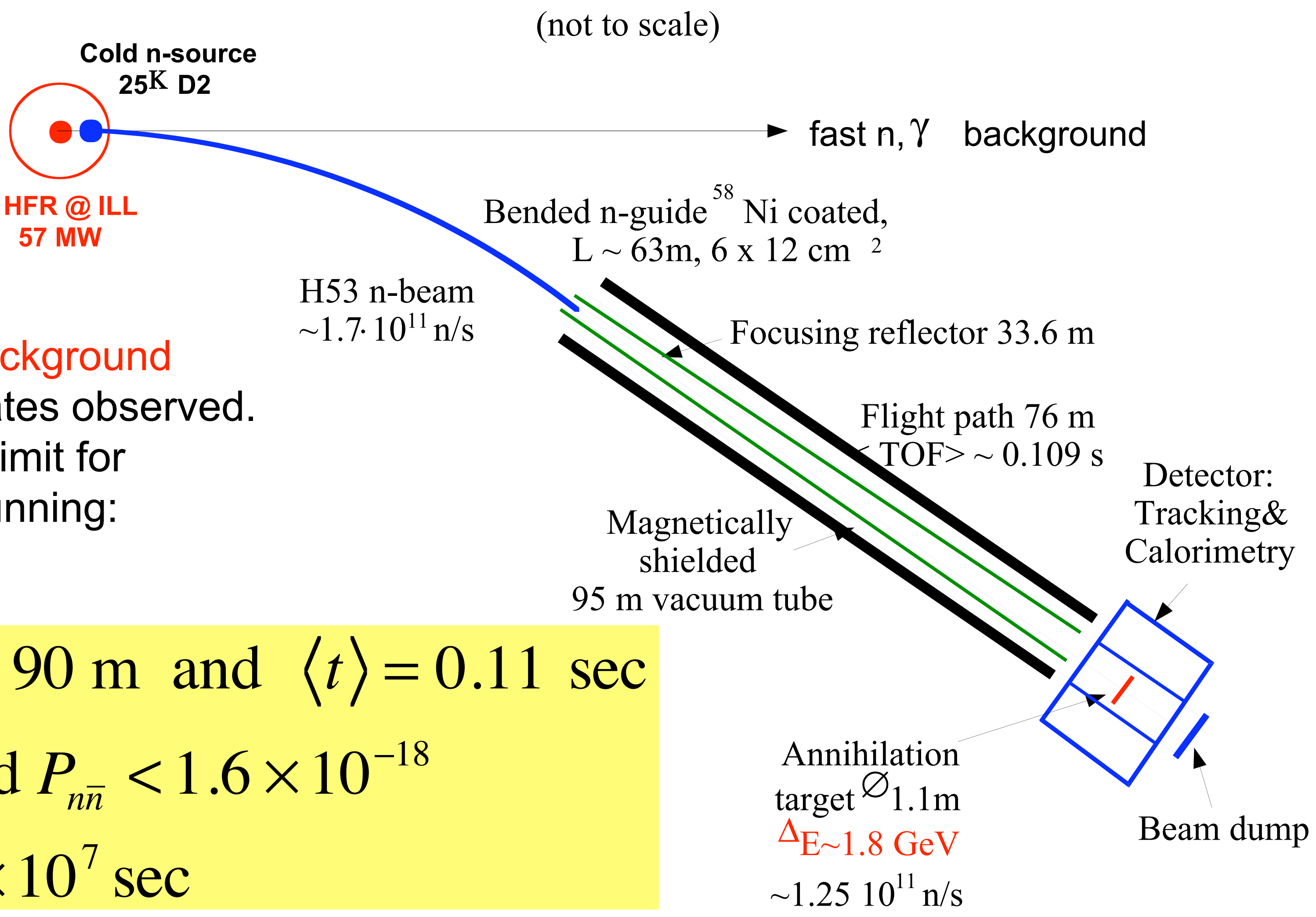
Neutron Moderator (LH2, LD2)

~MeV neutrons from fission or spallation, thermalized in ~ 20 collisions in ~ 100 μs

T (K)	E (meV)	λ (A)	v (m/sec)
300	25	1.6	2200
20	2	6.4	550



N-Nbar search at ILL (Heidelberg-ILL-Padova-Pavia)



(not to scale)

Cold n-source
25^{K} D2

fast n, γ background

HFR @ ILL
57 MW

Bended n-guide ^{58}Ni coated,
L ~ 63m, 6 x 12 cm^2

H53 n-beam
$\sim 1.7\cdot 10^{11}$ n/s

Focusing reflector 33.6 m

Flight path 76 m
<TOF> ~ 0.109 s

Detector:
Tracking&
Calorimetry

Magnetically
shielded
95 m vacuum tube

Annihilation
target ∅1.1m
ΔE~1.8 GeV

$\sim 1.25\ 10^{11}$ n/s

Beam dump

No GeV background

No candidates observed.
Measured limit for
a year of running:

with L ~ 90 m and $\langle t \rangle = 0.11$ sec

measured $P_{n\bar{n}} < 1.6 \times 10^{-18}$

$\tau > 8.6 \times 10^{7}$ sec

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

Quasifree Condition: B Shielding and Vacuum

$\mu B t << \hbar$ ILL achieved $|B|<10$ nT over 1m diameter, 80 m beam,one layer 1mm shield in SS vacuum tank, 1% reduction in oscillation efficiency (Bitter et al, NIM A309, 521 (1991). For new experiment need $|B|<\sim 1$ nT

If nnbar candidate signal seen, easy to “turn it off” by increasing B

$V_{opt} t << \hbar$:

Need vacuum to eliminate neutron-antineutron optical potential difference.
$P<10^{-5}$ Pa is good enough, much less stringent than LIGO

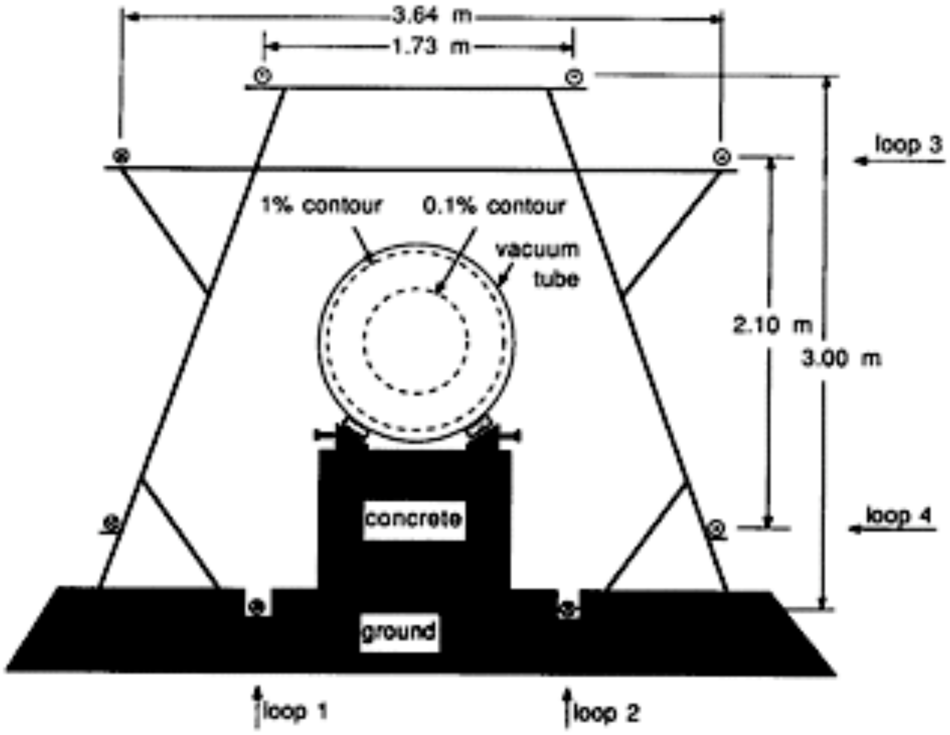
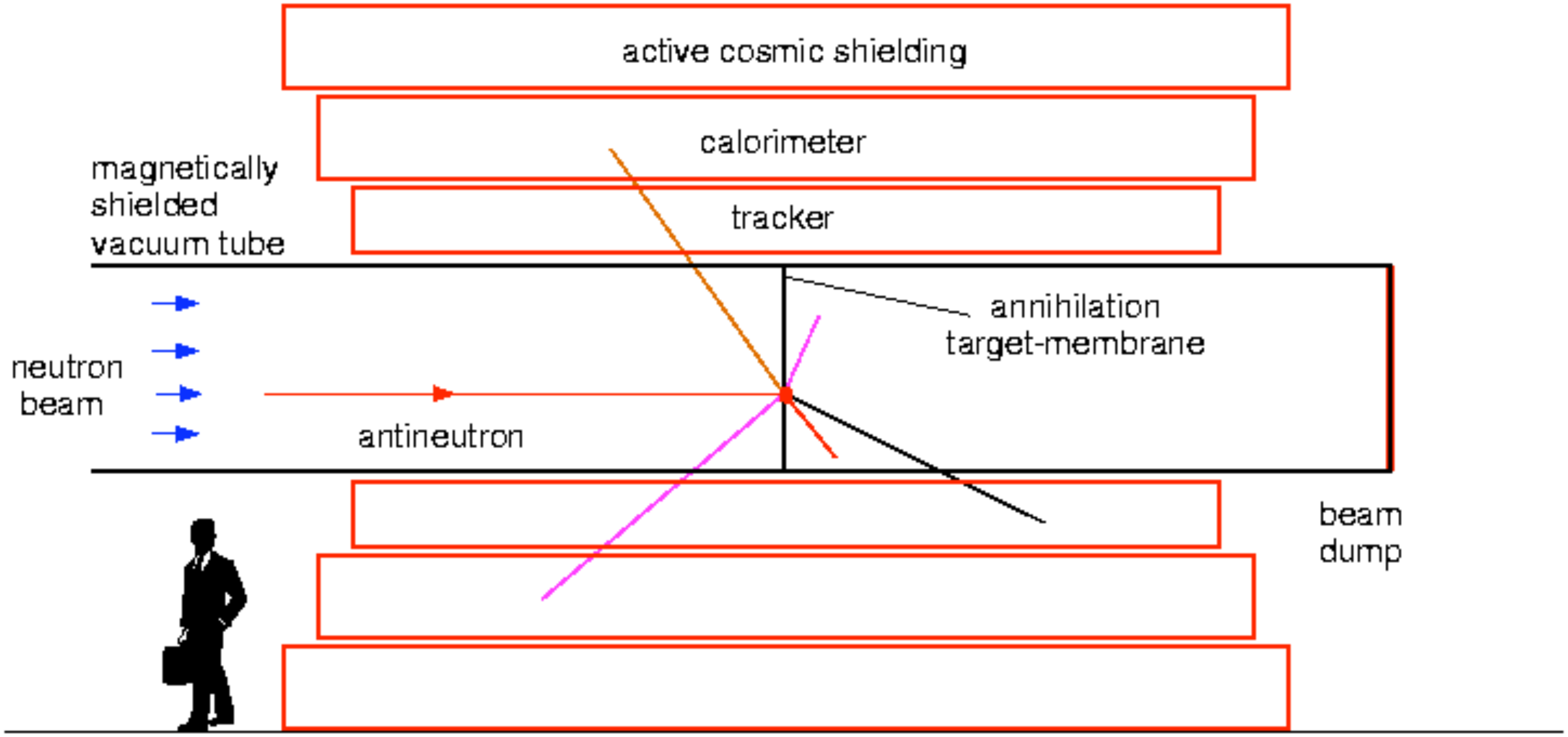


Fig. 10. The transverse field compensation system. Loops 1 and 2 are under 49 A current and compensate the horizontal field component; loops 3 and 4 are under 120 A current and compensate the vertical field component.

The conceptual scheme of antineutron detector



$$\boxed{\bar{n} + A \rightarrow \langle 5 \rangle \; pions \quad (1.8 \text{ GeV})}$$

Annihilation target: 130μ thick Carbon film, 1m diameter

$\sigma_{\text{annihilation}} \sim 4$ Kb $\qquad \sigma_{\text{nC capture}} \sim 4$ mb

vertex precisely defined. No background was observed

Antineutron detector at ILL: operating environment

~1E=11 n/sec strike 1m diameter, 130μ thickness carbon foil Foil stops any antineutron, but makes ~1E6 MeV gammas/sec and also scatters ~1% of the neutrons. 6Li-rich n absorbers needed inside vacuum chamber to suppress capture gammas. 1.3 mm thick 6LiF, 0.3 gm/cm2 still transmits pions into 2 gm/cm2 thick plastic scintillator trigger detectors.

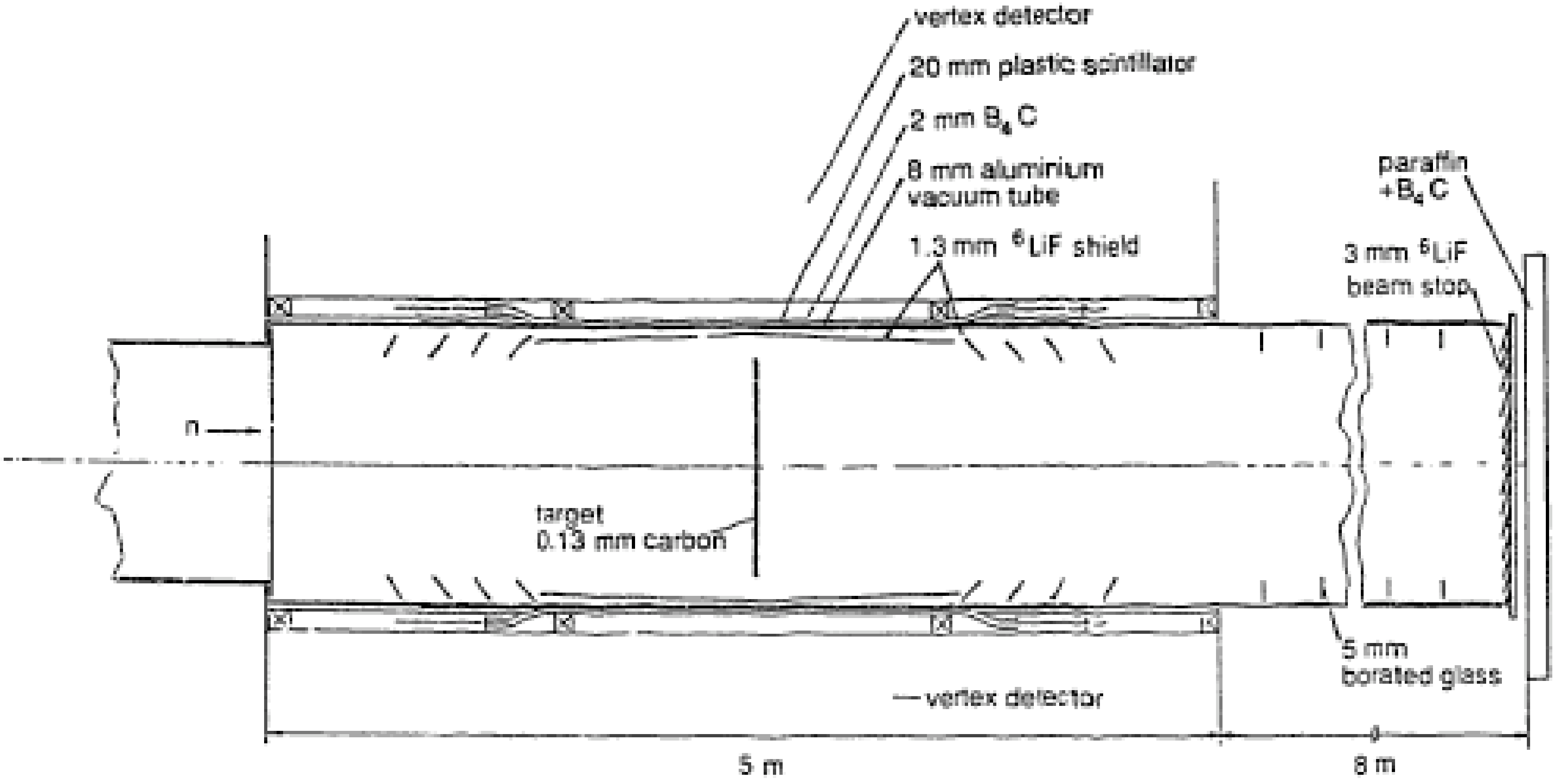


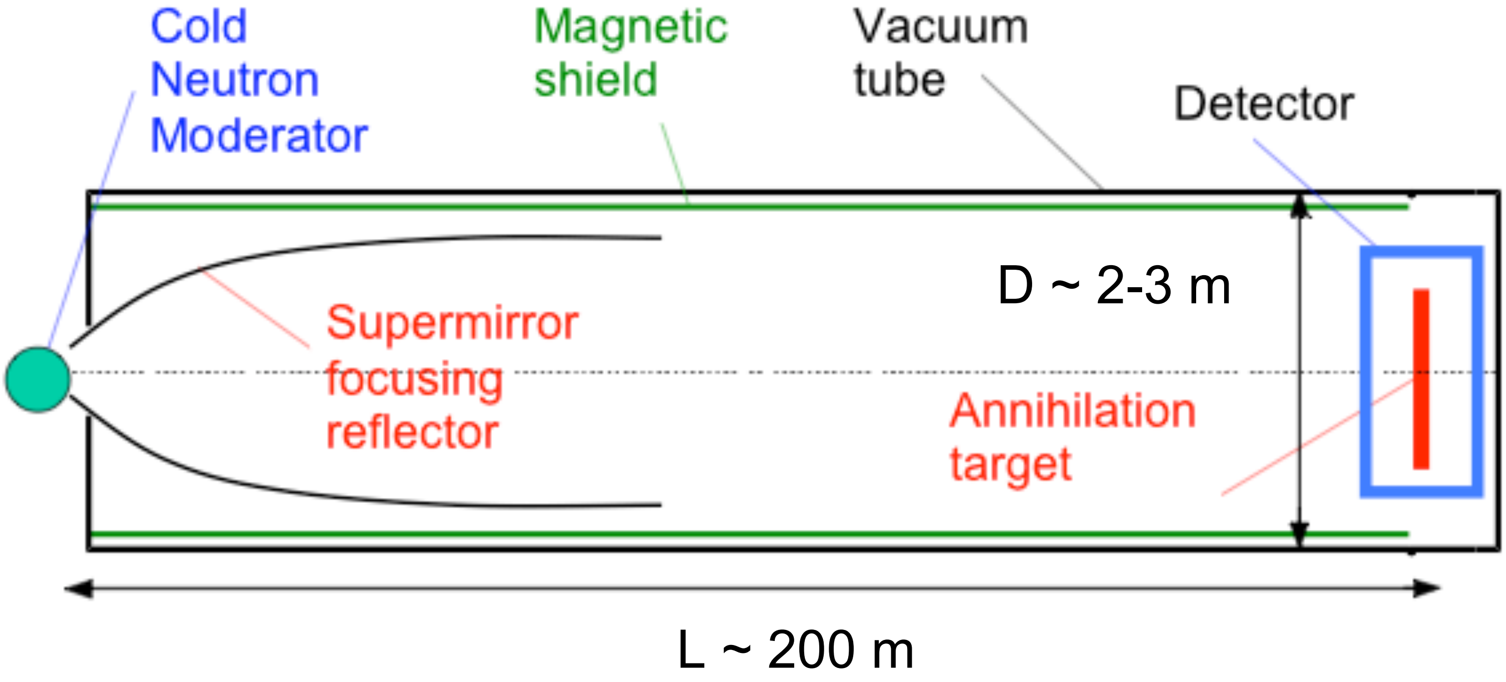
Fig. 1. The target region of the $n\bar{n}$ experiment and its surroundings.

F. Eisert et al, NIM A313, 477 (1992).

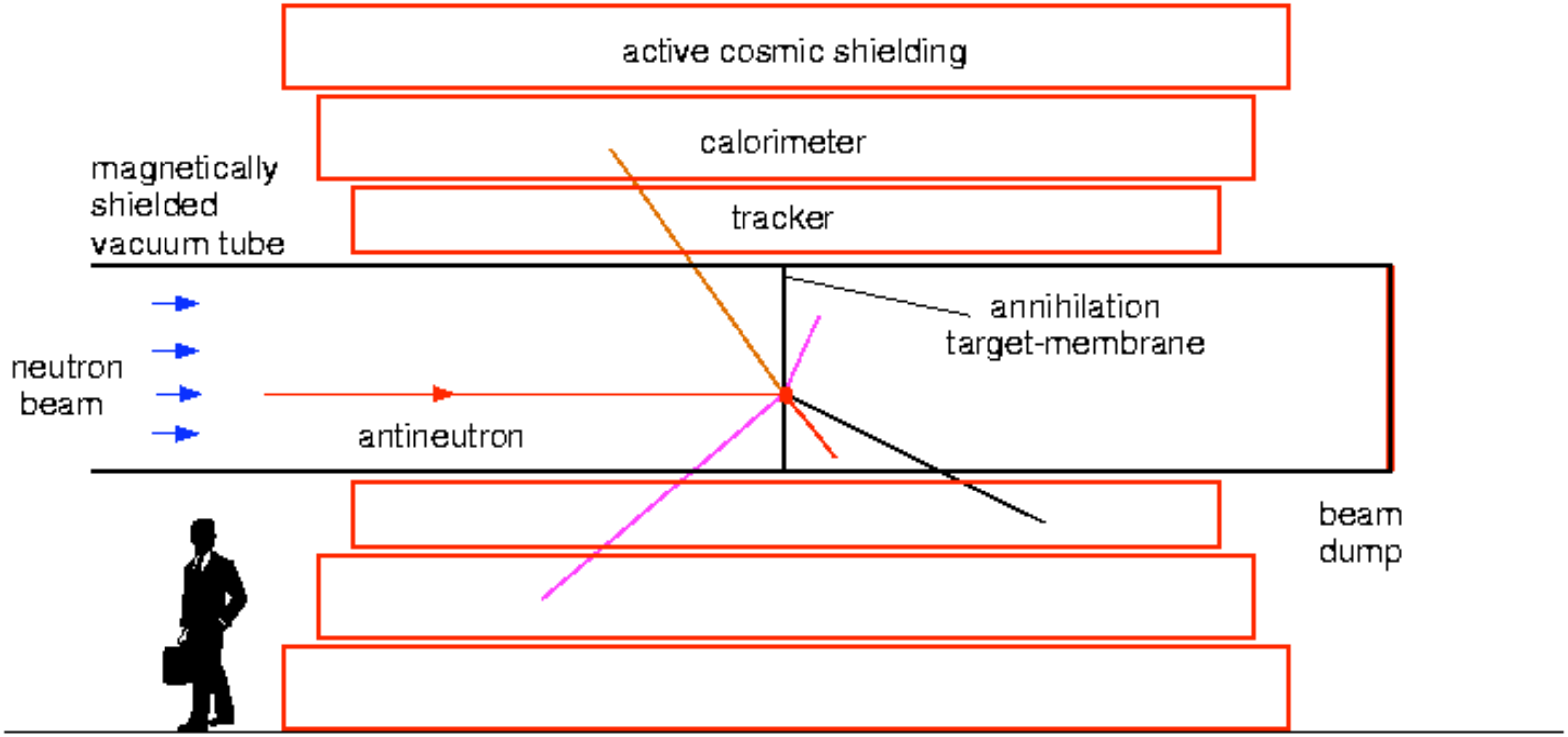
Better Free Neutron Experiment (Horizontal beam shown: vertical possible)

need slow neutrons from high flux source, access of neutron focusing reflector to cold source, free flight path of ~200m

Neutron guide/reflector straight-> source of new fast neutron background



Antineutron detector requirements



transport the 1.8 GeV in ~5 pions to the calorimeter (6Li n absorber+vac chamber wall+….)
Reconstruct vertex (ideally to ~100 micron thickness of nbar absorber: +/- 10 cm in ILL expt)
Reject ~1E+7 Hz few MeV gammas from target
NO background from either cosmics, or ~1 GeV n spallation target 100-200m away
No iron (too magnetic)
$$$$

Possible common issues with other Project X experiments: (1) tracker in vacuum?, (2) fast n backgrounds, (3) $$$ (4) ????