A Neutron – AntiNeutron Oscillation Experiment at Project X ?

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3 Questions

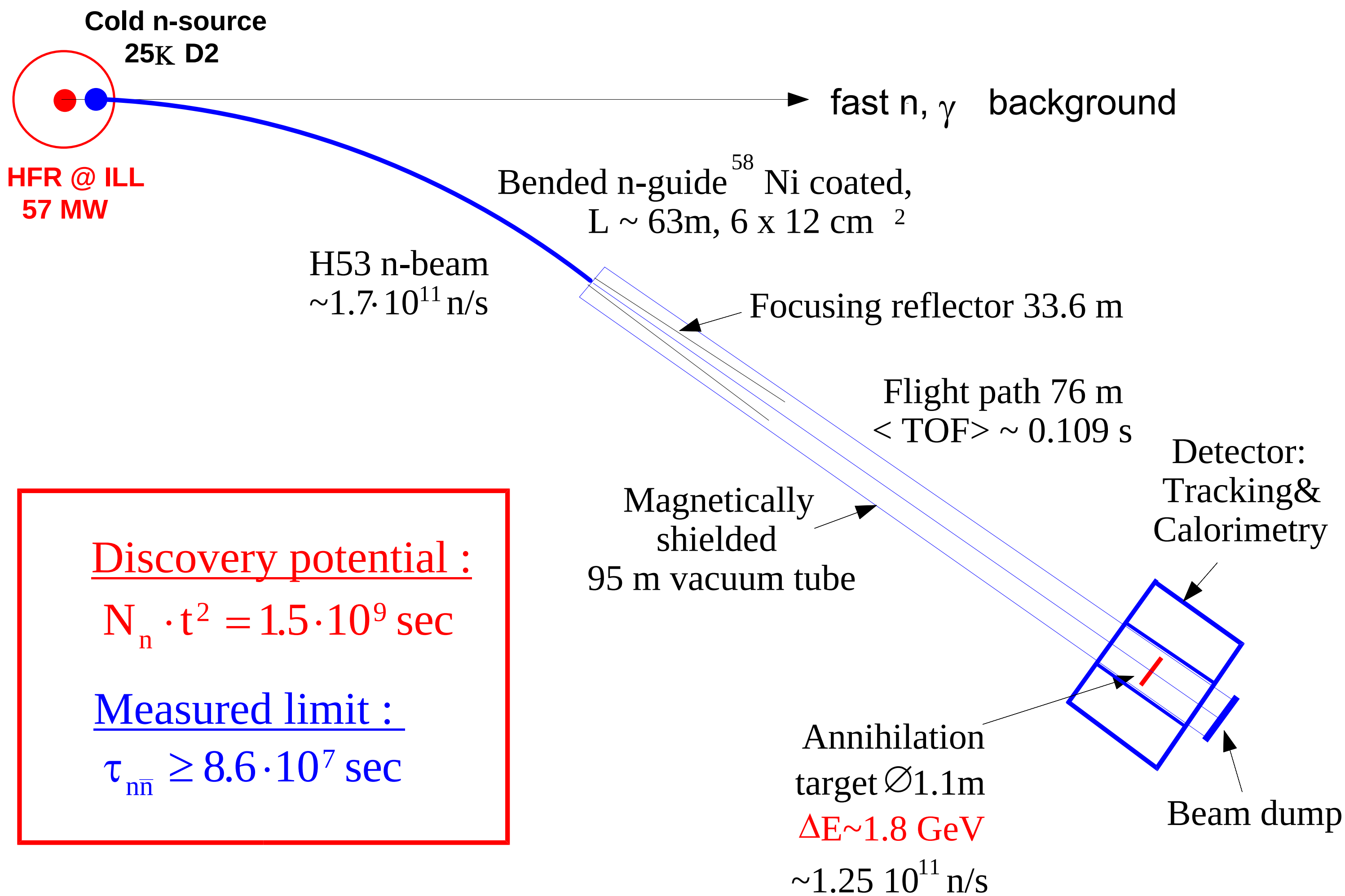
1. ***How much better well could we do at Project X?***

2. ***What would it cost?***

3. ***Is it worth doing?***

The 1989-91 ILL Experiment was thoughtfully done

(Dirk Dubbers - Monday)



Discovery potential :

$N_n \cdot t^2 = 1.5 \cdot 10^9$ sec

Measured limit :

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

1. How much better well could we do at Project X?

Possible improvements in sensitivity

$$FOM = Nt^2$$

- **Dedicated source**
- **Efficient coupling to experiment**
- **Slower Neutrons ("Cold", "Very Cold")** *(David Baxter - Monday)*

  (Gunter Muhrer - Monday)
- **Focusing neutrons by efficient ("high-m") mirror reflection**

  (Hiro Shimizu - Monday)
- **Maintain low background**

  (Sunanda Banneree- Monday)
- **Neutron manipulation by gravity ?**

  (Yuri Kamyshkov - Monday)

The ILL reactor

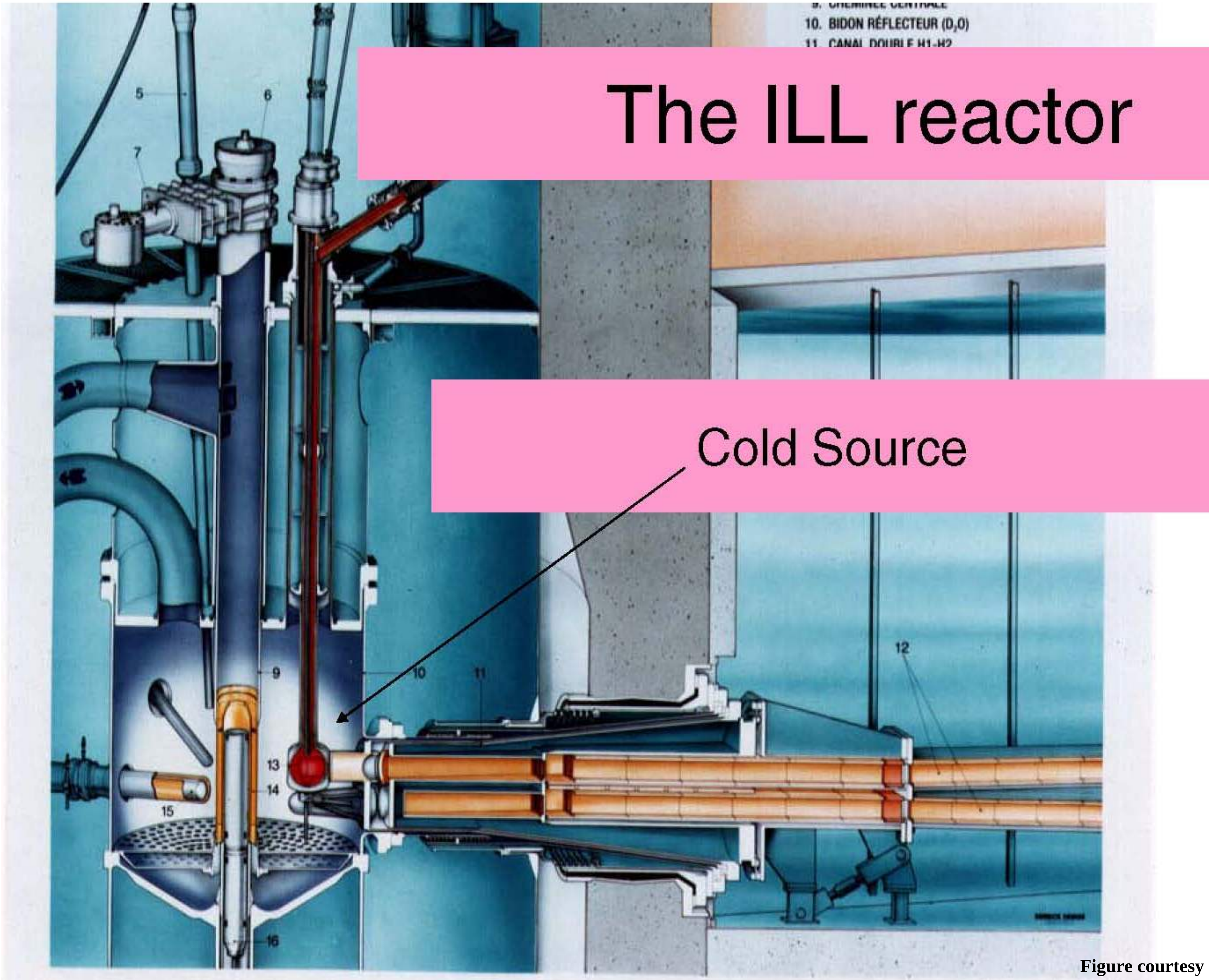
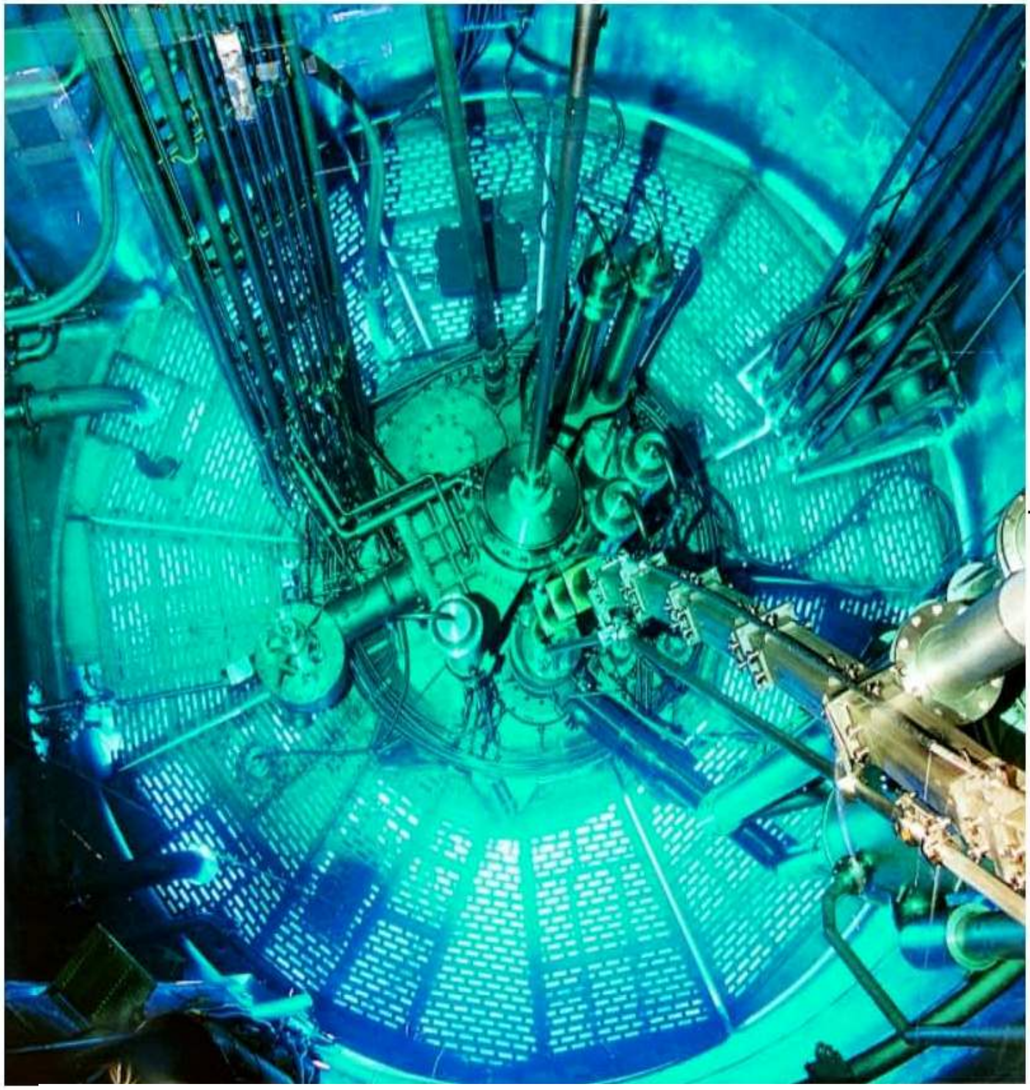
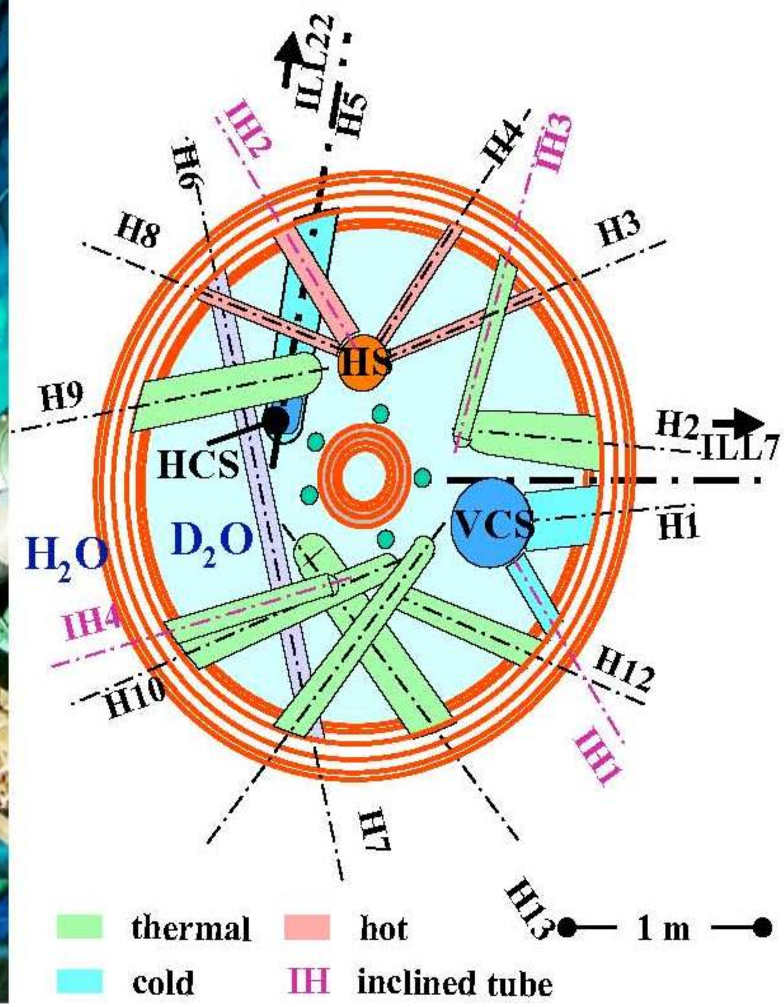


Figure courtesy ILL

The Institut Laue Langevin High Flux Reactor is optimized to serve many neutron beamlines





The High Flux neutron Source at the ILL

Figure courtesy ILL

At ~1.4 GeV, each incident proton liberates ~60 neutrons

Typical neutron energy 10's – 100 MeV

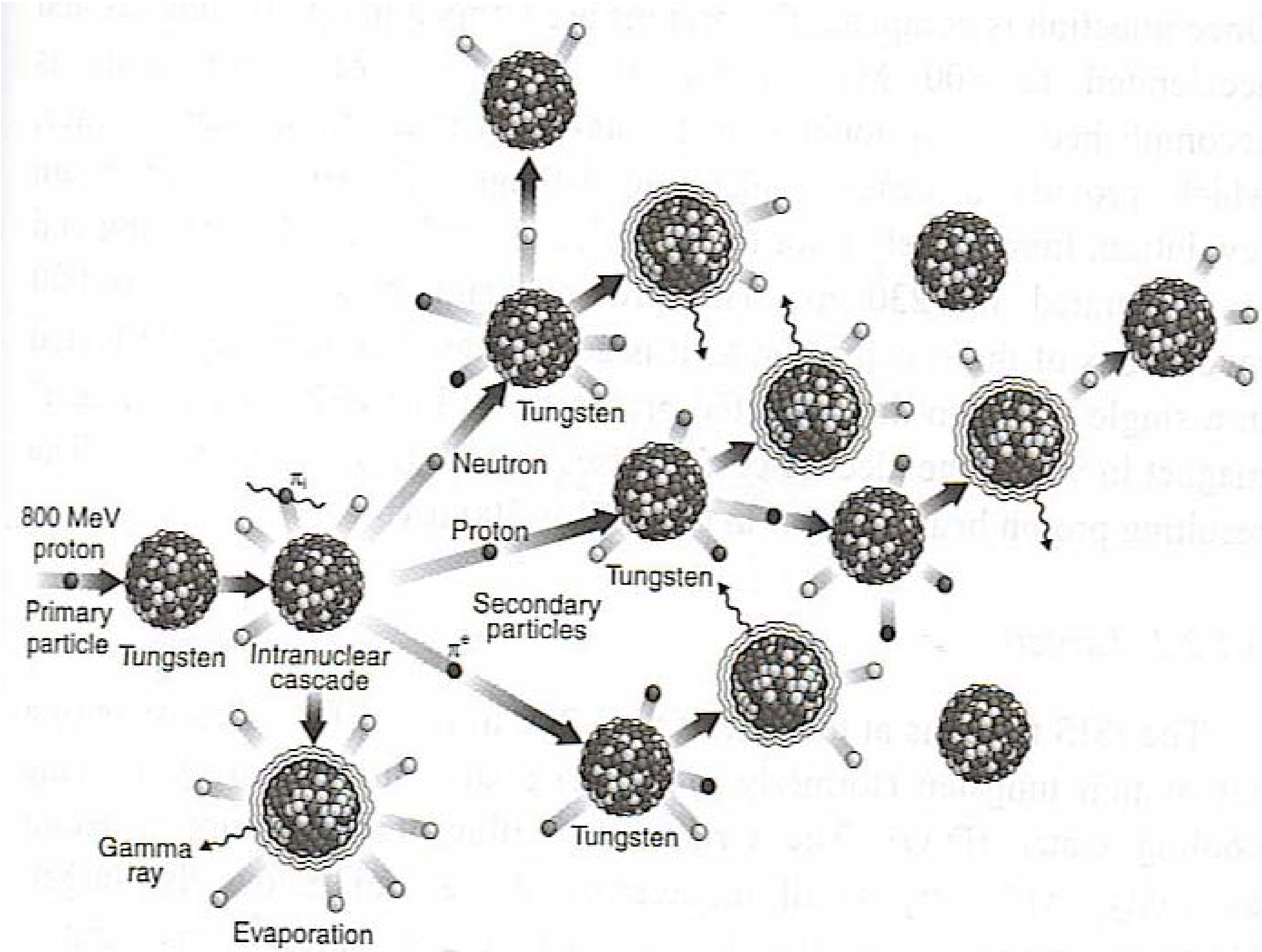


Figure courtesy R. Pynn

Dedicated Spallation Target with Cold/Very Cold Neutron moderator

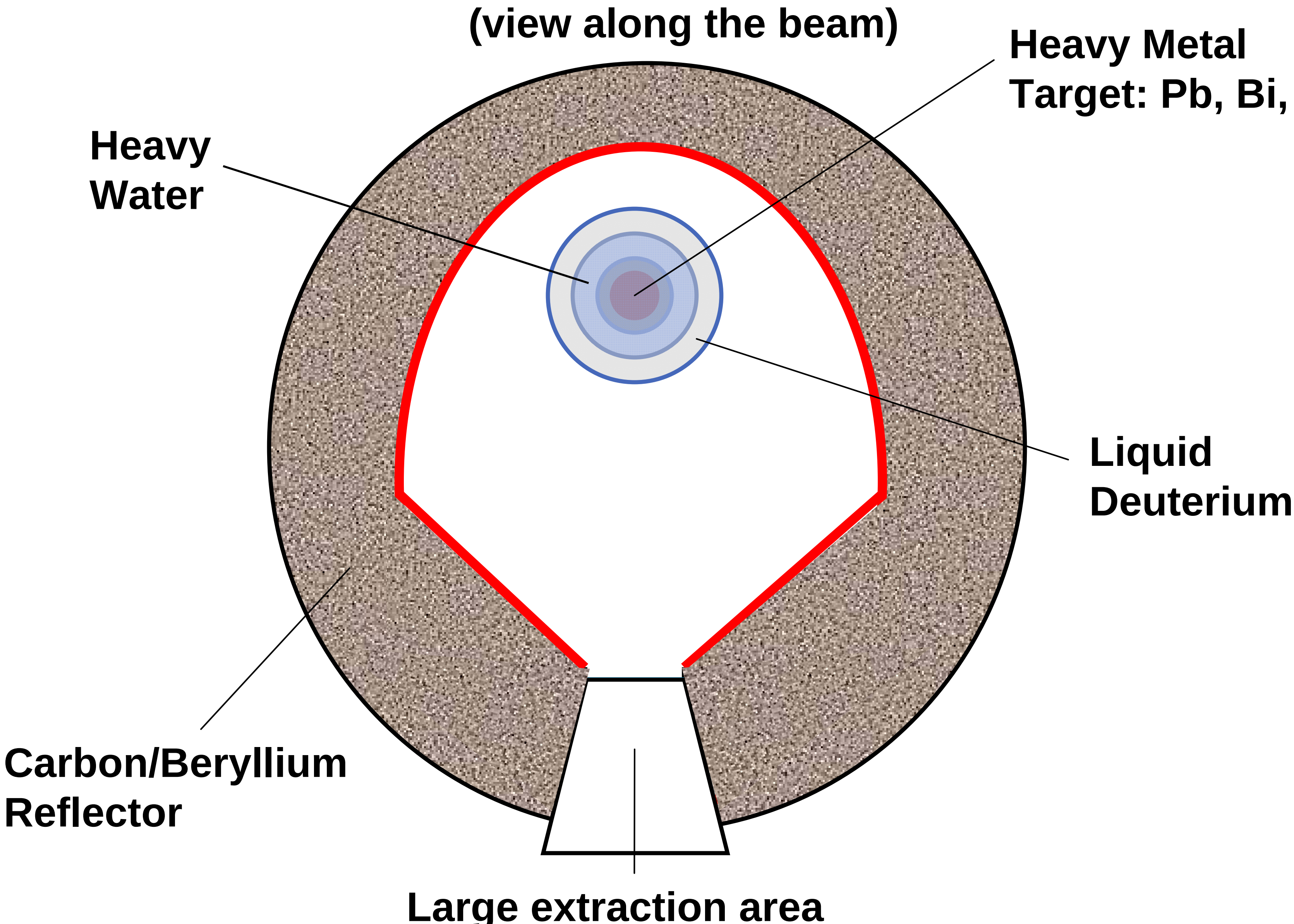
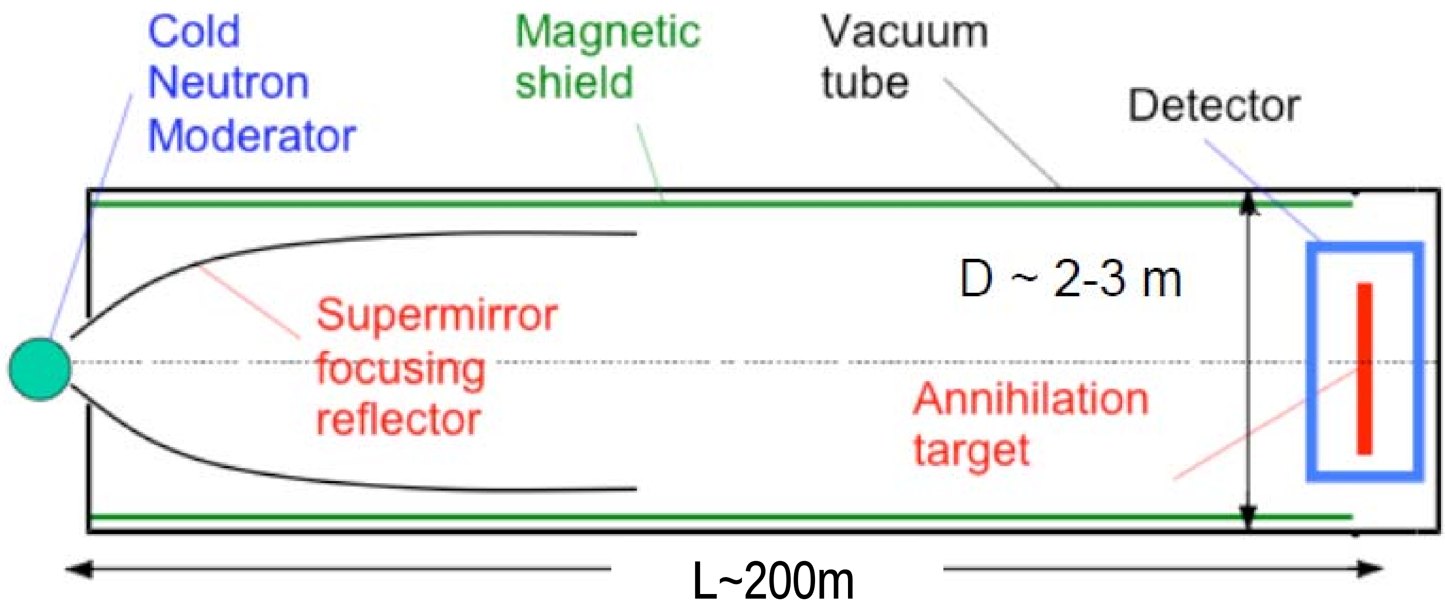


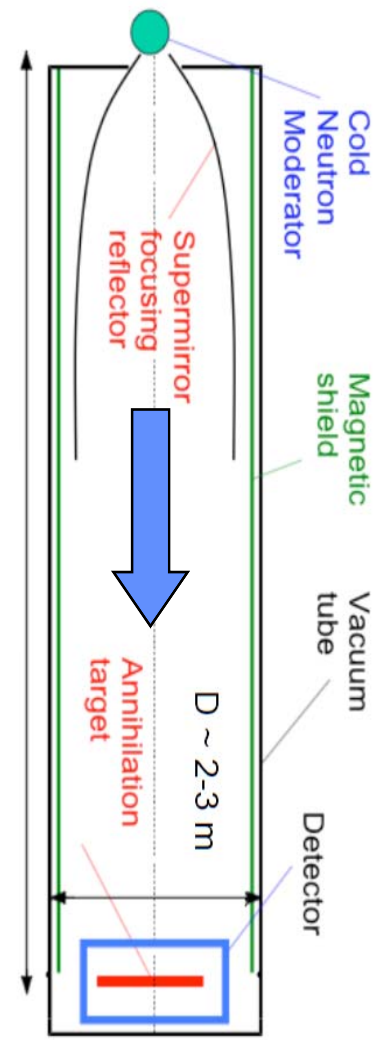
Figure courtesy ILL

Notional Scheme of Project X Experiment is Simple



No need for curved input guide for background reduction due to pulsed nature of spallation source

There may be gains if neutron flight path is vertical



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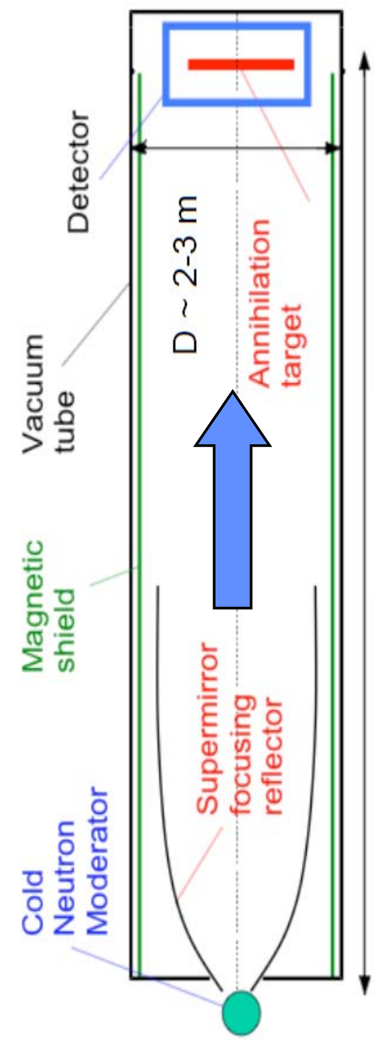
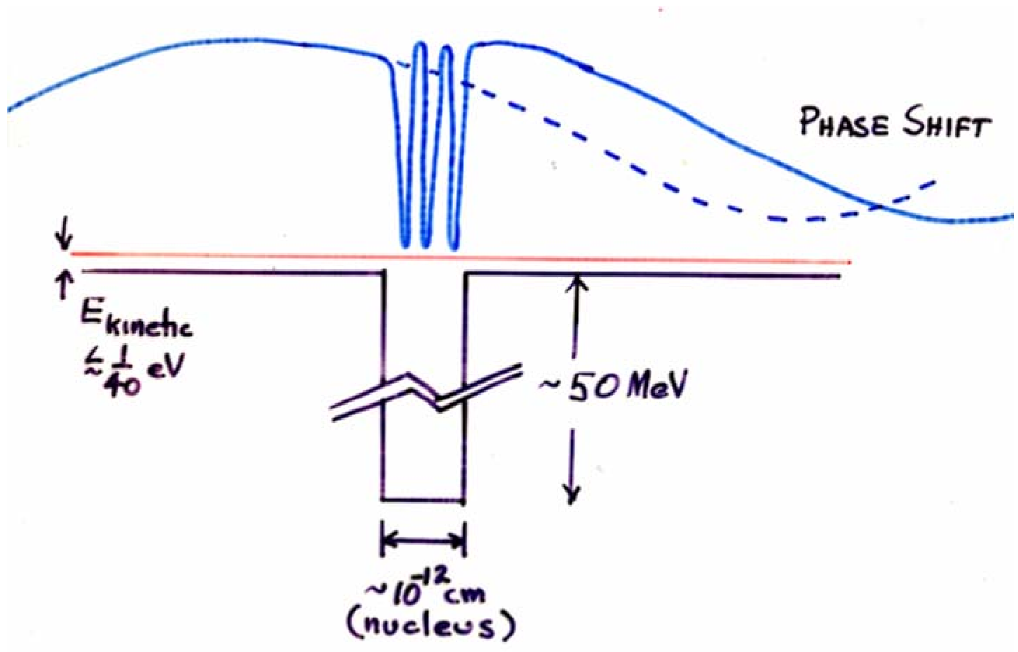


Need detailed Cost/Benefit Analysis

Coherent ("Optical") Interaction Between Neutrons and Matter



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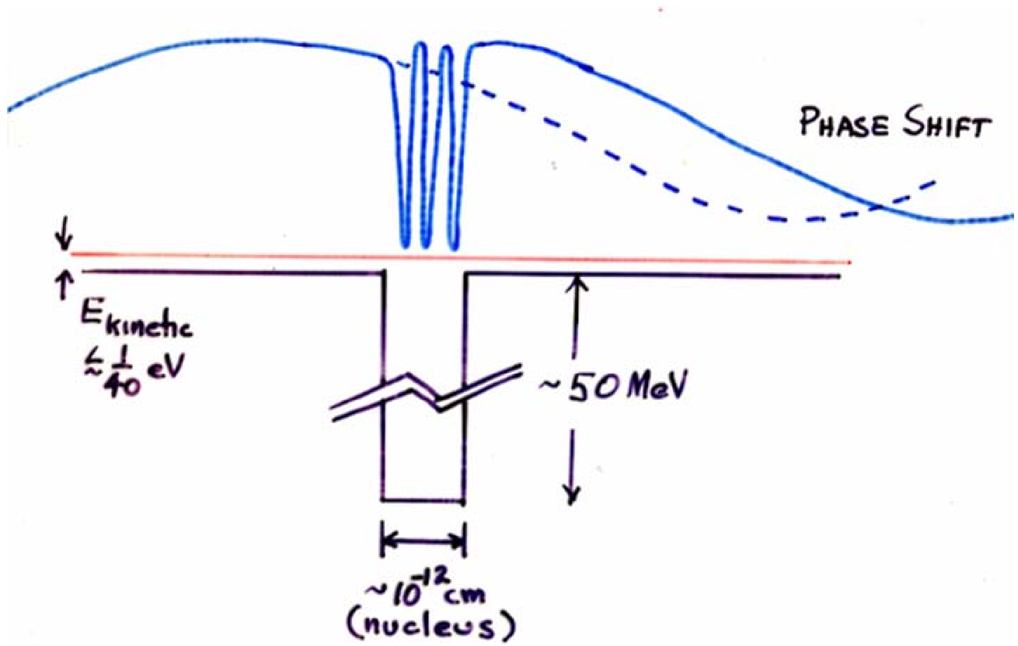
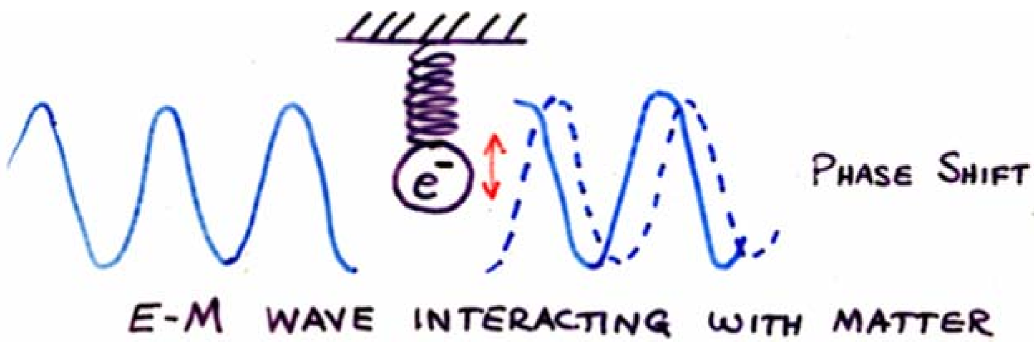
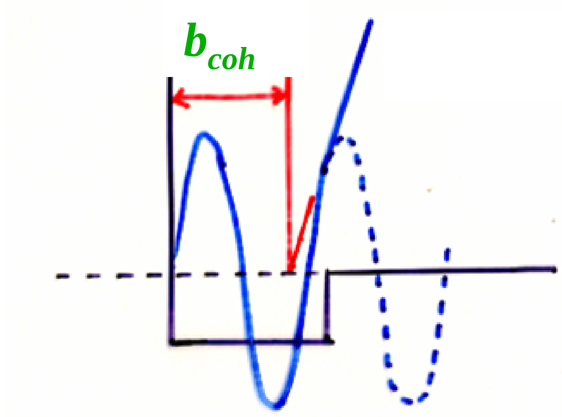
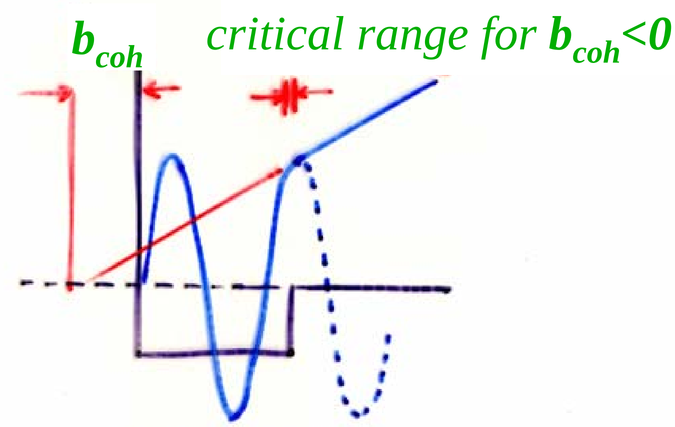




Phase shift leads to Index of Refraction

At low energies S-wave scattering dominates, phase shift is given by $\cot(\delta) = \frac{-1}{kb_{coh}}$





For most nuclear well depths and well sizes,
it is unlikely to obtain a positive coherent scattering length:

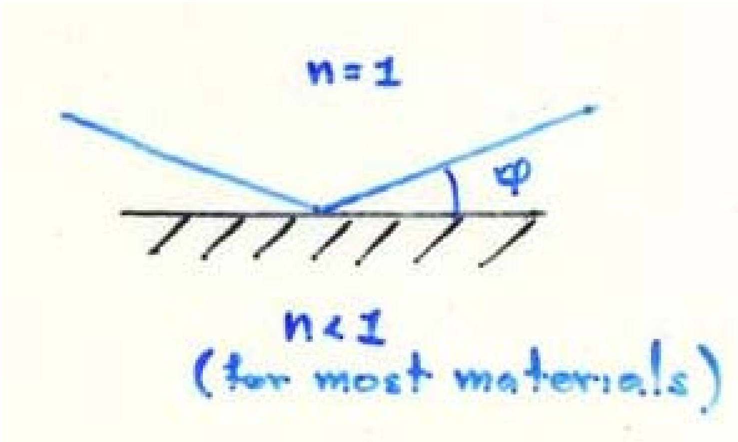
$$n = \sqrt{1 - \frac{N\lambda^2 b_{coh}}{\pi}}$$

*Index of refraction is therefore <1 for most nuclei **

**In the vicinity of A~50 (V,Ti,Mn) nuclear sizes are such that b_{coh}<1 and thus n>1*

Neutron Reflection from Matter

$$n^2 = 1 - \frac{\lambda^2 N b_{coh}}{2\pi} \longrightarrow \cos\theta_{crit} = n$$



Neutrons will undergo complete "external" reflection from a polished surface for most materials

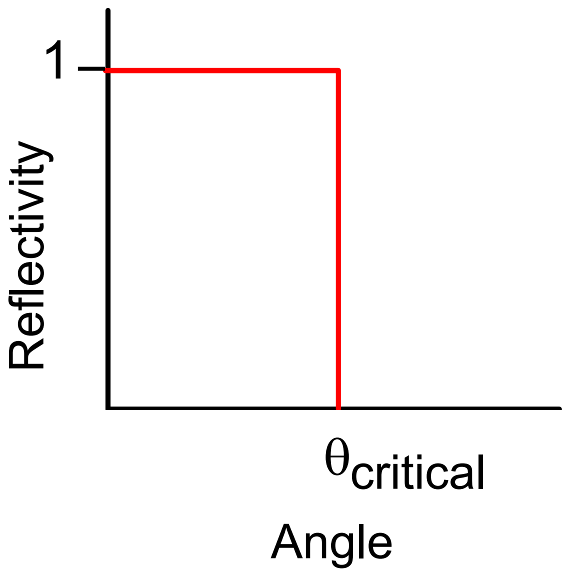
Ni or ^{58}Ni are particularly useful as a neutron mirror material

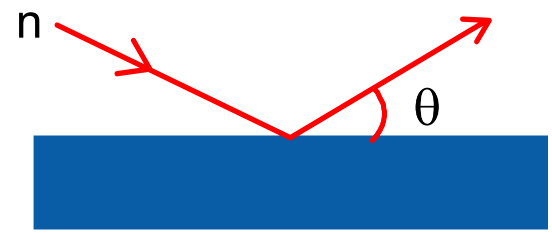
$$\theta_{crit}(Ni) \approx 1.7x10^{-3} / \lambda(Angstrom)$$

For most neutron beams this means $\theta_{crit} \leq 10^{-2}$

Reflectivity of Neutron Mirror

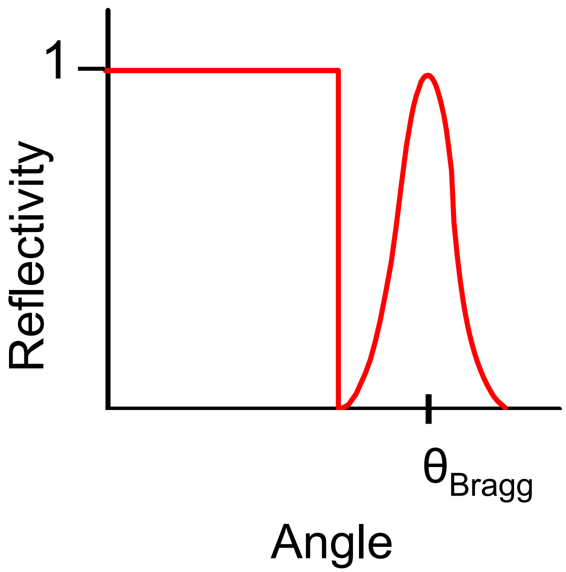
A Simple Neutron Mirror has Essentially Unit Reflectivity
Up to a Maximum Critical Angle

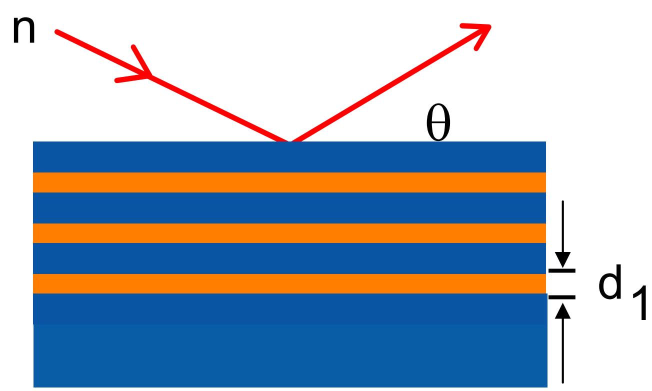




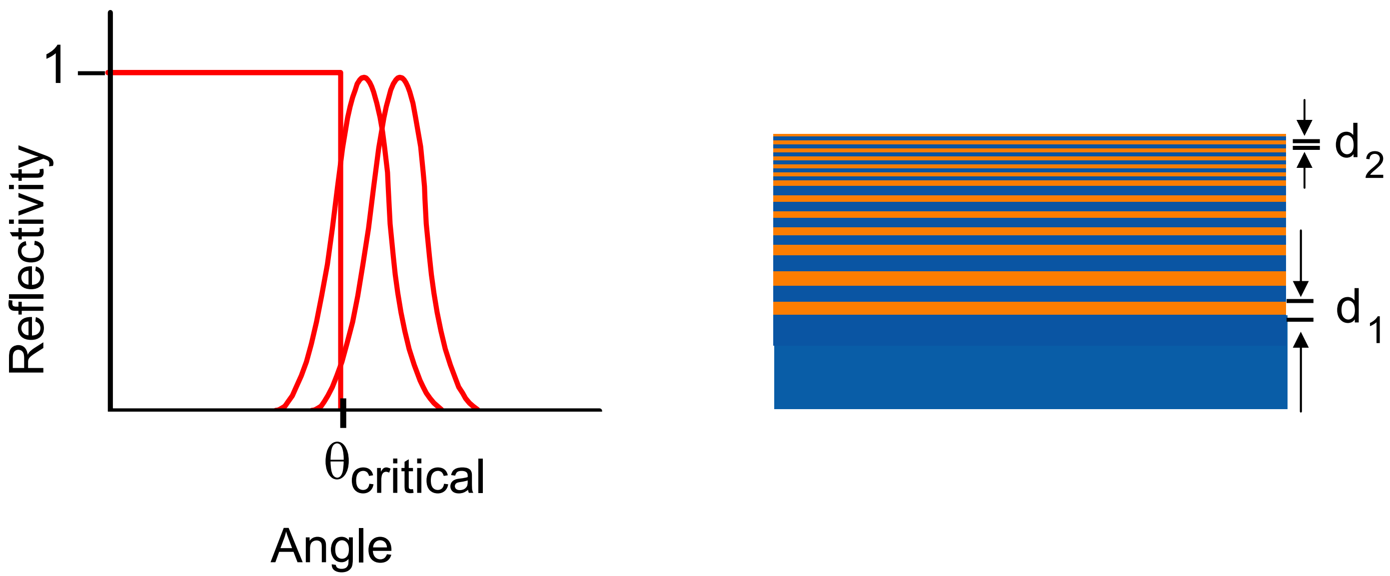
$\Theta_{critical} \cong 2$ *mR/Å for* ^{58}*Ni*

A Multilayer can add “Psuedo” Bragg Peak



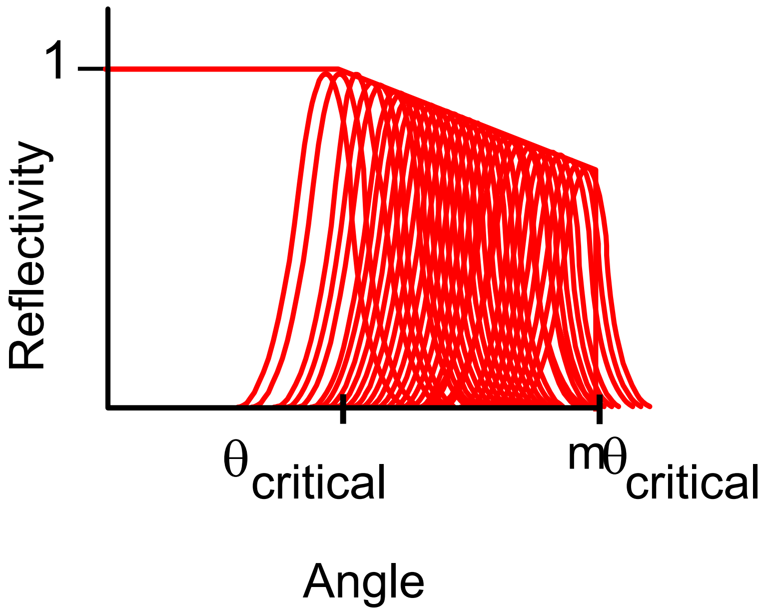


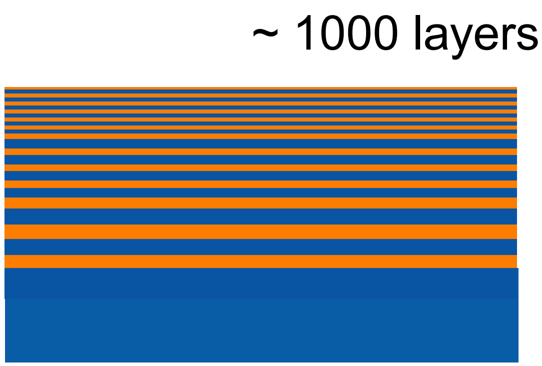
Additional Multilayers with different "d" add More Peaks



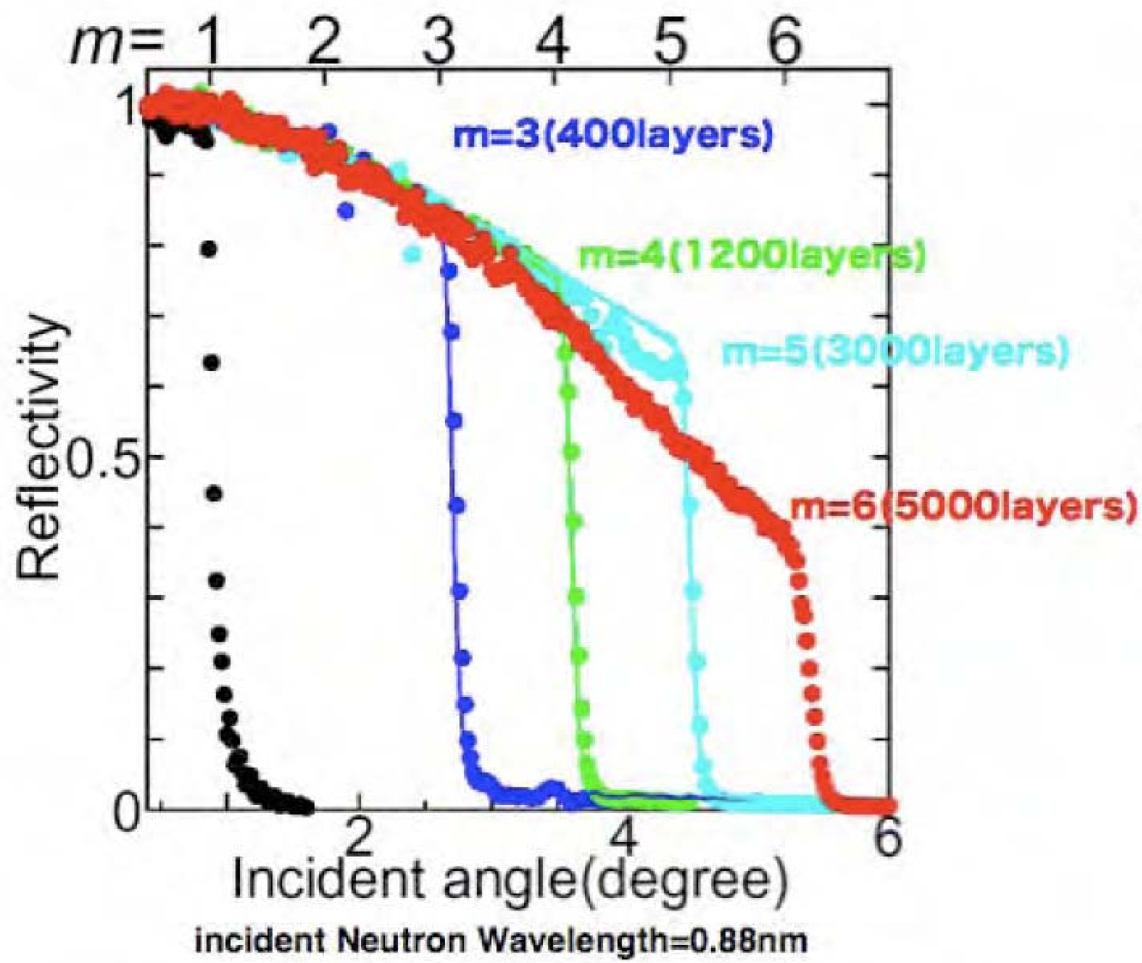
The "Supermirror" Extends the "Effective" $\theta_{critical}$

Commercial Supermirror Neutron Guides
are Available With m ≈ 3 - 4





Commercial Guides with m>6 are now available



M.Hino et al., Nucl. Instrum. Methods A529 (2004) 54

Gain in intensity goes as m^2

Possible improvements in sensitivity (Nt^2)

•Intrinsic source brightness (assume 1MW)	x 1/4
•Colder moderator (gain goes as λ^2)	x 2
•Coupling to experiment	x 2
•Larger moderator face ($30x30cm^2$ vs $6x12cm^2$)	x 12
•Use "high-m" neutron reflector (assume m=6)	x 36
• Longer experiment (200m vs 76m gain ~ L^2)	x 7

Estimated Sensitivity Gain ~$3x10^3$

Take away message: A substantial improvement is possible with only straightforward extension of existing technology

2. What would it cost?

Major Cost Drivers:

- **High Power Target/Moderator system**

  (Tony Gabriel - Monday)

- **Larger Area of “high-m” neutron mirrors**

- **Large volume, high vacuum flight path**

- **Large volume magnetic shields**

  (Mike Snow - Monday)

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Log (Estimated Cost in $M) = 8 ± 0.3 *

**represents a total WAG by the presenter and does not necessarily reflect the views of U of TN, ORNL, DOE,…or my collaborators.*

3 Questions

1. **How much better well could we do at Project X?**

   MUCH BETTER... BUT NEED DETAILED SIMULATIONS

2. **What would it cost?**

   NEED PRELIMINARY ENGINEERING

3. **Is it worth doing?**

   NEED ANSWERS TO 1.& 2. PLUS THEORY

How to prepare for Snowmass 2013

1. ***MCNP/Thermal modeling of the source design & neutron optics simulation (e.g. Mcstass).***

2. ***Conceptual Engineering Design & Preliminary cost estimate – need FNAL engineers***

3. ***Thoughtful theoretical analysis of discovery potential given experimental reach and cost***