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Large-area cost-effective technologies for n-nbar

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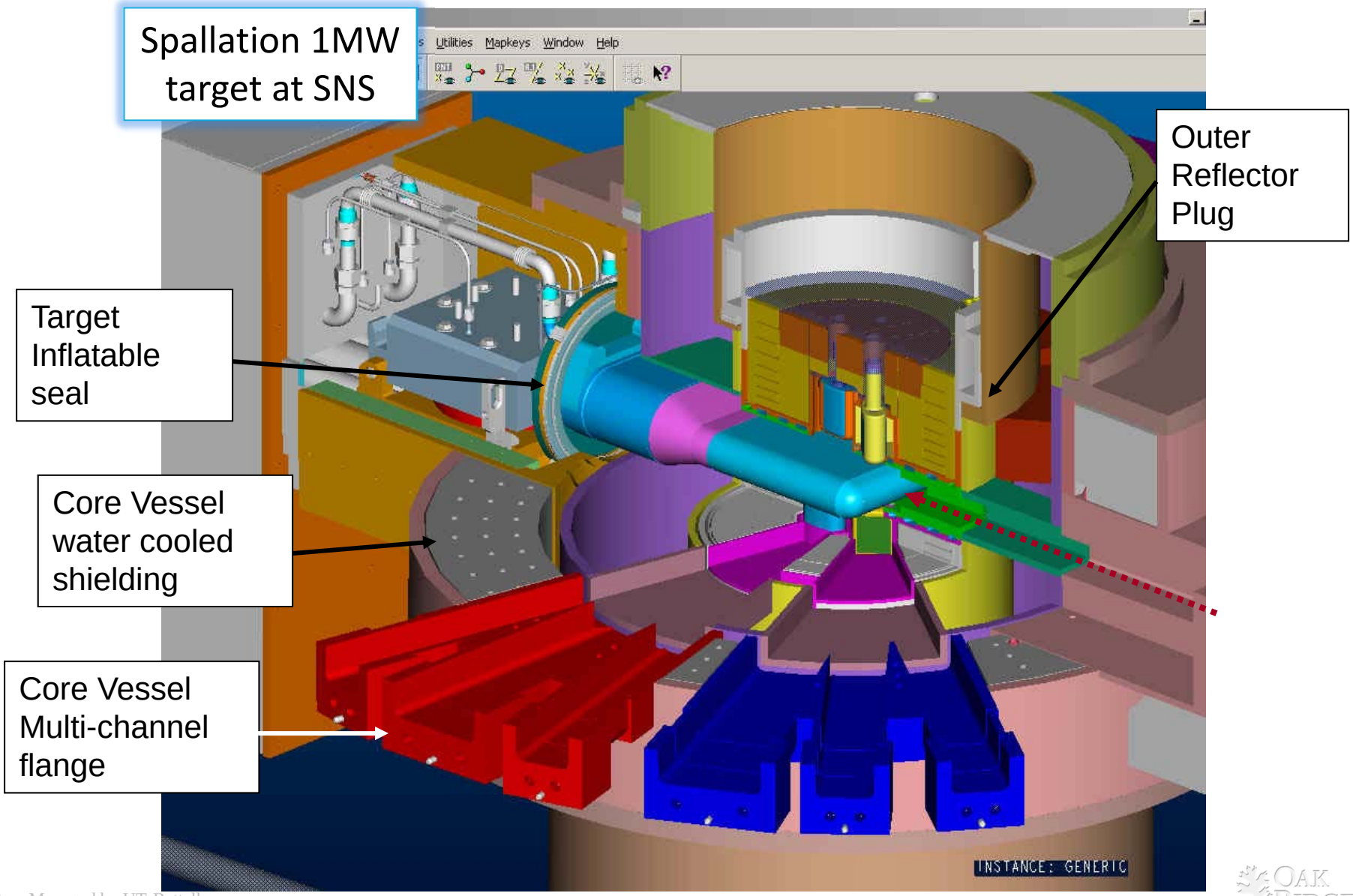
WG13: Large-Area Cost-Effective Detector Technologies

LACE group addressed two areas:

(a) Technologies for N-Nbar (this summary)

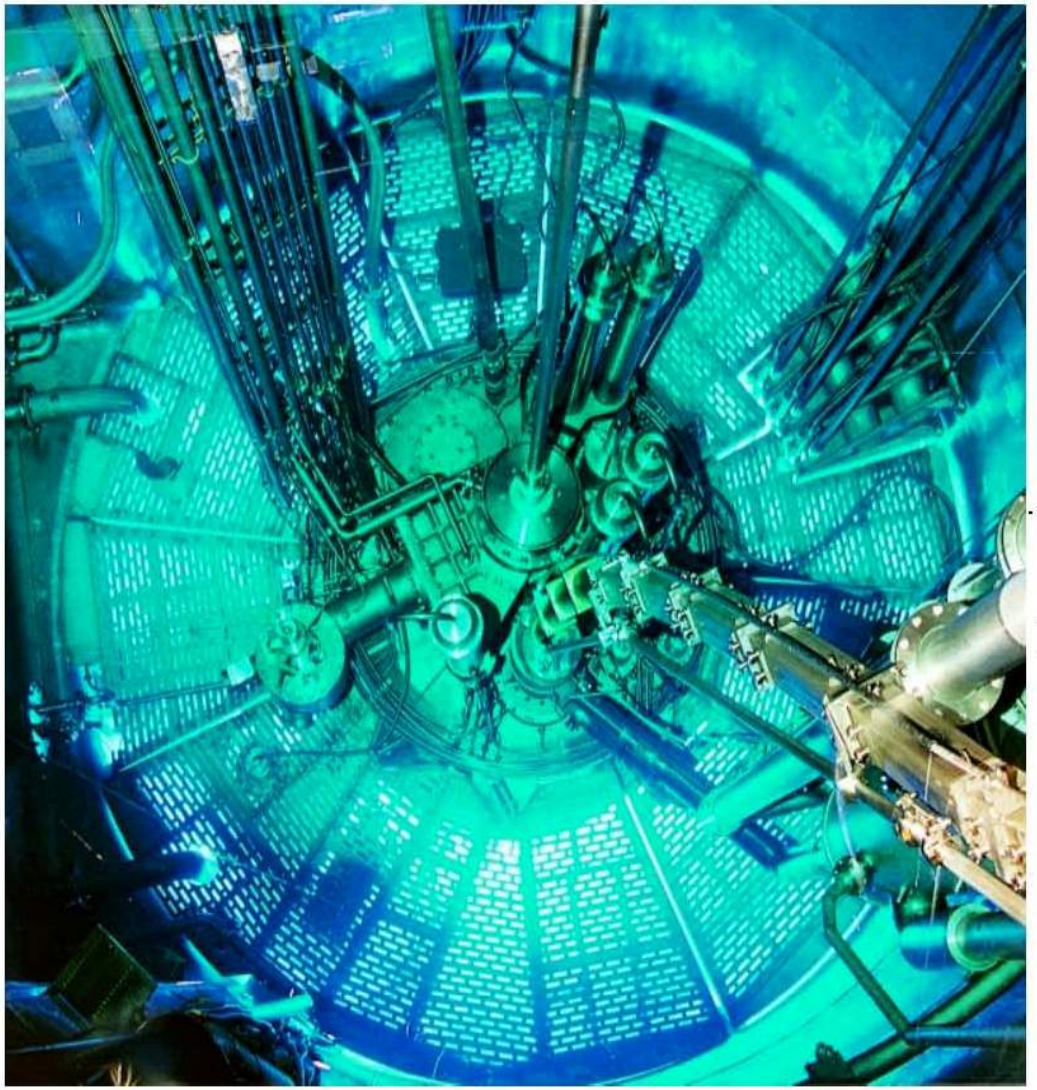
(b) Detector Technologies for ν and PDK
(Mayly Sanchez – next summary)

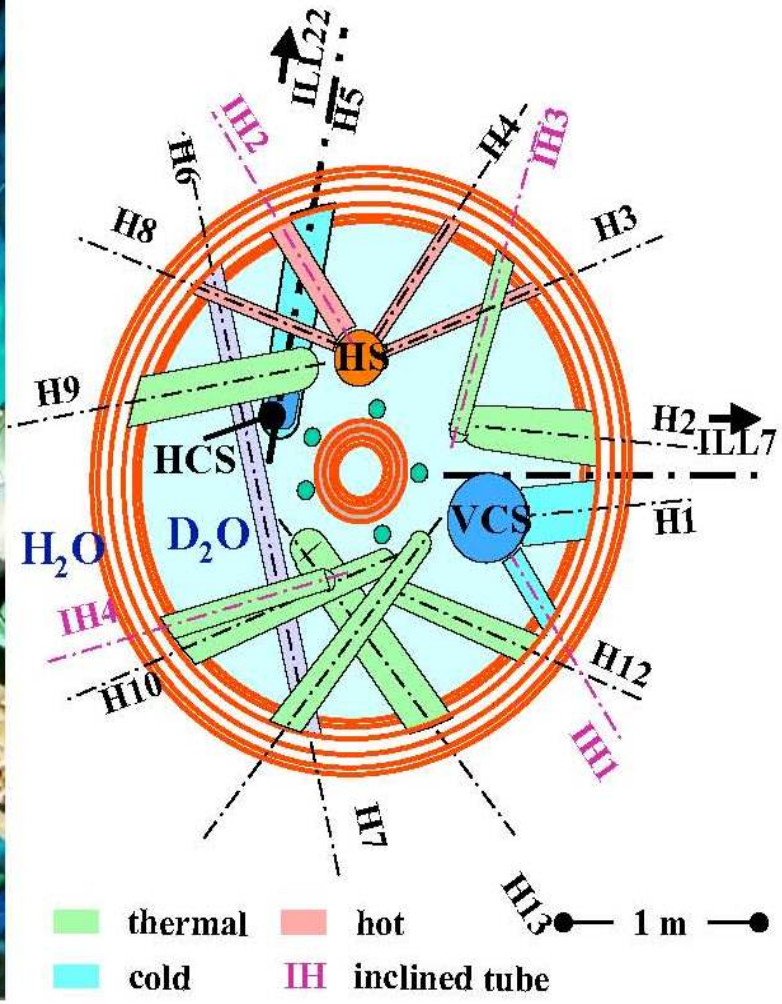
Why project X is unique for n-nbar?



Tony Gabriel/SNS

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



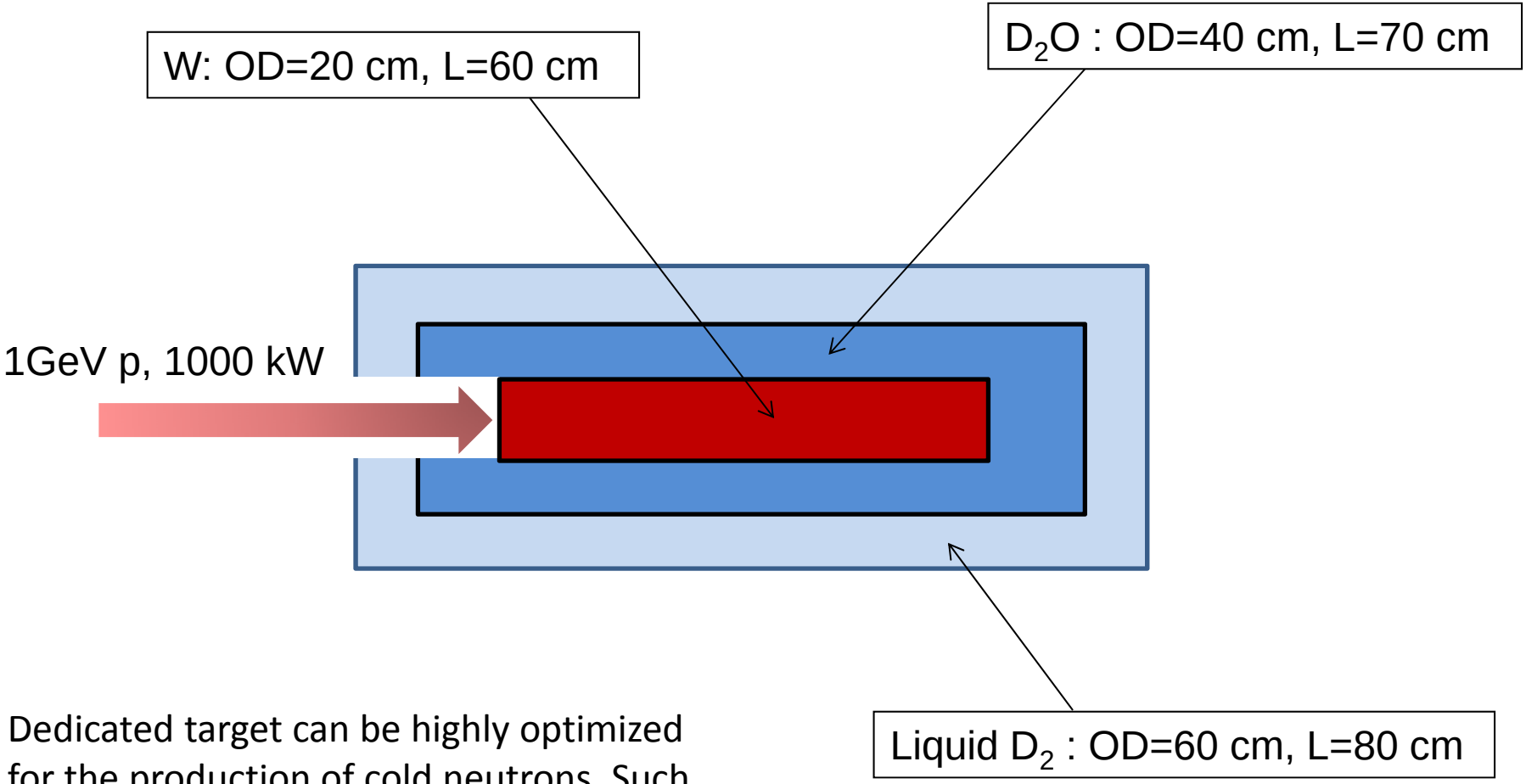


The High Flux neutron Source at the ILL

Geoff Greene/UT

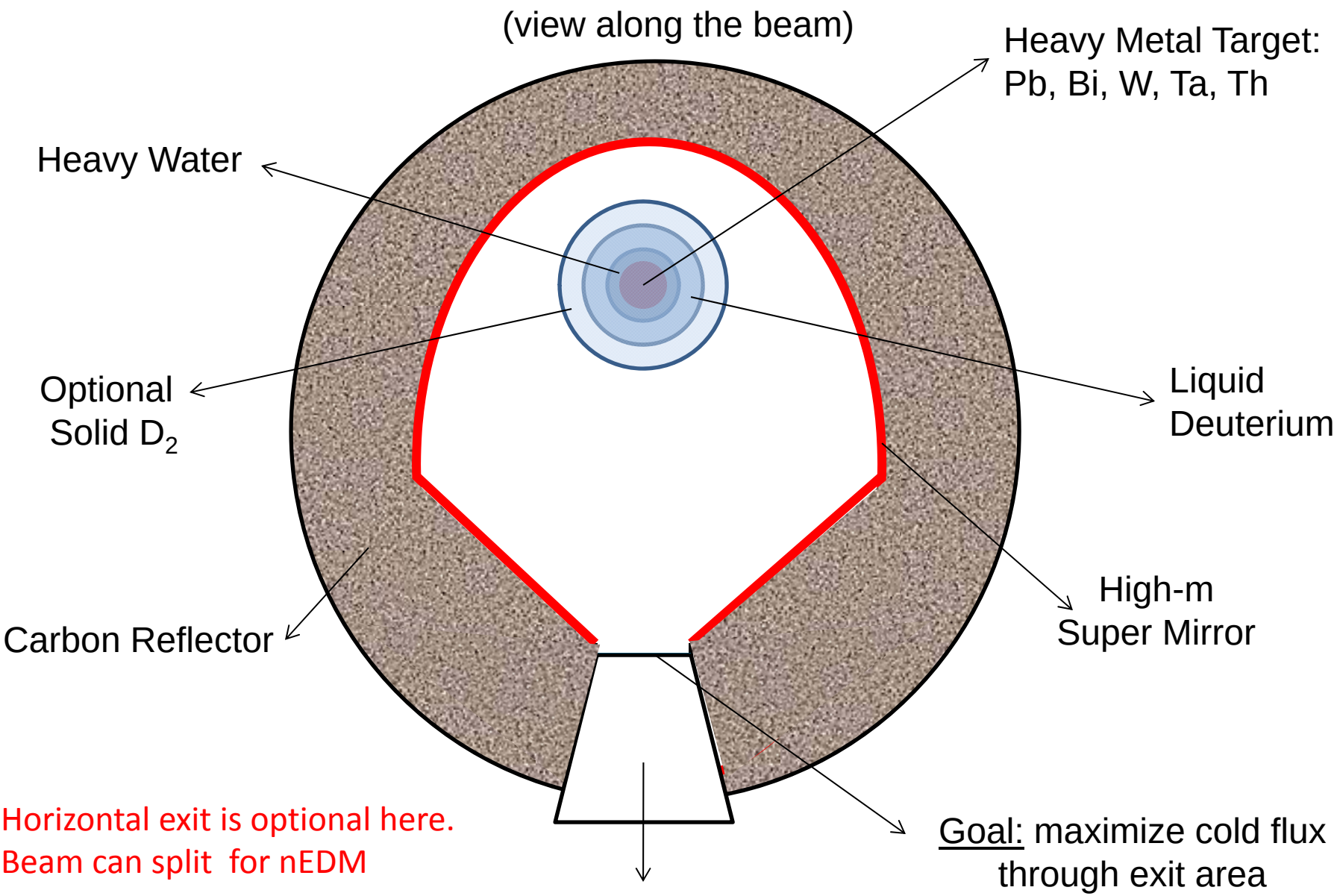
Generic configuration of 4π-emitting source target

Model for simulations and optimization

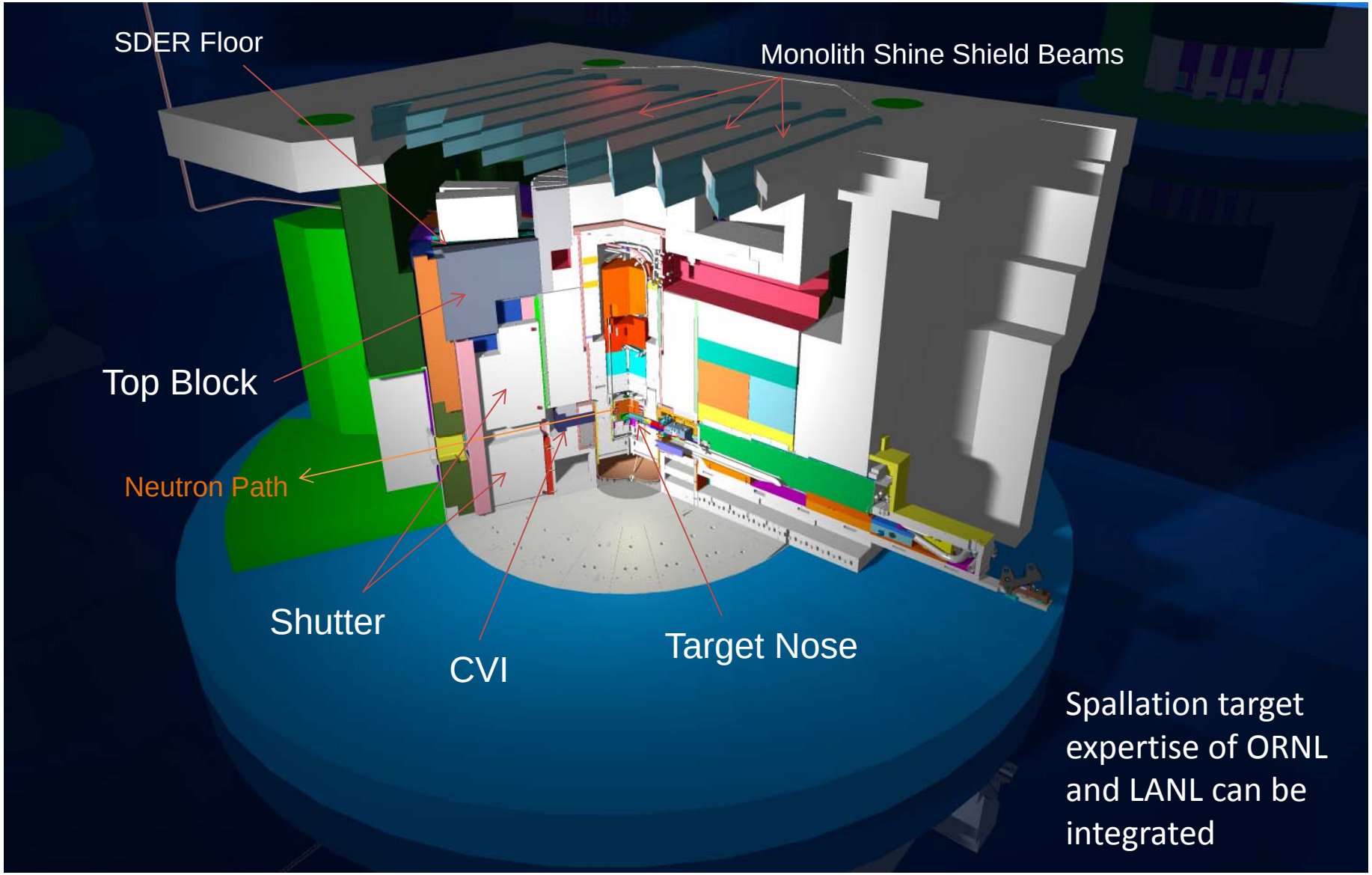


Dedicated target can be highly optimized for the production of cold neutrons. Such opportunity has not been exploited before.

Dedicated spallation target with enhanced vertical Cold & VCN & UCN production



SNS Target Monolith Components



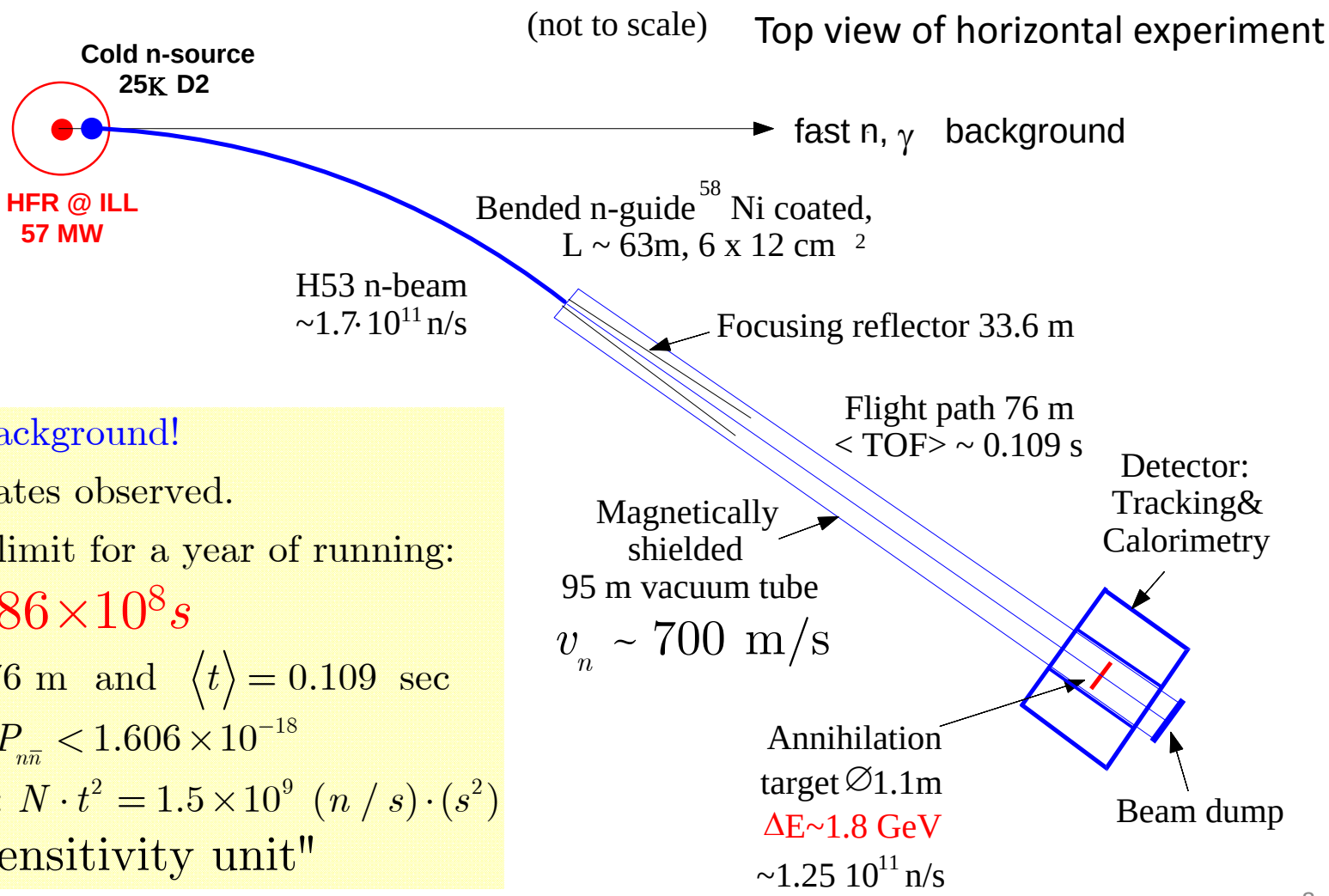
Spallation target expertise of ORNL and LANL can be integrated

Tony Gabriel/SNS

Previous n-nbar search experiment with free neutrons

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

Z. Phys., C63 (1994) 409



No GeV background!

No candidates observed.

Measured limit for a year of running:

$$\tau_{n\bar{n}} > 0.86 \times 10^8 s$$

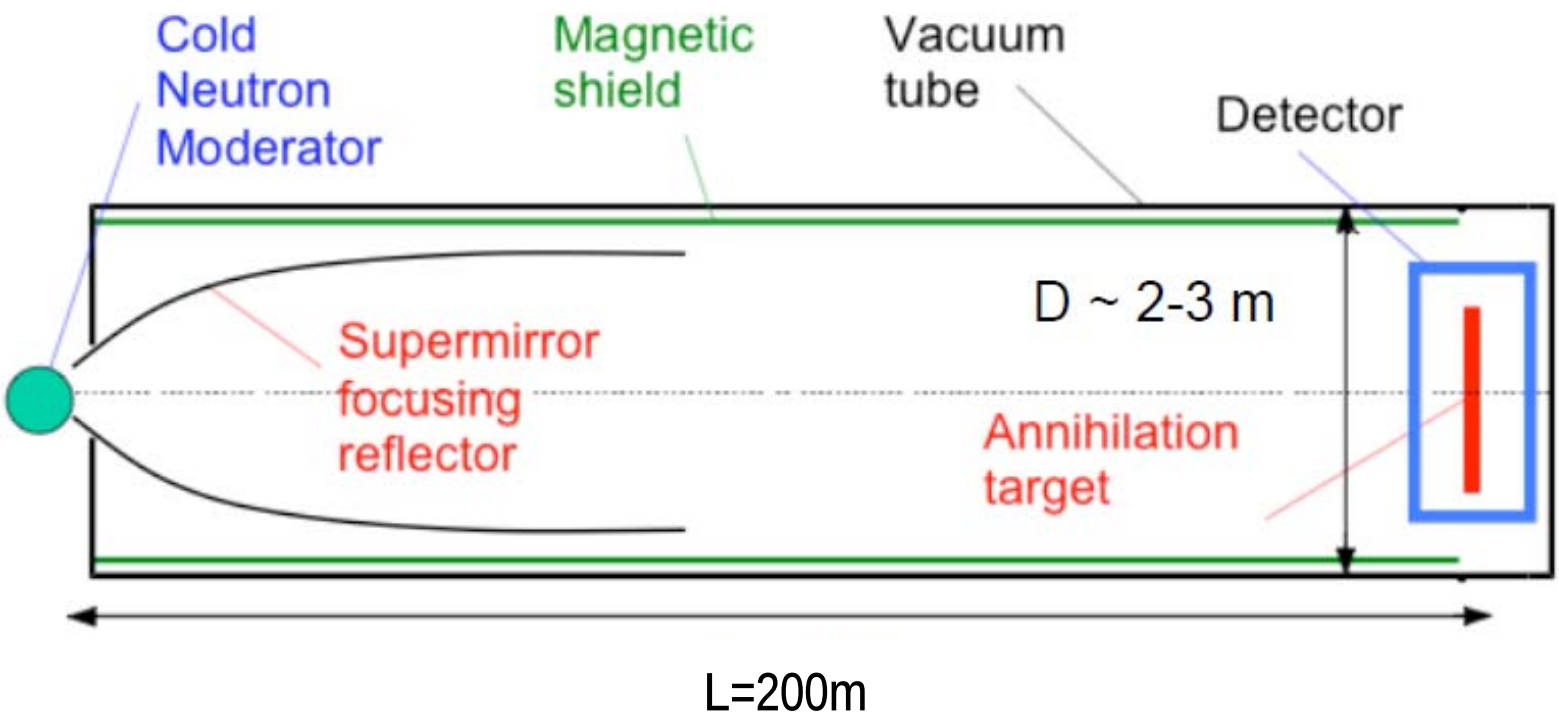
with L ~ 76 m and $\langle t \rangle = 0.109$ sec

measured $P_{n\bar{n}} < 1.606 \times 10^{-18}$

sensitivity: $N \cdot t^2 = 1.5 \times 10^9 \ (n / s) \cdot (s^2)$

$\doteq$ "ILL sensitivity unit"

Advanced Scheme of ILL-like experiment (Stage 1)



Pulsed mode of target operation might be useful for fast n and γ background suppression.

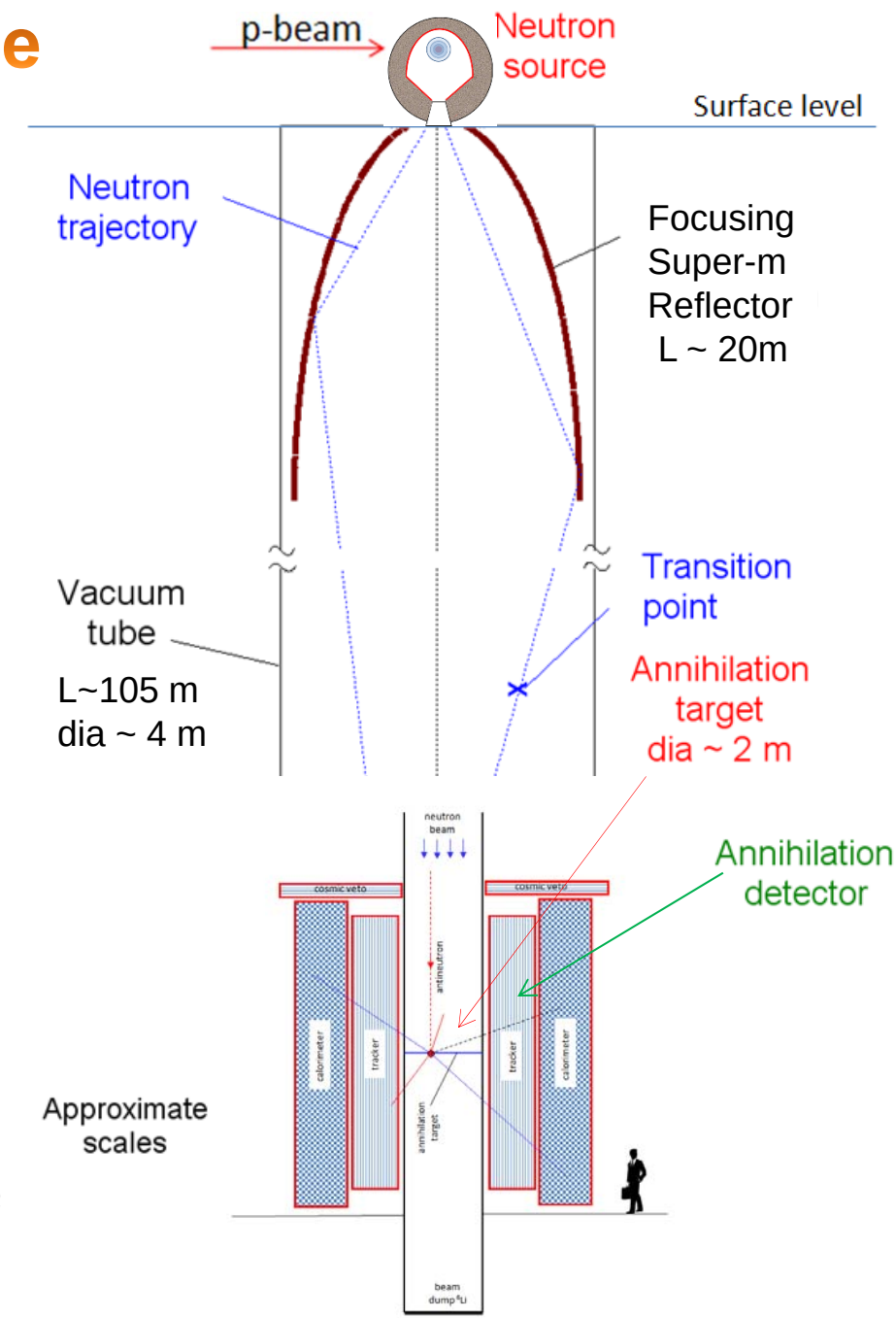
Top-Down vertical scheme

- Can combine most of improvements;
- CW or pulsed;
- Max UCN (<10 m/s) enrichment will be most advantageous;
- Cold and VCN are also used;
- Ultimate combination of all improvements should boost the sensitivity by factor > 1,000 u times several years of operation

$$h = v_0 t + \frac{1}{2} g t^2$$

$$105\ \mathrm{m} = 100\ \mathrm{m/s} \cdot 1\ \mathrm{s} + 4.9\ \mathrm{m/s^2} \cdot 1^2\ \mathrm{s^2}$$

$$105\ \mathrm{m} = 10\ \mathrm{m/s} \cdot 3.7\ \mathrm{s} + 4.9\ \mathrm{m/s^2} \cdot 3.7^2\ \mathrm{s^2}$$



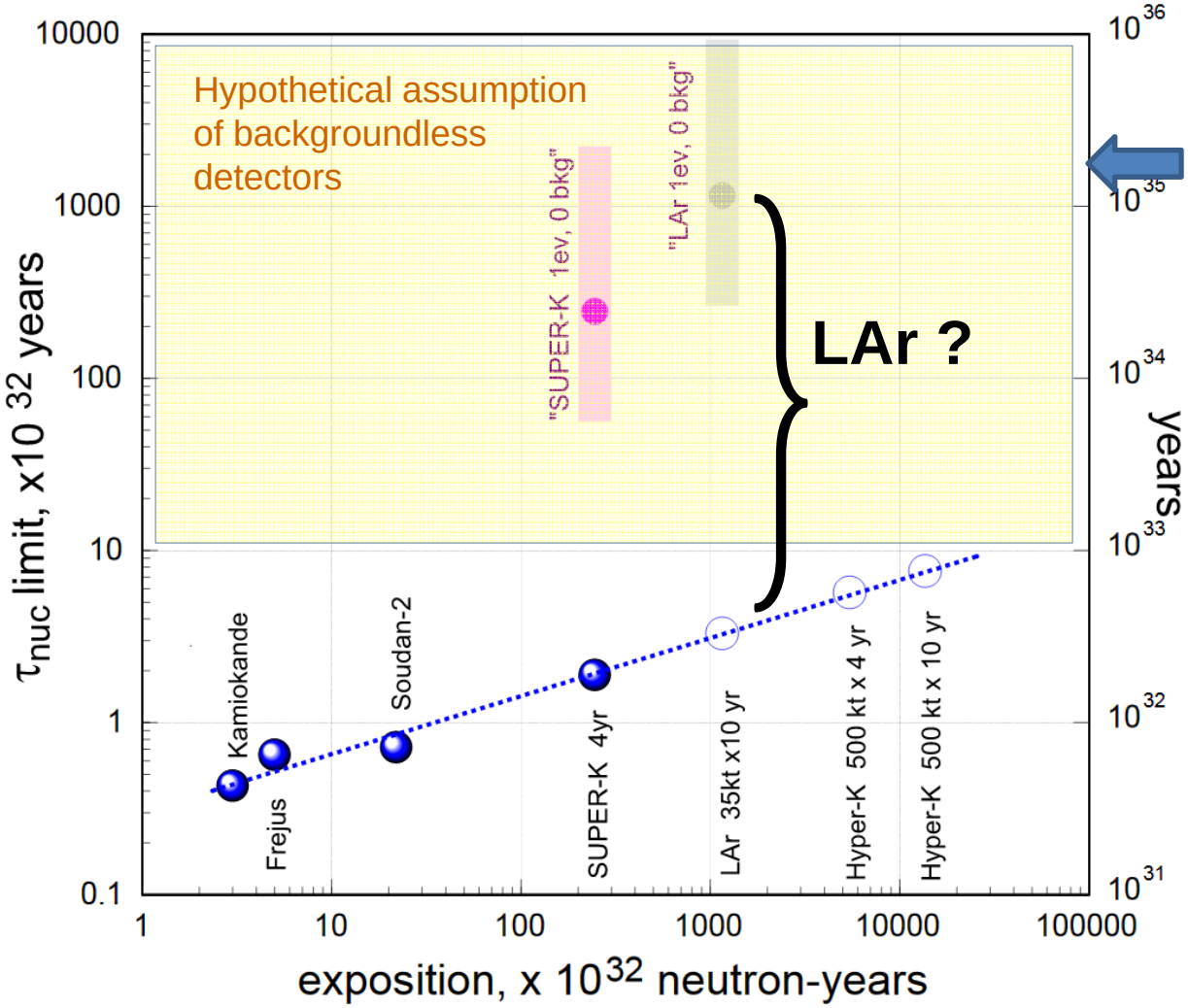
Physics goals of staged NNbarX

$$1 \text{ ILL unit of sensitivity} = \mathrm{N} \times \overline{t^2} = 1.5 \times 10^9 \ \ n \cdot s$$

τ	ILL units	
0.86×10^8 s	1u	←Free neutrons at ILL (1994)
3.45×10^8 s	16u	←Super-K now, 22.5kt, 4 years
5.5×10^8 s	40u	←Goal of NNbarX Stage 1
7.5×10^8 s	76u	←Hyper-K 500kt, 10 years
1×10^{10} s	13,500u	← Goal of NNbarX Stage ≥ 2
1×10^{11} s	1,350,000u	←Theory wish (further R&D)

Optimization of performance of various configurations vs cost is a goal of our studies towards Snowmass 2013

Comparison with intranuclear n-nbar search



Ultimate goal of NNbarX sensitivity. Absence of background is critically important

24 candidate events in Super-K might contain several genuine n-nbar events.
Backgroundless detectors needed to explore nnbar > 10^{33} years.
Can atmospheric neutrinos and nnbar signals be separated in LAr detectors?

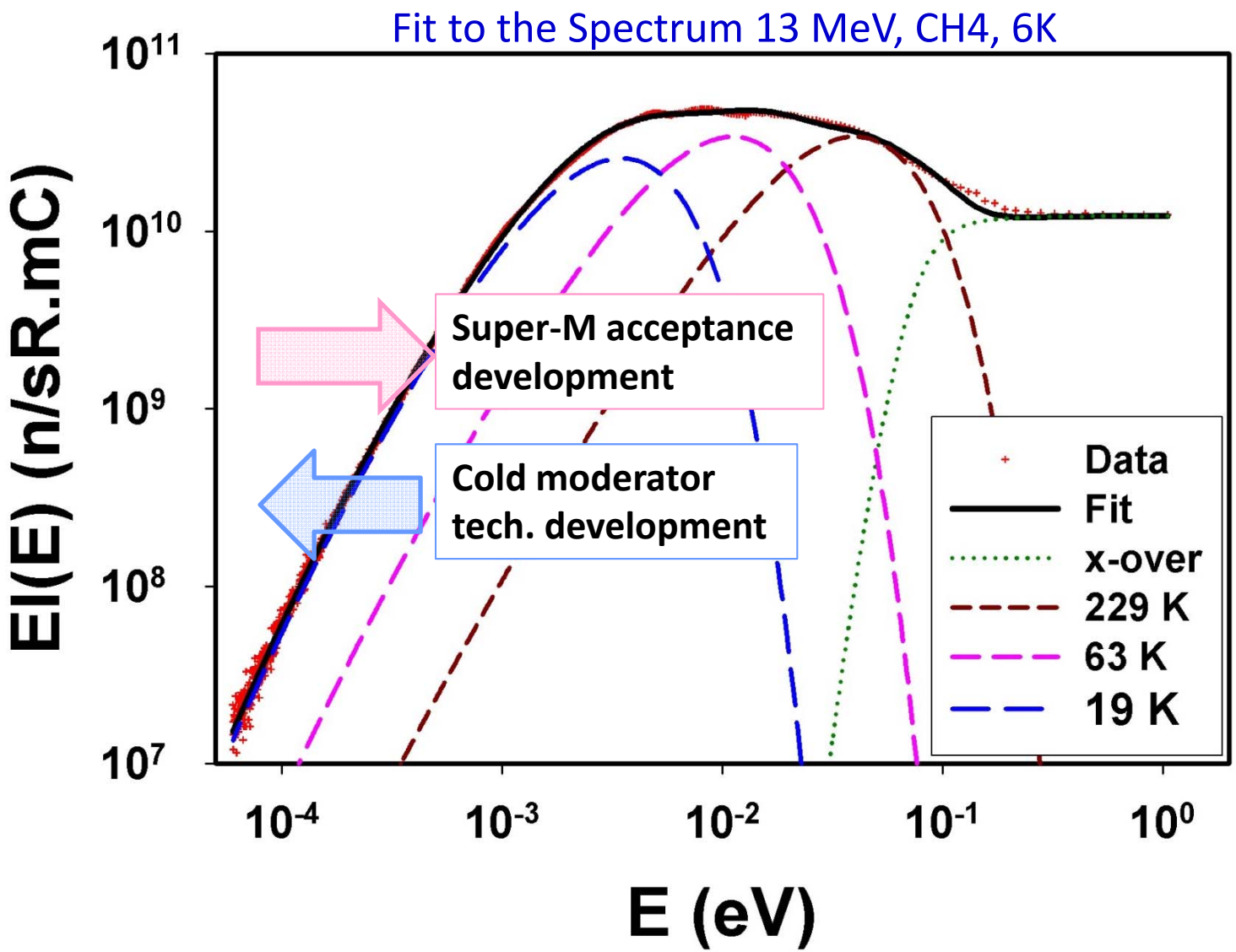
Possible improvements in sensitivity

- Dedicated source (advantage of Project X)
- Efficient source coupling to experiment
- Maximize source and target parameters
- Slower Neutrons ("Cold" $\rightarrow$ "Very Cold" $\rightarrow$"Ultra Cold") R&D
- Focusing neutrons by efficient ("high-m") mirror reflection
- Maintain low background by shielding
- Neutron manipulation by gravity (vertical layout)

Various factors are correlated. Performance optimization should include cost as a parameter.

Discussion at PXPS have addressed technology improvements, resolution of known issues and directions of R&D

Colder moderator R&D at Indiana University / CEEM



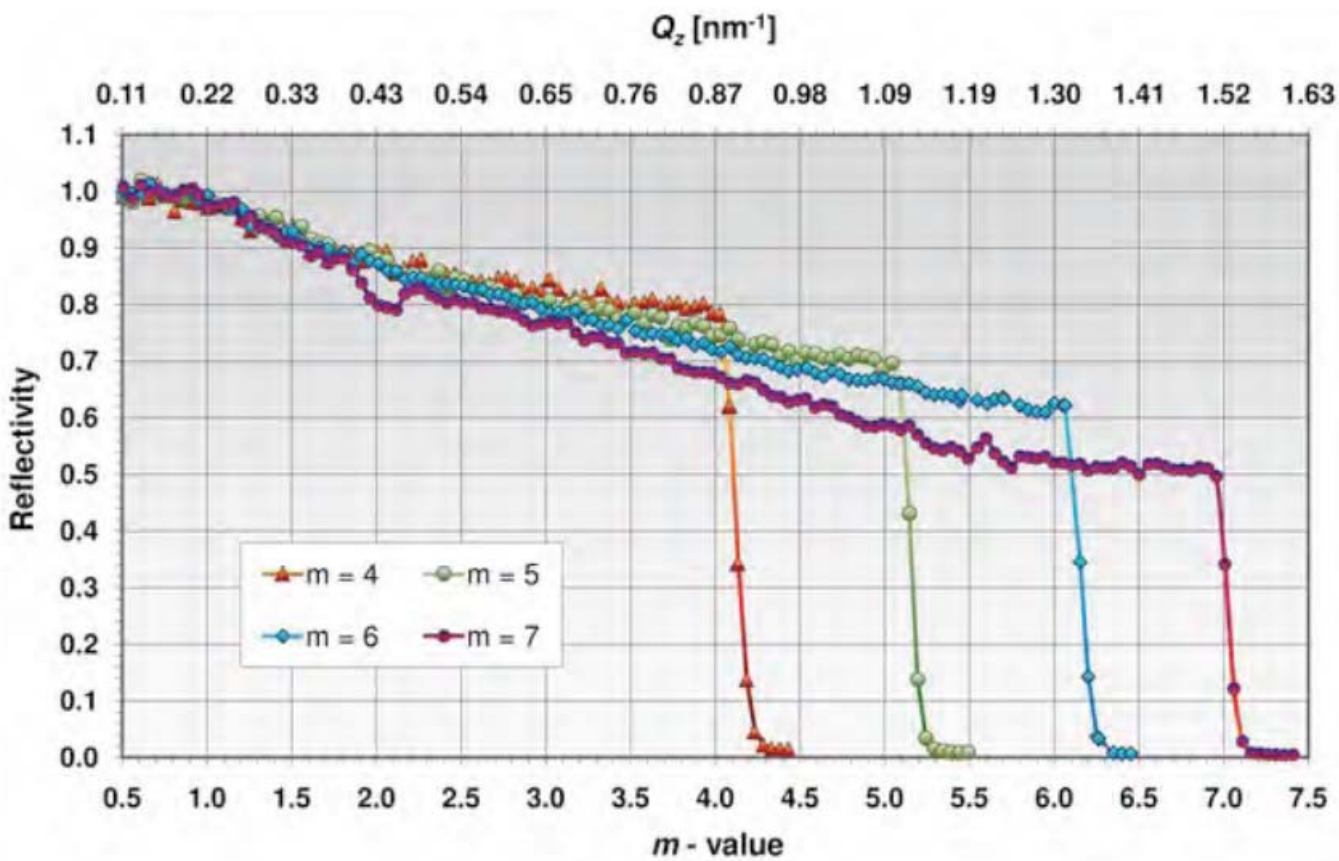
Dave Baxter, Chen-Yu Liu

Progress in enabling technology

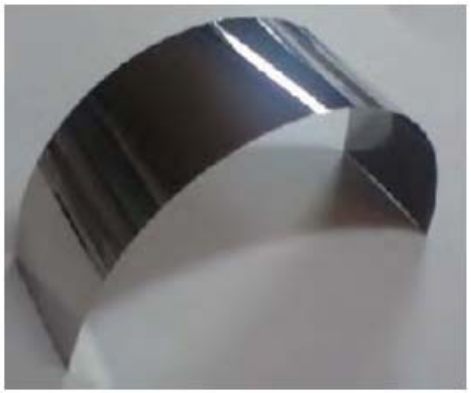
m=4-7 Supermirrors

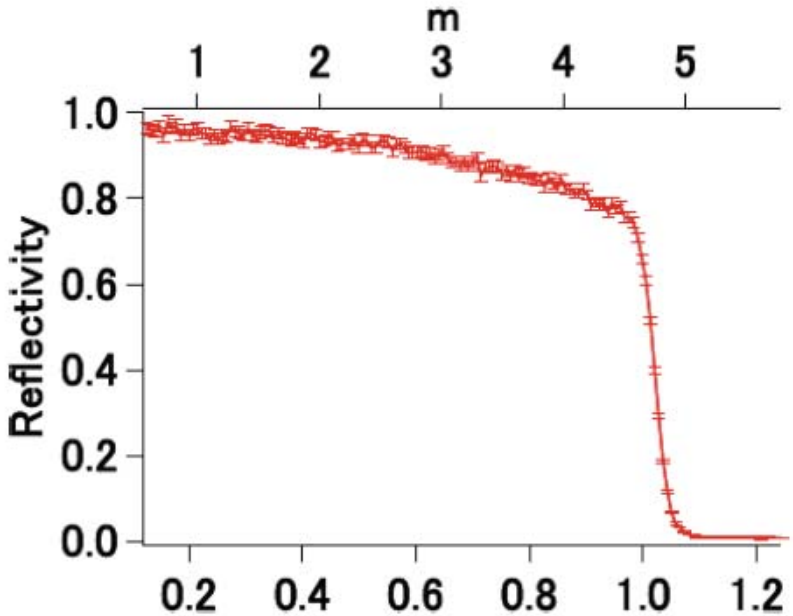
http://www.swissneutronics.ch/

Supermirror: commercially available up to m=7 ($v_\perp$=50m/s)



Substrateless Supermirror





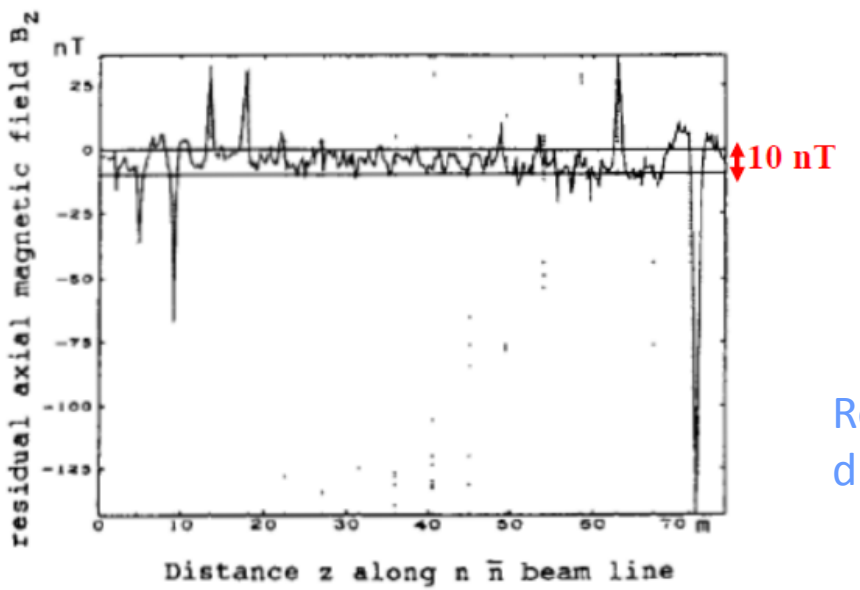
no substrate (radiation hardness expected)

DLC Supermirror?

Magnetic Shielding in ILL (1991) experiment

$B(z)$ with mumetal ∅ 1.1 m
+ active compensation (changing environmental field)
+ demagnetization

50 Hz axial plus
1 Hz radial



$\mu_{eff} = 2\times10^6$

Measured twice daily

Restriction on μmetal diameter due to the size of annealing oven

0.984±0.003 quasifree efficiency

T. Bitter et al.,
NIM A **309**, 521 (1991)
U. Kinkel,
Z. Ph. C **54**, 573 (1992)

Alternative idea of sub-nT magnetic shielding

Magnetic Shielding At Petersburg Nuclear Physics Institute

Pre-bended, pre-annealed μmetal tiles arranged in multilayer shield

Separated panel construction for segmented shield developed for Neutron EDM experiment

Mike Snow

Photo courtesy A. Serebrov

Shielding in Target region

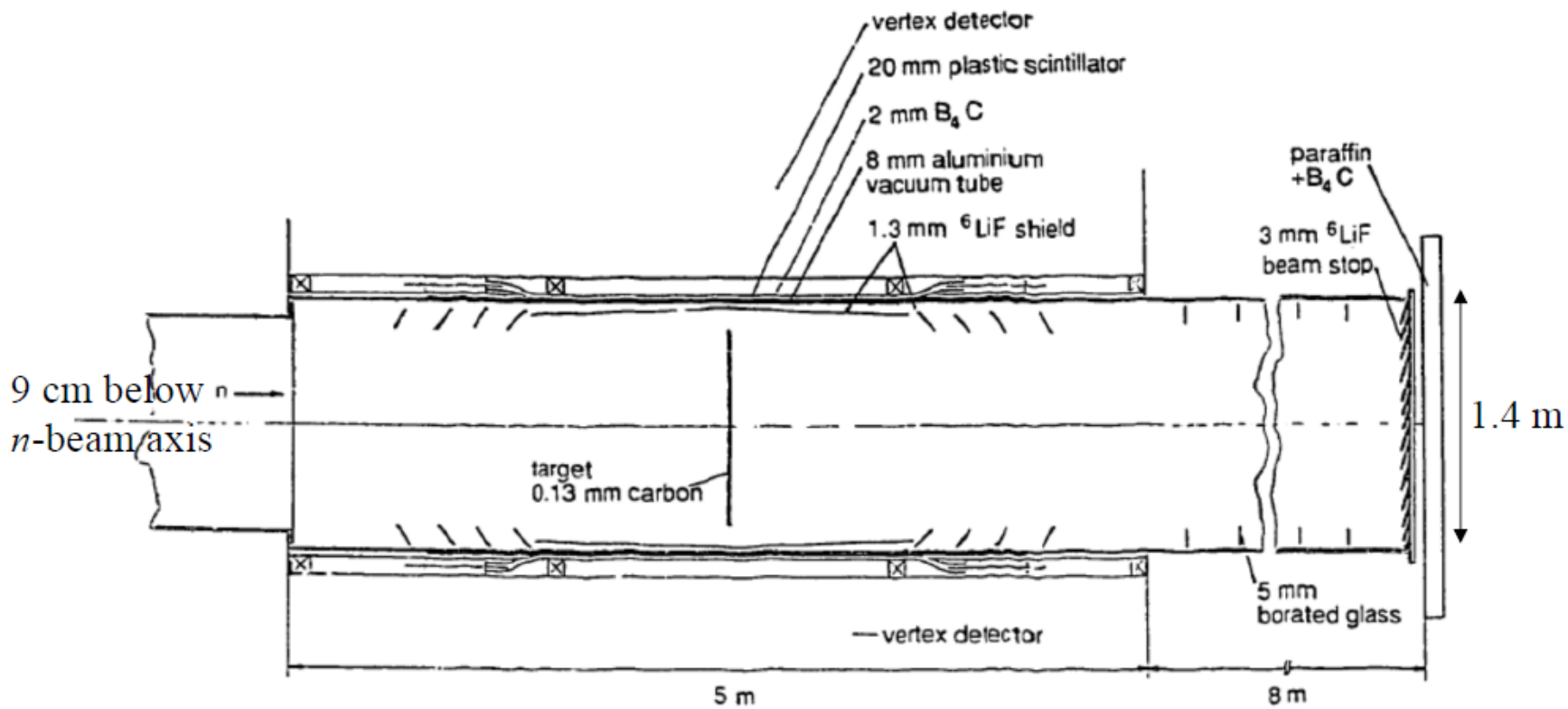


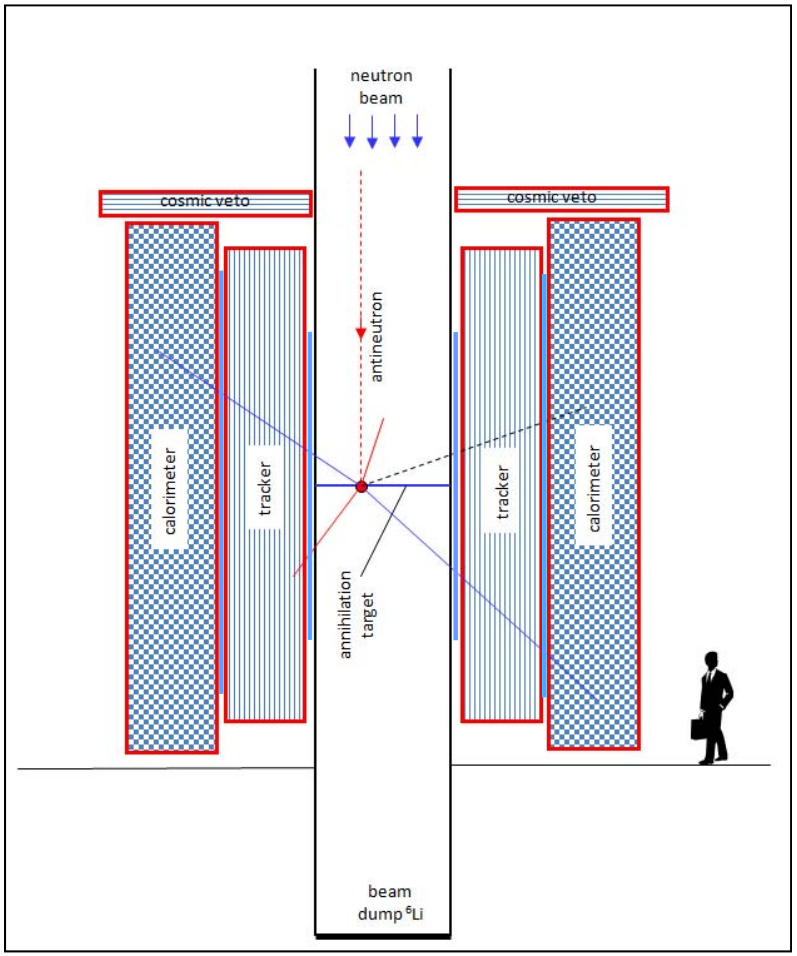
Fig. 1. The target region of the n$\bar{n}$ experiment and its surroundings.

Fermilab 18.06.2012

Dirk Dubbers/Heidelberg

10^7 γ/s ILL $\Rightarrow$ 10^8 γ/s at PX ST

Annihilation Detector



$$\text{Annihilation feature: } \overline{n} + C \rightarrow \langle 5\pi \rangle$$

- Use ideas of backgroundless ILL detector;
- Can be Vertical and Horizontal;
- Tracker for vertex to thin carbon target;
- Calorimeter for trigger and energy reco;
- TOF before and after tracker to remove vertices of particles coming from outside;
- Cosmic veto;
- Intelligent shielding to minimize (n,γ) emission.

Interactions with TOF, Calorimeter and Tracker working groups during PXPS stimulated our studies of the detector requirements.

Feasibility conclusion of Dirk Dubbers/Heidelberg

(one of the leaders of ILL experiment in 1991)

In upscaled n-nbar experiment:

1. Magnetic shielding on 1 nT scale is feasible with state-of-the-art techniques.

2. Radiation background, beam related, should be improved by using thinner and cleaner target and tighter ^{6}LiF shield.

3. Annihilation detector with higher track resolution is desirable.

NNbarX Collaboration:

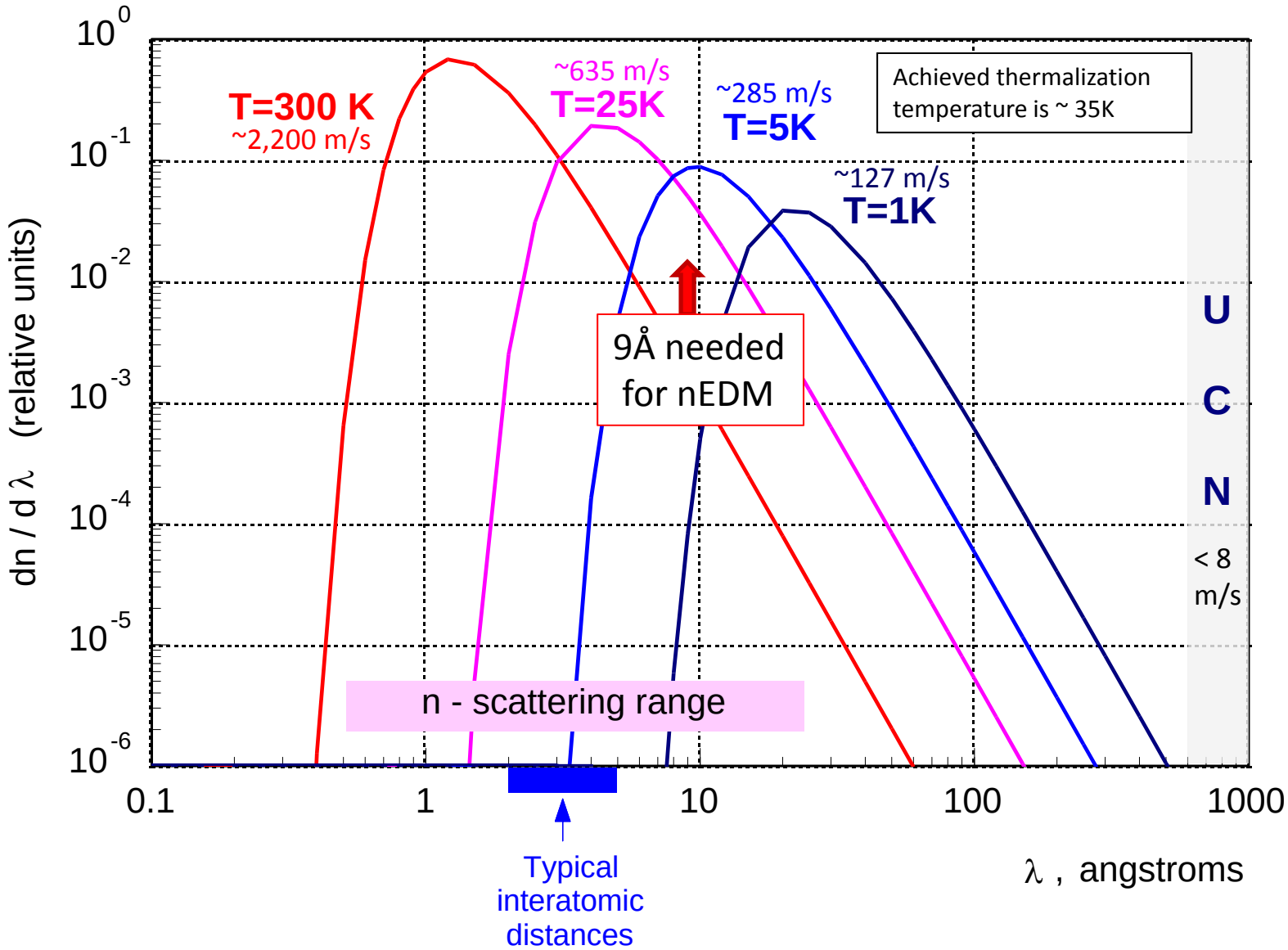
Indiana University,
North Carolina State University,
[LANL],
U. Tennessee,
[ORNL/SNS],
FNAL,
CSUDH,
SINP/INDIA,
VECC/INDIA,
IUAC/INDIA,
Nagoya U./JAPAN
PNPI/RUSSIA,

Theory support group: R. Mohapatra, K. Babu, R. Shrock, I. Gogoladze,
R. Cowsik, A. Vainshtein, G. Dvali, Z. Berezhiani, A. Dolgov, L. Okun, and more

Roadmap to Snowmass'2013

- Expression of Interest to FNAL for n-nbar experiment at Project X (summer 2012)
- R&D proposals from Universities (including expertize of SNS/ORNL and LANL) to DOE for the development of the concepts of very cold neutron source for the Project-X 1-MW spallation target and optimization of n-nbar experiment configuration, performance, and cost.
- R&D in India on magnetic shielding and TPC tracker for n-nbar.
- R&D in Japan on super-mirror optics.

Simulations and engineering study with optimization of performance and cost for various Staging Options. Deliverable information for Snowmass:

Options	Sensitivity	Cost	Concerns
…			
…			

Maxwellian spectra of thermalized neutrons at temperature T