TRIUMF

CANADA’S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

Canadian Spallation Ultracold Neutron Source

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(Winnipeg, Manitoba, ORNL, TRIUMF, NCSU, Caltech, RCNP, SFU, LANL, KEK, Tokyo, UNBC, Osaka, Kentucky)

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d’un consortium d’universités canadiennes, géré en co-entreprise à partir d’une contribution administrée par le Conseil national de recherches Canada

Summary

- We propose to construct the world's highest-density source of UCN at TRIUMF
- The source will be used carry out fundamental and applied research
- Experiments:
  - gravity levels
  - n-lifetime
  - surface science
  - n-EDM

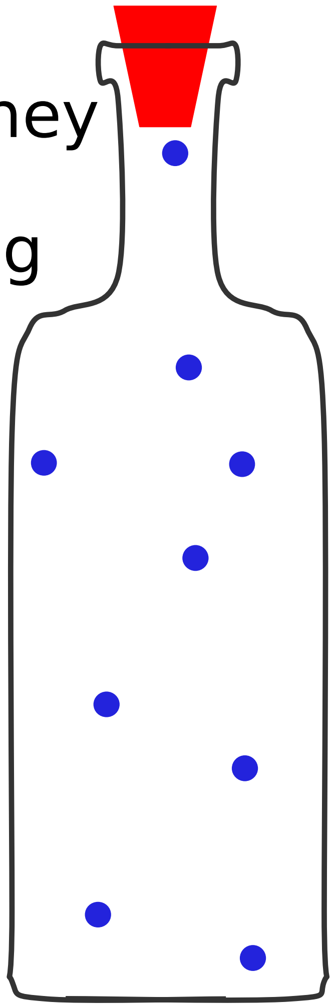
(gravity levels, n-lifetime, surface science: near term)

(n-EDM: longer term)

How we will succeed

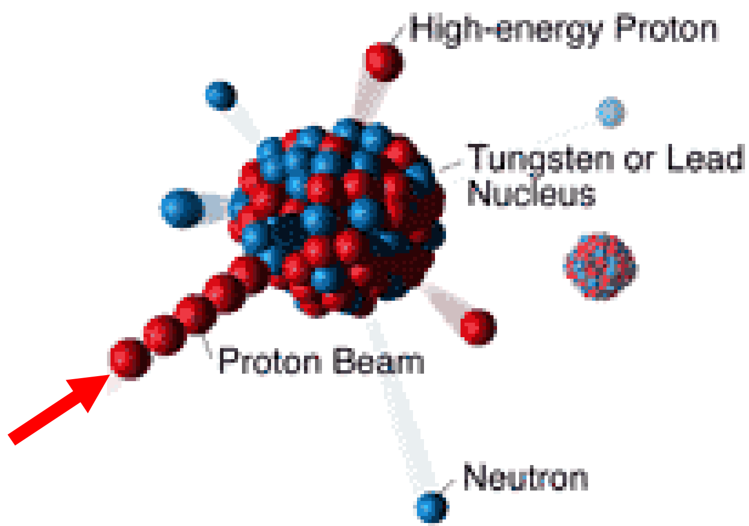
- Huge commitment from expert Japanese group (Masuda) on UCN source project.
- The TRIUMF high-intensity 500 MeV proton beam is required to reach high UCN density.
- Canadian university-group expertise in fundamental neutron physics.
- Exciting UCN physics experiments supported internationally (Japan, USA, Canada)

Ultracold Neutrons

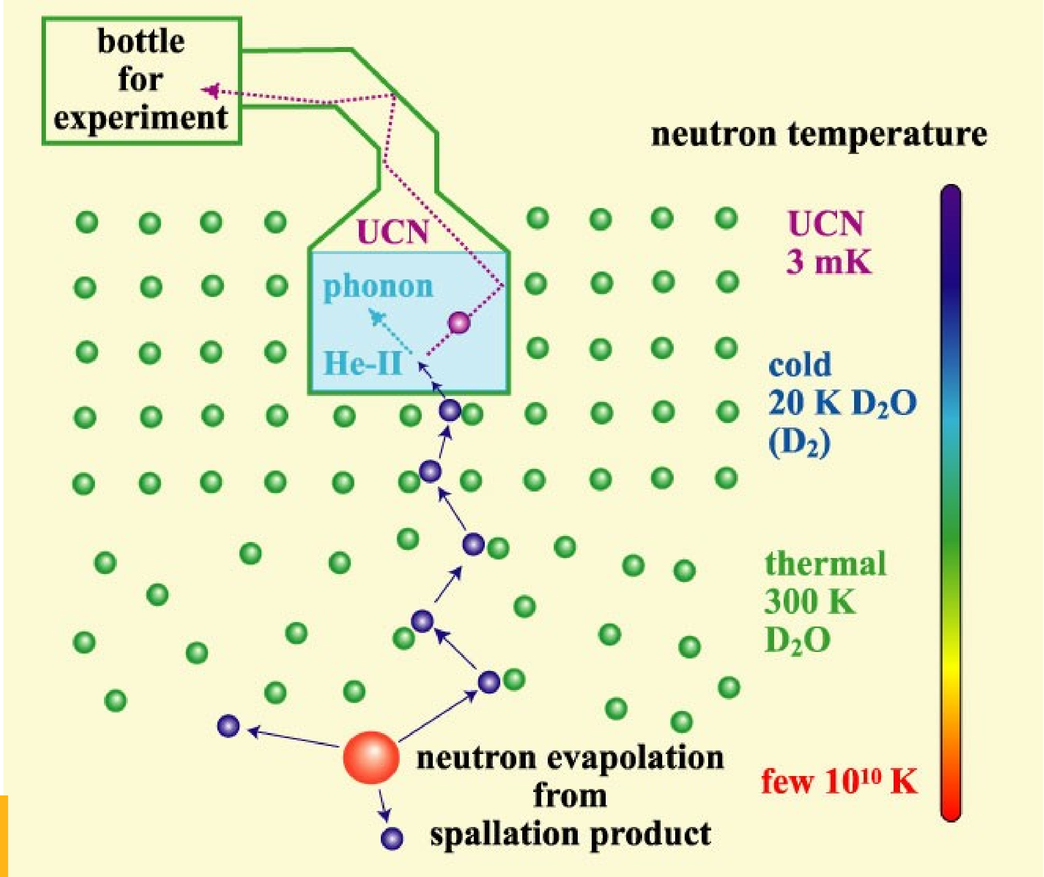


- UCN are neutrons that are moving so slowly that they are totally reflected from surfaces of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - gravity: V=mgh (h < 3 m)
  - weak interaction (allows UCN to decay)
  - magnetic fields: $V=-\mu \cdot B$ (100% polarization)
  - strong interaction
- Experiments at UCN sources are chronically limited by UCN density. TRIUMF can provide the world's largest density.

How to make UCN

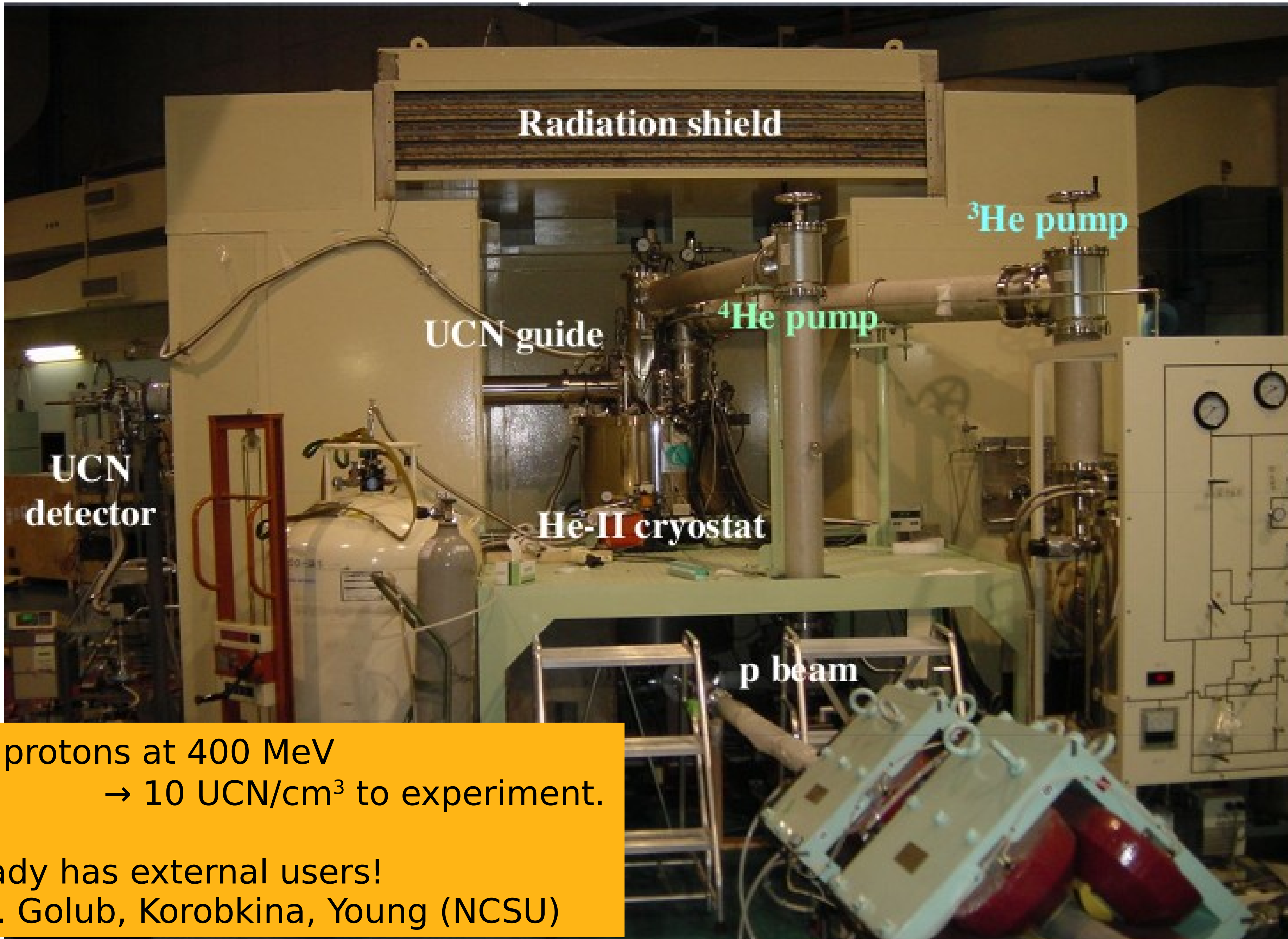


- Liberate neutrons by proton-induced spallation.
- Moderate (thermalize) in cold (20 K) D_2O.
- Cold neutrons then "downscatter" to near zero energy (4 mK) in superfluid helium through phonon production.



<u>Unique to TRIUMF!</u> Most others use SD_2

RCNP UCN Source (Masuda, et al)



1 μa protons at 400 MeV
→ 10 UCN/cm^3 to experiment.

Already has external users!
- e.g. Golub, Korobkina, Young (NCSU)

Gain Factors for TRIUMF

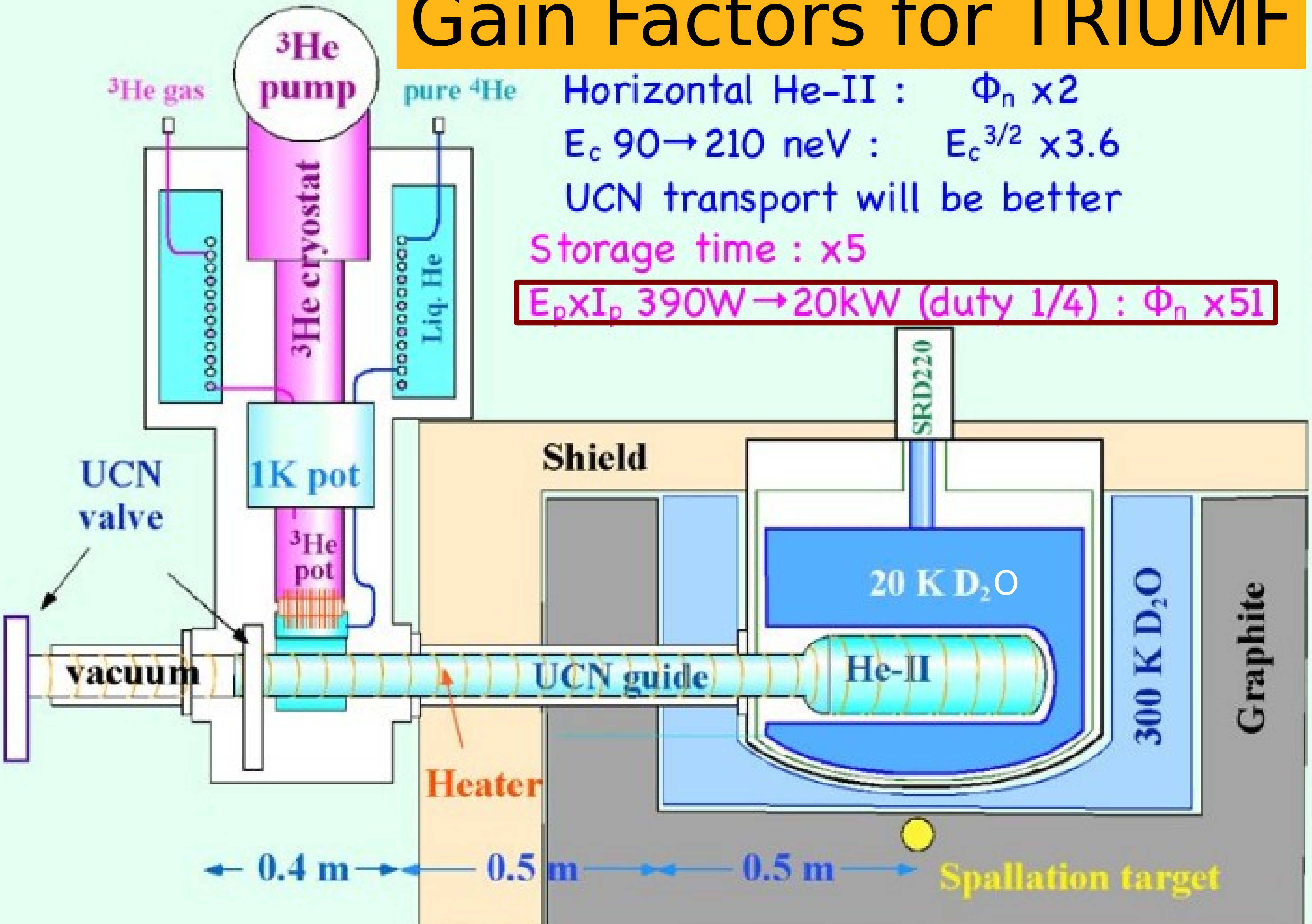
Horizontal He-II : Φ_n x2

E_c 90→210 neV : $E_c^{3/2}$ x3.6

UCN transport will be better

Storage time : x5

$E_p x I_p$ 390W→20kW (duty 1/4) : Φ_n x51



Future Upgrade: D_2O ice → LD_2 : x5

World's UCN projects

	source type	E_c neV	P_{UCN} /cm³/s	T_s s	ε_{ext}	ρ_{UCN} /cm³ source/exp.
TRIUMF	spallation He-II	210	0.4×10^4 (10L)	150	~1	3×10^5 (20L) $1\text{-}5 \times 10^4$
ILL	n beam He-II	250	10	150	~1	**/1000
SNS	n beam He-II	134	0.3 (7L)	500	1	**/150
LANL *	spallation SD2	250	4.4×10^4 (240cm³)	1.6	1.3×10^3/ 4.4×10^4	**/120
PSI	spallation SD2	250	2.9×10^5 (27L*)	6	0.1	2000 (2m³) /1000
NCSU	reactor SD2	335	2.7×10^4 (1L)	**	**	1300/**
Munich	reactor SD2	250	**	**	**	1×10^4/**

Experiments

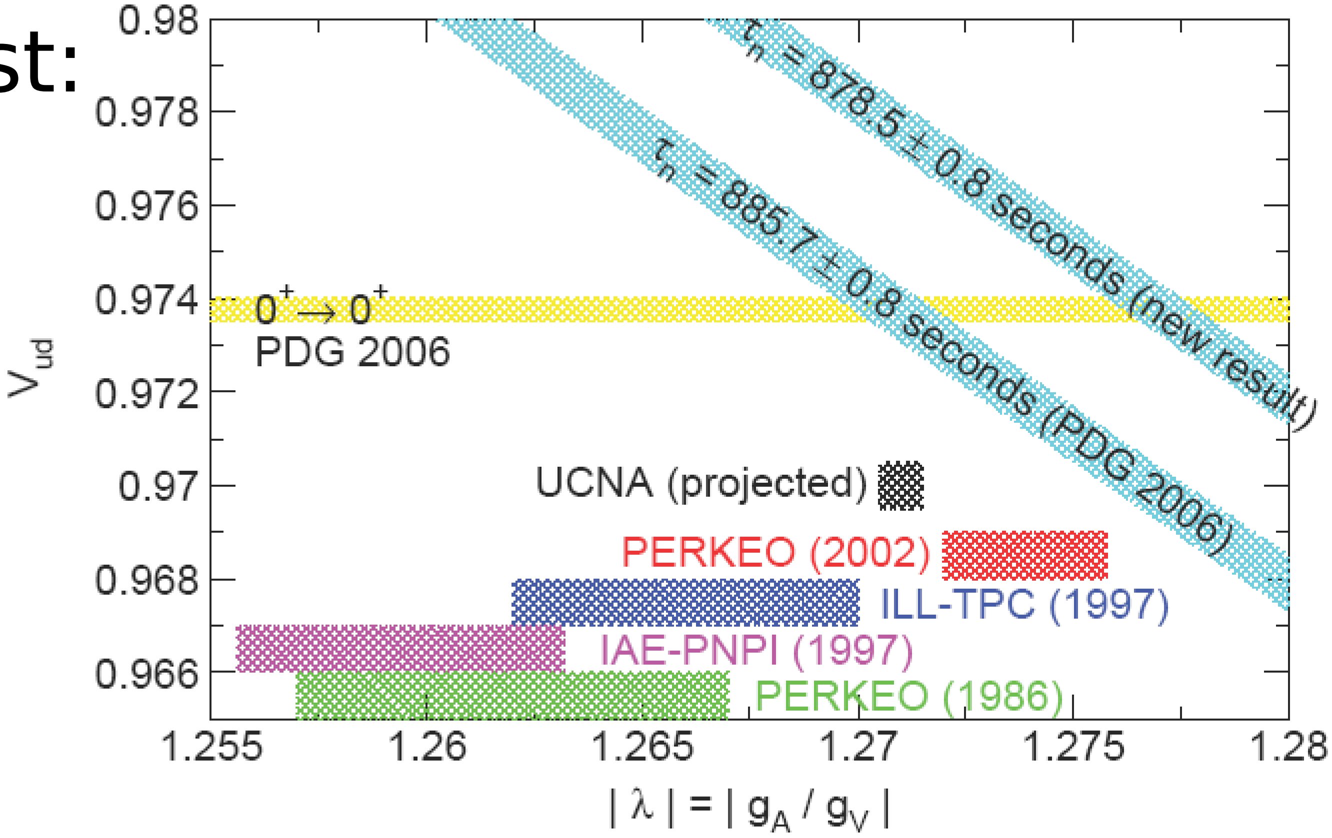
- n-lifetime
- gravity levels
- surface science
- n-EDM

near term (n-lifetime, gravity levels, surface science)

longer term (n-EDM)

Neutron Lifetime

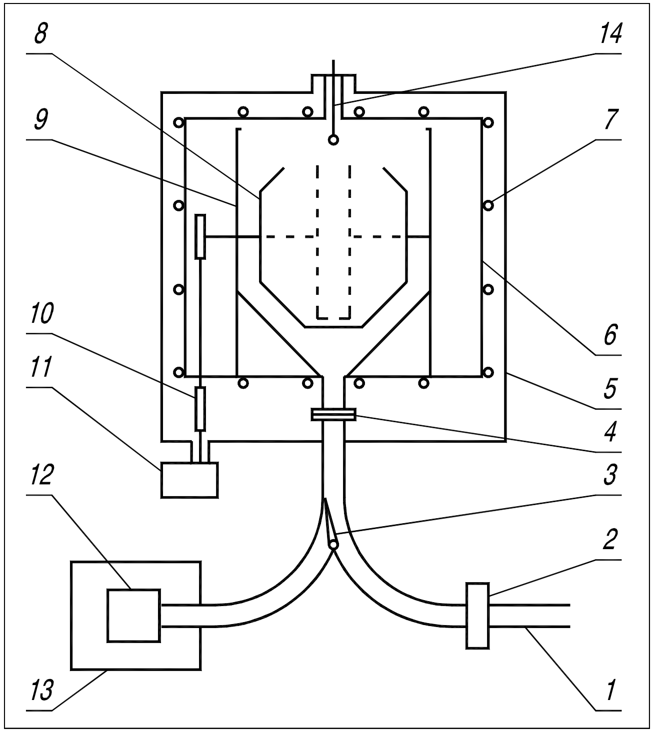
- Physics interest:
  - BBN
  - V_{ud}



- Currently a 6.5 sigma discrepancy between n-lifetime experiments

Neutron Lifetime

- Basic experiment: trap UCN for varying amounts of time
- All previous precise experiments used material traps
- Wall effects give dominant systematic effects

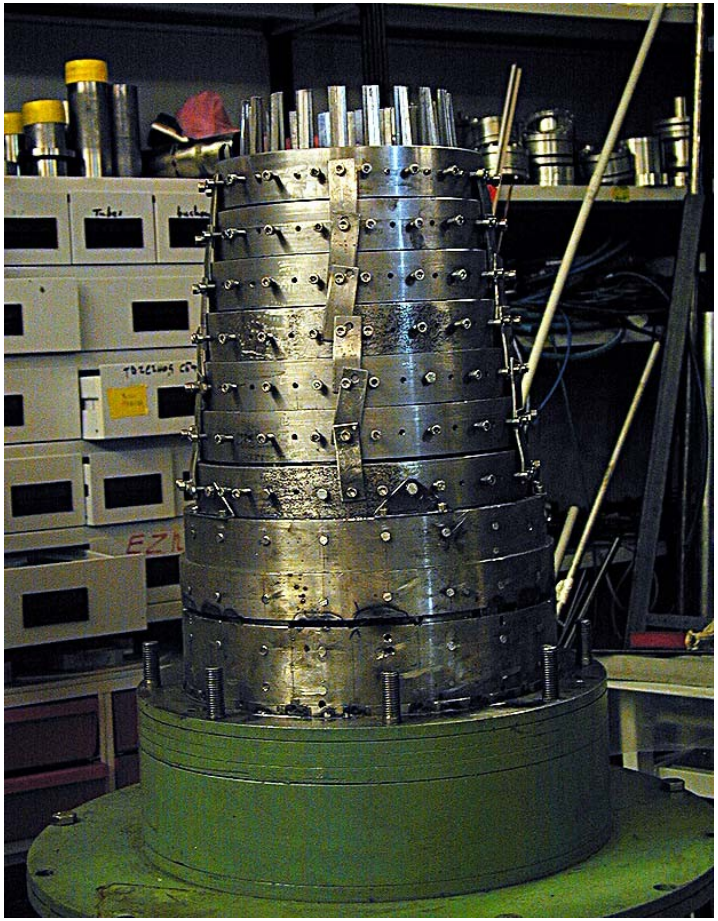


<- Gravitrap

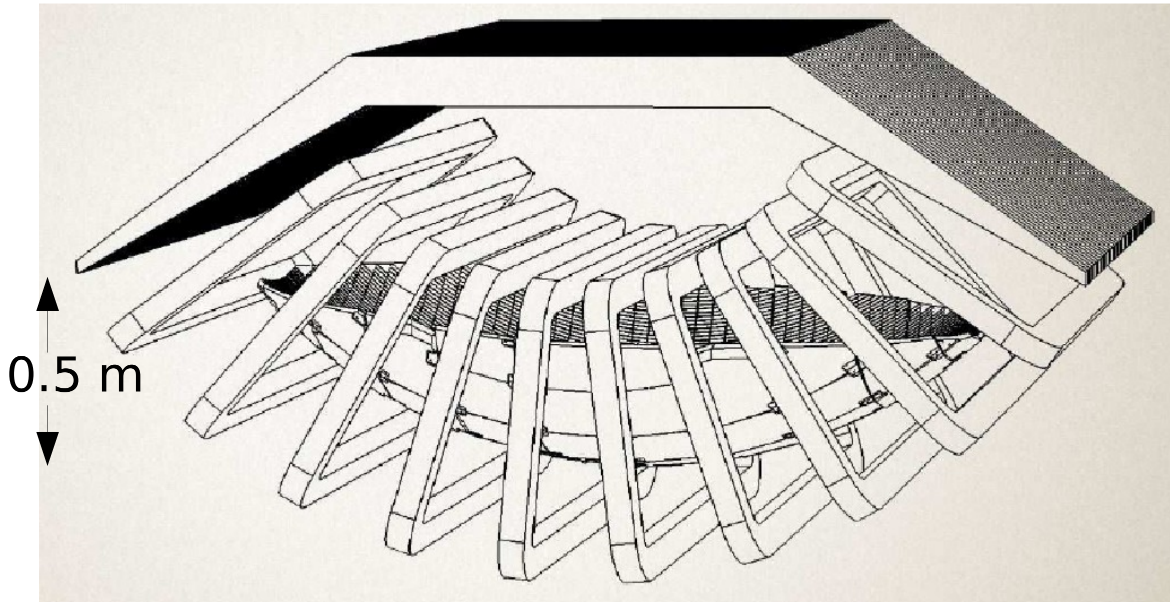
Permanent magnet trap ->

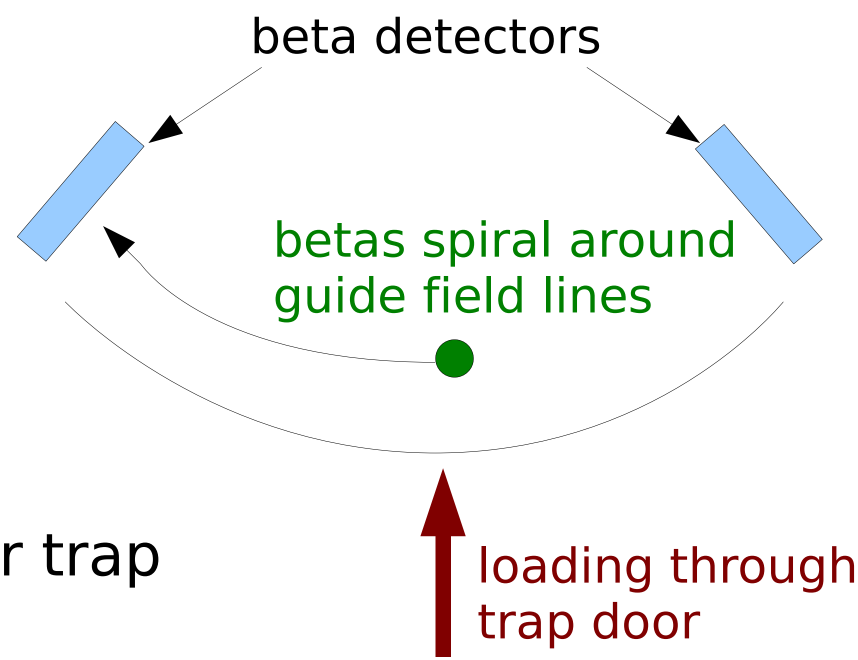
(both at ILL)

- New efforts to trap UCN magnetically
- marginally trapped orbits
- NEED MORE UCN!!!



Magneto-Gravitational Trap for Neutron Lifetime (Bowman et al)



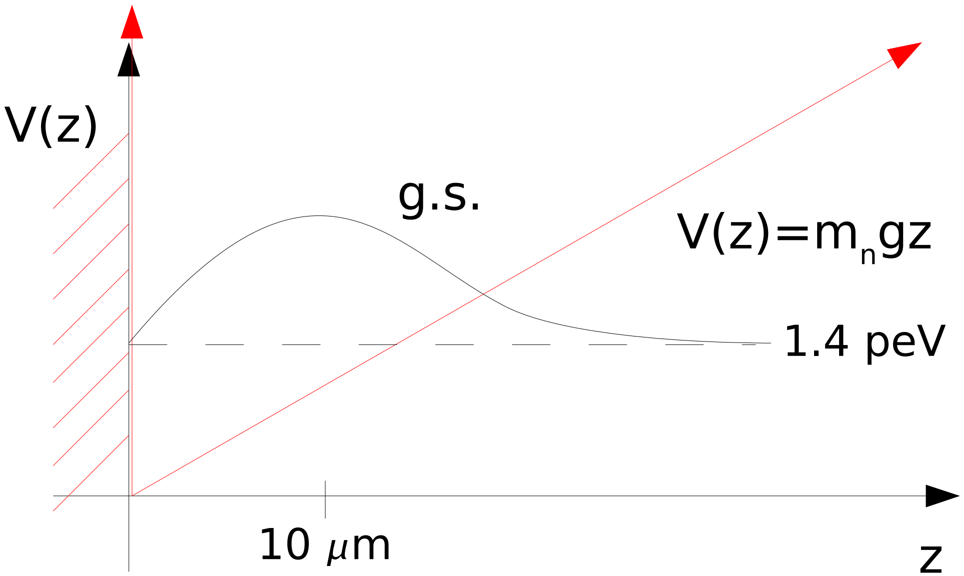


- Shallow Halbach array + gravity for trap
- Guide field for decay betas
- Marginally trapped neutrons experience chaotic orbits and are ejected rapidly
- Goal precision $\delta\tau_n \sim 0.1$ s
- Requirements: Efficient trap loading, effective n-“cleaning”, high UCN density

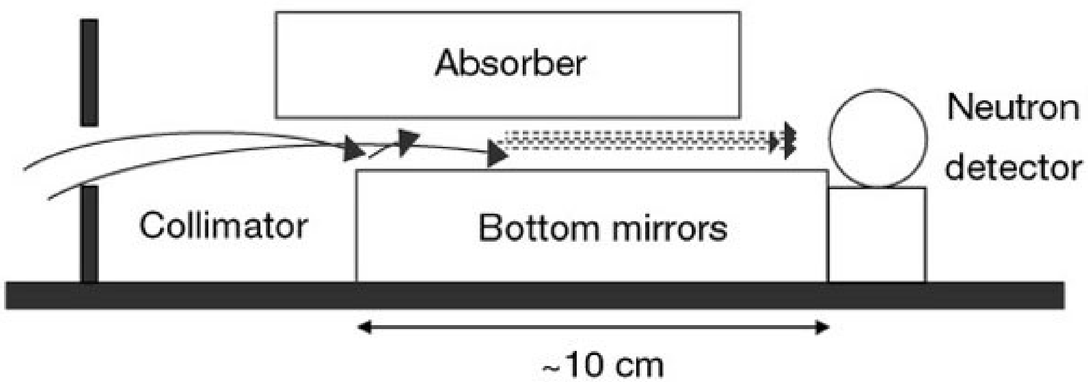
N-lifetime Plans for TRIUMF

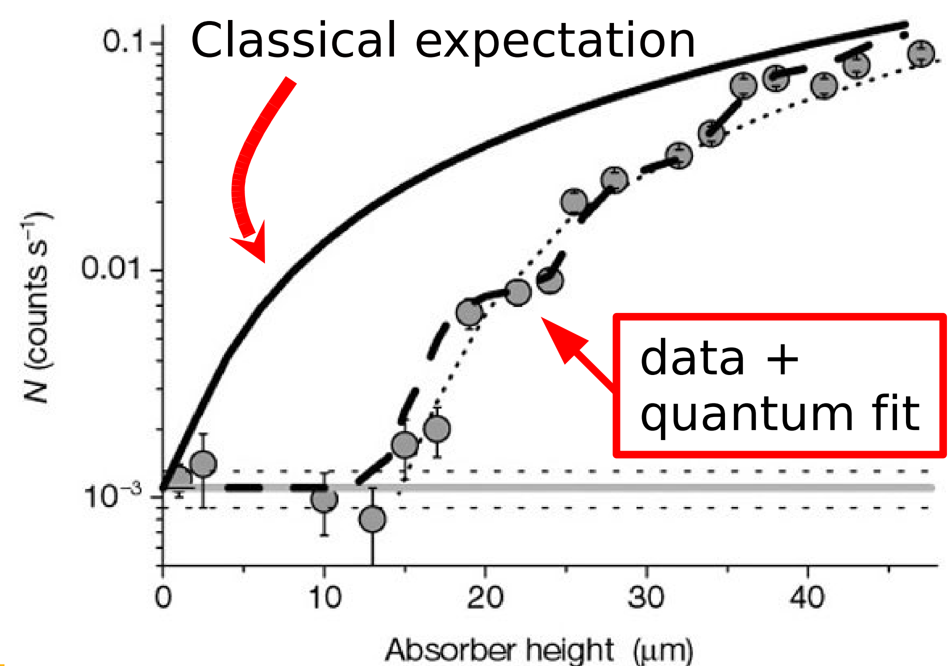
- Theoretical work on trap dynamics completed at LANL (some remaining issues with trap loading)
- Prototype under construction at LANL
- Goal is for test experiment at LANL UCN source
- TRIUMF experiment would build on preliminary work done at LANL
- Candidate for a first physics experiment using the TRIUMF UCN source
- Current common collaborators:
  - J.D. Bowman, B. Filippone, T. Ito, B. Plaster

UCN Quantum States in Gravity



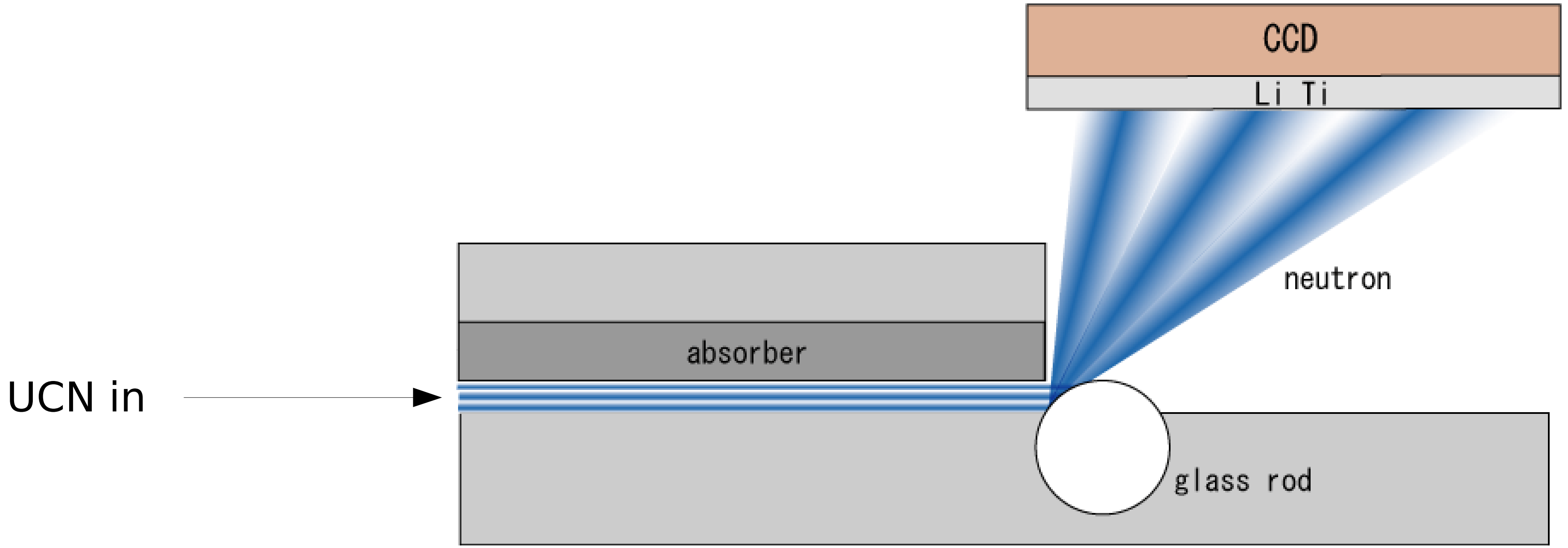
- Confine UCN in 1D by gravity
- Experimental results have been used to place limits on
  - 10 um scale modifications to gravity
  - extra dimensions
  - axions





Further experiments:
- Bottle the UCN to increase time the UCN is contact with the mirror.
- Excite resonant transitions between quantum states.
- Increase purity of states by preselection.
- Goal: improve precision on energy of state and hence increase sensitivity to modifications to gravity.

Concept for Improved Experiment (Komamiya group)



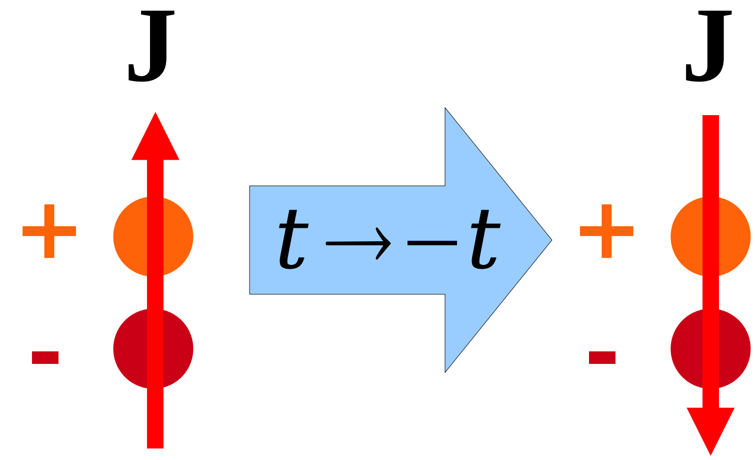
- Features:
  - glass rod “magnifier”
  - Li-coated CCD readout

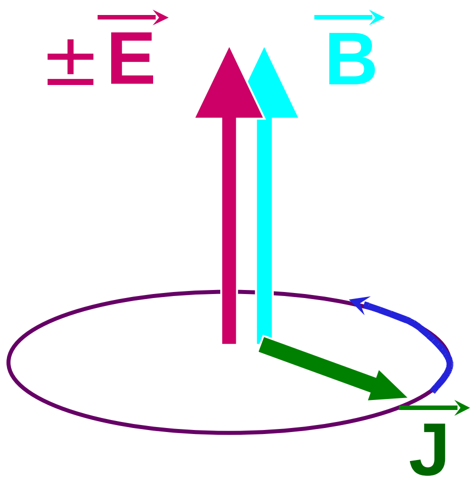
Plans for TRIUMF

- Experiment would be initiated and led by Japanese groups (S. Komamiya, et al).
- Because development work is already underway, this is a good candidate for a first experiment (along with n-lifetime).

Neutron Electric Dipole Moment (n-EDM)

- Existence of EDM implies violation of Time Reversal Invariance
- CPT Theorem then implies violation of CP conservation





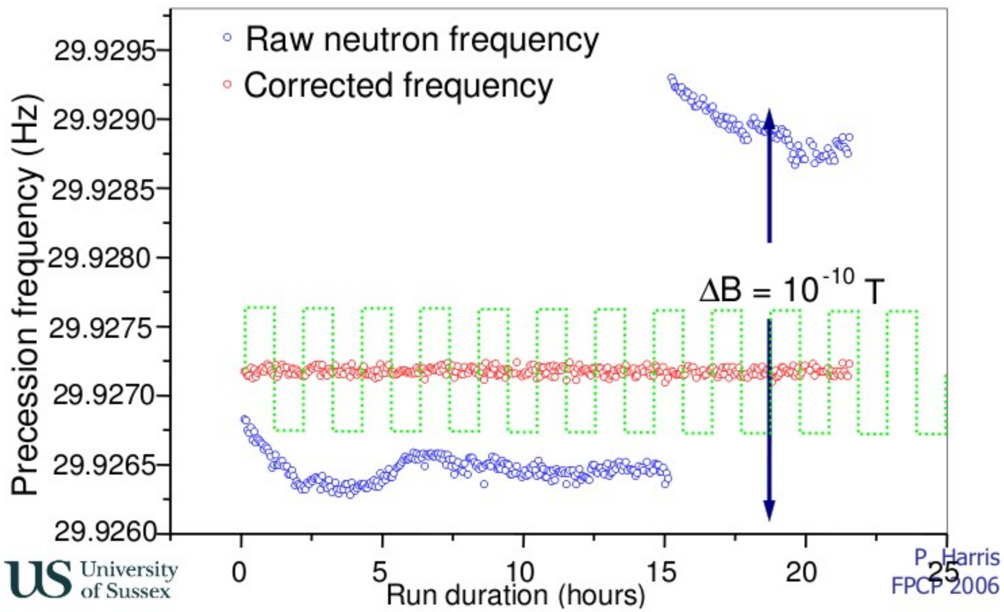
$$h\nu = 2\mu_n B \pm 2\mathrm{d}_e E$$

- Present Exp. Limit < $3\text{x}10^{-26}$ e-cm
- Standard Model value: 10^{-31} e-cm
- Supersymmetry or Multi-Higgs models can give 10^5xSM
- Significant discovery potential with new high sensitivity *n*-EDM experiment

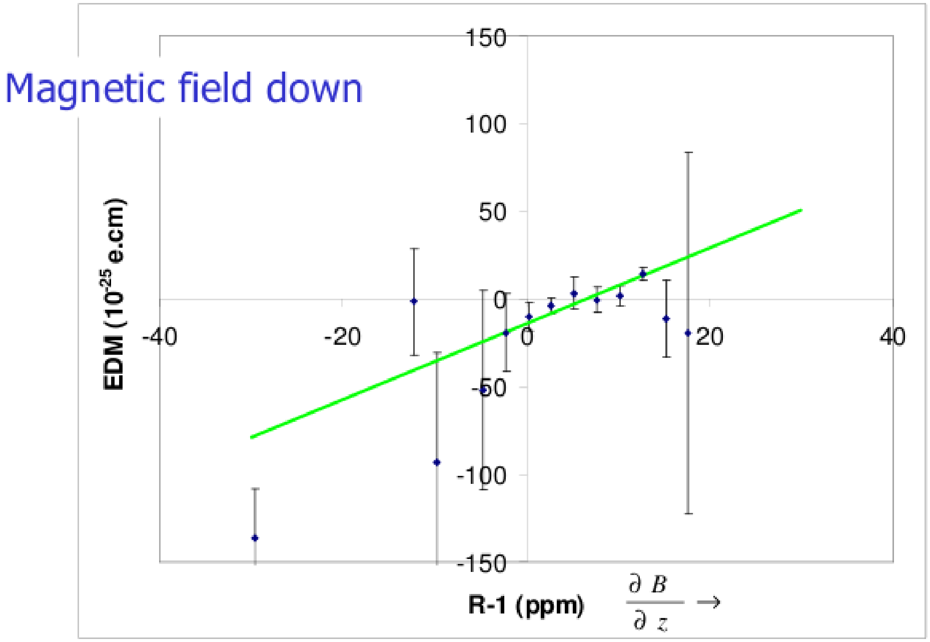
n-EDM Systematics

- magnetic field variations
- leakage currents
- geometric phase effect
  - false EDM arising from field inhomogeneity and E x v.

(co)magnetometry



comagnetometry



false EDM (GP) effect

Past and Future n-EDM efforts

- Oxford-ILL expt. ($d_n < 3\times10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (ILL, Sussex, RAL)
  - 1000 UCN/cc, in superfluid 4He
- SNS
  - 430 UCN/cc, in superfluid 4He
- PSI
  - 1000 UCN/cc, in vacuo
- TRIUMF: 5×10^4 UCN/cc

Plans for TRIUMF

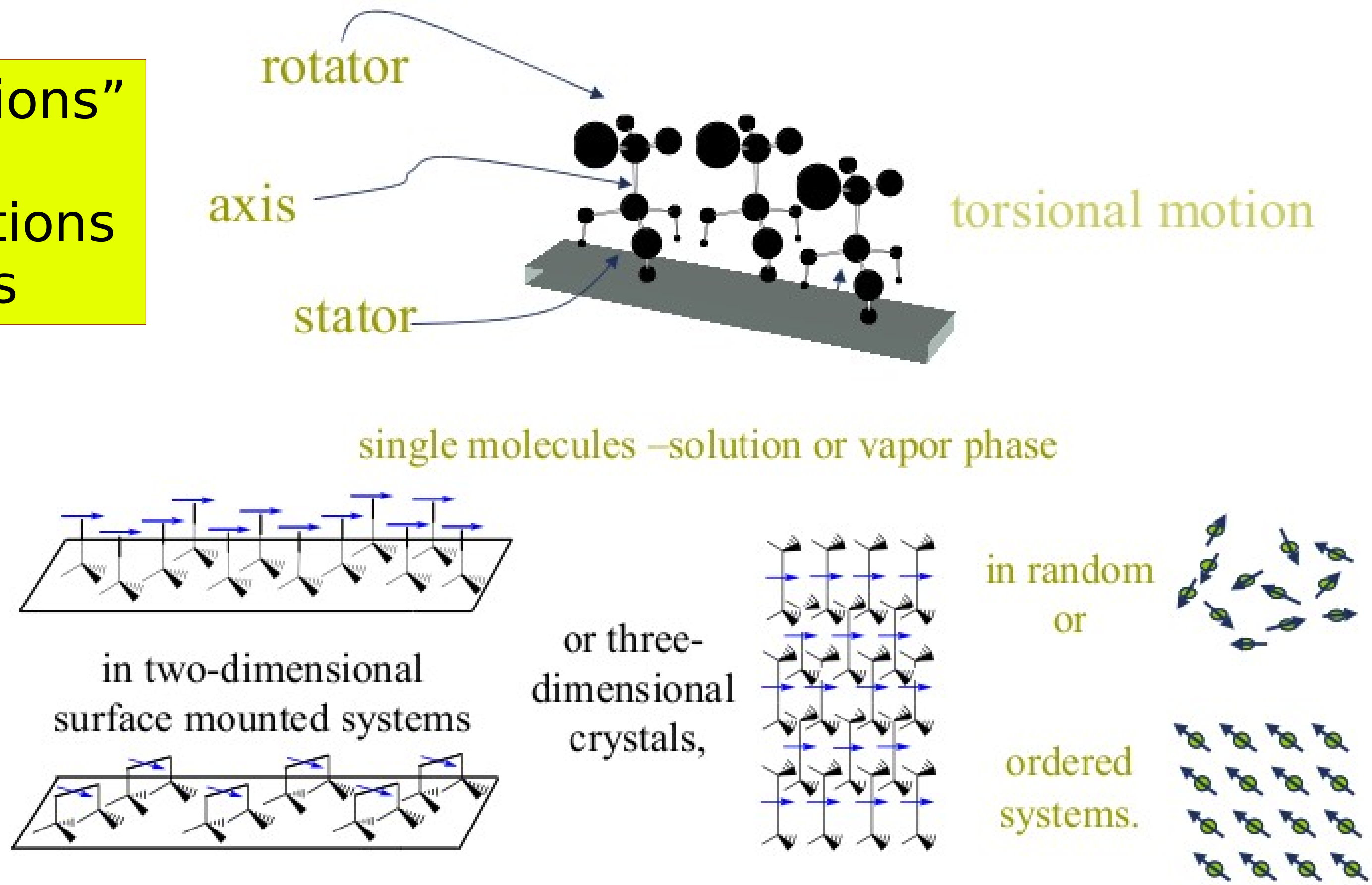
- Begin with modified ILL, SNS, or PSI setup
  - higher UCN density allows smaller cell size
    - smaller GP effect
  - development of magnetometers, Ramsey-resonance technique (Masuda)
- proposal ~ 2011
- expect number of EDM-experienced collaborators to grow if UCN source is approved:
  - B. Filippone, R. Golub, T. Ito, E. Korobkina, M. Hayden, B. Plaster

Surface Physics

- Use UCN to study 10 nm thin surface films
  - e.g. our application: "inelastic scattering reflectometry" (UCN ISR), sensitive to low-energy excitations, particularly of hydrogen-containing materials
  - compare two methods of inelastic scattering detection:
    - UCN loss measurements
    - detect upscattered neutrons
- High intensity UCN source is needed for this new field to be opened up.

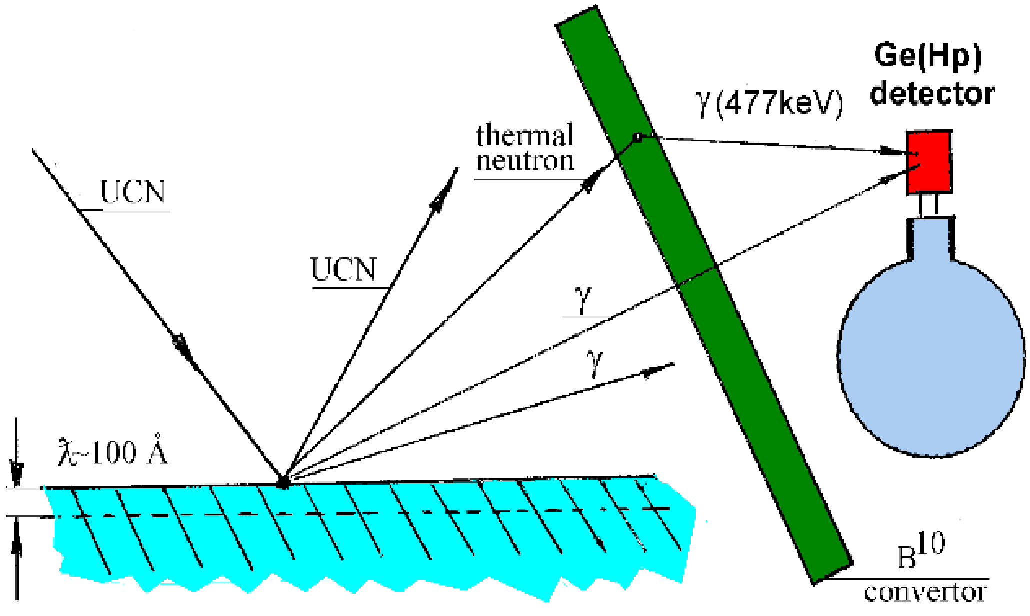
Application of UCN ISR: Artificial Molecular Rotors

"low-energy excitations"
=
rotations and vibrations of big molecules



- "Smart surfaces" research – surfaces that change their properties when subjected to external stimuli (drug delivery example)

Basic Apparatus



- Simultaneous measurement of UCN loss rate and converter gammas isolates UCN ISR from e.g. (n,gamma) losses.

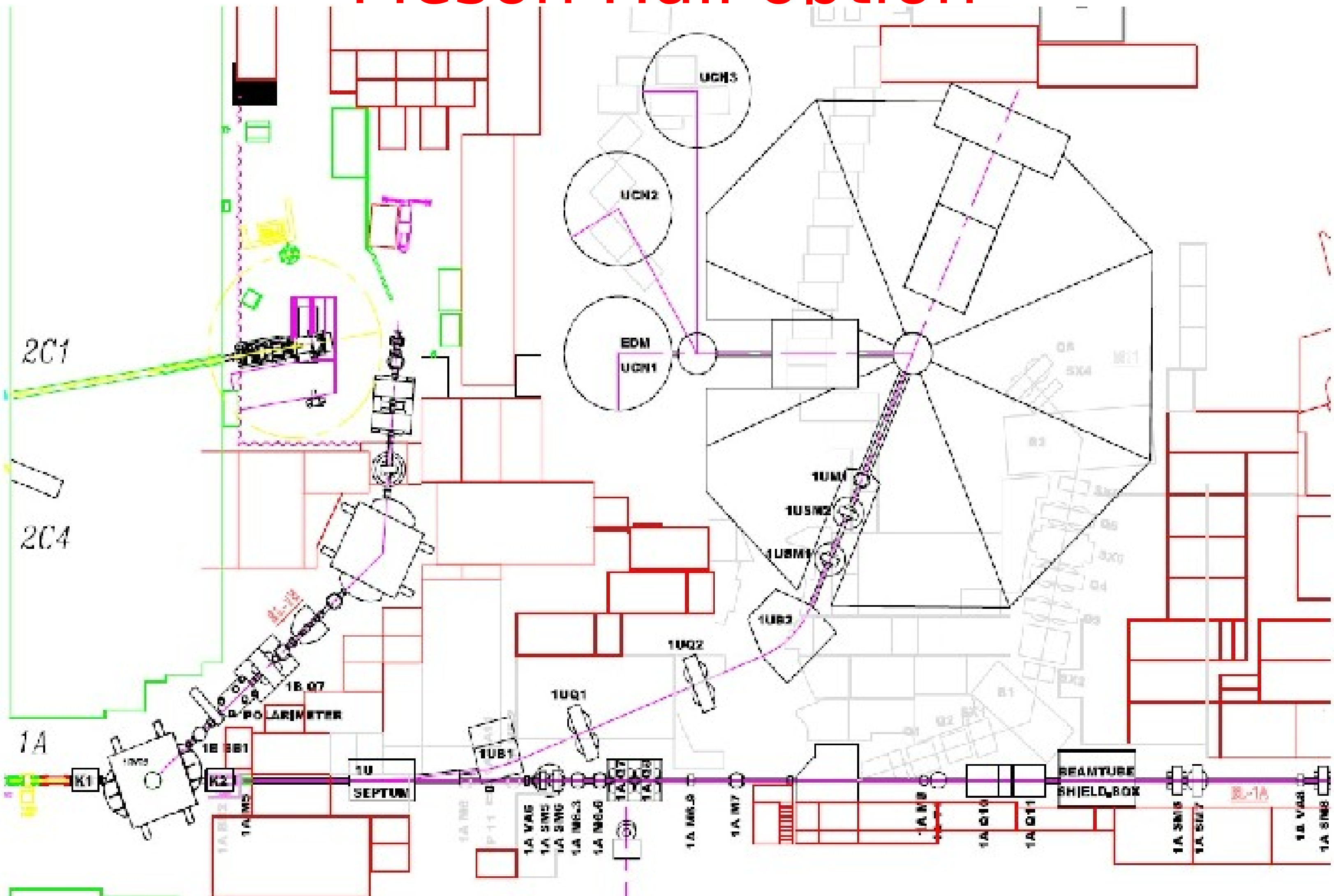
UCN ISR apparatus for TRIUMF

- Design of cryostat and first proof-of-principle experiments have been carried out. (Hahn-Meitner Inst., ILL)
- Need higher UCN flux.
- R. Golub, E. Korobkina, L. Clarke (NCSU)
- Potentially large user-base in “smart surfaces” community

UCN Overall timeline

- Before 2012 – develop UCN source in Japan
- 2012-3 – Install, commission at TRIUMF
- First experiments (n-lifetime, gravity, surface physics) 2012-2015
- longer term: EDM, 2014 and beyond

Implementation at TRIUMF
Meson Hall option



- Beamline design (J. Doornbos, G. Clark)
- Kicker feasibility, design (M. Barnes)
- Shielding estimates (A. Trudel)
- Layout (above) (S. Austen, C. Davis)

- Cost/Sched/Manpower (V. Verma, W.D. Ramsay, C. Davis)
- ...and many useful discussions with E. Blackmore, R. Baartman, ...

Preparations for CFI NIF request

- Request through The University of Winnipeg (top project selected by university committee – NOI in prep.)
- Overall cost ~$10M
- CFI NIF provides 40% of total cost.

Proposed cost breakdown (rough numbers)

CFI NIF	$4M
Japanese collaborators	$4M
TRIUMF	$2M

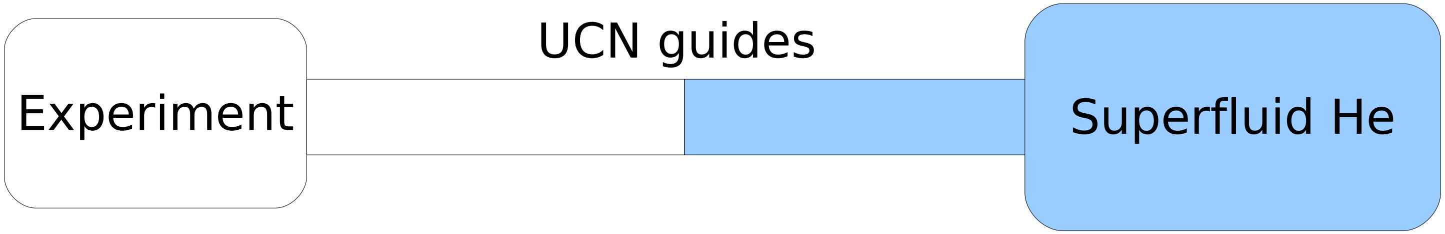
- Detailed cost+manpower breakdown, discussion provided in draft proposal.

Canadian university cosignatories: J. Martin (Winnipeg), M. Hayden (SFU), E. Korkmaz (UNBC), J. Birchall, M. Gericke, S. Page, W. van Oers (Manitoba)

Conclusion

- Canada has an opportunity to construct a world-leading UCN facility at TRIUMF.
- Proposal to CFI NIF in preparation through U. Winnipeg. Matching supplied by TRIUMF and Japan.
- Detailed cost/sched/manpower estimates, and more detailed design, underway.

Why UCN *density* is the most important factor



- UCN behave like an ideal gas
- As long as the experiment volume is much less than the total volume, UCN density is the most important factor.
- This is the case for every experiment we are pursuing for TRIUMF.

UCN Source Design and How We Would Achieve the World's Highest UCN Density

- Most other proposed sources use solid deuterium (ortho) at ~4K
  - ice quality
  - Fermi potential
  - para fraction, H-contamination
- We would use superfluid He-II (Masuda et al PRL)
  - lower specific production
  - NO loss mechanisms.

Budget and Manpower Summary from Proposal (Current Version)

equipment

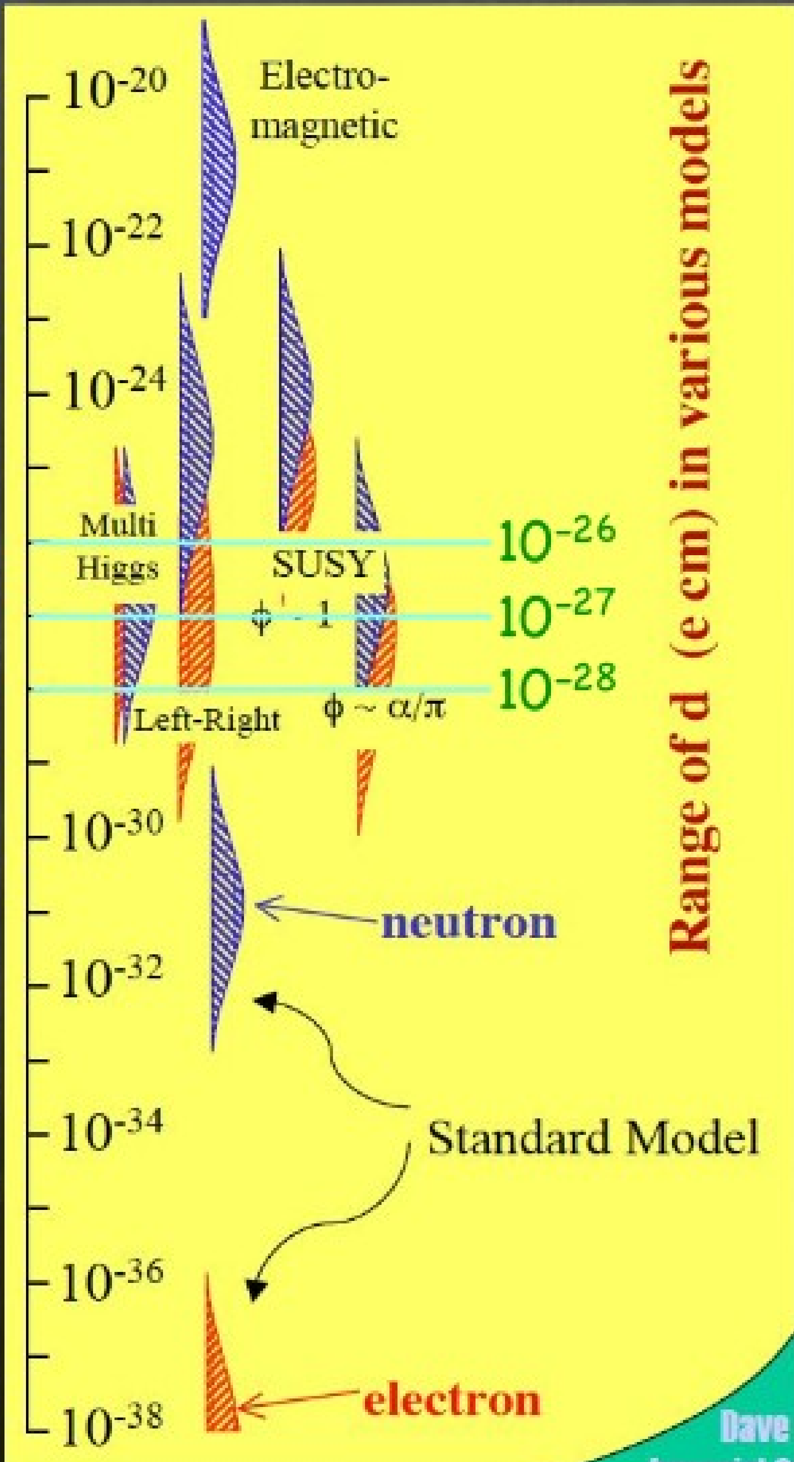
Item	Source	Cost
Proton beamline	Canada	$2330 k
Spallation target and remote handling	Canada	$130 k
Shielding	Canada	$1820 k
Install Japanese sections	Canada	$40 k
Grand Total Canada	Canada	$4320 k
UCN source	Japan	$2100 k
UCN moderators and system	Japan	$1000 k
neutron EDM equipment	Japan	$1900 k
Grand Total Japan	Japan	$5000 k
Total Equipment		$9320 k

person-years

Item	Phys	Engr	Desn	Mach	Cntrl	Tech	Total
Proton beamline	1.5	6.0	3.9	2.2	1.1	8.0	22.7
Spallation target	0.3	0.3	0.5	0.5		0.5	2.1
Shielding	0.9	0.7				0.5	2.1
Installing Japanese sections	1.6	1.6	1.0	0.5	0.5	1.4	6.6
Grand Total							33.5

EDM history

Theory



Experiment