TRIUMF
CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS
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An Ultracold Neutron Source for TRIUMF

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(University of Winnipeg, TRIUMF, North Carolina State University, Research Center for Nuclear Physics, Osaka University, Simon Fraser University, KEK, University of Manitoba, University of Tokyo)

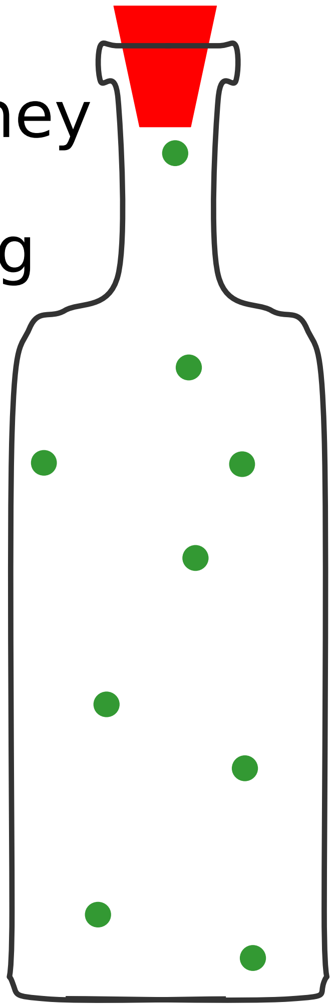
LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

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

Outline

1. Introduction to Ultracold Neutrons (UCN)
2. UCN physics experiments
3. Source work at RCNP for TRIUMF
4. Plans for TRIUMF experiments

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: $V=-\mu \bullet B$ (100% polarization)
  - strong interaction
- Experiments at UCN sources are chronically limited by UCN density. TRIUMF has the potential to be a world leader in this regard.

UCN Source at TRIUMF would be a world-class facility

	Source type	E_c and τ_s	UCN density $\rho_{UCN}(UCN/cm^3)$
TRIUMF 5 kW_{av} proton	0.8K He-II	E_c = 210 neV τ_s = 150 s	1.8×10^4 at experimental port
Grenoble 60MW reactor	0.5K He-II	E_c = 250 neV τ_s = 150 s	1000 in He-II
SNS cold neutron beam	0.3K He-II	E_c = 134 neV τ_s = 500 s	430 in He-II
Munich 20MW reactor	SD_2	E_c = 250 neV	10^4 in source
North Carolina 1 MW reactor	SD_2	E_c = 335 neV	1300 in source
PSI 12 kW_{av} proton	SD_2	E_c = 250 neV τ_s = 888 s	2000 in source
Los Alamos 2.4 kW_{av} proton	SD_2	E_c = 250 neV τ_s = 2.6 s	120 in source

The Most Successful UCN Physics Experiments to Date

- n-EDM
- n-Lifetime
- Quantization of neutron energy levels in Earth's gravitation field

all were done at ILL, Grenoble, France

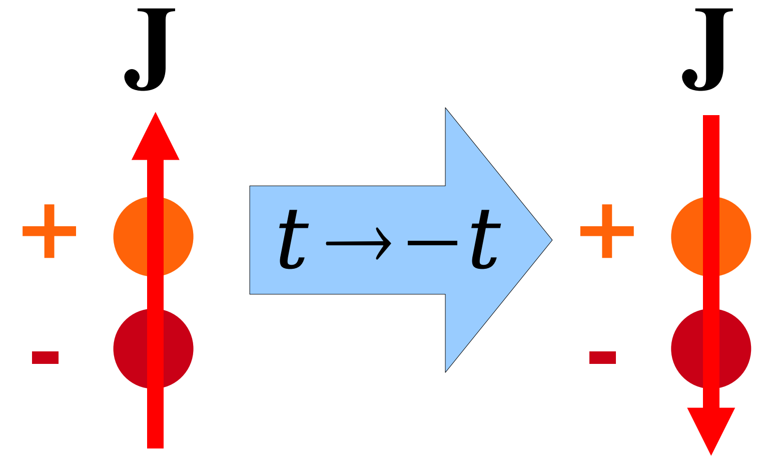
all were limited by the density of UCN that could be achieved

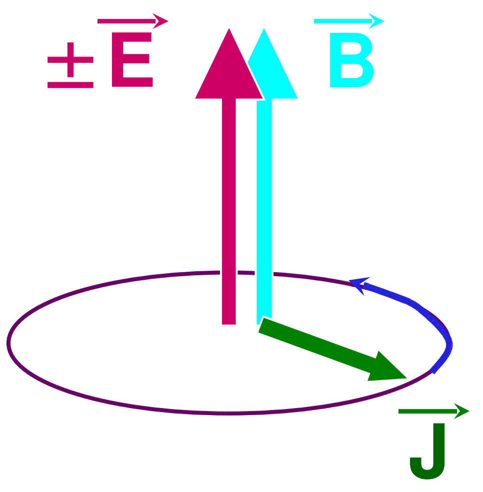
Future UCN Experiments

- n-EDM
  - in vacuo (PSI)
  - in 4He/3He (SNS)
  - CryoEDM (ILL)
  - KEK/JPARC
- n-Lifetime
  - gravito-magnetic bottle (LANL)
  - magnetic bottle in 4He (SNS)
  - multiple ILL proposals
- Gravity Levels
  - ILL
- β-Decay Correlations (A)
  - UCNA (LANL)
- r-process, free neutron target
- $n\bar{n}$ oscillations
- mirror neutrons
- surface physics
- physics of UCN production
  - e.g. O2

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 < 0.63×10^{-25} e-cm
- Standard Model value: 10^{-31} e-cm
- Supersymmetry or Multi-Higgs models can give 10^{5}xSM
- Significant discovery potential with new high sensitivity *n*-EDM experiment

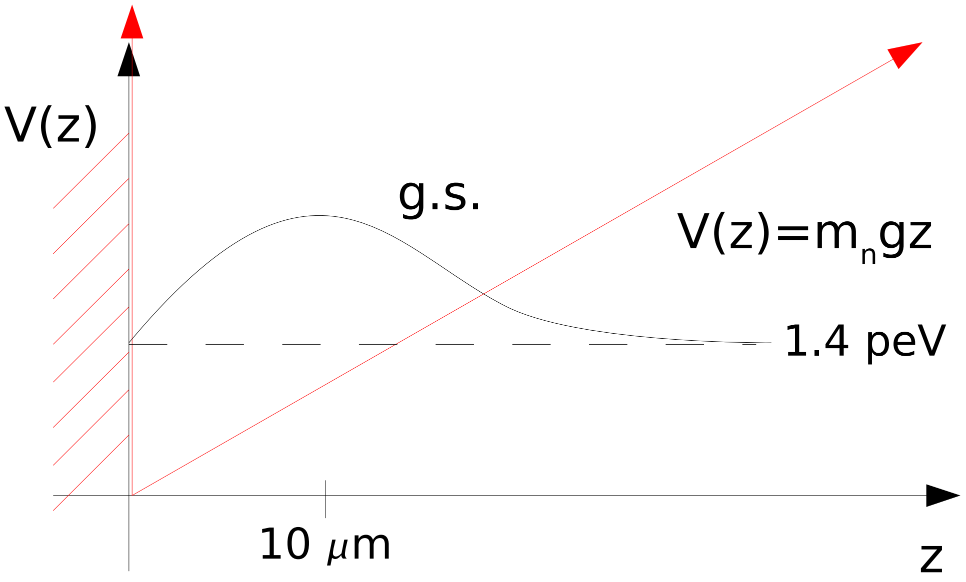
n-EDM Projects

- SNS n-EDM: 430 UCN/cc
- ILL CryoEDM: 1000 UCN/cc
- TRIUMF: 18000 UCN/cc

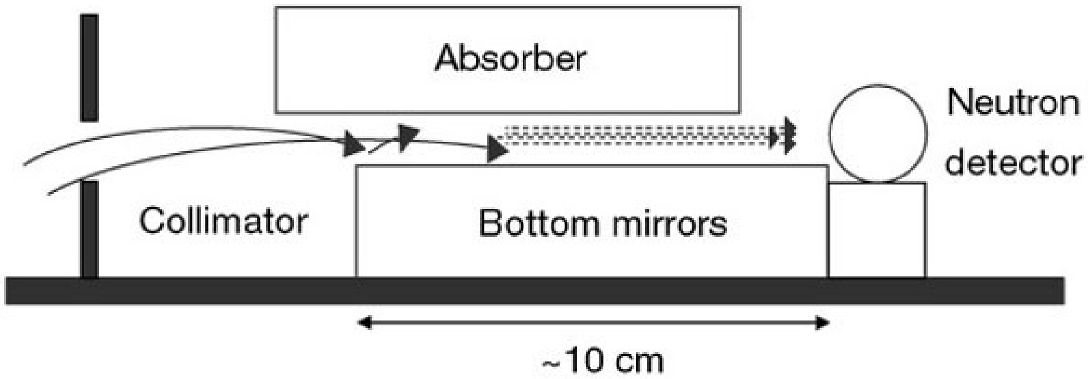
all numbers are “proposed”

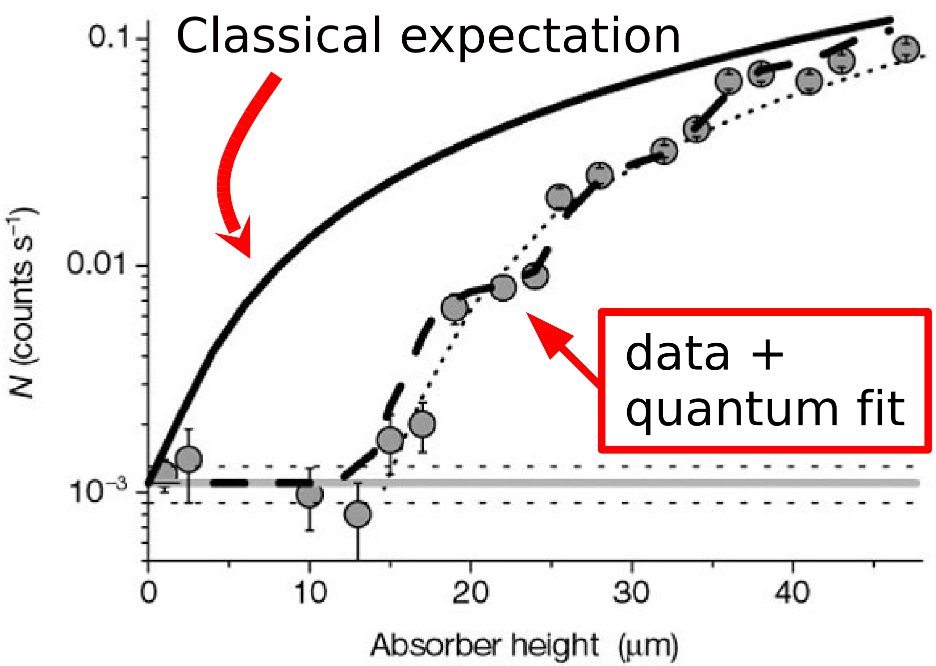
- TRIUMF experiment would be *in vacuo* using similar (room temperature) techniques of previous generation of n-EDM.
- Complementary to SNS/ILL, which are conducted *in superfluid helium*.
- The TRIUMF approach is possible because of the increased UCN density, which can give smaller measurement volume, hence less sensitivity to systematic effects.

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:

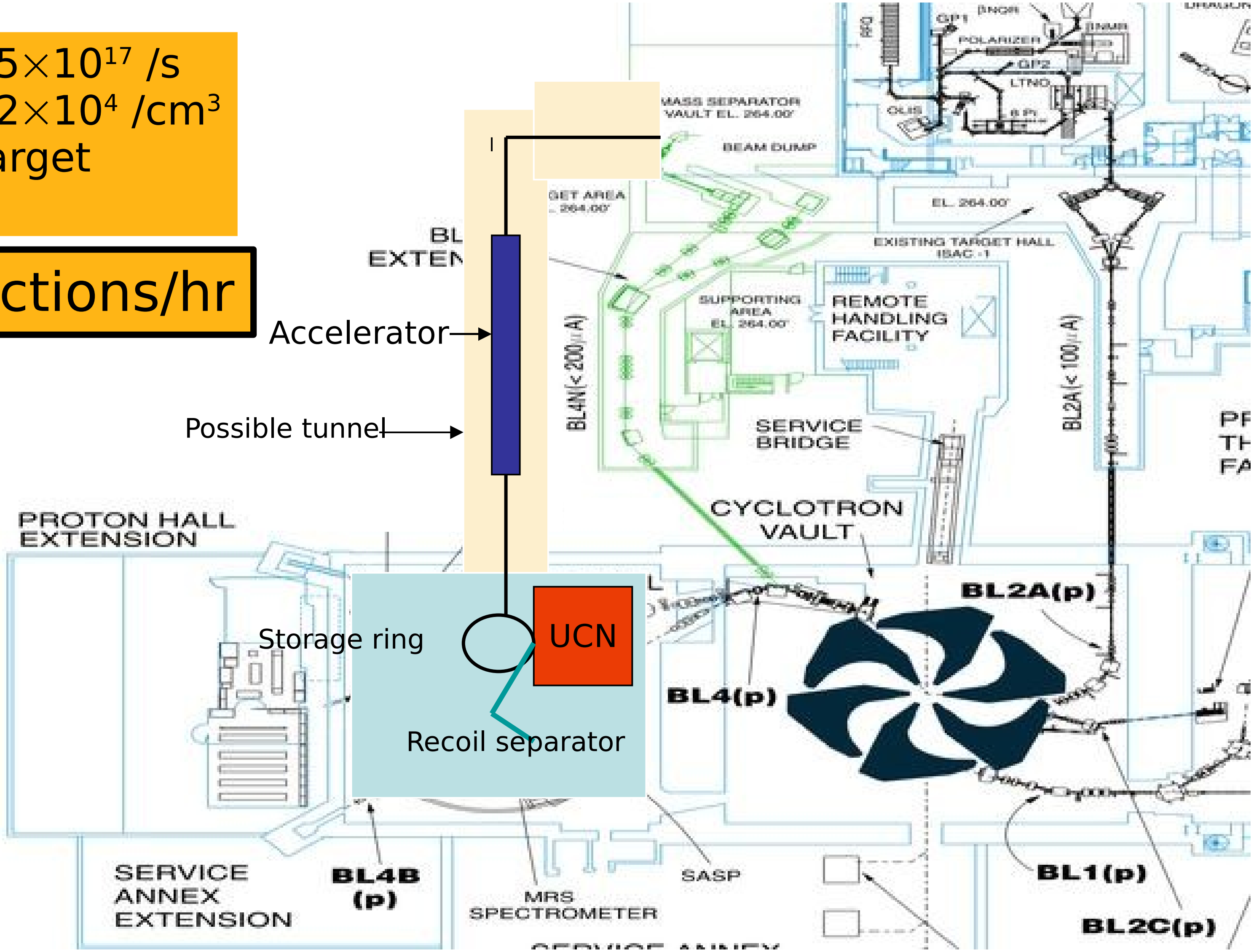
- Bottle the UCN to increase time the UCN is contact with the mirror.
- Excite resonant transitions between quantum states.
- Increase purity of states by preselection.
- Goal: improve precision on energy of state and hence increase sensitivity to modifications to gravity.

Measuring (n,ɣ) cross sections of the r-process

radioactive species stored in ring interact with free neutron (UCN) target.

- ^{132}Sn current 5×10^{17} /s
- UCN density 2×10^{4} /cm^3
- metre-long target
  $\sigma \sim 100$ mb

⇒ 50 interactions/hr

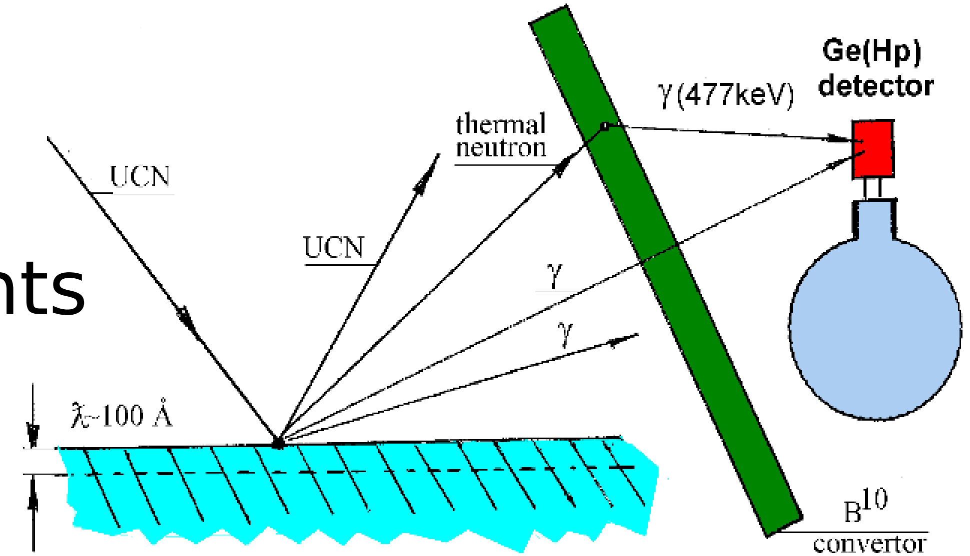


L. Buchmann (TRIUMF)

New field of physics unique to TRIUMF

Surface Physics

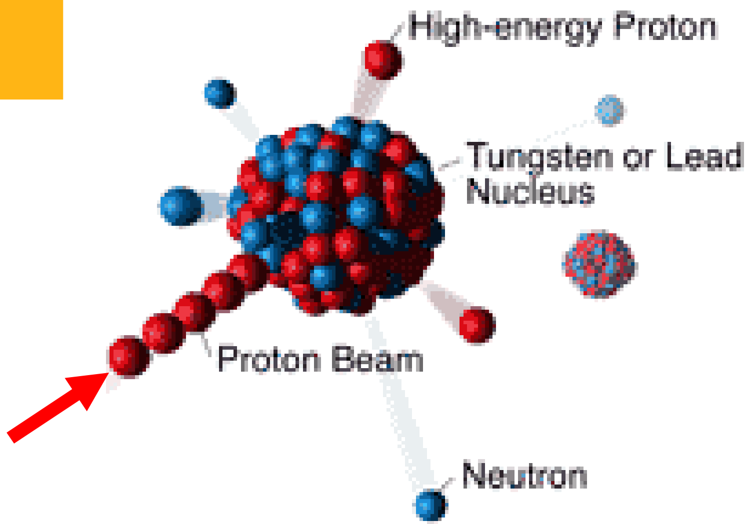
- Many ideas to use UCN to study 10 nm thin surface films
  - (n,gamma)
  - UCN loss measurements
  - n scattering
  - reflectometry
    - polarization for magnetic films
- shown to be sensitive to low-frequency excitations (interesting for surface physics)
- In all cases, lack of UCN worldwide is the problem

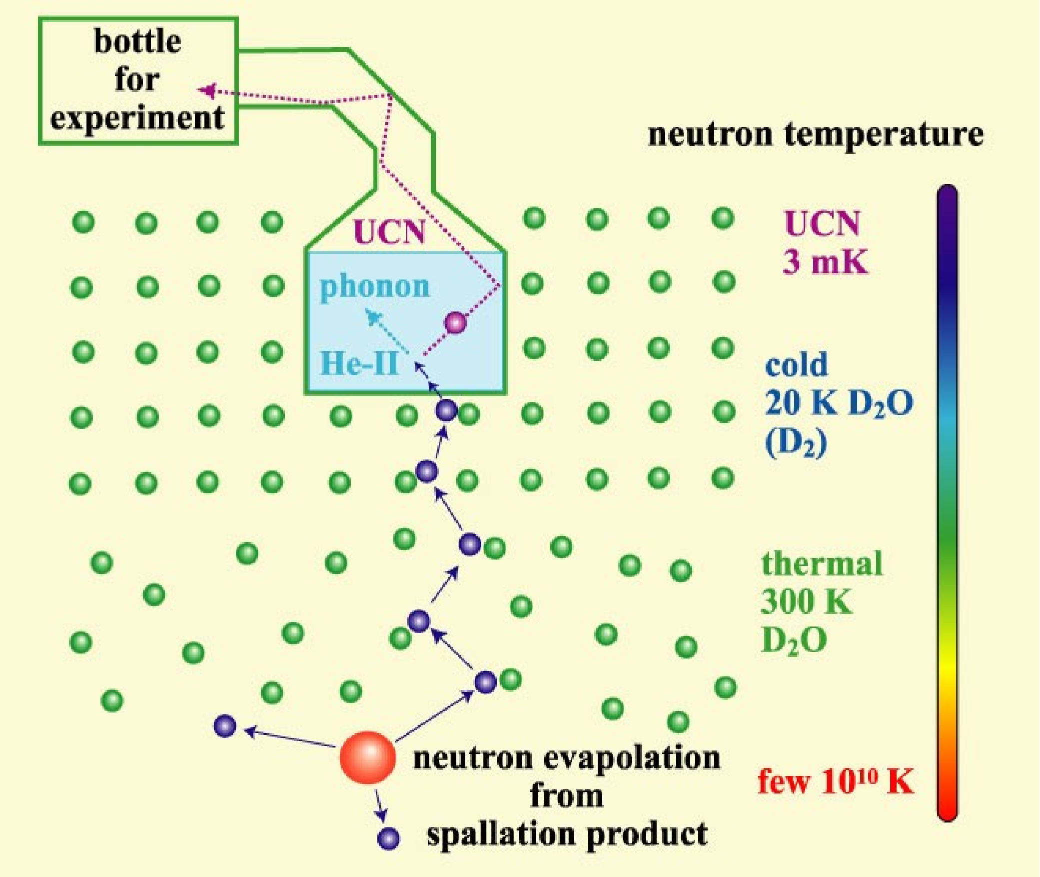


E. Korobkina, NCSU

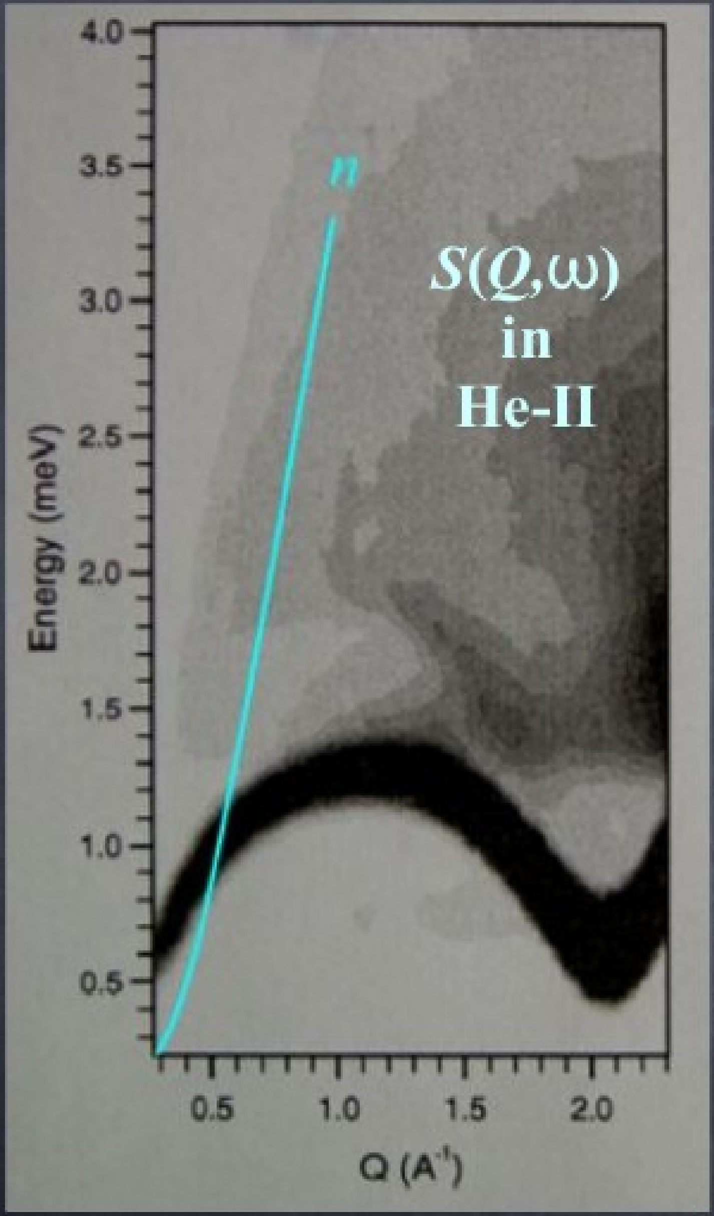
How to make UCN

- 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.





Superthermal UCN production in He-II

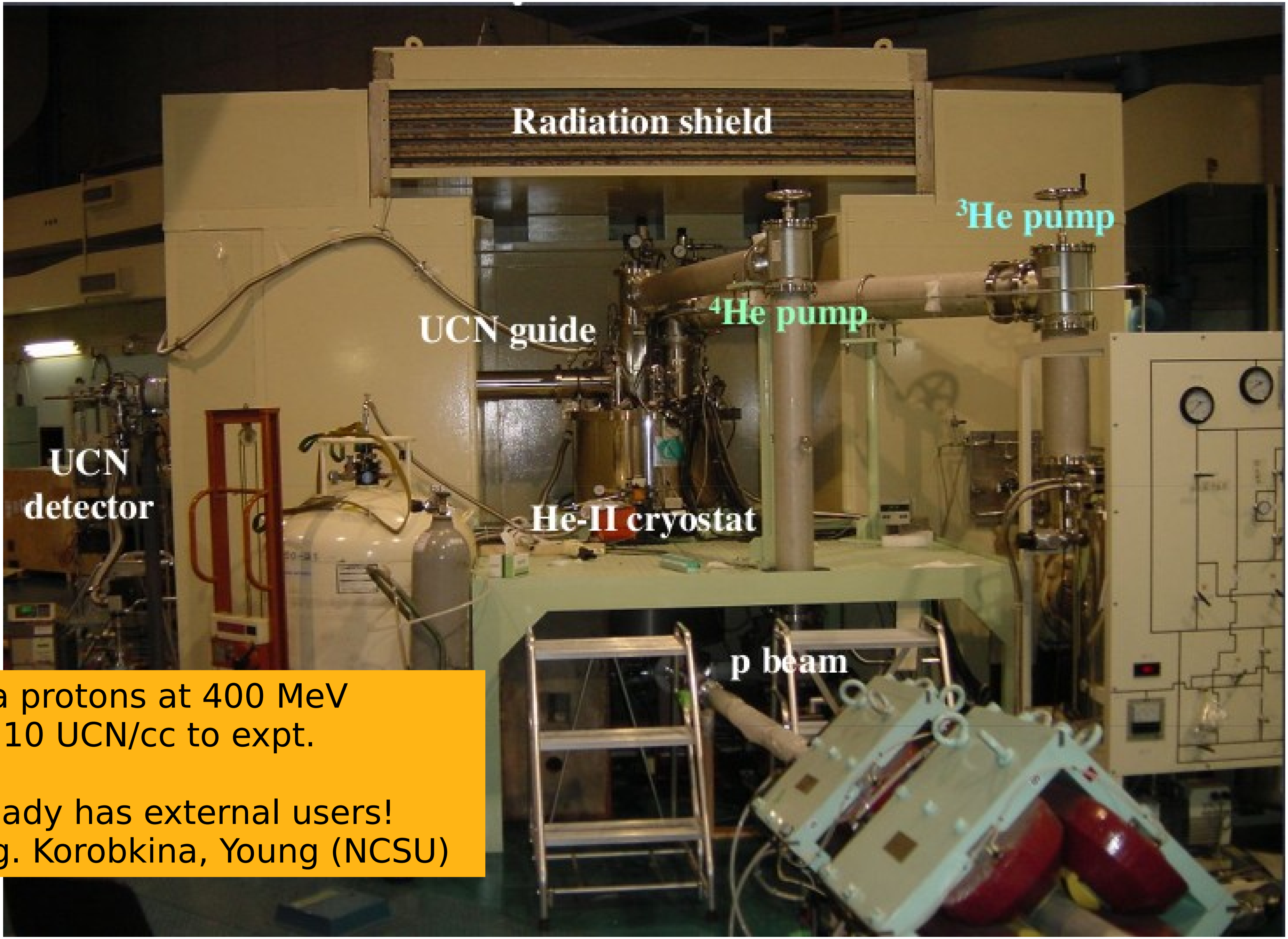


M.R. Gibbs et al. (1999)

Coherent inelastic neutron scattering in He-II

<u>Unique to TRIUMF!</u>
Most other proposed sources use solid deuterium instead of superfluid helium

RCNP UCN Source (Masuda, et al)



1 ua protons at 400 MeV
=> 10 UCN/cc to expt.

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

Gain Factors for TRIUMF

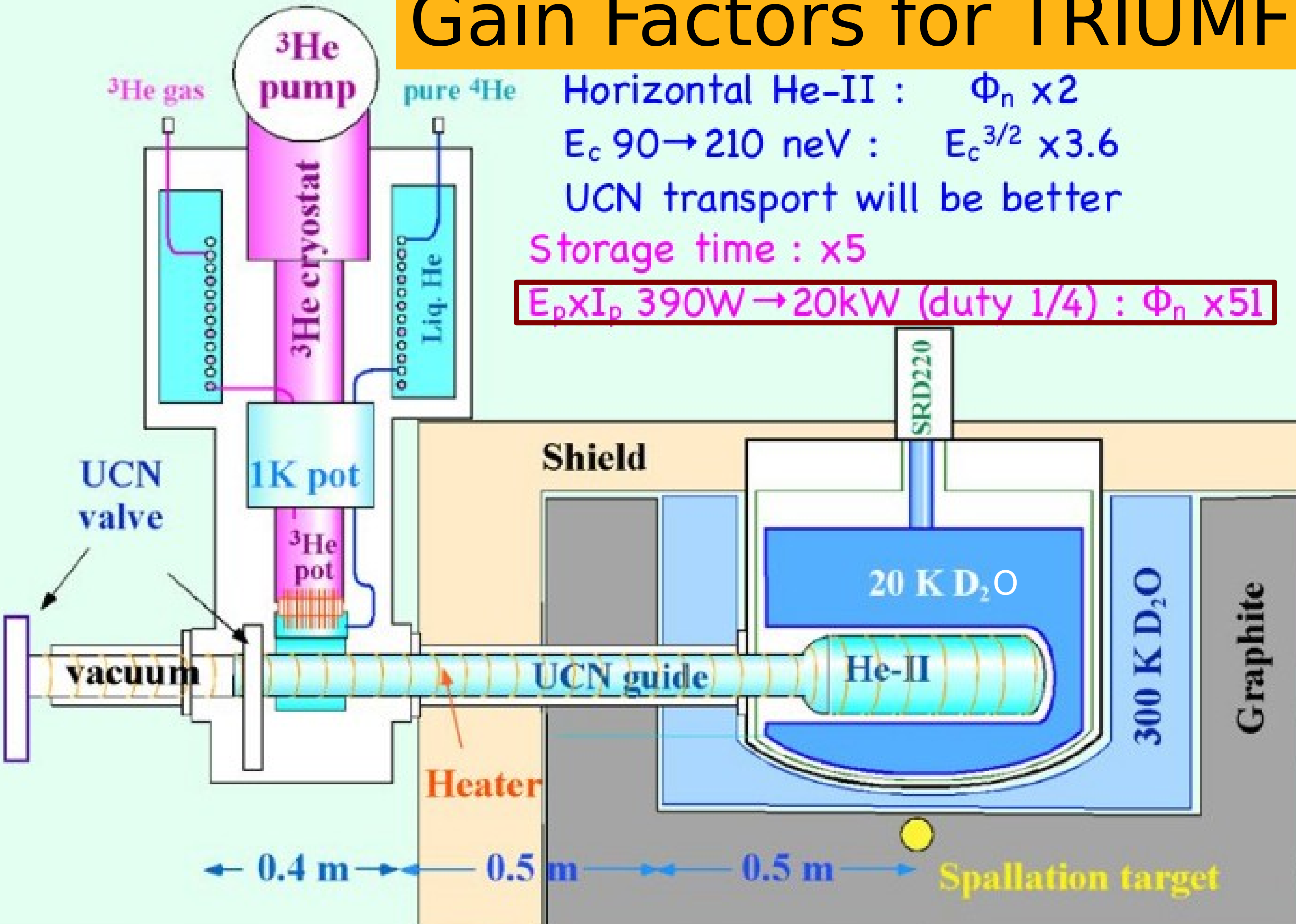
Horizontal He-II : Φ_n x2

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



Recent Progress on UCN at TRIUMF

- Aug. 2007 TUG working group (Canadians + Masuda), draft white paper.
- Sept. 2007 International UCN Workshop (+ world experts).
- Sept. 2007 Presentation to TRIUMF Board of Management
- Phone meetings relating to conceptual design
- Nov. 2007 ACOT
- More design discussions, now looking at Meson Hall.
- Dec. 2007 AGM + new whitepaper for 5yp

International Workshop: UCN Sources and Experiments

September 13-14, 2007
TRIUMF, Vancouver, Canada
http://www.triumf.info/hosted/UCN

~25 speakers from all over the world
ILL, FRM-II, NCSU, LANL, PSI, KEK, Mainz, ...

Supported by TRIUMF and TUNL

Speakers at TRIUMF UCN Workshop Sept. 13-14, 2007

H. Abele, Heidelberg

S. Baessler, Mainz/UVa

L. Buchmann, TRIUMF

M. Daum, PSI

S. Gardner, U. Kentucky

P. Geltenbort, ILL

E. Gutsmiedl, Munich FRM-II

R. Golub, NCSU

B. Filippone, Caltech

P. Huffman, NCSU

T. Ito, LANL

E. Korobkina, NCSU

C.-Y. Liu, Indiana U.

M. Makela, LANL

J.W. Martin, U. Winnipeg

Y. Masuda, KEK

P. Mumm, NIST

J. Nico, NIST

J. Ng, TRIUMF

M. Pospelov, U. Victoria / Perimeter Inst.

J.-M. Poutissou, TRIUMF

W.M. Snow, Indiana U.

F. Wietfeldt, Tulane U.

A. Young, NCSU

G. Hampel, Mainz

K. Hickerson, Caltech

talks available from
http://www.triumf.info/hosted/UCN

Results of TRIUMF UCN Workshop

- Very strong statement from the international UCN community (particularly R. Golub) that a spallation He-II source should be pursued. Masuda clearly regarded as a leader in this field.
- TRIUMF would be an ideal venue for such a source.
- Many interesting physics experiments would be possible with the higher UCN densities achievable at this source.

TRIUMF UCN Schedule

- Prior to 2011, pursue development of new UCN cryostat for TRIUMF at RCNP, Osaka.
  - This would allow us to demonstrate all the gain factors from horizontal extraction, better UCN guides, etc. (aside from beam power)
- After 2011, begin construction of UCN source at TRIUMF (2011 = “after completion of Pi-e-nu experiment”).
- 2011-12 first beam and begin physics

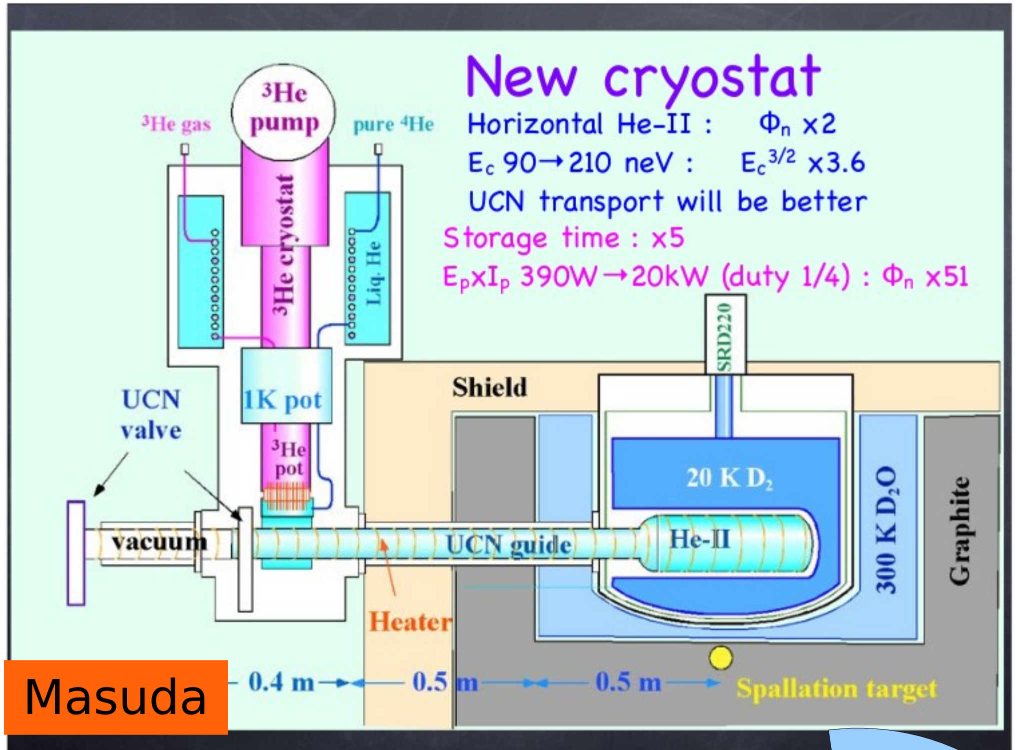
UCN Physics Plan

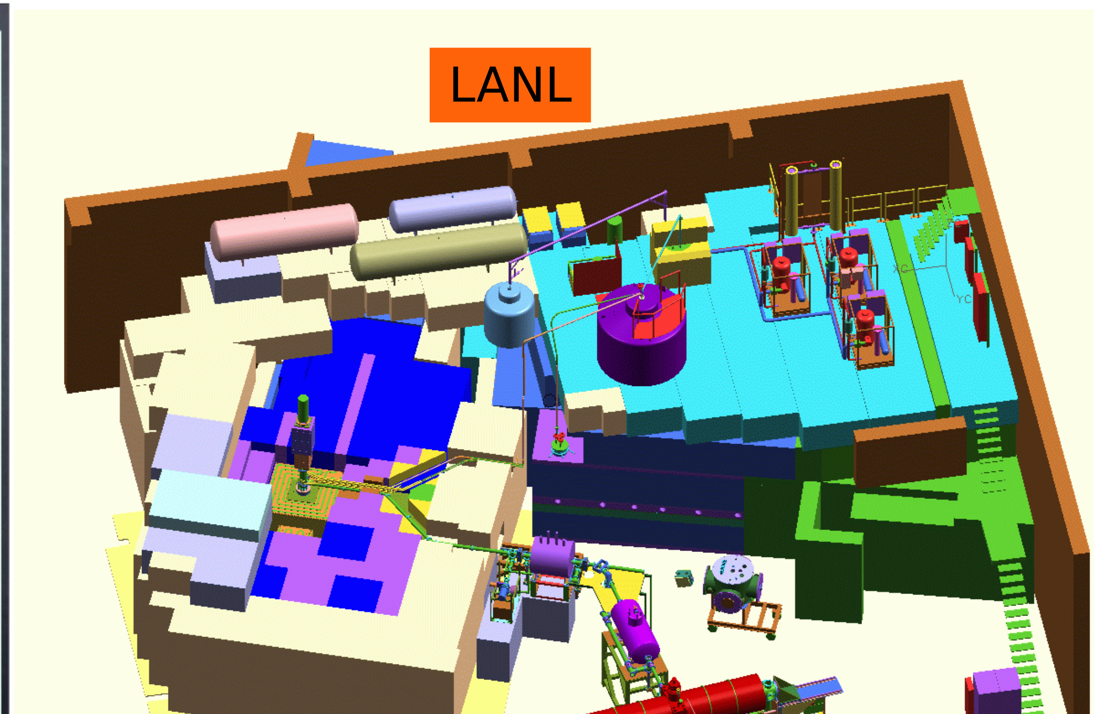
- Conduct one initial high-profile, world's best, fundamental physics experiment (top candidates: gravity, n-lifetime)
  (proposal to NSERC 2009-10)
- Simultaneous development of surface physics apparatus (2010)
- Developments towards future n-EDM experiment (many new collaborators!)
- Other large-scale experiments (e.g. R-process, nnbar) (2015-)

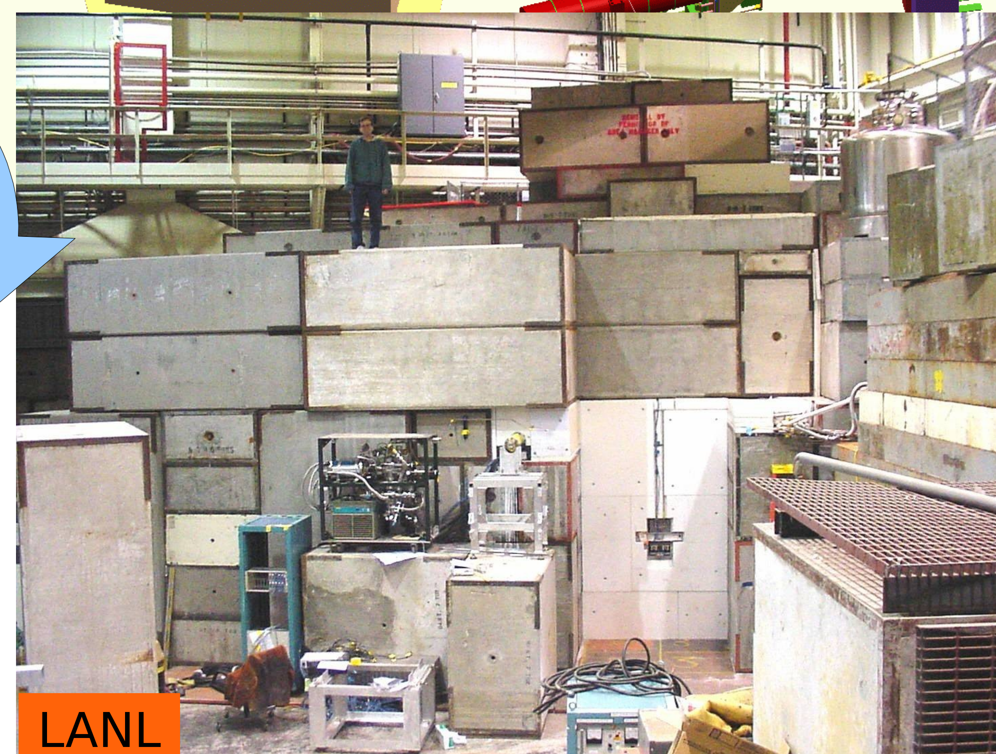
Making UCN a Reality at TIRUMF

- Location – new idea: Meson Hall?
- Beam sharing.
- Space (12m x 12m source + 12m x 6m expts)
- For precision physics experiments, it is highly advantageous to pulse the UCN source. E.g. RCNP uses 1 min beam on, 3 mins beam off. During beam off, UCN can be counted (or their decays, etc.)
  - achieve pulsing by delivering beam to well-shielded dump, periodically diverting to UCN using kicker.

Conceptual to technical design for the UCN source and experiment



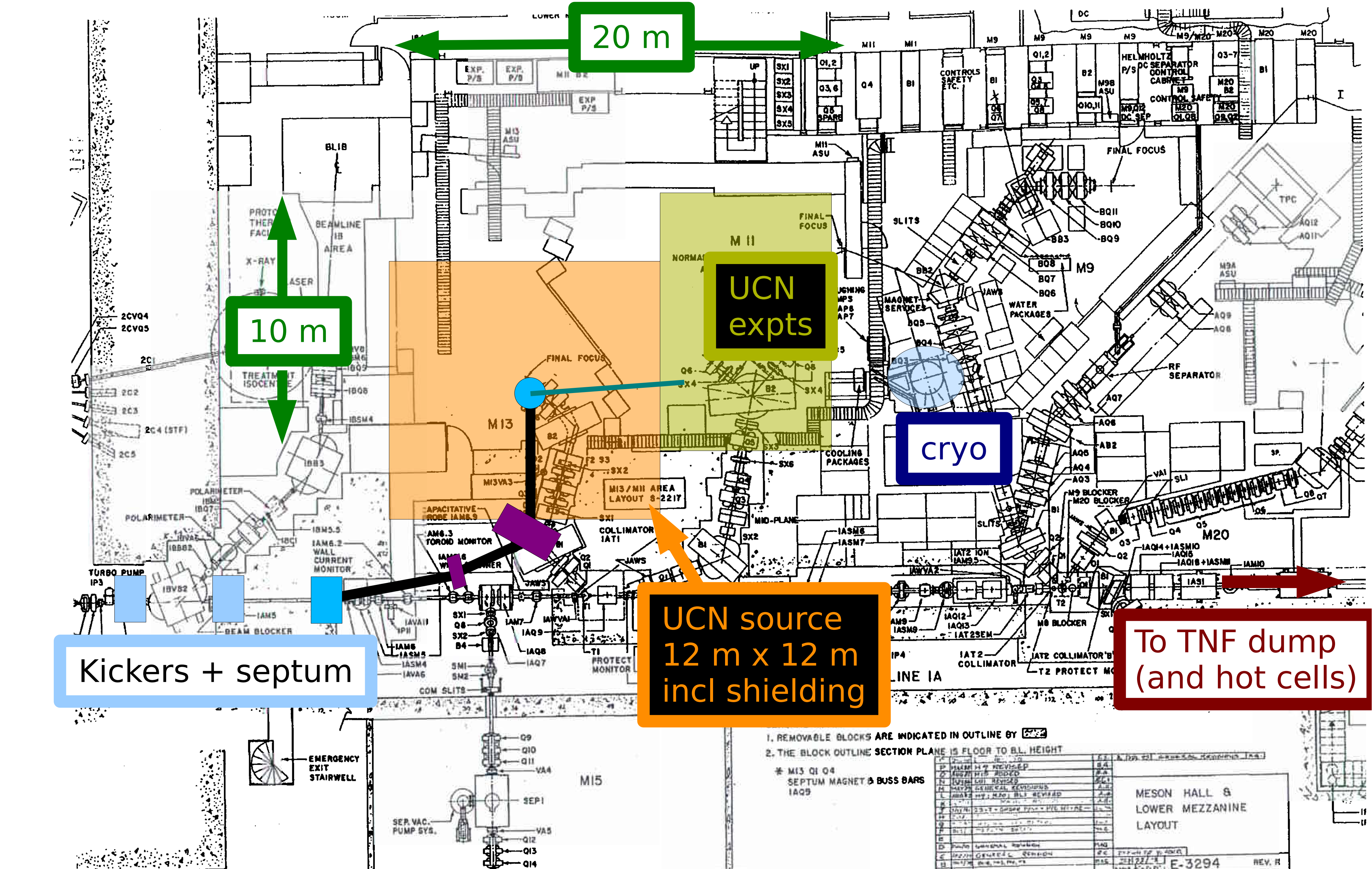




Other Issues:

- radiation, remote handling
- cryogenics
- neutronics
- division of labor
  - Masuda, Golub very interested in cryogenics and neutronics
  - Acsion (private company in Pinawa, MB) interested in neutronics (MCNP)
  - need TRIUMF support to bring to fruition

New Concept for Meson Hall
– Use M13/M11 area, and TNF dump



Funding + Collaboration

- Y. Masuda (Japan) request 2.4 M$ CAD for UCN source + EDM development (submitted Nov. 2007). The proposal explicitly outlines a plan to construct the source in Japan, and move it to TRIUMF.
- Intention to submit a CFI proposal from the Canadian groups in 2008-9 for the remaining infrastructure.
- Primary needs from TRIUMF at this time
  - ideas
  - engineering support

  ... to make the CFI proposal a success.
- New collaborators: R. Golub, M. Hayden, RCNP, Osaka, Tokyo groups. (EDM experts and interests)

Ultracold Summary

- An opportunity exists to create the world's highest density UCN source at TRIUMF.
- A flagship physics experiment done this facility would be the world's best.
- UCN program is tied to the ISAC program in terms of both physics and facility.
- We are pursuing this unique and timely opportunity.

Back-ups

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

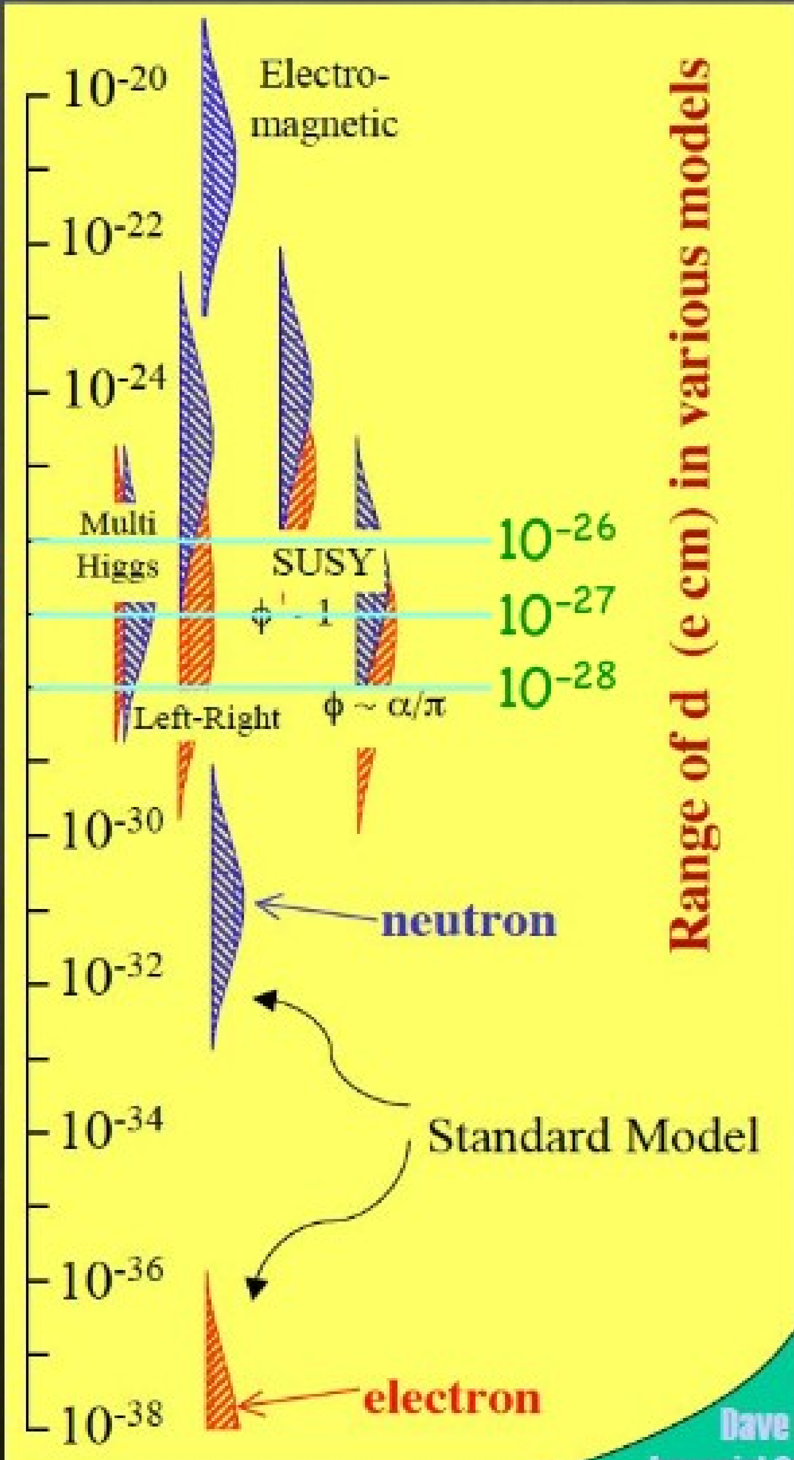
- Most other proposed sources use solid deuterium (ortho) at ~4K
  - ice quality
  - Fermi potential
  - para fraction, H-contamination
- We would use superfluid He-II (Masuda et al PRL)
  - lower specific production
  - NO loss mechanisms.

Cryogenics/Shielding Numbers from Masuda

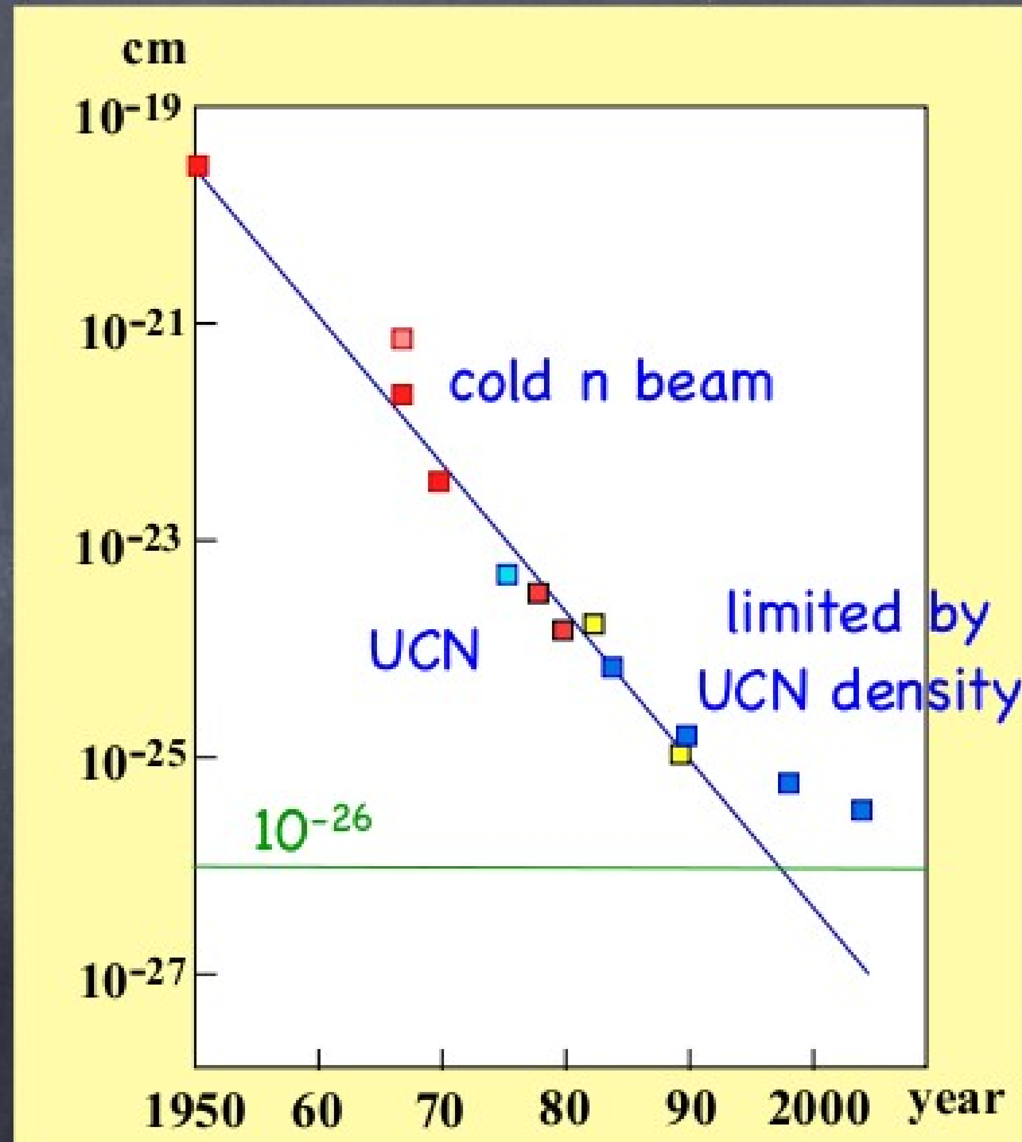
- According to MC + estimates, for time-avg p-beam power of 12 kW in W target:
  - 0.45e12 n/cm2/s in He-II
  - 2.3 W in He-II
  - 30-60 W in 20 K D2O
  - 1.7 kW in 300 K D2O
- Masuda's current 3He pump can take 8 W.
- Clever arrangement of 208Pb can reduce gamma-heating of He-II even lower.
- Radiation #'s consistent/lower cf. LANL.

EDM history

Theory

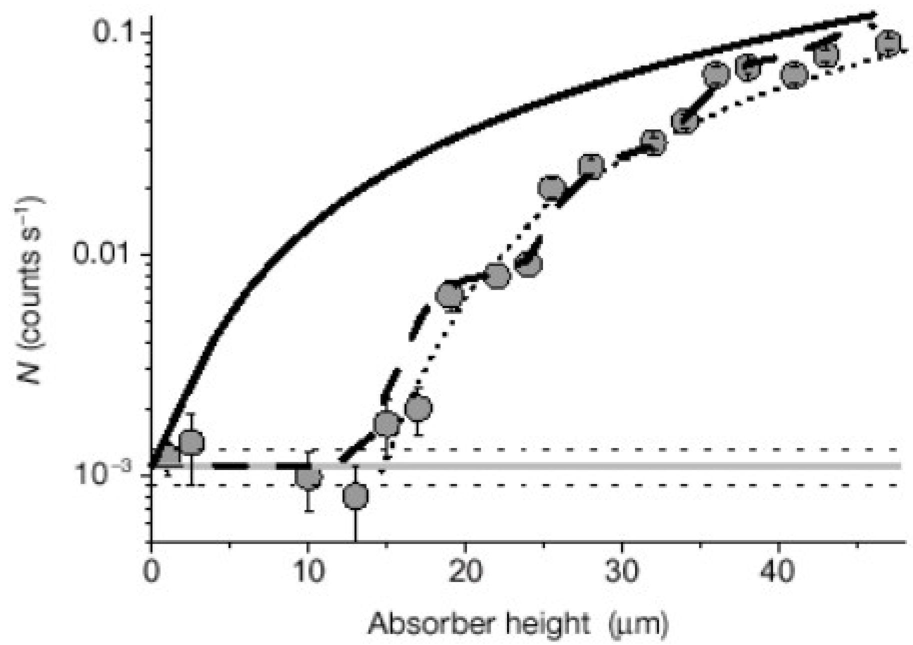


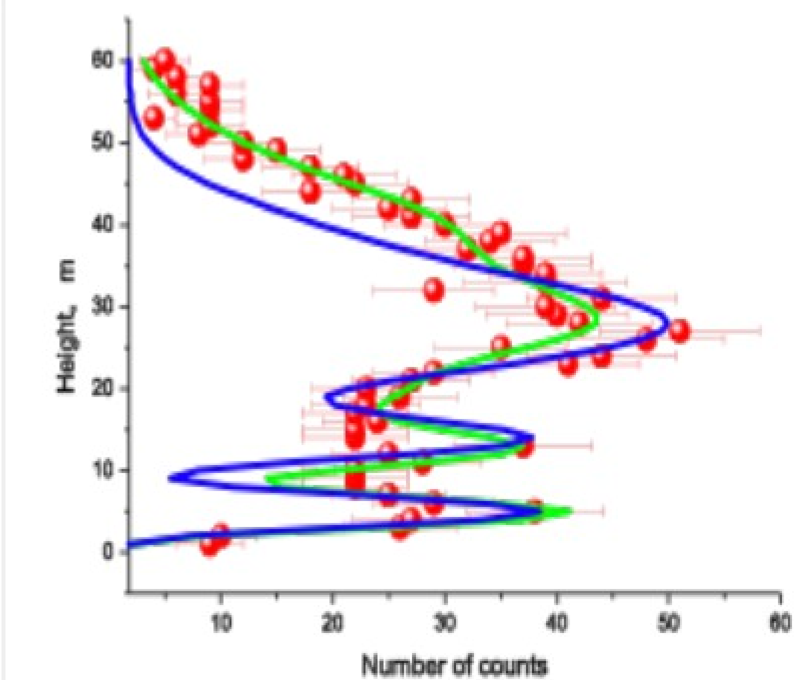
Experiment

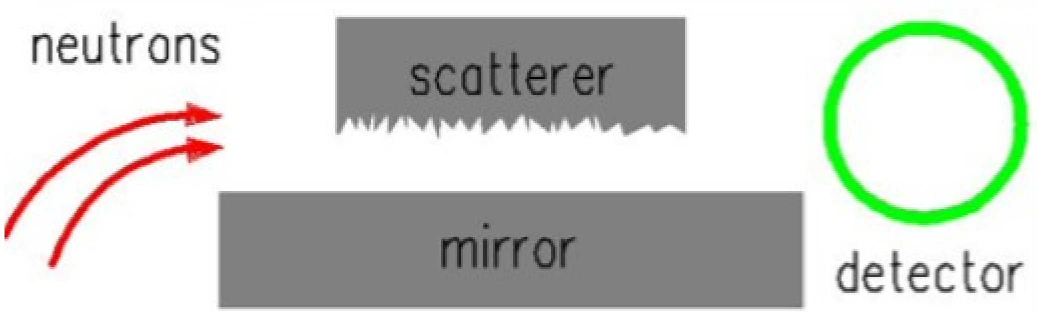


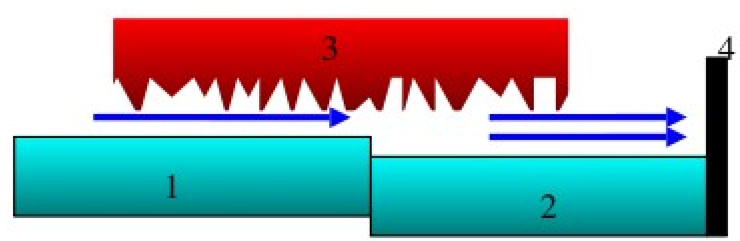
UCN quantum states in gravity

- test of gravity at 10 um scale









Agenda
from townhall meeting (Aug. 07)

Aug. 1

morning - plenary session, charge, and introduction of working groups

12:00 lunch

13:00 Welcome + Charge (Martin) (10+5)
13:15 UCN Sources Worldwide and for TRIUMF (Masuda) (45+10)
14:10 Photofission, (gamma,n) Sources and UCN (Behr) (10+10)
14:30 coffee (30)
15:00 SCRF joint session: Electron Linac Design (Koscielniak) (20+10)
15:30 UCN Infrastructure and Proton Hall Floorplan (Davis) (10+10)
15:50 Proton Hall Radiation Limits (Trudel) (10)
16:00 Discussion (Chair: Davis) (30)
16:30 tour of proton hall? (if desired) (Davis) (30)

Aug. 2

09:00 Continued infrastructure Discussion (60)
10:00 UCN Physics Intro (Martin) (10+5)
10:15 UCN Beta Decay (Melconian) (20+10)
10:45 coffee (30)
11:15 n-EDM (Masuda and/or Hayden?) (20+10)
11:45 radioactive beams (Buchmann) (10+10)

12:05 lunch

13:15 gravity levels (Konaka) (5+10)
13:30 other physics (Martin) (15+10)
13:55 discussion of physics priorities and strategy (chair: Martin) (35)
14:30 begin writing
- more joint sessions
- draft Aug. 3 morning presentation

Aug. 3

morning - presentations of results from the working groups.