TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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TRIUMF Ultracold Neutron Source

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(Winnipeg, ORNL, TRIUMF, NCSU, Caltech, Manitoba, 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

UCN presentations

- J. Martin – Overview and Physics
- Y. Masuda – UCN source technology
- W.D. Ramsay – TRIUMF Facility

Outline

1. Introduction, Project Overview
2. UCN physics experiments and TRIUMF
3. Timelines, Cost

The last point will be covered again in Des Ramsay's talk.

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

  near term
  - n-EDM

  medium term
  - free neutron target (for r-process)

  far future

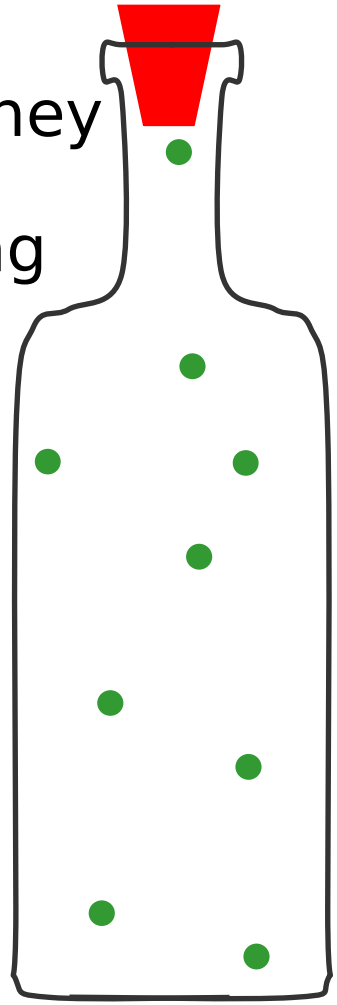
Our goal for this SEEC

- Desire to submit a CFI NIF proposal in October (LOI due in June).
- We hope that the SEEC recommends that the project move forward, specifically, that engineering design support from TRIUMF be allocated immediately.
- This gives us the best chance of success.

Physics with UCN

- Properties of UCN
- Experiments under consideration for TRIUMF
  - n-EDM
  - n-Lifetime
  - Gravity levels
  - free neutron target
  - surface physics (UCN ISR)

Ultracold Neutrons



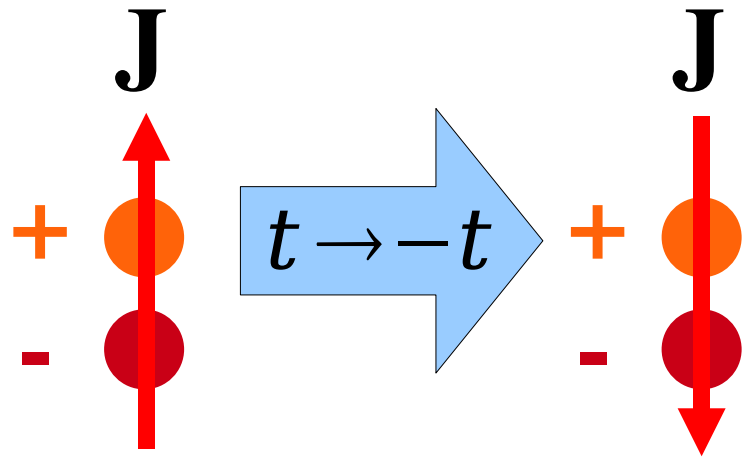
- UCN are neutrons that are moving so slowly that they are totally reflected from surfaces of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - gravity: $V=mgh$ ($h < 3$ 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.

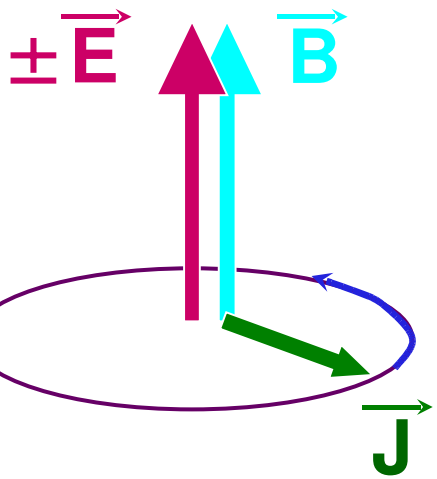
World's UCN projects

	source type	E_c neV	P_{UCN} /cm^3/s	T_s s	ε_{ext}	ρ_{UCN} /cm^3/s source/exp.
TRIUMF	spallation He-II	210	0.4×10^4 (10L)	150	~1	3×10^5 (20L) /5×10^4
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 (240cm^3)	1.6	1.3×10^3/ 4.4×10^4	**/120
PSI	spallation SD2	250	2.9×10^5 (27L*)	6	0.1	2000 (2m^3) /1000
NCSU	reactor SD2	335	2.7×10^4 (1L)	**	**	1300/**
Munich	reactor SD2	250	**	**	**	1×10^4/**

Neutron Electric Dipole Moment (n-EDM)

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





$$h\nu = 2\mu_n B \pm 2 d_e E$$

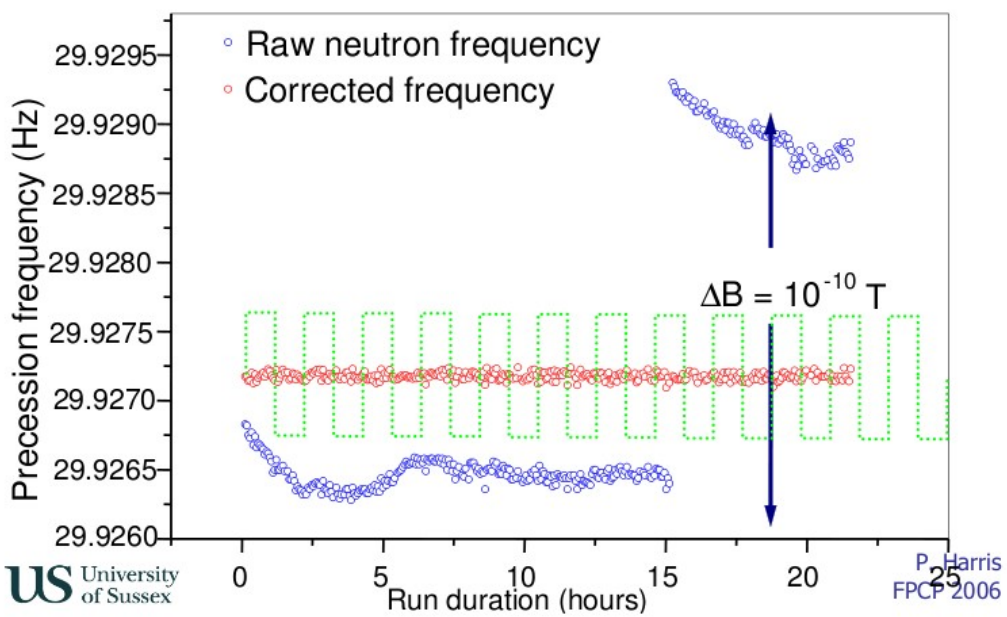
- Present Exp. Limit < 3×10^{-26} e-cm
- Standard Model value: 10^{-31} e-cm
- Supersymmetry or Multi-Higgs models can give 10^5xSM
- Significant discovery potential with new high sensitivity *n*-EDM experiment

n-EDM Systematics

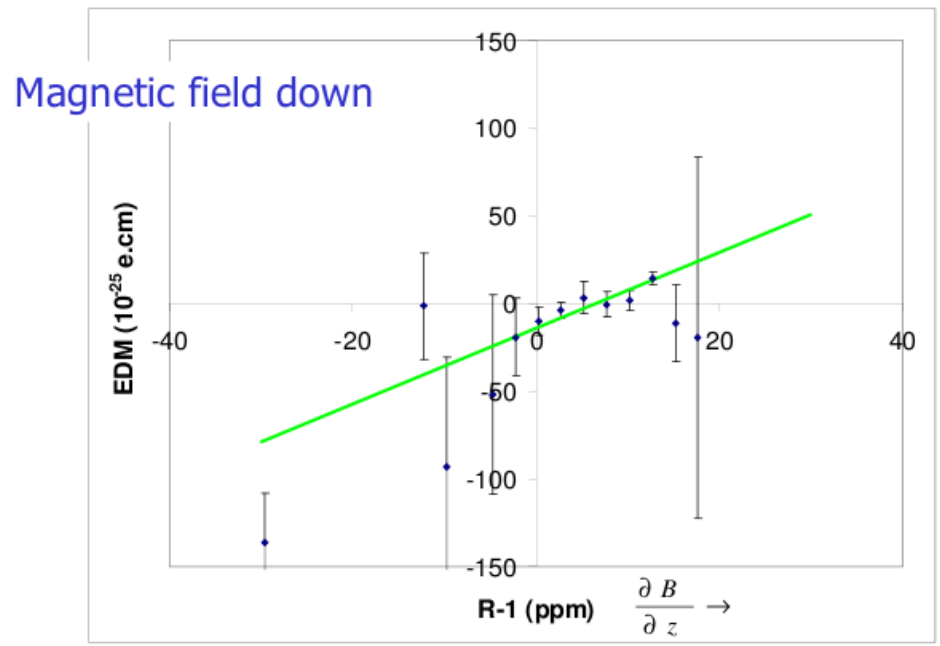
- magnetic field variations
- leakage currents

(co)magnetometry

- geometric phase effect
  - false EDM arising from field inhomogeneity and E x v.



comagnetometry



false EDM (GP) effect

Past and Future n-EDM efforts

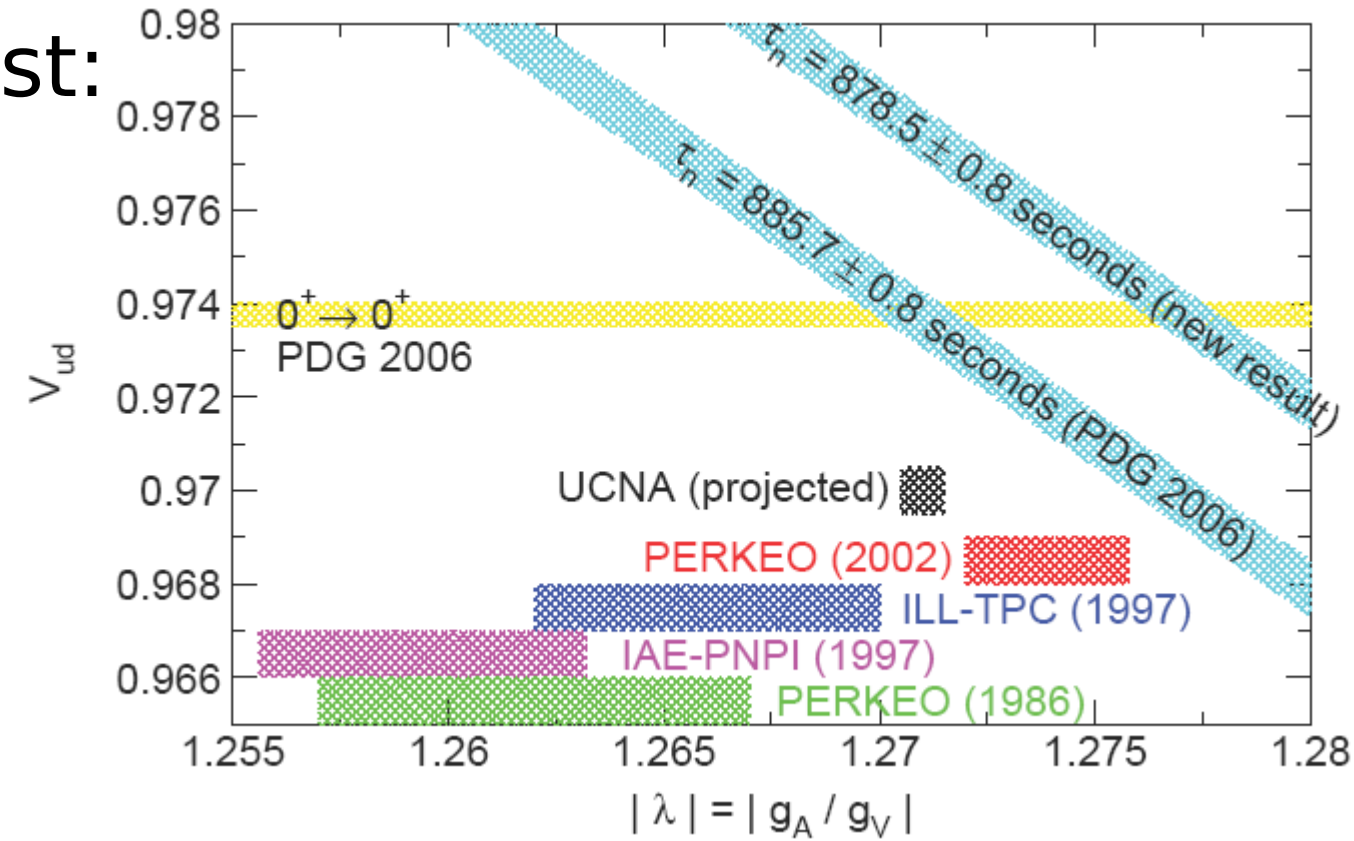
- Oxford-ILL expt. ($d_n < 3\times10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (ILL, Sussex, RAL)
  - 1000 UCN/cc, in superfluid 4He
- SNS
  - 430 UCN/cc, in superfluid 4He
- PSI
  - 1000 UCN/cc
- TRIUMF: 5×10^4 UCN/cc

Plans for TRIUMF

- Begin with modified ILL, SNS, or PSI setup
  - higher UCN density would allow 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

Neutron Lifetime

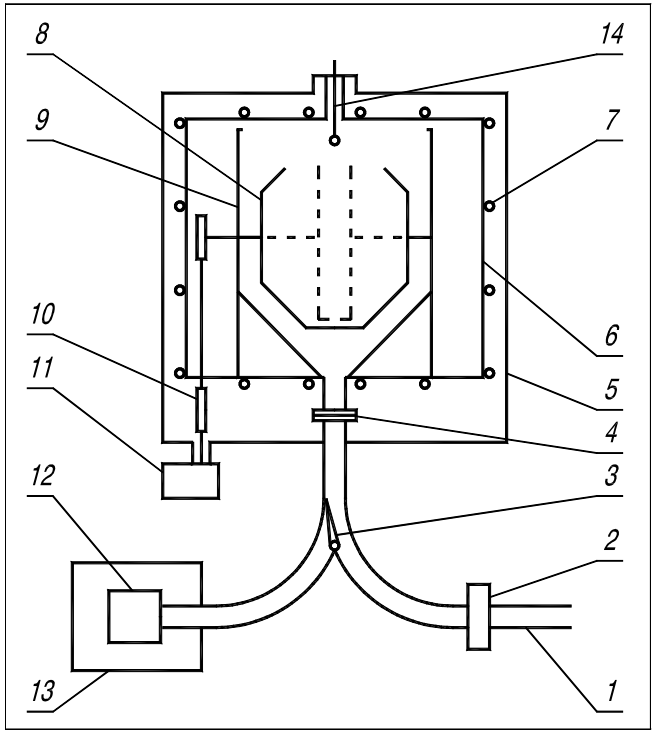
- Physics interest:
  - BBN
  - V_{ud}



- Currently a 6.5 sigma discrepancy between most recent, precise measurement and average of all previous measurements

Neutron Lifetime

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

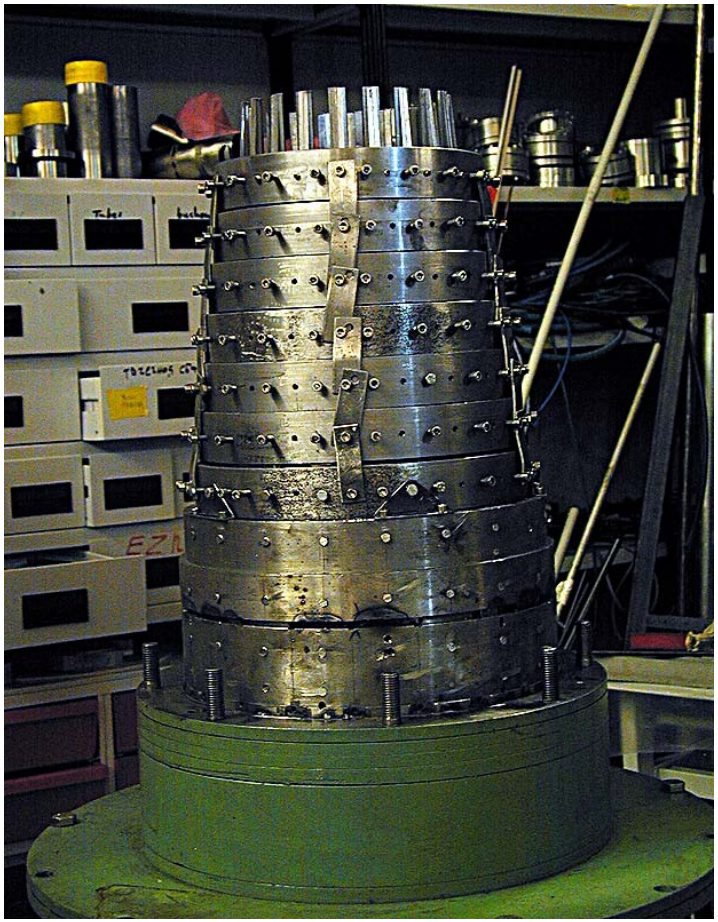


<- Gravitrap

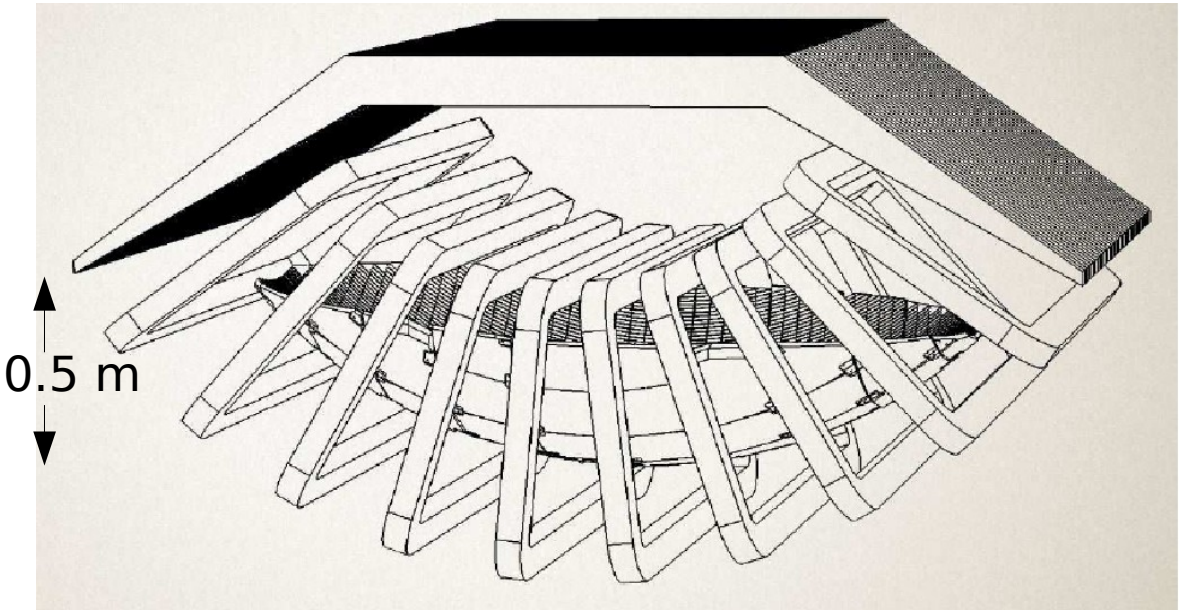
Permanent magnet trap ->

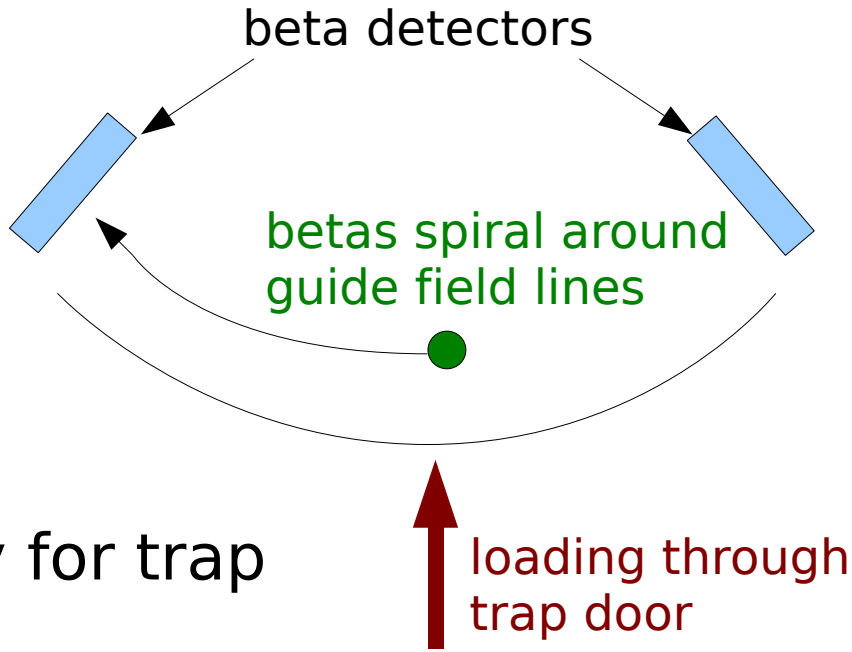
(both at ILL)

- New efforts to trap UCN magnetically
- marginally trapped orbits
- lack of UCN



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



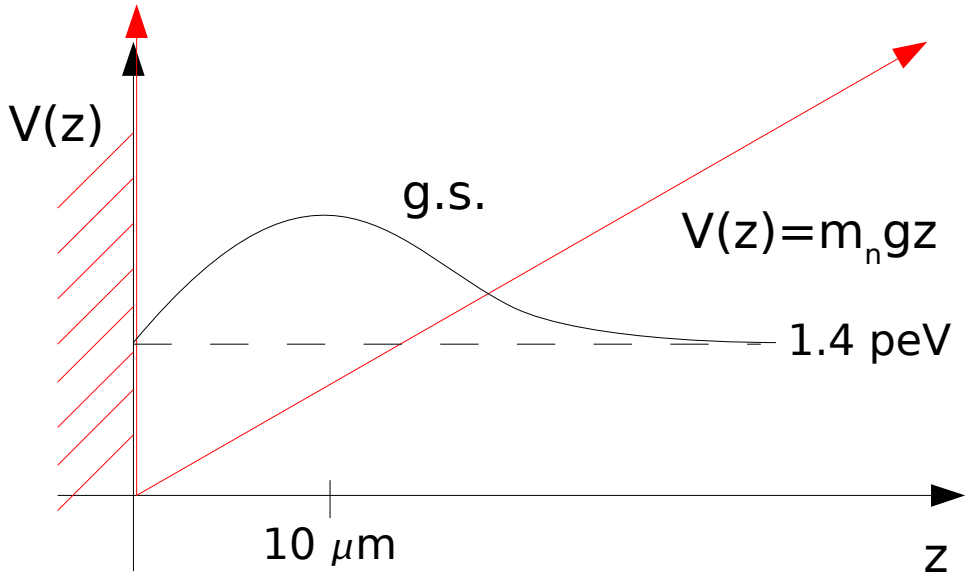


- Shallow Halbach array + gravity for trap
- Guide field for decay betas
- Marginally trapped neutrons experience chaotic orbits and are ejected rapidly
- Goal precision tau_n ~ 0.1 s

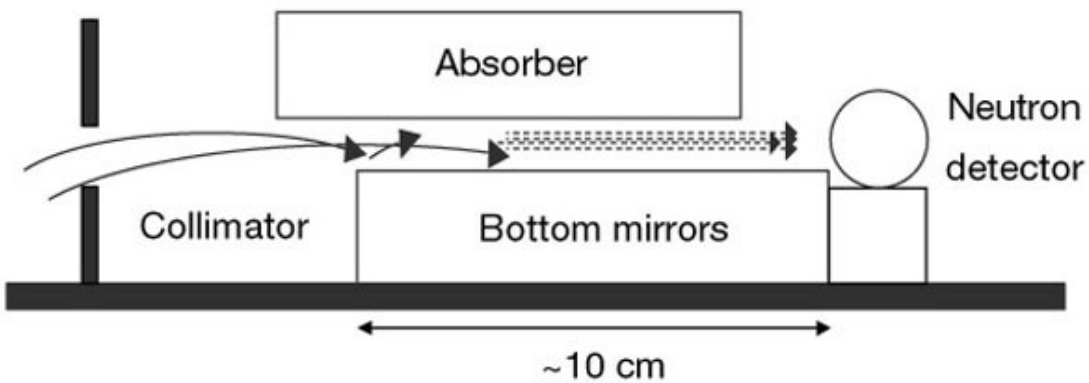
TRIUMF plans

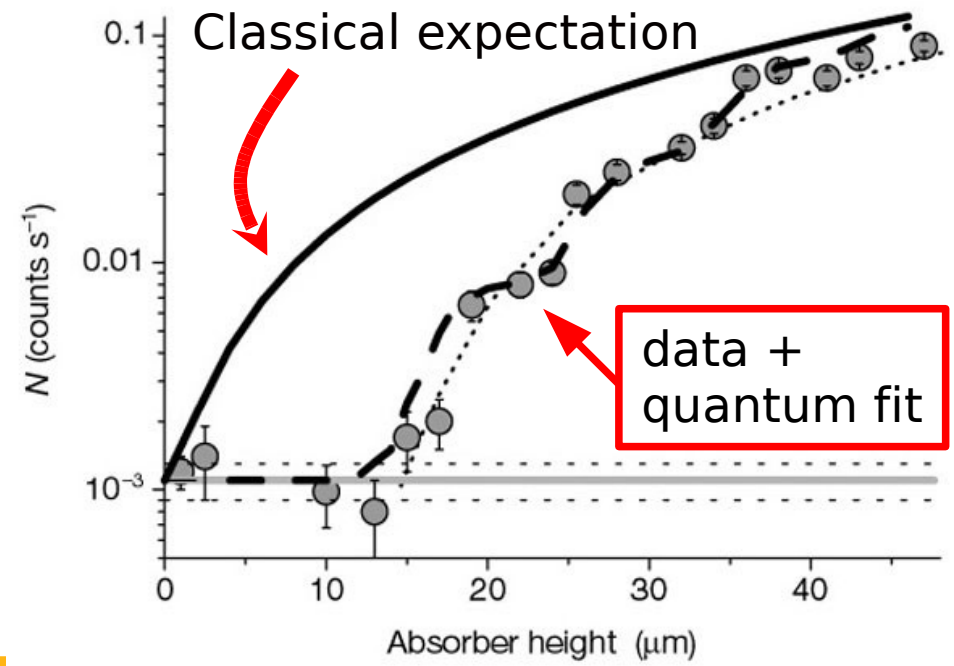
- Theoretical work on trap dynamics completed at LANL (some remaining issues with trap loading)
- Prototype under construction at LANL
- Goal is for test experiment at LANL UCN source
- TRIUMF experiment would build on preliminary work done at LANL
- Candidate for a first physics experiment using the 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

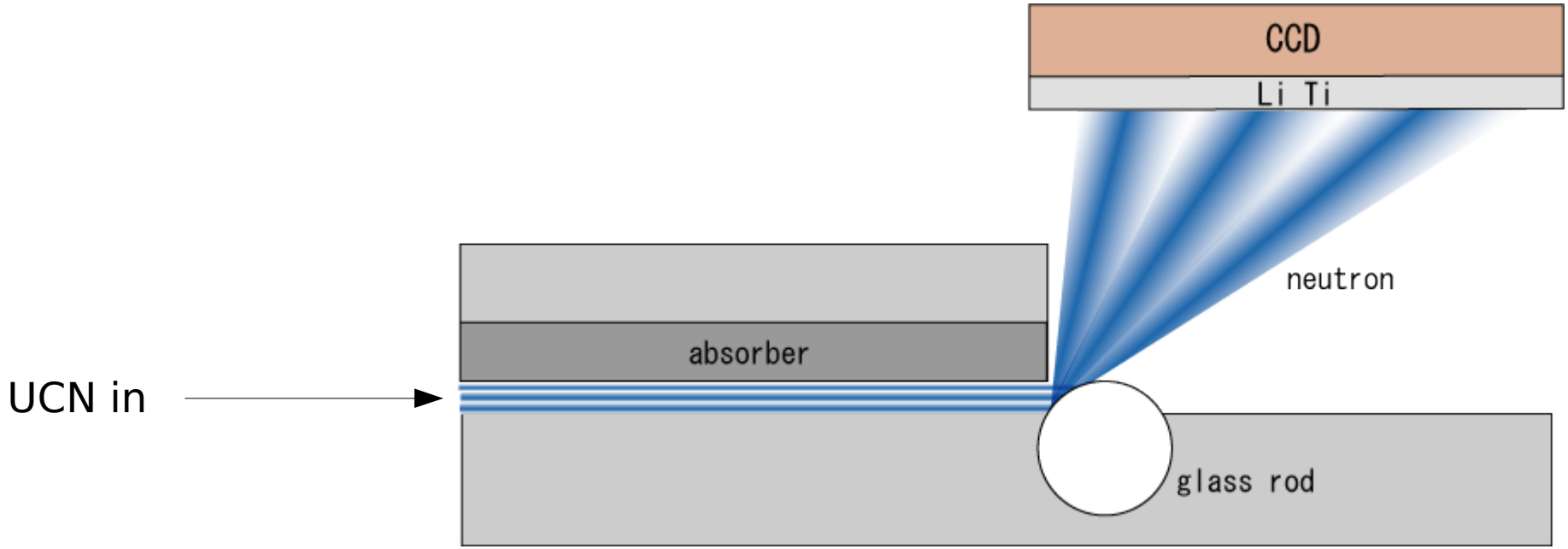




Further experiments:

- 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

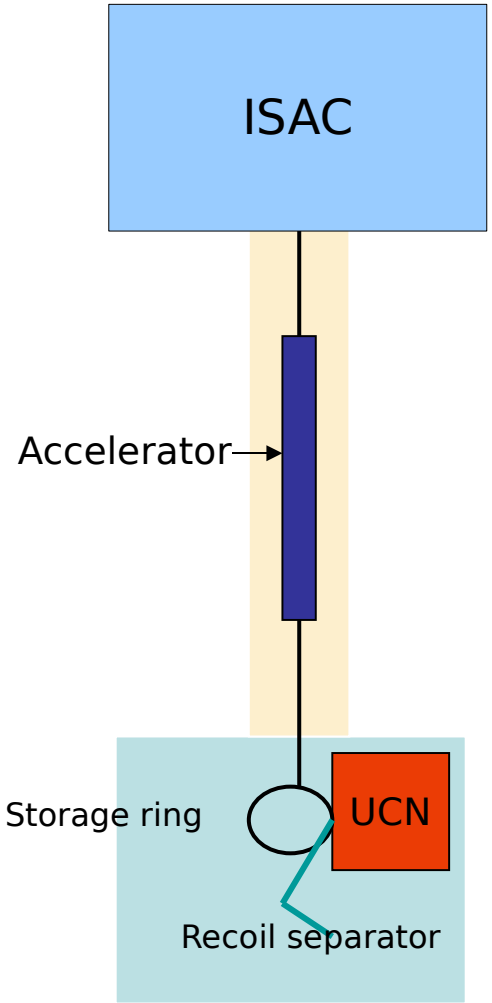
- Experiment would be initiated and led by Japanese groups (S. Komamiya, et al).
- Because development work is already underway, this is a good candidate for a first experiment (along with lifetime).

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

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

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

$\Rightarrow$ 50 interactions/hr



L. Buchmann
(TRIUMF)

Features:
- Extremely well-defined beam energy, reaction kinematics.
- neutron target doesn't affect stored beam at all, therefore no target density effects
- Also: stable beams, s-process.

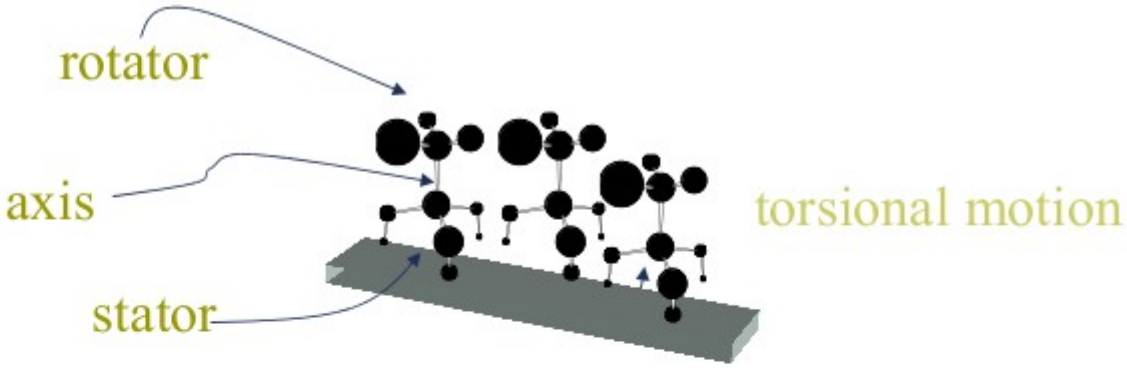
New field of physics unique to TRIUMF

Surface Physics

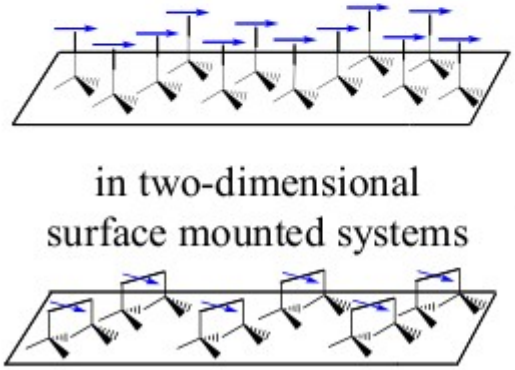
- Many ideas to use UCN to study 10 nm thin surface films
  - e.g. our application: “inelastic scattering reflectometry” (UCN ISR), sensitive to low-energy excitations, particularly of hydrogen-containing materials
  - compare two methods of inelastic scattering detection:
    - UCN loss measurements
    - 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

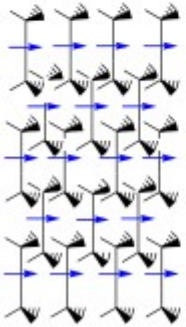


single molecules –solution or vapor phase



in two-dimensional
surface mounted systems

or three-
dimensional
crystals,

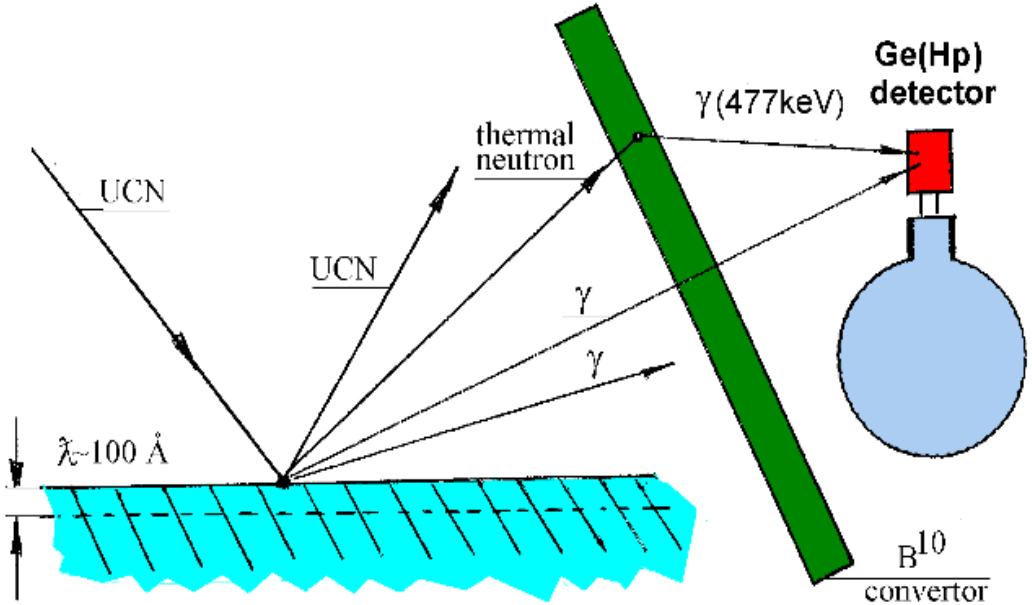


in random
or

ordered
systems.

- "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

Preparations for CFI NIF request

- Overall capital equipment ~10M (some manpower built in)
- CFI NIF provides 40% of total cost.

Proposed cost breakdown (rough numbers)

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

- Modest cost to TRIUMF
- Need detailed engineering and realistic numbers!!!

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

Overall timeline

- Before 2012 – develop UCN source in Japan
- 2012 – Install at TRIUMF
- First experiments 2012-2015
- medium term: EDM, 2014 and beyond
- Longer term projects:
  - free neutron target for r-process
  - nnbar oscillations?

Questions & Answers

General questions:

1) Many of the proposals will require significant manpower. What are the impacts on TRIUMF resources and manpower of each proposal? How many projects can TRIUMF accomplish simultaneously? Can more science be accomplished by further focusing the proposals?

- Detailed cost and manpower estimates have not been done at this time. We anticipate that engineering support from TRIUMF for a resource and manpower estimate would be recommended by the SEEC if the UCN project were successful in the review.

3) What is the operational flexibility of the proposed program?

- The technical requirements of a UCN source can be worked out so that the program would run concurrently with ISAC and muSR.

Questions & Answers

UCN questions:

1) Why do it at TRIUMF instead of JPARC?

- The phase-2 upgrade of J-PARC starts in April 2009. First in-line for the phase-2 project is to complete the phase-1 facilities. There are no muon beamlines but targets and only a few neutron beamlines. The highest priority for J-PARC is to upgrade the proton intensity for the neutrino, hadron, muon and spallation neutron facilities. Another high priority phase-2 upgrade is the neutron transmutation facility.

- The UCN source (at JPARC) would require a new beamline/target station, and it is not even part of the potential phase-2 projects yet. Construction is not expected to start at least in the next 5-years. A dedicated beamline and target station at the end of the upgraded J-PARC linac for UCN could provide even higher UCN density, although it is costly ($40M) and there are a lot of technical challenges to overcome.

- Experience gained in the operation of the UCN source at TRIUMF would open the door to overcome such technical challenges.

Questions & Answers

UCN questions:

2) What is the flagship experiment for the UCN source?

- Near term: neutron life time, gravity level quantization
- Medium term: EDM
- Long term: free neutron target
- Nanosurface science would create a new user community at TRIUMF, as it happened in the case of muSR.

3) Do the cost estimates include all of the costs associated with the high power spallation target? Can you compare the projected costs to the experience at PSI?

- The beam current for UCN is 40uA at the peak current and 10uA for the average current. This is significantly lower than ISAC currents (100 uA). The beam current is similar to LANL UCN source and not like PSI source, thanks to the efficient superfluid helium method for UCN production. In the meson hall, there already exists the remote handling transport system and hot cell available for this level of source. These systems are used for handling 150uA targets in the meson hall, and the same system can be used for UCN. A sliding system to replace the spallation target is required, similar to the one developed and working at LANL. Engineering support from is required to do the detailed design. With support from the SEEC on the physics case, we hope to get such engineering support from experts at TRIUMF.

Questions & Answers

UCN questions:

4) Is there enough manpower at TRIUMF to commission the UCN source? Can you discuss the manpower that was needed at PSI?

- From experience we can comment on the commissioning of the LANL UCN source, which as stated in 3) is similar in scale and in beam current. The manpower available at LANL, in terms of researchers based at LANL, is consistent with the manpower already available to us at TRIUMF. During commissioning of the UCN source, the LANL-based crew was supplemented with manpower from the various university groups. We expect that a similar relationship would occur at TRIUMF. Manpower would be heavily supplemented by Japanese collaborators in particular, since it is the group of Y. Masuda that has the true expertise required.

5) Can one use the UCN source for a neutron antineutron oscillation experiment?

- This is a very exciting possibility that we have considered. It can be done. It is not yet clear if a cold neutron beam is a better way than UCN for n-nbar oscillations. Further study is required to clarify this point. Certainly an n-nbar oscillation experiment would require the utmost best performance of the UCN source, and a very large and expensive experimental apparatus. In our minds, the n-nbar project therefore fits into the category of “longer term” projects, such as the free neutron target. Indeed the n-nbar project would be particularly well-suited to TRIUMF because of TRIUMF's excellent detector fabrication facilities and expertise with large-scale detectors for high-energy physics experiments.

Questions & Answers

UCN questions:

6) Is there other nuclear astrophysics that one can do with a UCN storage cell?

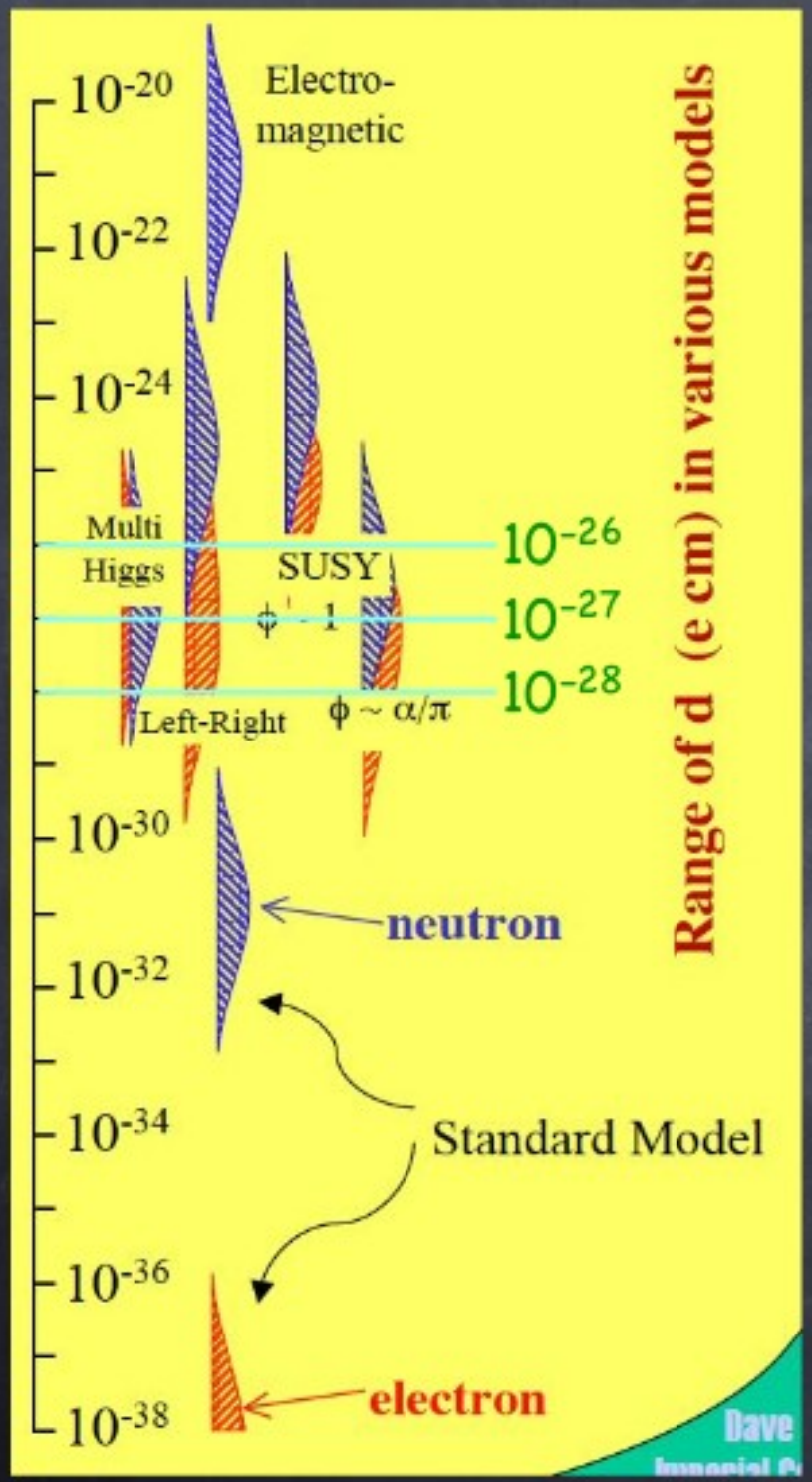
- Yes! Since the collision of radioactive beam with radioactive target has not previously been accessible, there is a wide program of measurements that could be pursued. Particular eactions of interest in astrophysics are neutron capture reactions outside the fission region, all the way from heavy lithiums to uranium and lead where fission barriers are of interest. (n,p) reactions of medium mass, proton rich nuclei are also of interest. In nuclear structure, neutron scattering from light neutron rich isotopes would be of interest for studies of halo nuclei. Even precision measurements on stable light nuclei would likely be of interest; however, a detailed answer would require a careful examination of the cross-sections and energies.

7) Will the neutron EDM and or the neutron lifetime be the most pressing scientific questions by the time this source is ready?

- While the current discrepancy among the neutron lifetime experiments might be resolved by the time this source is ready, the neutron lifetime experiment proposed by Bowman aims at a determination at the 0.1 s level, more precise than what most experiments are currently capable of, and requiring higher UCN density than all previous experiments. The neutron EDM project remain a topic of intense study which would perhaps increase in interest if a nonzero EDM is discovered. Otherwise experiments would continue until the SM prediction (10^{31} e-cm) is reached. The techniques developed at TRIUMF could therefore represent a step toward even higher precision future experiments. We also note that the quantized gravity levels, and development of applications in surface nanoscience have their own important science goals.

EDM history

Theory



Experiment