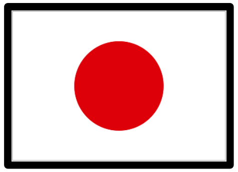
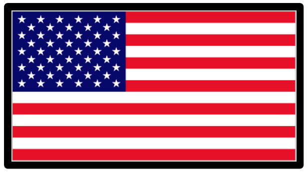
Neutron Electric Dipole Moment Search with a Spallation Ultracold Neutron Source at TRIUMF

Spokespeople: Y. Masuda (KEK), J.W. Martin (Winnipeg)

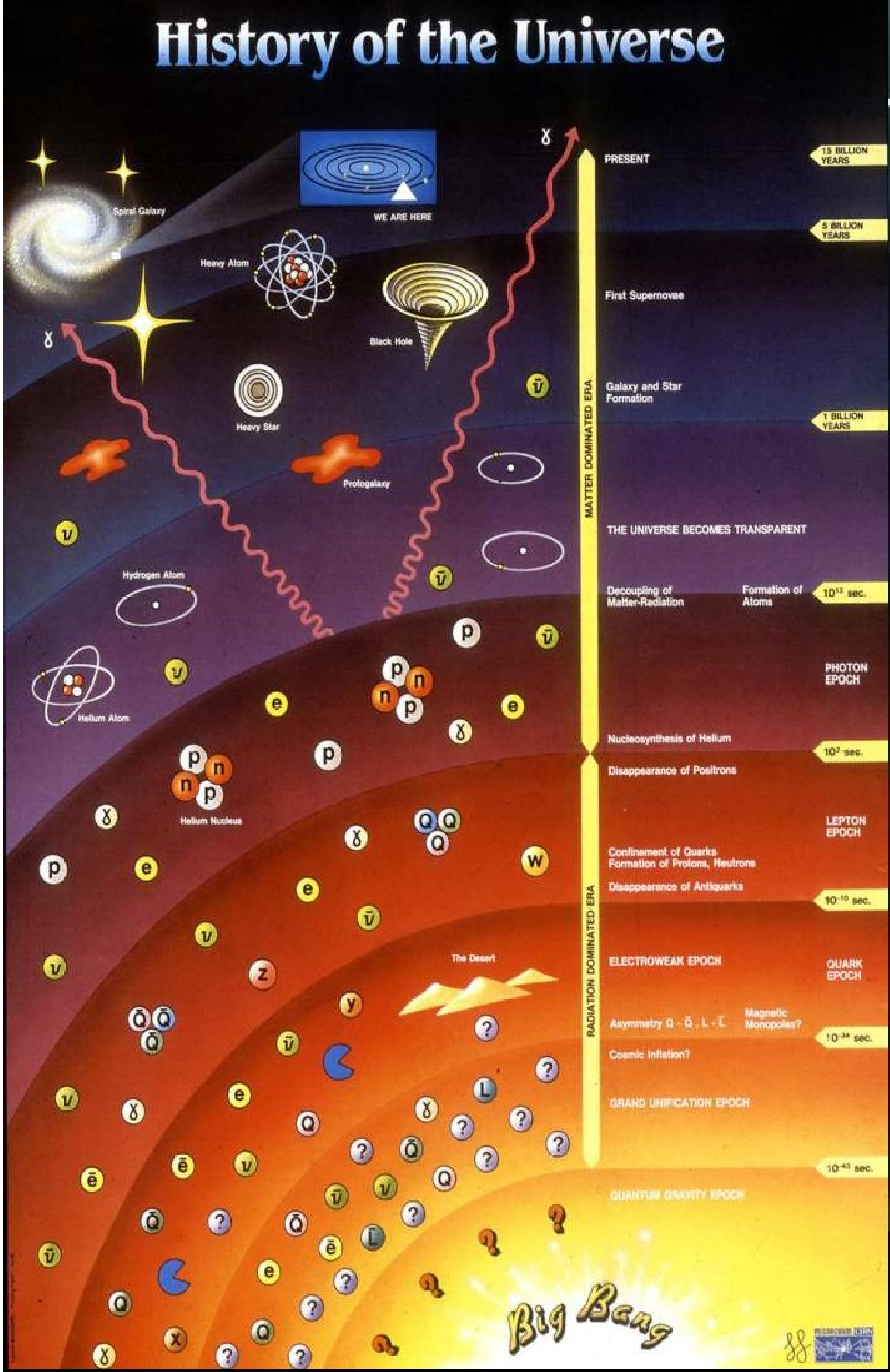
Collaborators: T. Adachi, K. Asahi, M. Barnes, C. Bidinosti, J. Birchall, L. Buchmann, C. Davis, T. Dawson, J. Doornbos, W. Falk, M. Gericke, R. Golub, K. Hatanaka, S. Jeong, S. Kawasaki, A. Konaka, E. Korkmaz, E. Korobkina, L. Lee, R. Mastumiya, K. Matsuta, M. Mihara, A. Miller, T. Momose, W.D. Ramsay, S.A. Page, H. Takahashi, K. Tanaka, I. Tanihata, W.T.H. van Oers, Y. Watanabe

(KEK, Titech, Winnipeg, Manitoba, TRIUMF, NCSU, RCNP, UNBC, UBC, Osaka)

Antimatter Puzzle

"The Baryon Asymmetry of the Universe"

- Just after the Big Bang, there were equal parts matter and antimatter.
- Why is there so little antimatter in our universe today?
- Or, why is there any matter at all?



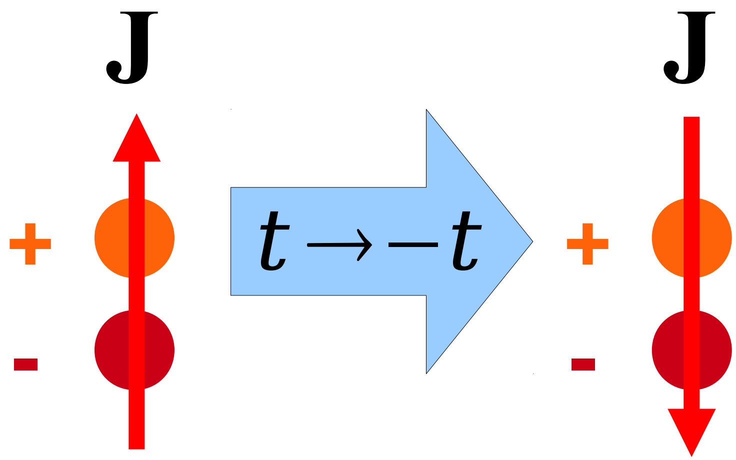
CP violation

- CP symmetry: Take all particles and change them to their antiparticles (C). Then reflect all coordinates through the origin (P). The laws of physics should be the same.
- If CP symmetry is *violated* then physics is not the same for particle and antiparticle.
- Hence we can have different numbers of them today.
- CP viol. discovered 1964
- But not enough of it.

Searches for new sources of CP violation.

- People looking very closely at strange and bottom quarks – still not enough CP violation.
- Another method: If $E = mc^2$ is correct, then time-reversal symmetry (T) is the same as CP symmetry.
- Very precise test of time-reversal symmetry: search for a non-zero permanent electric dipole moment of a fundamental particle.

Electric Dipole Moments and Time Reversal Symmetry



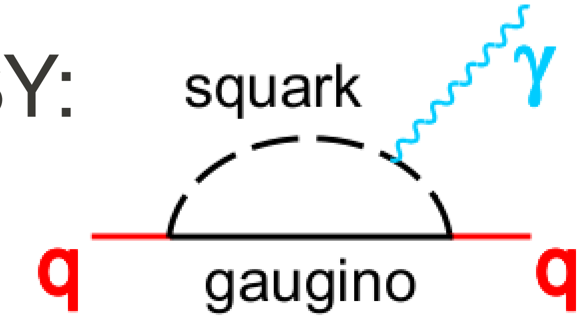
$$d_n \Rightarrow \not{T} \Rightarrow \not{CP}$$

New sources of CP violation are required to explain the baryon asymmetry of the universe.

EDM's and SUSY

- Scale of EDM's for quarks in SUSY:

$$d_q \sim \frac{\alpha}{\pi} \times \frac{m_q}{\Lambda_{SUSY}^2} \times \sin\theta_{CP}$$



from P. Harris, Sussex

- For "reasonable" values of new parameters:

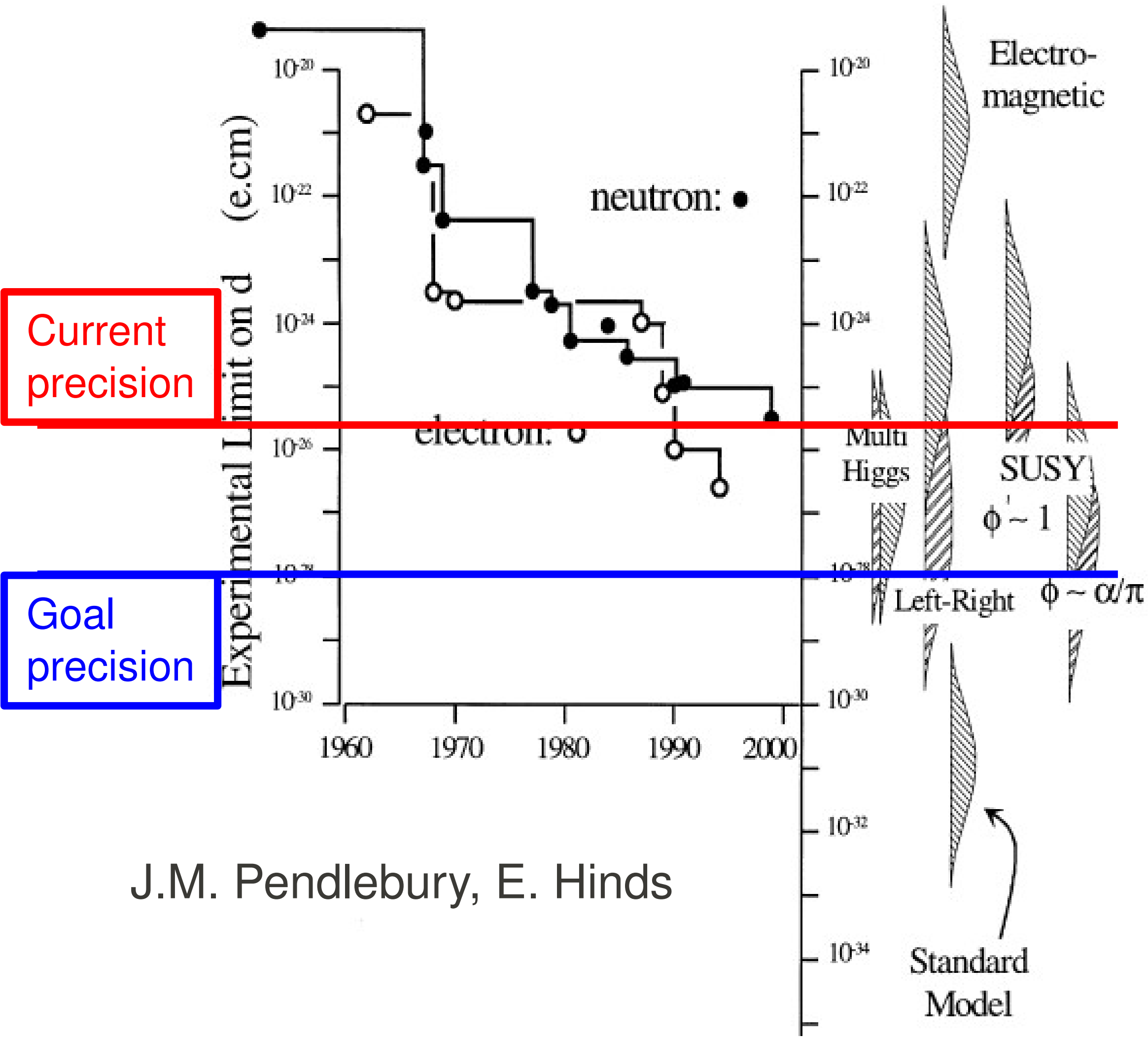
$$d_q \sim 3 \times 10^{-24}\, e \cdot cm$$

- According to neutron EDM measurements:

$$d_u < 2 \times 10^{-25}\, e \cdot cm \qquad d_d < 5 \times 10^{-26}\, e \cdot cm$$

- Unattractive solution:
  - Λ_{SUSY} > 2 TeV and/or θ_{CP} < 0.01
  - "SUSY CP problem"

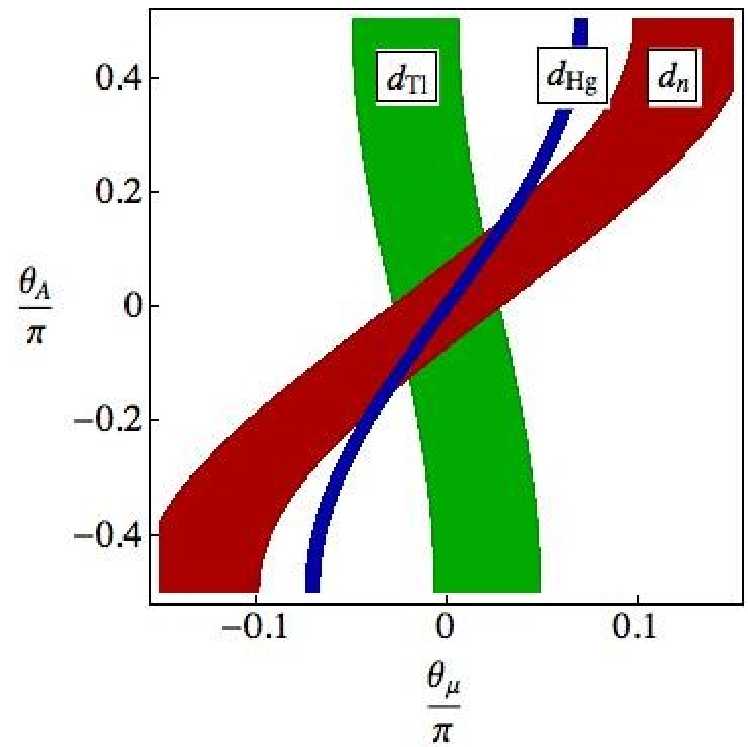
EDMs, the SM, and beyond



J.M. Pendlebury, E. Hinds

A. Ritz, M. Pospelov, et al

SUSY M = 1 TeV, tanβ = 3

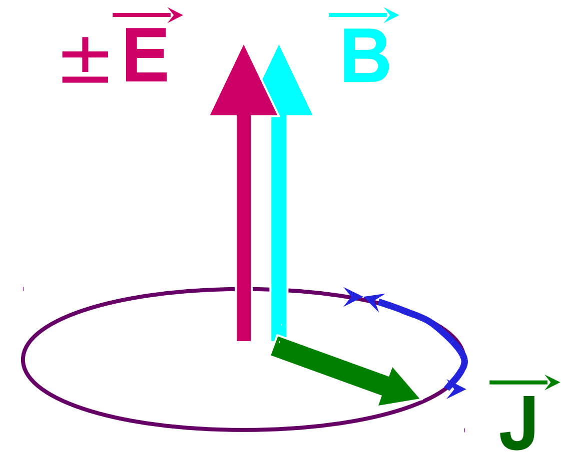


Note: universality assumptions are now even being tested

- “n-EDM has killed more theories than any other single experiment!”

Neutron Electric Dipole Moment (n-EDM, d_n)

Experimental technique:
- put UCN in a bottle with *E*-, *B*-fields
- search for a change in spin precession frequency upon *E* reversal.

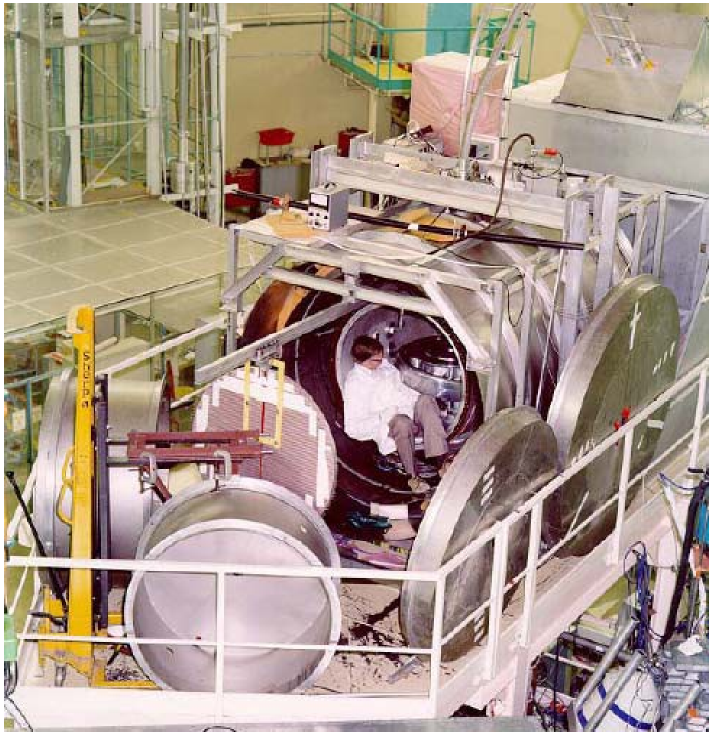


$$h\nu = 2\mu_n B \pm 2\mathrm{d}_e E$$

• Complementary in both physics sensitivities and experimental technique to Rn-EDM, Fr-EDM @ ISAC.

Past and Future n-EDM efforts

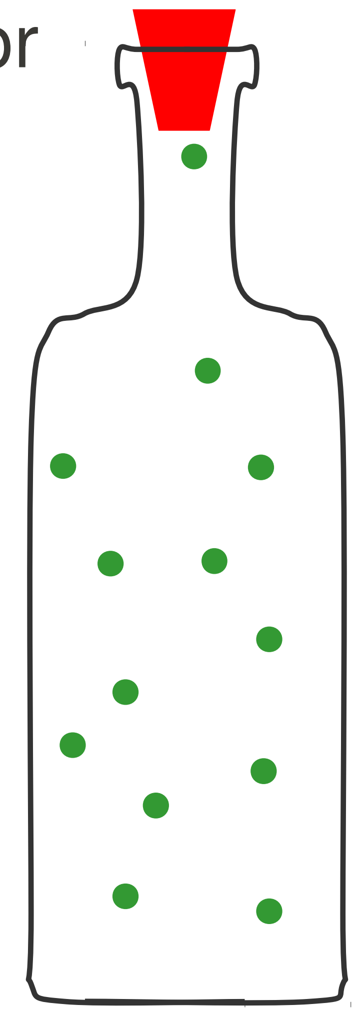
- Sussex-RAL-ILL expt. ($d_n < 3\times10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (Sussex-RAL-ILL)
  - 1000 UCN/cc, in superfluid ^{4}He
- SNS
  - 430 UCN/cc, in superfluid ^{4}He
- PSI
  - 1000 UCN/cc, in vacuo
- TRIUMF goal: 10,000 UCN/cc



Sussex-RAL-ILL experiment

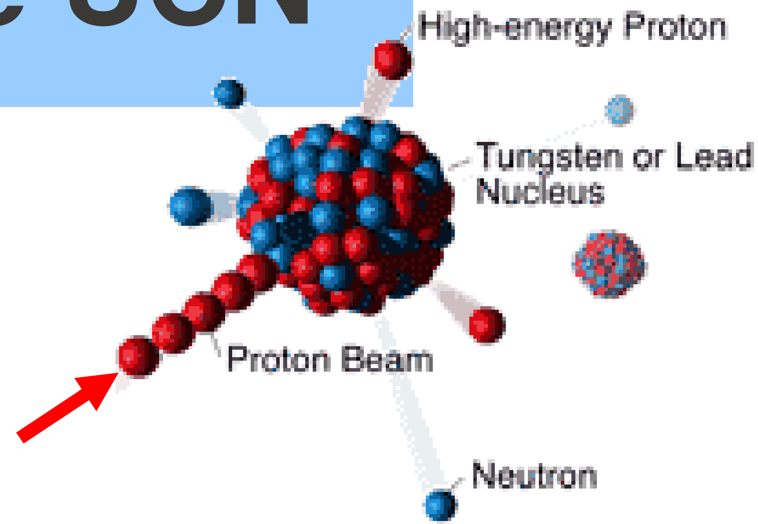
Ultracold Neutrons (UCN)

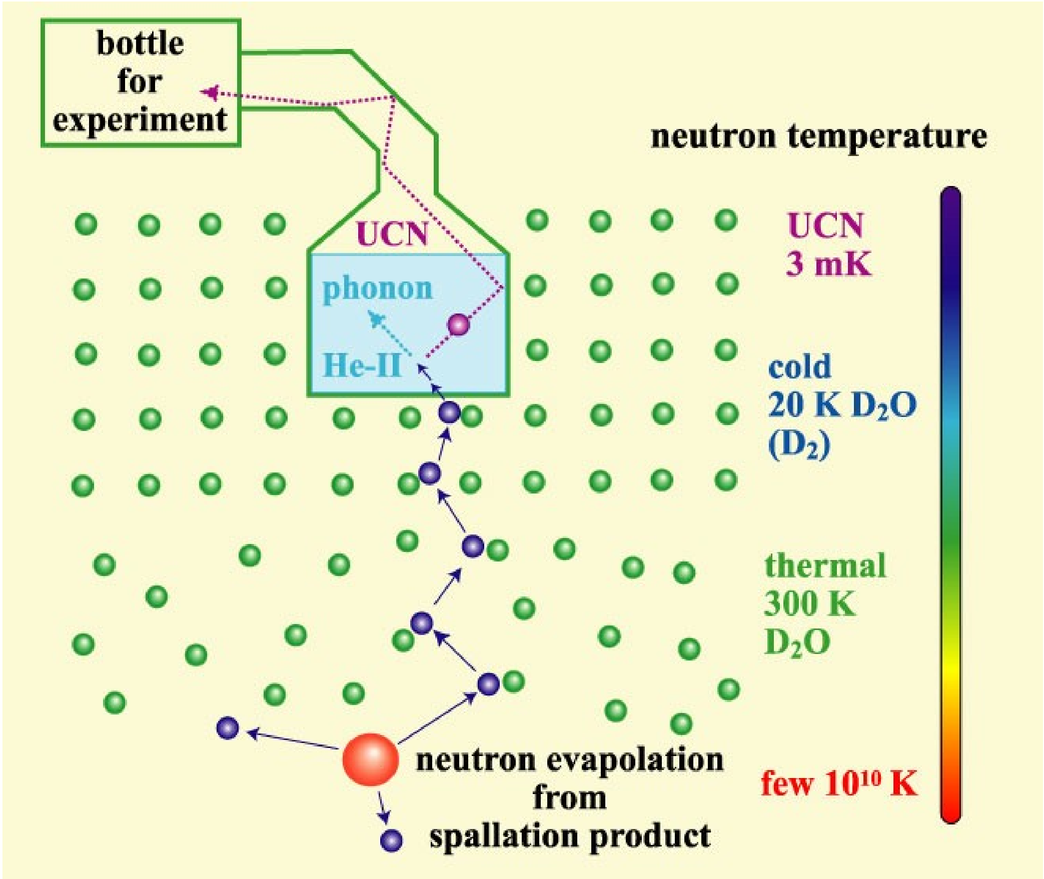
- UCN are neutrons that are moving so slowly that they are totally reflected from a variety of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s = 30 km/h
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - Gravity: $V=mgh$ $mg = 100$ neV/m
  - Magnetic: $V=-\mu\bullet B$ $\mu = 60$ neV/T
  - Strong: $V=V_{eff}$ $V_{eff} < 335$ neV
  - Weak: $\tau = 885.7$ s = 15 mins



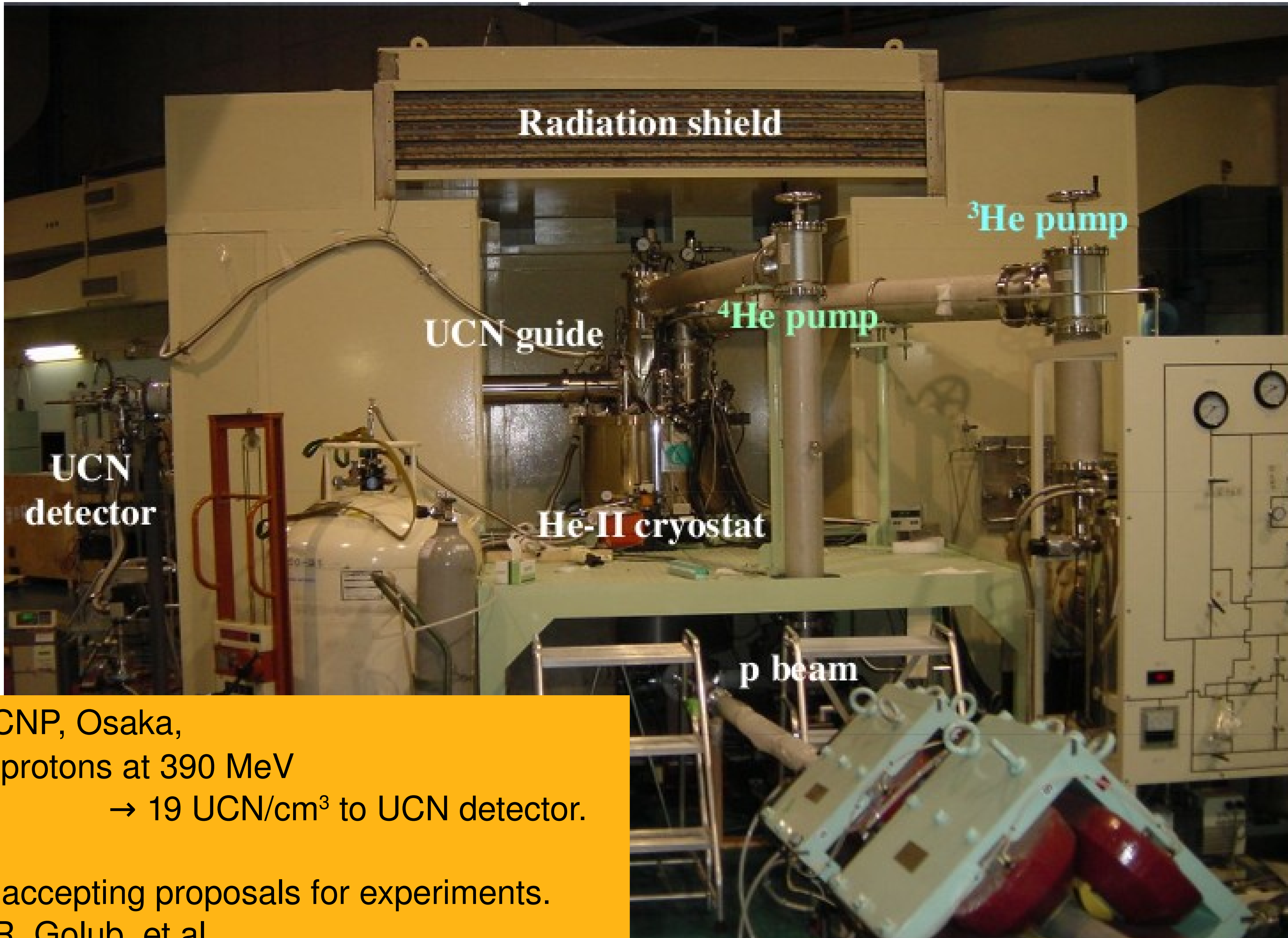
New method to make UCN

- 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.





KEK UCN Source (Masuda, et al)

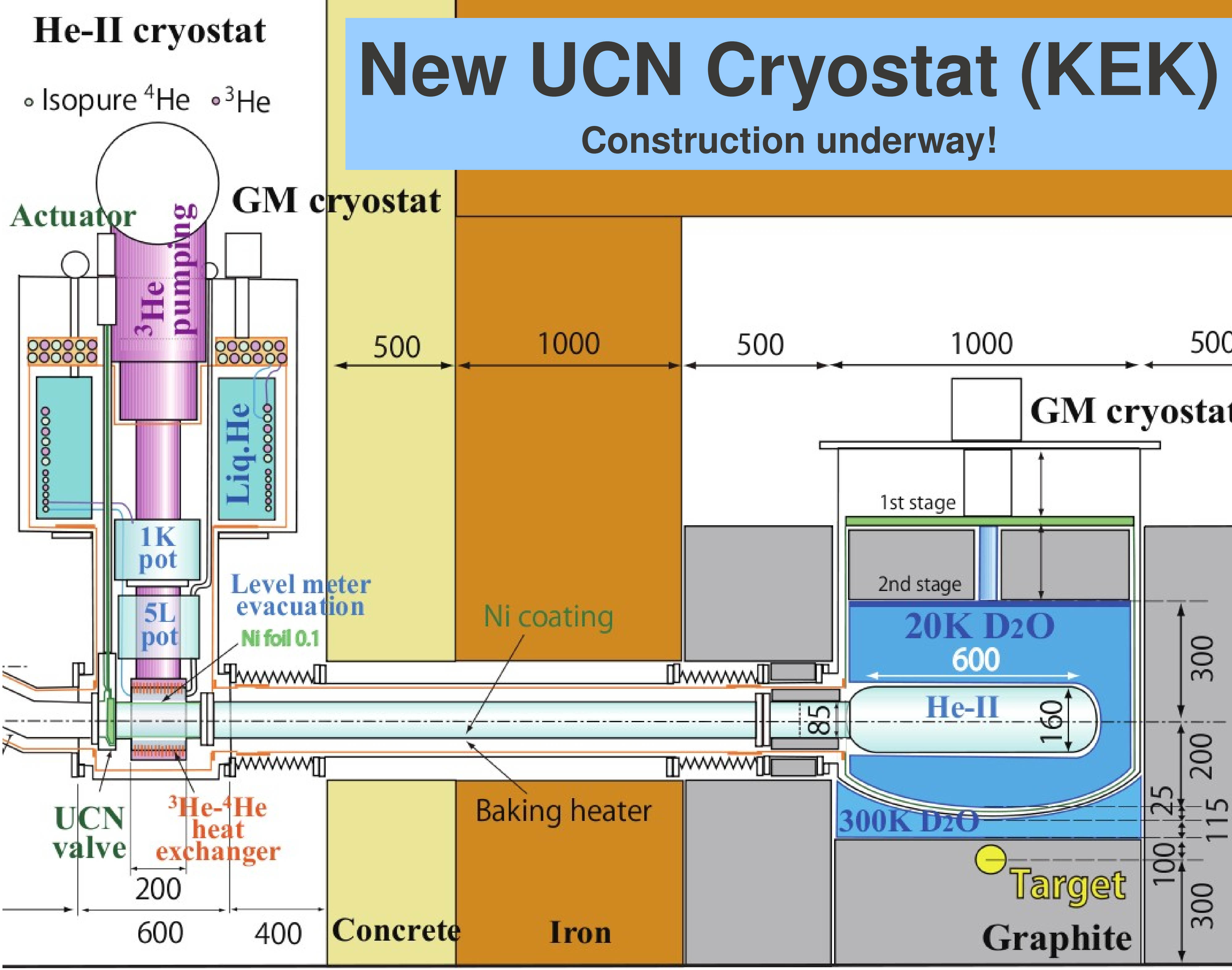


At RCNP, Osaka,
1 μa protons at 390 MeV
→ 19 UCN/cm^3 to UCN detector.

Now accepting proposals for experiments.
e.g. R. Golub, et al.

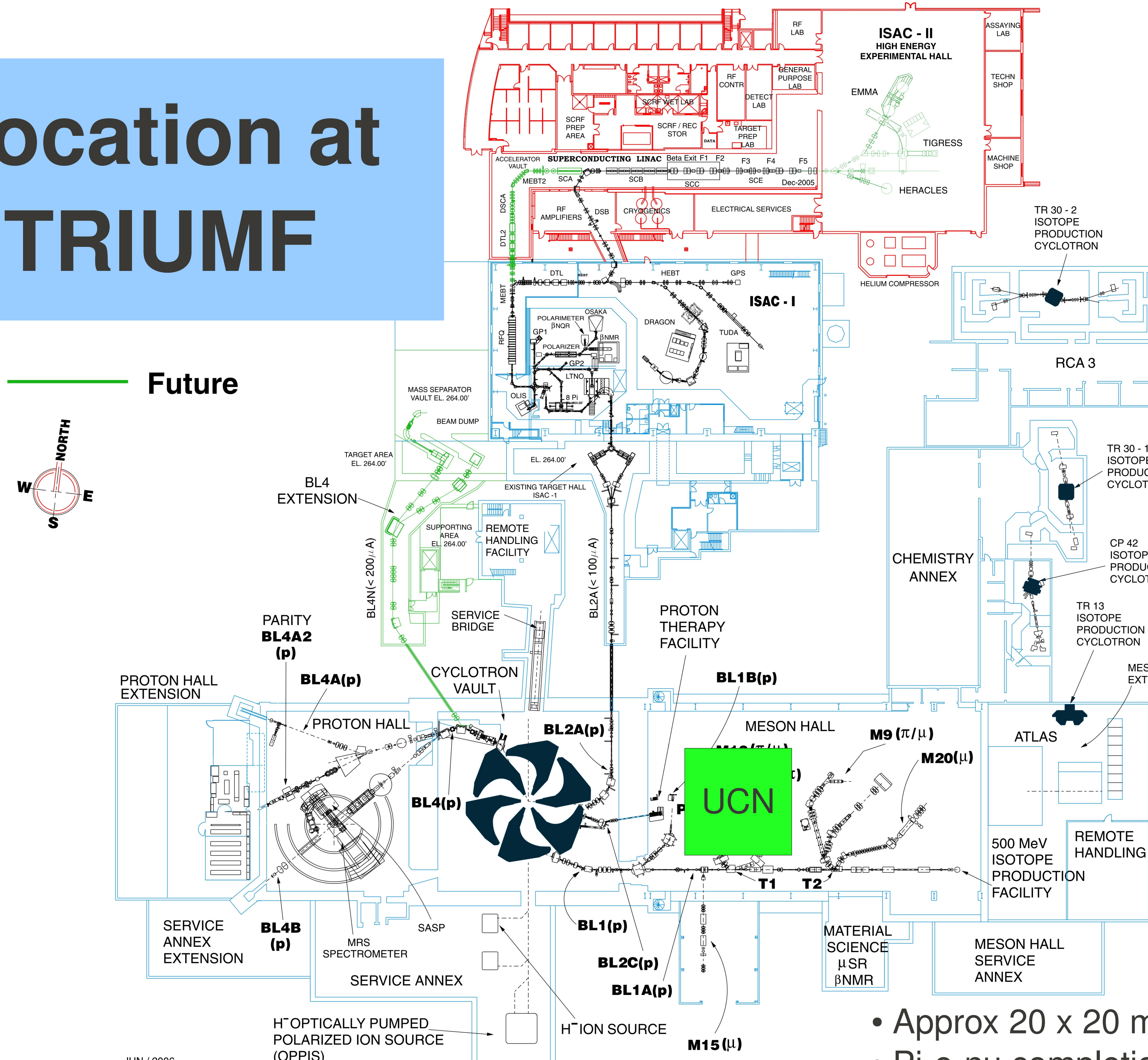
New UCN Cryostat (KEK)

Construction underway!



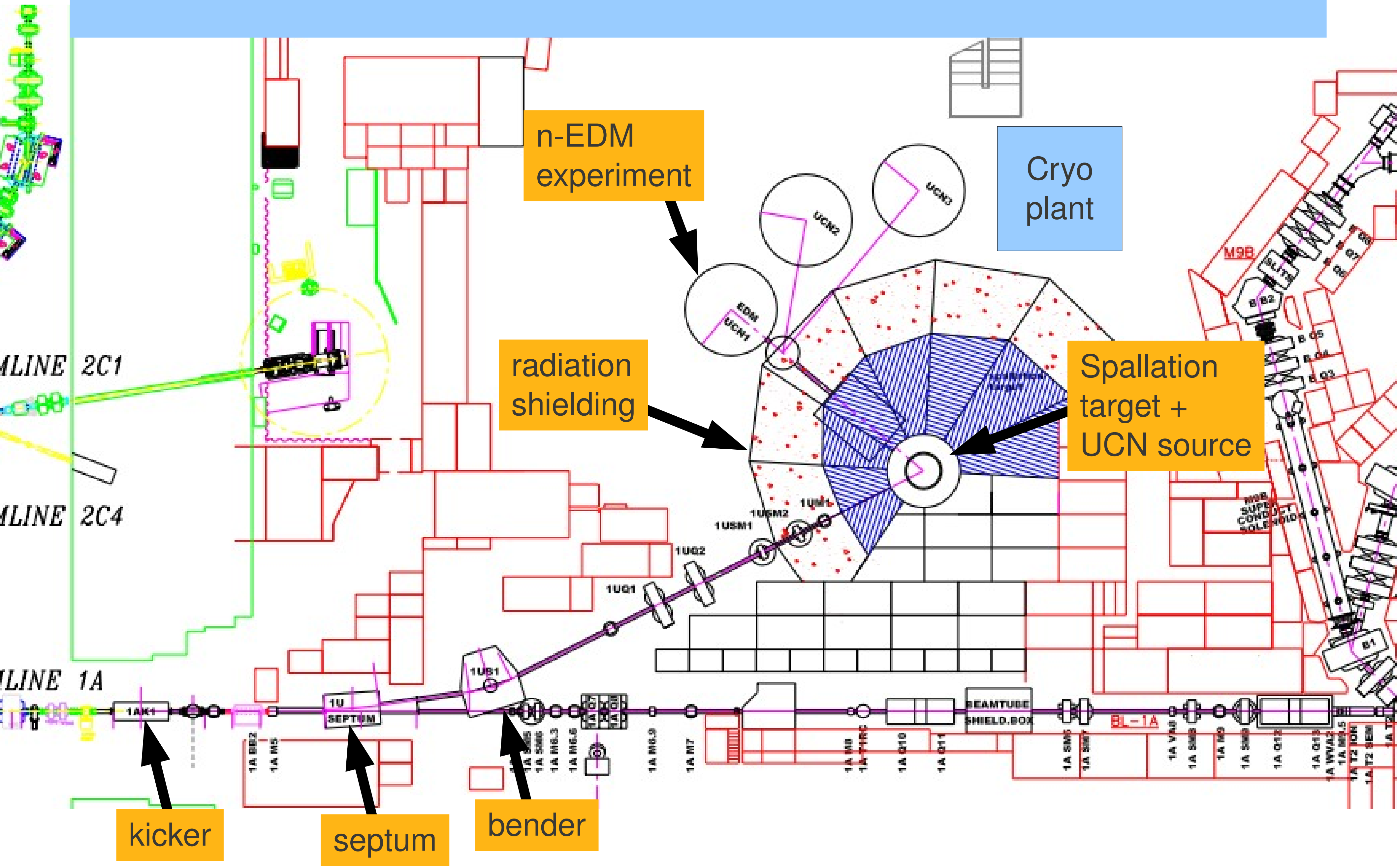
- Gain Factors (40 μA @ 500 MeV):
  - Beam energy, power x 70
  - Production volume x 1.5
  - Storage lifetime x 2.5
  - Transport eff x 2
  - $E_c^{3/2}$ (from 90 to 210 neV) x 3.5
- Goal: 10,000 UCN/cm^3 in EDM cell.
- Lumi upgrade at RCNP to 10 μA allows tests thru summer 2014.
- Longer running time at TRIUMF (8 months/yr vs few weeks)

Location at TRIUMF

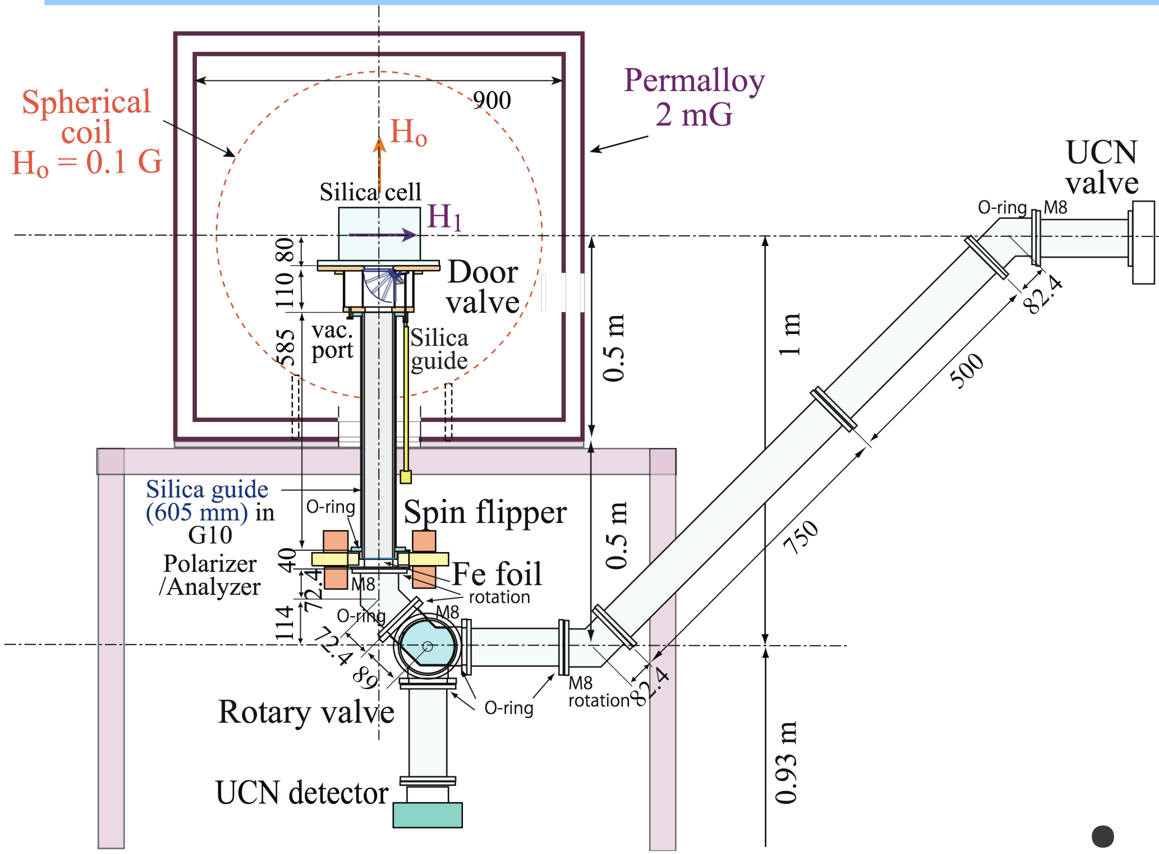


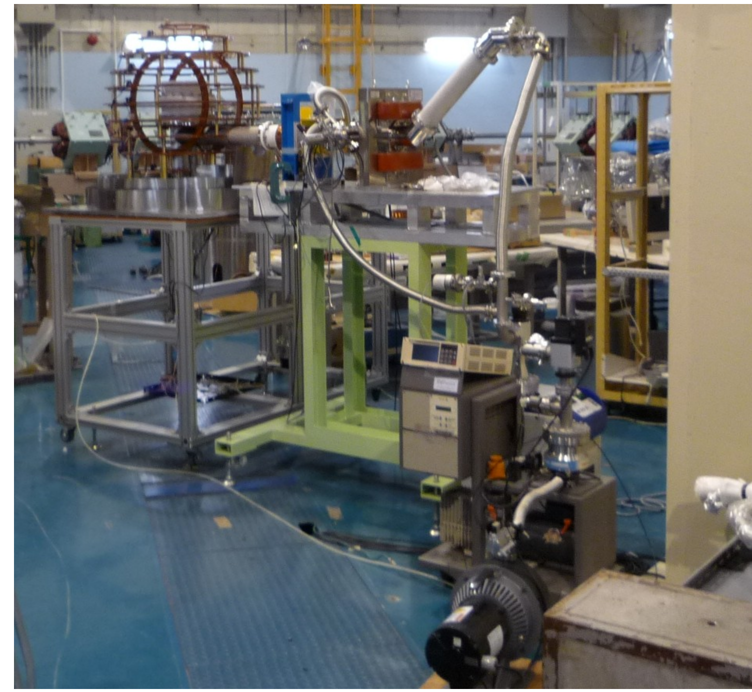
- Approx 20 x 20 m^2 box
- Pi-e-nu completion 2011

Layout in Meson Hall



n-EDM development in Japan

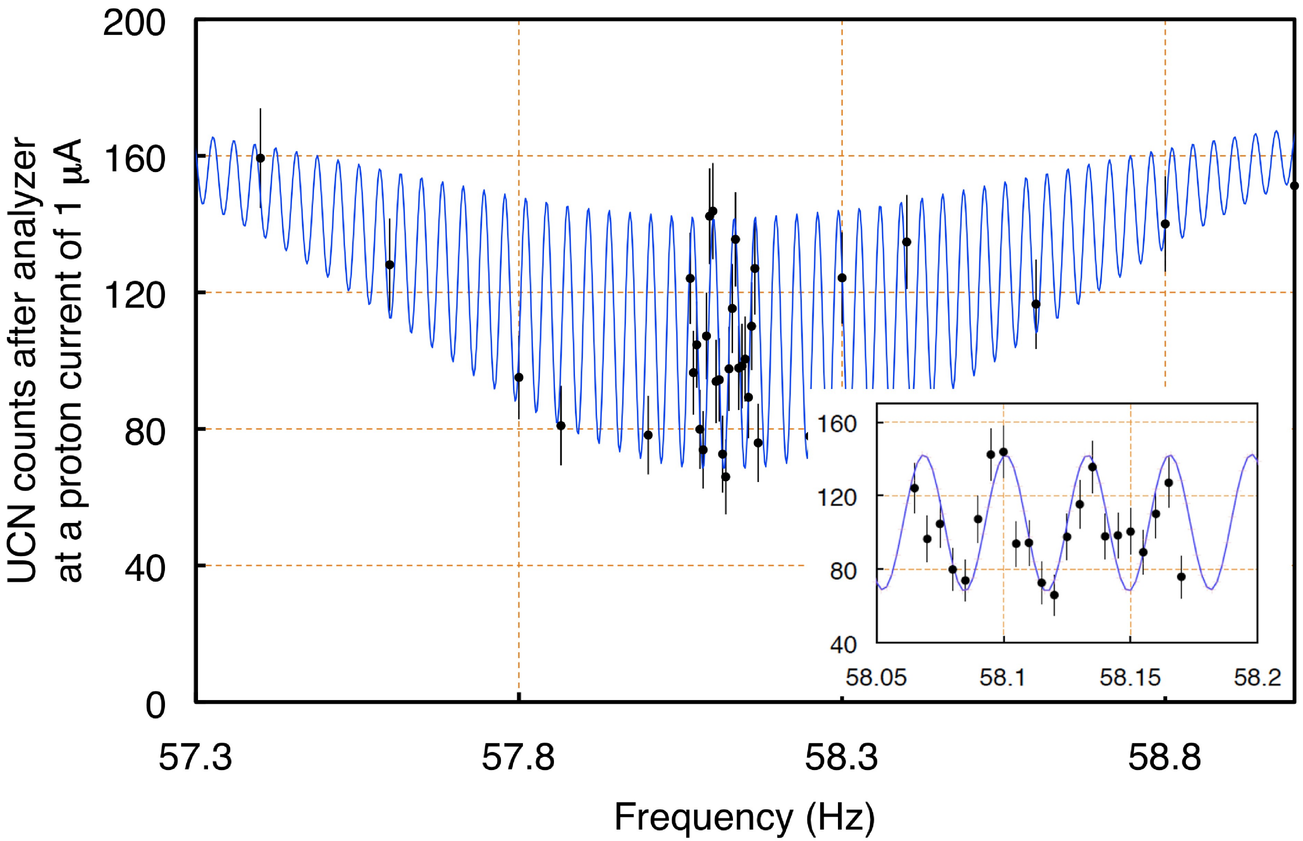




Masuda, et al. Beam tests July, December 2009, April 2010, early 2011.

- Development of:
  - Comagnetometers
  - Ramsey resonance
  - New B-field geometry
  - HV, EDM cell

Ramsey Resonance Results



Dec. 2009, achieved:
T_2 ~ 300 ms

April 2010, achieved:
T_2 > 30 s !!!

becoming competitive with ILL, where T_2 = 120 s (typ.)

$$\sigma\left(d_n\right) = \frac{\hbar}{2\alpha E T\sqrt{N}} \quad \text{(stat)}$$

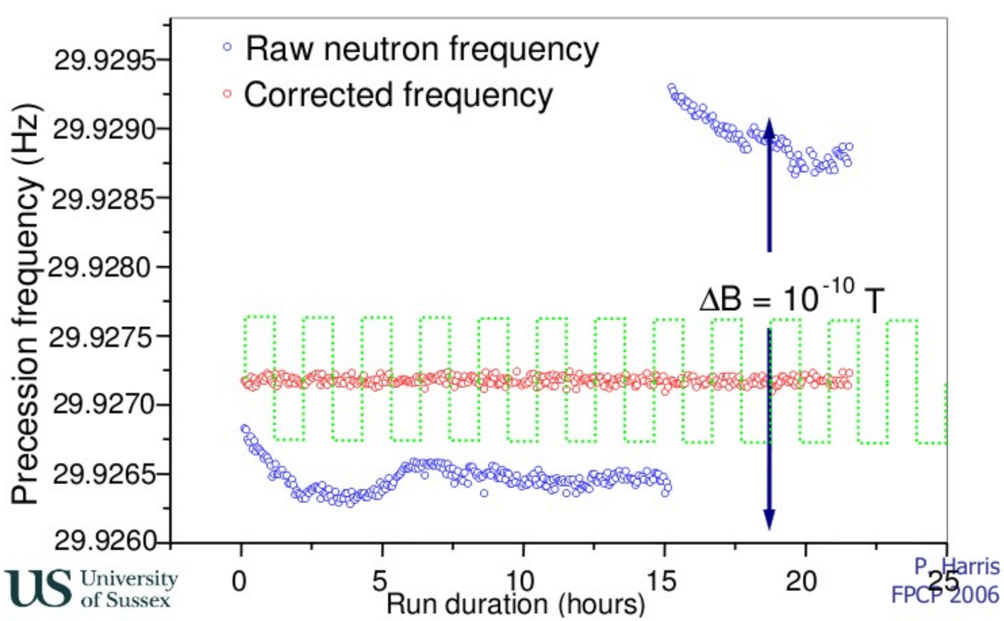
Nearing state-of-the-art in low-field NMR!

- Successful demonstration of technique behind precision EDM measurements.
- Data-taking run in Feb. 2011 – studies of homogeneity, stability of B-field.

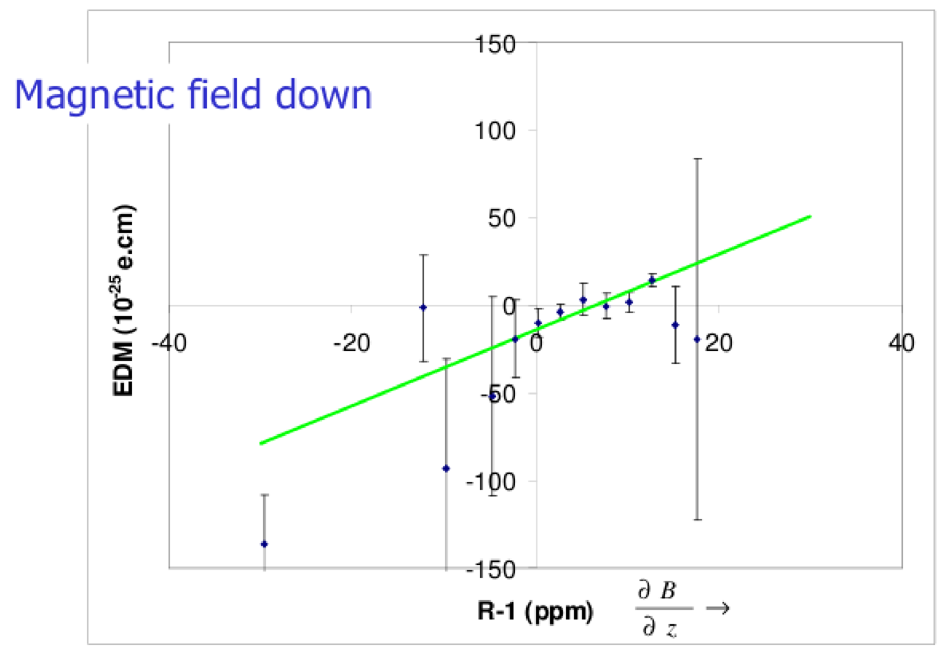
n-EDM Systematics

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

(co)magnetometry



comagnetometry



false EDM (GP) effect

Xe-129 buffer-gas nuclear spin comagnetometer

- Masuda-san's idea: leak polarized Xe-129 into the EDM cell with the neutrons and watch spins precess.
- Xe-129 pressure must be large
  - Xe-Xe Collisions -> small MFP -> small GPE.
  - Ring-down signal picked up by SQUID.
- Xe-129 pressure must be small
  - Electrical breakdown at higher pressures.
  - UCN absorption by Xe-129.
- There is a range of pressures in mTorr range that seems to work! Other idea: optical pickup (Chupp).

Complementarity

Project	H_0 field	magnetometer	EDM cell	magnetic shielding
KEK / RCNP / TRIUMF	***spherical coil***	***^{129}Xe buffer gas co-magnetometer***	***small*** **T = 300 K**	***finemet/ superconductor***
Sussex / RAL / ILL	solenoid	n at E = 0 magnetometer	large T ~ 0.5 K	μ metal superconductor
SNS	cosθ coil	^{3}He co-magnetometer	large T ~ 0.5 K	μ metal superconductor
PSI	cosθ coil	Cs multi-magnetometer	large T = 300 K	μ metal

Another major difference: our UCN source is *totally* different.

Schedule and Goals

Phase	Goals	Year
RCNP	T_2 to 130 s, HV	2011
	New source, improved UCN density	2011-12
	Horizontal EDM experiment, improvement of UCN density in EDM cell to 900 UCN/cm^3, SC polarizer, precision Xe comagnetometry	2012-13
	In 20 days production running, $d_n < 1 \times 10^{-26}$ e-cm	2013-14
TRIUMF	Commissioning and first experiment with same setup.	2015-16
	Further improvements to magnetic shielding, (co)magnetometry, EDM cell, detectors, $d_n < 1 \times 10^{-27}$ e-cm	2016-17
	Improvements to cold moderator, magnetic shielding, beam current, targetry, remote handling, cryogenics, (co)magnetometry, $d_n < 1 \times 10^{-28}$ e-cm	2018-

Project Status Report

- International Review held at TRIUMF Sept 20-21, 2010, quote from committee report:

  “The committee strongly endorses the program and finds excellent potential for the group to contribute on a significant and competitive level to the worldwide efforts. The committee was impressed by the effort and creativity within the collaboration. The Japan-Canada UCN project has to be considered as an important research opportunity for KEK, RCNP, and TRIUMF, as well as for university collaborators to take on a leadership role in an exciting research field.”

- KEK-TRIUMF-Winnipeg-RCNP MOU signed January 2011. CFI funds released.

Summary

- Neutron EDM experiment and UCN source have been developed by KEK, will be transported to TRIUMF 2014.
  Goals of 10^{-26} -> 10^{-27} -> 10^{-28} e-cm.
- UCN source would be world-class facility for experiments even beyond EDM: e.g. Neutron lifetime, Neutron Gravity levels experiment, Neutron beta-decay, nn oscillation search, neutron-ion interactions.

Thank you!

Osaka, Feb. 2011

U. Winnipeg and TRIUMF

neutron/muon Chris (Wiebe)

Xe Chris
(Bidinosti)

me

CFI
Award
Announcement
Jan 2011.

- J.W. Martin, C. Bidinosti, C. Wiebe are TRIUMF users + new faculty in subatomic physics 2011.

Advantages of our UCN approach

- Liquid (superfluid) converter technology
  - Strong against thermal and radiation stresses
- Order of magnitude lower beam current
  - Less instantaneous radiation, heat, shielding
- Unique opportunity!
  - TRIUMF has ideal infrastructure
  - Able to develop new UCN source technology unique to all others
  - Opportunity for world's best in the future.

Advantages of our EDM approach

- Use established methods at room temperature.
- Smaller EDM cell and new DC coil geometry exploiting higher UCN density to suppress systematics.
- New Xe buffer-gas comagnetometer idea to further suppress systematics.
- Availability of new UCN source.

- Add BAU relation to EDM