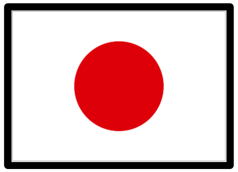
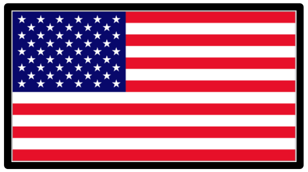
Neutron Electric Dipole Moment Search with a Spallation Ultracold Neutron Source at TRIUMF

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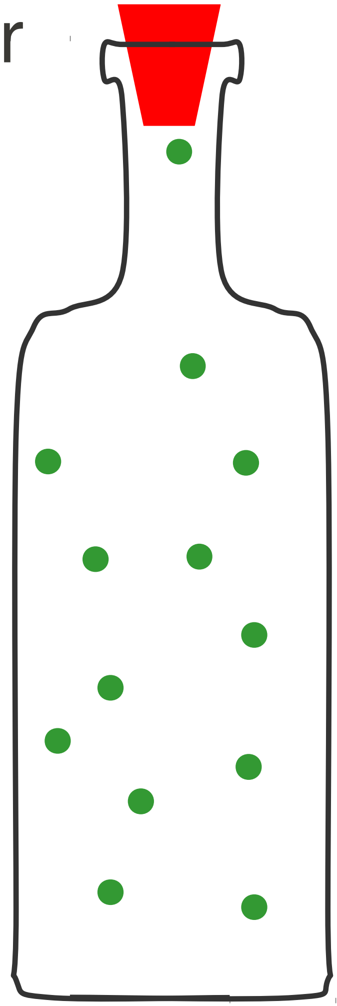
(KEK, Titech, Winnipeg, Manitoba, TRIUMF, NCSU, RCNP, UNBC, UBC, Osaka)

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 = 20 mph
  - 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



Physics Experiments for the TRIUMF UCN Source

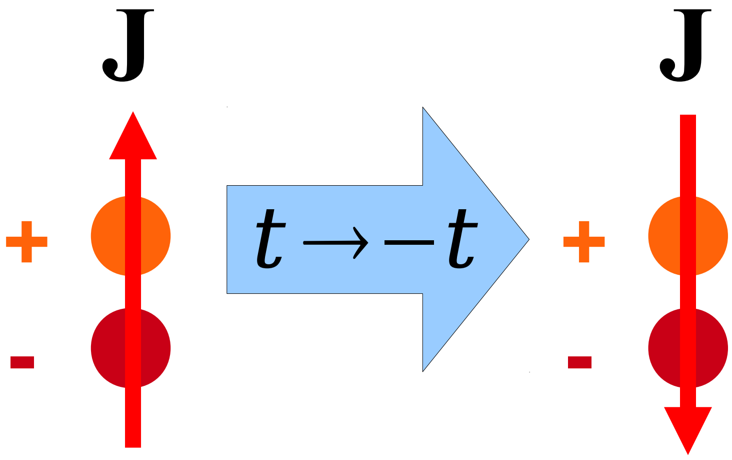
- neutron EDM
- gravity levels
- neutron β-decay
- $n\bar{n}$-oscillations
- Free n target

near term

dreams

All ideas / letters / proposals welcome

Neutron Electric Dipole Moment
(n-EDM, d_n)

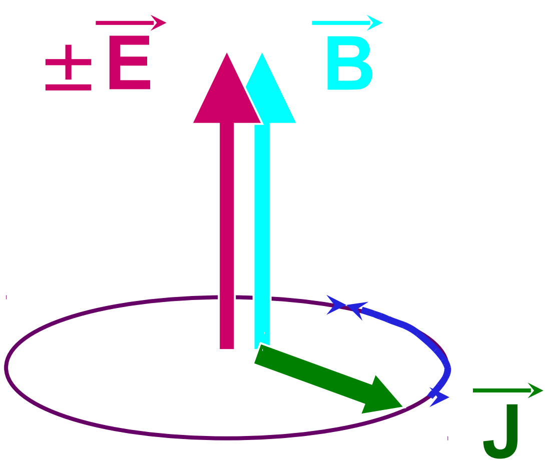


$$d_n \Rightarrow \not{T} \Rightarrow \not{CP}$$

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

- Complementary to Rn-EDM, Fr-EDM @ ISAC.

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

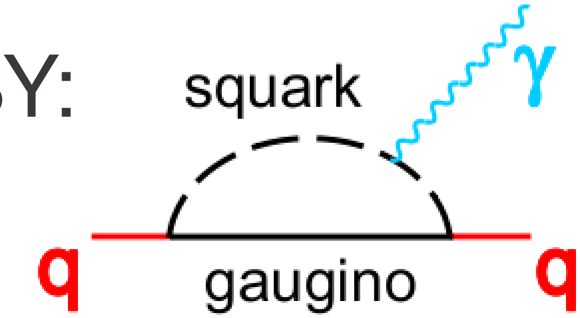


$$h\nu = 2\mu_n B \pm 2\mathrm{d}_e E$$

EDM's and SUSY

- Scale of EDM's for quarks in SUSY:

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



from P. Harris, Sussex

- For "reasonable" values of new parameters:

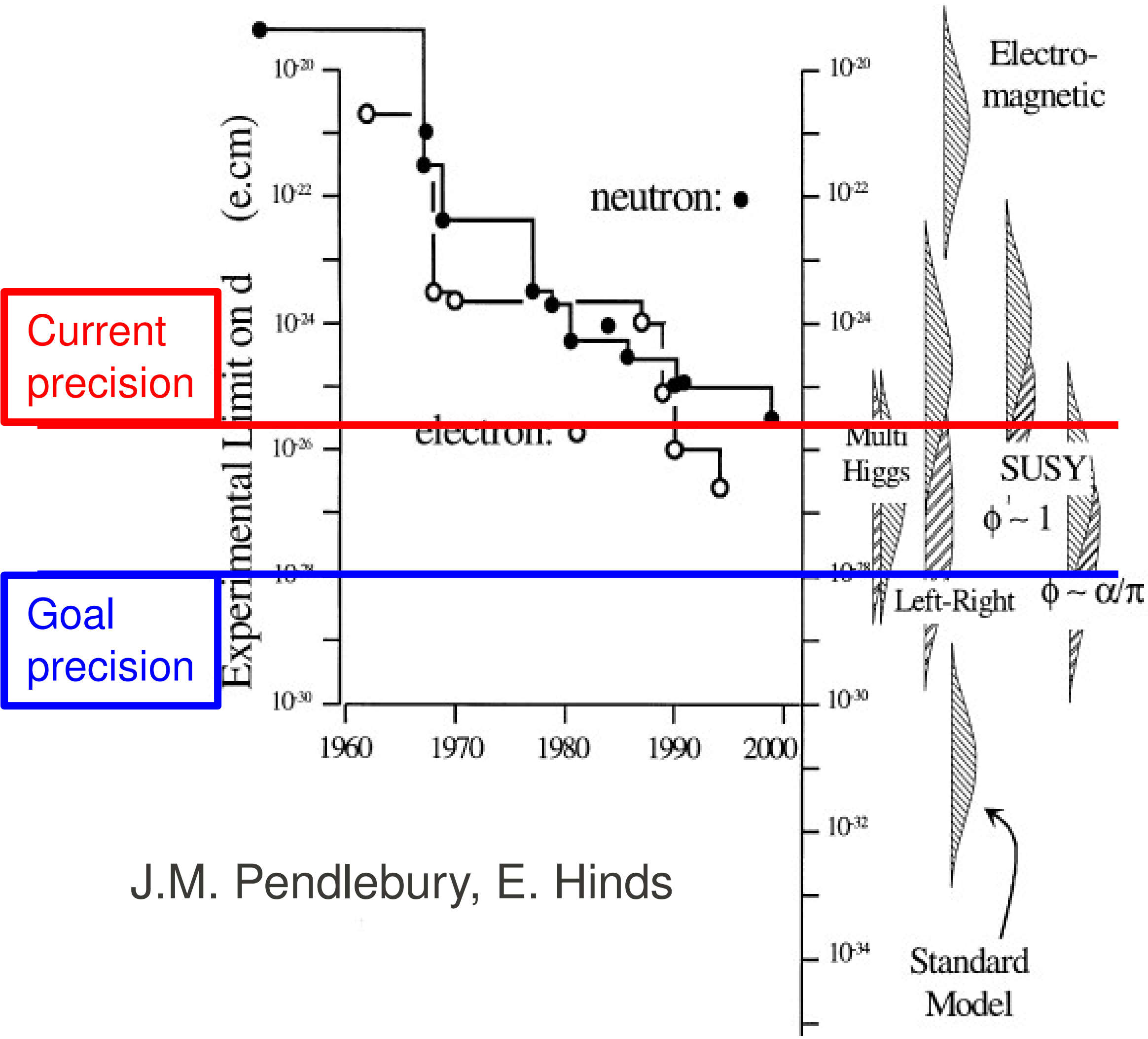
$$d_q \sim 3 \times 10^{-24} e \cdot cm$$

- 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"

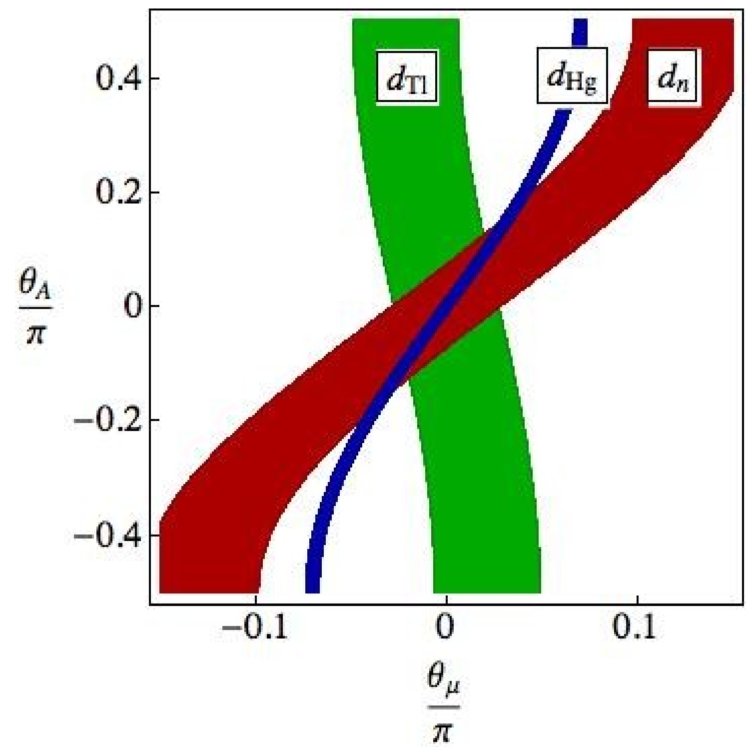
EDMs, the SM, and beyond



J.M. Pendlebury, E. Hinds

A. Ritz, M. Pospelov, et al

SUSY M = 1 TeV, tanβ = 3

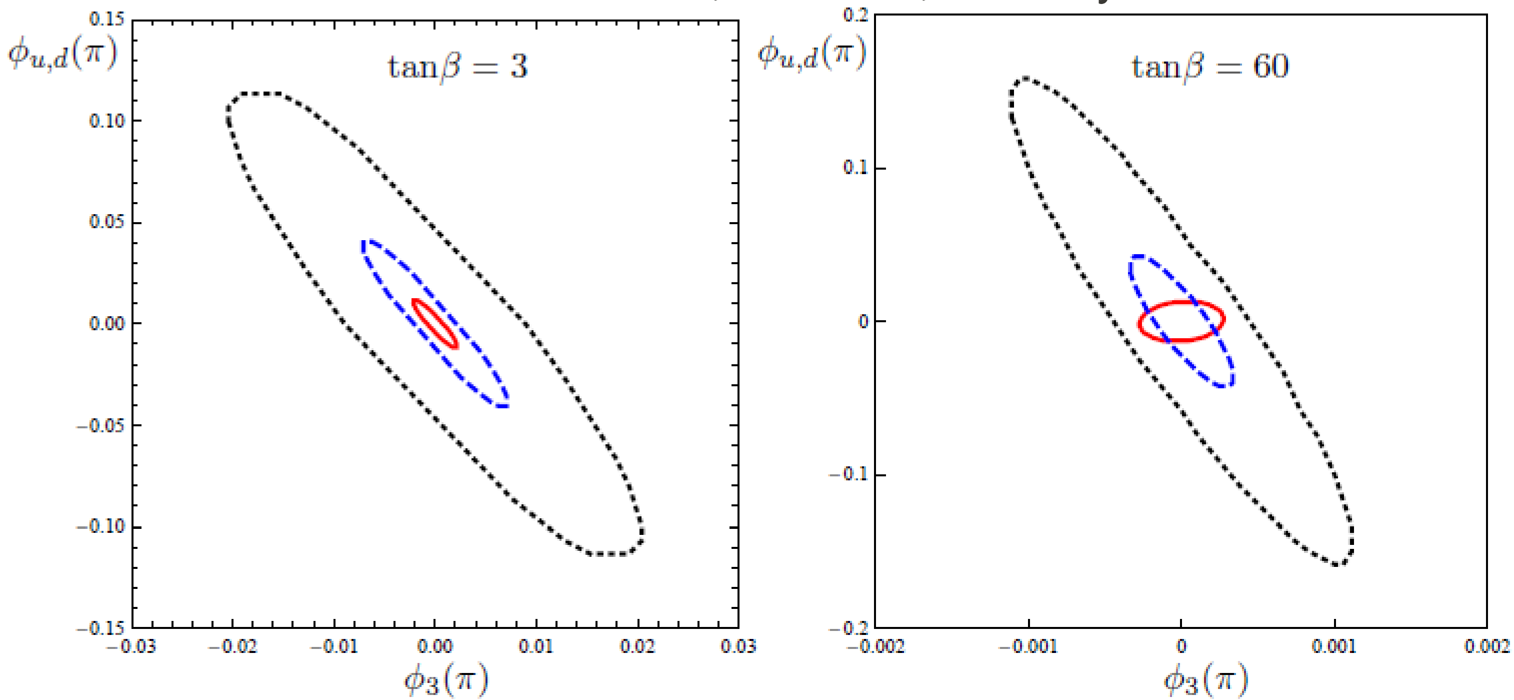


Note: universality assumptions are now even being tested

- Ultimate goal: reach the SM limit (still 5 orders of magnitude to go)

Testing Universality in MSSM

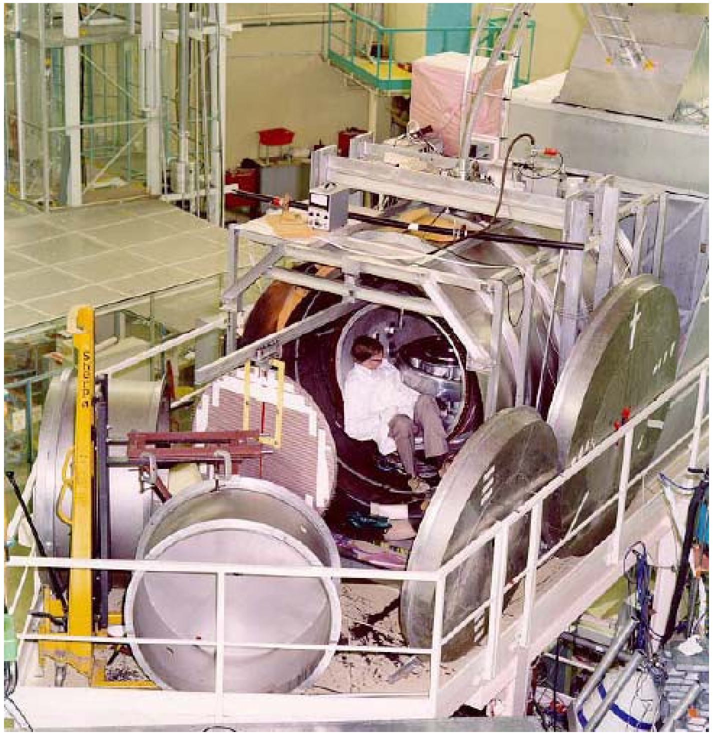
Li, Profumo, Ramsey-Musolf JHEP 1008, 062 (2010)



- Open up to full MSSM parameter space.
- Scan parameters obeying neutron, Tl, Hg limits.

Past and Future n-EDM efforts

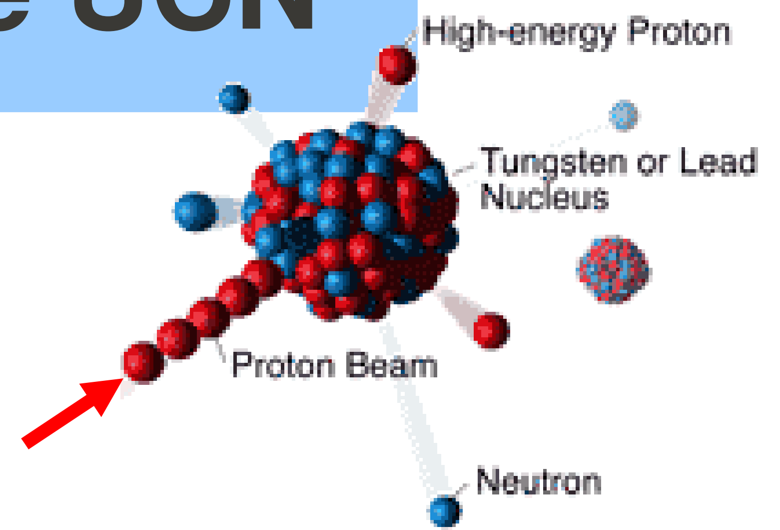
- Sussex-RAL-ILL expt. ($d_n < 3 \times 10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- New experiments:
  - CryoEDM (Sussex-RAL-ILL)
  - SNS
  - PSI
  - Japan-Canada (us)
- Different superthermal sources
- Various approaches for EDM

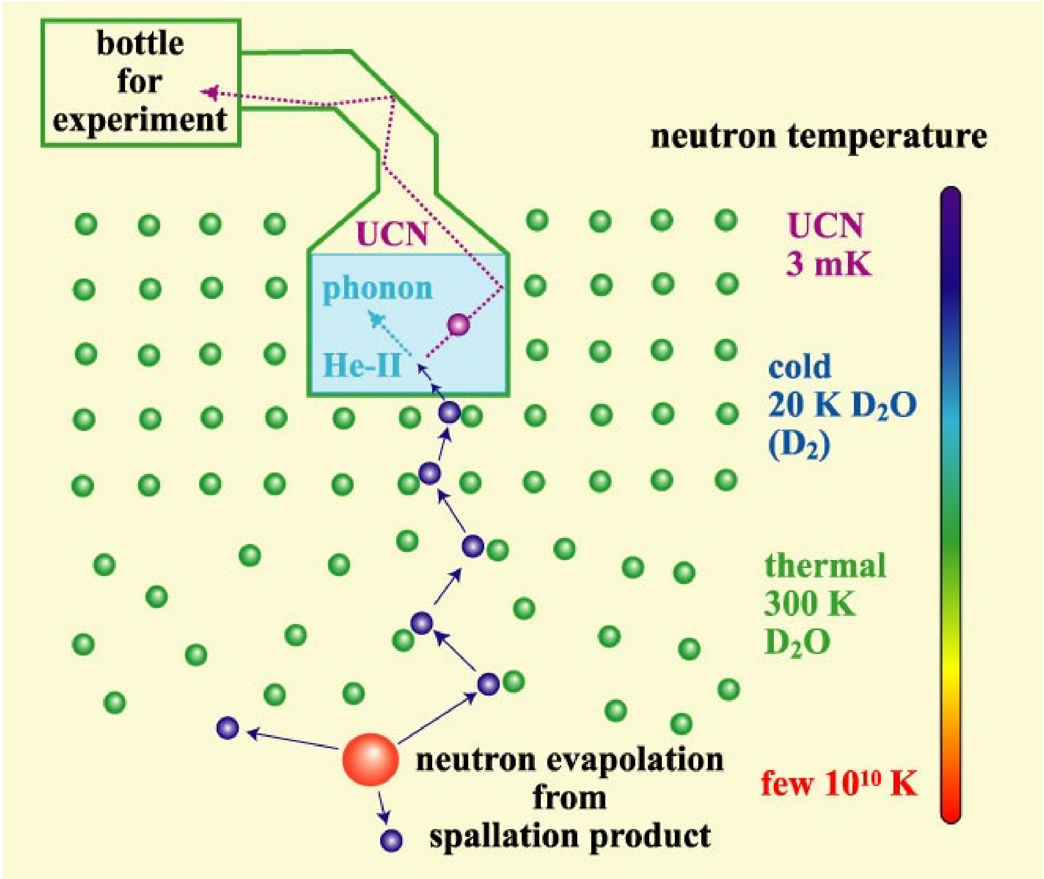


Sussex-RAL-ILL experiment

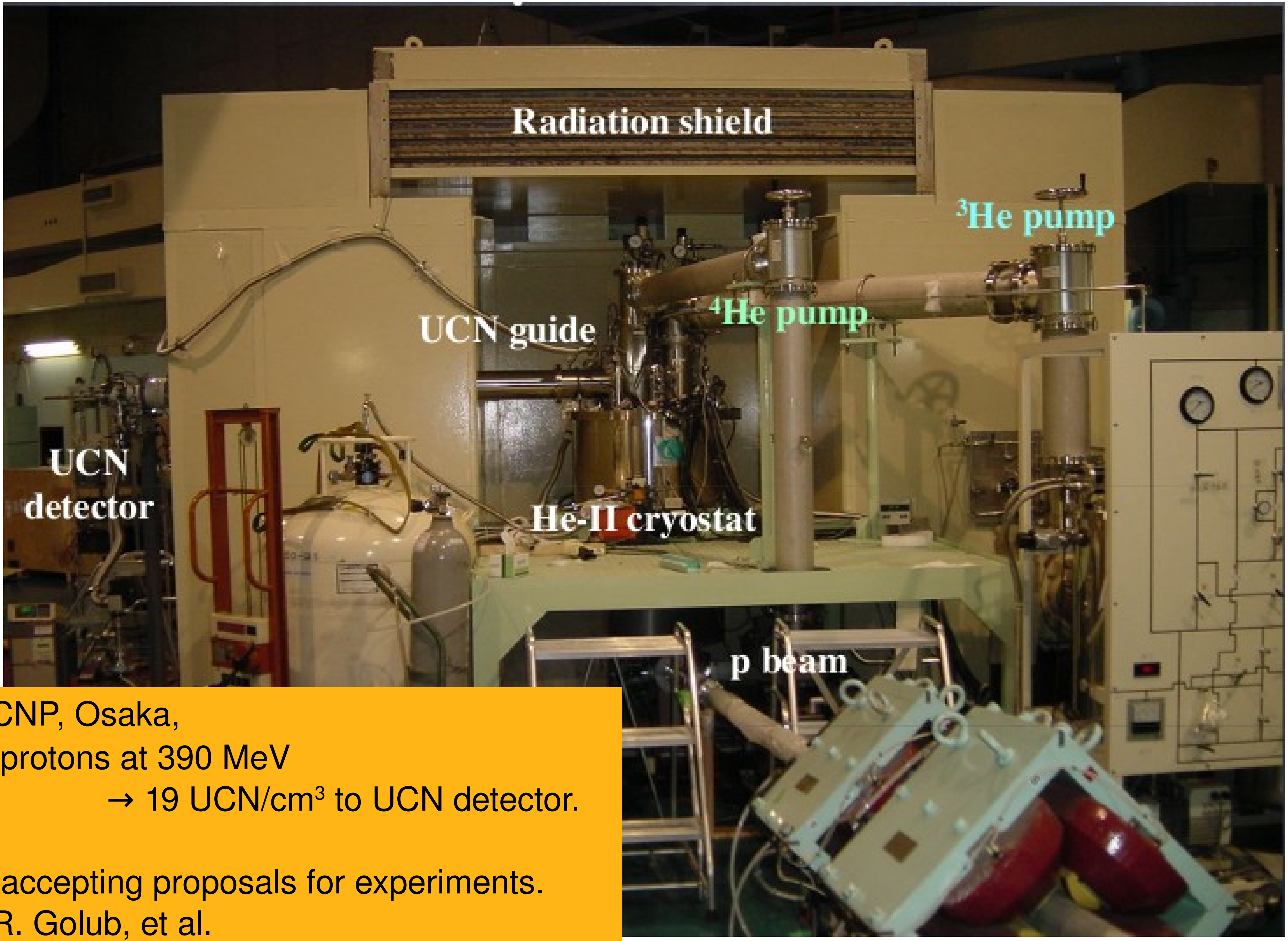
New method to make UCN

- 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)

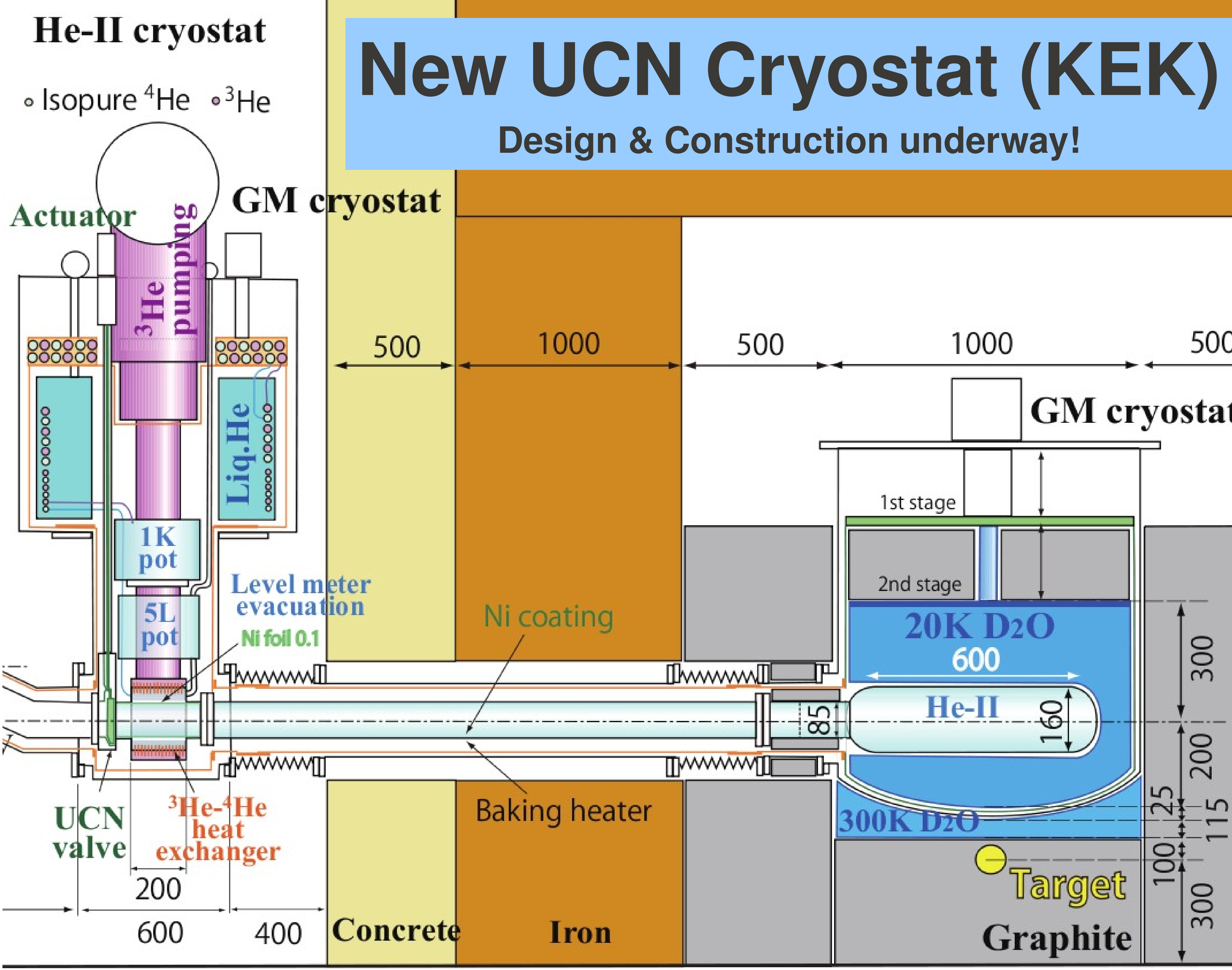


At RCNP, Osaka,
1 μa protons at 390 MeV
→ 19 UCN/cm^3 to UCN detector.

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

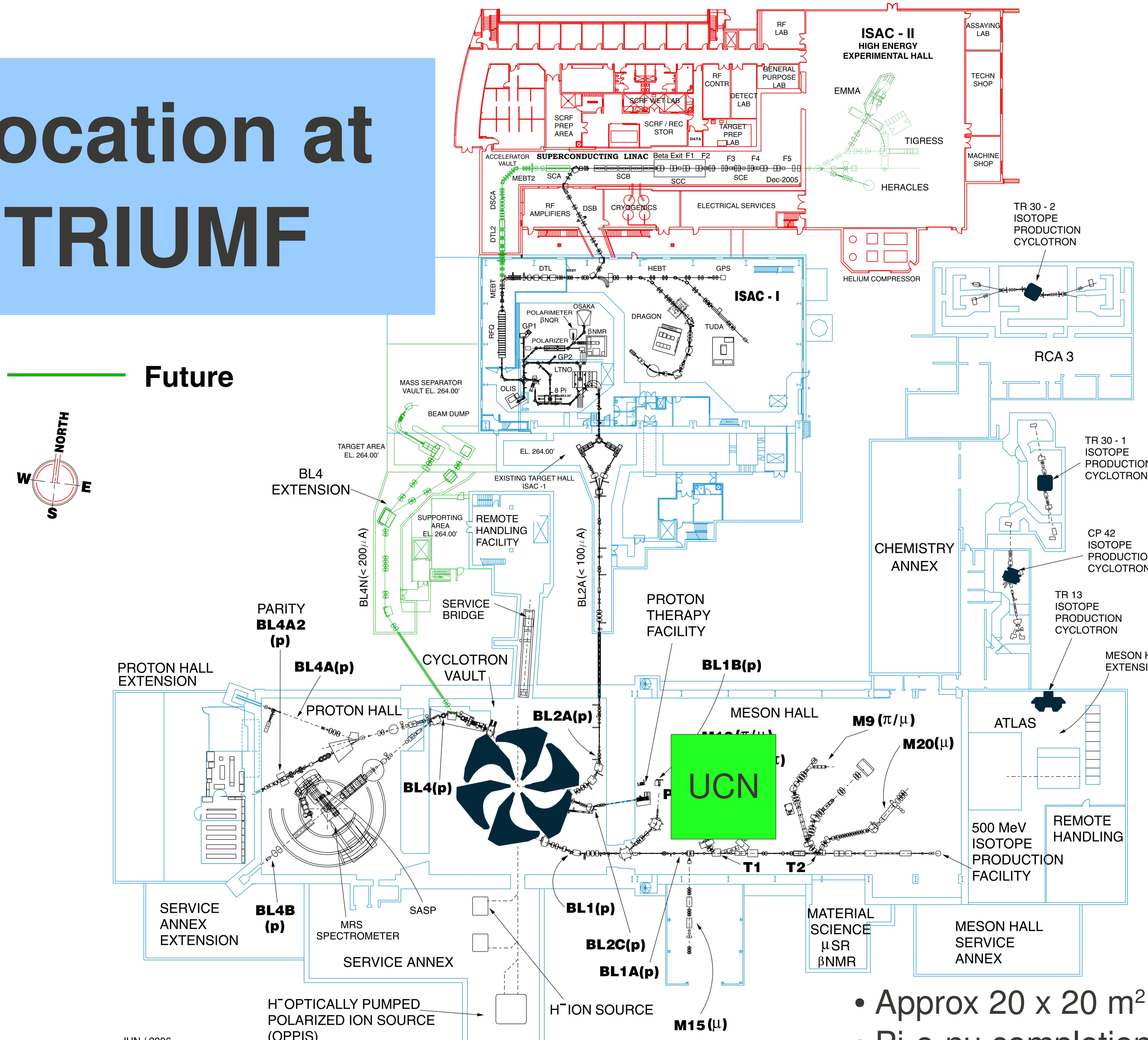
New UCN Cryostat (KEK)

Design & Construction underway!



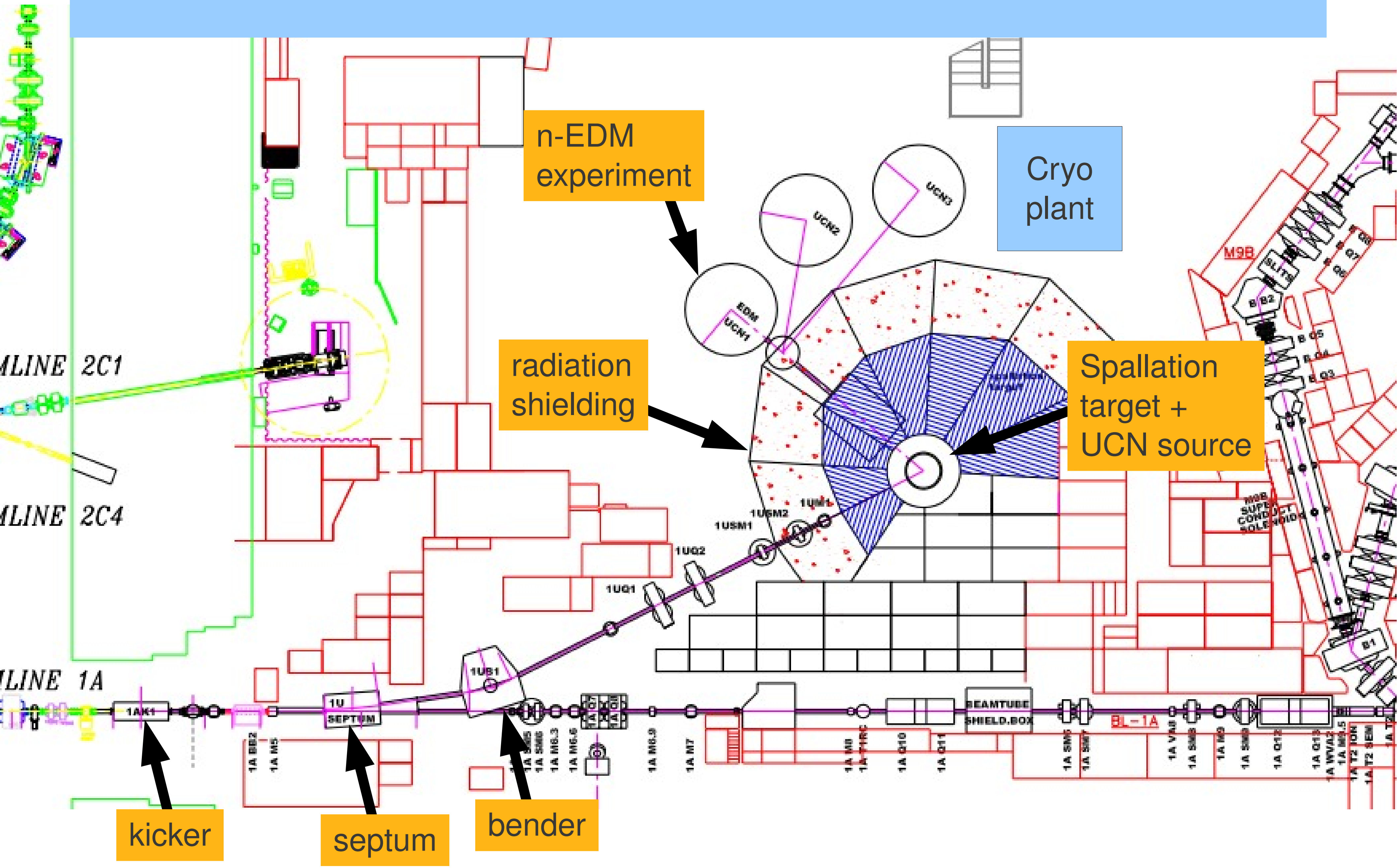
- Gain Factors (40 μA @ 500 MeV):
  - Beam energy, power x 70
  - Production volume x 1.5
  - Storage lifetime x 2.5
  - Transport eff x 2
  - $E_c^{3/2}$ (from 90 to 210 neV) x 3.5
- Goal: 5000 UCN/cm^3 in EDM cell.
- Lumi upgrade at RCNP to 10 μA allows tests thru summer 2014.
- Longer running time at TRIUMF (8 months/yr vs few weeks)

Location at TRIUMF



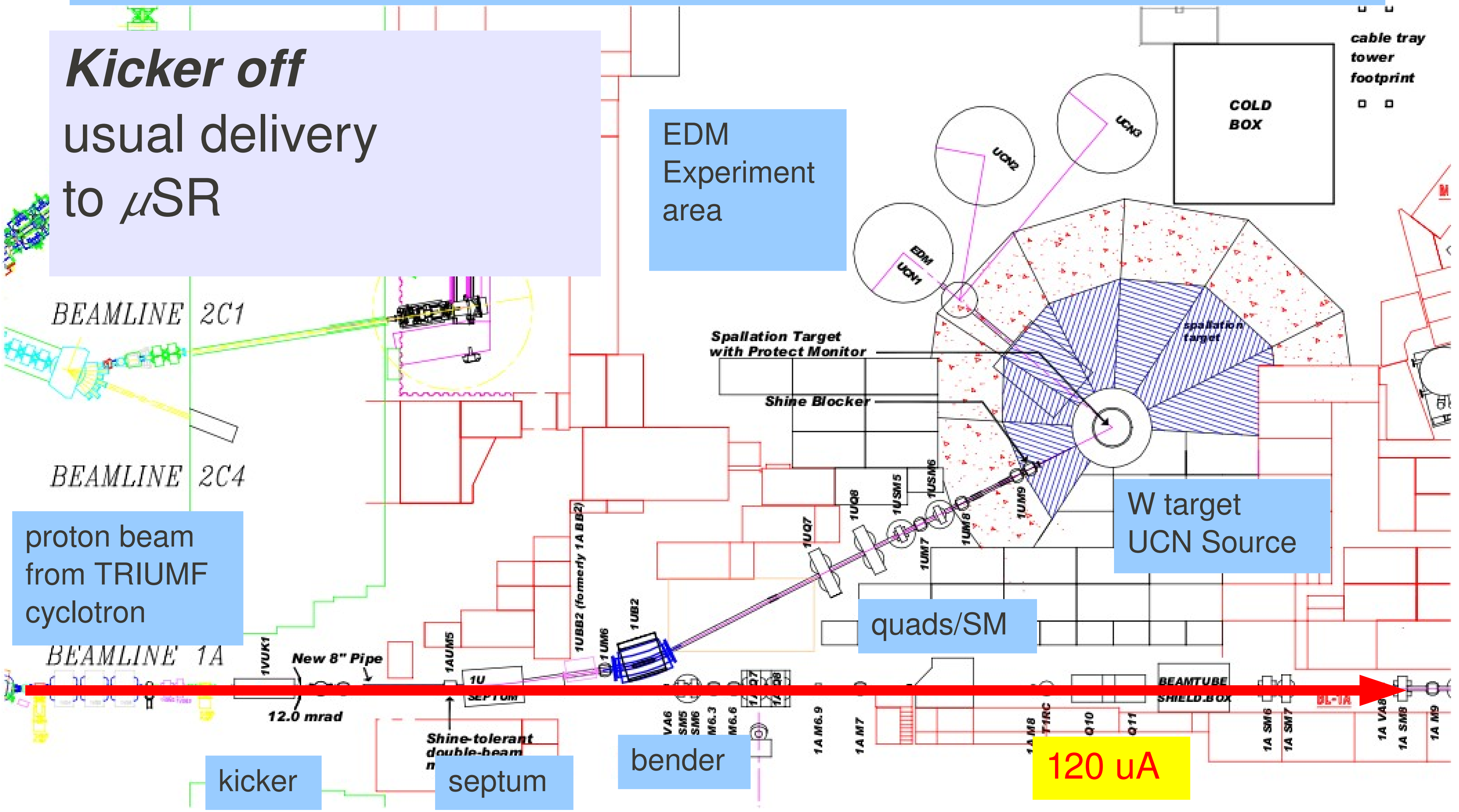
- Approx 20 x 20 m^2 box
- Pi-e-nu completion 2011

Layout in Meson Hall



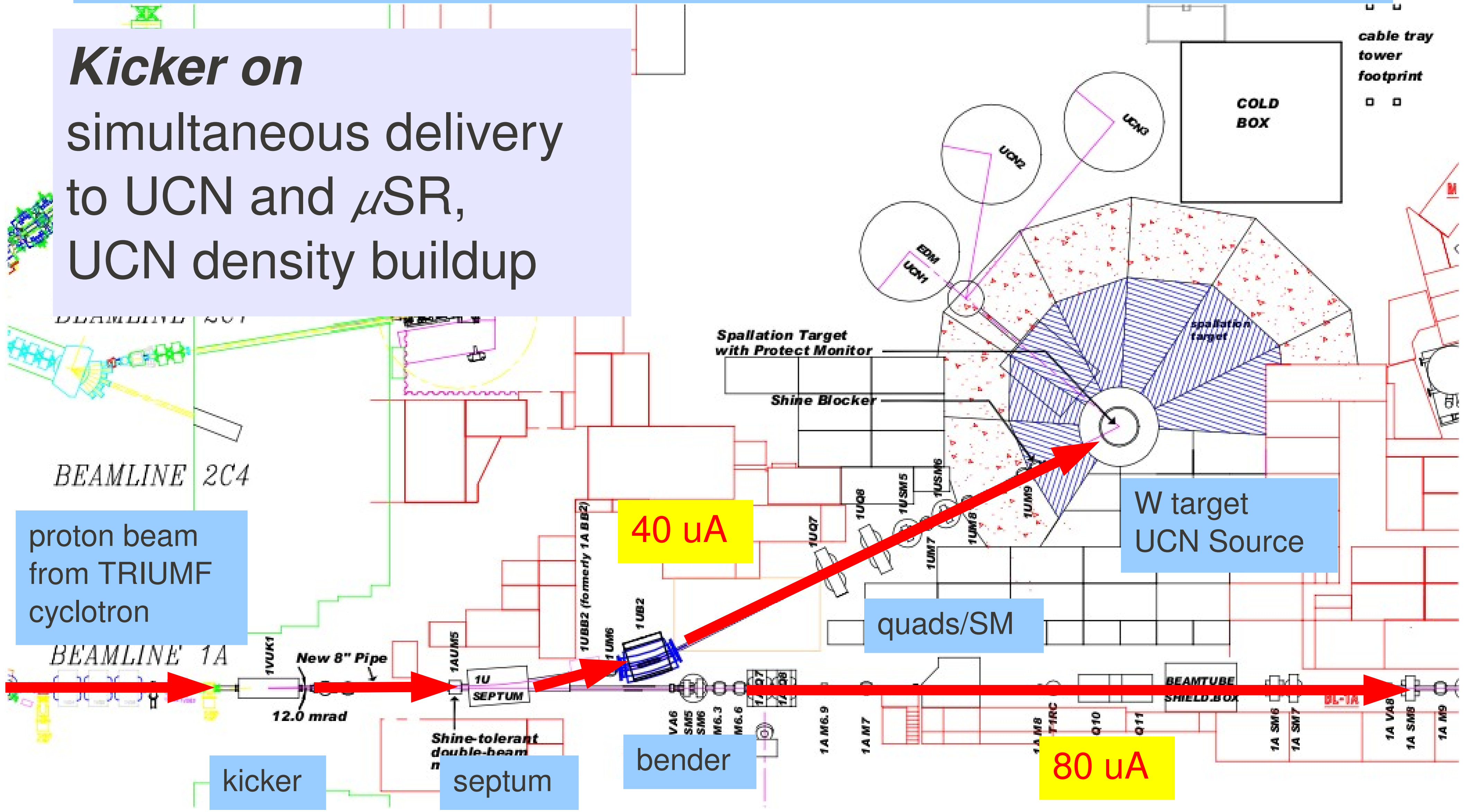
Layout and Overview

Kicker off
usual delivery
to μSR



Layout and Overview

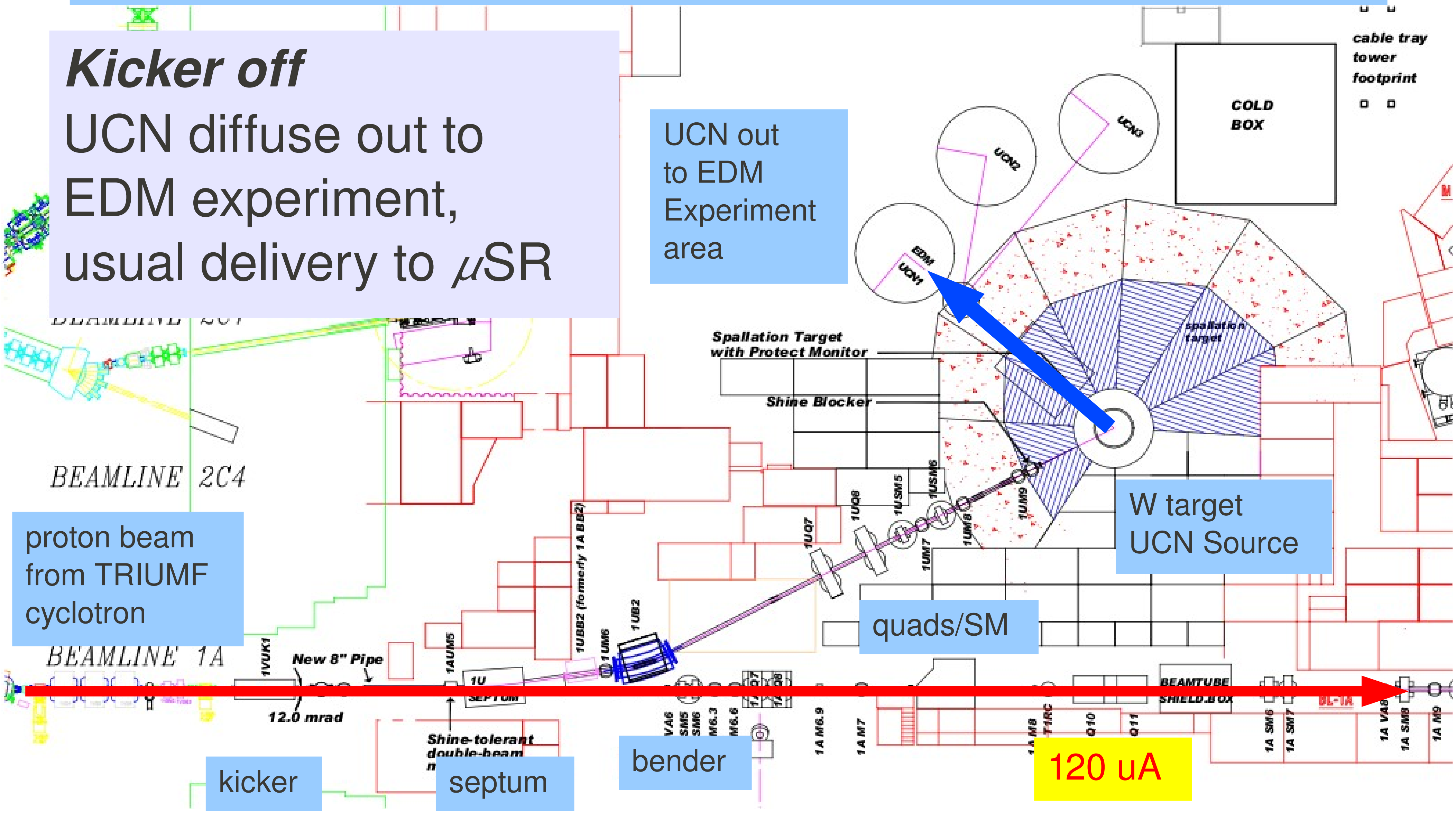
Kicker on
simultaneous delivery to UCN and μSR,
UCN density buildup



Layout and Overview

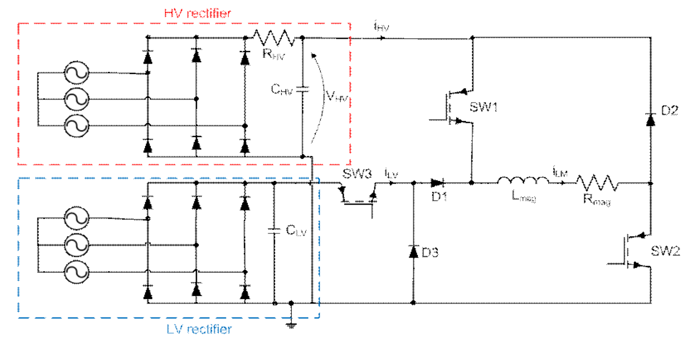
Kicker off

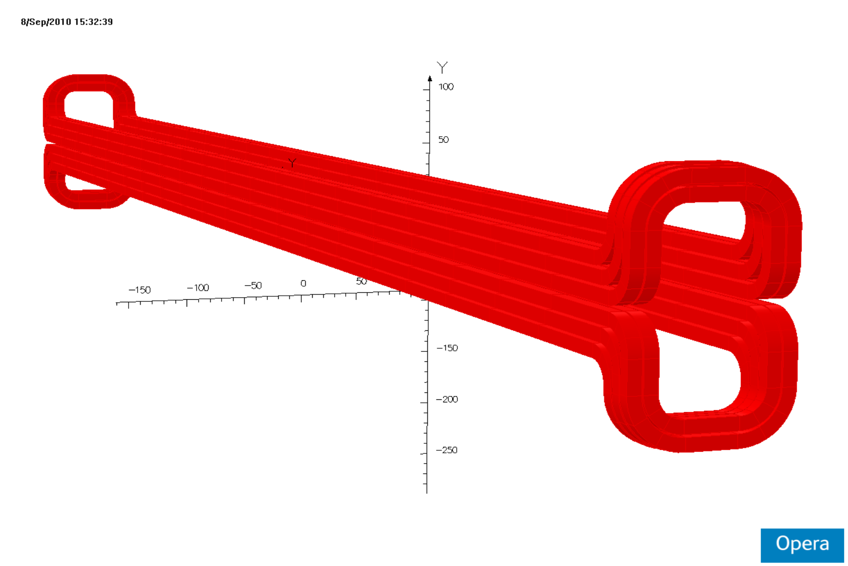
UCN diffuse out to EDM experiment, usual delivery to μSR



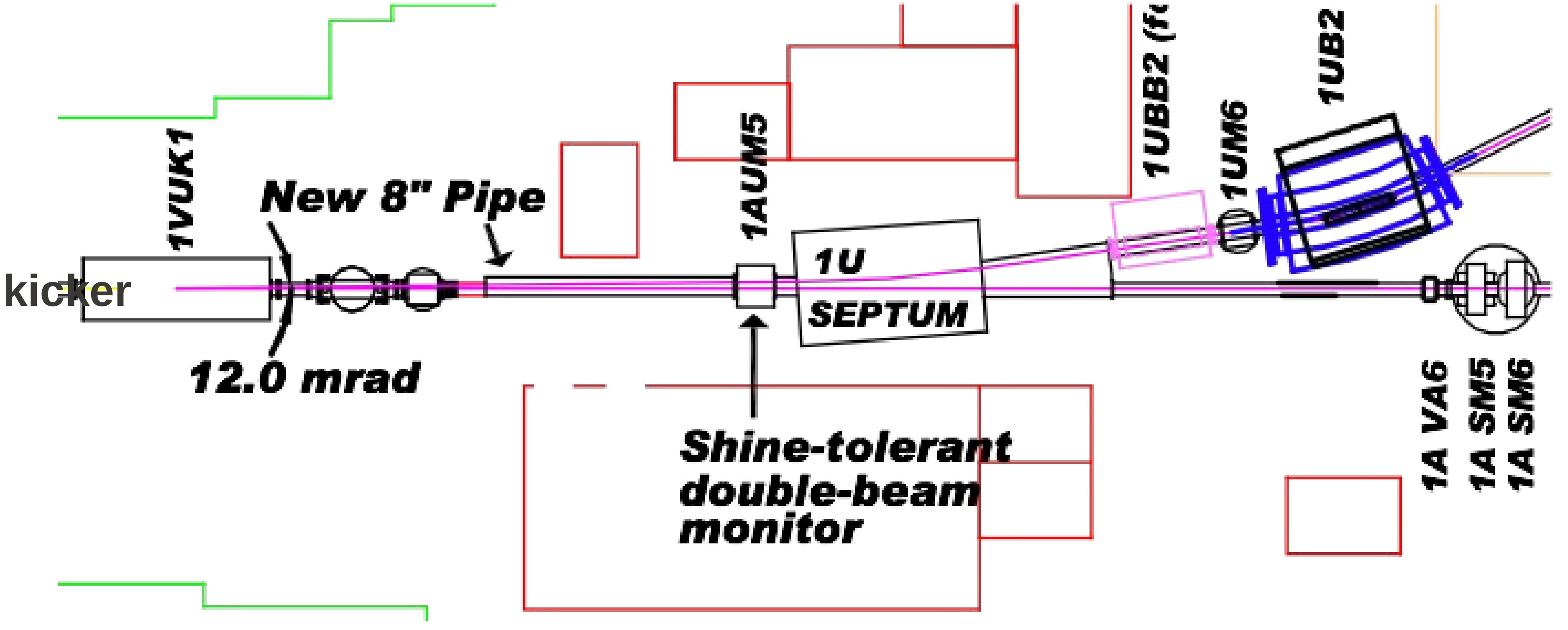
Kicker

- Redirect 1A beam into UCN line on kHz timescale using existing TRIUMF beam structure.
- Integrated 7% to UCN, 93% to CMMS users.
- TRIUMF/CERN design
  - HV SS switches
  - Fast dipole magnet
- Engineering design.





UCN beam line magnets

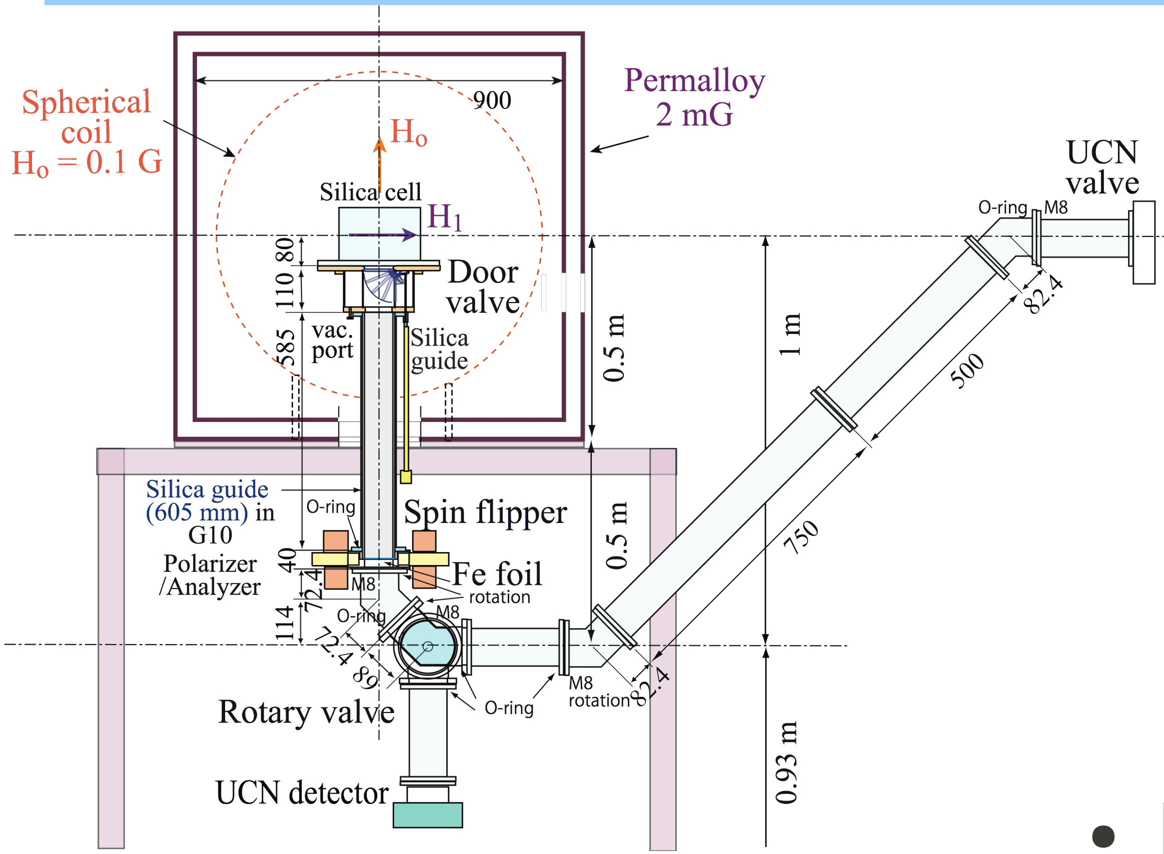


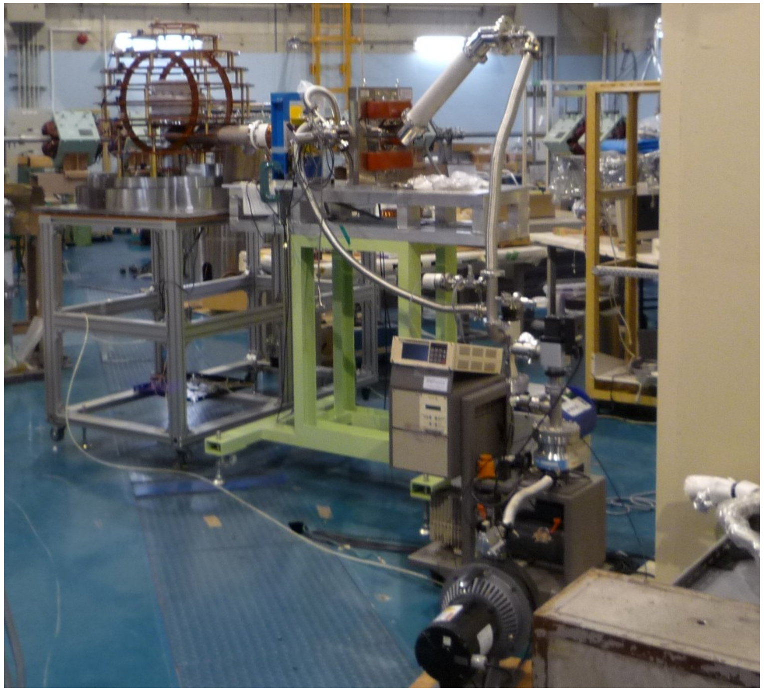
- Septum/bender magnets to be contributed by KEK
  - Lambertson design for septum
  - Sector design for bender (design completed by KEK almost ready for bids)

Other Technical Progress at TRIUMF

- Target and Remote Handling
  - Conceptual design, RCNP / TRIUMF collaboration
- Radiation Shielding conceptual design, cost
- Cryo Plant
  - Leveraged by cash & in-kind contributions from KEK
- Project Management, Cost, Schedule, Human resources, Gantt charts, MOU's, etc.

n-EDM development in Japan

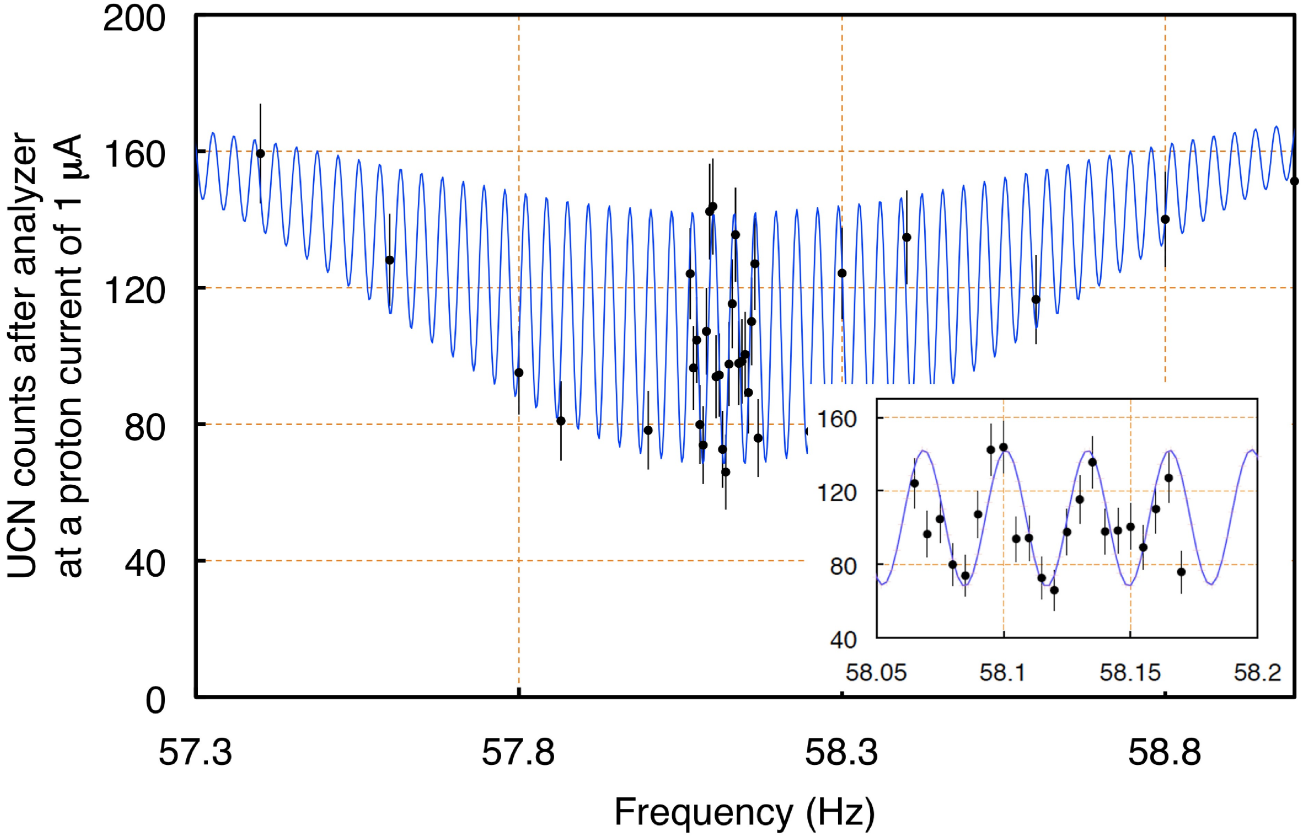




Masuda, et al. Beam tests July, December 2009, April 2010, early 2011.

- 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.)

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

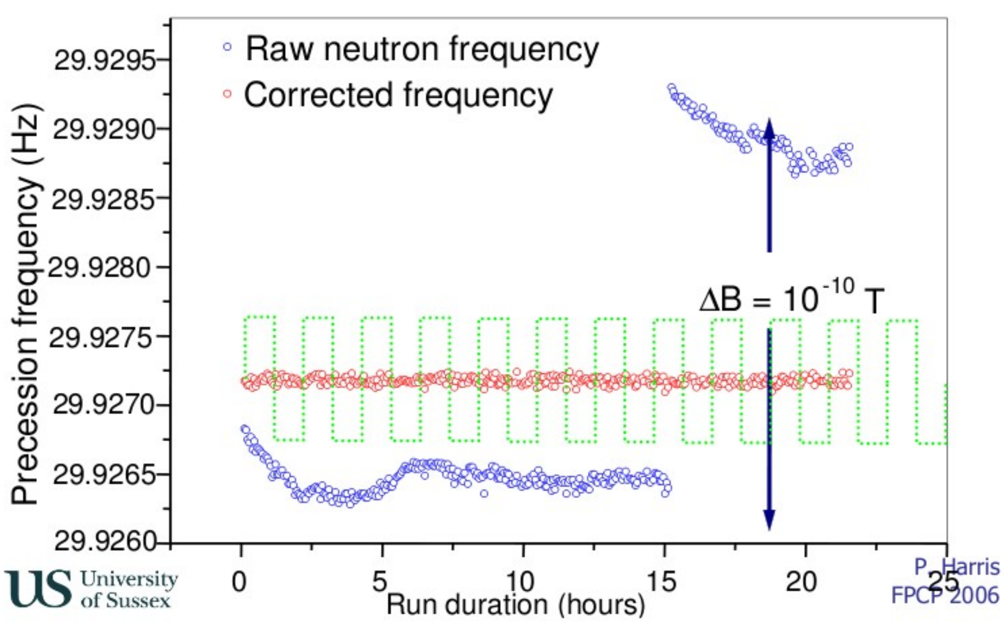
Nearing state-of-the-art in low-field NMR!

- Successful demonstration of technique behind precision EDM measurements.
- Improve field homogeneity, profile, magnitude, shielding for longer T_2, Jan 2011.

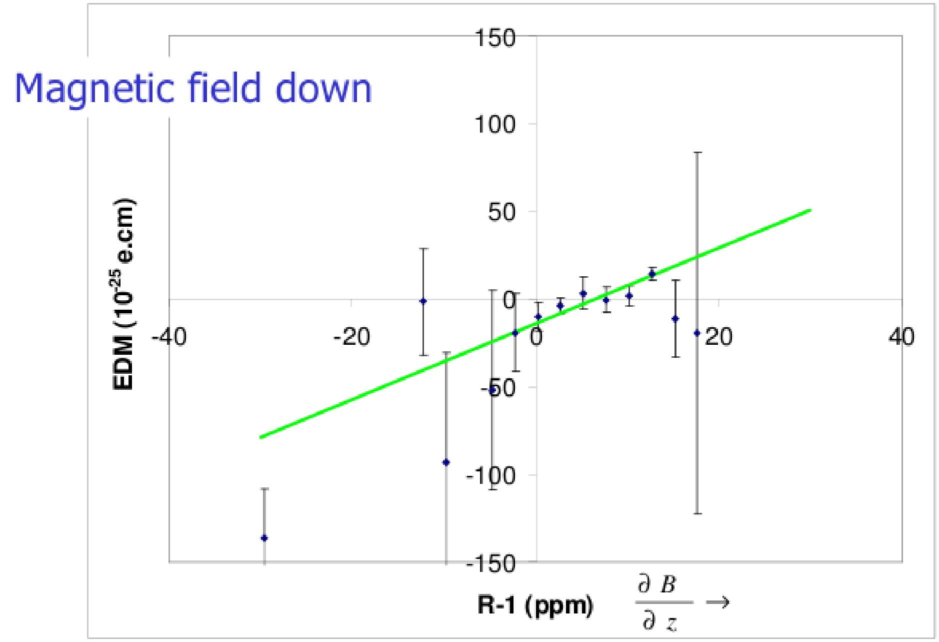
n-EDM Systematics

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

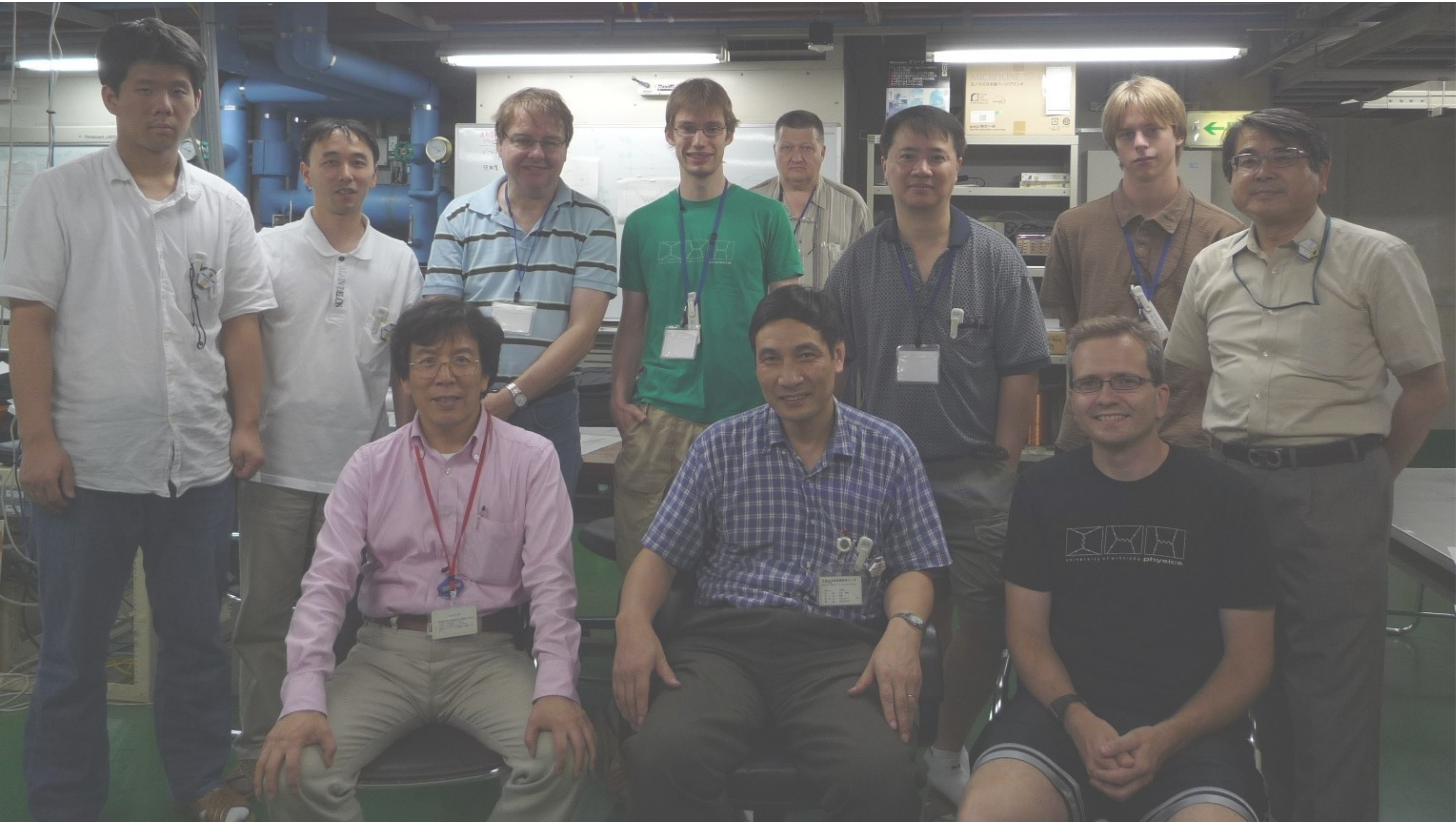
  "The committee strongly endorses the program and finds excellent potential for the group to contribute on a significant and competitive level to the worldwide efforts. The committee was impressed by the effort and creativity within the collaboration. The Japan-Canada UCN project has to be considered 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."

- Top priority is to sign MOU (KEK-TRIUMF-RCNP-Winnipeg); it is required to release *any* CFI, MB, Winnipeg funds in Canada.

Summary

- Neutron EDM experiment and UCN source have developed in Japan, transported to Canada 2014.
  Goals: 10^{-26} -> 10^{-27} -> 10^{-28} e-cm.
- UCN source would be world-class facility for experiments beyond EDM: e.g. Neutron lifetime, Neutron Gravity levels experiment, Neutron beta-decay, $n\bar{n}$ oscillation search, neutron-ion interactions.

Thank you!



Osaka, July 2009.

Funding Status

- UCN source installation infrastructure
  - Support in Canada from CFI (Winnipeg), TRIUMF, Acsion Industries, MB Gov't.
  - Japan JSPS (Y. Masuda), plus additional KEK internal funds, RCNP Osaka internal funds.
- EDM experiment
  - Support in Japan by same + additional JSPS support to be sought.
  - Some CFI support received (Winnipeg).
  - Further NSERC/CFI/other support to be sought.

Funding Status

- HQP + Travel
  - NSERC support ramping FY2010-2013.
  - Supplementary support for new collaborators is being sought FY2011-2013.
  - Support through Winnipeg CFI matching
- General status
  - International Review of Program at TRIUMF Sept. 20-21, 2010.
  - Need signed MOU (KEK-RCNP-TRIUMF-Wpg)

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.