Ultracold Neutrons at TRIUMF

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NSERC
CRSNG

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

Outline:

- UCN Production and source
- Physics experiments at the UCN source: neutron EDM
- Materials science with UCN? with VCN?
- The future of neutron scattering in Canada?

TRIUMF

International Spallation Ultracold Neutron Source

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

Collaborators: T. Adachi, K. Asahi, J. Birchall, J.D. Bowman, L. Buchmann, C. Davis, T. Dawson, B.W. Filippone, M. Gericke, R. Golub, K. Hatanaka, M. Hayden, T.M. Ito, S. Jeong, A. Konaka, E. Korobkina, E. Korkmaz, L. Lee, R. Mastumiya, K. Matsuta, M. Mihara, A. Miller, W.D. Ramsay, S.A. Page, B. Plaster, I. Tanihata, W.T.H. van Oers, Y. Watanabe

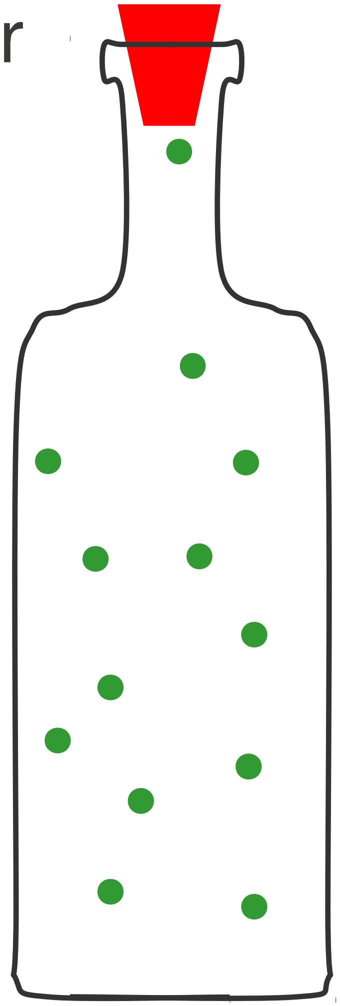
(KEK, Titech, Winnipeg, Manitoba, ORNL, TRIUMF, NCSU, Caltech, RCNP, SFU, LANL, Tokyo, UNBC, Osaka, Kentucky)

We propose to construct the world's highest density source of ultracold neutrons and use it to conduct fundamental and applied physics research using neutrons.

Funding secured in Canada (CFI) and Japan

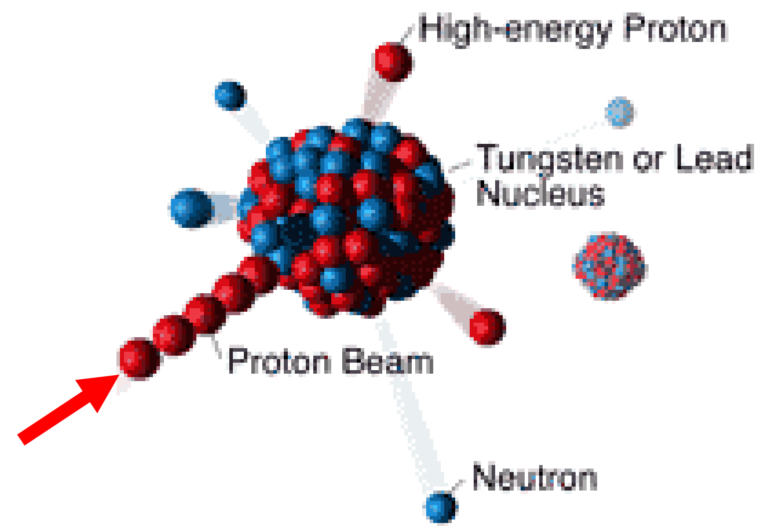
Ultracold Neutrons (UCN)

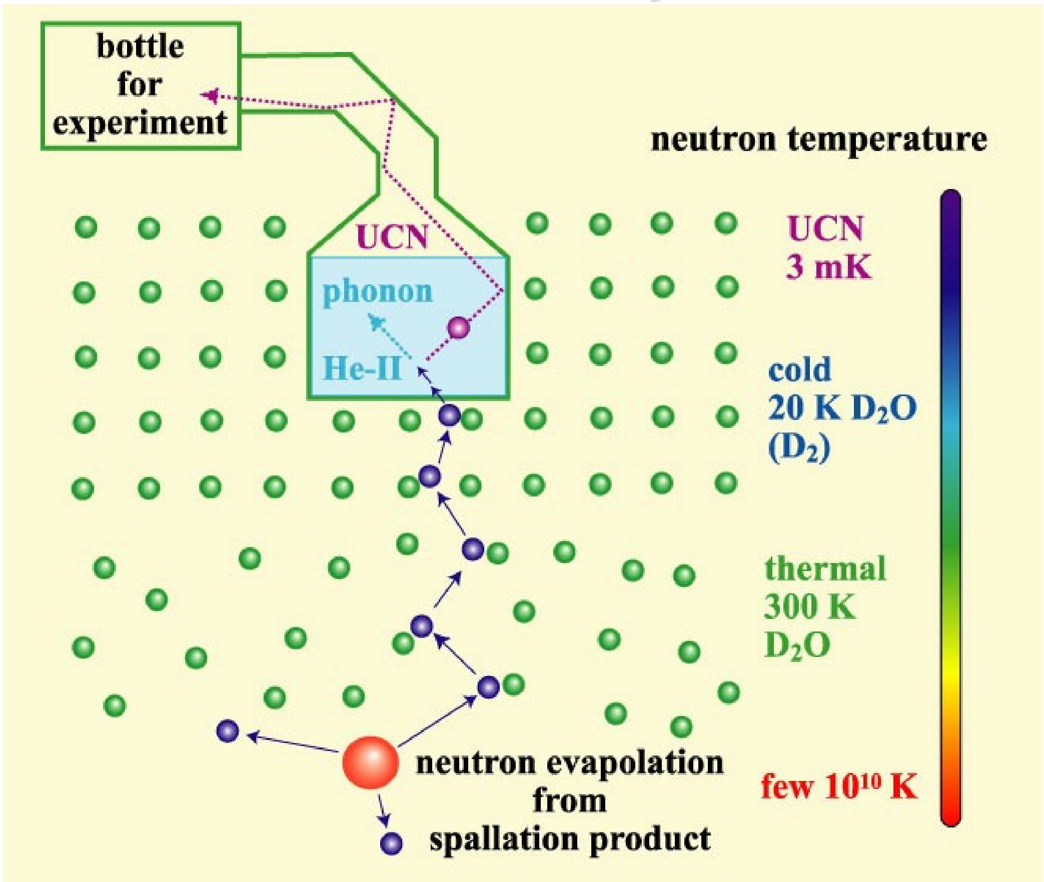
- UCN are neutrons that are moving so slowly that they are totally reflected from a variety of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s = 30 km/h = 20 mph
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - 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



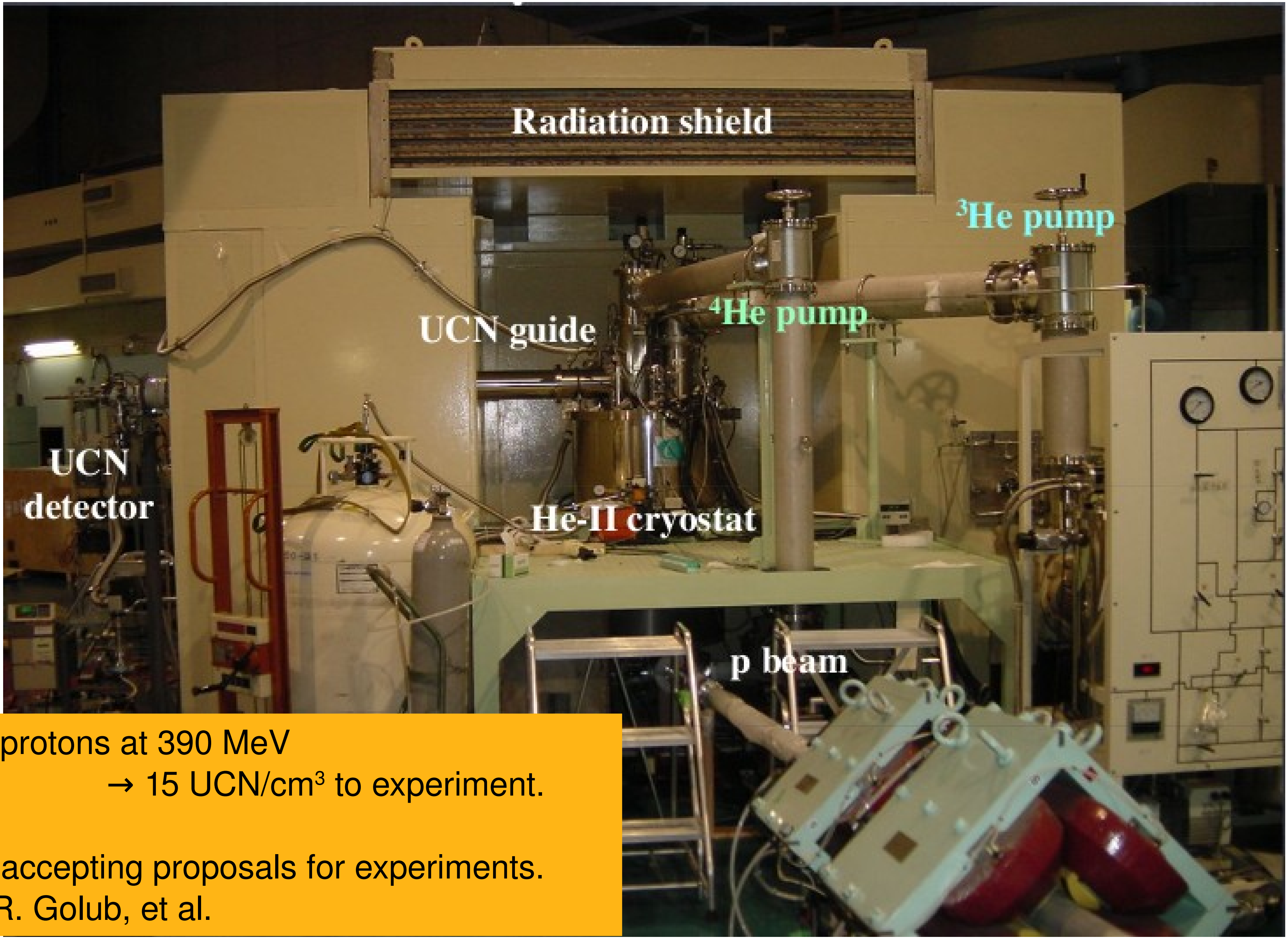
How to make UCN

- 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.





Japan UCN Source (Masuda, et al)

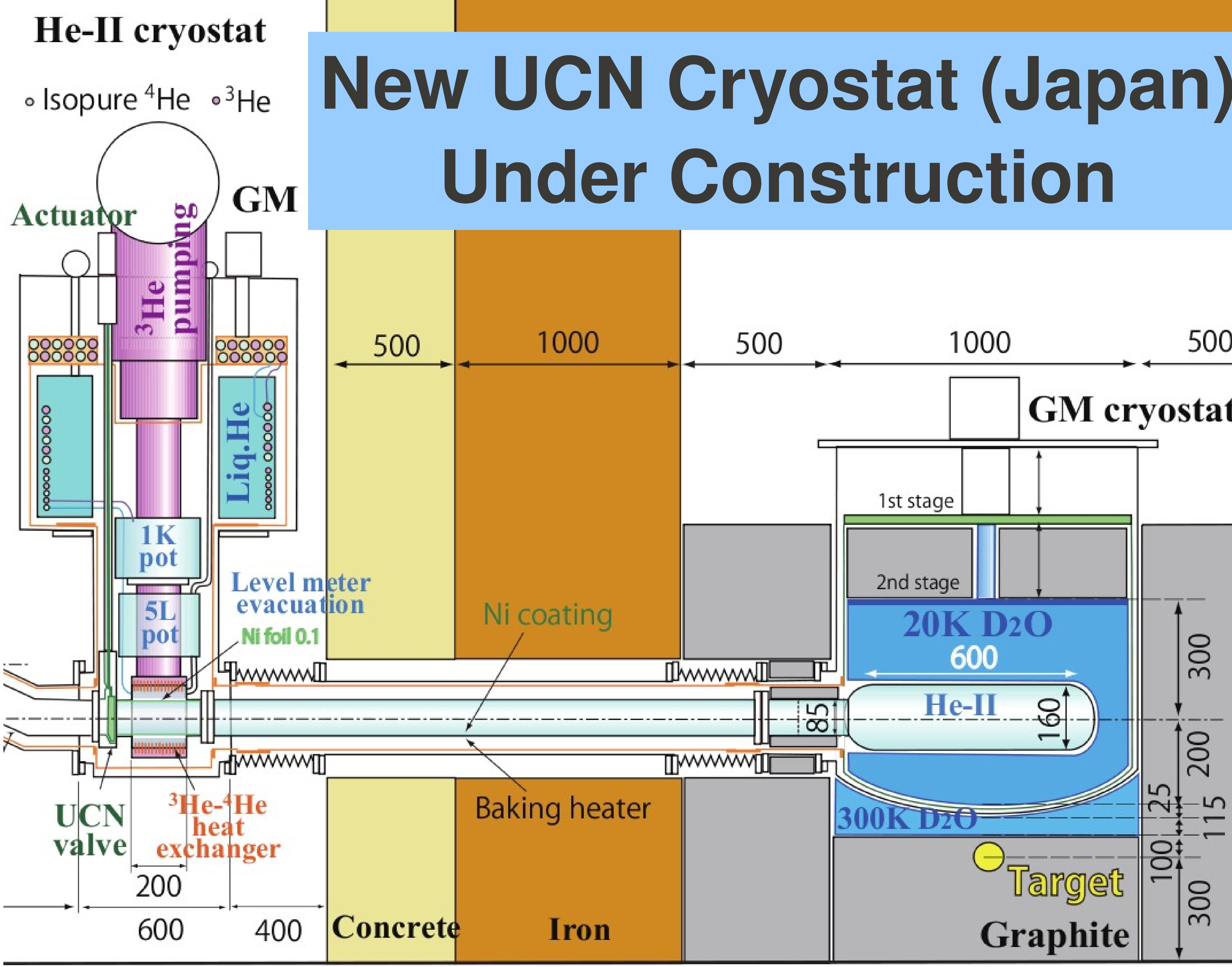


1 μa protons at 390 MeV
→ 15 UCN/cm^3 to experiment.

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

- Beam parameters for UCN source at TRIUMF:
  - 500 MeV protons at 40 μA
- At RCNP, Osaka:
  - 390 MeV protons at 1 μA
- A fifty-fold increase in beam power.
- Cyclotron operates ~ 8 months/yr.

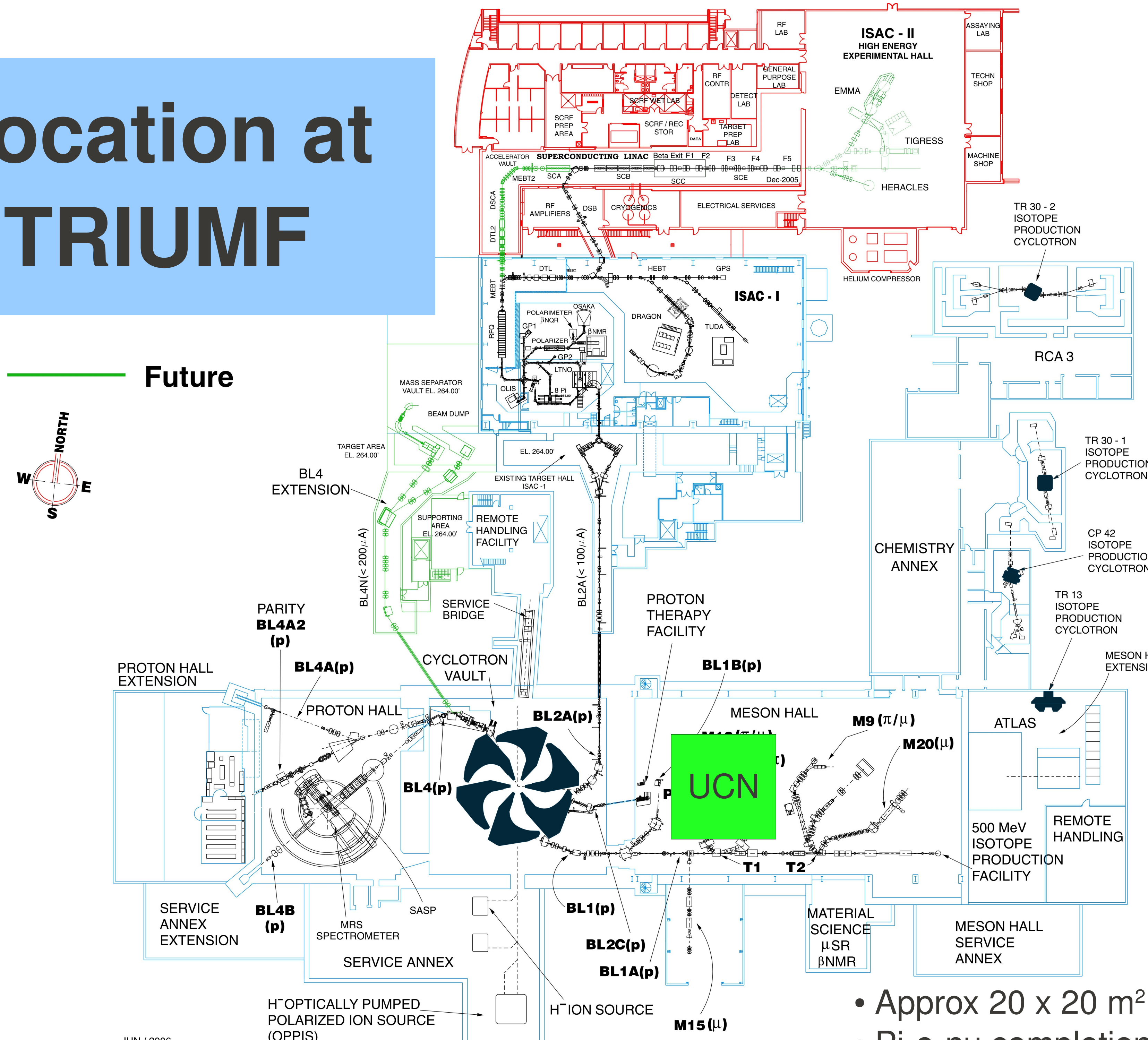
New UCN Cryostat (Japan) Under Construction



World's UCN projects

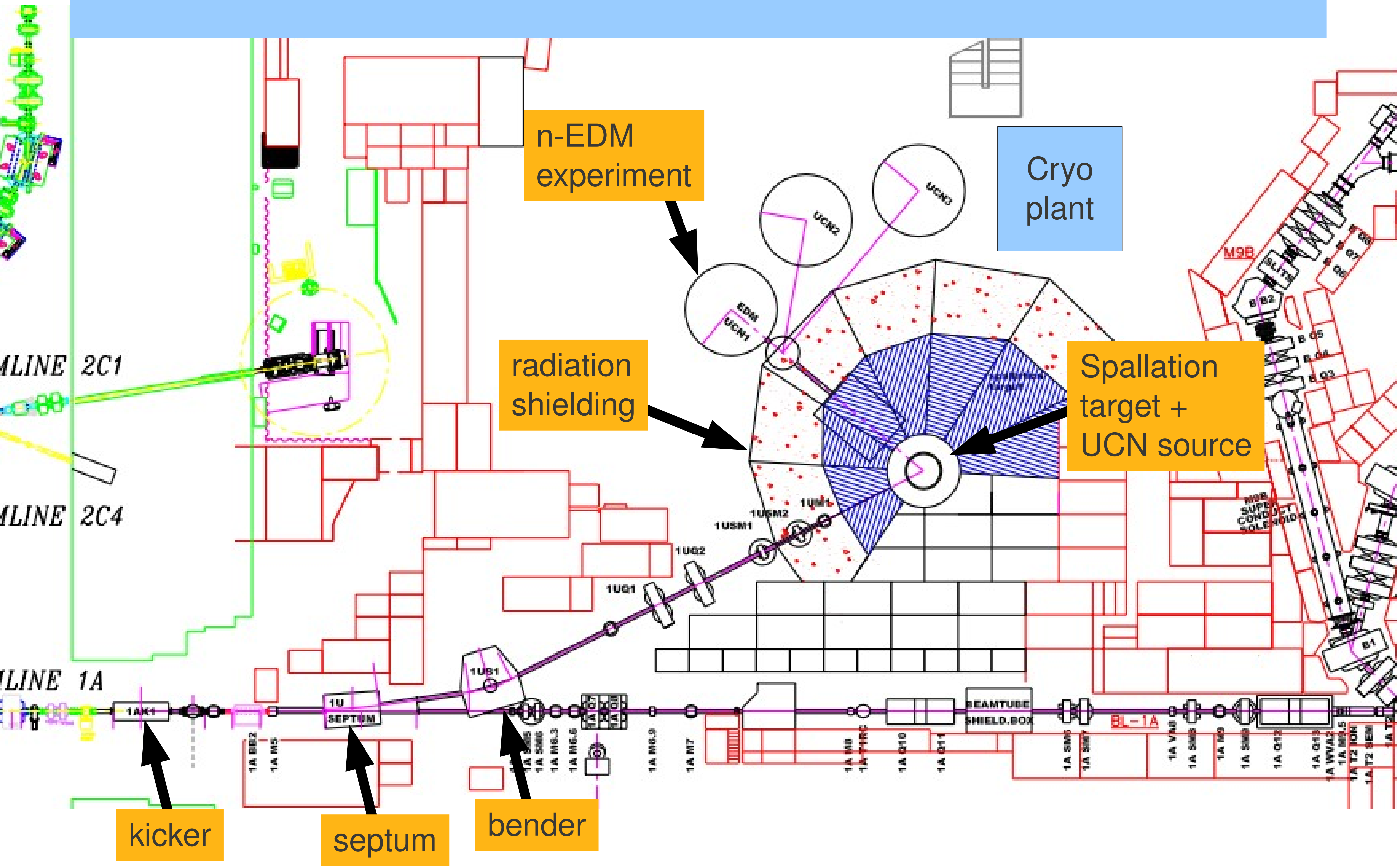
	source type	E_c neV	P_{UCN} /cm^3/s	τ_s s	ε_{ext}	ρ_{UCN} /cm^3 source/exp.
TRIUMF	spallation He-II	210	0.4×10^4 (10L)	150	~1	3×10^5 (20L) 1-5 x 10^4
ILL	n beam He-II	250	10	150	~1	**/1000
SNS	n beam He-II	134	0.3 (7L)	500	1	**/150
LANL *	spallation SD2	250	4.4×10^4 (240cm^3)	1.6	1.3×10^3/ 4.4×10^4	**/120
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/**

Location at TRIUMF



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

Layout, April 2010



Physics Experiments for the TRIUMF UCN Source

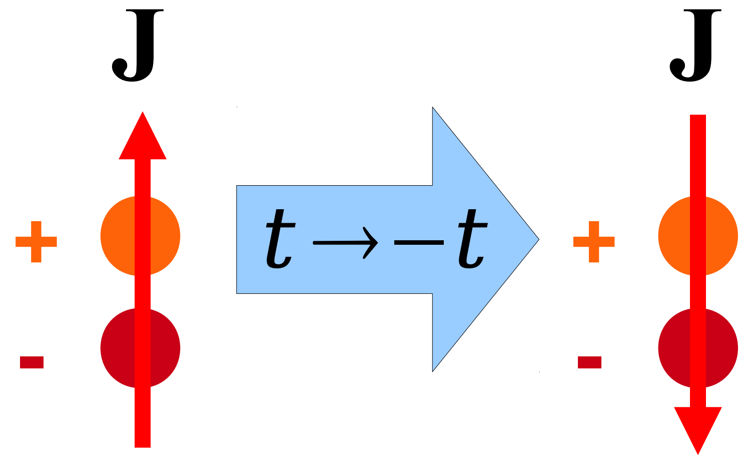
- neutron lifetime
- gravity levels
- **n-EDM**
- $n\bar{n}$-oscillations
- Free n target
- Quantum mechanics / computing
- Surface physics / VCN line?

near term (neutron lifetime, gravity levels, n-EDM)

dreams ($n\bar{n}$-oscillations, Free n target)

Open for ideas / letters / proposals

Neutron Electric Dipole Moment (n-EDM, d_n)



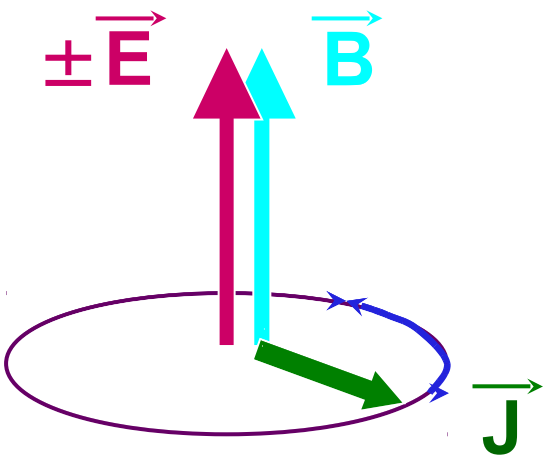
$$d_n \Rightarrow \not{T} \Rightarrow \not{CP}$$

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

- Complementary to Rn-EDM TRIUMF ISAC.

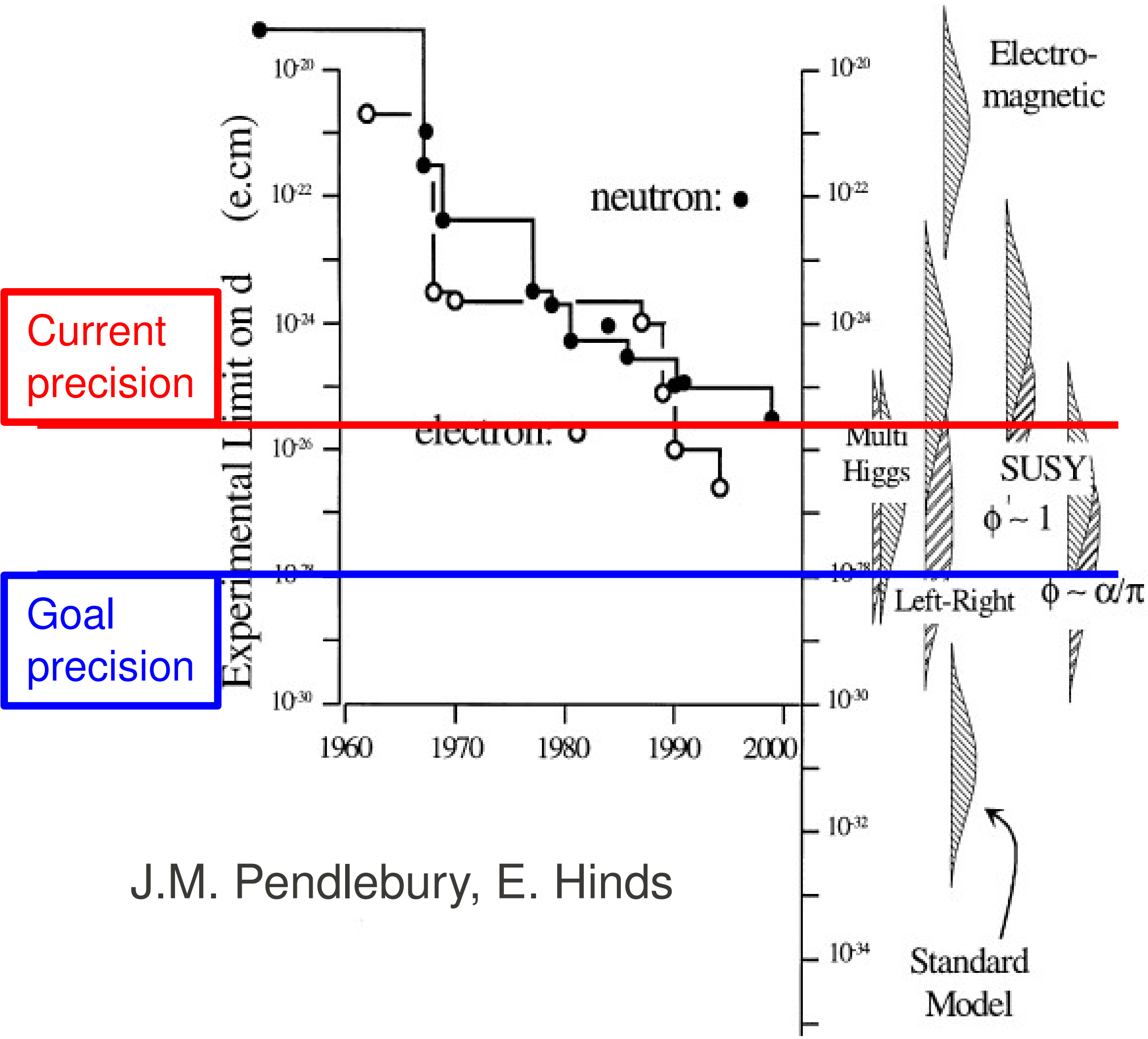
Experimental technique:

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



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

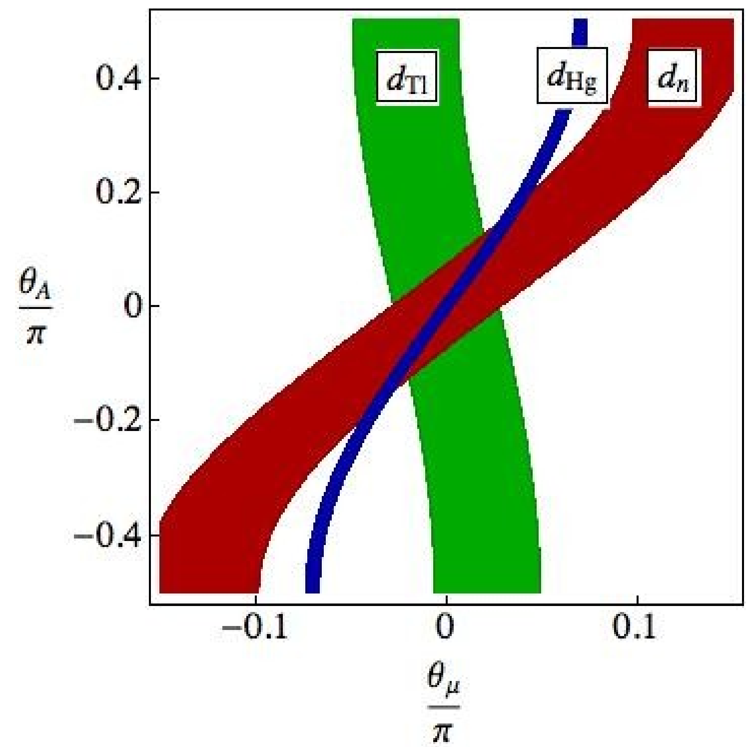
EDMs, the SM, and beyond



J.M. Pendlebury, E. Hinds

A. Ritz, M. Pospelov, et al

SUSY M = 1 TeV, tanβ = 3

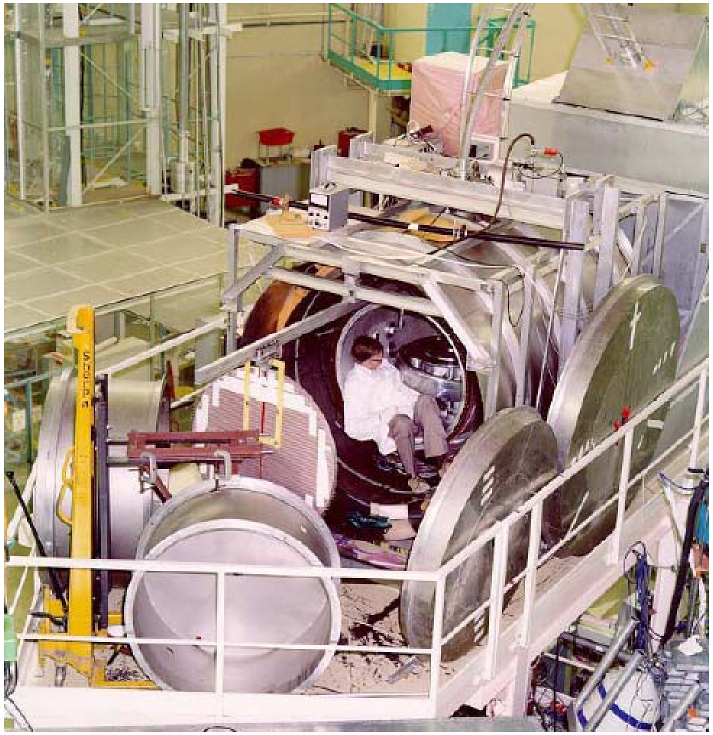


Note: universality assumptions are now even being tested

- Ultimate goal: reach the SM limit

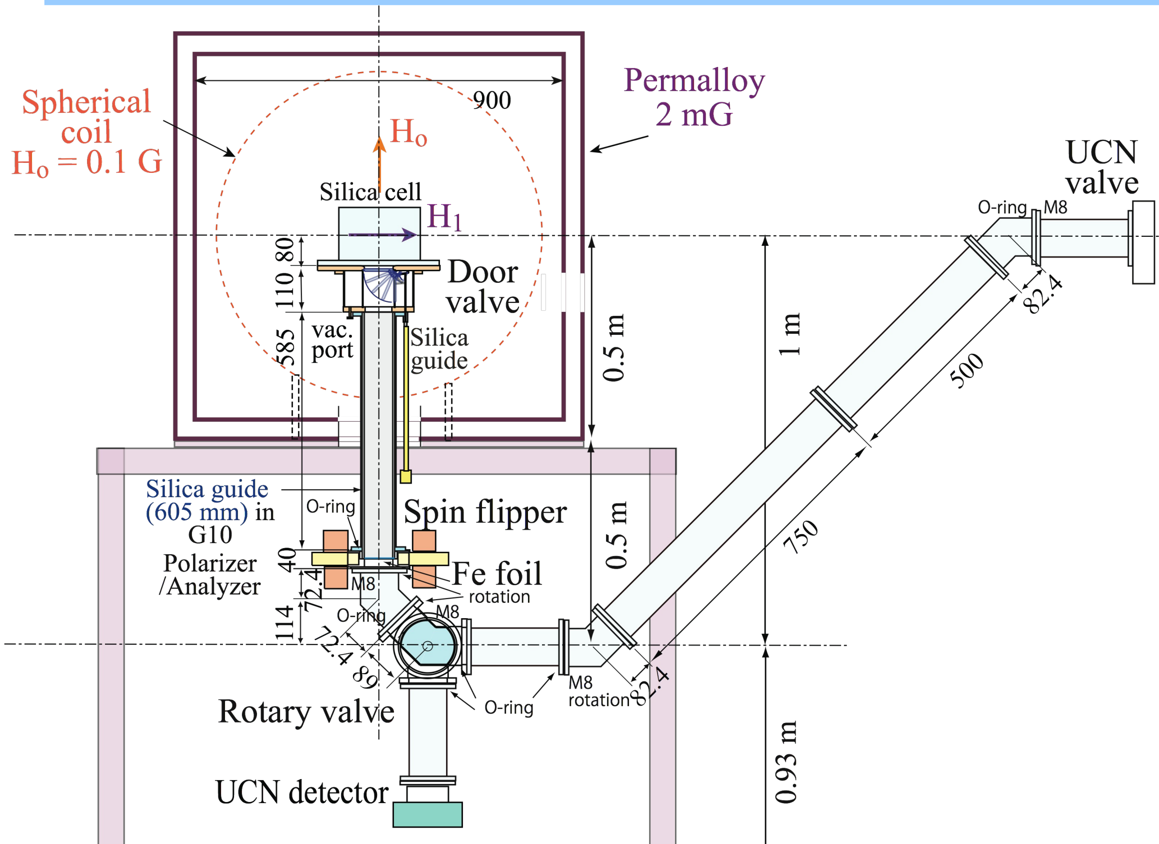
Past and Future n-EDM efforts

- 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: 10,000 UCN/cc

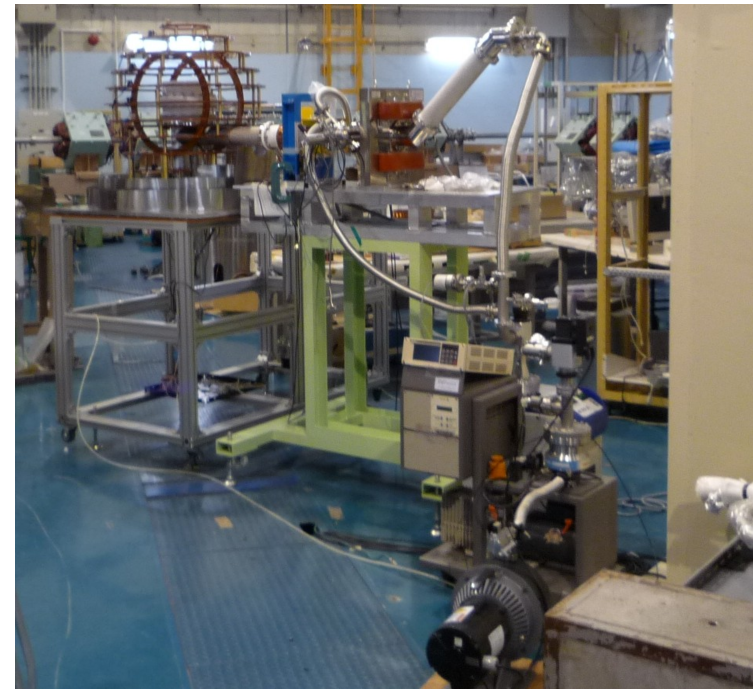


Sussex-RAL-ILL experiment

n-EDM development in Japan

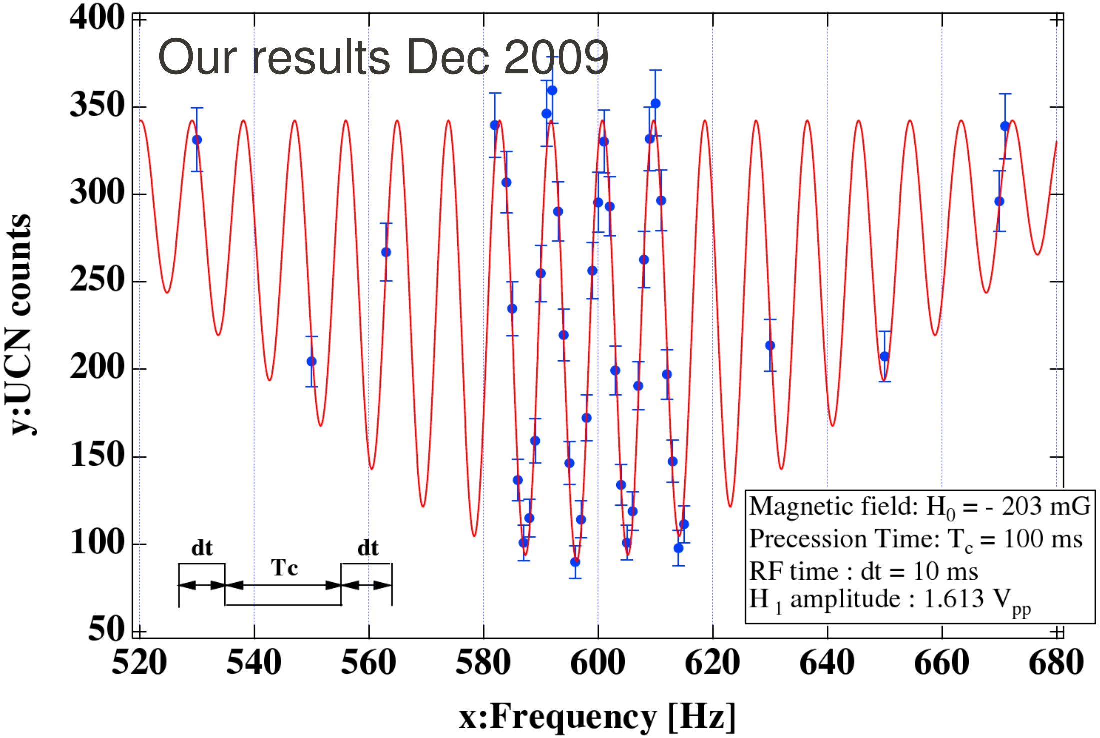


- Masuda, et al. Beam tests July, December 2009, April 2010 8-13.



- Development of:
  - Comagnetometers
  - Ramsey resonance
  - New B-field geometry

Ramsey Resonance Results
Y. Masuda, et al, in preparation



Dec. 2009, achieved:

T_2 ~ 300 ms

April 2010, achieved:

T_2 > 30 s !!!

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

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

- Successful demonstration of the basic technique behind precision EDM measurements.
- Improvements in field homogeneity, profile, magnitude, shielding for longer T_2.

EDM Statistics

- ILL:

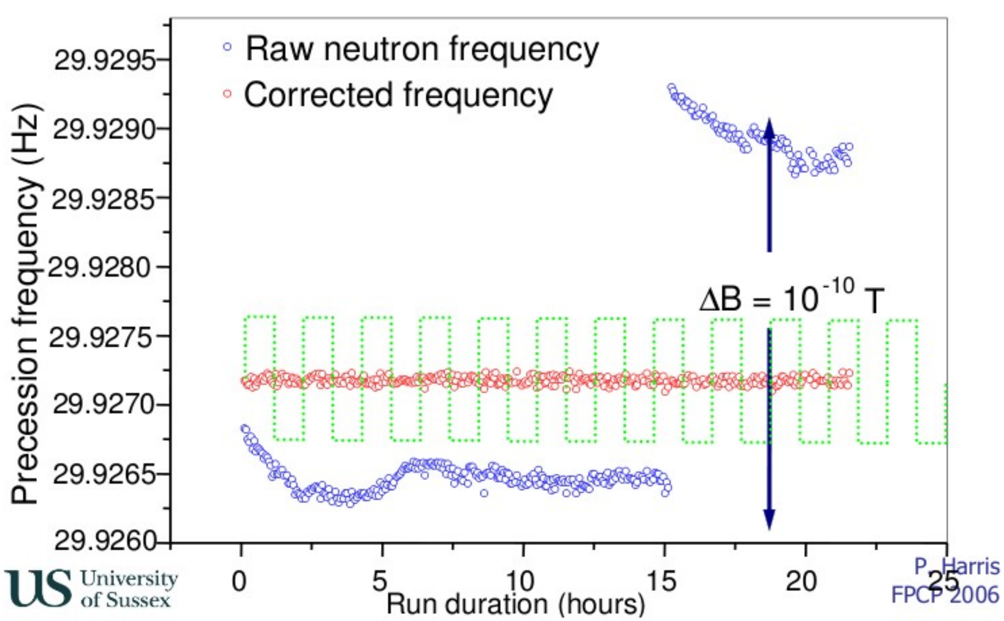
$$\sigma\left(d_n\right) = \frac{\hbar}{2\alpha E T\sqrt{N}}$$

  - α=0.64, τ=130 s, E=10 kV, N=14000 UCN/cycle
  - 1 UCN/cc: $\sigma(d_n)$=1.7 x 10^{-25} e-cm/day
  - Final stat. error: $\sigma(d_n)$=1.5 x 10^{-26} e-cm
- TRIUMF with increased UCN density:
  - 10^4 UCN/cc: $\sigma(d_n)$=1.7 x 10^{-27} e-cm/day
- e.g. SNS projected:
  - $\sigma(d_n)$ ~ 3 x 10^{-27} e-cm/day (B. Filippone, FNAL seminar 06)

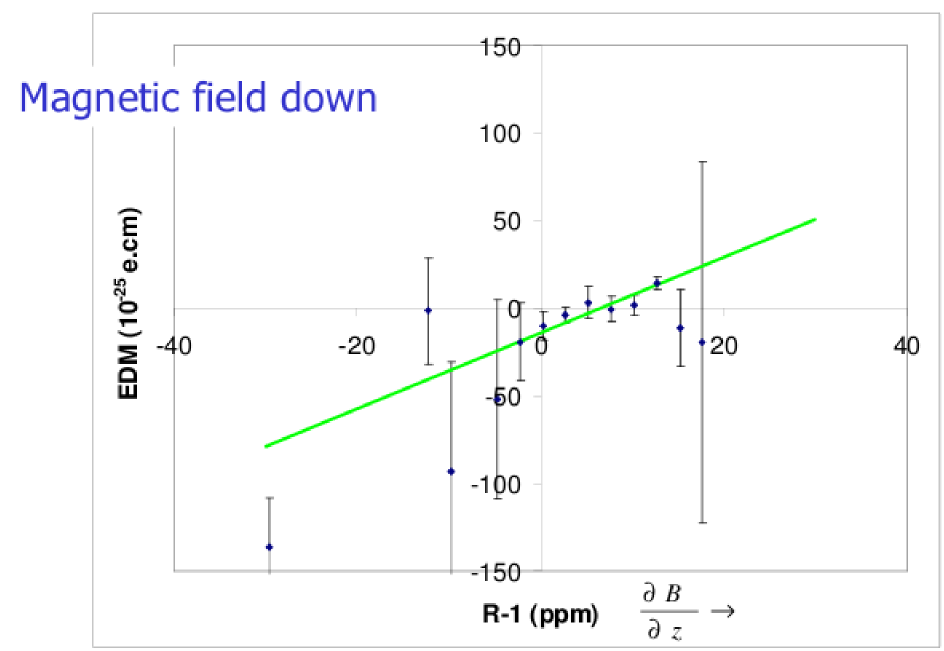
n-EDM Systematics

- 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

n-EDM at TRIUMF

- Complete experiments in Japan, 2009-2012.
- Develop LOI/proposal for TRIUMF ~ 2010-11.
- Unique aspects of the EDM work in Japan:
  - New UCN production mechanism aiming for highest density
  - Higher UCN density allows smaller cell size
  - New DC coil geometry
  - Xe comagnetometer

We gratefully welcome new collaborators to this exciting experiment!!!

UCN and you!
research opportunities

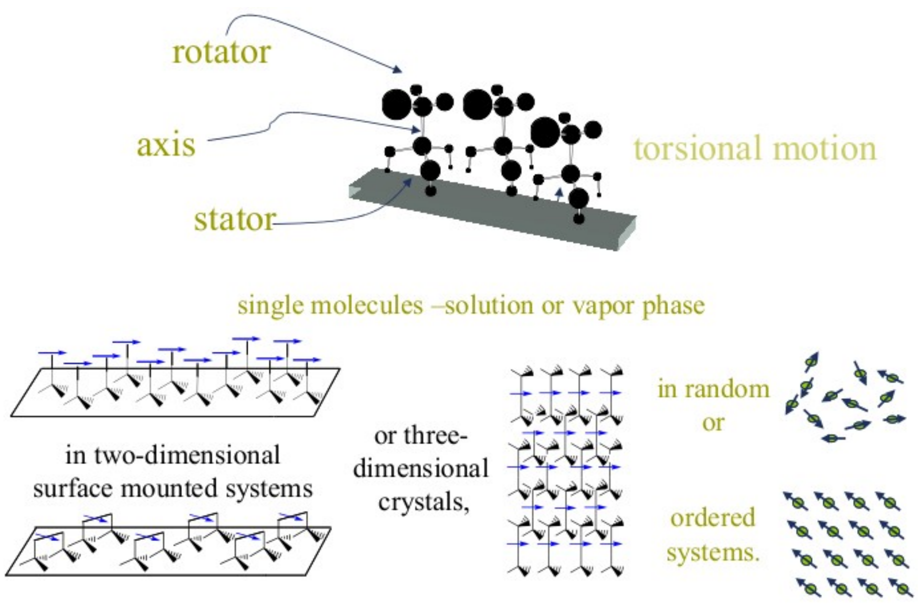
- Development state-of-the-art technology in low-field NMR, related to medical MRI's. Precision (co)magnetometry, shielding.
- Quantum mechanics and quantum computing studies using UCN spins.
- Development of UCN detectors.
- Electronics, DAQ (MIDAS), data collection, analysis, and simulation.
- Development of future UCN experiments - lifetime, gravity, quantum computing, surface physics, others.

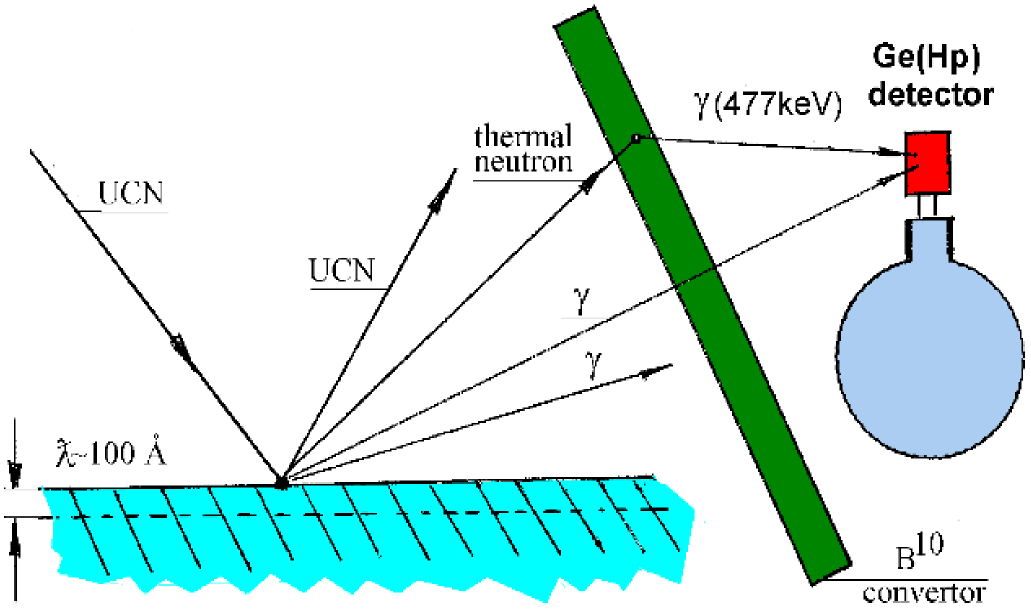
Timeline

- June 2009: Source funded in Canada and Japan
  - JSPS, CFI, TRIUMF, Acsion Ind., Govt of MB, UWpg.
- 2009-12:
  - develop UCN source in Japan, EDM experiment
  - preparations and design at TRIUMF
  - develop collaborations and proposals for experiments
- 2012-14: Install, commission at TRIUMF
- 2014-15: First experiments

Surface Chemistry and Physics

- Use UCN to study 10 nm thin surface films
  - UCN microscope
  - inelastic scattering reflectometry (UCN ISR)
    - UCN upscattering off a big molecule



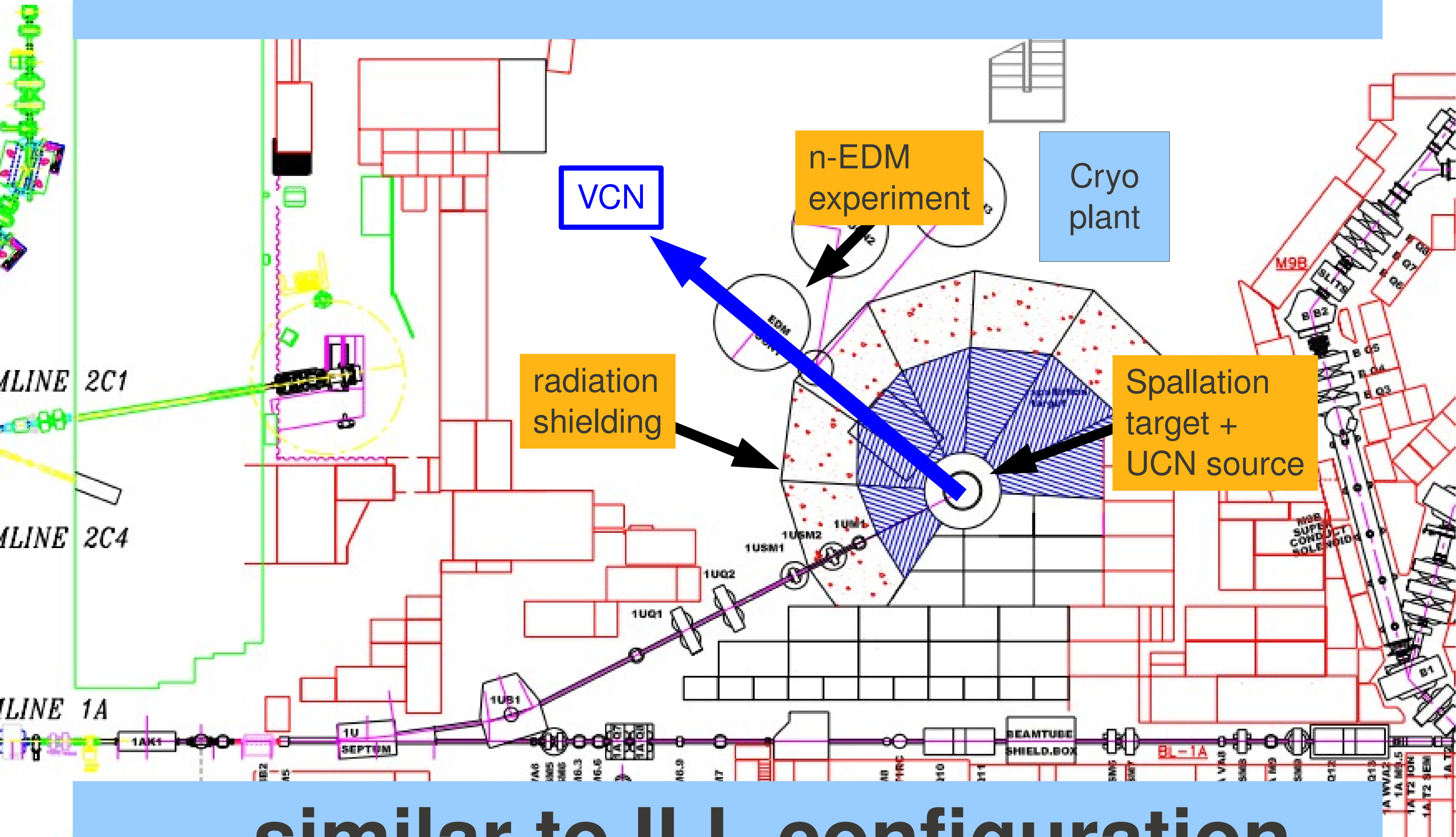


UCN ISR apparatus for TRIUMF

- 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)

Needs clever physics and chemistry ideas!
UCN potential as new probe of surfaces.

VCN line is possible ...



... similar to ILL configuration

The future of neutrons in Canada?

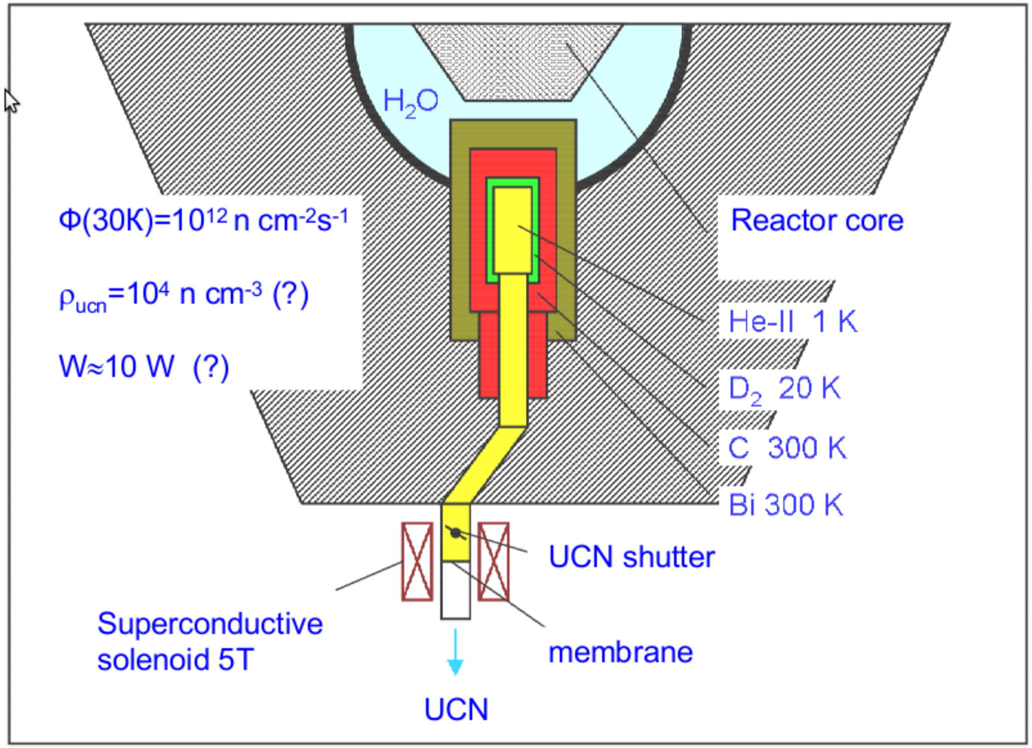
- New nuclear reactor for neutron scattering.
- A new UCN source should be proposed, too!
  - could be based on TRIUMF UCN source

People are already thinking about a "Super-UCN Source" at a facility like this.

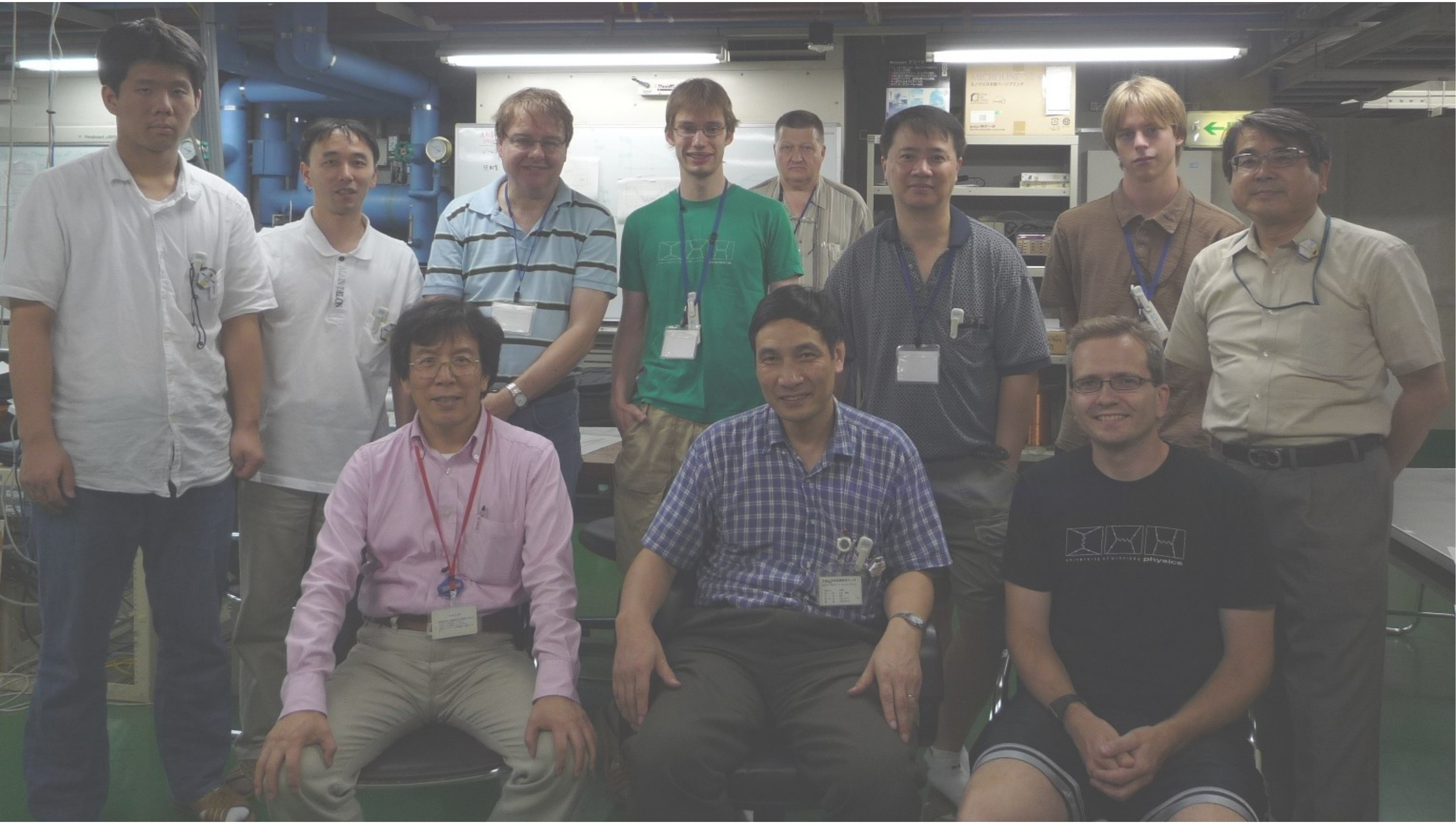
e.g. Serebrov, et al,
At the WWR-M reactor,
Gatchina, Russia

e.g. similar concept explored for the FRM-II reactor in Munich, Germany

Conceptual idea of UCN source at WWR-M reactor

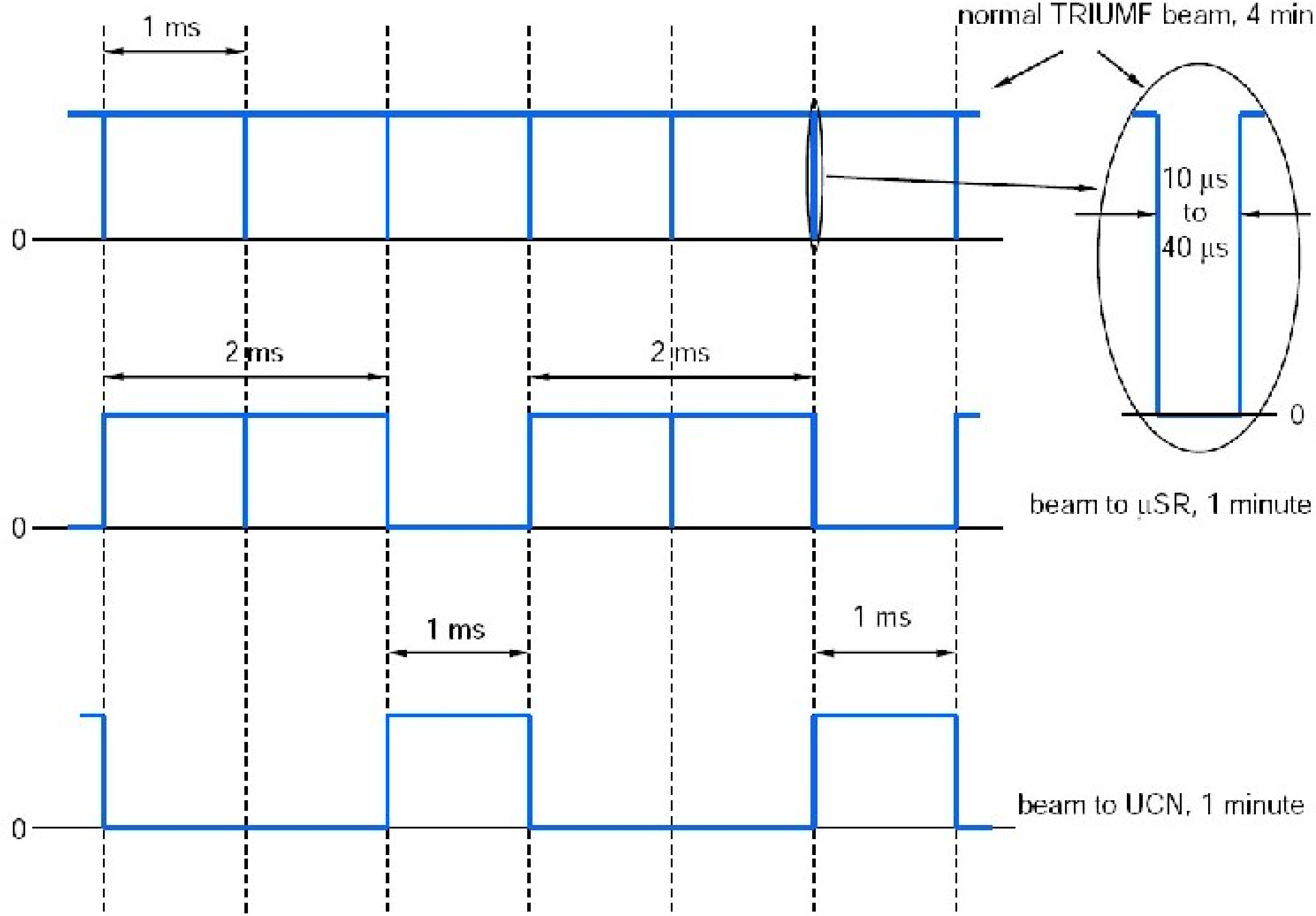


Thank you!



Osaka, July 2009.

Kicker Concept



- Downstream users affected only at 7% level.
- UCN data when cyclotron is on (8 months/yr.)

Summary of CFI request

Item	Cost	Funding Source
UCN cryostat system	$4M	Japanese collaborators
Beamline	$2M	TRIUMF 5YP request
Kickers, shielding, spallation target	$4.225M	CFI NIF
Moderator design	$0.675M	Manitoba + Acsion Industries
Total	$10.9M	+$0.25 M UWpg

TRIUMF support for University Initiatives

- UCN cryostat system includes:
  - Existing UCN source ($2M)
  - Modifications to source for TRIUMF ($2M)
    - Horizontal extraction, improved guide technology, etc.
- Canadian money for physics experiments:
  - separate budget from NSERC.