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

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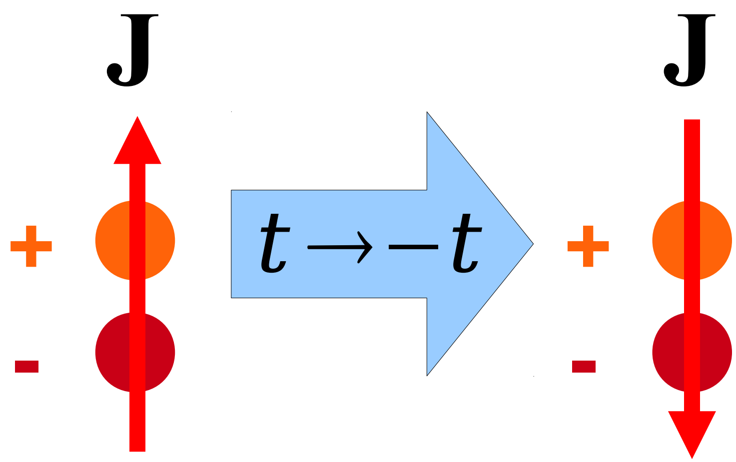
(KEK, Titech, Winnipeg, Manitoba, TRIUMF, NCSU, RCNP, UNBC, UBC, Osaka)

TRIUMF

KEK-TRIUMF Symposium 2011

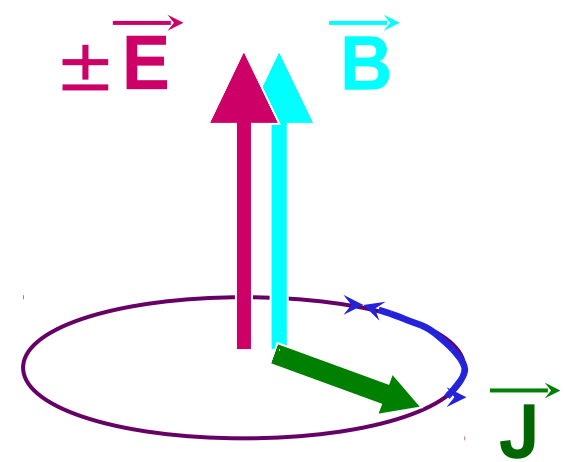
Neutron Electric Dipole Moment (n-EDM, d_n)



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

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

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



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

One slide from my talk last year

- 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."

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

Monetary Status Nov. 2011

- MOU signed in January 2011
- CFI funds released in Canada April 2011.
- New NSERC funds for new Canadian collaborators (Bidinosti, Falk, Konaka, Miller, Momose) April 2011.
- Valuation of pre-existing Japanese in-kind support (UCN source) completed July 2011. (KEK/JSPS please keep records about FY2009 and beyond)
- New CFI (Xe) funds at U. Wpg Feb. 2011.
- New NSERC funds requested Oct. 2011 (Jamieson + detector, cryo, and data-acquisition equipment).
- New CFI (Xe, lasers) requested at UBC (Momose)

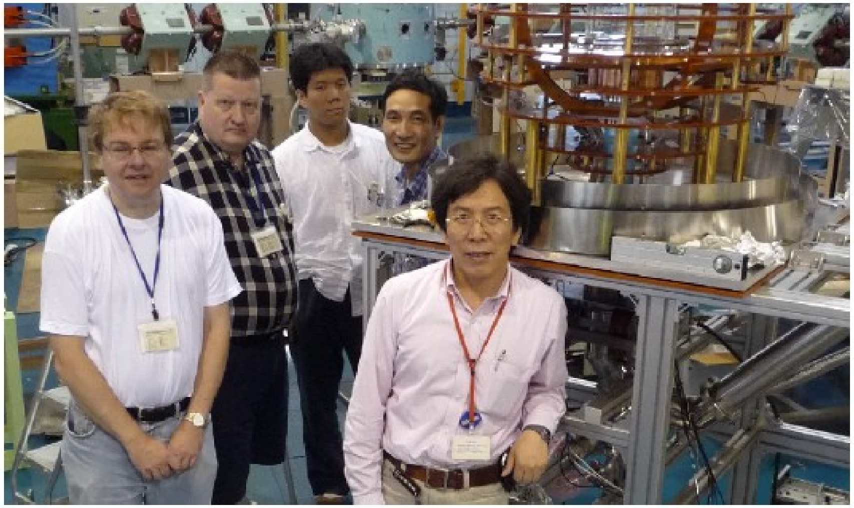
Important KEK contributions as Agreed in MOU

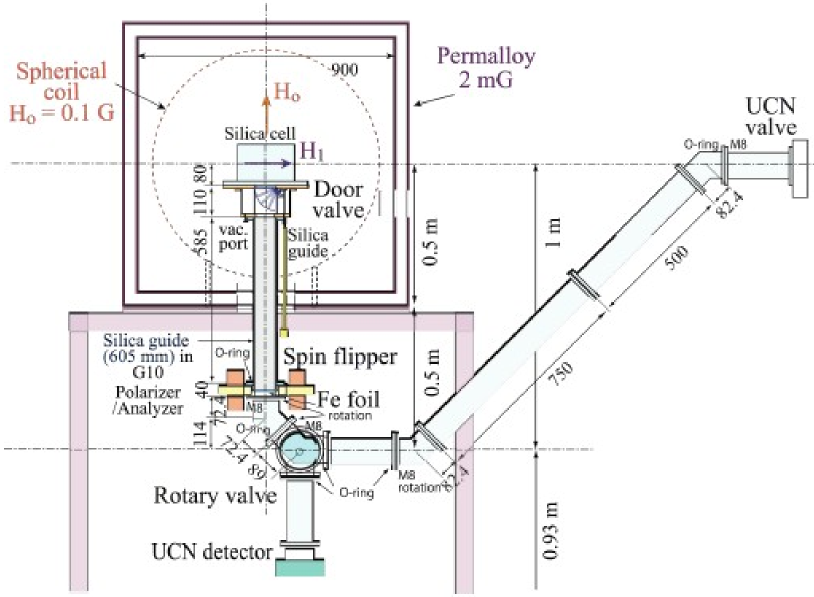
- JSPS support (Masuda)
  - UCN source + EDM experiment
- Internal support (Masuda) - FY2010-2014
  - Beamline magnets (bender and septum)
  - Cryo equipment
  - EDM equipment

We are very grateful for KEK internal support. Crucial for successful completion of project.

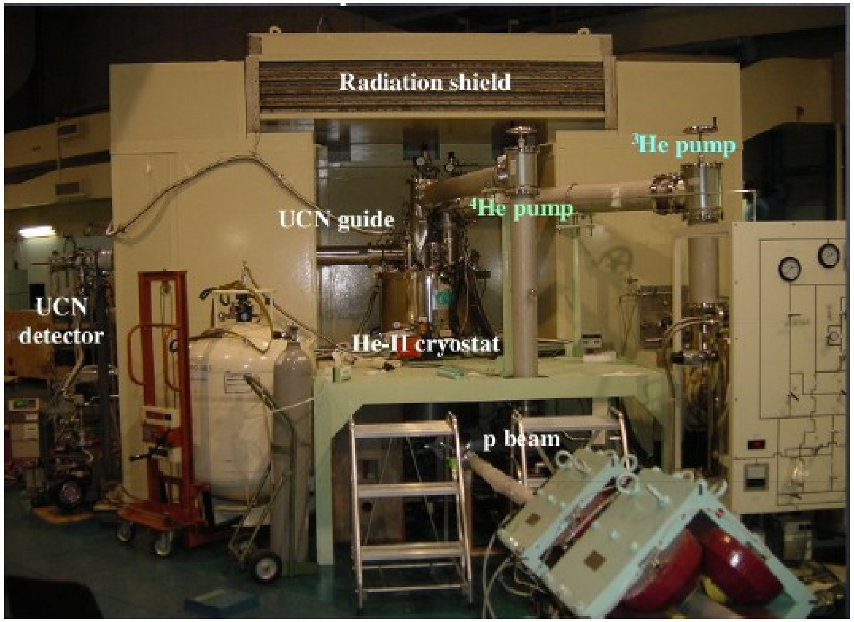
Japan-Canada nEDM experiment

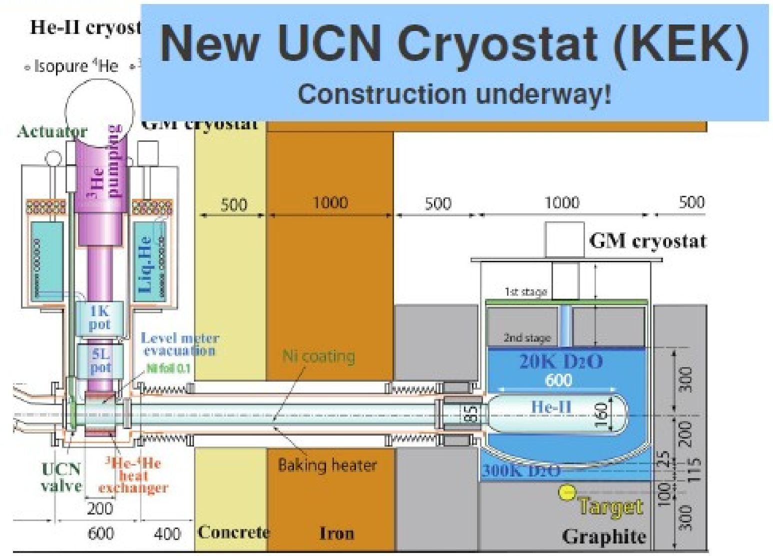
- Spherical coil for DC field
- Xe-129 nuclear-spin buffer-gas comagnetometer
- Room-temp experiment, keeping EDM cell size small, anticipating gains in UCN density
- Modern magnetic shielding, cost reduced with cell size
- Superfluid He-4 UCN source
- Basic prototype in operation

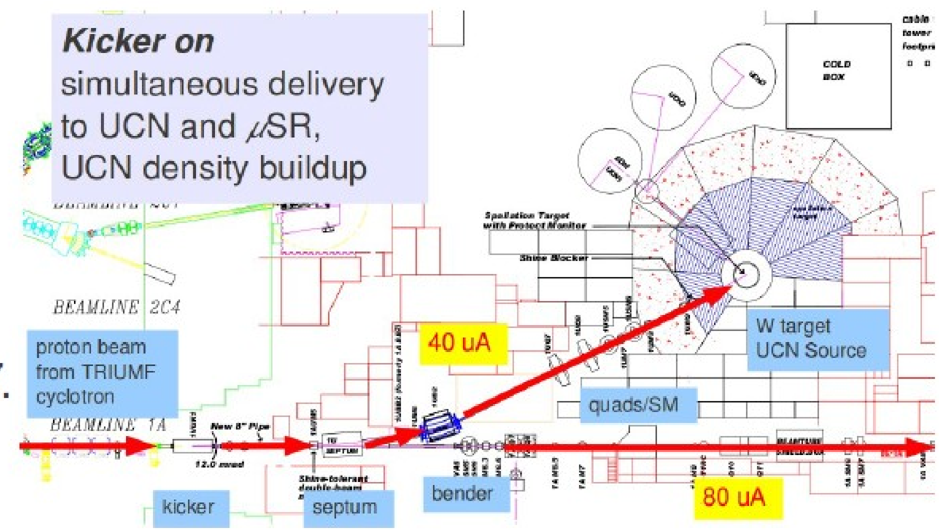




Schedule and Goals







RCNP Phase (-2014)

- Goal $d_n < 1 \times 10^{-26}$ e-cm

TRIUMF Phase (2015-)

- Goal $d_n < 1 \times 10^{-27}$ e-cm by 2017.
- Improve to $d_n < 1 \times 10^{-28}$ e-cm.

courtesy: J.W. Martin

TRIUMF

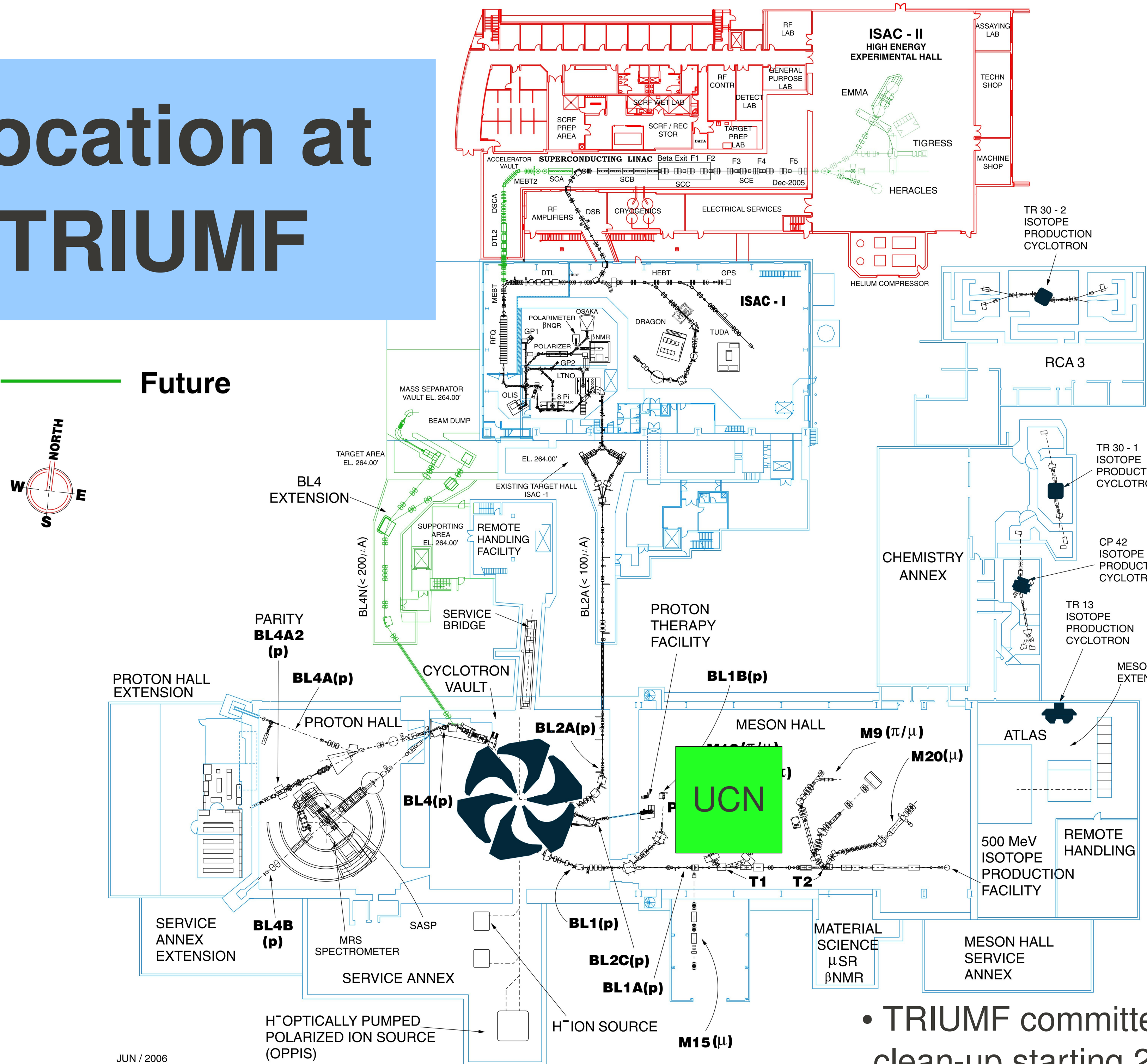
CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

- 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 2014.
- Longer running time at TRIUMF (8 months/yr vs few weeks)

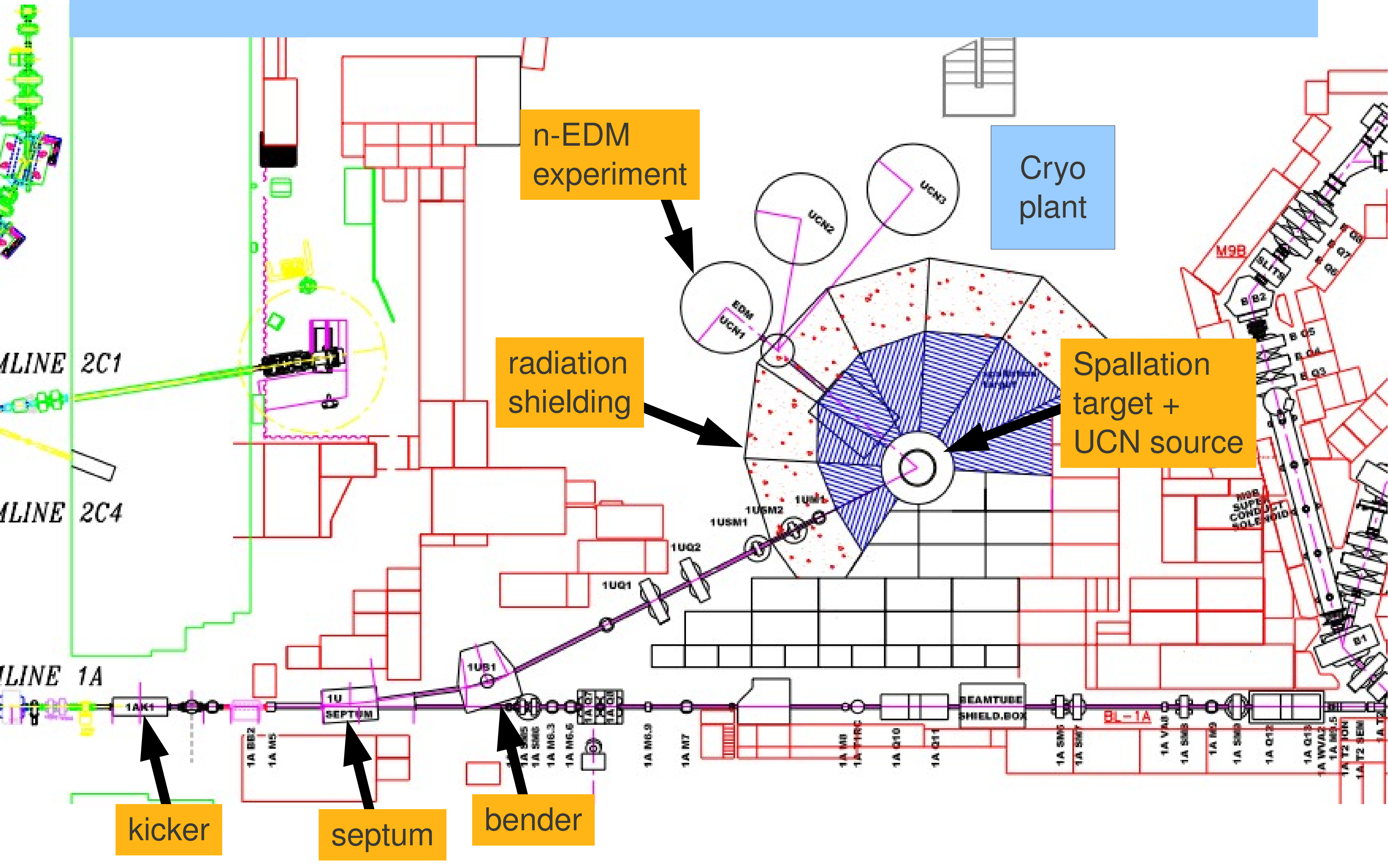
Location at TRIUMF

Future

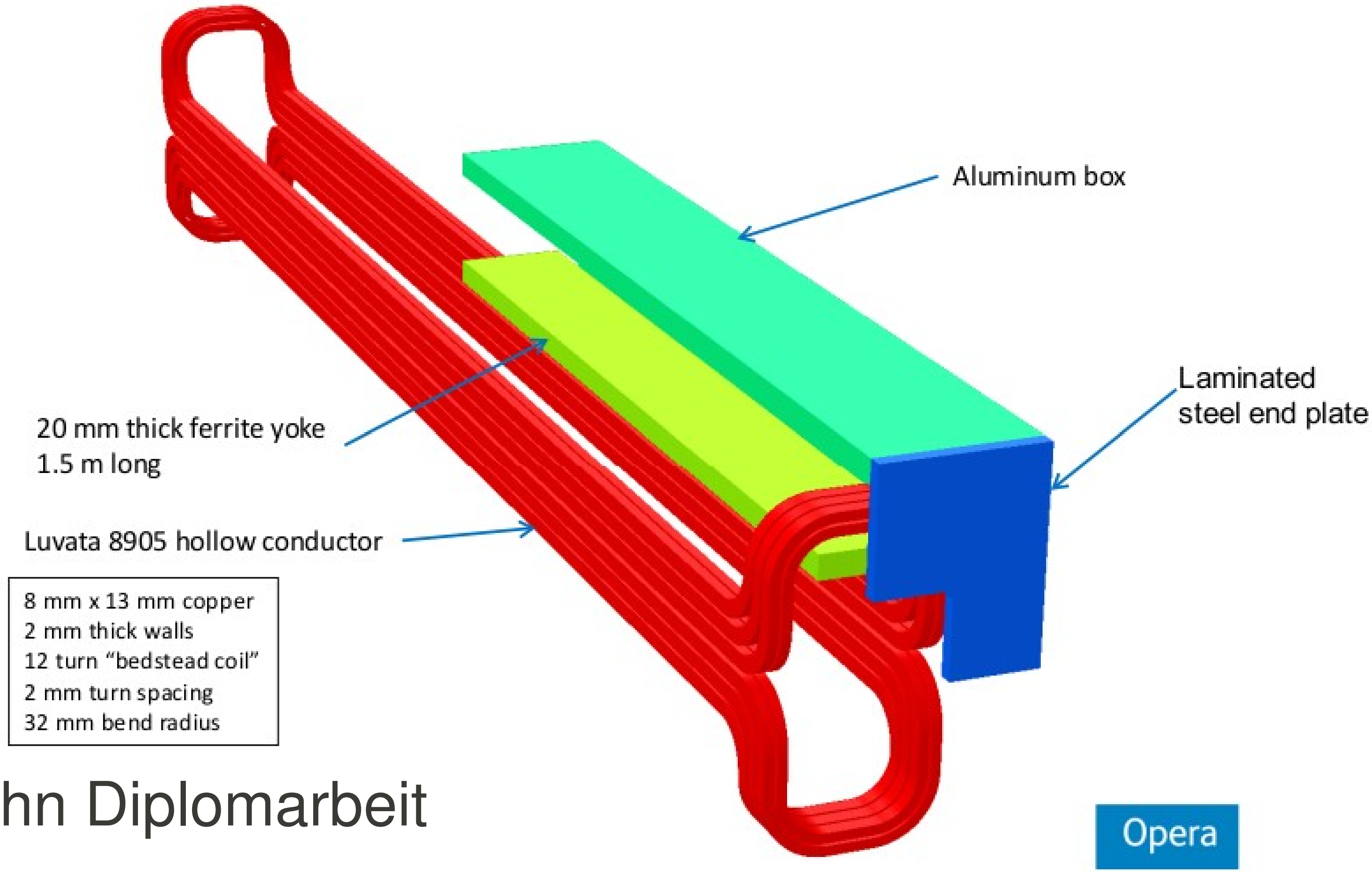


- TRIUMF committed to area clean-up starting 2013.

Layout in Meson Hall



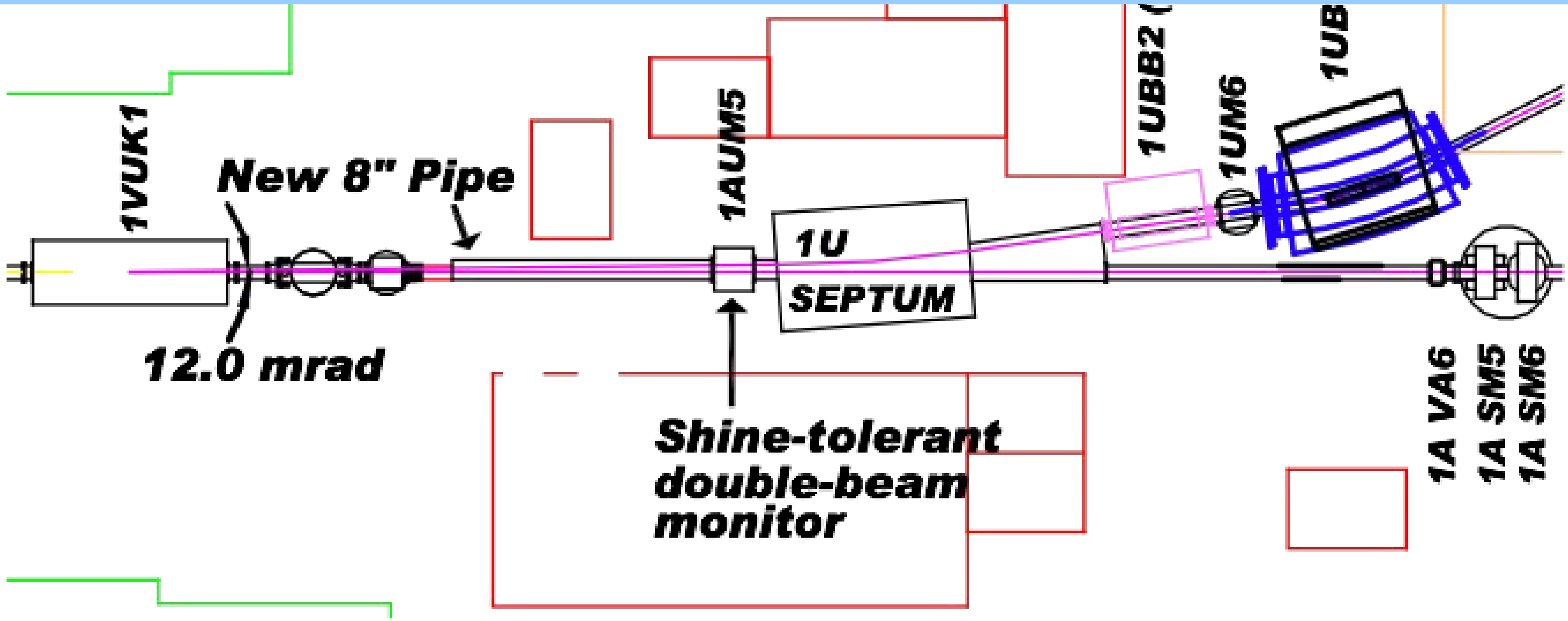
Kicker design completed August 2011



- M. Hahn Diplomarbeit
- Power supply simulations complete
- Engineering drawings preparing for bidding.

M. Hahn, M. Barnes,
A. Miller, W.D. Ramsay

Beamline



- Septum/bender magnets designed and built by KEK
  - Sector design for bender (under construction FY2011)
  - Lambertson design considered for septum (FY2012)
- Beamline specs and other components identified by TRIUMF (some recycled KEK-B components, too!)

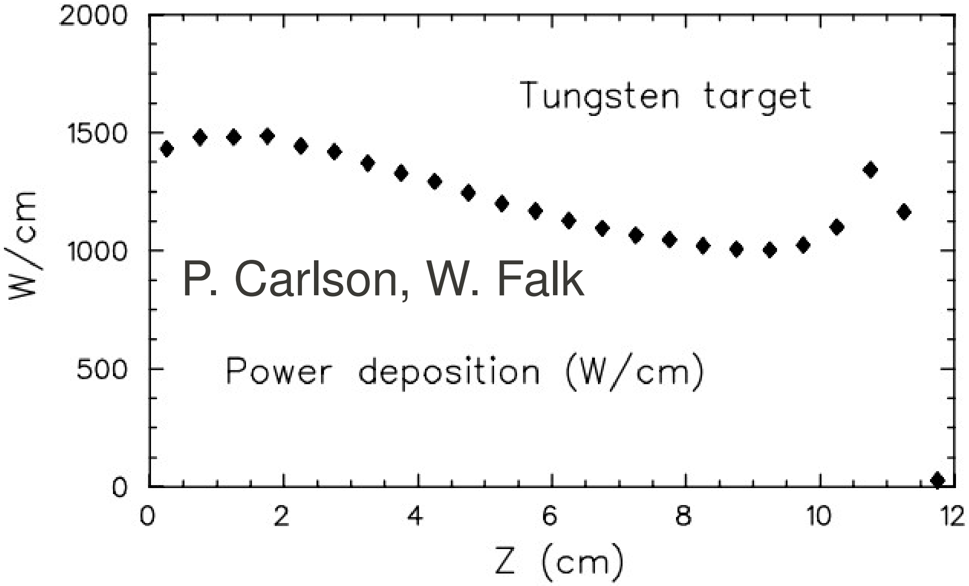
H. Tanaka, H. Takahashi, A. Miller, C. Davis, new TRIUMF project engineer (hiring)

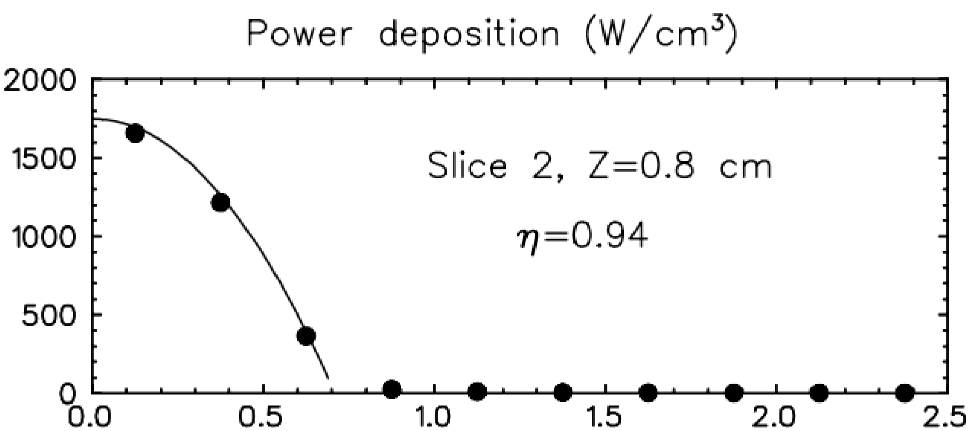
Target

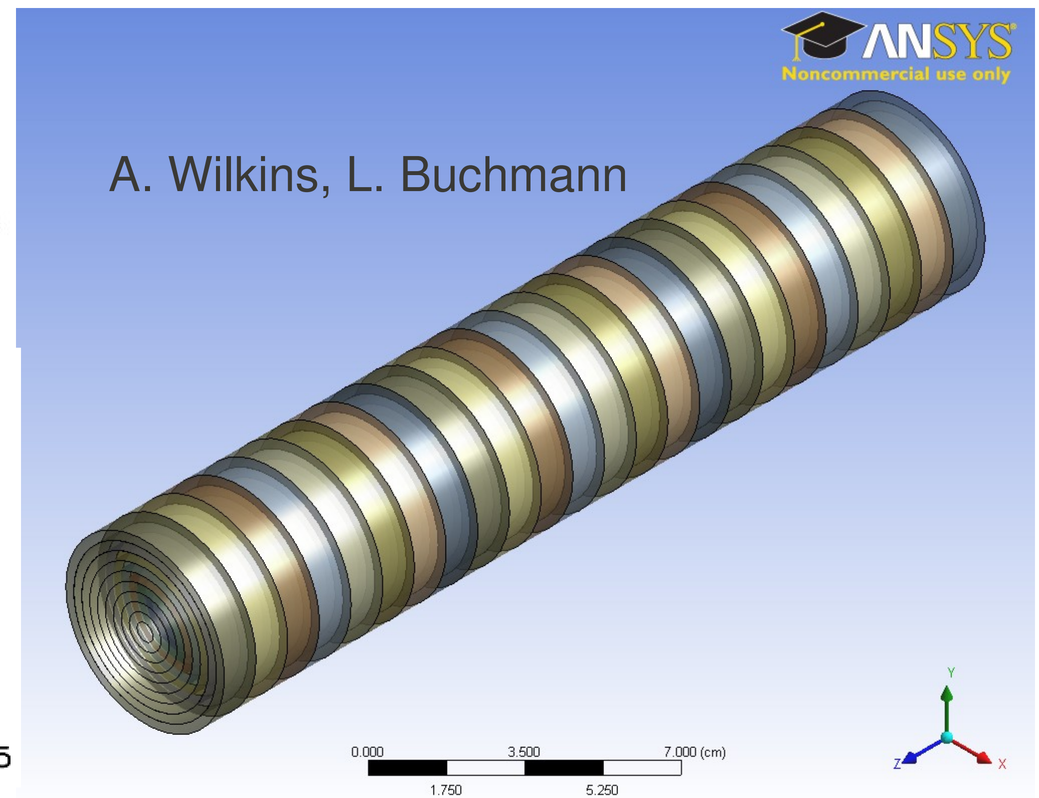
- Target meeting with PSI experts (M. Wolmuther, K. Kirch) Aug. 2011.
  - Identified water-cooled solid targets as best option (neutrons vs. complexity/cost)
  - Necessary to understand neutronics for optimization (W vs Pb).
- TRIUMF-RCNP-KEK-Manitoba collaboration
  - MCNPX/PHITS neutron/heat simulations, possibly new solid D_2O experiments.
  - ANSYS heat transport simulations
  - Build and test, remote handling design

Target

- MCNPX inputs to ANSYS





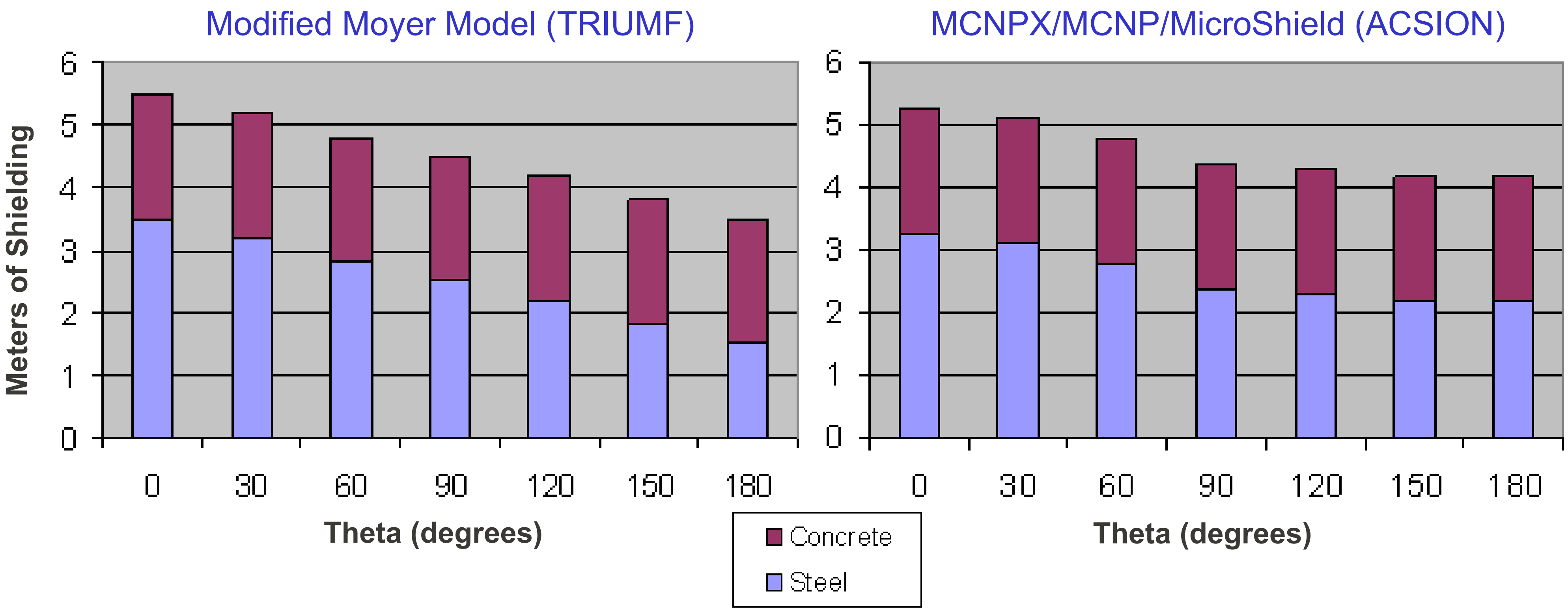


Longitudinal and radial slices.

Also, reproducing the work of Watanabe-san and Hatanaka-san on neutronics using PHITS.

First Results from new Shielding Simulations

Shielding Requirement to reduce dose rate to 3μSv/hr

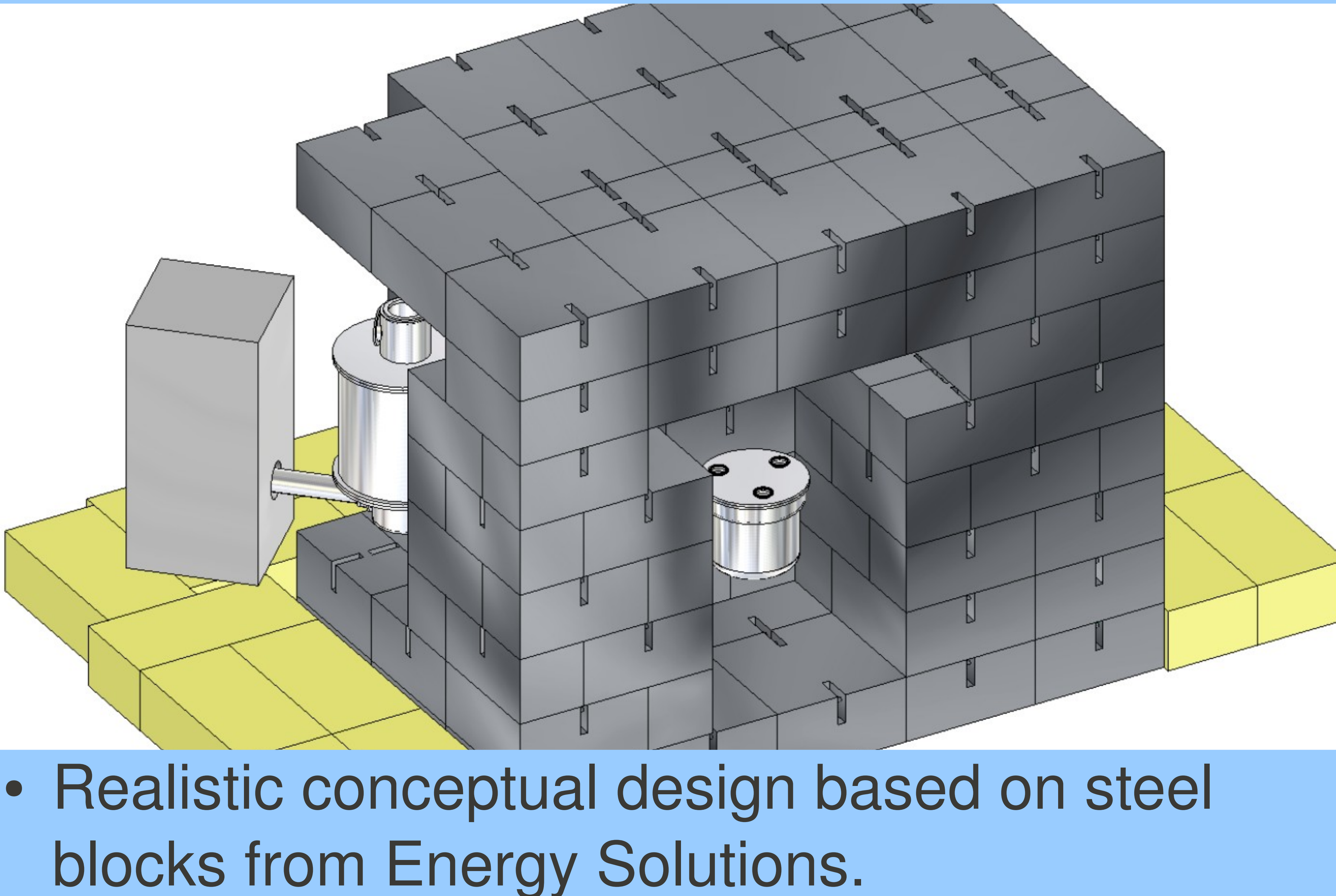


Preliminary Results:

Reasonably good agreement at forward angles.

At backward angles (> 120°), Moyer Model underpredicts shielding requirements slightly.
→ But ***little or no*** cost impact in this region (150°–180°) because this would be within the main BL1A shielding ***(and the 3μSv/hr constraint irrelevant)***

Shielding and Neutronics



- Realistic conceptual design based on steel blocks from Energy Solutions.

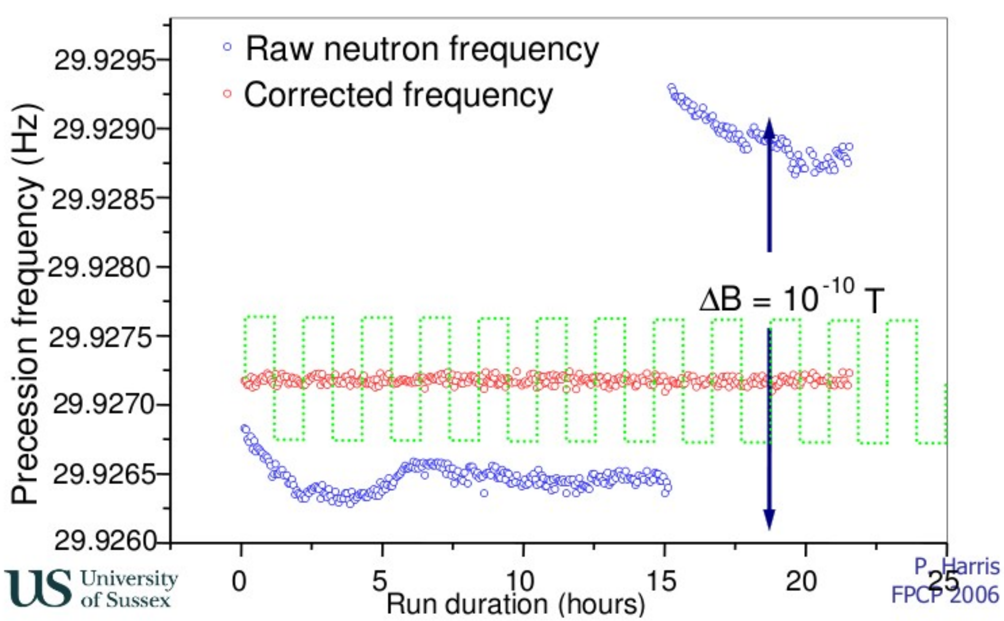
n-EDM Experiment

- Canadian involvement:
  - R&D aspects of Xe (co)magnetometry
    - Testing polarizer, low-field NMR, SQUID's, flux-gates, magnetic shielding.
    - 2-photon comagnetometry concept, superradiance.
  - New detectors – Li-doped glass scintillator.
  - Simulation
    - B-field homogeneity from magnetic shielding
    - Geant4 particle tracking and spin tracking

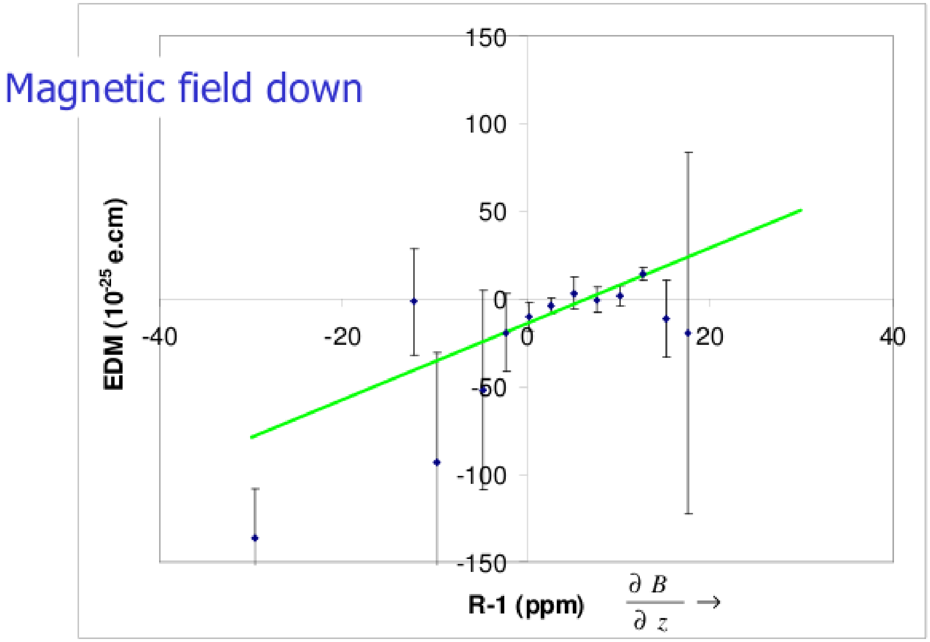
n-EDM Systematics

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

(co)magnetometry



comagnetometry



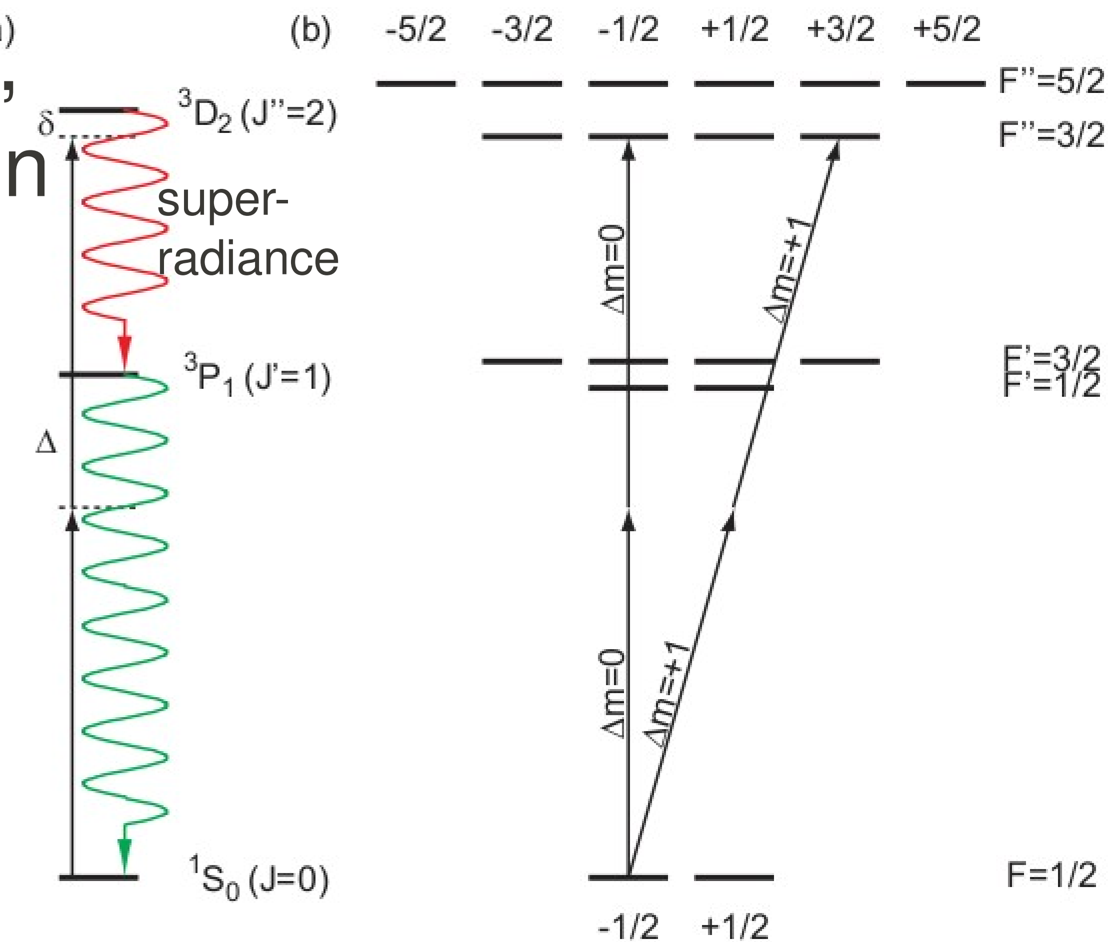
false EDM (GP) effect

Xe-129 buffer-gas nuclear spin comagnetometer

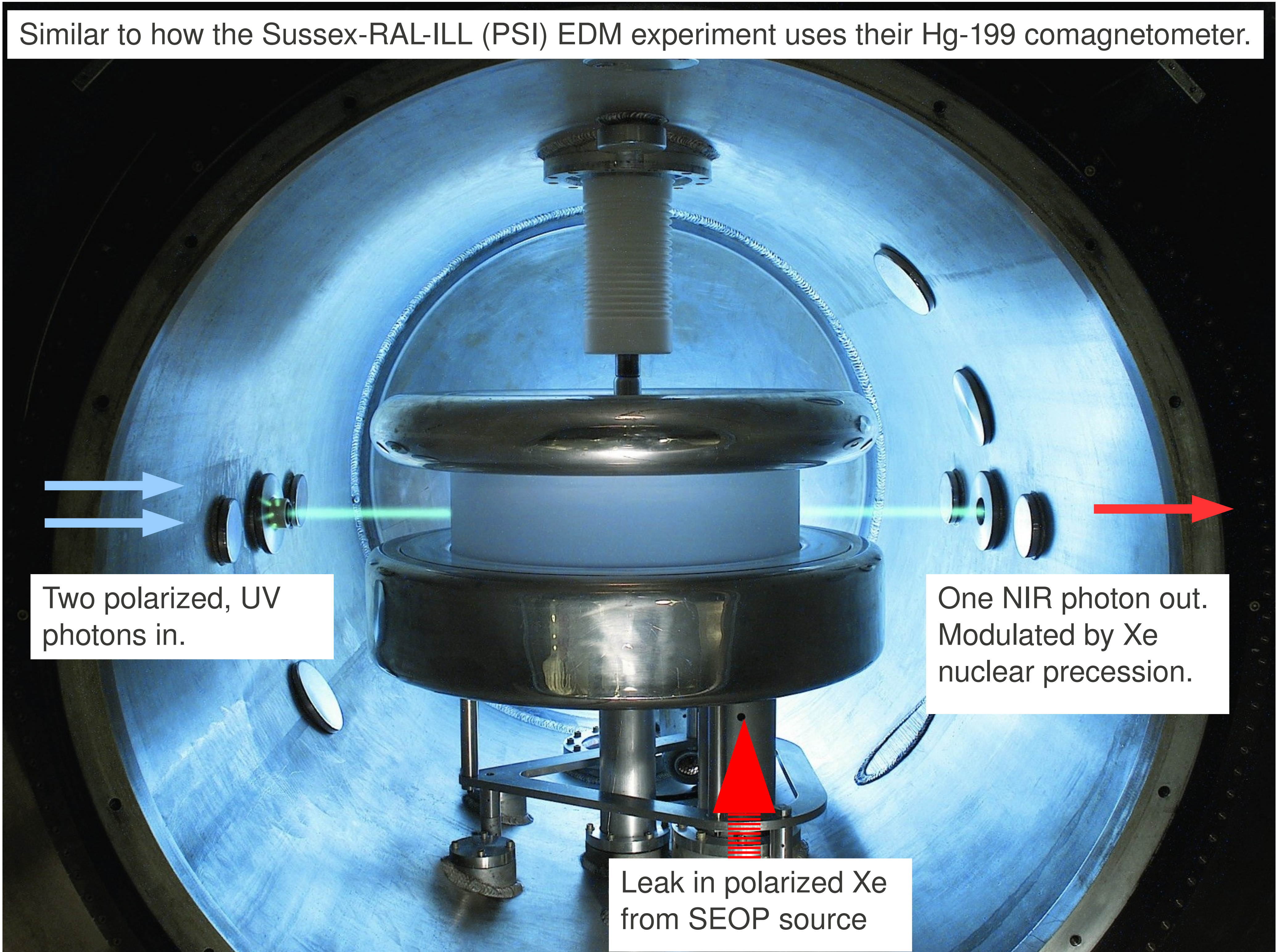
- Masuda-san's idea: leak polarized Xe-129 into the EDM cell with the neutrons and watch spins precess.
- Xe-129 pressure must be large
  - Xe-Xe Collisions -> small MFP -> small GPE.
  - Ring-down signal picked up by SQUID.
- Xe-129 pressure must be small
  - Electrical breakdown at higher pressures.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

New ideas: Optical readout of Xe-129 spins

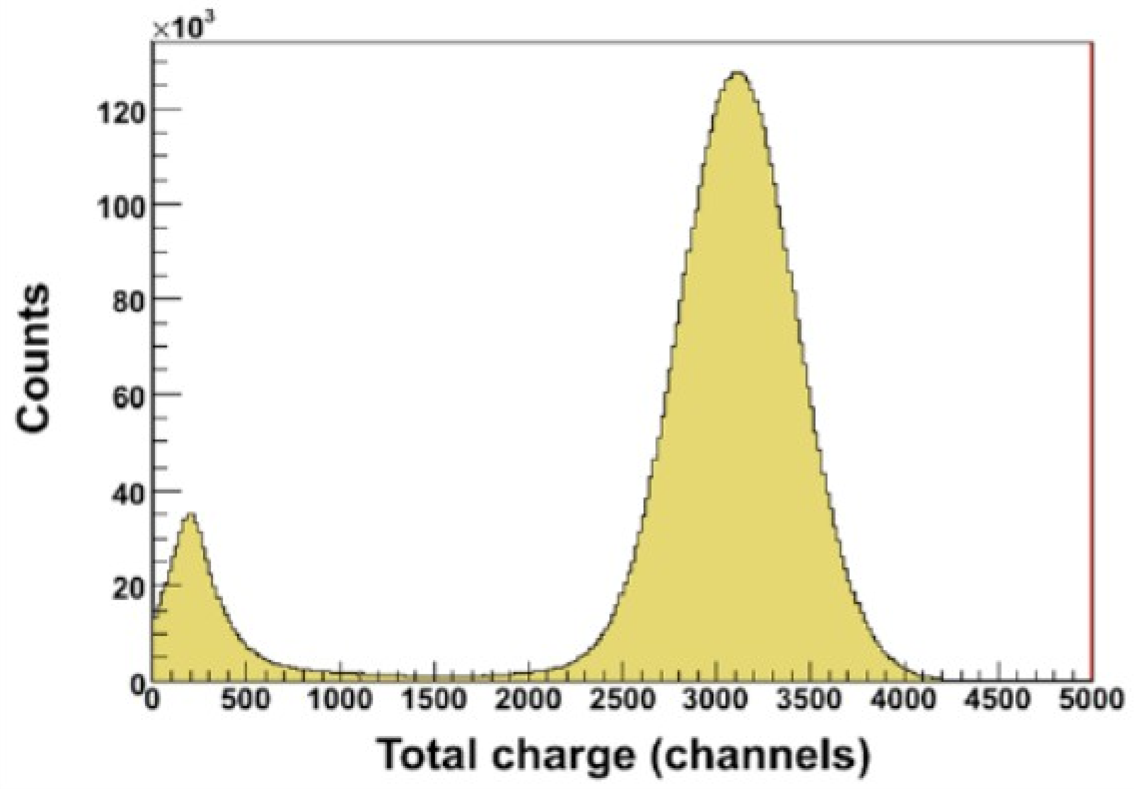
- Polarized two-photon transition $\Delta m=2$ selection rule occurs for nuclear spin aligned (T. Chupp)
- Chupp: absorption, or index of refraction
- New idea: use superradiance (T. Momose)
- 2-photon transition, decays, and superradiance now seen @UBC

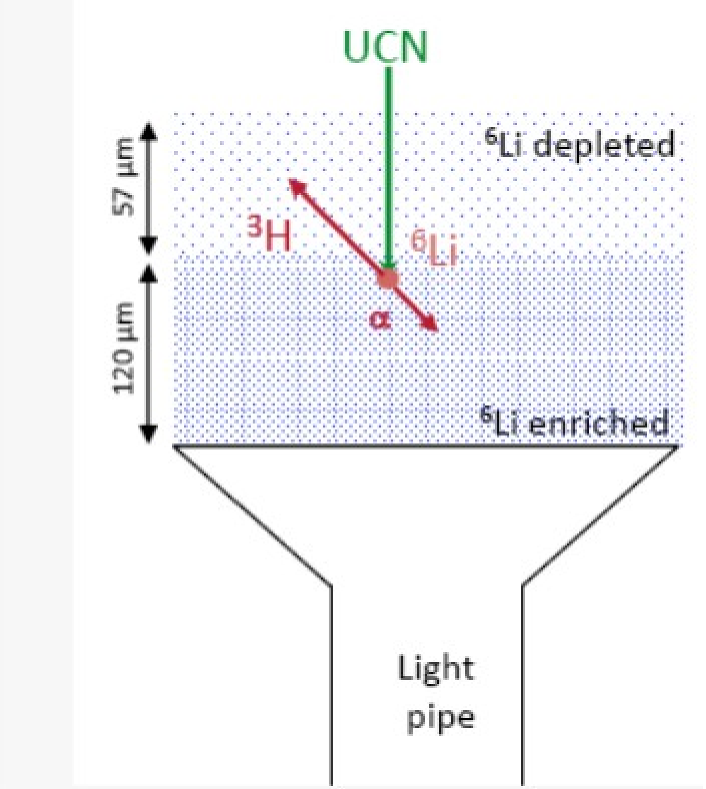


E. Miller, T. Momose


Similar to how the Sussex-RAL-ILL (PSI) EDM experiment uses their Hg-199 comagnetometer.
Two polarized, UV photons in.
One NIR photon out. Modulated by Xe nuclear precession.
Leak in polarized Xe from SEOP source

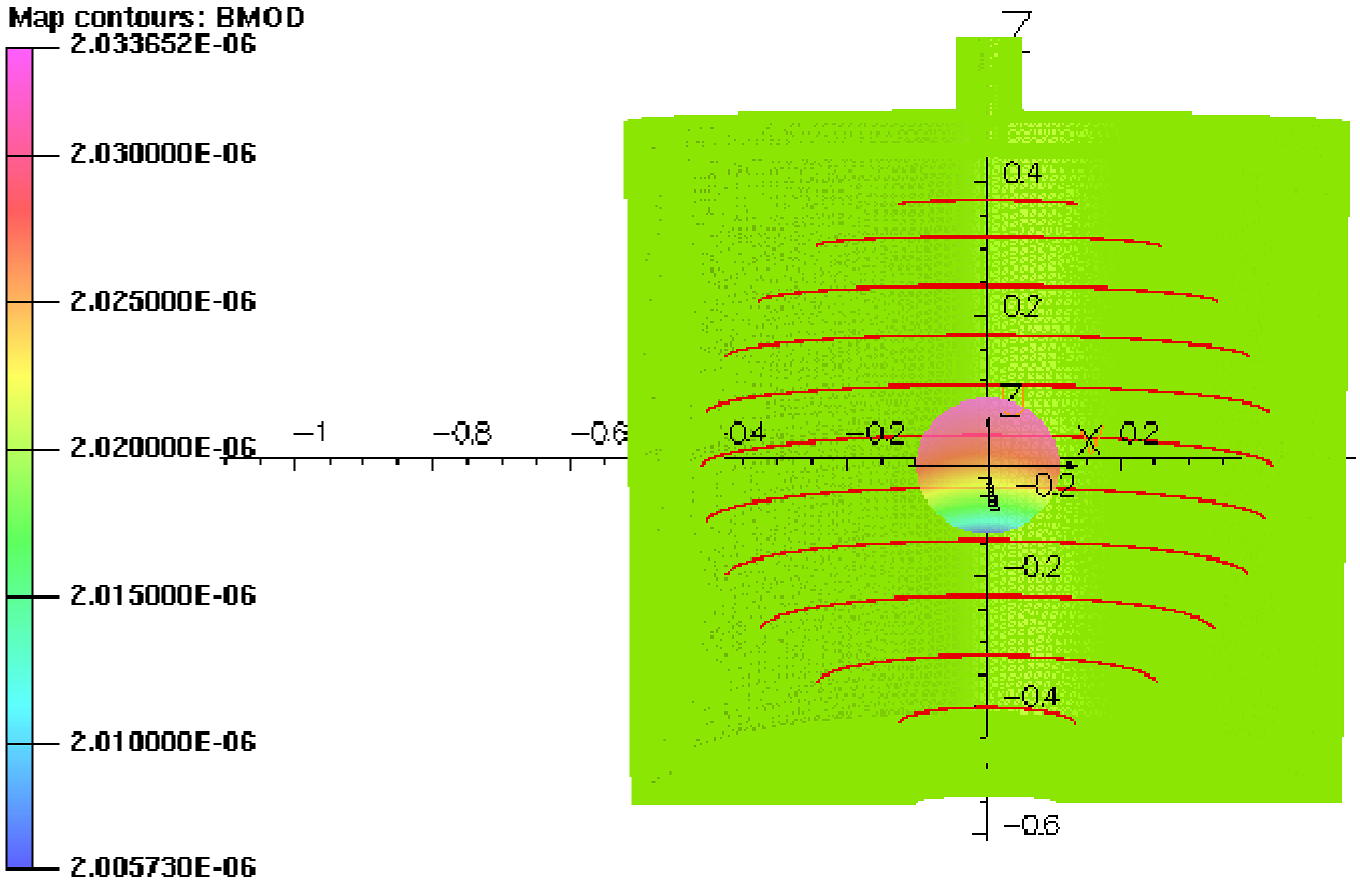
Detectors





- Developed by PSI group, 98% eff relative to 3He counter, fast, pulse-shape discrimination, FPGA electronics.
- Use for UCN detector, multiple UCN monitors.
- Funds requested in Canada; new faculty, postdocs

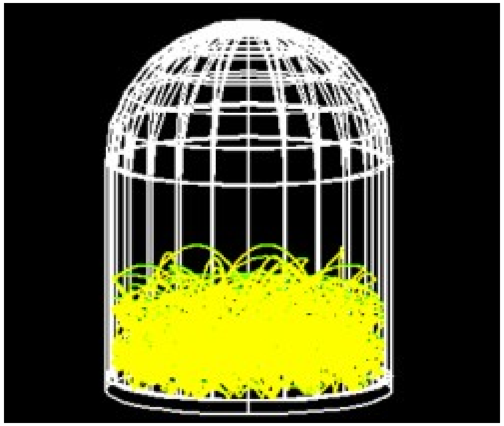
B-field shielding/homogeneity



- Order-of-magnitude homogeneity, and shielding factor understood (OPERA, COMSOL)

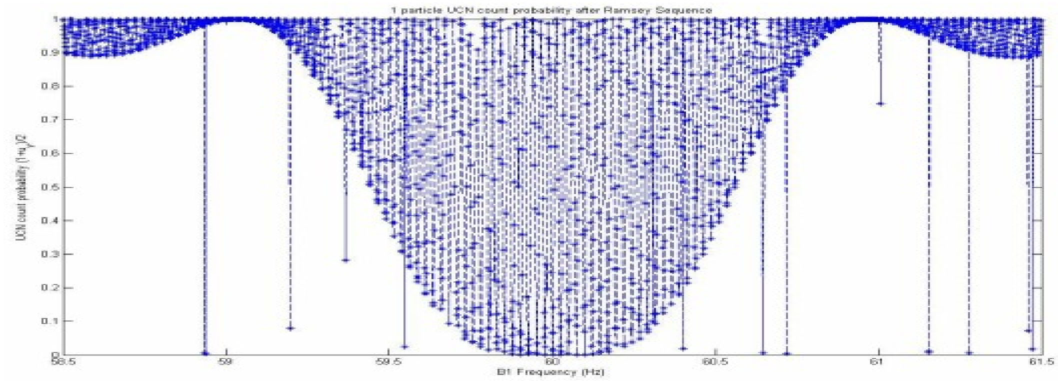
Florian Fischer, Diplomarbeit. August 2011.

Geant4 UCN



Gary Yan,
Eric Miller

- Started with PSI code
- Added, to up-to-date Geant4:
  - New Geant4 classes (gravity)
  - Spin tracking with t-dep RF fields
  - Non-relativistic particles
- Results to be included in next official Geant4 release.
- Now studying EDM systematics.



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-

Summary

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

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.