TUCAN EDM

TRIUMF Ultra-Cold Advanced Neutron project

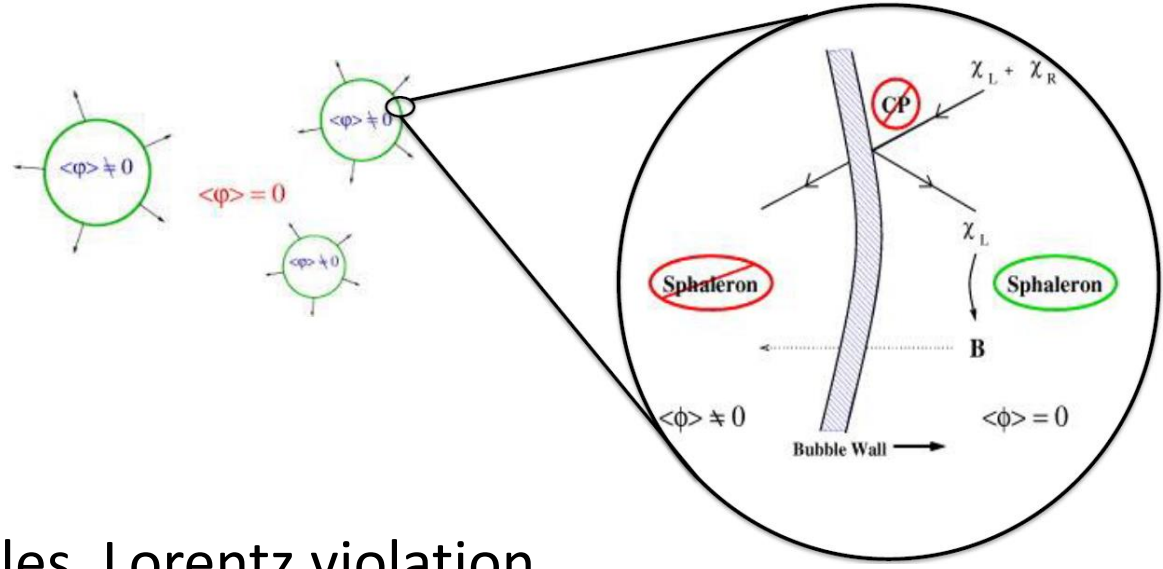
Jeff Martin

TUCAN Collaboration

IPP Townhall, July 16, 2020

Physics of Neutron Electric Dipole Moment

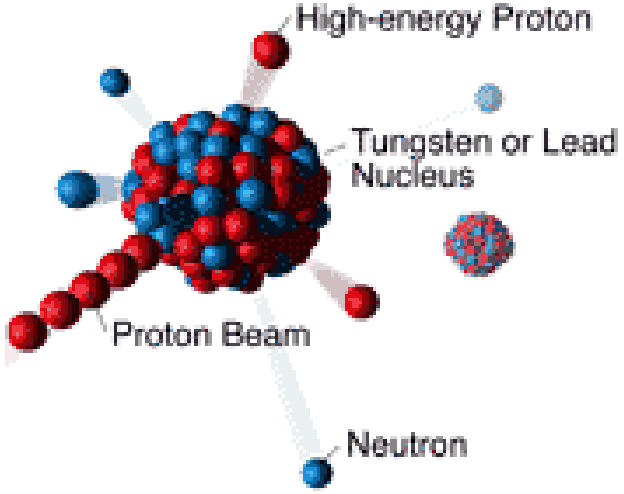
- Search for new sources of CP violation beyond the standard model.
- Motivated by:
  - SUSY CP problem / new TeV-scale physics
  - Baryogenesis scenarios, e.g. electroweak baryogenesis
  - Strong CP problem / Peccei-Quinn, axions
- Ancillary measurements:
  - Precision clock comparison (axionlike particles, Lorentz violation, background cosmic field, …)
  - Time-dependent EDM's (axionlike dark matter)

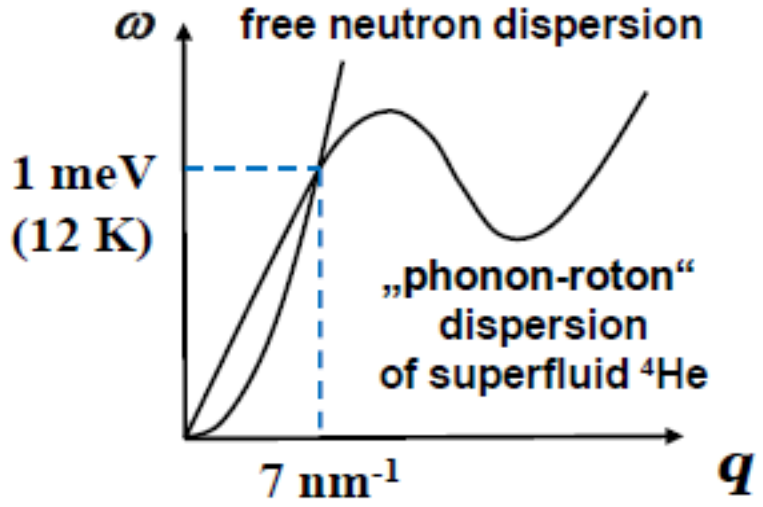


Frequency measurement requiring lots of neutrons and stable magnetic field

Neutron EDM – experimental status and TUCAN goal

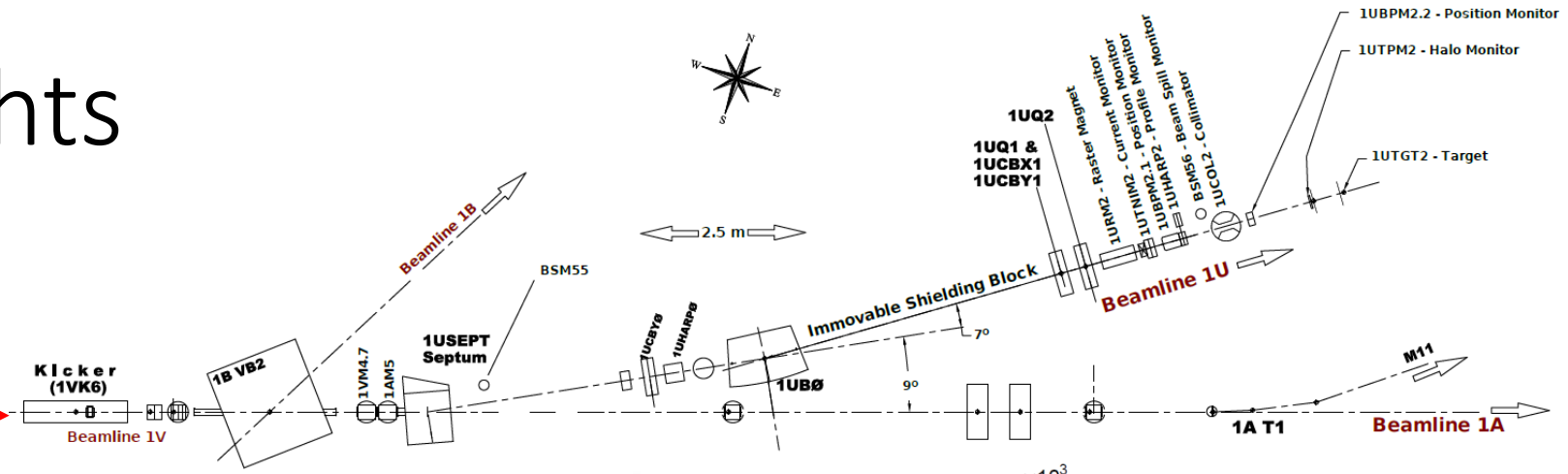
- New result for free neutrons:
  $d_n < 1.8 \times 10^{-26}$ e-cm (90% c.l.)
  - PSI nEDM experiment, C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020).
- Many groups pursuing $\delta d_n \sim 10^{-27}$ e-cm measurement as next step (TUCAN goal). (See backup slides for list of EDM experiments and UCN sources.)
- Main unique features of TUCAN:
  - Spallation driven, superfluid helium source – unique combination
  - Room-temperature EDM apparatus using dual measurement cell in MSR, unique ideas in magnetometry, coils, possible Xe comagnetometer, …



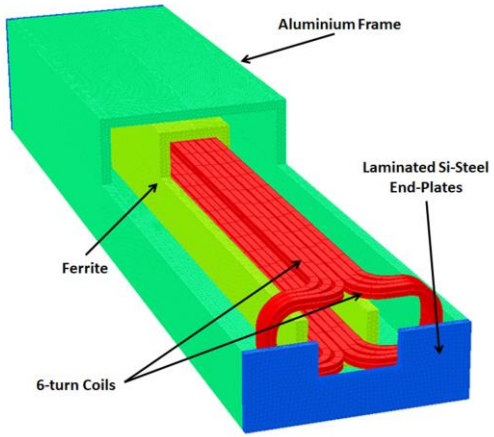


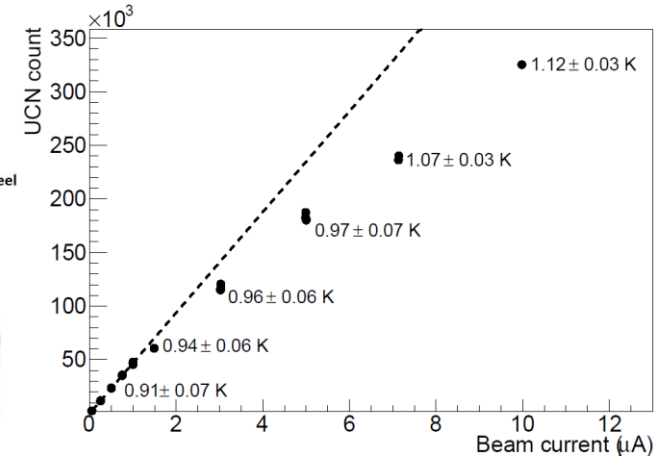
Recent highlights

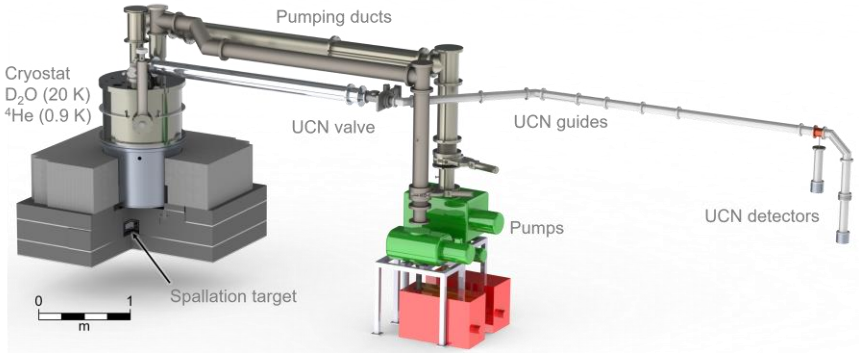
protons



- UCN source prototype operated at TRIUMF
  - TUCAN Collab., PRC 99, 025503 (2019).
- Proton beamline in operation
  - TUCAN Collab., NIM A 927, 101 (2019).
  - TUCAN Collab., PRAB 22, 102401 (2019).
- Technical papers on neutron moderation, magnetic fields, sensors, comagnetometry, UCN detectors.

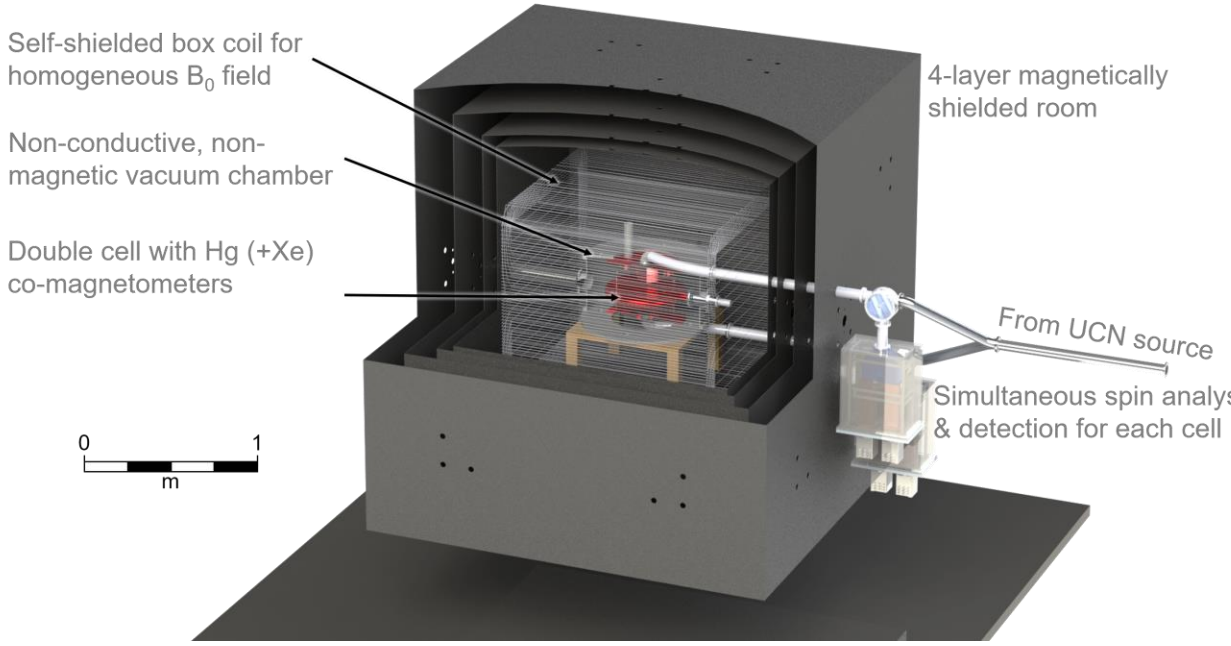


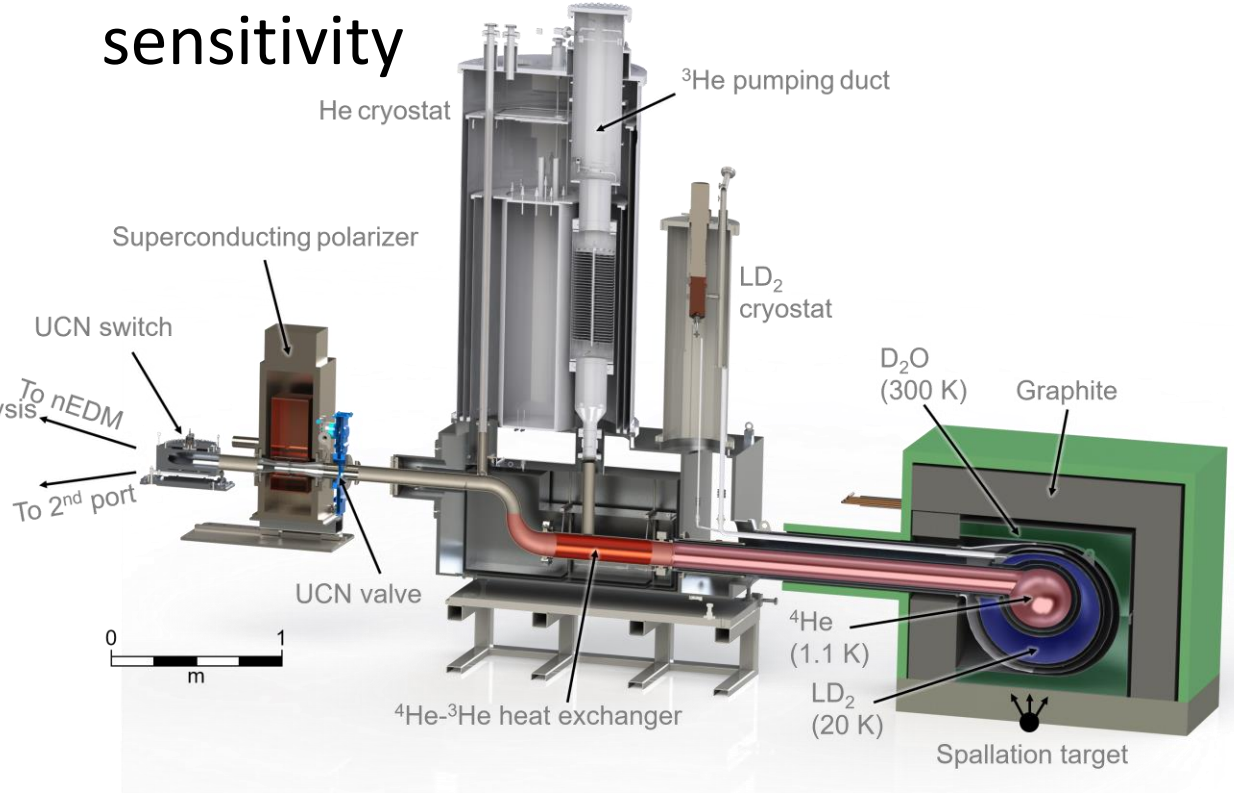




Plans for next five years

- 2021-22: UCN source installation and commissioning
- 2022: MSR installation, begin precision magnetometry in situ
- 2023: nEDM commissioning, thereafter data-taking
- Helium liquefaction upgrade in Meson Hall needed to reach full sensitivity





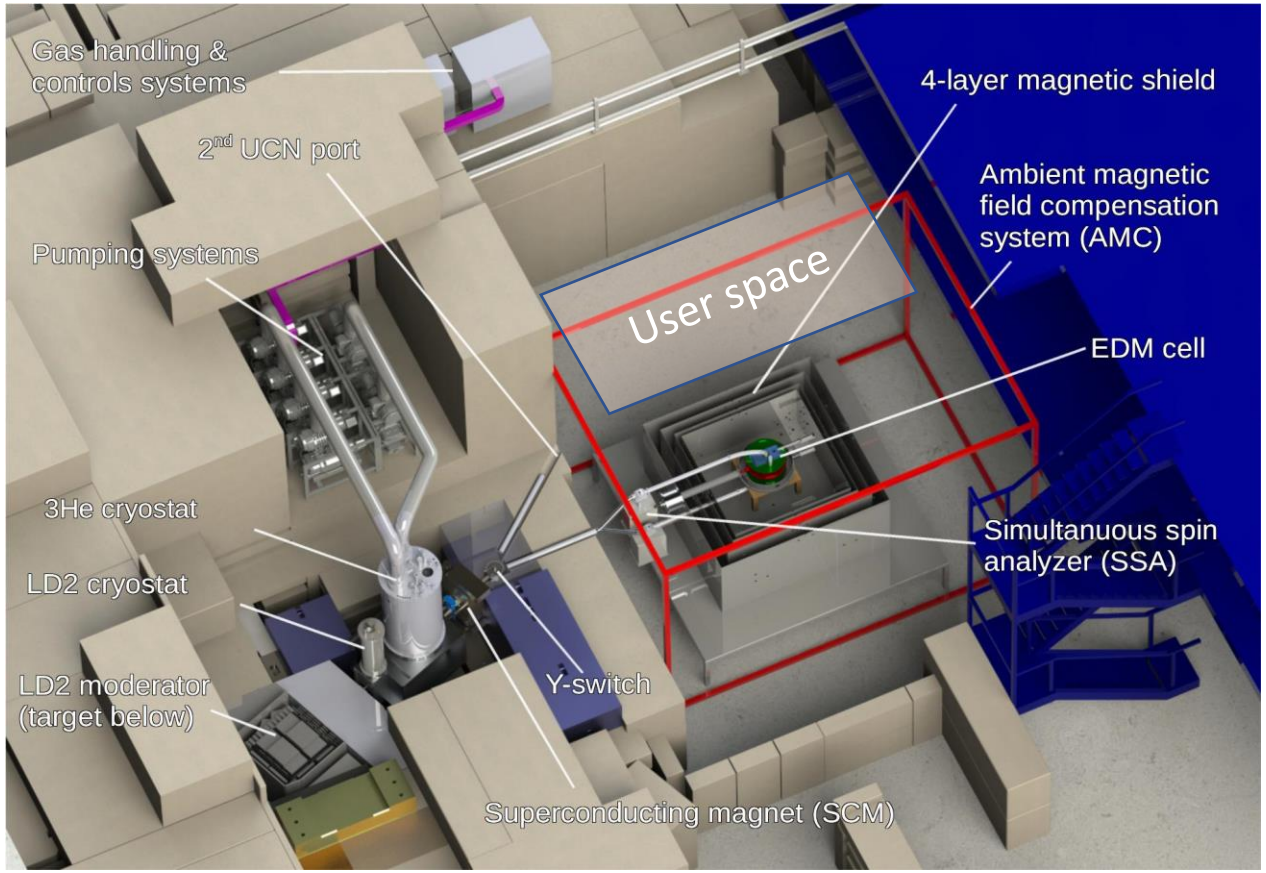
Collaboration, budgetary, and HQP

- Japan-Canada collaboration
- Source upgrades and EDM experiment funded by CFI IF 2017 award and JSPS (and TRIUMF, provinces, industry in-kind)
- 14 NSERC cosignatories, 5.95 FTE
  - $550k/yr from NSERC SAPES
  - $101k/yr from CRC Tier 1 award (till 2025)
  - Supports 4 PDF and 8 grad students, constrained travel.
- Ideal support would allow 5 PDF and 14 grad students, and travel.

- Supportive environment for women, Indigenous students
- Examples:
  - B. Franke supervision/support of women students, TRIUMF role in promoting diversity and hiring women scientists.
  - Winnipeg supervision of Indigenous students, development of new Indigenous programs, university-wide priority of “Indigenization”

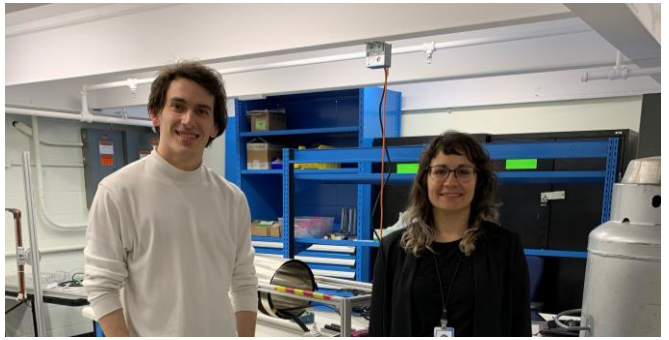
Plans for 2027-36

- EDM data analysis and possible additional data taking
- Upgrades to UCN source or EDM experiment
  - E.g. Xe comagnetometer
- UCN source designed as user facility with second port available for other experiments:
  - Neutron lifetime puzzle
  - Neutron gravity levels experiment
  - Exotic interactions
  - Bring your ideas!



Broader societal impacts

- Technology development and training in:
  - Beamline design, target design
  - neutron physics, neutron and radiation detectors, cryogenics
  - magnetometry, low-field NMR, laser physics
  - high-voltage design
  - data-acquisition systems, and computer simulation.



Opportunities for collaboration, and physical distancing

- Based on examples from R&D, there are many opportunities for university involvement:
  - UCN detector development and testing (Winnipeg, Manitoba)
  - UCN source cryogenics (Winnipeg, Manitoba)
  - UCN guide coating facility (Winnipeg)
  - CN experiment analysis (Winnipeg, KEK)
  - Hg comagnetometer development (UBC)
  - Cs magnetometer development and testing (Winnipeg, Manitoba)
  - Internal coil design (Winnipeg, Manitoba)
  - External coil design (RCNP Osaka)
  - Beam physics and magnetic mapping (UBC students)
- Each has students and/or university-based PDF/RA involved.

- Running at TRIUMF:
  - Ran the prototype UCN source one month per year 2017-2019.
  - Cryogenic testing of the UCN source upgrade at TRIUMF over the next two years. Expect two PhD's (UBC, Manitoba) focused on cryogenic aspects.
  - UCN production from upgraded source 2022.
  - Magnetically shielded room installed 2022 will serve as focal point for magnetic and sensor testing.
  - EDM commissioning/running 2023 and beyond.
  - Future projects.
- Good opportunity to get involved now in local particle physics project at TRIUMF.

Conclusions

- Strong physics interest with tight constraint placed on CP violation.
- Highly competitive field with many new ideas, technologies.
- Next generation of experiment aims at 10^{-27} e-cm uncertainty, order of magnitude improvement on recent new limit from PSI.
- TUCAN has made good progress making first UCN at TRIUMF using unique superfluid helium UCN source
- TUCAN source upgrade and EDM experiment installation ongoing, commissioning, running, and analyzing data into the future.
- User facility for other projects (neutron lifetime, gravity levels, exotic interactions…), collaborators welcome!

Backups

TUCAN Collaboration

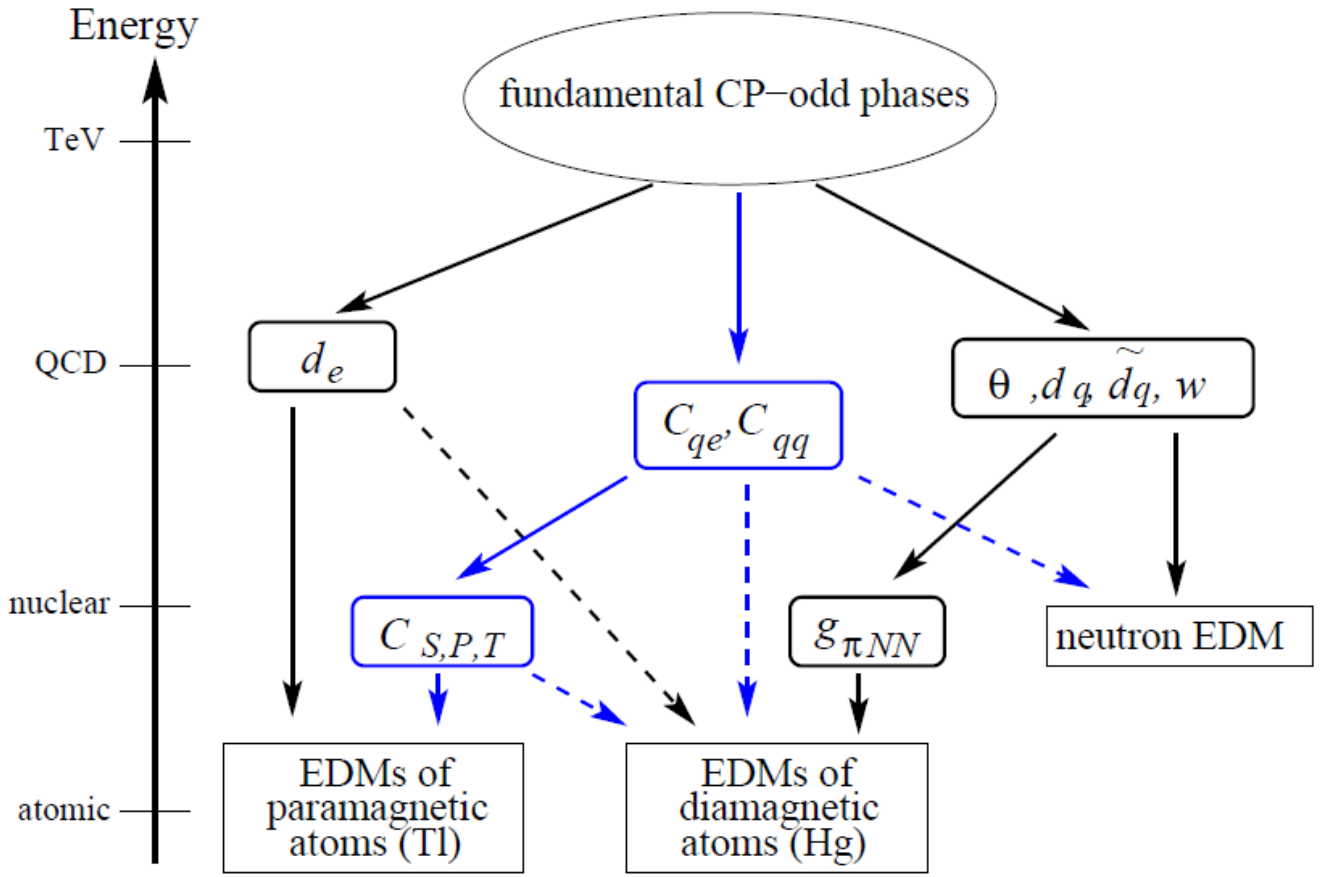
B. Bell[1,2], C. Bidinosti[3], C. Davis[2], B. Franke[2,4], M. Gericke[5], P. Giampa[2], S. Hansen-Romu[5], K. Hatanaka[6], T. Hayamizu[7], T. Higuchi[6], G. Ichikawa[8], S. Imajo[6], B. Jamieson[3], S. Kawasaki[8], M. Kitaguchi[9], W. Klassen[5], A. Konaka[2], E. Korkmaz[10], F. Kuchler[2], M. Lang[5], M. Lavvaf[5], T. Lindner[2,3], K. Madison[4], Y. Makida[8], R. Mammei[3], J. Mammei[5], J. Martin[3], R. Matsumiya[2], M. McCrea[3], E. Miller[4], K. Mishima[8], T. Momose[4], T. Okamura[8], H. J. Ong[6], R. Picker[2,11], W. D. Ramsay[2], W. Schreyer[2], H. Shimizu[9], S. Sidhu[11,2], S. Stargardter[5], I. Tanihata[6], S. Vanbergen[4,2], W. van Oers[2,5], Y. Watanabe[8], N. Yamamoto[9]

1. McGill, 2. TRIUMF, 3. Winnipeg, 4. UBC, 5. Manitoba, 6. RCNP Osaka,
7. RIKEN, 8. KEK, 9. Nagoya, 10. UNBC, 11. SFU

Spokespeople: K. Hatanaka (Japan), J. Martin (Canada)

Heritage of EDM's – how New Physics enters

$d_e < 1.1 \times 10^{-29}$ e-cm
(ACME ThO)



$d_n < 1.8 \times 10^{-26}$ e-cm
(PSI nEDM collab.)
$d_n < 1.6 \times 10^{-26}$ e-cm
(U. Wash Hg-199)

- Figure: M. Pospelov & A. Ritz, Ann. Phys. **318**, 119 (2005).
- See also: J. Engel, M. Ramsey-Musolf, U. van Kolck, Prog. in Part. and Nucl. Phys. **71**, 21 (2013).
  T. Chupp, P. Fierlinger, M. Ramsey-Musolf, and J. Singh, Rev. Mod. Phys. 91, 015001 (2019).

Planned Neutron EDM Experiments around the World

• PSI	spallation so-D_2, magnetic fields	analysis/upgrading
• PanEDM (ILL/Munich)	reactor He-II, 1st MSR	commissioning
• ILL/PNPI/Gatchina	dual cell, 2nd best nEDM meas't	upgrading
• LANL	spallation so-D_2 UCN source	2021-
• TUCAN (Japan/Canada)	spallation He-II, MSR	upgrading, 2022-
• SNS	fully cryogenic source/experiment	2023-
• ILL/ESS n-beam	intense pulsed neutron beam	R&D, 2025-
• J-PARC crystal	high E in crystal	R&D

Survey of UCN Sources Worldwide

Place	Neutrons	UCN converter	Status
ILL	Reactor, CN	Turbine	Running
J-PARC	Spallation	Doppler shifter	Running
ILL SUN-2	Reactor, CN	Superfluid He	Running
ILL SuperSUN	Reactor, CN	Superfluid He	Future
RCNP/KEK/TRIUMF	Spallation	Superfluid He	Running/Upgrading
Gatchina WWR-M	Reactor	Superfluid He	Future
LANL	Spallation	Solid D2	Running/Upgrading
Mainz	Reactor	Solid D2	Running
PSI	Spallation	Solid D2	Running/Upgrading
NCSU Pulstar	Reactor	Solid D2	Installing
FRM-II	Reactor	Solid D2	Future

KEK-TRIUMF combination of spallation target and superfluid helium is unique.
Upgrade schedule is competitive with other leading sources of UCN.