TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Using Xe-129 co-magnetometer as a tool to improve the upper limit for nEDM

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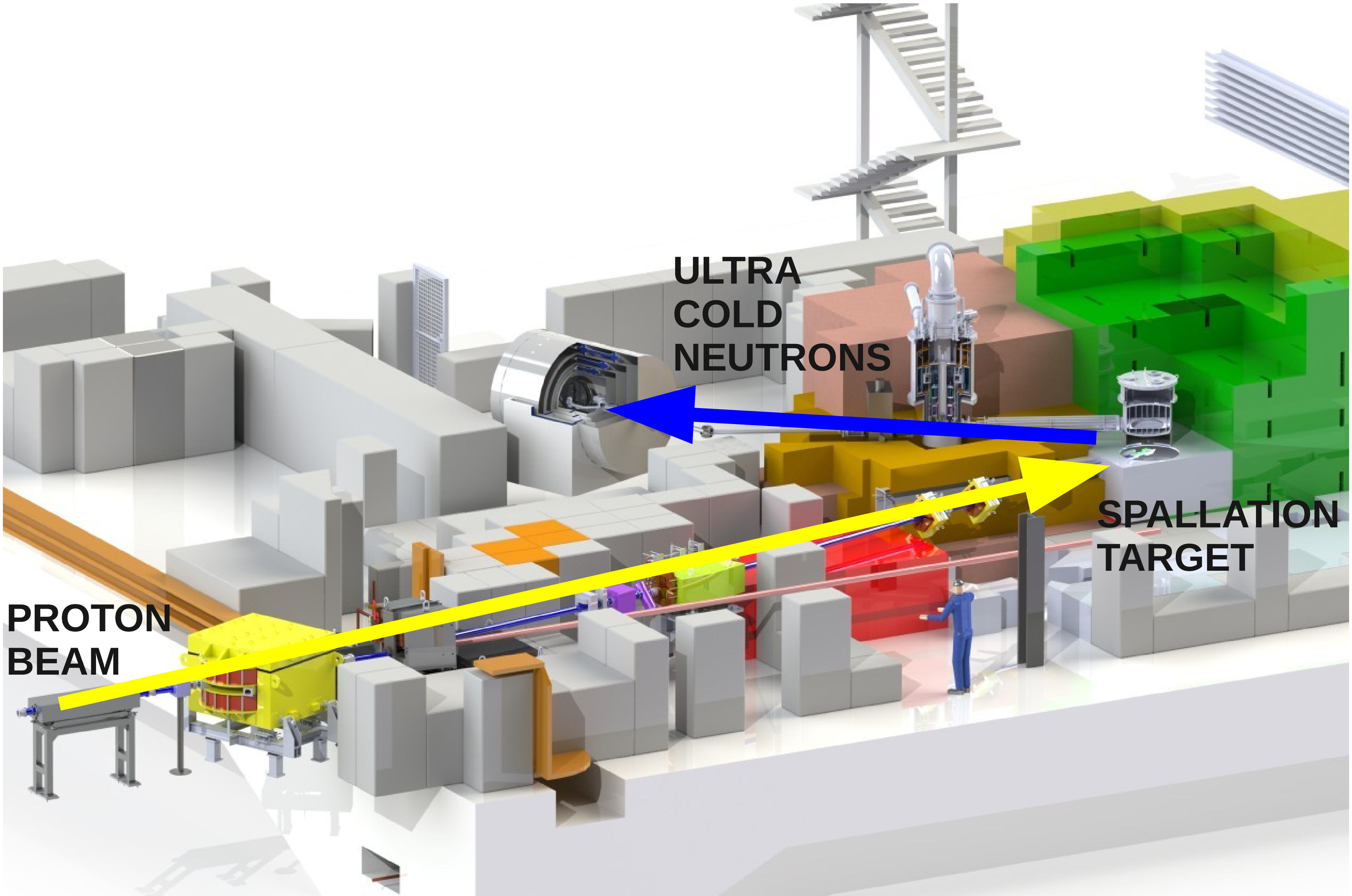
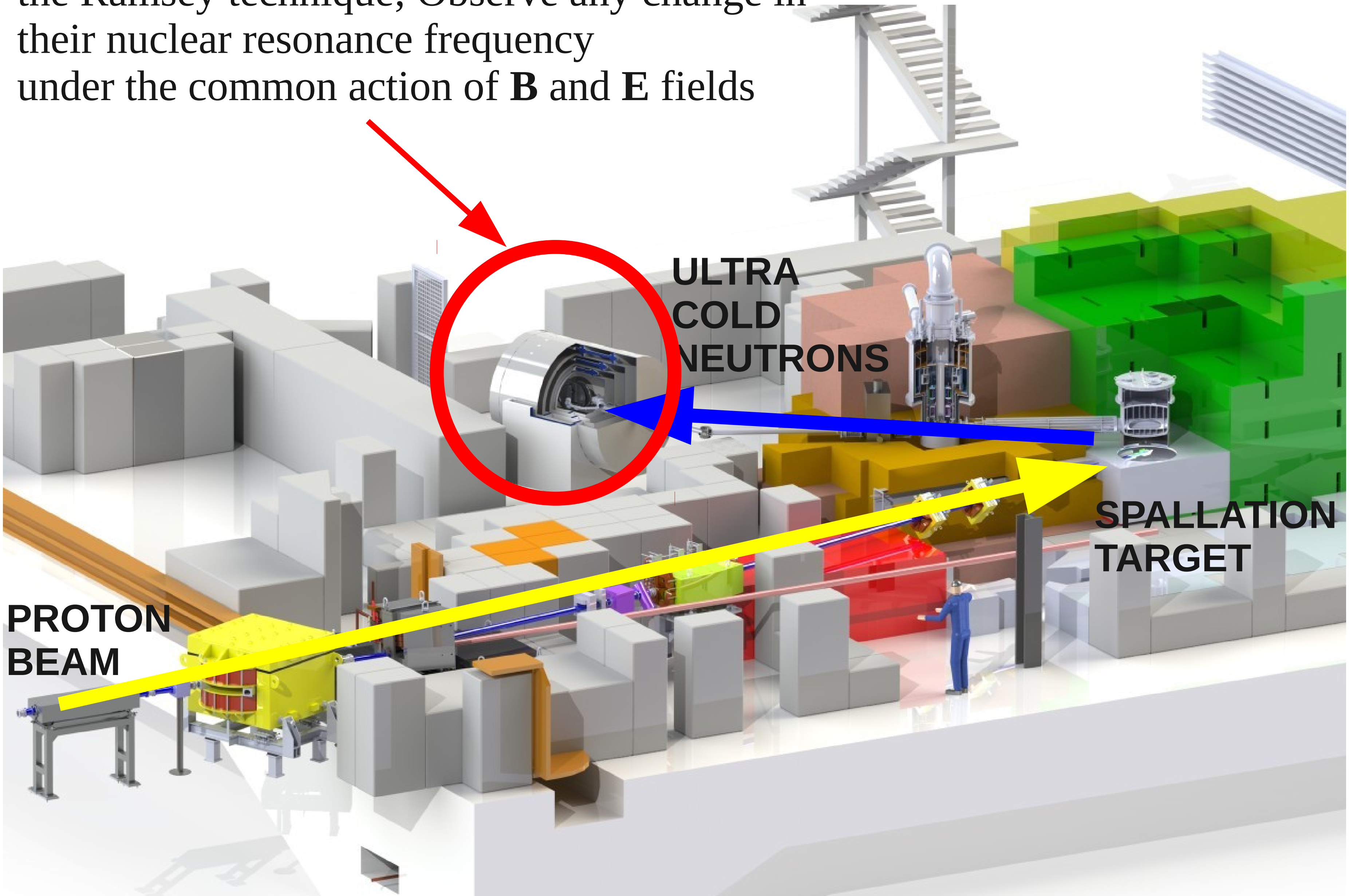
Neutron Electric Dipole Moment (nEDM) Experiment at TRIUMF
(TRIUMF, UoWinnipeg, UoManitoba, UBC, RCNP)

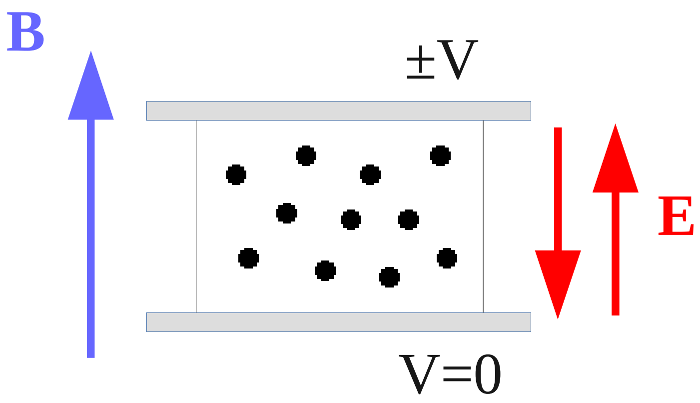


Neutron Electric Dipole Moment (nEDM) Experiment at TRIUMF (TRIUMF, UoWinnipeg, UoManitoba, UBC, RCNP)

Neutrons are stored in a cell and undergo the Ramsey technique; Observe any change in their nuclear resonance frequency under the common action of **B** and **E** fields



Comparing the E and B dependance of the resonance frequency shift



Nuclear Resonance Frequency

$$h\nu_o = -2\mu B \mp 2dE$$

Under E reversal (keeping B constant)

$$h\delta\nu_o = -2d\left(E_{(\uparrow\uparrow)} - E_{(\uparrow\downarrow)}\right) \rightarrow \delta\nu_o = \frac{-4dE}{h}$$

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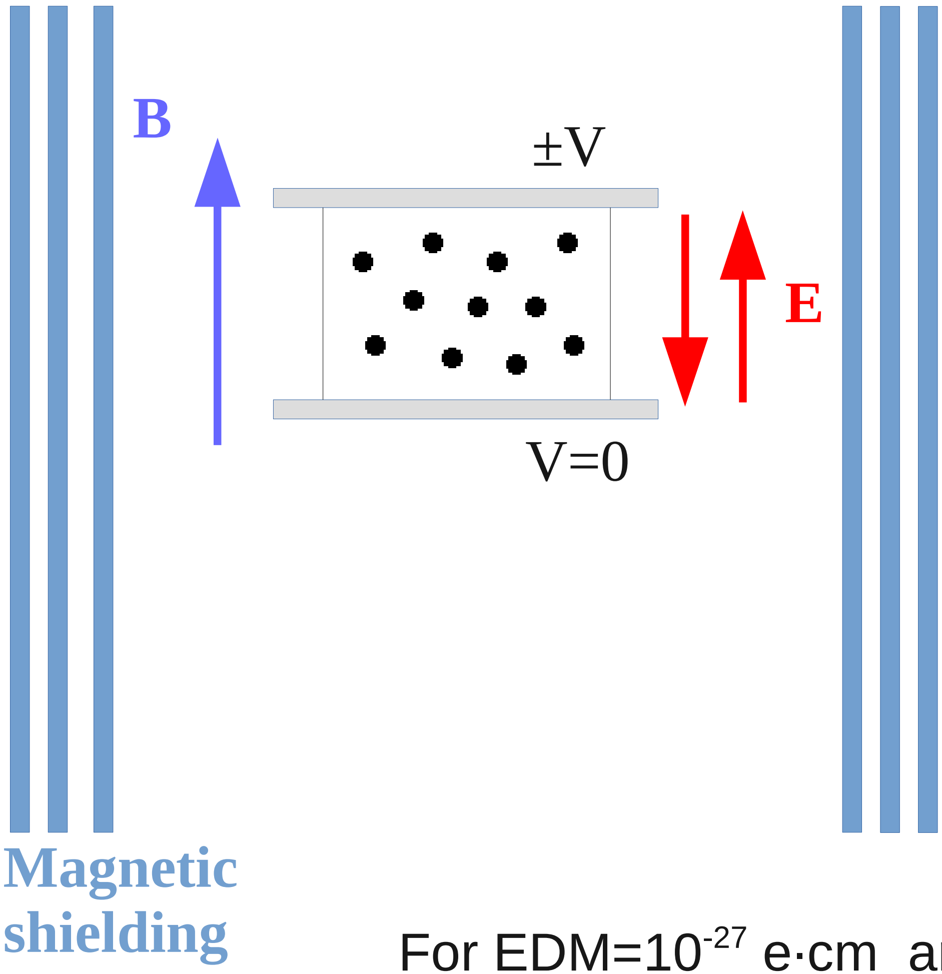

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For EDM=10^{-27} e·cm and E=10 kV/cm: $|\delta\nu_o| = 9$ nHz

For $\Delta B = 0.4$ fT $\quad |\delta\nu_B| = 2\mu\frac{\Delta B}{\hbar} = 9$ nHz

Unknown magnetic fluctuations can produce FALSE nEDM signal !!

We can gain a factor of 100 by averaging over e.g. 10,000 measurements:

$\Delta B_{max} = 40$ fT

Monitoring the B-field changes with a co-magnetometer

Fluxgates, SQUIDs etc can only be placed outside the neutron bottle providing only an approximate estimation of the magnetic field fluctuations seen by the neutrons.

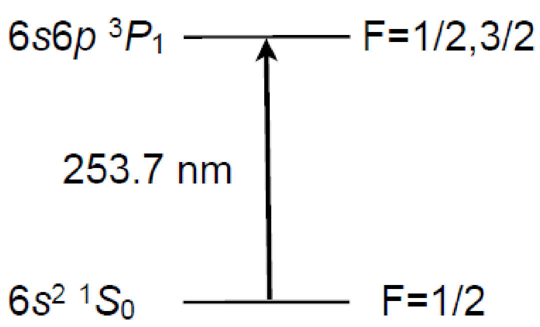
We need a magnetometer that occupies the SAME VOLUME with neutrons

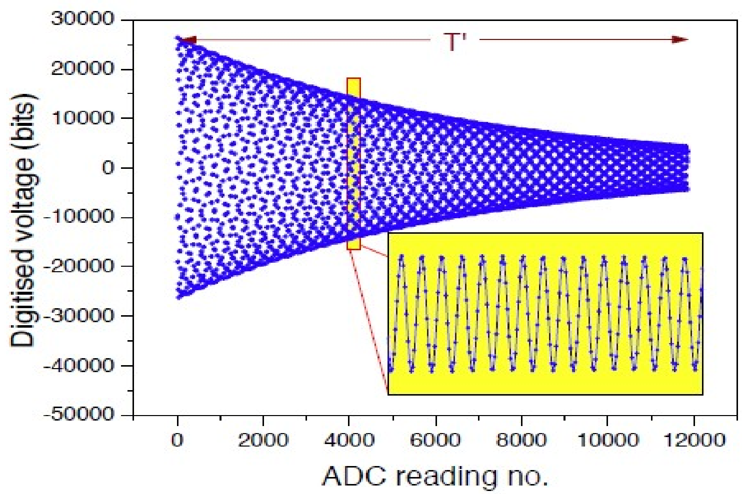
^{199}Hg co-magnetometer has been used in the ILL/RAL/Sussex nEDM experiment

A. ^{199}Hg atoms are polarised along z.

B. A transverse RF pulse at ^{199}Hg resonance frequency forces the spins to precess on the xy-plane (8 Hz at 1 μT)

C. A beam of polarised light from ^{204}Hg discharge lamp traverses the cell in the x-direction. Its absorption depends on the x-component of the spin polarisation which varies sinusoidally with time at the Larmor frequency. (10-100 fT resolution)

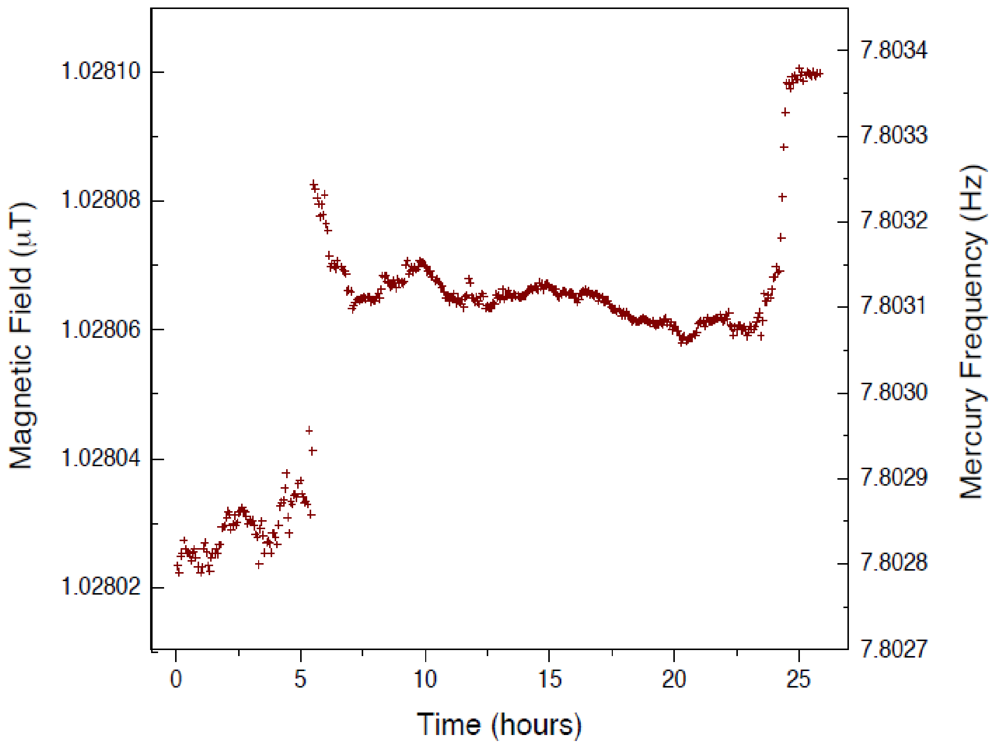




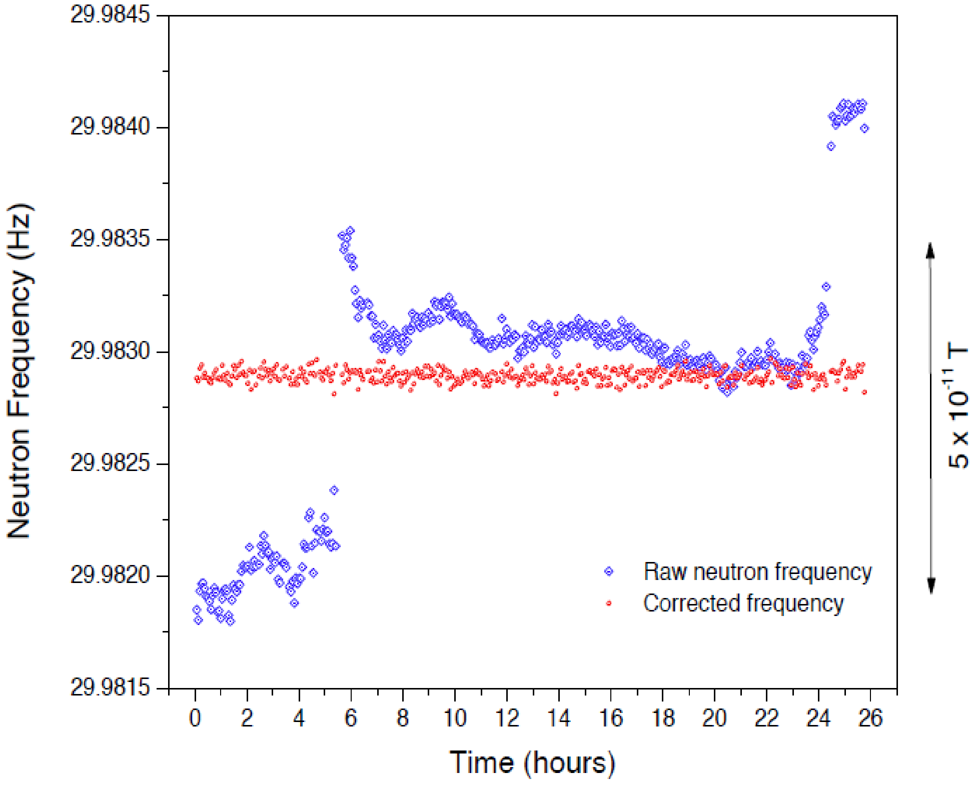
S. K. Lamoreaux 1989 Nucl. Instrum.Methods A284 43
Green et al. Nucl. Instr. Meth. Phys. Res. A404, 381 (1998)

Correction of the B-field fluctuation effect on neutron resonance frequency with the ^{199}Hg co-magnetometer

^{199}Hg frequency shift



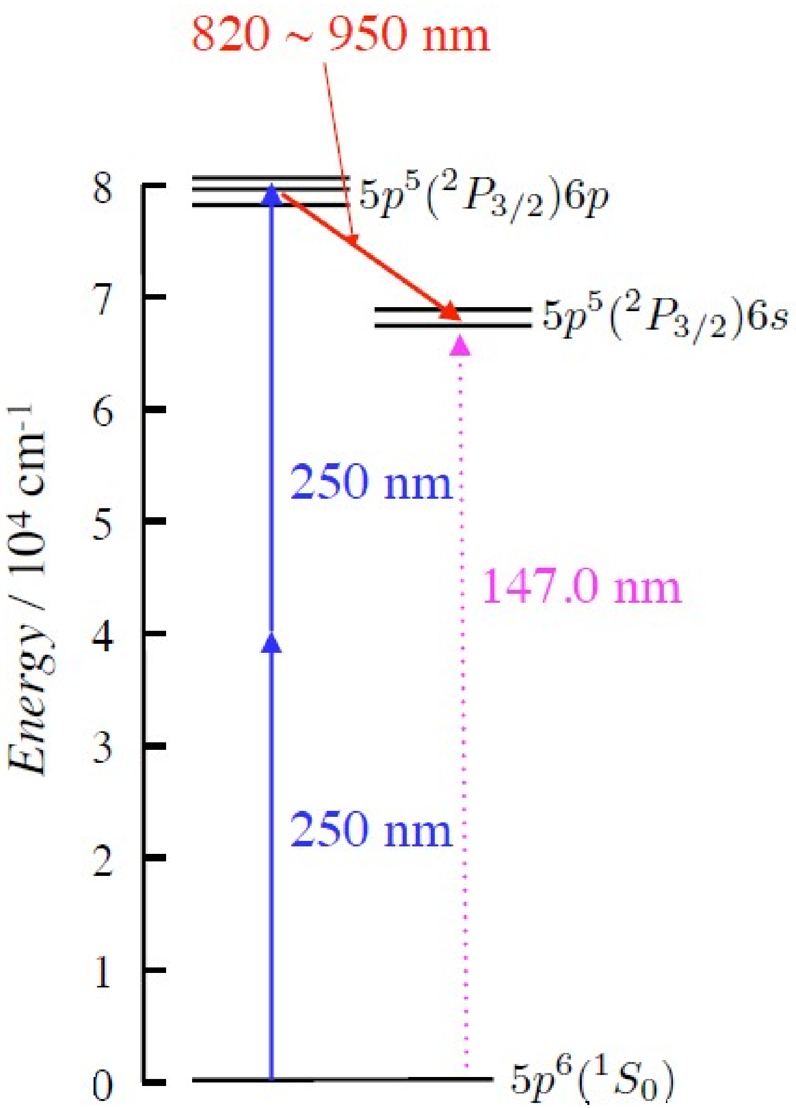
Neutron frequency shift



Green et al. Nucl. Instr. Meth. Phys. Res. A404, 381 (1998)

^{129}Xe co-magnetometer

[T. Mamose, E. Miller (UBC)]



^{129}Xe compared to ^{199}Hg has:

1. Higher ionisation potential
2. 100 times smaller neutron absorption cross section

Gyromagnetic Ratio

	neutron	^{199}Hg	^{129}Xe
γ/2π [MHz/T]	-29.16	7.65	-11.77

(The same sign reduces the systematics)

Process

A. Polarised by spin exchange optical pumping between Rb and Xe atoms (*J. Martin C. Bidinosti (UWinnipeg)*)

B. Two (252 nm) photon excitation to the 2nd excited state *(proposed by T.Chupp and A. Leanhardt)*

C. Detect the IR (~900 nm) spontaneous emission (~2.5 ns)

^{129}Xe and ^{199}Hg dual co-magnetometer

1/ Improve systematics by data cross checking

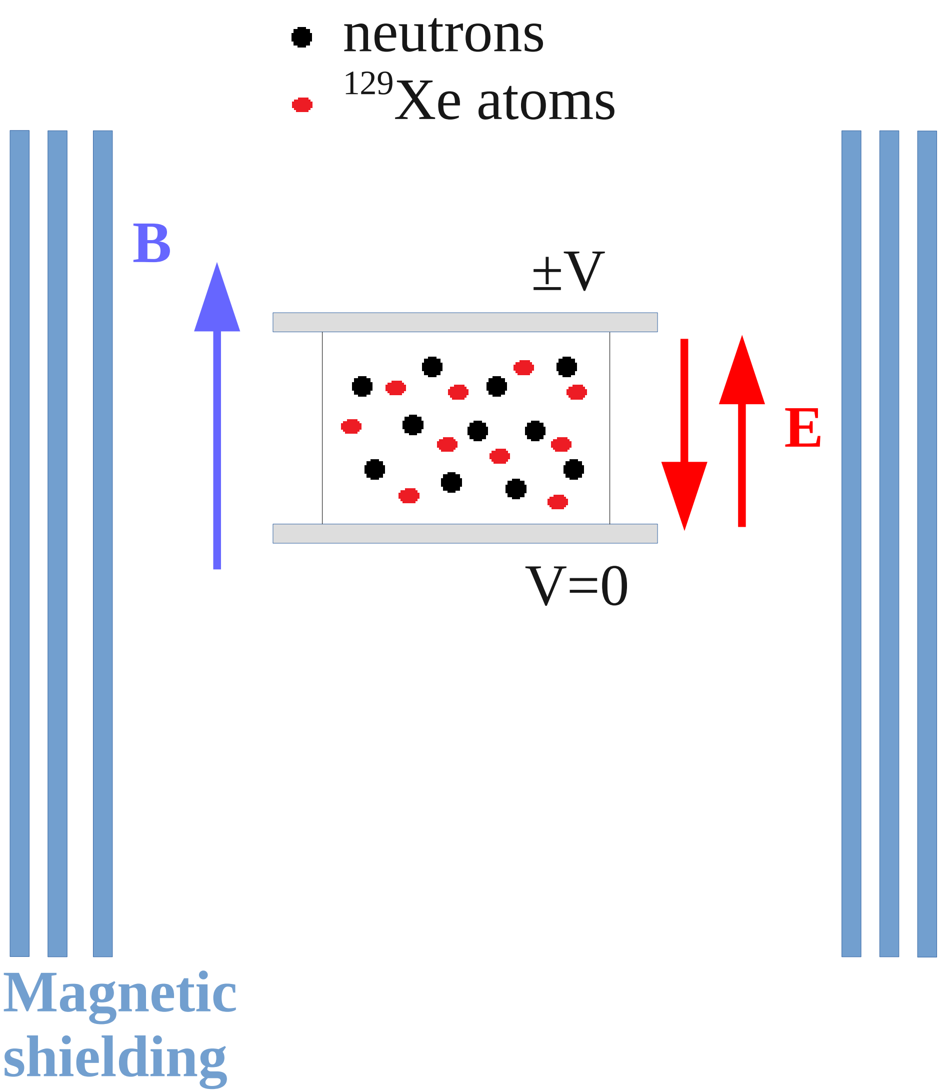
2/ Easy implementation as the laser requirements are quite similar
(the transition lines are ^{199}Hg: 253.7 nm ^{129}Xe: 252.4 nm)

3/ ^{129}Xe atomic EDM limit is very close to that of neutron (2.9×10^{-26} e ·cm) :

$$d_{Xe-129} < \left(0.7 \pm 3.3 \pm 0.1\right) \cdot 10^{-27} \text{ e} \cdot \text{cm}$$

Needs to be improved by at least one or even better by two orders of magnitude.
We can conduct ^{129}Xe atomic EDM measurement using the ^{199}Hg as co-magnetometer

^{129}Xe atoms number density VS statistical sensitivity



Statistical senitivity

$$\sigma_d \propto \frac{1}{E \cdot \sqrt{N}} \cdot \left(\frac{\hbar}{2T_s}\right)$$

↑ ^{129}Xe density → ↑ Optical signal

↑ ^{129}Xe density → ↓ Neutron density N (via absorption & up-scattering)

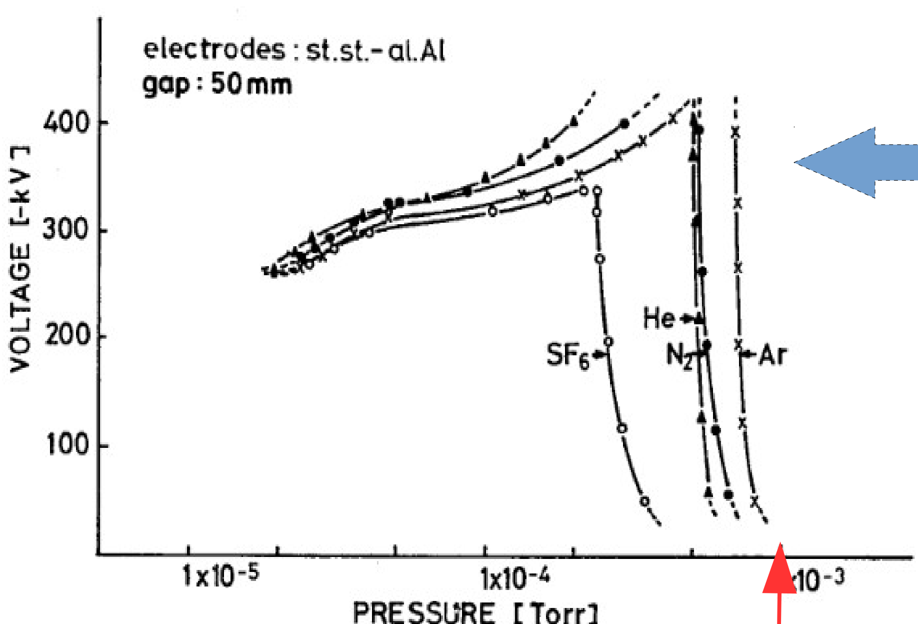
↑ ^{129}Xe density → ↓ Breakdown Voltage

High Voltage (HV) tests at TRIUMF

Conduct HV tests up to 100-125 kV with ^{129}Xe gas alone and in mixture with other gases (^{199}Hg, ^{4}He).

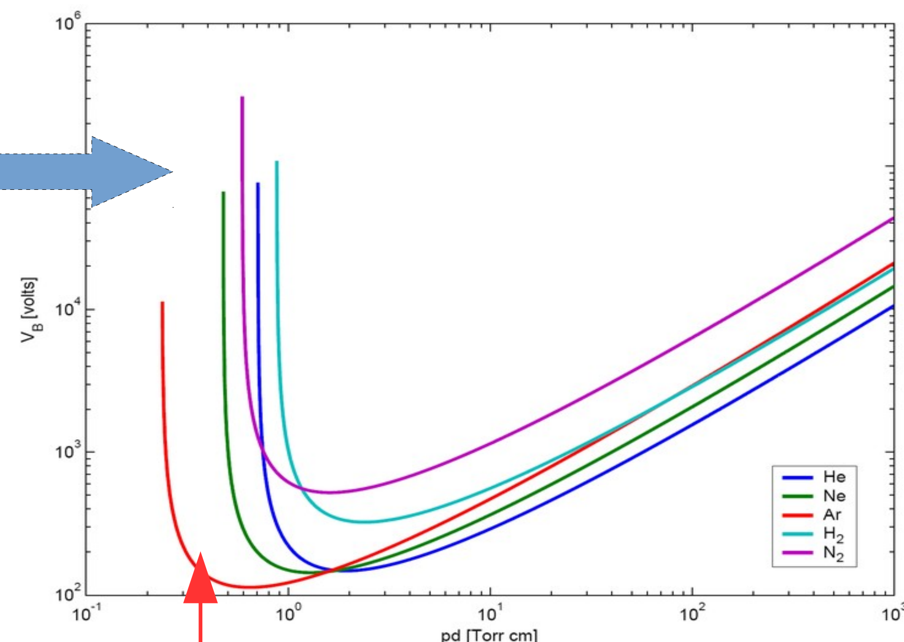
The dielectric properties of ^{129}Xe to be explored at high voltages (V=100 kV across 10 cm) and in the range of 1-5 mTorr where there is lack of experimental data (Pressure·distance=P·d=1-5·10^{-2} [Torr ·cm]).

Yamamoto 1977 Jpn. J. Appl. Phys. 16 343



P·d=0.5·10^{-2} [Torr ·cm]

Paschen curve (1889, Wied. Ann., 37, 69)



P·d=50·10^{-2} [Torr ·cm]

High Voltage (HV) tests/plans at TRIUMF

Conduct HV tests up to 100-125 kV with ^{129}Xe gas alone and in mixture with other gases (^{199}Hg, ^{4}He).

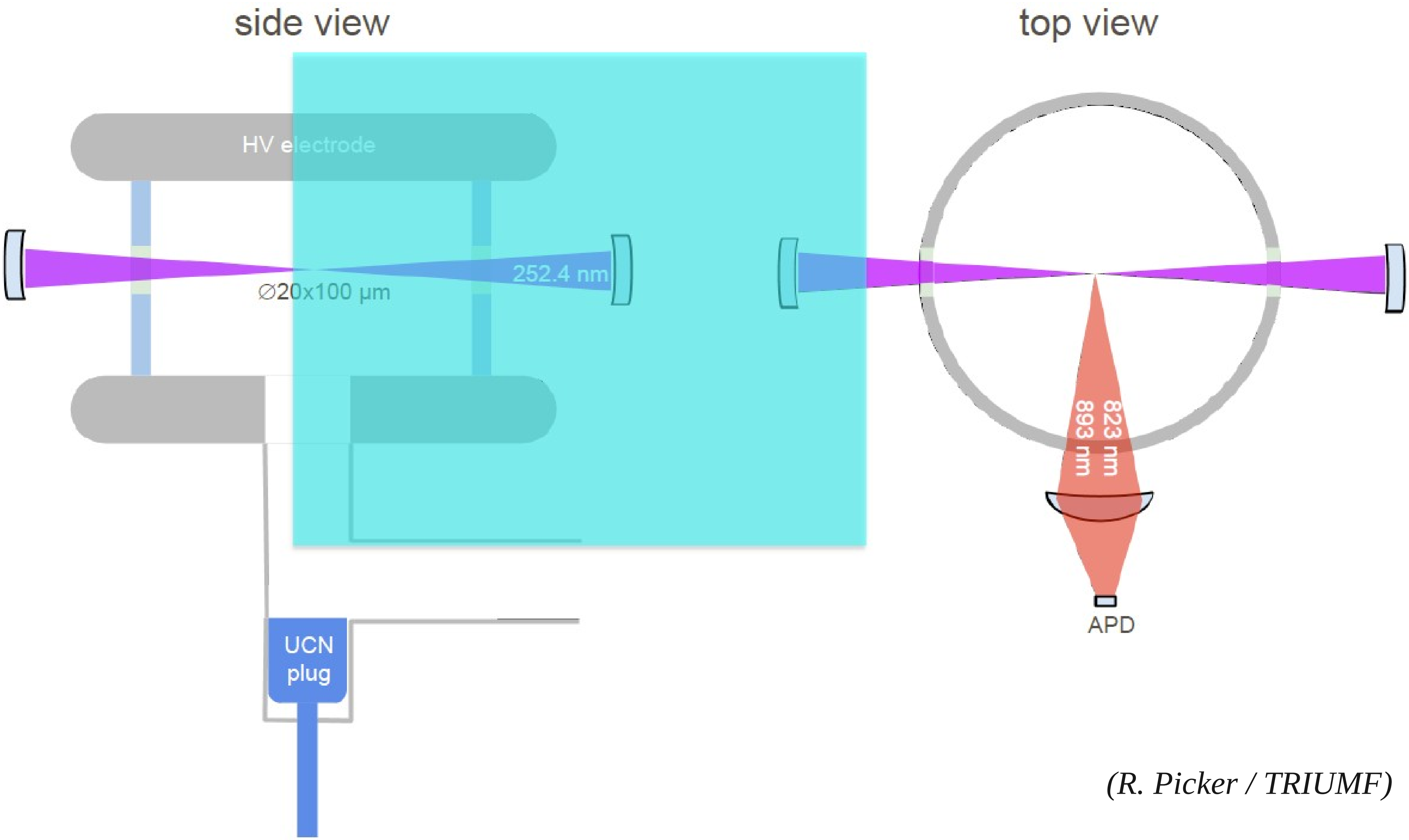
The dielectric properties of ^{129}Xe to be explored at high voltages (V=100 kV across 10 cm) and in the range of 1-5 mTorr where there is lack of experimental data (Pressure·distance=P·d=1-5·10^{-2} [Torr ·cm]).

Find the optimum (partial) pressure conditions and electrode separation to maximise the breakdown voltage.

Design the HV setup for the nEDM experiment at TRIUMF:

- To provide uniform and stable (~10-15 kV/cm) electric field throughout the cell
- Include UV and IR transparent windows on the cell side walls for co-magnetometer purposes

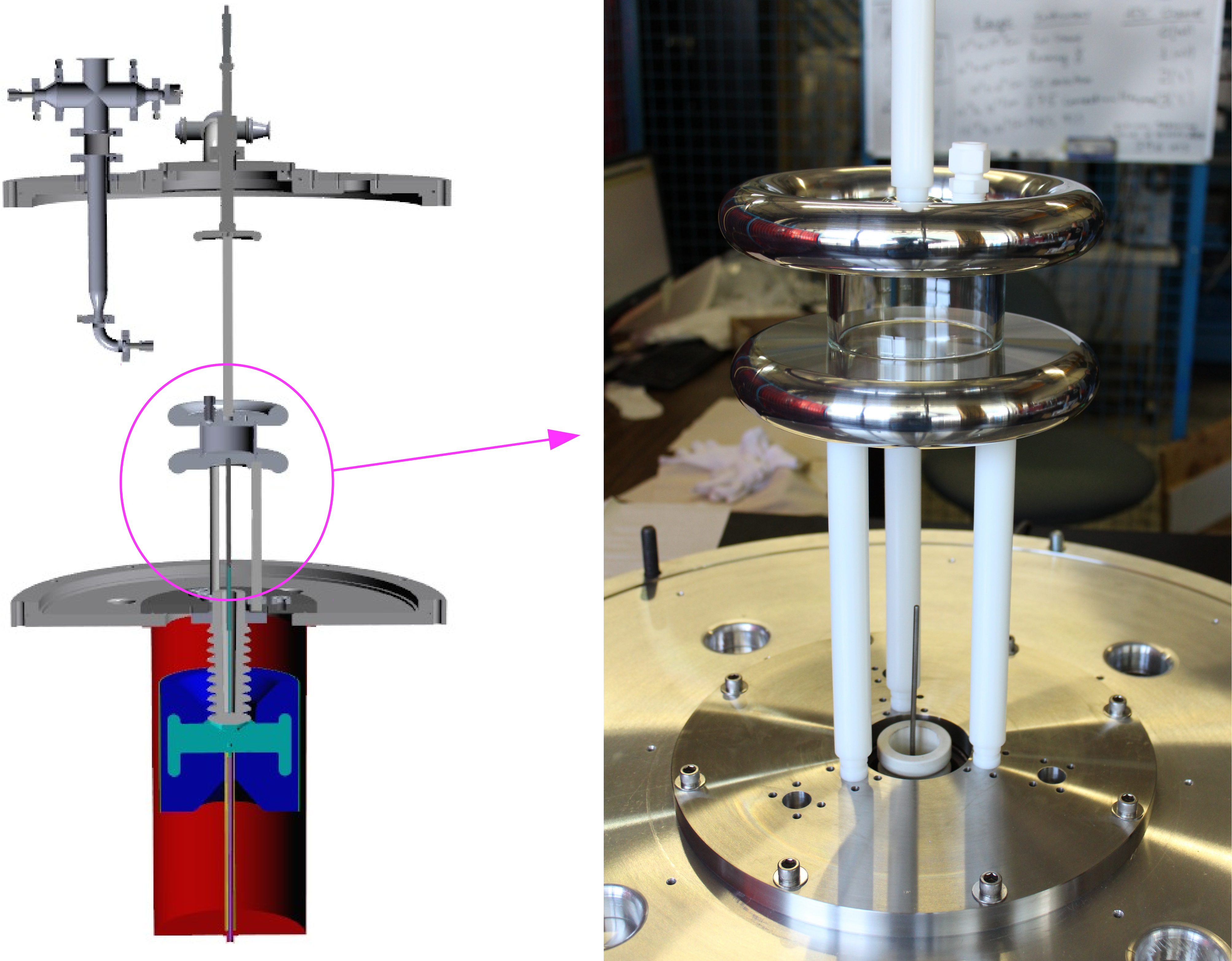
Neutron cell concept

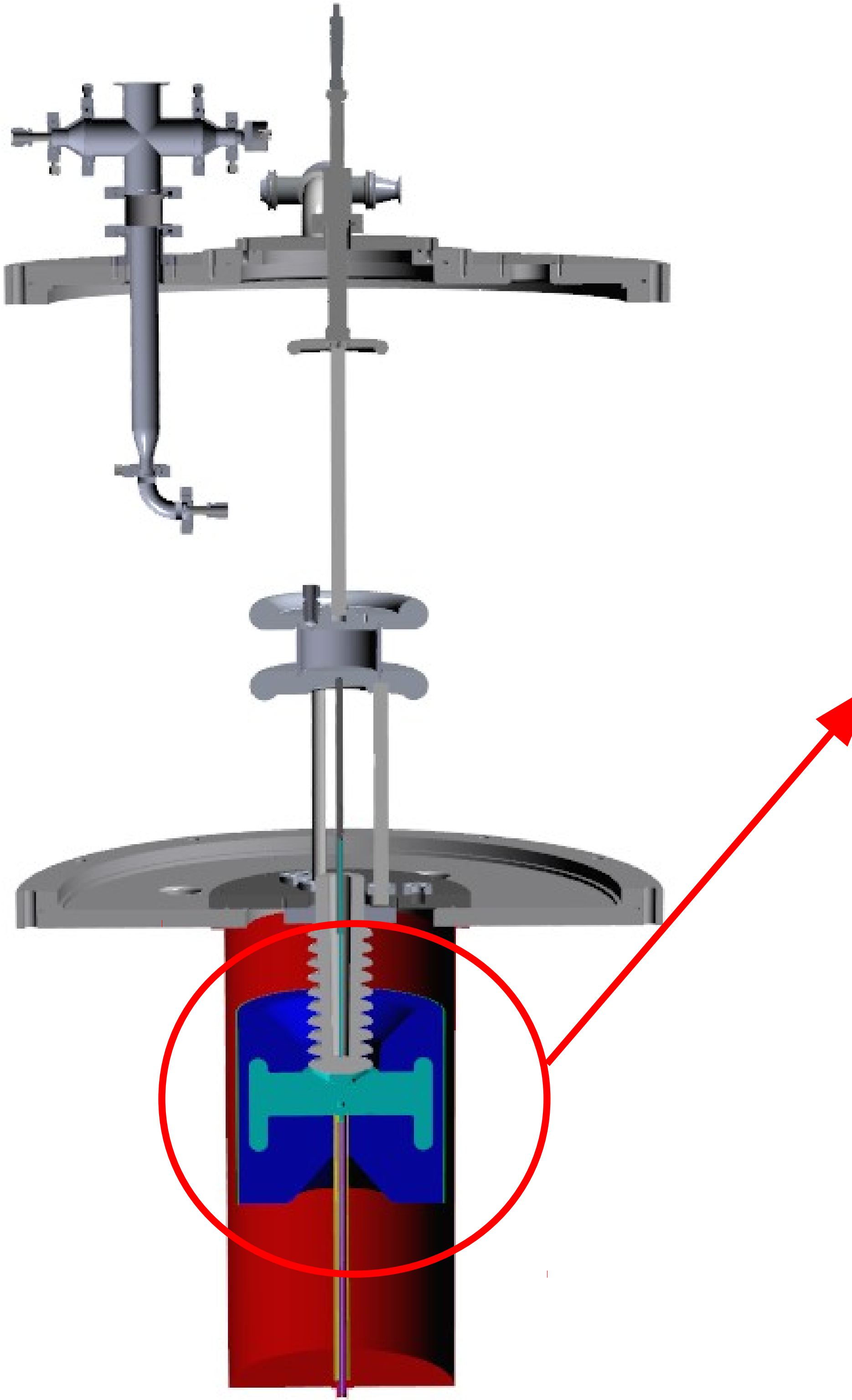


(R. Picker / TRIUMF)

High Voltage tests setup

(R. Picker, M. Losekamm TRIUMF)





Last issue to resolve before attempt test:

HV feedthrough connection to the HV power supply:

1. Reduce the HV gradient at the connection point of the feedthrough to the HV cable (e.g. corona ring or equivalent)

2. Dielectric material

3. Grounding

Summary

- The co-magnetometer technique has been successfully used in the ILL/RAL/Sussex nEDM experiment reducing the systematics (related to B-field changes) by more than one order of magnitude compared with older experiments.

- ^{129}Xe properties make it a better co-magnetometer candidate than ^{199}Hg as it can potentially allow for larger neutron density and electric field strength and therefore improve the statistical sensitivity.

- Using ^{129}Xe and ^{199}Hg in conjunction can potentially reduce the systematics and allow for ^{129}Xe atomic EDM measurement.

- High Voltage tests will be conducted at TRIUMF to optimise the co-magnetometer(s) gas pressure(s) and electrode separation.