TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

High Voltage studies with Xe-129 for an nEDM experiment at TRIUMF

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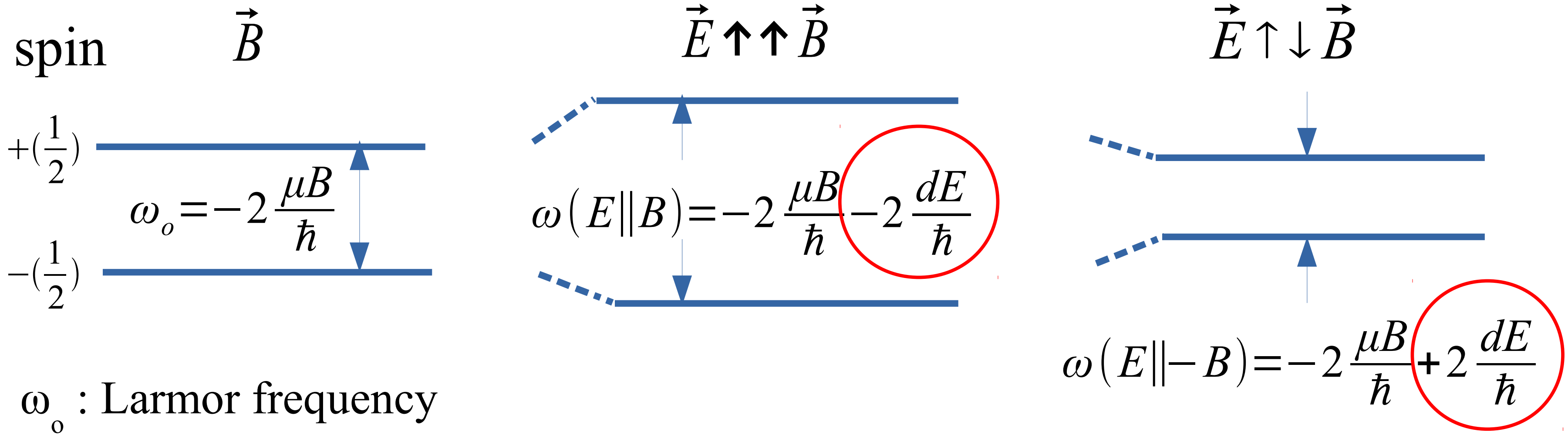
Talk layout

- Spin precession frequency of neutrons in the presence of magnetic (B) electric (E) fields
- Using ^{129}Xe/ ^{199}Hg co-magnetometer to monitor the B-field changes
- Investigating the dielectric properties of ^{129}Xe in the 1 mTorr range
- High voltage setup at TRIUMF
- Current status and next steps
- Summary

Spin precession frequency of neutrons in the presence of magnetic (B) and electric (E) fields



ω_o : Larmor frequency

μ : magnetic dipole moment (MDM)

d : electric dipole moment (EDM)

If $\Delta B = 0$

Upon $\vec{E}$ reversal: $\delta \nu_o = \frac{-4\,dE}{h}$

But $\Delta B \neq 0$

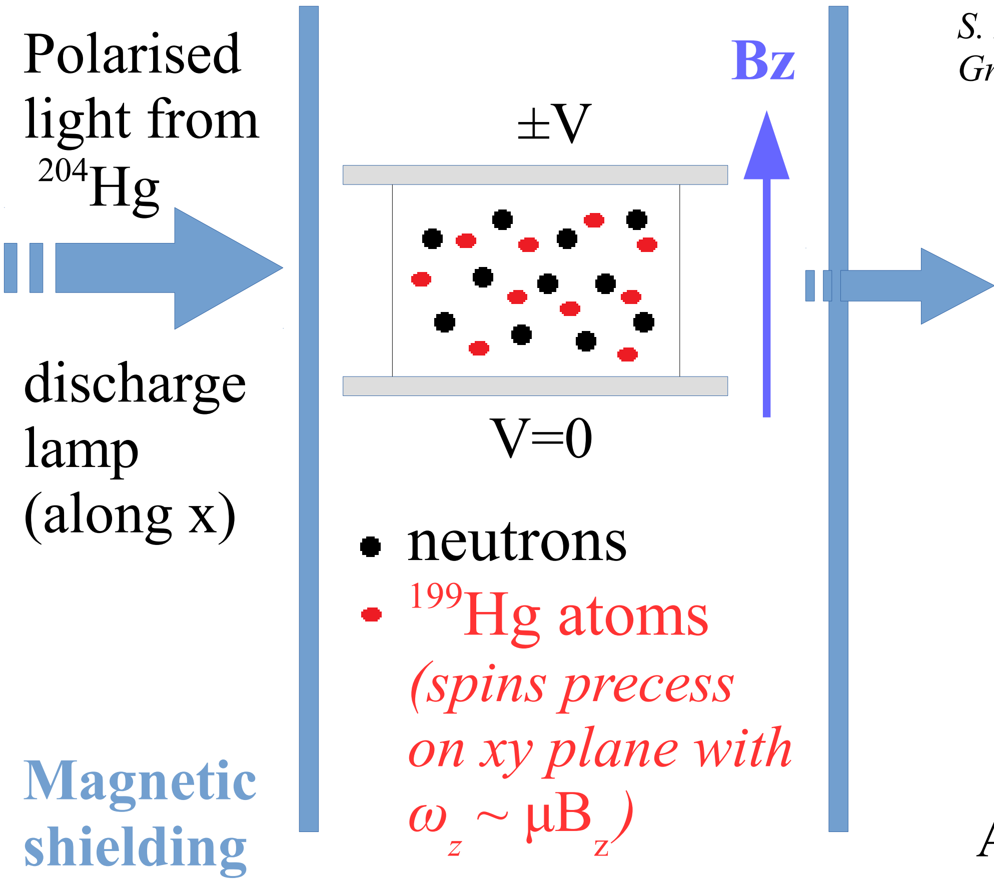
$$2\mu\frac{\Delta B}{\hbar} = \frac{4\,dE}{\hbar} \Rightarrow \Delta B = 40\ fT$$

(over 10,000 runs if $d = 10^{-27}\ e\cdot cm$ and E=10 kV/cm)

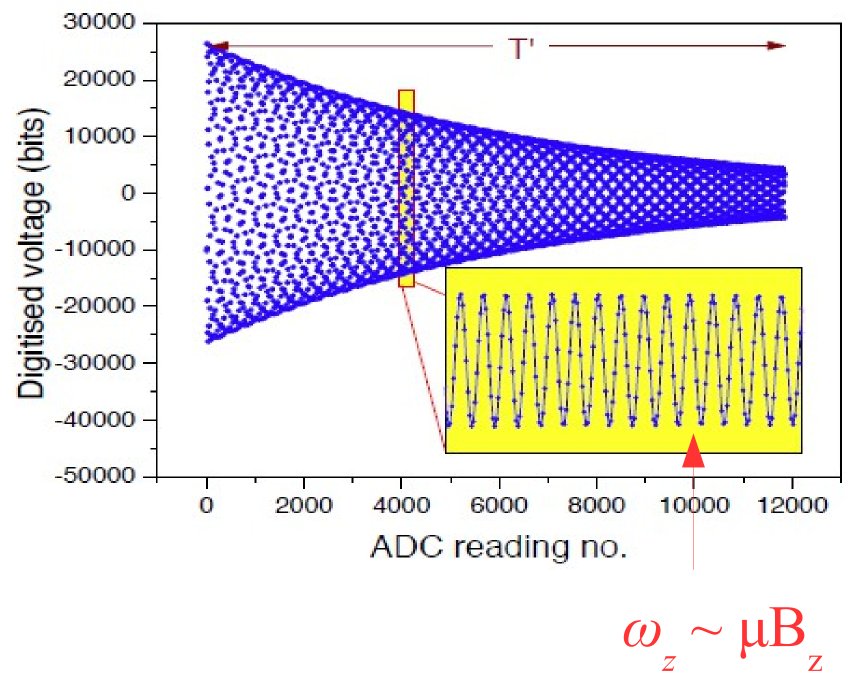
Unknown magnetic field fluctuations can produce a false EDM signal

Using ^{199}Hg co-magnetometer to monitor the B-field changes

- B-field fluctuations are one of the main sources of systematics
- An atomic co-magnetometer occupies the **same space** with neutrons and can accurately monitor the magnetic temporal changes



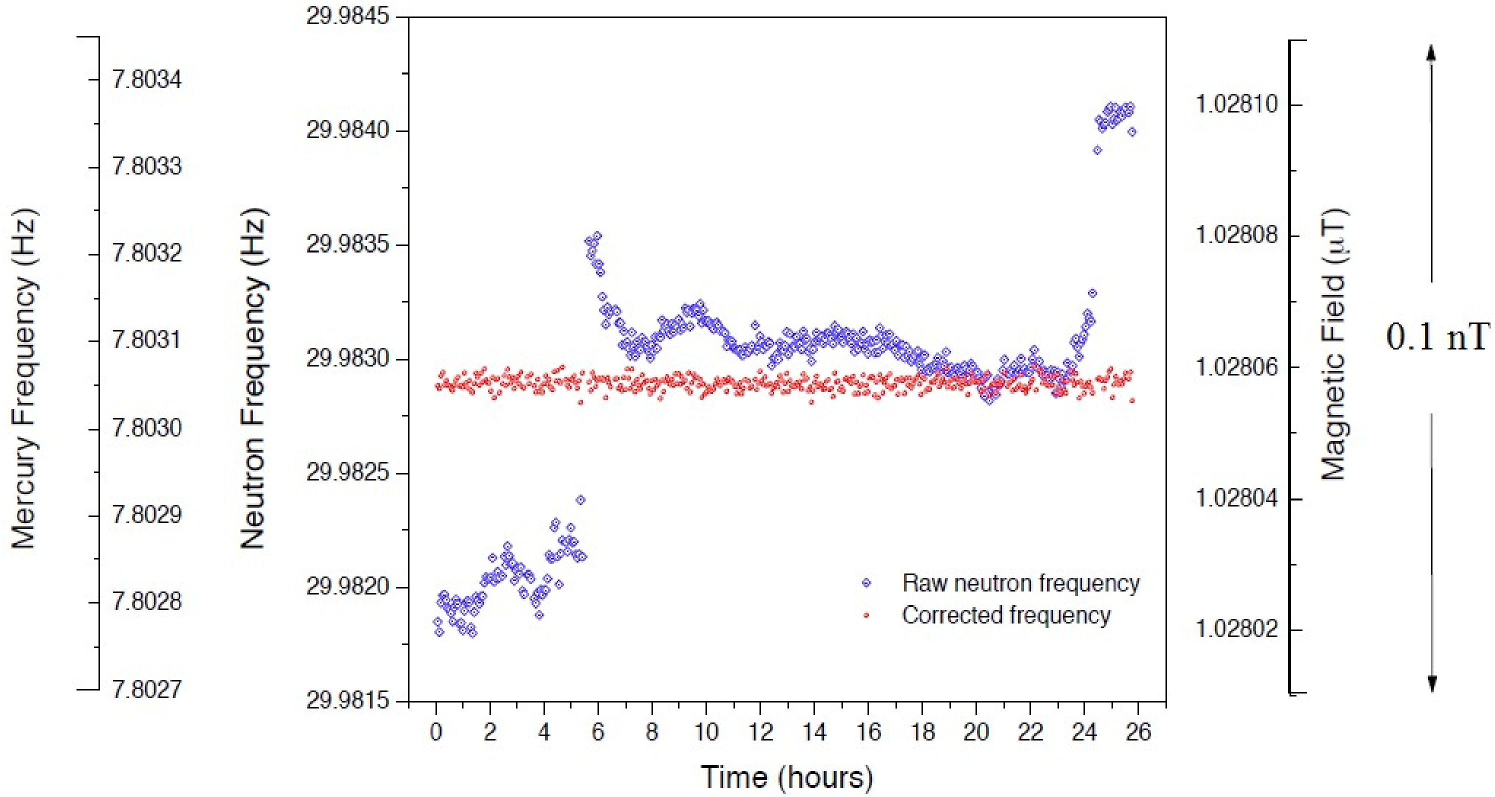
S. K. Lamoreaux 1989 Nucl. Instrum.Methods A284 43c
Green et al. Nucl. Instr. Meth. Phys. Res. A404, 381 (1998)



Absorption ~ x-component of the spin polarisation (10-100 fT resolution).

Using ^{199}Hg co-magetometer to monitor the B-field changes

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



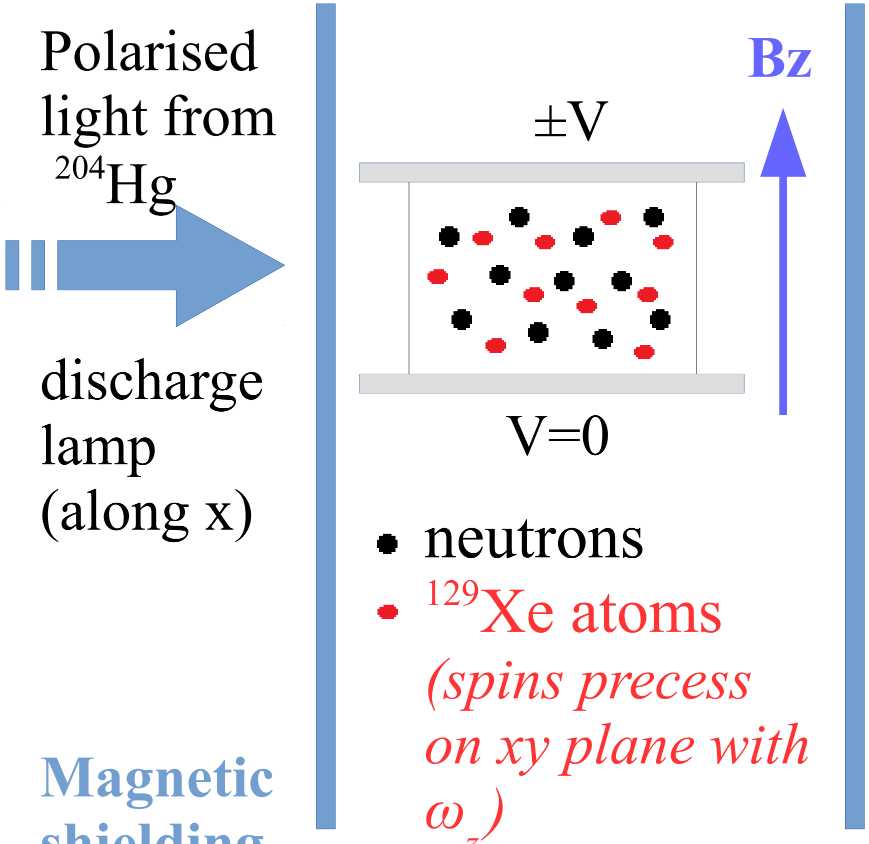
^{129}Xe compared to ^{199}Hg has:

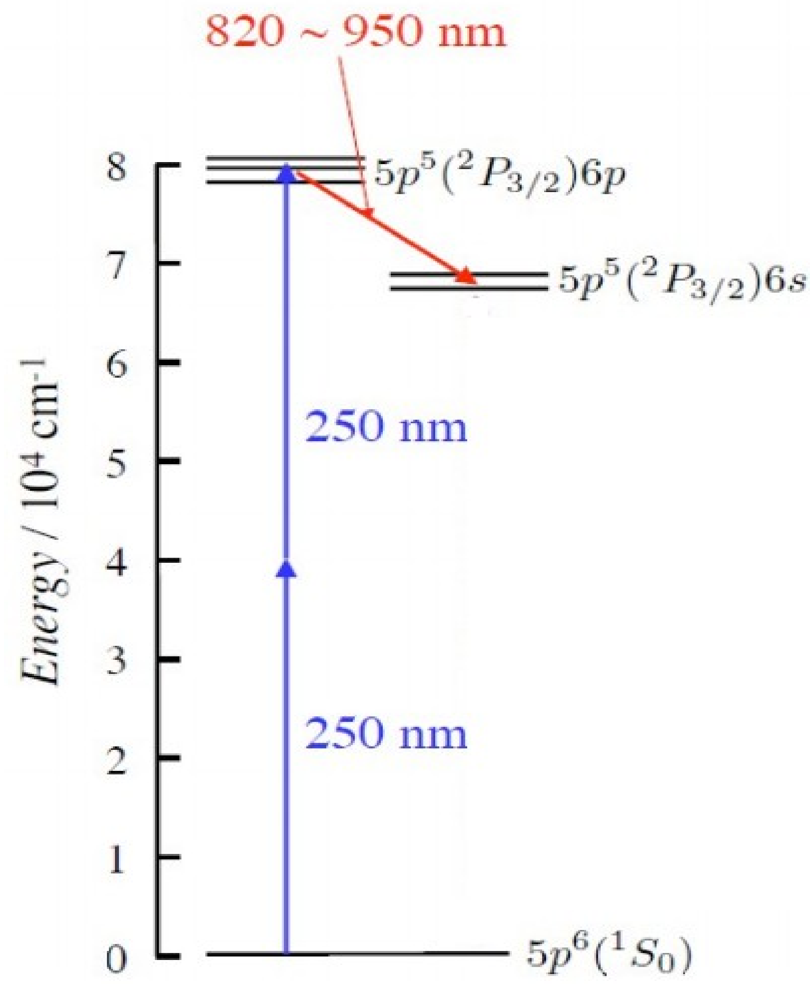
1. neutron absorption $\sigma_{Xe} = \frac{1}{100}\sigma_{Hg}$
2. same sign of gyromagnetic ratio

Dual ^{129}Xe + ^{199}Hg co-magnetometer

Improve systematics by data cross checking

Using ^{129}Xe co-magnetometer to monitor the B-field changes





- ^{129}Xe 2-photon emission
- detect a ~ 900 nm emitted photon

Investigating the dielectric properties of Xe

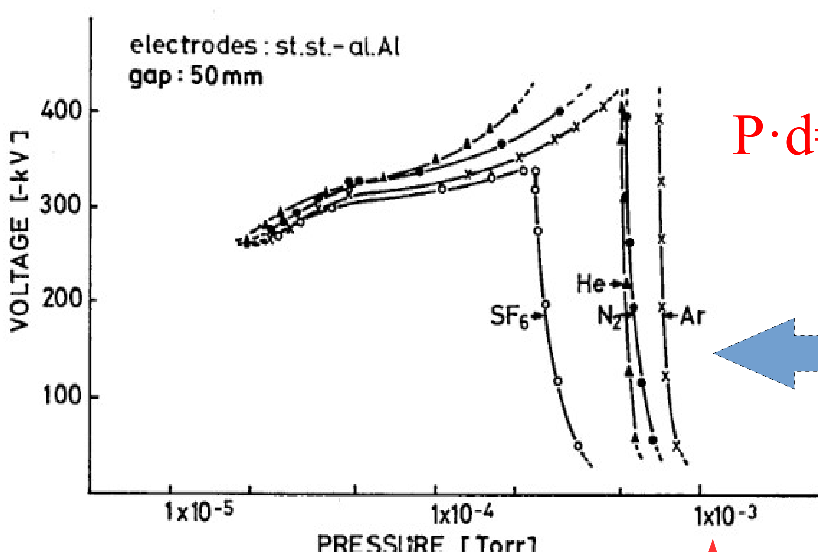
- ↑ ^{129}Xe density → ↑ Optical signal
- ↑ ^{129}Xe density → ↓ Neutron density N (via absorption & up-scattering)
- ↑ ^{129}Xe density → ↓ Breakdown Voltage

Statistical sensitivity

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

E=Electric field
N=neutron numb. density
Ts = neutron storage time

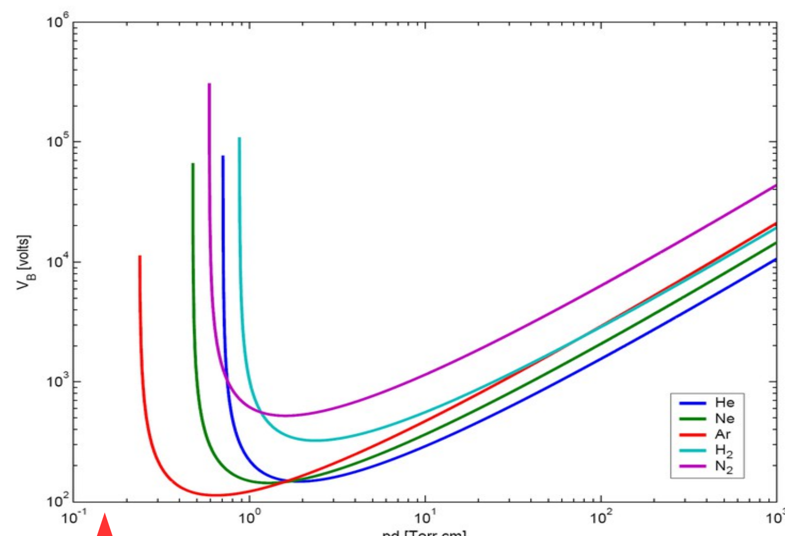
Yamamoto 1977 Jpn. J. Appl. Phys. 16 343



$P\cdot d=0.5\cdot 10^{-2}$ [Torr ·cm]

$P\cdot d=0.1\text{-}5\cdot 10^{-2}$ [Torr ·cm]

F. Paschen 1889 (Wied. Ann., 37,69)
http://commons.wikimedia.org/



$P\cdot d=50\cdot 10^{-2}$ [Torr ·cm]

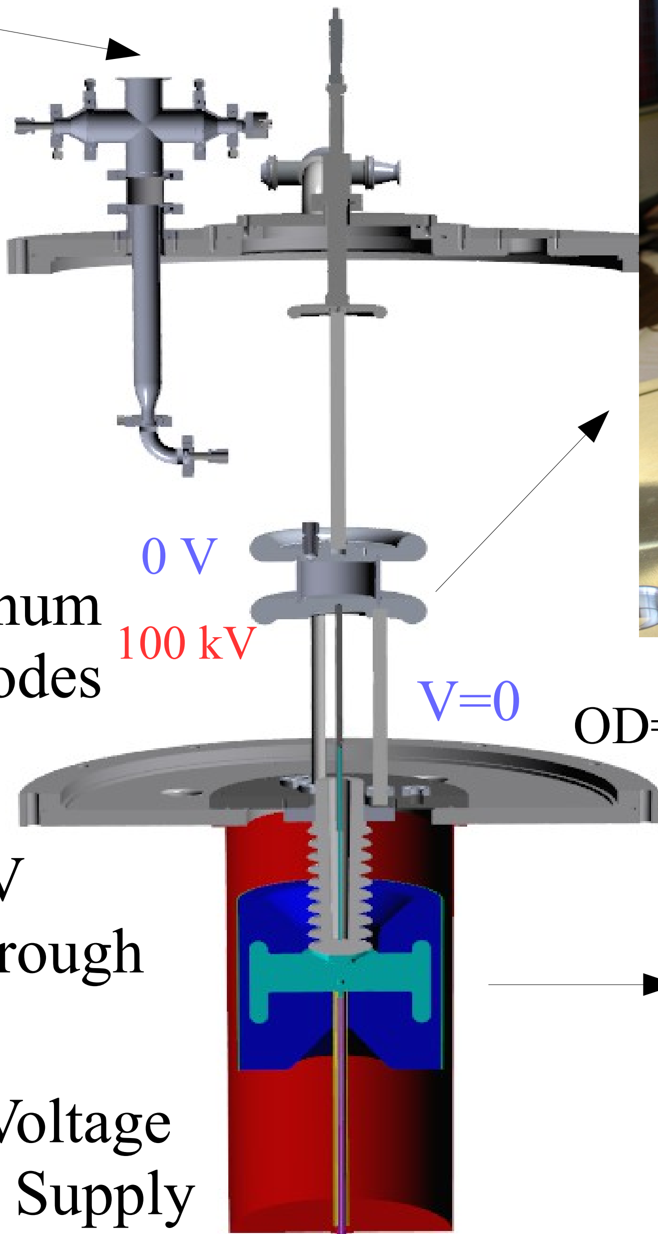
High voltage setup at TRIUMF

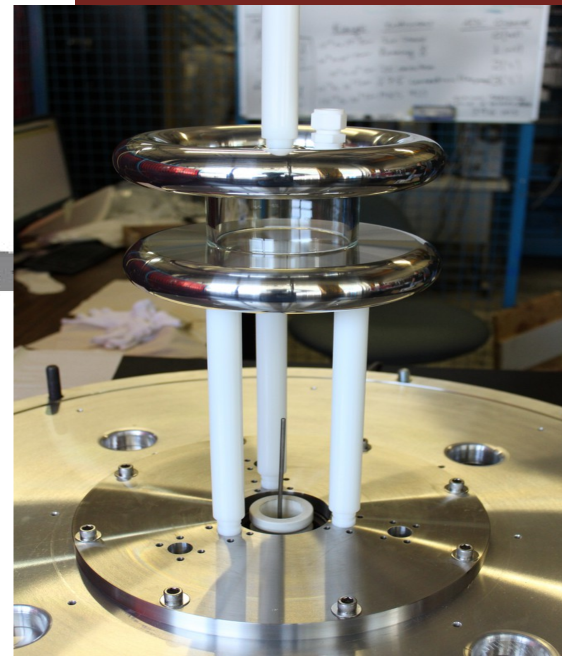
Gas filling

Flat aluminum electrodes

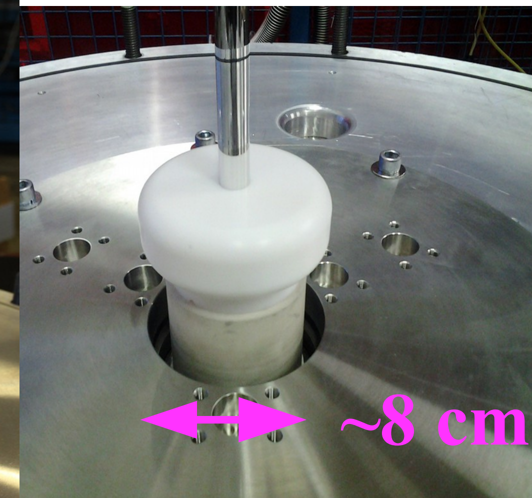
100 kV feedthrough

High Voltage Power Supply



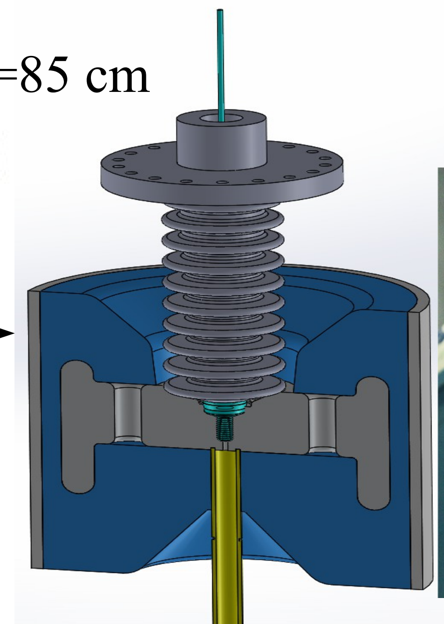


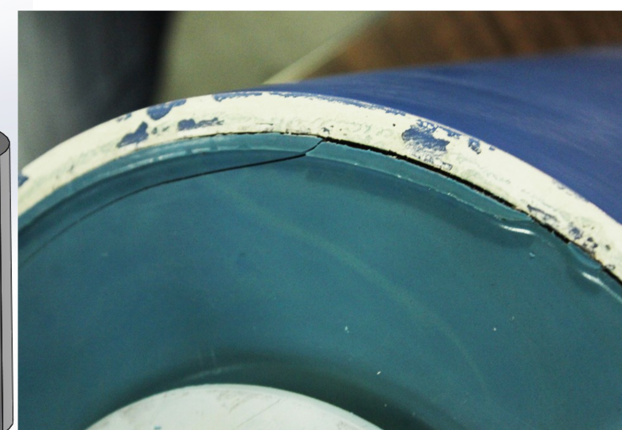
HV



V=0

OD=85 cm

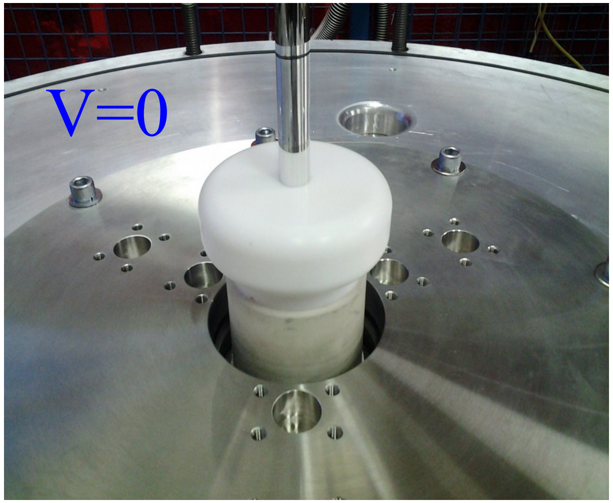


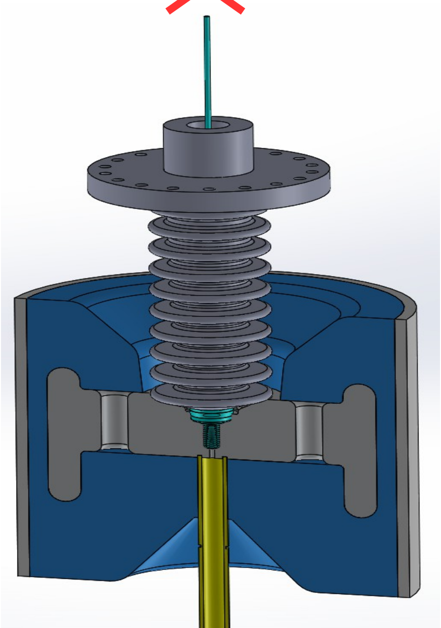


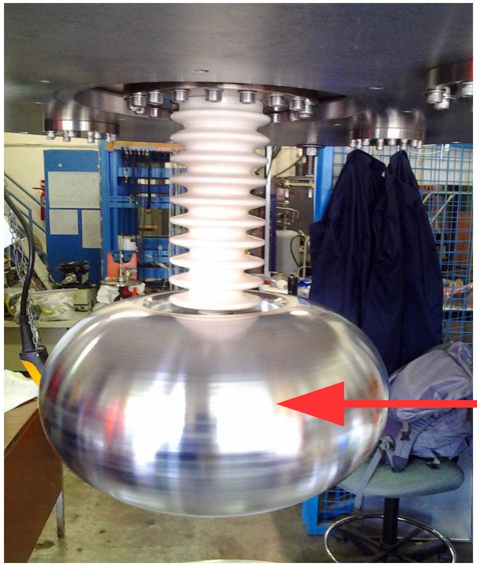
High voltage setup at TRIUMF

Lessons learnt:

- Keep it simple by minimizing interfaces
- Maximize the distance of the grounded parts from the high voltage feed-through
- Eliminate sharp edges/holes
- Remove metal and carbon depositions from the ceramic (sandblasting) +smooth its surface







High voltage setup at TRIUMF

Incorporated the changes to a new setup

Gas filling inlet

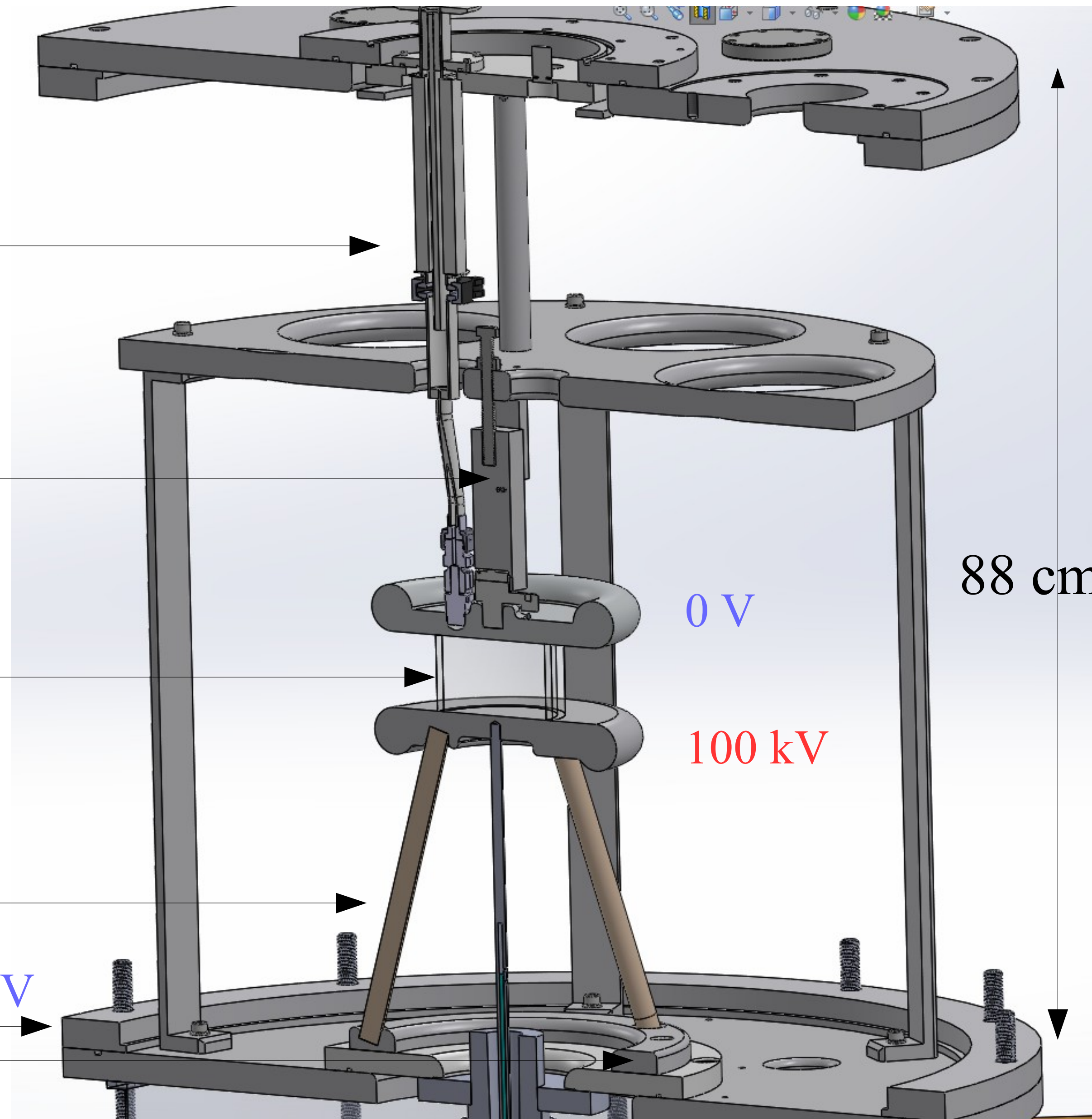
Top electrode pusher.

Aluminum electrodes separated by a glass insulator

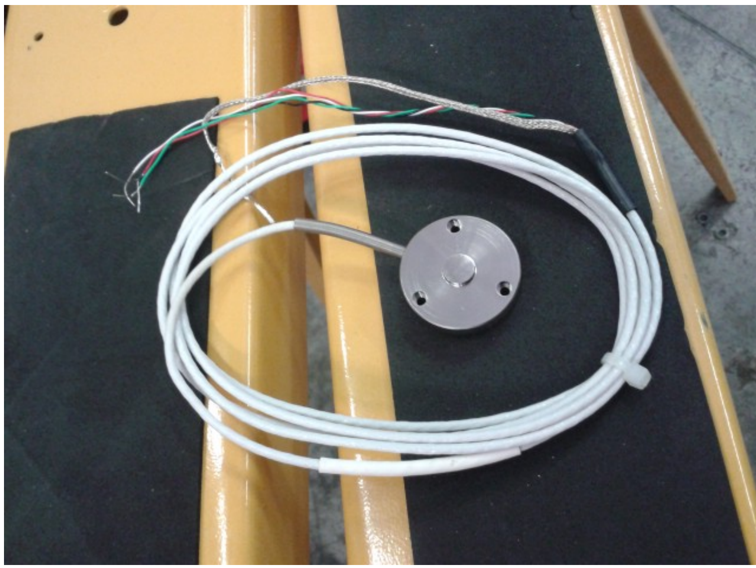
Ceramic support rods.

0 V

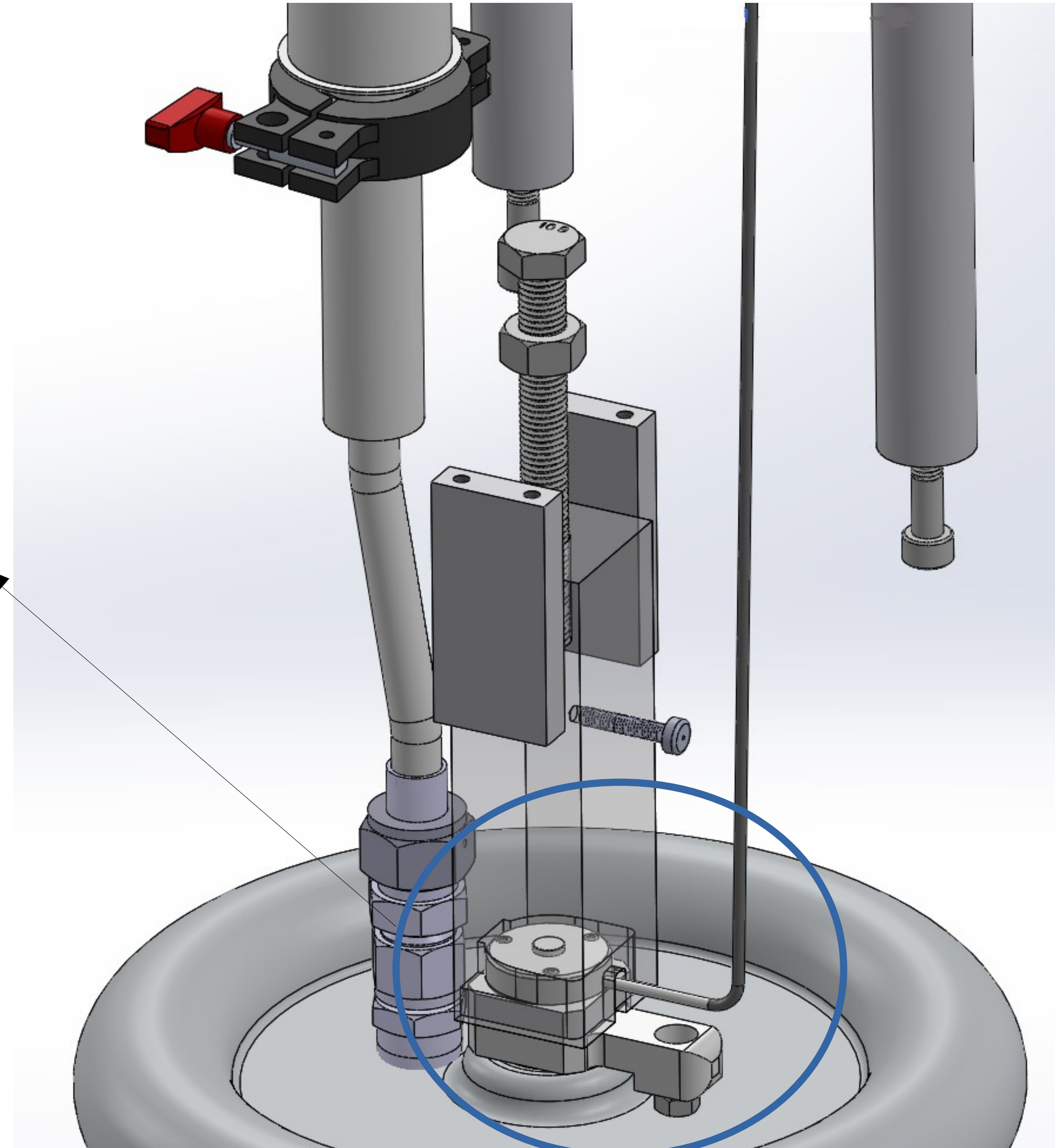
Wider support ring



High voltage setup at TRIUMF

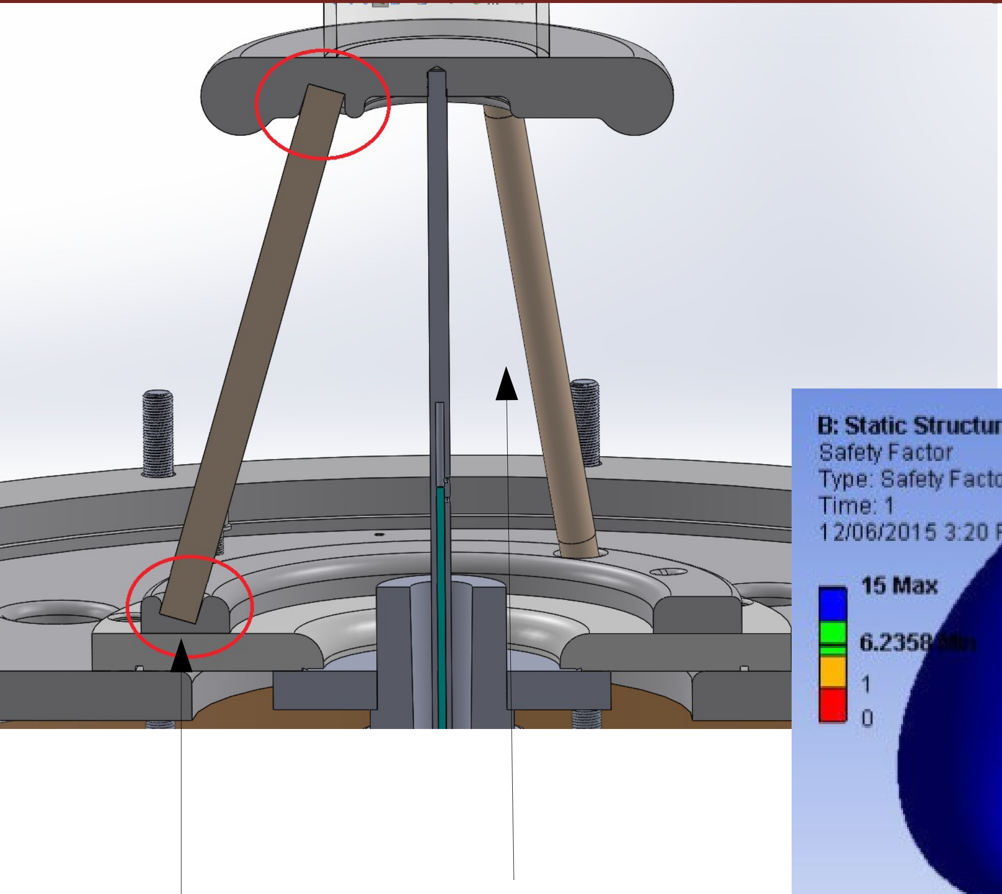


Load Cell 0-500 lbs
(LCGB-500 Omega)
http://www.omega.ca/pptst/LCGB.html



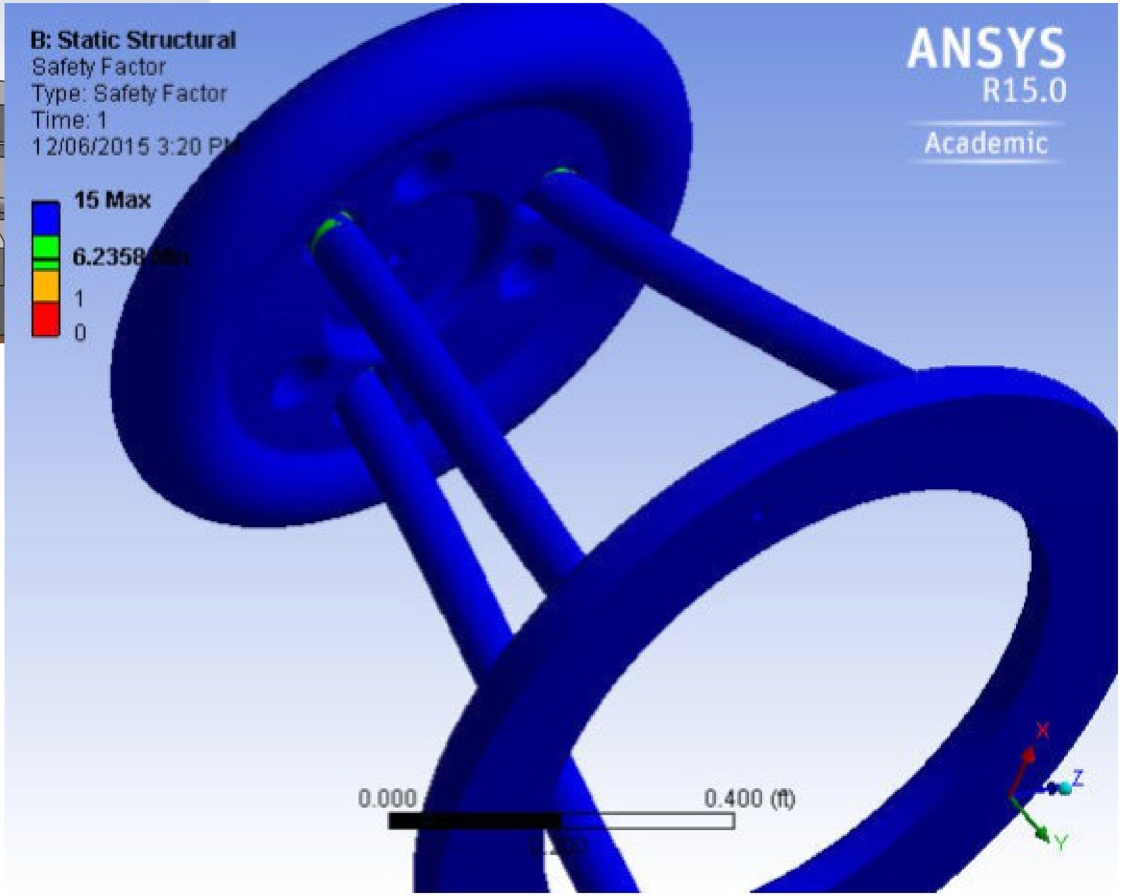
ANSYS Stress simulations

Sealing force ~ 500 lbs
Ceramic tensile yield=1400 psi
Safety factor = 6.2

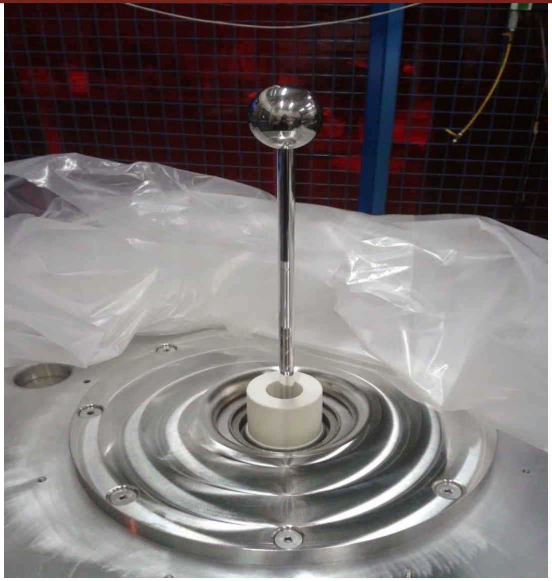


Wider support alu ring.

Ceramic support rods.



Current status + Next steps



Current status:

- ✓ 100 kV with a steel ball in vacuum
- ✓ Most of the parts of the new setup are ready

Our next tests:

- Assembly and test in vacuum and with gas

Next R&D steps:

- Study different geometries and materials for the electrodes to deliver as high as possible electric field.

Summary

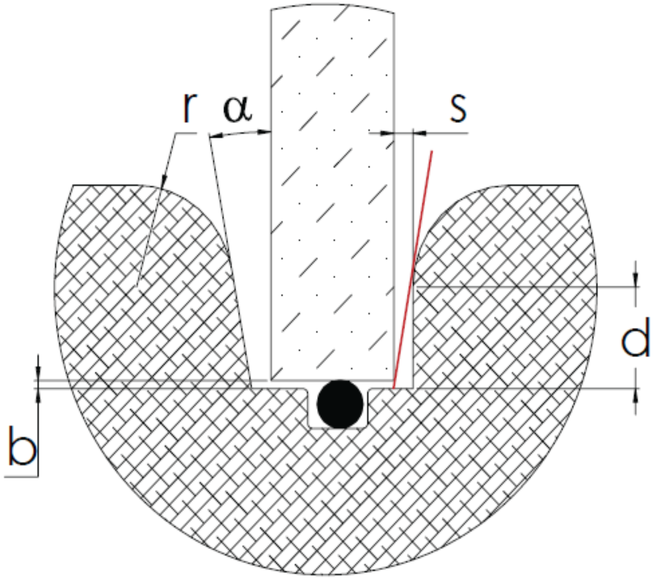
R&D work is carried out at TRIUMF to develop the high voltage system for the nEDM experiment which will deliver an electric field:

- $E \sim 12$ kV/cm
- Uniform $[(E_{transv}/E)_{max} = 1\%]$
- Stable

..across the neutron storage cell in the presence of ^{129}Xe (and possibly ^{199}Hg) co-magnetometer.

Backup slides

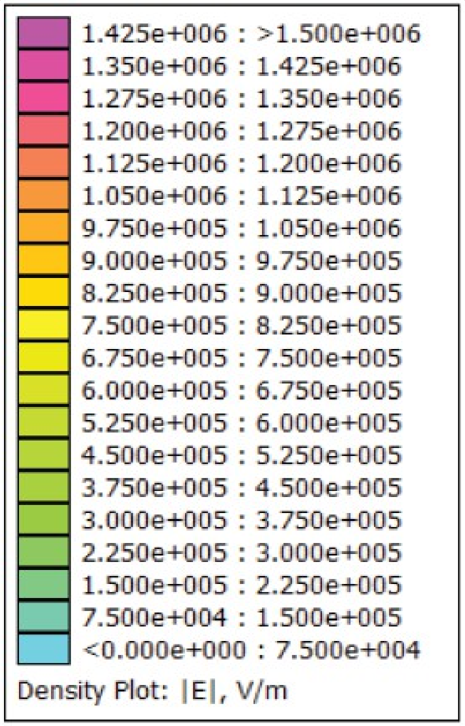
Next steps / Trench+O-ring groove geometry

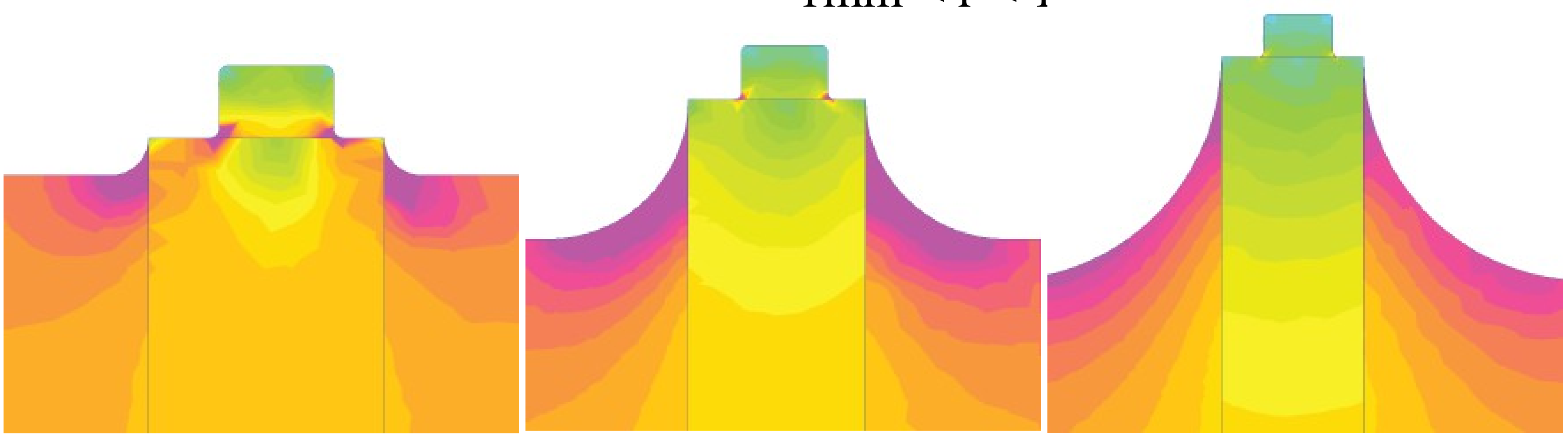


$1 \text{ mm} < r < 10 \text{ mm}$
$1\text{mm} < d < 10 \text{ mm}$
$0 < s < 2 \text{ mm}$
$0 < b < 0.1 \text{ mm}$
$0 < \alpha < 10^{o}$

M. Losekamm
B.Sc. Thesis

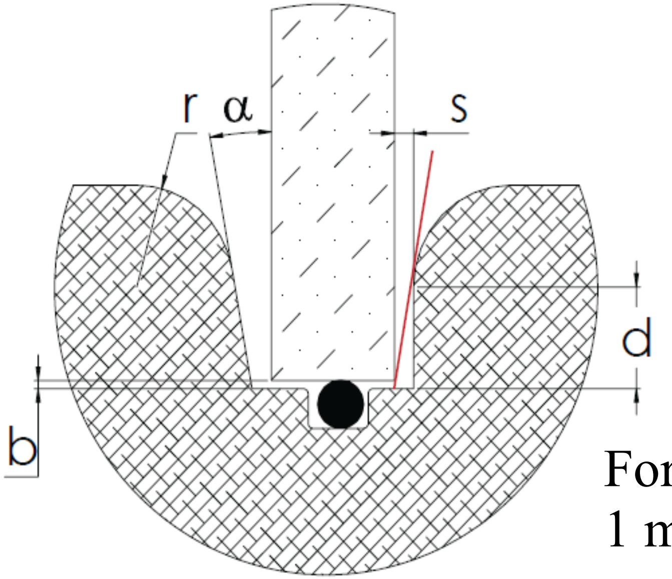
For: $d=s=b=\alpha=0$
$1\text{mm} < r < 10 \text{ mm}$



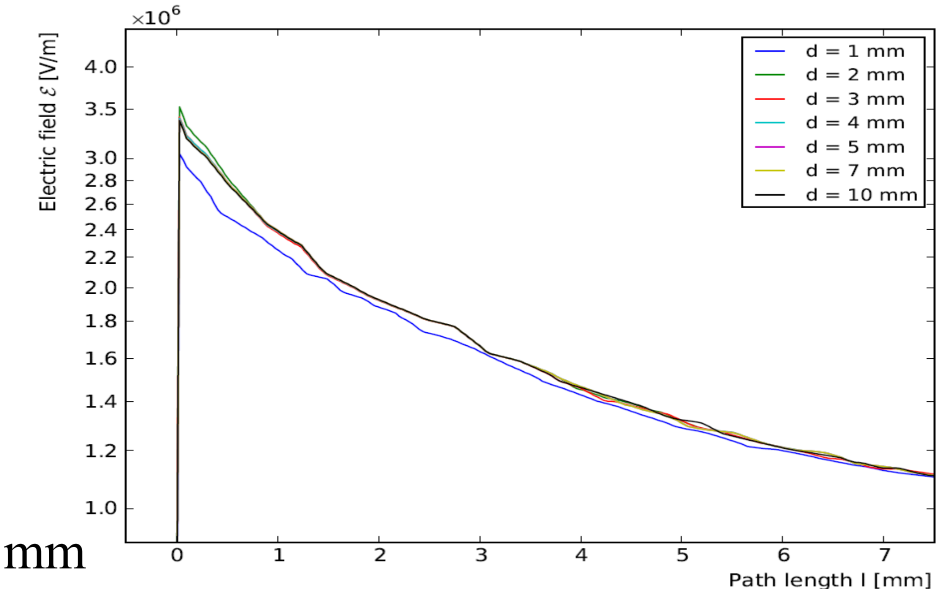


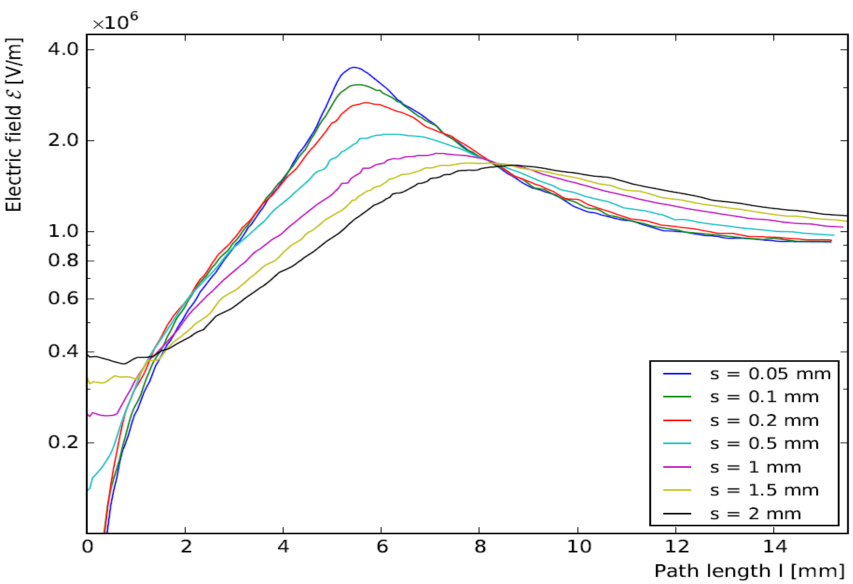
R=1 mm R=5 mm R=10 mm

Next steps / Trench+O-ring groove geometry

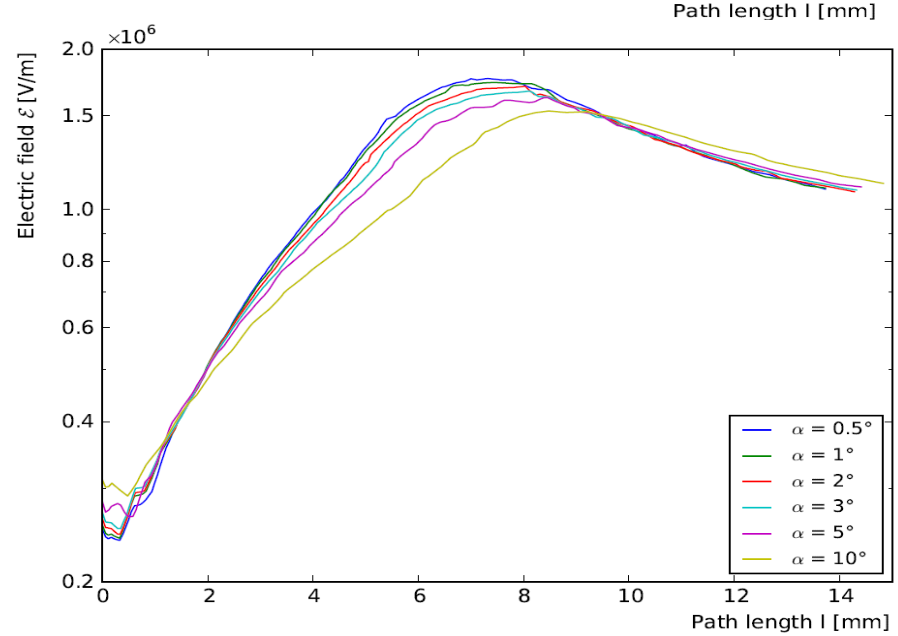


For r= 5 mm:
1 mm < d < 10 mm





For r=5 mm, d= 5 mm: 0 < s < 2 mm



For r=5 mm, d= 5 mm, s=1mm: 0 < α < 10°

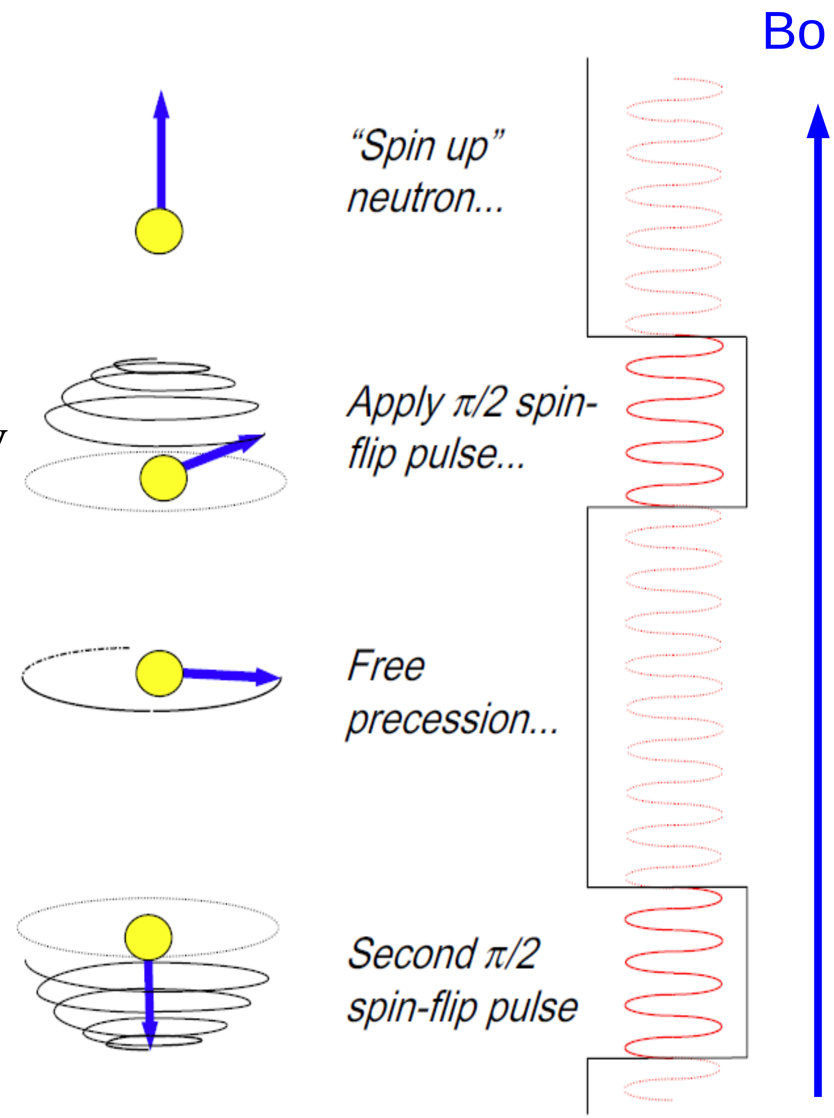
neutron Electric Dipole moment

Initially neutron spin is aligned with Bo

RF pulse on xy-plane near Larmor frequency

Accumulated phase: $\varphi = (\omega - \omega_o)\, t_{ph}$ **E** ↑ or ↓

Depending on the accumulated phase the Second RF pulse will turn the spin up or down



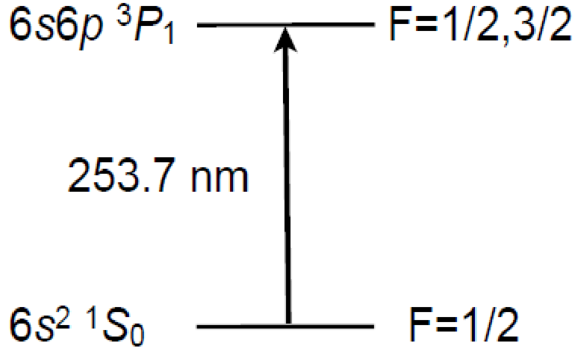
N. F. Ramsey, Phys. Rev. 76 996 (1949)

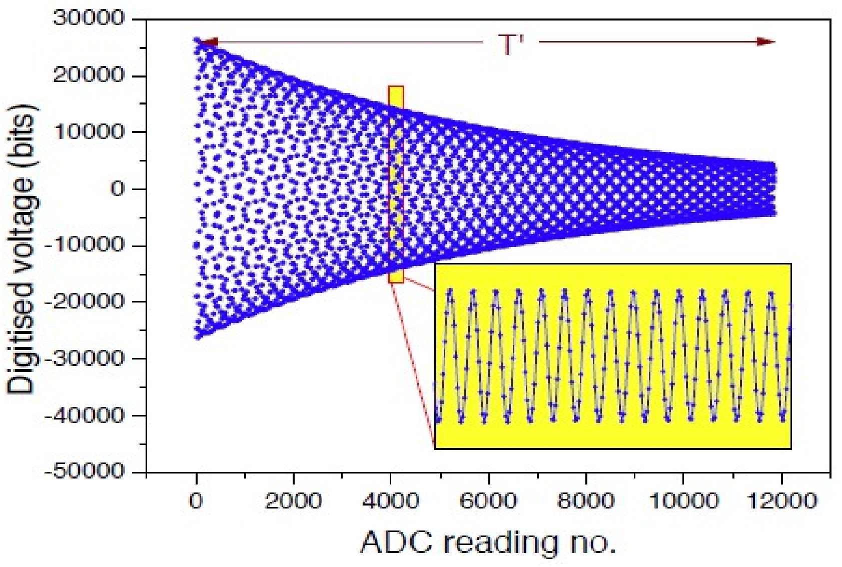
Correction of the B-field fluctuation effect on neutron resonance frequency with the ^{199}Hg co-magnetometer

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 43c
Green et al. Nucl. Instr. Meth. Phys. Res. A404, 381 (1998)

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

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

1. 100 times smaller neutron absorption cross section
2. Same sign of gyromagnetic ratio with neutron
3. ^{129}Xe atomic EDM limit is very close to that of neutron (2.9×10^{-26} e·cm) :

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

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

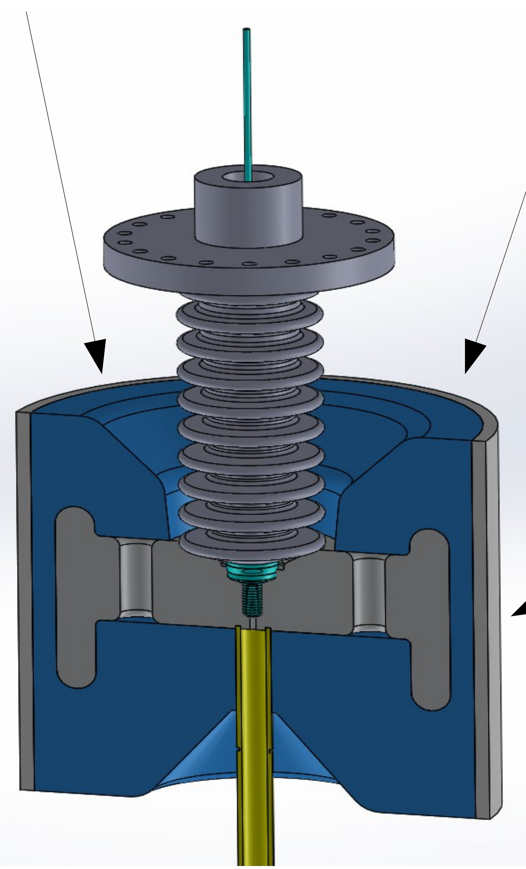
Dual ^{129}Xe + ^{199}Hg co-magnetometer

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)

High voltage setup at TRIUMF

1st attempt: lessons learnt

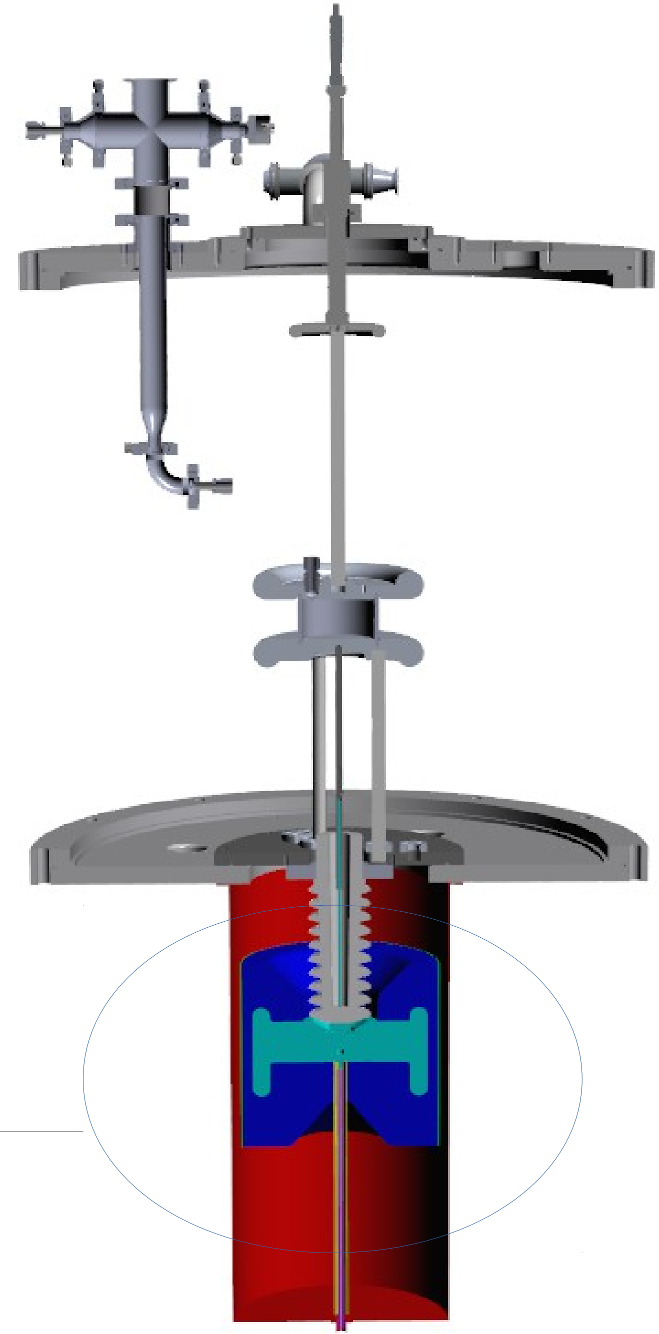
Epoxy



Nylon cylinder (metal coated inner+top surface for grounding)

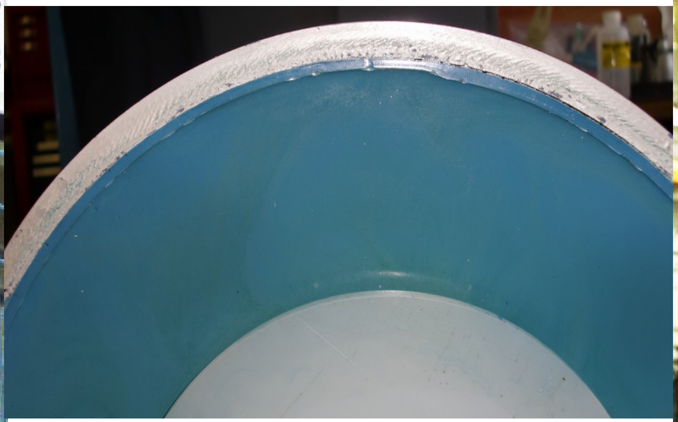
Aluminum shield (HV)

To the Power supply

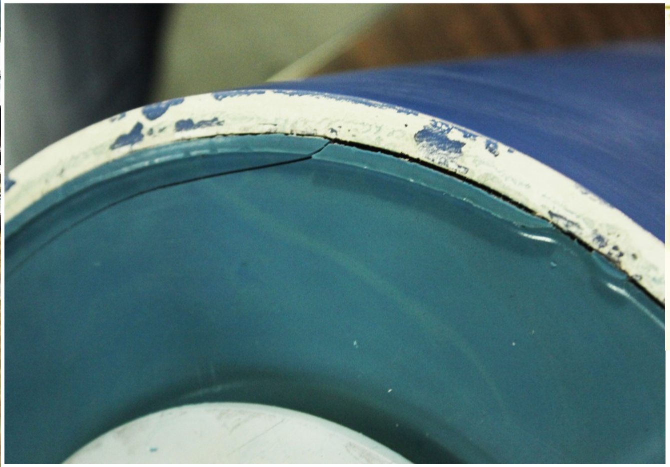


High Voltage Power Supply

High voltage setup at TRIUMF



t=0



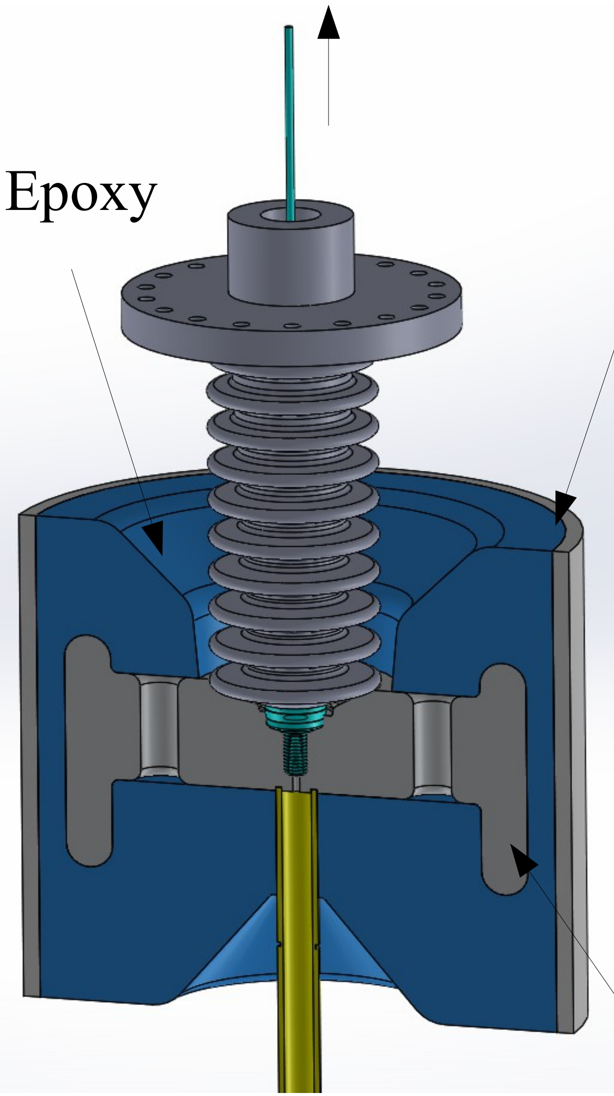
t=24hrs (crack+gap)

Proved not trivial to handle materials of different thermal expansion coefficient.

High voltage setup at TRIUMF

To the HV electrode

Epoxy

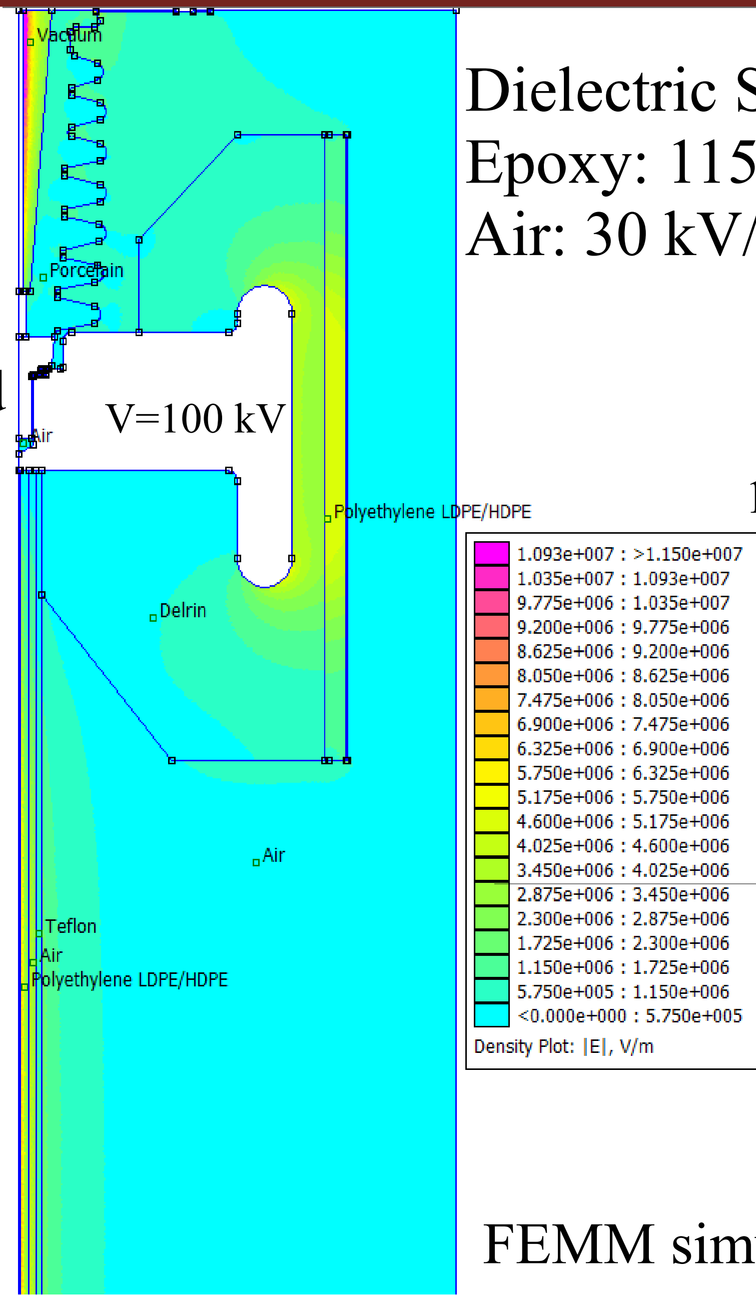


Nylon cylinder (metal coated inner+top surface for grounding)

(V=0)

Aluminum shield (HV)

To the Power supply



Dielectric Strength
Epoxy: 115 kV/cm
Air: 30 kV/cm

115 kV/cm

30 kV/cm

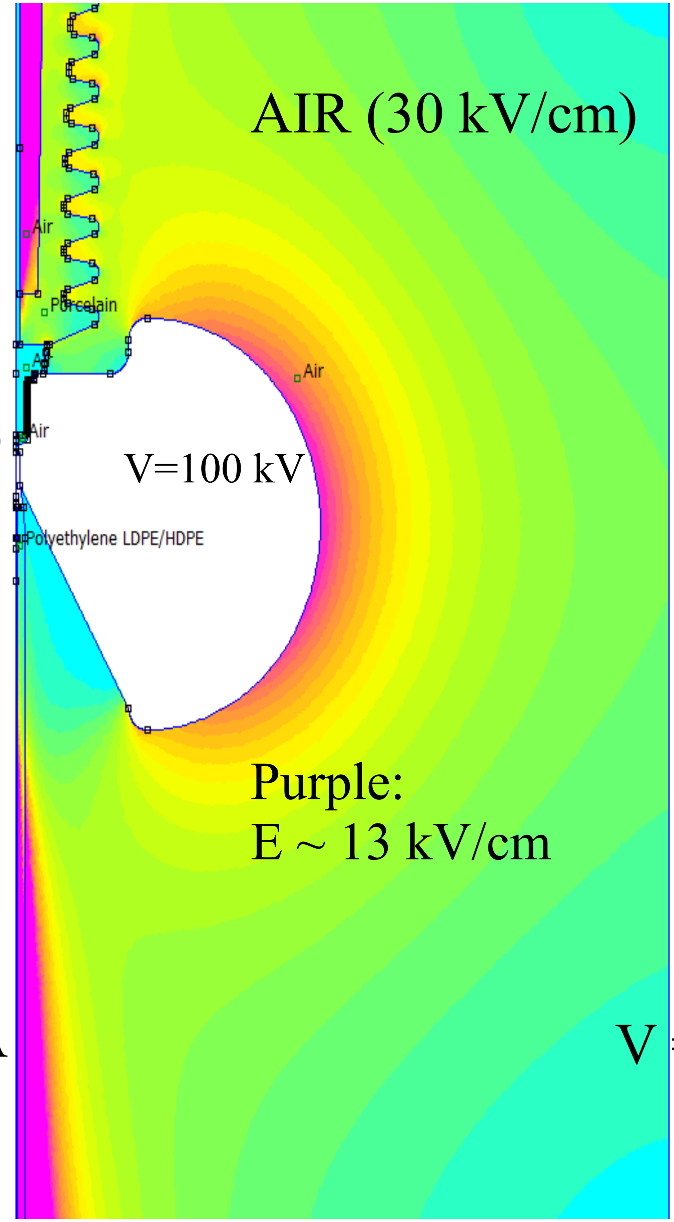
FEMM simulations

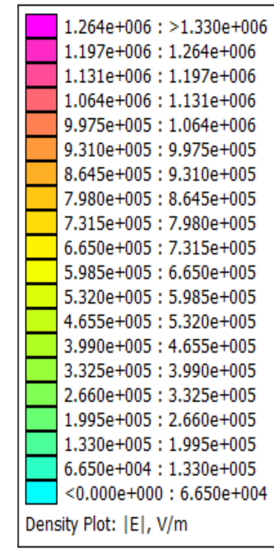
High voltage setup at TRIUMF

Aluminum corona ring (not polished) in air within a wide Faraday cage ($R_{cage} \sim 2.5 R_{cor.\ ring}$)

Reached feedthrough Voltage specification (100 kV)

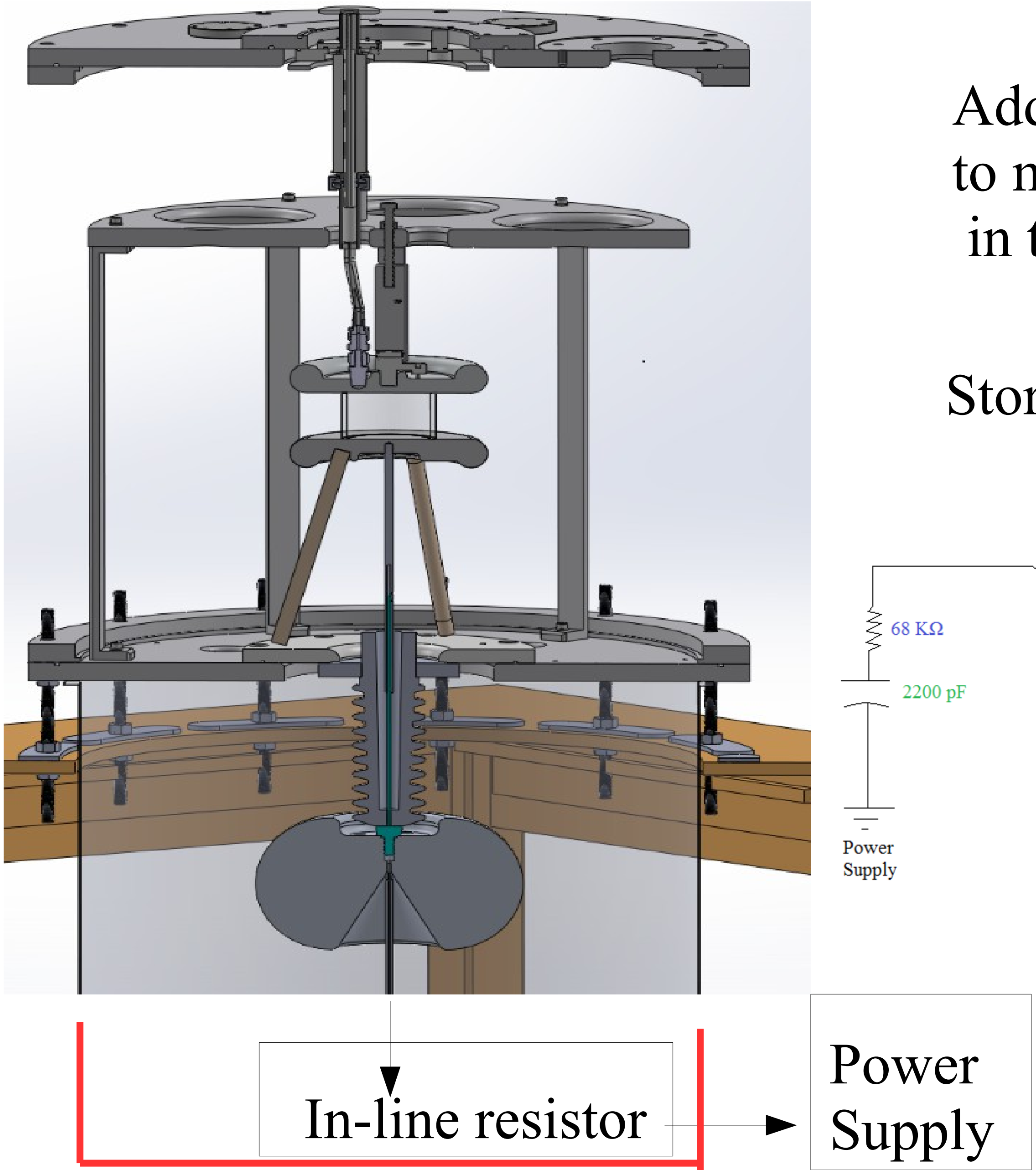
To a GAMMA 125 kV Power Supply (neg. Voltage)





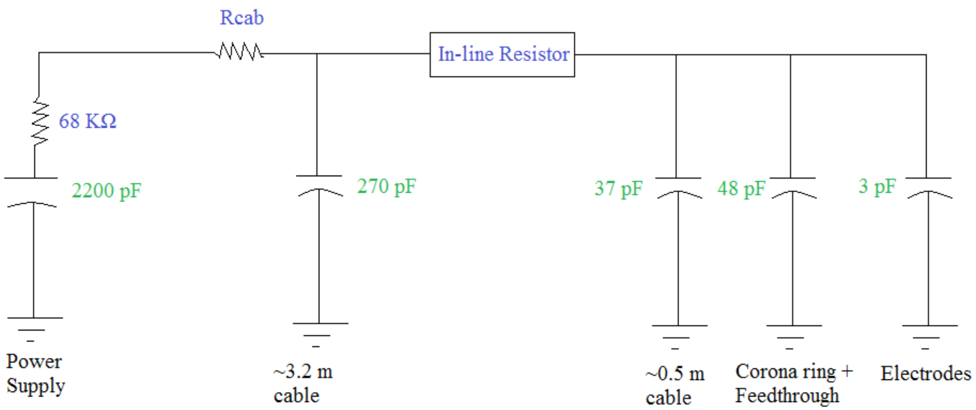
FEMM simulations

High voltage setup at TRIUMF



Add an in-line 1 GΩ resistor to minimize energy dissipation in the event of a breakdown

Stored energy @ 100 kV = 12.4 J



nEDM experiment layout

$$h\delta\nu_o = -2 d_n \left(E_{(\uparrow\uparrow)} - E_{(\uparrow\downarrow)}\right)$$

$\delta\nu_o$: resonance frequency shift

E: applied electric field

d_n: neutron edm