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Progress on the high-voltage and EDM cell studies for the TRIUMF neutron EDM experiment

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Postdoc

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- long UCN storage times (>200 s)
- large and tight UCN valve (d>50 mm)
- good UCN/Xe/Hg depolarization properties
- grant access for UV laser and visible readout
- non-magnetic!
- ideally non-metallic (Johnson noise)
- maintain large, uniform high-voltage (>13 kV/cm, <1%)
- very small leakage current (~pA)
- gas tight (very low leak rate)
- double cell, orientation?

MISSION: IMPOSSIBLE ?

neutronEDM@TRIUMF aims to use a dual co-magnetometer:

$^{199}Hg/^{129}Xe$:

-> dual comagnetometer allows for B_0 determination independend of comagnetometer GPE
-> ^{129}Xe precession in same direction as neutrons
-> ^{129}Xe has 100 times smaller neutron absorption cross-section compared to ^{199}Hg

	n	^{199}Hg	^{129}Xe
$\gamma/2\pi$ [Hz/μT]	-29.16	7.65	-11.77
UCN capture σ [barns]		2150	21

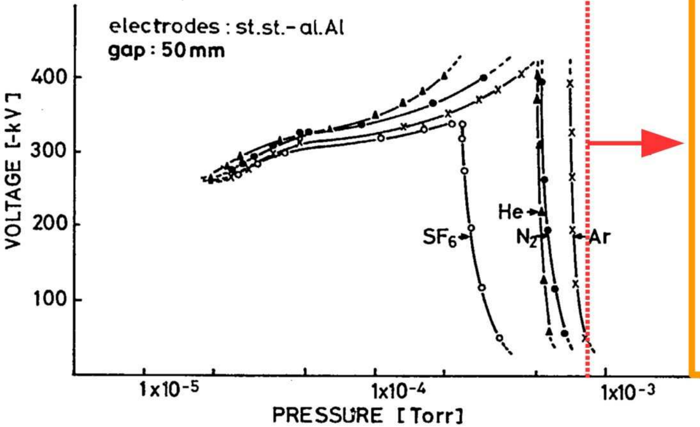
Goals of the HV test setup:

Determine gas partial pressures compatible with optical readout, neutrons and E-fields

-> evaluate E-field breakdown properties for xenon in pressure range:

p = 0.1 to 10 mTorr for various distances 2-10 cm (equal to 0.2 - 100 mTorr*cm)

Yamamoto, Jpn. J. Appl. Phys. 16 343 (1977)



Missing data for electric field breakdown in gases:

few – several hundreds mTorr*cm

Xenon?
Geometry?

Schoenhuber, IEEE Trans. Power App. Syst. 88, 100 (1969)

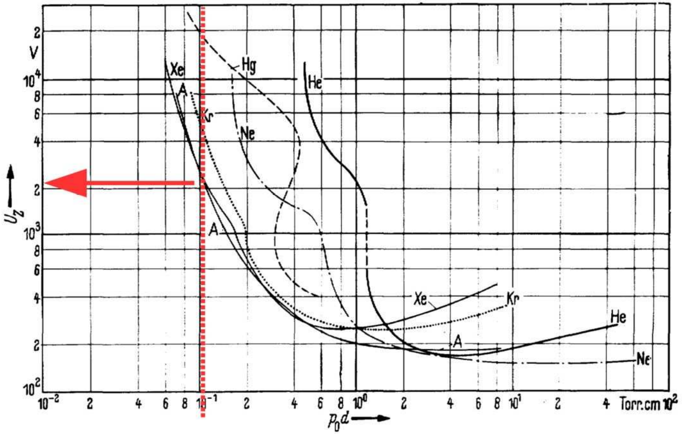


Fig. 7. Breakdown characteristics of the noble gases. Hg characteristic from [13].

-> extend to gas mixtures of xenon and mercury

-> high voltage compatibility of potential EDM cell materials/geometries

TRIUMF high voltage test setup 2014-2016

Feeding > 100 kV:

100 kV feedthrough

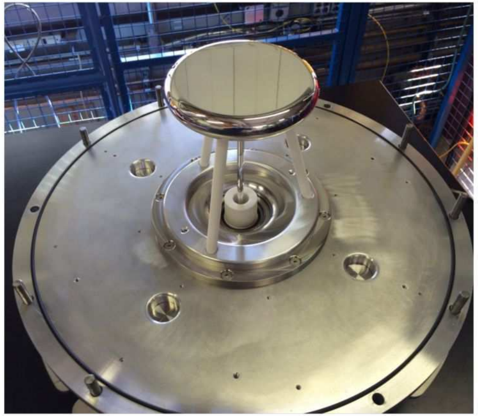
Aluminium corona ring
(not polished)

Ground cage ($R_{cage} \sim 2R_{cor.ring}$)

to GAMMA -125 kV supply

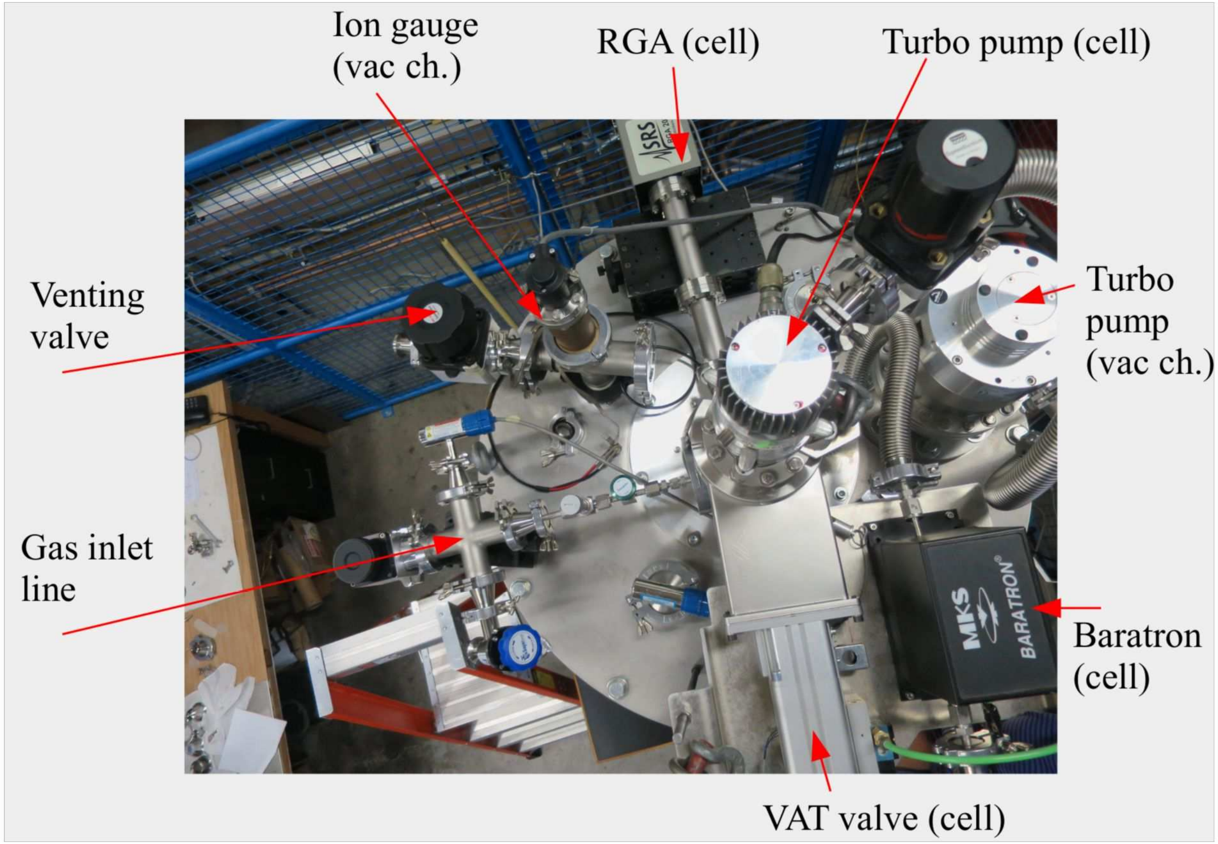
Resistor (1 GOhm)

Test with electrode in air:



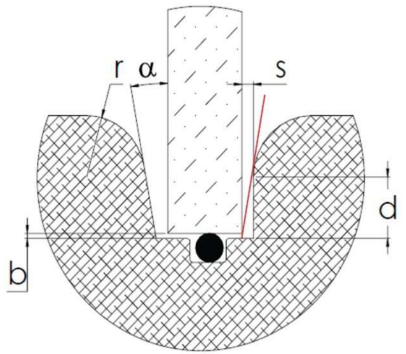
-> breakdown/sparking issues solved

2016 new vacuum chamber -> routinely operating with voltages up to -100kV



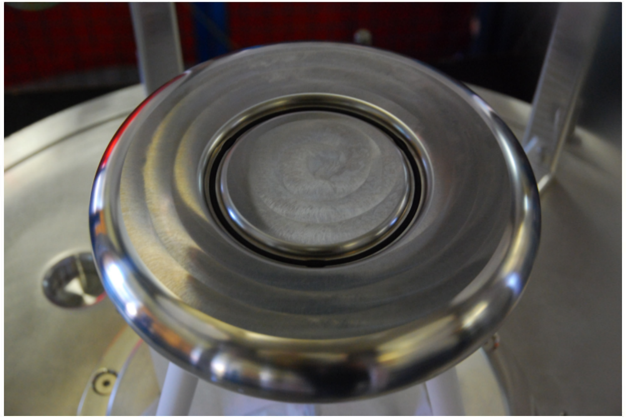
Electrodes with O-ring groove

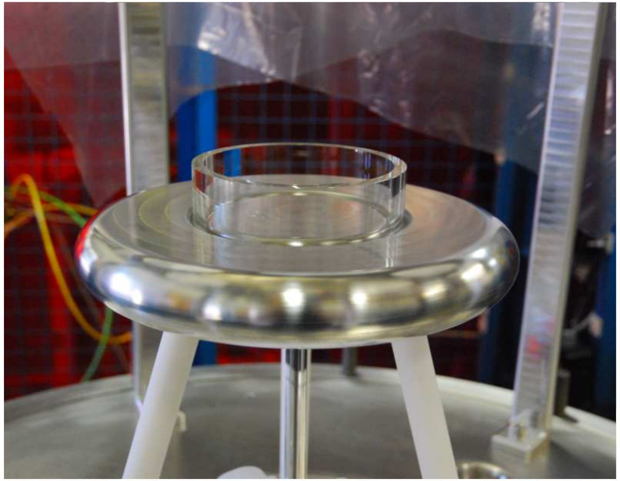
Manufactured electrodes to axially seal the EDM cell using O-rings
-> see test results later



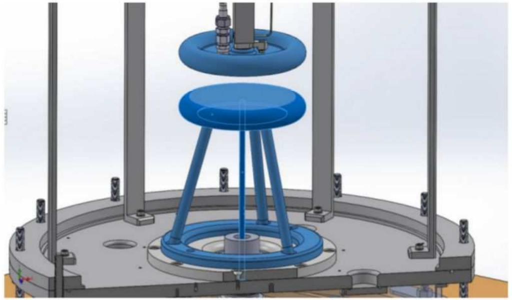
For: d=s=b=α=0
1mm < r < 10 mm

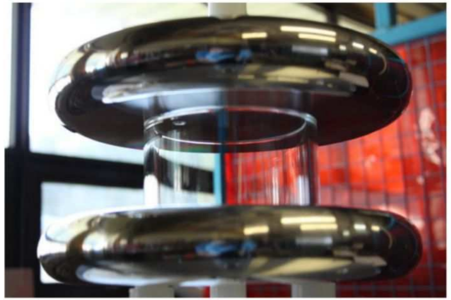
R=1 mm R=5 mm R=10 mm





100 kV / 7.7 mm = **129.5 kV/cm**. 76 kV / 2.2 cm = **34.5 kV/cm**



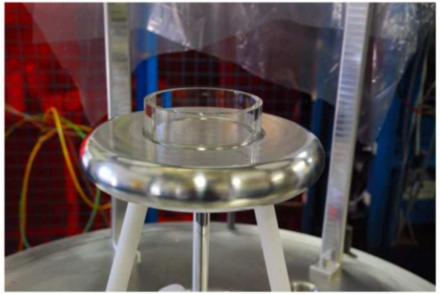


Deliver max HV (100 kV) to one of the electrodes. ✓

HV tests in vacuum: Flat (and polished) electrodes w/ and w/o glass insulator between them. ✓

HV tests in vacuum: Grooved (un-polished) electrodes w/ glass insulator between them. ✓

35 mm glass insulator



Vmax=100 kV → Eav~33 kV/cm (flat)
Emax ~ 55 kV/cm (groove)

Setup the gas filling system.

HV test with gas(es): ^{129}Xe, ^{4}He, N_2 (and ^{199}Hg later on)

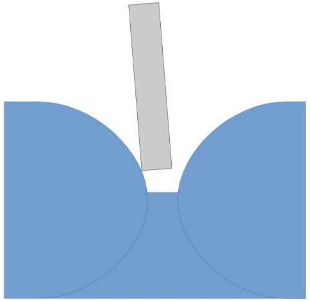
Tests with O-ring groove and axially sealed glass cylinders

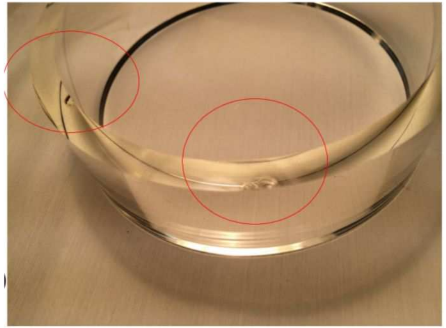
Apply force to top electrode to compress O ring (~30%)

Imprecise glass insulators had point contacts

-> cells did not seal well with (cheap) imprecise glass cylinders

-> chips on the glass (force and high voltage breakdown induced?)

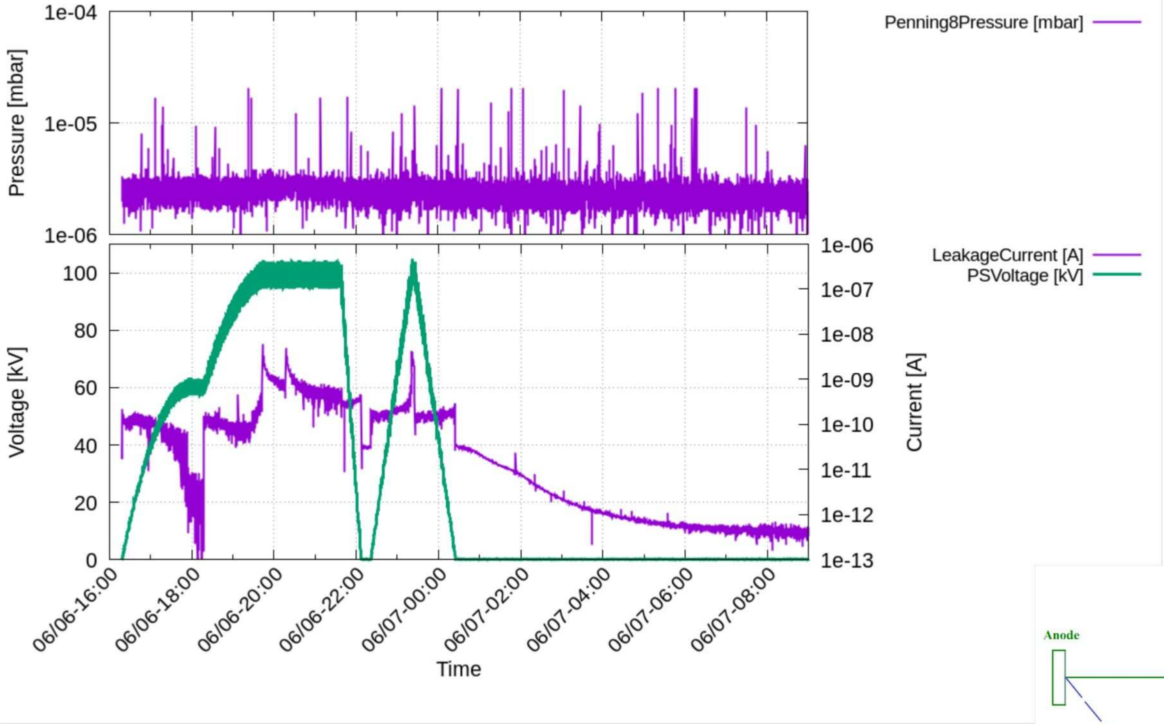


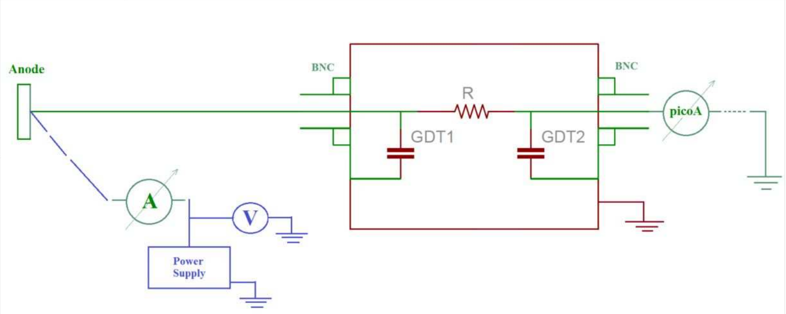


Screw sets applied force to the top electrode

Load cell to measure force on electrodes

Test with PE cylinder with no force on electrode

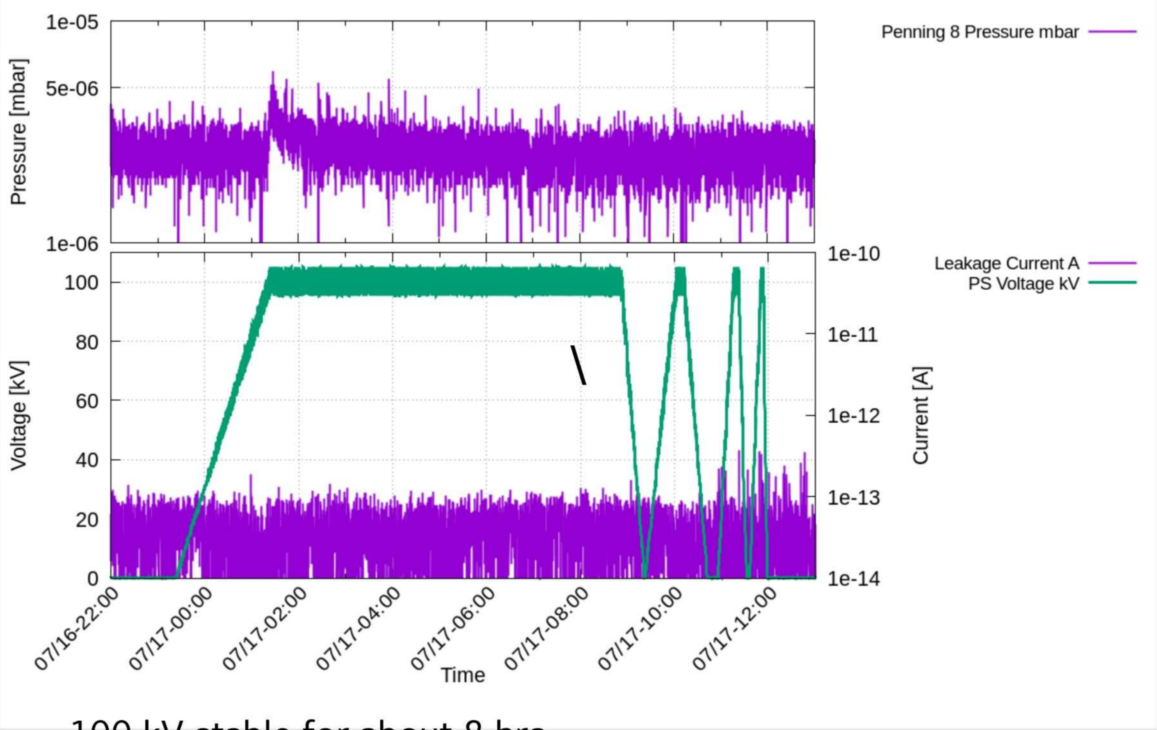




100 kV at 9cm distance -> 10.5 kV/cm

First test with PE as insulator

Test with PE cylinder and O rings

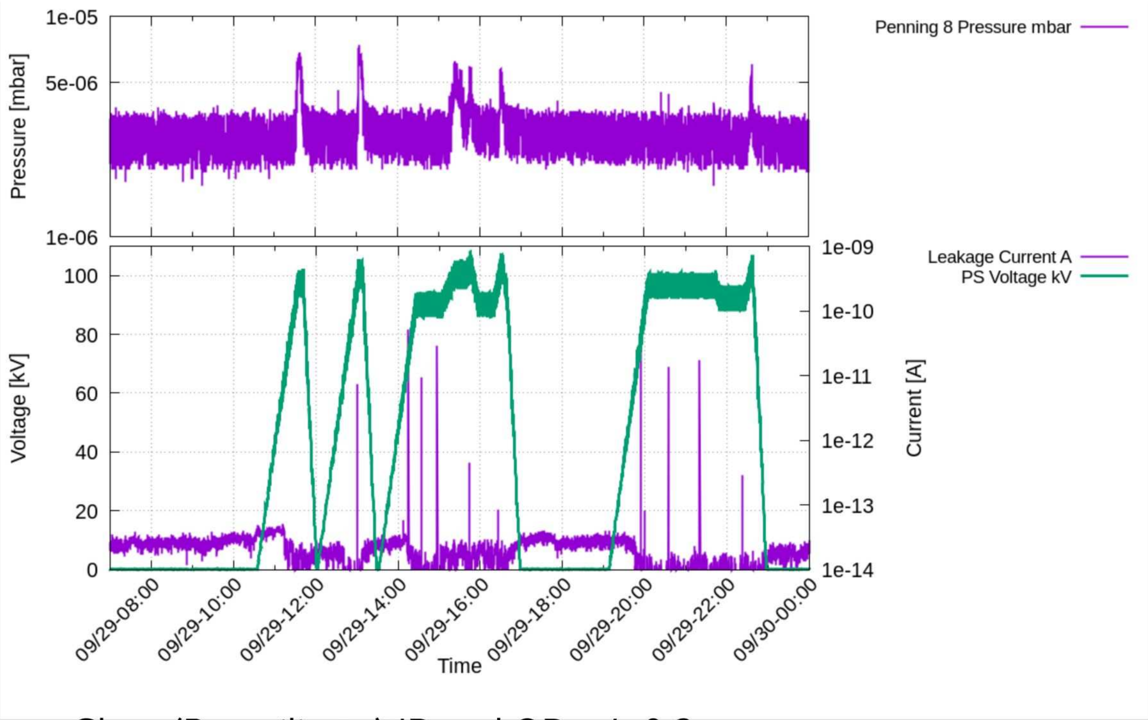


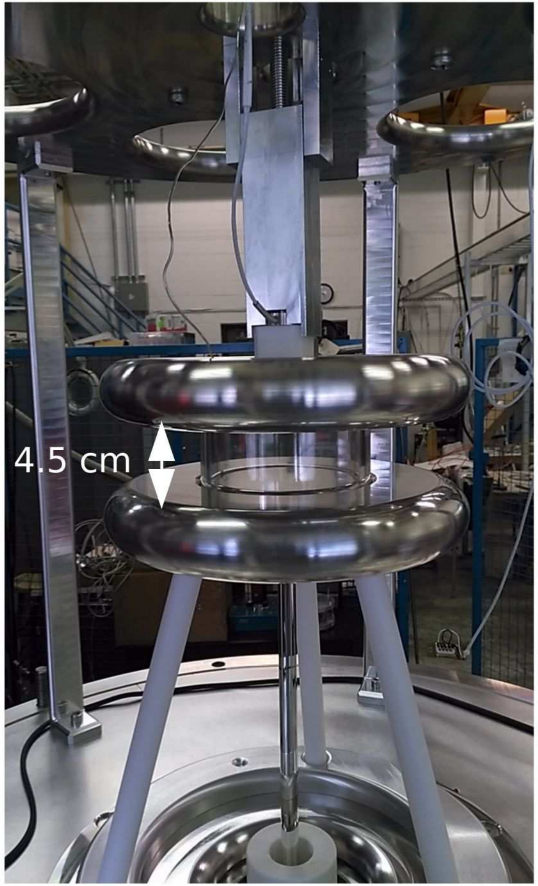
100 kV stable for about 8 hrs

Ramp up in 20/15min, ramp down in 10/5 min

Leakage current reading baseline very/too low

Test with precisely machined glass cylinder



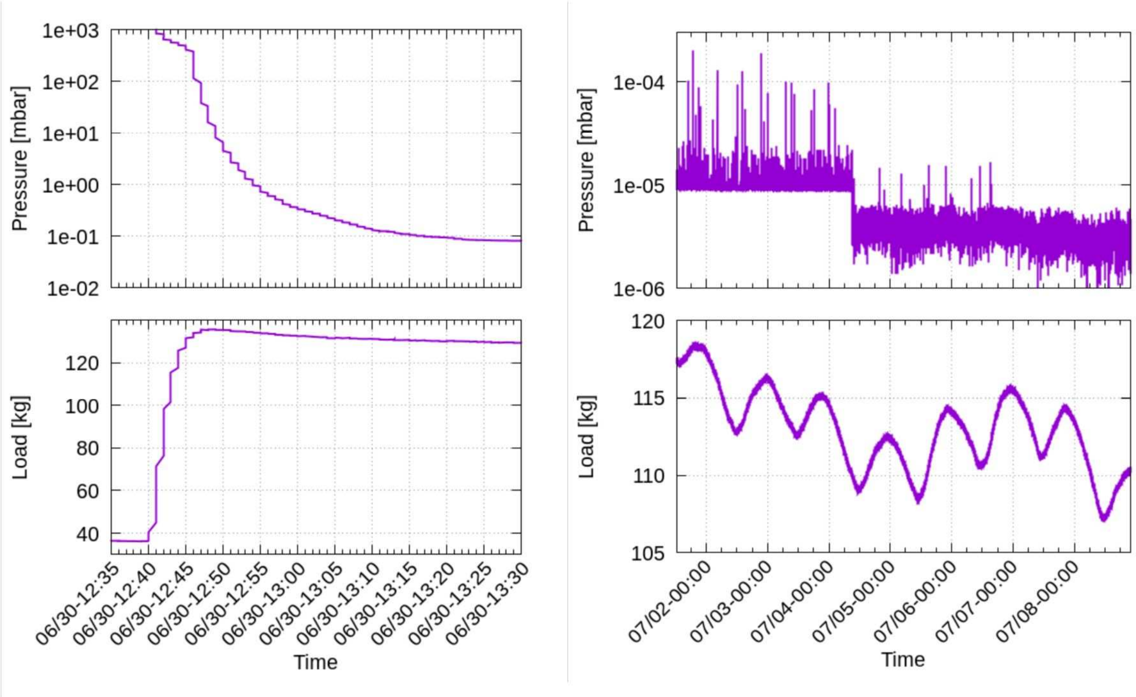


Glass (Borosilicate) ID and OD +/- 0.2 mm

100 kV at 4.5cm distance -> 22 kV/cm

Leakage current reading baseline very/too low

Load cell drift and axial sealing

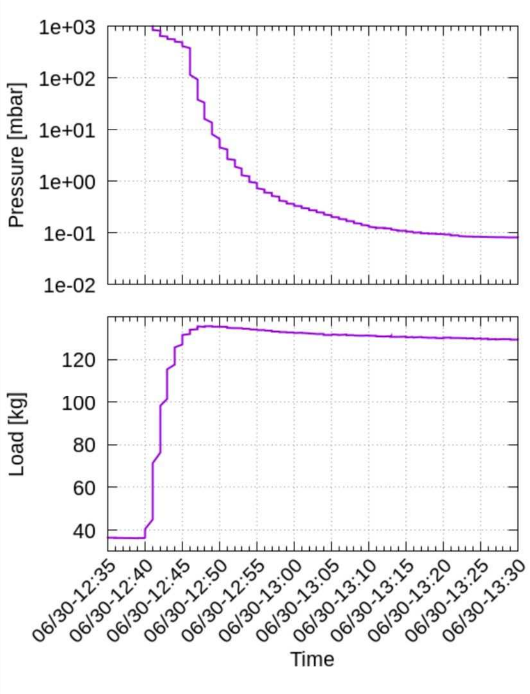


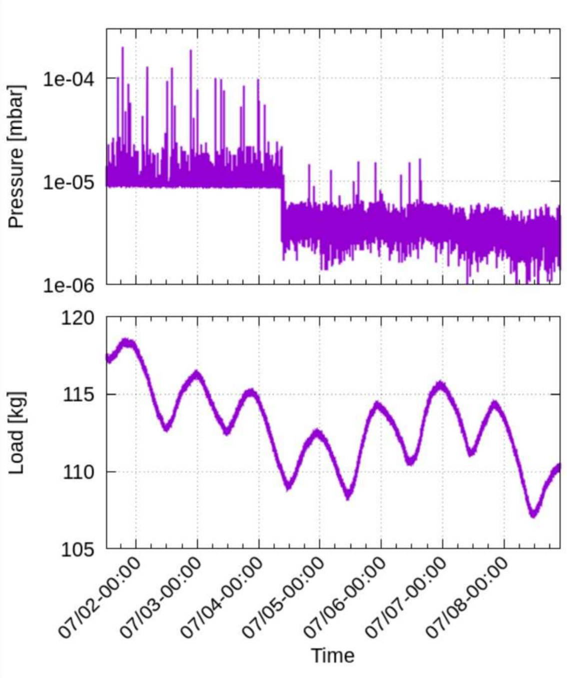
Load cell changes from 35 kg to 135kg when evacuating chamber

At constant pressure reading varies by several %

-> effect on gas leakage from cell?

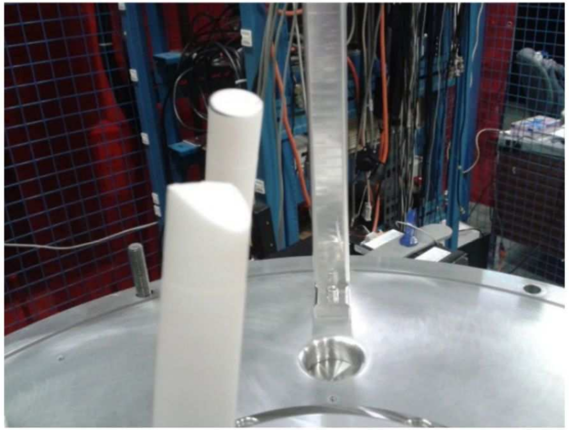
Load cell drift and axial sealing





For this sealing method we need to find the source of the drifts for a reliable seal

Delrin rods don't break but may flex, -> return to Macor



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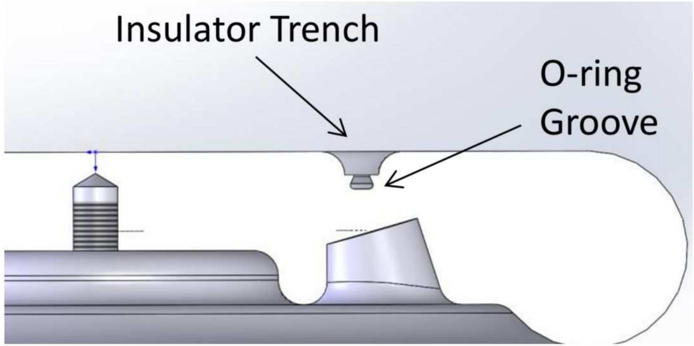
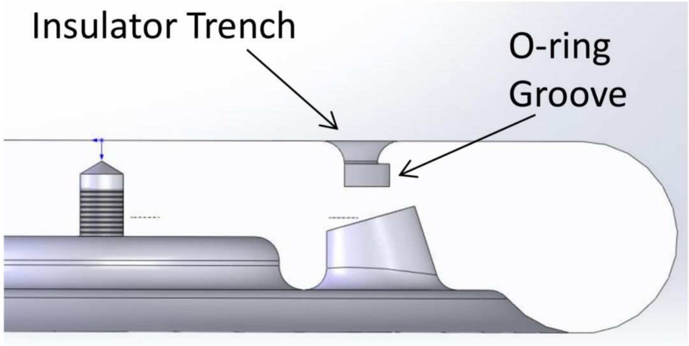
Radial sealing of the cell: Simulations and tests

Axial seal



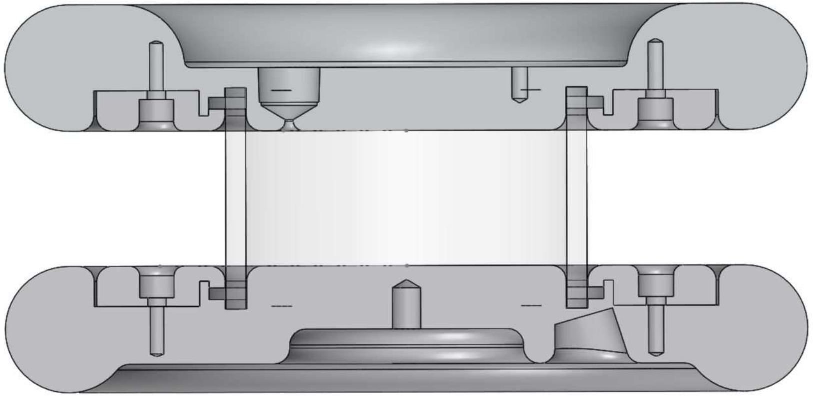
Radial seal



Sean Vanbergen (co-op student 2017)

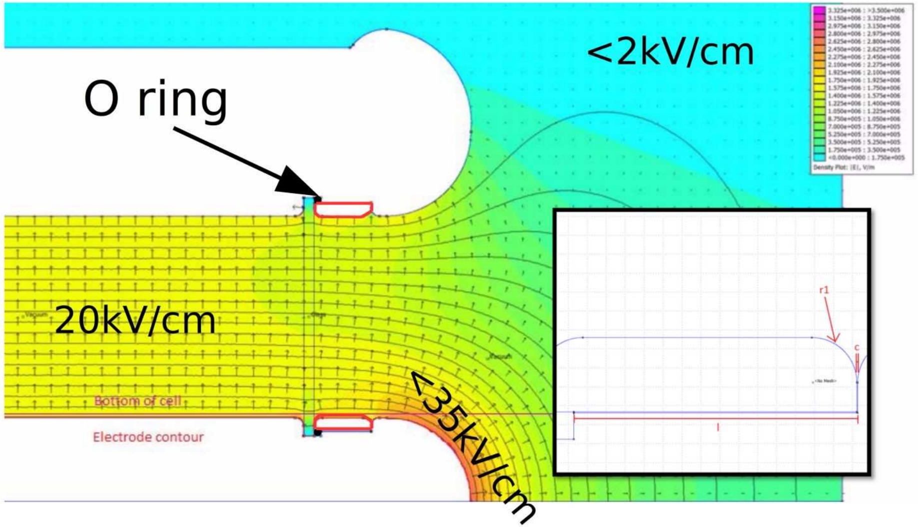
<u>Radial seal</u>

- easier centering of the insulator ring
- no force on glass-metal surface (vs axial seal)
- no potentially drifting force needed
- implementation in EDM setup easier



Radial sealing of the cell: Simulations and tests

Electric field simulations show no significant issues due to split electrode design



First simulations of screws and hole show no significant electric field issues

-> careful design to minimize effects

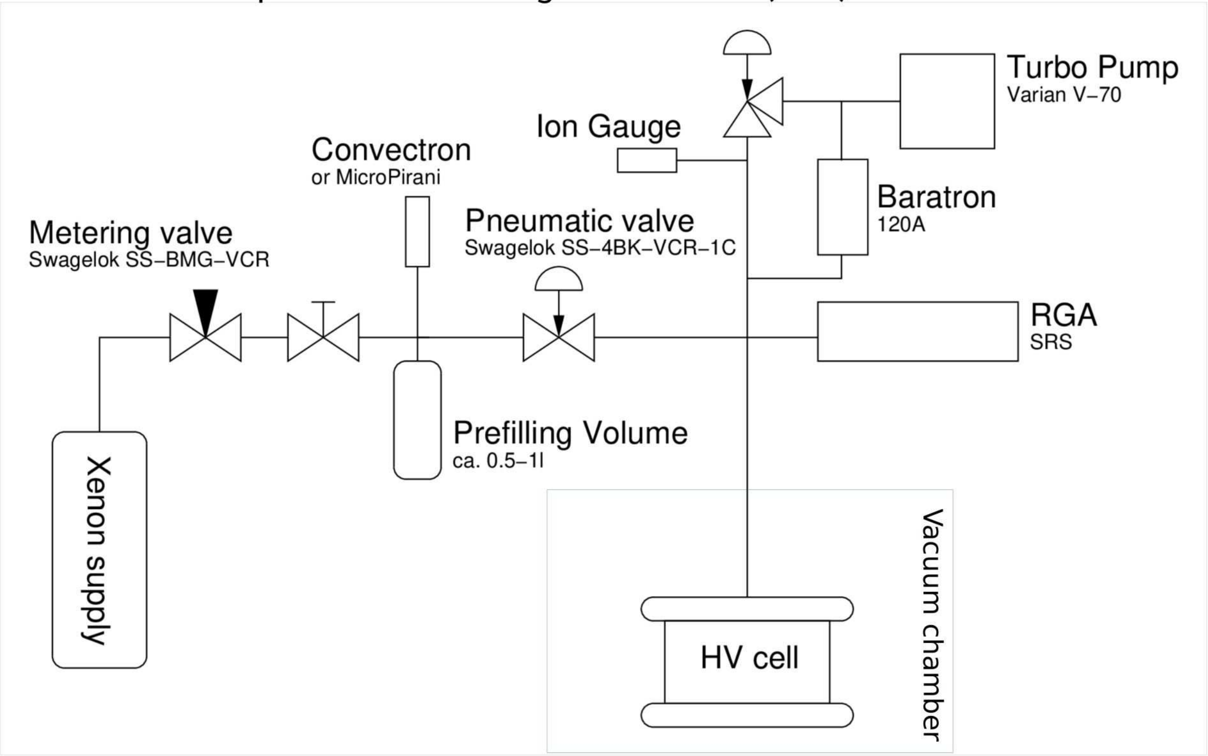
Tested the radial sealing method

Sean Vanbergen (co-op student 2017)

Configuration	Leak Rate (atm-cc/s)
Plastic Cylinder	>1e-4
Steel Cylinder	6e-7
Glass Cylinder	<1.3e-9

Filling of 10^{-4} to 10^{-2} mbar of xenon

Metal sealed system on top of vacuum chamber
-> reduce permeation during the HV test (~ hr)

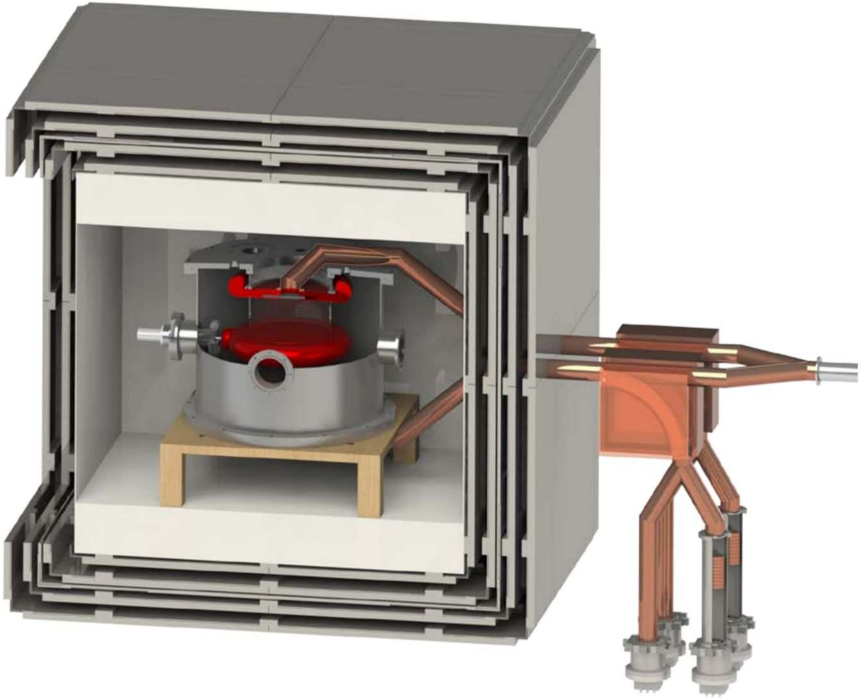


Example:
1 L cell volume
0.5 L prefilling volume
1 mbar prefilling pressure

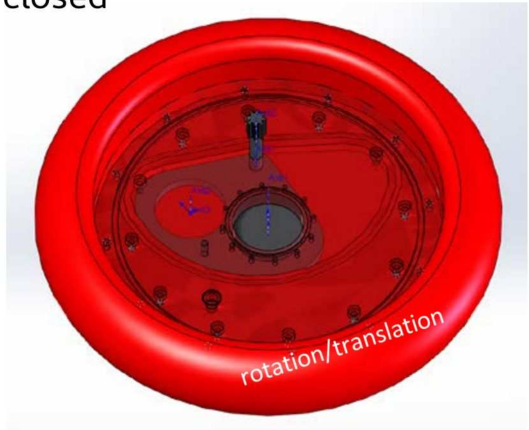
Filling #	Cell pressure [mbar]
1	*3.33E-01*
2	*1.11E-01*
3	*3.70E-02*
4	*1.23E-02*
5	*4.12E-03*
6	*1.37E-03*
7	*4.57E-04*
8	*1.52E-04*
9	*5.08E-05*
10	*1.69E-05*

EDM cell door mechanism design

Early design stage of neutron EDM components



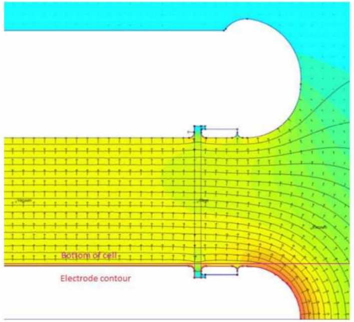
closed



open

Started PENtrack simulations of neutrons in EDM cell looking into v x E effects

- simulated electric field as input
- net motion of neutrons -> false EDM if E field inhomgeneities exist
- rotational net motion decays due to diffuse reflection



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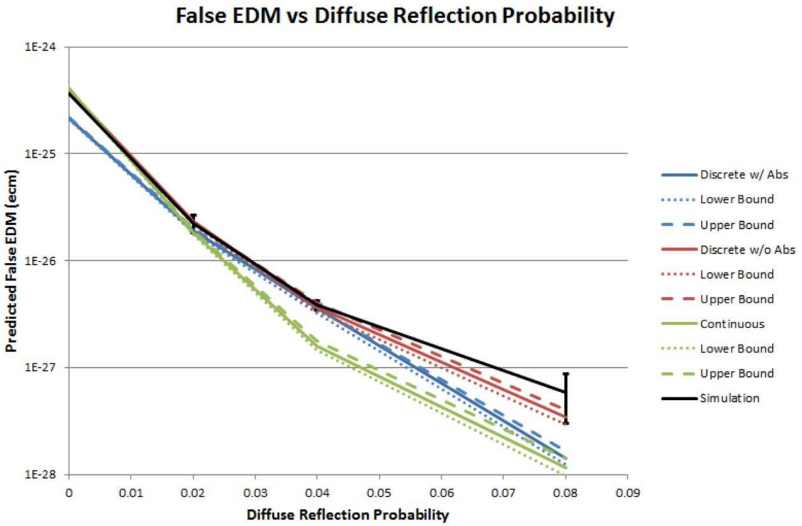

Second order: Deviation btw E-field “up” and “down”

$$d_f = \frac{\hbar}{4E}\frac{{v_{xy}}^2}{2B_z c^4}\left(E_{\uparrow\uparrow}^2 - E_{\uparrow\downarrow}^2\right)$$

Field Deviation	Analytic fEDM (ecm)	Simulated fEDM (ecm)
1%	7.10×10^{-29}	$5.77\times10^{-29} \pm 3.84\times10^{-32}$
5%	3.49×10^{-28}	$2.83\times10^{-28} \pm 1.88\times10^{-31}$
10%	6.80×10^{-28}	$5.51\times10^{-28} \pm 3.66\times10^{-31}$
20%	1.29×10^{-27}	$1.05\times10^{-27} \pm 6.92\times10^{-32}$

Summary

The good news:

- well working test setup to apply up to 100 kV
- first HV tests of different insulators (Borosilicate, PE)
- xenon filling currently being set up

Next steps:

- determine sealing method (axial vs radial seal)
- reliable leakage current measurement (also at high potential)
- introduce xenon at pressures of interest
- First breakdown tests using xenon (in 2017)

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Thank you!
Merci!

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Dual comagnetometers offer much more than redundancy

C.A. Miller, March, 2014

Following the treatment of Pendlebury et al. (2004) for the case of specular reflection of either of two fast-moving comagnetometer species *a* and *b* in a cylindrical cell, the frequency shift due to the GPE in the non-adiabatic case is given in, e.g., the case of parallel E and B fields, by

$$\Delta\omega_{\uparrow\uparrow} = \gamma^2\, \partial B_{0z}/\partial z\; v_{xy}^2\, |E| \,/\, (2c^2\omega_0^2) \bullet [-\gamma^2 B_0^2 R^2 / v_{xy}^2\, (1+2\cos^2\alpha)/3]$$
$$= -\gamma^2 R^2\, \partial B_{0z}/\partial z\; |E| \,/\, (2c^2)\, (1+2\cos^2\alpha)/3$$

The angle α characterizes the specular orbit. If the particle distribution in the trap is uniform in space and the velocities are isotropic, then the probability distribution function for the occupation of orbits characterized by α is

$$P(\alpha) = (4/\pi)\sin^2\alpha$$

Averaging the factor $(1+2\cos^2\alpha)/3$ using the weight function $P(\alpha)$ yields ½. Hence

$$\Delta\omega_{\uparrow\uparrow} = -\gamma^2 R^2\, \partial B_{0z}/\partial z\; |E| \,/\, (4c^2)$$

The crucial point is that this expression is quadratic in γ. Each fill of the EDM cell yields a measurement of ω_a and ω_b for the two comagnetometer species. E.g.,

$$\omega_{a\uparrow\uparrow} = \gamma_a B_0 - \gamma_a^2 R^2\, \partial B_{0z}/\partial z\; |E| /(4c^2) + \gamma_a^3 R^2 B_0 E^2 /(4c^2)$$
$$\omega_{b\uparrow\uparrow} = \gamma_b B_0 - \gamma_b^2 R^2\, \partial B_{0z}/\partial z\; |E| /(4c^2) + \gamma_b^3 R^2 B_0 E^2 /(4c^2)$$

The effective value of R^2 can be measured by introducing various values of large artificial axial magnetic field gradients $\partial B_{0z}/\partial z$ together with electric field E.

Hence for each fill, these two equations can be solved for the two unknowns
B_0 and $\partial B_{0z}/\partial z$
so that the determination of B_0 is insensitive to the comagnetometer GPE