TRIUMF

# EDM cell and HV test setup

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TRIUMF

# Requirements – EDM cell

| | First guess figure | Comments |
|---|---|---|
| Insulator/Coating resistivity | > $10^{18}$ Ohm cm | False EDM |
| Electrode-insulator leak | < $10^{-7}$ mbar*l/s | Comagnetometer sensitivity ~10-100 fT; Contamination? |
| EDM cell vacuum | < $10^{-6}$ mbar | Contamination – Comag sensitivity, EDM sensitivity |
| E-field magnitude | ~200kV | EDM sensitivity - E |
| E-field ramping speed | ~50s? | EDM sensitivity - N |
| E-field uniformity | >99% | Electrode conductivity (thin conductive layer, non-metallic)<br>Electrode deformation < 0.5mm?<br>Electrode (top-ground-bottom) alignment 0.1-1°?<br>Comag/UCN inlets, UV windows |
| EDM cell alignment to B-field | ~ 0.01-1°? | False EDM |
| E-field magnitudes for opposite polarities | <1%? | False EDM |
| EDM cell height | < 15cm | EDM sensitivity – UCN counts, E-field |
| EDM cell diameter | > 18cm | EDM sensitivity – UCN counts |
| UCN storage | > 130 s | EDM sensitivity - $\tau$ |
| UCN polarization lifetime | > 500s | EDM sensitivity - $\tau$ |
| HV compatible coatings | Preserve lifetimes to ~% over 200 days? | EDM sensitivity - $\tau$ |
| Electrode surface | Smooth? | Reduce sparks, non-symmetric for opposite polarities |
| Hg/Xe polarization lifetime | > 500s | Comagnetometer sensitivity ~10-100fT? |
| UV windows | > 98%? | Comagnetometer sensitivity ~10-100fT? |
| Non-magnetic/non-magnetizable materials | < pT (at ~cm distance) | Permanent magnetic dipoles |
| Non-metallic materials | Johnson noise, induced currents ~fT | Magn. field gradients, magn background <10ft? |

Brainstorming 1.5

# High voltage power supply

- (First) quote (Heinzinger, Sept 2016):
  - Cost: EUR 50k
  - Current: 0 - 1mA
  - Voltage range: 0 – 200kV (eg 13 kV/cm at 15cm)
  - Stability: < $10^{-5}$ (8h)
  - Ripple: < $10^{-5}$ pp (+/- 50 mV)
  - Polarity switch: only mechanical, 180° rotation
    evaluated options with PSI,
    two high voltage supplies are
    more economical



- Other suppliers: Gamma, FUG, …
- 200kV feedthrough (MSR, vacuum chamber)

# High voltage breakdown tests

## Motivation

- $^{199}$Hg/$^{129}$Xe dual comagnetometer allows for $B_0$ and $dB_{0z}/dz$ determination
  - $^{129}$Xe precession in same direction as neutrons
  - $^{129}$Xe has 100 times smaller neutron absorption cross-section compared to $^{199}$Hg

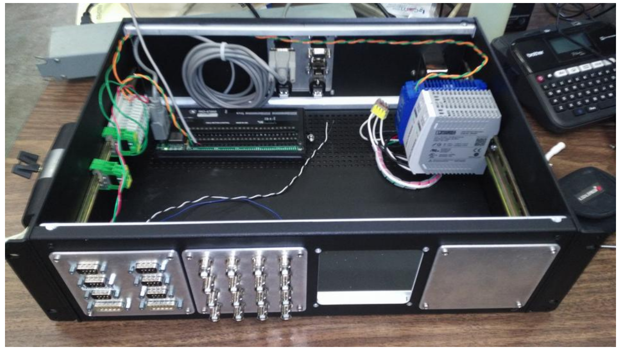
  ➔ HV breakdown data for xenon pressures btw 1e-4mbar to 1e-2mbar

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

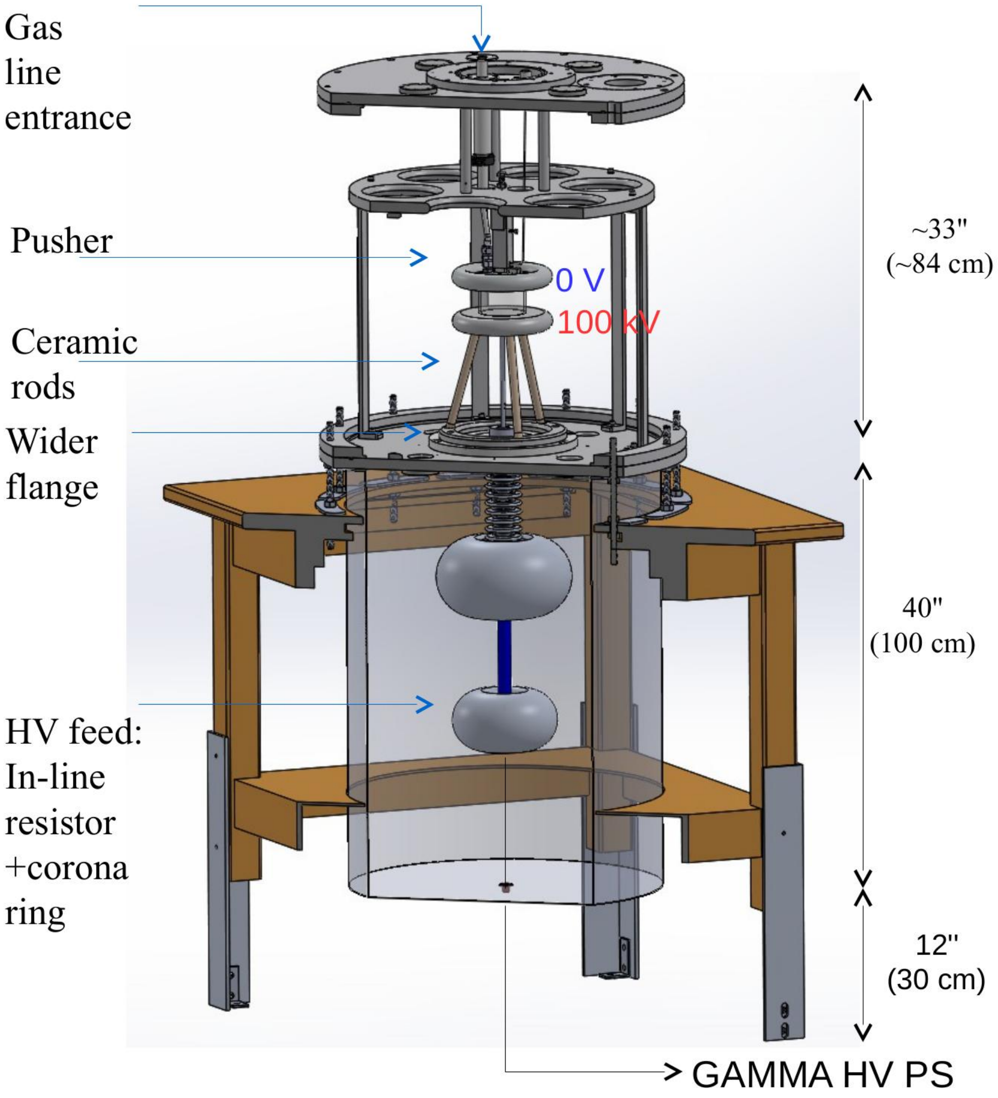
- Also: HV test of materials, coatings...

## Since last collaboration meeting

- Leak test of axially sealed EDM cell
- Machining of radially sealing split electrodes
- Gas filling system had high permeation through O-ring seals
  - ➔ Newly built using metal seals
- Improved DAQ system
  - ➔ New DAQ box
  - ➔ Software



# High voltage test setup at TRIUMF




Suppy -125kV

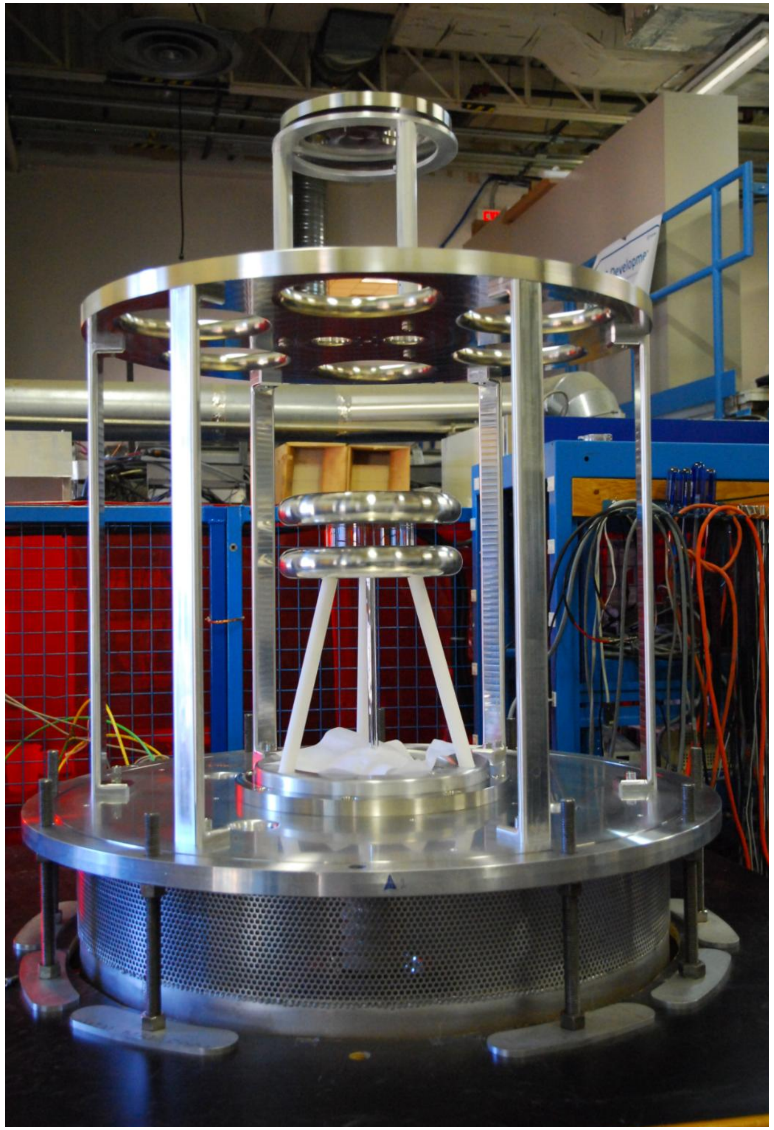
Feedthrough 100kV

1GOhm resistor

Routinely operating at voltages up to 100kV

Tested insulators without breakdown/trips

| | |
|---|---|
| Glass: | 22 kV/cm |
| PE: | 10.5 kV/cm |

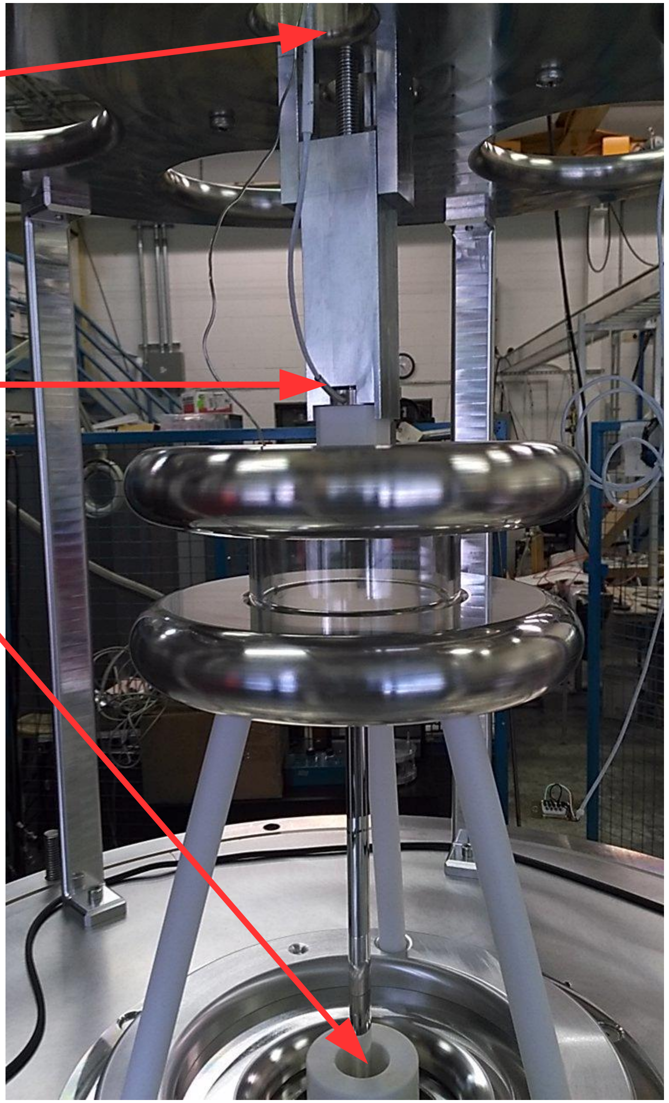


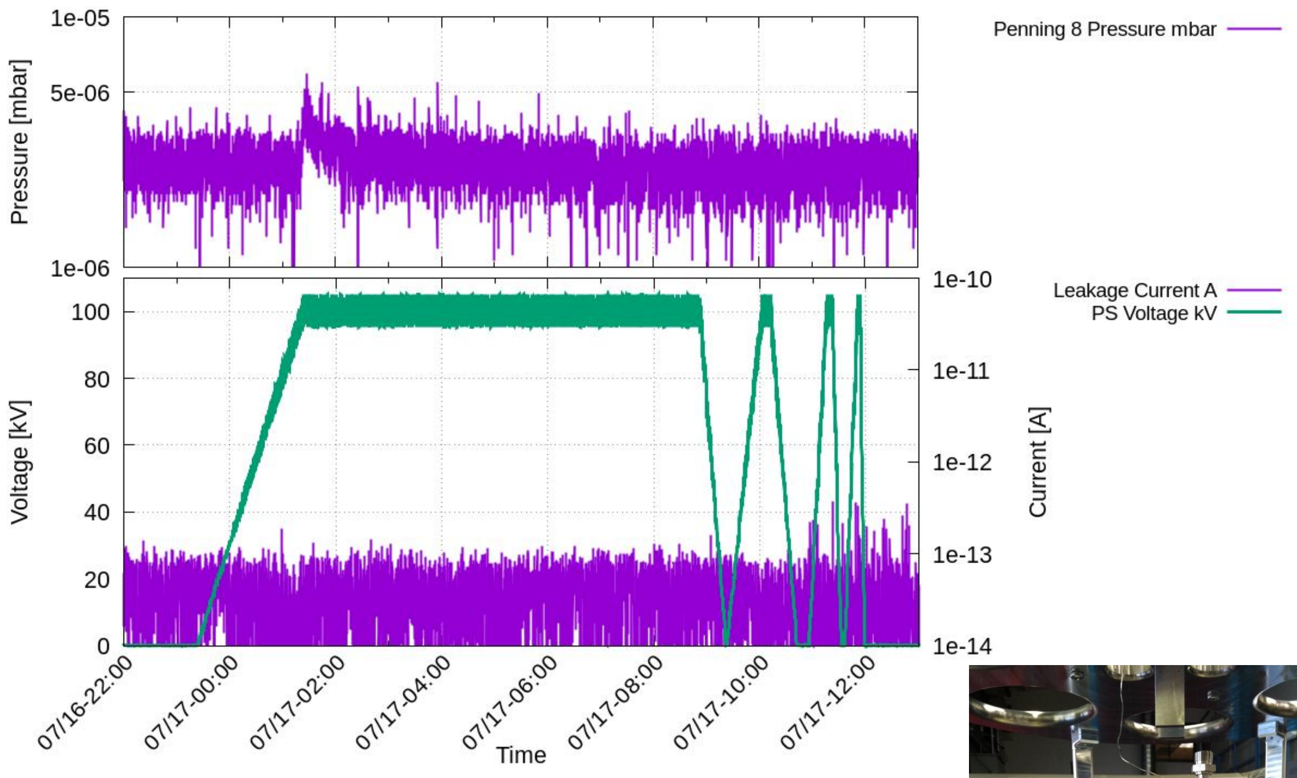
# High voltage test setup at TRIUMF

Screw sets applied force to the top electrode

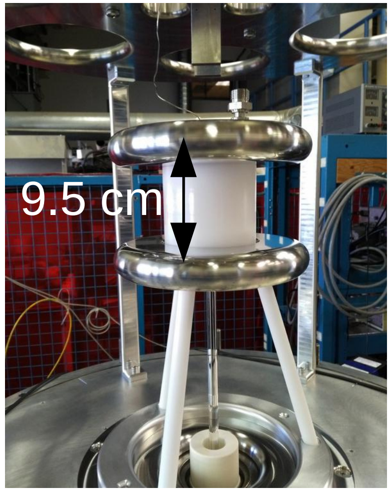
Load cell to measure force on electrodes

HV feedthrough



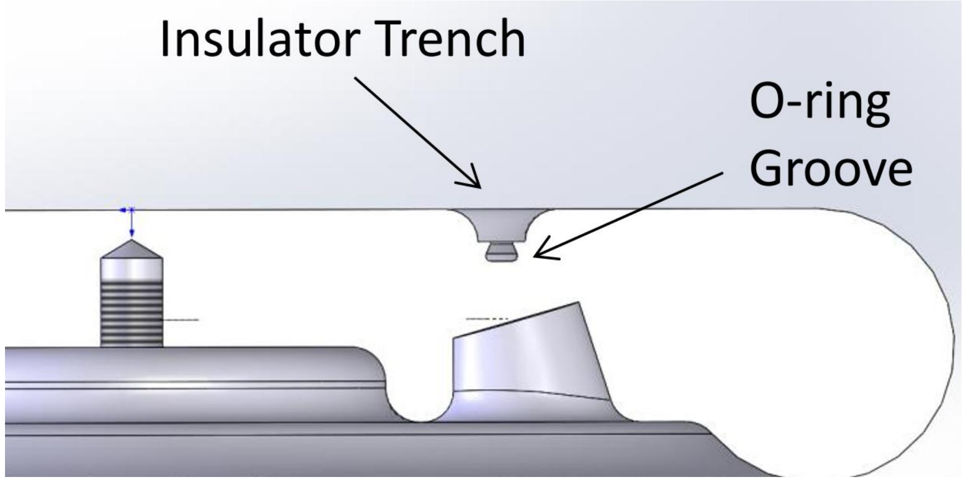



- Not specially treated PE cylinder
- HV ramps of 100kV/10 min

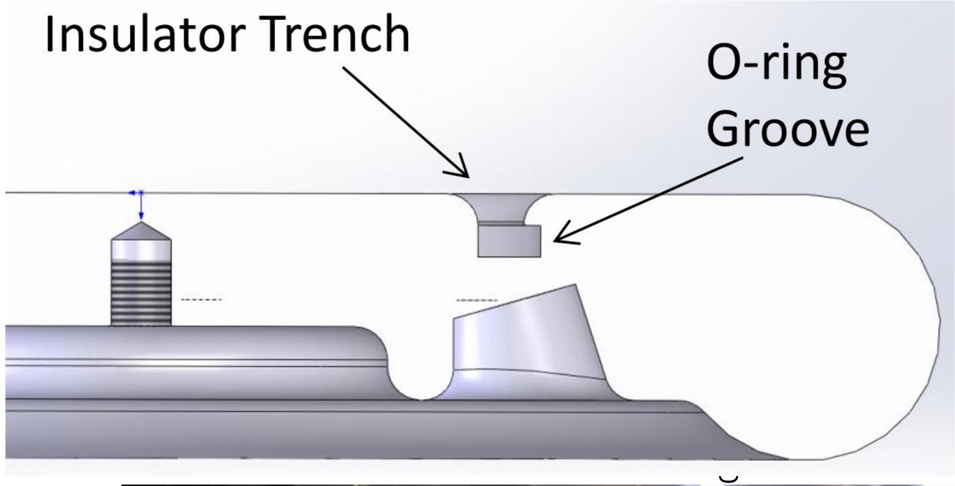


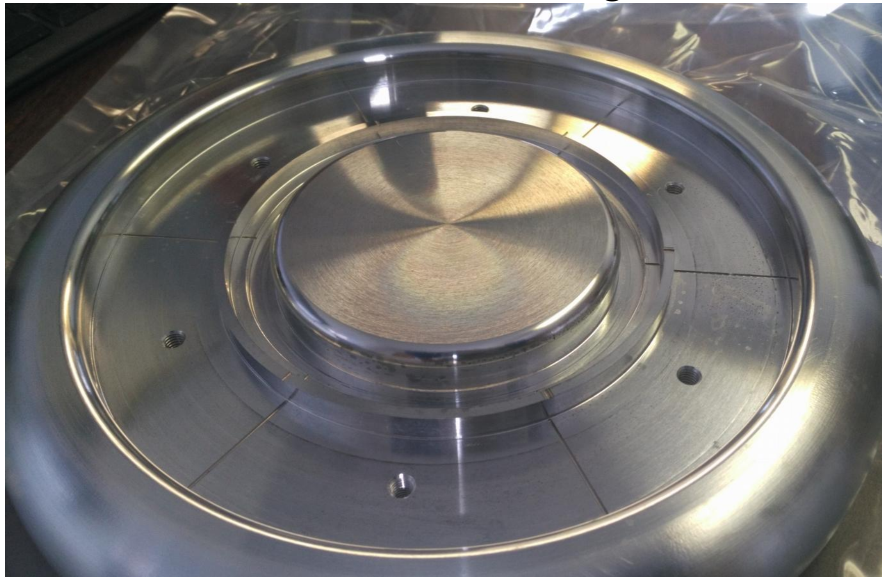
# High voltage test setup – Sealing the cell

Axial seal




Radial seal



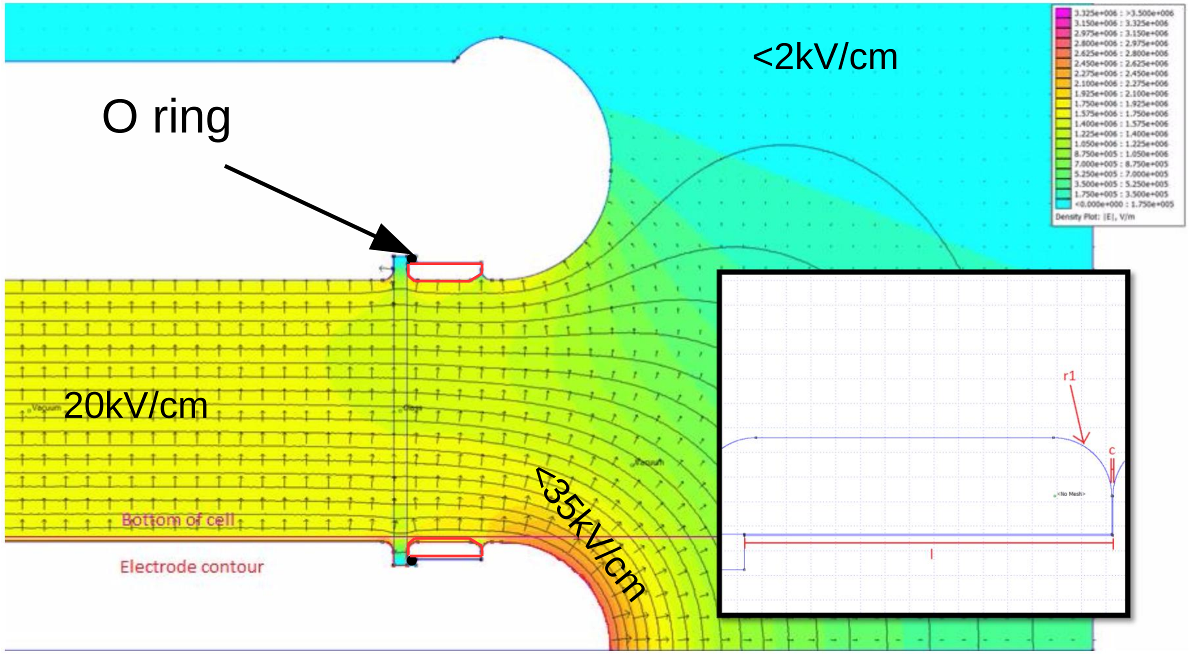



Radial seal

- easier centering of the insulator ring
- no force on glass-metal surface (vs axial seal)
- implementation in EDM setup easier
- electrodes machined, ready for testing?

# High voltage test setup – Radial seal tests

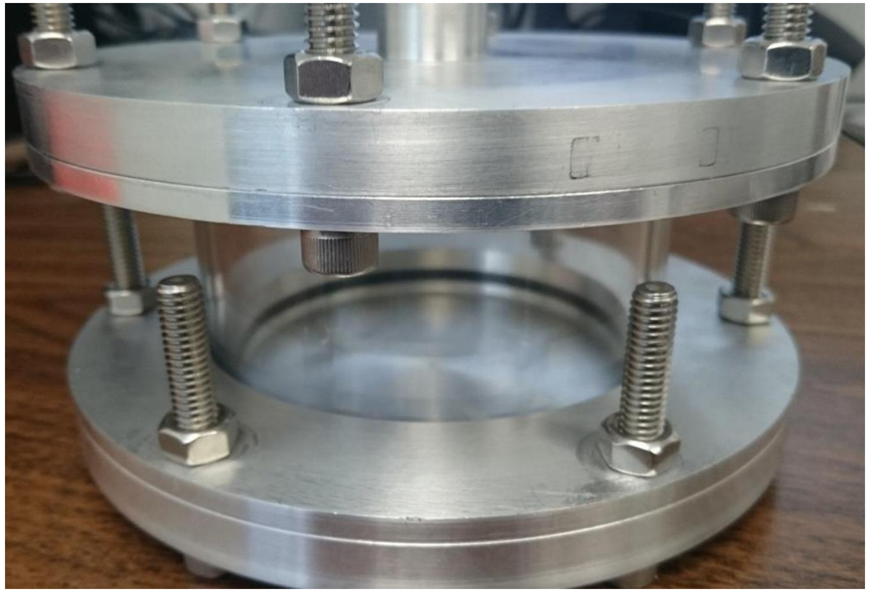
Electric field simulations:
- no significant issues due to split electrode design




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 |

# High voltage test setup – HV cell leak check

- Precisely machined glass insulator rings for axial seal
- Set up leak test inside vacuum chamber

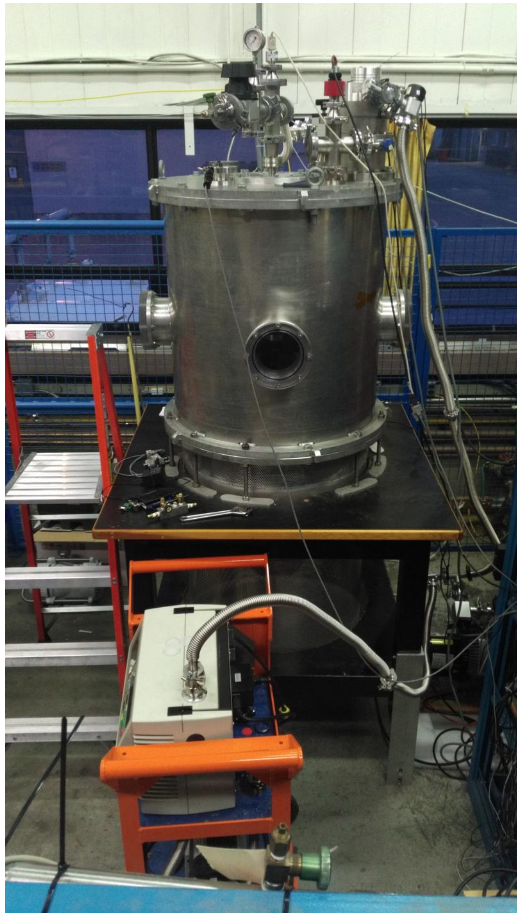
Leak rates at different load cell settings

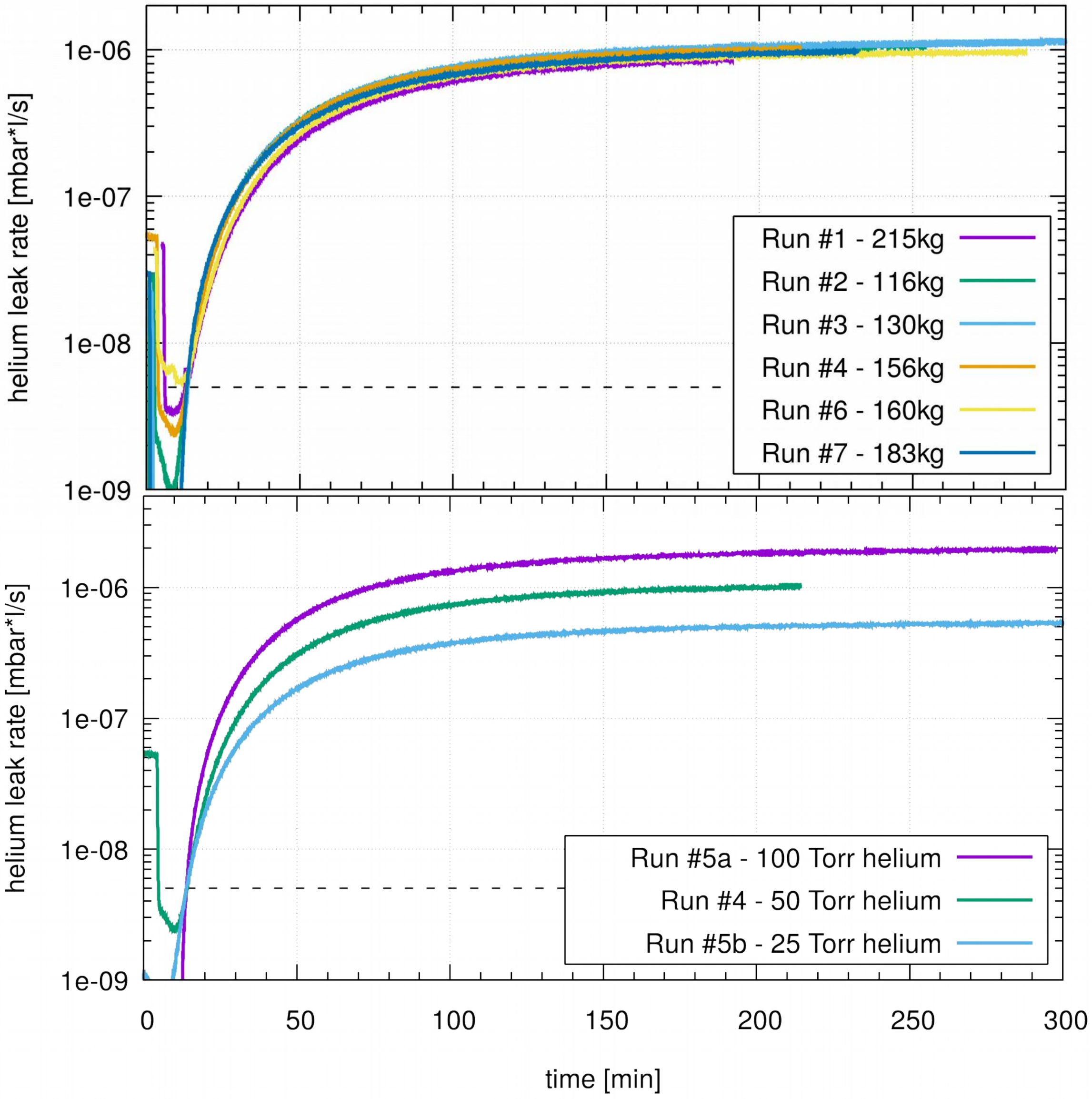
➔ find load cell force threshold?

➔ test reproducability and stability

➔ determine helium leak rate vacuum chamber) for axially sealed HV cell

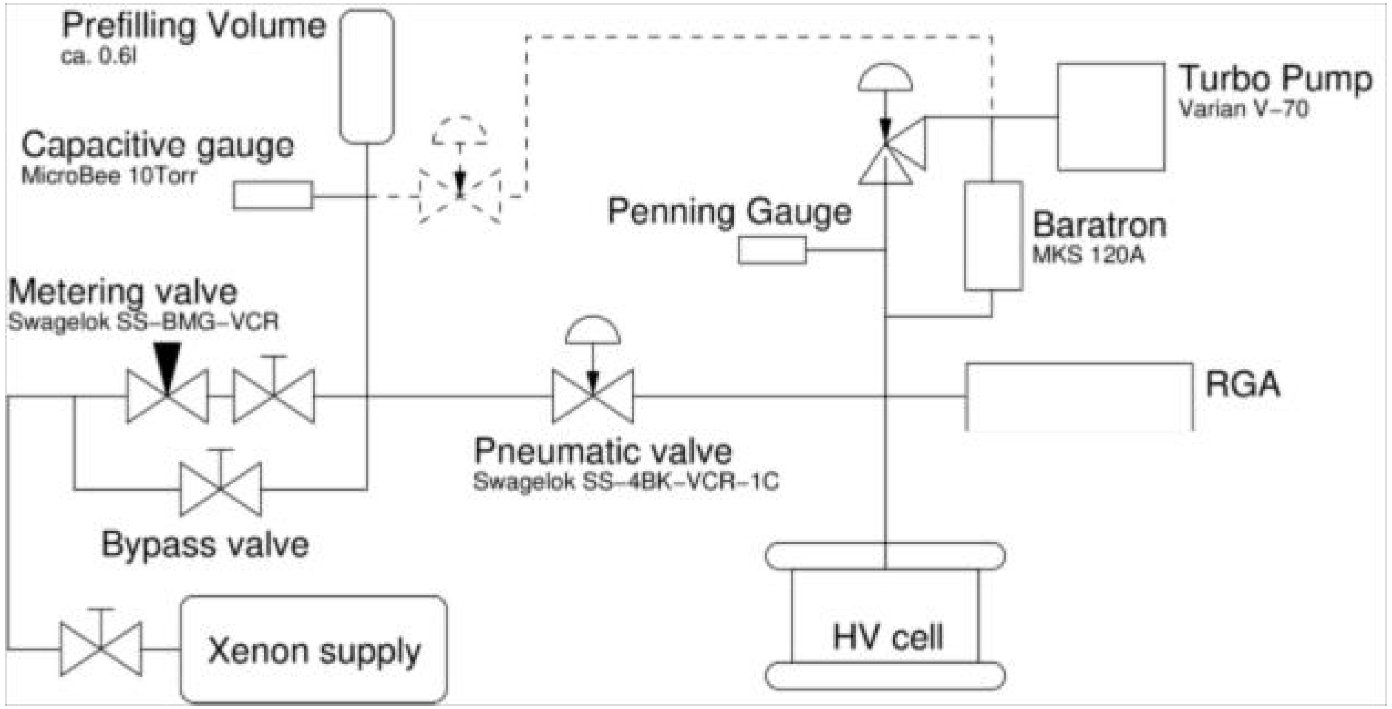
| Run | Load cell setting [kg] | Load cell final [kg] | Helium pressure [Torr] |
|---|---|---|---|
| 1 | 64.8 | > 215 | 50 |
| 2 | 47.2 | 116 | 50 |
| 3 | 55 | 130 | 50 |
| 4 | 62.1 | 156 | 50 |
| 5a | 62.1 | 154 | 100 |
| 5b | 62.1 | 154 | 25 |
| 6 | 60.6 | 160 | 50 |
| 7 | 63.0 | 183 | 50 |





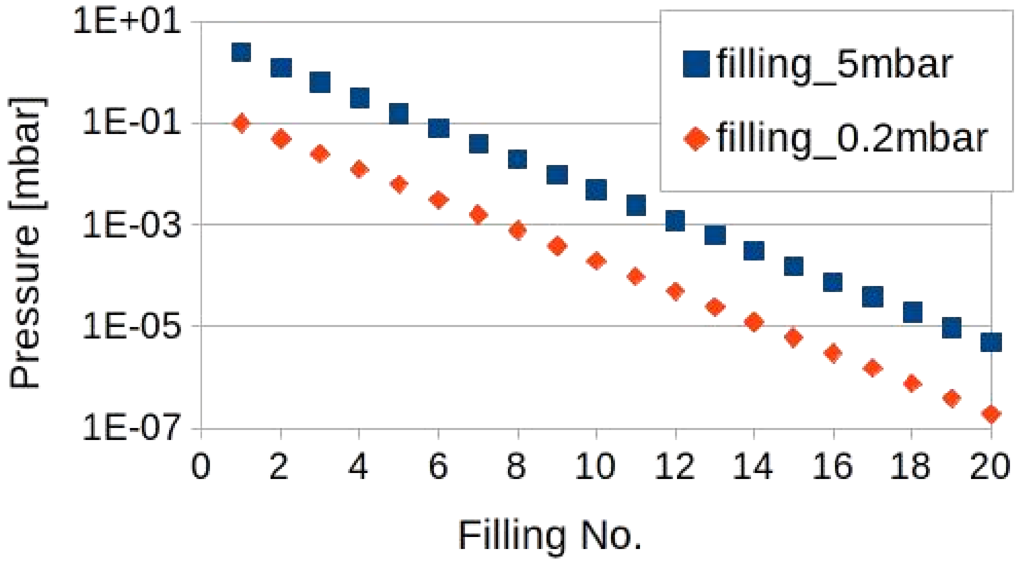
# High voltage test setup – Gas filling

Idea: batch-filling HV cell volume from prefilling volume of 1-10 Torr



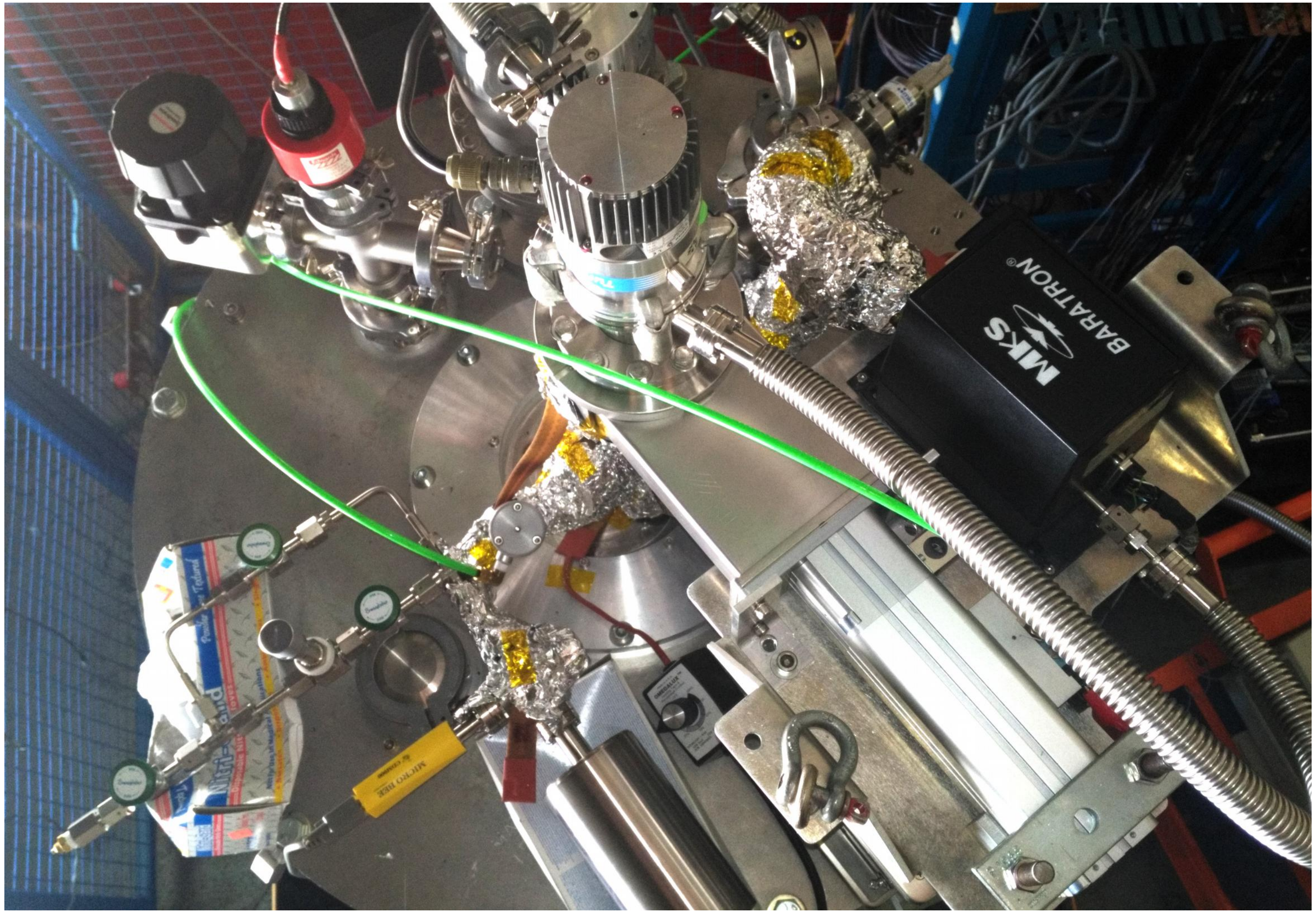

Pressures

| | |
|---|---|
| Range of interest: | $10^{-4}$ to $10^{-2}$ mbar |
| Measurement range: | $10^{-5}$ to $10^{-1}$ mbar |
| Background | < $10^{-6}$ over hrs |




To do: Pressure inside the HV cell vs. measurement on top
Vacuum level and stability when not pumping

# High voltage test setup – Gas filling installed




# High voltage test setup – Planning first tests

Breakdown voltage (Paschen law)

$$V_b = \frac{Bpd}{\ln Apd - \ln[\ln(1 + 1/\gamma_{se})]}$$

A – saturation ionization in the gas for particular E/p

B – related to excitation and ionization energies

$\gamma_{SE}$ – number of secondary electrodes emitted per incident positive ion (depends also on electrode material)

| Gas | $A$ ($cm^{-1}$ $Torr^{-1}$) | $B$ (V $cm^{-1}$ $Torr^{-1}$) | Range of $E/p$ (V $cm^{-1}$ $Torr^{-1}$) |
|---|---|---|---|
| He | 2.8 | 77 | 30–250 |
| Ne | 4.4 | 111 | 100–400 |
| Ar | 11.5 | 176 | 100–600 |
| Kr | 15.6 | 220 | 100–1000 |
| Xe | 24 | 330 | 200–800 |
| $H_2$ | 4.8 | 136 | 15–600 |
| $N_2$ | 11.8 | 325 | 100–600 |
| $O_2$ | 6.5 | 190 | 50–130 |
| $CH_4$ | 17 | 300 | 150–1000 |
| $CF_4$ | 11 | 213 | 25–200 |

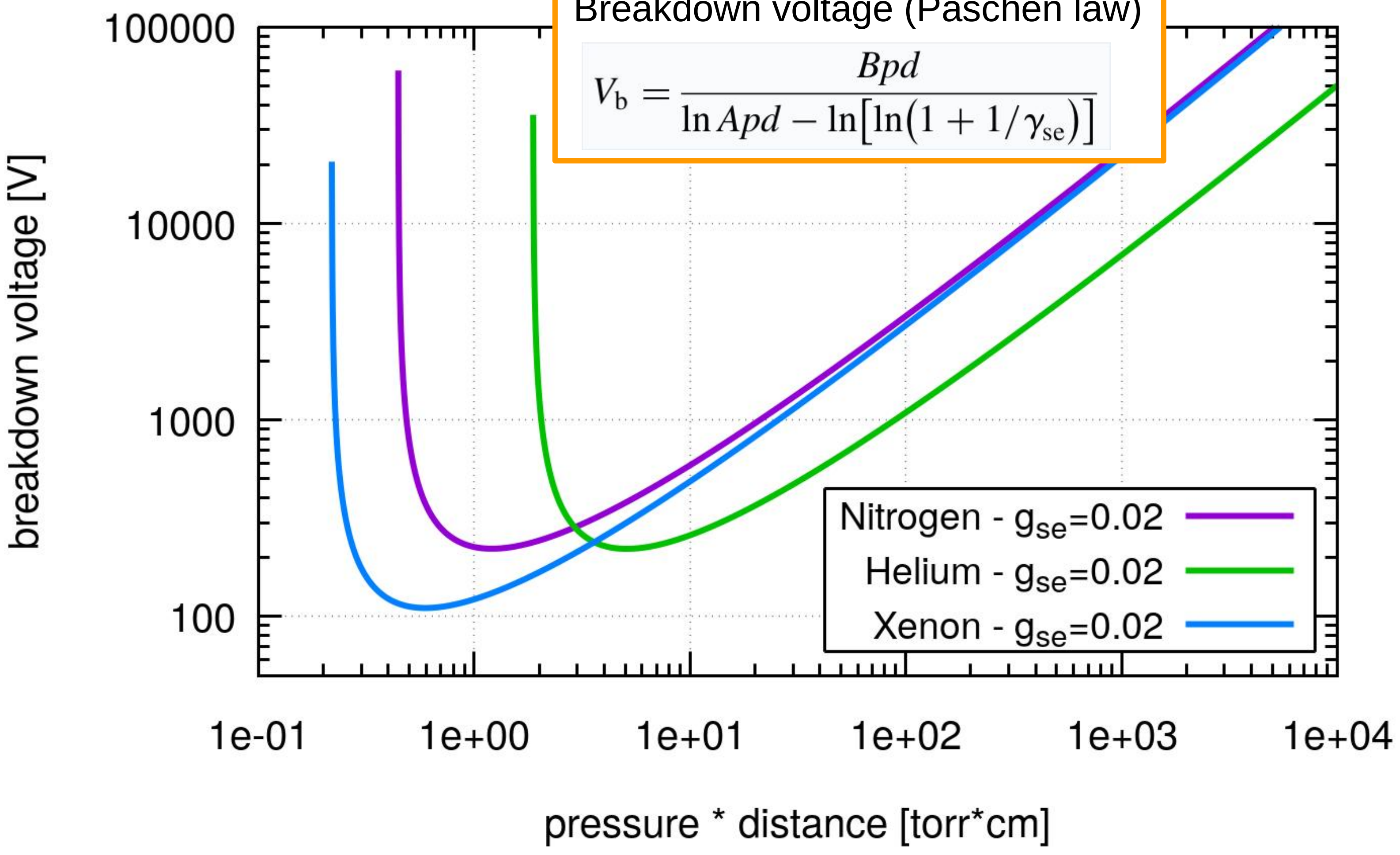
*Source*: Fits to data supplied by Petrović and Marić (2004).

Lieberman, Principles of plasma discharges and materials processing, Wiley (2005)

Validity of experimentally determined A,B: 10-1000 V/(cm*torr)

Neutron EDM cell (10 kV/cm, 1e-2 Torr) $10^6$ V/cm/Torr)

# High voltage test setup – Planning first tests




$$V_b = \frac{Bpd}{\ln Apd - \ln\left[\ln\left(1 + 1/\gamma_{se}\right)\right]}$$

Expected breakdown in nitrogen

Electrode distance 6.5cm

Axially sealed cell

| Pressure [Torr] | p*d [Torr*cm] | Breakdown [V] |
|---|---|---|
| 0.015 | 0.1 | ? |
| 0.031 | 0.2 | ? |
| 0.046 | 0.3 | ? |
| 0.061 | 0.4 | ? |
| 0.077 | 0.5 | ~700 |
| 0.092 | 0.6 | ~300 |
| 0.15 | 1 | ~200 |
| 0.31 | 2 | ~200 |
| 0.77 | 5 | ~300 |
| 1.5 | 10 | ~600 |
| 15 | 100 | ~4000 |
| 77 | 500 | ~10000 |

# Summary

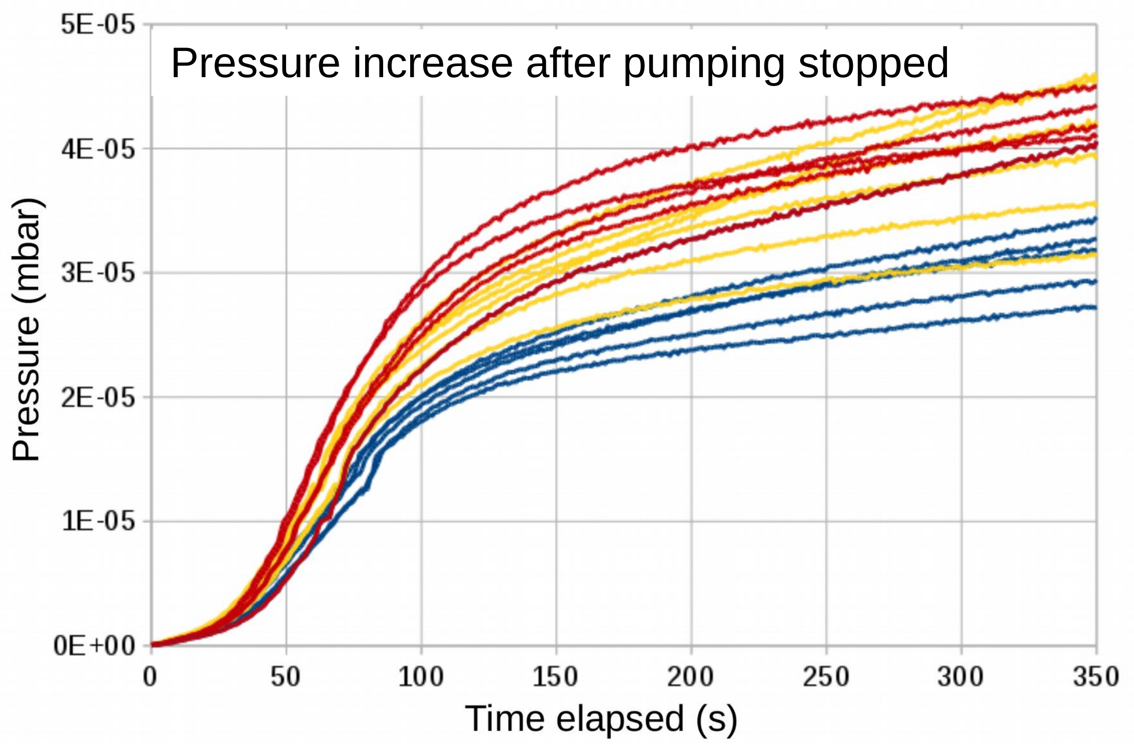
- Many HV/EDM cell requirements to be figured out!
  - many depending on other subsystems, mainly magnetic fields

- HV test setup getting ready for first HV breakdown tests with gas ($N_2$, He, Xe,…)
  - Ready for first tests
  - Need to fix leak for low pressure tests

- Produce and test coatings (dPS,…)

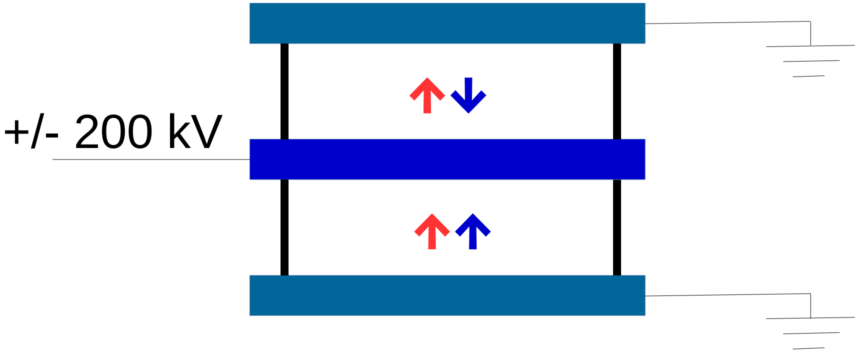
- Look into low-conductivity (eg. coated) electrodes

- Merge HV testing with comagnetometer development?



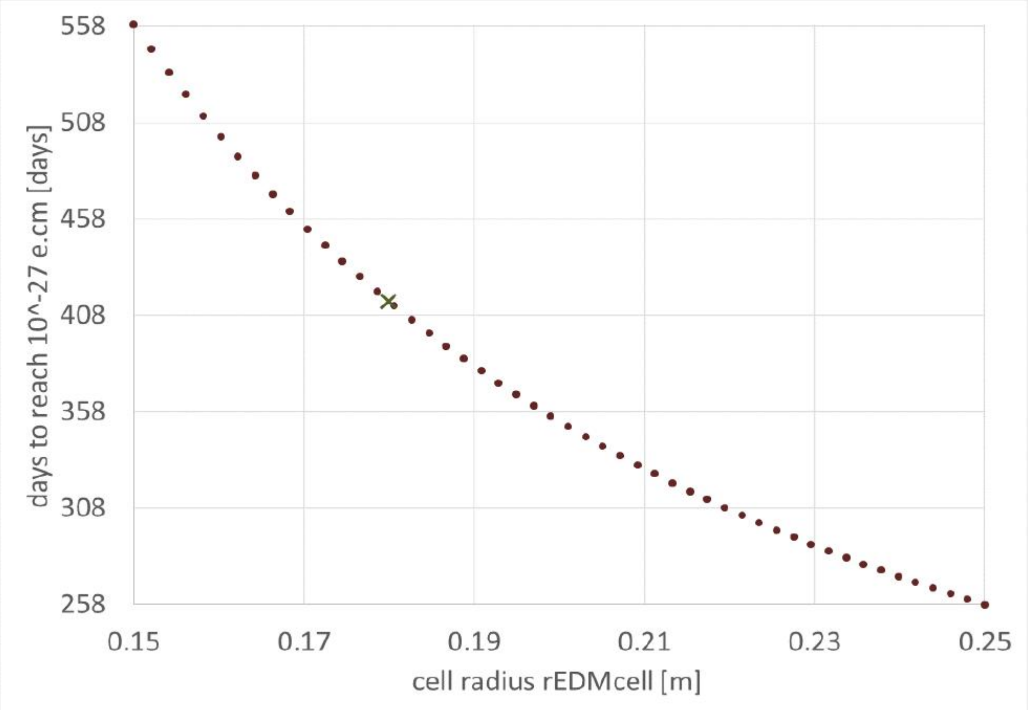
# Backup slides

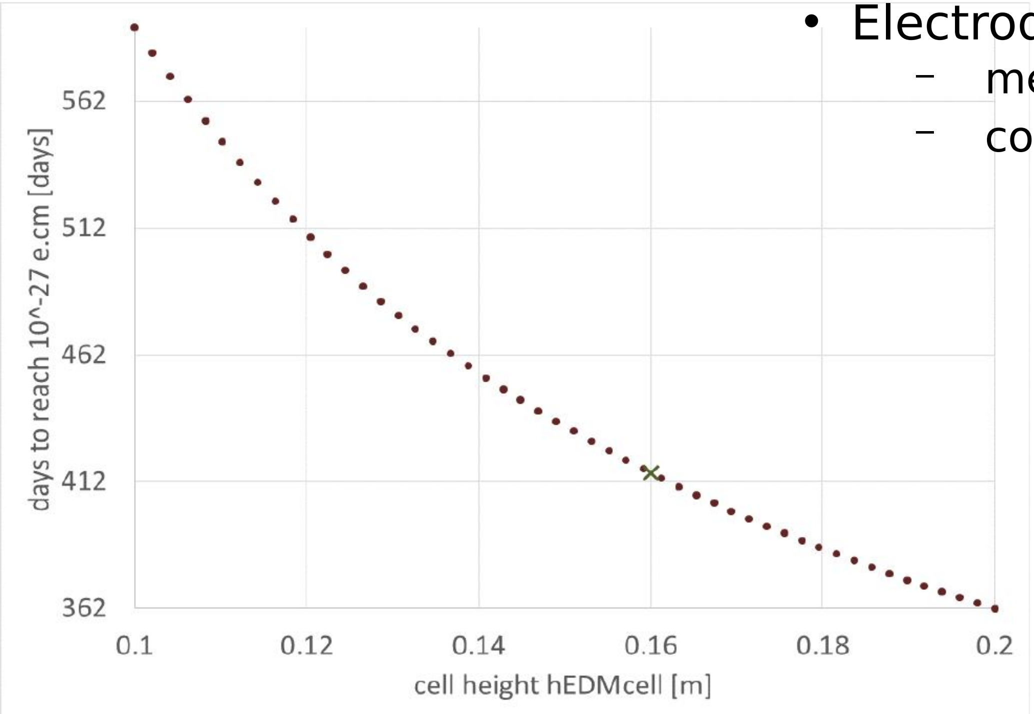
# Baseline design of the measurement cell?




- Double cell (↑↓, ↑↑)
- Height: 16 cm
- Diameter: 36 cm
- Volume: 16 L
- Wall material: Glass, Quartz, PS, PE?
- Aluminium electrodes (thickness?)

- Materials:
  - (d)PE (214 neV)
  - (d)PS (161 neV)
  - $^{11}$BN (330 neV?)
  - $^{11}B_4C$ (235 neV?)
  - $C_3N_4$ (390neV?)
- Electrodes
  - metallic coatings
  - cond. plastics



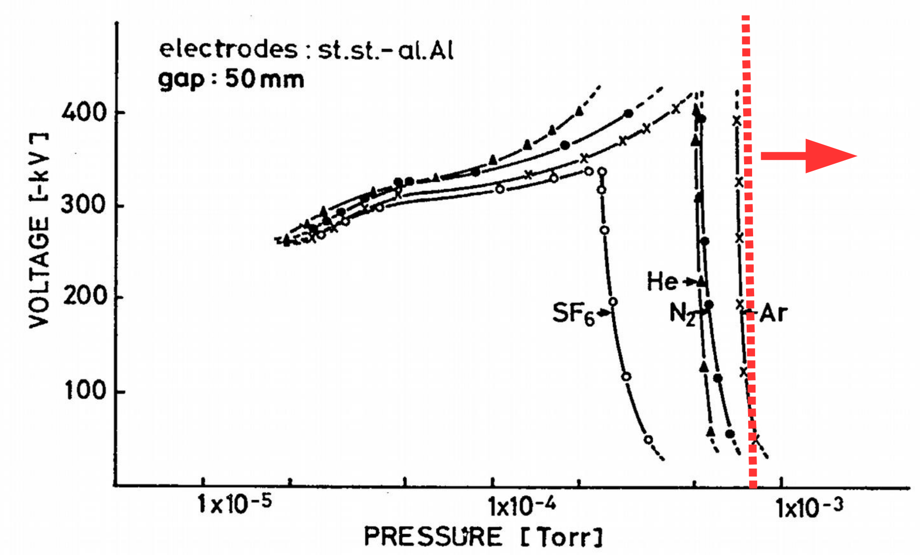



# High voltage breakdown of xenon (and others)

-> 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?

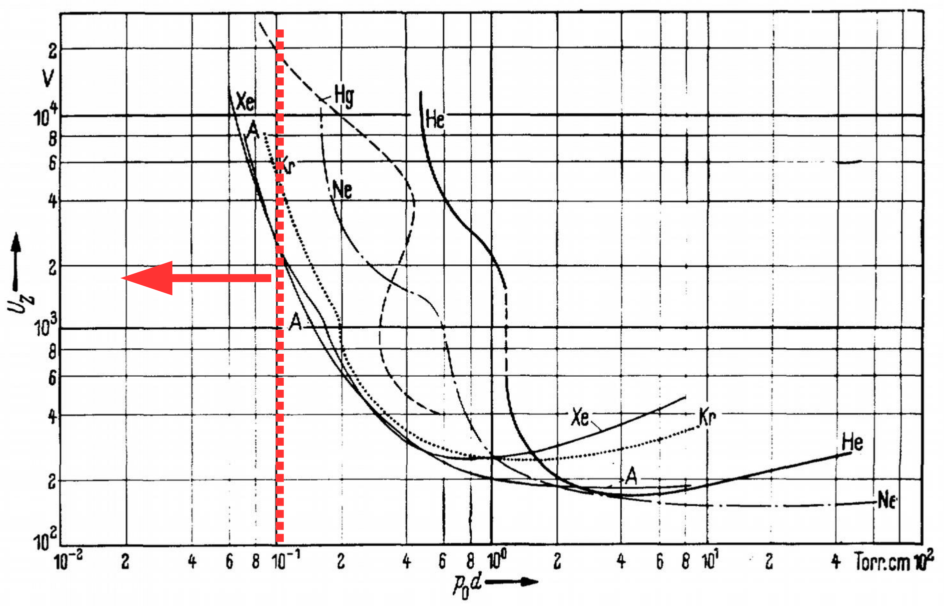



Fig. 7. Breakdown characteristics of the noble gases. Hg characteristic from [13].

-> extend to gas mixtures of xenon and mercury

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