TRIUMF

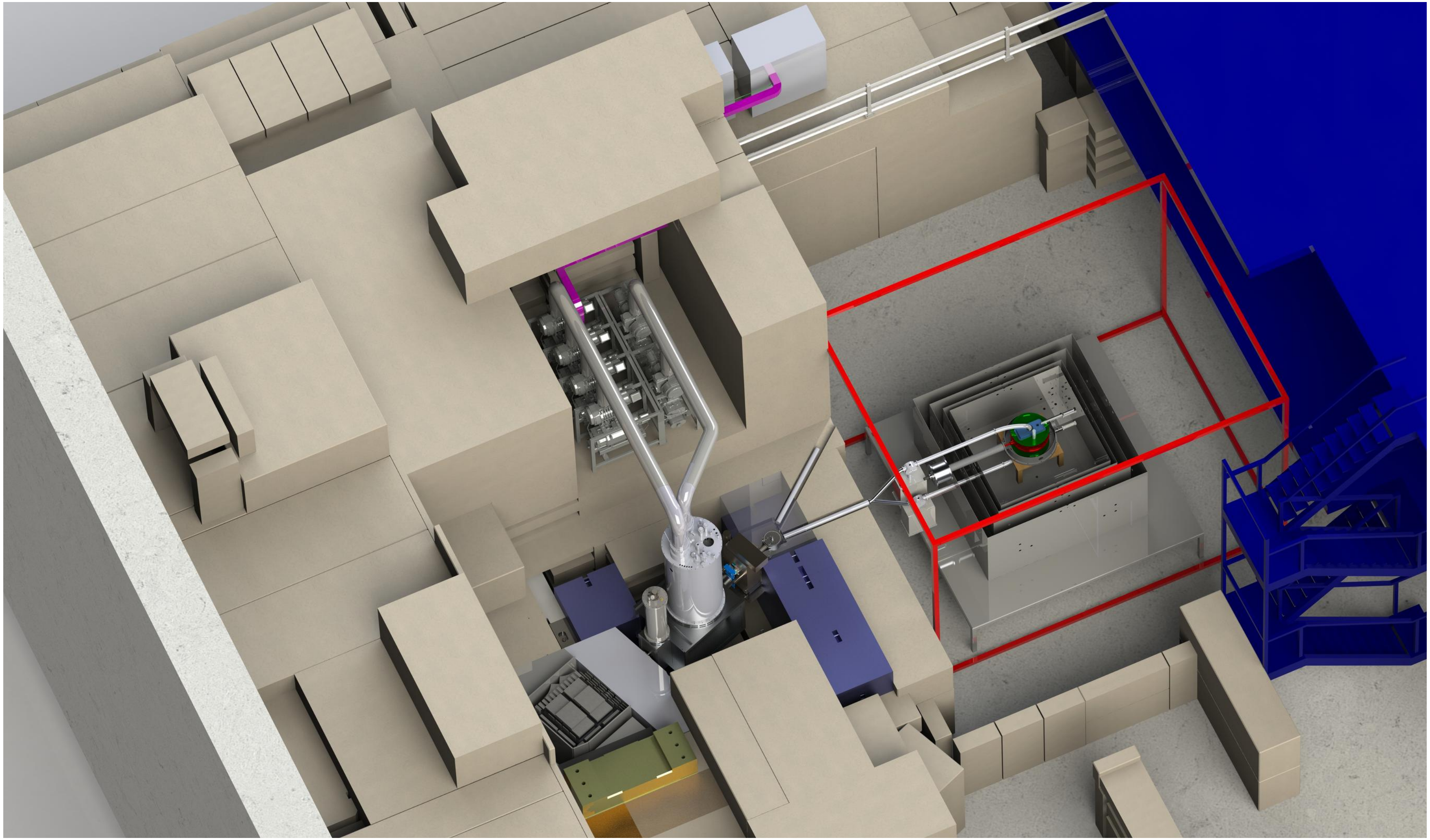
nEDM precession cell, HV, vacuum

Insulator, electrodes, coatings, UCN valve
HV power supply, HV feed, HV Simulations

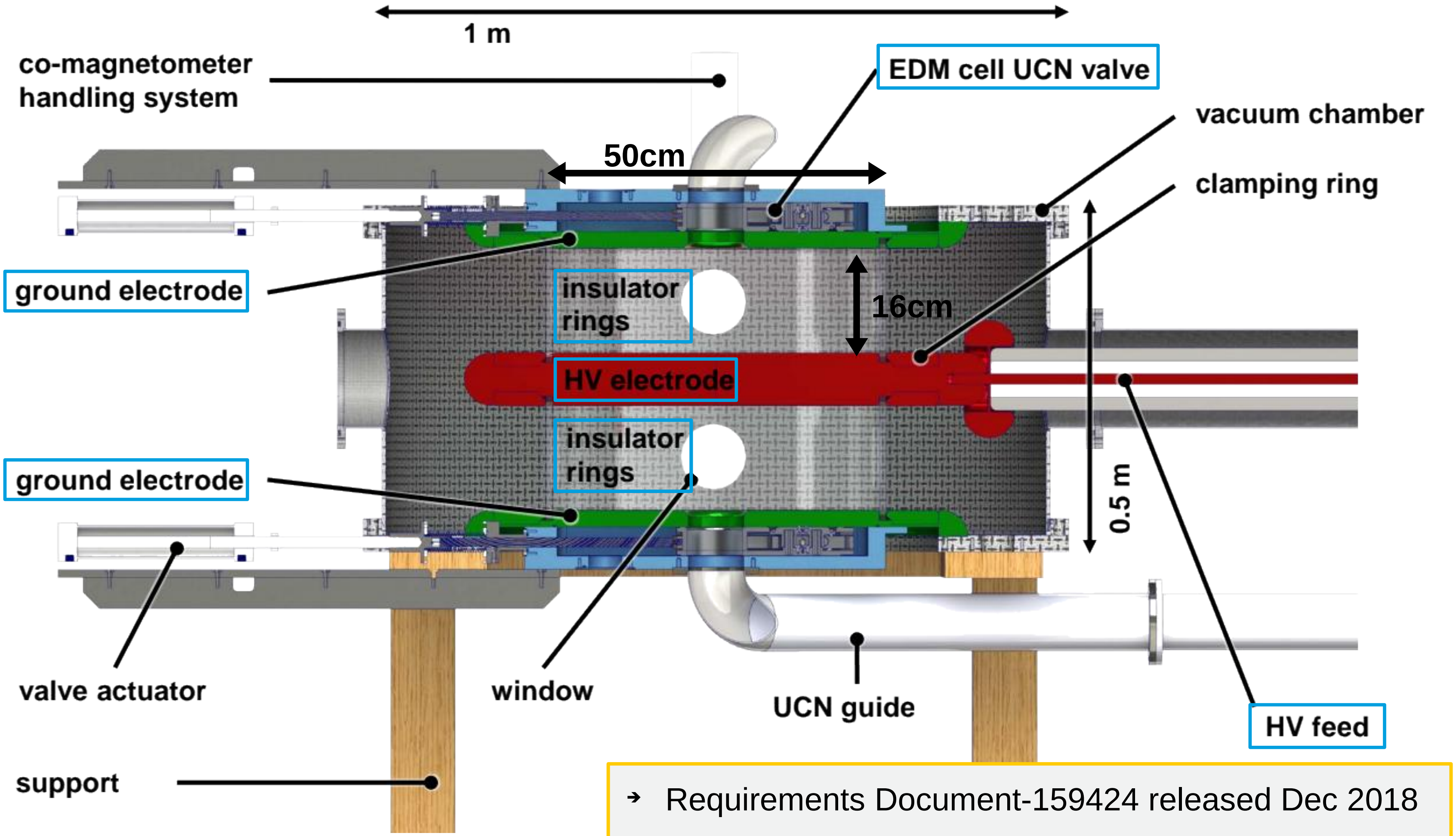
R. Picker, **F. Kuchler**, S. Vanbergen
D. Rompen, C. Marshall, S. Horn, I. Nikonov

EAC review, Feb 7th 2020

EDM Overview



Overview



- Requirements Document-159424 released Dec 2018
- Interfaces to almost all subsystems

Vacuum chamber: Baseline design

Cylindrical vacuum chamber

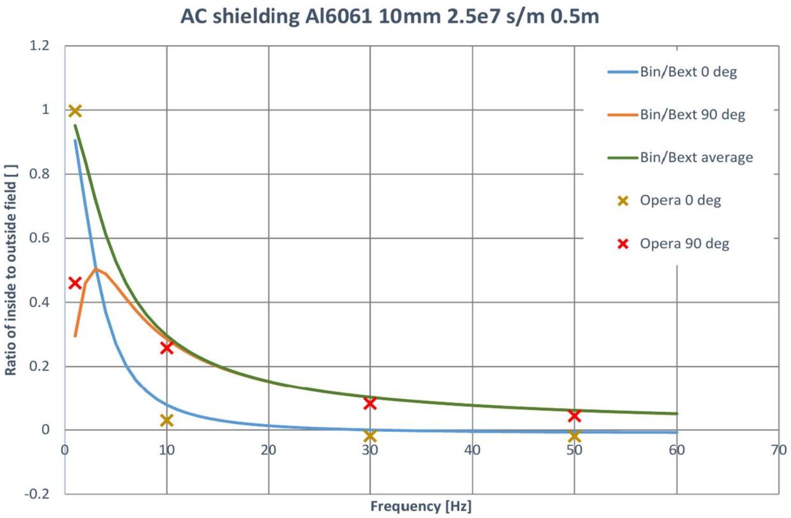
- Electrodes form part of top lid
- 1 m diameter, 0.5 m height
- low-conductivity material 0.1 to 10^6 S/m
  - Eddy currents distort the oscillating B1 spin flip field
  - Still provides ground reference

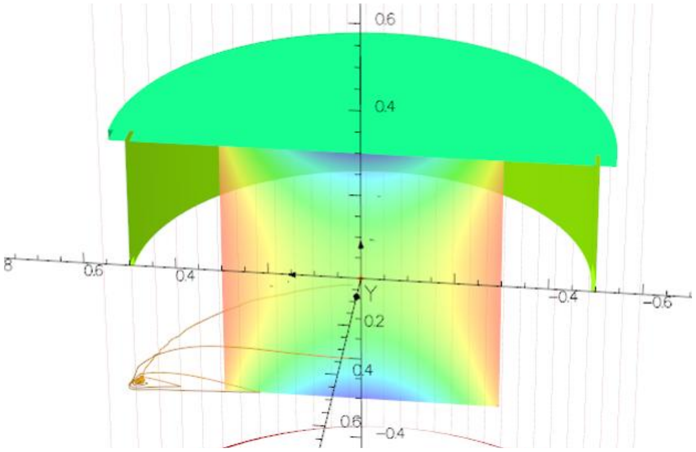
Candidate materials

- Titanium: ~10^6 S/m
- ESD plastics (Delrin, PEEK,…): 0.1-10 S/m
- Glass fiber (G10,...)

Estimated vacuum level better than 1 x 10^{-5} mbar:

- 2x 60mm diameter, 1.5m length pumping lines
  - small (off-center) penetrations in MSR
- Single 300L turbo pump sufficient





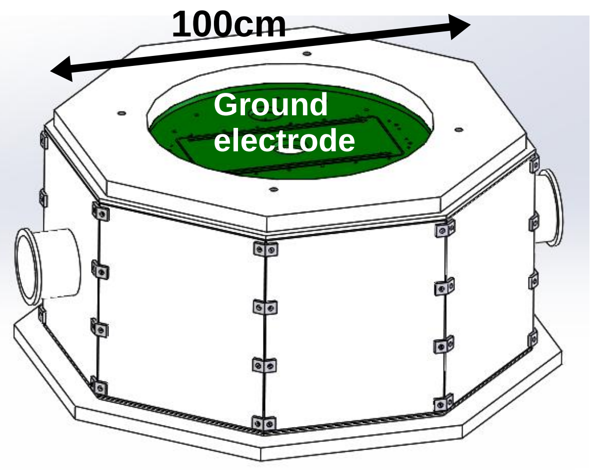
FEMM simulation results for metallic vacuum chamber effects on B1 magnetic field

R. Picker, F. Kuchler, SciTech Engineer

Vacuum chamber: Status and plans

Concept design options

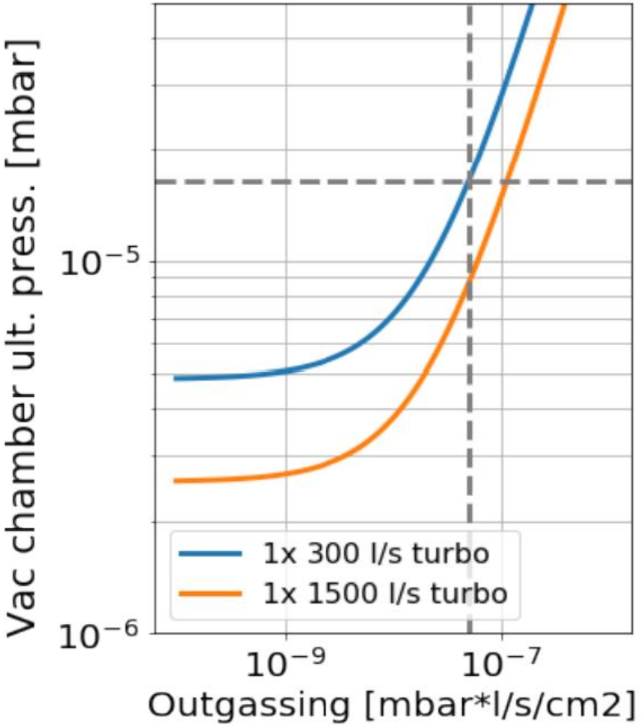
- Evaluate manufacturing options:
  - large (non-metallic) cylinder
  - octagon chamber
    (less costly, build at TRIUMF)
- Stress evaluation
  (top plate and octagon chamber)
- Possibly build small scale prototype chamber
  (in particular for octagon design)



Octagon chamber concept

Candidate materials

- Evaluate cost and feasibility
- Outgassing tests to confirm expected vacuum level



Confirm pumping penetration sizes and locations for MSR

R. Picker, F. Kuchler, SciTech Engineer

EDM cell: Baseline design and options

- Two vertically stacked cells

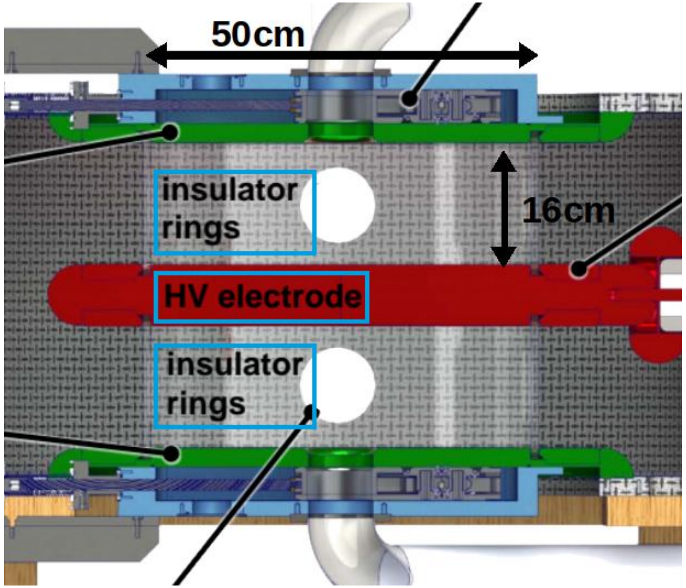
Insulator

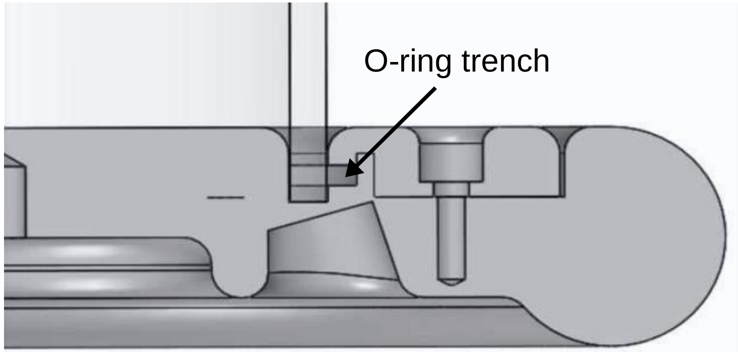
- Inner diameter 500mm
- Height ~180mm, hence cell height 160mm
- Candidate materials: Rexolite, PEEK, fused quartz
- Deuterated polymer coating (dPS, dPE)

Electrodes

- Central electrode: +/- ≥200 kV applied
- Ground electrodes part of vacuum chamber
- Electric field inhomogeneity < 3%
- Candidate bulk materials: Al, Cu, conductive plastics
- Candidate coatings: DLC, NiP (non-magnetic?)
- Split design to provide radial seal

Gate-type UCN valve





Radial sealing concept

R. Picker, F. Kuchler, S. Vanbergen, SciTech Engineer

EDM cell: Baseline design and options

- Two vertically stacked cells

*Investigating smaller cell heights: 100, **130mm***

Insulator

- Inner diameter 500mm
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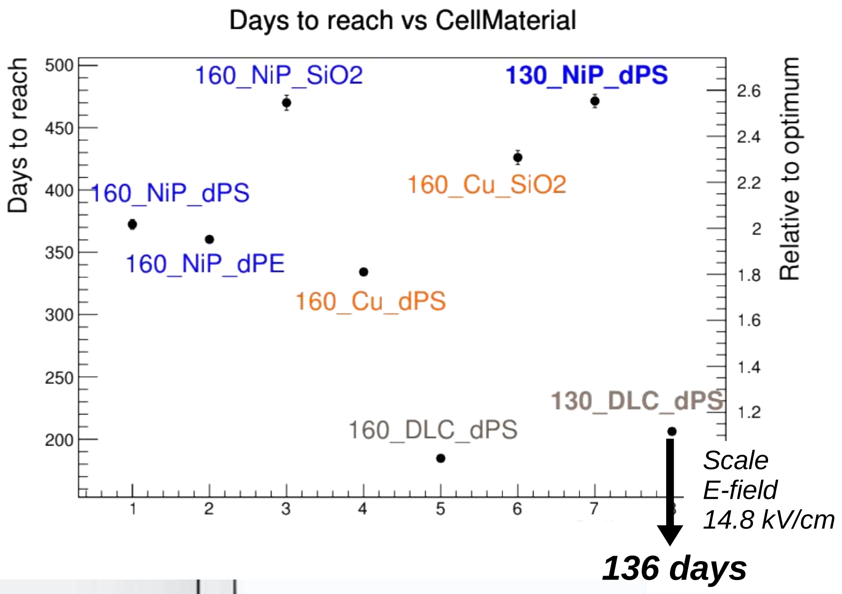
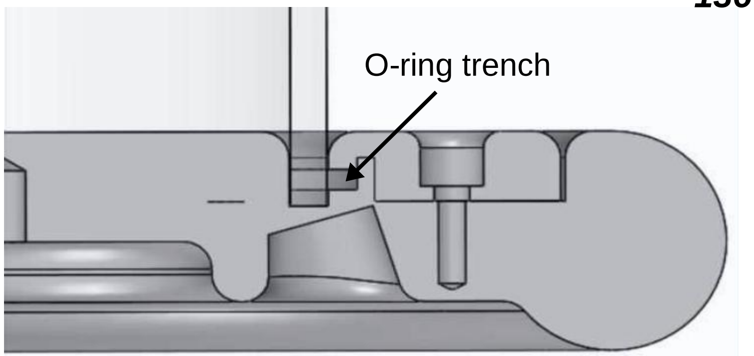




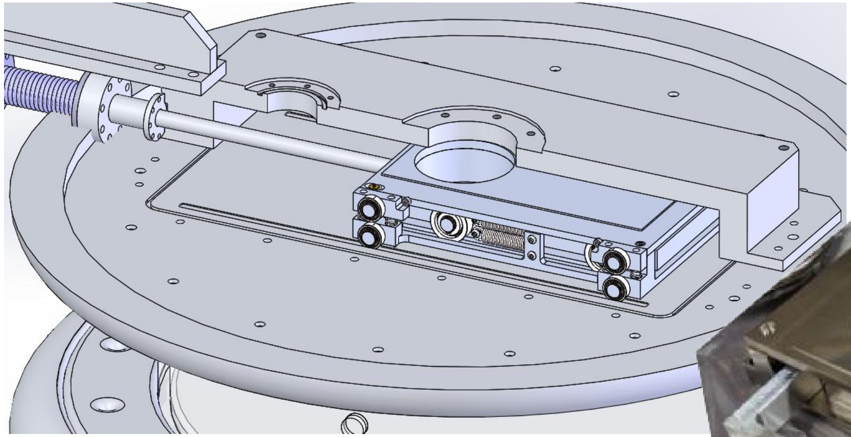
Radial sealing concept

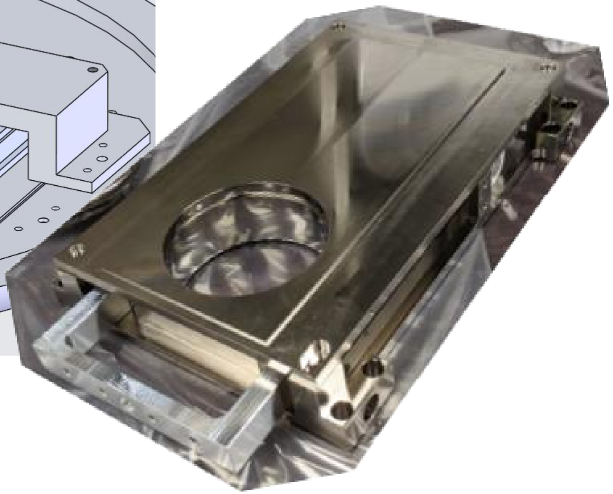
R. Picker, F. Kuchler, S. Vanbergen, SciTech Engineer

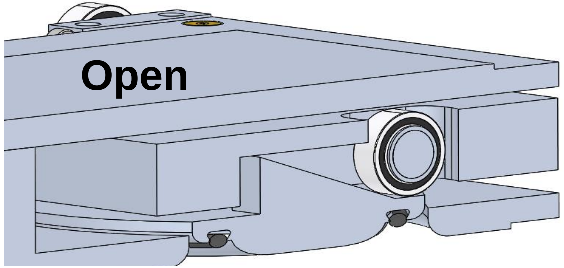
EDM cell: UCN valve

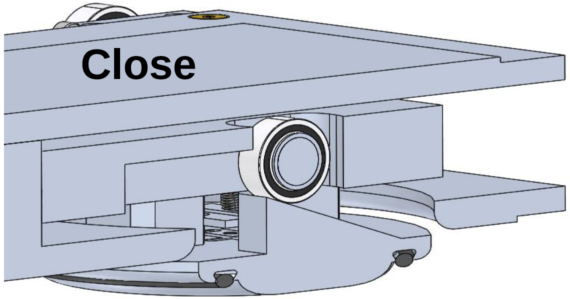
Requirements

- Low leak rate < 1x10^{-5} mbar*l/s
- UCN storage > 120 s
- UCN transmission > 95%
- Transition open-close < 2s
- Cavity depth < 5mm
- Lifetime > 100000 cycles









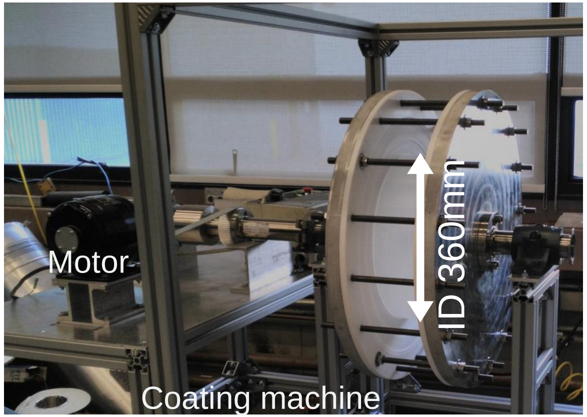
Prototype design

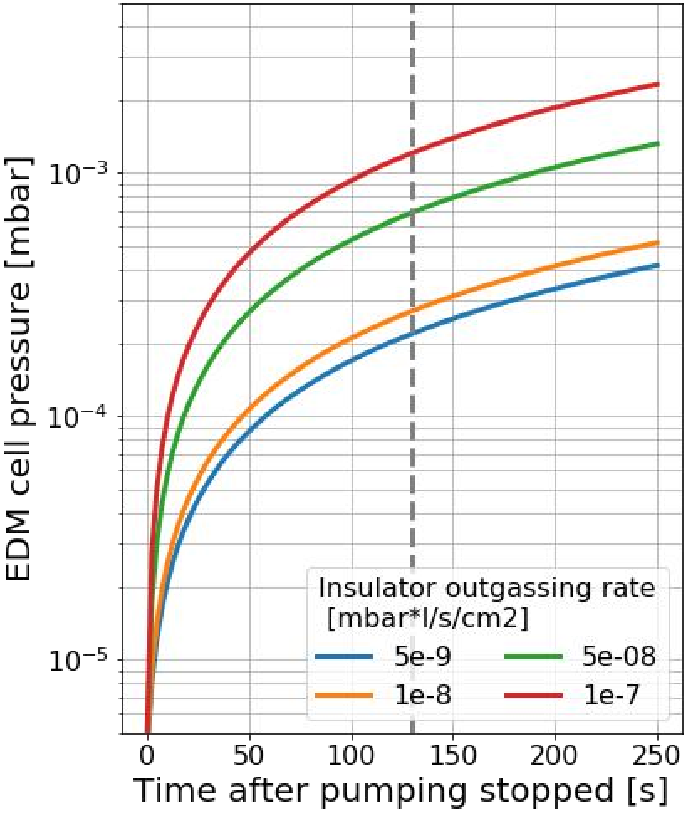
- Sliding gate-type valve linearly actuated (vs linear-rotary design)
- Door 85mm ID
  (upscaling or reducer to match UCN guide)
- Non-magnetic
- Detailed design and engineering done at TRIUMF

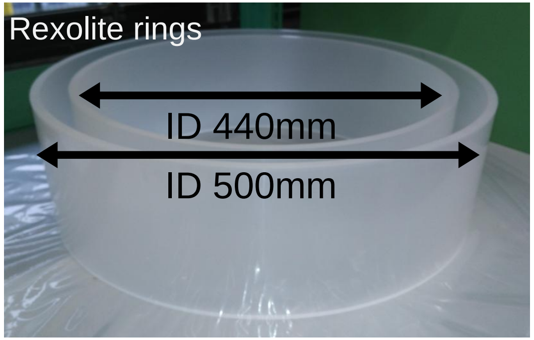
R. Picker, S. Vanbergen, V. Tiepo, I. Nikonov

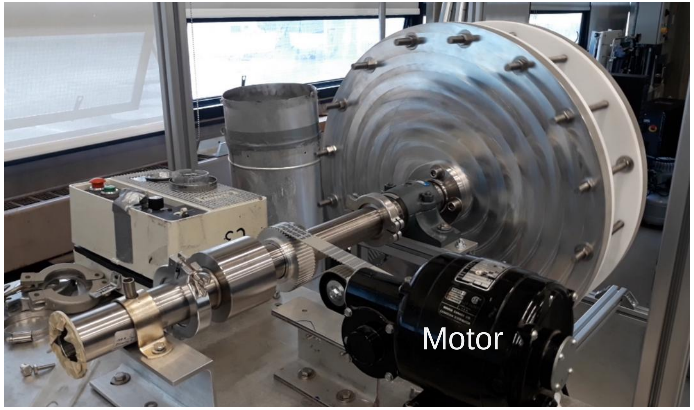
EDM cell: Insulator coating

- Coating machine capable of coating substrates up to 600mm diameter and 1000mm length (insulator rings, UCN guides)
- Ready for coating tests with dPS (at RT)
- Upgrade with thermal enclosure (up to 150 C) planned:
  - dPE coatings
  - vacuum baking to reduce outgassing









F. Kuchler, I. Nikonov, D. Rompen

EDM cell: Status and plans

Electrodes:

- FEMM simulations ongoing to determine details of ground and central electrodes (based on statistics optimization and systematics)
- UCN simulations for various electrode materials/coatings underway
- Qualification of candidate materials, eg NiP

DLC seems beneficial over NiP
Fused quartz suitable for phased approach?

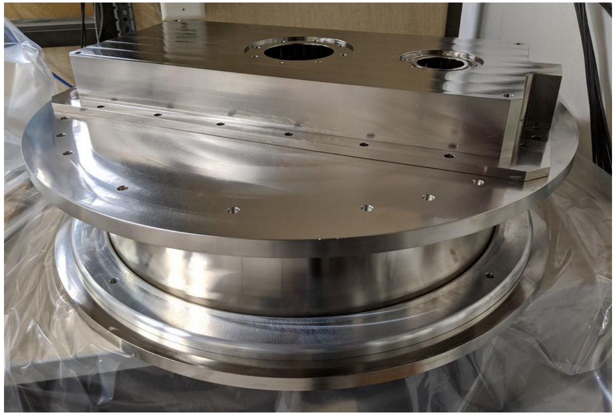
Insulator:

- UCN simulations for various insulator materials/coatings
- Coating facility for (large) insulator rings ready
- Plan to coat small sized rings (ID 101mm) of glass, PEEK, Rexolite, quartz
  - Tests in high-voltage setup (-100 kV)
  - Monitoring leakage current with prototype PCB

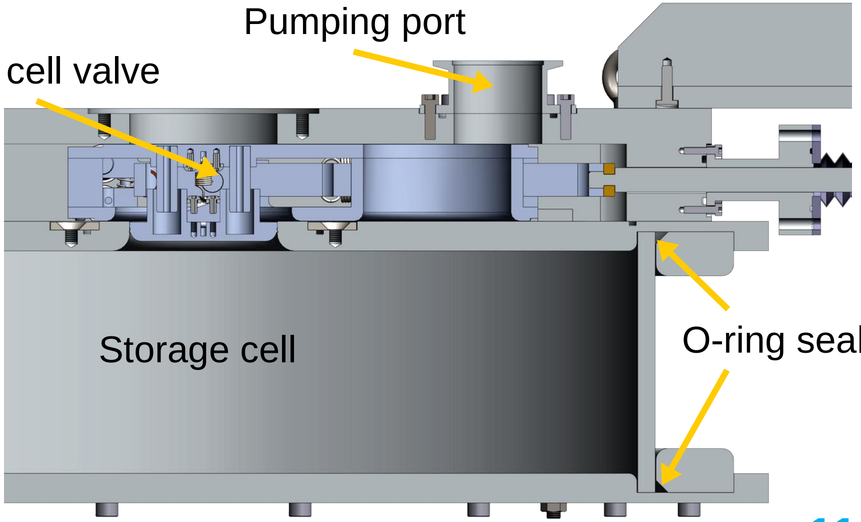
EDM cell: Status and plans

Prototype development:

- UCN gate-type valve ready for assembly and testing (after small modifications)
- Full sized (500mm) EDM storage cell prototype built
  - Radial seal leak testing under way
  - UCN storage test of NiP coated aluminum to compare vs dPS on Rexolite (possible as early as spring 2020)



EDM storage cell prototype



Considerations:

- Simulations on v x E systematics
- Evaluate option of horizontally stacked cells (at this stage only requires foreseeing additional MSR holes)

R. Picker, F. Kuchler, S. Vanbergen, SciTech Engineer

High voltage system: Baseline concept

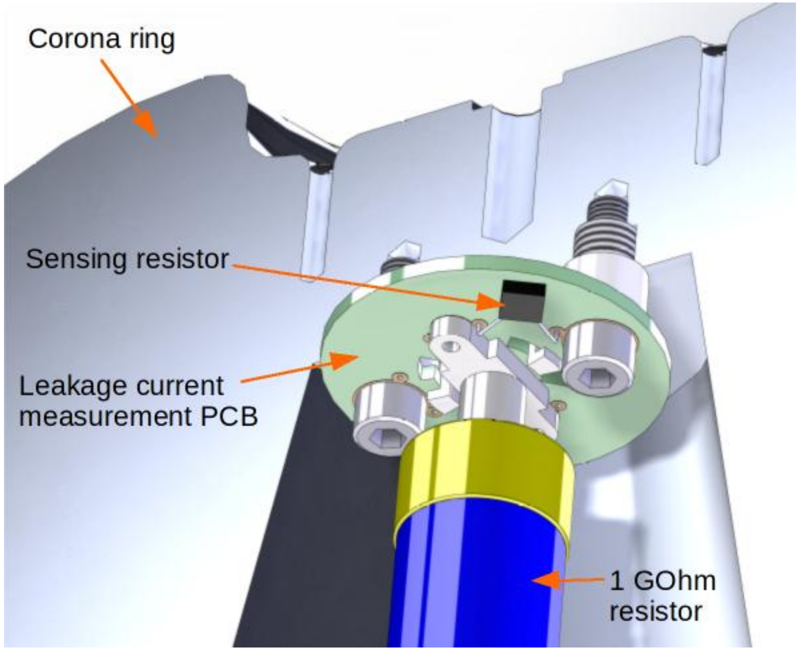
Voltage goal is 200 kV over 160mm → electric field >12 kV/cm

HV supply

- Available up to 300kV for high reproducibility and stability
  e.g. Heinzinger PNChp series, FUG, Spellman, Glassman
- Polarity switching using:
  - HV relays and two supplies (eg Heinzinger)
  - Motor-driven dial (eg FUG)

Leakage current monitor

- For ground and HV side
- 100 pA sensitivity, kHz bandwidth
- Optically switchable gain
- Power over fibers



Leakage current monitor concept design

R. Picker, F. Kuchler, SciTech electrical engineer

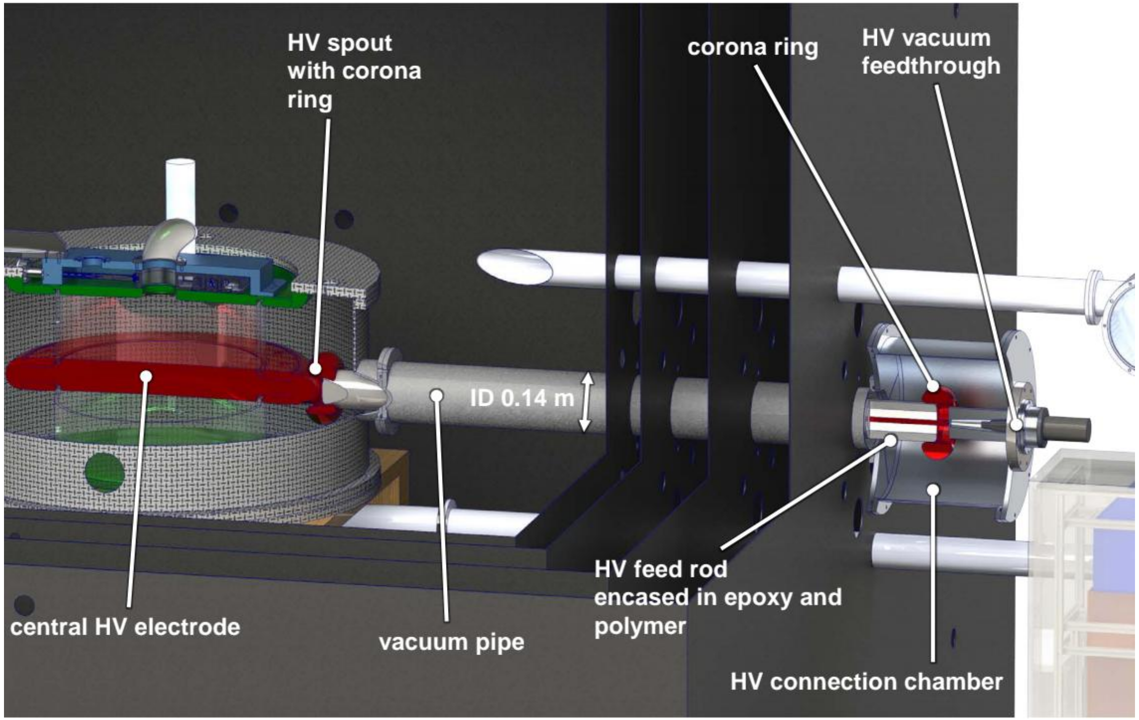
High voltage vacuum feed conceptual design

Commercial non-magnetic HV feed-through

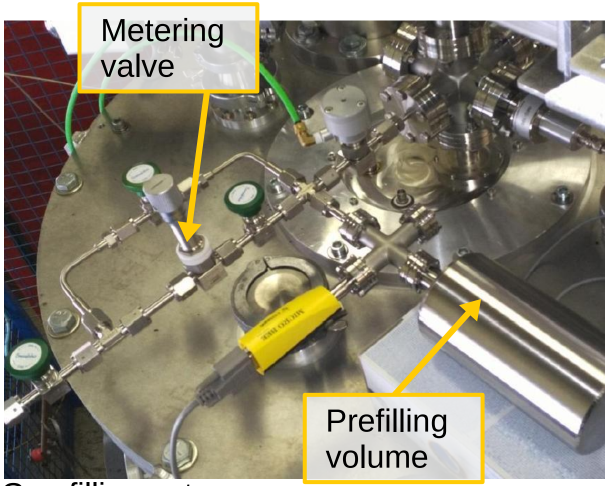
- Availability and cost?
- Non-magnetic cable and connector?
- In contact with manufacturers (Dielectric Sciences, MPF)

Standard (magnetic) feed-through

- Connection chamber outside MSR
- 14cm ID feed: epoxy, PE and vacuum layers
- 4cm ID feed: PE insulator, gap-less design



High voltage: Test setup and breakdown measurements



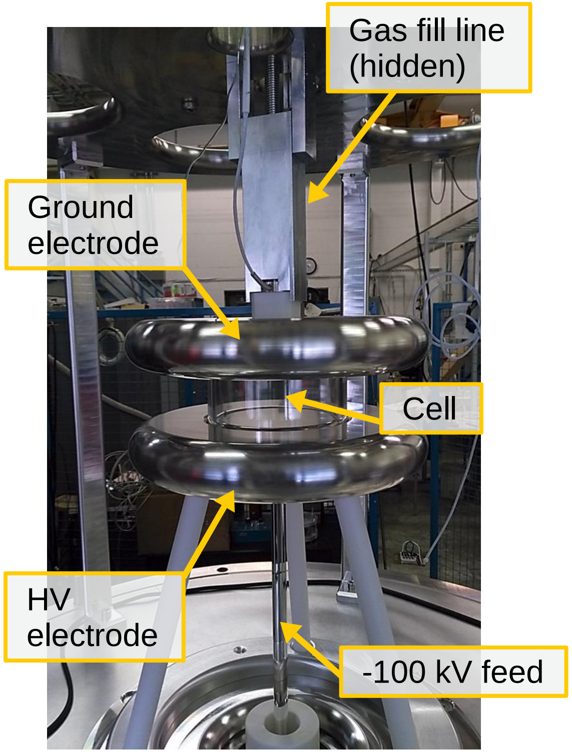
Gas filling setup

- Determine xenon breakdown strength vs pressure for use as additional comagnetometer species
- Insulator material/coating high-voltage tests
  (test cell size OD 114mm, almost full size prototype possible)

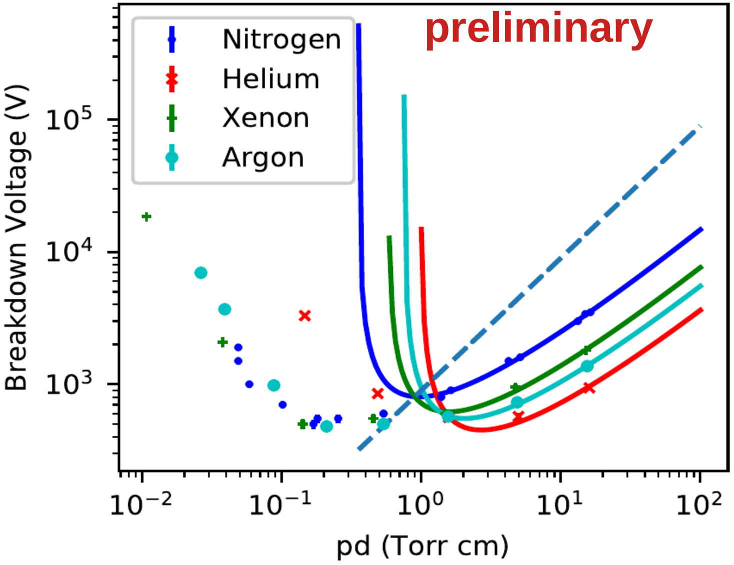
- Uncertainties in pressure measurement
  - better pressure gauges installed
  - pressure measurement calibration

- Monitor gas composition in cell

- Lower pressure range <1x10^{-2} mbar currently limited by outgassing
  - pressure rise during HV ramp



Gas breakdown results for electrode distance 6cm



F. Kuchler

High voltage system: Status and plans

- HV feed
  - Finalize conceptual design → defines size of central MSR penetration
  - Evaluate commercially available options for non-magnetic HV feed and HV cable/conncetor
  - Prototype HV feed can be tested in HV test setup (-100 kV)

- Manufacture prototype leakage current monitor
  - Test and develop DAQ on ground side of HV test setup
  - HV side testing with new corona ring

- Procurement of HV power supply of at least 200 kV

Summary

Concept designs

- Vacuum chamber, EDM cell, HV feed options, leakage current monitor

Accomplishments

- UCN cell valve prototype designed and manufactured
- Polymer coating machine built
- Prototype “cell” ready for testing UCN storage lifetime
- First HV breakdown measurements with various gases in small test cell

Feedback requests

- Commercial non-magnetic HV feed and cable
- Experience with candidate materials for insulator, vacuum chamber, coatings

Thank you!

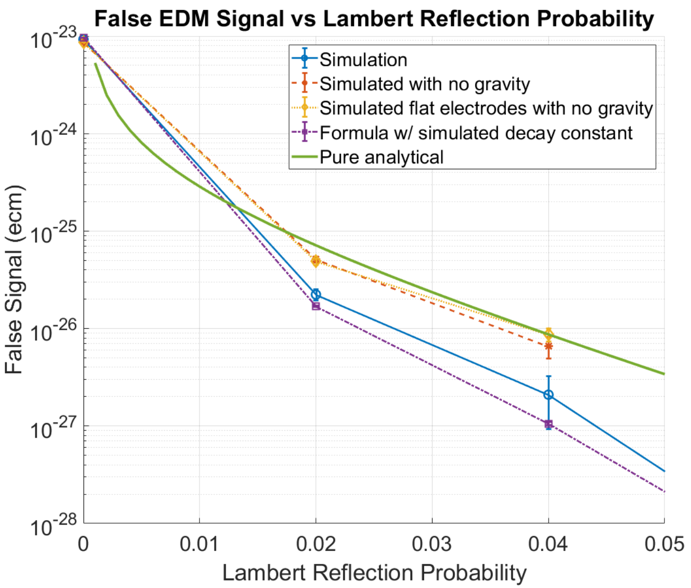
Backup slides

EDM cell height and material simulation results

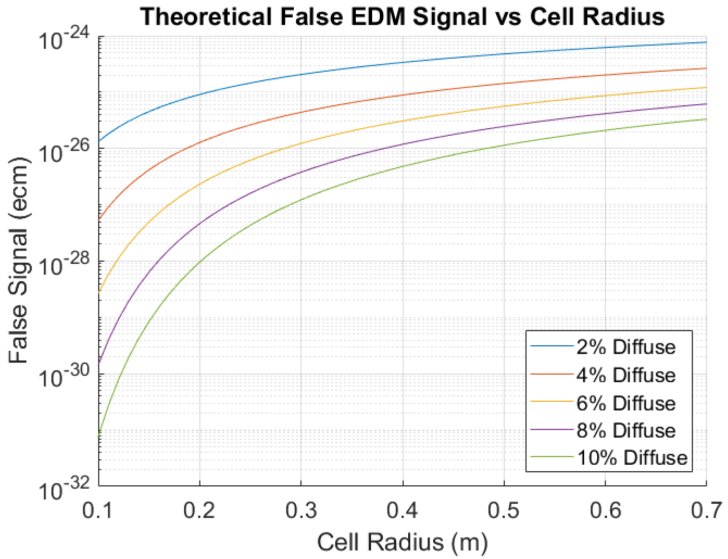
Cell	E Field (kV/cm)	Days	t_{Ramsey} (s)	N_{coll}
cell160_NiP_dPS	10	**541 ± 6**	141	2501369
cell160_DLC_dPS	10	**265 ± 3**	171	3985394
cell160_NiP_dPS	12	**372 ± 4**	140	2508011
cell160_DLC_dPS	12	**184 ± 2**	167	4192824
cell130_NiP_dPS	14.8	**310 ± 4**	130	2040657
cell130_DLC_dPS	14.8	**136 ± 2**	167	3674857
cell160_NiP_dPS	20	**134 ± 2**	140	2471084
cell160_DLC_dPS	20	**66 ± 1**	166	4182288

EDM cell: v x E systematics

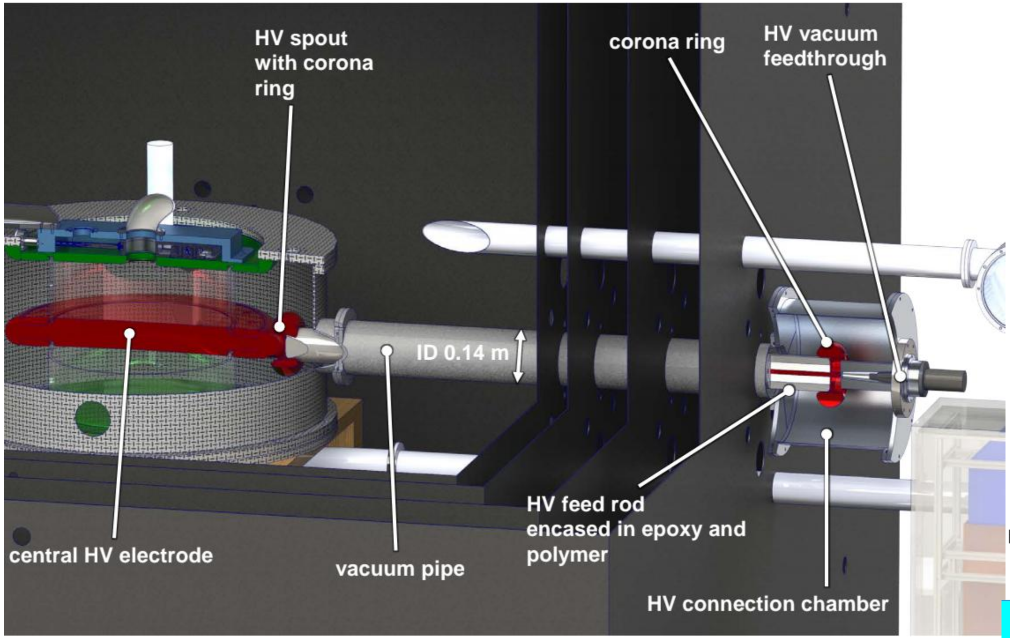
- Significant systematic contribution caused by inhomogeneity of electric field in combination with possible uniform motion of the neutrons
- Contributed 0.78×10^{-27} ecm uncertainty previously, goal of < 0.40×10^{-27} in new measurement
- PENTrack simulations to study magnitude of these effects and mitigation
- Largest contribution from rotational motion of neutrons



- Rotational effect depends on:
  - Radial inhomogeneity of electric field
  - Decay time of rotational motion due to randomizing Lambert diffuse reflections
  - Timing of measurement sequence (a short wait before starting precession significantly reduces effect)
- Need low inhomogeneity, rough cell surface to increase decay rate
- Larger cell predicted to increase decay time and make systematics worse, so favors not making cell too large



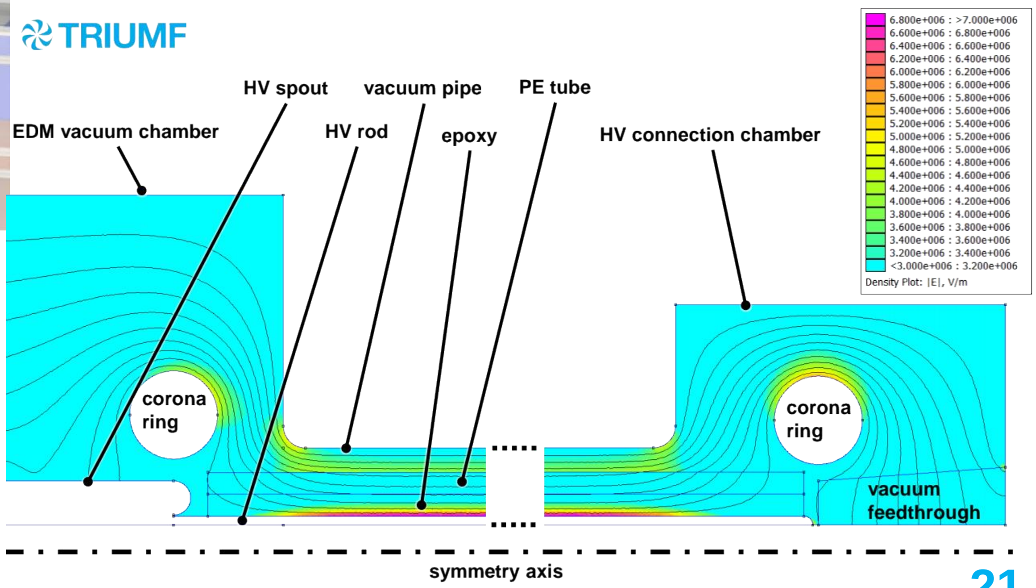
High voltage vacuum feed conceptual design



- Commercial non-magnetic feed-through available?
- Standard feed-through into connection chamber outside MSR
  - 14cm ID feed with epoxy, PE and vacuum layers
  - Corona rings to shield connections
  - Electric field strength <50kV/cm in vacuum

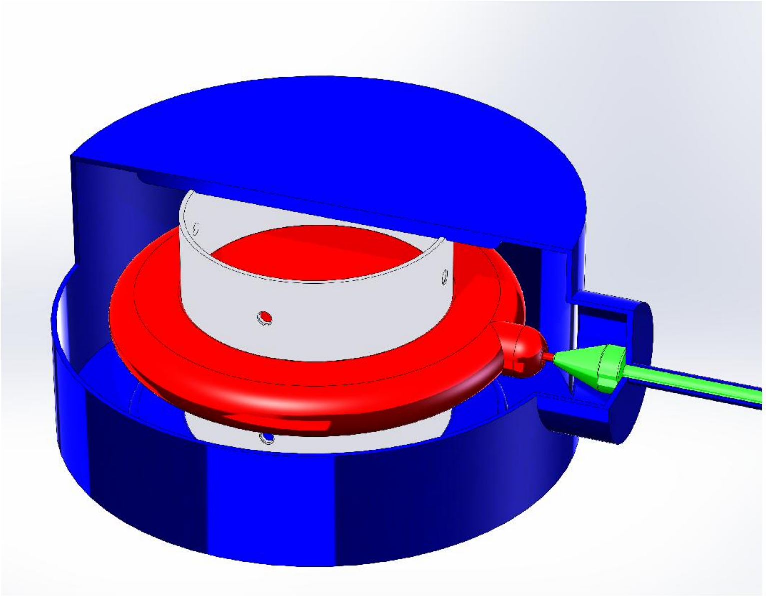
- Provides vacuum pumping line

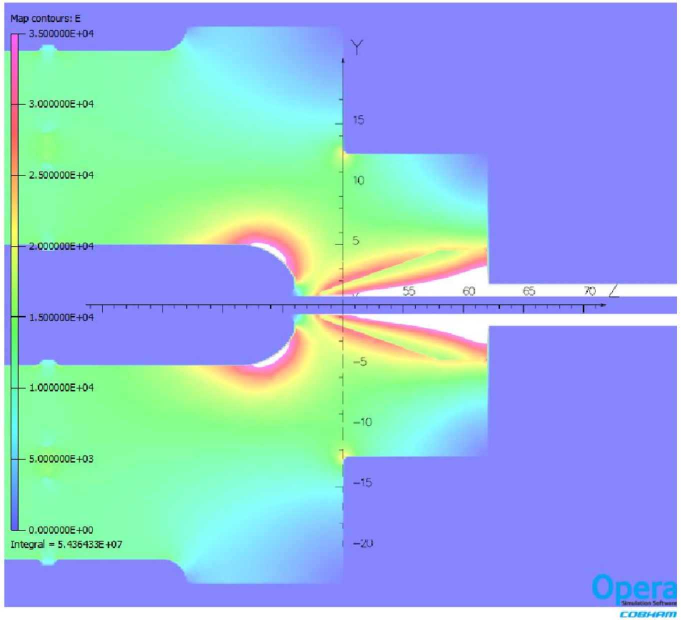
BUT: Large penetration through MSR



R. Picker

High voltage gap-less feed conceptual design





40mm OD ground sleeve

PE insulator with cone covering high electric field regions

15mm rod at 200 kV

Reduces the MSR penetration to <50mm

HV rod/tube with plastics insulator (e.g. HDPE) filling a ground sleeve tube

Requires gap-less manufacturing of a 1-1.5m long feed

Shrink fitting has bee successfully used: C. Cantini, JINST **12** P03021 (20170

Electric field strength <50kV/cm in vacuum

F. Kuchler