TRIUMF

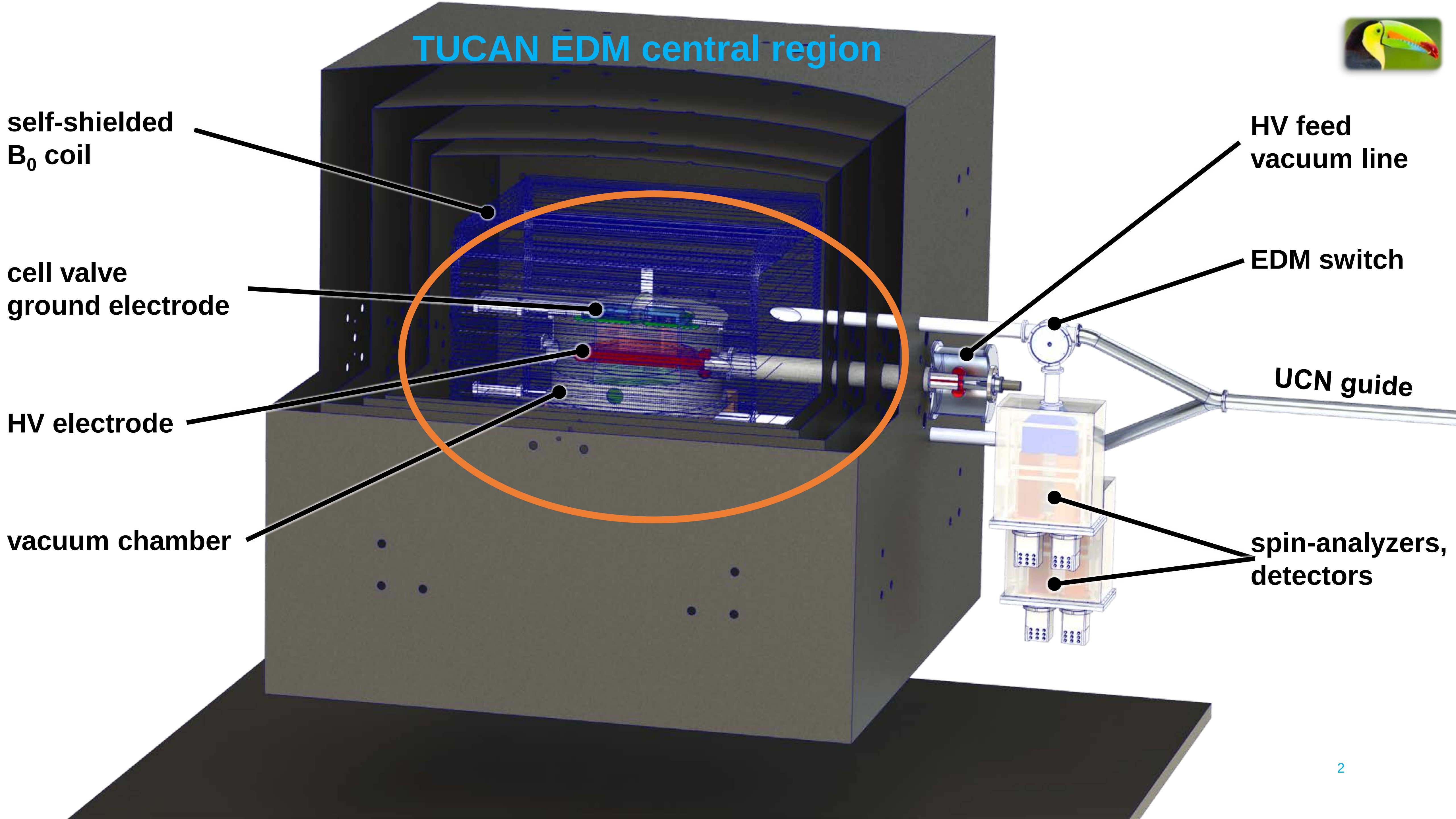
TUCAN EDM central region

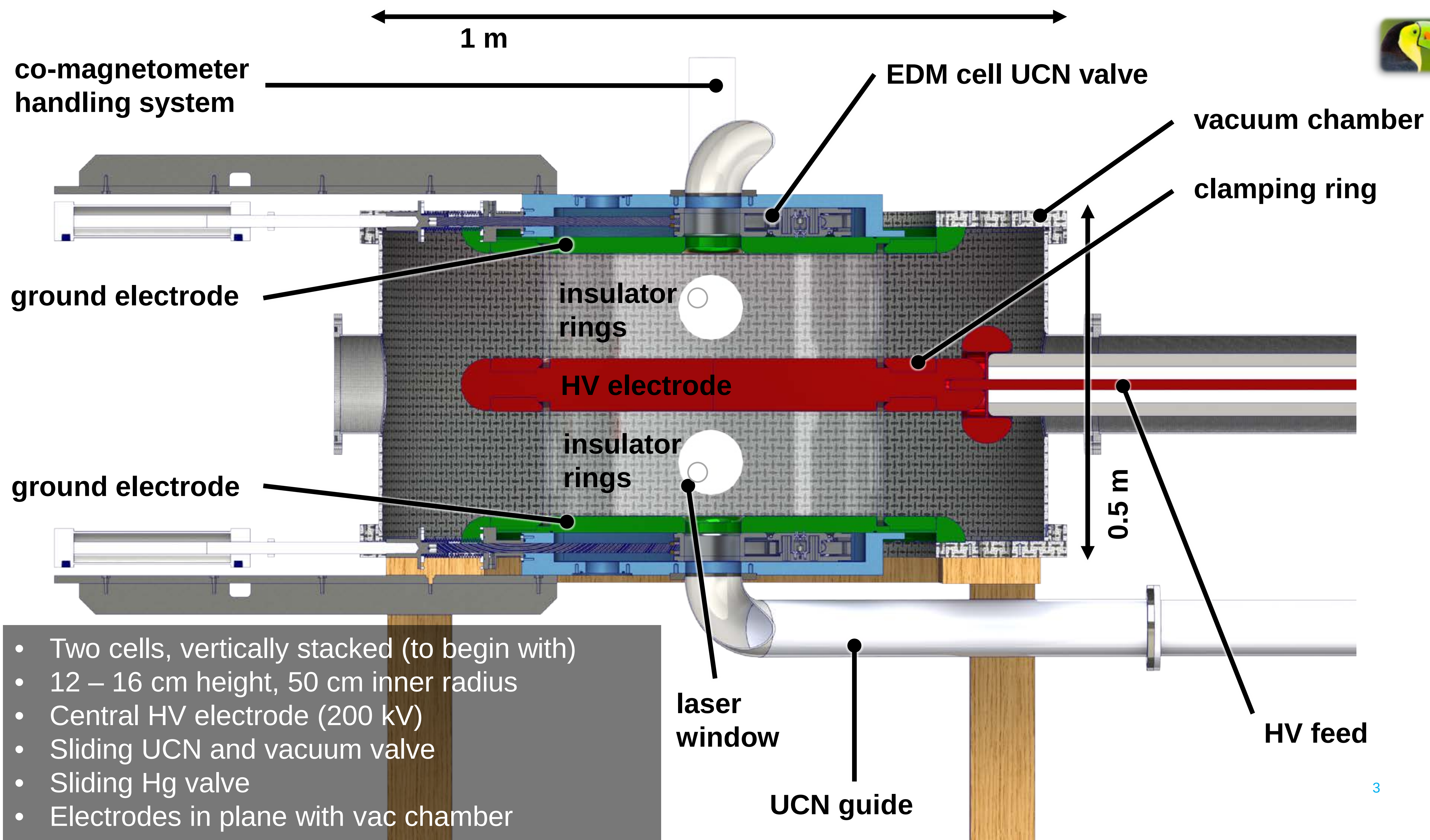
R. Picker for the TUCAN collaboration

Content:

- TUCAN nEDM central region
- Eddy currents
- Superfluid helium UCN source parameters

TUCAN EDM central region





- Two cells, vertically stacked (to begin with)
- 12 – 16 cm height, 50 cm inner radius
- Central HV electrode (200 kV)
- Sliding UCN and vacuum valve
- Sliding Hg valve
- Electrodes in plane with vac chamber

A heads up…

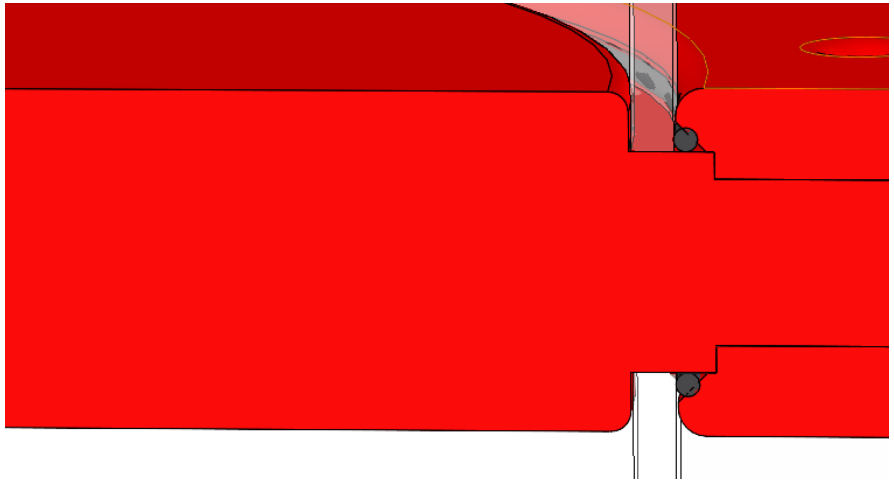
We have solved very little at this point…

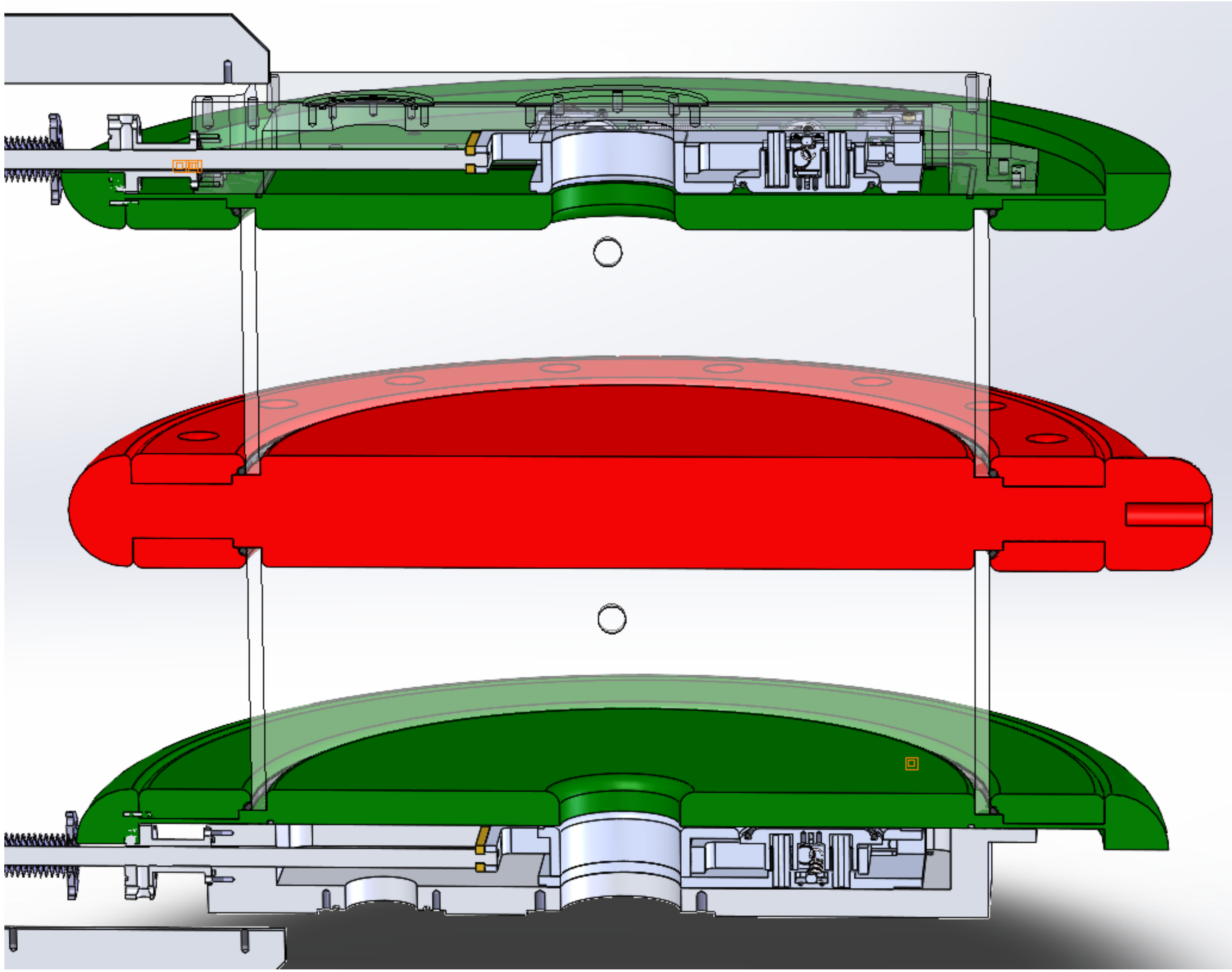
… but we have very promising concepts and/or prototypes for most items.

The cells

- radial seal to avoid large axial forces required to press O ring in axial direction
- O-ring clamping feature in electrodes

- Materials:
  - electrodes Al with NiP or DLC coating (see Russel Mammei's presentation)
  - insulator dPS, but SiO does not reduce EDM sensitivity a lot





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EDM cells

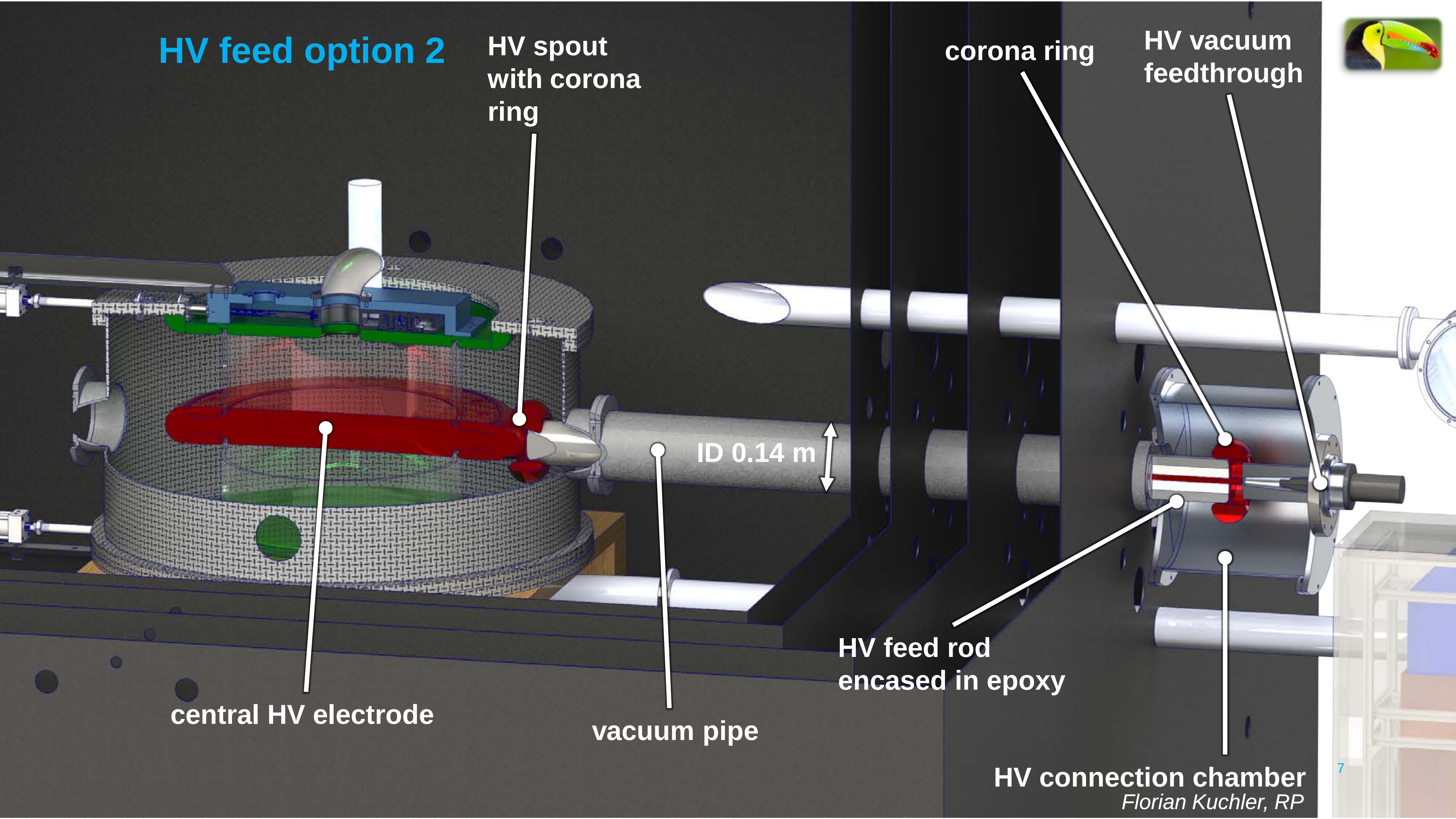
Common HV design of electrodes to most recent EDM experiments:

- Flat electrodes, rounded outside
- Trenches for insulator

HV feed options

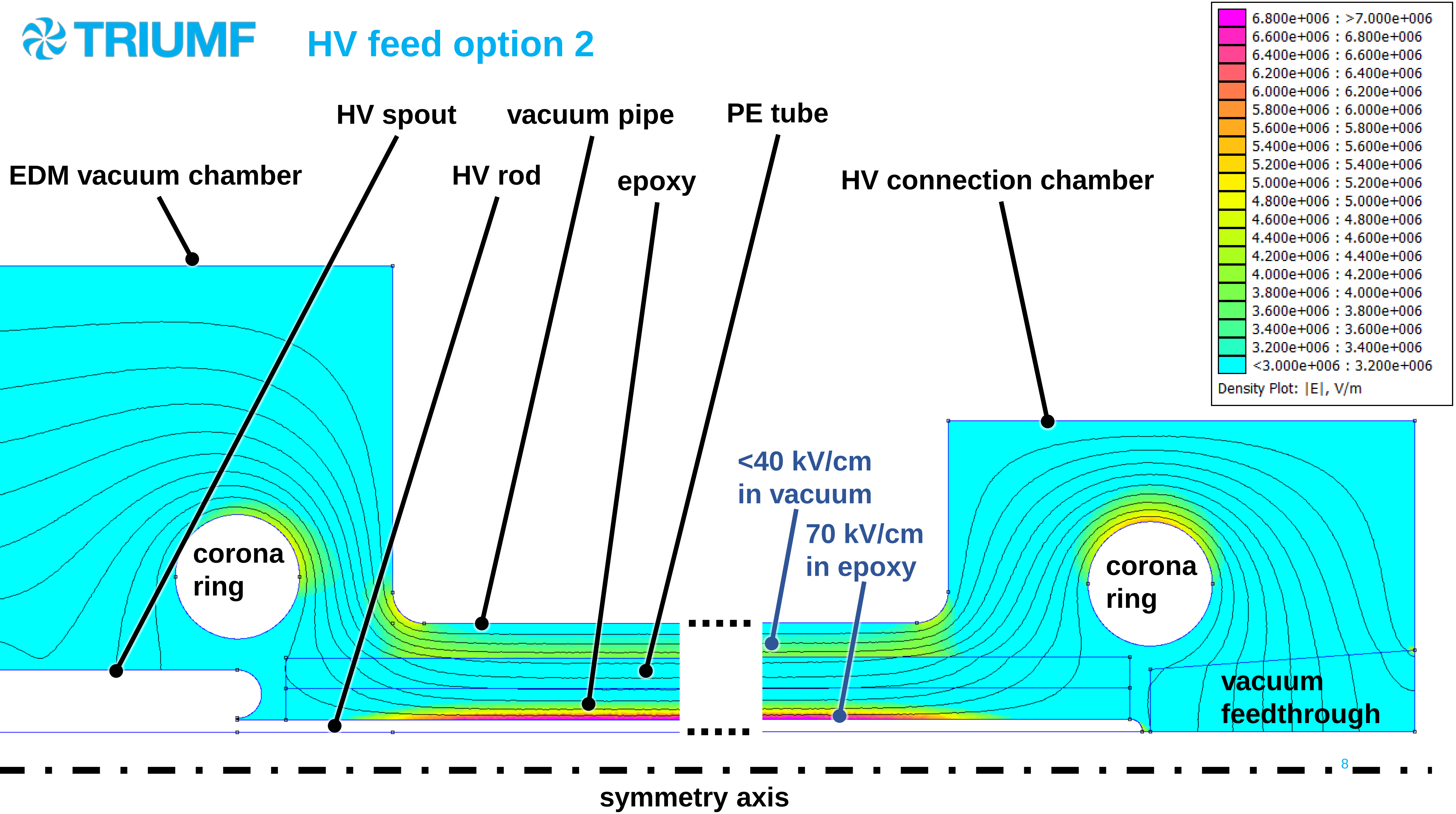
1. cable penetrates MSR, vacuum feedthrough inside MSR
   - vacuum feedthrough and cable need to be non-magnetic
   - could not find manufacturer
   - discussions with Florian Piegsa
2. vacuum tube and feed inside vacuum penetrate MSR
   - vacuum feedthrough can be magnetic, off the shelf
   - MSR hole size required: 150 mm
3. combine vacuum feedthrough and pin
   - Basically self built vacuum penetration
   - Cable does not go into MSR

HV feed option 2



Florian Kuchler, RP

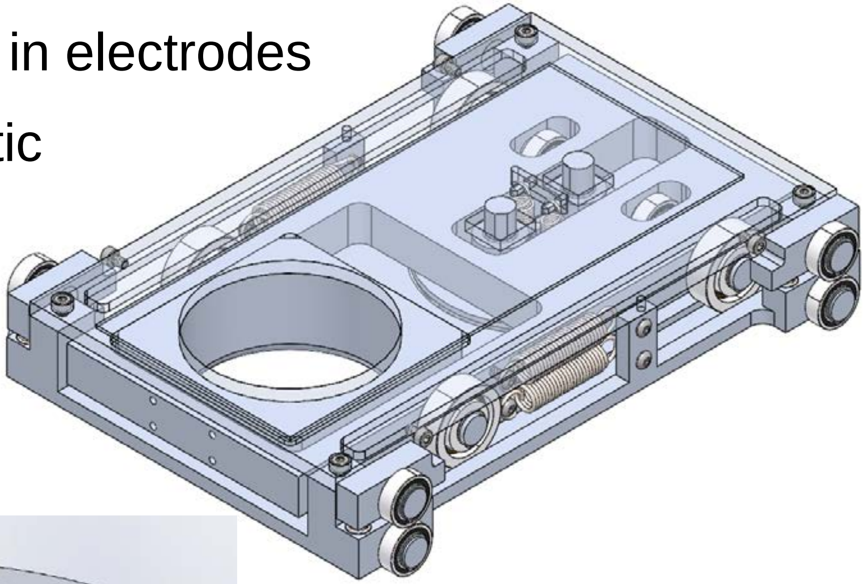
HV feed option 2

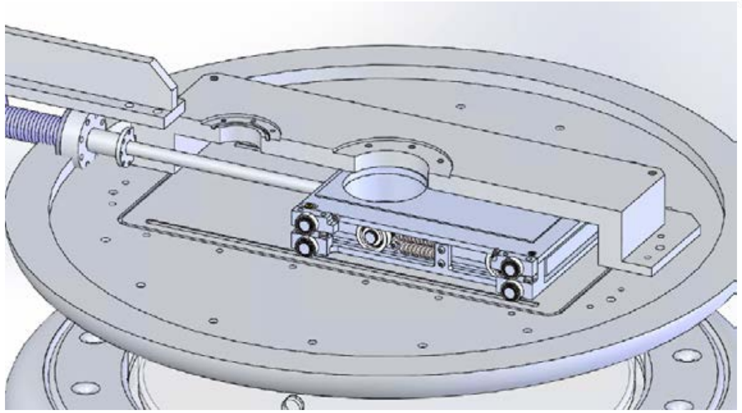


The EDM cell UCN valve

Requirements

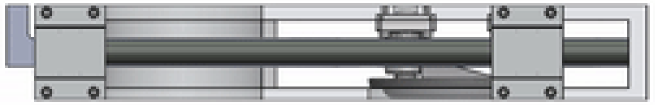
- vacuum tight
- high transmission, long storage lifetime
- small cavity in electrodes
- non-magnetic





Our prototype

- sliding valve derived from VAT valve design
- protection ring slides in place
- inclined plane and roller to push plug
- springs to retain plug
- plug extends into EDM cell cavity
- pneumatic actuation
- Al coated with NiP (or DLC)
- CuBe springs, ceramic bearings



early animation of functionality

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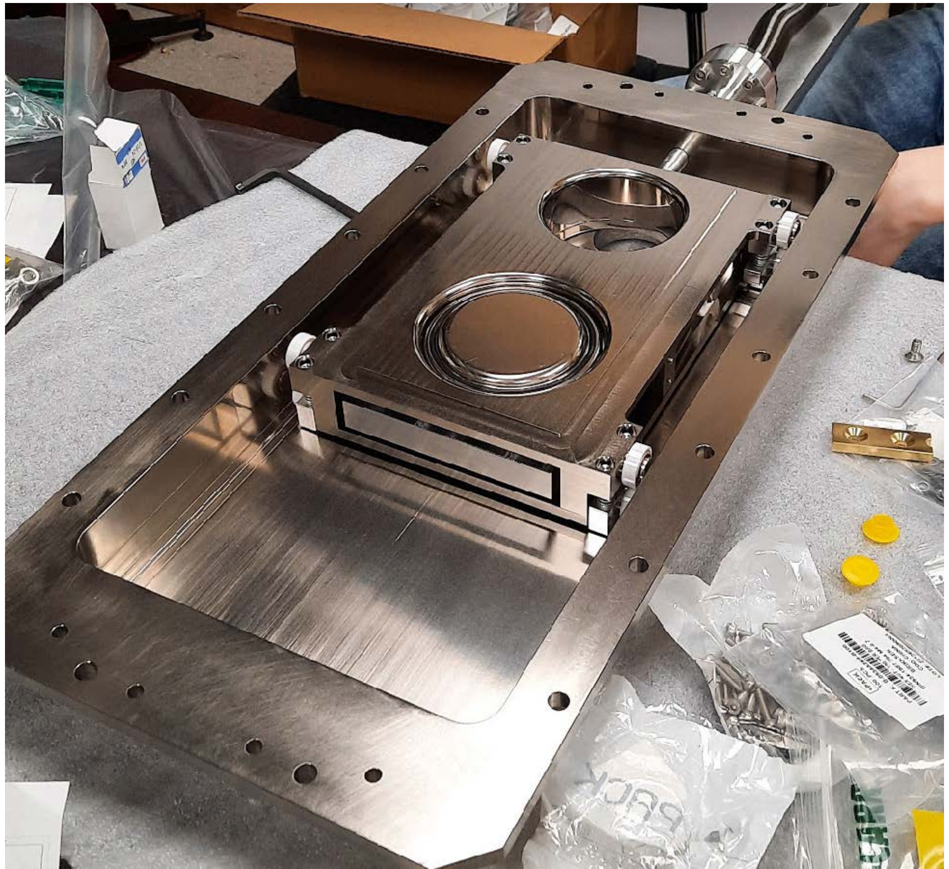
Pictures and status of valve end EDM cell prototype

- Prototype EDM cell and valve built end of 2019
- Sidelined in first half of 2020 due to source development
- Currently debugging, mechanical tests
- Vacuum tests look good so far
- UCN storage experiments possible as soon as UCN available again at TRIUMF



Sean Vanbergen

EDM central region and the B_1 pulse

Pi/2 spin-flip pulses

- AC magnetic field with f = 30 Hz for neutrons, 8 Hz for Hg at B_0= 1 µT
- Induces Eddy currents in conducting materials
- These Eddy currents can create inhomogeneity in the field and cause phase lag.

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$$

Skin depth δ, permeability μ, conductivity σ
For Al and 30 Hz, δ=1.8 cm

Components affected

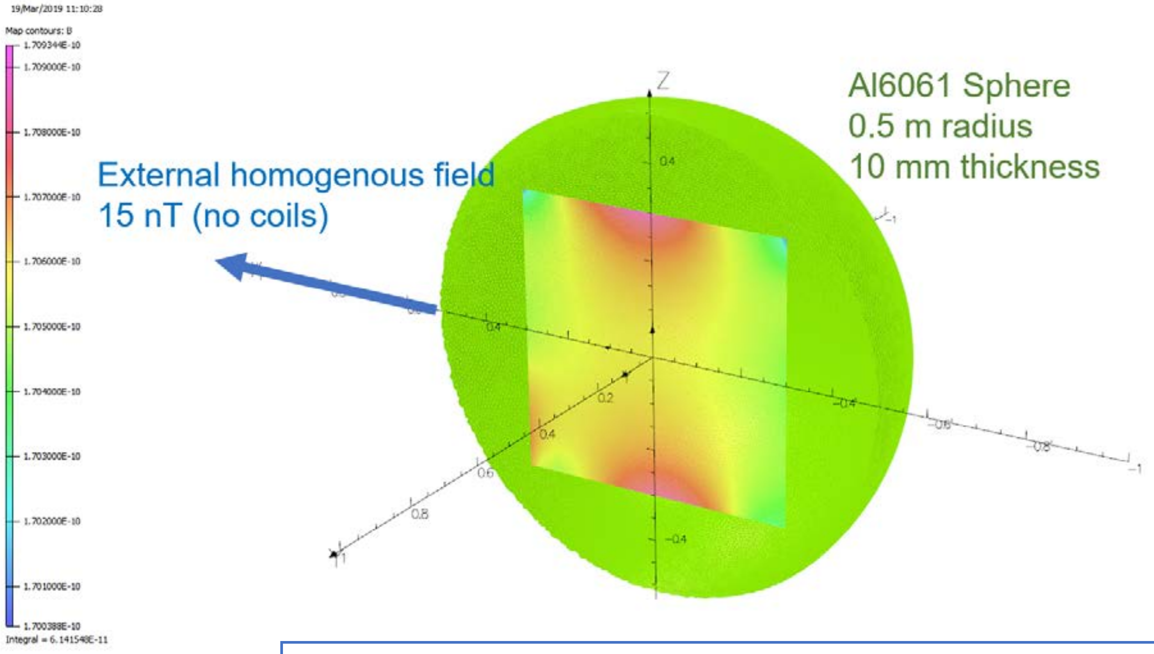
If not for the Eddy currents (and Johnson noise when pushing below 10^{-27} ecm) we would build these components from non-magnetic metals

- EDM Electrodes
- Vacuum chamber and flanges
- Valves, guides

We need to assess the effect of Eddy currents during the spin-flip pulse on EDM sensitivity.

Very simple example: spherical cow

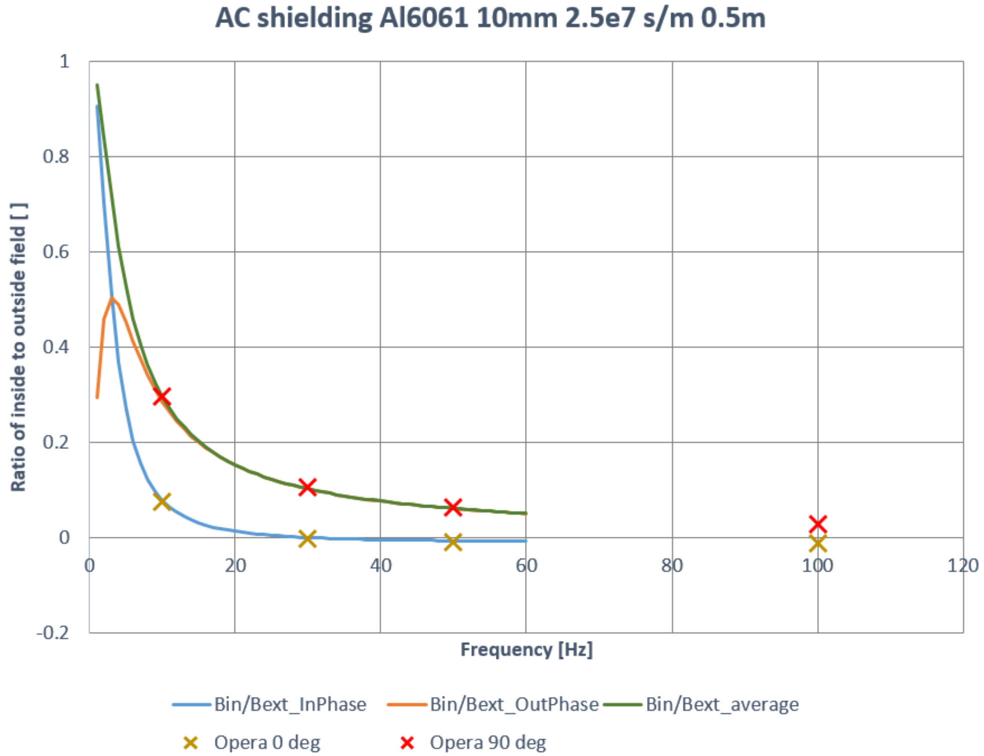
- 15 nT external field in x direction
  - Necessary for a 2 s neutron spin flip at 30 Hz
- Spherical Al shell of 10 mm thickness



Main takeaway message:

- At 30 Hz field attenuated by one order of magnitude
- Phase angle close to 90 degrees, so field is a quarter period behind B_1 coils

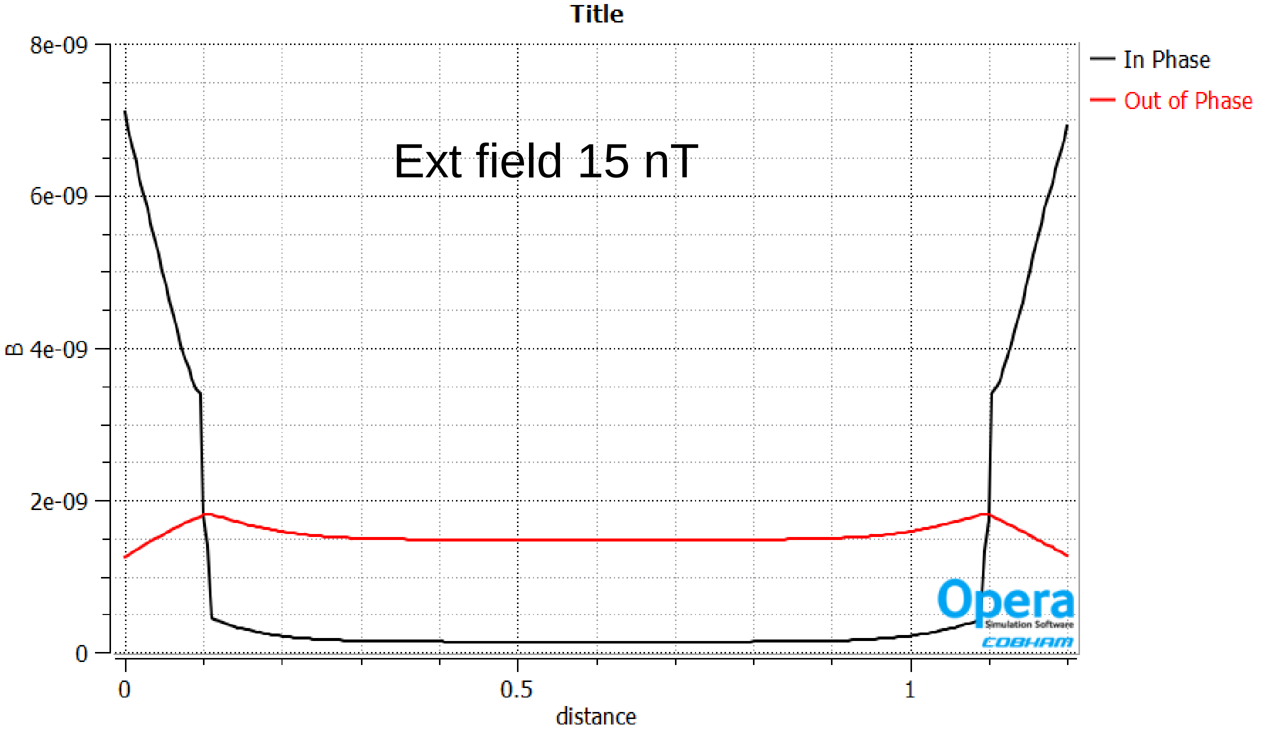
- Magnetic field in center (analytic) as a function of frequency



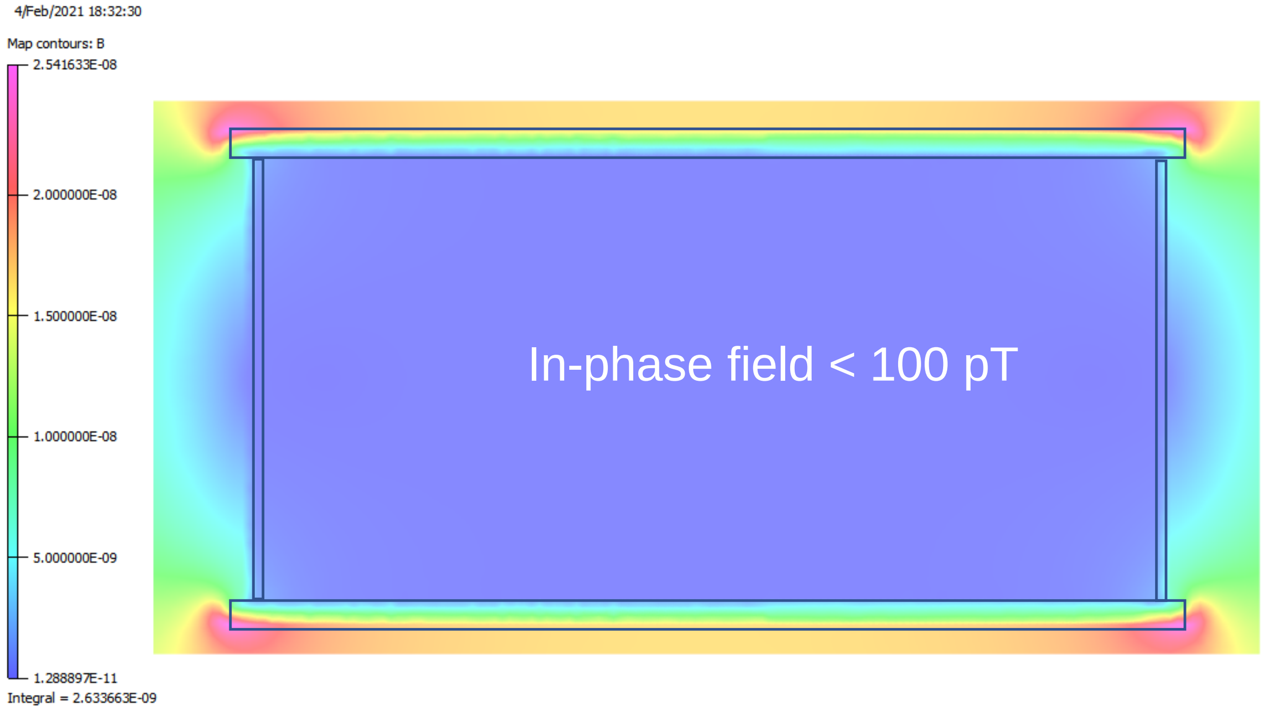
- Opera FEM doublecheck agrees well with analytical data.

TRIUMF Cylindrical EDM vacuum chamber

- 1 m ID, 0.46 m height
- Flanges 2.54 cm
- Cylindrical wall thickness 10 mm
- 30 Hz



Horizontal straight line plot through center



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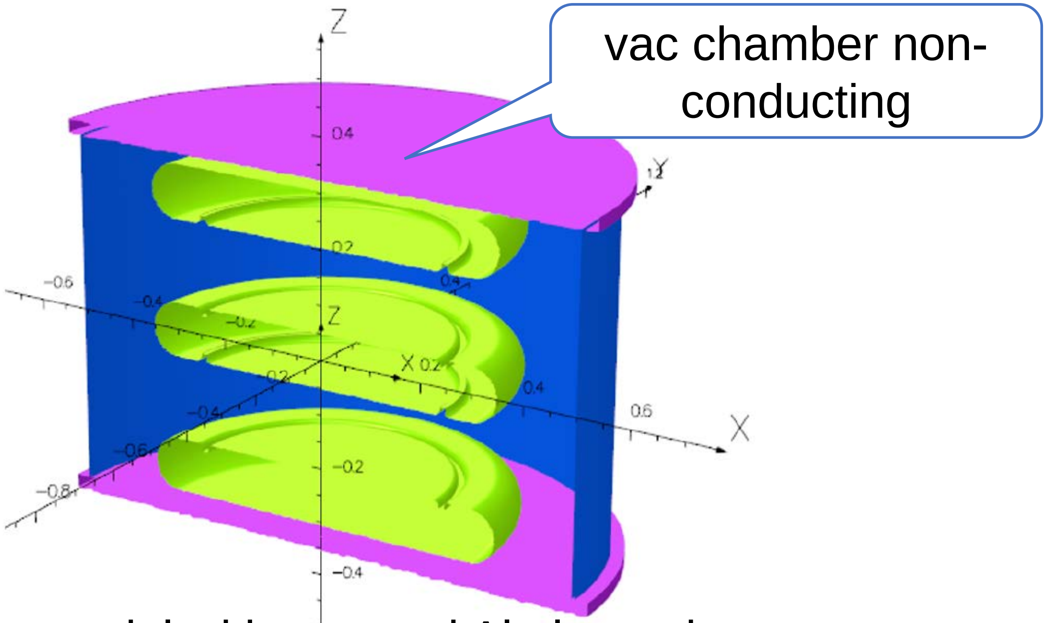
EDM electrodes and the B_1 pulse

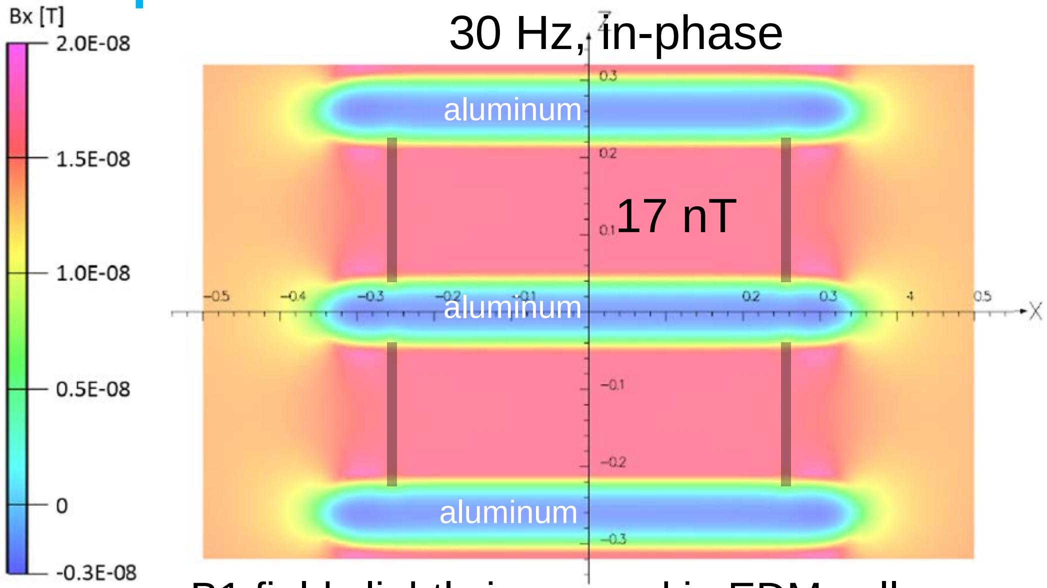
Investigating effect on EDM sensitivity

1. Opera simulation to calculate field and export 3D field maps
2. Run PENTrack spin tracking simulations of Ramsey cycle (BMT eq. $\dot{S} = \left(-\frac{2\mu}{\gamma\hbar}B' + \omega_T\right) \times S$)
3. Determine length of B_1 pulse
4. Determine visibility α for different materials

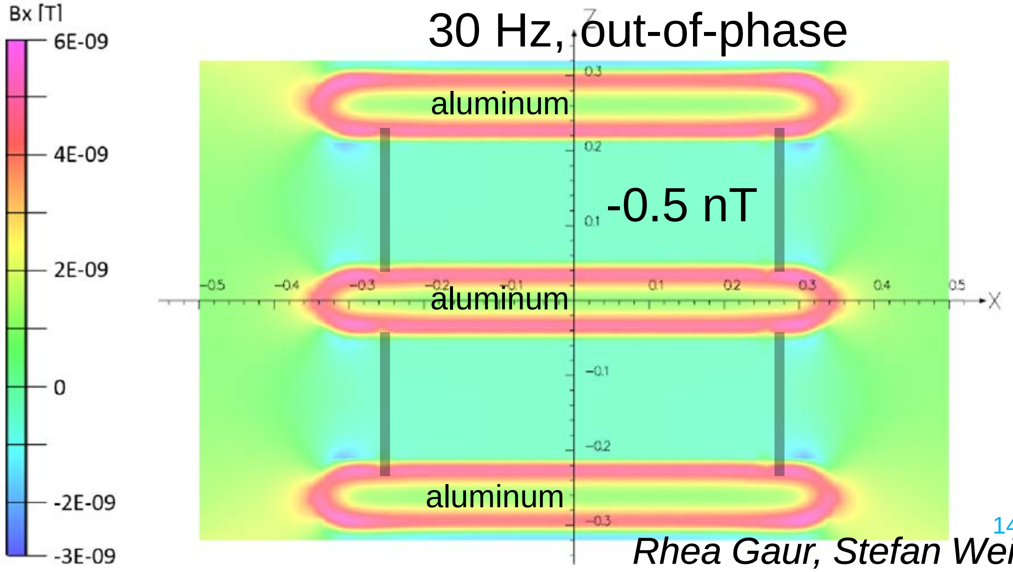


Opera model with grooved Al electrodes

1. Opera results



B1 field slightly increased in EDM cells.



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EDM electrodes and the B_1 pulse

Wiggles from linear oscillating field (vs rotating)

3. Determine B_1 pulse length

- Larmor and B_1 frequency are known at 29.16 Hz (B_0=1 µT)
- B_1 field from Opera simulations
- Change B_1 pulse duration for optimal visibility α

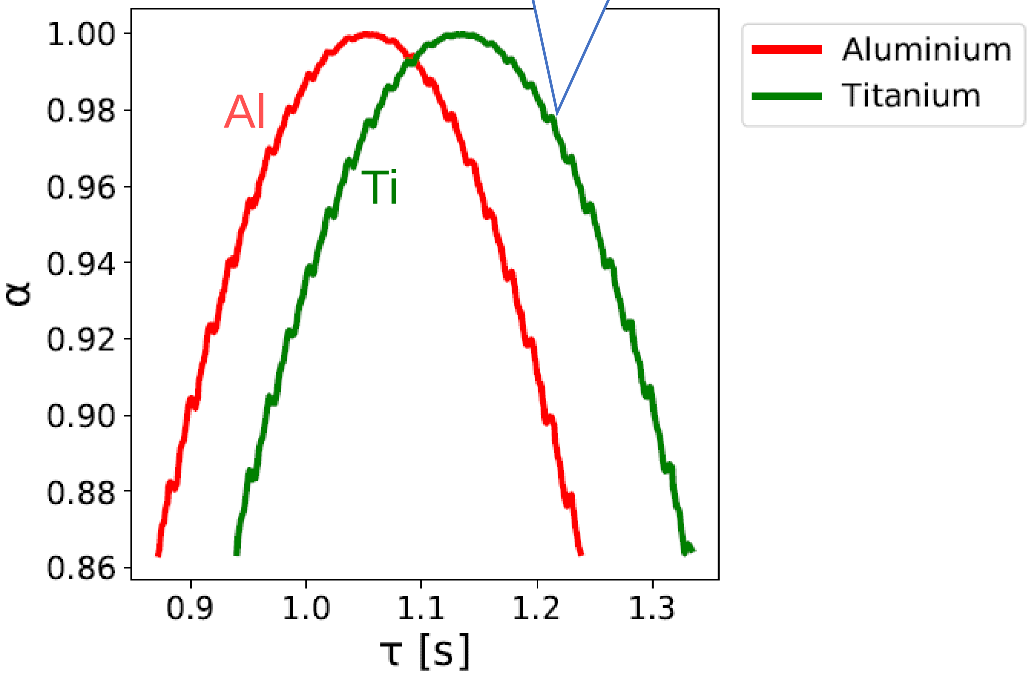


Figure 3.22: Visibility of the aluminium and titanium model as a function of τ. A frequency of 29.1646931 Hz was used.

100 particles simulated per data point

Rhea Gaur, Stefan Weitz, RP

EDM electrodes and the B_1 pulse

4. Determine effect on visibility

This is using 4 points on Ramsey curve and fitting of central fringe

- Titanium shows no visibility degradation compared to non-conducting electrodes
- Aluminum electrodes decrease visibility by around 2%

- Caveat: we see some effect of resolution of the B field table, which we have to investigate further.

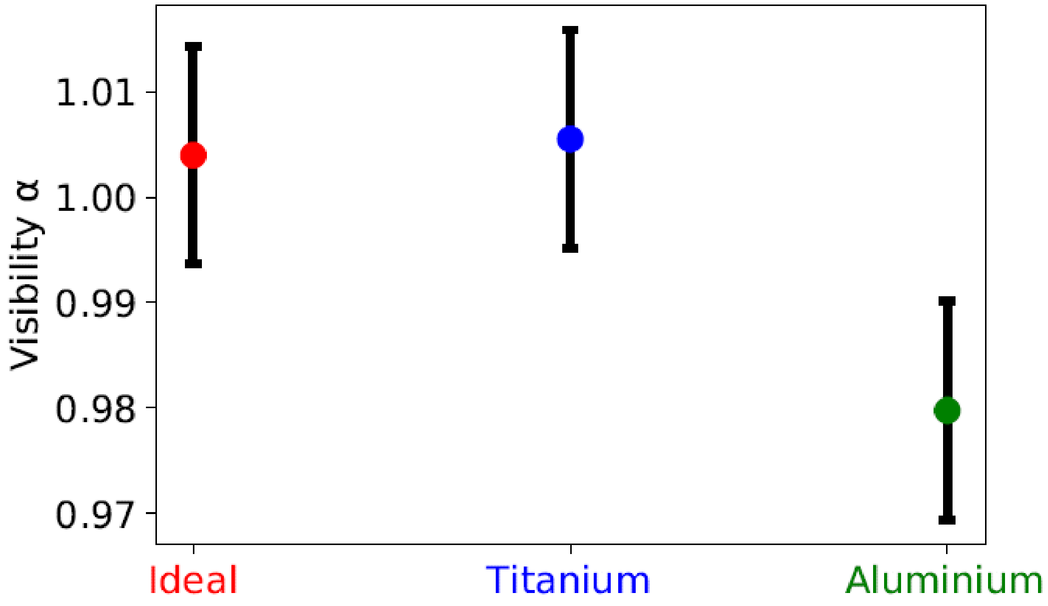
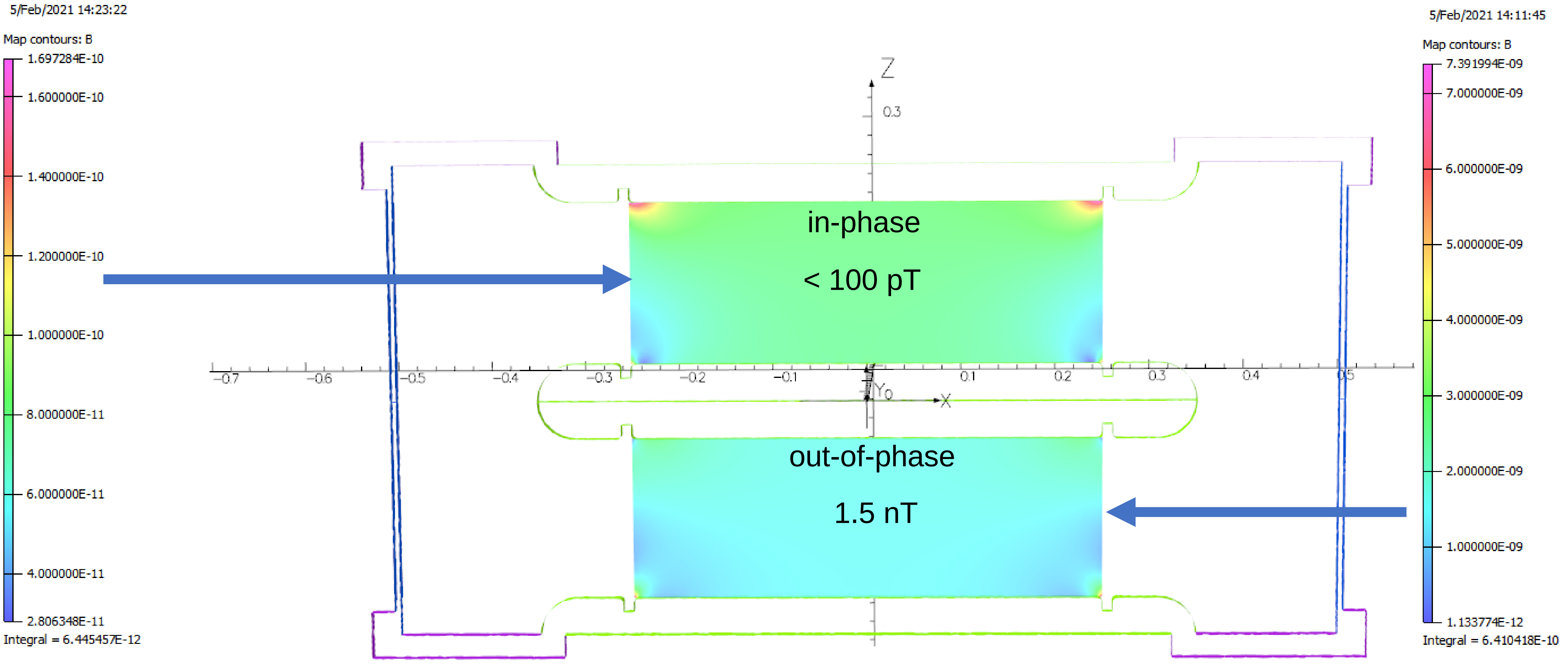


Figure 3.27: Obtained visibility α and its uncertainty of the ideal, titanium and aluminium model. Here T equals 10 s and τ equals the respective value of Table 6.

10^5 particles simulated per data point

Next step: vacuum chamber and electrodes

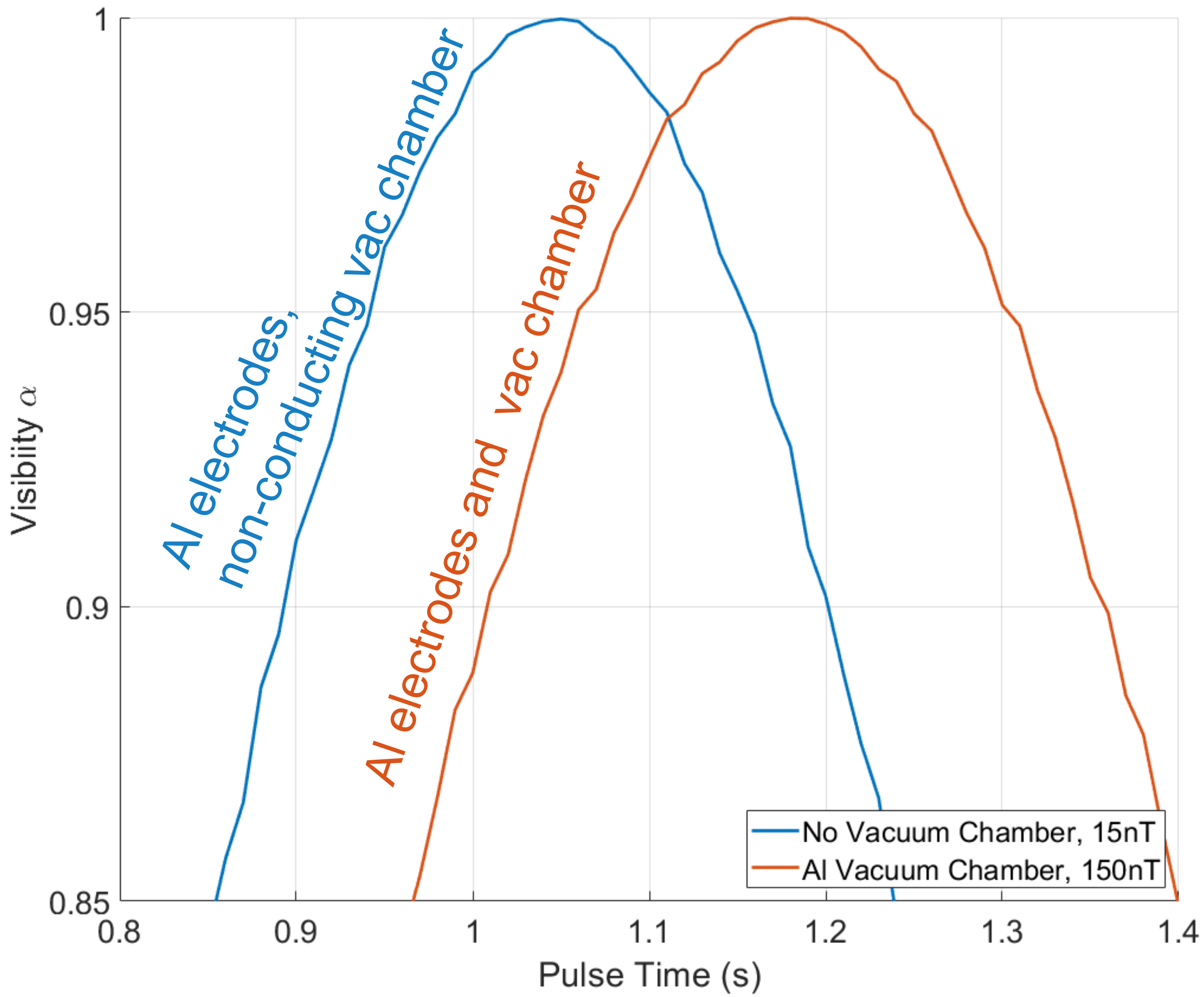
First results with Al vacuum chamber and electrode



Sean Vanbergen, RP

Next step: vacuum chamber and electrodes

First results with Al vacuum chamber and electrode



- Visibility scan looks promising
- External field needs to be 10 x times higher than without vacuum chamber

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Eddy current summary

- We are contemplating to start the EDM with Al electrodes and vacuum chamber
- B_1 coils can be built to provide an order of magnitude higher current

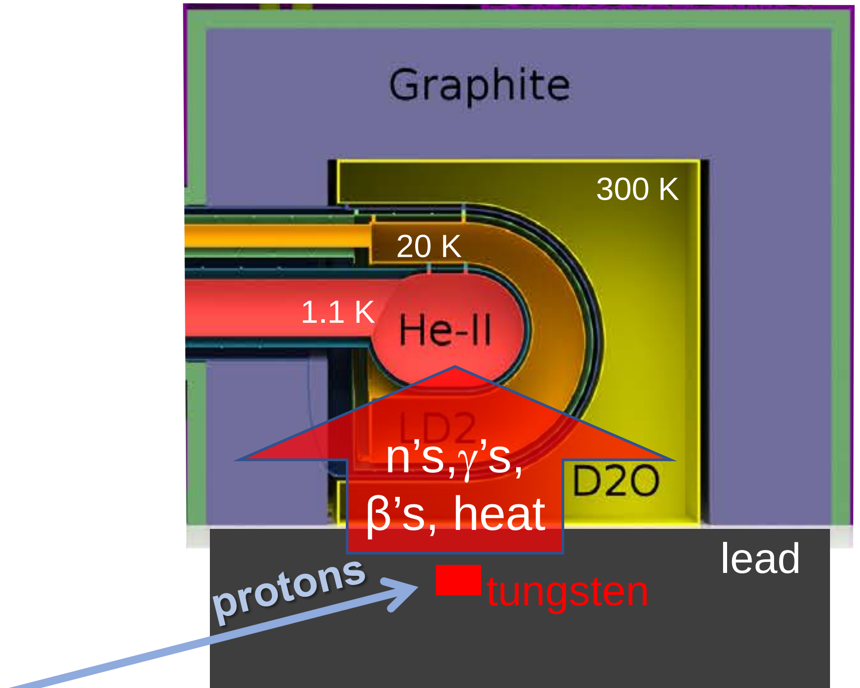
- Next steps:
  - Include more detailed geometry of EDM cell valve and vacuum chamber
  - Perform more field table resolution sensitivity studies

Superfluid helium source performance

- A few thoughts about performance parameters of superfluid helium sources

Superfluid helium reactor or spallation UCN source main performance parameters (mainly cryo and rad)

(Disclaimer: not directly applicable to CN beam to UCN sources)



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Superfluid helium reactor or spallation UCN source main performance parameters (mainly cryo and rad)

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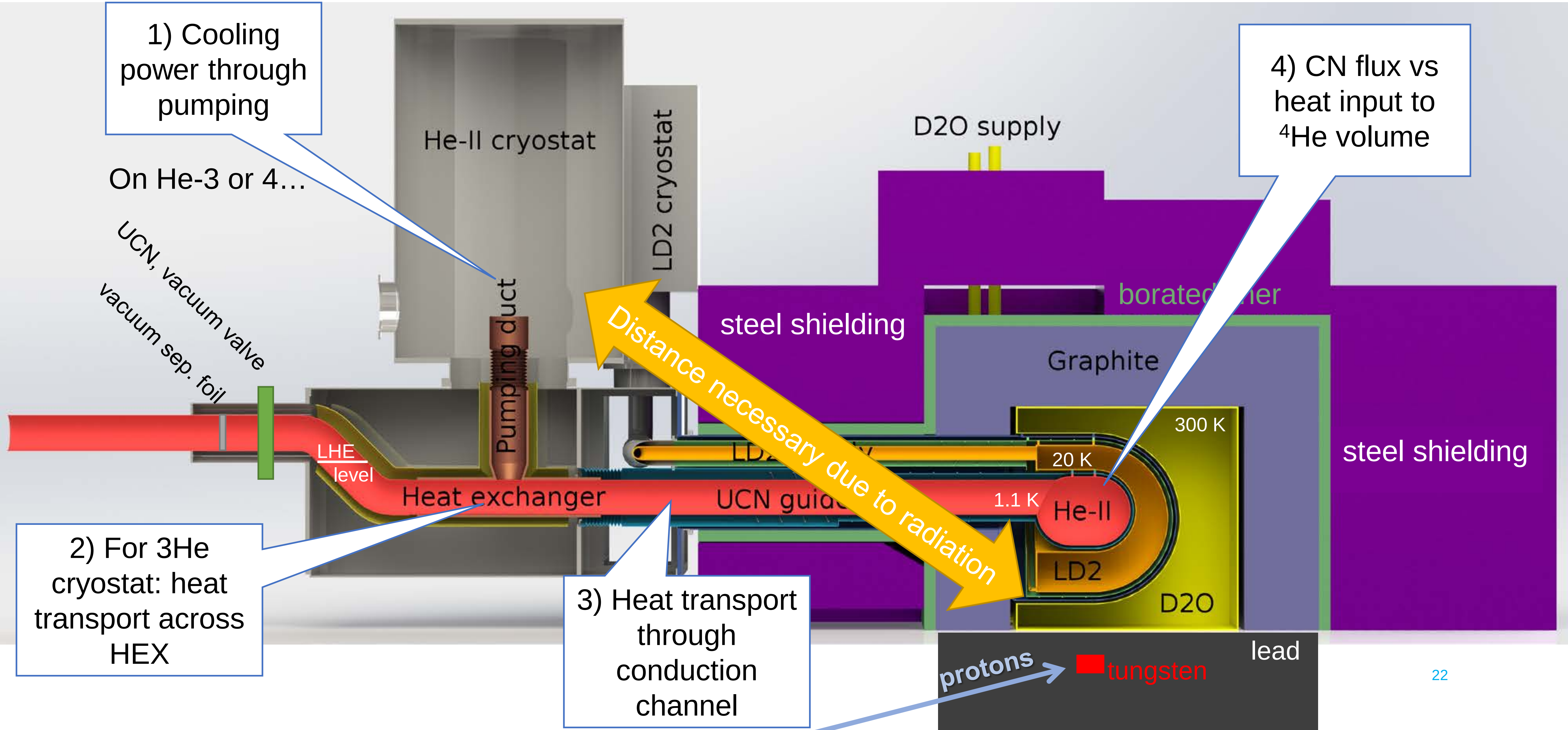
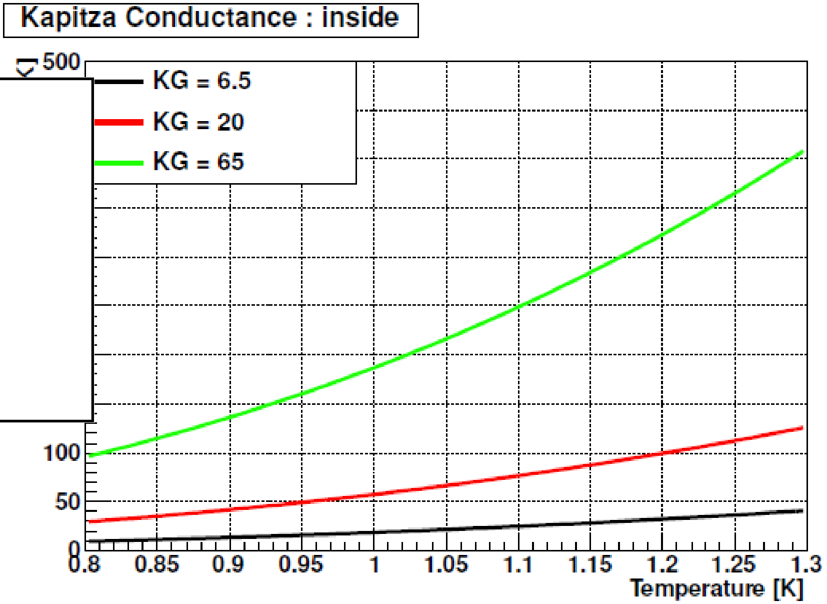


Parameter breakdown

1) Cooling power throu pumping

- cooling power ∝ pump speed
- ^{3}He: 10 W cooling power at 0.9 K requires pump speed around 5000 m^3/h
- Pressure drop important

- ^{3}He boiling curve
- heat transport on interfaces between ^{3}He, Cu in HEX and ^{4}He
- Kaptiza conductance $\propto T^3$
- around 1 m^2 for 10 W at 0.9 K and ΔT =0.1 K



transport acro HEX

sport

n

- normal component (NC) carries heat in superfluid helium
- at 1 K, there is very little NC
- heat flux 20 times smaller than at 2 K

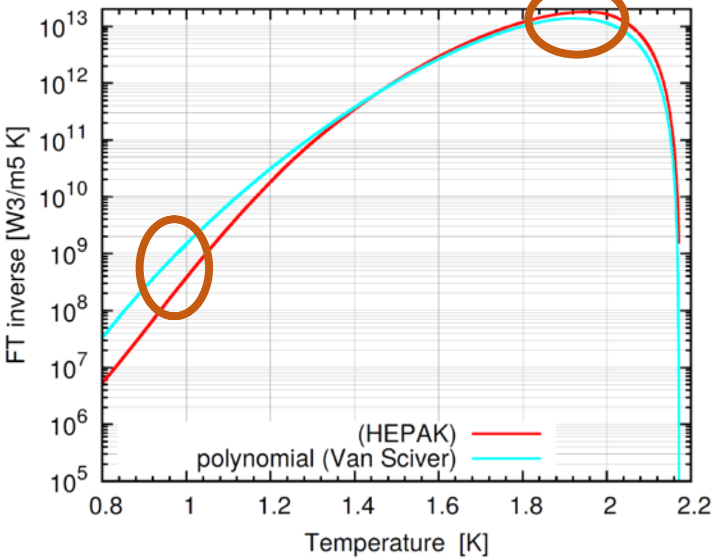
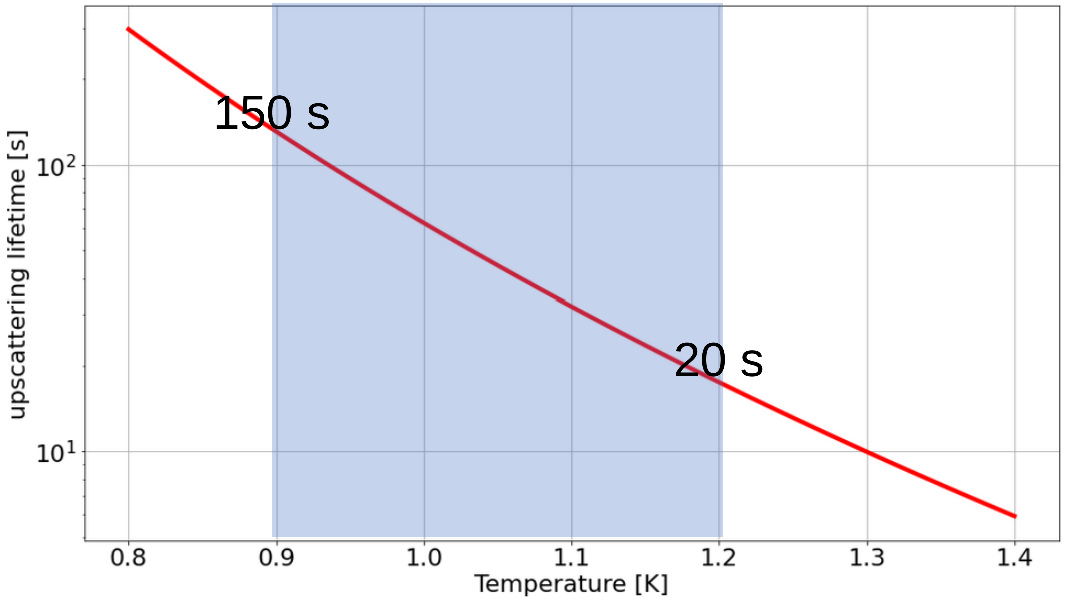


Figure 1.1: Heat transfer function, $f(T)^{-1}$, as a function of Temperature.

- see Wolfgang Schreyer's presentation tomorrow

^{3}He vs ^{4}He cryostat

UCN upscattering in ^{4}He

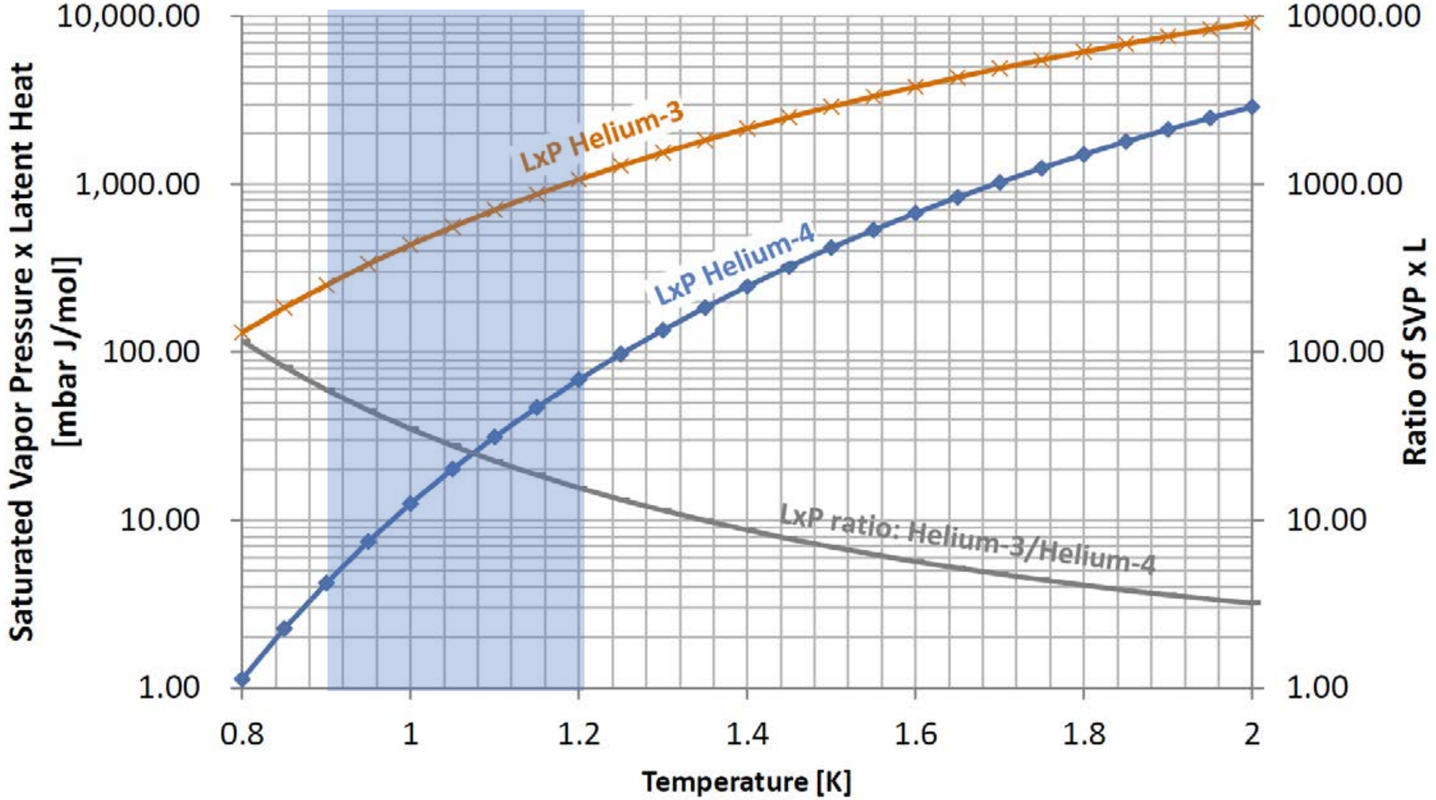


$$\tau_{up} \approx \frac{1}{0.016\frac{1}{sK^7} \cdot T^7}$$

Best fit to vertical source experiments.

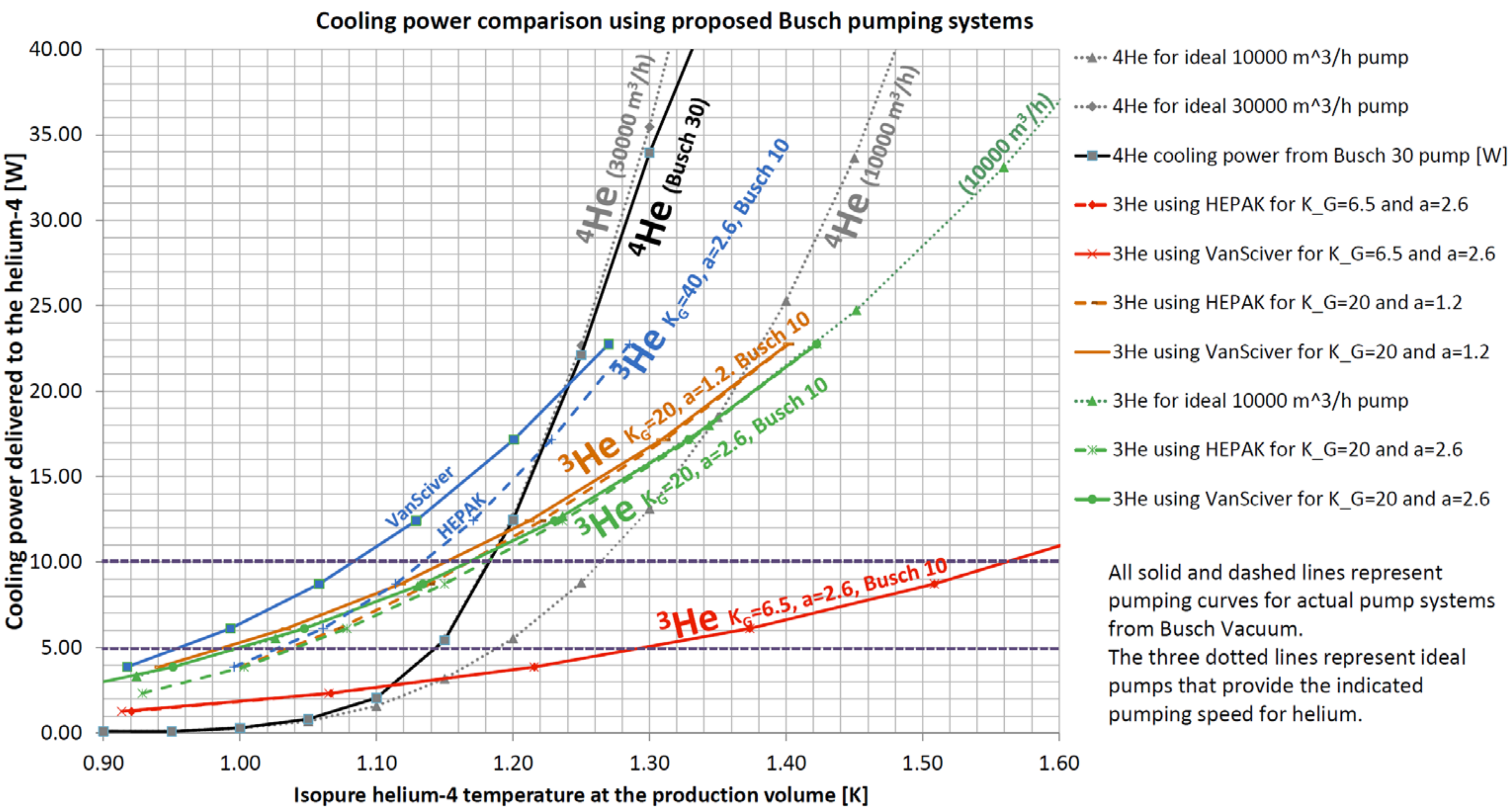
To be competitive with LD2 sources, keep temperature low.

Figure of merit for cooling power



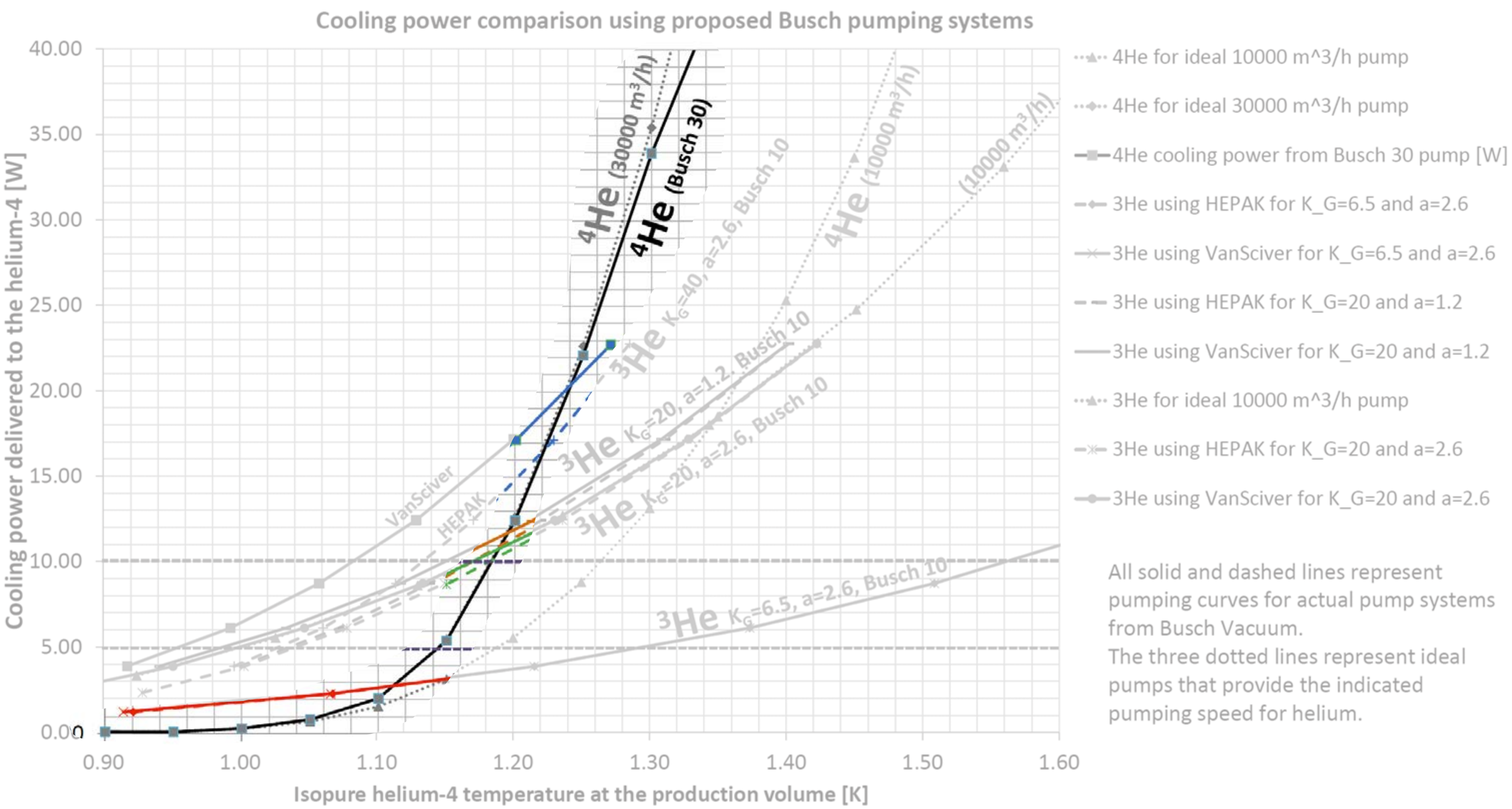
At 1 K cooling power of ^{3}He fridge 30 times larger than ^{4}He fridge.

Temperature in production volume vs cooling power



All solid and dashed lines represent pumping curves for actual pump systems from Busch Vacuum.
The three dotted lines represent ideal pumps that provide the indicated pumping speed for helium.

Temperature in production volume vs cooling power



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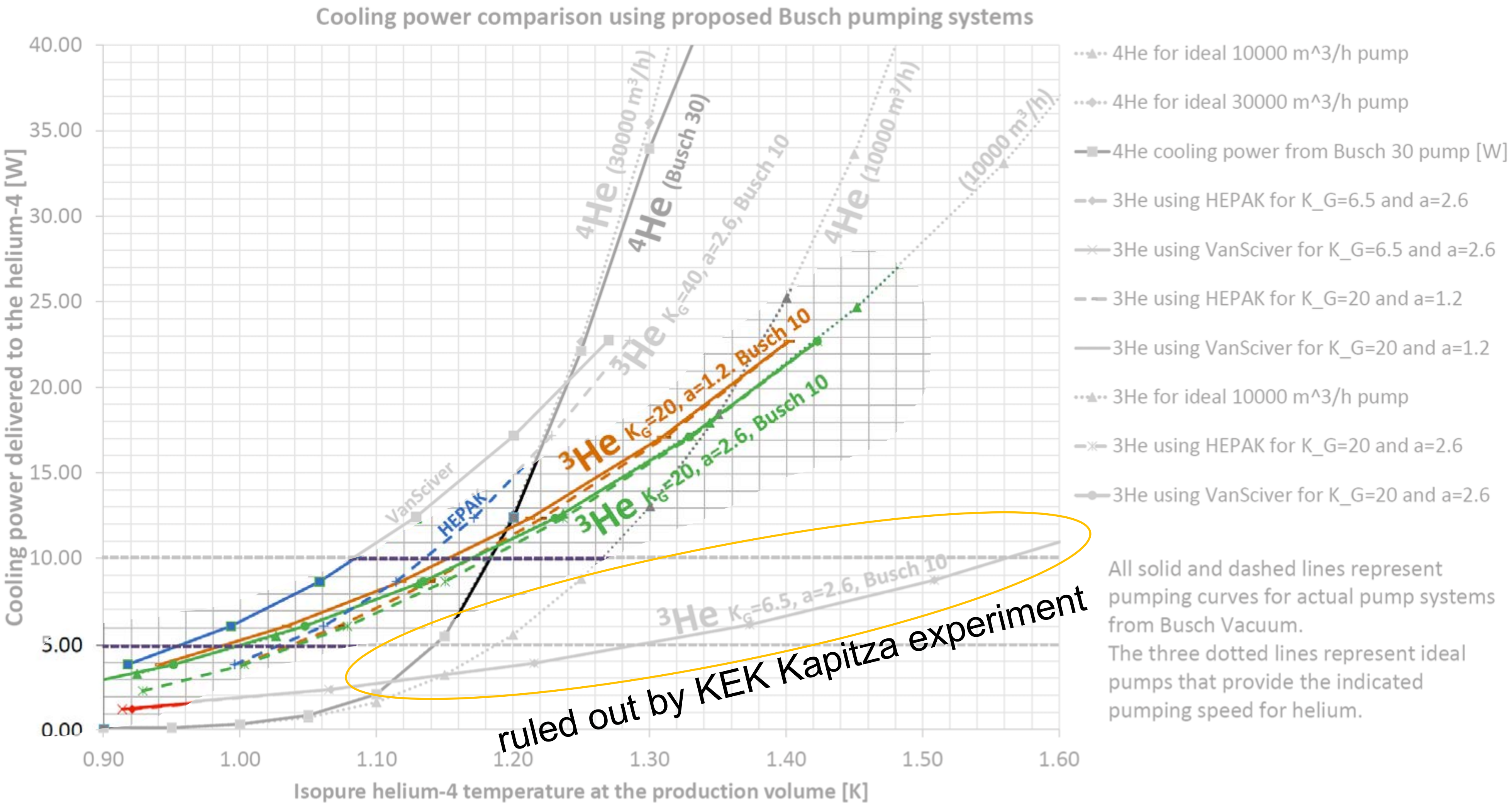

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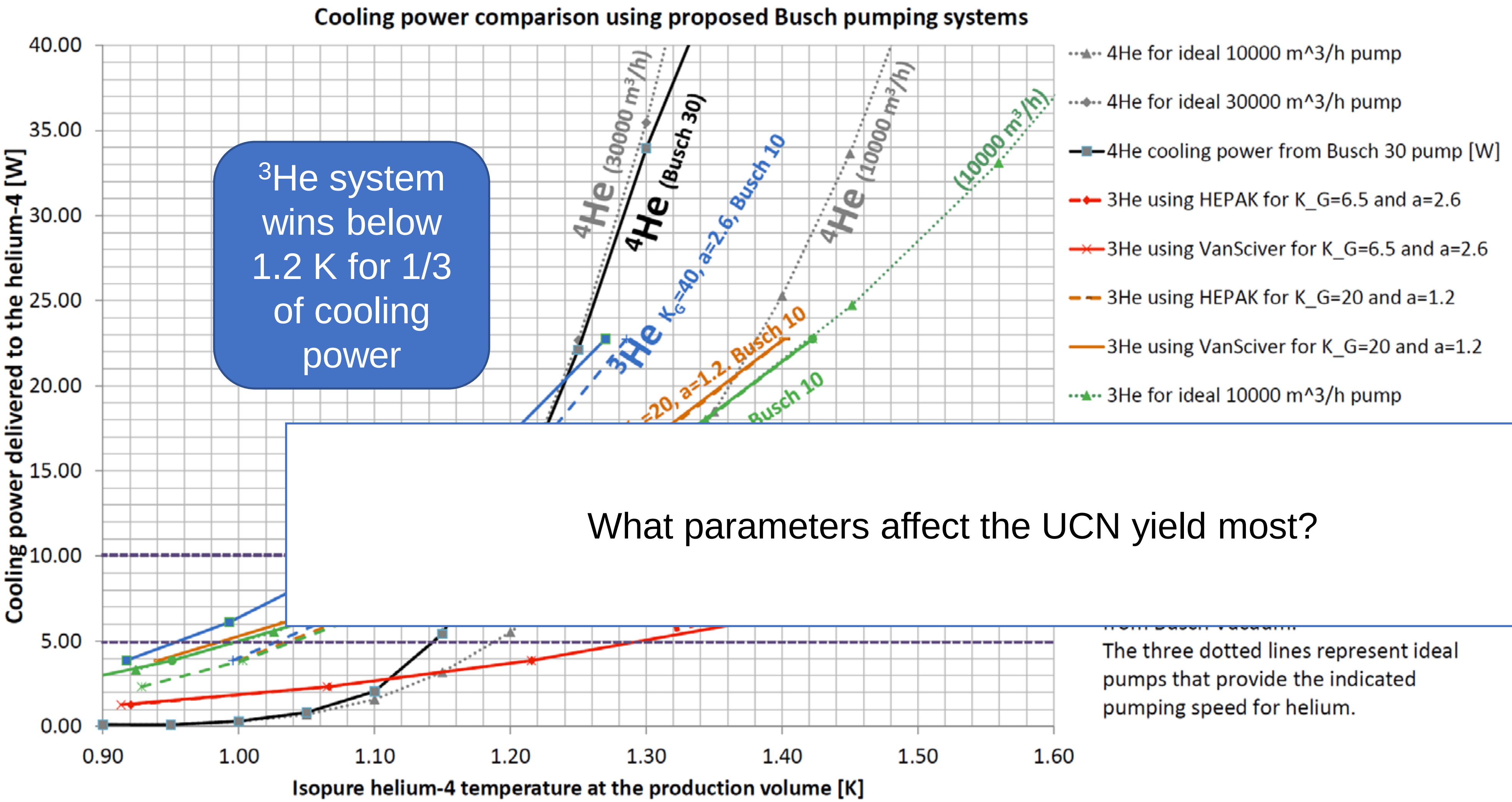
Temperature in production volume vs cooling power



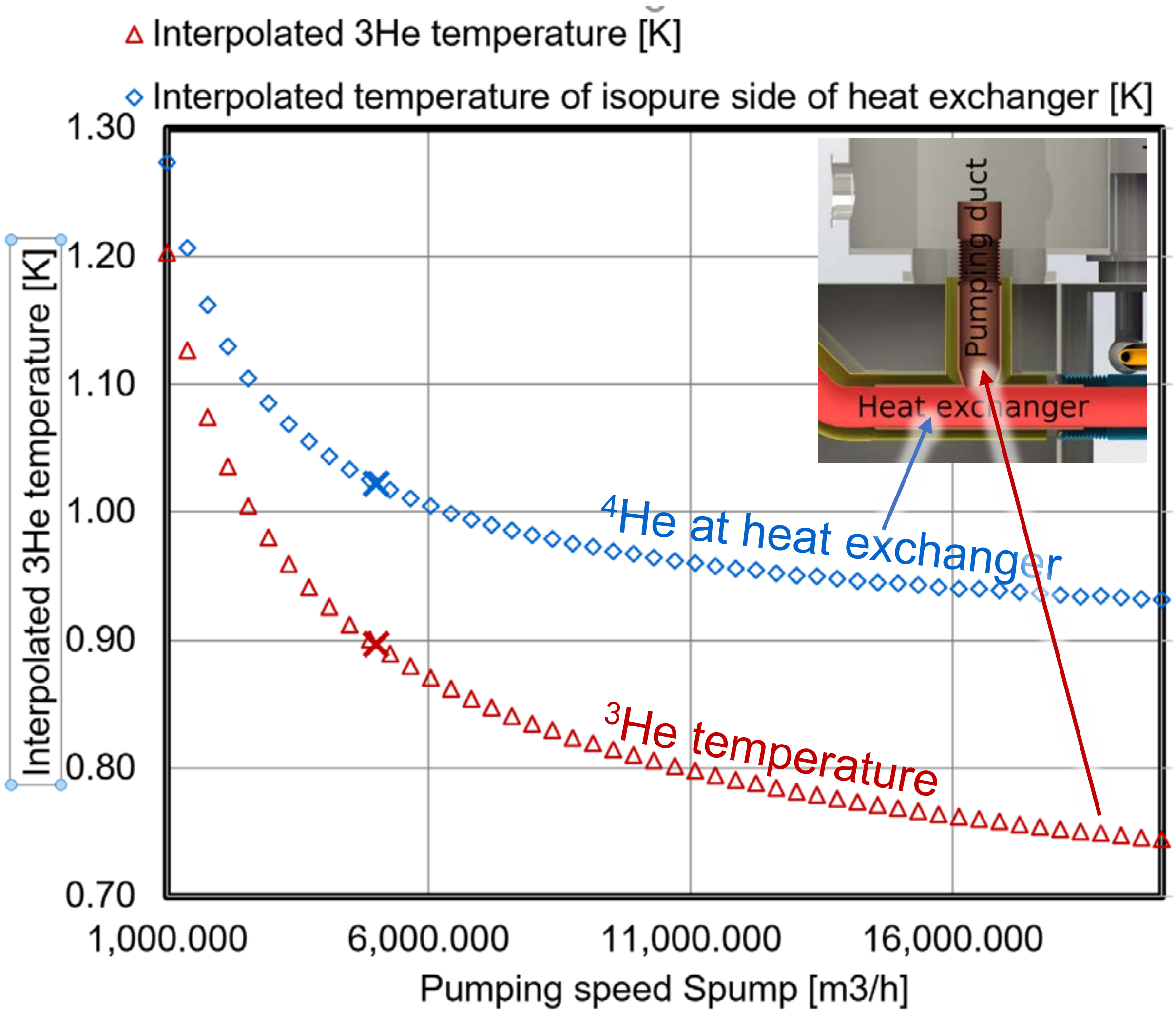
^{3}He system wins below 1.2 K for 1/3 of cooling power

What parameters affect the UCN yield most?

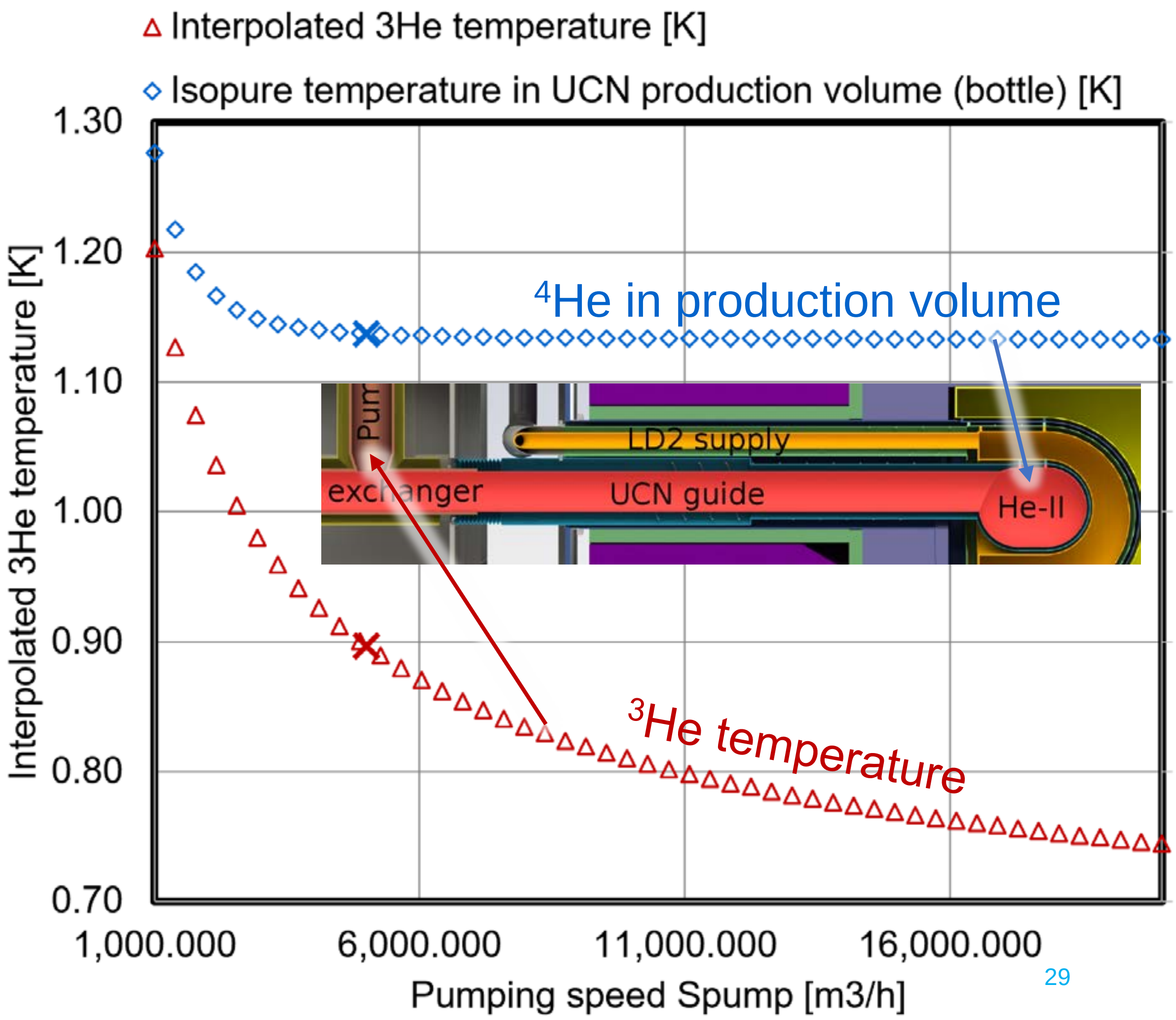
1) Increasing pumping speed

Plots from a fully parametrized model of the source taking cryogenics and UCN storage into account.

Kapitza conductance makes temperature reduction small



Heat conductance in ^{4}He eliminates the drop almost completely



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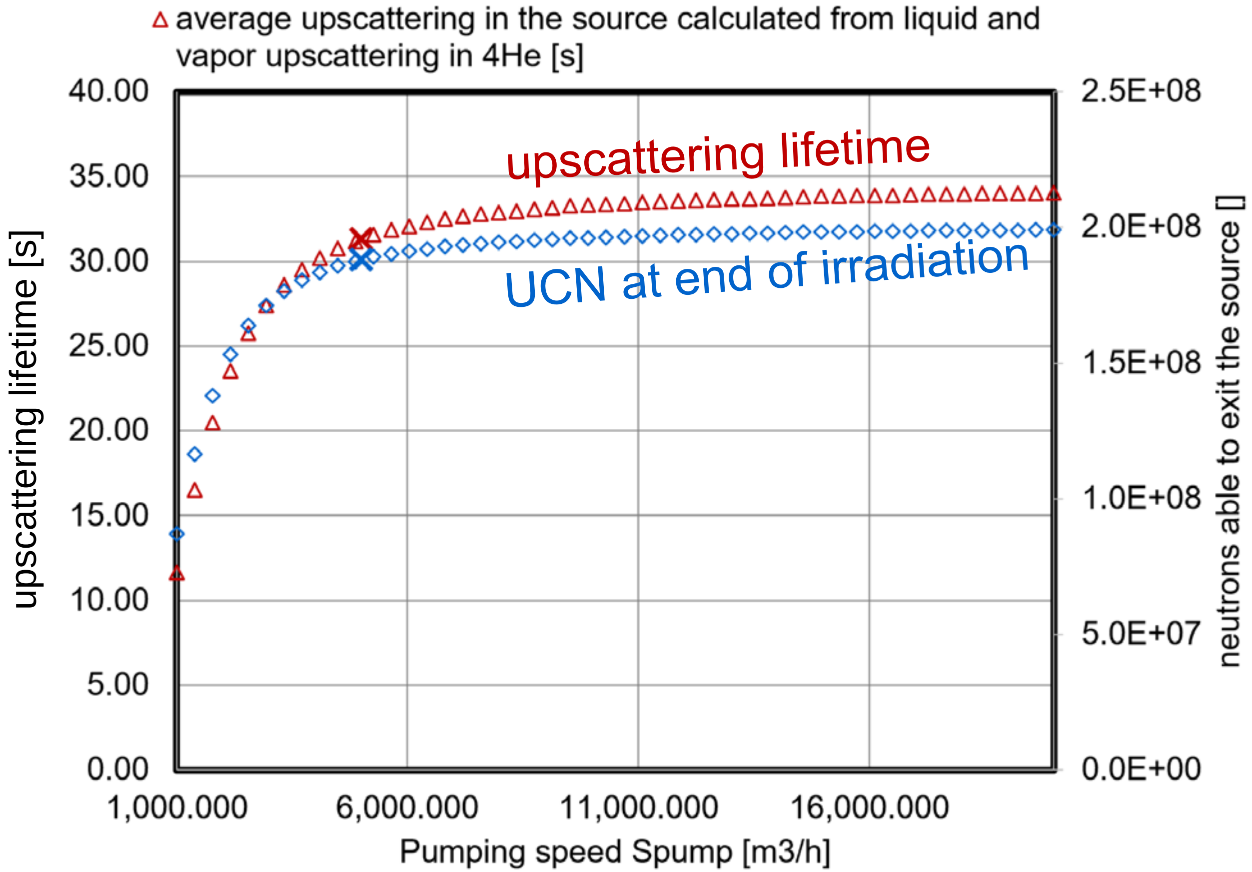
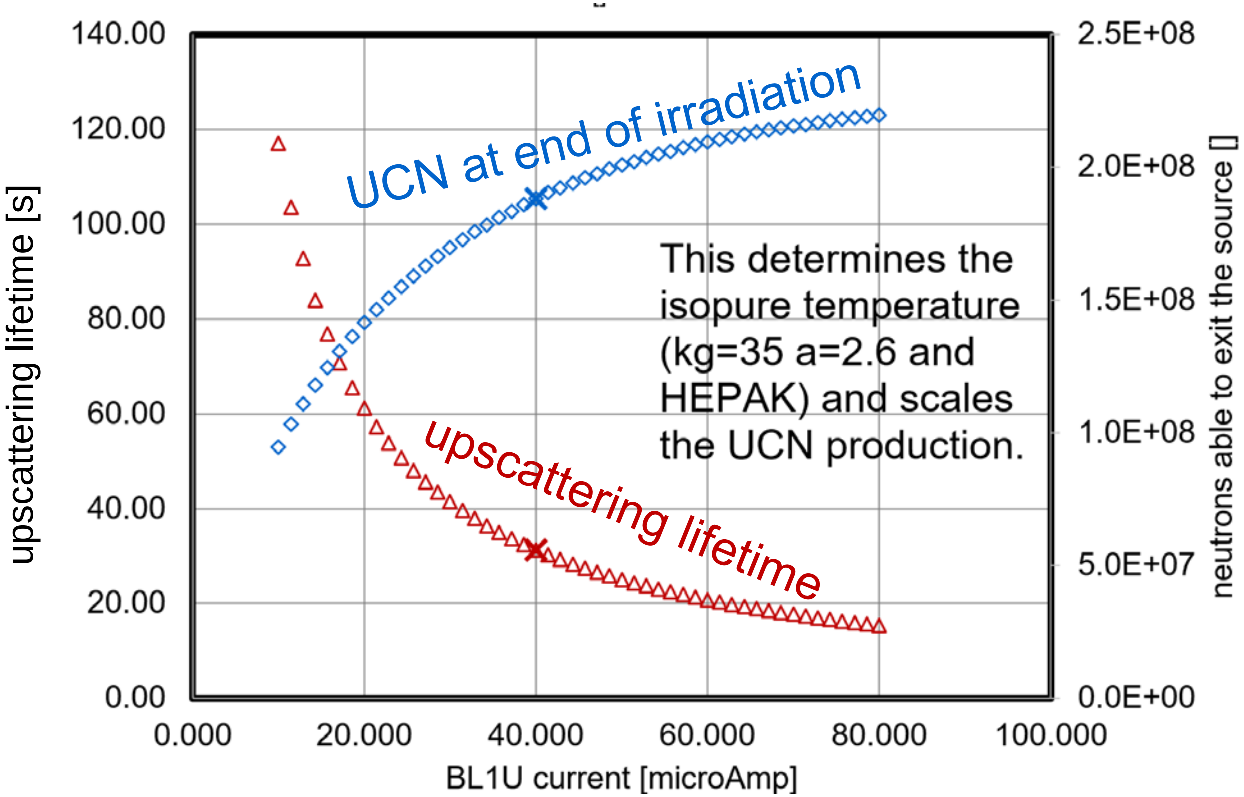
1) Increasing pumping speed

4) Increasing beam current

UCN yield plateaus



beam current ∝ heat input
beam current ∝ UCN production



Significant UCN yield increase possible?

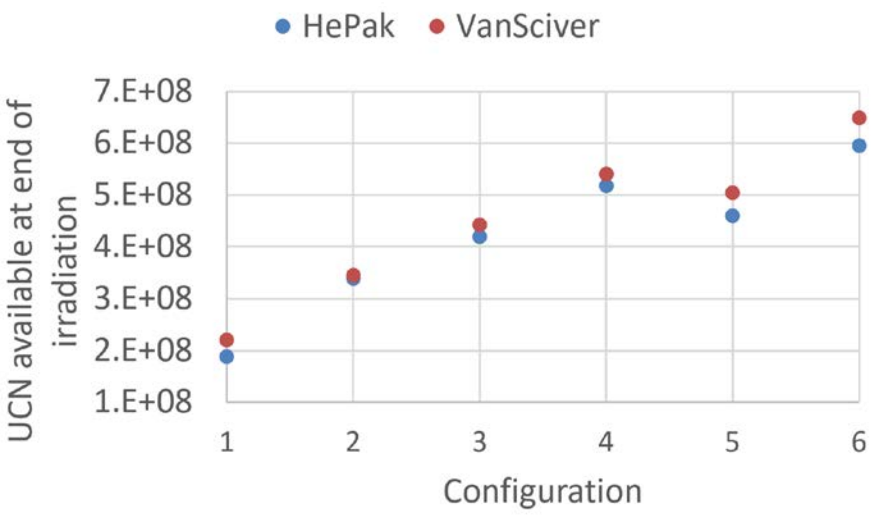
Parameter						
Conduction channel, HEX ID [m]	0.15	0.30				
3 Helium volume [l STP]	646	1239				
Pumping Speed [m^3/h]	5000		10000		20000	
beam current [uA]	40			80	40	80
HePak						
upscattering lifetime [s]	31.3	62.5	89.8	41.6	107.8	50.9
total source loss time [s]	21.5	38.8	47.9	29.6	52.5	34.0
UCN available [UCN]	**1.9E+08**	**3.4E+08**	**4.2E+08**	**5.2E+08**	**4.6E+08**	**6E+08**
multiplier	**1.00**	**1.81**	**2.23**	**2.75**	**2.44**	**3.17**
days to reach 1e-27 ecm [days]	705	714	579	468	527	407

Better heat transport through He and HEX

$$$

Increasing cooling power

Increasing UCN production and heat input



Summary – EDM central region

- Central EDM region design is progressing with some open challenges

Summary – Helium source parameters

- ^{3}He fridge design has its limitations, but is quite robust against parameter changes
- Increasing the yield much further is a very substantial endeveaur!

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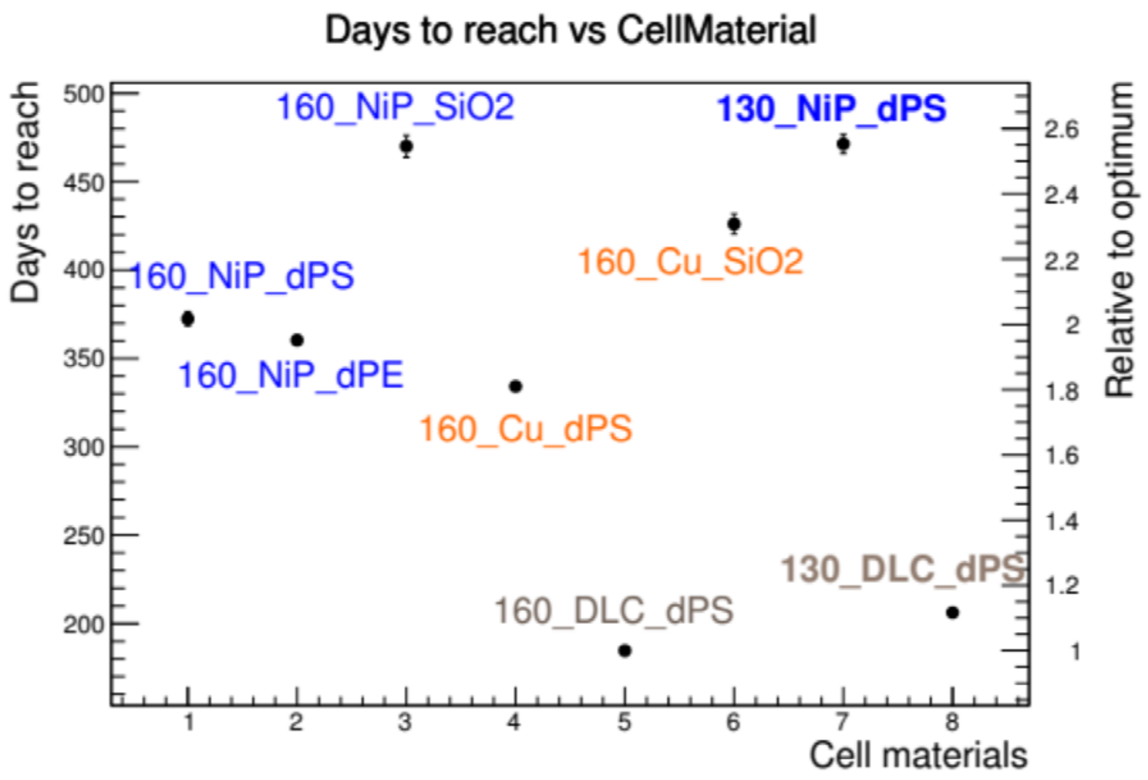
Thanks

Discovery, accelerated

Varying cell materials



Fermi potential: $U_F = V_F - iW_F$

Material	V_F (neV)	W_F (neV)
NiP (assumed)	213	0.113
NiP (exp)	213	0.035 – 0.06
NiP LowT	213	0.07
dPS	171	0.05
dPE	209	0.06
Cu	171	0.072
DLC	269	0.063
SiO_2	91	0.017

1. Insulator coating doesn't seem to have a large effect; ratio of W to V has a larger effect
2. Staged approach: could start with Cu electrodes and quartz insulators
3. **All nEDM simulations assumed a W_F(NiP) = 0.113**
4. Golub: avg loss probability per bounce $\mu(E) \sim W_F / V_F$ (Eq. 2.70)
5. W_F(NiP) = 0.05 gives roughly the same ratio as DLC