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Development of a caesium magnetometer array for the n2EDM experiment

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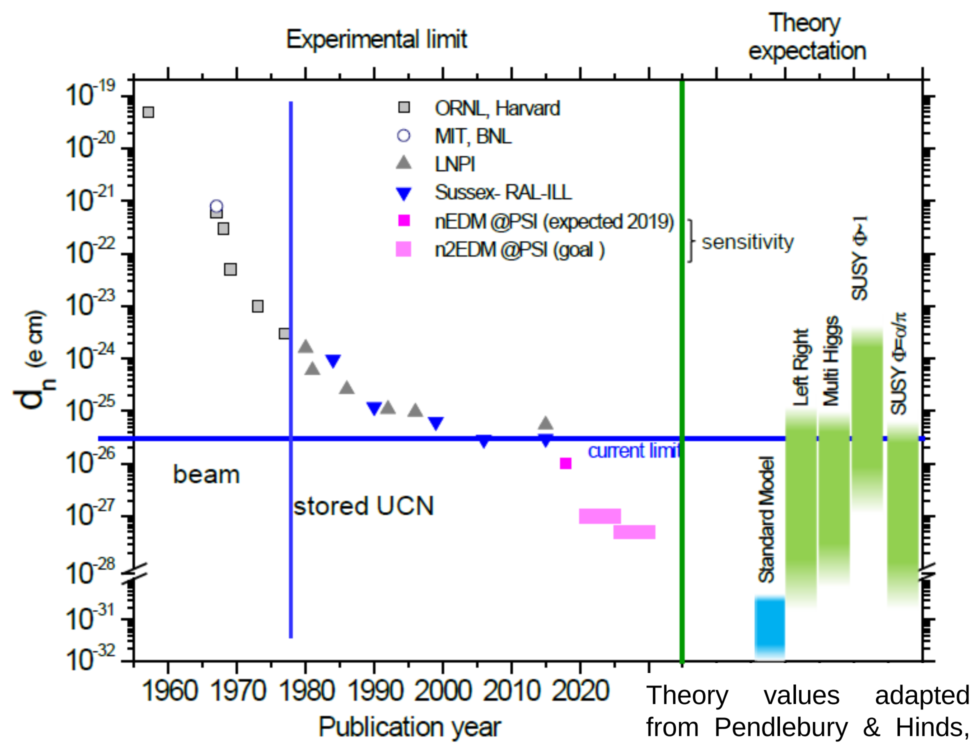
1 - n2EDM experiment

- **Searching for the neutron electric dipole moment d_n**

The **baryon asymmetry of the Universe** (BAU, i.e. prevalence of matter over antimatter) could be explained by the combination of three criteria [Sakharov, JETP Lett.(1967)].

One of these suggests larger sources of CP violation than accounted for in the **Standard Model** (SM). A neutron **electric dipole moment** (EDM) d_n violates CP.

Theories beyond the SM, predict larger values for d_n, **much closer to the current experimental limit (3 x 10^{-26} *e*.cm with 90% C.L. [Pendlebury et al., PR D (2015)]).**



Theory values adapted from Pendlebury & Hinds, NIM-A 440 (2000) 471

Goal: increase the sensitivity of the d_n measurement, down to 1.1 x 10^{-27} *e*.cm [Abel et al., arXiv:1811.02340 (2018)] in order to:

find its value

or

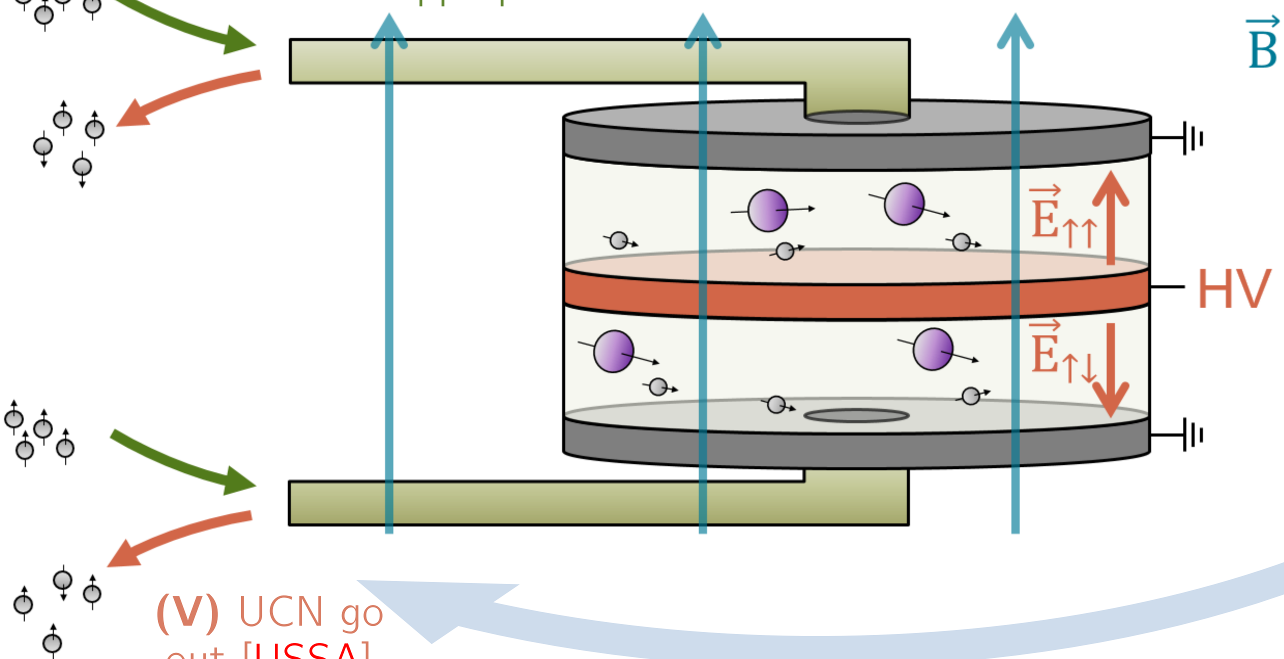
increase its limit

1 - n2EDM experiment

- **Principle**

(I) Polarised **ultra cold neutrons** (UCN) fill in the double chamber. Low kinetic energy of UCN allows them to be stored in appropriate vessels.

(II) $\pi/2$ spin flip pulse



(III) Precession for 180 s

(IV) $\pi/2$ spin flip pulse

(V) UCN go out [USSA]

(VI) Get $\omega_{\uparrow\uparrow/\uparrow\downarrow}$ from:

- UCN $_{\uparrow/\downarrow}$ counts
- ω_{Hg}(^{199}Hg magnetometer)

If $d_n \neq 0$, then $\omega_{\uparrow\uparrow} \neq \omega_{\uparrow\downarrow}$ and

$$d_n = \frac{\hbar}{4E}(\omega_{\uparrow\uparrow} - \omega_{\uparrow\downarrow})$$

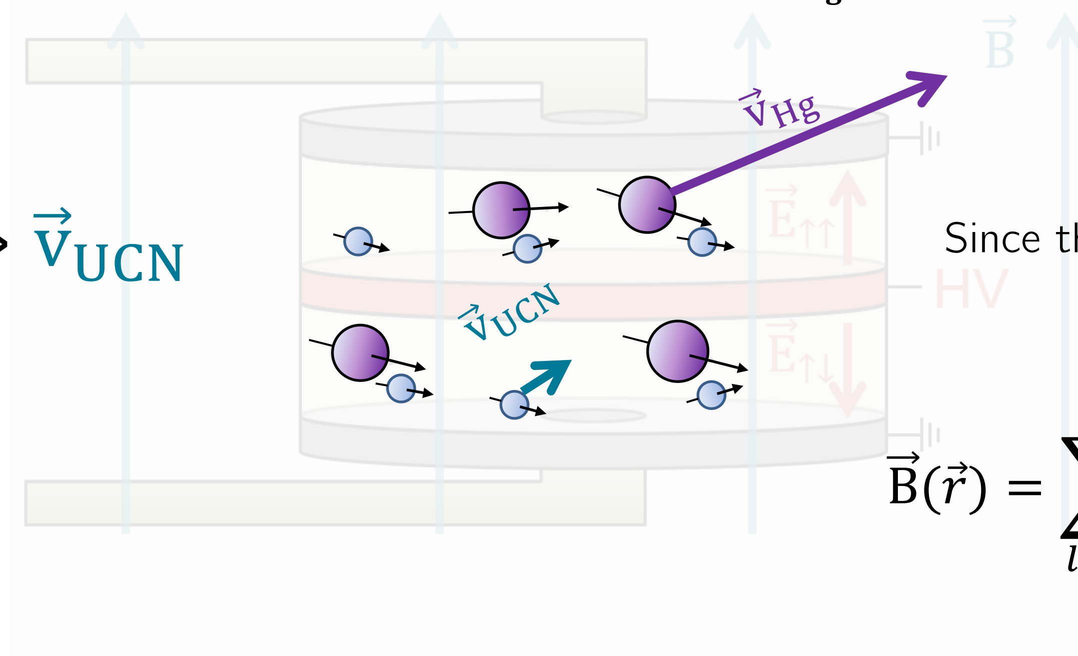
1 - n2EDM experiment

- $d^{\text{false}}_{\text{Hg}\rightarrow\text{UCN}}$ **problem**

The $\omega_{\uparrow\uparrow/\uparrow\downarrow}$ correction with ω_{Hg} leads to a systematic shift of d_{n}:

– the **false neutron EDM** $d^{\text{false}}_{\text{Hg}\rightarrow\text{UCN}}$.

$\vec{\text{v}}_{\text{Hg}} \gg \vec{\text{v}}_{\text{UCN}}$



Since the field in n2EDM can be described as:

$$\vec{\text{B}}(\vec{r}) = \sum_{l,m} \text{G}_{l,m} \begin{pmatrix} \Pi_{x,l,m}(\vec{r}) \\ \Pi_{y,l,m}(\vec{r}) \\ \Pi_{z,l,m}(\vec{r}) \end{pmatrix}$$

The systematic mimics a d_n, but it can be calculated

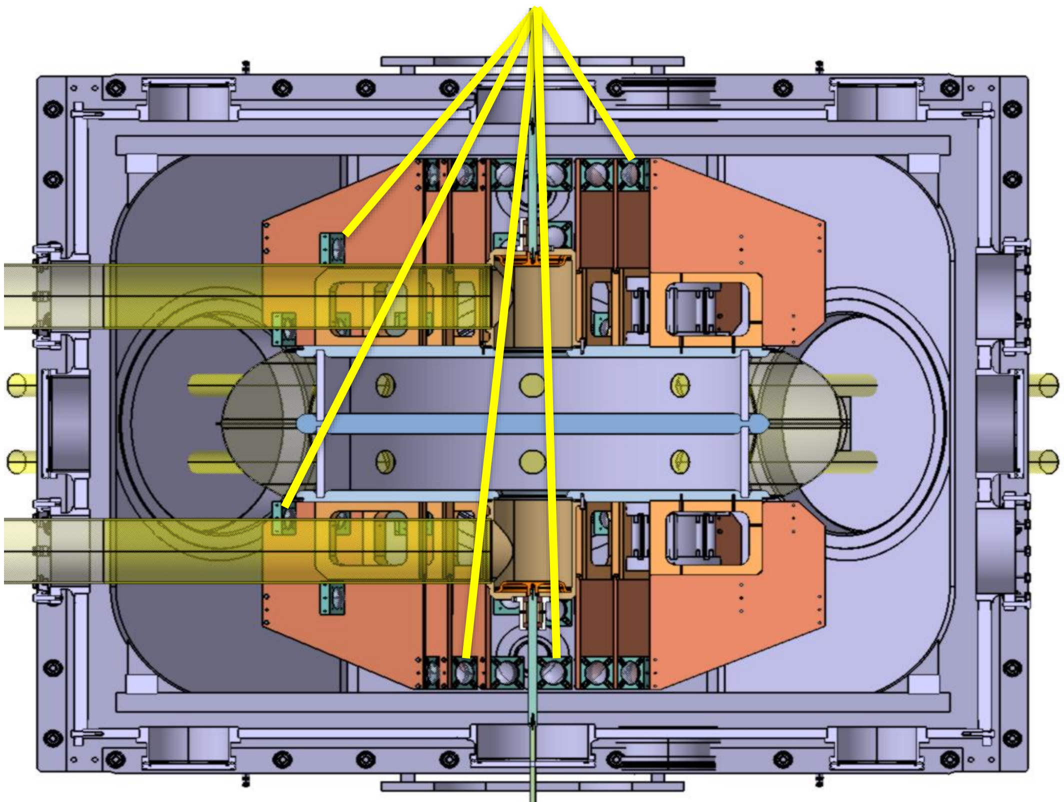
$$d^{\text{false}}_{\text{Hg}\rightarrow\text{n}} = -\frac{\hbar\gamma_{\text{n}}\gamma_{\text{Hg}}}{2c^2} \sum_{l,m} \text{G}_{l,m} \langle \rho \Pi_{\rho,l,m} \rangle$$

[Abel et al., arXiv:1811.06085 (2018)]

1 - n2EDM experiment

- $d^{\text{false}}_{\text{Hg}\rightarrow\text{UCN}}$ **solution**

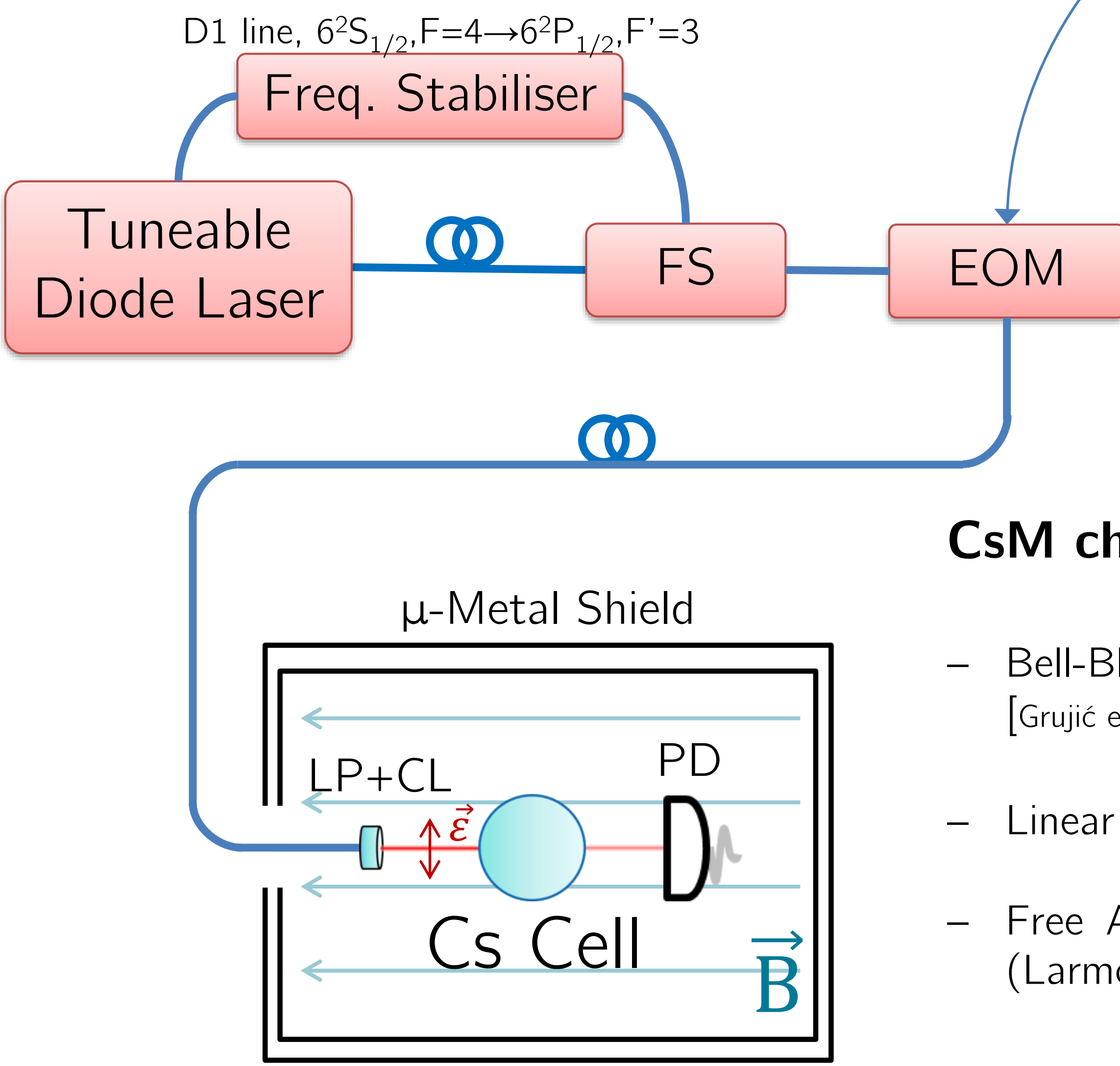
Monitor $|\vec{B}|$ for different xyz positions in the n2EDM experiment with an **array of caesium magnetometers** (CsM).

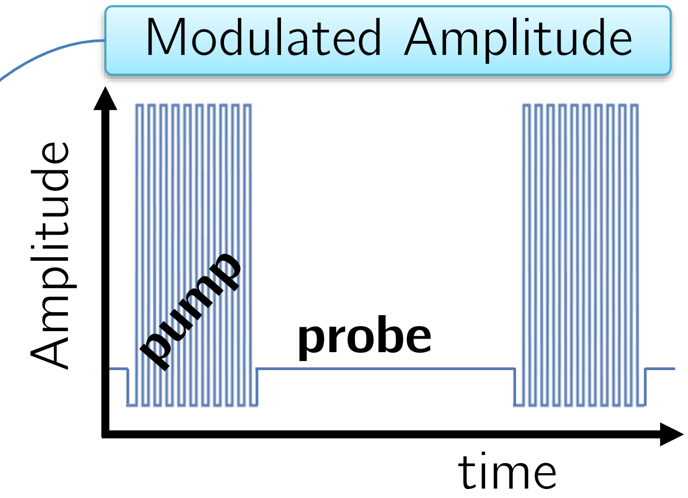


$|\vec{B}|$ at CsM xyz → $G_{l,m}$ are calculated → $d^{\text{false}}_{\text{Hg}\rightarrow\text{UCN}}$ is characterised
(**Goal:** $\Delta d^{\text{false}}_{\text{Hg}\rightarrow\text{UCN}} < 4 \times 10^{-28} e \cdot \text{cm}$)

2 – Magnetometer

- **Optical path**



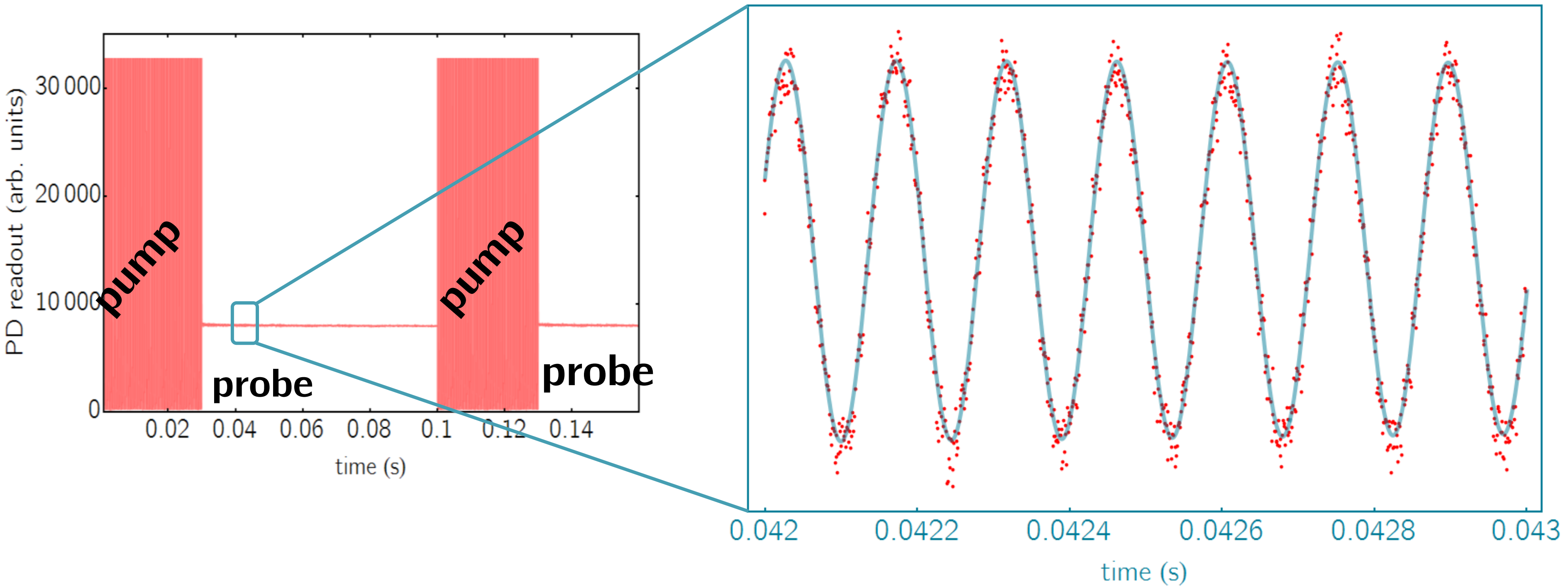


CsM characteristics:

- Bell-Bloom type, with modulated amplitude [Grujić et al., EPJ D (2015)]
- Linear polarisation $\vec{\varepsilon} \perp \vec{B}$
- Free Alignment Precession (FAP) at $2\omega_L$ (Larmor frequency)

2 – Magnetometer

- **Signal analysis**



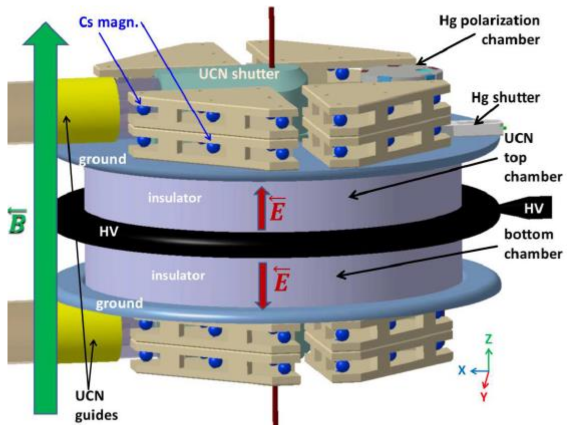
The recorded probe signal is demodulated to obtain ω_L.

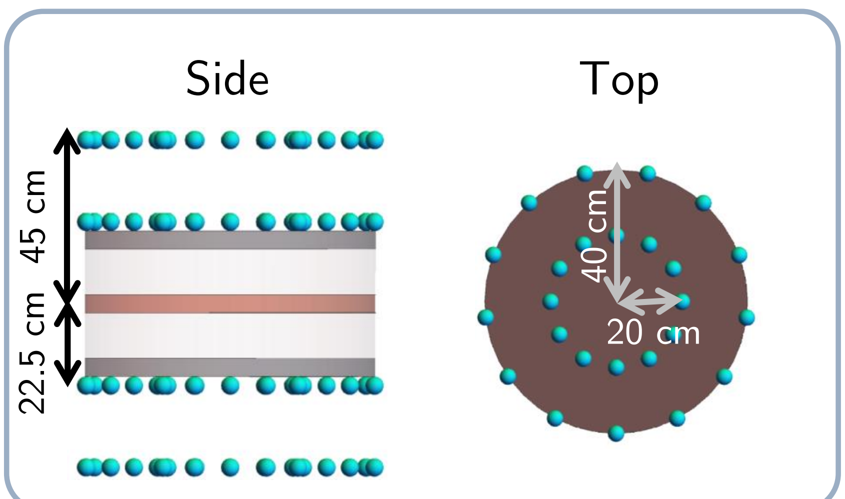
Each CsM provides a $|\vec{\mathrm{B}}| = \frac{\omega_L}{\gamma_{\mathrm{Cs}}}$ measurement at a rate of 10 Hz.

3 – CsM array

- **Testing the original symmetric arrangement (I)**

The structure in the figure below inspired the geometry initially considered, i.e. a cylindrical symmetry was used.





For an initial field arrangement with known $G_{l,m}$

Calculate $\vec{B}$ at the CsM xyz positions

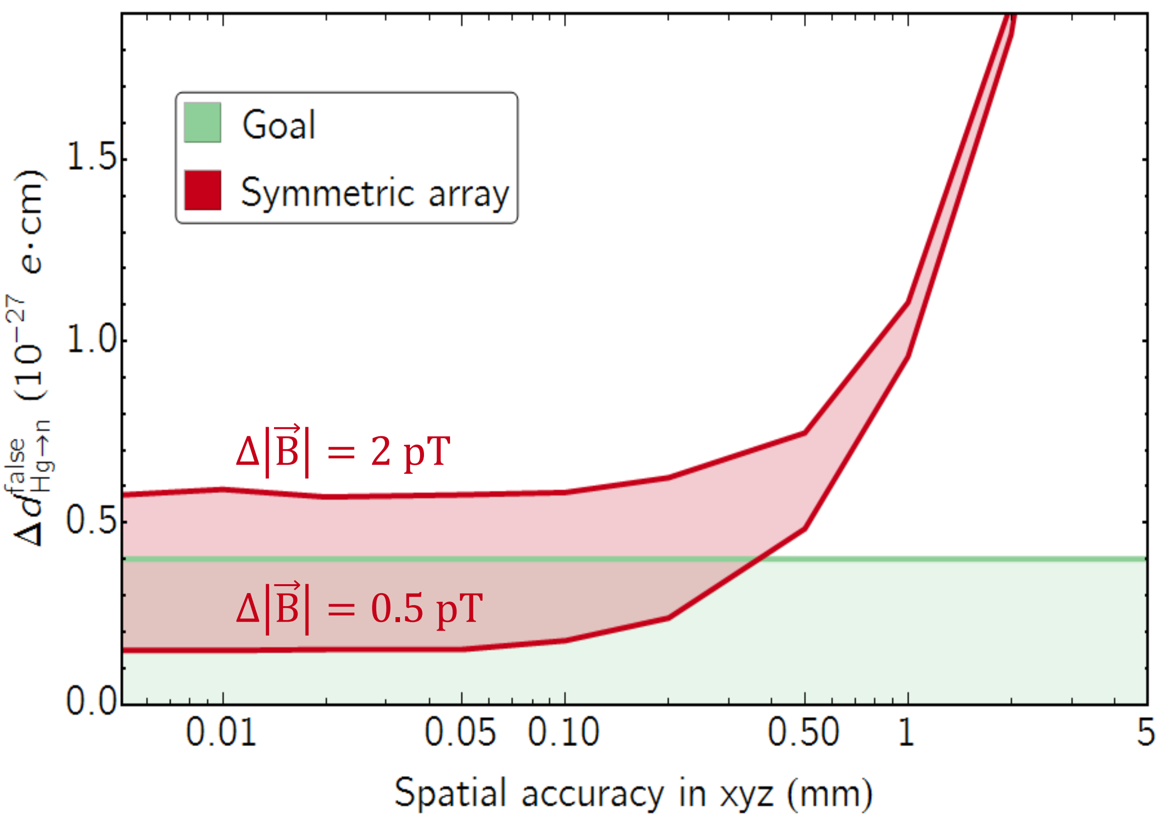
Randomise both xyz and $|\vec{B}|$

Calculate $G_{l,m}$

$d_{Hg\to n}^{false}$ $\Delta d_{Hg\to n}^{false}$

3 – CsM array

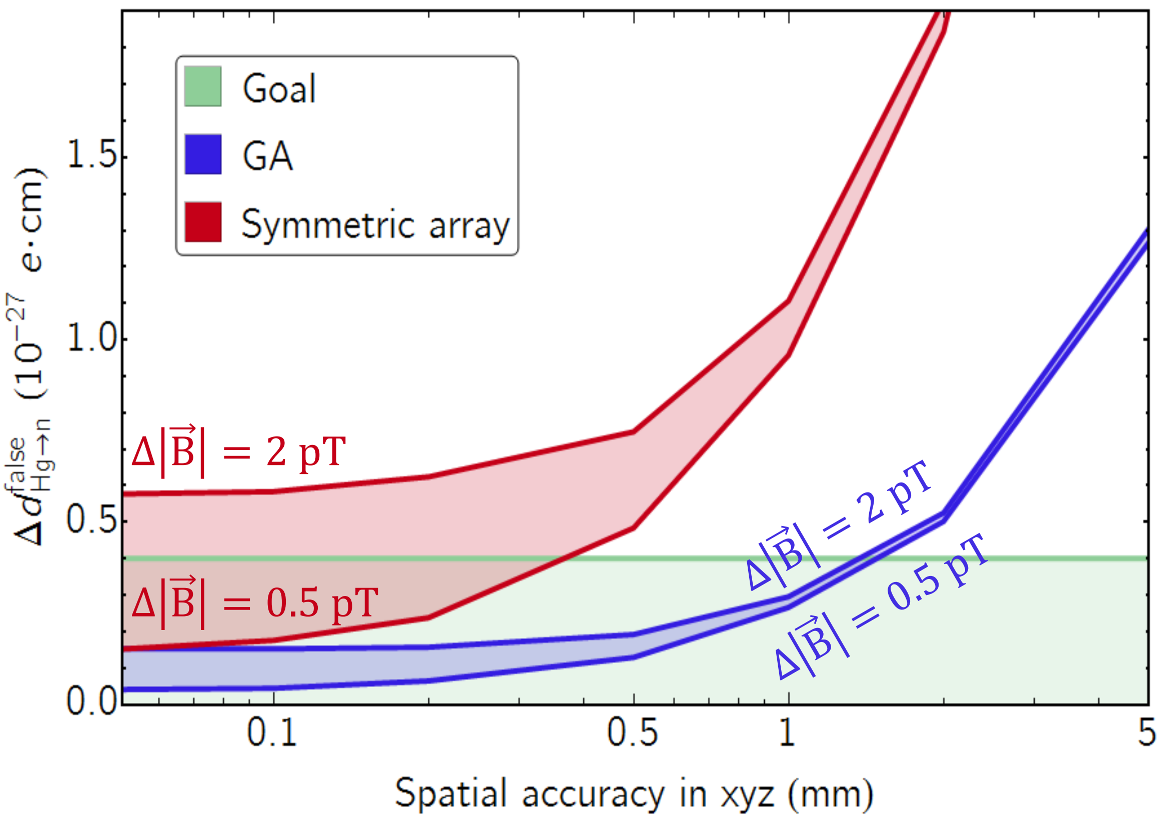
- **Testing the original symmetric arrangement (II)**



Even for the most stringent spatial resolutions, a field uncertainty $\Delta|\vec{B}|$ of 2 pT prevents a proper characterization of the systematic.

3 – CsM array

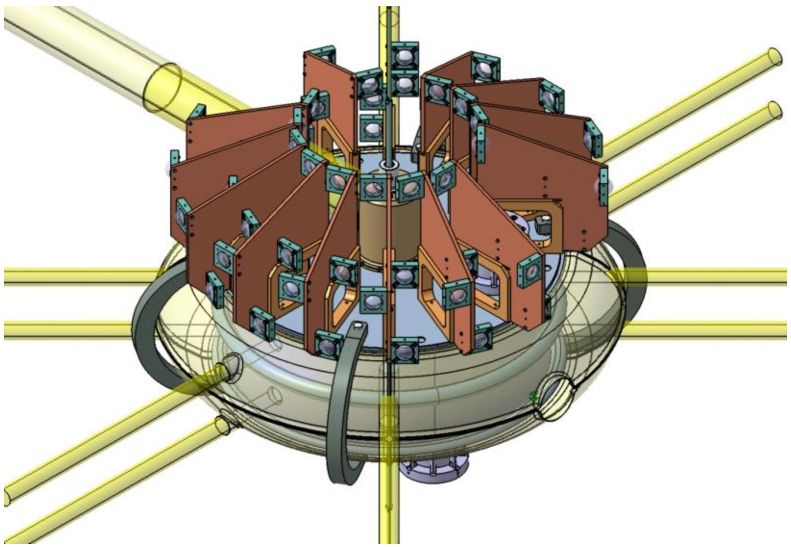
- **Testing a genetic algorithm (GA) solution (I)**



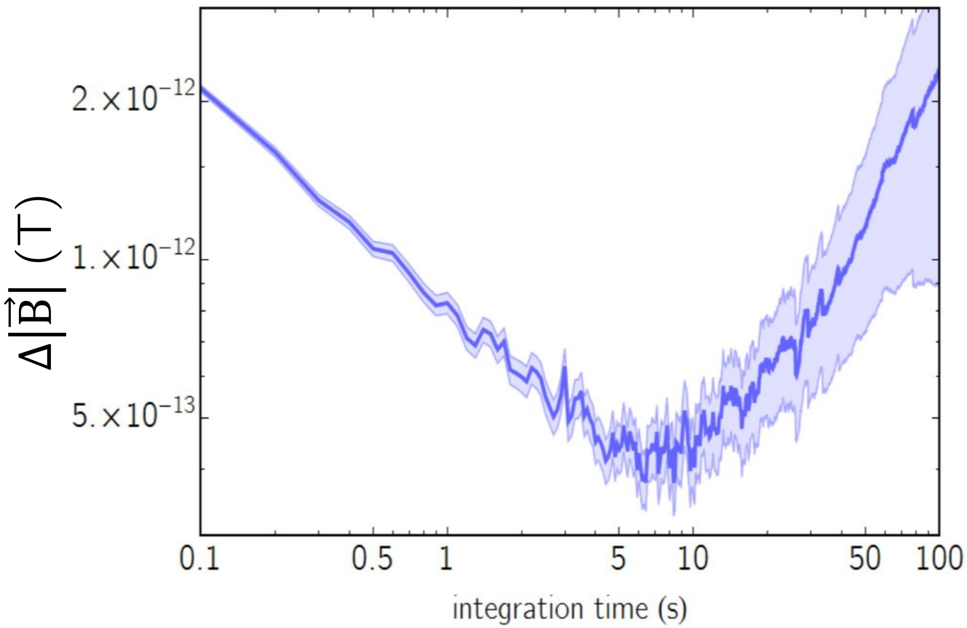
Certain array configurations relax the field and spatial resolutions constraints of CsM, without compromising the original goal of $\Delta d^{\text{false}}_{\text{Hg}\to\text{UCN}} < 4 \times 10^{-28}$ *e*.cm

3 – CsM array

- **Testing a genetic algorithm (GA) solution (II)**



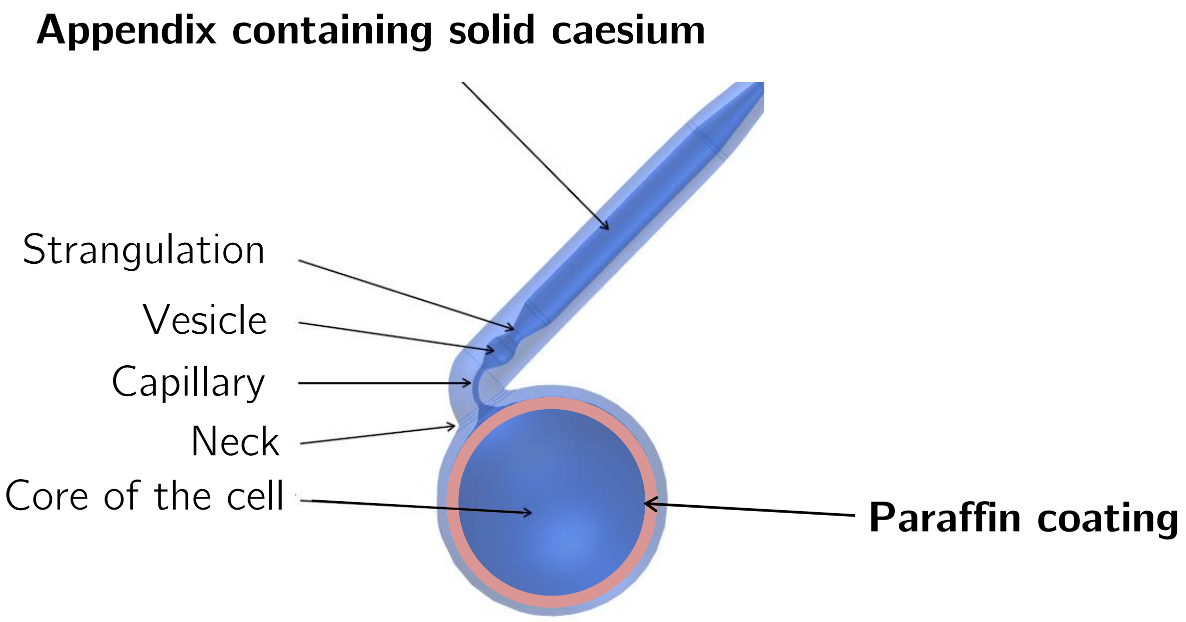
View of the positions of the CsM in plates on the top of the double chamber.



Considering the possible $|\vec{B}|$ resolutions of CsM, the only thing left is the assembly of such array, with 104 CsM.

4 – Discussion maybe?

- **Glassblowing experience**



Is there someone willing to share some glassblowing experience/tips?

Conclusion

1. Purpose of the n2EDM experiment.
2. Explanation of one of the most challenging systematic shifts in the neutron EDM measurement, the $d_{Hg\rightarrow n}^{false}$, and its characterisation with CsM.
3. Description of the CsM to be used.
4. Depiction of the CsM array to mount.

Thank you for your time