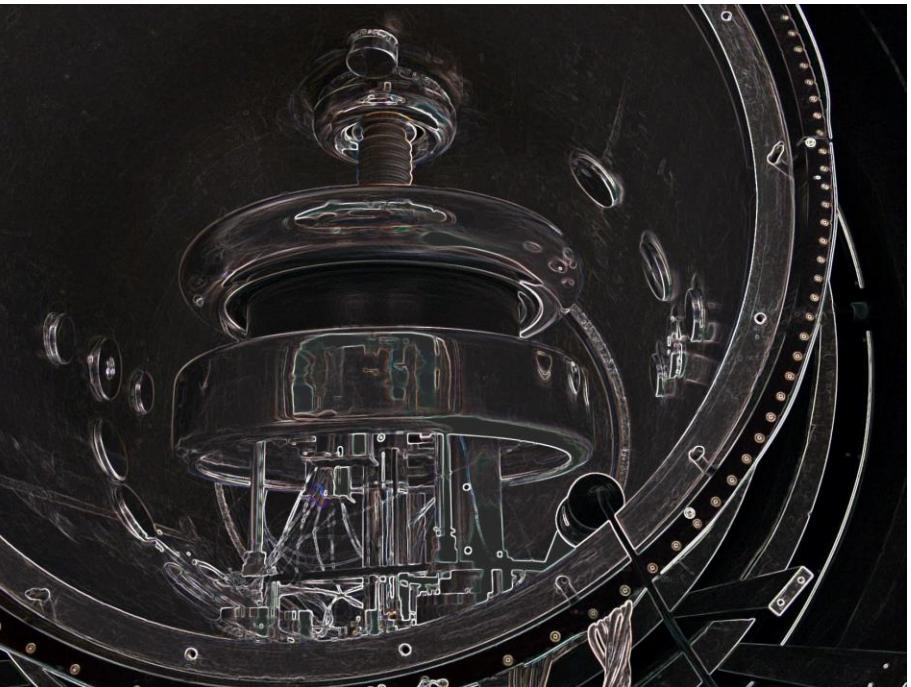


# Focus on nEDM experiment



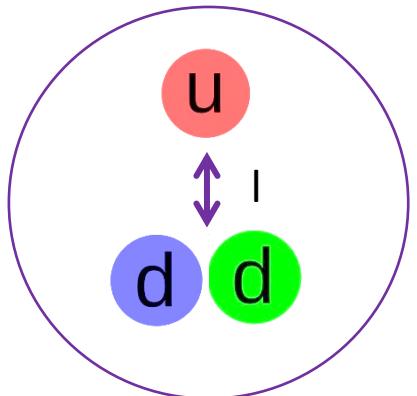
## What is an EDM?

---

$$H = -\vec{\mu}_n \cdot \vec{B} - \vec{d}_n \cdot \vec{E} = \frac{hf_n}{2}$$

30 Hz in  $1\mu\text{T}$

58 nHz in  $12 \text{ KV/cm}$



$$d_n = 2/3 e^* l$$

$$l = 0.1 r_n \rightarrow d_n = 4 \cdot 10^{-14} \text{ e.cm}$$

$$\text{But } d_n < 1.8 \cdot 10^{-26} \text{ e.cm (90% C.L.)}$$

We have this quantity, that is breaking P, T and CP symmetries.

## What is an EDM?

---

The neutron EDM is essentially free of SM background!

$$d_n = d_n^{CKM} + 10^{-16} \text{ e.cm } (\theta) + 10^{-24} \text{ e.cm } \left( \frac{200 \text{ GeV}}{M} \right)^2 \sin(\varphi_{CP})$$

$$L_{eff} = L_{QCD} + \theta \frac{\alpha_S}{8\pi} \epsilon^{\mu\nu\rho\sigma} G_{\mu\nu}^a G_{\rho\sigma}^a$$

# Electroweak baryogenesis

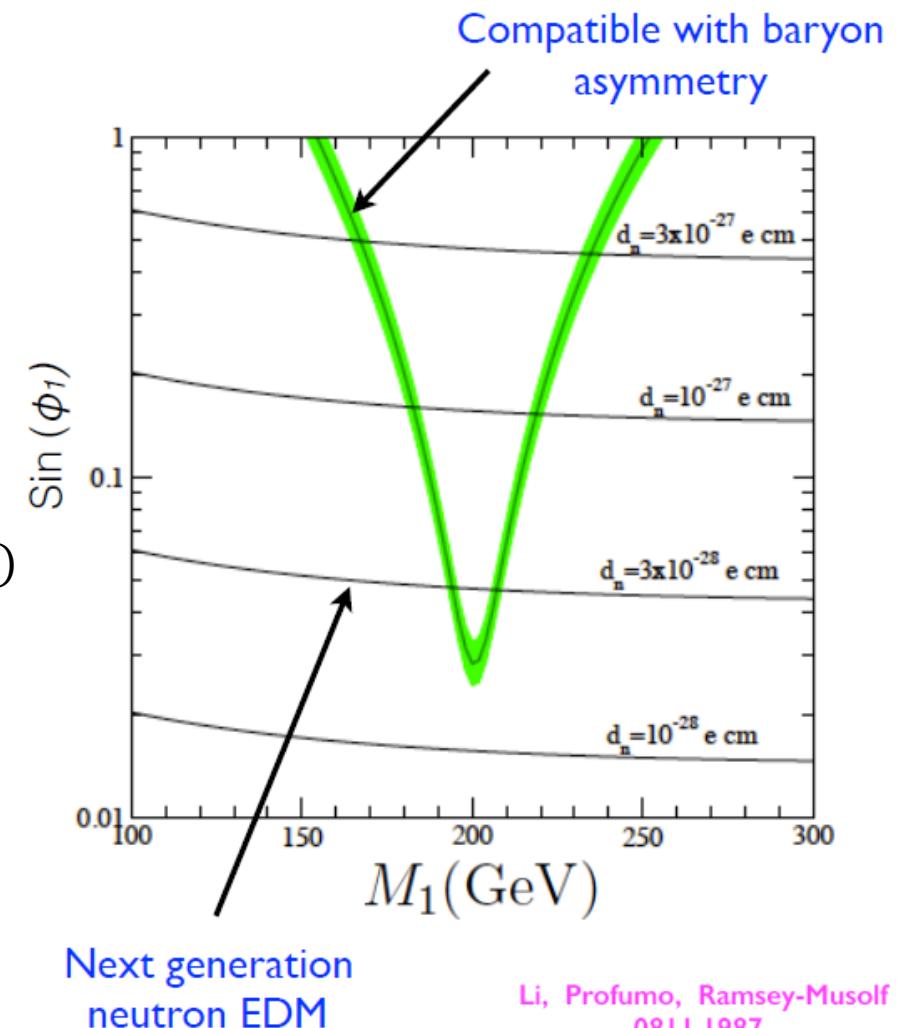
New CP violating phases contributes to

- \* baryonic asymmetry of the universe
- \* neutron EDM

$$d_n = d_n^{CKM} + 10^{-16} \text{ e.cm} (\theta) + 10^{-24} \text{ e.cm} \left( \frac{200 \text{ GeV}}{M} \right)^2 \sin(\varphi_{CP})$$

The nEDM is the most stringent test of electroweak baryogenesis

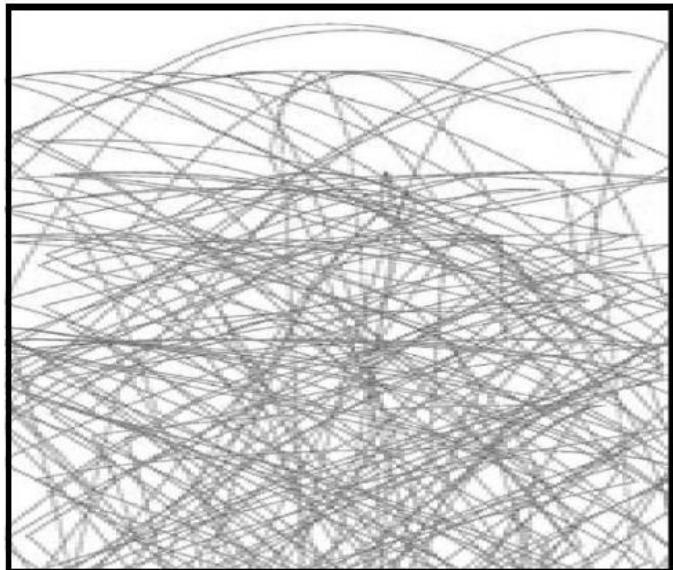
Another possibility is the leptogenesis



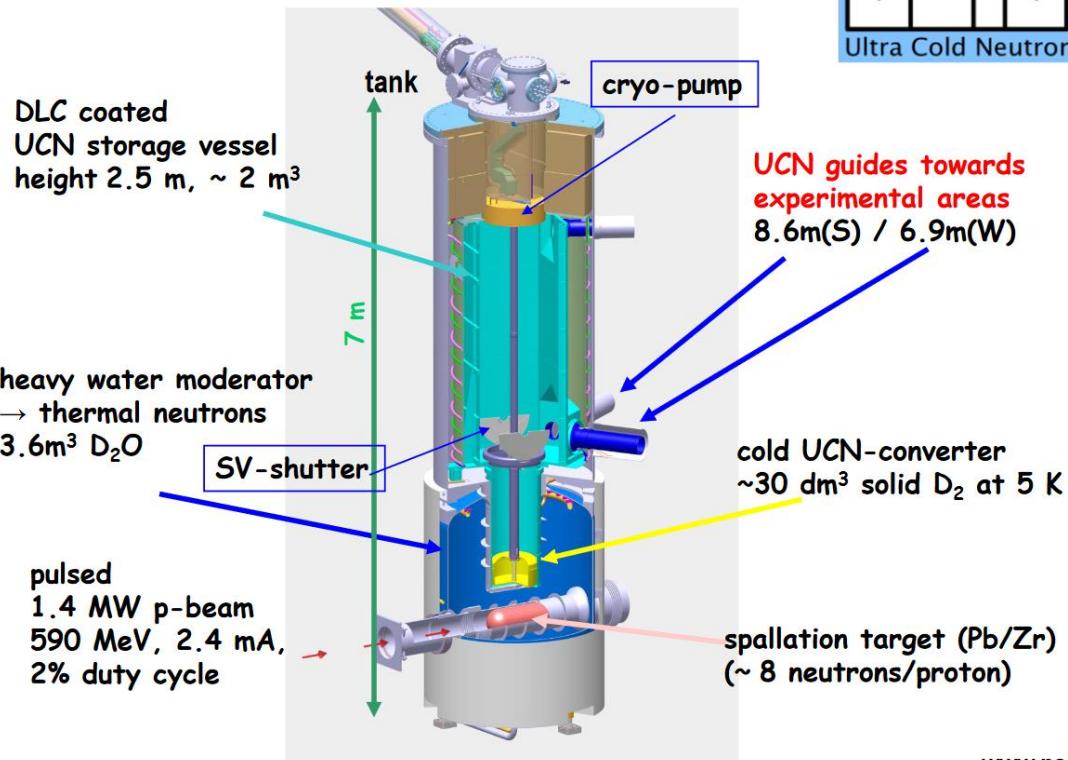
Picture by V. Cirigliano

# The search for the neutron EDM

Neutrons reflected for all incidence angles: UCNs



$$\begin{aligned}\lambda_n &\approx 800 \text{ \AA}; \\ v_n &\approx 5 \text{ m/s}; \\ T_n &\approx 2 \text{ mK}; \\ E_n &\approx 130 \text{ neV}\end{aligned}$$



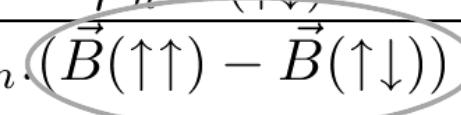
[www.psi.ch/ucn/](http://www.psi.ch/ucn/)



## The search for the neutron EDM

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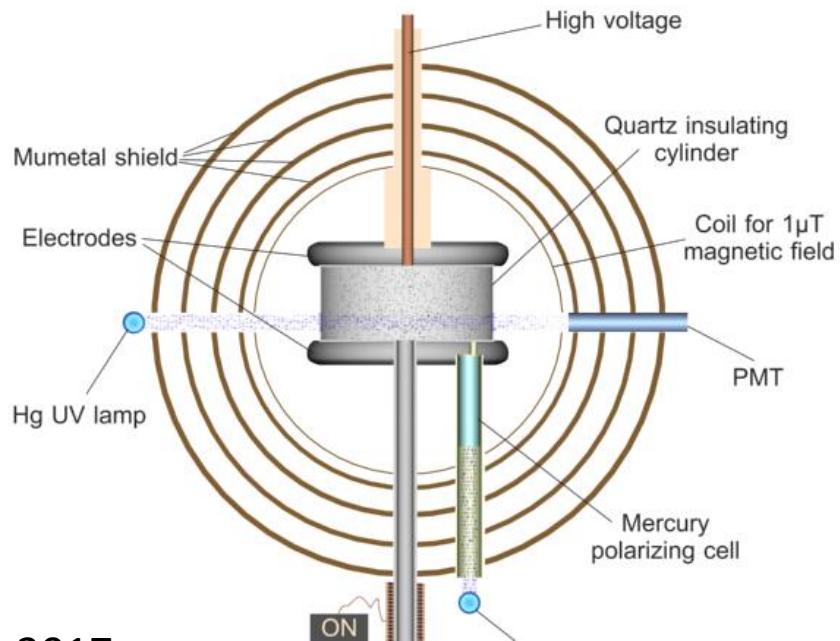
First limitation .... Magnetic field fluctuations

$$\begin{aligned} h f_n (\uparrow\uparrow) &= 2 \vec{\mu}_n \cdot \vec{B}(\uparrow\uparrow) + 2 \vec{d}_n \cdot \vec{E}(\uparrow\uparrow) \\ h f_n (\uparrow\downarrow) &= 2 \vec{\mu}_n \cdot \vec{B}(\uparrow\downarrow) - 2 \vec{d}_n \cdot \vec{E}(\uparrow\downarrow) \\ \hline h(f_n (\uparrow\uparrow) - f_n (\uparrow\downarrow)) &= 2 \vec{\mu}_n \cdot (\vec{B}(\uparrow\uparrow) - \vec{B}(\uparrow\downarrow)) - 2 \vec{d}_n \cdot (\vec{E}(\uparrow\uparrow) + \vec{E}(\uparrow\downarrow)) \end{aligned}$$


# The search for the neutron EDM

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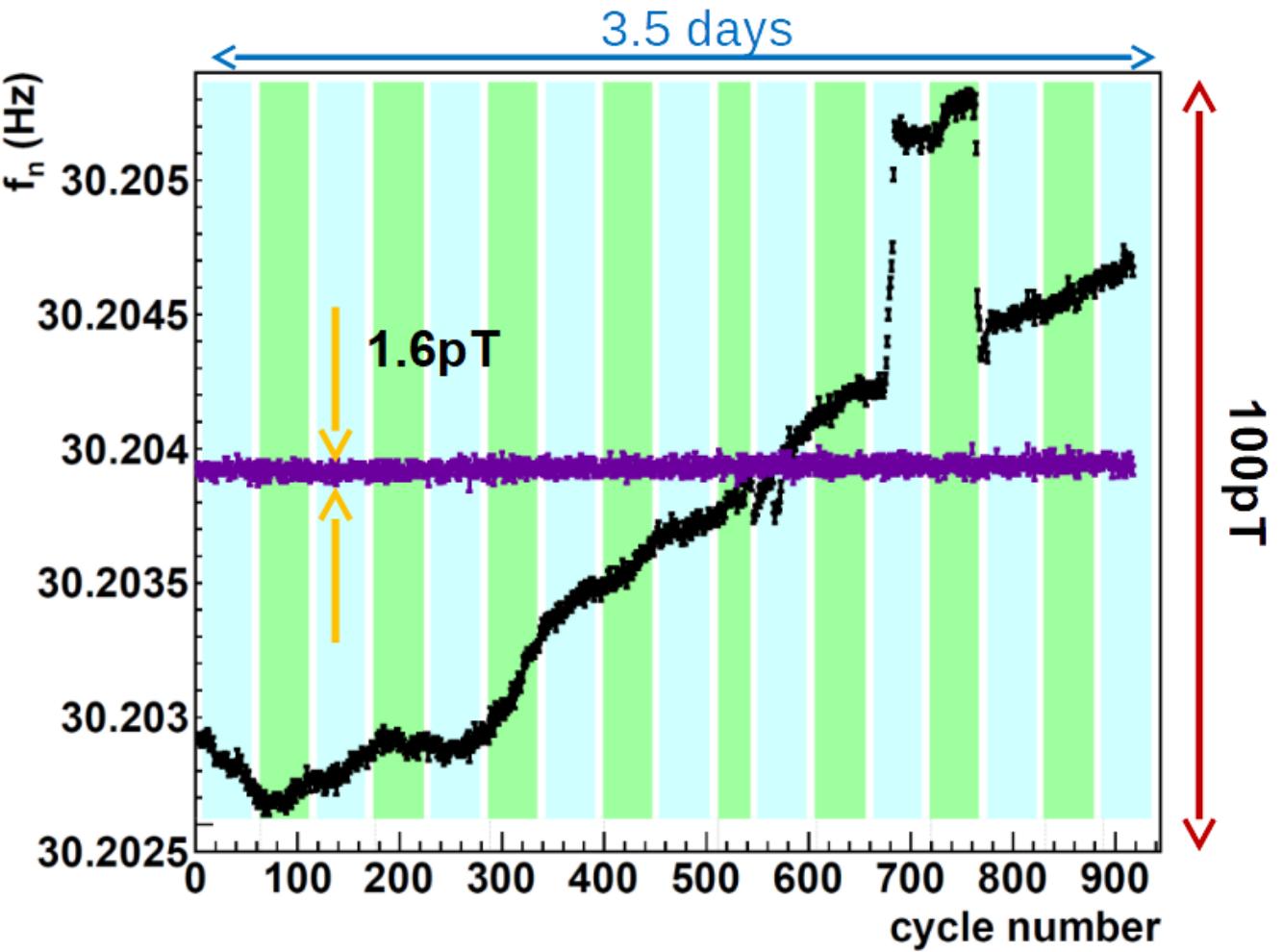
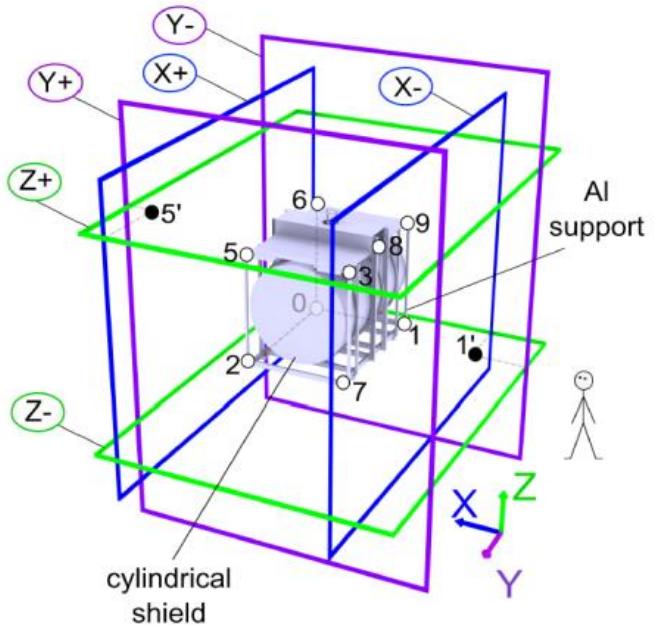


Mercury co-magnetometer (1998)

$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n B_n}{\gamma_{Hg} B_{Hg}} = \frac{\gamma_n}{\gamma_{Hg}}$$

Cesium magnetometer array (2009)

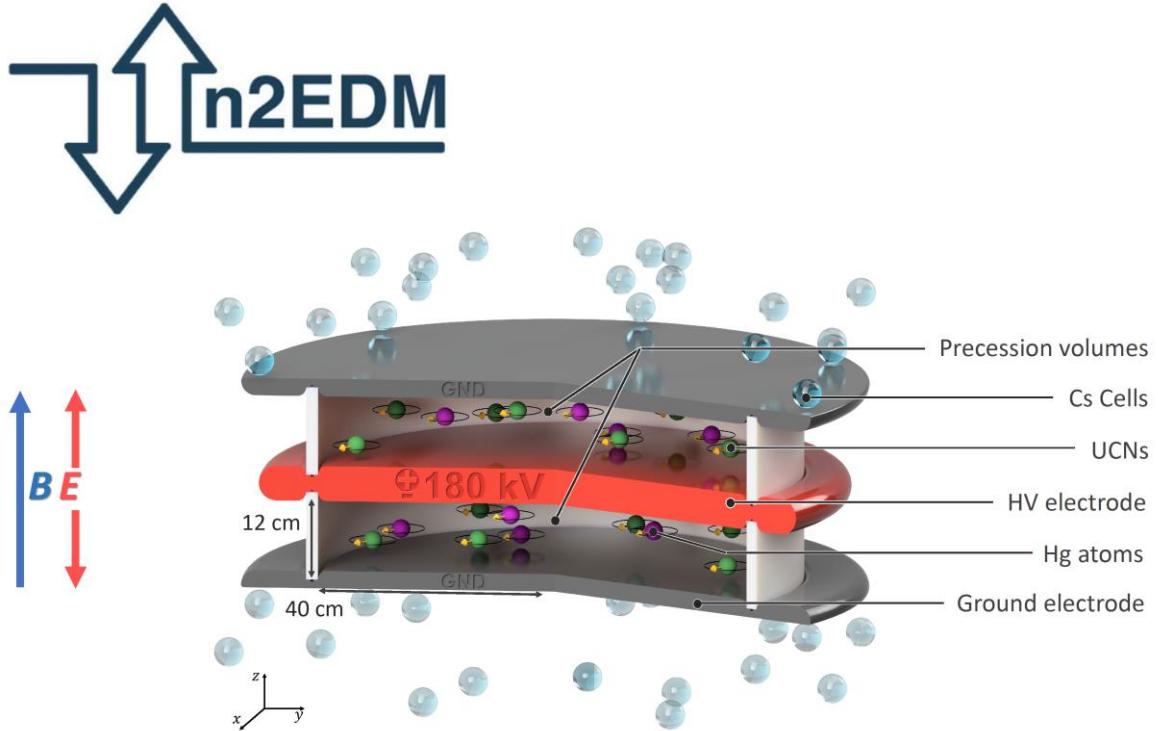
# The search for the neutron EDM



# The search for the neutron EDM

First limitation .... Magnetic field fluctuations

$$\begin{aligned}
 h f_n (\uparrow\uparrow) &= 2 \vec{\mu}_n \cdot \vec{B}(\uparrow\uparrow) + 2 \vec{d}_n \cdot \vec{E}(\uparrow\uparrow) \\
 h f_n (\uparrow\downarrow) &= 2 \vec{\mu}_n \cdot \vec{B}(\uparrow\downarrow) - 2 \vec{d}_n \cdot \vec{E}(\uparrow\downarrow) \\
 \hline
 h(f_n (\uparrow\uparrow) - f_n (\uparrow\downarrow)) &= 2 \vec{\mu}_n \cdot (\vec{B}(\uparrow\uparrow) - \vec{B}(\uparrow\downarrow)) - 2 \vec{d}_n \cdot (\vec{E}(\uparrow\uparrow) + \vec{E}(\uparrow\downarrow))
 \end{aligned}$$



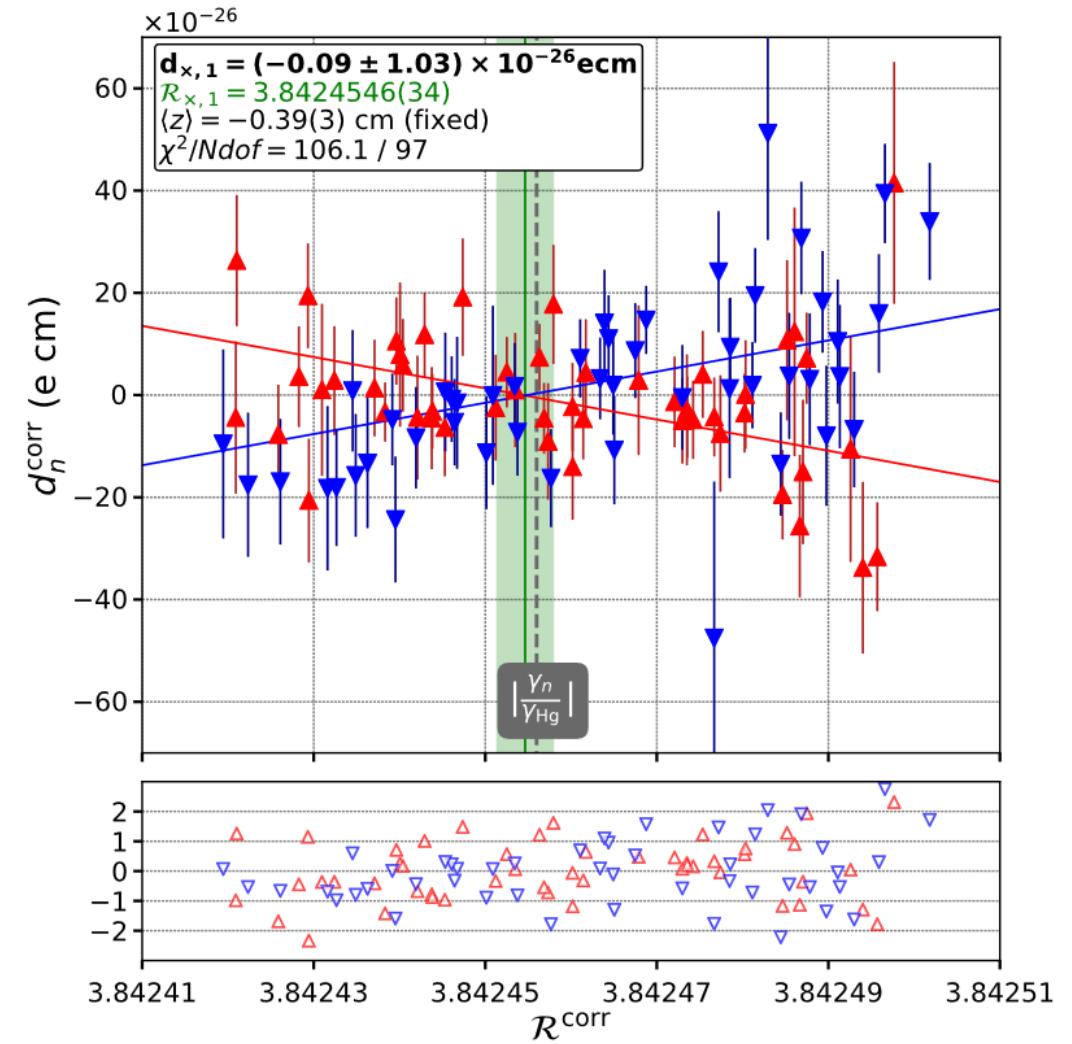
$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n B_n}{\gamma_{Hg} B_{Hg}} = \frac{\gamma_n}{\gamma_{Hg}}$$

$$d_n = \frac{\pi h f_{Hg}}{4|E|} (\mathcal{R}_{\uparrow\downarrow}^T - \mathcal{R}_{\uparrow\uparrow}^T + \mathcal{R}_{\uparrow\downarrow}^B - \mathcal{R}_{\uparrow\uparrow}^B)$$

# The search for the neutron EDM

TABLE I. Summary of systematic effects in  $10^{-28} e.\text{cm}$ . The first three effects are treated within the crossing-point fit and are included in  $d_x$ . The additional effects below that are considered separately.

| Effect  | Shift     | Error     |                                  |
|---|-----------|-----------|----------------------------------|
| Error on $\langle z \rangle$                        | ...       | 7         | $(0 \pm 68)$                     |
| Higher-order gradients $\hat{G}$                    | 69        | 10        | $(33 \pm 14)$                    |
| Transverse field correction $\langle B_T^2 \rangle$ | 0         | 5         |                                  |
| Hg EDM [8]  | -0.1      | 0.1       |                                  |
| Local dipole fields                                 | ...       | 4         | $(-71 \pm 81)$                   |
| $v \times E$ UCN net motion                         | ...       | 2         |                                  |
| Quadratic $v \times E$                              | ...       | 0.1       |                                  |
| Uncompensated $G$ drift                             | ...       | 7.5       |                                  |
| Mercury light shift                                 | ...       | 0.4       |                                  |
| Inc. scattering $^{199}\text{Hg}$                   | ...       | 7         |                                  |
| <b>TOTAL</b>  | <b>69</b> | <b>18</b> | <b><math>(-38 \pm 99)</math></b> |



$$d_n = (0.0 \pm 1.1_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-26} e.\text{cm}.$$

# The search for the neutron EDM

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TABLE I. Summary of systematic effects in  $10^{-28} e.\text{cm}$ . The first three effects are treated within the crossing-point fit and are included in  $d_x$ . The additional effects below that are considered separately.

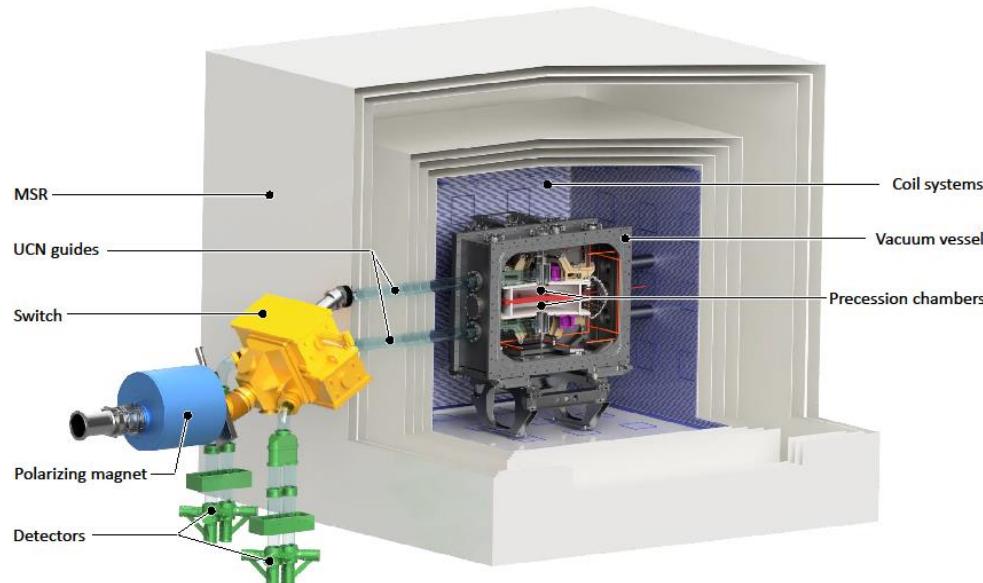
| Effect  | Shift | Error |
|---|-------|-------|
| Error on $\langle z \rangle$                        | ...   | 7     |
| Higher-order gradients $\hat{G}$                    | 69    | 10    |
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| Uncompensated $G$ drift                             | ...   | 7.5   |
| Mercury light shift                                 | ...   | 0.4   |
| Inc. scattering $^{199}\text{Hg}$                   | ...   | 7     |
| TOTAL   | 69    | 18    |

How to build n2EDM to push further the limit?

- Double chamber concept + Co-magnetometer
- Design
  - To push up the statistic  
-> make your spectrometer bigger
  - To push down the systematic error  
-> make your spectrometer smaller

$$d_n = (0.0 \pm 1.1_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-26} e.\text{cm.}$$

# n2EDM



|                         | nEDM 2016                  | n2EDM baseline             |
|-------------------------|----------------------------|----------------------------|
| chamber diameter $D$    | DLC & dPS<br>47 cm         | DLC & dPS<br>80 cm         |
| $N$ (per cycle)         | 15'000                     | 121'000                    |
| $T$                     | 180 s                      | 180 s                      |
| $E$                     | 11 kV/cm                   | 15 kV/cm                   |
| $\alpha$                | 0.75                       | 0.8                        |
| $\sigma(f_n)$ per cycle | 9.6 $\mu$ Hz               | 4.5 $\mu$ Hz               |
| $\sigma(d_n)$ per day   | $11 \times 10^{-26}$ e·cm  | $2.6 \times 10^{-26}$ e·cm |
| $\sigma(d_n)$ (final)   | $9.5 \times 10^{-27}$ e·cm | $1.1 \times 10^{-27}$ e·cm |

Switch  
Hg polarisation chamber  
Mapper

Data management  
Analysis  
Systematic effects

Thomas BOUILLAUD  
Ksenia SVIRINA  
Selim TOUATI  
Romain VIROT

Benoit CLEMENT  
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Guillaume PIGNOL  
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DéTECTEURS et INSTRUMENTATION)  
O. Bourrion, C. Vescovi (Service ÉLECTRONIQUE)

## n2EDM in reality ....

