PAUL SCHERRER INSTITUT

PSI

Georg Bison, for the n2EDM collaboratrion :: Paul Scherrer Institute

Systematic uncertainties caused by magnetic dipoles

nEDM Workshop 2023

n2EDM

PSI nEDM result

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

Effect	shift	error
Error on $\langle z \rangle$	-	7
Higher order gradients $\hat{G}$	69	10
Transverse field correction $\langle B_T^2 \rangle$	0	5
Hg EDM[8]	-0.1	0.1
Local dipole fields	-	4
$v \times E$ UCN net motion	-	2
Quadratic $v \times E$	-	0.1
Uncompensated G drift	-	7.5
Mercury light shift	-	0.4
Inc. scattering ^{199}Hg	-	7
TOTAL	69	18

10^{-28} $e$cm

Measurement of the Permanent Electric Dipole Moment of the Neutron. Abel et al., Phys. Rev. Lett. **124**, 081803

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n2EDM → $\pm 0.1_{\mathrm{stat}} \pm 0.03_{\mathrm{sys}}$

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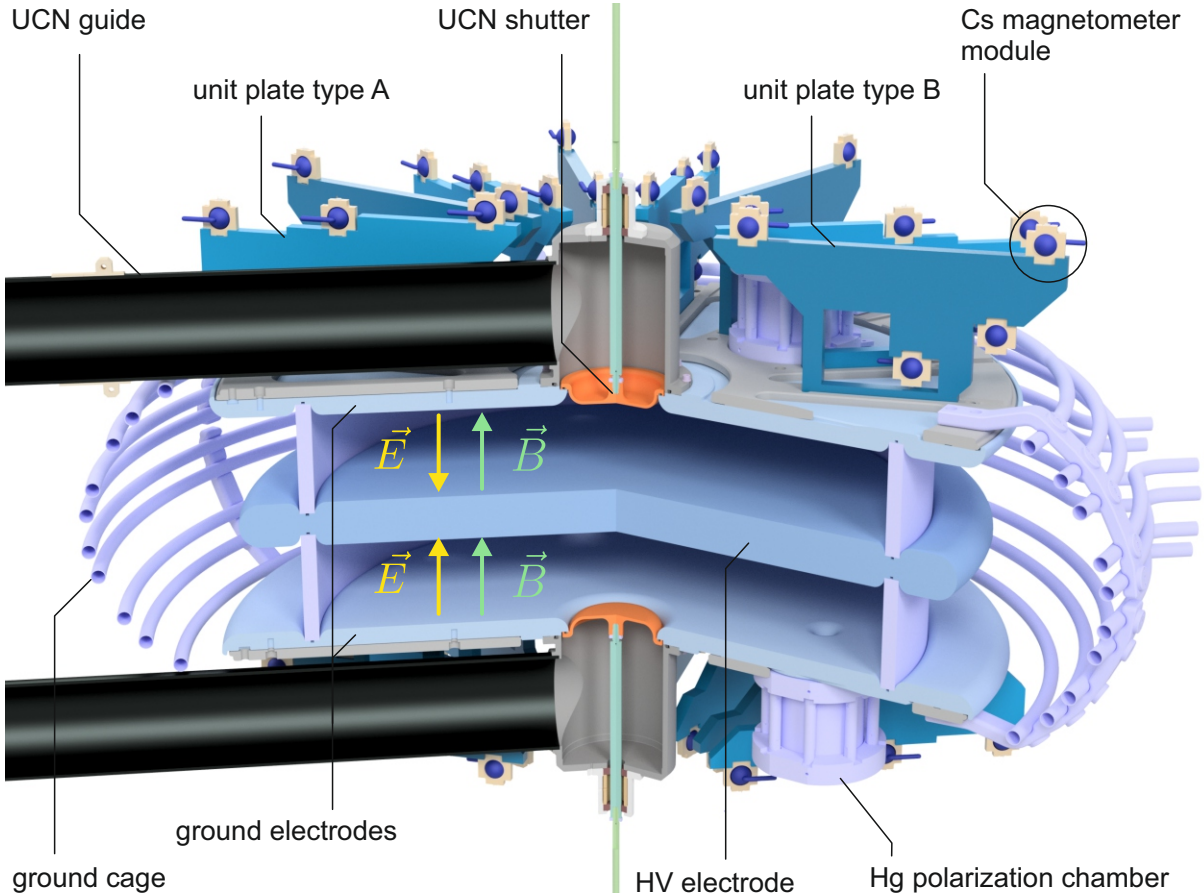
10^{-28} ecm

10^{-27} statistics

need

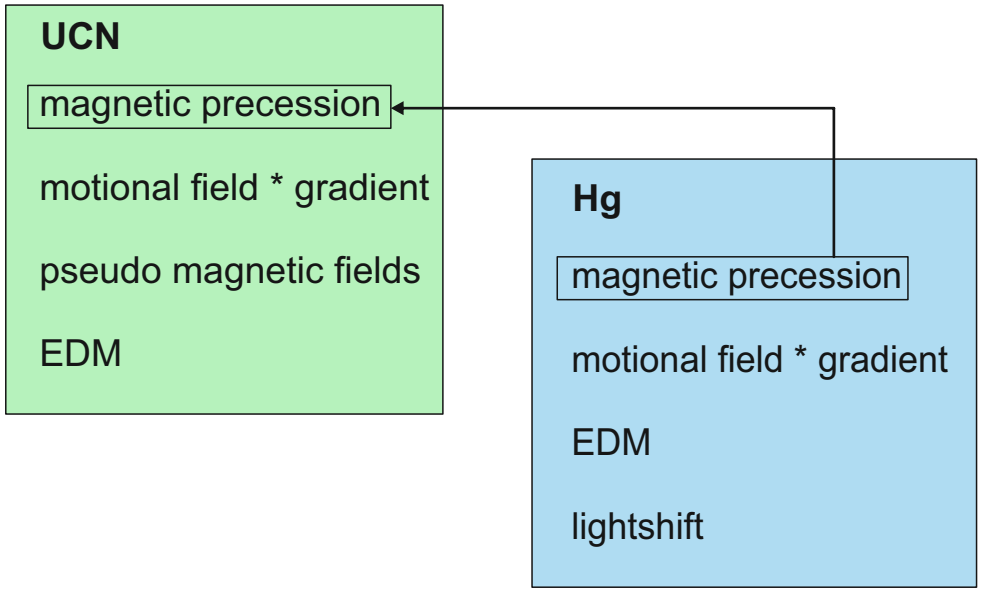
10^{-28} systematics

Overview n2EDM



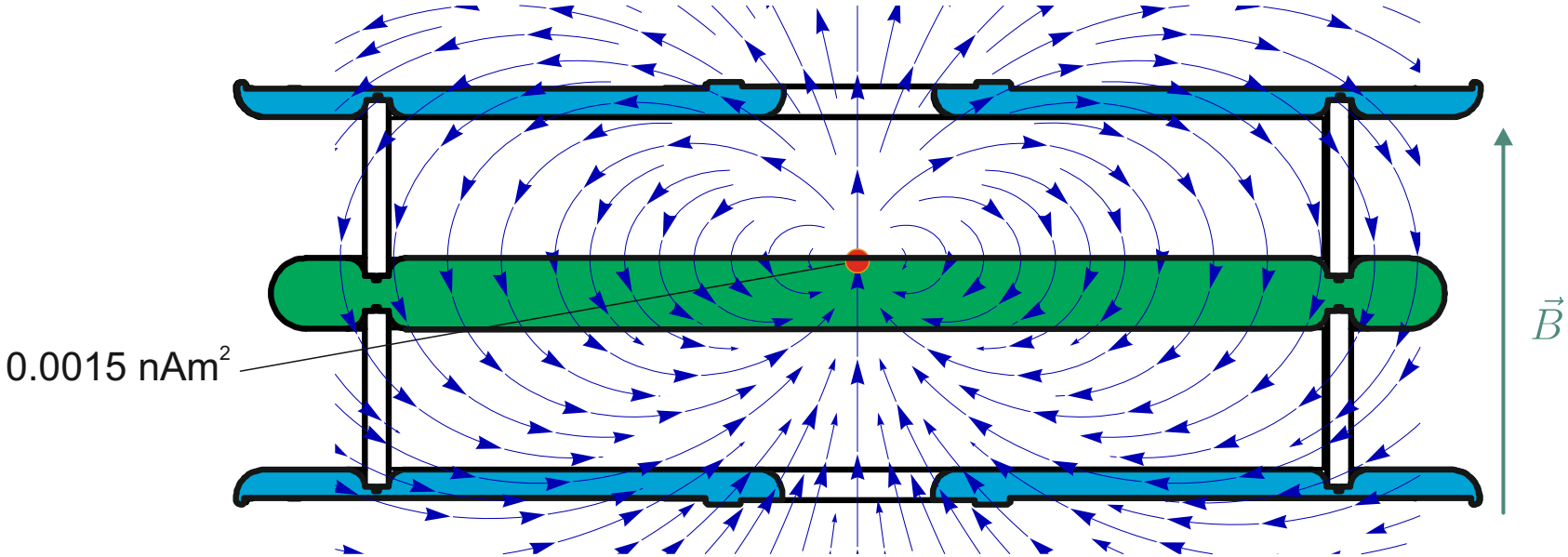
Magnetometry Strategy

contributions to the Larmor frequency



Correlated Dipoles

$3\ 10^{-28}$ e cm @ 15 kV $\Rightarrow$ $\Delta\nu$ = 2.1 nHz $\Rightarrow$ ΔB = 0.075 fT



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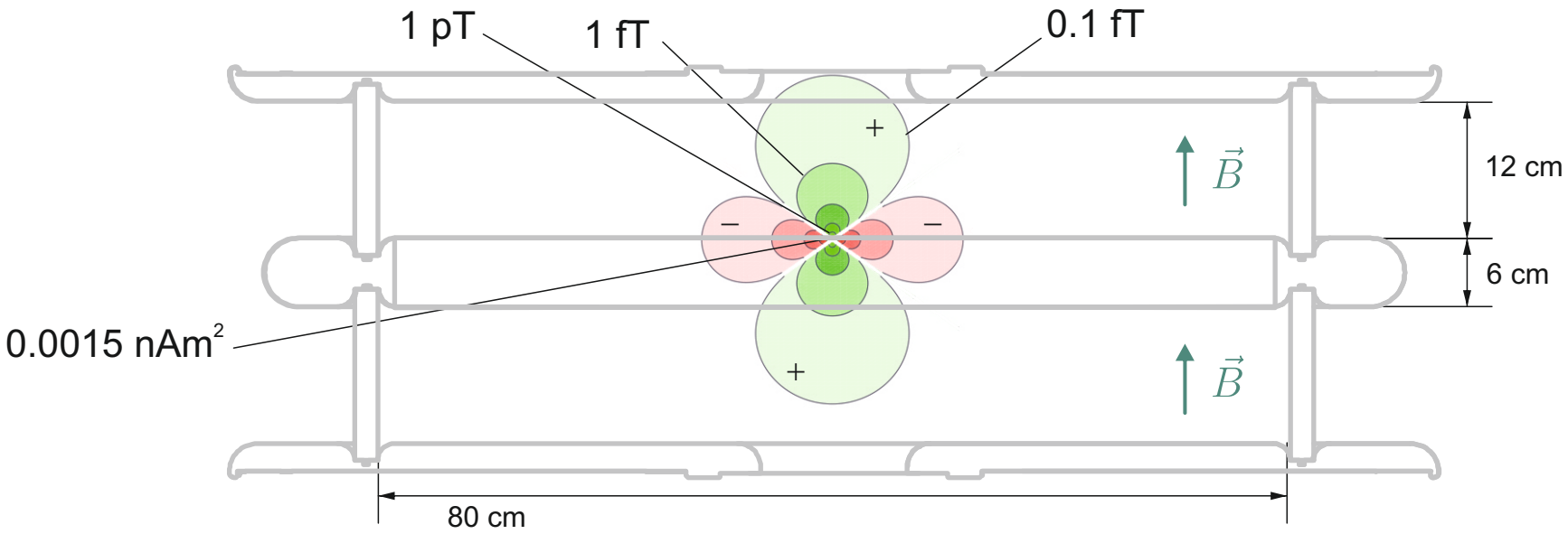

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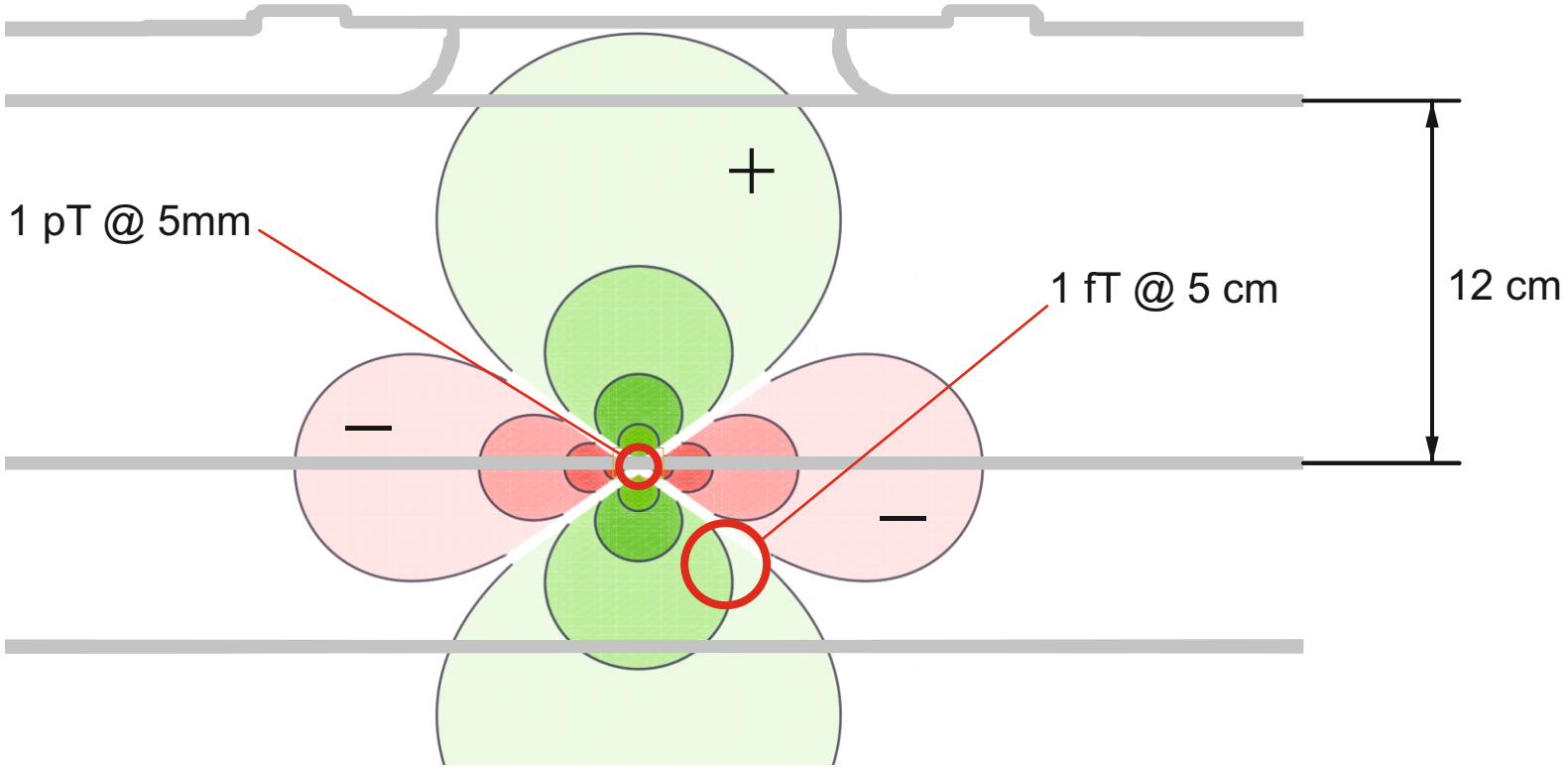

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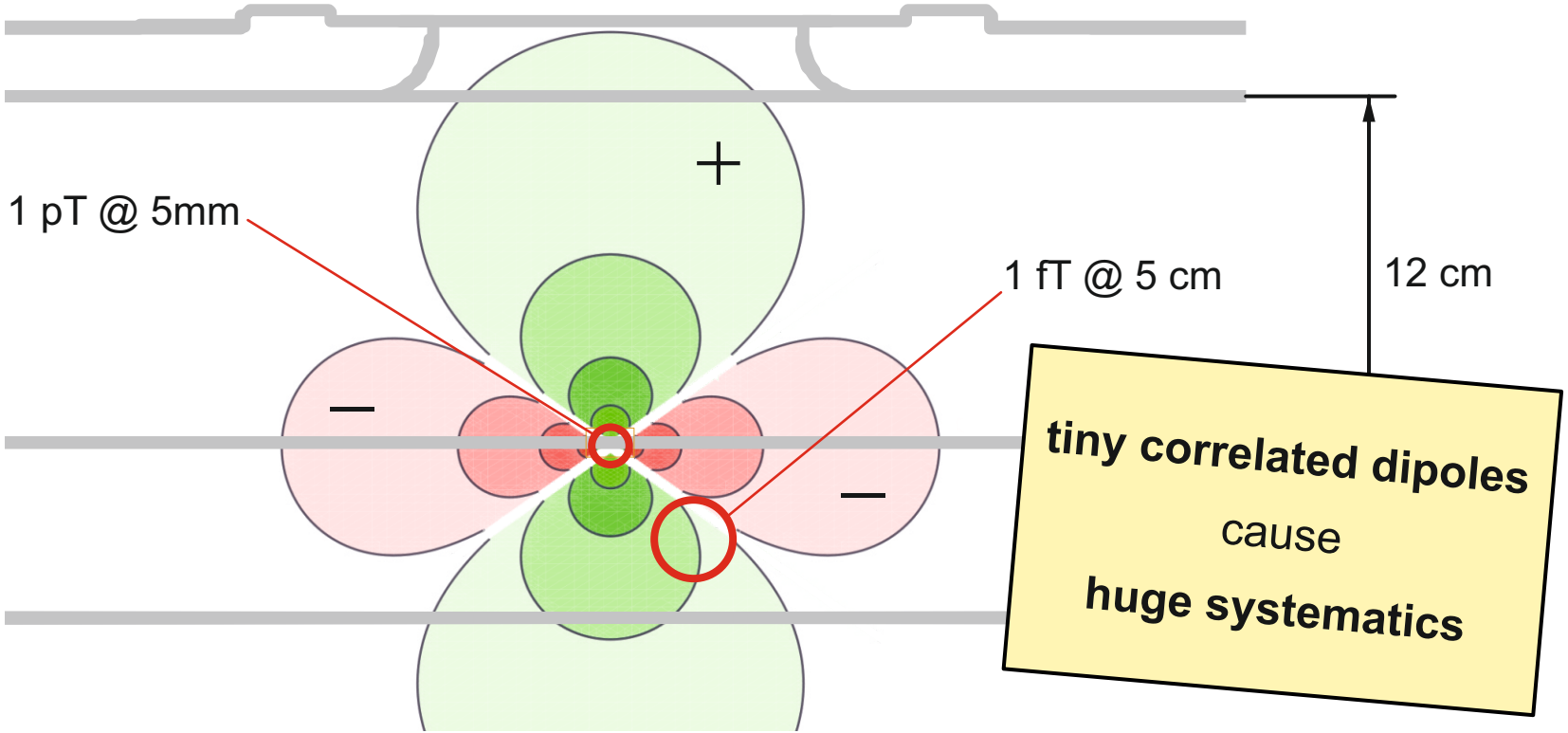
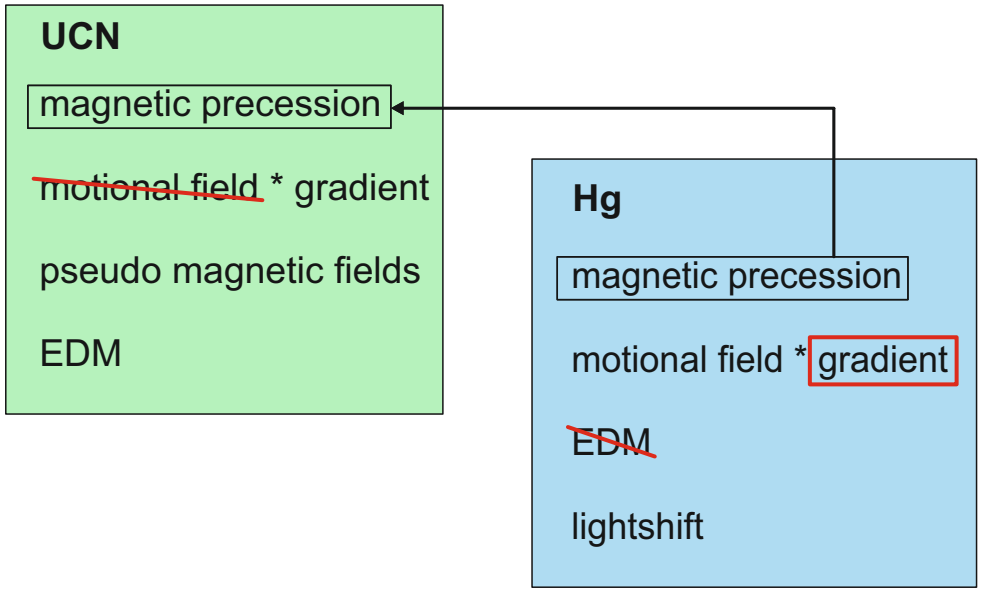


Magnetometry Strategy

contributions to the Larmor frequency



Magnetometry Strategy

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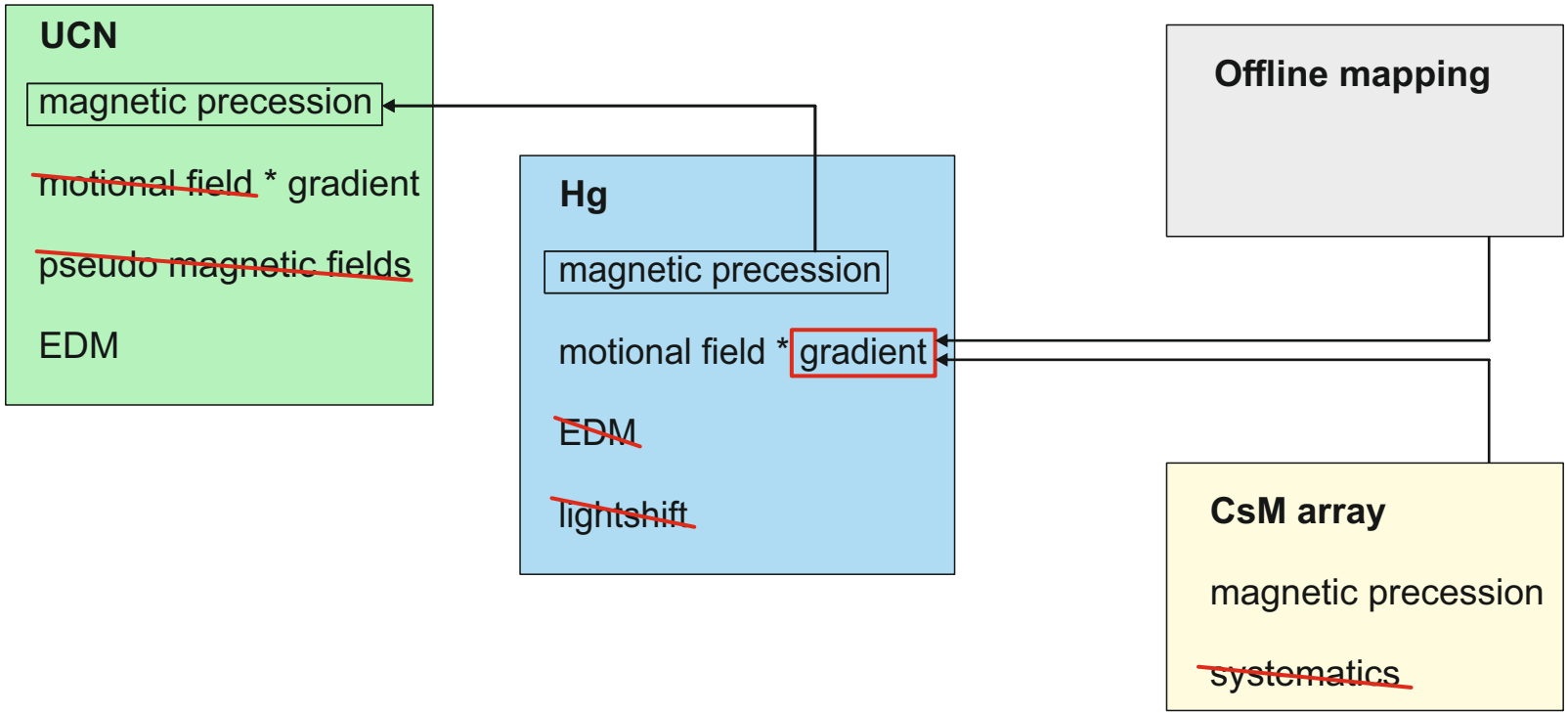
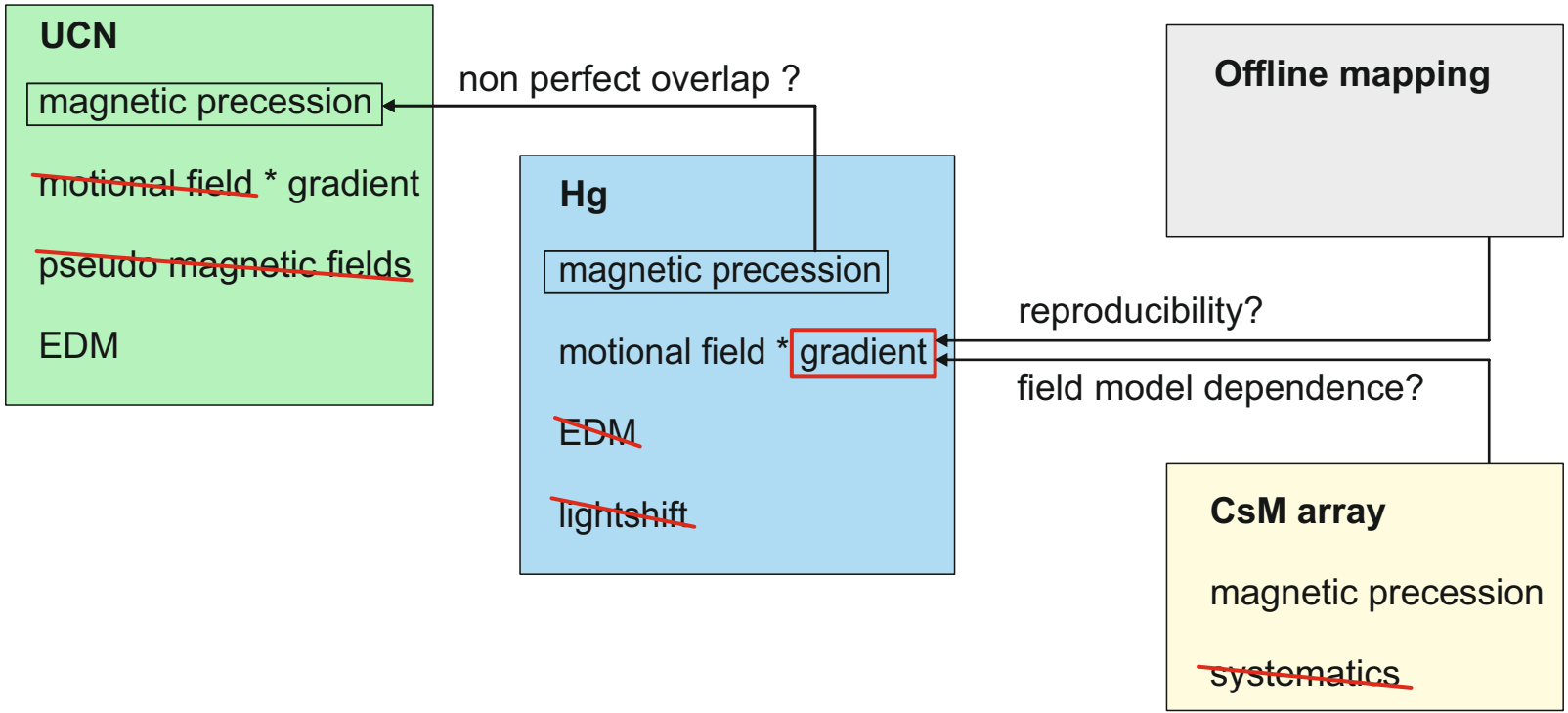


Magnetometry Strategy

contributions to the Larmor frequency



Magnetometry Strategy

contributions to the Larmor frequency

$$d_{\text{false}} = \underbrace{\frac{\hbar\,\gamma_{Hg}\,\gamma_n}{2c^2}}_{C} \langle x B_x + y B_y \rangle$$

Offline mapping

reproducibility?

field model dependence?

CsM array

magnetic precession

~~systematics~~

Electric-dipole-moment searches: Reexamination of frequency shifts for particles in traps, G. Pignol & S. Roccia, Phys. Rev. A 85, 042105 (2012)

Calculating false EDMs

choose magnetic field: B0 + gradient/dipole

field magnitude at Cs positions B_i

multipole order 3..10

$$G_j = \sum_i M_{ij}^{-1} B_i$$

$$d_{Cs}^{f1} = C \sum G_j S_j^1$$

$$d_{Cs}^{f2} = C \sum G_j S_j^2$$

$$d_{Hg->n}^{f1} = \frac{C}{V} \int x B_x + y B_y \, dV_{C1}$$

$$d_{Hg->n}^{f2} = \frac{C}{V} \int x B_x + y B_y \, dV_{C2}$$

Calculating the false EDMs

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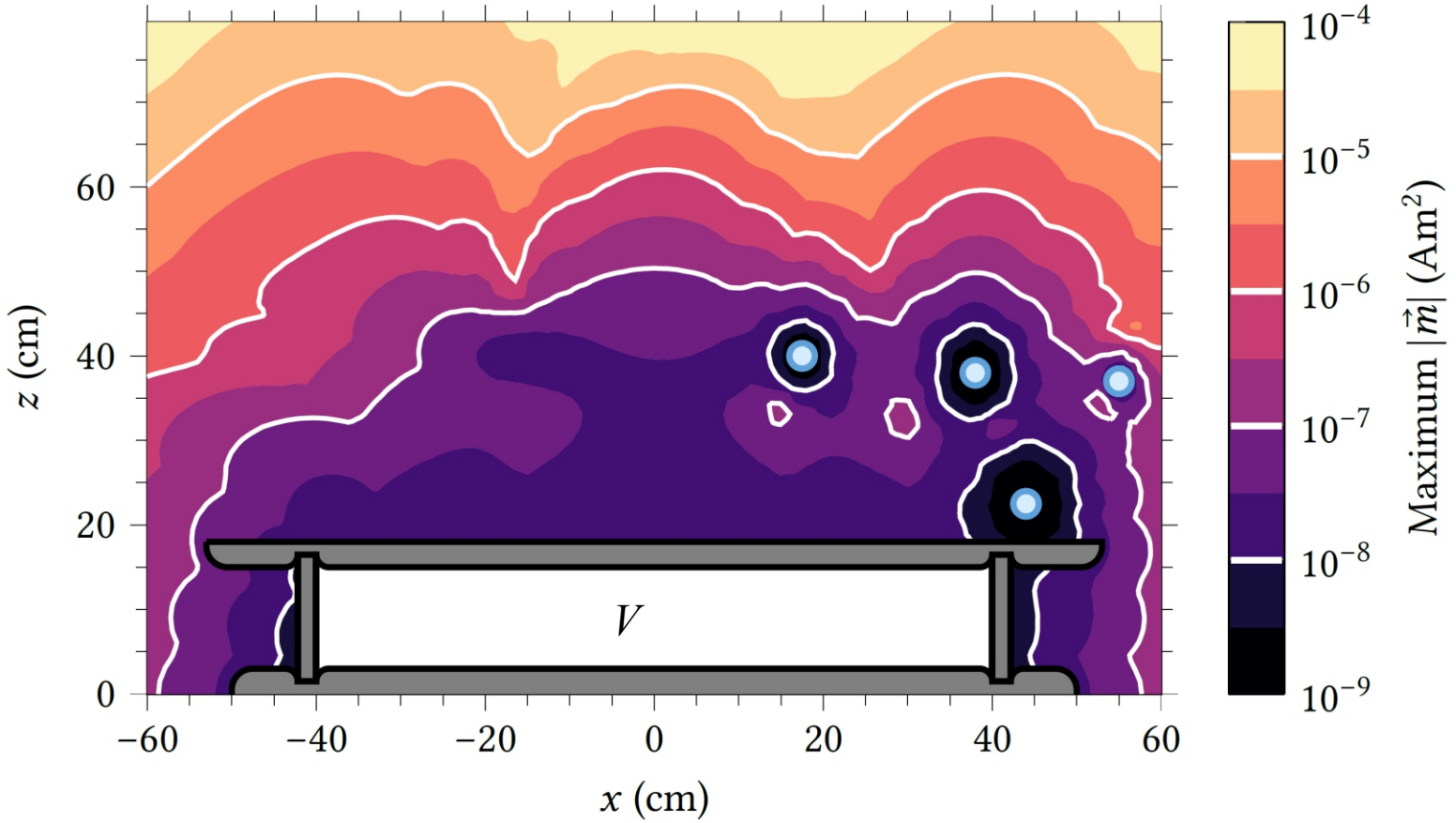
$$d_{Hg->n}^{f2} = \frac{C}{V} \int x B_x + y B_y \, dV_{C2}$$

multipole order 5

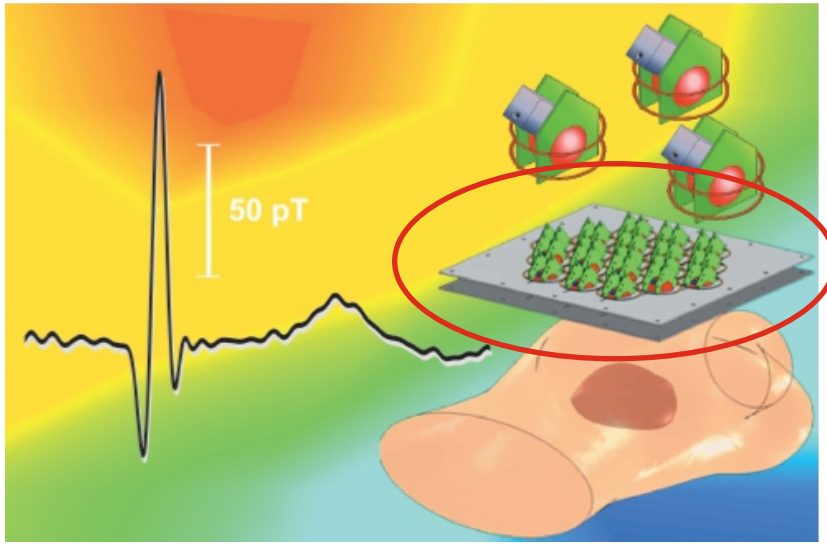
CsM positions

stack geometry

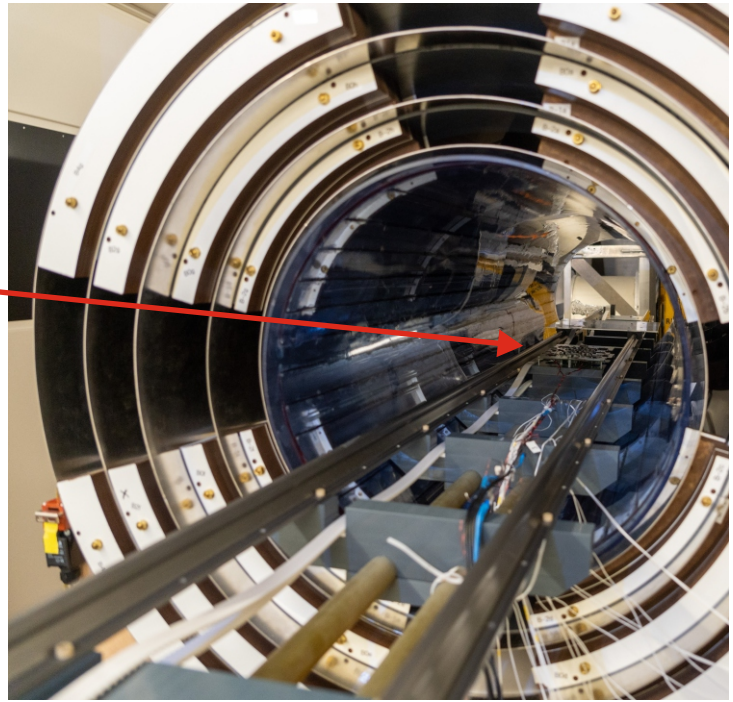
Dipole effect map



Magnetic dipole contamination



A room temperature 19-channel magnetic field mapping device for cardiac signals. GB et al., Appl. Phys. Lett. **95** (17): 173701 (2009).



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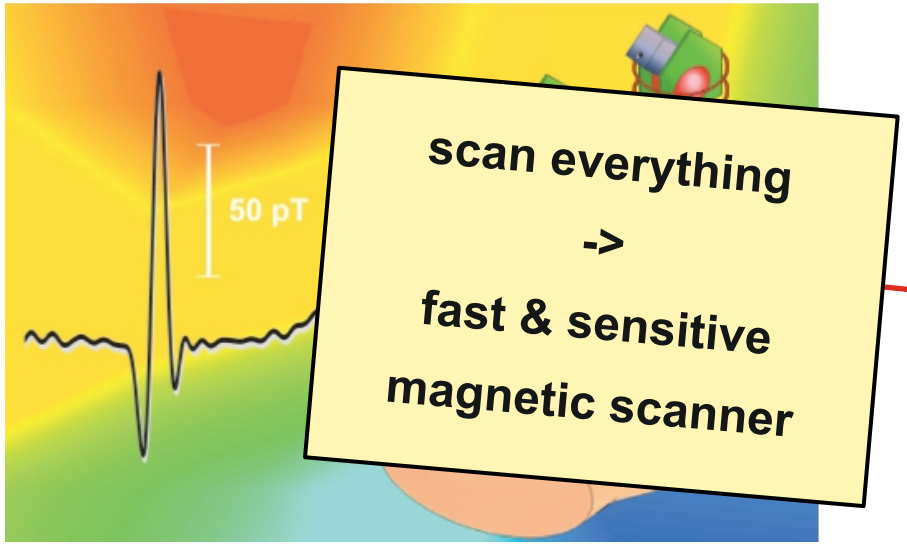

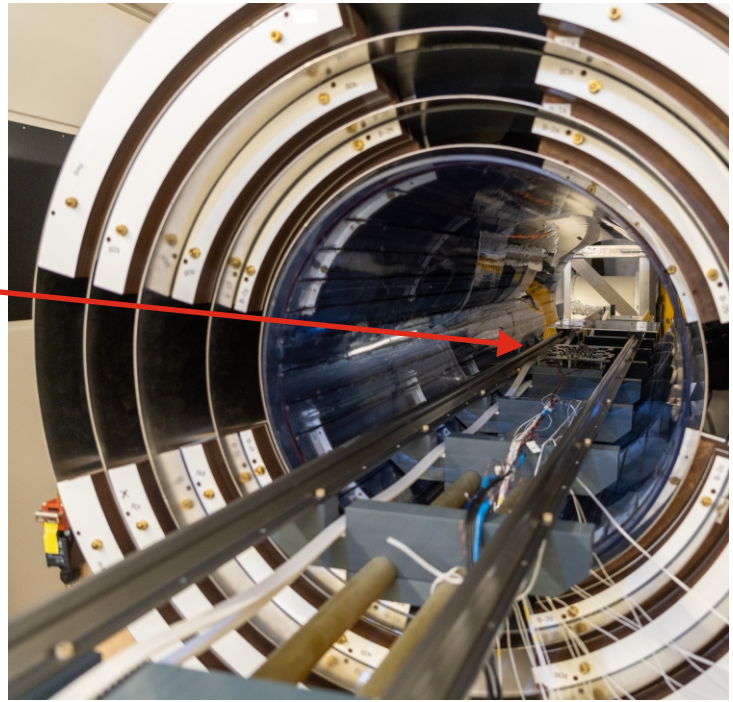

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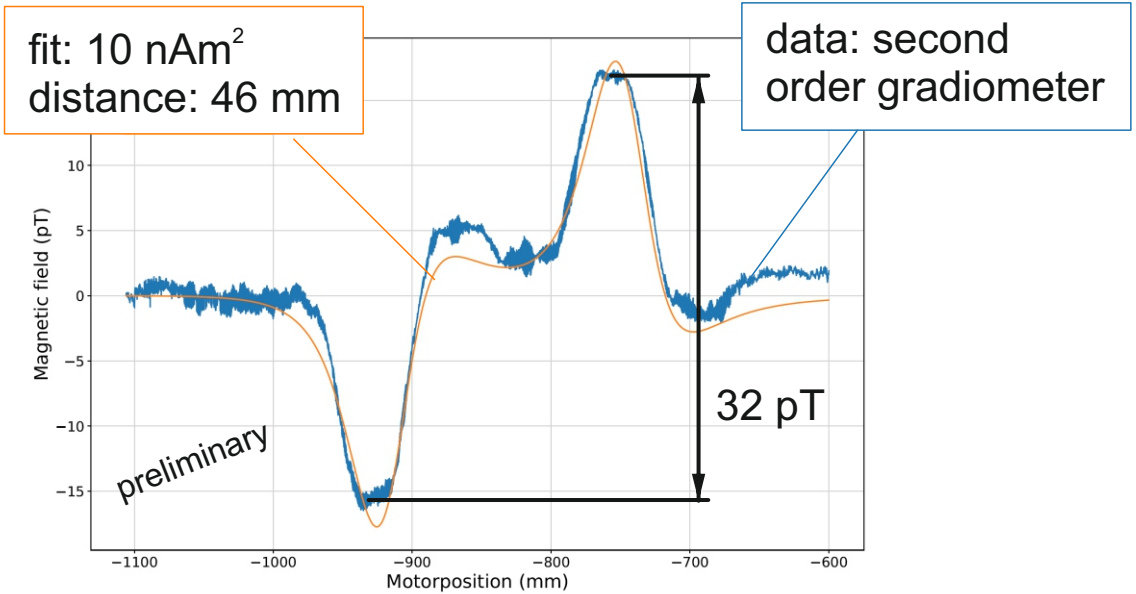
Magnetic dipole contamination

magnetize part with 30 mT → measure → demagnetize part

PEEK part alone, after repeated careful cleaning



Magnetic dipole contamination

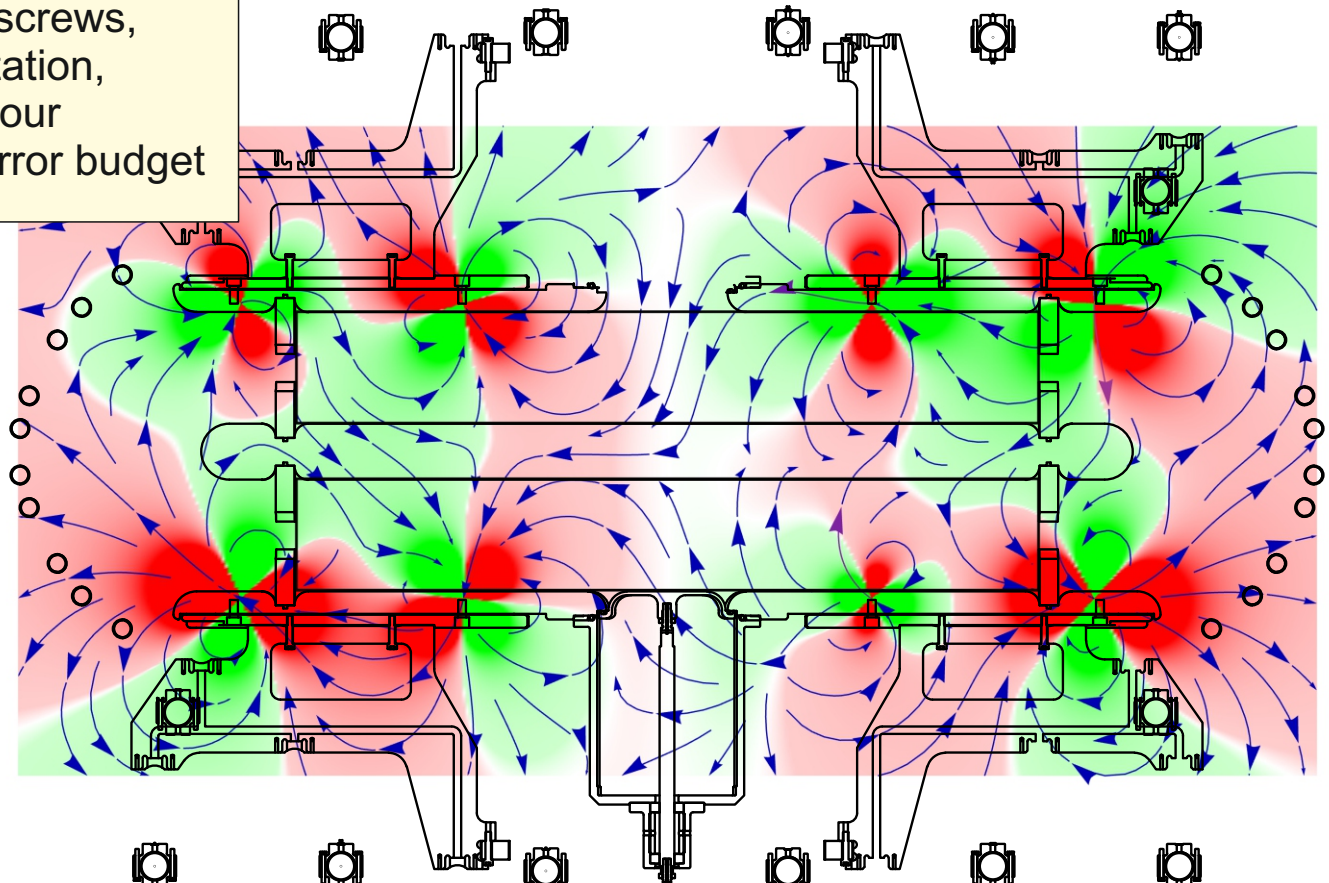
magnetize part with 30 mT → measure → demagnetize part

PEEK part alone, after repeated careful cleaning

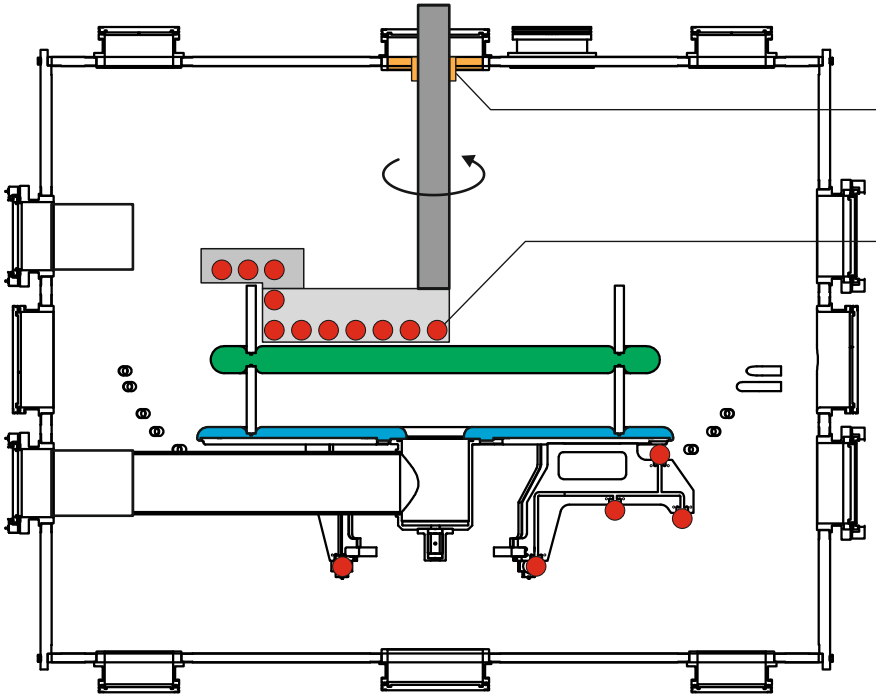
everything is magnetizable at some level

Random dipole configuration

all helicoils + screws, random orientation, worth 34% of our systematics error budget



Internal mapper



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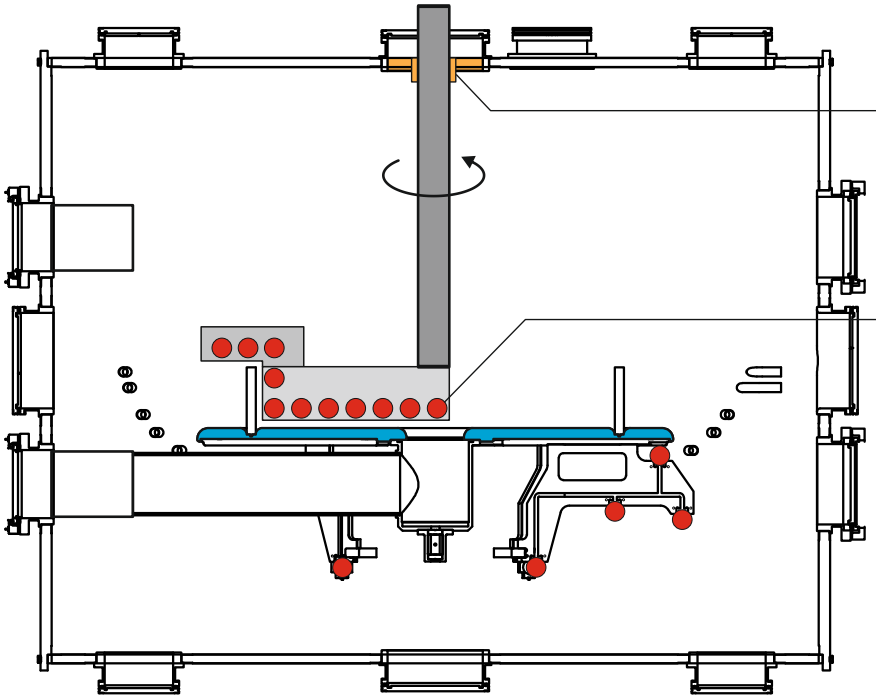
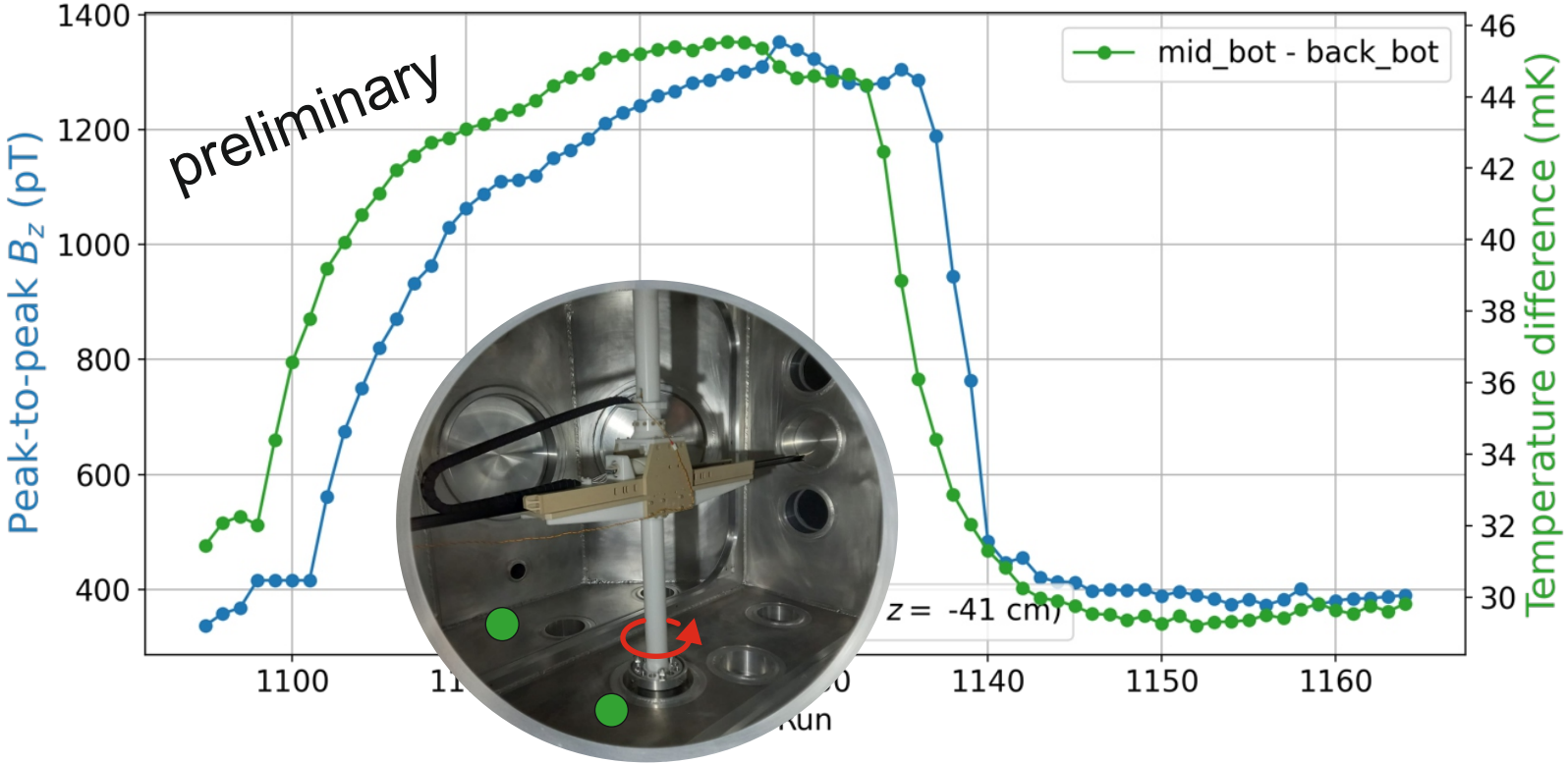


Thermo-magnetic effect



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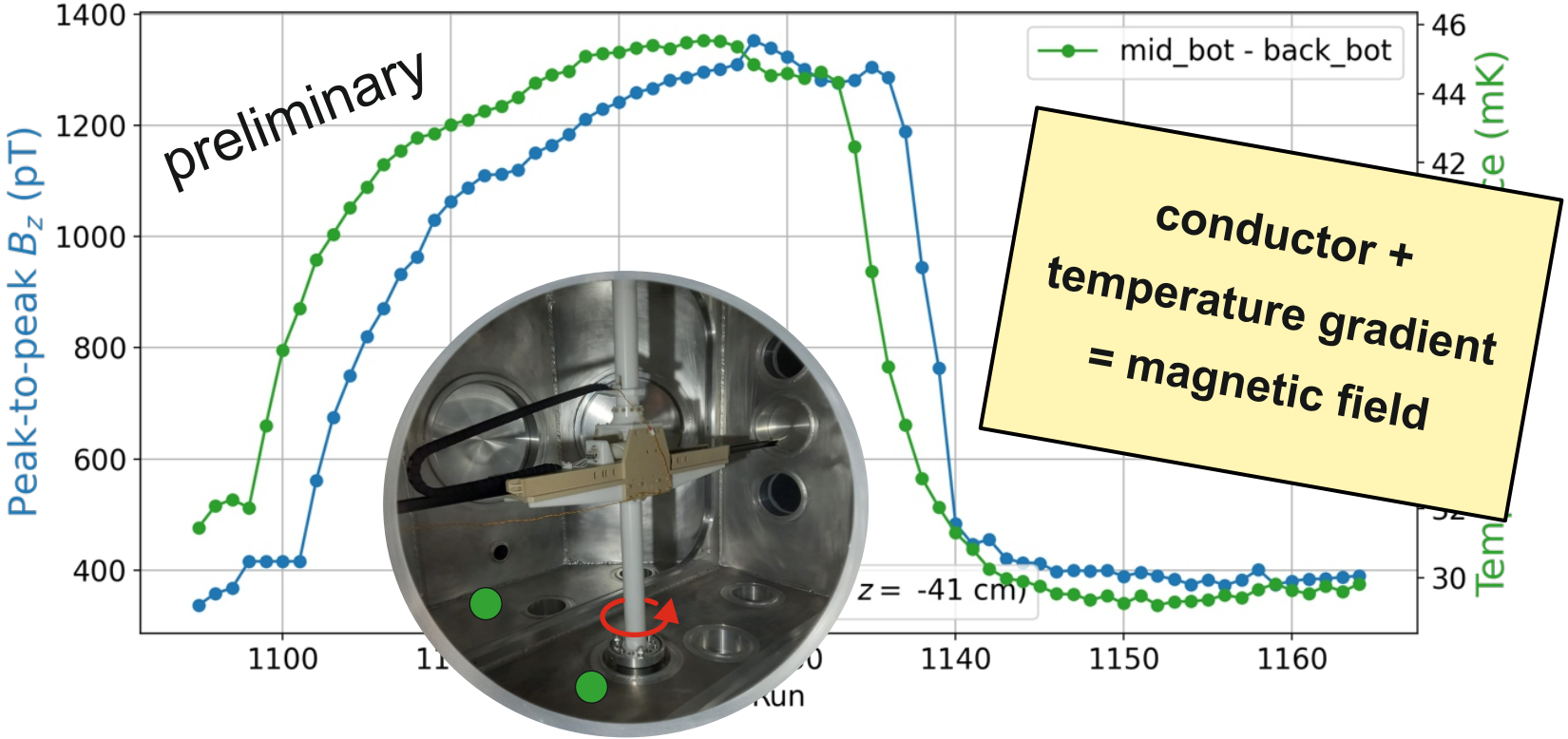

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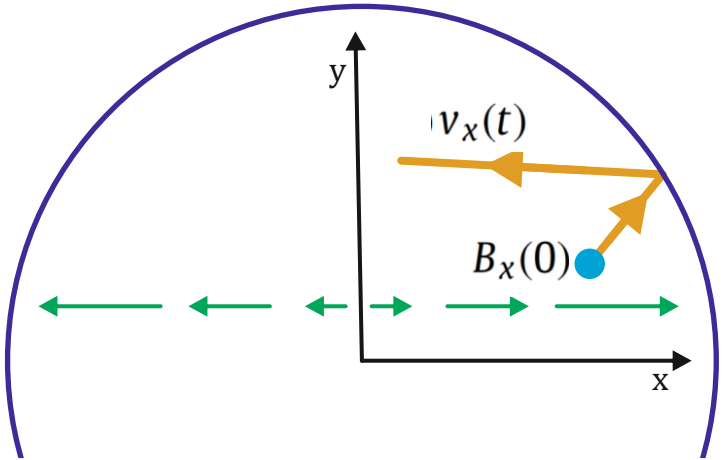
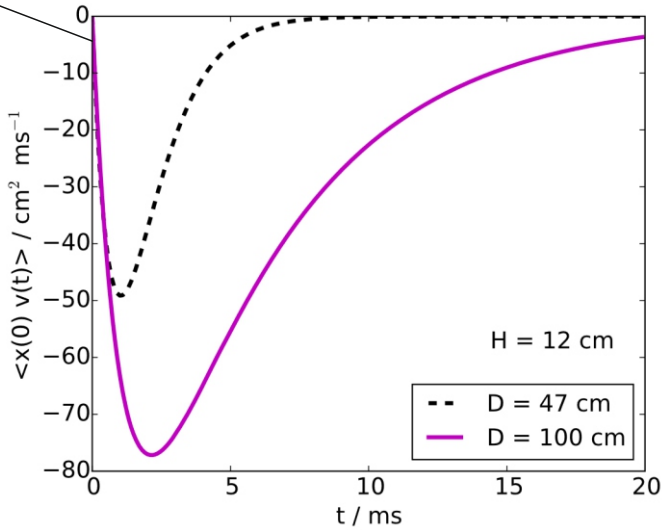
Magic Field

$$d_n^{\text{false}} = \frac{\hbar|\gamma_n\gamma_{\text{Hg}}|}{2c^2}\int_0^\infty \langle B_x(0)v_x(t) + B_y(0)v_y(t)\rangle \cos\omega t\, dt$$



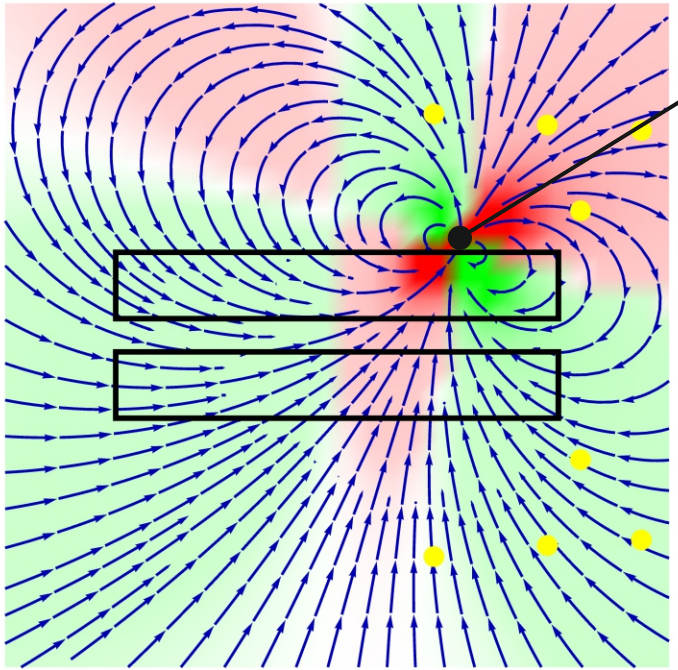


A magic magnetic field to measure the neutron electric dipole moment, G. Pignol, Phys. Lett. B, 793, pp 440-444 (2019).

Frequency shifts and relaxation rates for spin-1/2 particles moving in electromagnetic fields, G. Pignol, M. Guigue, A. Petukhov, and R. Golub, Phys. Rev. A 92, 053407 (2015).

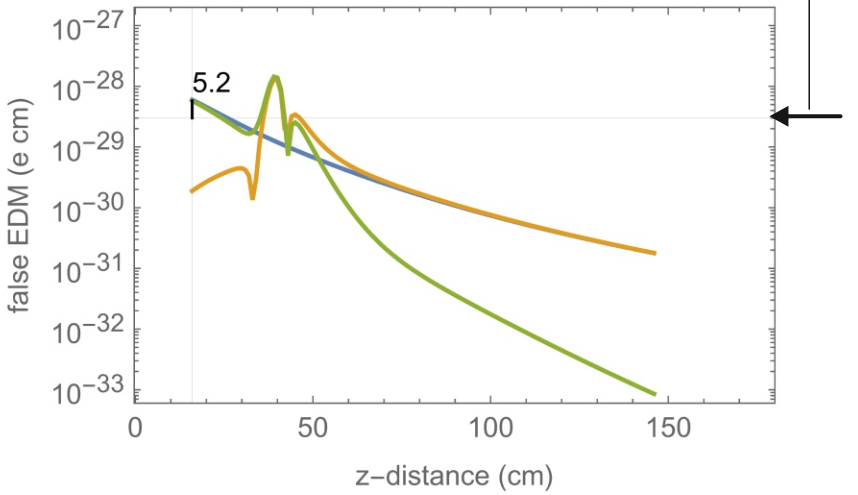
The nEDM collaboration

Dipole field



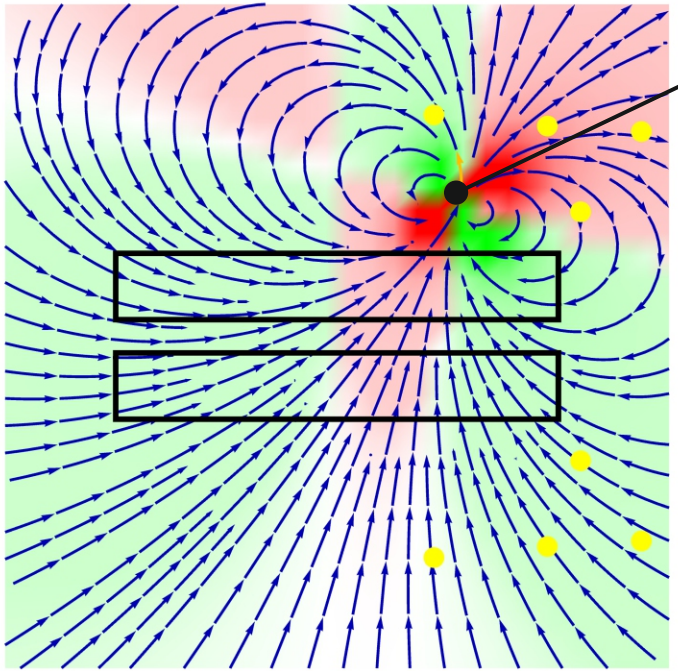
$|m| = 10\ \text{nA m}^2$

$3 \cdot 10^{-29}$ e cm



$d^{f1}_{Hg->n}$ d^{f1}_{Cs} $d^{f1}_{Hg->n} - d^{f1}_{Cs}$

Dipole field



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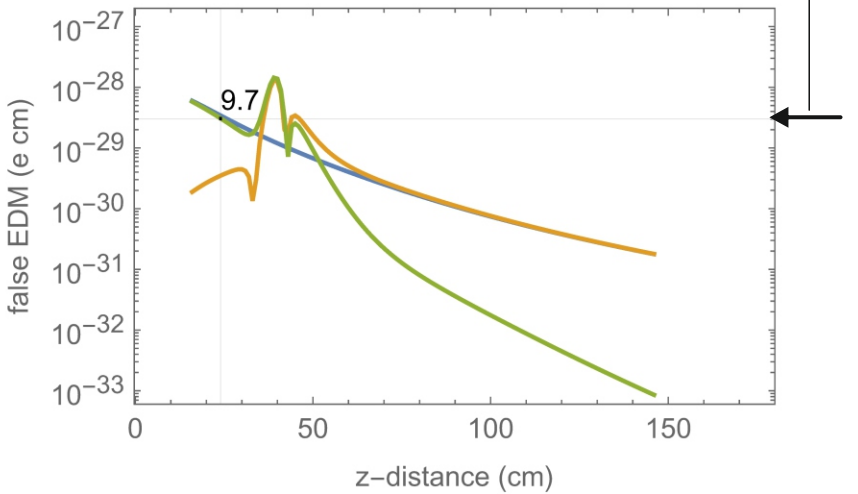

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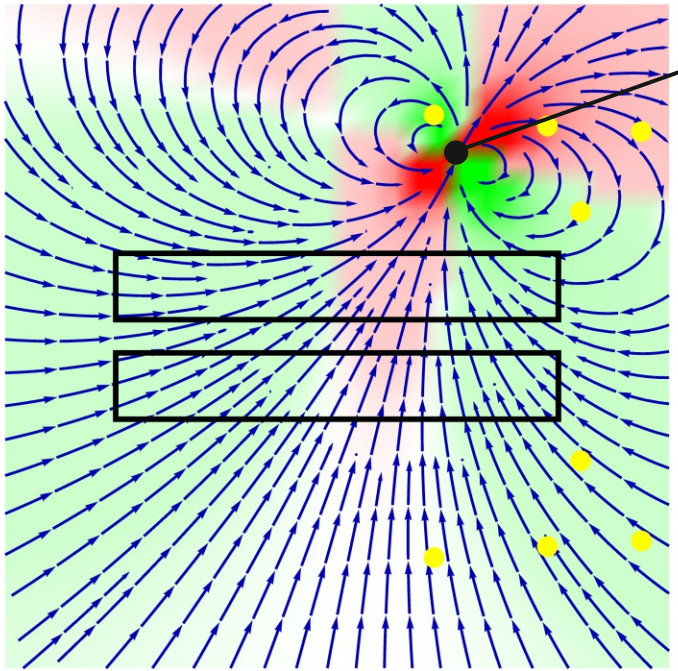

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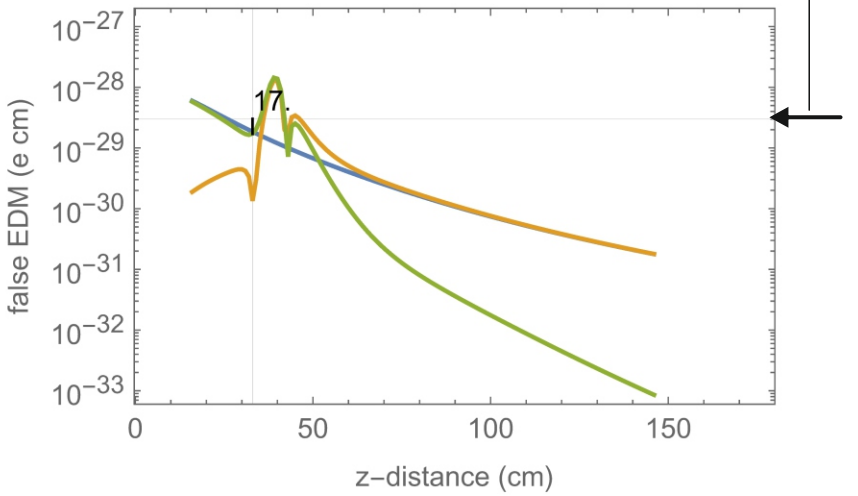

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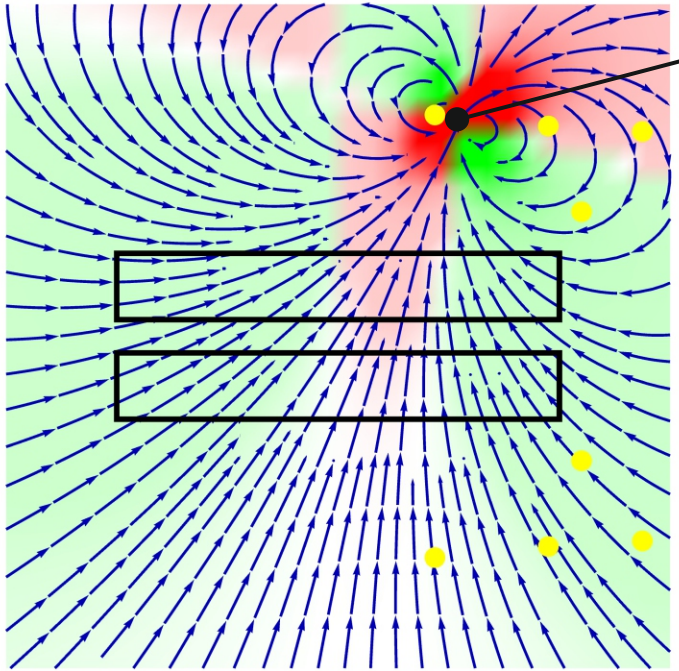

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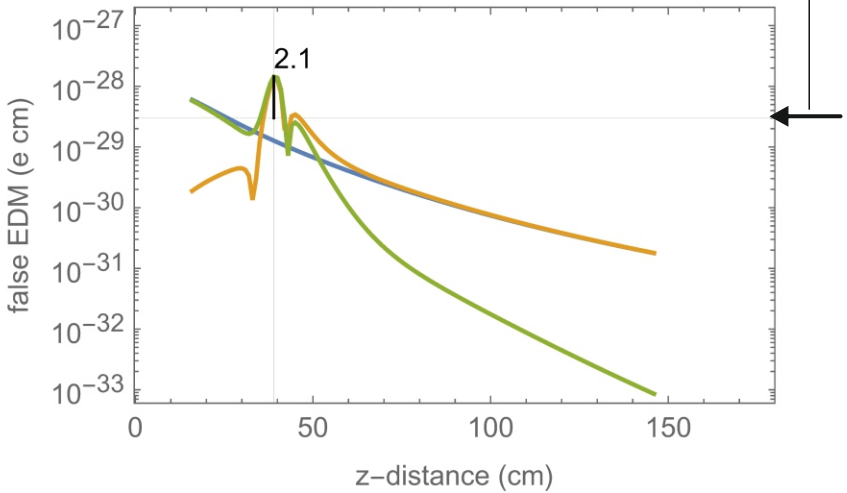

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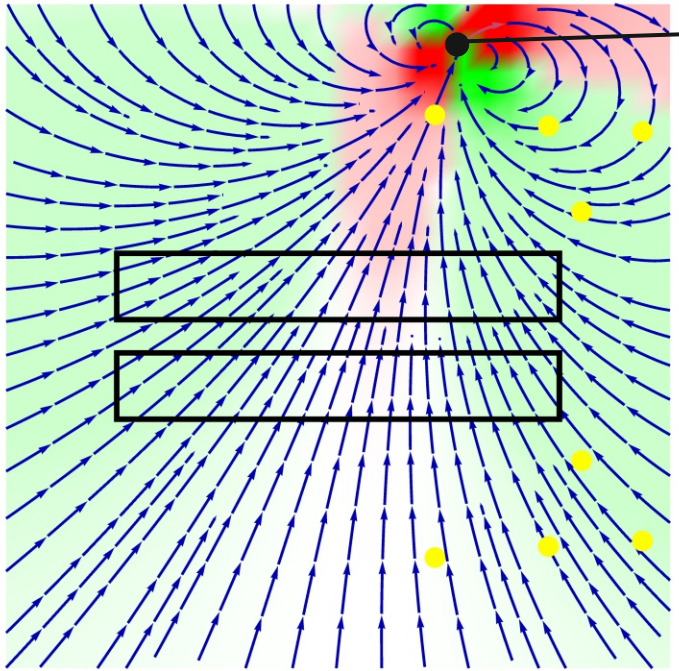

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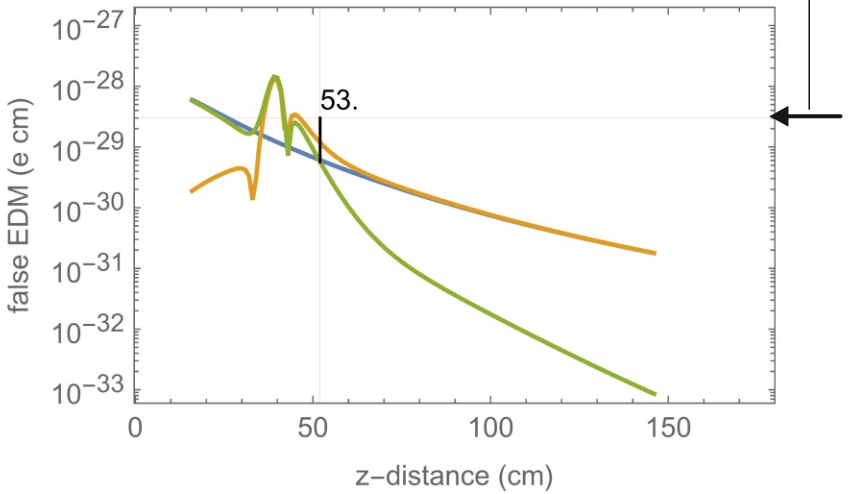
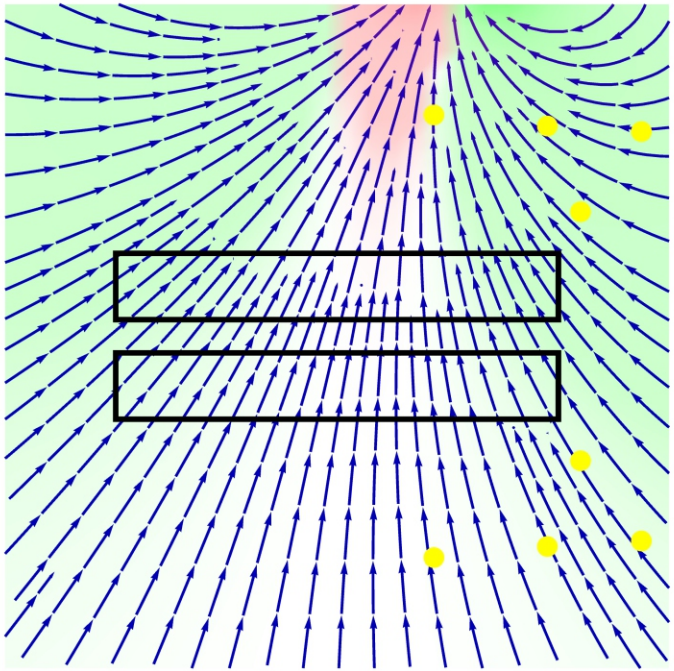
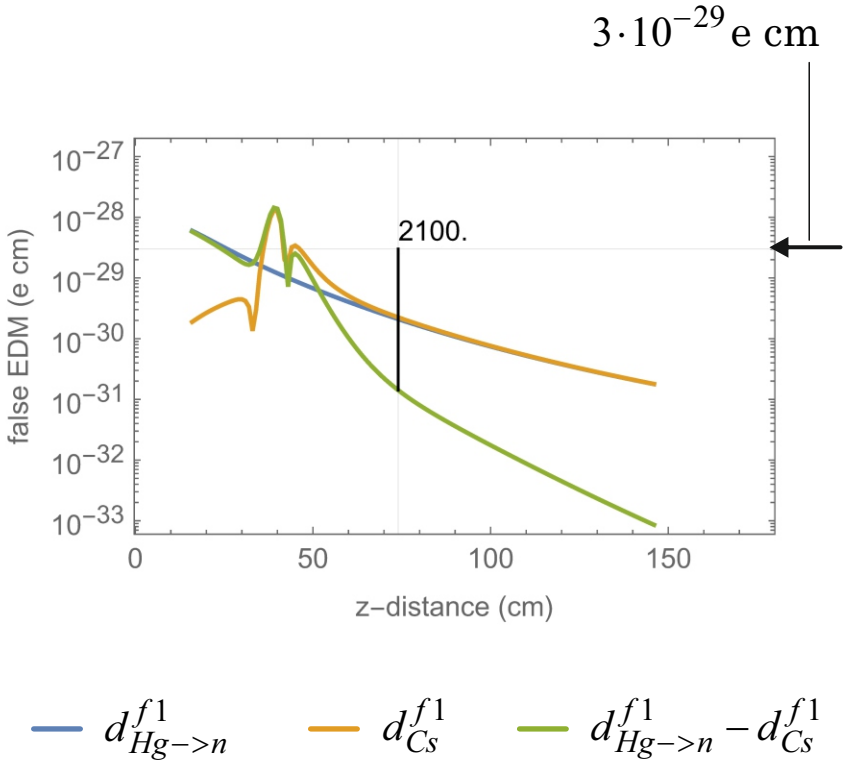


$d^{f1}_{Hg->n}$ d^{f1}_{Cs} $d^{f1}_{Hg->n} - d^{f1}_{Cs}$

Dipole field





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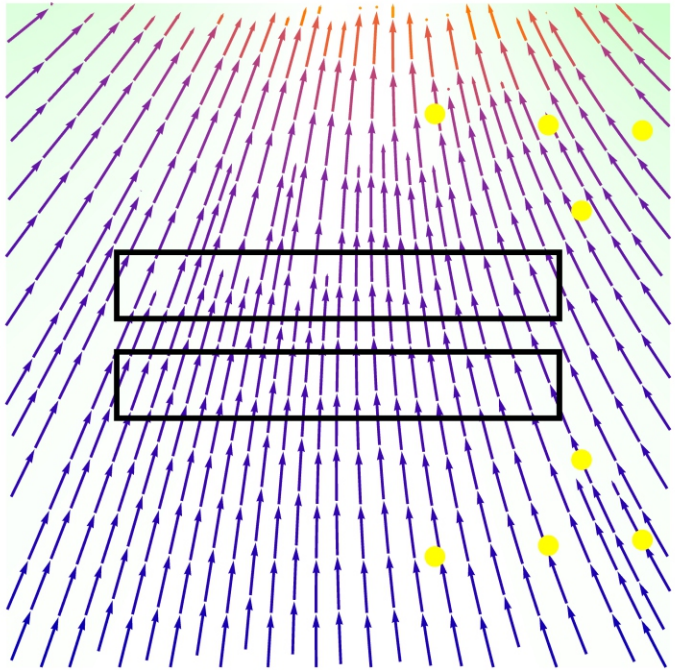
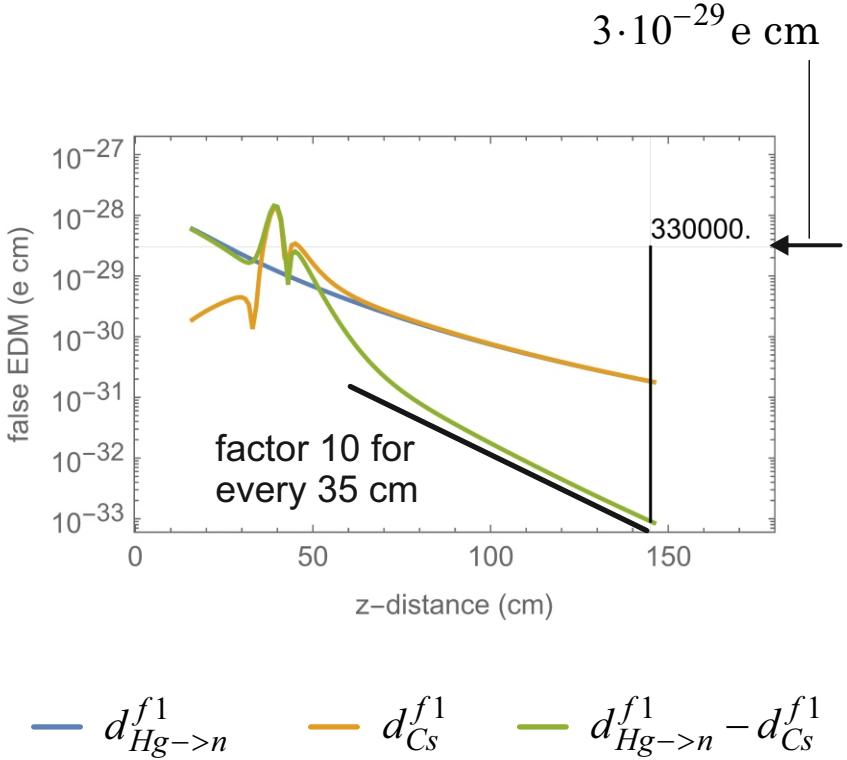
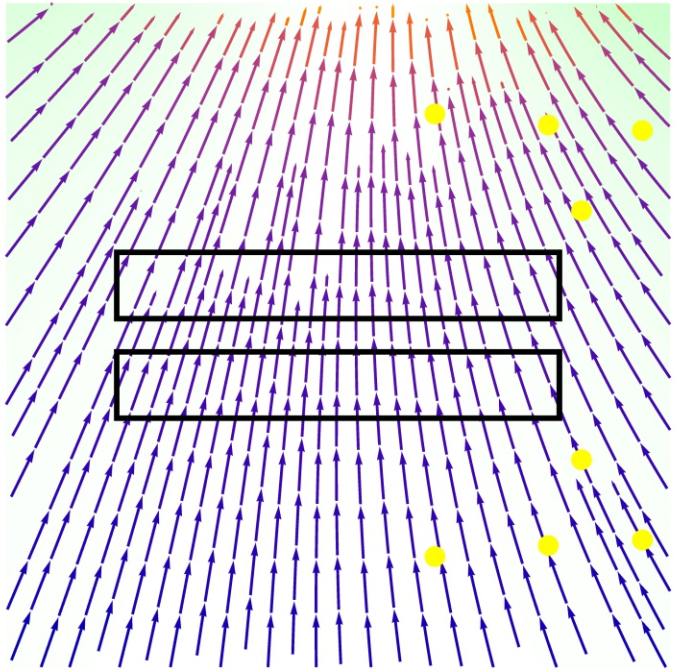
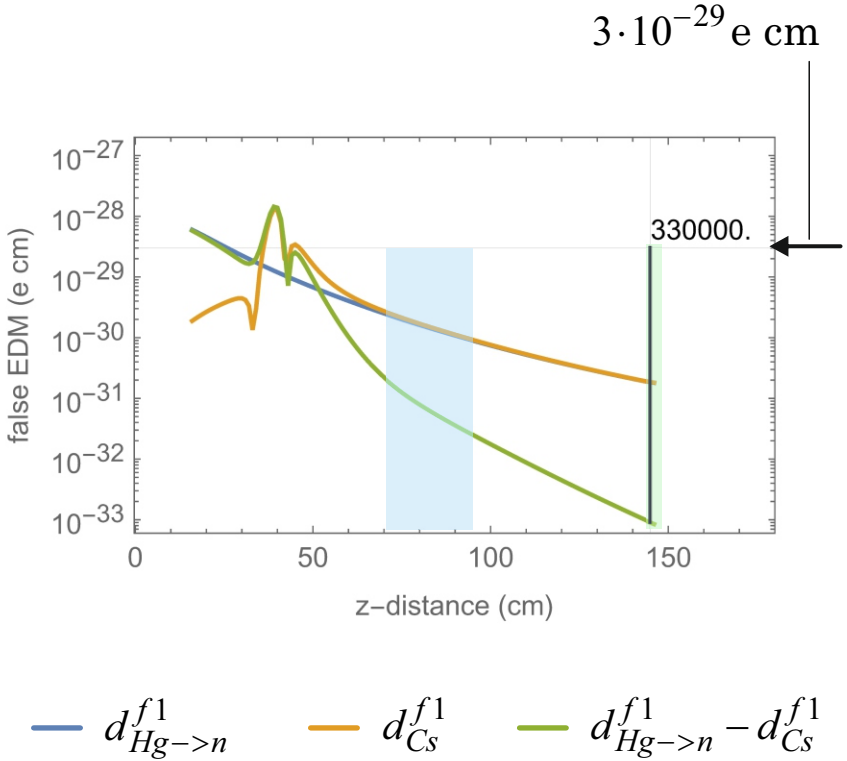


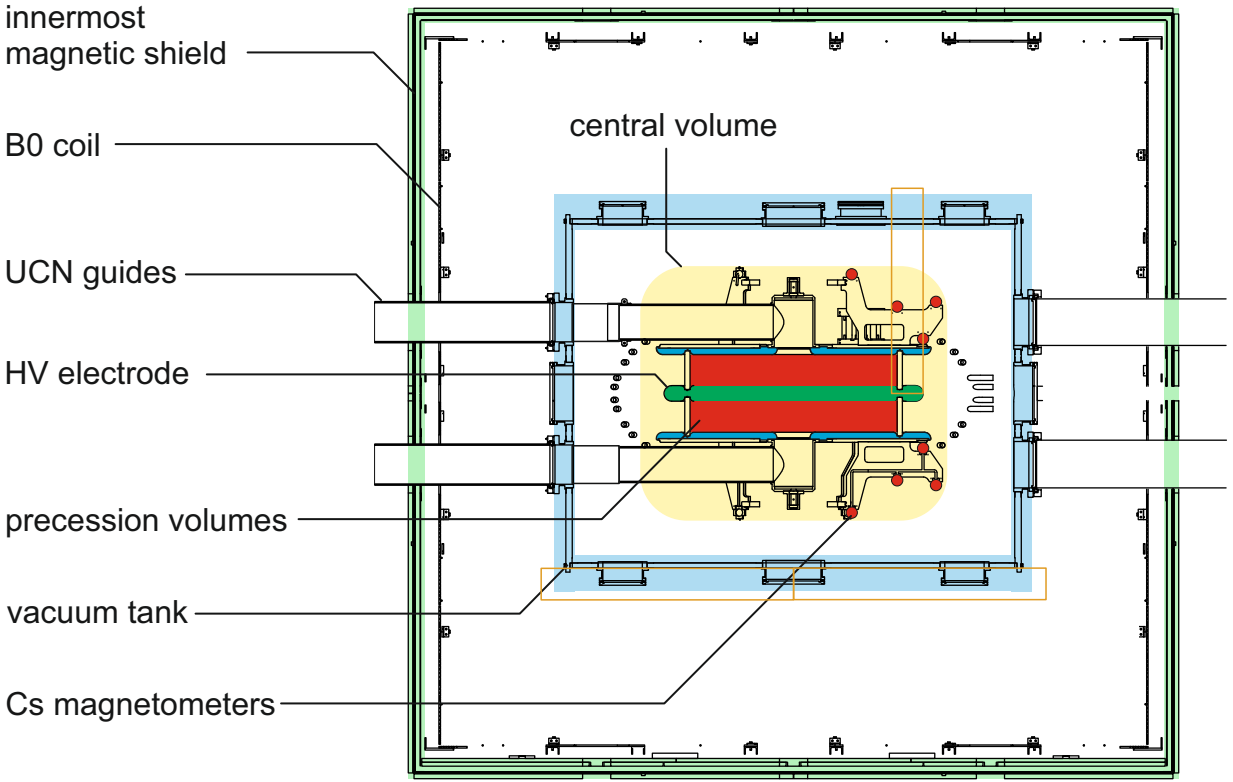


Dipole field





Innermost magnetic shield



Errors

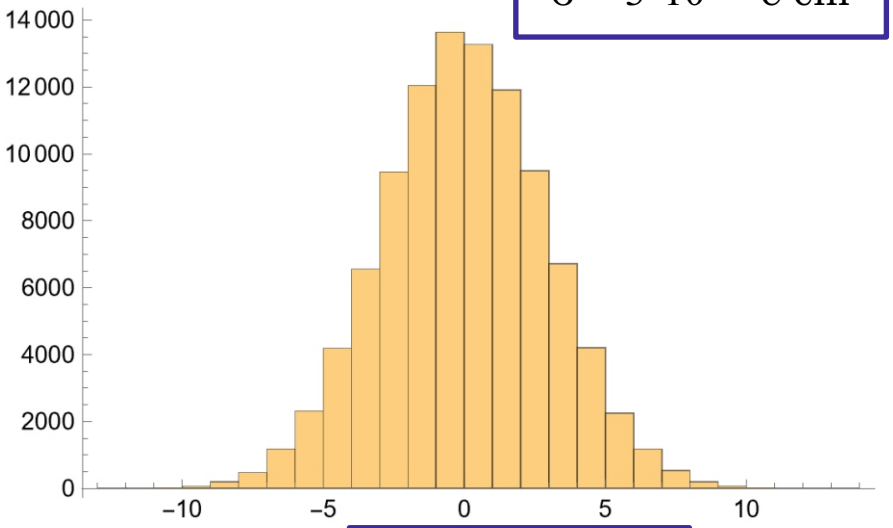
$\sigma = 7$ pT

field magnitude at Cs positions B_i

$$G_j = \sum_i M_{ij}^{-1} B_i$$

$$d_{Cs}^{f1} = C \sum G_j S_j^1$$

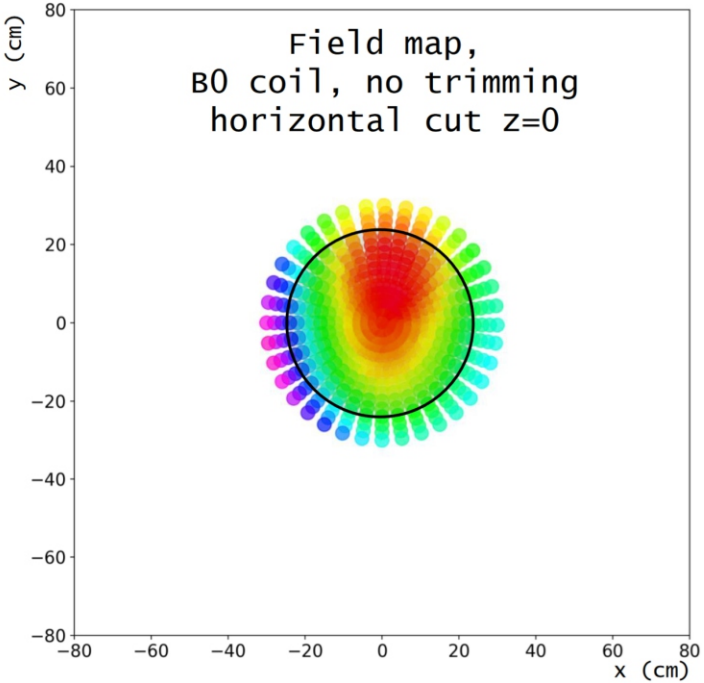
$$d_{Cs}^{f2} = C \sum G_j S_j^2$$

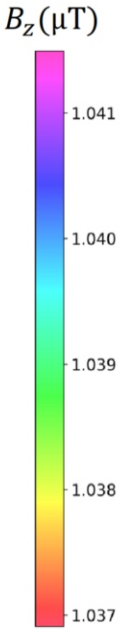


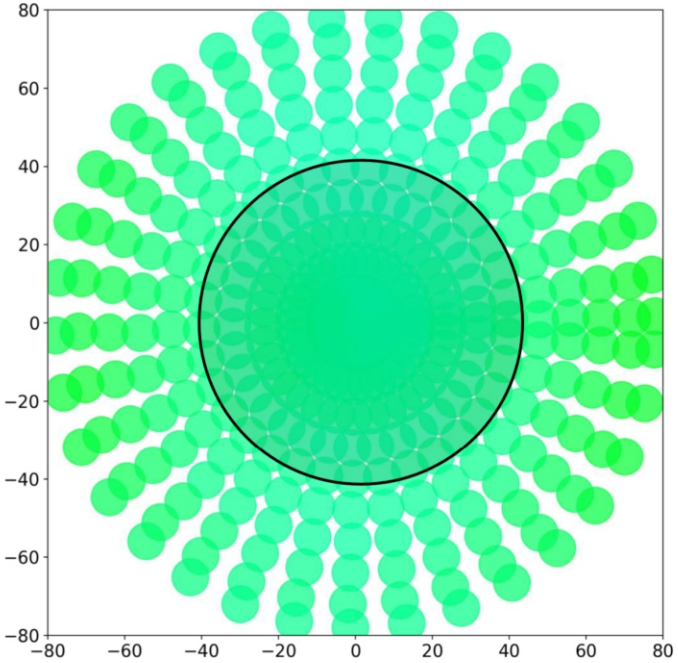
$\sigma = 3 \cdot 10^{-28}$ e cm

$d_{Cs}^{f} / \ 10^{-28}$ e cm

Mapper results without trim-coils







old experiment
ΔB = 860 ppm over 46 cm

n2EDM
ΔB = 60 ppm over 80 cm
expected neutron t2 time: >1500s