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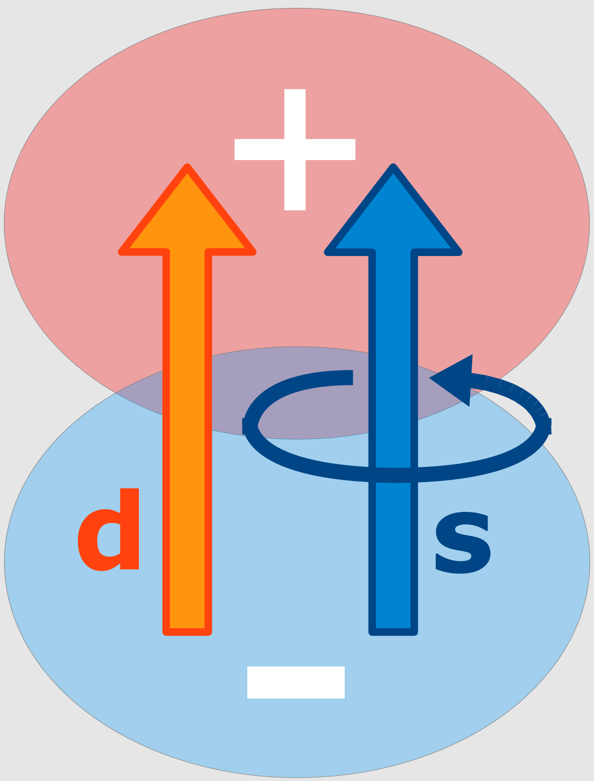
Excellence Cluster Universe

A new measurement of the EDM of 129-Xe

The Electric Dipole Moment

Electric Dipole Moment (EDM) of a charge distribution:



$$\mathbf{d} = \int \mathbf{r}\rho(\mathbf{r})d\mathbf{r}$$

dipole moment **d** directed along spin **s**

spin: axial vector

dipole moment: polar vector

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Non-zero EDM: CP and T violation

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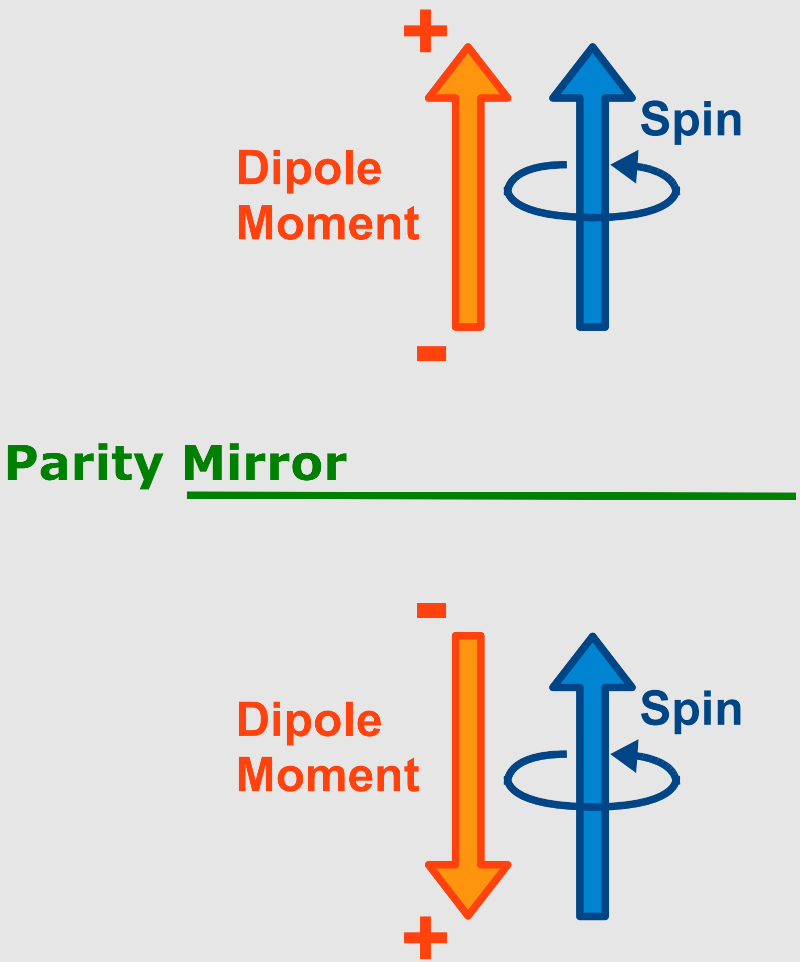
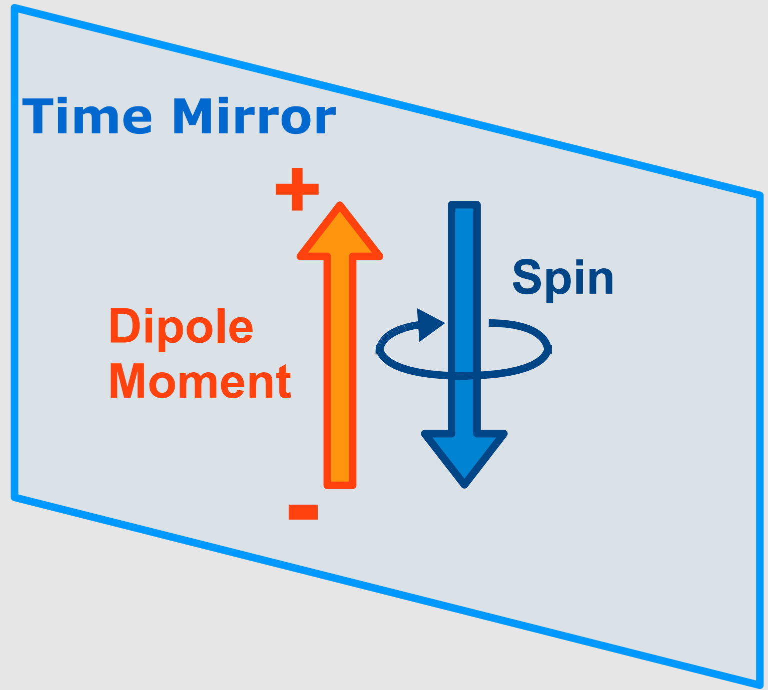


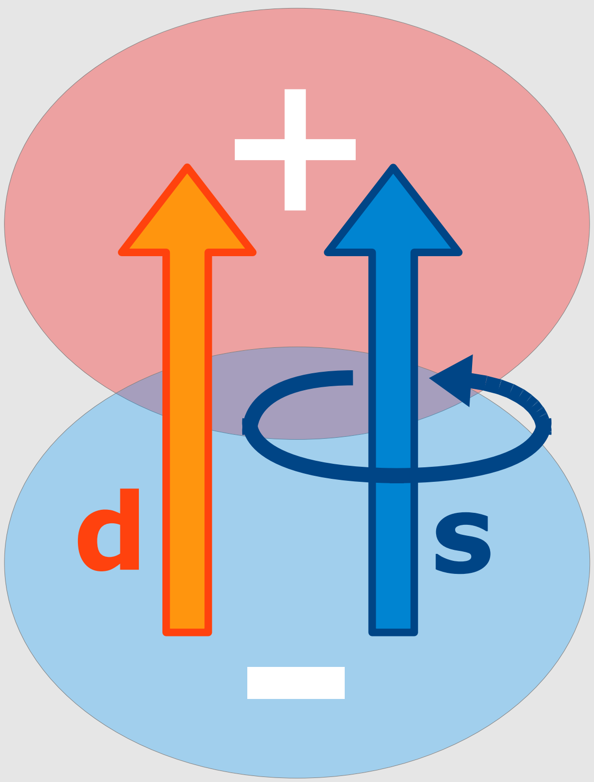


- Time-reversal violation
- Parity violation, hence CP violation

Motivation of EDM measurements

Non-zero EDM → CP and T violation

→ additional CP violation required to explain baryon asymmetry in the Universe (Sakharov conditions, 1967)



predictions from Standard Model (SM) extensions

→ close to current experimental limits

→ new physics beyond SM

EDM of diamagnetic atoms

EDM of neutral atom?

- electron-shell screens nucleon dipole moment
- Schiff moment $\sim Z^2$
  Schiff, Phys. Rev., **132**, 2194 (1963)

^{199}Mercury

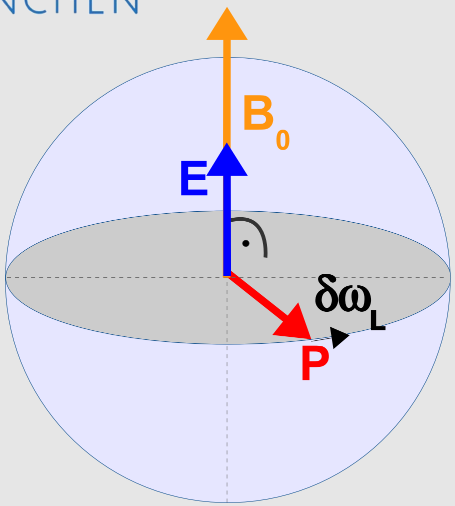
measured: $d_{199Hg} < 3.1 \times 10^{-29}$ ecm — Griffith, PRL **102**, 101601 (2009)

^{129}Xenon

measured: $d_{129Xe} < 7 \times 10^{-27}$ ecm — Rosenberry, Phys. Rev. Lett. **86**, 22 (2001)

predicted (SM): $d_{129Xe} \sim 1 \times 10^{-33} - 5 \times 10^{-34}$ ecm — Sushkov, JETP, **60**, 873 (1984)

Idea of Xe-EDM measurement

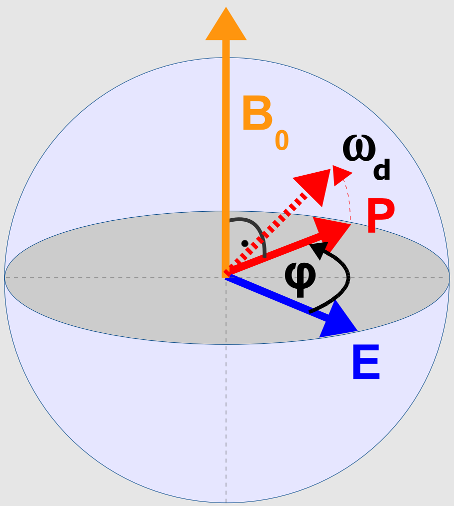


Spin polarized sample in B_0 field

Ramsey's method:

$E \parallel B_0$ ➡ $\hbar \omega_L = \mu B + dE$

➡ change in Larmor precession frequency



Our approach:

➡ rotating E-field with constant phase φ to P

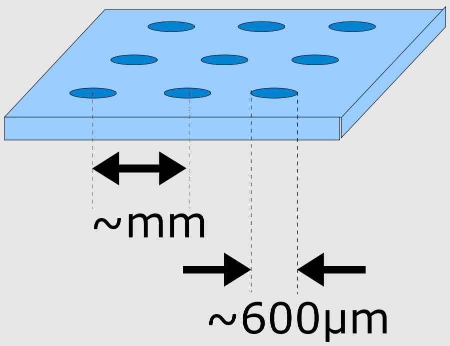
➡ precession $\omega_d \perp \omega_L$ with $\omega_d = \frac{dE}{\hbar}$

Microfabricated Xe-EDM chip

Micro-fabricated structure with (many) polarized liquid ^{129}Xe droplets

- high density
- many individual experiments in parallel
- transverse relaxation time T_2 > 1300s

Romalis, Phys. Rev. Lett., **87**, 6, (2001)



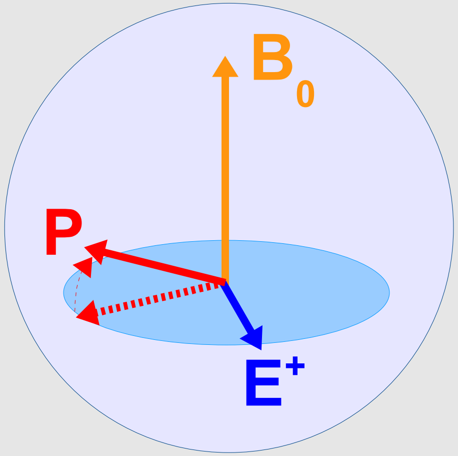
➡ array of eg. 5 or 9 droplets ➡ proof of principle with 3

➡ rotating E-field, but Ramsey's method (E || B) still possible

Measurement method

$P \perp E^+$

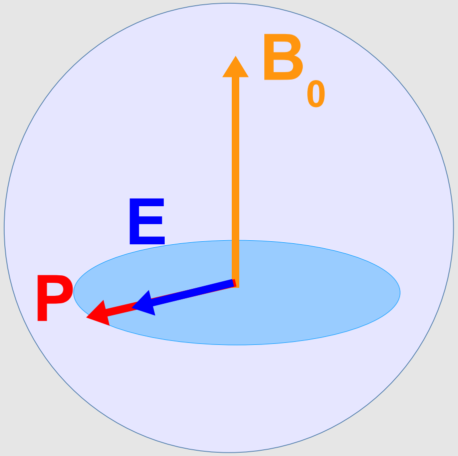
$(\varphi = \pi/2)$



experiment 1

$P \parallel E$

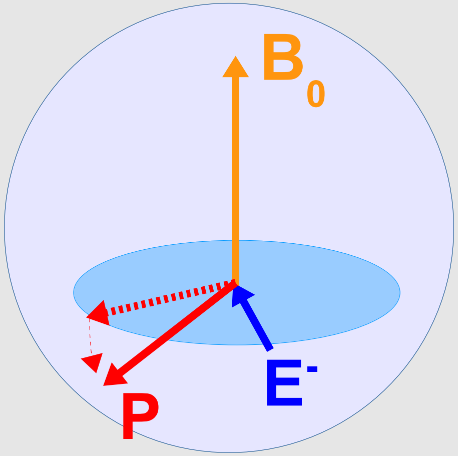
$(\varphi = 0)$



reference

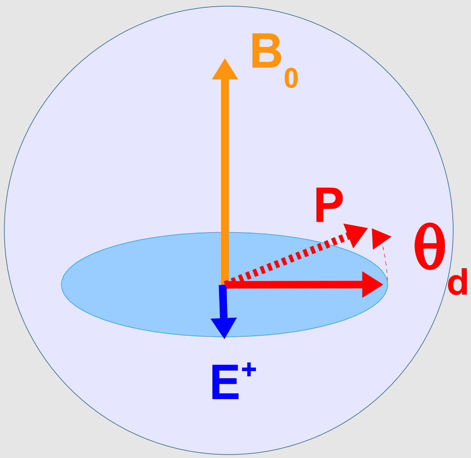
$P \perp E^-$

$(\varphi = -\pi/2)$



experiment 2

Measured signal



Accumulated phase:

(example: d~3x10^-29 ecm, E~10^5 V/cm, t=1000 s)

$$\theta_d^{\mathrm{exp1}} = -\theta_d^{\mathrm{exp2}} = \frac{\omega_d \tau}{2\pi} = \frac{dE\tau}{2\pi\hbar} \approx 10^{-6}$$

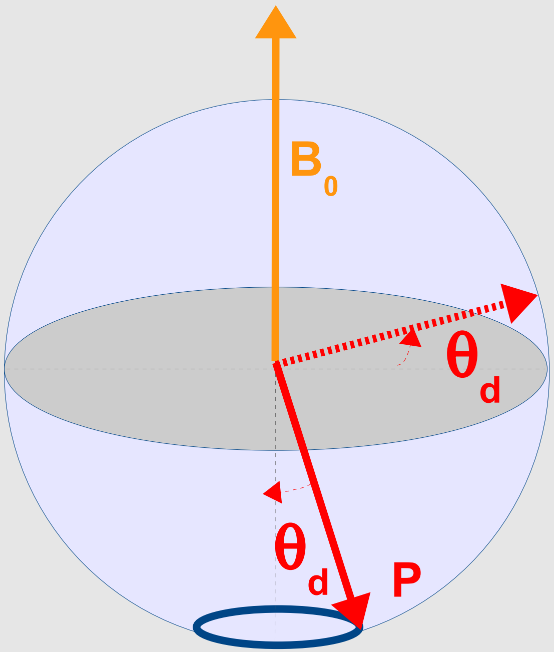
Analysis:

π/2 spin-flip → precession around B_0

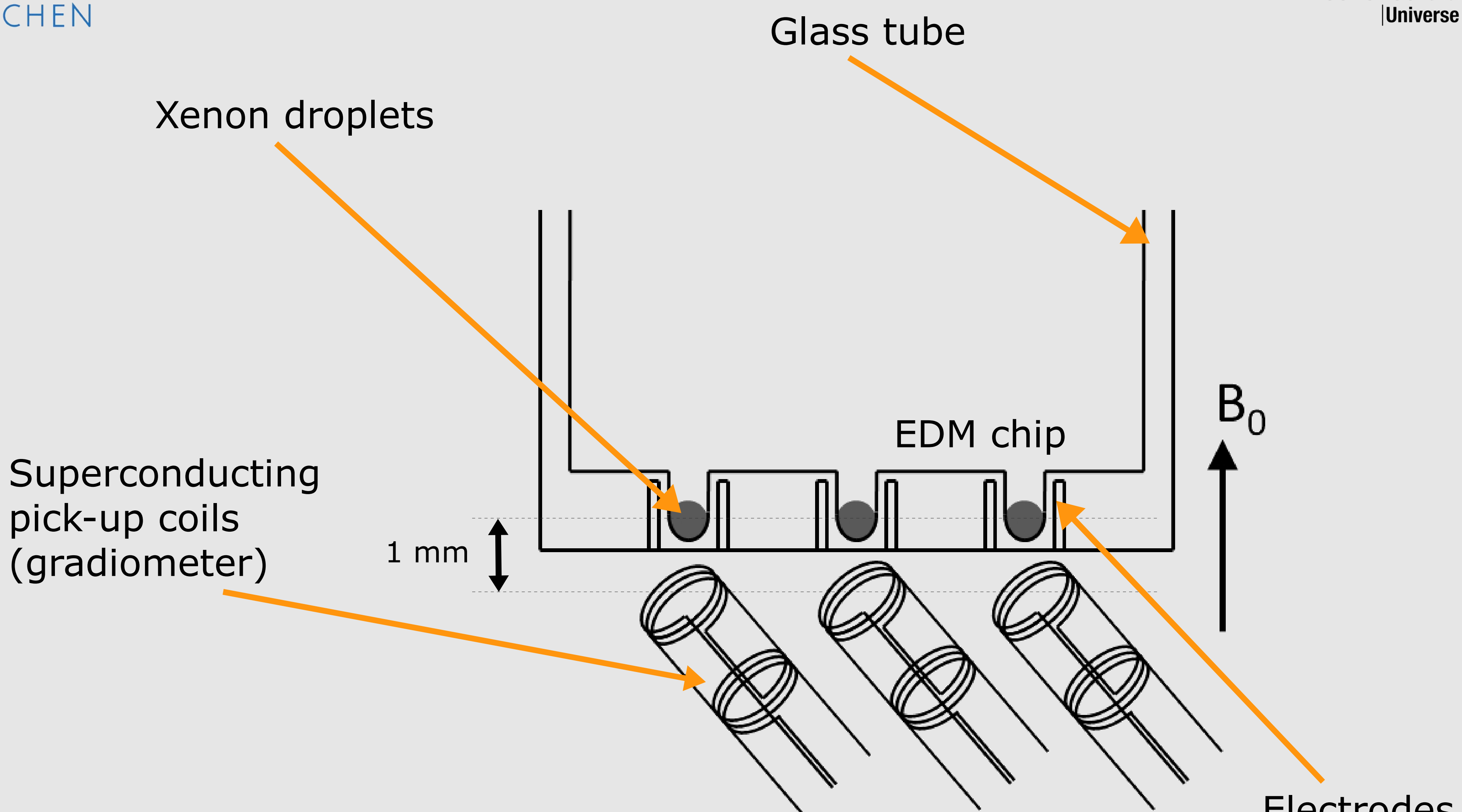
expected magnetic induction:

@ 1 mm distance ~ 150 fT

→ phase-shift of π between E^+ and E^-



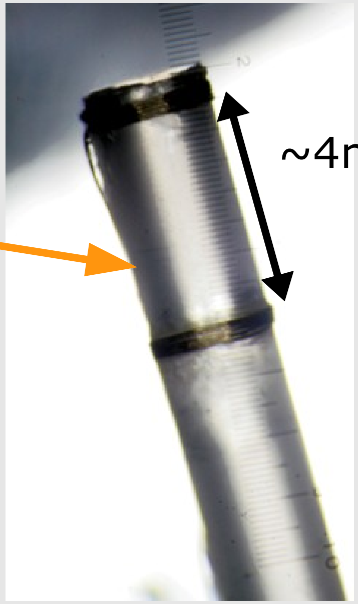
Realization



Measurement of transversal component

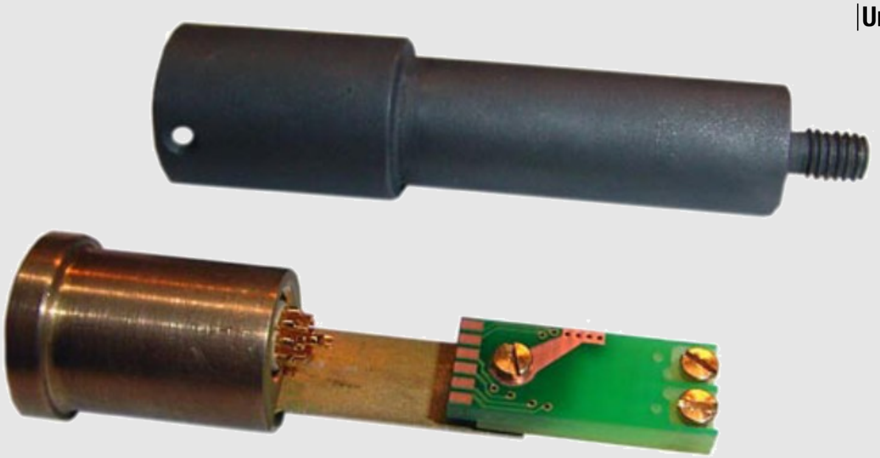
SQUID current sensors

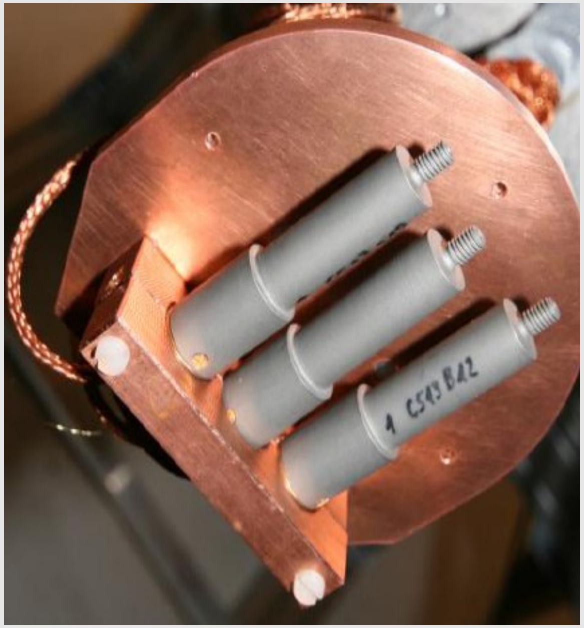
Pick-up coil



gradiometer coil

Nb wire (50µm) on 2mm sapphire rod





SQUIDs measure **current** through superconducting Nb wire

noise level @ PTB Berlin of **< 2 fT / sqrt(Hz)** (between 15-100 Hz)

→ sensitivity goal of d=10^{-30} ecm in one measurement

Status of the Setup

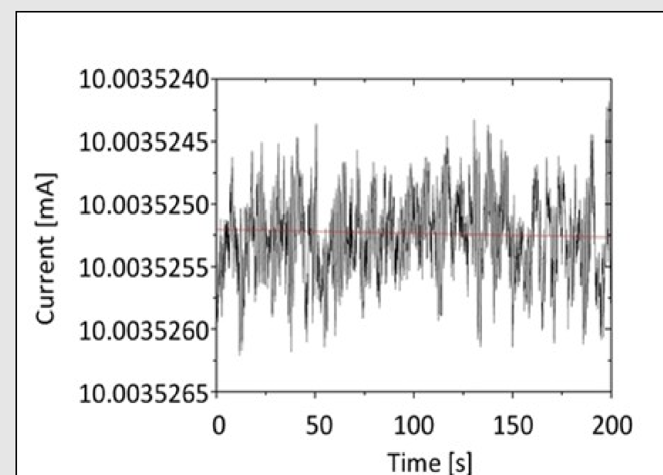
SQUID current sensors

5 layer μ-metal shield

shielding factor >200/layer

B_0 current source

10^{-8} current stability over 100s



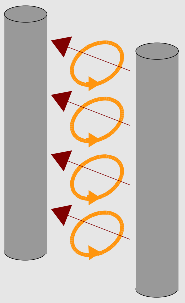
Systematic effects

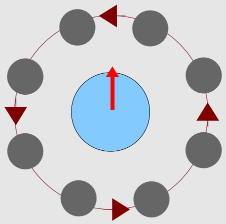
Magnetic field

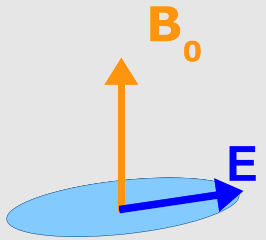
→ requirements less stringent (gradients, stability) $\omega_d \perp \omega_L$

Systematic effects:

- motional fields $B_m = \frac{1}{c^2} v \times E$
- AC currents
- circling currents
- E-field alignment
- cross-talk btw. droplets
- droplet geometry
- liquid specific issues
- no geometric phases







Sum of systematic effects < 10^{-31} ecm per measurement

Conclusion and Outlook

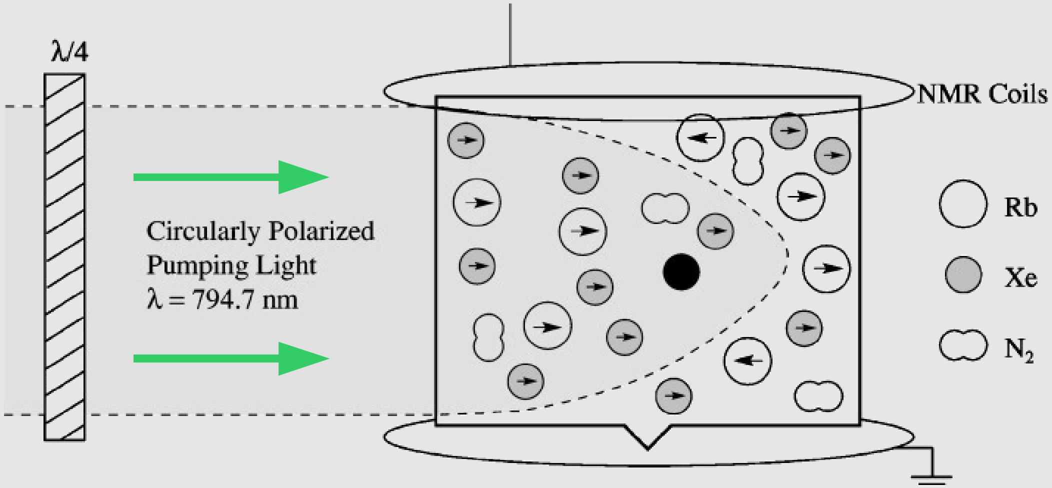
Summary

- new approach with different systematics
- simultaneous experiments incl. reference sample
- sensitivity goal of 10^{-30} ecm per measurement
- 10000 measurements → ultimate sensitivity of 10^{-32} ecm

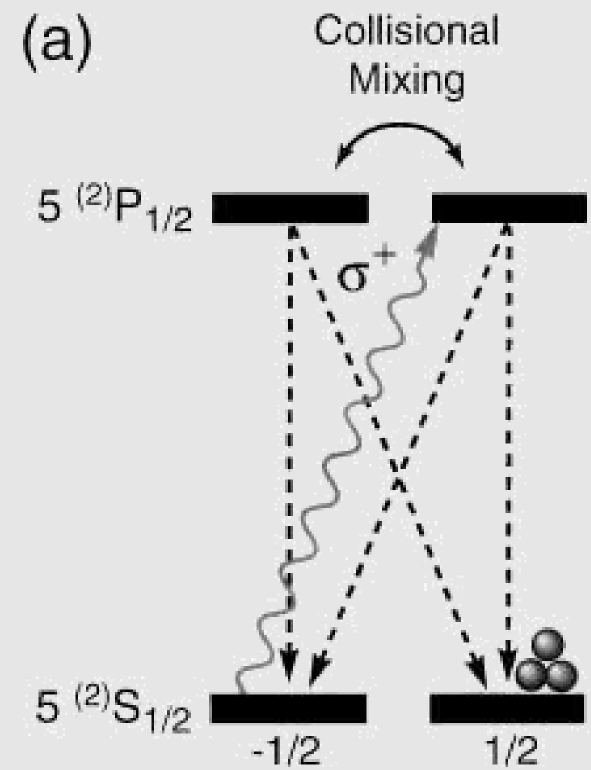
Goals for 2009

- produce liquid polarized xenon
- operate SQUIDs at design noise-level
  - xenon NMR signal

Polarized Xenon



+ ^{4}He gas for pressure broadening



Polarize Rb by optical pumping:

$S_{1/2,-1/2} \longrightarrow P_{1/2,1/2}$ ➡ populating $S_{1/2,1/2}$

Rb – Xe spin-exchange collisions

➡ e^--spin to nuclear spin polarization

➡ macroscopic polarisation **P**

➡ magnetic dipole