Monte Carlo simulation of PNPI double chamber nEDM spectrometer

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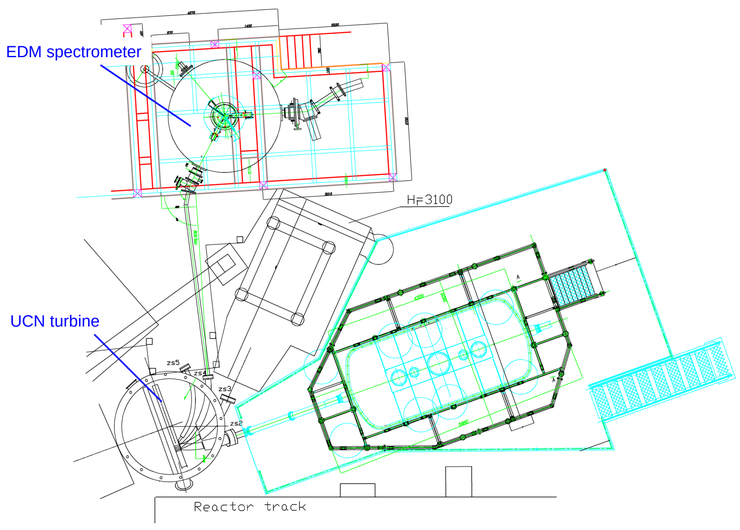
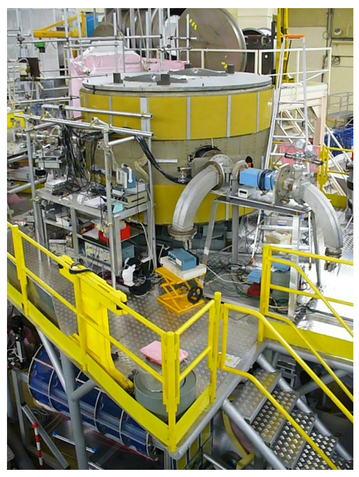
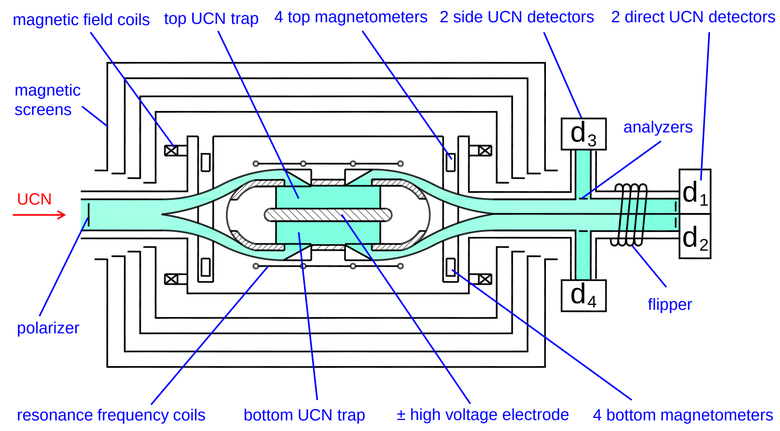
Plan of PNPI EDM spectrometer position at PF2/EDM at ILL



PNPI EDM spectrometer at ILL



Scheme of EDM spectrometer



Leakage currents

One of the possible reasons for the false EDM effect are leakage currents caused by a high voltage. In case of electric field polarity reversal they can run the same channels, changing their sign. Magnetic field connected with them also changes its sign and produces a false EDM effect.

In current-carrying wires the space distribution of leakage currents is determined uniquely, but leakage current running in the isolator depends from many factors, mainly from the isolator surface condition and the way the isolator and the electrode contact with each other. Certainly, the leakage currents direction along the isolator surface is determined by the direction of electric field, but there may be deviations caused by inhomogeneous surface conductance. The inhomogeneous surface conductance may be caused by breakdowns that took place in the course of the high-voltage setup training.

The fig. shows the scheme of leakage currents for a high-voltage chamber. Two horizontal lines symbolize current inputs with the contact point in the center of electrodes. Then current runs in the radial direction along the electrode to the contact point of the isolator and the electrode, then along the isolator end-wall to the point where breakdown used to occur, after that in the direction of the formed breakdown track and then makes the same way back to the center of another electrode.

Any leakage current j can be represented as a series of components j_z, j_r, j_φ in a cylindrical system of coordinates.

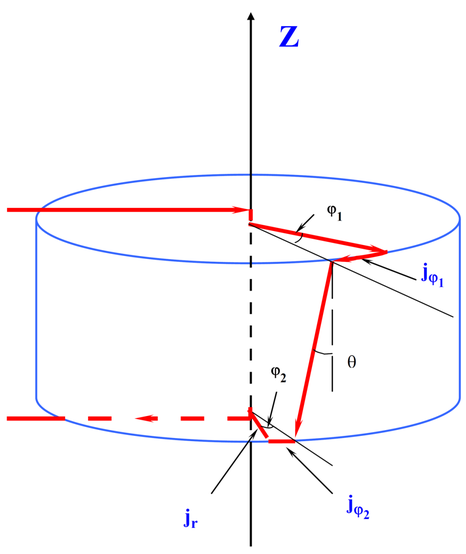
The j_z component creates a magnetic field perpendicular to the main leading field, therefore as the leakage currents sign reverses (their value remaining the same) the full vector of magnetic field stays the same in value. Thus the j_z component of leakage current is safe.

The j_r component can create a magnetic field directed along z-direction, but contributions of magnetic field to +z and -z directions are inter compensated.

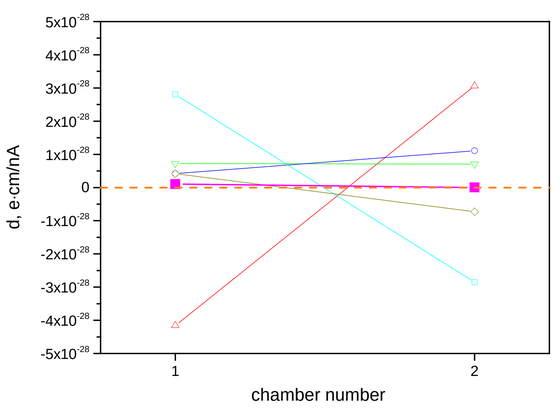
The j_φ component is the unsafest one, as a magnetic field is not compensated in a z-direction. For instance, the current j_φ running in the cylindrical surface of the chamber (in the isolator) creates a magnetic field in z-direction inside the chamber, and in -z-direction outside the chamber, and therefore they are not compensated.

The reasons for currents with the j_φ component can be the track from inclined breakdown along the isolator surface, leakage currents in the isolator surface, and leakage currents in the isolator end-wall.

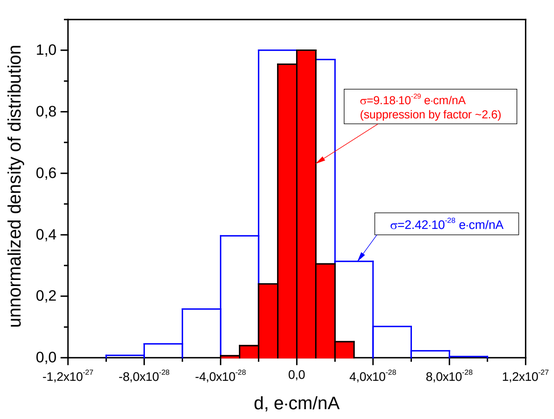
The complete account of all possible effects requires direct calculation of EDM measurements with leakage currents. Calculation of magnetic field caused by leakage currents was done with the help of the program «Radia». The breaking point was selected in a random way for this calculation. The so called breaking point is a place where breakdown already occurred and left a track which initiates the local leakage current. The contact point of the electrode and the isolator was selected by an equiprobable randomization of the angle φ_1 within a range of ±2.5°. Then the angle of inclined current in the isolator surface (θ) was selected. The angle θ was taken in vicinity of zero with a half-width of Gaussian distribution 15°. After that the angle φ_2 was randomized just like the angle φ_1. The average value of leakage currents was selected to be 1 nA with a width of Gaussian distribution 0.8 nA. The values of φ_1, φ_2, θ and the values of leakage currents were taken independently for each chamber.



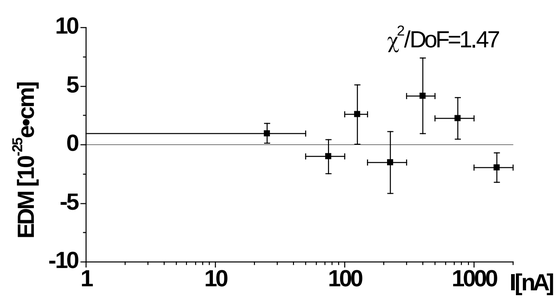
False effects from leakage currents



Distribution of false effects from leakage currents



Experimental data



Quadratic v×E

$$\vec{B} = -\frac{1}{c^2}\left[\vec{v}\times\vec{E}\right]$$

$$B_{eff} = \frac{4\pi}{c^2}\cdot 10^{-2}\cdot\frac{2}{3}v\cdot E \approx 100\ \text{pT}$$

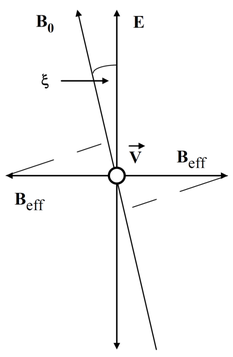
$$B = \sqrt{B_0^2 + B_{eff}^2} \approx B_0 + \frac{1}{2}\frac{B_{eff}^2}{B_0}$$

$$B - B_0 = \frac{1}{2}\frac{B_{eff}^2}{B_0} \approx 2.5\ \text{fT}$$

$D_f < 5\cdot 10^{-28}$ e·cm (one chamber, ΔE<10%)

Effect is compensated by double chamber scheme.

Non-parallelism B and E



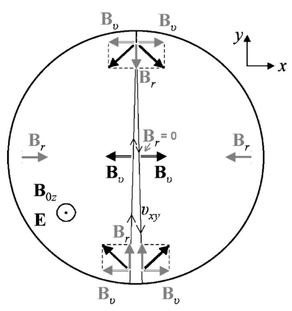
$$\Delta B = 2B_{eff}\cdot\xi$$

$$v_{av} = \frac{R}{T}\frac{1}{\sqrt{N}}$$

$$\xi = 10^{-3}\ \text{rad}$$

$$D_f = 0$$

Geometric phase



$$D_f = -\frac{J\hbar}{2}\left(\frac{\partial B_{0z}/\partial z}{B_{0z}^2}\right)\frac{v_{xy}^2}{c^2}\left[1-\frac{\omega_r^{*2}}{\omega_0^2}\right]^{-1}$$

$$\omega_r^{*2} = \frac{\pi^2}{6}\left(\frac{v_{xy}}{R}\right)^2 \qquad v_{xy}^2 = \frac{1}{3}v_{max}^2$$

$$\frac{\partial B_{0z}}{\partial z} = 0.86\ \text{nT/m}$$

$$D_f = 7.5\cdot 10^{-28}\ \text{e}\cdot\text{cm}$$

Systematic errors

Systematic effect	Value, e·cm
Leakage currents (<100 nA)	$1\cdot 10^{-26}$
Quadratic **v**×**E**	0
Non-parallelism **B** and **E**	0
Geometric phase	$7.5\cdot 10^{-28}$