Impact of a Double EDM Cell

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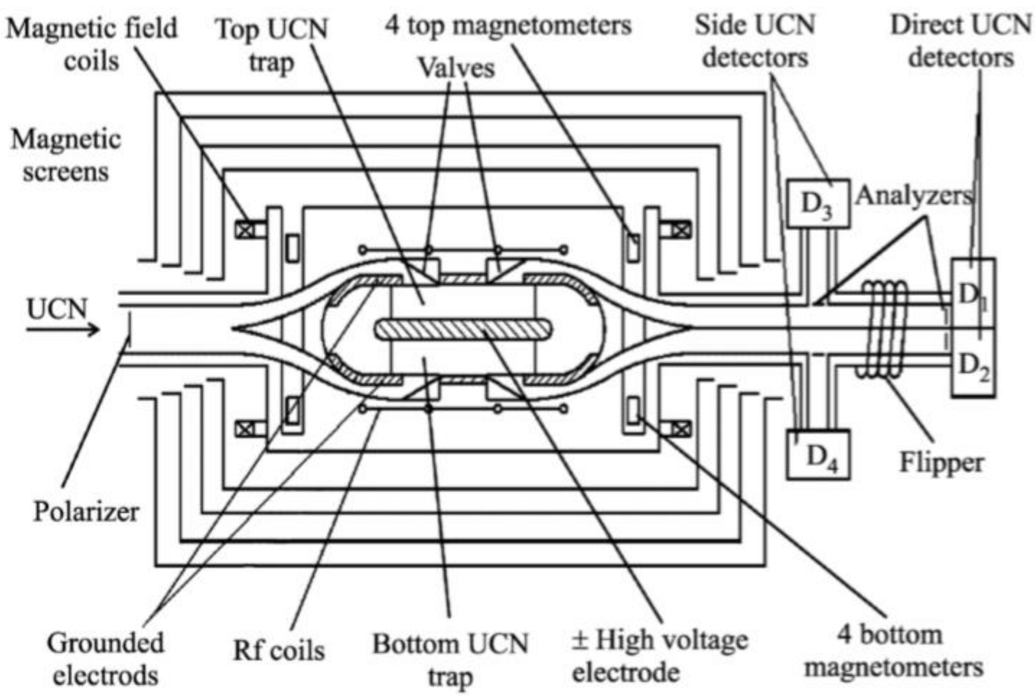
PNPI Double Cell



Serebrov et. al. New measurements of neutron electric dipole moment with double chamber EDM spectrometer, 2014

- No comagnetometer
- 8 Cs magnetometers
- 4 detectors
- Each detector's counts fit individually to Ramsey curve for 4 nEDM measurements
- No detailed analysis of individual systematic effects (except leakage currents, which were claimed to be small)
- 2014 result: $|d_n| < 5.5\text{x}10^{-26}\ e\text{cm}$ (PNPI + ILL reactors)

PNPI Analysis

- The analysis of uncertainty, as claimed by Serebrov, is encompassed by 4 linear combinations of the nEDM measurements from the detectors
- EDM measurement (claim that significant systematics are fully compensated by this averaging):

$$d_{\mathrm{n}} = \frac{1}{4}[(d_1 + d_2) + (d_3 + d_4)]$$

- Measure of systematics from effect of E field on resonance conditions:

$$\Delta\nu = \frac{1}{4}[(d_1 - d_2) + (d_3 - d_4)]$$

- Measure of systematics on neutron counts:

$$\Delta N = \frac{1}{4}[(d_1 - d_2) - (d_3 - d_4)]$$

- Compensation test:

$$\mathrm{Z} = \frac{1}{4}[(d_1 + d_2) - (d_3 + d_4)] = 0$$

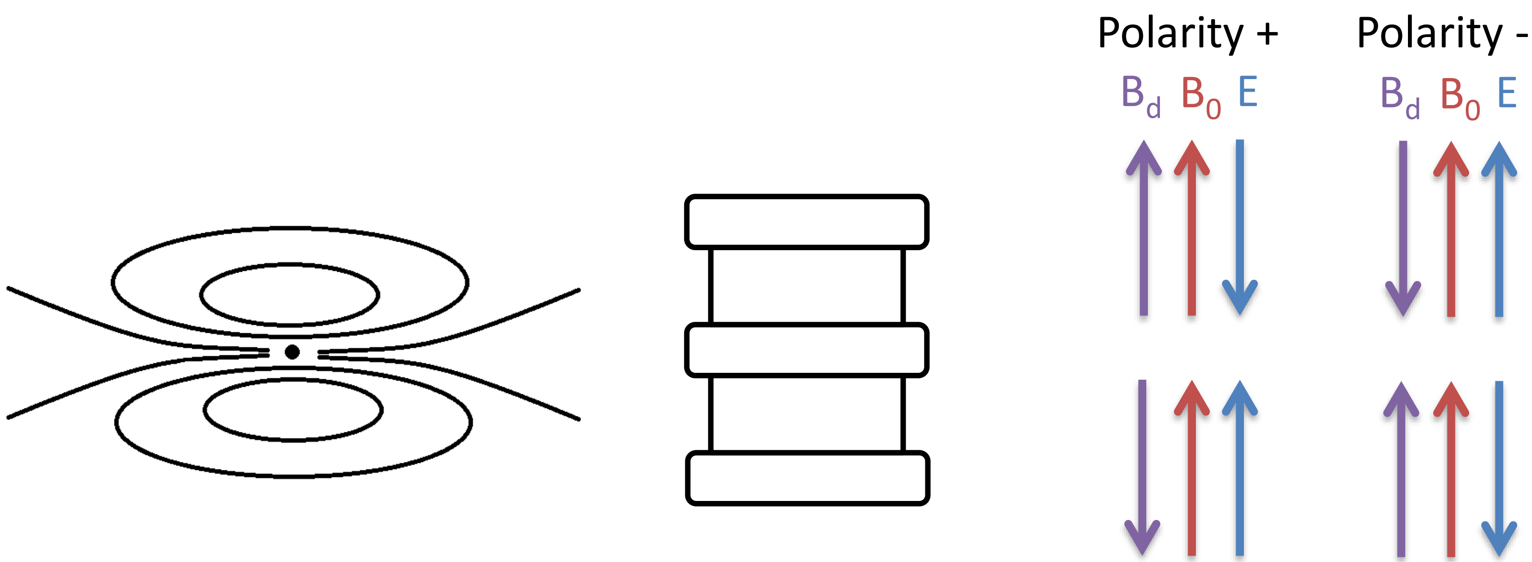
Example 1: Dipole at the HV Feed

The ILL analysis explored the idea of residual magnetization of the MSR, induced by the HV polarity changes, manifesting as a dipole at the HV feedthrough. The measurement would be sensitive to such a field because of the height difference between the Hg and neutrons, with a relative difference in the sensed field given by (r distance from cell centre to field source).

$$\frac{\delta B_d}{B_d} = \frac{3\Delta h}{r}$$

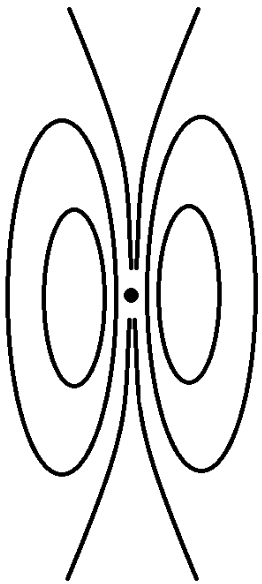
At ILL, for a single cell, the feedthrough was at the floor. Our planned feed for the double cell is on the MSR wall, intersecting the central electrode. The level of compensation via magnetometry may be different for this configuration.

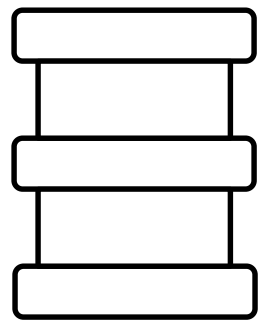
Dipole at the HV Feed 1

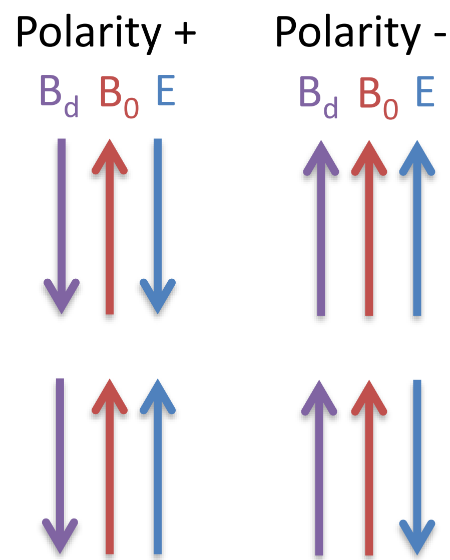


$$\hbar\Delta\omega_{\mathrm{t}} = \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 - B_{\mathrm{d}}\right) - 2d_{\mathrm{n}}(E)\right]$$
$$= 4d_{\mathrm{n}}E + 4\mu_{\mathrm{n}}B_{\mathrm{d}}$$
$$\hbar\Delta\omega_{\mathrm{b}} = \left[2\mu_{\mathrm{n}}\left(B_0 - B_{\mathrm{d}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d}}\right) - 2d_{\mathrm{n}}(E)\right]$$
$$= 4d_{\mathrm{n}}E - 4\mu_{\mathrm{n}}B_{\mathrm{d}}$$
$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_{\mathrm{b}}}{4E} + \frac{\hbar\Delta\omega_{\mathrm{t}}}{4E}\right) = d_{\mathrm{n}}$$

Dipole at the HV Feed 2





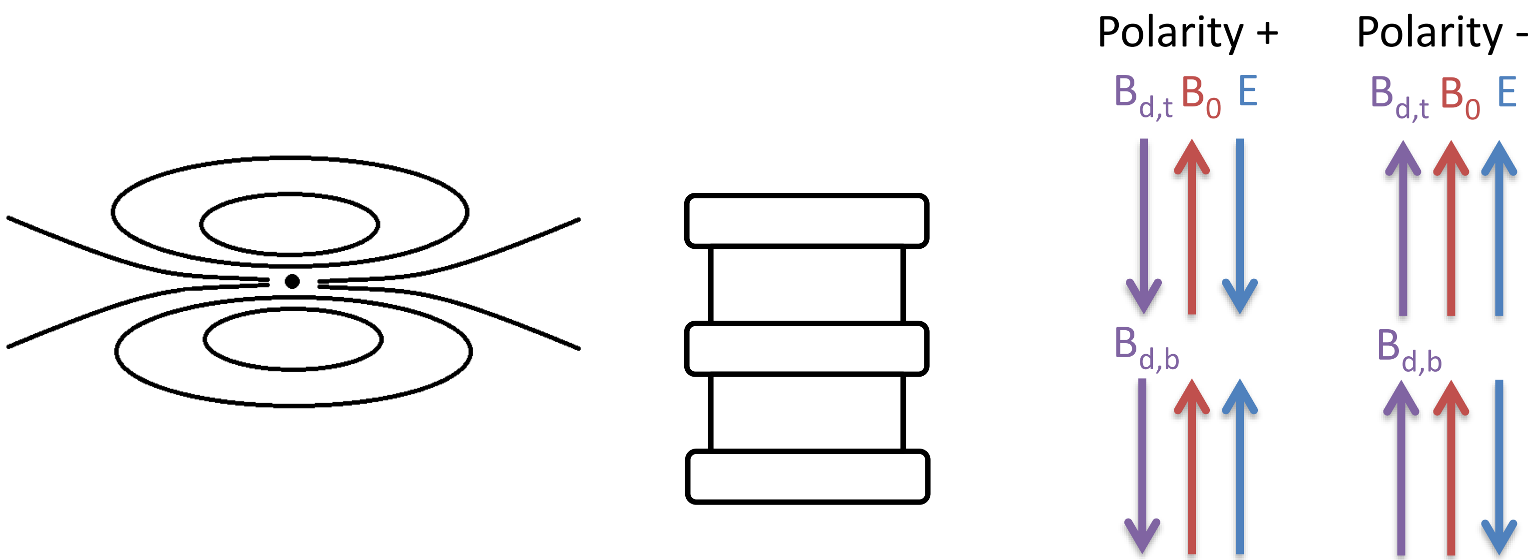


$$\hbar\Delta\omega_{\mathrm{t}} = \left[2\mu_{\mathrm{n}}\left(B_0 - B_{\mathrm{d}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d}}\right) - 2d_{\mathrm{n}}(E)\right]$$
$$= 4d_{\mathrm{n}}E - 4\mu_{\mathrm{n}}B_{\mathrm{d}}$$

$$\hbar\Delta\omega_{\mathrm{b}} = \left[2\mu_{\mathrm{n}}\left(B_0 - B_{\mathrm{d}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d}}\right) - 2d_{\mathrm{n}}(E)\right]$$
$$= 4d_{\mathrm{n}}E - 4\mu_{\mathrm{n}}B_{\mathrm{d}}$$

$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_{\mathrm{b}}}{4E} + \frac{\hbar\Delta\omega_{\mathrm{t}}}{4E}\right) = d_{\mathrm{n}} + \frac{\mu_{\mathrm{n}}}{E}B_{\mathrm{d}}$$

Dipole at the HV Feed 3



$$\hbar\Delta\omega_{\mathrm{t}} = \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d,t}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d,t}}\right) - 2d_{\mathrm{n}}(E)\right]$$

$$= 4d_{\mathrm{n}}E + 4\mu_{\mathrm{n}}B_{\mathrm{d,t}}$$

$$\hbar\Delta\omega_{\mathrm{b}} = \left[2\mu_{\mathrm{n}}\left(B_0 - B_{\mathrm{d,b}}\right) + 2d_{\mathrm{n}}(E)\right] - \left[2\mu_{\mathrm{n}}\left(B_0 + B_{\mathrm{d,b}}\right) - 2d_{\mathrm{n}}(E)\right]$$

$$= 4d_{\mathrm{n}}E - 4\mu_{\mathrm{n}}B_{\mathrm{d,b}}$$

$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_{\mathrm{b}}}{4E} + \frac{\hbar\Delta\omega_{\mathrm{t}}}{4E}\right) = d_{\mathrm{n}} + \frac{\mu_{\mathrm{n}}}{E}\left(B_{\mathrm{d,t}} - B_{\mathrm{d,b}}\right)$$

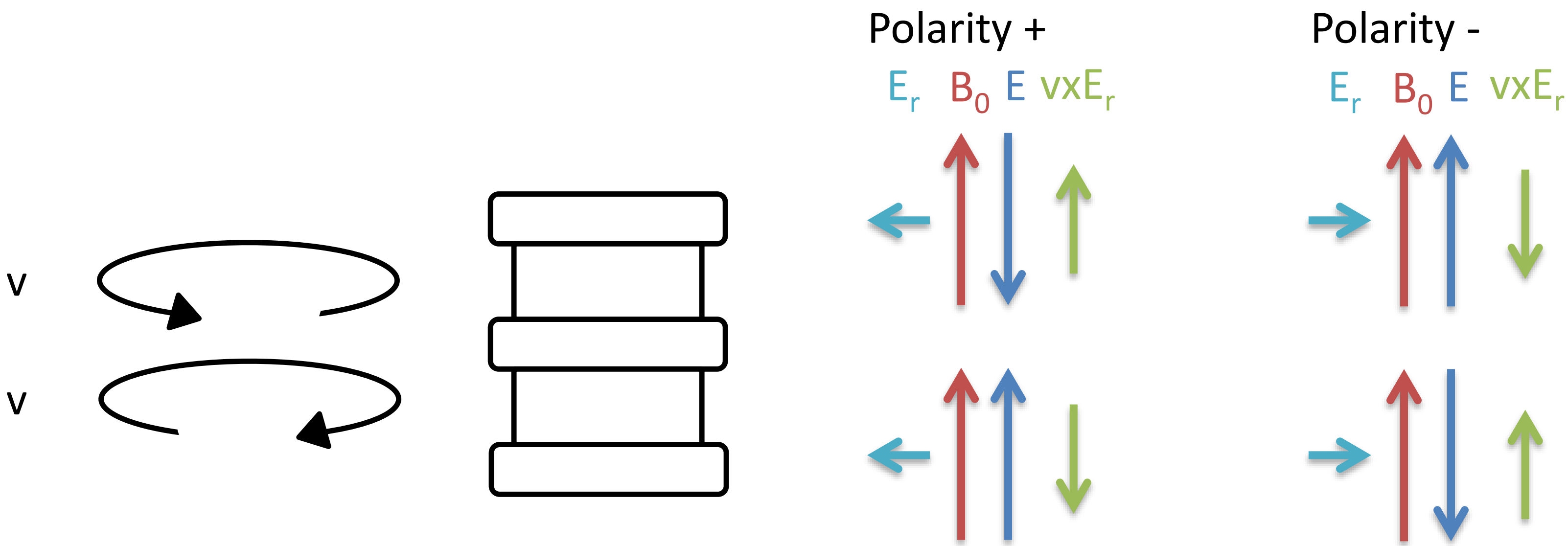
Example 2: Rotational vxE

The neutrons experience a motional magnetic field:

$$\boldsymbol{B}_v = \frac{\boldsymbol{E} \times \boldsymbol{v}}{c^2}$$

Radial electric inhomogeneity E_r (which reverses direction with HV reversal), with a net rotational flow v_r of neutrons in the cell, produces a magnetic component in the B_0 direction. This effect decays due to diffuse reflection, but still contributes a false EDM averaged over the precession time.

Rotational vxE 1

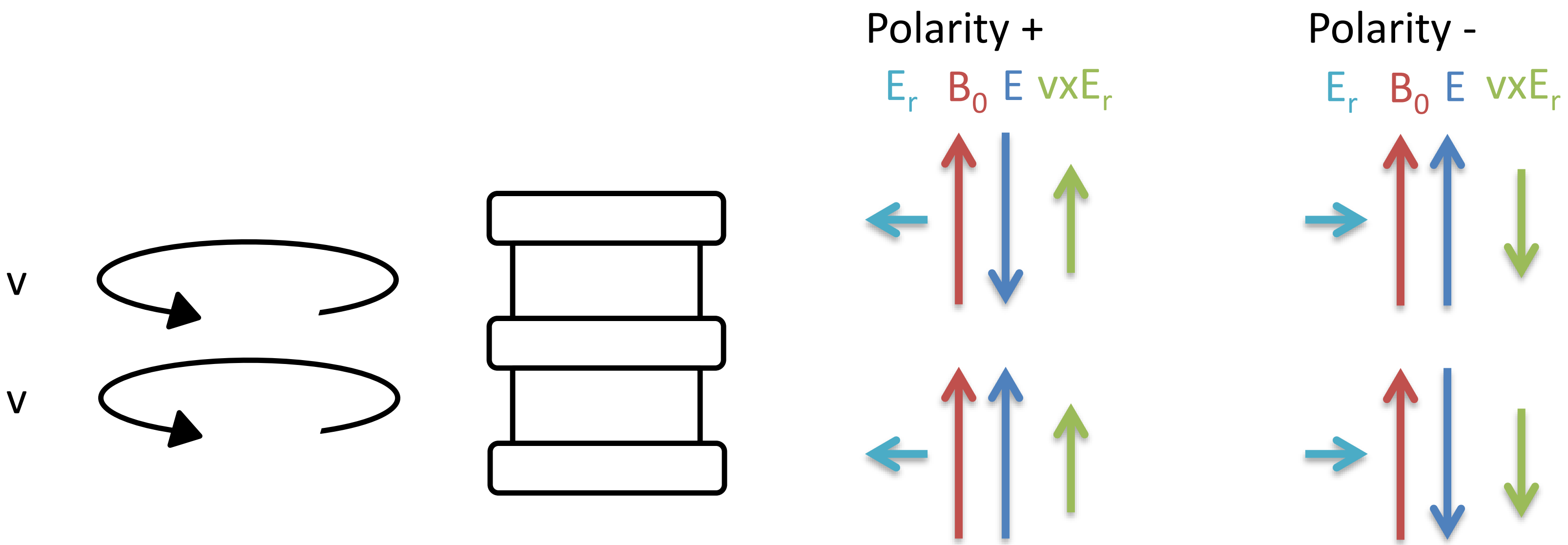


$$\hbar\Delta\omega_{\mathrm{t}} = [2\mu_{\mathrm{n}}(B_0 + vE_{\mathrm{r}}/c^2) + 2d_{\mathrm{n}}(E)] - [2\mu_{\mathrm{n}}(B_0 - vE_{\mathrm{r}}/c^2) - 2d_{\mathrm{n}}(E)]$$
$$= 4d_{\mathrm{n}}E + 4\mu_{\mathrm{n}}vE_{\mathrm{r}}/c^2$$

$$\hbar\Delta\omega_{\mathrm{b}} = [2\mu_{\mathrm{n}}(B_0 - vE_{\mathrm{r}}/c^2) + 2d_{\mathrm{n}}(E)] - [2\mu_{\mathrm{n}}(B_0 + vE_{\mathrm{r}}/c^2) - 2d_{\mathrm{n}}(E)]$$
$$= 4d_{\mathrm{n}}E - 4\mu_{\mathrm{n}}vE_{\mathrm{r}}/c^2$$

$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_{\mathrm{b}}}{4E} + \frac{\hbar\Delta\omega_{\mathrm{t}}}{4E}\right) = d_{\mathrm{n}}$$

Rotational vxE 2

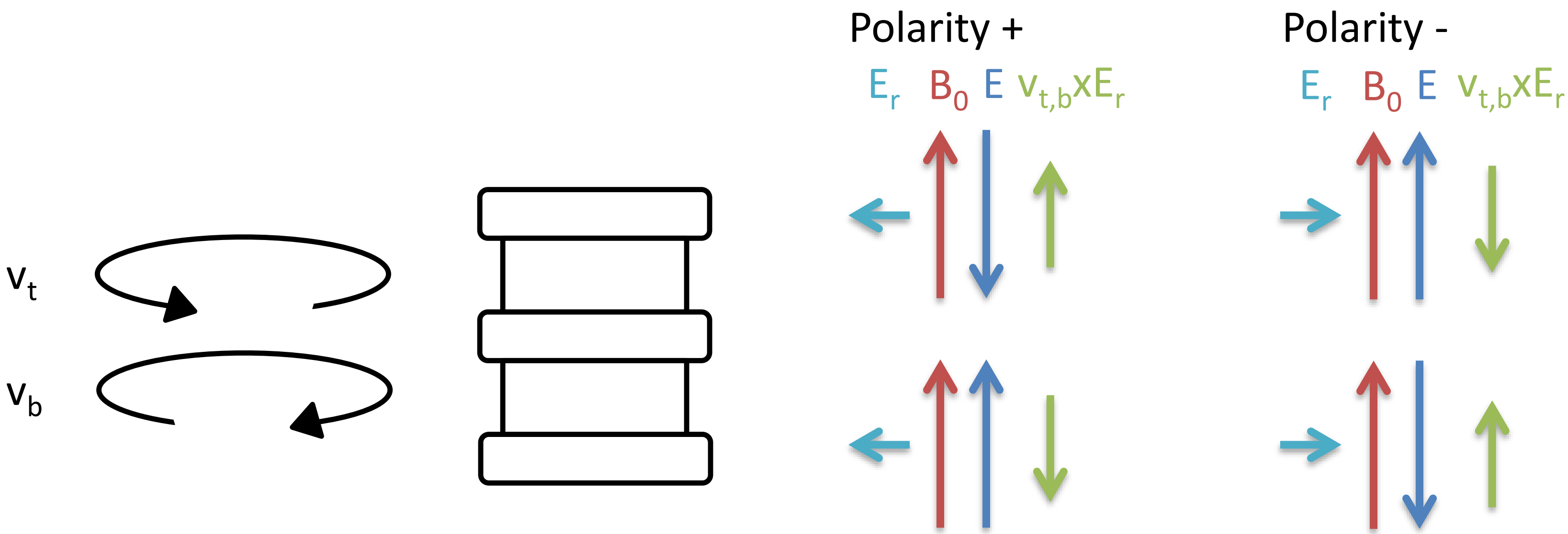


$$\hbar\Delta\omega_t = [2\mu_n(B_0 + vE_r/c^2) + 2d_n(E)] - [2\mu_n(B_0 - vE_r/c^2) - 2d_n(E)]$$
$$= 4d_nE + 4\mu_n vE_r/c^2$$

$$\hbar\Delta\omega_b = [2\mu_n(B_0 + vE_r/c^2) + 2d_n(E)] - [2\mu_n(B_0 - vE_r/c^2) - 2d_n(E)]$$
$$= 4d_nE + 4\mu_n vE_r/c^2$$

$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_b}{4E} + \frac{\hbar\Delta\omega_t}{4E}\right) = d_n + \frac{\mu_n vE_r}{c^2}$$

Rotational vxE 3



$$\hbar\Delta\omega_t = [2\mu_n(B_0 + v_t E_r/c^2) + 2d_n(E)] - [2\mu_n(B_0 - v_t E_r/c^2) - 2d_n(E)]$$
$$= 4d_n E + 4\mu_n v_t E_r/c^2$$

$$\hbar\Delta\omega_b = \left[2\mu_n\left(B_0 - v_b E_r/c^2\right) + 2d_n(E)\right] - \left[2\mu_n\left(B_0 + v_b E_r/c^2\right) - 2d_n(E)\right]$$
$$= 4d_n E - 4\mu_n v_b E_r/c^2$$

$$\frac{1}{2}\left(\frac{\hbar\Delta\omega_b}{4E} + \frac{\hbar\Delta\omega_t}{4E}\right) = d_n + \frac{\mu_n(v_t - v_b)E_r}{Ec^2}$$

Summary

- Using a double cell allows for the cancellation of systematic effects which correlate with E direction
- Effects which correlate with the HV polarity but not the E direction are not cancelled by the use of a double cell
- Asymmetry between the two cells reduces the degree of cancellation

Next Steps

- Broad studies of how each systematic effect is suppressed (or not) in the double cell configuration
  - Desired suppression of effects will set requirements on subsystem design
- Filling studies will be critical due to likely large asymmetry in UCN spectra for the top and bottom cells in a vertical orientation