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Feasibility of Measuring EDM in Spin Transparent Colliders

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Outline

1. Generalized Thomas-BMT equation
2. Spin Motion in Spin Transparent Colliders
3. Estimation of the limiting EDM value
4. Summary

Generalized Thomas-BMT equation

$$\vec{\mu} = (1 + G_M)\frac{e\hbar}{mc}\,\vec{S}, \qquad \vec{d} = G_E\frac{e\hbar}{mc}\,\vec{S}$$

MDM is magnetic dipole moment $\vec{\mu}$, EDM is electric dipole moment $\vec{d}$

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S}, \qquad \vec{\Omega} = (1 + G_M)\,\vec{B}_{rest} + \frac{\gamma - 1}{\gamma v^2}\,\vec{v} \times \vec{E}_{rest} + G_E\,\vec{E}_{rest}$$

Thomas precession

Spin rotation due to MDM

Spin rotation due to EDM

$\vec{B}_{rest}$, $\vec{E}_{rest}$ are magnetic and electric fields in the rest frame which are related with $\vec{B}$, $\vec{E}$ fields in the laboratory frame by the Lorentz transformation

Spin equation in the frame aligned with the particle velocity

$$\frac{d\vec{S}}{dz} \equiv \vec{S}' = \vec{W} \times \vec{S}$$

where z is coordinate along the design orbit in the accelerator frame.

$$\vec{W} = \vec{W}_\perp + W_\parallel \vec{\tau}, \qquad W_\parallel = (1 + G_M)\, H_\parallel - æ + G_E D_\parallel$$

$$\vec{W}_\perp = \gamma G_M \vec{H}_\perp + \gamma v \left(G_M - \frac{1}{\gamma^2 v^2} \right) \vec{D} \times \vec{\tau} + \gamma G_E \left(\vec{D}_\perp + \vec{v} \times \vec{H} \right)$$

Here $\vec{\tau} = \vec{v}/v$ is the ort along the particle velocity, γ is relativistic factor,
$\vec{H} = \chi \vec{B}/B\rho$, $\vec{D} = \chi \vec{E}/B\rho$ are magnetic and electric fields
in units of magnetic rigidity $B\rho$,

$$\chi = \sqrt{\left(1 + K_x y - K_y x\right)^2 + x'^2 + y'^2},$$

(x, y) are particle's transverse deviation from the design orbit,
$\vec{K}(z) = \left(K_x, K_y, 0\right)$ is the curvature of the design orbit.

Spin Motion at Linear Approximation

For the flat design orbit ($K_x = 0$) spin angular velocity $\vec{W} = \vec{W}_0 + \vec{w}$

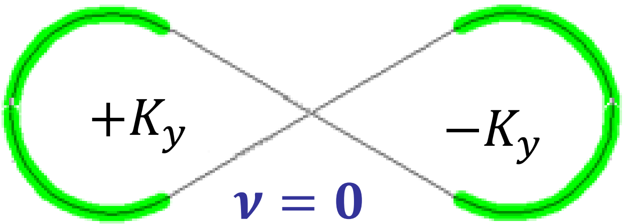
$$\begin{cases} W_{0x} = 0 \\ W_{0y} = \gamma G_M K_y \\ W_{0z} = 0 \end{cases} \qquad \begin{cases} w_x = -\gamma\, G_M\, \tau'_y - \gamma v\, G_E \tau'_x \\ w_y = \gamma G_M \tau'_x - \gamma v G_E \tau'_y \\ w_z = (1 + G_M)\left(H_z + K'_y y\right) + G_M K_y y' + G_E D_z \end{cases}$$

The spin frame orts $(\vec{e}_1^{\,s}, \vec{e}_2^{\,s}, \vec{e}_3^{\,s})$ for figure-8 ring **at Spin Transparency mode** are

$$\vec{e}_1^{\,s} = \vec{e}_y, \qquad \vec{e}_1^{\,s} + i\vec{e}_3^{\,s} = \exp\left(i\,\Psi_y\right)(\vec{e}_x + i\vec{e}_z), \qquad \Psi_y(z) = \gamma G_M \int_0^z K_y dz,$$

Average spin field $\vec{\omega}$ at the spin frame

$$\omega_i = \frac{L}{2\pi}\langle \vec{w} \cdot \vec{e}_i^{\,s} \rangle$$



In real lattice $\omega_2 = 0$,

$$\omega_1 + i\omega_3 = \boxed{G_E \frac{\Delta p}{m} \frac{L}{2\pi} \langle D'_x \frac{d}{dz} e^{i\Psi_y} \rangle} + i\, \boxed{(1 + G_M) \frac{L}{2\pi} \langle H_z e^{i\Psi_y} \rangle} + \boxed{\gamma G_M \frac{L}{2\pi} \langle \tau_y \frac{d}{dz} e^{i\Psi_y} \rangle}$$

where D_x is the radial dispersion function, Δp is the momentum deviation, H_z are solenoid fields for spin control

Due to imperfections

Analogy with Synchrotron Modulation of Energy

After compensation the resonance strength due to imperfection $(H_z = H_{comp} + h_z)$

$$\omega_1 + i\omega_3 = G_E \frac{\Delta p}{m} \frac{L}{2\pi} \langle D'_x \frac{d}{dz} e^{i\Psi_y} \rangle + i\,(1 + G_M) \frac{L}{2\pi} \langle h_z e^{i\Psi_y} \rangle$$

The problem is equivalent to the spin dynamics taking into account the synchrotron modulation of energy.

$$\vec{\omega} = \vec{\sigma}_E + \vec{\nu}(h_{zi})$$

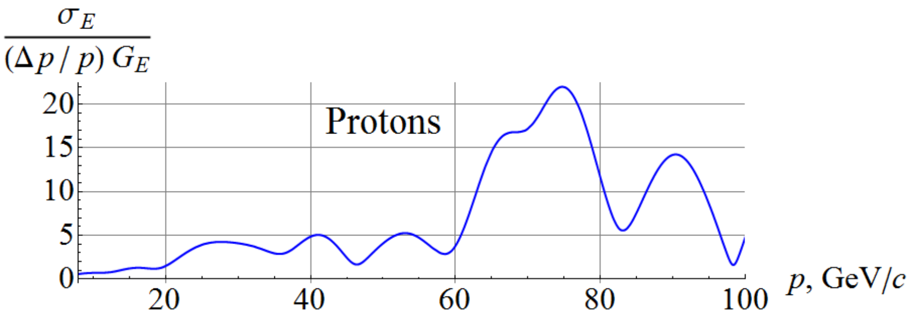
The effective "momentum spread" σ_E is proportional to the EDM and is determined by the ring's lattice. It's value depends on the energy and has interference maxima.

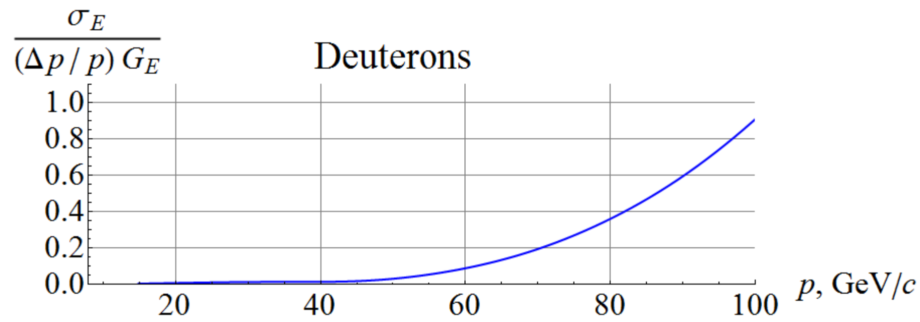
The synchrotron oscillations leads to the splitting of the single resonance into the series of sideband resonances $\nu = \nu_m$ which are equidistant from the single one

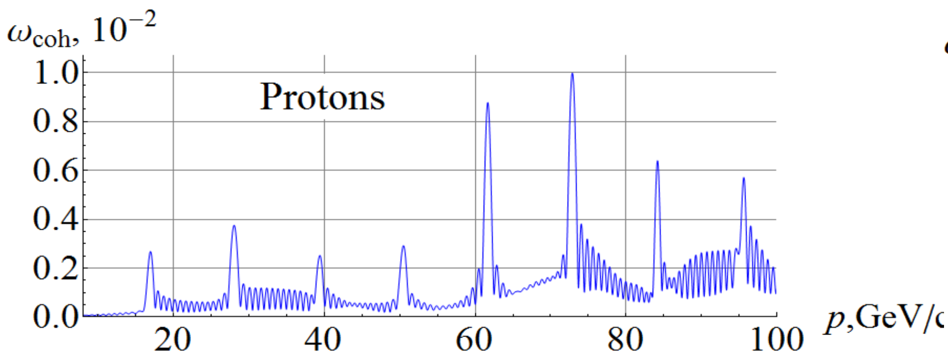
$$\nu_m = m\nu_\gamma, \qquad \omega_m \sim \omega_0 \left(\frac{\sigma}{2\nu_\gamma}\right)^m, \qquad \sigma \ll \nu_\gamma.$$

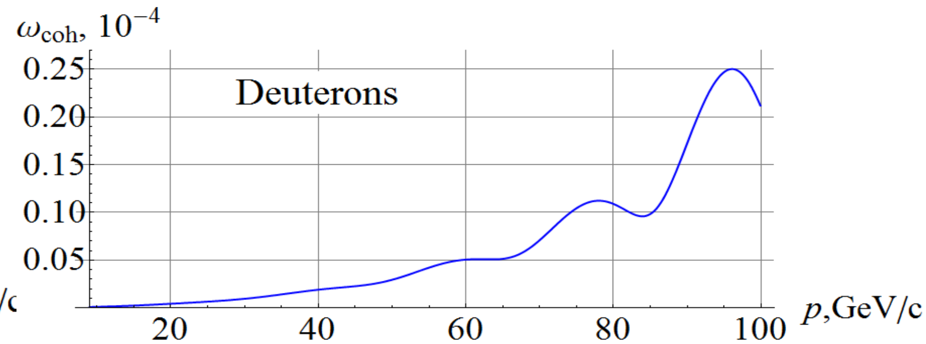
Problem of the EDM measurement is reduced to the measurement of the first sideband resonance strength.

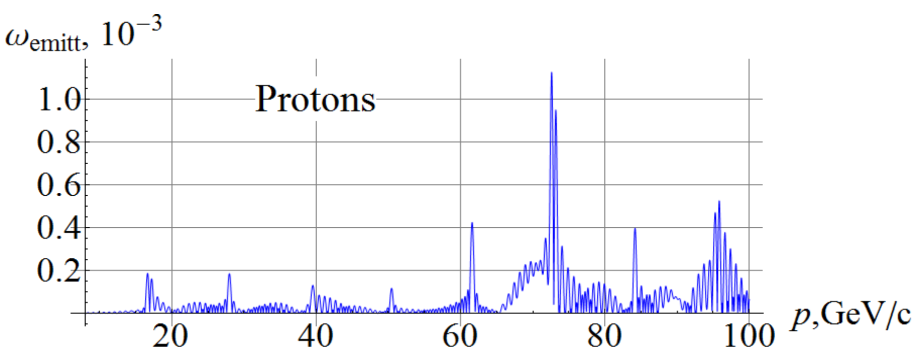
JLEC collider

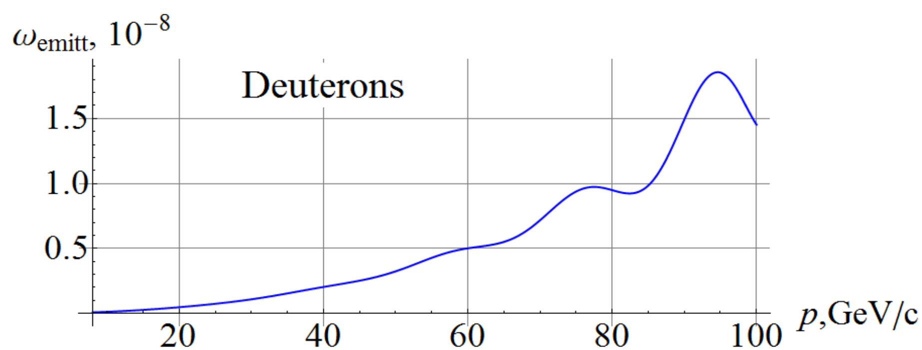






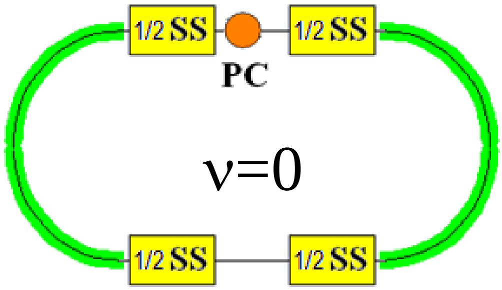


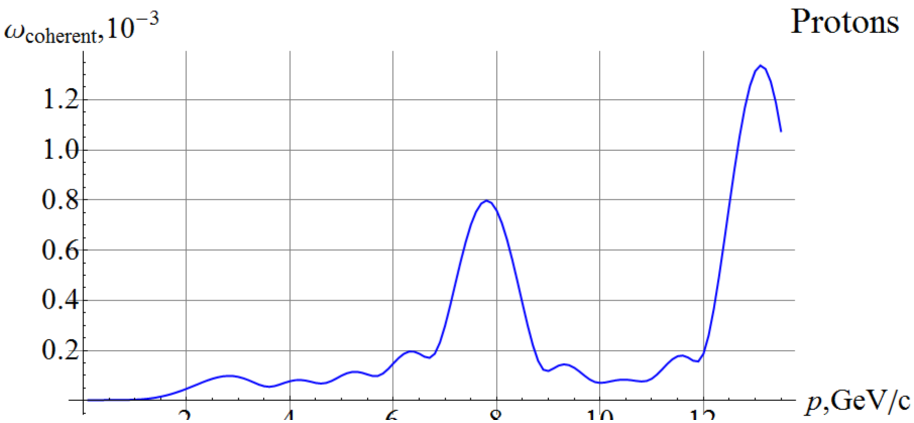


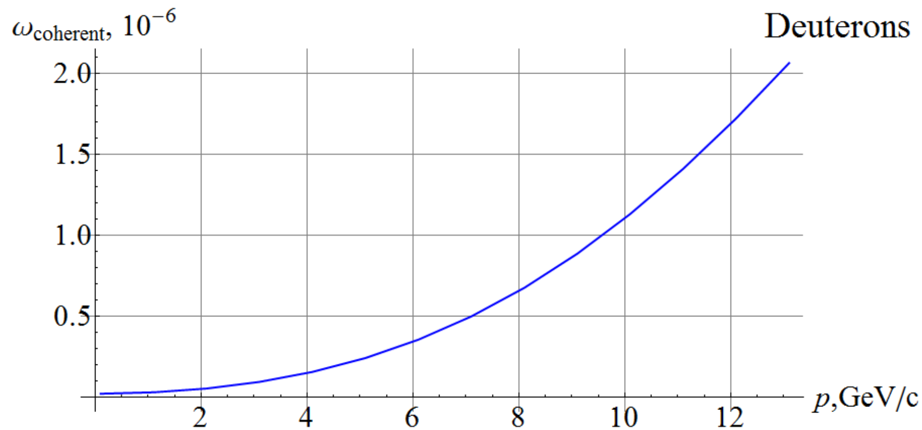


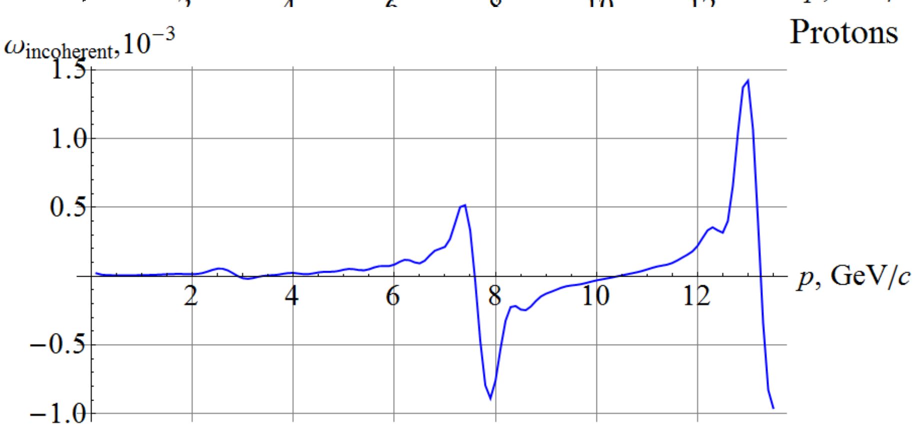
NICA collider

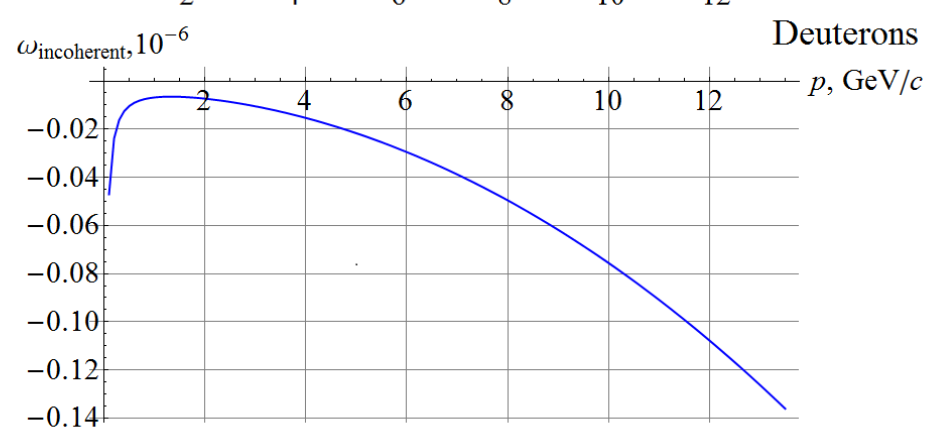
Spin dynamics at the NICA collider with two solenoidal snakes is equivalent to the JLIEC collider



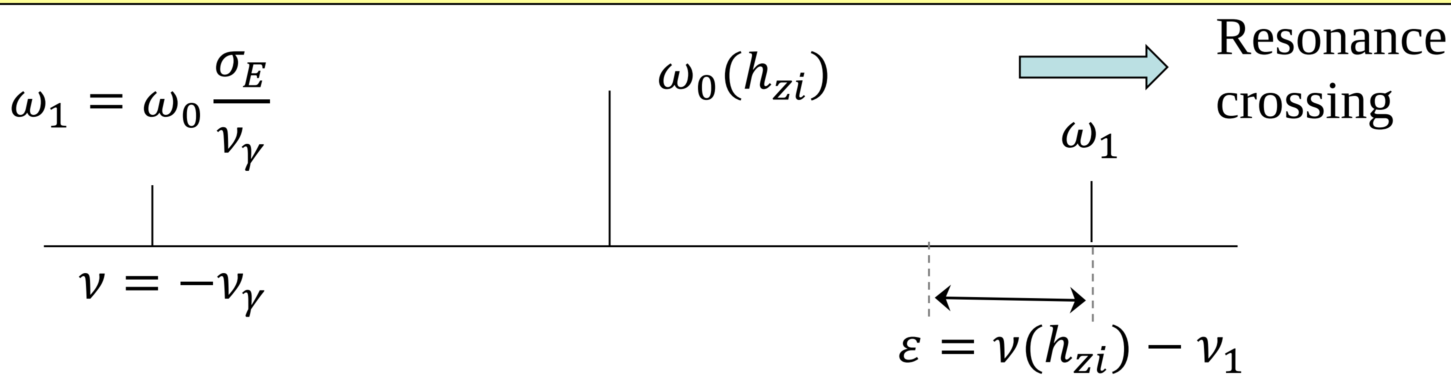








Estimation of the limiting EDM value



After fast crossing sideband resonance with constant speed ε' the next depolarization occurs (Froissart-Stora crossing)

$$D = \frac{\pi\omega_1^2}{\varepsilon'} = \frac{\pi\omega_0^2}{\varepsilon'}\frac{\sigma_E^2}{\nu_\gamma^2} \qquad \varepsilon' \sim \frac{\Delta\nu_\gamma\, c}{R\,\Delta t_{exper}} \qquad (\omega_0 \ll \nu_\gamma)$$

Estimation of the limiting EDM value for proton (protons)

$$D = 0.1, \quad \nu_\gamma = 10^{-3}, \quad \Delta\nu_\gamma = 10^{-6}, \quad \omega_0 = 10^{-4}, \quad \frac{\Delta p}{p} = 10^{-4}$$

$$\frac{\sigma_E}{G_E(\Delta/p)} = 10\,, \quad R = 80m, \quad \Delta t_{exper} = 30\ min$$

$$G_E \sim 3 \cdot 10^{-5}$$

Summary

- The Spin Transparency mode is applicable to measuring the EDMs of both protons and deuterons
- The idea of experiment is discussed
- The estimation of the limiting EDM values is presented

The Spin Transparency mode allows to carry out experiments with polarized beams at new precision level

Thank you for your attention!