Electromagnetic dipole moment and time reversal invariance violating interactions for high energy short-lived particles in bent and straight crystals at Large Hadron Collider

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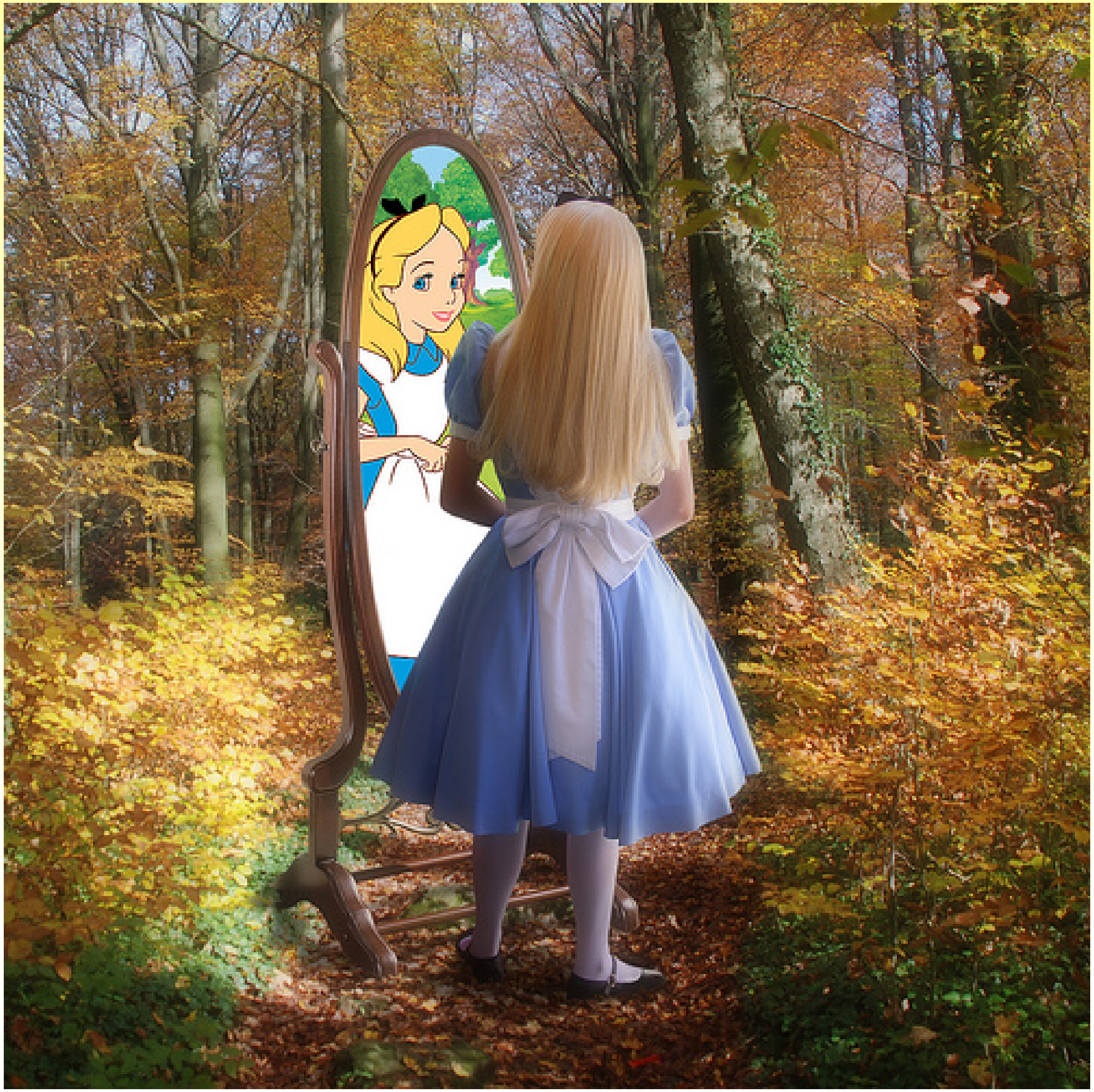
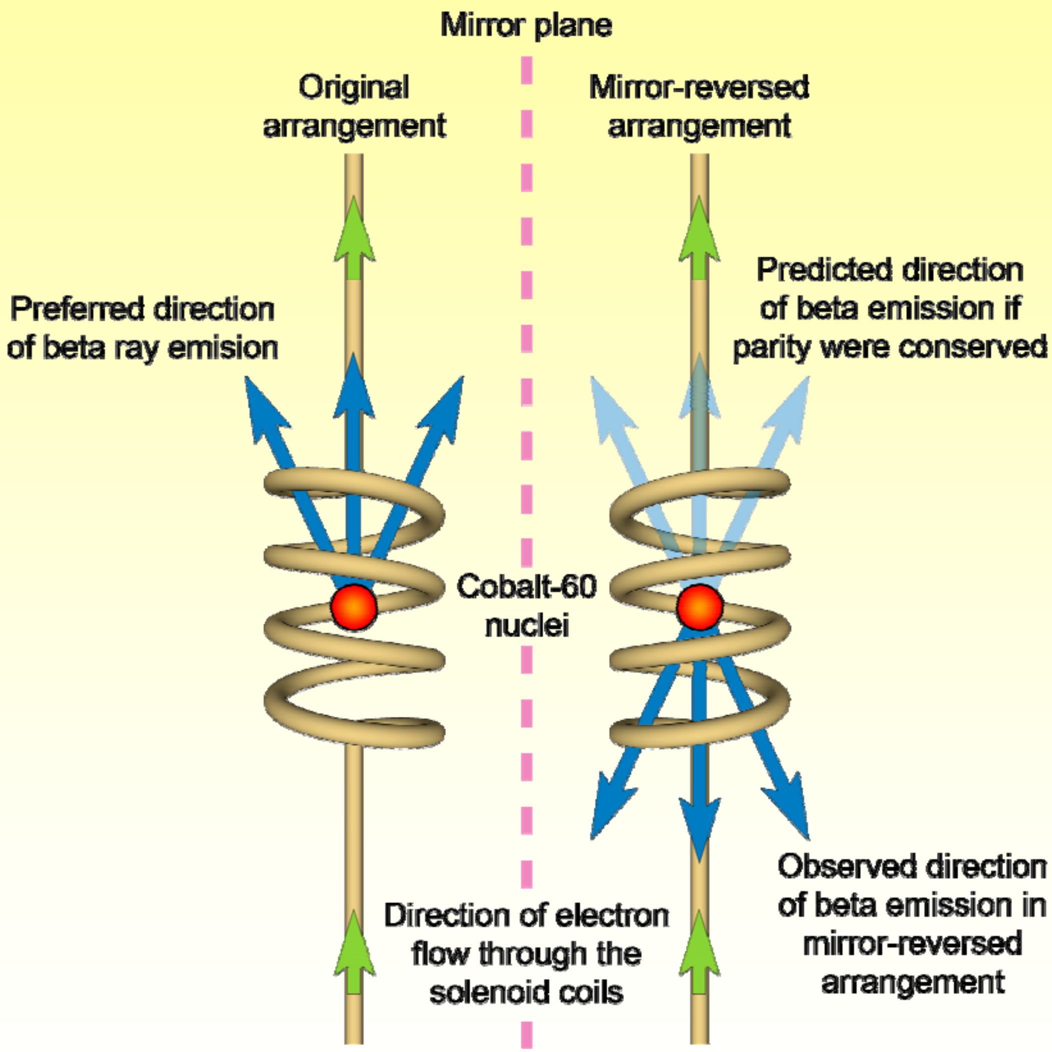
P non-invariance



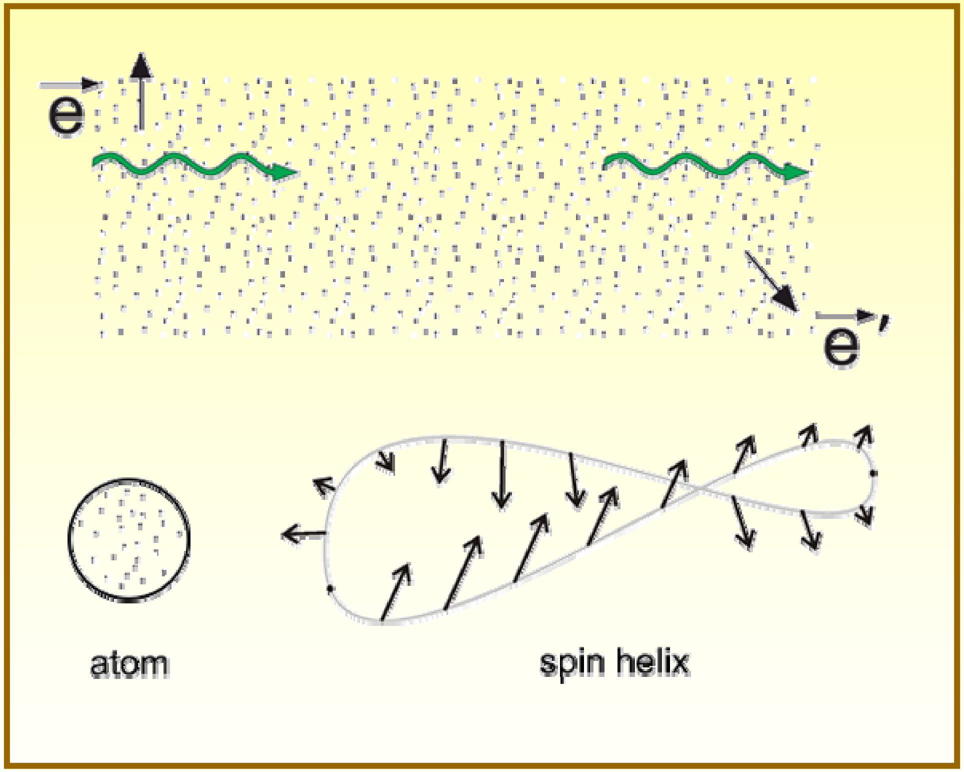
The Wu experiment



The Wu experiment, conducted in 1956 by the Chinese American physicist Chien-Shiung Wu in collaboration with the Low Temperature Group of the US National Bureau of Standards.

Tsung-Dao Lee and Chen-Ning Yang, the theoretical physicists who originated the idea of parity nonconservation and proposed the experiment, received the 1957 Nobel Prize in physics for this result.

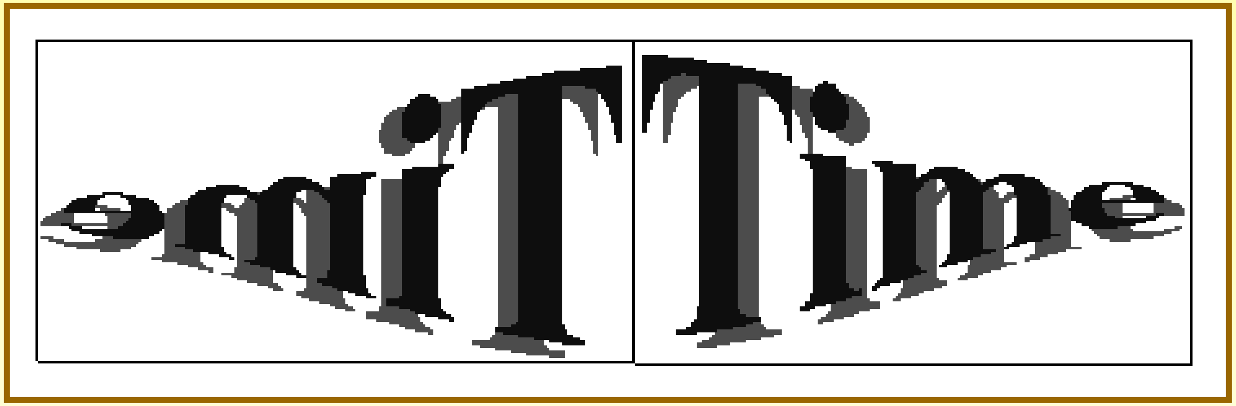
Optical gyrotropy caused by P-violating interactions



1957 Zeldovich I.B.
1978 Barkov L.M., Zolotarev M.S.

Neutral weak currents were later discovered in SLAC at deeply nonelastic electrons scattering by deutons.

T non-invariance



To be or not to be

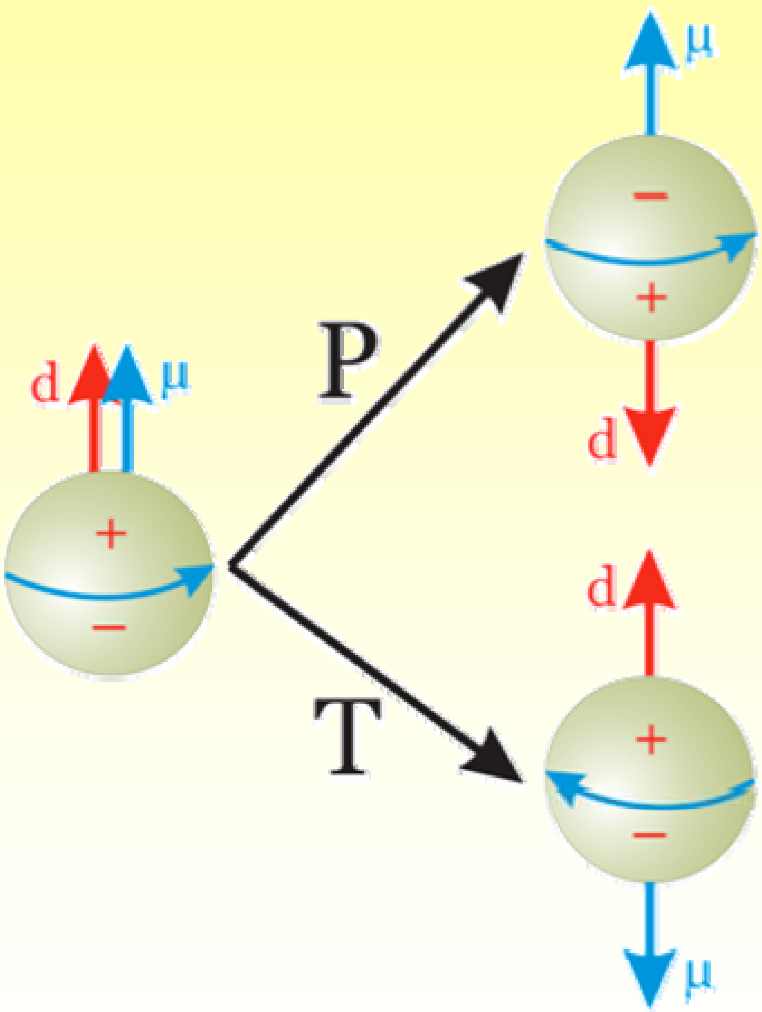
Role of CP violation in the matter/antimatter asymmetry of the Universe

Sakharov Criteria:

Particle Physics can produce matter/antimatter asymmetry in the early universe **IF** there is:

- Baryon Number Violation
- CP & C violation
- Departure from Thermal Equilibrium

T non-invariance

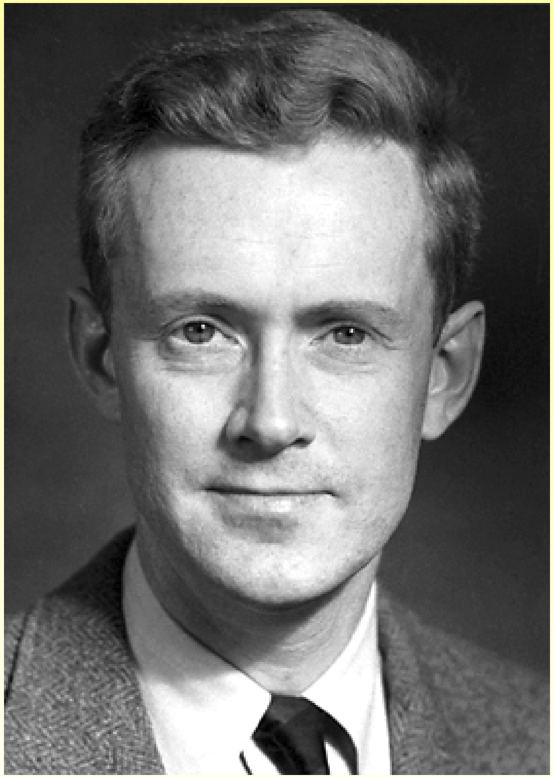


Non-Relativistic Hamiltonian

$$H = \underbrace{-\vec{\mu}\vec{B}}_{\substack{C-even \\ P-even \\ T-even}} - \underbrace{\vec{d}\vec{E}}_{\substack{C-even \\ P-odd \\ T-odd}}$$

Assume $\vec{\mu} = \mu \frac{\vec{J}}{J}$ and $\vec{d} = d \frac{\vec{J}}{J}$

First result for neutron EDM



E.M. Purcell and N.F. Ramsey (Phys. Rev. 78, 807 (1950)) pioneered
Neutron Beam Magnetic Resonance

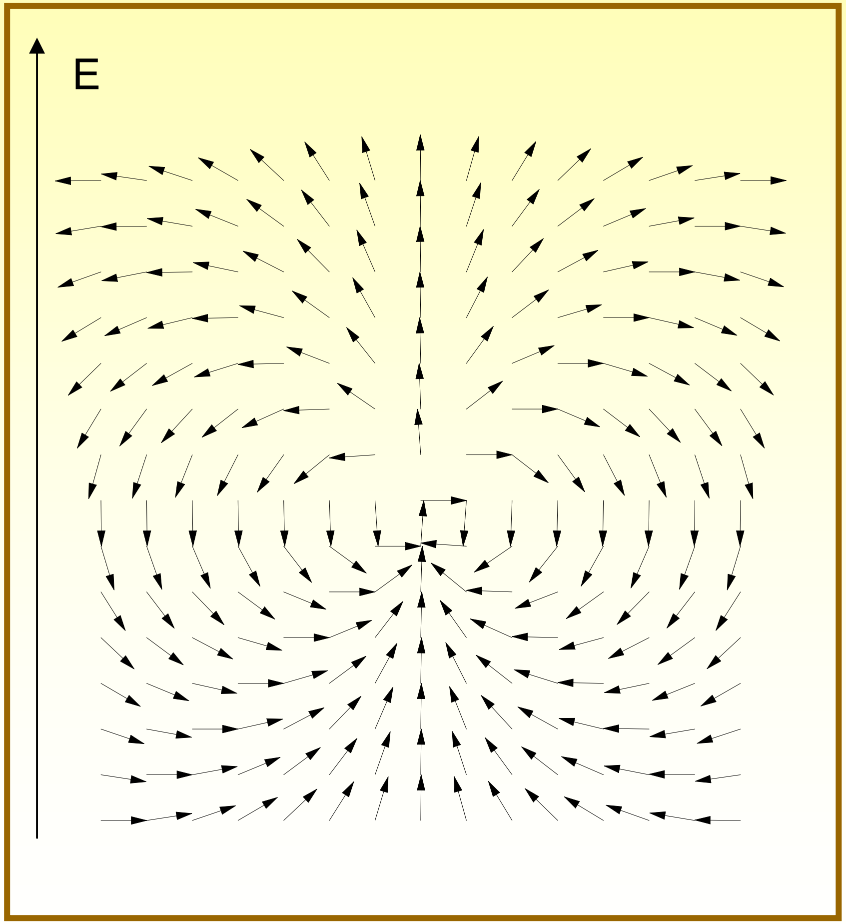
$$\boxed{D \leq 6 \cdot 10^{-25}\ \text{cm}}$$

Current limits on EDM

Particle	Limit/Measurement [e cm]	SM limit [factor to go]
e	$<1.05 \times 10^{-27}$	10^{11}
μ	$<1.8 \times 10^{-19}$	10^{8}
τ	$(-2.2 < d_\tau < 4.5) \times 10^{-17}$	10^{7}
n	$<2.9 \times 10^{-26}$	10^{4}
p	$<0.54 \times 10^{-23}$	10^{6}
Λ^0	$(-3.0 \pm 7.4) \times 10^{-17}$	10^{11}
$\nu_{e,\mu}$	$<2 \times 10^{-21}$	
ν_τ	$<5.2 \times 10^{-17}$	
Hg-atom	$<3.1 \times 10^{-29}$	$\leq 10^{4}$

Ann. Phys. (Berlin) 525, No 8-9, (2013)

New physical characterstic:
T-odd polarizability of atoms, nuclei and elementary particles

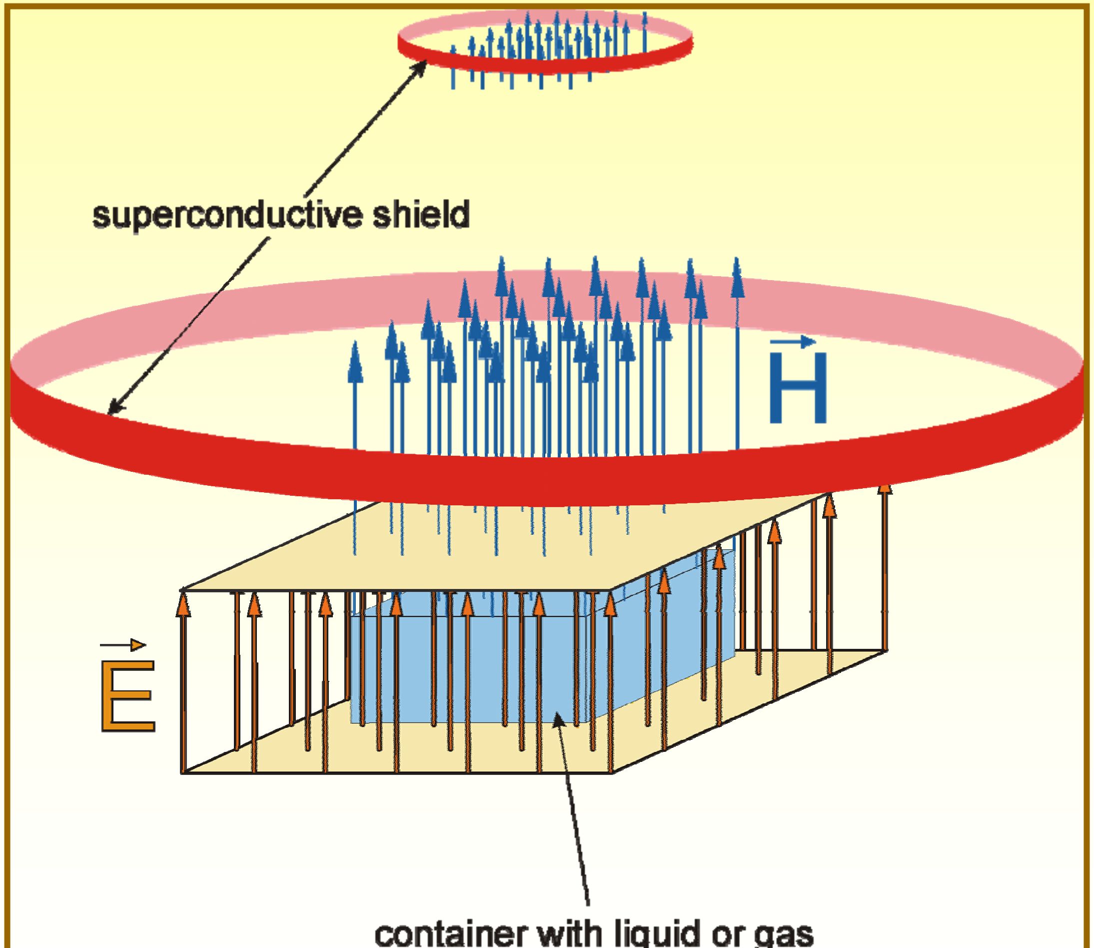


$$\boxed{d = \beta_S^T H}$$

$$\boxed{\mu = \beta_S^T E}$$

V.G. Baryshevsky,
P and T-noninvariant phenomena in the passage of atoms (nuclei) through a target of light, Yad. Fiz., pp. 48 , 1063–1066, (1988).

T-odd phenomenon of magnetic field generation by a static electric field in a medium and vacuum and T-odd polarizability of atoms nuclei and elementary particles

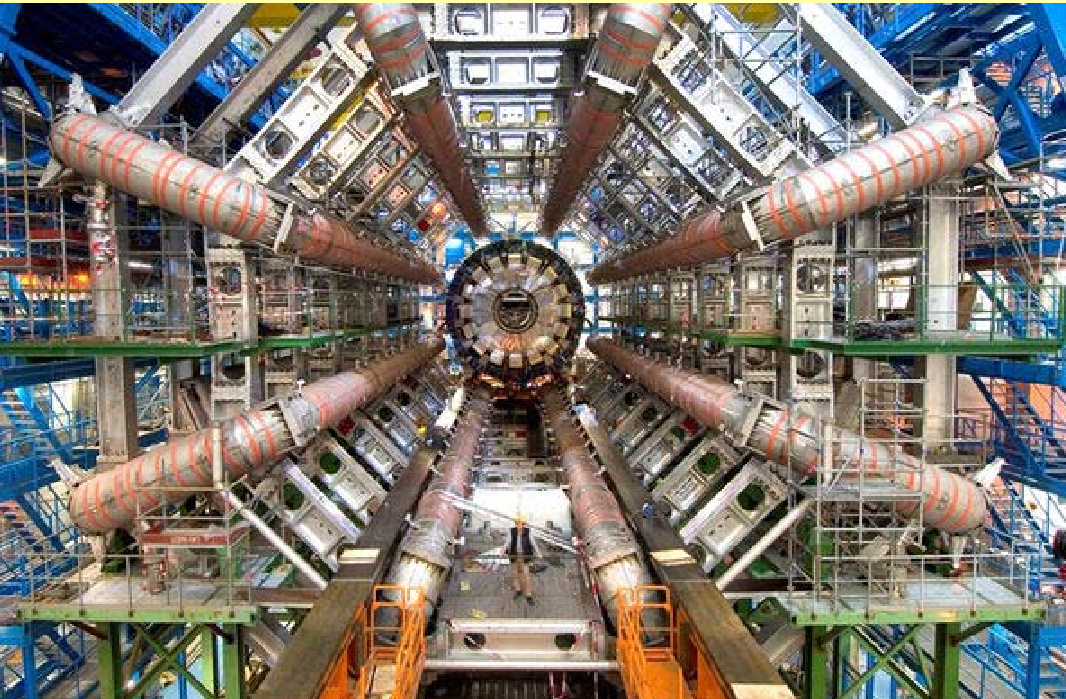


The way to

$$D \sim 10^{-30} \div 10^{-32}\ cm$$

V.G. Baryshevsky,
Time-Reversal-Violating Generation of Static Magnetic and Electric Fields and a Problem of Electric Dipole Moment Measurement, Phys.Rev.Lett. 93, 4 (2004) 043003

T non-invariance at LHC and FCC



Electrical dipole moment of heavy charm and beauty baryons

It was recently stated that heavy baryons EDM can be as great as the value $d \sim 10^{-17}$.

- F. Sala, JHEP 03, 061, (2014)
- A.E. Blinov, et all, Nucl. Phys. Proc. Suppl., 1 89, 257, (2009)
- Cordero-Cid, et all, J. Phys. G, 35, 02504, (2008)

But how can we measure EDM of unstable baryons?

Characteristics

Charmed baryons

$$\Lambda_c^+ : \tau = 0.2 \cdot 10^{-12} s; \quad m = 2286.46 MeV; \quad l_d = l_{decay} = \tau c \gamma = 6cm.$$

$$\Xi_c^+ : \tau = 0.44 \cdot 10^{-12} s; \quad m = 2467.8 MeV; \quad l_d = 13.2cm.$$

$$\Xi_c^0 : \tau = 0.1 \cdot 10^{-12} s; \quad m = 2470.88 MeV; \quad l_d = 3.3cm; \quad \gamma = 10^3$$

$$\Omega_c^0 : \tau = 7 \cdot 10^{-14} s; \quad m = 2695 MeV; \quad l_d = 2.1cm.$$

Bottom baryons

$$\Lambda_b^0 : \tau = 1.425 \cdot 10^{-12} s; \quad m = 5619.4 MeV; \quad l_d = 42.7\, cm; \quad \gamma = 10^3.$$

$$\Xi_b^0 : \tau = 1.49 \cdot 10^{-12} s; \quad m = 5788 MeV; \quad l_d = 44.7\, cm.$$

$$\Xi_b^- : \tau = 1.56 \cdot 10^{-12} s; \quad m = 5791 MeV; \quad l_d = 44.7\, cm.$$

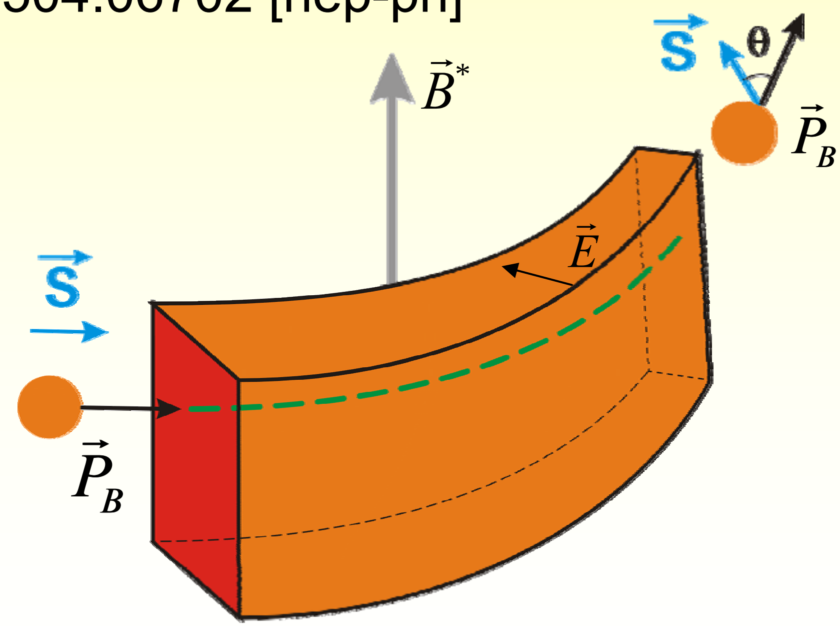
$$\Omega_b^- : \tau = 1.1 \cdot 10^{-12} s; \quad m = 6071 MeV; \quad l_d = 33\, cm.$$

Spin rotation effect of ultrarelativistic particles passing through a crystal

* **V.G. Baryshevsky**, Spin rotation of ultrarelativistic particles passing through a crystal, Pis'ma Zh. Tekh. Fiz., 5, 3 (1979), pp 182-184.

* **V.G. Baryshevsky**, Spin rotation and depolarization of high-energy particles in crystals at Hadron Collider (LHC) and Future Circular Collider (FCC) energies and the possibility to measure the anomalous magnetic moments of short-lived particles, arXiv:1504.06702 [hep-ph]

* **V.G. Baryshevsky**, The possibility to measure the magnetic moments of short-lived particles (charm and beauty baryons) at LHC and FCC energies using the phenomenon of spin rotation in crystals, Physics Letters B, V. 757, 2016, pp 426–429.



Particles spin rotation in bent crystal

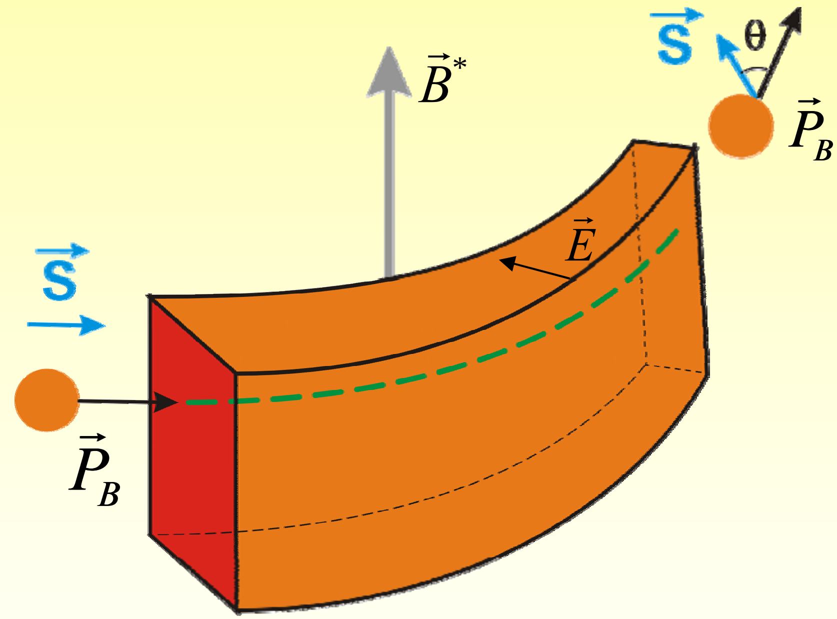
In particle rest frame

$$B^* \to \gamma E$$

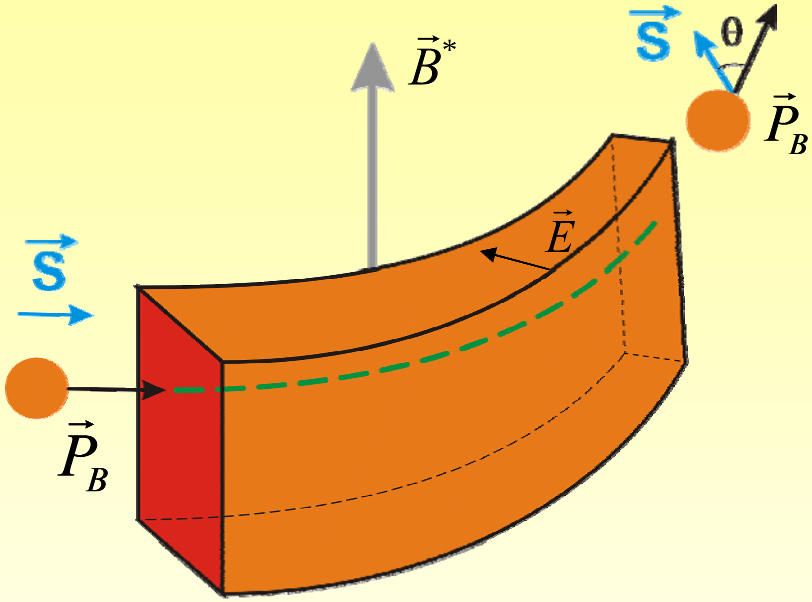
$$\omega' = \frac{2\mu' B^*}{\hbar} = \frac{2\mu' \gamma E}{\hbar}$$

In laboratory frame

$$\omega = \frac{\omega'}{\gamma} = \frac{2\mu' E}{\hbar}$$



First experiment to measure (g-2) rotation



E761 Collaboration, FERMILAB

”First observation of spin precession of polarized Σ^+ hyperons channeled in bent crystals”, LNPI Research Reports (1990-1991) 129.

Energy of Σ^+ : 200 – 300 GeV

D. Chen et all

”First Observation of Magnetic Moment Precession of Channeled Particles in Bent Crystals”, Phys. Rev. Lett. 69 (1992) 3286.

A.V. Khanzadeev, V.M. Samsonov, R.A. Carrigan, D. Chen

”Experiment to observe the spin precession of channeled relativistic Σ^+ hyperons” NIM 119 (1996) 266.

Electromagnetic dipole moment and particles spin rotation in bent crystals at Large Hadron Collider

Non-Relativistic Hamiltonian

$$H = \underbrace{-\vec{\mu}\vec{B}}_{\substack{C-even\\ P-even\\ T-even}} - \underbrace{\vec{d}\vec{E}}_{\substack{C-even\\ P-odd\\ T-odd}}$$

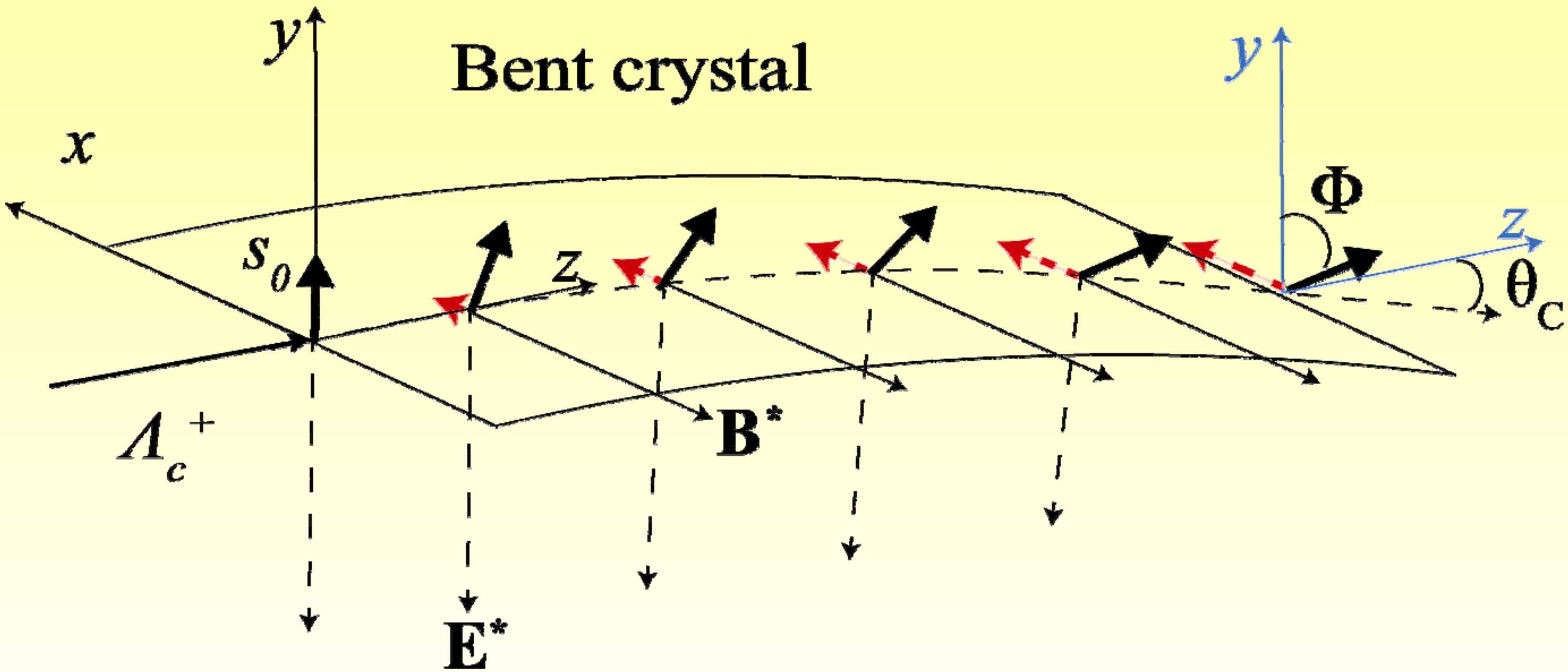
Relativistic equation

$$\frac{d\vec{S}}{dt} = -\frac{e(g-2)}{2mc}\left[\vec{S}\times\left[\vec{\beta}\times\vec{E}\right]\right] + \frac{d}{\hbar S}\left[\vec{S}\times\vec{E}\right].$$

• Botella F. J., Garcia Martin L. M., Marangotto D., et all, On the search for the electric dipole moment of strange and charm baryons at LHC, *Eur. Phys J.C.* **77**, 181 (2017), DOI 10.1140/epjc/s10052-017-4679-y.

• Bagli E., Bandiera L., Cavoto G., et all, Electromagnetic dipole moments of charged baryons with bent crystals at the LHC, *Eur. Phys J.C.*, (2017) 77:828, p. 1-19.

Electromagnetic dipole moment and particles spin rotation in bent crystals at Large Hadron Collider



Behavior of the spin rotation caused by magnetic moment and EDM. The figure is reprinted from Botella et all, On the search for the electric dipole moment of strange and charm baryons at LHC, *Eur. Phys J.C.* 77, 181 (2017). Black arrows represent spin rotation caused by magnetic dipole moment, red arrows represent spin rotation caused by electric dipole moment.

T non-invariance interactions at LHC and FCC

- **V.G. Baryshesky**, On the search for the electric dipole moment of strange and charm baryons at LHC and parity violating (P) and time reversal (T) invariance violating spin rotation and dichroism in crystal,
  arXiv: 1708.09799v1 [hep-ph], 31 Aug 2017.

- **V.G. Baryshesky**, Time reversal invariance violation for high energy charged baryons in bent crystals, arXiv:1803.05770v1 [hep-ph] 14 Mar 2018 ,
  Eur.Phys.J in press.

The index of refraction and effective potential energy of relativistic particles in matter

The wave number of the particle in vacuum is denoted *k, k′ = kn* is the wave number of the particle in medium. Expression for n does not contain ħ.

$$\boxed{n = 1 + \frac{2\pi N}{k^2} f(0)}$$

Boundary vacuum-medium

vacuum	medium
$E = \sqrt{\hbar^2 k^2 c^2 + m^2 c^4}$	$E_{med} = \sqrt{\hbar^2 k^2 n^2 c^2 + m^2 c^4}$

Kinetic energy of a particle in vacuum is not equal to that in medium.

Effective potential energy of particle interaction in matter

From the energy conservation condition we immediately obtain the necessity to suppose that a particle in medium possesses effective potential energy. This energy can be found easily from the evident equality:

$$E = E_{med} + U_{eff}$$

$$U_{eff} = E - E_{med} = -\frac{2\pi\hbar^2}{m\gamma} N f(E,0) = (2\pi)^3 N T_{aa}(\vec{k}' - \vec{k} = 0)$$

$$f(E,0) = -(2\pi)^2 \frac{E}{c^2\hbar^2} T_{aa}(\vec{k}' - \vec{k} = 0) = -(2\pi)^2 \frac{m\gamma}{\hbar^2} T_{aa}(\vec{k}' - \vec{k} = 0)$$

Effective potential energy of particle interaction with crystal

$$U(\vec{r}) = \sum_{\vec{\tau}} U(\vec{\tau}) e^{i\vec{\tau}\vec{r}} \qquad U(\vec{\tau}) = \frac{1}{V} \sum_{j} U_j(\vec{\tau}) e^{i\vec{\tau}\vec{r}_j}$$

$$U_j(\vec{\tau}) = -\frac{2\pi\hbar^2}{m\gamma} F_j(\vec{\tau})$$

$$F_j(\vec{k}' - \vec{k}) = f_j(\vec{k}' - \vec{k}) - i\frac{k}{4\pi} \int f_j^*(\vec{k}'' - \vec{k}') f_j(\vec{k}'' - \vec{k}) d\Omega_{k''}$$

Scattering amplitude of a particle with spin 1/2

$$\hat{F}(\vec{q}) = A_{coul}(\vec{q}) + A_s(\vec{q}) + (B_{magn}(\vec{q}) + B_S(\vec{q}))\vec{\sigma}[\vec{n}\times\vec{q}] +$$
$$+(B_{we}(\vec{q}) + B_{wnuc}(\vec{q}))\vec{\sigma}\vec{N}_w + (B_{EDM}(\vec{q}) + B_{Te}(\vec{q}) + B_{Tnuc}(\vec{q}))\vec{\sigma}\vec{q}$$

$$\vec{q} = \vec{k}' - \vec{k},\ \ \vec{n} = \frac{\vec{k}}{k},\ \vec{N}_w = \frac{\vec{k}' + \vec{k}}{|\vec{k}' + \vec{k}|}$$

Effective potential energy determined by the anomalous magnetic moment

$$\boxed{\hat{F}^{(1)}_{magn}(q) = B_{magn}(q)\vec{\sigma}[\vec{n}\times\vec{q}]}$$

$$\boxed{\hat{U}^{(1)}_{magn} = -\frac{e\hbar}{2mc}\frac{g-2}{2}E_{xplane}(x)\vec{\sigma}\vec{N}}$$

$$\boxed{\vec{N} = [\vec{n}_x\times\vec{n}],\ \vec{n}_x \parallel \vec{E}(x),\ \vec{n}_x \perp \vec{n},\ \vec{n} = \frac{\vec{k}}{k}}$$

Effective potential energy determined by the anomalous magnetic moment

$$\boxed{\hat{F}^{(2)}(\vec{q}=\vec{\tau}) = i\frac{k}{4\pi\hbar^2 c^2}\iint e^{-i\vec{\tau}\vec{r}_\perp}\left\{\overline{\left[\int \hat{V}(\vec{r}_\perp, z)dz\right]^2} - \left[\overline{\int \hat{V}(\vec{r}_\perp, z)dz}\right]^2\right\} d^2 r_\perp}$$

$$\hat{V}(\vec{r}_\perp, z) = V_{coul}(\vec{r}_\perp, z) + \hat{V}_{magn}(\vec{r}_\perp, z)$$

$$\boxed{\hat{U}^{(2)}_{magn}(x) = -i\frac{1}{4d_y d_z mc^2}\left(\frac{g-2}{2}\right)\frac{\partial}{\partial x}\overline{\delta V^2{}_{coul}(x)}\vec{\sigma}\vec{N}}$$

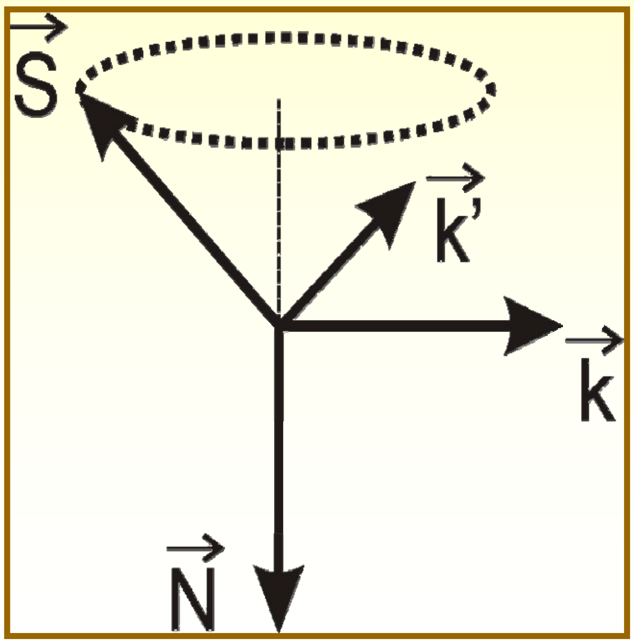
$$\boxed{\hat{U}_{magn}(x) = -(\alpha_m(x) + i\delta_m(x))\vec{\sigma}\vec{N}}$$

Effective potential energy determined by spin-orbit interaction

$$\hat{F}_{ssp-orb}(\vec{q}=\vec{\tau}) = B_s(\vec{\tau})\vec{\sigma}[\vec{n}\times\vec{\tau}]$$

$$\hat{U}_{ssp-orb} = -(\alpha_s + i\delta_s)\vec{\sigma}\vec{N}$$

Spin structure of $\hat{U}_s(x)$ is similar to the one of $\hat{U}_{magn}(x)$.



$$\vec{N} = [\vec{n}_x \times \vec{n}]$$

$$\alpha_s = -\frac{2\pi\hbar^2}{m\gamma d_y d_z}\frac{\partial N_{nuc}}{\partial x}B''$$

$$\delta_s = \frac{2\pi\hbar^2}{m\gamma d_y d_z}B'\frac{\partial N_{nuc}}{\partial x}$$

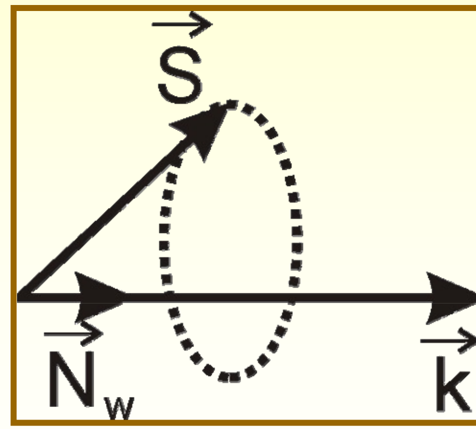
Effective potential energy determined by P-odd and T-even interactions

$$\hat{F}_w(\vec{q}) = (B_{we}(\vec{q}) + B_{wnuc}(\vec{q}))\vec{\sigma}\vec{N}_w$$

$$\boxed{\hat{U}_w(x) = \hat{U}_{we}(x) + \hat{U}_{wnuc}(x) = -(\alpha_w(x) + i\delta_w(x))\vec{\sigma}\vec{N}_w}$$

$$\alpha_w(x) = \alpha_{we}(x) + \alpha_{wnuc}(x)$$

$$\delta_w(x) = \delta_{we}(x) + \delta_{wnuc}(x)$$



$$\alpha_w(x) = \frac{2\pi\hbar^2}{m\gamma d_y d_z}(\tilde{B}'_{we}(0)N_e(x) + \tilde{B}'_{wnuc}(0)N_{nuc}(x))$$

$$\delta_w(x) = \frac{2\pi\hbar^2}{m\gamma d_y d_z}(\tilde{B}''_{we}(0)N_e(x) + \tilde{B}''_{wnuc}(0)N_{nuc}(x))$$

Effective potential energy determined by the electric dipole moment and other T-nonivariant interactions

$$\hat{F}_T(q) = (B_{EDM}(q) + B_{Te}(q) + B_{Tnuc}(q))\vec{\sigma}\vec{q}$$

$$\vec{q} = \vec{k}' - \vec{k}$$

$$\hat{U}_T(x) = \hat{U}_{EDM} + \hat{U}_{Te} + \hat{U}_{Tnuc} = -(\alpha_T(x) + i\delta_T(x))\vec{\sigma}\vec{N}_T$$

$$\hat{U}_{EDM}(x) = -(\alpha_{EDM}(x) + i\delta_{EDM}(x))\vec{\sigma}\vec{N}_T, \ \vec{N}_T = \vec{n}_x$$

$$\alpha_T(x) = \alpha_{EDM} + \alpha_{Te} + \alpha_{Tnuc}$$
$$\delta_T(x) = \delta_{EDM} + \delta_{Te} + \delta_{Tnuc}$$

$$\alpha_{Te(nuc)} = \frac{2\pi\hbar^2}{m\gamma d_y d_z}\tilde{B}''_{Te(nuc)}\frac{dN_{e(nuc)}(x)}{dx}$$

$$\delta_{Te(nuc)} = \frac{2\pi\hbar^2}{m\gamma d_y d_z}\tilde{B}'_{Te(nuc)}\frac{dN_{e(nuc)}(x)}{dx}$$

P and CP violating spin rotation in bent crystals

$$\boxed{ih \frac{\partial |\Psi(t)>}{\partial t} = \hat{U}_{eff} |\Psi(t)>}$$

$$\boxed{\vec{\xi} = \frac{<\Psi(t)|\vec{\sigma}|\Psi(t)>}{<\Psi(t)|\Psi(t)>}}$$

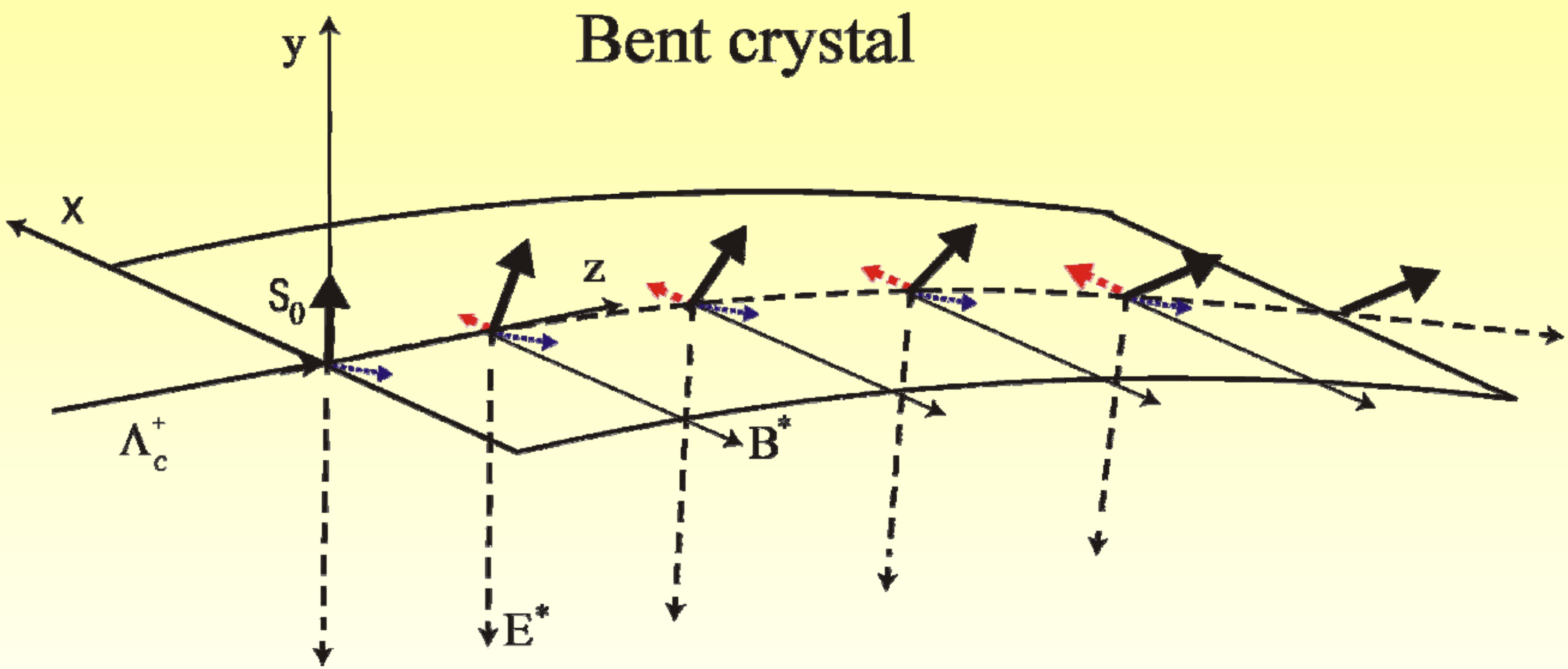
P and CP violating spin rotation in bent crystals

$$\frac{d\vec{\xi}}{dt} = \left[\vec{\xi} \times \vec{\Omega}_{mso}\right] - \frac{2}{\hbar}(\delta_m(x) + \delta_{s0}(x))\{\vec{N}_m - \vec{\xi}(\vec{N}_m\vec{\xi})\} +$$
$$+\left[\vec{\xi} \times \vec{\Omega}_T\right] + \frac{2}{\hbar}(\delta_{EDM}(x) + \delta_{Te}(x) + \delta_{Tnuc}(x))\{\vec{N}_T - \vec{\xi}(\vec{N}_T\vec{\xi})\} +$$
$$+\left[\vec{\xi} \times \vec{\Omega}_w\right] - \frac{2}{\hbar}\delta_w\{\vec{n} - \vec{\xi}(\vec{n}\vec{\xi})\}.$$

$$\vec{\Omega}_{mso} = \vec{\Omega}_{MDM} + \vec{\Omega}_{so} = -\left(\frac{e(g-2)}{2mc}E_x(x) + \frac{2}{\hbar}\alpha_{so}(x)\right)\vec{N}_m,$$
$$\vec{\Omega}_T = \vec{\Omega}_{EDM} + \vec{\Omega}_{Ten} = \frac{2}{\hbar}(dE_x(x) + \alpha_{Te}(x) + \alpha_{Tnuc}(x))\vec{N}_T,$$
$$\vec{\Omega}_w = \frac{2}{\hbar}\alpha_w\vec{n}.$$

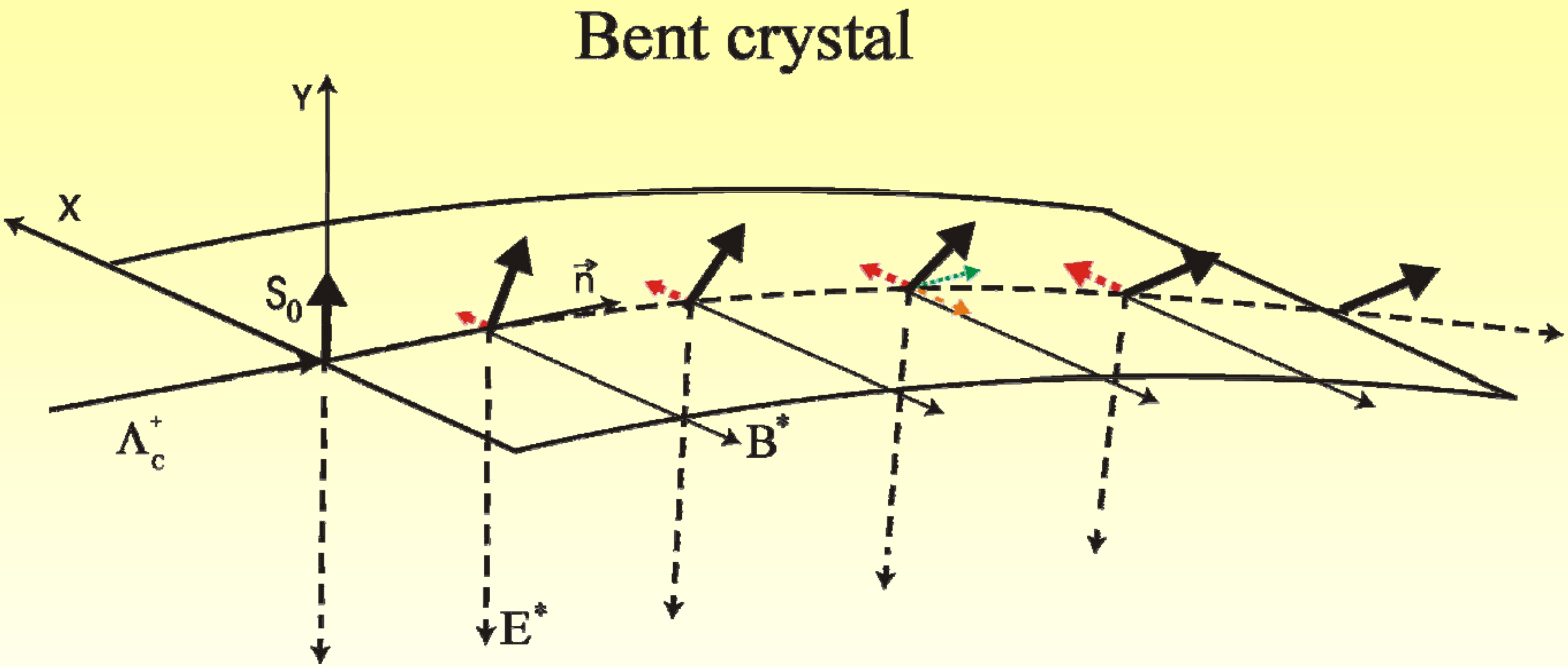
$$\vec{N}_m = [\vec{n} \times \vec{n}_x],$$
$$\vec{N}_T = \vec{n}_x,$$
$$\vec{n} = \frac{\vec{k}}{k}$$

P and CP violating spin rotation in bent crystals



Behavior of the spin rotation caused by magnetic moment and T-reversal violation interactions. Black arrows represent spin rotation about effective magnetic field (about bent axis, direction $\vec{N}_m$), red arrows represent spin rotation about electric field (direction $\vec{N}_T$), purple arrows represent new effect - magnetic spin rotation in direction $\vec{N}_m$, owing to T-reversal violation and P-violating interactions, is not shown here for simplicity.

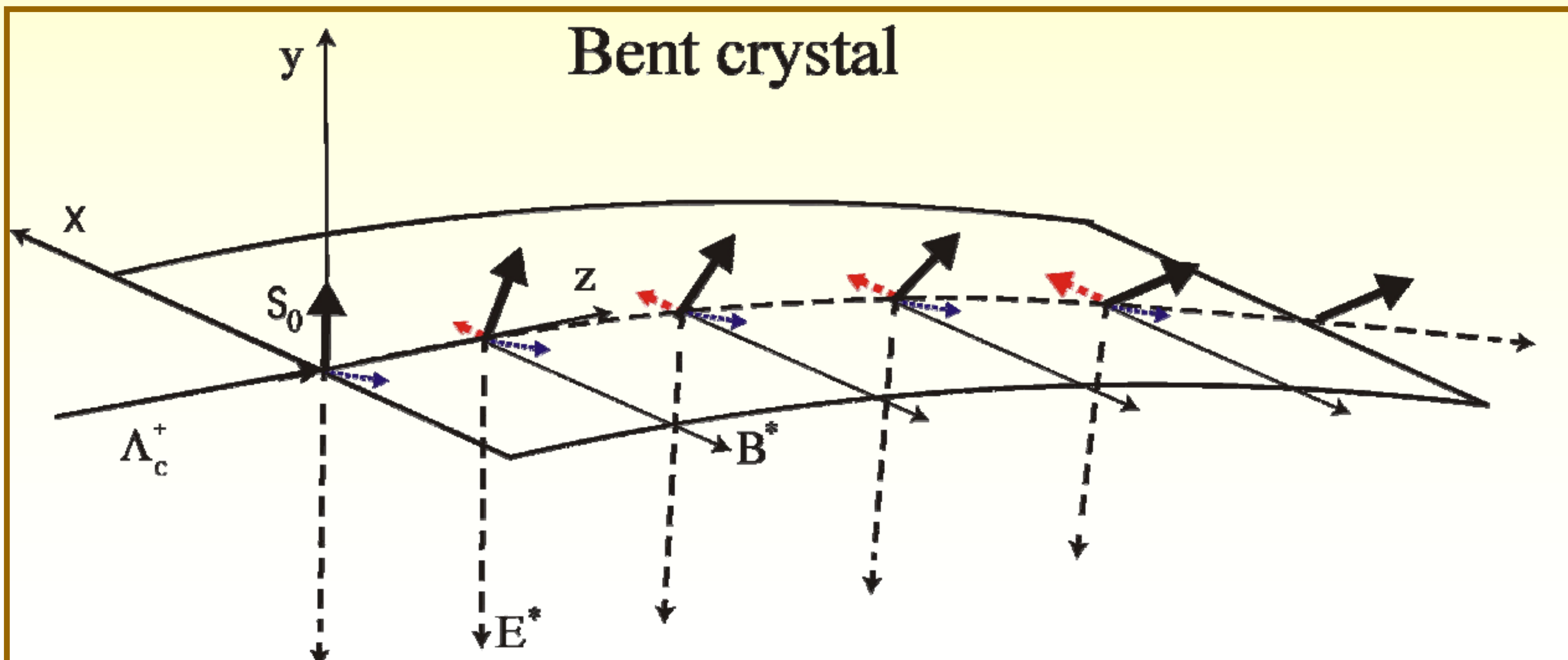
P and CP violating spin rotation in bent crystals



Behavior of the spin rotation caused by magnetic moment, T-reversal violation interactions (including EDM) and P-violation spin rotation about direction $\vec{n}$ and rotation in direction $\vec{n}$ (orange and green arrows).
Rotation in direction $\vec{N}_m$ and direction $\vec{N}_T$ is not shown for simplicity.
It is obvious that P-odd T-even interactions can imitate EDM rotation.

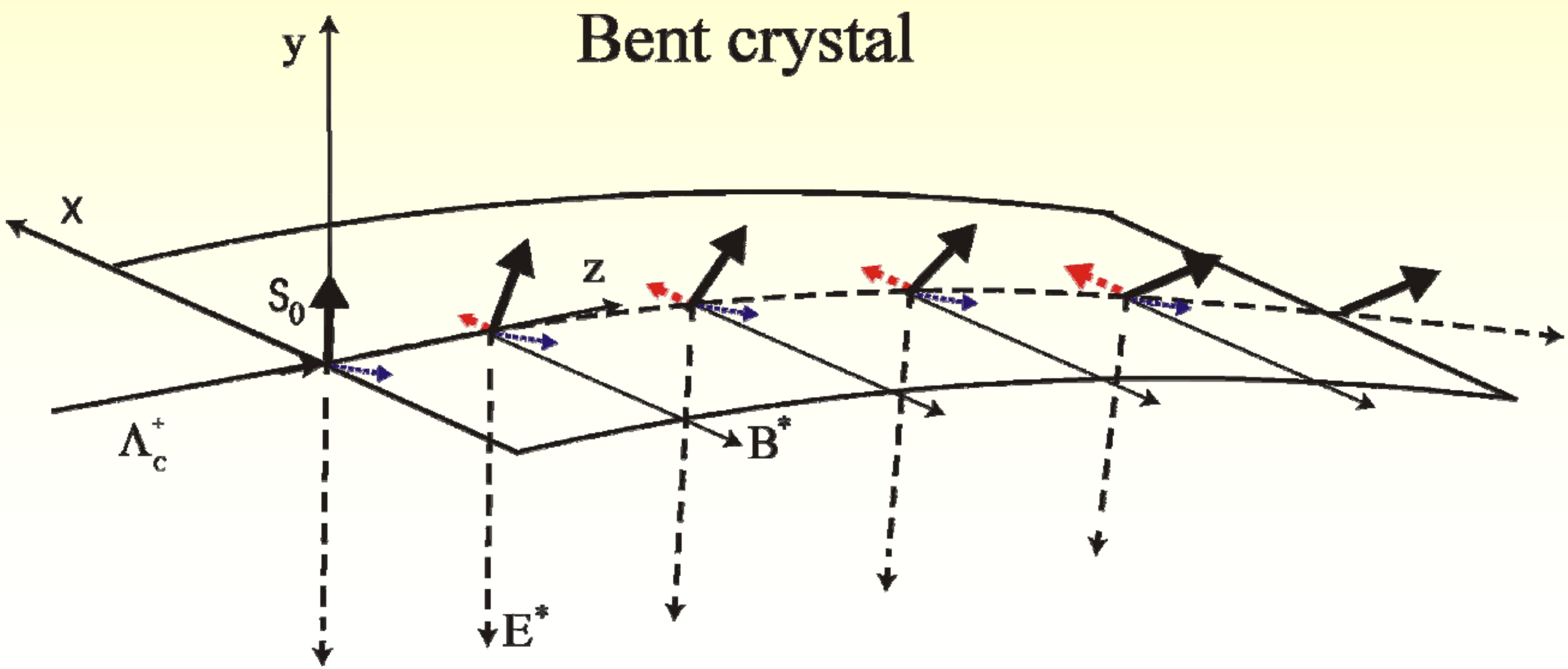
P and CP violating spin rotation in bent crystals

- Thus baryon spin rotates around three axes: effective magnetic field direction $\vec{N}_m \parallel \left[\vec{n}\times\vec{E}\right]$, electric field direction $\vec{N}_T \parallel \vec{E}$ and momentum direction $\vec{n}$.
- Contribution to rotations is determined by several types of interactions.
- Nonelastic processes in crystals result in the new effect: terms proportional to δ lead to hyperbolic rotation of the polarization vector in directions of vectors $\vec{N}_m$, $\vec{N}_T$ and $\vec{n}$.



Hyperbolic magnetic spin rotation and EDM measuring

The following estimation for the value δ_m can be obtained: $\delta_m \sim 10^8 - 10^9 \sec^{-1}$. The charm baryon EDM is predicted to be as large as $d \sim 10^{-17}$. Spin rotation frequency Ω_{EDM} determined by such charmed baryon EDM is $\Omega_{EDM} \sim 10^6 - 10^7 \sec^{-1}$. As a result, the nonelastic processes, which are caused by magnetic moment scattering, can imitate the EDM contribution.



P violating spin rotation in bent crystals

Precession frequency Ω_w is determined by the real part of the amplitude of baryon weak scattering by an electron (nucleus). This amplitude can be evaluated by Fermi theory for the energies, which are necessary for W and Z bosons production or smaller:

$$\boxed{ReB \sim G_F k = 10^{-5} \frac{1}{m_p^2} k = 10^{-5} \frac{\hbar}{m_p c} \frac{m\gamma}{m_p} = 10^{-5} \lambda_{cp} \frac{m\gamma}{m_p}}$$

For different particle trajectories in a bent crystal the value of precession frequency Ω_w could vary in the range $\Omega_w \sim 10^3 - 10^4 \sec^{-1}$. Therefore, when a particle passes $10\,cm$ in a crystal, its spin undergoes additional rotation around momentum direction at angle $\vartheta_p \sim 10^{-6} - 10^{-7}\ rad$ .The effect grows for a heavy baryon as a result of the mechanism similar to that of its EDM growth.

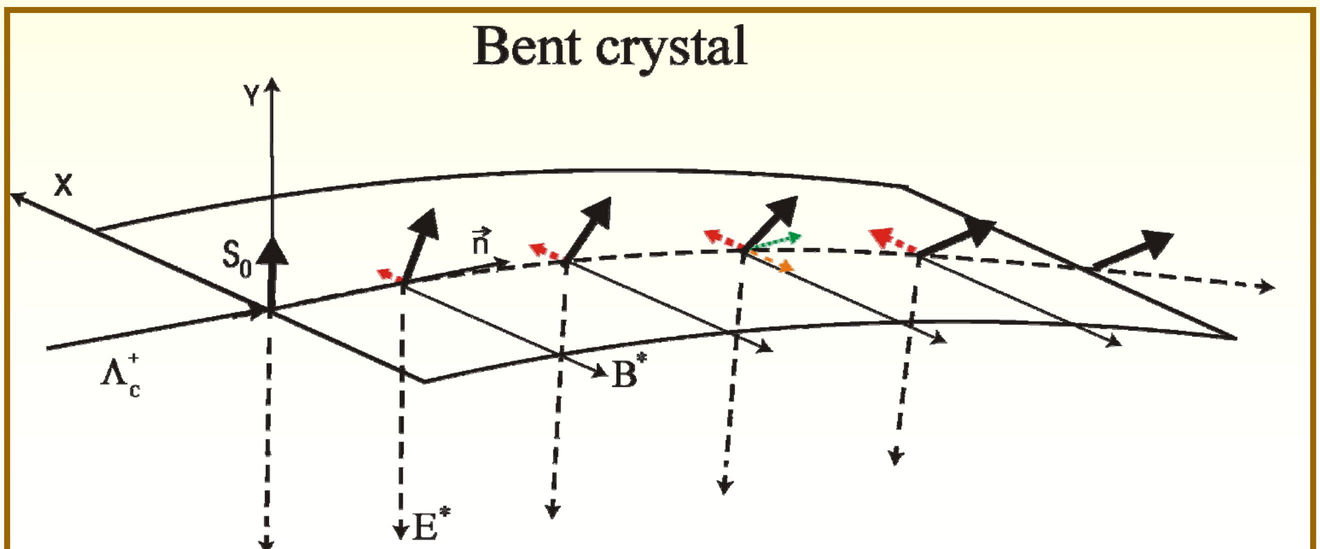
P violating spin rotation in bent crystals

Absorption caused by parity violating weak interaction also contributes to change in spin direction. This rotation is caused by the imaginary part of weak scattering amplitude and is proportional to the difference of total scattering cross-sections $\sigma\uparrow\uparrow$ and $\sigma\downarrow\uparrow$.

$$\sigma_{\uparrow\uparrow(\downarrow\uparrow)} = \int | f_{c(nuc)} + B_{0w} \pm B_w |^2 \, d\Omega$$

$$\sigma_{\uparrow\uparrow} - \sigma_{\downarrow\uparrow} = 2\int [(f_{c(nuc)} + B_{0w})B^* + (f_{c(nuc)} + B_{0w})^* B] d\Omega$$

When baryon trajectory passes in the area, where collisions with nuclei are important (this occurs in the vicinity of potential barrier for positively charged particles), the value $\delta_w \sim 10^6 - 10^7 \sec^{-1}$. Similar to the real part *ReB* for the case of heavy baryons the difference in cross-sections grows.

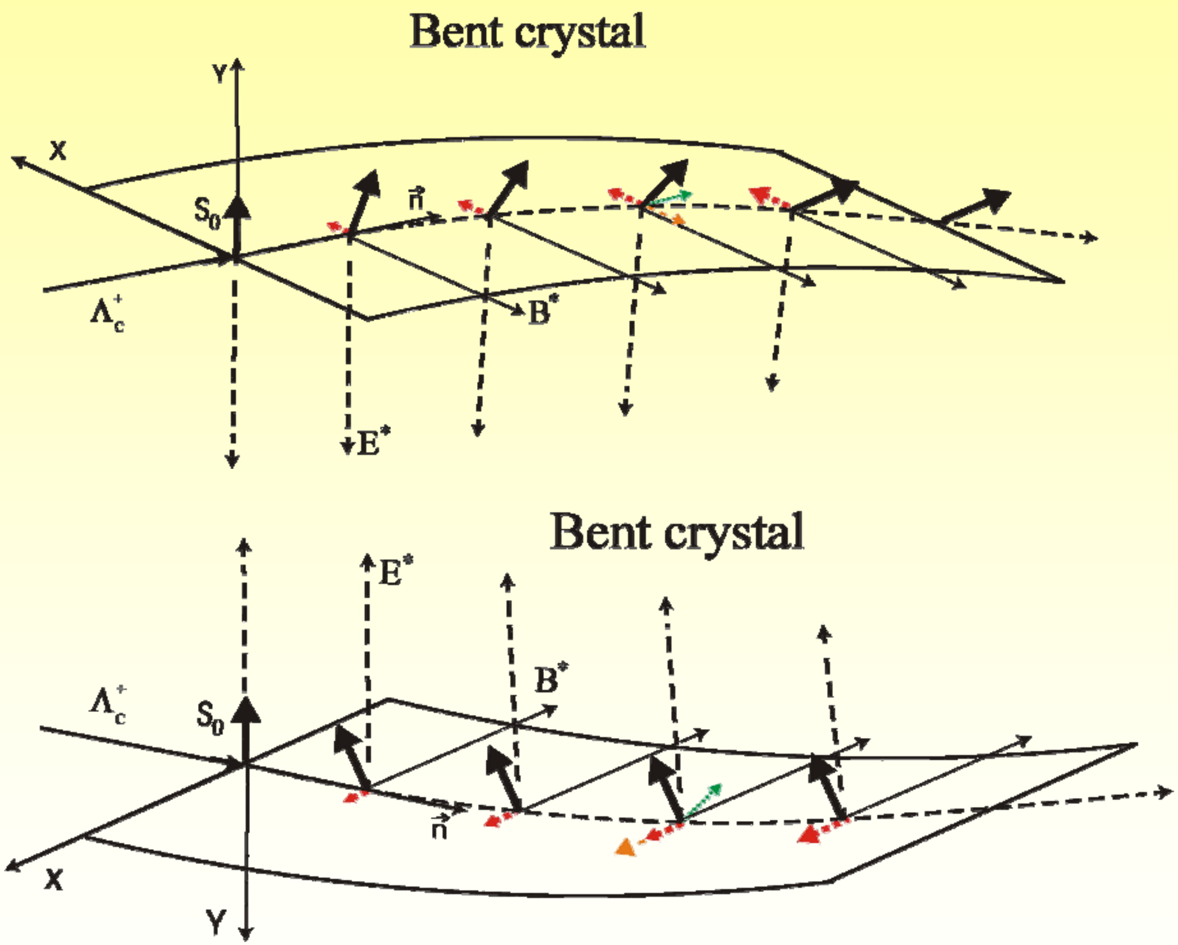


P and CP violating spin rotation in bent crystals

- Experiment on measuring EDM provides information on contributions of several T noninvariant interactions.Spin precession in bent crystals at LHC gives unique possibility for measurement CP violating and P violating interactions of charm, beauty and strange baryons

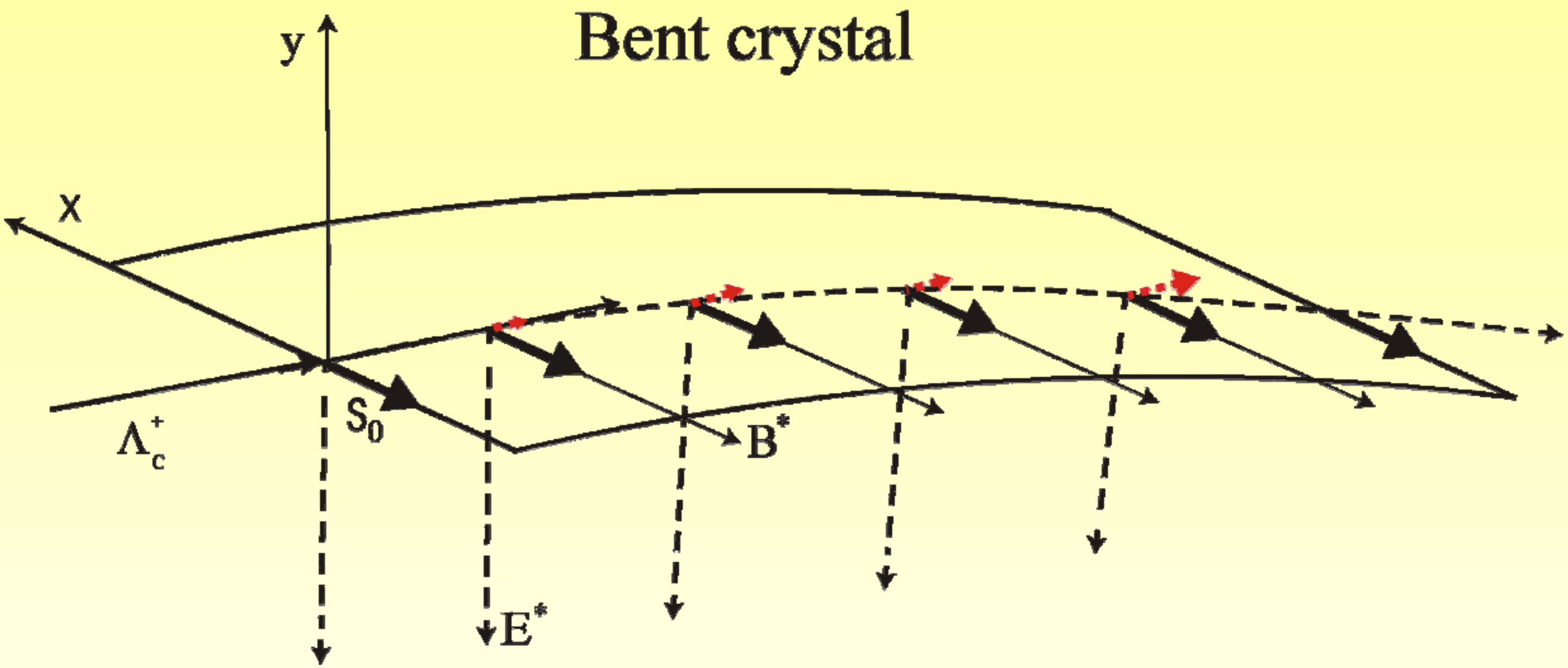
- New effect, which is caused by nonelastic processes arises – hyperbolic spin rotation to the direction of the bend axis, the direction of the electric field and the direction of the particle momentum. This effect can imitate T noninvariant rotation.

P and CP violating spin rotation in bent crystals



By turning the crystal 180° around the direction of incident baryon momentum One could observe that P_{odd} spin rotation does not change, while the sign of MDM and T_{odd} spin rotations does due to change of the electric field direction. Subtracting results of measurements for two opposite crystal positions one could obtain the angle of rotation, which does not depend on P_{odd} effect.

Separation of MDM and T



Separation of the contributions caused by MDM and T-odd spin rotation is possible when comparing experimental results for two initial orientations of polarization vector $\vec{\xi}$. Namely: $\vec{\xi} \parallel \vec{N}_m$ and $\vec{\xi} \parallel \vec{N}_t$, i.e. the initial $\vec{\xi}$ is parallel to the bending axis of the crystal or $\vec{E}$.

In real situation rotating the crystal by 90° so that direction of S_0 is parallel to B^* can be more convenient.

Conclusion

- When analyzing particle's spin rotation, which is caused by electric dipole moment interaction with electric field, one should consider both P_{odd}, T_{even} and P_{odd}, T_{odd} non-invariant spin rotations, resulting from weak interaction with electrons and nuclei

- It gives unique possibility for measurement of constants determining T_{odd}, P_{odd} (CP) violating interactions and P_{odd}, T_{even} interactions of baryons with electrons and nucleus (nucleons), similarly to possibility of measuring electric and magnetic moments of charm, beauty and strange baryons.

- New effect, which is caused by nonelastic processes arises – hyperbolic spin rotation to the direction of the bend axis, the direction of the electric field and the direction of the particle momentum

Thank you!