5th Georgian - German School and Workshop in Basic Science

"Spin dynamics studies in storage rings"

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Motivation

- Measure of the permanent separation of positive and negative electrical charges inside the particle itself
- It has the same direction of the spin vector



EDM violates parity P and time reversal symmetry T

• Assuming the CPT theorem to be valid, the combined CP symmetry is violated

Why it is important to study EDM

- A strong CP-violation source is required to solve the mistery of baryonantibaryon asymmetry of our universe
- The Standard Model predicts non-vanishing but unobservally small EDMs:

$$\left| d_{e}^{SM} \right| < 10^{-38} e \cdot cm$$
 $\left| d_{N}^{SM} \right| < 10^{-32} e \cdot cm$

- Discovery of a non-zero EDM would signal "new physics" CP violation
- Models beyond the SM predict EDM values that are detectable for current and future experiments





Strong CP problem

The SM source of CP violation is θ_{QCD}

$$d_n = -d_p = 3 \times 10^{-16} \theta_{QCD}$$
$$d_D = 0$$

Current experimental limits set

$$\theta_{QCD}$$
 < 10^{-10}

SUSY

Quark EDMs (d_u , d_d) and Quark-Color EDMs (d_u^c , d_d^c)

$$d_{n} = 1.4(d_{d} - 0.25d_{u}) + 0.83e(d_{u}^{c} + d_{d}^{c}) - 0.27e(d_{u}^{c} - d_{d}^{c})$$

$$d_{p} = 1.4(d_{d} - 0.25d_{u}) + 0.83e(d_{u}^{c} + d_{d}^{c}) + 0.27e(d_{u}^{c} - d_{d}^{c})$$

$$d_{D} = 1.4(d_{d} + d_{u}) + 0.2e(d_{u}^{c} + d_{d}^{c}) - 6e(d_{u}^{c} - d_{d}^{c})$$

Extremely important to measure on more than one system!

Highly sensitive to the Color EDMs

How to measure EDM for charged particles

 Impossible to trap charged particles in E-field



Injection in a **Storage Ring** with spin aligned to the velocity (Longitudinal Polarization)

• Freeze the horizontal spin precession and watch for the development of a vertical component

EDM SIGNAL

• External E-field produces a torque on the EDM:

$$\vec{\tau} = \vec{d} \times \vec{E} = \frac{d\vec{S}}{dt}$$

Spin precession in the vertical plane



Storage ring projects

BNL all electric ring for protons



R. Talman

EDM with E and B-fields at COSY



A. Lehrach

The frozen spin method

 Transverse electric and magnetic fields in a ring cause a spin precession in the plane of the trajectory defined by:

$$\vec{\omega}_G = \vec{\omega}_s - \vec{\omega}_c = -\frac{q}{m} \left\{ G\vec{B} + \left[G - \left(\frac{m}{p}\right)^2 \right] \frac{\vec{\beta} \times \vec{E}}{c} \right\}$$

BMT Equation



anomalous magnetic moment



spin precession frequency in the horizontal plane



particle revolution frequency

The aim is to cancel this anomalous spin precession:

$$\vec{\omega}_G = 0$$

Solutions for protons and deuterons

 $\vec{\omega}_G = 0$ $\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} = \vec{d} \times \vec{E}$

E field

$$\vec{\omega}_G = -\frac{q}{m} \left\{ G\vec{B} + \left[G - \left(\frac{m}{p}\right)^2 \right] \frac{\vec{\beta} \times \vec{E}}{c} \right\} = 0$$

Protons $G = 1.79 > 0 \rightarrow$ magic momentum:

$$G - \left(\frac{m}{p}\right)^2 = 0 \implies p = \frac{m}{\sqrt{G}} = 0.7 \frac{GeV}{c}$$

 $\vec{B} = 0 \rightarrow$ pure electric ring!

Deuterons $G = -0.14 < 0 \rightarrow$ no magic momentum: magnetic field with a radial outward electric field

$$E = \frac{GBc\beta\gamma^2}{1 - G\beta^2\gamma^2}$$



Spin tracking code

- For such a precision experiment is mandatory to perfectly know the space motion of the beam and the evolution of the spin motion inside the ring
- This yelds the necessity of a powerful tracking code that allows us to track both the position and the spin of particles circulating in the ring
- The Juelich collaboration decided to use the software COSY Infinity, developed by Martin Berz at the Michigan State University (MSU)
- My work is focused on benchmarking the spin tracking with this code in order to make it reliable for the test measurements and precursor experiments at COSY





Work plan

Use of COSY-Infinity for:

- reproduction of analytical spin dynamics solutions
- simulation of SCT test experiments at COSY
- support to the analysis of data taken during test experiments

(Final design of the new generation ring)

KHANKS FOR YOUR ATTENTION