Highlights of the JEDI collaboration

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JARA Annual Meeting, Aachen, Feb. 2015
JEDI Collaboration

JEDI = Jülich Electric Dipole Moment Investigations

≈ 100 members from 10 countries

Goal: Measurement of Electric Dipole Moments (EDM) of charged particles in storage rings.
Motivation: Electric Dipole Moment

Electric Dipole Moment (EDM):

- separation of positive and negative charge
- fundamental property of particles (like magnetic moment, mass, charge)
- existence of EDM for elementary particle is closely related to the dominance of matter over anti-matter in the universe

\[
\frac{|d|}{e} \approx \frac{\text{human hair}}{\text{diameter proton}} \approx \frac{\text{diameter earth}}{\text{diameter proton}}
\]
$$l(J^P) = \frac{1}{2}(\frac{1}{2}+)$$

Mass: $m = 1.00727646681 \pm 0.00000000009$ u

Mass: $m = 938.272046 \pm 0.000021$ MeV $^{[a]}$

$$\left| m_p - m_\overline{p} \right|/m_p < 2 \times 10^{-9}$, CL = 90% $^{[b]}$

$$\frac{q_\overline{p}}{m_\overline{p}}/\left(\frac{q_p}{m_p}\right) = 0.99999999999 \pm 0.00000000009$$

$$\left| q_p + q_\overline{p} \right|/e < 2 \times 10^{-9}$, CL = 90% $^{[b]}$

$$\left| q_p + q_e \right|/e < 1 \times 10^{-21}$ $^{[c]}$

Magnetic moment: $\mu = 2.792847356 \pm 0.0000000323$ $\mu_N$

$$(\mu_p + \mu_\overline{p}) / \mu_p = (-0.1 \pm 2.1) \times 10^{-3}$$

Electric dipole moment: $d < 0.54 \times 10^{-23}$ e cm

Electric polarizability: $\alpha = (12.0 \pm 0.6) \times 10^{-4}$ fm$^3$

Magnetic polarizability: $\beta = (1.9 \pm 0.5) \times 10^{-4}$ fm$^3$

Charge radius: $0.877 \pm 0.005$ fm

Magnetic radius: $0.777 \pm 0.016$ fm

Mean life: $\tau > 2.1 \times 10^{29}$ years, CL = 90% $^{[d]}$ (p → invisible mode)

Mean life: $\tau > 10^{31}$ to $10^{33}$ years $^{[d]}$ (mode dependent)
Matter-Antimatter asymmetry

- Universe started with the same amount of matter and antimatter.
- Today, matter dominates our universe.

What happened to the antimatter?

Anti-matter is hidden somewhere in the universe.

AMS searches for anti-particles in space.

Symmetry breaking mechanisms led to the disappearance of anti-matter and EDM of elementary particles.

JEDI searches for EDM of charged hadrons.
Experimental Method: Generic Idea

For all EDM experiments (neutron, proton, atoms, ...):
Interaction of $\vec{d}$ with electric field $\vec{E}$

For charged particles: apply electric field in a storage ring:

$$\frac{d\vec{s}}{dt} \propto d\vec{E} \times \vec{s}$$

In general:

$$\frac{d\vec{s}}{dt} = \vec{\Omega} \times \vec{s}$$

build-up of vertical polarization $s_\perp \propto |d|$
Test Measurements at COSY

unique storage ring for polarized protons and deuterons

⇒ ideal starting point for charged hadron EDMs

Recent achievements

- **Spin coherence time:** $\tau = 400 \text{ s}$
- **Spin tune:** $\bar{\nu}_s = -0.16097 \ldots \pm 10^{-10}$ in 100 s
Spin Coherence Time (SCT)

**Short Spin Coherence Time**

\[ \langle \vec{s} \rangle \rightarrow \langle \vec{p} \rangle \]

\[ \exp^{-t/20\,\text{s}} \]

cooled bunched beam \( \Rightarrow \) SCT = 20s

SCT similar to relaxation time in NMR (MRT)
Spin Coherence Time (SCT)

Large Spin Coherence Time

Horizontal Asymmetry Run: 2051

\[ \exp \left( -\frac{t}{400} \right) \]

using correction sextupole to correct for higher order effects leads to SCT of 400s.

SCT similar to relaxation time in NMR (MRT)
Spin Tune $\nu_s$

Spin tune: $\nu_s = \gamma G = \frac{\text{nb. of spin rotations}}{\text{nb. of particle revolutions}}$

$\vec{s} \times \vec{p} \propto 2\pi \gamma G$

Deuterons: $p_d = 1 \text{ GeV}/c \ (\gamma = 1.13), \ G = -0.14256177(72)$

$\Rightarrow \nu_s = \gamma G \approx -0.161$
Result:

- spin tune changes by $\approx 10^{-9}$ during one cycle with a precision of $10^{-10}$.
- this indicates energy variation of this order
- very sensitive tool to study systematic error
Summary

Spin physics, Storage ring COSY

$\vec{E}$-deflectors
FNAL, RWTH, Jülich ZEA

Ring design, Spin tracking
MSU, Cornell, BNL, BINP
Jülich JSC

Diagnostics
Jülich PGI, Jülich ZEA

Polarimeter
Ferrara, RWTH

Theory
Jülich IKP