Highlights of the JEDI collaboration

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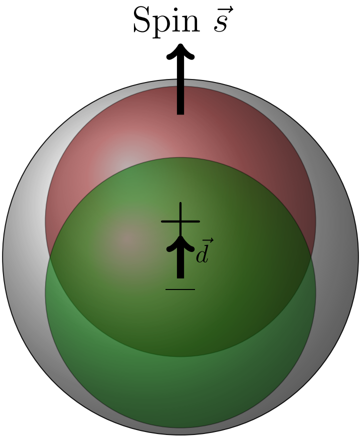
JEDI Collaboration

JEDI = **J**ülich **E**lectric **D**ipole Moment **I**nvestigations

$\approx$ 100 members from 10 countries

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

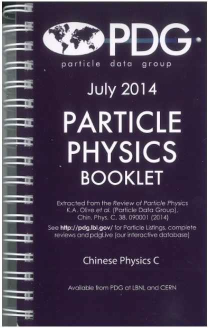
Motivation: Electric Dipole Moment



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

$$\frac{|\vec{d}|/e}{\text{diameter proton}} \approx \frac{\text{human hair}}{\text{diameter earth}}$$



p

$$I(J^P) = \tfrac{1}{2}(\tfrac{1}{2}^+)$$

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]

$\left|\frac{q_{\overline{p}}}{m_{\overline{p}}}\right| / (\frac{q_p}{m_p}) = 0.99999999991 \pm 0.00000000009$

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

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

Magnetic moment $\mu = 2.792847356 \pm 0.000000023\ \mu_N$

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

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 ± 0.005 fm

Magnetic radius = 0.777 ± 0.016 fm

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

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

Matter-Antimatter asymmetry

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

What happened to the anti-matter?

Anti-matter is hidden somewhere in universe.

AMS searches for anti-particles in space.

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

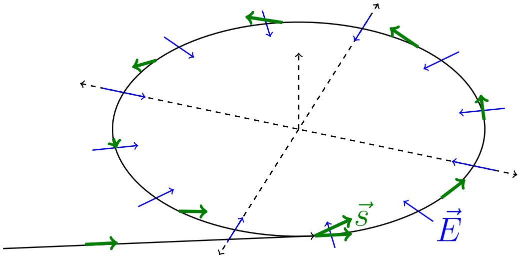
JEDI searches for **EDM** of charged hadrons.

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:



$$\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} \propto d\vec{E} \times \vec{s}$$

In general:

$$\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} = \vec{\Omega} \times \vec{s}$$

build-up of vertical polarization $s_{\perp} \propto |d|$

Test Measurements at COSY

unique storage ring for polarized protons and deuterons

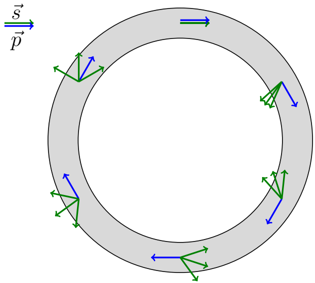
$\Rightarrow$ ideal starting point for charged hadron EDMs

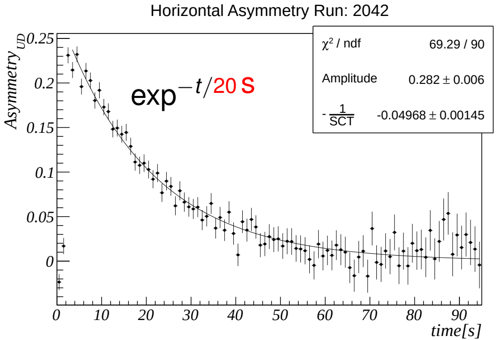
Recent achievements

- **Spin coherence time:** $\tau = 400$ s
- **Spin tune:** $\overline{\nu_s} = -0.16097 \cdots \pm 10^{-10}$ in 100 s

Spin Coherence Time (SCT)

Short Spin Coherence Time



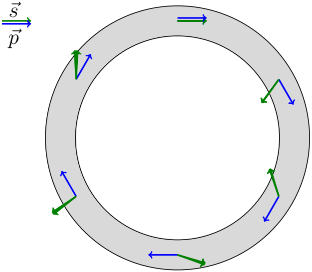


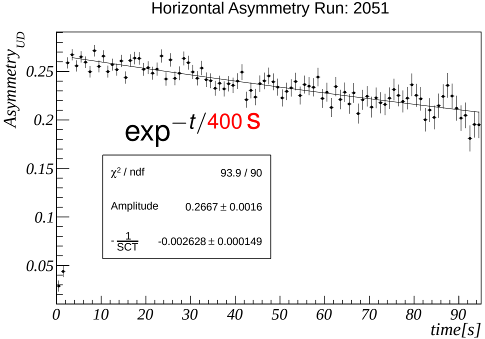
cooled bunched beam ⇒ SCT= 20s

SCT similar to relaxation time in NMR (MRT)

Spin Coherence Time (SCT)

Large Spin Coherence Time



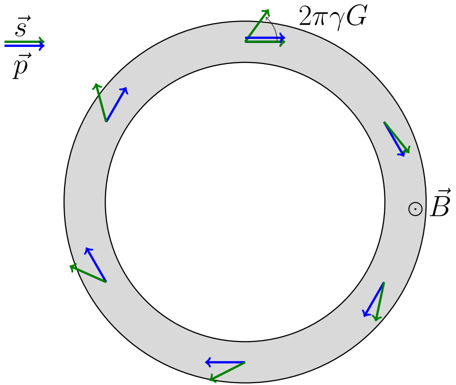


using correction sextupole to correct for higher order effects leads to SCT of 400s.

SCT similar to relaxation time in NMR (MRT)

Spin Tune ν_s

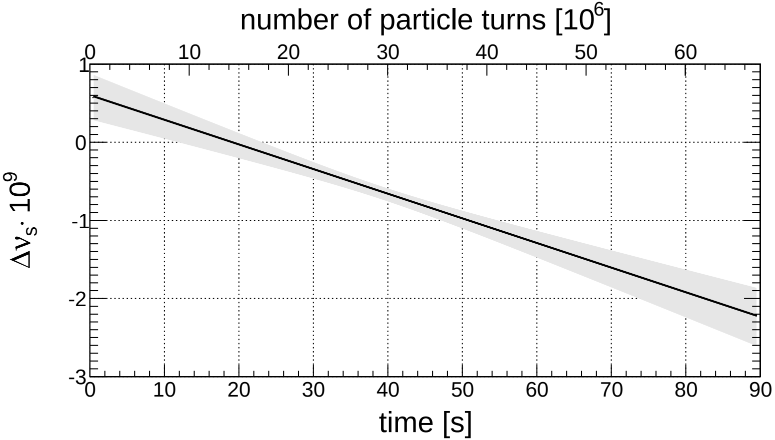
Spin tune: $\nu_s = \gamma G = \dfrac{\text{nb. of spin rotations}}{\text{nb. of particle revolutions}}$



deuterons: $p_d = 1$ GeV/c ($\gamma = 1.13$), $G = -0.14256177(72)$

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

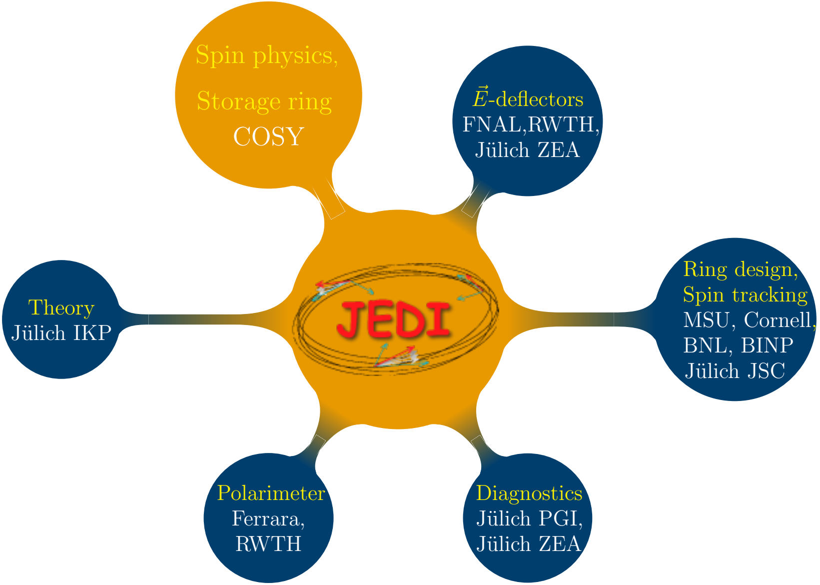
Spin tune measurements



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
Theory
Jülich IKP
JEDI
Ring design,
Spin tracking
MSU, Cornell,
BNL, BINP
Jülich JSC
Polarimeter
Ferrara,
RWTH
Diagnostics
Jülich PGI,
Jülich ZEA