5th Georgian-German School and Workshop in Basic Science

GGBSWBS '12

“EDM studies at COSY: Spin Coherence Time”

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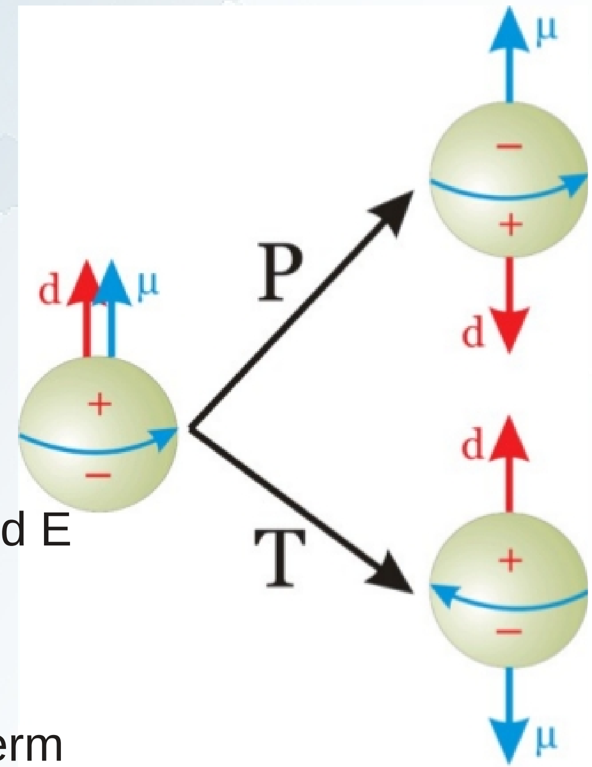
University and INFN of Ferrara

Tbilisi, August 6-10, 2012

How to measure the Electric Dipole Moment

Definition: permanent **charge displacement** within the particle volume which must **lie** along the **spin** axis



Neutral systems:

1951: First experiment. Purcell and Ramsey searched for **neutron edm.**

Basic idea: **apply E and look for the energy shift** $-\vec{d}\cdot\vec{E}$

- measurement of the precession frequency in the presence B and E

$$h\nu = 2\mu\vec{B} + 2d\vec{E}$$ (½ spin case)

- 2 cases, E parallel and antiparallel to B
- Subtracting the measured frequency cancels out the magnetic term

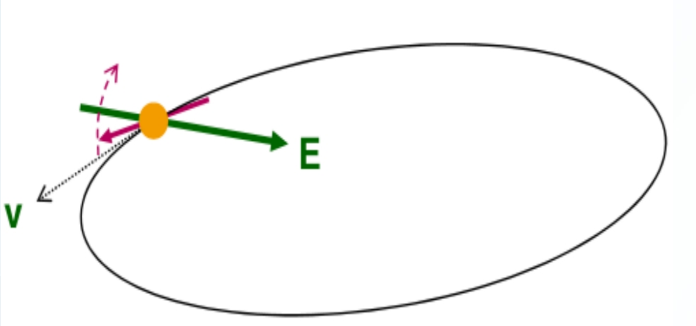
$$d = \frac{h\Delta\nu}{4E}$$

Charged particles

Basic idea doesn't work: charged particles would be lost in E

How to measure the EDM of a charged particle

Storage ring



- **Vertical B field** in laboratory frame → **Radial E field** In particle frame

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

EDM signal = spin precession in the vertical plane

How to measure the EDM of a charged particle

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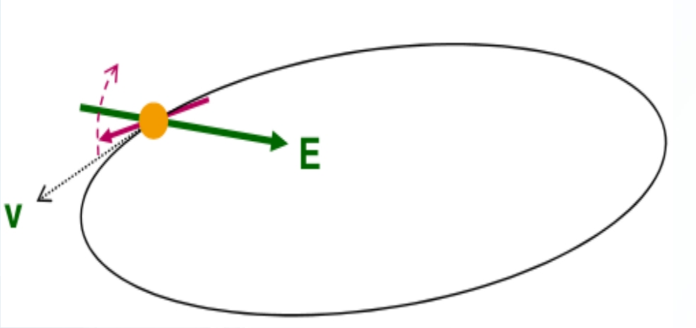

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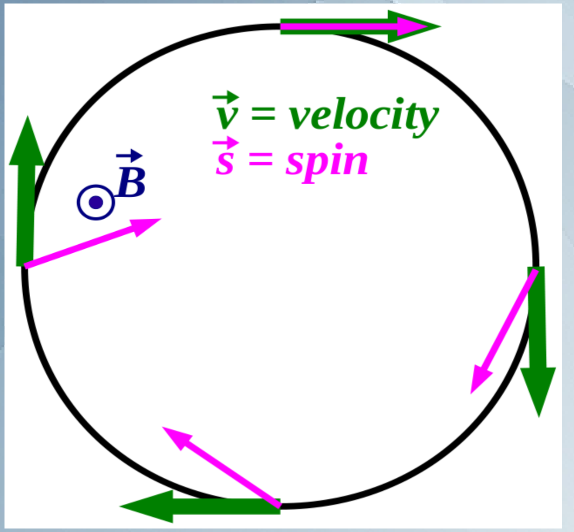
- Injection with **spin aligned along the velocity**
- Keep spin aligned with velocity



Any particle with an anomalous magnetic moment in a normal magnetic ring

How to measure the EDM of a charged particle

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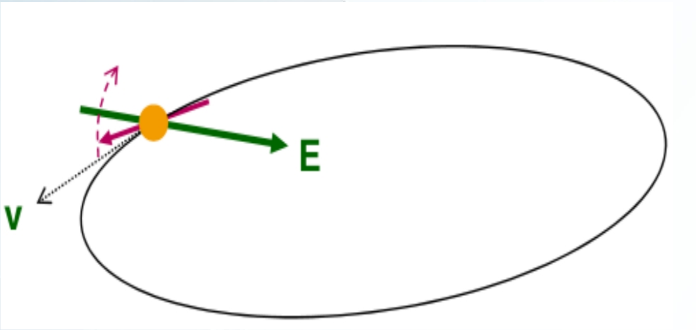

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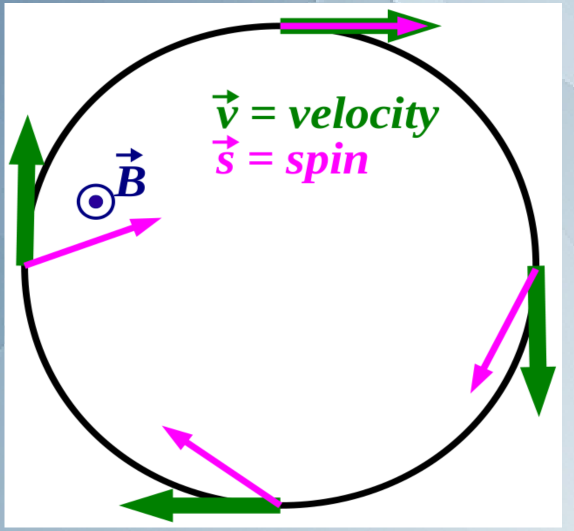
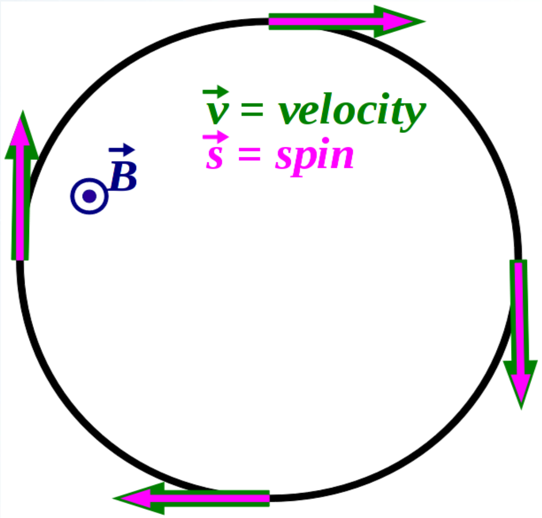


Any particle with an anomalous magnetic moment in a normal magnetic ring

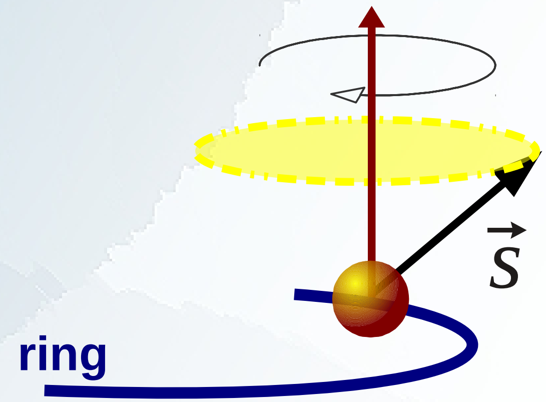
FROZEN SPIN Technique



Technical issue: vertical axis = the stable spin direction

1) Spin tune

At injection: vertically polarized → RF solenoid rotates the polarization into the horizontal (ring) plane



Spin tune $\boxed{\nu_s = G\,\gamma}$ **number of spin precession per turn**

Anomalous magnetic moment

<u>Relativistic gamma</u>

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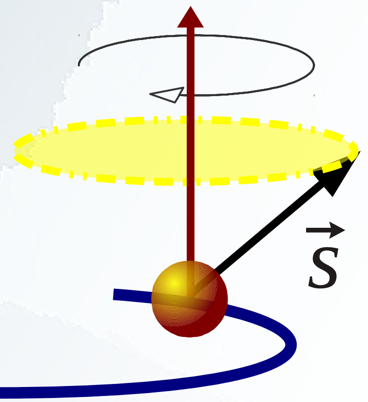

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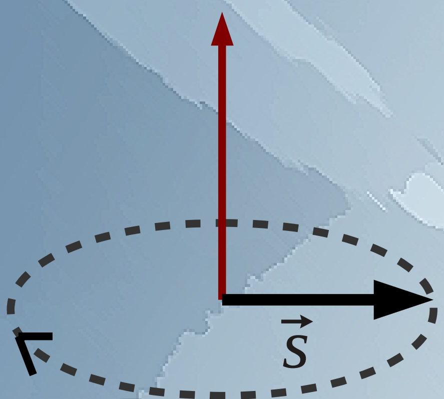
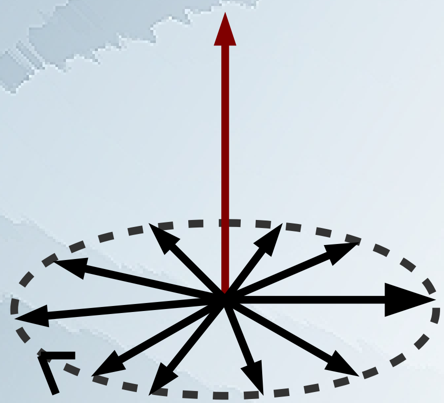
2) Spin Coherence Time





At injection:

all the spins are aligned

After some time:

Particles have **different velocities**

Spins out of phase in the horizontal plane

Horizontal polarization vanishes!

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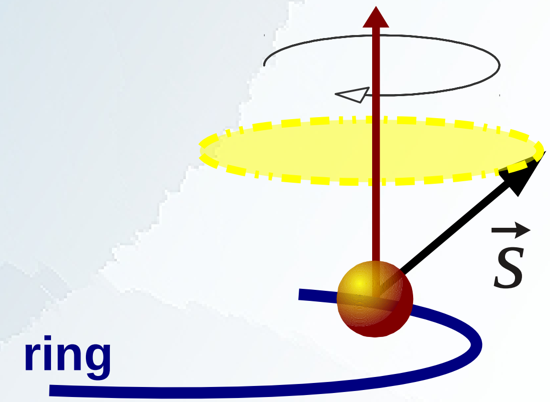

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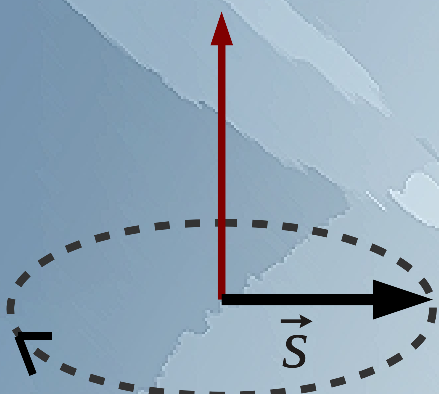

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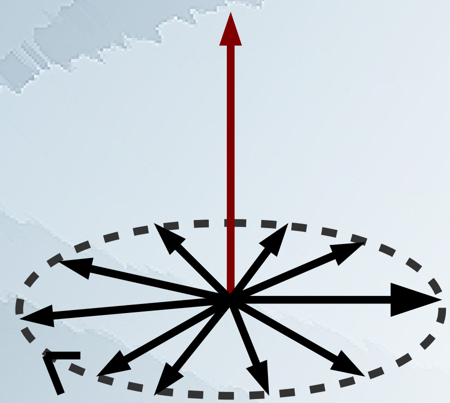


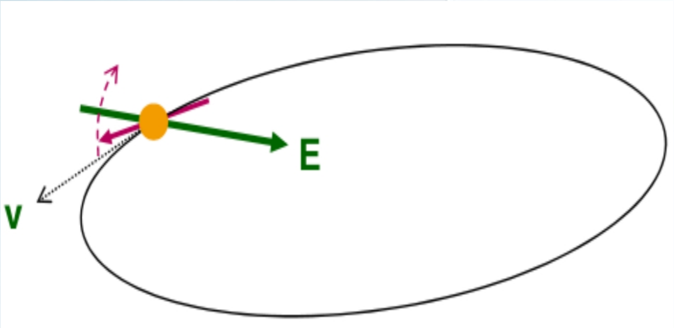
After some time:

Particles have **different velocities**

Spins out of phase in the horizontal plane → Horizontal polarization vanishes!

Horizontal pol. Lifetime
=
Observation time
=
Spin coherence time

Experimental example



- Minimal detectable precession $\theta \approx 10^{-6}\, rad$

- Assuming $d \approx 10^{-29}\, e \cdot cm$ and $E = 17\, MV/m$

$$\left.\begin{array}{l} \theta_{EDM} = \dfrac{2dE}{\hbar} t = 5\left(10^{-9} \dfrac{rad}{s}\right) t \\[2em] 1\, turn \approx 10^{-6}\, s \end{array}\right\} \quad \theta_{EDM} \approx \left(\dfrac{10^{-15}\, rad}{turn}\right)$$

- 10^9 turns needed to detect θ_{EDM}

- **Spin coherence time t>1000 s**

- $10^{-29}\, e \cdot cm$ precision $\longrightarrow$ 1 year of data taking

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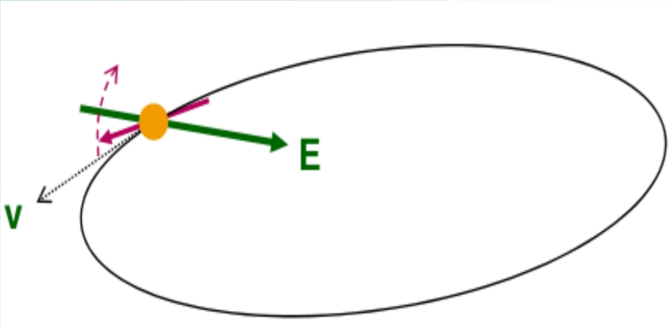

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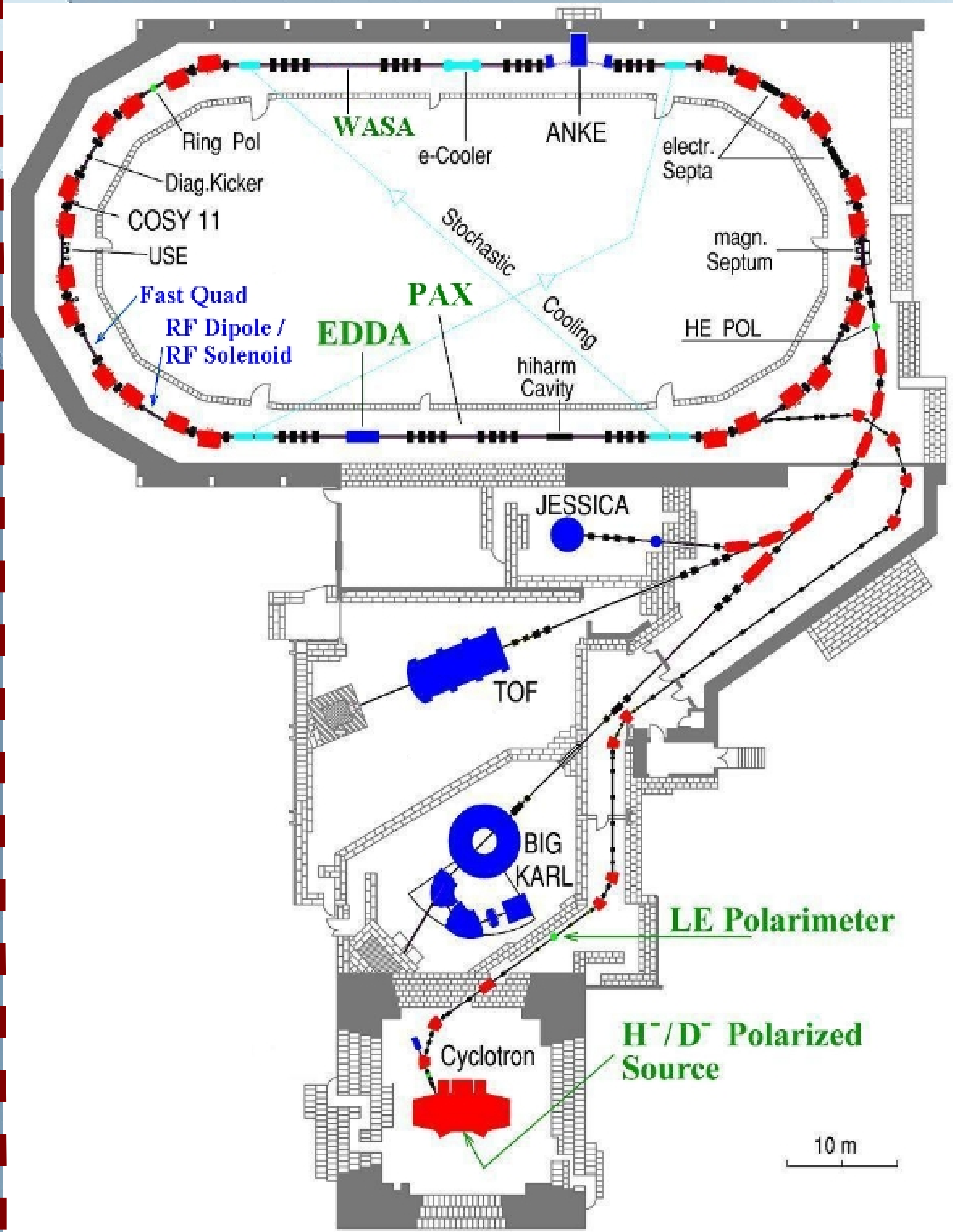
A storage ring for the deuteron EDM experiment does not exist yet

Feasibility studies @ COSY



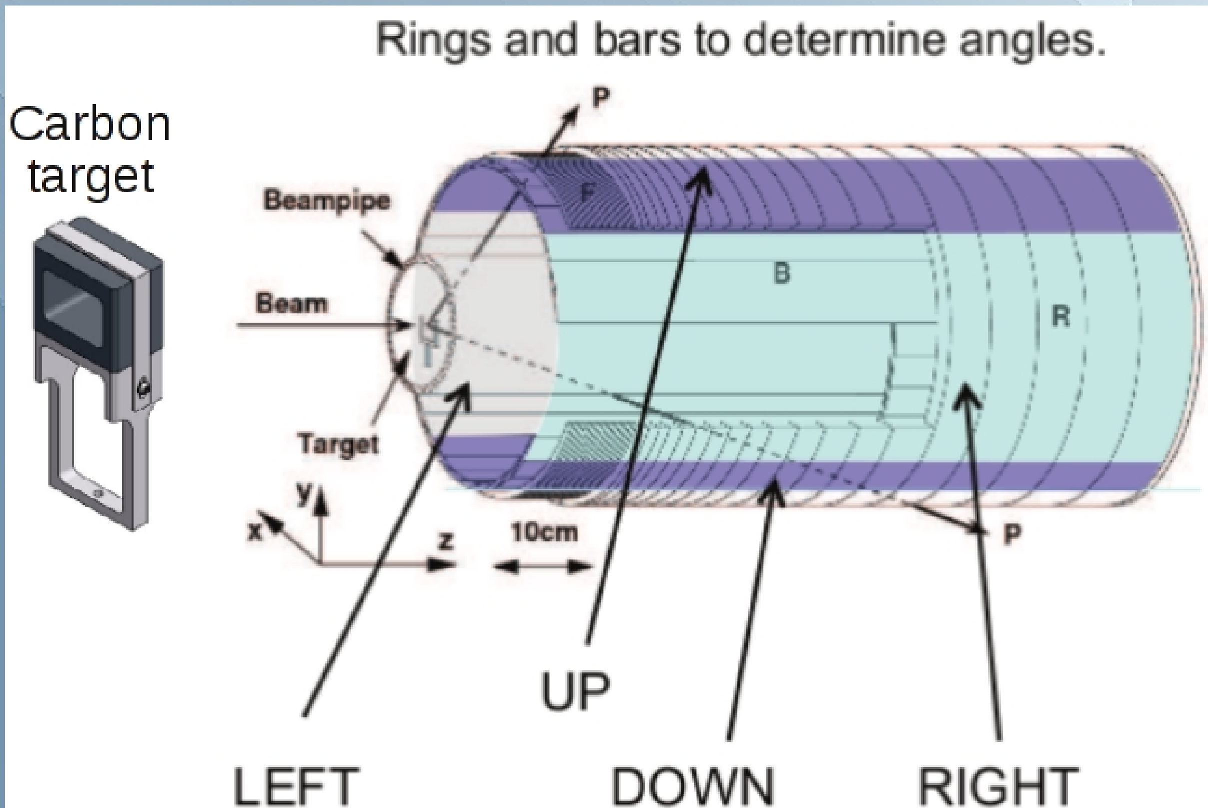
EDM ring properties

- **Momentum**: 1.0 GeV/c (deuteron)
- **Circumference:** >50 m (deuteron)

COSY ring

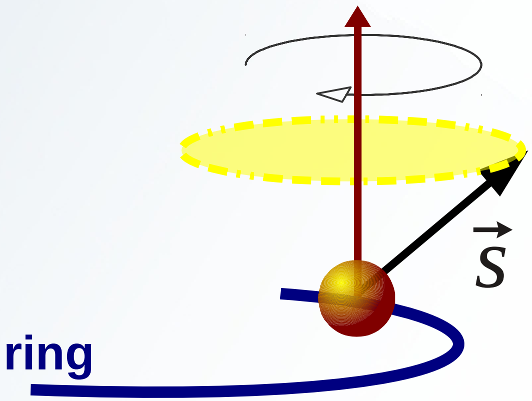
- **Momentum**: <3.7 GeV/c
- **Circumference:** 183 m
- Polarized proton and deuteron
- EDDA detector polarimeter
- Instrumentation available for manipulation of polarization and emittance

EDDA detector

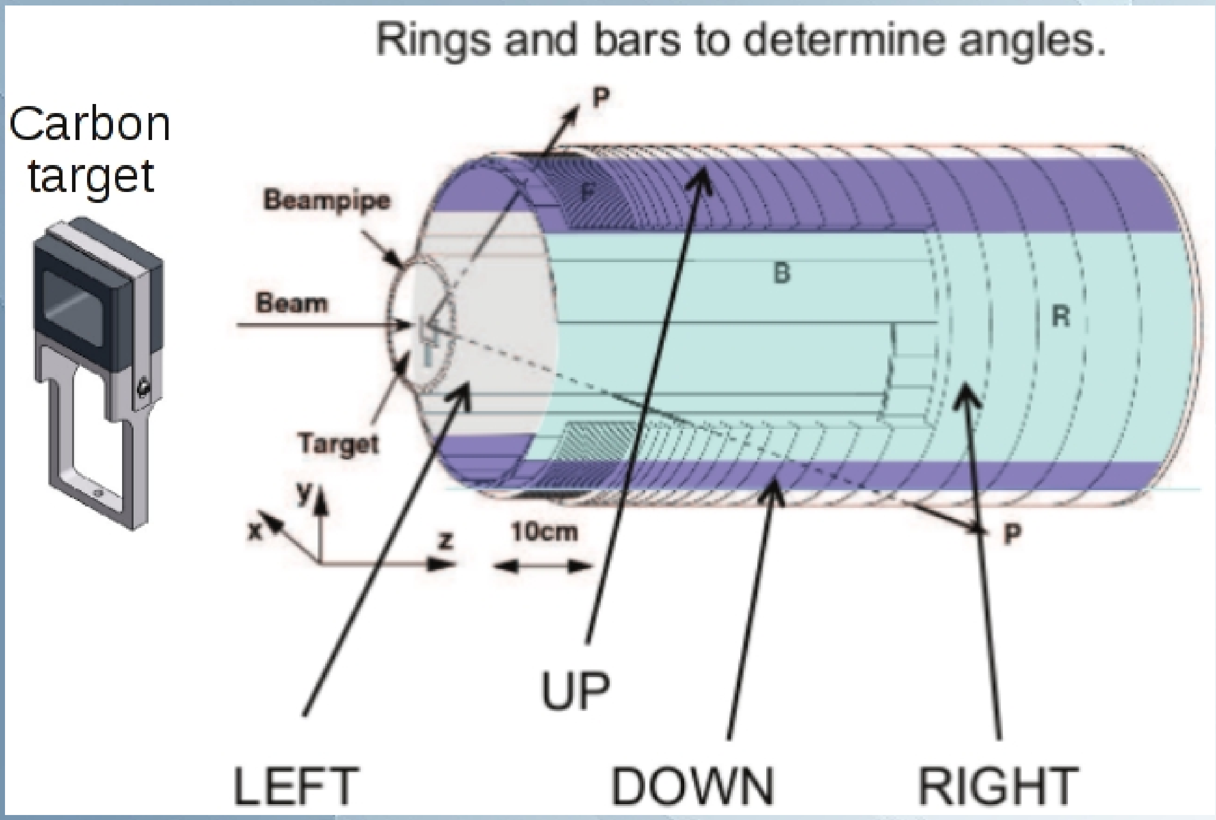


ASYMMETRY

$$\boxed{\epsilon_{EDM} = \frac{U - D}{U + D} \propto p_H}$$



EDDA detector



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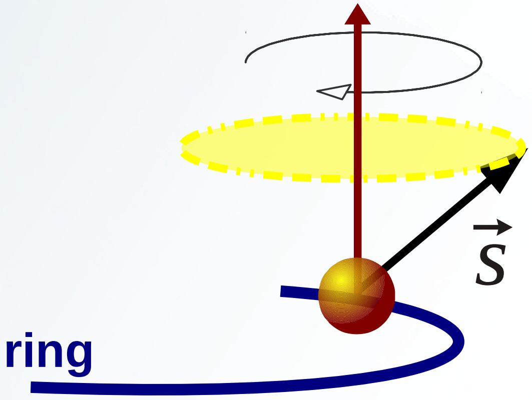


- Beam moves toward thick target → continuous extraction
- EDDA scintillators stop elastic deuterons from the target
- Elastic scattering → spin sensitive process (large cross section for d-C)

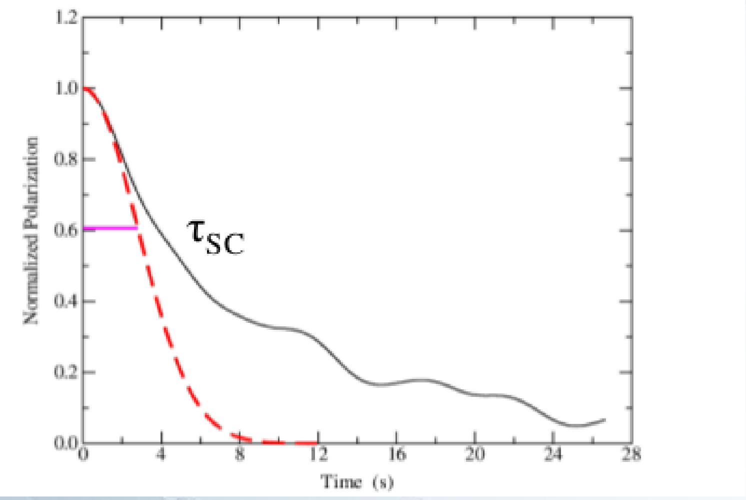
Spin coherence time study

dEDM experiments needs **a spin coherence time >1000s**

Run of May 2012

- Deuteron beam
- Polarized in the horizontal (ring) plane
- p=0.97 GeV/c

1) How can we measure the spin coherence time?
Horizontal polarization as a function of time



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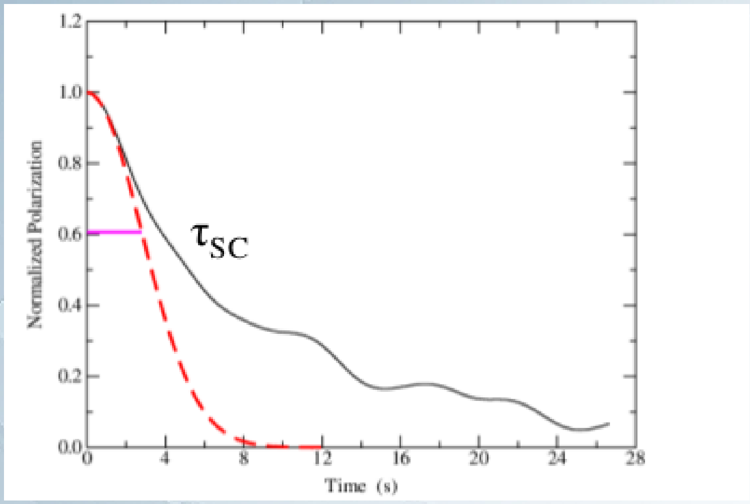

2) How does the **emittance affect** the spin coherence time?
- Ideal case: point like beam
- Reality: finite size = emittance

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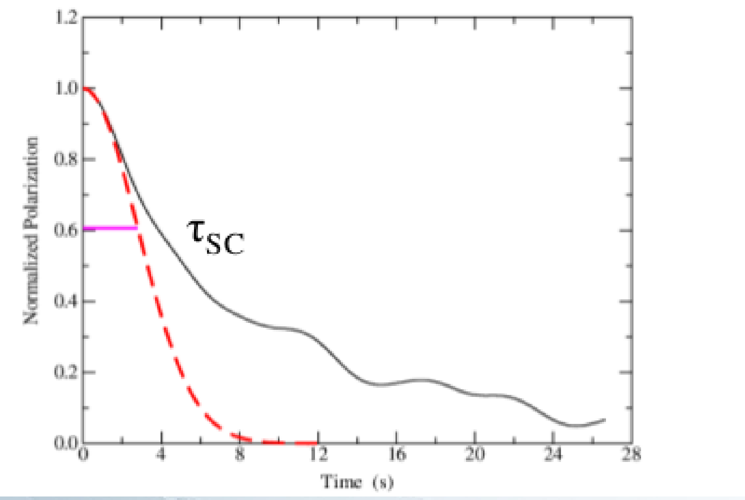

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- Ideal case: point like beam
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3) Can we do **corrections** to increase the spin coherence time?

- Sextupole magnets

Horizontal polarization as a function of time

Time-stamp system

- Count the turn number (1 turn≈ 1/(0.75 MHz)=1.33 μs)
- Compute the total spin precession ($2\pi\nu_s \approx 60°$)
- Bin by phase around the cycle (9 bins)
- Compute asymmetry in each bin

$$\boxed{\epsilon = \frac{U-D}{U+D} \propto p_h}$$

Spin direction circle

Filled for ≈ 2s

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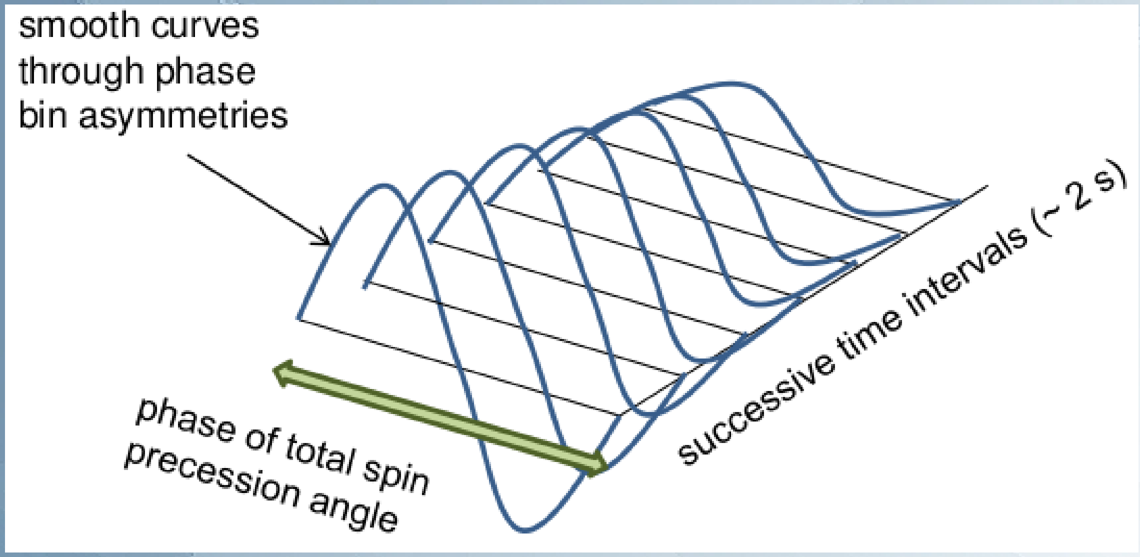

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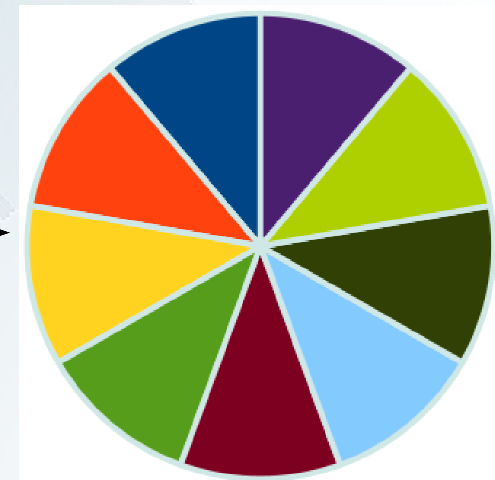

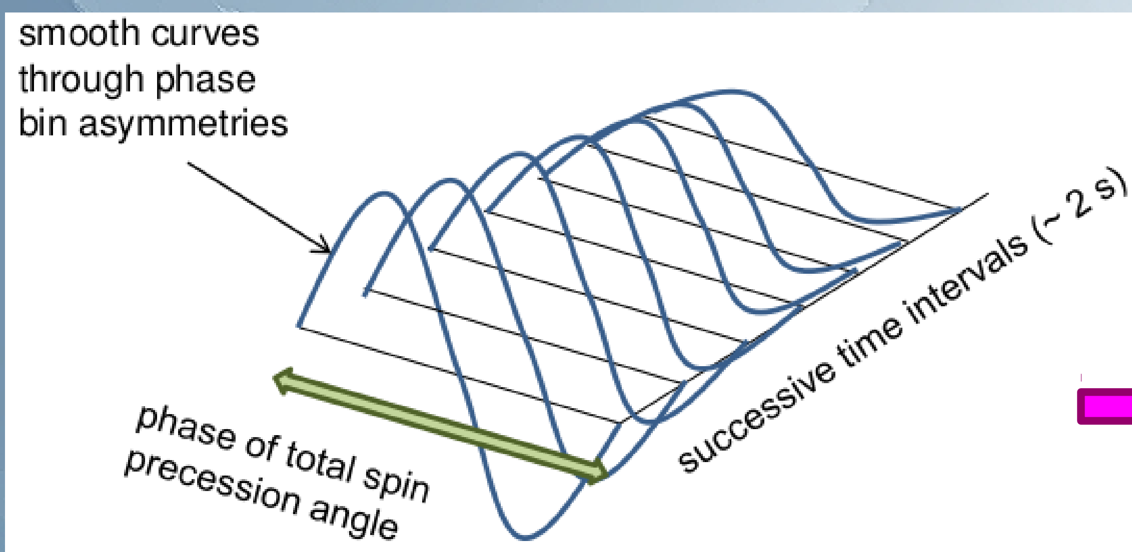

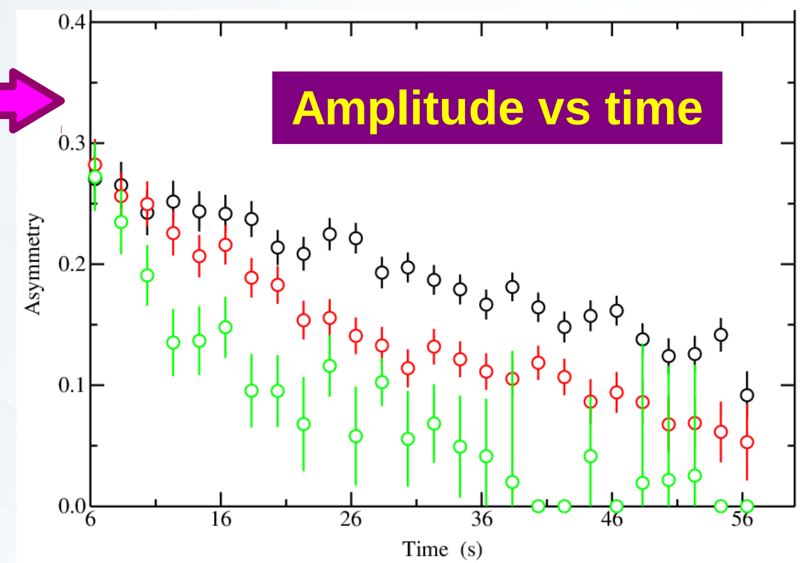

Precision requirements:

- Conversion of **turn number** into **precession angle**: **10^{-8}** rad/turn
- **Spin tune**: **10^{-7}**

Emittance effects on the spin coherence time

Particles undergo "**betatron oscillations**" = oscillations in the horizontal and vertical planes.

Longer path than the "reference particle"
Thus, higher velocity

Spin tune spread contribution

Expectation: $$\frac{1}{\tau_{SC}} \approx A \cdot \sigma_x^2 + B \cdot \sigma_y^2$$ Where σ is the Gaussian width

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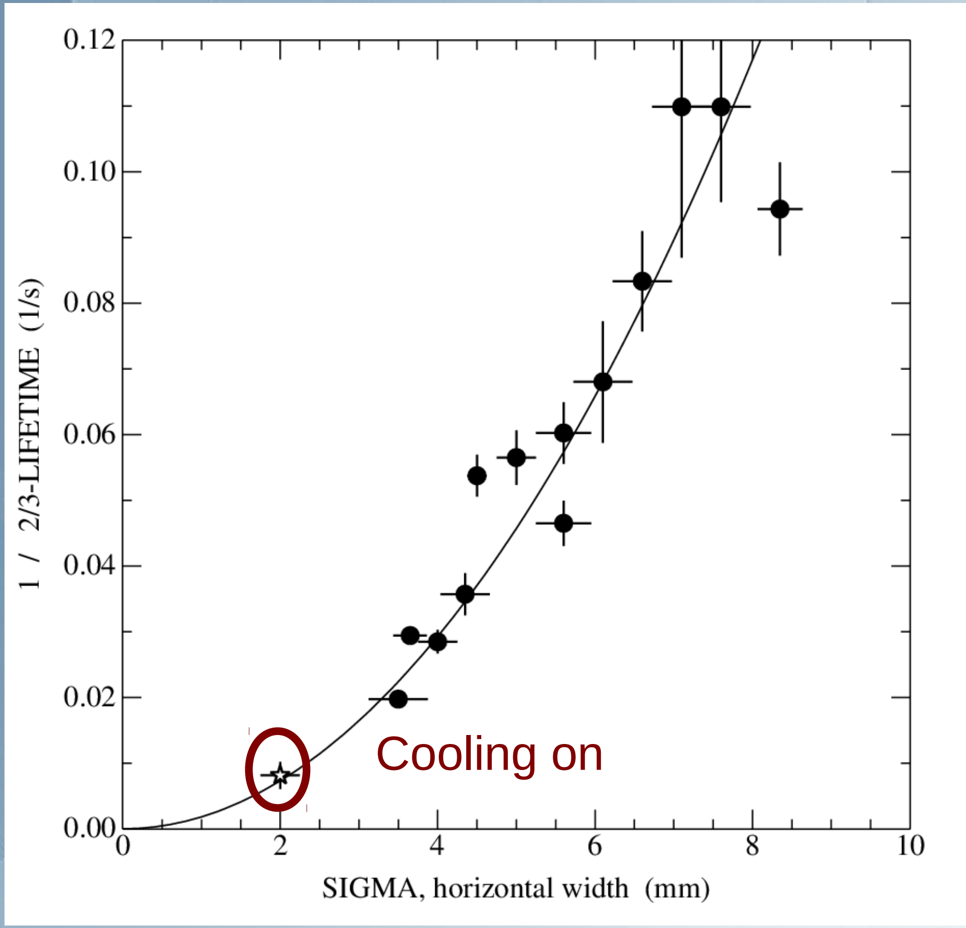
Because of machine acceptance problems.



τ_{SC} measurement for several <u>horizontal</u> profile widths

τ_{SC} = time required for the beam to lose 1/3 of its initial polarization

- Cooling on to reduce the phase space size
- Cooling off and heating to increase the horizontal profile
- Cooling off, heating off, data taking

Typically horizontal width > 4mm

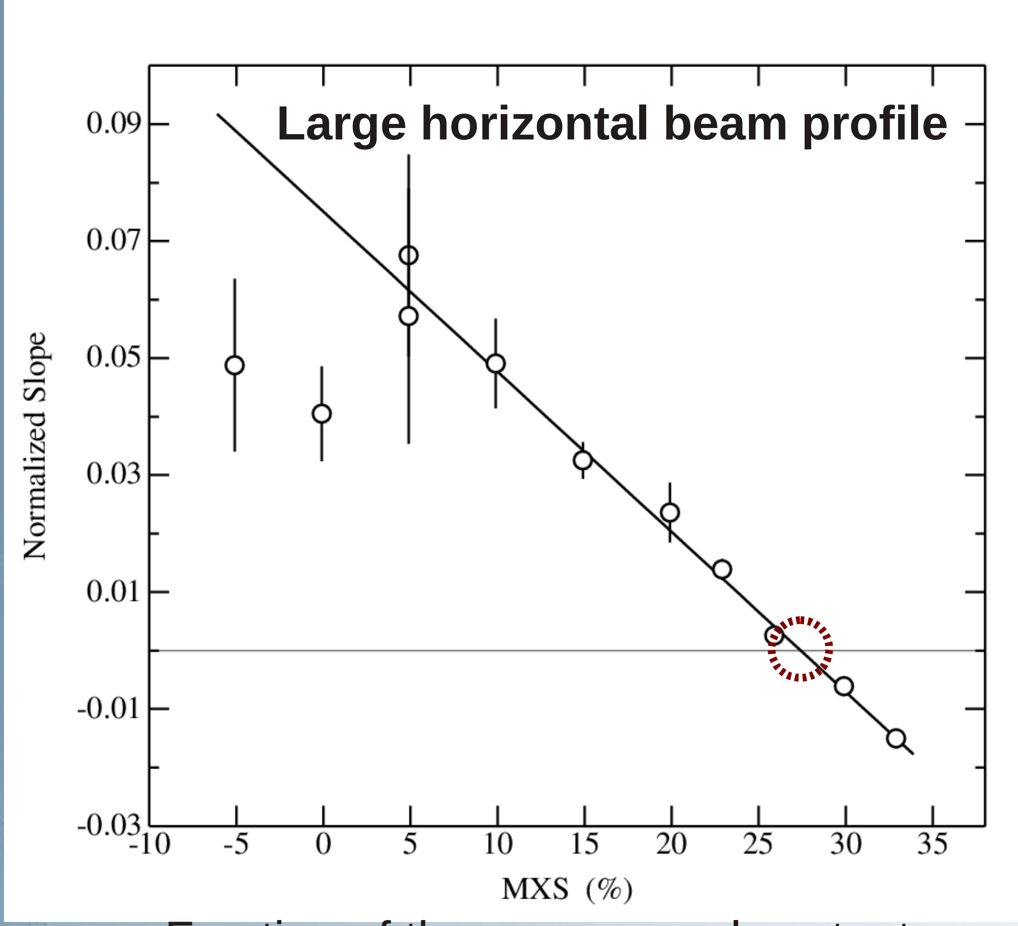
Sextupole fields corrections

$Sextupole\ field \propto r^2$ → Adjustment to the particle orbit → Remove spin tune spread

$$\frac{1}{\tau_{SC}} = (A + a_1 J)\sigma_x^2$$

Sextupole operating where β_x **is large**

τ_{SC} measurement for several sextupole strengths



Fraction of the power supply output

SETUP:

Sextupoles: MXS family where the horizontal beam size is large

Normalized slope:
- linear fit to the horizontal polarization.
- values for MXS<28% changed to positive
- slope normalized to the initial pol. value

Long lifetime≈ zero slope

If pol. dependence were exponential 1/(norm. slope) = exponential lifetime

Zero crossing: MXS=28%

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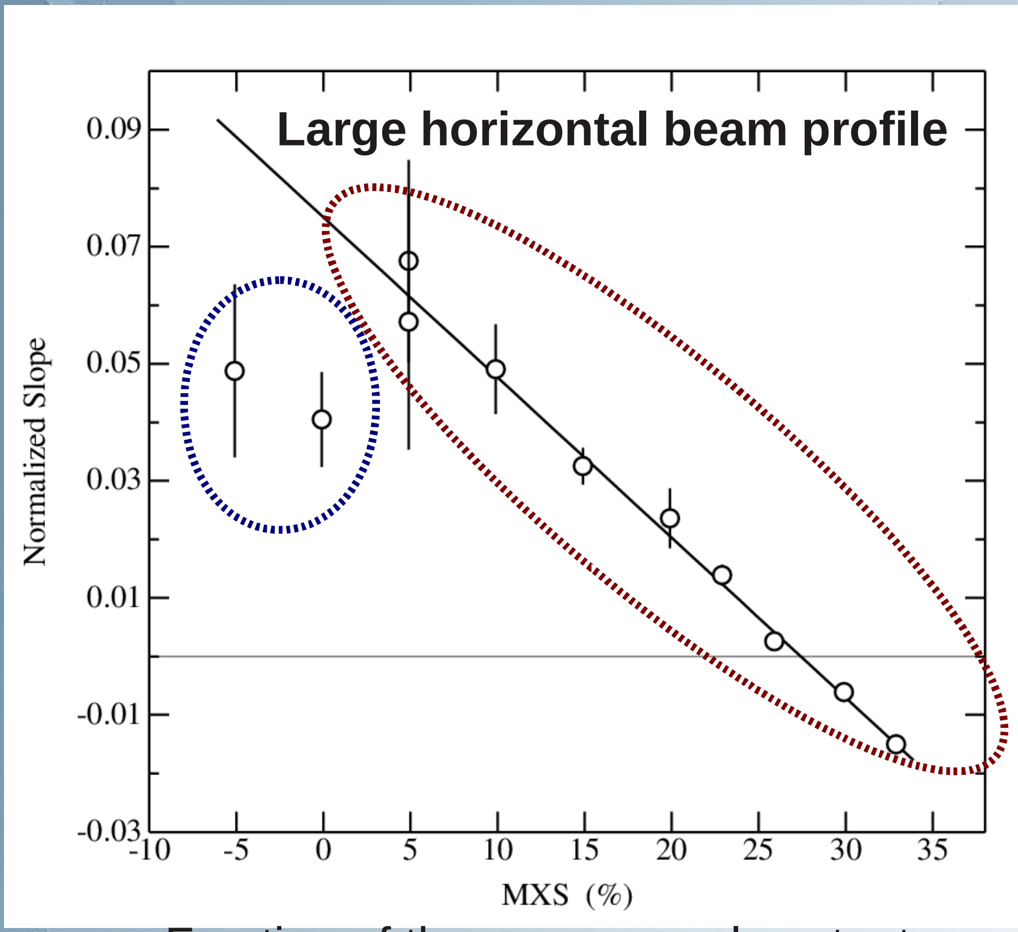

Fraction of the power supply output

Linear fit

- Best fit: MXS > 0%
- Lack of distortions near zero slope
- Lack of contributions shortening the pol. lifetime (e.g. vertical emittance, coupling to momentum spread)

Stray points

Longer lifetime... to be understood

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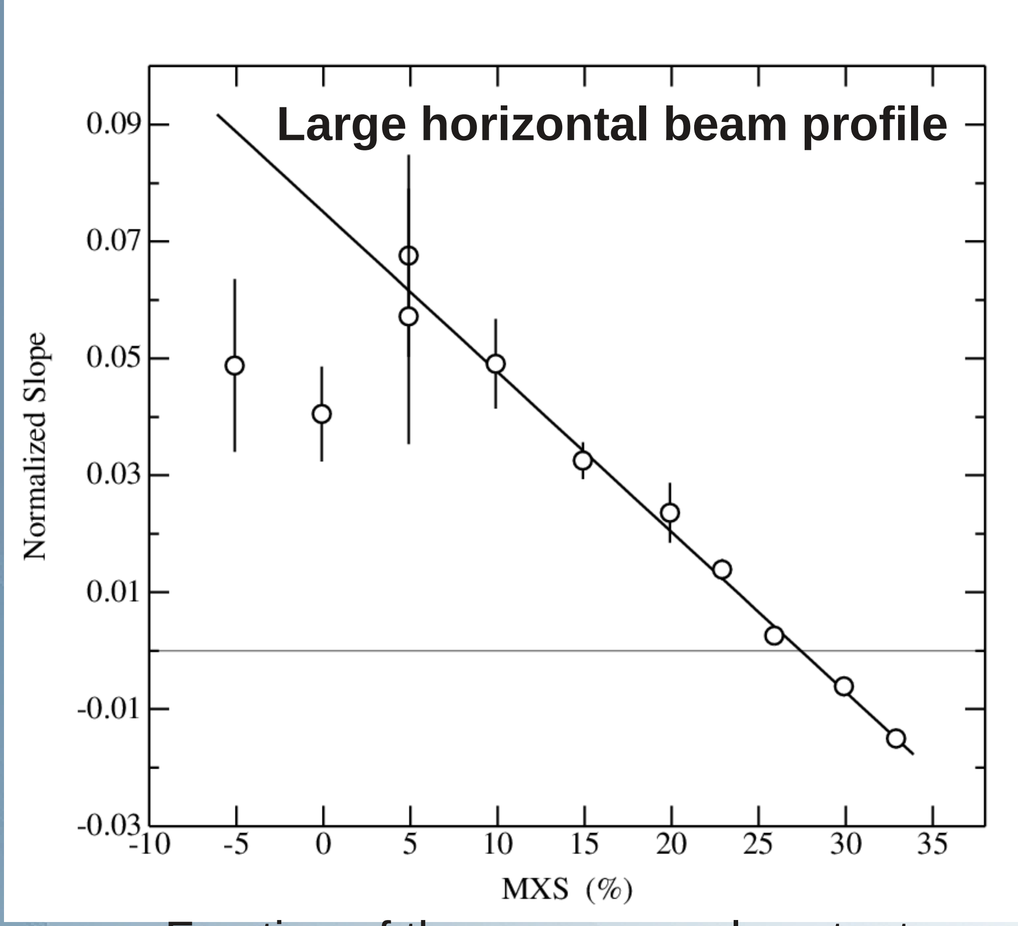

Fraction of the power supply output

<u>Comparison with:</u>

smaller beam profile

- Different slope
- Nearly the same zero crossing

continuously cooled beam

- Longest polarization lifetime = (318±40)s
- Weak dependence on the sextupole strength

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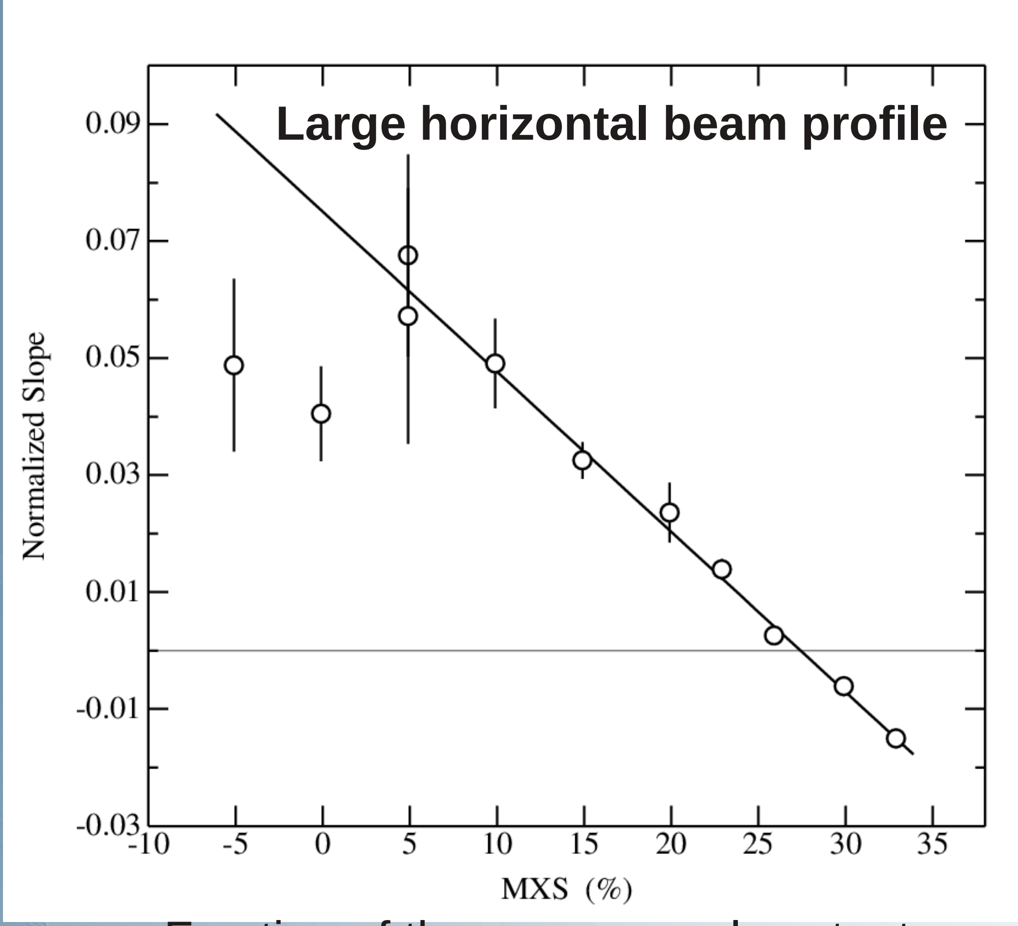

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Sextupole fields can be used to increase the spin coherence time up to 1000 s

CONCLUSIONS

Feasibility study at COSY for the measurement of an EDM of a charged particle with a storage ring

Spin coherence time study

- Development of a spin tracking system to measure the horizontal polarization as a function of time
- Horizontal emittance influence on the spin coherence time
- Sextupole corrections on the horizontal phase space

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Next run (February 2013)

- Sextupole cancellation may be made in both X and Y (simultaneously)
- Better documentation of the beam profiles
- Better control of the emittance

Spin coherence time collaboration

Z. Bagdasarian[1], P. Benati[2], S. Bertelli[2], D. Chiladze[1,3], J. Dietrich[3], S. Dimov[3,4], D. Eversmann[5], G. Fanourakis[6], M. Gaisser[3], R. Gabel[3], B. Gou[3], G. Guidoboni[2], V. Hejny[3], A. Kacharava[3], V. Kamerdzhiev[3], P. Kulessa[7], A. Lehrach[3], P. Lenisa[2], Be. Lorentz[3], L. Magallanes[8], R. Maier[3], D. Michedlishvili[1,3], W. M. Morse[9], A. Nass[3], D. Öllers[2,3], A. Pesce[2], A. Polyanskiy[3,10], D. Prasun[3], J. Pretz[5], F. Rathmnann[3], Y. K. Semertzidis[9], V. Schmakova[3,4], E. J. Stephenson[11], H. Stockhorst[3], H. Ströher[3], R. Talman[12], Yu. Valdau[3,13], Ch. Weideman[2,3], P. Wüstner[14].

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[13]*Petersburg Nuclear Physics Institute, Gatchina,* ***Russia***
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Thanks for your attention!