Achievements at COSY

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CERN, March 2017

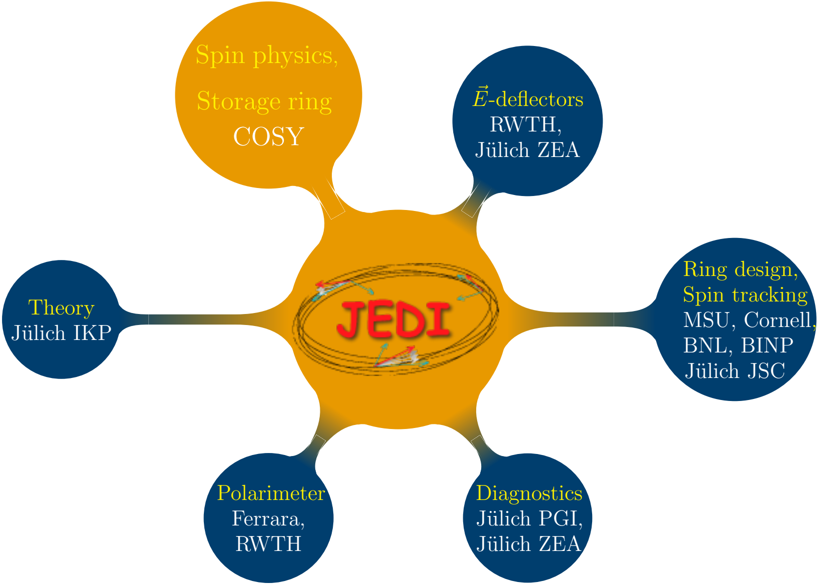
JEDI Collaboration

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.

JEDI



Spin physics,
Storage ring
COSY
$\vec{E}$-deflectors
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

Recent Achievements:

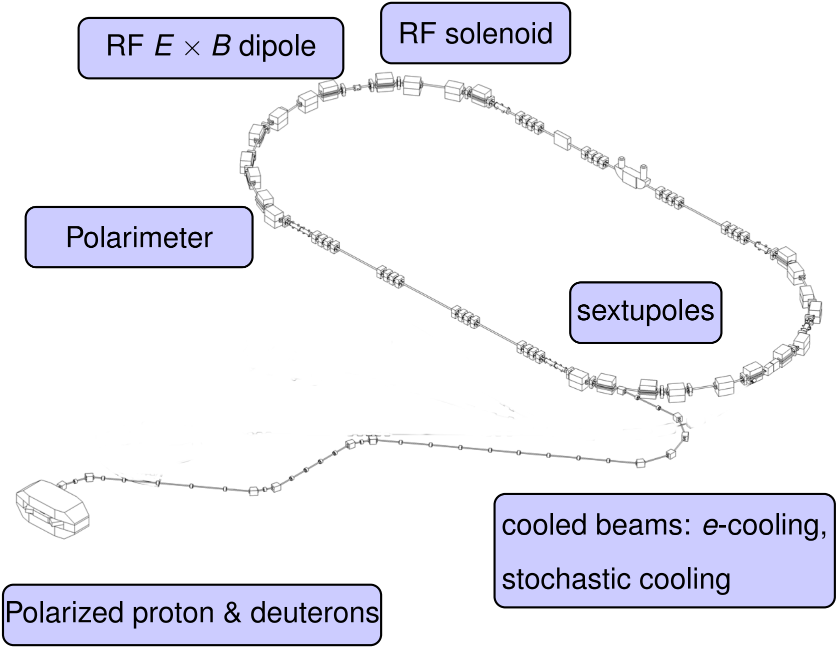
How do manipulate and measure a polarization with high precision!

1. Maximize spin coherence time (SCT)
2. Precise measurement of spin precession (spin tune)
3. Polarization phase locking with feed back system

Cooler Synchrotron COSY

COSY provides (polarized) protons and deuterons with
$p = 0.3 - 3.7\text{GeV}/c$
$\Rightarrow$ **Ideal starting point for charged hadron EDM searches**

COSY

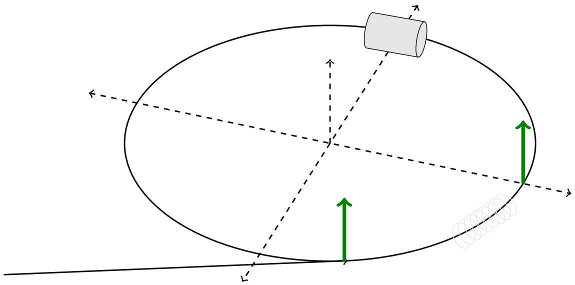

RF $E \times B$ dipole
RF solenoid
Polarimeter
sextupoles
cooled beams: e-cooling,
stochastic cooling
Polarized proton & deuterons

Important parameters

COSY circumference	183 m
deuteron momentum	0.970 GeV/c
$\beta(\gamma)$	0.459 (1.126)
magnetic anomaly G	≈ -0.143
revolution frequency f_{rev}	752543 Hz
cycle length	100-1500 s
nb. of stored particles/cycle	$\approx 10^9$
event rate at $t = 0$	5000 s^{-1}

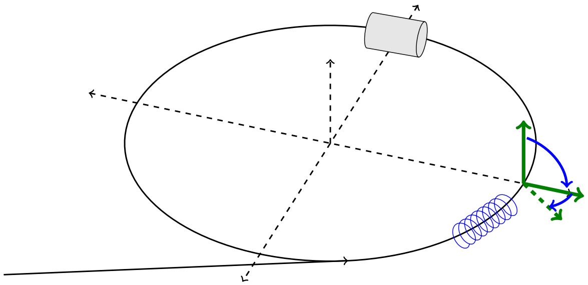
Experimental Setup at COSY

- Inject and accelerate vertically polarized deuterons to $p \approx 1$ GeV/c



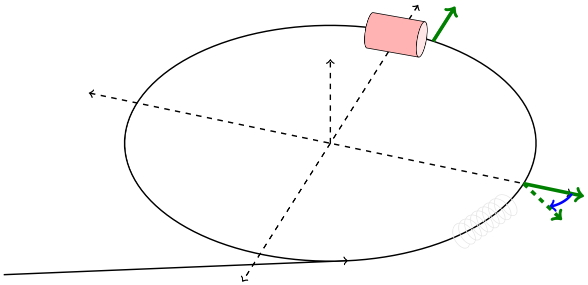
Experimental Setup at COSY

- Inject and accelerate vertically polarized deuterons to $p \approx 1$ GeV/c
- flip polarization with help of solenoid into horizontal plane, precession starts



Experimental Setup at COSY

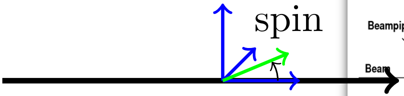
- Inject and accelerate vertically polarized deuterons to $p \approx 1$ GeV/c
- flip polarization with help of solenoid into horizontal plane, precession starts
- Extract beam slowly (in $\approx 100\,$s) on target
- Measure asymmetry and determine spin precession

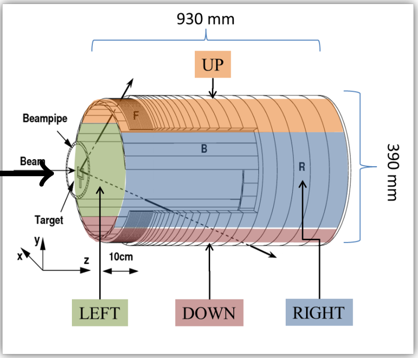


Polarimeter

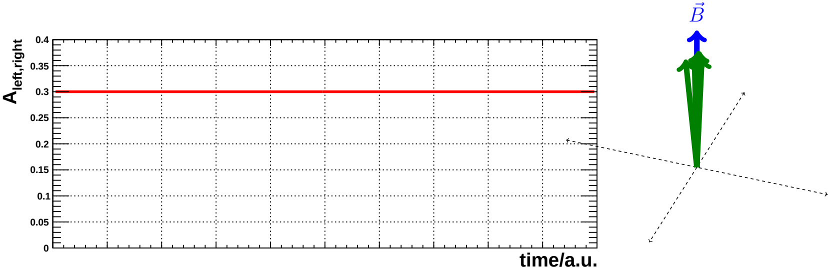
elastic deuteron-carbon scattering,
consists of four scintillator segments: left, right, up, down

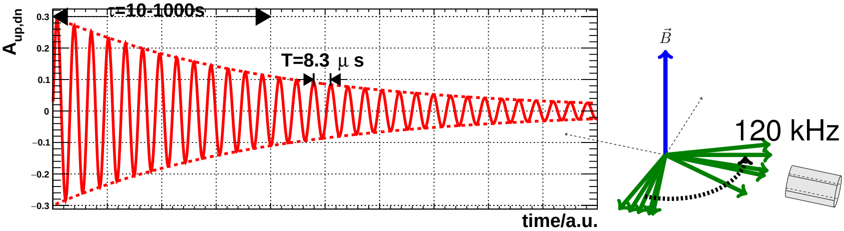
asymmetry $A_{up,down} \propto$ horizontal polarization $\rightarrow \nu_s = \gamma G$
asymmetry $A_{left,right} \propto$ vertical polarization $\rightarrow d$



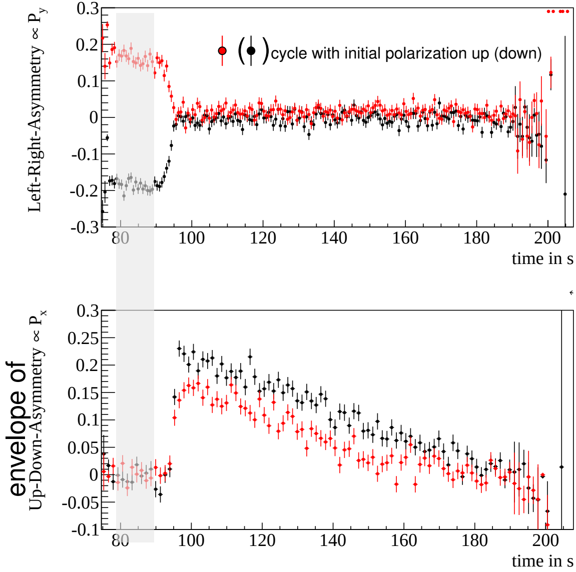


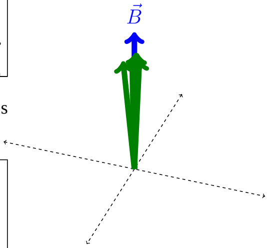
Asymmetries





Polarization Flip





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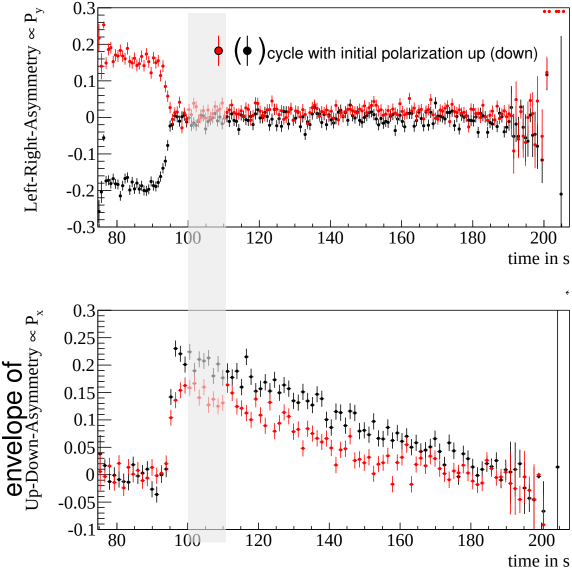

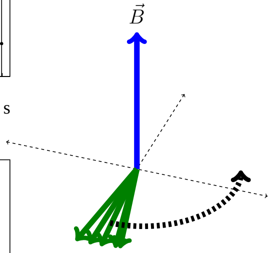

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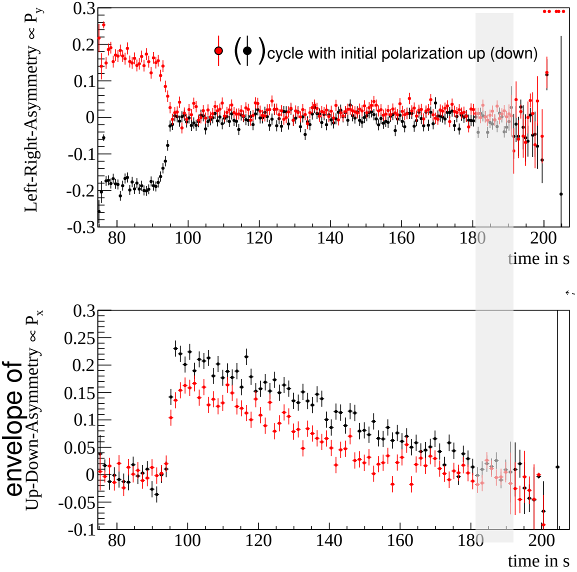
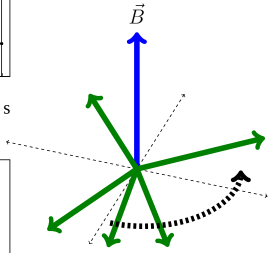
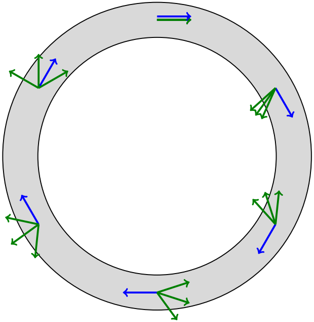
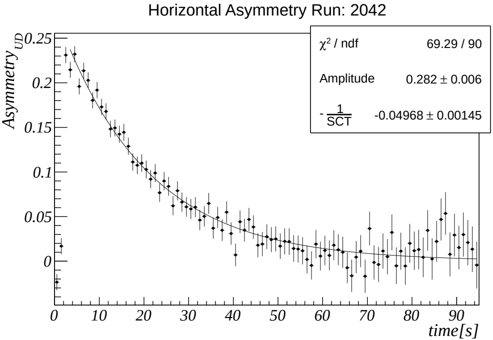




1.) Spin Coherence Time (SCT)

Short Spin Coherence Time





unbunched beam

$\Delta p/p = 10^{-5} \Rightarrow \Delta\gamma/\gamma = 2 \cdot 10^{-6}$, $T_{rev} \approx 10^{-6}\,\mathrm{s}$

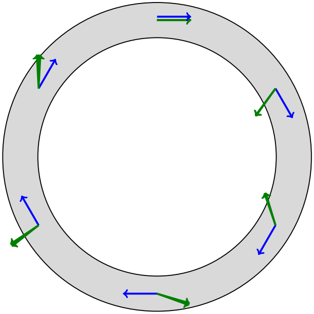
$\Rightarrow$ decoherence after $< 1\,\mathrm{s}$

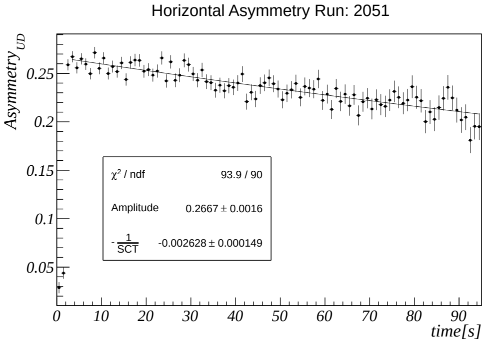
bunched beam eliminates 1st order effects in $\Delta p/p$

$\Rightarrow$ SCT τ = 20 s

1.) Spin Coherence Time (SCT)

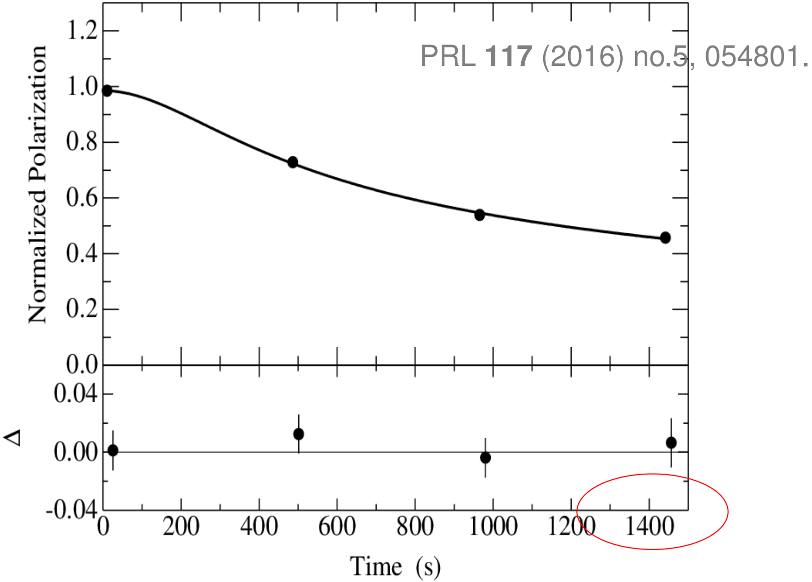
Long Spin Coherence Time





SCT of $\tau = 400$ s, after correction with sextupoles (chromaticities $\xi \approx 0$)

SCT: Longer Cycles



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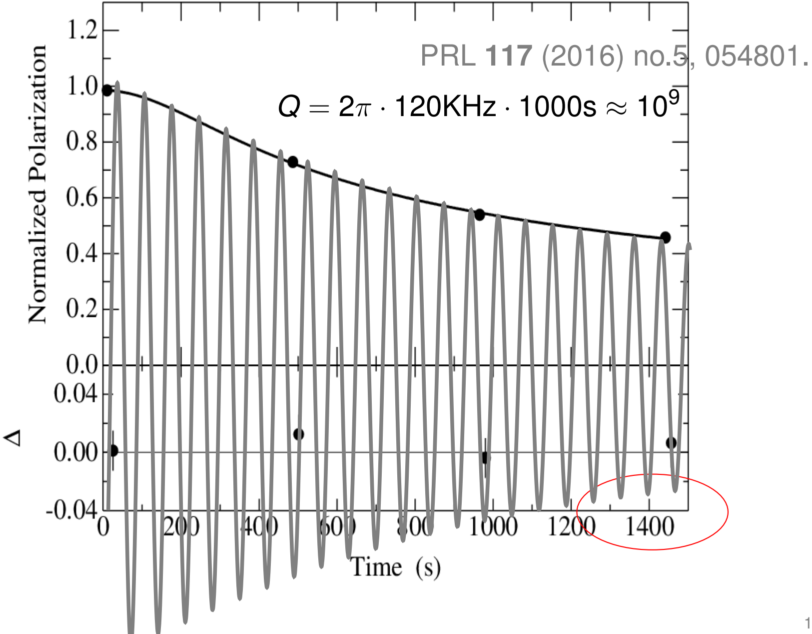
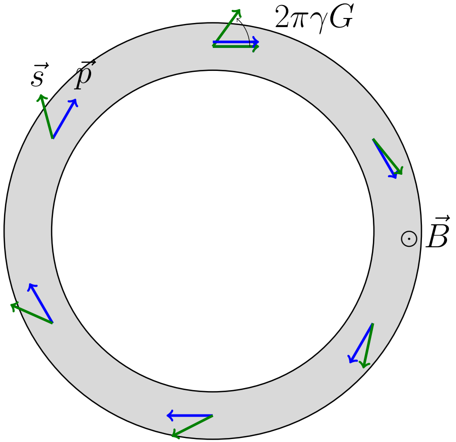


2.) Spin Tune ν_s

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

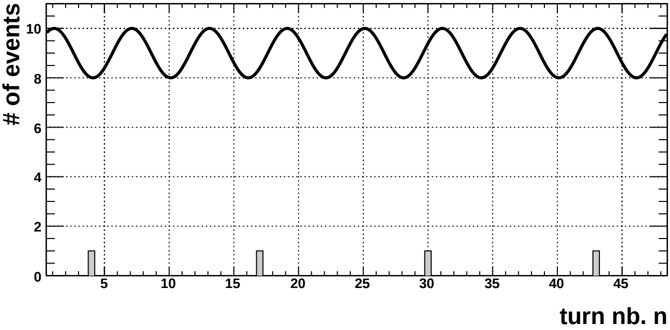


deuterons: $p_d = 1$ GeV/c ($\gamma = 1.13$), $G = -0.14256177(72)$

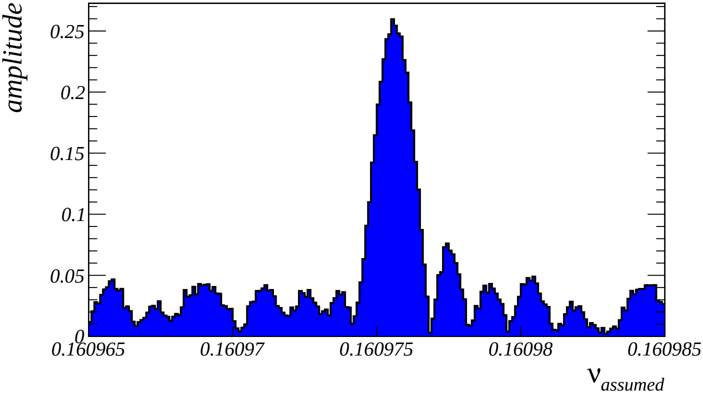
$\Rightarrow \nu_s = \gamma G \approx -0.161$

Spin Tune ν_s measurement

- Problem: detector rate $\approx$ 5 kHz, $f_{spin} = 120$kHz
  $\Rightarrow$ only 1 hit every 25th period
- not possible to use usual χ^2-fit
- try different algorithms,
  mapping, **Fourier analysis**, Maximum Likelihood

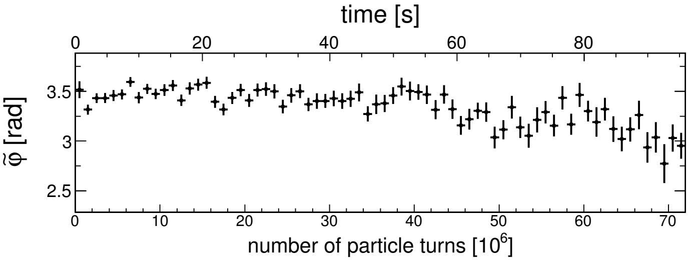


Fourier spectrum for 10^6 turns



- fix ν_s at maximum and look at phase vs. turn number
  phase is determined for turn intervals of 10^6 turns (≈ 1.3 s)

Results spin tune



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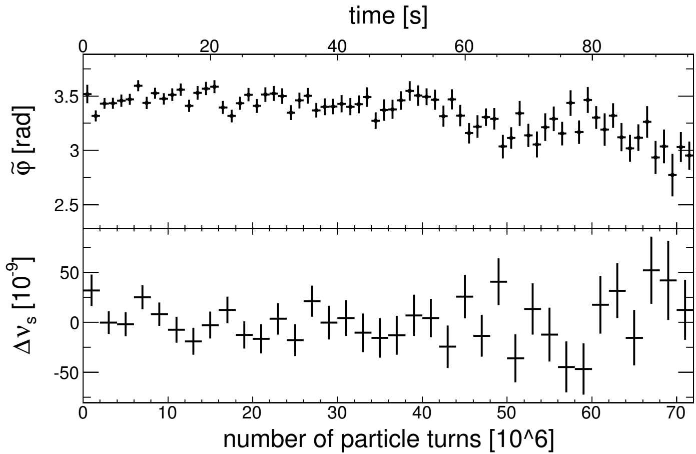
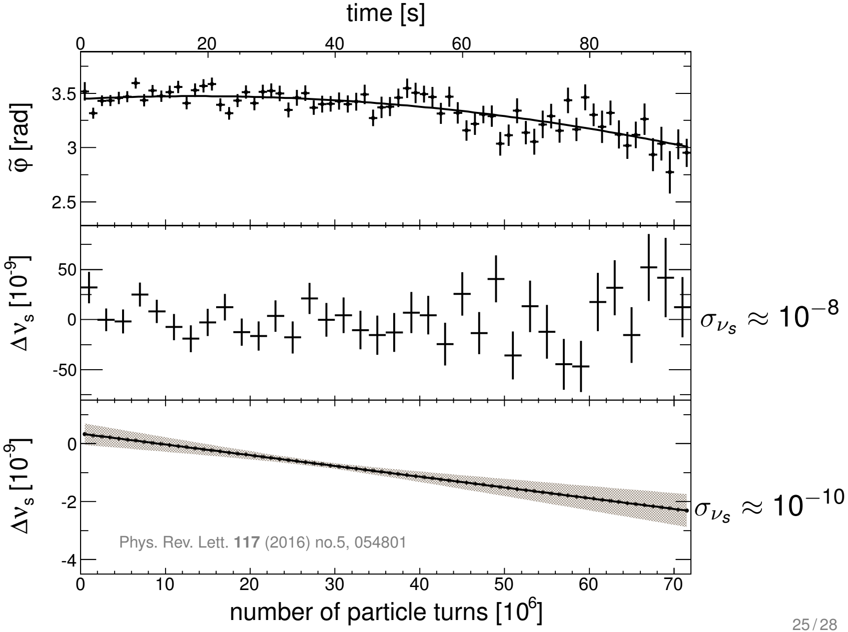


$\sigma_{\nu_s} \approx 10^{-8}$

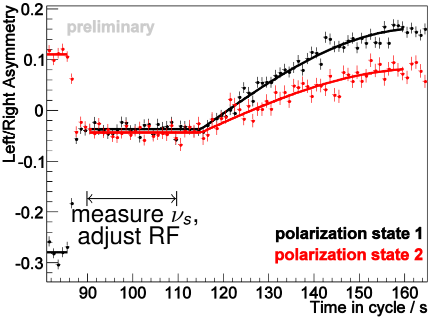
Results spin tune



Spin Tune Measurement

- $\sigma_{\nu_s} = 10^{-10}$, $\sigma_{\nu_s}/\nu_s = 10^{-9}$ in one cycle of $\approx 100\,s$
- Compare to muon $g-2$: $\sigma_{\nu_s}/\nu_s \approx 10^{-6}$ per year
  main difference: measurement duration 600μs compared to 100 s
- spin rotation due to electric dipole moment:
  $\nu_s = \frac{vm\gamma d}{es} = 5 \cdot 10^{-11}$ for $d = 10^{-24} e\,\mathrm{cm}$
  (in addition rotations due to G and imperfections)
- spin tune measurement can now be used as tool to investigate systematic errors
- spin tune measurement allows for feedback system to keep polarization aligned with momentum vector
  needed for final ring (frozen spin) and
  Wien filter method in magnetic ring

3.) Spin Feed back system



- polarization rotation in horizontal plane at $t = 85$ s
- COSY rf changed during cycle in steps of 3.7 mHz (f_{rev}=750603 Hz) according to online ν_s measurement,

- keeps phase between spin and RF solenoid constant
- solenoid (low amplitude) switched on at $t = 115$ s
- polarization goes back to vertical direction
- mandatory for **frozen spin** in dedicated ring

Summary

- Spin coherence times $> 1000\,\mathrm{s}$ reached
- spin tune can be measured with accuracy of 10^{-10} in $100\,\mathrm{s}$ cycle
- phase locking of spin precession within $\sigma = 0.21\,\mathrm{rad}$

(for deuterons at $p \approx 1$ GeV/c)