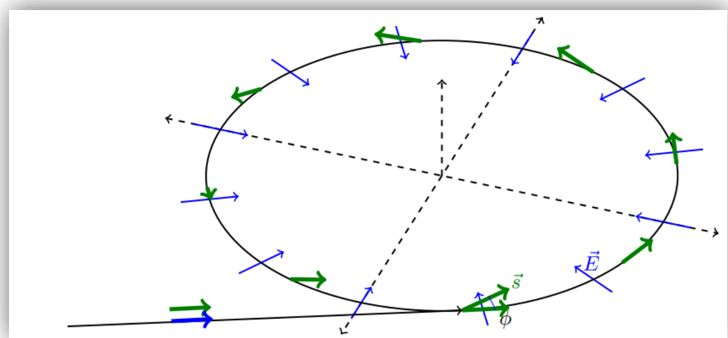
EDM Study at COSY

Recent Results

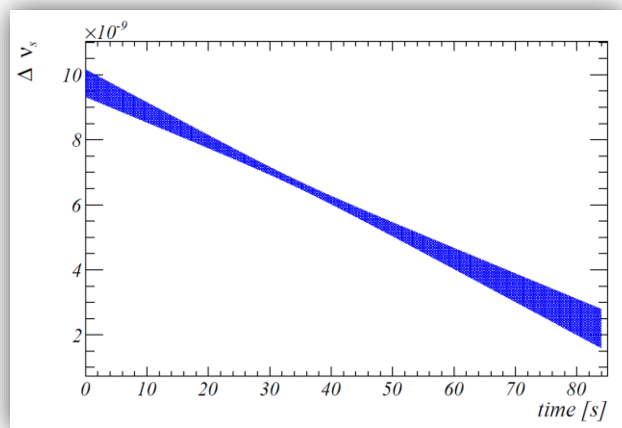
July 7, 2014 | Fabian Hinder on behalf of the JEDI Collaboration

Outline

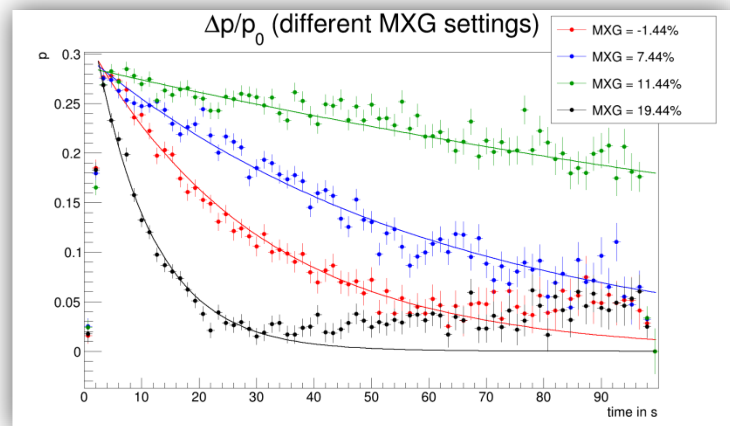
Motivation



Spin-Tune Measurement



Spin-Coherence-Time



Measure EDMs in Storage Rings

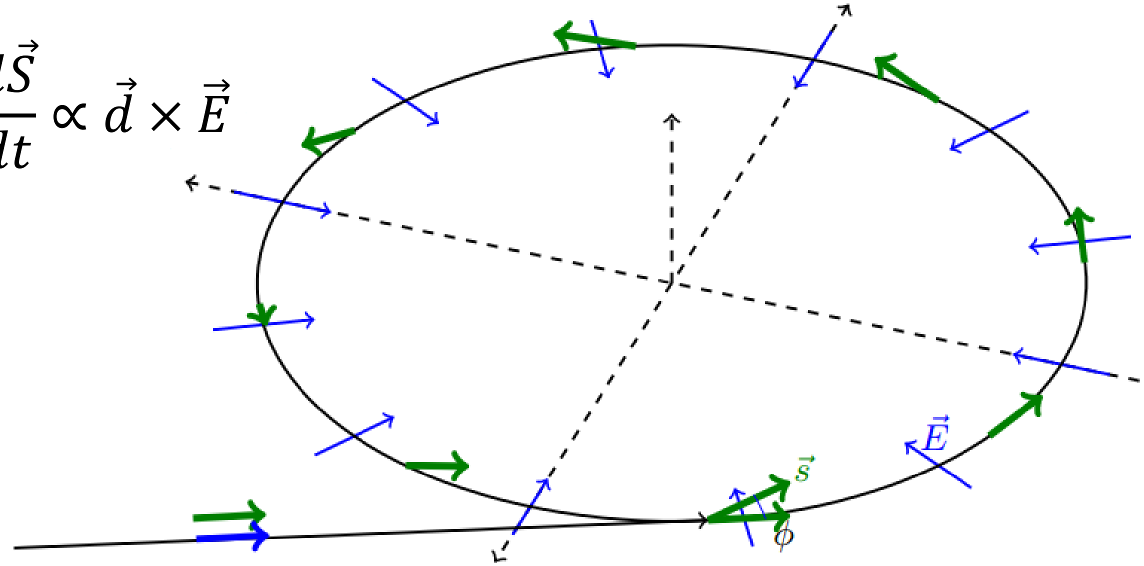
All EDM experiments:

- Interaction of field $\vec{E}$ and EDM $\vec{d}$

→ Spin rotates

- Problem with charged particles:
  They are accelerated

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



Generic Idea:
(Frozen Spin method)

1. Inject polarized particles with spin parallel to momentum
2. Apply radial electric field to particle in storage ring
3. Due to EDM $\vec{d}$ spin rotates out of horizontal plane
4. Measure build-up of vertical polarization $\propto \vec{d}$

Requirements to an EDM Storage Ring

- Polarized particle beam ($P \approx 0.8$)
- $\vec{E}$ and $\vec{B}$ fields ($E \approx 10\ \mathrm{MV/m}$)
- Polarimeter to measure the EDM build up
- Precise measurement of spin precession
- Long polarization lifetime ($\tau \approx 1000$ s)

Spin Motion in Storage Rings

Thomas BMT-Equation

$$\frac{d\vec{S}}{dt} = \vec{S} \times \vec{\Omega}_{MDM} + \vec{S} \times \vec{\Omega}_{EDM}$$

$$\vec{\Omega}_{MDM} = \frac{q}{m}\left(G\vec{B} - \left(G - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} - \frac{G\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\cdot\vec{B}\right)\right)$$

$$\vec{\Omega}_{EDM} = \frac{d}{s}\left(\vec{E} + c\vec{\beta} \times \vec{\mathrm{B}} - \frac{\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\cdot\vec{E}\right)\right)$$

	G
Proton	1.792847357
Deuteron	-0.142561769

Spin Motion in Pure Magnetic Ring

- Pure magnetic ring like COSY (vertical bending field)
- Particle with $d \approx 0$ ($\vec{\Omega}_{EDM} \ll \vec{\Omega}_{MDM}$)

$$\frac{d\vec{S}}{dt} = \vec{S} \times \vec{\Omega}_{MDM} + \vec{S} \times \vec{\Omega}_{EDM}$$

$$\vec{\Omega}_{MDM} = \frac{q}{m}\left(G\vec{B} - \left(G - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c} - \frac{G\gamma}{\gamma+1}\vec{\beta}(\vec{\beta}\cdot\vec{B})\right)$$

$$\vec{\Omega}_{EDM} = \frac{d}{S}\left(\vec{E} + c\vec{\beta}\times\vec{B} - \frac{\gamma}{\gamma+1}\vec{\beta}(\vec{\beta}\cdot\vec{E})\right)$$

Define: **Spintune** $:=$ Number spin turns relative to particle turns:

$$\nu := \frac{|\vec{\Omega}_{MDM}|}{\omega_{rev}} = \frac{\frac{q}{m}GB}{\frac{q}{m\gamma}B} = \gamma G$$

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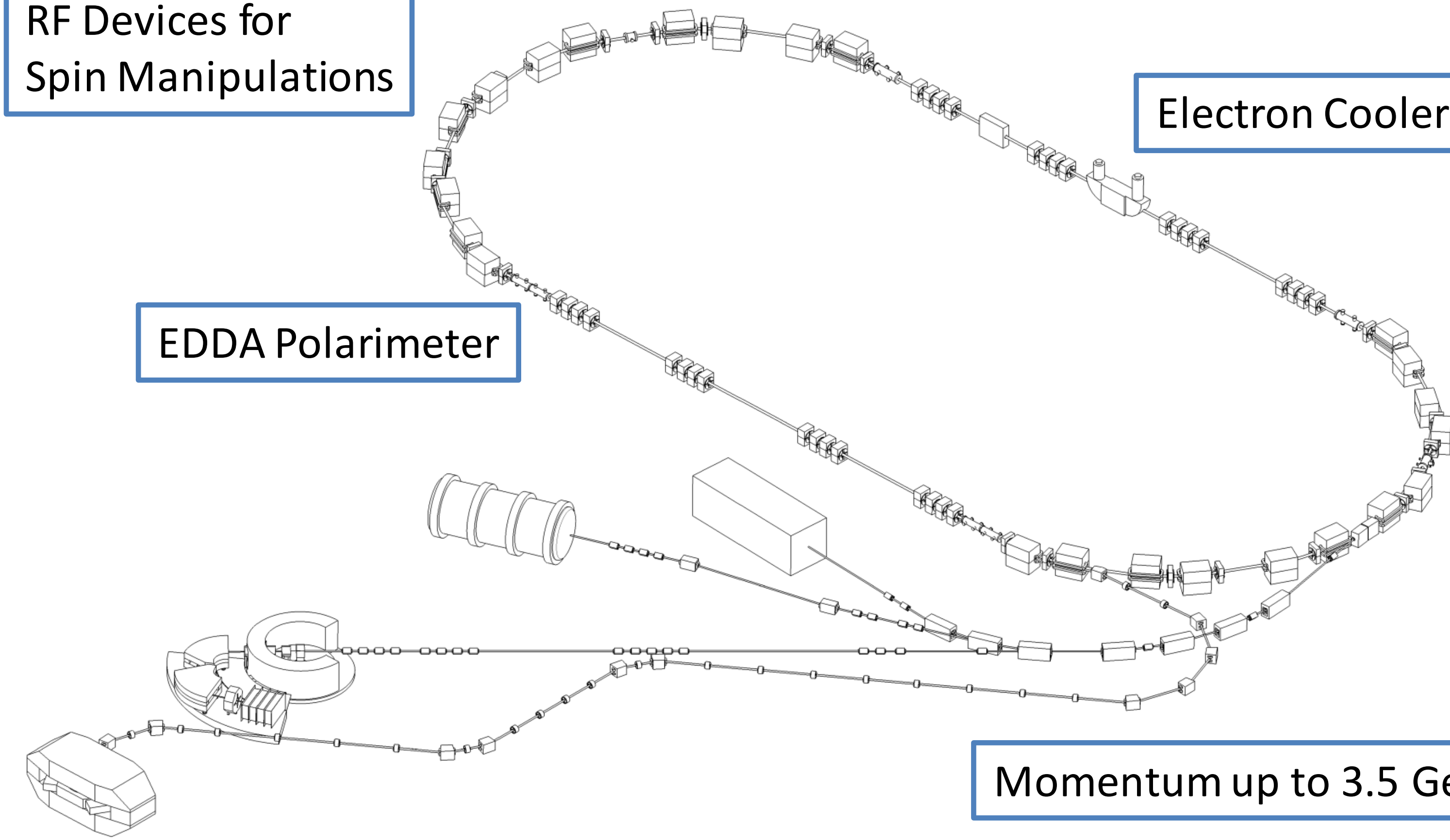
Cooler Synchrotron COSY in Jülich



EDDA Polarimeter

- ***Left-Right*** asymmetry

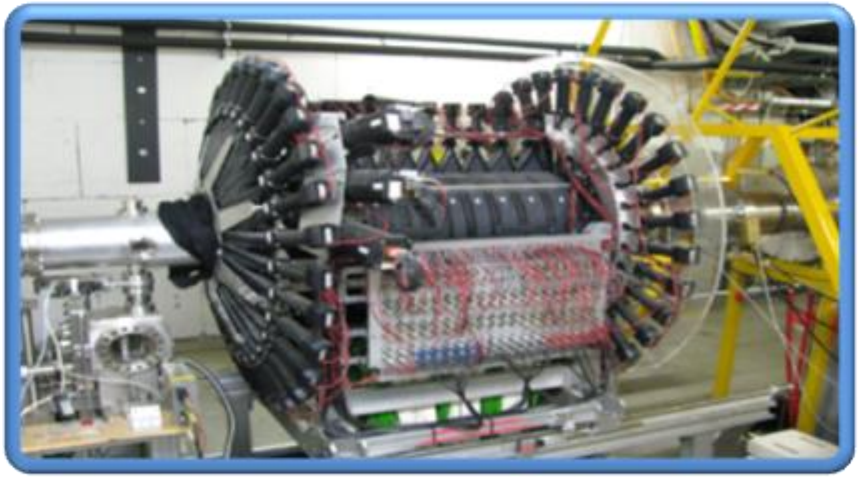
  ⇒ ***vertical*** polarization

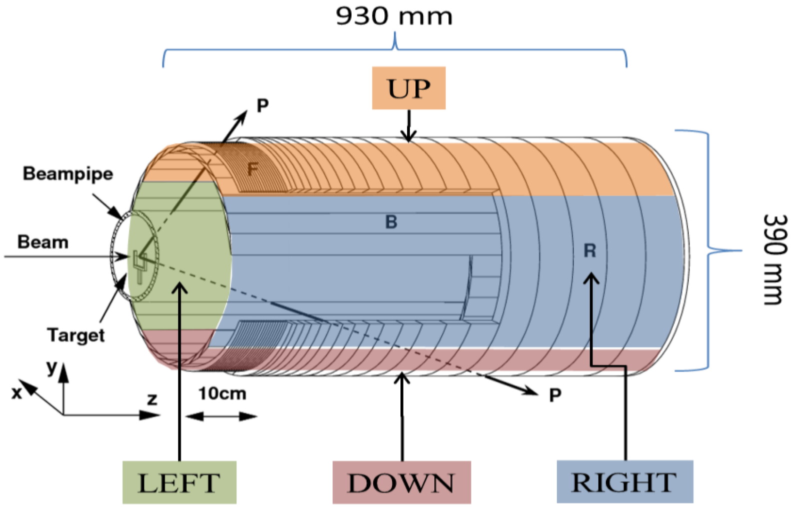
$$P_V \propto \epsilon_{ver} = \frac{N_l - N_r}{N_l + N_r}$$

- ***Up-Down*** asymmetry

  ⇒ ***horizontal*** polarization

$$P_H \propto \epsilon_{hor} = \frac{N_{up} - N_{dn}}{N_{up} + N_{dn}}$$





Spin Tune Measurement

Spin vector precesses with $f_{\mathrm{Spin}} = \nu f_{rev}$ in the horizontal plane

Asymmetry given by:

$$\epsilon_V(t) = \frac{N_{up} - N_{dn}}{N_{up} + N_{dn}} \approx AP(t)\sin(2\pi\nu f_{rev} t + \phi)$$

What do we expect? (Deuterons, $p = 0.97\ \mathrm{GeV/c}$)

$$\nu \approx 0.16, \qquad f_{rev} = 750\ \mathrm{kHz}$$

Spin precession frequency: $\nu \cdot f_{rev} \approx 125\ \mathrm{kHz}$

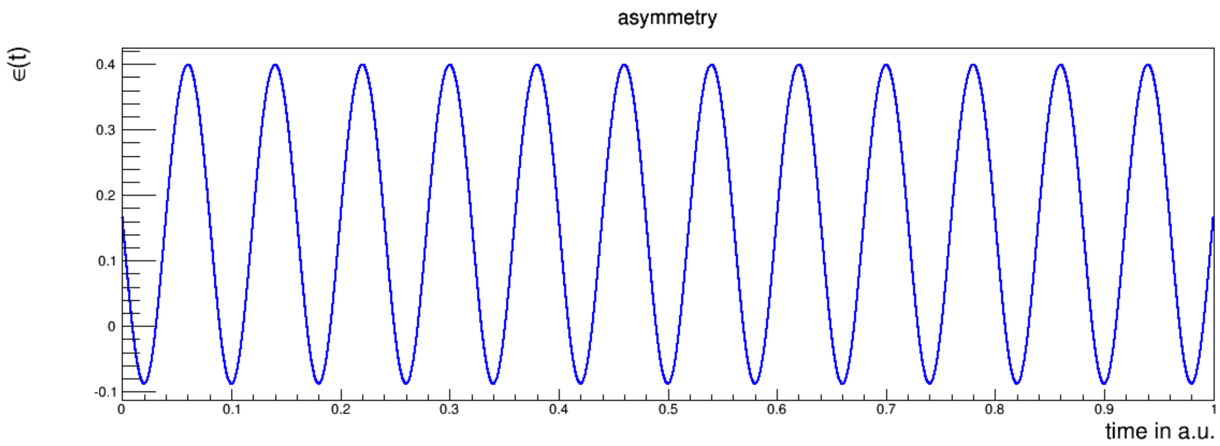
Detector rates: $5\ \mathrm{kHz}$

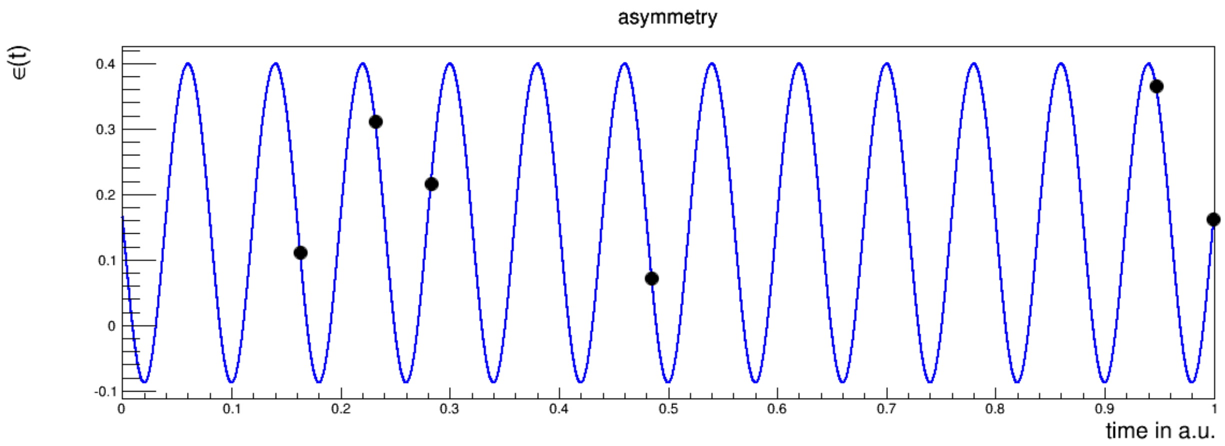
Only every 25th spin revolution is detected

$\Rightarrow$ No direct fit is possible

Recorded Events

Example: every 2nd spin precession is detected





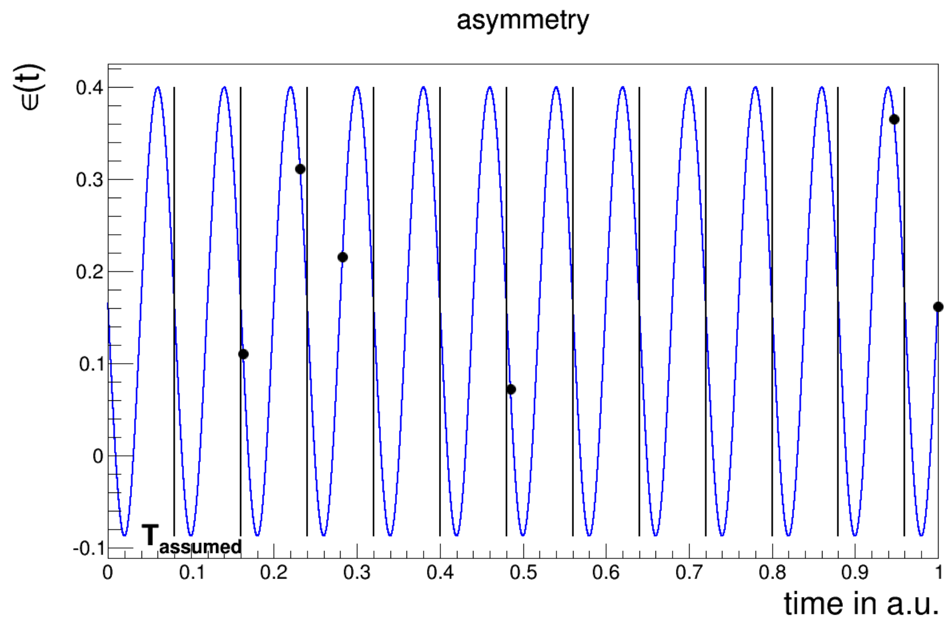
Mapping the Events

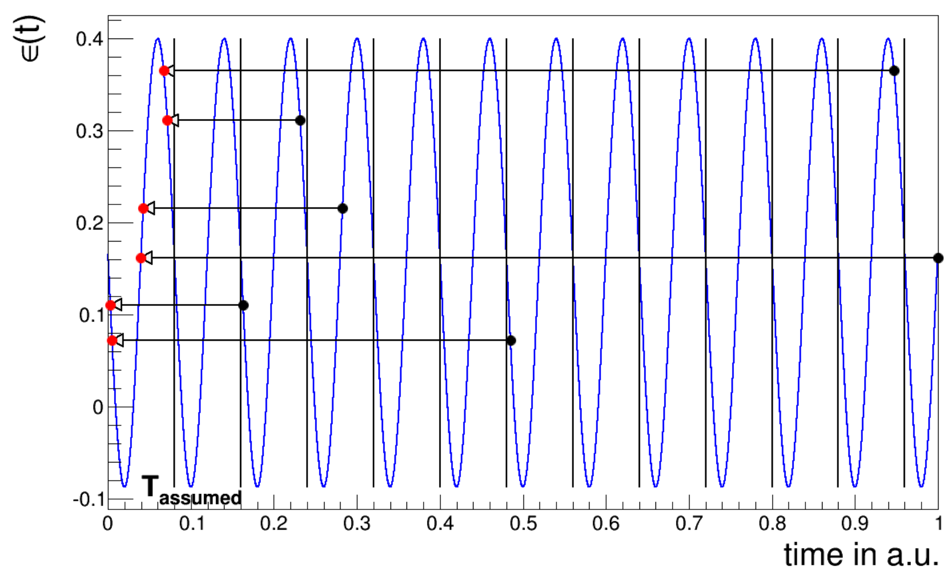
1. Assume Spin Tune $\nu_{assumed}$

$$T_{assumed} = \frac{2\pi}{\nu_{assumed} f_{rev}}$$

2. Map all events of a macroscopic time interval (2s) in first period:
$t' = mod(t, T_{assumed})$

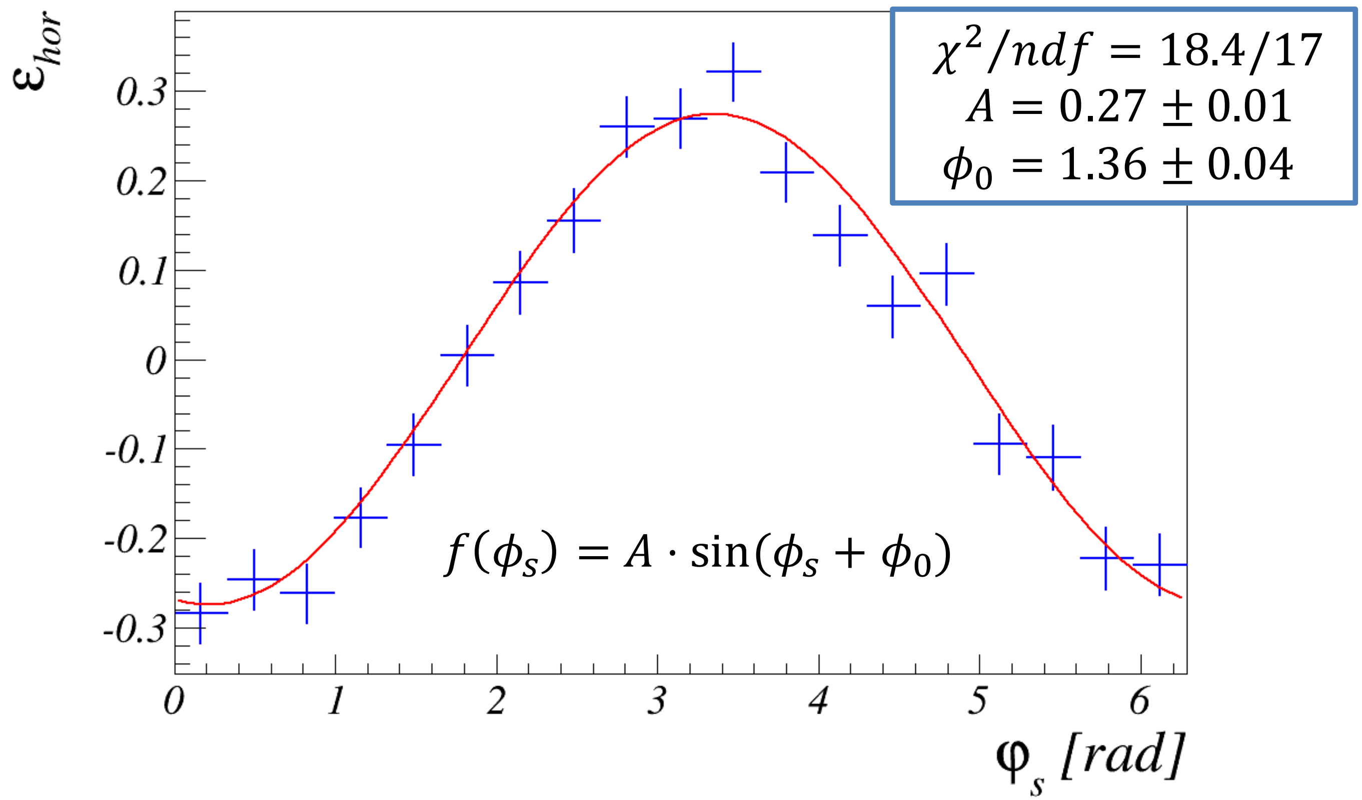
3. Fit asymmetry to first period





Fit Asymmetry to First Period

1. $T_{assumed}$
2. Mapping events
3. Fit asymmetry to first period

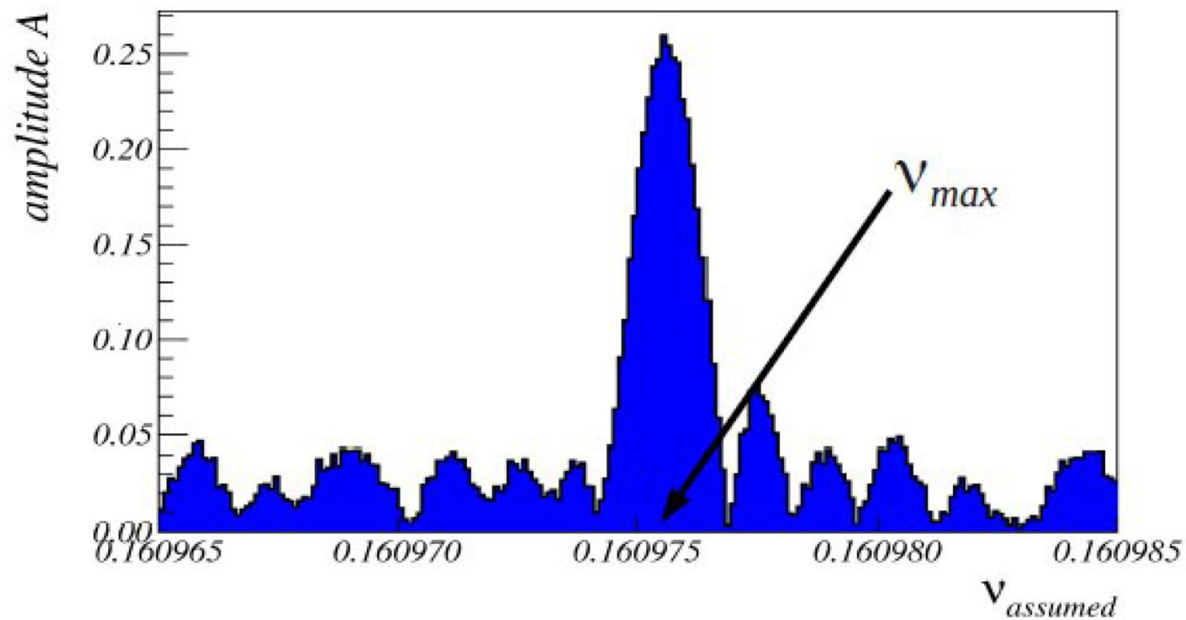


Extract amplitude $A \propto Polarisation$

Find Correct Spin Tune

1. $T_{assumed}$
2. Mapping events
3. Fit asymmetry to first period

- Vary $T_{assumed}$ and repeat steps 1 to 3
- Plot extracted parameter A vs $\nu_{assumed}$

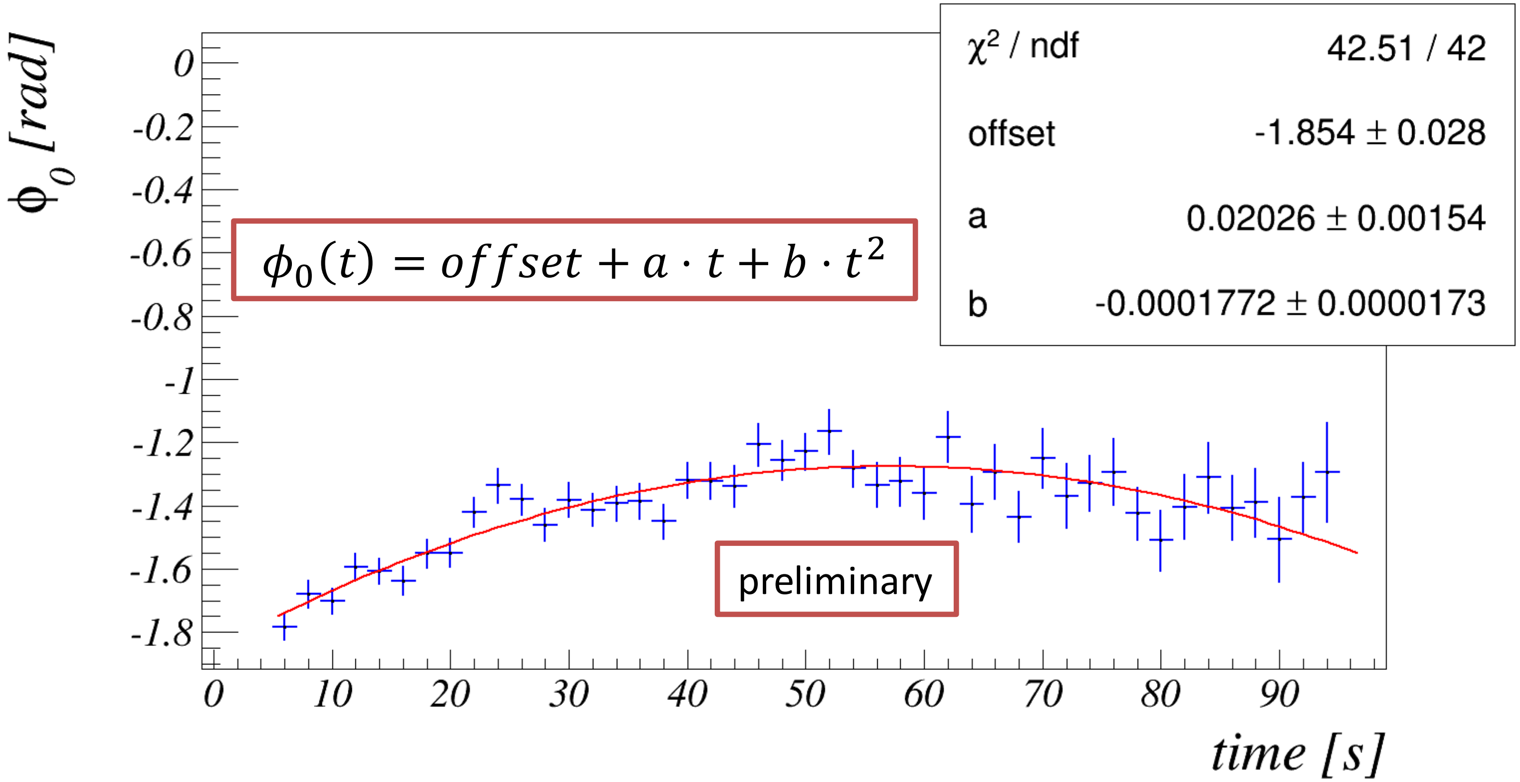


- ν_{max} is correct spine tune in macroscopic time interval $(2\ s)$
- $\nu_{max} = 0.160975 \pm 10^{-6}$

Spin Tune In Complete Cycle

- A cycle is one fill of COSY (cycle length: $\approx 100s$)
- Fix assumed spin tune to ν_{max}
- Map all events of a 2 second time interval in one period $T = \frac{2\pi}{\nu_{max} f_{rev}}$
- Fit $f(\phi_s) = A \cdot \sin(\phi_s + \phi_0)$ for every 2 second bin
- Extract phase ϕ_0
- Plot ϕ_0 against time in cycle

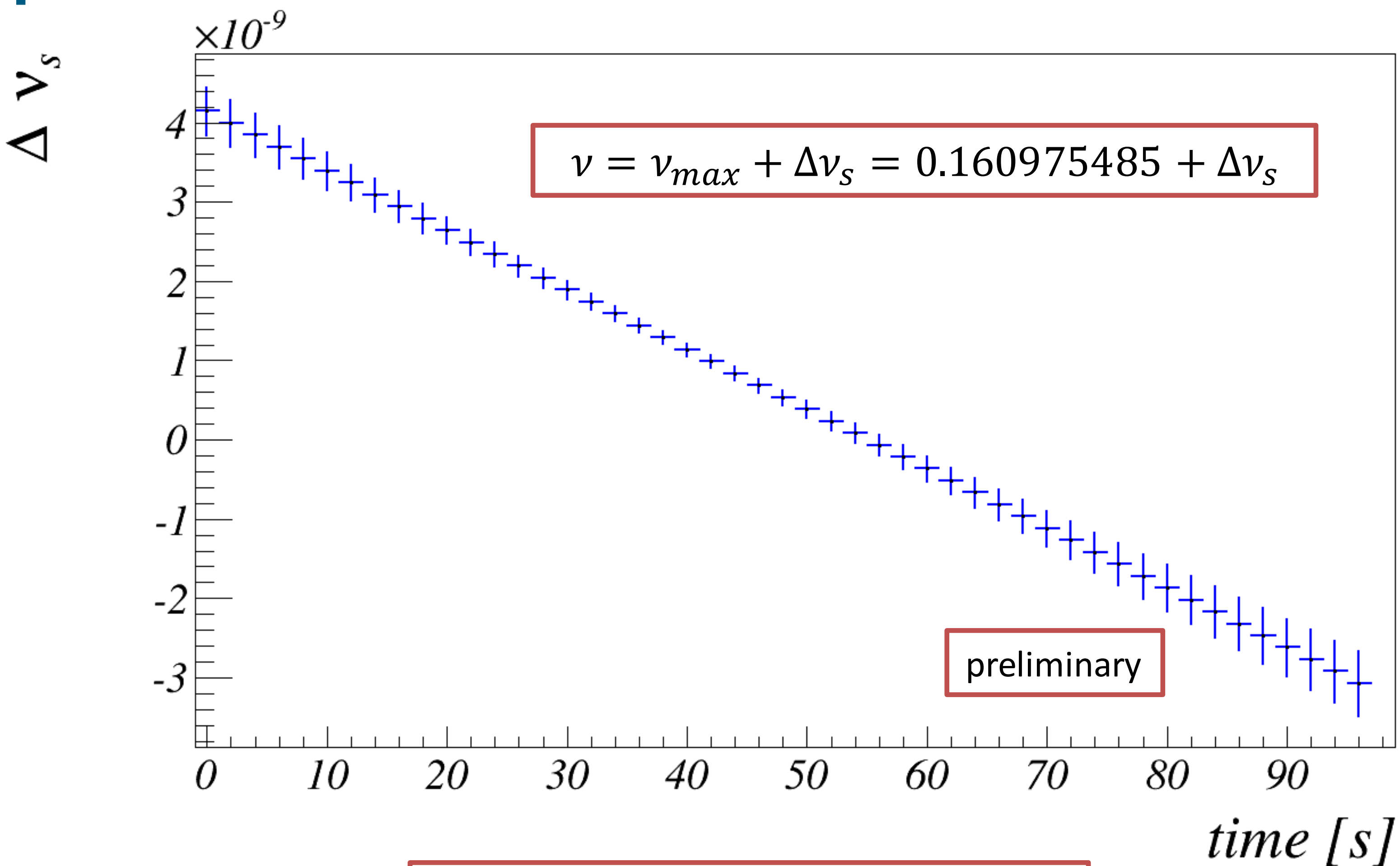
Phase ϕ_0 as a Function of Time



Calculate spin tune over one cycle by:

$$\nu(t) = \nu_{max} + \frac{1}{\omega_{rev}} \frac{\mathrm{d}\phi_0}{\mathrm{d}t}$$
$$= \nu_{max} + \frac{1}{\omega_{rev}} (a + 2b \cdot t)$$

Spin Tune as a Function of Time



$\frac{\sigma_\nu}{\nu} \approx \frac{10^{-10}}{0.16} = 6 \cdot 10^{-10}$ for one cycle

Compare sensitivity of Spin Tune ν_s

Experiment	Gedankenexperiment
$G \approx -0.14, d \approx 0$	$G = 0, d = 10^{-24}\mathrm{e \cdot cm}$
$\nu_s = \gamma G = -0.16$	$\nu_s = \frac{\beta c \gamma m d}{eS} = 5 \cdot 10^{-11}$

Compare to current sensitivity:
$\sigma(\nu_s) = 10^{-10}$ in a $100s$ measurement

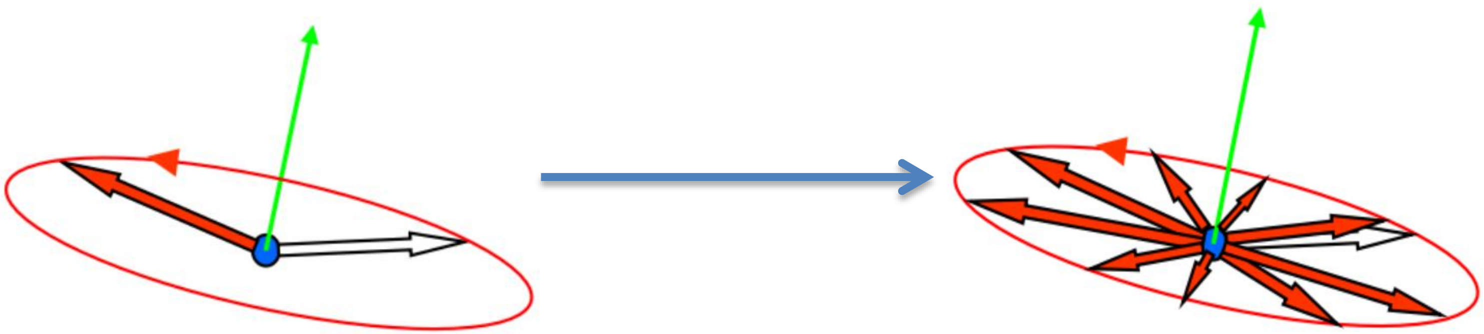
Summary Spin Tune

- Determination of spin tune in a macroscopic time interval of 2 seconds is possible due to mapping technic
- Precision $\frac{\sigma_\nu}{\nu} \approx 6 \cdot 10^{-6}$
- Due to phase fit spin tune change in one cycle is measurable
- Averaged spin tune in one cycle is known to $10^{-10} \Rightarrow \frac{\sigma_\nu}{\nu} \approx 6 \cdot 10^{-10}$
- Use Spin Tune measurements to study systematic effects at COSY

Spin Coherence Time (SCT)

- Sensitivity of an EDM measurement is proportional to polarization life time

- Spin precesses with $f_s = \gamma G \cdot f_{rev} \approx 120\ kHz$
- Energy spread leads to different spin precession frequencies



- Spins decohere –> Loss of polarization
- Typical time scale is the Spin Coherence Time (SCT)

Spin Coherence Time II

General form of the reciprocal SCT:

$$\frac{1}{\tau_{SCT}} \approx (C + c_1 S + c_2 L + c_3 G)\sigma_p^2$$

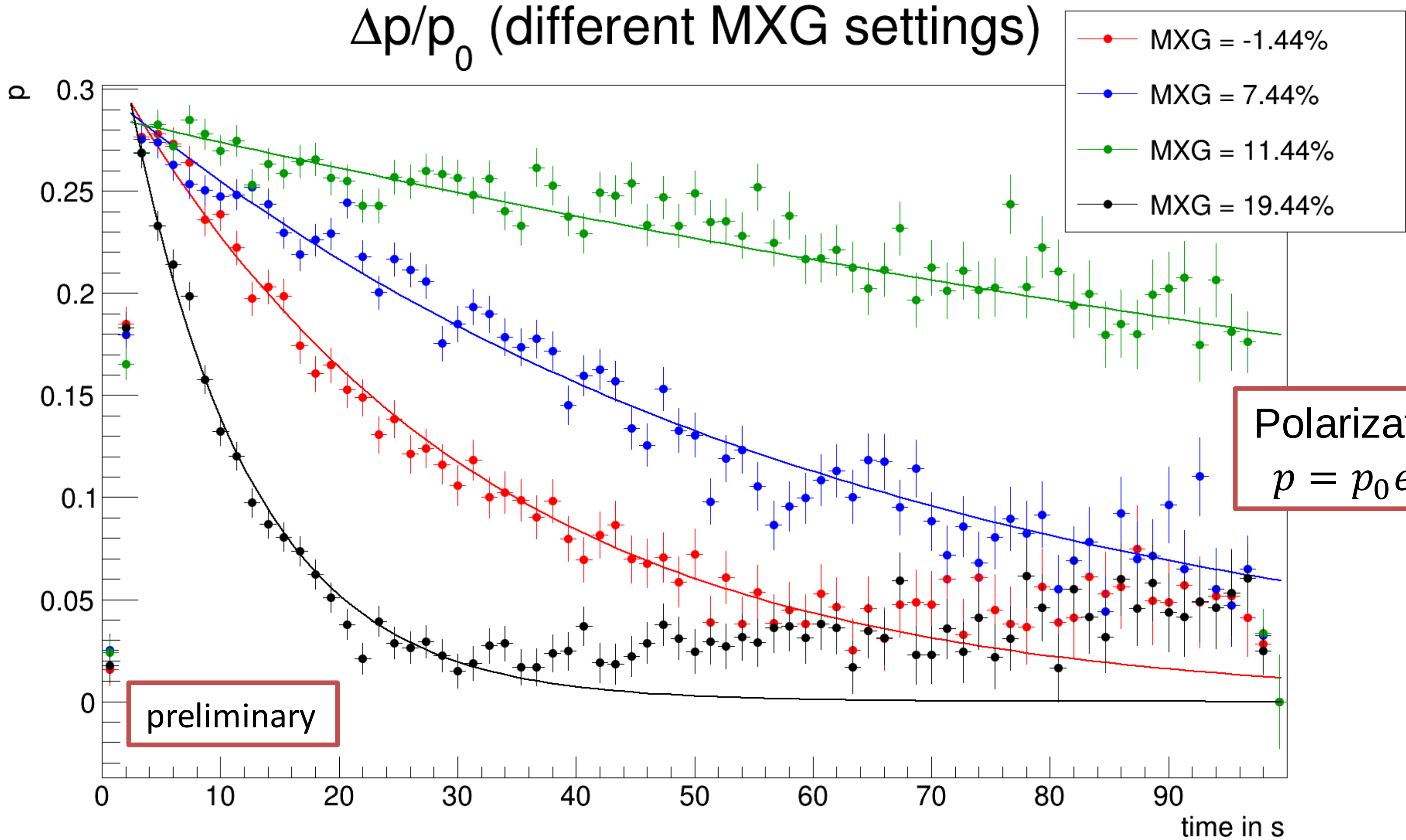
Path lengthening & momentum compaction

Sextupole strength of the magnet families (MXS, MXL, MXG)

Study influences of c_1, c_2 & c_3

1. Maximize σ_p (switching of the cooler and bunch the beam)
2. Vary sextupole settings MXS and MXG
3. Measure polarization lifetime (SCT)

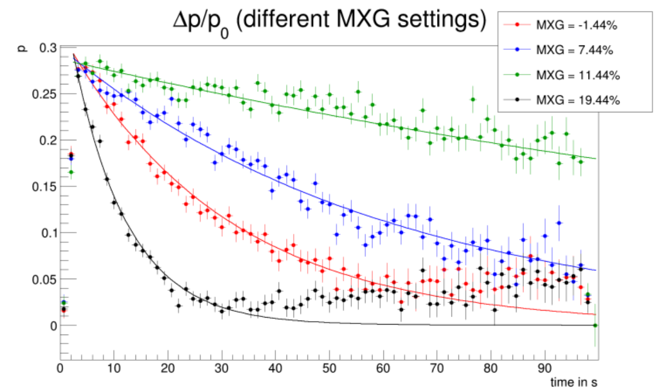
Scan of MXG value



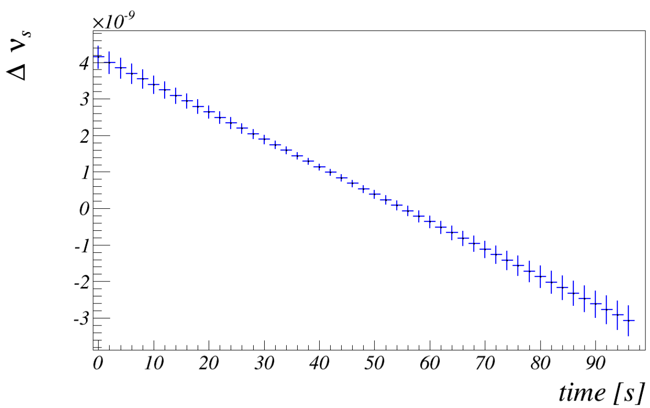
Polarization fit:
$p = p_0 e^{t/\tau_{SCT}}$

Best Spin Coherence Time: $\tau_{SCT} \approx 400s$

Summary & Outlook



- Best SCT until now: $\tau_{SCT} \approx 400\ s$
- Plans: Maximize SCT to $\tau \approx 1000s$



- Resolution of spin tune measurement:

$$\frac{\sigma_\nu}{\nu} \approx \frac{10^{-10}}{0.16} = 6 \cdot 10^{-10}$$

- Plans:
  Use Spin Tune as probe to study systematic effects, mimicking the EDM signal