Systematic Error Investigation of the Spin Tune Analysis for an EDM Measurement at COSY

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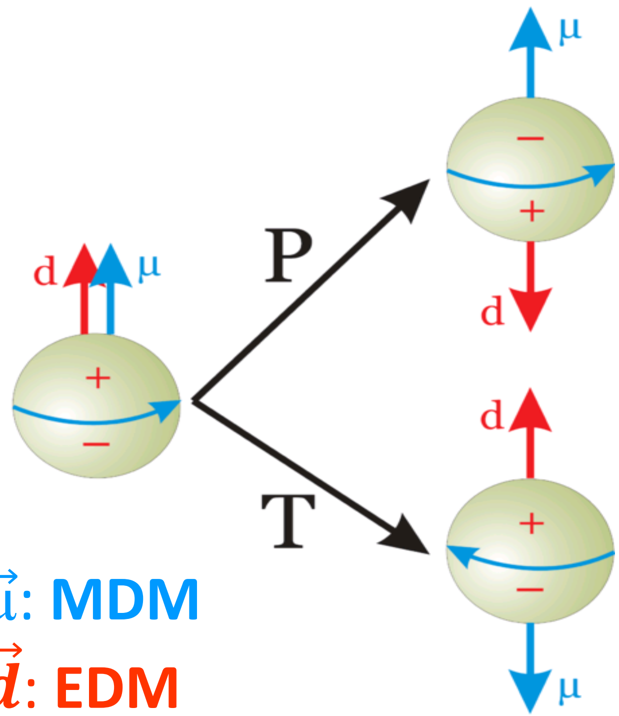
Introduction

- Motivation for an EDM (Electric Dipole Moment) search:
  - CP violation



$\vec{\mu}$: **MDM**

$\vec{d}$: **EDM**

EDM measurement tests violation of fundamental symmetries P and T

Challenge:
Disentangle EDM from systematic effects

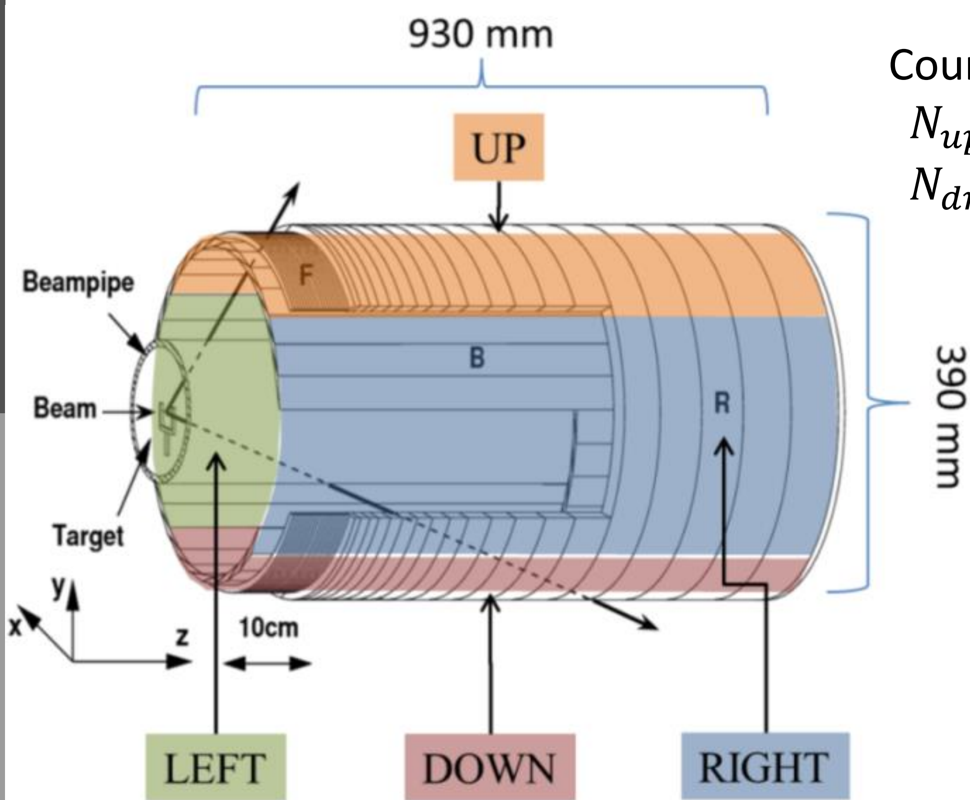
Systematic Tests of the Spin Tune Analysis

Spin Tune Measurement

@ COSY: deuteron beam with a momentum of 0.970 GeV/c

$$\nu_s = \frac{spin\ rotations}{particle\ revolutions} = \frac{|\Omega_s|}{|\omega_{cycl}|} \approx |\gamma G| \approx 0.1609$$

Spin-Precession: $f_S = \nu_s f_{rev} \sim 120$ kHz $\quad (f_{rev} = 750kHz)$



CountingRates:

$$N_{up}(t) = a_{up}(t) \cdot [1 + P(t)A \cdot \sin(2\pi f_S t + \varphi)]$$
$$N_{dn}(t) = a_{dn}(t) \cdot [1 - P(t)A \cdot \sin(2\pi f_S t + \varphi)]$$

a: Acceptance
P: Polarization
A: Analysing Power

Event rate: 5 kHz

500000 Events are detected for a 100 s cycle

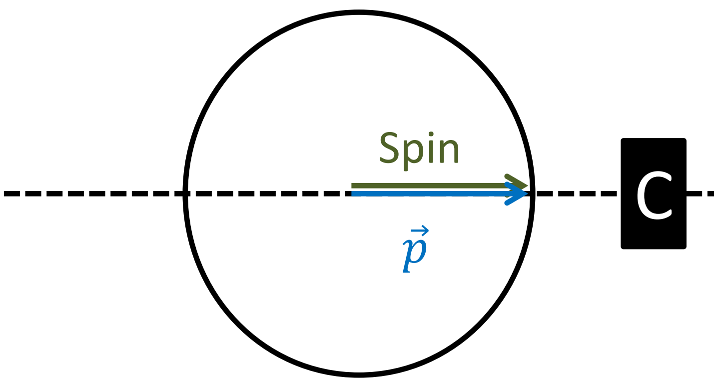
Asymmetry Measurement

CountingRates:

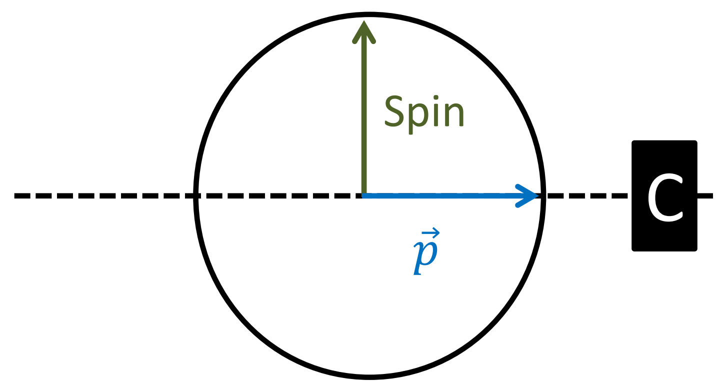
$$N_{up}(t) = a(t) \cdot [1 + P(t)A \cdot \sin(2\pi f_S t + \varphi)]$$
$$N_{dn}(t) = a(t) \cdot [1 - P(t)A \cdot \sin(2\pi f_S t + \varphi)]$$

Up-Down asymmetry (for constant a & PA)
⇒ ***horizontal*** polarization

$$\epsilon_{hor} = \frac{N_{up} - N_{dn}}{N_{up} + N_{dn}} = \mathrm{PA} \cdot \sin(2\pi f_s t + \varphi)$$



$\epsilon_{hor} = 0$



$\epsilon_{hor} = PA$

Measurement of the Spin Tune

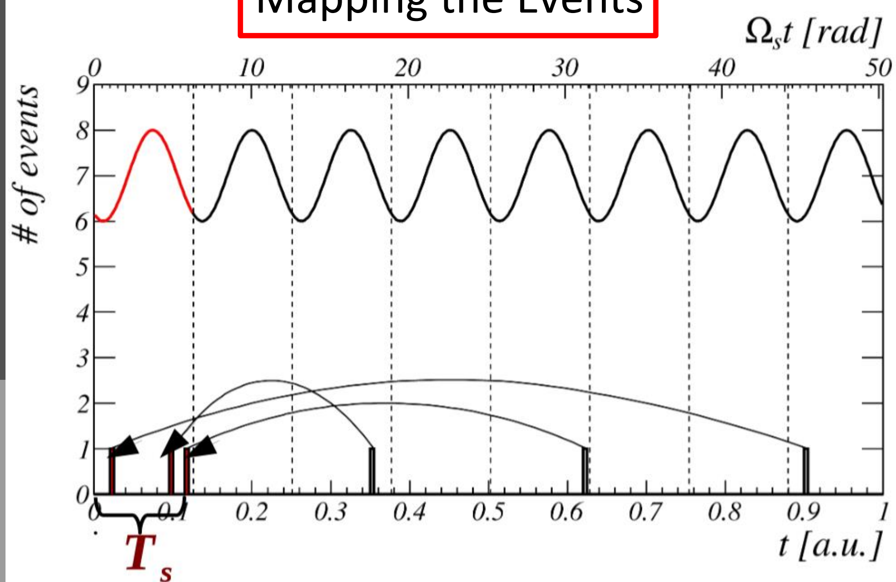
Problem:

- On average one hit in detector every 25th beam revolutions
  ⇒ No direct fit possible

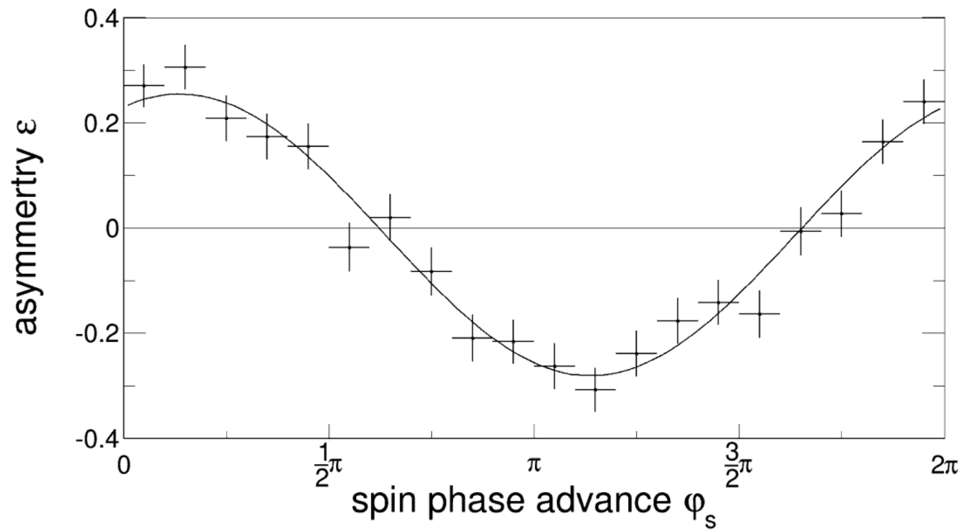
Solution:

- Map all events into first spin oscillation period
- Calculate asymmetry for an one second interval and fit a sine

Mapping the Events



Fit a sine and extract ν_s



Assumption: Acceptance a and Polarization PA are constant in this time interval

Generate Random Time Values

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1 Step: t

Generate Uniform time values [0,100] s

Assume a Linear Time dependency of Polarization and Acceptance

$$N_{up,dn}(t) = \begin{cases} a_{up}(1-\varepsilon_2 t)[1 + PA(1-\varepsilon_1 t)\cdot \sin(2\pi f_s t + \varphi)] \\ a_{dn}(1-\varepsilon_2 t)[1 - PA(1-\varepsilon_1 t)\cdot \sin(2\pi f_s t + \varphi)] \end{cases}$$

2 Step: Generate Uniform distribution for x_1 & x_2 [0,1]

Calculating a Probability with the generated t

$$p_{up}(t) = \frac{N_{up}(t)}{N_{up}(t) + N_{dn}(t)}$$

$p_{up} \leq x_1$ & $x_2 > a_{up}$ → Event in up-Detector

$p_{up} > x_1$ & $x_2 > a_{dn}$ → Event in dn-Detector

Mitglied der Helmholtz-Gemeinschaft

Data Simulation of three different Cases

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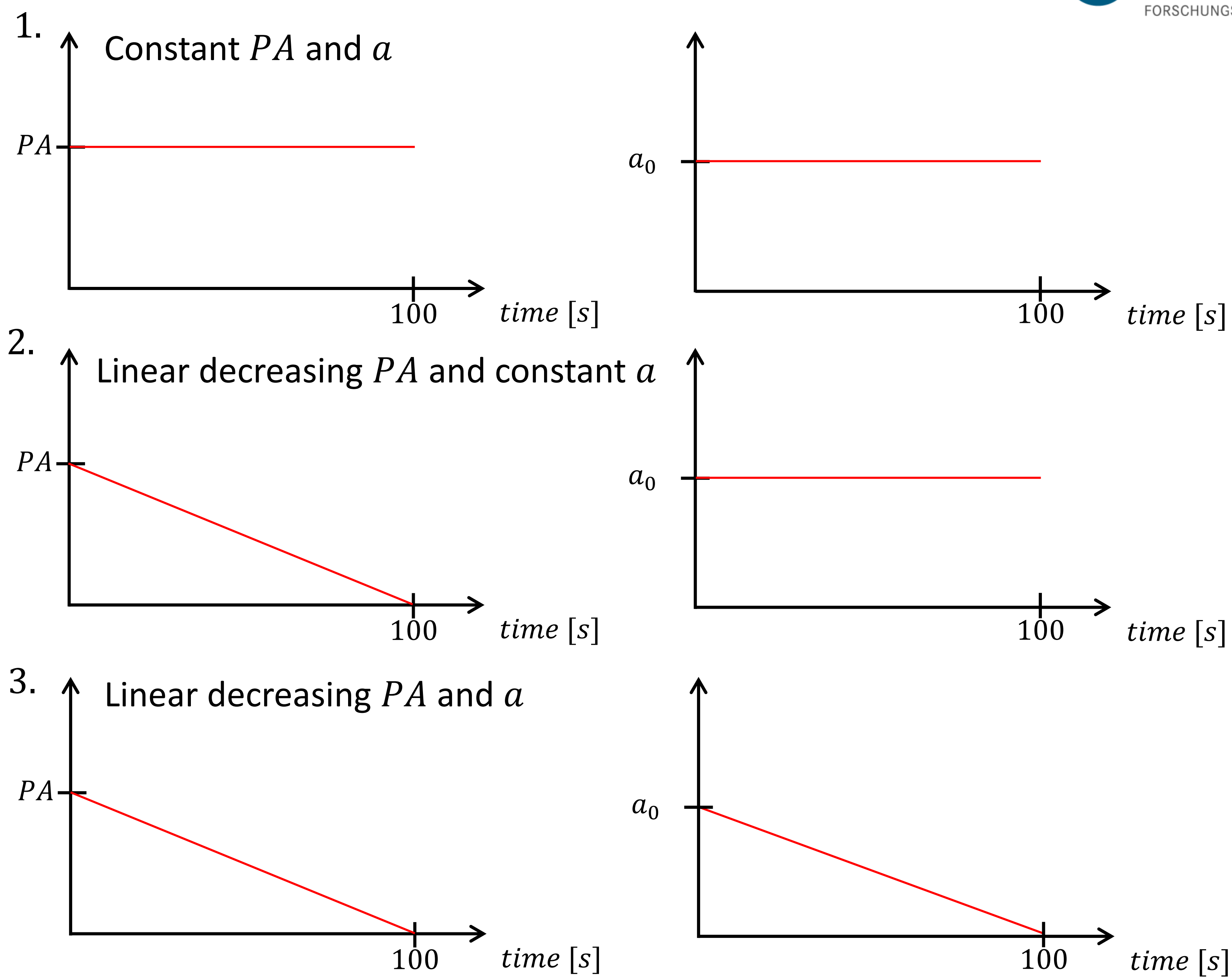


Analysis assumes a constant Polarization PA and Acceptance a

Parameters for fixed Spin Tune Simulations

$$N_{up,dn}(t) = \begin{cases} a_{up}(1-\varepsilon_2 t)[1 + PA\,(1-\varepsilon_1 t)\cdot \sin(2\pi f_s t + \varphi)] \\ a_{dn}(1-\varepsilon_2 t)[1 - PA\,(1-\varepsilon_1 t)\cdot \sin(2\pi f_s t + \varphi)] \end{cases}$$

Parameter	up	dn
a [%]	100	100
PA [%]	25	25
f_s [kHz]	120	120
φ [rad]	0	0

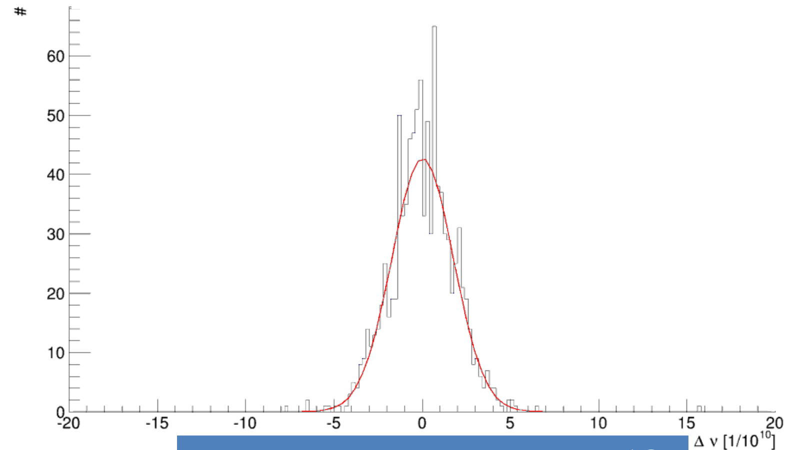
→ for each case 1000 data files with 500000 time values are generated for same Spin Tune

Spin Tune determination for the Simulations

- Analysis determines a ν_s for each simulation
- Variance of the Spin Tune $\Delta\nu_s$ is determined

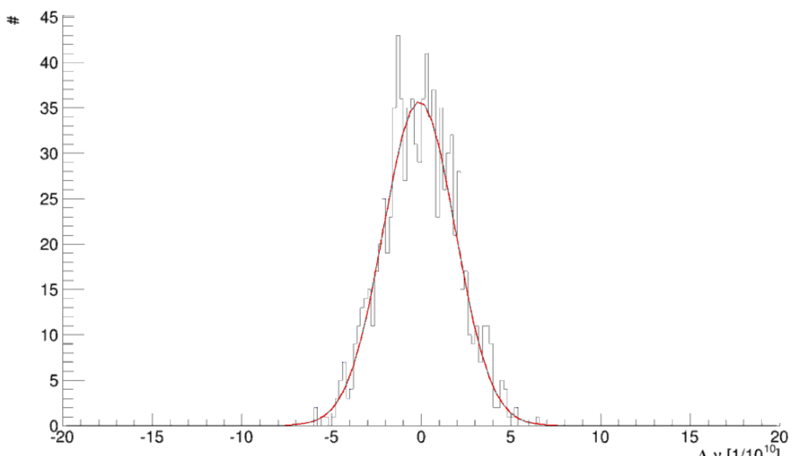
Systematic Error of the Spin Tune Analysis: 10^{-11}

Case 1: Constant PA and a



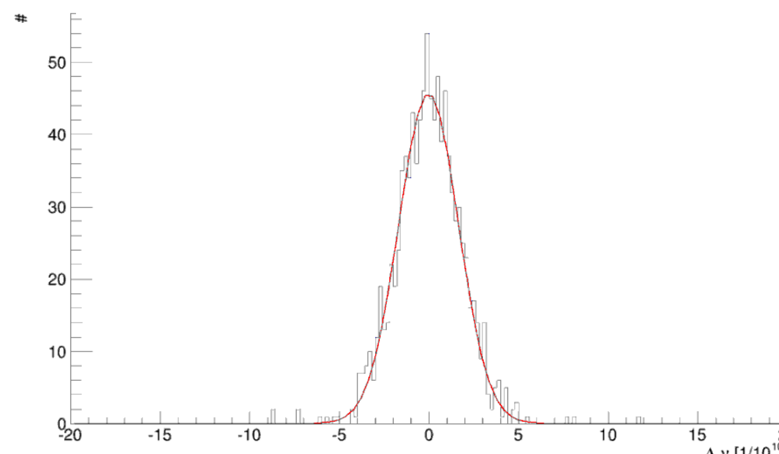
$\mu = (3.6 \pm 5.8) \cdot 10^{-12}$

Case 2: Linear decreasing PA and constant a



$\mu = (-9.5 \pm 6.9) \cdot 10^{-12}$

Case 3: Linear decreasing PA and a



$\mu = (-1.5 \pm 5.6) \cdot 10^{-12}$

Outlook & Summary

- The JEDI Collaboration developed a method to determine the Spin Tune with high precission

- The results show that the Spin Tune Analysis is robust: systematic error 10^{-11}

→ The statistical error for a real deuteron measurment is of the order 10^{-10}
Decreasing Polarization or Acceptance do not effect the Analysis Method