Polarimetry for monitoring long coherent spin precession and polarization based feedback

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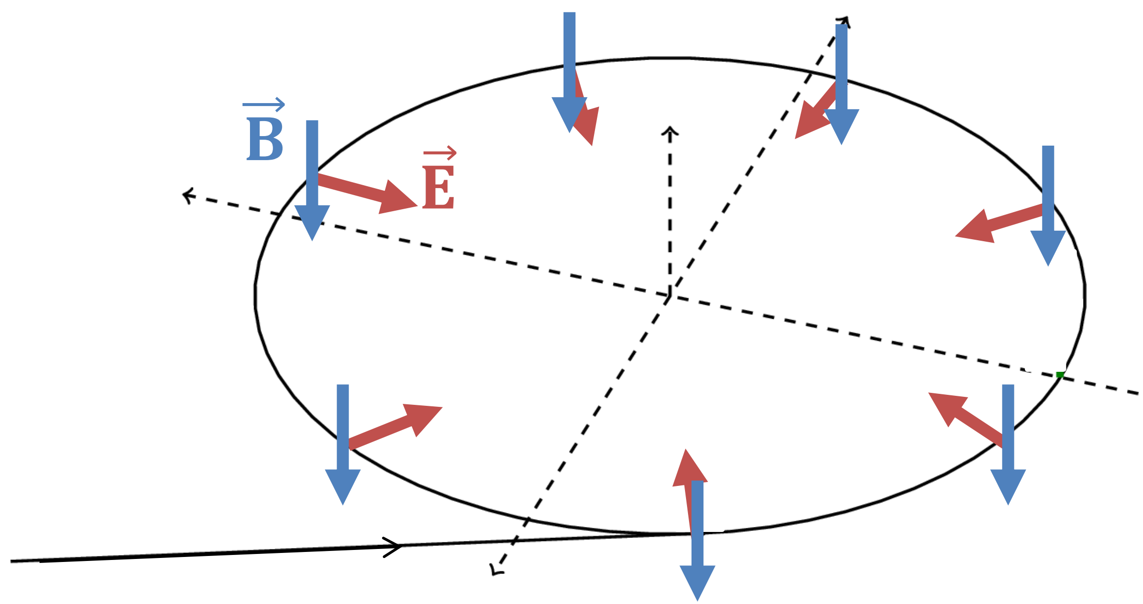
on behalf of the JEDI Collaboration

Beam Dynamics meets Diagnostics, November 4-6, 2015, Florence

Motivation

Planar magnetic and/or electric ring:

- invariant spin axis vertical
- spin in horizontal plane: precession around vertical axis



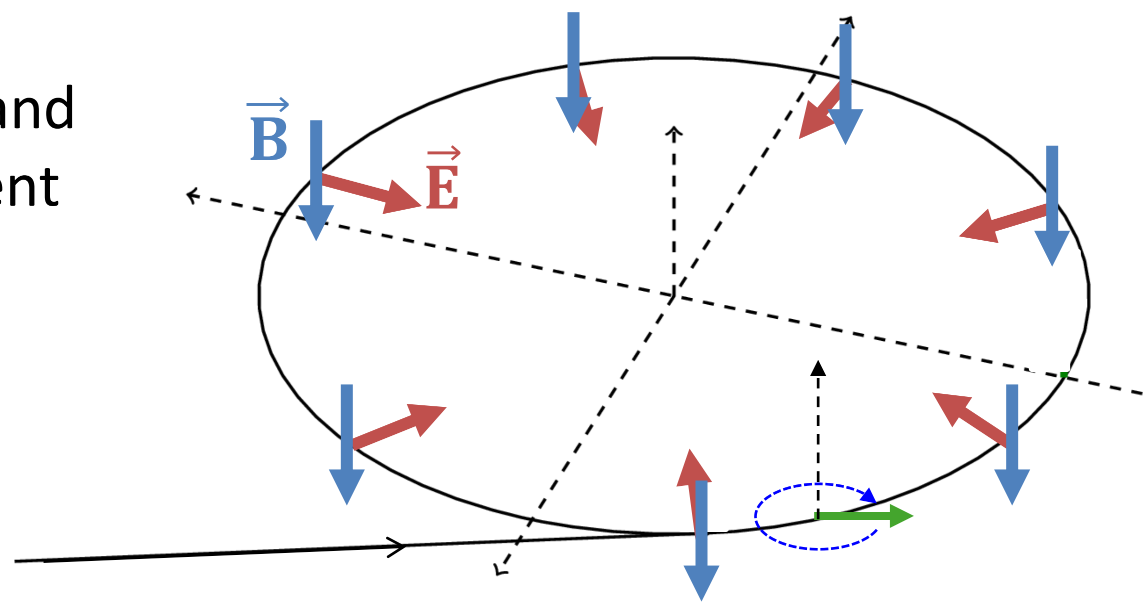
Motivation

Planar magnetic and/or electric ring:

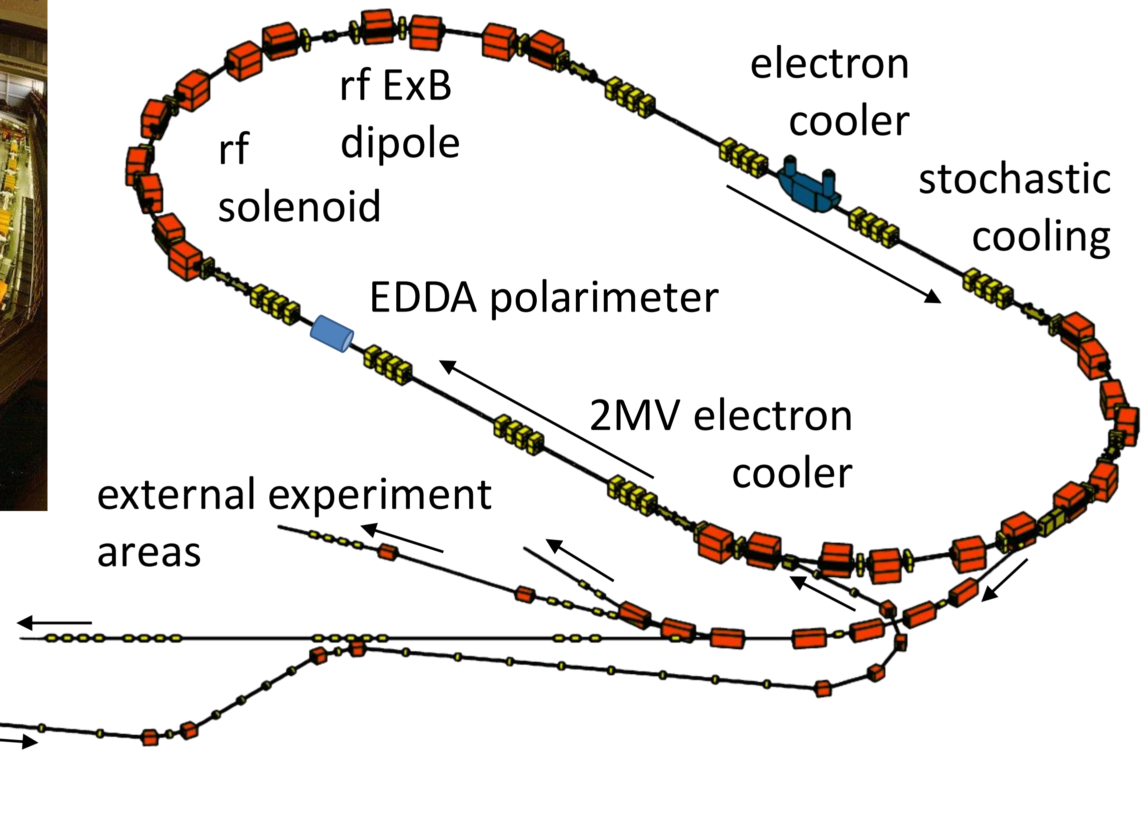
- invariant spin axis vertical

EDM measurement

- spin in horizontal plane: precession around vertical axis
  special case:
  frozen spin $\rightarrow f_{\text{precession}} = f_{\text{revolution}}$
- first goal:
  establish, maintain and monitor long coherent spin precession



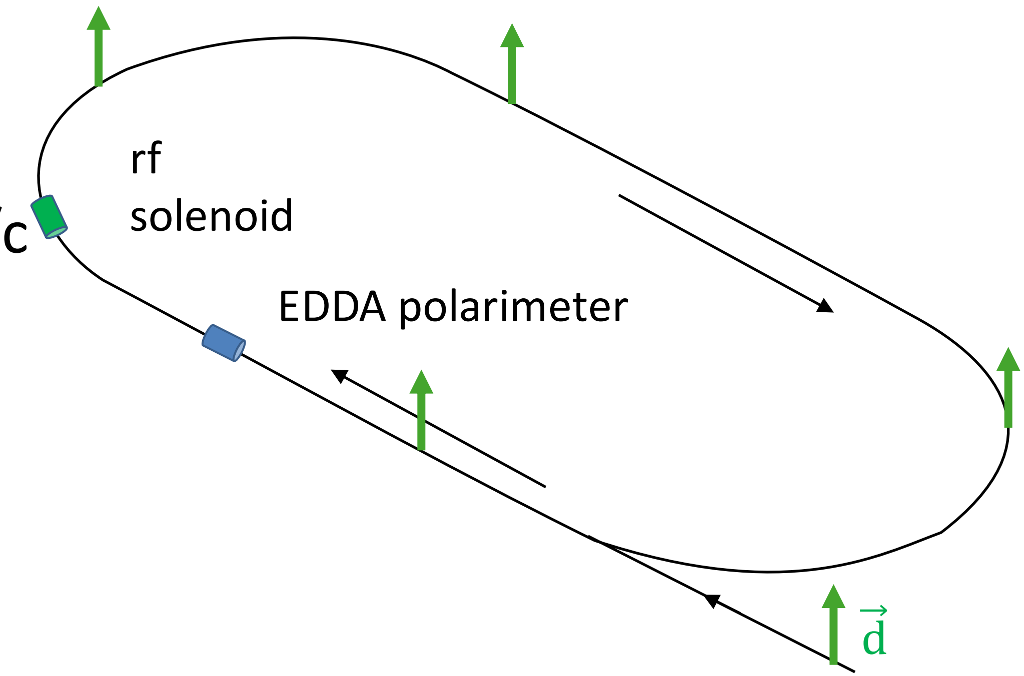
Cooler Synchrotron COSY



COSY provides cooled & polarized protons and deuterons with
p = 0.3 – 3.7 GeV/c

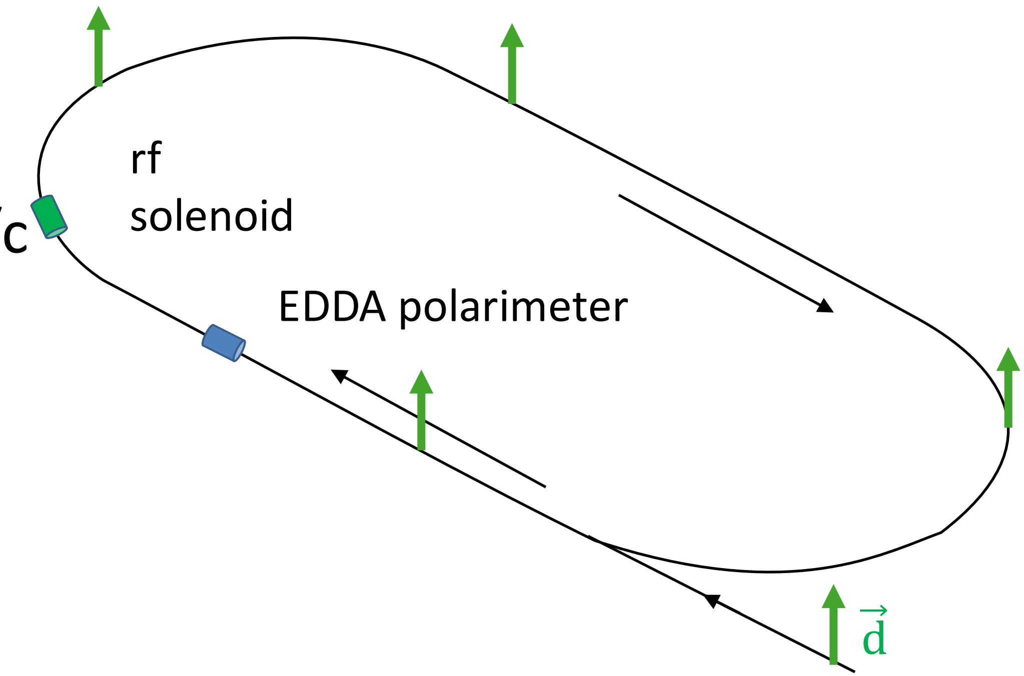
Experimental setup

1. inject and accelerate vertically polarized deuterons to p = 1 GeV/c



Experimental setup

1. inject and accelerate vertically polarized deuterons to p = 1 GeV/c
2. bunch and (pre-)cool



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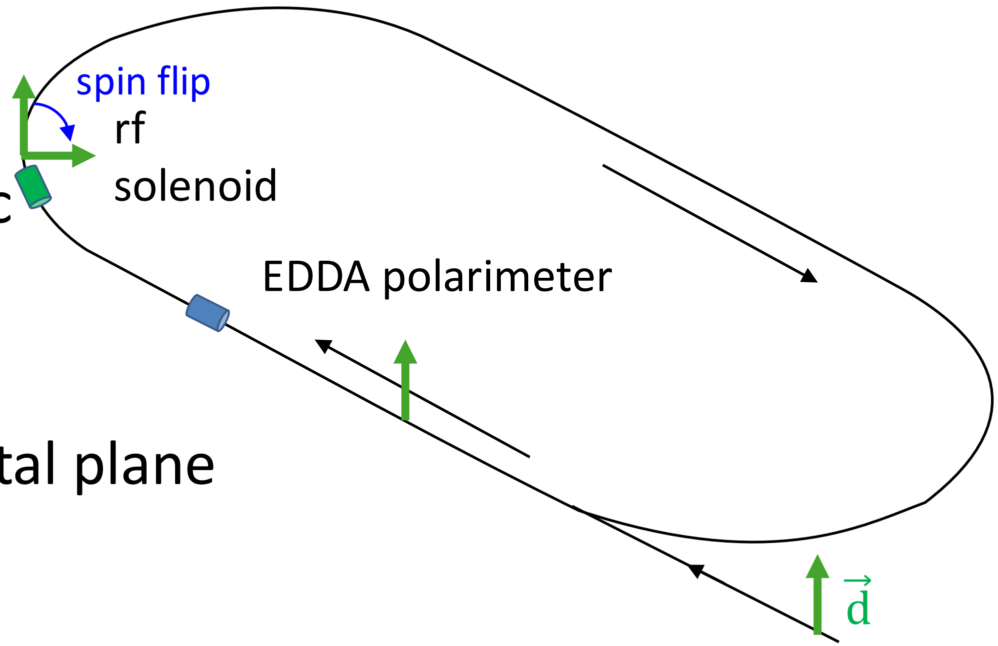

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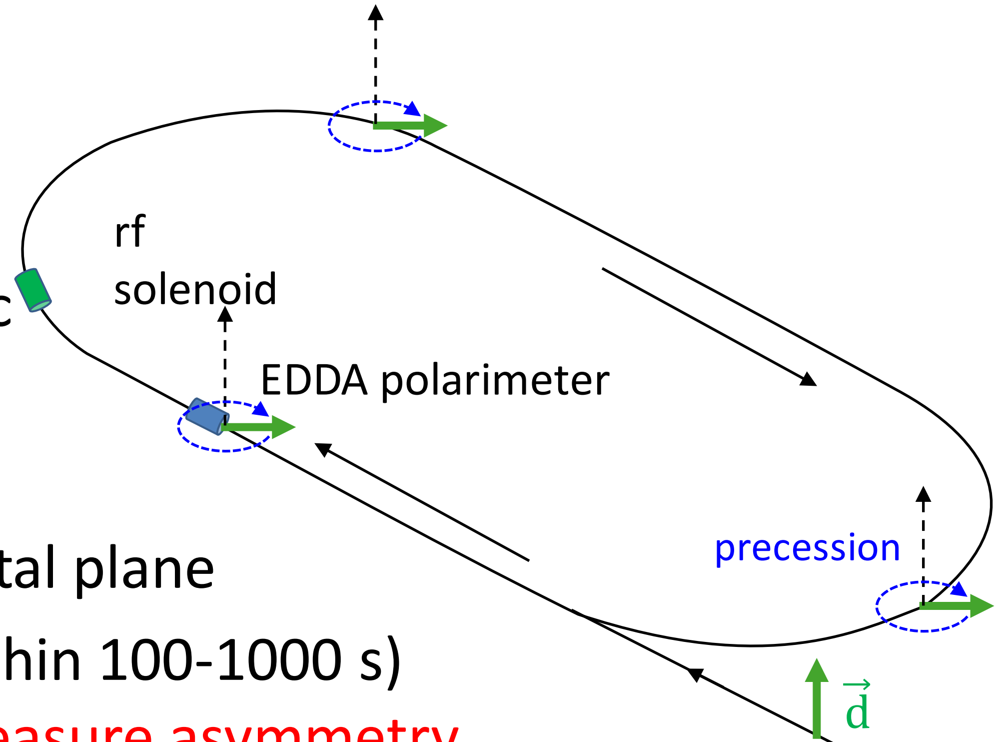


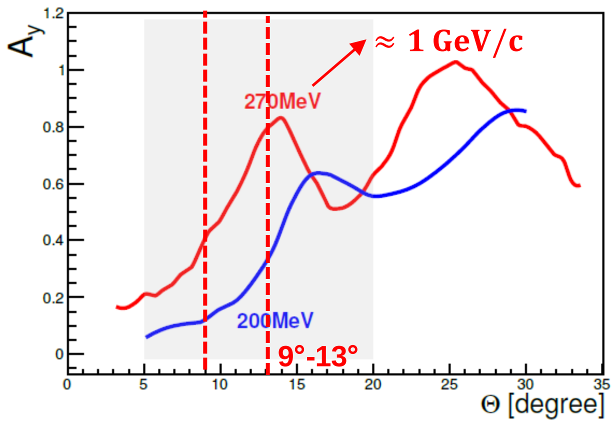
1. inject and accelerate vertically polarized deuterons to p = 1 GeV/c
2. bunch and (pre-)cool
3. turn spin by means of a RF solenoid into horizontal plane
4. extract beam slowly (within 100-1000 s) onto a carbon target, measure asymmetry and precisely determine spin precession

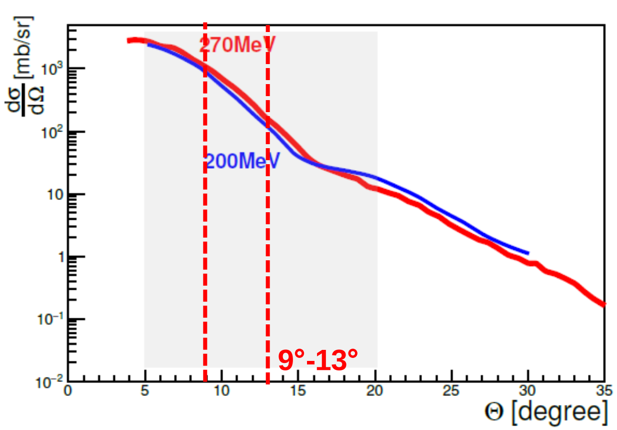
spin tune:

$$|\nu_s| = |\gamma G| = \frac{\text{spin precessions}}{\text{particle turn}} = \frac{f_{\text{prec}}}{f_{\text{rev}}} \approx \frac{120\text{ kHz}}{750\text{ kHz}} \approx 0.16$$

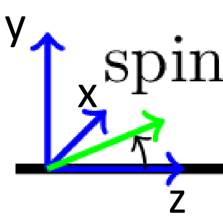
Polarimetry

- reaction: elastic d+C scattering
- up/down asymmetry $\propto P_x$ projection on x-axis
- left/right asymmetry $\propto P_y$ projection on y-axis

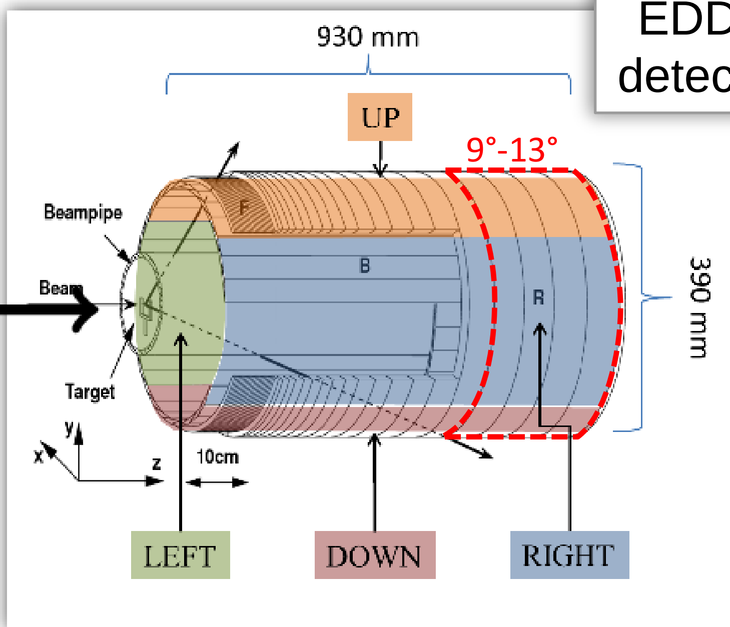




Y. Satou et al., Phys. Lett. B 549, 307 (2002)



EDDA detector



Asymmetry measurement

Detector signal

$$N^{up,down} = 1 \pm PA \sin\left(2\pi \cdot f_{\text{prec}} t\right)$$
$$= 1 \pm PA \sin(2\pi \cdot \nu_s \, n_{\text{turns}})$$

P: polarisation, A: analysing power

Asymmetry

$$\varepsilon = \frac{N^{up} - N^{down}}{N^{up} + N^{down}} = PA \sin(2\pi \cdot \nu_s \, n_{\text{turns}})$$

Challenges

- precession frequency $f_{\text{prec}} \approx 120$ kHz
- $\nu_s \approx -0.16$ → 6 turns / precession
- event rate ≈ 5000 s^{-1} → 1 hit / 25 precessions

→ no direct fit of the rates

Asymmetry measurement

„time stamping“

single reference clock

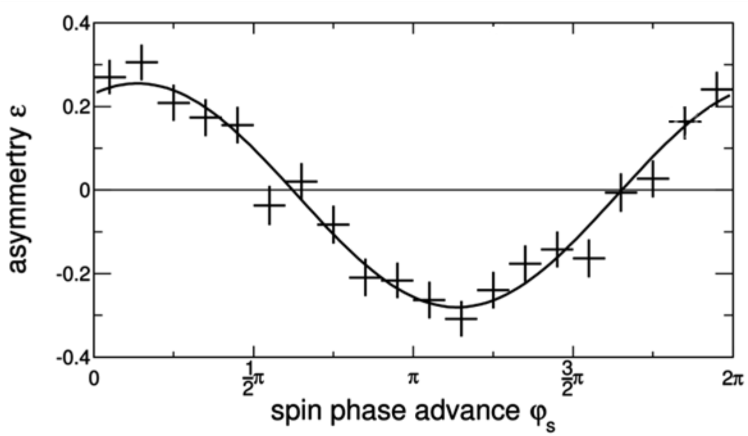
COSY rf → **TDC** → beam revolutions: counting turn number n

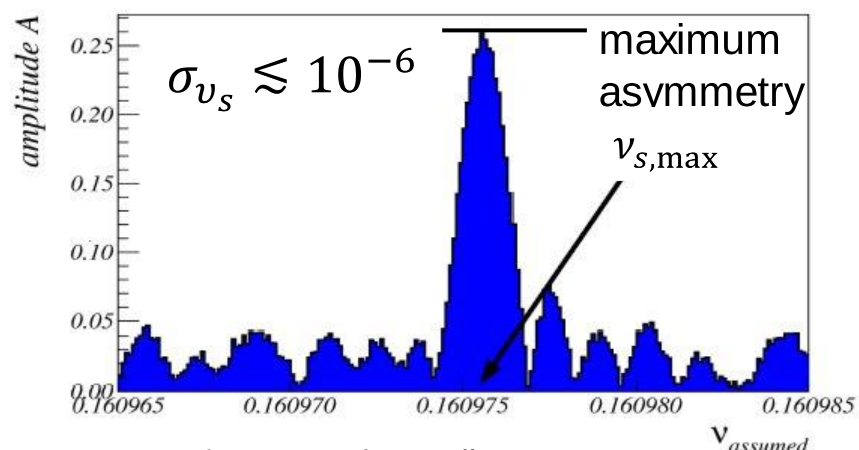
detector events → **TDC** → assign turn number n → phase advance $\varphi_s = 2\pi\nu_s n$

for intervals of $\Delta n = 10^6$ turns: $\varphi_s \to \varphi_s \bmod 2\pi$

scan ν_s in some interval around $\nu_s = \gamma G$

true ν_s *a priori* not known





see: “Measuring the polarization of a rapidly precessing deuteron beam” Phys.Rev. STAB 17, 052803 (2014)

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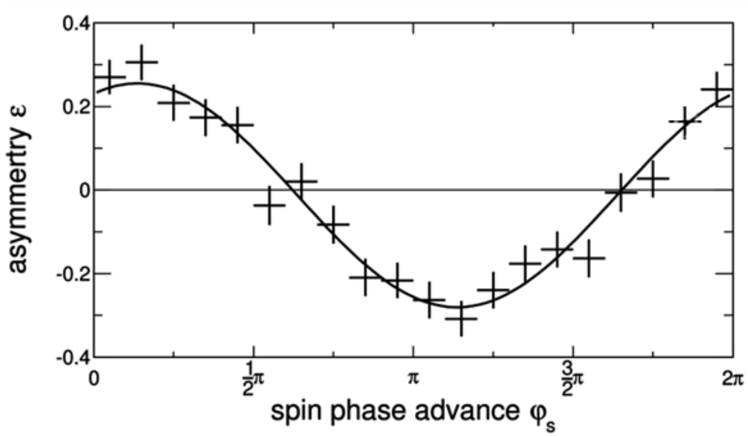

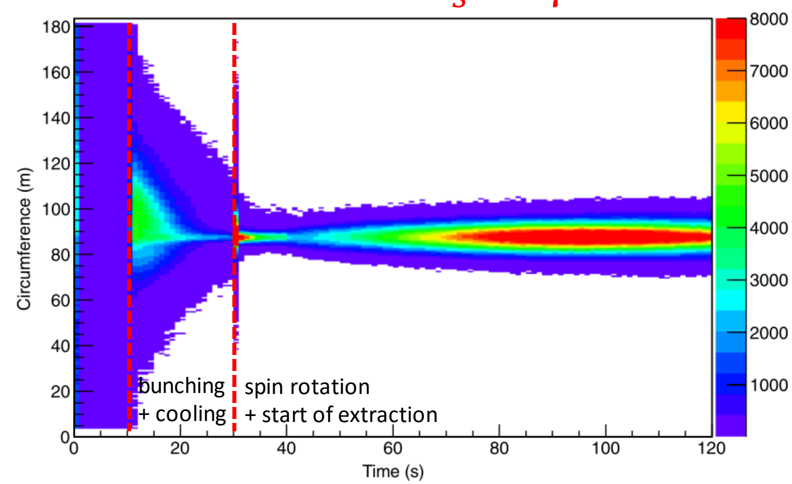

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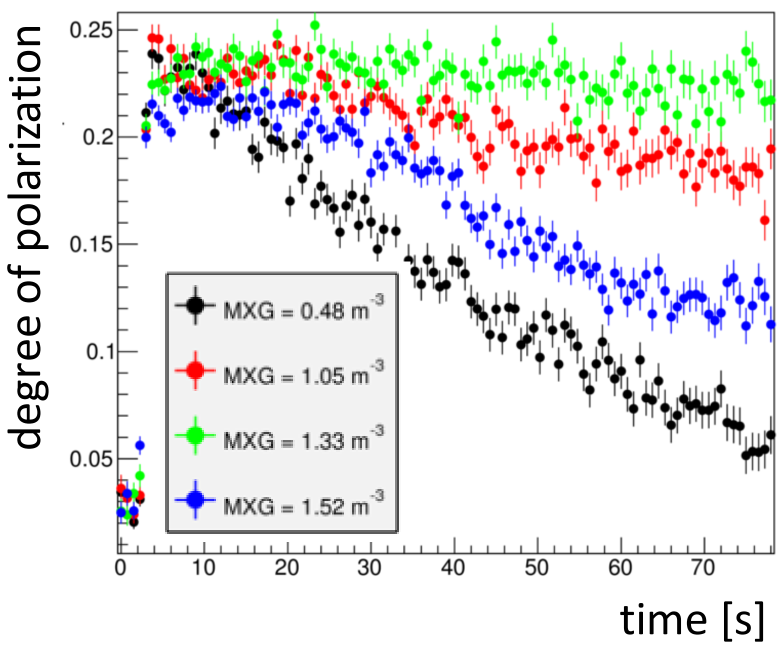
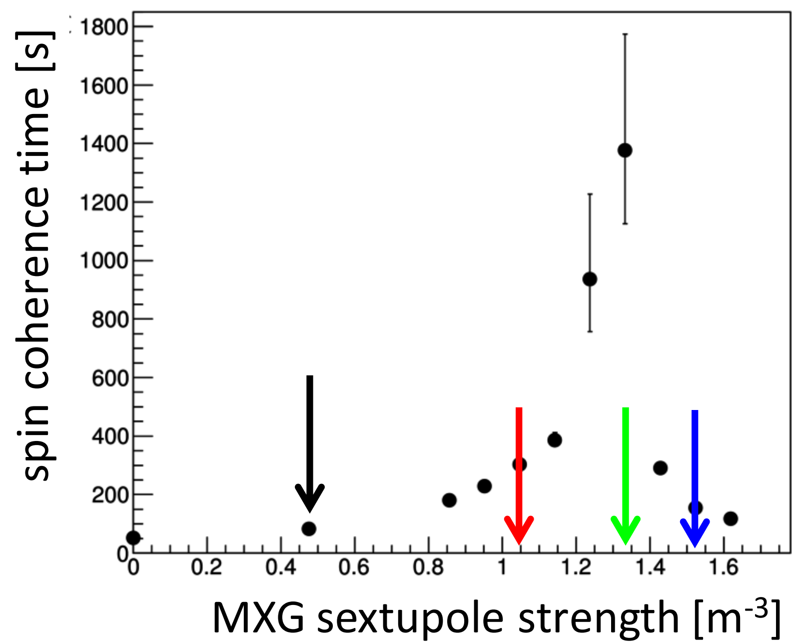
Application: spin coherence time (SCT)

Ensemble of ≈ 10^9 deuterons: coherent precession needed!

- unbunched beam: $\frac{\Delta\gamma}{\gamma} \approx 10^{-5} \implies$ decoherence in < 1s
- bunching: eliminate effects on $\frac{\Delta p}{p}$ in 1st order → $\tau \approx 20$ s
- correcting higher order effects using sextupoles

and (pre-) cooling → $\tau \approx 1000$ s





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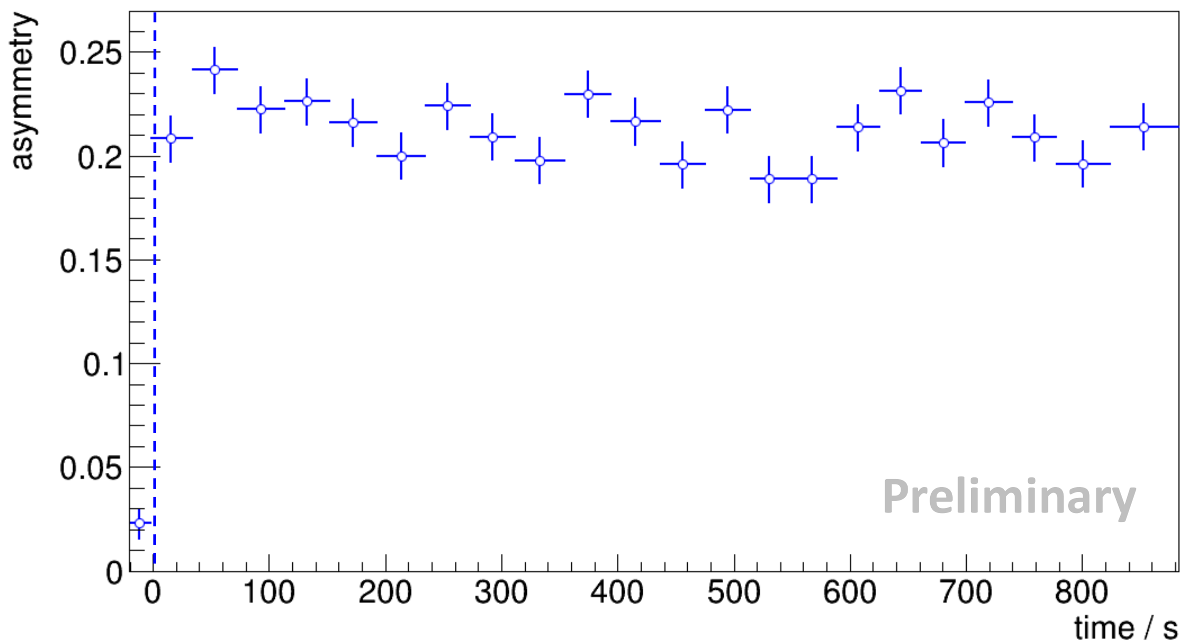


Application: SCT vs chromaticity

chromaticity: $\Delta Q_{x,y}/\Delta p$

($Q_{x,y}$: betatron tunes, p : momentum)

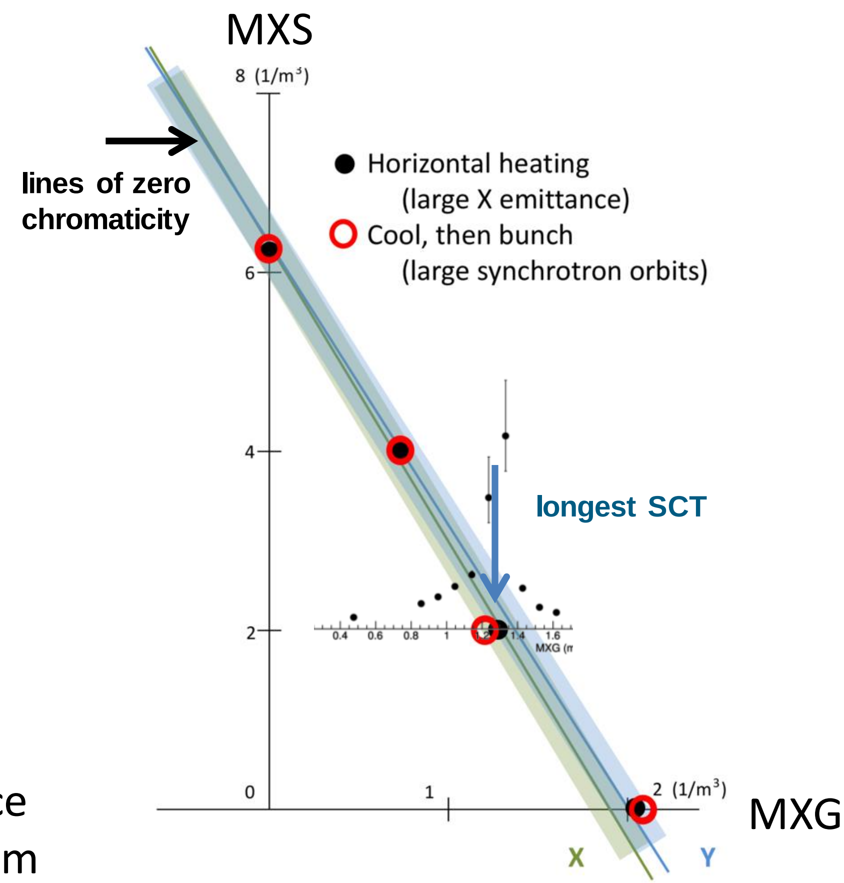
- also controlled by sextupoles (MXS, MXG: different sextupole families in COSY)
- compare:
  points of fixed* chromaticity

  ↕

  points of longest SCT

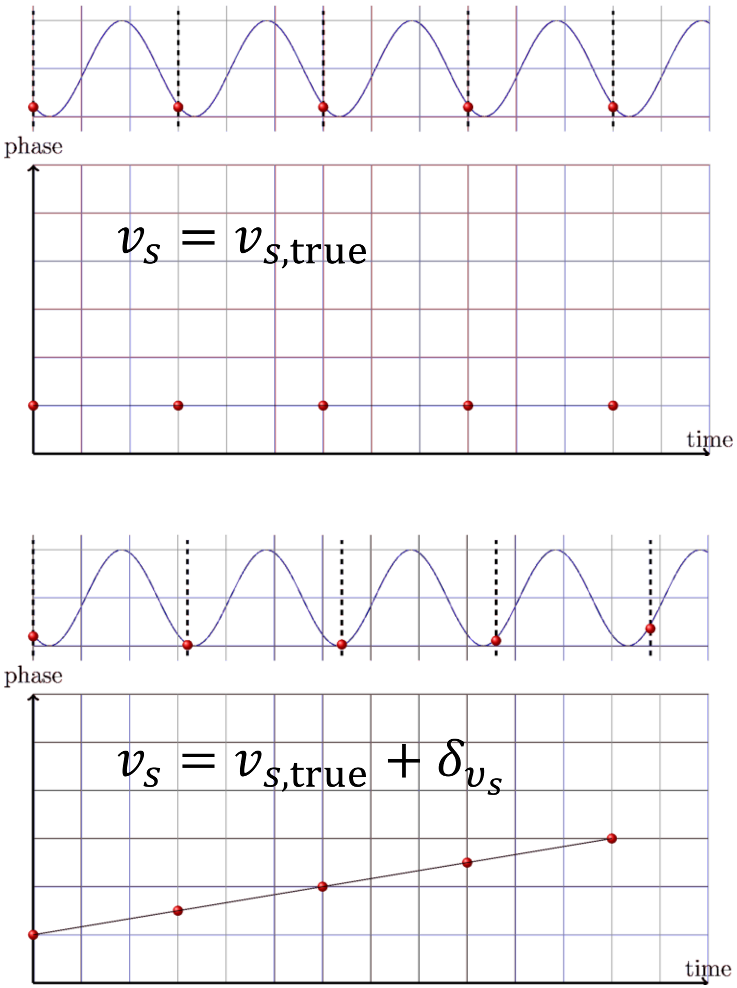
chromaticity settings and and longest SCT are correlated!

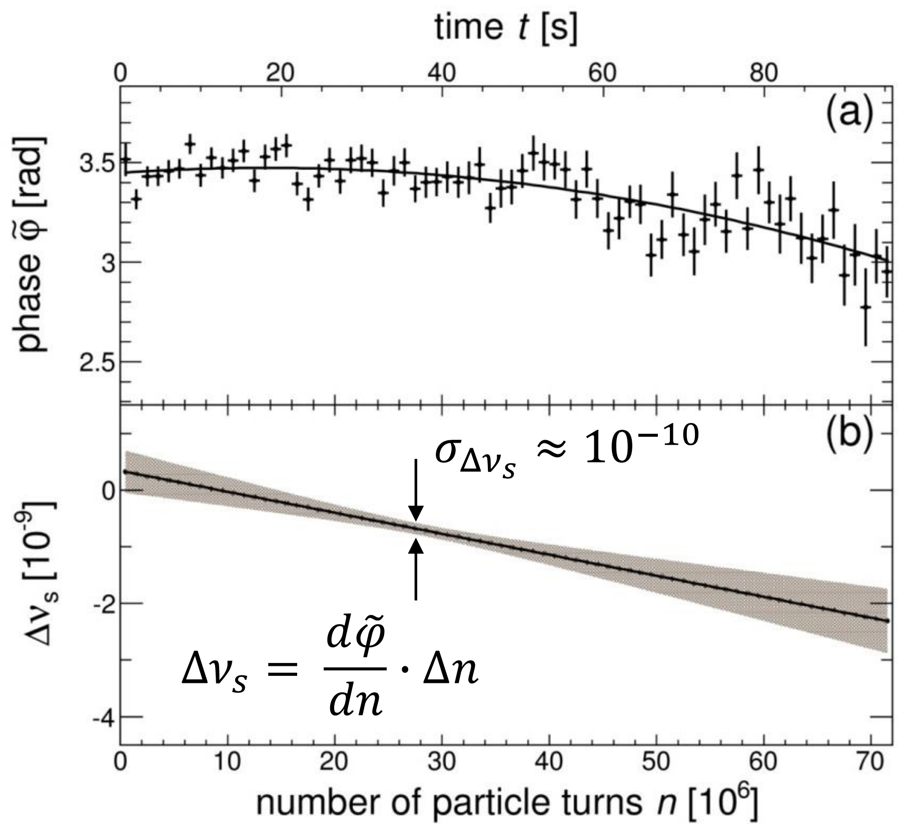
*Note: chromaticy ≈ zero is special for choice of particle type and beam momentum



Application: precise determination of ν_s

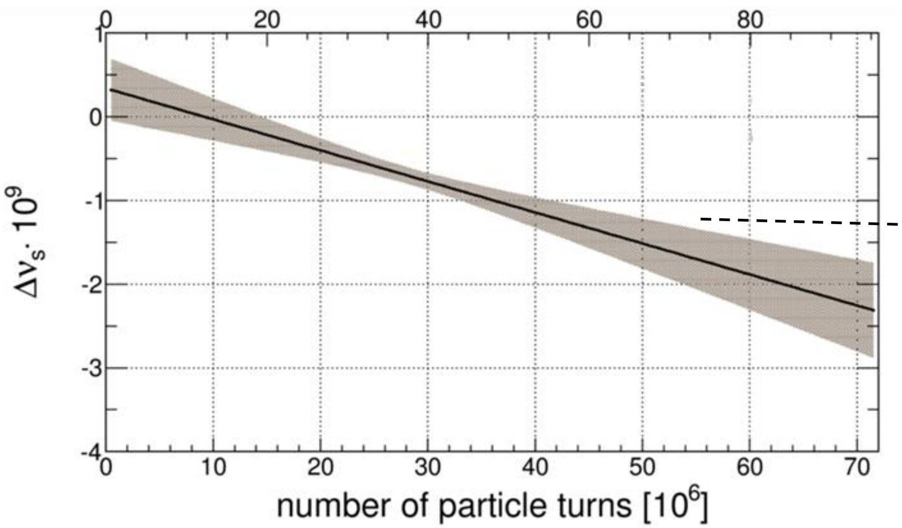
Monitoring phase of asymmetry (ν_s fixed):

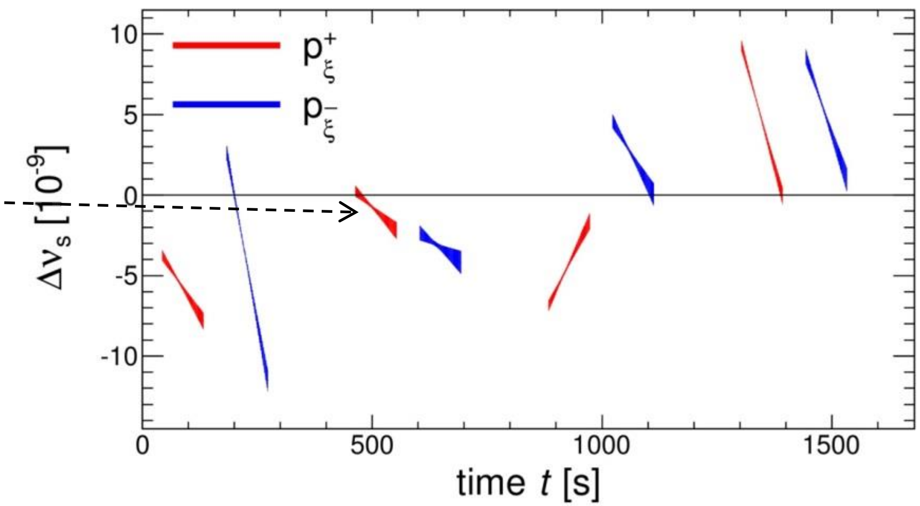




see: Phys.Rev.Lett. 115, 094801 (2015)

Application: precise determination of ν_s



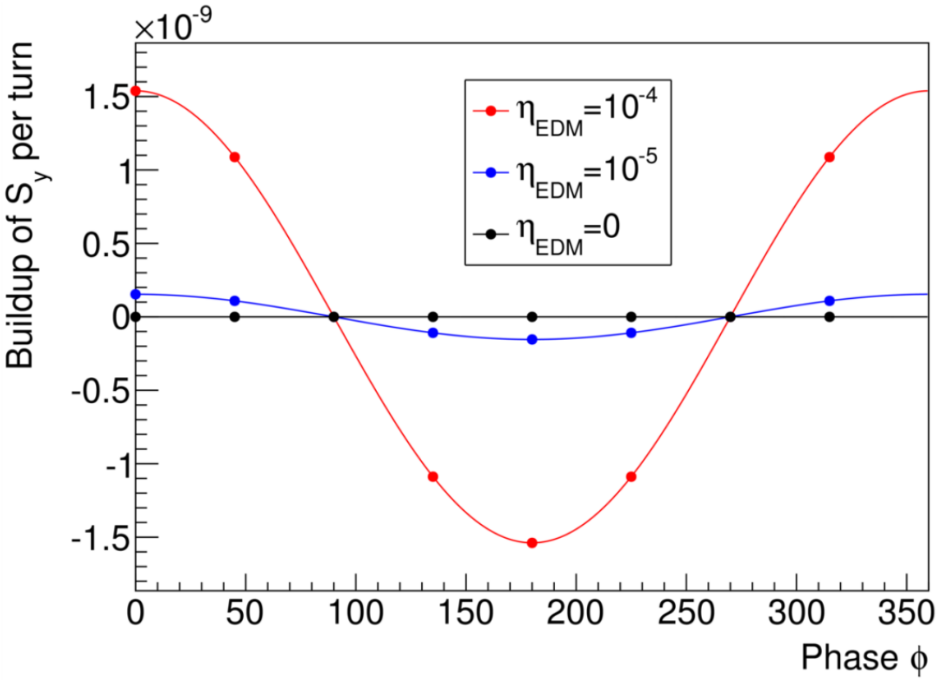


- spin tune ν_s can be determined to $\sigma_{\nu_s} \approx 10^{-8}$ in $\Delta t \approx 2s$
- average $\bar{\nu}_s$ in 1 cycle ($\approx$ 100s) determined to $\sigma_{\nu_s} \approx 10^{-10}$
- tool for: study long term stability of the ring
  dedicated online feedback systems
  probing ring imperfections

see: Phys.Rev.Lett. 115, 094801 (2015)

Spin tune: feedback system

Wien filter: signal build up (M. Rosenthal)



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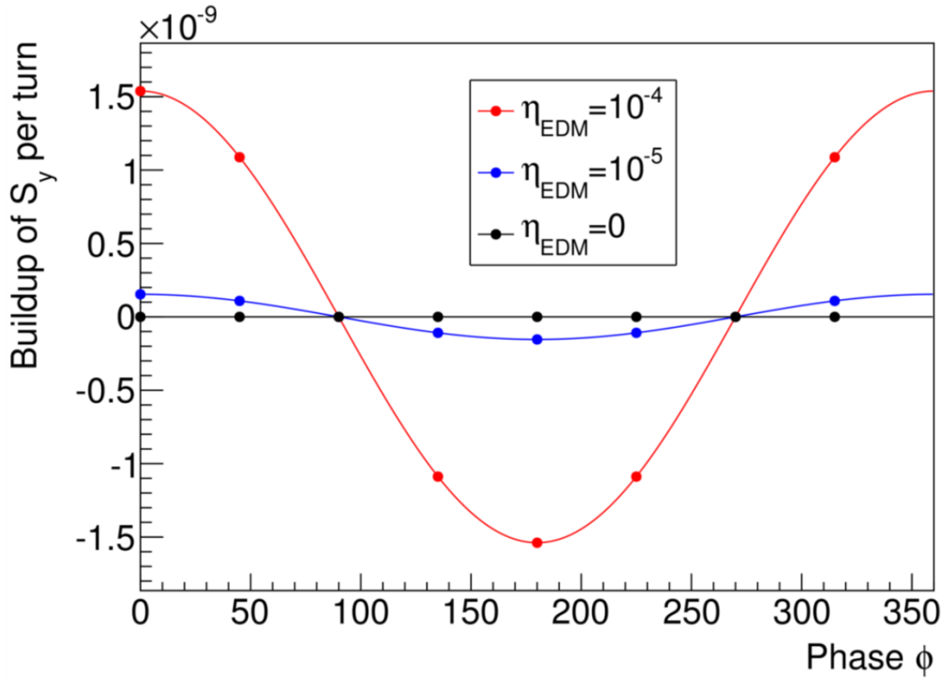
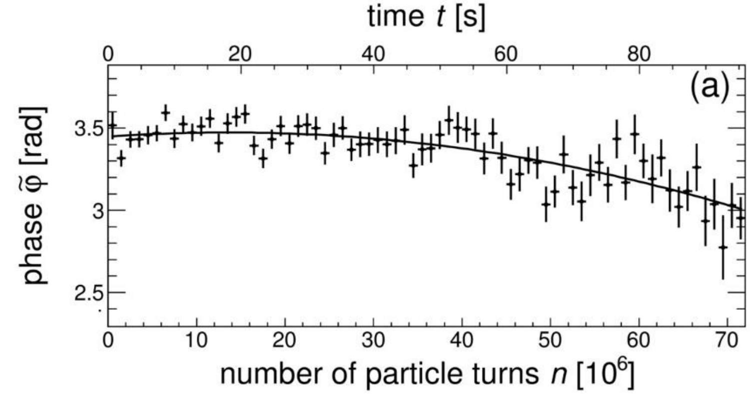


Phase variation per cycle



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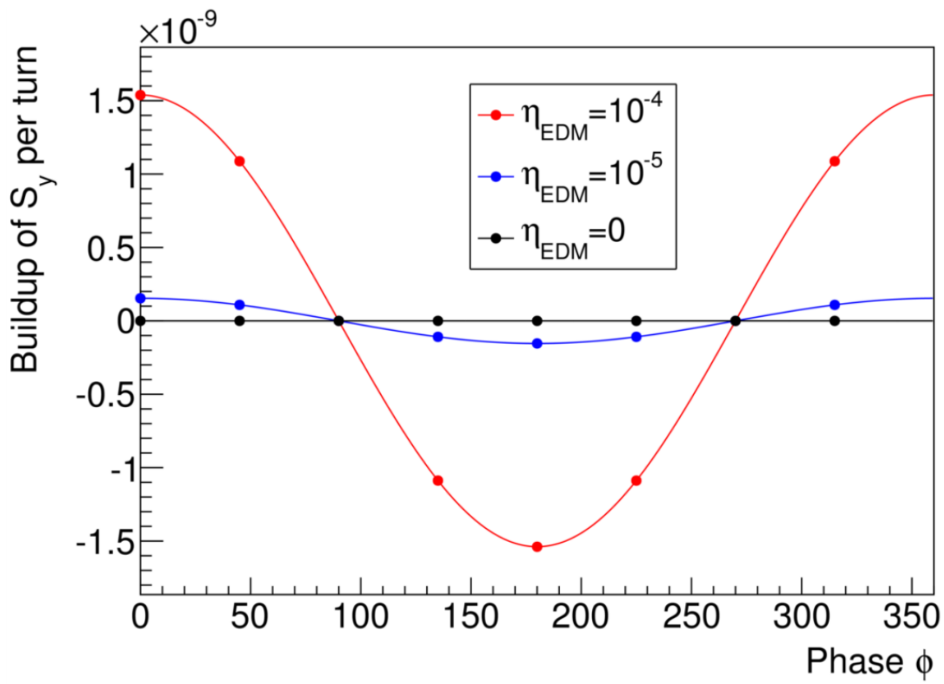

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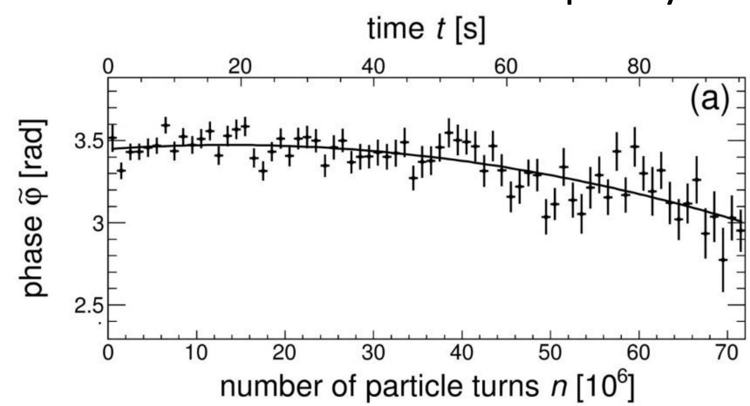
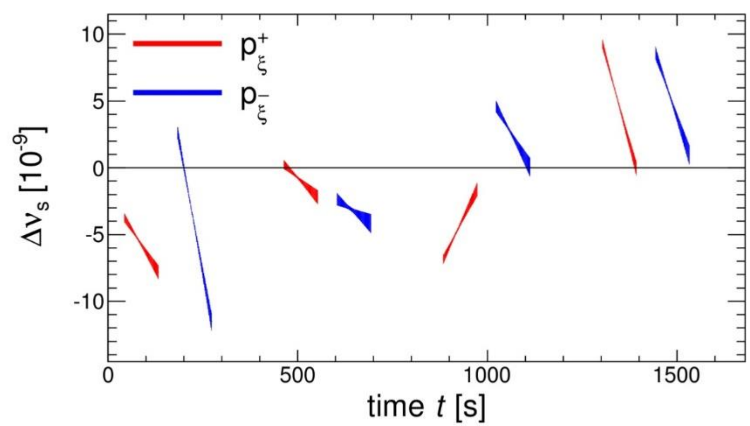


Variation cycle-by-cycle



Mitglied der Helmholtz-Gemeinschaft

Spin tune: feedback system

Challenges:

- maintain phase relation between precession & rf ExB dipole
- maintain resonance condition for rf solenoid & ExB rf dipole
- maintain frozen spin condition in a future dedicated ring

Idea:

- control and stabilize spin tune via COSY rf cavity:

$$\frac{\Delta\nu_s}{\nu_s} = \frac{\Delta\gamma}{\gamma} = \beta^2\frac{\Delta p}{p} = \frac{\beta^2}{\eta}\frac{\Delta f}{f}$$

- control relative phases by accelerating/decelerating spin precession

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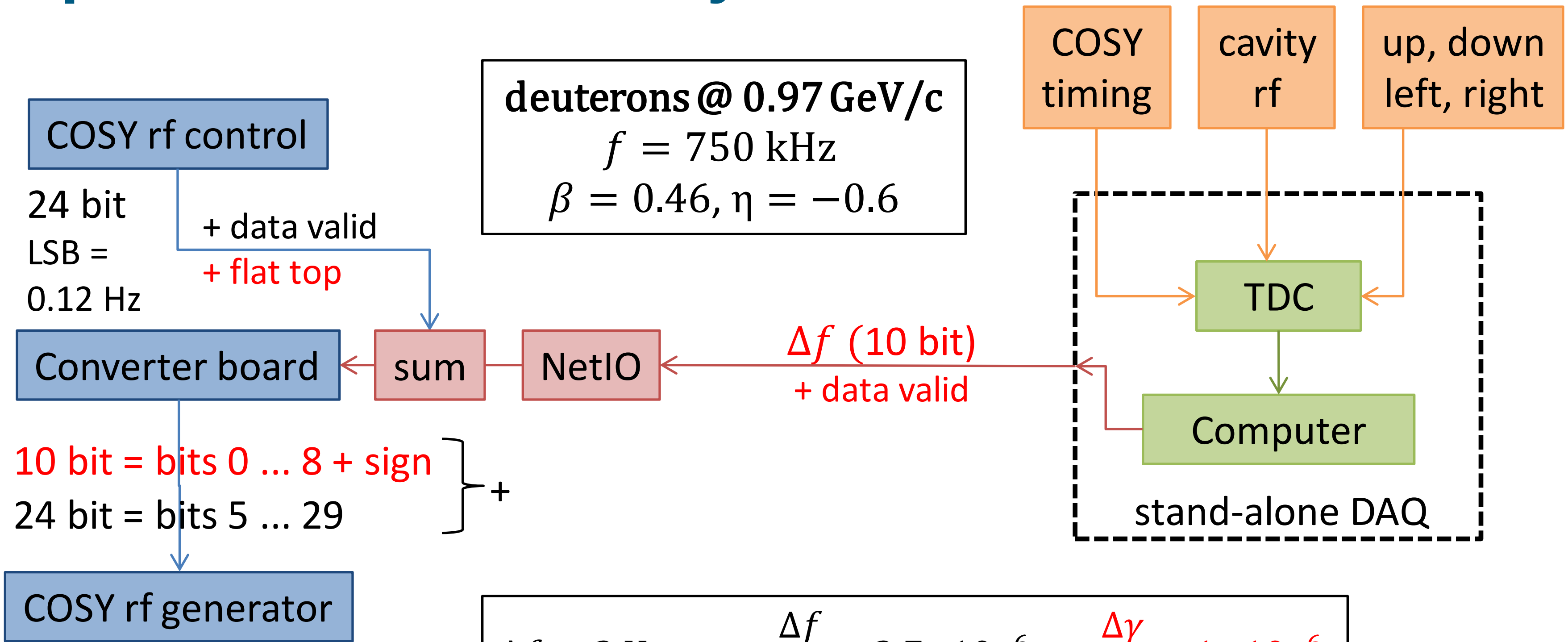
Spin tune: feedback system



32 bit
LSB =
3.7 mHz

10 bit
± 2 Hz

$$\Delta f = 2 \text{ Hz} \Rightarrow \frac{\Delta f}{f} = 2.7 \cdot 10^{-6} \Rightarrow \frac{\Delta\gamma}{\gamma} = 1 \cdot 10^{-6}$$ max

$$\Delta f = 3.7 \text{ mHz} \Rightarrow \frac{\Delta f}{f} = 5 \cdot 10^{-9} \Rightarrow \frac{\Delta\gamma}{\gamma} = 2 \cdot 10^{-9}$$ min

32 bit = 1 GHz / 64 ≈ 16 MHz
bits 29 ... 31 not used → $f_{max} \approx 2$ MHz

R&D with beam:
end of November 2015

Spin tune: probing ring imperfections

- EDM causes tilt of spin closed orbit

- tilt can also be caused by ring imperfections (e.g. field imperfections)

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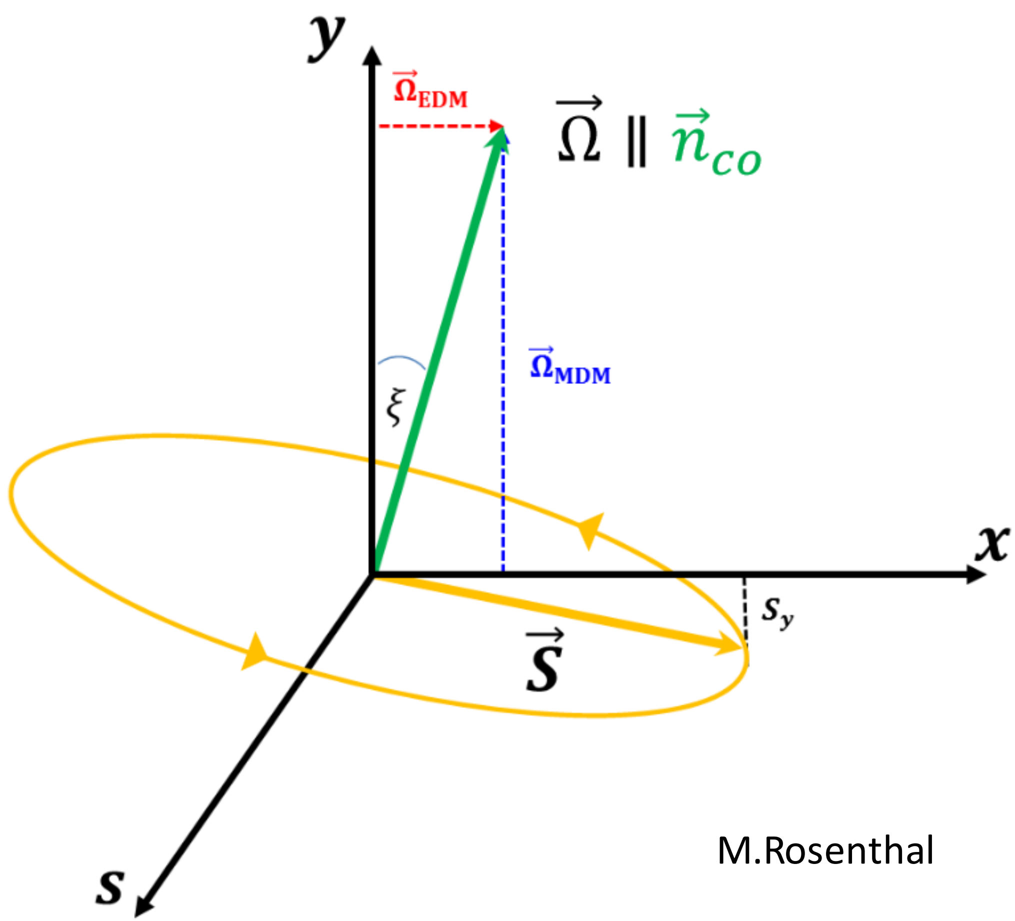
effect on spin tune



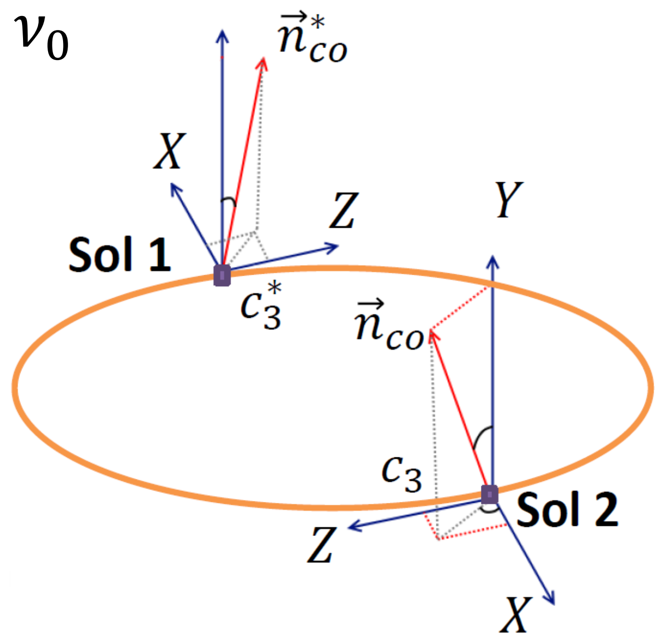
Spin tune: probing ring imperfections

- spin tune is perturbed by small kicks $\sim a$ by ring imperfections
$$\nu_0 = \gamma G + O(a^2)$$
- idea: probe imperfections by adding artificial imperfections spin kicks χ_1, χ_2 by means of e-cooler solenoids
- measure spin tune change
$$\Delta\nu_s = \nu_s(\chi_1, \chi_2) - \nu_0$$
- expectation

$$\Delta\nu_s \propto (y_\pm - a_\pm)^2$$

$$y_\pm = \tfrac{1}{2}(\chi_1 \pm \chi_2)$$

$a_\pm$: in-plane ring imperfections



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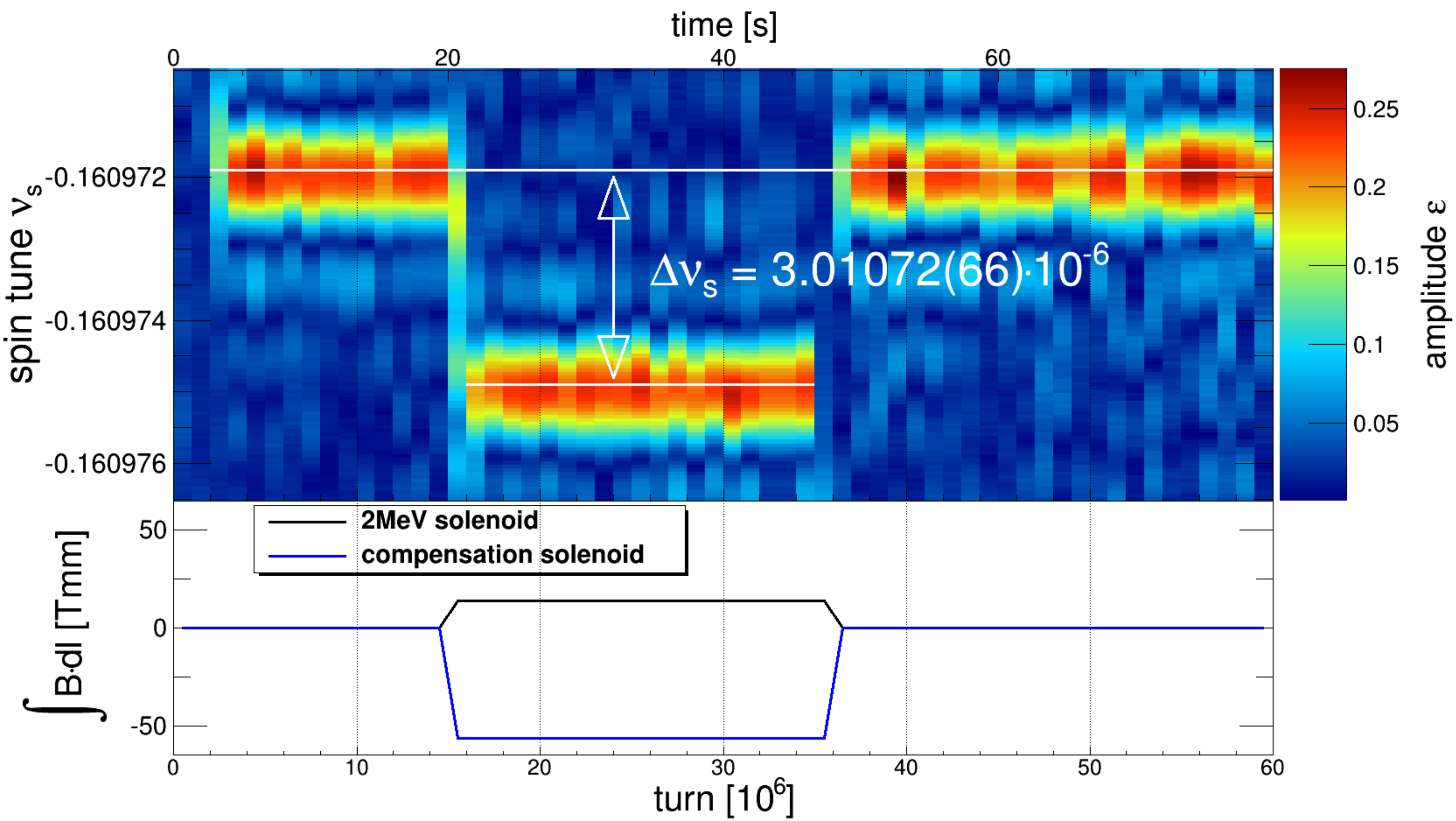
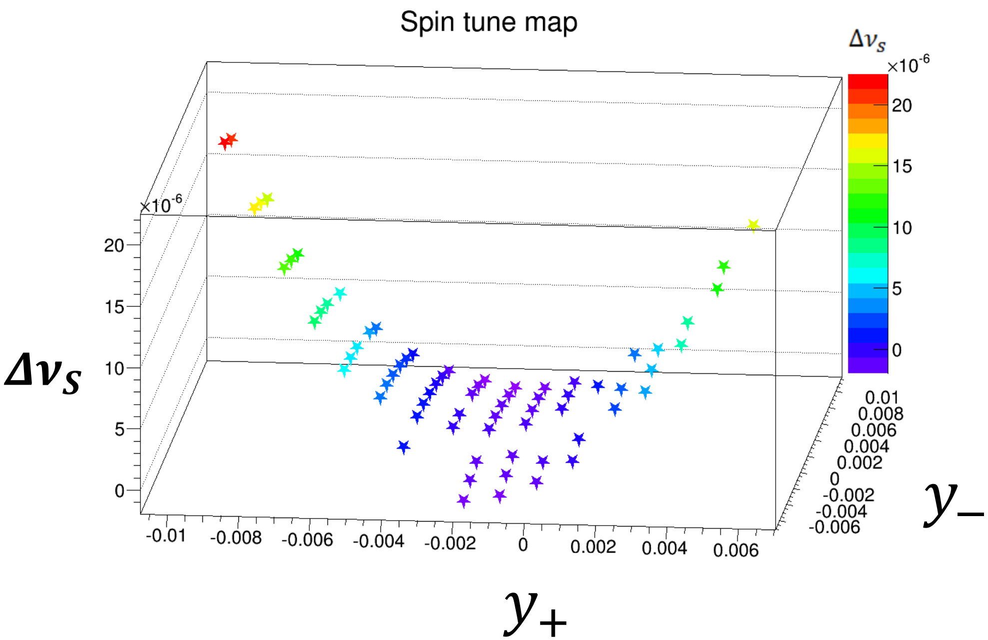
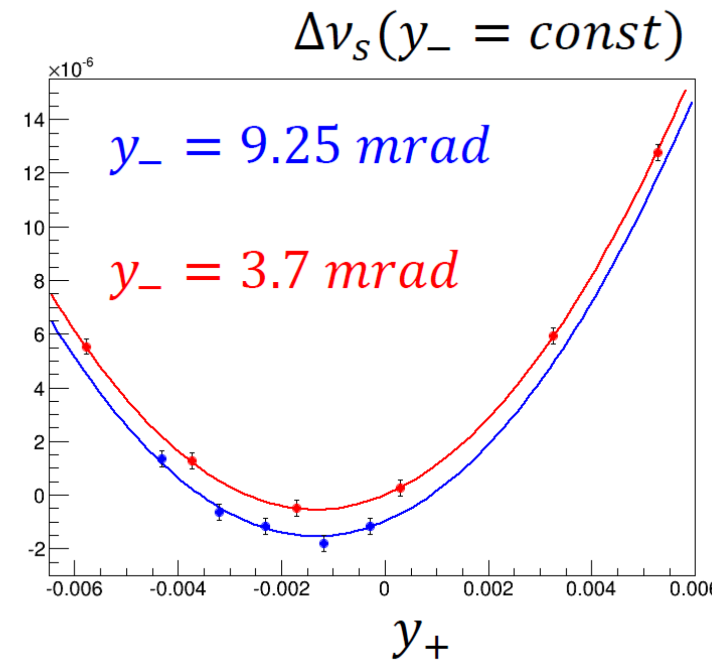
Spin tune: probing ring imperfections



Spin tune: probing ring imperfections

spin tune map:



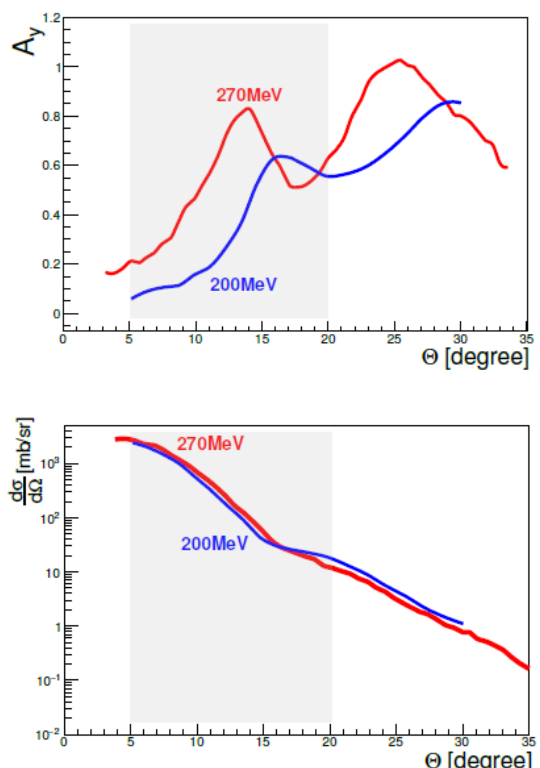


- parabolic behavior confirmed
- saddle point provides information on spin kicks by in-plane ring imperfections

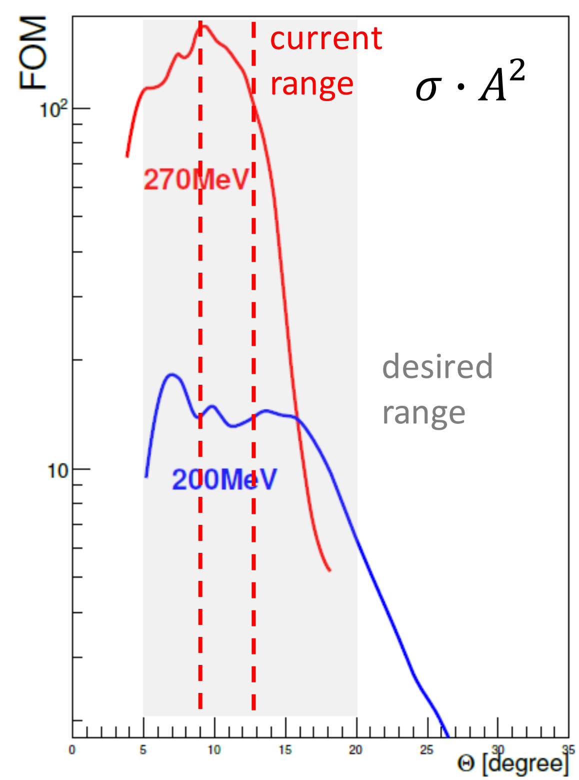
Outlook: Polarimeter development

Status:

- EDDA is in operation since about 20 years
- acceptance limits polarimeter efficiency → crucial for feedback system

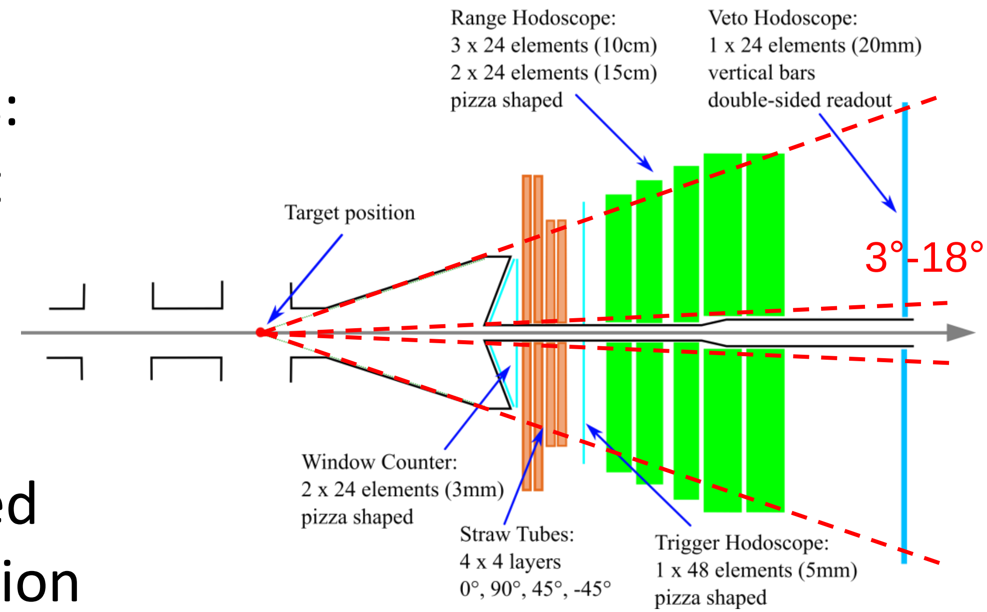


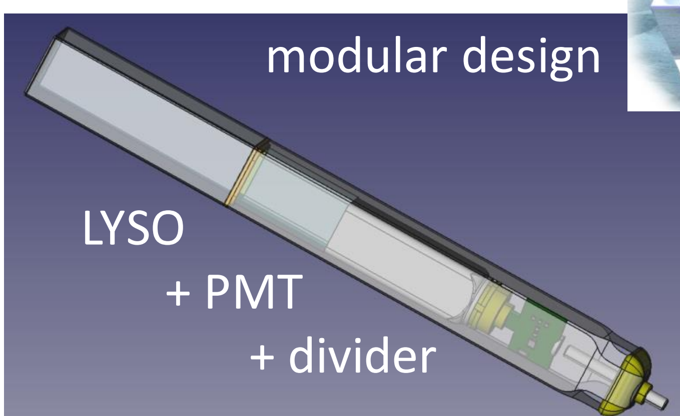
data: PLB 549, 307 (2002)

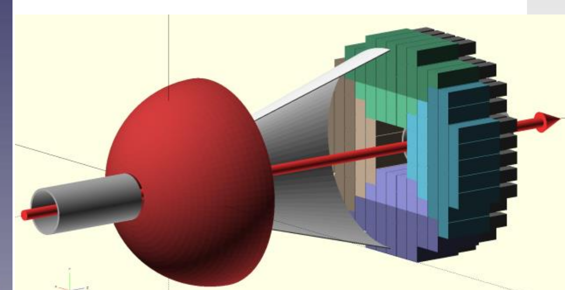


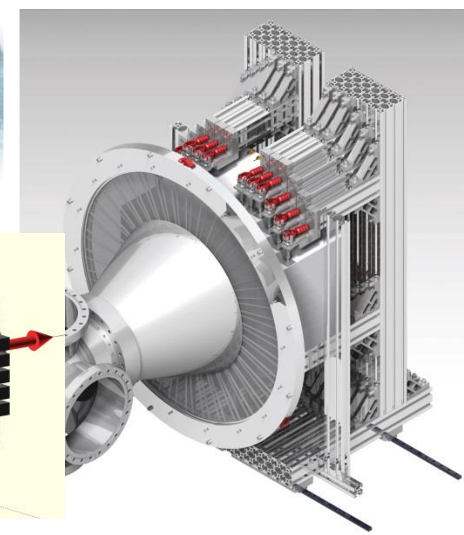
Outlook: Polarimeter development

- „database“ measurements: pC, dC analyzing powers at various beam momenta using the WASA-at-COSY forward detector
- development of a dedicated polarimeter for high precision EDM measurements









Summary

- Polarimetry + time stamping (single long range TDC)
  $\longrightarrow$ resolving fast spin precession
  $\longrightarrow$ extract polarization
  $\longrightarrow$ determine spin tune with high precision
- Applications
  $\longrightarrow$ tune accelerator for long spin coherence times ($\geq$ 1000s)
  $\longrightarrow$ stabilize spin tune and maintain phase lock to external rf signals (solenoid, ExB dipole), "feedback system"
  $\longrightarrow$ study spin tune response of accelerator parameters (field imperfections, orbit changes, …)
- Upcoming activities
  $\longrightarrow$ provide analyzing powers for pC and dC scattering
  $\longrightarrow$ development of a dedicated polarimeter for EDM measurements

JEDI

Jülich **E**lectric **D**ipole Moment **I**nvestigations:

- ≈ 100 members:
  Aachen, Daejeon, Dubna, Ferrara, Grenoble, Indiana, Ithaca, Jülich, Krakau, Michigan, Minsk, Novosibirsk, St. Petersburg, Stockholm, Tbilisi, …

- see
  http://collaborations.fz-juelich.de/ikp/jedi