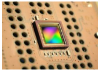
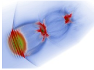
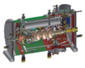
Matter and Technologies

High Precision Spin Manipulation at COSY

Sebastian Mey
Forschungszentrum Jülich

Hamburg, February 26, 2015

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Spin Motion in a Storage Ring

Thomas-BMT Equation: $\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \vec{S} \times \vec{\Omega}$

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

Free Precession

Thomas-BMT Equation: $\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \vec{S} \times \vec{\Omega}$

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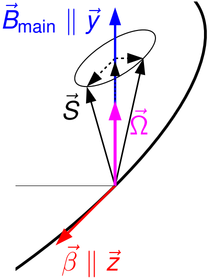
- ideal ring: only main bending dipoles
- additional spin precession per turn due to anomalous magnetic moment G
- spin tune $\nu_S = \gamma G$ is relative number of precessions per turn

! vertical polarization component S_y is constant



Driven Oscillation

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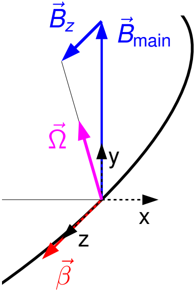
- additional perturbation field leads to tilt of precession axis
- oscillating RF field in phase with spin precession will lead to accumulation of spin kicks

⇒ rotation of $\vec{S}$ in vertical plane

⇒ oscillation of S_y

- resonant at all side bands $f_S = |n + \nu_s| f_{\text{rev}};\ n \in \mathbb{Z}$
- resonance strength is defined as vertical spin rotation per revolution



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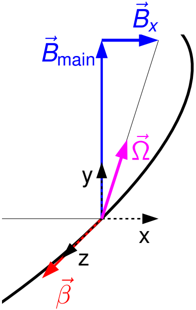

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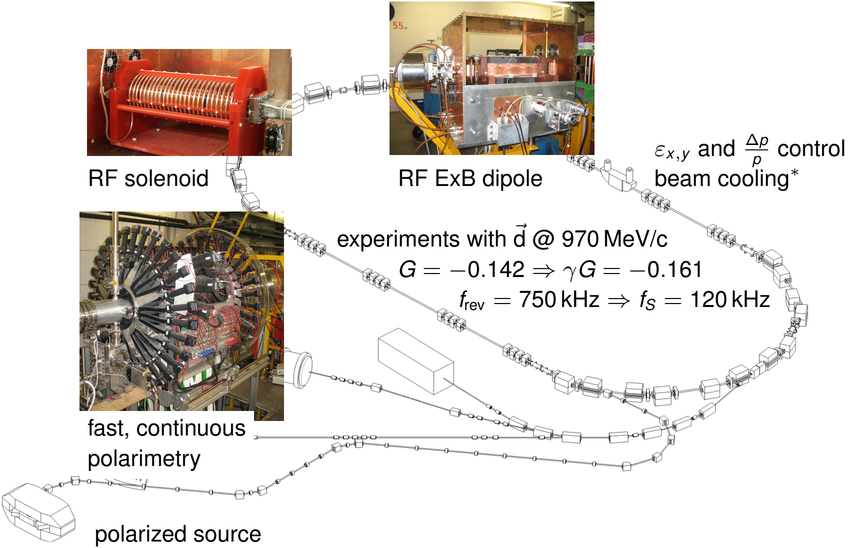
COSY as Spin Physics R&D Facility



[* → talk by V. Kamerdzhiev]

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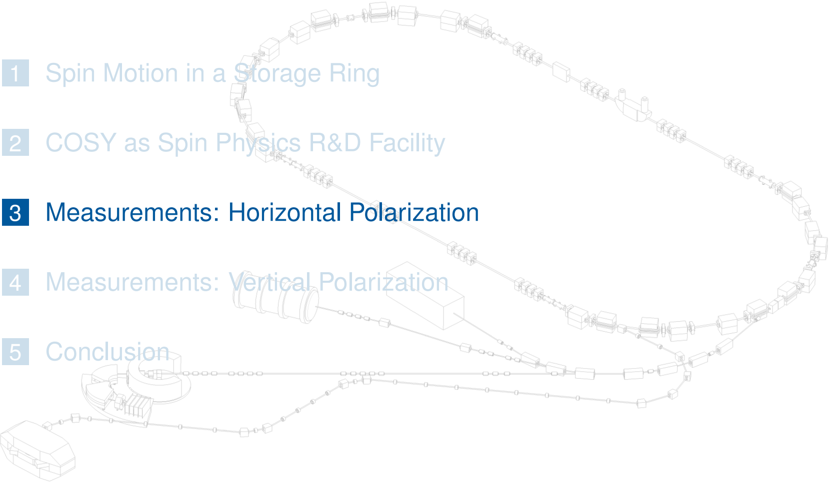


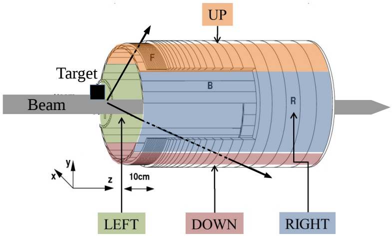
Fast Polarimetry

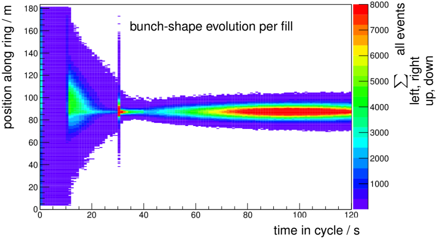
- massive carbon target as defining aperture, use slow extraction
- beam polarization ⇔ average over all particles' spins

⇒ asymmetries in $^{12}C(\vec{d}, d)$:

$$P_y \propto \epsilon_{lr} = \frac{N_{left} - N_{right}}{N_{left} + N_{right}}; \quad P_x \propto \epsilon_{ud} = \frac{N_{up} - N_{down}}{N_{up} + N_{down}}$$

- since 2012: high resolution timestamping for every event*





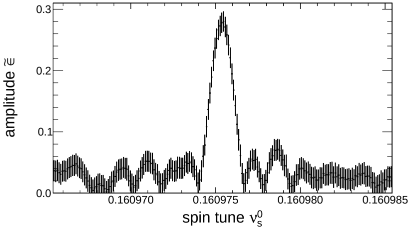
[* Z. BAGDASARIAN et al., Phys. Rev. ST Accel. Beams 17, 052803 (2014)]

Horizontal Polarization Measurement

- use RF flipper to rotate polarization in horizontal plane
- accumulate data in time bins
- time stamping $\Rightarrow$ determination of up-down-asymmetry signal in every bin:

$$P_x(t) \propto \tilde{\epsilon}\, \sin(2\pi\nu_s f_{\text{rev}} t + \phi)$$

- amplitude $\tilde{\epsilon}$ corresponds horizontal polarization



[D. Eversmann, JEDI Collaboration]

Spin Tune Evolution

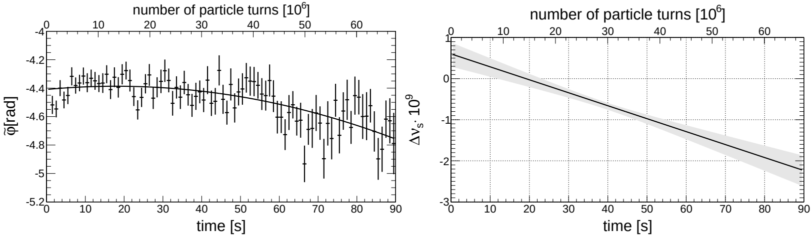
- fix determined spin tune to all other macroscopic bins
- observe phase evolution $\tilde{\phi}(t)$ over whole cycle

$\Rightarrow$ correlation of data from all time bins

- total spin tune change over time given by derivative of phase $\tilde{\phi}$

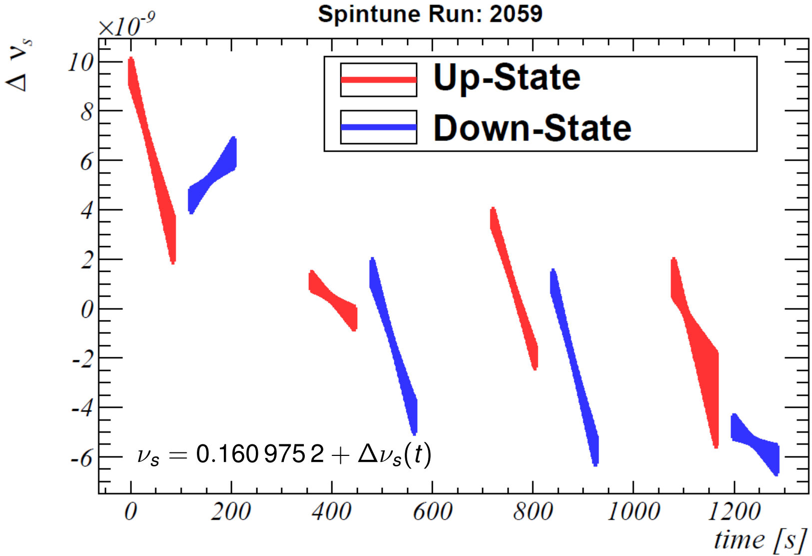
$$\nu_s(t) = \nu_s^0 + \frac{1}{2\pi f_{\text{rev}}} \frac{\mathrm{d}\tilde{\phi}}{\mathrm{d}t} = 0.1609752 + \Delta\nu_s(t)$$

- spin tune average over $\approx 100\,\mathrm{s}$ cycle determined to 10^{-9} (!)



[D. Eversmann, JEDI Collaboration]

Long Time Stability

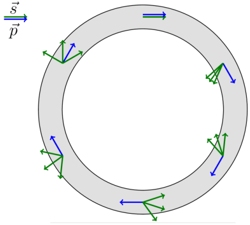


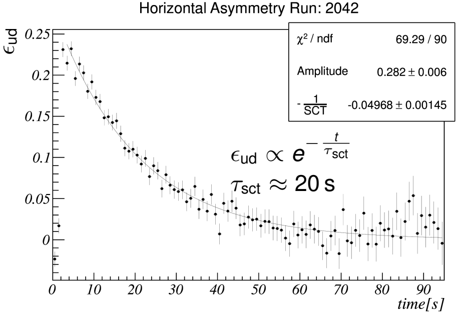
[D. Eversmann, JEDI Collaboration]

Amplitude Evolution ⇔ Spin Coherence Time

- spin precession frequency $f_s \approx \gamma G \cdot f_{\text{rev}}$
- averaging over particles' spins ⇒ use bunching to fix f_{rev} for all particles
- energy spread $\frac{\Delta\gamma}{\gamma}$ ⇒ spin tune spread

⇒ use beam cooling to minimize





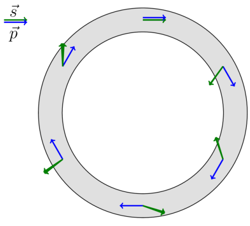
[D. Eversmann, JEDI Collaboration]

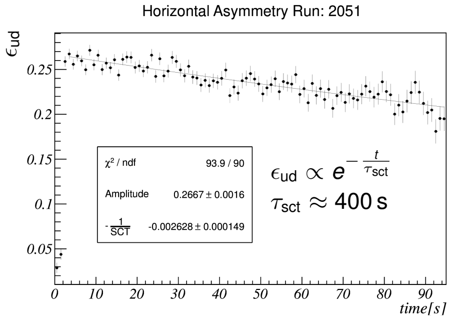
Canceling 2nd Order Effects with Sextupoles

- consider path lengthening effects

$$\frac{\Delta\gamma}{\gamma} \propto \frac{\Delta L}{L} \propto \left(\langle x\rangle^2, \langle y\rangle^2, \delta^2\right)$$

- three independent families of COSY sextupoles at locations with large β_x, β_y, D to compensate





$\epsilon_{ud} \propto e^{-\frac{t}{\tau_{sct}}}$

$\tau_{sct} \approx 400\,\mathrm{s}$

[D. Eversmann, JEDI Collaboration]

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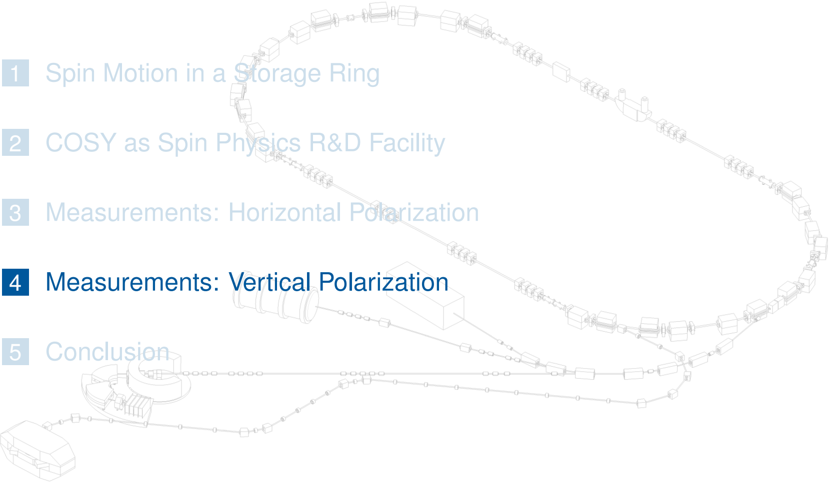


The RF ExB dipole in Wien Filter Configuration

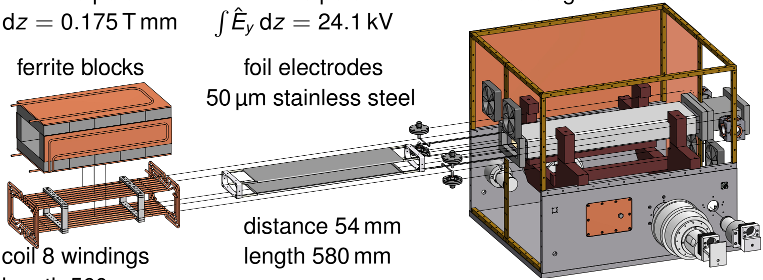
RF B dipole
$\int \hat{B}_x \, dz = 0.175\,\mathrm{T\,mm}$

RF E dipole
$\int \hat{E}_y \, dz = 24.1\,\mathrm{kV}$

shielding Box

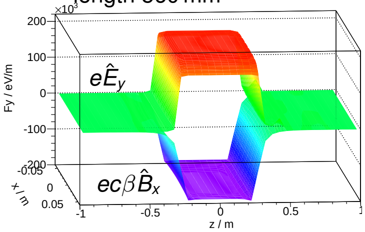
ferrite blocks

foil electrodes
50 µm stainless steel

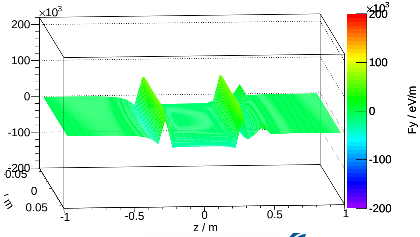


coil 8 windings
length 560 mm

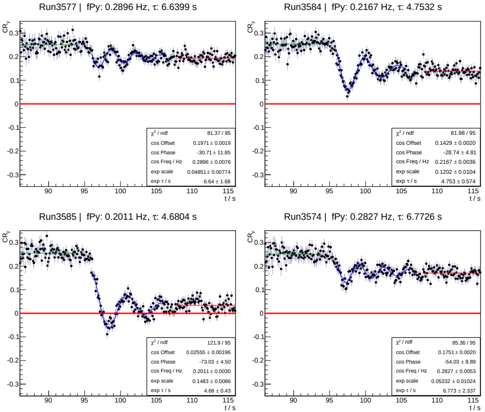
distance 54 mm
length 580 mm

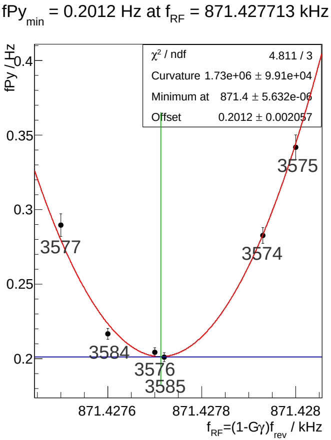


$\int \hat{F}_y \, dz \stackrel{!}{=} 0$



Driven Polarization Oscillation





- total spin flip only on resonance $\Rightarrow$ average polarization $\to 0$
- minimum of vertical polarization oscillation frequency f_{P_y}
- resonance strength is spin rotation per turn $\varepsilon = \frac{f_{P_y,\mathrm{min}}}{f_{\mathrm{rev}}}$

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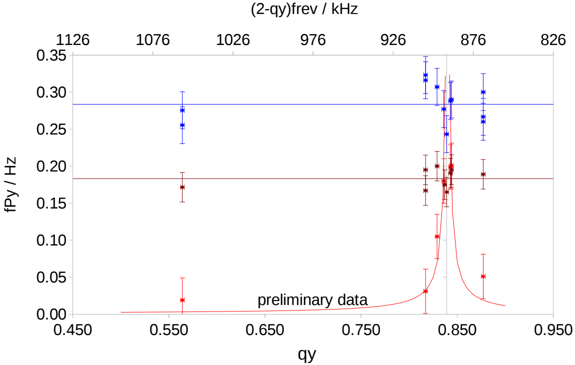
Determination of Lorentz Force Compensation

- RF Wien filter at $f_{S,-1} = 871.4277\,\text{kHz}$
- scan of betatron tune q_y determines influence of beam oscillations
- RF-solenoid: $f_{P_y} = \text{const.}$; RF-Wien-Filter: $f_{P_y} = \text{const.}$
- RF-dipole: interference with driven coherent beam osc.



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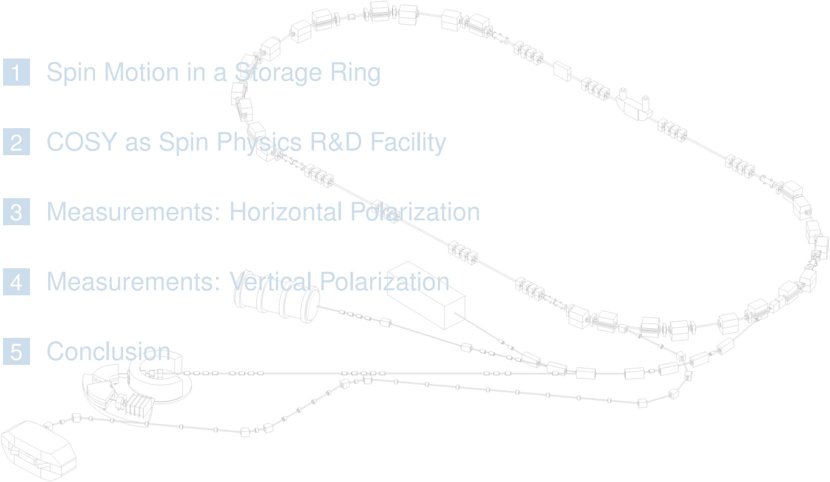
Conclusion

- JEDI-Collaboration: search for light hadrons' permanent EDM*
- accelerator $\equiv$ experiment $\Rightarrow$ aim for ultimate precision
  "conventional" accelerator
- utilize polarization as diagnostic tool, examples:
  - horizontal polarization:
  - spin tune measurements as high precision tool established
  - observation time for horizontal polarization pushed towards 1000 s mark

  - vertical polarization:
  - precision spin manipulation with minimal beam disturbance
  - resonance strength determination by means of frequency measurement

[*talk by A. Lehrach]

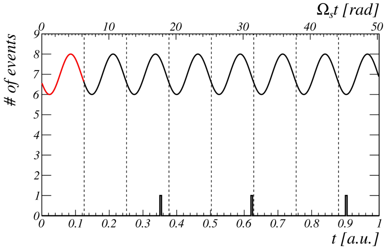
Content



Spin Tune per Time Bin

- use RF flipper to rotate polarization in horizontal plane
- detector signal: $N_{\text{up, down}}(t) \propto 1 \pm \sin(2\pi f_S t + \phi)$
- $f_S \approx \gamma G \cdot f_{\text{rev}} = 120\,\text{kHz}$, but event rate only $\approx 5\,\text{kHz}$

$\Rightarrow$ detector event only every 25th oscillation period



[J. Pretz, JEDI Collaboration]

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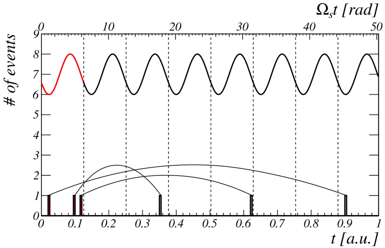
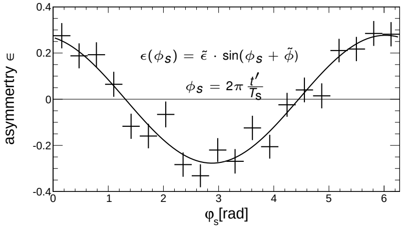
- time stamps $t \Rightarrow$ map all events of macroscopic bin into one assumed oscillation period $T_s \Leftrightarrow t' = \mod(t, T_s)$



[J. Pretz, JEDI Collaboration]

Spin Tune per Time Bin, cont.

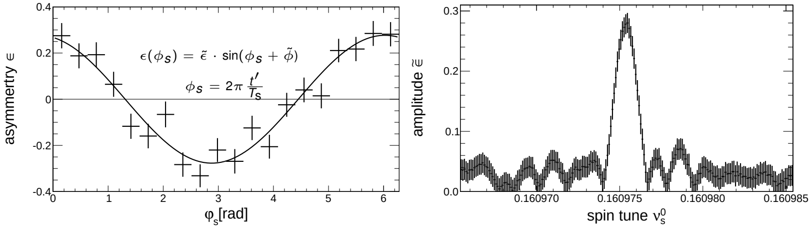
1. timestamps $t \Rightarrow$ map all events of macroscopic bin into one assumed oscillation period $T_s \Leftrightarrow t' = \mod(t, T_s)$
2. calculate asymmetries in one time period and fit oscillation
3. extract amplitude $\tilde{\epsilon} \propto$ polarization from fit



[D. Eversmann, JEDI Collaboration]

Spin Tune per Time Bin, cont.

1. timestamps $t \Rightarrow$ map all events of macroscopic bin into one assumed oscillation period $T_\mathrm{s} \Leftrightarrow t' = \mod(t, T_\mathrm{s})$
2. calculate asymmetries in one time period and fit oscillation
3. extract amplitude $\tilde{\epsilon} \propto$ polarization from fit
4. vary value of T_s, repeat
5. best spin tune manifests as maximum in spectrum of $\nu_s = \frac{2\pi}{T_s f_\mathrm{rev}}$



[D. Eversmann, JEDI Collaboration]