PROGRESS TOWARD A DIRECT MEASUREMENT OF THE DEUTERON ELECTRIC DIPOLE MOMENT AT COSY

HERAEUS SEMINAR 30.03.2021 I VERA SHMAKOVA FOR JEDI COLLABORATION

CHARGED PARTICLE EDM

- No direct measurement for charged hadron EDMs
- Potentially higher sensitivity (compared to neutrons):
  - longer lifetime
  - more stored polarized protons/deutrons
  - can apply larger electric fields in storage rings
- EDM of single particle type not sufficient to identify CPV source

THOMAS - BMT EQUATION

MDM

EDM

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S} = -\frac{q}{m}\left\{G_\gamma \vec{B} + \left(\frac{1}{\gamma^2 - 1} - G\right)\frac{\vec{\beta} \times \vec{E}}{c} + d\frac{m}{q\hbar S}\left(\vec{E} + c\vec{\beta} \times \vec{B}\right)\right\} \times \vec{S}$$

At storage rings: vertical $\boldsymbol{B}$ field, radial $\boldsymbol{E}$ field

MDM causes fast spin precession in horizontal plane

EDM causes slow spin rotation out of horizontal plane, up and down

In an all-electric storage ring, with the frozen spin condition, a radial electric field causes the spin to precess out of the storage plane linearly

THOMAS - BMT EQUATION

MDM EDM

$$\frac{d\vec{S}}{dt}=\vec{\Omega}\times\vec{S}=-\frac{q}{m}\{G_{\gamma}\vec{B}+(\frac{1}{\gamma^2-1}-G)\frac{\vec{\beta}\times\vec{E}}{c}+d\,\frac{m}{q\hbar S}(\vec{E}+c\,\vec{\beta}\times\vec{B})\}\times\vec{S}$$

At storage rings: vertical ***B*** field, radial ***E*** field

MDM causes fast spin precession in horizontal plane

EDM causes slow spin rotation out of horizontal plane, up and down

In **pure magnetic ring** motional electric field $(c\,\vec{\beta}\times\vec{B})$

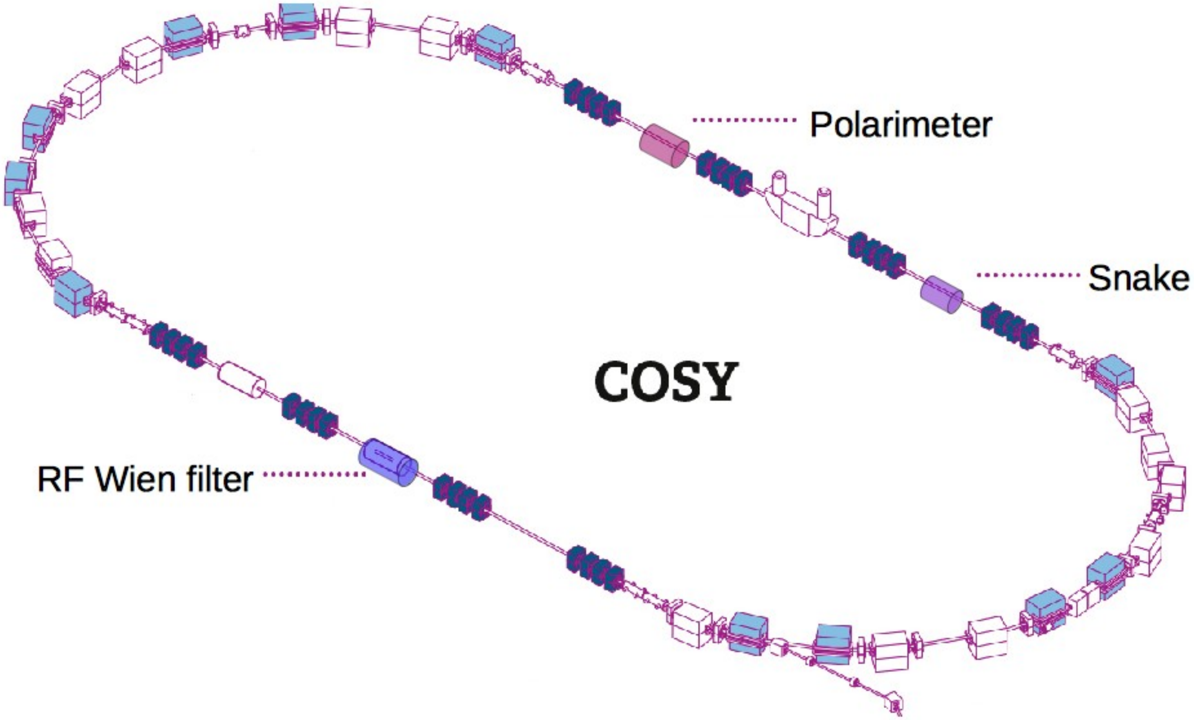
⇩

access to EDM

EDM AT COSY

COSY (Jülich, Germany)

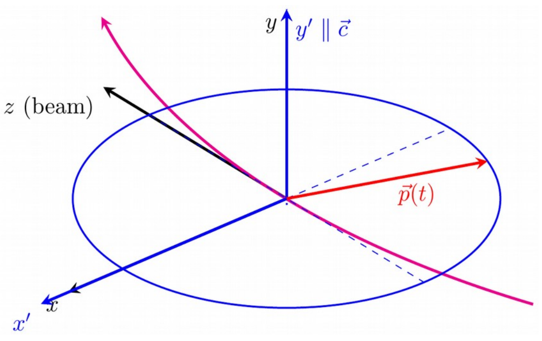
- magnetic storage ring
- polarized protons and deuterons
- Momenta p = 0.3 – 3.7 GeV/c



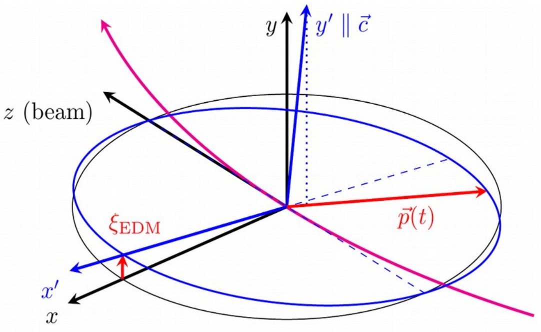
Starting point for EDM measurement

EFFECT ON PRECESSION AXIS

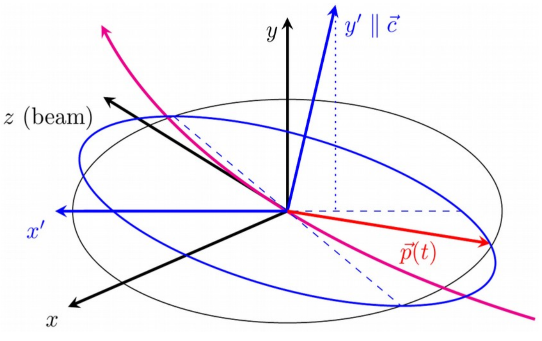
EDM absence case



EDM effect



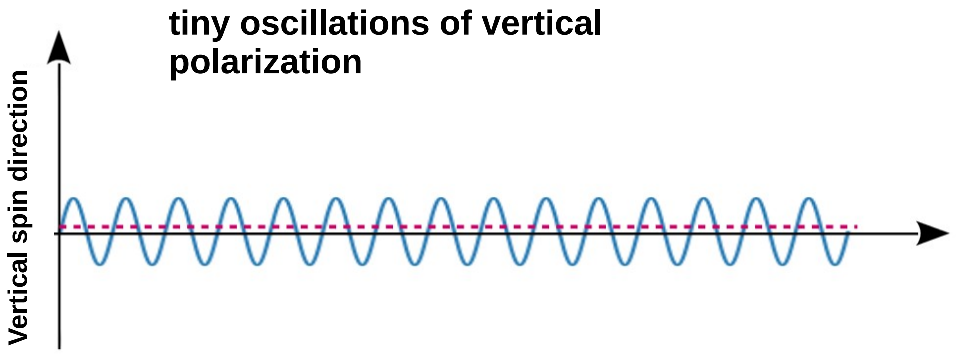
Magnetic misalignment effect



RF WIEN FILTER

In the magnetic ring
momentum ↑↑ spin ⇨ spin kicked up
momentum ↑↓ spin ⇨ spin kicked down

no accumulation of vertical asymmetry



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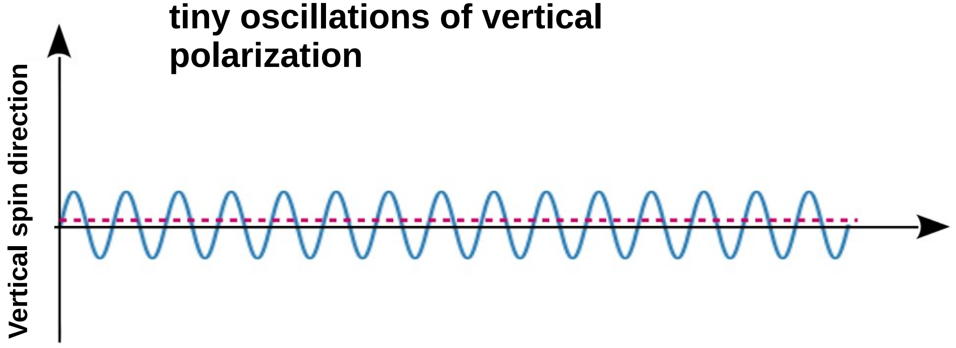
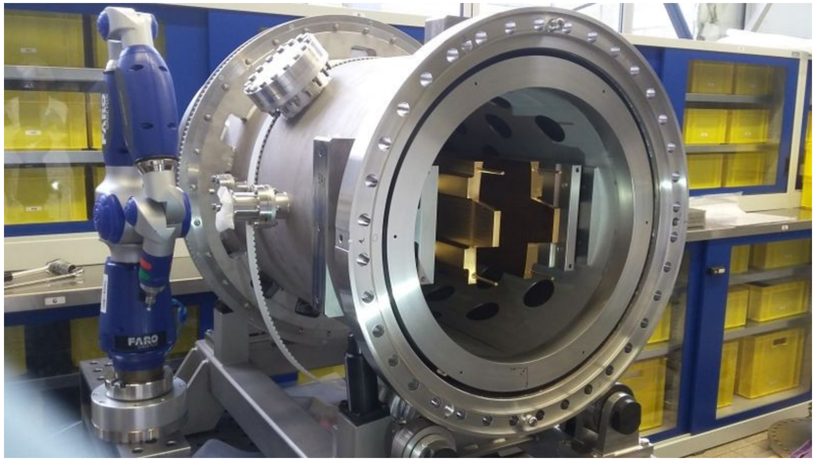


RF Wien filter

Heberling, Hölscher and ***J. Slim***

J. Slim et al. Nucl. Instrum. Methods Phys. Res. A 828, 116 (2016)

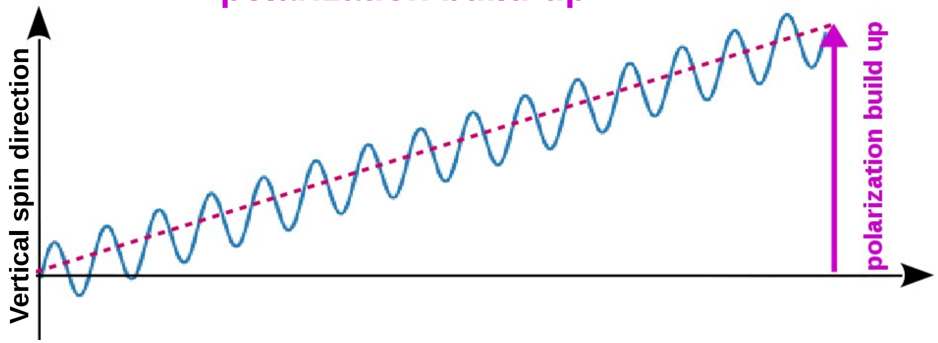
- Lorentz force $\vec{F}_L = q(\vec{E} + \vec{v} \times \vec{B}) = 0$
- $\vec{B} = (0, B_y, 0)$ and $\vec{E} = (E_x, 0, 0)$



phase lock between spin precession and RF Wien filter

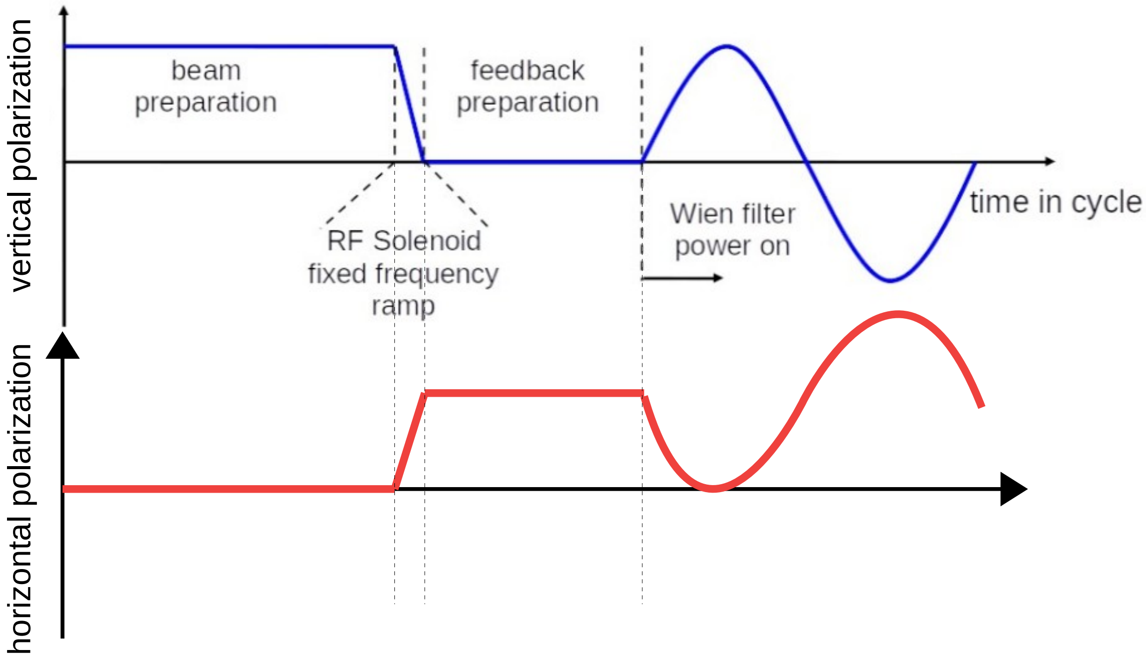
⇩

polarization build-up



PRINCIPLE OF MEASUREMENTS

The basic workflow

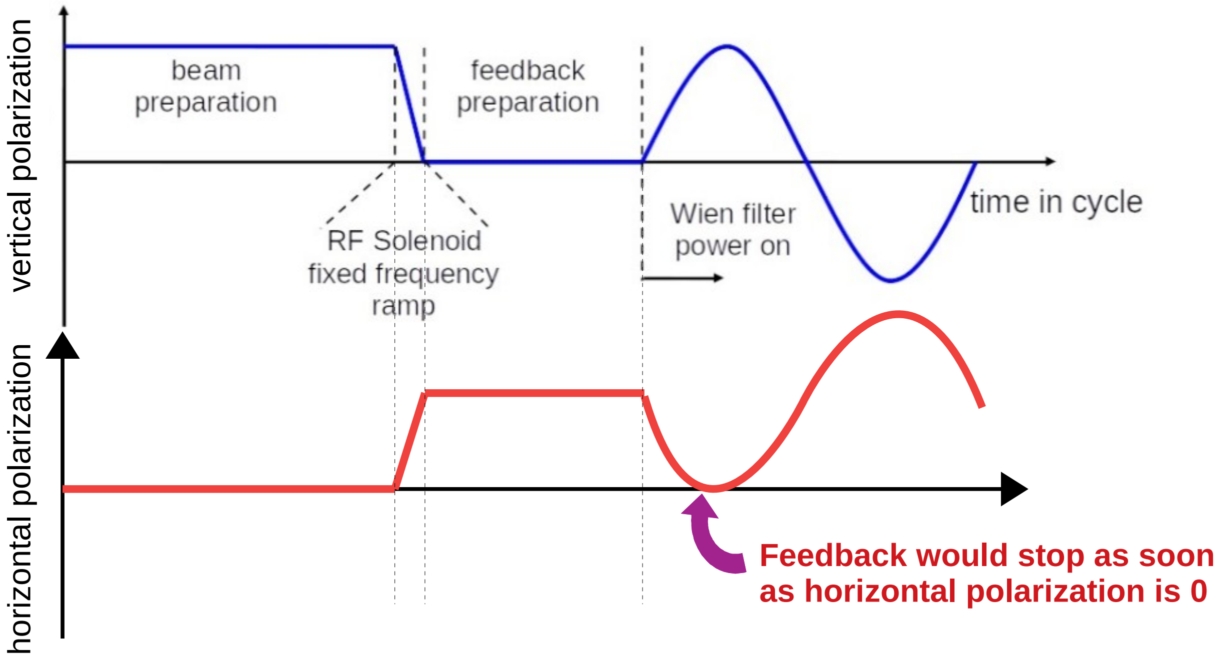


- Coherent ensembles in ring plane ➡ time of the horizontal polarization decoherence - "spin coherence time" - has to be longer then a measurement
  A. Wronska talk

- Spin precesses with 120 kHz.
- Wien filter operates on resonance f = 871.430 kHz
- Phase lock between spin precession and Wien filter

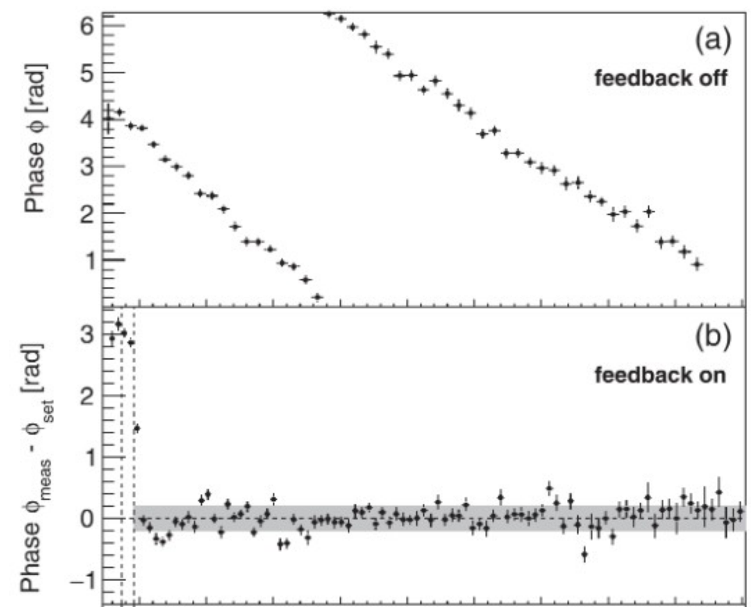
PRINCIPLE OF MEASUREMENTS

The basic workflow



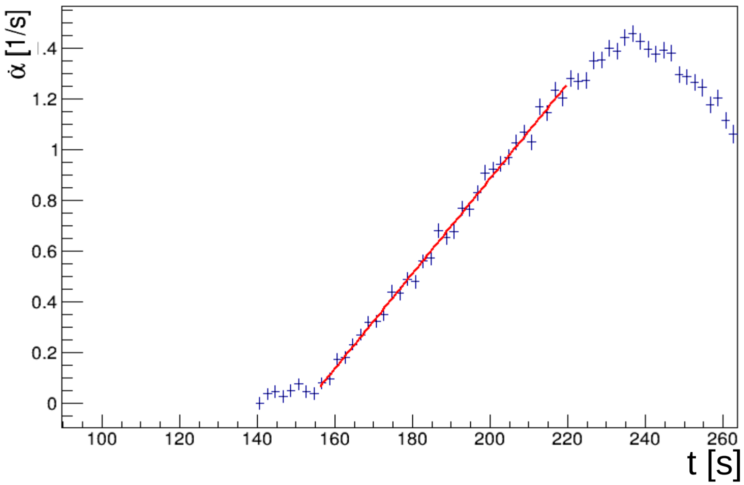
- Feedback monitors spintune and adjust WF frequency to maintain the relative phase between spin precession and Wien filter

- an error of 0.2 rad



POLARIZATION BUILD-UP

- Wien filter operated with B filed normal to the ring plane
- $\alpha(t) = \arctan\left(\frac{P_y}{P_{xz}}\right)$
- Observed initial slopes of polarization build-up variated of Wien filter and solenoid rotations
- Observed slopes would correspond to the EDM of ~10^{-17} e·cm



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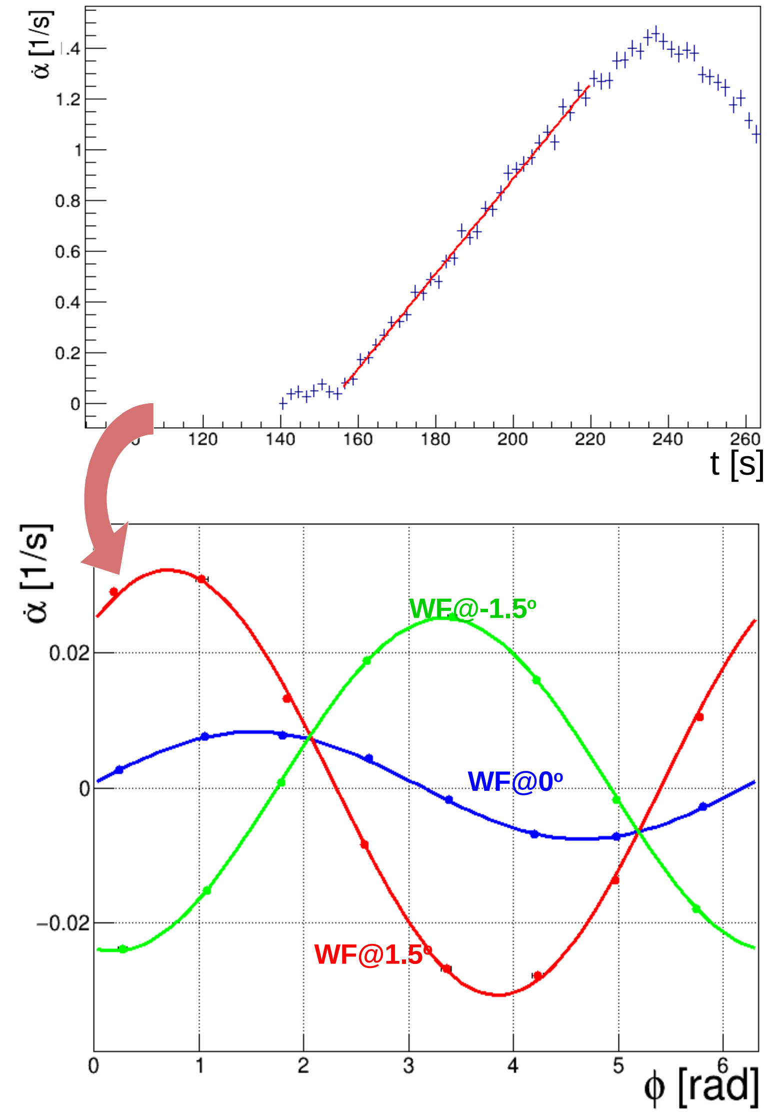

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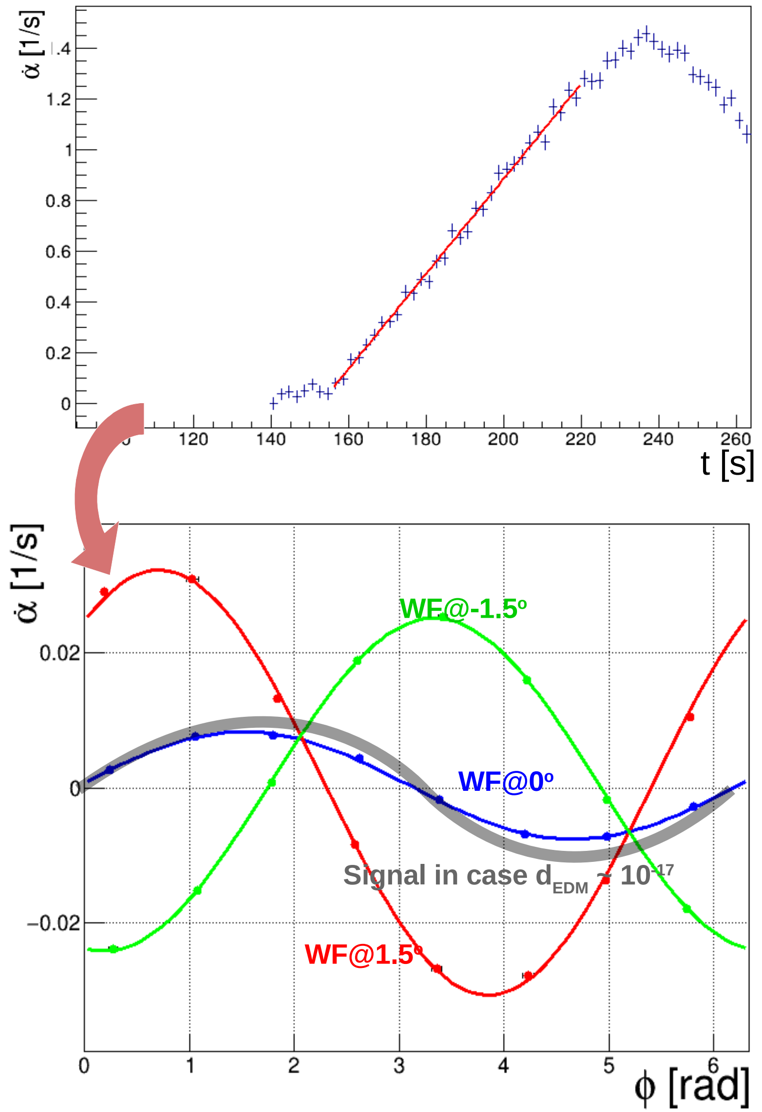


RESONANCE STRENGTH

9+9+14 points on 3 map

Parametric resonance strength based on initial slope $\varepsilon \simeq \frac{\dot{\alpha}}{\omega_{rev}}$

$$\varepsilon = \frac{\psi_{WF}}{4\pi} \sqrt{A_{WF}^2 (\phi^{WF} - \phi_0^{WF})^2 + A_{sol}^2 \left(\frac{\chi_0^{sol} + \chi^{sol}}{2 \sin(\pi \nu_s)} \right)^2} + \varepsilon_0$$

φ_0^{wf} = -3.80 +- 0.05 mrad

X_0^{sol} = -5.51 +- 0.05 mrad

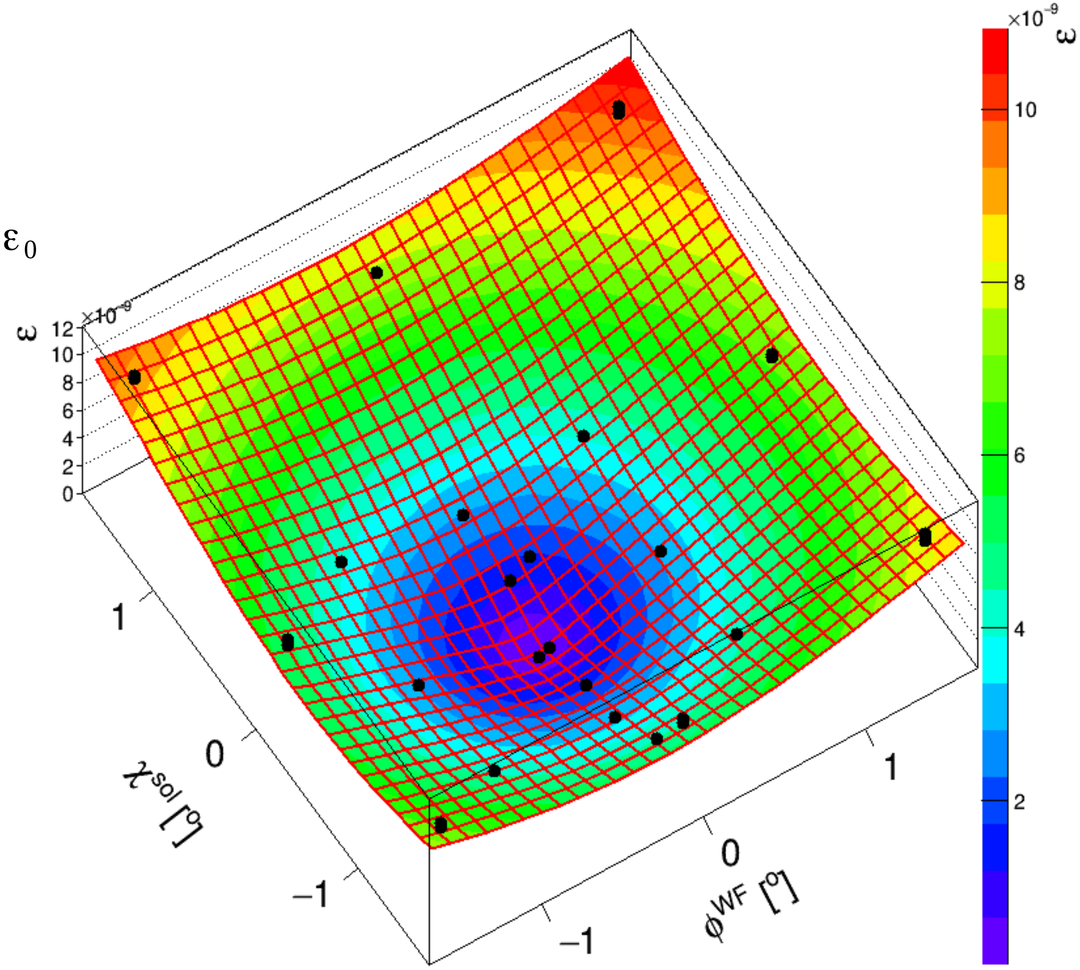
A_{WF} = 0.755 +- 0.004

A_{sol} = 0.919 +- 0.004

ε_0 = (-1.1 +- 0.1)e-10

Orientation of precession axis at location of RF Wien filter determined from the minimum of the surface

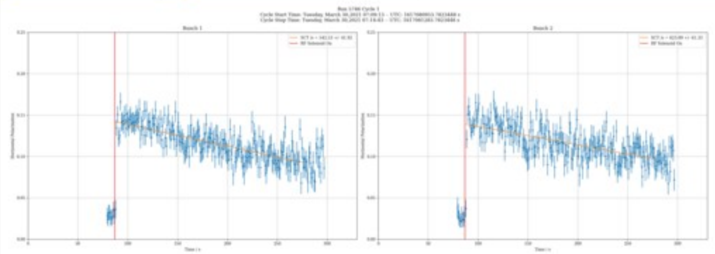
Spin tracking calculations should provide the orientation of precession axis without EDM



PRECURSOR II IS ONGOING

949	Tuesday, March 30, 2021, 07:09	run	5746	5746	Production	SCT measuerement (WF-off Snake-off) for map 3 point 3 WF angle @ -4 deg, Snake 0 A, Phase 5.4 rad	OJ, AK

Attachment 1: sct.png



946	Tuesday, March 30, 2021, 07:00	shift summary				all measurements for map3, point1-3 has been done.	AK,OJ

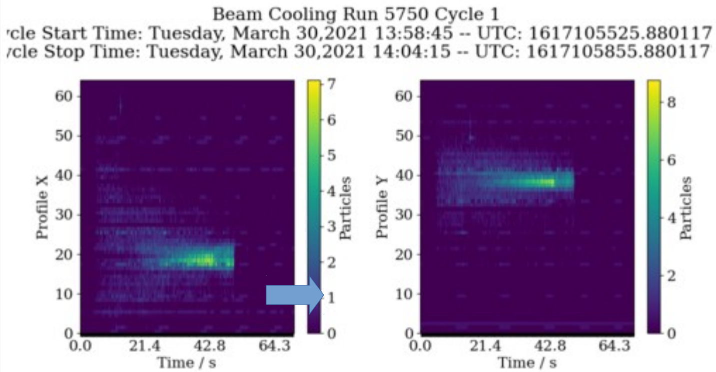
All these measurements has been recorded during day and night shift

- point 1: WF @-4, Snake at 0 A, phases (0, 0.9, 1.8, 2.7, 3.6, 4.5, 5.4),
- IPM measurement, WF on, Snake on,
- SCT measurement, WF off, Snake on,
- point 2: WF @-4, Snake at 4 A, phases (0, 0.9, 1.8, 2.7, 3.6, 4.5, 5.4),
- IPM measurement, WF on, Snake on,
- SCT measurement, WF off, Snake on,
- SCT measurement, WF off, Snake off,
- point 3: WF @-4, Snake at -4 A, phases (0, 0.9, 1.8, 2.7, 3.6, 4.5, 5.4),
- IPM measurement, WF on, Snake on,
- SCT measurement, WF off, Snake on,
- SCT measurement, WF off, Snake off,

Now Alex can come and rotate Wien filter to 4 degree (+70.36 mrad) and continue masurements untill 8:30 (2 MeV cooler test starts)

959	Tuesday, March 30, 2021, 06:41	run	5744	5744	Production	IPM measurement for map point 3 WF ON angle @ 0 deg, Snake 0 A,	KL, AN

Attachment 1: beamCooling.png



PRECURSOR II IS ONGOING

IMPROVEMENTS AT COSY

- Alignment campaigns of COSY magnet system
- Beam-based alignment **See T. Warner talk**
  PhD thesis T. Wagner ***T. Wagner et al. JINST 16 T02001 (2021)***
- New tool for fast tune and chromaticity measurement
  P. Niedermayer and B. Breitkeutz
- Slow control system
  I. Bekman and IKP4
- COSY signals and distribution was improved
  K. Laihem and V. Hejny
- Rogowski coils at the Wien filter place
  F. Abusaif ***See F. Abusaif talk***
- New JEDI polarimeter
  I. Keshelashvili and the polarimeter group
- 8 fast switchers to gate the WF power for 1 bunch of 2 of 4
  ➡ pilot bunch technique ***See J. Slim talk***
  J. Slim, A. Nass, F. Rathmann, G. Tagliente

SUMMARY

- First measurement of deuteron EDM was performed
- Experiment performed is a proof of principle of EDM measurement at storage rings
- Precursor II is ongoing right now
- COSY remains a unique facility for such studies

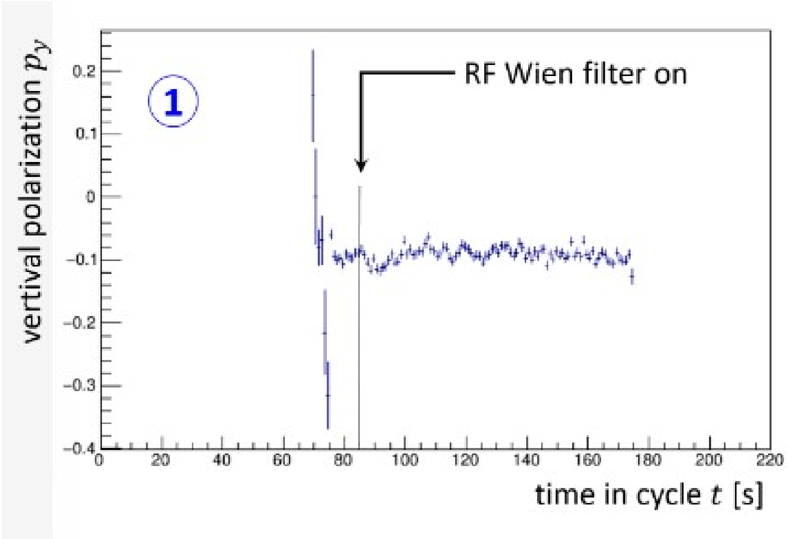
PILOT BUNCH

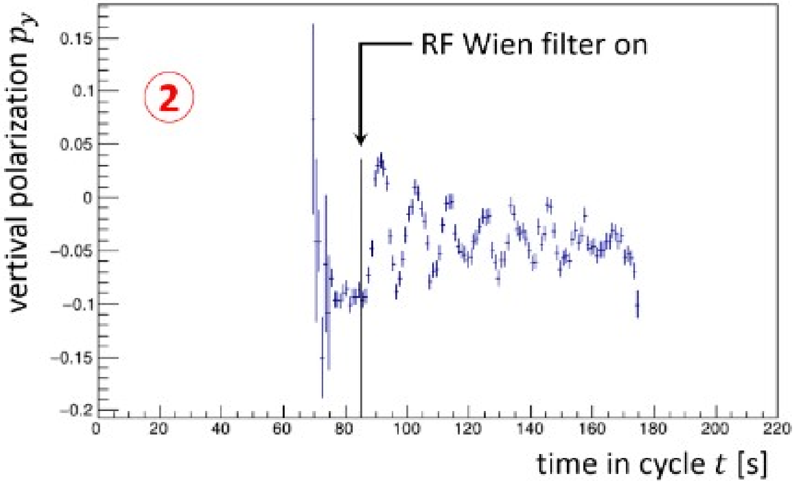
8 fast switchers to gate the WF power for 1 bunch of 2 of 4

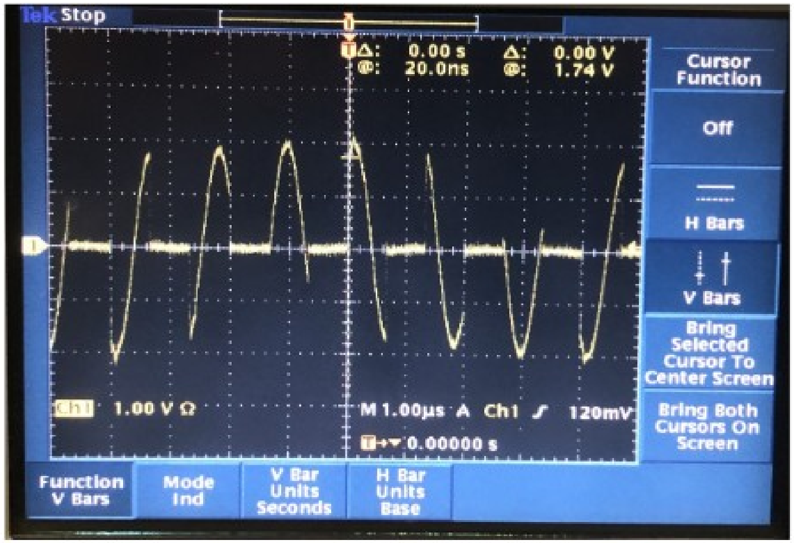
capable of short switch time ~ few ns

One bunch feels the power and oscillate

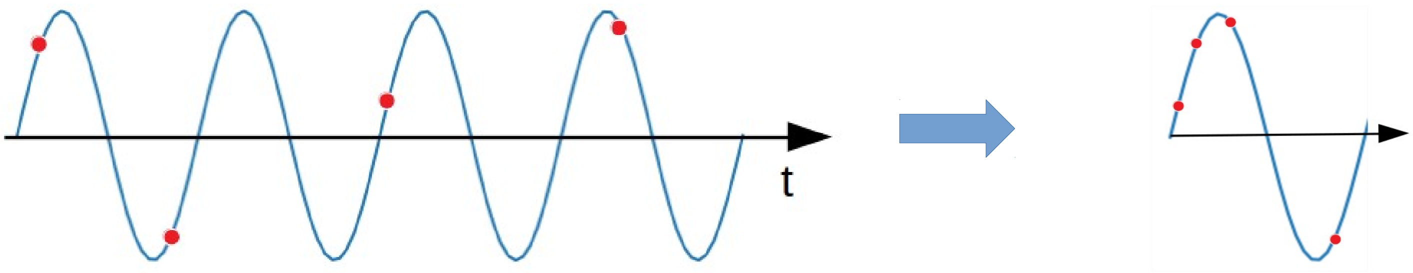
Another is a pilot bunch







SPINTUNE AND HORIZONTAL POLARIZATION



- Spin precesses with 120 kHz.
- With event rates of ~ 15000 s^{-1}, there is 1 hit per 10 precessions.
- Not possible to resolve horizontal oscillation directly
- Spintune is determined in each time bin with monitoring phase of measured horizontal asymmetry with fixed spin tune:

$$\nu_s(n) = \nu_s^{fix} + \frac{1}{2\pi}\frac{d\phi}{dn} = \nu_s^{fix} + \Delta\nu_s(n)$$