Karlsruhe Institute of Technology

FUTURE CIRCULAR COLLIDER Innovation Study

KARA Karlsruhe Research Accelerator

IBPT Institute for Beam Physics and Technology

Energy calibration with resonant depolarization & beam tests at KARA

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Karlsruhe Research Accelerator (KARA)

- KIT synchrotron lightsource & accelerator test facility
  - until 2015 known as „ANKA“

- Key parameters
  - Circumference: 110.4 m
  - Energy range: 0.5 - 2.5 GeV
  - RF frequency: 500 MHz
  - Revolution frequency: 2.715 MHz
  - Beam current up to 200 mA
  - RMS bunch length:
    - 45 ps (for 2.5 GeV)
    - down to a few ps (for 1.3 GeV)
  - Single or multi-bunch operation
  - TbT and BbB diagnostics

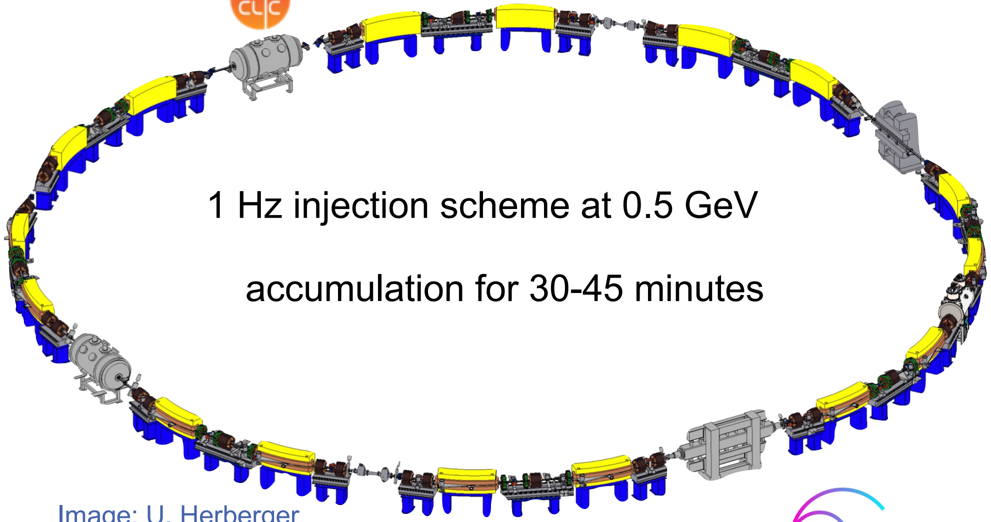

Image: U. Herberger

www.ibpt.kit.edu/kara

KARA – relevance in the context of FCC

~ 50 days of machine physics per year

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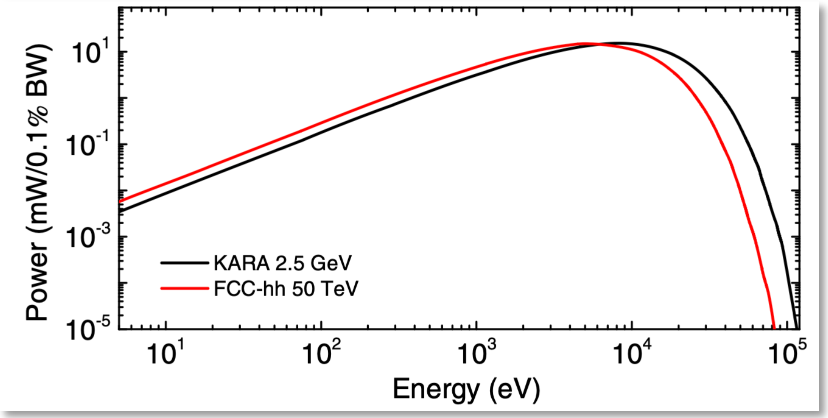
Synchrotron radiation spectrum similar to FCC-hh



BESTEX, 10.1103/PhysRevAccelBeams.22.083201

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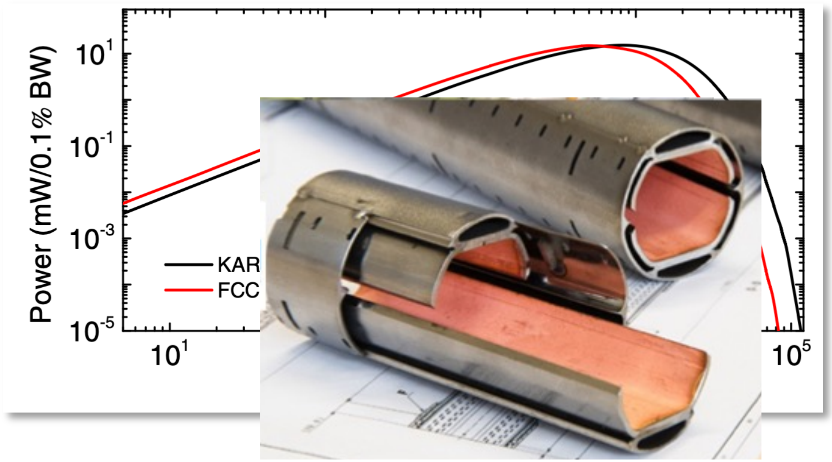

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KARA – relevance in the context of FCC

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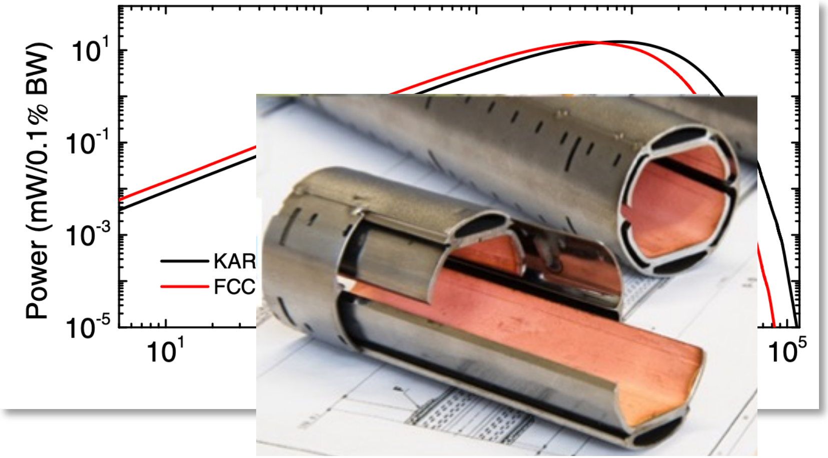
EuroCirCol
A key to New Physics

~ 50 days of machine physics per year

FCCIS

Synchrotron radiation spectrum similar to FCC-hh



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Task 2.5: Polarisation and energy calibration

- Energy measurements with highest possible precision required for FCC-ee
  → Resonant Spin Depolarisation
- Setup available at KARA

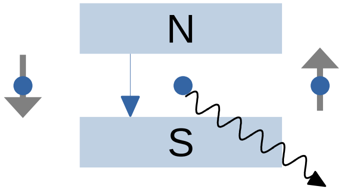
Electron beam polarisation

- Asymmetry in the spin-flip probability due to emission of synchrotron radiation leads to spin polarisation over time:

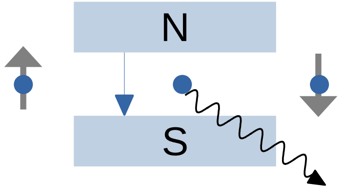
$$\tau_p = (w_{\uparrow\downarrow} + w_{\downarrow\uparrow})^{-1} = \frac{8\sqrt{3}}{15}\frac{m_0^2 c^2}{e^2 \hbar}\boxed{\frac{\rho^3}{\gamma^5}} \cdot 4\pi\varepsilon_0$$

- KARA, 2.5 GeV: ~ 9 minutes

More likely
(by factor ~25)



Less likely



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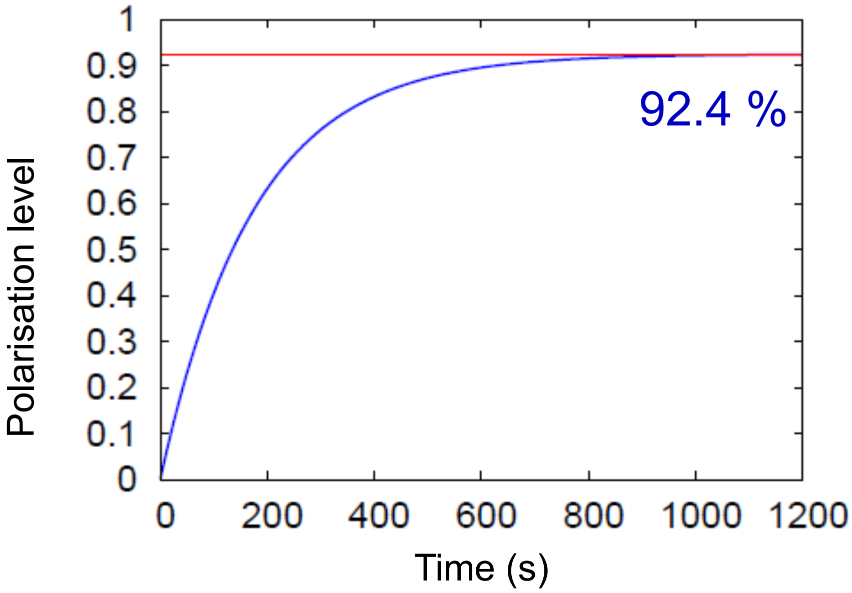

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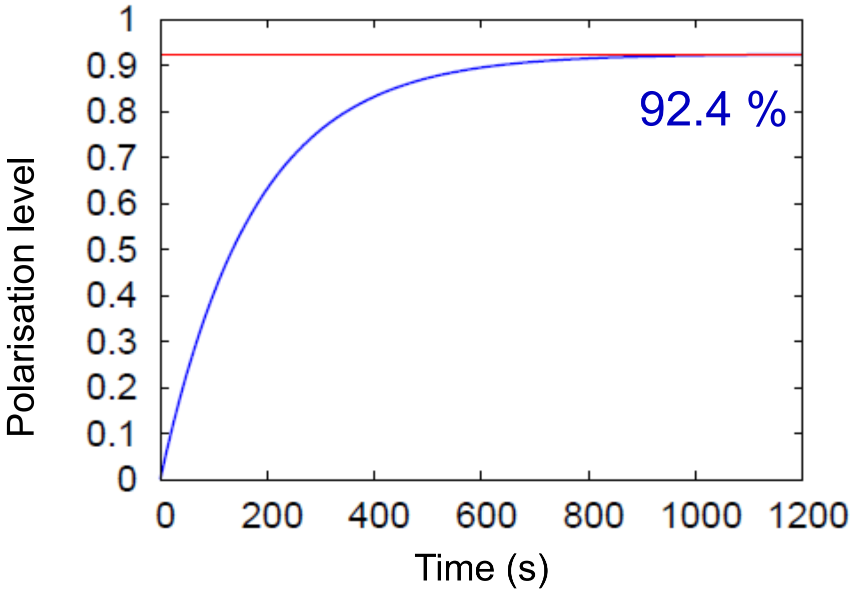
- KARA, 2.5 GeV: ~ 9 minutes
- Spin vector precedes in presence of electric and magnetic fields.
- Spin tune: number of precessions per turn

$$\nu = a\gamma$$



$$a = (g_e - 2)/2 = 0.001159652193$$
$$\gamma = E_{\mathrm{beam}}/m_0c^2$$

Resonant spin depolarization

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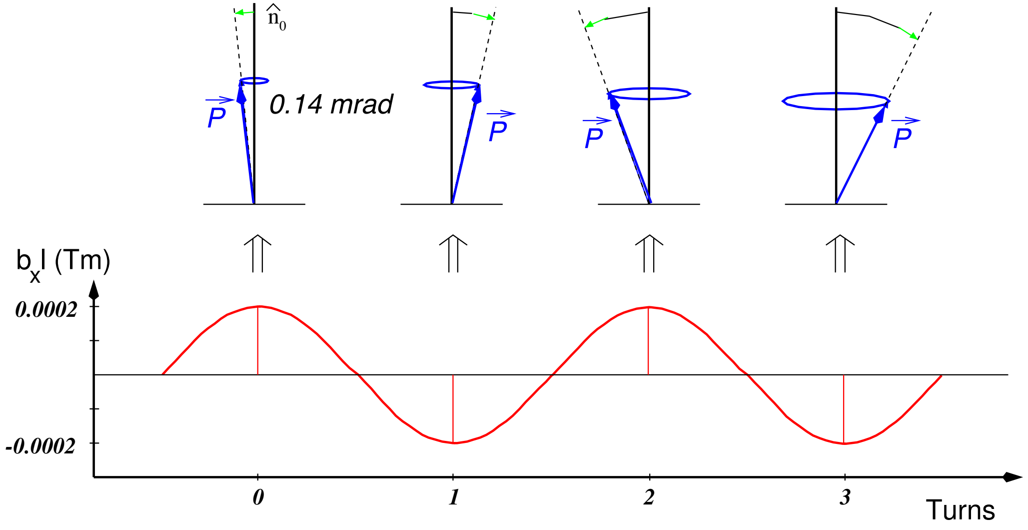
- If a horizontal excitation with spin-tune resonance is applied, the polarization is resonantly destroyed.
  → resonant spin depolarisation

$$f_{\mathrm{dep}} = (k \pm [\nu]) \cdot f_{\mathrm{rev}}$$



resonant polarization vector rotation for
$$\nu = n + 1/2, \quad n \in \mathbb{N}$$

RSD measurement technique at KARA

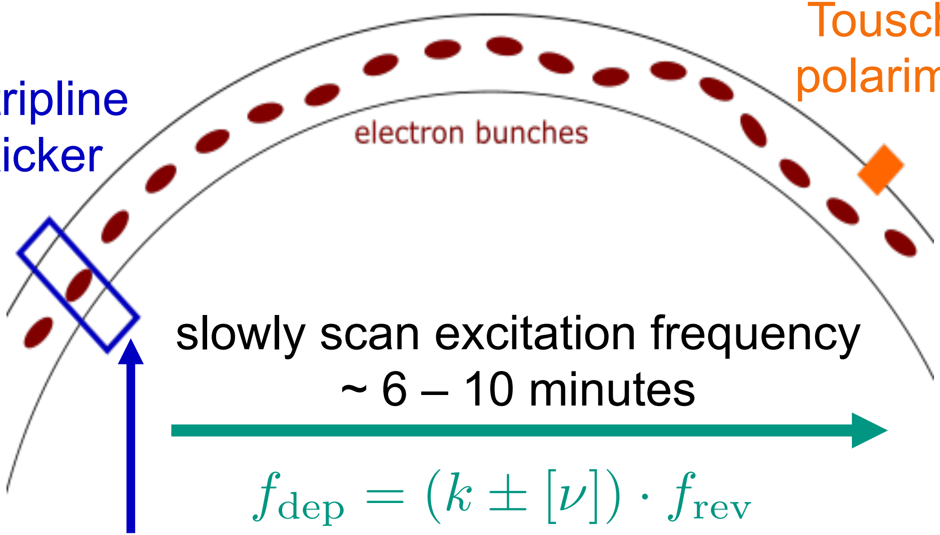
polarisation

wait
~20 minutes

resonant depolarisation

stripline
kicker

Touschek
polarimeter



slowly scan excitation frequency
~ 6 – 10 minutes

$$f_{\text{dep}} = (k \pm [\nu]) \cdot f_{\text{rev}}$$

excite beam

Touschek sensitive region

Measurement analysis

Change in Touschek lifetime because Møller scattering is dependent on polarization

→ **Change in loss rate visible at depolarization frequency**

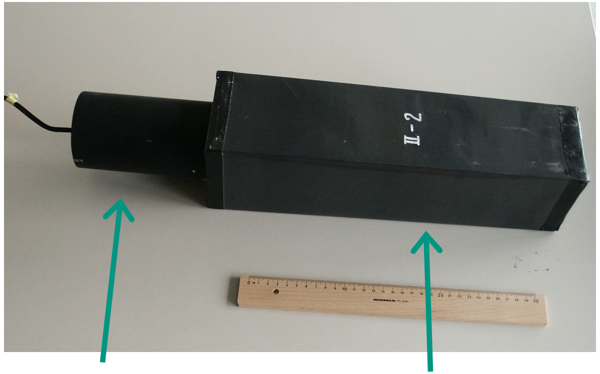
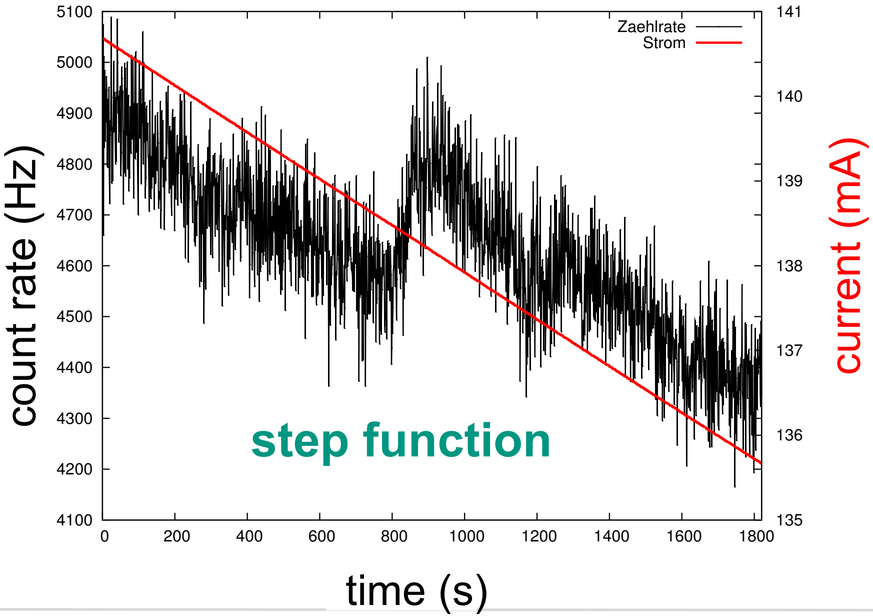


photo multiplier

lead-glass block



Goals of the measurements at KARA

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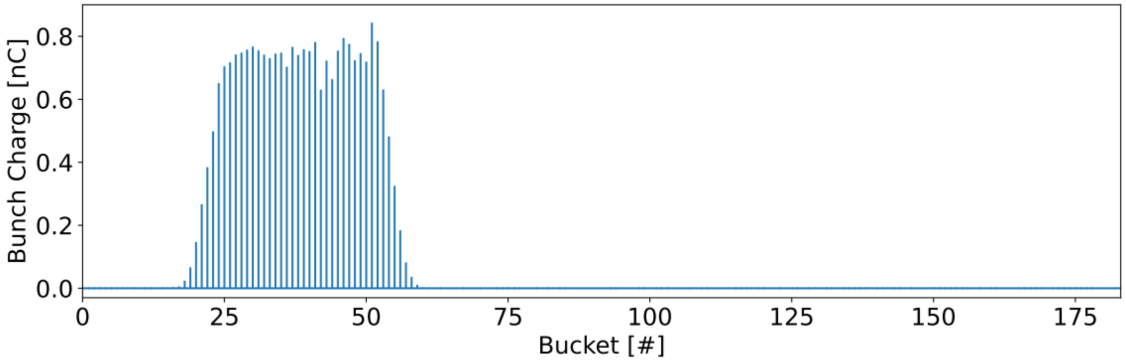
- Impact of scan velocity
- Impact of scan direction
- Impact of beam intensity
- Energy drifts
- Polarization level
- Beam optics and orbit

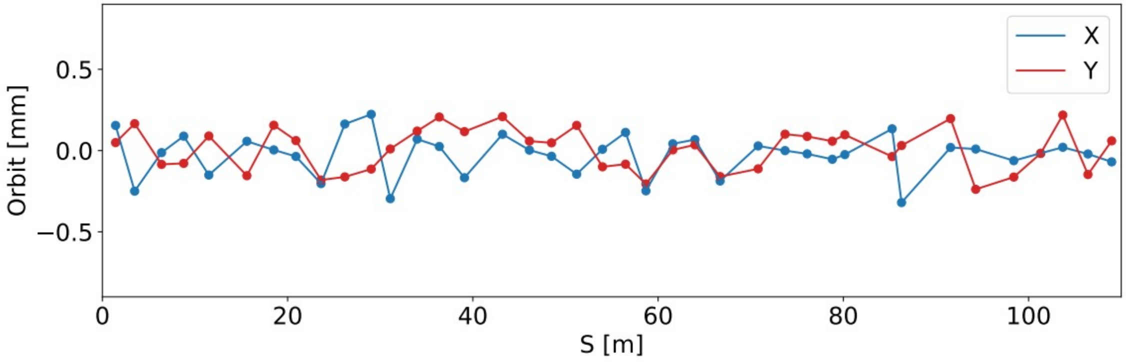
First beam time 30/10 & 31/10/2023

Beam set up

- 2.5 GeV beam energy
- ~ 30 bunches, one train
- 30 to 60 mA beam current



- Low closed orbit



Polarization time

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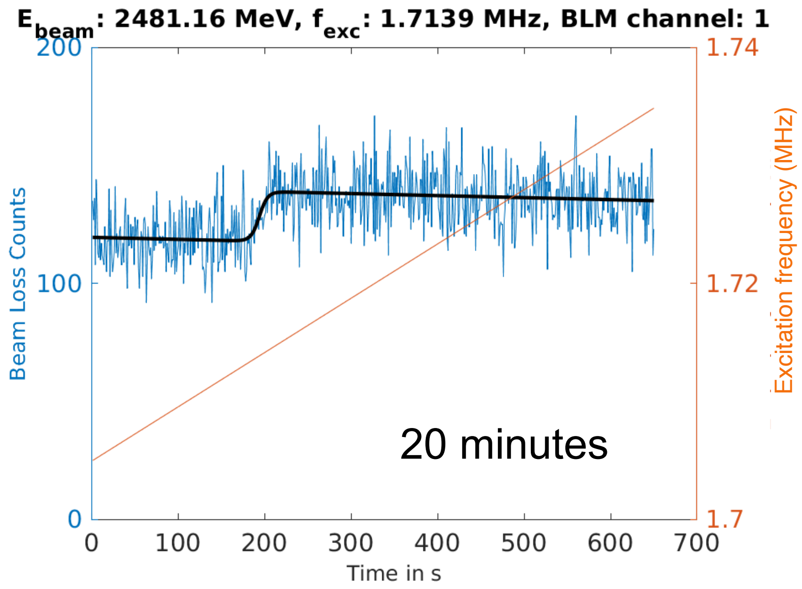
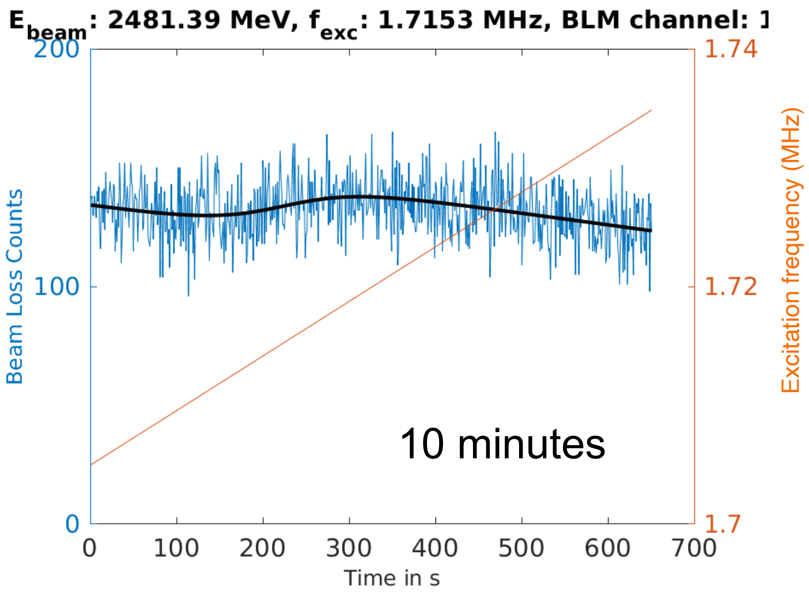
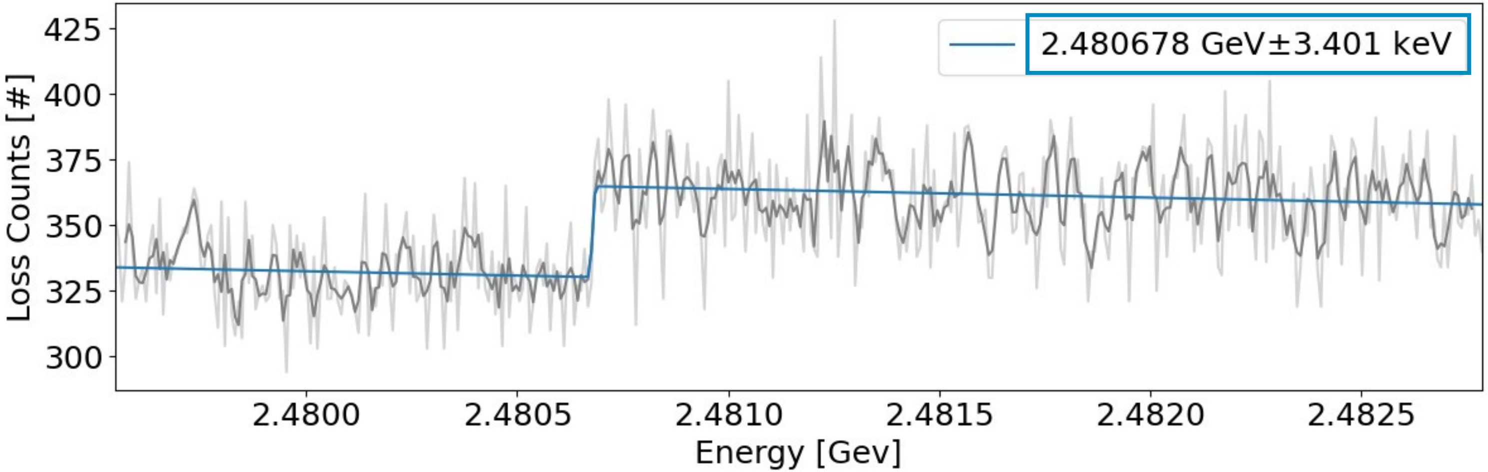




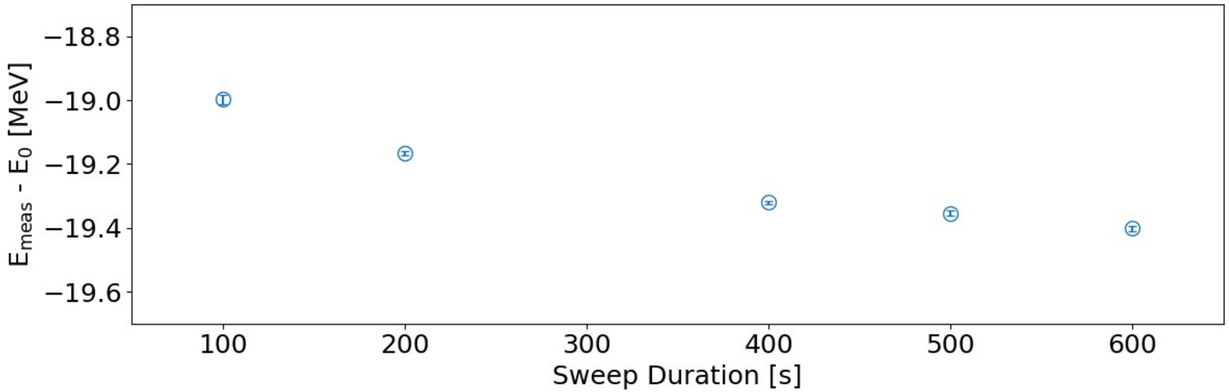
Scan quality depends on polarization time → 20 minutes between measurements

Data analysis



- Fit function: $F(E) = y_0 + \frac{h}{2}\mathrm{erf}((E - E_0)a) + bE + cE^2$
- Moving average over three values of the loss rate to reduce numerical uncertainties

Scan velocity



Blue: 1705 – 1725 kHz

Courtesy: J. Keintzel

- Scanning range: 1705 – 1725 MHz
- Corresponds to: 2.4795 – 2.4830 GeV
- Scan duration: 100 – 600 s

Scan velocity and scan direction

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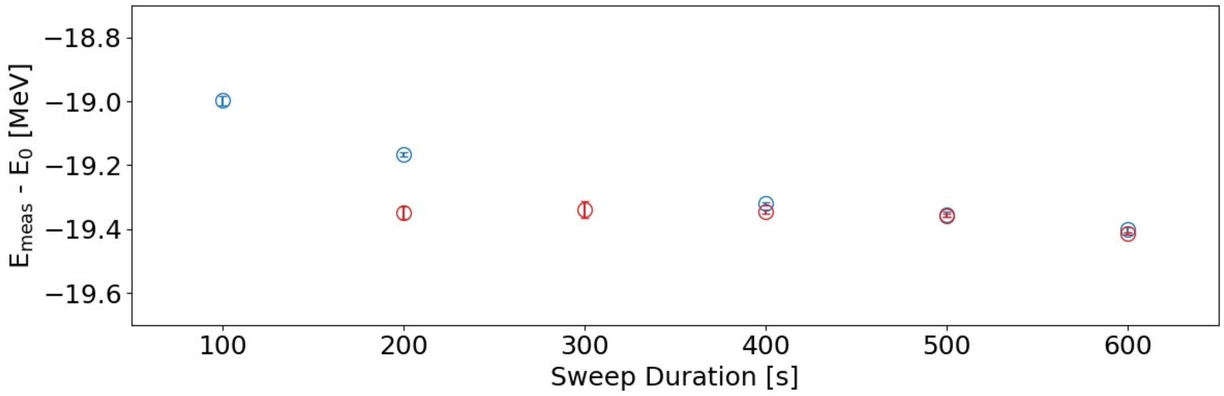


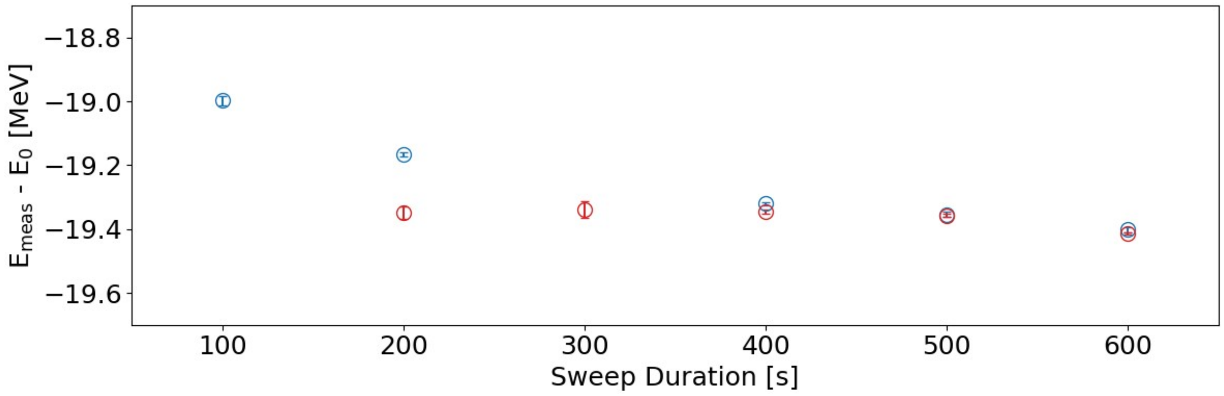
Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

Courtesy: J. Keintzel

- Scanning range: 1705 – 1725 MHz
- Corresponds to: 2.4795 – 2.4830 GeV
- Scan duration: 100 – 600 s
- Reversed scanning direction

Scan velocity and scan direction



Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

Courtesy: J. Keintzel

Observations

- 19.0 – 19.4 MeV lower beam energy
- Larger difference for fast scans
- From measurement or energy drift over time?

Scan velocity and scan direction II

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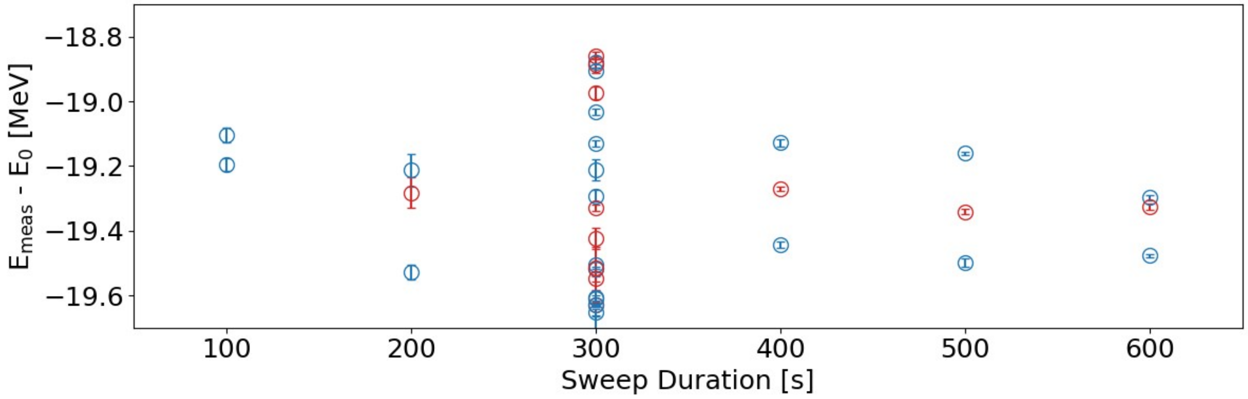


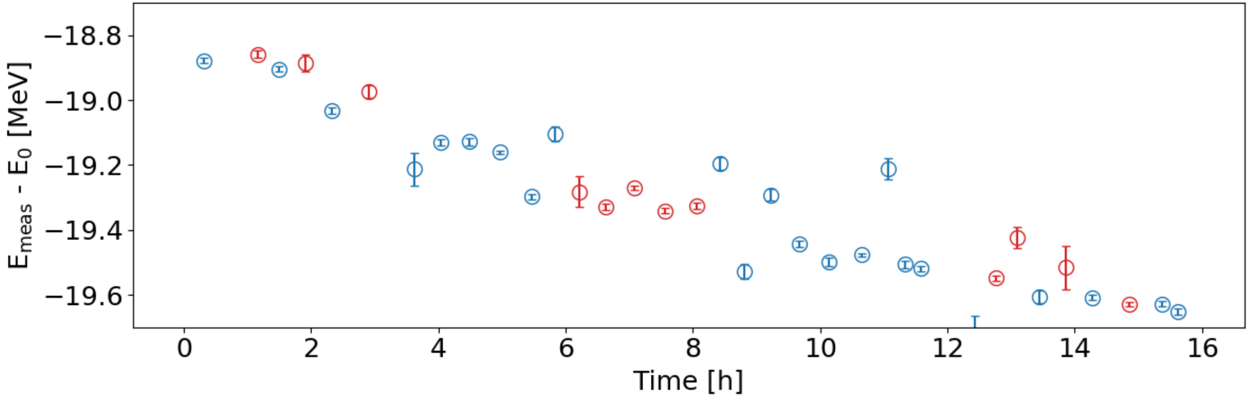
Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

Courtesy: J. Keintzel

- Automated remote measurement campaign
- Various RDP scans during 16 h at night
- No clear dependence on scan duration or direction

Energy drift over 16 h



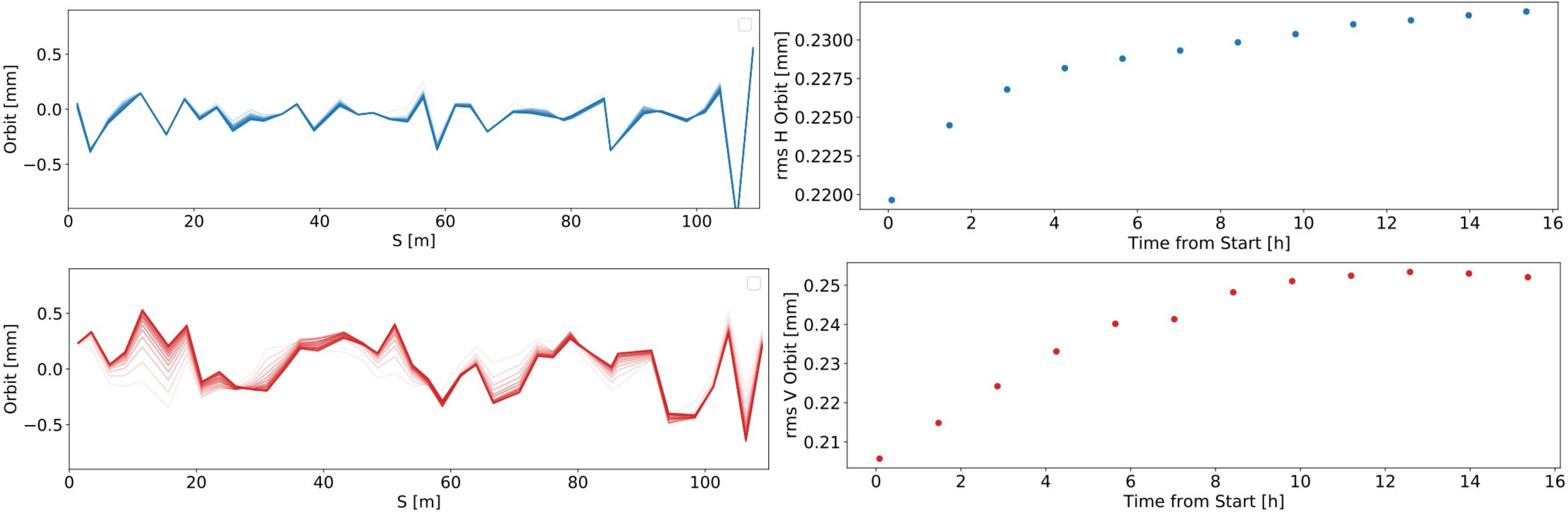
Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

Courtesy: J. Keintzel

- Second overnight measurement campaign of 34 RDP scans
- 0.8 MeV lower beam energy measured after 16 h
- Trend visible for both scanning directions with different velocities
- Sources to be investigated: orbit drifts, temperature drifts etc.

Orbit drifts during 16 h (one fill)



- Drifts in both planes (mainly vertically) but almost stable after 10 h
- Cannot (fully) explain energy drifts, since energy drift has linear trend

Status of measurements at lower energies

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- Challenges encounterd at 2.3 GeV
- No resonance measured so far.

- Could be critical since non-integer part .220 is close to our betatron non-integer tunes.
- At 2.5 GeV: low emittance optics (dispersion leak in all sections)
  Lower energies: achromatic optics (higher emittance and less Touschek)

- To be continued …

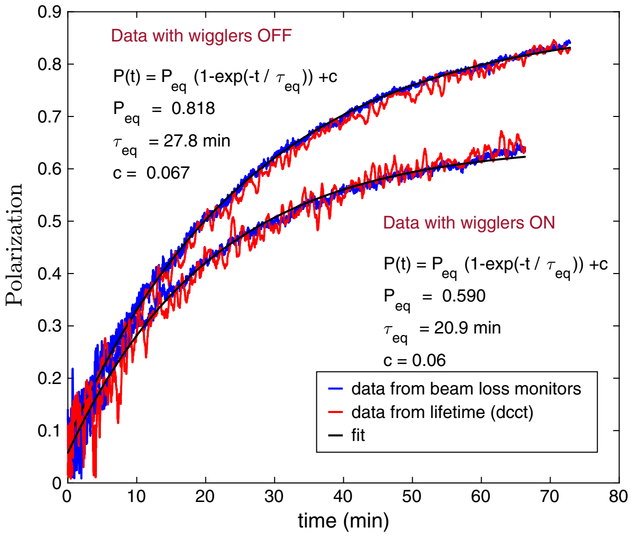
Energy (GeV)	Spin tune	Pol. time (s)	(min)	Depol. freq. (MHz)
2.5	5.673	567	9.4	1.74
2.4	5.446	675	11.2	1.21
2.3	5.220	835	13.9	3.31
2.2	4.993	1042	17.4	2.70
2.1	4.766	1316	21.9	2.08
2.0	4.539	1679	28.0	1.46
1.9	4.312	2170	36.2	3.56
1.8	4.085	2843	47.4	2.95
1.7	3.858	3784	63.1	3.56
1.6	3.631	5124	85.4	1.71
1.5	3.404	7075	117.9	1.10

Summary

- First RSD measurements in context of FCCIS performed at KARA
  - Nominal beam energy 2.5 GeV
  - Measured beam energy ~19.3 MeV lower for all scans
- RSD scans focusing on scanning direction and scanning speed
  - Energy drift observed during long-term measurements
  - Energy drift is independent of scanning speed and direction
- Measurements at lower energies need more attention
- New BLMs as counters for scattered electrons in commissioning

Outlook

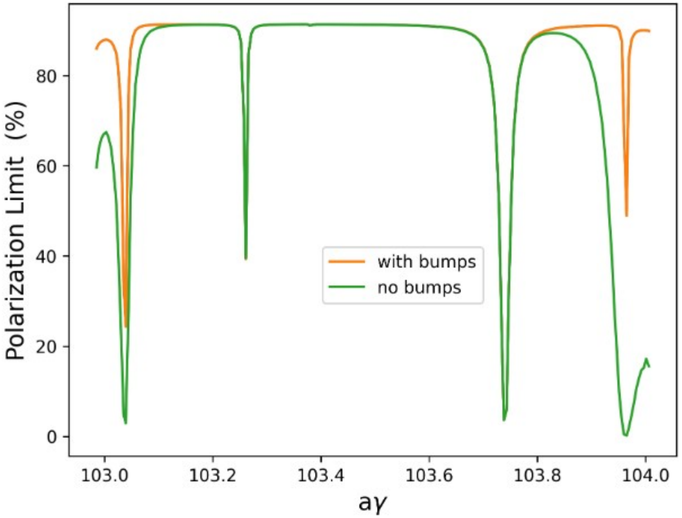
- Absolute polarization measurement



Example: Diamond LS

Phys. Rev. Accel. Beams **22**, 122801, 2019

- Spin matching with vertical orbit bumps



Courtesy: Y. Wu

Thank you for listening!

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Innovation Study

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

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