Resonant spin depolarization and Compton backscattering Experience at ANKA/KARA and possible beam tests

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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

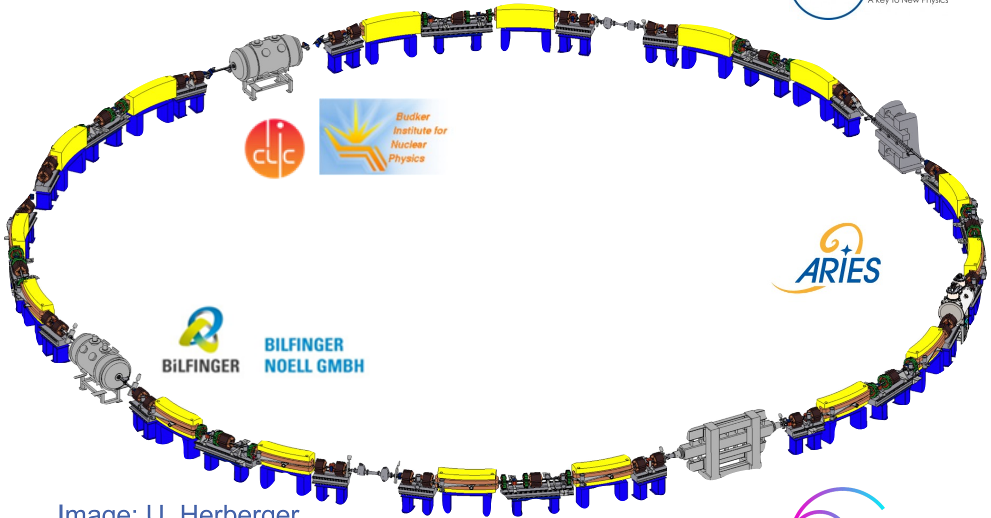
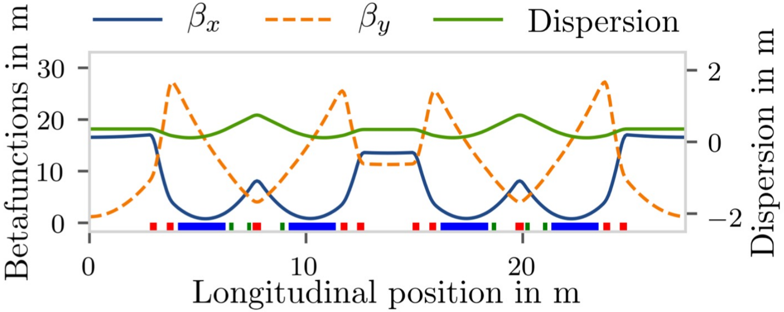
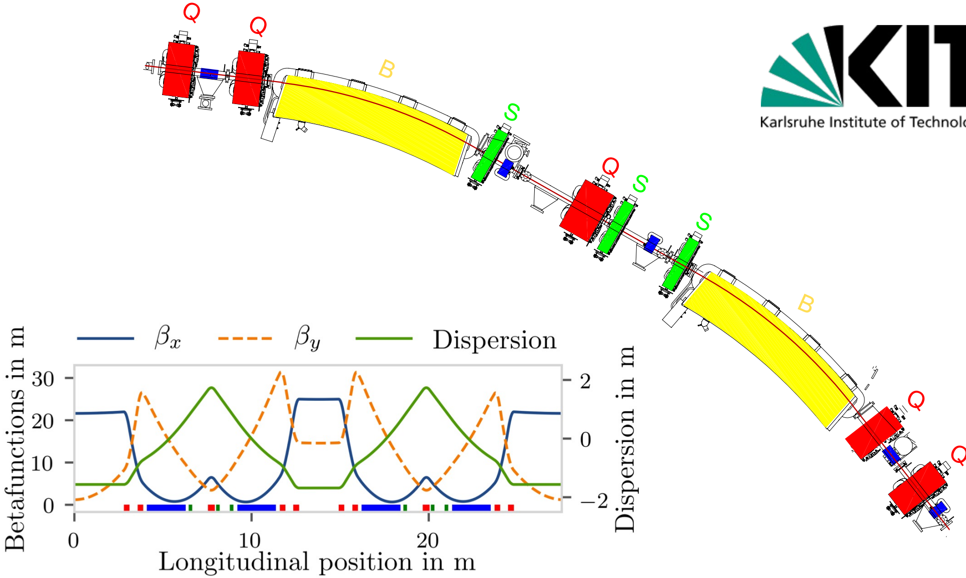


Image: U. Herberger

www.ibpt.kit.edu/kara

KARA operation modes





User optics: $\boldsymbol{\alpha}_c = 9 \times 10^{-3}$

Negative alpha optics: $\boldsymbol{\alpha}_c = -8 \times 10^{-3}$

- Operation modes in 2022:

  0.5/2.3/2.5 GeV user optics, 0.5/1.3 GeV low-alpha, 0.5/1.3 GeV negative alpha

Resonant spin depolarization – reminder

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- Asymmetry in the spin-flip probability due to emission of synchrotron radiation
  → build-up of transverse polarization
- Spin vector precedes in presence of electric and magnetic fields

$$\nu = a\gamma$$

$$a = (g_\mathrm{e} - 2)/2 = 0.001159652193$$
$$\gamma = E_\mathrm{beam}/m_0 c^2$$

- If a vertical excitation with spin-tune resonance is applied, the polarization is resonantly destroyed.
- The resonance is very narrow, so if the frequency of the depolarizer field is swept slowly, the resolution is very good.

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

- If depolarization occurs, spin tune and beam energy can be determined.

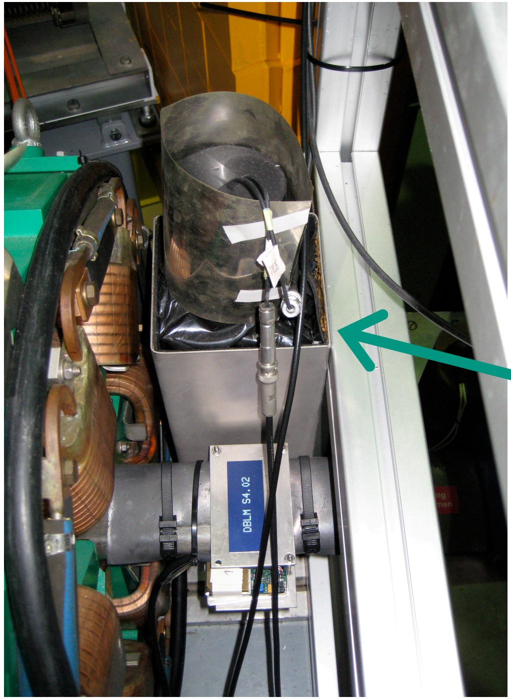
Resonant spin depolarization – history

- Since 2004: Setup to measure beam energy at ANKA/KARA with resonant spin depolarization
  - A.-S. Müllller *et al.*, "Energy calibration of the ANKA storage ring", https://accelconf.web.cern.ch/e04/PAPERS/THPKF022.PDF
- 2008: New frequency generator for the stripline kickers
  - T. Bückle, diploma thesis (German) https://publikationen.bibliothek.kit.edu/1000022044

$$\Rightarrow \frac{\Delta E}{E} = 2.88 \times 10^{-5}$$

- 2014: Setup updated: frequency generator replaced by bunch-by-bunch feedback system, new Matlab scripts for automated procedure including analysis
- Setup in operation since then: Measurement campaigns in 2015, 2020, 2021
  - momentum compaction factor and drift of beam energy

Resonant spin depolarization – setup



Toushek sensitive region

- Change in Touschek lifetime because Møller scattering is dependent on polarization
  → Change in loss rate visible at depolarization

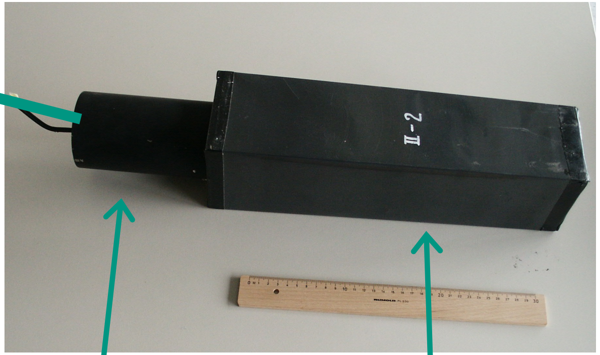


Photo multiplier

Lead-glass block

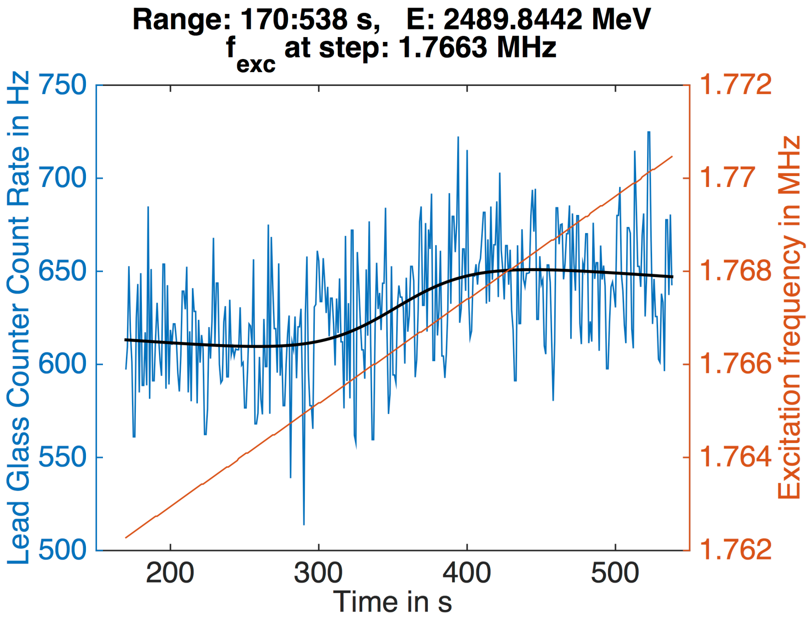
- Logging lossrate and excitation frequency
- Monitoring the vertical beam size to ensure that there is no betatron resonance

Resonant spin depolarization – analysis

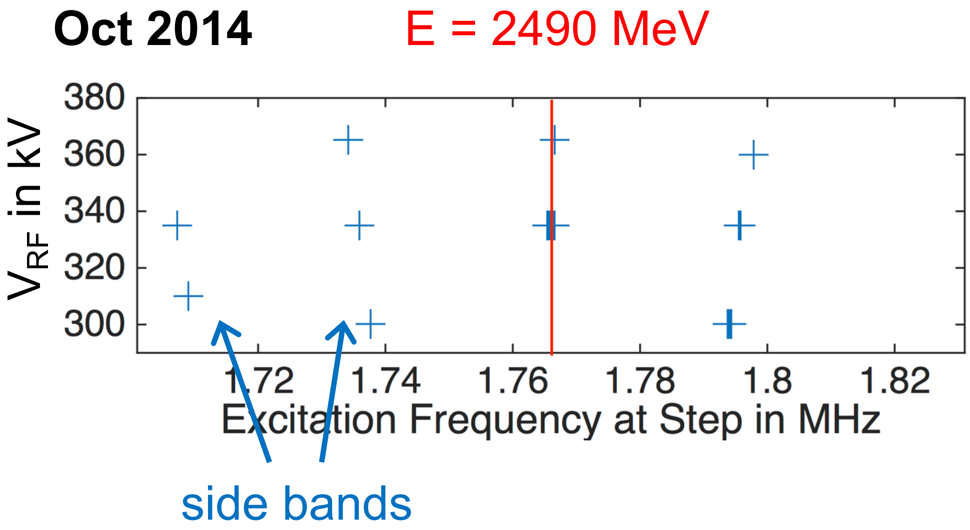
- Step function fit to determine frequency at which depolarization occurs

$$r(t) = a - b \cdot t + \frac{\Delta r}{1 + \exp\left(-\frac{t - t_d}{\sigma_d}\right)}$$

- Matlab script automatically
  - scans excitation frequency,
  - creates Elog entry, saves data
  - fits step function and creates plot.
- Typical relative energy uncertainties determined from the width σ_d are of the order of 2×10^{-5}.

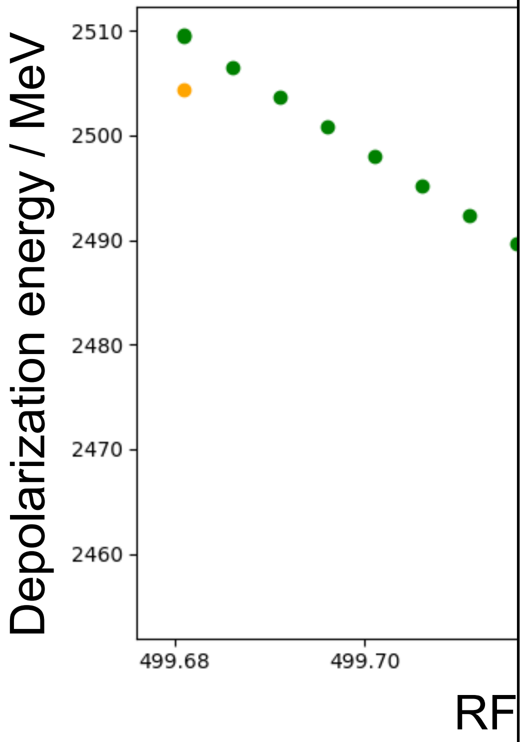


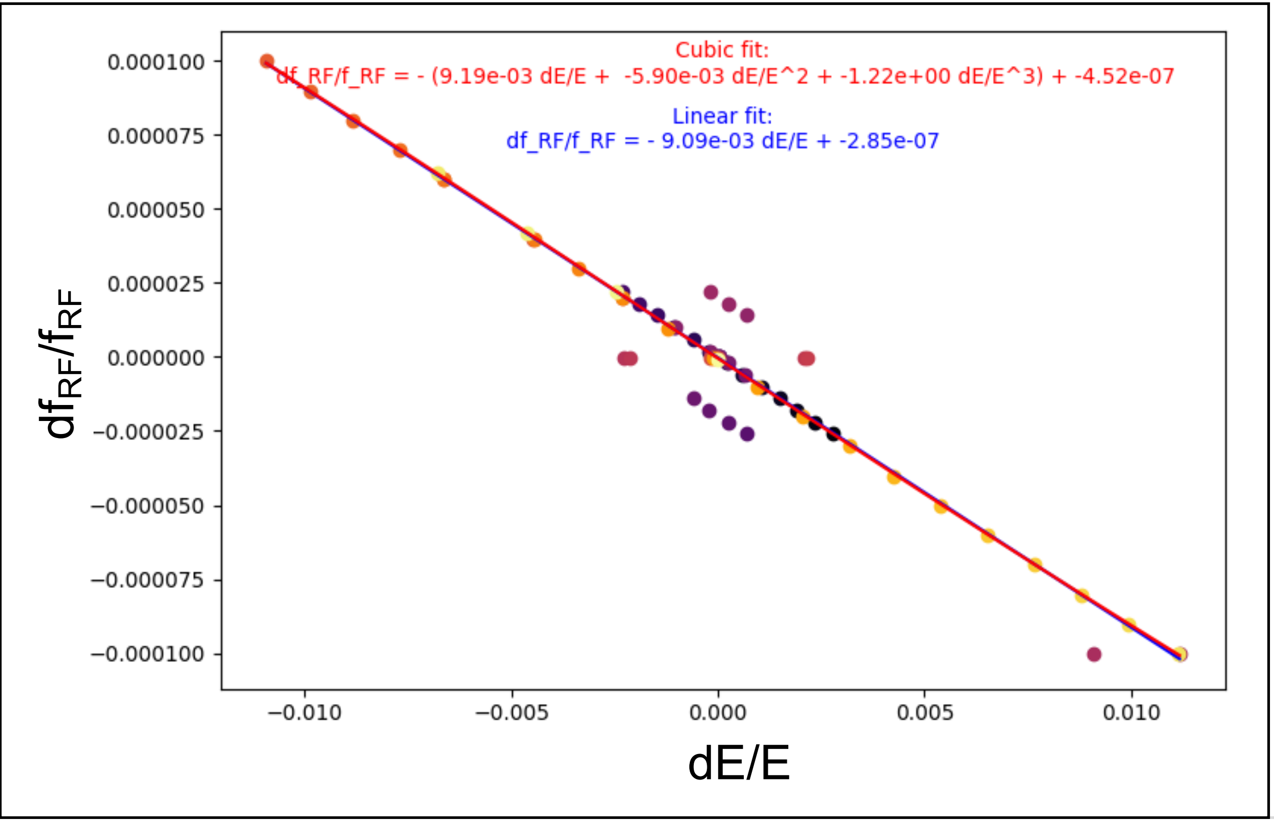
Resonant spin depolarization – results



- **Important:** Resonant depolarization also occurs on side bands!
- Variation of RF voltage changes synchrotron tune, but not beam energy
- Side band: excitation frequency shifts
- Energy band: excitation frequency stays the same

Results from 2021





Courtesy M. Brosi

Resonant spin depolarization at KARA

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- A reliable setup for resonant spin depolarization is installed and in operation
- Typical time for polarization build-up at 2.5 GeV: 10 min
- Matlab scripts are available that allow fully automated measurements
  - Change of beam energy via frequency modifications
  - Change of RF voltage
  - Scans of side bands
  - Read-out, analysis, visualization, and documentation

→ Measurements can be performed overnight

→ No idle time during polarization build-up

Outlook

- Scripts are currently written in Matlab but will be migrated to python
- A new BLM system is currently being installed, evaluations are going on, if it can be used for resonant spin depolarization
- Resonant spin depolarization at 2.3 GeV
- What are you interested in?

Compton backscattering at “ANKA”

- Precise energy measurement was required for lower energies (low alpha operation)
- RSD not feasible because of long polarization time

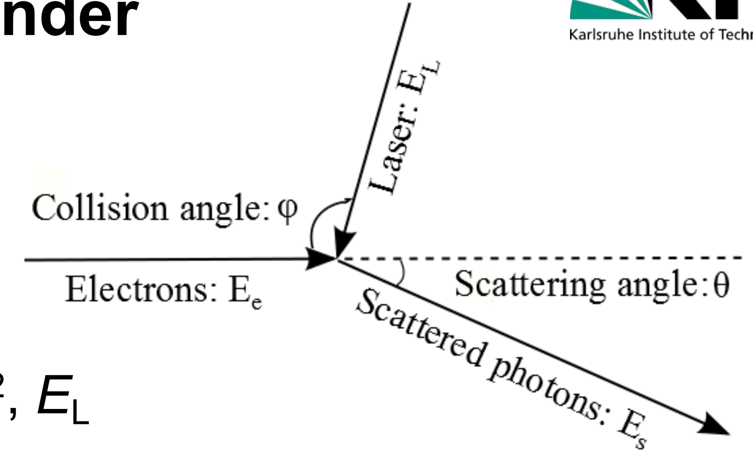
- **Doctoral dissertation of Cheng Chang:** “Precise determination of the electron beam energy with Compton backscattered laser photons at ANKA” (2016)
  - https://publikationen.bibliothek.kit.edu/1000051914

- IPAC’15 contribution C. Chang *et al.*, “First Results of Energy Measurements with a Compact Compton Backscattering Setup at ANKA” (2015)
  - https://accelconf.web.cern.ch/IPAC2015/papers/mopha040.pdf

Compton backscattering – reminder

- Energy of the scattered photons

$$E_\mathrm{s} = \frac{E_\mathrm{L}(1-\beta\cos\varphi)}{1-\beta\cos\theta + E_\mathrm{L}/E_\mathrm{e}[1-\cos(\theta-\varphi)]}$$



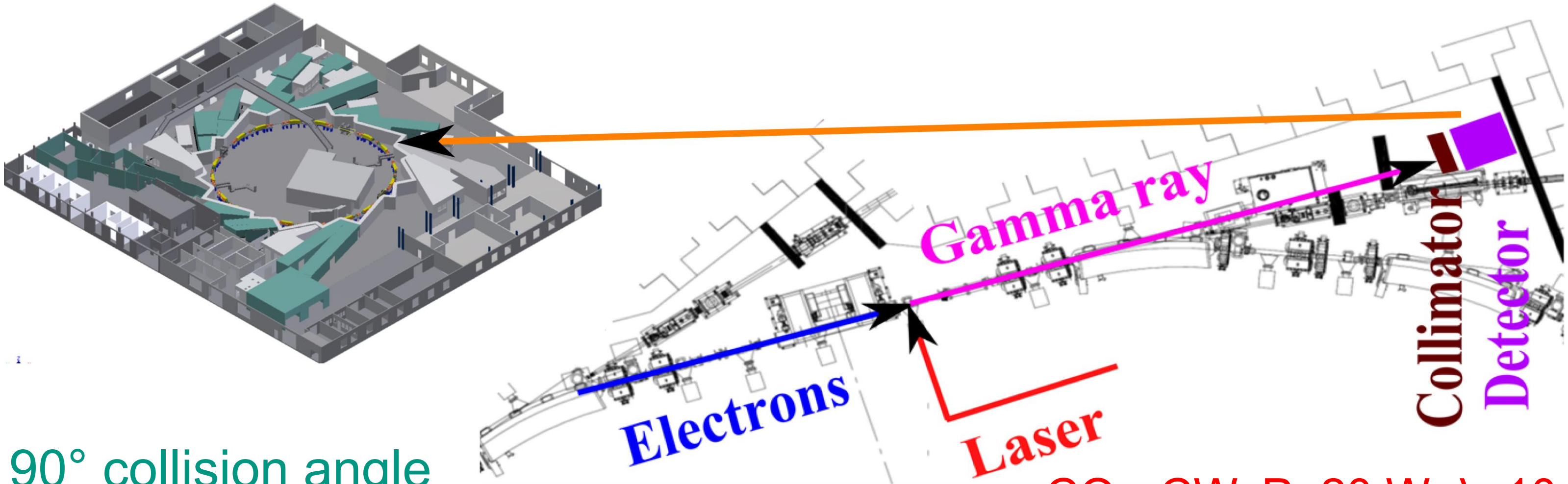
- With measured φ, E_max and known mc^2, E_L

$$\rightarrow\ E_\mathrm{e} \approx \frac{mc^2}{2\sin\frac{\varphi}{2}}\sqrt{\frac{E_\mathrm{max}}{E_\mathrm{L}}} \qquad (\theta = 0)$$

- Relative uncertainty

$$\frac{\sigma_\mathrm{e}}{E_\mathrm{e}} = \sqrt{\left(\frac{\sigma_{E_\mathrm{L}}}{2E_\mathrm{L}}\right)^2 + \left(\frac{\sigma_\varphi}{2\tan(\varphi/2)}\right)^2 + \left(\frac{\sigma_{E_\mathrm{max}}}{2E_\mathrm{max}}\right)^2}$$

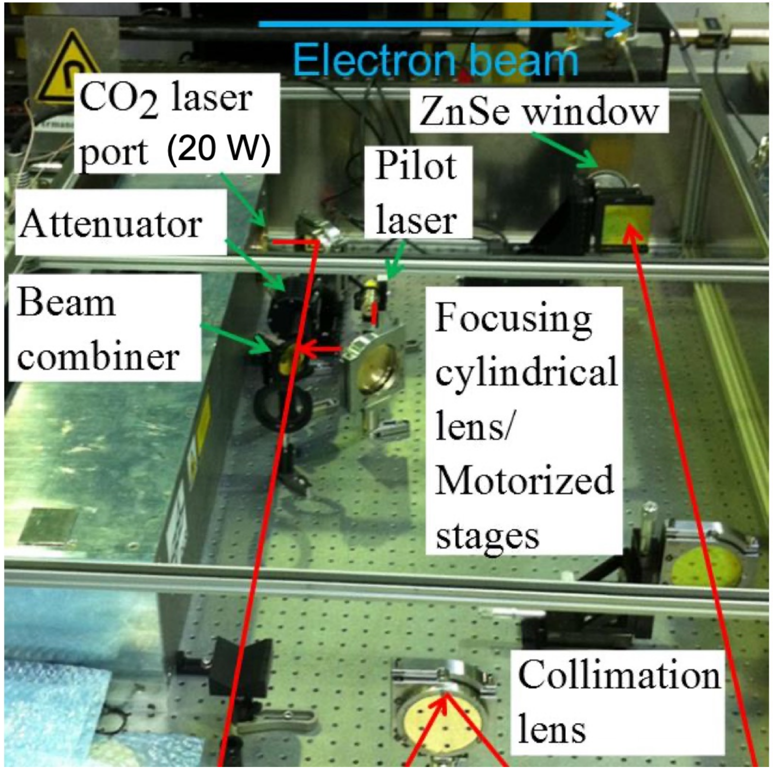
Former Compton backscattering setup at ANKA

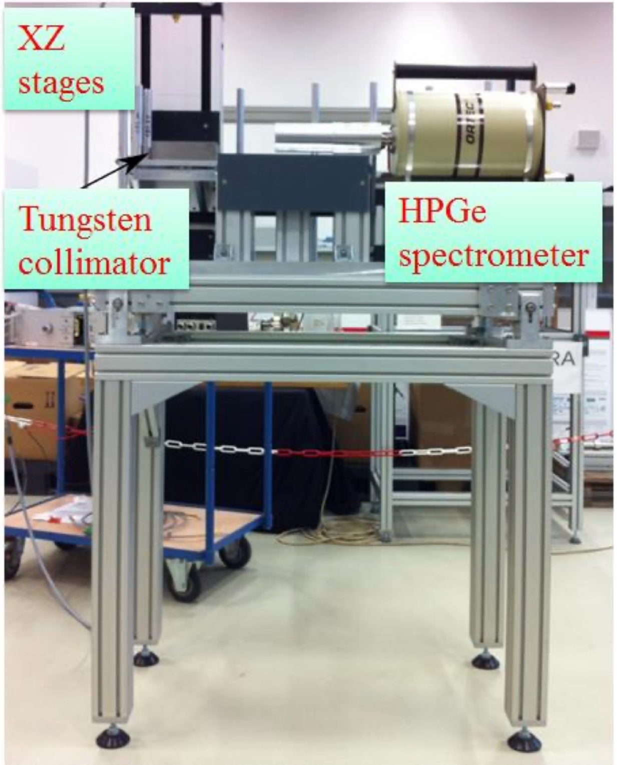


CO_2, CW, P=20 W, λ=10.2 μm

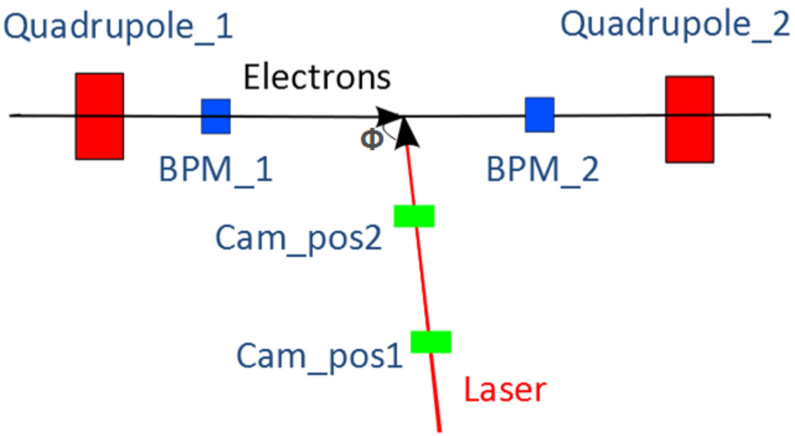
- 90° collision angle
- 0° scattering angle
- Very compact setup (laser coupled in via ion getter pump port)
- Detector used a temporarily free 0° frontend

Compton backscattering setup





Measurement of the collision angle



$$\frac{\sigma_e}{E_e} = \sqrt{\left(\frac{\sigma_{E_L}}{2E_L}\right)^2 + \left(\frac{\sigma_\varphi}{2\tan(\varphi/2)}\right)^2 + \left(\frac{\sigma_{E_{max}}}{2E_{max}}\right)^2}$$

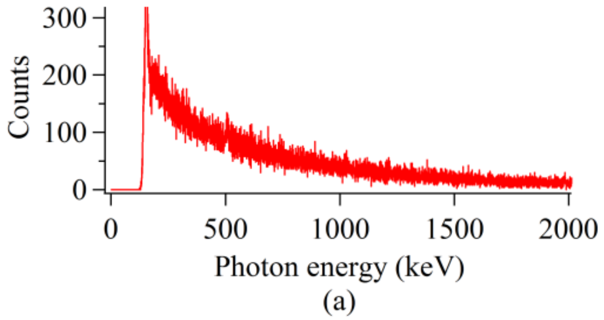
10^{-6}

- Collision angle crucial for energy precision
- Reference line: center of two quadrupoles
- Angle between laser direction and reference line measured with laser tracker and camera
- BPMs measure electron beam orbit relative to reference line

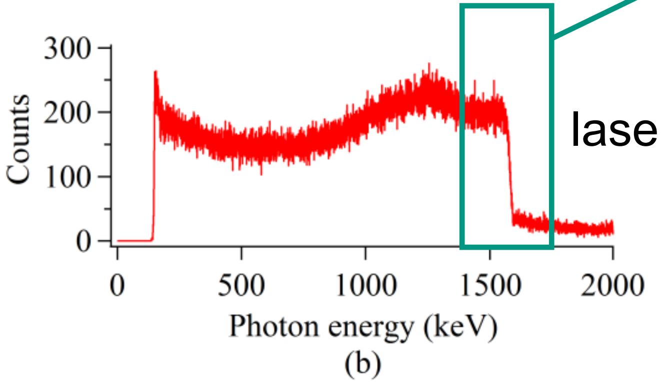
$\varphi = 91.620° \pm 0.012°$

$\sigma_\varphi/\tan(\varphi/2) = 2.0 \times 10^{-4}$

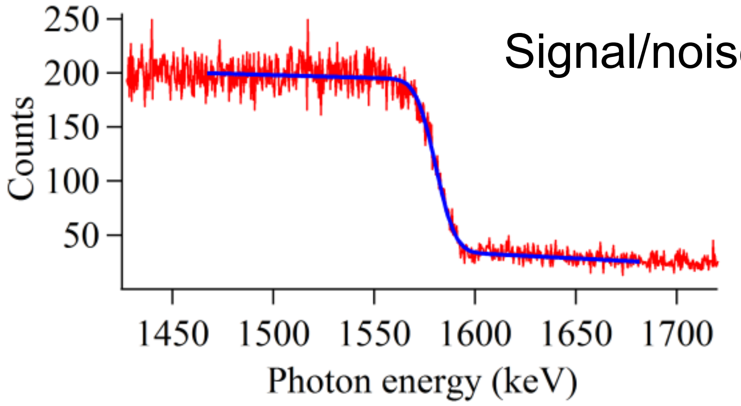
Compton backscattering – Evaluation



laser off



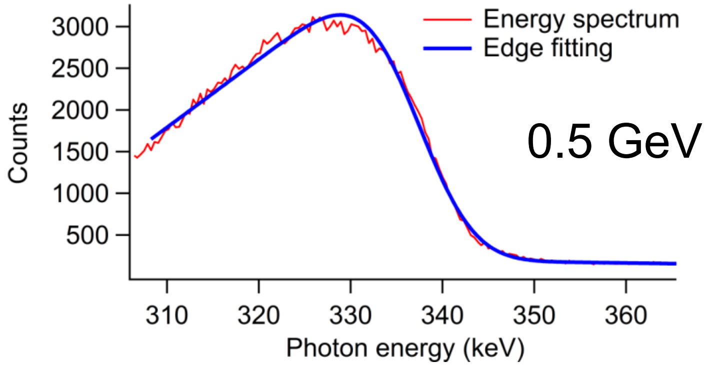
laser on

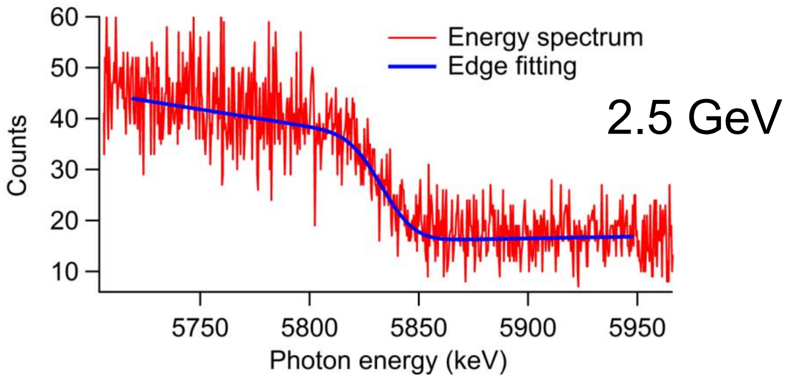


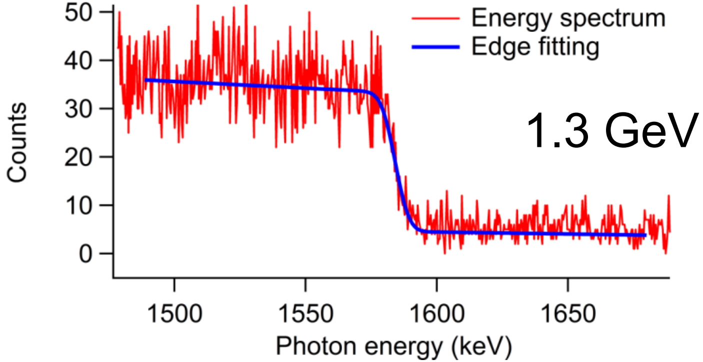
Signal/noise ~ 3

- Compton edge curve fit by a six parameter erfc-like function
- E_{max} = 1580.44 keV ± 0.28 KeV
- $\sigma_{Emax}/E_{max} = 1.8 \times 10^{-4}$ (χ^2/ndf~524/555)

Compton backscattering – results

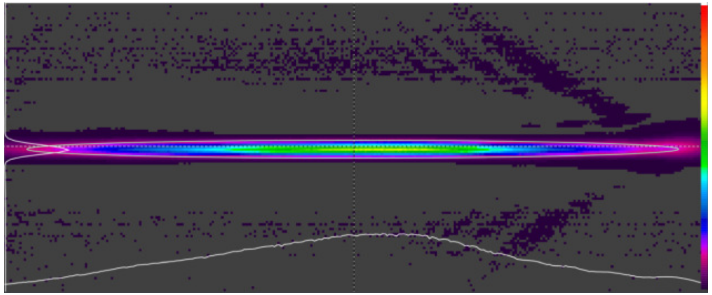






- 0.5 GeV: $E_e \pm \sigma_{Ee} = 494.11 \pm 0.06$ MeV
- 1.3 GeV: $E_e \pm \sigma_{Ee} = 1288.5 \pm 0.2$ MeV
- 2.5 GeV: $E_e \pm \sigma_{Ee} = 2472.6 \pm 0.4$ MeV

Challenges of our setup



- 90° collision angle reduces overlap of laser and electrons

→ Elliptical laser beam shape

- Biggest uncertainty from drifts of the laser spot over time
- Longer integration times at higher energies
- Detector needed to be recalibrated when it warmed up
- Detector calibration above 3 MeV required dedicated sources
- Alignment of collimator & detector

Compton backscattering – summary

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- We had a setup with 90° collision angle that worked with 10^{-4} precision and provided a compact alternative to small-angle setups.
- Setup was decommissioned in 2016 (new undulator has been installed and frontend was no longer available)
- We are happy to share our experience, especially if a setup with 90° collision angle is of interest for FCC-ee.

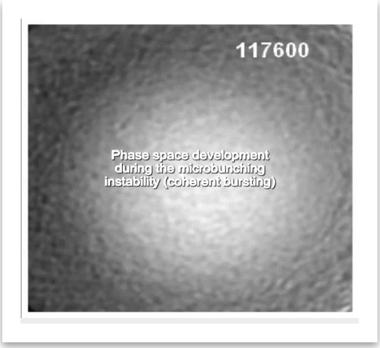
Potential beam tests at KARA

- Measurements of resonant spin depolarization

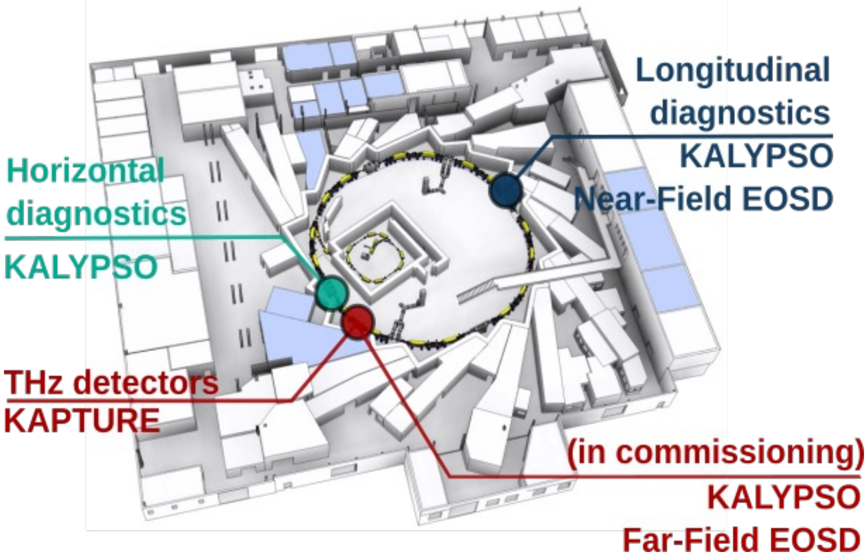
- Turn-by-turn and bunch-by-bunch diagnostics @KARA

phase space tomography

- Complete phase space image reconstructed from time interval of 61 µs
- “Randon morphing“ between independent measurement



S. Funkner et al. arXiv preprint, arXiv:1912.01323



Get in touch with us! ☺
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Karlsruhe Institute of Technology

KARA Karlsruhe Research Accelerator

IBPT Institute for Beam Physics and Technology

Thank you for your attention!

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