FUTURE CIRCULAR COLLIDER

CERN

Experiments at Existing Facilities - KARA

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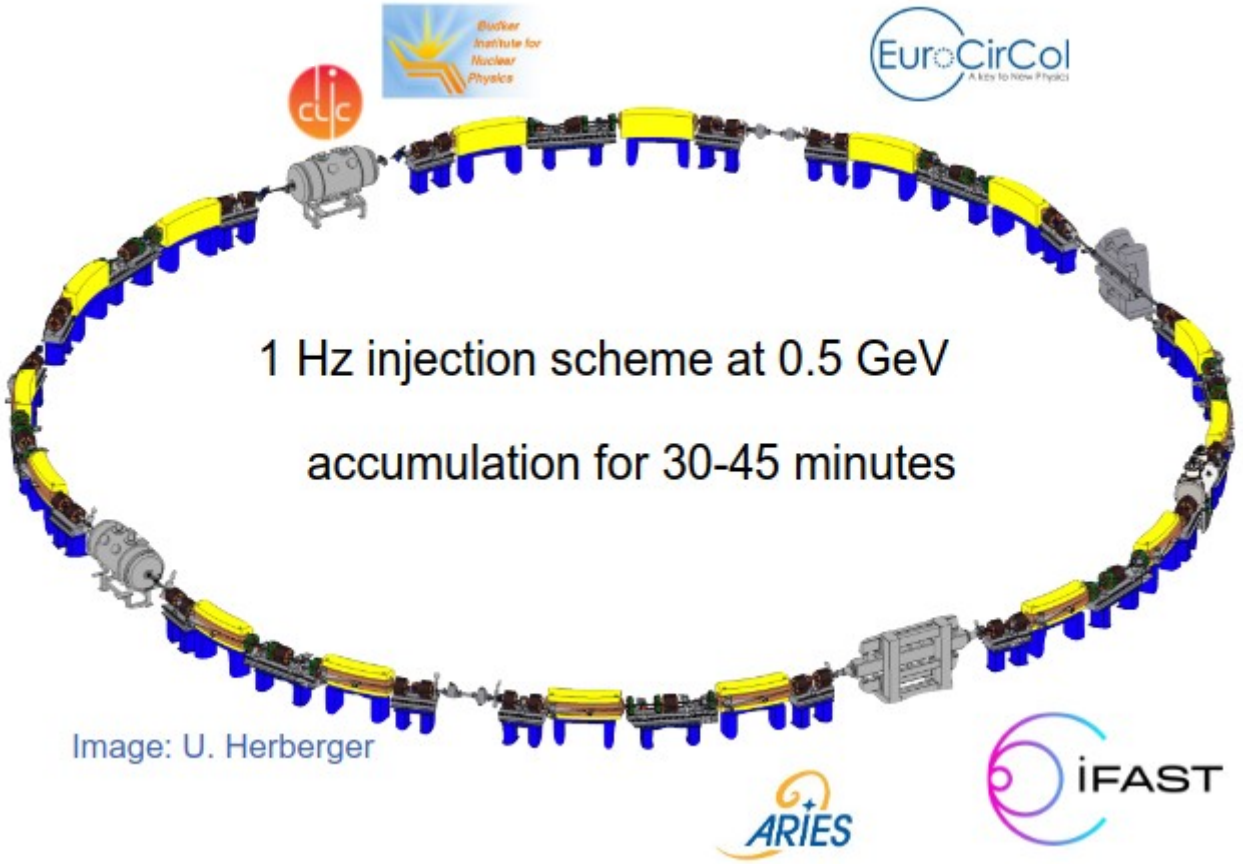
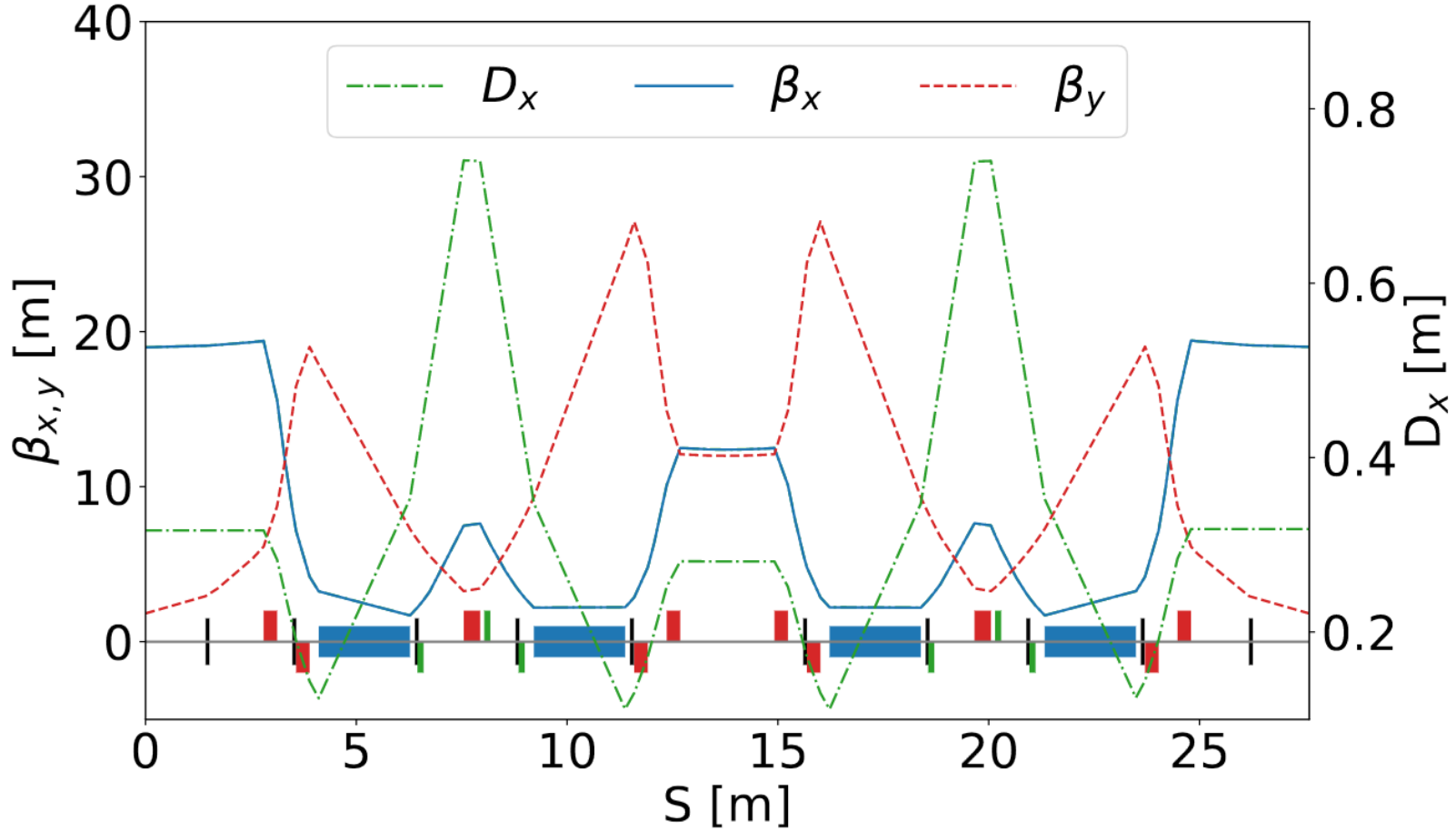
KARA

- KArlsruhe Reasearch Accelerator (KARA) at Karlsruhe Institute of Technology (KIT)
- Synchrotron light source user and test facility

Parameter	Value
Energy	0.5 - 2.5 GeV
Beam Current	0.1 - 200 mA
Harmonic Number	184
Circumference	110.4 m
RF	500 MHz
Tunes (horizontal / vertical)	6.77 / 2.82
Synchrotron Frequency	31 - 35 kHz



Lattice and Optics

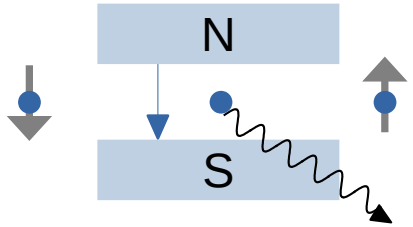


4 Dipoles 6 Sextupoles

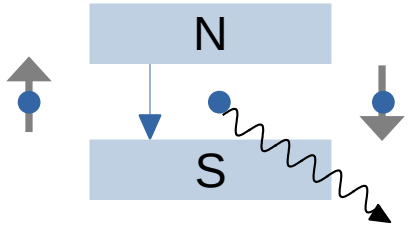
10 Quadrupoles 10 Beam Position Monitors

Polarization

More likely
(by factor ~25)



Less likely



- Statistically every 10^{10th} emitted synchrotron photon flips the spin
- Probability depends on the initial spin orientation

- Leads to a natural **polarization build-up** over time
- Orientation is **anti-parallel** to the guiding magnetic field
- In a flat synchrotron only vertical bending → vertical spin orientation
- Known as Solokov-Ternov-Effekt

- Maximum theoretical polarization of **92.4 %**
- Decreases typically with orbit and optics errors
- Polarization time at KARA: **~ 10 min at 2.5 GeV**

Spin Tune and Beam Energy

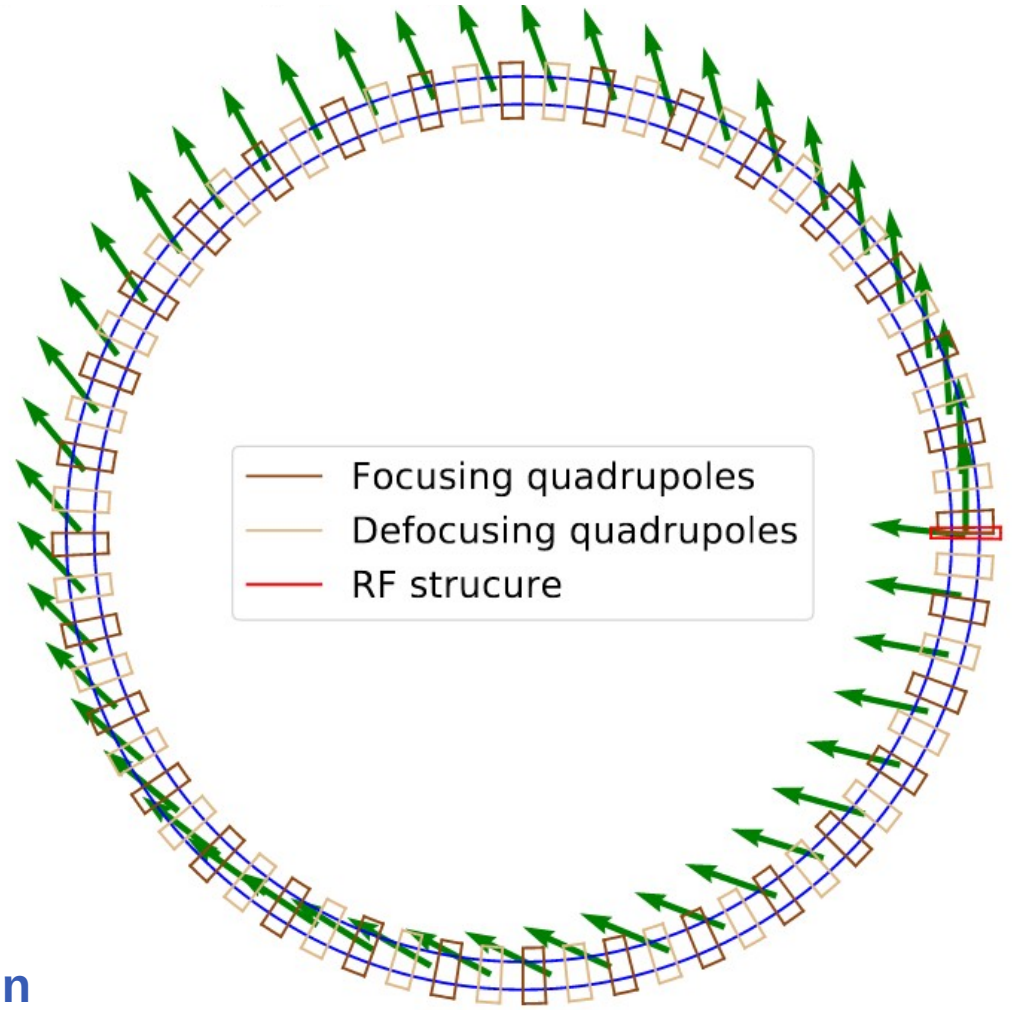
- Spin precesses through the lattice
- Spin tune ν: Number of spin precessions per turn

- In an error-free flat machine without solenoids
- Purely vertical spin orientation

a … gyro-magnetic anomaly
γ_{Rel} … Lorentz-factor

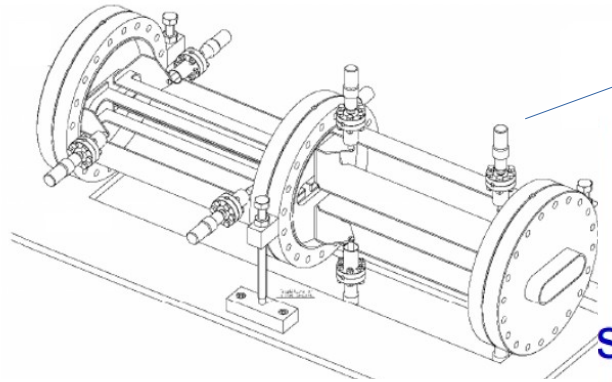
$$\nu = a * \gamma_{Rel}$$

Spin tune measurement ⟺ **Beam energy determination**



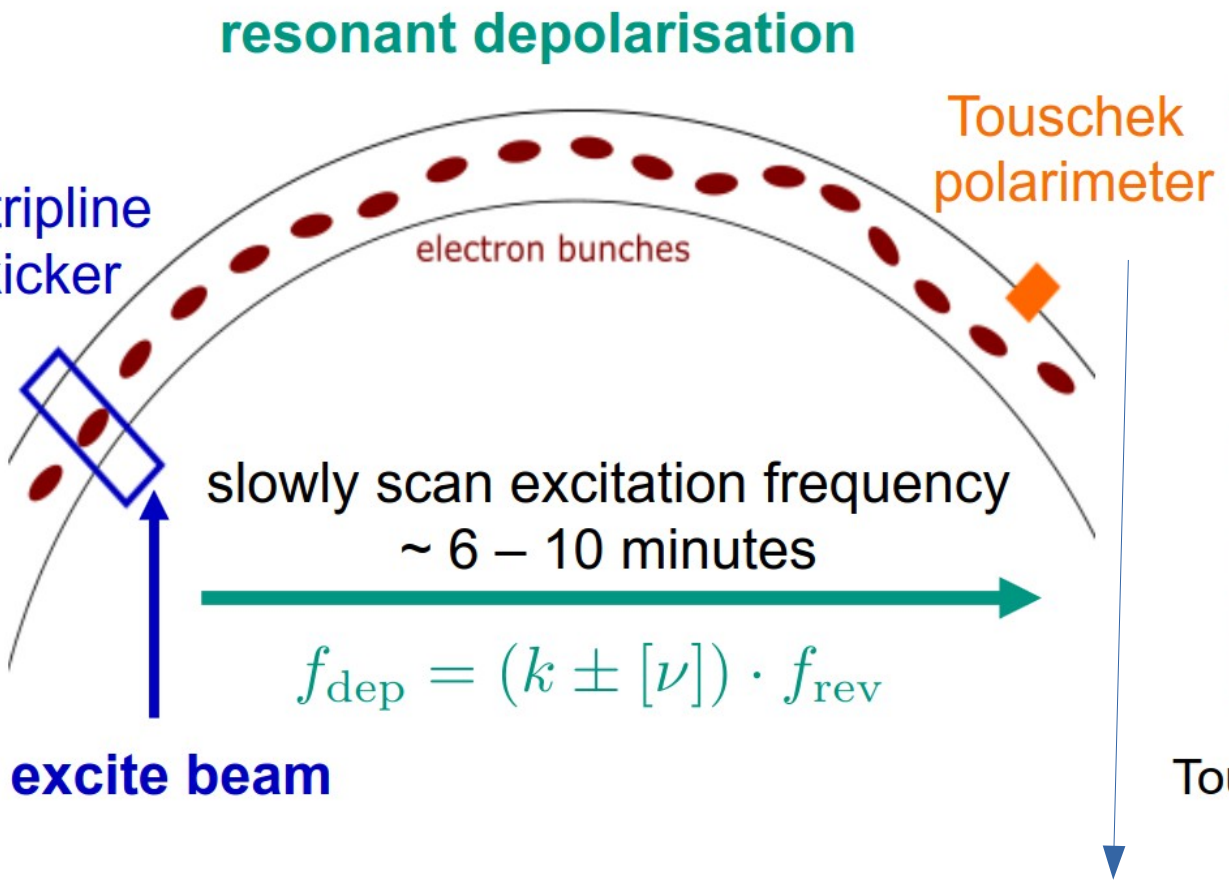
Courtesy: V. Caudan

RDP Measurement



Talk: W. Höfle, “First thoughts on the FCC depolarizer”

- Vertical stripline
- 30 cm long
- Field of 50 µT
- Kick of about 1.7 µrad



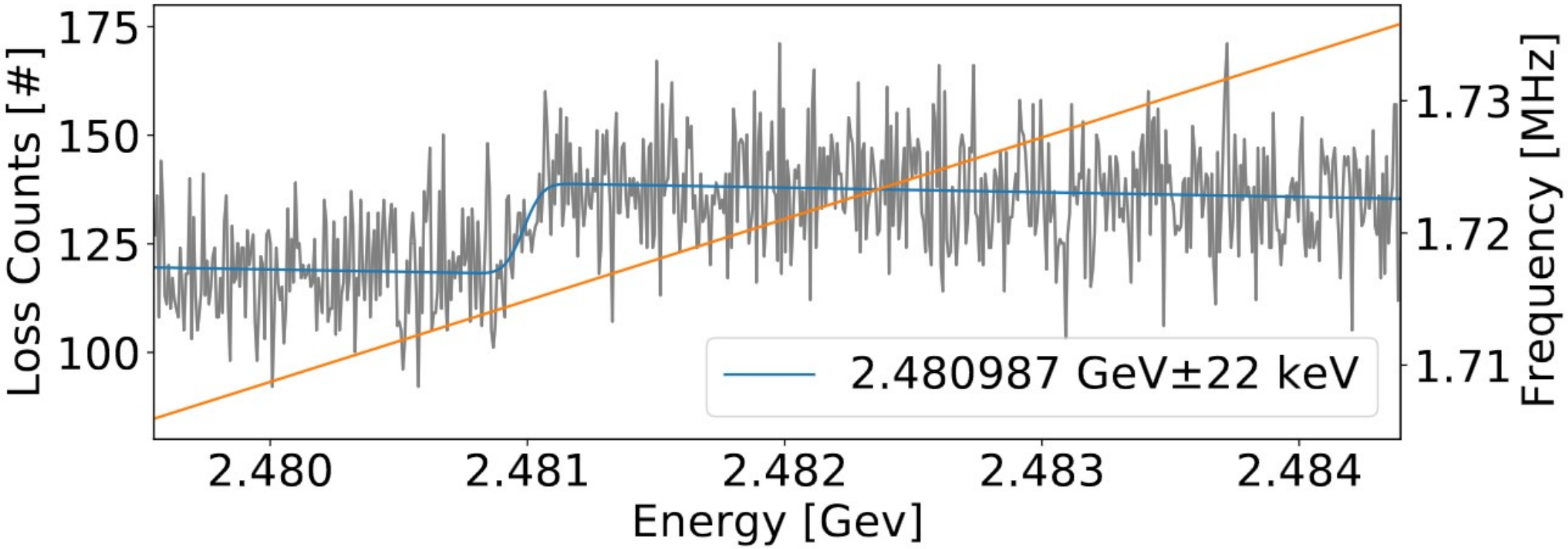
Touschek sensitive region

E. Blomley et al., IPAC’24, WEPG51

Talk: R. Kieffer, “The FCC Polarimeter”

RDP Scan Result

- Change in Touschek lifetime / scattering rate since Moller scattering depends on polarization
- Change of loss rate over depolarizing frequency gives spin



Goals of KARA Measurements

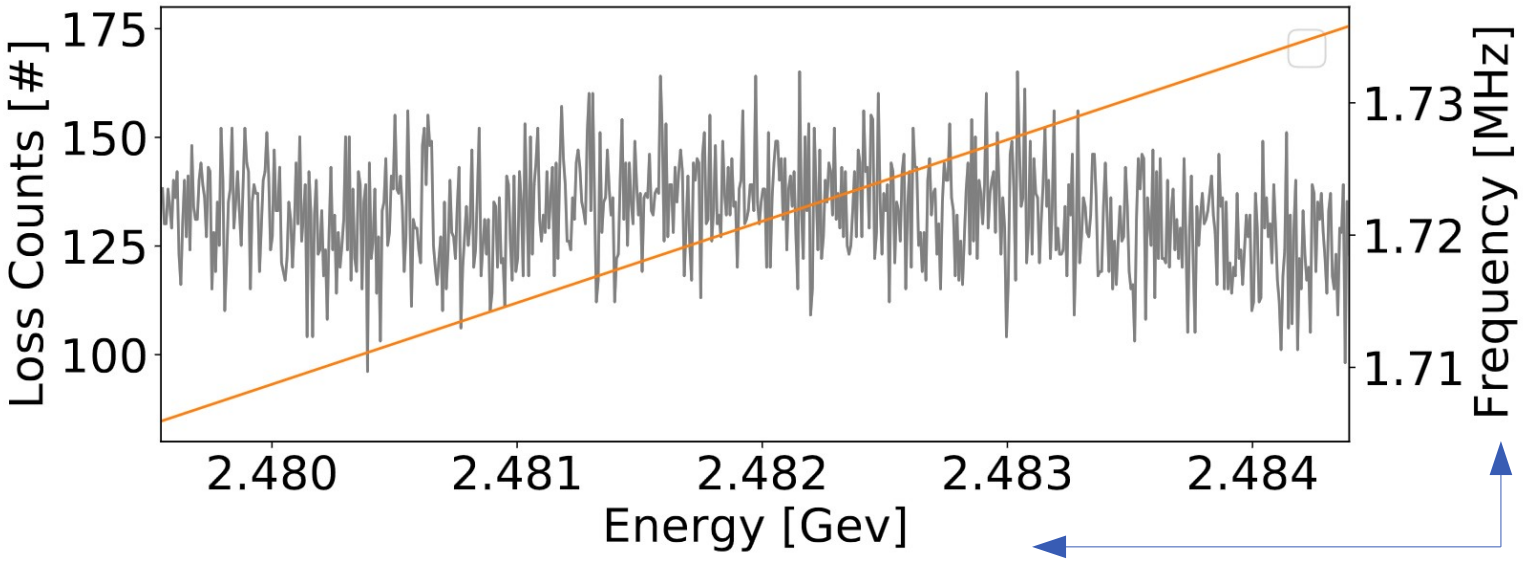
- Understand systematics and uncertainties of RDP scans
  - Impact of scan velocity
  - Impact of scan direction
  - Impact of beam intensity
  - Energy drifts ?
  - Beam orbit and optics

- Simulation of RDP scans at KARA could be studied

- Improved understanding of machine optics
  - Orbit drifts
  - Model accuracy
  - Linear optics and comparison to model
  - Non-linear and chromatic optics

Polarization Time

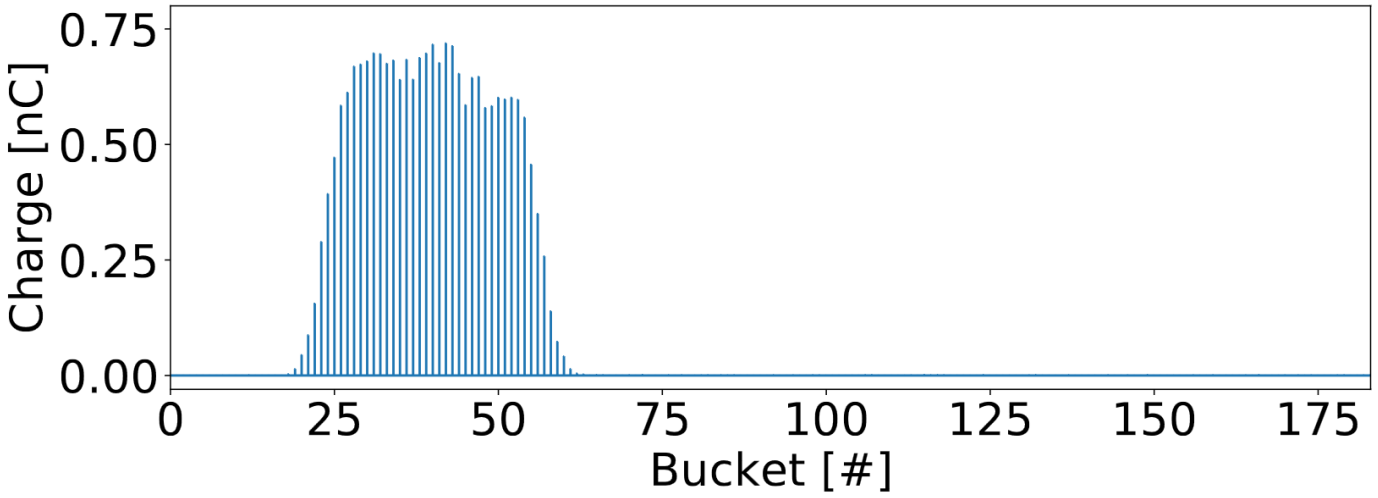
- Polarization needs to be build up –> ensure sufficient waiting time between scans
- 10 min for self polarization not sufficient –> 20 min in-between scans

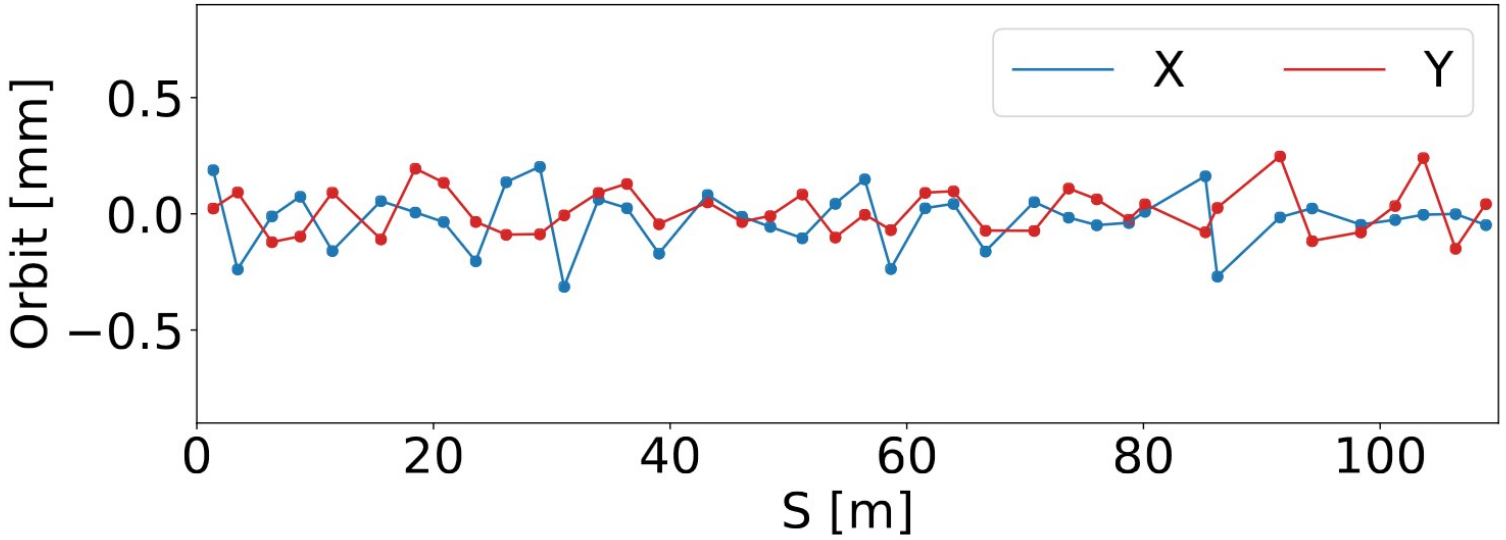


10 min self polarization before RDP scan

Set-Up

- 2.5 GeV beam energy
- About 30 circulating bunches
- 30 to 60 mA beam current





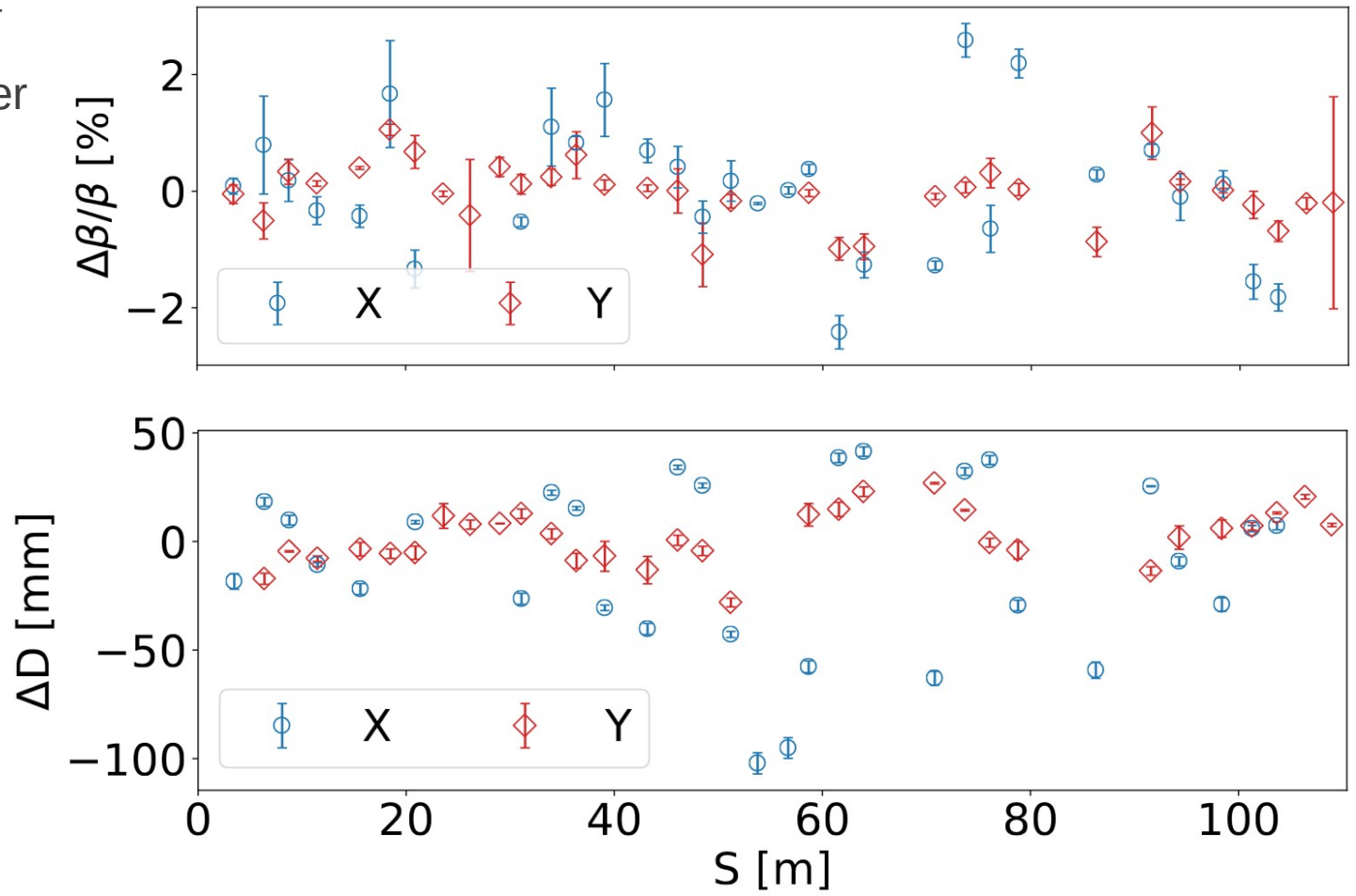
- Small closed orbit measured
  - 125 µm horizontal
  - 100 µm vertical

- Complementary: TbT optics measurements performed

Beam Optics Measurement

- Beam optics measured using TbT BPM data
- Beam excited using horizontal injection kicker
- CERN tools used for analysis

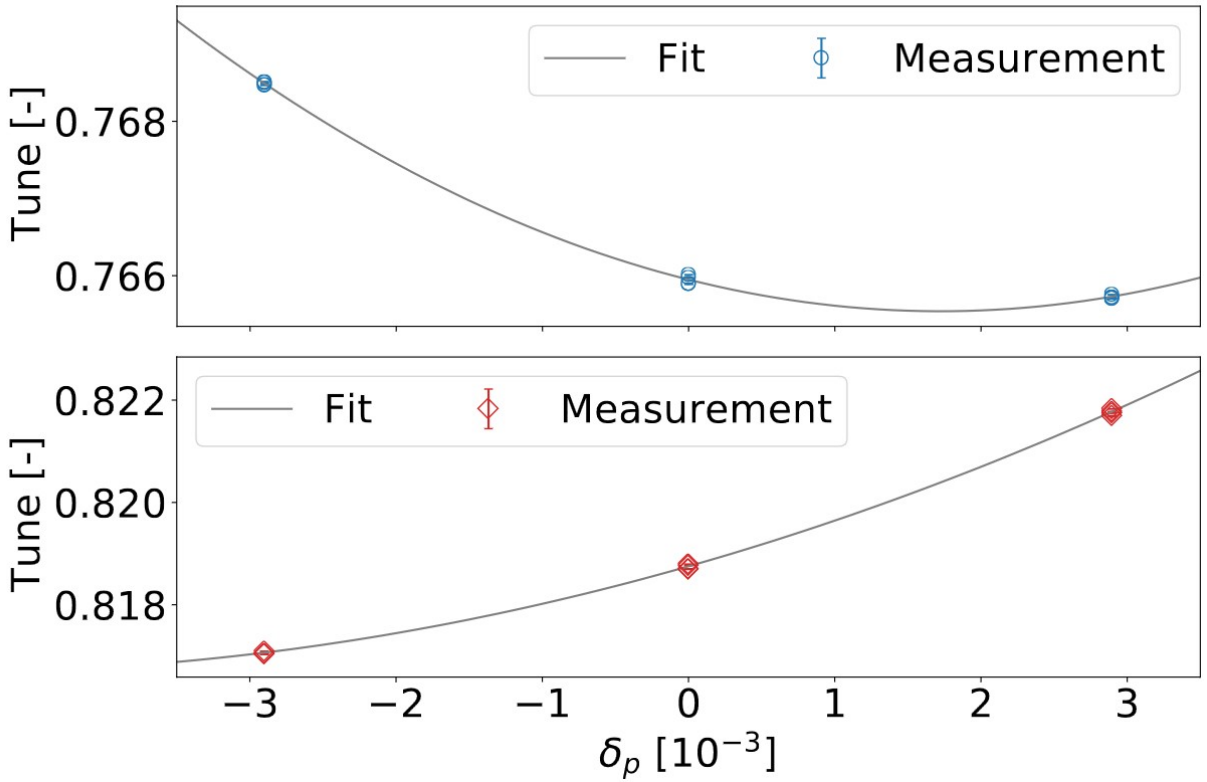
- rms β-beating with respect to model: **1.1 %**
- rms dispersion error of a few cm



Chromaticity

- First and second order chromaticity measured

  → Decoherence



- $Q_x' = -0.477 \pm 0.005$, $Q_x'' = 276 \pm 6$
- $Q_y' = -0.813 \pm 0.006$, $Q_y'' = 160 \pm 7$
- Model: $Q_x'' = 41$, $Q_y'' = 32$
- Attributed to octupolar fields due to feed-down from decapole component in bending magnets with transverse offset

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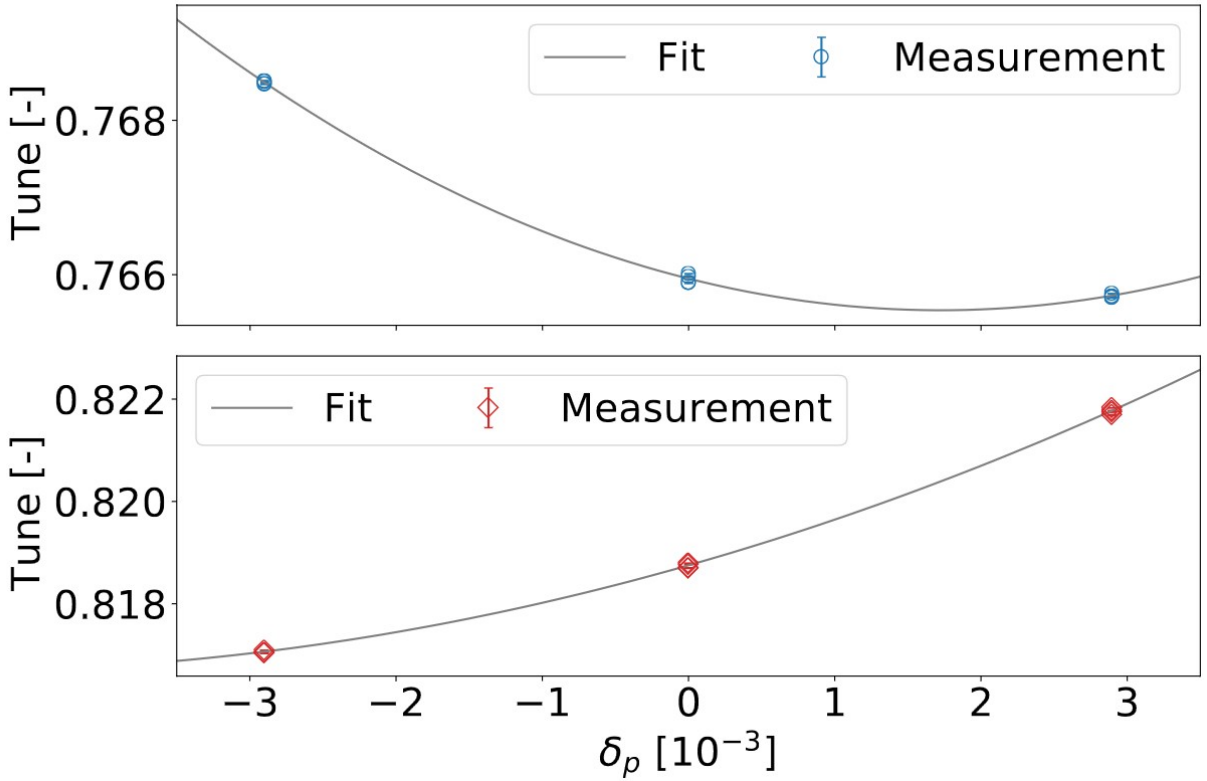
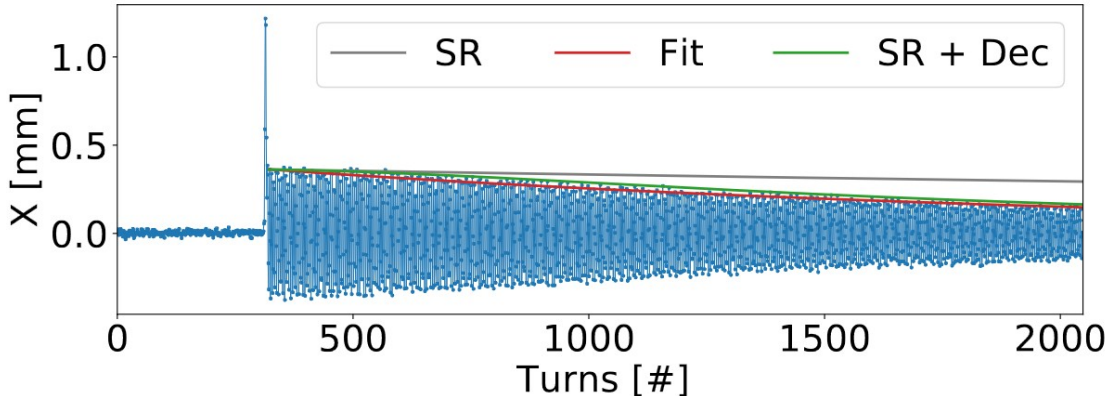
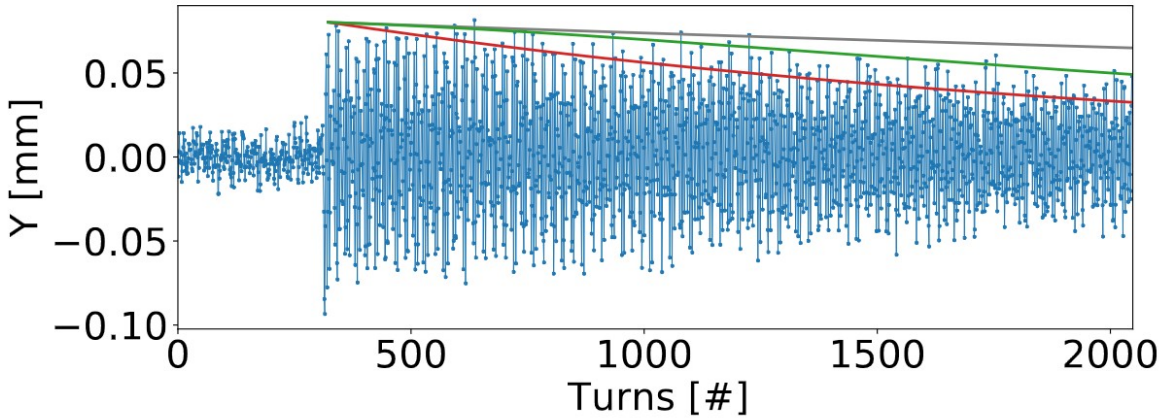






- Explains observed damping of TbT orbit

  → Very well understood storage ring

Fit of RDP Scans

Center of step-function

- Fit function applied $$F(E) = F_0 + (h/2)\ \mathrm{erf}\left((E - E_0)a\right) + bE + cE^2$$

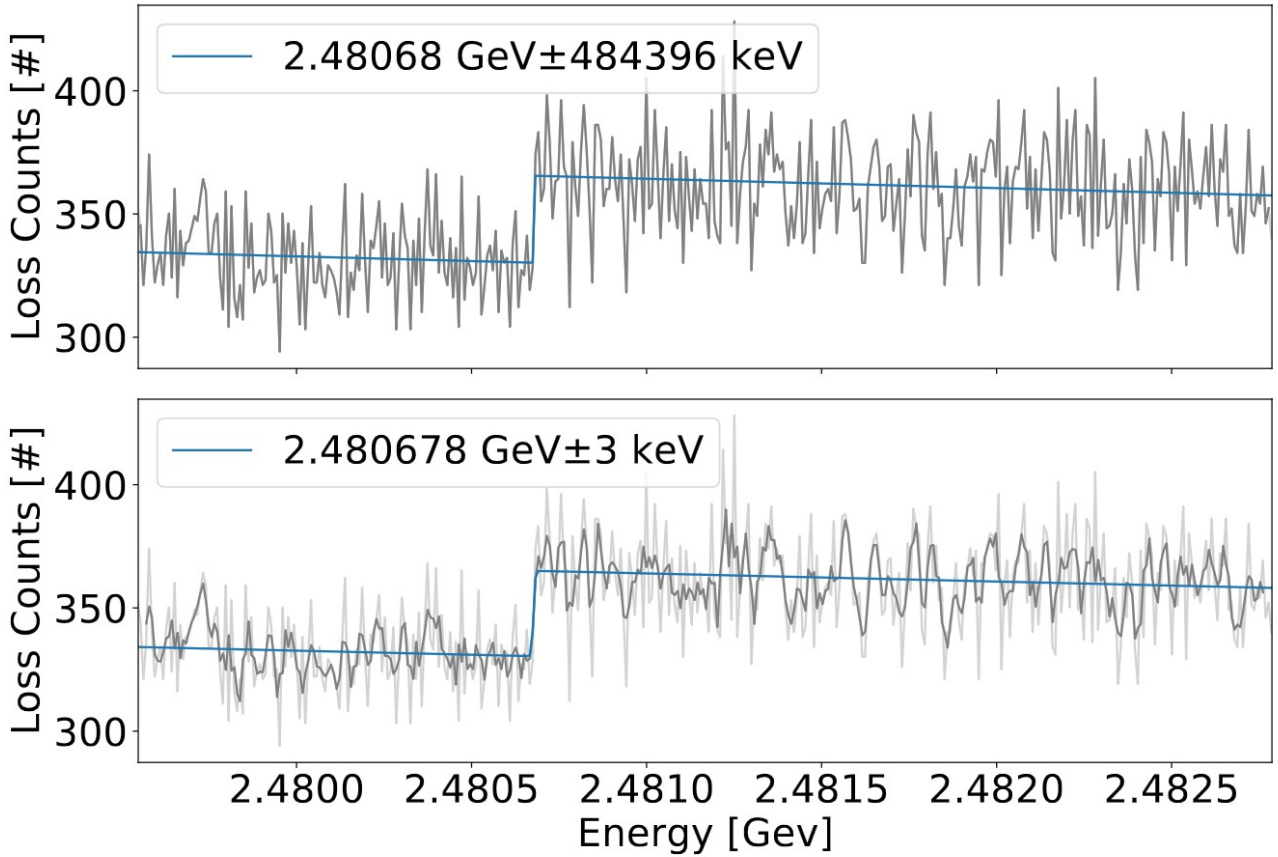
- To avoid numerical uncertainties

  loss rate averaged over 3 energy steps

- Very low fitting error of a few keV achieved

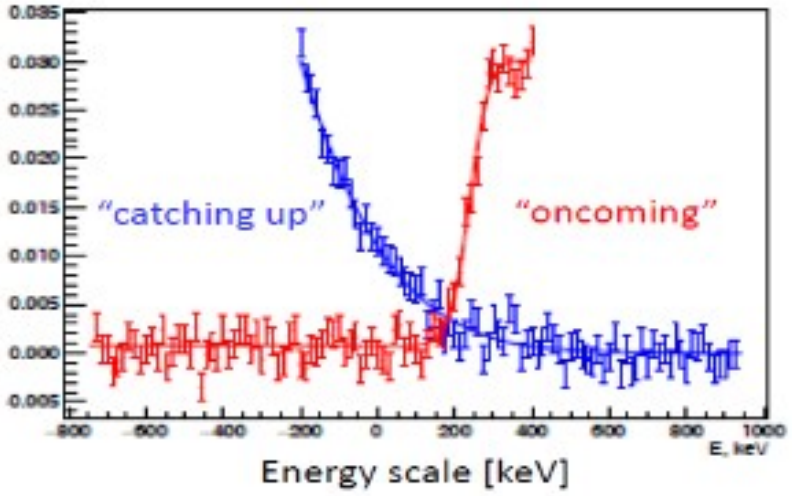
- Beam energy measured to about **2.481 GeV**

  -19 MeV with respect to 2.5 GeV

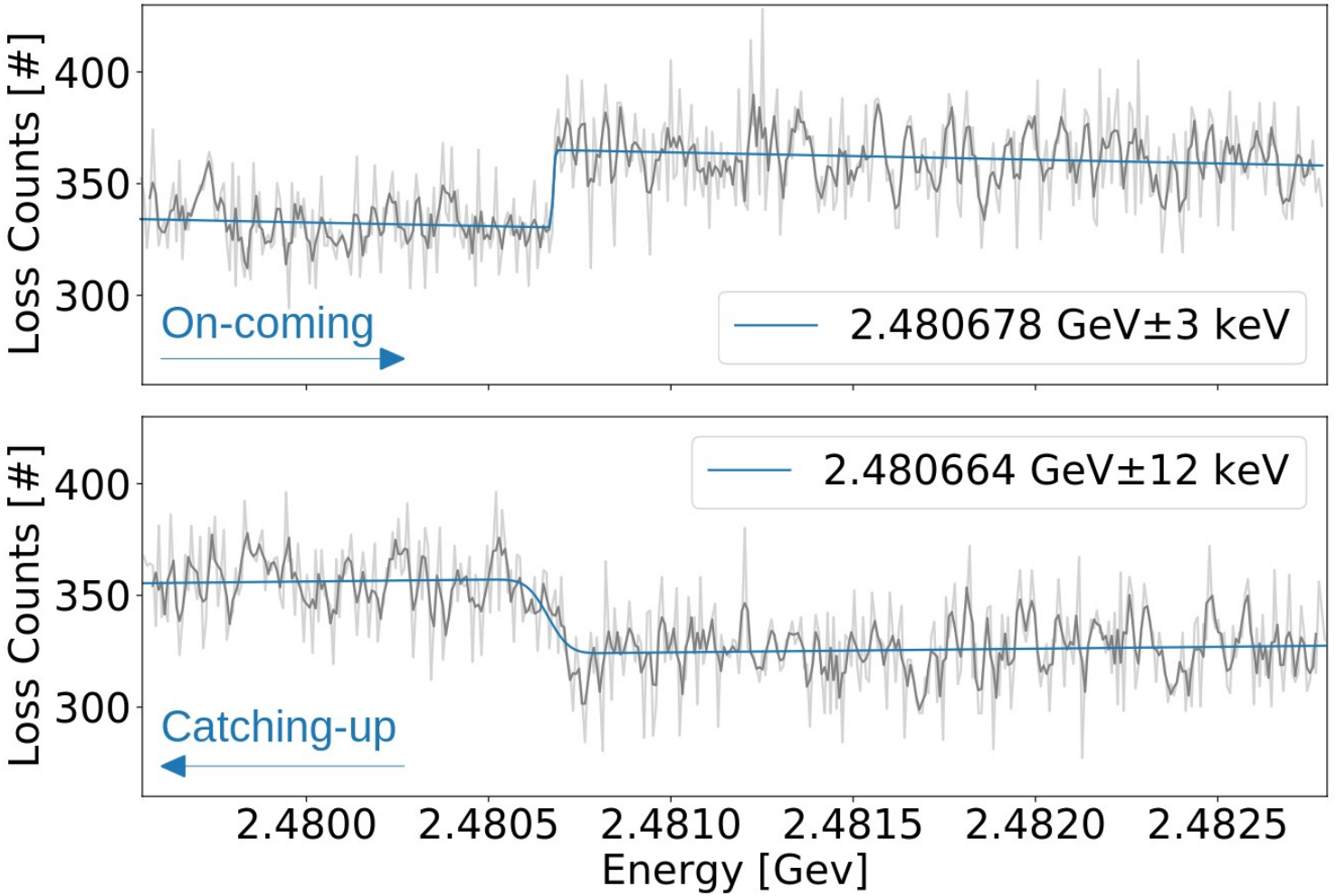


Scanning Directions

- 300 s scanning time in both directions
- Findings consistent with FCC simulations
- Suggests negative engergy drift



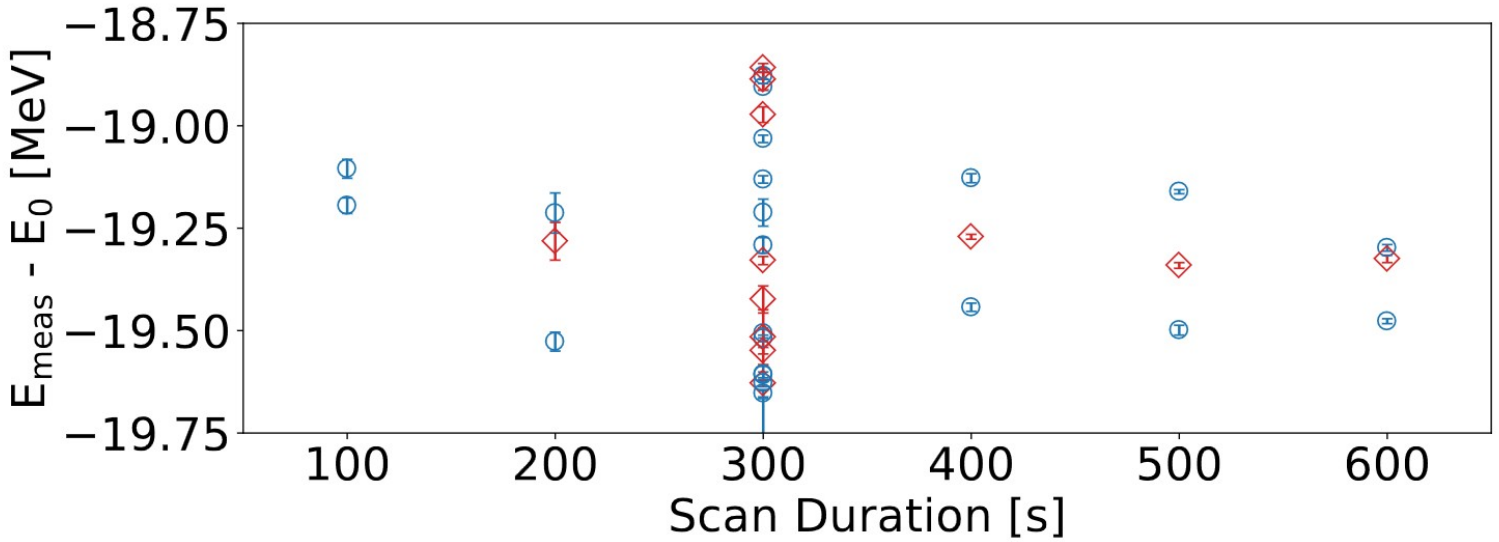
Courtesy: S. Nikitin, I. Koop



Scan Velocity and Direction

- Remote automated measurement campaign
- Various scans over long night of 16 h
- No clear dependence on scan duration or direction

- Scanning range from 1705 – 1725 kHz
- Corresponds to 2.4795 to 2.4830
- Scan duration 100 to 600 s
- Reverse scanned frequency range

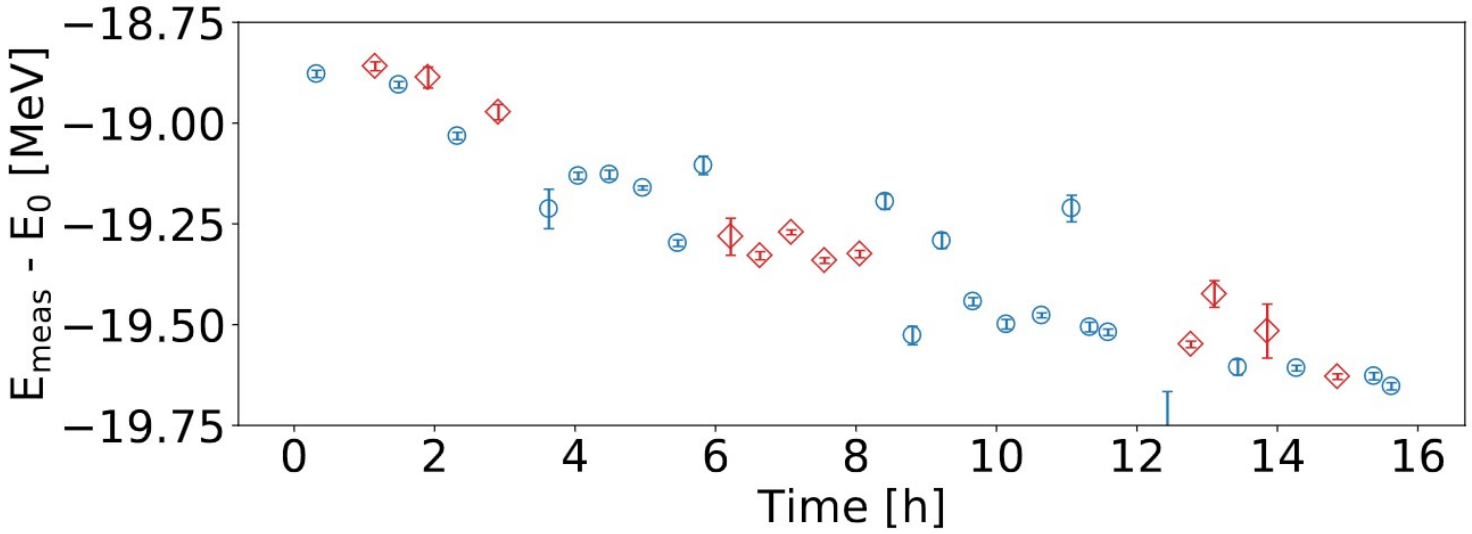


Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

Energy Drift Over 16h

- Measurement campaign performed over night with 34 RDP scans
- 0.8 MeV lower beam energy measured after 16 h compared to start of measurement
- Trend consistent for RDP scans in both scanning directions with various scanning velocities
- Possible source: temperature rise with constant RF-frequency leads to orbit drift



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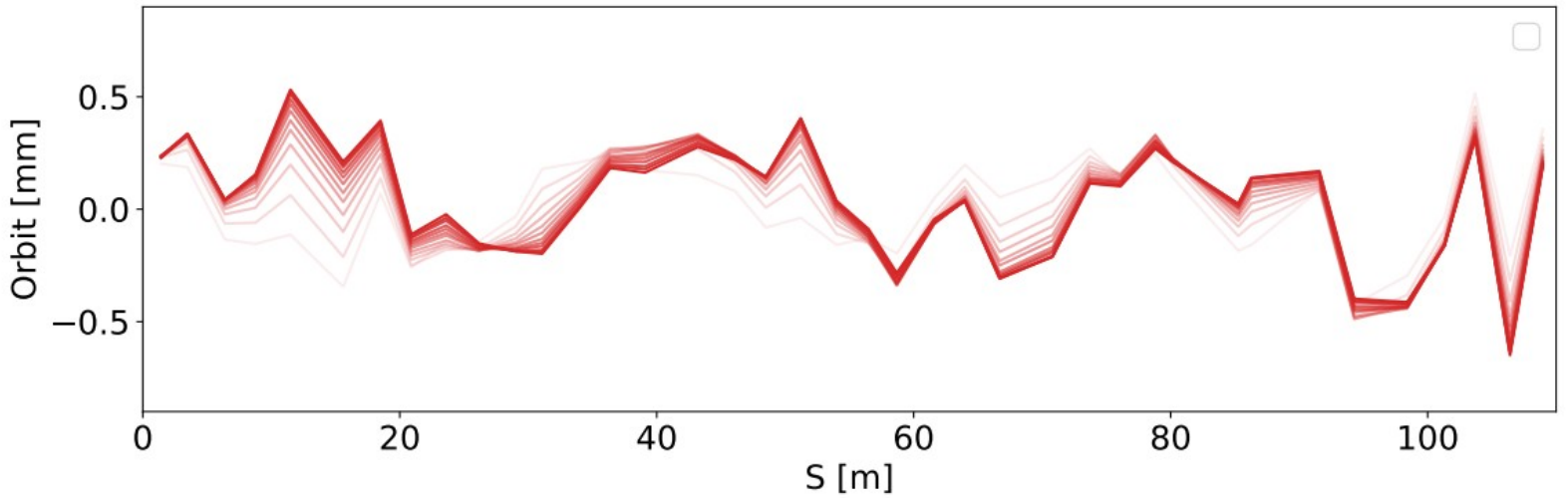


vertical orbit drift over 16h
from light to dark

Measurements at Lower Energy

- Challenges encountered at 2.3 GeV beam energy

- No resonance measured so far, possible reasons:
  - Spin tune close to betatron tune; enough polarization?
  - Optics not optimized at 2.3 GeV; large emittance?
  - At 2.5 GeV 2.481 GeV measured; wrong frequency?

- To be continued...

E [GeV]	ν [-]	τ [s]	τ [min]	F [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

- Successfully performed beam optics measurements using TbT BPM data and injection kicker excitation
  - Excellent agreement between linear optics and model
  - Measurements found second-order chromaticity, which explains measured decoherence

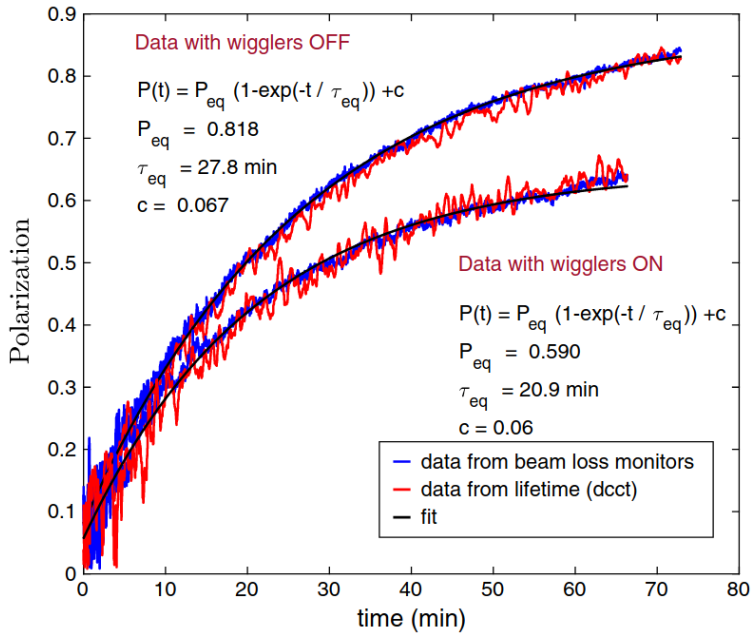
- RDP scans successfully performed at 2.5 GeV nominal beam energy
  - Measured beam energy systematically ~ 19.3 MeV lower for all scans
  - Energy drifts observed independent of scanning direction and velocity
  - First valuable insights on systematic errors on beam energy measurement

- RDP scans at 2.3 GeV beam energy to be investigated further

Outlook

Absolute polarization measurements

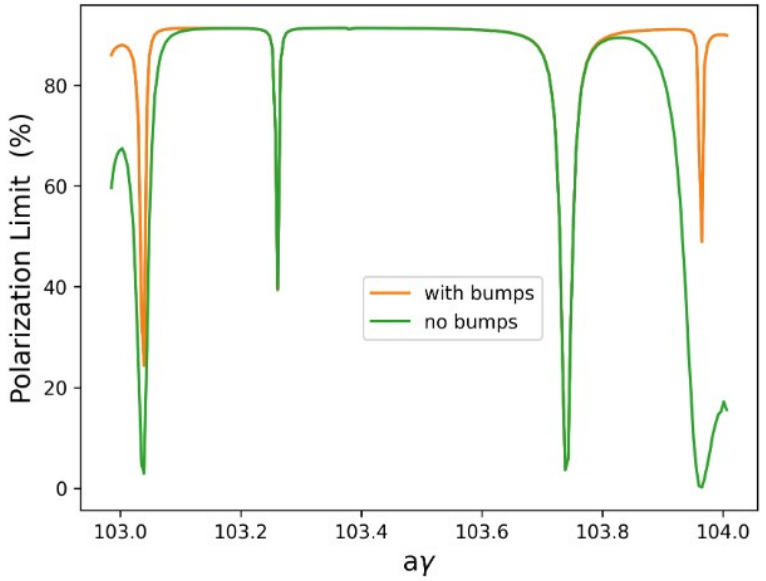
- Polarization level measured based on Touschek lifetime, e.g. at Diamond light source



Baier and Khoze (1968),
Phys. Rev. Accel. Beams 22, 122801, 2019

Spin matching with vertical orbit bumps

- Harmonic spin bumps to reduce spin diffusion and improve polarization
- Simulations performed for FCC



Courtesy: Y. Wu

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Thank you!

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