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# Polarization Studies at KARA

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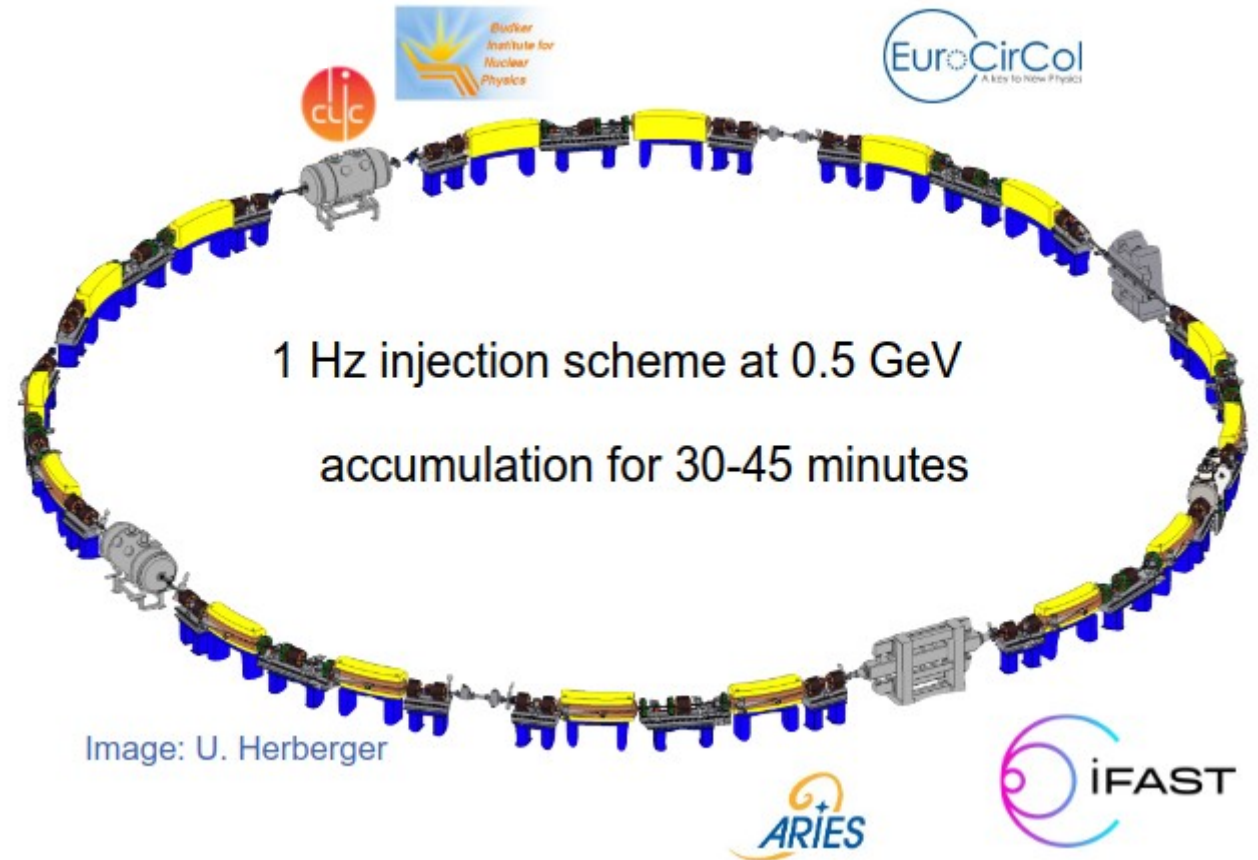
FCC Physics Workshop  
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01 February 2024



**FCCIS – The Future Circular Collider Innovation Study.**  
This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

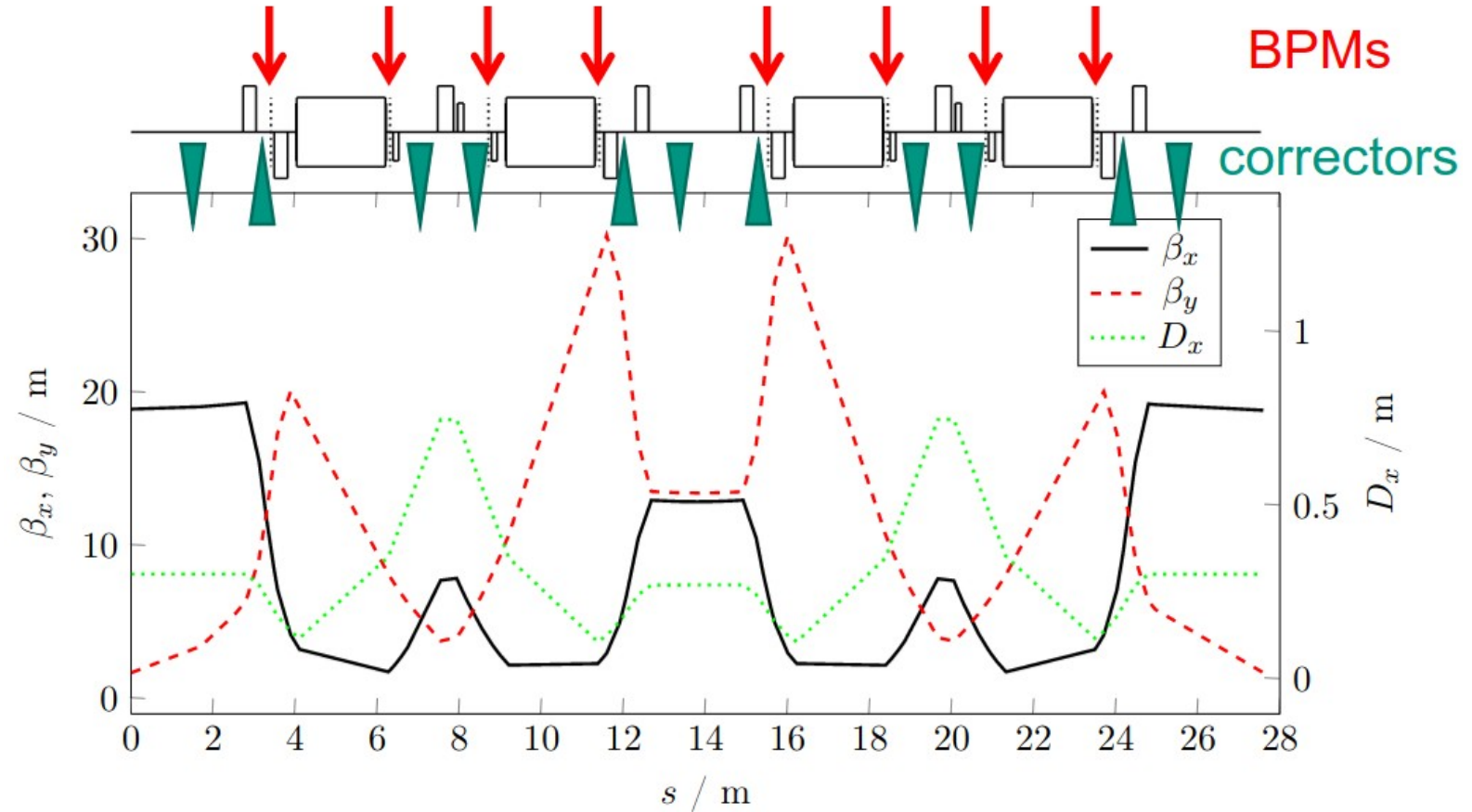
# KARA

- Karlsruhe Research Accelerator (KARA) at Karlsruhe Institute of Technology (KIT)
- Synchrotron light source and test facility
- Some key parameters:
  - 110.4 m circumference
  - 0.5 to 2.5 GeV beam energy
  - Up to 200 mA beam current
  - 2.715 MHz revolution frequency
  - Single or multi-bunch operation
  - Turn-by-Turn (TbT) diagnostics



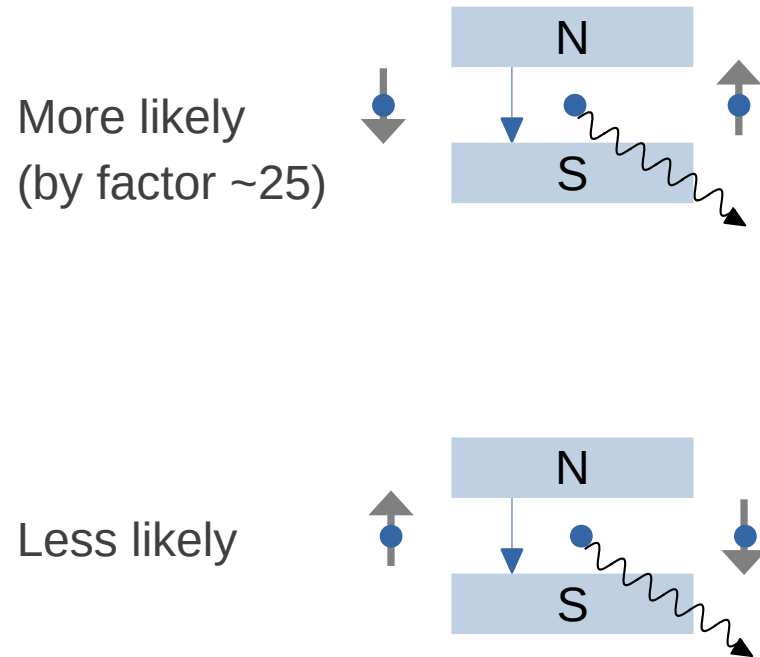
# KARA: Lattice and Optics

- 4 sectors
  - 8 BPMs each
- 4 straight sections
  - 2 BPMs each



sector 1 (one quarter)

# Polarization



- Statistically every  $10^{10\text{th}}$  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**

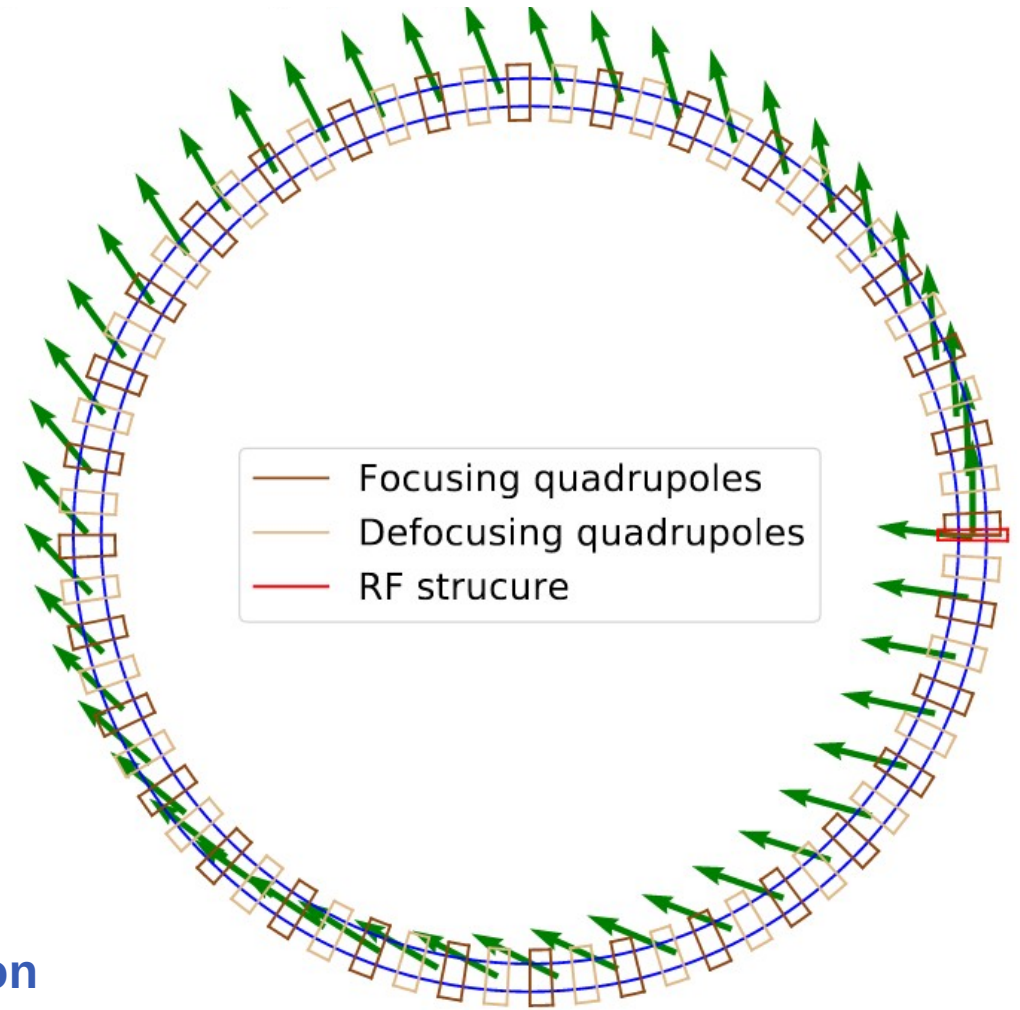
# Spin Tune and Beam Energy

- Spin precesses through the lattice
- Spin tune  $\nu$ : Number of spin precessions per turn
- In an error-free flat machine without solenoids
- Purely vertical spin orientation

$a$  ... gyro-magnetic anomaly  
 $\gamma_{\text{Rel}}$  ... Lorentz-factor

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

Spin tune measurement  $\longleftrightarrow$  Beam energy determination

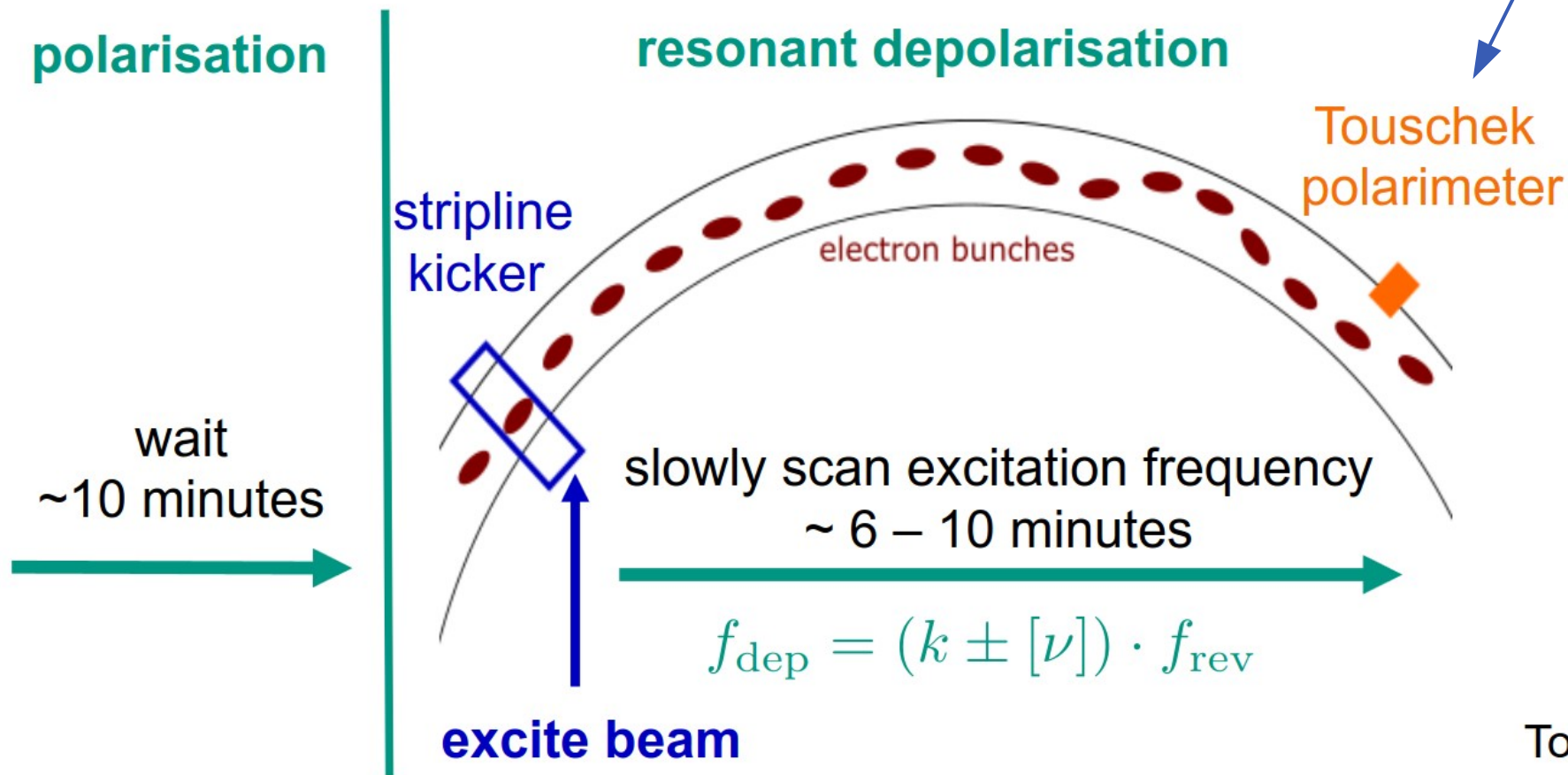


Courtesy: V. Caudan

# RDP Measurement

3D polarimeter in FCC

→ Talk: A. Martens

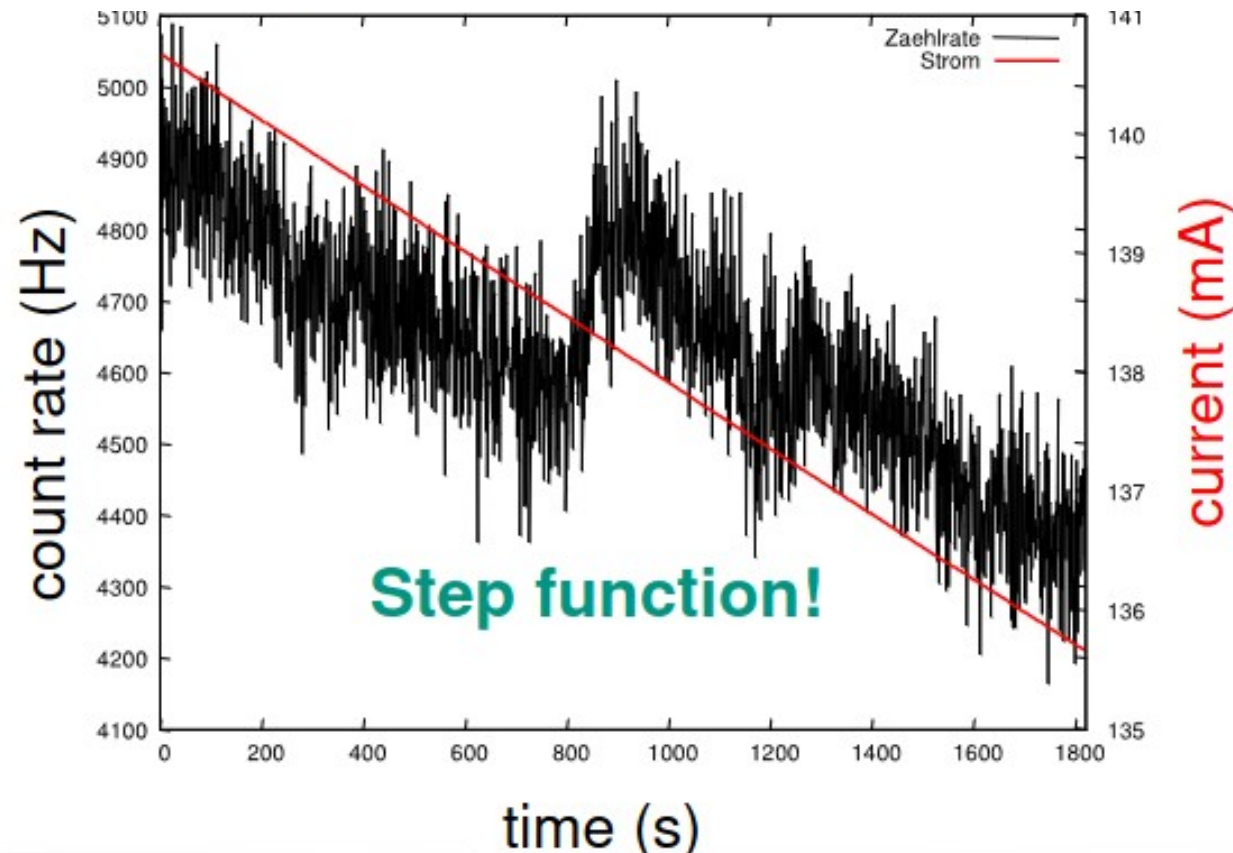


Touschek sensitive region



# 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 ?
  - Polarization level
  - Beam orbit and optics
- Simulation of RDP scans at KARA could be studied

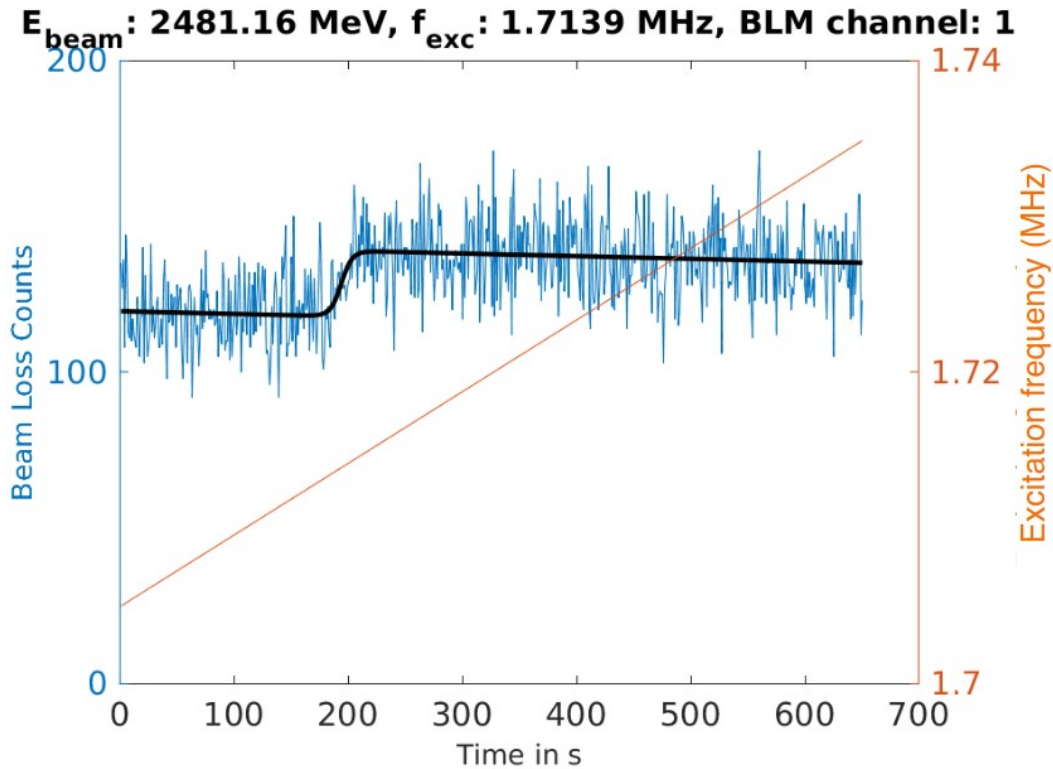


- Improved understanding of machine optics
  - Orbit drifts
  - Model accuracy
  - Linear optics and comparison to model
  - Non-linear and chromatic optics

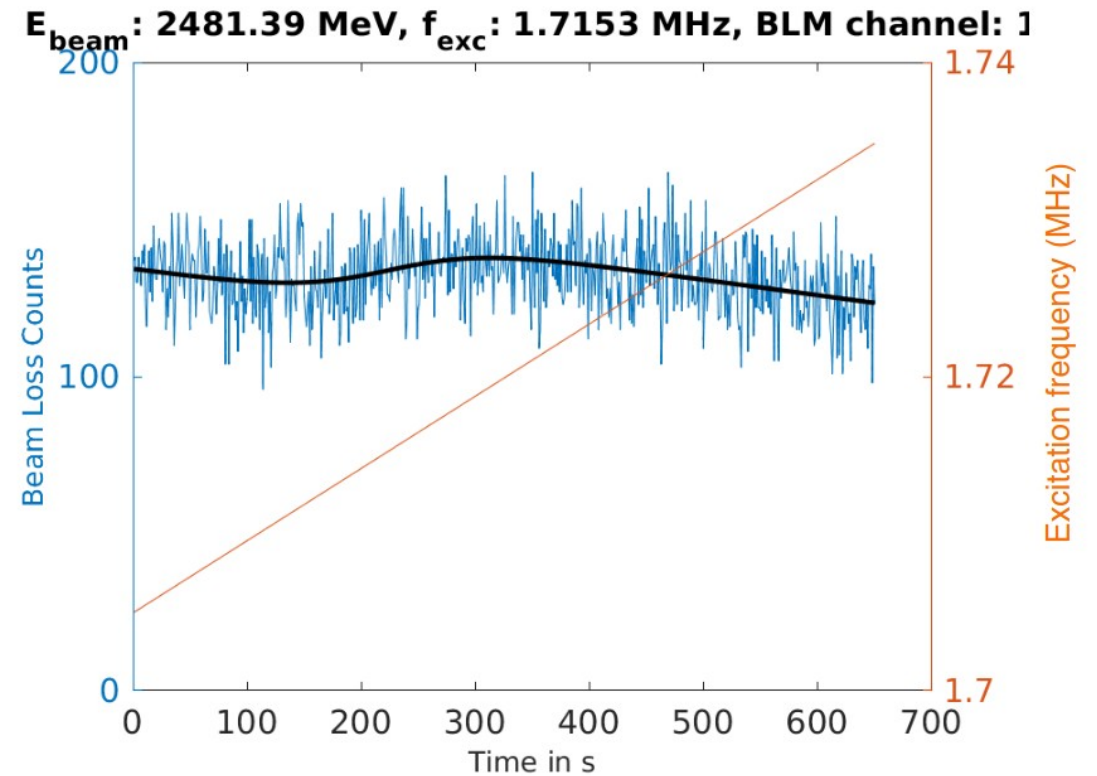


# Polarization Time

- Scan quality depends also on polarization level → always 20 min polarization time before scan



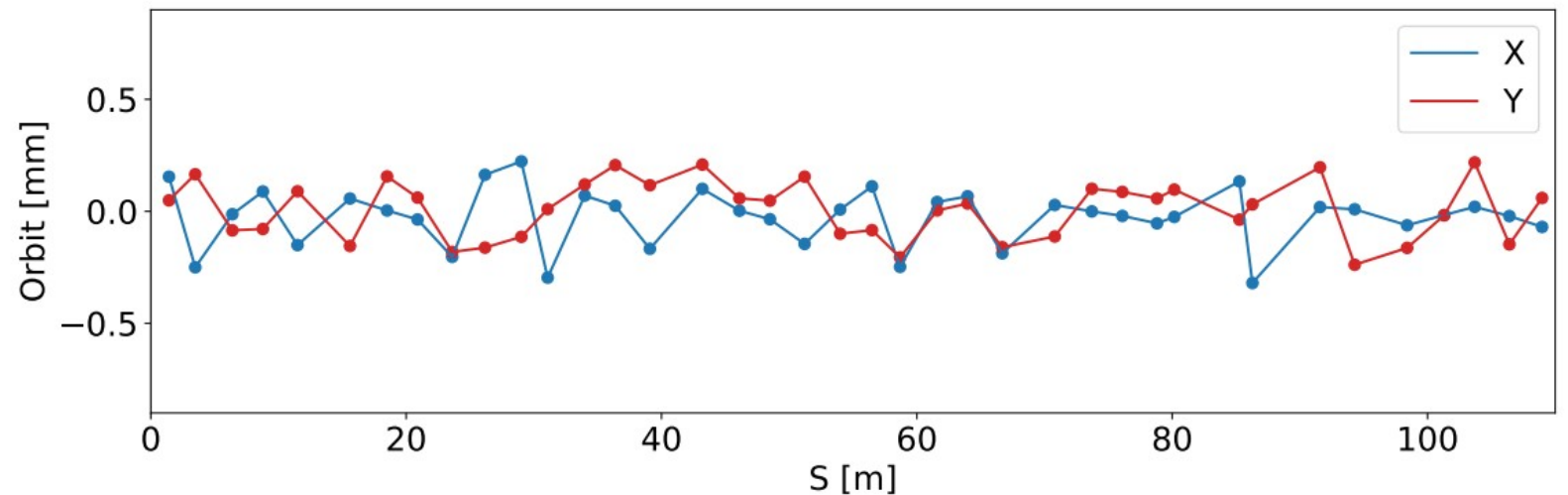
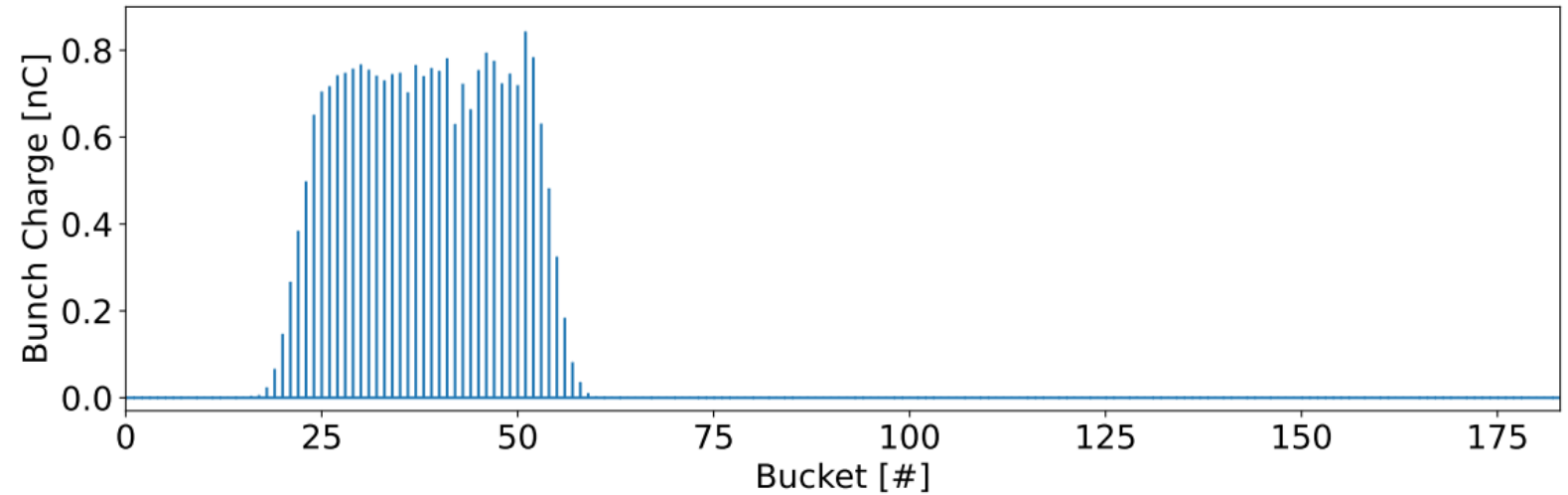
20 min self polarization before RDP scan



10 min self polarization before RDP scan

# Set-Up

- 2.5 GeV beam energy
- About 30 circulating bunches
- 30 to 60 mA beam current
  
- Very low closed-orbit measured
  
- First **fast optics measurements** for transverse beam parameters performed

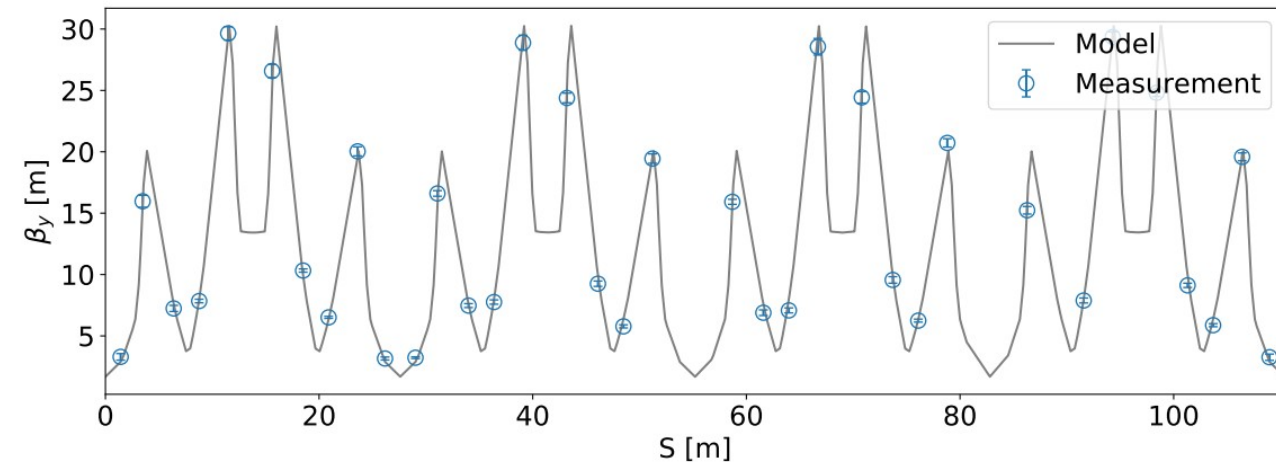
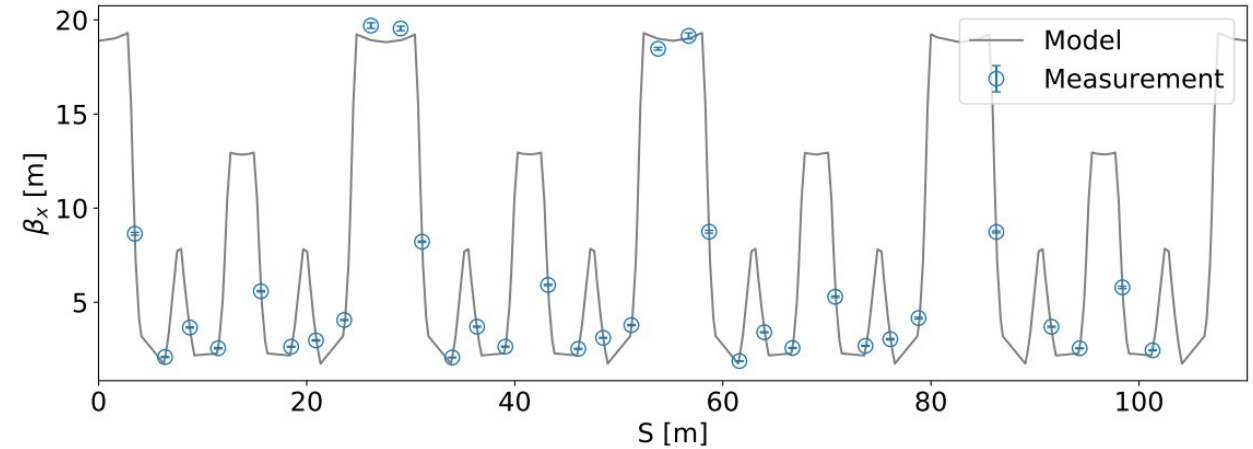


# Beam Optics Measurement

- Beam optics measured using TbT BPM data
- Injected kicker used for applying horizontal kick
- Analysed using codes developed at CERN:

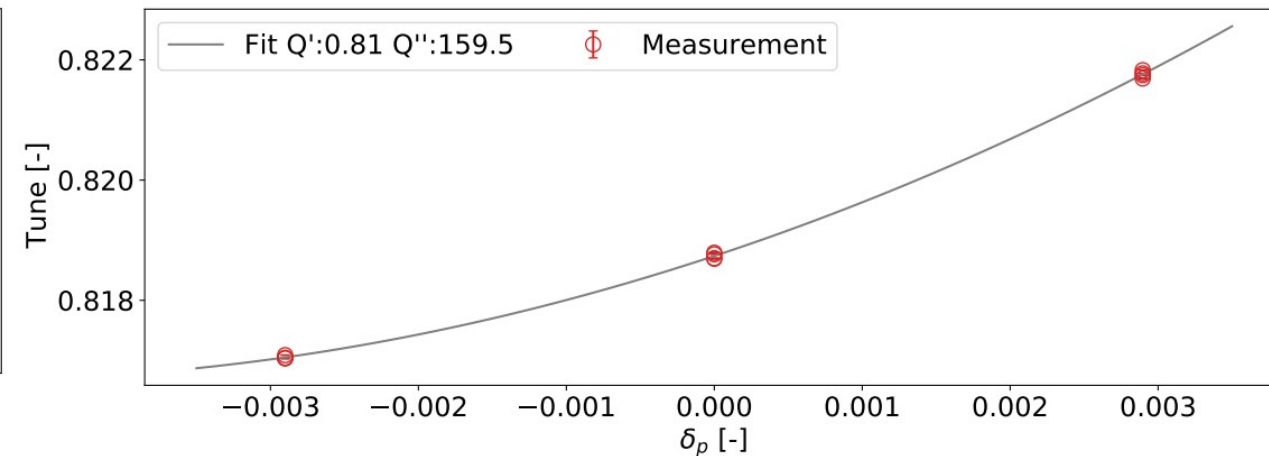
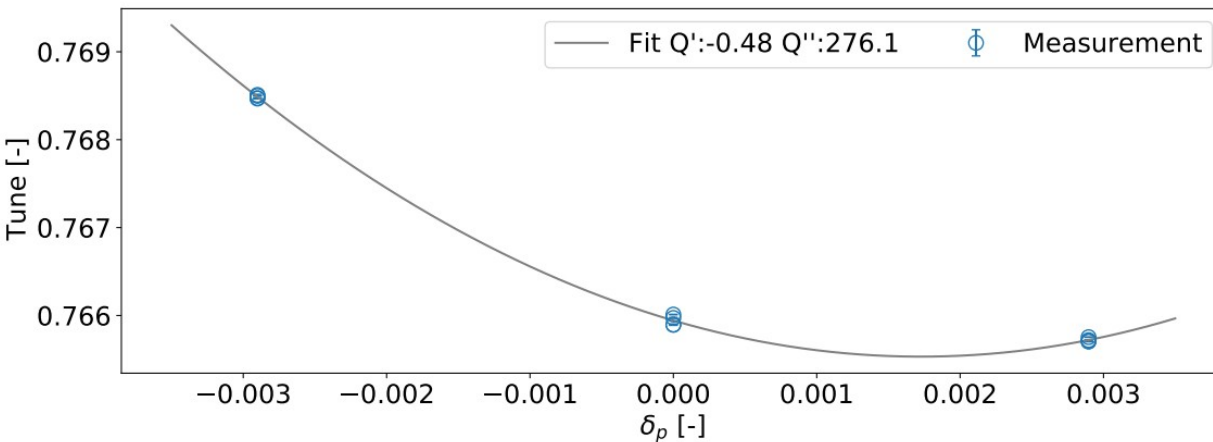
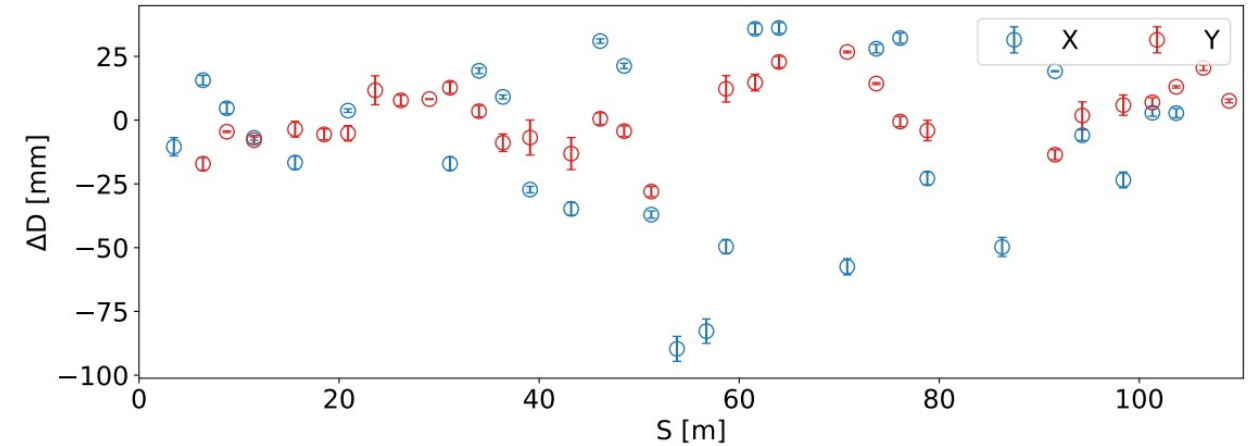
<https://github.com/pylhc/omc3>

- Amplitude reading from BPMs suitable
- rms  $\beta$ -beating with respect to model: **1.5 %**



# Chromatic Optics

- rms horizontal/vertical dispersion error of 35/12 mm
- Non-linear chromaticity present in the machine
- → To be further studied in future measurements



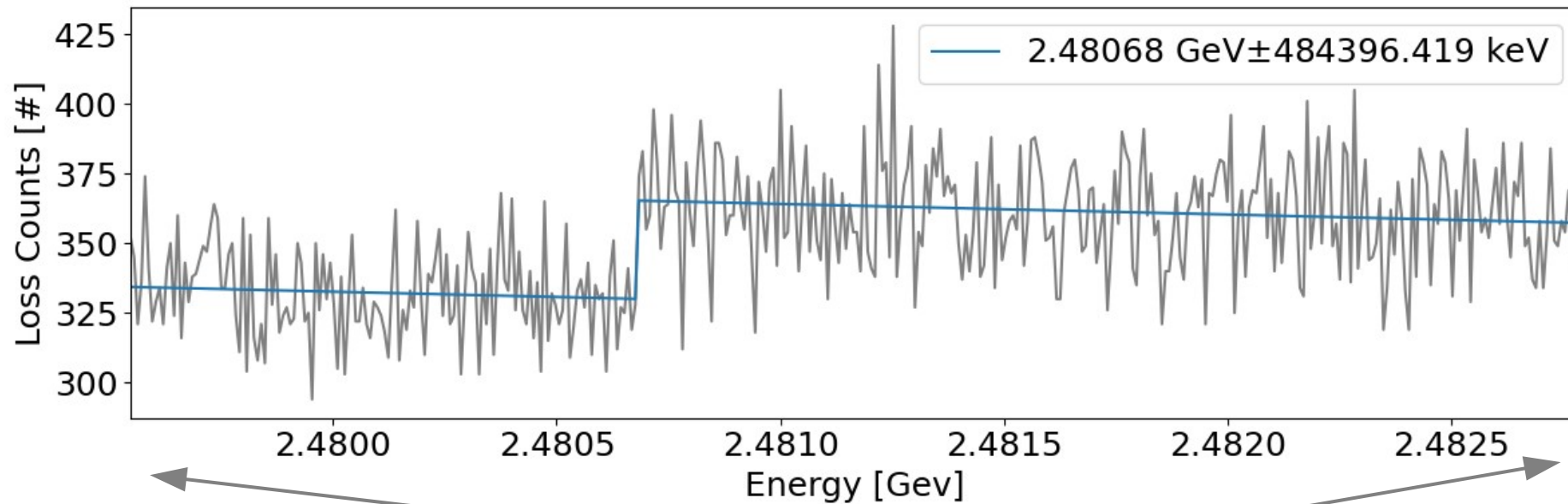
# Fit of RDP Scans

- Fit function applied

$$F(E) = y_0 + \frac{h}{2} \operatorname{erf}((E - E_0)a) + bE + cE^2$$

- Steep step leads to large numerical uncertainties

Center of step-function

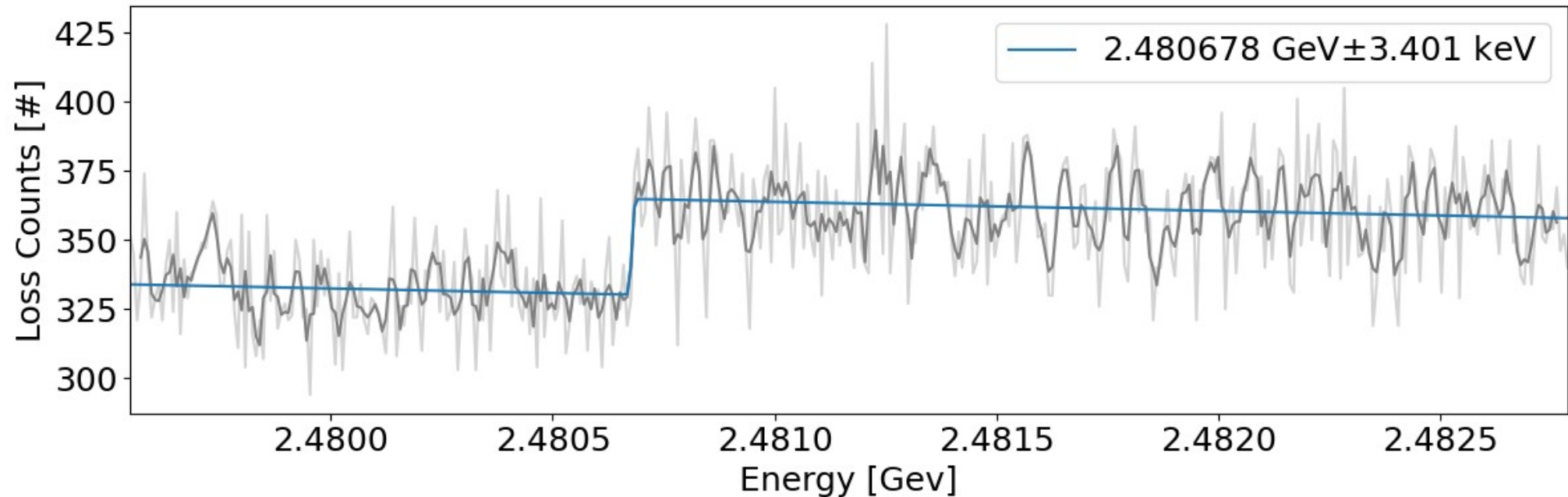


Corresponds to 1705 to 1725 kHz



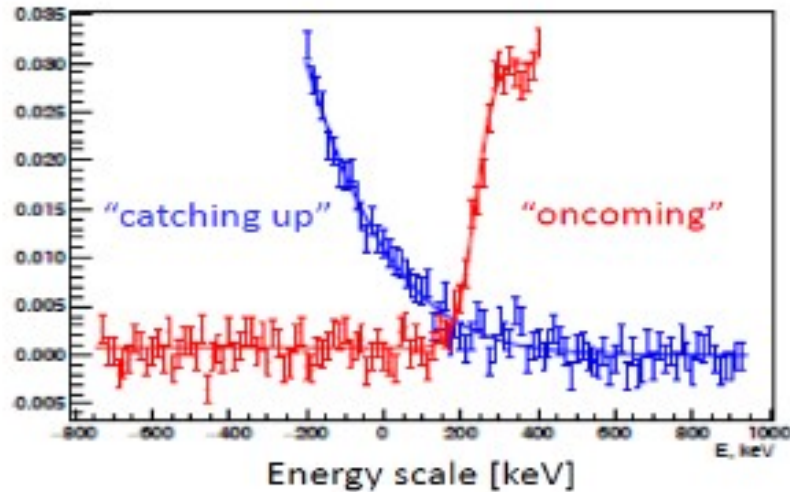
# Fit of RDP Scans

- 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)

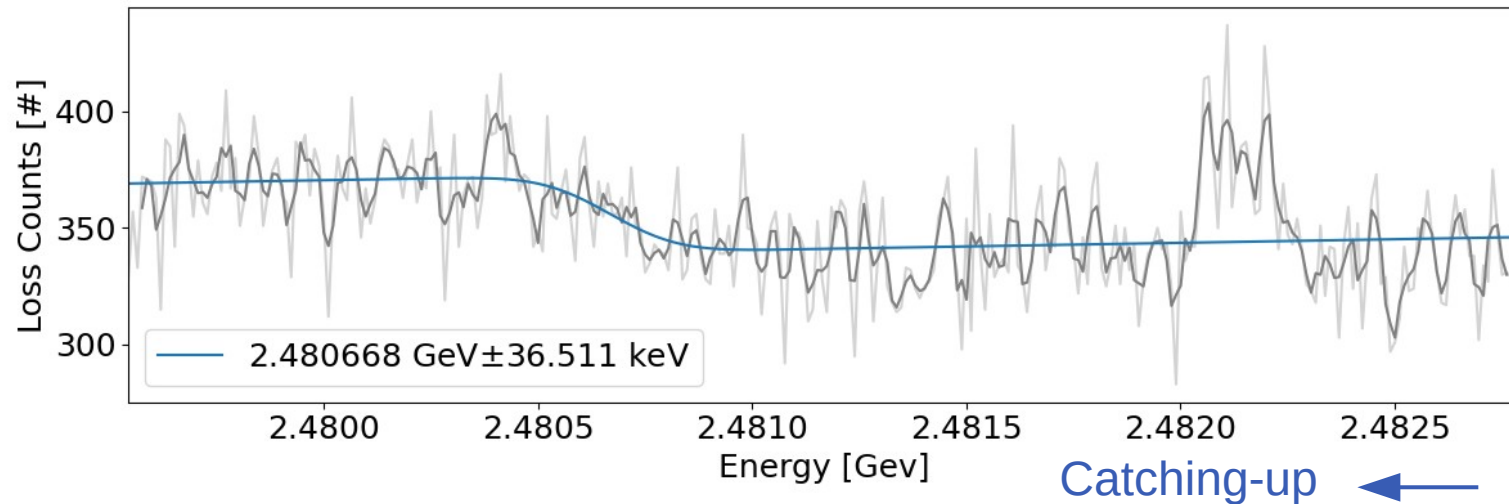
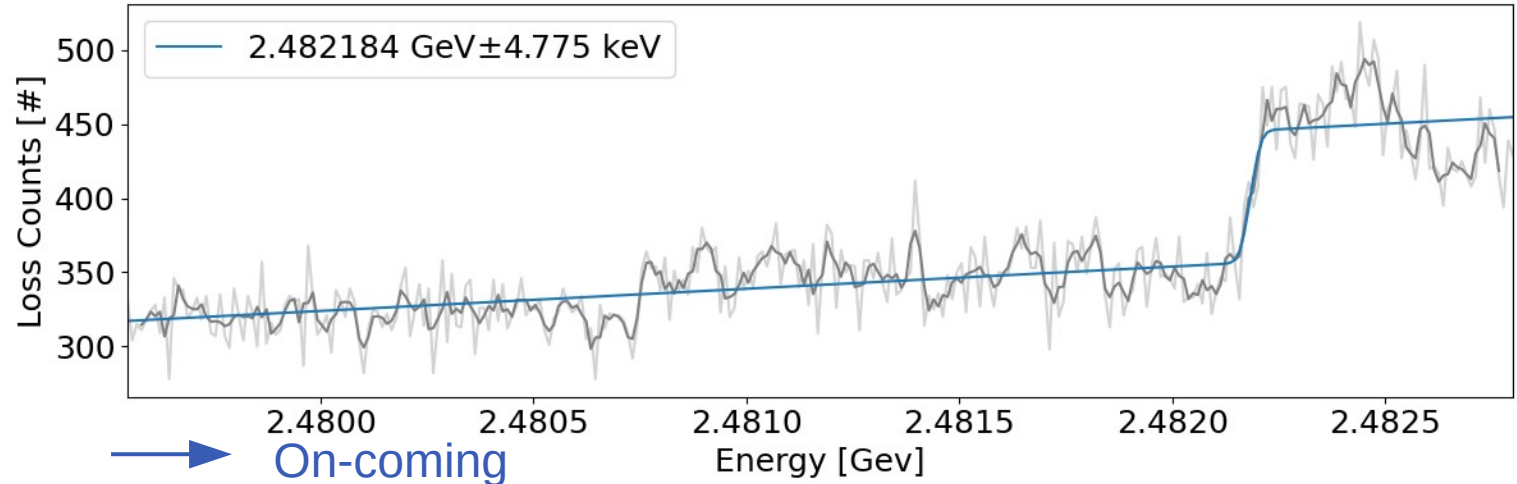


# Scanning Directions

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

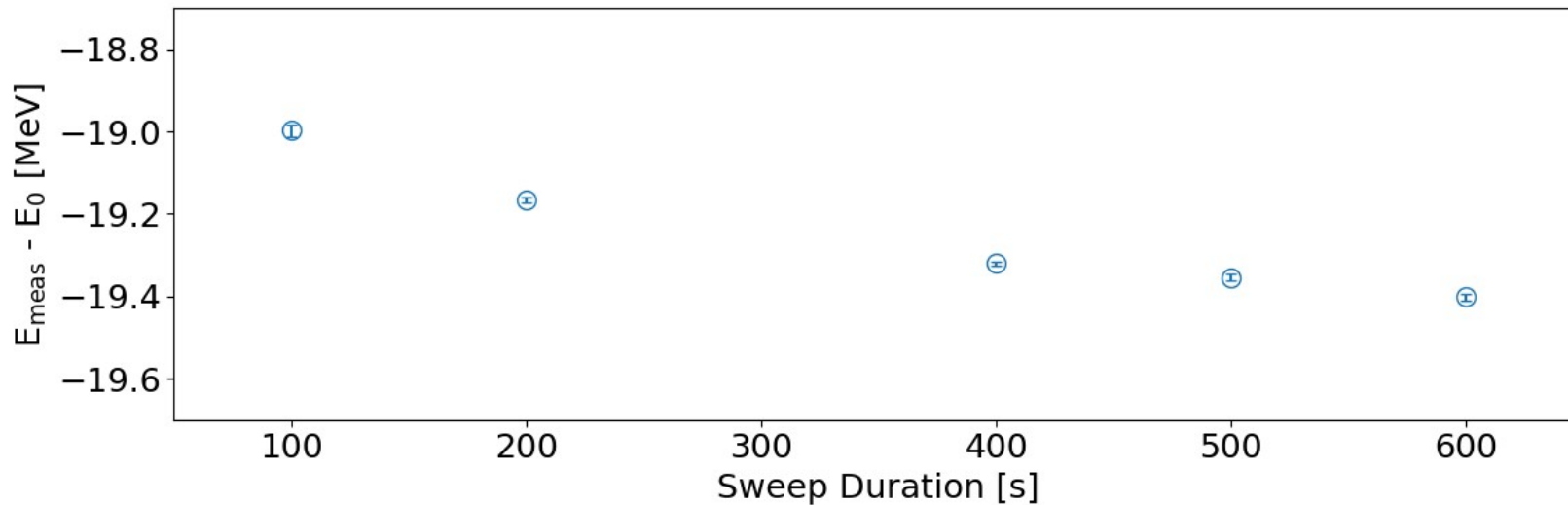


Courtesy: S. Nikitin, I. Koop



# Scan Velocity

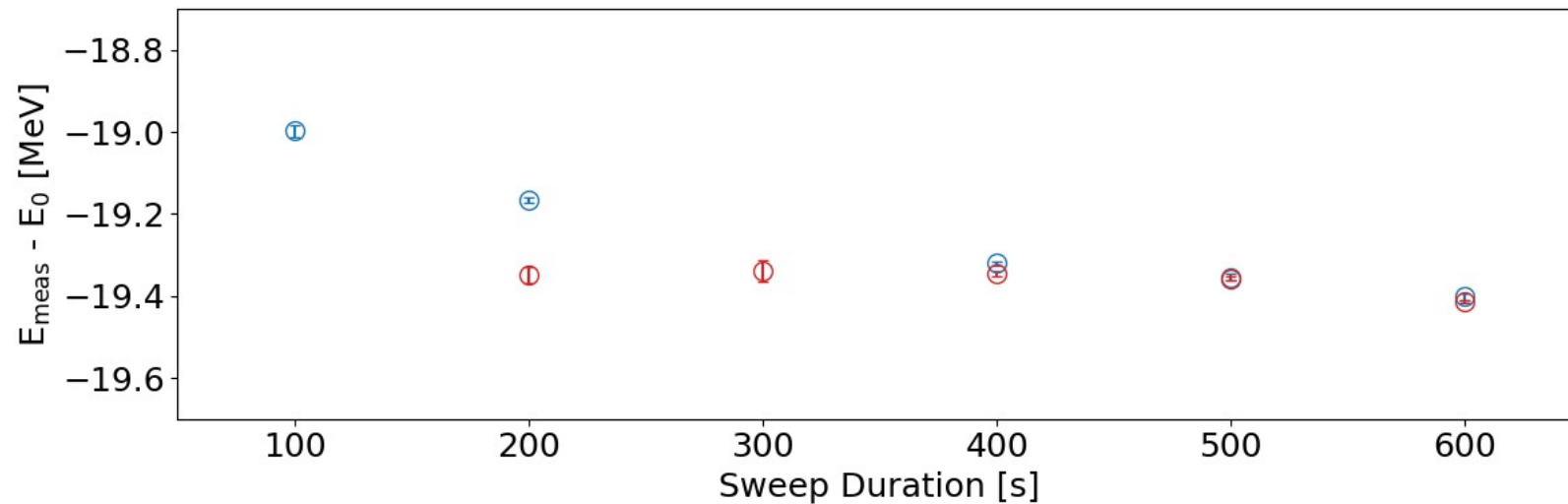
- Scanning range from 1705 – 1725 kHz
- Corresponds to 2.4795 to 2.4830
- Scan duration 100 to 600 s



Blue: 1705 – 1725 kHz

# Scan Velocity and Direction

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

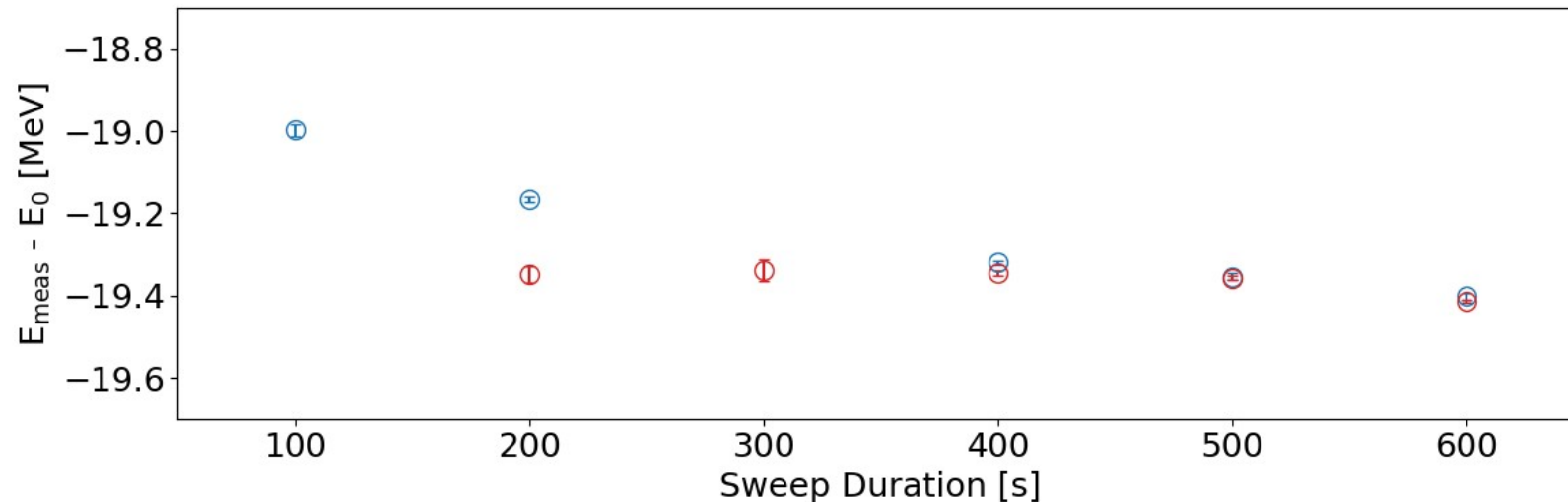


Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

# Scan Velocity and Direction

- Observations
  - 19.0 to 19.4 MeV lower beam energy measured
  - At fast scans measured energy diverge more
  - Energy drift or from measurement?
- Scanning range from 1705 – 1725 kHz
- Corresponds to 2.4795 to 2.4830
- Scan duration 100 to 600 s
- Reverse scanned frequency range

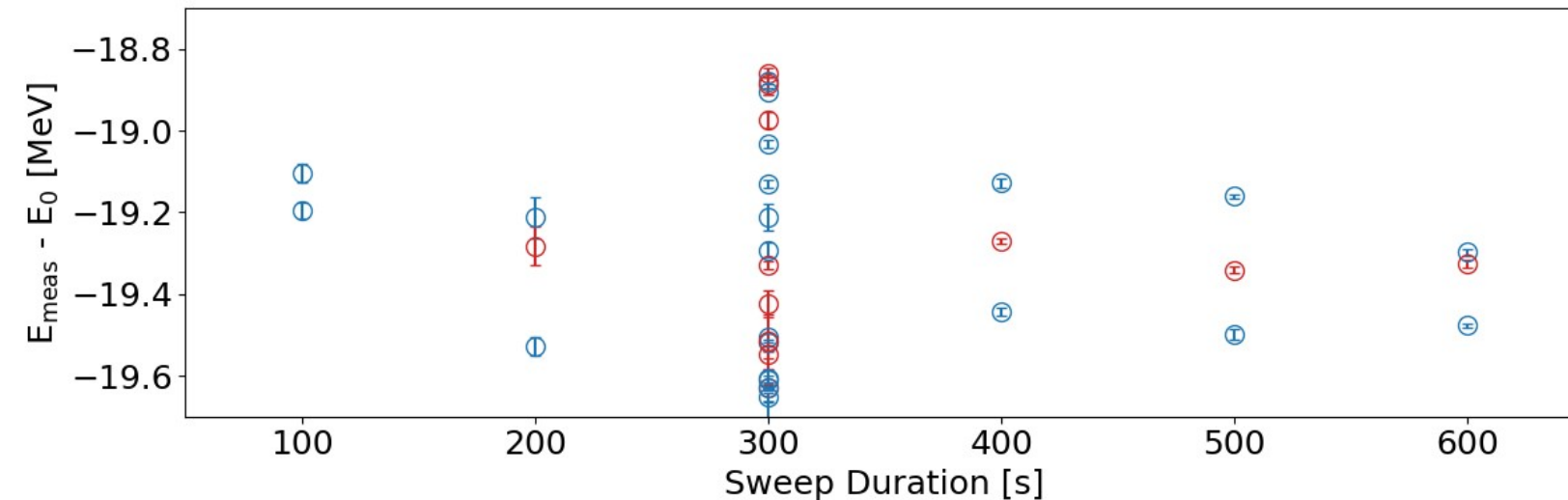


Blue: 1705 – 1725 kHz  
Red: 1725 – 1705 kHz



# Scan Velocity and Direction II

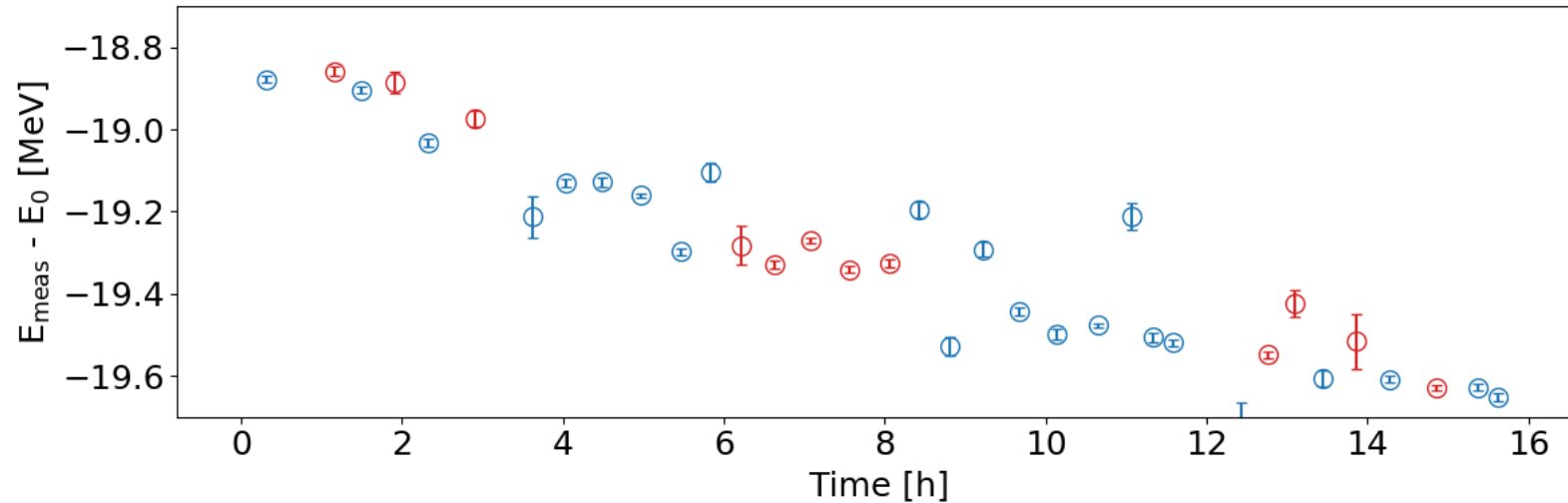
- Remote automated measurement campaign
- Various scans over long night of 16 h
- No clear dependence on scan duration or direction
- Scanning range from 1705 – 1725 kHz
- Corresponds to 2.4795 to 2.4830
- Scan duration 100 to 600 s
- Reverse scanned frequency range



Blue: 1705 – 1725 kHz  
Red: 1725 – 1705 kHz

# Energy Drift Over 16h

- Second 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
- RF-frequency constant; possible sources: orbit drifts, temperature drifts, power converters, etc.

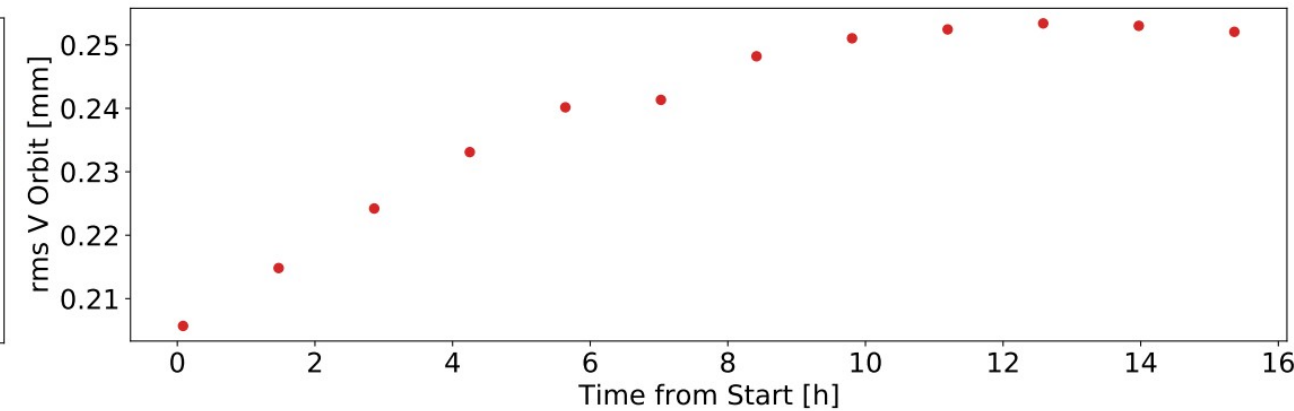
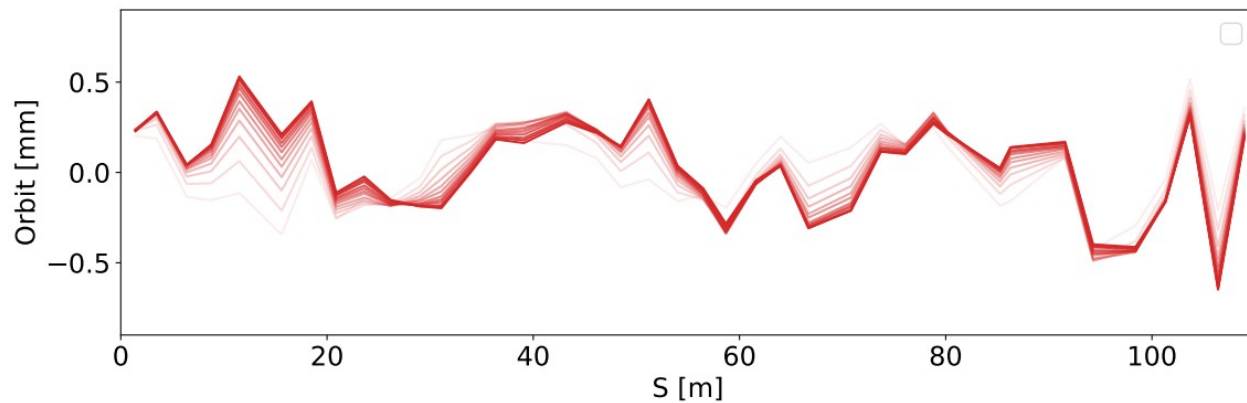
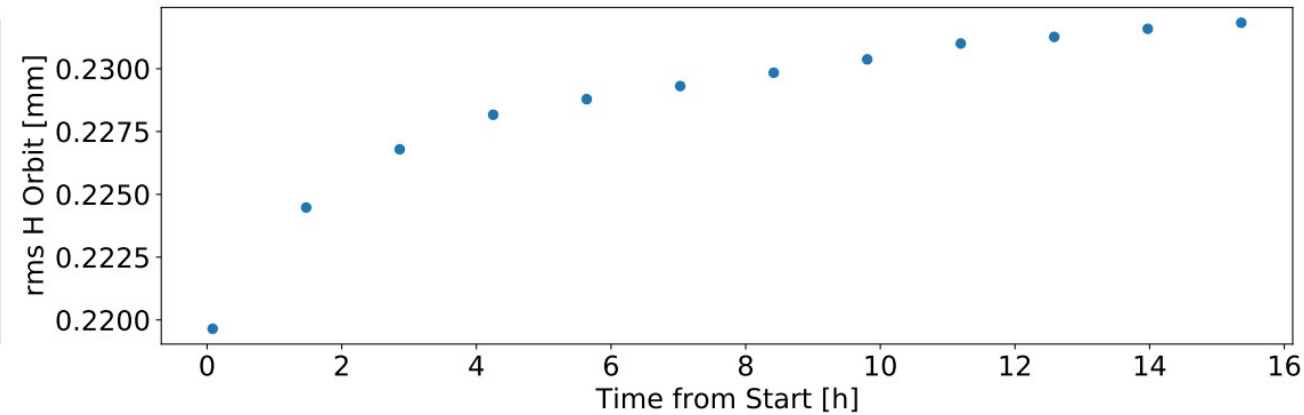
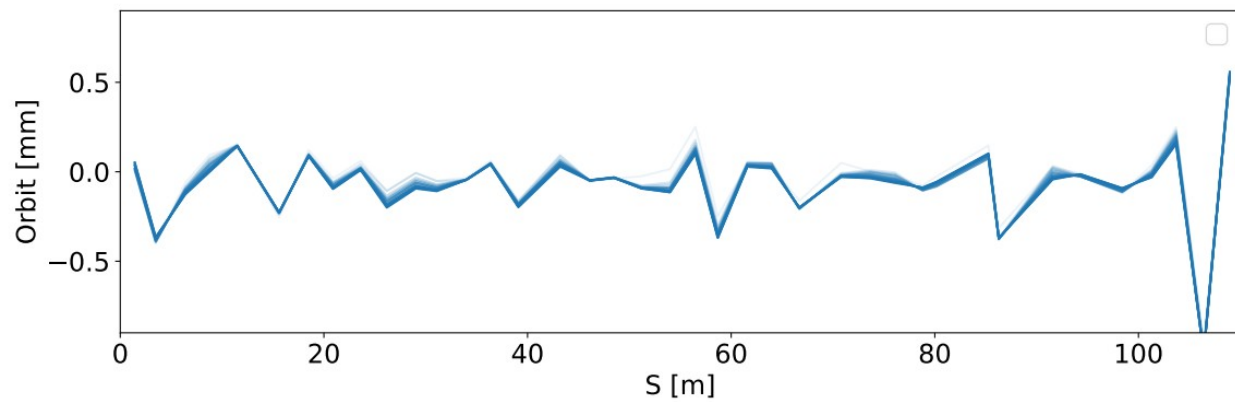


Blue: 1705 – 1725 kHz

Red: 1725 – 1705 kHz

# Orbit Drifts

- Orbit measured over whole fill of almost 16 h → orbit drifts in both planes observed, especially vertically
- Orbit almost stable after ~ 10 h but energy drift follows linear trend → cannot (fully) explain energy drift



# Summary

- Successfully performed beam optics measurements using TbT BPM data and injection kicker excitation
  - Good agreement between linear optics and model
  - Measurements suggest higher-order chromaticity, decoherence, etc.
- RDP scans successfully performed at 2.5 GeV nominal beam energy
  - Measured beam energy systematically  $\sim 19.3$  MeV lower for all scans
  - Energy drifts observed independent of scanning direction and velocity
  - First valuable insights on systematic errors on beam energy measurement

# 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...

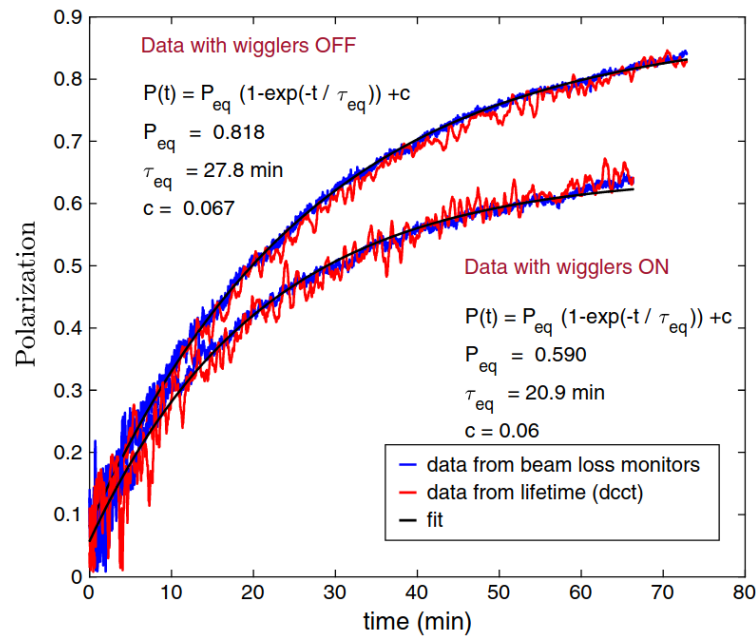
E [GeV]	$\nu$ [-]	$\tau$ [s]	$\tau$ [min]	F [MHz]
2.5	5.673	567	9.4	1.74
2.4	5.446	675	11.2	1.21
2.3	5.220	835	13.9	3.31
2.2	4.993	1042	17.4	2.70
2.1	4.766	1316	21.9	2.08
2.0	4.539	1679	28.0	1.46
1.9	4.312	2170	36.2	3.56
1.8	4.085	2843	47.4	2.95
1.7	3.858	3784	63.1	3.56
1.6	3.631	5124	85.4	1.71
1.5	3.404	7075	117.9	1.10



# Outlook

## Absolute polarization measurements

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

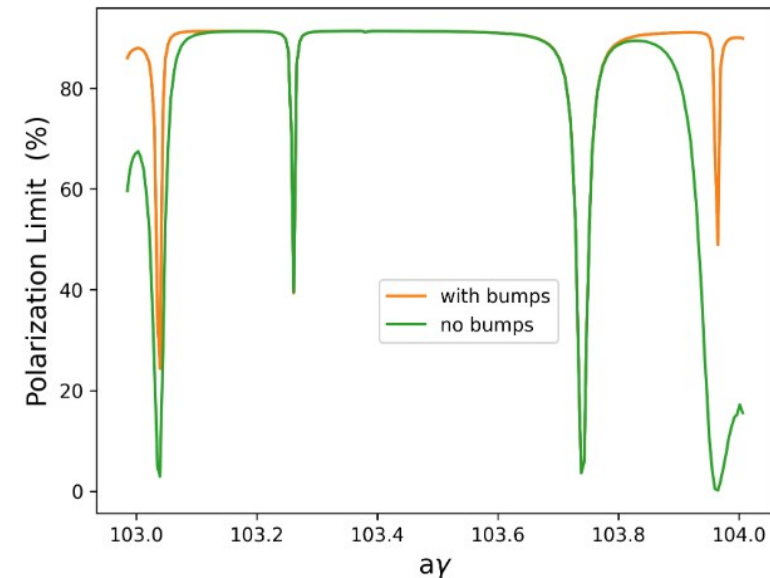


Baier and Khoze (1968),  
Phys. Rev. Accel. Beams 22, 122801, 2019



## Spin matching with vertical orbit bumps

- Harmonic spin bumps to reduce spin diffusion and improve polarization
- Simulations performed for FCC → [Talk: Y. Wu](#)



Courtesy: Y. Wu

# Thank you!

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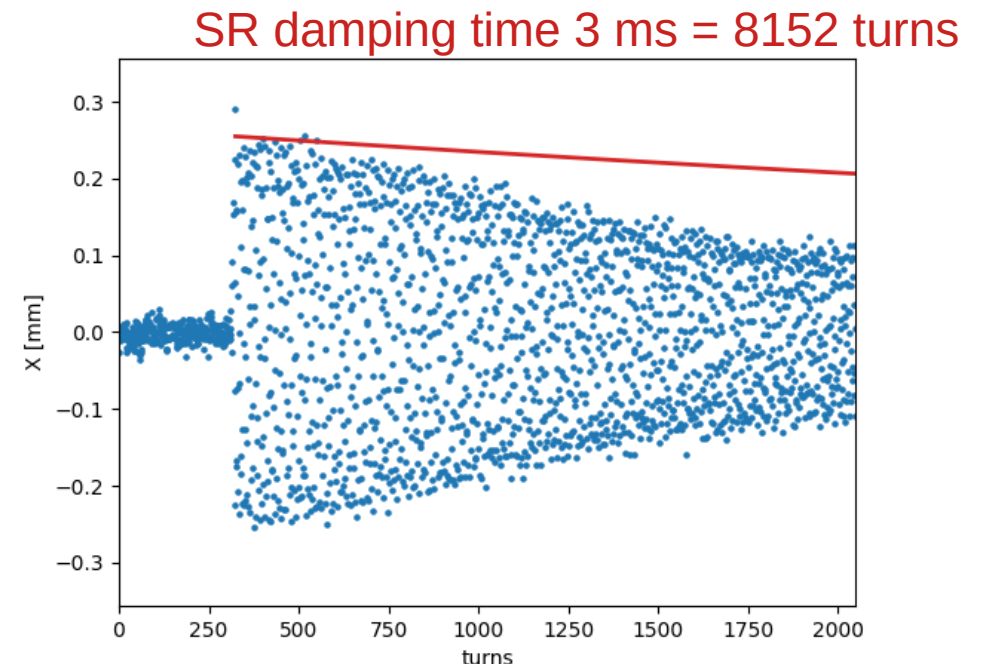
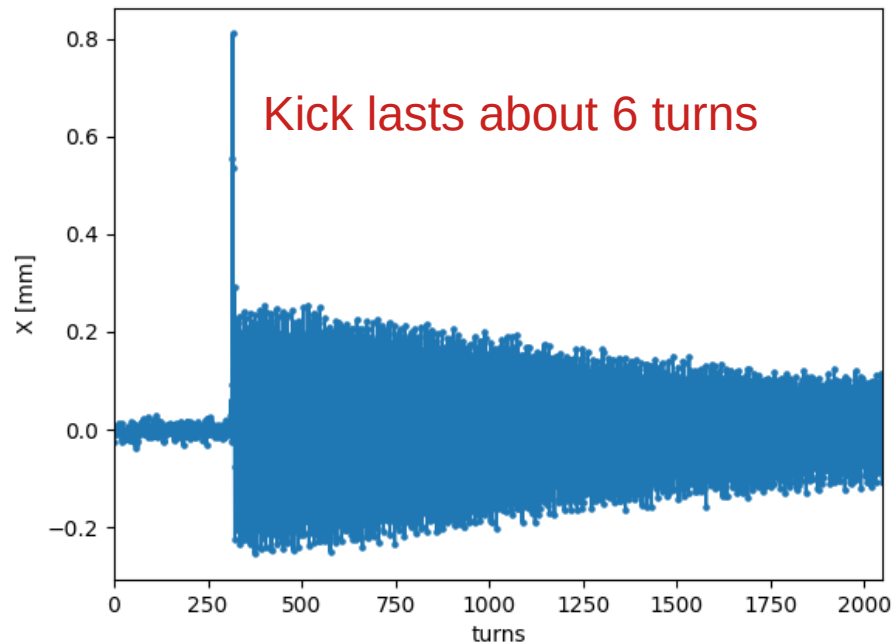
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# Optics Measurements

- Turn-by-turn BPM data recorded for all 39 BPMs (1 BPM not working)
- Kicks performed with horizontal injection kicker with various kick strengths
- Tried using transverse feedback system for beam excitation, no data recorded, but could be performed



# Automated Scans

