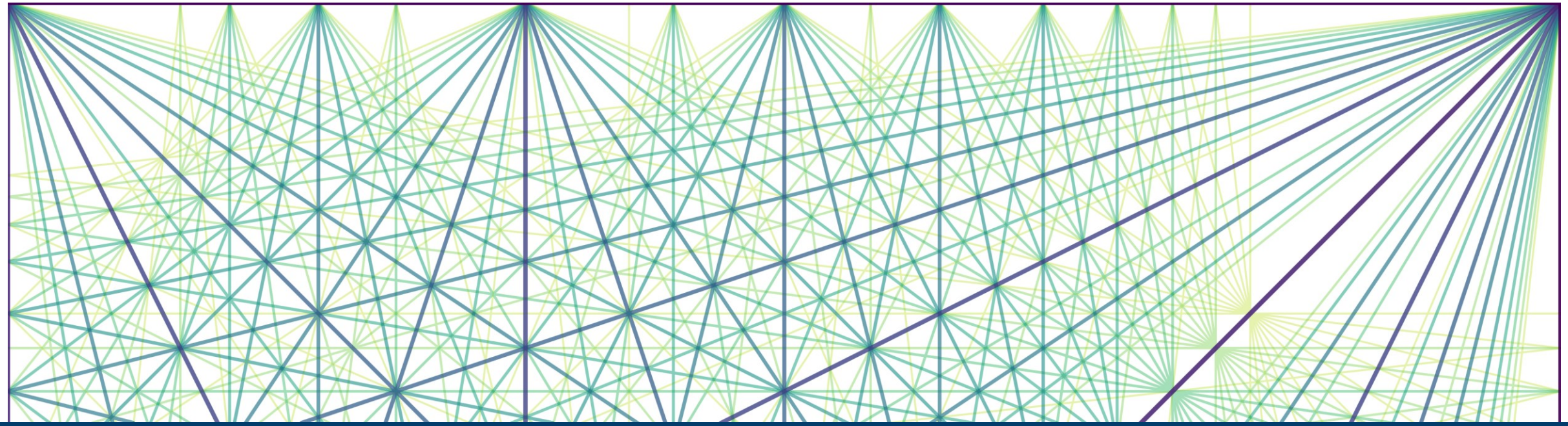


DEVELOPMENT OF A FAST BETATRON TUNE AND CHROMATICITY MEASUREMENT SYSTEM

March 17, 2021 I DPG Dortmund AKBP 6.1 I Philipp Niedermayer

Mitglied der Helmholtz-Gemeinschaft

III. Physikalisches Institut B

RWTH AACHEN UNIVERSITY

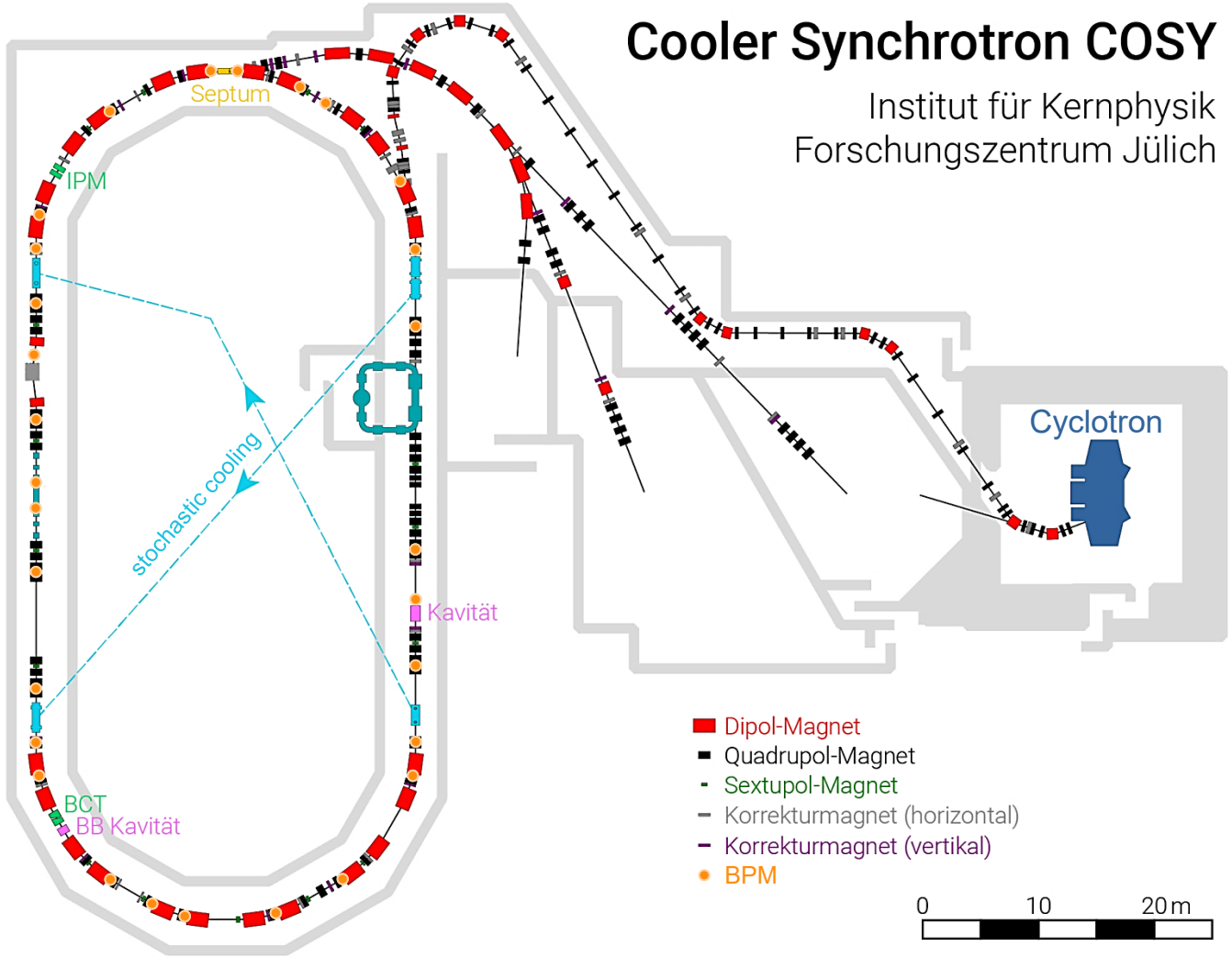
JÜLICH Forschungszentrum

OUTLINE

- Introduction and motivation
- Betatron oscillations and their excitation
- Tune determination from bunch-by-bunch position data
- Chromaticity measurement
- Summary

COOLER SYNCHROTRON COSY

- Polarized or unpolarized protons and deuterons
- Momentum range: 0.3 – 3.7 GeV/c
- Beam cooling systems
- 29 beam position monitors (BPMs)
  - Upgraded in 2017
  - Bunch-wise positioning
  - 100 µm precision



MOTIVATION

Based on bunch-by-bunch position measurements from BPMs:

- Build a fast and precise **tune measurement** system for bunched beams
  - → Routinely passive monitoring
  - → Track tune during acceleration
  - → Support COSY operation and Jülich Electric Dipole moment Investigations (JEDI)
- Build a **chromaticity measurement** system
  - → Routinely determination and compensation of chromaticity
  - → Parameter studies by the JEDI collaboration

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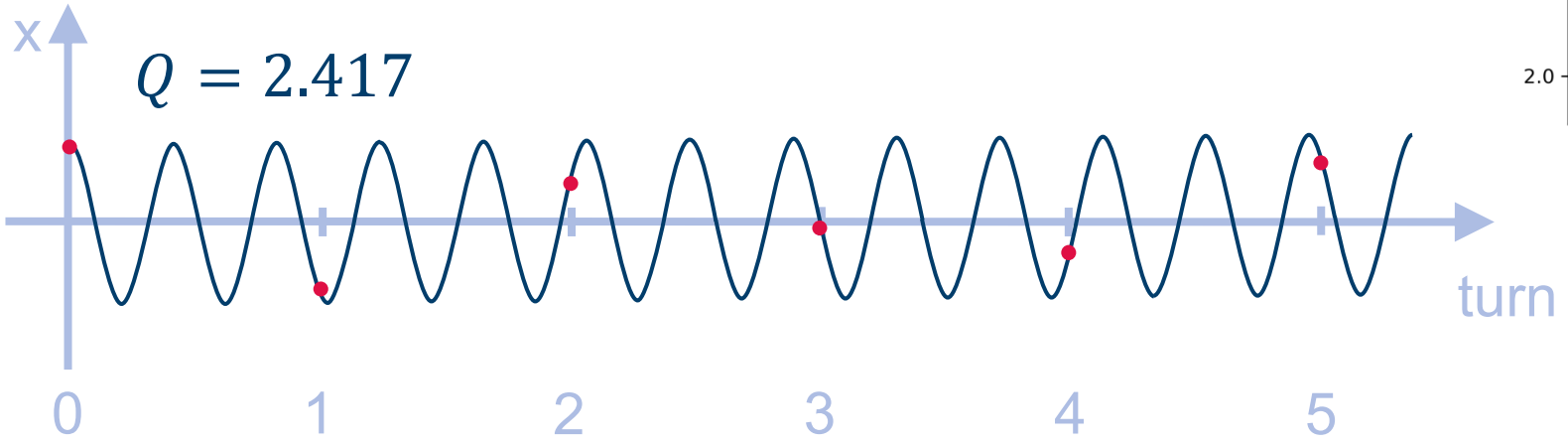
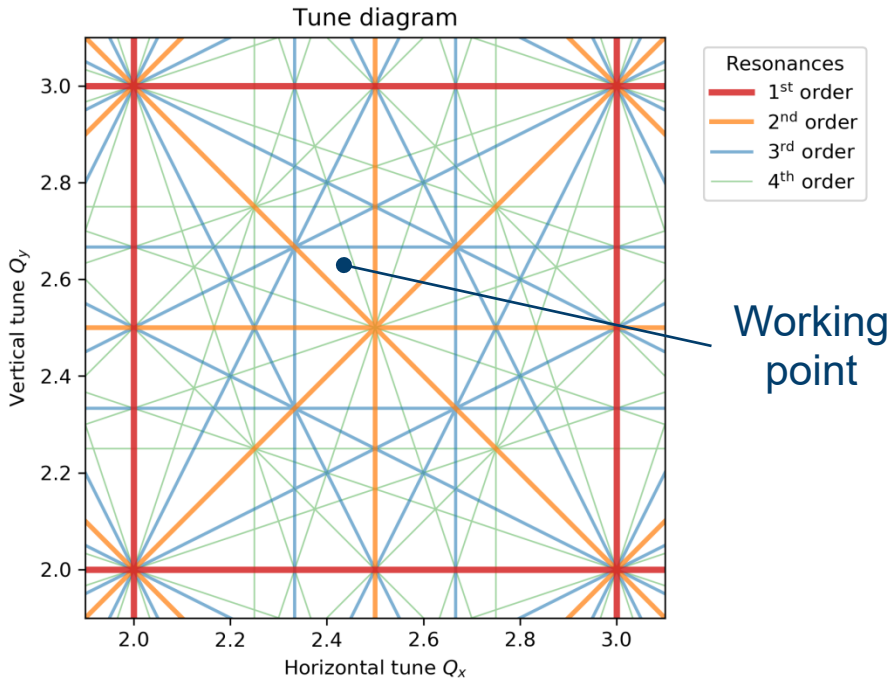
BETATRON OSCILLATIONS

Tune

- Transverse Betatron oscillations around orbit
- Tune Q = number of oscillations per turn
- Beam losses when magnetic errors add up resonantly

→ Measure tune from oscillation of beam position





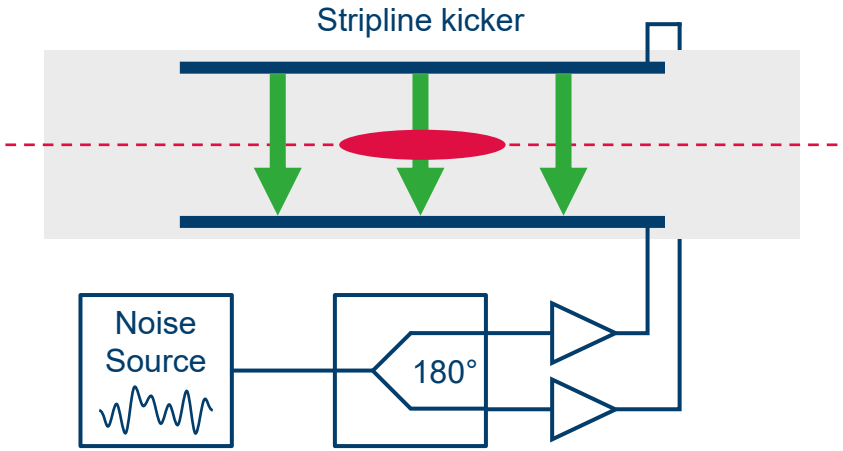
BETATRON OSCILLATIONS

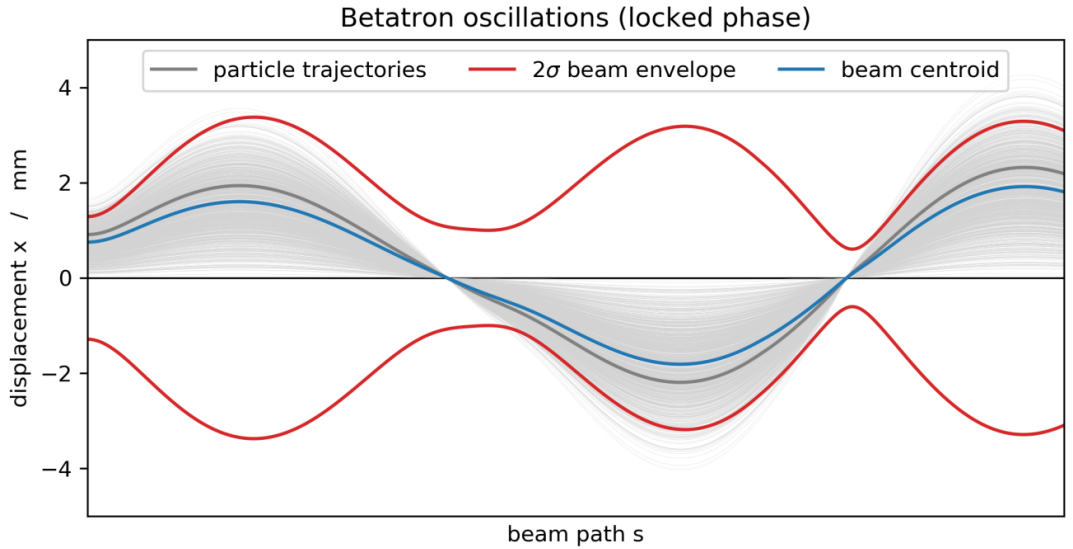
Excitation

- Incoherent oscillations: beam position constant
- Excitation with white noise in appropriate band

  → Coherent resonant Betatron oscillations

- Excitation scheme with stripline kicker:





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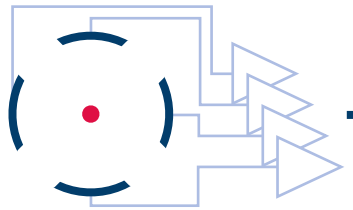
FAST TUNE MEASUREMENT

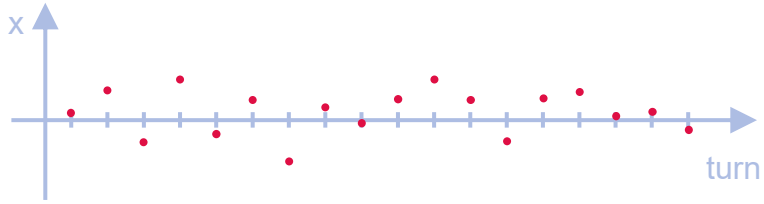
Method

- Excitation of betatron oscillations
- Bunch-by-bunch beam position measurement with BPMs
- Discrete Fourier transform and tune detection



Capacitive
Pick-Up

Libera Hadron
Beam Position Processor



Bunch-by-bunch positions

Image: i-tech

FAST TUNE MEASUREMENT

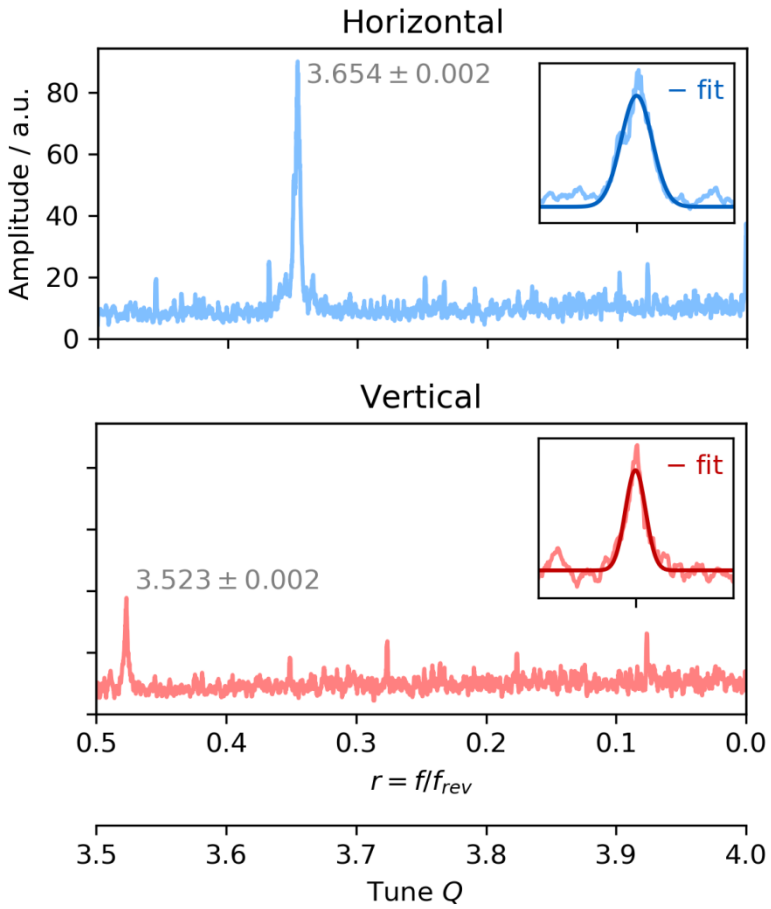
Tune detection

- Discrete Fourier transform
- Background subtraction & filtering
- Gaussian fit to resonance peak

- Nyquist–Shannon theorem: $f < f_{rev}/2$

  → Tune $Q = 3 + f/f_{rev}$ or $4 - f/f_{rev}$
- Absolute tune using model calculation

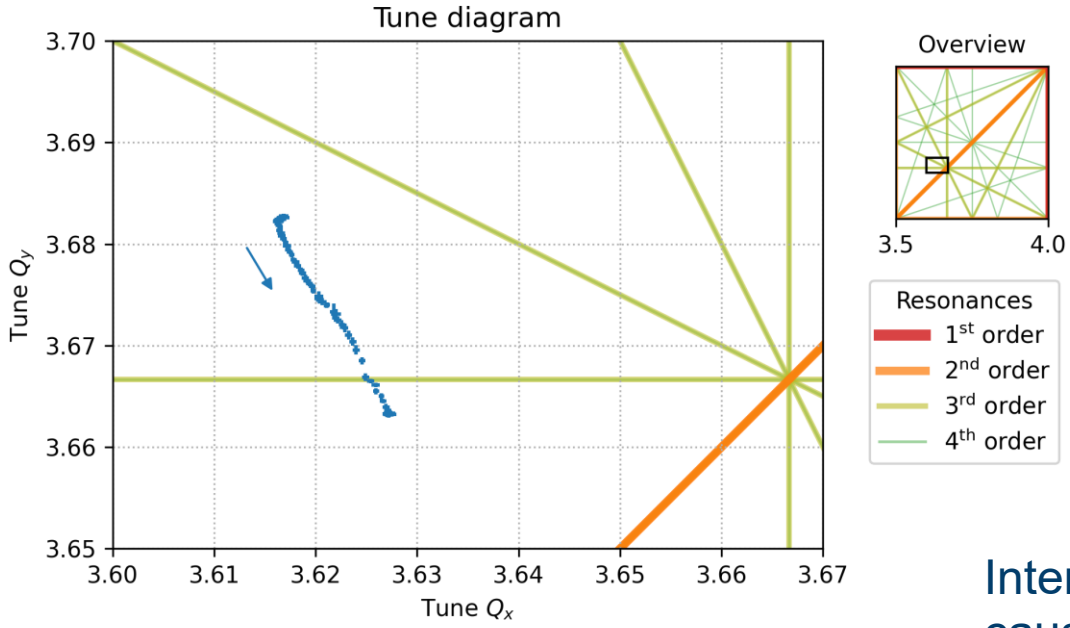
➔ Millisecond tune measurement with tree digit precision

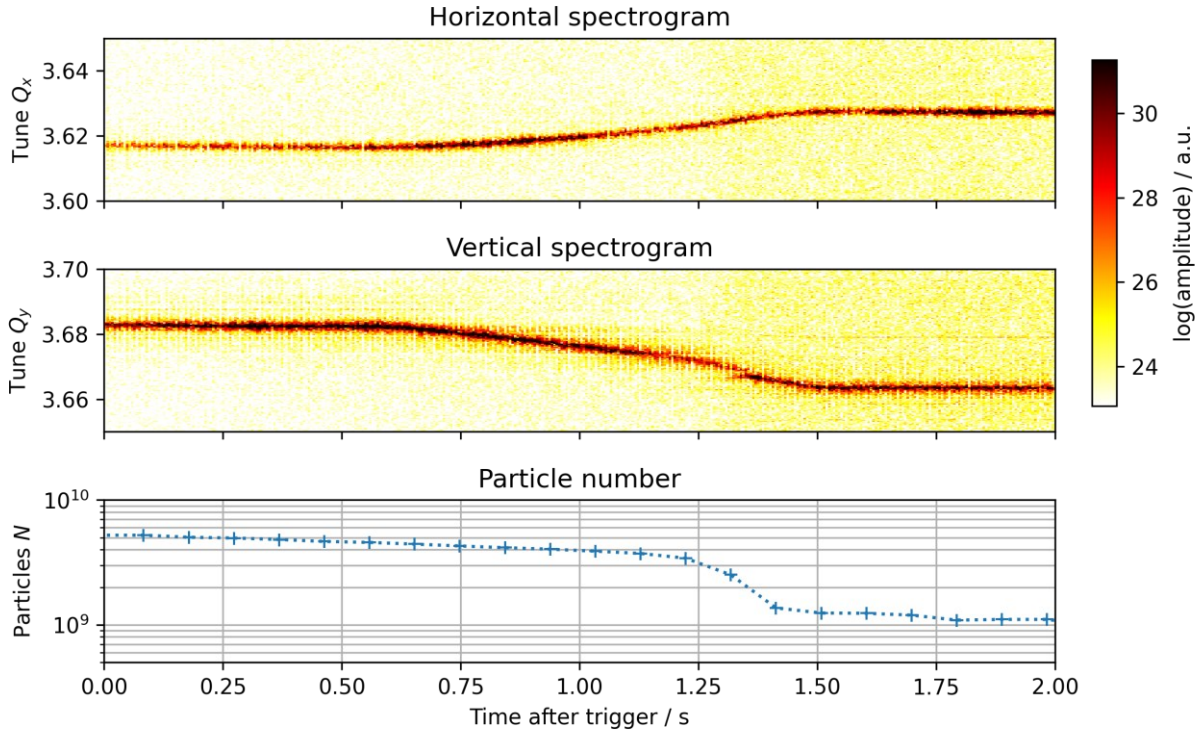


FAST TUNE MEASUREMENT

Continuous measurement

- Short-time Fourier transform
  - → Tune tracking over several seconds

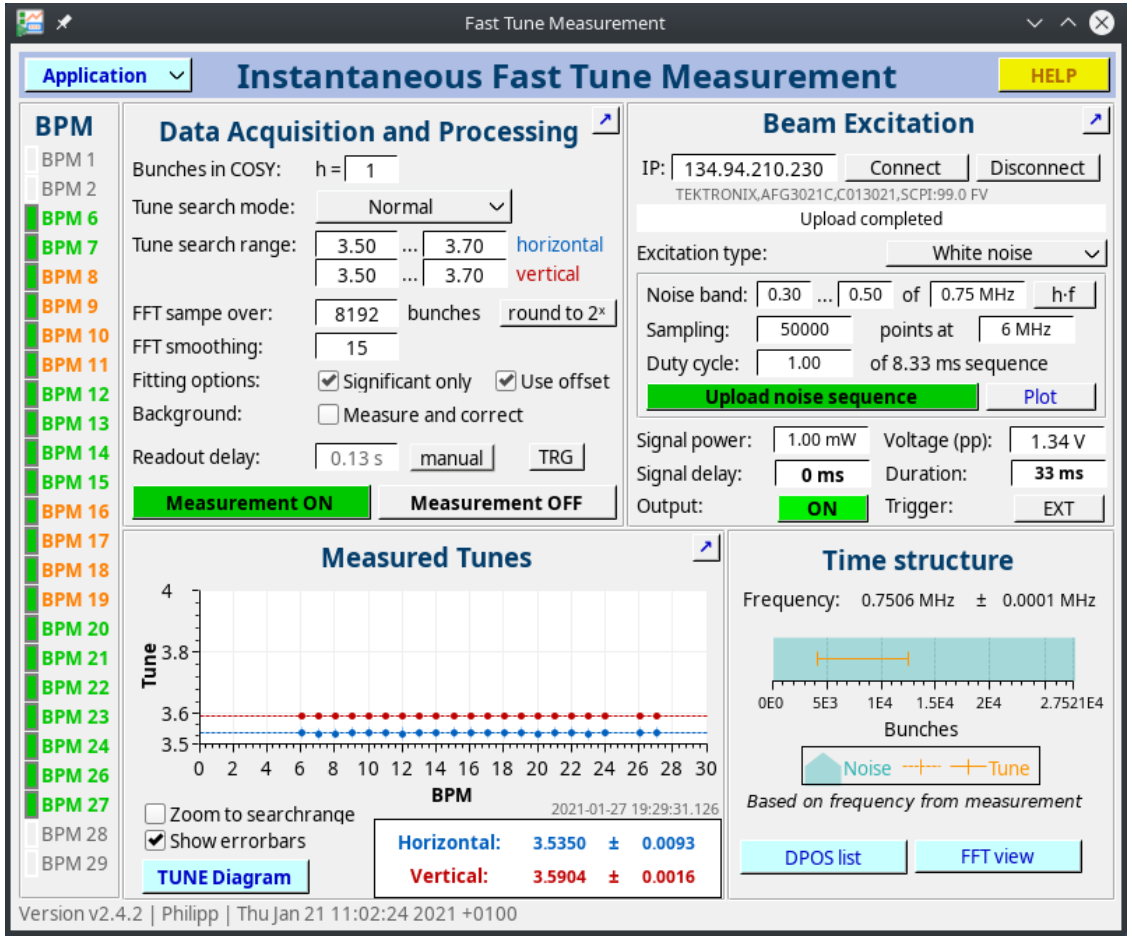


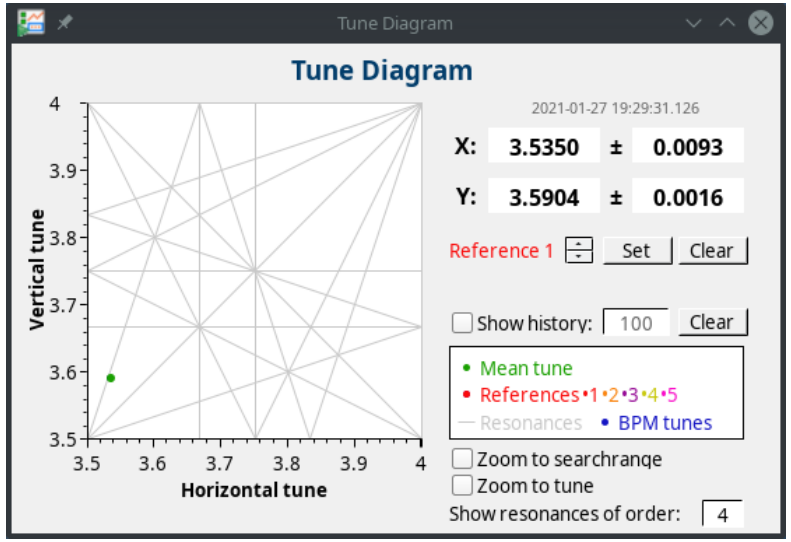


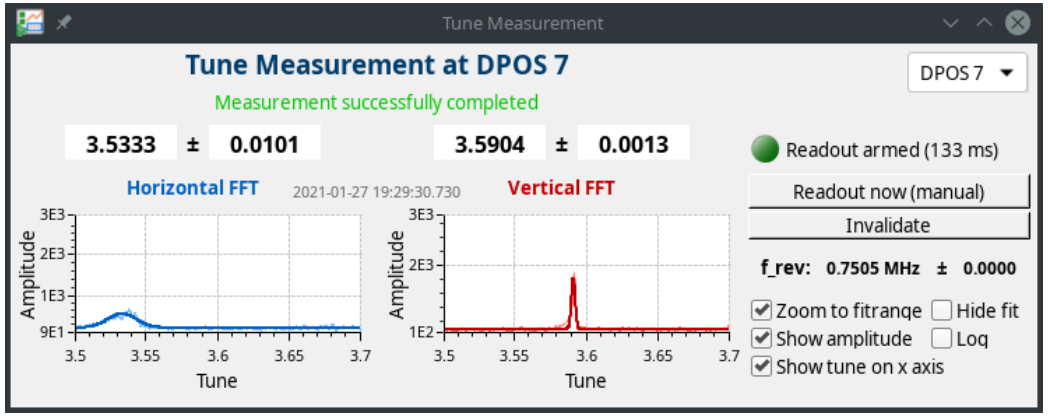
Intentional tune change between 0.5 and 1.5 s after trigger causing a beam loss due to crossing of a resonance.
Proton beam at 521 MeV/c

FAST TUNE MEASUREMENT

Control System Integration







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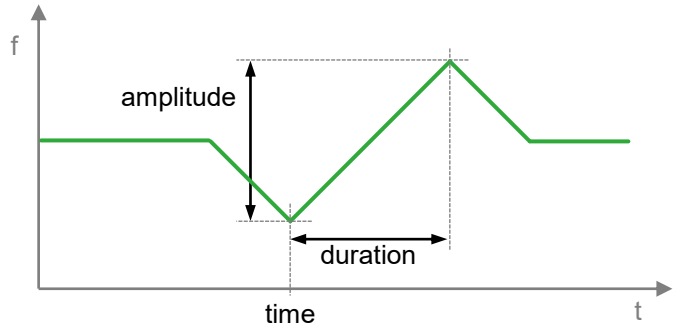
CHROMATICITY MEASUREMENT

- Chromaticity = tune dependence on momentum deviation

$$\xi = \frac{\Delta Q}{\Delta p/p} = \eta \frac{\Delta Q}{\Delta f_{\mathrm{rev}}/f_{\mathrm{rev}}}$$

→ Momentum distribution leads to tune spread

- Measurement procedure
  - → Change momentum with RF cavity (frequency sweep)
  - → Observe linear tune change
- Slip factor η from model calculation or separate measurement

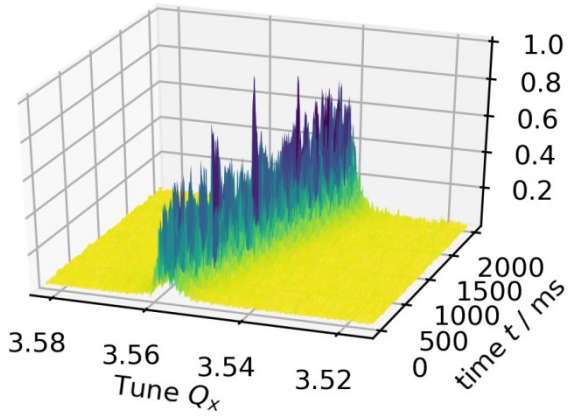


CHROMATICITY MEASUREMENT

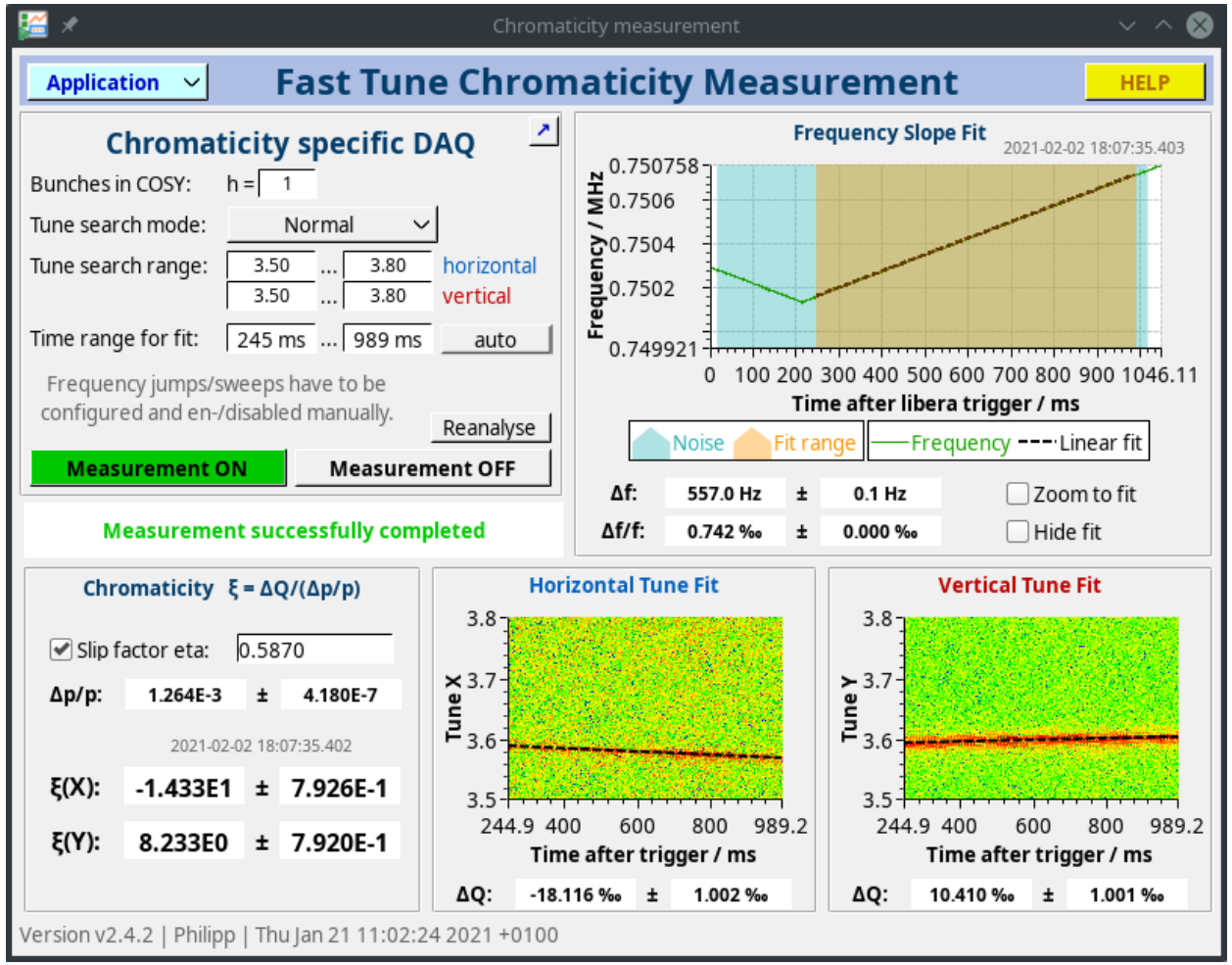
Control System Integration

- Linear frequency change
- Linear tune change

  → 2D moving Gaussian fit



Short-time Fourier transform



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SUMMARY

- Tune measurement for bunched beams based on bunch-by-bunch positions
  - Measurement time: ~ 20 ms → no measurable beam loss
  - Precision: ~ 10^{-3}
  - Continuous tune tracking
- Chromaticity measurement implemented
  - Measurement time: 0.1 ~ 1 s
- Outlook:
  - Measure tune for CW beams using ADC data
  - Measure Betatron oscillation phase advance

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Thank you!