Karlsruhe Institute of Technology

Beam position measurements: from pickups to stable beams at cSTART

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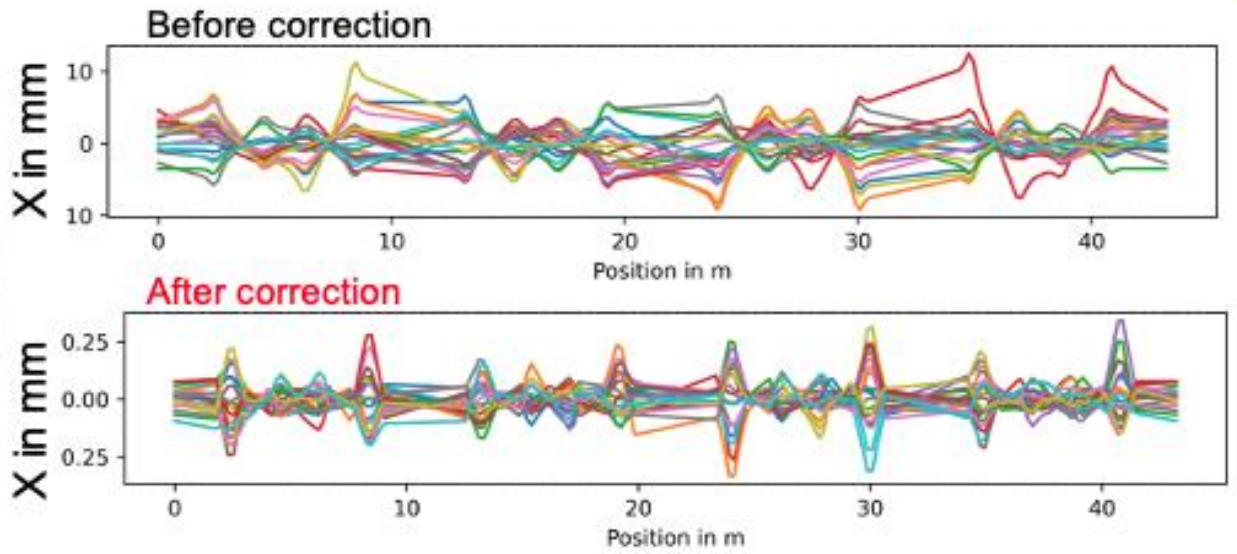
iFAST workshop, KIT, 18th-21st of March 2025



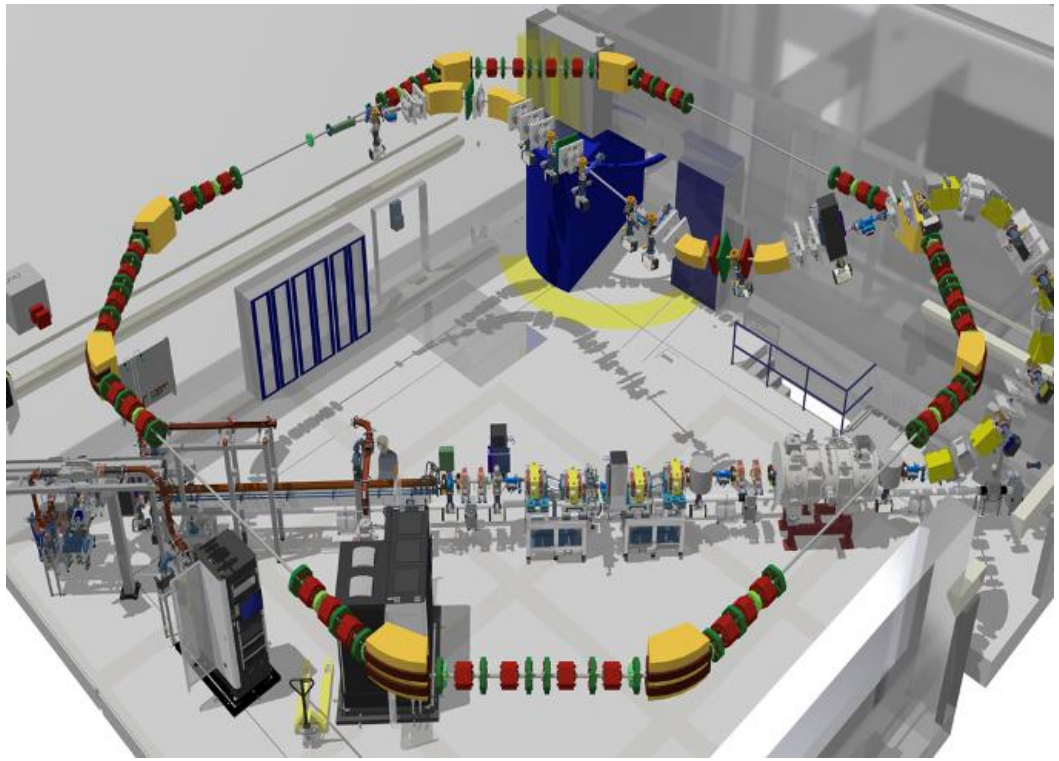
Outline

- General description of the cSTART project
  - Project goals
  - Overall layout
  - Parameters and dynamics
- The beam position system:
  - B-BPM design and specifications
  - A customised readout electronics
  - Tests on the readout prototype in the lab
  - Preliminary results on orbit corrections for the DBA lattice
- Perspectives
- Summary

cSTART goals

- cSTART[1]: compact STorage ring for Accelerator Research and Technology

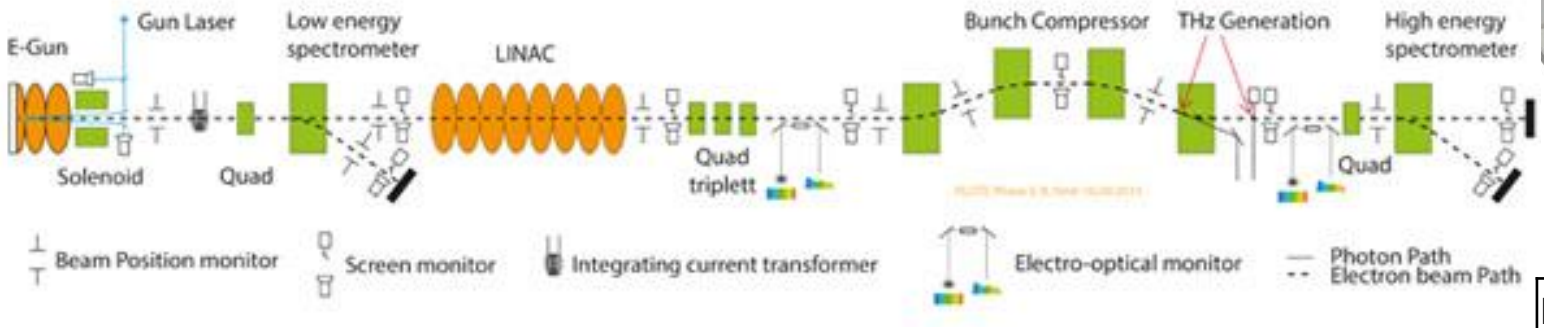
- Goals:
  - Demonstration of the injection of electron beams like / from a LPA (Laser Plasma Accelerator)
  - Storage of sub-ps bunches in a very large acceptance storage ring
  - Study of non-equilibrium beam physics



Courtesy Till Borkowski

[1] M. Schwarz *et al., Recent developments of the cSTART project, TU4P34, FLS2023,* DOI: 10.18429/JACoW-FLS2023-TU4P34

- Two injectors:
  - Phase 1: FLUTE[2] (Ferninfrarot Linac- und Test-Experiment) as a linac-based injector for early phases of the project
  - Phase 2: Laser Plasma Accelerators (LPA) as injector(s)



FLUTE Linac

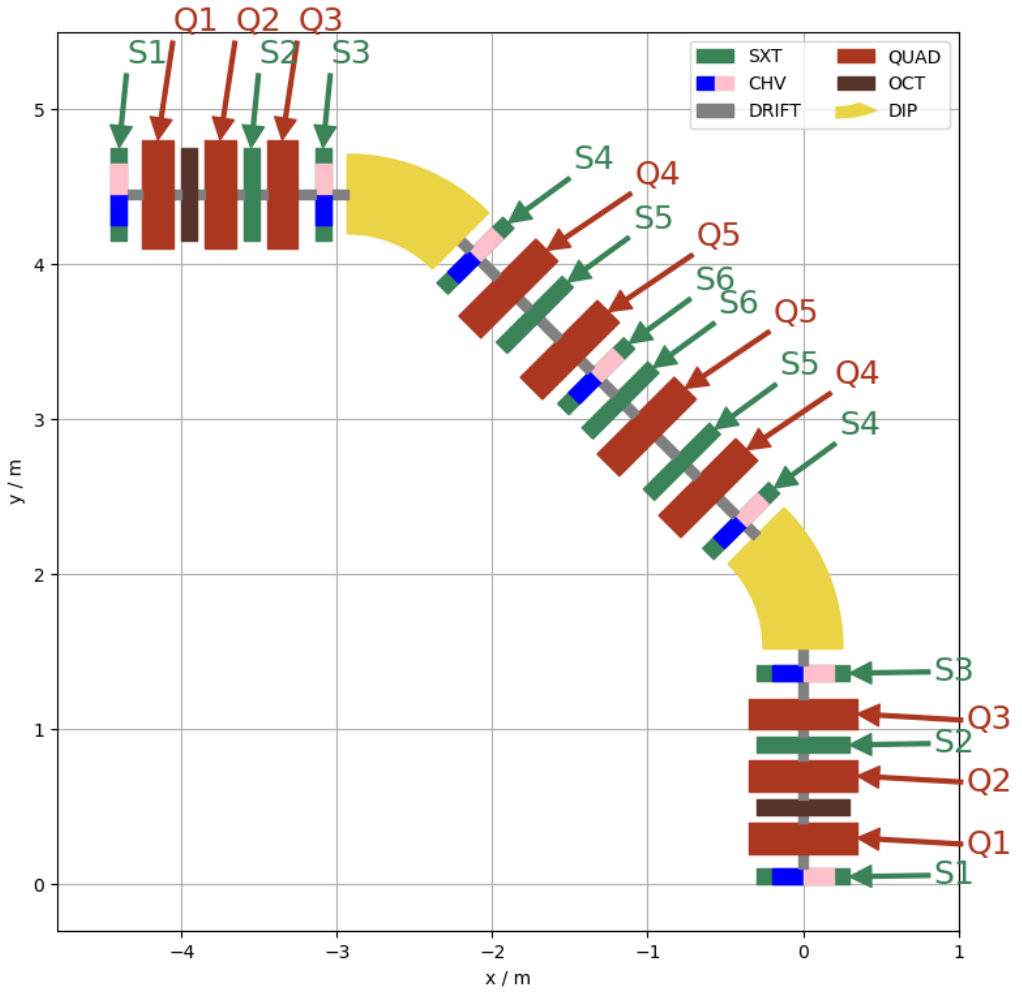
FLUTE main parameters

Energy	few MeV up to 90 MeV
Repetition Rate	up to 50 Hz
Electron Bunch Charge	up to 1nC
Electron Bunch Length	down to 1 fs
Spectral Band Coverage	up to 30 THz
THz E-field strength	up to 1 GV/m

[2] Nasse MJ *et al.*, FLUTE: a versatile linac-based THz source. Rev Sci Instrum. 2013 Feb;84(2):022705. doi: 10.1063/1.4790431. PMID: 23464187.

VLA-cSR layout

- A very compact DBA (double bend achromat) arc section filled with
  - Two families of bending magnets
  - Five families of quadrupoles
  - Six families of sextupoles (chromaticity correction, extra-winding coils as corrector magnets for orbit correction)
  - One family of octupoles
  - Diagnostics (BPM, BLD, Screens)
- Four straight sections hosting
  - Injection (septum and kicker)
  - RF cavity
  - Future experiments
  - Diagnostics (Stripline Kicker for tune measurements, ICT, screens)



VLA-cSR parameters

- The project aims to inject and store a single ultra-short electron bunch
- An on-axis injection scheme is planned with a storage period of 100 ms
- Long damping time allows the study of non-equilibrium beam dynamics
- The design of the DBA arcs allows the operation at different momentum compaction factors; low- and ultra-low alpha modes

Circumference of the storage ring	43.2 m
Operation mode	single bunch
Energy range	40 to 90 MeV
Energy spread	~2%
Bunch charge	1 pC to 1 nC
Bunch length within one turn	~10 fs up to~10 ps
Injection rate	1 to 10 Hz
Revolution / repetition frequency	6.94 MHz (144 ns)
Damping time (h / v / l) (50 MeV)	29.5, 26.5, 12.6 s
Nominal momentum compaction	14.8×10^{-3}
Reduced momentum compaction	3.9×10^{-3}

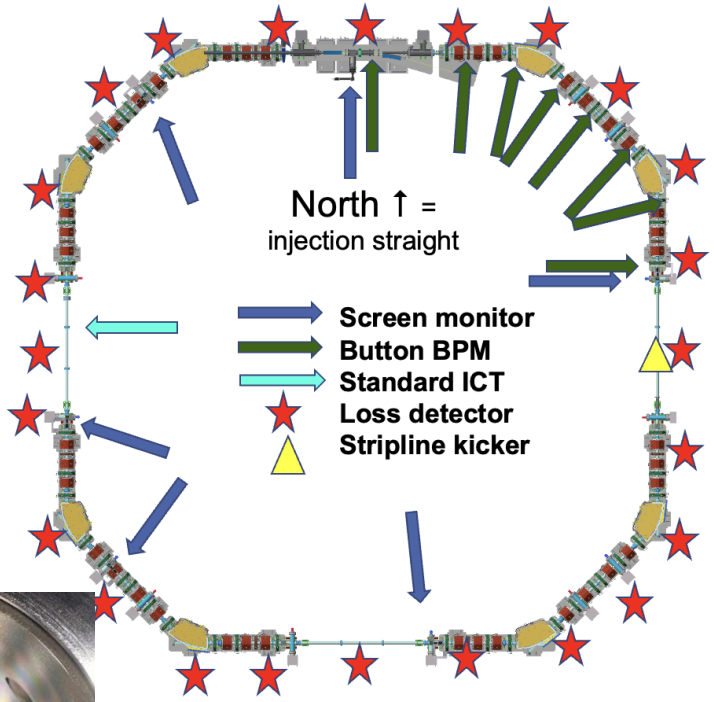
Special features and dynamics

- What makes the dynamics of the cSTART storage ring unique?
  - Low energy beams (long damping periods vs storage time, non-equilibrium beams)
  - Ultra-short bunches
  - Single bunch and high repetition rates
  - Mounted on a height of almost 4 m from the ground (alignment challenges)

- Conditions on beam position measurements:
  - Fast (turn-by-turn @ 6.94 MHz)
  - Resolution of 100 µm @ 100 pC (to avoid severe elongation of the LPA injected beam upon the first turn)

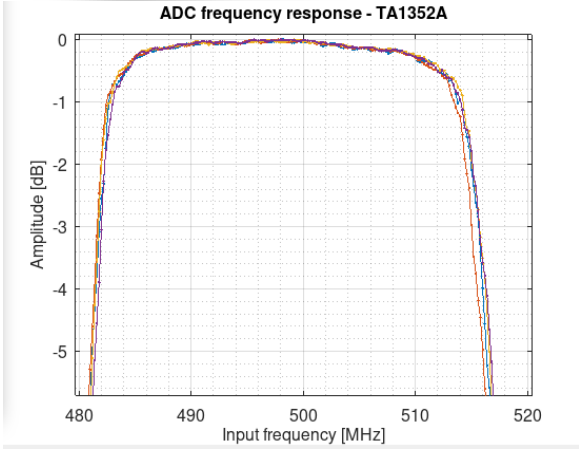
The B-BPM electrodes

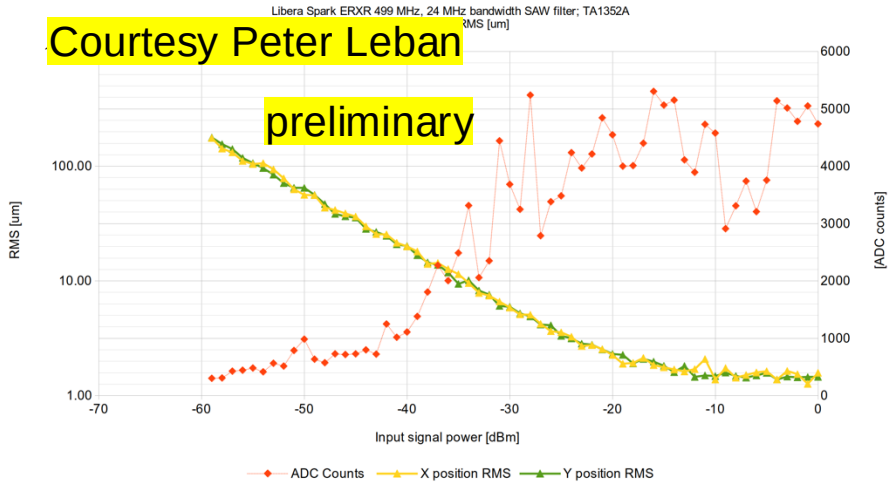
- Each arc will be equipped with 7 B-BPM (7 h/v orbit correctors) + 1 B-BPM in the injection section (29 in total)
- Beam pipe: 28 mm radius
- Design of electrodes:
  - The ESRF design (PMB Alcen)
  - Button radius = 5.5 mm
  - Button thickness = 2.5 mm
  - Button gap = 250 µm



The readout electronics

- A customised Libera Spark ERXR from iTech:
  - A different SAW filter (front-end filter) : central frequency 499 MHz and Bandwidth 33 MHz
  - ADC sampling frequency 117.95450 MHz
  - Triggers at 6.93850 MHz
- Why customised:
  - No overlap between signals of successive turns
  - 100 µm @ 100 pC
- i-Tech testing on one prototype: (signal generator with fixed pulse length 1 ns)
  - A scan over signal amplitude (corresponding to 1 pC to 1 nC bunch charge)
  - 100 µm @ 20 pC

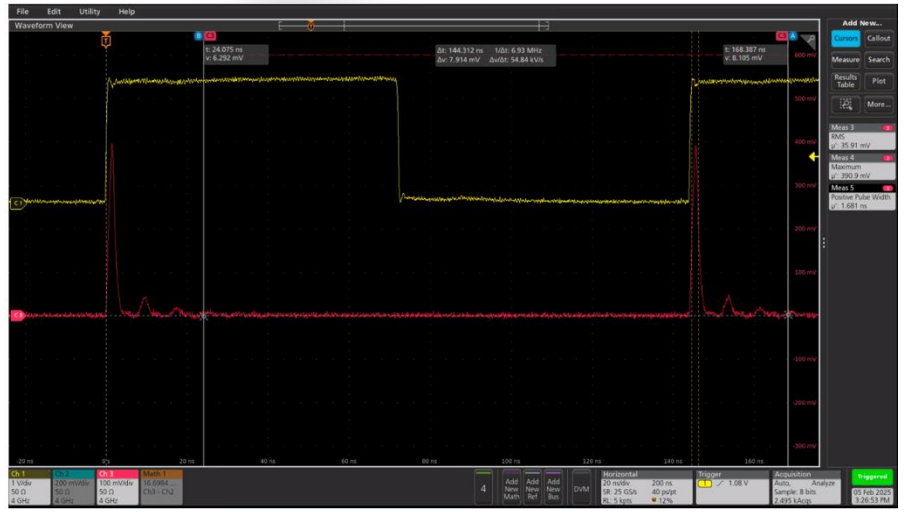


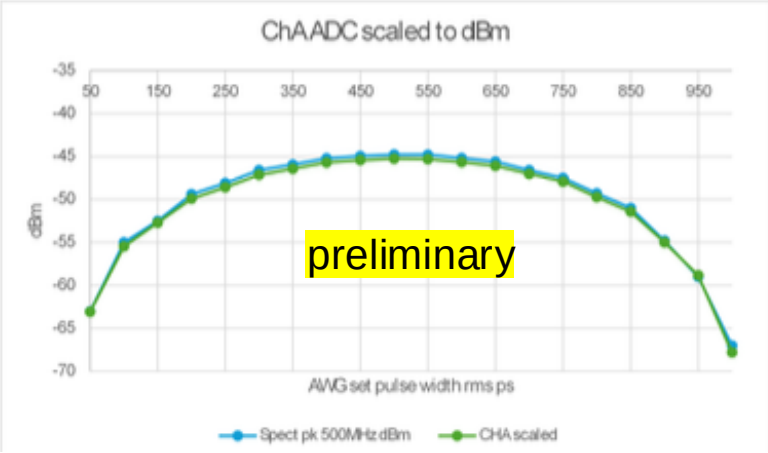


Ongoing tests at KIT (preliminary)

- Two different signal generators:
  - A pulsed signal at 6.9 MHz (variable pulse length and amplitude)
  - An AWG from Tektronix (50 GSps) (pulse length down to 50 ps)

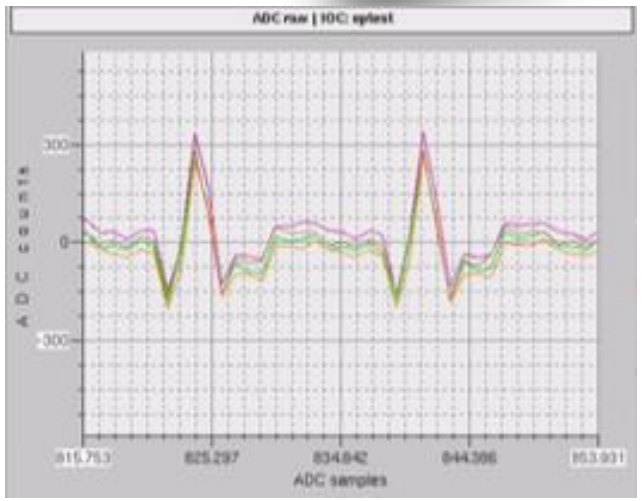
- Dependency over pulse width?
  - Set of measurements varying bunch length 50 ps to 1 ns
  - The integral of the ADC counts follow the profile of the 499 MHz component (measured with a spectrum analyzer) of the input signal from the AWG



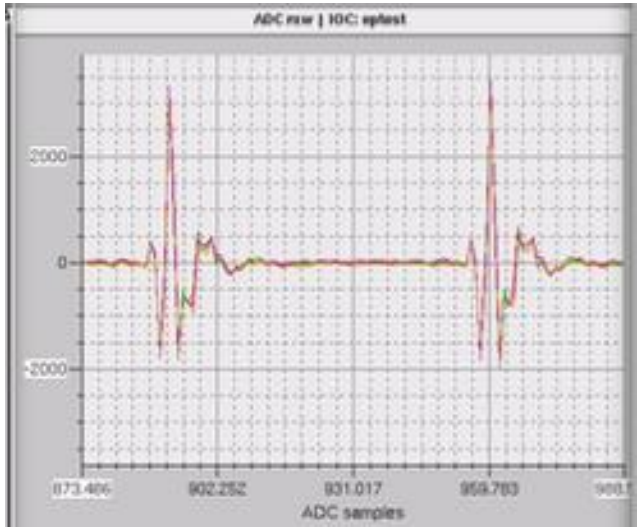


Turn-by-turn overlaps (preliminary)

- How much overlap is there between successive turns?
  - Generate pulses at 2, 3, 4 etc … times slower pulse frequency than the 6.9 MHz
  - Compare the integrated ADC counts for each frequency to the 6.9 MHz
    - 1 turn corresponds to 17 ADC samples
  - A preliminary estimation of 3% is calculated (acceptable)



6.9 MHz

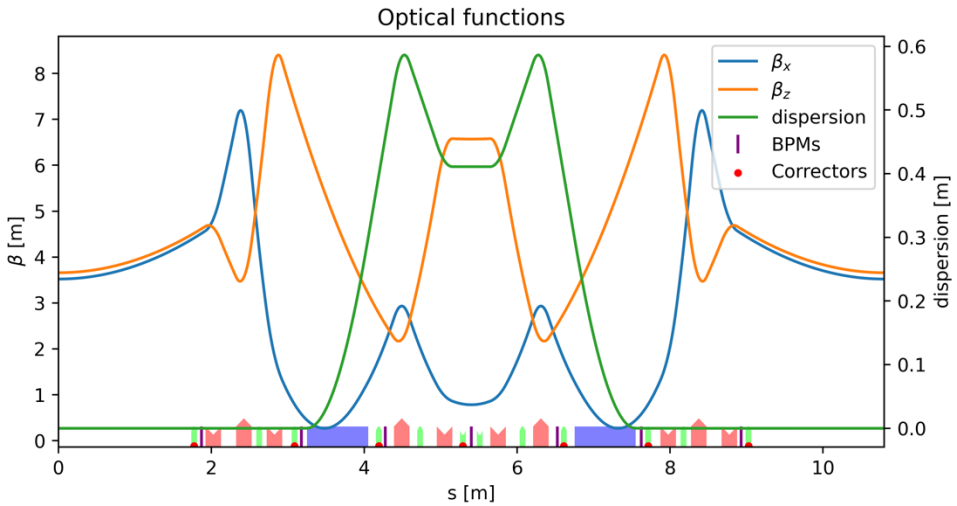


1.725 MHz

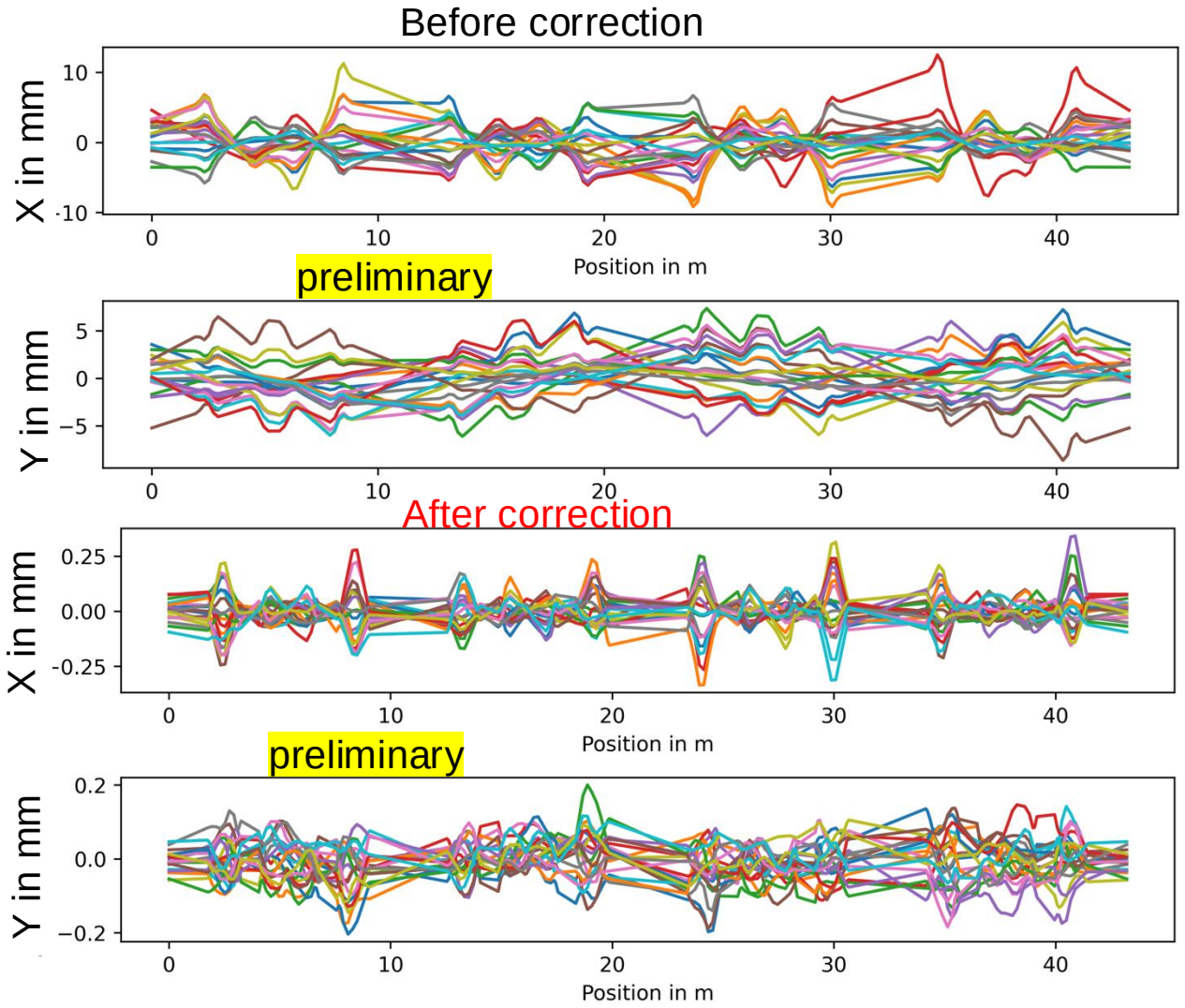
Orbit corrections (preliminary)

- In attempt to prove the satisfaction with the corrector magnet power supplies specifications

- Simulation conditions: (DBA lattice, 50 seeds)
  - Magnet Offsets: 200 µm
  - Magnet Roll/Pitch/Yaw: 800 µrad
  - NO magnetic field errors
  - BPM Noise: 100 µm
  - NO BPM Calibration
  - NO BPM Offsets



Orbit corrections (preliminary) II



- Bear in mind:
  - Some error sources were not simulated
  - Misalignment errors are considered for worse cases
  - No elongation studies of the electron bunch were accounted for .

Perspectives

- Tests:
  - Test runs with the signal generators are non-stop!
  - Testing with a real electron beam from FLUTE after the bunch compressor
- Orbit corrections including all errors sources and different lattices (DBA, low alpha and ultra-low alpha); effects on bunch elongation and strategies to cope with it.
- Study the possibility of getting a slow orbit feedback system running at cSTART
- Once tests and simulations are convincing; ordering of a mass production of the B-BPM electrodes and customised Libera SPARK ERXR electronics

A prototype of a B-BPM block installed at FLUTE

Summary

- cSTART storage ring has unique features allowing us to study non-equilibrium
- To guarantee stability of the beam and to avoid its strong elongation, beam position measurements need to be fast (turn-by-turn) and precise
- A prototype of a customised electronics based on Libera SPARK ERXR from iTech is being under test at KIT using signal generator and e^- beam at FLUTE
- Simulations of orbit corrections including all error sources and accounting to beam elongation are in progress

Acknowledgments:

The cSTART team:

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Thank you very much for your attention

Questions and/or Suggestions??