A MTCA based BPM System for PETRA IV

PETRA IV. NEW DIMENSIONS

12th International Beam Instrumentation Conference

SASKATOON, CANADA
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IBIC2023

Gero Kube

Saskatoon, 11.9.2023

on behalf of

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HELMHOLTZ

DESY.

Outline

- introduction: PETRA IV
- BPM requirements and boundary conditions
- system overview
- TbT resolution studies
- drift stability
- summary

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→ technical issues, pitfalls

→ not yet reached the ultimate system performance in all data paths

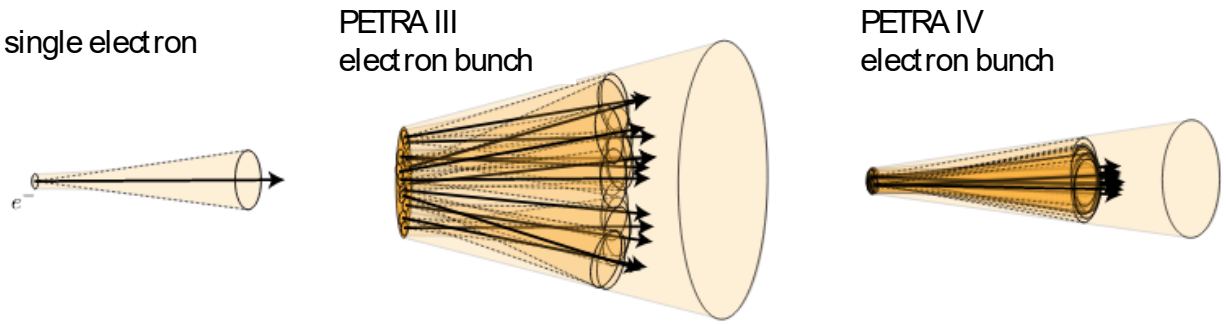
→ data taking still ongoing

(most of the data taken last week)

Diffraction Limited Storage Ring

Principle Ideas

Diffraction limit



- natural emittance scaling

$$\varepsilon_x \propto \gamma^2 \theta^3 \Gamma$$

$\gamma = {}^{E}/_{m_0 c^2}$ Lorentz factor

θ: bend. magnet angular deflection

Γ: magn. lattice design of storage ring

- emittance reduction
  - reduction of beam energy
    - → E defines radiation spectrum: $\hbar\omega_c \approx 0.665 E^2 B$
  - reduction of deflection angle θ per bend
    - → from double bend achromat (2)
      to multi-bend achromat (5,6,7,9,..)
    - → MAX-IV, ESRF-EBS, SIRIUS
    - → APS-U, PETRA IV, …

PETRA @DESY

History

- 1978 – 1986: e+e- collider PETRA (up to 23.3 GeV / beam) with circumference 2304 m
- 1988 – 2007: pre-accelerator PETRA II for HERA (p @40 GeV, e @12 GeV)
- since 2007: dedicated 3rd generation light source PETRA III, commissioned in 2009 TDR: DESY 2004-035

  → 14 beamlines (15 experimental stations) operating in parallel
- from 2014: staged extension project W. Drube *et al.*, 2016 https://doi.org/10.1063/1.4952814

  → up to 12 additional beamlines (presently not all of them in operation)

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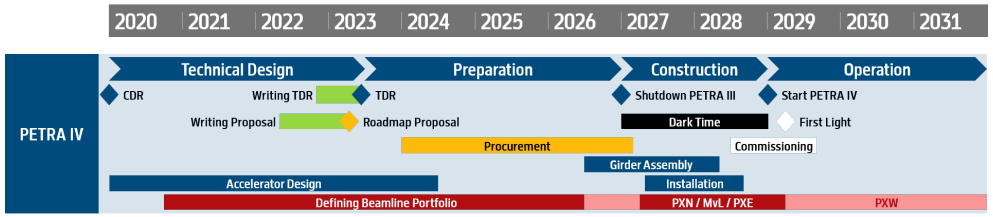
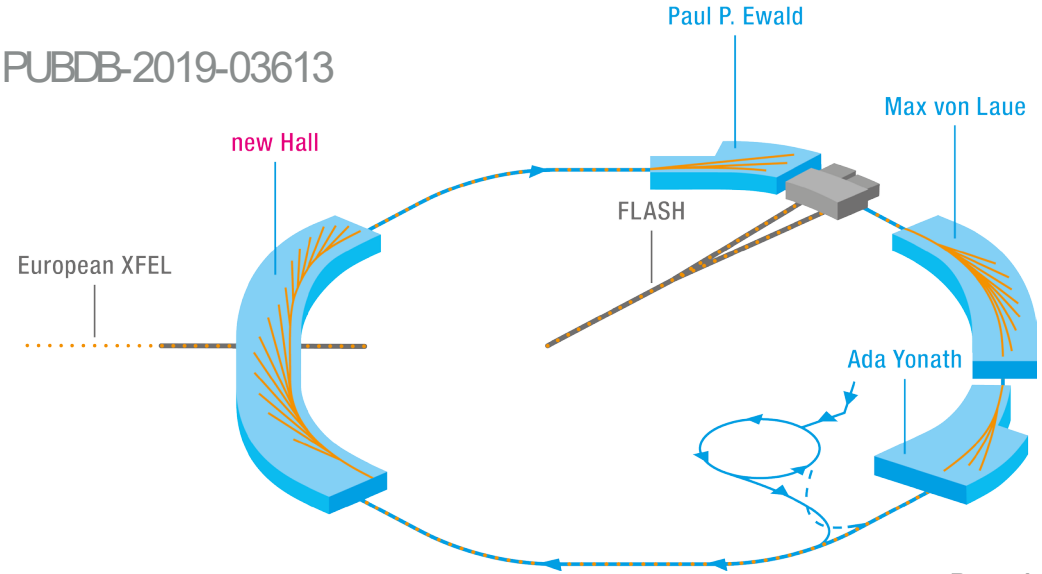
  → up to 12 additional beamlines (presently not all of them in operation)
- at present: work on PETRA IV project CDR: DOI: 10.3204/PUBDB-2019-03613

  ring-based diffraction limited light source

  Ch. Schroer *et al.*, J. Synchrotron Rad. 25 (2018) 1277



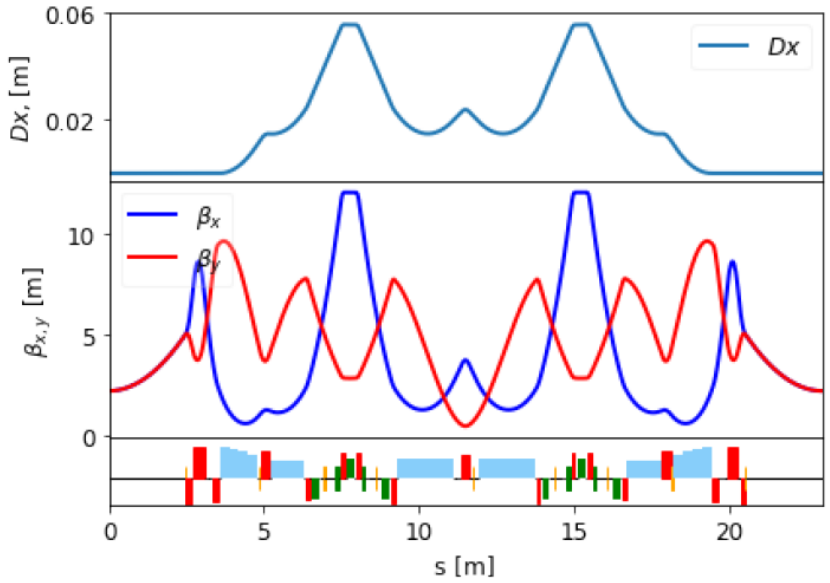


Layout and Parameters

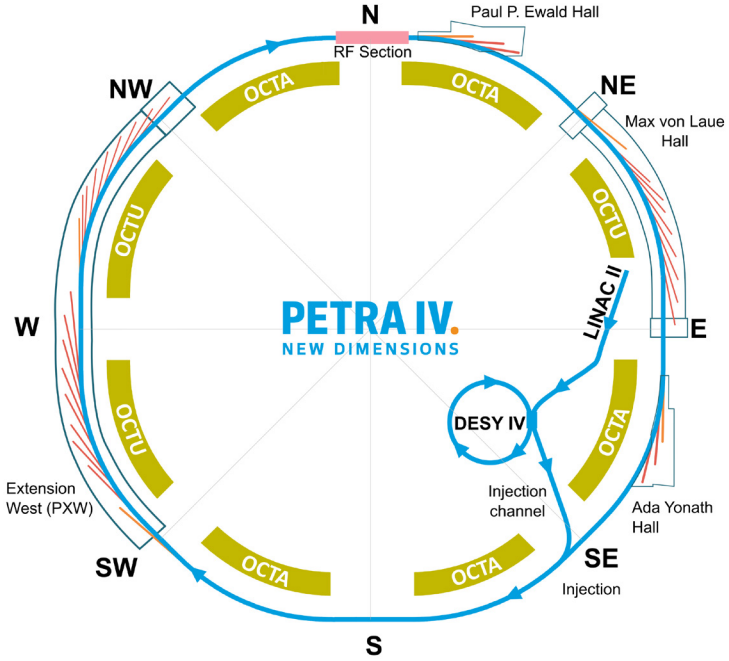
I. Agapov *et al.*, submitted to Phys. Rev. Accel. Beams

- Hybrid 6-Bend Achromat (H6BA) lattice
  - natural emittance: ε ≈ 43 pm.rad

    → use of damping wigglers: ε = 20 pm.rad



- general machine layout



Parameter	Value
Tunes ν_x,ν_y	164.18, 68.27
Natural chromaticity ξ_x,ξ_y	-230, -196
Corrected chromaticity ξ_x,ξ_y	6, 6
Momentum compaction factor α_C	$3.3\ 10^{-5}$
Standard ID space	4.9 m
$\beta_{x,y}$ at ID, standard cell	2.2 m, 2.2 m
$\beta_{x,y}$ at ID, flagship IDs	4 m, 4 m
Nat. hor. emittance ε_x with IDs, zero current	20 pm rad
Rel. energy spread δ_E with IDs, zero current	$0.91\ 10^{-3}$

$f_1 = 500$ MHz

$f_3 = 1.5$ GHz

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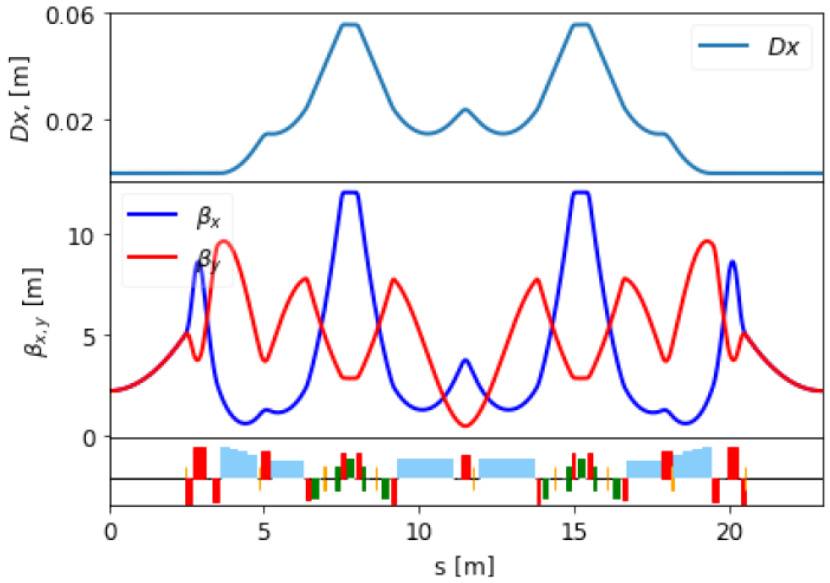

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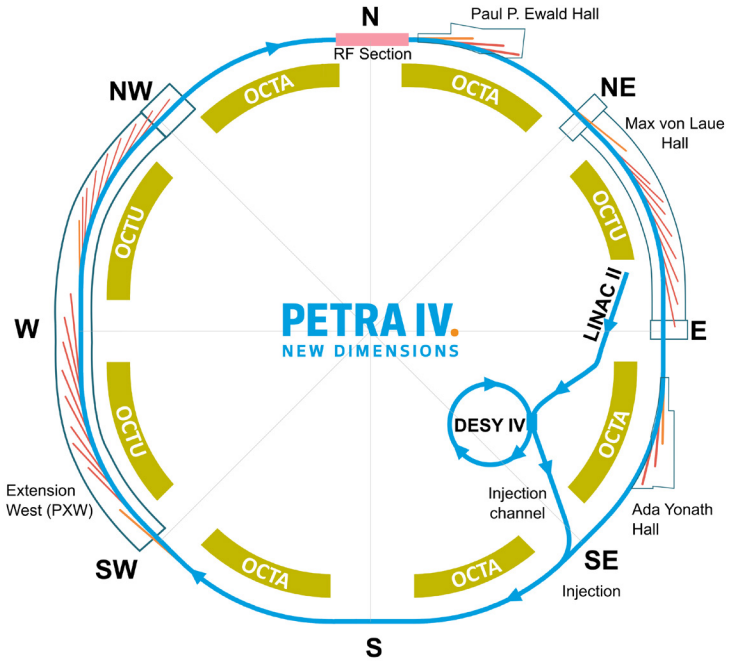

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  - brightness mode: 1920 bu. (Δt = 4ns) in 200 mA
  - timing mode: 80 bu. (Δt = 96ns) in 80 mA

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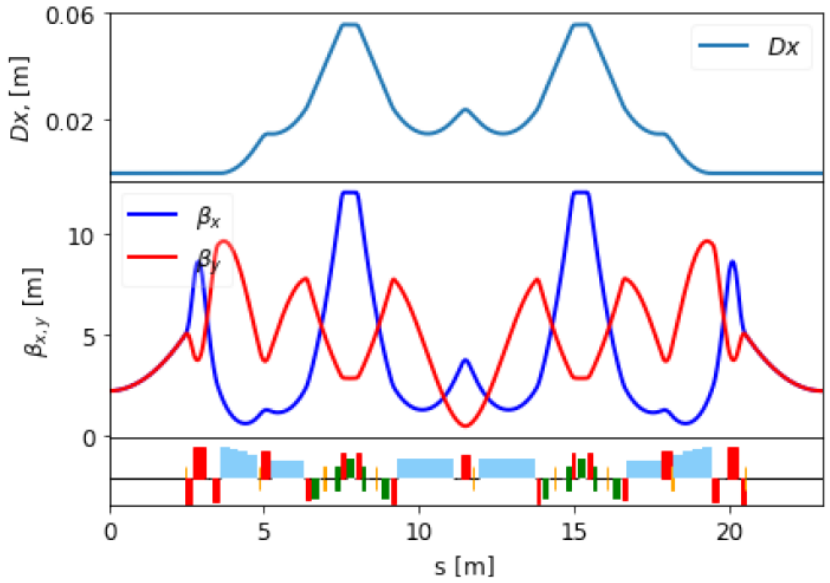

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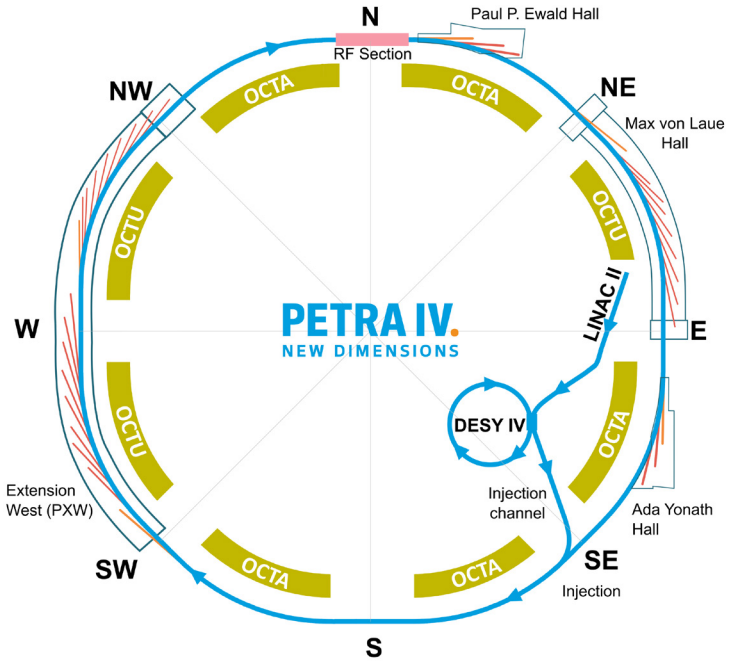

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- extensions (under discussion)
  - 3840 bu. (Δt = 2ns) operation (each bucket filled)
  - 40 bu. (Δt = 192ns) in 80 mA → ≈ 10^{11} particles / bunch

Beam Position Monitor (BPM) System for PETRA IV

Requirements

Beam commissioning → accuracy ⩽ 500 µm (BPM measurement accuracy must satisfy requirements for BBA)

- alignment errors of BPMs wrt. adjacent quadrupoles → ≤ 100 µm
- electronic offsets (differences in gain factors among readout channels) → Lambertson method
- electro-mechanical offsets (mechanical tolerances, asymmetries among the four buttons) → careful design

→ tolerance margin of 150 µm for each (+ additional safety margin)

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Post-commissioning and operation → **resolution & stability** (random errors that change over time → **BPM electronics**)

• resolution on single bunch / turn	(0.5 mA/bunch for commissioning)	< 10 µm
• resolution on closed orbit	(200 mA in 1600 bunches @ 1 kHz BW)	< 100 nm (rms)
• beam current dependence	(60 dB range, centered beam)	± 2 µm
• long term stability	(measured over 6 days, temperature span ±1°C within a stabilized rack)	< 1 µm

BPM System for PETRA IV

BPM Electronics: Boundary Conditions

Number of BPMs: about 800

- 9 BPMs per cell / 72 cells → 648 BPMs in arcs
- additional BPMs in short/long straight sections

790 BPMs (incl. spares: ~800)

→ cost / space are important factors

≤ 10 k€ (per channel)

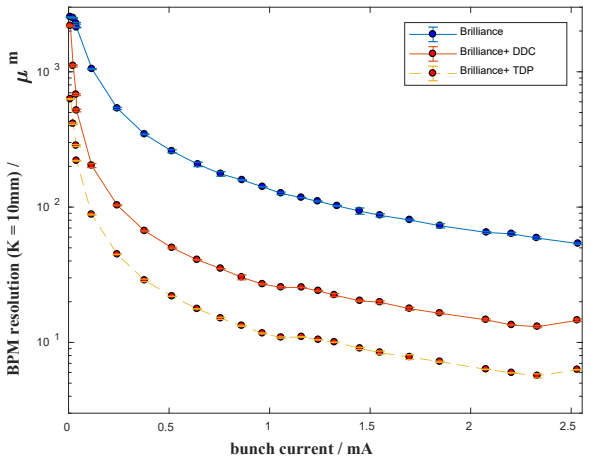
In-house development: no time and manpower → commercial solution

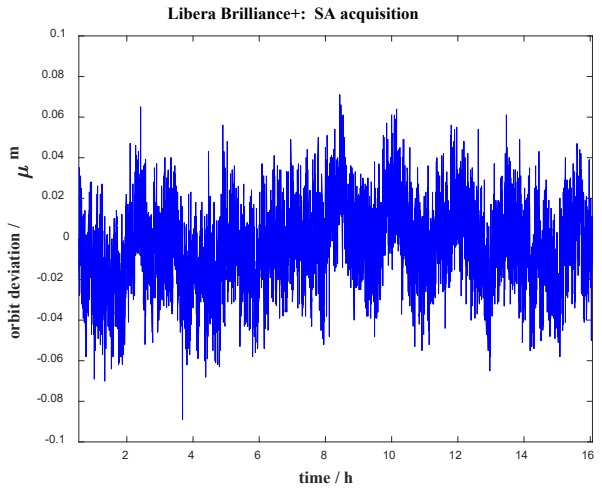
Libera Brilliance: will not fulfil requirements

G Kube *et al.*, Proc. IBIC2019, Malmö (Sweden) WEPP005.

Libera Brilliance+: would fulfil requirements

- in use at MAX-IV
- planned for APS-U





BPM System for PETRA IV

BPM Electronics: DESY Strategy

Drawback Libera Brilliance+

- long term stabilization starts at RF front-end ➡ influence of cable paths !
- about 10 years old technical platform ➡ obsolence of components

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DESY lab strategy: MTCA.4 as technical platform

Development project with industrial partner

- prototype development of MTCA.4 based BPM system
- long term stabilization scheme including cable paths
- functional prototype at end of TDR phase → fully equipped crate ready for tests at PETRA III

Long term strategy

- industrial partner brings in ability to perform mass production & QA for PETRA IV

BPM System for PETRA IV

Long-Term Drift Compensation

Long term stabilization scheme including cable paths

- pilot tone compensation
- external crossbar switching

BPM System for PETRA IV

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Long term stabilization scheme including cable paths

F. Schmidt-Föhre *et al.*, Proc. IBIC2021, Pohang (Korea) MOPP36.

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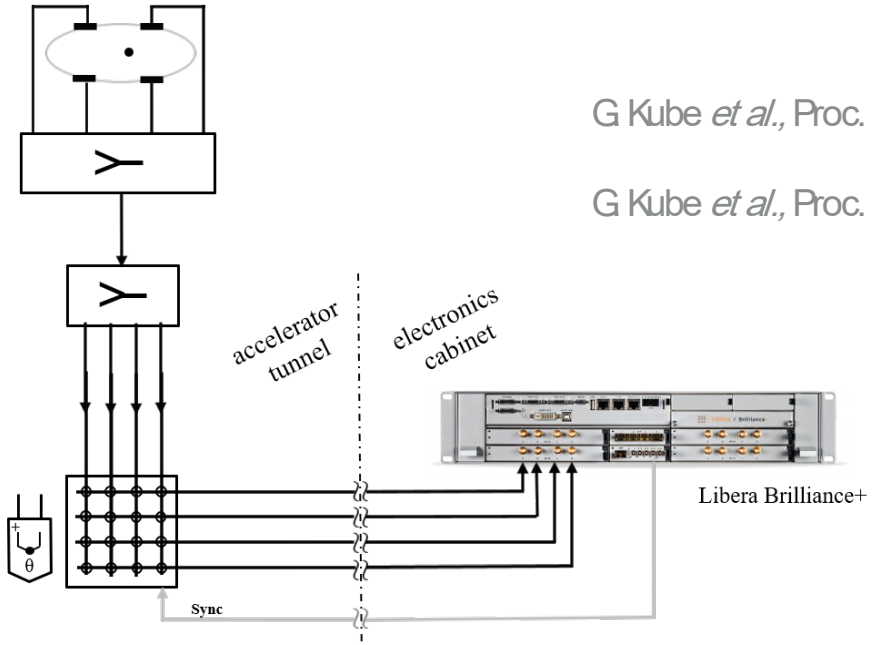
Proof-of-principle studies at PETRA III with modified Libera Brilliance+



G Kube *et al.,* Proc. IBIC2021, Pohang (Korea) MOPP30.

G Kube *et al.,* Proc. IBIC2022, Krakow (Poland) WEP08.

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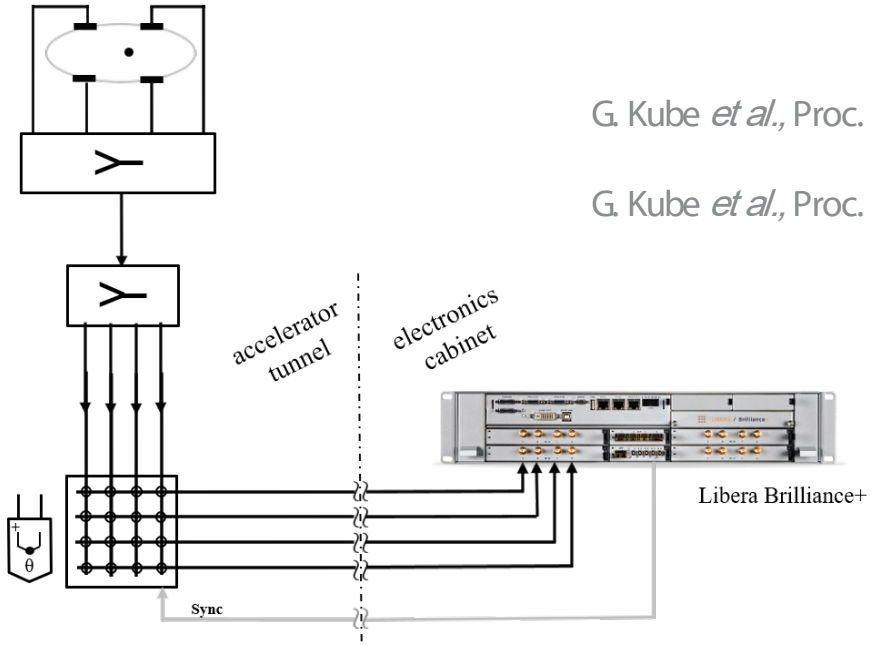

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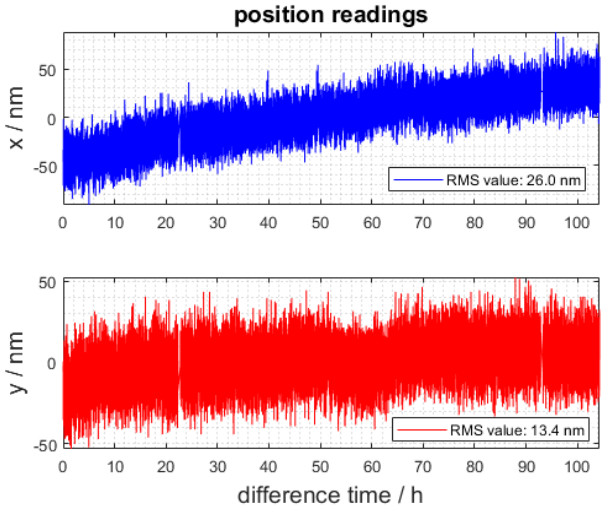
Long-term drift study

- 480 bunches @ 120 mA

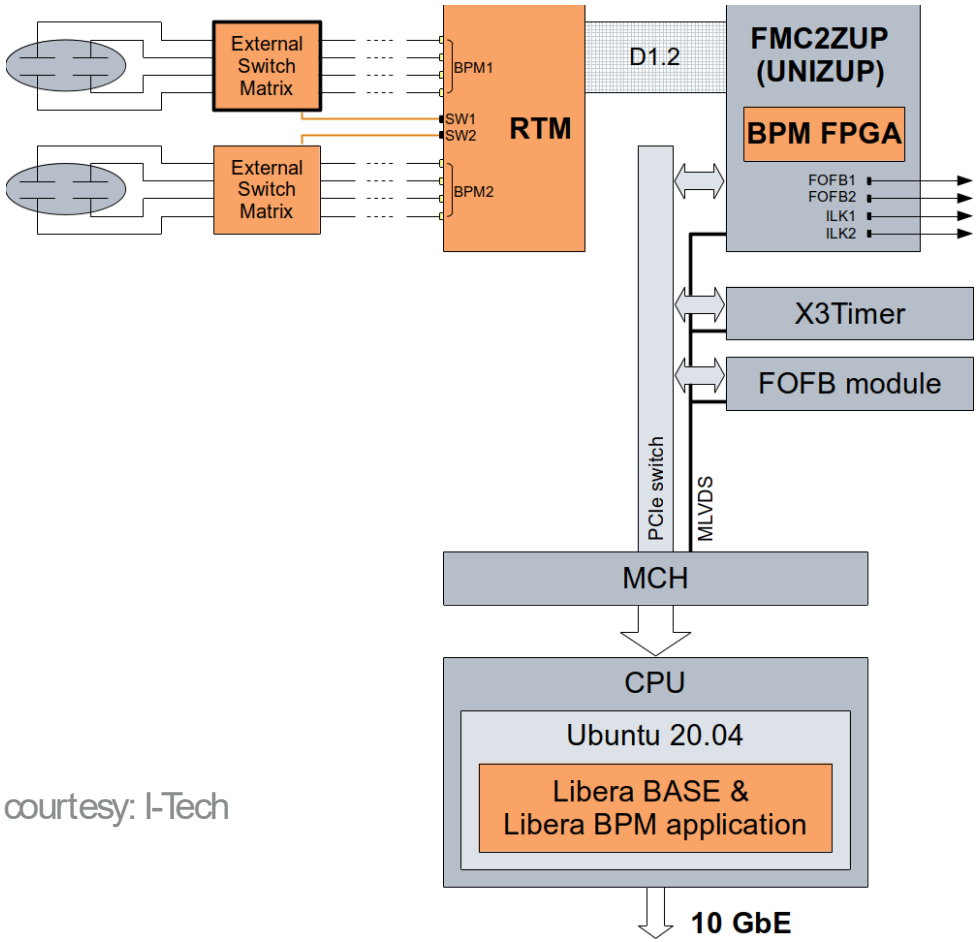


well within specifications
< 1 µm

MTCA.4 based BPM System

System Overview

Building blocks and interconnections



courtesy: I-Tech

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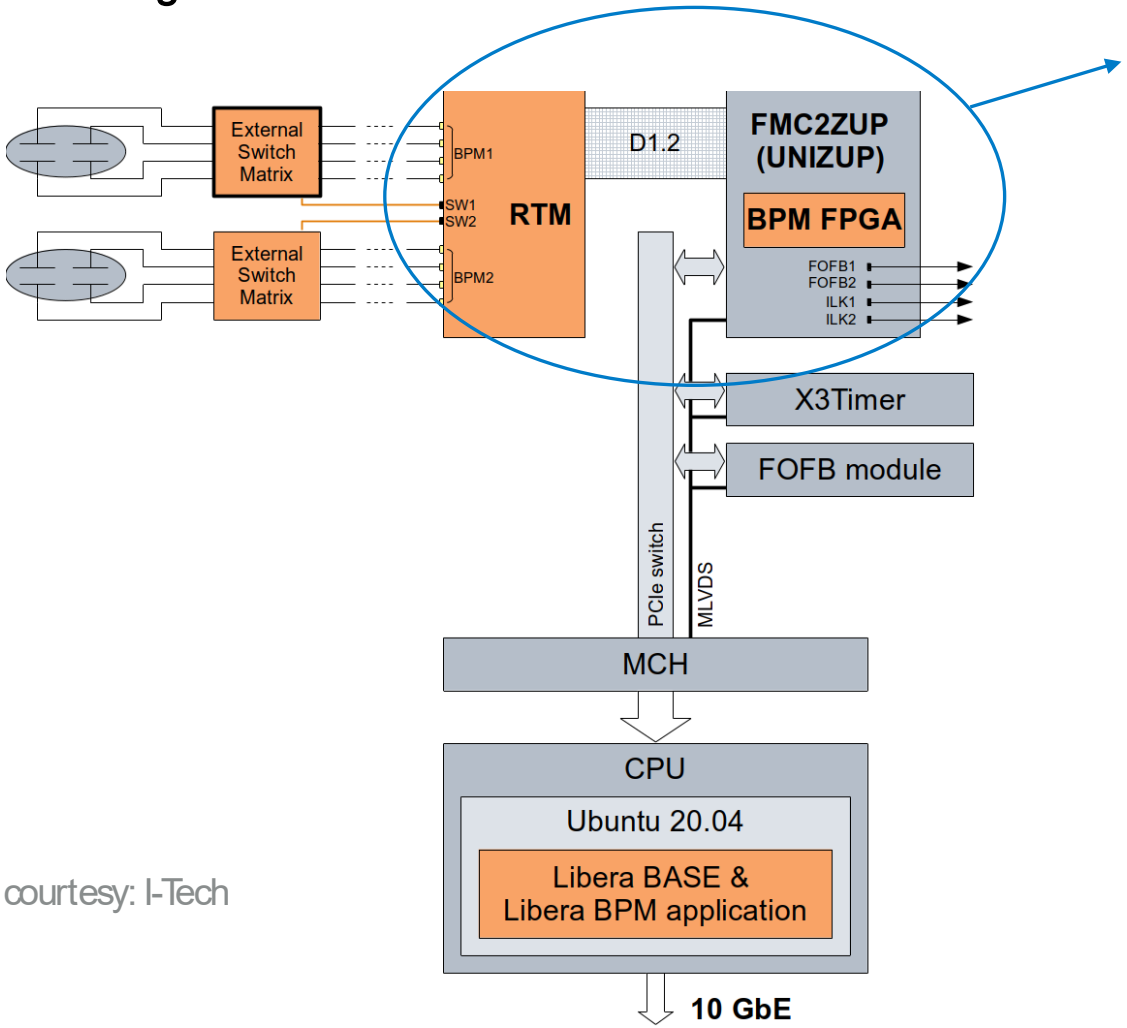

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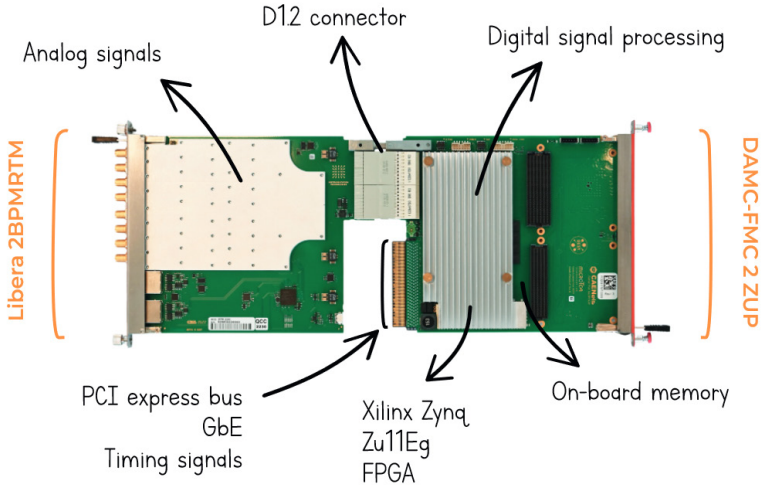

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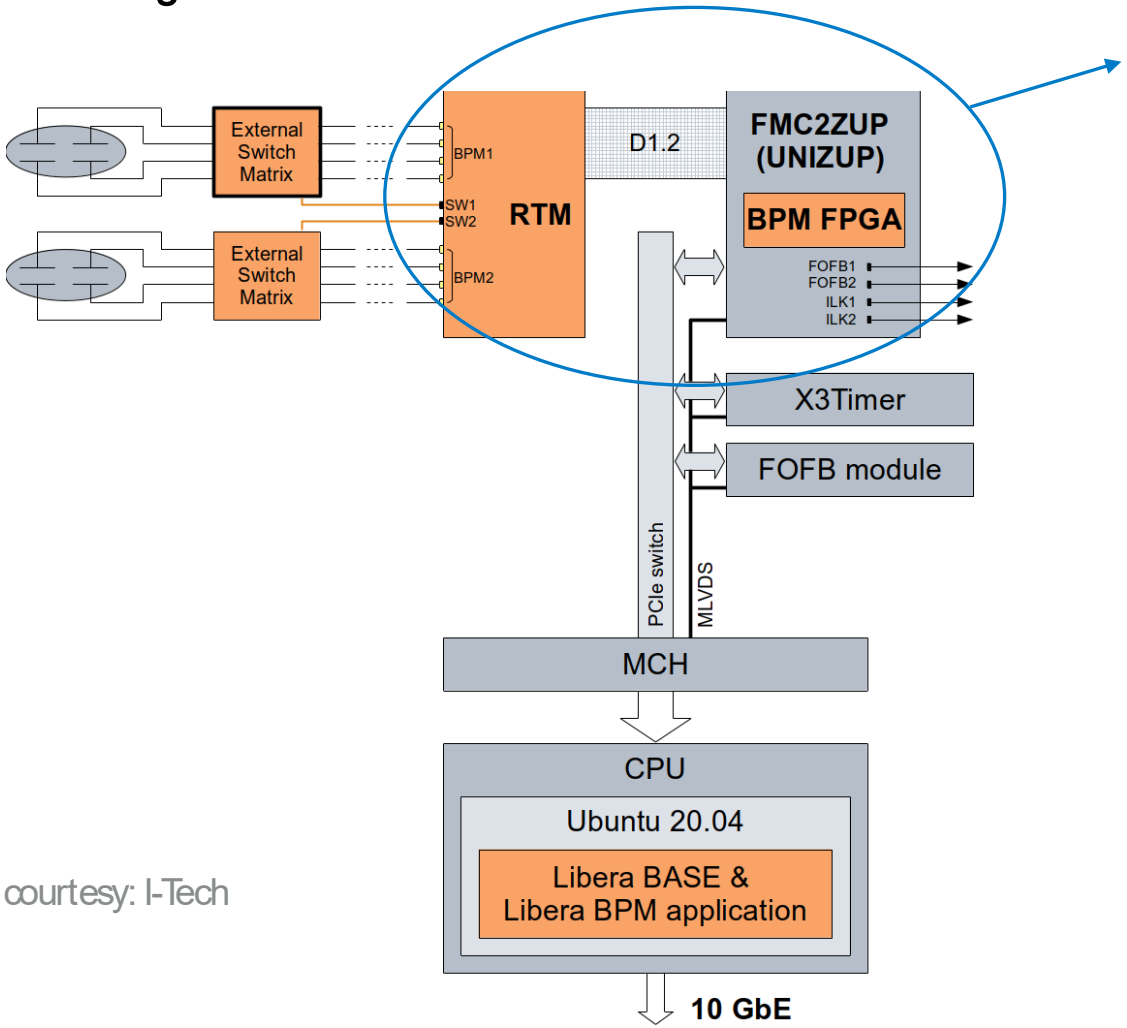

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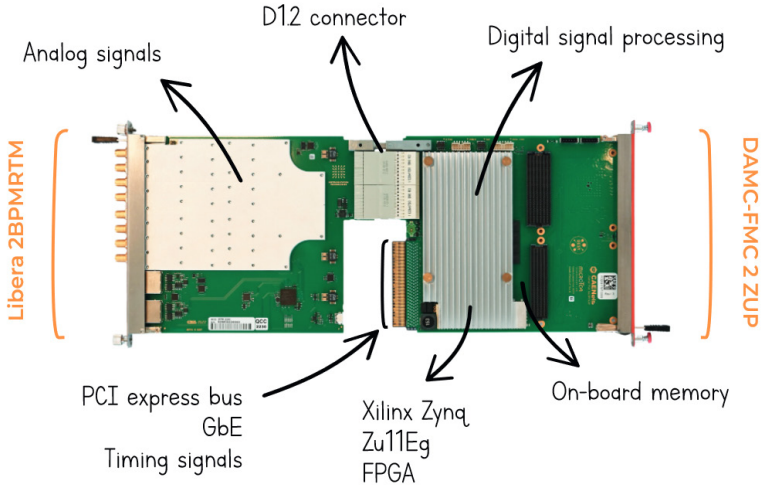


courtesy: I-Tech

Data paths

- slow acquisition (SA) data

  f_s = 10 Hz

- turn-by-turn (TbT) data

  f_s = 130.1 kHz

  (via DDC or TDP)

- fast acquisition (FA) data

  f_s = 10 kHz

- decimated TbT data

  $f_s \approx 2$ kHz

- ADC raw data

  $f_s \approx 117$ MHz

- Multi-TbT data

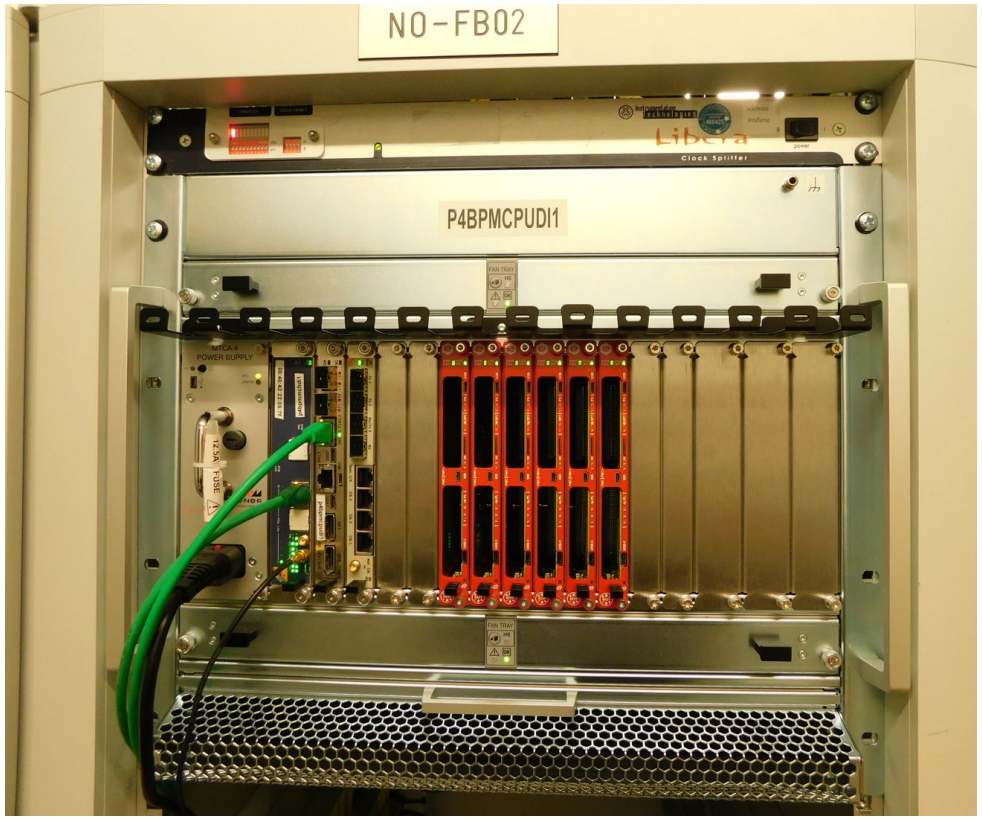
  (allow segmentation of TbT acquisition window)

MTCA Installation at PETRA III

System Overview

Prototype MTCA-based system installed at PETRA III: (end of 2022)

12 (8) BPMs, operated in parallel with existing Libera Brilliances



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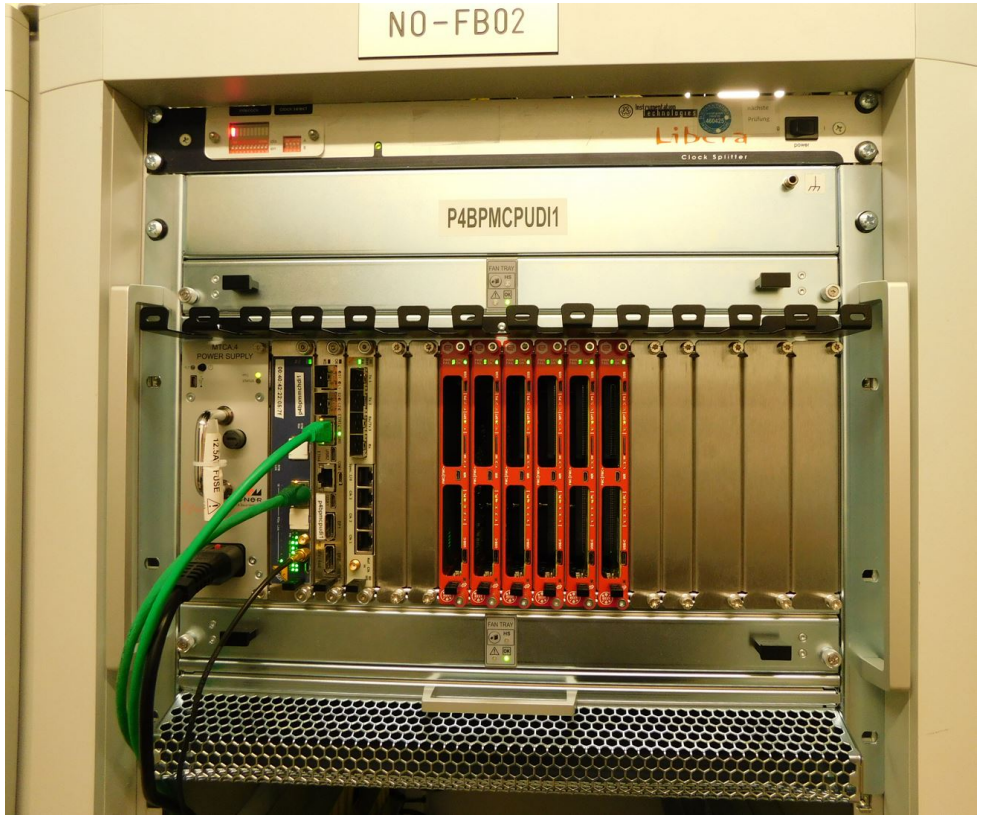
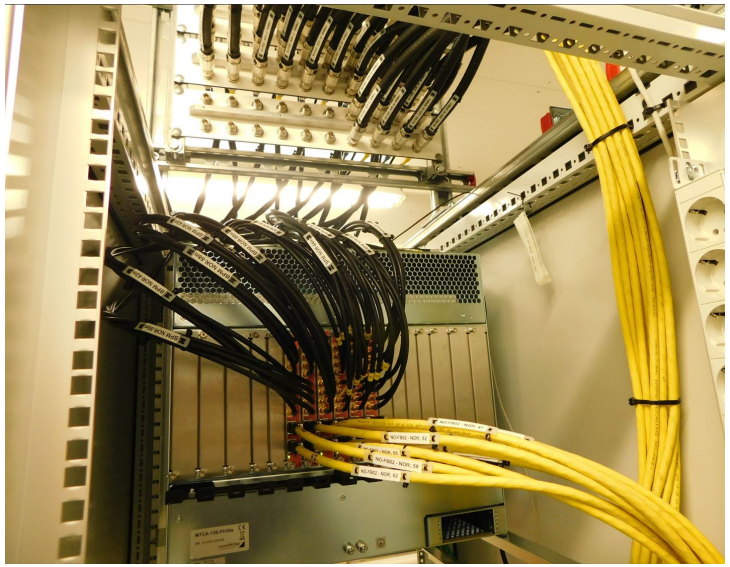




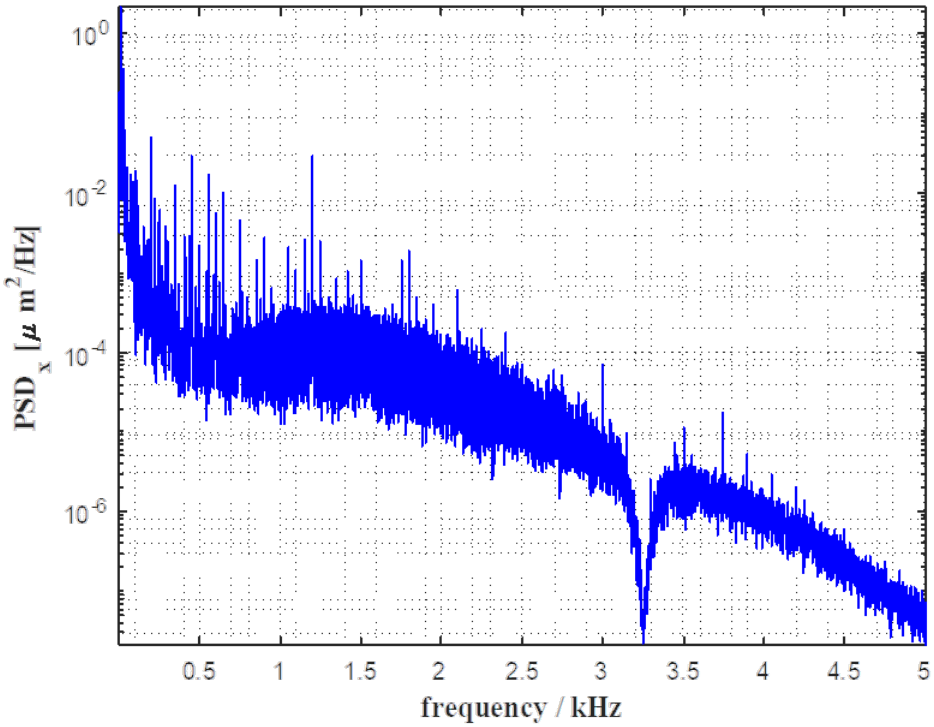
only 2 MTCA crates per rack

BPM Studies at PETRA III

Measurements with Beam (start spring 2023)

FA data path (fs = 10 kHz), BPM at undulator entrance

- standard user operation: 480 bunches @ 120 mA
- hor. beam spectrum (Power Spectral Density PSD_x)



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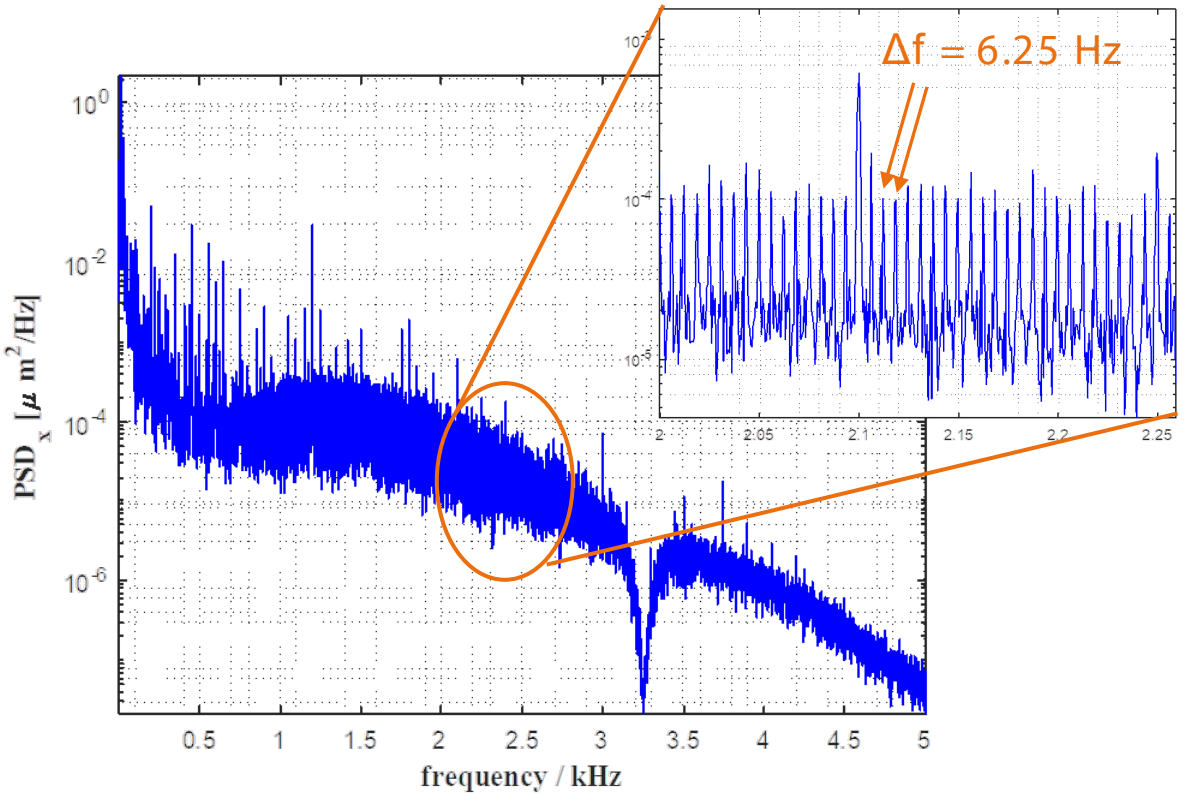

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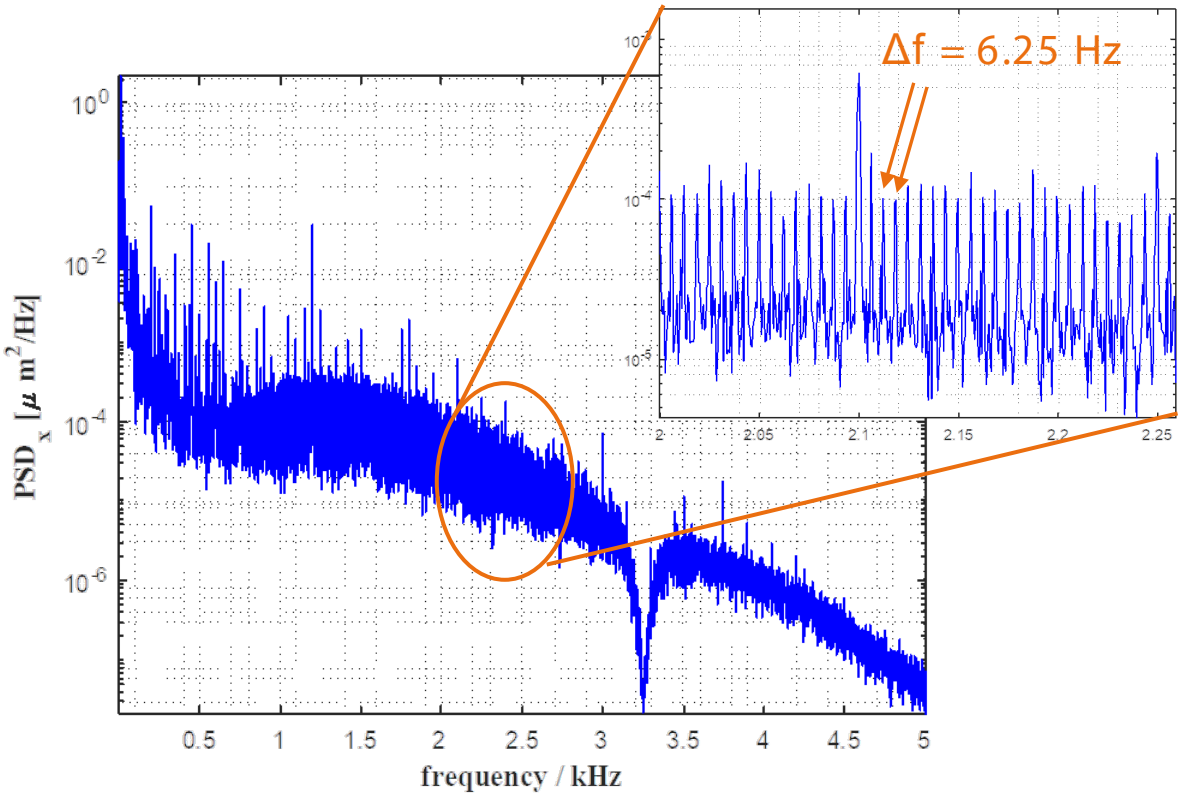
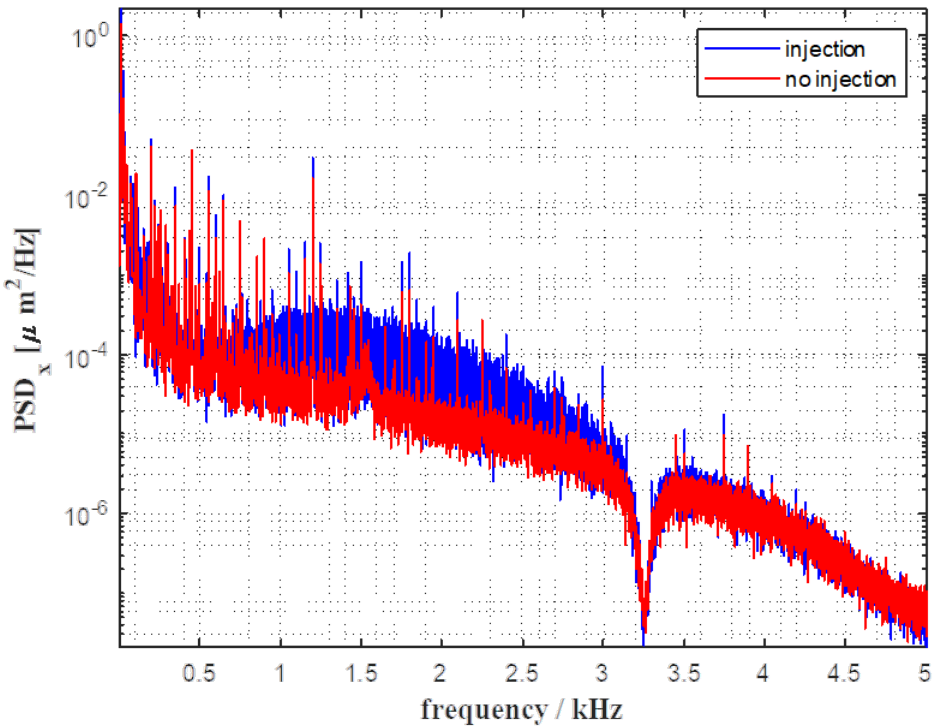


- 6.25 Hz: DESY II booster cycle ➡ influence from injection
- PSD_x with injection gated out:



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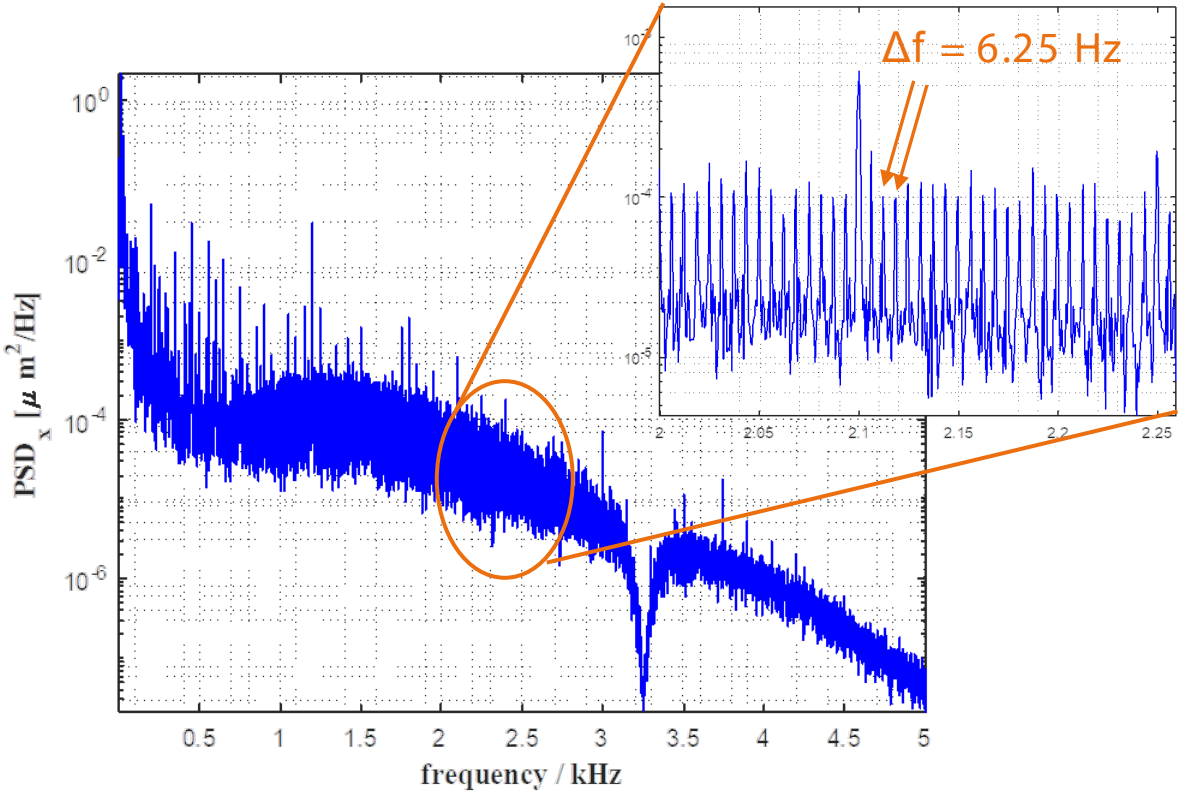

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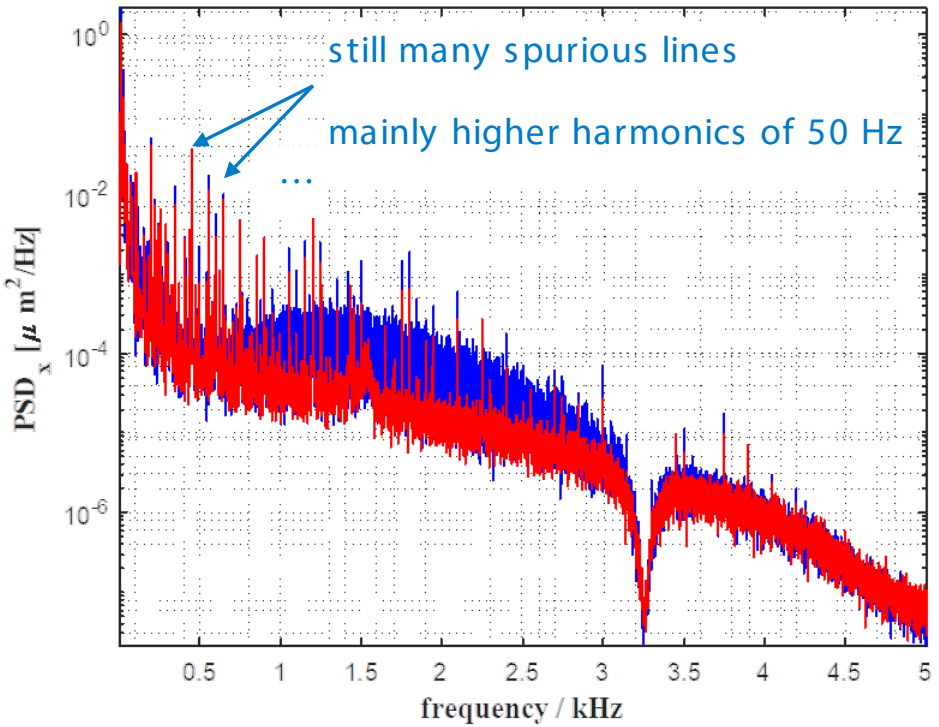

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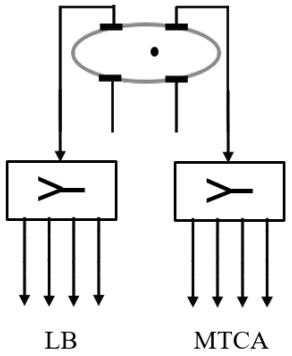
- install 4-way splitter in signal path (06/09/2023)
  - → all spurious lines eliminated
  - disadvantage: no orbit information from BPM
    - → studies restricted to single BPM



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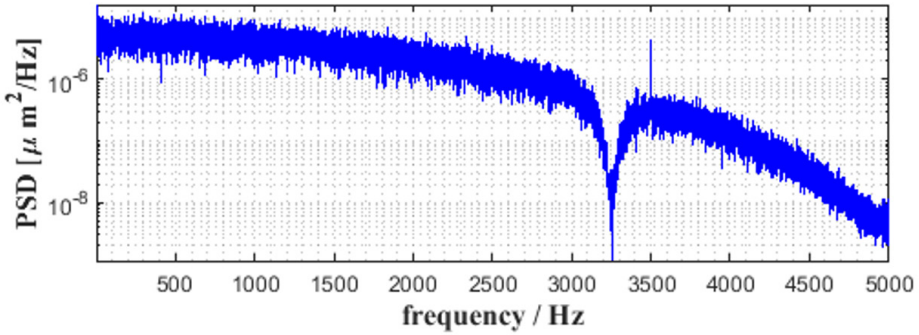
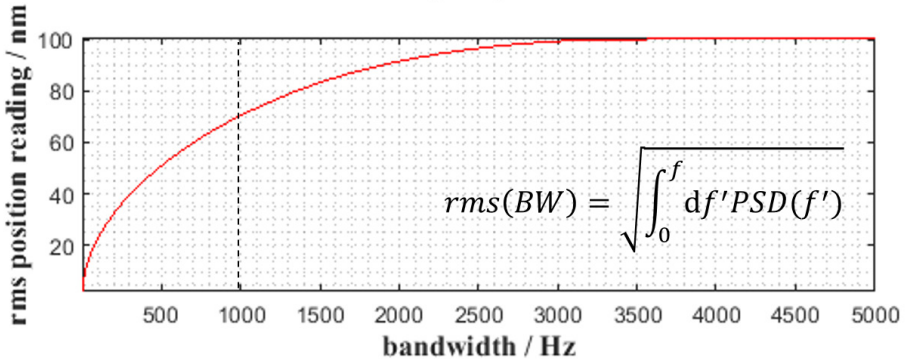


K_x = 10 mm



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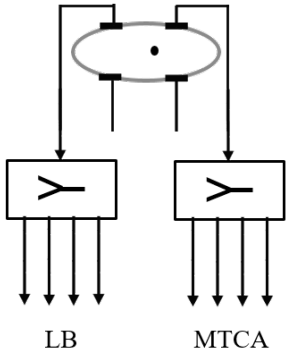
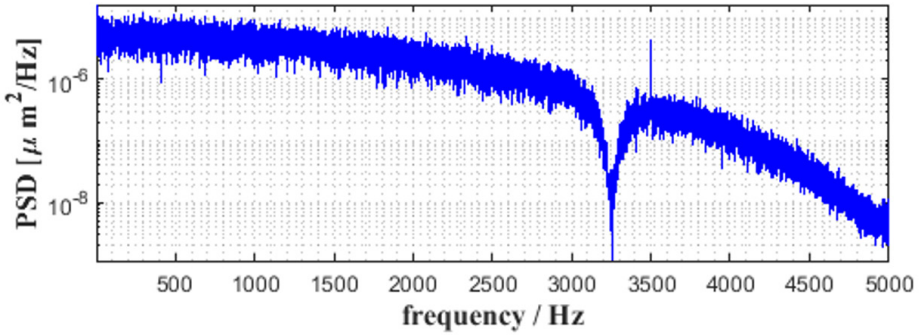
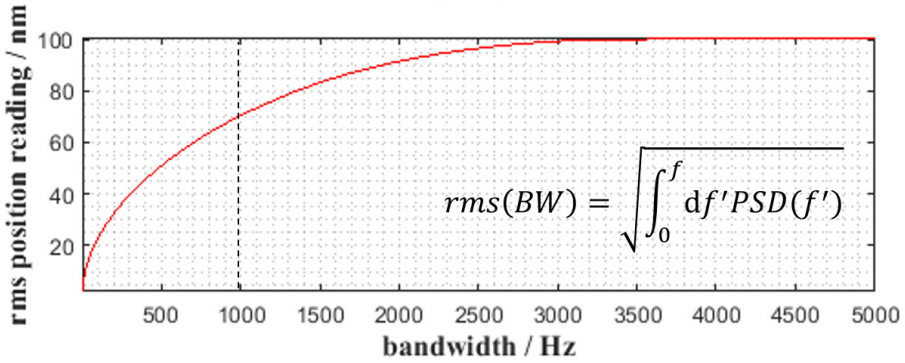
    - → studies restricted to single BPM



FA data path, BPM at undulator entrance



K_x = 10 mm



rms resolution

- specification: < 100 nm @ 1 kHz BW
- measurement: **70 nm** @ K = 10 mm
  - → PETRA IV: K < 10 mm

Comparison with Libera Brilliance

- TbT data path (f_0 = 130.1 kHz), rms for full BW
- Libera Brilliance: rms ≈ 1 µm
- MTCA system: rms ≈ 300 nm

→ significant improvement

BPM Studies at PETRA III

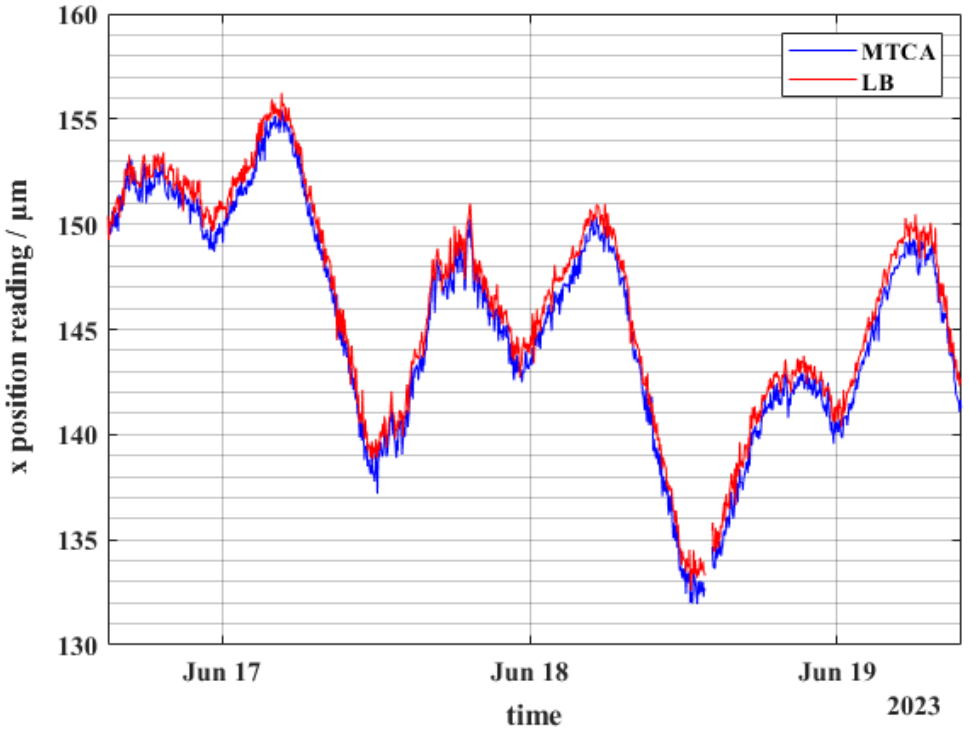
Long Term Stabilization

SA data path (fs = 10 Hz)

poster presentation: J. Lamaack (MOP021)

- no beam jitter cancellation

BPM in DBA cell



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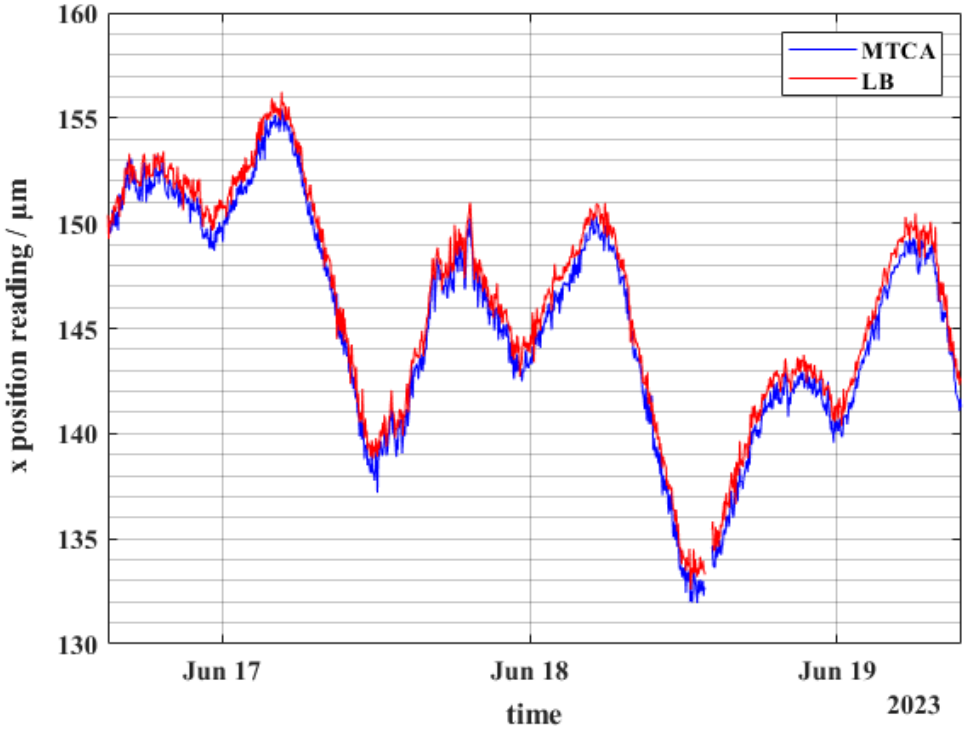
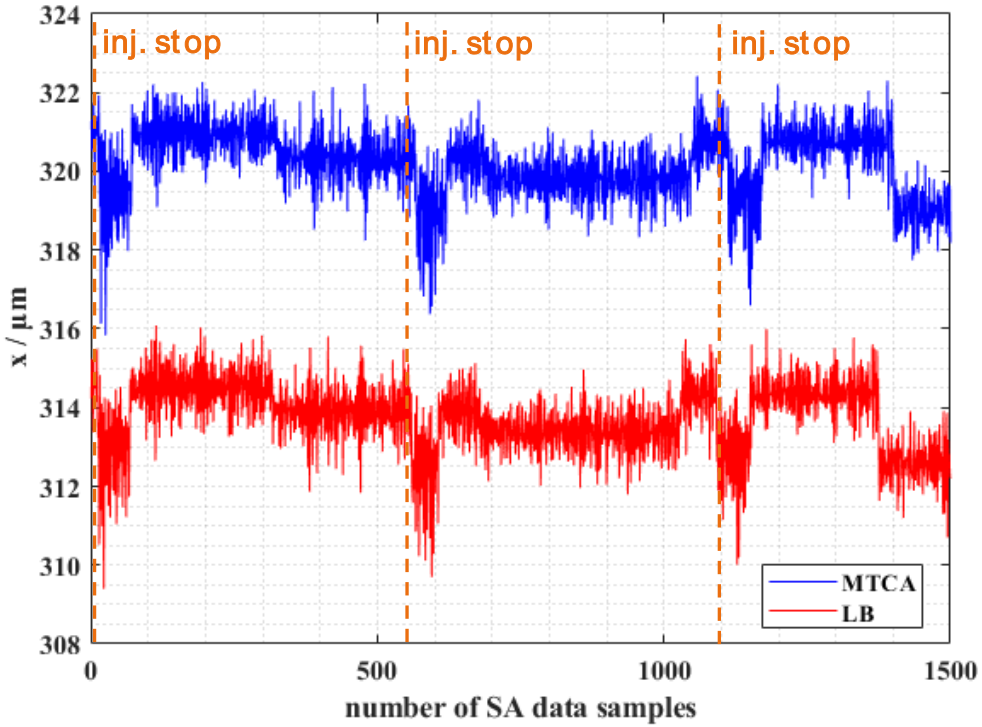


BPM at undulator entrance



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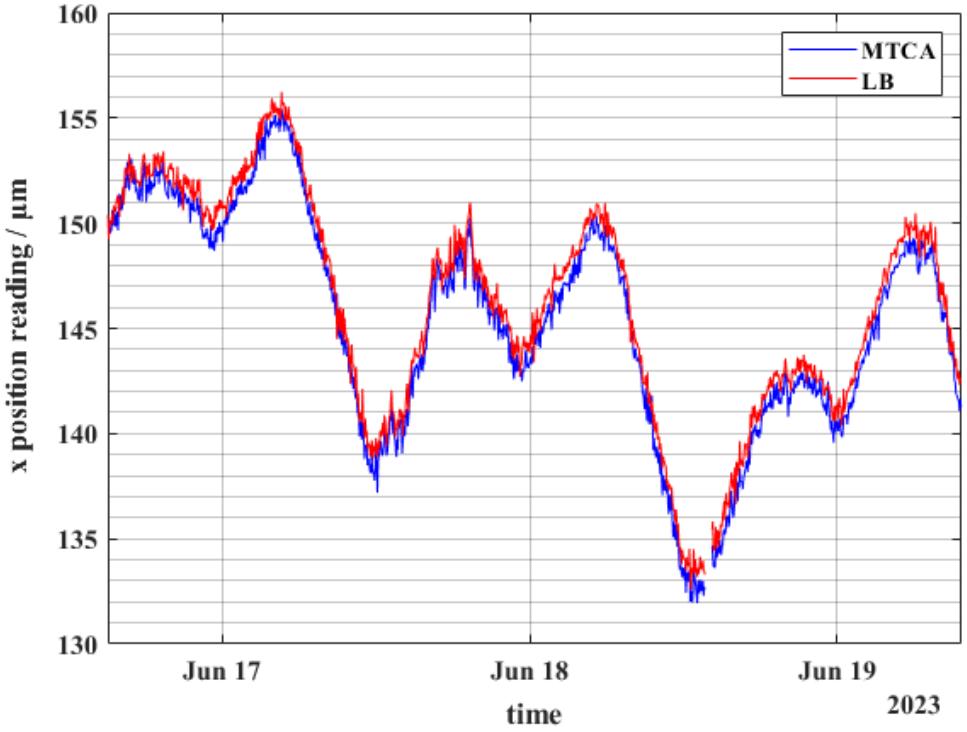

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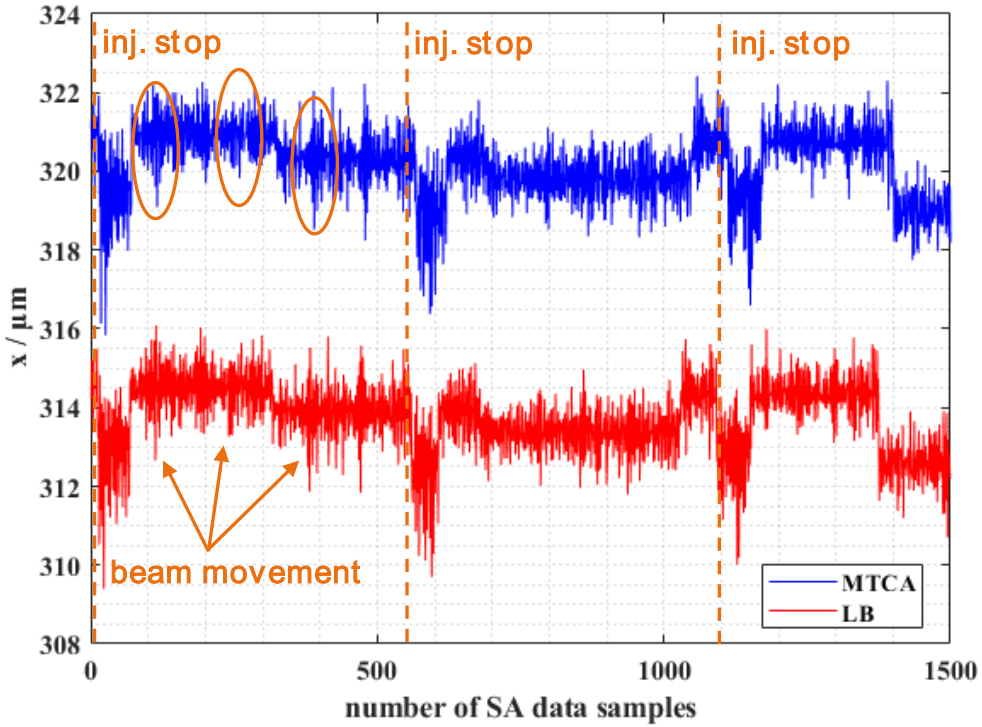


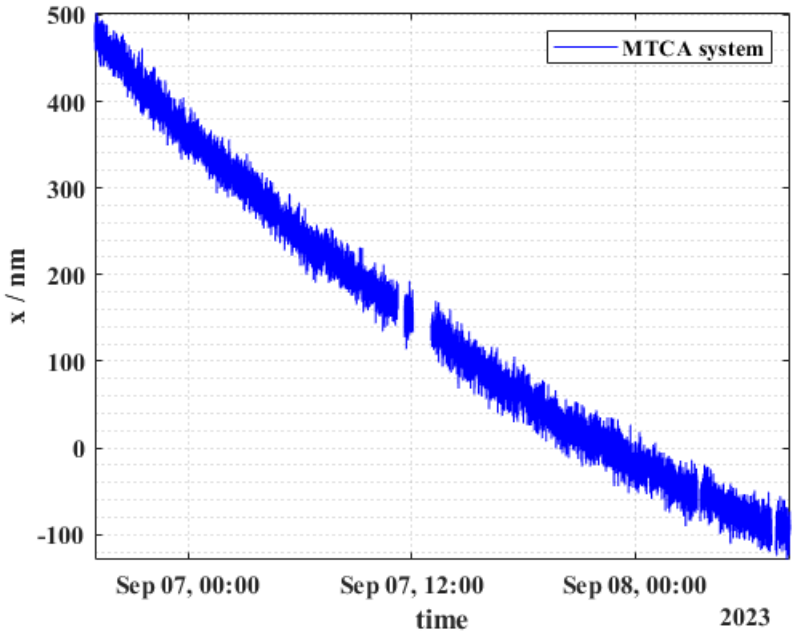
BPM Studies at PETRA III

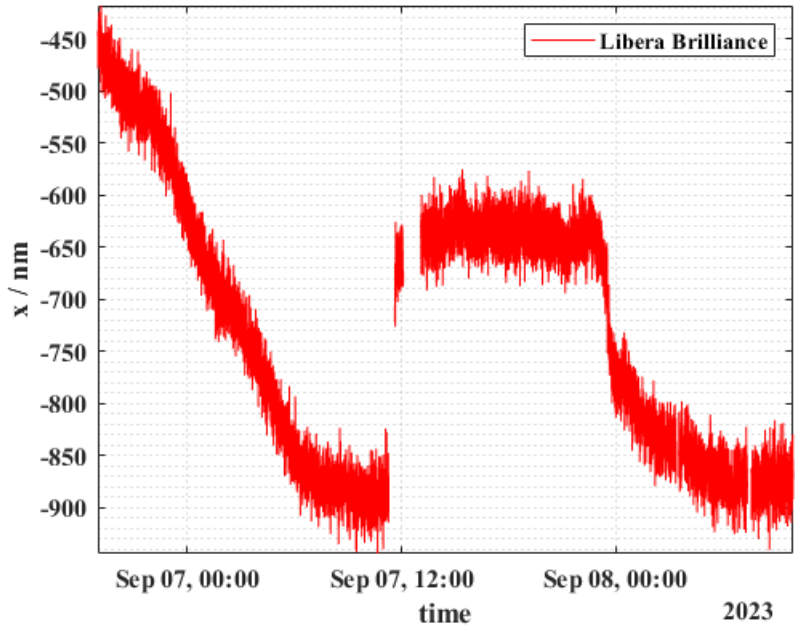
Long Term Stabilization with Beam Jitter Cancellation

SA data path (fs = 10 Hz)

- measurement for 1½ days
- specification: < 1 µm over 6 days
  - Brilliance: ~ 1.35 µm
  - MTCA: ~ 0.6 µm

} over 1½ day





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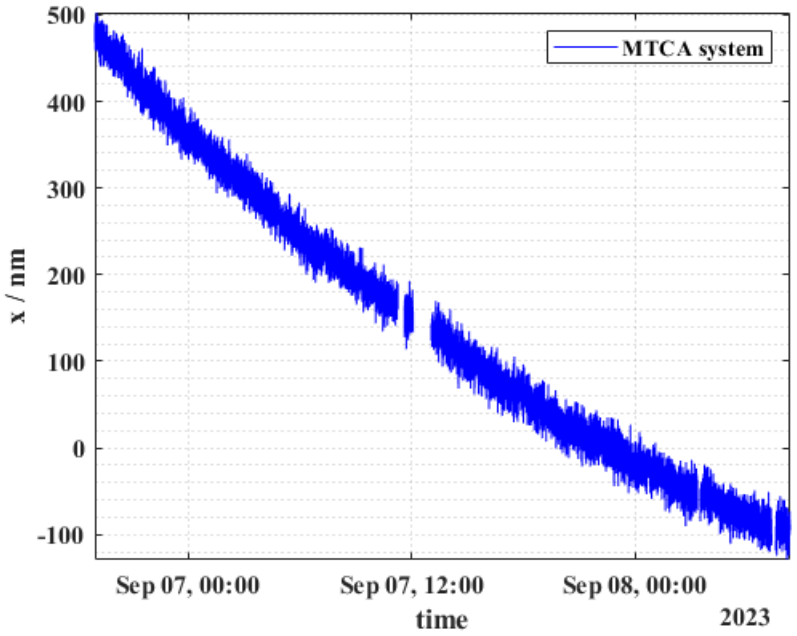
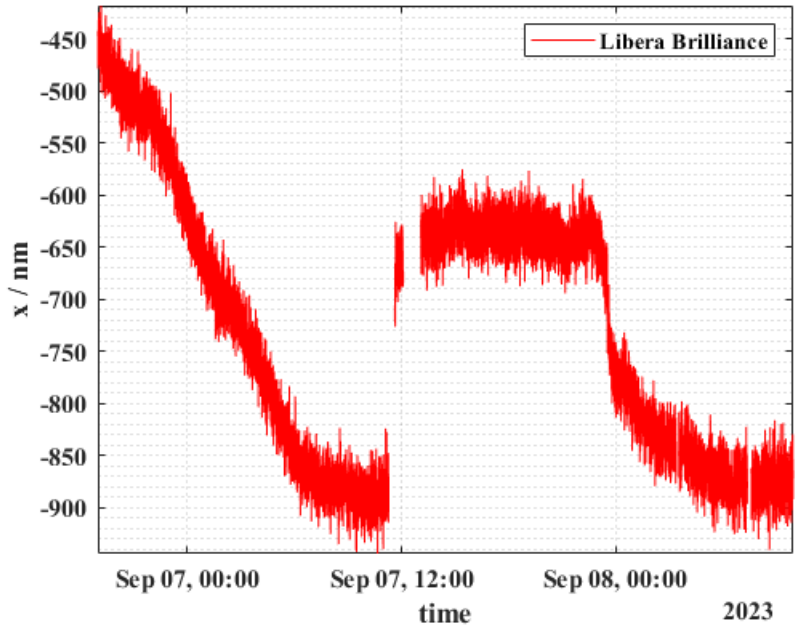
  - continuous (but smooth) drift in x (and y) data
  - assumption: quick & dirty setup with 4-way splitter

    → has to be investigated in detail after IBIC





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  - larger drift, especially after beam loss
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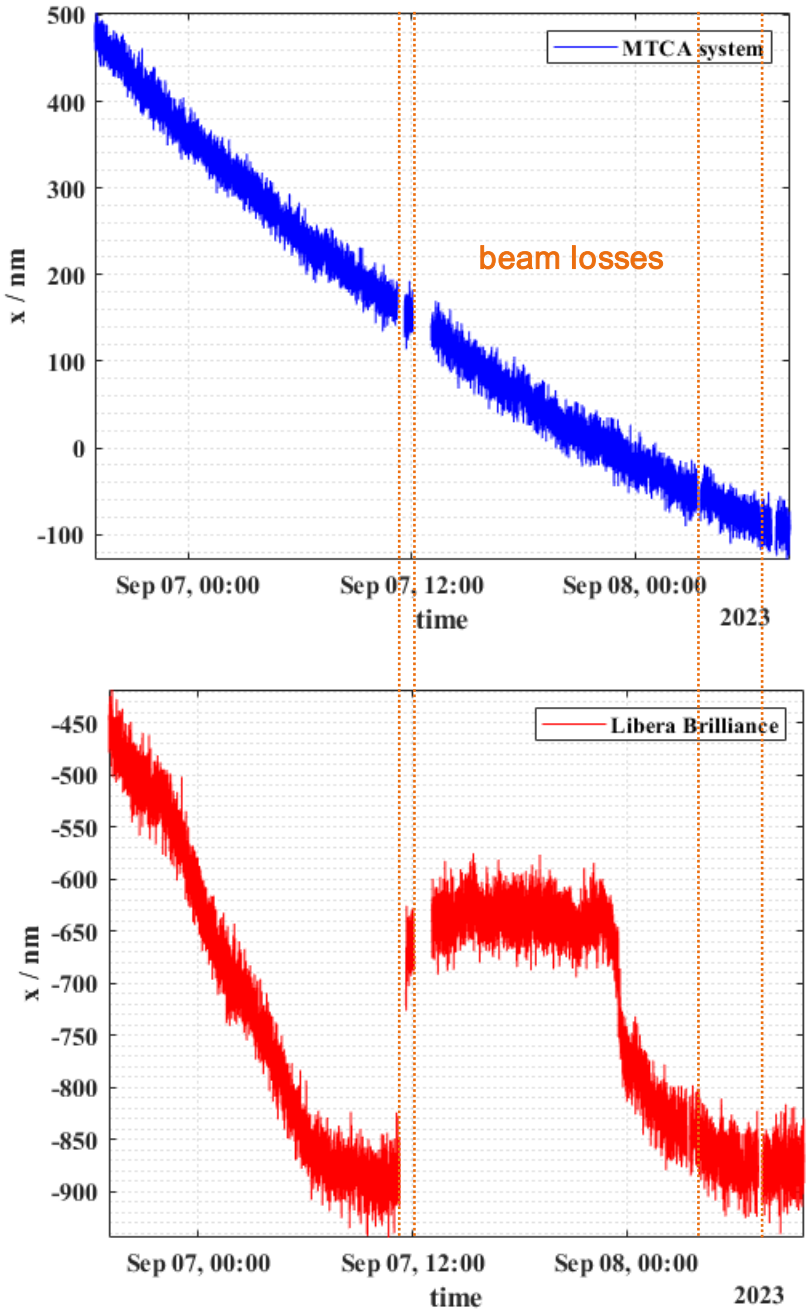

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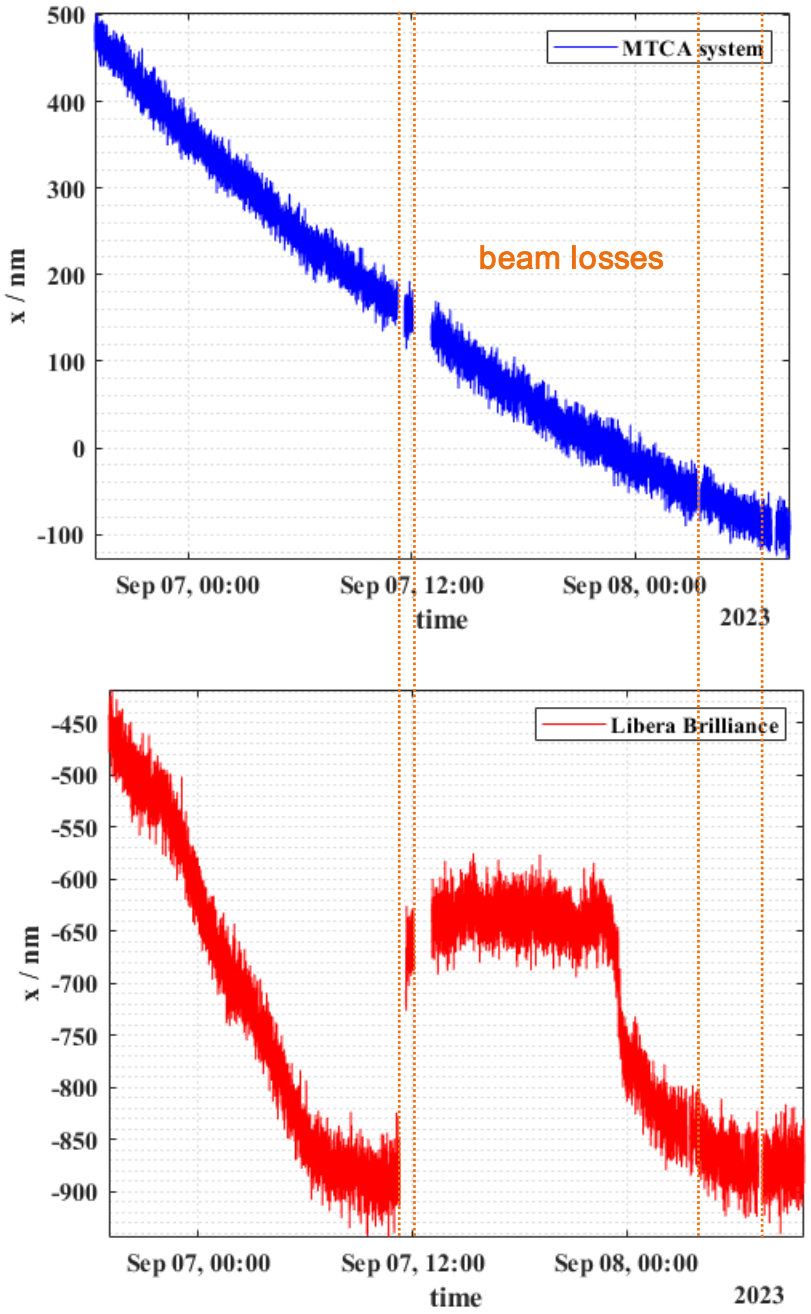
⇨ measurements will continue after IBIC



Summary

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- MTCA based BPM system continuously in operation since end of 2022

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- beam jitter mimicks electronics noise

  → has to be eliminated in order to be sensitive on monitor resolution
- closed orbit (& first turn) specifications fulfilled (FA and TbT data path)

  → significant improvement compared to Libera Brilliance

  → comparable to Libera Brilliance+
- long term stability

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  ⇨ has to be investigated and improved

..thank you very much for your attention

Contact

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