PETRA IV.
NEW DIMENSIONS

new BPM system for the PETRA IV project

Libera Workshop
April 2023

H.-T. Duhme / DESY
Libera Workshop, 15.5.2023

- ❑ Introduction
- ❑ Tests at Petra 3
- ❑ BPM System for PETRA IV
- ❑ Fast Orbit Feedback
- ❑ Pre-accelerator BPM concept

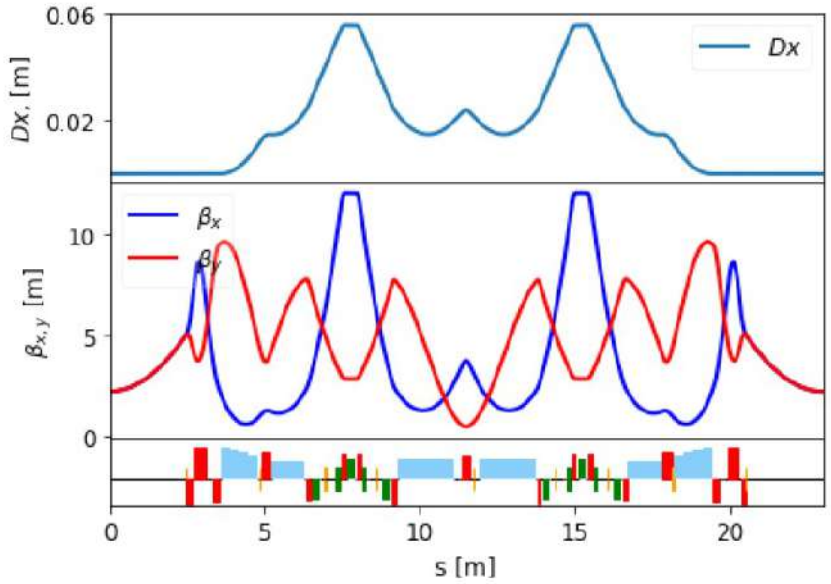
DESY Accelerator Complex (Hamburg, Germany)

User Facilities

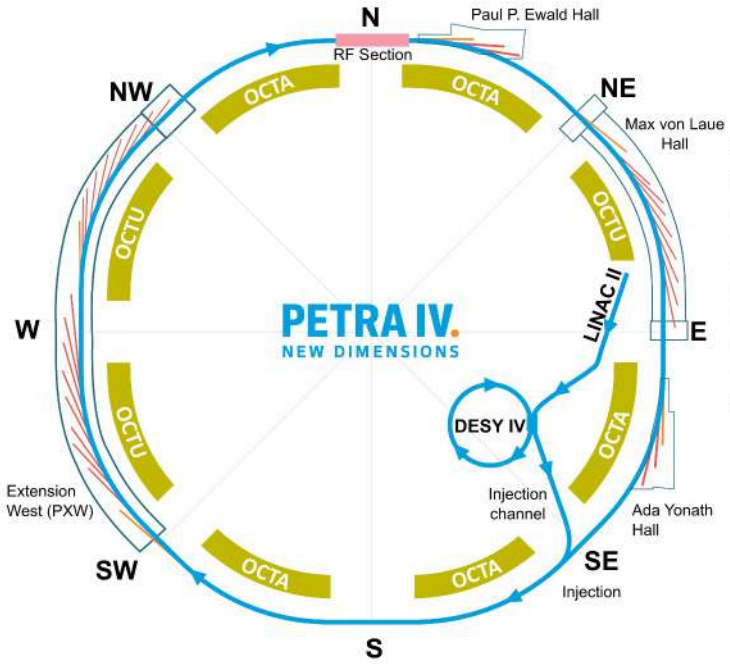
PETRA IV

Diffraction Limited Storage Ring → Multi Bend Achromat Lattice

- 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

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

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

- 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 System for PETRA IV

Requirements

Performance (Electronics)

- resolution on single bunch / turn (0.5 mA / bunch) < 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

First Turn Steering Tolerances (Mechanics & Electronics) < 500 µm

BPM System for PETRA IV

Boundary Conditions

Number of BPMs: about 700

- 9 BPMs per cell / 64 cells → 576 BPMs in arcs
- 8 BPMs in short, 12 BPMs in long straight sections

656 BPMs (incl. spares: ~700)

➡ cost / space are important factors

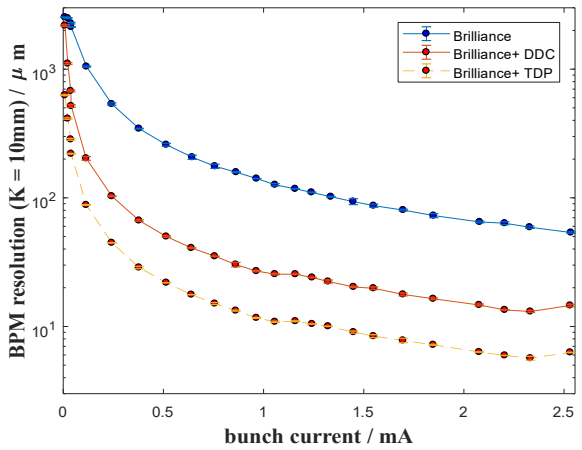
≤ 10 k€ (per channel)

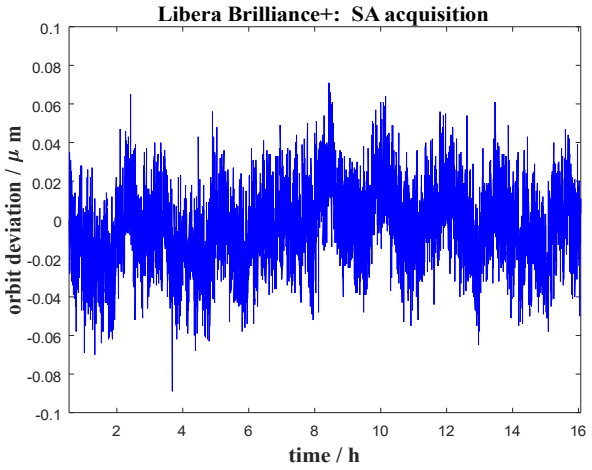
In-house Development: no time and manpower ➡ commercial solution

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

Libera Brilliance+: would fulfill requirements

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





BPM System for PETRA IV

DESY Strategy

Stabilization

- well proven technology
- stabilization of cable paths

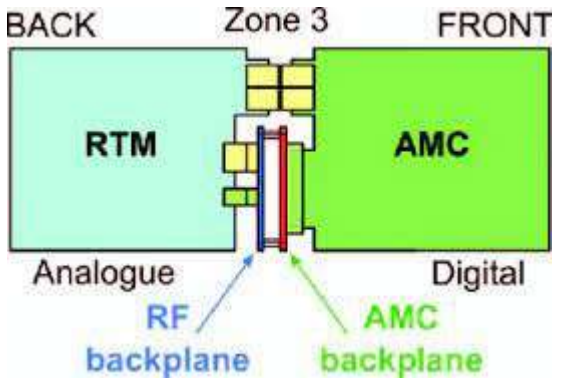
→ crossbar switching

→ separate analogue switching part, close as possible to Pickups

Development Project with I-Tech

- prototype development of MTCA.4 based BPM-RTM including ADCs work with an digital AMC Board class D1.3
- crossbar switching with separated switching matrix

DESY Lab Strategy: MTCA.4 as technical platform

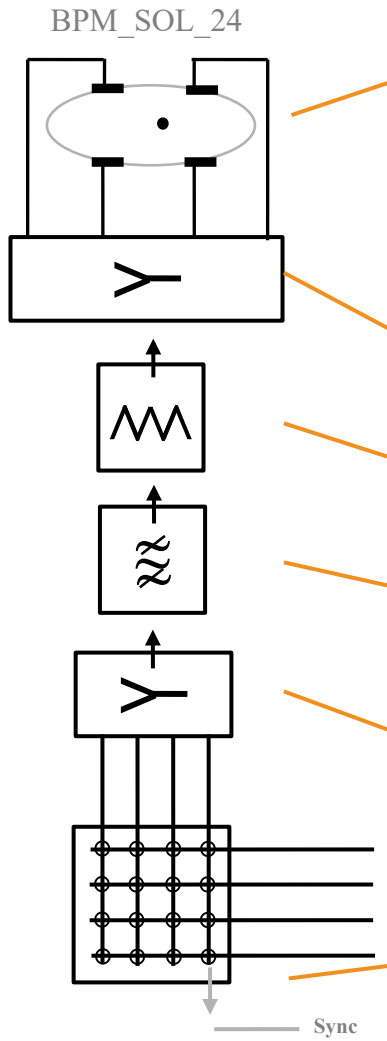


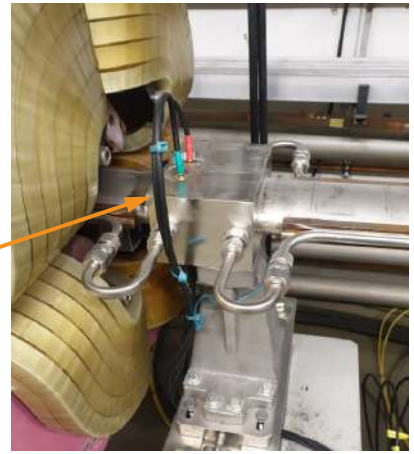
first Proof-of-Principle Measurements

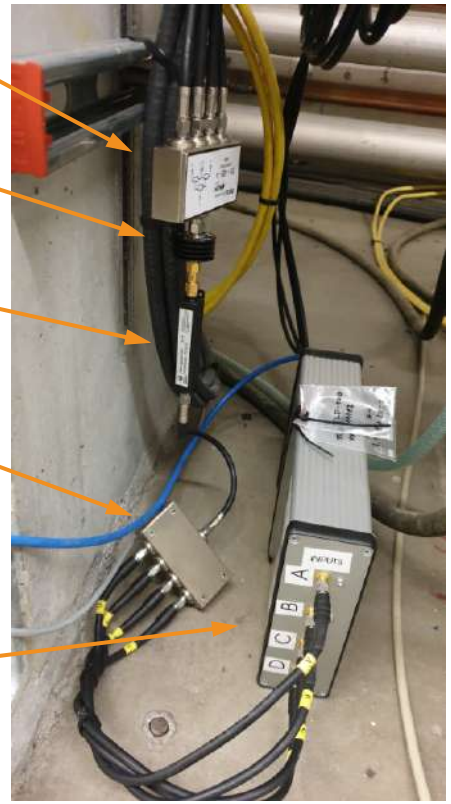
- lab measurements at I-Tech
- measurements with beam at PETRA III

Measurements at PETRA III

Test Setup

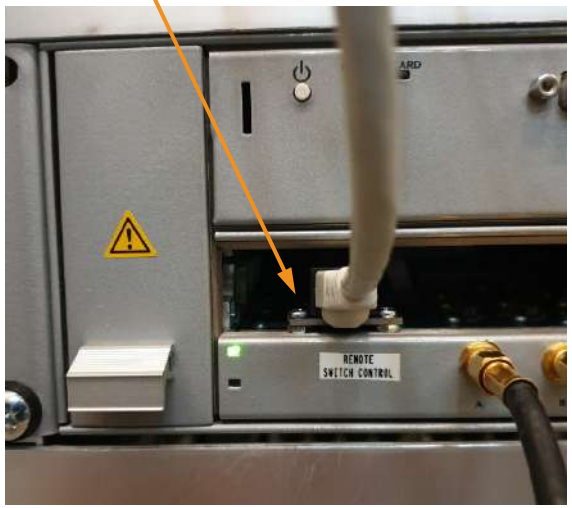






Libera Brilliance+

Sync



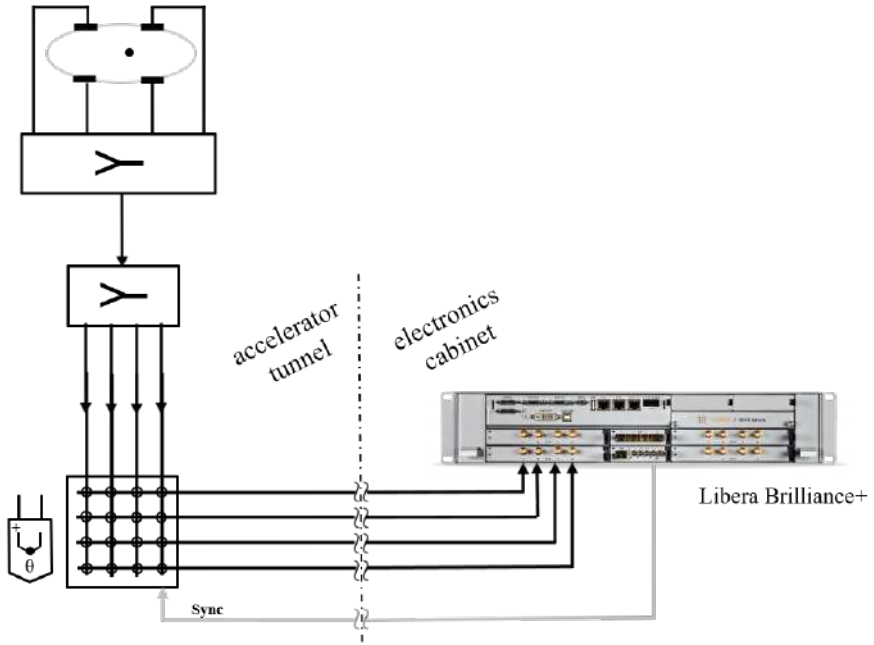
BPM System for PETRA IV

Long-Term Drift Compensation

long term stabilization scheme including cable paths

- external crossbar switching

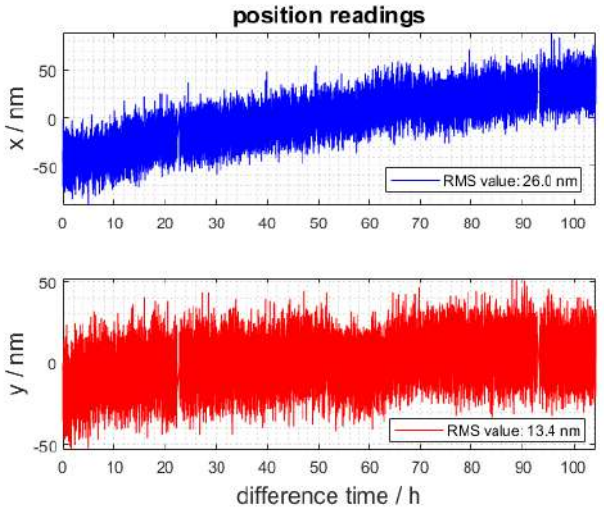
performance studies at PETRA III



long-term drift study

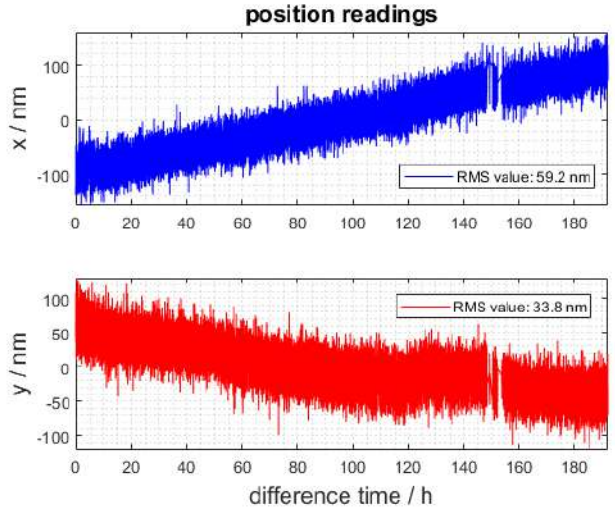
continuous mode

- 480 bunches @ 120 mA



timing mode

- 40 bunches @ 100 mA

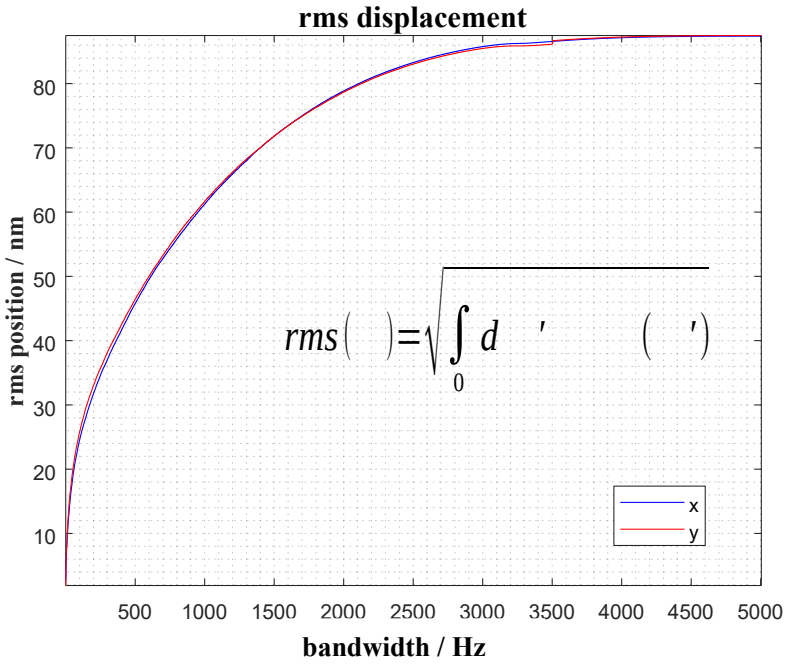


➡ well within specifications **< 1 µm**

BPM System for PETRA IV

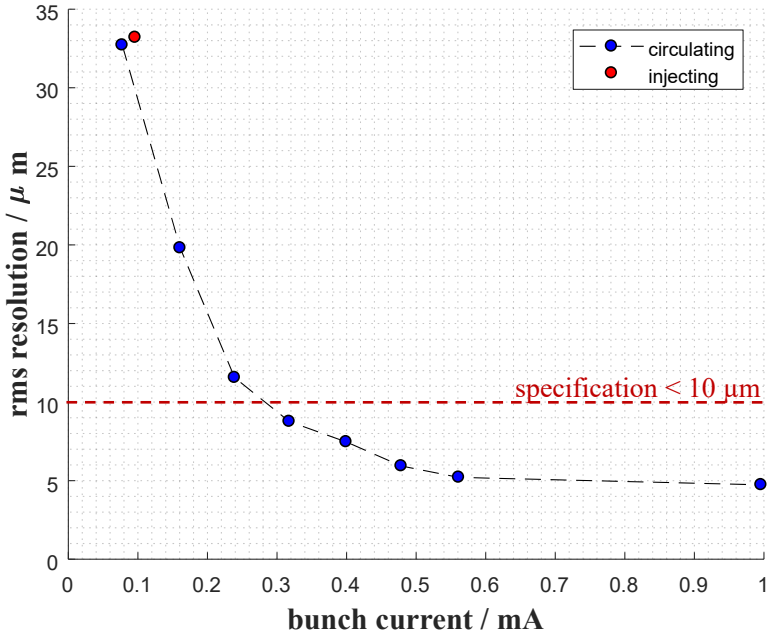
Additional Measurements at PETRA III

Closed Orbit Resolution



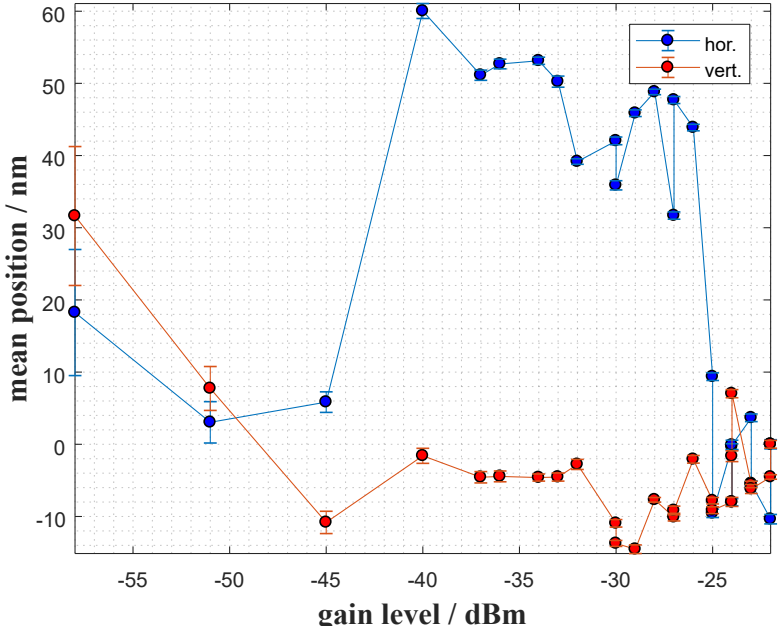
< 100 nm (rms)
@ 1 kHz BW

Single Bunch (Single Turn) Resolution



< 10 µm
0.5 mA bunch current

Beam Current Dependency (SA)



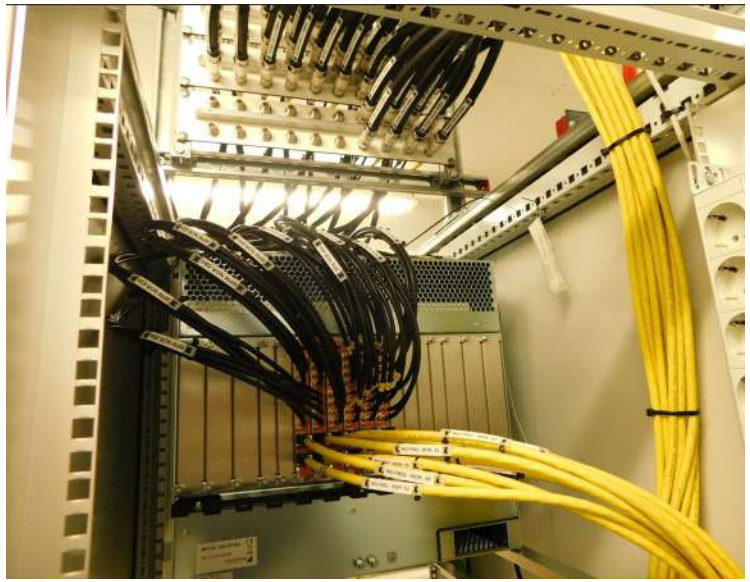
± 2 µm
60 dB range, centered beam

➡ well within specifications

BPM System for PETRA IV

Prototype Readout Electronics

prototype MTCA-based system installed at PETRA III : 12 (8) BPMs, operated in parallel with existing Libera Brilliance system



only 2 MTCA crates per rack

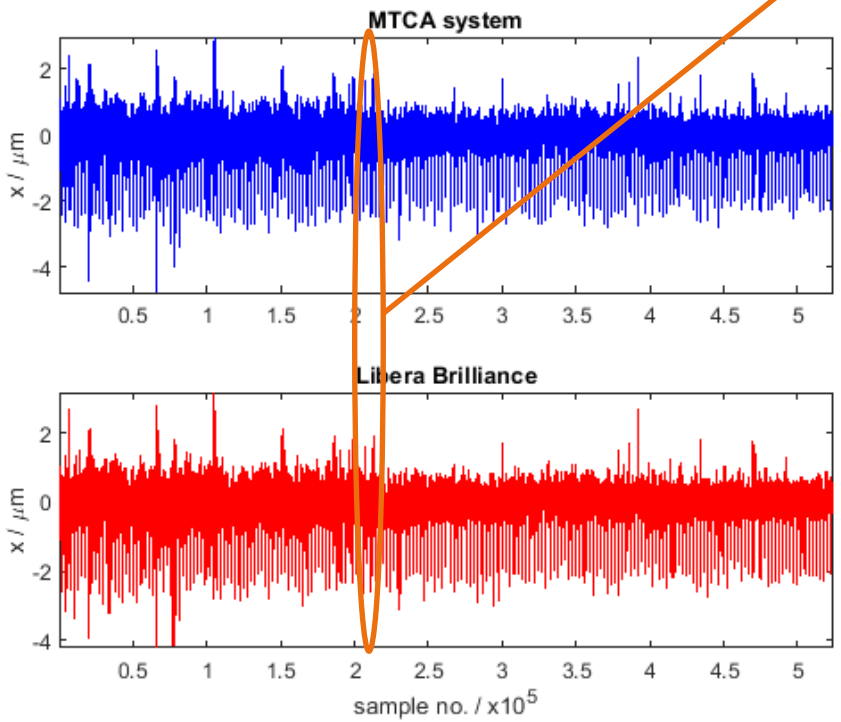
- data taking recently started with all data paths
  - ADC data
  - TbT / dec. TbT data (130.1 kHz / 2.0 kHz)
  - FA data (10 kHz)
  - SA data (10 Hz)

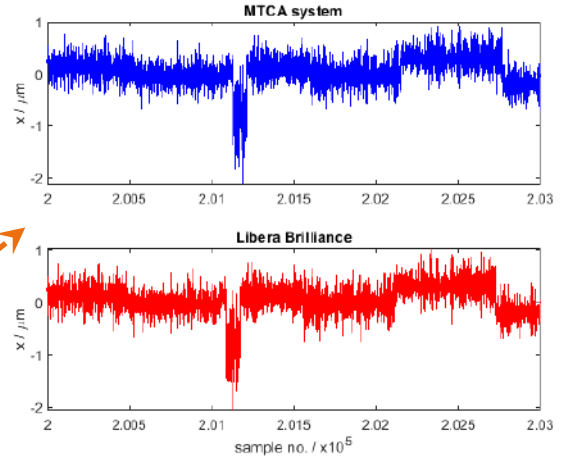
BPM System for PETRA IV

MTCA BPM Prototye Tests

SA data path

- 14.5 h data acquisition
- standard user operation: 480 bunches @ 120 mA

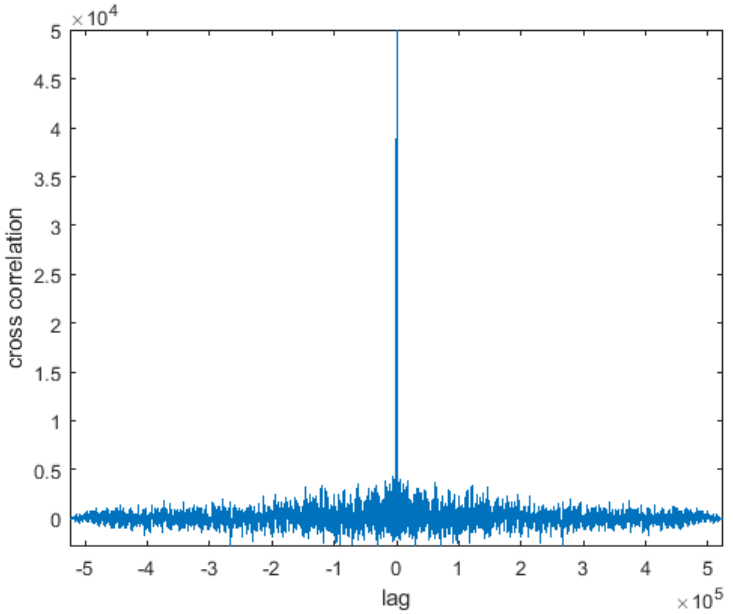




BPM_NOR_50

(undulator entrance)

cross correlation



both electronics see same signal

Fast Orbit Feedback (FOFB) System

FOFB: Parameters & Stability Requirements & Concept

courtesy: S. Pfeiffer (DESY)

Parameter	Value
Number of BPMs (x/y)	789
Number of fast correctors	522 (200H, 322V)
Synchrotron oscillation	600 Hz
Beam size at ID, standard cell	6.6 µm, 2.97 µm
Beam divergence at ID, standard cell	3.02 µrad, 1.34 µrad
at ID, standard cell	2.2 m, 2.2 m
Natural emittance	20 pm rad, 4 pm rad

Regulation concept

1 central control unit (GLO)

- The center as a node is not physically given by the infrastructure
  → Shifted close to RF system / timing system
  → Short path from GLO to LOC in experimental halls

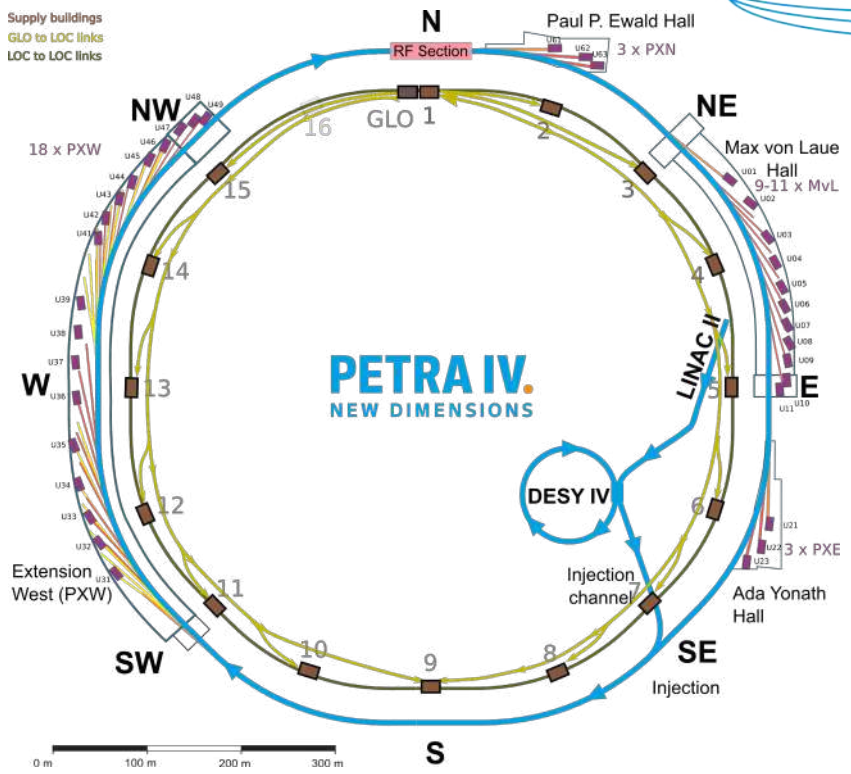
15 distributed local sections (LOC) acting as

- BPM collectors
- Transmitter to power supplies

Optical fiber communication links through the tunnel

- Global to all local systems → classical regulation scheme
- Local to local system → for local control scheme integrating experiments and potential redundancy upgrade

Requirements and status of PETRA IV Fast Orbit Feedback System, IBIC2022



Beam stability requirements:

Typically 10% of beam size (~300nm) and divergence (134nrad) at the IDs.

Remark: Some beamlines may require even 5%, 3%, … in future?

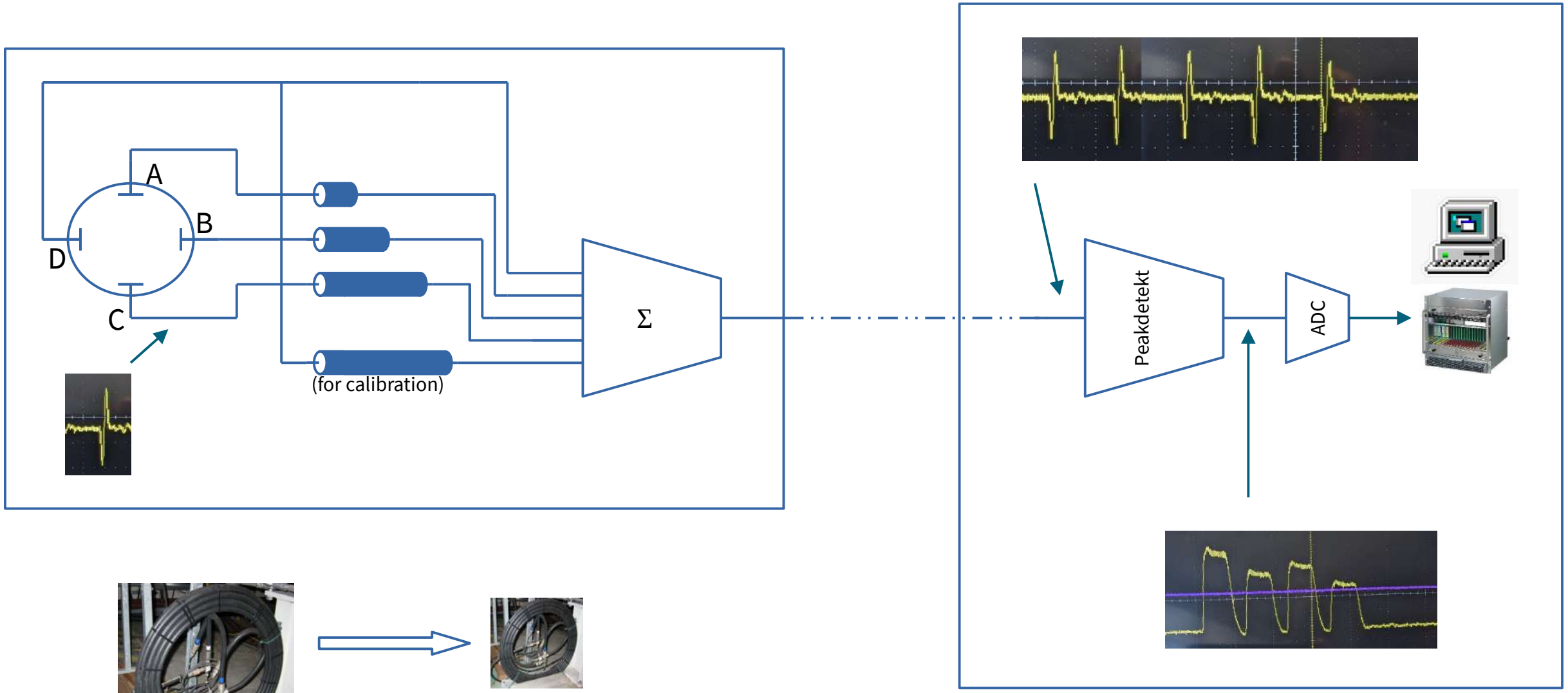
Fast Orbit Feedback (FOFB) System

FOFB: Parameters & Stability Requirements & Concept

Subsystem/Links	Delay	Comments
Beam position calculation	23	3 turns maximum delay
BPM processor to BPM datahub	<0.5	Backplane link
BPM datahub to LOC	~1	Optical link ~ 10s of meters (10 Gbps)
LOC electronics nodes	<1	Local data processing
LOC to GLO (two ways including encoding/decoding)	12.5	Max of 1250 m (10 Gbps)
GLO controller	20	Global data processing time
LOC to PS	~ 0.5	Optical link ~ 10s of meters (10 Gbps)
Power supply	15	Max input-out delay (estimate)
Corrector magnet power cable	1.5	Max cable length 300m
Total	**75**	Anticipated budget delay

pre-accelerator BPM System for Petra IV

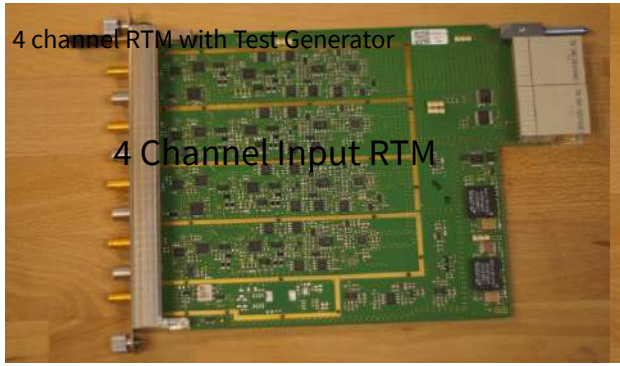
Delay line compensation for Cable and Electronic



Self calibrating allows smaller delay lines with more damping

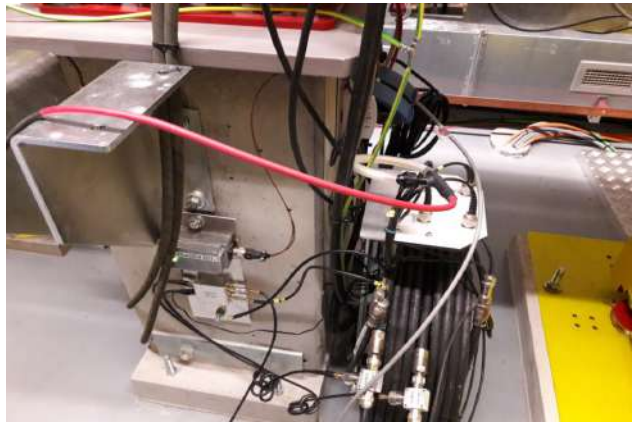
pre-accelerator BPM System for Petra IV

Same BPM Type as in Flash and XFEL



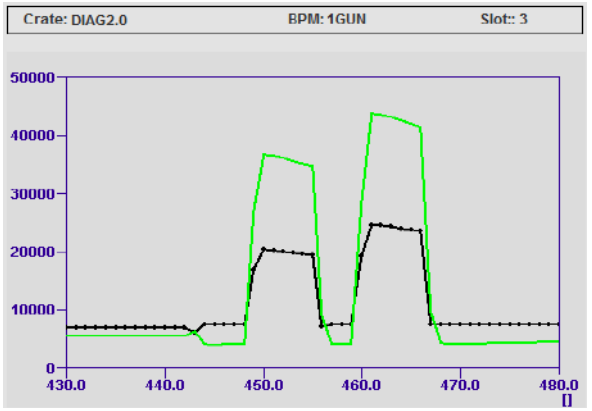
RTM

AMC



110ns Delay line

12 slot mtca.4 create



Thank you for your attention!