THE BEAM DIAGNOSTIC INSTRUMENTATION OF PETRA III

by K. Wittenburg; DESY

Starting with a short history of PETRA I – III

(Positron Electron Tandem Ring Accelerator)

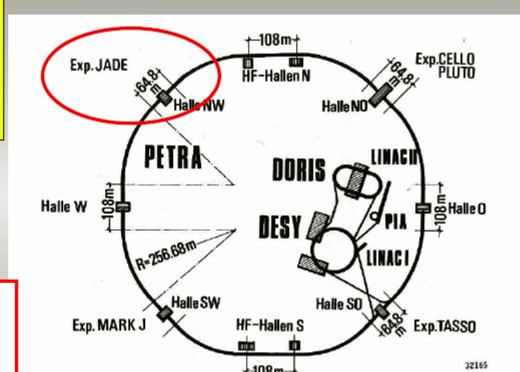
The PETRA e⁺e⁻ Storage Ring

Physics at PETRA from 1979-1986

•largest e⁺e⁻ accelerator at that time

The discovery of the gluon, the carrier particle of the strong nuclear force, in 1979 is counted as one of PETRAs biggest successes.

23.3 GeV / beam!!!



CME range (GeV)	Data taking period	Luminosity (pb^{-1})	$\sqrt{s}$ (GeV)	MH events
14.0	07-08/1981	1.46	14.0	1734
22.0	06-07/1981	2.41	22.0	1390
33.8-36.0	02/1981-08/1982	61.7	34.6	14372
35.0	02-06/1986	92.3	35.0	20925
38.3	10-11/1981	8.28	38.3	1587
43.4-46.6	06/1984-10/1985	28.8	43.8	3940

PETRA II
pre-accelerator for HERA (1988-2007)

12 GeV electrons and positrons;
40 GeV protons,

Syn. Rad. Fac. since 1995, equipped with undulators to create synchrotron radiation especially in the X-ray part of the spectrum.

PETRA III (2009)

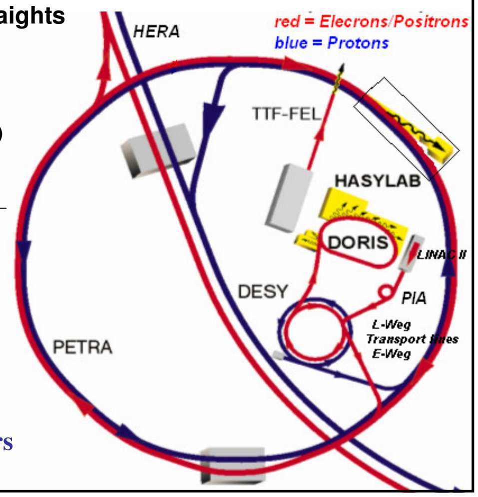
PETRA III

The PETRA upgrade project

- Reconstruction of 1/8 of PETRA (288 m) in a new experimental hall
- 9 new straight sections in the new arc, canted undulators → 14 separate undulator BLs
- 100 m damping wiggler in the long straights
- Renewal of the entire machine
- Renewal of injection system

(and removal of the blue)

Start commissioning at 1. Jan. 2009



Some Parameters:

E = 6 GeV

I = 100 mA (200 mA) – top-up

$\varepsilon \approx 1.0$ nm rad

$\kappa = 1\%$

960 or variable bunch patterns

Additional options for long undulators

PETRA III

Instrumentation for beam diagnostic

1. **BPM systems**
2. **Fast Orbit Feedback (>0.1 Hz to 300 Hz)**
   Slow Orbit Feedback (< 1 Hz) by Control System
3. **Multibunch Feedback (transversal and longitudinal) and Tune**
4. **Beam current and lifetime:**
   - **a) Bunch current AC** for toping up of individual bunches
   - **b) DC current** for precise current and lifetime measurement
5. **Emittance**:
   - a) **Synchrotron radiation**
     - i. **x-ray**
     - ii. **visible light (bunch length)**
   - b) **Laser wire scanner**
     No solid wire scanners, 15 micron Quartz-wire (non conducting) will burn at 0.7 mA (horizontal) and 7 mA (vertical) at 1 m/s wire speed.
   - c) **Screen monitors**
6. **X-Ray BPMs**
7. **Machine Protection System (MPS)**
   Signals from: Beam current, Beam position, beam pipe temperature, beam - stopper, RF

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PETRA III

The BPM System

The BPM-system has to serve for two major tasks:

Machine commissioning and development:
Single turn, single pass capability to acquire beam positions of the non-stored first turn or of each of consecutive turns is required. In this turn-by-turn operation mode the **resolution requirements are relaxed (50...100 µm)**.

Orbit feedback and observation:
In synchrotron light operation the beam orbit of the stored beam has to be kept constant to a reference orbit. All BPMs have to be squeezed to their maximum performance in terms of **resolution (1/10 of the beam width σ)** and reproducibility. To achieve this, the **bandwidth of the BPM-readout can be reduced to 300 Hz**, so averaged position measurements of many turns will be acquired. On the other hand the BPM system has to provide **position data with a frequency of about 130 kHz (turn by turn) to feed the fast orbit feedback** system. Even at that bandwidth the resolution of a BPM must not exceed the 50 µm range.

BPM requirements for fast orbit correction

=> Sub micron orbit stability
=> 0.3 µm resolution at 300 Hz bandwidth

Location (#) **Total 227 BPMs**	BPM shape	Required horizontal resolution σ (µm)	Required vertical resolution σ (µm)	Ultimate horizontal resolution σ (µm)	Ultimate vertical resolution σ (µm)	Monitor constant k: vert.; hor.
Old octants (106)	elliptical	10	10	0.5	0.5	16.9 ; 17.7
New octant (44)	octagon	2	**0.5**	0.5	**0.5**	16.8 ; 17.5
Next to undulators (16+5)	elliptical	2	**0.3**	**0.15**	**0.15**	5.26 ; 5.26
Straight Sections (26+2)	round	10	10	1.0	1.0	33.3 ; 33.3
Damping Wiggler (26+2)	racetrack	5	5	0.35	0.5	12.0 ; 16.4

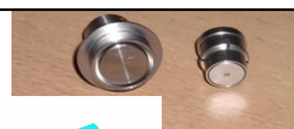
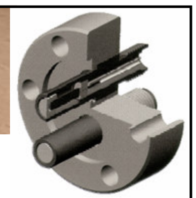
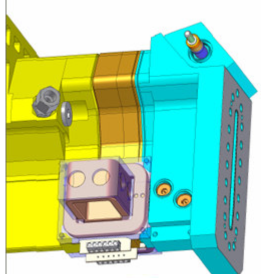
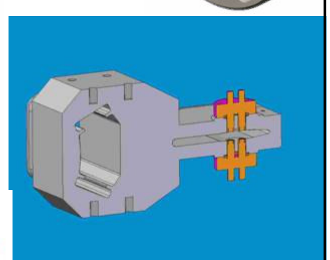
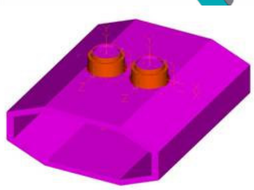
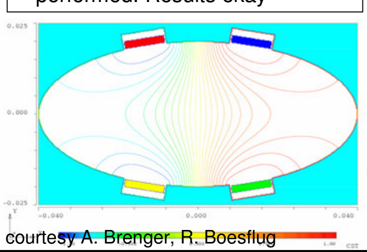
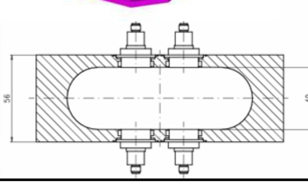
Orbit resolution requirements at certain locations at a bandwidth of B=300 Hz. The ultimate limits can be expected from the tightest requirement of a resolution of 0.5 µm for the new octant (taking into account the monitor constants).

courtesy K. Balewski

BPMs Pick-ups:

Use of commercial RF button feedthroughs already in use at TTF, HERA and transport lines.

- The supplied feedthroughs are individually tested (Vacuum und HF) and sorted for identical electrical response.
- Assembled BPM also tested in laboratory (shorts and response)
- All geometries are calculated (monitor constants, signal response, linearity)
- HOM simulations were performed. Results okay

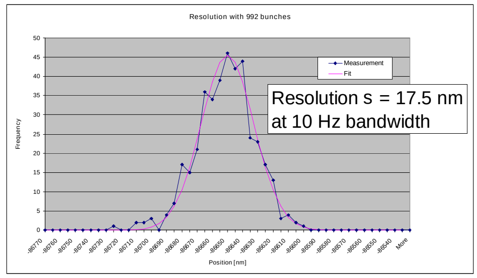

courtesy A. Brenger, R. Boesflug

BPM Readout electronic

Extensive tests of Libera Electron done:

- Slow orbit and TbT resolution
- Fast data readout for fast orbit feedback.
- Temperature dependence
- …

o Bunch pattern and current dependence (however, not so important for top-up operation)



=> LIBERA Brilliance
(improved specs.)

240 pieces arrived after less than 1 year. Few rejected, minor problems

BPM Readout electronic

All Liberas located in air-conditioned cabins (± 1 ^{0}C) together with feedback electronics

Signal at LIBERA Input (Switch)

beam offset 8mm both planes
cable: RFA 3/8"-50, length 20m

Amplitude 100 V,
LIBERA input max. 80 V
=> Attenuators 10 dB

Attenuators 10 dB

HF-MoMo (Movement Monitor)

Near the undulators the movement of the BPMs (relative to ground) will be measured with a resolution of better 1 mm. Different encoder systems were studied

Test of a commercial System in PETRAII failed: radiation problems, high failure rate.

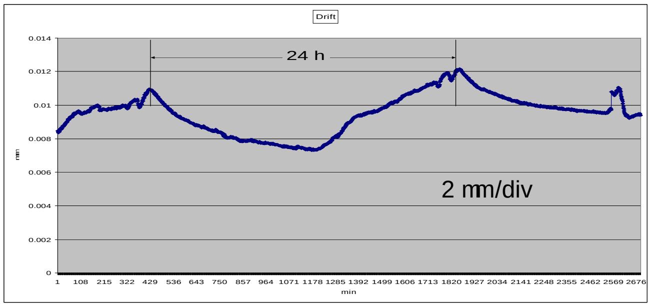
Choice of in-house wire-systems HF-MoMo
145 MHz signal on l /4 antenna picked up by 4 stiplines. Readout BPM like, bandwidth 1Hz.
Gap 8x8mm, linear 2x2 mm.

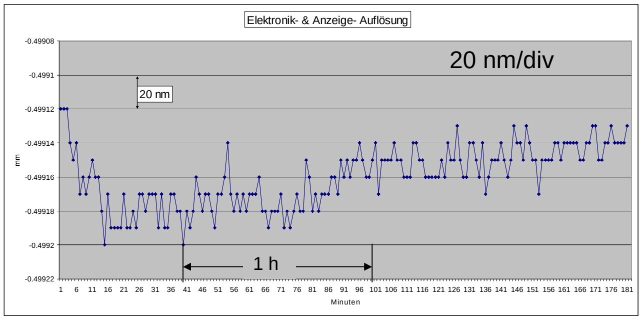
Laboratory-measurements on prototype

New hall:

Temperature stabilized to 0.1 ^{0}C.

All Magnets on aligned girders.





bandwidth:
1/60 Hz
max: 1Hz

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Fast Orbit Feedback

• Beam stability is one of the most important requirements in synchrotron light sources. For PETRA III RMS position errors must be limited to less than 1µm.

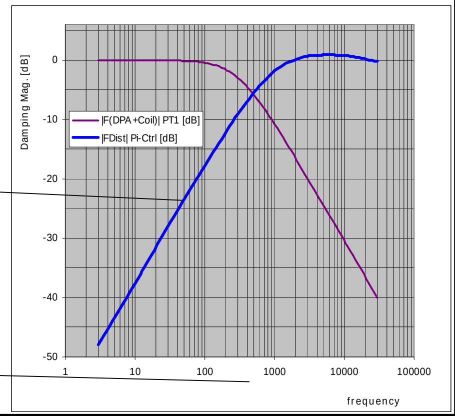
• Position errors at the insertion devices are expected to be around 10 µm in the horizontal and 3 µm in the vertical plane (vibrations due to culture noise), therefore a fast orbit feedback is necessary.
Foreseen capability to synchronize/interact with slow orbit correction.

•System requirements:

Orbit distortion reduction	-20dB at 50 Hz
Frequency range	0.1 Hz to 300 Hz

< -20dB at 50 Hz

goes beyond 300 Hz



Fast Orbit feedback setup

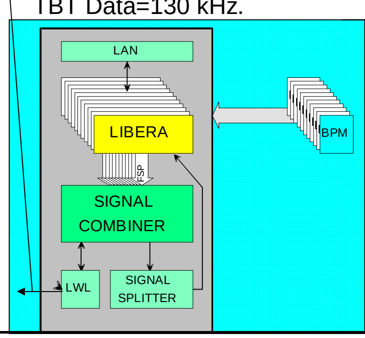
• Star topology

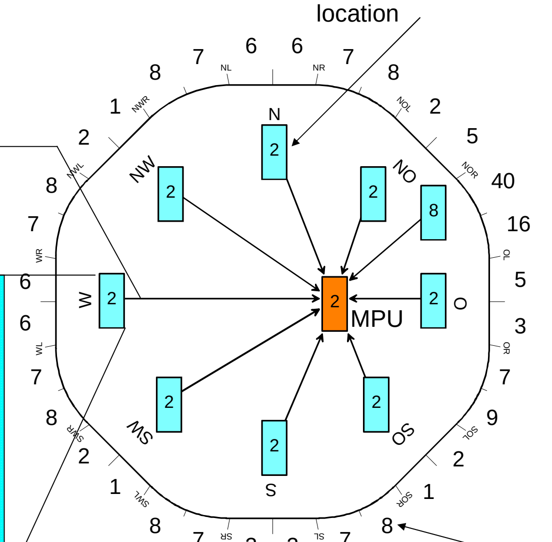
• 24 Monitor Racks

• total of 218 BPMs

• High speed fiber network with up to 200 MB/s synchronous data flow,
TBT Data=130 kHz.

Number of Racks at location





Number of BPMs at location

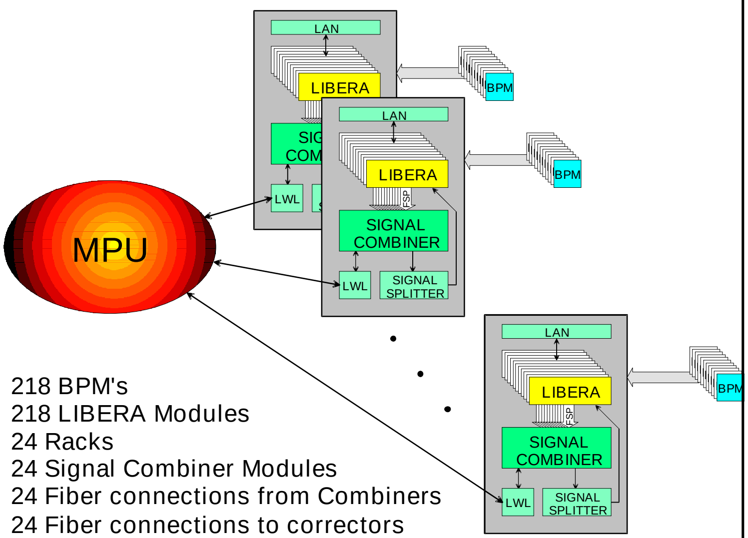
BPM signal processing and collection electronics

Main Processing Unit

Receives LIBERA TBT Data (not processed data). Hope to get better latency in MPU.

•Signal processing will be performed by using FPGA technology ALTERA Stratix II family (2S 60/90)

•Signal processing by using SVD and PID algorithms



218 BPM's
218 LIBERA Modules
24 Racks
24 Signal Combiner Modules
24 Fiber connections from Combiners
24 Fiber connections to correctors

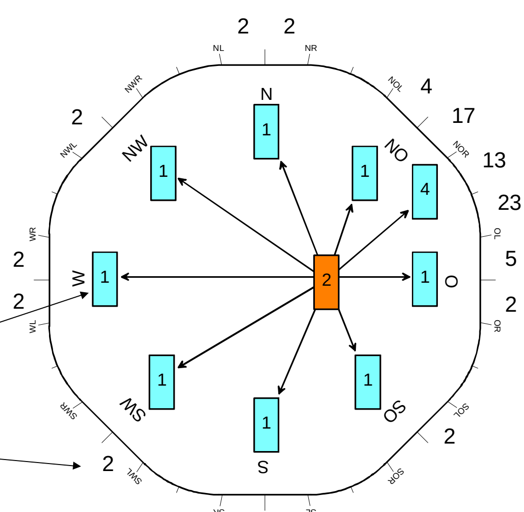
Corrector Coils and their Amplifier electronics

Completely end-to-end digital design with 16 bit resolution.

- 12 Digital Amplifier Racks
- 24 fiber connections
- total of 82 Coils & AMPs

The output data stream is distributed via fiber links to 82 digital power amplifiers (DPA) with individual current controllers.

The DPAs are controlled via CAN interface.



Number of Racks at location.

Number of corrector coils at location

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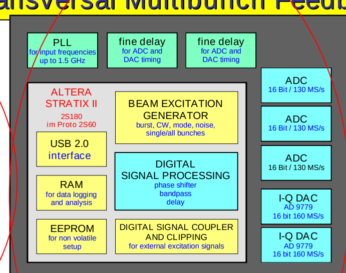
Transversal Multibunch Feedback

500 MHz
Stripline
BPM (2)



2 Kickers / Plane; BW>62.5MHz

Signal Processor
Board 130 MS/s

RF Front-End,
1 kHz - 62.5 MHz

Power Amplifier,
9 kHz - 250 MHz
4 * 250 W

The required minimum bandwidth is 62.5MHz determined by the shortest distance between bunches being 8 ns. Upgrade to 2 ns (250 MHz) possible

Tune (part of Transv. Multibunch Feedback)

Since the feedback systems will damp away any kind of excitation, the classical tune measurement can be performed only without feedback.

The tune measurement is part of the transversal multibunch feedback system. It contains a digital signal generator to feed different kind of signals bunch-synchronized to the kickers. Single bunch as well as multibunch excitations can be performed. In the single bunch mode the number of the bunch can be chosen while in the multibunch mode the frequency of each mode can be adjusted. Different excitation modes:

1) sinusoidal CW,

2) bursts with adjustable rate and length and

3) bandwidth-limited “white” noise.

A new(?) idea of tune measurement with feedback will be tested at PETRA III: An adjustable broadband noise will be added to the RF front-end output (and therefore to the kickers). In the frequency response this will be seen as a constant offset. At the tune resonance frequency a notch will appear due to the 180^0 phase shift of the feedback. These notches can be analyzed very precisely, even with running feedbacks and with a minimum of excitation.

Longitudinal Multibunch Feedback

position
independent

courtesy: M. Dehler, PSI

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Fast Current monitors (FCT):

FCT from Bergoz; DESY-specification
1.75 GHz bandwidth for round okay.
Resolution of bunch current < 1 mA with analog BW of 500 MHz, charge of each bunch for top-up.
elliptical (2x): Injection efficiency, BW 800 MHz
readout: LeCroy-scope. An average of 50 turns of each bunch will be displayed in the control room and send via Ethernet connection to the control system.

ACCT for transport lines

TTF2 type (inhouse, 2 halfs)

Bandwidth 150 MHz

Readout: ADC-Board from National Instruments, NI PXI-5182 with 8-Bit resolution, a sampling rate of 1GS/s and a bandwidth of 300MHz. Connection to control system by Labview server.

Located always at the beginning and the end of the transport lines to measure beam losses during the transport of each bunch. Also PIA and DESY are equipped to observe the bunch current during filling/bunching of PIA and the acceleration in DESYII.

DC Current Transformers (DCCTs)

Three PCT's (BERGOZ) from PETRAII will be re-used in PETRAIII. Experiences from HERA with this type of monitor showed a resolution of s <<1 ‰ (absolute: 3 mA of 61.7 mA)

Enables precise lifetime measurements

The readout is performed by a high precision DVM (Type HP 3458A with 16 - 24 bit resolution (depending on sampling rate) connected to the BERGOZ backend-electronics. The DVM averages over defined number of turns (depending on the required resolution).

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Emittance-measurement with x-ray

Two interchangeable X-ray optics:

Pinhole

0.5 mm thick tungsten blade with a circular hole of 20 mm. (20 mm resolution)

Compound reflective lens (RWTH Aachen)

N=31, 2 mm res. < 1 mm aligned

commercial x-ray camera
AA50 beam monitor Hamamatsu

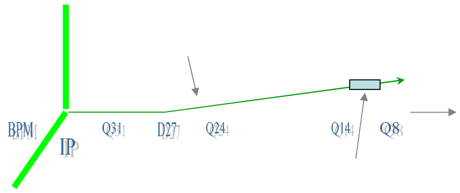
To reduce the SR heat load in front of the X-ray optics two absorbers are installed in the photon path.
Monochromator (silicon single crystal in (311) in Laue geometry) is water cooled.
X-ray camera consists of an X-ray converter system and a light collection optics. CCD camera: Hamamatsu 1.37M-pixels cooled CCD digital camera Orca C4742-80-12AG.

Optical Beam Line

For the main purpose of measuring the bunch length, a second optical beam line is currently under construction. A mirror will extract the optical part of the synchrotron radiation from a standard dipole and an optical transport line will guide the light into a hut outside the tunnel. In the beginning it is foreseen to perform measurements of the bunch length with fast optical elements like streak camera or Avalanche Photo Diodes (APD). But all optical elements are designed and proven to be as precise as possible (< l /20) to be prepared for optical beam size measurements as well.

Laser-Wire Scanner

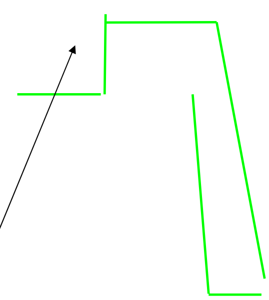
- 20Hz, 7.5 MW, 532nm, YAG Laser with a seeding to minimize shot-to-shot Jitter.
- BPMs before and at IP will allow to measure beam slope at IP.



- 12 layer segmented W-scintilator sandwich. Measures energy and position of the photons.
- Readout VME based (Power PC - Lynx) 40 MHz pipeline ADC

Collaboration: Royal Holloway (UL), University College London (UL), BESSY, DESY, J.A.I, EUROTeV

Laser-Wire Scanner



<u>Novel for Petra III:</u>
Beam Splitter = Longitudinal Pockels cell + Glan-Laser prism
Deflector = Transverse Pockels cell
Will allow to get rid of moving parts.
Allows scanning in both planes in < 30 s with a few % error.

(old: motorized mirrors, slow speed!)

s =74 mm

Screen Monitors

Mechanic:

25 phosphor screens (Ø 63.5 and 98 mm) are installed in the transport lines between the preaccelerators and PETRAIII.

Screen: 8 mm Al-layer covered with a thin layer of ZnS to avoid significant emittance blow-up. Therefore the three screens method can be applied to measure the emittance of the transported beam.

The driving mechanism: Pressed-air cylinder, electro-magnetic bar to allow the in-movement, spring to ensure always an automatic pullout of the screen in case of losing of the pressed air support.

1mm thick frameless ceramic screens before and after the injection septum, one in PETRA III to observe the injected beam.

Soft- and Hardware takes care not to drive the PETRA-screen into a stored beam.

Screen Monitors

Optic:

Readout by old fashion analog CCD cameras because of their much better radiation hardness.

Camera shielded by 50 mm lead house

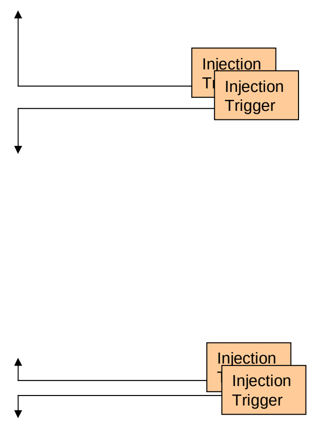
A mirror in the optical path can be driven in to image a reference grid to calibrate the camera (the reference lines on the screen are not precise enough for exact calibration).

Radiation hard camera prototype successfully tested. Used in high radiation environment (Septum, PIA).

Video Signals

# Cameras	Rack
4	
6	
4	
0	
9	
3 PETRA	

- New (general) video server is developed.
- Individual local Frame Grabbers with analogue output multiplexed to one PC-frame grabber in Server



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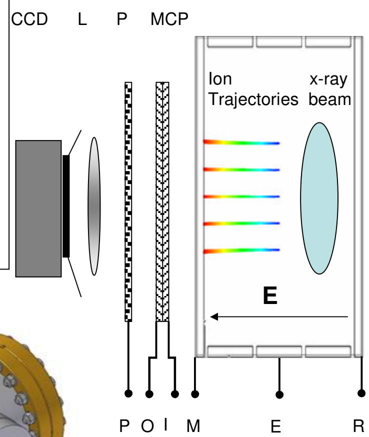
PETRA III

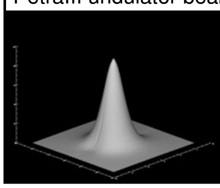
Residual Gas X-ray BPM (RGXBPM)

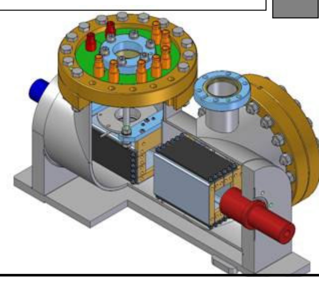
- **No Blade type** foreseen in PETRA III (uses halo)
- RGXBPM
  - \+ uses the full beam
  - \+ 1D beam image on P-screen (MCP ampl.)
  - \+ Center of gravity defines beam position
  - \+ Non destructive
  - \+ Spatial resolution < 10 µm

  - \- Needs gas bump (10^{-6} mbar)
    => differential pumping
  - \- MCP degradation



PetraIII undulator beam



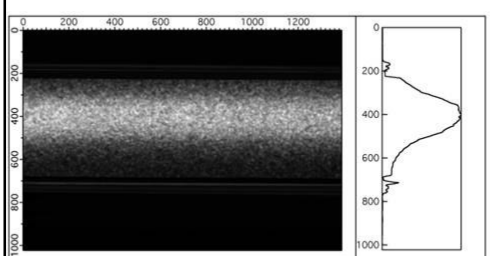


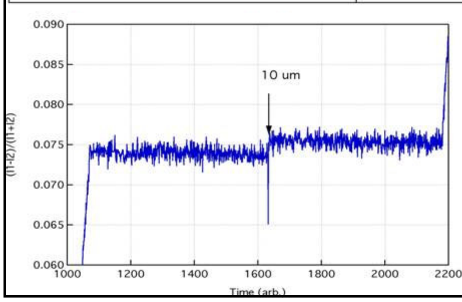
P. Ilinski: Status of RGXBPM for PETRA III, 17.04.2008, PETRA III meeting

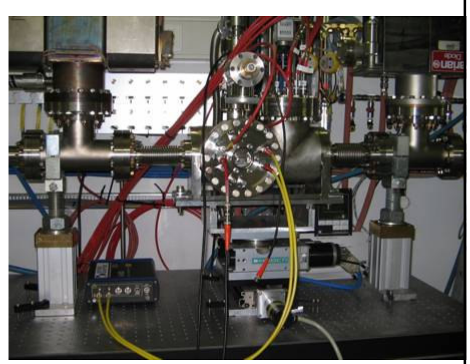
PETRA III

Residual Gas X-ray BPM resolution

ESRF ID6, 600 mm diamond window, I = 68 mA, 2.5 10-7 mbar, Exposure time = 300 ms







split MCP electrode readout
I = 80 mA, u34 gap = 20 mm,
E1 = 7 keV, 4.7 10^{-8} mbar, Signal level ~ 2mA

PETRA III

1. **BPM systems**
2. **Fast Orbit Feedback (>0.1 Hz to 300 Hz)**
   Slow Orbit Feedback (< 1 Hz) by Control System
3. **Multibunch Feedback (transversal and longitudinal)**
4. **Beam current and lifetime:**
   a) Bunch current AC for toping up of individual bunches
   b) DC current for precise current and lifetime measurement
5. **Emittance**:
   a) **Synchrotron radiation**
      i. **x-ray**
      ii. **visible light (bunch length)**
   b) **Laser wire scanner**
      No solid wire scanners, 15 micron Quartz-wire (non conducting) will burn at 0.7 mA (horizontal) and 7 mA (vertical) at 1 m/s wire speed.
   c) **Screen monitors**
6. **X-Ray BPMs**
7. **Machine Protection System (MPS)**
   Signals from: Beam current, Beam position, beam pipe temperature, beam - stopper, RF

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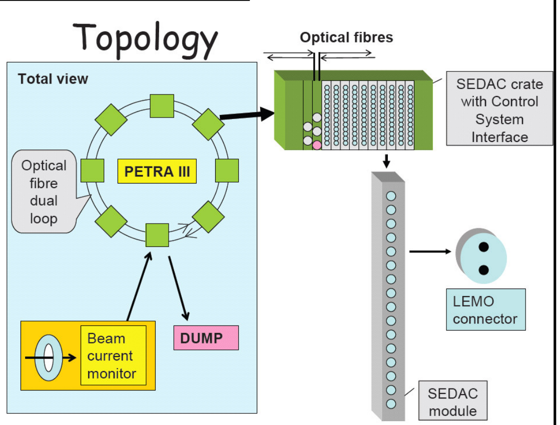
MPS System overview

- Dump the beam (HF off) in case of equipment failures or too large beam offsets, delay < 100 µs .
- Alarms sources: BPMs (Libera interlock output), Temperature System, Vacuum pump and valves, HF-System, power supplies, etc.
- The alarm-inputs to enabled/disabled by field bus commands or by predefined conditions. Conditions like low beam currents, large undulator gaps will disable individual inputs to allow machine studies without interference of the MPS.
- Redundant optical connection between PETRA Halls. Transfers of dump-information, beam current, time-synchronization, **and post mortem trigger**
- **“fail safe”** design
- **Keeps information who was the first!**



The local SEDAC field-bus is used to enable/disable the masks and the correlations of alarms as well as the status of the MPS. Not necessary for MPS activity!

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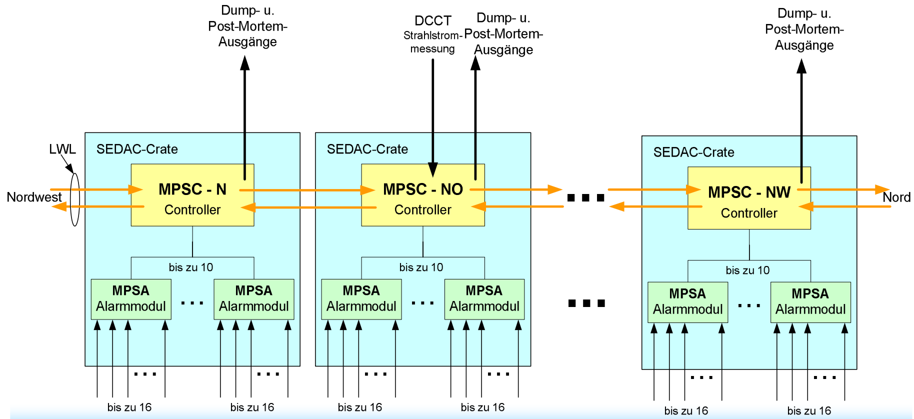
MPS modules

MPSA: Alarm-module – collects up to 16 potential-free contacts, use of masks in combination with beam current and combinations among themselves.

MPSC: Controller – collects the alarms within one crate, sends signals to dump and post mortem trigger and manages the communications along the LWL-loop



EMI tests done recently!

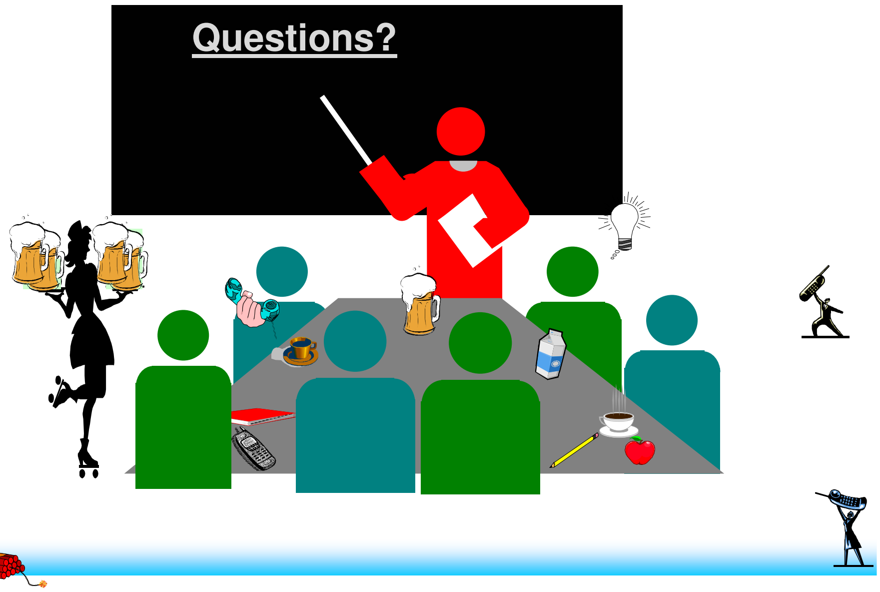
PETRA III

Conclusions

Plenty was done
Everything seems to be in good shape
- and in time!

(maybe not this talk?)

Cheers


Questions?