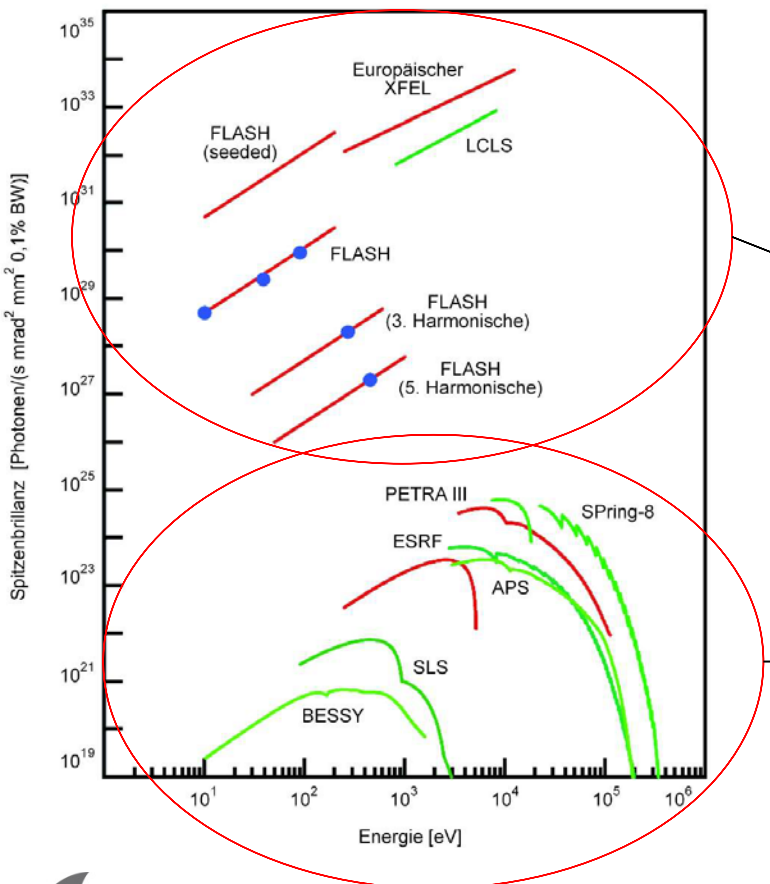
Diagnostics examples from 3rd generation light sources



See A. Cianchi's talk on Tuesday

This talk,
with a lot of help and pictures from J. Keil, DESY

and remember the talk of Joerg Wenninger

Kay Wittenburg
DESY

HELMHOLTZ | ASSOCIATION

DESY

Outline

A. Introduction

Examples

B. Beam Position Monitors, tasks

C. Orbit Concepts: Beam based alignment, corrections

D. Optic Functions: Beta-Function, Dispersion, Center Frequency …

E. Stabilizing the Orbit: Feedbacks

F. Beam Dynamic Parameters: Tune, Coupling, Chromaticity, Instabilities (MBFB)
BPM based

G. Beam Current: Transfer Efficiency, Lifetime (dynamic aperture, Touschek, …)

H. Beam size: Emittance, Coupling, Blow-up, Mismatch

I. Bunch length: Energy spread, Instabilities, Bunch purity

J. Energy: Resonant Depolarization

K. Beam Losses: Radiation Damage of Undulators

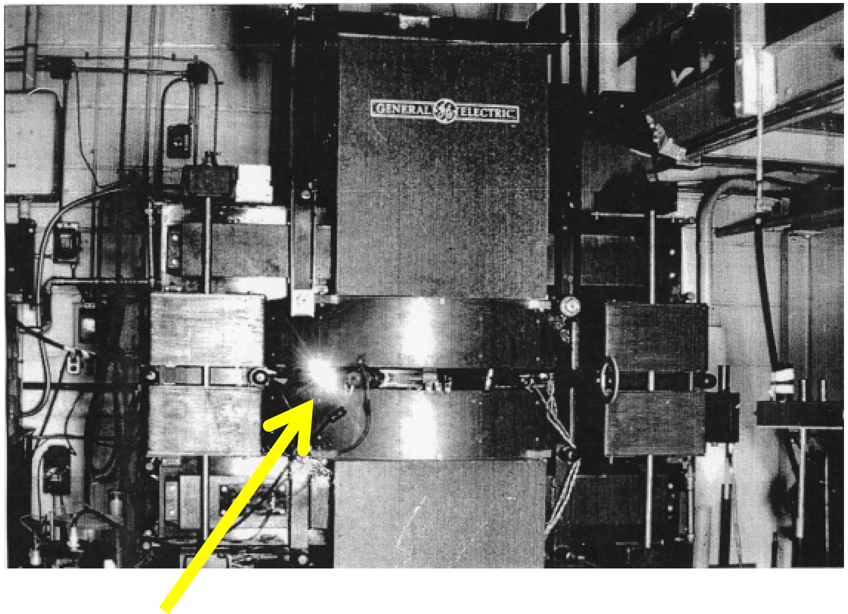
A. Intro: What is special at 3rd Generation Light Sources?

- Small beam size in undulators (≈ 150 / 5.0 μm) -> beam position stability < 0.5 μm (10% of beam size requested by users)) -> Orbit feedback -> Temperature stabilisation of environment and BPM electronic of < 0.1^0 C.
- Very small vertical emittance (10 prad) small horizontal emittance (1 nrad) -> small beam size to be measured, very small coupling
- Multibunch operation -> Instabilities -> Multibunch Feedback
- High beam current -> Instabilities, heat load of components
- Top-up mode for better stability -> Good beam current measurement

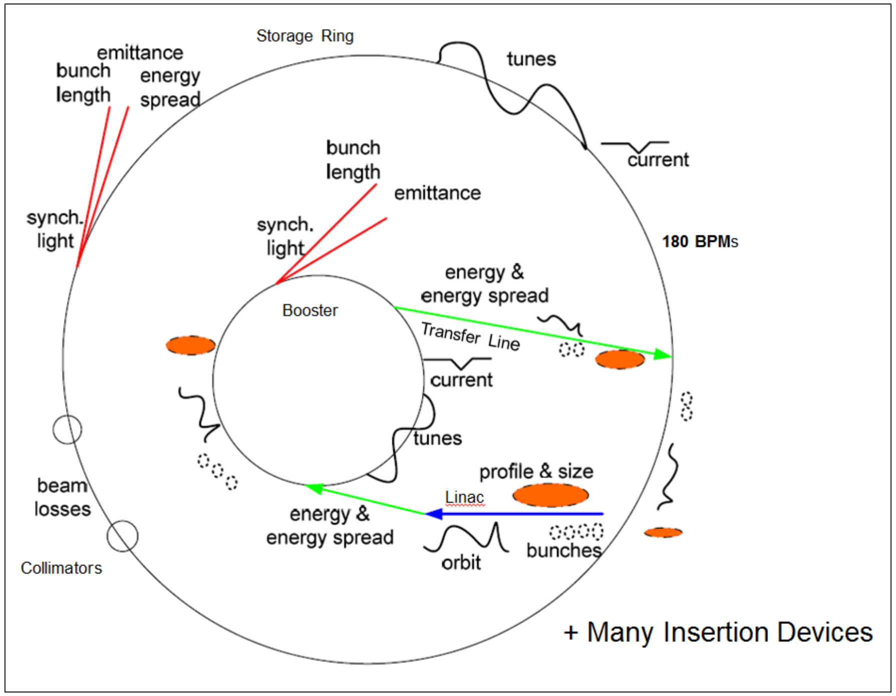
	year	E [GeV]	I [mA]	C [m]	ϵ_x [nm rad]	ϵ_y [pm rad]	K [%]	β_x [m]	β_y [m]	σ_x [μm]	σ_y [μm]
SLS	2001	2.4	400	288	5	35	0.7	1.4	0.9	84	5.6
CLS	2005	2.9	500	171	20.5	92	0.45	9.5	2.6	441	15.5
ASP	2006	3	200	216	6.98	63	0.9	9	2.45	251	12.4
SLS*	2006	2.4	400	288	5.5	5.5	0.1	1.4	0.9	84	2.1
Soleil	2007	2.75	500	354	3.7	37	1	4	1.77	122	8.1
Diamond	2007	3	300	562	2.7	27	1	4.6	1.5	111	6.4
SSRF	2008	3.5	300	432	3.9	39	1	3.6	2.5	118	9.9
PETRA III	2009	6	100	2304	1	10	1	20	5	141	7.1
ALBA	2010	3	400	269	4.3	40	0.9	2	1.3	93	7.2
ESRF-U	2011	6	300	844	4	10	0.25	35.2	2.52	375	5.0
NSLS-II	2015	3	500	792	0.9	8	0.89	1.5	0.8	37	2.5

Intro: A typical storage ring light source

> A typical storage ring light source consists of an injector, transport lines between accelerators, a storage ring, and a collection of surrounding beamlines and experimental stations



The 70MeV GE electron synchrotron and its visible synchrotron radiation in 1947



Typical 3rd Generation Light Source

Diagnosing NSLS-II: A New Advanced Synchrotron Light Source
Yong Hu,et al.; IBIC 2014

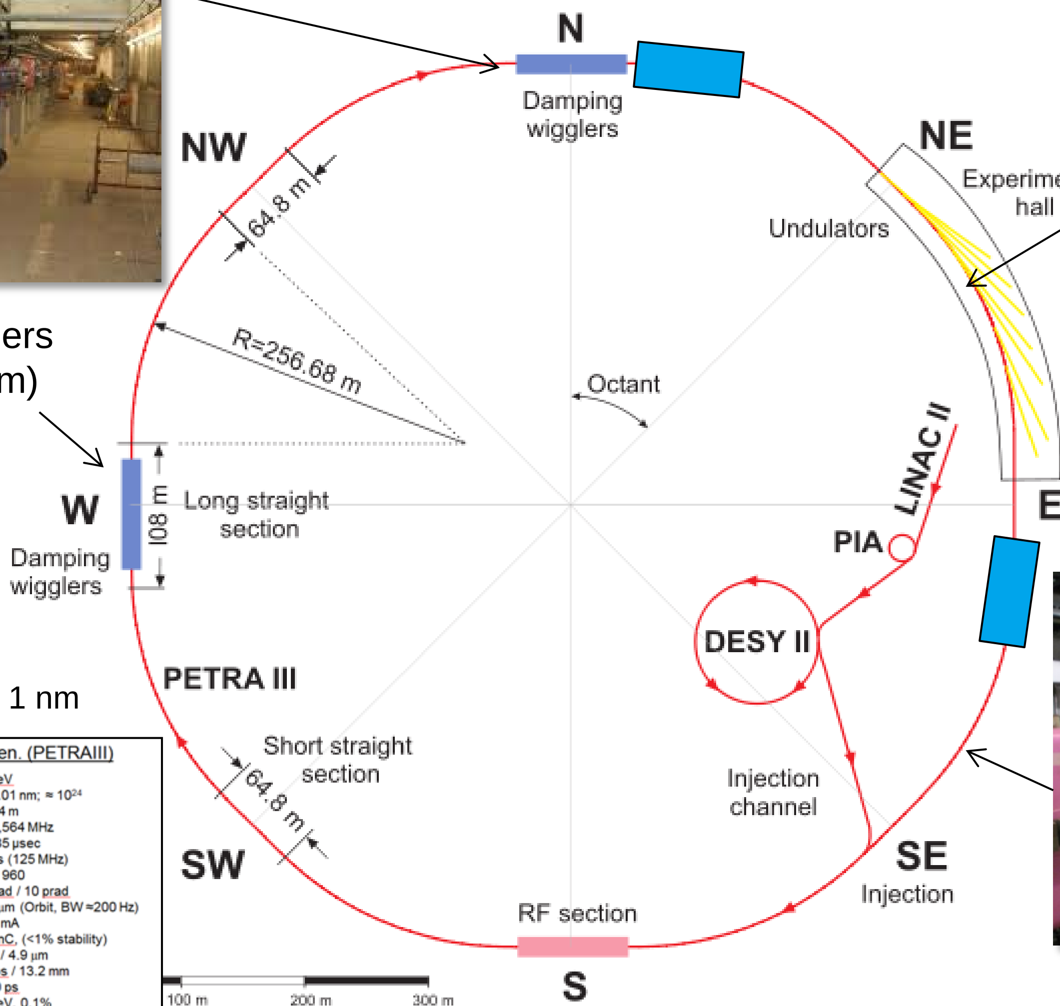
Intro: Many Examples from PETRA III; Layout of PETRA III


Straight sections N & W

20 damping wigglers (wiggler length 4 m)

Natural hor. Emittance 1 nm

PETRA III: Hybrid lattice of FODO and DBA cells




New octant

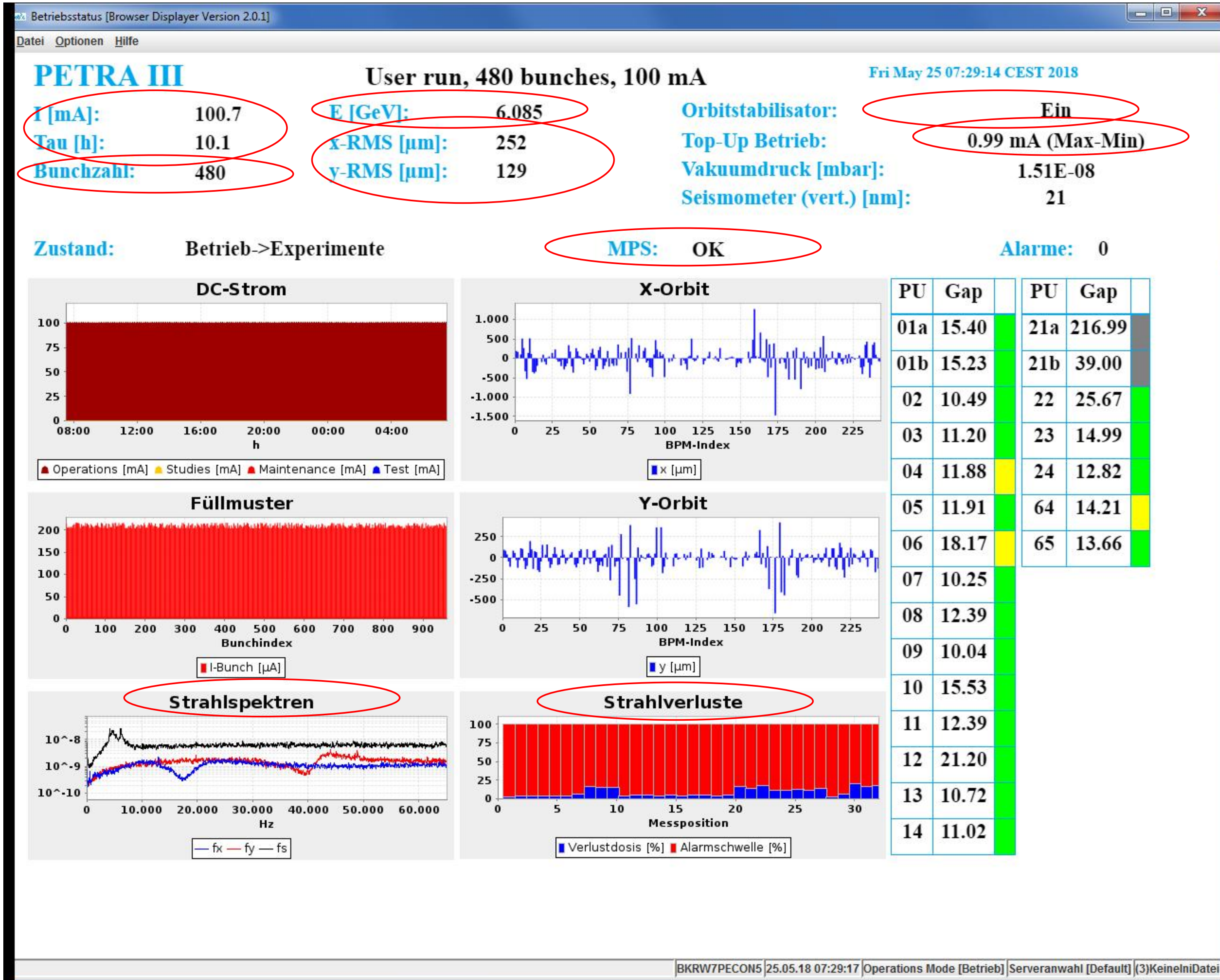
9 DBA cells
14 beam lines


Arcs and straight sections

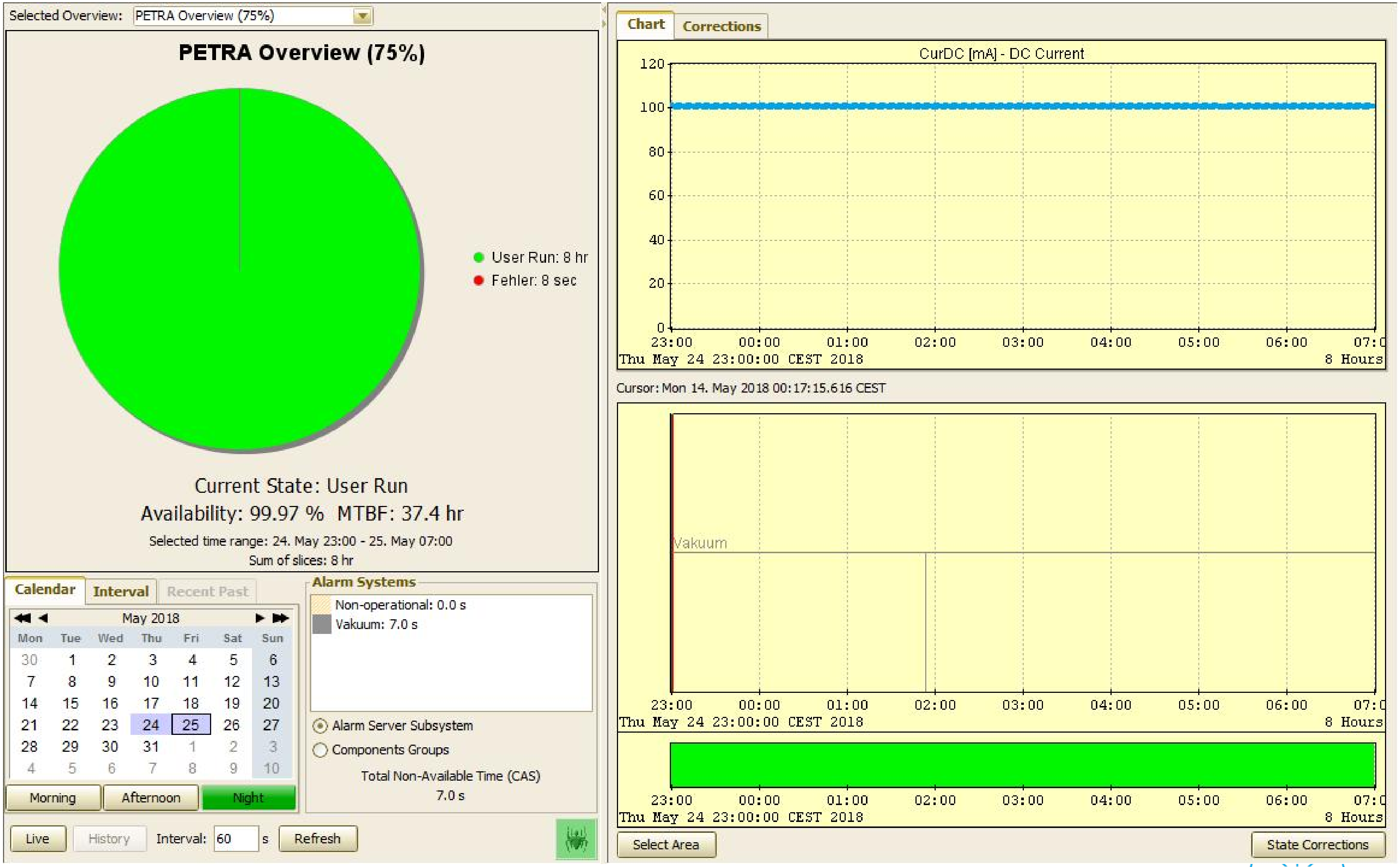
FODO cells

Parameter	3rd Gen. (PETRAIII)
Energy	6 GeV
Min. Wavelength of Radiation; brilliance	≈ 0.01 nm; ≈ 10^{24}
Circumference / length	2304 m
RF	499,564 MHz
Revolution / Repetition Time	7.685 µsec
Bunch Distance (min)	8 ns (125 MHz)
Bunch Number	40 - 960
Horizontal / Vertical Emittance	1 nrad / 10 prad
Beam position stability	0.5 µm (Orbit, BW ≈200 Hz)
Beam Current	100 mA
Bunch Charge	≤ 1 nC, (<1% stability)
Beam size at Undulator h / v	140 / 4.9 µm
Bunch Length (rms)	44 ps / 13.2 mm
Long. Feedbacks, arrival time jitter	≈ 10 ps
Beam Energy, Energy spread	6 GeV, 0.1%
Beam Losses	> few h lifetime
Tune	Fx = 16.95 kHz, Fy= 39.5 kHz
Synchrotron tune	Fs = 6.3 kHz
Chromaticity	Xxxx
Bunch purity	Better 10^{-7}
Diagnostic Needs:	average beam, except: charge, length

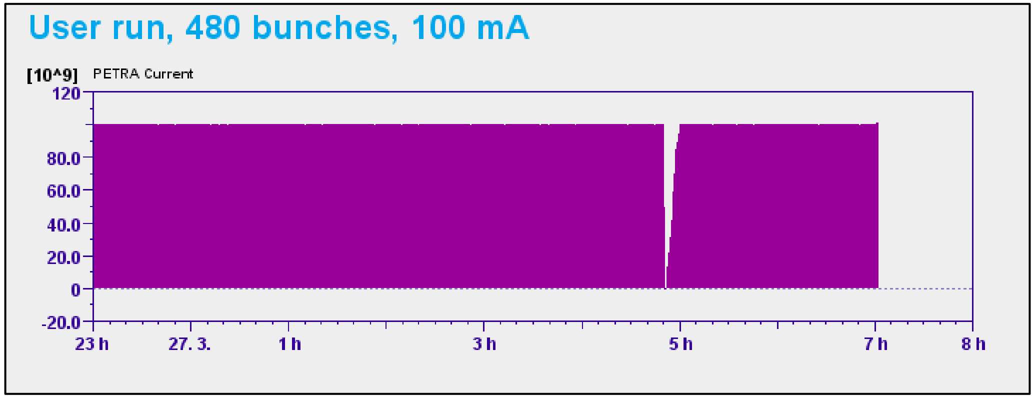
Intro: PETRA III Overview Screen



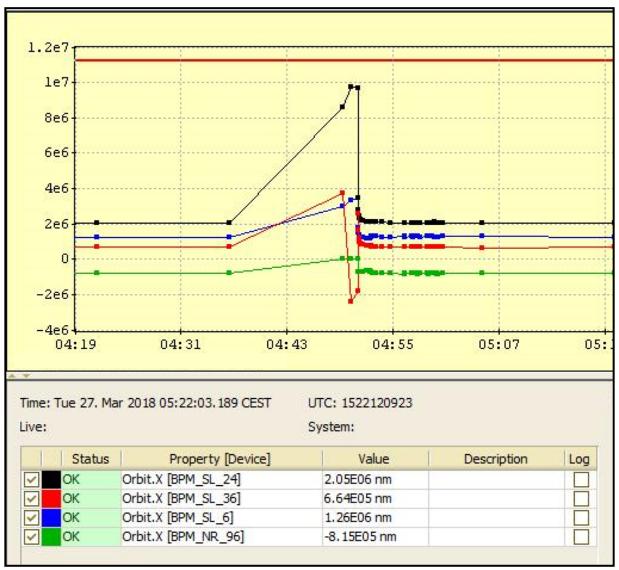
Intro: Performance



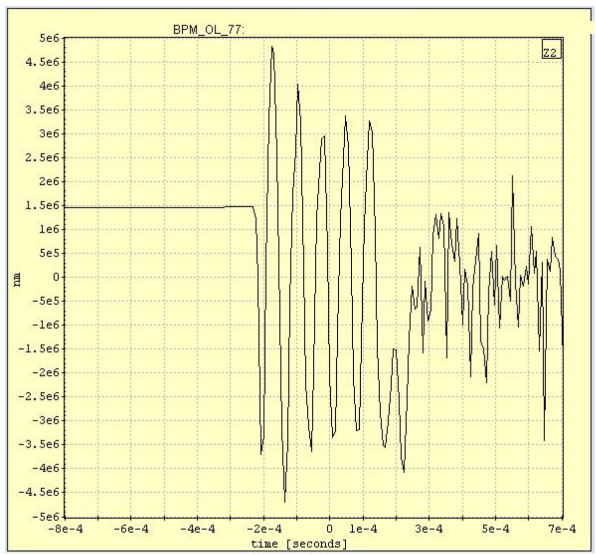
Intro: Error Scenario 1



BPM: Orbit

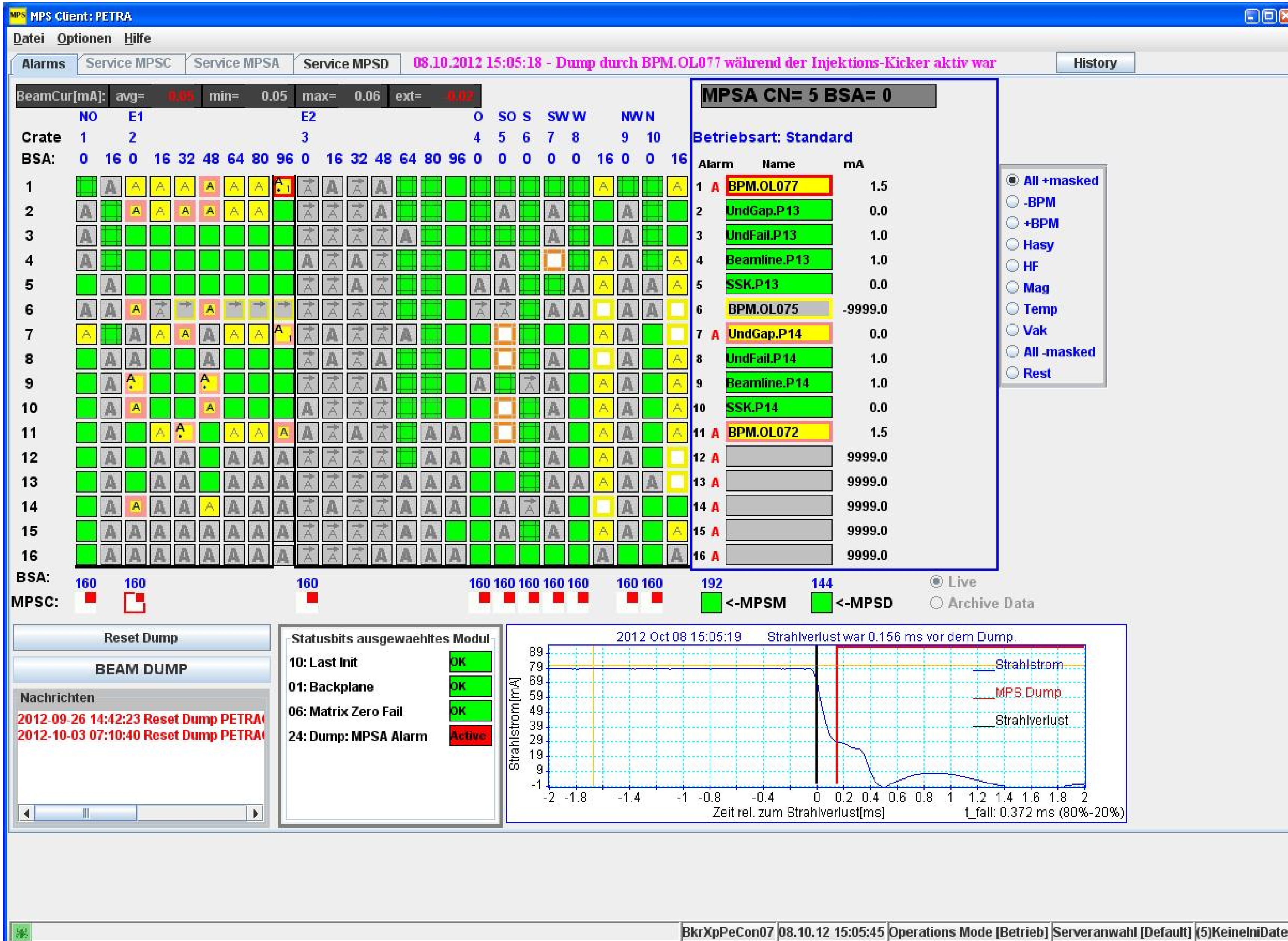


BPM: Turn-by-Turn



Injection Kicker Amplitude

Intro: Error Scenario 2



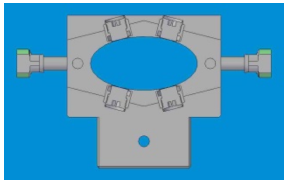
B. Beam Position Monitors (BPMs) -Tasks

> Orbit (Turn-by-Turn)
> Steering during Commissioning
> Precise Beam Position in Undulators (< 1 μm)
> Feedbacks (slow 10 s, fast 10 ms, Bunch-by-Bunch)
> Sub μm short and long term stability in undulators
> Tune
> Machine Protection
> …

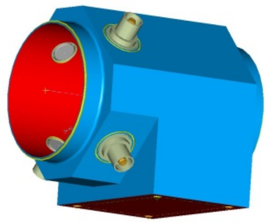
Beam Position Monitors (BPMs)

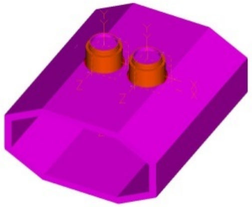
PETRAIII

> 226 BPMs - various geometries

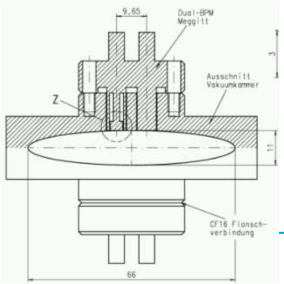


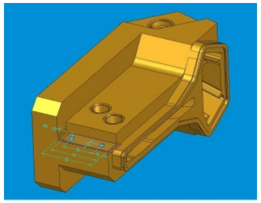
one type of RF - Front- / Backend



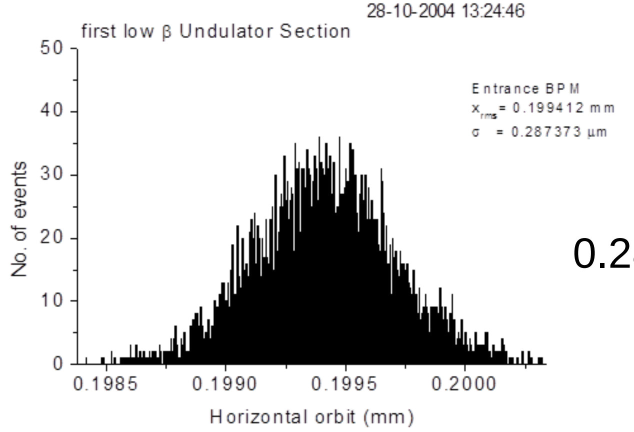


data rate 130 kHz (turn-by-turn)

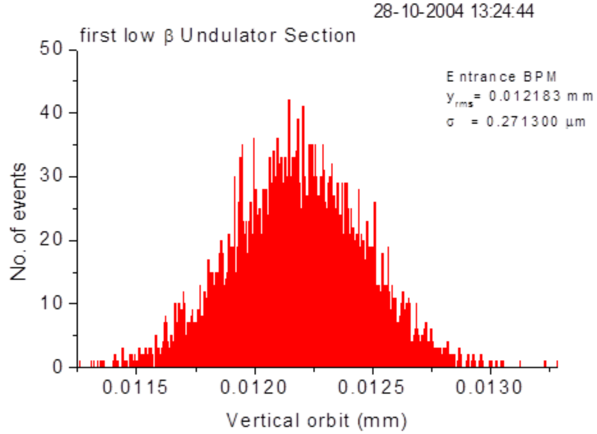




PETRA III BPM Resolution (< 1/10 of beam size in undulators



0.28 µm



0.27 µm

K. Balewski, DESY, IWBS 2004

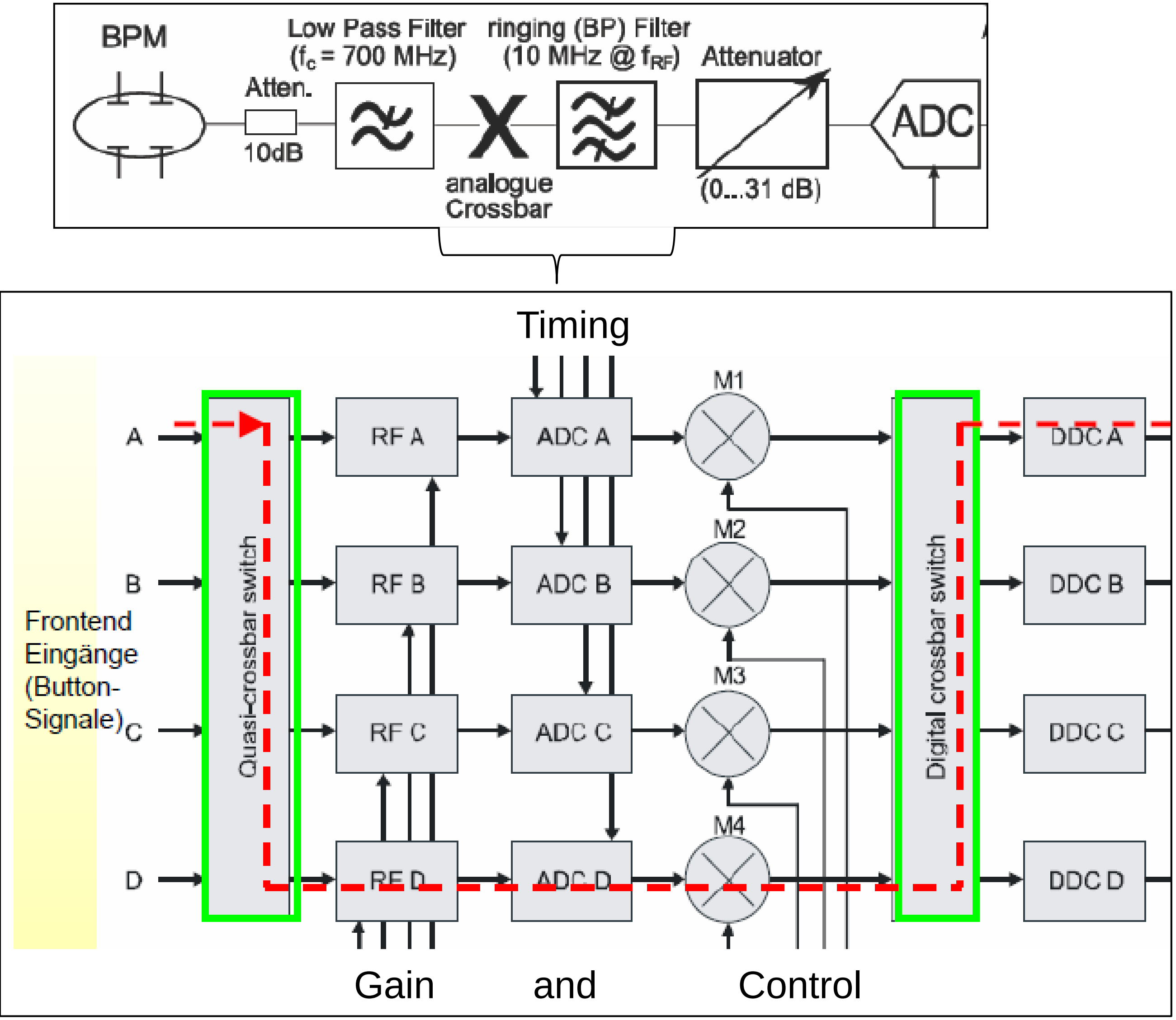
BPM stability

> 1) Electronic stabilization

> 2) Temperature stabilization

> 3) Mechanical movement (drift) of beam pipe

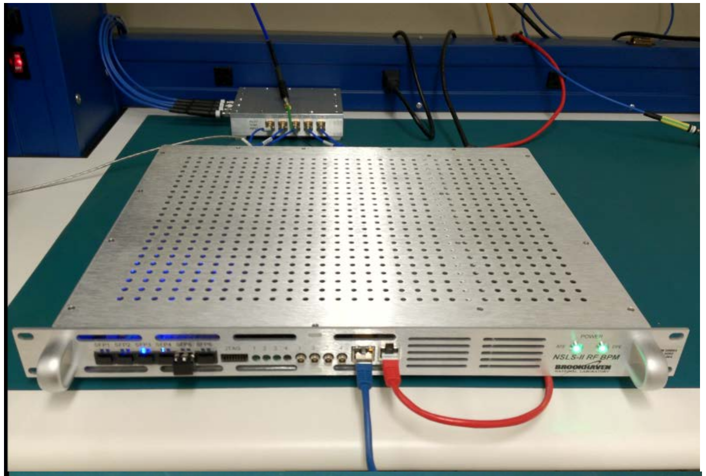
1) Electronic stabilization
a) Libera with switching crossbar for dynamic calibration

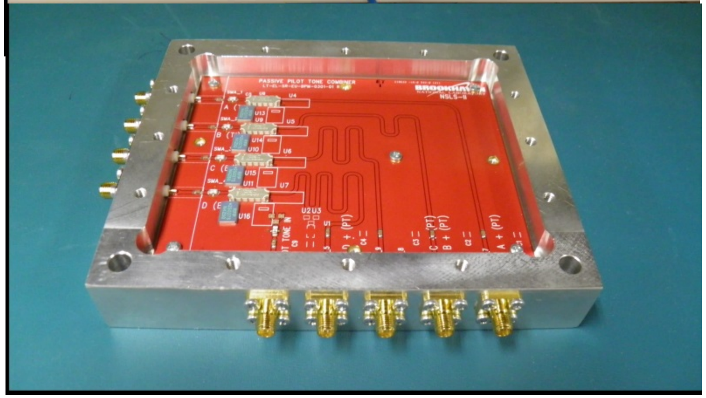


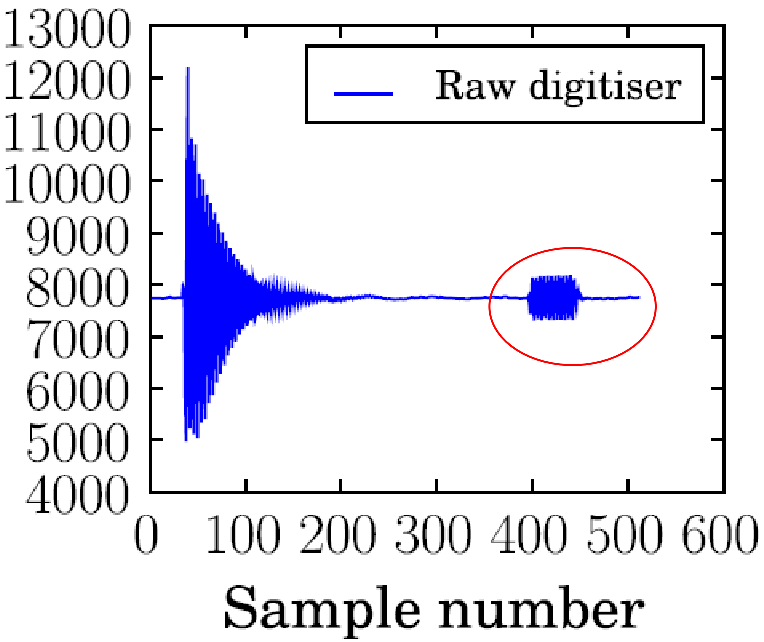
Switching crossbar removes different drifts of channels

$\Rightarrow$ Long term stabilization (I-Tech Patent)

1) Electronic stabilization
b) Pilot tone for dynamic calibration





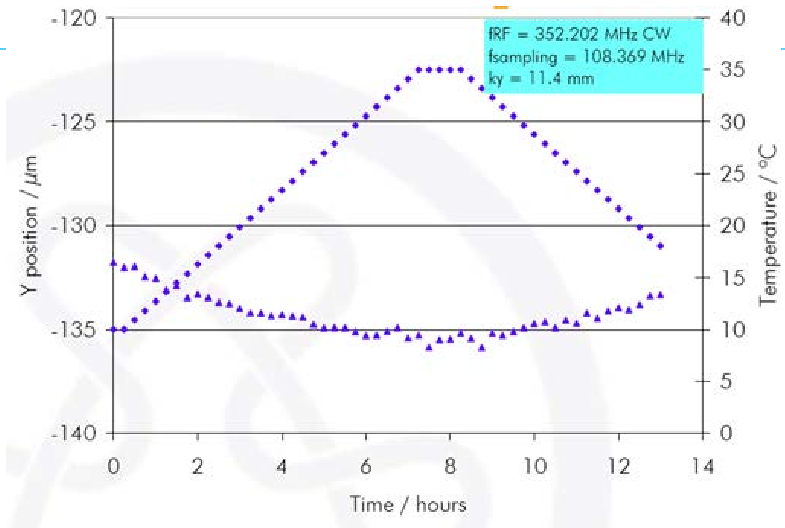


Cavity beam position monitor system for the Accelerator Test Facility 2
Y. I. Kim et al.; Phys. Rev. ST Accel. Beams 15,

An integrated RF synthesizer phase-locked to the ADC clock generates a programmable CW pilot tone for dynamic calibration. The pilot tone is combined with the beam signal within the Pilot Tone Combiner Module.

NSLS-II RF Beam Position Monitor Update
K. Vetter, et al., (BIW12)

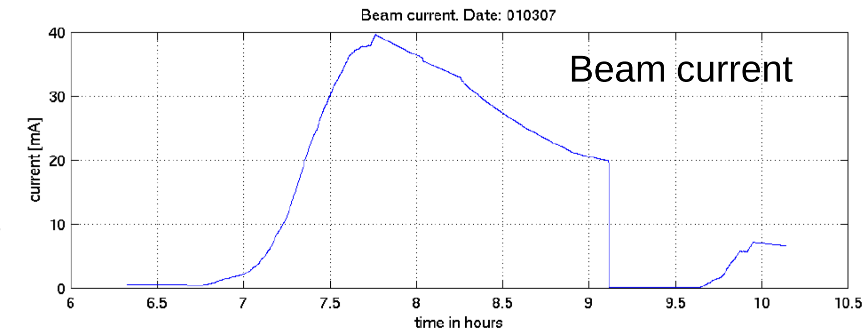
BPM stability: 2) Temperature stabilization



Problem: Electronic drift: 0.2 μm/^{0}C

Solution: Housing with ± 1° C temp. stabilization

Delta



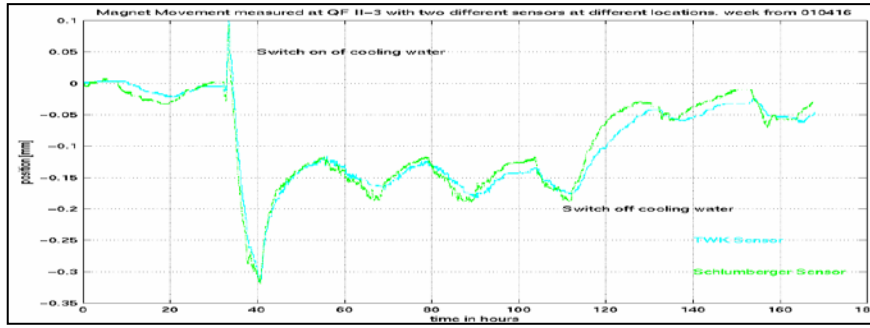
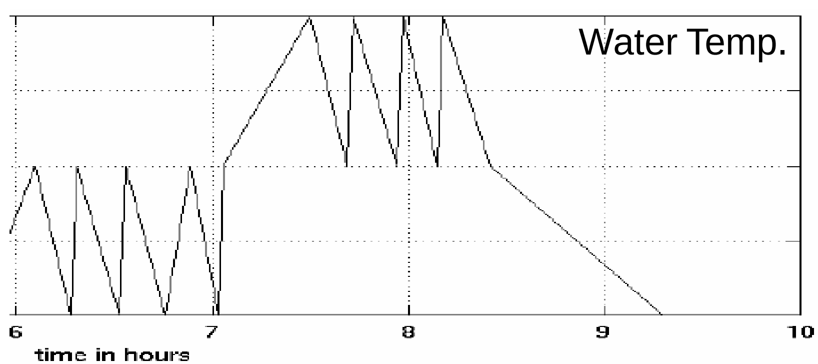


Figure 4: Quadrupole Position measured during one week with beam stored at low energy (750 MeV) (no influence due to synchrotron radiation). Start-up of the machine and daily changes are visible. The x-axis starts at Monday 0:00.

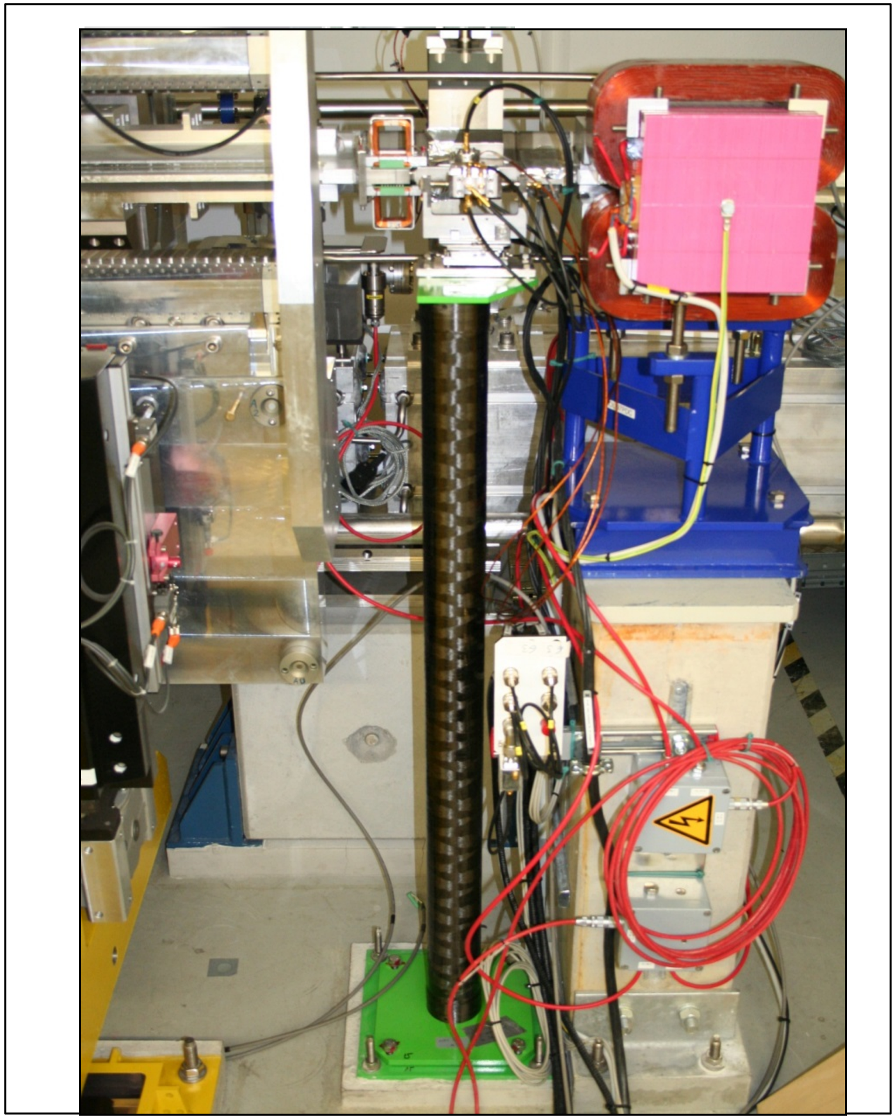
Figure 2: Installation of sensors before quadrupole magnets.



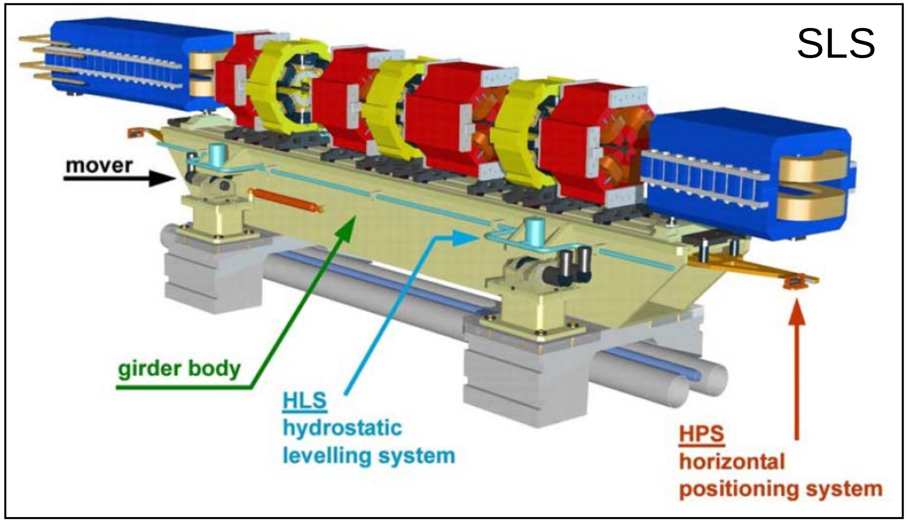
Position Sensors for Monitoring Accelerator Magnet Motion at the Dortmund Electron Accelerator G. Schmidt, etal.; EPAC02

BPM stability 3) Meas. of beam pipe movement

PETRAIII



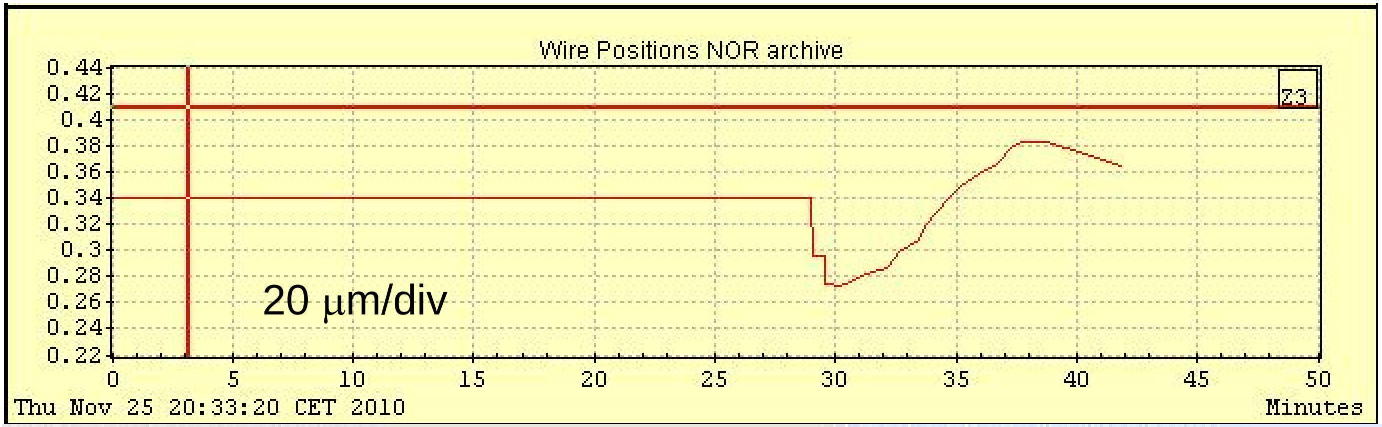
> Avoid QP touched by beam pipe
> Stable Girder
> Temp. control of tunnel better 1^0C



MECHANICAL ASPECTS OF THE DESIGN OF THIRD-GENERATION SYNCHROTRON-LIGHT SOURCES; S. Zelenika; Brunnen 2003, Synchrotron radiation and free-electron lasers* 337-362

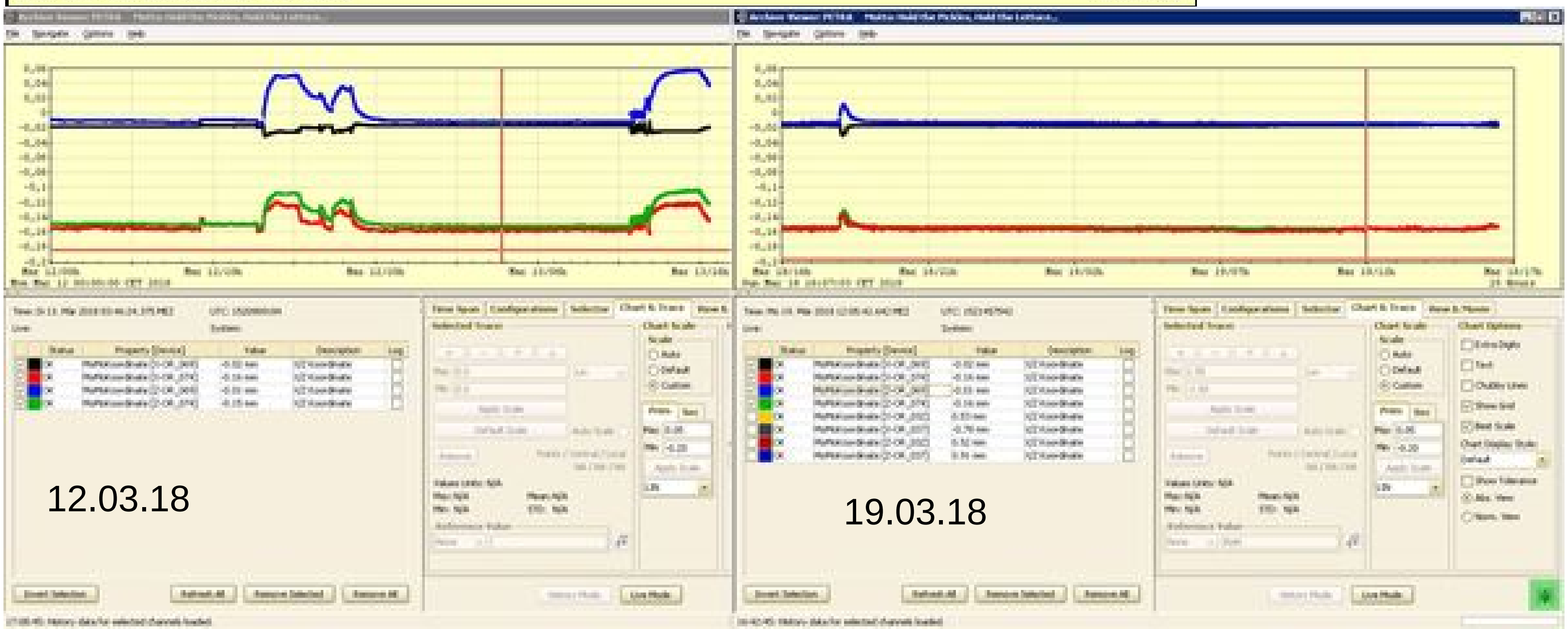
BPM stability 3) Meas. of beam pipe movement

PETRAIII



Top-Up helps

Blue green = z Koord.
Full scale 260 µm



C. Orbit Concept

1. What to do to find the „golden“ orbit?:

1. Find BPM reading in the middle of Quadrupoles (Beam Based Allignment)
2. Local orbit corrections to find best position at critial locations (aperture limits, Undulators, Wigglers)
3. Orbit is used to correct the Optic (Dispersion-funktion, Beta-Beat, center frequency, …)
4. Back to 2) Adjust best position at critial locations

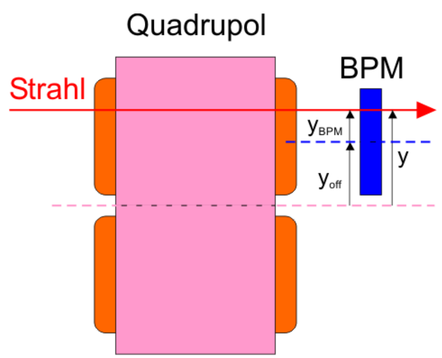
2. Stabilizing „golden“ Orbit

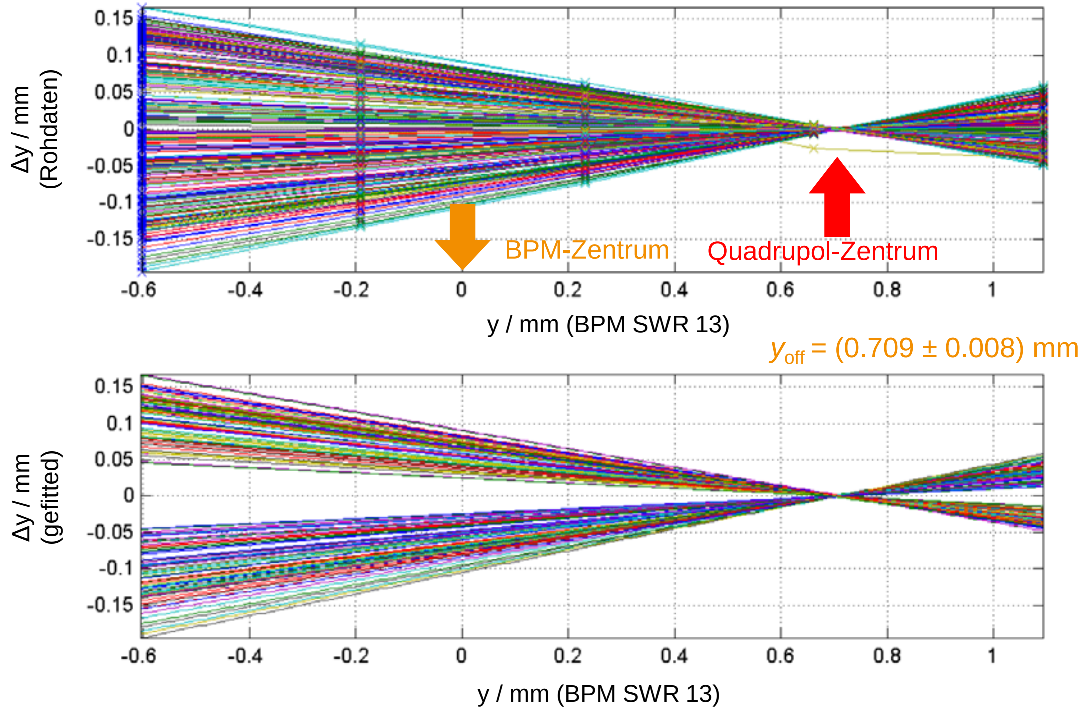
1. **Feed-Forward** at known changes (Injection, Gap-Movement of Undulators,…)
2. Active Orbit correction by Fast-**Orbit-Feedback** (incl. Main => BW > 50 Hz) and Slow Orbit correction to avoid long term drifts

Orbit correction: Beam-Based Alignment (BBA)

Goal

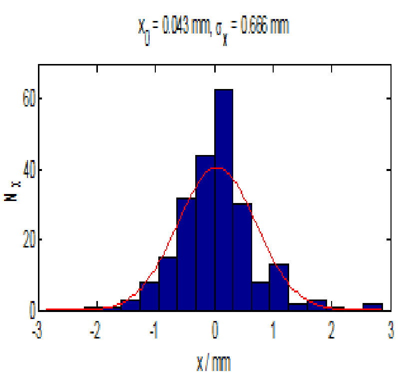
- Offset of BPM to QP center

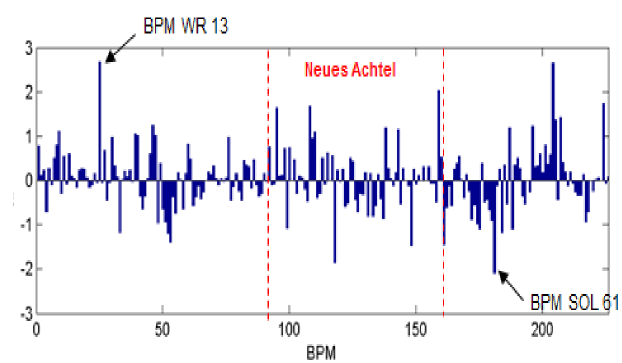




Procedure

- Move beam to many positions in BPM near QP
- Variation of QP current.
- Plot Difference-Orbit of some/all BPMs. If no dependence on QP current => beam is in the center of QP.
- Measure BPM offset for all BPMs



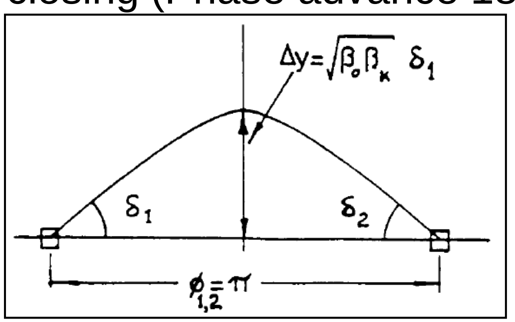


J. Keil : Beschleuniger-Betriebsseminar, 2010

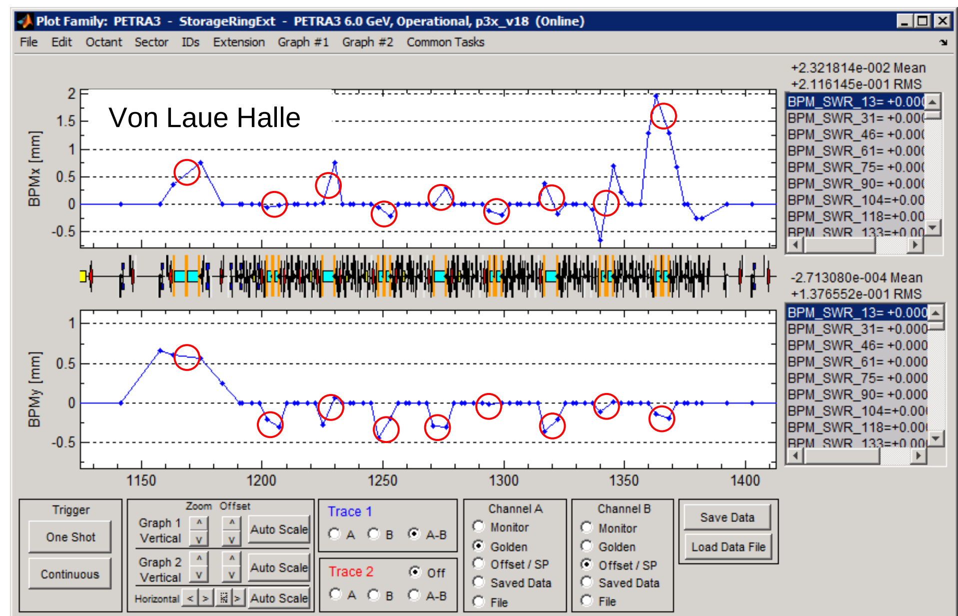
Orbit correction: Local correction

> **Local correction**

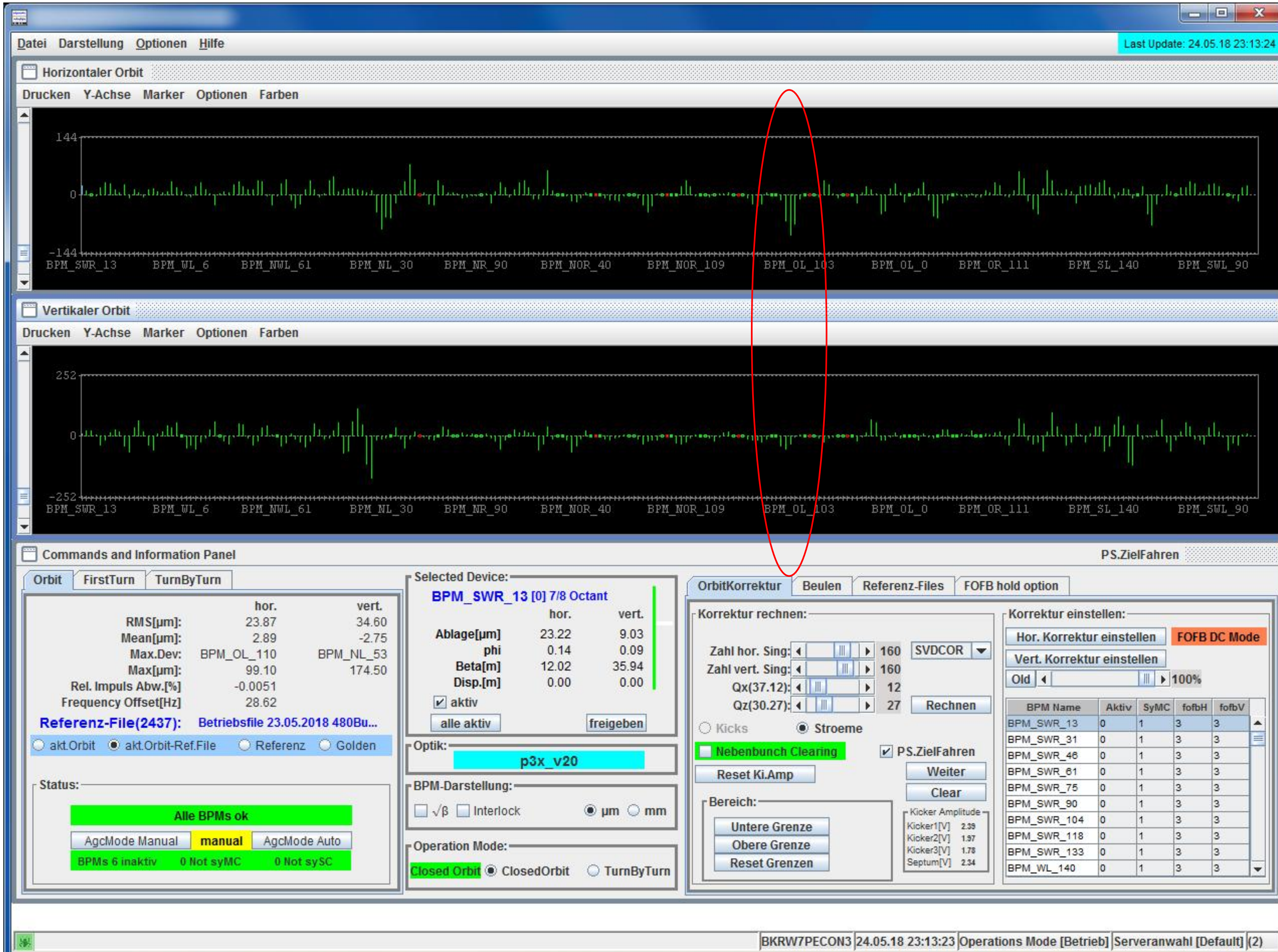
> Since the orbit stability is particularly important at some discrete locations like insertion devices or interaction points, the correction can be aimed at suppressing the orbit distortion only at these locations using a closed bump, leaving the rest of the machine uncorrected. Such a scheme requires min. 1 BPM for the orbit distortion and min. 2 correctors for the local cancellation of position, angle and the bump closing (Phase advance 180^0).



> Display of Difference-Orbit to “golden Orbit”



Orbit correction: Find optimal Position at critical Locations (Undulators, wigglers, …)



BPM Name	Aktiv	SyMC	fofbH	fofbV
BPM_SWR_13	0	1	3	3
BPM_SWR_31	0	1	3	3
BPM_SWR_46	0	1	3	3
BPM_SWR_61	0	1	3	3
BPM_SWR_75	0	1	3	3
BPM_SWR_90	0	1	3	3
BPM_SWR_104	0	1	3	3
BPM_SWR_118	0	1	3	3
BPM_SWR_133	0	1	3	3
BPM_WL_140	0	1	3	3

D. Orbit: Optic Functions: Beta-Function

Lattice Monitoring

The BPM TBT data can be used to extract the β-functions (during injections or machine studies) and the dispersion functions by using singular value decomposition (SVD): $B = U \times S \times V^{\dagger}$.[4] Different measurements are presented to be compared with one another so that the minor changes in the quadrupoles are visible to the operators. Fig. 1 shows that quadrupoles' change has impacted the β-function at y-direction.

The typical way: Stimulate beam oscillation with a short kicker pulse and measure beam position on successive turns after the excitation. The envelope of the measured positions follows the square root of beta

Quadrupole changes

$$\Delta Q = \frac{\beta}{4\pi} L \Delta K \quad \rightarrow \quad \beta = \frac{4\pi}{L}\frac{\Delta Q}{\Delta K}$$

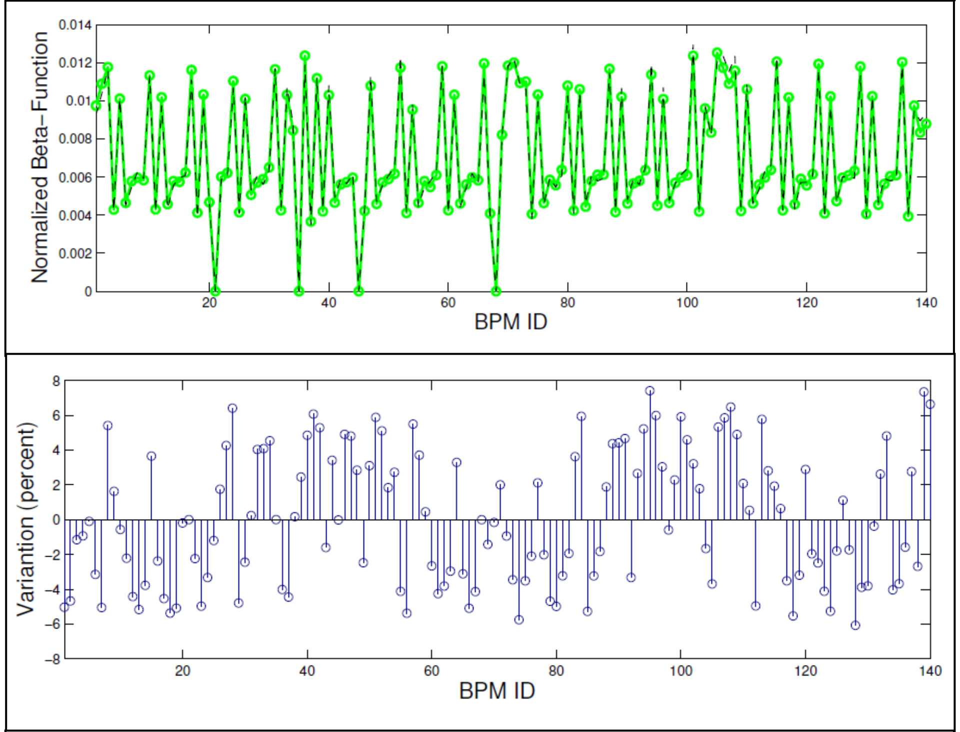


Figure 1: β-function varies with the quadrupoles' values. Top: β-function extracted from the TBT data at two different tunes. Bottom: percentage change of the β-function from one status to another.

Correlation Analysis of Beam Diagnostic Measurements in SSRF, Zhichu Chen et al, IPAC12, New Orleans

Orbit: Optic Functions: Beta Function by Orbit-Response Matrix

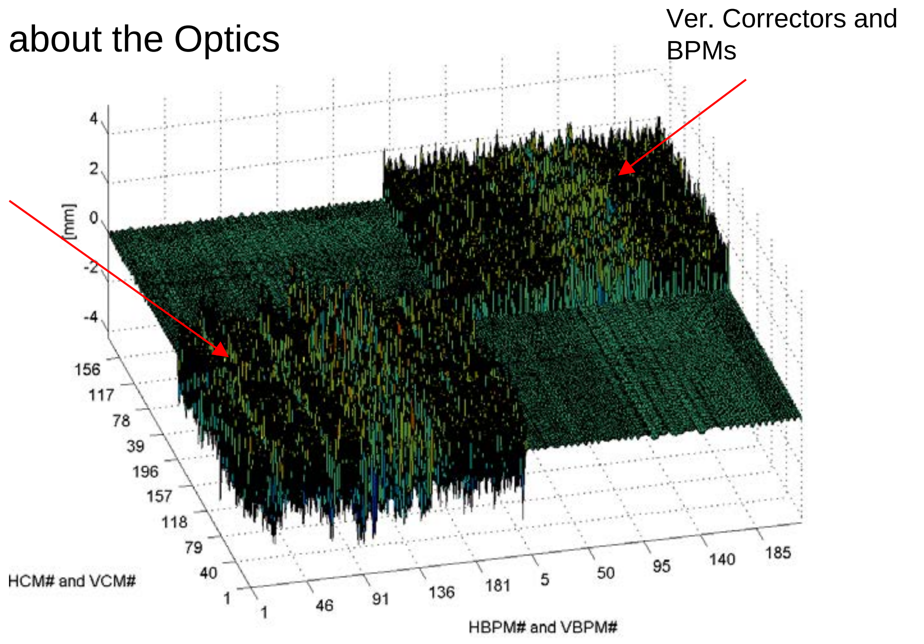
Definition (ORM)

$$C_{ij} = \frac{\Delta x_i}{\Delta \theta_j^x}$$ für *x*-plane (*y*-plane analog)

- Δx_i : Change of beam position at BPM *i* ($\Delta x \approx 1$ mm)
- $\Delta \theta^x_i$: Change of kick-angle if corrector *j* ($\Delta\theta \approx 50$ µm)
- The Elements of the Matrix contains Information about the Optics

Size of Matrix

- 226 BPMs
- 196/187 Correectors
- (226+226)·(196+187)
  = 173116 Elements!
- With no coppling, Matrix:
  ≈ 44000 Elemente



After some Algebra: Compare Meas. with Model

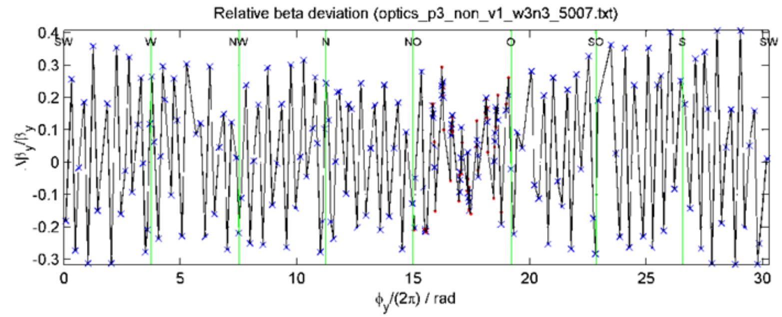
$$\chi^2 = \sum_{i,j} \frac{\left(C_{ij}^{\text{Modell}}(p_1, p_2, \ldots, p_N) - C_{ij}^{\text{Messung}}\right)^2}{\sigma_i^2}$$

„Standard“ at SR-Quellen (**LOCO**: **L**inear **O**ptics from **C**losed **O**rbits)

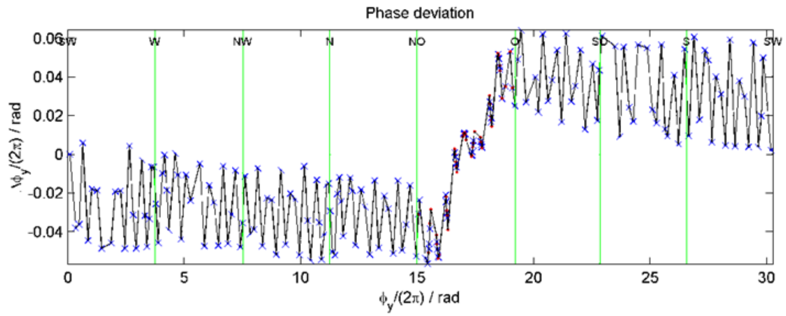
Optic: Optic Functions: Beta Beat, Phase

LOCO: Quadrupole gradients finding, beta beat reduction and dispersion correction, coupling correction and etc.;

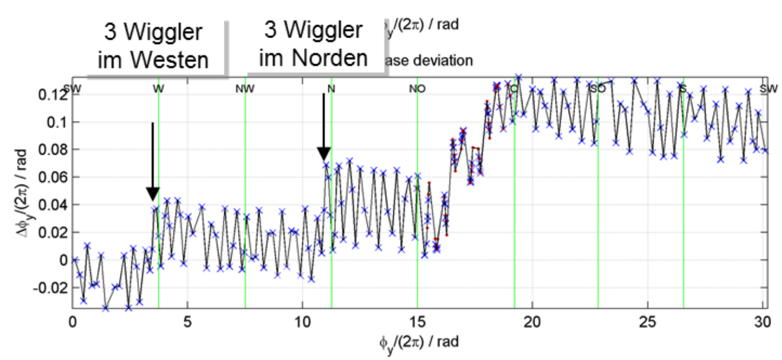
> Beta Beating = compare measurement with theory (very first measurement at PETRA III, now it is <1%.



> Phase Mismatch in Undulator section



> Optic model without damping wigglers: => Wiggler Optic model quite good



Orbit: Optic Functions: Dispersion Dx, Dy

Dispersion measurement

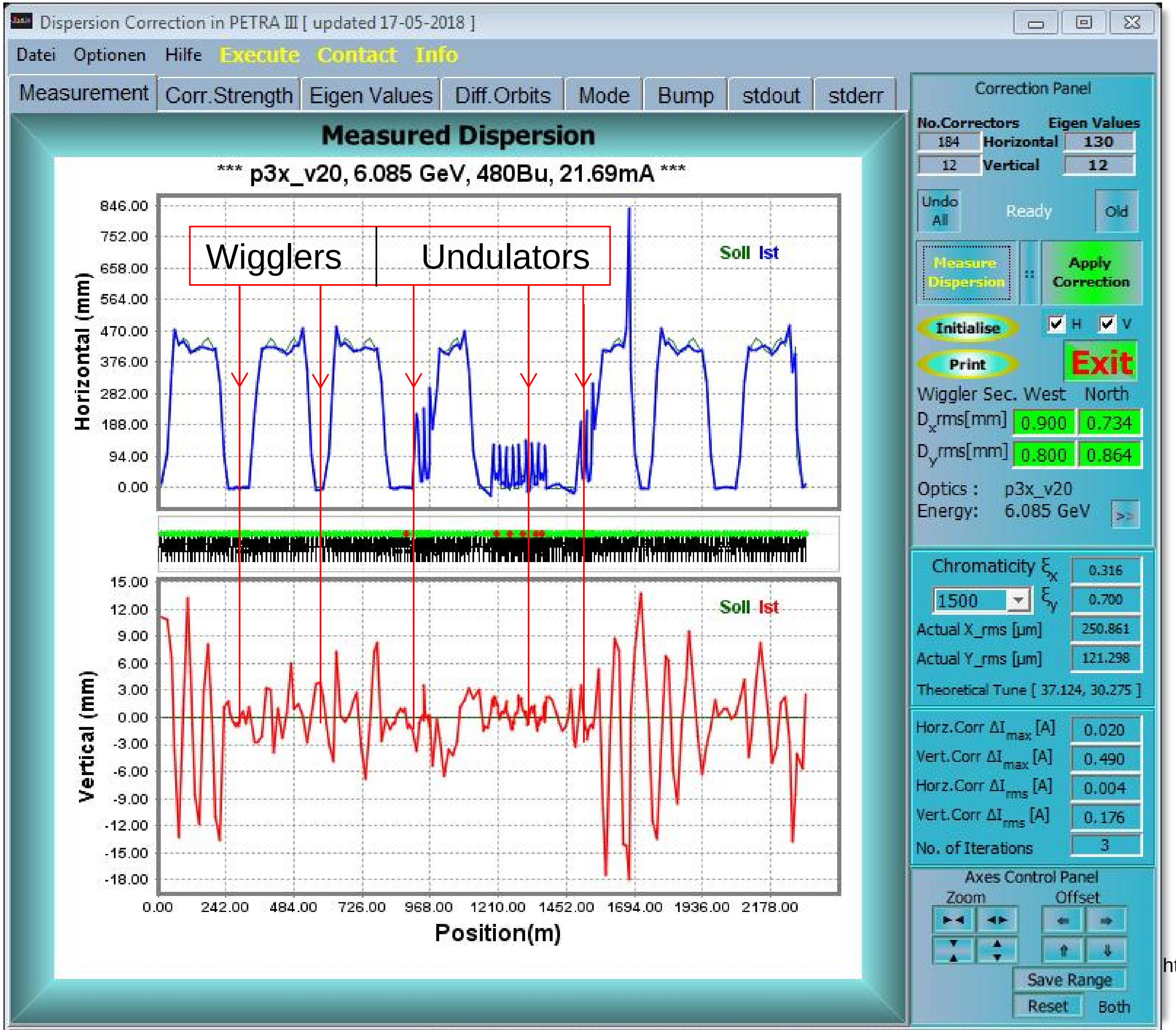
Measure orbit difference for energy change, get dispersion from $\Delta x = D_x \Delta p / p_0$. Main interest D_x but there might be residual D_y.

A beam momentum change is made by varying RF-frequency with constant magnets

$$\frac{\Delta\omega_{RF}}{\omega_{RF}} = \frac{\Delta\omega_0}{\omega_0} = -\eta_c \frac{\Delta p}{p_0}, \quad \Delta x = D_x \frac{\Delta p}{p_0}$$

A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

Orbit: Optic Functions: Dispersion Dx, Dy



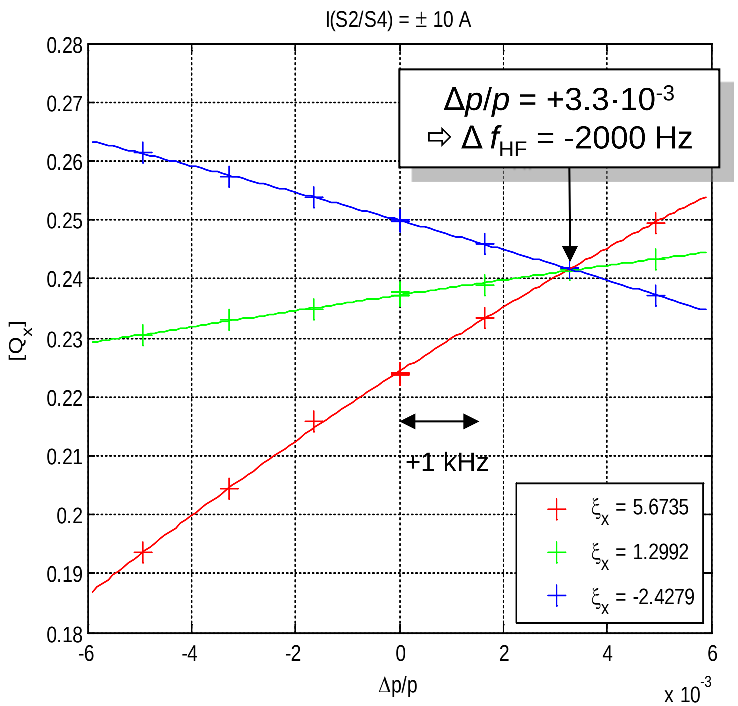
After correction

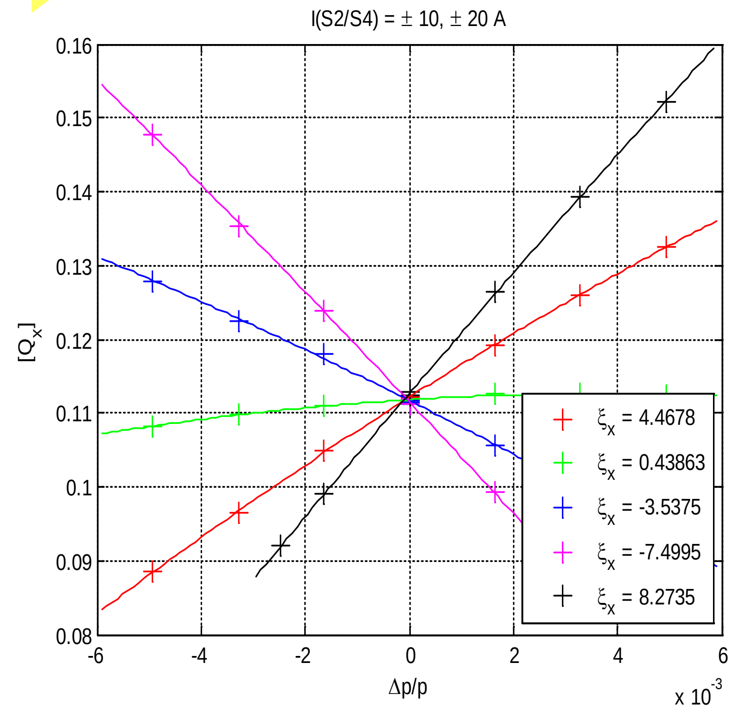
Orbit: Optic Functions: Center Frequency (Energy)

f_{HF}= 499666500 Hz

Δf = –2000 Hz

f_{HF}= 499664500 Hz





- Measurement of the Tune – Momentum dependence for different Chromaticities
- At the crossing, the orbit goes through the mean center of all Sextupoles and, with good approximation to center of Quadrupols.
- By moving the RF Frequency one adjusts the orbit to the circumference (C=2303.952 m at PETRA III) (= adjust to right energy)

J. Keil, DESY Beschleuniger-Betriebsseminar, Grömitz, 22. März 2010

Orbit Concept

1. After a few iterations the „golden“ orbit is fixed:

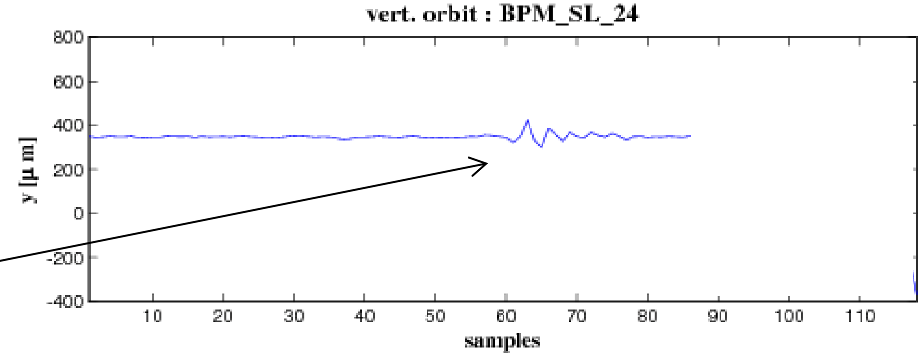
1. Find BPM reading in the middle of Quadrupoles (Beam Based Allignment)
2. Local orbit corrections to find best position at critial locations (aperture limits, Undulators, Wigglers)
3. Orbit is used to correct the Optic (hor. Dispersion-funktion, Beta-Beat, center frequency, …)
4. Back to 2) Adjust best position at critial locations
5. **Now =>**

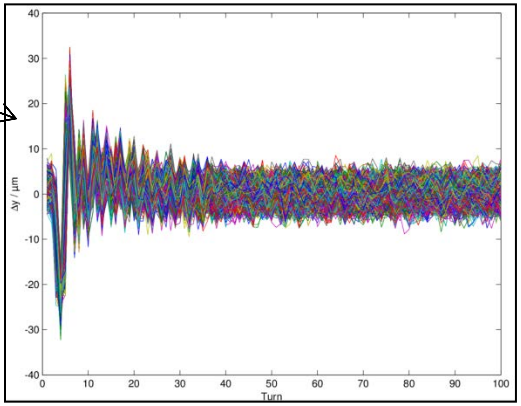
2. Stabilizing the „golden“ Orbit

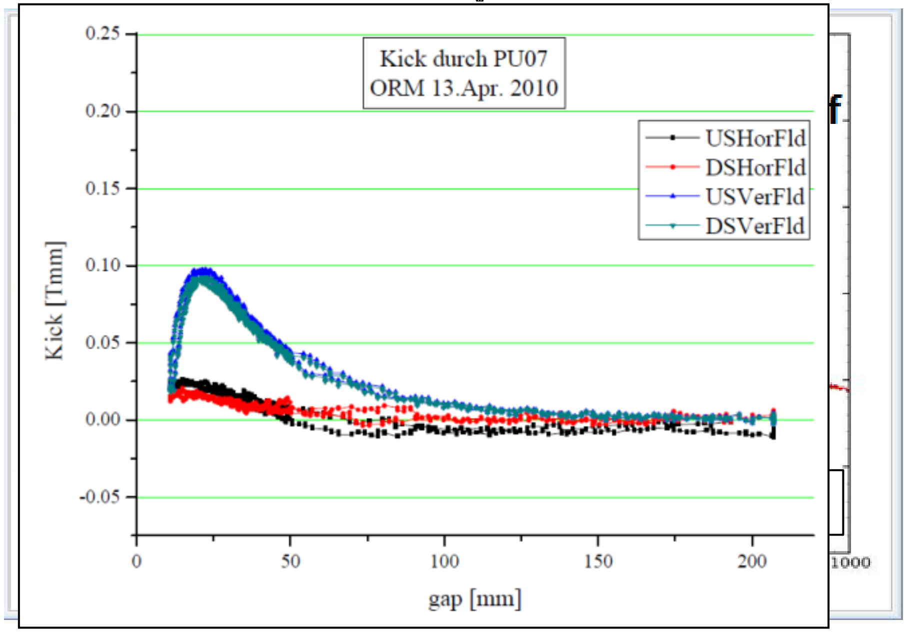
1. Feed-Forward at known changes (Injection, Gap-Movement of Undulators,…)
2. Active Orbit correction by Fast-Orbit-Feedback (incl. Main => BW > 50 Hz) and Slow Orbit correction to avoid long term drifts

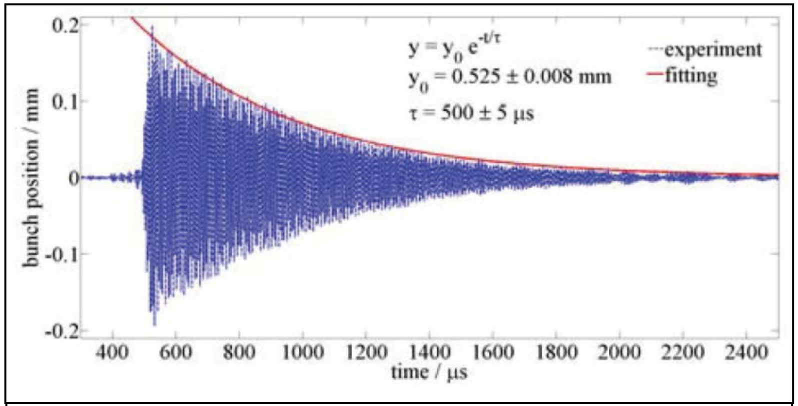
E. Stabilizing Orbit: Injection

- Nonlinearities within the injection orbit bump:
- Minimize Residual Jitter due to top up.
- Injection oscillations and damping of one bunch.
- Influence of Strayfield of Septums,
  Correction by Feed- Forward orbit bump







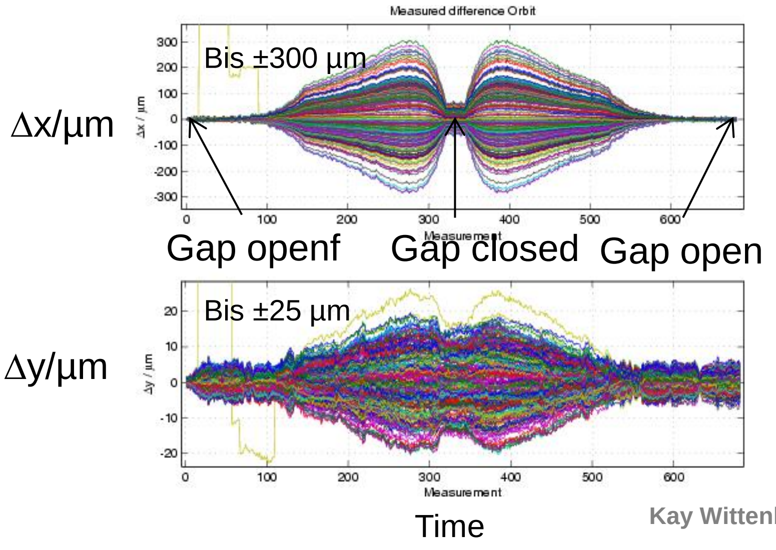


Bunch by Bunch Beam Diagnostics in SSRF
Yongbin Leng, et al.; IPAC12, New Orleans

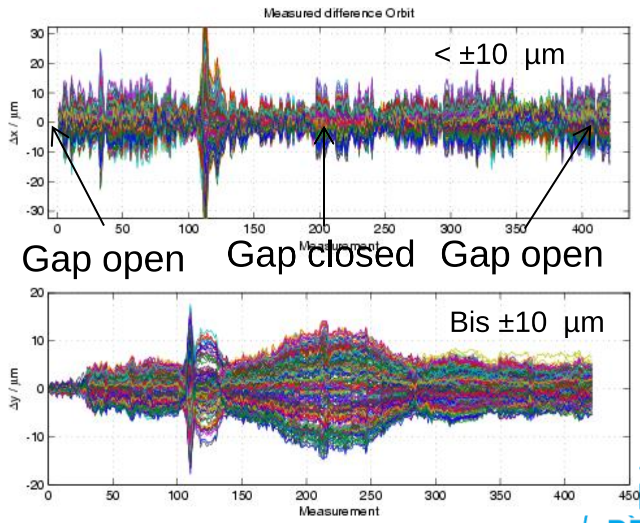
Orbit Stability: Feed-Forward for known Orbit-Distortions

- **Orbit-distrortion by moving Undulator Gaps**
- Orbit-Correktion by **lokale Feed-Forward** with **4 fast Correctors** (in front and behind Undulator)
- Correction Table calculated by ORM
- APPLE-Undulator PU04 needs 2D-table

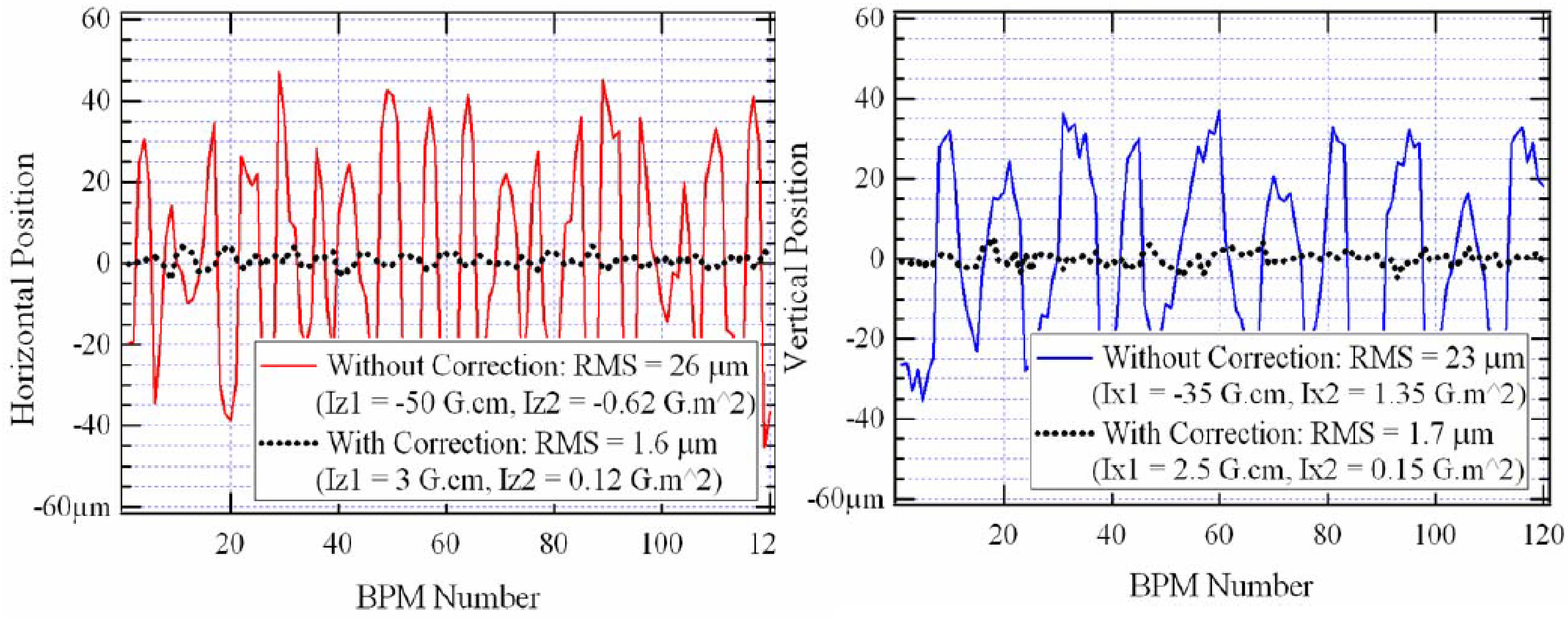
w/o Feed-Forward



with Feed-Forward

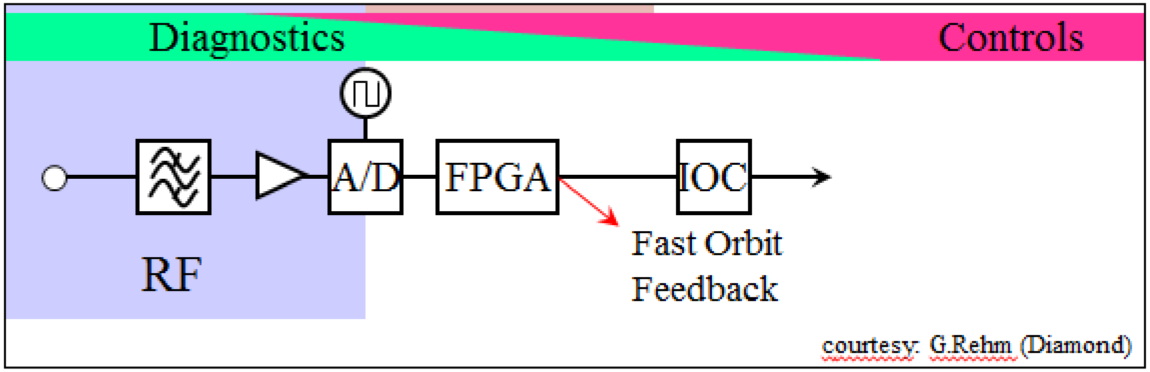


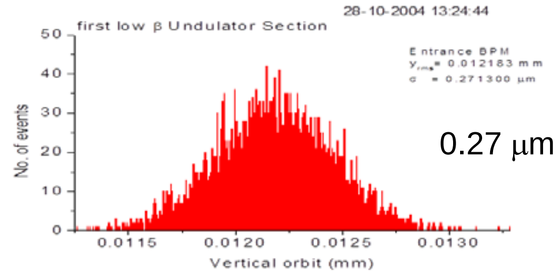
SOLEIL ID Feed-forward correction



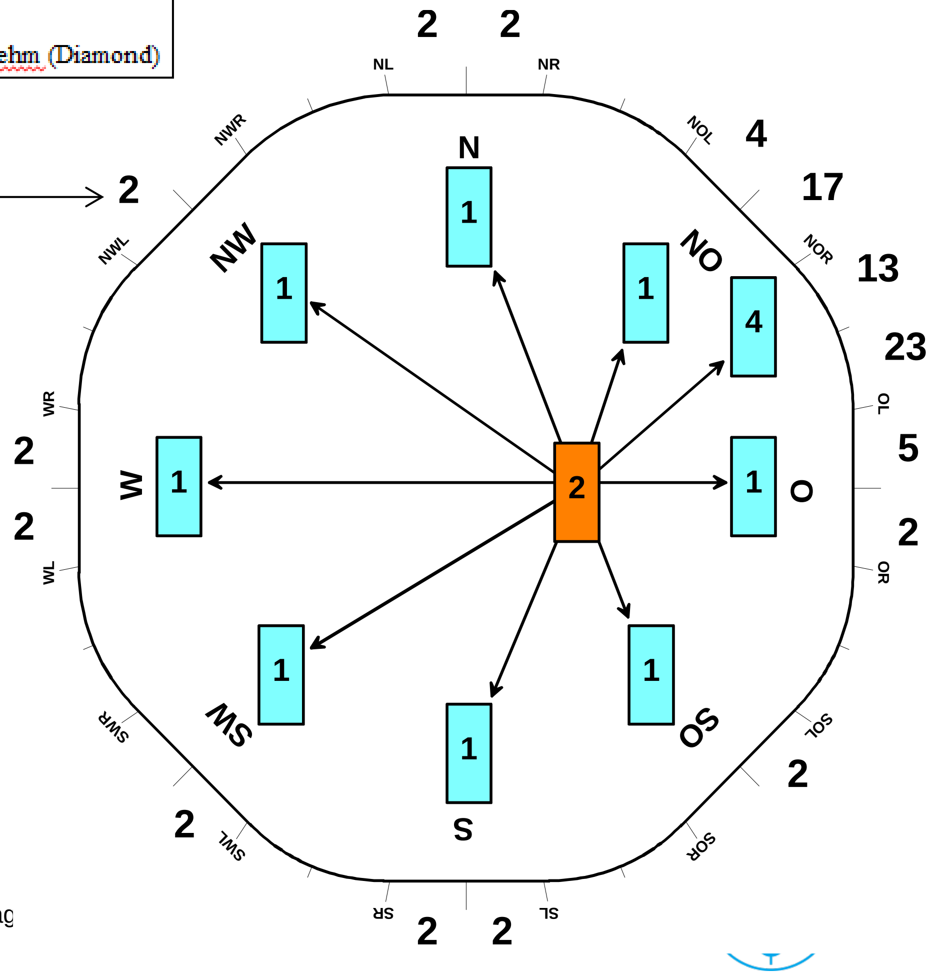
Courtesy A. Nadji

Stabilizing Orbit: Fast Orbit Feedback (BW >50 Hz)



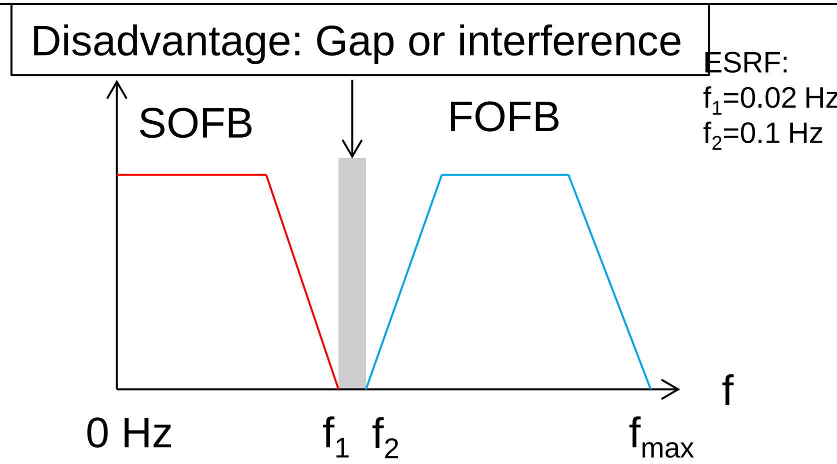


- Rate of orbit measurements: ≥4 kHz (226 BPMs)
- Data flow on cables (fiber optics)
- Digital controller (SVD & PID)
- 82 fat air coils and power amps
- Correctors: air coils
- BW ≤ 200 Hz
- Slow orbit correction (hours and days) by control system?

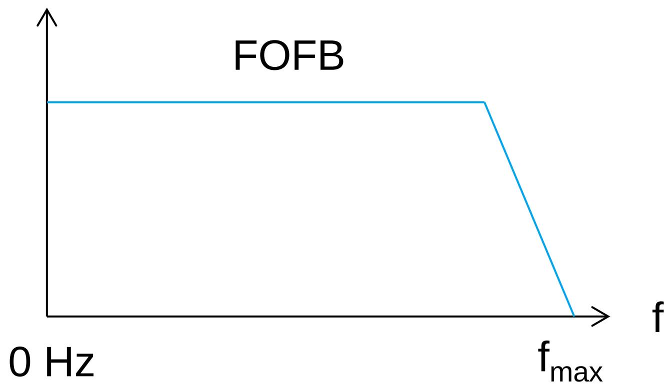


Stabilizing Orbit: One or Two Feedbacks?

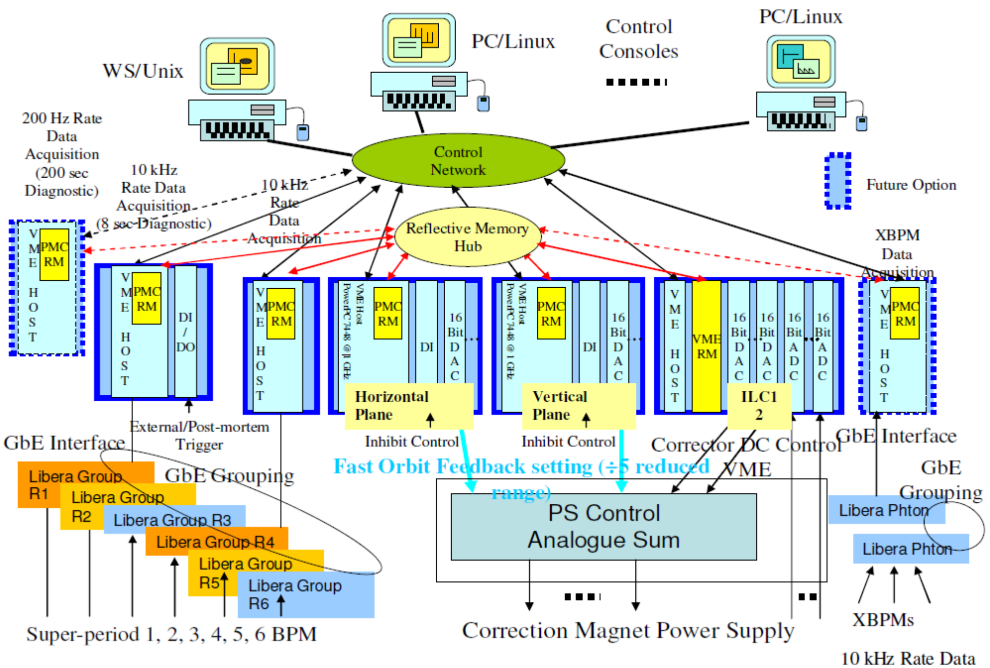
- 2 independent Feedbacks in different Frequency ranges
- **Slow-Orbit-Feedback**:0 Hz ... f_1
- **Fast-Orbit-Feedback:** f_2 … f_{max} ($f_2 > f_1$)



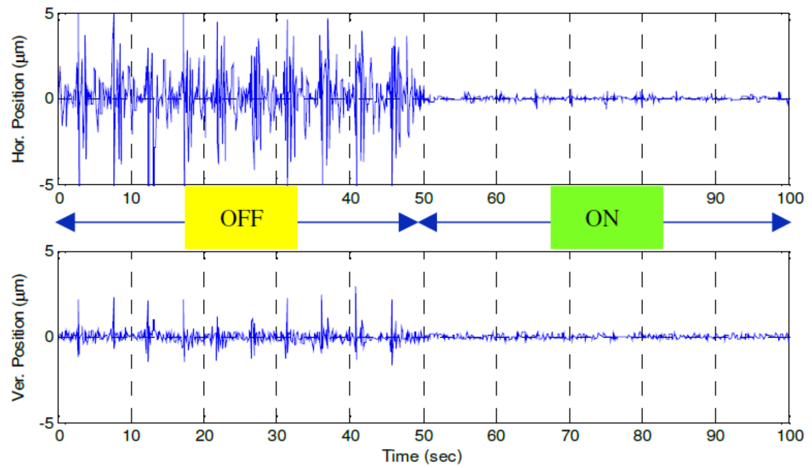
- 1 **(Fast)-Orbit-Feedback**
- Fast-Orbit-Feedback 0 Hz … f_{max}
- F_{max} ca. 200 Hz at PETRA III
- DC correction moves periodically from fast air coils to slow corrector magnets.

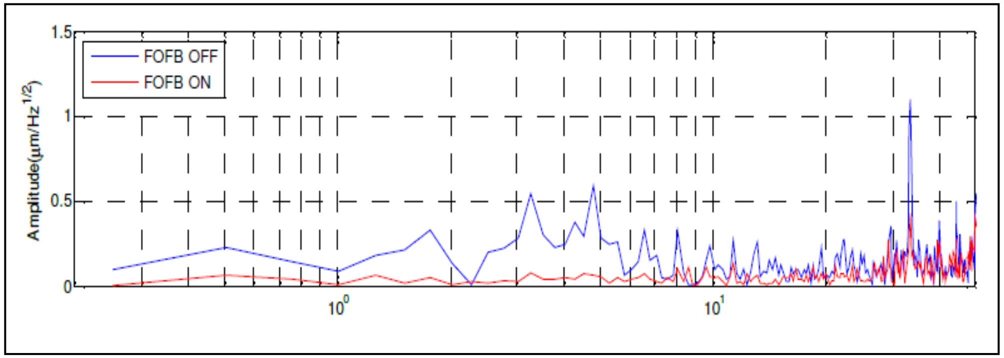


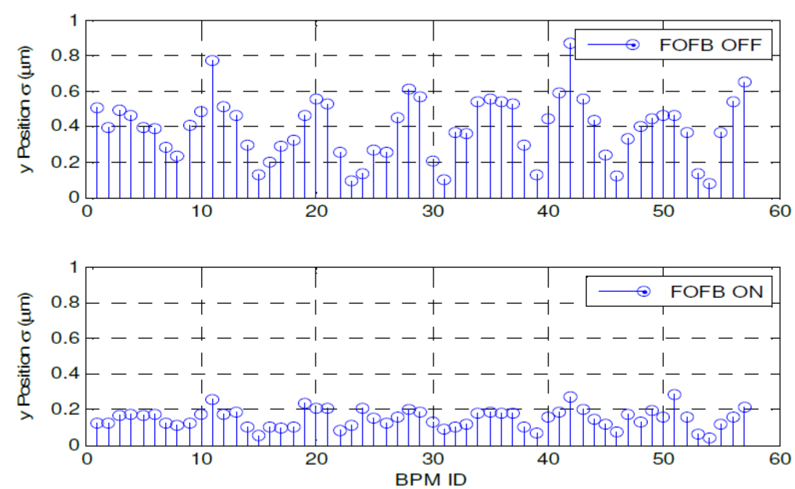
Stabilizing Orbit: Fast Orbit Feedback at TLS



Latency 620 μs -> DC to >50 Hz

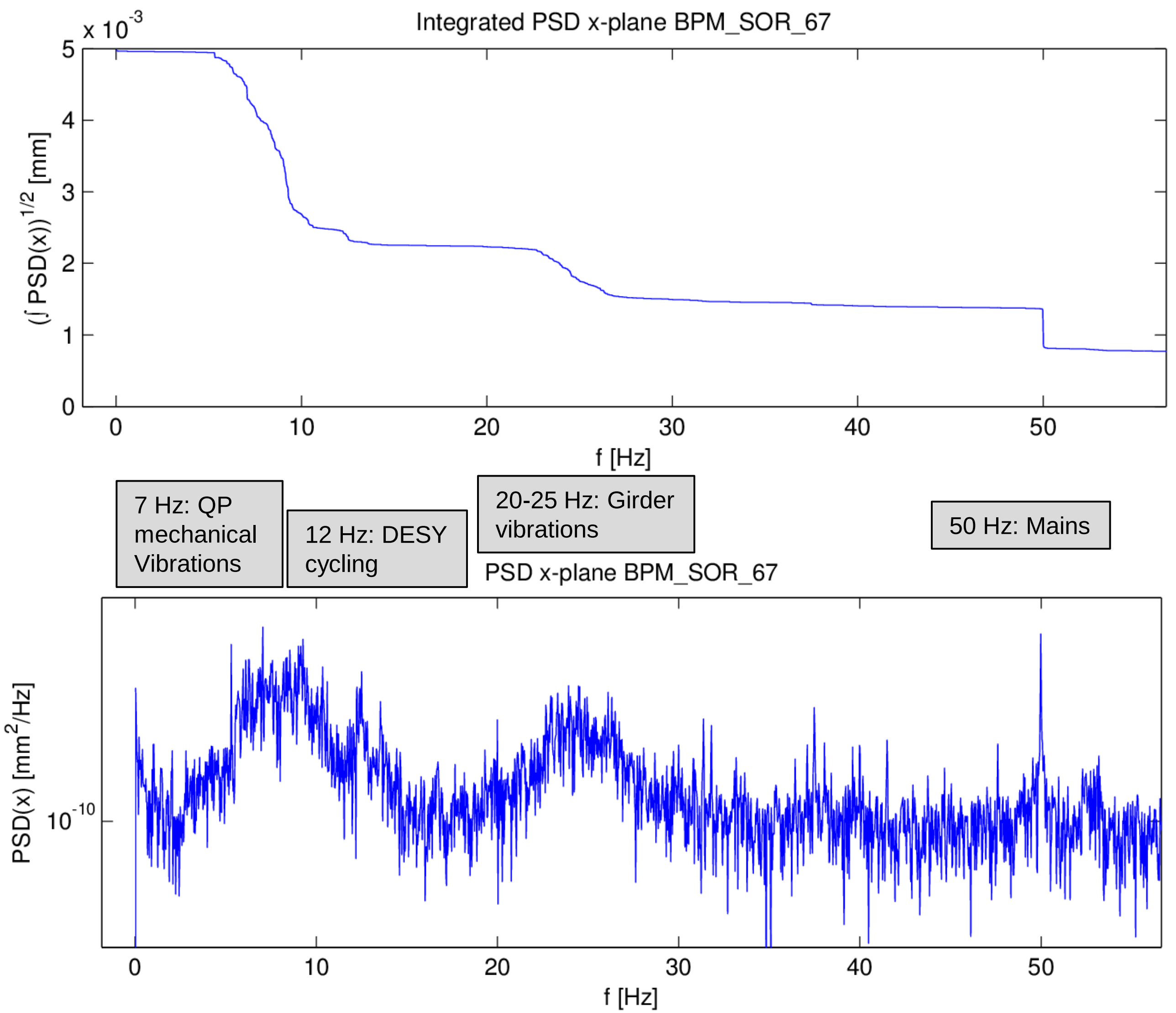




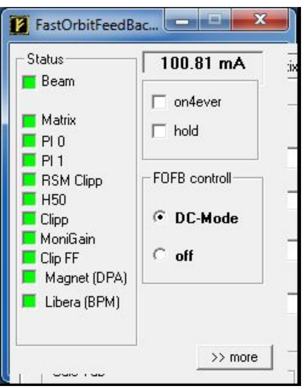


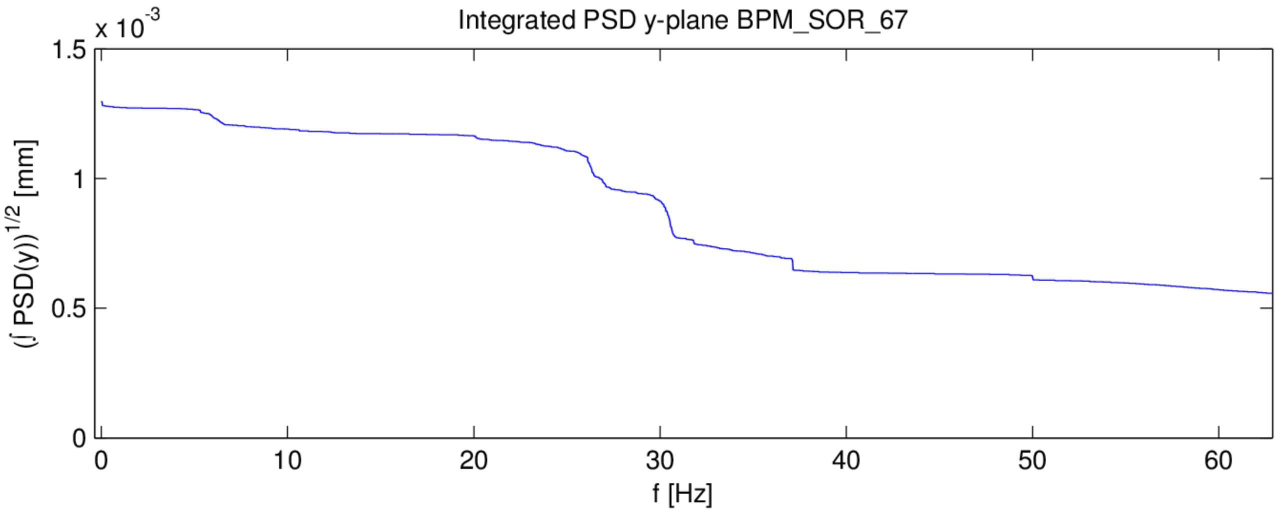
DIAGNOSTICS UPDATE OF THE TAIWAN LIGHT SOURCE; C. H. Kuo,et al.; BIW10, Santa Fe

Stabilizing Orbit: Fast Orbit FB off



Stabilizing Orbit: Fast Orbit FB on



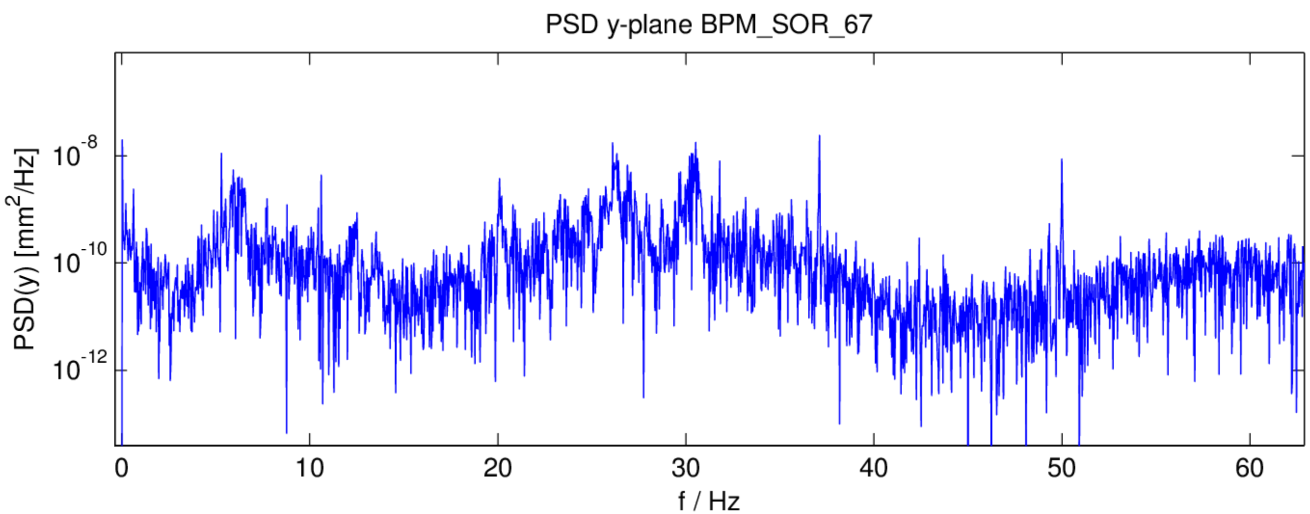


7 Hz: QP mechanical Vibrations

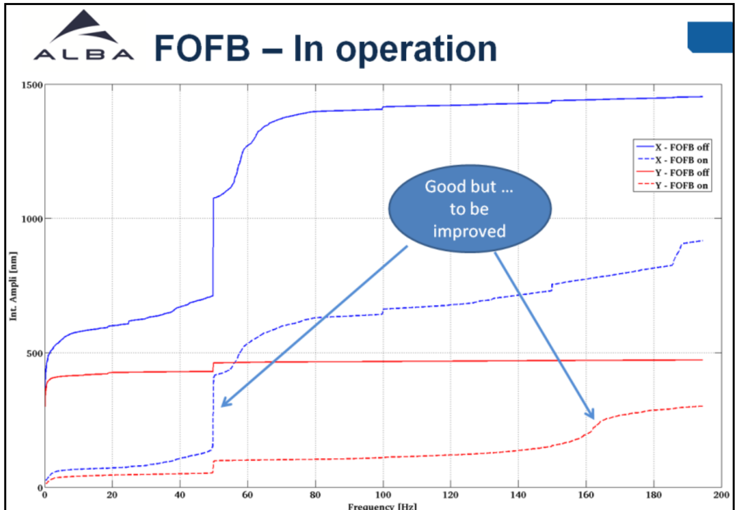
12 Hz: DESY cycling

20-25 Hz: Girder vibrations

50 Hz: Mains

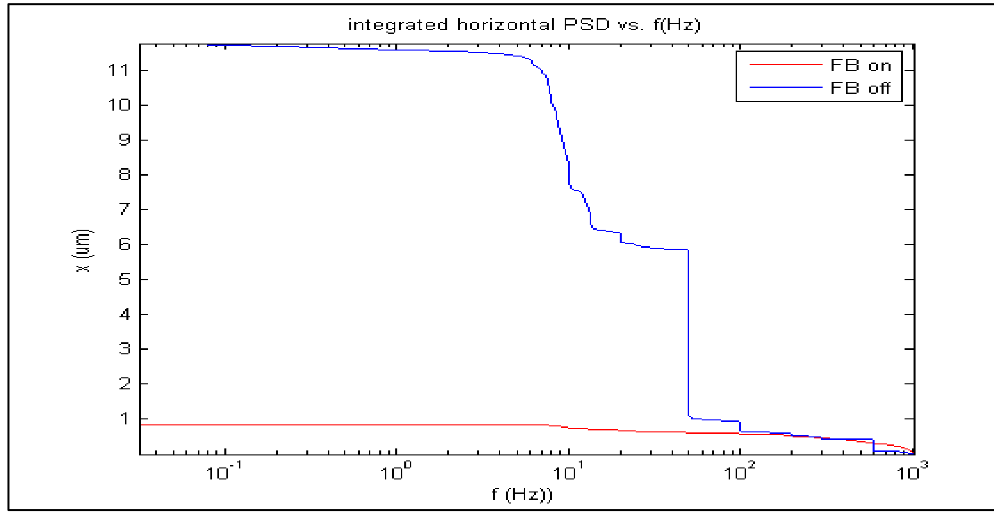


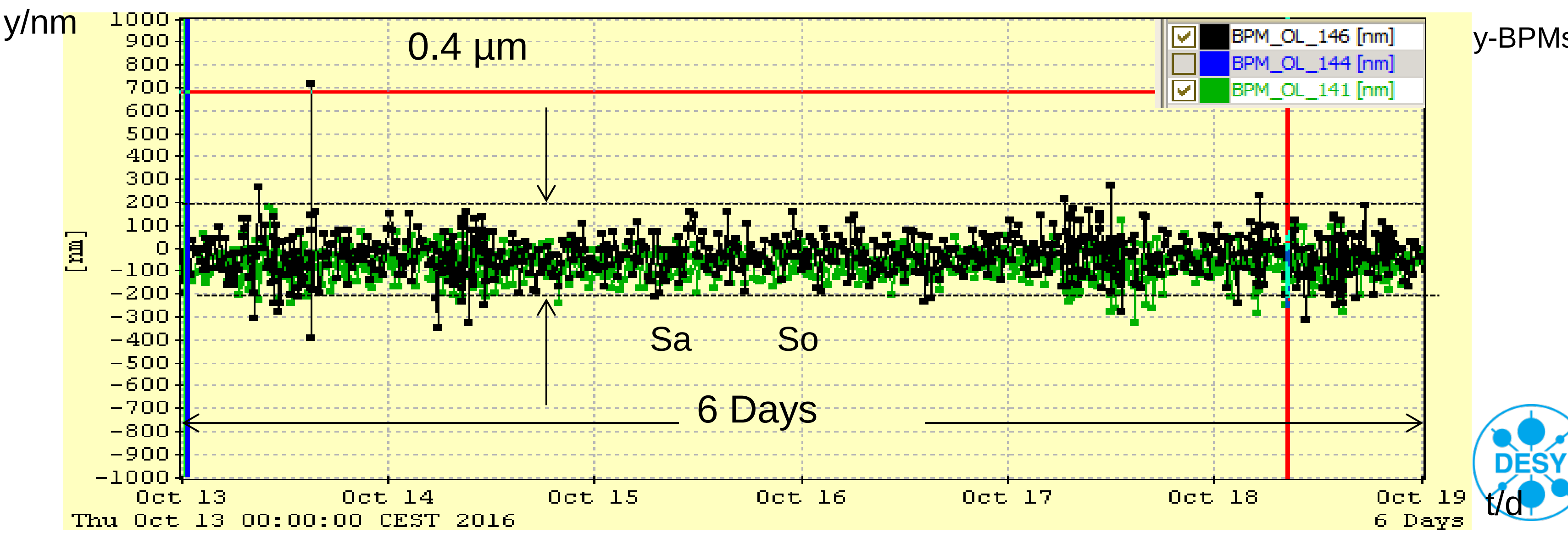
Stabilizing Orbit: Fast Orbit FB (BW >50 Hz)



A. Olmos, DEELS2015

PetraIII



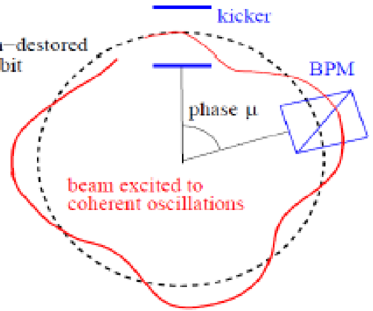


F. Beam Optic Parameters (BPM based measurements)

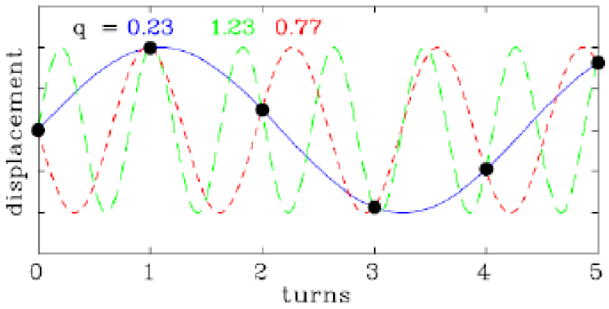
> Tune
> Synchrotron Oscillations
> Coupling
> Chromaticity
> Instabilities and bunch-by-bunch feedback

Tune

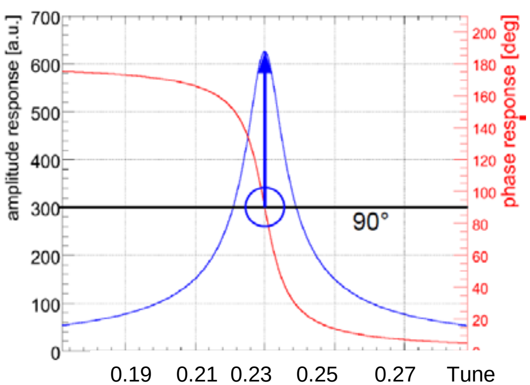
$$Q := \frac{1}{2\pi} \oint_C \mu(s) \mathrm{d}s \,,$$



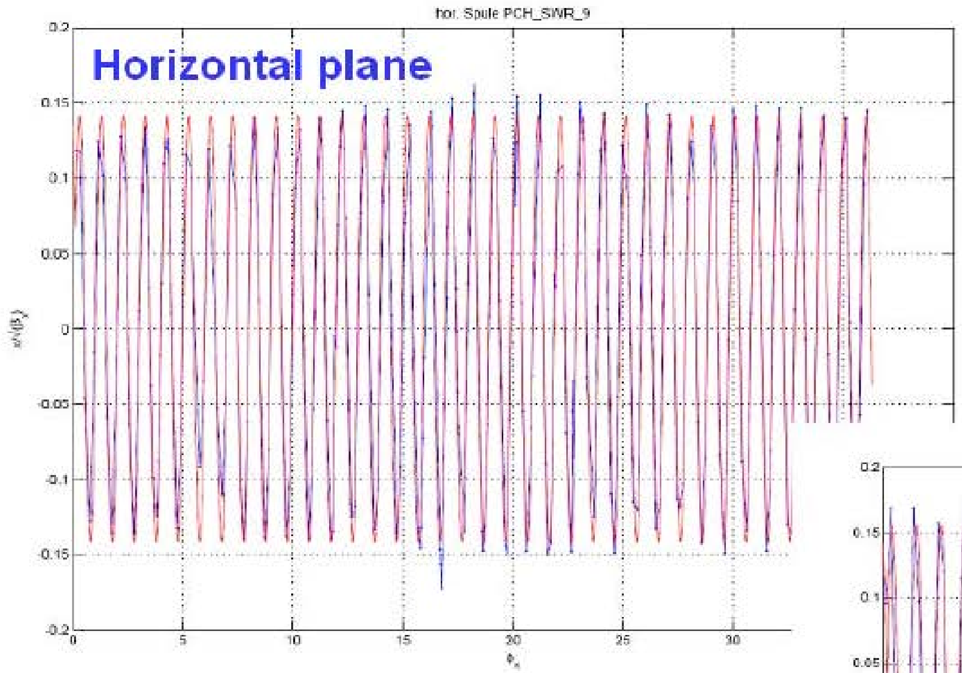
A single BPM records the position of an oscillating beam at every revolution



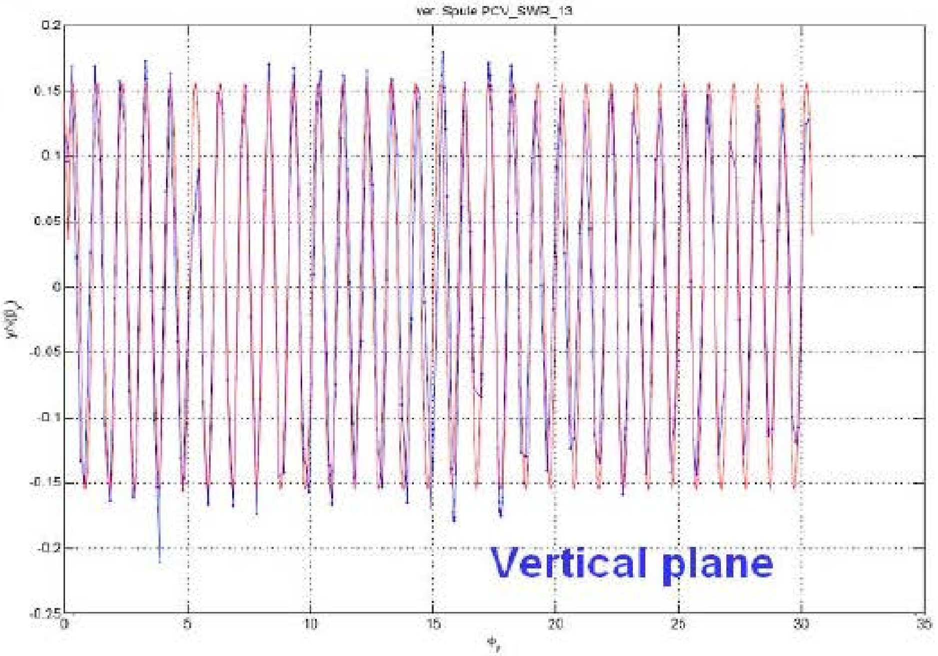
Beam position on six subsequent turns and the three lowest-frequency fits



Tune: Determination of integer part



$$Q = Q_{\text{int}} + q_{\text{frac}}$$



Fitted response agrees very well
In the horizontal plane with theory
Whereas there are phase errors in
The vertical plane close to the new
octant

COMMISSIONING RESULTS OF BEAM DIAGNOSTICS FOR THE PETRA III LIGHT SOURCE
K. Balewski et al.; DIPAC09, Basel, Switzerland

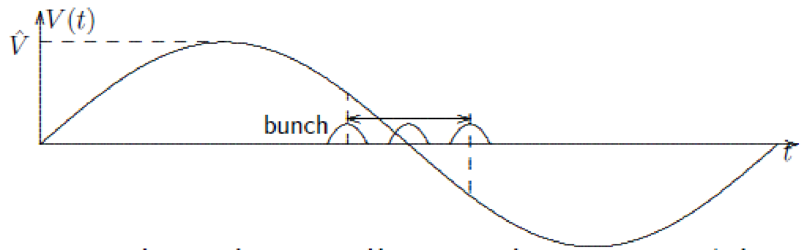
Synchrotron Oscillation (side band of tunes)

Synchrotron oscillation frequencies

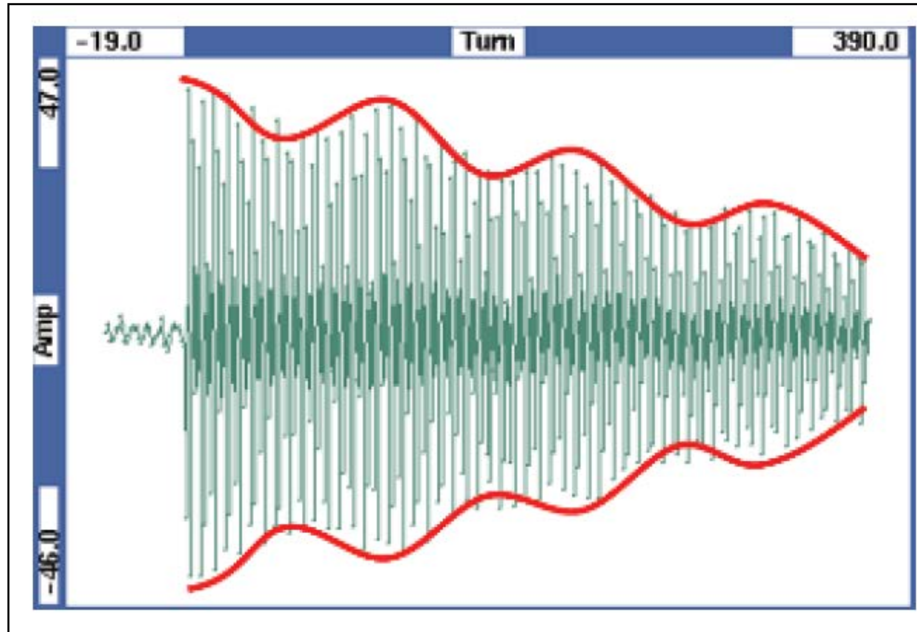
Single particle incoherent oscillation with frequency ω_s, not seen by intensity monitor.

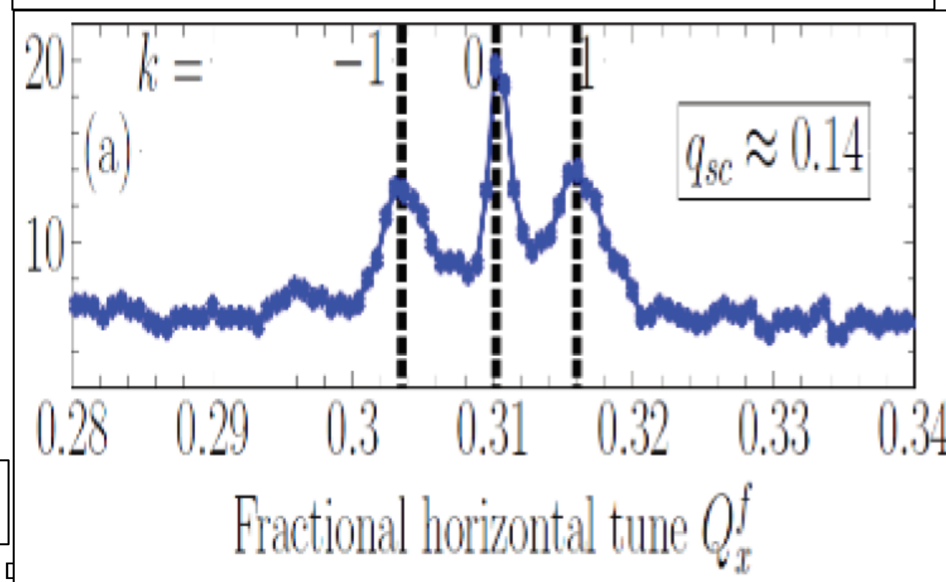
$$\omega_s = \omega_0 \sqrt{\frac{-e\eta_c h V_{RF} \cos\phi_s}{2\pi\beta^2 E_0}} \quad , \quad \eta_c = \alpha_c - \frac{1}{\gamma^2}.$$

Monitor sees coherent motion, like the center-of-mass dipole mode with frequency ω_{s1}



or quadrupole oscillation between, 'short time, large energy spread',vice versa, with ω_{s2}. They represent a phase/amplitude modulation with sidebands around $p\omega_0$.

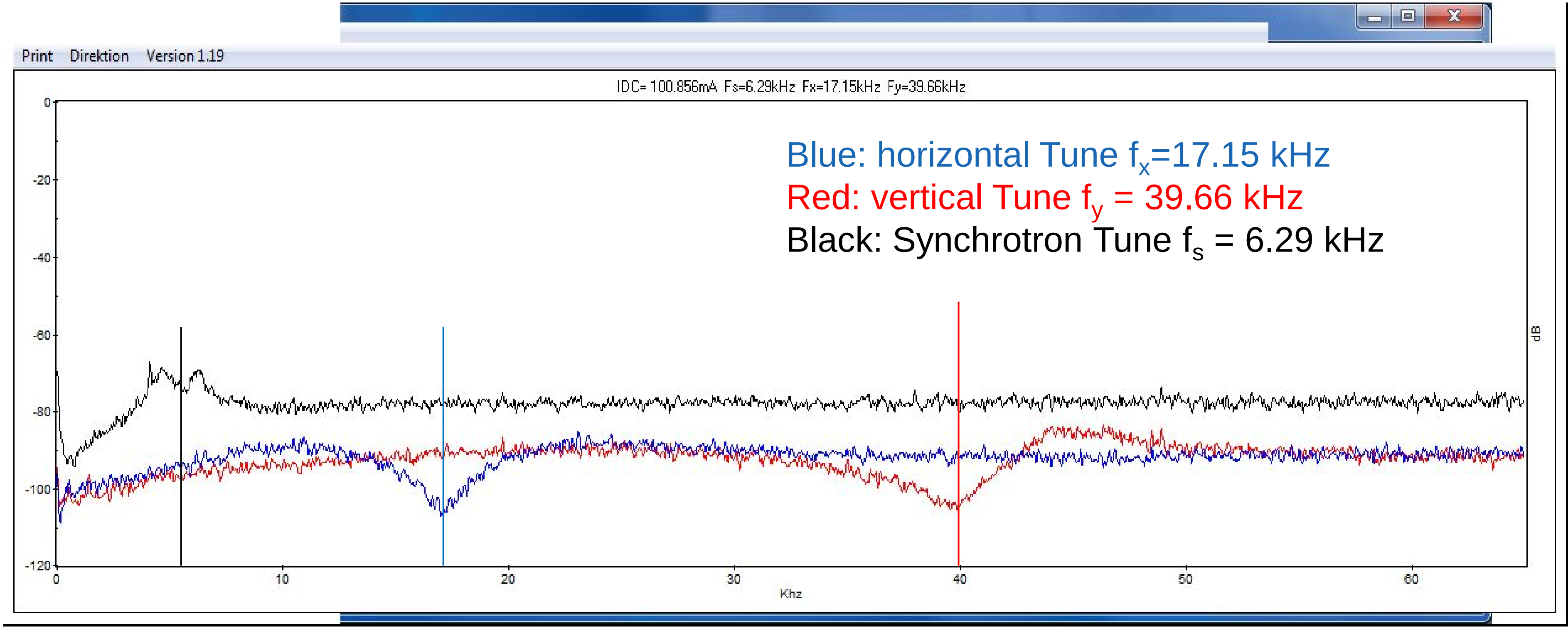




Beam Diagnostics Challenges for Beam Dynamics Studies, O.R. Jones [IBIC2016, Barcelona, Spain

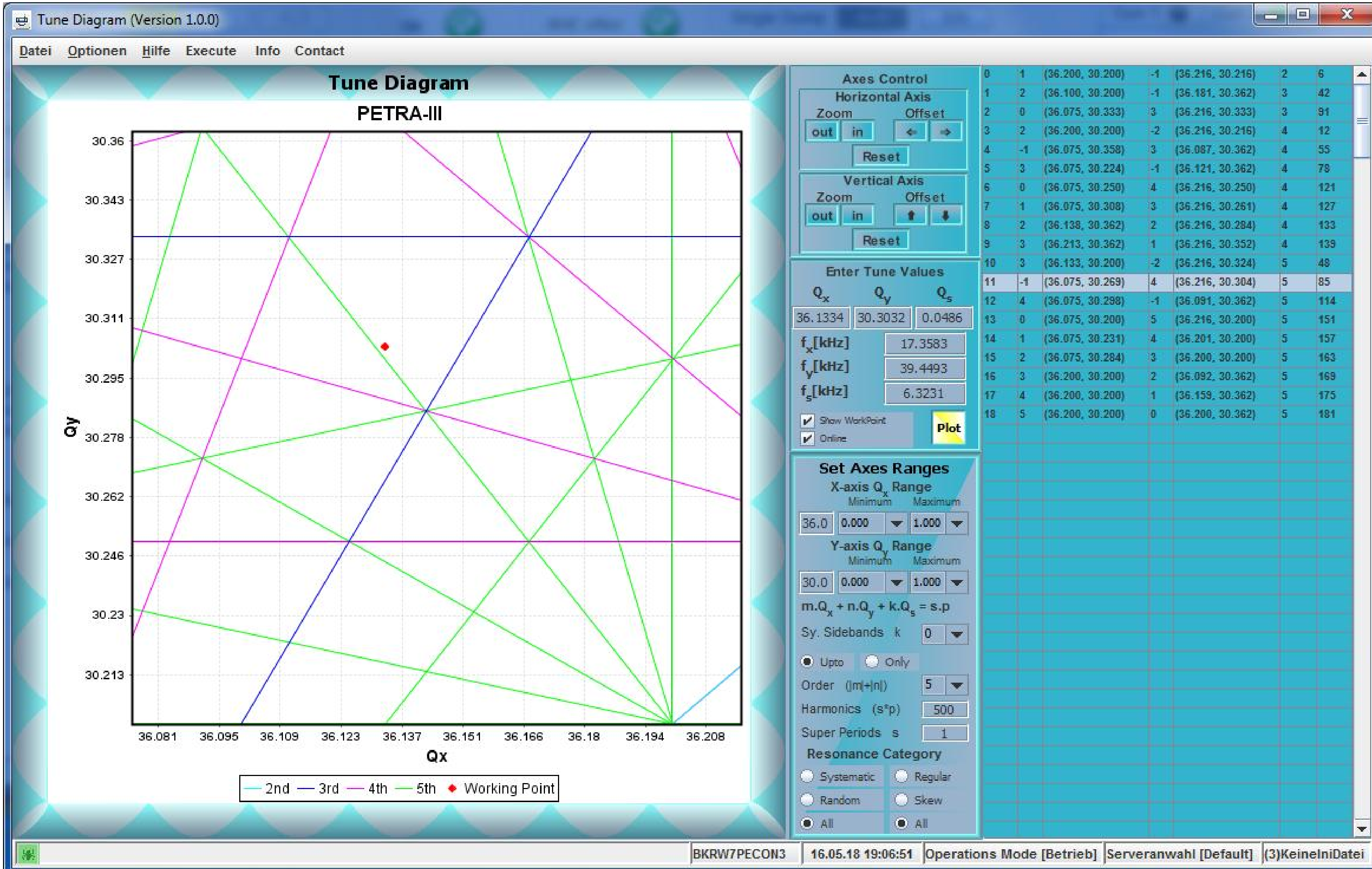
A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

Tune: Tune Signals



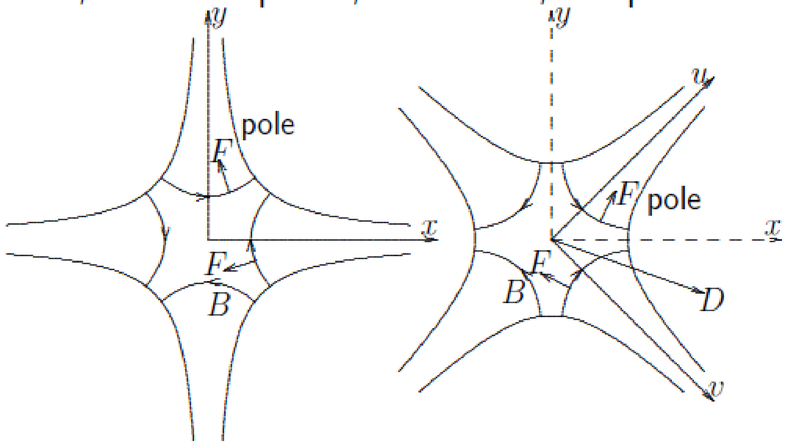
An adjustable broadband noise will be added to the RF front-end output (and therefore to the kickers). In the frequency response this will be seen as constant offset. At the tune resonance frequency a notch will appear due to the 180^0 phase shift of the feedback. These notches can be analyzed, **even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

Tune Diagram



Coupling measurement

Horizontal and vertical betatron oscillations are usually treated as independent. Some elements, rotated quads, solenoids, couple them



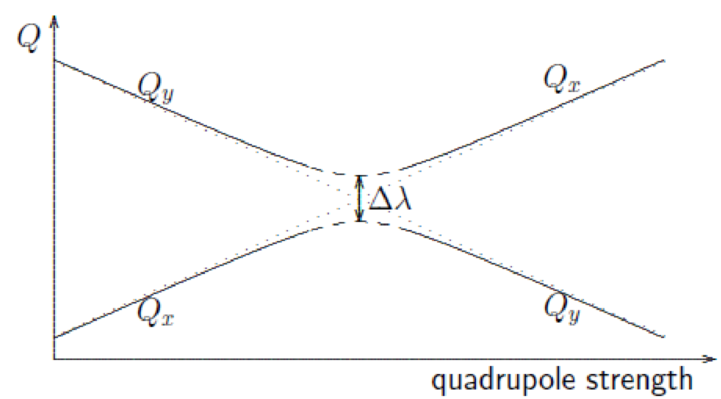
normal quadrupole rotated quadrupole

$$\ddot{x} + Q_x^2\omega_0^2 x = ky,\ \ \ddot{y} + Q_y^2\omega_0^2 y = kx$$

Closest tune approach:

Increasing F-quad approaches tunes to minimum value $\Delta\lambda$ and separate them again

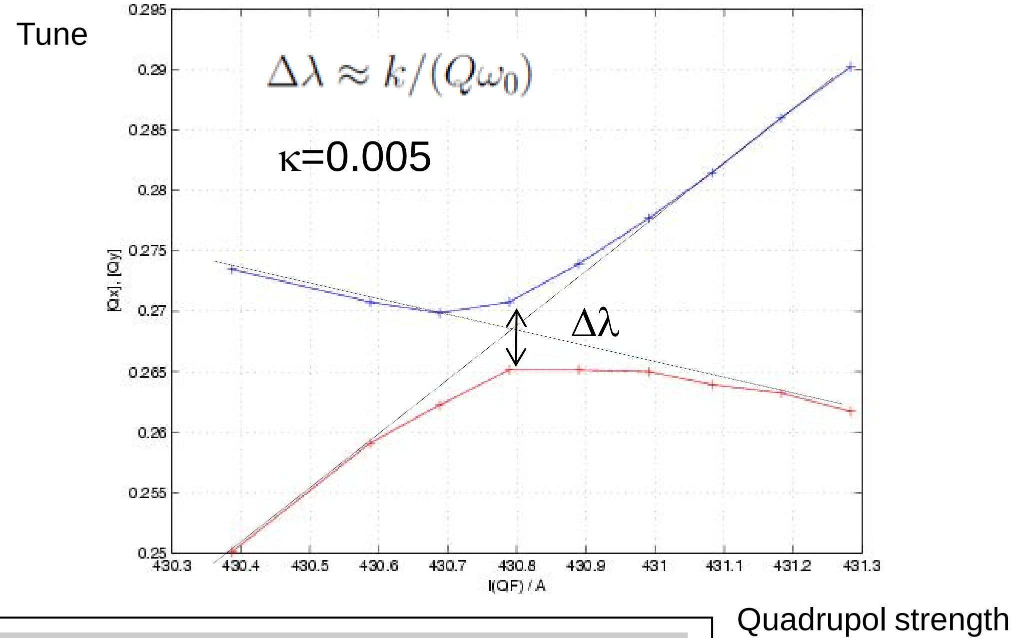
$$\Delta\lambda \approx k/(Q\omega_0)$$



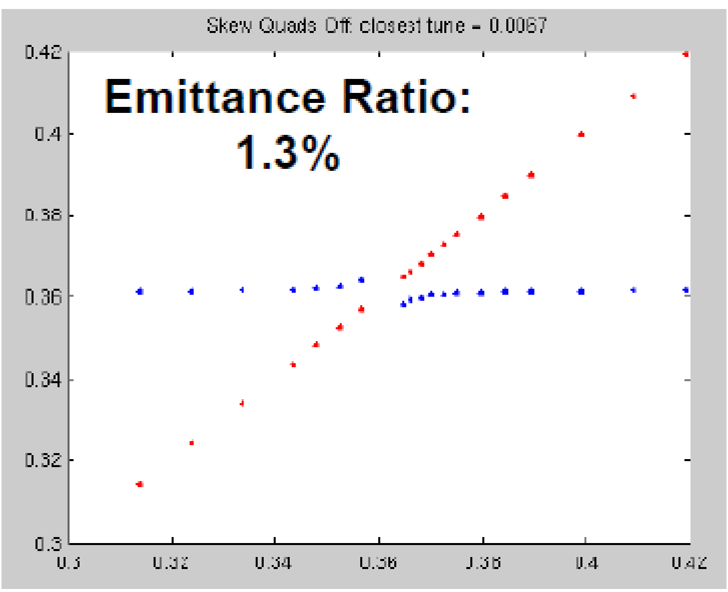
A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

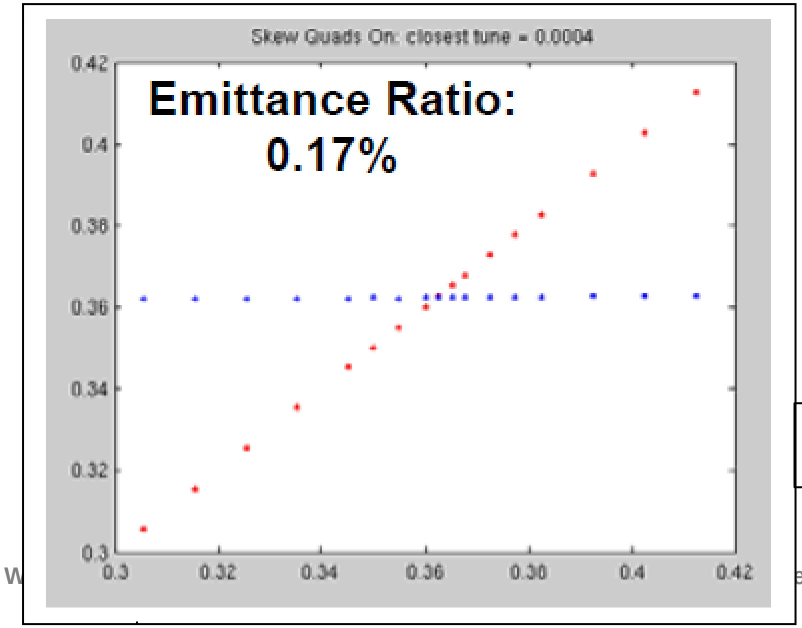
Coupling Measurements: Closest Tune Approach

- Very first measurement in PETRA III (2009)
  - Today almost no distance (0.1% coupling)



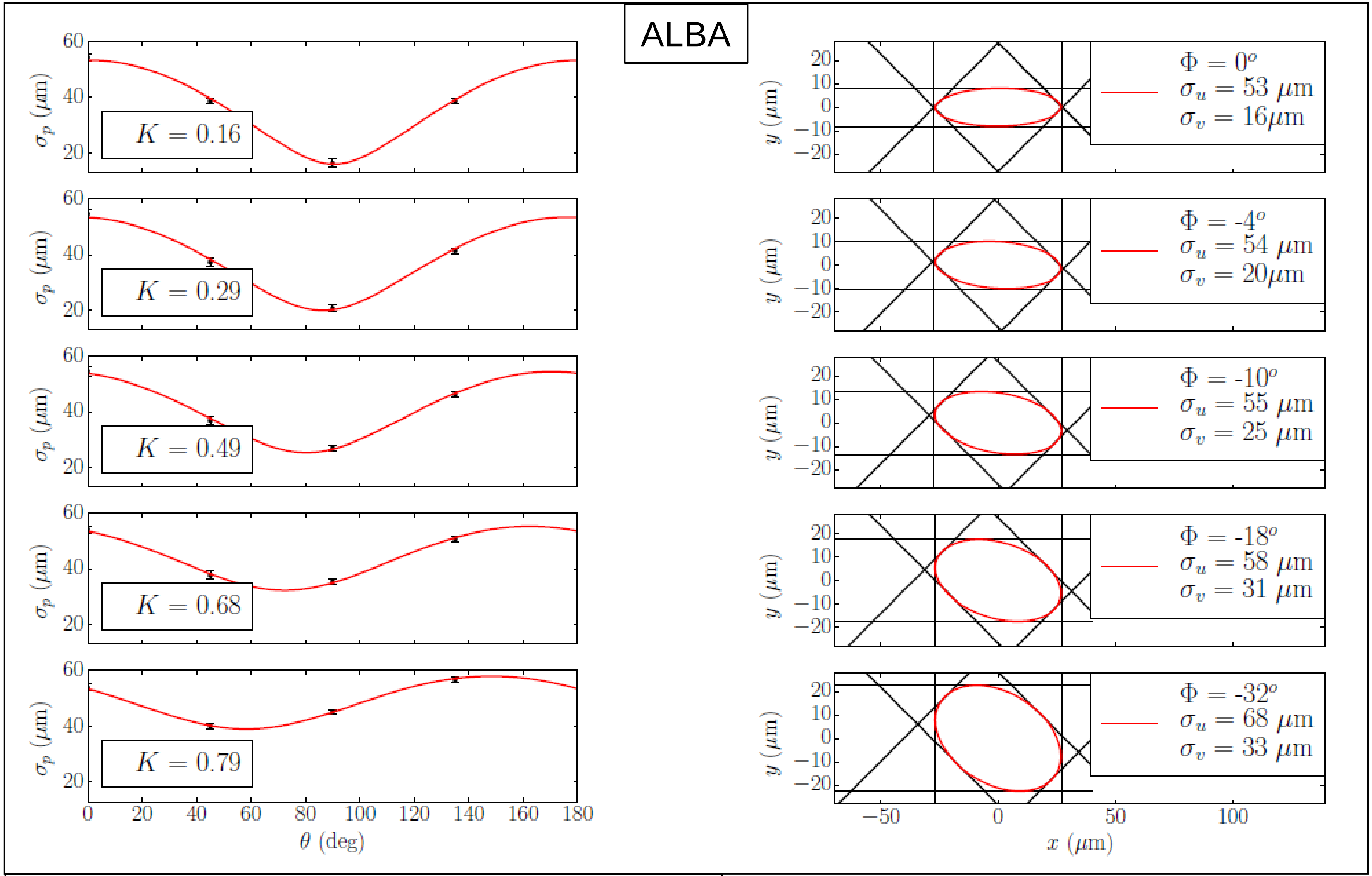
- Diamond:





R.P Walker, APAC07

Coupling Measurements: Beam size orientation

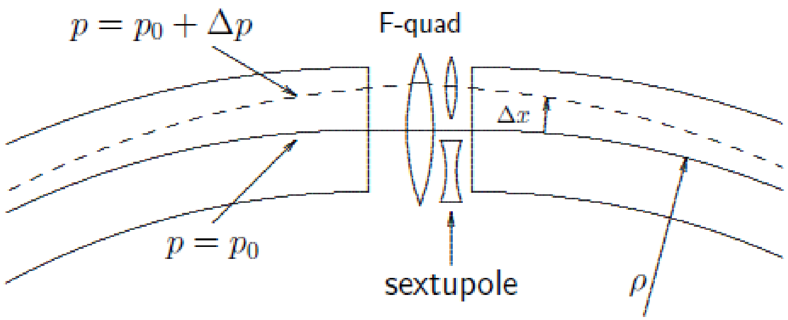


LONGITUDINAL AND TRANSVERSE BEAM DIAGNOSTICS US ING SYNCHROTRON RADIATION AT ALBA, Laura Torino, Thesis

Measure chromaticity

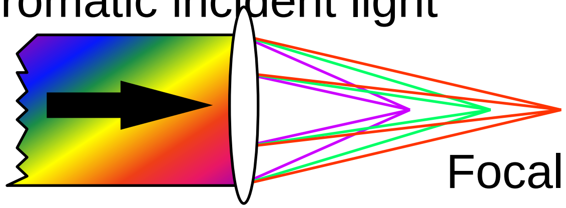
Chromaticity and change of momentum

$$Q' = \frac{dQ}{dp/p}, \quad \frac{dp}{p} = -\frac{1}{\eta_c}\frac{d\omega_{RF}}{\omega_{RF}}$$



To get the chromaticity we measure the tunes as a function of f_{RF}. This is done with the sextupoles on for the corrected and with them turned off for the natural chromaticity. The latter is also obtained by varying momentum through a dipole field change but keeping the beam on the nominal orbit going through the sextupole centers where they have no influence, this is based on $dp/p_0 = dB/B_0$.

Optics Analogy:



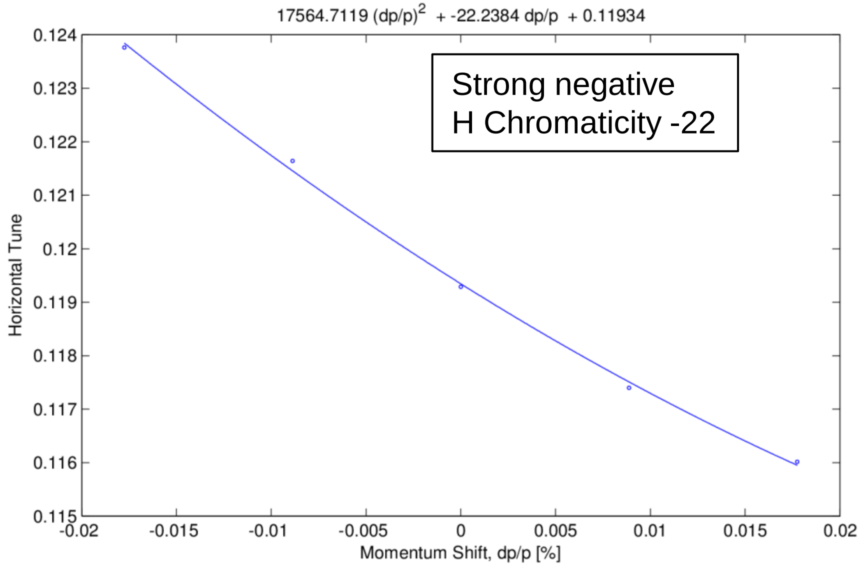
Spread in the Machine Tune due to Particle Energy Spread

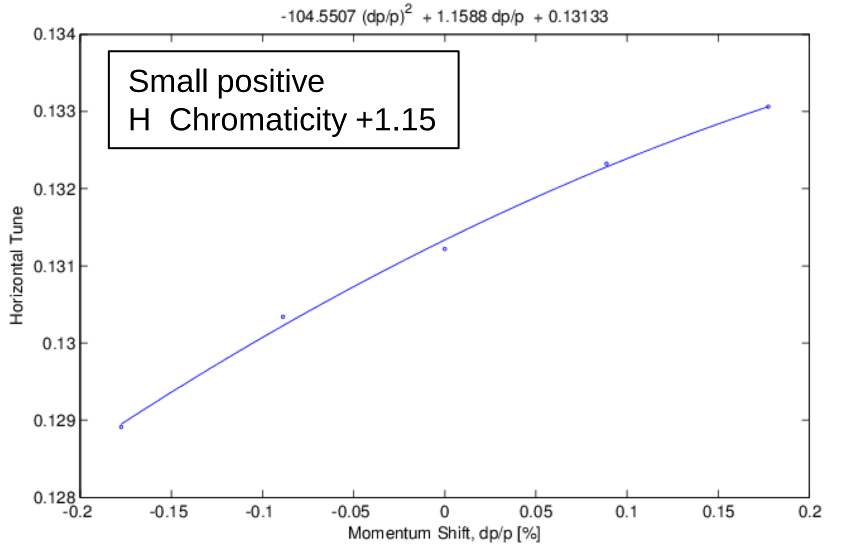
Controlled by Sextupole magnets

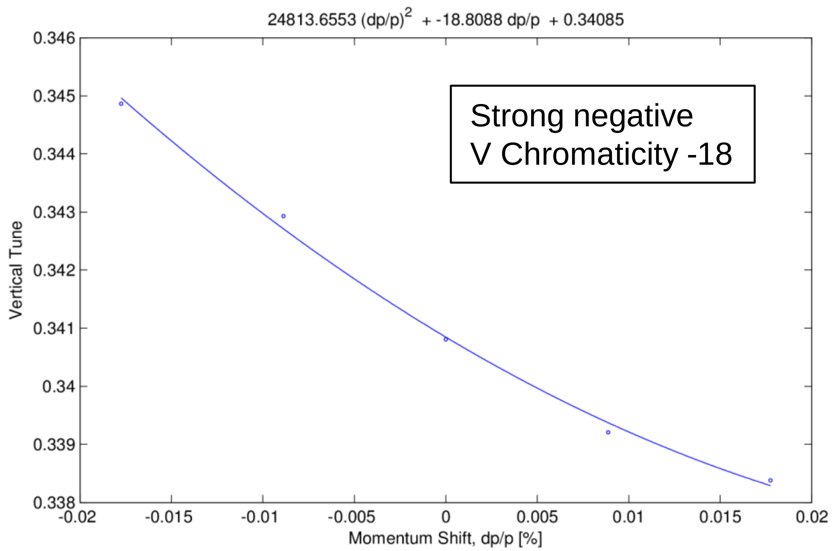
$$\Delta Q = Q' \frac{\Delta p}{p} = \left(\frac{1}{\gamma^2} - \alpha\right) Q' \frac{\Delta f}{f}$$

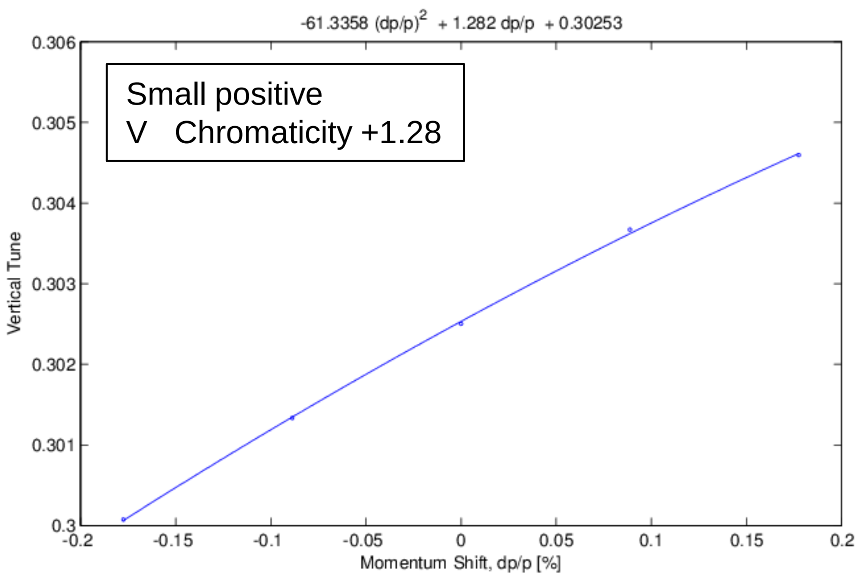
A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

Chromaticity Measurements





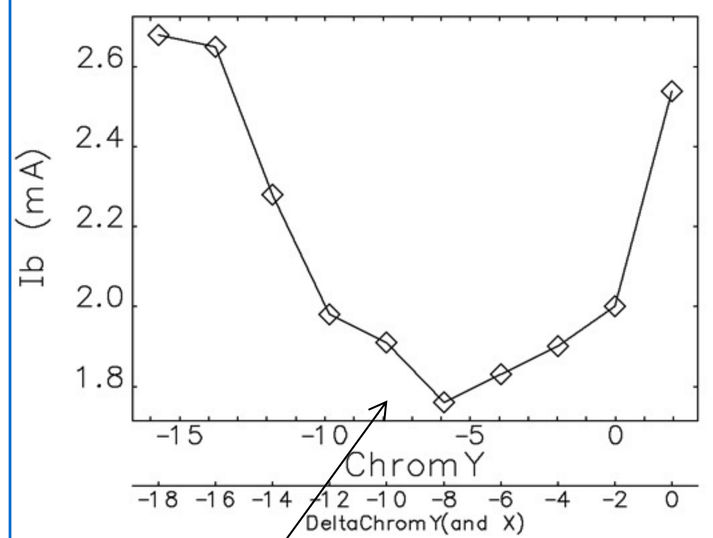




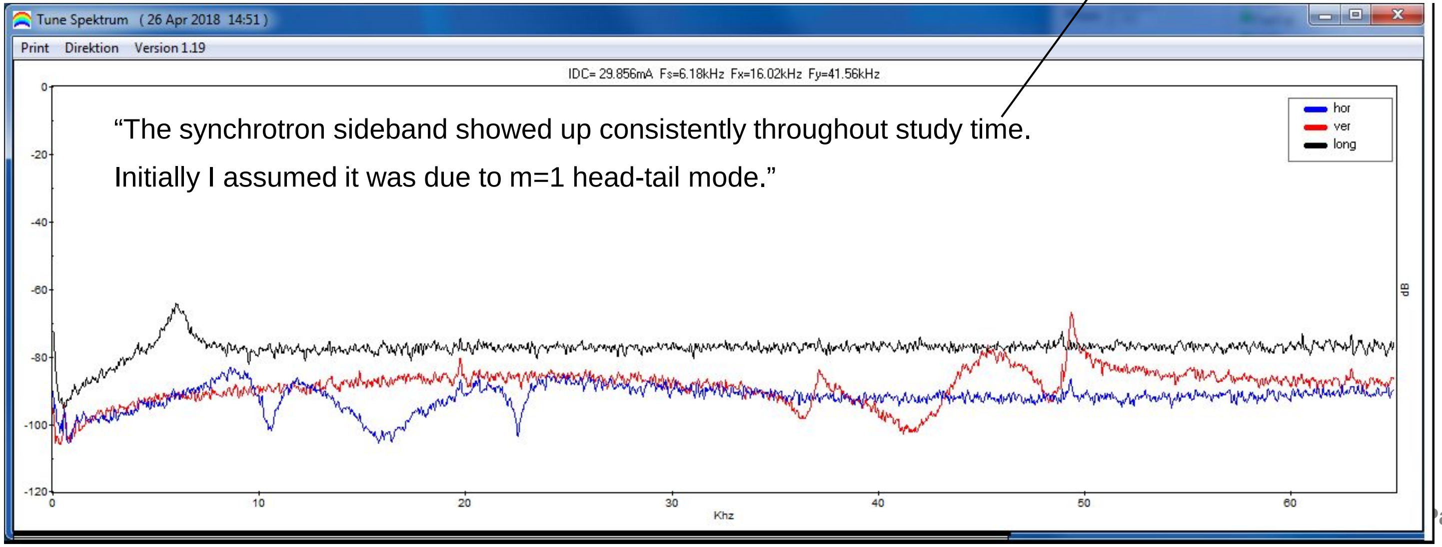
Nonlinearity by second order sextupoles cross talk terms

Chromaticity Measurements

- Negative Chromaticity drives instabilities and Injection becomes inefficient (=beam losses)
  - "Injection efficiency was ~60% at Cx,Cy < -10. This caused BLM warnings at Injection."
- Positive Chromaticity: Less beam losses at Injection



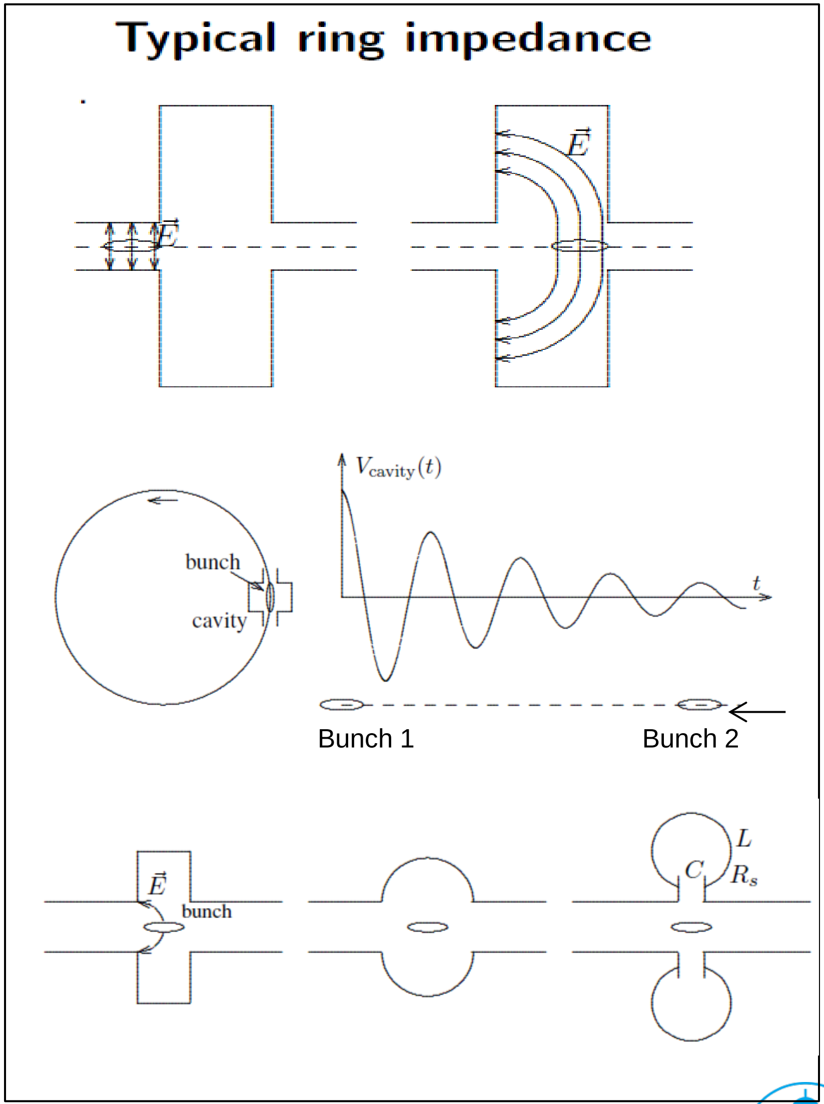
Test of very large negative Chromaticity



"The synchrotron sideband showed up consistently throughout study time. Initially I assumed it was due to m=1 head-tail mode."

Instabilities: Fast bunch-by-bunch feedbacks

- High Chromaticity is necessary for suppressing various kinds of beam instabilities (typ. exited by the narrow vertical gap of the undulators). Low Chromaticity is good for high injection efficiency. **To run with low Chromaticity a Fast bunch-by-bunch Feedback is required.**
- Instability threshold at about some 10 mA: Resistive Wall due to small gap in Undulators, HOM impedance, Ion trapping, Microwave, coupled bunch instability, …????
- Bunch-by-Bunch feedback. Due to wakefields and impedance, most high intensity rings need multibunch feedbacks to stabilize the beam.



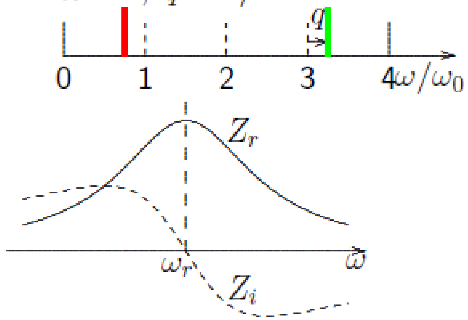
Instabilities: Fast bunch-by-bunch feedbacks

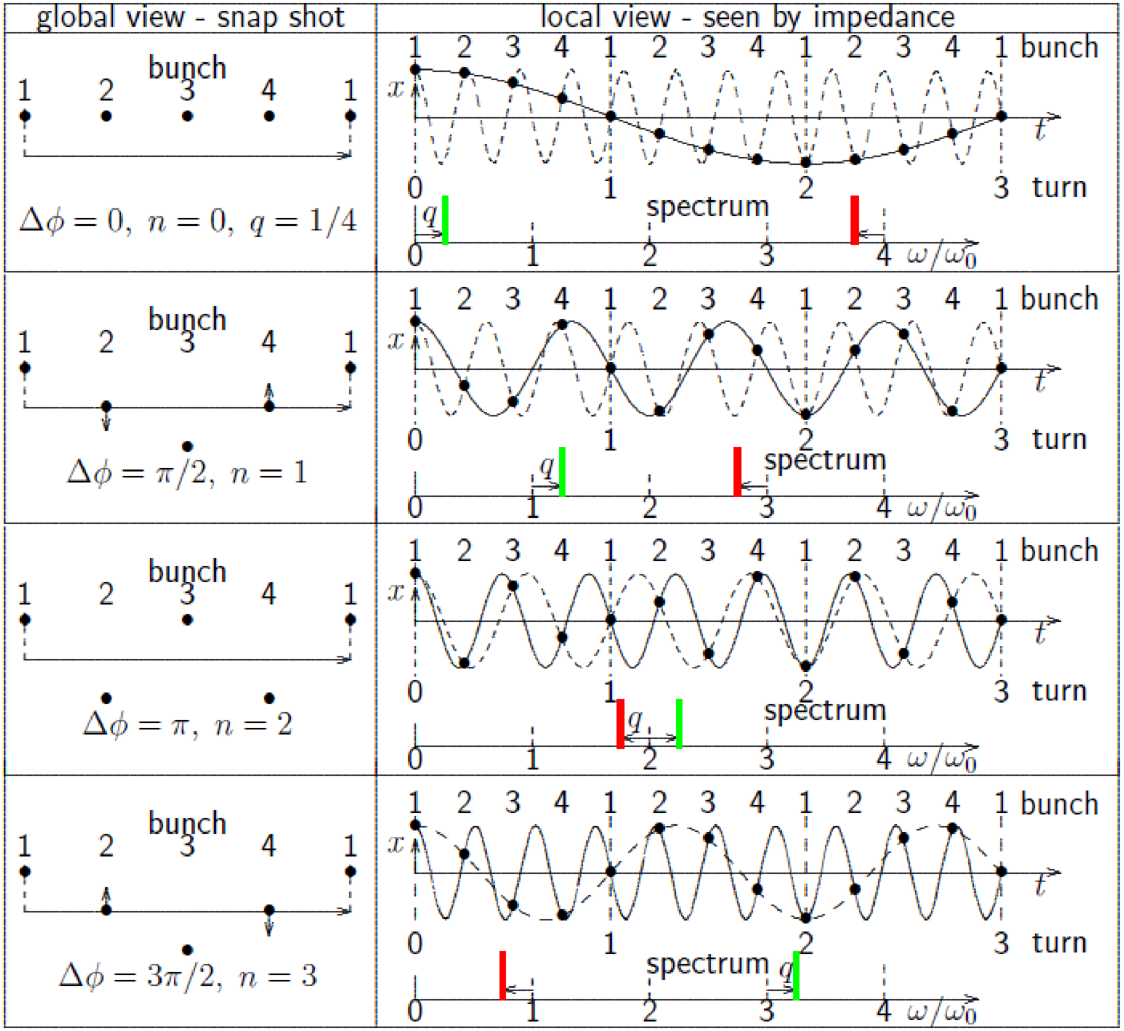
Transverse instability of many bunches

M bunches can oscillate in M independent modes $n = M\Delta\phi/2\pi$, phase $\Delta\phi$ between them seen in global view. Locally, bunches pass with increasing time delay shown as bullets fitted by upper (solid) and lower (dashed) side-band frequency. Higher frequencies can be fitted and spectrum repeats every $4\omega_0$.

$$\omega_{p\pm} = \omega_0(pM \pm (n+q))$$

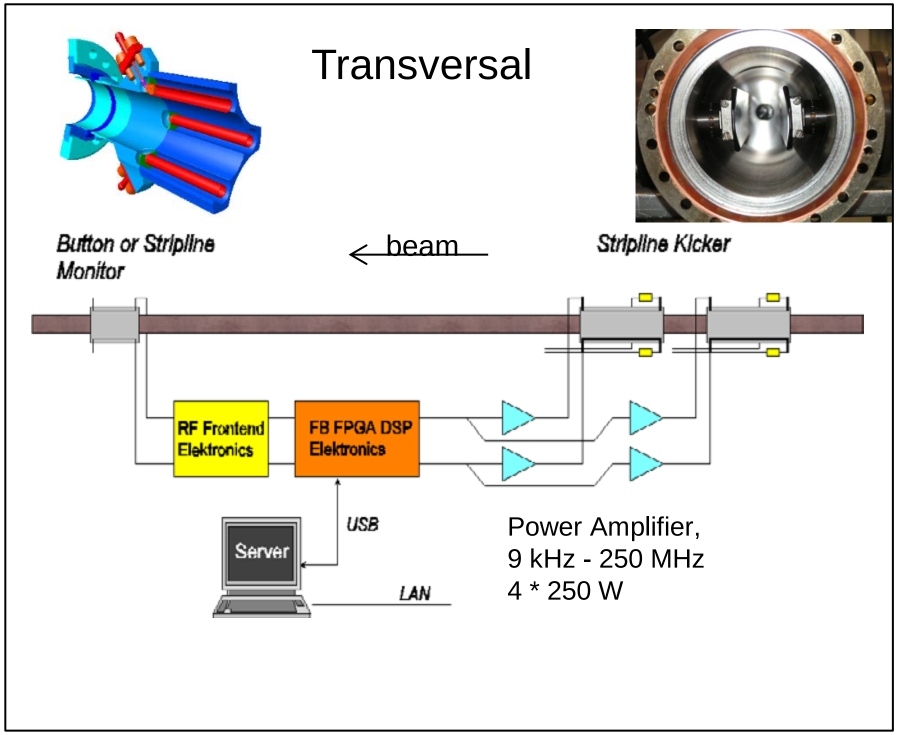
Spectrum $n=3,\ q=1/4$

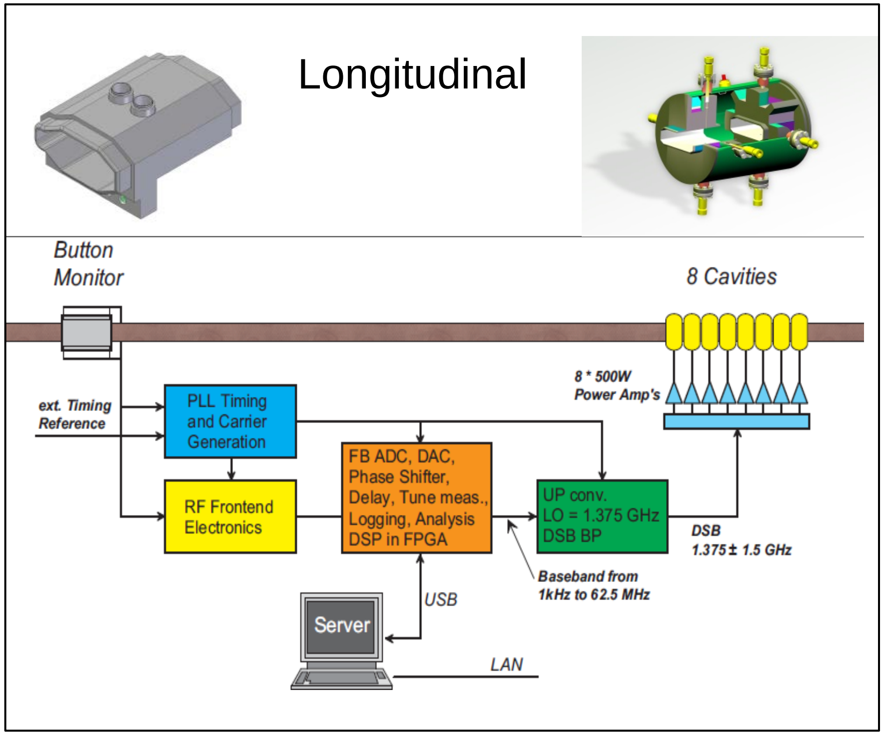




A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

Longitudinal and transversal fast B-by-B feedbacks



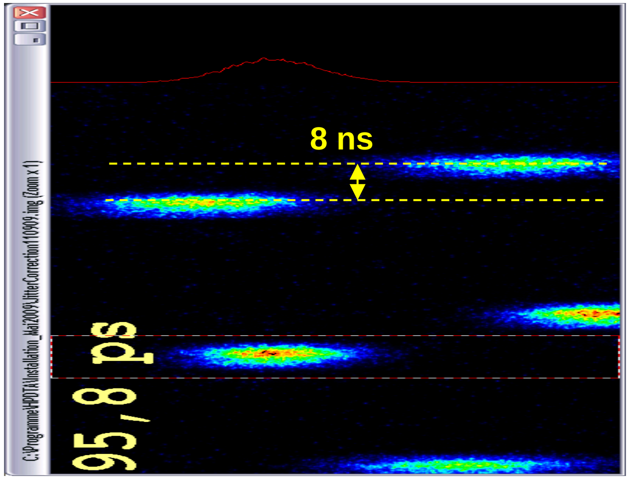


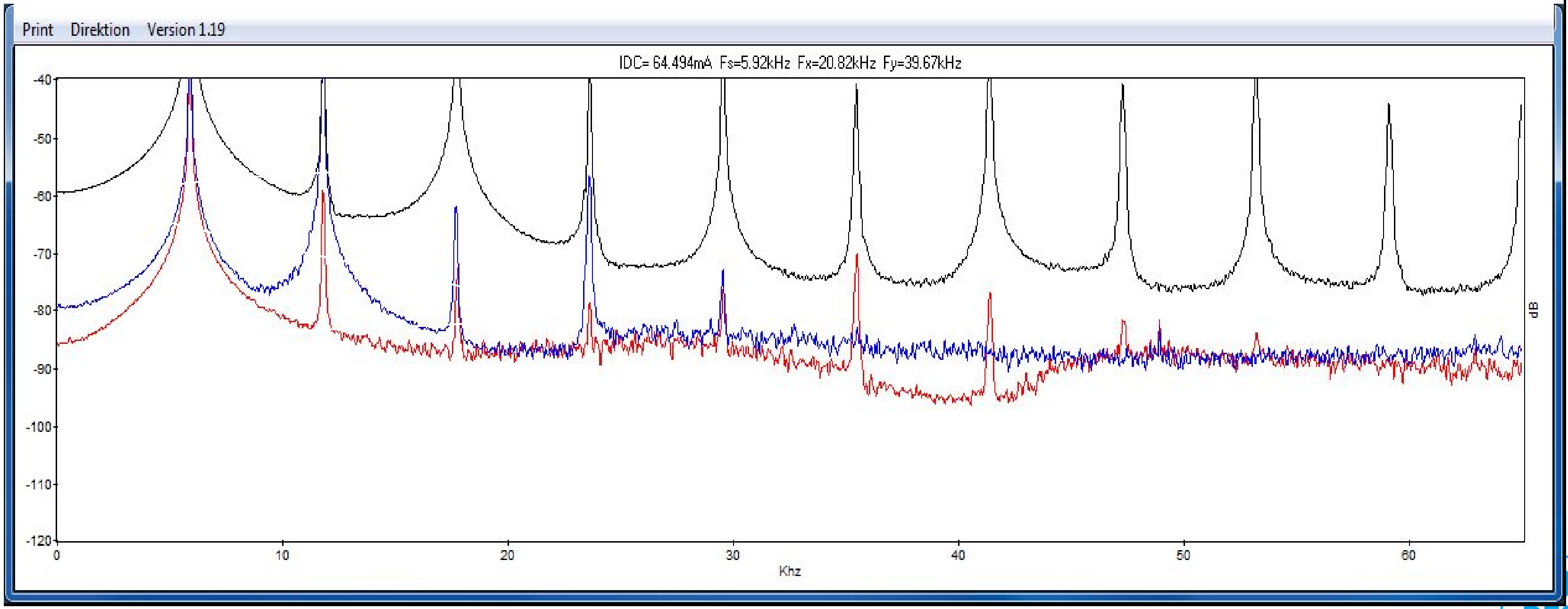
The required minimum bandwidth (62.5MHz) is determined by the shortest distance between bunches (8 ns at PetraIII)

courtesy
J. Klute (DESY)

> Longitudinal Feedback failure

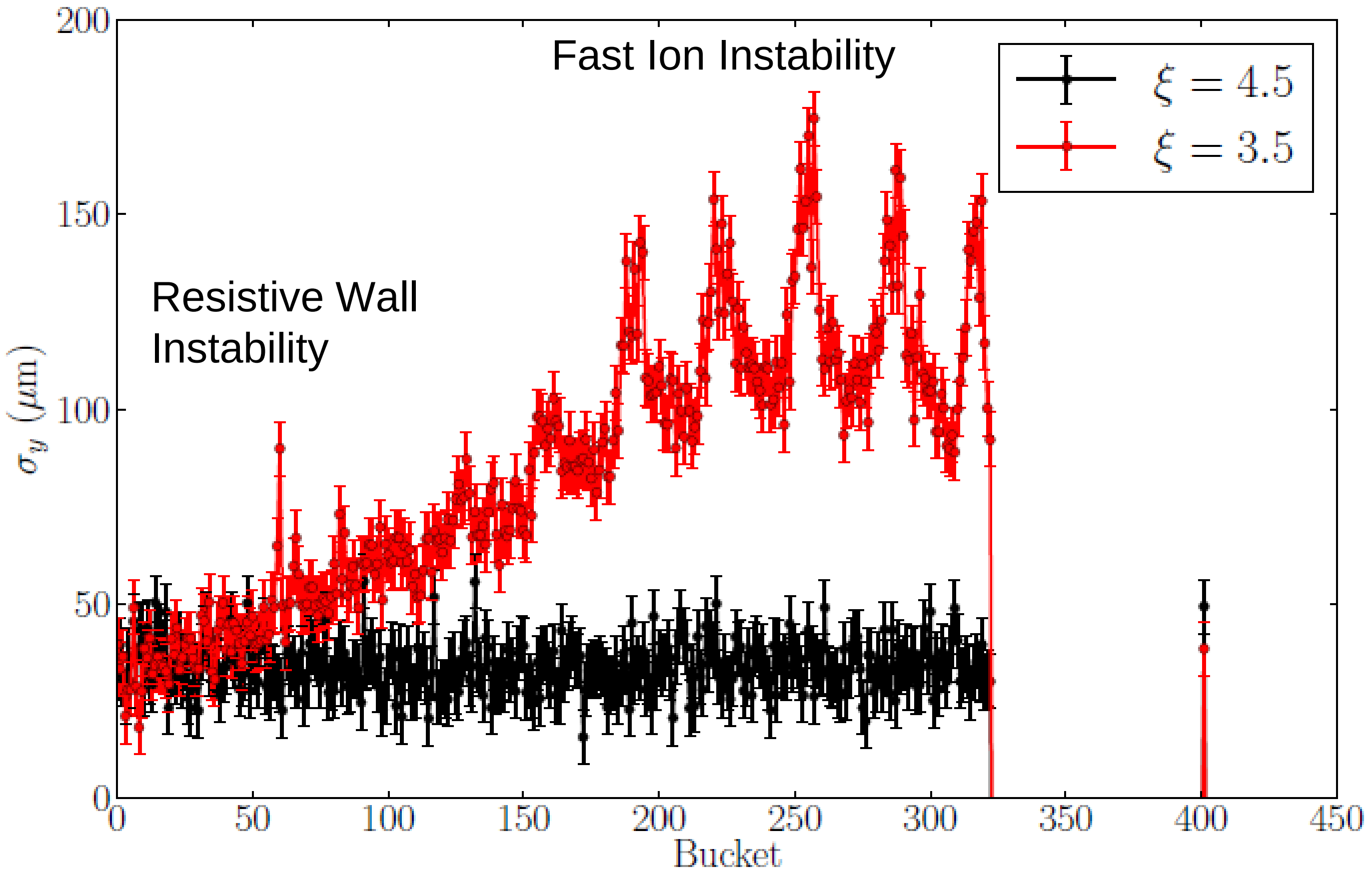
- Longitudinal Oscillations seen by Synchrotron oscillation peaks and by streak camera





Instability measured by Turn-by-Turn Size Observation

No bunch-by-bunch feedback at ALBA, Test at 130 mA hybrid filling



The size of the single bunch at RF-bucket 400 remains unchanged, indicating a sufficient gap to damp the instability.

For the nominal chromaticity ξ = 4.5 all the bunches have a similar beam size (black dots).

LONGITUDINAL AND TRANSVERSE BEAM DIAGNOSTICS US ING SYNCHROTRON RADIATION AT ALBA, Laura Torino, Thesis

G. Beam Current Measurement

- DC current, precise beam current and lifetime **(-limitations)**
- Bunch current (AC), bunch charge and filling pattern
- Sum of BPM Signals (very helpful at first beam steering)

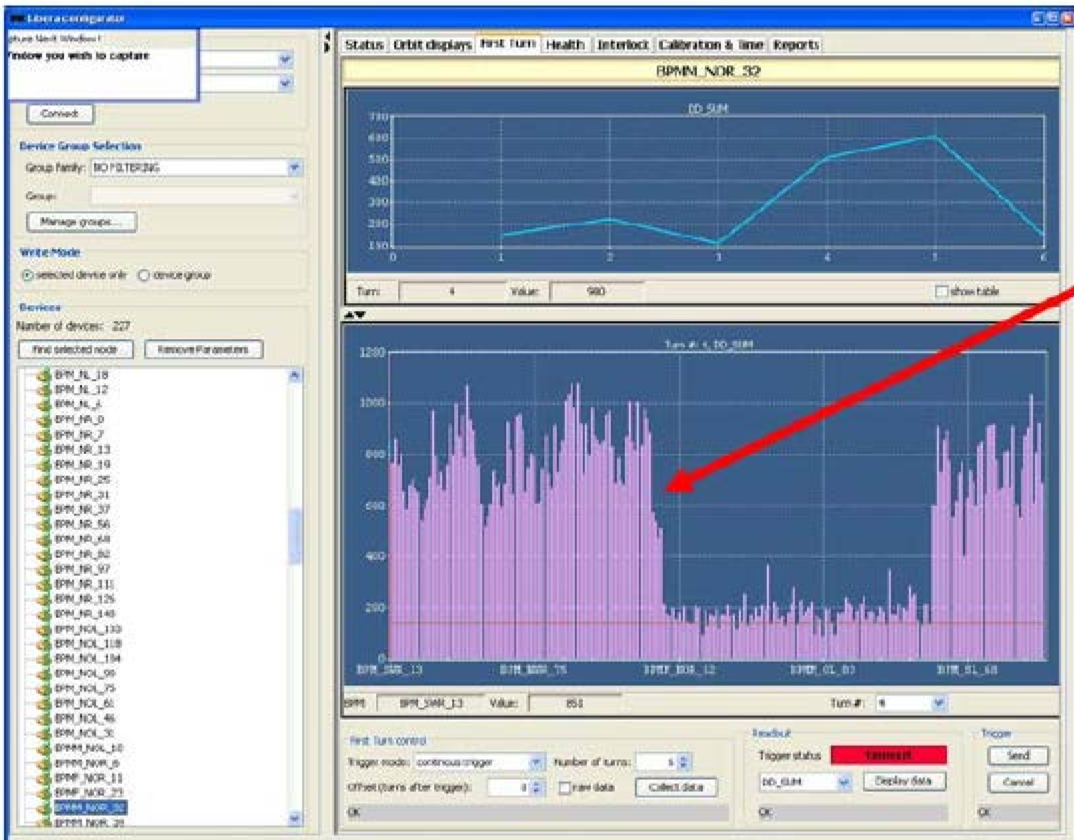
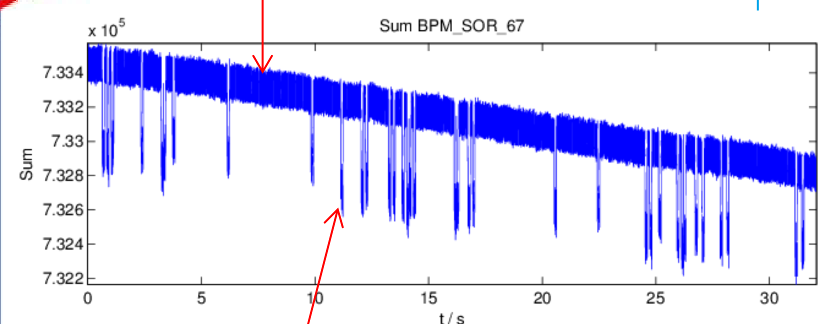


Figure shows the sum signal of BPM's

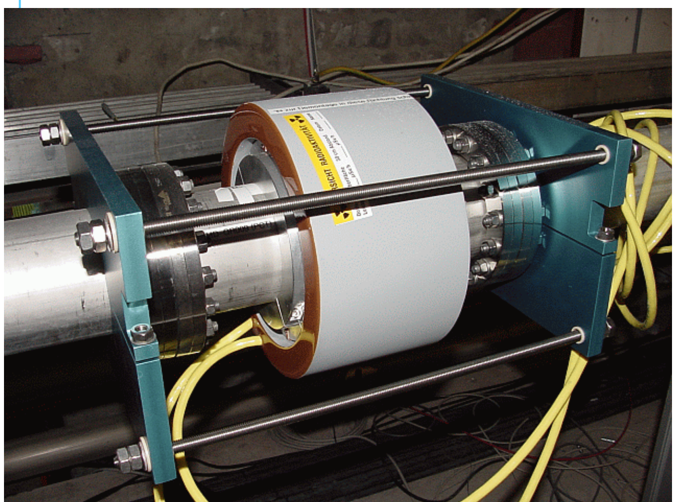


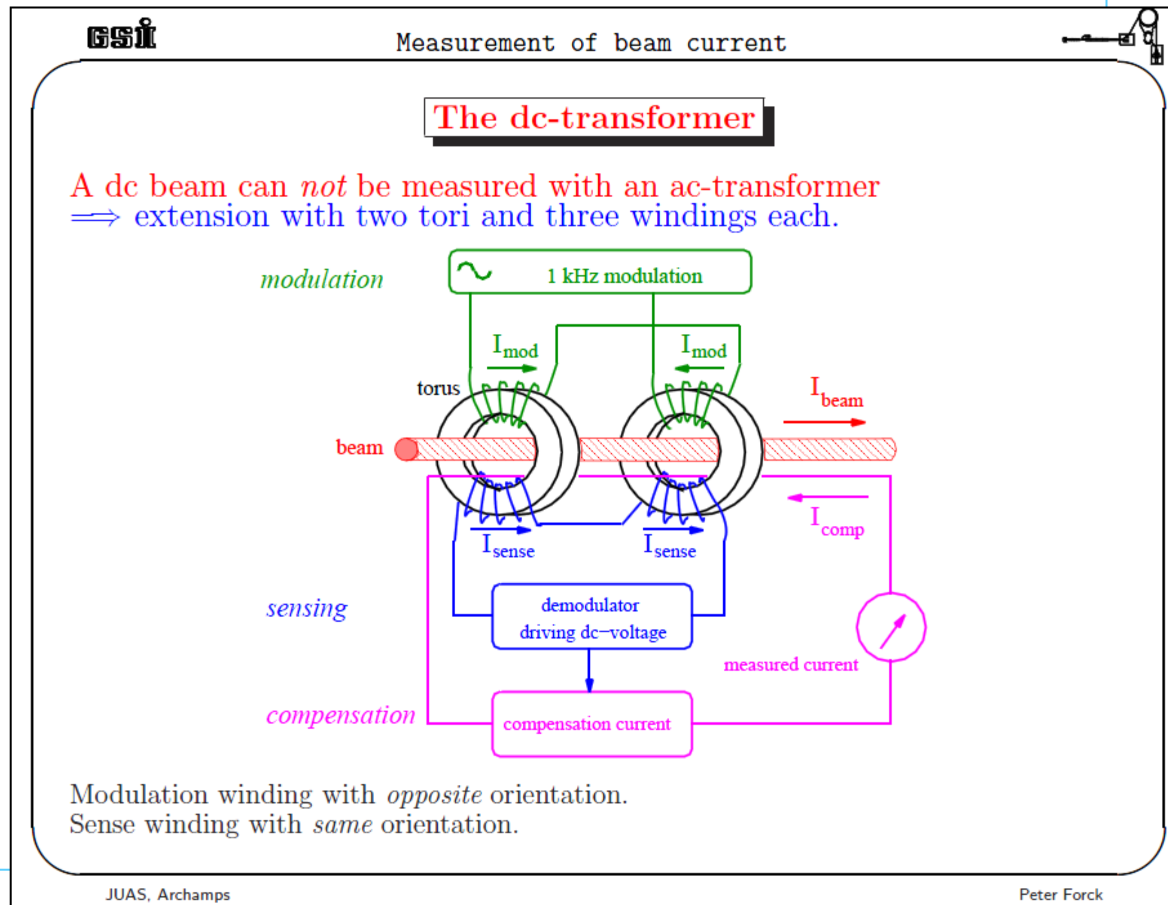
Spikes? Ask I-Tech!!!

DESY

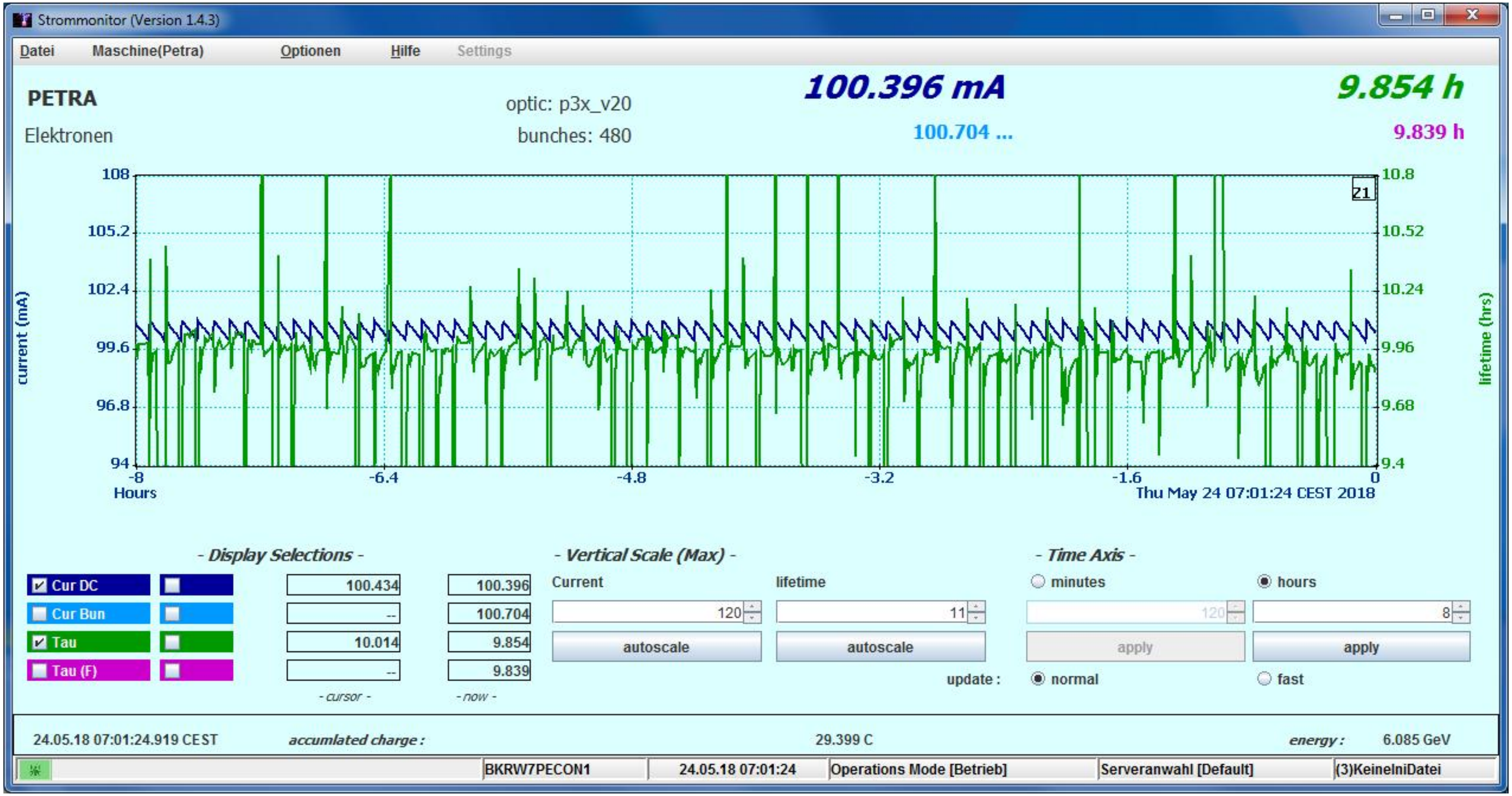
Beam Current Measurement: DC current

- Range: 1 mA – 200 mA, Circulating current,
- Resolution: < 3 μA, lifetime resolution < 0.1%
- Bandwidth: DC - 10 kHz





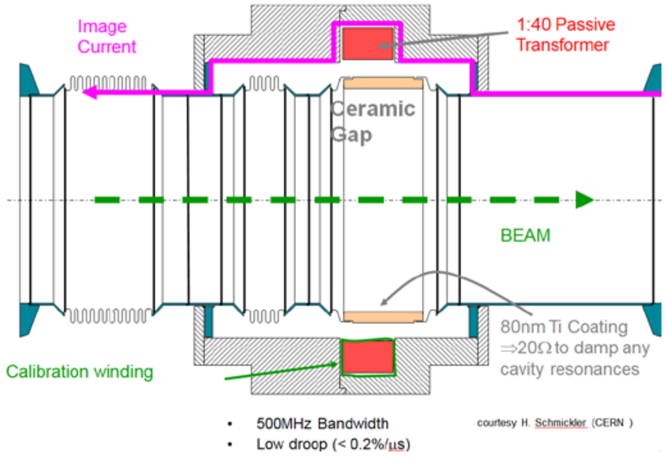
History of charge N and lifetime τ: $N(t) = N_0 * e^{-t/\tau}$

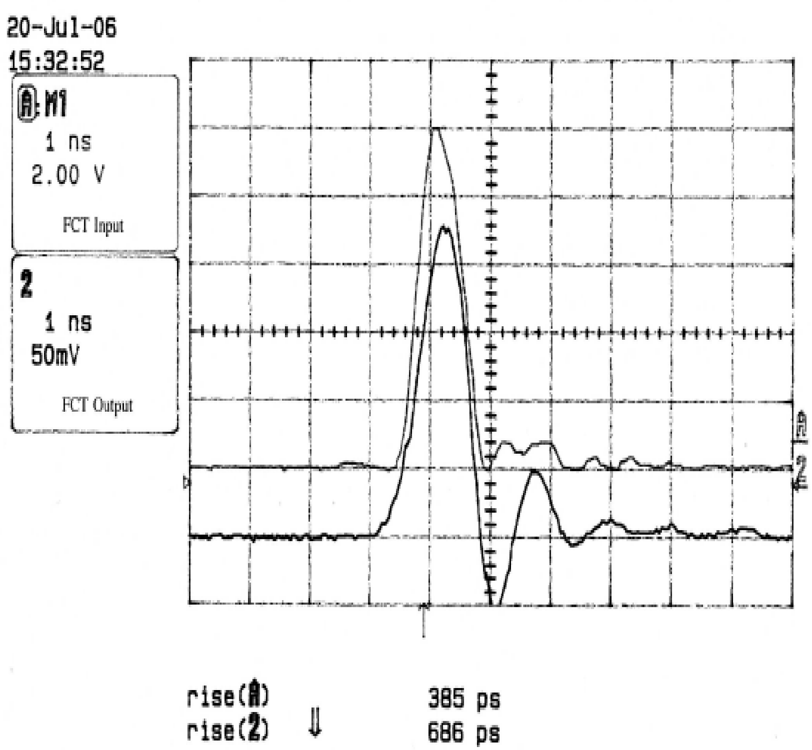


AC Bunch Current Measurement: Fast Current Transformer (FCT)

> Range: 10 μA – 10 mA

> Resolution: < 1 μA,
> Bunch current for defined filling and top-up (<1% Stability)



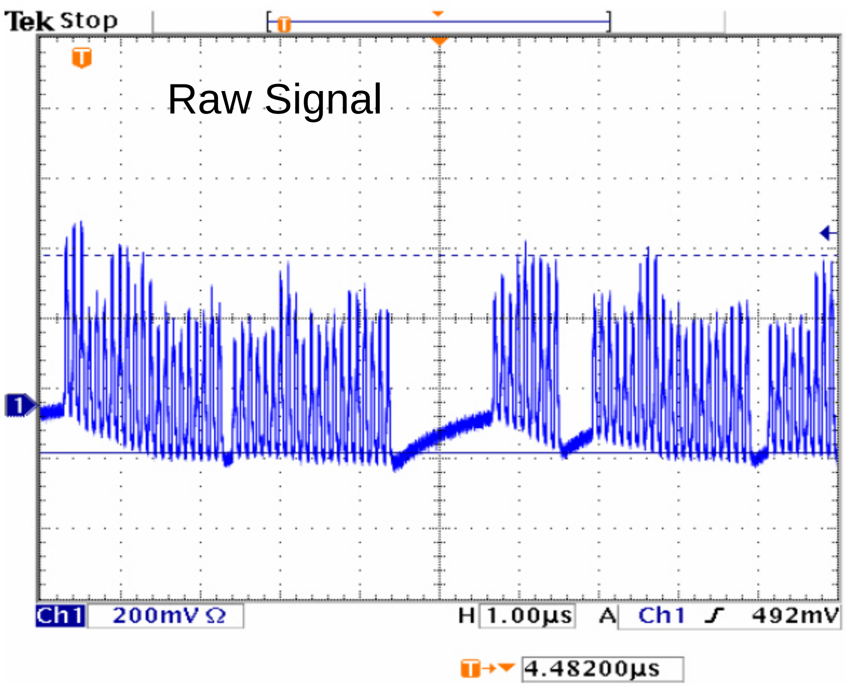


AC Bunch Current Measurement: Filling Pattern

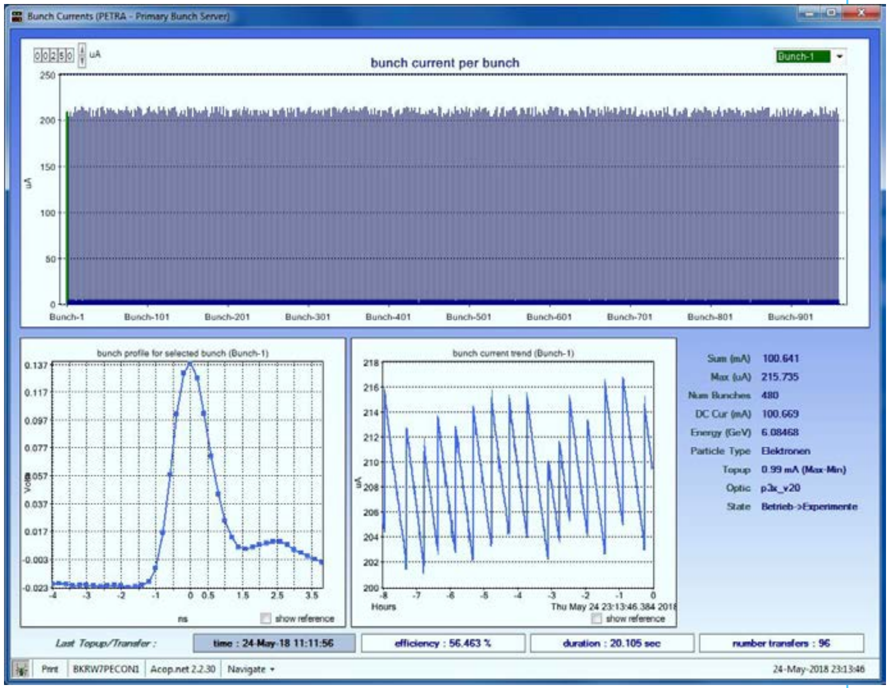
PETRAIII

> Range: 10 µA – 10 mA

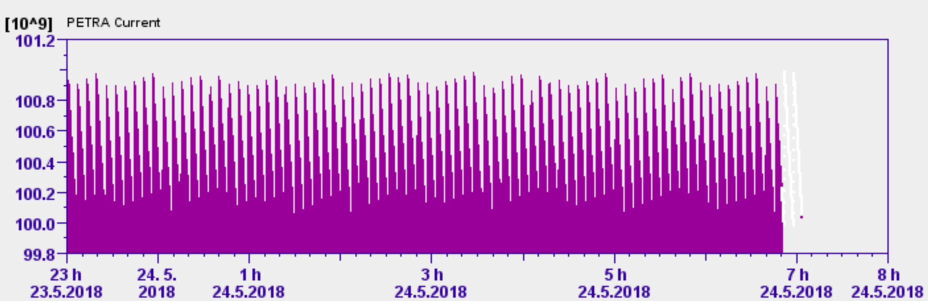
> Resolution: < 1 µA



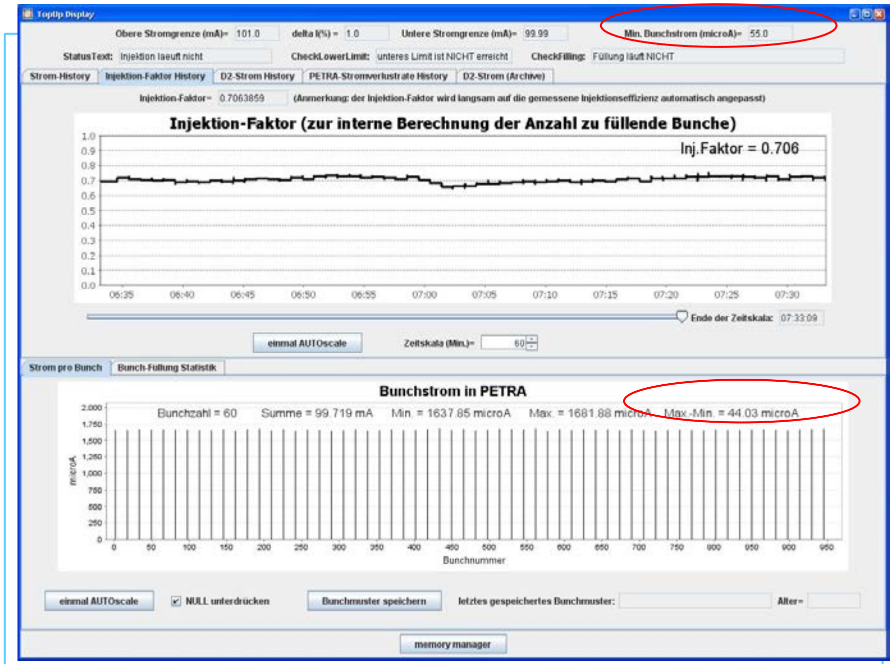
> Top up

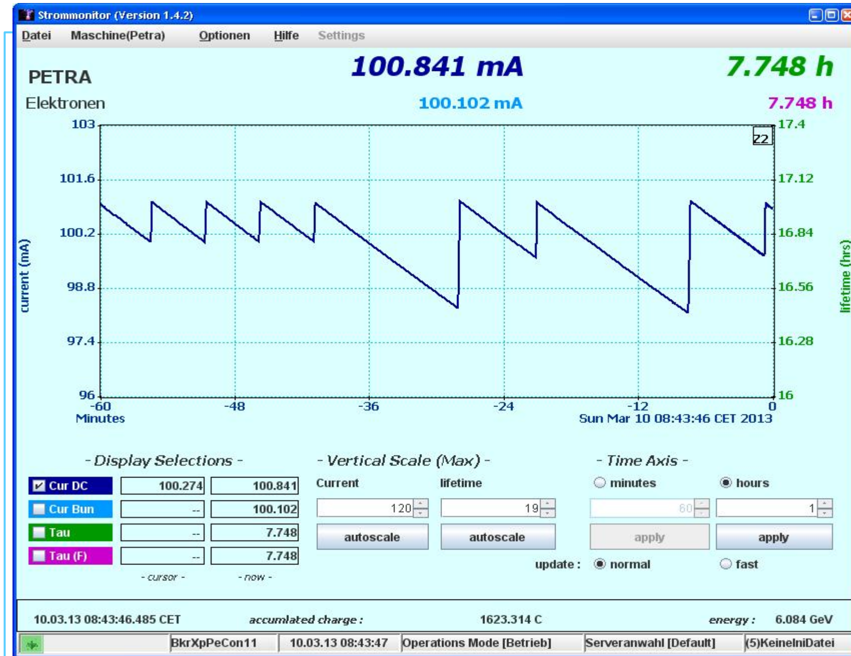


User run, 480 bunches, 100 mA



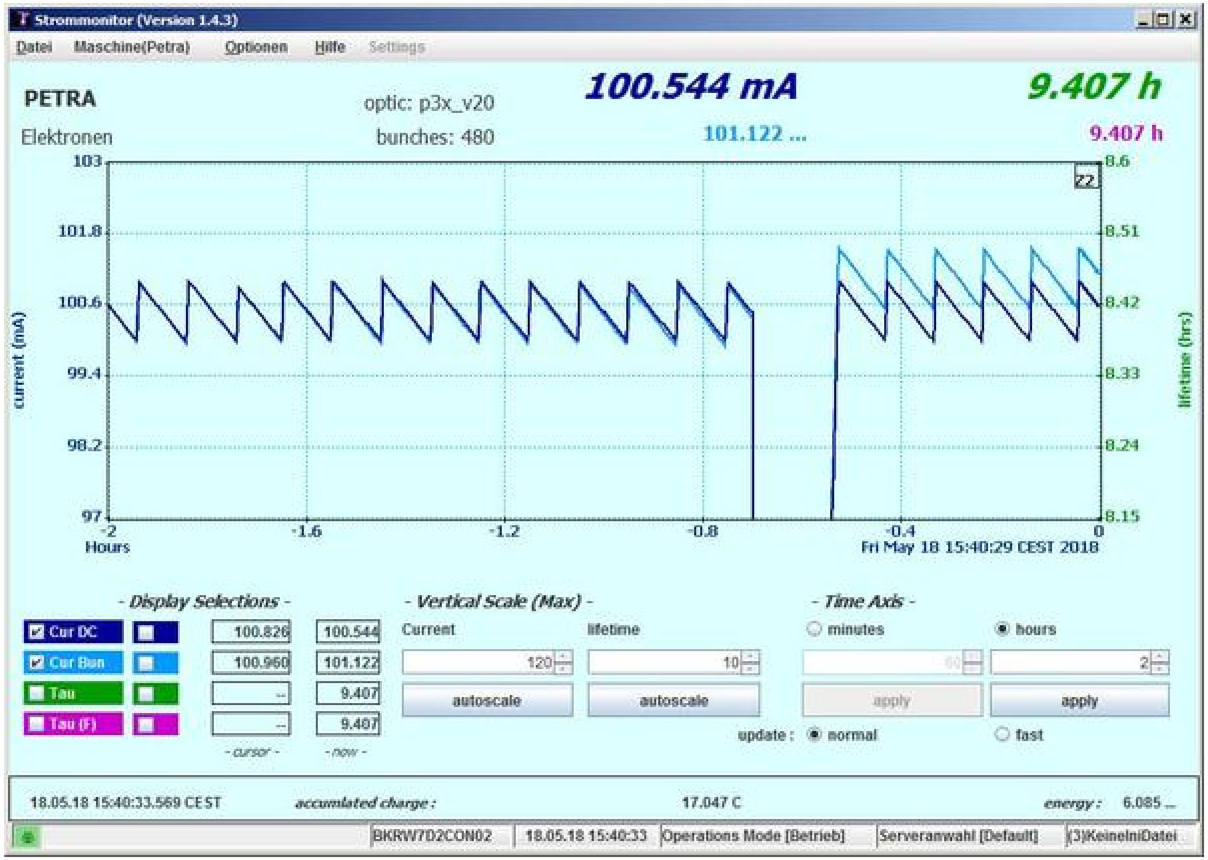
Beam Current Measurement: Transfer Efficiency





Why AC and DC Monitors?

Nice to crosscheck: Blue DC, light blue AC

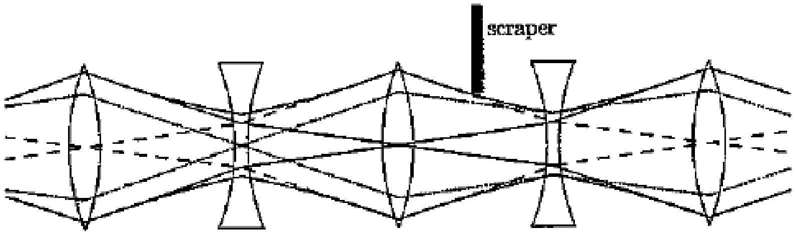


DESY

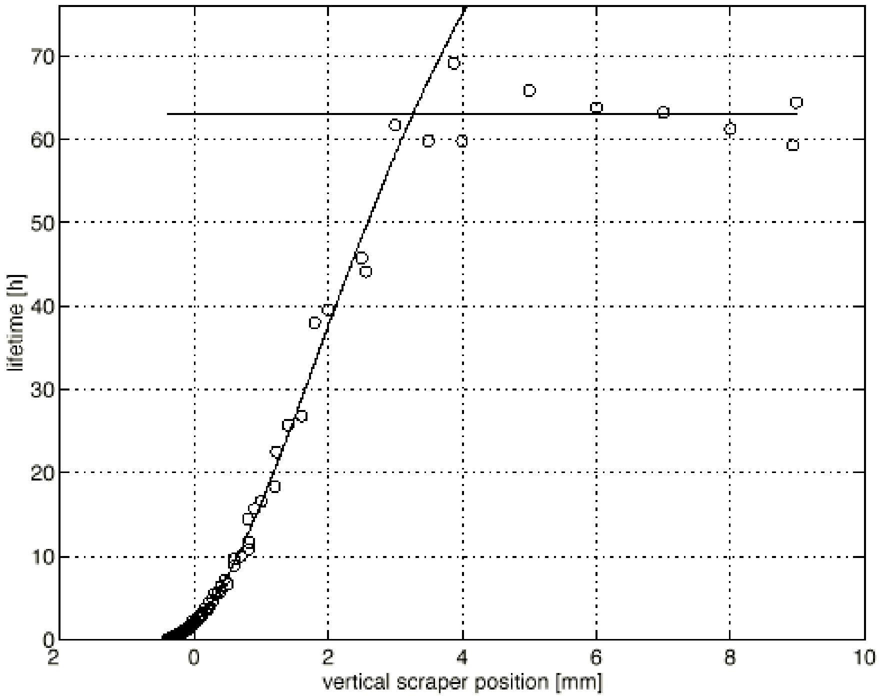
Lifetime Measurement: Dynamic Aperture

Measure dynamic acceptance

Dynamic acceptance gives normalized maximum betatron oscillation amplitude of beam optics, i.e. the maximum beam emittance. Limited by non-linear elements giving tune changes with amplitudes making oscillations unstable. Measured by exciting oscillation and increasing amplitude until life-time is short. To calibrate, scraper is moved into beam to a distance x_a where gets even shorter, acceptance $A = x_a^2/\beta$.



At life-time limit check tune in case of resonances. To avoid orbit distortion effects move scraper from both sides, window scraper.



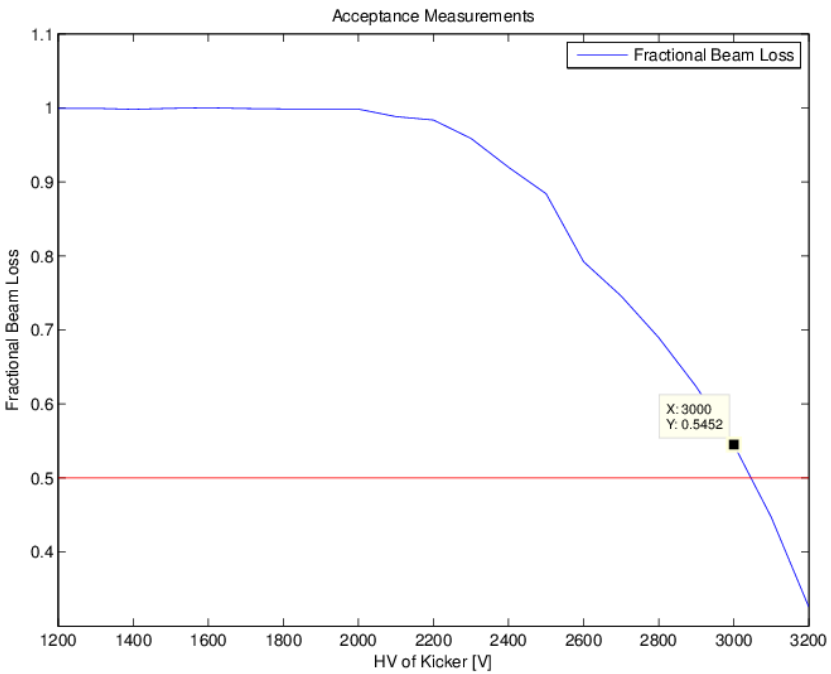
Scraper defines geometric aperture. At point with losses is dynamic aperture = geometric aperture

Accelerator Physics; Reported by Alan Jackson
http://www-als.lbl.gov/als/compendium/tr97/AccPhys.pdf

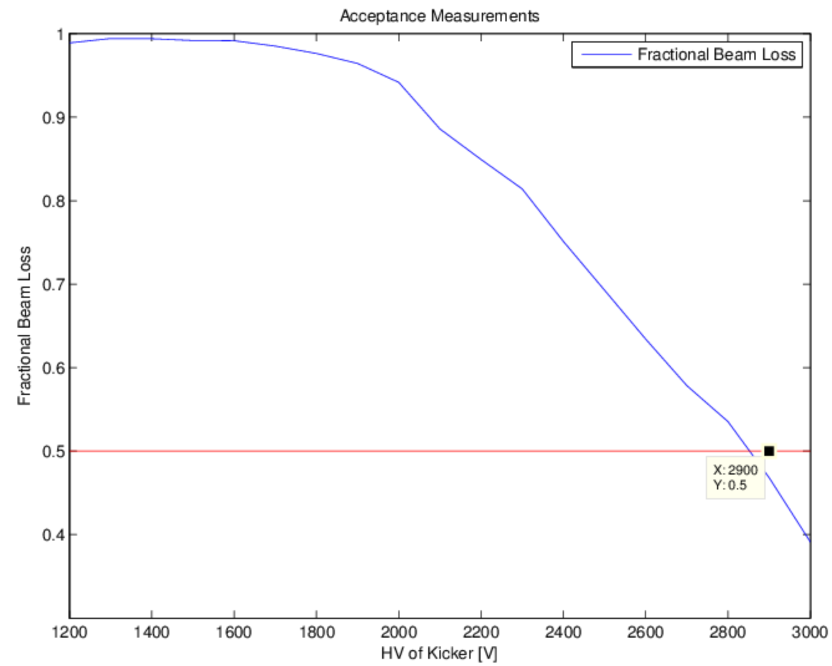
A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

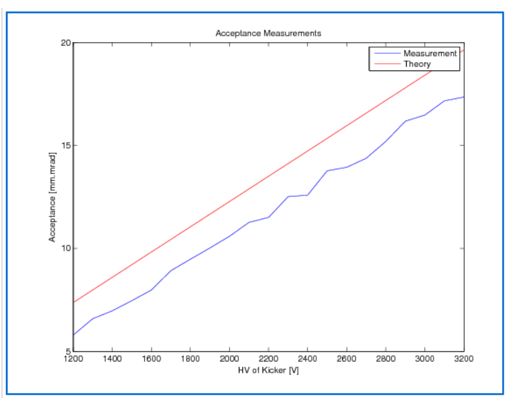
Dynamic Aperture: Measurement with Kicker

> With MBFB



> w/o MBFB





Kicker Calibration

Lifetime Measurement: Touschek Limited

The lifetime in an electron storage ring is usually determined by the following effects: the quantum lifetime (τ_q), elastic (τ_{el}) and inelastic scattering (τ_{inel}) of electrons by the residual gas atoms, scattering of electrons within the bunch (Touschek effect) (τ_{tou}), and trapping of charged particles in the beam potential (τ_{ion}). The total lifetime is given by:

$$\frac{1}{\tau_t} = \frac{1}{\tau_q} + \frac{1}{\tau_{inel}} + \frac{1}{\tau_{el}} + \frac{1}{\tau_{tau}} + \frac{1}{\tau_{ion}}$$

The functional dependencies of the lifetime effects on different machine parameters are as follows.

Quantum Lifetime:

$$\frac{1}{\tau_q} = \frac{1}{\tau_D}\frac{\Delta^2_{x,y,s}}{\sigma^2_{x,y,s}}\exp\left(-\frac{\Delta^2_{x,y,s}}{2\sigma^2_{x,y,s}}\right)$$

Elastic Scattering:

$$\frac{1}{\tau_{el}} = C_{el}\frac{1}{E^2}\left(\langle P\beta_x\rangle\frac{\beta_x}{\Delta_x^2} + \langle P\beta_y\rangle\frac{\beta_y}{\Delta_y^2}\right)$$

Inelastic Scattering:

$$\frac{1}{\tau_{inel}} = C_{inel}\langle P\rangle \ln\left(-\frac{1}{\Delta_s} + \frac{5}{8}\right)$$

Touschek Lifetime:

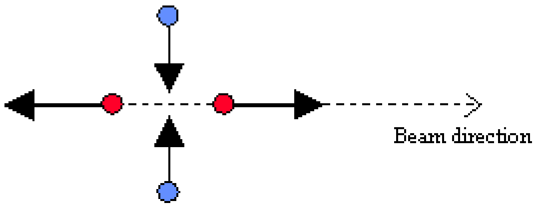
$$\frac{1}{\tau_{tou}} \approx C_{tou}\frac{1}{E^3}\frac{I_{bunch}}{\text{Volume}\,\Delta_s^2}f\left(\Delta_s\sigma'_x, E\right)$$

+ Intra beam scattering IBS ≈ $1/\gamma^4$

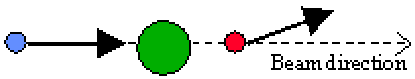
In these equations, $\Delta_{x,y}$ is the transverse aperture, $\beta_{x,y}$ the β-functions, and $\sigma_{x,y}$ the beam size at the position of the aperture. σ_s is the width of the longitudinal particle distribution, and Δ_s the longitudinal acceptance of the storage ring. The longitudinal acceptance can be determined by the size of the rf bucket or by the dynamic acceptance.

Accelerator Physics
Reported by Alan Jackson
http://www-als.lbl.gov/als/compendium/tr97/AccPhys.pdf

Lifetime Measurement: Touschek Limited

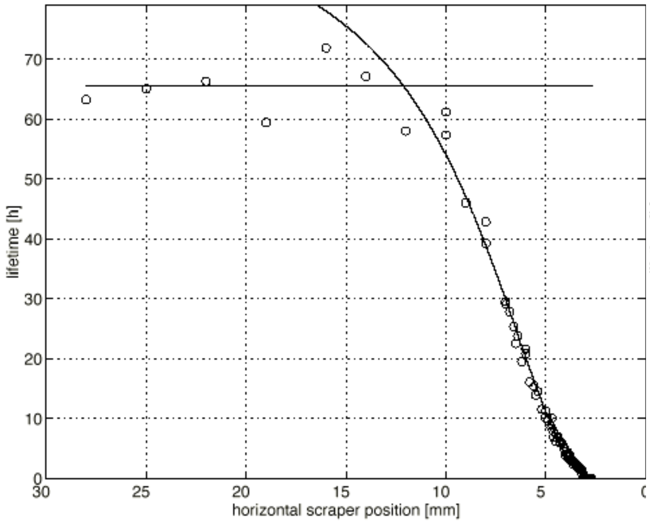


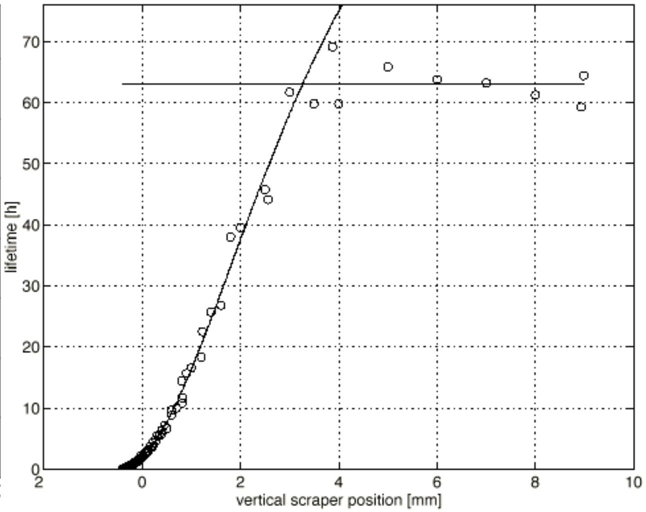
Touschek effect: Particles inside a bunch perform transverse oscillations around the closed orbit. If two particles scatter they can transform their transverse momenta into longitudinal momenta. If the new momenta are outside the momentum aperture the particles are lost. Good locations for the detection of Touschek scattered particles are in high dispersion sections following sections where a high particle density is reached. Since the two colliding particles loose and gain an equal amount of momentum, they will hit the in- and outside walls of the vacuum chamber. In principle the selectivity of the detection to Touschek events can be improved by counting losses at these locations in coincidence.



Coulomb scattering: Particles scatter elastically or inelastically with residual gas atoms or photons or emit a high energy photon (SR). This leads to betatron or synchrotron oscillations and increases the population of the tails of the beam. If the amplitudes are outside the aperture the particles are lost. Losses from elastic scattering occur at aperture limits (small gap insertions, septum magnet, mechanical scrapers and other obstructions). If, in an inelastic Coulomb collision, the energy carried away by the emitted photon is too large, the particle gets lost after the following bending magnet on the inside wall of the vacuum chamber.

Lifetime Determination: Scraper Measurements





Quantum Lifetime:

$$\frac{1}{\tau_q} = \frac{1}{\tau_D}\frac{\Delta^2_{x,y,s}}{\sigma^2_{x,y,s}}\exp\left(-\frac{\Delta^2_{x,y,s}}{2\sigma^2_{x,y,s}}\right)$$

Elastic Scattering:

$$\frac{1}{\tau_{el}} = C_{el}\frac{1}{E^2}\left(\langle P\beta_x\rangle\frac{\beta_x}{\Delta^2_x} + \langle P\beta_y\rangle\frac{\beta_y}{\Delta^2_y}\right)$$

Inelastic Scattering:

$$\frac{1}{\tau_{inel}} = C_{inel}\langle P\rangle \ln\left(-\frac{1}{\Delta_s} + \frac{5}{8}\right)$$

Touschek Lifetime:

$$\frac{1}{\tau_{tou}} \approx C_{tou}\frac{1}{E^3}\frac{I_{bunch}}{\text{Volume}\,\Delta^2_s} f\left(\Delta_s \sigma'_x, E\right)$$

This information allows one to calculate the contributions of the different lifetime effects to the total lifetime. **As the current per bunch is very small,** the Touschek lifetime is very large.

The measured lifetime as function of horizontal scraper position was fitted to the following curve:

$$\frac{1}{\tau}(\Delta_x) = \begin{cases} \text{const.} & \text{if } \Delta_x > A_x \\ \frac{1}{\tau_{tou+inel}} + C_{el}\frac{1}{E^2}\langle P\rangle\left(\langle\beta_x\rangle\frac{\beta_x}{\Delta^2_x} + \langle\beta_y\rangle\frac{\langle\beta_y\rangle}{\Delta^2_y}\right) & \text{if } \Delta_x < A_x \end{cases}$$

Results	5 mA	400 mA
quantum lifetime τ_q	∞	∞
elastic scattering lifetime τ_{el}	85 hours	>18 hours
inelastic lifetime τ_{inel}	265 hours	>55 hours
Touschek lifetime τ_{tou}	≈200 hours	2.2 hours
total lifetime τ_t	50 hours	>1.9 hours

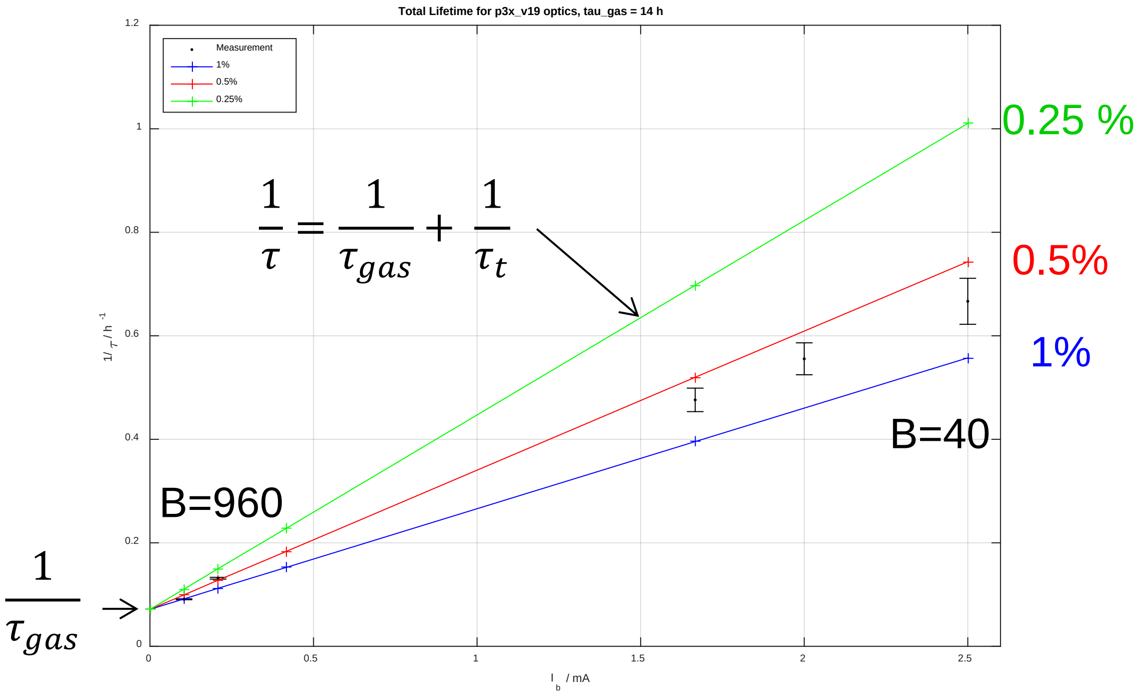
In these equations, $\Delta_{x,y}$ is the transverse aperture, $\beta_{x,y}$ the β-functions, and $\sigma_{x,y}$ the beam size at the position of the aperture. σ_s is the width of the longitudinal particle distribution, and Δ_s the longitudinal acceptance of the storage ring. The longitudinal acceptance can be determined by the size of the rf bucket or by the dynamic acceptance.

Accelerator Physics
Reported by Alan Jackson
http://www-als.lbl.gov/als/compendium/tr97/AccPhys.pdf

Beam Lifetime vs. Single Bunch Current

A measurement of the lifetime at the same total current but with varying bunch currents is shown. As the gas pressure does not change in this experiment, the slope of the curve gives the change of the IBS and Touschek lifetime with bunch current. Remember, the Touschek lifetime changes with the bunch volume, thus any variations of the measurement conditions might change the result.

- Extrapolation for I_b= 0 mA: Beam-gas life time 14.0 h
- Color lines: Theory (IBS + Touschek scattering from ELEGANT) for 1%, 0.5% and 0.25 % coupling



→ Estimation of coupling: ~0.6%

Measurement Conditions:

- I = 100 mA
- U = 20 MV (= 9 + 11 MV)
- $f_{x,y}$ = 17.2 / 39.4 kHz
- f_s = 6.16 kHz

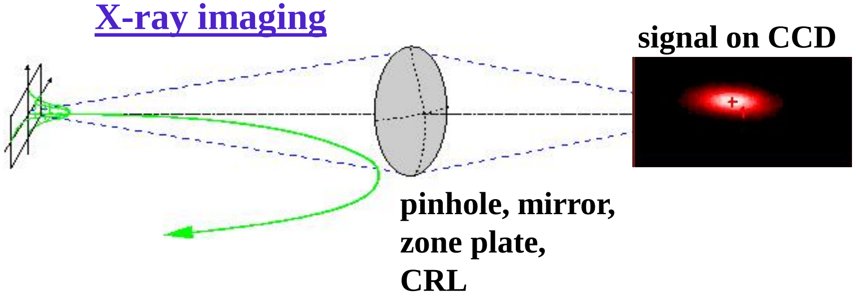
J. Keil, PETRA III-Meeting
20. November 2017

DESY

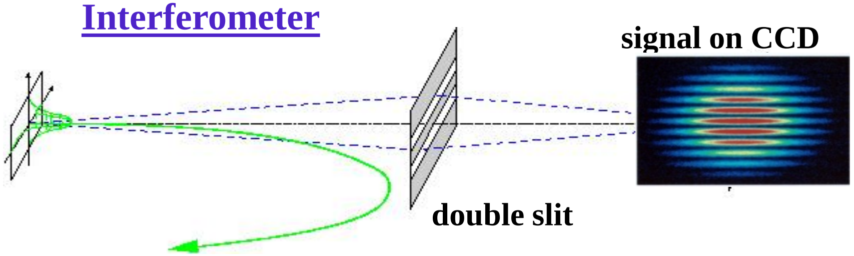
H. Beam Size and Emittance

Dedicated Diagnostics Beamlines

X-ray imaging



Interferometer



Visible; now 2-Dimensional

courtesy G. Kube (DESY)

Beam size at Undulator h / v: 140 / 4.9 μm

> Resolution requirement: ≈10 μm (beam) at higher β-function in ring

Problems:

> (Visible) Synchrotron Radiation is diffraction limited (≈ 200 μm)

Solutions:

> **X-ray (diffraction ≈ 10 μm)**

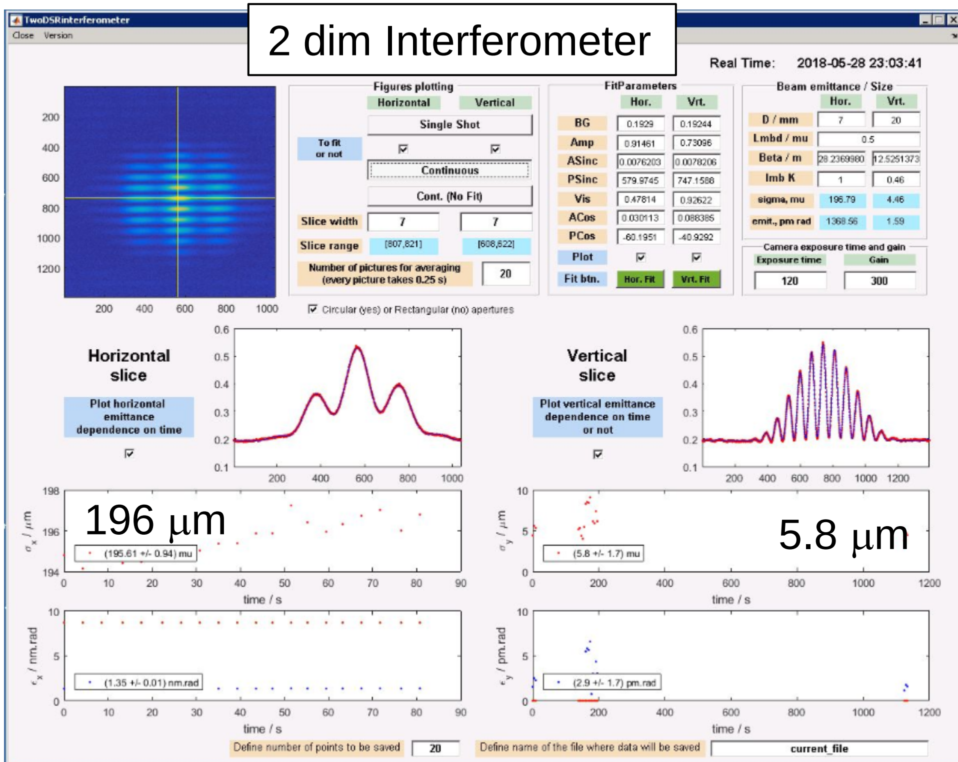
- **Interferometer**
- **Pin Hole Camera**
- **π Polarization PSF-Method**
- **…**

$$I = I_0 \left\{ \frac{J_1\left(\frac{2\pi a x}{\lambda f}\right)}{\left(\frac{2\pi a x}{\lambda f}\right)} \right\}^2 \times \left\{ 1 + V \cos\left(\frac{2\pi D x}{\lambda f}\right) \right\}$$

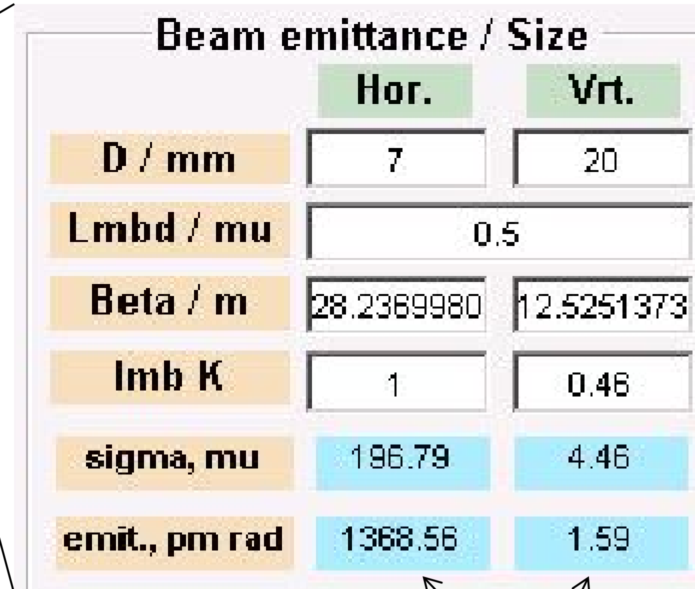
$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

I_0 Intensity of the interferogram
J_1 Bessel function of the first kind
a Half diameter of the pinhole
f Focal distance between the first lens and the CCD
λ Radiation wavelength
V Visibility $\simeq \frac{I_{Max} - I_{min}}{I_{Max} + I_{min}}$
D Distance between the pinholes centers
L Distance between the source and the double pinholes system

Beam size: Emittance by knowing the β-function, dispersion D and Δp/p (=σ_s) at the monitor

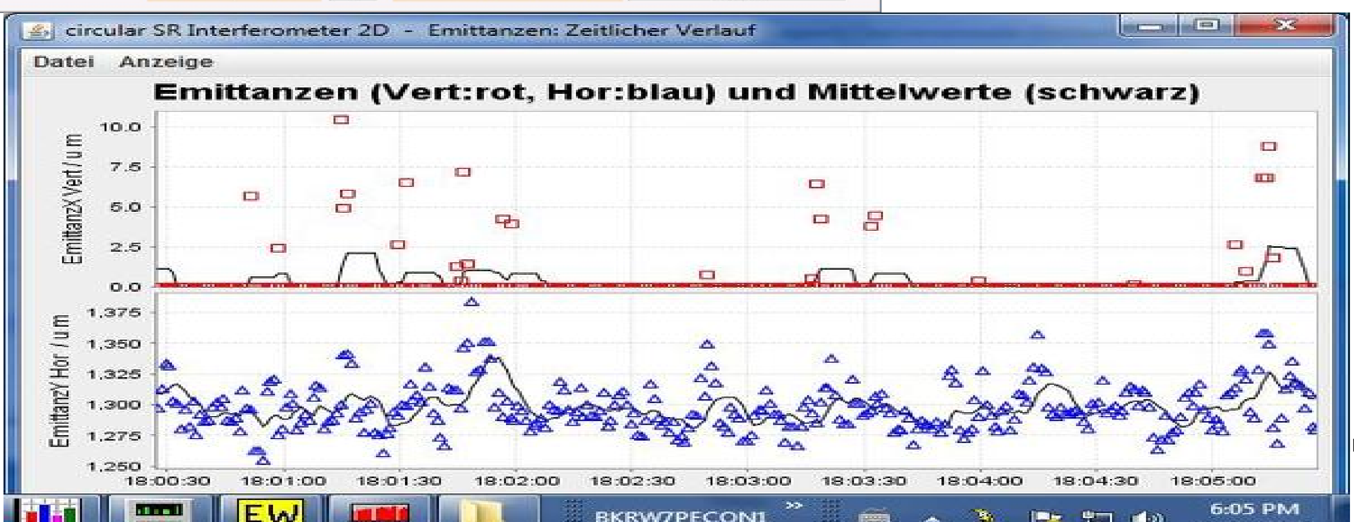


Zoom



	Hor.	Vrt.
D / mm	7	20
Lmbd / mu	0.5	
Beta / m	28.2369980	12.5251373
Imb K	1	0.46
sigma, mu	196.79	4.46
emit., pm rad	1368.56	1.59

≈ 0.1% coupling



Emittance ε:

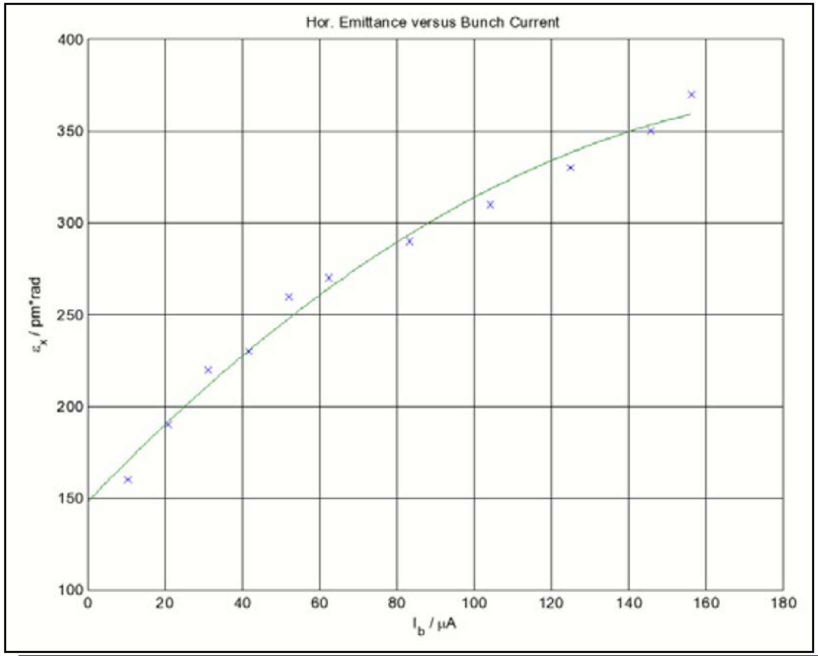
$$\varepsilon_z = \frac{\sigma_z^2}{\beta_z},$$

$$\sigma_x^2 = \beta_x \varepsilon_x + D^2 \sigma_\delta^2$$

Emittance variations: IBS, Touschek

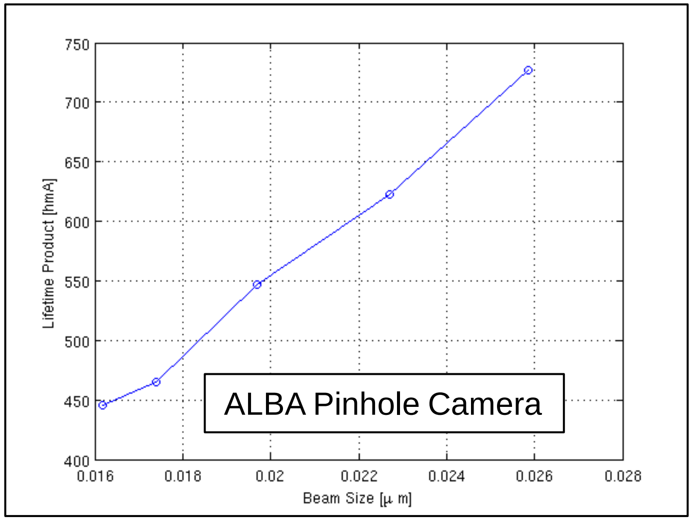
IBS increases the beam dimensions	Touschek effect limits the beam lifetime

Example: Emittance increase due to **intra-beam scattering** which leads to an increase of the beam dimensions in all three dimensions.-> **Simultaneous transverse and longitudinal measurements needed**

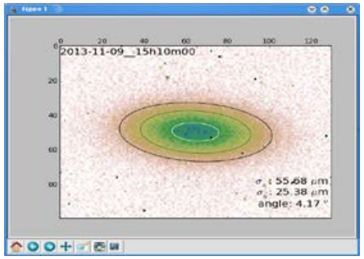


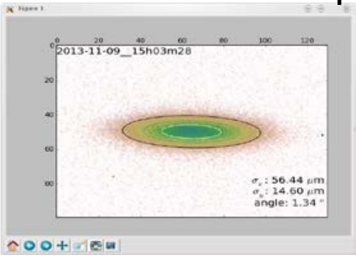
Horizontal emittance versus single bunch current at PETRA III, 3 GeV Test run

Example: Correlation between beam lifetime and beam size while reducing coupling.-> Touschek Lifetime



0.5% 0.1 % coupling

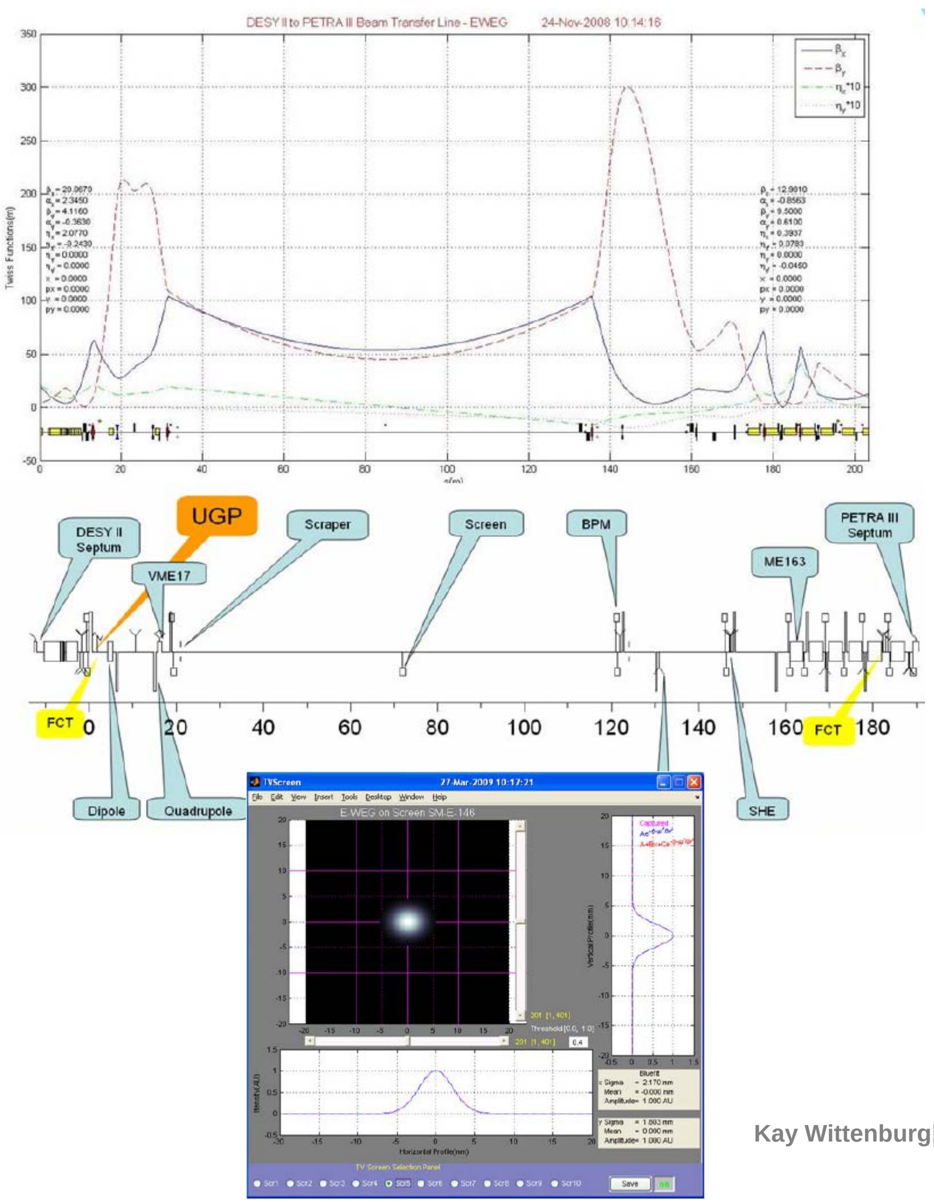




U. Isiso, Beam Size Measurements at ALBA, DEELS2014

Beam Dynamics Activities at PETRA III, Alexander Kling and Rainer Wanzenberg, Beam Dynamics Newsletter No. 62, 2013

Emittance at Injection: DESYII -> PETRA III



Quadrupole Scan Method

For the quadrupole scan method measurements with one screen monitor downstream a quadrupole is already sufficient. By changing the focusing strength k of a quadrupole upstream of the screen all elements of the Σ_1-matrix at the entrance of the quadrupole can be determined. One screen is sufficient because the total transfer matrix $M = M_q(k) \cdot M_d$ will change with k.

The N measurements of the beam size σ_j^2 at the screen at position 2 can be written in matrix form as

$$\begin{pmatrix} \sigma_1^2 \\ \sigma_2^2 \\ \cdots \\ \sigma_N^2 \end{pmatrix} = \begin{pmatrix} M_{1,11}^2 & 2M_{1,11}M_{1,12} & M_{1,22}^2 \\ M_{2,11}^2 & 2M_{2,11}M_{2,12} & M_{2,22}^2 \\ \cdots & \cdots & \cdots \\ M_{N,11}^2 & 2M_{N,11}M_{N,12} & M_{N,22}^2 \end{pmatrix} \cdot \begin{pmatrix} \Sigma_{1,11} \\ \Sigma_{1,12} \\ \Sigma_{1,22} \end{pmatrix}$$

and can be solved (if $N > 3$) for the vector on the right side by using a least-squares fit minimizing the χ^2-function

$$\chi^2 = \sum_{j=1}^{N} \left(\frac{\sigma_j^2 - M_{j,11}^2 \Sigma_{11} - 2M_{j,11}M_{j,12}\Sigma_{12} - M_{j,22}^2 \Sigma_{22}}{2\sigma_j \Delta(\sigma_j)} \right)^2$$

with the errors of the beam size measurements $\Delta(\sigma_j)$ taken from a 2D-fit of the beam profiles.

DESY

Emittance at Injection: DESYII -> PETRA III

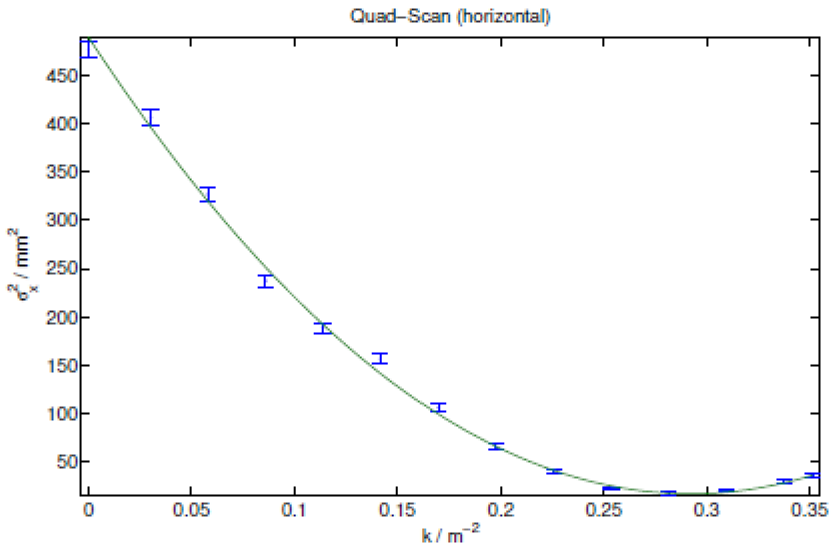
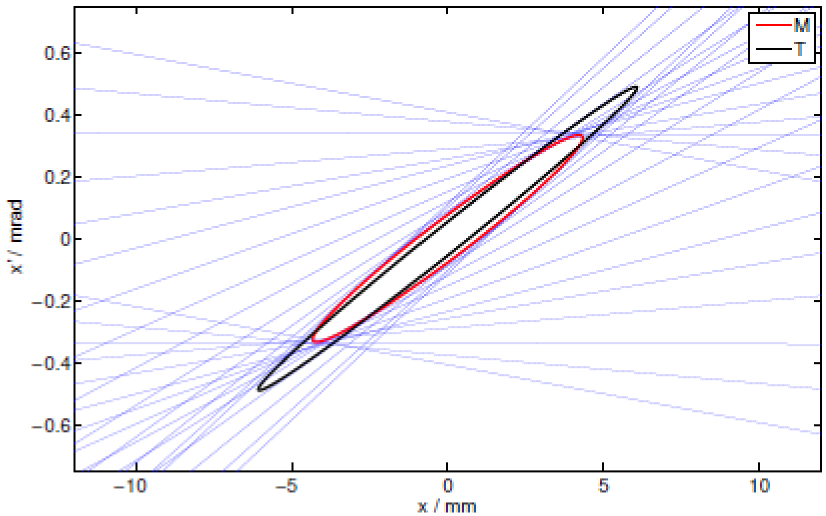


Figure 3: Square of the horizontal beam size as a function of the focusing strength of quadrupole QE019.

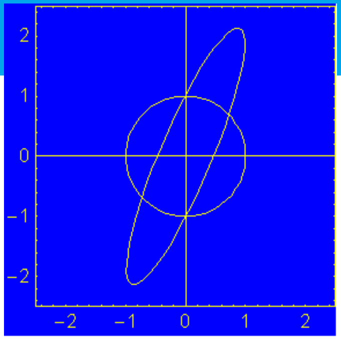
Table 1: Results of the Quadrupole Scan Measurements

	Theory		Measurement	
	5 GeV	6 GeV	5 GeV	6 GeV
ϵ_x / nm·rad	241	331	253 ± 6	335 ± 12
ϵ_y / nm·rad	24	33	10 ± 0.5	15 ± 0.5
β_x / m	111	111	53 ± 2	56 ± 2
β_y / m	120	120	56 ± 4	56 ± 3
α_x	-8.9	-8.9	-3.8 ± 0.1	-4.2 ± 0.2
α_y	11.9	11.9	6.2 ± 0.4	5.9 ± 0.3

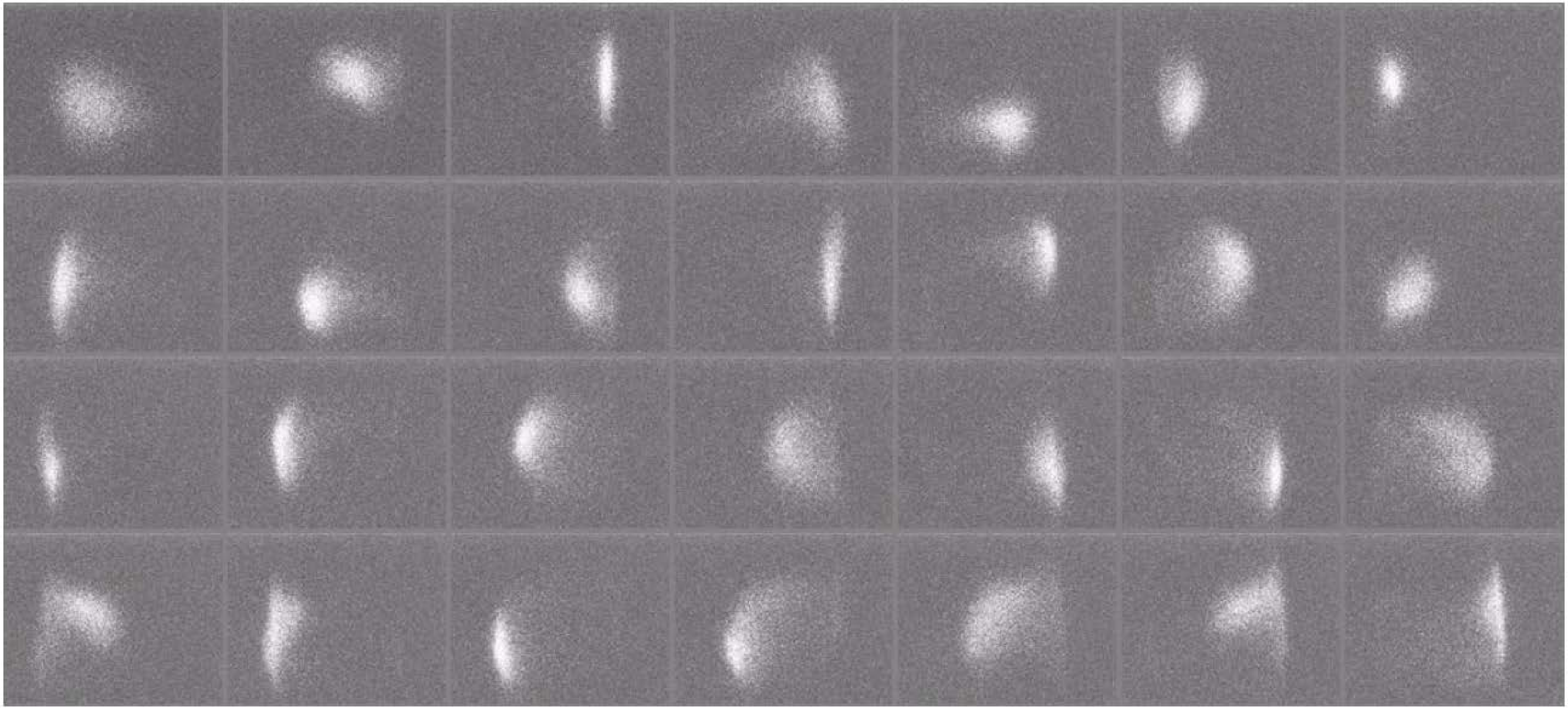
Quadrupole_Scan_Measurements_in_the_Beam_Transport_Line between DESY II and PETRA III; J. Keil etal., IPAC'17, Copenhagen, Denmark



Beam Size: Optic Mismatch



Beam quadrupole oscillations due to injection optic mismatch by fast gated SR light camera



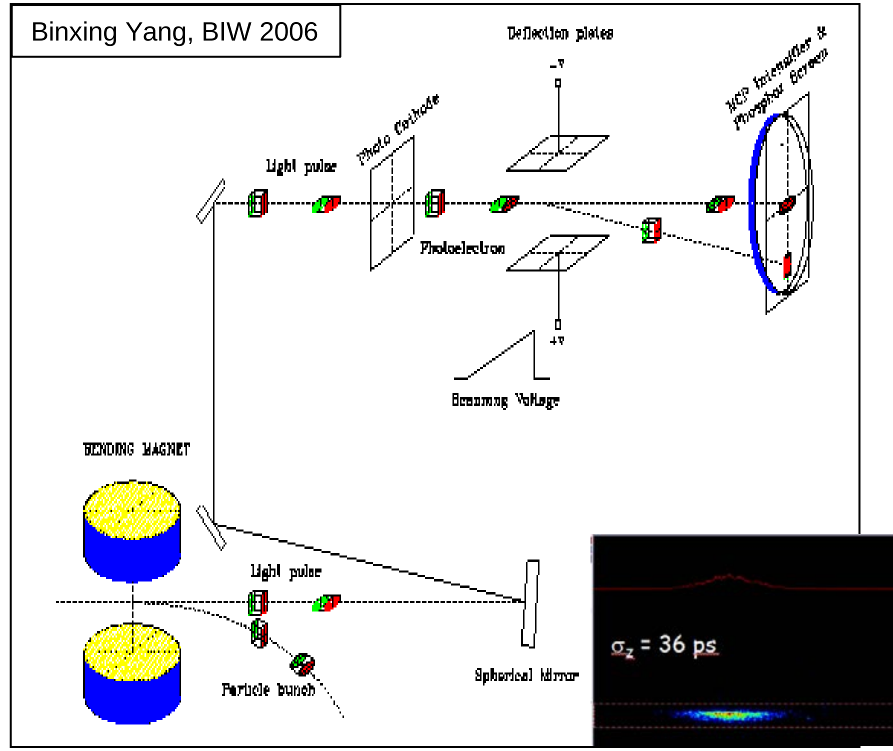
Diagnostics for Physics Applications at SPEAR3, J.J. Sebek, et al.; BIW12, Newport News

I. Bunch Length; Devices

3rd Generation: req. resolution ≈ 2 ps

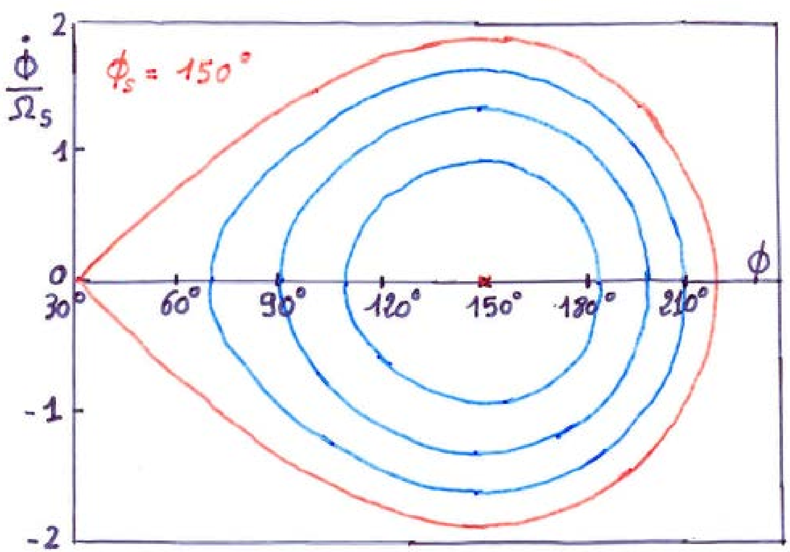
- > Optical Streak Camera
- > Fast Photodiodes
- > Incoherent spectral analysis
- > At low α Optics:
  - Electro-Optical Sampling
  - Coherent SR,
  - …
- > …

Binxing Yang, BIW 2006



Bunch Length; what defines bunch length in the machine?

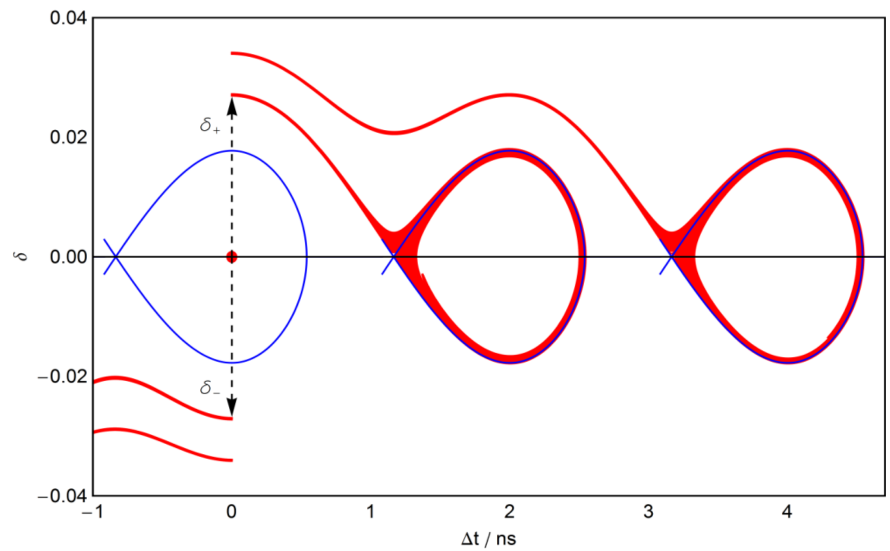
> Long. synchrotron oscillation defines bunch length to ≈ 40 ps



$\dot{\Phi}^2/\Omega_S \sim \Delta E/E,\ \Phi \sim z \sim t$

Area within the separatrix is called "RF bucket".

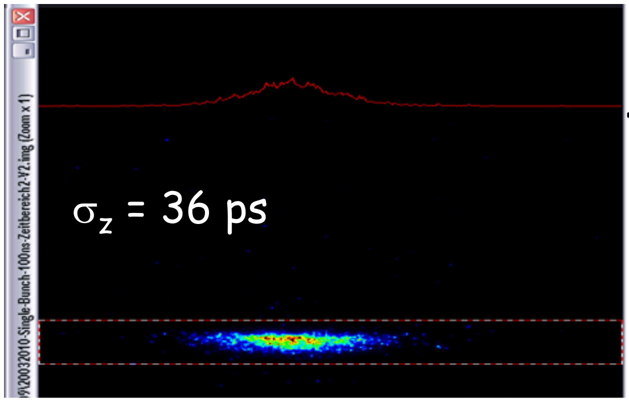
CERN Accelerator School



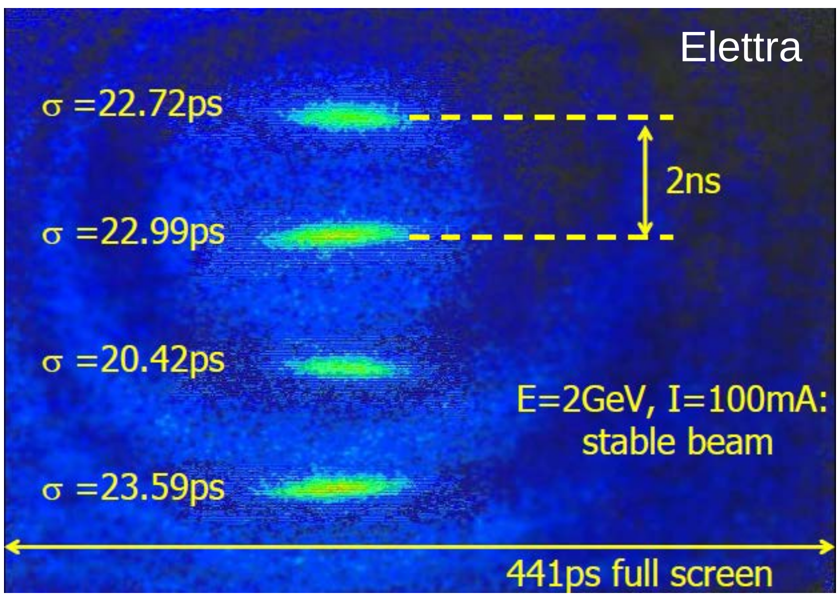
Touschek scattering and recapturing in following buckets shown in the longitudinal phase space

Bunch length measurements, Energy spread

Stable beam conditions



<-PETRAIII



courtesy M. Ferianis, Elettra; H.Ch. Schröder, DESY

Energy Spread:

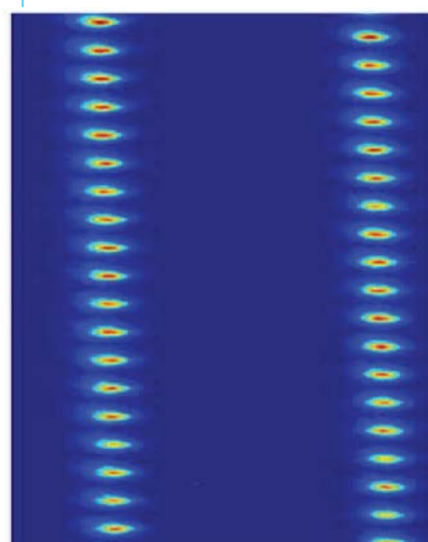
> Beam width enhancement at high dispersion ~ Energy spread

> Bunch Length ~ Energy spread

$$\sigma = \alpha/2\pi f_s * \Delta p/p$$

with α = momentum compaction factor, f_s = synchrotron frequency

σ = 36 ps => $\Delta p/p = 1.1 \cdot 10^{-3}$ at PETRA III



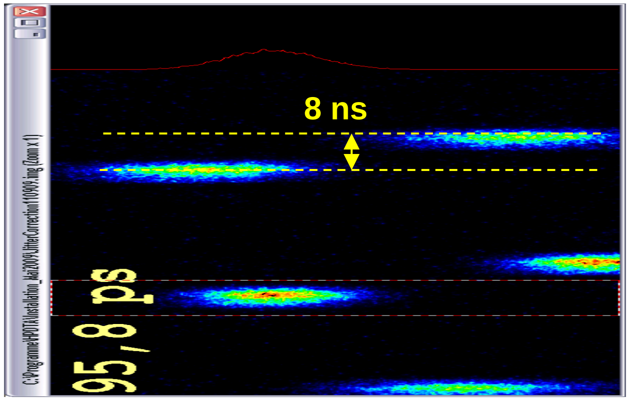
Stable beam, Multibunch Feedback on

Bunch by Bunch Beam Diagnostics in SSRF
Yongbin Leng, et al, IPAC12, New Orleans

Bunch length measurements

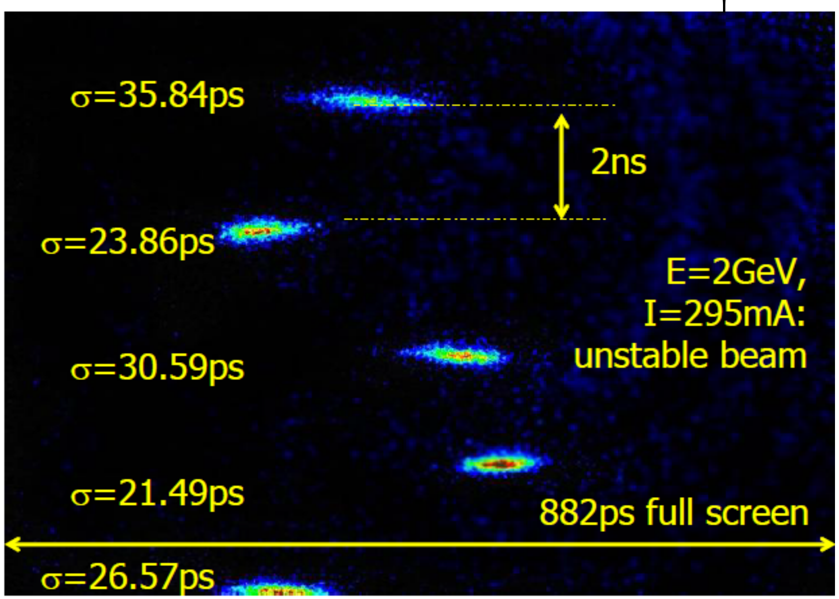
Unstable beam conditions

> Multibunch Feedback: off



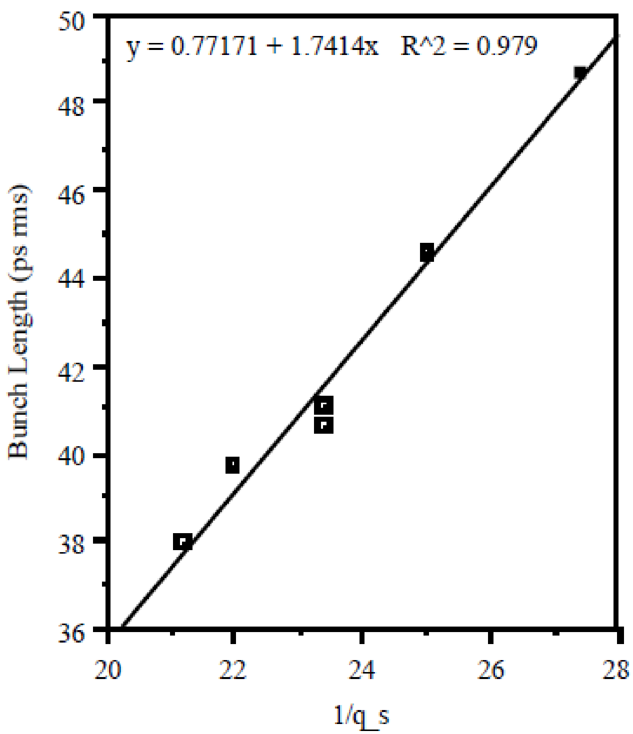
<-PETRAIII

Elettra



courtesy M. Ferianis, Elettra; H.CH. Schröder, DESY

Bunch Length measurements: α_c

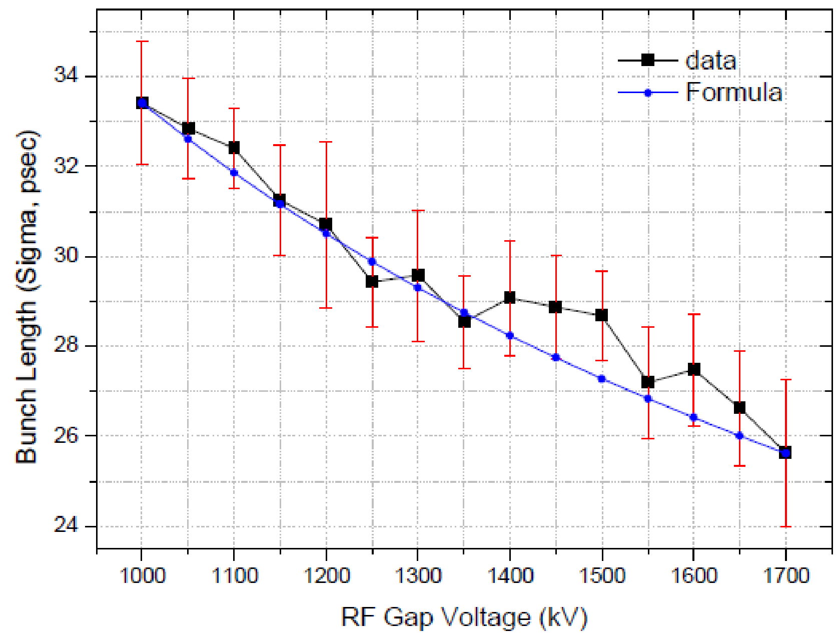


$$\sigma = \alpha / 2\pi f_s * \Delta p / p$$

FIGURE 3. Variation of bunch length with the inverse of the synchrotron tune, for a single bunch at 1 mA.

=> Momentum Compaction Factor α_c

A. S. Fisher at al., Streak-Camera Measurements of the PEP-II High-Energy Ring, BIW'98

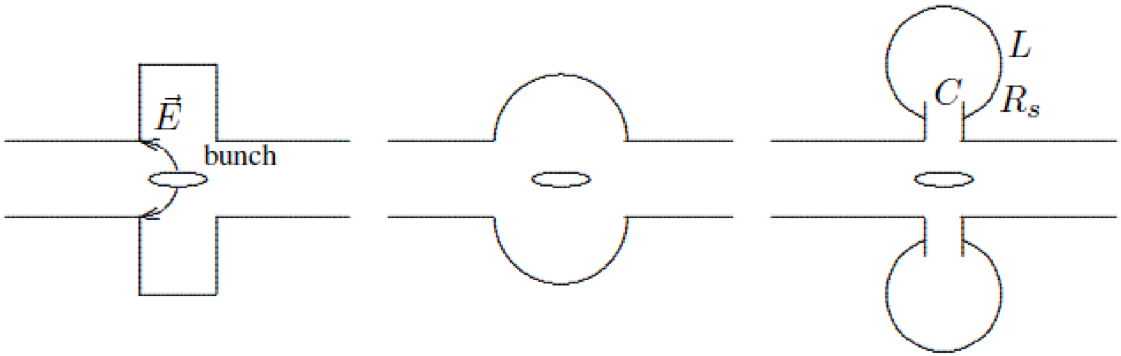


$$\sigma_z = \sqrt{\frac{2\pi\alpha_c E \sigma_E^2}{hV\cos\phi_s \omega_{rev}^2}}$$

,where σ_z is the bunch length, α_c is the momentum compaction factor, E is the beam energy, h is the harmonic number, V is RF gap voltage, ϕ_s is the synchronous phase, and ω_{rev} is the angular revolution frequency.

Commissioning of a New Streak Camera at TLS for TPS Project, C.Y. Liao, IBIC2013

Ring Impedance



A ring may have many aperture changes which can form cavity-like objects as shown in Fig. 67 in exaggerated form. They have many resonances, each being approximated by an RLC resonator having a resonant frequency ω_{ri}, shunt impedance R_{si}, and quality factor Q_i. We develop their impedances $Z_i(\omega)$ for small frequencies $\omega < \omega_\mathrm{r}$, where it is inductive

$$Z(\omega) = R_{si}\frac{1 - jQ\frac{\omega^2-\omega_\mathrm{r}^2}{\omega\omega_\mathrm{r}}}{1 + \left(Q\frac{\omega^2-\omega_\mathrm{r}^2}{\omega\omega_\mathrm{r}}\right)^2} \approx j\frac{R_{si}\omega}{Q\omega_\mathrm{r}} + \ldots .$$

Summing over all aperture changes and their resonances we get the inductance L of a ring at low frequencies $\omega \ll \omega_{ri}$. It turns out that its impedance divided by the mode number $n = \omega/\omega_0$ is a useful parameter which gives a good description of the ring impedance at low frequencies:

$$\left|\frac{Z}{n}\right|_0 = \sum_k \frac{R_{sk}\omega_0}{Q_k\omega_{rk}} = L\omega_0 = L\frac{\beta c}{R} .$$

A. Hofmann, Dynamics of beam diagnostics, CAS Dourdon 2008

$$\omega \;= \omega_r \;\rightarrow\; Z_\mathrm{r}(\omega_r) \text{ has a maximum while } Z_\mathrm{i}(\omega_r) = 0$$
$$|\omega| < \omega_r \;\rightarrow\; Z_\mathrm{i}(\omega) > 0 \text{ (inductive)}$$
$$|\omega| > \omega_r \;\rightarrow\; Z_\mathrm{i}(\omega) < 0 \text{ (capacitive)}$$

Bunch length vs. bunch current: Ring Impedance

Below the microwave threshold, we can fit the measured bunch lengthening versus bunch current I_b to Zotter's potential-well distortion formula [7]:

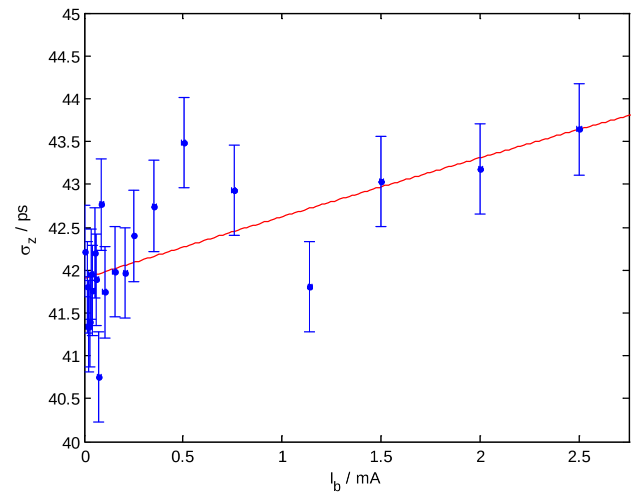
$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} = \frac{1}{\sqrt{2\pi}}\frac{\alpha_c e I_b}{E_0 \nu_{s0}^2}\left(\frac{c}{\omega_{\text{rev}}\sigma_{z0}}\right)^3 \text{Im}\left[\left(\frac{Z}{n}\right)_{\text{eff}}\right] \quad (2)$$

to find the reactive component of the effective impedance and so estimate the ring's broadband inductance L:

$$L\omega_{\text{rev}} = \text{Im}\left[\left(Z/n\right)_{\text{eff}}\right] \quad (3)$$

Here E_0 is the beam energy and ν_{s0} is the low-current synchrotron tune.

PETRA III



Im(Z/n$_{\text{eff}}$) = -0.038 Ω/m

J. Keil, Low Emittance Rings 2014 Workshop, INFN-LNF

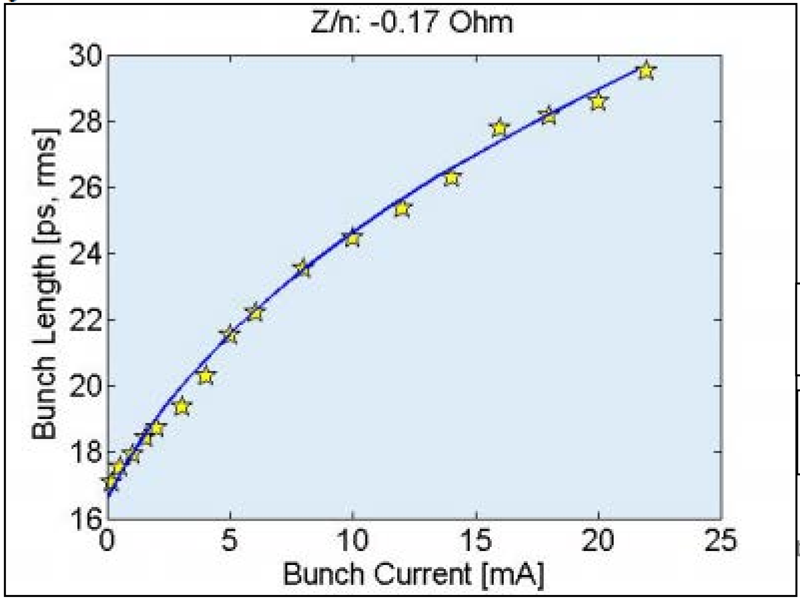


Figure 5: rms bunch length vs. single-bunch current. The fitted curve yields σ_τ=16.7ps and Z/n=-0.17Ω.

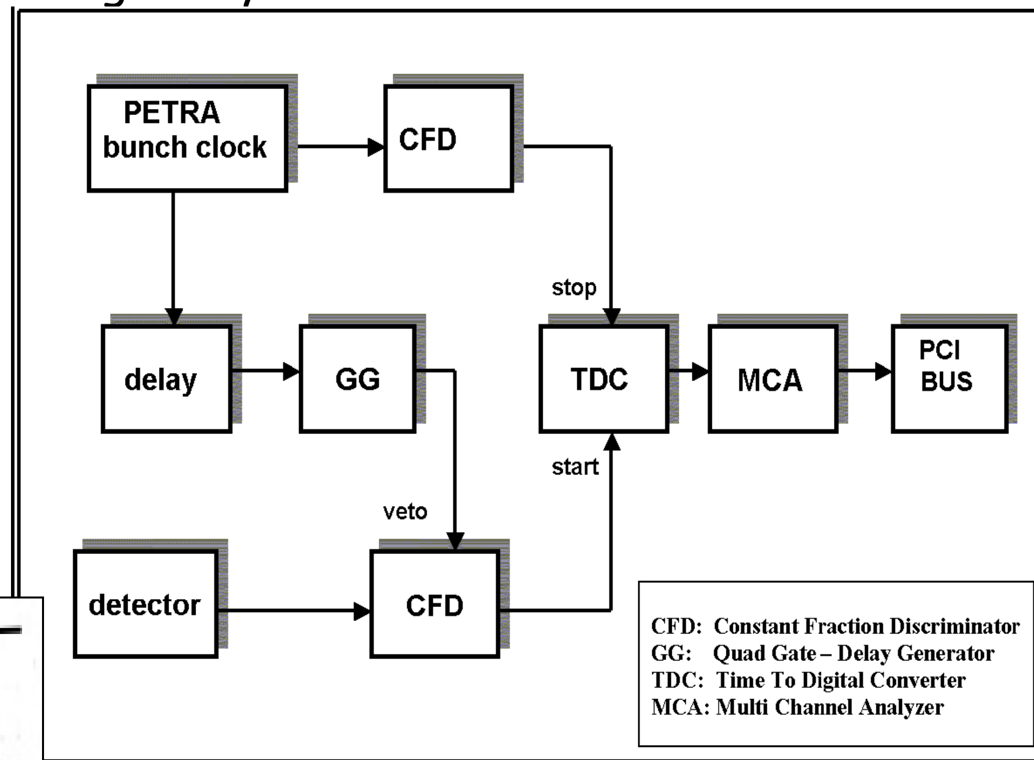
Bunch Length Measurements in SPEAR3
Jeff Corbett et al., PAC 07,

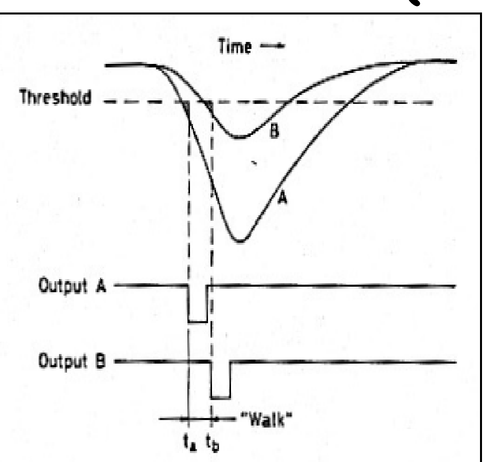
Bunch length: Bunch Purity measured by TCSPC

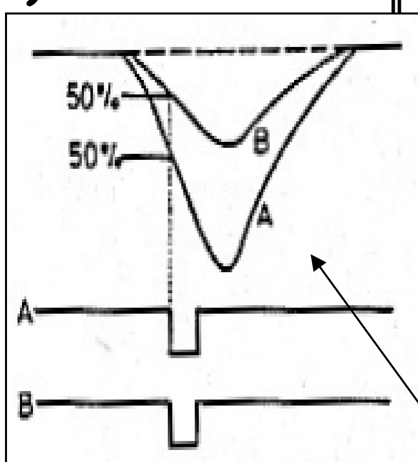
Time-correlated single photon counting method

The **arrival time of single photons** emitted by the electron bunches passing through a particular dipole in the storage ring **is measured**. The photon arrival time is measured relative to a clock pulse which is **synchronized to the bunch revolution** frequency via the storage ring RF system.

The amplified signal is analyzed using a time-to-digital-converter (**TDC**) and a multichannel-analyzer (**MCA**). To reduce the influence of the so-called "walk" and to reduce the background due to electronic noise the amplified detector signal is filtered by a **constant-fraction-discriminator (CFD)**.





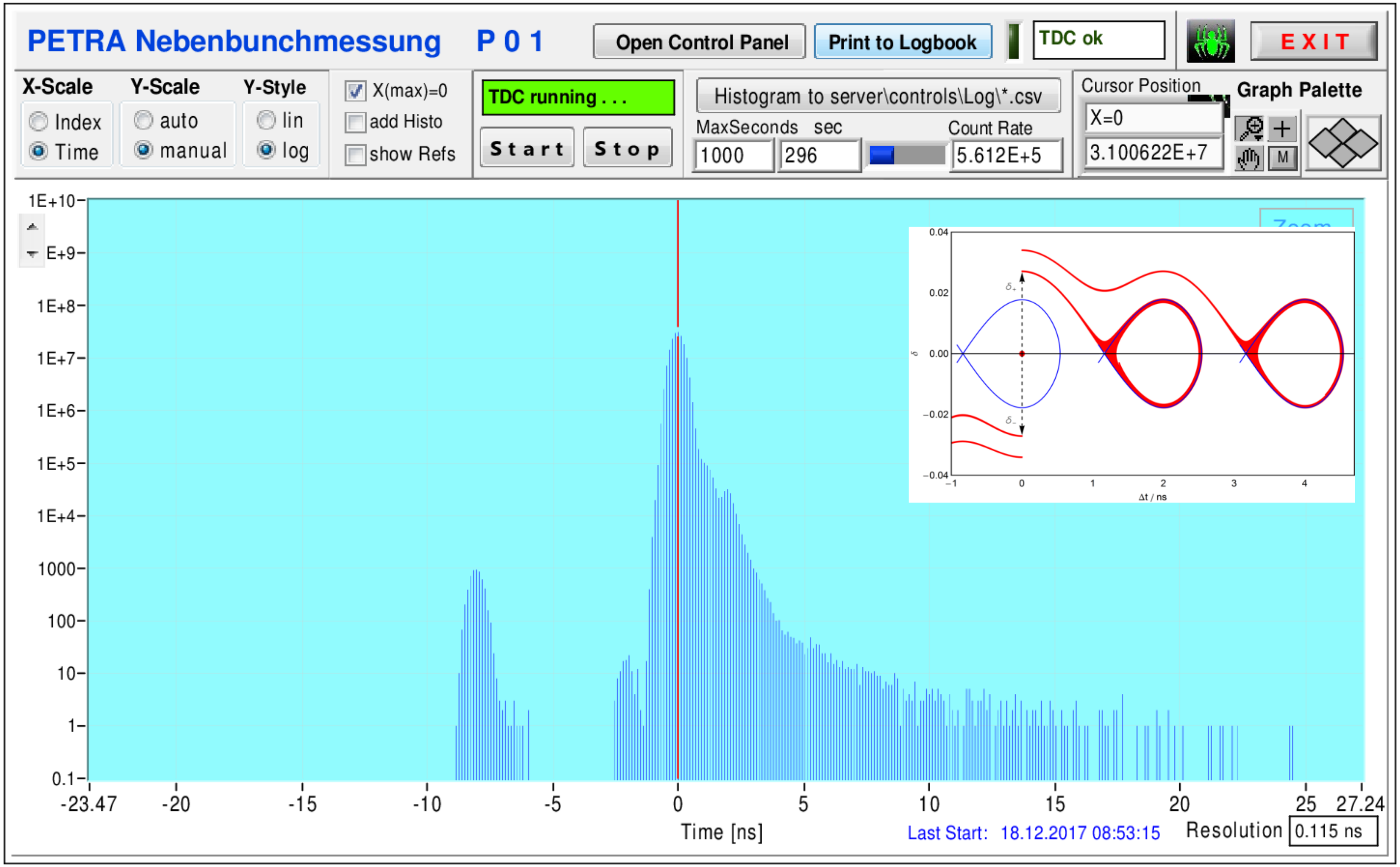


CFD

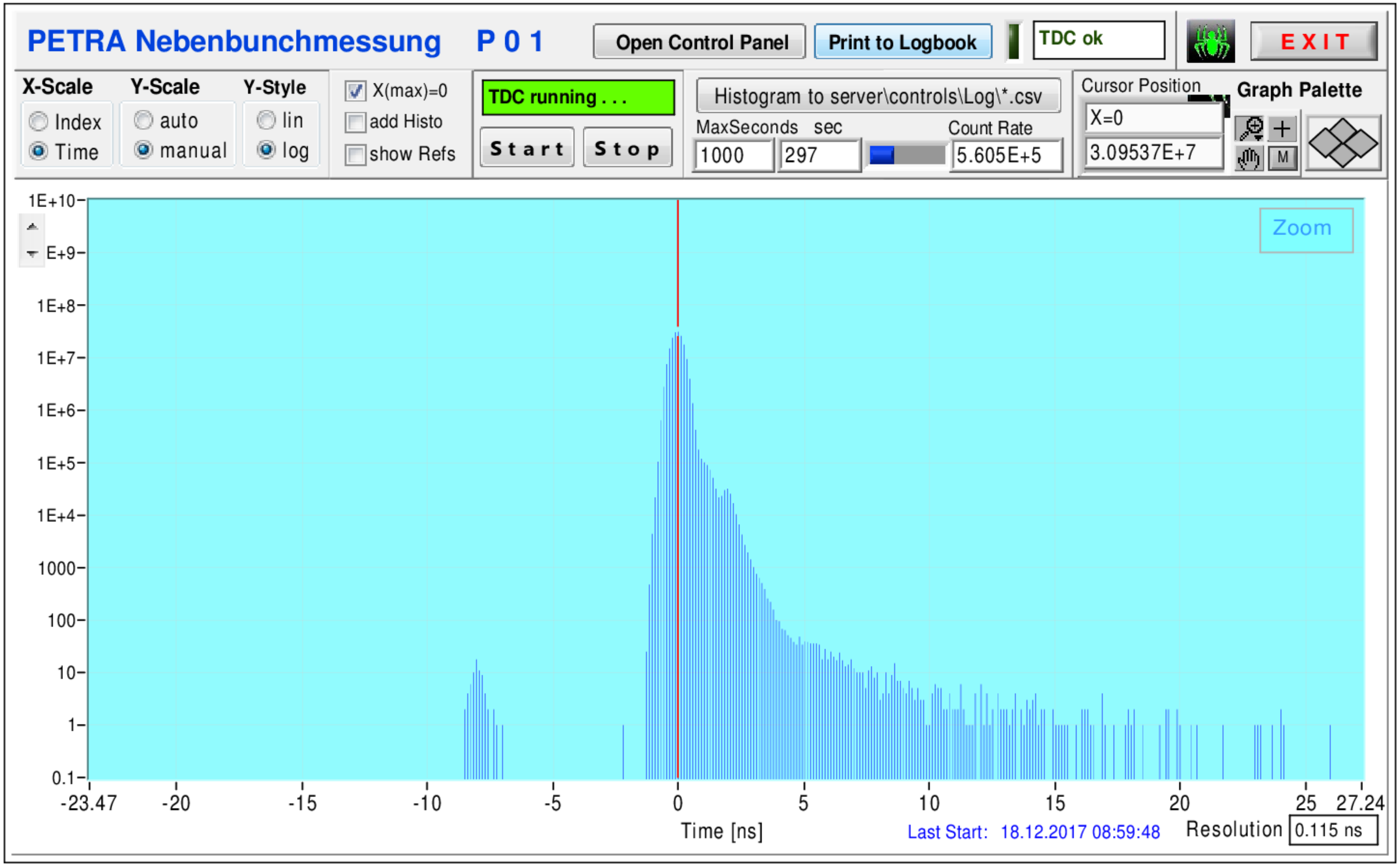
PARASITIC BUNCH MEASUREMENT IN e+/e– STORAGE RINGS, H. Franz et al., DIPAC 2003

Bunch Purity

Methode often used for filling pattern measurement at 500 MHz (2 ns) bunch distance

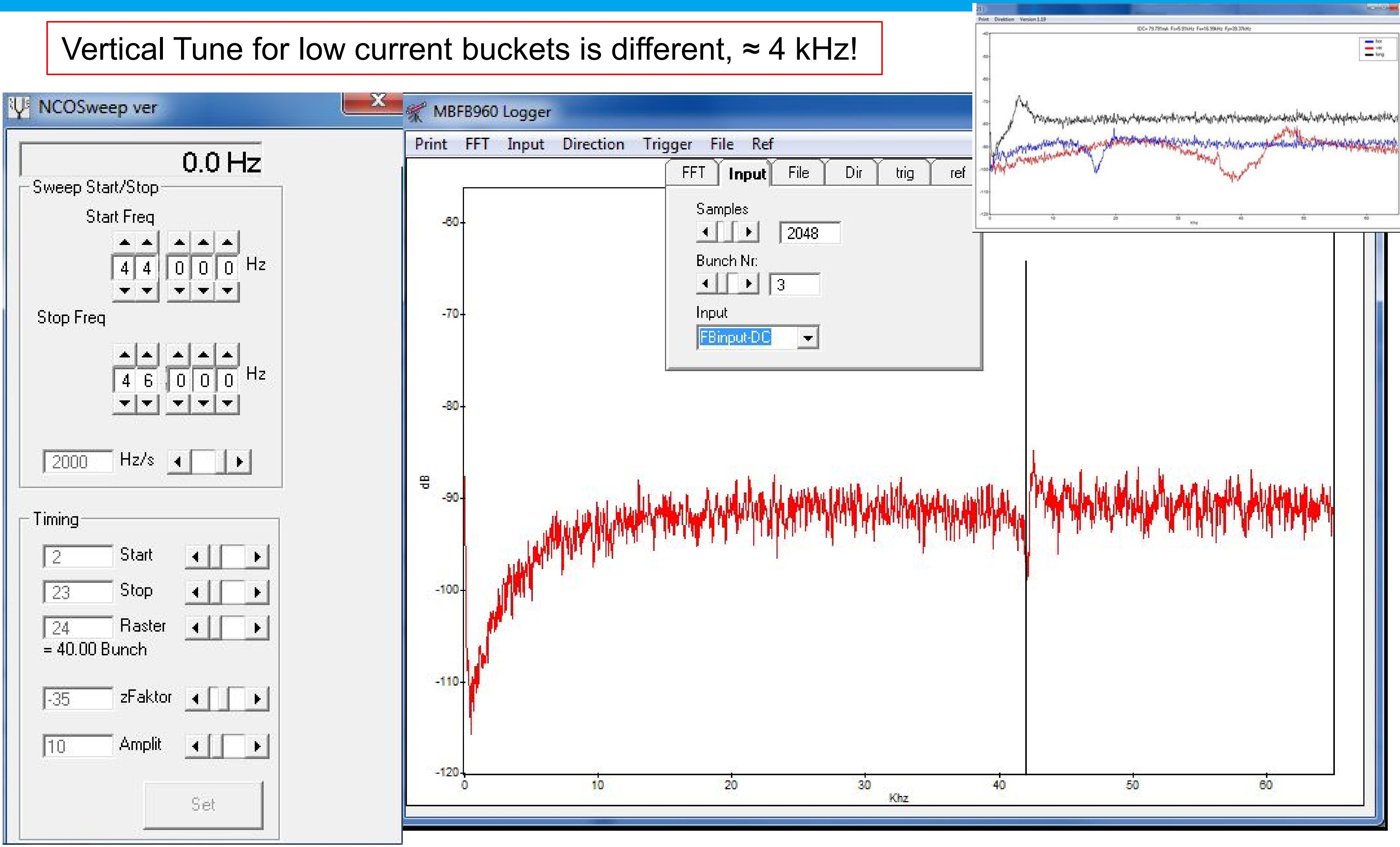


Bunch Cleaning



Bunch Cleaning by Tune excitation

Vertical Tune for low current buckets is different, ≈ 4 kHz!



Sweep for about 500 ms

BUNCHPURITYMEASUREMENTSATPETRAIII
J. Keil et al., IPAC2016, BEXCO, Busan Korea

Bunch Cleaning

The cleaning system we presently use at the ALS is based on the scheme in operation at the Spring 8 storage ring [11] and tested at the ESRF [12]. The system layout is shown in Fig. 6, two signals are mixed together, amplified and sent to a transverse kicker that applies the excitation to the beam. One of the signals is a sinusoidal excitation at the frequency of one of the transverse tune sidebands, while the other is a pseudo-square wave synchronous with the ring RF and with zero amplitude crossing at the position of each of the bunches that needs to be preserved. After the mixing, the resulting signal is still a resonant excitation at the selected tune frequency but with zero amplitude at the position where "good" buckets are located. Such a signal, properly

the vertical tune sidebands. The sinusoidal frequency is actually swept over a bandwidth of 4 kHz to account for tune shift on amplitude effects. The kicker, a stripline with a

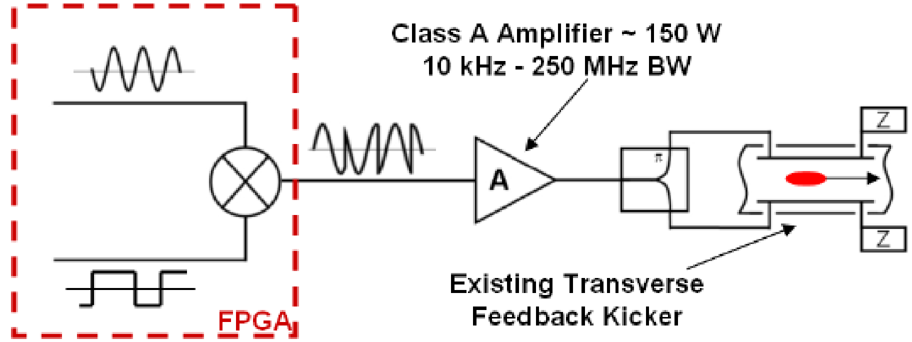
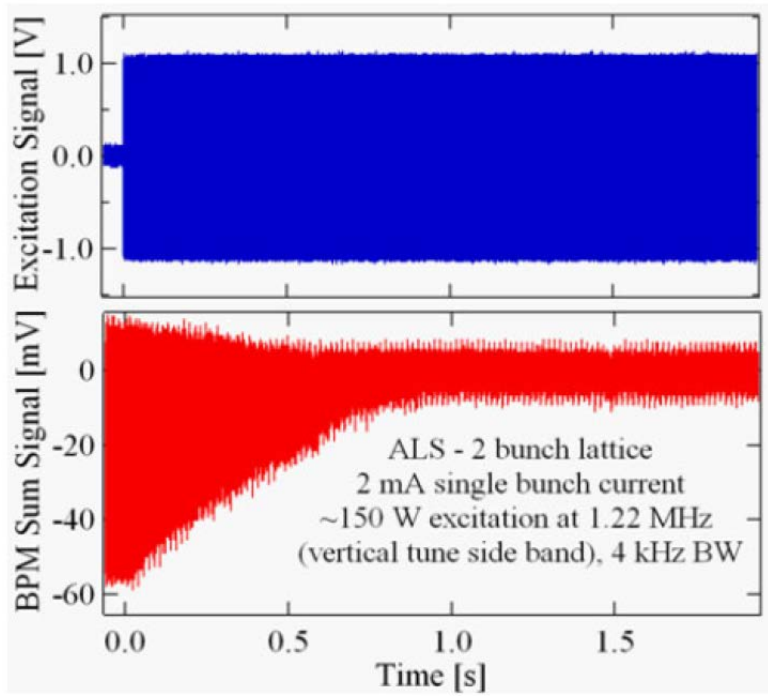


Figure 6. Bunch cleaning system layout.



Recent beam measurements and new instrumentation at the Advanced Light Source; Fernando Sannibale BIW08,Tahoe City

J. Beam Energy

Energy:

> Use of Dipole Calibration ≈ 1‰ but energy is 1% off at PETRAIII?

> Photon Based Measurements

> Resonant Depolarization ($\Delta E/E \approx 10^{-5}$)

Energy Measurement by Resonant Depolarization

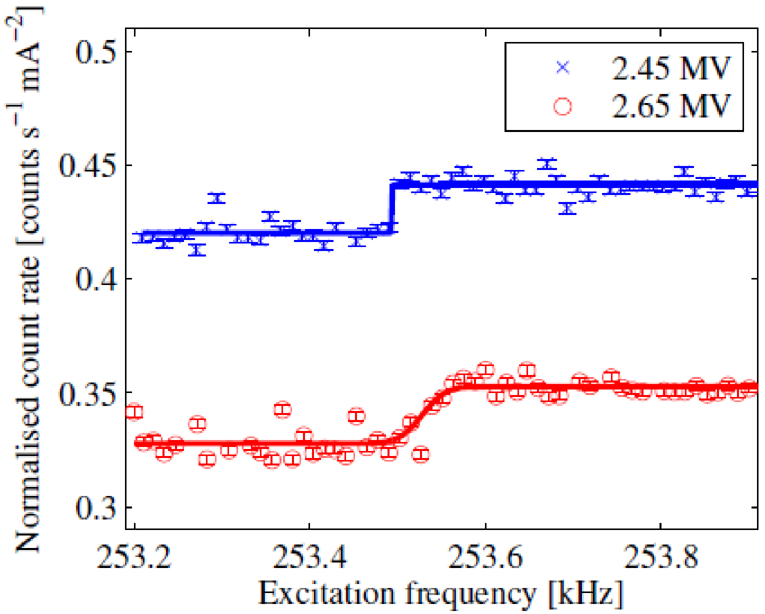
- **Idea:**
- Polarization of electron beams in storage rings is a diagnostic tool we get for free. A beam of electrons with spins of random orientations develops polarization under the Sokolov-Ternov effect.
- The average over all particles of the number of spin oscillations per revolution is defined as the spin tune (depends on Energy):

$$\nu = f_{spin}/f_{rev} = \frac{(g_e - 2)/2}{m_0 c^2} E_0$$

- g_e *=electron spin g-factor* = 2.002319
- Depolarize beam by exciting beam on ν, eg. by using vertical betatron tune striplines kickers.

At the SPEAR3 electron storage ring. The beam energy has been measured as 2.997251 (7) GeV, representing a relative uncertainty of 3×10^{-6}.

- **Measurement**
- Touschek cross-section depends on electron beam polarization -> Use loss monitor rate as a measure for polarization level.

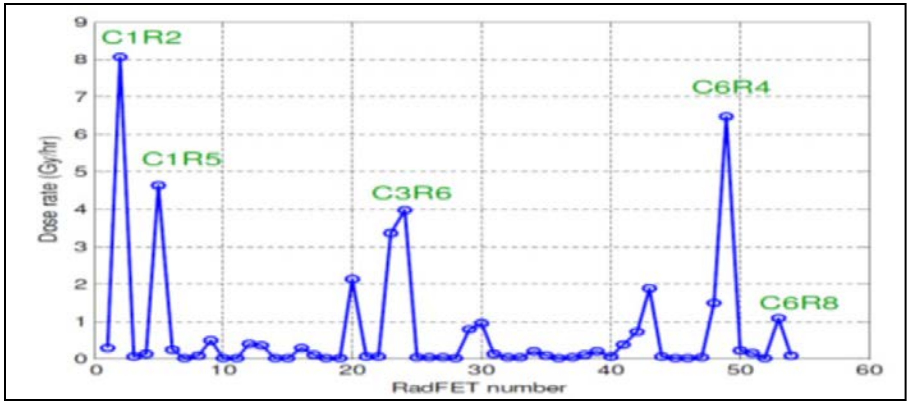


Resonant Depolarization (indep. of f_s)

Resonant Spin Depolarisation Measurements at the SPEAR3 Electron Storage Ring; K.P. Wootton,IPAC12

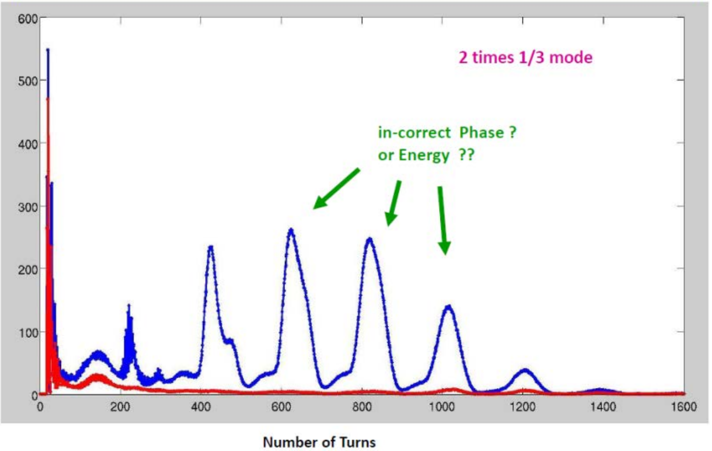
K. Beam Losses

Beam Losses around the Ring



The Role of Beam Diagnostics in the Rapid Commissioning of the TPS Booster and Storage Ring, P.C. Chiu, et al.; IBIC2015, Melbourne

Beam Loss over Time:



K. Scheid, ESRF, DEEL2014

ANKA

Figure 1: Installed PIN Diode Beam Loss Monitor with its power supply.

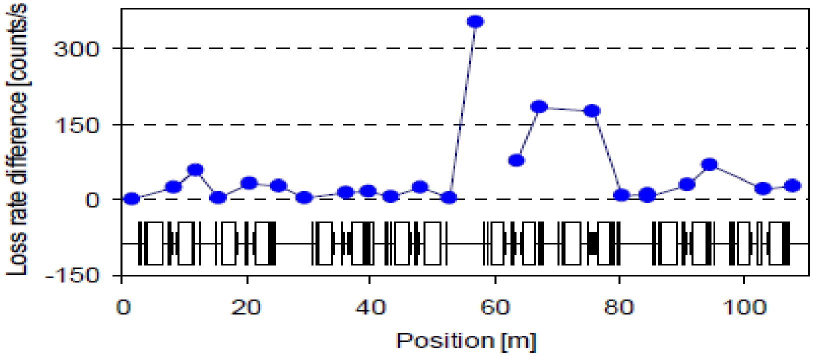
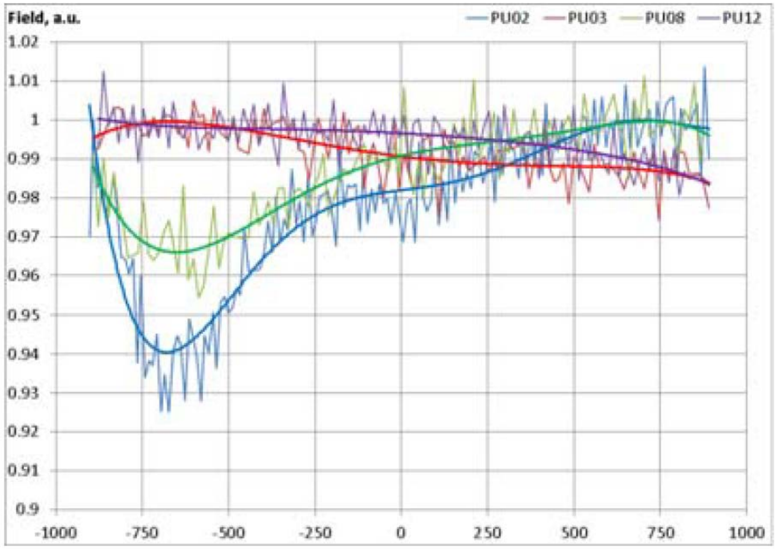


Figure 7: Losses during injection

STUDIES USING BEAM LOSS MONITORS AT ANKA
F. Pérez, et al,; EPAC 2004

Beam Losses in Undulators: Radiation Damage



Field reduction in undulators by radiation damage

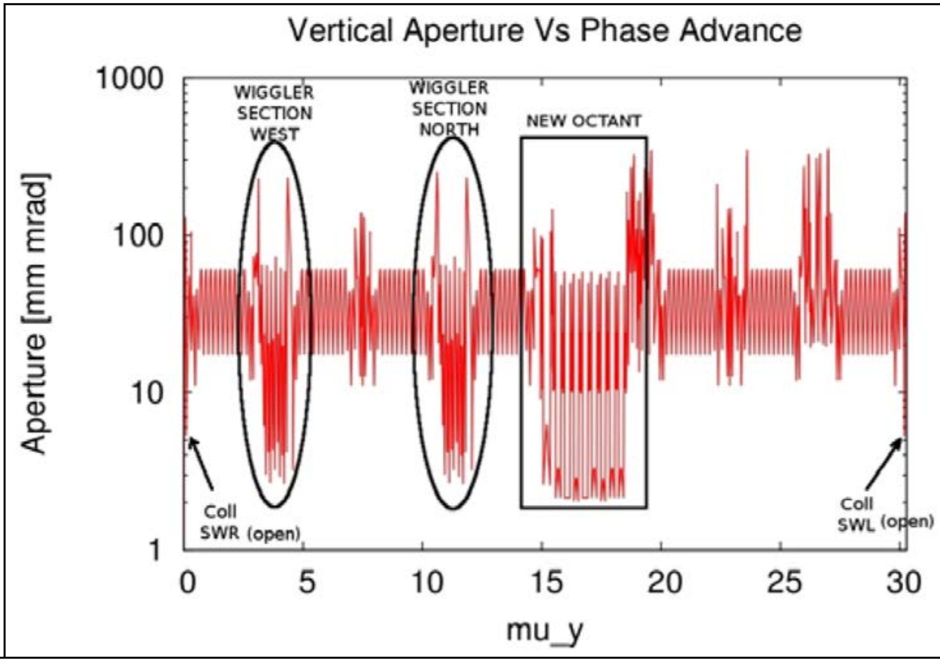
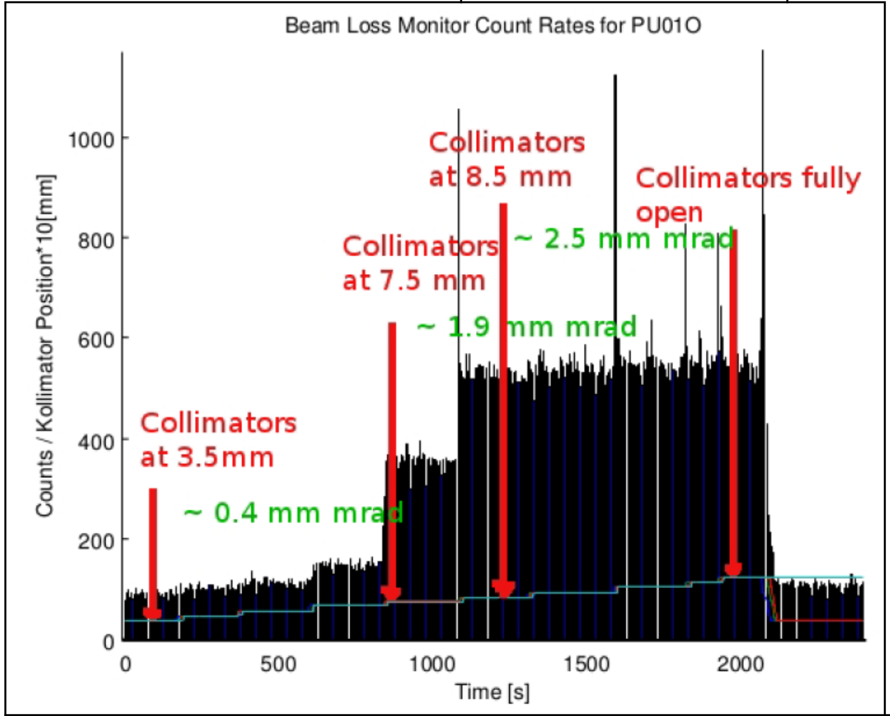


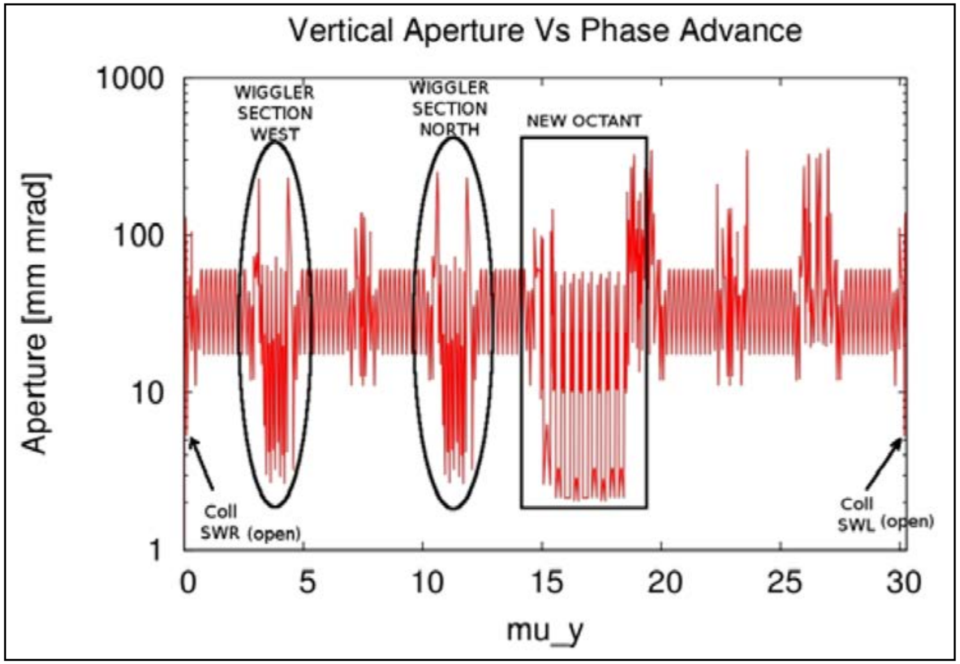
Figure 5: Normalized vertical aperture in PETRA III. Small vertical apertures are set by absorbers in the wiggler sections west and north and by the small gap chambers at the IDs in the new octant. The movable vertical collimators are closed down to ~0.4 mm mrad during user operation.

Beam Dynamics Activities at PETRA III, Alexander Kling and Rainer Wanzenberg, Beam Dynamics Newsletter No. 62, December 2013

Beam Losses in Undulators (small single bunch current)

2 areas independent of collimator position





100mA stored beam in 960 bunches

Figure 6: Counts measured at PIN-diode PU01(out) during top up operation with 100mA stored in 960 bunches. The set values of the collimators are varied during the measurement from nominal 3.5 mm (0.4 mm mrad) to fully open corresponding to 12 mm (4.8 mm mrad). The aperture set by the small gap undulator chamber at PU01 corresponds to 2.5 mm mrad.

Beam Dynamics Activities at PETRA III, Alexander Kling and Rainer Wanzenberg, Beam Dynamics Newsletter No. 62, December 2013

Beam Losses in Undulators (high single bunch current)

Not independent of collimator position

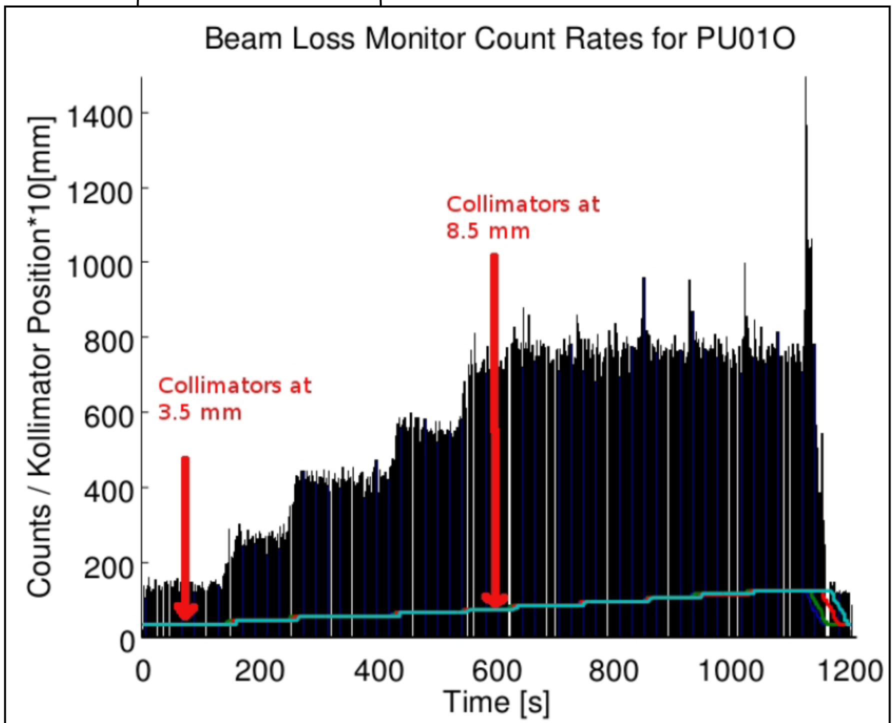
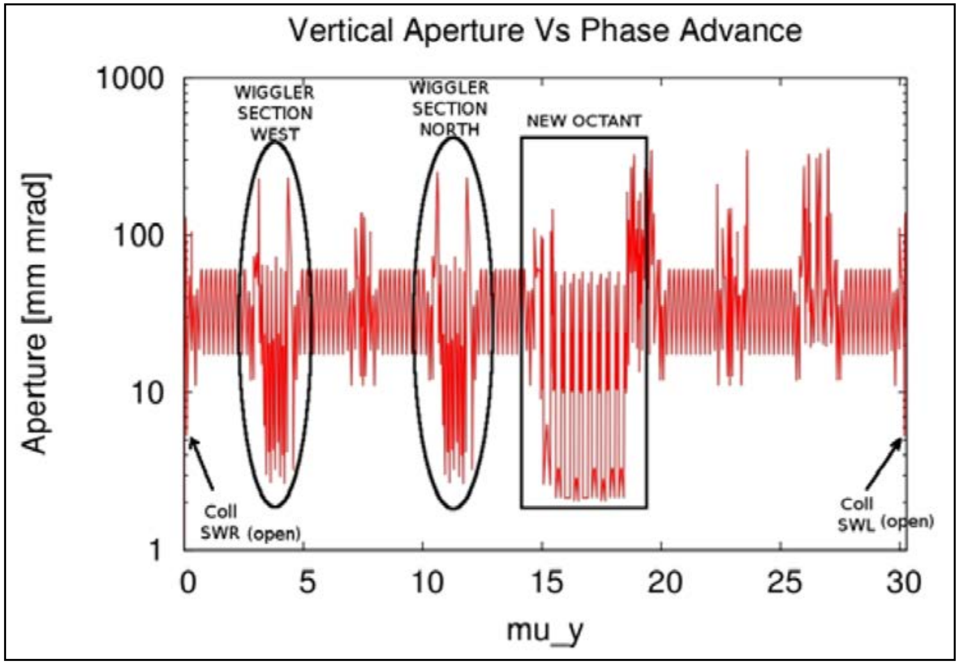


Figure 7: Counts measured at PIN diode PU01(out) during top up operation with 50mA stored in 40 bunches. The set values of the collimators are varied during the measurement from nominal 3.5 mm (0.4 mm mrad) to fully open corresponding to 12 mm (4.8 mm mrad). The aperture set by the small gap undulator chamber at PU01 corresponds to 8.5mm (2.5 mm mrad).



50 mA in 40 bunches

Lifetime dominated by Touschek scattering (around the ring!)

Beam Dynamics Activities at PETRA III, Alexander Kling and Rainer Wanzenberg, Beam Dynamics Newsletter No. 62, December 2013

An Outlook: Going to smaller Emittances