Beam feedbacks for control

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- Motivation
- Basic designs
- Examples for orbit feedbacks
- Monitor systems for longitudinal FB
- Longitudinal FB

Motivation for beam-FB

Motivation to use beam based feedbacks:

$\Rightarrow$ to improve machine stability

$\Rightarrow$ to increase machine performance

$\Rightarrow$ to enhance operability of machine

$\Rightarrow$ to improve the reproducibility

Why beam based?

-Because of technical, physical or financial reasons acceleration subsystems cannot be made drift/jitter free

-Ultimate goal: beam needs to be stable (not sub-systems)

-Beam based measurement can be more accurate

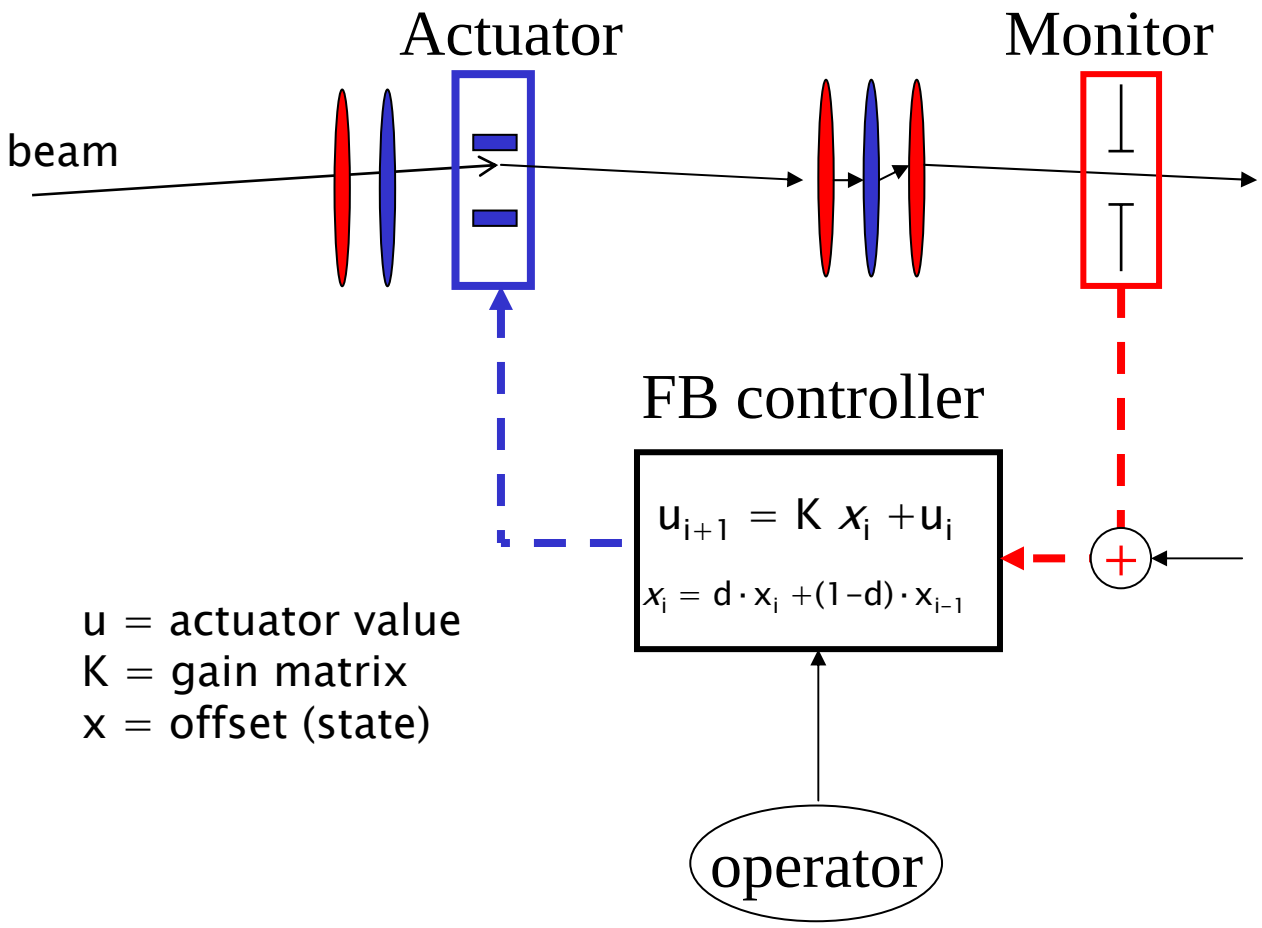
Errors sources

- for ‘slow’ drifts
  - Temperature changes in tunnel, buildings, devices, etc…
  - Regulators in electronics (vans, temperature controller, ripple of PS…)
  - Electromagnetic interference (other machines, civilization ,…)
  - Minor faults in linac devices and machine components
  - Ground motions
  - …
- fast variations and jitter
  - -RF phase and amplitude jitter
  - -Thermal heating within macro-pulse
  - -Photo cathode laser (power, profile, pointing stability)
  - -Fast injection or extraction kicker
  - -Multi-bunch effects (HOMs)
  - -Beam loading effects
  - -Feedback kicker !
  - -…

More reasons for beam based FB

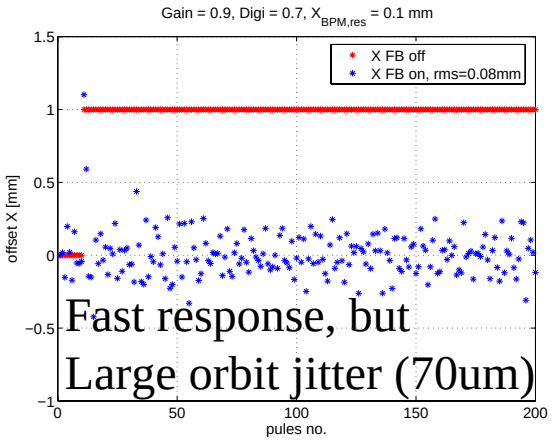
- decouple machine sections
  - -Injector orbit from orbit into linac
  - -Linac orbit into collimator
  - -Orbit through collimator from orbit in undulator, etc.
- decouple machine parameters
  - - RF phase change from orbit variation
  - - Momentum compaction from bunch length variation
  - - Charge and orbit, energy, bunch length
  - => significant step to understanding of machine performance
- enhance reproducibility of machine settings
  - - Independent of operator, asier to track
  - - Rely on stability of monitors instead of magnets, laser or RF
- compensate for faulty hardware
  - - e.g. sudden jump in orbit due to steerer problems, rapid phase drifts
- slow keeps fast FB in dynamic range
- much fast then operator response!

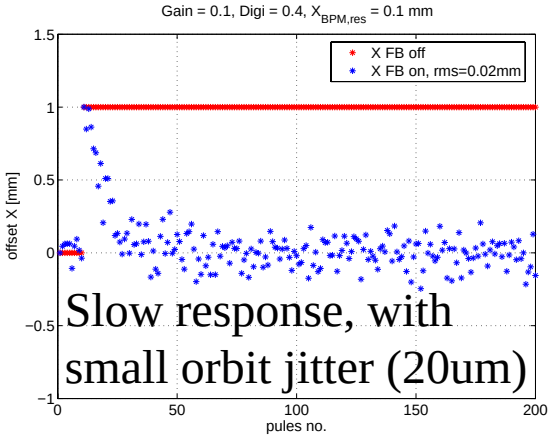
Scheme of beam-based FB



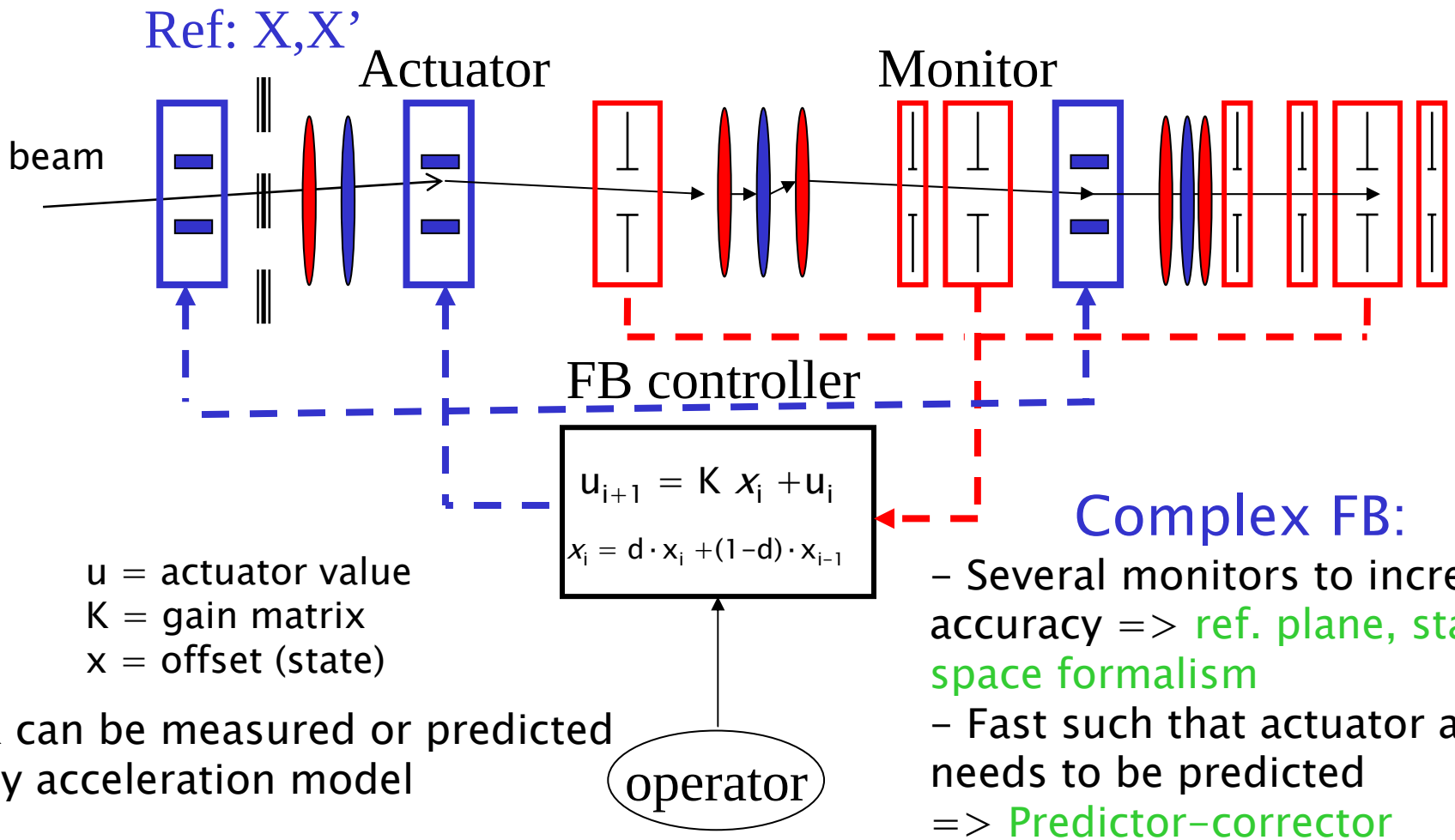
u = actuator value
K = gain matrix
x = offset (state)

Illustration of effect of FB parameters





Scheme of beam-based FB



u = actuator value
K = gain matrix
x = offset (state)

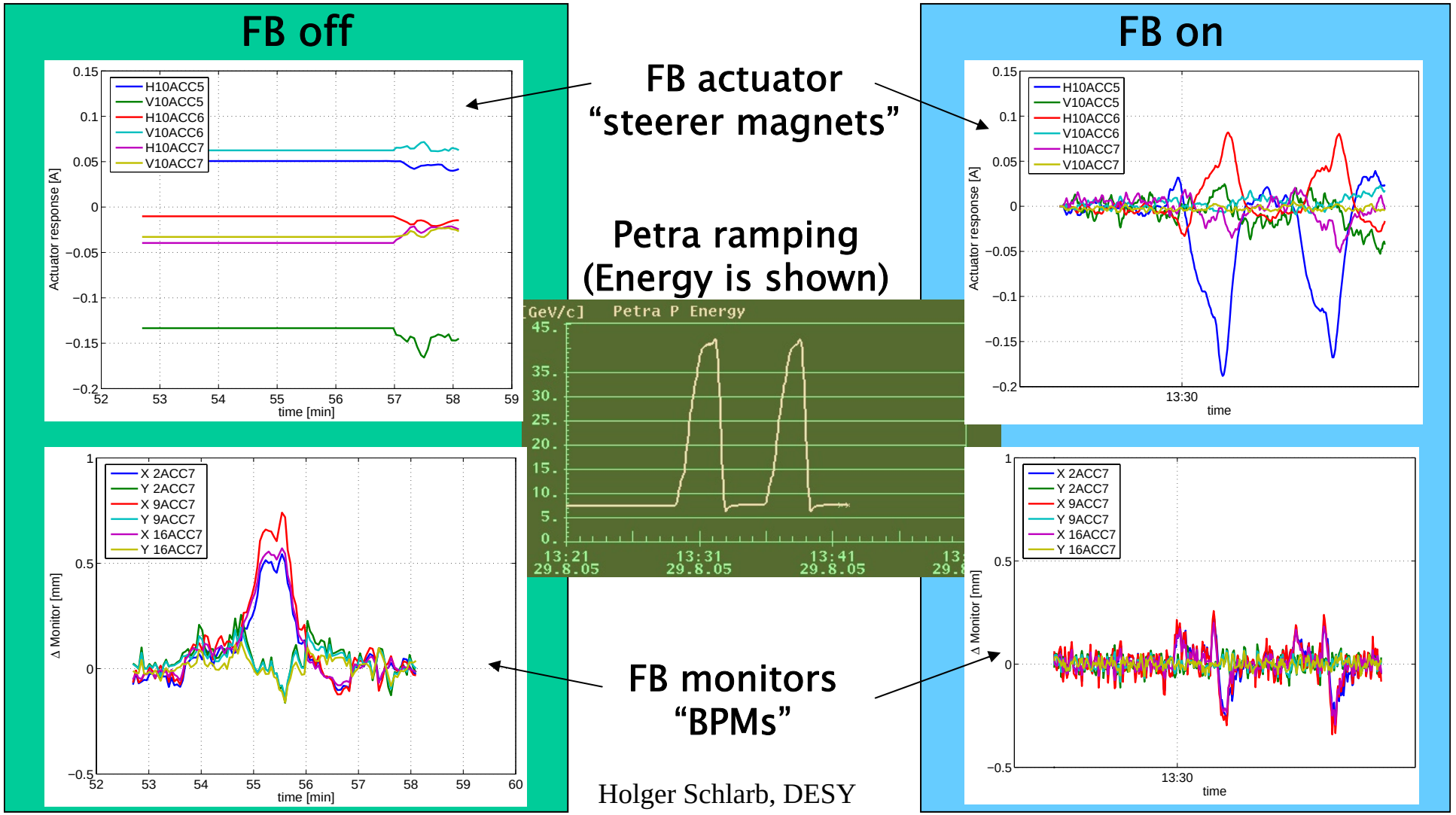
K can be measured or predicted by acceleration model

Complex FB:

- Several monitors to increase accuracy => ref. plane, state space formalism
- Fast such that actuator action needs to be predicted => Predictor-corrector formalism of dig. control theory
-Cascaded FBs …

See.: L. Hendrickson et al. (SLAC)

Example 1: slow orbit correction -magnetic perturbation by PETRA-



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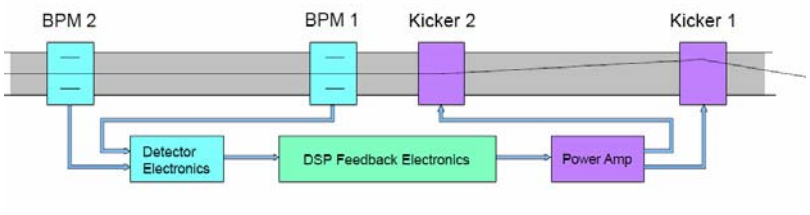
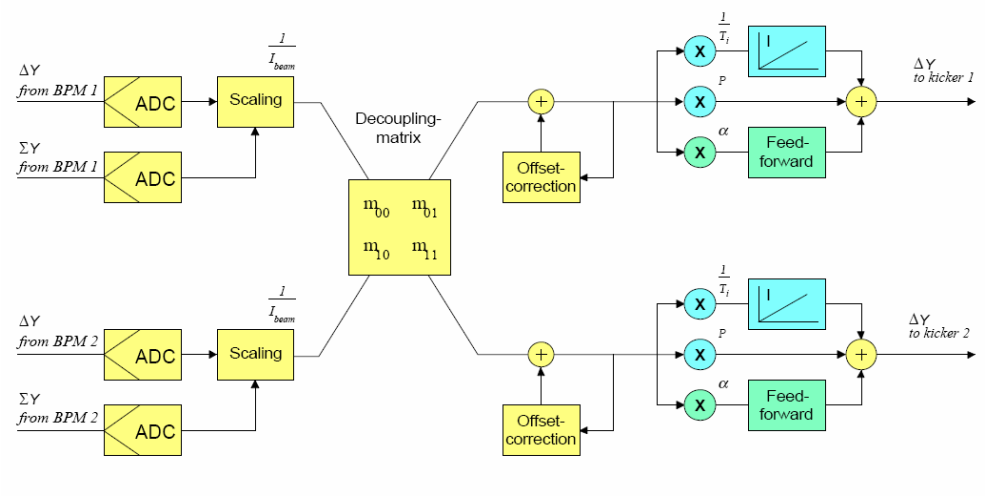
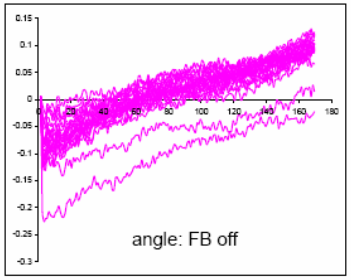
Example 2: fast orbit correction (TTF1) - orbit variation in macro-pulse 160us-

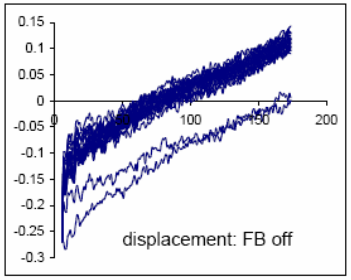
FB scheme:

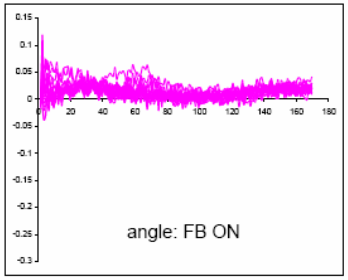


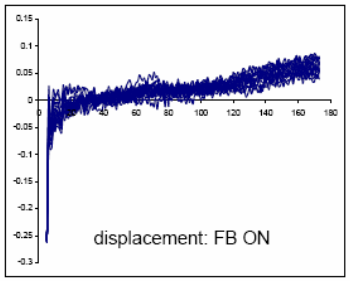
Fast controller:

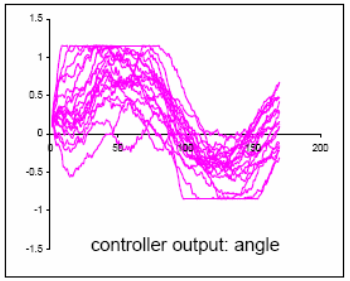


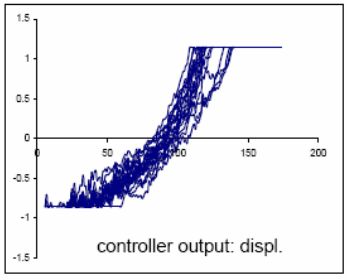








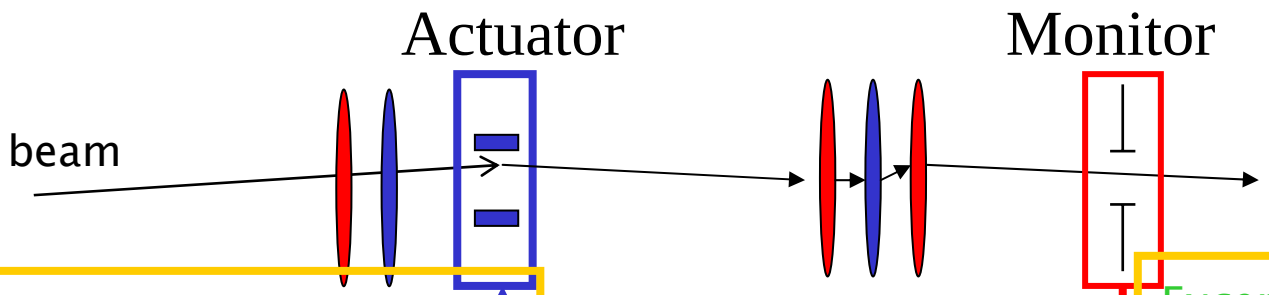




1/17/2006

Courtesies: Balewski, Duhme, Klute, Obier (DESY)

Exception handling: 80% of the work!



Exception handling Actuator
- in operation?
- read back == set point
- dynamic range?
- still in action
- responding?

Exception handling controller
- Acc. Model
- Data base
- Filters
- Predictor
- Loop parameter
- User interface
- Response matrix
- Communication

Exception handling Monitor
- in operation?
- rms noise performance!
- dynamic range?
- coupling?
- non-linear response
- timing ok

Exception handling beam
- beam modes
- machine mode
- transmission
- beam interlock
- RF sub-systems in operation
- Fast FB in operation
- Slow FB in operation

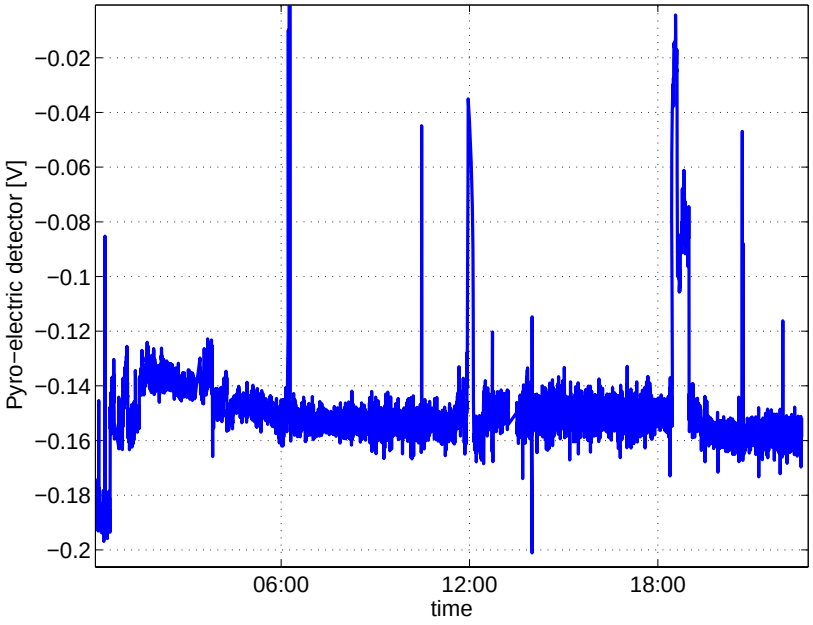
- Particular critical for open loop systems
- Acceptance of operators

Beam based longitudinal FB

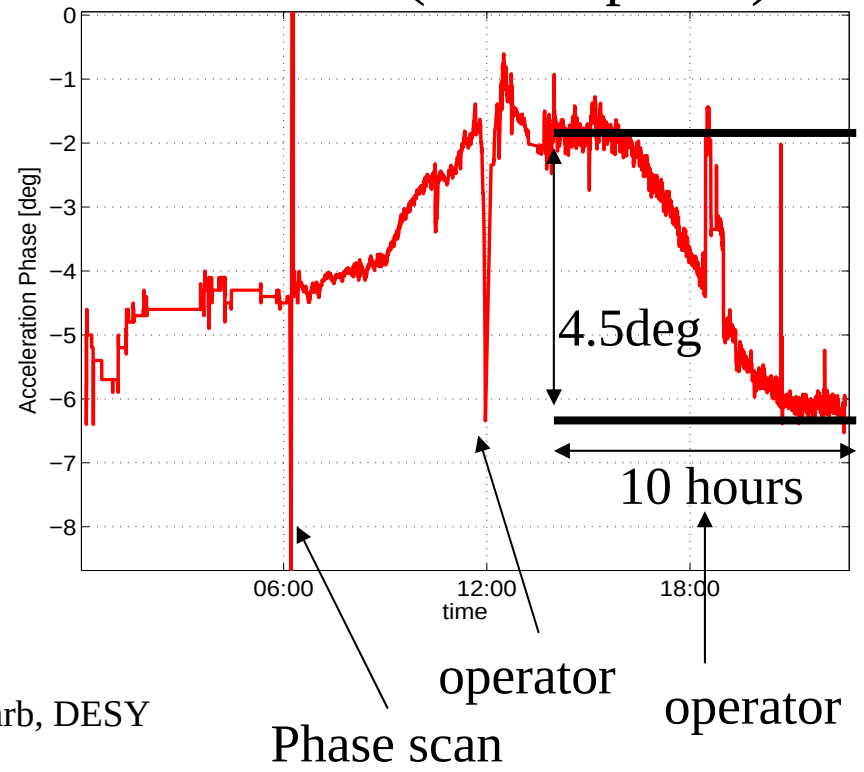
Particular critical for FEL due to compression of electron bunch

Examples: ‘Bunch length monitor’ to detect phase drifts (day/night)

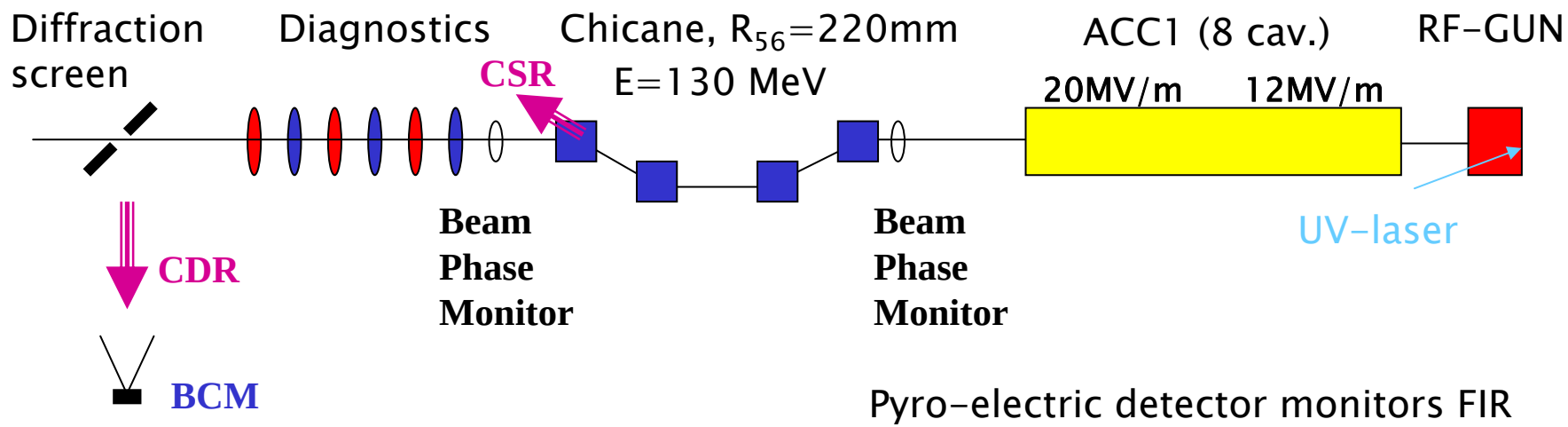
Monitor



Actuator (ACC1 phase)



Beam compression monitor (BCM) for RF ACC1 feedback



$$P = P_0(\lambda)\, T(\lambda)\, \rho^2(\lambda)\, N_e^2$$

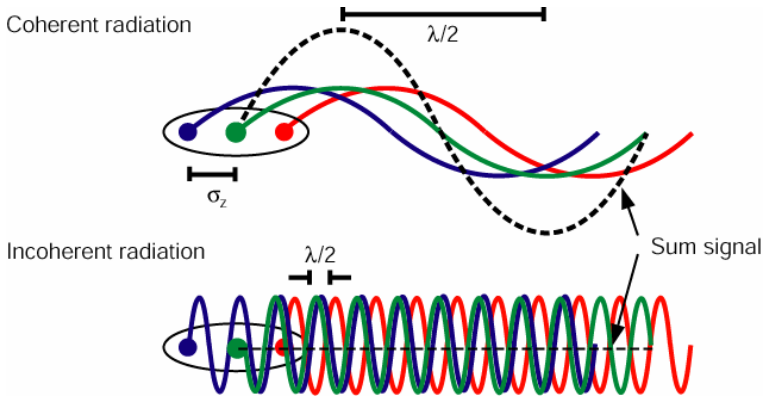
Form factor of bunch

Transfer function + detect response

Power emitted by single electron

Energy detected from bunch ~ $1/\sigma_z$

Pyro-electric detector monitors FIR power emitted by diffraction radiator



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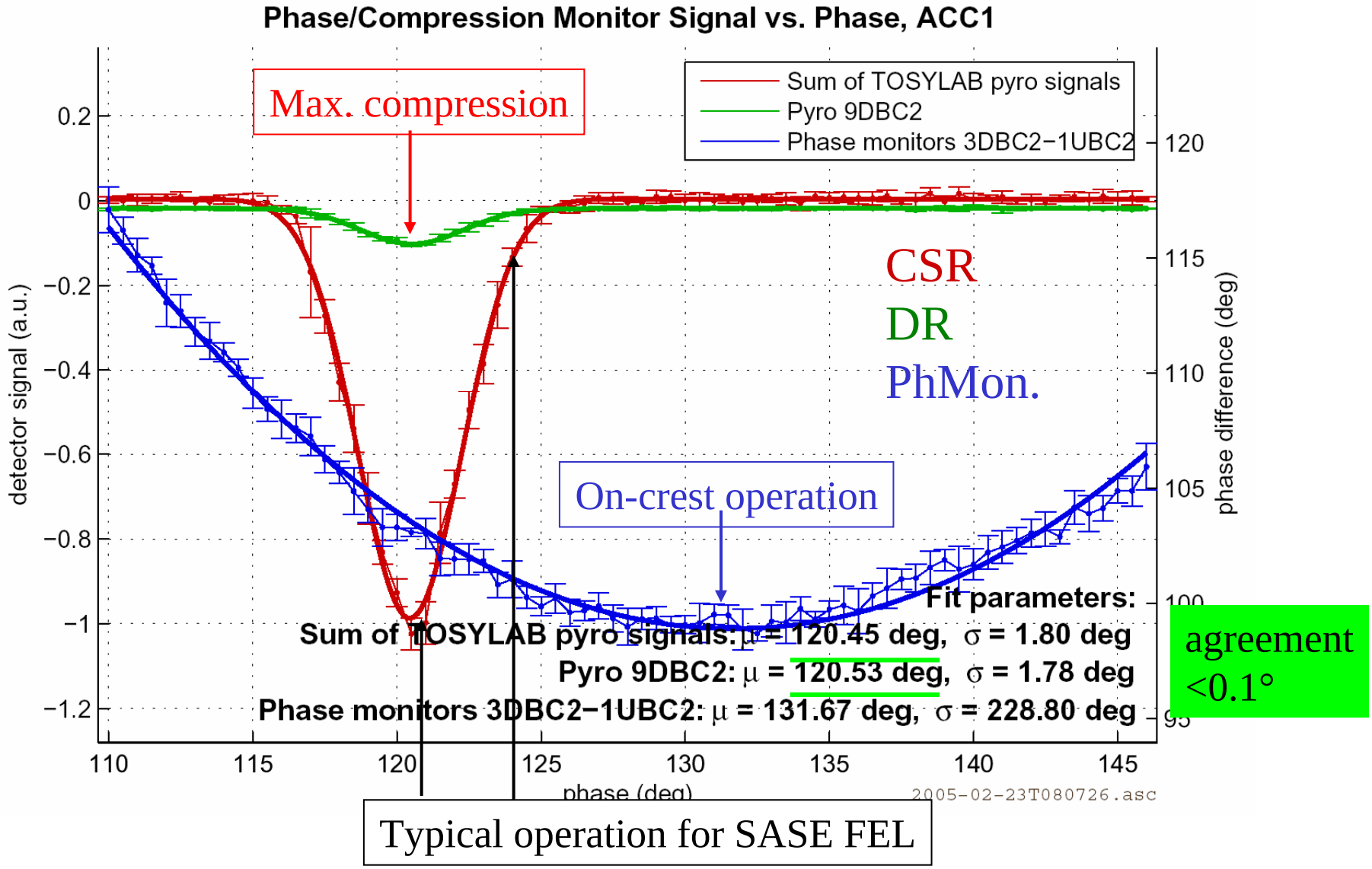


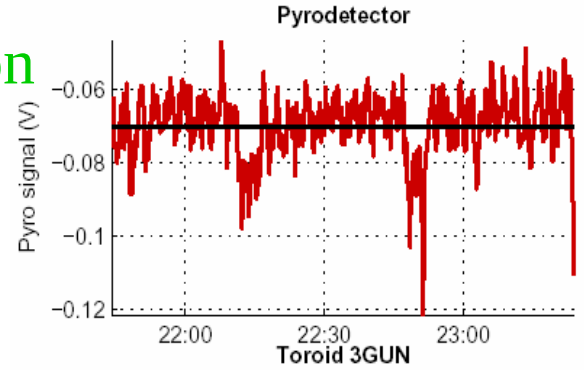
agreement <0.1°

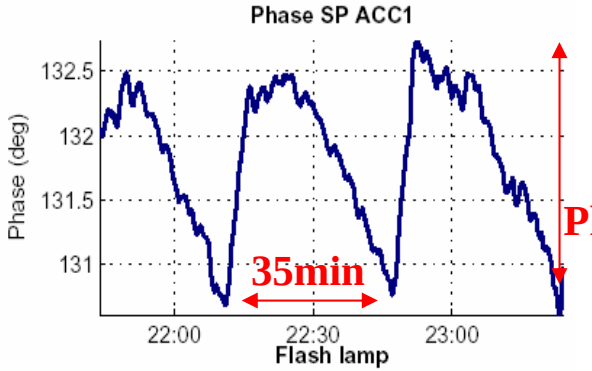
Slow feedback for acc. phase, charge, acc amp.

Monitor signal

Actuator responds

Compression monitor



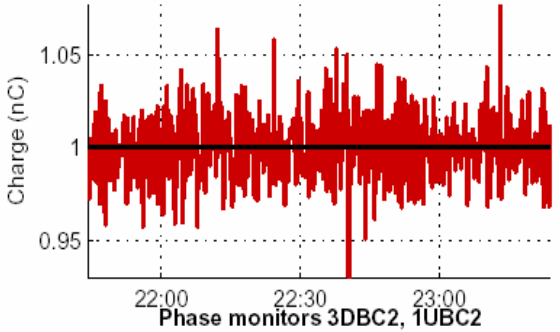


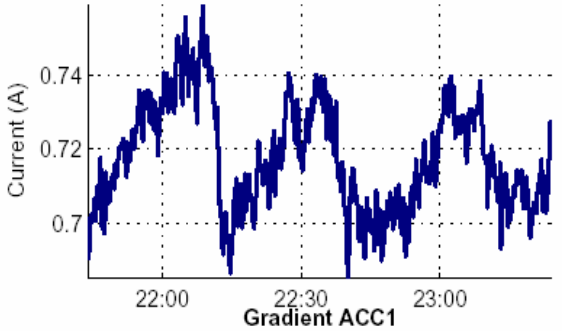
Acceleration phase

PkPk = 2°

Large phase drifts observed!!!

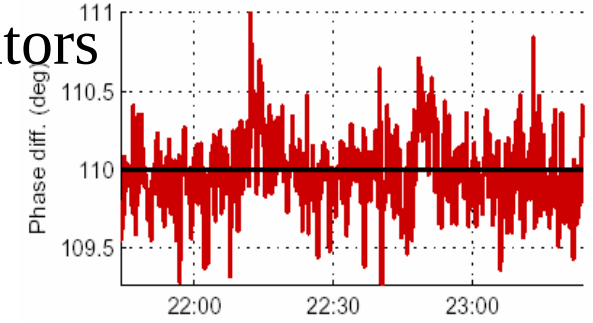
Charge

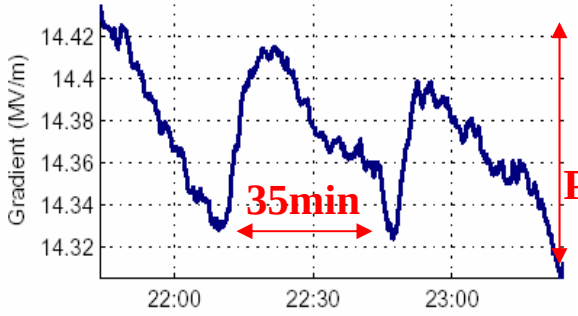




Laser power

Phase monitors (Energy)





Acceleration gradient

PkPk = 1%

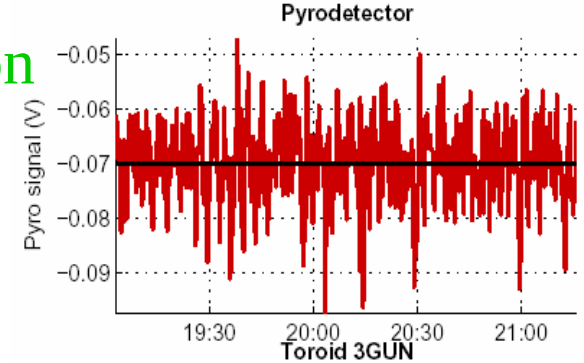
Large ampl. drifts observed!!!

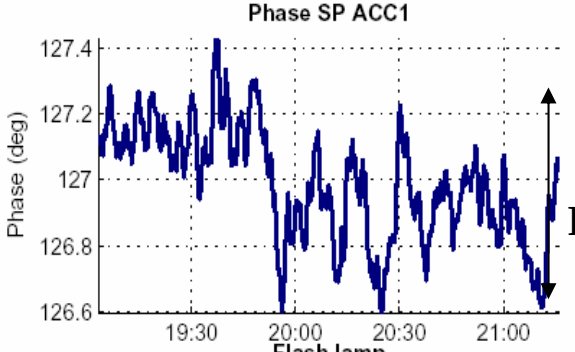
Slow feedback for acc. phase, charge, acc amp.

Monitor signal

Actuator responds

Compression monitor



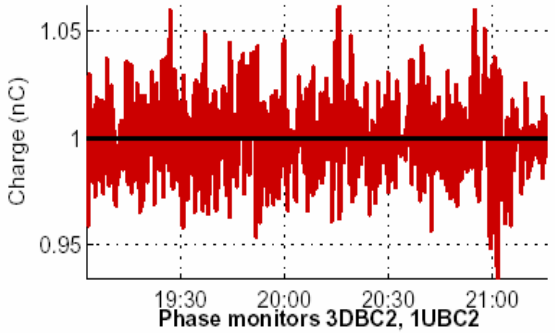


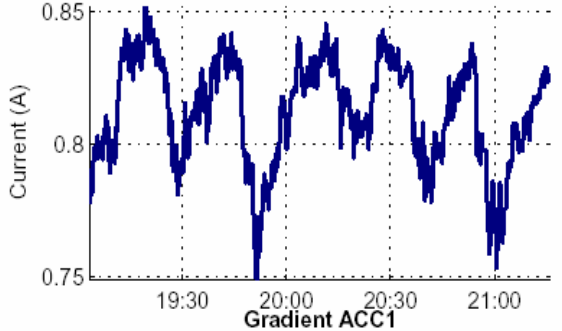
Acceleration phase

PkPk = 0.7°

Reasonable phase drift (~0.1° rms)

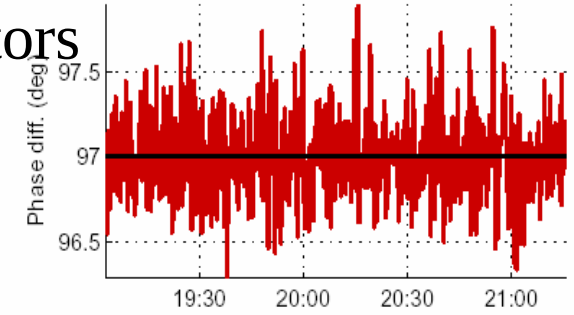
Charge

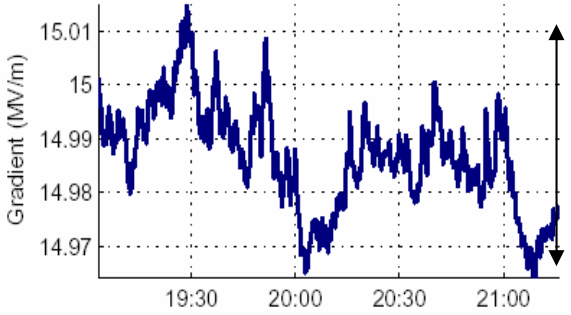




Laser power

Phase monitors (Energy)





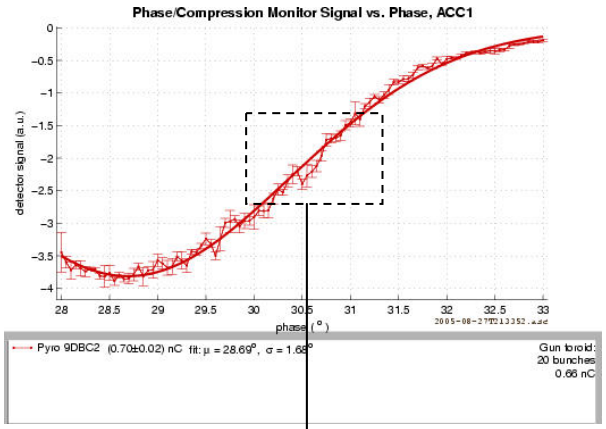
Acceleration gradient

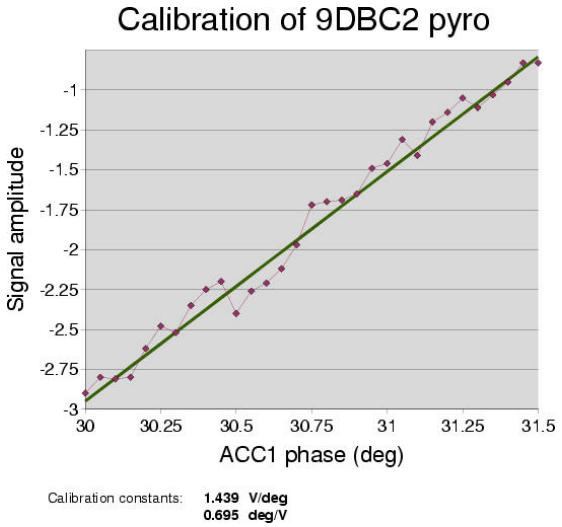
PkPk = 0.4 %

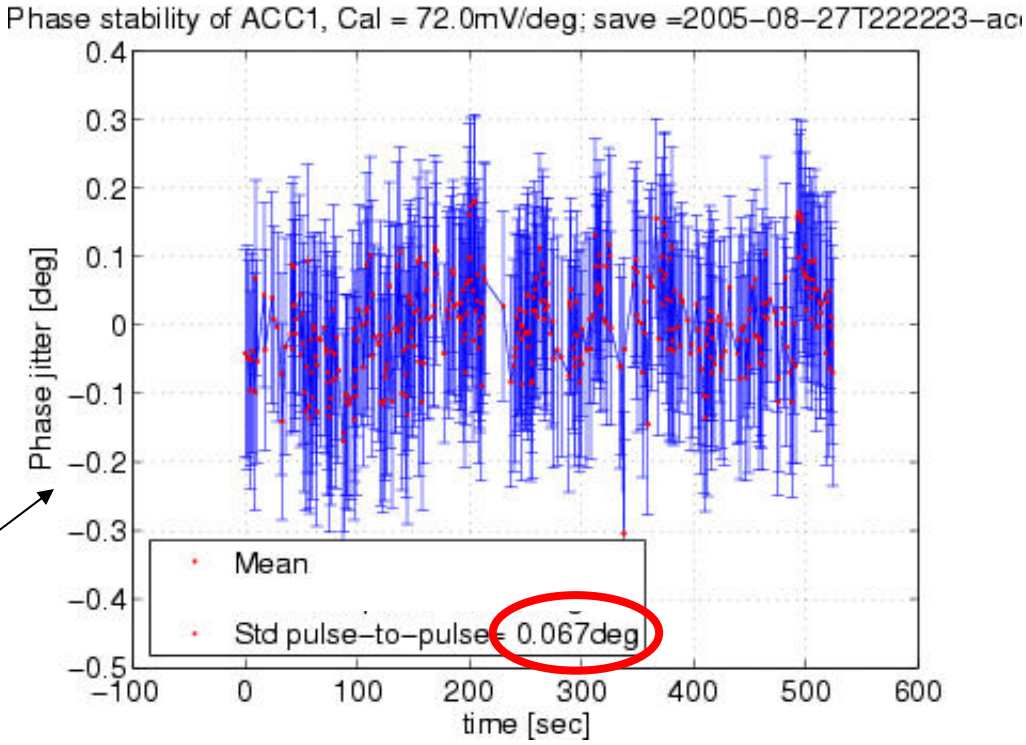
Limited by monitor system

Regulation of temperature controller in LLRF rack switched off

Phase stability with pyro-detector



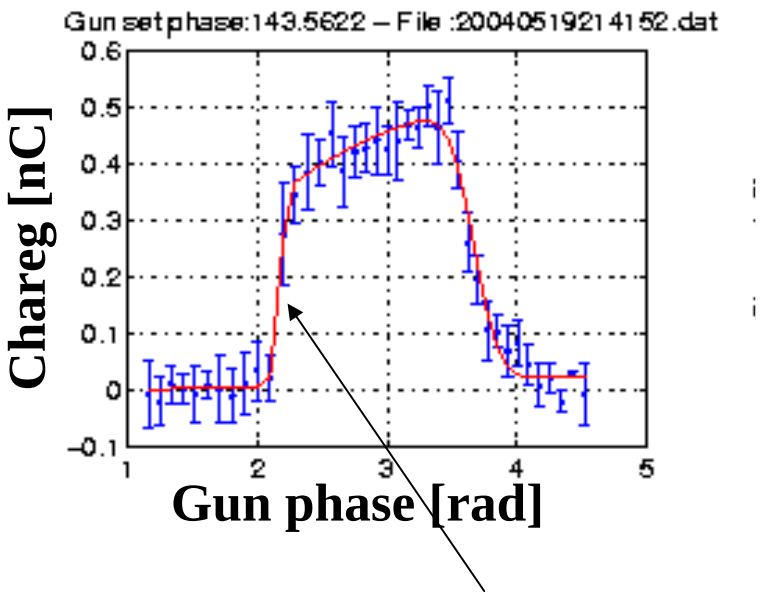




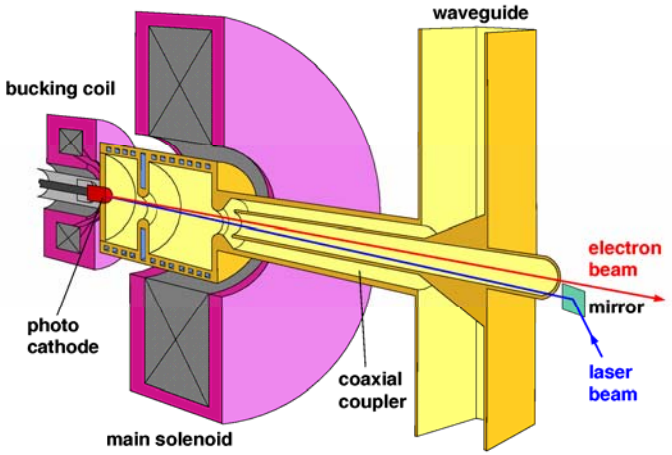
But! This is the phase stability between the beam arrival into the acceleration module relative to the RF phase!!!

=> Major contribution is likely from laser

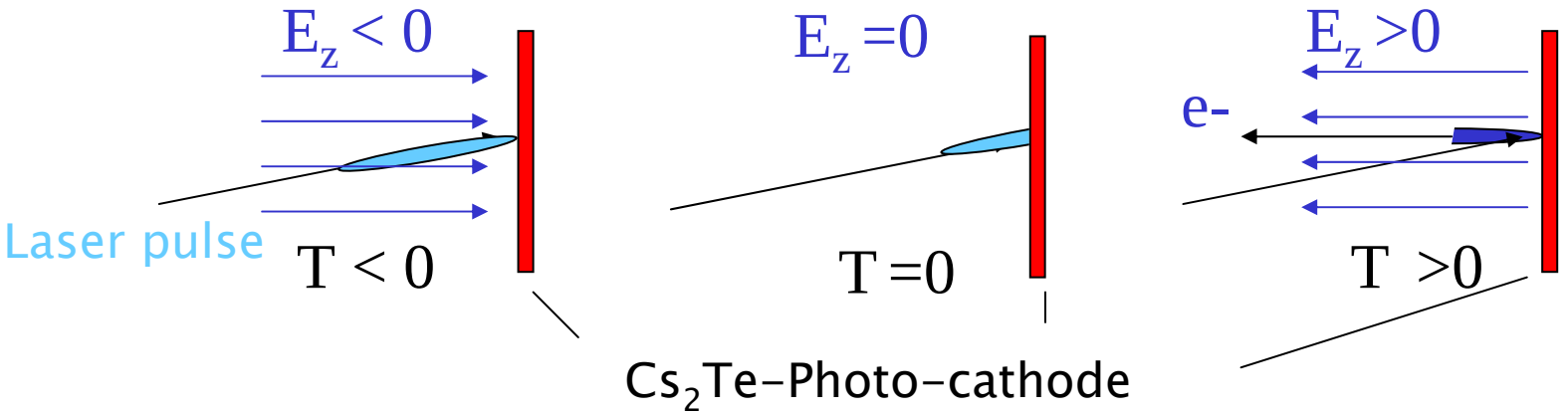
Beam based measured
- of gun versus laser phase -



RF gun design (K. Flötmann)



Sharp rising edge can be used to determine timing



Beam based measured
- of gun versus laser phase -

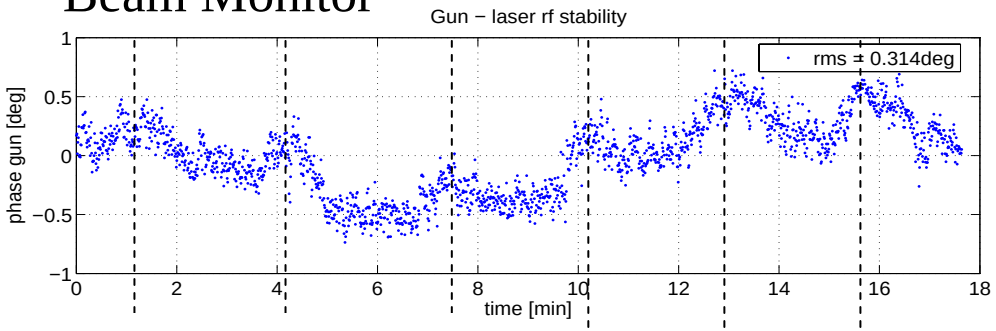
⇒Phase drifts in RF gun since it is correlated to reflected power phase

⇒Phase drifts are caused by temperature changes in RF gun

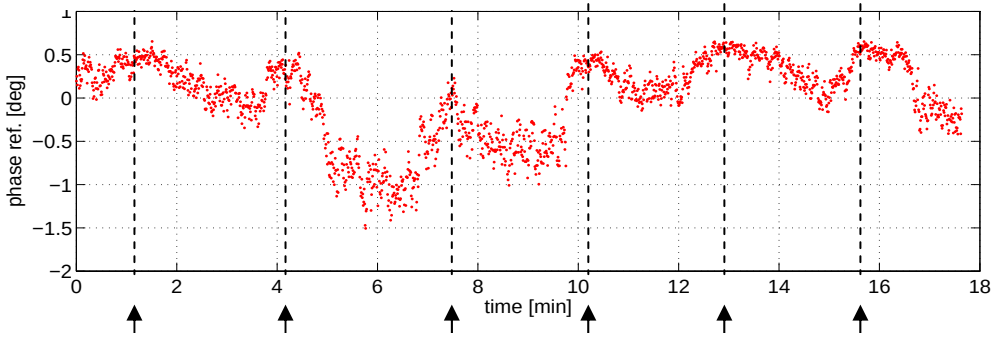
⇒Used to debug FPGA based gun RF controller

⇒First idea to use pilot bunches (-30deg to regular phase) for b-b FB control

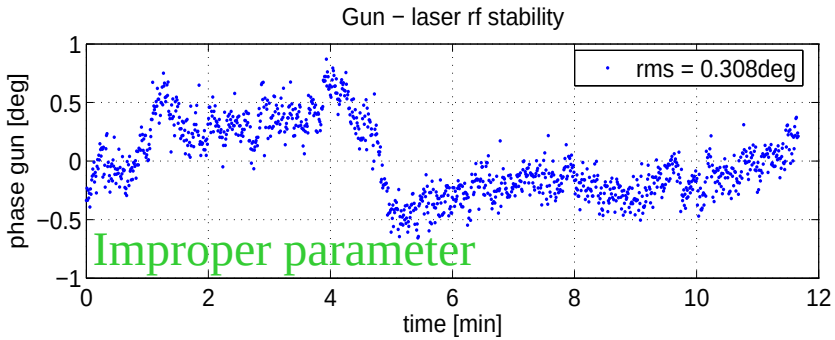
Beam Monitor

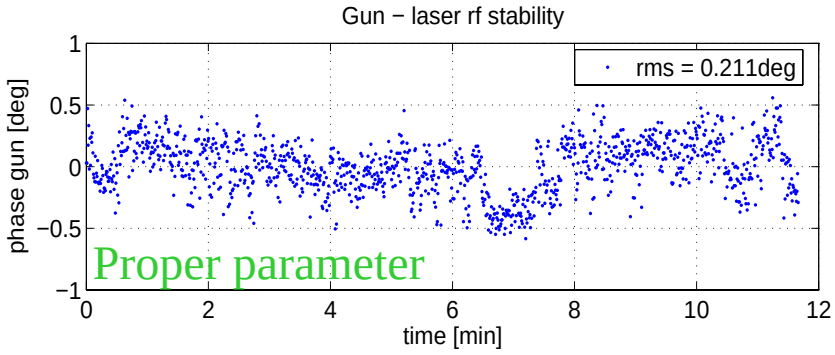


RF monitor (Pref)



FPGA RF Control

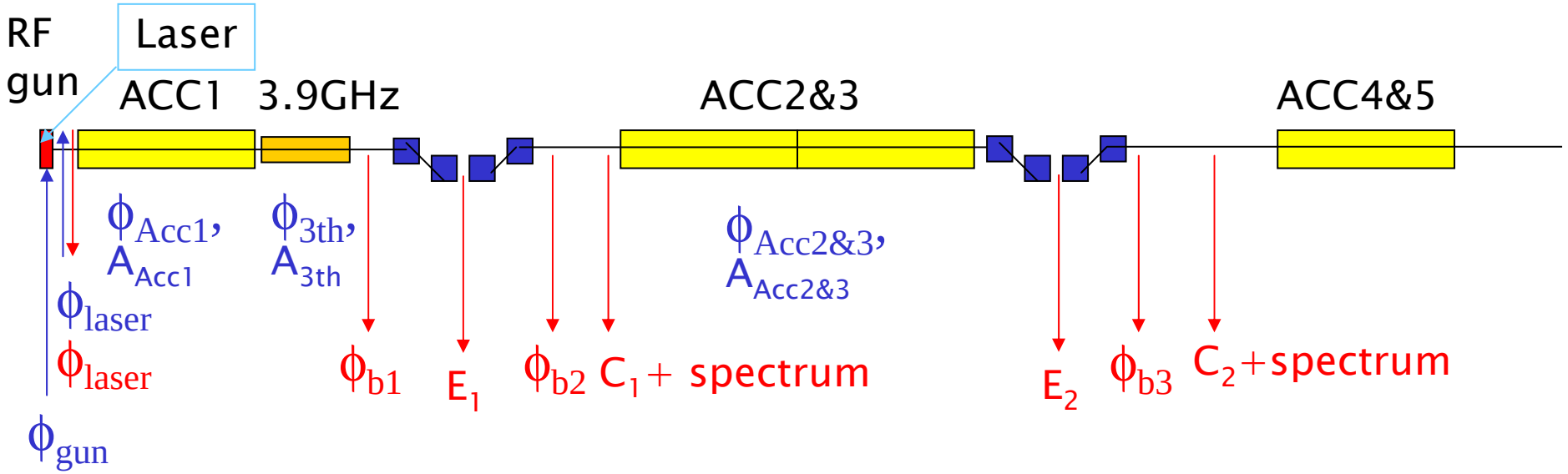




Time constant of gun cooling water regulation ~ 2-3min

Courtesies: Koprek, Hoffmann (DESY)

Longitudinal FB with 3th harmonic



Monitors: arrival phase laser, up stream BC1, downstream BC1&2
energy BC1, BC2, compression downstream BC1&BC2
very like longitudinal bunch shape also required

Actuators: laser phase, gun phase, phase & ampl. ACC1 & ACC23

Response Act->Mon: strongly depending on operation point

End of the talk

and

thanks for you attention!