Beam Instrumentation & Beam Diagnostics

Today

CAS 2011 Hermann Schmickler (CERN)

Instrumentation---Diagnostics

- Instrumentation: summary word for all the technologies needed to produce primary measurements of direct beam observables.
- Diagnostics: making use of these instruments in order to:

  - operate the accelerators (orbit control…)
  - improve the performance of the accelerators
    ex: avoid beam losses, high brillance/luminosity
  - deduce further beam parameters or performance indicators of the machine by further data processing
    ex: chromaticty measurements, betatron matching, bunch arrival time
- - detect equipment faults

Instrumentation <-> Diagnostics

a BPM (yesterdays talk) delivers two values:
X,Y…the transverse position of the beam.
It delivers these values per machine turn/beam passage or per bunch passage in the BPM.
- Diagnostics usage:
Closed Orbit (=: CO)
- inspection/Correction
- automated real time feedback
- dispersion (CO for different momentum)
Turn by Turn data:
- machine optics (values of beta function, phase advances)
- tune, chromaticty

!!! The details of the diagnostics usage determine the specifications of the instruments. !!!

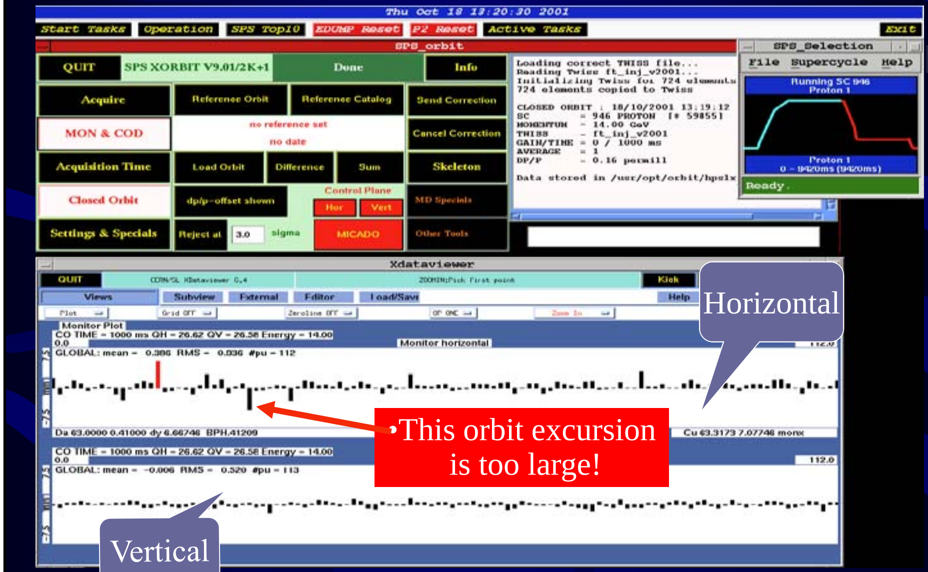
Outline

- Optimization of Machine Performance
  (“the good days”)
  → Orbit correction, Beam threading
  → Luminosity: basics + LEP luminosity tuning
- Various Diagnostics (“the fun days”)
  → Tune & chromaticity measurements
  → Dynamic effects: tune and chromaticity control
  → Bunch arrival time in FEL

That is what gets reported on in conferences

- Trying to make the machine work
  (2 examples of “the bad days”)
  → The beam does not circulate!
  → The beam gets lost, when changing the beta*

Orbit Acquisition



```
Loading correct TWISS file...
Reading Twiss ft_inj_v2001...
Initializing Twiss for 724 elements
724 elements copied to Twiss

CLOSED ORBIT : 18/10/2001 13:19:12
SC           = 946 PROTON  [# 59855]
MOMENTUM     = 14.00 GeV
TWISS        = ft_inj_v2001
GAIN/TIME    = 0 / 1000 ms
AVERAGE      = 1
DP/P         = 0.16 permill

Data stored in /usr/opt/orbit/hpslx
```

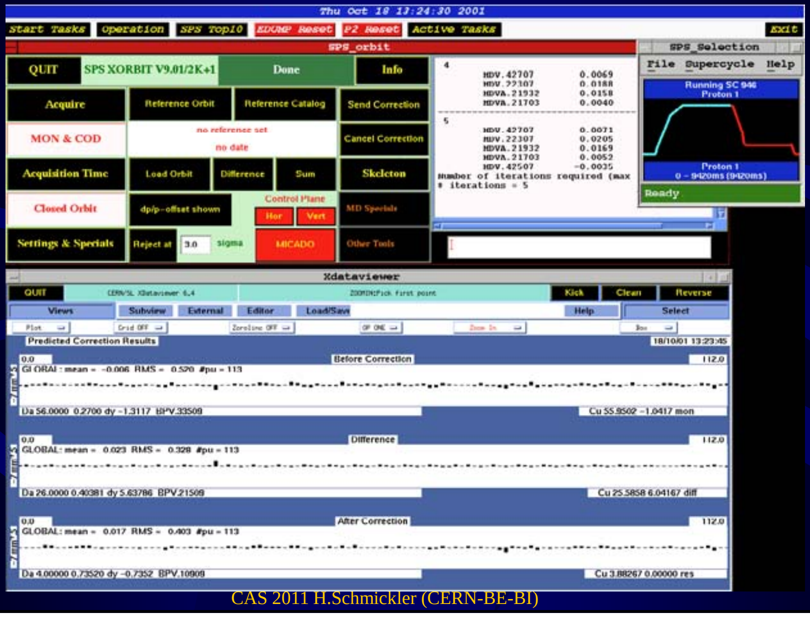
```
CO TIME = 1000 ms QH = 26.62 QV = 26.58 Energy = 14.00
0.0
GLOBAL: mean = 0.386 RMS = 0.836 #pu = 112
Da 63.0000 0.41000 dy 6.66746 BPH.41209
Cu 63.3173 7.07746 monx
CO TIME = 1000 ms QH = 26.62 QV = 26.58 Energy = 14.00
0.0
GLOBAL: mean = -0.006 RMS = 0.520 #pu = 113
```

Horizontal

- This orbit excursion is too large!

Vertical

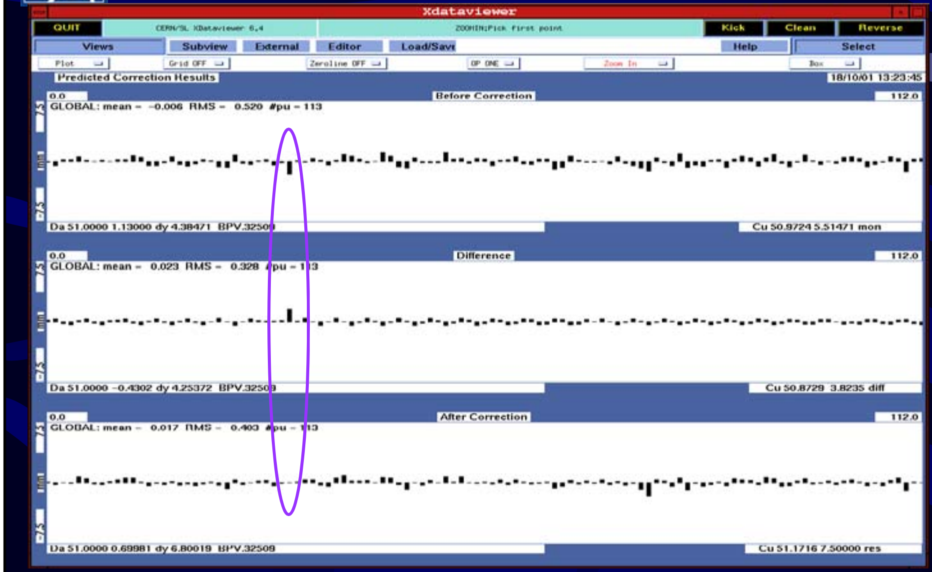
Orbit Correction (Operator Panel)



```
4
         HDV.42707          0.0069
         HDV.22307          0.0188
         HDVA.21932         0.0158
         HDVA.21703         0.0040
--------------------------------------
5
         HDV.42707          0.0071
         HDV.22307          0.0205
         HDVA.21932         0.0169
         HDVA.21703         0.0052
         HDV.42507         -0.0035
Number of iterations required (max
# iterations = 5
```

```
0.0
GLOBAL: mean = -0.006 RMS = 0.520 #pu = 113
Da 56.0000 0.2700 dy -1.3117 BPV.33509
Cu 55.9502 -1.0417 mon
0.0
GLOBAL: mean = 0.023 RMS = 0.328 #pu = 113
Da 26.0000 0.40381 dy 5.63786 BPV.21509
Cu 25.5858 6.04167 diff
0.0
GLOBAL: mean = 0.017 RMS = 0.403 #pu = 113
Da 4.00000 0.73520 dy -0.7352 BPV.10909
Cu 3.88267 0.00000 res
```

Orbit Correction (Detail)



Predicted Correction Results

18/10/01 13:23:45

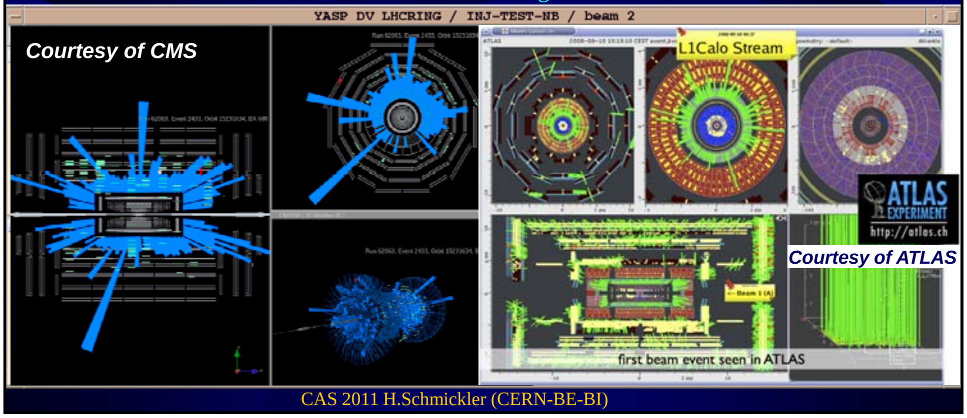
```
GLOBAL: mean = -0.006  RMS =  0.520  #pu = 113
Da 51.0000 1.13000 dy 4.38471  BPV.32509          Cu 50.9724 5.51471 mon

GLOBAL: mean =  0.023  RMS =  0.328  #pu = 113
Da 51.0000 -0.4302 dy 4.25372  BPV.32509          Cu 50.8729  3.8235 diff

GLOBAL: mean =  0.017  RMS =  0.403  #pu = 113
Da 51.0000 0.69981 dy 6.80019  BPV.32509          Cu 51.1716 7.50000 res
```

Beam Threading

- Threading the beam round the LHC ring (very first commissioning)
  - → One beam at a time, one hour per beam.
  - → Collimators were used to intercept the beam (1 bunch, 2×10^9 protons)
  - → Beam through 1 sector (1/8 ring)
    - correct trajectory, open collimator and move on.

Beam 2 threading

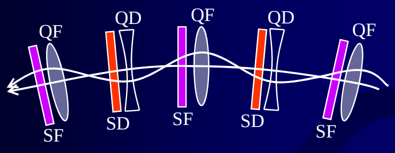
BPM availability ~ 99%



Outline

- Optimization of Machine Performance
  (“the good days”)
  - → Orbit measurement & correction
  - → Luminosity: basics + luminosity tuning
- Diagnostics of transverse beam motion:
  Important tools to stabilize performance at high levels
  - → Tune & chromaticity measurements
  - → Dynamic effects: orbit, tune and chromaticity control
- Trying to make the machine work
  (2 examples from “the bad days”)
  - → The beam does not circulate!
  - → The beam gets lost, when changing the beta*

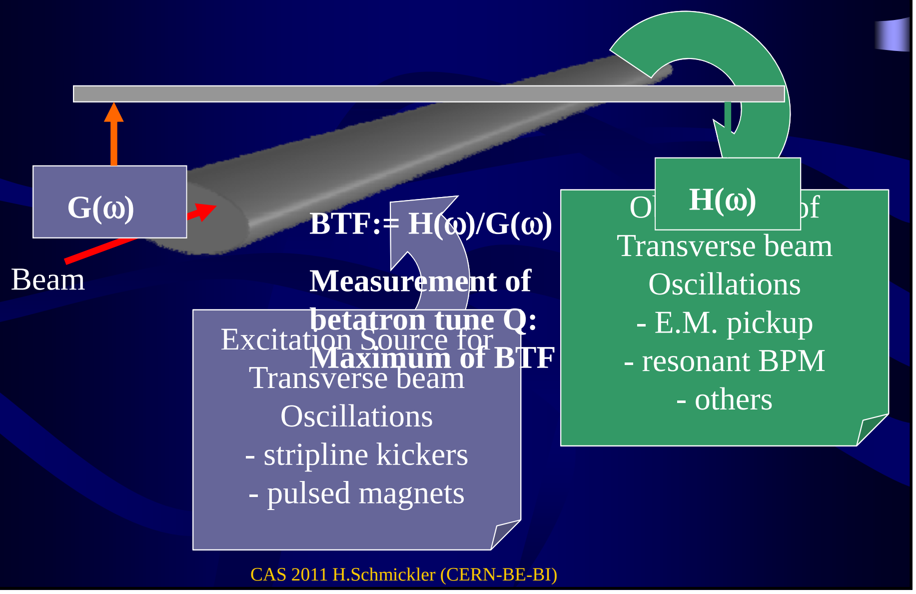
Measurement of Q (betatron tune)



Characteristic Frequency
of the Magnet Lattice
Produced by the strength of the
Quadrupole magnets

- Q – the eigenfrequency of betatron oscillations in a circular machine
  - → One of the key parameters of machine operation
- Many measurement methods available:
  - → different beam excitations
  - → different observations of resulting beam oscillation
  - → different data treatment

Principle of any Q-measurement



BTF:= H(ω)/G(ω)

Measurement of betatron tune Q: Maximum of BTF

Excitation Source for Transverse beam Oscillations
- stripline kickers
- pulsed magnets

O[illegible] of Transverse beam Oscillations
- E.M. pickup
- resonant BPM
- others

Simple example: FFT analysis

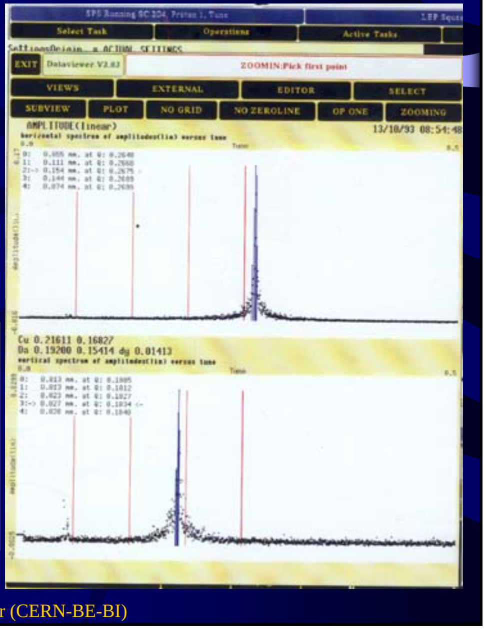
G(ω) == flat
(i.e. excite all frequencies)

Made with random noise kicks

Measure beam position over many consecutive turns

apply FFT → H(ω)

BTF = H(ω)

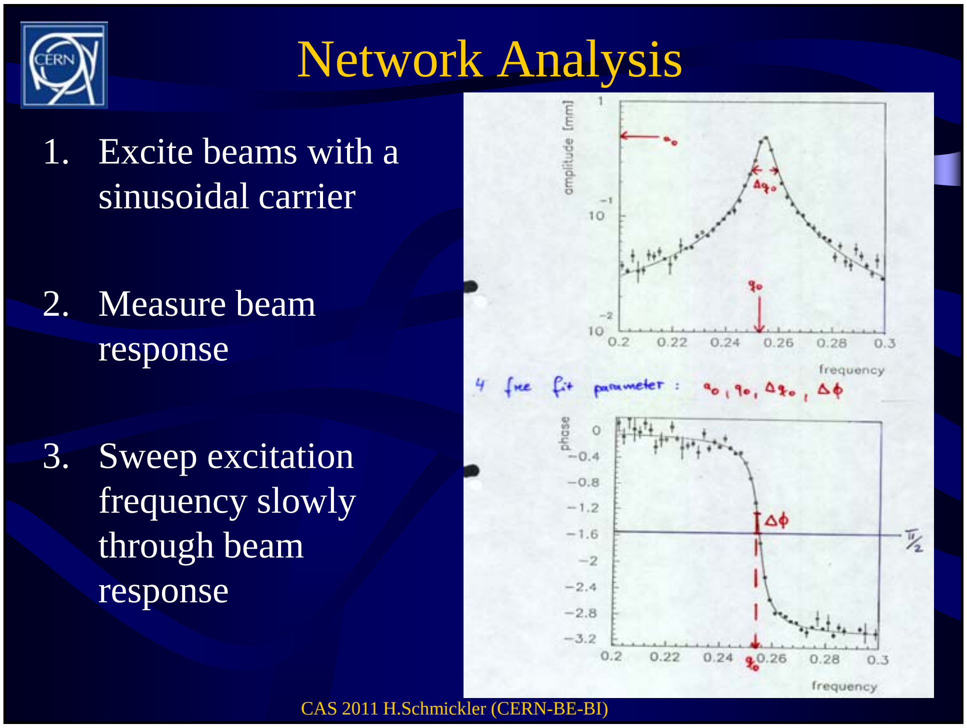


13/10/93 08:54:48

horizontal spectrum of amplitudes(lin) versus tune

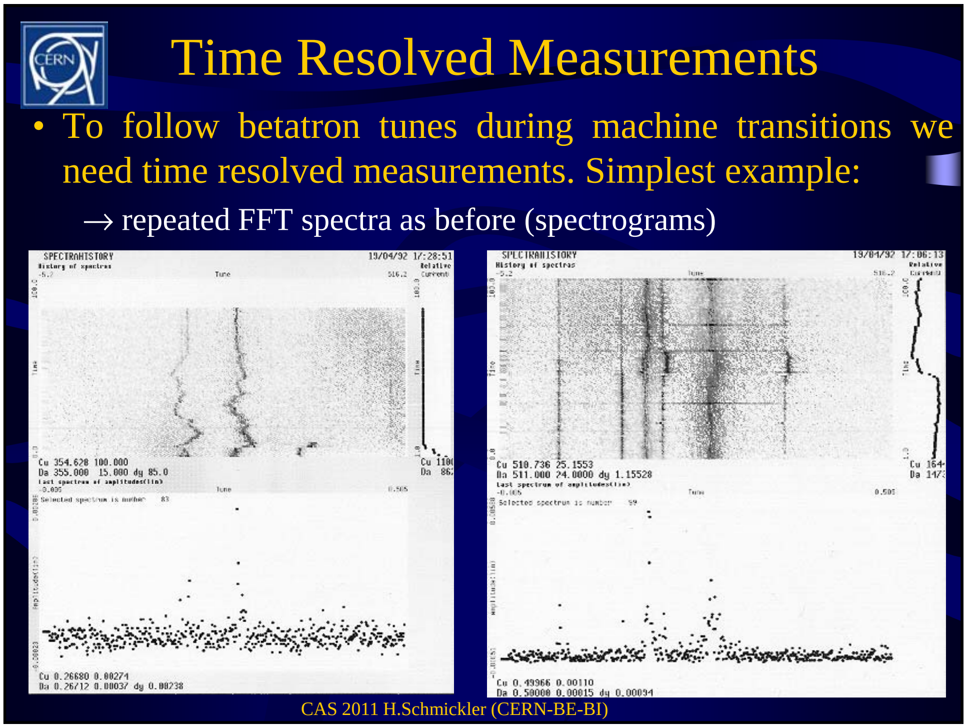
Cu 0.21611 0.16827
Da 0.19200 0.15414 dq 0.01413

vertical spectrum of amplitudes(lin) versus tune



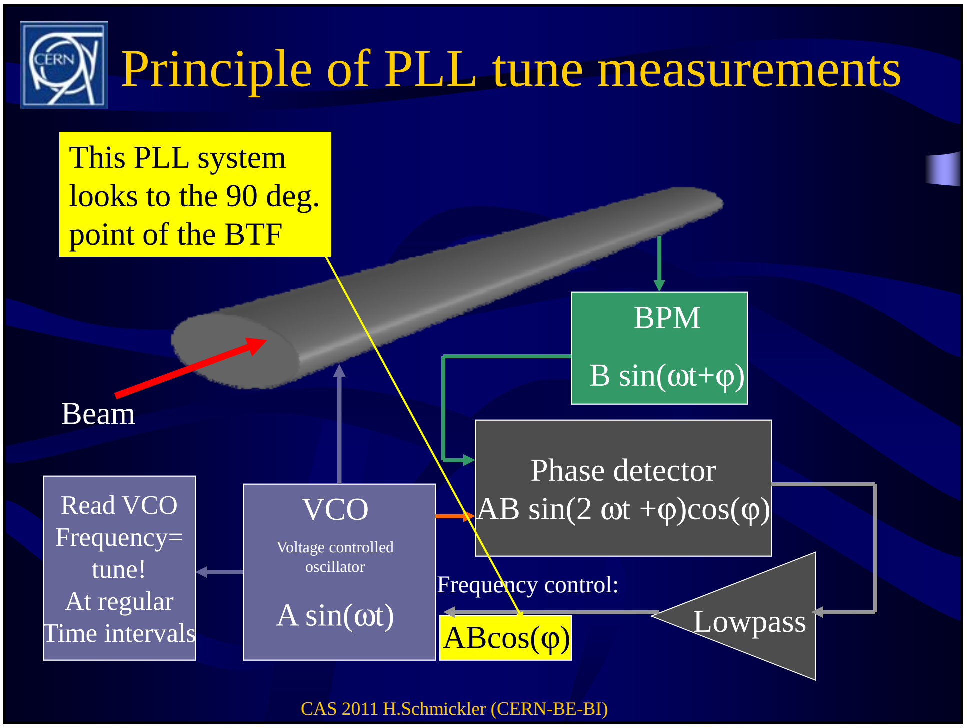
Network Analysis

1. Excite beams with a sinusoidal carrier
2. Measure beam response
3. Sweep excitation frequency slowly through beam response



Time Resolved Measurements

- To follow betatron tunes during machine transitions we need time resolved measurements. Simplest example:
  - → repeated FFT spectra as before (spectrograms)



Principle of PLL tune measurements

This PLL system looks to the 90 deg. point of the BTF

Beam

BPM

B sin(ωt+φ)

Phase detector

AB sin(2 ωt +φ)cos(φ)

Read VCO Frequency= tune!

At regular Time intervals

VCO

Voltage controlled oscillator

A sin(ωt)

Frequency control:

ABcos(φ)

Lowpass

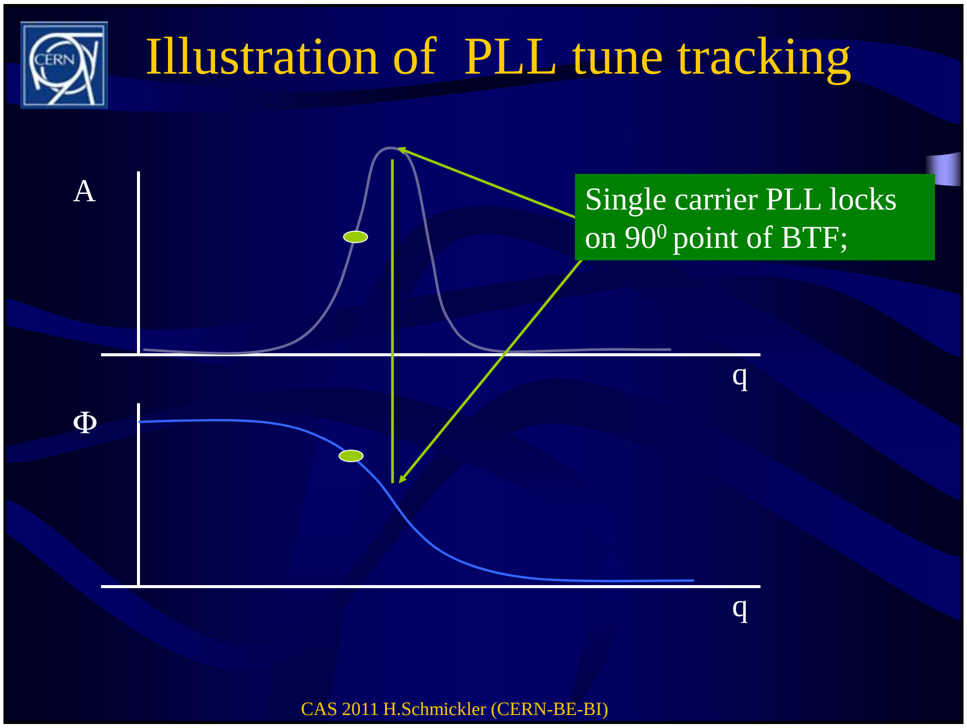
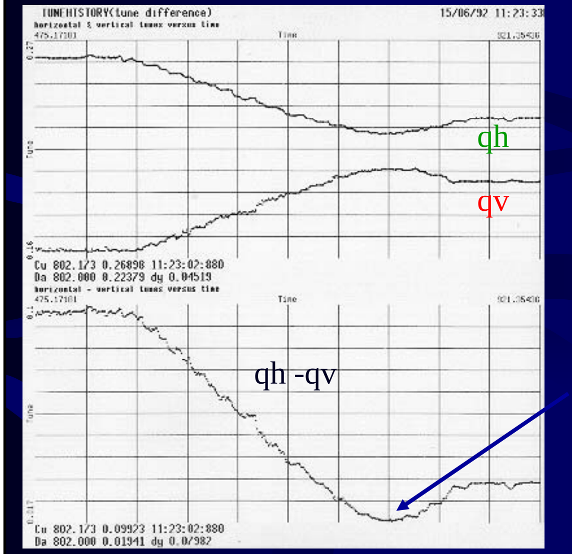


Illustration of PLL tune tracking

Single carrier PLL locks on 90^0 point of BTF;

Example of PLL tune measurement



In this case continuous tune tracking was used whilst crossing the horizontal and vertical tunes with a power converter ramp.

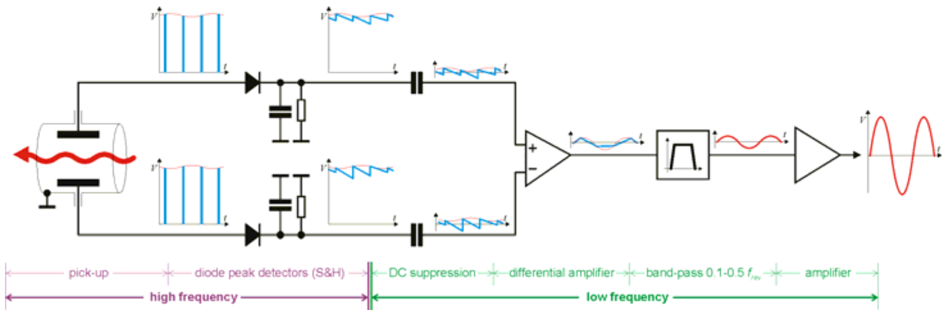
Closest tune approach is a measure of coupling

Getting BPM resolutions below the nm for diagnostics on hadron beams without emittance diluation

- Aperture of BPM approx. 50 mm or more
- Wide band electronics thermal noise limit: 10^-5 of aperture
- Narrow band front-end gains factor 10…100
- State of the art commercial BPM system reaches 5nm/sqrt(Hz), i.e. LHC turn by turn measurement (11 kHz) about sqrt(11000)* 5 nm = 0,5 um rms noise.

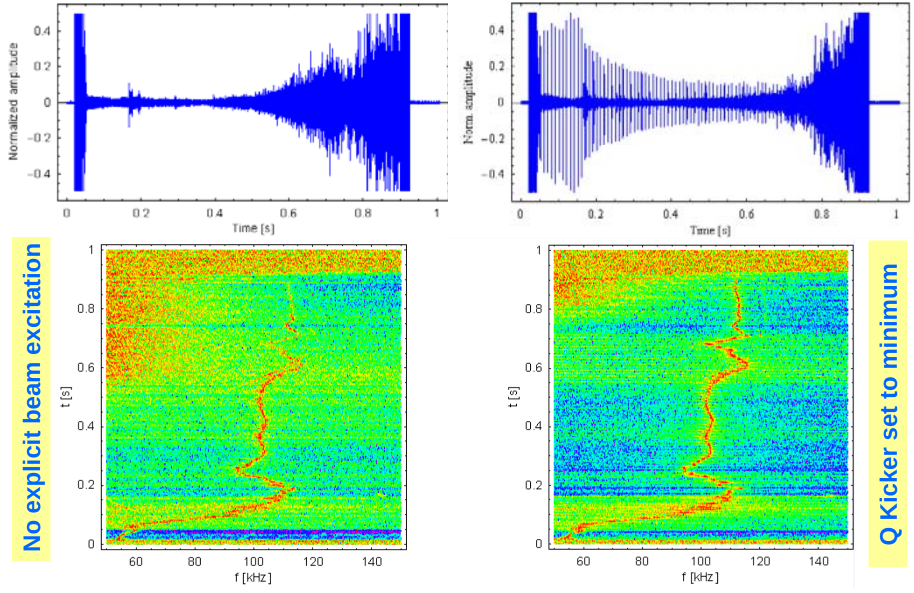
- Different approach:
  BBQ electronics: “Zoom in” getting high sensitivity for beam oscillations, but loosing absolute information of DC = closed orbit information.

Direct Diode Detection (3D) – the principle



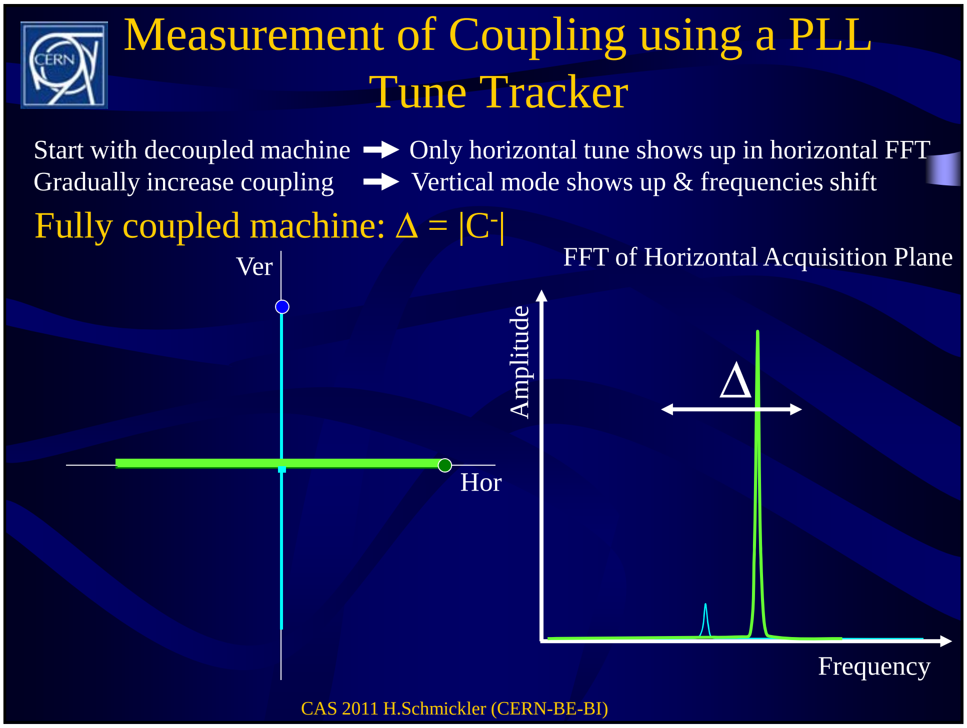
- Peak detection of position pick-up electrode signals (“collecting just the cream”)
- f_r content converted to the DC and removed by series capacitors
- beam modulation moved to a low frequency range (as after the diodes modulation is on much longer pulses)
- A GHz range before the diodes, after the diodes processing in the kHz range
- Works with any position pick-up
- Large sensitivity
- Impossible to saturate (large f_r suppression already at the detectors + large dynamic range)
- Low frequency operation after the diodes
  - High resolution ADCs available
  - Signal conditioning / processing is easy (powerful components for low frequencies)

Results from the PS (AD cycle)



No explicit beam excitation

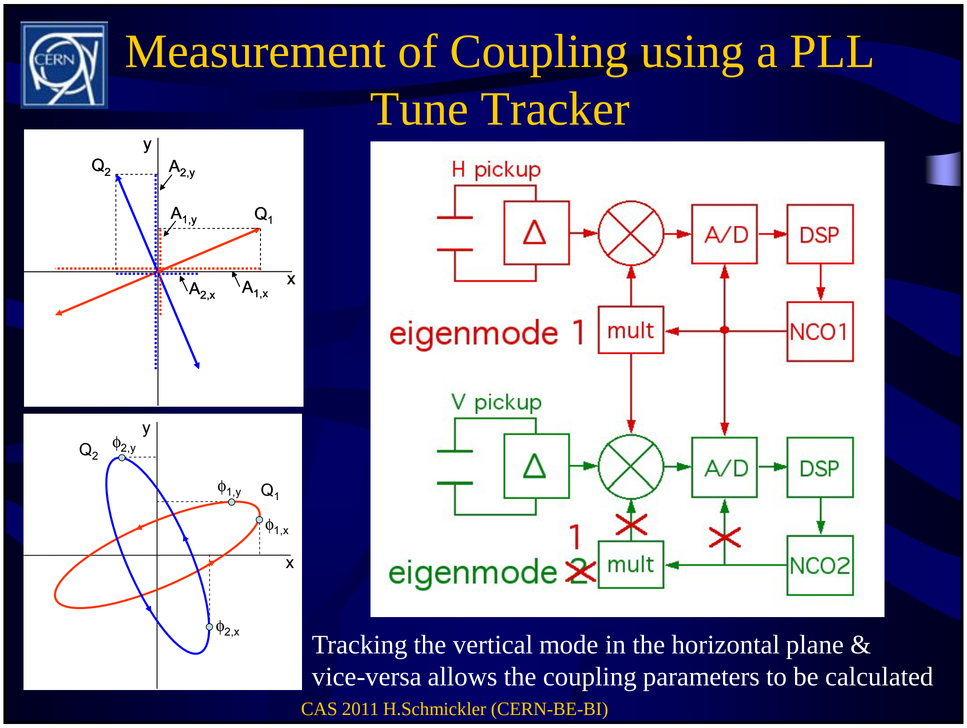
Q Kicker set to minimum



Measurement of Coupling using a PLL Tune Tracker

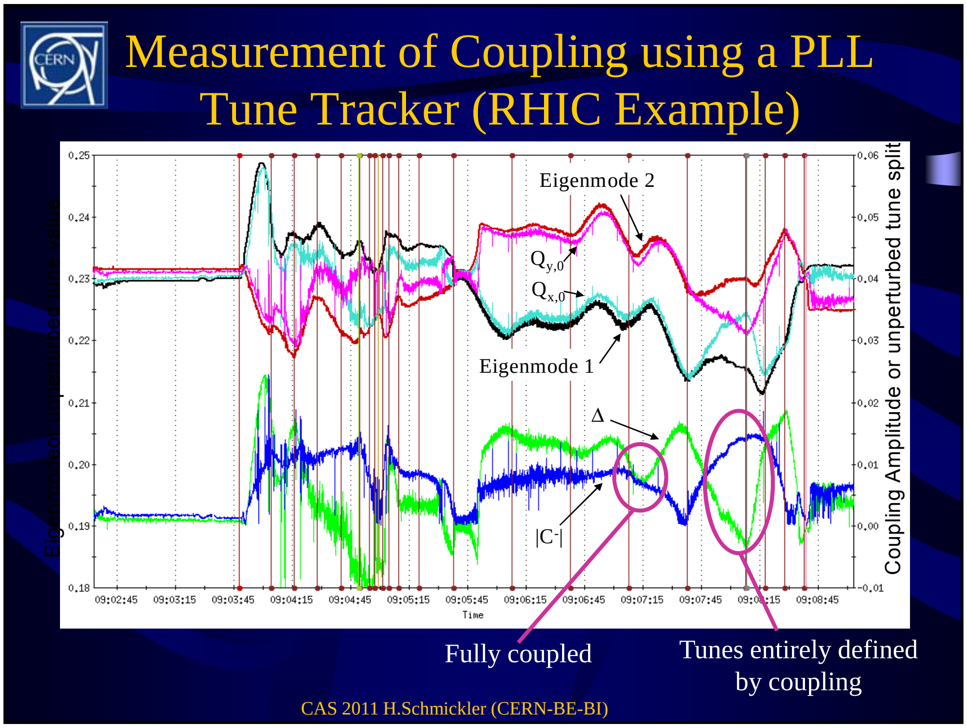
Start with decoupled machine ➔ Only horizontal tune shows up in horizontal FFT
Gradually increase coupling ➔ Vertical mode shows up & frequencies shift

Fully coupled machine: $\Delta = |C^-|$



Measurement of Coupling using a PLL Tune Tracker

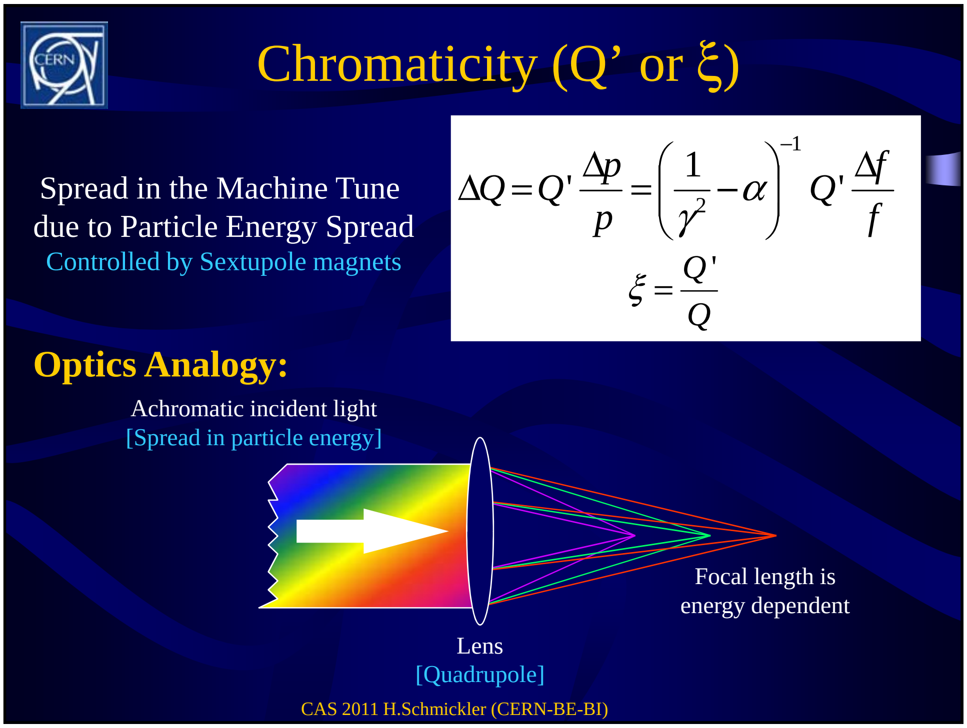
Tracking the vertical mode in the horizontal plane & vice-versa allows the coupling parameters to be calculated



Measurement of Coupling using a PLL Tune Tracker (RHIC Example)

Fully coupled

Tunes entirely defined by coupling



Chromaticity (Q’ or ξ)

Spread in the Machine Tune
due to Particle Energy Spread
Controlled by Sextupole magnets

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

$$\xi = \frac{Q'}{Q}$$

Optics Analogy:

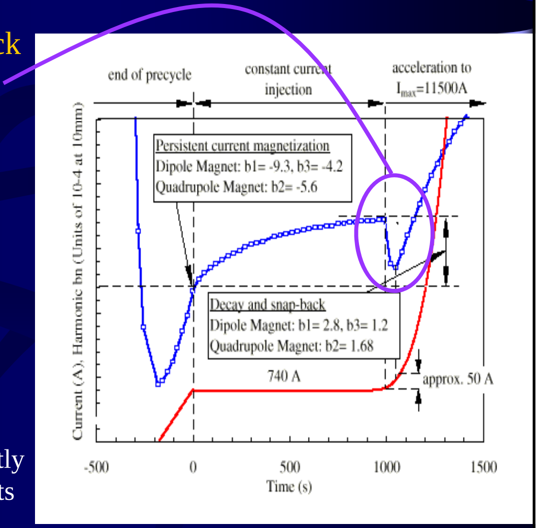
Achromatic incident light
[Spread in particle energy]

Focal length is energy dependent

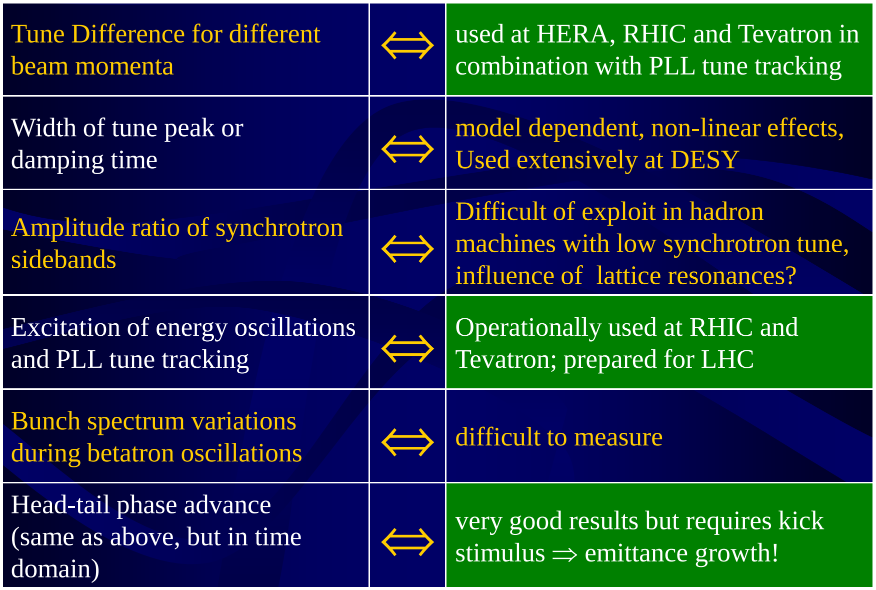
Lens
[Quadrupole]

Chromaticity – Its Importance for the LHC?

- Change in b3 during snap-back
  - →Change in Q’ of ~150 units
- Nominal operation requires ΔQ’ < 3
- Correction by:
  - →Feed-forward tables from magnet/chromaticity measurements
  - →On-line feedback from b3 measurements on reference magnets
  - →Possible on-line feedback directly from chromaticity measurements

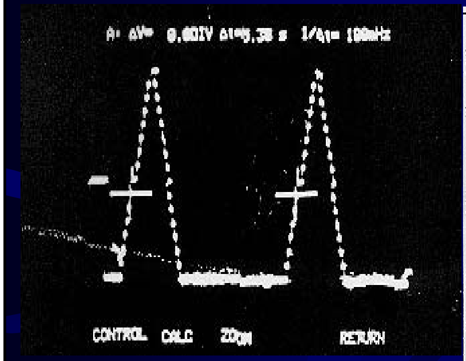


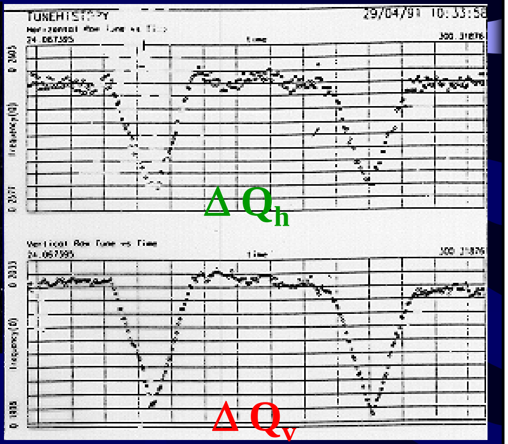
Chromaticity - What observable to choose?



Tune Difference for different beam momenta	⟺	used at HERA, RHIC and Tevatron in combination with PLL tune tracking
Width of tune peak or damping time	⟺	model dependent, non-linear effects, Used extensively at DESY
Amplitude ratio of synchrotron sidebands	⟺	Difficult of exploit in hadron machines with low synchrotron tune, influence of lattice resonances?
Excitation of energy oscillations and PLL tune tracking	⟺	Operationally used at RHIC and Tevatron; prepared for LHC
Bunch spectrum variations during betatron oscillations	⟺	difficult to measure
Head-tail phase advance (same as above, but in time domain)	⟺	very good results but requires kick stimulus ⇒ emittance growth!

Q’ Measurement via RF-frequency modulation (momentum modulation)





Applied Frequency Shift
Δ F (RF)

Amplitude & sign of chromaticity calculated from continuous tune plot

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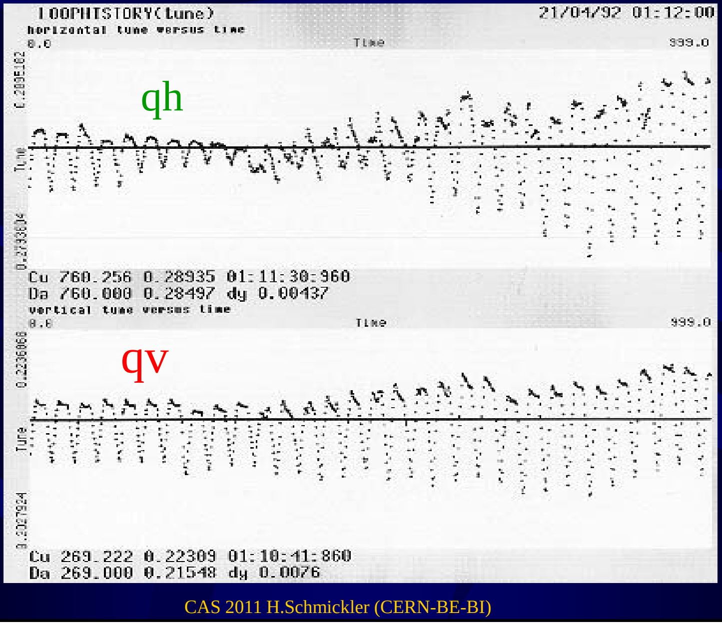
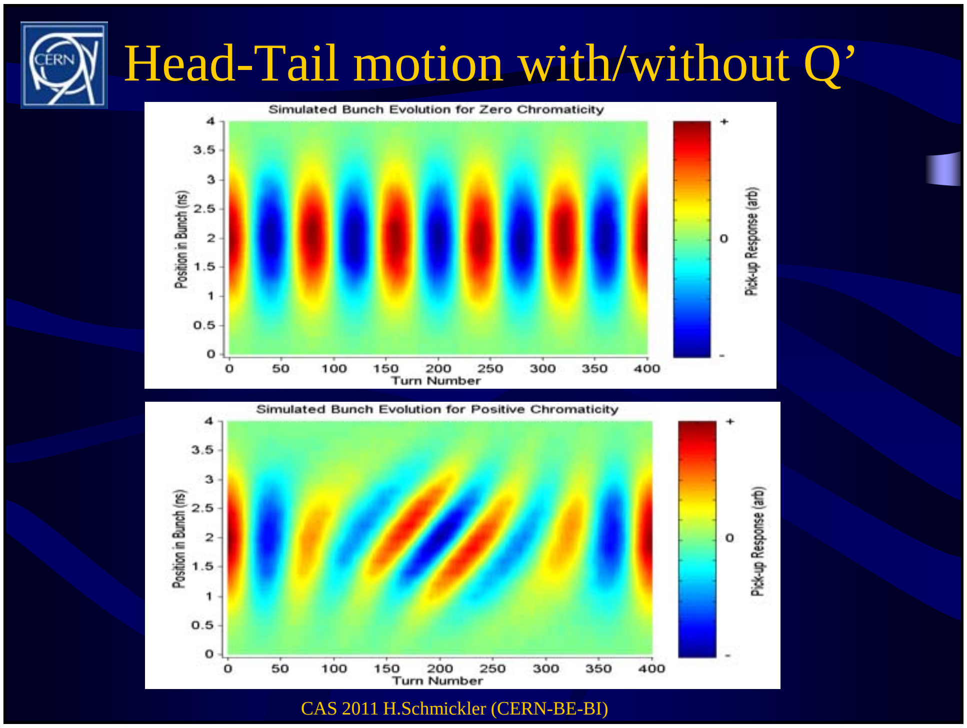
Measurement Example during LEP β-squeeze



```
Cu 760.256 0.28935 01:11:30:960
Da 760.000 0.28497 dy 0.00437
```

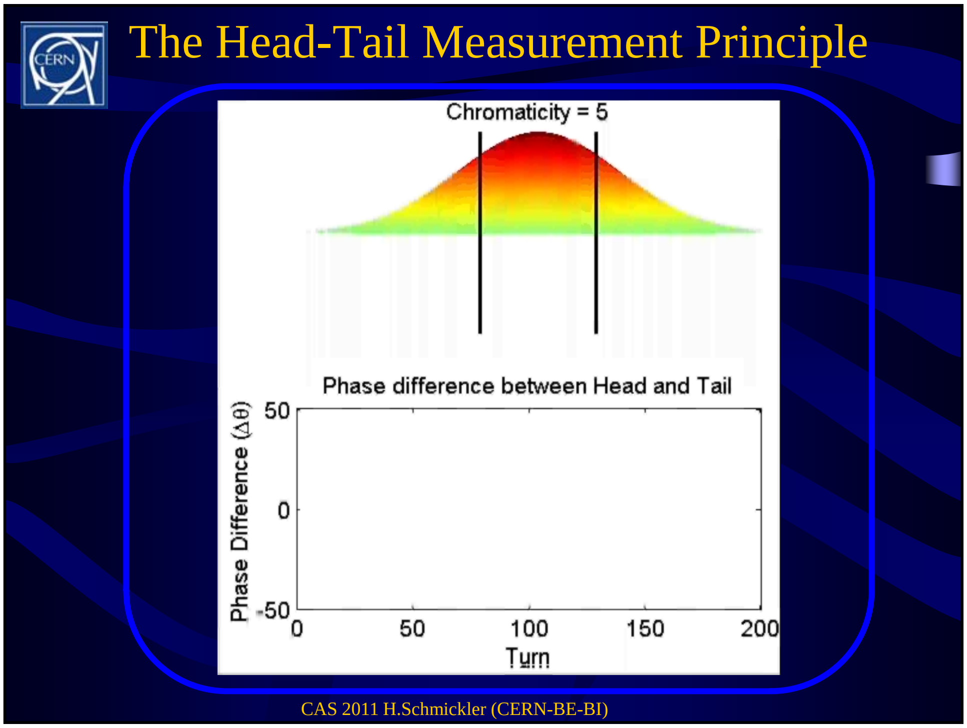
```
Cu 269.222 0.22309 01:10:41:860
Da 269.000 0.21548 dy 0.0076
```



Head-Tail motion with/without Q’

Simulated Bunch Evolution for Zero Chromaticity

Simulated Bunch Evolution for Positive Chromaticity

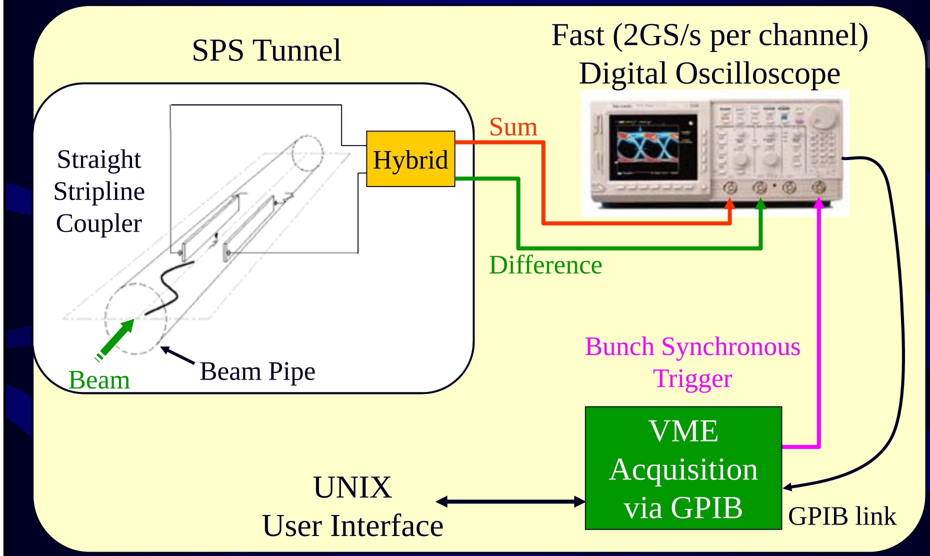


The Head-Tail Measurement Principle

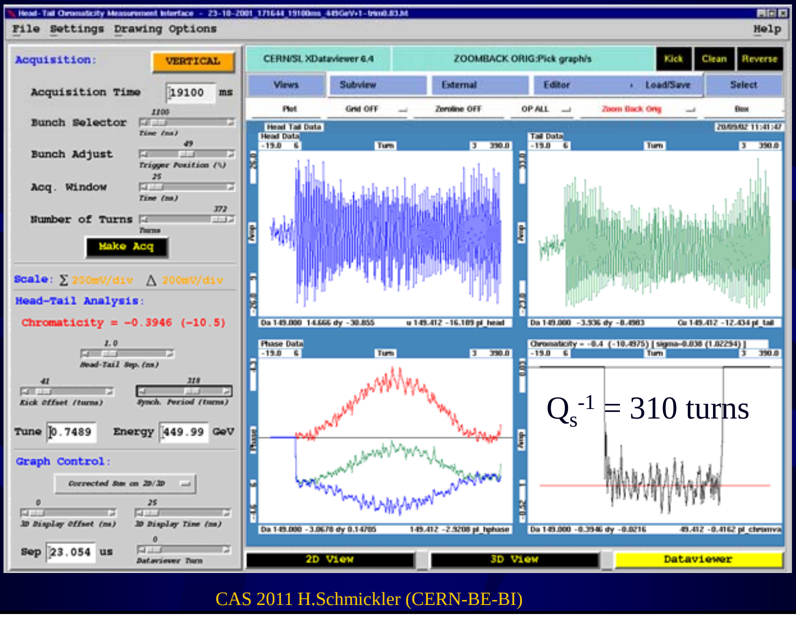
Chromaticity = 5

Phase difference between Head and Tail

Head-Tail System Set-up (SPS)



Measuring Q' (Example 1: low Qs)



Acquisition:

Acquisition Time 19100 ms

Bunch Selector 1100 Time (ns)

Bunch Adjust 49 Trigger Position (%)

Acq. Window 25 Time (ns)

Number of Turns 372 Turns

Scale: Σ 200mV/div Δ 200mV/div

Head-Tail Analysis:

Chromaticity = -0.3946 (-10.5)

1.0 Head-Tail Sep. (ns)

41 Kick Offset (turns)

318 Synch. Period (turns)

Tune 0.7489 Energy 449.99 GeV

Graph Control:

Corrected Sum on 2D/3D

0 3D Display Offset (ns)

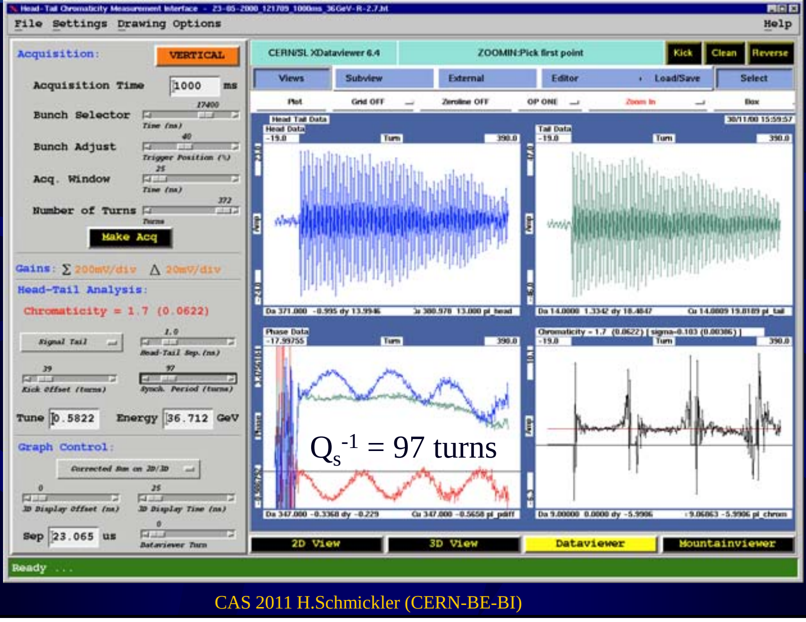
25 3D Display Time (ns)

Sep 23.054 us

0 Dataviewer Turn

Q_s^{-1} = 310 turns

Measuring Q' (Example 2: high Qs)



Head-Tail Chromaticity Measurement Interface - 23-05-2000_121709_1000ms_36GeV-R-2.7.txt

Acquisition: VERTICAL

Acquisition Time 1000 ms

Bunch Selector 17400 Time (ns)

Bunch Adjust 40 Trigger Position (%)

Acq. Window 25 Time (ns)

Number of Turns 372 Turns

Gains: Σ 200mV/div Δ 20mV/div

Head-Tail Analysis:

Chromaticity = 1.7 (0.0622)

Signal Tail

Head-Tail Sep. (ns) 1.0

Kick Offset (turns) 39

Synch. Period (turns) 97

Tune 0.5822 Energy 36.712 GeV

Graph Control: Corrected Δm on 2D/3D

3D Display Offset (ns) 0

3D Display Time (ns) 25

Sep 23.065 us

Dataviewer Turn 0

Ready ...

$Q_s^{-1} = 97$ turns

Luminosity & Beam-Beam Tune Shift

- Luminosity
- Normalized emittance
- Beam-beam tune shift

Number of Bunches

Bunch Intensity

$$L = f_{rev} \frac{MN^2}{4\pi\sigma_*^2}$$

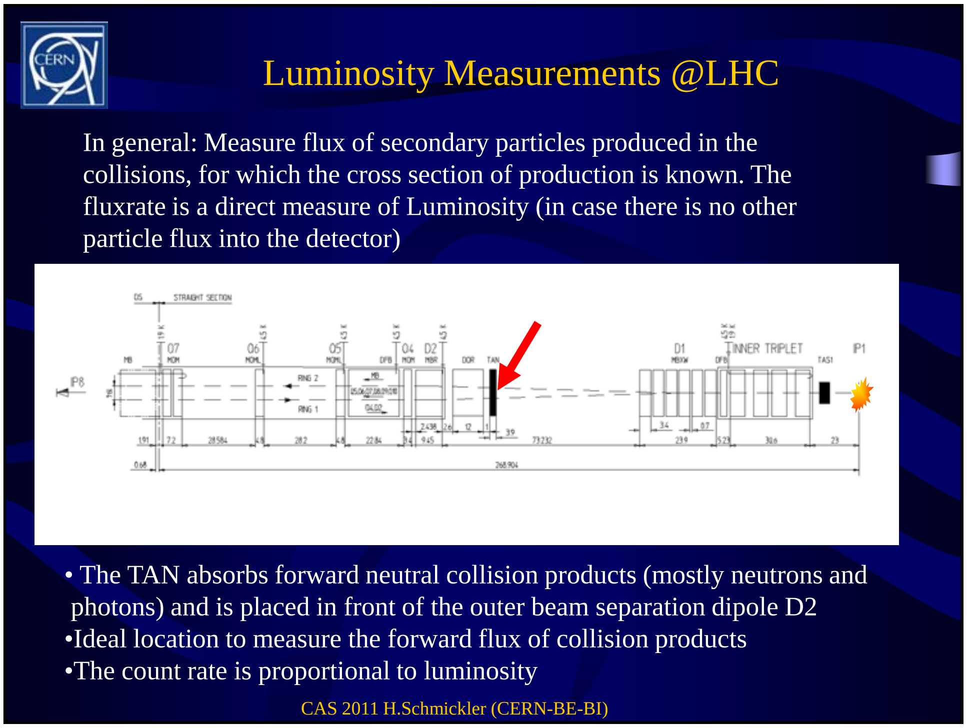
Beam size at the IP

$$\varepsilon_N = \gamma \frac{\sigma_*^2}{\beta_*}$$

$$\Delta\nu_{bb} = \frac{Nr_p}{4\pi\varepsilon_N} \leq 0.006 \text{ (LHC)}$$

$$\therefore \quad L = f_{rev} \frac{MN\gamma\Delta\nu_{bb}}{\beta_*}$$

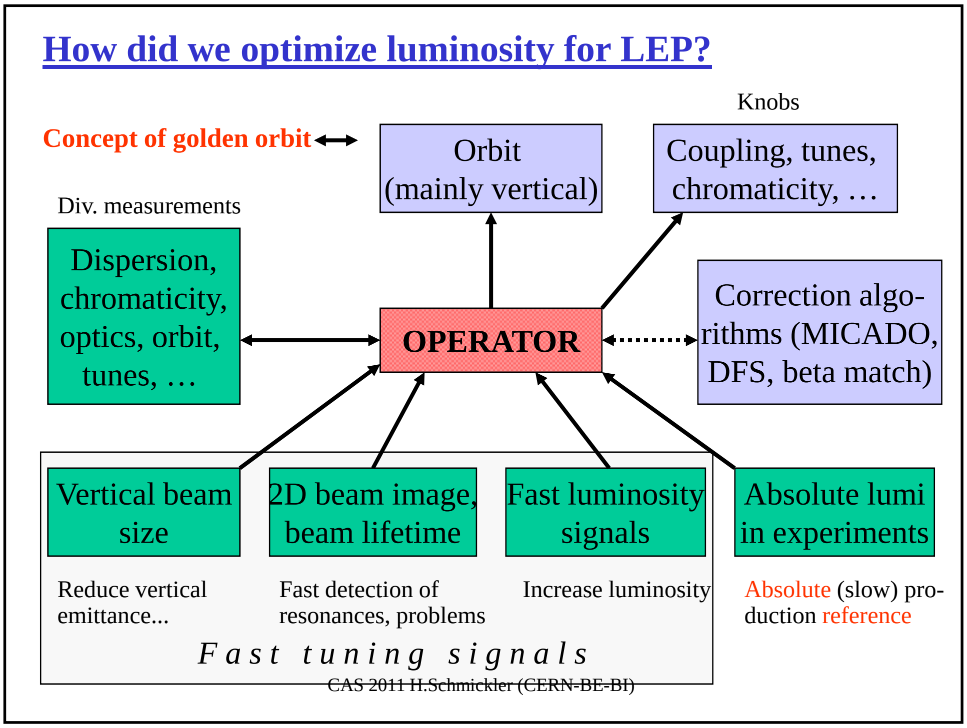
- To maximize L and minimize the stored energy, increase N to the tune shift limit, choose a large number of bunches (M) and a small β_*



Luminosity Measurements @LHC

In general: Measure flux of secondary particles produced in the collisions, for which the cross section of production is known. The fluxrate is a direct measure of Luminosity (in case there is no other particle flux into the detector)

- The TAN absorbs forward neutral collision products (mostly neutrons and photons) and is placed in front of the outer beam separation dipole D2
- Ideal location to measure the forward flux of collision products
- The count rate is proportional to luminosity



How did we optimize luminosity for LEP?

Knobs

Concept of golden orbit

Orbit (mainly vertical)

Coupling, tunes, chromaticity, …

Div. measurements

Dispersion, chromaticity, optics, orbit, tunes, …

OPERATOR

Correction algorithms (MICADO, DFS, beta match)

Vertical beam size

2D beam image, beam lifetime

Fast luminosity signals

Absolute lumi in experiments

Reduce vertical emittance...

Fast detection of resonances, problems

Increase luminosity

Absolute (slow) production reference

Fast tuning signals

Why does it work?

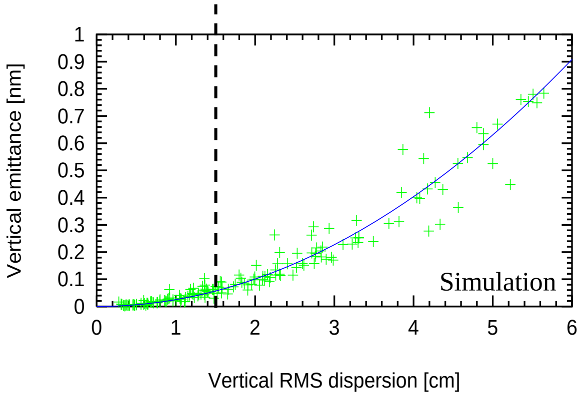
Experience:

Reduce vertical beam size meas. (local)

Reduction in vertical RMS emittance

Increase in luminosity

Typical LEP 99 performance



- RMS vertical emittance mainly due to vertical dispersion.
- Vertical IP spot size mainly due to RMS emittance.

Main usage of beam size signals:

BEUV	Continuous 2D image of beam Fast detection of beam resonances, problems, …
BEXE	Sensitive, continuous display of vertical spot sizes. Use for precision tuning of vertical emittance and luminosity. Used heavily for beam optimization!

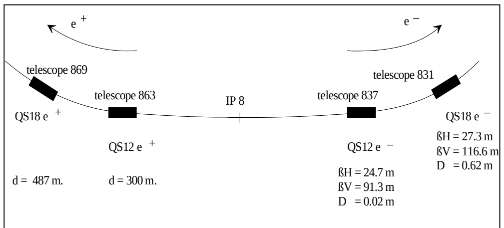
Direct measurement of beam sizes in LEP:

Via synchrotron radiation emitted by beam …

1) BEUV

Near ultra-violet range

Real time 2D image of beam



Synchrotron Light Telescopes layout in LEP

R. Jung (CERN-SL-95-63 BI)

Integrate 224 turns, all bunches. Absolute precision limited by diffraction, mirror deformation, …

"Determination of emittance below 0.25 nm difficult."

R.Jung. "*Precision emittance measurements in LEP with imaging telescopes, comparison with wire scanner and x-ray detector measurements*." CERN-SL-95-63 BI.

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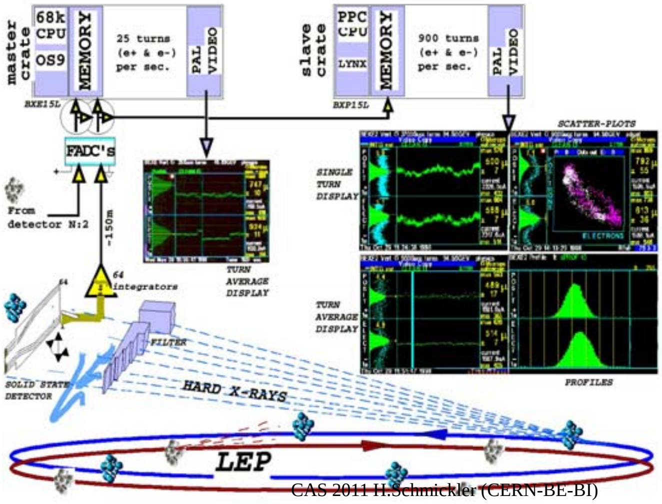
2) BEXE

X-ray range

Accurate measure of vertical beam size

Vertical beam size down to 300 µm with 1% precision… ("TURN AVERAGE DISPLAY" for fast



R.Jones et al. "*Real time display of the vertical beam sizes in LEP using the BEXE X-ray detector and fast VME based computers*". CERN-SL-99-056-BI.

Luminosity monitoring:

1) **Luminosity monitors of the experiments**

Absolute reference
Slow time response (~ minutes)
Large fluctuations

2) **LEP luminosity monitors (16 Tungsten-Silicon calorimeters in IP**

E. Bravin et al. “*Luminosity measurements at LEP*”. CERN-SL-97-072-BI.

Luminosity per IP

Problems at high energy of LEP II:
Double background rate
Four times smaller Bhabba cross section

Not very much used

3) **Luminosity estimate from beam lifetime**

Fastest response. First year of operational use…

LEP lifetime well understood:

(E.g. H. Burckhardt, R.Kleiss. Beam Lifetimes in LEP. EPAC94)

Different regimes:

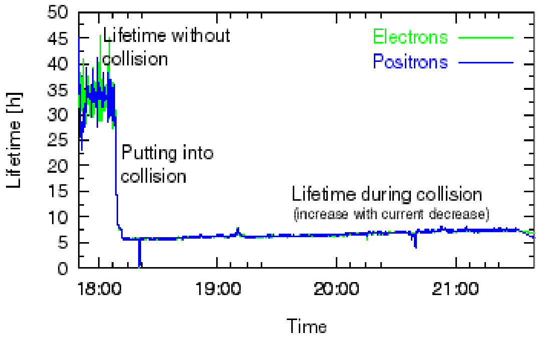
1) Without collision:

Compton scattering on thermal photons, beam-gas scattering.

τ_0 = 32 h.

2) In collision:

Radiative Bhabha scattering or beam-beam bremsstrahlung.



Formula for luminosity:

(in convenient units for LEP2 parameters)

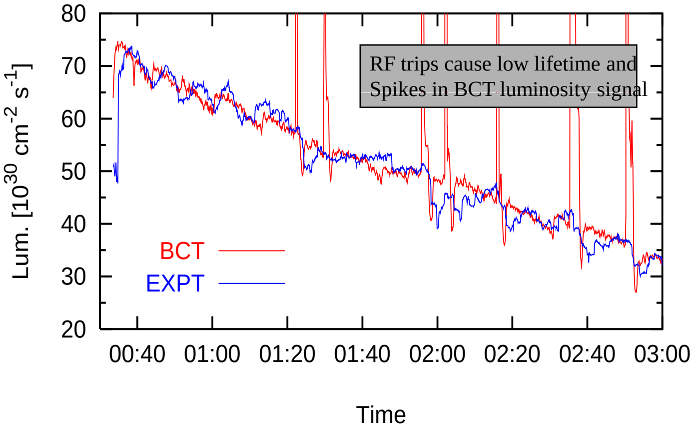
$$\boxed{L\ [10^{30}\,cm^{-2}s^{-1}] = 671.2 \cdot i_{bunch}\quad [mA] \cdot \left(\frac{1}{\tau\quad [h]} - \frac{1}{\tau_0\quad [h]} \right)}$$

Data suggests 758.5 Measured with BCT

Performance improved by increasing signal to noise ratio!

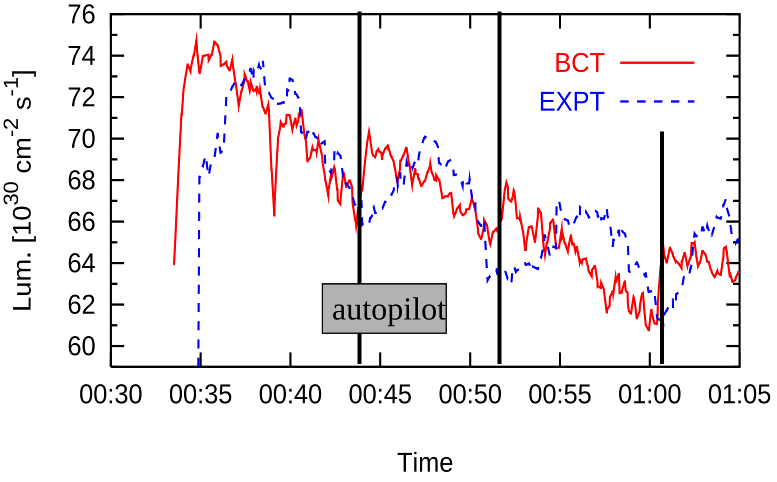
Luminosity from BCT / experiments:

Fill 6653, 101 GeV,
30-Oct-1999



RF trips cause low lifetime and Spikes in BCT luminosity signal

Very good agreement… BCT signal less noisy and much faster!

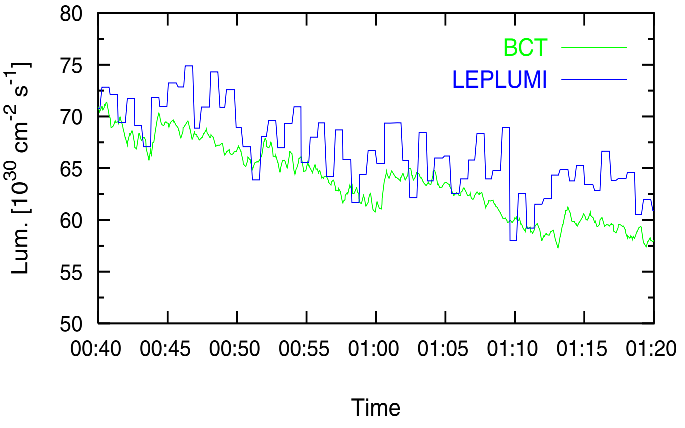


Clearly see effect of autopilot every 7-8 minutes (3% effect)

Both visible from experiments and BCT (faster)!

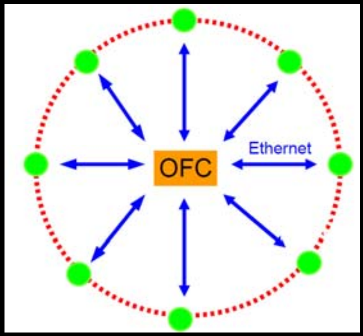
Compare LEPLUMI and BCT data:

LEPLUMI data is averaged over all four IP's!



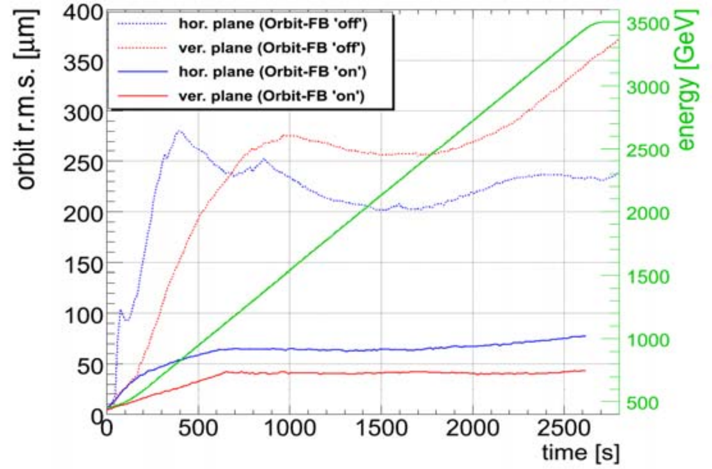
Reasonable agreement, but LEPLUMI is less accurate. Not much used

LHC Routine Operation - Feedbacks



- Opted for central global feedback system regrouping:
  - Orbit, energy, tune (operational)
  - Chromaticity, coupling (tested)
- Initial requirements:
  - Chromaticity expected to be most critical parameter for real-time control
    - Large perturbations foreseen & tight tolerances required
  - BUT
    - Large losses during early ramps changed focus to tune followed by orbit feedback
  - Orbit-Feedback is the largest and most complex LHC feedback:
    - 1088 BPMs → 2176+ readings @ 25 Hz from 68 front-ends
    - 530 correction dipole magnets/plane, distributed over ~50 front-ends
  - Total >3500 devices involved
    - more than half the LHC is controlled by beam based feedbacks!

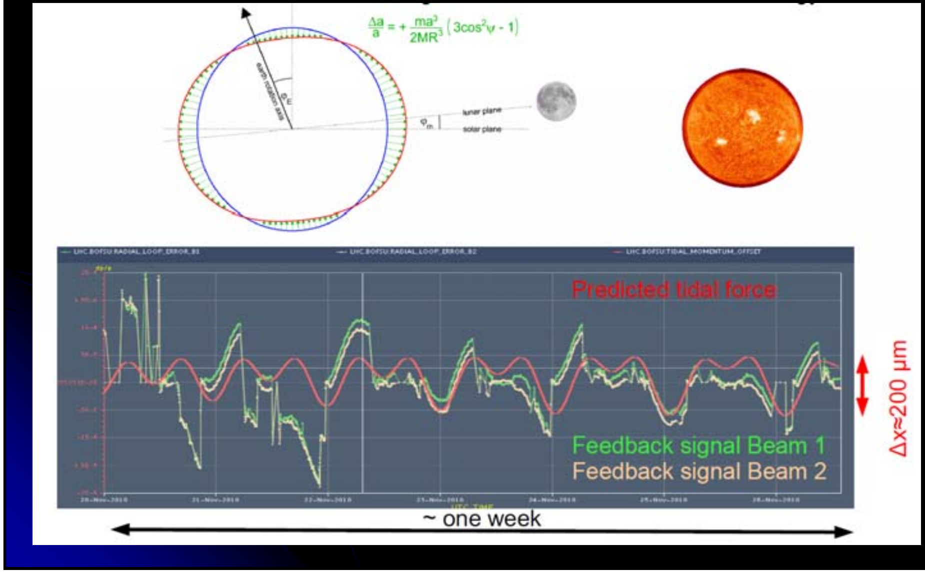
Orbit Feedback in the LHC



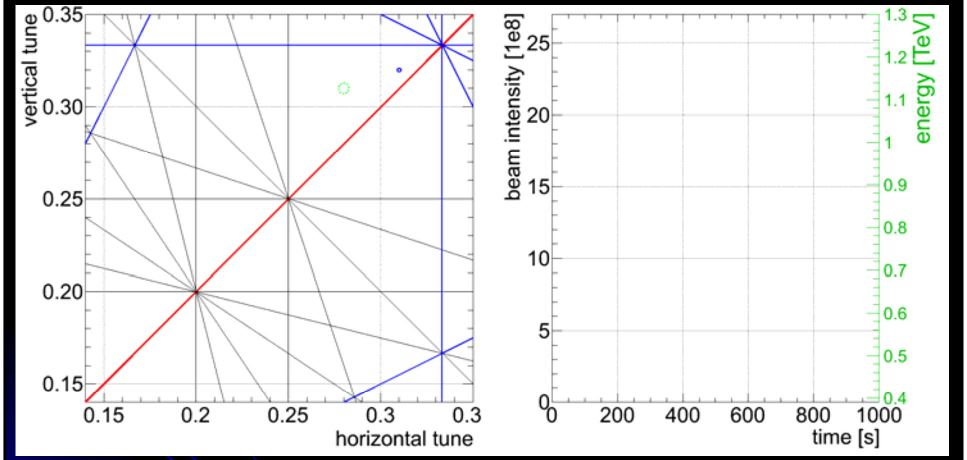
- Bandwidth of 0.1 Hz with BPM data supplied at 25Hz
- Regularised SVD approach to calculate applied correction
- Can maintain orbit stability to better than ~70µm globally & ~20µm in the arcs

Orbit Feedback in the LHC

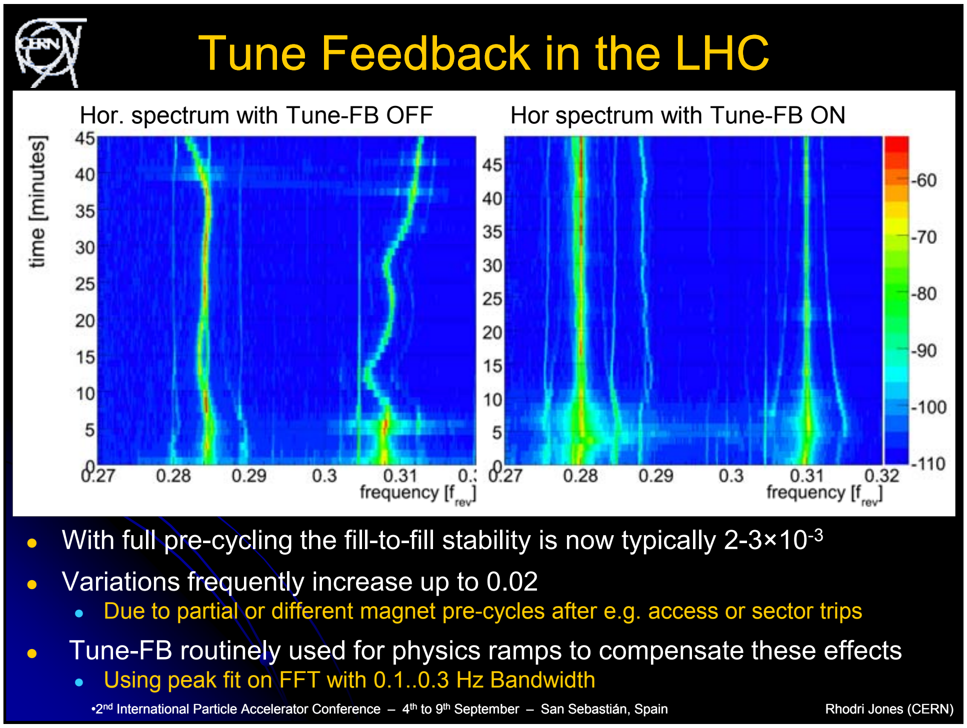
- Earth Tides dominating Orbit Stability during Physics



The LHC Tune System

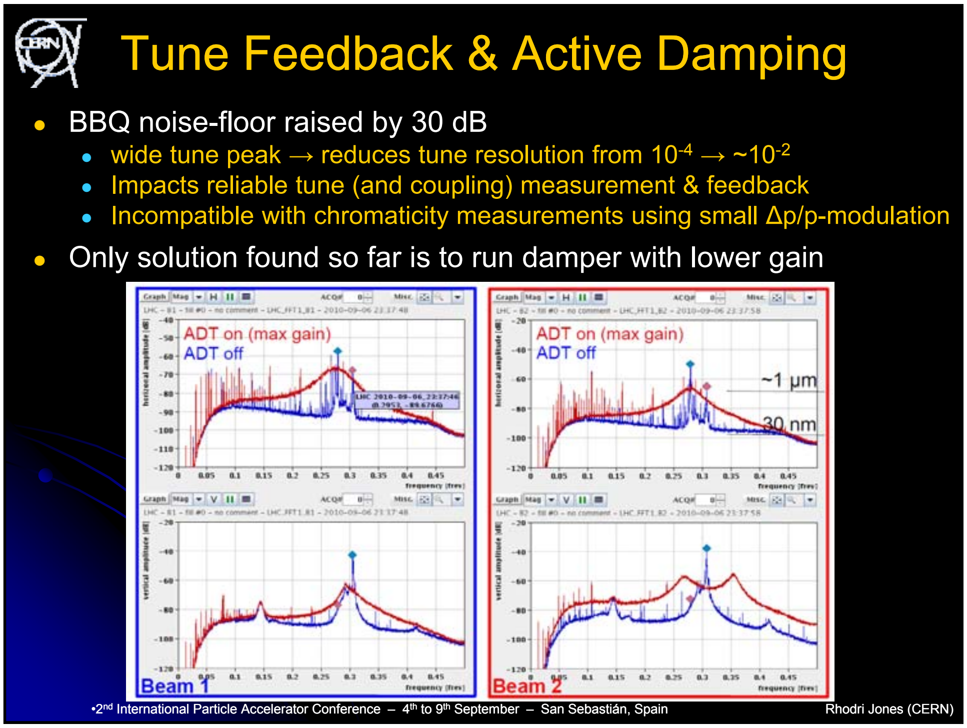


- Base Band Tune (BBQ) Measurement System
  - Direct diode detection, heavy filtering & baseband acquisition using audio ADCs
  - Shows extremely high sensitivity
  - Most measurements possible with residual beam oscillations
    - No need for PLL system with tune determination using FFT peak fitting



Tune Feedback in the LHC

- With full pre-cycling the fill-to-fill stability is now typically 2-3×10^{-3}
- Variations frequently increase up to 0.02
  - Due to partial or different magnet pre-cycles after e.g. access or sector trips
- Tune-FB routinely used for physics ramps to compensate these effects
  - Using peak fit on FFT with 0.1..0.3 Hz Bandwidth



Tune Feedback & Active Damping

- BBQ noise-floor raised by 30 dB
  - wide tune peak → reduces tune resolution from 10^{-4} → ~10^{-2}
  - Impacts reliable tune (and coupling) measurement & feedback
  - Incompatible with chromaticity measurements using small Δp/p-modulation
- Only solution found so far is to run damper with lower gain

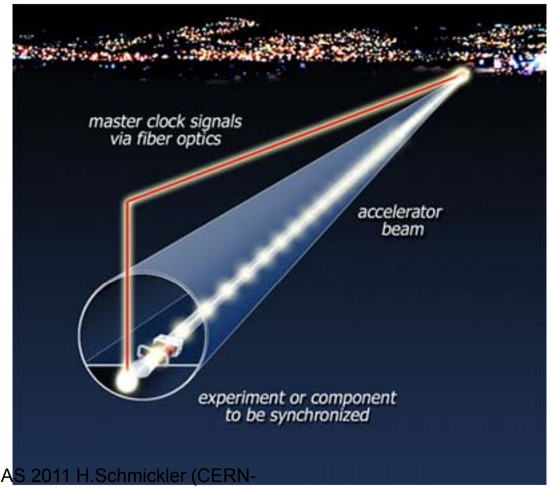
Synchronization of (distant) accelerator components down to the femtosecond

Speed of light:

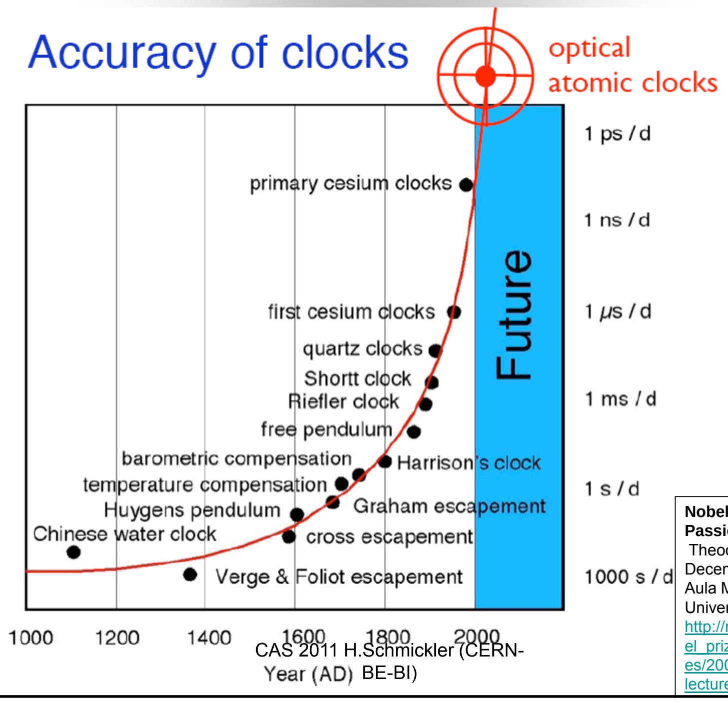
= 3*10^8 m/s

= 0.3 um/ fs

1) Clock stability
2) Distribution over length

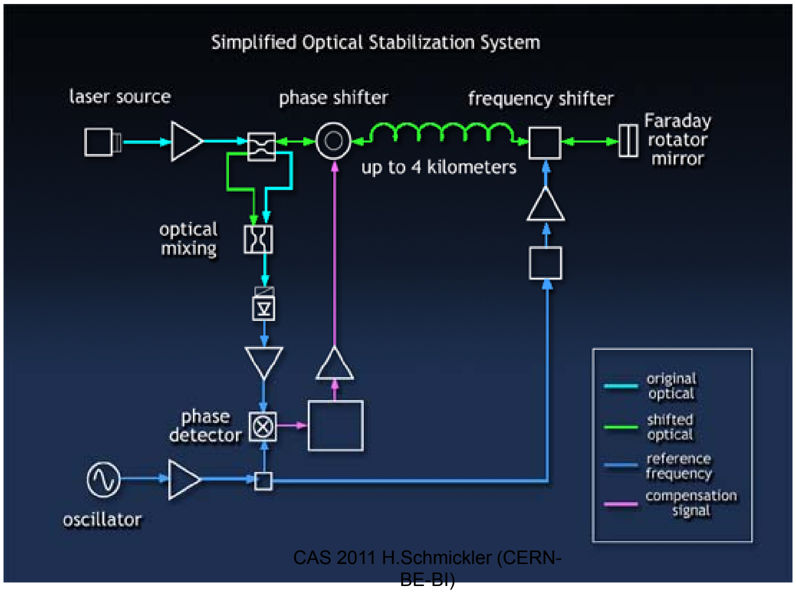


Accuracy of clocks

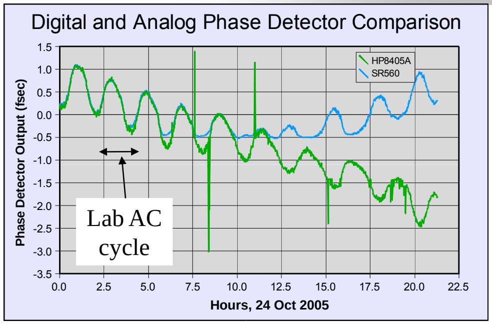


Nobel Lecture
Passion for Precision
Theodor W. Hänsch
December 8, 2005, at Aula Magna, Stockholm University.
http://nobelprize.org/nobel_prizes/physics/laureates/2005/hansch-lecture.html

All based on stable synch. signal and stabilized links



Compare phase at the end of fiber with reference to establish stability.


Digital and Analog Phase Detector Comparison

Measure slow drift (<1 Hz) of fiber under laboratory conditions

Compensation for several environmental effects results in a linear drift of 0.13 fsec/hour and a residual temperature drift of 1 fsec/deg C.

Environmental factors

- Temperature: 0.5-1 fsec/deg C
- Atmospheric pressure: none found
- Humidity: significant correlation
- Laser Wavelength Stabilizer: none
- Human activity: femtosecond noise in the data

J. Byrd, *Progress in femtosecond timing distribution and synchronization for ultrafast light sources* BIW06

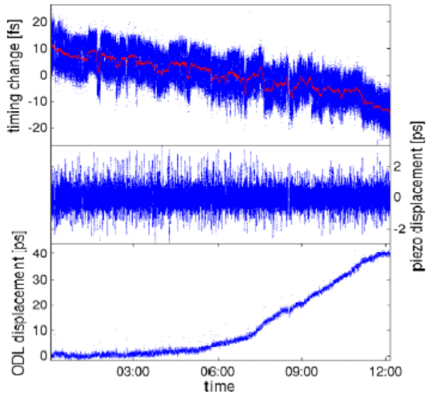
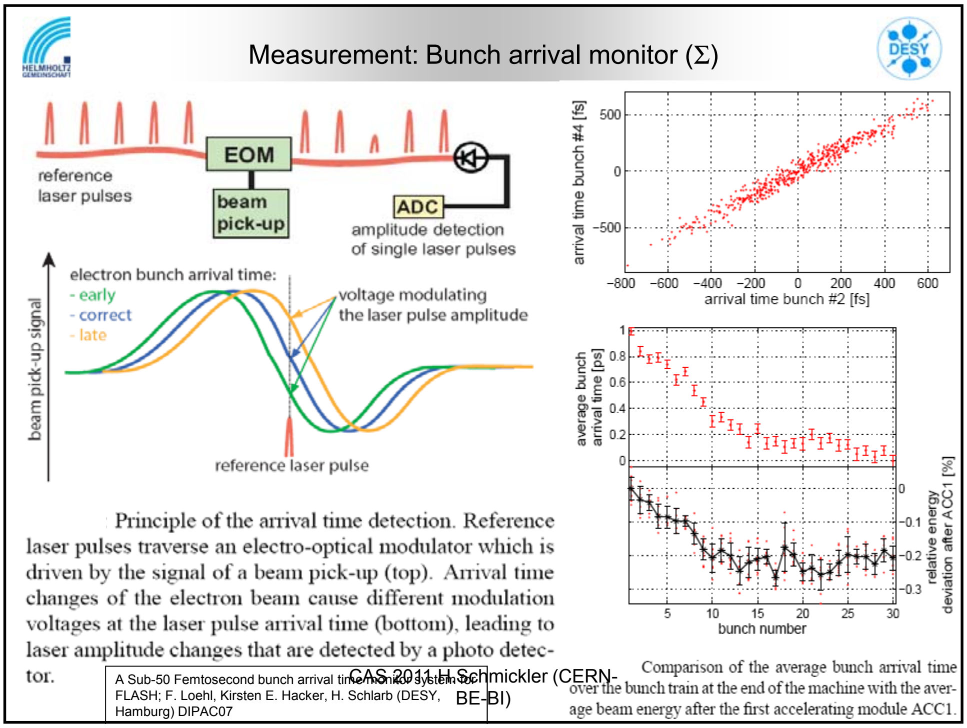


Figure 5: Out of loop drift measurement of a 400 m long fiberlink. Top: end of link timing change (blue). Over 12 hours the rms jitter is (7.5 ± 1.8) fs with a timing drift of 25 fs. The red line indicates changes with a time constant of 100 s. The timing jitter faster than 100 s is (4.4 ± 1.1) fs.

First prototype of an optical cross-correlation based fiber-link stabilization for the FLASH synchronization system; Florian Loehl, Holger Schlarb (DESY, Hamburg), Jeff Chen, Franz Xaver Kaertner, Jung-Won Kim (MIT, Cambridge, Massachusetts), DIPAC07

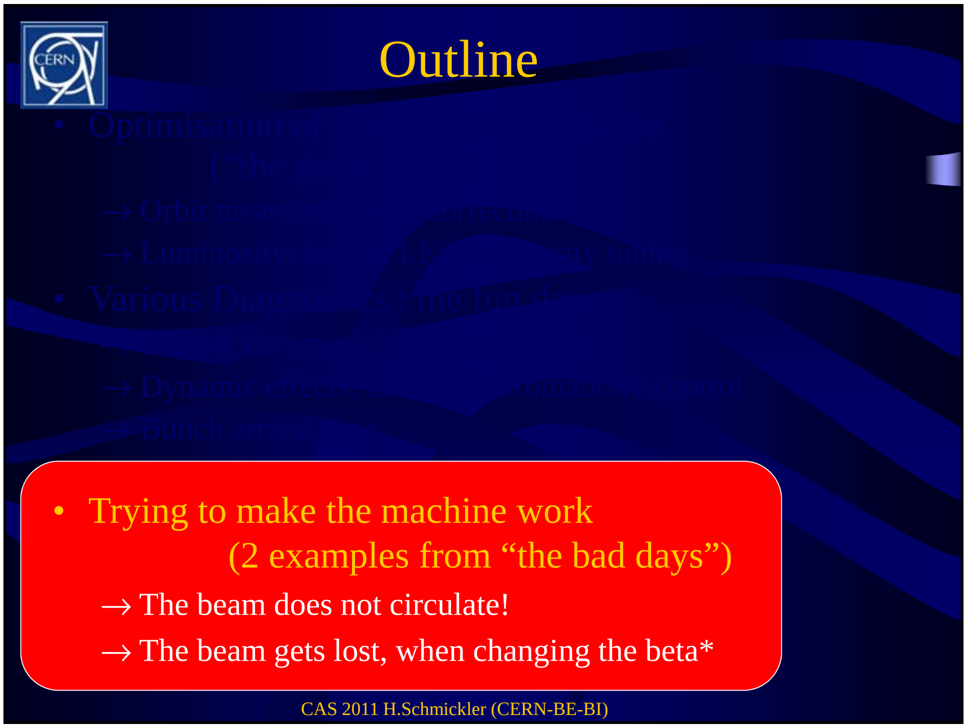


Measurement: Bunch arrival monitor (Σ)

Principle of the arrival time detection. Reference laser pulses traverse an electro-optical modulator which is driven by the signal of a beam pick-up (top). Arrival time changes of the electron beam cause different modulation voltages at the laser pulse arrival time (bottom), leading to laser amplitude changes that are detected by a photo detector.

Comparison of the average bunch arrival time over the bunch train at the end of the machine with the average beam energy after the first accelerating module ACC1.

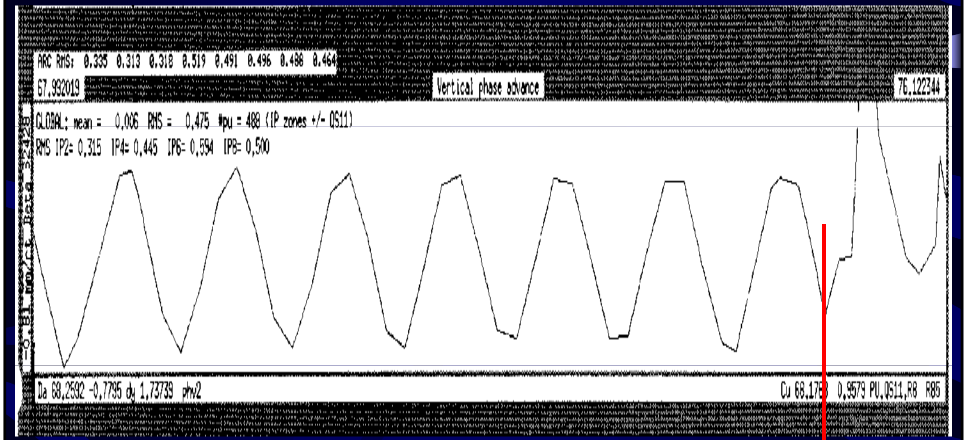
A Sub-50 Femtosecond bunch arrival time monitor system for FLASH; F. Loehl, Kirsten E. Hacker, H. Schlarb (DESY, Hamburg) DIPAC07



Outline

- Optimisation of Mach[illegible] [illegible]formance
  ("the go[illegible])
  → Orbit measurement [illegible] correction
  → Luminosity: bas[illegible] LE[illegible] [illegible]sity tuning
- Various Diagnostics ; the fun da[illegible]
  → Tune & chromaticit[illegible]
  → Dynamic effects: [illegible] [illegible]romaticity control
  → Bunch arrival [illegible]
- Trying to make the machine work
  (2 examples from "the bad days")
  → The beam does not circulate!
  → The beam gets lost, when changing the beta*

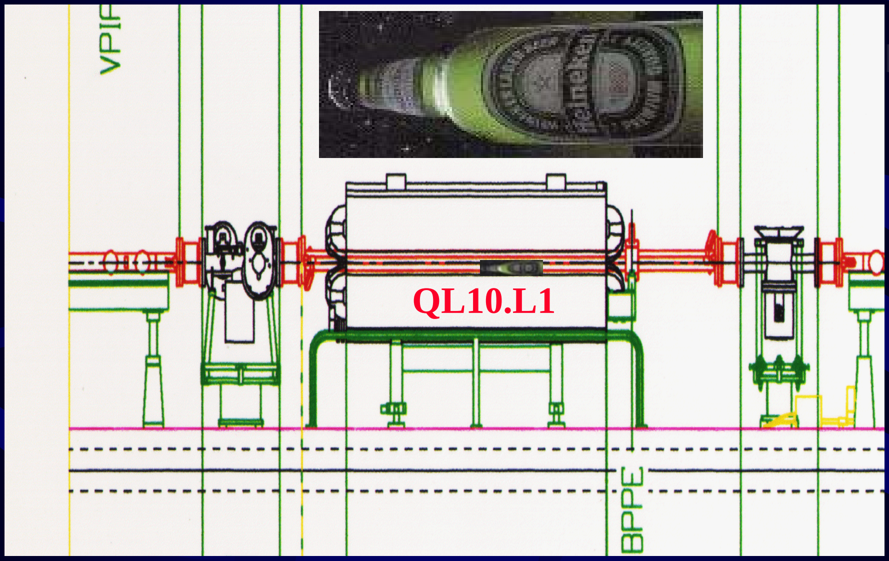
LEP – No Circulating Beam



Positrons →

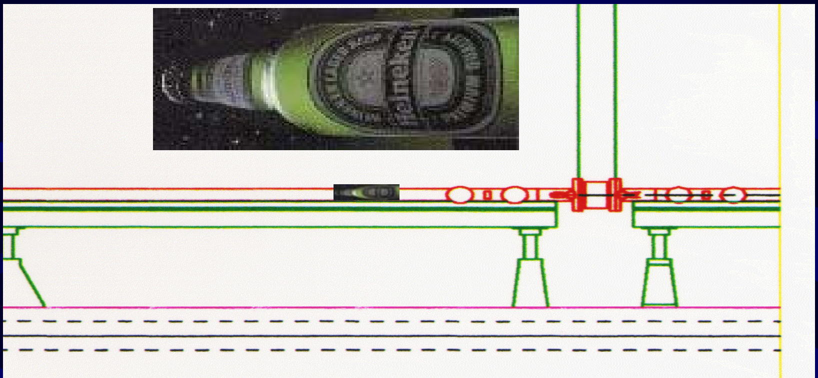
QL10.L1

Zoom on QL1



QL10.L1

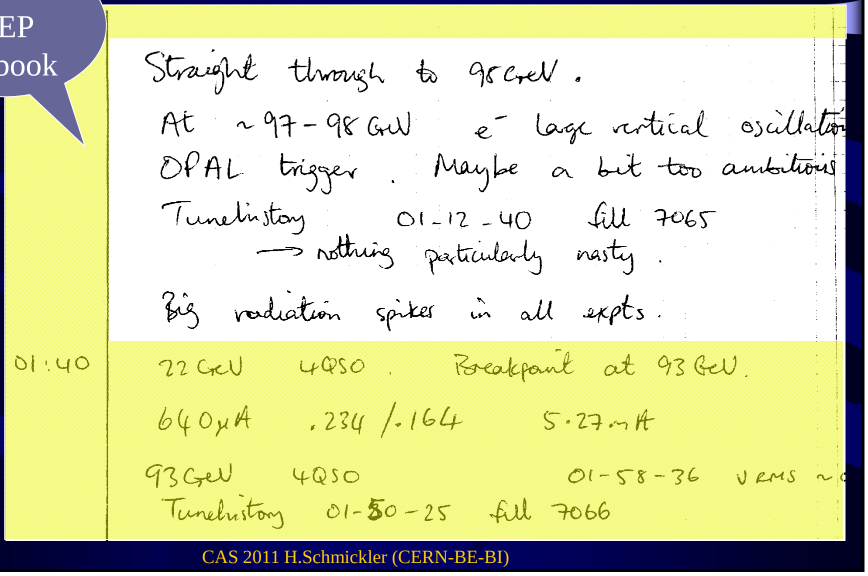
& 10 metres to the right …



Unsociable sabotage: both bottles were empty!!

LEP Beams Lost During Beta Squeeze

From LEP logbook



Straight through to 95 GeV.

At ~97-98 GeV e^- large vertical oscillatio

OPAL trigger. Maybe a bit too ambitious

Tunehistory 01-12-40 fill 7065

→ nothing particularly nasty.

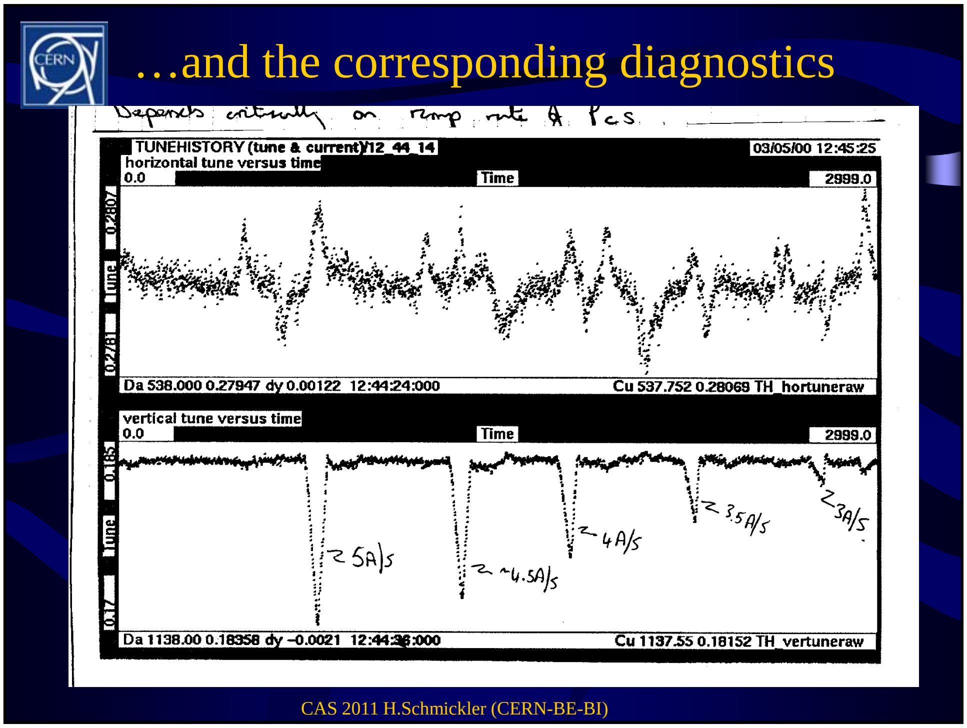
Big radiation spikes in all expts.

01:40 22 GeV 4QS0. Breakpoint at 93 GeV.

640μA .234 /.164 5.27 mA

93 GeV 4QS0 01-58-36 V RMS ~

Tunehistory 01-50-25 fill 7066



…and the corresponding diagnostics

Depends critically on ramp rate & PCs.

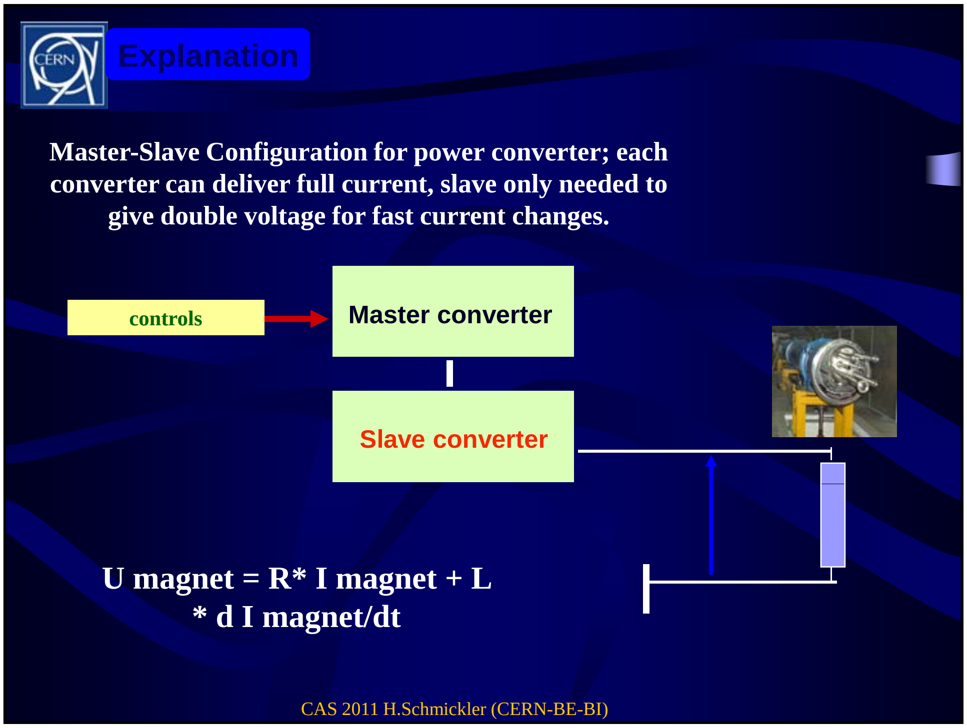
TUNEHISTORY (tune & current)/12_44_14 03/05/00 12:45:25

horizontal tune versus time

Da 538.000 0.27947 dy 0.00122 12:44:24:000 Cu 537.752 0.28069 TH_hortuneraw

vertical tune versus time

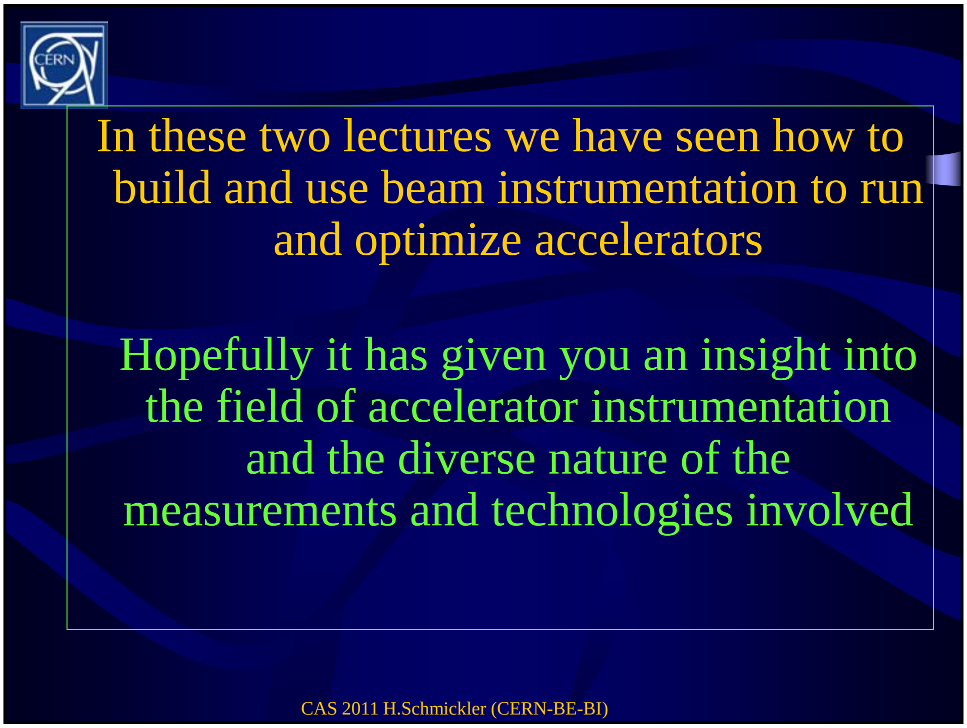
Da 1138.00 0.18358 dy −0.0021 12:44:36:000 Cu 1137.55 0.18152 TH_vertuneraw



Explanation

Master-Slave Configuration for power converter; each converter can deliver full current, slave only needed to give double voltage for fast current changes.

$$U_{magnet} = R * I_{magnet} + L * dI_{magnet}/dt$$



In these two lectures we have seen how to build and use beam instrumentation to run and optimize accelerators

Hopefully it has given you an insight into the field of accelerator instrumentation and the diverse nature of the measurements and technologies involved