Quadrupole Pick-Ups at CERN & Fermilab

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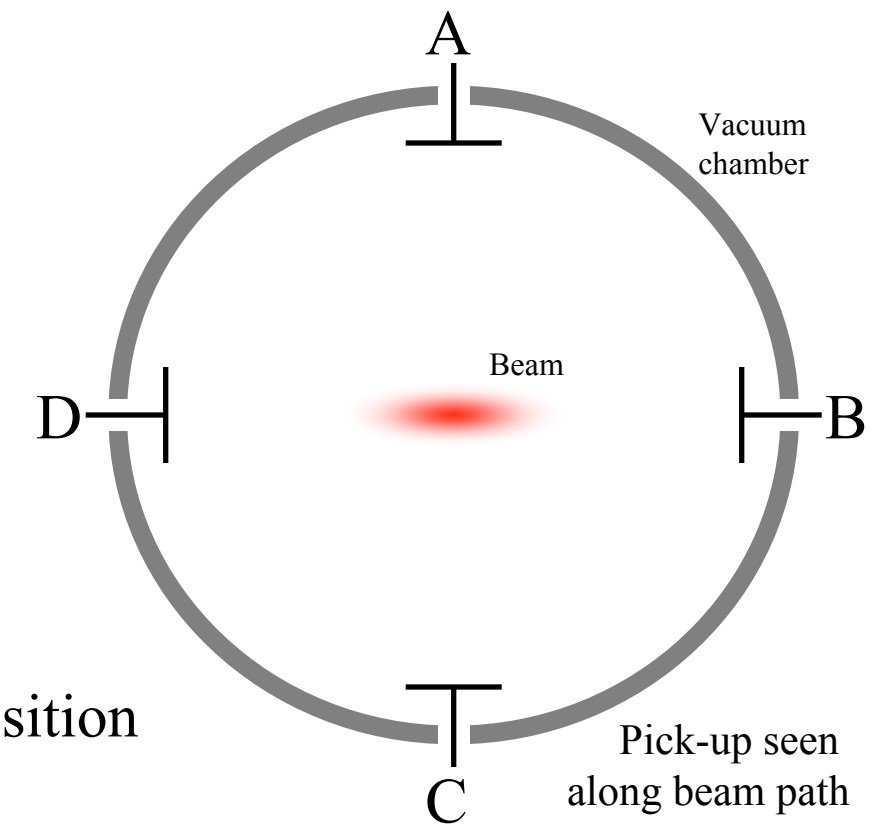
Talk outline

- The quad pick-ups in the CERN PS
- The quad pick-up in the Fermilab AA
- Possibilities for LHC (and Tevatron)

What is a quadrupole pick-up?

- A pick-up sensitive to the r.m.s. beam size.
- Uses the small non-linear terms in electrode response to particle position to measure <u>quadrupole moment.</u>
- Quadrupole moment is a measure of ellipticity.

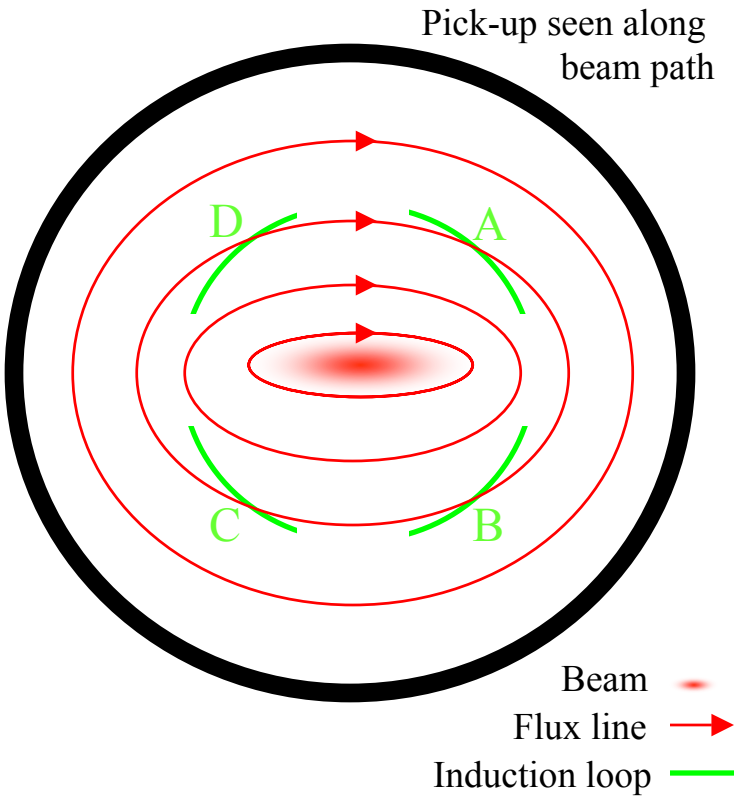


$$\frac{B-D}{A+B+C+D} \propto x = \text{horizontal position}$$

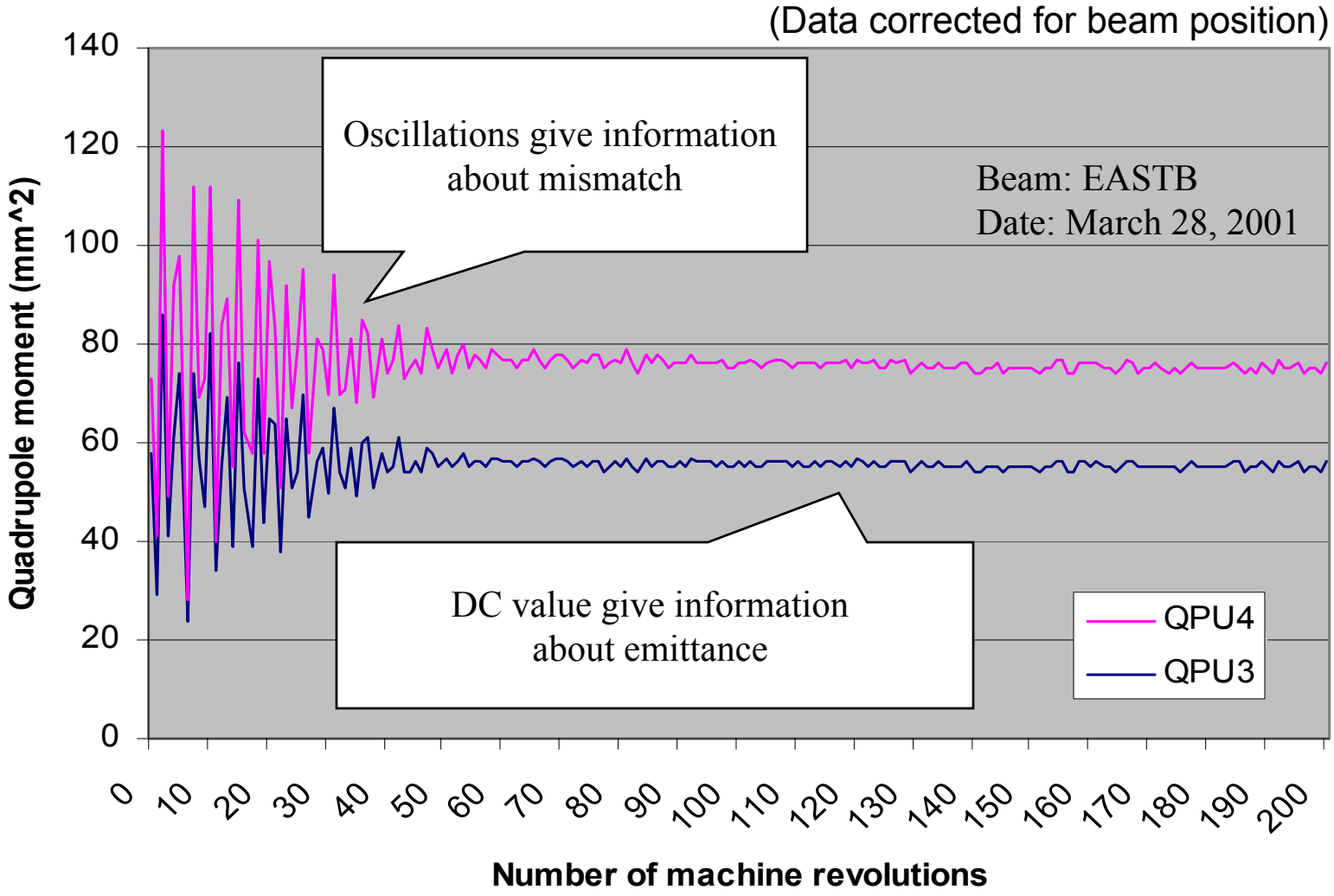
$$\frac{(B+D)-(A+C)}{A+B+C+D} \propto \sigma_x^2 - \sigma_y^2 + x^2 - y^2 = \text{quadrupole moment}$$

PS pick-ups

- **Magnetic coupling.**
  - Insensitive to radiation
  - Signal on 50Ω
- **Intensity signal is suppressed by pick-up geometry (coupling to the radial field component).**
- **Bandwidth ~25 MHz (covers full bunch spectrum at injection)**
- **Two pick-ups installed in machine.**

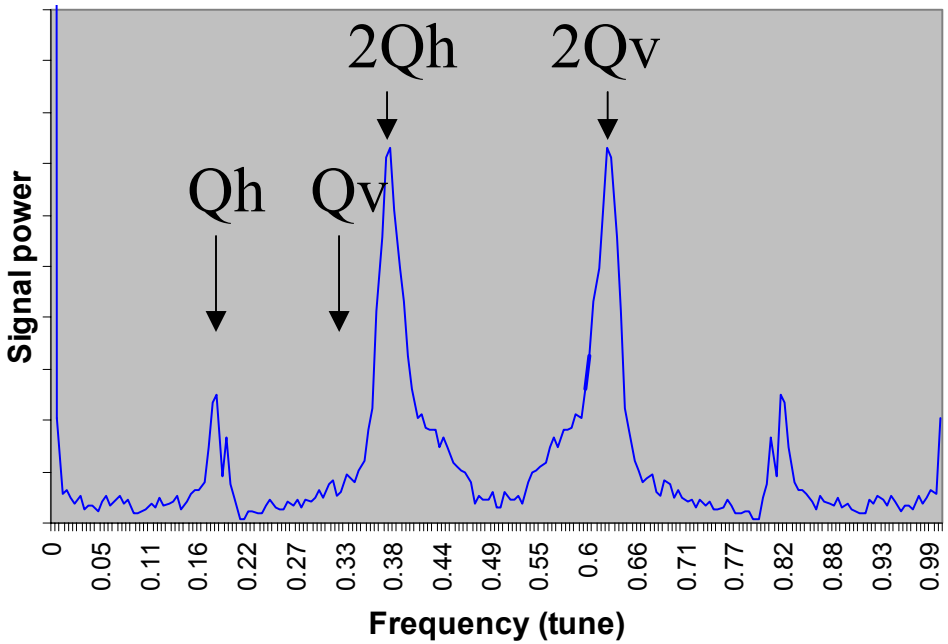


Ouput signals (Time Domain)

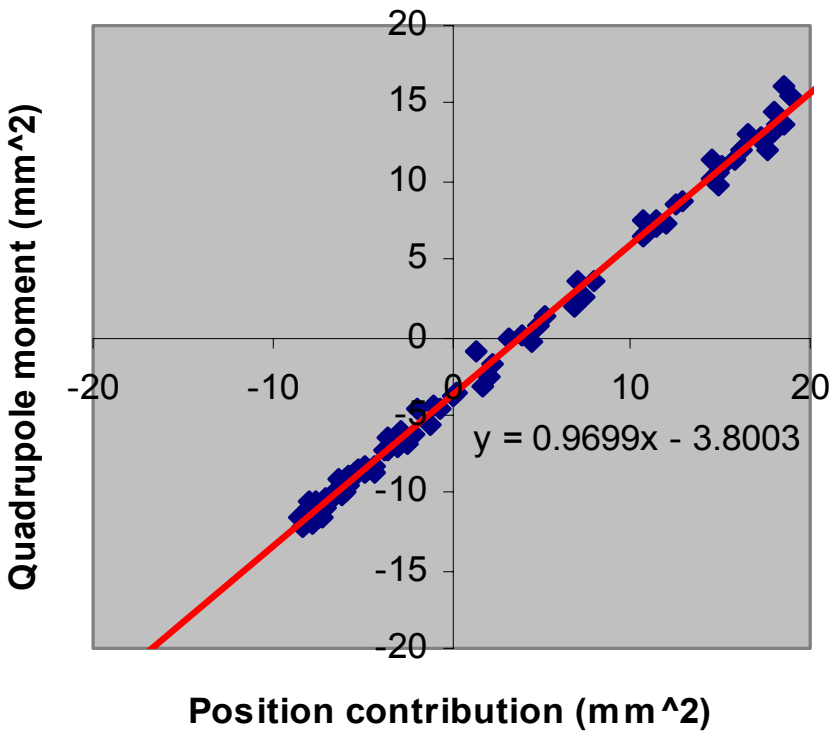


Output signals (Frequency Domain)

- Peaks are wide due to fast decoherence (caused by space charge tune spread).
- Working point in PS machine often make signals overlap in frequency domain.
- Need two pick-ups in optically different locations to separate H/V quad signal components!

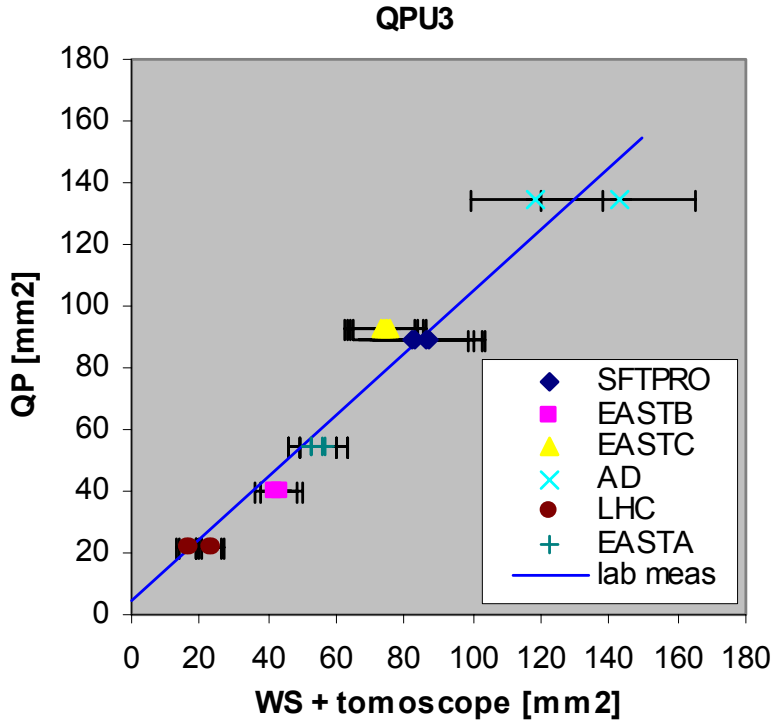


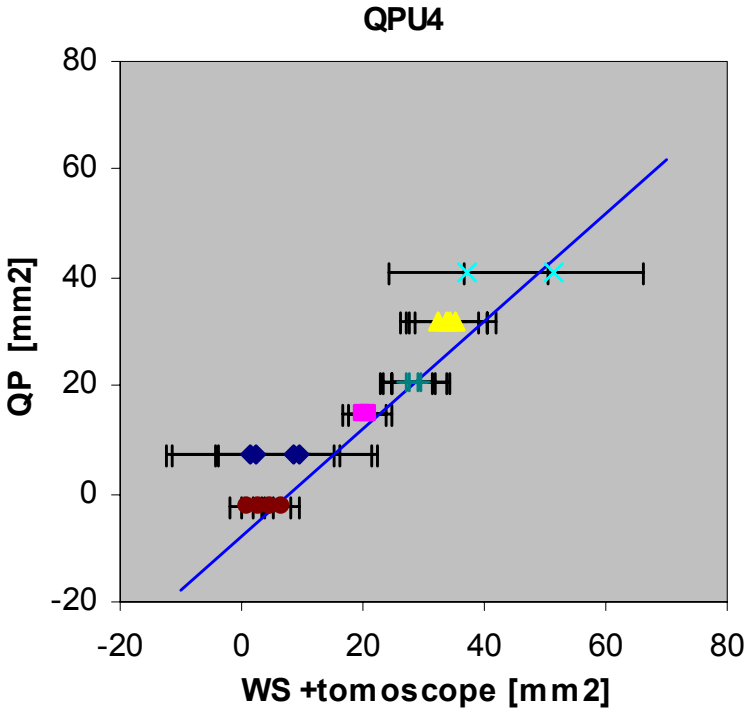
Position contribution to quad moment



- Data with only beam position oscillations (taken after filamentation).
- Quadrupole moment versus its expected position contribution x^2-y^2 should be straight line with unit slope, as obesrved.
- The position contribution can be subtracted with good accuracy!

Comparison with Wire Scanners



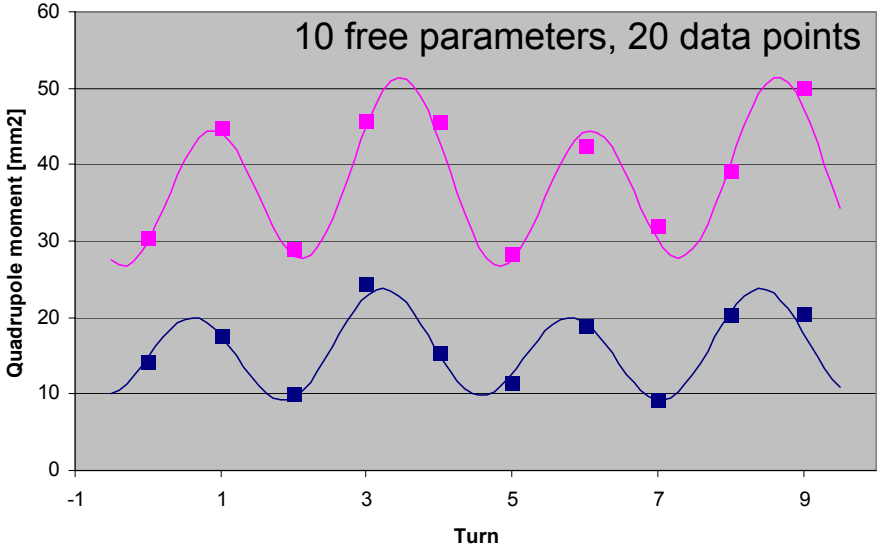


- **Comparison Quad PU vs. Wire-scanner on stable beam.**
- **Several different beam types.**

- **Systematic error bar from:**
  - Beta function ~10%
  - Dispersion ~10%
  - Mom. spread ~3%

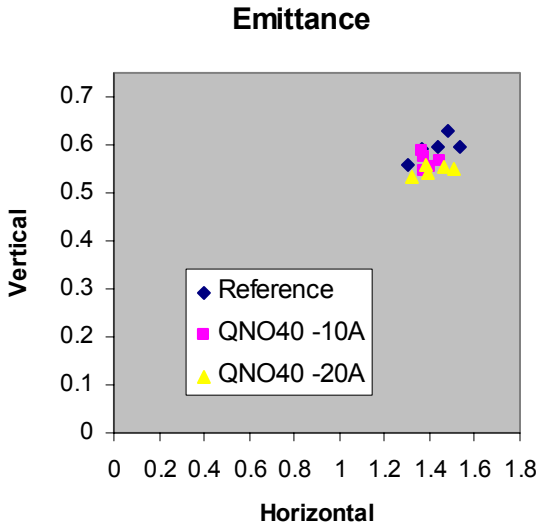
Measurement of matching

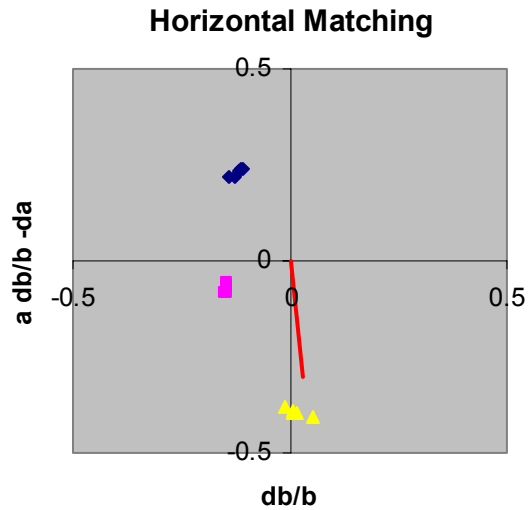
$$\kappa \propto \sigma_x^2 - \sigma_y^2 =$$
$$\varepsilon_x(\beta_x + \underbrace{\Delta\beta_x}_{2q_x}) - \varepsilon_y(\beta_y + \underbrace{\Delta\beta_y}_{2q_y}) +$$
$$+\sigma_p^2(D_x^2 + D_x\underbrace{\Delta D_x}_{q_x} + \underbrace{\Delta D_x^2}_{2q_x} - \underbrace{\Delta D_y^2}_{2q_y})$$

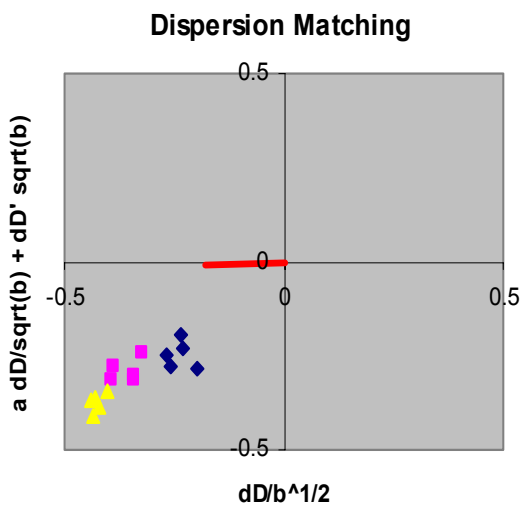


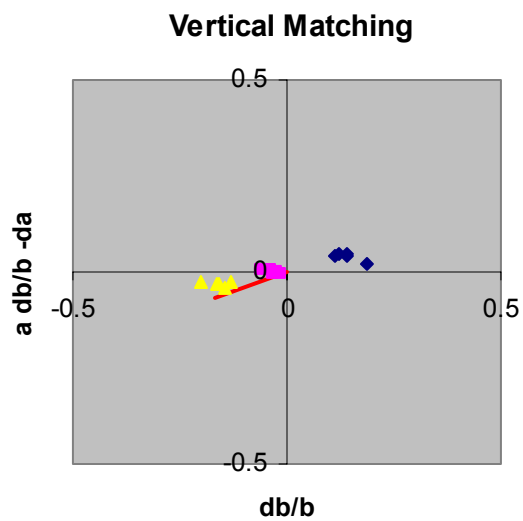
- **Simultaneous fit to the two pick-up signals gives:**
  - Injected emittances.
  - Betatron mismatches.
  - Horizontal dispersion mismatch.
- **"Best fit" tunes gives information on space charge.**
- **Fixed tune give wrong fit results for matching parameters.**

Injection matching measurement









- **Betatron mismatch**

$$k_\beta = \begin{pmatrix} \dfrac{\Delta\beta}{\beta} \\ \dfrac{\Delta\beta}{\beta}\alpha - \Delta\alpha \end{pmatrix}$$

- **Dispersion mismatch**

$$k_D = \begin{pmatrix} \dfrac{\Delta D}{\sqrt{\beta}} \\ \dfrac{\Delta D}{\sqrt{\beta}}\alpha + \sqrt{\beta}\Delta D' \end{pmatrix}$$

Measurement of filamented emittance

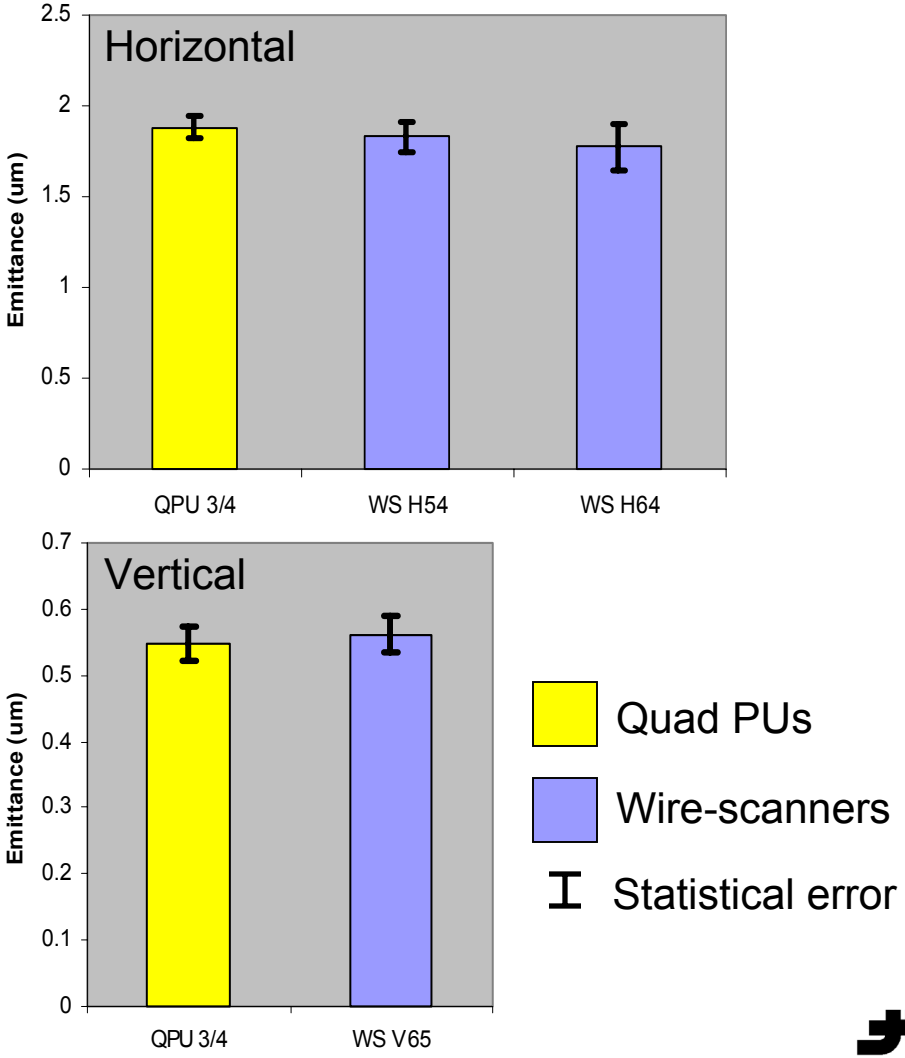
- For a stable beam, the emittance can be calculated from only two pick-up readings.

$$\kappa = \sigma_x^2 - \sigma_y^2$$

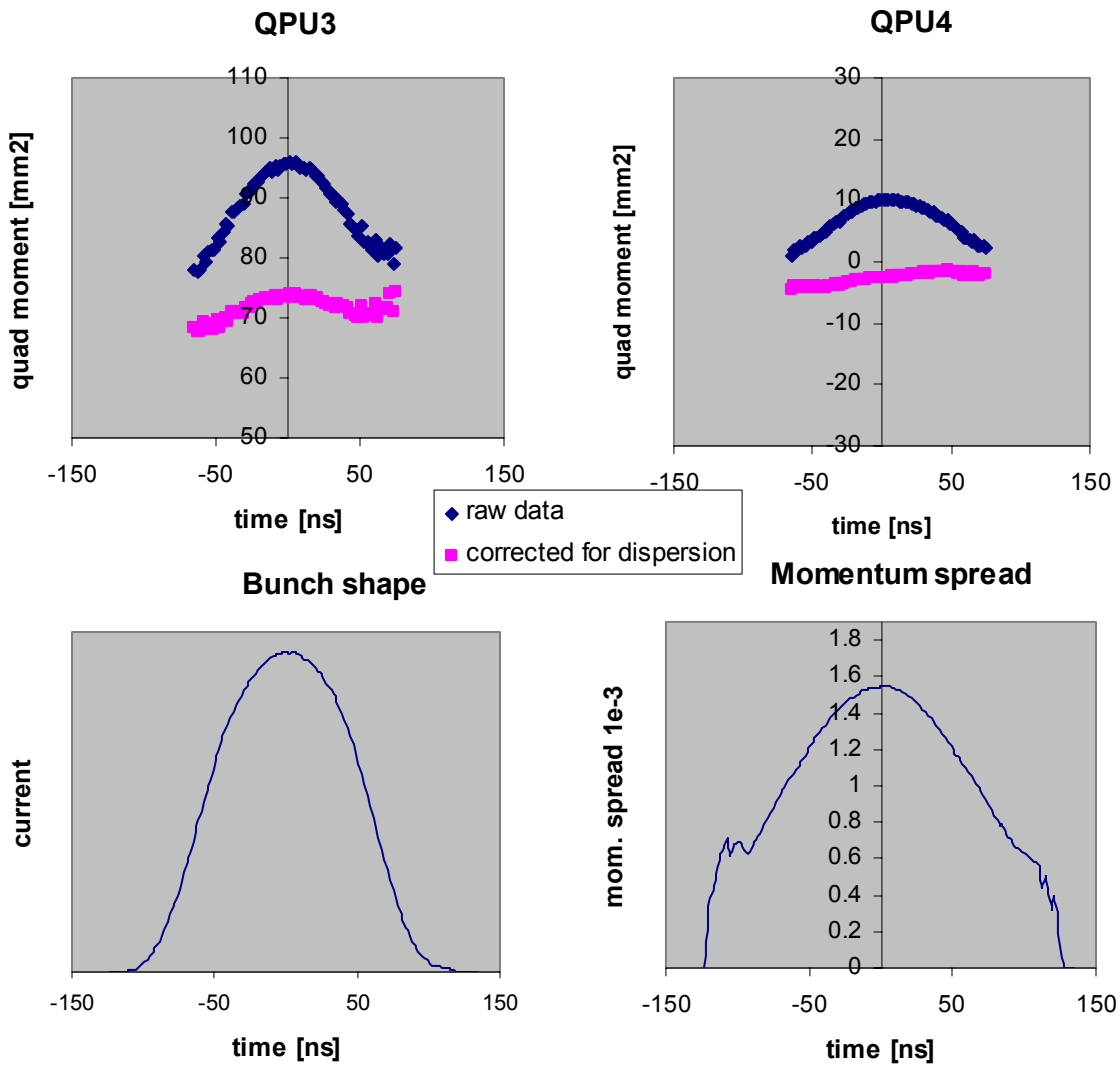
$$\kappa_1 = \varepsilon_x \beta_{x1} - \varepsilon_y \beta_{y1} + \sigma_p^2 D_{x1}^2$$

$$\kappa_2 = \varepsilon_x \beta_{x2} - \varepsilon_y \beta_{y2} + \sigma_p^2 D_{x2}^2$$

- Different horizontal/vertical beta function ratios at the two pick-ups are required.
- Signal noise can be reduced by averaging over many turns.



Measurements within the bunch

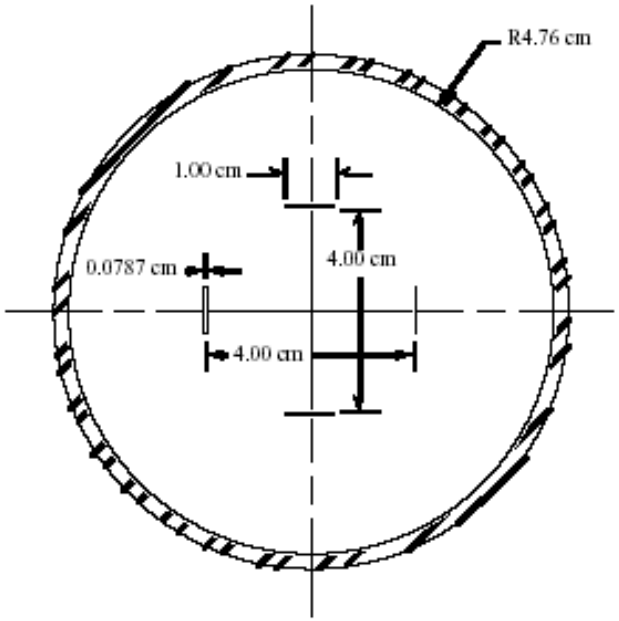


- Normalized for intensity in each point separately.
- Variation in quad moment along bunch mainly due to dispersion and momentum spread.

Fermi Pbar Accumulator 2-pickup

- Un-terminated strip-line.
- Motors to center pickup on beam.
- LP preamps (only 1st harmonic) in tunnel.
- Can inject calibration signal to balance preamps.
- No hybrid used. Plate signals sampled directly on 14 bit ADCs at up to 10 MHz (16x per revolution).

- Injected beam is a train of typically 7-35 bunches at 53 MHz (1/12-5/12 of the circumference).

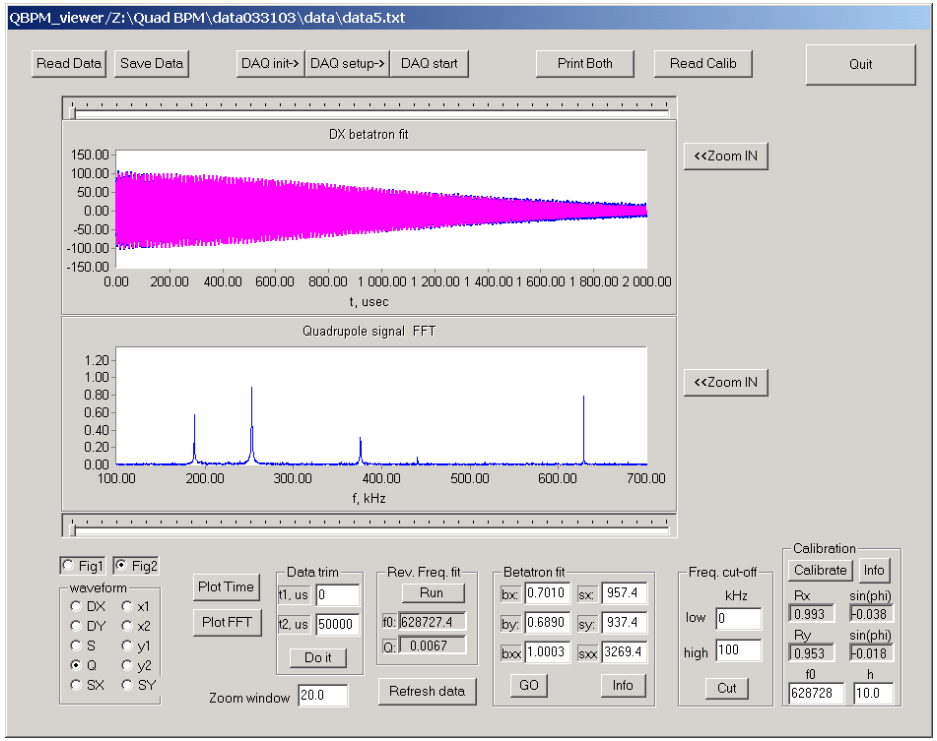


Ref: Vladimir Nagaslaev

Lessons from beam measurements

- Initial transient signal due to intensity step and limited bandwidth.
- Beam loss on electrodes at injection.
- Fast decoherence due to large chromaticity at extraction orbit.

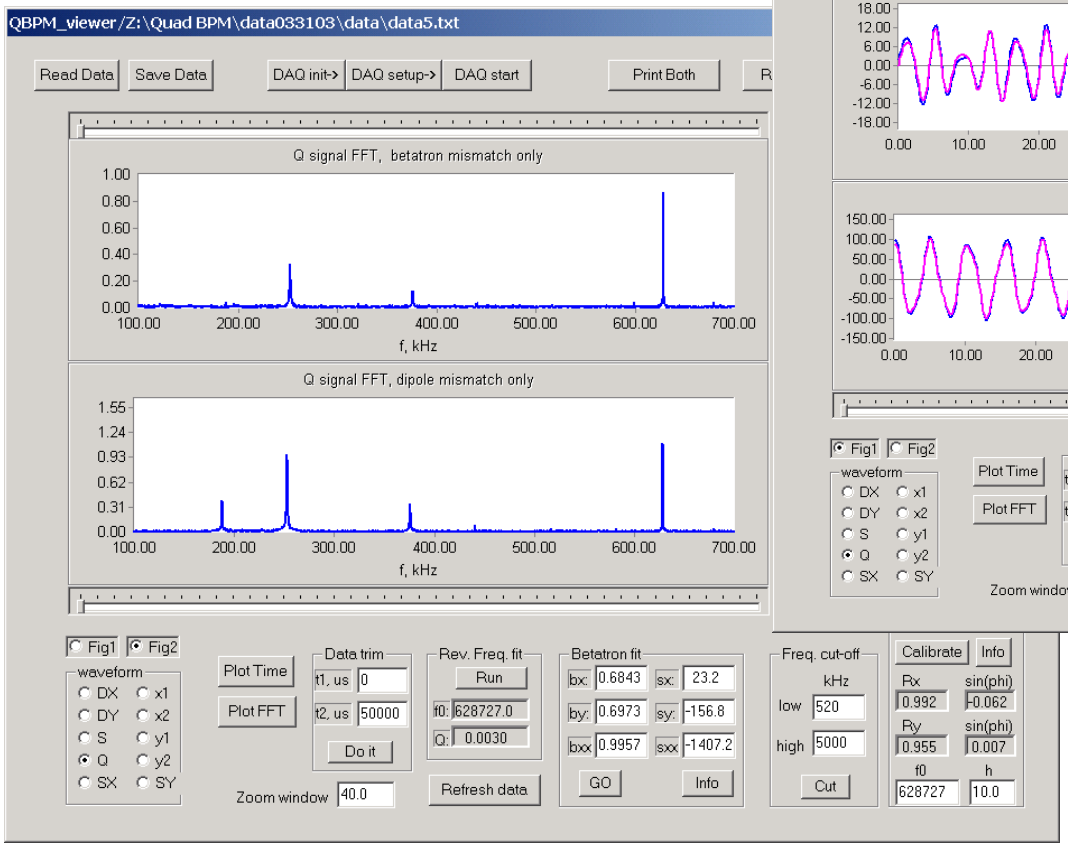
- This makes it hard to interpret data from parasitic measurements
- With lowered chromaticity (dedicated measurements) performance is adequate.

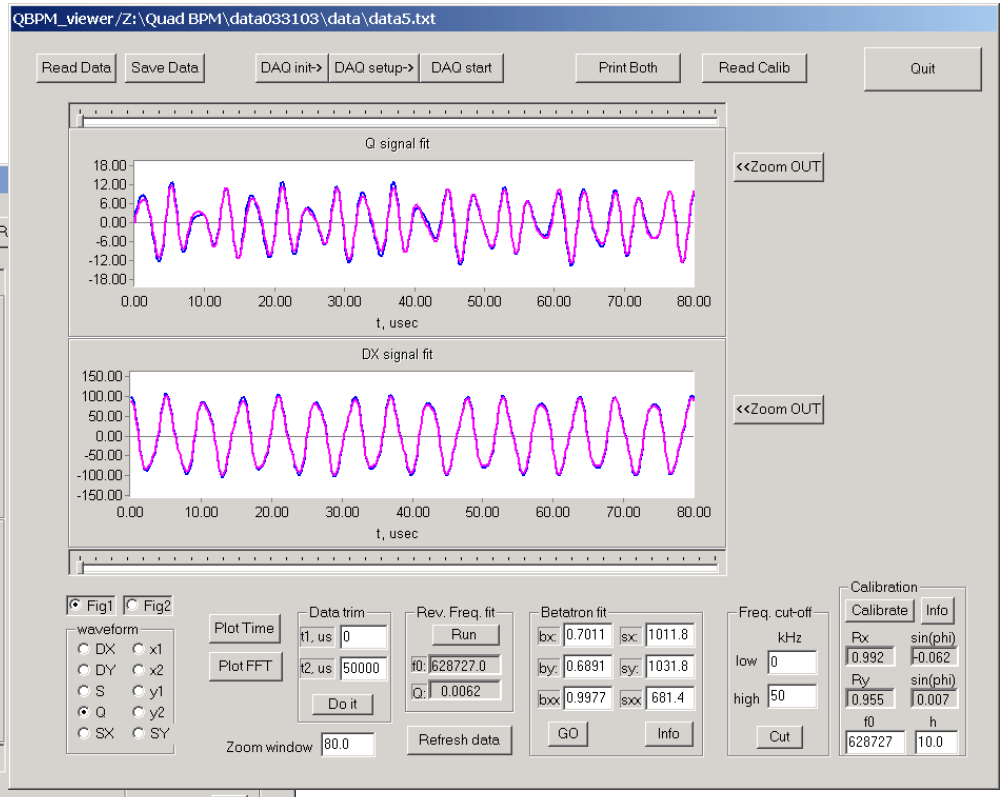


Ref: Vladimir Nagaslaev

Measurements with low chromaticity

Time domain data fits the model





Frequency componenets behave as expected when changing steering and matching

Ref: Vladimir Nagaslaev

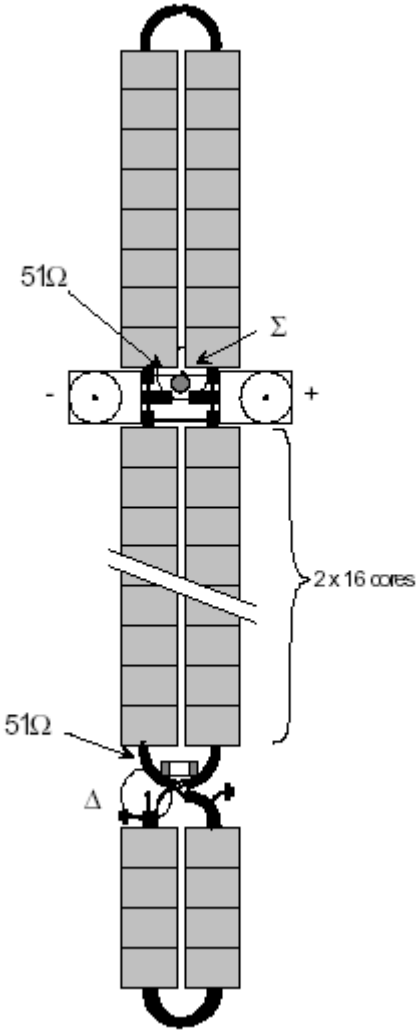
Quad pick-ups in the LHC?

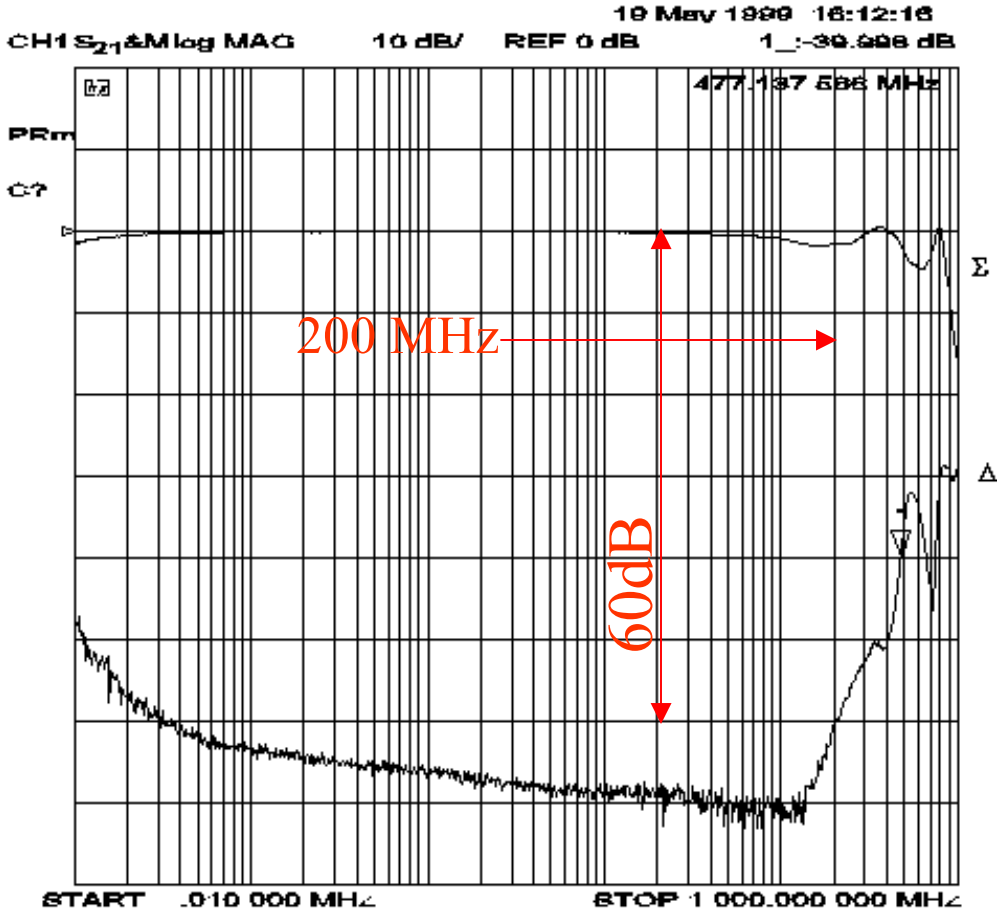
- **Are they wanted/needed?**
- **What is the time resolution required?**
  - Single turn (BW=f_{rev}) is the minimum, and may be adequate e.g. for dedicated measurements (pilot bunch?). Relatively straight-forward to build.
  - Single bunch (BW=f_{rep}) is desirable e.g. for parasitic measurements during normal operation. Requires some R&D.
  - Intra-bunch resolution (BW=1/t_{bunch}) helpful to diagnose e.g. head-tail motion, but may not be needed if beam is properly set up. May be difficult to achieve for LHC (~GHz).
- **The better the time resolution, the easier it is to understand what's going on (less dependent on assumptions).**

How build a wideband quad pick-up?

- The PS pick-up's common mode rejection is limited at high frequencies by resonances in the magnetic induction loop.
- Reducing the loop dimensions could perhaps gain a factor 3-4 in frequency, but also reduces coupling.
- Removing the resonances require breaking the loop and adding matched terminations $\Rightarrow$ strip-lines.
- With a good WB hybrid, can get >60dB CMRR over ~200 MHz bandwidth (see CERN PS/BD Note 99-09).

Wide-band hybrid coupler





Four-decade hybrid,
J.M. Belleman,CERN
PS/BD/Note 99-09

Summary

- **In the PS:**
  - Betatron mismatch of a few percent could be detected (both amplitude and phase).
  - Emittance was measured, in rather good agreement with wire-scanners.
- **In the Fermi pbar accumulator:**
  - Clean signals (mismatch) obtained in dedicated studies.
  - Difficult to interpret parasitic measurements.
- **For the LHC:**
  - Single turn (narrow band) should be straight-forward.
  - Single bunch (wide band) needs some work, but seems possible using e.g. stripline couplers and WB hybrids.
  - Tevatron could act as test-bench and benefit from LHC design work.