Linear and non-Linear Correction using Turn-by-Turn BPM Data

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Thanks to: M. Aiba, R. Bartolini, H. Braun, R. Calaga, K. Kubo, S. Kuroda, T. Naito, T. Okugi, J. Urakawa, Y. Papaphilippou and F. Zimmermann

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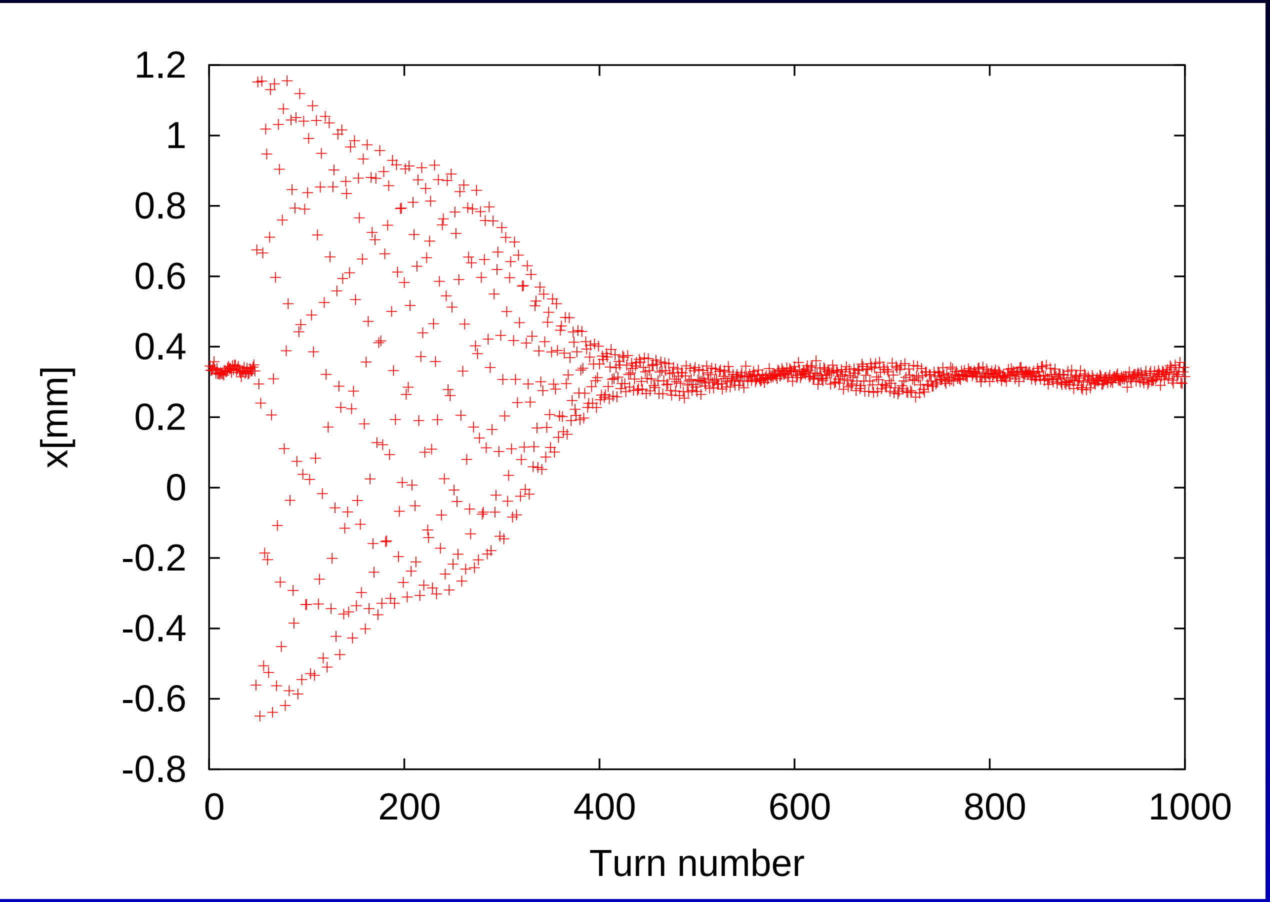
Turn-by-turn BPM data



→ A single-turn kick excites betatron motion.

→ Filamentation damps the centroid oscillation.

Measurement from BPM data

Momentum reconstruction from 2 BPMs:

$$p_{12}(N) = (x_1(N) + x_2(N)\sin\delta)/\cos\delta$$

Description of the motion:

$$\begin{aligned} x_1(N) - ip_{12}(N) \;=\; & \sqrt{\beta_{x1}}\Big\{\sqrt{2I_x}e^{i(2\pi\nu_x N + \psi_{x_1})} - \\ & 2i\sum_{jklm} j f^{(1)}_{jklm}(2I_x)^{\frac{j+k-1}{2}}(2I_y)^{\frac{l+m}{2}} \times \\ & e^{i[(1-j+k)(2\pi\nu_x N+\psi_{x_1})+(m-l)(2\pi\nu_y N+\psi_{y_1})]}\Big\} \end{aligned}$$

$\rightarrow \psi_{x_1}$ and $f^{(1)}_{jklm}$ can be inferred from the FFT

What is f_{jklm}?

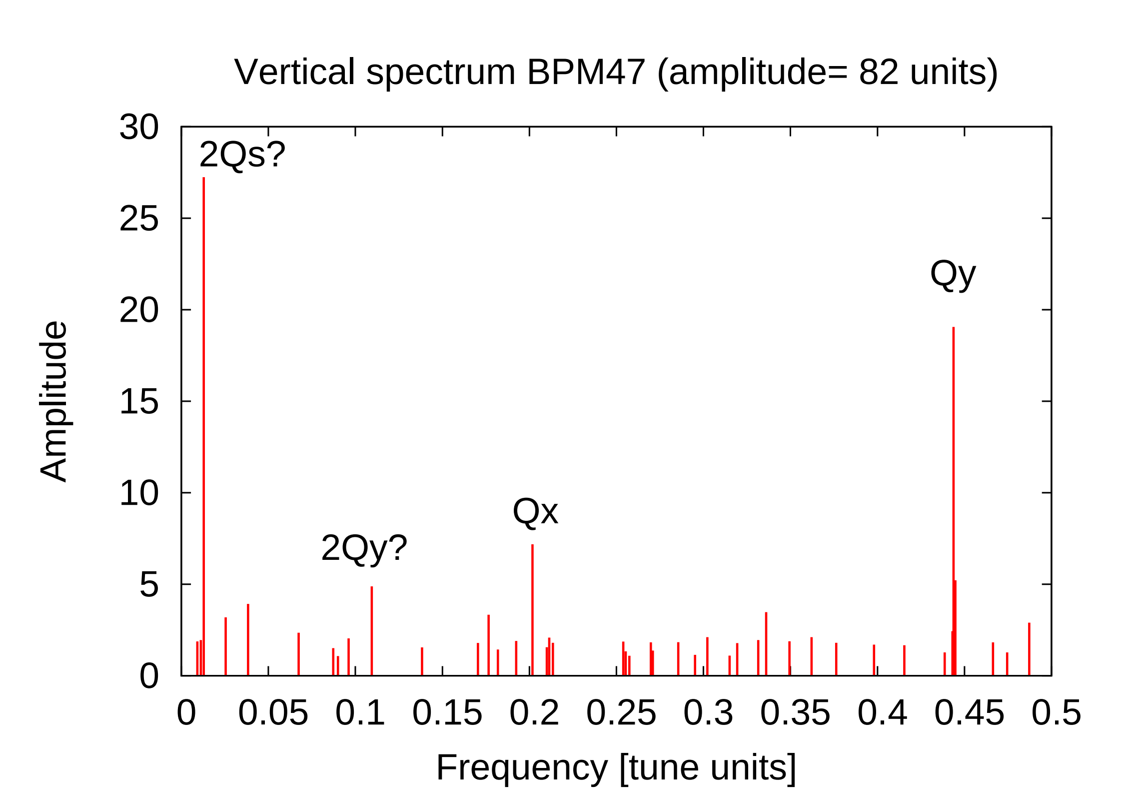
It is proportional to the Hamiltonian term h_{jklm}:

$$f_{jklm} = \frac{h_{jklm}}{1 - e^{-i2\pi[(j-k)Q_x+(l-m)Q_y]}} .$$

It drives resonances and spectral lines:

Term	Resonance	Type	Line	Plane
f_{1001}	(1,-1)	skew	$-Q_y$	H
f_{3000}	(3,0)	norm.	$-2Q_x$	H
f_{0210}	(2,1)	skew	$2Q_x$	V
f_{0030}	(0,3)	skew	$-2Q_y$	V

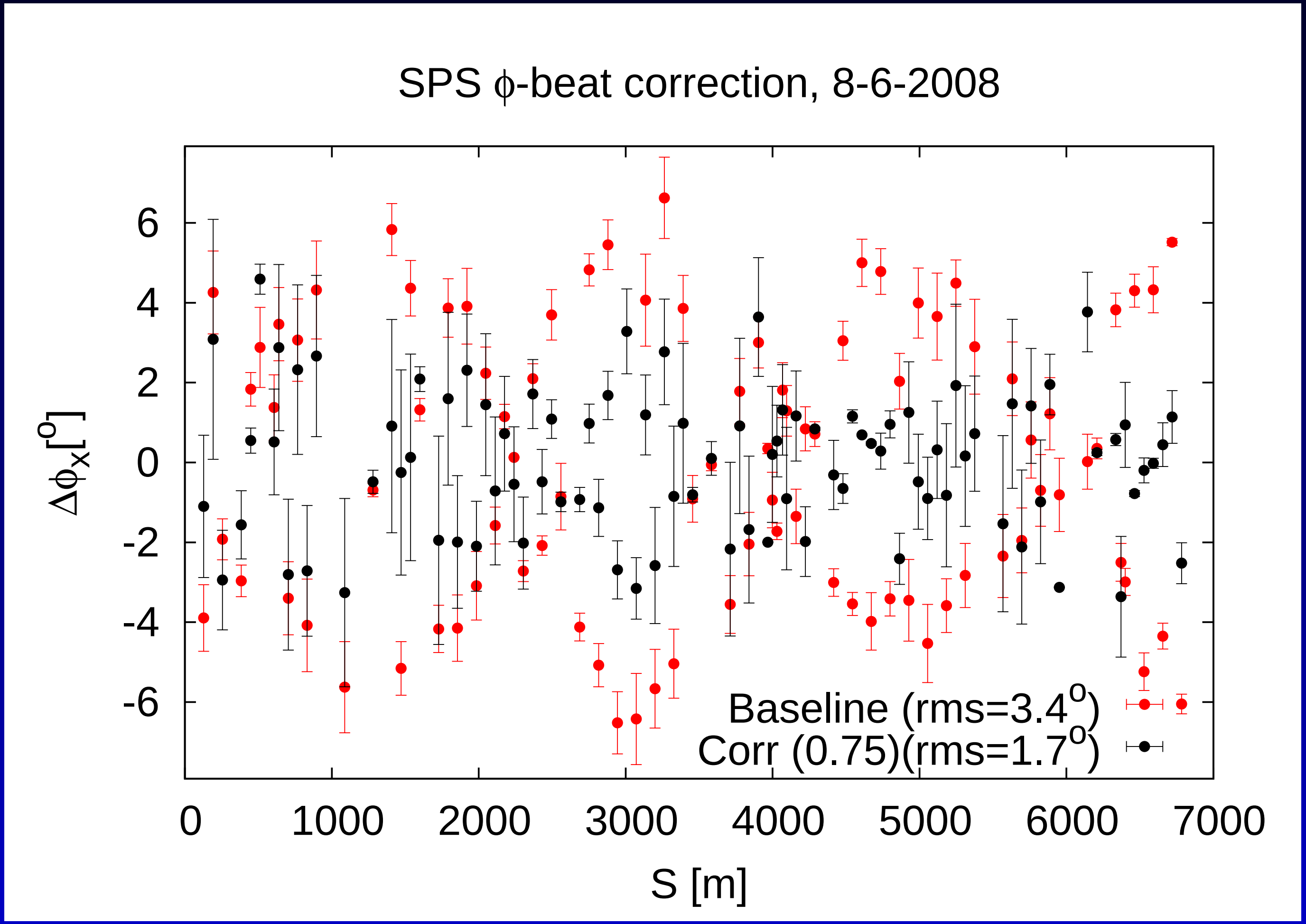
Spectrum example



Q_x line comes from linear coupling.

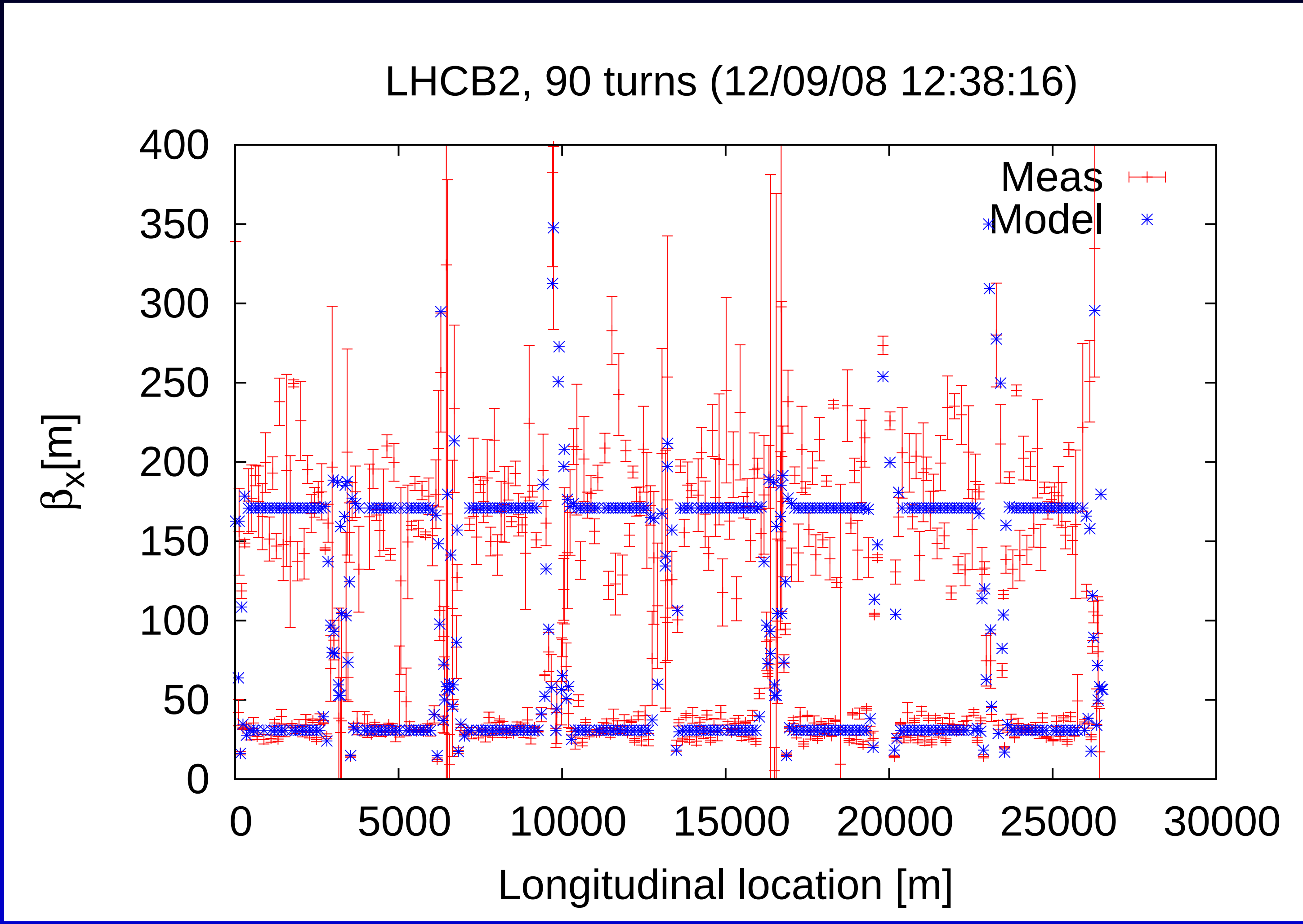
$2Q_y$ line related to resonance (0,3). This resonance is driven by skew sextupoles.

SPS phase-beating correction



ϕ-beating decreased by a factor of two after a single ϕ measurement and correction in the SPS

LHC (beam2) first 90 turns



β obtained from $\Delta\phi$ between 3 BPMs

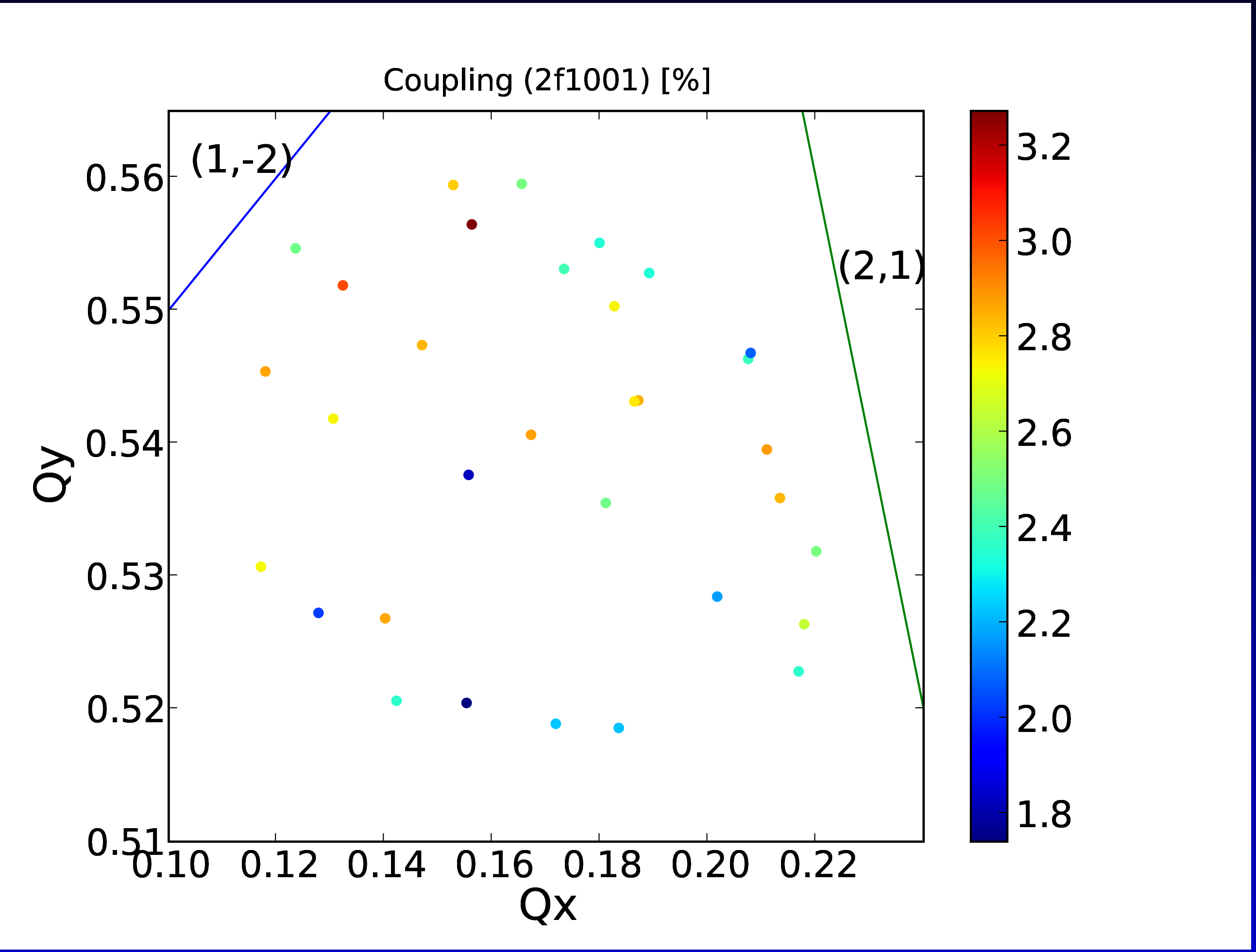
Coupling measurement: f_{1001}

$$2|f_{1001}| = \sqrt{\frac{\mathrm{line}(0,1)_{\mathrm{h}}}{\mathrm{line}(1,0)_{\mathrm{h}}} \frac{\mathrm{line}(1,0)_{\mathrm{v}}}{\mathrm{line}(0,1)_{\mathrm{v}}}}$$

$\longrightarrow$ Calibration independent
$\longrightarrow$ Kick independent

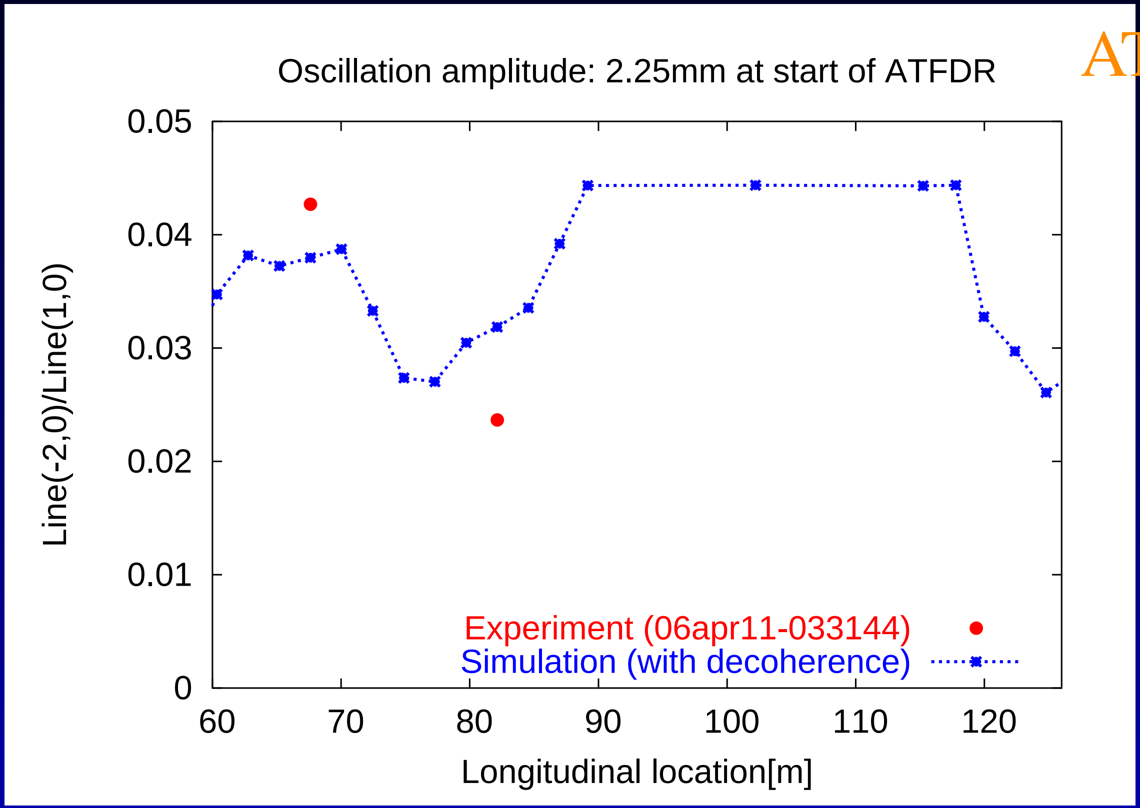
$\longrightarrow$ Model independent

Measuring f_{1001} in ATF (2007)



Average coupling = 2.5% $\pm$ 0.3%, (quite flat).

Measuring (3,0) Resonance

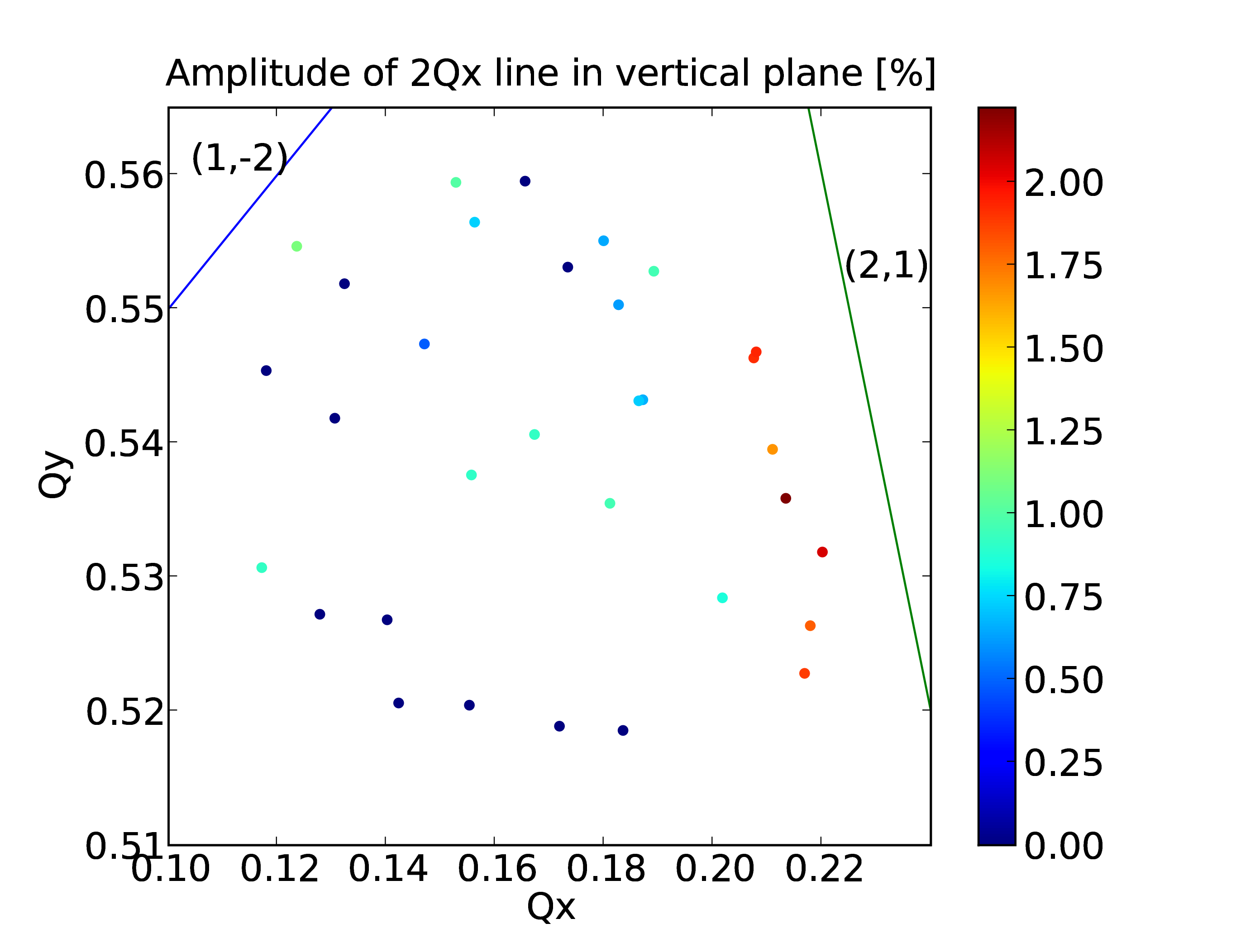


ATF report 06-08

Horizontal resonance (3,0) succesfully probed via spectral line -2Q_x.

However vertical plane totally unprobed.

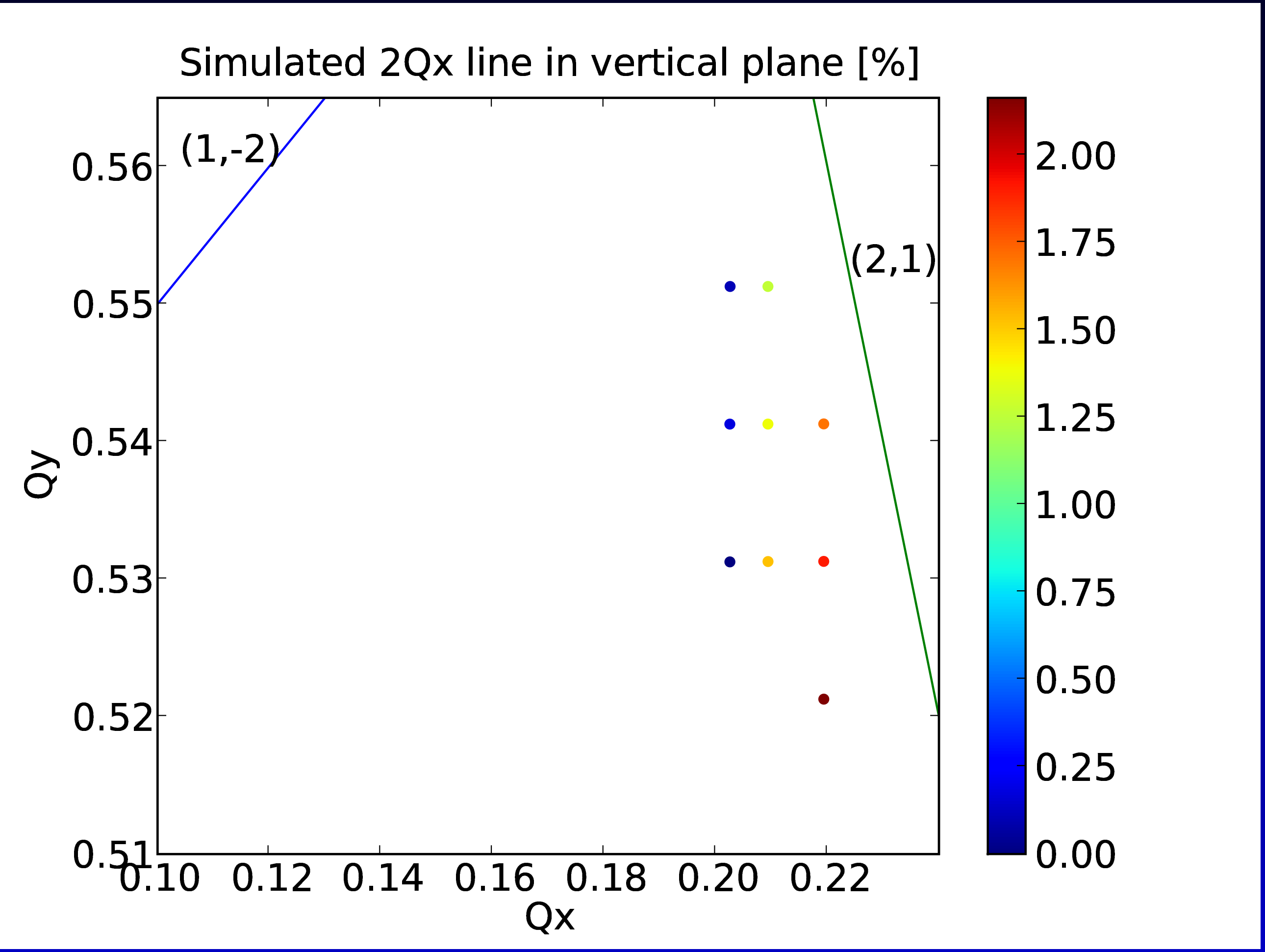
Measuring skew resonance (2,1)



→ Clear correlation between line and resonance!

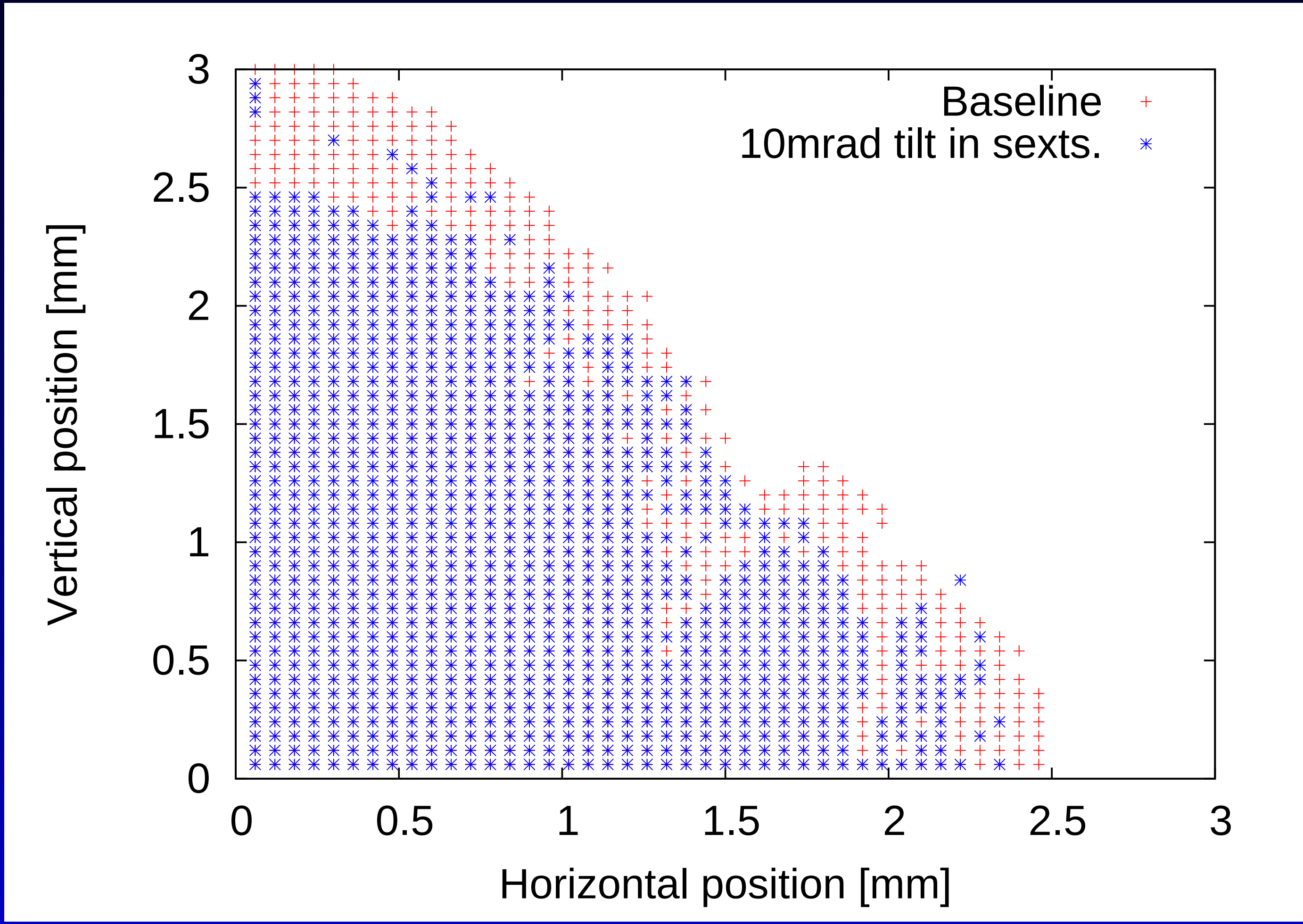
→ And it seems to be large!

Simulating resonance (2,1)



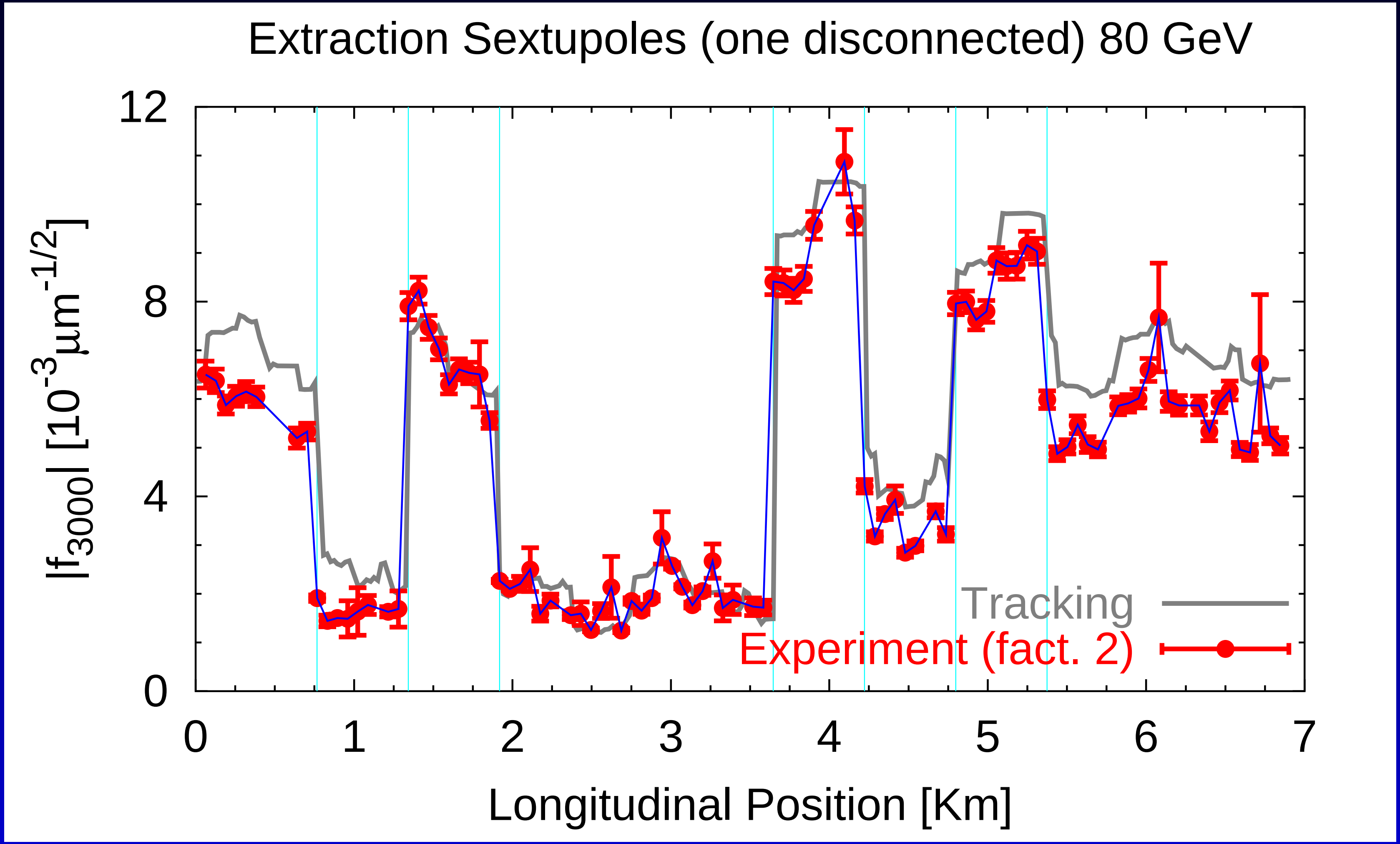
→ 10mrad random tilts at the sextupoles are required to reproduce the measurement.

Computing DA with sextupole tilts



→ 10mrad tilts certainly have an impact on DA!

SPS missing sextupole



http://www.tesisenxarxa.net/TESIS_UV/AVAILABLE/TDX-0219104-131907/rogelio.pdf

DIAMOND experience

- Measurement of sextupolar spectral lines amplitudes at all BPMs
- Correction based on matrix inversion until amplitudes match simulation
- 10% lifetime increase in DIAMOND !
- EPAC 08 - THPC053

Conclusions

- Turn-by-turn BPM data provides all linear and non-linear information on the beam dynamics
- Mature and precise algorithms have been developed over years in many accelerators
- First promising tests in ATF2 using only 4 BPMs
- Hope that many turn-by-turn BPMs be made available in ATF2
- DIAMOND proved non-linear correction using these techniques!