Ring Diagnostics with the AC Dipole
- Lessons for LHC from the Tevatron -

AC Dipole Meeting
March 6, 2009
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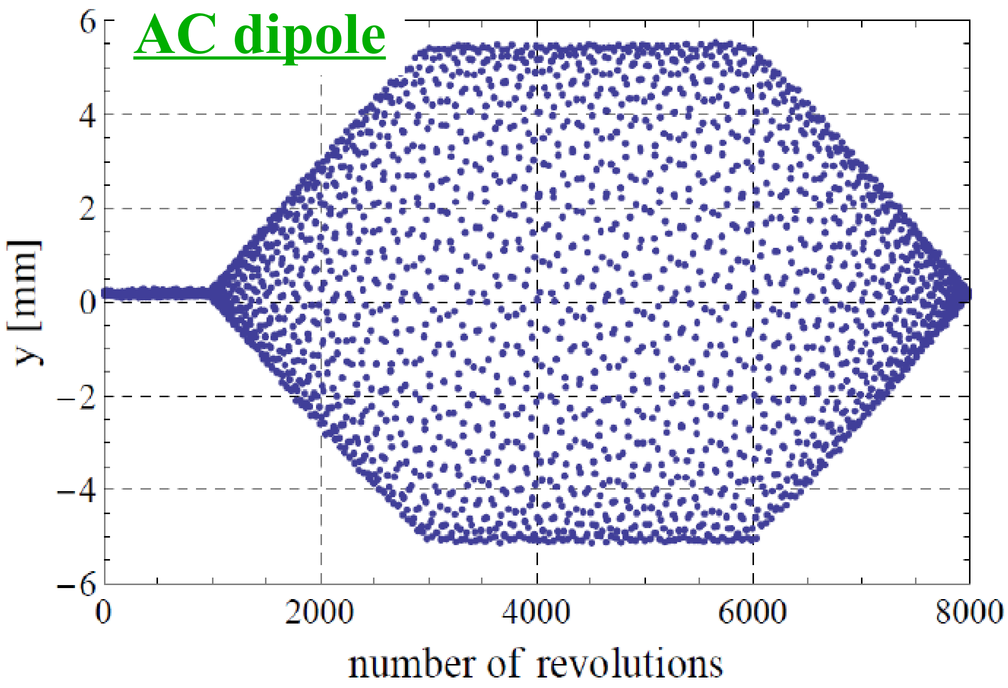
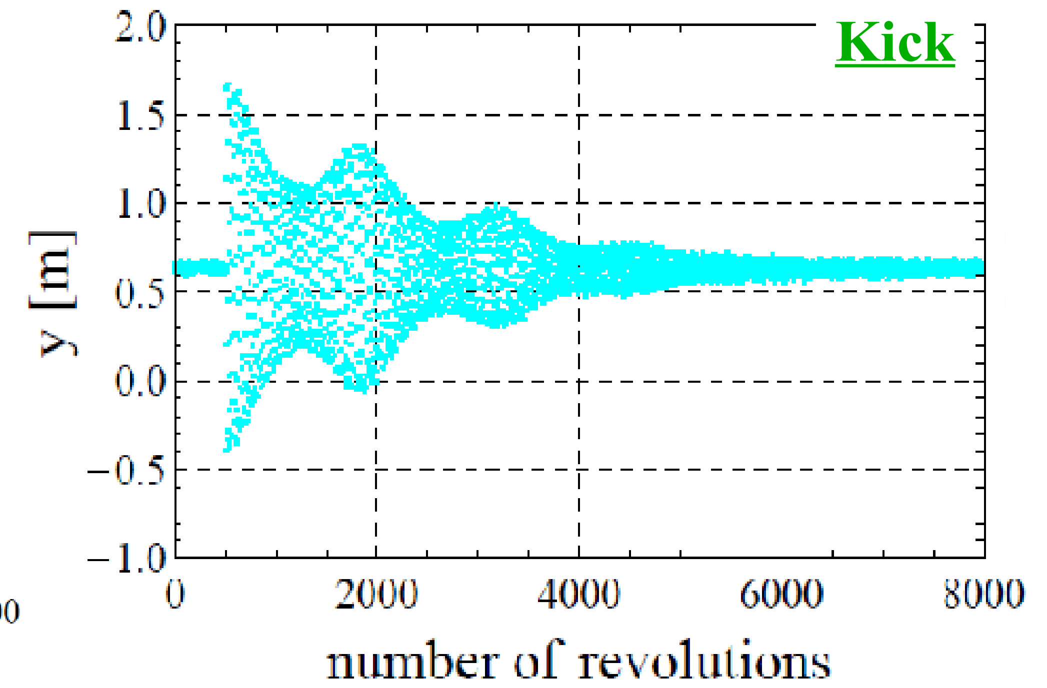
Introduction to the AC Dipole

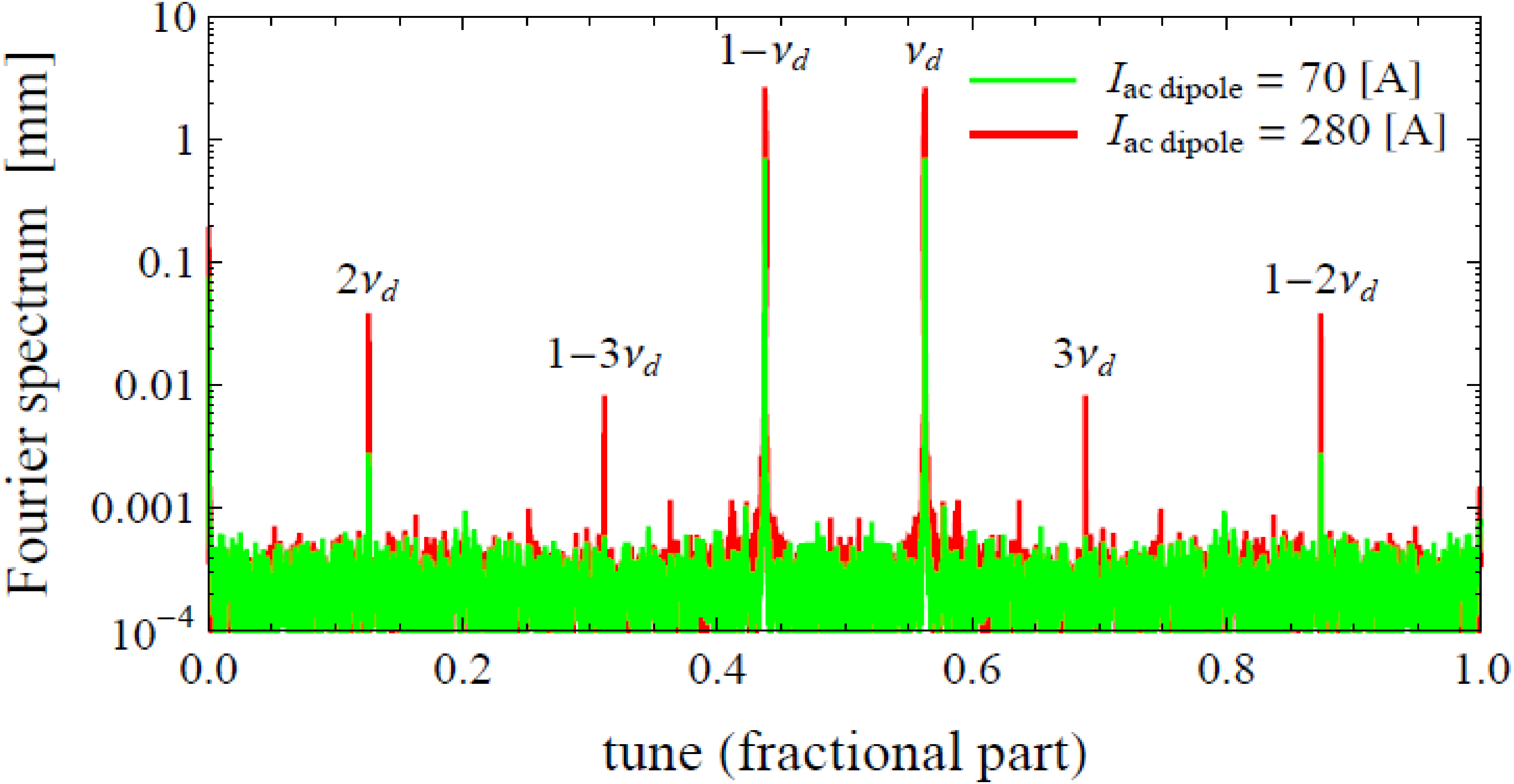
- An oscillating dipole field (Qd ~ Q) drives the beam.
- Optics measurements from turn-by-turn data.
- 4 AC dipoles in LHC, 2 in RHIC, and 1 in the Tevatron.
- Advantages:
  1. No decoherence
  2. No emittance growth
  3. Large excitation (in many cases larger than kicker/pinger)



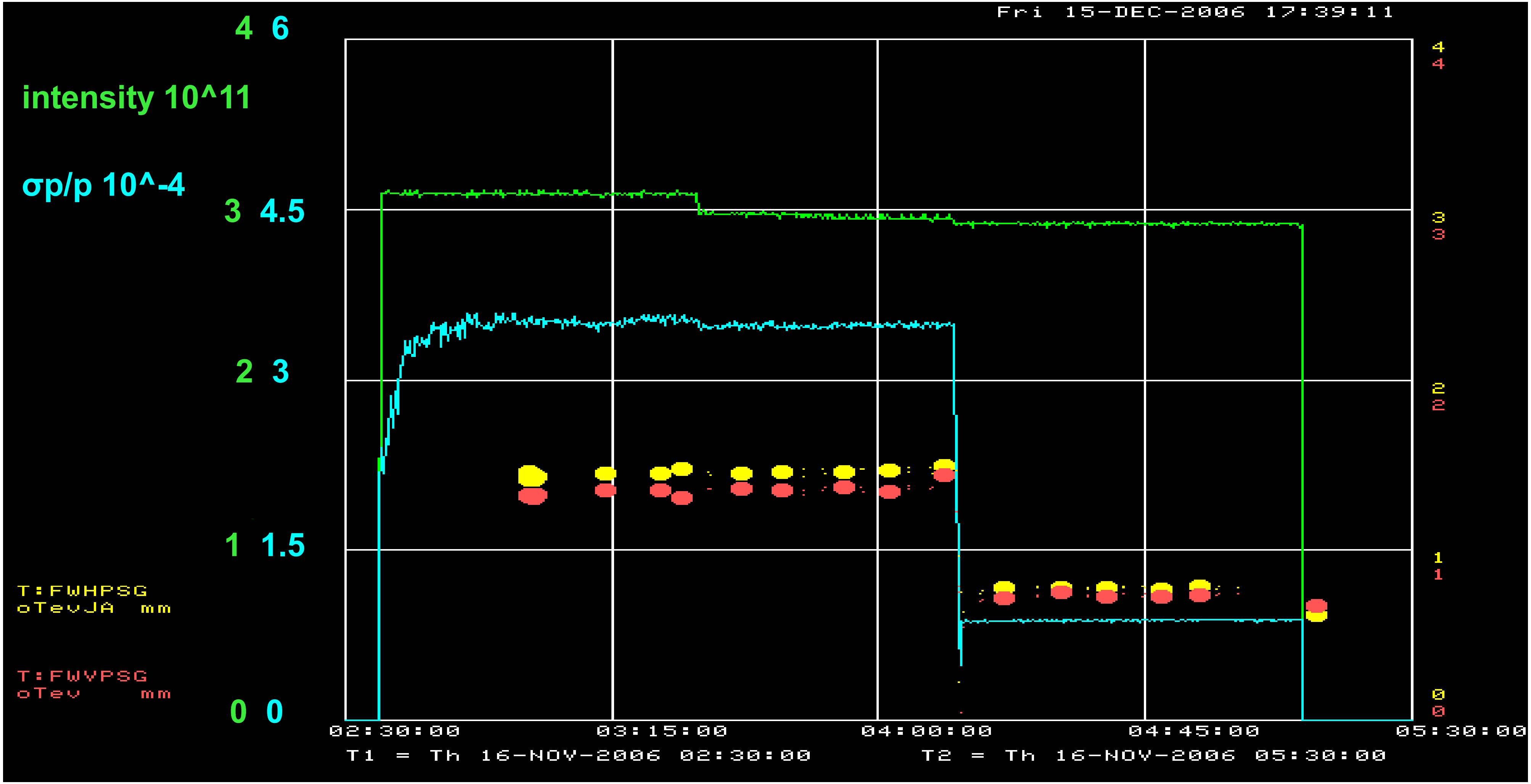


AC dipole is suited for spectral analysis.

- Interpolation is not necessary to determine amplitude.
- All the higher betatron modes have tunes (integer)*Qd.

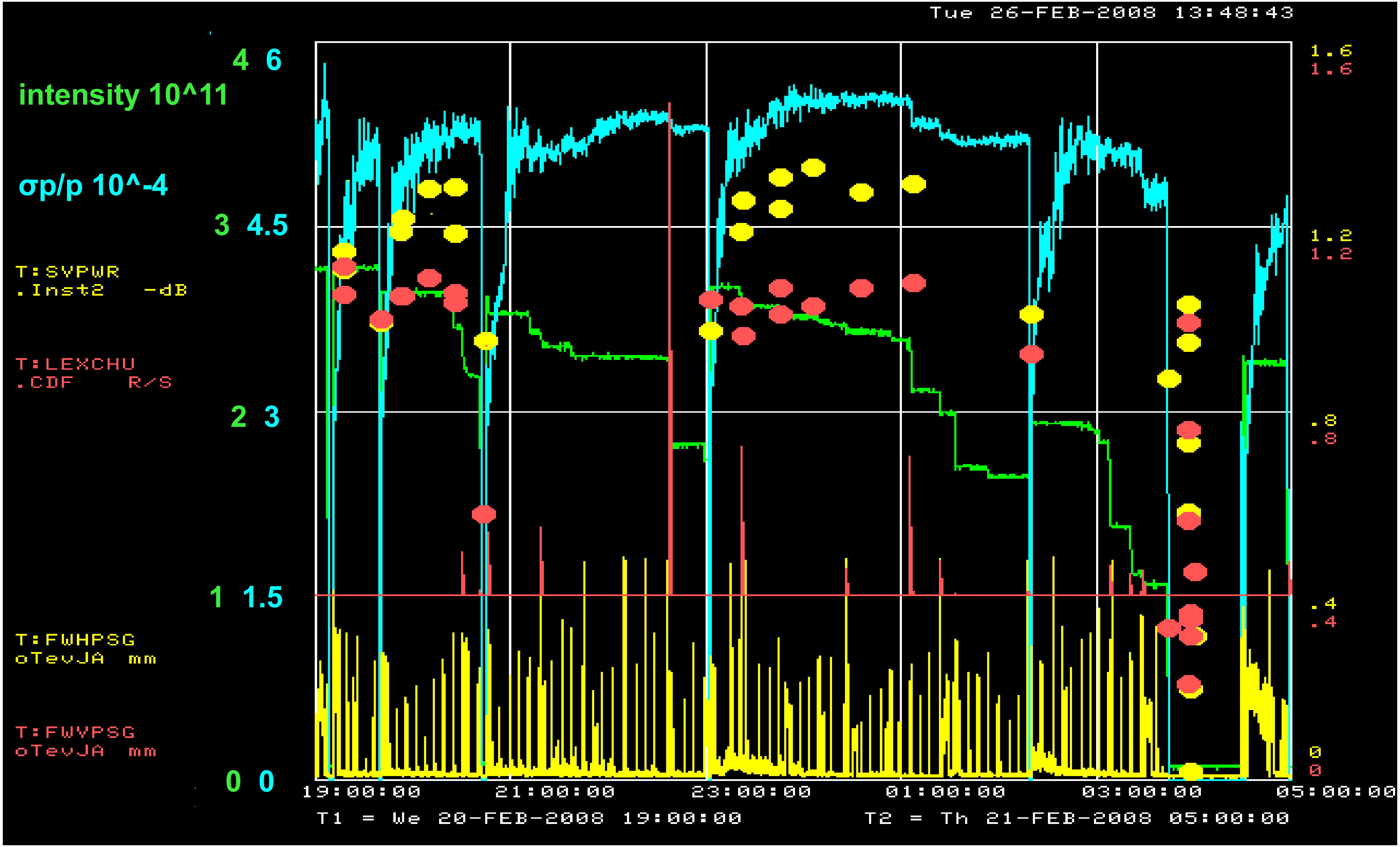


A Typical AC Dipole Operation in the Tevatron



- $|\delta|$ must be larger than 0.015 @ 150 GeV and 0.01 @ 980 GeV
- So far the Tevatron AC dipole is used ~200 times and no abort or quench.

A Not So Typical Operation in the Tevatron

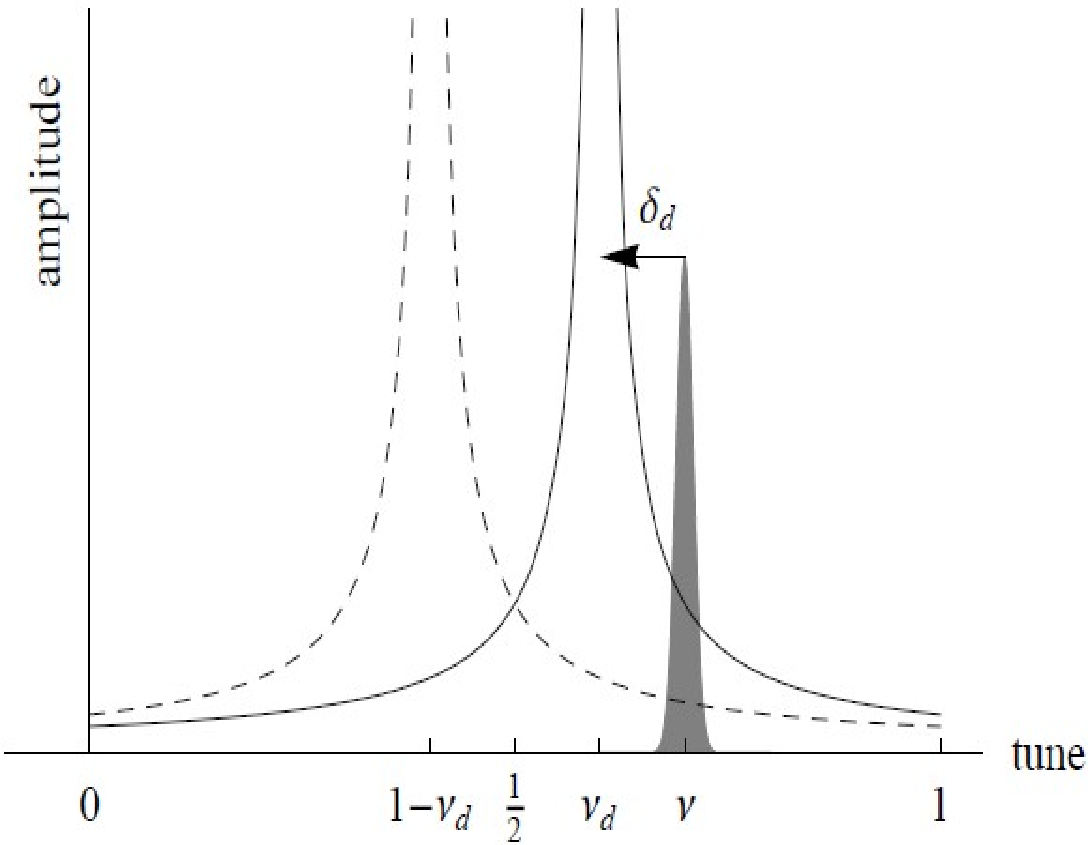


Difference & Sum Resonances of Driven Motion

$$x_d(n;s) = \frac{(B\ell)_{\rm ac}\sqrt{\beta(s_{\rm ac})\beta(s)}}{4(B\rho)\sin(\pi(Q_d-Q))}\cos[2\pi Q_d n + \psi(s) - \psi(s_{\rm ac}) + \pi(Q_d-Q)\,{\rm sgn}(s-s_{\rm ac}) + \chi]$$
$$- \frac{(B\ell)_{\rm ac}\sqrt{\beta(s_{\rm ac})\beta(s)}}{4(B\rho)\sin(\pi(Q_d+Q))}\cos[2\pi Q_d n - \psi(s) + \psi(s_{\rm ac}) + \pi(Q_d+Q)\,{\rm sgn}(s-s_{\rm ac}) + \chi]$$

$$\lambda = \frac{\sin[\pi(Q_d-Q)]}{\sin[\pi(Q_d+Q)]} \simeq \frac{\pi\delta}{\sin(2\pi Q)}$$

Sum resonance produces artificial beta-beat and phase-beat:
- Amplitude of the beta-beat: 2λ (~6% for $|\delta| = 0.01$)
- Amplitude of the phase-beat: λ (~2 deg $|\delta| = 0.01$)



A Parametrization of Driven Motion

$$x_d(n;s) = A_d\sqrt{\beta_d(s)}\cos[2\pi Q_d n + \psi_d(s) - \psi_d(s_{\rm ac}) + \chi]$$

$$A_d = \frac{(B\ell)_{\rm ac}\sqrt{\beta(s_{\rm ac})(1-\lambda^2)}}{4(B\rho)\sin[\pi(Q_d - Q)]}$$

$$\frac{\beta_d(s)}{\beta(s)} = \frac{1+\lambda^2 - 2\lambda\cos[2\psi(s) - 2\psi(s_{\rm ac}) - 2\pi Q\,{\rm sgn}(s-s_{\rm ac})]}{1-\lambda^2}$$

$$\tan[\psi_d(s) - \psi_d(s_{\rm ac}) - \pi Q_d\,{\rm sgn}(s-s_{\rm ac})] = \frac{\tan(\pi Q_d)}{\tan(\pi Q)}\tan[\psi(s) - \psi(s_{\rm ac}) - \pi Q\,{\rm sgn}(s-s_{\rm ac})]$$

$$\psi_d(s) = \int_0^s \frac{d\bar{s}}{\beta_d(\bar{s})}\,, \quad \alpha_d(s) = -\frac{1}{2}\frac{d\beta_d(s)}{ds}\,, \quad \gamma_d(s) = \frac{1+\alpha_d(s)^2}{\beta_d(s)}$$

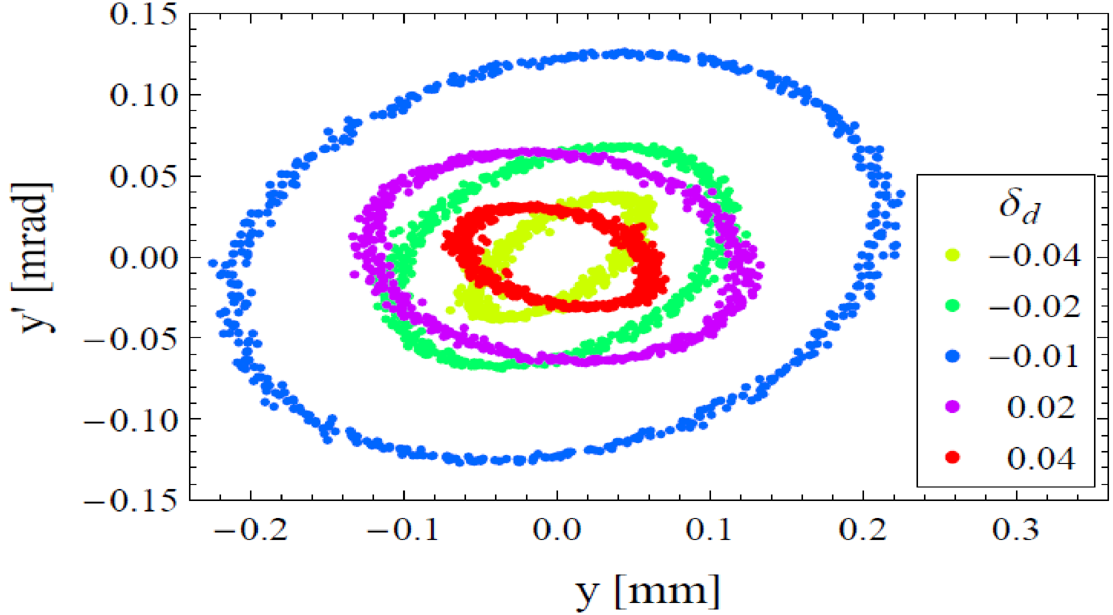
$$\gamma_d^2 x_d^2 + 2\alpha_d x_d x_d' + \beta_d x_d'^2 = A_d^2$$

On the first order of λ (or δ)

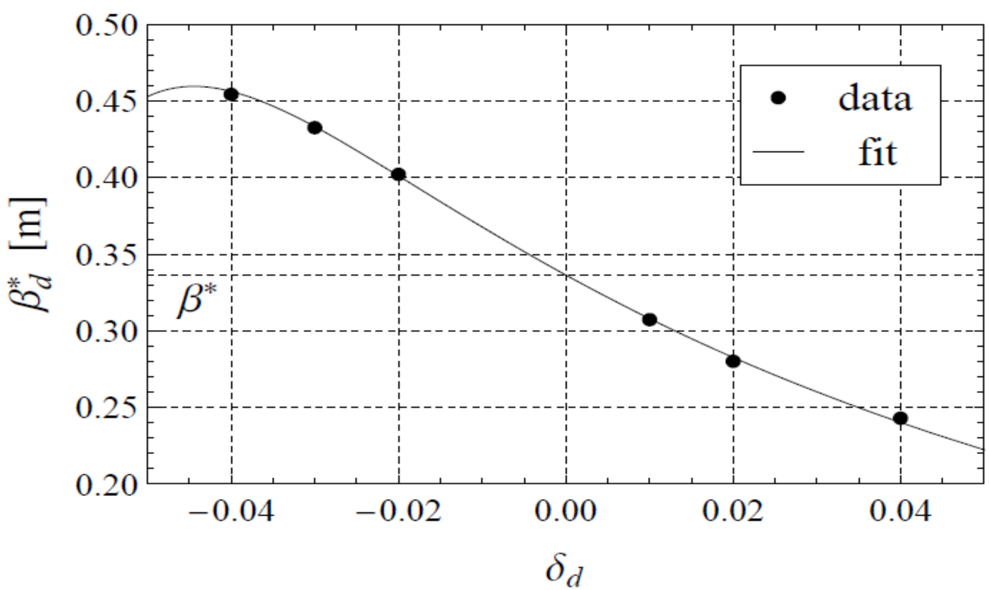
$$\frac{\beta_d(s)}{\beta(s)} \simeq 1 - 2\lambda\cos[2\psi(s) - 2\psi(s_{\rm ac}) - 2\pi Q\,{\rm sgn}(s-s_{\rm ac})]$$

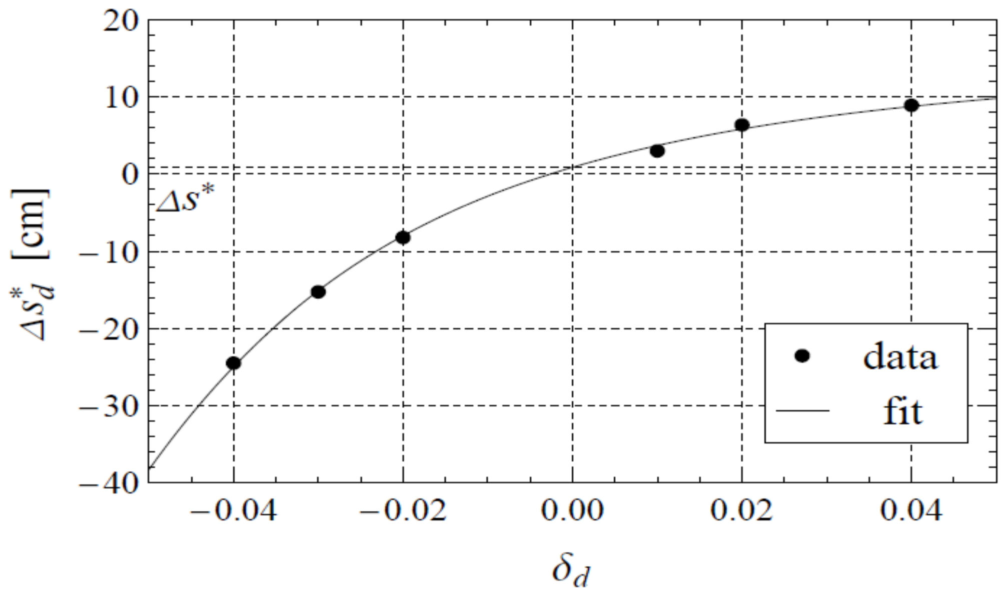
$$\psi_d(s) - \psi(s) \simeq \lambda\sin[2\psi(s) - 2\psi(s_{\rm ac}) - 2\pi Q\,{\rm sgn}(s-s_{\rm ac})] + \lambda\sin[2\psi(s_{\rm ac}) - 2\pi Q] + 2\pi\delta\Theta(s-s_{\rm ac})$$

Diagnostics of an Interaction Point

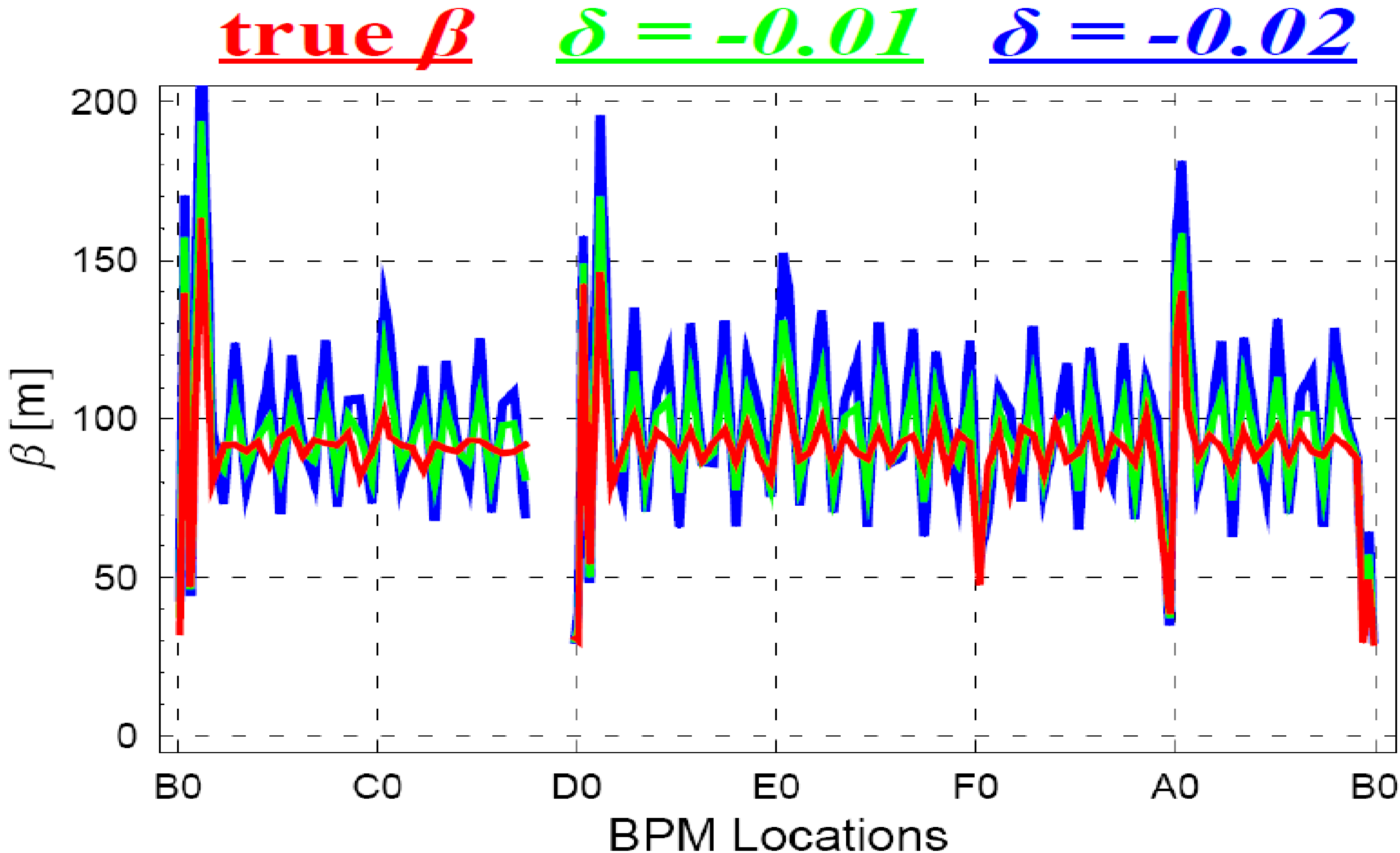


Phase space mapping at IP (from 2 BPM's in a collision straight section)

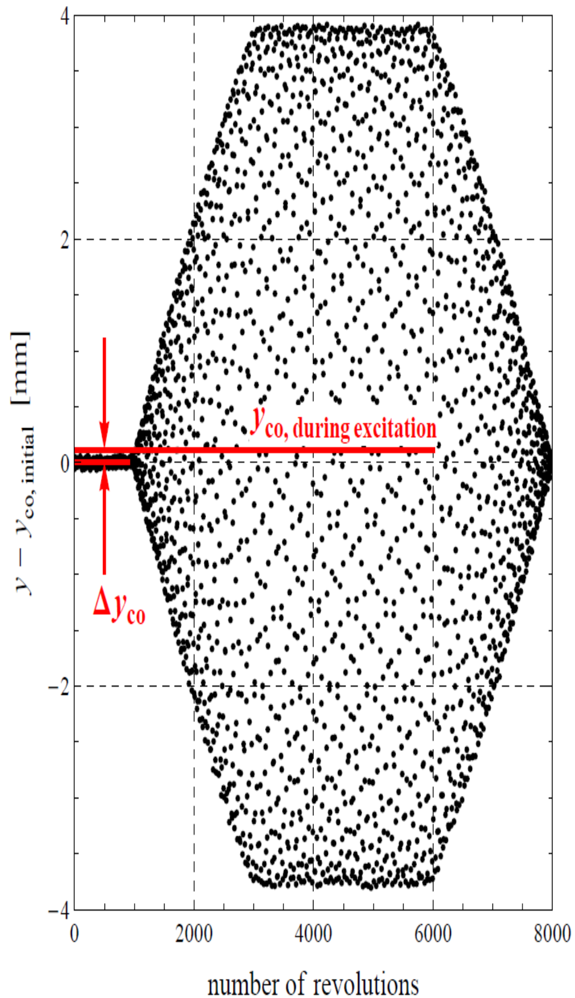


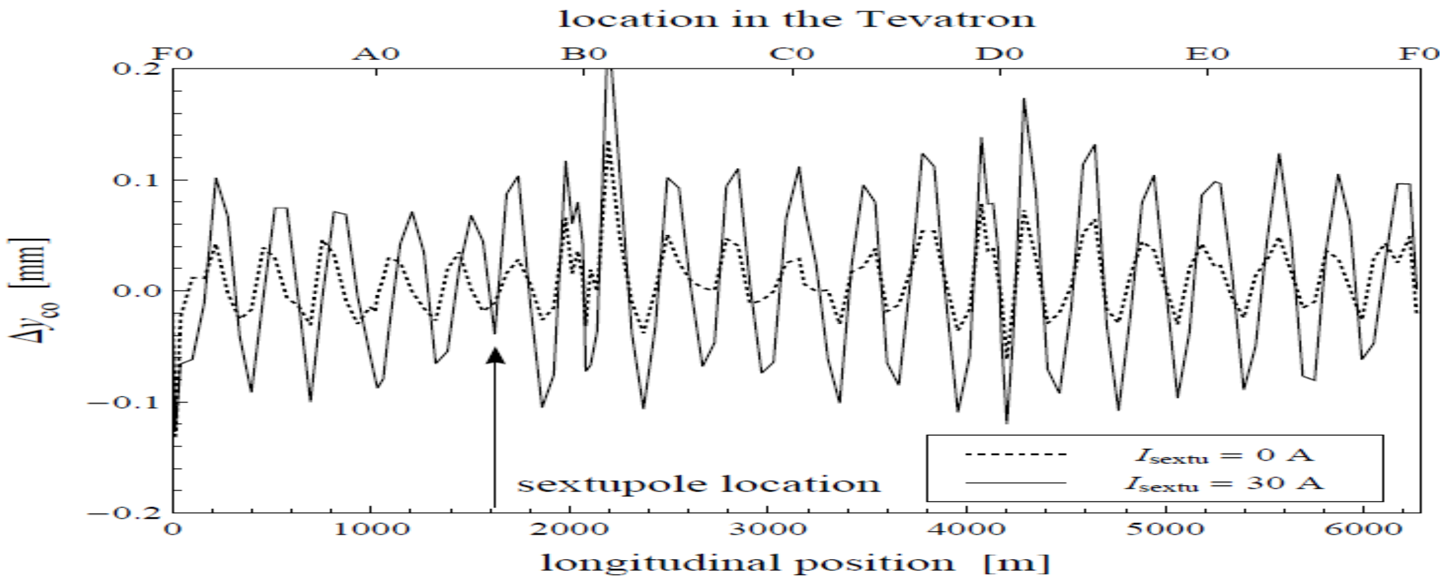


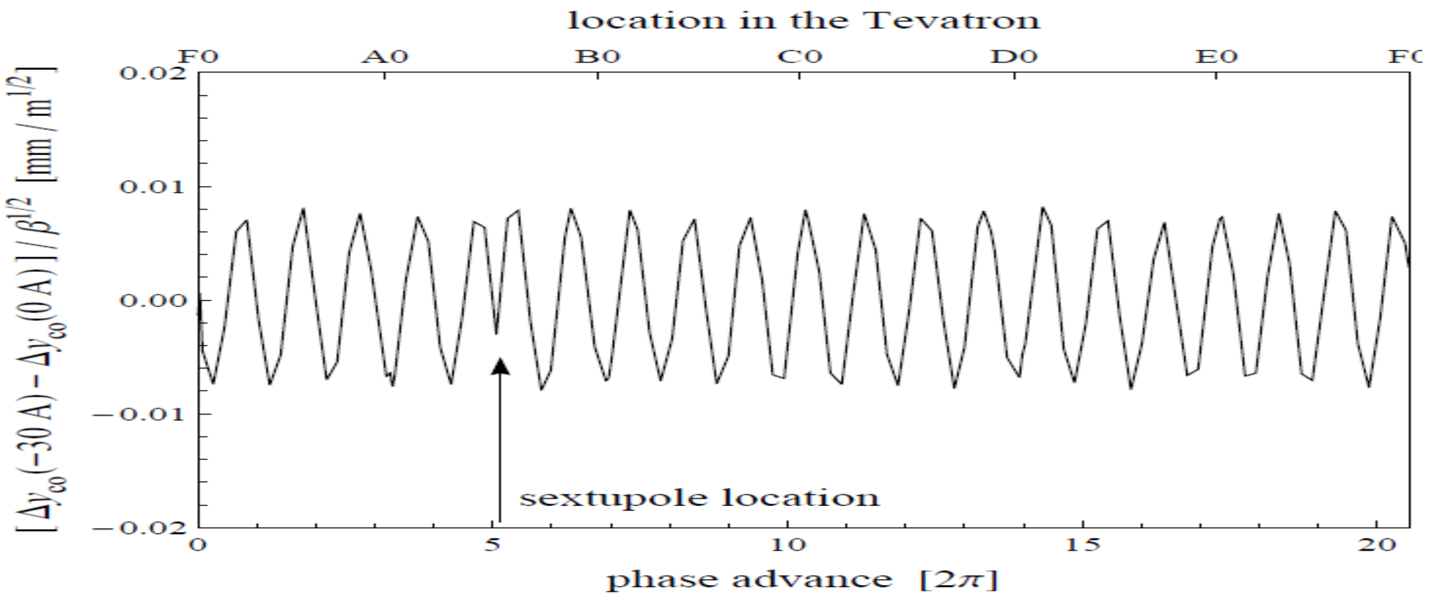
Ring-wide Beta Measurement



Sextupole Measurements from Orbit Shifts

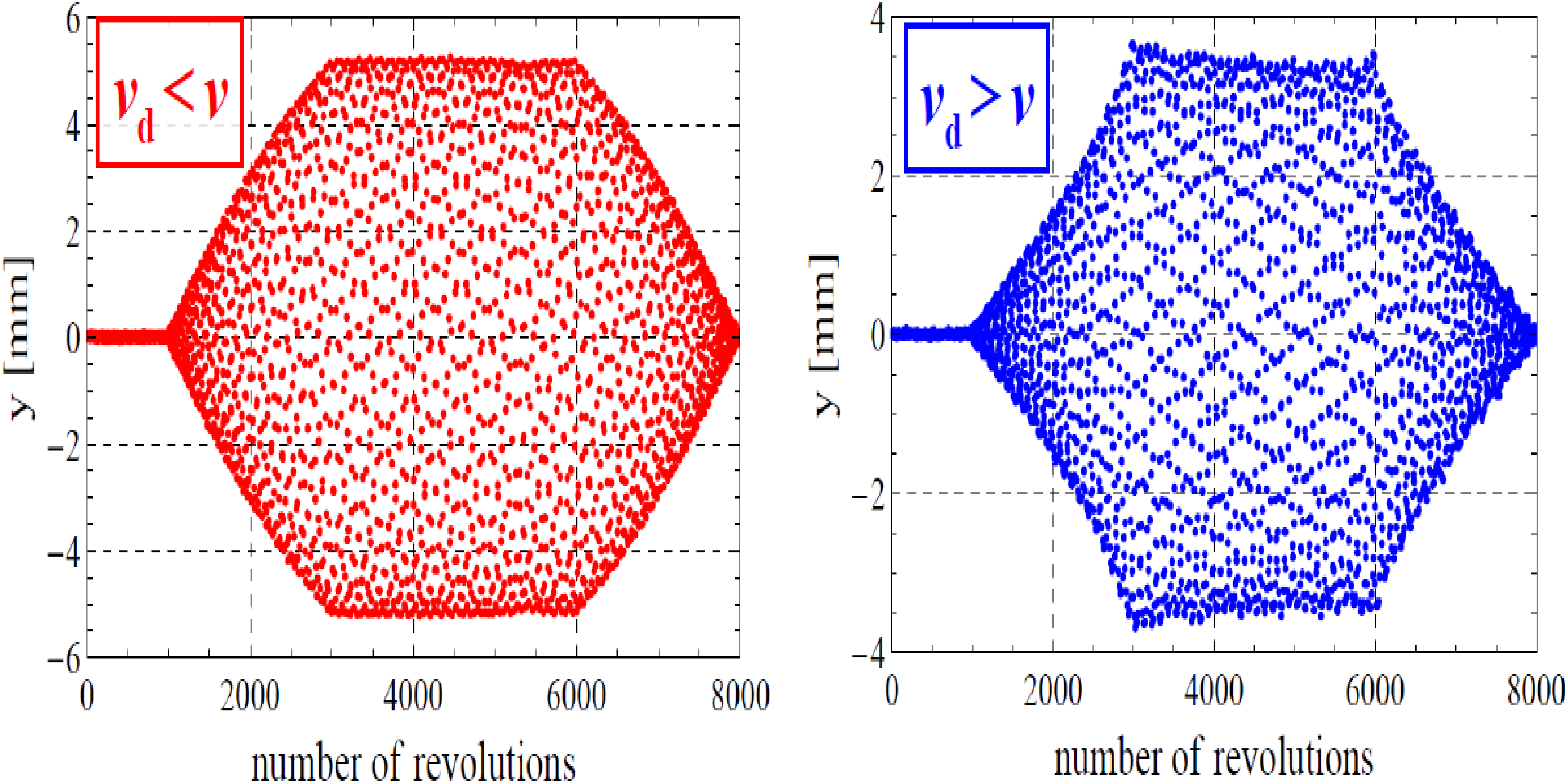






Detuning Measurements from Amplitude Response

$$\frac{\theta_{ac}\sqrt{\beta_{ac}\beta(s)}}{4\sin|\pi(\nu_d-\nu-\delta\nu(J))|}$$



Effects of Sum Resonance on Coupling and Higher Order Measurements

For instance, driving terms of the difference and sum resonances are modified from

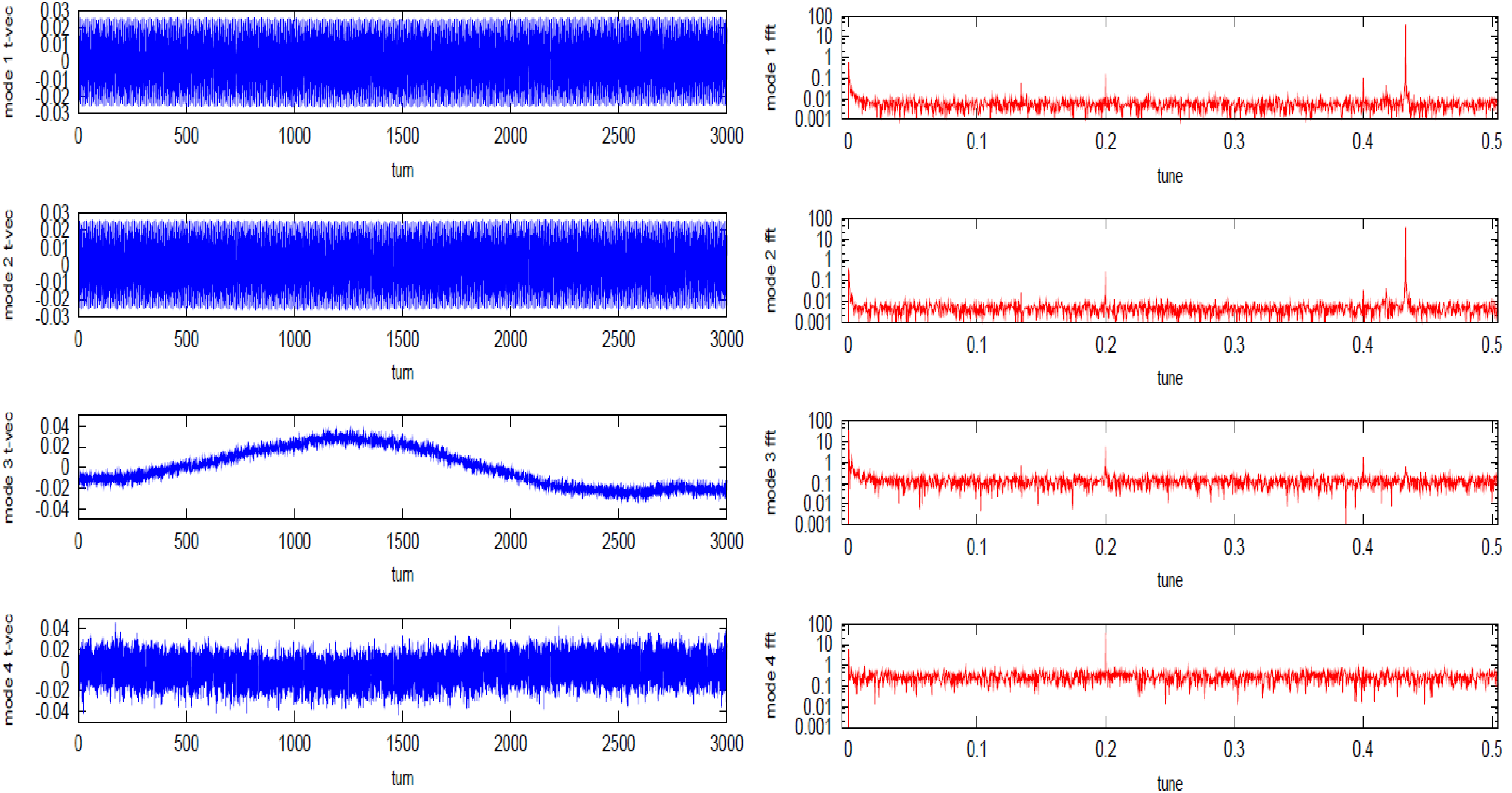
$$w_{\mp}(s) = \oint d\bar{s}\, \frac{B'_x(\bar{s})\sqrt{\beta_x(\bar{s})\beta_y(\bar{s})}}{4(B\rho)\sin[\pi(Q_x \mp Q_y)]}\, e^{i(\psi_x(\bar{s})\mp\psi_y(\bar{s}))+\pi i(Q_x \mp Q_y)\mathrm{sgn}(s-\bar{s})}$$

to

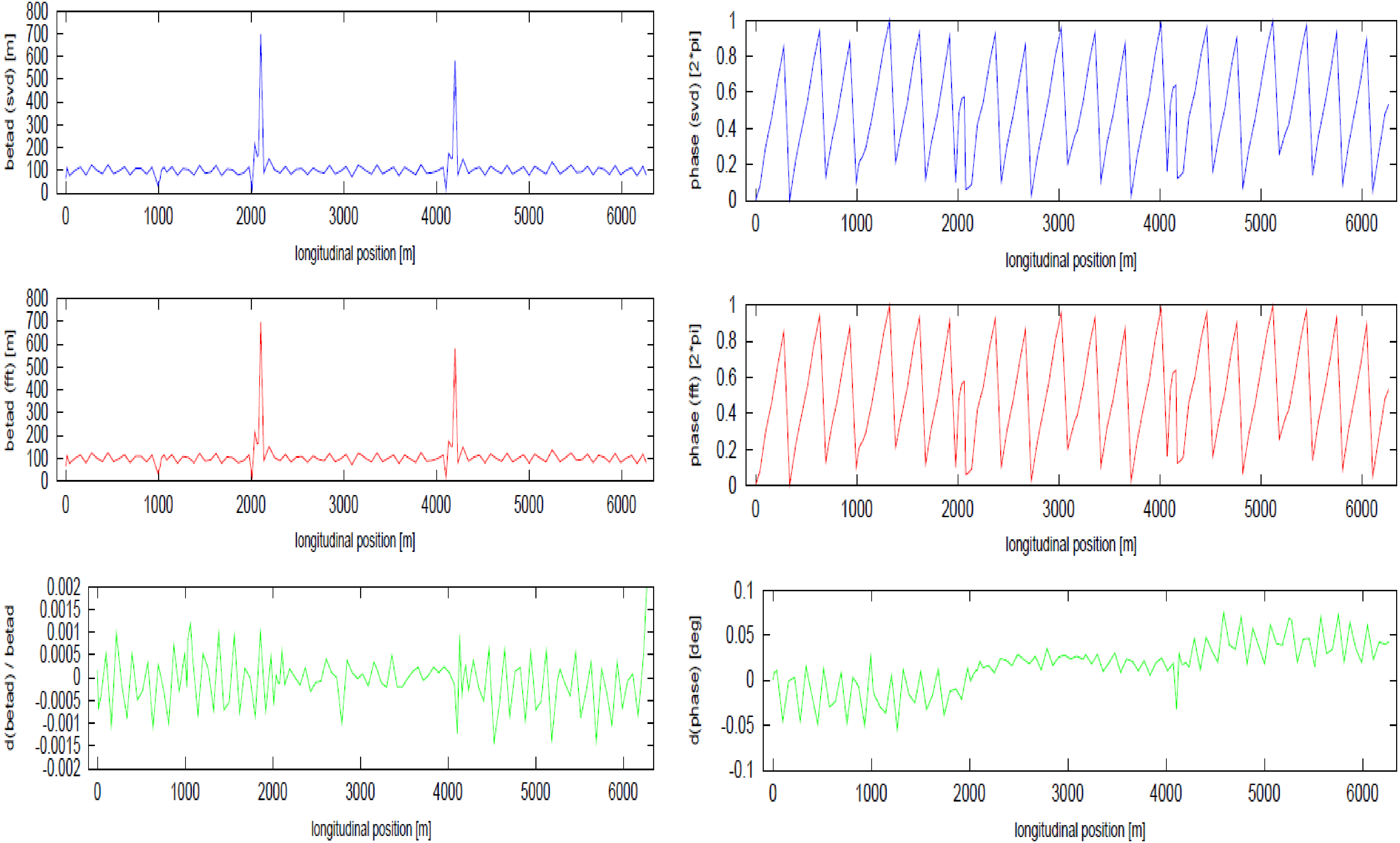
$$w_{d,\mp}(s) = \oint d\bar{s}\, \frac{B'_x(\bar{s})\sqrt{\beta_{x,d}(\bar{s})\beta_y(\bar{s})}}{4(B\rho)\sin[\pi(Q_d \mp Q_y)]}\, e^{i(\psi_{d,x}(\bar{s})\mp\psi_y(\bar{s}))+\pi i(Q_d \mp Q_y)\mathrm{sgn}(s-\bar{s})}$$

MIA Applied to the AC Dipole Excitation

- Does MIA have an advantage for the AC dipole excitation?
- There are residual modes.

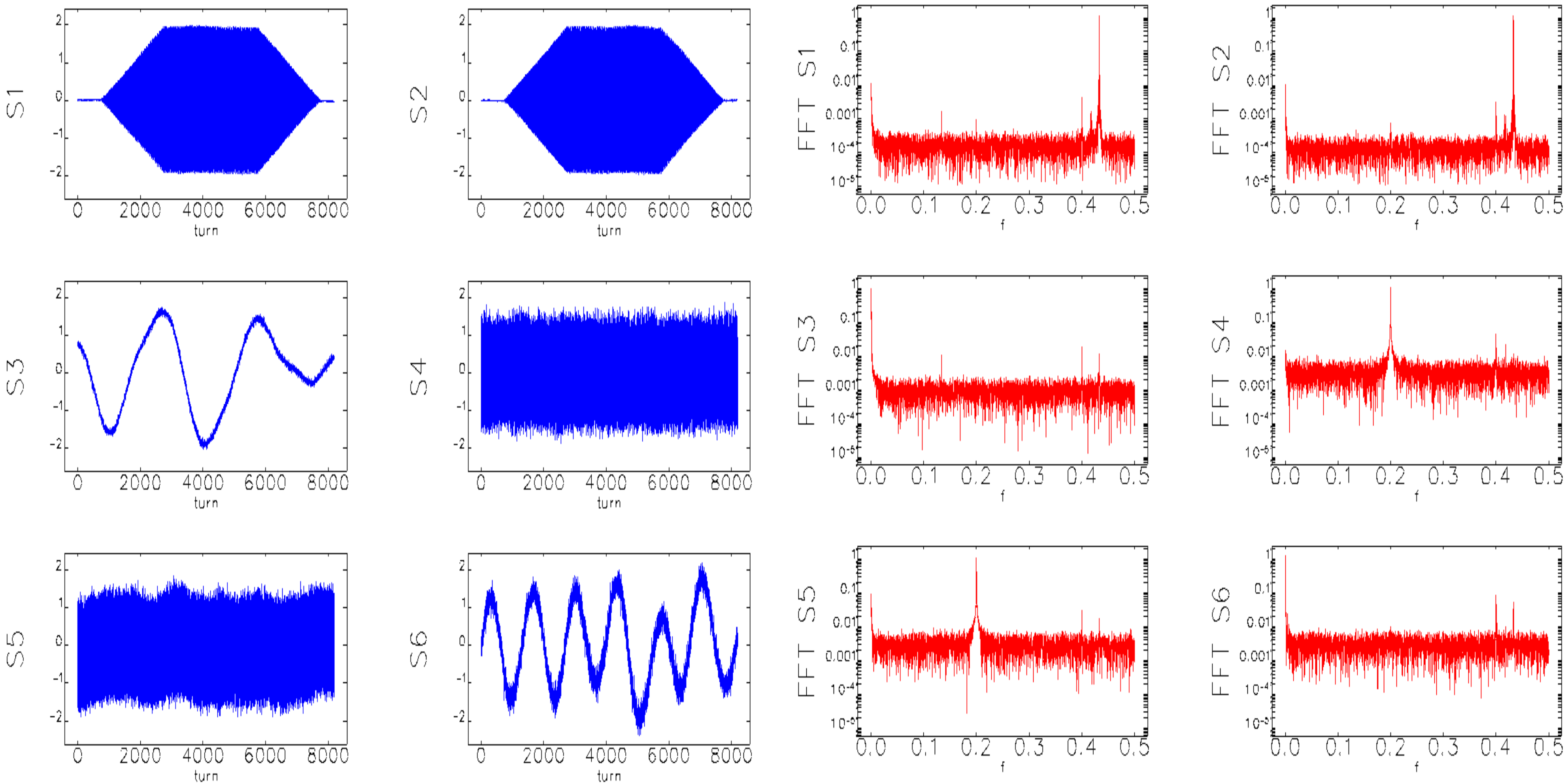


Beta and Phase: MIA vs. Fourier Analysis



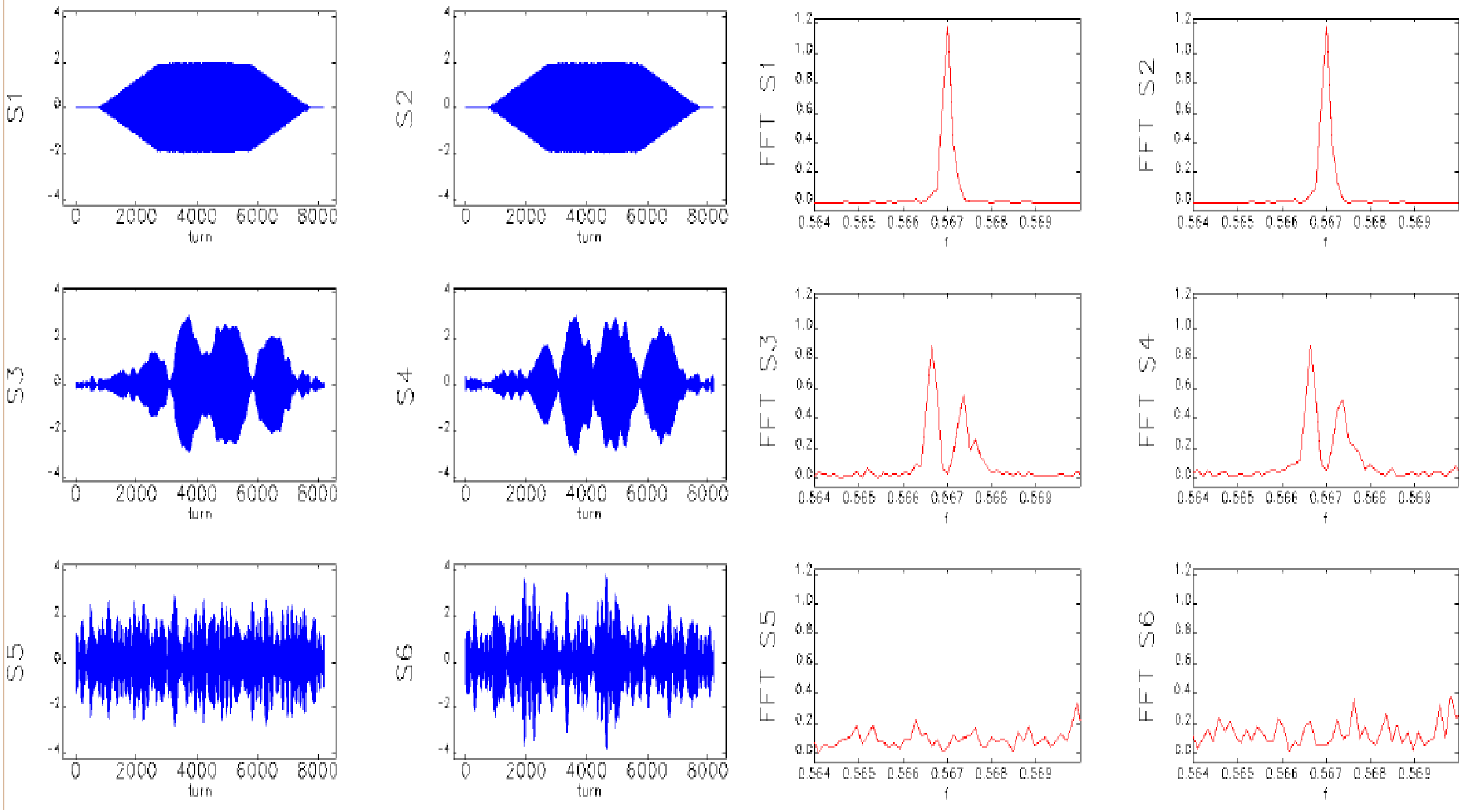
ICA Applied to the AC Dipole Excitation

- ICA slightly better than MIA?
- Turn-by-turn is not necessary to measure vibrational modes.



courtesy of Alexey Petrenko

ICA Applied to the AC Dipole Excitation (FFT-widowed data)



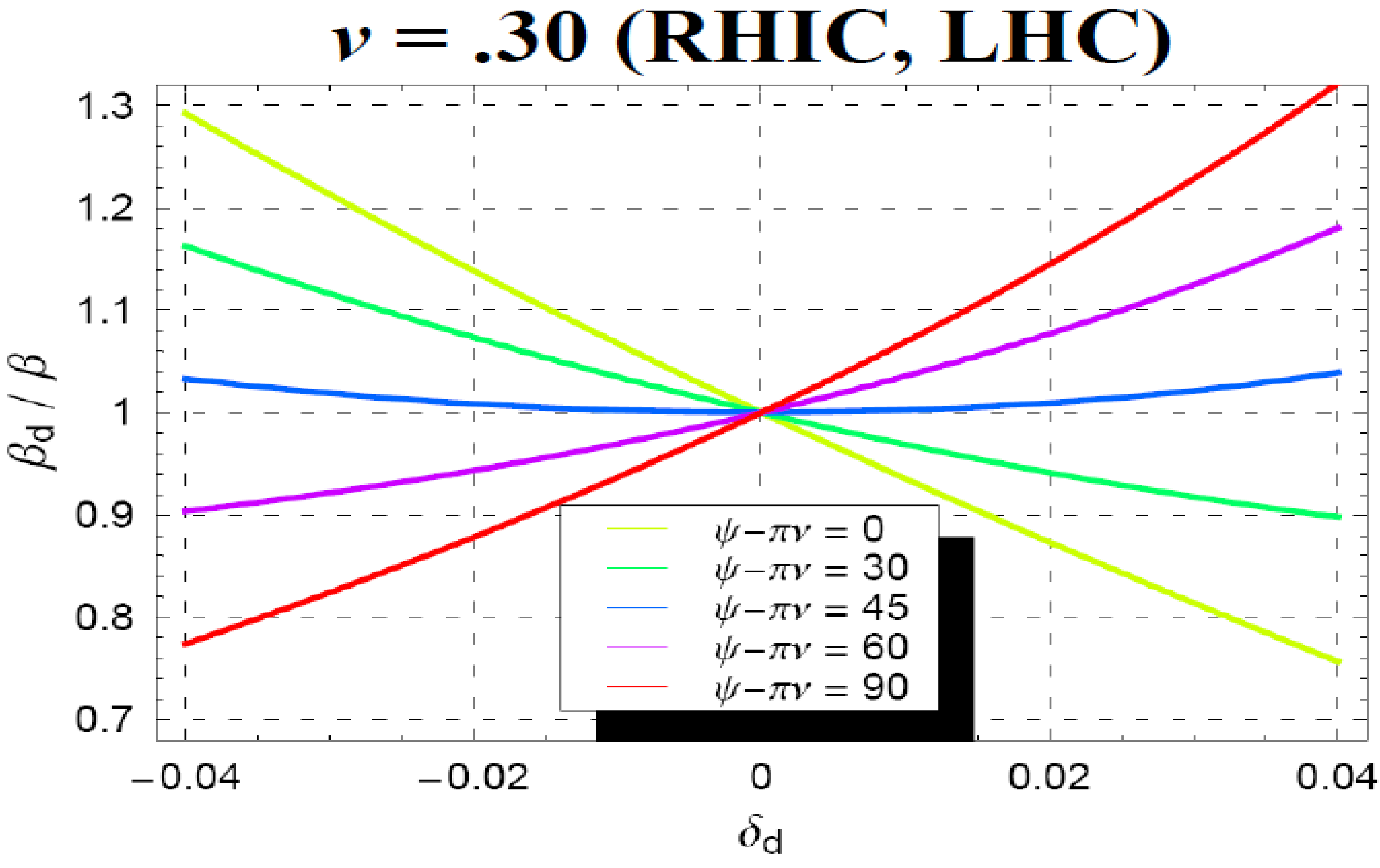
Plan?

- I can stay at CERN starting from ~June.
- Local coupling measurements in RHIC.
- Summarize nonlinear dynamics study performed in the Tevatron.

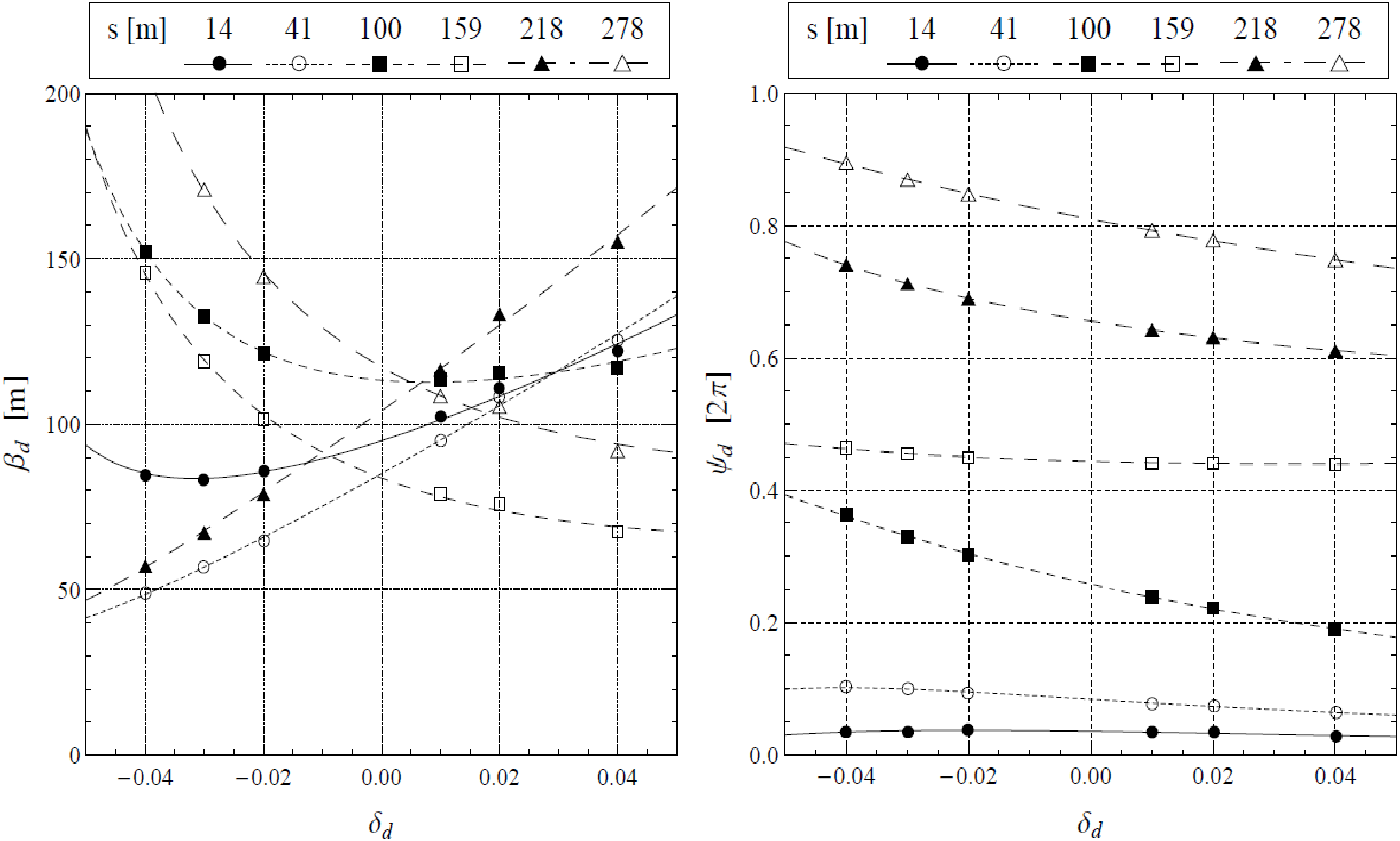
- MIA/ICA is suited for the kick excitation?
- Yiton's virtual accelerator concept?

Backup Slides

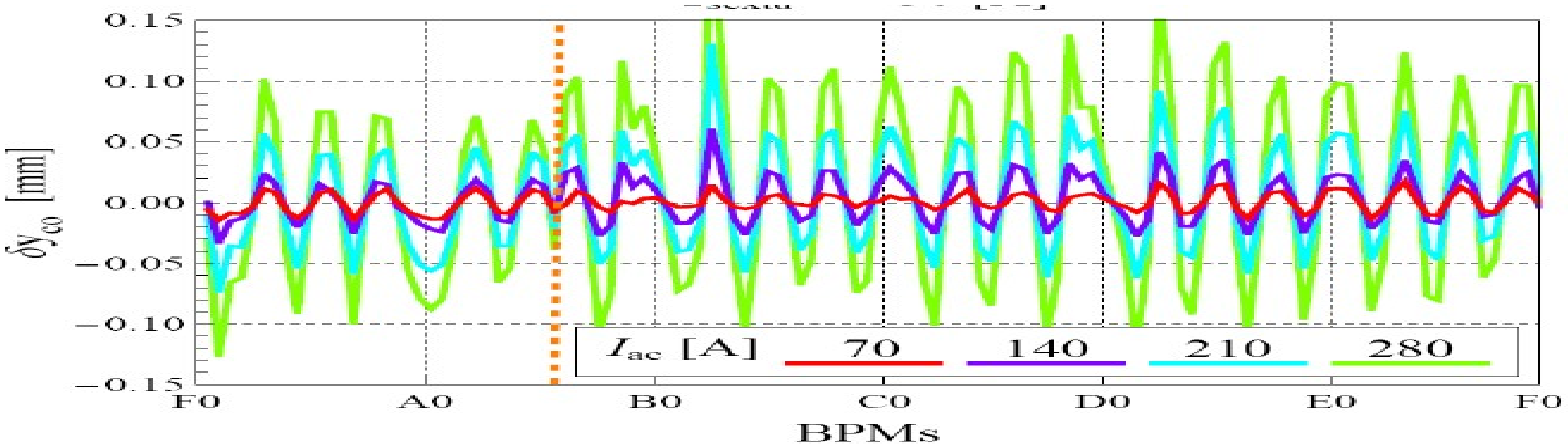
Beta vs. Betad for LHC (Simulation)

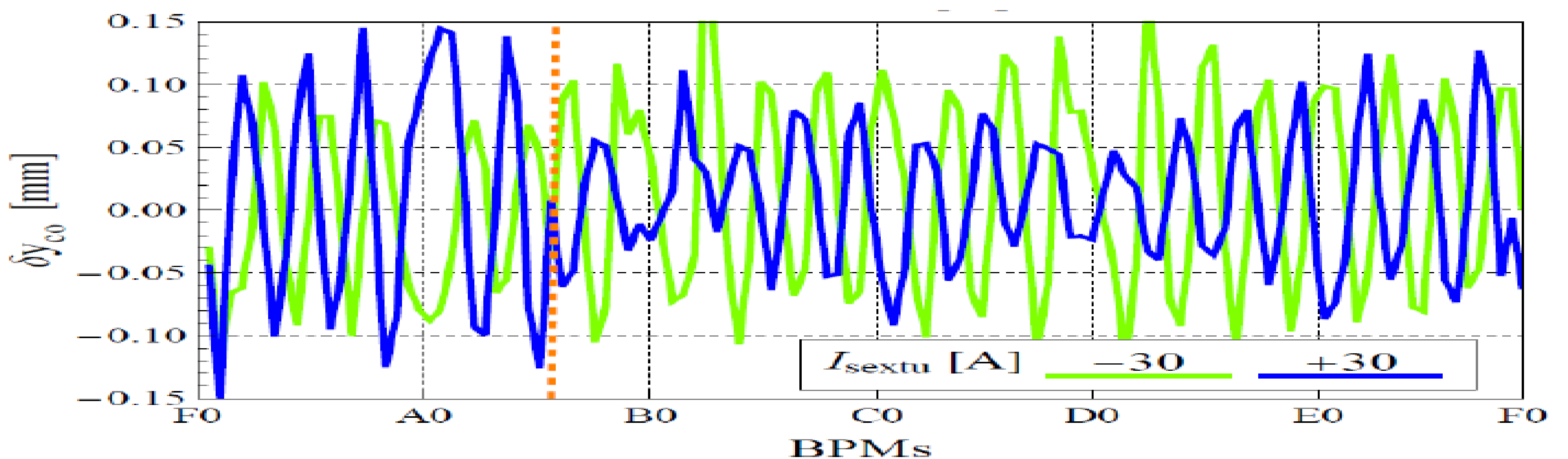


Beta and Phase Measurements



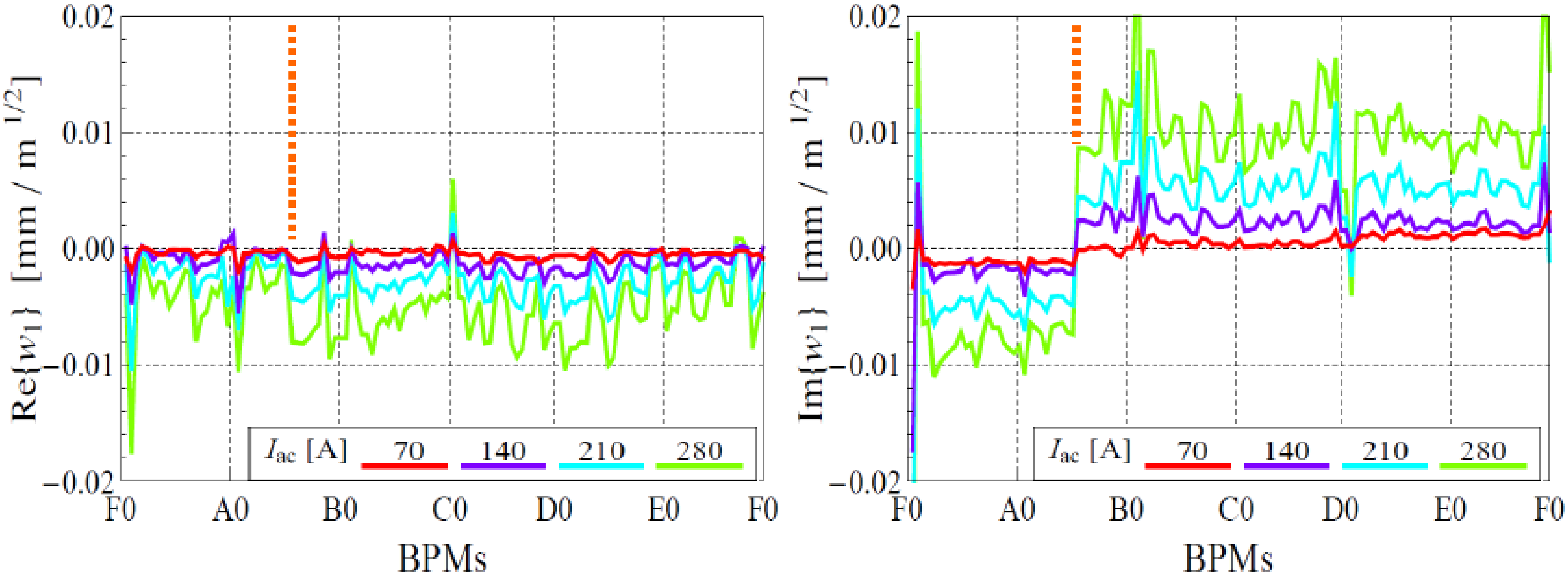
Sextupole Measurements from Orbit Shifts (2)





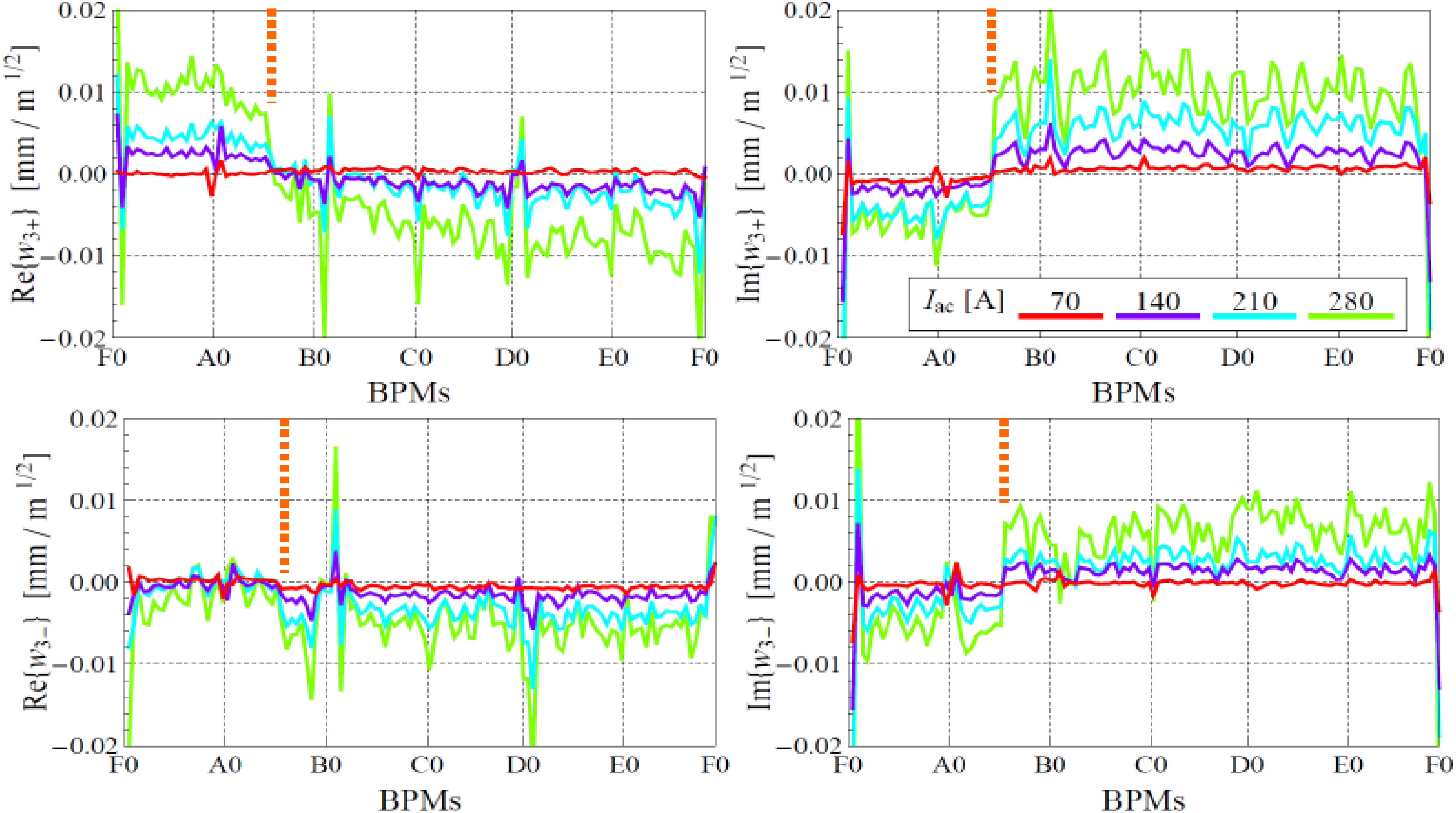
Generating Function of the 1st Order Mode

- A fixed sextupole current, different AC dipole current.
- The strength of the sextupole is determined from the step size.
- The kick strength depends on the action.
- The action is not factored out, here.
- The BPM nonlinearity will be considered in future analyses.

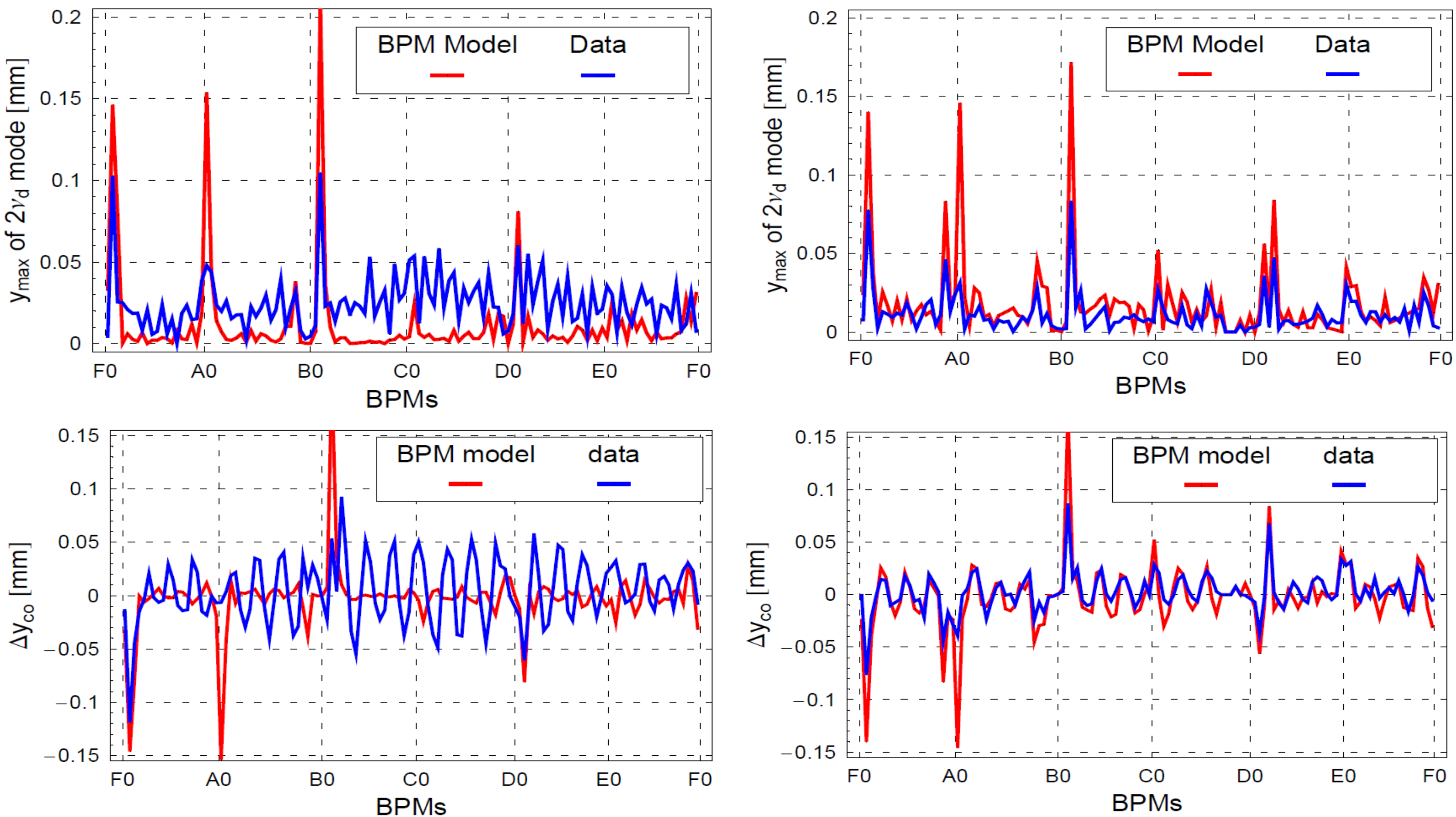


Generating Function of the 3rd Order Mode

- A similar analysis is possible for the 3rd order mode (Two same condition).
- Two generating functions for resonances of $2\nu_d - \nu$ and $2\nu_d + \nu$.



Effects of BPM Nonlinearity on Resonance Driving Term Measurements



Note for Coupled Harmonic Oscillators

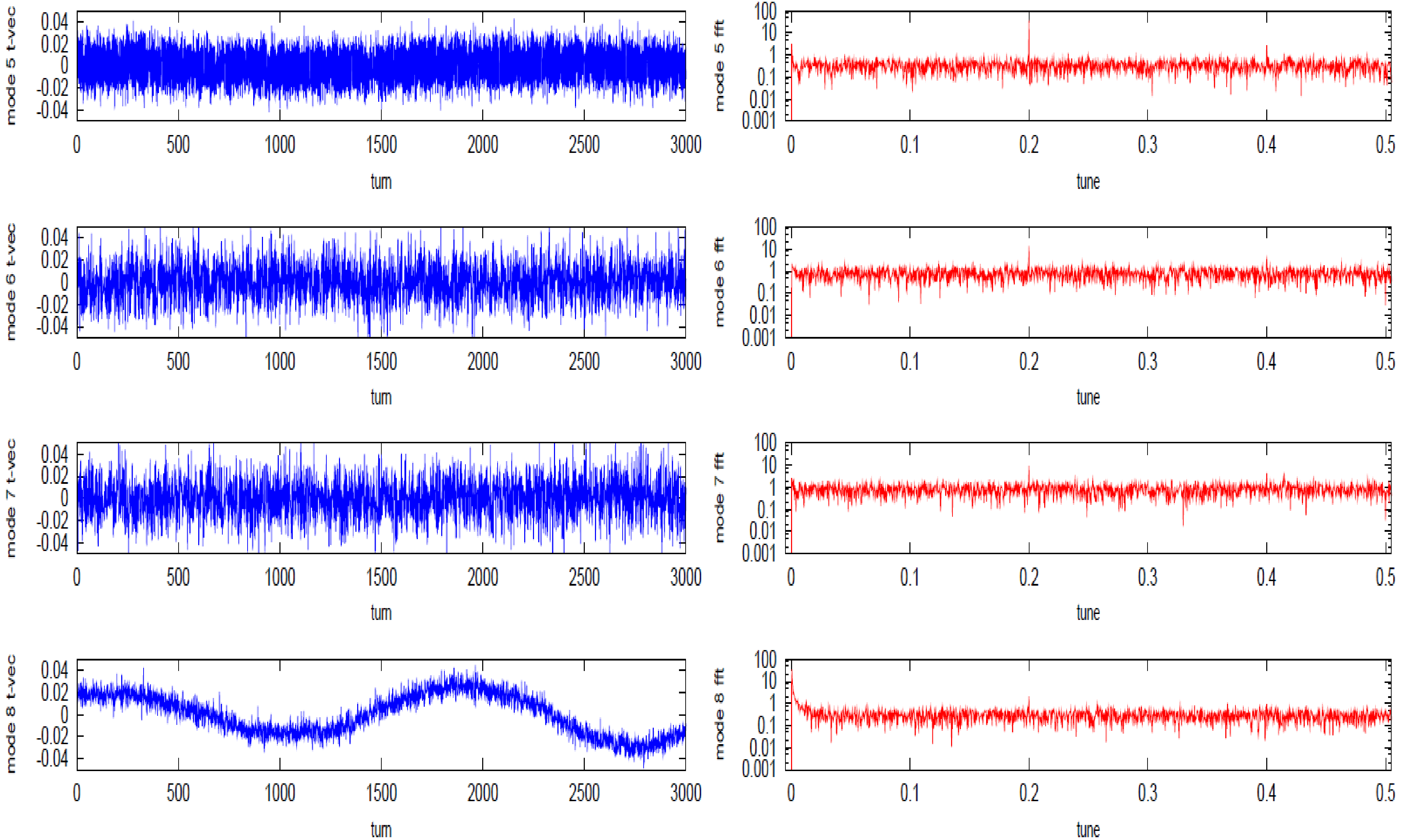
Equations of motion for coupled driven harmonic oscillators:

$$\frac{d^2x}{dt^2} + \omega_x^2 x = \kappa y + a\cos(\omega_d t)$$
$$\frac{d^2y}{dt^2} + \omega_y^2 y = \kappa x$$

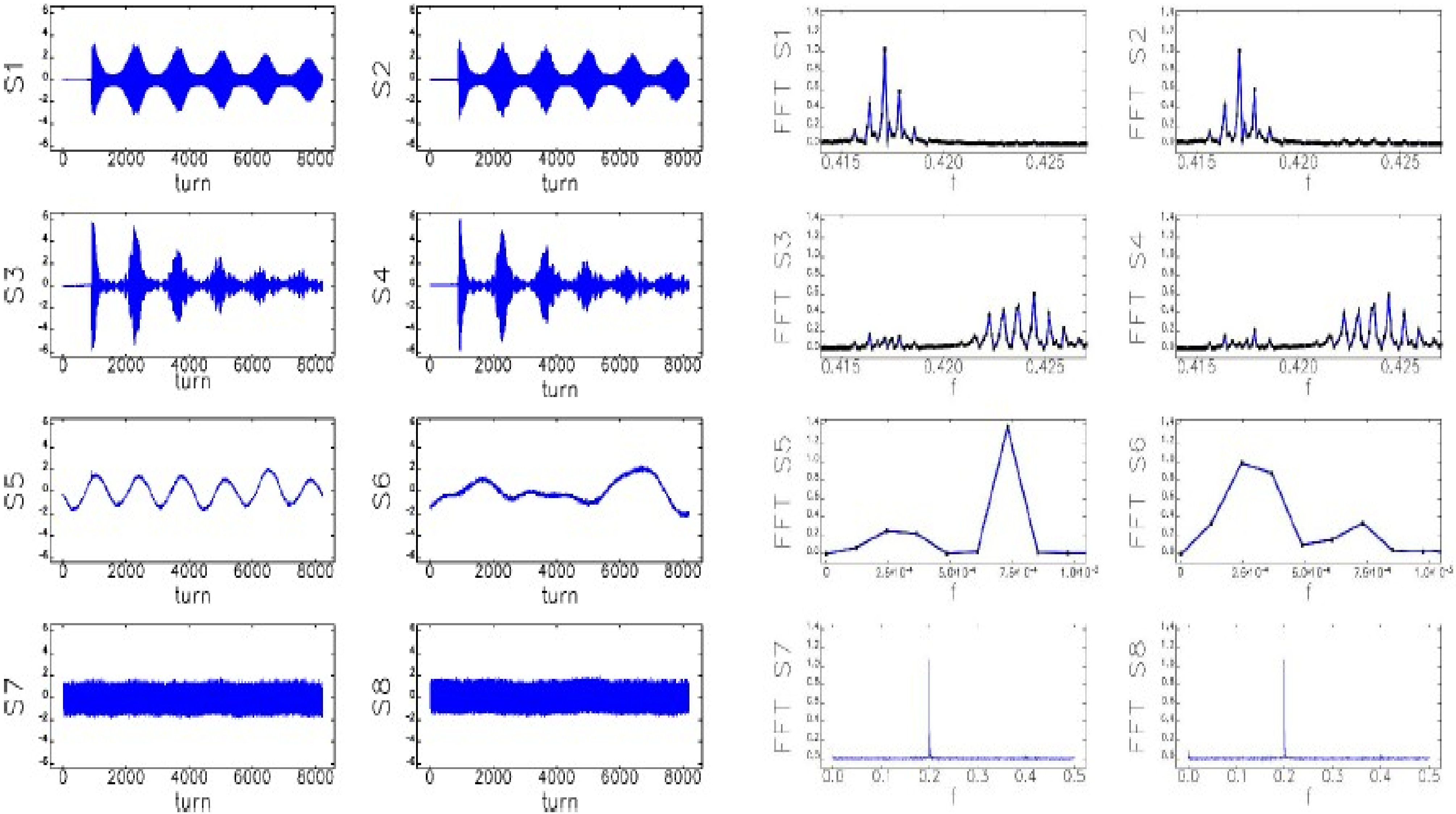
After rotated to the eigen coordinates:

$$\frac{d^2u}{dt^2} + \omega_u^2 u = b\cos(\omega_d t)$$
$$\frac{d^2v}{dt^2} + \omega_v^2 v = c\cos(\omega_d t)$$

MIA Applied to the AC Dipole Excitation



ICA for a Kick Excitation



From Petrenko et al. EPAC08