FLS 2012: Deterministic Approaches

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Outline

1. What's Known.
2. SR LS "Thermodynamics" (physics limitations).
3. An IBS Limited (deterministic) Approach: ~~TME~~ => no "Chromaticity Wall".
4. Chromatic Control: (deterministic approach).
5. ~~Pseudo-Knobs~~: A Leading Order (reductionist) Approach.
6. Signal Processing 101.
7. "Closing-the-Loop": In the Control Room (deterministic approach).
8. Model Based Control by Thin Clients (deterministic approach).

Challenge:

When a (brute force) numerical approach doesn't "cut it", how to "fix it"?

What's Known

[1] K.W. Robinson "Radiation Effect in Circular Electron Accelerators" Phys. Rev. 111 (1958).
[2] M. Sommer "Optimization of the Emittance of Electrons (Positrons) Storage Rings" LAL/RT/83-15 (1983).
[3] L. Teng "Minimum Emittance Lattice for Synchrotron Radiation Storage Rings" FNAL/TM-1269 (1984), ANL LS-17 (1985).
[4] Y. Baconnier et al "Emittance Control of the PS $e^{\pm}$ Beams Using a Robinson Wiggler" NIM A235 (1985).
[5] H. Wiedemann "Future Development of Synchrotron Radiation Sources at Stanford" PAC87.
[6] G. Brown et al "Operation of PEP in a Low Emittance Mode" PAC87.
[7] R.P. Walker et al "General Design Principles for Compact Low Emittance Synchrotron Radiation Sources" PAC87.
[8] H. Wiedemann "An Ultra-Low Emittance Mode for PEP Using Damping Wiggler" NIM A266 (1988).
[9] M.G. Minty et al "Emittance Reduction via Dynamic RF Frequency Shift at the SLC Damping Rings" SLAC-PUB-7954 (1988).
[10] G. Wüstefeld et al "The Analytical Lattice Approach for the Ring Design BESSY II" EPAC1988.
[11] V. Litvinenko "Storage Ring-Based Light Sources" FLS1999.
[12] M. Böge et al "Commissioning of the SLS Using CORBA Based Beam Dynamics Applications" PAC01.
[13] P. Emma, T. Raubenheimer "Systematic Approach to Storage Ring Design" PRST-AB 4 (2001).
[14] J. Guo, T. Raubenheimer "Low Emittance e^-/e^+ Storage Ring Design Using Bending Magnets with Longitudinal Gradient" EPAC02.
[15] R. Nagaoka, A. Wrülich "Emittance Minimization with Longitudinal Dipole Field Variation" NIM 575A (2007).

SR LS "Thermodynamics"

- The horizontal emittance is given by (isomagnetic lattice)

$$\varepsilon_x = \tau_x \langle \mathcal{H}_x \cdot D_\delta \rangle, \qquad \sigma_\delta^2 = \tau_E \langle \mathcal{H}_x \cdot D_\delta \rangle,$$

$$\varepsilon_x\ [\mathrm{nm{\cdot}rad}] = 7.84 \times 10^3 \cdot \frac{(E\ [\mathrm{GeV}])^2 F}{J_x N_\mathrm{b}^3}$$

N_b is the no of dipoles, $J_x + J_z = 3$, $F \geq 1$. No dipole gradients => $J_x \approx 1$.

- With damping wigglers, the natural horizontal emittance ε_x scales with the radiated power

$$\frac{\varepsilon_{x\mathrm{w}}}{\varepsilon_{0x}} \approx \frac{U_0}{U_0 + U_\mathrm{w}}, \qquad \frac{\sigma_{\delta_\mathrm{w}}}{\sigma_{\delta_0}} = \sqrt{\frac{1 + \dfrac{8}{3\pi}\dfrac{B_\mathrm{w}}{B_0}\dfrac{U_\mathrm{w}}{U_0}}{1 + \dfrac{U_\mathrm{w}}{U_0}}}$$

i.e., on behalf of σ_δ. High end Insertion Devices requires $\sigma_\delta \leq 1 \times 10^{-3}$.

Intrabeam Scattering (IBS)

Equilibrium

$$\varepsilon_x = \varepsilon_x^{SR} + \varepsilon_x^{IBS} = \tau_x(E^{SR})\langle \mathcal{H}_x \cdot (D_\delta^{SR}(\rho) + D_\delta^{IBS})\rangle,$$

$$\sigma_\delta^2 = \tau_\delta(E^{SR})(D_\delta^{SR}(\rho) + D_\delta^{IBS})$$

where

$$\delta \equiv \frac{E - E_0}{E_0}, \qquad \mathcal{H}_x \equiv \tilde{\eta}^T \tilde{\eta}, \qquad \bar{\eta} \equiv \begin{bmatrix} \eta_x \\ \eta'_x \end{bmatrix}, \qquad \tilde{\eta} \equiv A^{-1}\bar{\eta}, \qquad A^{-1} = \begin{bmatrix} 1/\sqrt{\beta_x} & 0 \\ \alpha_x/\sqrt{\beta_x} & \sqrt{\beta_x} \end{bmatrix}.$$

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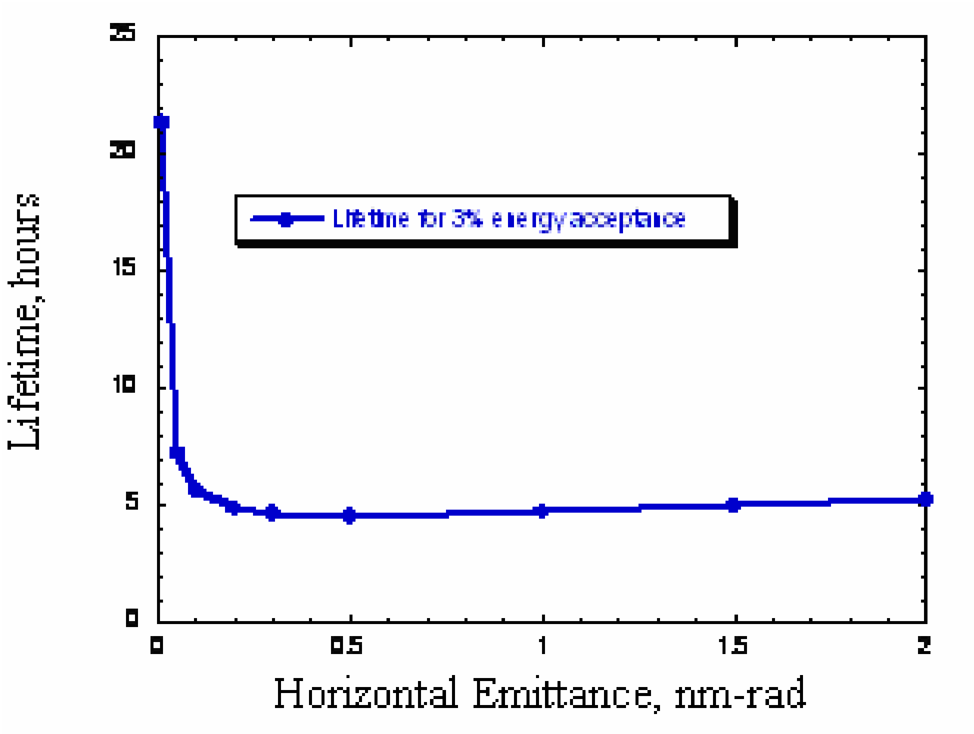
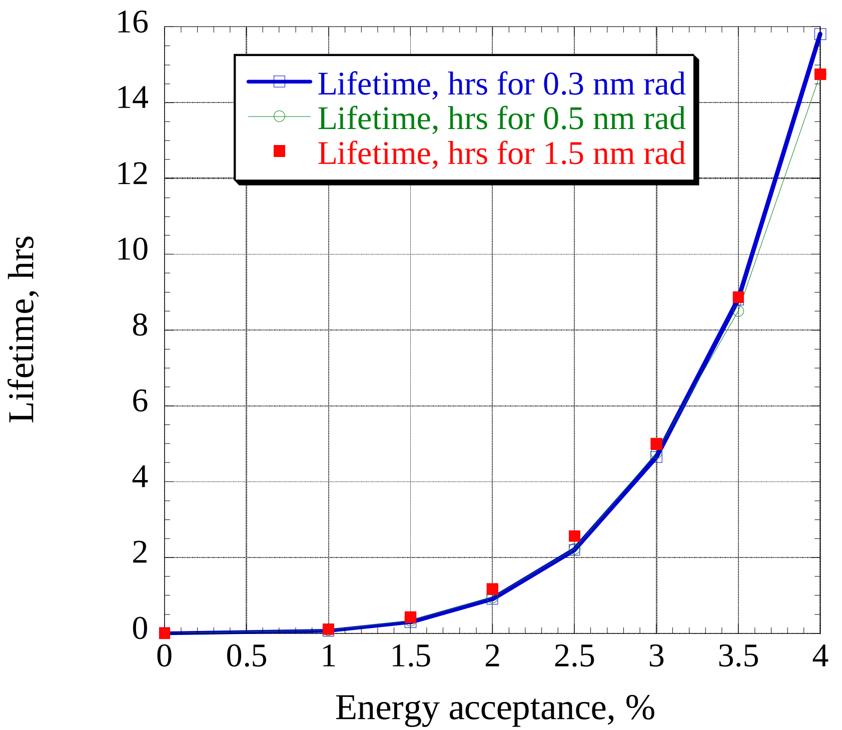
Touschek Life Time Trade-Offs (NSLS-II CDR, 2006)





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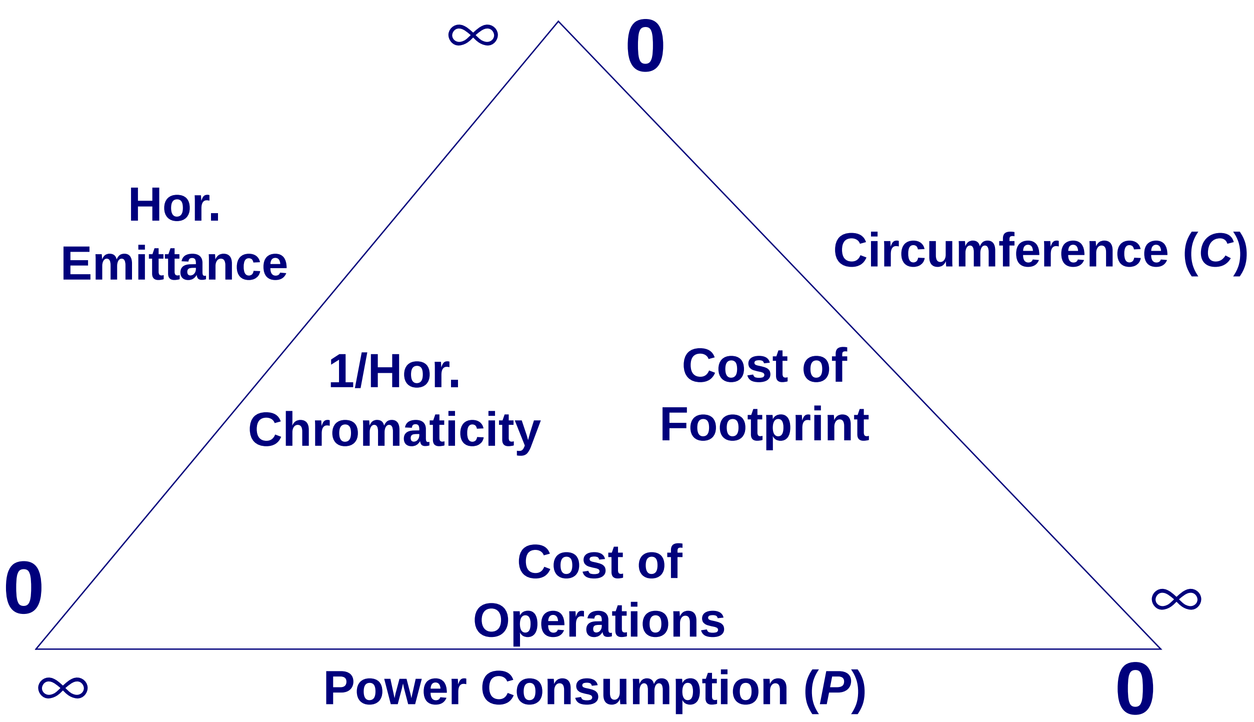
An IBS Limited (deterministic) Approach

1. **Hor. emittance (natural): damping $\leftrightarrow$ diffusion.**
2. **Optimize (globally, for Insertion Devices):**



- **Since**

$$\varepsilon_x \sim \frac{1}{\rho^2 \cdot P},$$

  ρ **bend radius.**
- **Fundamental limit is IBS:** $(2-3) \cdot \varepsilon_{x\,\mathrm{IBS}}$.

- **PETRA-3, NSLS-II, and MAX-IV avoid the "chromaticity wall" with damping wig-glers and a 7-BA. A TME (reductionist) artifact; by ignoring (linear) chromaticity.**

NSLS-II CDR (2006): Parametric Evaluation

Table 4.2.3 Storage Ring Parameters for Number of DBA Lattice Cells Varying from 32 to 24.

Lattice	DBA32	DBA30	DBA28	DBA26	DBA24
Circumference [m]	822	780	739	697	656
Bend magnet radius [m]	25	25	25	25	25
Straight sections [n x (m)]	16x(8, 5)	15x(8, 5)	14x(8, 5)	13x(8, 5)	12x(8, 5)
Horizontal emittance, ε_x (bare) [nm-rad]	1.7	2.1	2.6	3.2	4.1
Horizontal emittance, ε_x (full set of damping wigglers) [nm-rad]	0.5	0.6	0.7	0.8	1.1
Straight Section Utilization					
8 m straights					
RF and injection	3	3	3	3	3
Damping wigglers	8	8	8	8	8
Undulators	5	4	3	2	1
5 m straights					
Undulators	16	15	14	13	12

- ε_x^{IBS} = 0.2 – 0.25 nm·rad.
- *C*: ~$1 M/m.

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Implementations

- N_b^3: DBA, TBA -> 7BA. Reduced peak dispersion => a stiffer (nonlinear) system (of ODEs) for chromatic control.

<u>MAX-IV</u> (7BA-20 => relaxed optics, by innovative engineering $\varepsilon_x = 0.26$).

PEP-X "baseline" (<u>TME</u> $\varepsilon_x = 0.16$) -> "<u>ultimate</u>" (2.8×MAX-IV $1/2.8^3 \to \varepsilon_x = 0.012$).

<u>USR7</u> (10BA-40 in the Tevatron tunnel $\varepsilon_x = 0.003$, @11 GeV).

- $J_x \leftrightarrow J_z \Rightarrow \varepsilon_x \leftrightarrow \sigma_\delta$: gradient dipoles (incl. *s*-dependent), Robinson wigglers, orbit (i.e., "dipoles") in the quadrupoles. Insertion Devices => $\sigma_\delta \le 1 \times 10^{-3}$.

- *F*: chromatic straights (effective hor. emittance). Symmetric lattice => dispersion at the RF cavity.

- $\varepsilon_x \leftrightarrow \sigma_\delta$: damping wigglers. Requires achromatic straights => $F = 3$). But also provide "free" beamlines. Insertion Devices => $\sigma_\delta \le 1 \times 10^{-3}$.

Nota Bene: While facilities based on DBAs, after converting to chromatic straights, to my knowledge, have only reported the *relative* improvement.

Chromatic Control: First Principles

Challenge: How to control the swamp of undesirable terms generated by (linear) chromatic correction for a strongly focusing lattice?

$$M = A^{-1} e^{D_{V} + \dots} e^{D_{K_2}} A$$

Zero the undesirable terms in *V*; a highly over constrained problem. The most effective approach: use symmetry (reduces *all* terms). For example, linear achromats (in the phase-space variables): DBA, TBA, 7BA, etc.

Traditional design strategies:

1. **Avoidance (weakly focusing rings with high periodicity): Introduce two chromatic families and choose the working point so that systematic resonances are avoided.**
2. **Anti-symmetry (FODO lattices): Introduce two chromatic families separated by horizontal- and vertical phase advance of $k\pi$, $k = \text{odd}$. However, this will drive h_{20001} and h_{00201} systematically.**
3. **Higher order achromats (strongly focusing lattices): define a unit cell, repeat it *N* times, and choose the phase advance so that all the 1st and 2nd order driving terms are cancelled. However, the working point is now on an integer.**

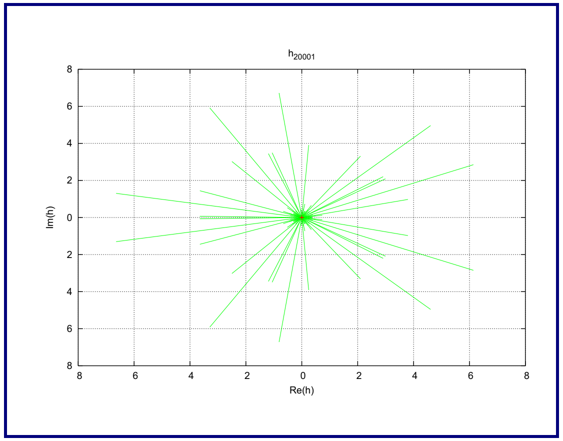
Example: 5-Cell Second Order Achromat

1. Introduce two chromatic sextupole families.
2. The first order driving terms are cancelled by e.g.:

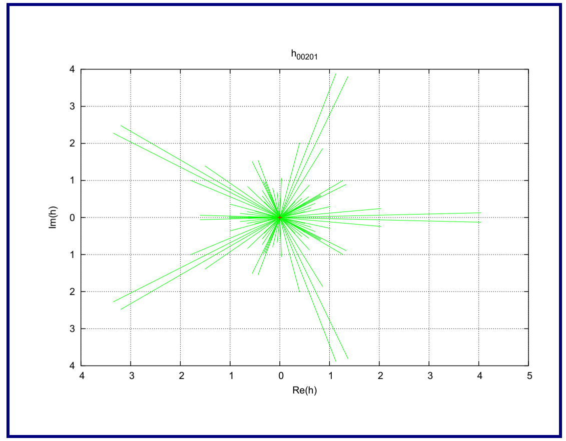
Cell	$\nu_{x,y}$	ν_x	$2\nu_x$	$2\nu_y$	$3\nu_x$	$\nu_x - 2\nu_y$	$\nu_x + 2\nu_y$
1	(8/5, 3/5)=(1.60, 0.60)	1.60	3.20	1.20	4.80	0.40	2.80
2		3.20	6.40	2.40	9.60	0.80	5.60
3		4.80	9.60	3.60	14.40	1.20	8.40
4		6.40	12.80	4.80	19.20	1.60	11.20
5		8.00	16.00	6.00	24.00	2.00	14.00

3. Introduce 1 more chromatic and 5 geometric (i.e., a total of 9 families => *full control of all the first order driving terms*); to provide leeway for the choice of working point (SLS Tech Note 9/97).
4. The required number of sextupole (-> multipole) families, placement, etc. can be evaluated & optimized by analyzing the rank conditions for the Jacobian of the driving terms (J. Bengtsson et al NIM 404, 1998).

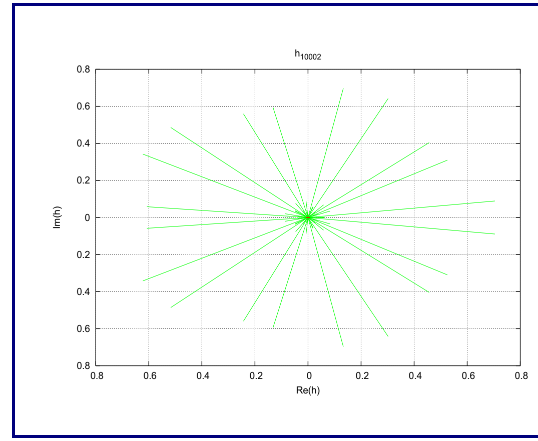
First Order Chromatic Effects Cancelled Over 5 Cells



h_{20001}

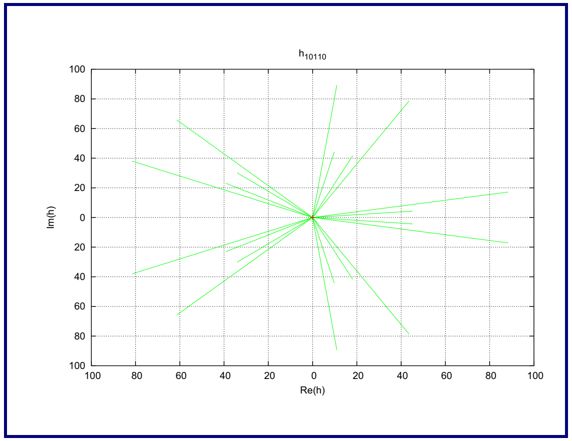


h_{00201}

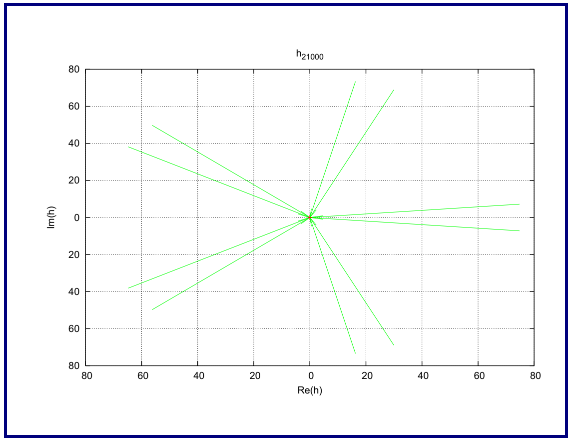


h_{10002}

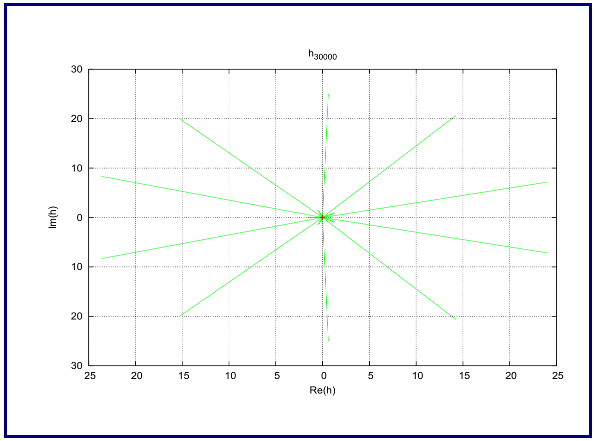
First Order Geometric Effects Cancelled over 5 Cells



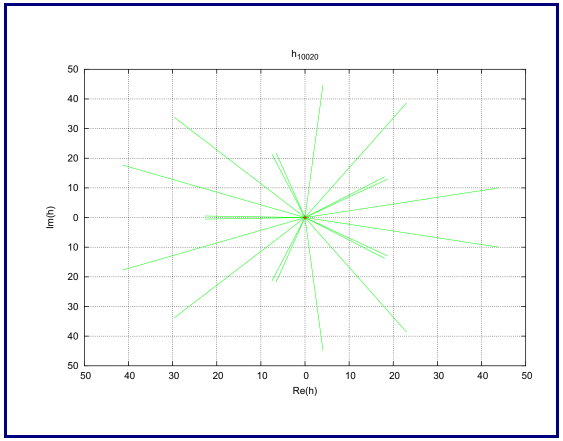
h_{10110}



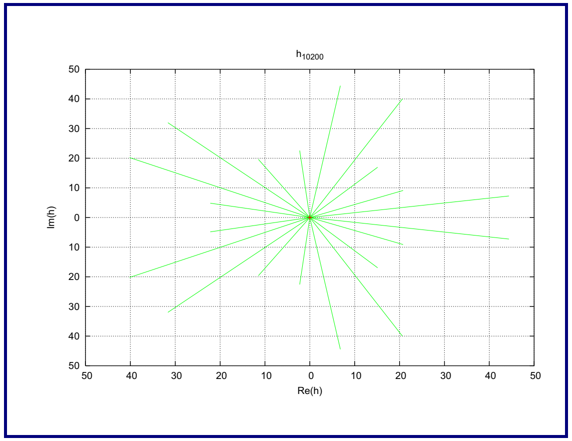
h_{21000}



h_{30000}



h_{10020}



h_{10200}

NSLS-II: Higher Order Achromats

				First Order						Second Order				Third Order				
				Geometric				Chromatic		Geometric				Geometric				
Cell	ν_x	ν_y		ν_x	$3\nu_x$	$\nu_x-2\nu_y$	$\nu_x+2\nu_y$	$2\nu_x$	$2\nu_y$	$4\nu_x$	$4\nu_y$	$2\nu_x-2\nu_y$	$2\nu_x+2\nu_y$	$5\nu_x$	$\nu_x-4\nu_y$	$\nu_x+4\nu_y$	$3\nu_x-2\nu_y$	$3\nu_x+2\nu_y$
1	1.500	0.625	6/4, 5/8	1.50	4.50	0.25	2.75	3.00	1.25	6.00	2.50	1.75	4.25	7.50	-1.00	4.00	3.25	5.75
2	3.000	1.250		3.00	9.00	0.50	5.50	6.00	2.50	12.00	5.00	3.50	8.50	15.00	-2.00	8.00	6.50	11.50
3	4.500	1.875		4.50	13.50	0.75	8.25	9.00	3.75	18.00	7.50	5.25	12.75	22.50	-3.00	12.00	9.75	17.25
4	6.000	2.500		6.00	18.00	1.00	11.00	12.00	5.00	24.00	10.00	7.00	17.00	30.00	-4.00	16.00	13.00	23.00
1	1.400	0.600	7/5, 6/10	1.40	4.20	0.20	2.60	2.80	1.20	5.60	2.40	1.60	4.00	7.00	-1.00	3.80	3.00	5.40
2	2.800	1.200		2.80	8.40	0.40	5.20	5.60	2.40	11.20	4.80	3.20	8.00	14.00	-2.00	7.60	6.00	10.80
3	4.200	1.800		4.20	12.60	0.60	7.80	8.40	3.60	16.80	7.20	4.80	12.00	21.00	-3.00	11.40	9.00	16.20
4	5.600	2.400		5.60	16.80	0.80	10.40	11.20	4.80	22.40	9.60	6.40	16.00	28.00	-4.00	15.20	12.00	21.60
5	7.000	3.000		7.00	21.00	1.00	13.00	14.00	6.00	28.00	12.00	8.00	20.00	35.00	-5.00	19.00	15.00	27.00
1	1.500	0.583	9/6, 7/12	1.50	4.50	0.33	2.67	3.00	1.17	6.00	2.33	1.83	4.17	7.50	-0.83	3.83	3.33	5.67
2	3.000	1.167		3.00	9.00	0.67	5.33	6.00	2.33	12.00	4.67	3.67	8.33	15.00	-1.67	7.67	6.67	11.33
3	4.500	1.750		4.50	13.50	1.00	8.00	9.00	3.50	18.00	7.00	5.50	12.50	22.50	-2.50	11.50	10.00	17.00
4	6.000	2.333		6.00	18.00	1.33	10.67	12.00	4.67	24.00	9.33	7.33	16.67	30.00	-3.33	15.33	13.33	22.67
5	7.500	2.917		7.50	22.50	1.67	13.33	15.00	5.83	30.00	11.67	9.17	20.83	37.50	-4.17	19.17	16.67	28.33
6	9.000	3.500		9.00	27.00	2.00	16.00	18.00	7.00	36.00	14.00	11.00	25.00	45.00	-5.00	23.00	20.00	34.00

~~Pseudo-Knobs~~: Leading Order (reductionist) Approach

- As an attempt to introduce more knobs, one may (artificially) reduce the symmetry of a multipole family. However, while a free parameter is obtained to control the leading order terms, the approach will (systematically) drive the next order(s).
- So, for a systematic approach (of any scheme), effects (at least) one order beyond the "knobs" must be included in the analysis.

The impact on NSLS-II is summarized in Tech Note 90, 2009:

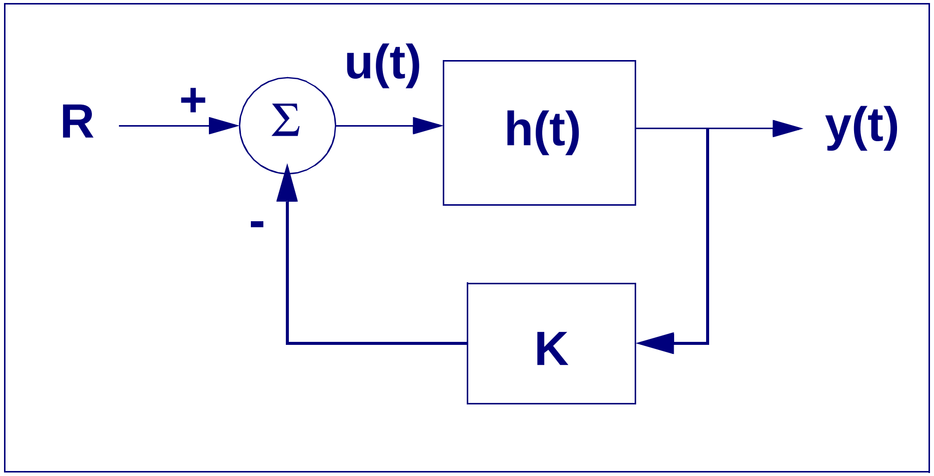
Order	Hor/Ver	Contr. for δ = 2.5%	Contr. for δ = 3.0%
0	(33.45, 16.37)	(33.45, 16.37)	(33.45, 16.37)
1	(−0.017, −0.037)	(−0.0004, −0.001)	(−0.001, −0.001)
2	(−65.9, 10.1)	(−0.041, 0.006)	(−0.059, 0.009)
3	$(-3.3\times10^2, 2.1\times10^2)$	(−0.005, 0.003)	(−0.009, 0.006)
4	$(2.8\times10^4, -2.7\times10^3)$	(0.011, −0.001)	(0.023, −0.002)
5	$(-9.1\times10^5, -6.1\times10^4)$	(−0.009, −0.001)	(−0.022, −0.001)

TABLE 2. Residual Chromaticity for the Oct, 2008 Baseline (working point #4, 3+6 sextupole families, $\xi_{x,y}$ = (0, 0)).

Order	Hor/Ver	Contr. for δ = 2.5%	Contr. for δ = 3.0%
0	(33.42, 16.35)	(33.42, 16.35)	(33.42, 16.35)
1	(0.0, 0.0)	(0.0, 0.0)	(0.0, 0.0)
2	(−50.8, 15.4)	(−0.032, 0.010)	(−0.045, 0.014)
3	$(-2.0\times10^3, 2.0\times10^2)$	(−0.032, 0.003)	(−0.055, 0.005)
4	$(6.2\times10^4, -1.6\times10^3)$	(0.024, 0.001)	(0.050, 0.001)
5	$(-1.2\times10^6, -1.1\times10^5)$	(−0.012, −0.001)	(−0.030, −0.003)

TABLE 3. Residual Chromaticity for Translated Chromatic Sextupole Pair (3+14 sextupole families, $\xi_{x,y}$ = (0, 0)).

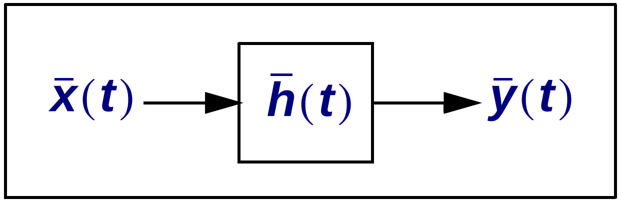
“Closing-the-Loop”



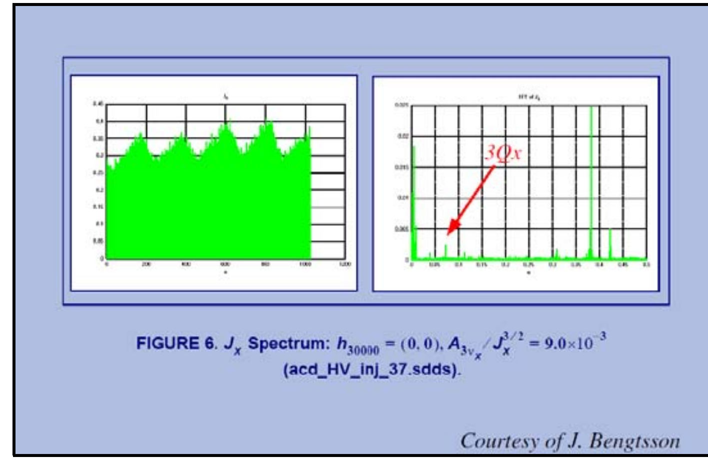
Strategies (an iterative process):

- **Design (“feed-forward”): model, guidelines, engineering, reality checks, etc.**
- **In the control room (“feed-back”, e.g. commissioning): Model Based Control, Orbit Response Matrix, Turn-by-Turn BPM data, etc.**

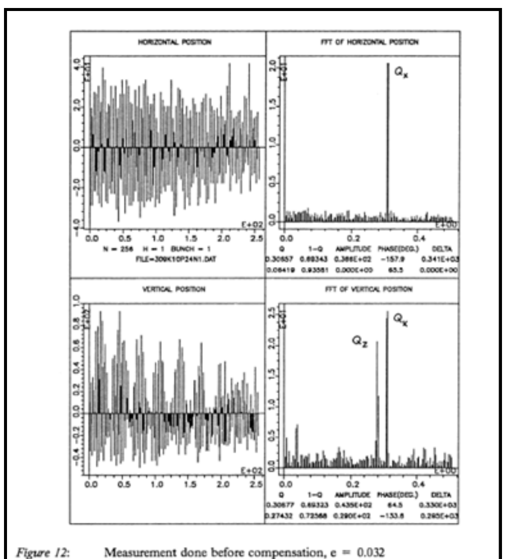
Beam Transfer Function & Model Based Control



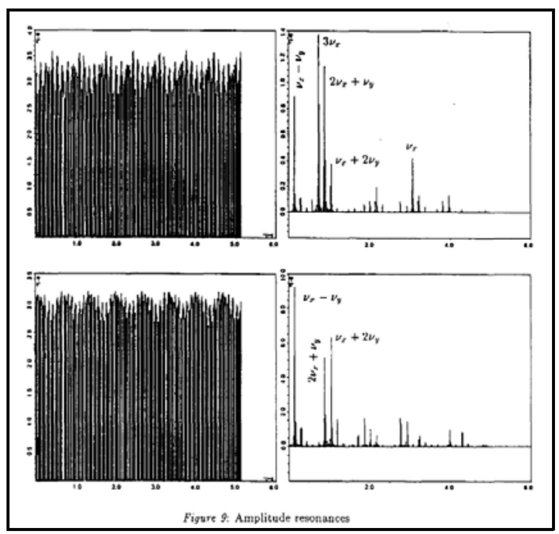
RHIC, 2006 (AC dipole)



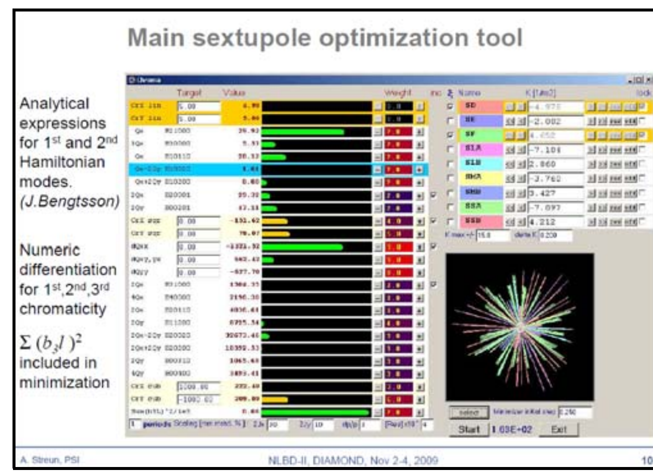
LEAR, 1988 (pinger)



SSC, 1990 (tracking)



SLS, 2007- (pinger)



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Discrete Fourier Transform (DFT)

The Discrete Fourier Transform (DFT) is defined by

$$x_k = \sum_{n=0}^{N-1} X_n e^{i2\pi kn/N}, \qquad k = 0, 1, \ldots, N-1$$

where

$$X_n = \frac{1}{N}\sum_{k=0}^{N-1} x_k e^{-i2\pi kn/N}, \qquad n = 0, 1, \ldots, N-1$$

Typical window functions

Rectangular: $$e^{i2\pi k\nu_0}\mathrm{rect}\left(\frac{k}{N}\right) \to \mathrm{sinc}(\pi(n - N\nu_0)),$$

Sine: $$e^{i2\pi k\nu_0}\sin\left(\pi\frac{k}{N}\right) \to \frac{1}{2\pi}\frac{\sin(\pi(n - N\nu_0 - 1/2))}{(n - N\nu_0)^2 - (1/2)^2},$$

Hann: $$e^{i2\pi k\nu_0}\sin^2\left(\pi\frac{k}{N}\right) \to -\frac{1}{2}\frac{1}{(n - N\nu_0)^2 - 1}\mathrm{sinc}(\pi(n - N\nu_0))$$

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Numerical Analysis of Fundamental Frequency

It has become fashionable to use (Laskar, 1993, NAFF)

$$\mathrm{Max}\{|X(\nu)|\} = \mathrm{Max}\left\{\left|\sum_{k=0}^{N-1} w_k x_k e^{-i2\pi k\nu}\right|\right\}$$

i.e., to solve numerically for a Hann window

$$w_k = \sin^2\left(\frac{\pi k}{N}\right), \qquad 0 \le k \le N-1$$

and component wise spectrum deconvolution by Gramm-Schmidt ortogonaliza-tion.

Frequency Domain Approach: Interpolation Formula

A more direct approach is to use a two-step (nonlinear) interpolation formula for the spectrum. For example, the frequency of a peak is given by:

$$\text{Rectangular:} \qquad \nu = \frac{1}{N}\left(n - 1 + \frac{1}{1 + A_{n-1}/A_n}\right),$$

$$\text{Sine:} \qquad \nu = \frac{1}{N}\left(n - \frac{3}{2} + \frac{2}{1 + A_{n-1}/A_n}\right),$$

$$\text{Hann:} \qquad \nu = \frac{1}{N}\left(n - 2 + \frac{3}{1 + A_{n-1}/A_n}\right)$$

While the resolution of the discrete spectrum is only $\sim 1/N$, it is thus improved to $\sim 1/N^{\alpha}$, $\alpha = 2, 3, 4$, respectively; i.e., ignoring the impact of noise (=> academic).

Taking the effect of noise into account gives instead

$$\langle \delta\nu^2 \rangle = \frac{1}{\mathrm{SNR}^2}\frac{2}{N^2} \sim \frac{1}{N^3}.$$

Clearly, a time-domain approach has the same (fundamental) limitation.

For e.g. $N = 256$ with 1% or 5% noise we obtain $\delta\nu \sim 4\times10^{-5}, 2\times10^{-4}$, respectively.

Signal Processing 101: Windowing

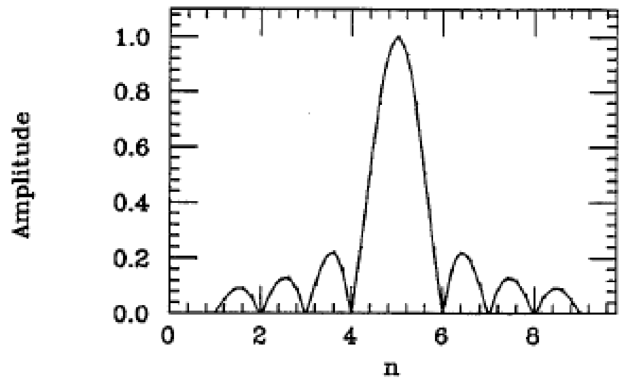

Figure 7: Rectangular window

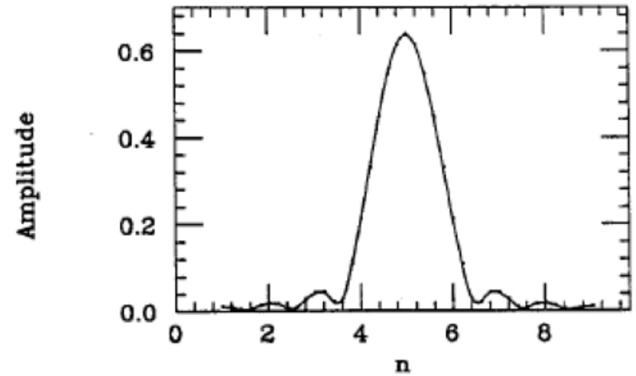

Figure 8: Sine window

$$\nu = \frac{1}{N}\left[k - 1 + \frac{A(k)}{A(k-1) + A(k)}\right], \qquad k - 1 \leq N\nu \leq k \quad .$$

$$\nu = \frac{1}{N}\left[k - 1 + \frac{2A(k)}{A(k-1) + A(k)} - \frac{1}{2}\right], \qquad k - 1 \leq N\nu \leq k$$

First Order Sextupolar Modes (SLS 9/97)

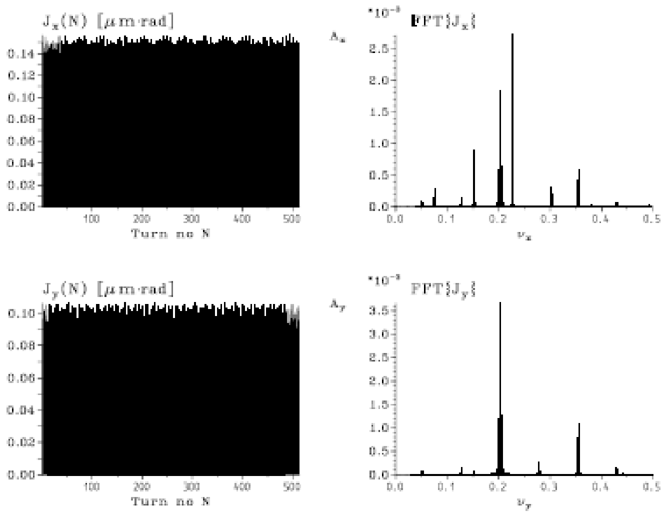

Figure 7: Perturbation of the Action Variables.

$$
\begin{aligned}
J_x(N) &= J_x + \frac{A_{21000}(2J_x)^{3/2}}{\sin(\pi\nu_x)}\cos\left(\hat{\phi}_{21000} + \phi_x + N2\pi\nu_x\right) \\
&+ \frac{A_{10110}\sqrt{2J_x}2J_y}{\sin(\pi\nu_x)}\cos\left(\hat{\phi}_{10110} + \phi_x + N2\pi\nu_x\right) \\
&+ \frac{3A_{30000}(2J_x)^{3/2}}{\sin(3\pi\nu_x)}\cos\left[\hat{\phi}_{30000} + 3(\phi_x + N2\pi\nu_x)\right] \\
&+ \frac{A_{10020}\sqrt{2J_x}2J_y}{\sin[\pi(\nu_x - 2\nu_y)]}\cos\left[\hat{\phi}_{10020} + \phi_x - 2\phi_y + N2\pi(\nu_x - 2\nu_y)\right] \\
&+ \frac{A_{10200}\sqrt{2J_x}2J_y}{\sin[\pi(\nu_x + 2\nu_y)]}\cos\left[\hat{\phi}_{10200} + \phi_x + 2\phi_y + N2\pi(\nu_x + 2\nu_y)\right] \\
&+ O\left(b_3^2\right), \\
J_y(N) &= J_y - \frac{2A_{10020}\sqrt{2J_x}2J_y}{\sin[\pi(\nu_x - 2\nu_y)]}\cos\left[\hat{\phi}_{10020} + \phi_x - 2\phi_y + N2\pi(\nu_x - 2\nu_y)\right] \\
&+ \frac{2A_{10200}\sqrt{2J_x}2J_y}{\sin[\pi(\nu_x + 2\nu_y)]}\cos\left[\hat{\phi}_{10200} + \phi_x + 2\phi_y + N2\pi(\nu_x + 2\nu_y)\right] \\
&+ O\left(b_3^2\right) \qquad (156)
\end{aligned}
$$

where

$$
\hat{\phi}_{ijkl0} \equiv \phi_{ijkl} - \pi[(i-j)\nu_x + (k-l)\nu_y] \qquad (157)
$$

On-Line Control of First Order Driving Terms

the frequency spectrum of the betatron motion. We deliberately excite the first order modes with the following values

$$\begin{aligned} A_{30000} &= 6.944, \quad \phi_{30000} = -1.8\,\text{deg}, \\ A_{10020} &= 16.10, \quad \phi_{10020} = 54.0\,\text{deg}, \\ A_{10200} &= 8.26, \quad \phi_{10200} = -70.2\,\text{deg} \end{aligned} \qquad (165)$$

An easy calculation with formula (156) for the initial conditions

$$Jx = 1.5\times 10^{-7}, \quad \phi_x = 0.0, \quad Jy = 1.0\times 10^{-7}, \quad \phi_y = 90.0^\circ \qquad (166)$$

gives the spectrum

f	A_x	ϕ_x	A_y	ϕ_y	
$3\nu_x$	5.0×10^{-9}	-45.0 deg	–	–	
$\nu_x - 2\nu_y$	3.0×10^{-9}	90.0 deg	6.0×10^{-9}	-90.0 deg	(167)
$\nu_x + 2\nu_y$	1.0×10^{-9}	45.0 deg	2.0×10^{-9}	45.0 deg	

Figure 7 shows the tracking results. Fourier analysis and interpolation of the tracking data gives

f	A^*_x	ϕ^*_x	A^*_y	ϕ^*_y	
$3\nu_x$	5.3×10^{-9}	-45.1 deg	–	–	
$\nu_x - 2\nu_y$	2.9×10^{-9}	-82.6 deg	5.8×10^{-9}	94.6 deg	(168)
$\nu_x + 2\nu_y$	1.0×10^{-9}	49.6 deg	1.9×10^{-9}	49.0 deg	

The phase of $\nu = \nu_x - 2\nu_y$ appears with the wrong sign since it is $1-\nu$ that appears in the spectrum due to aliasing. Let us simply point out then,

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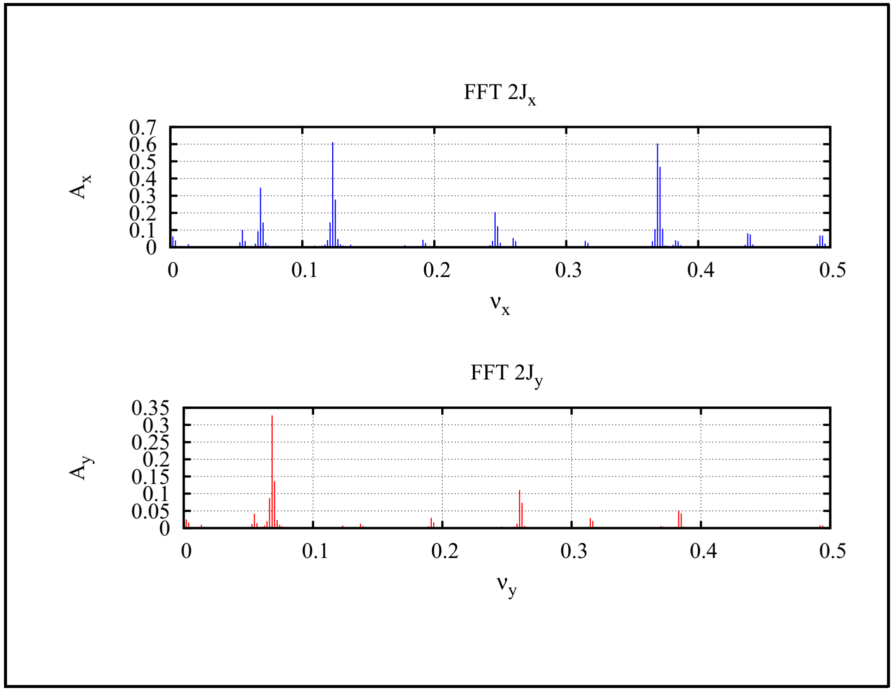
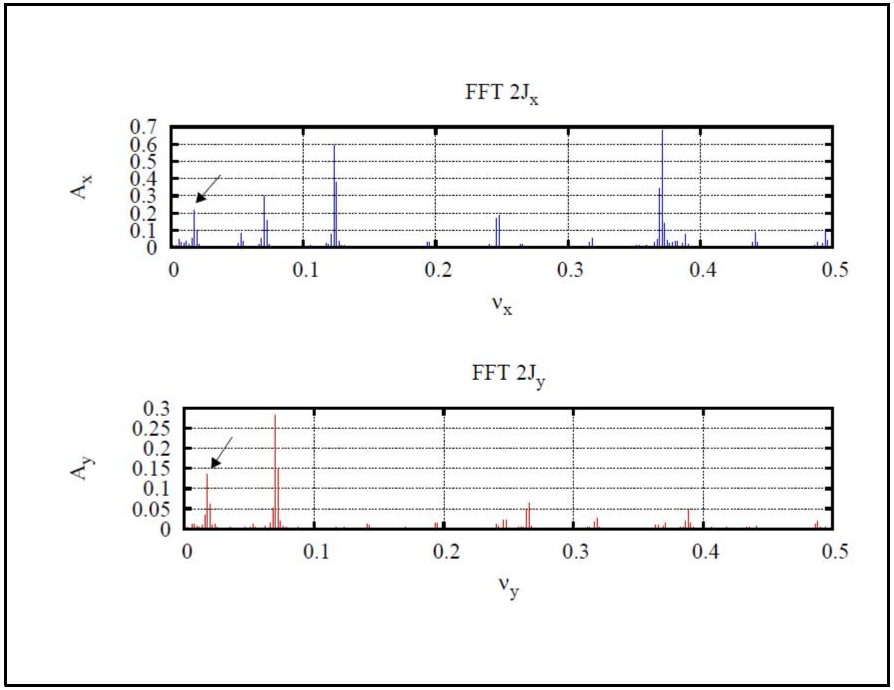
Example: Source Analysis





NSLS-II nominal spectrum
$\nu_{x,y} = [33.12, 16.19]$.

With a decapole component =>
$3\nu_x - 2\nu_y$

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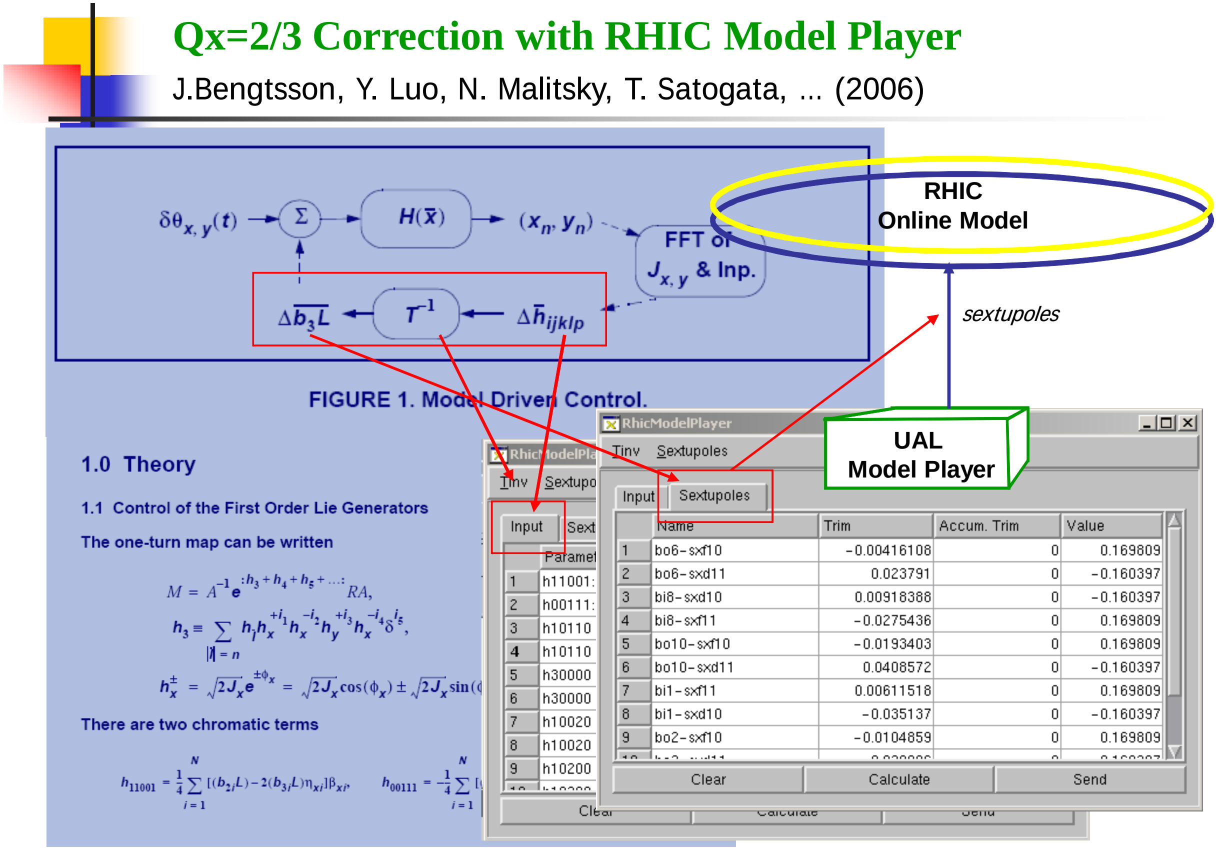
RHIC: Model Based Control (PAC07)



Nikolay Malitsky, APEX Workshop 2006

Challenges:

- Only two chromatic families. However, the 12 arcs have independent power supplies.
- More knobs vs. reduced lattice symmetry.
- Sextupole circuits later rewired to provide 12 independent, symmetric knobs.
- Status (on chromatic control) given at CERN, 2011.

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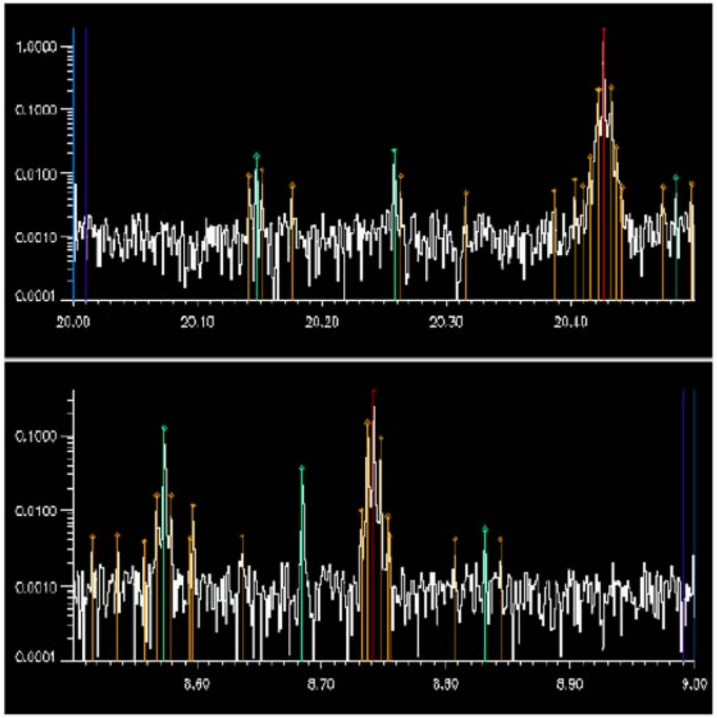
Beam Studies SLS (2007)



Resonance guesses

example: set

$$h_{10020} = 6 \cdot 10^{-9} \cdot e^{2\pi/3}\ m^2$$

with auxiliary sextupoles and pinger magnets

↓

try to identify resonances

$$aQ_x + bQ_y = n$$

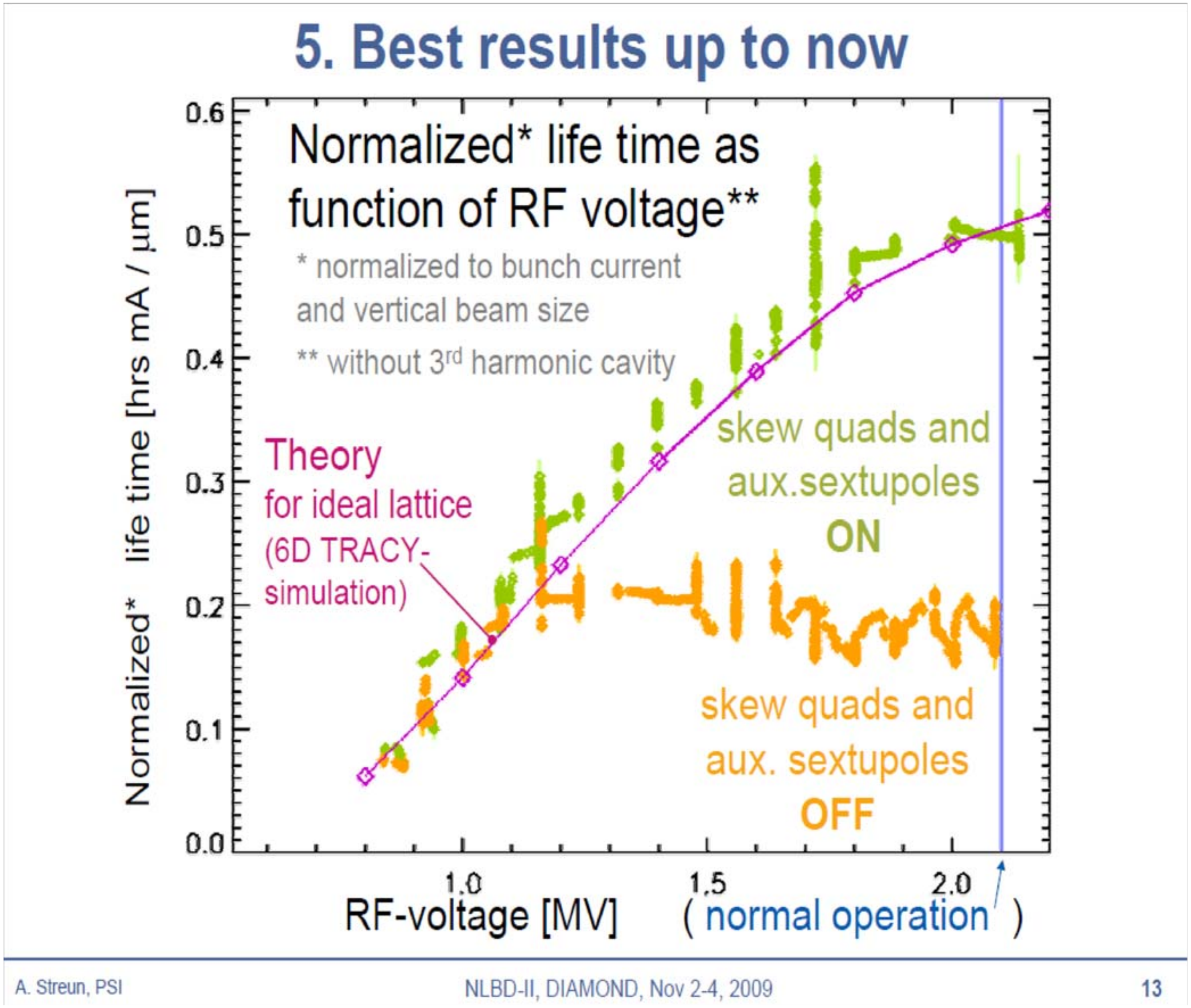
	peak [mm]	Tune	Guess	min.dist.	[a	b	n]
X	1.83895	20.42643					
3	0.02222	20.25797	20.25803	-0.000003	[1	-1	12]
4	0.01860	20.14714	20.14714	0.000001	[3	0	61]
9	0.00845	20.48409	20.48394	0.000039	[1	-2	3]
Y	0.39925	8.74197					
1	0.12353	8.57357	8.57357	-0.000000	[1	-1	12]
3	0.03584	8.68453	8.68446	0.000017	[1	-2	3]
9	0.00554	8.83162	8.83160	0.000005	[1	2	38]

1000 turn FFT
sine window
peak interpolation

A. Streun, PSI   NLBD-II, DIAMOND, Nov 2-4, 2009   11

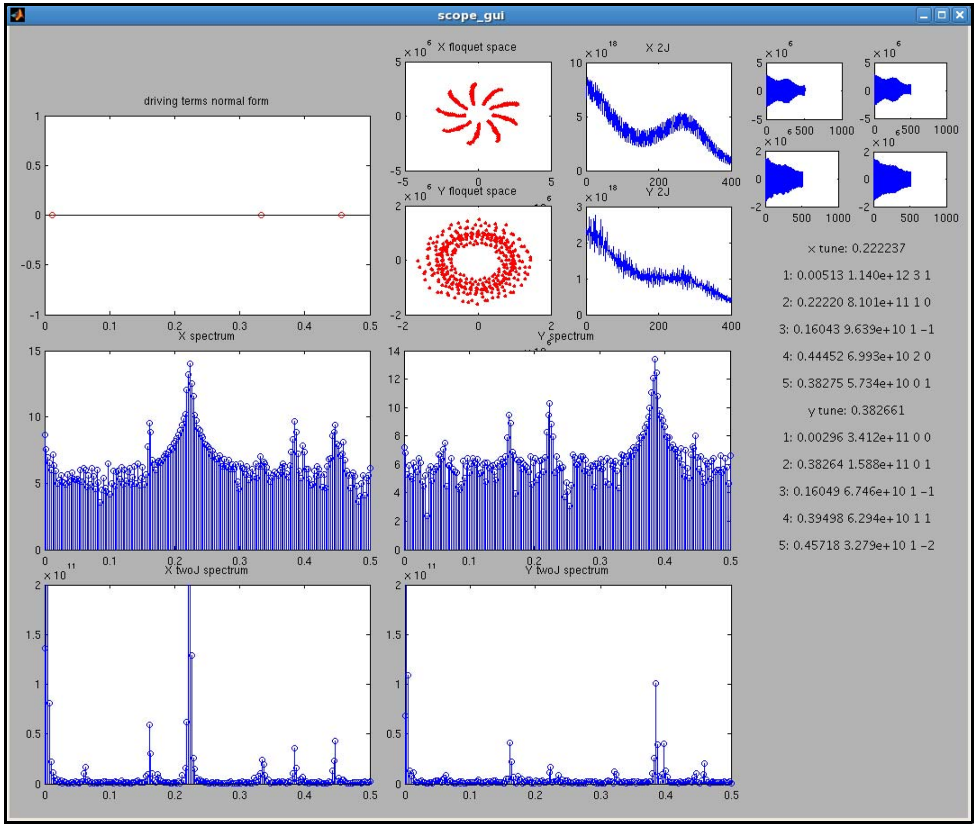
A. Streun, 2009.

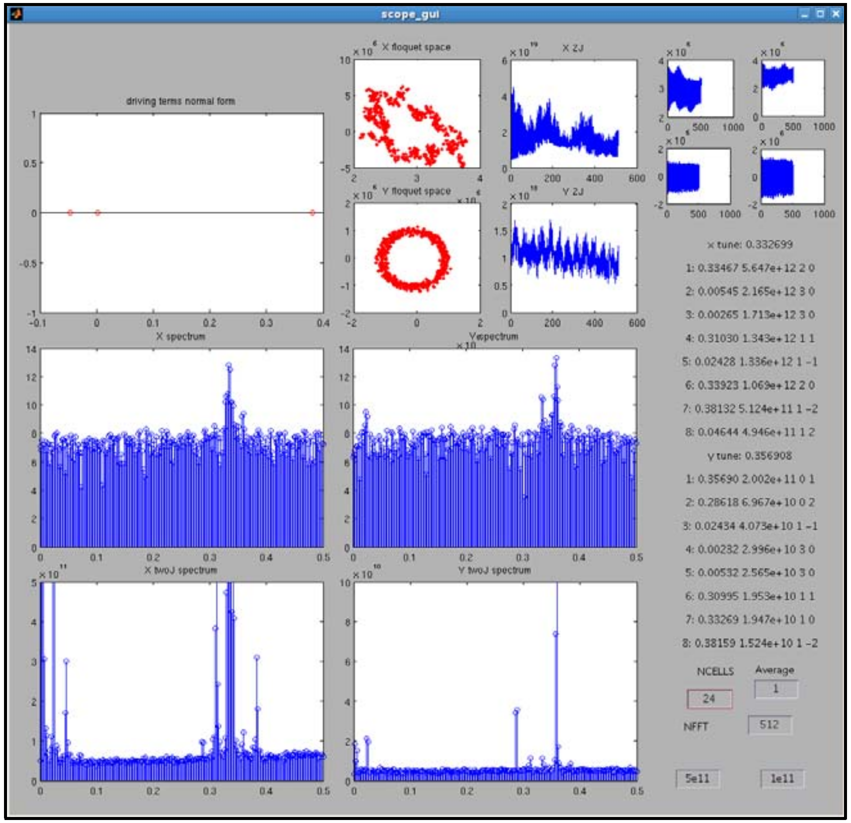
Control of Off-Momentum Aperture (SLS)



A. Streun, 2009.

Control of Nonlinear Resonances at DIAMOND (2010)



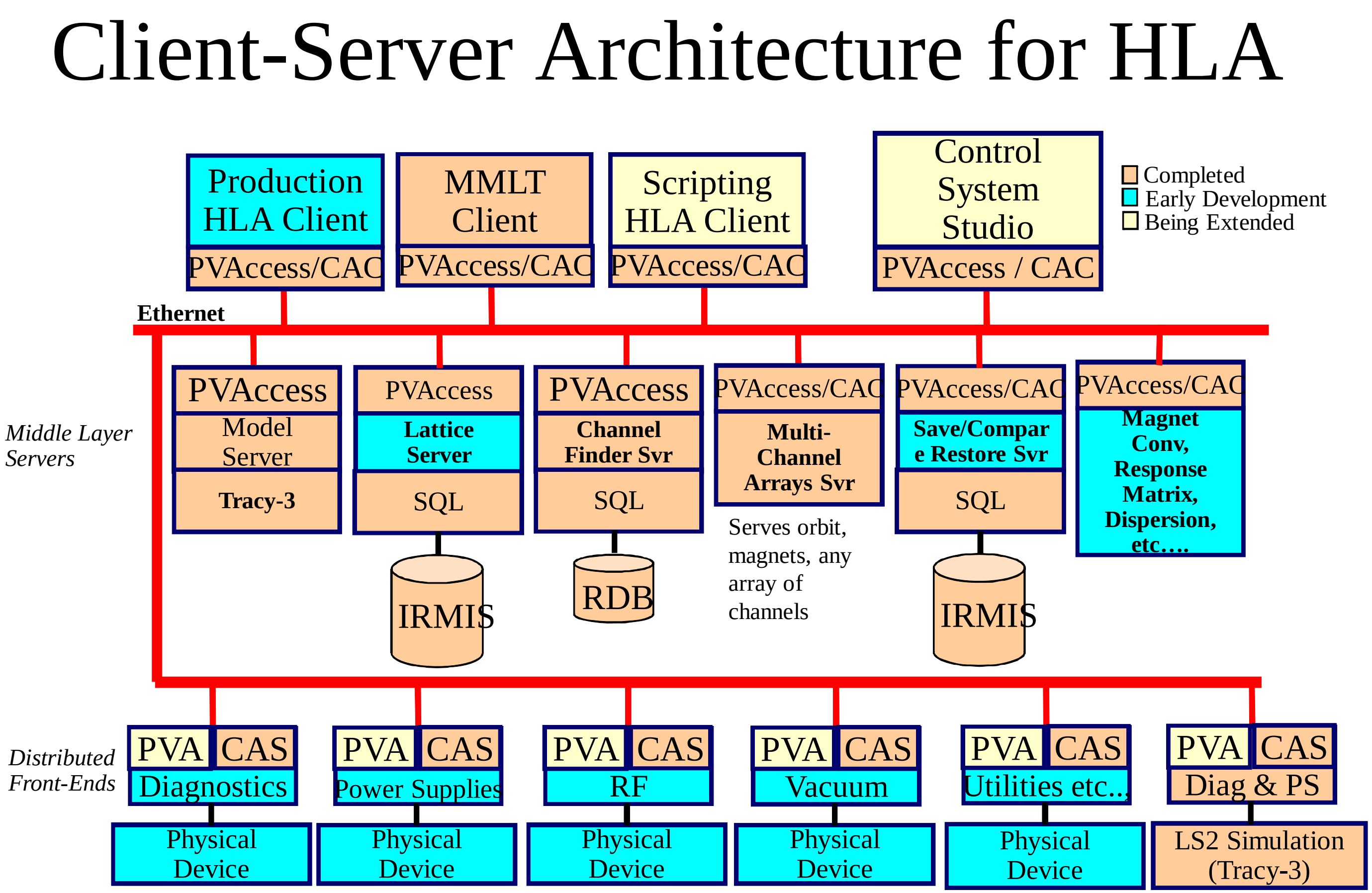


$\nu_x + 2\nu_y = 52$ **compensated.**

$3\nu_x = 82$ **compensated.**

In collaboration with R. Bartolini, I. Martin, and J. Rowland.

Model Based Control by Thin Clients



- **In collaboration with B. Dalesio CD2, 2007.**

Improved by G. Shen, L. Yang, and J. Choi:

- **Tracy-4: Tracy-3 interfaced to Python and Lex/ Yacc based lattice parser.**
- **Name srv, Twiss srv, etc.**

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Conclusions

1. We have shown how a first principles, rather than the traditional TME (reductionist) approach, provides a systematic strategy for the design of an IBS limited synchrotron light source. In particular, the insights gained from a proper understanding the scaling laws; governed by physics.
2. And summarized on how this approach was used for the NSLS-II CDR (2006). In particular, how come a DBA-30 with damping wigglers, outperformed the originally proposed TBA-24 (2×SLS).
3. Similarly, MAX-IV has avoided the “TME trap” (i.e., the “chromaticity wall”) as well, by implementing a (realistic) 7BA (with relaxed optics); by clever engineering.
4. Which recently inspired PEP-X to re-baseline.
5. We have also shown how the control theory problem for a (nonlinear) system ODEs, can be pursued all the way to the control room. By controlling the Lie generators (i.e., the equations of motion) directly. Facilitated by a scalable (aka client/server) software architecture for model-based control.
6. Bottom line, a “round beam” synchrotron light source is now within the horizon.