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Tune Spreads and Tune Splitting due to Random Field Errors in RHIC

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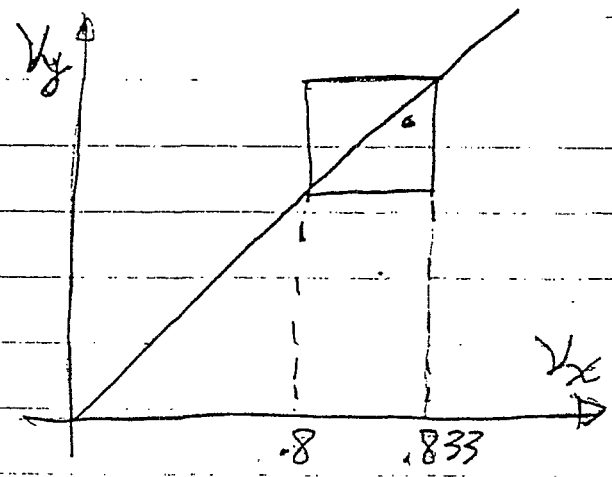
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George Parzen

November 5, 1987

Desired V-spread

Goal is to stay within box shown - and not cross resonances below 10th order



ΔV (beam-beam) $\approx 6 \times .004 = .024$

What is ΔV due to random b_k, a_k ?

Low Amplitude Non-resonance Result

For small enough ϵ_x, ϵ_y , $\delta = \Delta p/p$ and not near a resonance

$\Delta V = \Delta V(\delta, \epsilon_x, \epsilon_y)$

Example, ΔV due to Sextupoles

$$\Delta V_x = C_x \delta + a E_x + b E_y$$

$$\Delta V_y = C_y \delta + c E_x + d E_y$$

To find ΔV -spread, compute $\Delta V_x, \Delta V_y$ along the line $E_x + E_y = E_t$, $E_t = 6.5$ for RHIC at $\delta = 30$ for several values of δ .

See Fig 1 for Sextupole Result

For sextupoles, $\Delta V \approx 5 \times 10^{-3}$ for $\beta^* = 3$ lattice.

Sextupole ν -s spread

$\beta^* = 3$ lattice

$E_x + E_y \leq 6.5$, $C_x = C_y = 0$

$\Delta \nu \leq 5 \times 10^{-3}$

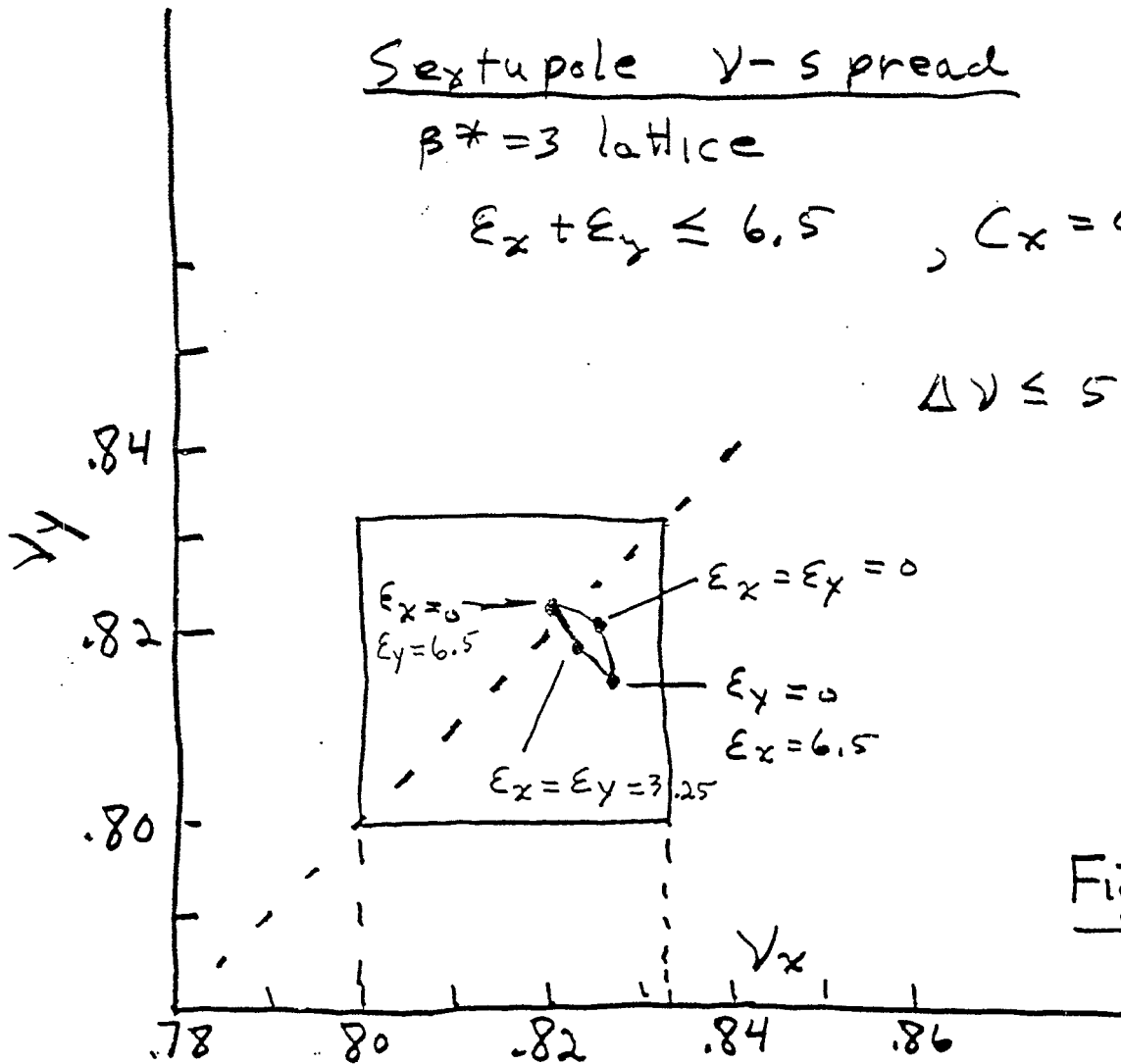


Fig 1

ν -spread near Coupling Resonances

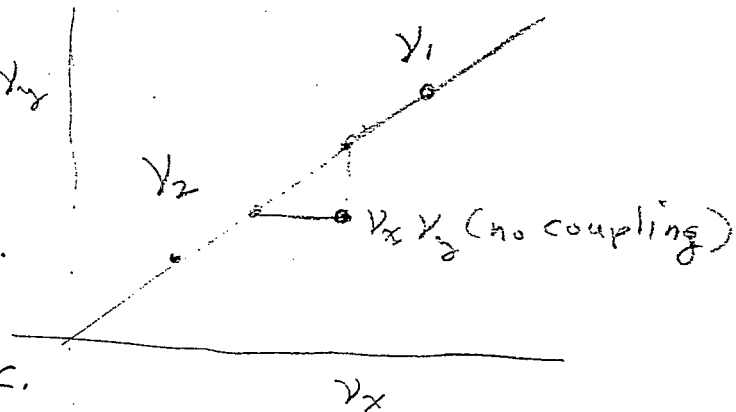
Tracking results ^{point to} something going on not indicated by low amplitude non-resonance result.

Linear Coupling Resonance (Review)

Both x and y motion contain two ν -values

$$x \cong A_1 e^{i\nu_1\theta} + A_2 e^{i\nu_2\theta} + c.c.$$

$$y = B_1 e^{i\nu_1\theta} + B_2 e^{i\nu_2\theta} + c.c.$$



Both x and y have the same ν -values ν_1 and ν_2

Splitting $\nu_1 - \nu_2 \cong 2 |\Delta\nu_{11}|$
 $\Delta\nu_{11}$ is coupling stop-band

For RHIC, without Magnet Shuffling, $\Delta\nu_{11, \max} \cong .03$
 and $\nu_1 - \nu_2 \lesssim .06$

Linear coupling gives a ν -splitting, but not a ν -spread.

Non-Linear Coupling Resonance ν -shifts

ν -splitting depends on ϵ_x, ϵ_y

Fig 2 shows Tracking Result for ν_y versus χ_0 , initial x -betatron oscillation, when $\nu_0 = 0$ or $f = .005$.

ν_y splitting increases with χ_0
At largest χ_0 , $\chi_0 = 18 \text{ mm}$, $\epsilon_x = 6.5$,
 ν -splitting is $\Delta\nu = .034$

This ν -splitting is a ν -spread; all intermediate ν -values reached at lower values of χ_0 .

V-spread due to Non-linear Coupling

$\delta = \Delta p/p = 0.005$

Seed 2

$E_y = 0$ ($\psi_0 = 0$)

$\Delta V_{max} = 1.034$

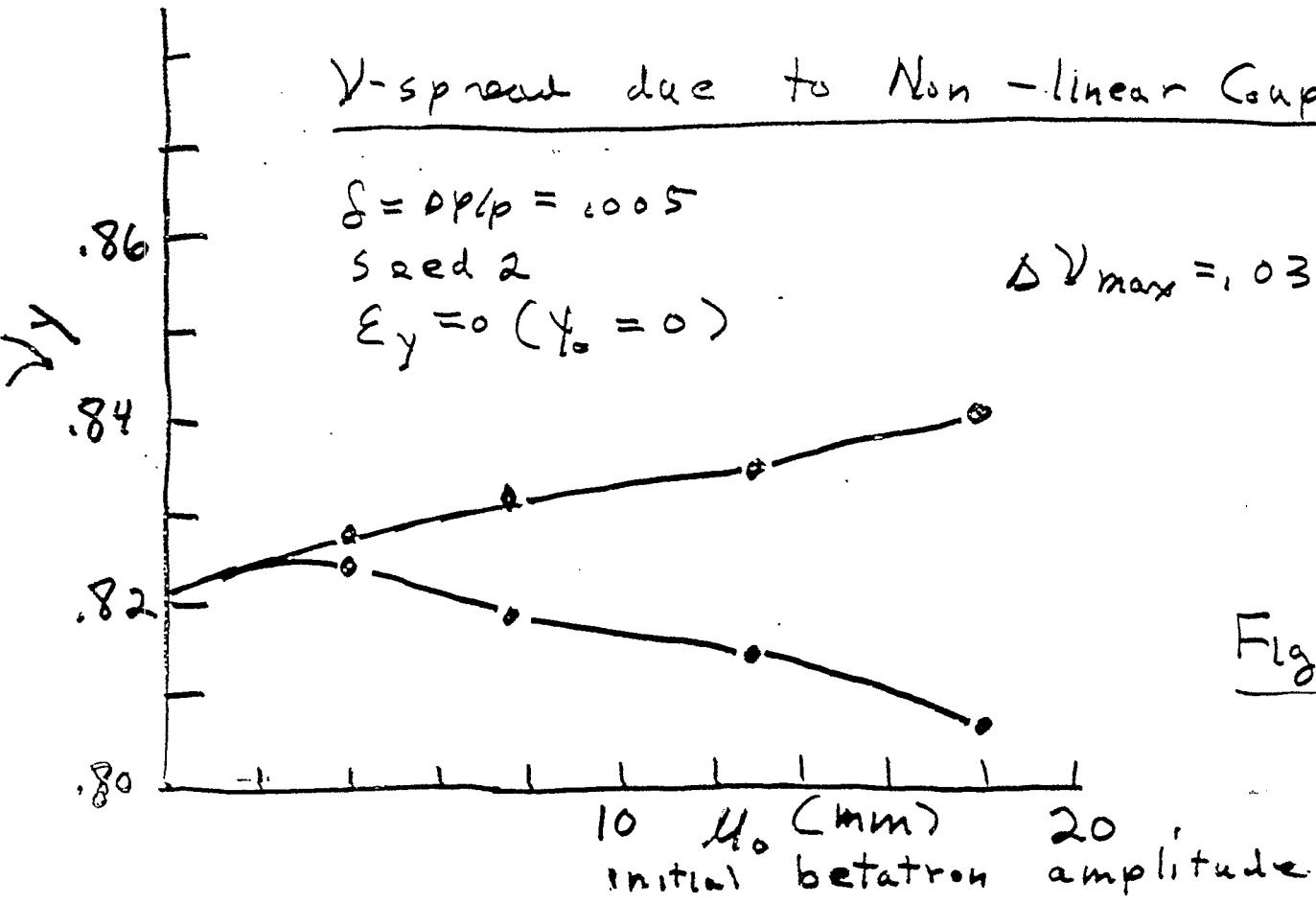


Fig 2

V-Spread Study for 10 Sets of Random Field Errors

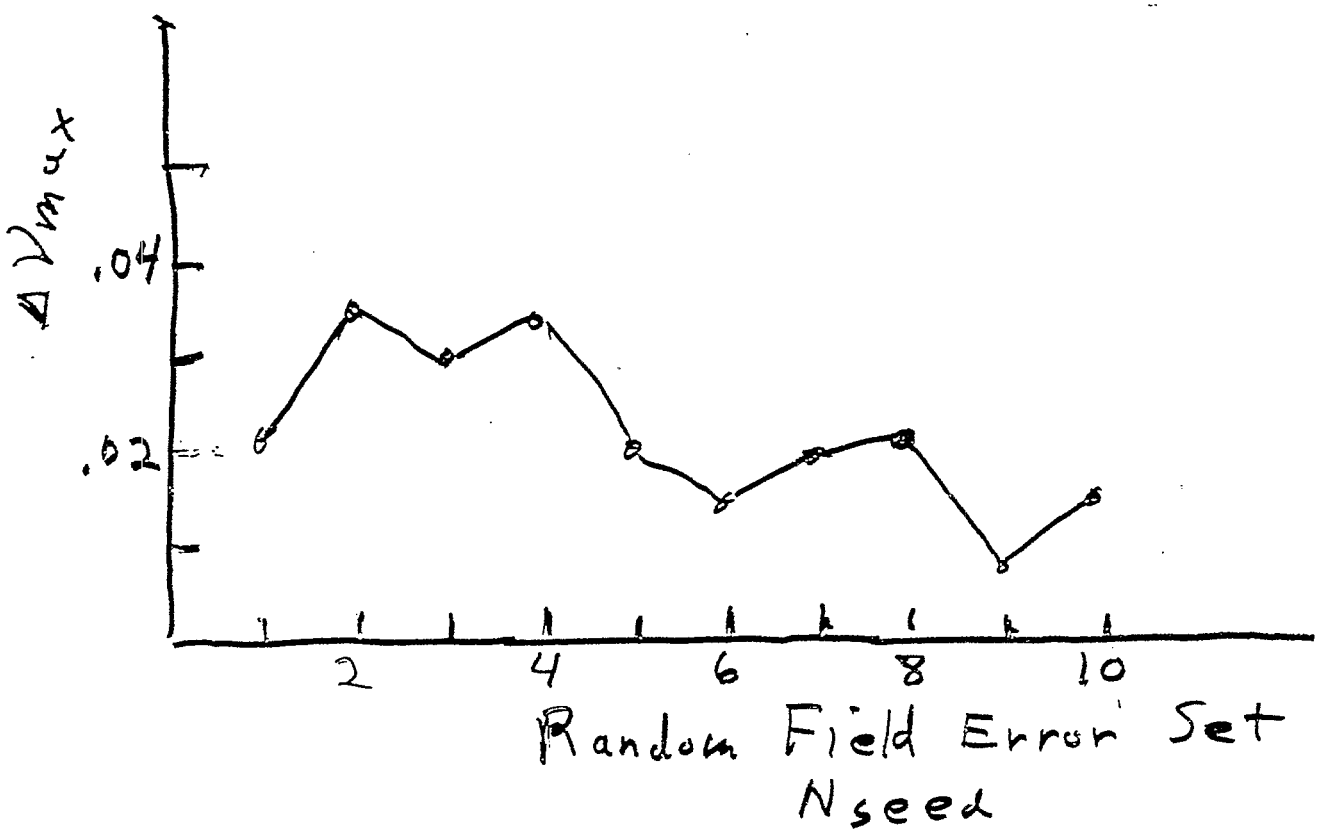
(7)

$$\epsilon_x + \epsilon_y = 6.5$$

Seed		$\epsilon_x = \epsilon_y = 3.25$	$\epsilon_x = 0, \epsilon_y = 6.5$	$\epsilon_y = 0, \epsilon_x = 6.5$	ΔV_{max}
Seed 3	$\delta = .005$ V_x	.828, .817, .823, .832	.827, .818, .823, .831	.830	.029
	V_y	.822, .818, .828, .833	.822, .819, .828, .831	.830, .817	
	$\delta = -.005$ V_x	.818	.823, .833	.839	
	V_y	.818	.822, .833	.810, .839	
Seed 1	$\delta = .005$ V_x	.818	.827, .821, .815	.834	.020
	V_y	.819	.821, .815, .827	.834, .814	
	$\delta = -.005$ V_x	.821, .825	.828, .820	.818	
	V_y	.823, .818, .820	.820	.824, .819	
Seed 2	$\delta = .005$ V_x	.830	.828, .825	.841	.034
	V_y	.820	.825, .822, .829	.841, .807	
	$\delta = -.005$ V_x	.827	.820, .830	.831	
	V_y	.821	.820	.831, .816	
Seed 4	$\delta = .005$ V_x			.834	.033
	V_y			.816, .834	
	$\delta = -.005$ V_x			.842	
	V_y			.809, .842	
Seed 5	$\delta = .005$ V_x			.833, .837	.019
	V_y			.817, .833	
	$\delta = -.005$ V_x			.834	
	V_y			.834, .815	
Seed 6	$\delta = .005$ V_x			.829	.024
	V_y			.829, .819	
	$\delta = -.005$ V_x			.835	
	V_y			.811, .835	

	$E_x = E_y = 3.25$	$E_x = 0, E_y = 6.5$	$E_y = 0, E_x = 6.5$	ΔY_{max}
Seed 7				
$\delta = .005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.831 .817, .831	
$\delta = -.005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.835 .816, .835	.019
Seed 8				
$\delta = .005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.826 .826, .822	
$\delta = -.005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.837 .814, .836	.022
Seed 9				
$\delta = .005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.828 .821, .825, .828	
$\delta = -.005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.826 .826, .820, .831	.011
Seed 10				
$\delta = .005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.829 .819, .830	
$\delta = -.005$ $\begin{matrix} Y_x \\ Y_y \end{matrix}$			.832 .817, .832	.015

V-splitting Versus N_{seed}
 $\epsilon_y = 0$, $M_0 = 18$ mm



Scenario for ΔV -spread

at the start

$$\Delta V_{\text{beam-beam}} \sim .024$$

$$\Delta V_{\text{(betatron osc)}} \sim \text{small}$$

after many hours

Beam grows due to intrabeam scattering

$$\Delta V_{\text{beam-beam}} \sim .008$$

$$\Delta V_{\text{(betatron osc)}} \sim .02$$

Also, these ΔV are to some extent not additive

$\Delta V_{\text{beam-beam}} \rightarrow$ Large at small betatron osc.
Small at large betatron osc

$\Delta V_{\text{(betatron osc,)}} \rightarrow$ Small at small betatron osc.
Large at large betatron osc.

Multipole Breakdown - Tune Splitting

(11)

Initial $\epsilon_y = 0$, $\epsilon_x = 6.5$, $\mu = 18\text{mm}$

K_{max}		Seed 3	Seed 8
no	v_x	.829	.829
b_k, a_k	v_y	.819	.819
2	v_x	.827	.842
	v_y	.818, .827	.807, .841
3	v_x	.825	.846
	v_y	.817, .825	.846, .801
4	v_x	.839	.841
	v_y	.801, .839	.841, .806
5	v_x	.838	.840
	v_y	.803, .838	.840, .807
6	v_x	.837	.839
	v_y	.837, .804	.839, .807
7	v_x	.836	.839
	v_y	.836, .804	.839, .807
8	v_x	.836	.840
	v_y	.836, .805	.840, .807
9	v_x	.837	.840
	v_y	.837, .805	.840, .806
10	v_x	.836	.840
	v_y	.836, .806	.840, .807
Δv_{max}		.030	.033
S		-.005	-.005

Which multipoles b_k, a_k are responsible for the v -splitting? In above, k_{max} is the highest multipole present.

Answer not clear.