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## Effects of Random Quadrupole Field Errors and Their Correction

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Effects of Random Quadrupole Field Errors  
and Their Correction

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September 8, 1987

(1)

## Effects of Random Quadrupole Errors

Small magnet aperture generates large random  $a_1, b_1$ , which cause the following effects:

Random  $b_1$  causes random  $\Delta \beta_x/\beta_x, \Delta \beta_y/\beta_y$  and random  $\Delta X_p$ , horizontal dispersion.

Random  $a_1$  causes coupling and random  $\Delta Y_p$ .

These effects can cause loss of aperture, and can worsen the beam-beam interaction.

They may also reduce the dynamic aperture, since the particles reach further out in the magnets.

## Linear Effects of Random $q_1, b_1$

(2)

$$q_1 = 16.8 \times 10^{-5} / \text{cm}, b_1 = 8.4 \times 10^{-5} / \text{cm} \quad (\text{rms})$$

projected by J. Herrera

Linear effects can be found  
from analytical results or by tracking.  
The agreement is good.

$$\left( \frac{\Delta \beta}{\beta} \right)_{\max} \approx 15\%$$

$$\Delta X_p (\Omega_F)_{\max} = 34 \text{ m}, 20\% \text{ of } X_p$$

$$\Delta Y_p (\Omega_D)_{\max} = 48 \text{ m} \quad 30\% \text{ of } X_p$$

~~At~~ At Crossing Point

$$\Delta X_p, \max = 1 \text{ m}, 20\% \text{ change in beam size}$$

$$\Delta Y_p, \max = 12 \text{ m}, 34\% \text{ "}$$

$\frac{1}{2}$  integer Stop band,  $\Delta v = 0.23$  half-width

Coupling Stop band  $\Delta v_{\max} = 0.33$  half-width

The two stop-bands also give a measure  
of the size of the  $v$ -shifts.

## Previous History

At one time, magnet shuffling was not considered feasible, and tracking studies were not yet being done for RHIC.

Because of the large linear effects, and fears of possible losses in aperture, a correction system for the random  $a_1, b_1$  was (~~proposed~~) proposed ~~#~~ having 36 independent  $b_1$  and  $q_1$  ~~power supplies~~

At some later time, shuffling the magnets to reduce the linear effects of the random  $q_1, b_1$  was being taken more seriously.

Also tracking studies seemed to indicate ~~#~~ little loss in aperture.

The suggestion was made that we commit ourselves to magnet shuffling and drop the proposed  $q_1, b_1$  correction system.

However, later tracking studies, that included the higher systematic field errors like  $b_{10}, b_{12}, b_{14}, b_{16}, b_{18} \dots$  in the dipoles, indicated a large loss in aperture,  
 $A_{SL} = 17 \text{ mm} \rightarrow A_{SL} = 14 \text{ mm}$ .

Also, the tracking studies were not quite correct, as the linear coupling was not corrected.

The tracking studies have now been repeated including correction of the linear coupling, and a more recent estimate of the systematic multipoles.

## Results of Tracking Studies

### The Higher Systematic $b_K$ , ~~bk~~

The lower  $b_K$  are made close to zero. The higher  $b_K$ , e.g.  $b_{10}, b_{12}, b_{14}, b_{16}$ , can be much larger than the corresponding random  $b_K$ . The linear effects due to the random  $a_i$ , cause the particles to reach further out from the center of the magnet, where the presence of the higher systematic  $b_K$  may cause a loss in dynamic aperture.

### Requirements for the Tracking study

- ① The linear coupling introduced by the random  $a_i$ , has to be removed by exciting a skew quadrupole correction system. This also removes the splitting in the  $\lambda$ -values associated with linear coupling.

(2) The shift in the  $\gamma$ -values caused by the random  $b_i$ , has to be removed by exciting the quadrupoles of the  $\gamma$ -value correction system

(3) The field multipoles have to include not only the random field errors but also the expected systematic field multipoles, particularly the higher systematic  $b_{ik}$  like  $b_{10}, b_{12}, b_{14}$ , etc in the dipoles.

The expected systematic multipoles in the dipoles were provided by P. Thompson (RHIC-MD-56)

# Stability Limits

versus  $\Delta P/P$

with -

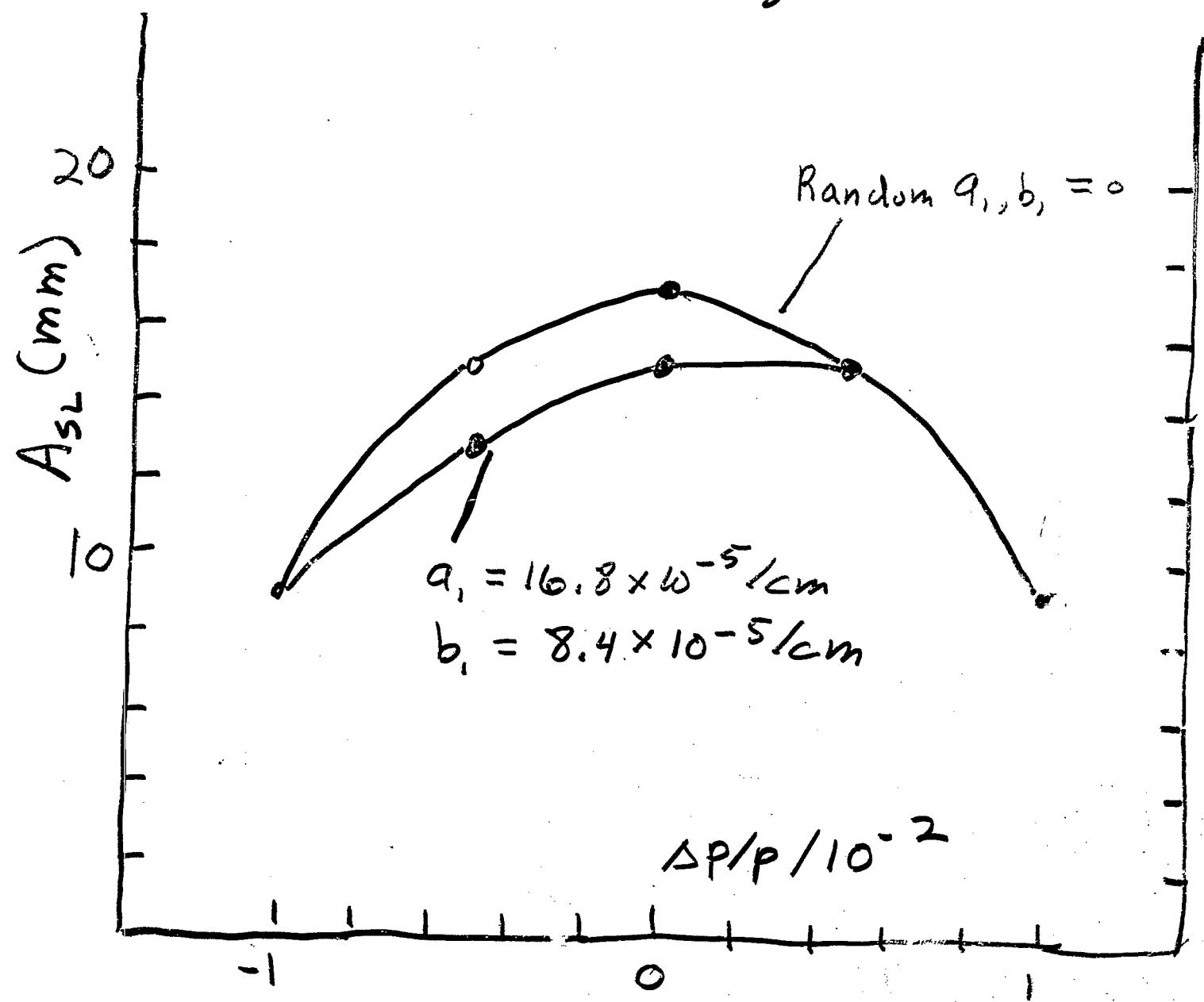
Random Errors  $a_k, b_k \quad k \leq 10$

And

Systematic Errors  $b_k \quad k \leq 18$

And

Random  $a_i, b_i$



## Effect of Shuffling the Magnets

The linear effects of the random  $a, b$ , may be reduced by about a factor of 4 (S. Ohnuma, Tech. Note, RHIC-15)

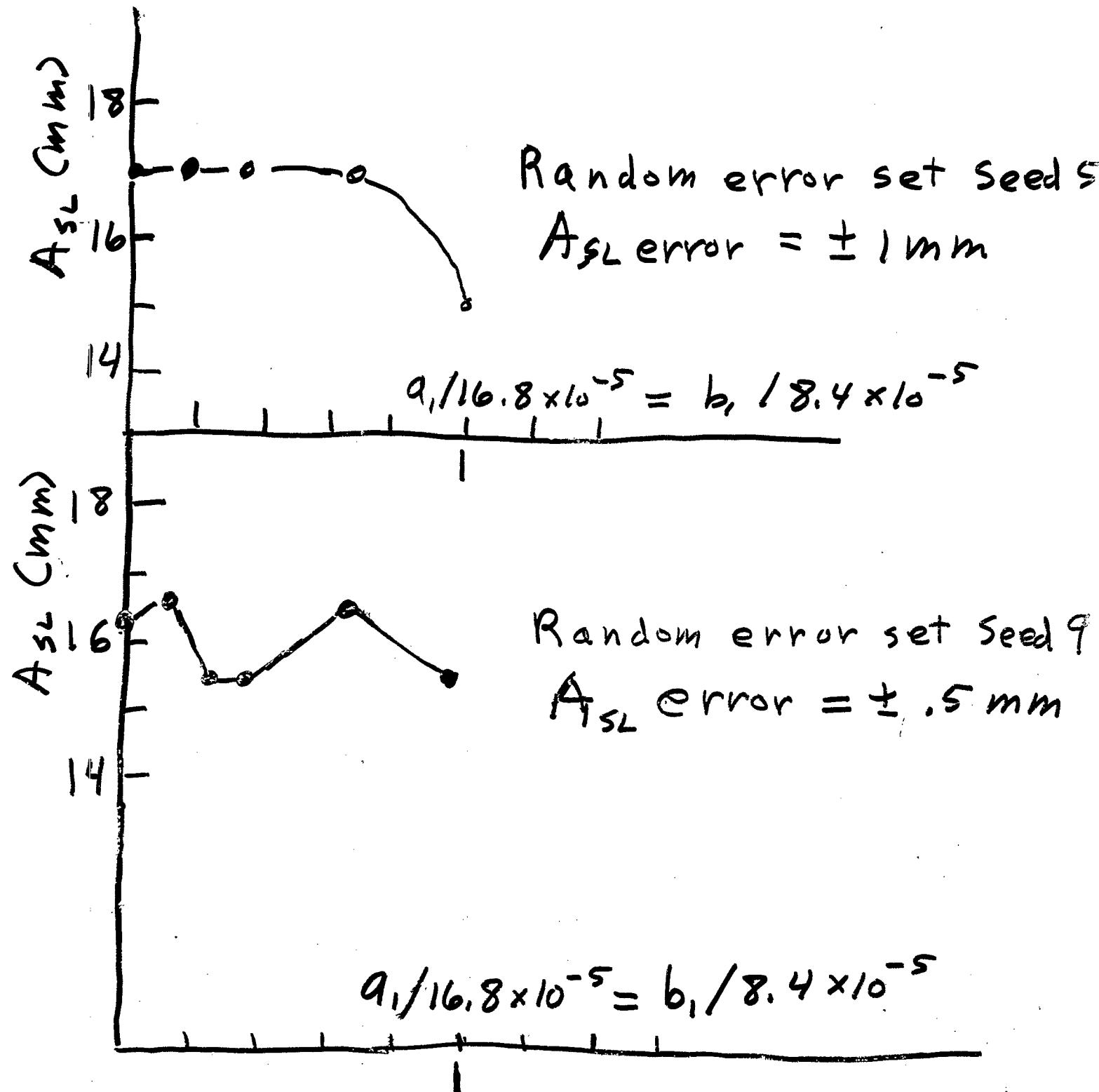
... The effect of Shuffling on the dynamic aperture may be studied, in a rough way, by simply reducing the size of the random  $a, b$ .

~~These results, shown on the next slide,~~

# Stability Limits

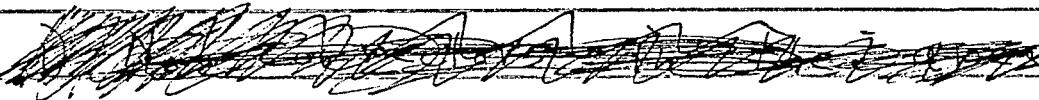
Versus

The size of Random  $a_1, b_1$   
 $\Delta p/p = 0$



Random

## Proposed $a_1, b_1$ Correction System



- ① Shuffling of the magnets to reduce the linear effects by about a factor of 4
- ② 2 families of Skew quadrupoles to control the linear coupling. These are located near Q2, Q3
- ③ Correctors for controlling the beam-beam interaction at the crossing point.

The insertion quadrupole trims can correct  $\Delta B_x/B_x$ ,  $\Delta B_y/B_y$  and  $X_p$  at the crossing point.

Provision for  $a_1$  correctors at  $X_p \neq 0$  locations for controlling the vertical dispersion at the crossing points. These may not be available on the first day.