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Effects of Random Quadrupole Field Errors and Their Correction

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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 ΔX_p, horizontal dispersion.

Random a_1 causes coupling and random ΔY_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 a_1, b_1

$a_1 = 16.8 \times 10^{-5}/cm$, $b_1 = 8.4 \times 10^{-5}/cm$ (rms)
projected by J. Herrera

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

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

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

$\Delta Y_p (Q_D)_{max} = .48\ m$ 30% of X_p

At Crossing Point

$\Delta X_{p,max} = .1\ m$, 20% change in beamsize
$\Delta Y_{p,max} = .12\ m$, 34% " "

½ Integer Stop band, $\Delta \nu_{max} = .023$ half-width

Coupling Stop band $\Delta \nu_{max} = .033$ half-width

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

Previous History

At one time, magnet shuffling was not considered feasibile, 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 ~~prosed~~ proposed having 36 independent b_1 and a_1 power supplies

At some later time, shuffling the magnets to reduce the linear effects of the random a_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 $a_1 b_1$ correction system.

However, later tracking studies that included the higher systematic field errors like b_{10}, b_{12}, b_{14}, b_{16}, b_{18}... in the dipoles, indicated a large loss in aperture,
$A_{SL} = 17 mm \rightarrow A_{SL} = 11 mm$.

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 bk, [illegible]

The lower bk are made close to zero. The higher bk, e.g. b_{10}, b_{12}, b_{14}, b_{16}, can be much larger than the corresponding random bk. The linear effects due to the random a_1 b_1 cause the particles to reach further out from the center of the magnet, where the presence of the higher systematic bk may cause a loss in dynamic aperture.

Requirements for the Tracking Study

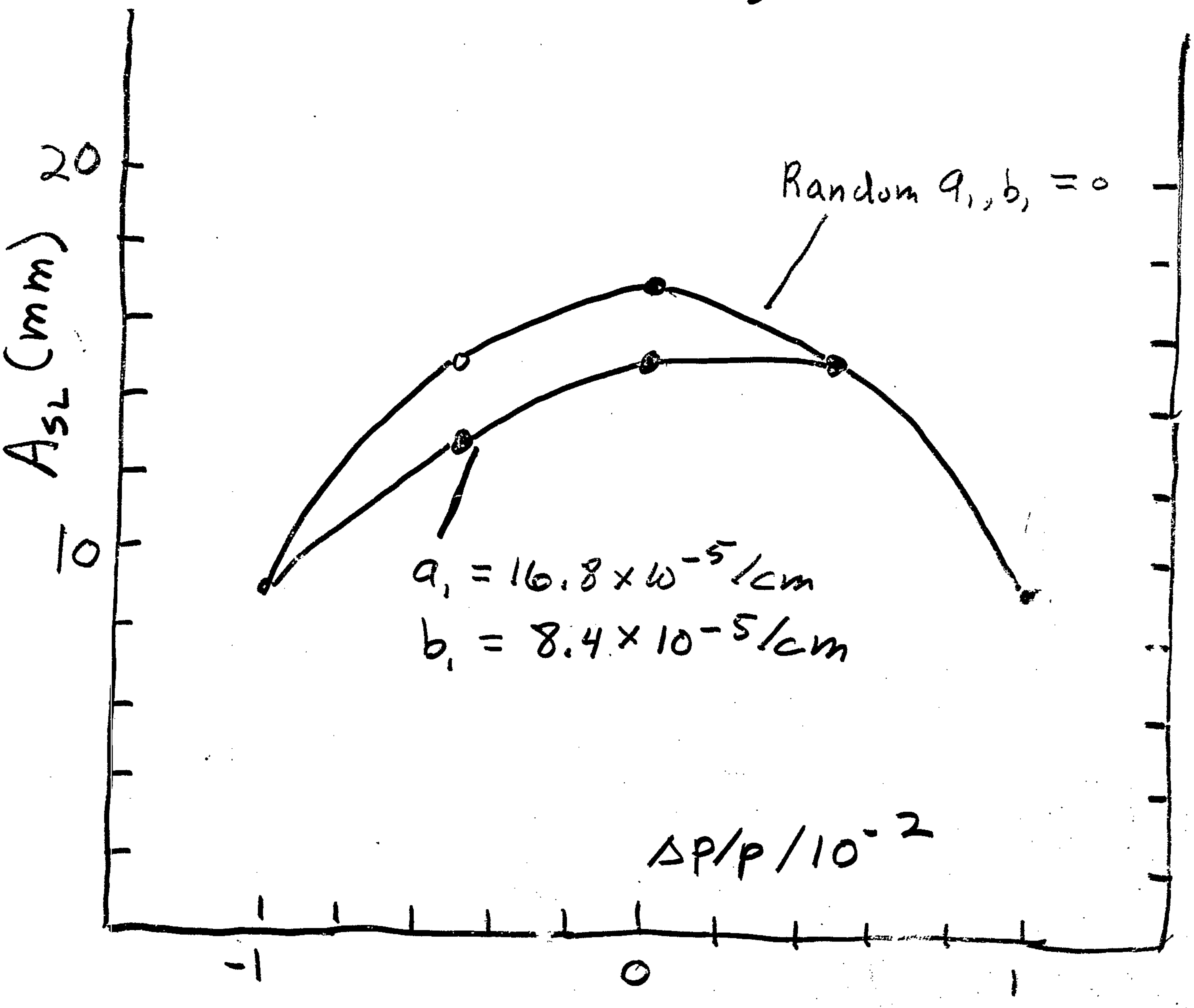
(1) The linear Coupling introduced by the random a_1 has to be removed by exciting a skew quadrupole correction system. This also removes the splitting in the ν-values associated with linear Coupling.

(2) The shift in the ν-values caused by the random b_1 has to be removed by exciting the quadrupoles of the ν-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_k 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 $K \leq 10$
And
Systematic Errors b_K $K \leq 18$
And
Random a_1, b_1



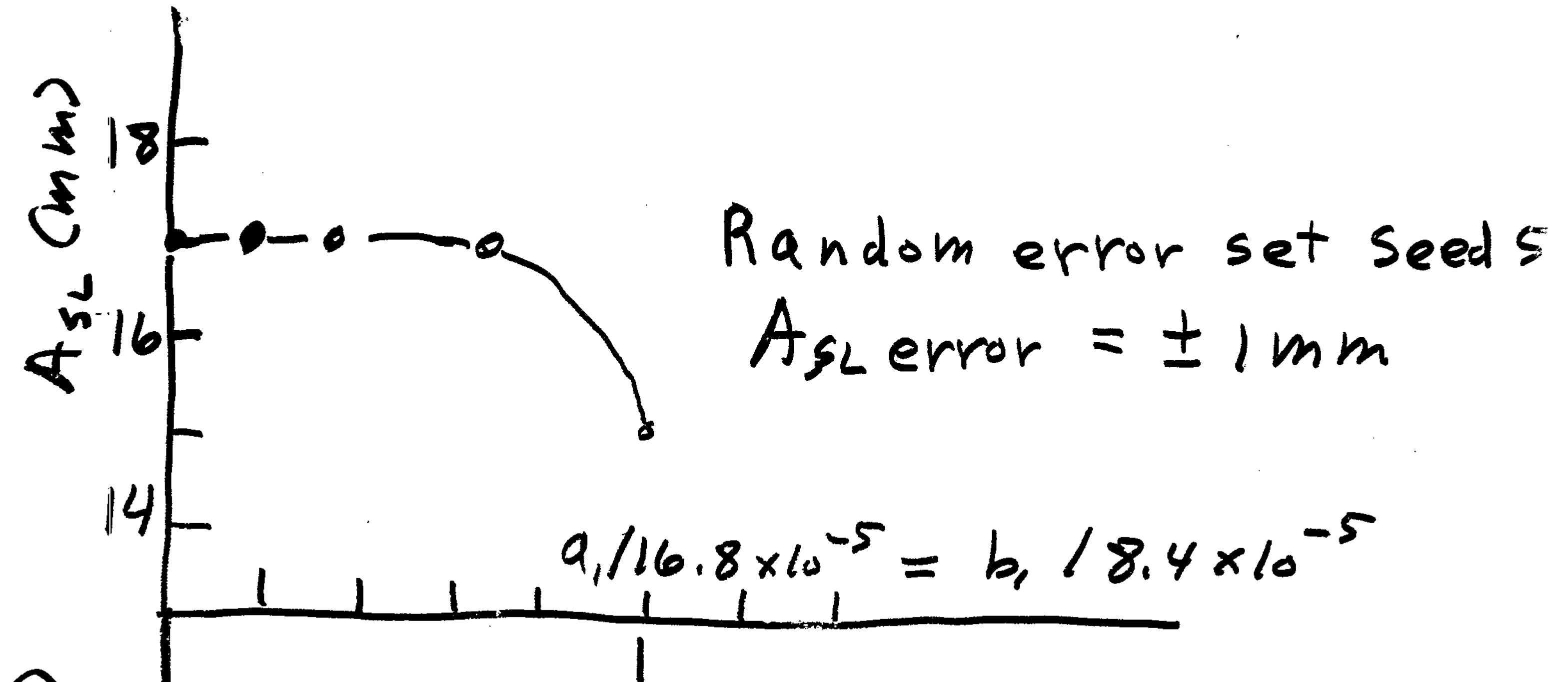
Effect of Shuffling the Magnets

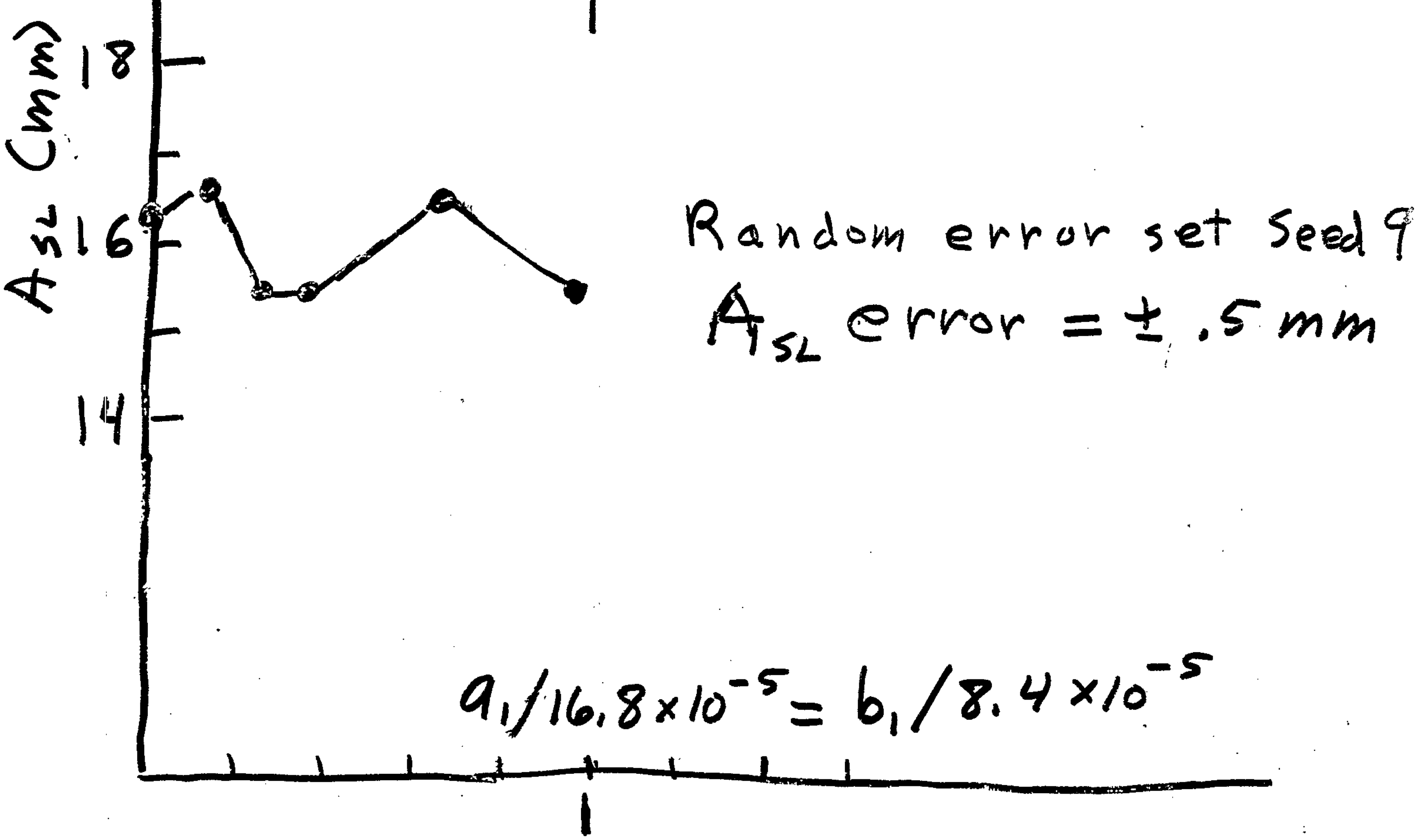
The linear effects of the random $a_1 b_1$ may be reduced by about a factor of 4 (S. Ohnuma, Tech. Note, RHIC-15)

The effect of Shuffling on the dynamic aperture may be studied, in a rough way, by simply reducing the size of the random a_1, b_1.

~~(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 $\Delta\beta_x/\beta_x$, $\Delta\beta_y/\beta_y$ 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.