

Higher Order Magnet Field Multipoles Aperture Effects, and Tracking Studies

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January 1986

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USDOE Office of Science (SC)

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RHIC-AP-25

HIGHER ORDER MAGNET FIELD MULTIPOLES
APERTURE EFFECTS, AND TRACKING STUDIES

G. Parzen

January 15, 1986

Review of Tracking Theory (my view)

The instabilities are non-resonant;
not associated with the ν -values going
to some resonance line, $m\nu_y + n\nu_x = q$

The instabilities are not stochastic -
they happen quite fast.

No particular resonance dominates. Classical
non-linear theory does not apply. Effect
is complicated, and probably cannot be
described by simple analytical results.

Review of RHIC Results

Random b_k , $b_k \approx (k+1) b_0 / R^k$

$R = 40 \text{ mm}$, $b_0 \approx 1 \times 10^{-4}$

$A_{sL} \approx 19 \text{ mm}$, random b_k only

$\nu_x \approx \nu_y \approx 28.824$

A_{SL} Multipole Breakdown

Single multipoles

Random bk only

$$\gamma_x = 28.827$$

$$\gamma_y = 28.822$$

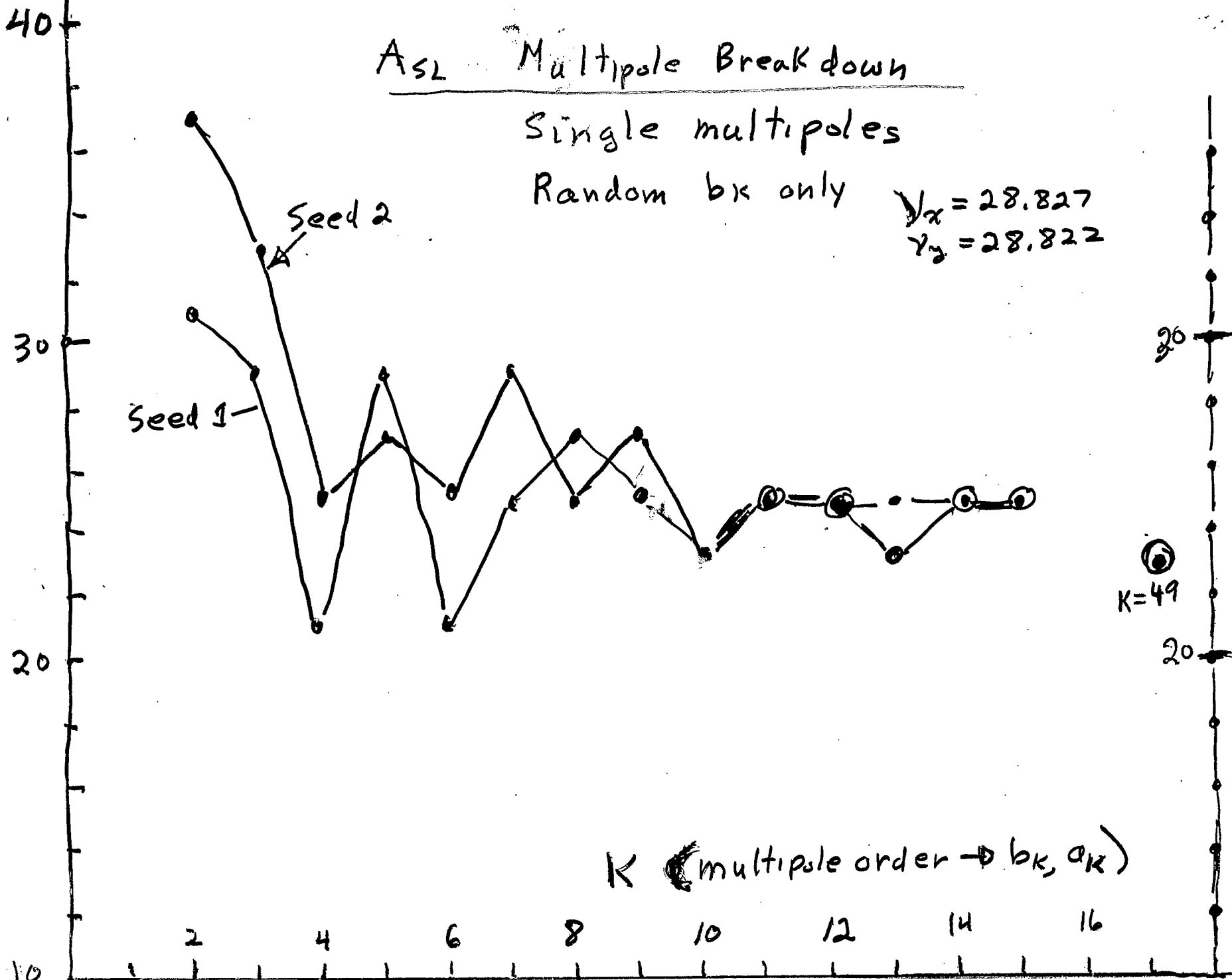
A_{SL} (mm)

Seed 1

Seed 2

$K=49$

K (multipole order $\rightarrow b_K, a_K$)



(2a)

Tracking Studies seem to indicate that $A_{SL} \rightarrow \text{constant} \approx 24 \text{ mm}$ when K gets large

Is this possible?

Is it due to point multipoles being used instead of distributed multipoles?

Point Multipoles versus Distributed Multipoles

Classical N.L. Theory $\rightarrow A_{SL} \xrightarrow{k \rightarrow \infty} \text{constant} \approx R$
for point b_k

$A_{SL} \xrightarrow{k \rightarrow \infty} 0$
for distributed b_k

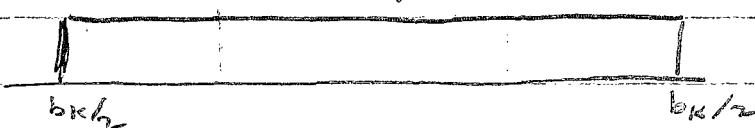
Classical theory Result

$$V - V_{res} \approx \underbrace{\int ds e^{i\theta} \beta \left(\frac{\beta}{\beta_0} \right)^{(k-1)/2} b_k}_{\text{factor}} \cdot A_{SL}^{k-1}$$

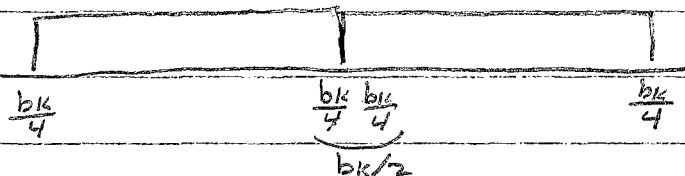
factor $\xrightarrow{k \rightarrow \infty} 0$ for distributed b_k

Distributed Multipoles in Tracking

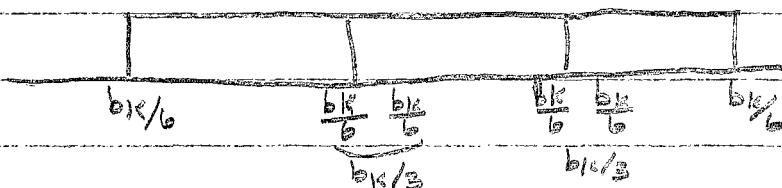
point b_k



2 intervals



3 intervals

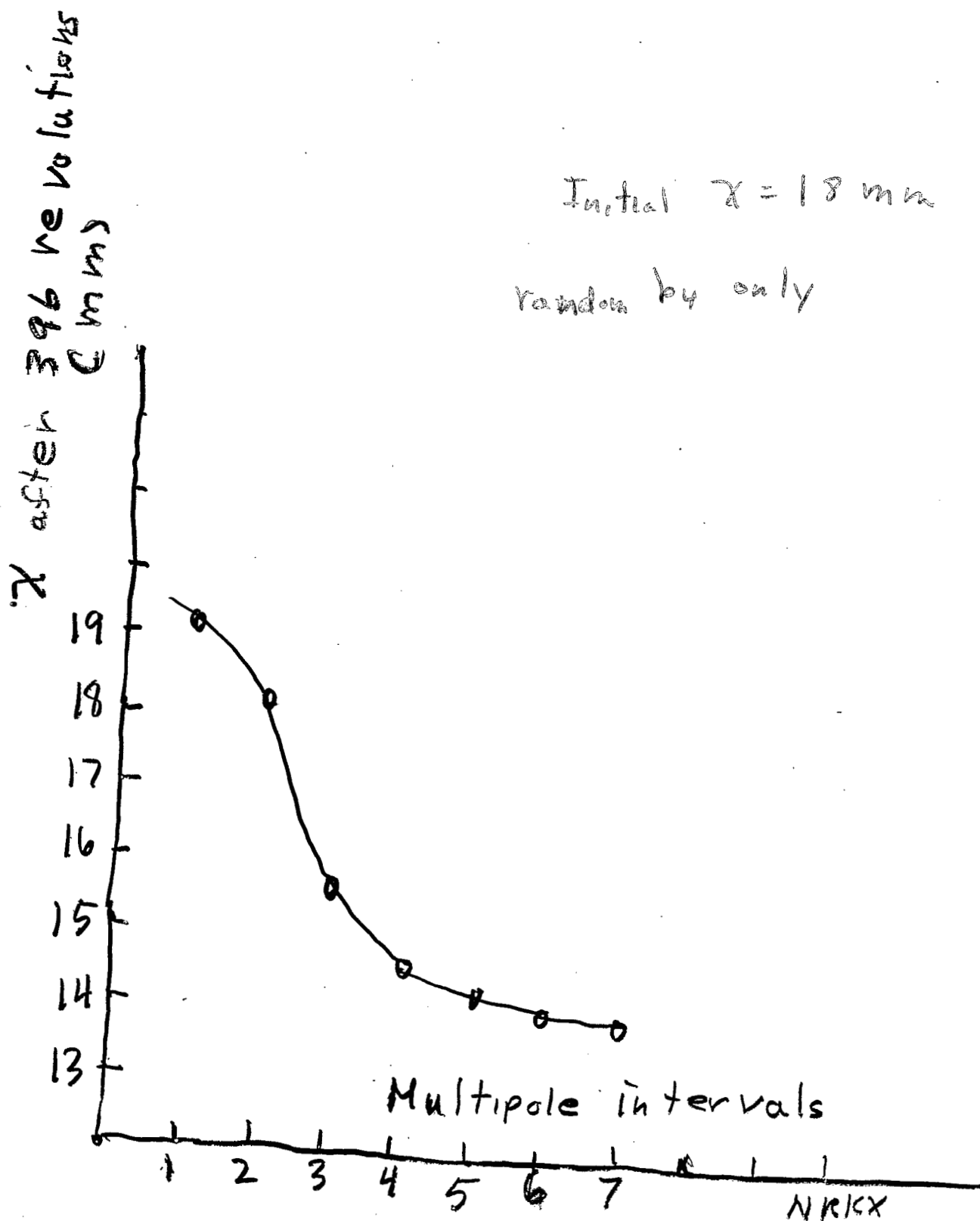


Equivalent to using 2nd order Runge-Kutta.

Convergence as Multipole Intervals are increased

Initial $\chi = 18$ mm

random by only



Distributed Multipole Results

Increasing the number of intervals to describe the multipoles, changes results significantly. However, A_{SL} (the stability limit) is not changed. Occasionally A_{SL} is increased by 2 mm for some runs.

Point multipoles appear to give essentially the correct result for A_{SL} .

⑤

A_{SL} for High order b_k

$$A_{SL} \xrightarrow[k \rightarrow \infty]{} 24 \text{ mm}$$

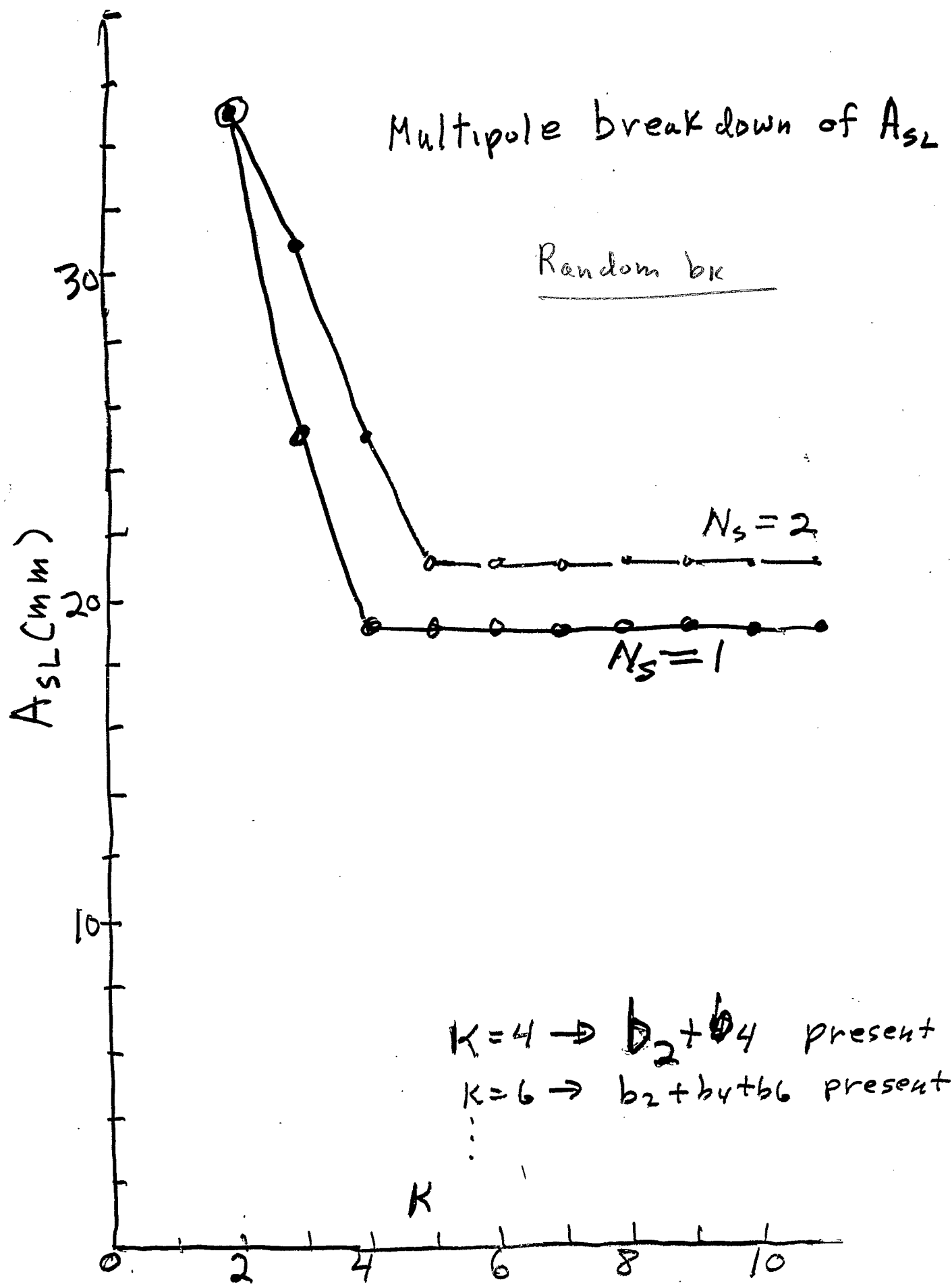
for b_k random case

What are the consequences?

How many b_k needed to determine A_{SL} ?

I don't need up to $k=50$
I just need up to $k \approx 6$

(see next slide)



Higher b_k produce a wall at about 24 mm; For $x \leq 24$ mm, they have little effect. Thus if lower b_k produce $A_{SL} \approx 19$ mm, the higher b_k do not affect A_{SL} .

Higher b_k Limit A_{SL} to $A_{SL} \leq 24$ mm

Even if I correct many of the lower b_k , say for $k \lesssim 10$, I can't do better than $A_{SL} \sim 24$ mm.

Systematic b_k

Possible problem. I expect the higher systematic b_k to be larger than the higher random b_k

$$b_k \approx \frac{b_0}{k^k} x 10^{-4}$$

$$b_0 \approx (k+1) \times 10^{-4} \text{ random } b_k$$

$$b_0 \approx 300 \times 10^{-4} \text{ not unlikely for systematic } b_k$$

$$b_0 \sim 1 \text{ is possible for systematic } b_k$$

Systematic b_K , RHIC Results

<u>b_K, systematic used</u> (from RHIC Proposal)					
<u>Dipole</u> K	b_K	$b_K * R^K / 10^{-4}$	<u>Quads</u>		
			K	b_K	$b_K * R^K / 10^{-4}$
2	17	44			
4	-5.9	-38	5	—	0
6	1.6	17	9	—	.005
8	-.4	-10	13	.2	94
10	.1	7	17	-.12	-361
12	-.1	-10	21	.0075	-145
14	-.1	-72	25	.015	1914
16	-.13	-239			
18	.080	378			
20	.0030	36			

\uparrow $x(K+1)$ for random b_K

Results for $\left\{ \begin{array}{l} \text{Dipoles} \\ K = 14 \rightarrow 20 \\ \text{Quads} \end{array} \right\}$ from H. Hahn Tech Note

Note, $A_{SL} \sim b_K^{1/K}$ or large change in b_K
produce small changes in A_{SL} for large K

FINAL $b_K, \text{systematic}$

measured results

K	$b_K (\text{in}^{-K}/10^{-4})$	$b_K * R^K / 10^{-4}$
$R = 38 \text{ mm}$		
2	.99	2.2
3	-.27	-.91
4	-.76	-3.8
5	-.05	-.38
6	6.69	76.
7	.02	.34
8	-15.69	-404
9	.01	.38
10	5.25	302
12	-1.1	-142
14	.12	35.
16		
17		

Aperture Results (Tracking Results)

A_{SL} including $b_{K, \text{systematic}}$

For $b_{K, \text{sys}} (K=1 \rightarrow 20) + b_{K, \text{ran}} (K=1 \rightarrow 10)$

$$A_{SL} = 15 \text{ mm}$$

For $b_{K, \text{sys}} (K=1 \rightarrow 20)$; no $b_{K, \text{ran}}$

$$A_{SL} = 19 \text{ mm}$$

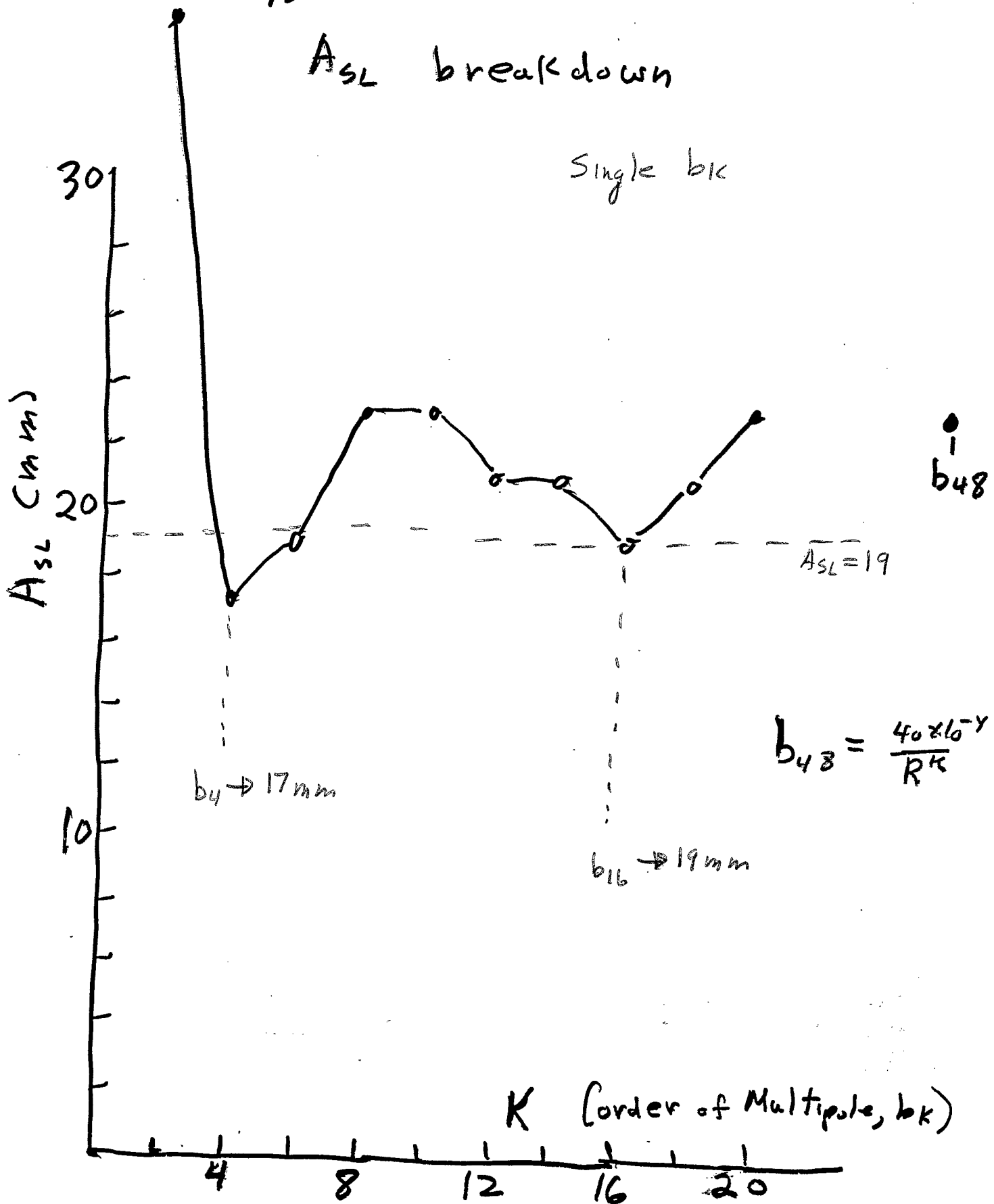
Same as $b_{K, \text{random case}}$

$b_{K, \text{systematic}}$, multiple breakdown
(see next page)

Systematic bk

 A_{SL} breakdown

Single bk



For $b_{k,sys}$ ($k=10 \rightarrow 20$) + $b_{k,ran}$ ($k=1 \rightarrow 10$)

$$A_{SL} = 17 \text{ mm}$$

Even if ~~all~~ ^{all lower} $b_{k,sys}$ for $k=1 \rightarrow 9$
are eliminated, one gets
 $A_{SL} = 17 \text{ mm}$

There is the possibility, and some
indication, that proper choice
of lower $b_{k,sys}$ ($b_k \neq 0$) can increase
 A_{SL}

Non-point $b_{k,sys}$ tests

Distributed $b_{k,sys}$ produce
only small changes in the results.

FNAL Aperture Results

$b_{K,sys}$ all alone $\rightarrow A_{SL} = 21 \text{ mm}$ ($\beta_K = 100$)

addition of $b_{K,tran}$ reduces A_{SL} to
 $A_{SL} = 19 \text{ mm}$ ($\beta_K = 100$; $y \approx 0$ results)

Tracking results of Gelfand and Willeke

Willeke says Tevatron aperture ~~is~~ largely
 due to $b_{K,sys}$. I think both,
 $b_{K,sys}$ and $b_{K,tran}$, are important

Note, Tevatron A_{SL} for $x \approx y$
 maybe $A_{SL} \approx 15 \text{ mm}$.

Conclusions for RHIC Magnets

- 1) $A_{SL} \approx 17$ mm may result from systematic b_K .
- 2) Possibility of choosing lower b_K to improve A_{SL} .
 $b_K = 0$ is not necessarily optimum solution.
- 3) Watch out for very large higher b_K (b_{16} etc. ...)