



BNL-101681-2014-TECH

RHIC/AP/25;BNL-101681-2013-IR

Higher Order Magnet Field Multipoles Aperture Effects, and Tracking Studies

G. Parzen

January 1986

Collider Accelerator Department
Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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

$\nu_x \approx \nu_y \approx 28.824$

AsL Multipole Breakdown

Single multipoles

Random bk only

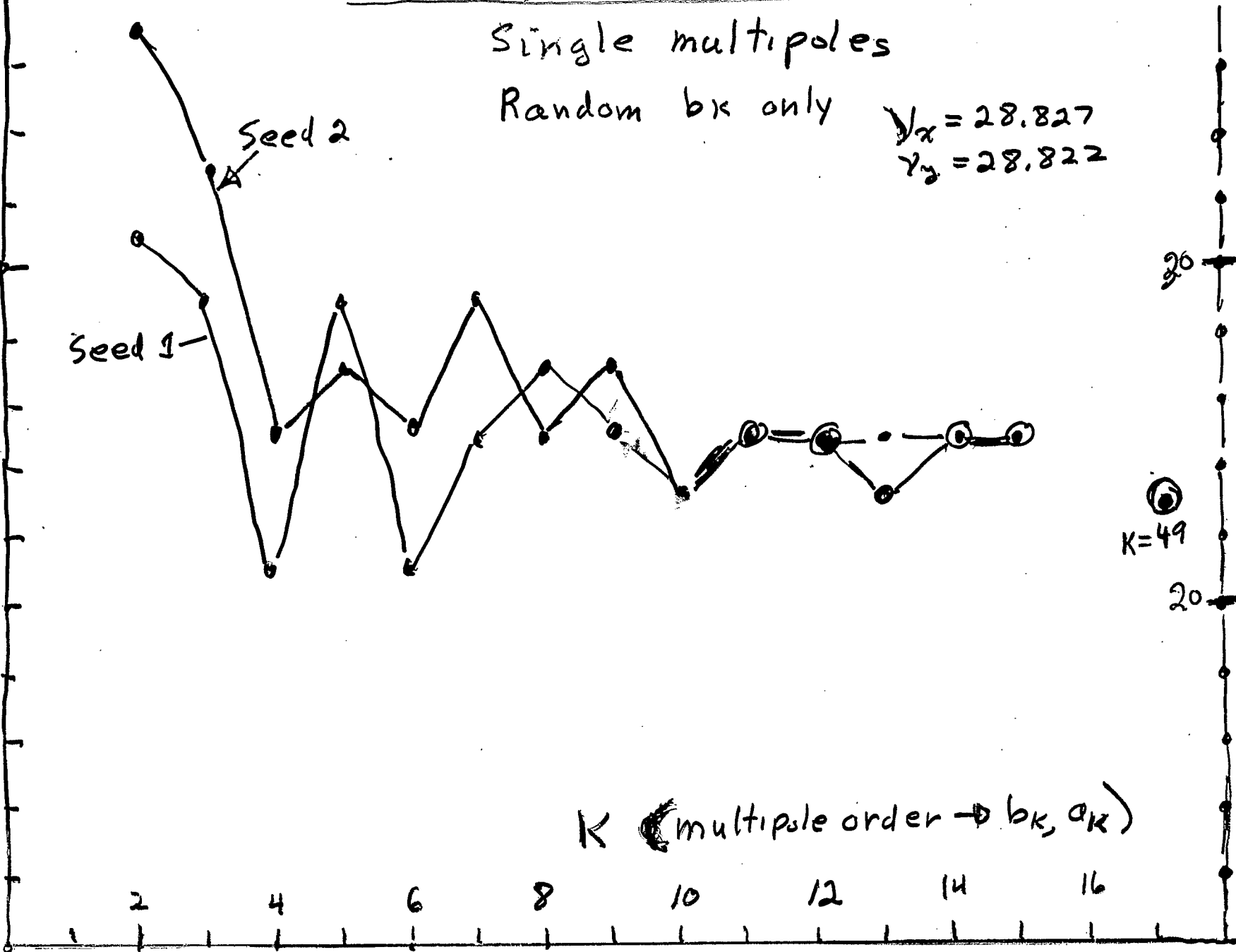
$$\gamma_x = 28.827$$

$$\gamma_y = 28.822$$

AsL (mm)



Seed 2
A
Seed 1



Ⓞ
K=49

K (multipole order $\rightarrow b_k, a_k$)

2

4

6

8

10

12

14

16

(2a)

Tracking studies seem to indicate that $A_{SL} \rightarrow$ constant ≈ 24 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

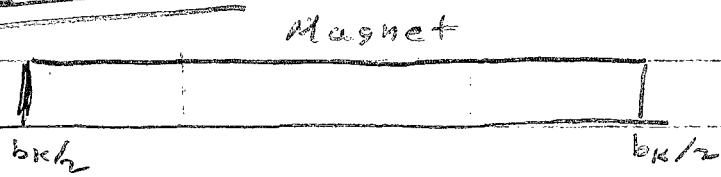
$$V - V_{res} \approx \int ds e^{i\theta} \beta \left(\frac{\beta}{\beta_0} \right)^{(k-1)/2} b_k \cdot A_{SL}^{k-1}$$

factor

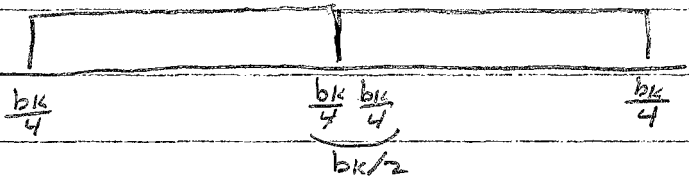
factor $\xrightarrow{k \rightarrow \infty} 0$ for distributed b_k

Distributed Multipoles in Tracking

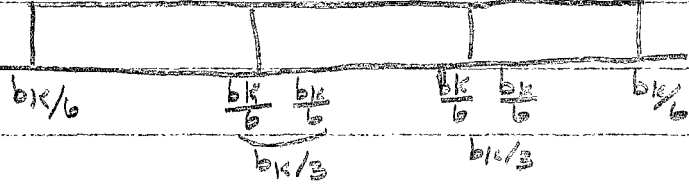
point b_k



2 intervals



3 intervals

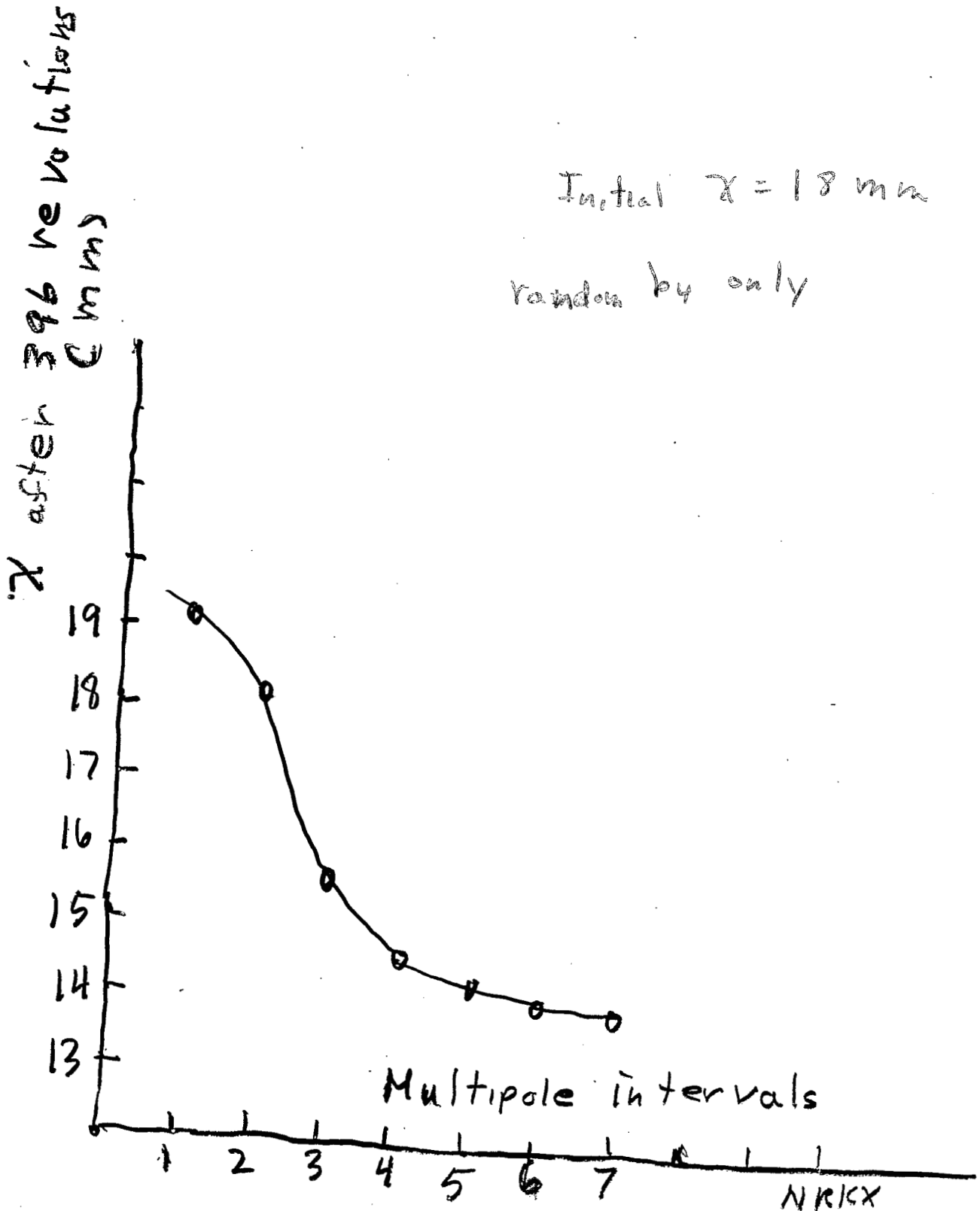


Equivalent to using 2nd order Runge-Kutta.

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 2mm for some runs.

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

A_{SL} for High order b_k

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

for b_k random case

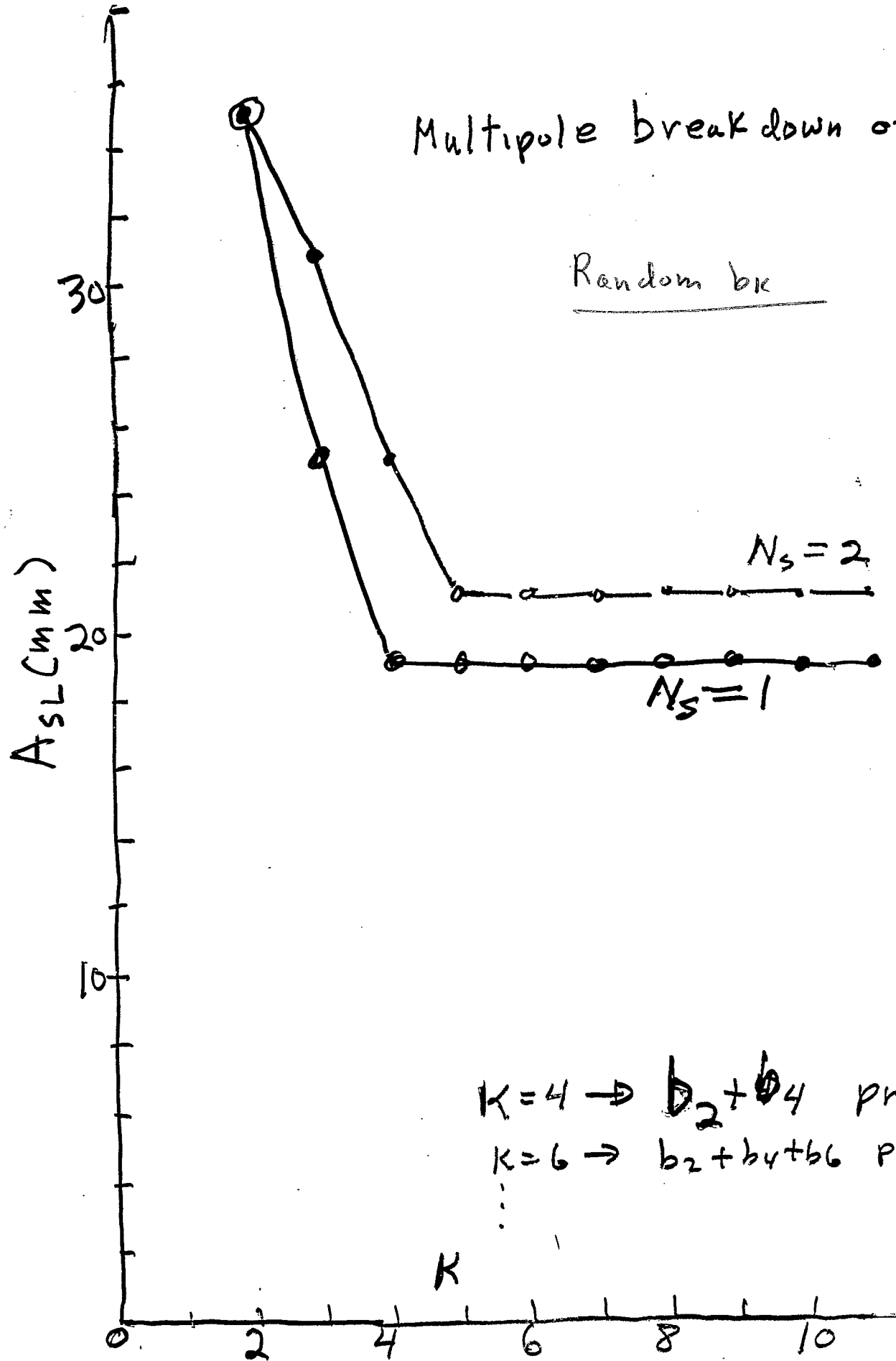
What are the consequences?

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)

Multipole breakdown of A_{SL}



Higher b_k produce a wall or 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 $A_{SL} \approx 24$ mm.

(8)

Systematic b_k

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

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

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

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

$b_0 \sim 1$ is possible for systematic b_k

Systematic b_{ik} , RHIC Results

<u>b_{ik}, systematic used</u> (from RHIC Proposal)					
<u>Dipole</u> K	b_{ik}	$b_{ik} * R^k / 10^{-4}$ R = 40mm	<u>Quads</u>		
			K	b_{ik}	$b_{ik} * R^k / 10^{-4}$
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			

↑ $x(k+1)$ for random b_{ik}

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

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

FINAL $b_k, \text{systematic}$

measured results

k	$b_k (in^{-k}/10^{-4})$	$b_k * R^k / 10^{-4}$ $R = 38 \text{ mm}$
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 $b_{k, systematic}$

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

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

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

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

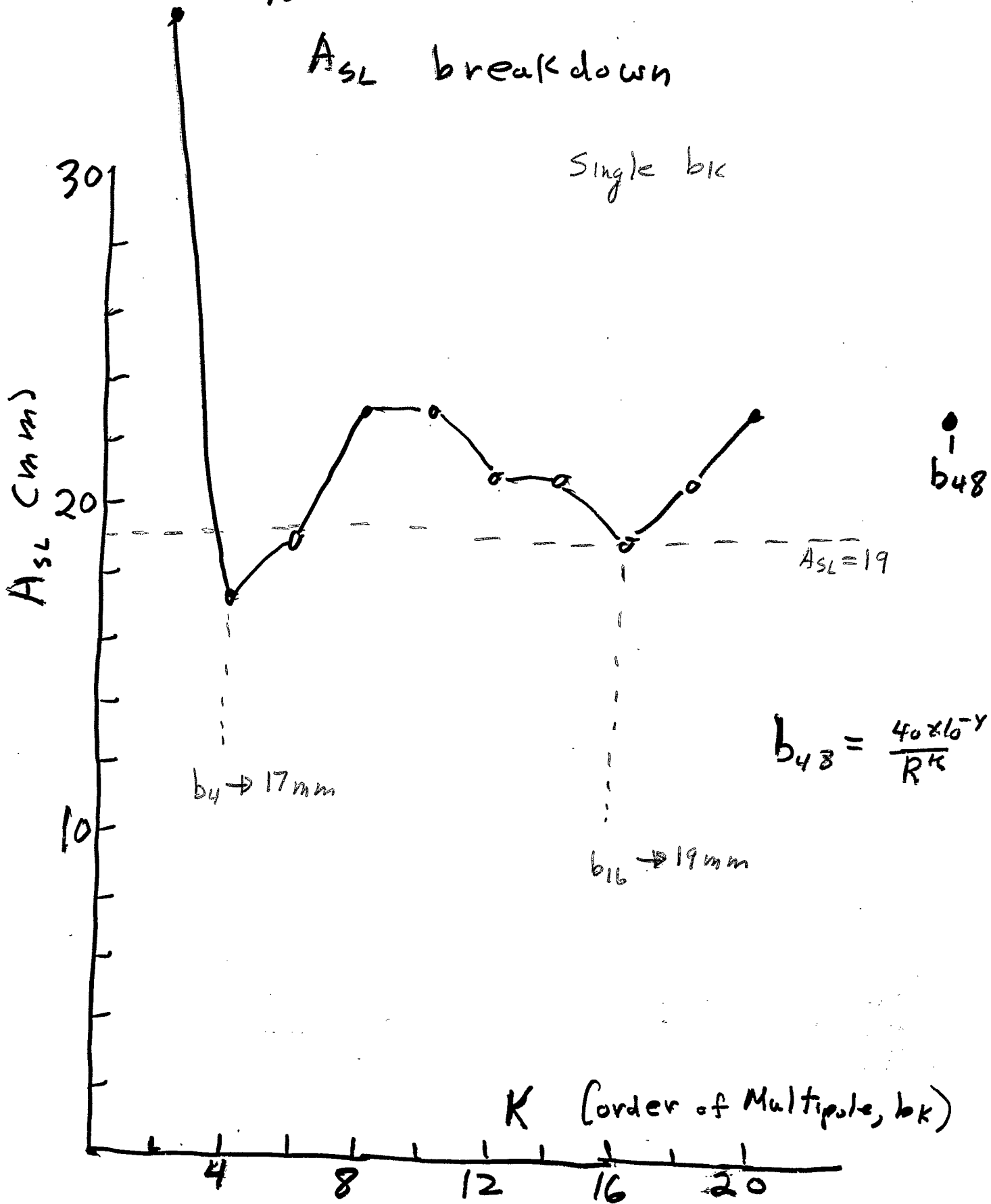
Same as $b_{k, random}$ case

$b_{k, systematic}$, multiple breakdown
(see next page)

Systematic bk

ASL breakdown

Single bk



b_{48}

$ASL = 19$

$b_4 \rightarrow 17mm$

$b_{16} \rightarrow 19mm$

$$b_{48} = \frac{40 \times 10^{-7}}{R^k}$$

K (Order of Multiple, 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 $b_{k,sys}$ ($b_{k,sys} \neq 0$) 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 $\rightarrow A_{SL} = 21 \text{ mm}$ ($\beta_{pc} = 100$)

addition of $b_{K,tran}$ reduces A_{SL} to
 $A_{SL} = 19 \text{ mm}$ ($\beta_{pc} = 100$; $y \approx 0$ 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 $b_{K,ren}$, are important

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

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...)