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Higher Order Magnet Field Multipoles Aperture Effects, and Tracking Studies

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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
 $\nu_x \approx \nu_y \approx 28.824$

AsL Multipole Breakdown

Single multipoles

Random bk only

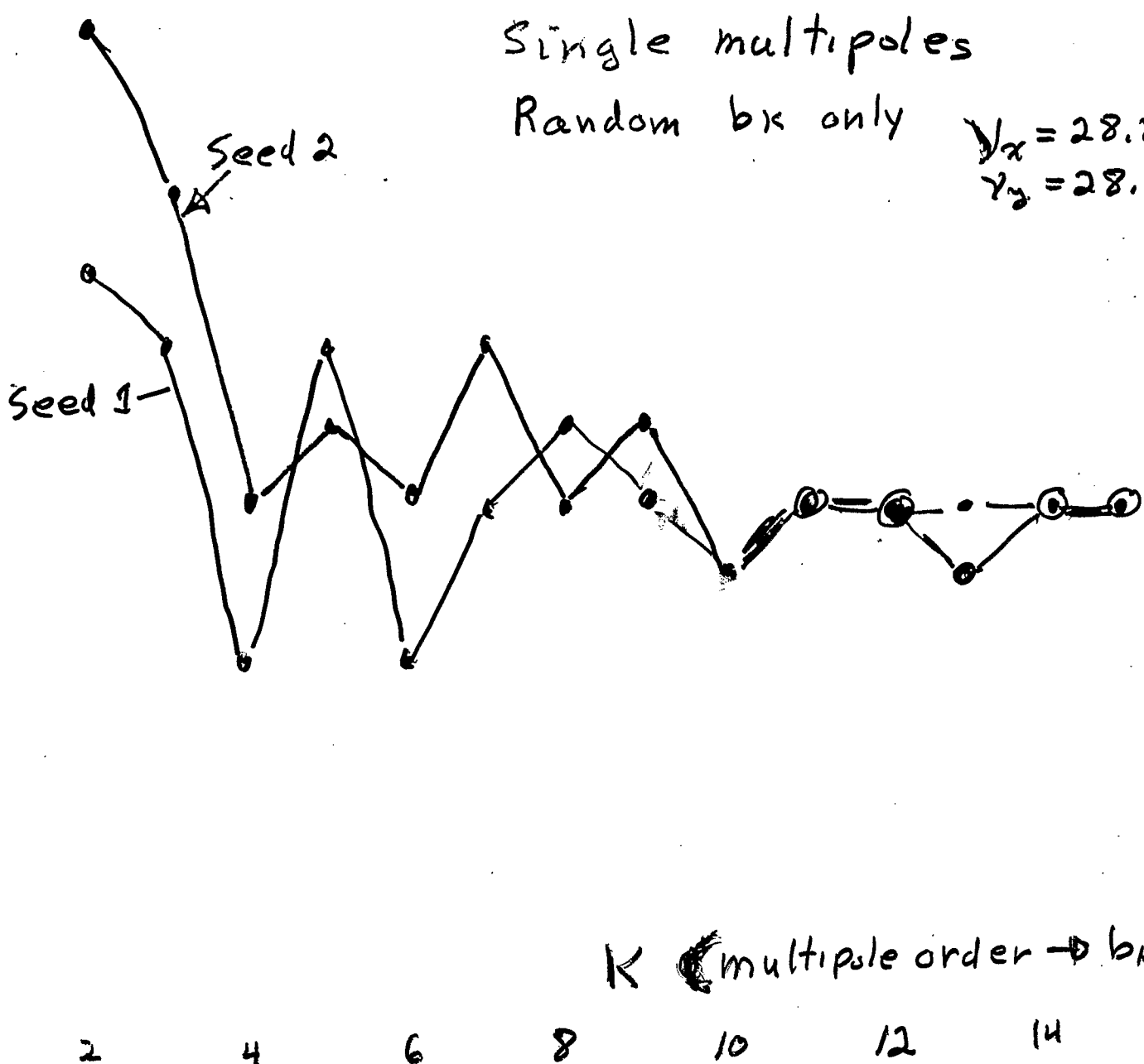
$$\gamma_x = 28.827$$

$$\gamma_y = 28.822$$

AsL (mm)



Seed 2
A
Seed 1



Ⓞ
K=49

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

(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

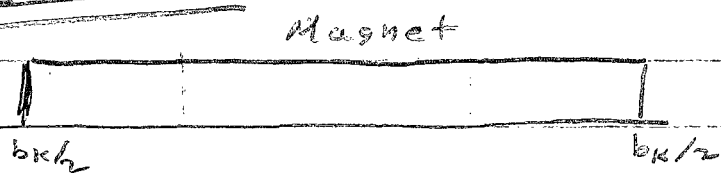
$$V - V_{res} \approx \int ds e^{i\theta} \beta \left(\frac{\beta}{\beta_0} \right)^{k-1/2} b_k A_{SL}^{k-1}$$

factor

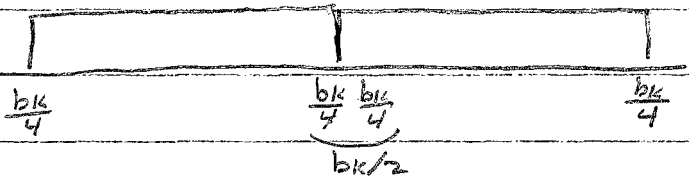
factor $\xrightarrow{k \rightarrow \infty} 0$ for distributed b_k

Distributed Multipoles in Tracking

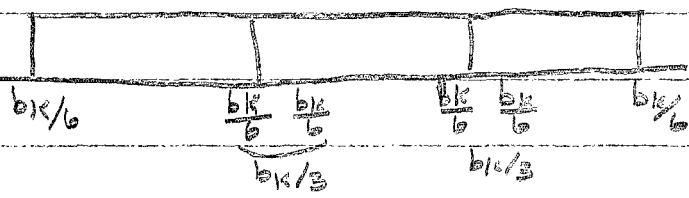
point b_k



2 intervals



3 intervals

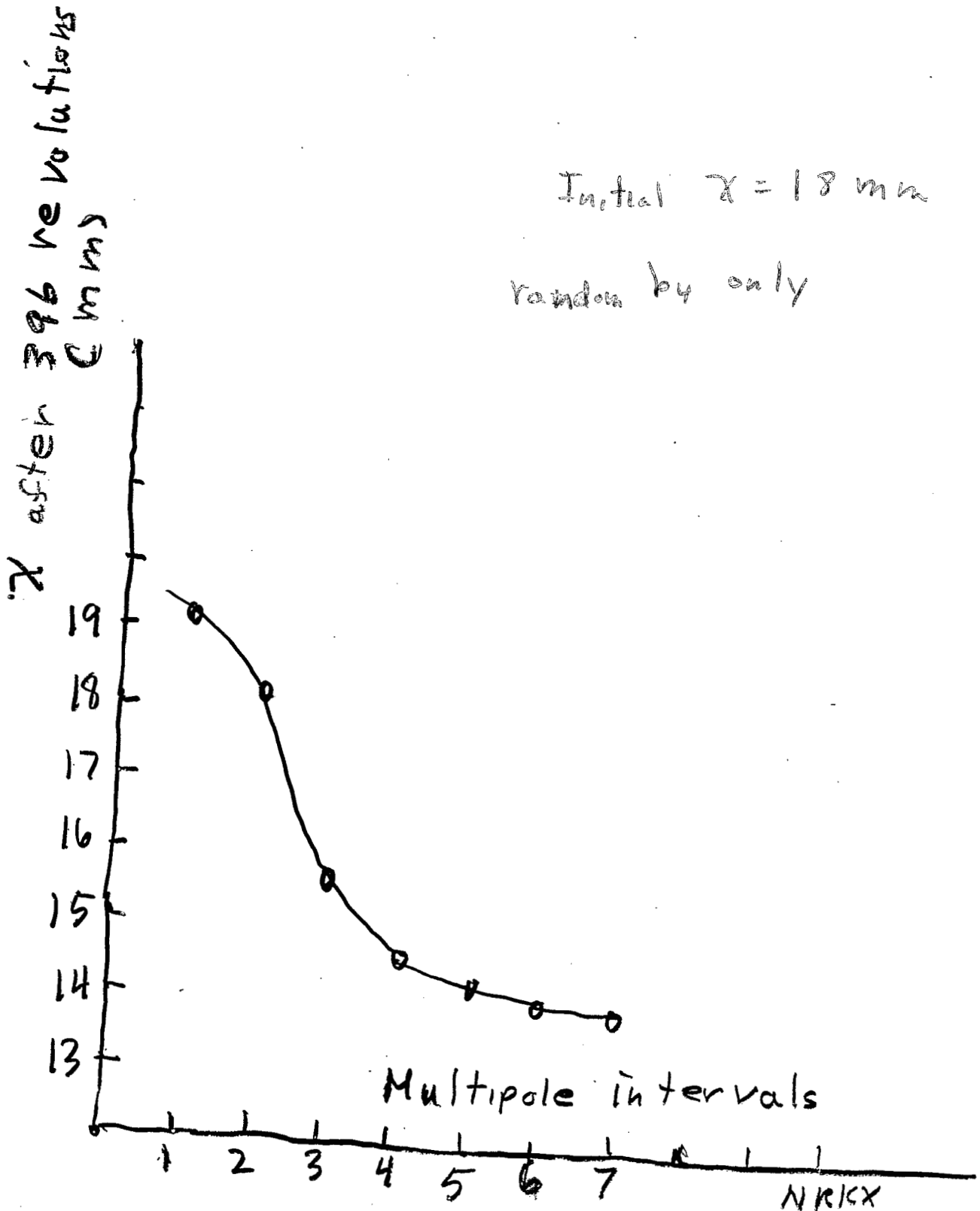


Equivalent to using 2nd order Runge-Kutta.

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

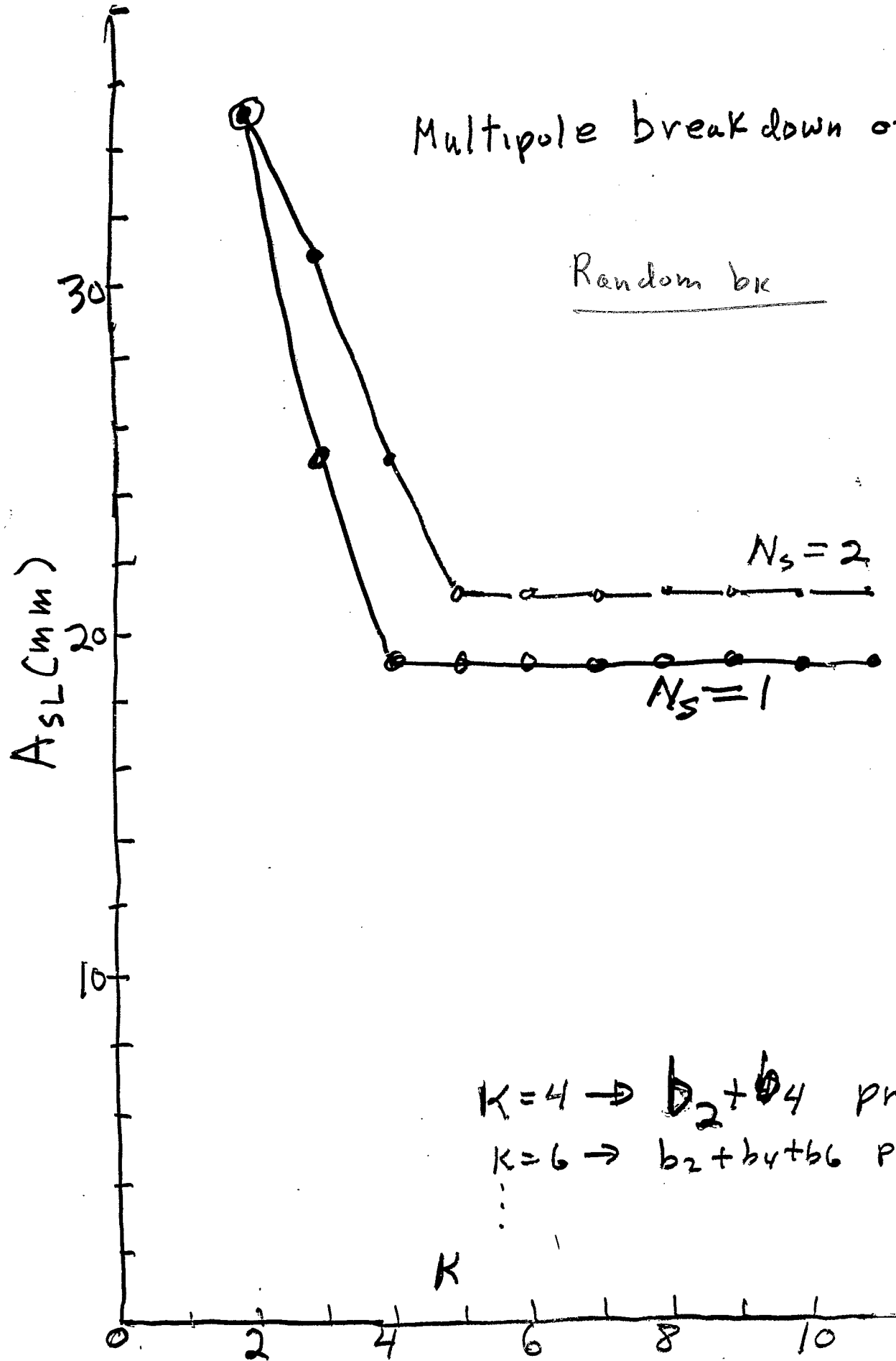
What are the consequences?

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

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

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

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

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

Systematic b_k , RHIC Results

<u>$b_k, \text{systematic}$ used</u> (from RHIC Proposal)						
<u>Dipole</u>		$R = 40\text{mm}$				
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 $\times (k+1)$ 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	$b_k (in^{-k}/10^{-4})$	$b_k * R^k / 10^{-4}$ $R = 38 \text{ mm}$
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 $b_{k, ran}$

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

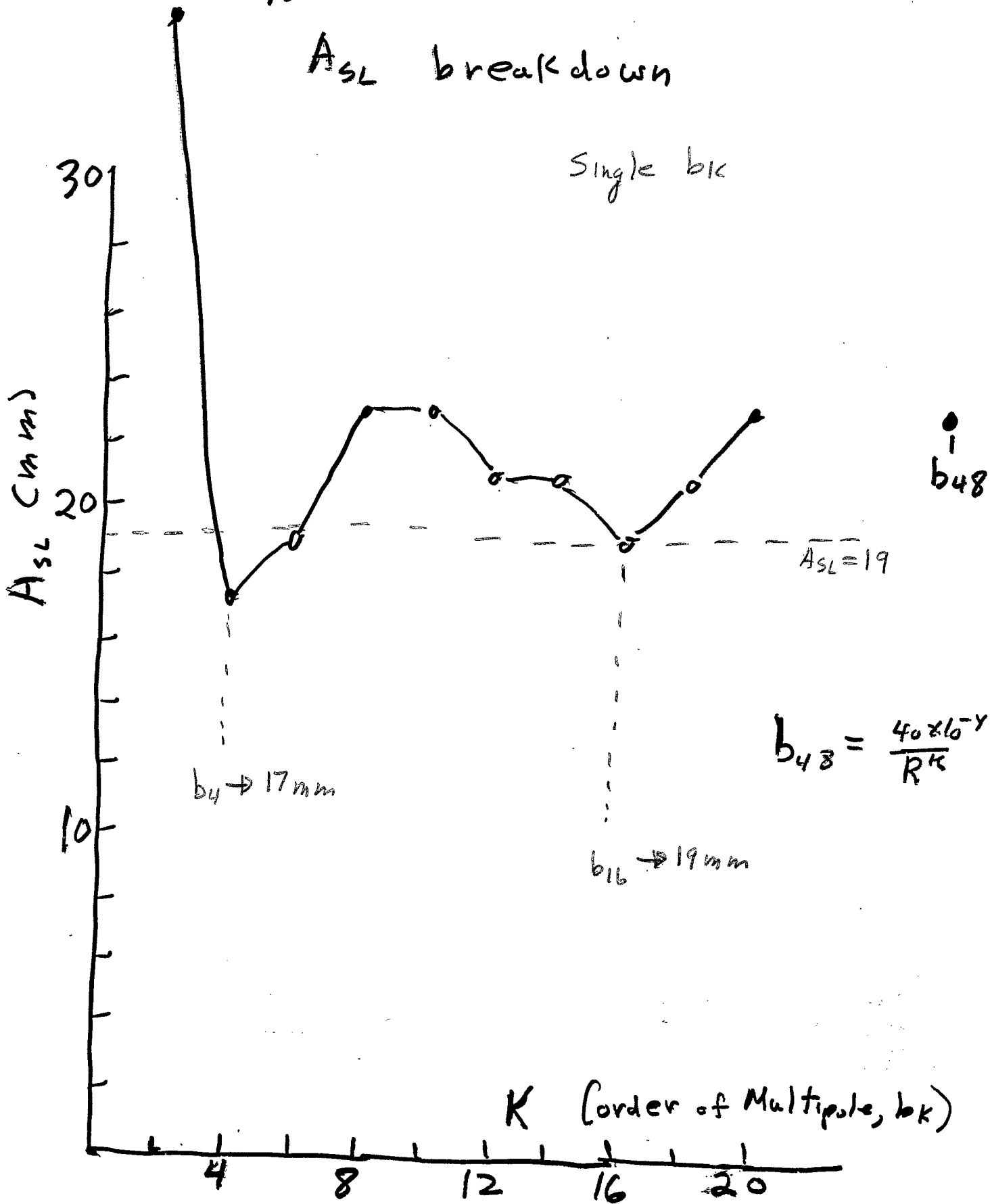
Same as $b_{k, random}$ case

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

Systematic bk

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 $b_{k,sys}$ ($b_{k,sys} \neq 0$) 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} . $b_x = 0$ is not necessarily optimum solution.

3) Watch out for very large higher b_k (b_{16} etc...)