STAR Note #50

Tests of Proximity Mesh Dynode Tubes and Evaluation of Shingle Counters

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1 Introduction

The Physics goals of STAR, particularly for complete particle identification, demand a comprehensive Time of Flight (TOF) system. The necessity for a timing resolution of at least 100 picoseconds for a highly segmented cylindrical counter of 2 m radius and 5 m length in a 5 kG magnetic field puts a severe demand on the available technology. The goals of the TOF subsystem are as follows:

Particle Identification:

- Pion/Kaon up to Pmax = 1.6 GeV/c
- Proton/Kaon up to Pmax = 2.8 GeV/c

Operate at interaction rates to 10^3 and 10^7 for Au-Au and pp respectively.
Return trigger level information within 100 ns

Trigger:

1. Multiplicity information (Analog, Digital)
2. Pattern recognition of event topology
3. Rare or exotic event selection through combination of timing information and multiplicity.

2 Photomultiplier Tube Choice and Evaluation

Placing the phototubes directly in the 5 kG field is now a technical reality. This was made possible by the advent of a new phototube design, the Mesh dynode tube[1, 2]. Further advances in the development of this tube design, the proximity mesh dynode structure with the dynodes close to the photocathode to reduce the transit time spread, (TTS), has resulted in a magnetic field insensitive tube with a single electron TTS of 100 to 150 ps. Four such tubes, Hamamatsu R3432-01, were evaluated. These are 15 stage, one inch diameter tubes, with an active area of 2 sq. cm. Tube bases supplied by Hamamatsu were used. These bases used standard linear dynode resister string. No attempt was made to optimize the performance of the bases. The anode output was fed into a 50 ohm splitter to provide signals for the discriminator and ADC's. At 2000 V the one MIP signal was approximately 900 mV, (before the splitter). Three tubes performed satisfactorily, while the fourth had only 1/2 the nominal gain. Details of the measurements and results are described in the tests discussed below.

3 Shingle Geometry Evaluation

Tests of the shingle geometry using the R3432 phototube at zero field were done in the M-11 beam line at TRIUMF. A minimum ionizing beam of 300 MeV/c Π^- was used. The setup is shown in figure 1. Scintillators S1 and S2 were 1cm $\times$ 1cm $\times$ 0.6cm thick paddles used to define the beam size. S3 was 5 cm $\times$ 8 cm and was used to monitor the beam intensity. TS was a double ended scintillator used to determine the start time. It consisted of a 2cm $\times$ 2cm $\times$ 10cm bar of BC418 viewed at both ends by two Hamamatsu R2083 fast phototubes, TS1 and TS2. The "shingle' scintillator to be tested, viewed by one or two R3432's T1 and T2, was placed between S1 and S2. The various scintillator combinations tested are listed in Table 1.

Scintillators Tested		
Type	Dimensions	# Tubes
BC408	1.5 cm $\times$ 1.5 cm $\times$ 42 cm	2 R3432
BC408	1.5 cm $\times$ 3.0 cm $\times$ 125 cm	1 R3432
BC420	1.5 cm $\times$ 1.5 cm $\times$ 42 cm	2 R3432
BC420	1.5 cm $\times$ 3.0 cm $\times$ 63 cm	1 R3432
BC418	2 cm $\times$ 2 cm $\times$ 10 cm	2 R2083

Table 1: Various scintillator combinations tested.

The electronics are shown in figure 2. The discriminators were Phillips 708 octal 300 MHz leading edge discriminators, and the TDC was a Phillips 7186 with 25 ps/channel resolution. A Phillips 715 CFD was also used in some tests. The signal from S1 was used for the common start of the TDC. As can be seen from Figure 2, an event required a coincidence between

S1, S2, and S3 and TS1 and TS2. When this was satisfied all pulse heights and TDC's were read into a computer via CAMAC and stored on magnetic tape for later analysis.

Offline the data were corrected for leading edge pulse height walk, using the formula

$$T^1 = T_{meas} + A\left(\frac{1}{\sqrt{Q_0}} + \frac{1}{\sqrt{Q}}\right)$$

where Q is the ADC pulse height, Q_0 is a reference pulse height, and A is an empirically determined constant, depending on the time constants of the tube and scintillators. The walk corrected times were then corrected for the S1 time jitter using the TS counter

$$\begin{aligned} T &= \frac{(T_1 + T_2)}{2} - \frac{(T_{S1} + T_{S2})}{2} && \text{double ended} \\ T &= T_1 - \frac{(T_{S1} + T_{S2})}{2} && \text{single ended} \end{aligned}$$

The measured widths of these time distributions correspond to

$$\begin{aligned} \sigma_m^2 &= \frac{\sigma_T^2}{2} + \frac{\sigma_{TS}^2}{2} && \\ \sigma_{bar}^2 &= \sigma_m^2 - \frac{\sigma_{TS}^2}{2} && \text{double ended} \\ &= \frac{\sigma_T^2}{2} && \\ \sigma_m^2 &= \sigma_{T1}^2 + \frac{\sigma_{TS}^2}{2} + \sigma_x^2 && \\ \sigma_{T1}^2 &= \sigma_m^2 - \frac{\sigma_{TS}^2}{2} - \sigma_x^2 && \text{single ended} \end{aligned}$$

where σ_m^2 is the measured variance, σ_T^2 is the variance of one R3432, σ_{TS}^2 is the variance of one R2083, and σ_x^2 is the variance due to the one cm^2 beam spot size. Tubes of the same type are assumed to have equal variances. σ_{bar}^2 is the variance that would be measured using a double ended TOF element. The value for the TS variance was obtained from the equations

$$\begin{aligned} T_{diff} &= TS_1 - TS_2 + 2nx/c \\ \sigma_{diff}^2 &= \sigma_{TS_1}^2 + \sigma_{TS_2}^2 + 4\sigma_x^2 \\ \sigma_{TS}^2 &= \frac{\sigma_{diff}^2}{2} - 2\sigma_x^2 \end{aligned}$$

where n is the index of refraction for the scintillator ($\sim$1.59), x is the position of the beam spot and σ_x^2 is $\Delta xn/2.34c < 20\mathrm{ps}$. σ_x^2 was taken to be zero in the following results.

The results are listed in Table 2. Excellent results were obtained for the TS counter with a bar resolution of 37 ps!. The performance of the shingle counters was adequate or better. The results indicate that the time resolution was limited by the pulse height. (also see below). The 1.6 cm diameter of the the R3432 covered only 86% of the 1.5 cm $\times$ 1.5 cm bar and 44% of the 1.5 cm $\times$ 3.0 cm bar. Thus one would expect $\sqrt{2}$ worse performance from the larger area bar. At the same time, the case with the beam incident on the 3.0 cm length should give the same pule height and thus the same performance as the 1.5 $\times$ 1.5 cm bar. The data in table 2 support this conclusion.

Empirically, long scintillator bars have a time resolution given by

$$\sigma = a\sqrt{L/N_e}$$

where L is the bar length in cm and N_e is the average number of photoelectrons collected. (usually taken as a MIP at the center of the bar.). The constant a depends on the scintillator decay constants, tube rise time fraction of the light collected, and details of the electronics.

The origin of this formula is easily understood. The time jitter depends on the statisitics of the arrival of the leading edge of the light pulse. This in turn depends on the inverse of the square root of the photo-electron density per unit time of the leading edge. Since the time spread is given by

$$t = \frac{L(1/\cos\vartheta - 1)}{c}$$

the photoelectron density is then proportional to

$$N_e = \frac{N_0 t \Pi r^2}{tw}$$

where t is the thickness of the scintillator, N_0 is the number of photons generated per unit length, w is the width of the scintillator and r is the radius of the photocathode. The term $\Pi r^2/tw$ accounts for the fraction of the light collected by the photocathode. We have assumed that t and w are greater than or equal to $2r$. Collecting all the constants we find that

$$\sigma = a\sqrt{Lw/\Pi r^2}$$

The data from table 2 is shown on such a plot in figure 3 for BC408 and figure 4 for BC420. From these figures we can estimate the behaviour of the proposed 2.6 cm $\times$ 1.5 cm $\times$ 23 cm shingle counters. Thus the worst resolution expected, $L = 23$ cm, would be 87 ps for BC420 and 103 ps for BC408. Sigmas less than 50 ps can be expected for events striking near the tube.

The tranist time of the pulse is shown in figures 5 and 6. The time is given by a linear relation to the length with constants of 74.7 ps/cm for BC408 and 80.2 ps/cm for BC420. The time delay for light in material with index of refraction 1.58 is 53 ps/cm for straight travel and 83 ps/cm for rays traveling at the critcal angle. Clearly the latter was more nearly the case for our tests. This indicates that the threshold used was too high, (or the gain was too low). Thus we might obtain better results with more gain. Finally we show the spread around the transit time curve in figures 7 and 8. It should be noted that the the worst case shown, 42 ps, represents a beam position error of only 0.5 cm. The apparatus was not aligned to better than this. The spread between the 3.0×1.5 and 1.5×3.0 results represents the residual spread not corrected by the walk correction. It is at most ± 25 ps for the 25 cm data. The worst case, shown in figure 5, for the 62.5 cm data is due to the very low pulse height, again suggesting that the gain was too low.

4 Conclusions and Further Tests

We have evaluated the scintillator performance for BC408 and BC420 using the R3432 proximity mesh dynode photomultiplier at zero field. Very good results were obtained. A system resolution of better than 100 ps seems feasible, with walk corrections.

Price quotes from BICRON indicate that BC404, which is faster than BC408, is actually cheaper. Price quotes from PolyCast indicate that acrylic based scintillators will be much cheaper, as little is one fourth the cost of BC408! Samples of these two scintillators have been ordered for evaluation for use as the shingle counters. BC408 will have to be used for the long bars, due to its long attenuation length. Tests in a 5 kG field are also planned. From the literature[2], the field is not expected to degrade the time resolution by more than 20%.

We would like to thank Dr. J. M. Poutissou, Associate Director of TRIUMF for providing us the beam time and all the necessary help during these tests. Thanks are due also to all other TRIUMF staff whose cooperation made our stay at TRIUMF enjoyable.

References

[1] S. Suzuki, *et. al.*, IEEE Trans. on Nuc. Sci. Vol 33. No. 1 (1986) p. 377.

[2] G. Finset, *et. al.*, NIM A290 (1990) 450-466.

Timing Results						
Type	Cross Section	X(cm)	Sigma(ps)	DISC	Bar(ps)	%
BC408	1.5 × 1.5	10	61	LE	50	86
	1.5 × 1.5	21	63	LE	46	86
	1.5 × 1.5	32			50	86
	1.5 × 3.0	5	85	LE		44
	1.5 × 3.0	25	113	LE		44
	1.5 × 3.0	63	193	LE		44
	3.0 × 1.5	5	51	LE		44
	3.0 × 1.5	25	74	LE		44
BC420	1.5 × 1.5	10	45	LE	41	86
	1.5 × 1.5	15	50	LE	37	86
	1.5 × 1.5	21	56	LE	35	86
	1.5 × 1.5	27	72	LE	37	86
	1.5 × 1.5	32	83	LE	41	86
	1.5 × 1.5	21	98	CFD	69	86
	1.5 × 3.0	5	55	LE		44
	1.5 × 3.0	10	75	LE		44
	1.5 × 3.0	25	100	LE		44
	1.5 × 3.0	25	123	CFD		44
	3.0 × 1.5	5	38	LE		44
	3.0 × 1.5	10	41	LE		44
	3.0 × 1.5	25	68	LE		44
BC418	2 × 2	5	53	LE	38	100

Table 2: Beam traversed the length shown first in the cross section column. X is the distance from the beam spot to the phototube. Sigma gives the results for the single tube analysis. LE means leading edge timing (Phillips 708) with pulse height corrections. CFD means constant fraction timing (Phillips 715). The bar column gives the results for the double ended analysis. The column labeled % gives the fraction of light collected.

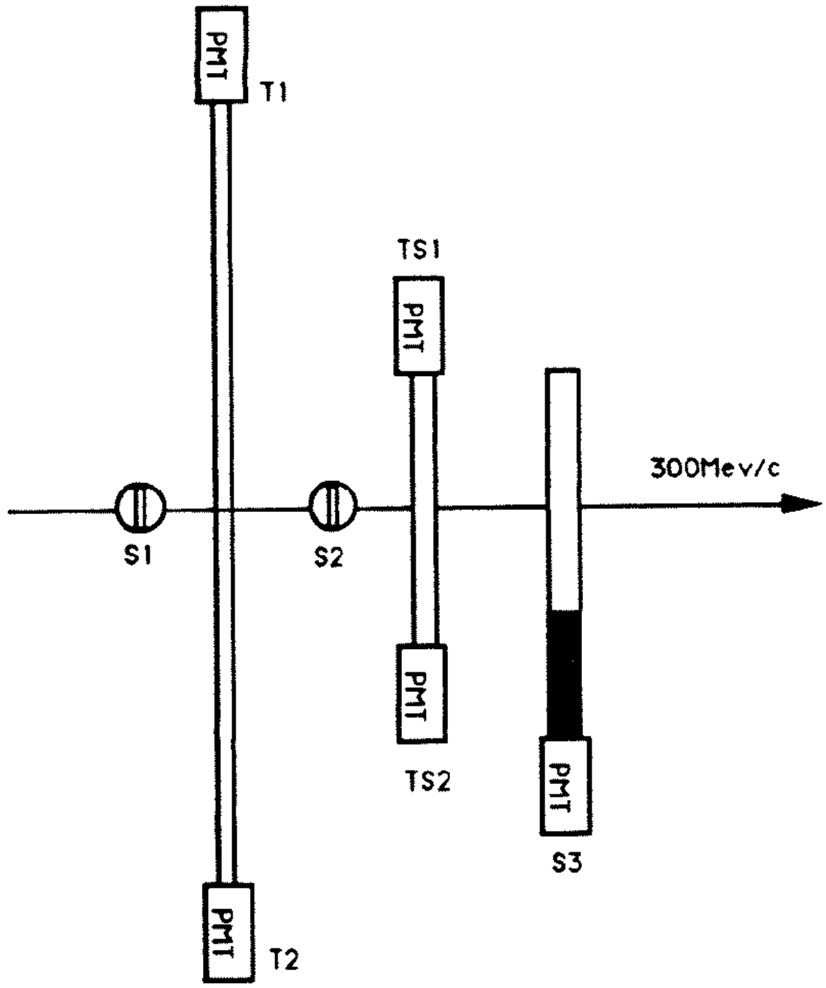

Figure 1: Experimental Setup

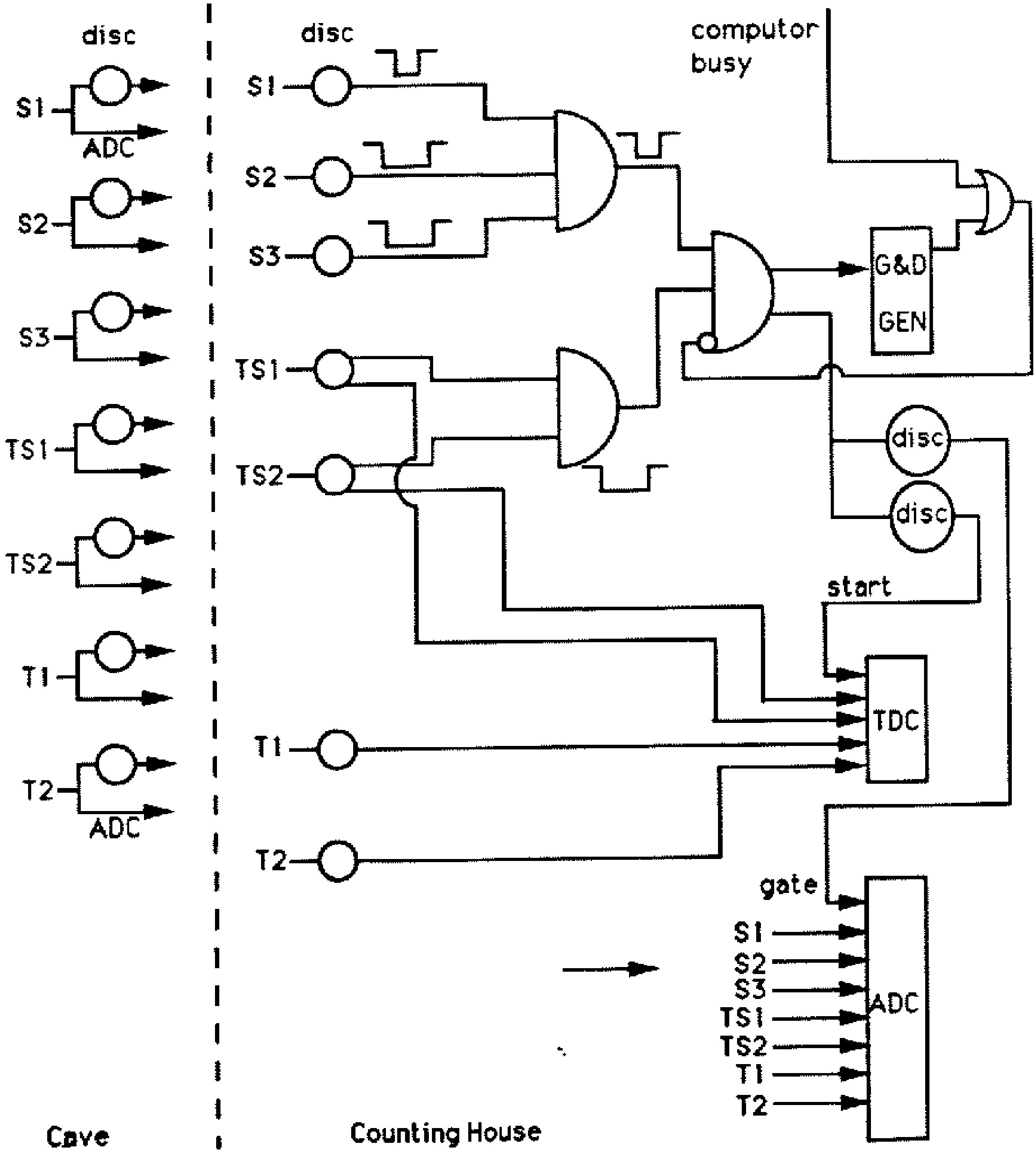

Figure 2: Electronics Block Diagram

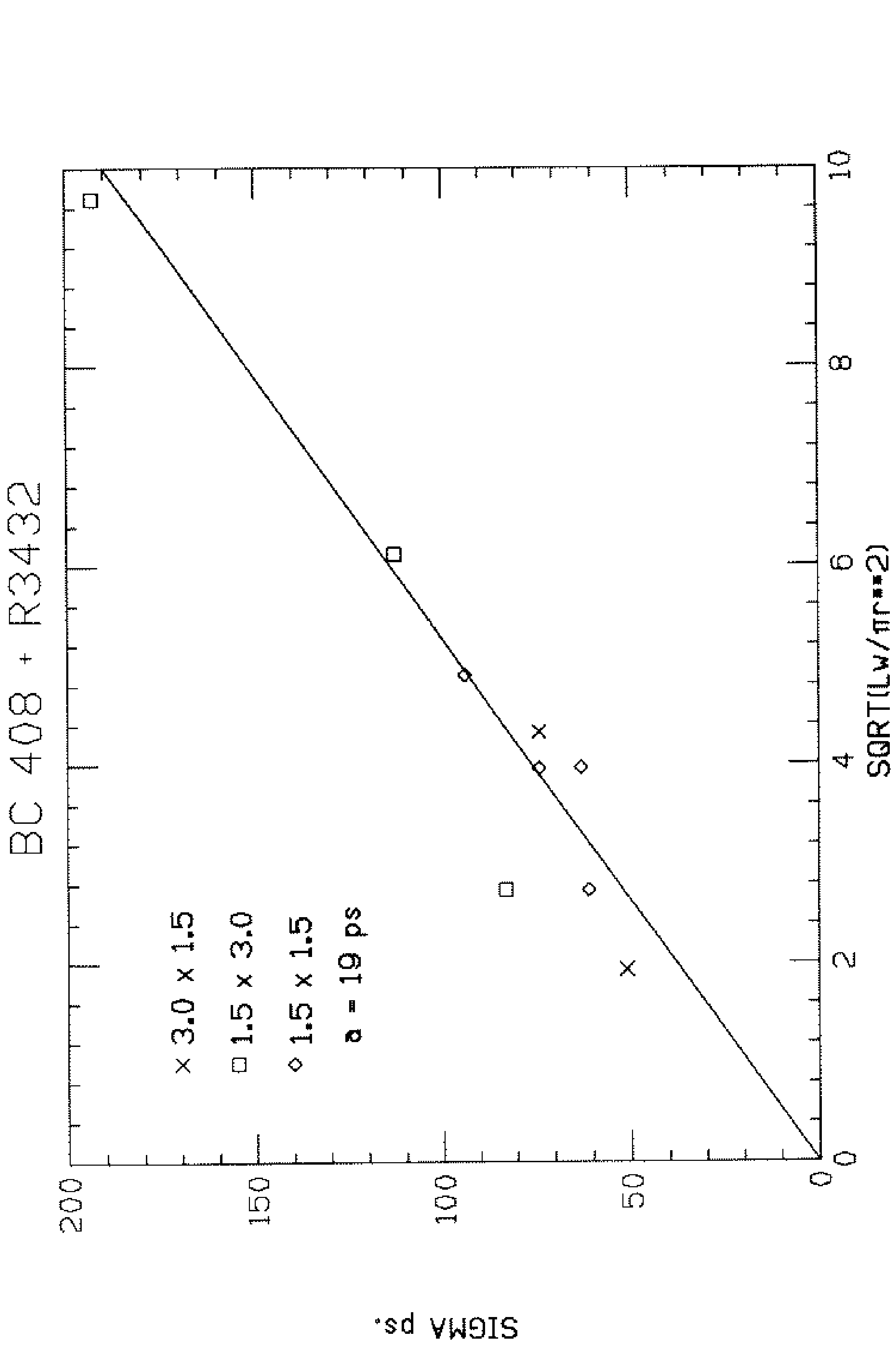
BC 408 + R3432
× 3.0 x 1.5
□ 1.5 x 3.0
◇ 1.5 x 1.5
a = 19 ps
SQRT(Lw/πr**2)
SIGMA ps.
0
2
4
6
8
10
0
50
100
150
200

Figure 3:

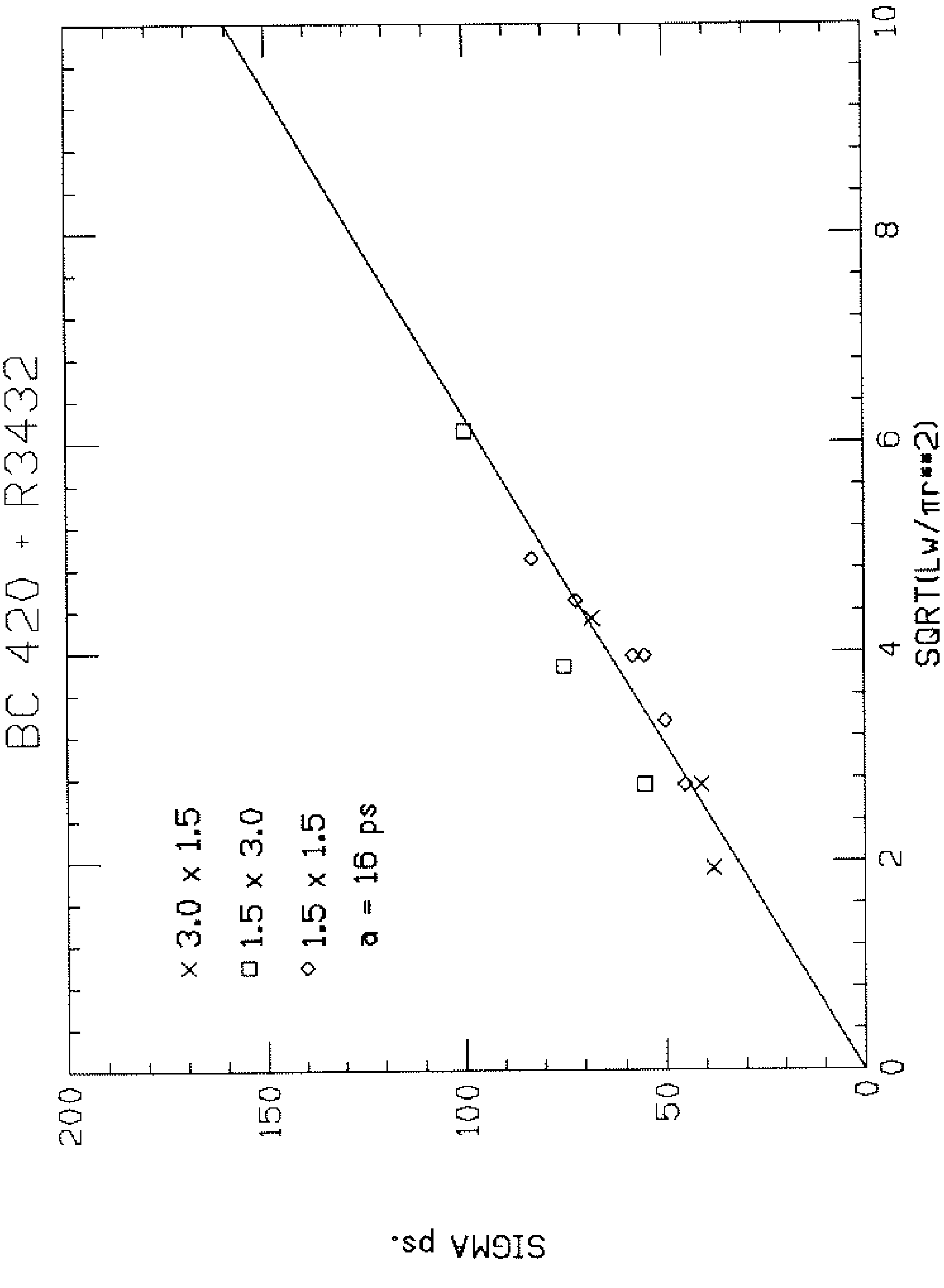
BC 420 + R3432
× 3.0 x 1.5
□ 1.5 x 3.0
◇ 1.5 x 1.5
a = 16 ps
SIGMA ps.
SQRT(Lw/πr**2)
0
50
100
150
200
0
2
4
6
8
10

Figure 4:

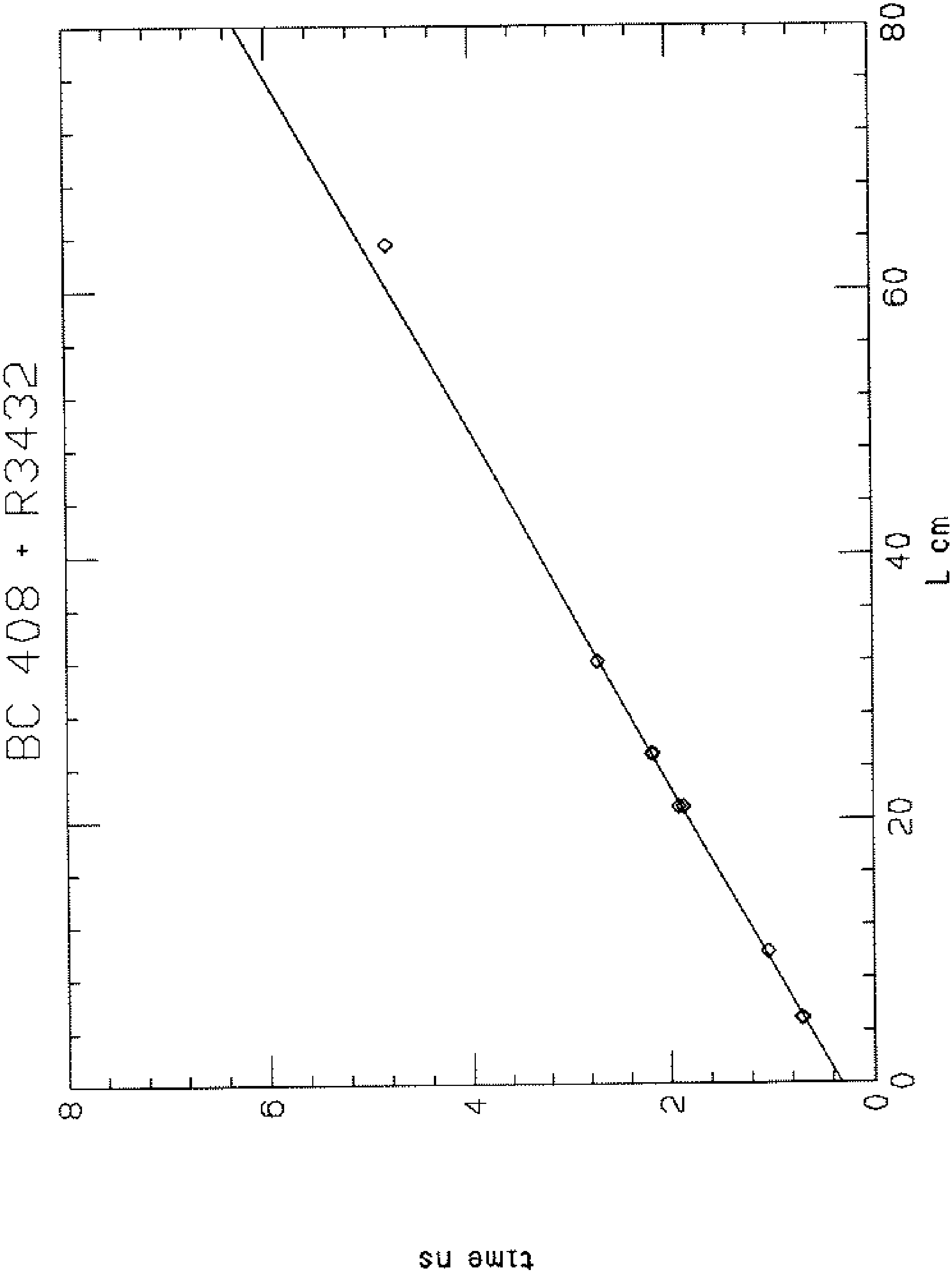

Figure 5:

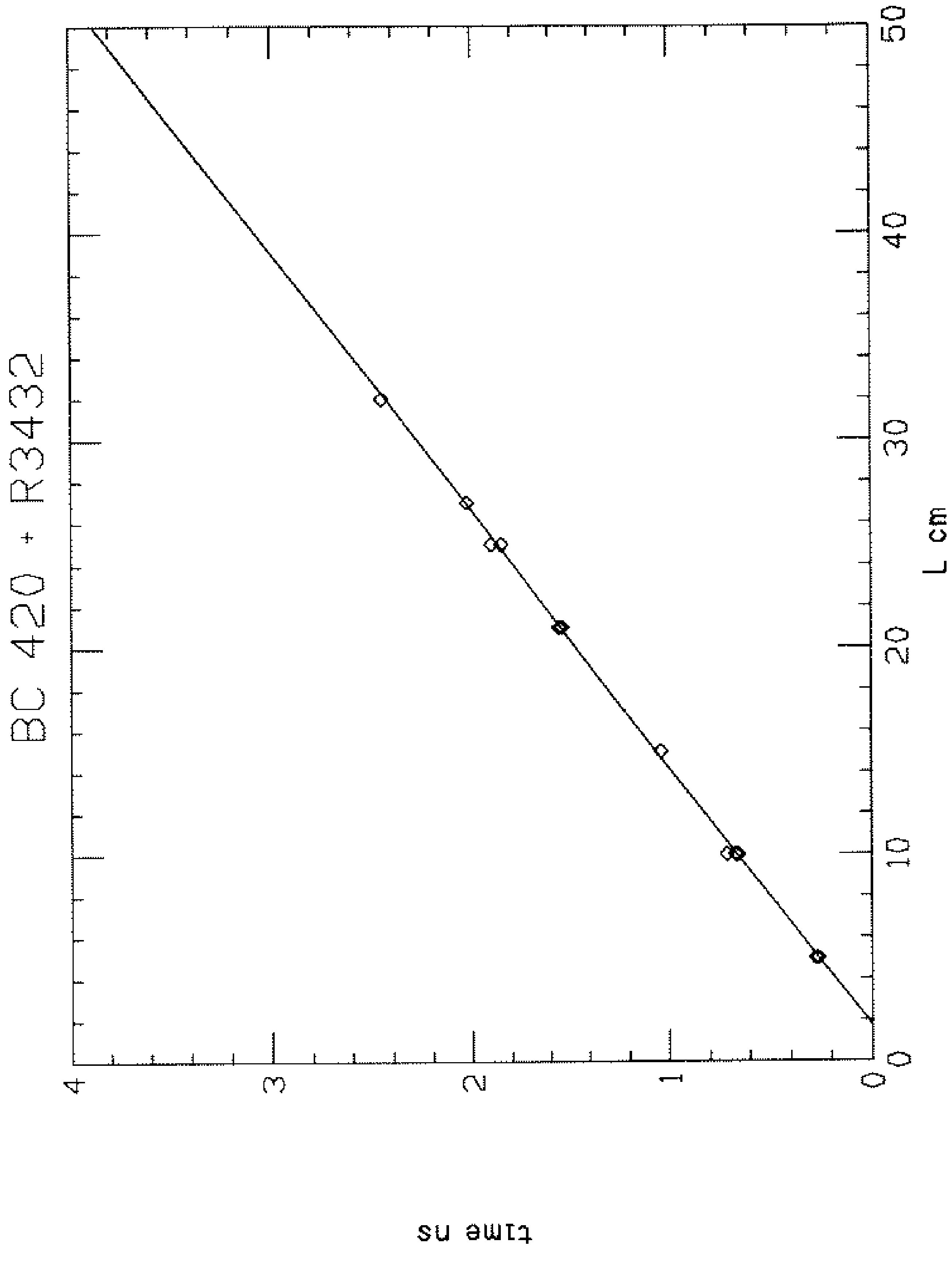

Figure 6:

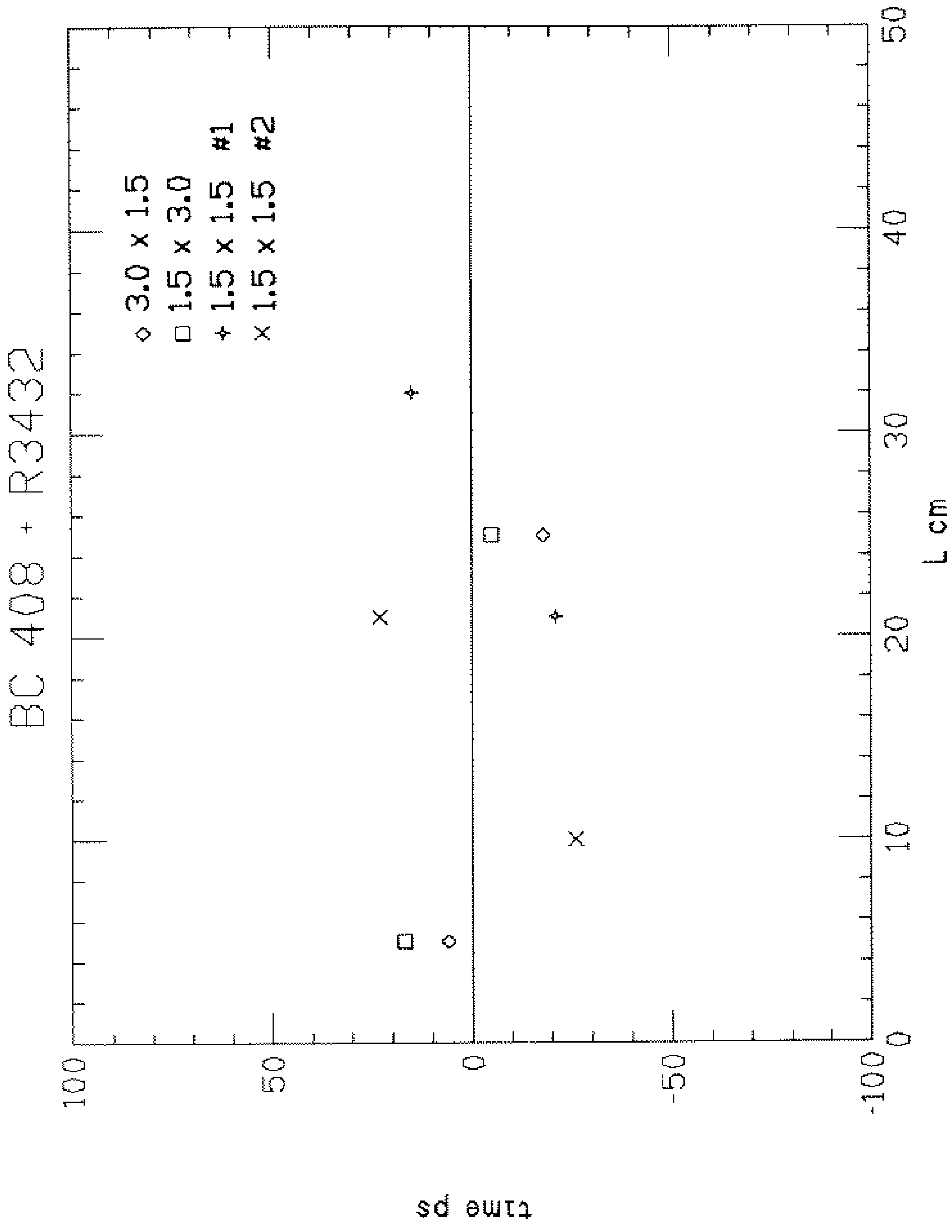
BC 408 + R3432
◇ 3.0 x 1.5
□ 1.5 x 3.0
+ 1.5 x 1.5 #1
× 1.5 x 1.5 #2
time ps
L cm
100
50
0
-50
-100
0
10
20
30
40
50

Figure 7:

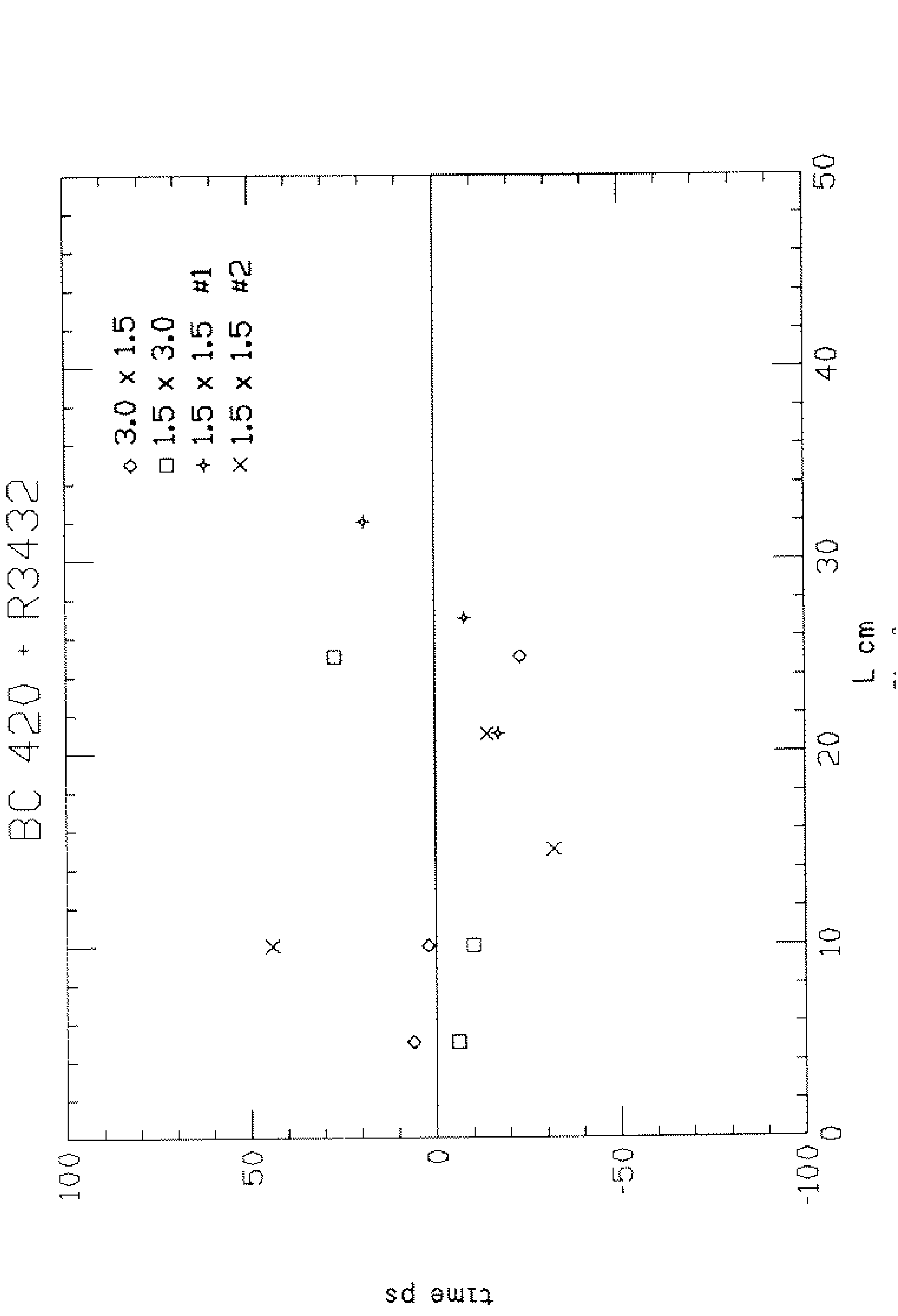
BC 420 + R3432
3.0 x 1.5
1.5 x 3.0
1.5 x 1.5 #1
1.5 x 1.5 #2
time ps
L cm
100
50
0
-50
-100
0
10
20
30
40
50

Figure 8: