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# EMITTANCE DILUTION IN TRANSFERS FROM THE MAIN RING TO THE TEVATRON

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## I. Introduction

An apparent growth in emittance is observed in proton and antiproton transfers from the Main Ring to the Tevatron, and figure 1 shows some examples from recent shots. This analysis attempts to understand the sources of this apparent growth. We will restrict our studies to the vertical plane for simplicity ( i.e. the vertical dispersion in the Tev is zero and we can extract the vertical emittance from one flying wire), however some of our results immediately apply to the horizontal plane.

The analysis is based upon 5 data sets:

1. ILAM studies 2/23/92 (Tev log 34, p 205)
2. IQUAD studies 3/2/94 (Tev log 34, p 281)
3. TeV VS MR studies 3/2/94 (Tev log 34,p 282 )
4. RECENT SHOTS (before 4/8/94)
5. SHOT 4749

The very first use of the data will be to get rid of the word apparent in the first paragraph. The beam size measured at the flying wire is assumed to be proportional to $\sqrt{\beta\varepsilon}$ and hence if our assumption about the beta function at the flying wire is wrong, then our extracted value for the emittance will be wrong. In comparing the two machines we need to know the beta function at both flying wires; if either or both are wrong (barring a common systematic error) then our growth comparison will be erroneous. However, during the regular tuning of reverse injection for a shot, there is an opportunity to measure the emittance of the same bunch after it has been injected into the Tev and then reinjected into the Main Ring. Figure 2 shows this common comparison for some recent shots. It should be noted that the procedure utilized implies that the wire is flown in the same direction for both flies shown in the figure. It is evident that in the range of MR emittances from 10-13$\Pi$, that there is a minimum blow up of 3-4Π, and it is possible to do worse. For the rest of this report we shall drop the word apparent.

## II. Analysis

The analysis of this report is mainly based upon FN-458[1] by M. Syphers and chapter seven in Edwards and Syphers [2]. (J. Marriner has also made a spread sheet which is useful for varying different parameters.) Page 32 of FN-458 is attached as appendix 1 with some annotations added. An important point for us to observe is that there is a functional difference in the dependence of the blow up of the initial emittance between a beta function mismatch and a steering error or dispersion function mismatch. This fact led us to take the data set on 3/2/94 which compared the Tev emittance to the Main Ring emittance for a wide range of Main Ring emittances.

## III. Tev vs MR 3/2/94

Figure 3 shows the result of this study. The data is for 7 turns, 11 bunches, coalesced beam (with one noted exception), a value of IQUAD equal to 50 amps (discussed below), and small injection errors as monitored by turn by turn data. Larger values of the Main Ring emittance were obtained by pinging the beam and smaller values of the Main Ring emittance were obtained by scraping the beam vertically at VF16 where the vertical dispersion is ~-.2 m (hopefully this implied that we were not momentum scraping). With no scraping and the pinger off, the Main Ring emittance was around 12Π with a corresponding Tev emittance of about 16.5Π .

One can fit the data with various parameterizations as shown in figures 4,5, and 6. However, there are other ways to present the data in order to try to deduce the mechanisms responsible for the observed emittance growth. If all the growth were due to lattice function problems then plotting the data as a ratio of Tev to MR as a function of MR emittance would yield a horizontal line, and figure 7 shows that we certainly do not have that behavior. The most interesting way to present the data is shown in figure 8 where the Tev - MR is plotted as a function of MR emittance. I believe that there is clear evidence for scraping even at values as small as 15Π in the MR. ( A caveat is that this is also near the point where we switched from scraping to pinging.) If we refit the lower part of the data before the kink to a straight line we have the fit shown in figure 9 and it is the value of the slope and intercept from this fit that we will use later. To set the stage for the rest of the paper, we can come up with some reasonable estimate for the intercept of 1Π (dispersion mismatch and multiple scattering in the vacuum windows), however the value of the slope, 1.35, is difficult to explain without a very large beta (and/or alpha) mismatch between the machines.

## IV. Dispersion Mismatch

There are reasons to suspect that there could be problems with a vertical dispersion mismatch between the MR and the Tevatron. Not only is the transfer from the MR to the Tev accomplished by a vertical dog leg, but there is vertical dispersion in the MR due to the overpasses and there is supposedly zero vertical dispersion in the Tevatron. Ming-Jen Yang has made a study of the vertical dispersion in the MR at 8 GeV and table I shows his results:

| | D49 | E11 |
|---|---|---|
| Predicted | -.686m | -.414m |
| MJY measurement | -.83m | -.65m |

Table I. Vertical Dispersion Comparison at E0

This is good agreement, so we have assumed that we know the values of Dy and D'y at the end of the D49 MR quads at 150 GeV from Synch. J. Marriner has made a small transport deck and translated these values to the beginning of the Tev E11 quad, where the results are $\Delta D = .236$m and $\Delta D' = .0073$. Assuming values of $\beta=59.865$, $\alpha=.0449$, and using a value for coalesced beam [3] $\sigma_{p/p} = 5E{-}4$ in the formula for dispersion mismatch one can calculate an additive factor of .5Π. Uncoalesced beam has a momentum spread that is a factor of four smaller than coalesced[3], and the effect goes as the square of the momentum spread, hence we would expect to see very little effect from a dispersion mismatch for uncoalesced beam. Table II gives our experimental results from the 3/2/94 study. We did not take 3 turn coalesced data, however we have plotted the 3 turn data on figure 3 (the cross), and it is very close to the other data points in the same region of MR emittance. The table shows that the effect from the dispersion mismatch is small, even at the very low values of emittance where one could have hoped to observe a Π/2 addition. There can also be an effect from a momentum mismatch between the two machines, but for any reasonable value of the synchrotron oscillation amplitude the momentum mismatch is smaller than the internal momentum spread. J. Marriner has included this effect in his spread sheet and the effect is calculated to be negligible for reasonable values of the momentum mismatch. In discussing shot 4749 later we will also indicate that momentum mismatch is not the main source of our problem.

| | | MAIN RING | TEVATRON |
|---|---|---|---|
| SCRAPING | COALESCED | 2.7 | 4.6 |
| | UNCOALESCED | 2.7 | 4.6 |
| | | | |
| 3 TURN | COALESCED | | |
| | UNCOALESCED | 9.4 | 13.3 |
| | | | |
| NORMAL | COALESCED | 12.1 | 17.2 |
| | UNCOALESCED | 11.9 | 17.1 |

Table II. Coalesced vs Uncoalesced Comparison
Vertical Emittance (Πmmmr)

## V. Vacuum Windows

In the attempt to determine all the possible sources of injection emittance growth, the fact that there were vacuum windows between the MR and the Tevatron was rediscovered. The windows are for both forward and reverse injection and the windows are supposedly .002" Titanium[4]. Using the multiple scattering formula $< \Theta^2 > = [14.1 \text{ MeV/c/p}]^2 * (L/L_{Rad})$ , with the radiation length of Titanium equal to 3.56 cm, we have $< \Theta^2 > = 1.24\text{E-}11$ radians. This implies an emittance growth of .5Π independent of the initial emittance (where we have used a value of 90m for the beta function at the window). Note for our reverse injection studies that we traverse two window and hence we would expect 1Π growth from the windows alone in figure 2.

## VI. Injection Steering

There have been a number of studies concerning injection steering errors and usually the coupling can be confusing. We have chosen an ILAM study from 2/23/94 to report since the simple model from FN-458 appears to bear some resemblance to the data as shown in figure 10. Again one can speculate that the data at large oscillation amplitudes has some scraping which is why there is better agreement at small oscillation amplitudes and the data lies systematically below the model at larger amplitudes.

We will now discuss one of the most important data sets that we have, and it is not a deliberate study but rather just an examination of one shot, #4749. Figure 11 shows a summary sheet for the proton vertical emittance and figures 12 and 13 show turn by turn data for two of the proton bunches, and it is clear that we have been presented with data corresponding to different oscillation amplitudes. Figure 14 shows the emittance growth as a function of the estimated oscillation amplitude along with the prediction of the model from FN-458. Please note the different scales! An additional piece of information is given is figure 15 which indicates that there was essentially no synchrotron oscillation for this shot. The data in figure 14 appears to have some relationship to the model and if we extrapolate to zero oscillation amplitude (and from figure 15,small synchrotron oscillation amplitude), we see that there is still an appreciable apparent growth in emittance. (The first section notwithstanding, we have to use "apparent" here since some of this effect may be due to the assumed beta function at the flying wire, remember that we know that not all of the growth can be explained this way due to the behavior shown in figure 2.)

## VII T:IQUAD STUDIES

We are slowly working our way to saying that there is an amplitude function mismatch between the machines. This mismatch could be the result of the lattice functions of the machines being different from their design values, or the transfer between the machines could be at fault. Fortunately there is only one focusing element in the transfer line from the MR to the Tev and this quad is T:IQUAD. One success of this study was to discover that the current in IQUAD had been incorrectly read back by a factor of two probably from its installation. This has not led to any breakthrough however. Table IV gives the results of a study varying the correct current in IQUAD and the errors are simply statistical. It should be mentioned that IQUAD steers the beam and injection was retuned when necessary to have a smooth turn by turn. Figure 16 presents the ratio of the Tev to the MR as a function of the current in IQUAD. The curve is a second order fit to the data and if one asks where the minimum of the curve would be, it is a current of 56 amps. However the difference between 40 amps (which is historically where IQUAD really ran - old setting of 20 amps) and 56 amps is only a difference between a Tev emittance (assuming a MR emittance of 12.1) of 17.4 and 17.3 $\Pi$ mmmr. One still might try running IQUAD higher to verify this; the supply is a 50 amp supply and before the factor of two error was found, varying the setting from 25 to 50 amps did nothing. The next question is whether the variation of IQUAD produces calculable results. To facilitate comparison with the analysis on page 27 of FN- 458 we have replotted figure 16 by normalizing the smallest ratio to 1 and we show the results in figure 17 along with the expected results from Syphers' analysis, in terms of the parameterizations. (We have also demonstrated that Sypher's analysis and Marriner's transport + spread sheet are comparable when using the same assumptions - to compare to the data the crosses and boxes should probably be shifted to the right by 20 amps.) The comparison is not good, however if we claim that part of the problem might have been scraping when the mismatch was greatest then we can ask what is the result if we throw away the data points corresponding to the largest Tev emittances. Figure 18 shows that the results follow the model more closely. It is not satisfying to resort to massaging data in this manner, but it does make sense.

| IQUAD(A) | MR E pimmmr | TeV E pimmmr |
|---|---|---|
| -50 | 12.2 ± .2 | 22.2 ± 1.2 |
| -25 | 11.8 ± .1 | 19.6 + .7 |
| 0 | 12.2 ± .3 | 19.3 ± .6 |
| 10 | 12.1 ± .3 | 17.9 ± .8 |
| 20 | 12.2 ± .3 | 17.8 ± .8 |
| 25 | 11.8 ± .2 | 17.3 ± .5 |
| 30 | 12.0 ± .3 | 17.7 ± .9 |
| 40 | 12.1 ± .4 | 17.2 ± .7 |
| 50 | 12.2 ± .7 | 17.7 ± 1.2 |

Table IV. IQUAD STUDY

## VIII PBAR INJECTION

What about pbars? Do they suffer a similar fate? Stan Pruss helped make figure 19 which again plots Tev emittance as a function of MR emittance. What is nice about this data is that the pbar emittances are usually smaller than proton emittances so that we can use shots to look in a different range than normal proton emittances. The fit to the proton data shown in figure 5 is good in this range so we have overlaid the pbar data on the proton data with the curve merely to guide the eye to the trend of the proton data and the results are shown in figure 20. The lower envelope of the pbar data and the proton curve nicely overlap, and the fact that there is an upward scatter of the pbar data reflects the fact that steering errors can make things worse. There does appear to be the same qualitative behavior in the proton and pbar data.

## IX SUMMARY

We have learned that:

1. There may some scraping at 15-20Π
2. Dispersion mismatch is not a big effect
   a. calculated to be .5Π for coalesced
   b. measured to be small
   c. momentum mismatch not big effect
3. There is a .5Π blowup from the vacuum window
4. Steering is important and calculable
   a. coupling can be confusing but ILAM studies made sense
   b. Shot 4749 analysis made sense
5. Shot 4749 demonstrates there is a residual problem after steering and momentum mismatch effects are taken into account.
6. MR to MR shows (1Π + [+3Π or factor of 1.3])/2
7. T:IQUAD is probably ok but had a factor of 2 error in readback
8. The minimum Tev emittance can be parametrized in terms of the MR emittance (with no scraping) as E(Tev) = 1Π + 1.35E(MR). The 1Π can be considered to be the sum of the window and dispersion mismatch, and the difference in the slope from 1 can be considered to be compounded of lattice function mismatches between the two rings and scale errors at the flying wire.

## X CONCLUSION

There is an amount of emittance growth that is probably related to a mismatch in $\beta,\alpha$ between the MR and the Tev. The exact amount is difficult to tell since the mismatch also affects the $\beta$ at the flying wire. A better estimate of the $\beta$ function of the flying wire along with a knowledge of $\beta,\alpha$ at the injection point would enable a calculation that would tell us if there is anything else we have missed. An indication of the amount of beta function mismatch at E11 necessary for a given emittance blowup is given in table V.

| BETA AT E11 | MULTIPLIER |
|---|---|
| 30 | 1.24 |
| 40 | 1.09 |
| 50 | 1.01 |
| 59.449 | 1 |
| 70 | 1.01 |
| 80 | 1.04 |
| 90 | 1.08 |
| 100 | 1.14 |
| 110 | 1.19 |
| 120 | 1.25 |
| 135 | 1.35 |

Table V. Emittance blow up for Beta mismatch at E11.

## RECOMMENDATIONS

These recommendations are not all needed, i.e.. they are not orthogonal.

1. Measure the $\beta,\alpha$ of the MR at the D49 BPM and predict $\beta,\alpha$ at the upstream end of the MR Lambertsons. Ming-Jen Yang and Guan Wu are working on this.

2. Measure the $\beta$ function at the MR flying wire.

3. Measure the $\beta$ function at the Tev flying wire.

4. Predict the $\beta,\alpha$ at the upstream end of the E11 Tev Quads.

5. Repeat the variation of MR emittances but reinject back into the MR. This would be a very clear indicator of the type of blowup.

## REFERENCES


1. M. J. Syphers, Injection Mismatch and Phase Space Dilution, FN-458
2. D. A. Edwards and M.J. Syphers, An introduction the Physics of High Energy Accelerators, John Wiley and Sons 1993
3. Ioanis Kourbanis, private communication
4. Fermilab Mechanical drawing 8000-MC-142329

APPENDIX
(From FN-458)


Summary

The transverse phase space dilution factors due to injection amplitude function, position, and dispersion function errors are given by

$$F_\beta \sim \frac{\sigma^2}{\sigma_o^2} = 1 + \frac{1}{2}\left[\frac{(\Delta\beta/\beta)_{eq}}{\sqrt{1 + (\Delta\beta/\beta)_{eq}}}\right]^2 = D$$

where $\left(\frac{\Delta\beta}{\beta}\right)_{eq} \equiv (D - 1) + \sqrt{D^2 - 1}$

and $D = \frac{1}{2}\left[\beta_1\gamma_2 + \beta_2\gamma_1 - 2\alpha_1\alpha_2\right]$ ;

$$F_x \sim \frac{\sigma^2}{\sigma_o^2} = 1 + \frac{1}{2}\left[\frac{\Delta x_{eq}}{\sigma_o}\right]^2$$

$\Rightarrow$ independent of initial $\mathcal{E}$

where $\Delta x_{eq} \equiv \sqrt{\Delta x^2 + \left(\beta\Delta x' + \alpha\Delta x\right)^2}$ ;

$$F_D \sim \frac{\sigma^2}{\sigma_o^2} = 1 + \frac{1}{2}\left[\frac{\Delta D_{eq}\sigma_p}{\sigma_o}\right]^2$$

$\Rightarrow \frac{1}{2}\pi$

$\Rightarrow$ independent of initial $\mathcal{E}$

where $\Delta D_{eq} \equiv \sqrt{\Delta D^2 + \left(\beta\Delta D' + \alpha\Delta D\right)^2}$ .

Note: $\sigma_o \equiv \sqrt{\frac{\epsilon_n\beta_o}{6\pi(\gamma\beta)}}$


multiple scattering
in .002 Ti window

$\Rightarrow \Delta\mathcal{E} \sim 6\pi(\beta\gamma)\frac{\beta\Theta^2}{2} = \frac{1}{2}\pi$

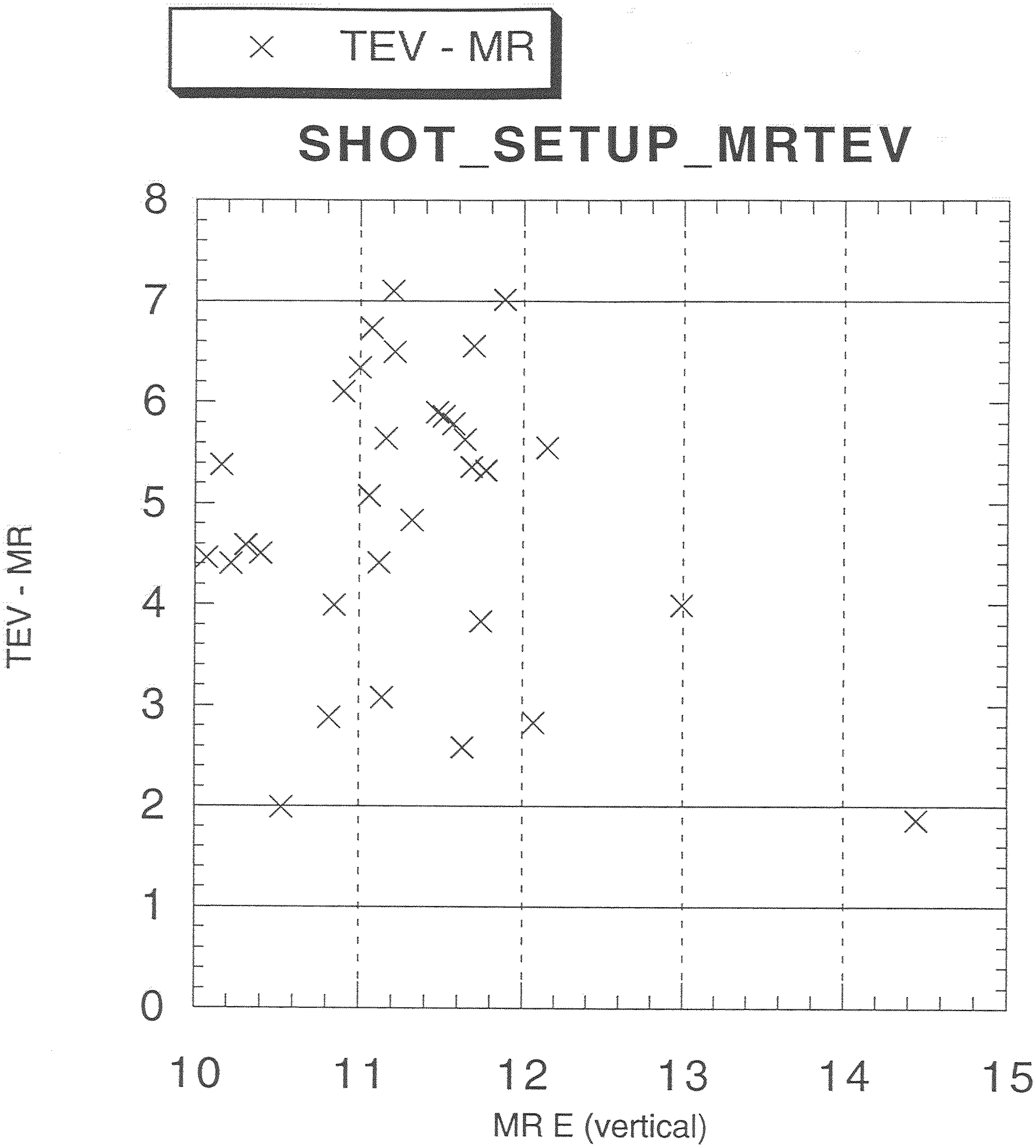
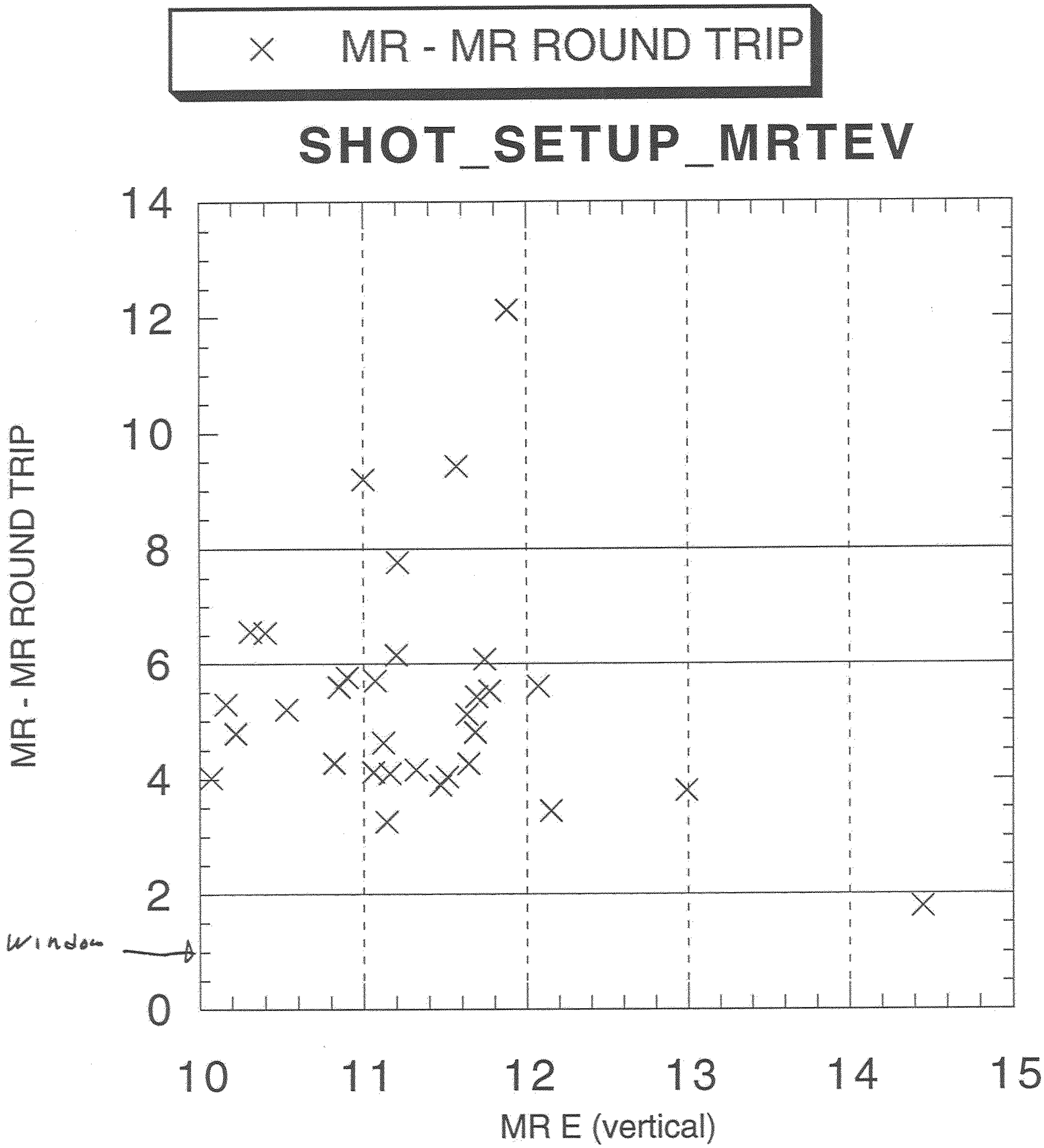

TEV - MR
SHOT_SETUP_MRTEV
8
7
6
5
4
3
2
1
0
TEV - MR
10
11
12
13
14
15
MR E (vertical)

Figure 1.



MR - MR ROUND TRIP
SHOT_SETUP_MRTEV
14
12
10
8
6
4
2
0
MR - MR ROUND TRIP
Window
10
11
12
13
14
15
MR E (vertical)


Figure 2.

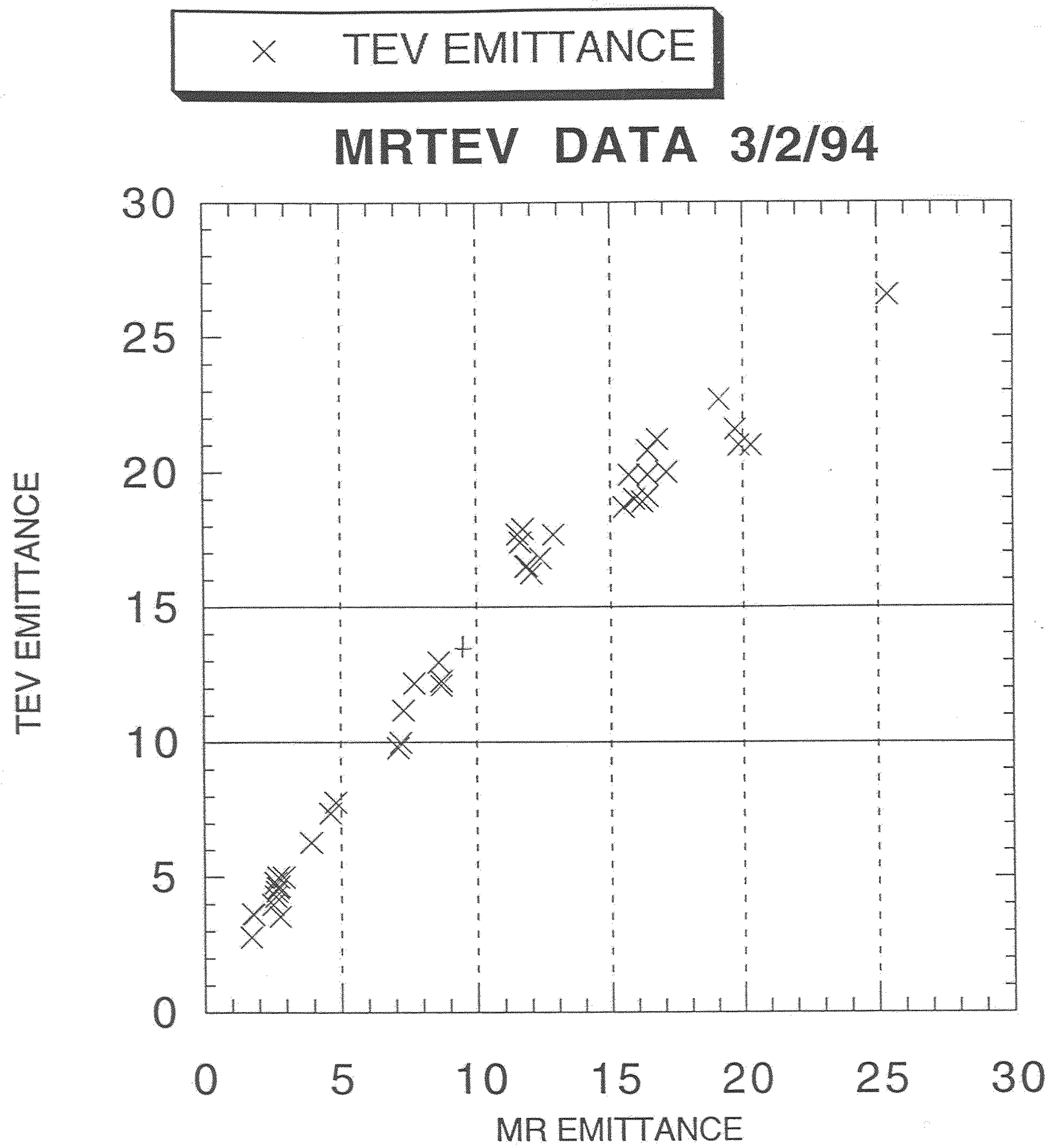



Figure 3.

+ uncoalesced

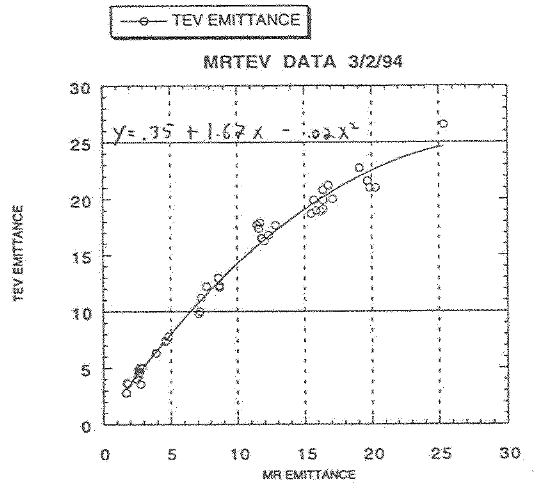



Figure 5

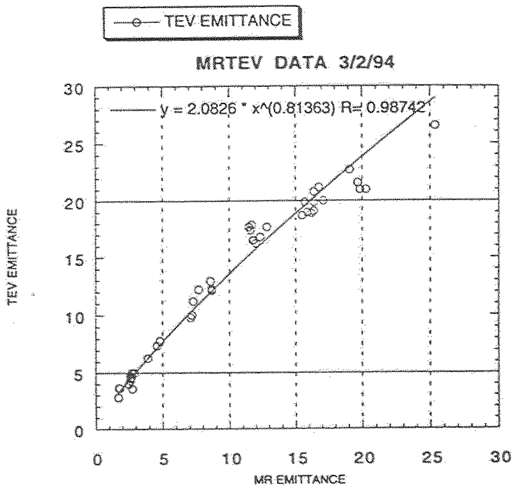



Figure 6

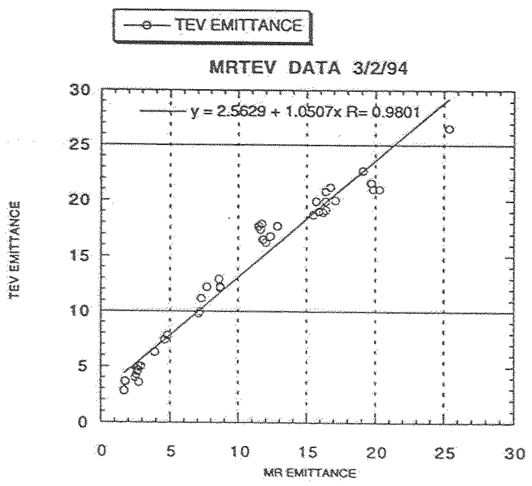



Figure 4.

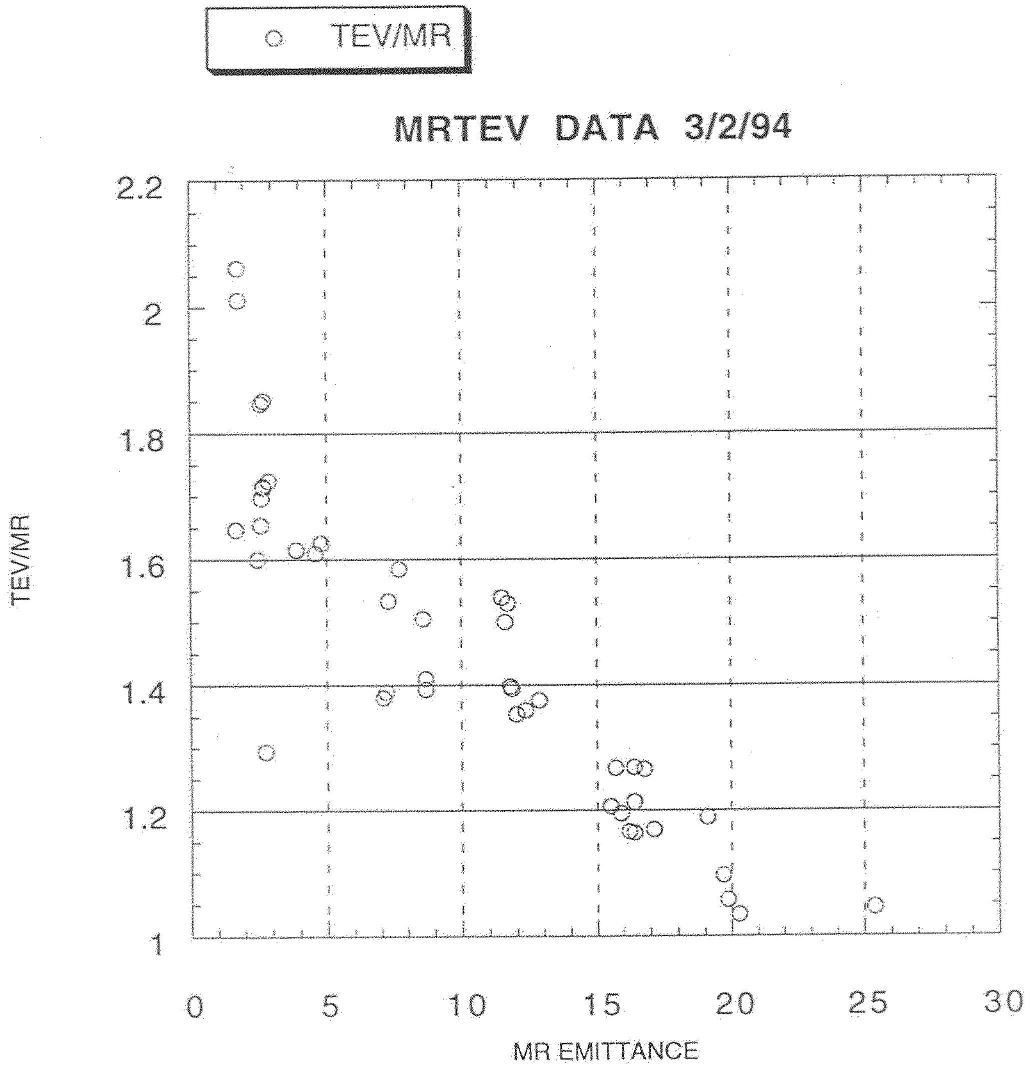
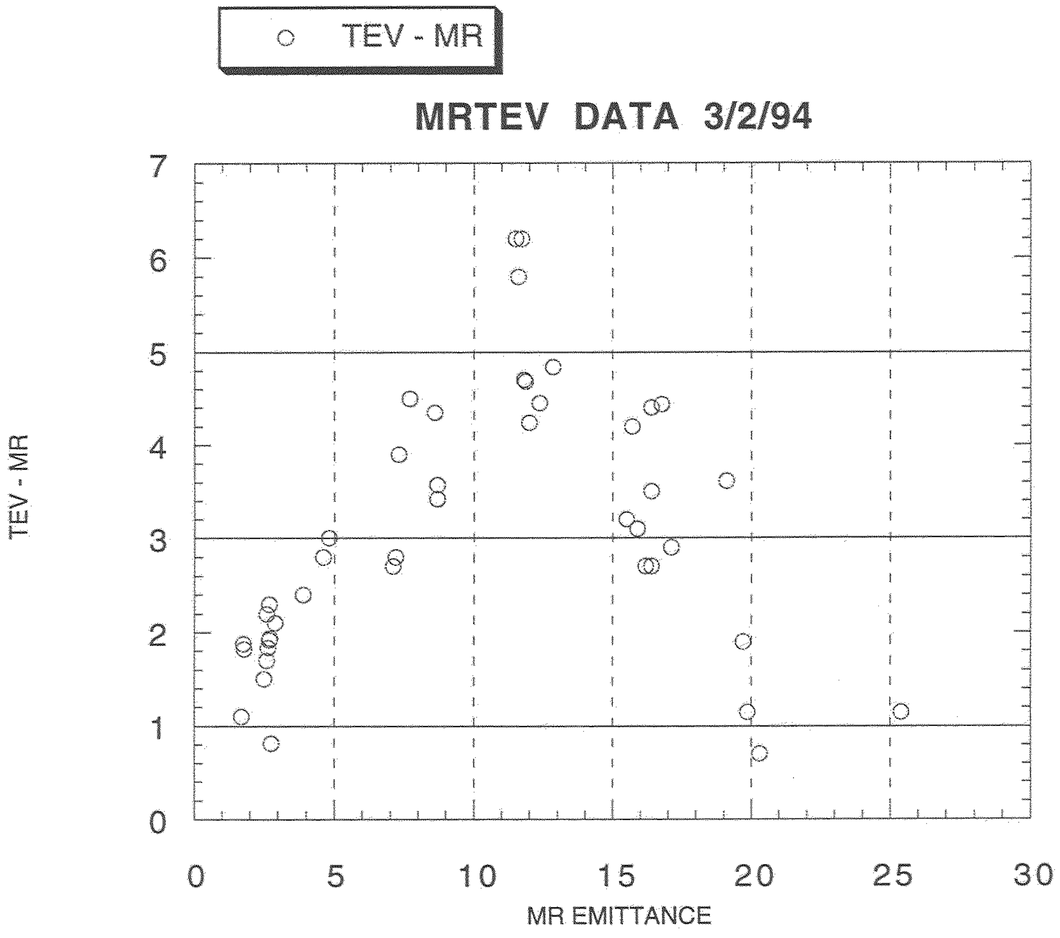
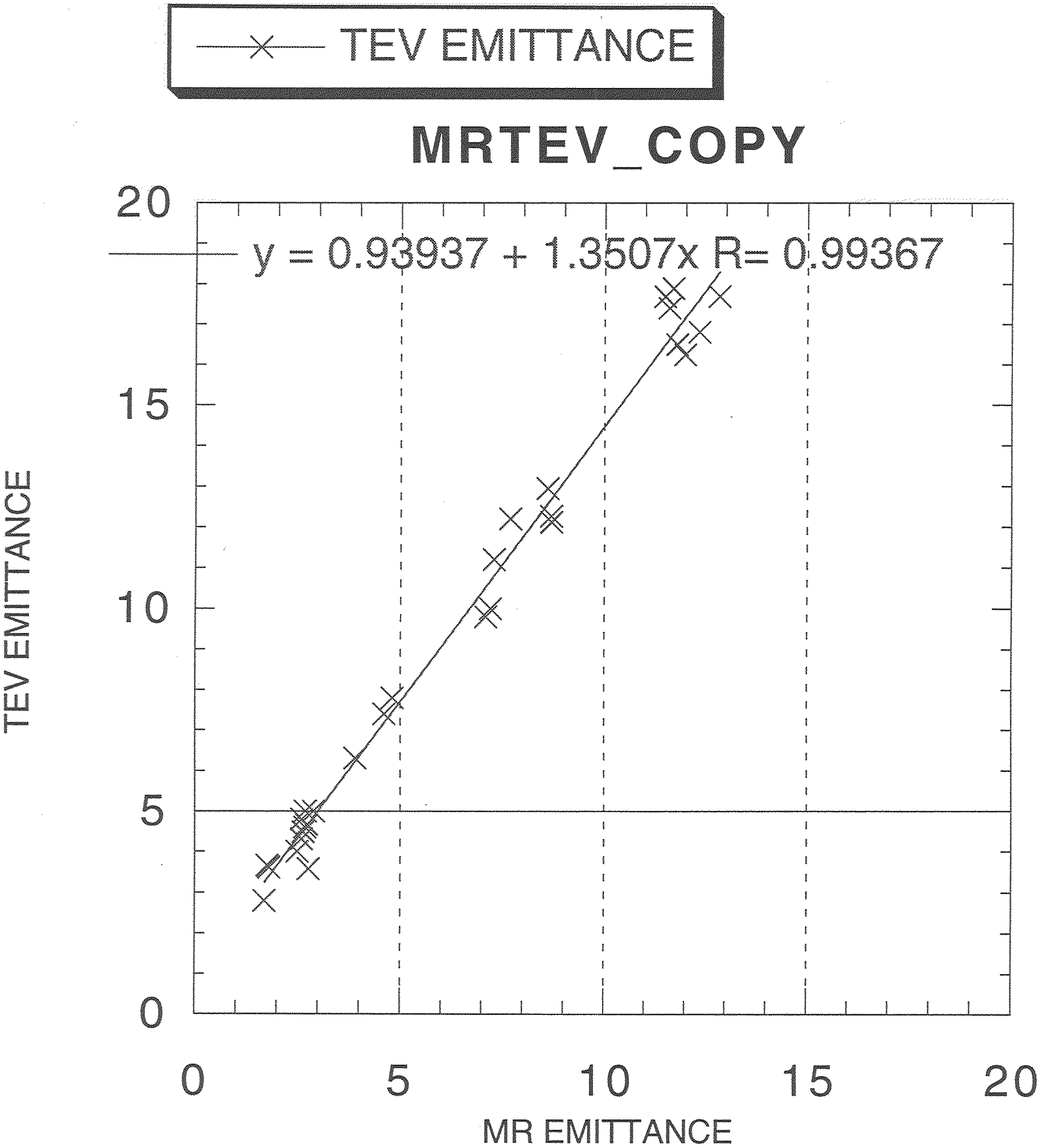

TEV/MR
MRTEV DATA 3/2/94
2.2
2
1.8
1.6
1.4
1.2
1
TEV/MR
0
5
10
15
20
25
30
MR EMITTANCE

Figure 7.



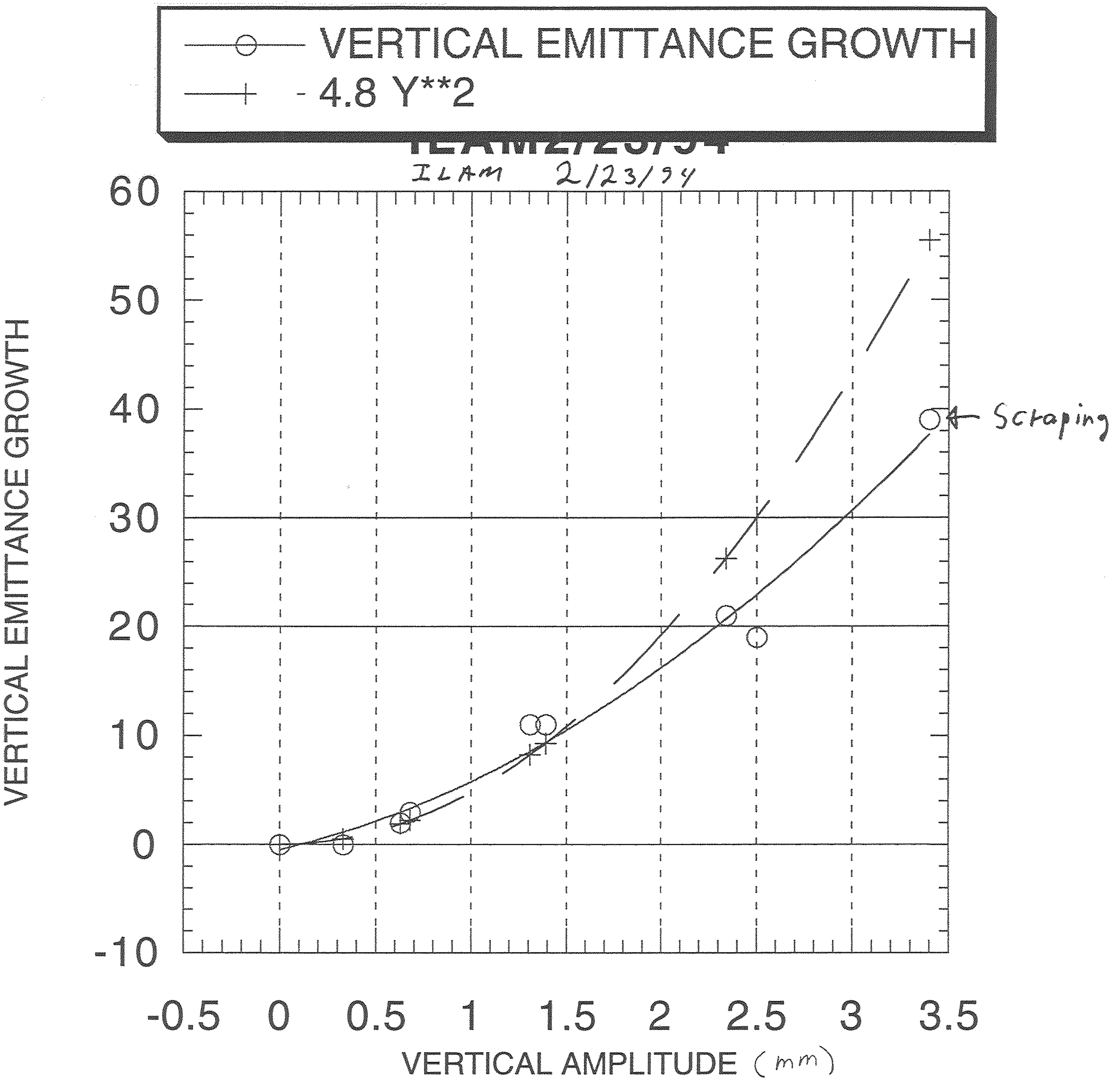
TEV - MR
MRTEV DATA 3/2/94
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
MR EMITTANCE
TEV - MR


Figure 8.



TEV EMITTANCE
MRTEV_COPY
y = 0.93937 + 1.3507x R= 0.99367
TEV EMITTANCE
MR EMITTANCE
0
5
10
15
20


Figure 9.



VERTICAL EMITTANCE GROWTH
- 4.8 Y**2
ILAM 2/23/94
60
50
40
30
20
10
0
-10
VERTICAL EMITTANCE GROWTH
Scraping
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
VERTICAL AMPLITUDE (mm)


Figure 10.

NO neg osc

Console Location 8,
None

16-MAR-1994 16:48

# PROTON VERTICAL FW

SHOT NUMBER 4749 FILE NUMBER 5 MON 14-MAR-94 10:17:57

| | ENERGY | P1 | P2 | P3 | P4 | P5 | P6 | WT.AVG | |
|---|---|---|---|---|---|---|---|---|---|
| Main Ring injection | 8.938 | 10.83 | 9.456 | 10.4 | 11.11 | 8.577 | 12.1 | 10.41 | pi-mm-mrad |
| Main Ring flattop | 150 | 8.213 | 7.786 | 8.305 | 8.455 | 7.962 | 8.382 | 8.183 | pi-mm-mrad |
| Main Ring extraction | 150 | 9.531 | 9.502 | 9.436 | 9.842 | 9.876 | 9.858 | 9.688 | pi-mm-mrad |
| Tevatron P1 injection | 150 | 16.34 | nobeam | nobeam | 532.1 | nobeam | nobeam | 22.1 | pi-mm-mrad |
| Tevatron P2 injection | 150 | 17.06 | 16.94 | nobeam | nobeam | nobeam | nobeam | 17 | pi-mm-mrad |
| Tevatron P3 injection | 150 | 16.39 | 16.76 | 15.78 | nobeam | nobeam | nobeam | 16.32 | pi-mm-mrad |
| Tevatron P4 injection | 150 | 17.15 | 17.67 | 15.85 | 16.66 | nobeam | nobeam | 16.85 | pi-mm-mrad |
| Tevatron P5 injection | 150 | 16.79 | 17.24 | 16.05 | 16.41 | 15.58 | nobeam | 16.39 | pi-mm-mrad |
| Tevatron P6 injection | 150 | 18.03 | 18.1 | 16.86 | 17.09 | 16.99 | 16.47 | 17.23 | pi-mm-mrad |
| Tevatron open helix | 150 | 18.31 | 19.37 | 17.18 | 18.67 | 17.08 | 18.09 | 18.11 | pi-mm-mrad |
| Tevatron A1 injection | 150 | 18.43 | 19.23 | 17.41 | 19.22 | 18.26 | 17.76 | 18.39 | pi-mm-mrad |
| Tevatron A2 injection | 150 | 18.05 | 18.53 | 16.68 | 18.3 | 19.38 | 18.19 | 18.23 | pi-mm-mrad |
| Tevatron A3 injection | 150 | 19.37 | 18.98 | 17.32 | 18.9 | 19.62 | 19.35 | 18.96 | pi-mm-mrad |
| Tevatron A4 injection | 150 | 20.66 | 19.33 | 16.36 | 18.21 | 19.33 | 18.33 | 18.71 | pi-mm-mrad |
| Tevatron A5 injection | 150 | 19.62 | 20.56 | 18.03 | 18.91 | 19.51 | 19.17 | 19.31 | pi-mm-mrad |
| Tevatron A6 injection | 150 | 20.29 | 19.86 | 19.41 | 19.07 | 18.65 | 18.46 | 19.25 | pi-mm-mrad |
| Tevatron before ramp | 150 | 22.49 | 20.92 | 21.58 | 20.39 | 21.08 | 19.47 | 20.94 | pi-mm-mrad |
| Tevatron on ramp | 500 | 25.46 | 23.62 | 24.46 | 22.97 | 24.36 | 22.19 | 23.78 | pi-mm-mrad |
| Tevatron flattop | 900 | 28.53 | 26.72 | 27.52 | 25.64 | 27.37 | 24.99 | 26.73 | pi-mm-mrad |
| Tevatron BD Step 15 | 900 | 31.51 | 29.61 | 30.11 | 28.66 | 30.1 | 27.7 | 29.55 | pi-mm-mrad |
| Tevatron collisions | 900 | 35.32 | 32.79 | 33.24 | 32.69 | 33.81 | 31.41 | 33.16 | pi-mm-mrad |
| | | 6.81 | 7.44 | 6.8 | 6.84 | 5.71 | 6.6 | | |
| | | .54 | .67 | .45 | .38 | .3 | .23 | | |
| | $\varepsilon$ | 1.4 | 2.2 | .97 | .7 | .43 | .25 | | |

T:EIBUS1 0 amps
C:B0Q1 85.55 amps

$\Delta \varepsilon_{P_2-P_6}$ should be $4.8[.6^2 - .3^2] = 1.3$ to $1.5$

Figure 11.

1.57

Console Location 8,
Storage Scope Emulation

17-MAR-1994 09:37

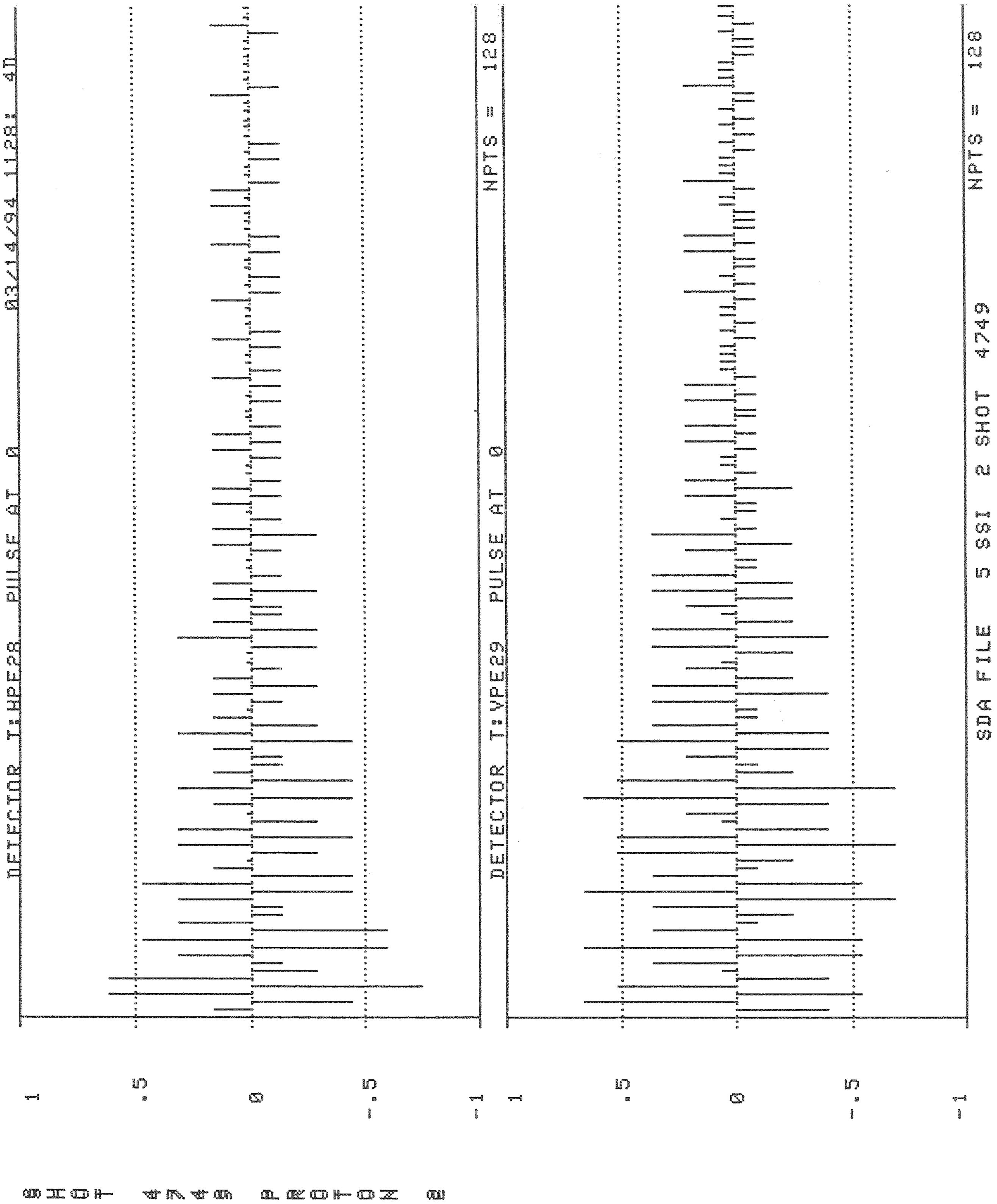



Figure 12.

Console Location 8,
Storage Scope Emulation

16-MAR-1994 16:51

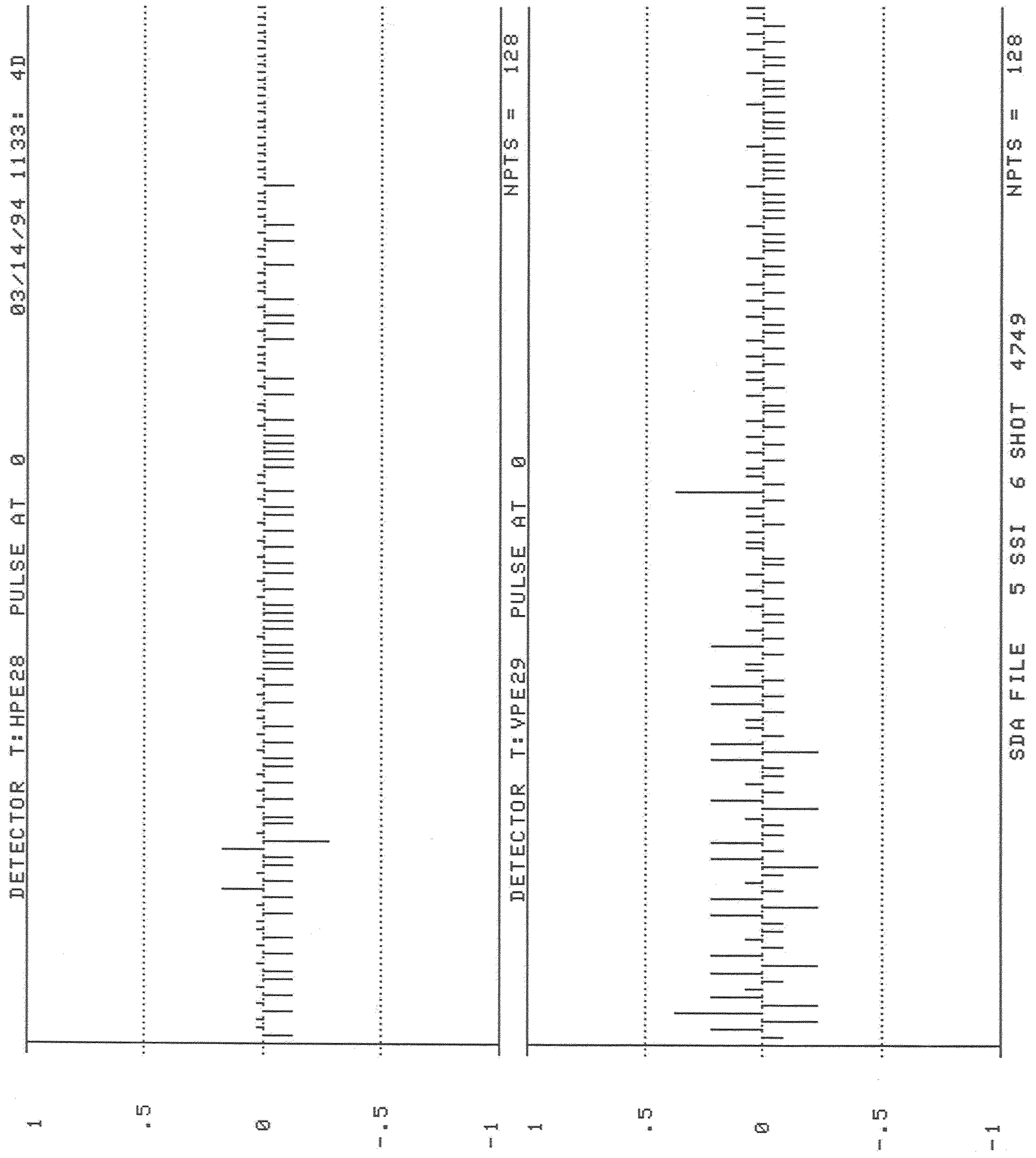



Figure 13.

SHOT 4749 PROTON 6

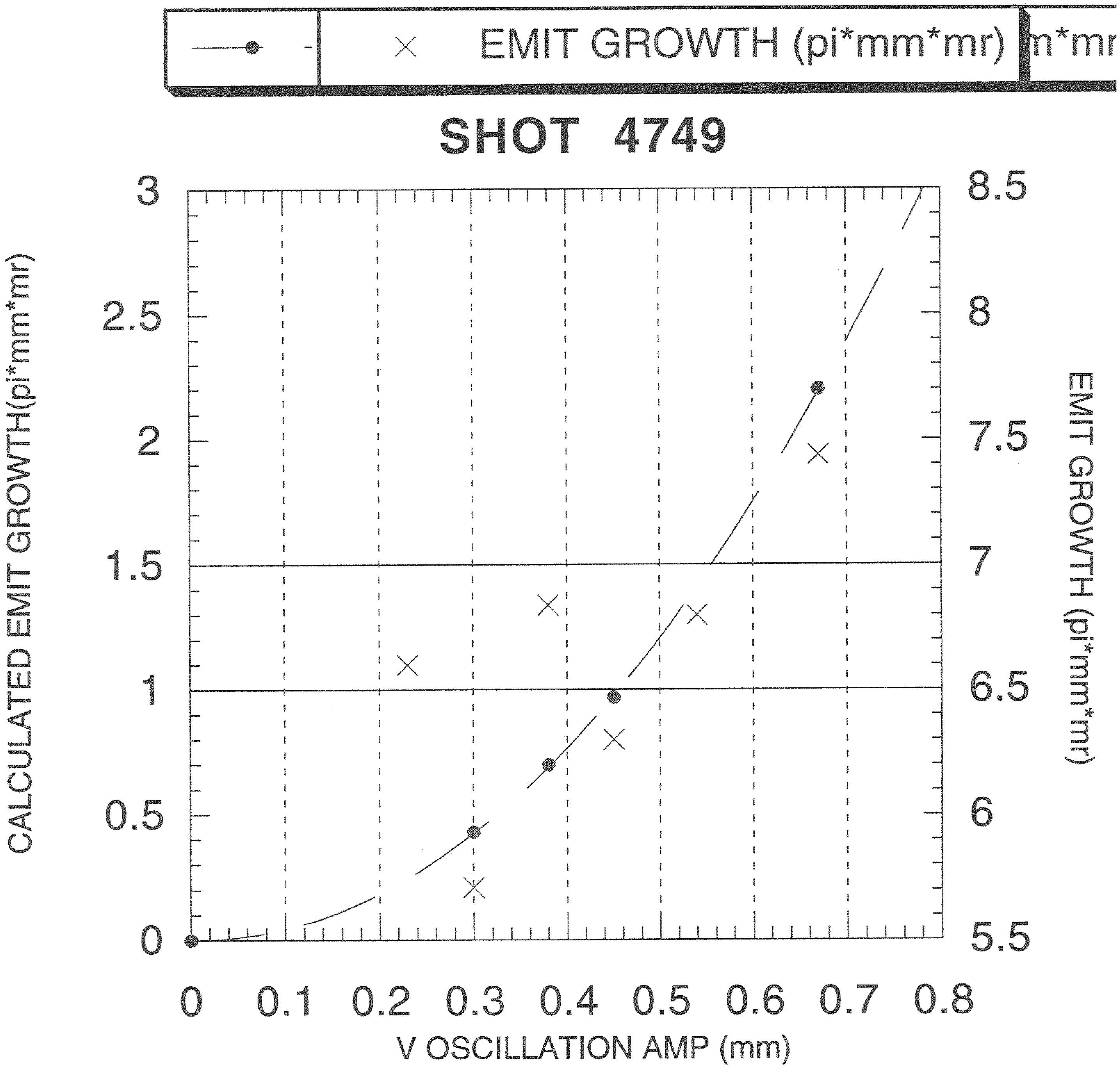

EMIT GROWTH (pi*mm*mr)
n*mr
SHOT 4749
CALCULATED EMIT GROWTH(pi*mm*mr)
EMIT GROWTH (pi*mm*mr)
V OSCILLATION AMP (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.5
1
1.5
2
2.5
3
5.5
6
6.5
7
7.5
8
8.5

Figure 14.

Console Location 8, 16-MAR-1994 16:49
Storage Scope Emulation

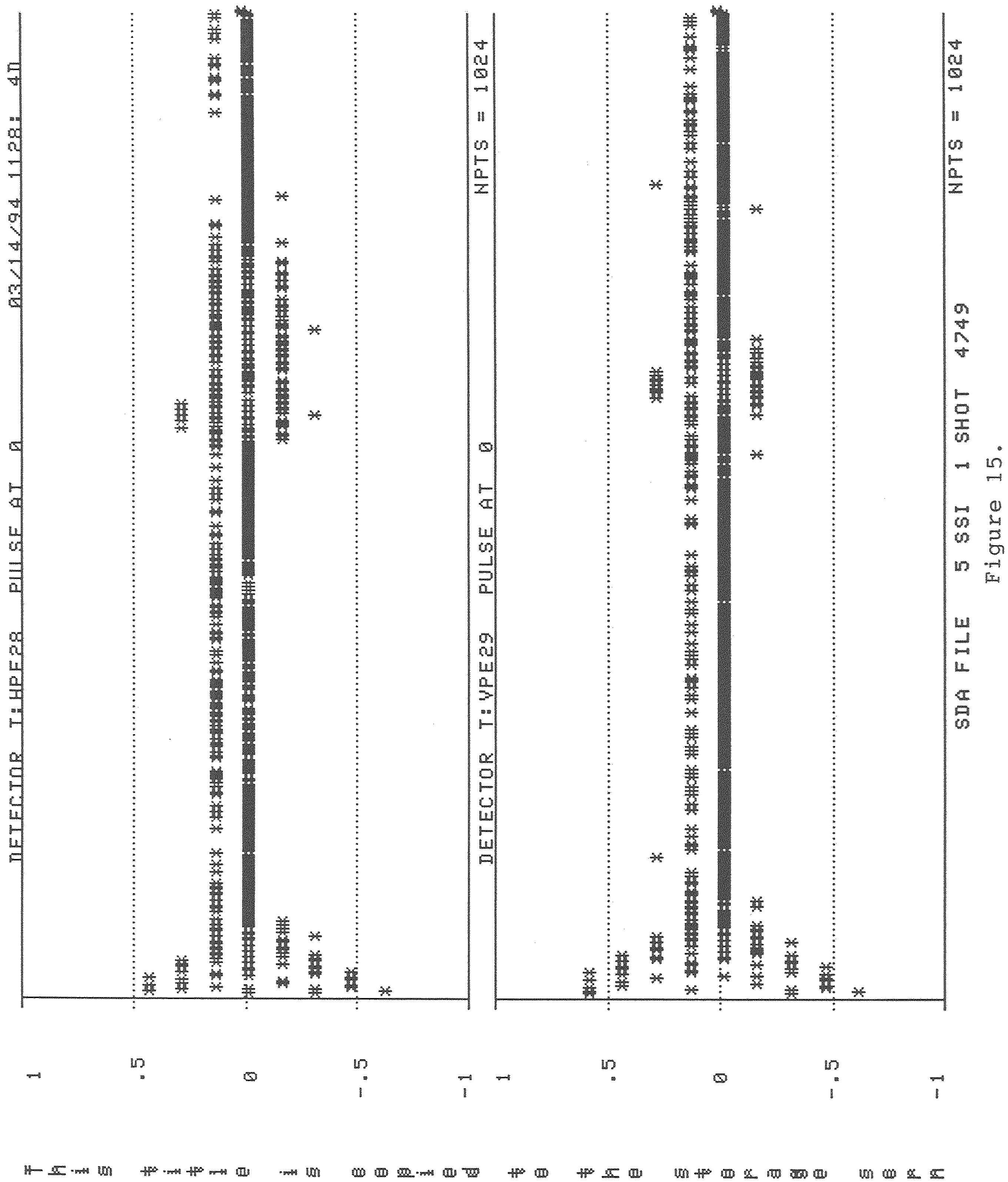



Figure 15.

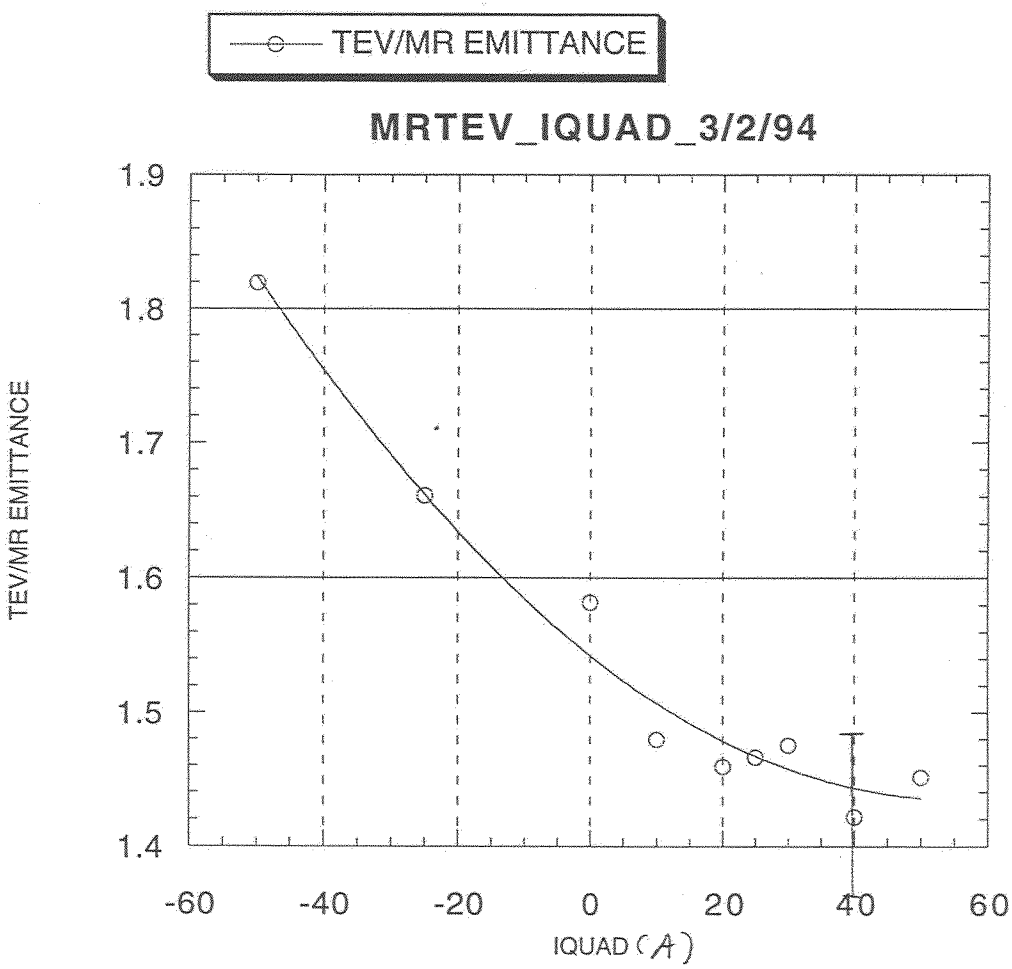


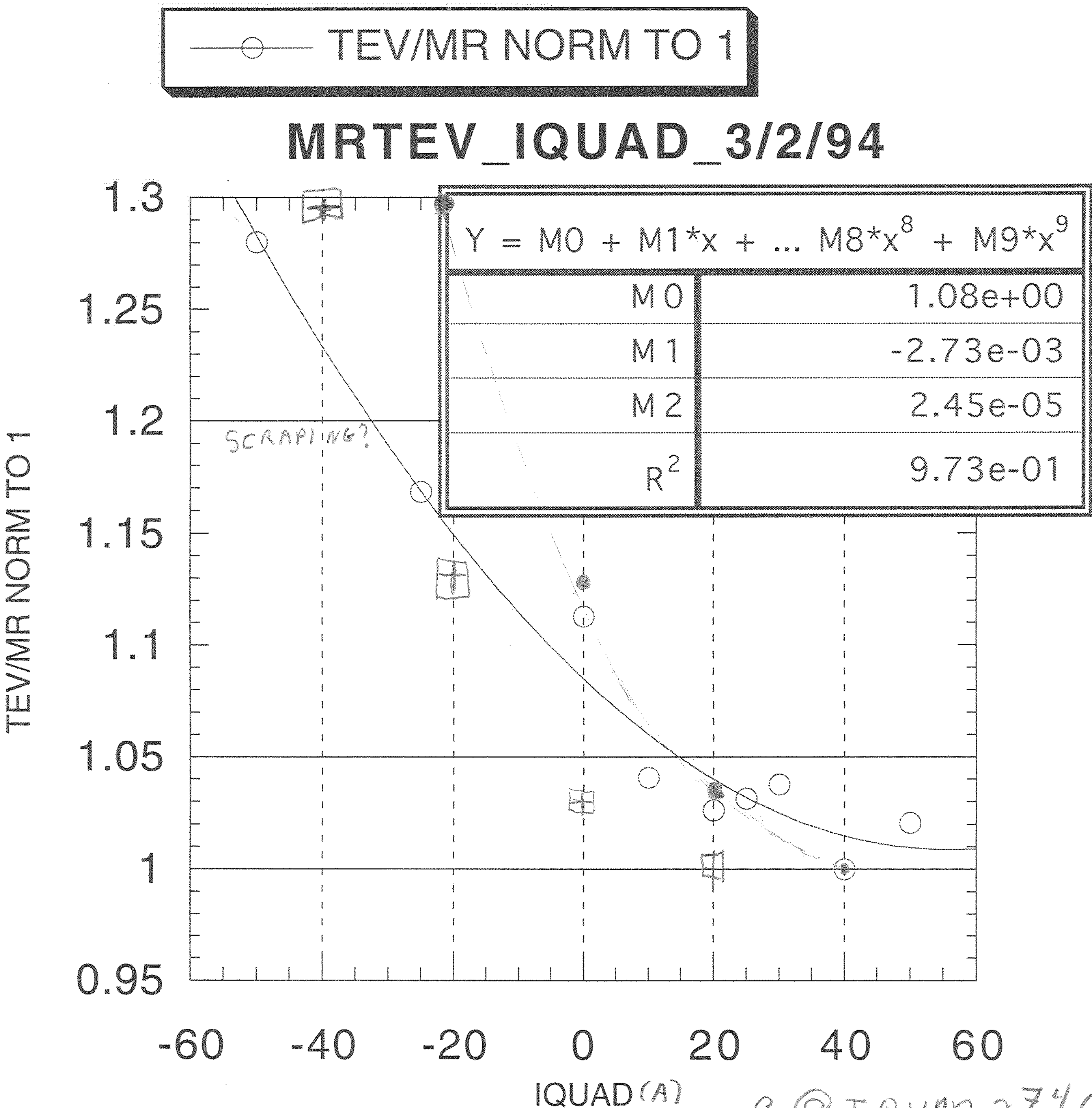

Figure 16.

$MR_{\varepsilon_v} = 12.1 \Rightarrow TeV\,\varepsilon = 17.3\big|_{I=}$

$= 17.4\big|_{I=}$

56 amps $\Rightarrow dy/dx = 0$

$y = 1.54 - .003886x + 3.4884\ 10^{-5} x^2$




β @ IQUAD ~ 74 m

$I_0$ = 40A ⇒ F = 142 m

$$\frac{\sigma^2}{\sigma_0^2} = 1 + \frac{1}{2}\left(\frac{\beta}{F}\right)^2\left(\frac{\Delta I}{I_0}\right)^2$$

$$= 1 + \frac{1}{2}\left(\frac{\beta}{F(I_0)}\right)^2\left[1 - 2\frac{I}{I_0} + \frac{I^2}{I_0^2}\right]$$

• SYPHERS $= 1.13 - 6.5\,10^{-3} * I + 8.2\,10^{-5} * I^2$

○ DATA $= 1.08 - 2.7\,10^{-3} * I + \underbrace{2.45}\,10^{-5}\, I^2$

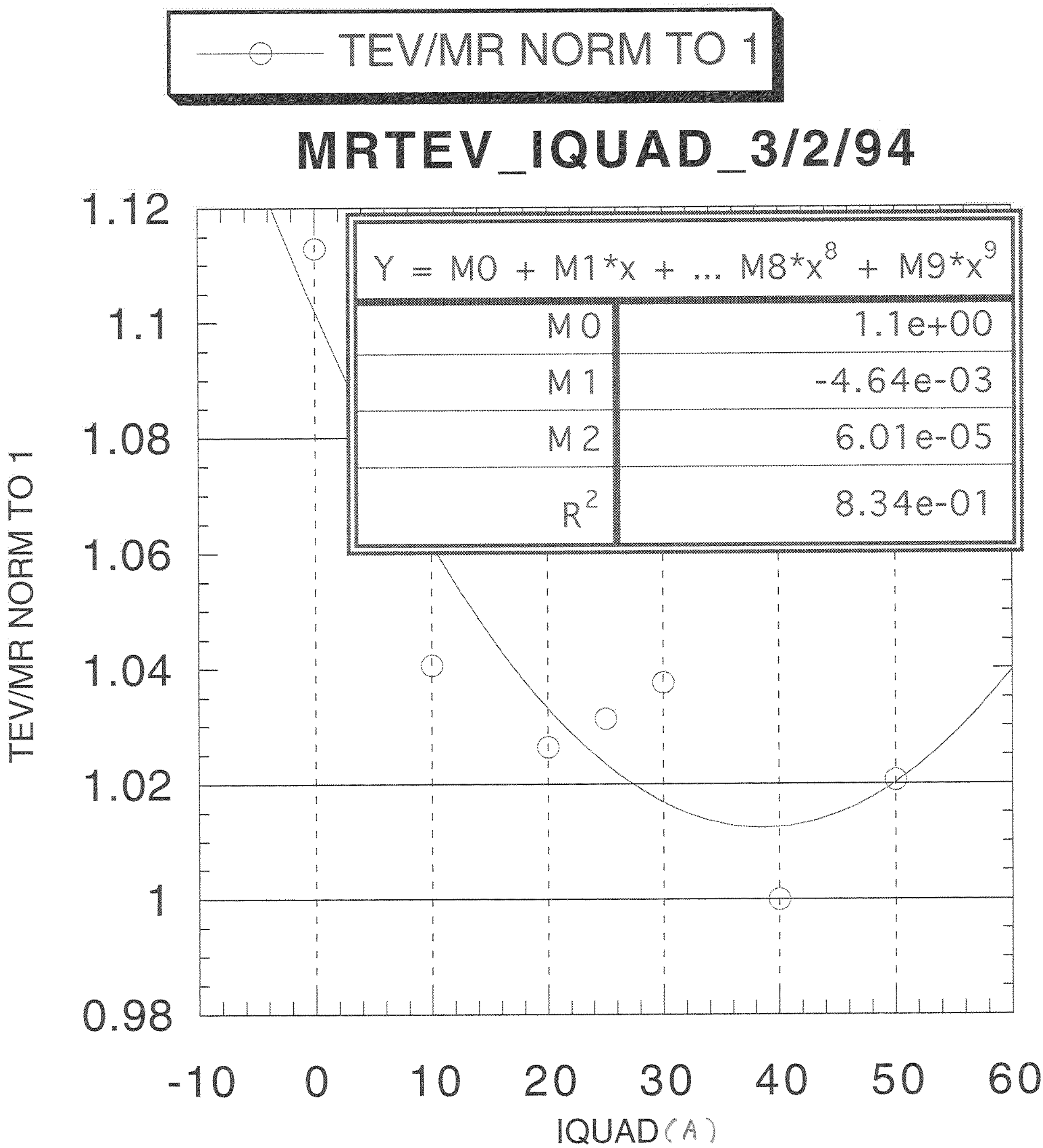
SCRAPING?

+ = Transport + Marriner spread sheet

□ = Syphers @ $I_0$ = 20A

⇒ Same F as Marriner

Figure 17.




SYPHERS $\frac{\sigma^2}{\sigma_0^2} = 1.13 - 6.5\,10^{-3} * I + 8.2\,10^{-5} * I^2$

DATA $= 1.10 - 4.6\,10^{-3} * I + 6.0\,10^{-5} * I^2$

Figure 18.

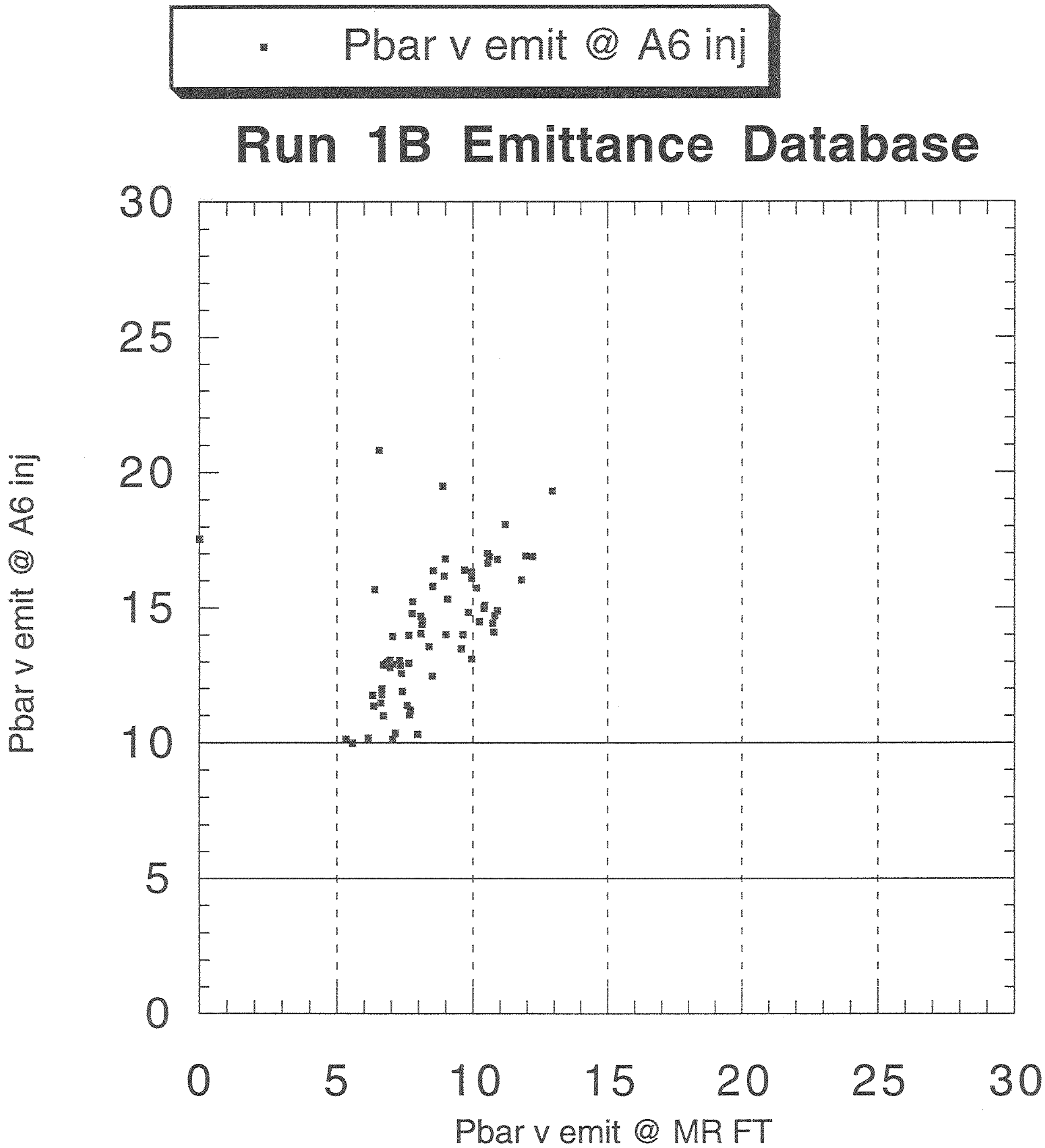

Pbar v emit @ A6 inj
Run 1B Emittance Database
Pbar v emit @ A6 inj
Pbar v emit @ MR FT
0
5
10
15
20
25
30

Figure 19.

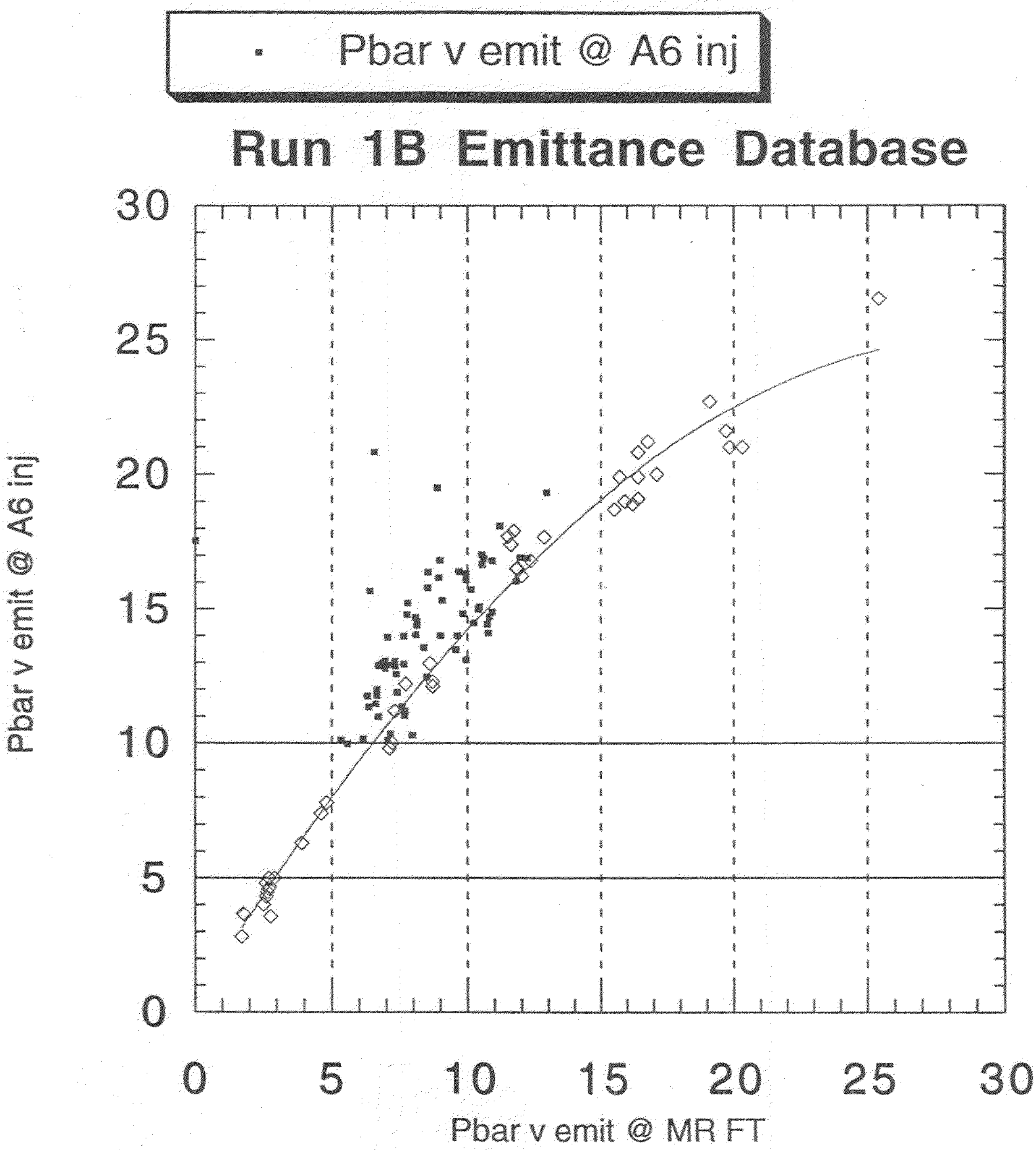

Pbar v emit @ A6 inj
Run 1B Emittance Database
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pbar v emit @ MR FT
Pbar v emit @ A6 inj

Figure 20.