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Wide-Band Neutrino Beams

At 1000 GeV

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I. Introduction

In TM-839[1] S. Mori discussed various broad-band neutrino and antineutrino beams using 1000 GeV protons on target. A new beam (SST) has been designed which provides the same neutrino flux as the quadrupole triplet (QT) while suppressing the wrong sign flux by a factor of 18. It also provides more than twice as much high energy antineutrino flux than the sign-selected bare target (SSBT) and in addition, has better neutrino suppression. While it is possible to increase the flux obtained from the single horn system over that listed in TM-839, the conclusion which states "any horn focussing system seems to be of marginal use for Tevatron neutrino physics", is unchanged.

Neutrino and antineutrino event rates and wrong sign backgrounds were computed using NUADA[2] for a 100 metric ton detector of radius 1.5 meters at Lab C. The neutrino and antineutrino cross-sections were taken to be 0.62×10^{-42} *E and 0.30×10^{-42} *E (meter^2/GeV) respectively. The parameterization of FN-341[3] is used for particle production with 1000 GeV protons on target.

Due to radiation considerations and the existing transformer location, the horn beam is placed in its usual position inside the Target Tube. All other beams are placed in Fronthall. Thus, for the wide-band Fronthall trains a decay distance of 520 meters is used, versus 400 meters for the horn train.

II. Single Horn

The horn has been particularly useful in Bubble Chamber experiments because of its high event rate. Figure 1 shows the Mori Horn[4] geometry used at 400 GeV and a configuration that would be more suitable at 1000 GeV. The horn is capable of collecting pions and kaons within a given P_t. Moving the horn further downstream of the target will allow it to focus the same P_t, however one gives up some angular acceptance. For a detector radius of 1.5 meters there is only about a 10% gain in flux with increased distance between the target and the horn. The results of the "increased distance horn" along with the SST are compared in Figure 2. The horn current is 80k Amps, the value used in past running periods, and a value that has proved to be operationally reliable.

III. Quadrupole Triplet(QT) & The Sign-Selected Bare Target (SSBT)

Because of the large mass of the counter experiments and the high flux provided by these wideband beams, most experiments prefer beams that enhance the high energy flux and suppress the low energy component. To study neutral current events, it is also important that these beams achieve a high level of sign-selection, so that neutrino and antineutrino events can be distinguished.

Because of their simplicity, reliability, and because their properties are well understood, the QT and SSBT have seen extensive use in the past at high energy. The quadrupole triplet has been used primarily for neutrinos and the sign-selected bare target has been used for antineutrinos.

Figure 3 shows a comparison between neutrino event rates for Quadrupole Triplet[5] and the SST. The wrong sign background for the SST is reduced significantly with only a minimal loss in event rate.

Figure 4 shows a comparison between antineutrinos event rates for a sign-selected bare target and SST. Since the SST contains quadrupoles it gives a higher event rate, and at the same time has a lower wrong sign background than the SSBT.

IV. Sign-Selected Triplet (SST)

A beam (SST) has been designed which keeps the high neutrino flux of a quad triplet, increases the antineutrino flux over a SSBT and reduces the wrong sign backgrounds of both. The SST is a basic quadrupole triplet between two bending magnets.

The optics of the quadrupoles are set so that 300 GeV/c is point to parallel. At Tevatron energies the high energy secondaries are produced preferentially in the very forward direction. Thus pointing the train axis at small angles away from the 0^0 line between the target and the detectors is sufficient to keep down the wide-band background. For neutrino running, a large amount of flux is lost if the field of the first bending magnet is made large enough to dump the primary protons. The bend value chosen is sufficient to reduced the neutrino wrong sign background to a few percent for neutrino energies greater than 20 GeV. For neutrinos the primary proton beam dumps in Enclosure NW4 (Enclosure 100).

The results of keeping the same angular acceptance, same bending angles and tuning the SST quadrupoles at 600 GeV/c (artificially high gradients which are not attainable with conventional magnets) is shown in Figure 5. The low energy component is suppressed while negligible gains are made at the high energies. This shows it is not worth pursuing a 600 GeV/c solution using conventional magnets for the purpose of increasing the high energy flux.

Similar principles apply to the SST when it is tuned for antineutrinos, except the primary protons must be dumped upstream. This requirement combined with a desire to keep the wrong sign background low led to a different bend angle for neutrino and antineutrino beams. Figure 4 shows that the wrong sign background for the antineutrino SST is a few per cent for energies between 80 GeV/c and about 500 GeV/c. Except at the very lowest energies the SST is superior to the SSBT. At higher and higher antineutrino energies, the wrong sign background continues to grow until it eventualy surpasses the signal.

A schematic of the SST for positives and negatives is shown in Figure 6. Only the primary proton beam position and angle are changed when going from neutrinos to antineutrinos. No elements require physical movement. The position and angle changes are accomplished with two pretarget EPB bending magnets. A list of elements, and field strengths and positions are in Table I.

V. Tuning

As previously mentioned, the wrong sign background is kept low because the high energy production is primarily forward and the bends are kept sufficently high. It should be noted that the axis angle of the train together with the amount of bending done by the train magnets (for all momentum) are equally important factors. For example one may decide to enhance a lower energy range than the SST by scaling the magnet values to that lower energy. In effect when the magnets are scaled the SST begins to look more and more like a pure quadrupole triplet. As the magnets are scaled down, the low energy flux indeed increases but the background increases proportionally faster. When it is important to keep the background low, only the quadrupoles should be scaled, not the bends. Figure 7 illustrates this principle. In one case the SST is tuned at 100 GeV (quads only, keeping the train bends fixed) and in the other all the magnets are scaled to 100 GeV.

Finally it is to be noted that the SST could be transformed into a Quad Triplet by increasing the bend directly upstream of the target to point at 0^0 to the detectors. The train bends are then turned off and the downstream three quadrupoles along with the last bend are moved horizontally less than 1 inch (Dashed line in Figure 6).

Experience from the past quadrupole triplet train shows that the elements that need to be moved will have residual radioactivity levels of 100 to 200 mr/hour after the beam has been off about six months, well within a tolerable level.

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TABLE I.

List of Elements

Z Center	X Center	Y Center	Element	Field	Comment
3018.3	-0.65	744.99	H. EPB Bend	15.3	7.6 for $\bar{\nu}$
3029.3	-0.66	745.02	V. EPB Bend	16.1	
3040.3	-0.68	745.04	V. EPB Bend	16.1	
3075.5	-0.72	745.04	H. EPB Bend	-10.9	15.1 for $\bar{\nu}$
3083.5	-0.73	745.04	Target		
3089.0	-0.73	745.04	Collimator		
3098.5	-0.73	745.04	EPB Bend	-6.0	-15.2 for $\bar{\nu}$
3110.0	-0.72	745.04	3Q120	-5.0	
3120.5	-0.72	745.04	Beam Dump #1		
3132.5	-0.71	745.04	Beam Dump #2		
3144.0	-0.70	745.04	4Q120	+4.6	
3155.5	-0.69	745.04	4Q120	+4.6	
3181.5	-0.67	745.04	4Q120	-5.5	
3193.0	-0.66	745.04	4-5-72 Bend	+6.7	

TABLE II.

Total charged current and neutral current event rates for a detector of radius 1.5 meters, 10^{13} incident protons, and 100 metric tons.

TRAIN	ν	$\bar{\nu}$
Horn (80 k Amps)	13.32	0.63
300 GeV Quad Triplet	9.92	1.62
600 GeV Quad Triplet	3.41	0.39
$\bar{\nu}$ SSBT	0.03	1.01
ν SST	8.45	0.09
$\bar{\nu}$ SST	0.04	1.07

References

1. S. Mori, Do We Need a Horn for Tevatron Neutrino Physics, TM-839, December 26, 1978.

2. D.C. Carey, NUADA - A Neutrino Flux Computer Program, June, 1975.

3. A. Malensek, Empirical Formula for Thick Target Particle Production, Fn-341, October 12, 1981.

4. S. Mori, Wide-Band Single Horn System II, TM-720, February 16, 1977.

5. L. Stutte, presented at the Neutrino Workshop at Fermilab, November 30, 1982.

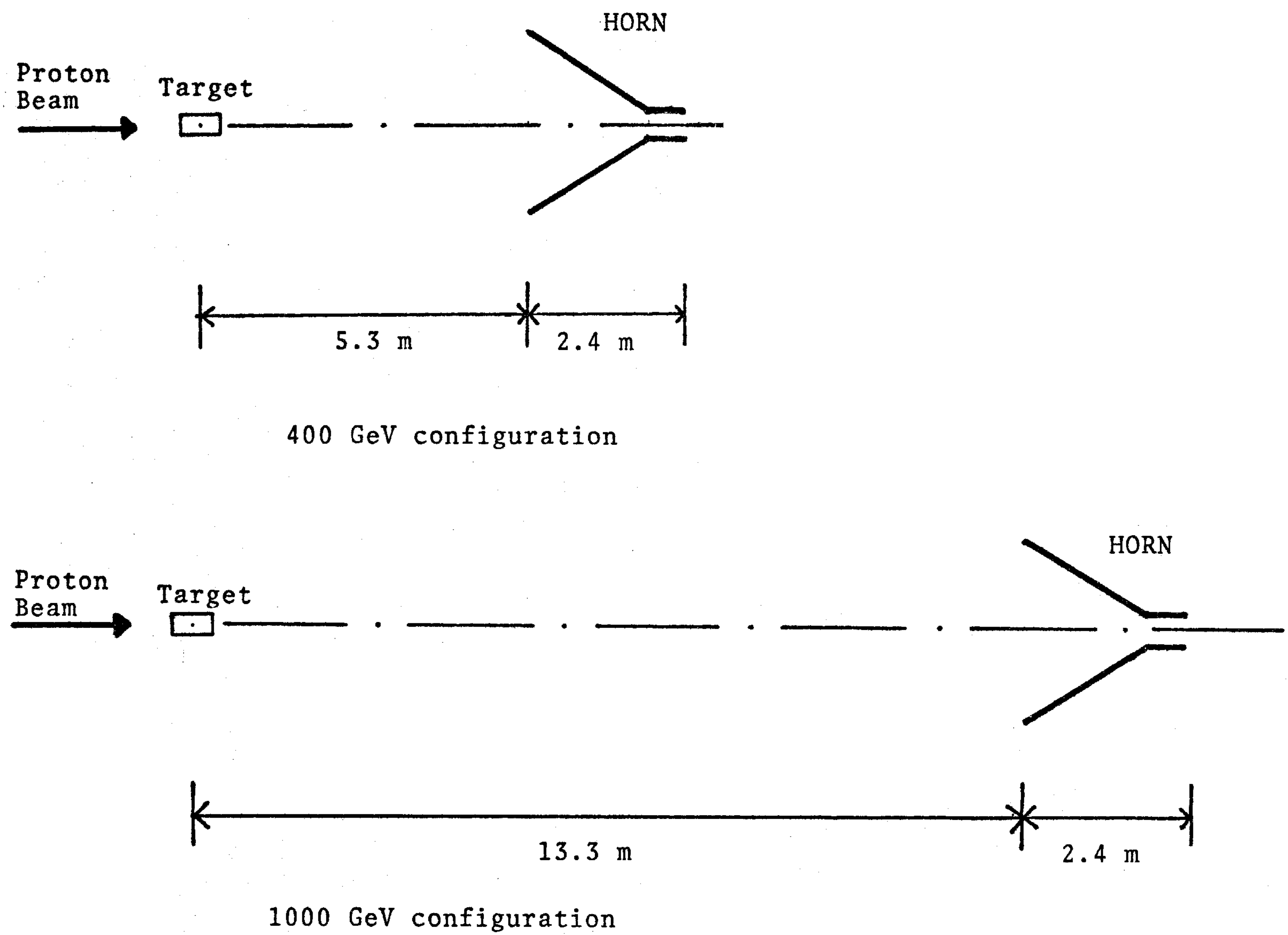

HORN
Proton Beam
Target
5.3 m
2.4 m
400 GeV configuration
HORN
Proton Beam
Target
13.3 m
2.4 m
1000 GeV configuration

FIGURE 1

Neutrino Event Rate/GeV/10^{13}/100 Tons

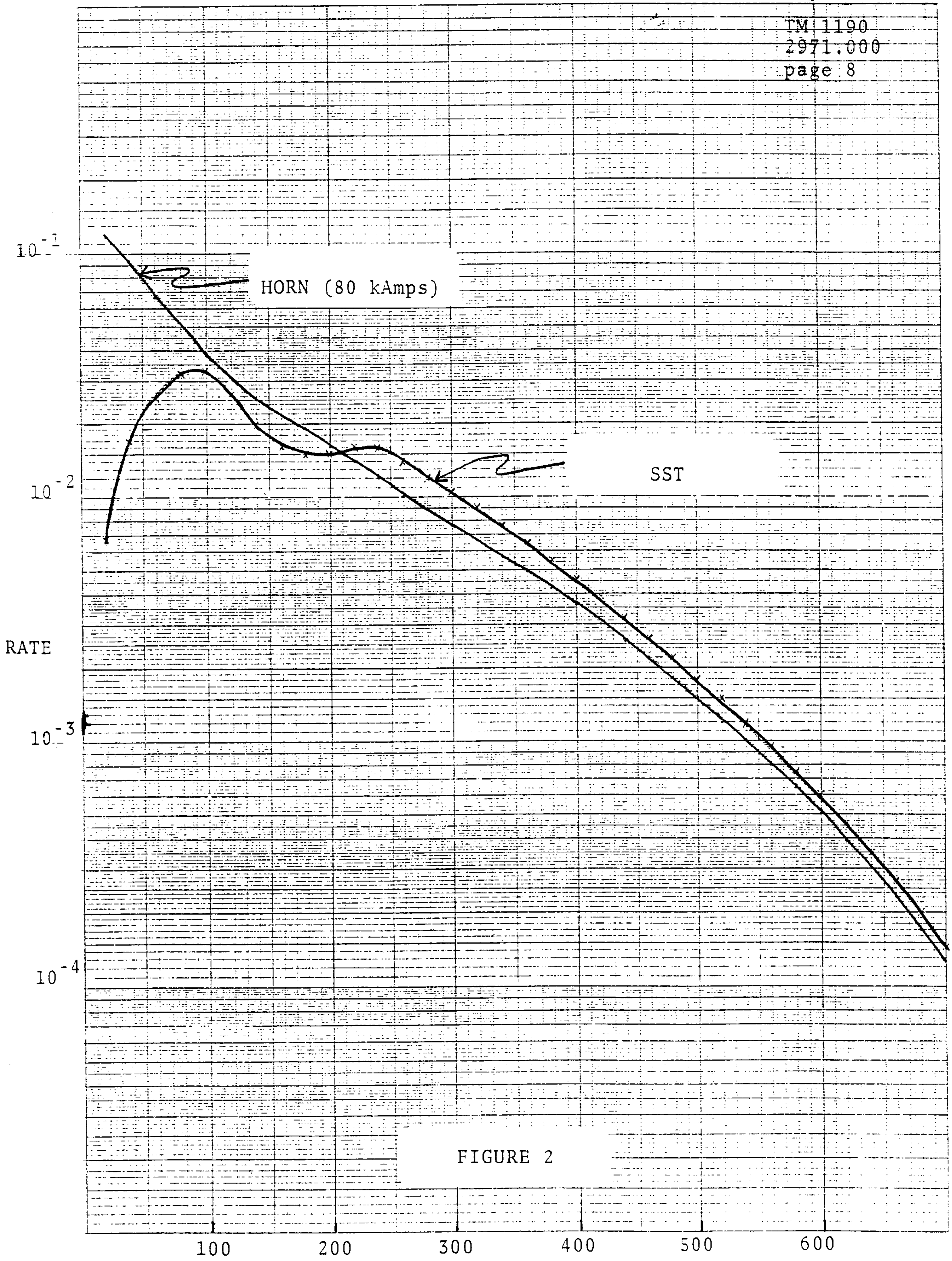


FIGURE 2

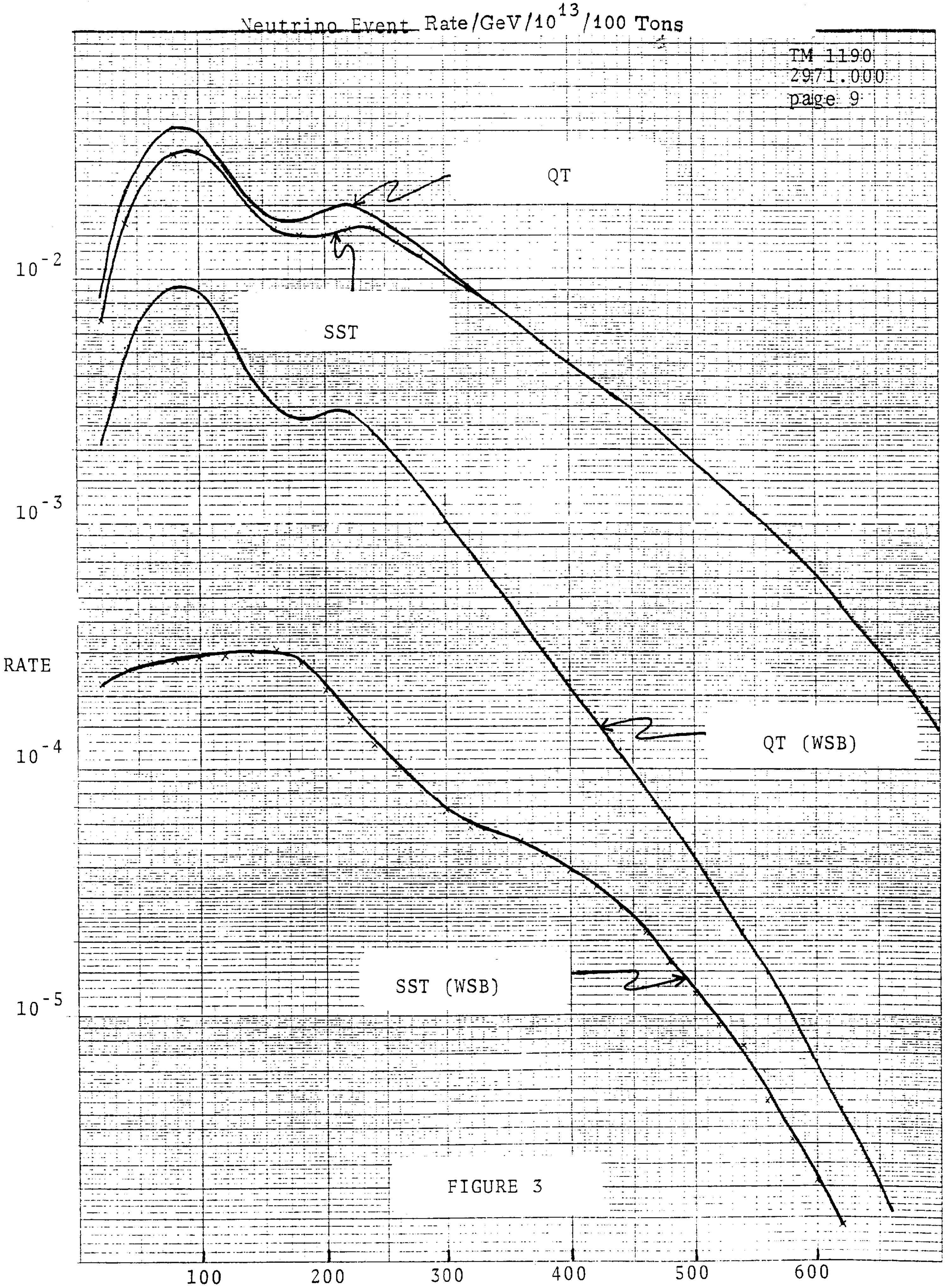

Neutrino Event Rate/GeV/10^13/100 Tons
QT
SST
QT (WSB)
SST (WSB)
RATE
10^-2
10^-3
10^-4
10^-5
100
200
300
400
500
600

FIGURE 3

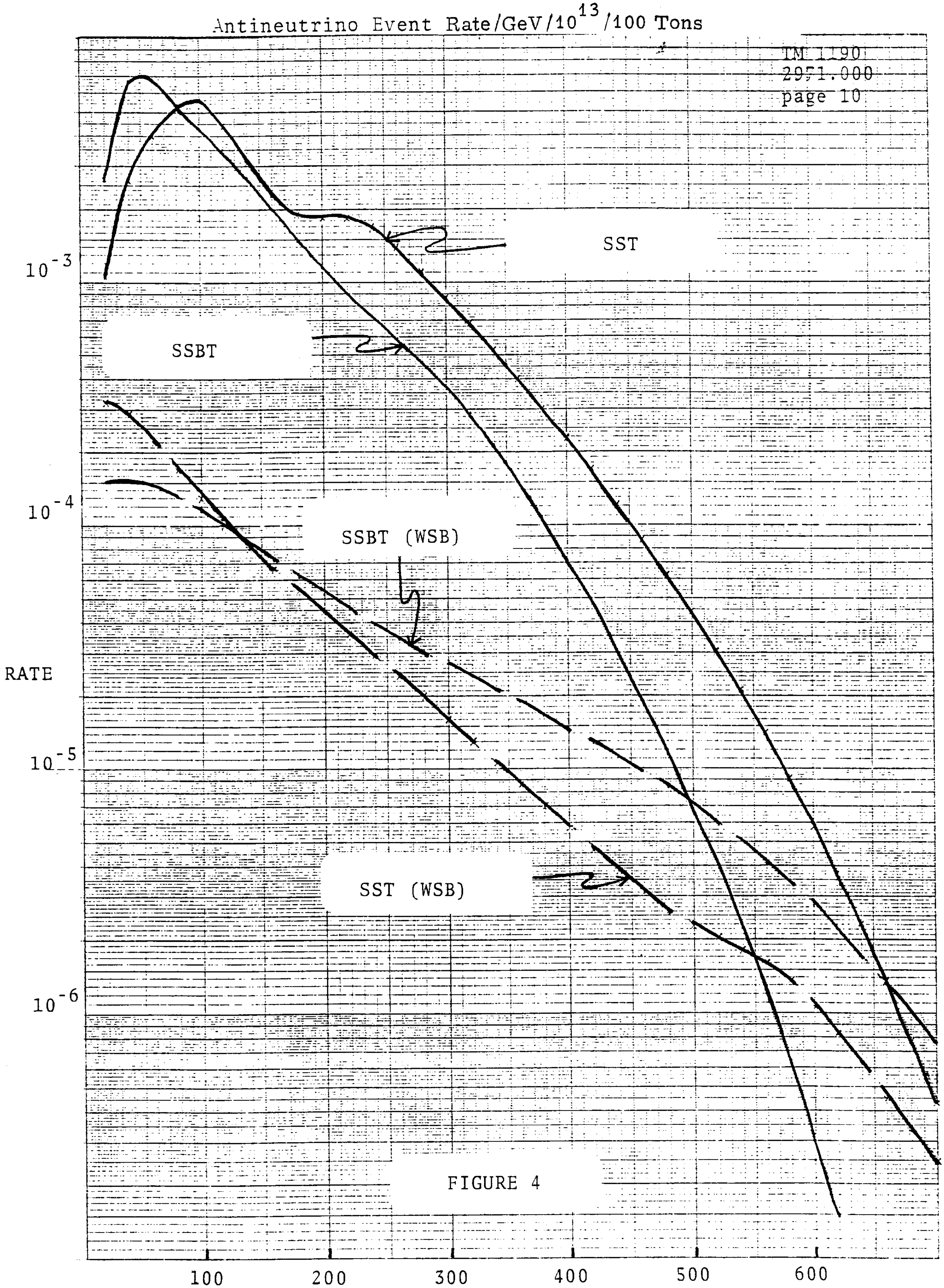

Antineutrino Event Rate/GeV/10^{13}/100 Tons
RATE
10^{-3}
10^{-4}
10^{-5}
10^{-6}
SST
SSBT
SSBT (WSB)
SST (WSB)
100
200
300
400
500
600

FIGURE 4

Neutrino Event Rate/GeV/10^{13}/100 Tons

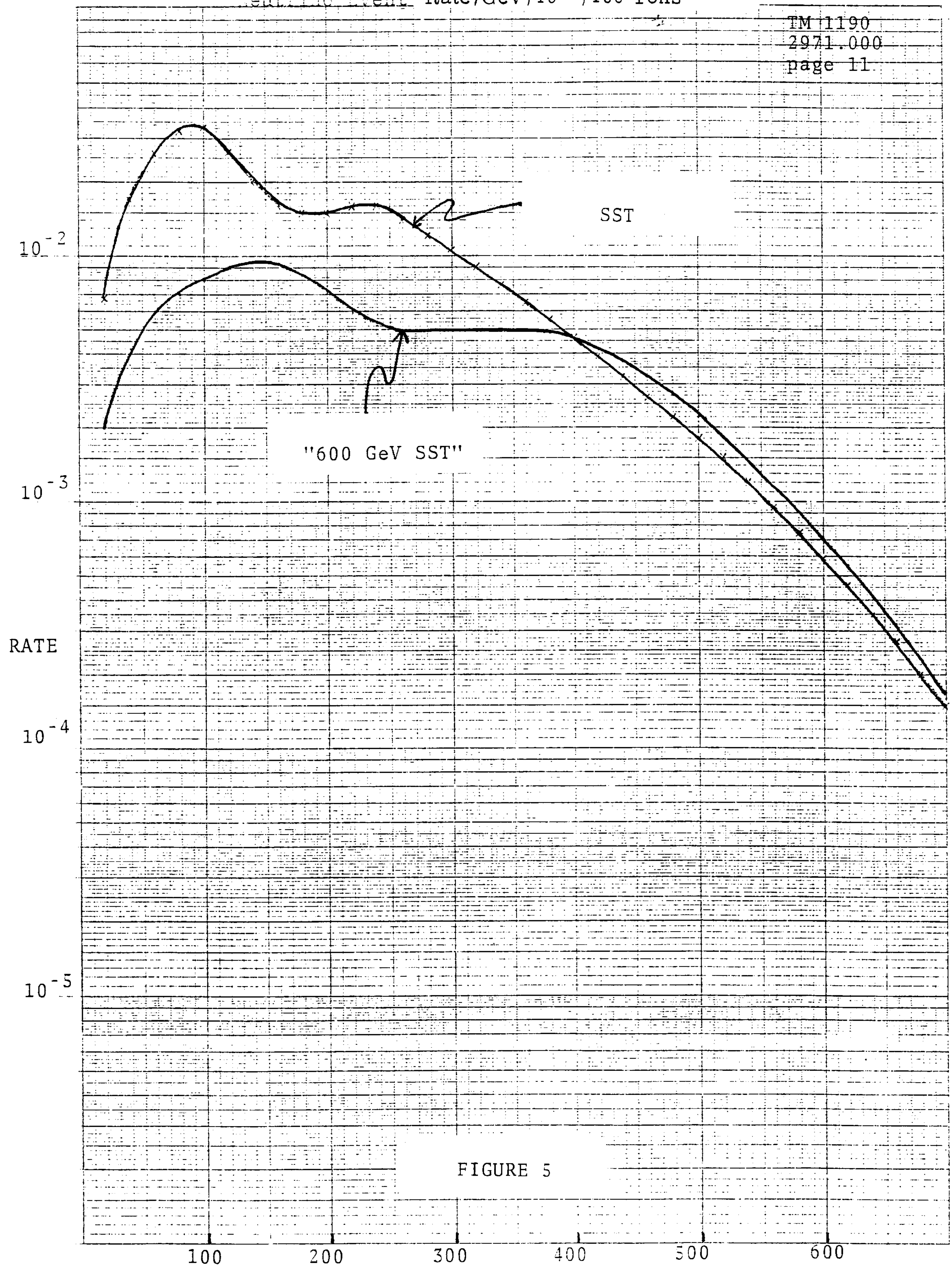
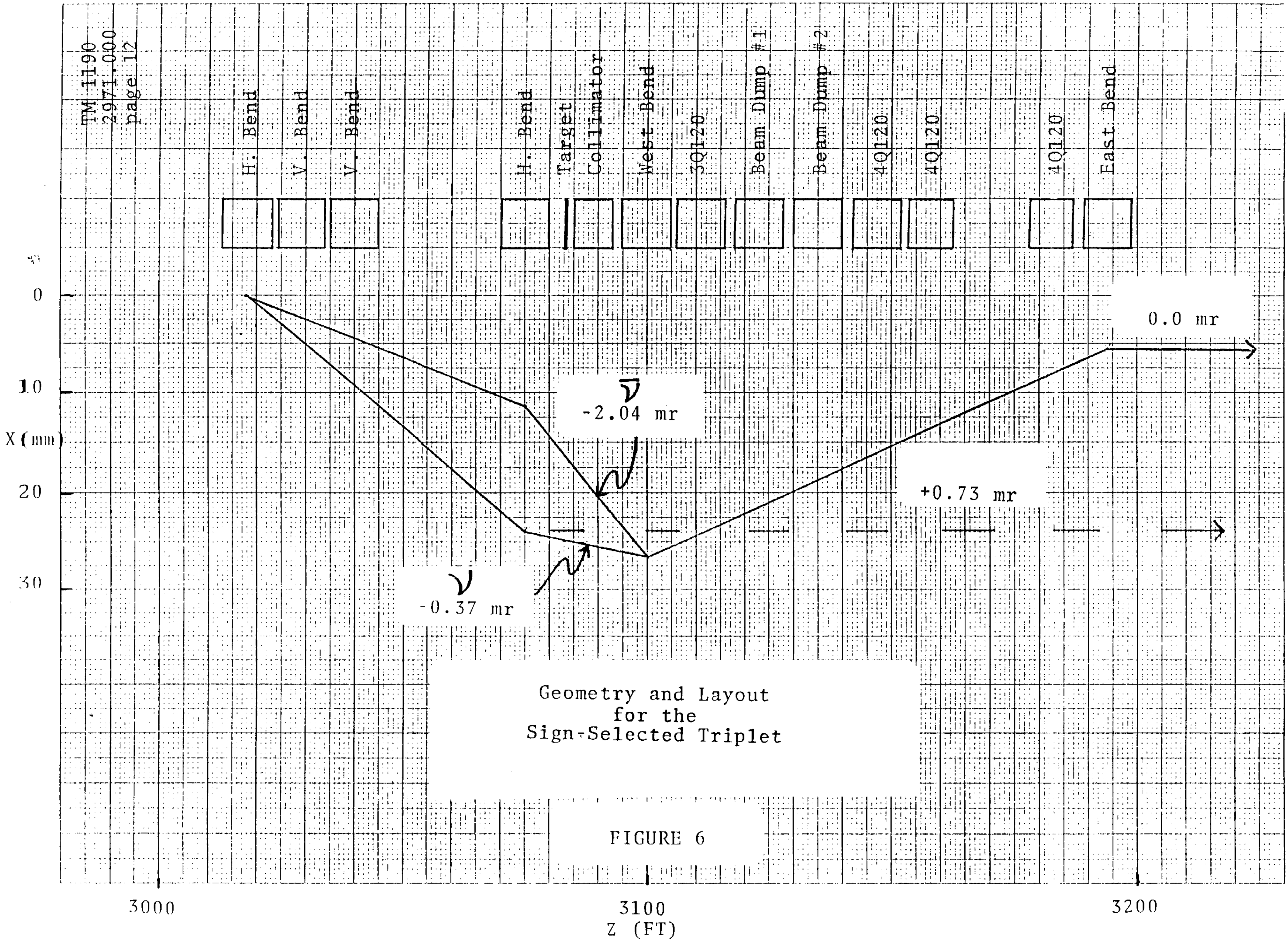


FIGURE 5



Geometry and Layout
for the
Sign-Selected Triplet

FIGURE 6

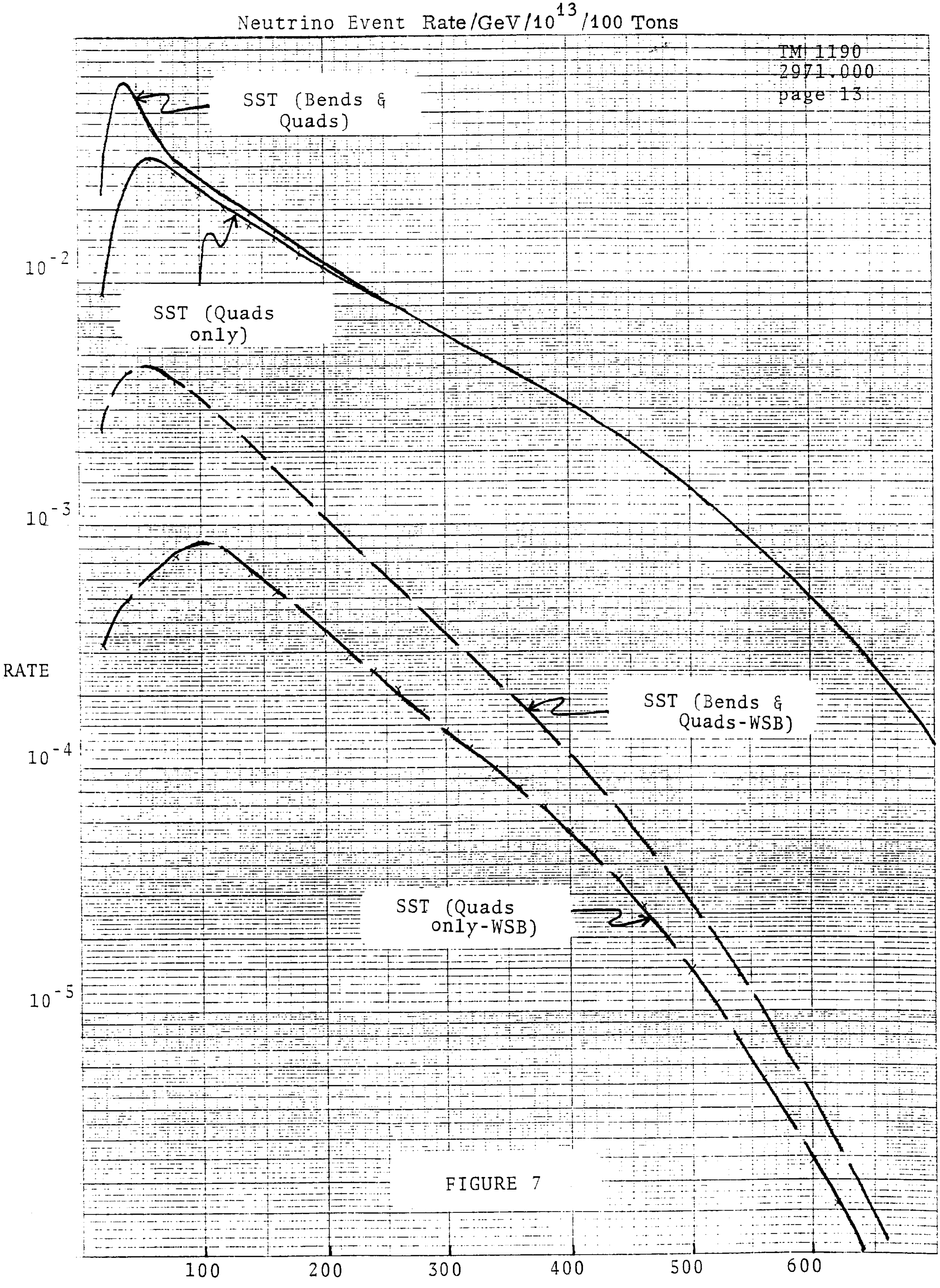

Neutrino Event Rate/GeV/10^{13}/100 Tons
SST (Bends & Quads)
SST (Quads only)
SST (Bends & Quads-WSB)
SST (Quads only-WSB)
RATE
10^{-2}
10^{-3}
10^{-4}
10^{-5}
100
200
300
400
500
600

FIGURE 7