SSC-N-182

SSC INTERACTION PILEUP TAG

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MAY 27, 1986

Introduction.

Multiple interactions at the SSC low-beta interaction regions cause a serious background problem for a number of interesting physics processes.[1] The parameters list of the Conceptual Design Report[2] gives, for luminosity $10^{33}\text{cm}^{-2}\text{sec}^{-1}$ and an inelastic cross section of 90 mb, a reaction rate of 9.0×10^7 Hz. With a bunch spacing of 4.8 meters,[2] beam crossings have a period of 16 nanoseconds and there is an average of 1.4 reactions per beam crossing. Thus, if a beam crossing contains a reaction, there is a 74% chance that there is more than one.

Present detectors have typical time resolution corresponding to several beam crossings. A major effort must be made to develop fast signal detectors in order to minimize the interaction pileup or event overlap effect.[3] If, for example, sufficiently fast and efficient tagging layers in the tracking chambers and calorimeters were developed with reasonable segmentation, it would be possible to associate jet clusters and leptons with individual beam crossings. However, even when identification with an individual bunch crossing is achieved, a significant overlap of interactions within a single beam crossing would still occur. That is, multiple interactions within the same beam crossing could either mask or simulate an interesting event.

It is likely that diffraction scattering interactions are benign. They will therefore be ignored in our analysis and we assume that a remaining 60 mb inelastic cross section is of concern for the pileup problem. The average rate of such reactions is about one per beam crossing and 42% of the beam crossings with interactions have such pileup.

An efficient and sensitive overlap tag would make it possible to isolate single-interaction beam crossings and would permit the study of pileup-sensitive pro-

cesses at higher luminosity than otherwise possible. In some cases such studies would be concurrent with full luminosity running.

The purpose of this note is to point out that if the total energy of the extreme forward high energy particles from beam crossing reactions are recorded by coarse calorimetry having time resolution good enough to distinguish beam crossings, then beam crossings with single interactions can be isolated and tagged.

Detector Response.

The geometry in the vertical plane for the high-beta interaction region is shown in Figure 1.[2] The pileup-tag detector modeled in this study combines three distinct calorimeter systems. The first is an electromagnetic calorimeter which accumulates photon energy which comes predominantly from π^0 decay. It is placed in the neutral beam dump downstream of the first vertical separation of the two proton beams. It accepts forward angles up to 0.25 mr which just clears the IR quadrupole exit aperture of 40 mm diameter. The second is a neutral hadron calorimeter placed immediately behind the electromagnetic calorimeter in the neutral beam dump. It accepts neutrons and fast lambdas and K^0's also for angles up to 0.25 mr. The third calorimetric system detects positive hadrons which leave the beam pipe after exiting BV1. It is important that protons of highest energy be intercepted and it is supposed that collimators in front of BV2, BV3, BV4, and Q4 are instrumented for hadron calorimetry. For the present study it is assumed that positively charged particles produced between energies of 10 and 18.8 TeV and with angles below 0.25 mr are recorded by calorimetry. The calorimeter system is replicated in the other beam direction. However, central and forward physics calorimeters have not been included.

ISAJET[4] has been run with its "MINBIAS" option at 40 TeV center-of-mass energy to obtain the distribution of total energy per nondiffractive inelastic interaction recorded by the forward calorimeter system described above. For reference, the stable particle multiplicity is shown in Figure 2. (The π^0 is taken to

be stable for this purpose.) Although the multiplicity is high, most of the energy is carried by just a few leading particles in the very forward core of the beam jets. We assume that the energy detected in the beam jet for interesting events is the same as that for the nondiffractive inelastic events generated with ISAJET. However, it is more likely that the interesting event will have high transverse momentum or have missing neutrals that will reduce the forward-energy signal. Thus interesting events may be more cleanly distinguished from pileup than that found in this approximate analysis.

The angular distribution for the electromagnetic energy flow is shown in Figure 3. The detected electromagnetic energy for 1, 2, and 3 (nondiffractive) interactions per beam crossing is shown in Figure 4. It should be noted that the electromagnetic detector is also used to provide the luminosity monitor for beam profile, alignment and centering.[2] The electromagnetic signal alone would provide poor pileup tagging so the hadronic calorimeters have been added. The neutral hadron energy flow, shown in in Figure 5, exhibits an extremely sharp peaking within the forward calorimeter's aperture. Figure 6 shows the distribution of detected energy for neutral hadrons produced in 1, 2, and 3 interactions per beam crossing. It shows that frequently a major portion of the forward jet energy is carried by highly collimated neutral hadrons. However, in one-third of the single interactions, no neutral hadron energy is detected. The positive hadron energy flow distribution is shown in Figure 7. Note that the peak is very sharp within the angles accepted by the forward detector system and that it carries a much larger energy share than the others. However, there is substantial fluctuation because of loss of the highest energy protons which travel close to the beam as well as because of the low energy and angle cutoffs. The response for 1, 2, and 3 interactions per beam crossing is shown in Figure 8.

A useful pileup tag requires that the calorimeter responses be combined. The combined energy response of the electromagnetic, neutral hadron and positive hadron calorimeters is shown in Figure 9 for 1, 2, and 3 interactions per beam crossing. A cut at 40 TeV would remove nearly half of the two-interaction beam

crossings and most of the three-interaction beam crossings without loss of the single interaction beam crossing events. If a cut were made at 16 TeV, 43% of the single-interaction and only 5% of the two-interaction and less than 0.2% of the three-interaction beam crossings would remain.

Pileup Rates.

The SSC Conceptual Design Report[2] uses a 4.8 meter proton bunch spacing. At design luminosity there is an average of about one nondiffractive inelastic event per bunch crossing. Figure 10 shows as a function of luminosity (a) the total rate for such interactions and (b) the rate for beam crossings with any number of interactions. The curves labeled 1, 2, and 3 are the rate for beam crossings containing just one, two, and three interactions respectively.

If the energy detected by the calorimeters described above is used as a pileup tag by imposing a 16 TeV cut, the rates for 1, 2, and 3 interactions per beam crossing are reduced by factors of 0.43, 0.054, and 0.002 respectively. The results are shown by the dashed curves labeled $1'$ and $2'$, the three interaction case now being below scale. The effectiveness can be judged in the following way. To achieve the same low level of multiple interaction background without the pileup tag, the luminosity would have to be reduced by a factor of 10. The rate for single-interaction beam crossings would then be down by a factor of about three from that at full luminosity with the pileup tag in effect.

It should be noted that the quantitative results described here depend sensitively on the tail of distributions generated by a Monte Carlo program. The beam jets are poorly understood even at presently available energies and extrapolation to SSC energies is hazardous. However, it has been verified that the LUND color-string fragmentation Monte Carlo program gives substantially the same results for energy flow and calorimeter response for the same geometry. By the same token, small improvements in the coverage of the pileup calorimeters would have dramatic affects on the tails of the distributions and hence on the

quality of the pileup tag.

Detector Design.

A fast-response calorimetric detector has to be developed for the proposed overlap tag to work. The single-interaction signal has an rms spread of about 50% at 17 TeV. A calorimeter system characterized by a resolution better than $(3000/E^{1/2})\%$ (E in GeV) would be adequate. Therefore, the overall forward calorimeter system can be very, very coarse by conventional standards which are 50% at 1 GeV. This fact and the very low required gain suggest that a simple hardware configuration can be developed.

The radiation environment is severe: at the peak of the core of the electromagnetic shower hundreds of megarads per year are developed in each electromagnetic detector for full luminosity. But this is just what is to be detected! A parallel multiplate ionization chamber with very thin gaps (for fast response) and with very low gain is a good detector candidate. Gas scintillator or liquid scintillator filled gaps can also be considered. Very long light channels are possible because of the very low sensitivity requirements. In either case gas or liquid could be rapidly refreshed. No transverse segmentation is required for the tagging and only a coarse longitudinal sampling is needed so that a very rugged assembly could be used. Thermal cooling is essential: over 20 Watts is developed in each electromagnetic detector.

Conclusion.

By installing crude but fast hadron calorimetry in the neutral beam dump and around the beam pipe beyond the first vertical bend away from the IRs as well as electromagnetic calorimetry in the neutral beam dump, a useful tag of single-interaction beam crossings (Figure 9) can be readily achieved. This could also provide a diagnostic device for determining the luminosity of individual crossing beam bunches.

The modelling of the response of the positive hadron calorimeters has been particularly crude. Because of the encouraging results found here, a more detailed study is warranted. Furthermore, were it possible to imbed a crude detector in the collimator in front of the interaction-region quadrupoles the sensitivity and efficiency of the pileup tag could be greatly improved.

REFERENCES

1. H. A. Gordon and P. D. Grannis, Design and Utilization of the SSC, p541, Snowmass, 1984
2. SSC Conceptual Design Report, SSC Central Design Group, March 31, 1986
3. Report of the Task Force on Detector Research and Development for the Superconducting Super Collider, SSC-SR-1021, June, 1986
4. ISAJET 5.20, F. E. Paige and S. D. Protopopescu, Brookhaven National Laboratory, 1986

FIGURE CAPTIONS

1. Figure 5.11-5 from the SSC Conceptual Design Report showing the arrangement of the high-beta interaction region in the vertical plane.

2. ISAJET-5.20 particle multiplicity for nondiffractive inelastic interactions.

3. Photon (π^0) energy flow as a function of polar angle.

4. Distribution of the calorimeteric energy response for photons (π^0) with $\theta < 0.25$mr for 1, 2, and 3 nondiffractive inelastic interactions per beam crossing.

5. Neutral hadron energy flow as a function of polar angle.

6. Distribution of the calorimetric energy response for neutral hadrons with $\theta < 0.25$mr for 1, 2, and 3 nondiffractive inelastic interactions per beam crossing.

7. Positive hadron energy flow as a function of polar angle.

8. Distribution of the calorimeteric energy response for positive hadrons with $\theta < 0.25$mr and energy between 10.0 and 18.8 GeV for 1, 2, and 3 nondiffractive inelastic interactions per beam crossing.

9. Distribution of combined electromagnetic, neutral-hadron, and positive-hadron detected energy for 1, 2, and 3 nondiffractive inelastic interactions per beam crossing.

10. Rates as a function of luminosity: (a) total interaction rate, (b) total rate for beam crossings containing any number of interactions. The labels 1, 2, and 3 refer to rates for just one, two, or three interaction crossings. The solid curves are without the overlap tag and the dashed curves are for an overlap energy response cut of 16 TeV for the forward calorimeter system.

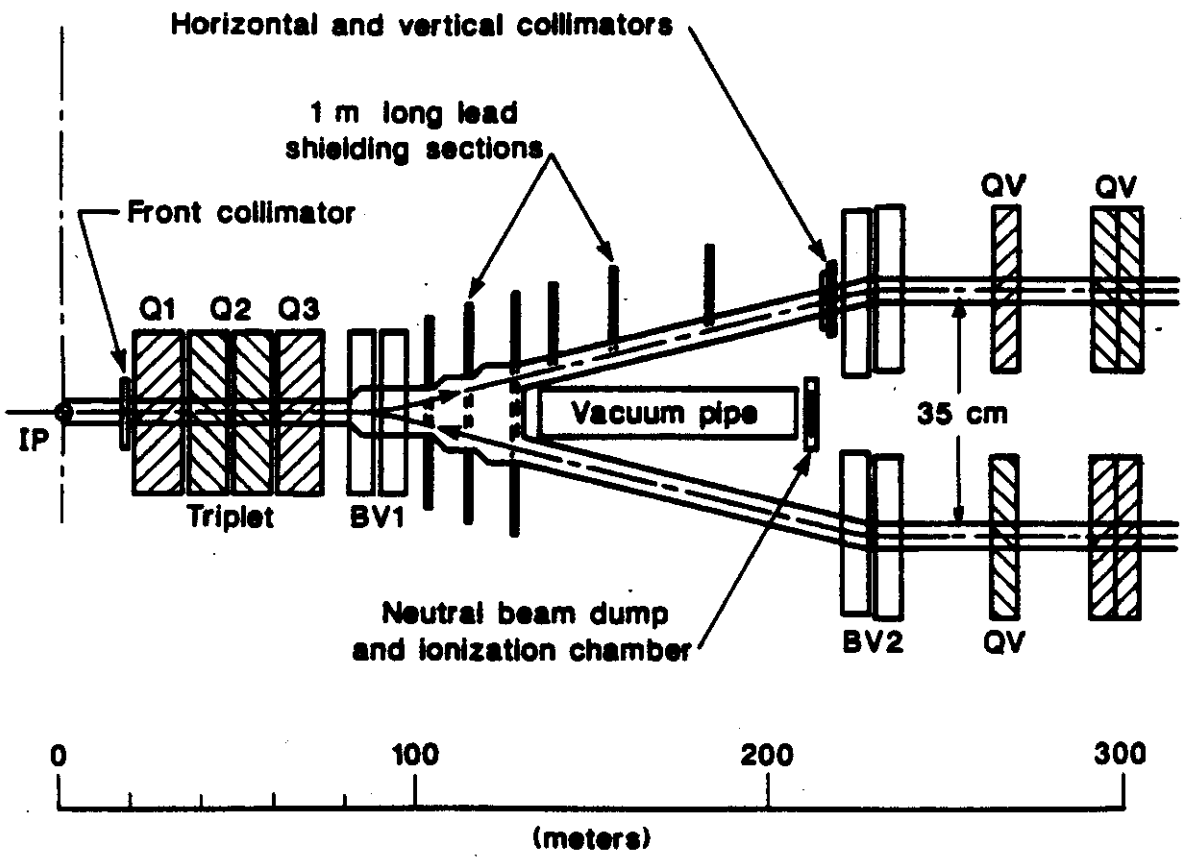

Figure 5.11-5. Beam pipe, shielding, collimator, and neutrals dump arrangements in a typical high-luminosity IR.

Figure 1.

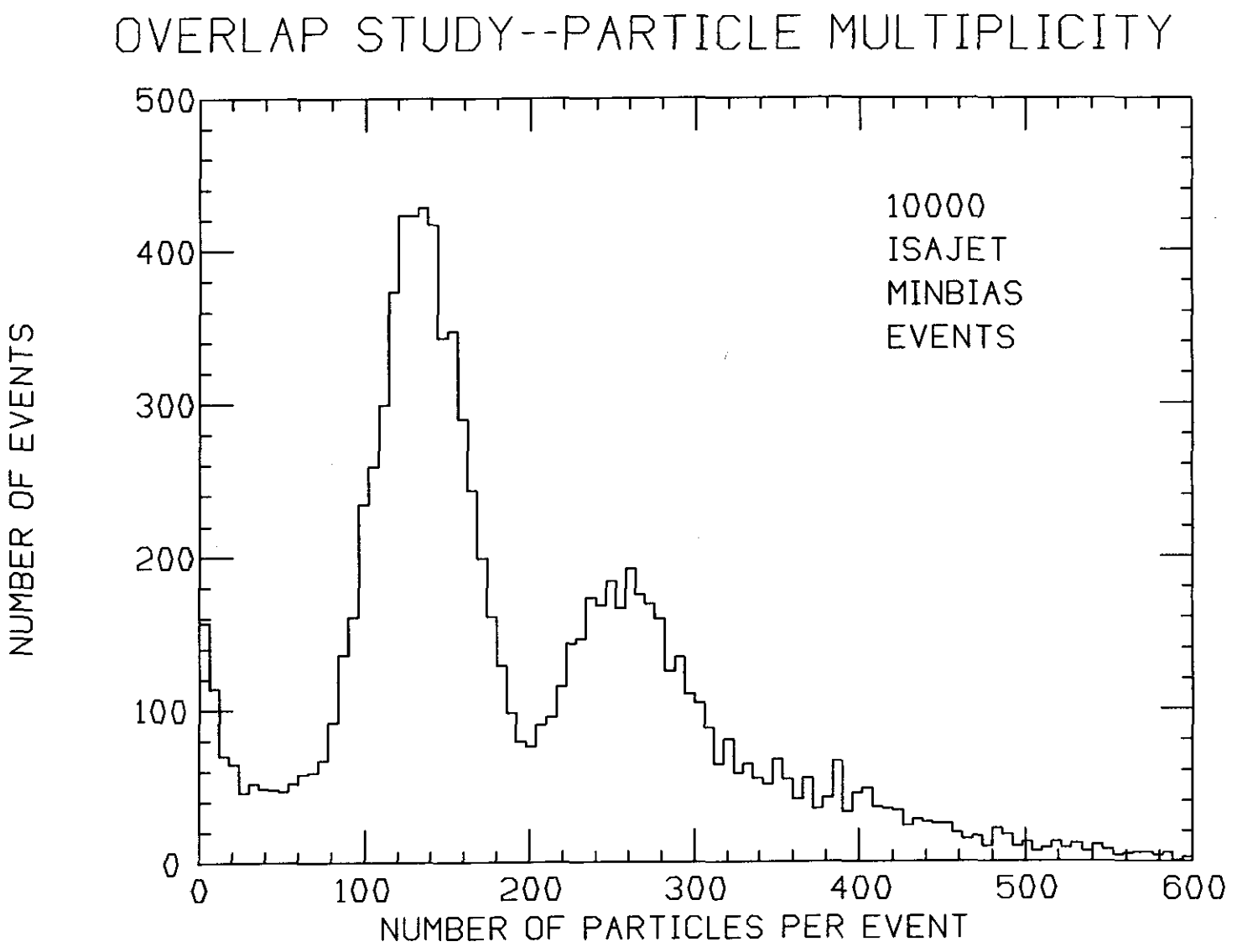
OVERLAP STUDY--PARTICLE MULTIPLICITY
10000
ISAJET
MINBIAS
EVENTS
NUMBER OF EVENTS
NUMBER OF PARTICLES PER EVENT
0
100
200
300
400
500
600

Figure 2.

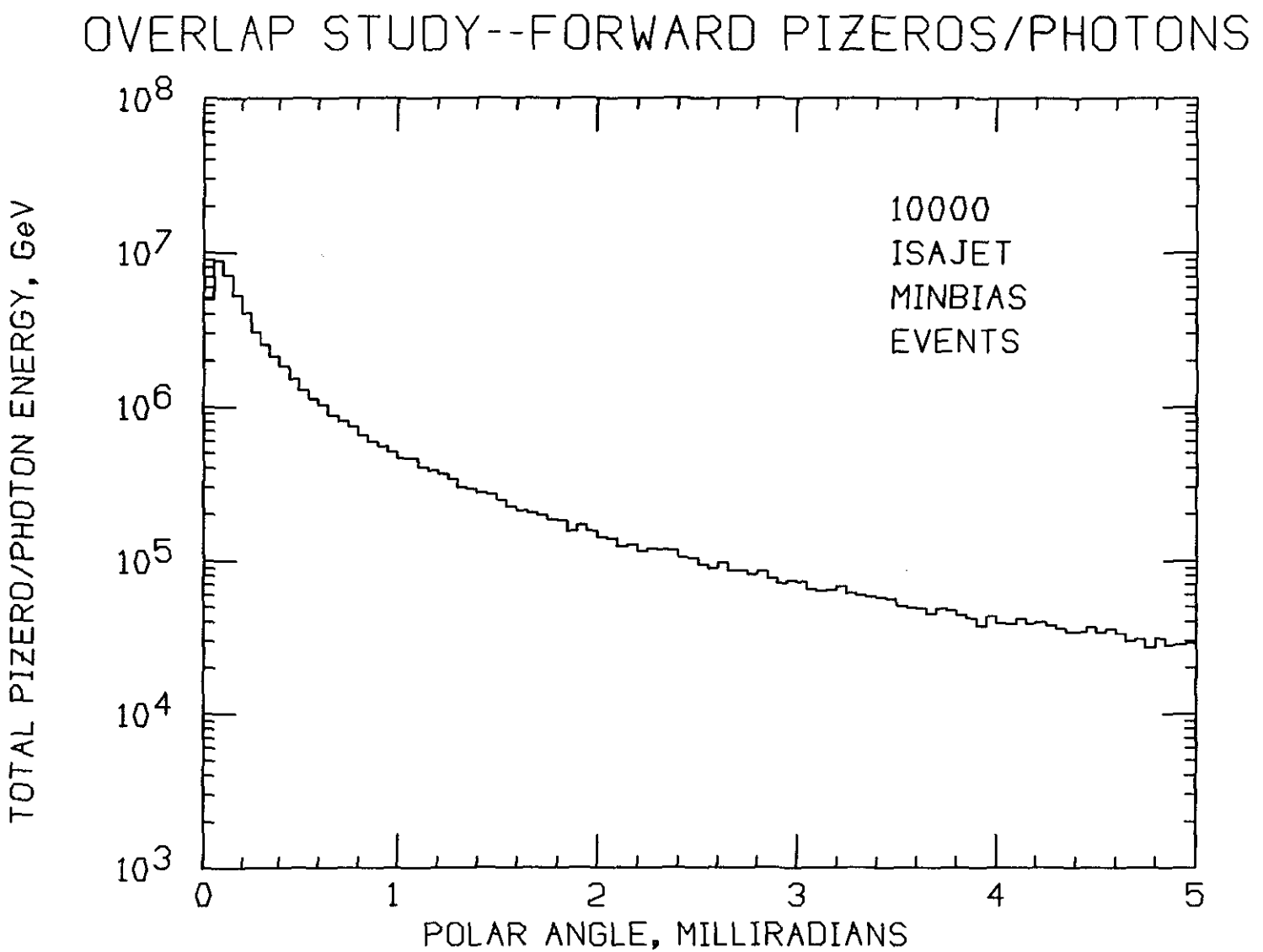
OVERLAP STUDY--FORWARD PIZEROS/PHOTONS
TOTAL PIZERO/PHOTON ENERGY, GeV
10^8
10^7
10^6
10^5
10^4
10^3
0
1
2
3
4
5
POLAR ANGLE, MILLIRADIANS
10000
ISAJET
MINBIAS
EVENTS

Figure 3.

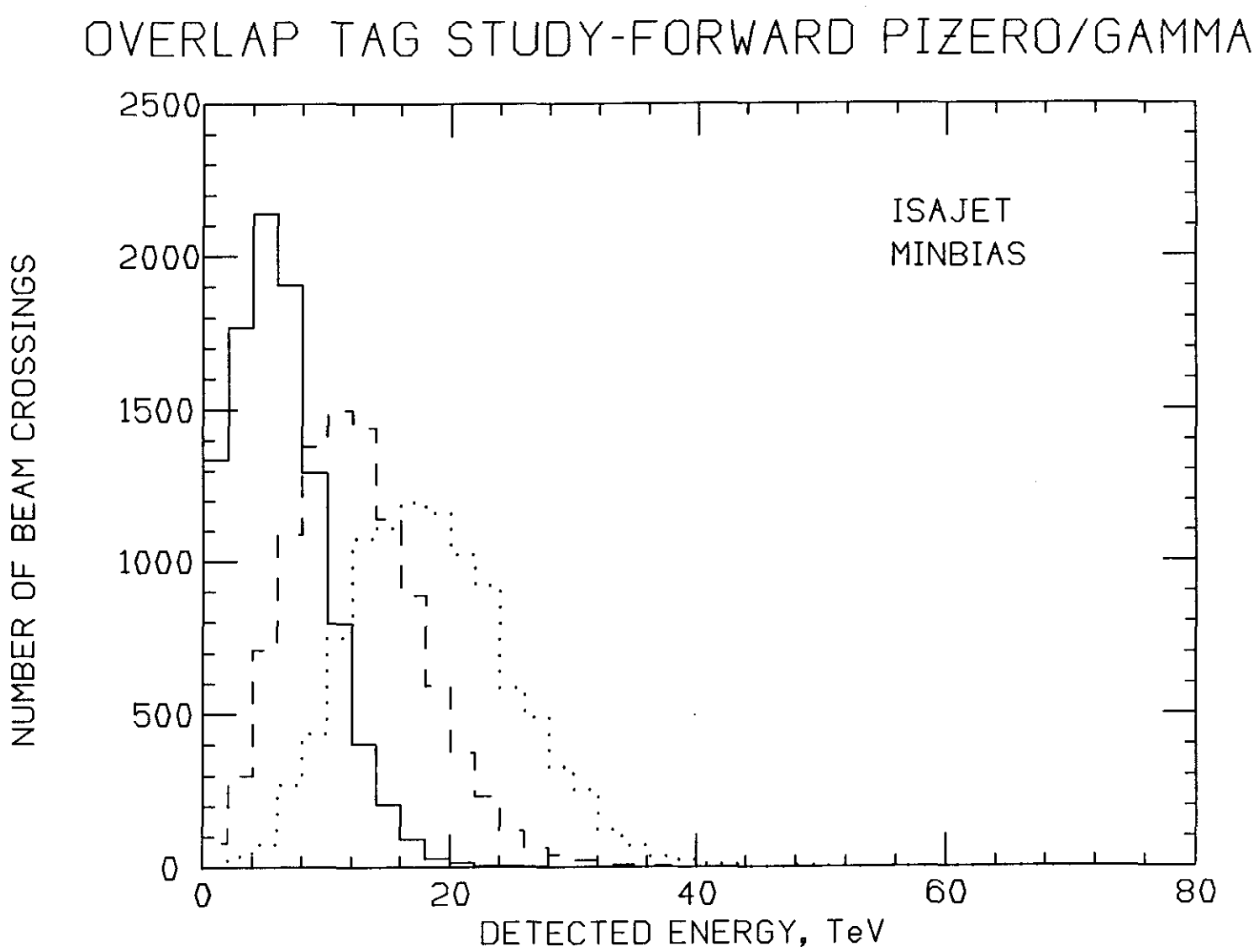
OVERLAP TAG STUDY-FORWARD PIZERO/GAMMA
ISAJET
MINBIAS
NUMBER OF BEAM CROSSINGS
2500
2000
1500
1000
500
0
0
20
40
60
80
DETECTED ENERGY, TeV

Figure 4.

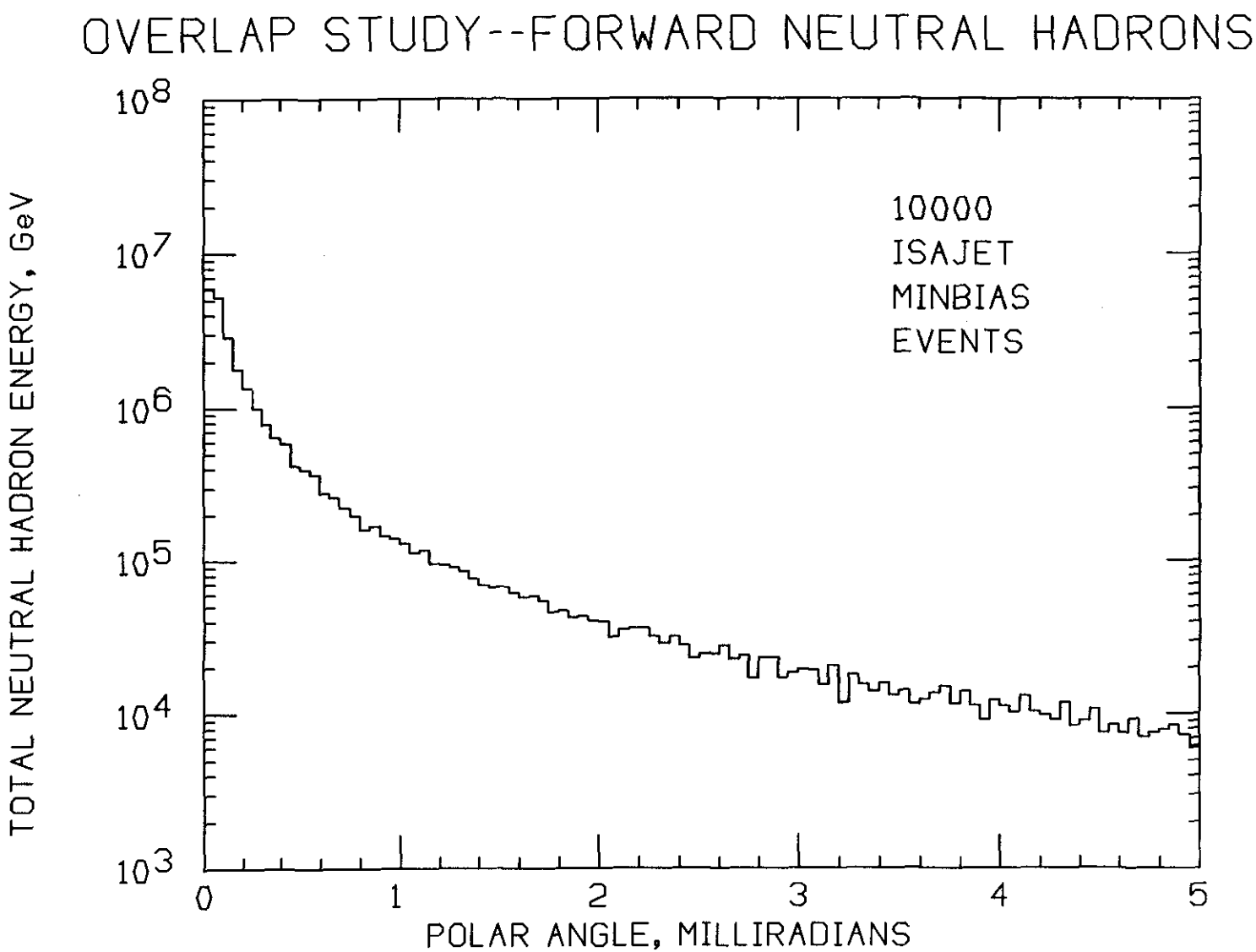
OVERLAP STUDY--FORWARD NEUTRAL HADRONS
TOTAL NEUTRAL HADRON ENERGY, GeV
10^8
10^7
10^6
10^5
10^4
10^3
10000
ISAJET
MINBIAS
EVENTS
0
1
2
3
4
5
POLAR ANGLE, MILLIRADIANS

Figure 5.

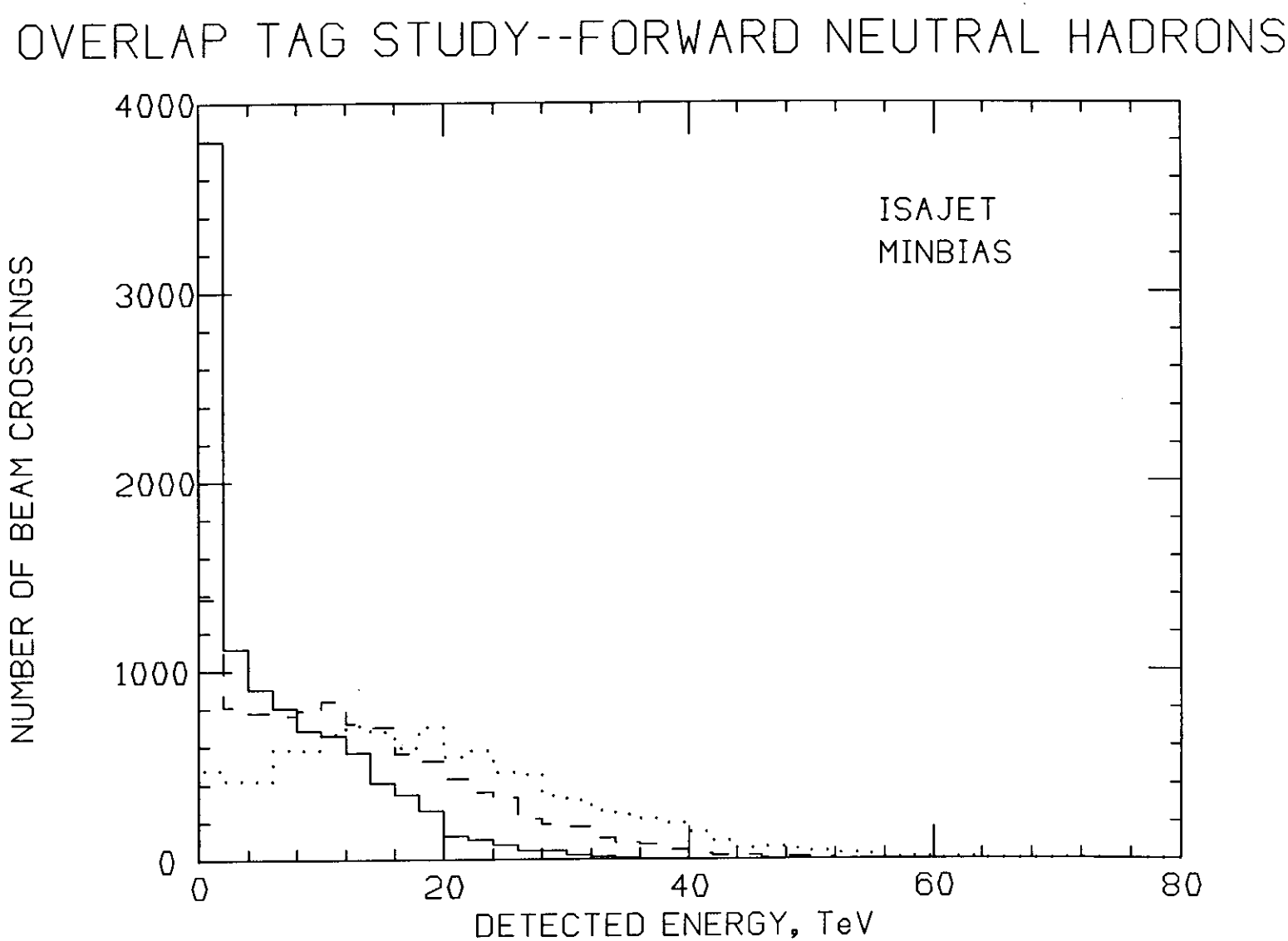
OVERLAP TAG STUDY--FORWARD NEUTRAL HADRONS
ISAJET
MINBIAS
NUMBER OF BEAM CROSSINGS
4000
3000
2000
1000
0
0
20
40
60
80
DETECTED ENERGY, TeV

Figure 6.

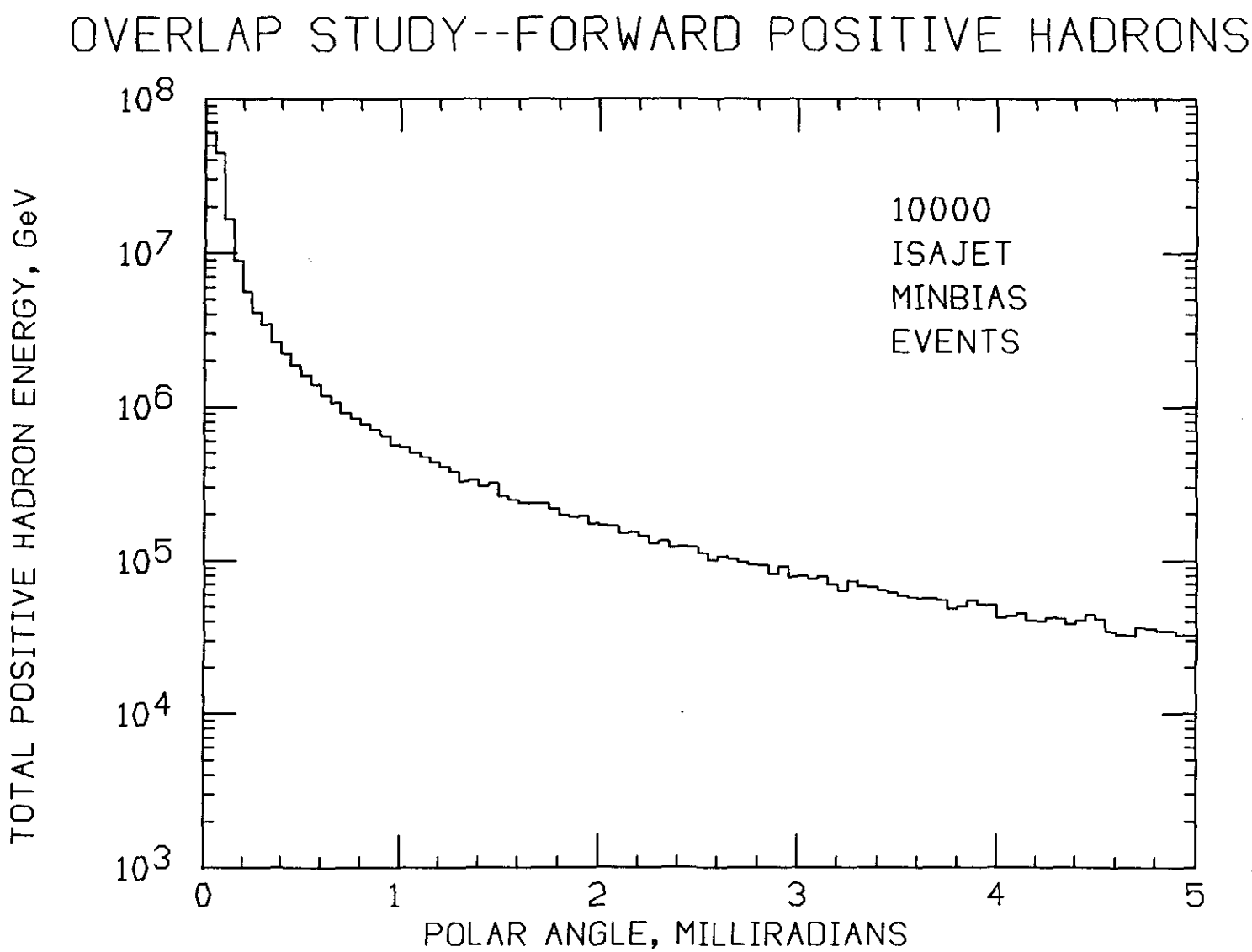
OVERLAP STUDY--FORWARD POSITIVE HADRONS
TOTAL POSITIVE HADRON ENERGY, GeV
10^8
10^7
10^6
10^5
10^4
10^3
0
1
2
3
4
5
POLAR ANGLE, MILLIRADIANS
10000
ISAJET
MINBIAS
EVENTS

Figure 7.

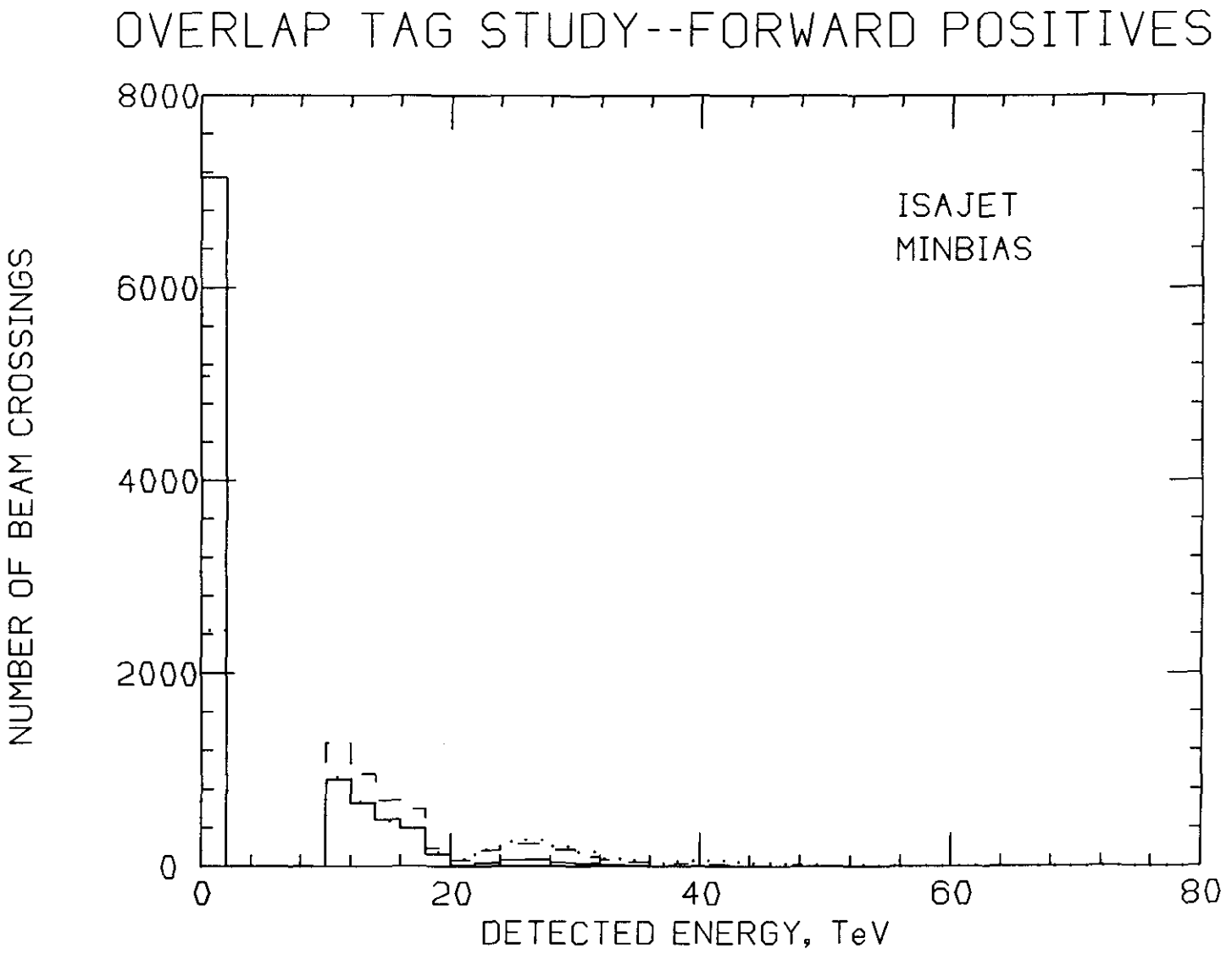
OVERLAP TAG STUDY--FORWARD POSITIVES
ISAJET
MINBIAS
NUMBER OF BEAM CROSSINGS
8000
6000
4000
2000
0
0
20
40
60
80
DETECTED ENERGY, TeV

Figure 8.

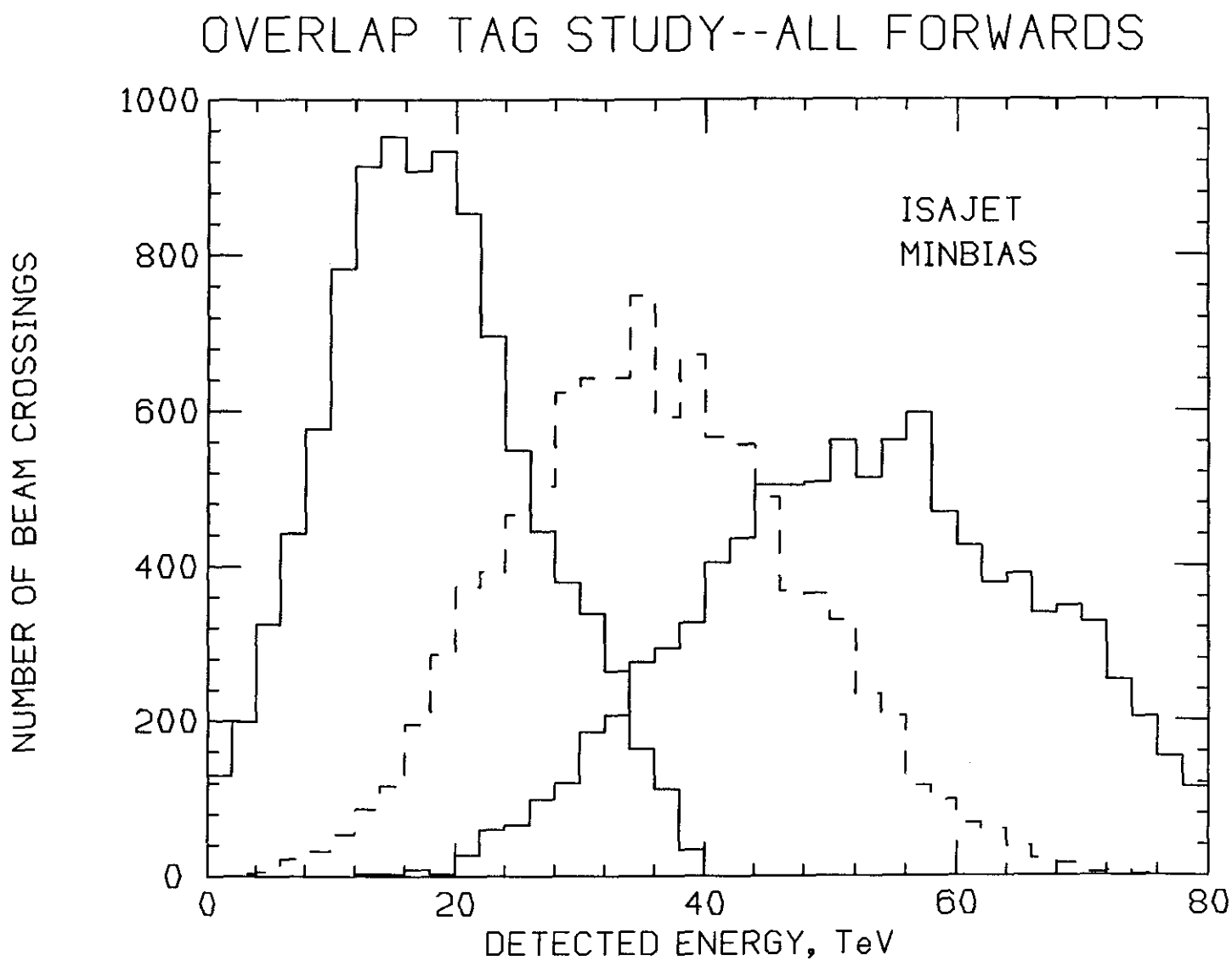
OVERLAP TAG STUDY--ALL FORWARDS
ISAJET
MINBIAS
NUMBER OF BEAM CROSSINGS
DETECTED ENERGY, TeV
0
200
400
600
800
1000
0
20
40
60
80

Figure 9.

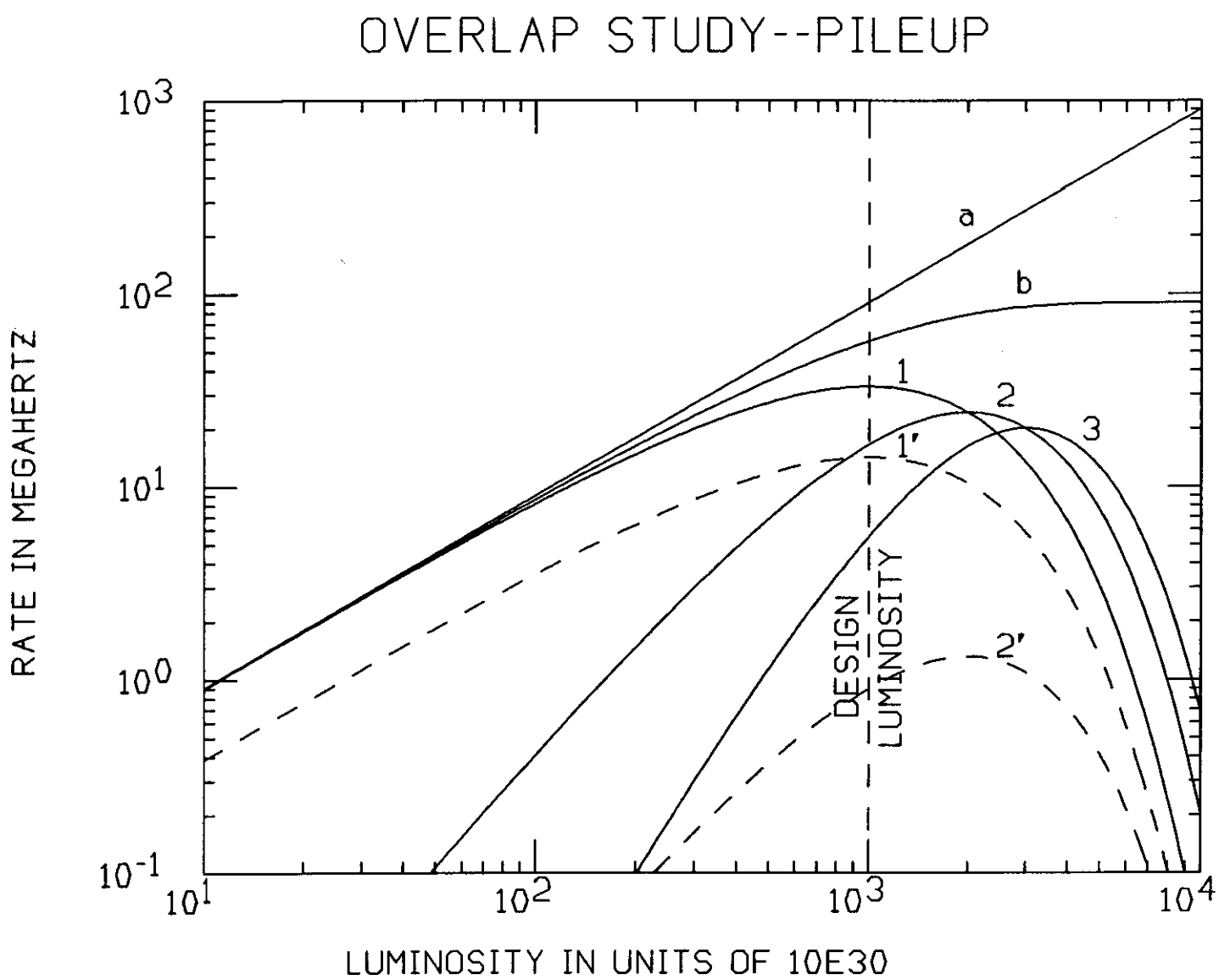
OVERLAP STUDY--PILEUP
RATE IN MEGAHERTZ
LUMINOSITY IN UNITS OF 10E30
10^3
10^2
10^1
10^0
10^{-1}
10^1
10^2
10^3
10^4
a
b
1
2
3
1'
2'
DESIGN
LUMINOSITY

Figure 10.