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SOLENOIDAL DETECTOR NOTES

CALORIMETER FIRST LEVEL TRIGGER RATES AT THE SSC

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Calorimeter First Level Trigger Rates at the SSC

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ABSTRACT

The trigger rates using simple calorimeter algorithms relevant to the 1st level triggers are calculated for the SSC at $\sqrt{s}$ = 40 TeV with L = $10^{33}\text{cm}^{-2}\text{sec}^{-1}$. The effect of pileup (event overlap) to the trigger rates and the efficiency of some physics events are studied. Also, the effect of simple electron isolation algorithm and charged track requirement is estimated.

INTRODUCTION

At the SSC the interaction rate of 10^8 Hz is expected from the total p-p cross section of about 100 mb at $\sqrt{s} = 40$ TeV and L = $10^{33}\text{cm}^{-2}\text{sec}^{-1}$. Since the data rate at the final stage is limited to 10 - 10^3 Hz by the data acquisition system and the computing power in the off-line analysis, the trigger rate should be reduced by several orders of magnitude from the original interaction rate. In order to achieve this large reduction factor, the trigger system must be constructed with several stages as done in the existing hadron - hadron collider experiments. The beam crossing rate of every 16 nsec in SSC accelerator forces the 1st level (prompt) trigger to be a pipe-lined structure and all the detector data should be kept till the decision of 1st level trigger is made. The processing time of 1st level trigger is limited and it is preferred to use simple algorithms and quantities. Also, the 1st level trigger should be rather 'general' than 'specific'. The 1st level trigger is expected to reduce rate by factor 10^3 to 10^4 from original interaction rate so that the 2nd level trigger can have enough time to do more sophisticated algorithm for further rate reduction.

Therefore, it is important to estimate the rates for basic quantities which would be provided with actual detector and trigger architecture. The calorimeter is one of the essential components of 1st level trigger. Here, the rate of some of the calorimeter quantities are calculated and presented.

EVENT GENERATION AND SIMULATION

The calculation is done in two steps. First, the background events are generated using ISAJET[1] (version 6.21) at $\sqrt{s} = 40$ TeV. In order to estimate the background rates in the region relevant to the 1st level trigger including minimum bias events, the process 'TWOJET' in ISAJET are used with wide rapidity (y) range and low p_t limit for primary jets. The ranges used here are: $-8 < y < 8$ and $5 < p_t < 200$GeV/c. This gives a total cross section of 90 mb which is about same as the expected total cross section ($\sim$ 100 mb). In order to get enough statistics for high p_t region, events are generated in 6 steps of p_t ranges.

Second, for the generated events the calorimeter signals are simulated based on simple calorimeter simulation program CALSIM[2] . The original CALSIM is modified in the following aspects:

- o Energy sharing between neighboring cell is taken into account. The average lateral shower spread is parametrized and energy deposit in neighboring cells is calculated according to it.
- o Energy deposit in the EM calorimeter is separately kept for EM cluster study.
- o Energy deposit in the EM part for hadrons is simulated with very simple way. Hadrons deposit all energy in EM part with given probability (1% is used here).
- o Muons give minimum ionizing energy deposit in calorimeter (simply constant value of 3 GeV is used).

The cell size is chosen as size of a 'Trigger Tower' which is supposed to consist of several readout cells ganged together. A rather corse trigger tower cell size ($\Delta y = 0.15$ and $\Delta\phi = 2\pi/32$) is chosen in the calculation here. The energy resolution of calorimeter is assumed to be $\Delta E/E = 0.15/\sqrt{E}$ for EM part and $\Delta E/E = 0.50/\sqrt{E}$ for Hadron part, respectively.

The following calorimeter quantities are considered:

- o ET_TOT: total sum of transverse energy ET
- o ET_MISS: missing transverse energy
- o ET_CLSTR: ET of cluster (simply taken as single trigger tower)
- o ET_JET: ET of jet found by GETJET[2] with $\Delta R = 0.5$ (for comparison)
- o ET_EM: ET of EM cluster (tower with $E_{HAD} < 0.2 \times E_{EM}$)

RESULTS

The results are presented in terms of the rate (Hz) which is converted from cross section assuming $L = 10^{33}\text{cm}^{-1}\text{sec}^{-1}$ (i.e. 1 mb corresponds to 10^6 Hz). The rates for background vs ET_TOT, ET_MISS, ET_CLSTR, and ET_JET are shown in Fig. 1 - 4. The rates are presented in two plots for each case: a)

The (differential) rate at given quantity value; b) The trigger rate with given threshold value for the quantity. This is given by integrating the differential rate a) from threshold value to infinite. In order to minimize statistical effect, the integration was done after smoothing the distribution shown in a).

The effect of energy resolution and segmentation of calorimeter is also checked with different resolution and segmentation. No significant effect is seen for energy resolutions. For segmentation, again no significant effect is found except E_CLSTR rate.

Effect of Pileup (Event Overlap)

Since the beam crossing rate of the SSC is 60 MHz, one expects average 1.6 interactions in one beam crossing assuming interaction rate of 10^8 Hz. When two or more interactions occur in the same beam crossing, these events overlap together and appear as one event in the detector. For calorimeter triggers, the effect of overlap would be large because overlapped events give falsely large energy deposit. Since the separation of neighboring beam crossing is only 16 nsec, even signals of events in different beam crossing could be overlapped (pileuped) when the time response of the detector is not fast enough. In order to estimate event overlap effect, the rates are calculated by superimposing several background 'TWOJET' events in CALSIM according to the Poisson distribution with average value of 1.6 and 5. The former corresponds to the detector whose response is fast enough to resolve each beam crossing completely, while the latter corresponds to the detector which 'effectively' sees events in 3 beam crossing as one event. Note that the effect of pileup actually depends on the detail of time evolution of signal and above simple-minded estimation might not be good.

The results are shown in Fig. 5-8 for ET_TOT, ET_MISS, ET_CLSTR, and ET_JET. As already seen in existing hadron collider experiments, the effect to ET_TOT is quite large.

Electron Trigger Rates

Since most of the new physics signatures involve leptons, the electron trigger is quite important. Especially in the 1st level trigger, the calorimeter gives an essential role. One of the simplest logic to identify EM cluster is select towers which have most of the energy deposit in EM part and no or only small deposit in Hadron part. Here, the towers which satisfy $E_{HAD} < 0.2 \times E_{EM}$ are defined as EM clusters. Fig. 9 show the rate vs ET_EM for single, double, and triple EM cluster triggers. Fig. 10 shows the contribution of real electron and hadrons to the single EM cluster trigger. As expected, the dominant component is photons (originated from π^0). Therefore, one would expect that the rate can be reduced by requiring radial (stiff) track segments matching to calorimeter EM cluster (in case of magnetic detector), though it might be difficult to do in 1st level trigger. To estimate this effect, the charged particles with $p_t > 5$ GeV/c are assumed to give radial track segment signal in tracking trigger. Fig. 11 shows the single EM cluster trigger rates without/with track segment matching requirement. For track matching, the cases with and without z information for track segments are considered. Since this does not include any accidental track segments produced by overlapping low p_t tracks, the calculation gives more or less underestimation.

Most of new physics signatures also give leptons to be isolated. Note that the EM cluster definition already implicitly requires electron to be isolated with tower size, since the EM cluster condition is not satisfied if there are hadrons in the same tower which would gives deposit in Hadron part. The more explicit isolation requirement is examined. An 'isolated' EM cluster is defined as EM cluster which has small energy deposit in hadron part of surrounding 8 cells (The sum is still less than 0.2 $\times E_{EM}$). The rate vs ET_EM for 'isolated' EM cluster is shown in Fig. 12. The rate does not reduced so much in case without track segment requirement, but in case with track requirement the rate seems reduced quite a lot by isolation requirement.

Effect of event overlap for EM cluster rate is such that rate goes up approximately N times for average event overlap of N events.

Efficiency for Physic Events

For any quantity, the trigger rate can be reduced to any value by raising the threshold. However, the threshold should be kept low enough to keep the efficiency of the interesting physics events to be good enough. To examine how good are the various triggers studied above, the trigger efficiencies should be checked various physics processes. As an example, the Higgs production process (H $\rightarrow W^+W^- \rightarrow$ e+ν+jets) is chosen, since this process gives all signatures studied above: isolated electron, missing ET, and jets. The mass of Higgs is chosen to be 400 GeV/c^2. The events are generated using ISAJET program. The total cross section of the process is 0.46 pb including branching ratios.

The results are shown in Fig. 13-18 for no pileup and average 5 events pileup cases. Now a) shows the differential cross section and b) shows the efficiency vs threshold value for each set. Table 1 summarizes the threshold values for required reduction factor of 10^3 (10^4) and the efficiency for the Higgs events with corresponding threshold for various quantities studied above ($|y| < 3$ case). The case of event overlap with average 5 events is compared with no event overlap case.

The author wishes to thank Dr. Y.Takaiwa for providing ISAJET program package and help and discussions for proceeding the calculations. He also wishes to express his thanks to Prof. Y.Watase for giving opportunity to participate series of related workshops and his encouragement throughout of this work.

REFERENCES

1) F.E.Paige and S.D.Protopopescu, BNL-37066 (1985).

2) F.E.Paige, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for the High Energy/High Luminosity Hadron - Hadron colliders, Fermilab (1985), Page 51.

Table 1

	10^3 reduction				10^4 reduction			
	No pileup		Pileup (Av=5)		No pileup		Pileup (Av=5)	
	Thres	Effic	Thres	Effic	Thres	effic	Thres	Effic
Unit	GeV	%	GeV	%	GeV	%	GeV	%
ET_TOT	235	95	810	45	365	70	920	25
ET_MIS	45	87	60	76	75	60	80	53
ET_CLSTR	24	98	46	85	56	75	68	62
ET_JET	50	97	75	92	100	75	110	71
ET_EM	9	93	16	87	19	86	28	76
Iso ET_EM	9	90	14	87	17	85	24	73

FIGURE CAPTIONS

Fig.1. Rates vs ET_TOT for background: for $|y| < 4.95$, $|y| < 3$, and $|y| < 1.5$.

Fig.2. Rates vs ET_MISS for background: for $|y| < 4.95$, $|y| < 3$, and $|y| < 1.5$.

Fig.3. Rates vs ET_CLSTR for background: for cluster multiplicity 1, 2, and 3. ET_CLSTR is minimum ET of the cluster with given cluster multiplicity.

Fig.4. Rates vs ET_JET for background: for jet multiplicity 1, 2, and 3. ET_JET is minimum ET of the jet with given jet multiplicity.

Fig.5. Rates vs ET_TOT for background: for cases with no overlap, overlap with average 1.6 events, and overlap with average 5 events.

Fig.6. Rates vs ET_MISS for background: for cases with no overlap, overlap with average 1.6 events, and overlap with average 5 events.

Fig.7. Single cluster trigger rates vs ET_CLSTR for background: for cases with no overlap, overlap with average 1.6 events, and overlap with average 5 events.

Fig.8. Single jet trigger rates vs ET_JET for background: for cases with no overlap, overlap with average 1.6 events, and overlap with average 5 events.

Fig.9. Rates vs ET_EM for background: for EM cluster multiplicity 1, 2, and 3. The minimum ET of the EM cluster with given EM cluster multiplicity is taken as ET_EM.

Fig.10. The components of single EM cluster trigger rate vs ET_EM for background: The contribution due to electron, due to hadrons, and total is shown.

Fig.11. Effect of track requirement to the single EM cluster trigger rate for background. Three cases are shown: calorimeter only; require charged track with $p_t > 5$ GeV/c matching in ϕ view only; same but matching in both ϕ and Z view.

Fig.12. Single isolated EM cluster trigger rate vs ET_EM for background. Effect of track requirement is shown by three cases: calorimeter only; require charged track with $p_t > 5$ GeV/c matching in ϕ view only; same but matching in both ϕ and Z view.

Fig.13. Rates vs ET_TOT for Higgs production: H(400 GeV) $\rightarrow W^+W^- \rightarrow e + \nu$ + jets. Two cases are shown: no overlap and overlap with average 5 events.

Fig.14. Rates vs ET_MISS for Higgs production: H(400 GeV) $\rightarrow W^+W^- \rightarrow e + \nu$ + jets. Two cases are shown: no overlap and overlap with average 5 events.

Fig.15. Single cluster trigger rates vs ET_CLSTR for Higgs H(400 GeV) $\rightarrow W^+W^- \rightarrow e + \nu$ + jets. Two cases are shown: no overlap and overlap with average 5 events.

Fig.16. Single jet trigger rates vs ET_JET for Higgs H(400 GeV) $\rightarrow W^+W^- \rightarrow$ e + ν + jets. Two cases are shown: no overlap and overlap with average 5 events.

Fig.17. Single EM cluster trigger rates vs ET_EM for Higgs H(400 GeV) $\rightarrow W^+W^-$ $\rightarrow$ e + ν + jets. Two cases are shown: no overlap and overlap with average 5 events.

Fig.18. Single isolated EM cluster trigger rates vs ET_EM for H(400 GeV) $\rightarrow$ $W^+W^- \rightarrow$ e + ν + jets. Two cases are shown: no overlap and overlap with average 5 events.

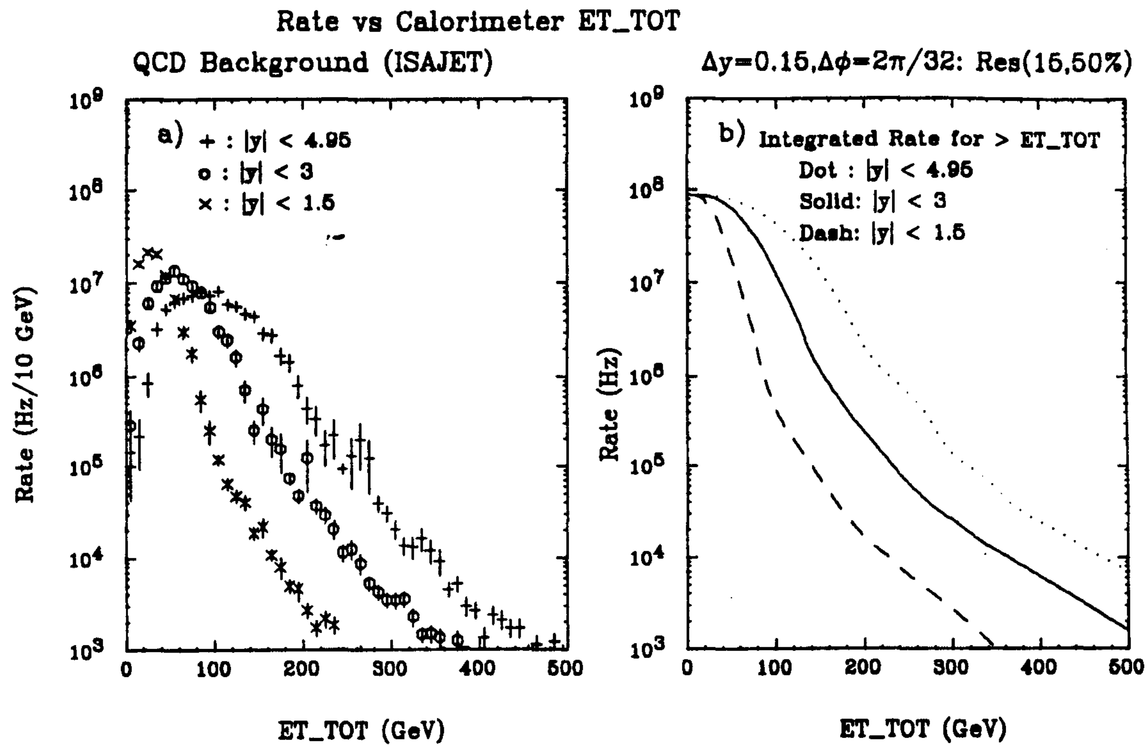

Rate vs Calorimeter ET_TOT
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) + : |y| < 4.95
o : |y| < 3
× : |y| < 1.5
Rate (Hz/10 GeV)
ET_TOT (GeV)
b) Integrated Rate for > ET_TOT
Dot : |y| < 4.95
Solid: |y| < 3
Dash: |y| < 1.5
Rate (Hz)
ET_TOT (GeV)

Fig. 1

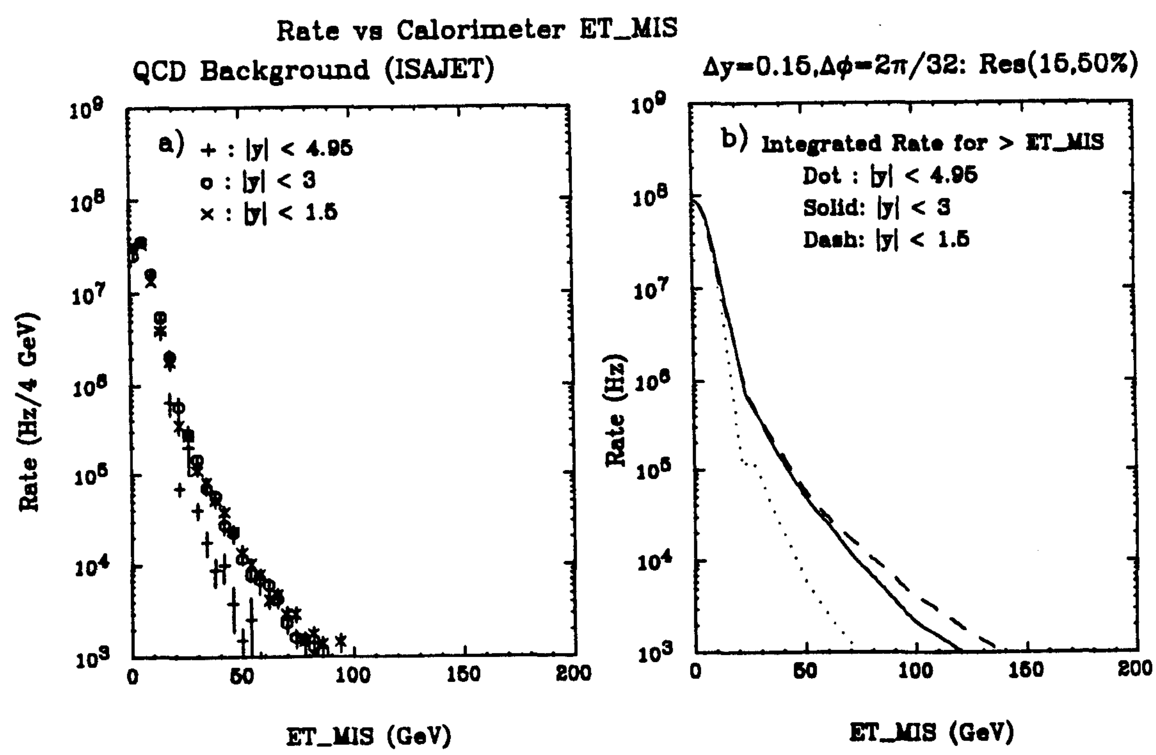

Rate vs Calorimeter ET_MIS
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) + : |y| < 4.95
o : |y| < 3
× : |y| < 1.5
Rate (Hz/4 GeV)
ET_MIS (GeV)
b) Integrated Rate for > ET_MIS
Dot : |y| < 4.95
Solid: |y| < 3
Dash: |y| < 1.5
Rate (Hz)
ET_MIS (GeV)

Fig. 2

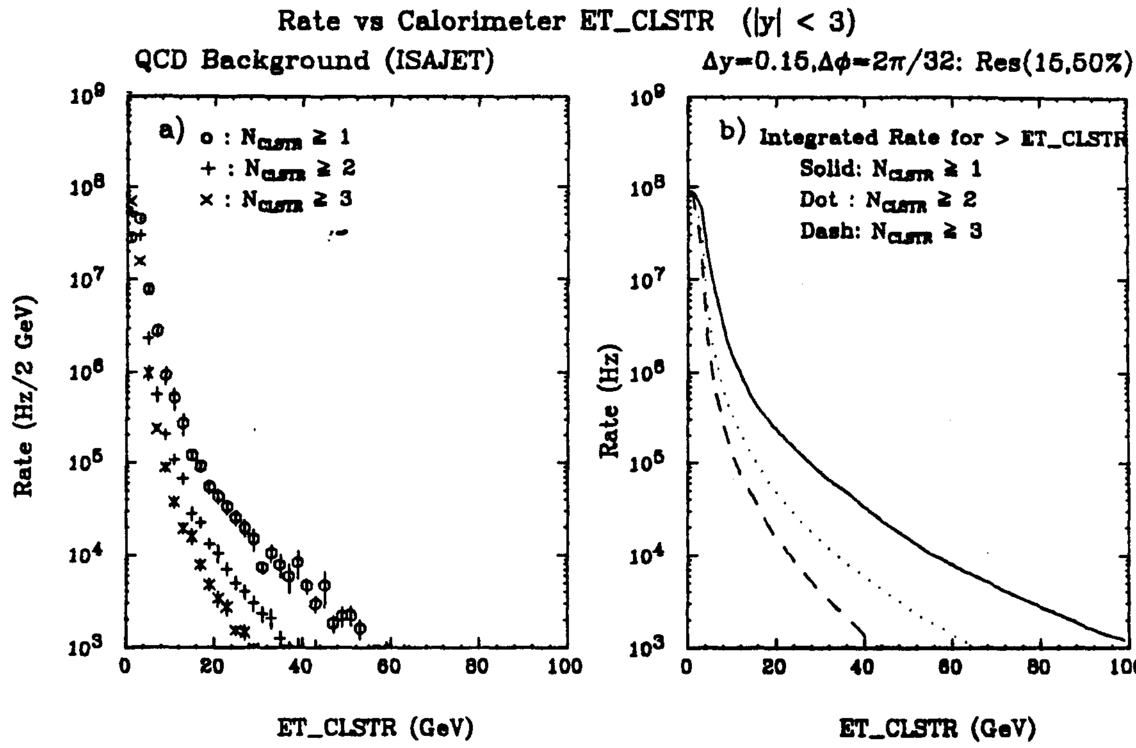

Rate vs Calorimeter ET_CLSTR (|y| < 3)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) o : N_CLSTR ≥ 1
+ : N_CLSTR ≥ 2
× : N_CLSTR ≥ 3
Rate (Hz/2 GeV)
ET_CLSTR (GeV)
b) Integrated Rate for > ET_CLSTR
Solid: N_CLSTR ≥ 1
Dot : N_CLSTR ≥ 2
Dash: N_CLSTR ≥ 3
Rate (Hz)
ET_CLSTR (GeV)

Fig. 3

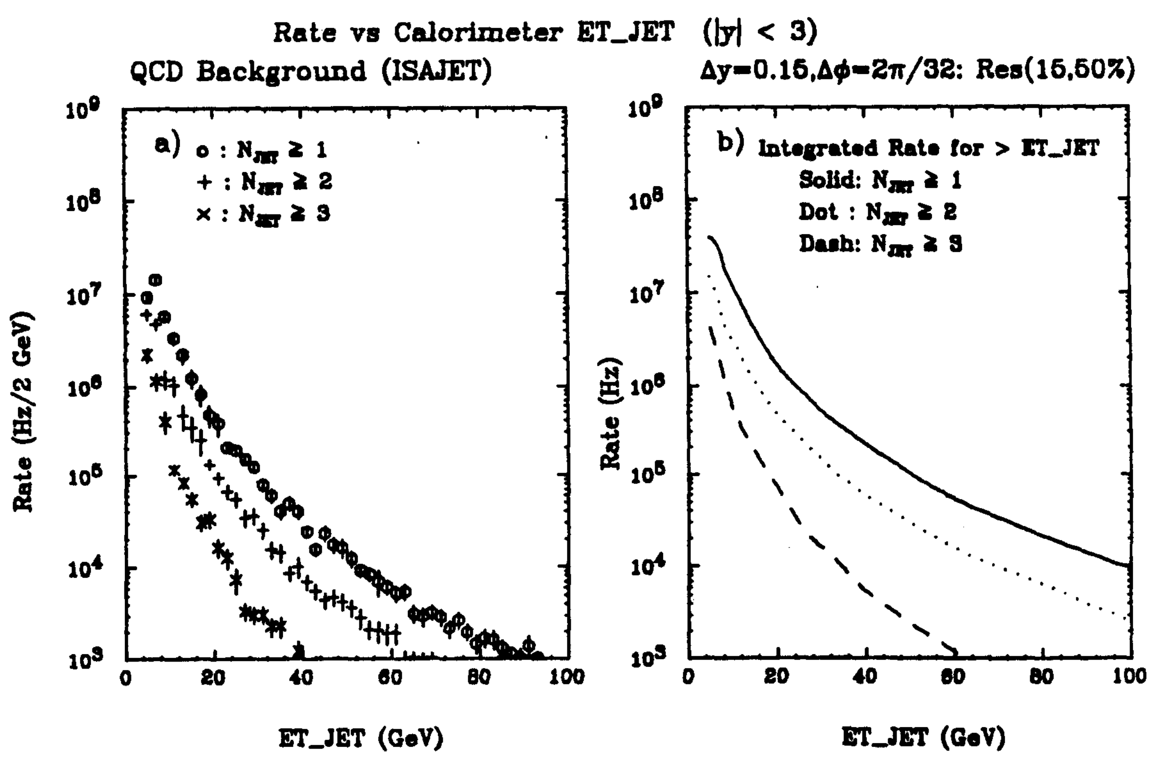

Rate vs Calorimeter ET_JET (|y| < 3)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) o : N_JET ≥ 1
+ : N_JET ≥ 2
× : N_JET ≥ 3
Rate (Hz/2 GeV)
ET_JET (GeV)
b) Integrated Rate for > ET_JET
Solid: N_JET ≥ 1
Dot : N_JET ≥ 2
Dash: N_JET ≥ 3
Rate (Hz)
ET_JET (GeV)

Fig. 4

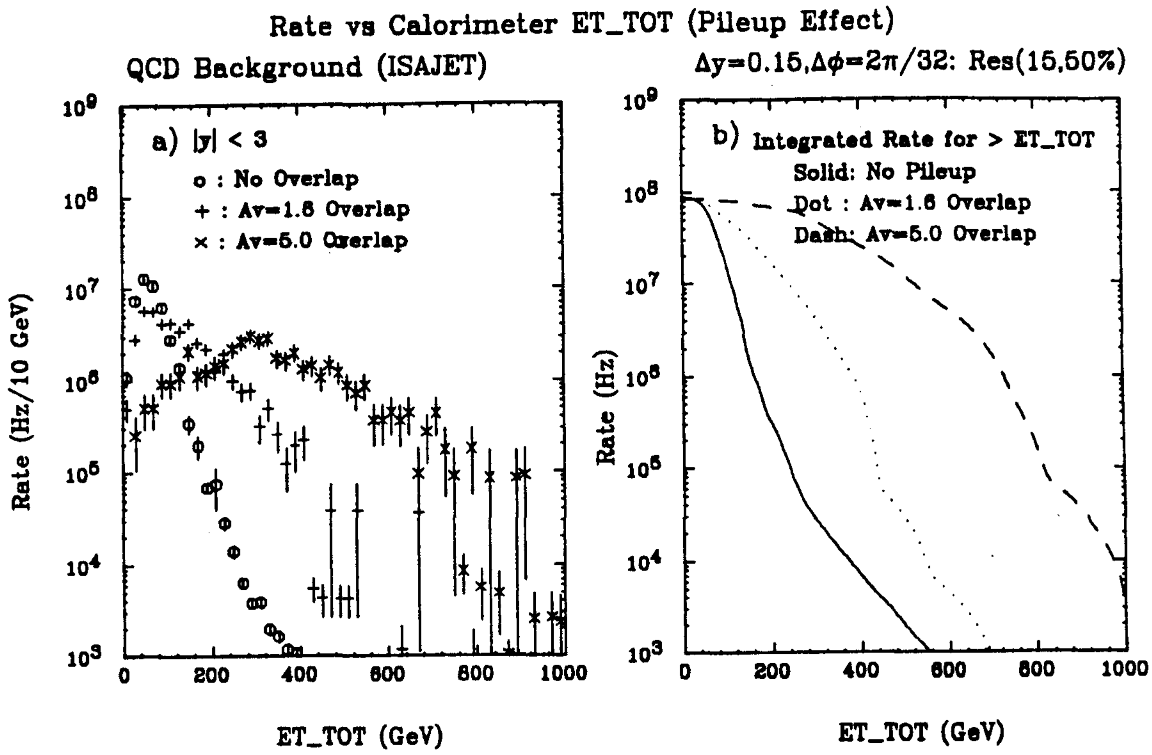

Rate vs Calorimeter ET_TOT (Pileup Effect)
QCD Background (ISAJET)
Δy=0.15,Δϕ=2π/32: Res(15,50%)
a) |y| < 3
o : No Overlap
+ : Av=1.6 Overlap
× : Av=5.0 Overlap
Rate (Hz/10 GeV)
ET_TOT (GeV)
b) Integrated Rate for > ET_TOT
Solid: No Pileup
Dot : Av=1.6 Overlap
Dash: Av=5.0 Overlap
Rate (Hz)
ET_TOT (GeV)

Fig. 5

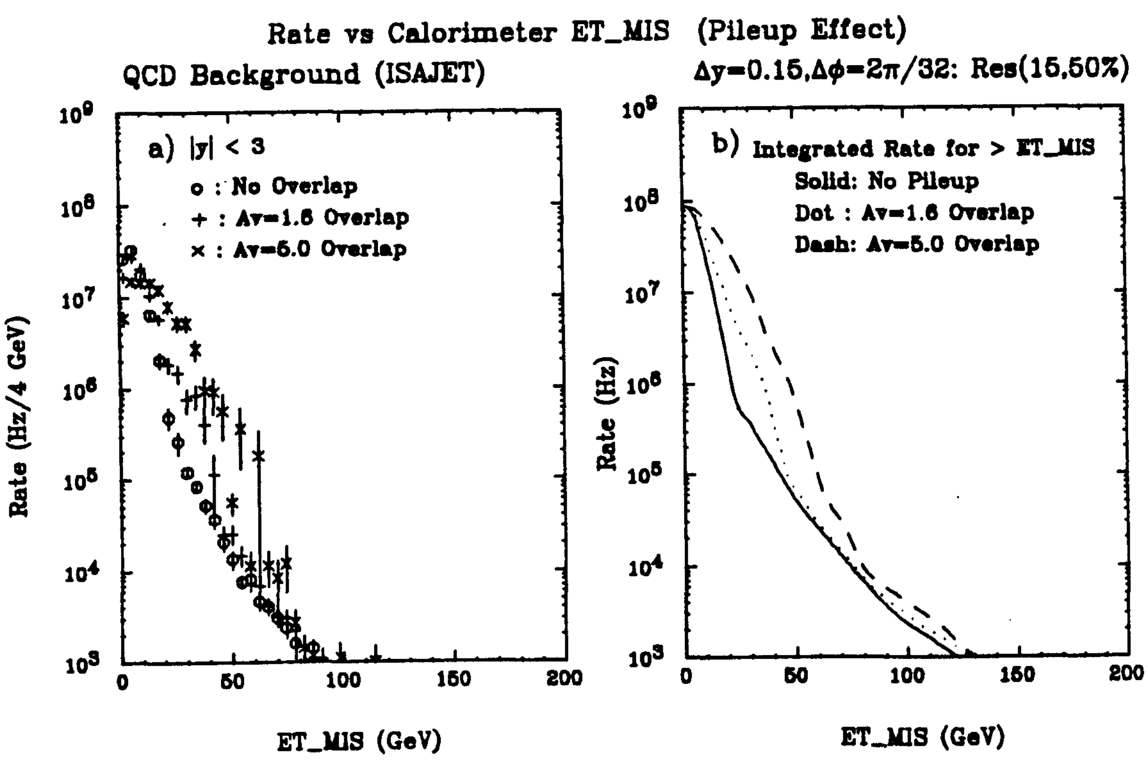

Rate vs Calorimeter ET_MIS (Pileup Effect)
QCD Background (ISAJET)
Δy=0.15,Δϕ=2π/32: Res(15,50%)
a) |y| < 3
o : No Overlap
+ : Av=1.6 Overlap
× : Av=5.0 Overlap
Rate (Hz/4 GeV)
ET_MIS (GeV)
b) Integrated Rate for > ET_MIS
Solid: No Pileup
Dot : Av=1.6 Overlap
Dash: Av=5.0 Overlap
Rate (Hz)
ET_MIS (GeV)

Fig. 6

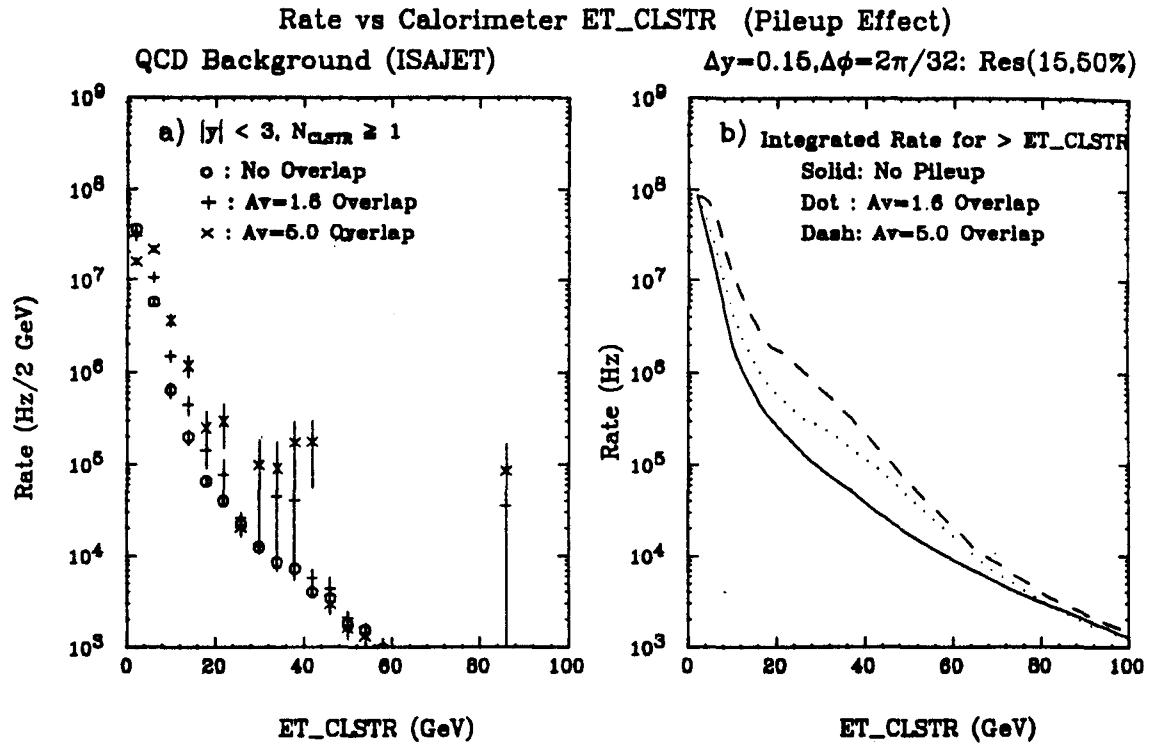

Rate vs Calorimeter ET_CLSTR (Pileup Effect)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_CLSTR ≥ 1
o : No Overlap
+ : Av=1.6 Overlap
× : Av=5.0 Overlap
Rate (Hz/2 GeV)
ET_CLSTR (GeV)
b) Integrated Rate for > ET_CLSTR
Solid: No Pileup
Dot : Av=1.6 Overlap
Dash: Av=5.0 Overlap
Rate (Hz)
ET_CLSTR (GeV)

Fig. 7

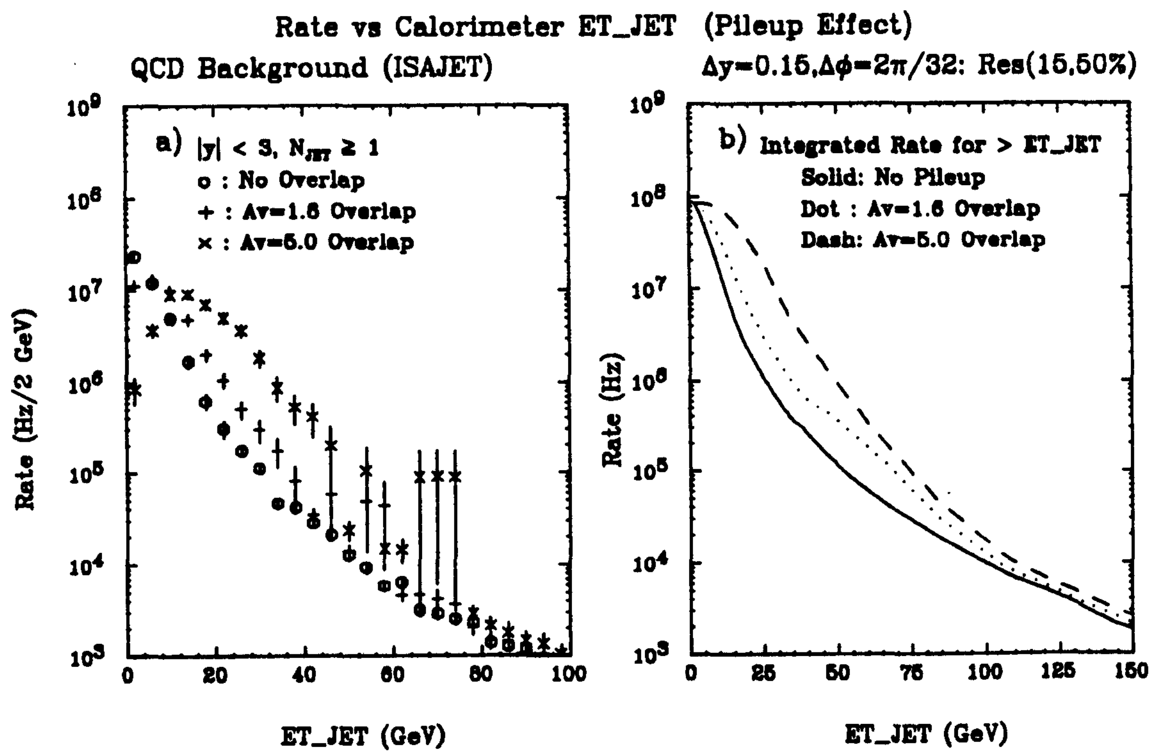

Rate vs Calorimeter ET_JET (Pileup Effect)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_JET ≥ 1
o : No Overlap
+ : Av=1.6 Overlap
× : Av=5.0 Overlap
Rate (Hz/2 GeV)
ET_JET (GeV)
b) Integrated Rate for > ET_JET
Solid: No Pileup
Dot : Av=1.6 Overlap
Dash: Av=5.0 Overlap
Rate (Hz)
ET_JET (GeV)

Fig. 8

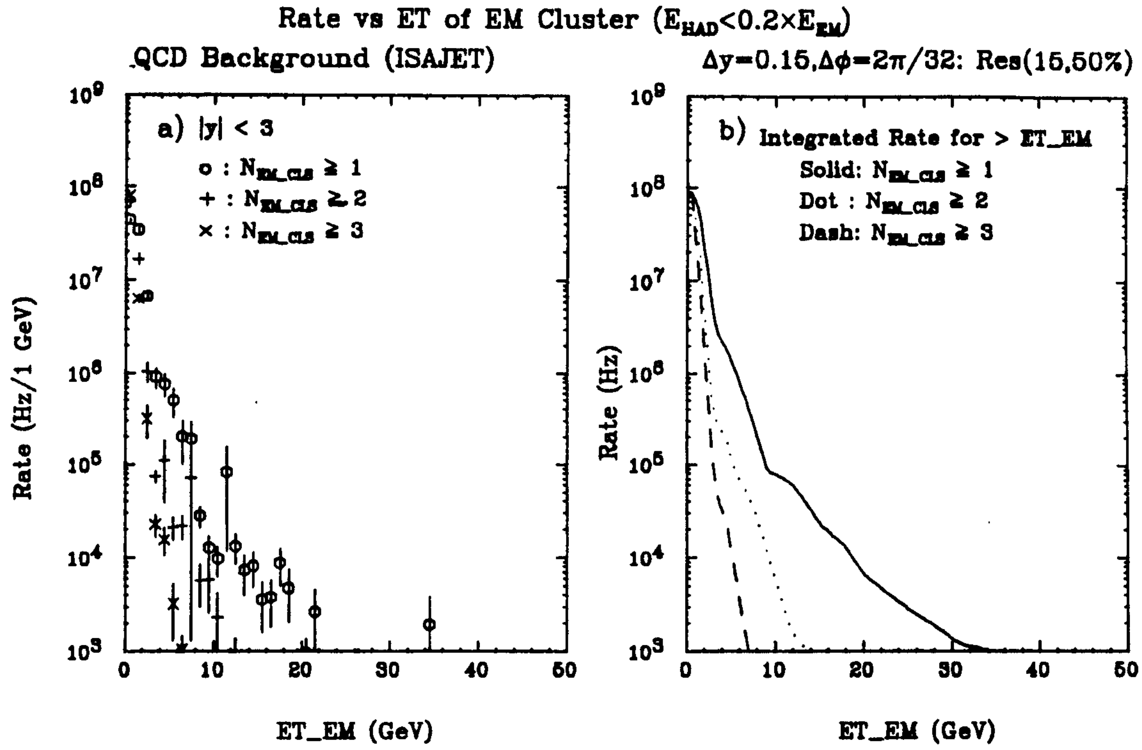

Rate vs ET of EM Cluster (E_HAD<0.2×E_EM)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3
o : N_EM_CLS ≥ 1
+ : N_EM_CLS ≥ 2
× : N_EM_CLS ≥ 3
Rate (Hz/1 GeV)
ET_EM (GeV)
b) Integrated Rate for > ET_EM
Solid: N_EM_CLS ≥ 1
Dot : N_EM_CLS ≥ 2
Dash: N_EM_CLS ≥ 3
Rate (Hz)
ET_EM (GeV)

Fig. 9

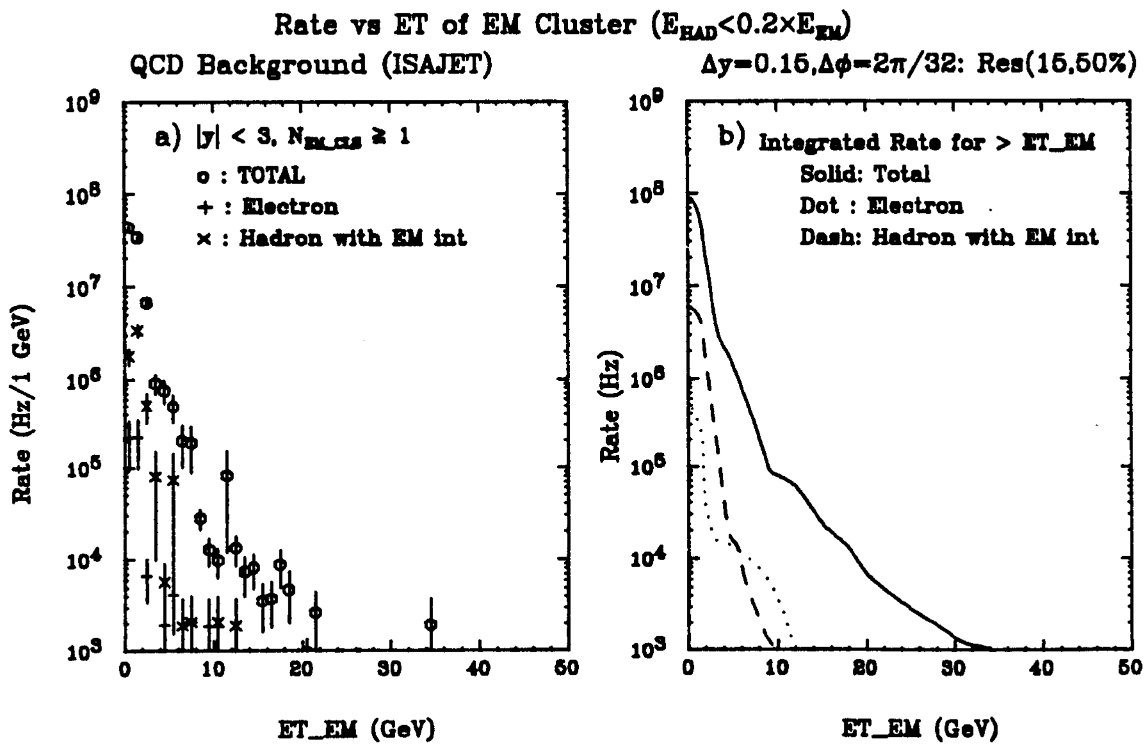

Rate vs ET of EM Cluster (E_HAD<0.2×E_EM)
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_EM_CLS ≥ 1
o : TOTAL
+ : Electron
× : Hadron with EM int
Rate (Hz/1 GeV)
ET_EM (GeV)
b) Integrated Rate for > ET_EM
Solid: Total
Dot : Electron
Dash: Hadron with EM int
Rate (Hz)
ET_EM (GeV)

Fig. 10

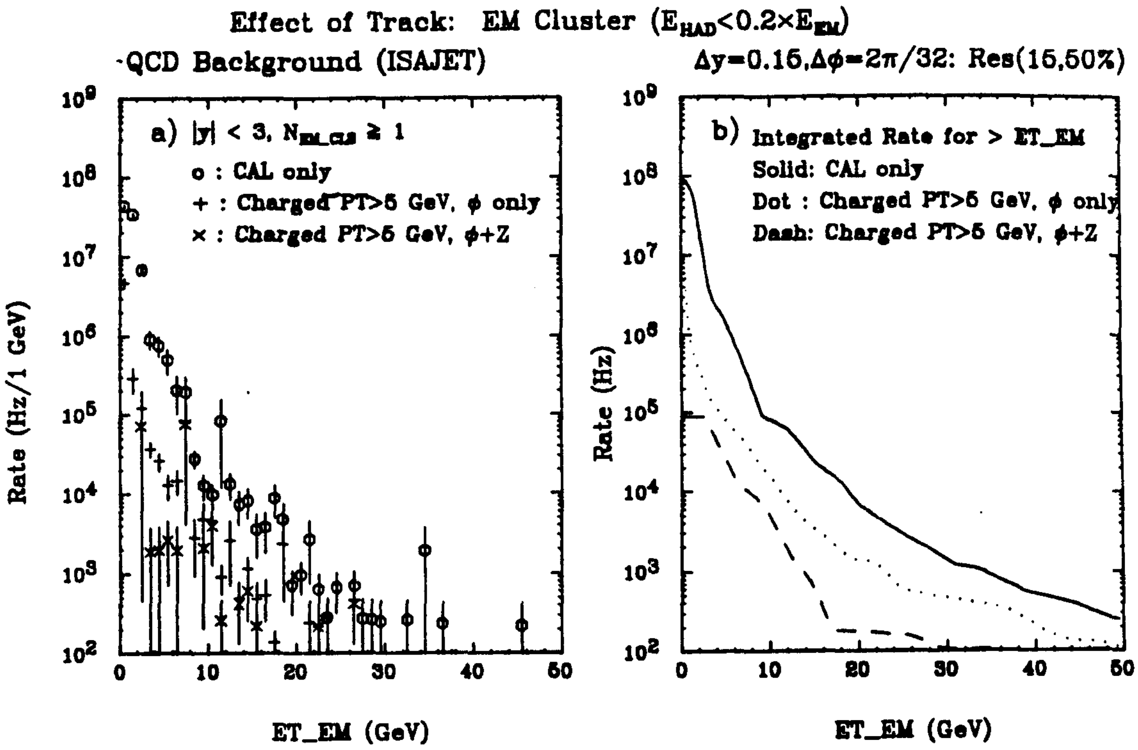

Effect of Track: EM Cluster (E_{HAD}<0.2×E_{EM})
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_{EM_CLS} ≥ 1
o : CAL only
+ : Charged PT>5 GeV, φ only
× : Charged PT>5 GeV, φ+Z
Rate (Hz/1 GeV)
ET_EM (GeV)
b) Integrated Rate for > ET_EM
Solid: CAL only
Dot : Charged PT>5 GeV, φ only
Dash: Charged PT>5 GeV, φ+Z
Rate (Hz)
ET_EM (GeV)

Fig. 11

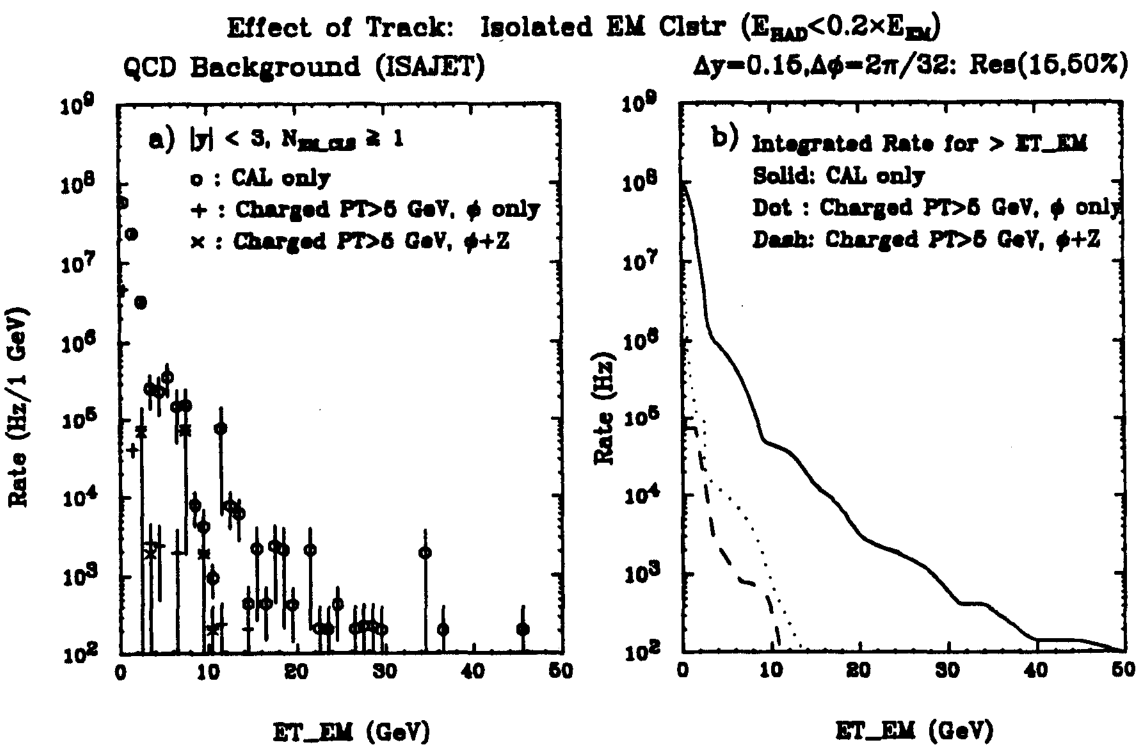
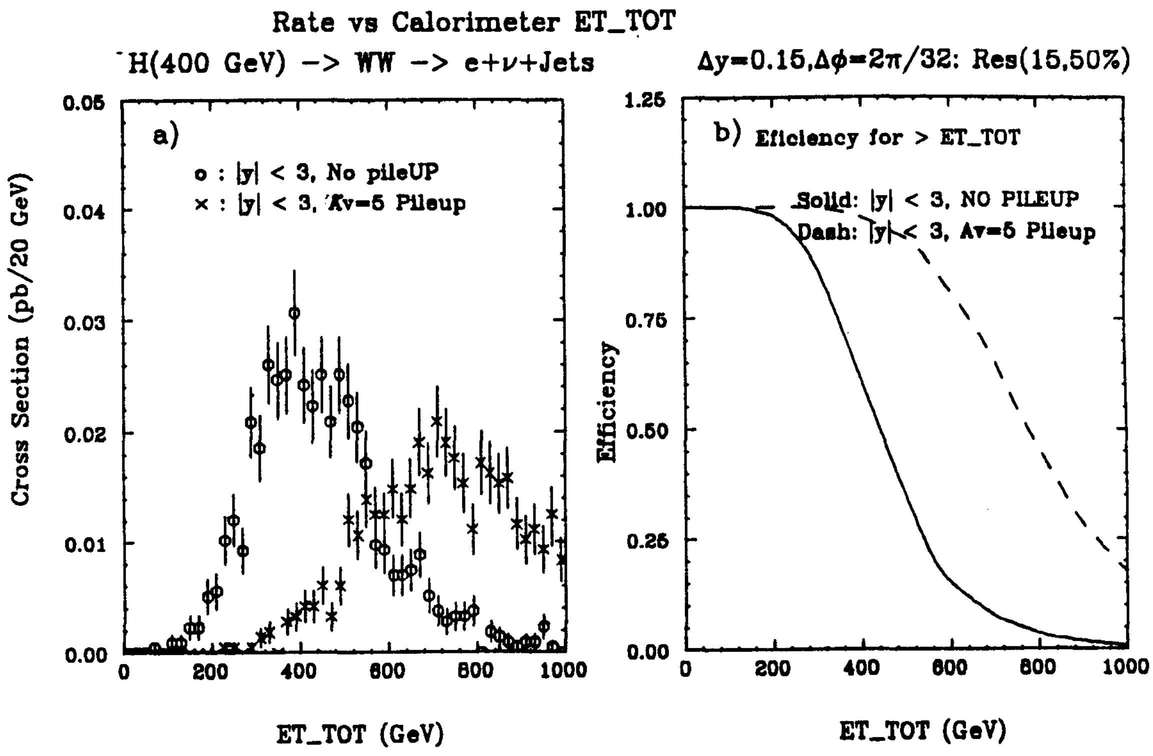
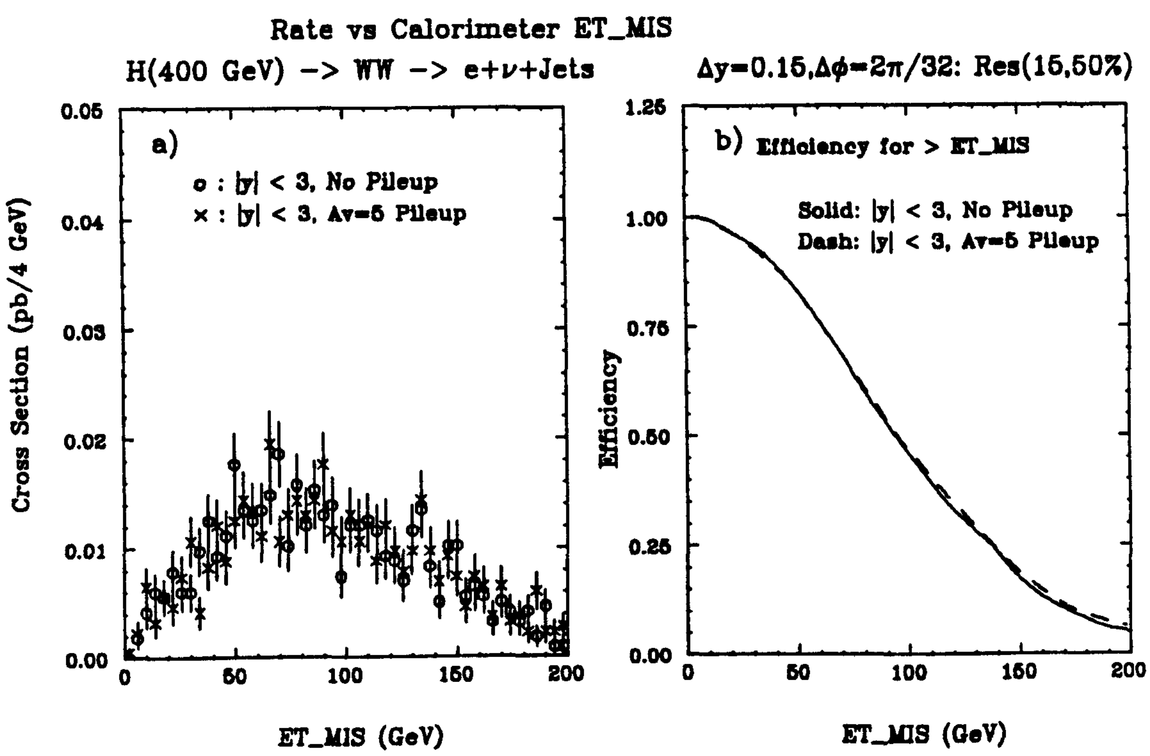

Effect of Track: Isolated EM Clstr (E_{HAD}<0.2×E_{EM})
QCD Background (ISAJET)
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_{EM_CLS} ≥ 1
o : CAL only
+ : Charged PT>5 GeV, φ only
× : Charged PT>5 GeV, φ+Z
Rate (Hz/1 GeV)
ET_EM (GeV)
b) Integrated Rate for > ET_EM
Solid: CAL only
Dot : Charged PT>5 GeV, φ only
Dash: Charged PT>5 GeV, φ+Z
Rate (Hz)
ET_EM (GeV)

Fig. 12



Rate vs Calorimeter ET_TOT
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a)
o : |y| < 3, No pileUP
× : |y| < 3, Av=5 Pileup
Cross Section (pb/20 GeV)
ET_TOT (GeV)
b) Efficiency for > ET_TOT
Solid: |y| < 3, NO PILEUP
Dash: |y| < 3, Av=5 Pileup
Efficiency
ET_TOT (GeV)

Fig. 13



Rate vs Calorimeter ET_MIS
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a)
o : |y| < 3, No Pileup
× : |y| < 3, Av=5 Pileup
Cross Section (pb/4 GeV)
ET_MIS (GeV)
b) Efficiency for > ET_MIS
Solid: |y| < 3, No Pileup
Dash: |y| < 3, Av=5 Pileup
Efficiency
ET_MIS (GeV)

Fig. 14

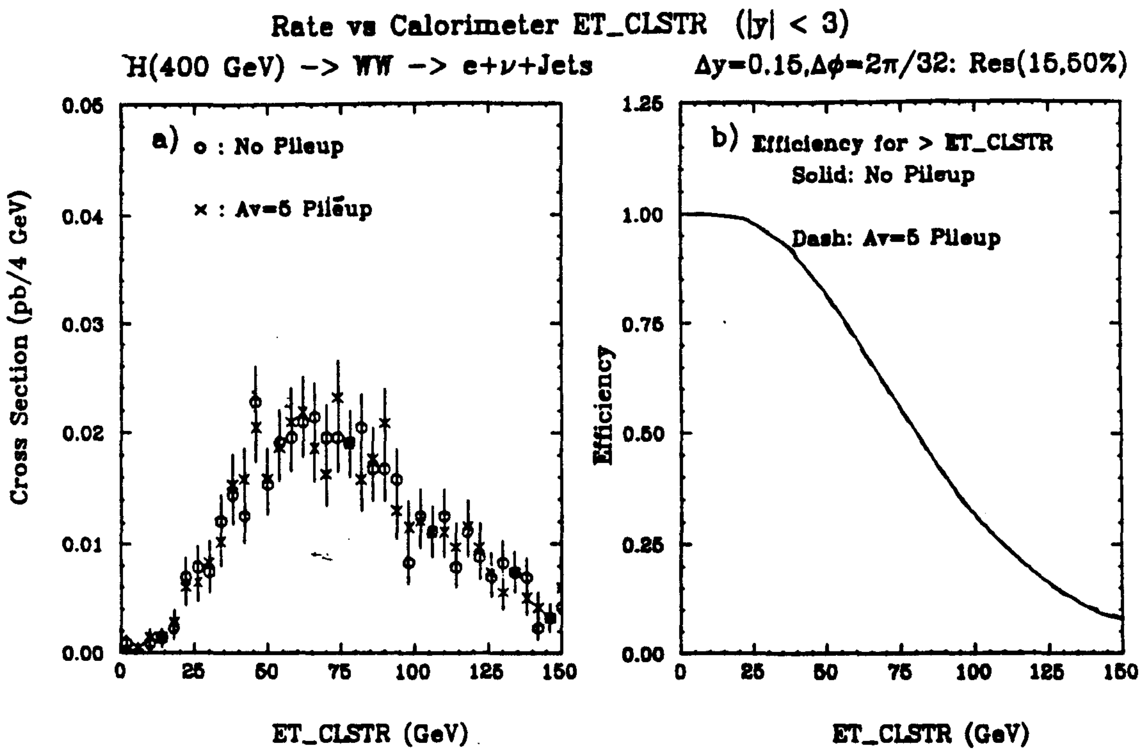

Rate vs Calorimeter ET_CLSTR (|y| < 3)
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) o : No Pileup
× : Av=5 Pileup
Cross Section (pb/4 GeV)
ET_CLSTR (GeV)
b) Efficiency for > ET_CLSTR
Solid: No Pileup
Dash: Av=5 Pileup
Efficiency
ET_CLSTR (GeV)

Fig. 15

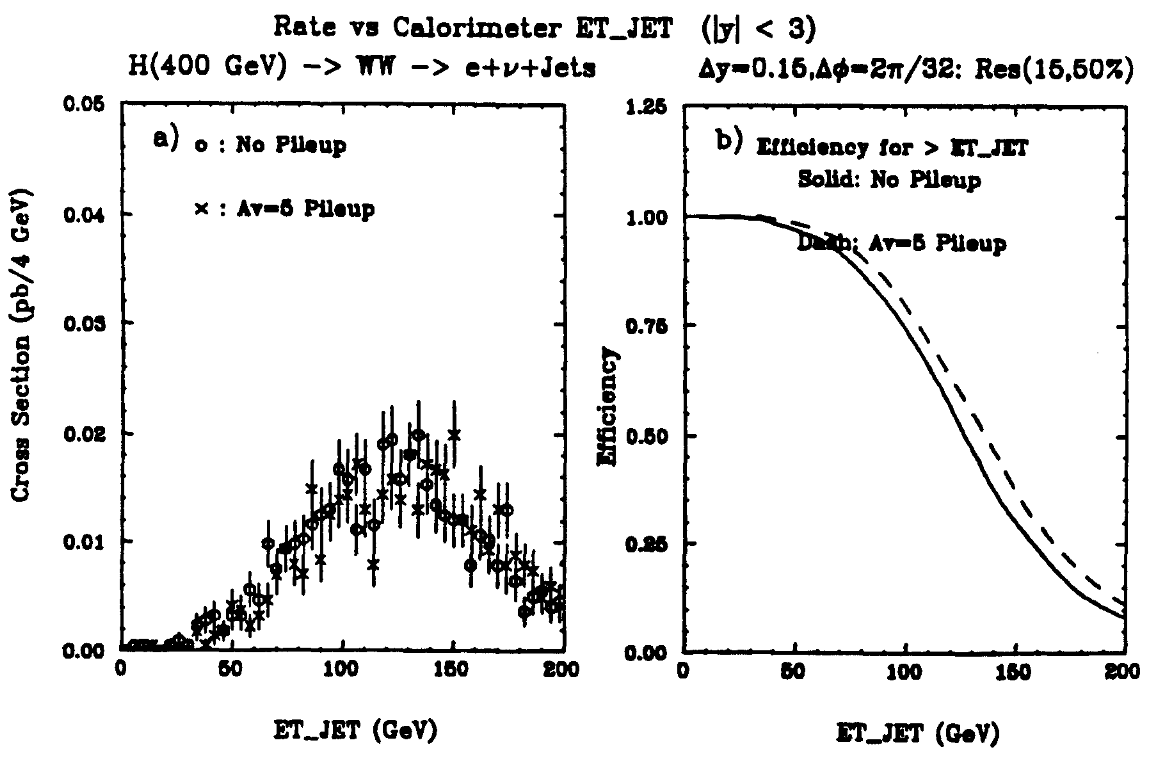
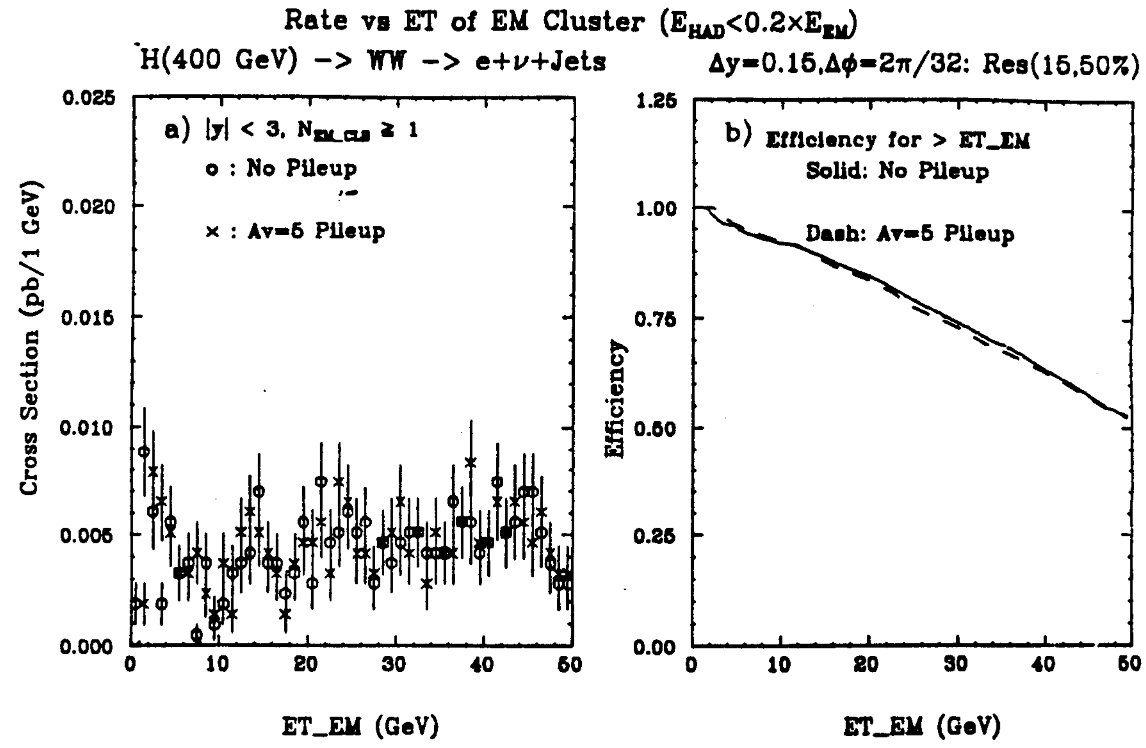
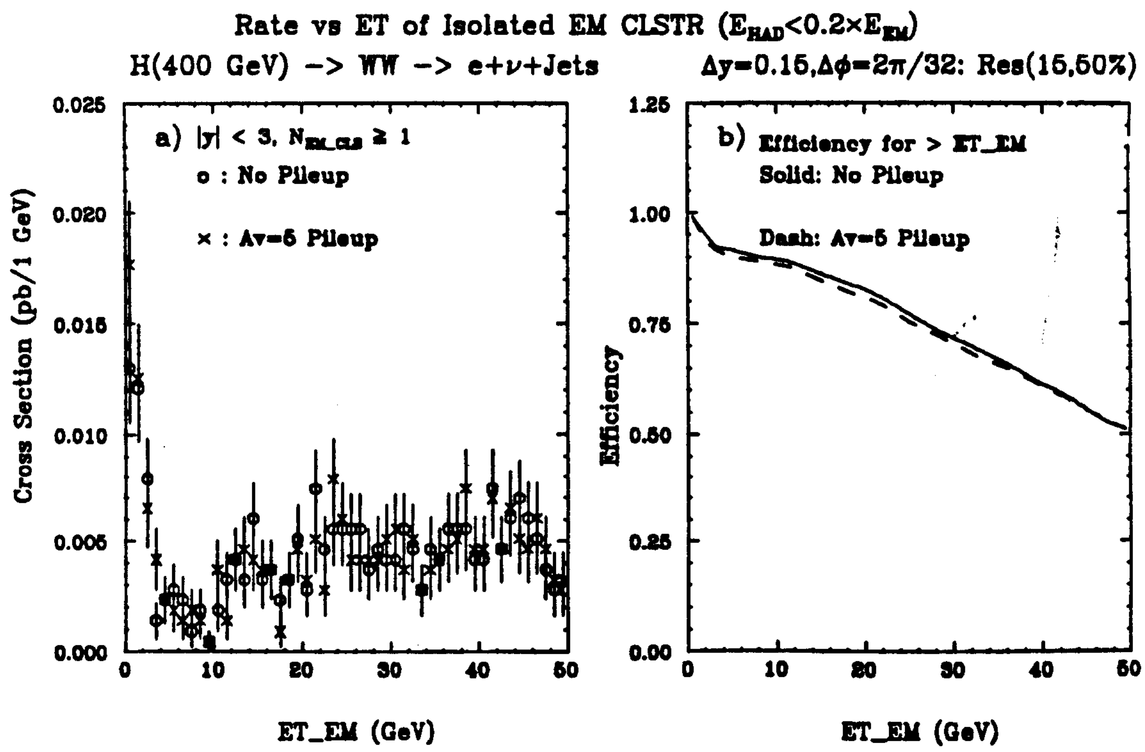

Rate vs Calorimeter ET_JET (|y| < 3)
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) o : No Pileup
× : Av=5 Pileup
Cross Section (pb/4 GeV)
ET_JET (GeV)
b) Efficiency for > ET_JET
Solid: No Pileup
Dash: Av=5 Pileup
Efficiency
ET_JET (GeV)

Fig. 16



Rate vs ET of EM Cluster (E_{HAD}<0.2×E_{EM})
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_{EM_CLS} ≥ 1
o : No Pileup
× : Av=5 Pileup
Cross Section (pb/1 GeV)
ET_EM (GeV)
b) Efficiency for > ET_EM
Solid: No Pileup
Dash: Av=5 Pileup
Efficiency
ET_EM (GeV)

Fig. 17



Rate vs ET of Isolated EM CLSTR (E_{HAD}<0.2×E_{EM})
H(400 GeV) -> WW -> e+ν+Jets
Δy=0.15,Δφ=2π/32: Res(15,50%)
a) |y| < 3, N_{EM_CLS} ≥ 1
o : No Pileup
× : Av=5 Pileup
Cross Section (pb/1 GeV)
ET_EM (GeV)
b) Efficiency for > ET_EM
Solid: No Pileup
Dash: Av=5 Pileup
Efficiency
ET_EM (GeV)

Fig. 18