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How Thick Should the GEM Barrel Calorimeter Be?

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A simulation study of particles exiting the calorimeter from ordinary two jet events for the GEM detector at the SSC is reported. The overall rate of particles exiting the hadron filter as well as the source of these particles are determined for a constant thickness calorimeter following the GEM baseline tracking volume. Criteria are defined by which the thickness of the calorimeter can be gauged and the minimum thickness determined. From these criteria it is determined that for the rapidity range $0.0 < |\eta| < 1.3$ that 12λ of calorimeter are needed.

Introduction

A very important consideration in the optimization of the design of any muon spectrometer for SSC detectors is the level of backgrounds from hadron spectrometer for SSC detectors is the level of backgrounds from hadron punchthrough and decay. These backgrounds not only affect the ability to observe signals from rare processes at the SSC, but also the ability to form a low-rate muon trigger. An outstanding issue which must be understood before embarking on the construction of the muon spectrometer is the minimum hadron absorber thickness demanded by SSC physics needs. This is particularly important in the GEM detector where all the absorbing material lies inside of the muon system. The amount of filter material required will set the scale for the muon spectrometer in both size and cost. Since the hadron absorber will be composed of expensive hadron calorimetry, the thickness requirement for the hadron absorber will impact the calorimetry cost if it is greater than that required for good hadron energy resolution $(9-10\lambda)$. In this era of "design to cost" it is therefore very important to study and determine the calorimeter thickness necessary to effectively trigger, identify, and measure muons of physics interest while not overwhelming the SSC detector budget.

In this paper, results of a simulation study of particle rates in the muon spectrometer as a function of calorimeter thickness are reported. For the study, $q\bar{q}$ events were generated via ISAJET and particle rates outside the calorimeter were divided into prompt muons from quark leptonic decays, muons from π/K decays occuring in the inner tracking region, and hadron induced debris exiting the calorimeter (punchthrough). To estimate the punchthrough rate for various calorimeter thicknesses, the PCHTHR code [1] was utilized. Considering only the rates of particles outside the calorimeter, criteria are defined by which a minimum calorimeter thickness requirement is determined. This should be considered as a lower limit for the minimum calorimeter depth requirement. In the near future, detailed muon trigger and muon system performance requirements may require the calorimeter to be even deeper. After a brief discussion of the simulation, results are presented for particle rates in rapidity intervals.

The Criteria for Evaluating Calorimeter Depth

Absolute Rates

For the muon system, the limiting factor will be the rate of particles in the first muon detector layers after the calorimeter. This rate should be sufficiently low that a level 1 muon trigger can be formed which is efficient for muons of interest, namely muons from Ws and Zs (about 10–20GeV/c in transverse momentum). In the barrel region, the trigger components proposed for GEM are RPCs. These devices have been tested recently at CERN [2] and found to handle rates $20 - 50\text{Hz/cm}^2$ without significant loss of efficiency. Assuming this technology, a criteria can then be defined:

Criteria 1: At the highest SSC luminosity, the rate of particles exiting the barrel calorimeter should be less than 20Hz/cm^2.

For the purposes of this study the highest SSC luminosity was assummed to be $L = 10^{34}\text{cm}^{-2}$. By particles I mean all particles which the RPCs are sensitive to. This includes all charged particles and also potentially photons and neutrons exiting the calorimeter. The latter has not yet been considered and is under investigation at this time. Further trigger requirements are not addressed in this report and may impose additional depth requirements.

Punchthrough vs Real Muon Rates

In considering criteria for evaluating the calorimeter depth, it is useful to consider the source of the particles exiting the calorimeter. Charged particles entering the barrel muon system will be mainly of three sources: 1) Prompt muons from quark decays, 2) the muons from π/K decays in the inner tracking volume before the calorimeter, and 3) the hadron-induced particles leaking out the back of the calorimeter (hadron punchthrough. The first two sources produced muons before entering the calorimeter and so the calorimeter material serves merely to range out these muons. Therefore the reason for calorimeter depth beyond that needed for good hadron energy resolution is to reduce the rate of hadron punchthrough. Assuming therefore that the calorimeter is not already so thick that it serves only to range muons, then the following two criteria can be defined by which we can gauge the benefits of additional calorimeter thickness:

Criteria 2.1: The overall particle rate exiting the calorimeter from hadron punchthrough should be much less than the sume of the rates from prompt muons and muons from π/K decays.

Criteria 2.2: The rate of particles with transverse momentum above a trigger threshold from hadron punchthrough should be much less than that from prompt muons and muons from π/K decays.

Criteria 2.1 was used by D. Green et. al. [3] to determine the calorimeter depth requirements for the SDC detector. A parameterization of the punchthrough probability from the WA1 data was used to determine the punchthrough rate. The main difference is the size of the tracking volume. The 2m radius of the tracking volume will give 2.7 times more rate of muons from decays than the GEM tracking volume of 75cm radius will give. Hence, considering only Criteria 2.1, it was thus found for SDC that the rate of muons from π/K decays dominate for calorimeter depth greater than 7λ and determined that no additional calorimeter thickness was required by the muon system over that needed by the calorimeter itself for good hadron energy resolution.

The Simulation

For the determination of particles rates after the calorimeter, TWOJET events have been generated using the ISAJET generator in the JET P_T range $4\text{GeV/c} < P_T < 5000\text{GeV/c}$ and top quark mass $M_t = 140\text{GeV/c}^2$. The event sample was compiled in various P_T subintervals in order to have increased statistics at high P_T while generating the entire SSC $p\bar{p}$ cross section (140mb) The events were weighted by the cross section when filling the histograms.

The generated particles pass through a fast simulation of a tracking volume and calorimeter. Muons traversing the "calorimeter" lose energy at 218MeV per interaction length where an interaction length is defined as the mean nuclear interaction length. The above energy loss is the average minI energy loss in U and Pb. Decays in flight of π/K were calculated in a tracking volume 0.75m in radius and 4.4m in length. Muons from the decays were assummed to be in the direction of the parent hadron with energy thrown according to the kinematics of the two body decays.

The hadron punchthrough was simulated using the PCHTHR code which produces 4-vectors for the punchthrough particles. The code was derived from GEANT simulation of single pions of various momenta incident on iron absorber of various thickness. The resultant punchthrough showers were recorded and probability tables prepared for the punchthrough probability, shower multiplicity, individual particle type, momentum, spatial position, and exiting angle relative to the incident track. The probability tables were incorporated into a single subroutine which was called for stable hadrons particles from the ISAJET generated events. The PCHTHR code, while superior to simple parameterizations, assummes that a lambda of Fe is equivalent to a lambda of any material. It has been found from GEANT simualtion that Pb has slightly more absorptive power per lambda than solid Fe. The PCHTHR code also assummes no magnetic field in the calorimeter material. The addition of a non zero magnetic field in the calorimeter should serve to suppress the punchthrough. The PCHTHR code can be considered a conservative estimate of the punchtrough.

Several runs were made over the same 150k event sample (various P_T ranges in ISAJET) with a constant depth calorimeter of 6, 8, 10, 12, 14, and 16lambda thickness. Rates were then recorded for each source of particles exiting the calorimeter in rapidity bins 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-2.5.

Results

Absolute Rates

Figure 1 shows the total rate (kHz) at $L = 10^{33}\text{cm}^{-2}$ per 0.1 unit of rapidity for calorimeter thickness ranging from 6 to 16λ. There are large reductions in rate between 6λ and 8λ (factor ~ 8) and between 8λ and 10λ (factor ~ 4). For thickness greater than 10λ, the rate reduction per additional calorimeter thickness slows becoming about a factor 2 reduction per 2λ increase in calorimeter depth about 12λ. This slowing of the rate reduction with calorimeter depth is due to the punchthrough particles becoming muon dominated. Figure 2 shows the transverse momentum distribution of particles exiting 12λ of calorimeter in the barrel region. Most of these particles (more than 90%) have $P_T < 1.3\text{GeV/c}$ and will curl around completely in the muon tracking region between the calorimeter and the coil and result in two hits per layer. Figure 3 shows the rate per unit area (Hz/cm^2) at 10^{33}cm^{-2} expected in the first layer of the

Cal Depth	Rate at $\eta = 0$	Rate at $\lvert\eta\rvert = 1.3$
6λ	70Hz/cm^2	400Hz/cm^2
8λ	9	60
10λ	3	20
12λ	1.2	6
14λ	0.9	4
16λ	0.5	2

Table 1: Muon Rates at 10^{34}cm^{-2} in barrel

barrel muon system for different calorimeter depths. The first layer is positioned at R=370cm. The rate at 12λ agrees within factor of 2 with the result of B. Zhou et. al. reported in the GEM LOI. The rates are summarized in Table 1 where $L = 10^{34}\text{cm}^{-2}$ luminosity has been assummed. Assuming a factor 3 uncertainty in the numbers, in order to satisfy Criteria 1, a minimum of 10λ of calorimeter are required at 90° ($\eta = 0$) and 12λ at 30° ($|\eta| = 1.3$).

Punchthrough vs Real Muon Rates

Figure 4 shows the particle rate in bins of 0.5 units of rapidity exiting a constant thickness calorimeter at SSC design luminosity 10^{33}cm^{-2}. Shown for each thickness from 6λ to 16λ are the rates of all charged particles and the rate of charged particles of transverse momentum more than 10GeV/c. The solid histogram shows the total particle rate and the dashed, dot-dashed, and dotted histograms show the prompt, decay muon, and punchthrough particle components of the total rates respectively. In the barrel region, $|\eta| < 1.3$, the hadron punchthrough component dominates the overall particle rate for calorimeter depths $< 12\lambda$. For $\geq 12\lambda$ all 3 components of particles exiting the calorimeter have comparable rates. Figure 5a shows for $|\eta| < 0.5$ the total rate of charged particles exiting the calorimeter (solid curve) and the rate from real muons (prompt muons and π/K decays in the tracker – dashed curve) and punchthrough particles (dot-dashed curve) for a 75cm inner radius for the calorimeter. Figure 5b shows the same result if the inner radius of the calorimetrer was increased to 100cm where only the decay component is then expected to increase. If criteria 2.1 is satisfied when the fraction of the total rate from hadron punchthrough is less 1/3, then it can be seen for both cases shown in figure 5, that criteria 2.1 is satisfied for 12λ and higher of calorimeter depth. Considering only particles with $P_T > 10\text{GeV/c}$ in figure 4, the rate coming from prompt muons dominates for calorimeter depths of 10λ and above. So, assuming that we satisfy Criteria 2.2 if the fraction of the particle rate above 10 GeV/c from hadron punchthrough is less than 1/3 of the total, then Criteria 2.2 is satisfied in the barrel region for 10λ and higher calorimeter depth.

In the forward region, the rates become dominated by the decay component for calorimeter depth more than 8λ. But the overall charged particle rate is more than an order of magnitude larger than it is in the barrel region. Hence detector component occupancies and detailed trigger requirements must be considered in evaluating the calorimeter depth in the endcap region. This is not considered here.

Conclusions

Criteria	Depth at $\eta = 0$	Depth at $|\eta| = 1.3$
1	10	12
2.1	12	10
2.2	10	10

Table 2: Depth Requirements imposed by Criteria 1 and 2

Table 2 summarizes the calorimeter depth requirements resulting from Criteria 1 and 2. To satisfy all criteria considered requires a calorimeter of minimum 12λ depth over the barrel region. Consideration has not been given to detailed muon system performance requirements such as muon identification, triggering, and momentum measurement. Also, the effects of neutrons and gammas exiting the calorimeter has not been considered. Therefore this should be considered a lower estimate of the calorimeter depth requirement.

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References

[1] See for example transparancies talk given by R. McNeil at the GEM Collaboration meeting July 17, 1991.

[2] RD5 Collaboration, Status Report, CERN/DRDC/91-53 1992.

[3] D. Green, et. al., Depth Requirements in SSC Calorimeters, FERMILAB-FN-570, 1991.

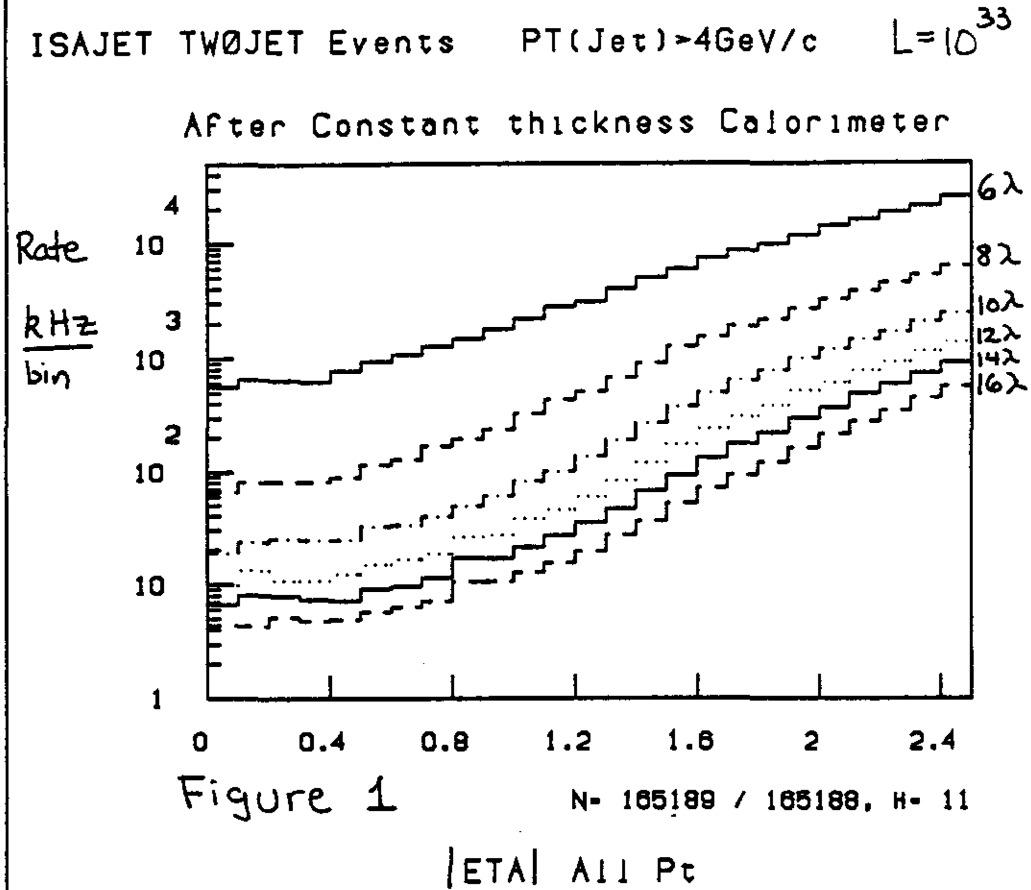


Figure 1

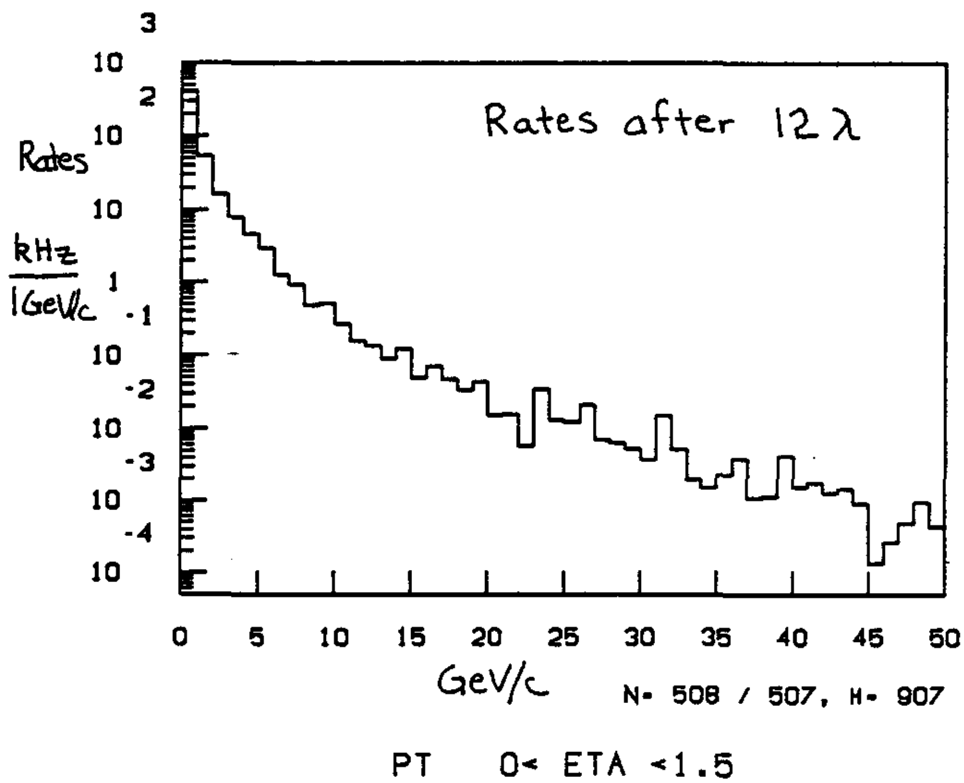
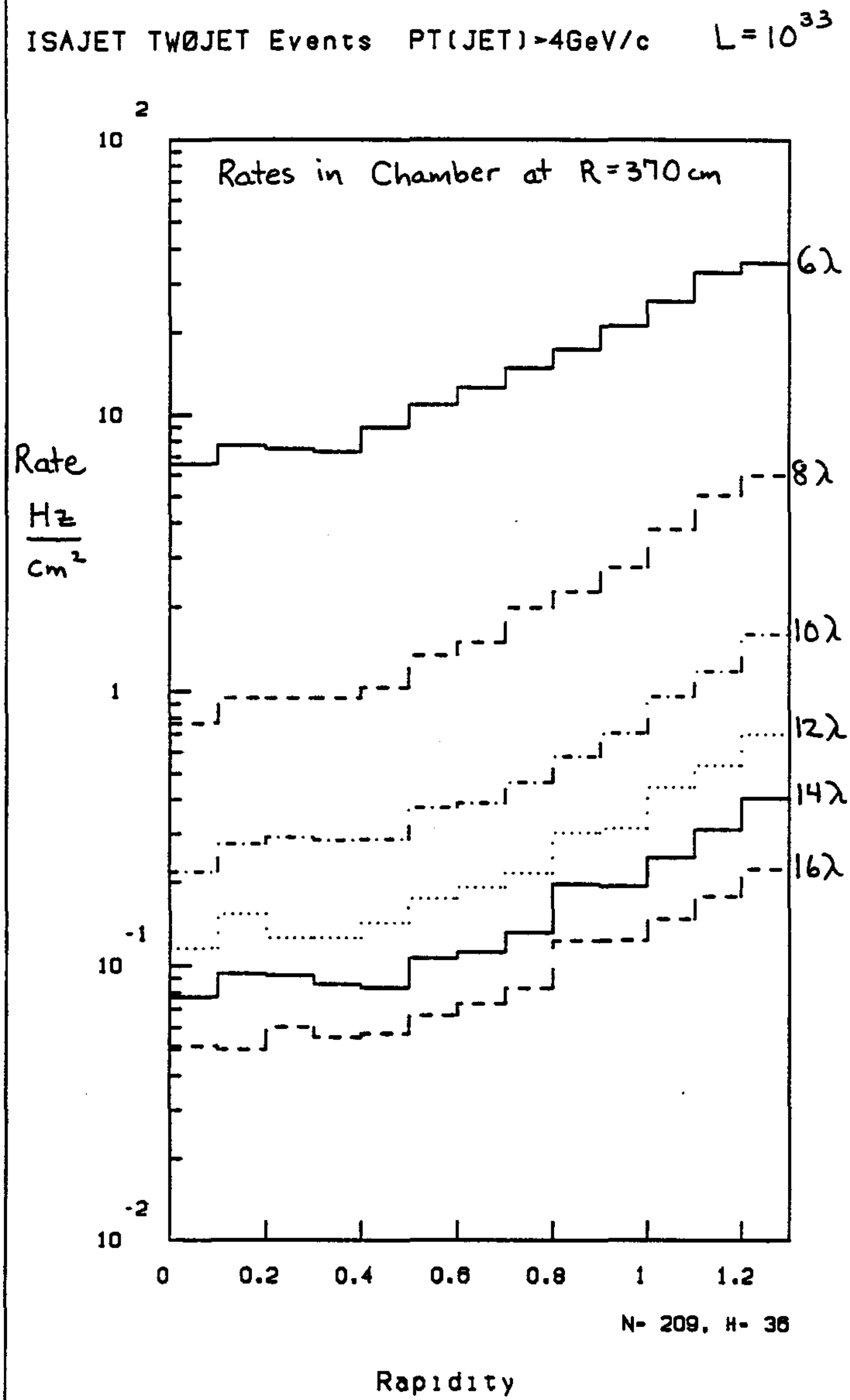
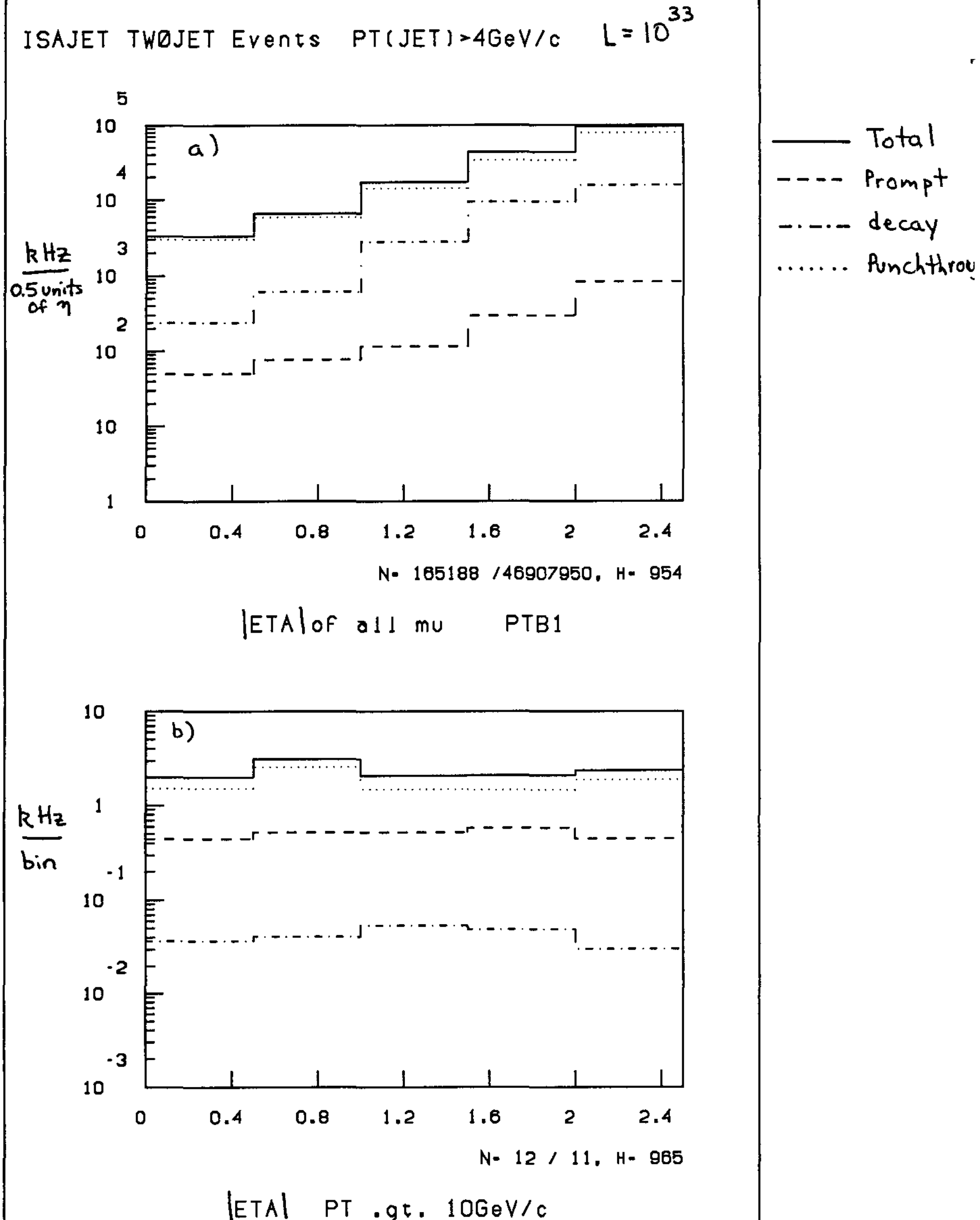


Figure 2



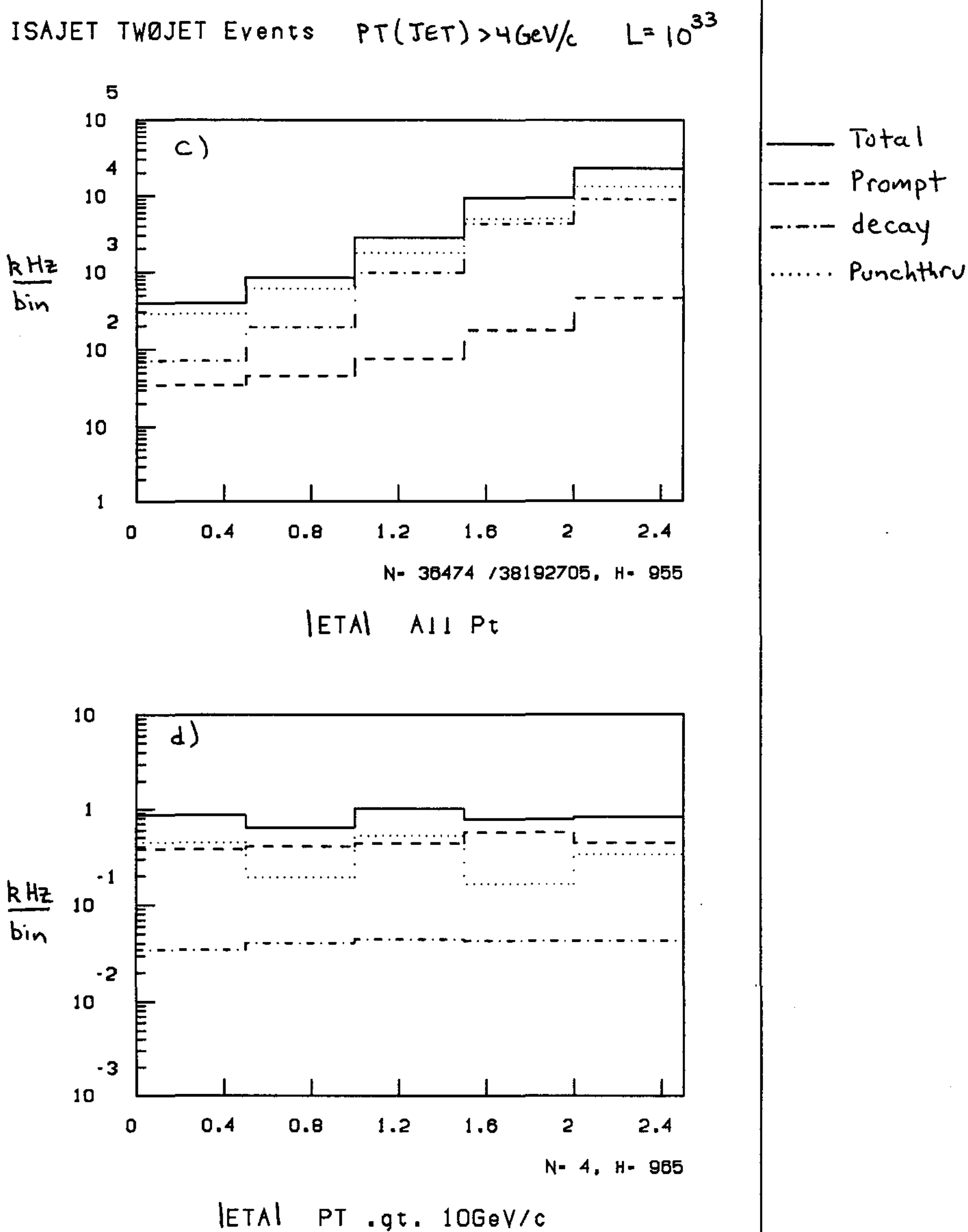
Rates after Constant Thickness Calorimeter

Figure 3



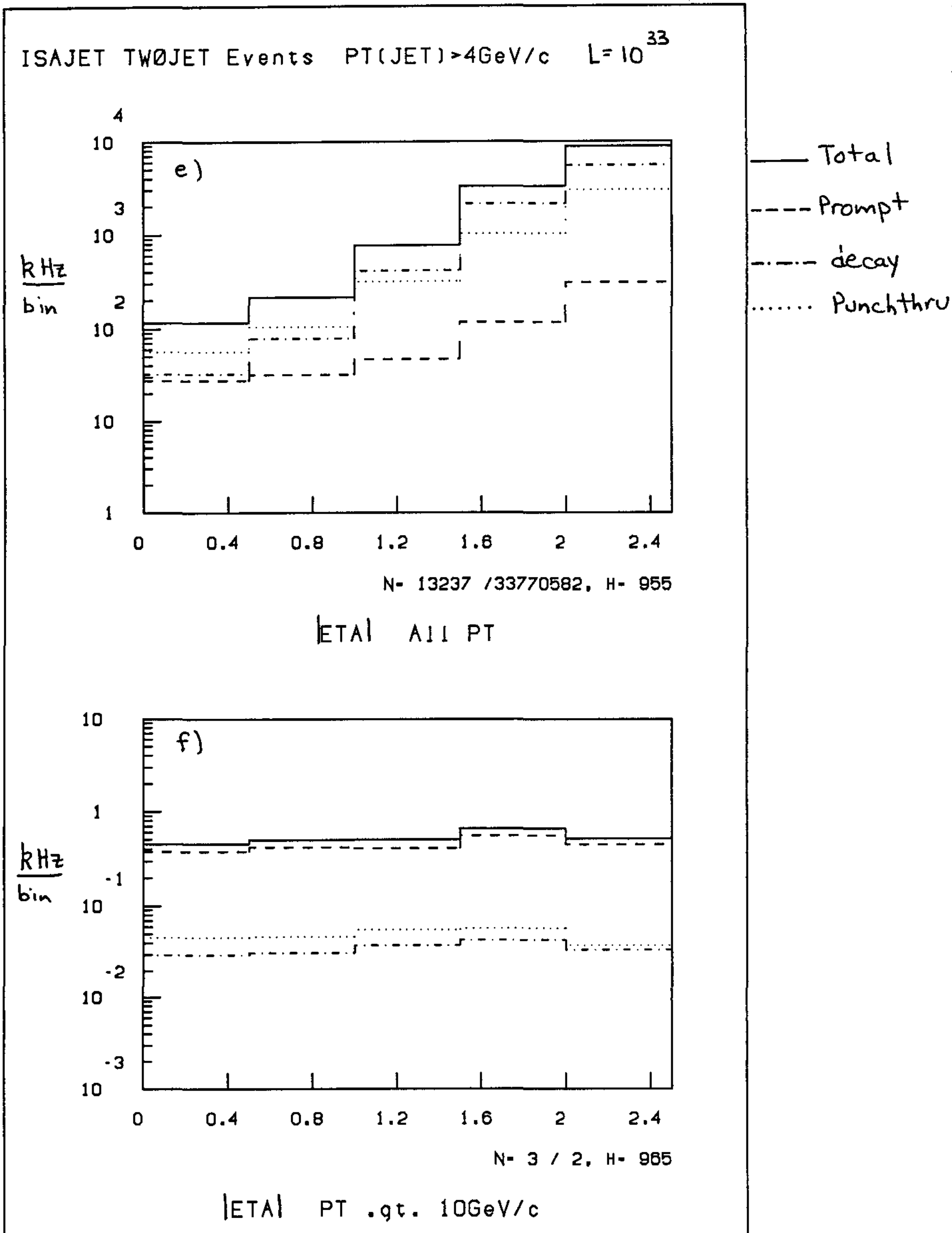
Rates after Constant Thickness Calorimeter - 61

Figure 4a-b



Rates after Constant Thickness Calorimeter - 81

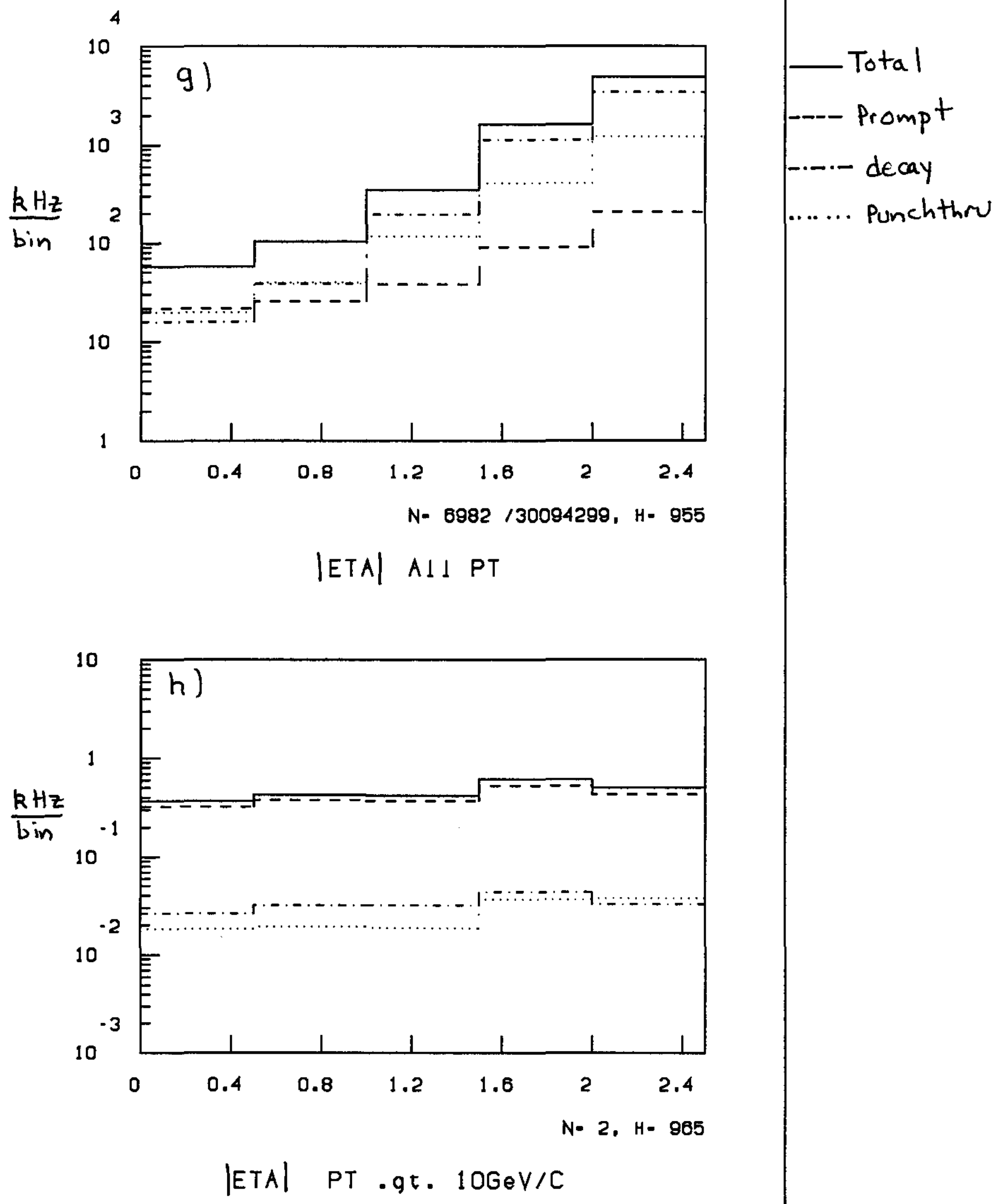
Figure 4c-d



Rates after Constant Thickness Calorimeter - 101

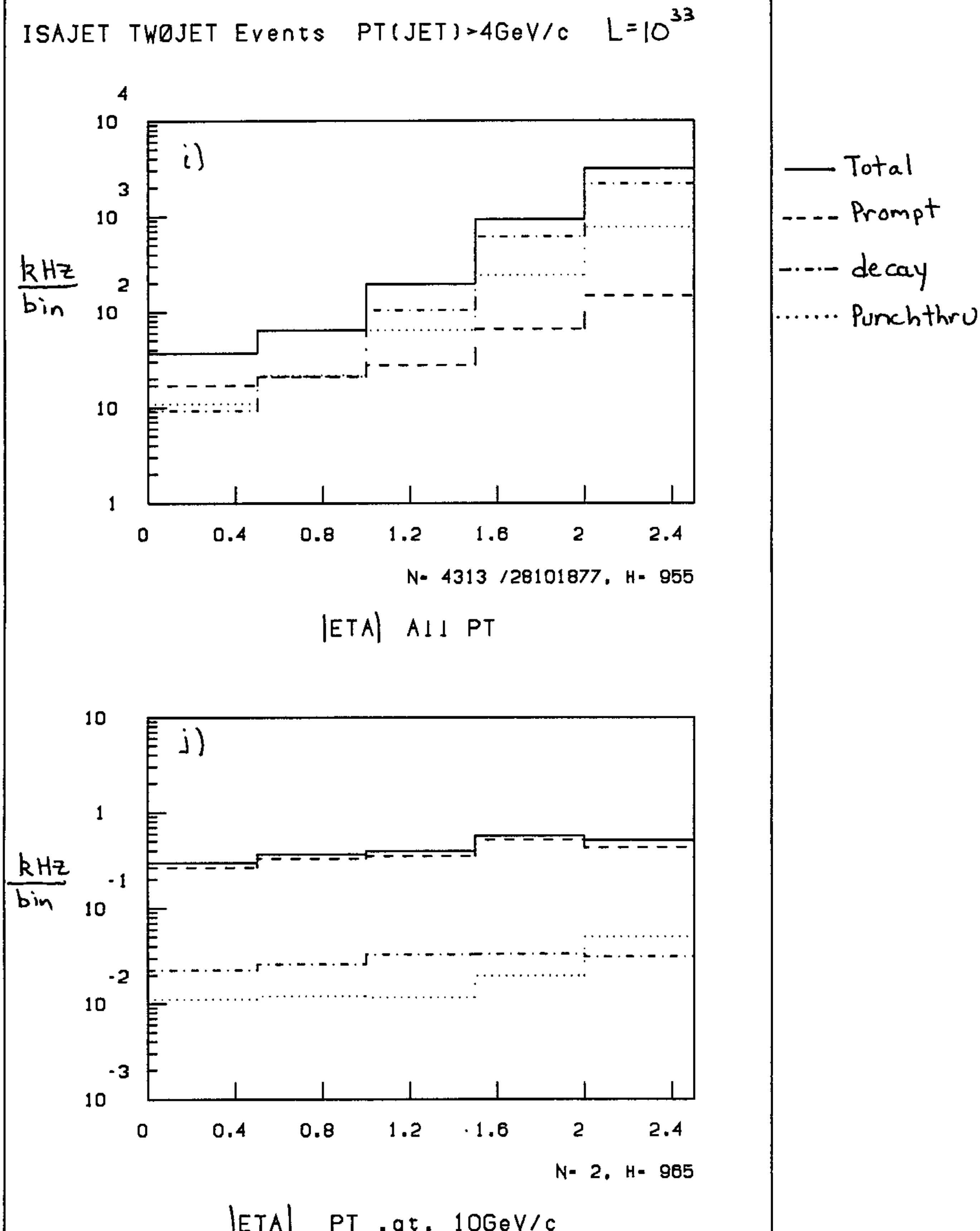
Figure 4e-f

ISAJET TWØJET Events PT(JET)>4GeV/c $L=10^{33}$



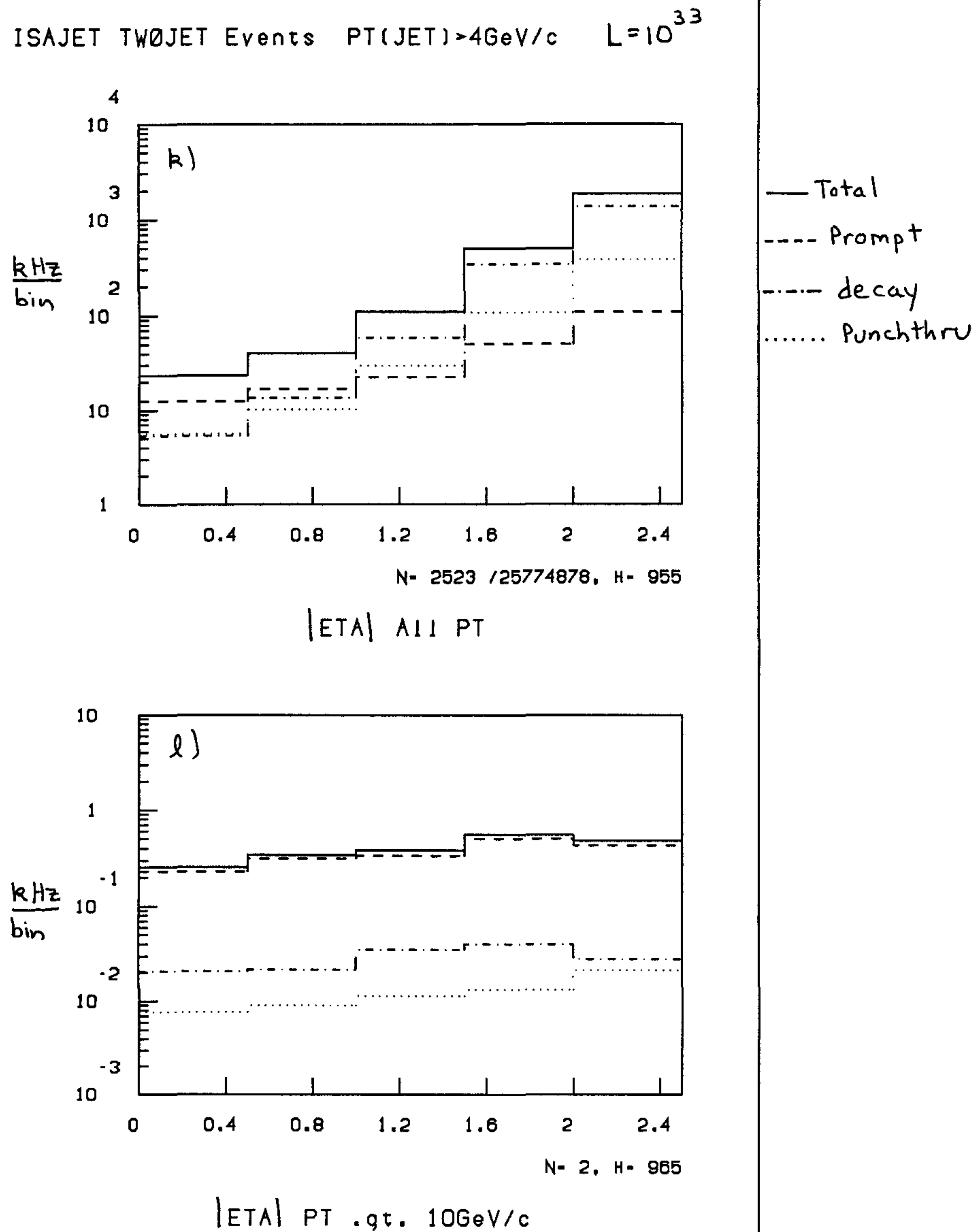
Rates after Constant Thickness Calorimeter - 121

Figure 4 g-h



Rates after Constant Thickness Calorimeter - 141

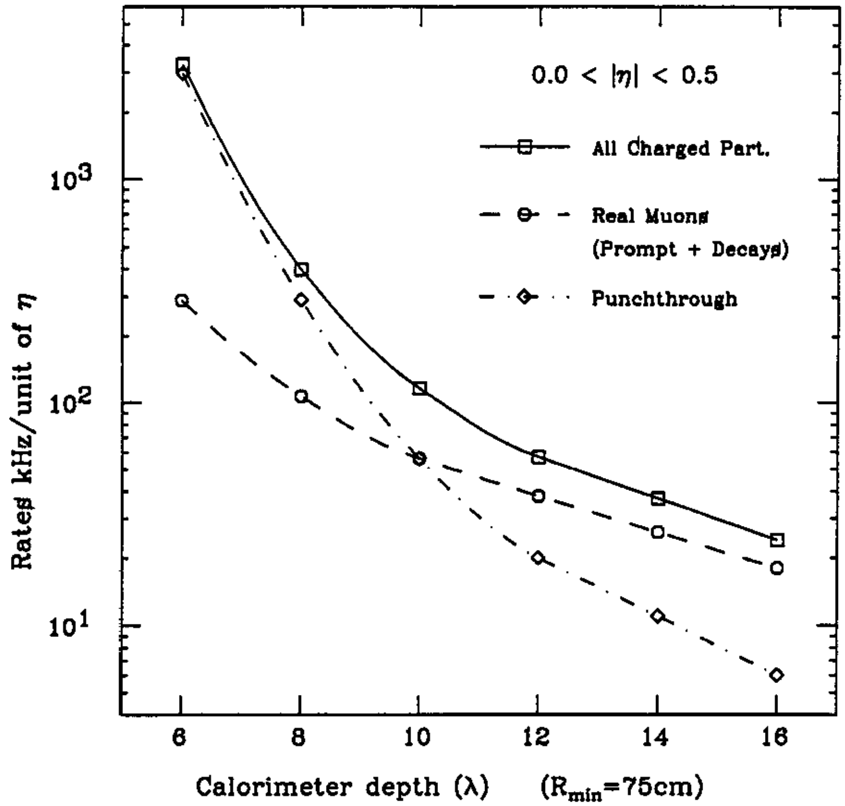
Figure 4 i-j



Rates after Constant Thickness Calorimeter - 161

Figure 4 k-l

a)



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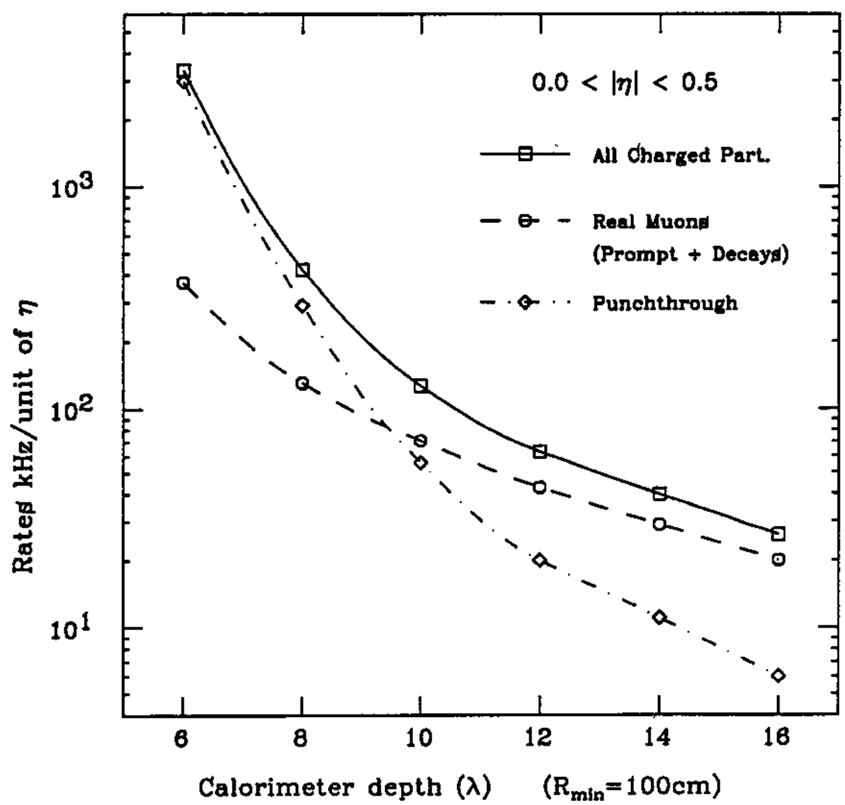

Figure 5. Rates in barrel region after calorimeter for two values of the inner calorimeter radii: a) 75cm and b) 100cm