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Separation of Higgs Event Vertex from Minimum Bias Events

Hiroaki Yamamoto
California Institute of Technology

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Abstract:

Precise event vertex determination is very important for the measurement of the intermediate mass Higgs decaying into two γs. This note summarizes the result of the selection of the Higgs event vertex using the charged particle multiplicity when there are minimum bias events in the same bunch crossing. The probability to select the correct vertex is 85 to 95%, depending on the model of minimum bias events, for the Higgs mass range of 80 to 160 GeV, and the result is insensitive to the track reconstruction efficiency.

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Hiroaki Yamamoto
Lauritsen Laboratory
California Institute of Technology
Pasadena, CA 91125

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Precise event vertex determination is very important for the measurement of the intermediate mass Higgs decaying into two γs. This note summarizes the result of the selection of the Higgs event vertex using the charged particle multiplicity when there are minimum bias events in the same bunch crossing. The probability to select the correct vertex is 85 to 95 %, depending on the model of minimum bias events, for the Higgs mass range of 80 to 160 GeV, and the result is insensitive to the track reconstruction efficiency.

1 Introduction

The importance of the event vertex z resolution in discovering a narrow $\gamma - \gamma$ resonance, like intermidiate mass Higgs, has been pointed out (e.g., see R-Y Zhu CALT-68-1777). The standard option of SSC is $L = 10^{33} cm^{-2} s^{-1}$ with a bunch crossing frequency of 62.5 MHz, which corresponds to 0.016 mb^{-1} integrated luminosity per crossing. The proton-proton inelastic cross section is around 140mb at this energy, giving rise to a 'minimum bias' event background of on the average 2 events. Although GEM detector is designed to give the z position resolution of each event vertex of 1mm, if the correct Higgs event vertex is not selected to calculate the direction of γs, the significance of the signal is degraded.

The number of charged tracks coming from the Higgs event vertex and that coming from the minimum bias event are different (See Fig.3, discussed later). In this note, the probability is calculated to select the Higgs event vertex using this multiplicity information.

The counting of the charged track depends on the track reconstruction efficiency. The probability is calculated assuming different reconstruction efficiencies, 100% to 80% per track, and it was found that the probability does not depend on the efficiency in this range.

2 Simulation

Two Monte Carlo programs, PYTHIA 5.5 and ISAJET 6.4.6, are used to simulate events. PYTHIA is used to generate Higgs events and minimum bias events, and ISAJET is used to generate minimum bias events. These two MC use different models to simulate minimum bias events. ISAJET is more well tuned to reproduce the observed data. Because the beam jets are not well understood, the probability is calculated using these two models to estimate the uncertainty of the theoretical prediction.

The total cross sections of the minimum bias events calculated by PYTHIA and ISAJET with default parameter sets are 96mb and 137mb respectively. This difference by itself is not so important, because 1) they include different processes in the definition of minimum bias events and 2) MC programs cannot do good jobs for very low multiplicity events. Unfortunately, these two programs give fairly distinctive predictions for those distributions which should not suffer these ambiguities (e.g., see Fig.3).

No detector simulation is included. The detector is assumed to cover up to rapidity 2.5, both for the gammas and charged tracks. Higgs event selection can be done independent of the vertex determination, so the detection of gammas is assumed to be perfect, and no isolation cut to select the gammas from Higgs particle is applied. For the charged tracks, several reconstruction efficiencies were used to estimate the dependence of the prediction on the track reconstruction. The efficiency is applied to each track, independent of the rapidity or p_t.

The size of a bunch is around 5 cm along the beam direction, and the probability of the overlapping of two vertices with resolution of 1mm is around 1%. So the overlapping of two vertices is not includes in this study.

3 Formulation

The Higgs event vertex selection is done in two steps. In the first step (primary cut), vertices in a bunch are selected from which enough amount of charged tracks are coming out to reconstruct the vertex. In the second step (vertex selection), the number of charged tracks coming from each vertex which passed the primary cut are compared, and choose the vertex from which the largest number of charged tracks are coming out.

The over all efficiency to tag the Higgs vertex is determined by

$$A_H = \sigma_1^H / \sigma_0^H$$

where σ_0^H is the cross section determined by the Higgs event selection, and σ_1^H is that which pass the primary cut. The average number of minimum bias events is given by

$$\mu = \sigma_1^{MB} \times 0.016mb^{-1}$$

where σ_1^{MB} is the cross section of the minimum bias events which pass the primary cut.

Given the probability that the Higgs event (minimum bias event) which passes the primary cut has n tracks, $f_H(n)$ ($f_{MB}(n)$), the probability that the Higgs event has the largest number of tracks in an event with m minimum bias events is calculated as

$$\wp_m = \sum_{n=0}^{\infty}(f_H(n) \times \sum_{\ell=0}^{m} {}_mC_\ell F_{MB}(n-1)^\ell f_{MB}(n)^{m-\ell} w(m-\ell)),$$

where

$$F_{MB}(n) = \sum_{\ell=0}^{n} f_{MB}(\ell),$$

the probability that a minimum bias event has equal to or less than n tracks, and $w(n)$ is the probability to select a correct vertex when n minimum bias events have the same multiplicity as the Higgs vertex.

This includes cases where some of the minimum bias events have the same multiplicity as the Higgs vertex. If a vertex is chosen randomly in such cases, $w(\ell) = 1/(\ell+1)$. If additional selection criteria is used, $w(\ell)$ can be larger than that, but the overall gain is only a few %, and $w(\ell) = 1/(\ell+1)$ is used in this study. With $w(\ell) = 1$ for $\ell = 0$ and 0 other wise, this equation becomes a simpler and easy to understand form.

$$\wp_m = \sum_{n=0}^{\infty}(f_H(n) \times F_{MB}(n-1)^m).$$

Combining this and the Poisson distribution for the number of minimum bias events per bunch crossing, the probability to select the Higgs events is given by the following equation.

$$P(\mu) = A_H \sum_{m=0}^{\infty} \wp_m \times p_\mu(m)$$

where

$$p_\mu(m) = \frac{e^{-\mu}\mu^m}{m!}.$$

A simple example is in order. If the multiplicity distribution is uniform, and the maximal multiplicity of the Higgs event is M_H and that of the minimum bias event is M_{MB}, then

$$\wp(m) = (1-\alpha) + \frac{\alpha}{1+m}$$

$$P(\mu) = A_H((1-\alpha) + \frac{\alpha}{\mu}(1-e^{-\mu}))$$

where $\alpha = M_{MB}/M_H$ and w was set to 0. Then, $P(\mu = 1.3, \alpha = \frac{1}{3}) = A_H \times 0.85$ and $P(\mu = 1.3, \alpha = \frac{1}{6}) = A_H \times 0.93$. Roughly speaking, these are the results presented in the following.

4 Primary Cut

The primary cut is the selection of vertices in a event the location of which is well measured. In this study, a vertex is assumed to pass this cut if the vertex has equal to or larger than n_0 charged tracks with $p_t \geq p_{t0}$ with rapidity less than η_0.

This cut also helps to reduce the minimum event vertices. But the cut should be loose enough so that the loss of the signal is minimal. (The loss mentioned here is the loss of the probability to identify the Higgs event vertex, and the signal itself is retained 100%.)

In this and next section, it is assumed that all charged tracks are reconstructed. The effect of the imperfect charged track reconstruction is discussed in the following section.

Fig.1 shows the cross sections, σ_1^H, after the primary cut with various sets of parameters. The cross section has been calculated using PYTHIA 5.5. Fig.2 shows the average number of minimum bias events per bunch crossing. In this figure, two predictions are included, one by PYTHIA 5.5 (thin lines) and the other by ISAJET 6.4.6 (thick lines). As can be seen from this figure, these two models give fairly different predictions about the minimum bias events.

Fig.3 shows the multiplicity distributions of charged tracks with $\eta \leq 2.5$ and $p_t \geq 200MeV$ in those events which pass the primary cut with $\eta_0 = 2.5, p_{t0} = 200MeV, n_0 = 4$. This very loose cut is chosen to show the distribution as close as possible to the original model prediction. Three kinds of events are compared, 120 GeV Higgs, minimum bias events predicted by PYTHIA 5.5 and minimum bias events predicted by ISAJET 6.4.6. One can see clear difference between PYTHIA and ISAJET prediction.

In the following study, the following criteria is used for the primary cut.

- $\eta_0 = 2.5$
- $p_{t0} = 200MeV$
- $n_0 = 12$

With this cut, over 98% of the signal is retained and the average number of minimum bias events per bunch crossing is predicted to be 1.37 by PYTHIA and 1.43 by ISAJET.

5 Event Vertex Selection

Fig.4 shows charged multiplicity distributions of events which pass the primary cut, with different kinematical selection for counting the number of tracks. The multiplicity is the number of charged tracks with $p_t \geq p_{t1}$ in $\eta \leq \eta_1$. In each figure, three distributions, 120 GeV Higgs and two minimum bias events, are shown.

Fig.4-1) is the distribution of charged tracks with $p_t \geq 1GeV$ with $\eta \leq 2.5$. This set of p_t and η cut gives the best probability to find the Higgs event vertex defined above. Fig. 5 shows the probability as a function of the cut conditions, p_{t1} and η_1. In Fig.5-1) and 2), two predictions are shown, one using PYTHIA minimum bias events and the other using ISAJET minimum bias events.

If too wide kinematical range is used for counting charged tracks, the tail of the minimum bias events spreads out too much to high multiplicity side, as is shown in Fig.4-3). If one uses too narrow kinematical range, the multiplicity distribution of the signal shrinks down to low multiplicity side, as is shown in Fig.4-4).

Fig.4-2) compares the signal and background which pass a tight primary cut condition, $\eta_0 = 1.5, p_{t0} = 600MeV$ and $n_0 = 12$. As is clear from this figure, it is easy to separate the signal from background, but with this primary cut, the loss of the signal is almost 50%, as is shown in Fig.1.

6 Effect of Track Reconstruction Efficiency

So far, it was assumed that all charged tracks can be reconstructed. In order to see the effect of the failure of charged track reconstruction, the probability was calculated assuming different track reconstruction efficiencies, from 100% to 80%.

Fig.6 shows multiplicity distributions in various events, with the best selection parameters. In each figure, three distributions are shown corresponding to 100%, 90% and 80%.

The average number of minimum bias events per bunch crossing changes from 1.37 to 1.25 for PYTHIA minimum bias event and 1.43 to 1.14 for ISAJET minimum bias event. The efficiency for selecting the Higgs events changes very little, because the change of the multiplicity distribution does not affect much about the fraction of the low multiplicity tail of the signal.

The probability to select the Higgs event vertex changes very little within this range of track reconstruction efficiency. The decrease of the minimum bias event is completely compensated by the change of the multiplicity distribution toward the lower side in the signal.

7 Summary

The following table shows the probability to select the Higgs event vertex in events with minimum bias events piled up, with two models of minimum bias events.

Higgs mass (GeV)	PYTHIA MinBias $\mu = 1.37$	ISAJET MinBias $\mu = 1.43$
80	0.83	0.95
120	0.86	0.96
160	0.88	0.97

The primary vertices are selected by requiring that there are 12 or more charged tracks with $p_t \geq 200MeV$ within $\eta \leq 2.5$. Among these vertices, the vertex was selected as the Higgs vertex which has the largest number of charged tracks associated with $p_t \geq 1GeV$ within $\eta \leq 2.5$. These probabilities does not depend on the track reconstruction efficiencies if the efficiency is larger than 80%.

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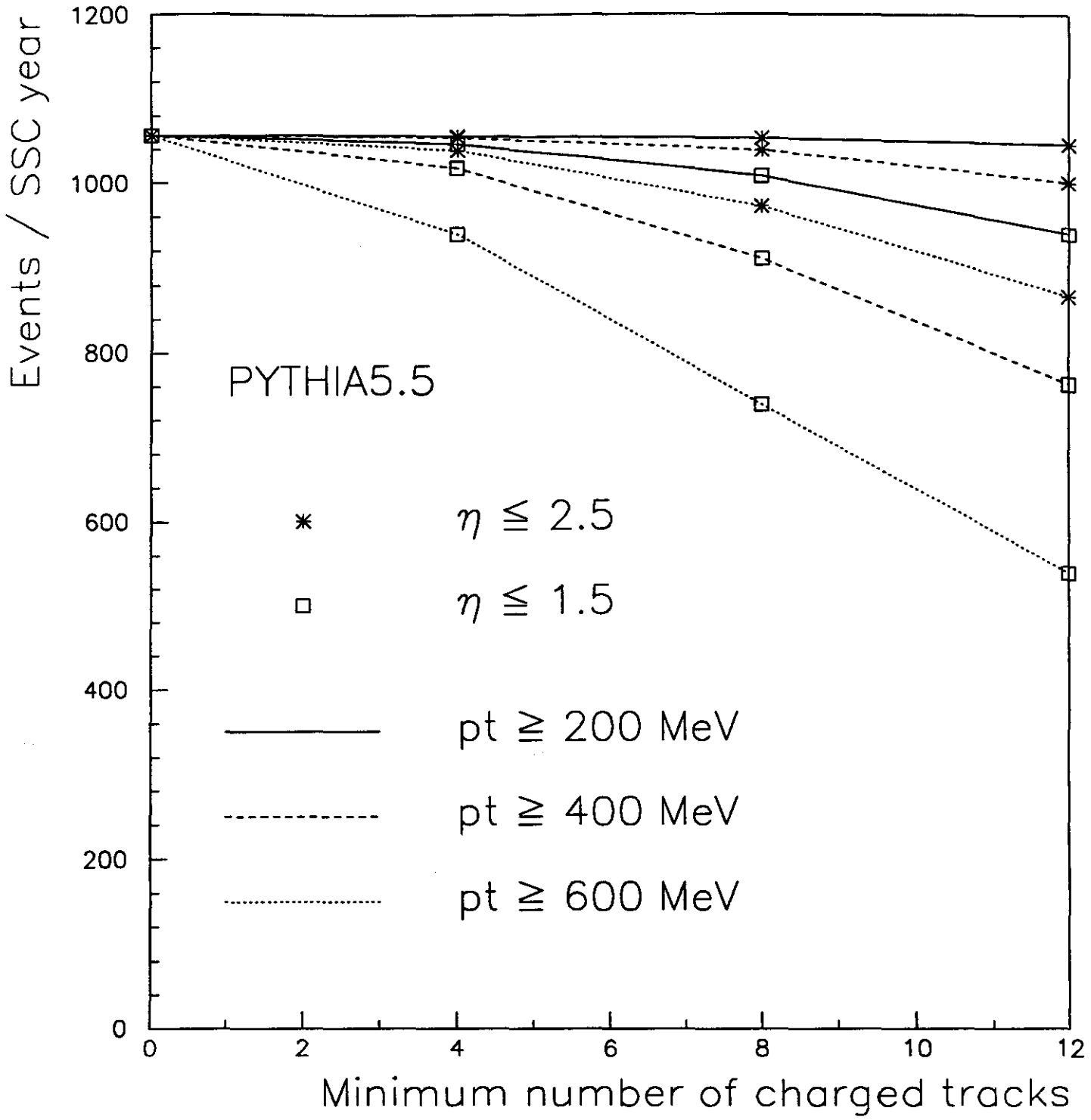


Fig. 1 Higgs(120GeV) Vertex Selection efficiency

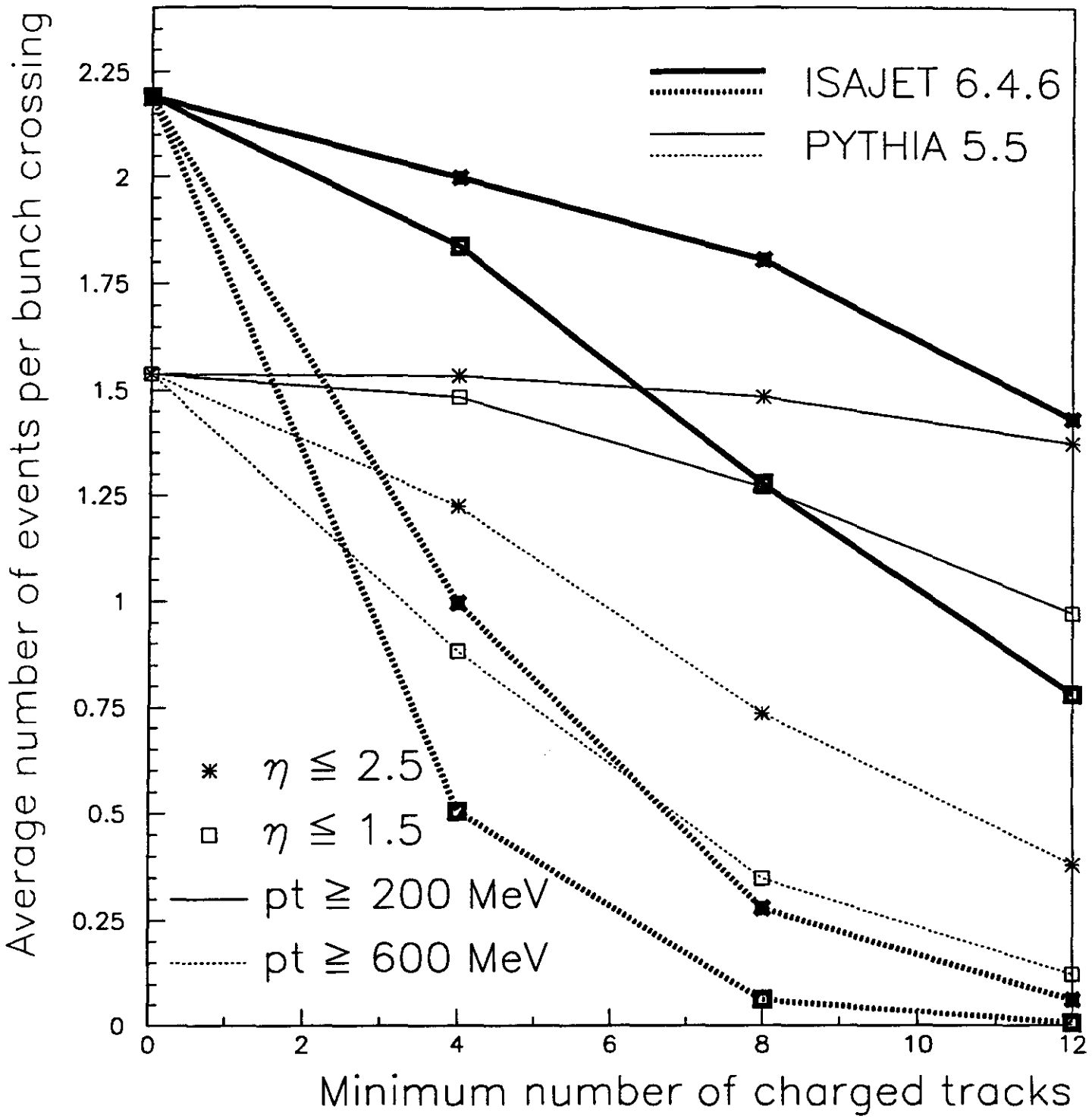


Fig. 2 MB event Vertex Selection efficiency

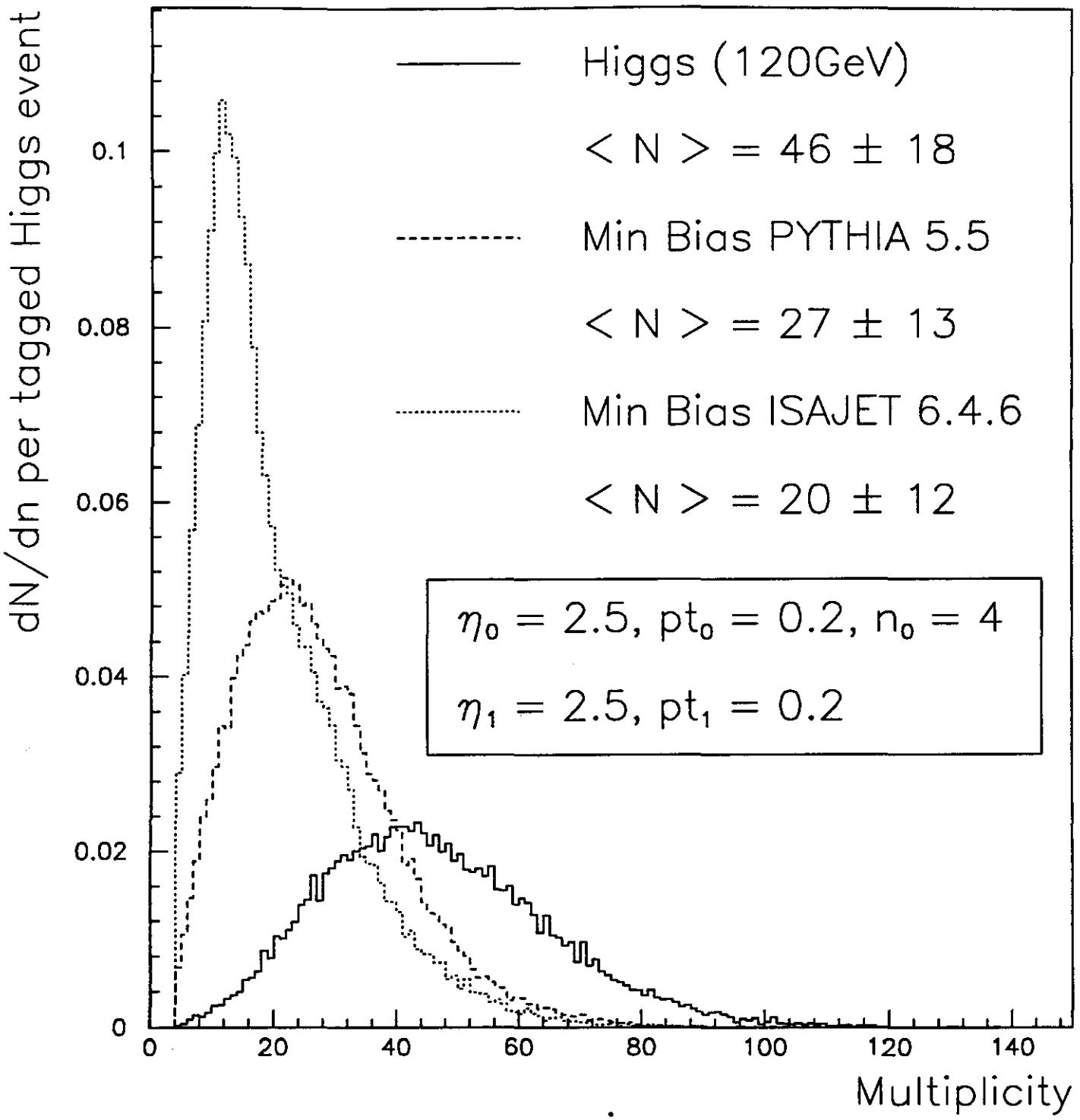


Fig. 3 Multiplicity Distribution - No cut

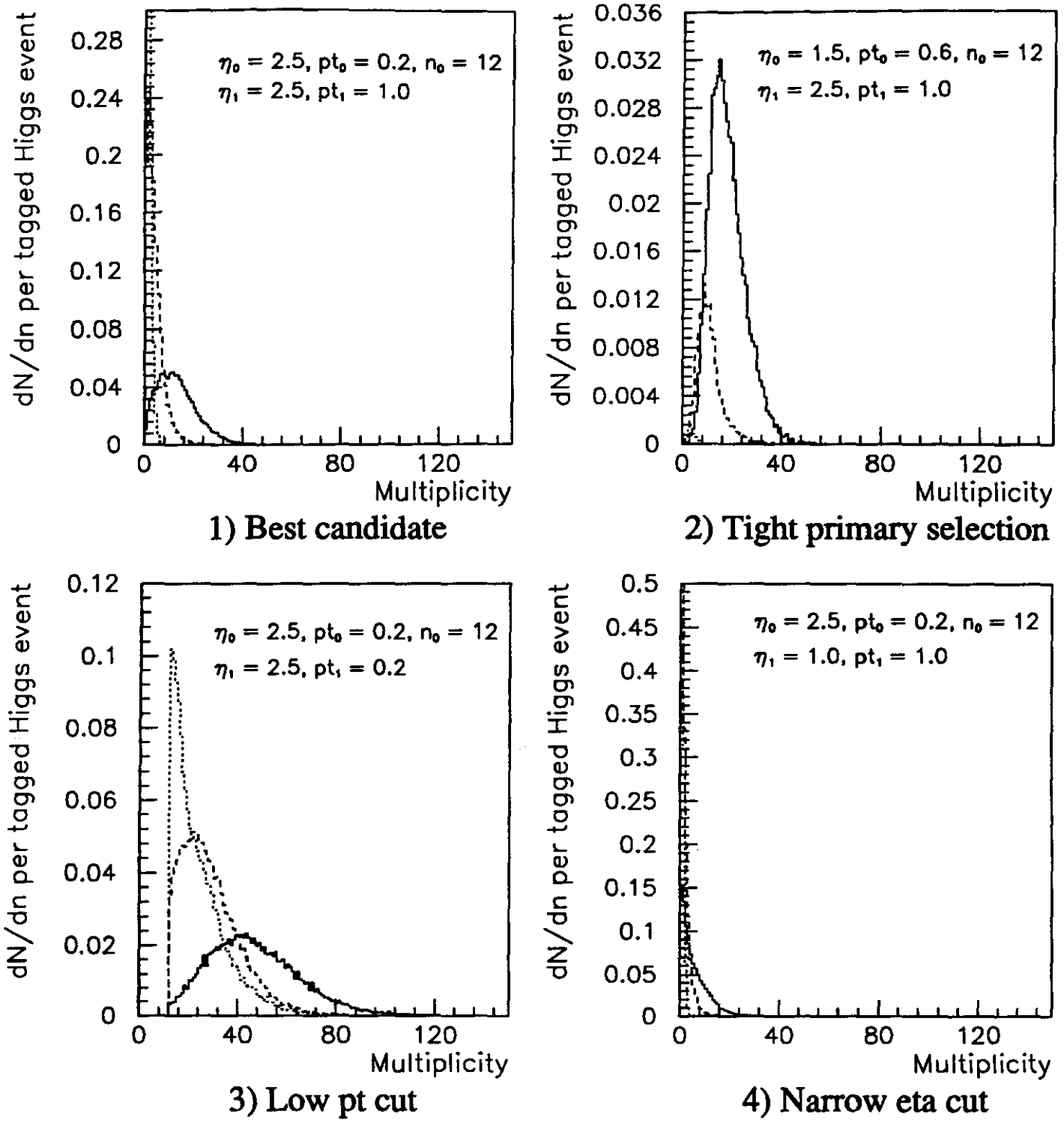
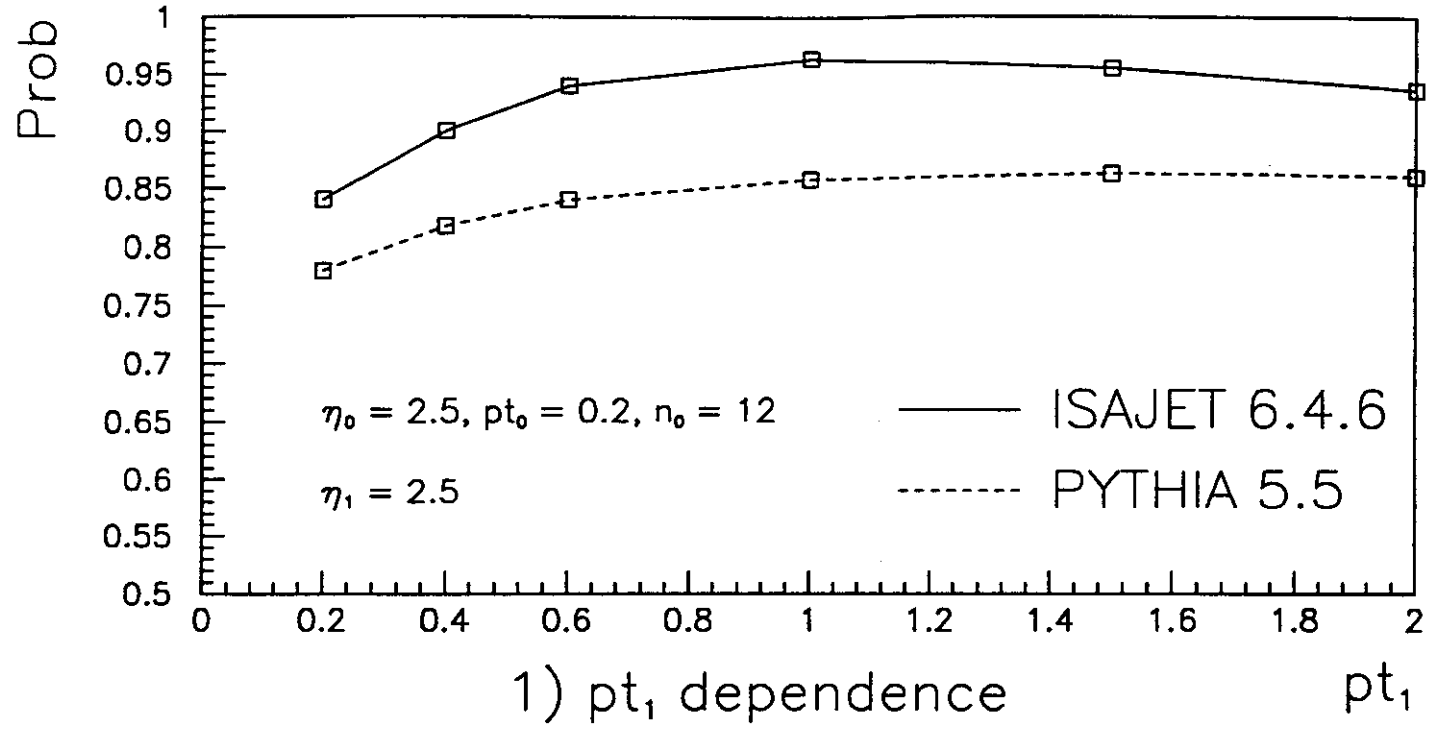


Fig. 4 Multiplicity distribution - Choice



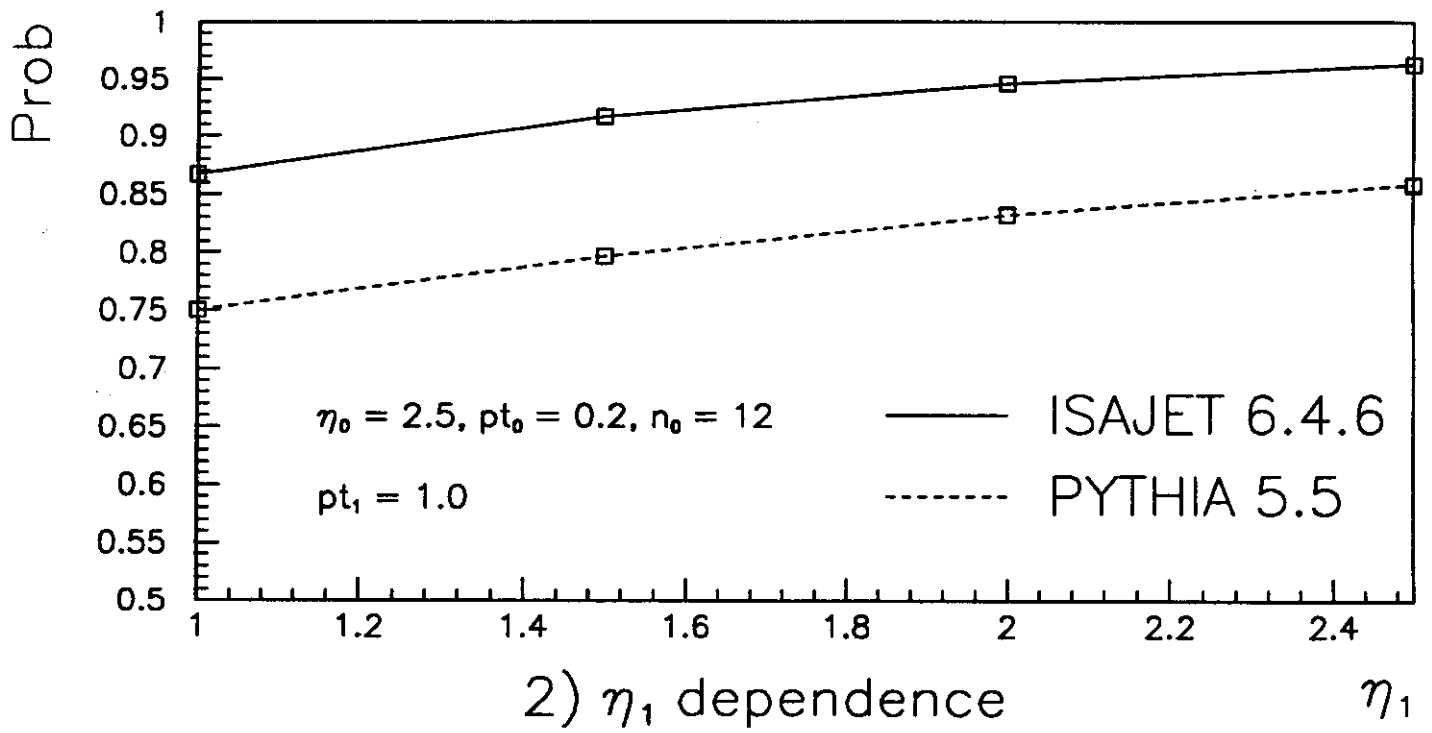


Fig. 5 Probability to select Higgs event vertex

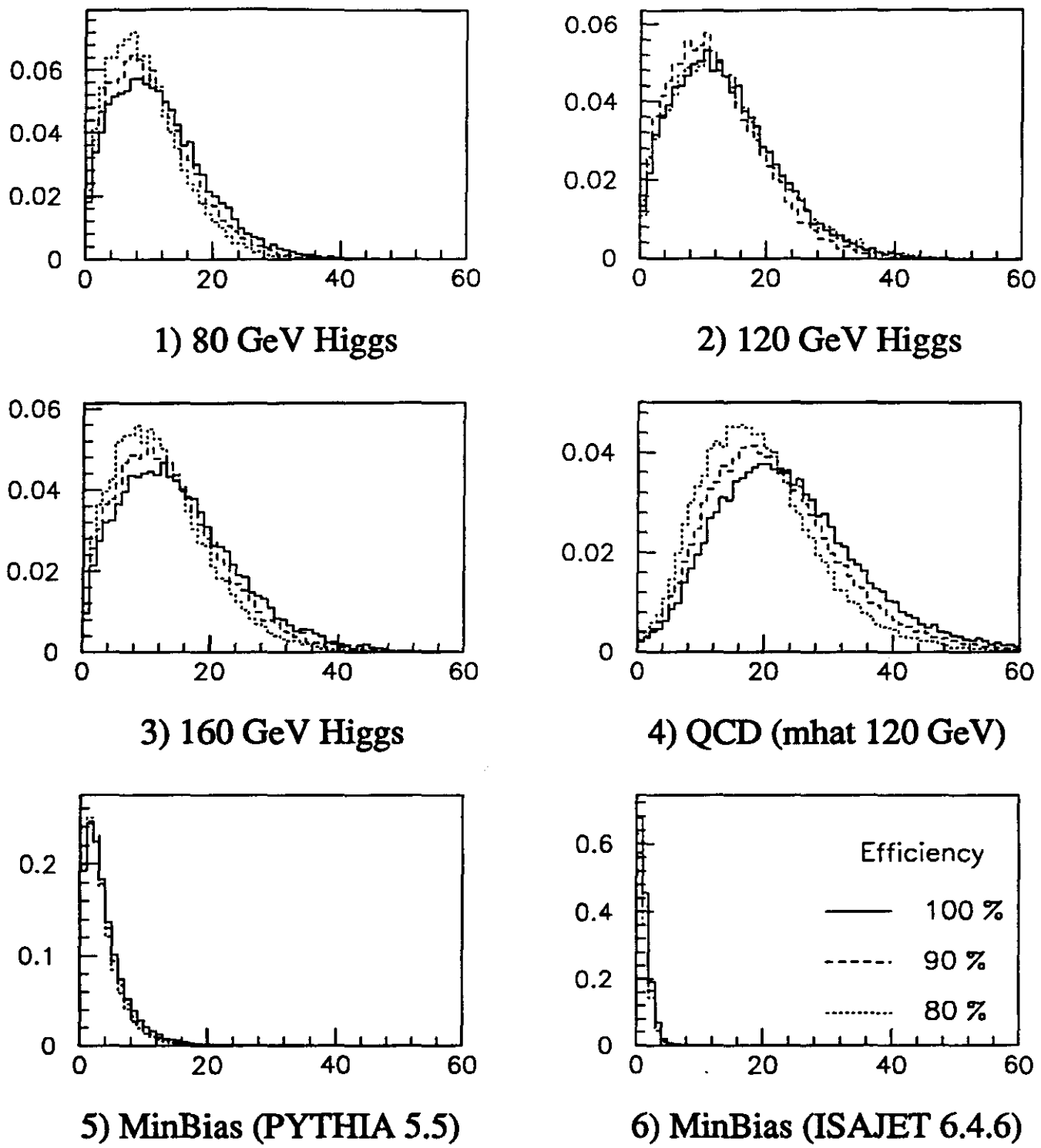


Fig. 6 Multiplicity and Track reconstruction efficiency