π^0 Reconstruction within the full simulation framework

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A study of π^0's reconstruction within the full simulation of the LDC detector at ILC is presented. The impact of constrained fits is shown and a method to reconstruct π^0's in physics events is exposed.

1 Introduction

Neutral pions are an important part of the particle content in hadronic events: in $t\bar{t}$ or hZ events at $\sqrt{s}$=500 GeV, they represent 20% of the visible energy. This result points out that π^0's reconstruction has an impact on Particle-Flow and on detector optimisation. It is thus important not only to identify and reconstruct photons but to go further and to identify π^0's .

Studies aiming at reconstructing π^0's within the full simulation framework are exposed in this document. The software context is developped in a first part. Details on the calibration of the electromagnetic (EM) calorimeter are given in a second part. The constrained fit method applied on single π^0's is described in a third section. An approach to reconstruct π^0's in physics events is exposed in a fourth part.

2 Framework of the study

The full simulation chain was composed of the following steps: event generation has been performed with `Pythia v6.321`[1], the `GEANT4` based full Monte Carlo simulation with `Mokka v06.02`[2] and the reconstruction with `Marlin v00-09-05` [3] and `MarlinReco v00-02` [4]. Analyses were performed with `Root v5.10.00` [6]. The detector model used was LDC00[2]. Events generated were composed of single photon, of single π^0 or of all π^0's coming from $hZ \rightarrow b\bar{b}\nu\bar{\nu}$ at $\sqrt{s}$=500 GeV.

3 EM calorimeter calibration

The EM calorimeter has to be calibrated before addressing the π^0's reconstruction. For this single photons have been generated with `Mokka` and reconstructed with `Marlin` at the following energies: 0.25, 0.30, 0.35, 0.40, 0.50, 1, 2, 4, 10, 25, 50 GeV (angular coverage: $0 \leq \theta \leq \pi/2$ with a step of 0.1 and $0 \leq \Phi \leq 2\pi$ with a step of $2\pi/16$). The goal of the calibration procedure was to evaluate α_0 and β_0 in $E_\gamma^{clus} = \alpha_0(E_1^{30} + \beta_0 E_{31}^{40})$ where E_i^j is the sum of the raw energies deposited in the silicon cells of the i-to-j layers. All the hits were used (no clustering algorithm applied). The β_0 parameter is firstly evaluated by minimizing $\sigma(E_1^{30} + \beta E_{31}^{40})/ < E_1^{30} + \beta E_{31}^{40} >$. α_0 is then given by the mean value of $E_\gamma^{truth}/(E_1^{30}+\beta_0 E_{31}^{40})$ where E_γ^{truth} is the Monte-Carlo truth energy of the generated photon. The results are $\beta_0 = 3.0 \pm 0.1$, α_0=27.62±0.03 and α_0=28.83±0.05 for the central and the endcap parts respectively.

	Barrel		Endcap	
Energy resolution	$\frac{\sigma_E}{E} = 1.6\% \oplus \frac{12.4\%}{\sqrt{E}}$		$\frac{\sigma_E}{E} = 1.4\% \oplus \frac{12.1\%}{\sqrt{E}}$	
Non linearity	$< 2.5\%$		$< 5\%$	
	E<1.5 GeV	E>1.5 GeV	E<1.5 GeV	E>1.5 GeV
θ resolution (mrad)	$\sigma_\theta = 0.34 + \frac{0.94 sin\theta}{\sqrt{E}}$	$\sigma_\theta = 0.02 + \frac{1.4 sin\theta}{\sqrt{E}}$	$\sigma_\theta = 0.26 + \frac{0.55 cos\theta}{\sqrt{E}}$	$\sigma_\theta = 0.007 + \frac{0.96 cos\theta}{\sqrt{E}}$
Φ resolution (mrad)	$\sigma_\Phi = 0.39 + \frac{1.01}{\sqrt{E}}$	$\sigma_\Phi = 0.01 + \frac{1.56}{\sqrt{E}}$	$\sigma_\Phi = 0.94 + \frac{1.5}{\sqrt{E}}$	$\sigma_\Phi = 0.02 + \frac{2.9}{\sqrt{E}}$

Table 1: LDC00 EM calorimeter resolutions after calibration

Once the EM calorimeter is calibrated, the performance in terms of energy and angular resolution as well as on linearity may be evaluated. Results are summarized in table 1.

4 Single π^0 fit

To study neutral pion reconstruction within the full simulation framework, single π^0 have been generated with `Mokka` at the following energies: 0.4, 0.6, 0.7, 1.2, 4.9, 12.4, 29.5 GeV and for similar values in (θ, Φ) as indicated in part 3. A clustering has been performed with the `TrackWiseClustering` processor [5]. Events with exactly two clusters were selected.

To correct for mismeasurements and fluctuations, a constrained fit has been applied on cluster pairs with the minimization of the following χ^2:

$$\chi^2 = \sum_{i=1}^{2} \frac{(E_i^{cl} - E_i)^2}{\sigma_{E_i}^2} + \sum_{i=1}^{2} \frac{(\theta_i^{cl} - \theta_i)^2}{\sigma_{\theta_i}^2} + \sum_{i=1}^{2} \frac{(\Phi_i^{cl} - \Phi_i)^2}{\sigma_{\Phi_i}^2} \quad (1)$$

where $E_i^{cl}, \theta_i^{cl}, \Phi_i^{cl}$ are the energy and angles of the i-th cluster. E_i, θ_i, Φ_i are the corrected energy and angles coming out of the fit procedure. The values of the variances $\sigma_{E_i}^2, \sigma_{\theta_i}^2, \sigma_{\Phi_i}^2$ were set to the estimation of table 1.

Only events for which the fit has converged, the number of iterations was less than 5, and the χ^2 of the fit is less or equal than 3.9 were selected. The impact of the fit on the energy resolution is shown on figure 1. The gain is spectacular at very low energies (few hundred MeV) where the resolution is ten times better after the fit. A similar study with single π^0's coming from hZ $\rightarrow b\bar{b}\nu\bar{\nu}$ events has shown that the constrained fit divides the relative energy resolution by a factor of two (from 7.4% to 3.4%).

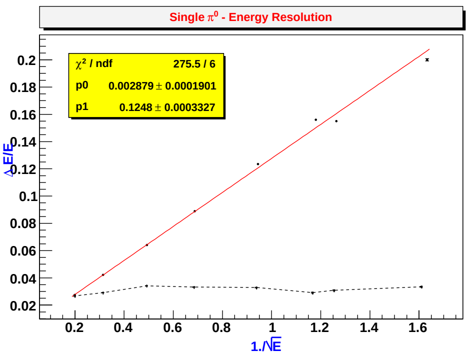

Figure 1: Energy resolution $\Delta E/E$ as a function of $1./\sqrt{E}$ for single π^0 before (full line) and after (dashed line) application of a constrained fit.

5 Method to reconstruct π^0 in physics events

The number of π^0's produced in a given physics event can be quite large: for $\mathrm{hZ} \to \mathrm{b\bar{b}}\nu\bar{\nu}$ events at $\sqrt{\mathrm{s}}$=500 GeV, 12 to 13 π^0 on average are produced leading to more than 20 clusters in the EM calorimeter.

Cluster pairs have to be formed so as to reconstruct π^0's . A strategy is thus needed to perform a correct pairing (ie association of clusters coming from the same π^0) and to minimize fake pair production. A study has been performed using MC-truth information of photons coming from π^0 decays in $\mathrm{hZ} \to \mathrm{b\bar{b}}\nu\bar{\nu}$ events at $\sqrt{\mathrm{s}}$=500 GeV and $\mathrm{hhZ} \to \mathrm{b\bar{b}b\bar{b}}\nu\bar{\nu}$ at $\sqrt{\mathrm{s}}$=800 GeV. Energies and angles of the photons were smeared according to the resolutions given in table 1. The "clusters" (here defined as the smeared MC-truth photons) were then associated on the basis of a probability depending on the mass of the pair, and/or the angle between the two objects. The pair giving giving the highest probability was selected and the corresponding clusters were removed from the cluster list. To quantify the quality of the procedure, we have used the ratio of the energy sum of pairs coming from π^0's (which we know from MC) divided by the total π^0 energy of the event. The figure 2 shows clearly the importance of the reconstructed mass in our estimator. When the angle is also used, a slight improvement is observed: the mean value of the $E_{\pi^0}(goodpairs)/E_{\pi^0}(all)$ is 75% (rms:23%) when the mass is used. It increases to 78% (rms: 21%) when the mass and the angle information are combined.

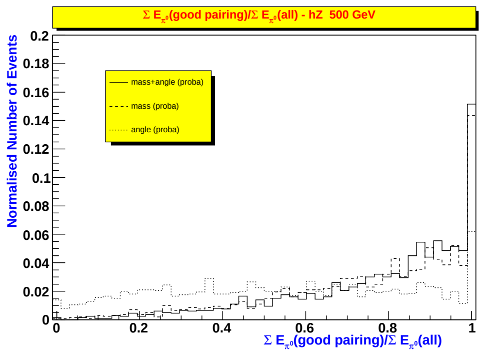

Figure 2: Fraction of good π^0 energy for $\mathrm{hZ} \to \mathrm{b\bar{b}}\nu\bar{\nu}$ events at $\sqrt{\mathrm{s}}$=500 GeV . The results are given for three estimators using the mass, the opening angle and the mass+the opening angle of the cluster pairs.

6 Conclusion

A study on various aspects of π^0 reconstruction was presented in this document. It was shown that constrained fits on single π^0 greatly improve the energy resolution in particular at low energies . A strategy to reconstruct π^0's in physics events was developped. Using an estimator based on the mass and the angle of cluster pairs, it was shown that 77% to 78% of the total π^0 energy in $\mathrm{hZ} \to \mathrm{b\bar{b}}\nu\bar{\nu}$ events at $\sqrt{\mathrm{s}}$=500 GeV could be tagged properly.

References

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[2] http://polywww.in2p3.fr/activites/physique/geant4/tesla/www/mokka/mokka.html

[3] http://ilcsoft.desy.de/marlin

[4] http://www-flc.desy.de/ilcsoft/ilcsoftware/MarlinReco

[5] `TrackwiseClustering` in MARLIN presented by Dennis Martsch - ILC Software Workshop June 2005

[6] http://root.cern.ch

[7] http://lcio.desy.de/