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Measurement of η Production in Quark Jet and Gluon Jet from Z Hadronic Decays at LEP

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Abstract

The production of η meson has been measured with data collected in 1991, 1992 and 1993 by the L3 experiment at LEP. Compared with predictions from parton shower Monte Carlo with different fragmenation models, we observe that the η production in quark enriched jet agrees well with the predictions but in gluon enriched jet it is enhanced at high momentum range.

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1 Introduction

The large amount of hadronic Z decays collected by the L3 detector enables us to carry out a detailed study on the dynamics of strong interactions. The production of quark pair from e^+e^- annihilation is well described by the perturbative QCD while the subsequent non-perturbative hadron formation is still in an exploratory state, guided by phenomenological models and asymptotic predictions. Figure 1 depicts the basic scenario of a three-jet event where the third jet (jet 3) comes from hard gluon bremsstrahlung.

In this paper we report a measurement of η meson production in quark enriched jet and gluon enriched jet to study the difference in hadronization between primary quarks and gluons. The result is compared with Monte Carlo predictions. There exist two Monte Carlo programs, JETSET [1] and HERWIG [2], which can generally describe well the process $\mathrm{e^+e^-} \rightarrow$ hadrons. Both programs implement a parton cascade based on perturbative QCD calculations, while the non-perturbative hadronization phase is described by either string (JETSET 7.3) or cluster fragmentation (HERWIG 5.8) models.

The η meson is well suited for studying the hadronization since it is mainly produced directly from the fragmentation cascade, not from the decays of other hadrons. There exists a phenomenological model [3] which predicts enhanced production of isoscalar mesons in gluon jets. Several experimental studies [4–6] have been carried out as suggested by this model. Due to low statistics, so far no definite experimental conclusion has been drawn.

With the data taken by the L3 detector from 1991 to 1993, we have increased our statistics by a factor five compared to what we had in our earlier paper [6]. A careful analysis is carried out again on this subject.

2 The L3 Detector

The L3 detector is described in detail in reference [7]. It consists of a central tracking chamber, a high resolution electromagnetic calorimeter composed of bismuth germanium oxide (BGO) crystals, a ring of plastic scintillation counters, a uranium and brass hadron calorimeter with proportional wire chamber readout, and an accurate muon chamber system. These detectors are installed in a 12 m diameter magnet which provides a uniform field of 0.5 T along the beam direction.

The central tracker consists of a time expansion chamber(TEC) with high spatial resolution in the plane normal to the beam, and a Z-chamber mounted just outside the TEC, supplementing the r/ϕ measurements with z-coordinates.

The material preceding the barrel part of the electromagnetic detector amounts to less than 10% of a radiation length. In this region the energy resolution is 5% for photons and electrons of energy around 100 MeV, and is less than 2% for energies above 1 GeV. The angular resolution of electromagnetic clusters is better than 0.5° for energies above 1 GeV.

3 Event Selection

The selection of events of the type $\mathrm{e^+e^-} \rightarrow$ hadrons is based on the tracking information from the central tracker and the energy measured in the electromagnetic and the hadron calorimeters. Events are accepted if they have high multiplicity, high and well balanced visible energy [8].

A total number of 1.6 million events are selected as hadronic events in the data taking period from 1991 to 1993.

To forms jets in a event, we use the LUCLUS jet finding algorithm [9] which is based on an unscaled resolution parameter d_{join} measured in GeV. Two calorimetric clusters are combined into one if the transverse momentum (defined as d) of either cluster with respect to the vector sum of their momenta dose not exceed the pretertermined d_{join} value. This procedure is repeated until all combinations of either two remaining clusters has d greater than d_{join}. The remaining clusters are then called jets. Jets are ordered according to their energies, jet 1 being the most energetic one. To reject spurious jets, we require each jet must have energy greater than 5 GeV and more than 4 constituent calorimetric clusters. At $d_{join} = 5$ GeV, 0.7 million events are selected as three-jet events. We refer events with two jets as two-jet events and events with three or more jets as three-jet events (The four or five jet events are about 13% of this sample).

The η is reconstructed from its two photon decay channel. The selection criteria for photon are as follows:

- the BGO cluster must be in the barrel region, $\mid cos\theta \mid \leq 0.74$;
- the energy of the cluster must be greater that 500 MeV;
- the cluster must be 50 mrad away to any charged particles;
- the lateral shower shape of the cluster muct be consistent with that of an electromagnetic shower.

In order to reduce the combinational background related to the π° decays, we exclude all photons entering into a two-photon combination with invariant mass inside the π° window ($0.113 < m_{\gamma\gamma} < 0.157$). The number of η is determined by a fitting of a Gaussian distribution for the signal plus a third order polynomial for the background, as shown in figure 2. An η belongs to a jet if it is the closest one in direction.

We use two Monte Carlo generators JETSET and HERWIG in this analysis to justify our selection criteria and to calculate the efficiency. The generated events are passed through the L3 detector simulation [10], which implements a detailed description of the detector and takes into account the effects of energy loss, multiple scattering, interactions and decays in the beam pipe and the detector materials. These events are processed with the same reconstruction and analysis programs as used for the experimental data. In this analysis we use 1.7 million JETSET events and 0.4 million HERWIG events. Applying the jet finding algorithm in both data and Monte Carlo samples we get very close percentages of three-jet event in both data and Monte Carlo at the same d_{join} value.

Since at LEP both JETSET and HERWIG have been tuned to overall event properties, we carry out studies to ensure that Monte Carlo can reproduce data in individual jet. Good agreement between data and Monte Carlo in individual jet is found on variables used in the selection of η, so we believe that our selection criteria and the efficiencies calculated from Monte Carlo are not biased.

4 The η Production Rates

To determine whether a jet originates from a primary quark or from a hard gluon bremsstrahlung, we use JETSET Monte Carlo events, and match in direction the reconstructed jet to the primary quark. We call a jet a quark jet if it can match to a primary quark and a gluon jet if it is not the closest one to either one of the two primary quarks. At $d_{join} = 5$ GeV, this study shows that in two-jet event, the two jets can match with the two primary quarks with a mean match angle of 3 degrees; in three-jet event the first two most energetic jets have 88% quark jet purity, while the third energetic jet has 79% gluon jet purity. These numbers do not strongly depend on d_{join} value from 3 GeV to 7 GeV. So we chose $d_{join} = 5$ GeV in our analysis.

With recontruction efficiency estimated from JETSET and HERWIG, we calculate the η production in different event types, taking into account the following correction factors: the inefficiecy from the central tracker (0.88%), the inefficiency of BGO (4.0%) and the hadron event selection efficiency (99.1%). Table 1 gives the results based on efficiencies estimated from JETSET and HERWIG. The production rates agree with each other within errors.

The possible sources of the systematic errors are obtained by varying the photon selection cuts. An additional error coming from the uncertainty in the detector inefficiency which is determined by comparing the π° and η rates in different geometrical regions of the detector. A small error due to the limited statistics of Monte Carlo events is also included.

Hadron	event type	JETSET	HERWIG
π°	two-jet	$8.30 \pm 0.03 \pm 0.45$	$7.60 \pm 0.03 \pm 0.42$
	three-jet	$11.32 \pm 0.04 \pm 0.58$	$9.63 \pm 0.04 \pm 0.56$
	all	$9.66 \pm 0.03 \pm 0.51$	$8.53 \pm 0.02 \pm 0.48$
η	two-jet	$0.72 \pm 0.02 \pm 0.07$	$0.71 \pm 0.02 \pm 0.06$
	three-jet	$1.12 \pm 0.03 \pm 0.11$	$1.00 \pm 0.03 \pm 0.08$
	all	$0.91 \pm 0.02 \pm 0.09$	$0.85 \pm 0.02 \pm 0.07$

Table 1: the π°, η production in different event types based on efficiencies from JETSET and HERWIG. The first error is statistic and the second is systemaic.

The η production rate in each jet in the two- and three-jet events is also measured using reconstruction efficiecies and correction factors estimated by Monte Carlo for individual jets. The systematic errors are obtained in the same way as mentioned above. Table 2 and table 3 give the η production (and π° production as a comparison) in each jet of two-jet events and three-jet events. The Monte Carlo predictions are normalized to our measurement in table 1, since Monte Carlos cannot predict the absolute multiplicity of η [11, 12]. Good agreement between data and the Monte Carlo predictions in each jet is observed after the normalization.

		JETSET		HERWIG	
Hadron	Jet	Meas.	Pred.	Meas.	Pred.
π°	1	$4.32 \pm 0.02 \pm 0.14$	4.25	$3.98 \pm 0.02 \pm 0.14$	3.91
	2	$3.87 \pm 0.02 \pm 0.09$	3.98	$3.54 \pm 0.02 \pm 0.08$	3.65
η	1	$0.37 \pm 0.02 \pm 0.05$	0.37	$0.36 \pm 0.02 \pm 0.06$	0.37
	2	$0.34 \pm 0.02 \pm 0.06$	0.35	$0.33 \pm 0.02 \pm 0.07$	0.34

Table 2: The π°, η production in two-jet events compared with JETSET and HERWIG. The efficiecies based on the Monte Carlo used. The first error is statistic and the second is systemaic.

		JETSET		HERWIG	
Hadron	Jet	Meas.	Pred.	Meas.	Pred.
π°	1	$3.97 \pm 0.03 \pm 0.12$	4.01	$3.46 \pm 0.02 \pm 0.16$	3.39
	2	$3.64 \pm 0.03 \pm 0.09$	3.74	$3.08 \pm 0.02 \pm 0.10$	3.13
	3	$3.05 \pm 0.02 \pm 0.06$	3.05	$2.60 \pm 0.01 \pm 0.12$	2.62
η	1	$0.36 \pm 0.02 \pm 0.07$	0.40	$0.39 \pm 0.02 \pm 0.10$	0.36
	2	$0.32 \pm 0.02 \pm 0.07$	0.37	$0.32 \pm 0.02 \pm 0.11$	0.33
	3	$0.35 \pm 0.01 \pm 0.05$	0.31	$0.29 \pm 0.01 \pm 0.05$	0.27

Table 3: The π°, η production in three-jet events compared with JETSET and HERWIG. The efficiecies based on the Monte Carlo used. The first error is statistic and the second is systemaic.

5 The η Momentum Spectra

The momentum spectrum (the x_p distributions) of η is measured for both two-jet and three-jet events, and for quark enriched (the two jets from two-jet event and the first two jets of three-jet event) and gluon enriched (the third jet of three-jet event) jets. Because of insufficient statistic in HERWIG Monte Carlo sample, the measurement here is performed only with efficiencies and correction factors calculated from JETSET. For each momentum bin (expressed in $x_p = P_{hadron}/E_{beam}$ the two photon invariant mass spectrum is reconstructed and the η production rate is determined as before. The systematic errors are estimated as mentioned above. The results on the normalized production cross sections in different x_p bins are given in table 4, table 5 and shown in figure 3, figure 4. A χ^2 is calculated for the comparison of data and Monte Carlo. The Monte Carlo predictions agree well with the measurements in two-jet events, as well as the first two jets in three-jet events, but at high x_p ranges an excess in data is seen in jet 3 compared with the Monte Carlo predictions, this gives rise to a χ^2 5.37 compared with JETSET and 3.42 compared with HERWIG. Figure 5 shows the comparison of the η momentum spectra in quark enriched jet and in gluon enriched jet between data and Monte Carlo predictions. We see the measured η momentum spectrum in quark enriched jet agree well with Monte Carlo predictions while in gluon enriched jet the measurement excess at high momemtum range. Similar results can be found in reference [5]. Based on this measurment, we conclude that the discrepancy between data and Monte Carlo on the η momentum spectrum in our previous paper [11] comes mainly from the gluon jet.

For a comparison, figure 6 shows the x_p distributions of π° in three-jet events compared with JETSET predictions. Monte Carlo describes well the π° momentum spectra of in each of the three jets. Very similar results are also got in comparison with HERWIG and in two-jet events.

6 Conclusion

The η meson production in each jets of the two- and three-jet event are measured with the 1991, 1992 and 1993 data collected by the L3 detector. After normalizing the Monte Carlo to our measurements, both JETSET and HERWIG reproduce well the η production as well as it's momentum spectra in jet 1 and jet 2 of two-jet events and jet 1 and jet 2 of the three-jet events. In jet 3 of three-jet events, an enhancement of the η production is observed at high momentum range compared with Monte Carlo predictions.

7 Acknowledgments

We wish to express our gratitude to the CERN accelerator divisions for the excellent performance of the LEP machine. We acknowledge the effort of all engineers and technicians who have participated in the construction and maintenance of this experiment.

	x_p range	Measurement	JETSET Pred.	HERWIG Pred.
J	0.018< x_p < 0.05	2.713 ± 0.226 ± 0.404	3.188	2.934
E	0.05 < x_p < 0.09	1.820 ± 0.132 ± 0.279	1.681	1.600
T	0.09 < x_p < 0.13	1.099 ± 0.129 ± 0.337	1.073	1.078
	0.13 < x_p < 0.17	0.743 ± 0.106 ± 0.240	0.718	0.727
1	0.17 < x_p < 0.30	0.430 ± 0.055 ± 0.131	0.355	0.376
		χ^2	0.39	0.22
J	0.018< x_p <0.05	2.646 ± 0.235 ± 0.392	3.216	2.995
E	0.05 < x_p <0.09	1.623 ± 0.135 ± 0.235	1.694	1.590
T	0.09 < x_p <0.13	0.922 ± 0.100 ± 0.342	1.000	1.002
	0.13 < x_p <0.17	0.836 ± 0.139 ± 0.321	0.628	0.633
2	0.17 < x_p <0.30	0.402 ± 0.059 ± 0.172	0.275	0.299
		χ^2	0.63	0.33

Table 4: The η production in different momentum ranges in two-jet events compared with JETSET and HERWIG. The efficiencies based on JETSET. The first error is statistic and the second systemaic. χ^2 is the comparison between the measurement and Monte Carlo predictions.

	x_p range	Measurement	JETSET Pred.	HERWIG Pred.
J	0.018< x_p < 0.05	3.100 ± 0.377 ± 1.194	3.661	3.040
E	0.05 < x_p < 0.09	1.787 ± 0.228 ± 0.735	2.010	1.768
T	0.09 < x_p < 0.13	1.376 ± 0.152 ± 0.269	1.183	1.084
	0.13 < x_p < 0.17	0.828 ± 0.116 ± 0.162	0.746	0.730
1	0.17 < x_p < 0.30	0.384 ± 0.044 ± 0.097	0.339	0.352
		χ^2	0.25	0.31
J	0.018< x_p < 0.05	2.795 ± 0.491 ± 1.069	3.899	3.156
E	0.05 < x_p < 0.09	1.764 ± 0.173 ± 0.565	2.135	1.860
T	0.09 < x_p < 0.13	1.025 ± 0.147 ± 0.237	1.103	1.059
	0.13 < x_p < 0.17	0.689 ± 0.074 ± 0.144	0.617	0.618
2	0.17 < x_p < 0.30	0.249 ± 0.029 ± 0.042	0.228	0.247
		χ^2	0.43	0.08
J	0.018< x_p < 0.05	3.899 ± 0.326 ± 0.698	4.665	3.796
E	0.05 < x_p < 0.08	2.191 ± 0.116 ± 0.426	1.906	1.837
T	0.08 < x_p < 0.11	0.996 ± 0.061 ± 0.123	0.798	0.860
	0.11 < x_p < 0.155	0.534 ± 0.034 ± 0.089	0.306	0.342
3	0.155< x_p < 0.20	0.215 ± 0.021 ± 0.038	0.109	0.121
		χ^2	5.37	3.42

Table 5: The η production in different momentum ranges in three-jet events compared with JETSET and HERWIG. The efficiencies based on JETSET. The first error is statistic and the second systemaic. χ^2 is the comparison between the measurement and Monte Carlo predictions.

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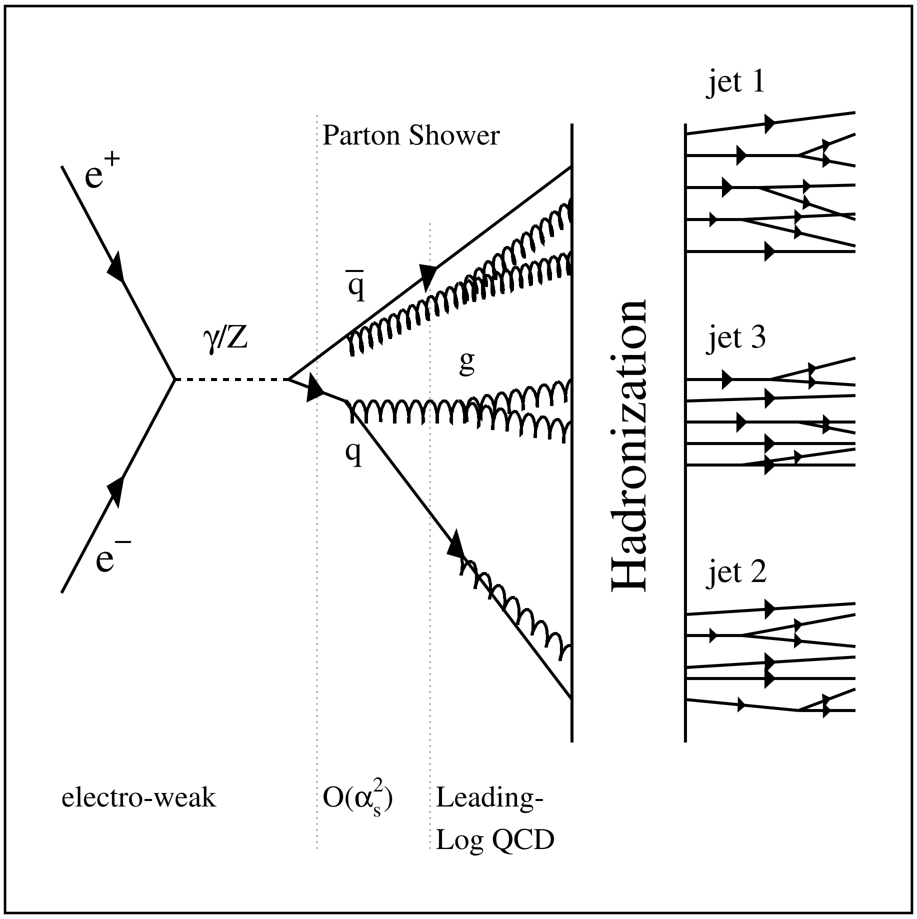

Figure 1: Schematic representation of a three-jet event.

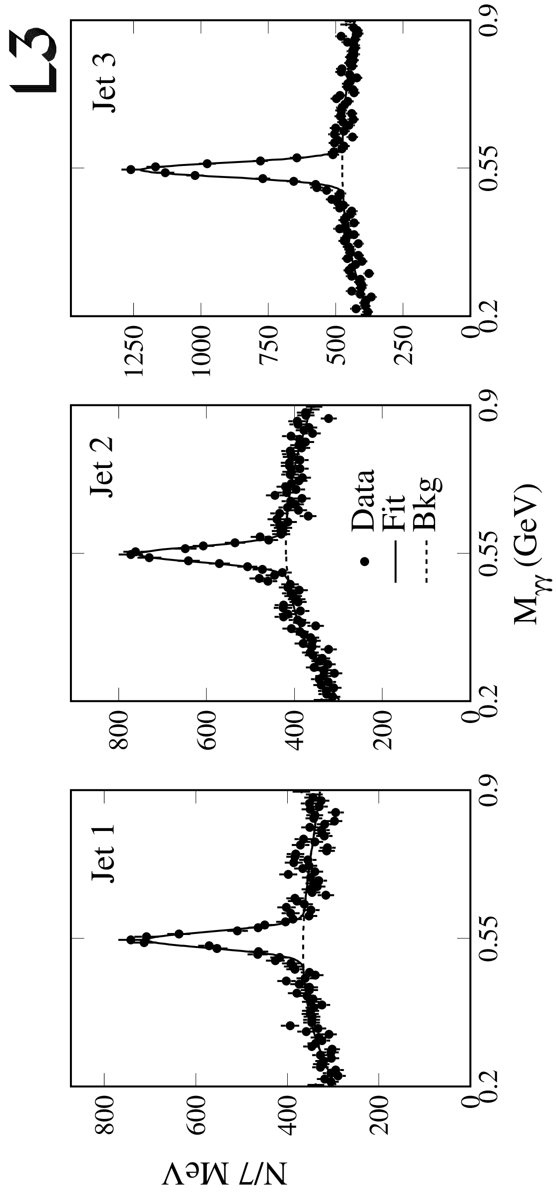

Figure 2: The $\gamma\gamma$ mass spectra for η reconstruction in 3-jet events.

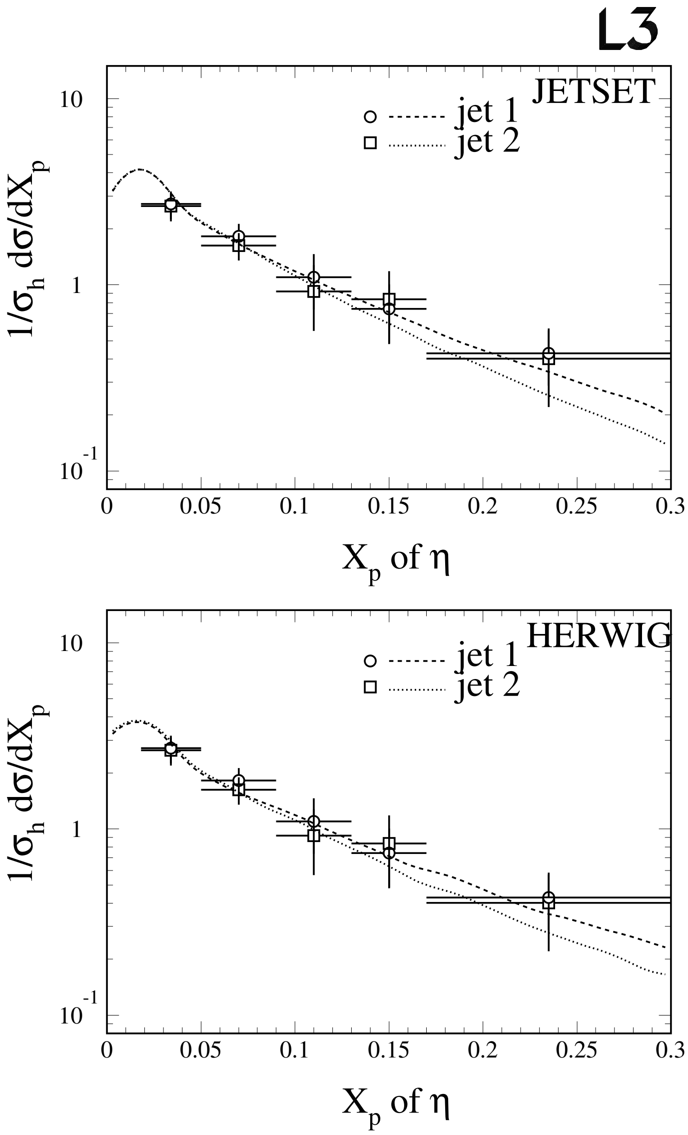

Figure 3: The η momentum measurement in two-jet events. The dots are measurement with efficiencies based on JETSET, the lines are Monte Carlo generator level predictions.

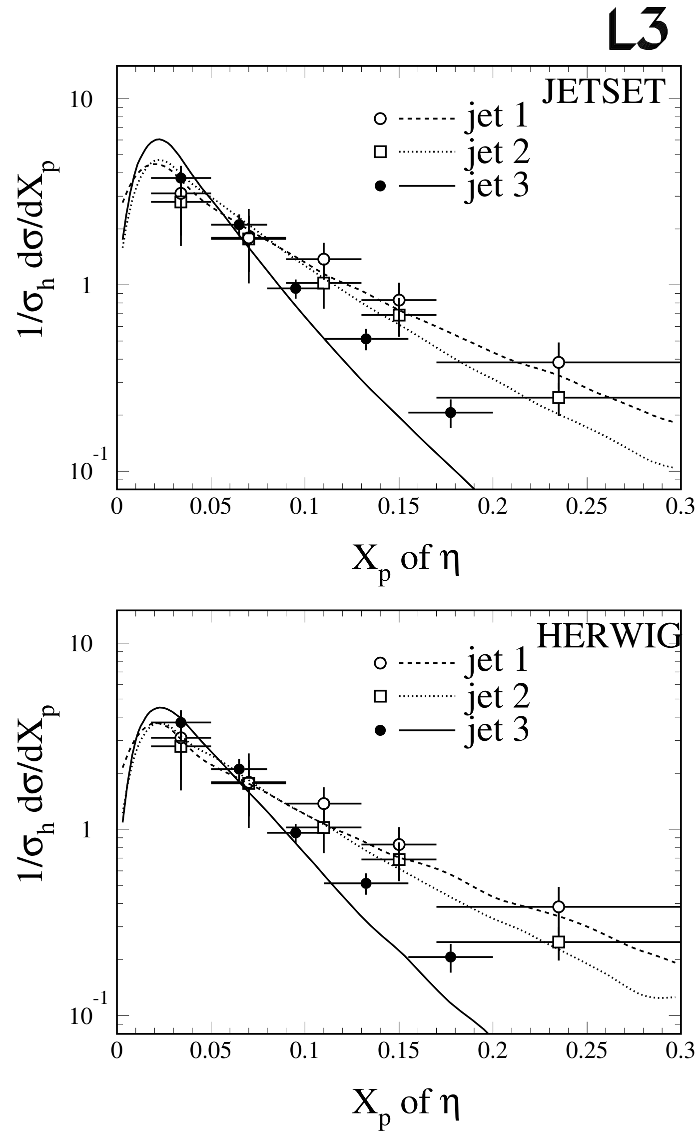

Figure 4: The η momentum measurement in three-jet events. The dots are measurement with efficiencies based on JETSET, the lines are Monte Carlo generator level predictions.

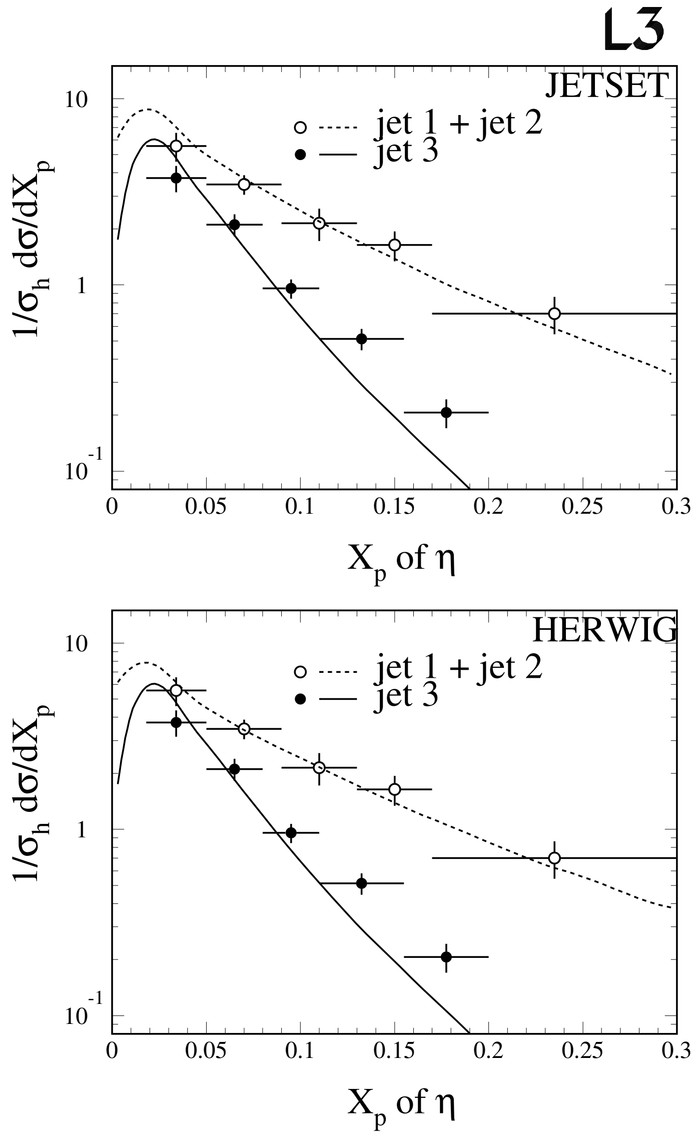

Figure 5: The η momentum measurement in quark enriched jet and in gluon enriched jet. The dots are measurement with efficiencies based on JETSET, the lines are Monte Carlo generator level predictions.

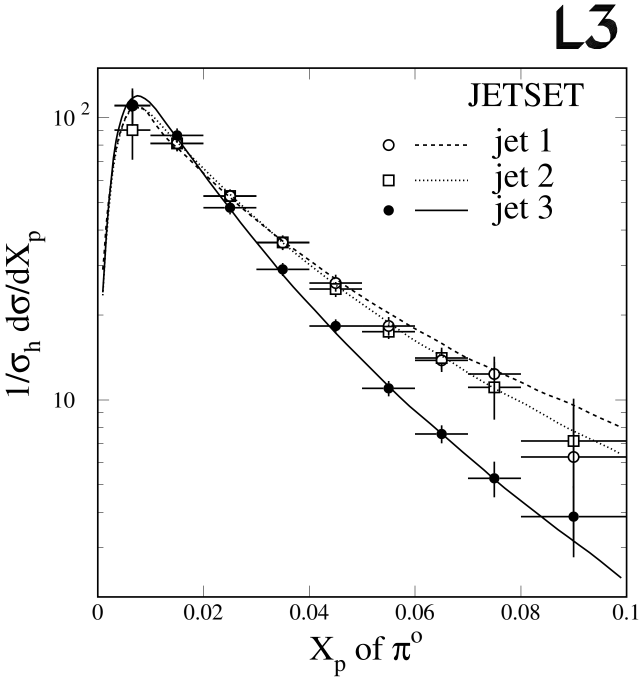

Figure 6: The π° momentum measurement in three-jet events compared with JETSET predictions.