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Search for η_b in Two-Photon Collisions with the L3 Detector at LEP

The L3 Collaboration

Abstract

A search for the pseudoscalar meson η_b is performed in two-photon interactions at LEP2. The data sample corresponds to a total integrated luminosity of $610 \mathrm{pb}^{-1}$ collected at the centre-of-mass energies from 189 GeV to 209 GeV. Preliminary results of the analysis in the η_b mass region are presented. Several candidate events are found in different final states.

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1 Introduction

Two-photon collisions are well suited for the study of pseudoscalar mesons, for which $J^{PC} = 0^{-+}$. The η_c, $c\bar{c}(1S)$ state, has been studied [1] and a value $\Gamma_{\gamma\gamma} = 6.9 \pm 1.7 \pm 2.1$ keV has been measured. The high energy and luminosity makes LEP a good environment to search also for the η_b, the $b\bar{b}$ state, not yet observed [2]. A first investigation by ALEPH [3] observes a candidate event in the channel $K^0_S K^- \pi^+ \pi^- \pi^+$ with a mass $m = 9.30 \pm 0.02 \pm 0.02$ GeV and upper limits on $\Gamma_{\gamma\gamma}$:

$$
\begin{aligned}
\Gamma_{\gamma\gamma}(\eta_\mathrm{b}) \times \mathrm{BR}(\eta_\mathrm{b} \rightarrow 4 \text{ charged particles}) &< 48 \text{ eV} \\
\Gamma_{\gamma\gamma}(\eta_\mathrm{b}) \times \mathrm{BR}(\eta_\mathrm{b} \rightarrow 6 \text{ charged particles}) &< 132 \text{ eV} \quad .
\end{aligned}
$$

Many theoretical estimates [4] exist from potential models and lattice QCD of the mass difference, Δm, between the η_b and the Υ ($m_\Upsilon = 9.46$ GeV). The predictions lie between 30 and 150 MeV. The partial decay width of the η_b into two photons, $\Gamma_{\gamma\gamma}(\eta_b)$ is expected to be $\simeq 500$ eV.

Here a search is presented which uses the L3 data sample collected at the centre-of-mass energies, $\sqrt{s}$, from 189 GeV to 209 GeV, corresponding to a total integrated luminosity of 610pb^{-1} . The formation of the η_b in quasi-real two-photon interactions $e^+e^- \rightarrow e^+e^-\eta_b$ is studied through the decay into four and six charged particles only or associated with a π^0. In the last case, because of G-parity conservation, the decay products must include a $\mathrm{K}^+\mathrm{K}^-$ pair.

For each channel a continuum mass spectrum and the η_b resonance are generated with the EGPC [5] Monte Carlo. This generator describes the two-photon process as the convolution of the luminosity function $\mathcal{L}_{\gamma\gamma}$ for transverse photons [6], the photon form factors and a two-photon sate of mass $W_{\gamma\gamma}$. The $W_{\gamma\gamma}$ state subsequently decays into a particular channel according to Lorenz invariant phase-space. The Monte Carlo generates the resonance as:

$$
\sigma(\gamma\gamma \rightarrow R) = \frac{8\pi(2J+1)M^2\Gamma_{\gamma\gamma}\Gamma}{W^2_{\gamma\gamma}[(M^2 - W^2_{\gamma\gamma})^2 + (M\Gamma)^2]}, \tag{1}
$$

where J is the spin, M the mass and Γ the width of the resonance R. The η_b mass is set to 9.4 GeV and the total width to the same value of the η_c, $\Gamma = 13.6$ MeV. The two-photon width $\Gamma_{\gamma\gamma}$ is taken equal to 1 keV, so that the ratio of the measured cross section to that obtained by Monte Carlo integration gives the measured value of $\Gamma_{\gamma\gamma}$ in keV. The $e^+e^- \rightarrow e^+e^-\eta_b$ cross-section depends on the luminosity function and on the form factors used. In the present analysis we use an infinite pole form factor, $\mathrm{F}(\mathrm{Q}^2)=1$, compatible with our measurement of the η_c production [1]. This gives an expected production cross-section $\sigma(e^+e^- \rightarrow e^+e^-\eta_b)$ of 0.251 pb at $\sqrt{s}=$ 189 GeV and 0.264 pb at $\sqrt{s}=$ 206 GeV for $\Gamma_{\gamma\gamma} = 0.5$ keV.

The background from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ is generated by the JAMVG [7] program. All Monte Carlo events are passed through the L3 detector simulation based on the GEANT [8] and GEISHA [9] programs. Time dependent detector inefficiencies, as monitored during the data taking period, are also simulated.

2 Data selection

The L3 detector [10] is suitable for the study of two-photon processes since events with few tracks and a low energy deposit in the detector are selected by a track trigger [11] with a threshold on the track transverse momentum, $p_t > 150$ MeV.

The charged particles are measured in the central tracker in the polar angle $13^o \leq \theta \leq 167^o$. The photons are detected by the electromagnetic calorimeter in the barrel region, $42^o \leq \theta \leq 138^o$, and in the forward and backward regions, $11.6^o \leq \theta \leq 38^o$.

For quasi-real photon interactions the $e^{\pm}$ in the final state are mainly scattered at very small polar angles and go undetected. The $e^+e^- \rightarrow e^+e^-\eta_{\rm b}$ events are selected by requiring four or six tracks with charge balance and two isolated electromagnetic clusters in case of a π^0 decay.

- A track must have at least 12 out of a maximum of 62 hits in the central tracker, with less than 40% of the hits missing over the track lenght.
- The tracks must be consistent with particles coming from the primary vertex. The distance of closest approach to the beam in the transverse plane is required to be less than 2 mm.
- A photon is an electromagnetic cluster with energy greater than 80 MeV and no nearby tracks in a cone of 0.2 rad half angle. To exclude photons near the edges of the detector a fiducial cut $14^o \leq \theta \leq 35^o$ and $45^o \leq \theta \leq 135^o$ is applied. The $\gamma\gamma$ mass spectrum is shown in Fig.1 for four and six tracks events.
- The reconstructed π^0 mass is required to be inside $105 - 165$ MeV. A one-constraint fit is applied to improve the mass resolution and the background is reduced by rejecting events with $\chi_{{\rm f}it} > 3$. The events selected after the fit are indicated as dashed area in Fig.1.
- No other track or electromagnetic bump must be present in the event.
- Events are excluded if a photon conversion is detected, i.e. when, assigning the electron mass to an opposite charge pair, the effective mass of the pair is smaller than 50 MeV.
- The $\gamma\gamma \rightarrow \tau^+\tau^-$ background is reduced in the four track events by requiring the invariant mass of 3π to be greater than 1.9 GeV(Fig.2). Only 2% of $\eta_{\rm b}$ events are eliminated by this cut.
- To ensure that no final state particle of the resonance decay has escaped detection, the squared vectorial sum of the transverse momenta of all detected particles, $\sum \vec{p_t}^2$, is required to be smaller than 0.1 GeV^2(Fig.3).

The ionisation loss measurement, dE/dx, has a good π/K separating power only for tracks with a momentum below 0.5 GeV. As the momenta of the decay particles of the $\eta_{\rm b}$ extend from 0.15 to 3 GeV the dE/dx has a very weak separating power. The mass of the charged particles is therefore considered to be that of a pion. The uncertainty due to π-K misidentification is studied for each $\eta_{\rm b}$ candidate.

The mass spectra of the selected events are presented in Fig. 4 and 5. All spectra are characterised by an enhancement near threshold followed by an exponential decrease, a few candidates are found in the signal region, chosen between 9 and 10 GeV. The number of events observed between 7 and 12 GeV are given in Table 1. A display of the candidate events in the transverse plane is presented in Fig. 6, 7 and 8.

2.1 Efficiency, mass resolution and background

Samples of 50000 η_b events for each final state and four different $\sqrt{s}$ values from 189 GeV to 206 GeV have been generated. In Table 2 the mass resolution and the total efficiencies, including acceptance and selection cuts are given. Trigger inefficiencies are negligeable. The total efficiency depends on the nature of the particles in the channel, the variation due to this effect is given in the table. The mass shift, due to (π/K) misidentification is also indicated.

The mass spectra of the channels under study are well represented by a two-photon cross-section slowly decreasing with $W_{\gamma\gamma}$. For each channel 500000 events have been generated with a uniform mass spectrum. By comparing the mass spectra to the data we obtain a good agreement by weighting each MC event with an exponential function $\exp(-cW_{\gamma\gamma})$, with c $\simeq$ 1 GeV^{-1}. The MC events thus obtained are superimposed to the data in Fig. 4 and 5.

The main background due to $e^+e^- \to e^+e^-\tau^+\tau^-$ events, it is estimated with a MC sample six times larger than the data. This contamination is also presented in Fig. 4 and 5.

Inclusive channels can also be a source of background, when one or more particles go undetected. We estimate this background by using the exclusive channels with an higher number of particles and by considering the side bands of the π^0, it is found to be smaller than 1%.

The individual backgound contributions to the signal region, 9 to 10 GeV, are given in Table 3.

3 Results

In Table 4 two possible values of the candidates mass are listed together with the mass resolution, assuming first that all tracks are pions if no π^0 is present and that there is a $\mathrm{K^+K^-}$ pair otherwise. The η_b is expected to decay through two gluons, which are flavour blind. We calculate then an average mass, using different π/K hypothesis, by assuming that the production of pions and kaons is equally probable.

The cross section for each channel i is obtained by :

$$\sigma_i = \frac{N_i - B_i}{\mathcal{L}\varepsilon_\rangle}.$$

Here N_i is the number of the observed events, B_i the expected background, ε_i the total efficiency and $\mathcal{L} = 610$ pb^{-1} the integrated luminosity for the data between $\sqrt{s} = 189$ GeV and $\sqrt{s} = 209$ GeV. Upper limits at 95% confidence level [3] for $\Gamma_{\gamma\gamma}(\eta_\mathrm{b})\times\mathrm{BR}(\eta_\mathrm{b})$ are calculated for each channel. The results are listed in Table 4.

In Fig. 9 the mass spectrum, obtained by adding all channels together is presented. Assuming that the η_b branching ratio for each channel is the same, the combined upper limit for $\Gamma_{\gamma\gamma}(\eta_\mathrm{b})\times$ BR(η_b) is 0.2 keV.

References

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Channel	7-8 [GeV]	8-9 [GeV]	9-10 [GeV]	10-12 [GeV]
4tr	2	0	1	0
4tr π^0	2	0	0	0
6tr	1	1	1	0
6tr π^0	4	0	1	0

Table 1: Number of events retained in different $W_{\gamma\gamma}$ mass regions after final selection.

Channel	Resolution (MeV)	(K/π) Mass shift (MeV)	Total efficiency %
4tr	297 ± 3	110	4.7 ± 1.9
4tr π^0	259 ± 8	95	1.9 ± 0.7
6tr	254 ± 4	310	3.6 ± 0.6
6trπ^0	231 ± 7	265	0.94 ± 0.15

Table 2: Detector resolution, mass shift due to (K/π) ambiguity and total efficiency for the different channels as obtained from Monte Carlo.

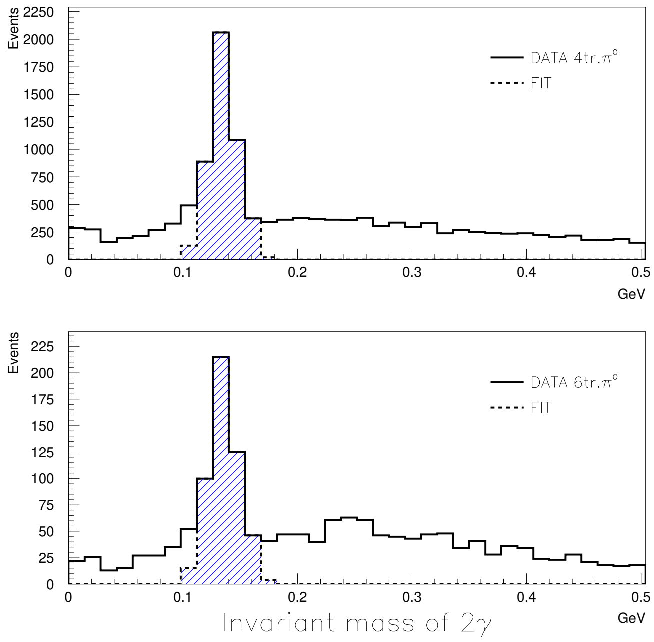


Figure 1: The mass of the two gammas detected in the electromagnetic calorimeter for four and six track data samples. The events selected after the constraint fit on π^0 are indicated by the dashed area.

Channel	Exclusive	$\tau\tau$
4tr	0.21 ± 0.04	0.04 ± 0.04
4tr π^0	0.08 ± 0.01	0.04 ± 0.04
6tr	0.31 ± 0.04	0.34 ± 0.05
6trπ^0	0.14 ± 0.02	0.15 ± 0.06

Table 3: The expected background events in the region 9-10 GeV from the continuum production of the exclusive channel, from $e^+e^- \to e^+e^-\tau^+\tau^-$ events and from inclusive channels.

Channel	Minimum Mass (GeV)	Average Mass (GeV)	Cross section (pb)	Upper limit of $\Gamma_{\gamma\gamma}\times$ BR (keV)
4tr	9.89	10.02 ± 0.32	0.026	0.3
4tr π^0	—	—	—	0.5
6tr	9.39	9.70 ± 0.40	0.021	0.4
6tr π^0	9.99	10.21 ± 0.38	0.120	1.4

Table 4: Mass of the η_b candidates in the channels studied at $189 \leq \sqrt{s} \leq 208$ GeV. The first column gives the minimal value of the mass obtained assuming that all tracks are pions if no π^0 is present and that there is a K^+K^- pair otherwise. The second column gives the average mass of all possible π/K combinations; the error includes detector resolution and misidentification uncertainty. The corresponding cross-section and the 95% confidence level limit for the two-photon width times branching ratio are also listed.

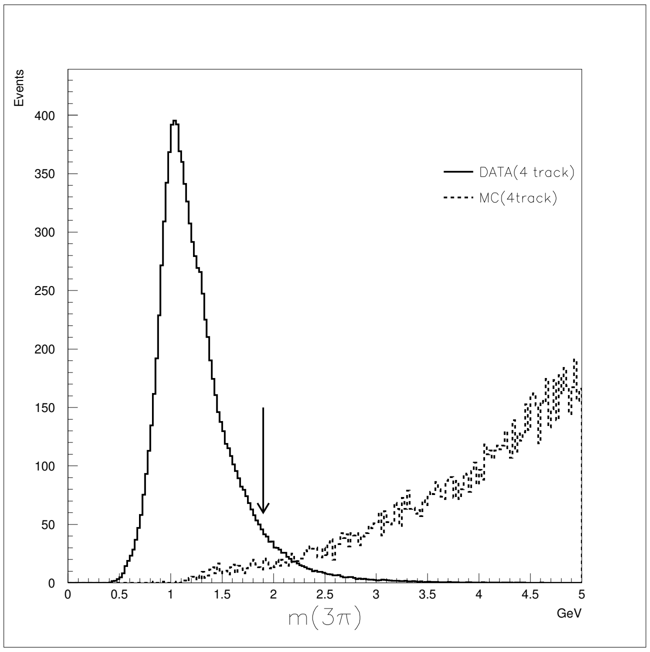


Figure 2: The mass plot of the three pion combinations in the 4 tracks sample compared to the Monte Carlo of η_b production. The arrow is indicating the cut used to select the η_b events.

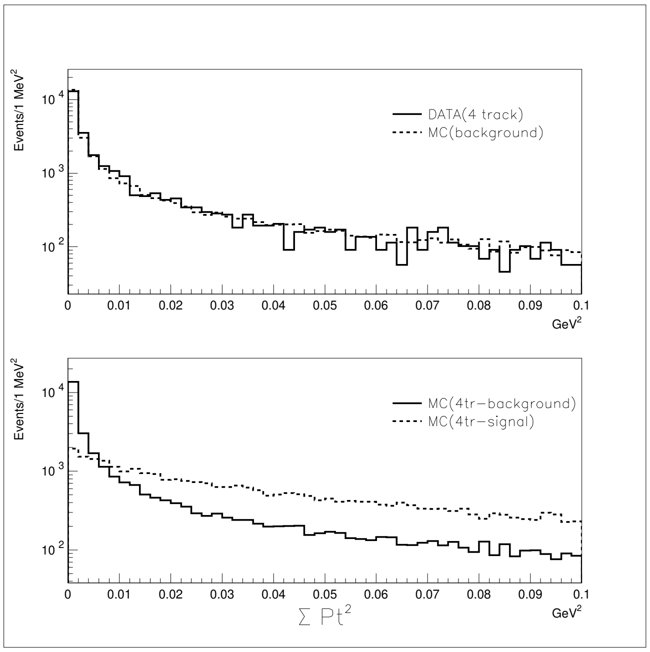


Figure 3: The$\sum \vec{p_t}^2$ distribution for four-track events: The data are compared to the Monte Carlo of the continuum in the upper histograms. In the lower histograms the MC distribution for η_b production (dashed line), compared to the continuum MC, shows a much wider distribution due to the degrading of the resolution at high masses.

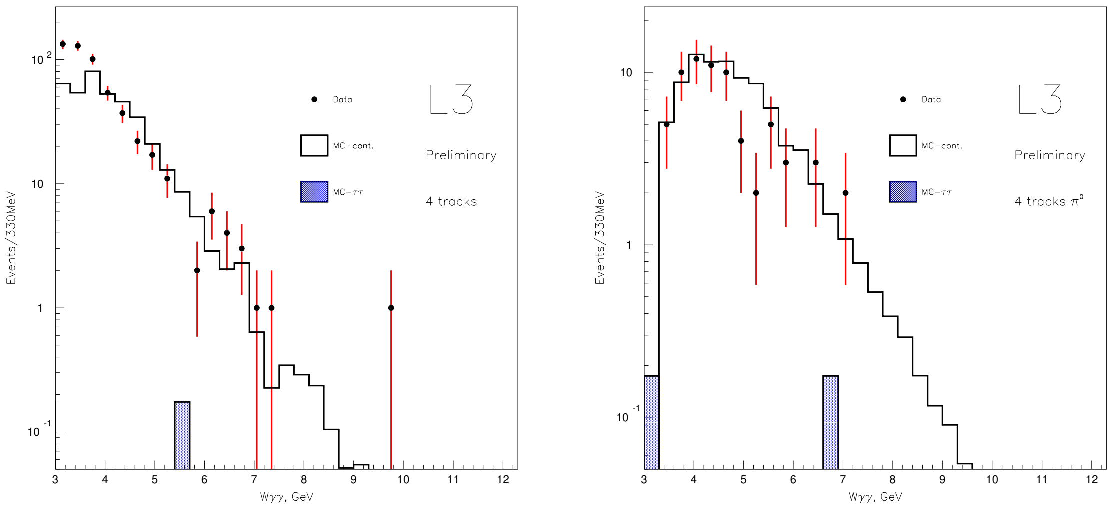


Figure 4: The mass distribution of selected events for the 4 tracks (*left*) and 4 tracks π^0 (*right*)channels. Superimposed to the data is the expected number of events from the exclusive channels. The $e^+e^- \to e^+e^-\tau^+\tau^-$ background is shown as a shaded area.

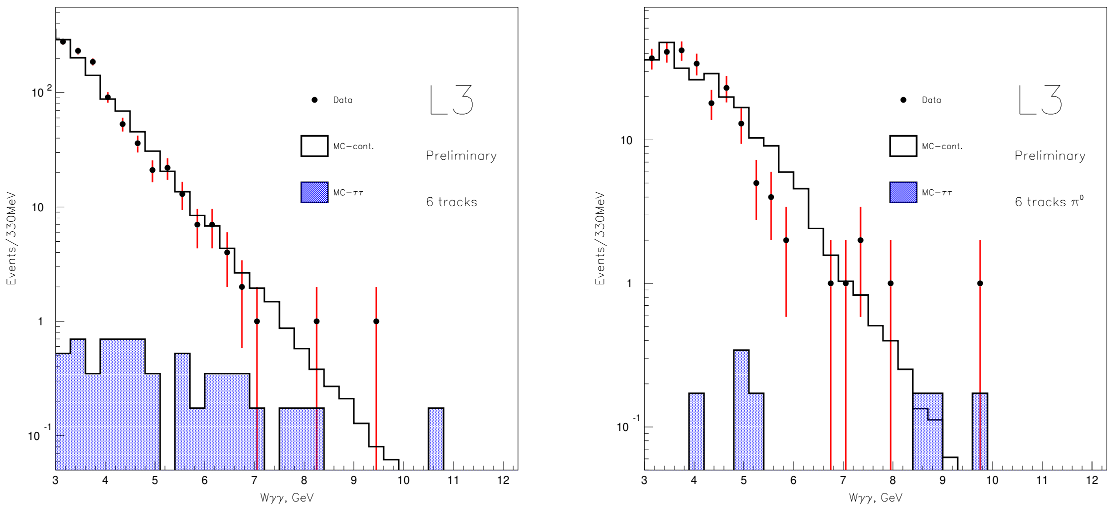


Figure 5: The mass distribution of selected events for the 6 tracks(*left*) and 6 tracks π^0 (*right*) channels. Superimposed to the data is the expected number of events from the exclusive channels. The $e^+e^- \to e^+e^-\tau^+\tau^-$ background is shown as a shaded area.

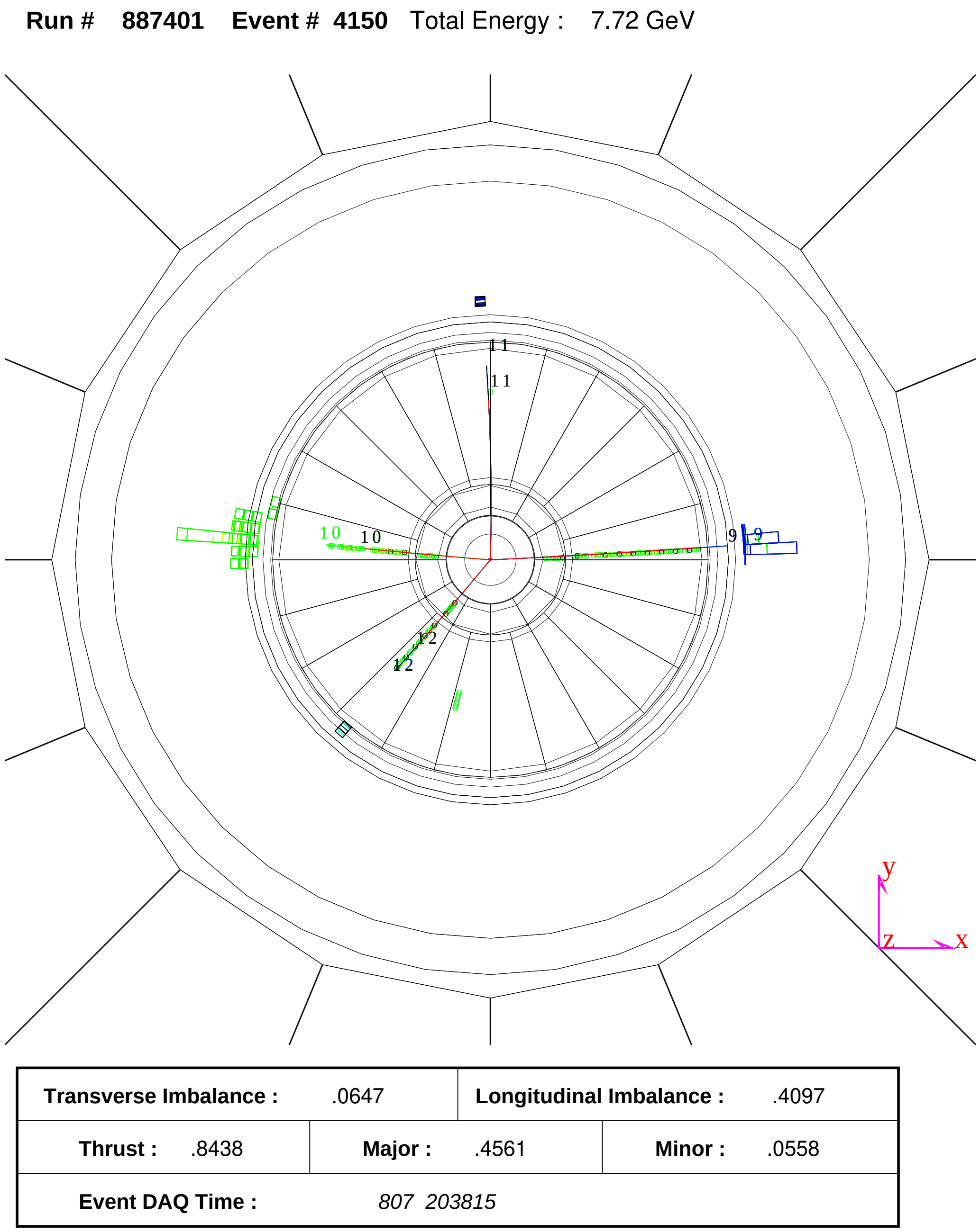
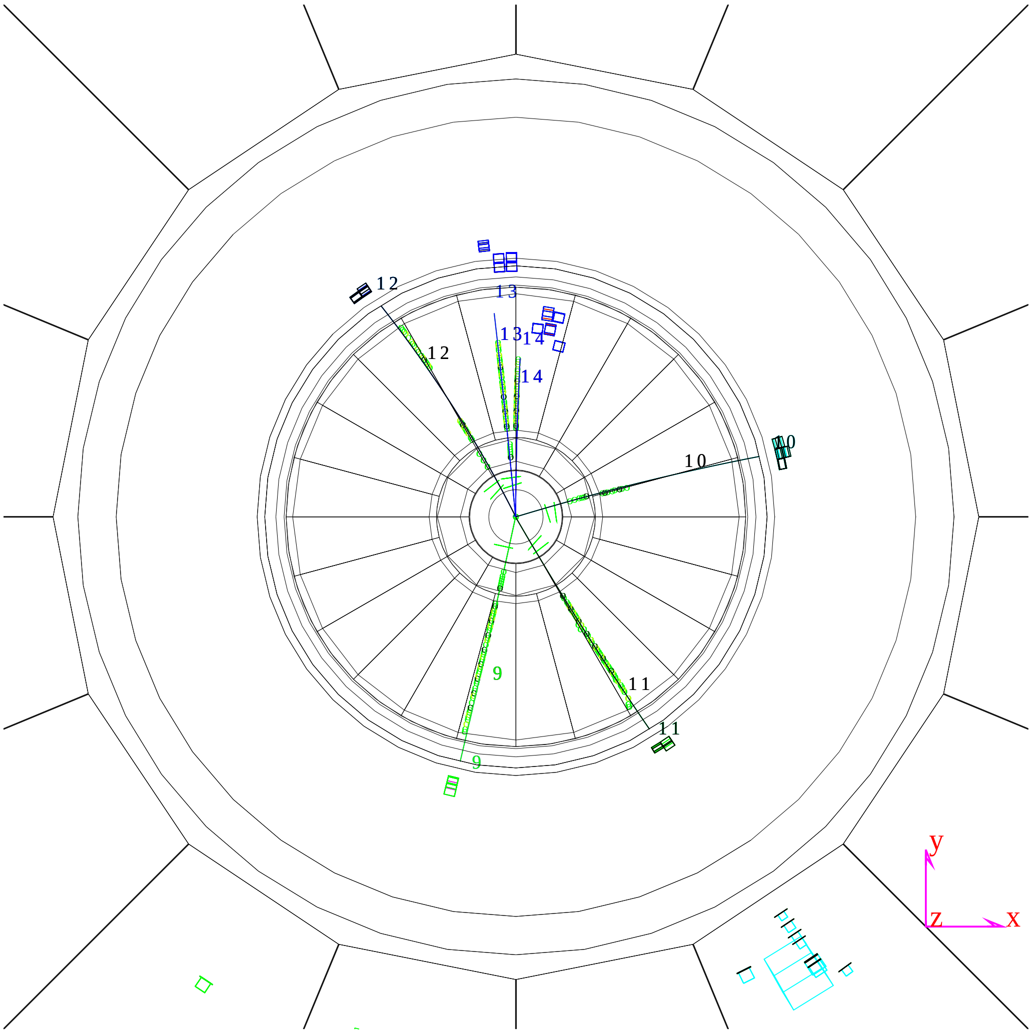


Figure 6: The scan of a selected event for the 4 tracks channel. $M = 10.02 \pm 0.32$ GeV

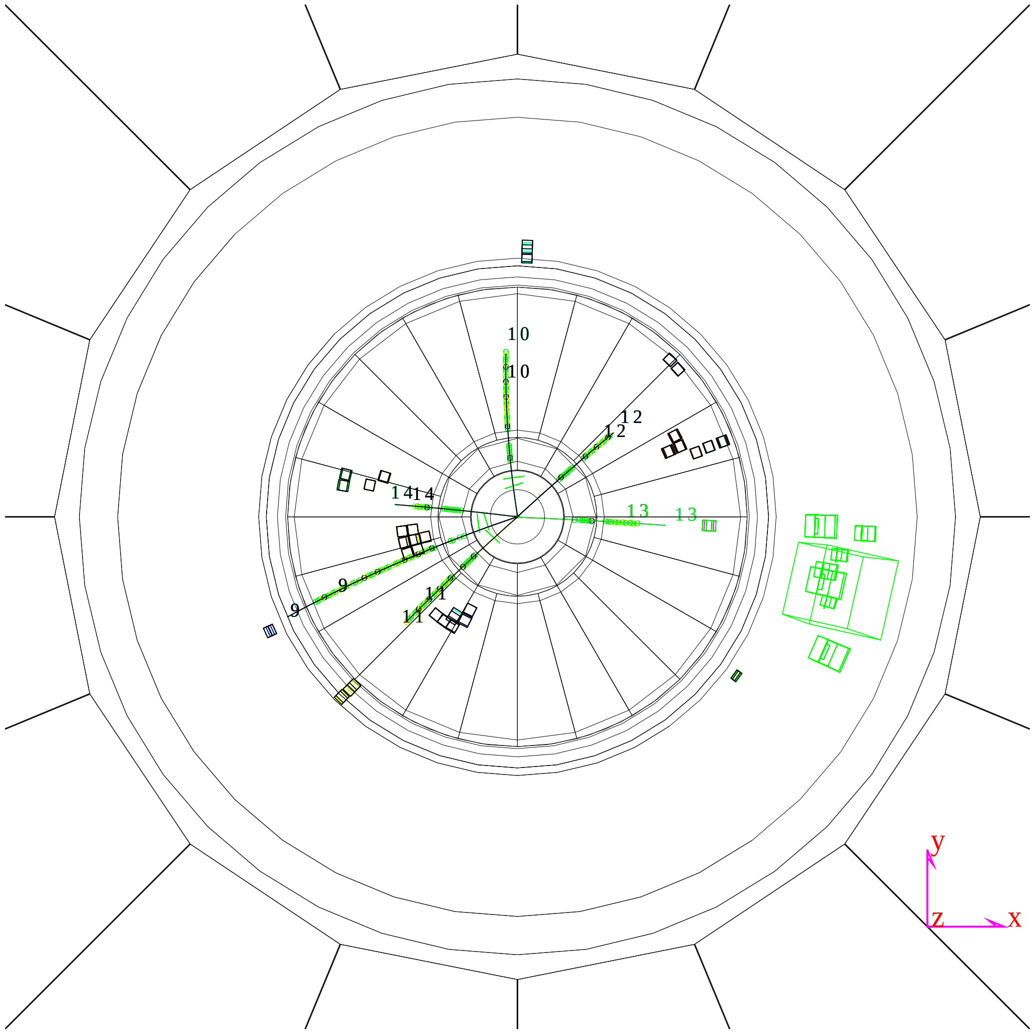
Run # 838601 Event # 4025 Total Energy : 10.16 GeV



Transverse Imbalance :	.1337		**Longitudinal Imbalance :**	-.6699	
Thrust :	.6831	**Major :**	.6328	**Minor :**	.2424
Event DAQ Time :	*607*	*43*			

Figure 7: The scan of a selected event for the 6 tracks channel. $M = 9.70 \pm 0.34$ GeV

Run # 760602 Event # 1742 Total Energy : 6.20 GeV



Transverse Imbalance :	.1714		**Longitudinal Imbalance :**	-.2062
Thrust : .9189		**Major :** .2457		**Minor :** .1538
Event DAQ Time :	*990721 201420*			

Figure 8: The scan of a selected event for the 6 tracks π^0 channel. $M = 10.24 \pm 0.34$ GeV

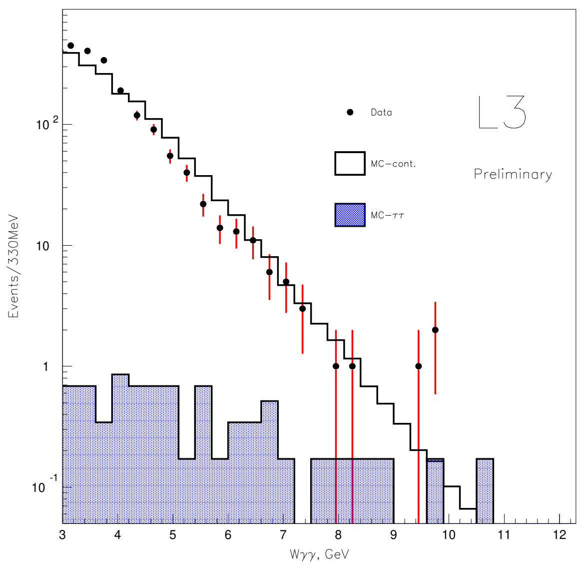


Figure 9: The mass spectrum of all analysed channels added together. Superimposed to the data is the expected number of events from the exclusive channels. The $e^+e^- \to e^+e^-\tau^+\tau^-$ background is shown as a shaded area.