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Abstract: **Session: Beyond the Standard Model**

Study of Multi-lepton Production with the ZEUS detector at HERA

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Abstract

A search for events containing high-transverse-momentum isolated electrons or a pair of tau leptons in the final state is performed with the ZEUS detector at HERA using an integrated luminosity of 296 pb^{-1}. The measured di- and tri-electron event yields as well as the number of di-tau events are found to be in agreement with the predictions from the Standard Model.

1 Introduction

The large center-of-mass energy of the electron[1]-proton collisions at HERA allows the production of events with two or more leptons with high transverse momentum (P_T) in the final state. The Standard Model (SM) cross section for the production of a lepton pair is dominated by the two photon process, $\gamma\gamma \to l^+l^-$, and can be accurately predicted [1]. In the region of large invariant masses, multi-lepton production may be also sensitive to new physics and so the measurement of the multi-lepton event yields is particularly interesting. The H1 Collaboration has reported an excess of events in both di-electron and tri-electron samples at large di-electron masses [2].

In the analysis presented here, events with two (or more) isolated high-P_T electrons or a pair of tau leptons, both decaying leptonically, were selected and compared with the predictions of the SM. The analysis is based on the data samples collected by the ZEUS experiment in the period 1996 − 2005, corresponding to an integrated luminosity of 296 pb^{-1}. The total sample includes 152 pb^{-1} of e^-p data and 144 pb^{-1} of e^+p data. In the years 1994 − 1997 data were recorded at $\sqrt{s} = 300$ GeV and in the period 1998 − 2005 at $\sqrt{s} = 318$ GeV. Since 2003 HERA has been running with longitudinally polarized electron beams.

2 Monte Carlo Simulation

The GRAPE [3] Monte Carlo (MC) program was used to simulate multi-lepton events. It is based on the electroweak matrix elements at tree level for the $\gamma\gamma$, γZ^0 and Z^0Z^0 sub-processes, as well as internal γ/Z^0 conversion.

The dominant background processes to multi-electron production are those in which one or more fake electrons are reconstructed in the final state. The main contribution comes from neutral current (NC) deep inelastic scattering (DIS) events where hadrons or photons are incorrectly identified as electrons. QED Compton events can also contribute if the final state photon is misidentified as an electron. The NC DIS and QED Compton events were simulated with the DJANGOH [4] and COMPTON 2.0 [5] MC programs, respectively.

For the di-tau analysis, final states with one muon and one (or more) electrons are searched for. The background comes from cosmic events and from the di-muon production, in which the beam electron mimics the decay electron from the tau and one muon is lost in the beam pipe or failed to be identified in the ZEUS detector.

[1] In the following the term “electron” is used to refer to both electrons and positrons.

The ZEUS detector response was simulated using a program based on GEANT [6]. The generated events were passed trough the detector simulation, subjected to the same trigger requirements as the data and processed by the same reconstruction programs.

3 Event Selection

3.1 Multi-electron sample

The following criteria were imposed to select multi-electron events.

- electron identification: an algorithm which combined information from the energy deposits in the calorimeter and, when available, tracks measured in the central tracking detectors was used to identify the electron candidates. For each electron candidate in the central region[2], which lie within the acceptance of the central tracking detector (CTD) ($17° < \theta_e < 164°$), the energy was required to be greater than 10 GeV and a track had to be matched with the energy deposit in the calorimeter. The matched track was required to have a momentum of at least 5 GeV and a distance of closest approach between the energy deposition and the track of less than 8 cm. Forward electrons ($\theta_e < 17°$) were also required to have an energy greater than 10 GeV while, for electrons in the rear ($\theta_e > 164°$) region of the calorimeter the energy requirement was decreased to 5 GeV;
- isolation: to ensure high purity each identified electron candidate was required to be isolated such that the total energy not associated with the electron in an $\eta - \phi$ cone of radius 0.8 centred on the electron was less than 0.3 GeV. Only for electrons in the central region, this isolation requirement was complemented by the request that no track, other than the matching track, was contained in an $\eta - \phi$ cone of radius 0.4 centred on the electron;
- primary vertex: events were required to satisfy $|Z_{\rm vtx}| < 50$ cm, i.e., the Z coordinate of the *ep* interaction vertex, reconstructed using tracks in the central detectors, was required to be in the centre of the detector.

The final multi-electron events were selected by requiring at least two central candidates of which the first had to have $P_T > 10$ GeV and the second $P_T > 5$ GeV. Additional electron candidates were identified according to the above selection criteria but without

[2] The ZEUS coordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, the Y axis pointing up and the X axis pointing towards the centre of HERA. The polar angle, θ, is measured with respect to the proton beam direction. The coordinate origin is at the nominal interaction point.

any additional P_T requirement. In the following we will refer to the events with two and three electron candidates in the final state as the di-electron ("ee") and tri-electron ("eee") samples, respectively.

3.2 Di-tau sample

In the di-tau search[3] only the leptonic decay modes of two taus elastically produced were considered, excluding the case where both taus decayed to charged leptons of the same flavour (ee and $\mu\mu$ final state). The main experimental signature was hence the presence in the final state of at least one electron and exactly one muon.
These were the criteria imposed to select di-tau events.

- electron identification: the same algorithm and similar selection criteria as used in the multi-electron analysis were used to identify electrons. Each electron candidate in the angular region $\theta_e < 2.6$ rad was required to have an energy greater than 4 GeV and to be isolated such that the total energy in an $\eta - \phi$ cone of radius 0.8, not associated with the electron, was less than 5.0 GeV. A matching track of momentum greater than 2 GeV and a distance of closest approach of less than 10 cm was required for electron candidates within the acceptance of the CTD;
- muon identification: an algorithm combining information from the calorimeter, the muon detectors and the tracking detectors was used to identify the muon candidate. Each muon condidate was required to have transverse momentum $P_{T,\mu} > 2$ GeV and to be matched with a track. Events with extra muon candidates which were identified with looser selection criteria than above were rejected;
- number of good tracks: events which had a number of good tracks[4] less than one or greater than 3 were discarded. If there were more than one good track in the event, one of the good tracks was required to match the electron candidate;
- primary vertex and $E - p_Z$: the same requirement as in the multi-electron analysis was applied to the primary vertex and in addition, to reduce di-muon background, the quantity $E - P_Z = (E - P_Z)_{\rm CAL} + (E - p_Z)_{\mu,\rm track}$ was required to be below 45 GeV;
- elastic events: the selection of elastic di-tau events was obtained by requiring that the energy in the first and second inner rings of the forward calorimeter was smaller than 1 GeV;

[3] The di-tau search was limited to the $e^- p$ data sample collected in the year 2005 and corresponds to a luminosity of 135 pb^{-1}.
[4] A good track was defined as a track in the fiducial volume of the CTD having a transverse momentum greater than 150 MeV.

- collinearity angle: to suppress cosmic events background, events in which the angle between the electron and the muon was smaller than 0.1 rad or larger than 2.7 rad were rejected.

The final selection was designed to further suppress the di-muon background. Events which had an additional calorimeter deposit consistent with a mip but not found by the muon algorithm were rejected. Additionally, events with a measured electron charge equal to -1 were required to have $\theta_e < 1$ rad.

4 Results

The measured event yields for the di-electron and tri-electron samples together with the SM expectations are presented in Table 1. The observed yields are in agreement with the SM both for $M_{12} > 50$ GeV and for $M_{12} > 100$ GeV, where M_{12} is the invariant mass of the two highest-P_T electrons. No events were observed with more than three identified electrons.

The distributions of the transverse momentum, $P_{T,i}$, and polar angle, $\theta_{e,i}$, of the i^{th} highest-P_T electron in the final state are shown in Fig. 1 (“ee” sample) and Fig. 2 (“eee” sample) and are well described by the SM. The distributions as a function of the invariant mass M_{12} of the di-electron and tri-electron samples are presented in Fig. 3 and Fig. 4, respectively. The SM gives a good description of the measurements up to the largest di-lepton invariant masses measured. The event displays of the highest M_{12} events in the di- and tri-electron samples are shown in Fig. 5.

In the di-tau search, after the final selection, three events remained to be compared with 2.0 ± 0.8 expected from the di-tau process, while the contribution from the di-muon background was found to be less than 0.2 events. The event displays of these three data events are shown in Fig. 6 to Fig. 8. All three events had exactly one electron candidate.

The distributions of the polar angle and of the transverse momentum of the electron and muon coming from the decays of the tau candidates are shown in Fig. 9. Also shown in the figure are the missing P_T of the event and the $e-\mu$ invariant mass. All the measured distributions are compatible with the SM predictions.

5 Conclusions

The production of multi-electrons with high-transverse momenta has been studied in $e^{\pm}p$ scattering at HERA. The measurement is based on the large e^+p and e^-p data samples collected by the ZEUS experiment in the years $1996-2005$ and corresponds to a total integrated luminosity of 296 pb^{-1}. The measured event yields with two and three high-P_T electrons in the final state are found to agree with the SM predictions up to the largest di-electron invariant masses measured. A search for di-tau events, limited to the leptonic decay channel, has also been performed yielding results compatible with the SM expectations.

References

[1] J.A.M Vermaseren, Nucl. Phys. **B 229**, 347 (1983).

[2] H1 Coll., A. Aktas et al., Eur. Phys. J. **C 31**, 17 (2003).

[3] T. Abe, Comp. Phys. Comm. **136**, 126 (2001).

[4] H. Spiesberger, HERACLES *and* DJANGOH*: Event Generation for ep Interactions at HERA Including Radiative Processes*, 1998, available on `http://www.desy.de/~hspiesb/djangoh.html`.

[5] T.Carli et al., in *Proceedings of the Workshop on Physics at HERA*, p. 1468. DESY, 1991.

[6] R. Brun et al., GEANT3, Technical Report CERN-DD/EE/84-1, CERN, 1987.

Selection	Data	SM	GRAPE	QEDC	NC
$e^{+}p$ (L=144 pb^{-1})					
"ee" $M_{12} > 50$ GeV	26	31 ± 5	25 ± 3	2 ± 0.4	4 ± 1.4
"ee" $M_{12} > 100$ GeV	1	0.8 ± 0.4	0.5 ± 0.1	0.2 ± 0.2	$0.10^{+0.13}_{-0.09}$
"eee" $M_{12} > 50$ GeV	6	8 ± 1	8 ± 1	< 0.06	< 0.2
"eee" $M_{12} > 100$ GeV	1	$0.40^{+0.2}_{-0.03}$	0.40 ± 0.03	< 0.01	< 0.2
$e^{-}p$ (L=152 pb^{-1})					
"ee" $M_{12} > 50$ GeV	27	36 ± 5	23 ± 3	4 ± 0.9	9 ± 1.9
"ee" $M_{12} > 100$ GeV	0	0.7 ± 0.3	0.4 ± 0.1	0.2 ± 0.2	$0.10^{+0.13}_{-0.10}$
"eee" $M_{12} > 50$ GeV	6	7 ± 0.8	7 ± 0.8	< 0.07	< 0.2
"eee" $M_{12} > 100$ GeV	0	$0.40^{+0.2}_{-0.03}$	0.40 ± 0.03	< 0.01	< 0.2

Table 1: *The observed and predicted multi-electron event yields for the "ee" and "eee" samples defined in the text. The results are shown separately for the $e^{-}p$ and $e^{+}p$ data and for $M_{12} > 50$ GeV and $M_{12} > 100$ GeV. The quoted uncertainties include the uncertainty on the energy scale, the one from the luminosity measurement as well as the statistical uncertainty of the MC. Upper limits of 68 % CL are given in case where no MC event was remained after the event selection.*

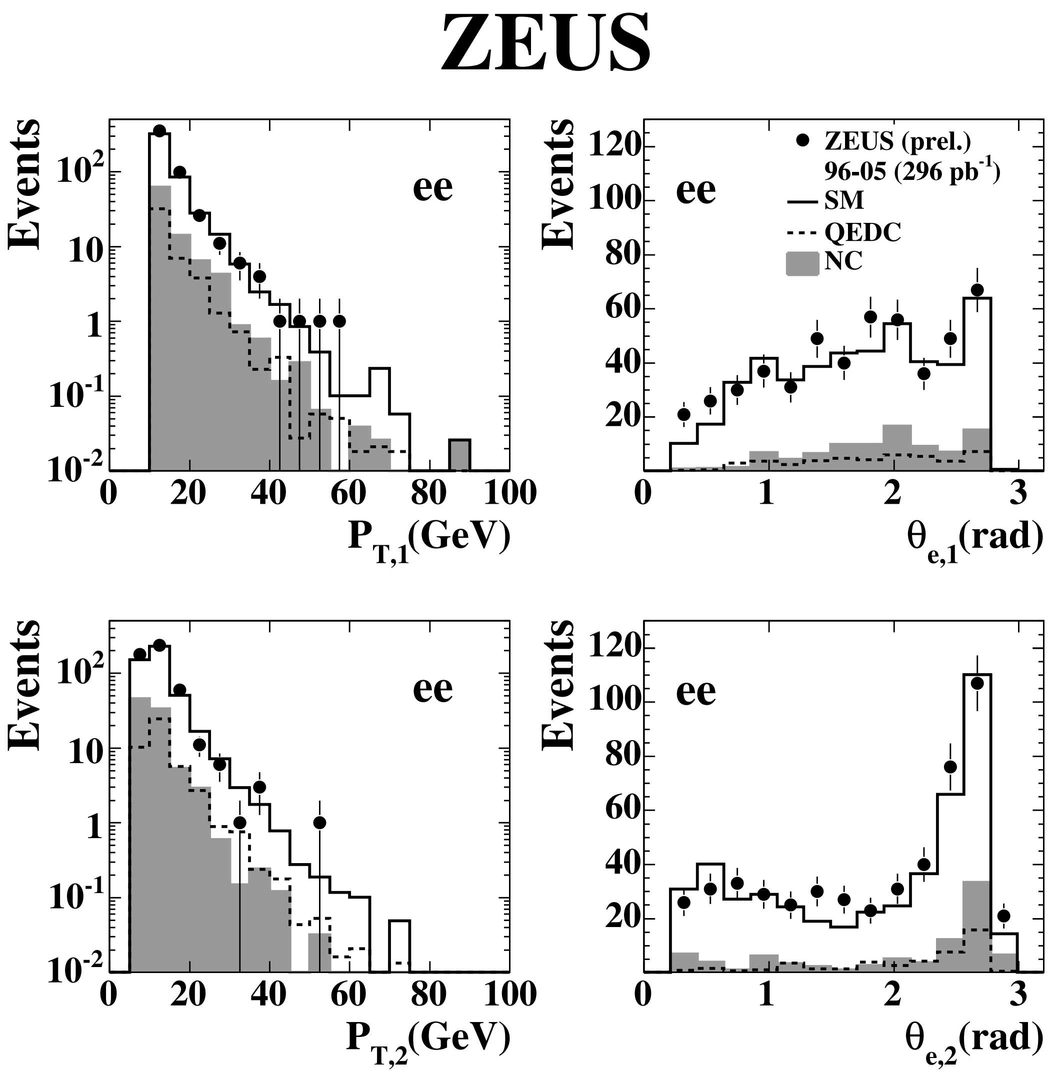

Figure 1: *"ee" sample: Comparison of the measured trasverse momentum and polar angle distributions of the two high-P_T electrons (dots) with the SM expectactions (solid line). The contributions due to QED Compton and NC DIS processes are also shown as dashed and shaded histograms, respectively.*

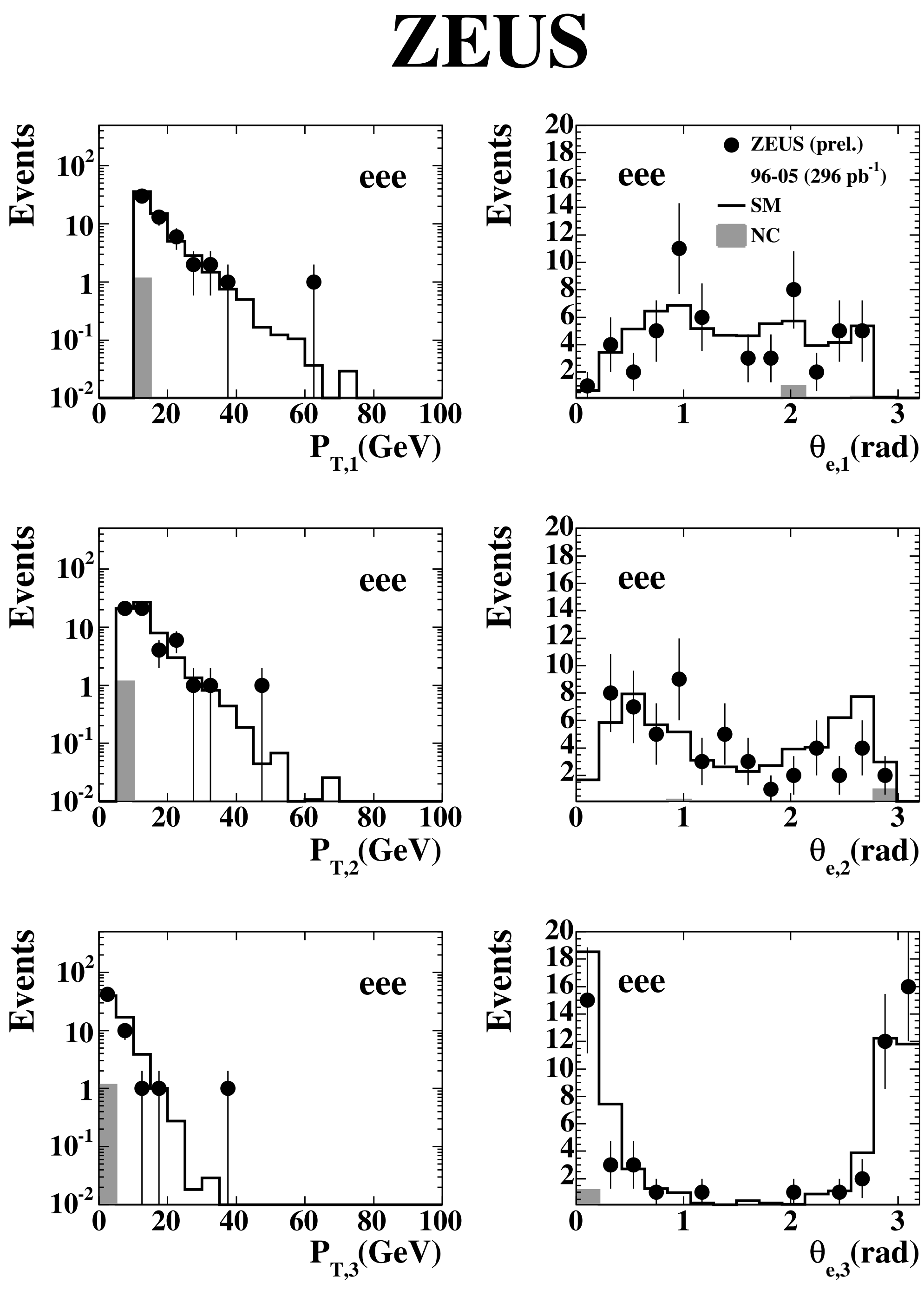

Figure 2: *"eee" sample: Comparison of the measured trasverse momentum and polar angle distributions of the three high-P_T electrons (dots) with the SM expectactions (solid line). Other details as in the caption to Fig.1.*

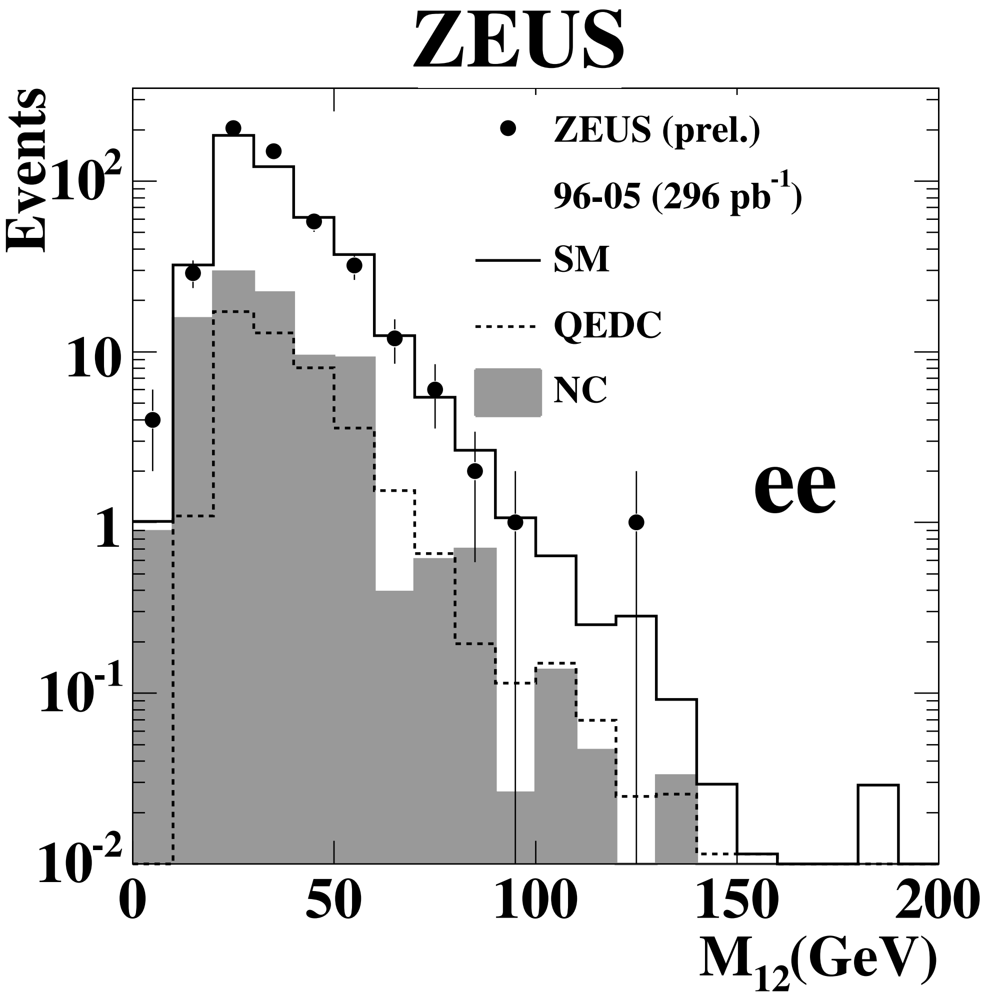

Figure 3: *"ee" sample: Comparison of the measured distribution of the invariant mass, M_{12}, of the two high-P_T electrons (dots) with the SM expectaction (solid line). Other details as in the caption to Fig.1.*

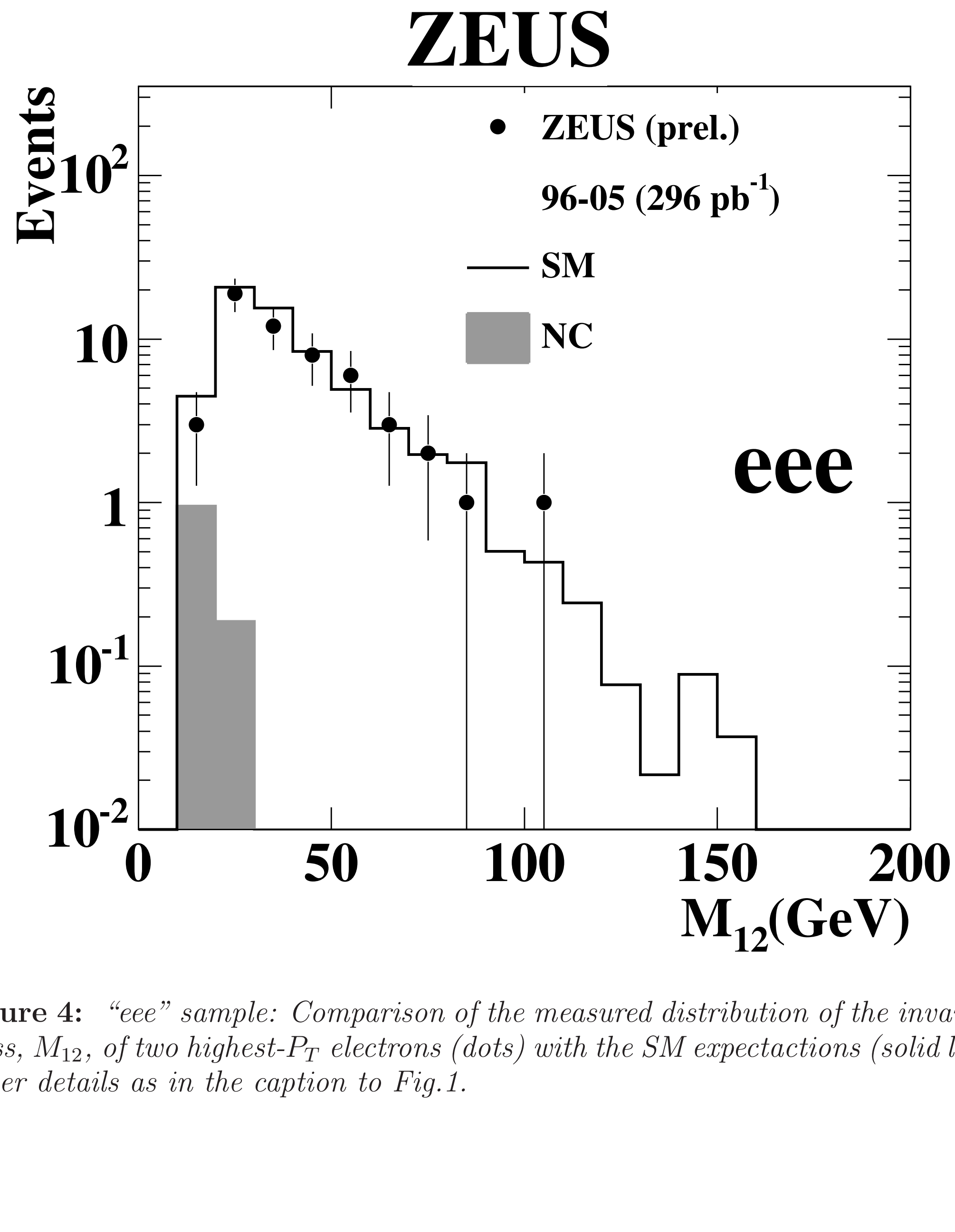

Figure 4: *"eee" sample: Comparison of the measured distribution of the invariant mass, M_{12}, of two highest-P_T electrons (dots) with the SM expectactions (solid line). Other details as in the caption to Fig.1.*

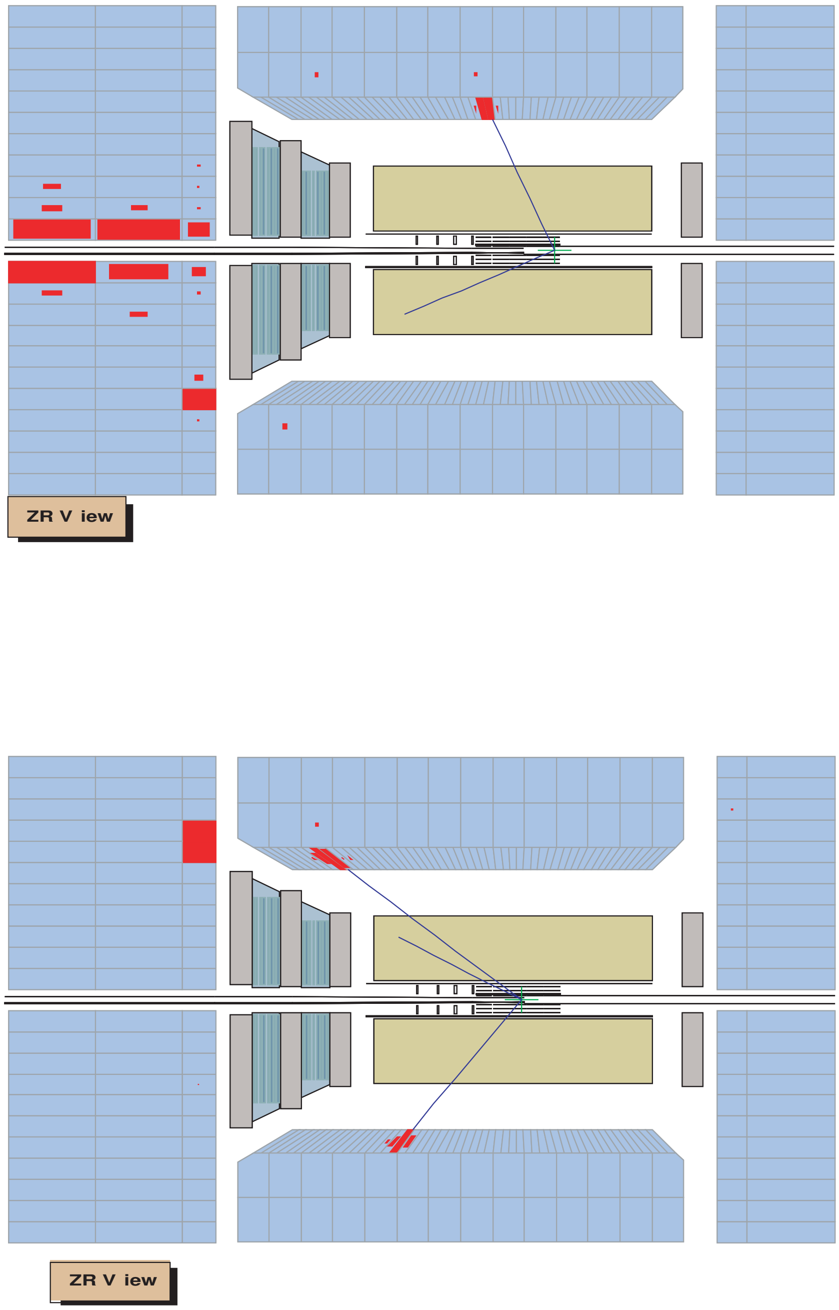

Figure 5: *(Top) Display of the highest* M_{12} *event of the "ee" sample:* $M_{12} = 123$ *GeV,* $P_{T,1} = 55$ *GeV and* $P_{T,2} = 54$ *GeV. (Bottom) Display of the highest* M_{12} *event of the "eee" sample:* $M_{12} = 103$ *GeV,* $P_{T,1} = 62$ *GeV,* $P_{T,2} = 47$ *GeV and* $P_{T,3} = 35$ *GeV.*

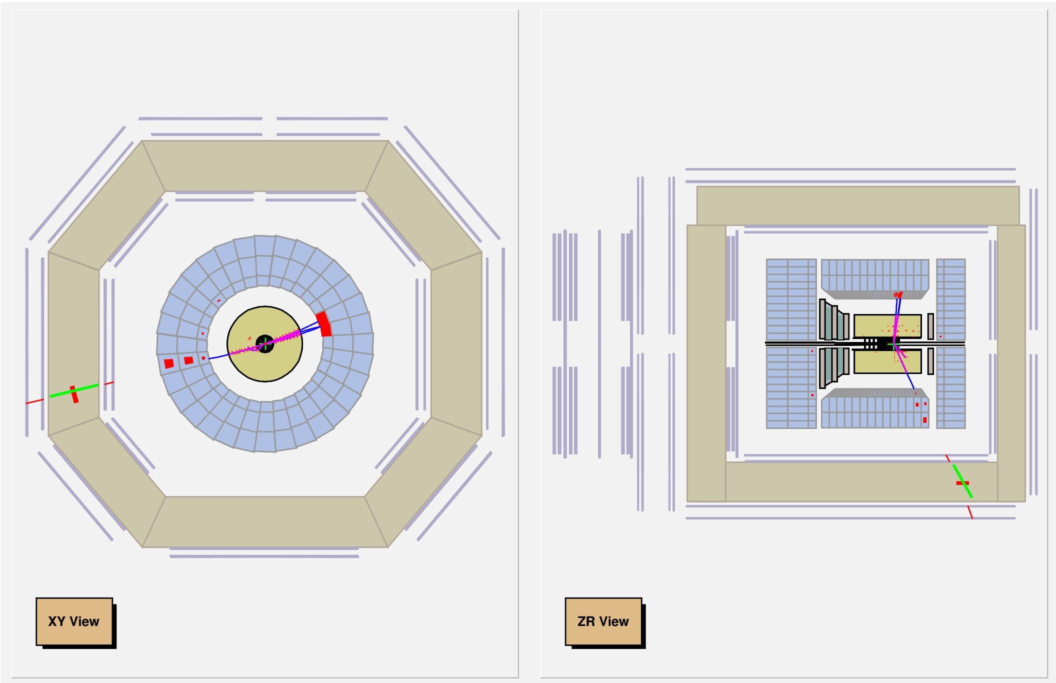

Figure 6: *Display of the first event of the three selected di-tau candidate events. The values of the* $e-\mu$ *invariant mass,* $M_{e,\mu}$*, the transverse momentum of the muon,* $P_{T,\mu}$*, and the the transverse momentum of the electron,* $P_{T,e}$*, are:* $M_{e,\mu} = 15.7\ GeV$*,* $P_{T,\mu} = 4.8\ GeV$ *and* $P_{T,e} = 12.6\ GeV$*, respectively.*

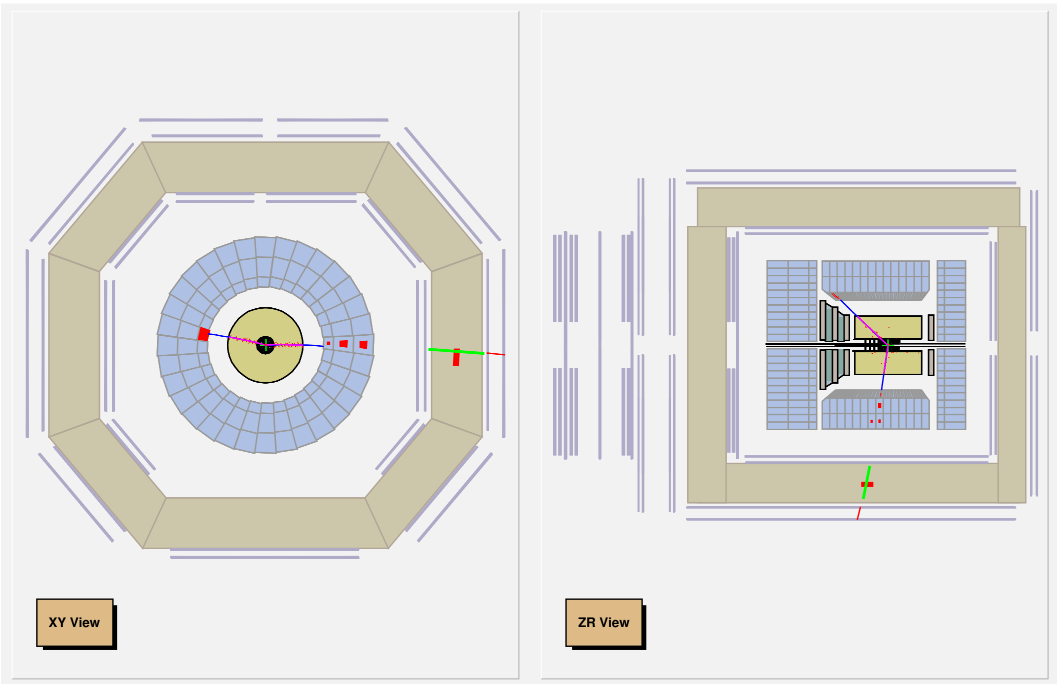

Figure 7: *Display of the second event of the three selected di-tau candidate events. The values of the* $e-\mu$ *invariant mass,* $M_{e,\mu}$*, the transverse momentum of the muon,* $P_{T,\mu}$*, and the the transverse momentum of the electron,* $P_{T,e}$*, are:* $M_{e,\mu} = 9.8\ \ GeV$*,* $P_{T,\mu} = 4.9\ \ GeV$ *and* $P_{T,e} = 3.5\ \ GeV$*, respectively.*

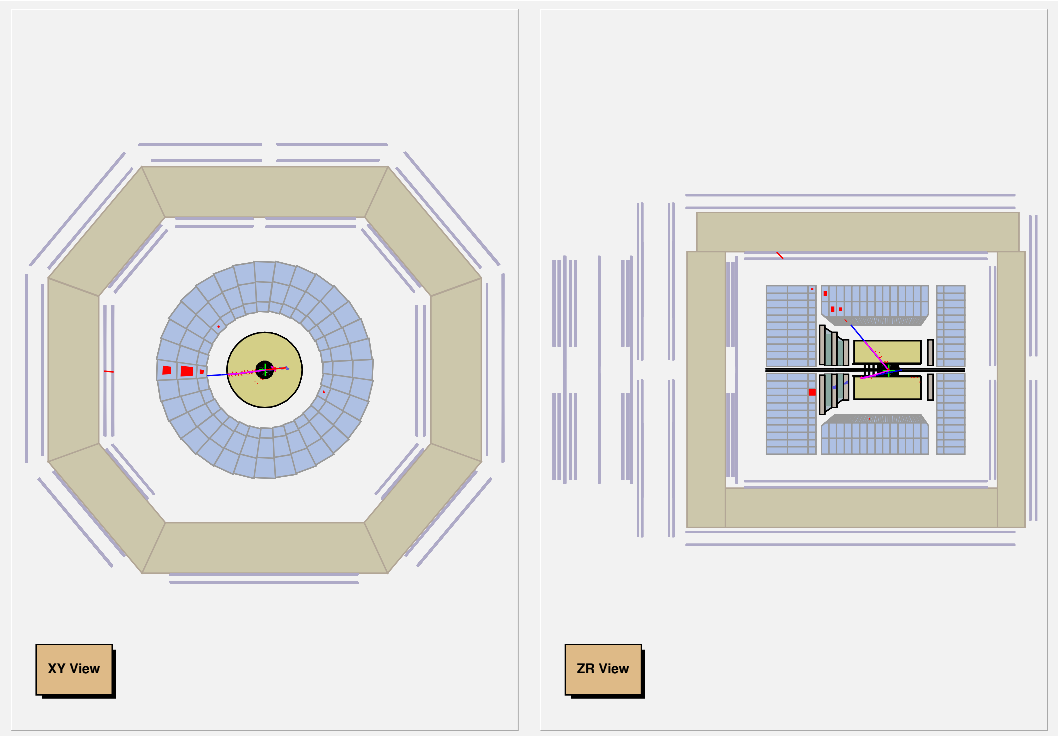

Figure 8: *Display of the third event of the three selected di-tau candidate events. The values of the e−μ invariant mass, $M_{e,\mu}$, the transverse momentum of the muon, $P_{T,\mu}$, and the the transverse momentum of the electron, $P_{T,e}$, are: $M_{e,\mu} = 5.8$ GeV, $P_{T,\mu} = 4.2$ GeV and $P_{T,e} = 1.4$ GeV, respectively.*

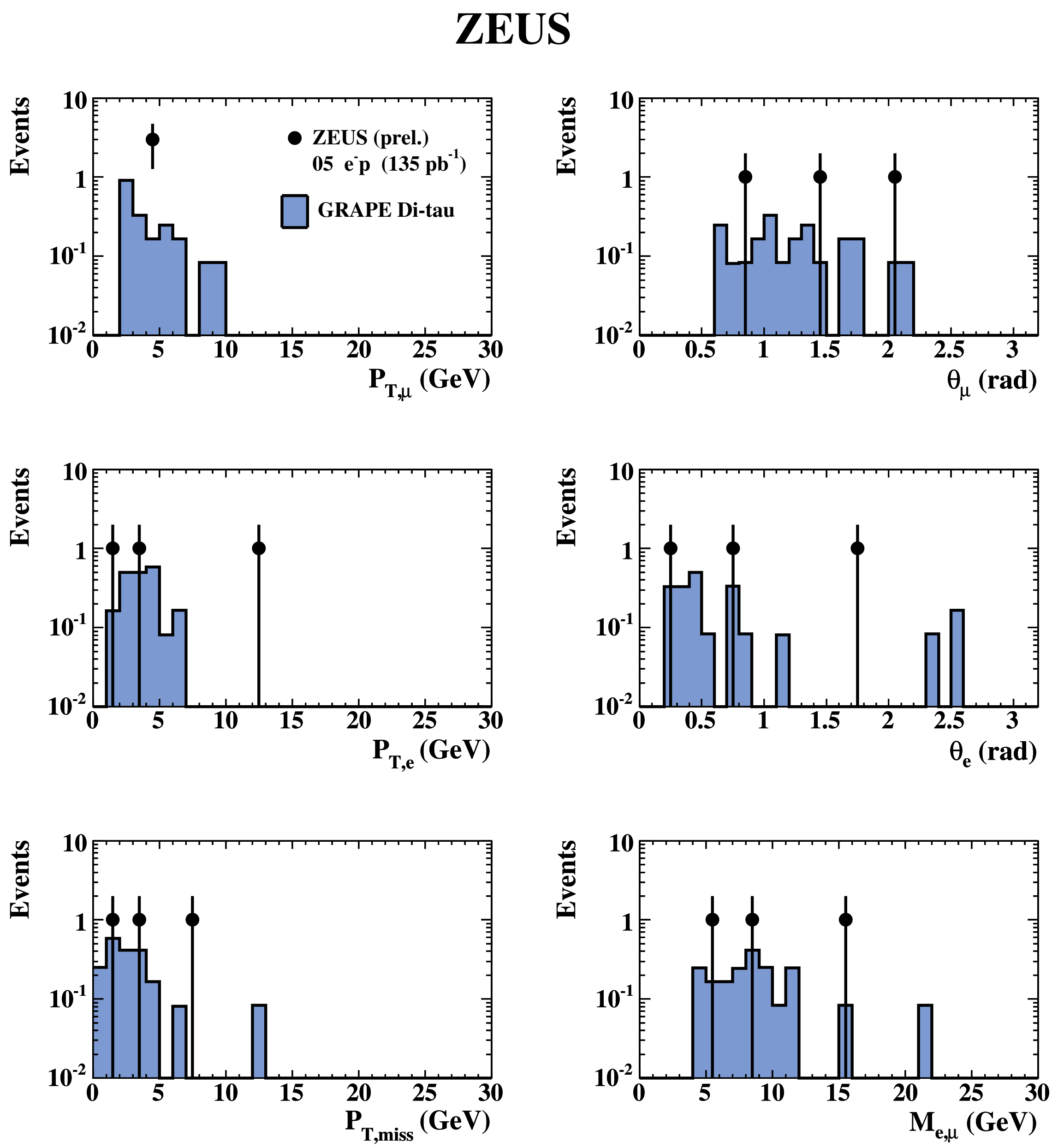

Figure 9: *Di-tau sample: Comparison of the measured distribution of polar angle and transverse momentum of the final state electron and muon (dots) with the SM expectactions (shaded histograms). Also shown are the comparisons for the missing* P_T *and the* $e - \mu$ *invariant mass.*