DØnote 4537-Conf

Search for the Associated Production of Chargino and Neutralino in Final States with Two Electrons and an Additional Lepton

The DØ Collaboration

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A search has been performed for the trilepton decay signature from the associated production of the lightest chargino and the next-to-lightest neutralino in leptonic channels with two electrons within the context of minimal Supersymmetry. The search uses data taken with the DØ detector at the Fermilab Tevatron $p\bar{p}$ collider at a center-of-mass energy of 1.96 TeV corresponding to an integrated luminosity of 249±16 pb^{-1}. We find one candidate event passing our optimized cuts, with the expected background of 0.7 ± 0.5 events. This result provides input to a combined trilepton analysis, which constrains associated production of charginos and neutralinos beyond existing limits.

Preliminary Results for Summer 2004 Conferences

I. INTRODUCTION

Supersymmetry (SUSY [1]) postulates a symmetry between bosonic and fermionic degrees of freedom and predicts the existence of a supersymmetric partner for each standard model particle. The present analysis searches for the associated production of the charged and neutral partners of the electroweak gauge and Higgs bosons (charginos and neutralinos) in final states with two electrons, a third lepton and large missing transverse energy. The analysis is based on the Minimal Supersymmetric extension of the Standard Model (MSSM) with R-parity conservation [1]. The model predicts the associated production of the lightest chargino ($\tilde{\chi}_1^{\pm}$) and the next-to-lightest neutralino ($\tilde{\chi}_2^0$) at $\mathrm{p\bar{p}}$ colliders with subsequent decays into fermions and the LSP (the lightest supersymmetric particle, $\tilde{\chi}_1^0$) [2]. This note describes the search for purely leptonic decay modes using a selection of final states with two electrons and a third track, optimized for the process $\mathrm{p\bar{p}} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow \ell \mathrm{ee}\nu\tilde{\chi}_1^0\tilde{\chi}_1^0$. As a guideline, the results are interpreted in the more specific minimal supergravity model (mSUGRA) with chargino and neutralino masses mainly following the relation $m_{\tilde{\chi}_1^{\pm}} \approx m_{\tilde{\chi}_2^0} \approx 2m_{\tilde{\chi}_1^0}$. The points in mSUGRA parameter space considered here are characterized by slepton masses close to the chargino/neutralino masses, which lead to an enhanced leptonic branching fraction. The chargino/neutralino decay mode depends on the mass relation to the scalar partners of the charged leptons (sleptons). The present note focusses on 3-body decays via off-shell gauge bosons and sleptons (see Fig. 1), which are enhanced with respect to the cascade decay via sleptons for slepton masses comparable or larger than the chargino/neutralino masses.

Searches for supersymmetric particles have been performed in $\mathrm{e^+e^-}$ collisions at LEP [3] and in $\mathrm{p\bar{p}}$ collisions at DØ [4] and CDF [5]. No evidence for these particles has been found so far. LSP masses below 40 GeV are excluded in MSSM models with GUT relations by the LEP experiments. In mSUGRA, the LSP lower mass limit is found at 50-60 GeV [3]. For large slepton/sneutrino masses, chargino masses are excluded nearly up to the kinematic production threshold of 103 GeV at LEP [3] by direct searches. Higgs searches at LEP yield indirect sensivity also for the mass region beyond the chargino production threshold.

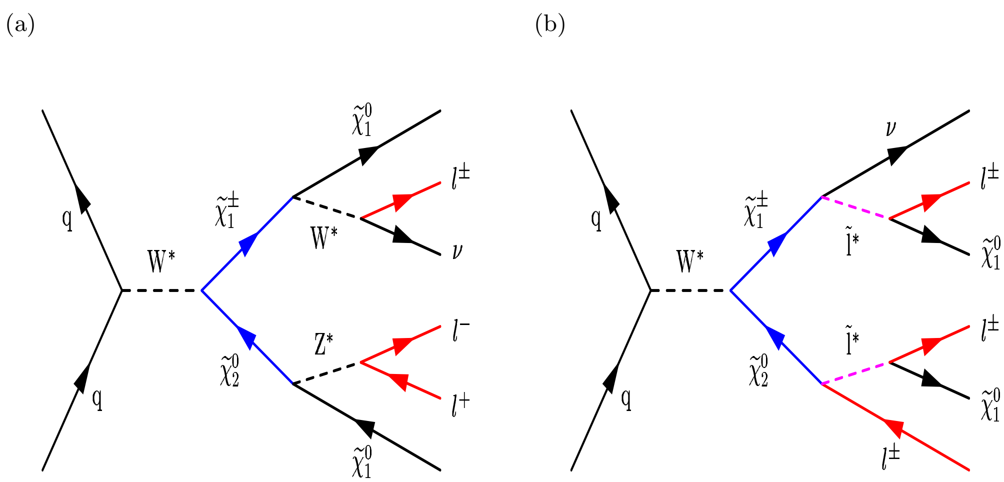

FIG. 1: Production and decay modes for the signal points considered in the present analysis.

II. DATA AND MC SAMPLES

The analysis is based on data collected from April 2002 to April 2004 by the DØ detector at the Fermilab Tevatron $\mathrm{p\bar{p}}$ collider at a center-of-mass energy of 1.96 TeV and corresponds to an integrated luminosity of 249±16 $\mathrm{pb^{-1}}$. All simulated signal and standard model processes are generated using PYTHIA 6.202 [6] and processed through the full detector simulation. Signal parameter combinations have been generated for $\tan\beta = 3$ and chargino masses in the range of 95-130 GeV. The total cross section $\sigma \times \mathrm{BF}(\mathrm{p\bar{p}} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow 3\ell)$ varies between 0.5 and 0.1 pb. A detailed description of the generated reference points is given in Table I. Major background sources are $\mathrm{Z}\gamma \rightarrow \mathrm{ee}$, $\mathrm{W} + \gamma \rightarrow \mathrm{e}\nu + \gamma$, and $\mathrm{WW} \rightarrow \mathrm{ee}\nu\nu$. Multijet background from QCD production is determined directly from data.

III. EVENT SELECTION

The selection starts with two tight electrons. The presence of a third charged lepton (electron, muon or tau lepton) is used by selecting an isolated high-quality track. The LSP and the neutrinos typically cause a considerable amount of missing energy in the event, which is used to discriminate the signal from the dijet and $Z\gamma$ background. The selection procedure is summarized briefly in Table II. It will be justified and described in more detail in the following.

The selection requires two electrons with $p_T > 8, 12$ GeV, passing energy isolation, high electromagnetic energy fraction, and loose shower shape cuts. They are required to match in η and ϕ with a reconstructed track of $p_T > 1$ GeV. An electron likelihood based on tracking and calorimeter quantities is used to further enhance the purity of the electron sample. Both electrons must stem from the primary vertex and be reconstructed in detector $|\eta| < 3.0$ with at least one electron in the central region (detector $|\eta| < 1.1$). To reduce the background from photon conversions, at least one hit in the inner SMT is required for the next-to-leading electron. This requirement is replaced by a tightened likelihood cut for events with a vertex outside the SMT acceptance.

Figure 2a shows the distribution in data, background and signal of the invariant dielectron mass at this stage of the selection. Most of the $Z \to ee$ events are rejected by requiring the invariant dielectron mass to be in the range $15\,\mathrm{GeV} < M < 60\,\mathrm{GeV}$. The large fraction of remaining back-to-back $Z\gamma \to ee$ is reduced by requiring $\Delta\phi_{e,e} < 2.9$.

In events with jets, the scaled $\not\!\!E_T$, an estimate of the impact of fluctuations of the jet energy deposition on the $\not\!\!E_T$, is defined as:

$$\textit{scaled}\ \not\!\!E_T = \frac{\not\!\!E_T}{\sqrt{\sum\left(\sqrt{E_{jet}} \times \sin(\theta\ (jet)) \times |\cos(\Delta\phi(jet, \not\!\!E_T))|\right)^2}}. \quad (1)$$

Figure 2b shows the distribution in data, background and signal of the scaled $\not\!\!E_T$ before the application of the cut. Events with a scaled $\not\!\!E_T$ lower than 8 $\sqrt{\mathrm{GeV}}$ are discarded. The $t\bar{t}$ contribution is reduced by requiring the E_T of the leading jet to be lower than 80 GeV.

Figure 2c shows the distribution in data background and signal of the $\not\!\!E_T$ at this stage of the selection. Events with $\not\!\!E_T < 20\,\mathrm{GeV}$ are discarded. In order to reduce background with large $\not\!\!E_T$ due to a poorly measured electron energy events with an electron-$\not\!\!E_T$ transverse mass below 15 GeV are discarded. A slight excess in the data with regard to the background expectation is observed at this stage of the analysis, which is compatible with the statistical and systematical background uncertainty.

The remaining background, consisting mostly of $Z\gamma \to ee$, $W \to e\nu$, and WW events, is significantly reduced by requiring an additional isolated track, well-separated from the two electron candidates ($\Delta R > 0.4$), stemming also from the primary vertex and with $|\eta| < 2.6$. Track isolation is achieved by requiring the p_T sum of further reconstructed tracks within a 0.1-0.4 hollow cone around the track to be $p_T < 1\,\mathrm{GeV}$. The isolation cone is choosen to be also efficient for tracks from τ decays. Further quality cuts require a track DCA < 0.03 cm, no SMT-only tracks, at least 14 CFT hits for CFT-only tracks and at least 17 Hits otherwise. Figure 2d shows the distribution in data, background and signal of the p_T of the leading quality track at this stage of the selection. At least one track with $p_T > 3$ GeV is required for the slection.

Remaining $Z\gamma \to ee$ events are expected to have both low values of $\not\!\!E_T$ and p_T(track). Figure 3 shows the distribution in $\not\!\!E_T \times p_T$(track) for data, background and signal after applying the jet related cuts and after requiring a third track with $p_T > 3$ GeV.

Finally, we require the product of $\not\!\!E_T$ and p_T(track) to be larger than 250 $(\mathrm{GeV})^2$.

TABLE I: Properties of SUSY reference points; All points have $\tan\beta$=3, $\mu > 0$ and $A_0 = 0$.

Pt	m_0 [GeV]	$m_{1/2}$ [GeV]	$m_{\tilde{\chi}^0_2}$ [GeV]	$m_{\tilde{\chi}^\pm}$ [GeV]	$m_{\tilde{\ell}_R}$ [GeV]	$m_{\tilde{\tau}1}$ [GeV]	$m_{\tilde{\chi}^0_1}$ [GeV]	$\sigma\times$ BF [pb]	# evts
1	68	160	98	93	98	97	52	0.47 pb	11600
2	72	165	102	97	102	101	57	0.39 pb	17500
3	76	170	106	101	106	105	59	0.32 pb	25700
4	80	175	110	105	110	109	62	0.27 pb	23900
5	84	180	114	110	114	113	64	0.21 pb	25400
6	88	185	118	114	118	117	67	0.18 pb	22000
7	106	205	135	132	136	135	72	0.07 pb	17500

TABLE II: summary of the event selection

(1) Preselection	p_T > 8 GeV, 12 GeV spatial track match electron shower shape large electron likelihood electrons from primary vertex at least one electron in the central calorimeter at least 1 Hit in the inner SMT for | z0 |< 35cm likelihood tightened for | z0 |> 35cm
(2) Anti Z → ee	15 GeV < inv. mass < 60 GeV $\Delta\phi$(el) < 2.9
(3) Anti-Jet Cuts	anti $t\bar{t}$: no jet with $E_T > 80$ GeV scaled $\not{E}_T > 8.0\sqrt{\text{GeV}}$
(4) Anti-DrellYan	transverse mass (e+$\not{E}_T$) > 15 GeV $\not{E}_T > 20$ GeV
(5) Track	$p_T > 3.0$ GeV
(6) $\not{E}_T$ and track	$\not{E}_T \times p_T$ (track) > 250GeV^2

TABLE III: Number of candidate events observed and background events expected at different stages of the selection

Cut	Data	Sum BG	Zγ →ee	W→eν	Z→ $\tau\tau$	WW/WZ	fakes
1 Presel	23035	21540±79±513	19737±77	21.31±2.11	159±6	23.23±0.77	1471±38
2 Anti-Z	2182	2149±32±51	1440±21	14.54±1.75	37.6±2.8	5.47±0.75	648±25
3 Anti-Jet	1515	1506±27±36	1117±18	12.88±1.64	19.7±2.0	4.64±0.33	451±21
4 Anti-DY	33	20.86±2.18±6.4	5.96±1.20	9.99±1.45	0.39±0.29	3.93±0.31	3.11±1.76
5 Track	7	2.45±1.26±1.04	0.81±0.44	1.31±0.52	0.00±0.21	0.28±0.08	0.00±0.4
6 Tr×$\not{E}_T$	1	0.68±0.38±0.28	0.25±0.25	0.24±0.22	0.00±0.00	0.14±0.06	0.00±0.00

IV. RESULTS

Numbers of candidate events observed and of background events expected after application of the successive selections are listed in Table III. Selected data and background events are in agreement. One candidate is selected. The background expectation is expectation is $0.7 \pm 0.4 \pm 0.3$ events mostly Zγ → ee, W → eν and WW → eνeν. The error on the background expectation is dominated by the limited Zγ → ee and W → eν statistics. The numbers of events expected for the SUSY samples are shown in Table IV. They are in the range of 0.7-2.3 events in the final selection. The resulting limit on the cross section × leptonic branching fraction is also shown in this table. The selected candidate event is displayed in Figure 4. It consists of two same sign high-quality electrons and a third track with transverse momentum of 9 GeV. The properties of the event are summarized in Table V.

Systematic uncertainties stem from various sources. A large contribution comes from the 6.5% error on the integrated luminosity. Further systematic uncertainties are related to the jet calibration (1-2 % of the signal estimate and 10-15% of the background estimate) and the MC jet smearing (2% of the signal estimate and up to 10% of the background estimate). The smearing of electrons and $\not{E}_T$ contribute with 1% and 3%. In addition various MC efficiency corrections contribute to the systematic error, mainly corrections on the track match efficiency (1.5 %) and the trigger simulation (1.5 %). This results in a systematic error for the background estimate of 41% in the final selection. The systematic error on the signal expectation adds up to 3-10%.

V. CONCLUSIONS

A search has been performed for the trilepton decay signature from the associated production of the lightest chargino and the next-to-lightest neutralino in leptonic channels with two electrons, using data corresponding to an integrated luminosity of 249±16 pb^{-1}. The analysis is nearly but not yet sensitive for mSUGRA points in the mass range beyond the LEP chargino limits, but can gain sensitivity from the addition of the e+μ and the μ+μ topologies.

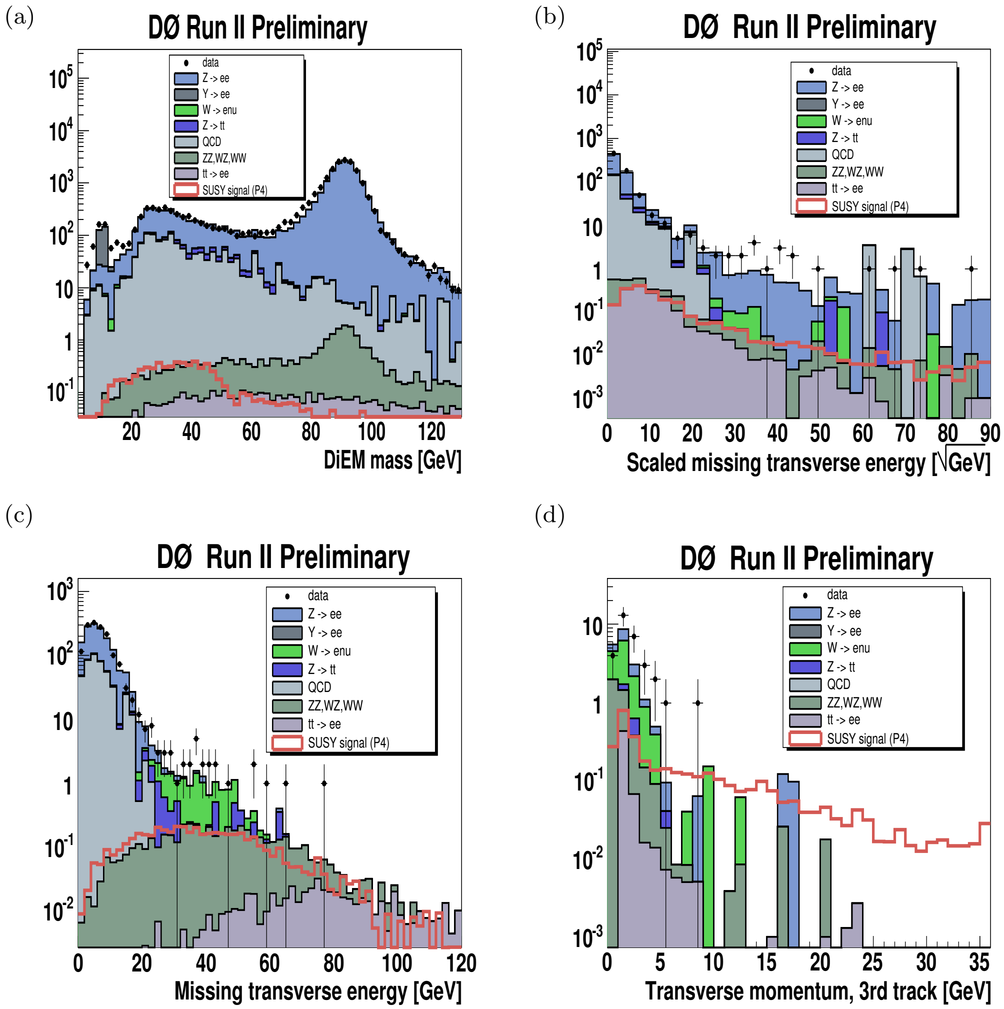

FIG. 2: Distribution of (a) the invariant dielectron mass at the preselection level (b) the scaled missing transverse energy for the low invariant mass selection (c) the missing transverse energy after the jet related cuts and (d) the track transverse momentum after the cut on $\not\!\!E_T$ and the transverse mass for data (points with error bars), background simulation (histograms, complemented with the QCD expectation) and signal expectation for point 3 (empty histogram).

Acknowledgments

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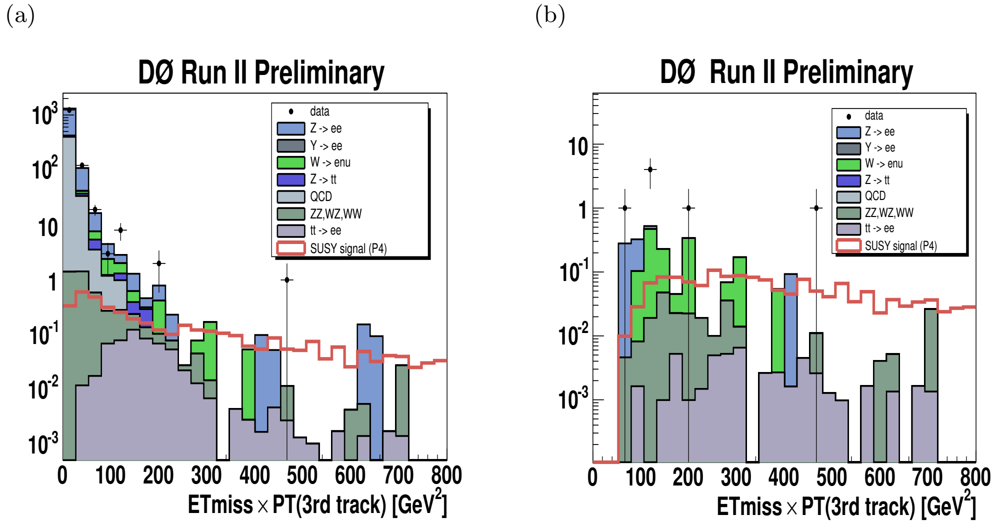

FIG. 3: Distribution of the product of track momentum and $\not\!\!E_T$ (a) after applying the jet related cuts and (b) before applying the final cut for data (points with error bars), background simulation (histograms, complemented with the QCD expectation) and signal expectation for point 3 (empty histogram).

TABLE IV: Number of signal events expected at different stages of the selection. For the final cut, also the signal efficiency is presented.

Cut	Point 1	Point 2	Point 3	Point 4
(1) Presel	10.58± 0.33	9.32± 0.23	7.78±0.16	6.85±0.14
(2) Anti-Z	9.23± 0.31	8.03± 0.21	6.67±0.14	5.72±0.13
(3) Anti-Jet	7.90± 0.28	6.86± 0.20	5.66±0.13	4.91±0.12
(4) Anti-DY	6.16± 0.25	5.33± 0.17	4.46±0.12	3.87±0.10
(5) Track	3.27± 0.18	2.89± 0.13	2.38±0.09	2.09±0.08
(6) Tr×$\not\!\!E_T$	2.33±0.15±0.11	2.21±0.11±0.09	1.83±0.08±0.08	1.65±0.07±0.09
(6) efficiency (3ℓ) [%]	2.00±0.13	2.28±0.11	2.29±0.09	2.46±0.10
limit on $\sigma \times$ BF(3ℓ) [pb]	0.72(0.82)	0.62(0.73)	0.59(0.70)	0.58(0.63)

Cut	Point 5	Point 6	Point 7
(1) Presel	5.52±0.11	5.25±0.11	2.30±0.05
(2) Anti-Z	4.63±0.10	4.32±0.10	1.91±0.04
(3) Anti-Jet	4.04±0.09	3.80±0.09	1.66±0.04
(4) Anti-DY	3.27±0.08	3.14±0.08	1.49±0.04
(5) Track	1.80±0.06	1.72±0.06	0.82±0.03
(6) Tr×$\not\!\!E_T$	1.43±0.05±0.09	1.39±0.06±0.08	0.70±0.03±0.02
(6) efficiency (3ℓ) [%]	2.74±0.10	3.10±0.12	3.80±0.15
limit on $\sigma \times$ BF(3ℓ) [pb]	0.53(0.62)	0.45(0.49)	0.39(0.43)

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TABLE V: Properties of the selected candidate event

	E_T[GeV]	η	detector η	ϕ
leading electron	33.2	-0.97	-0.77	3.37
next-to-leading electron	25.7	-2.19	-2.05	2.97
track	8.6	0.67		5.87
$\not\!\!E_T$	52.1			0.12

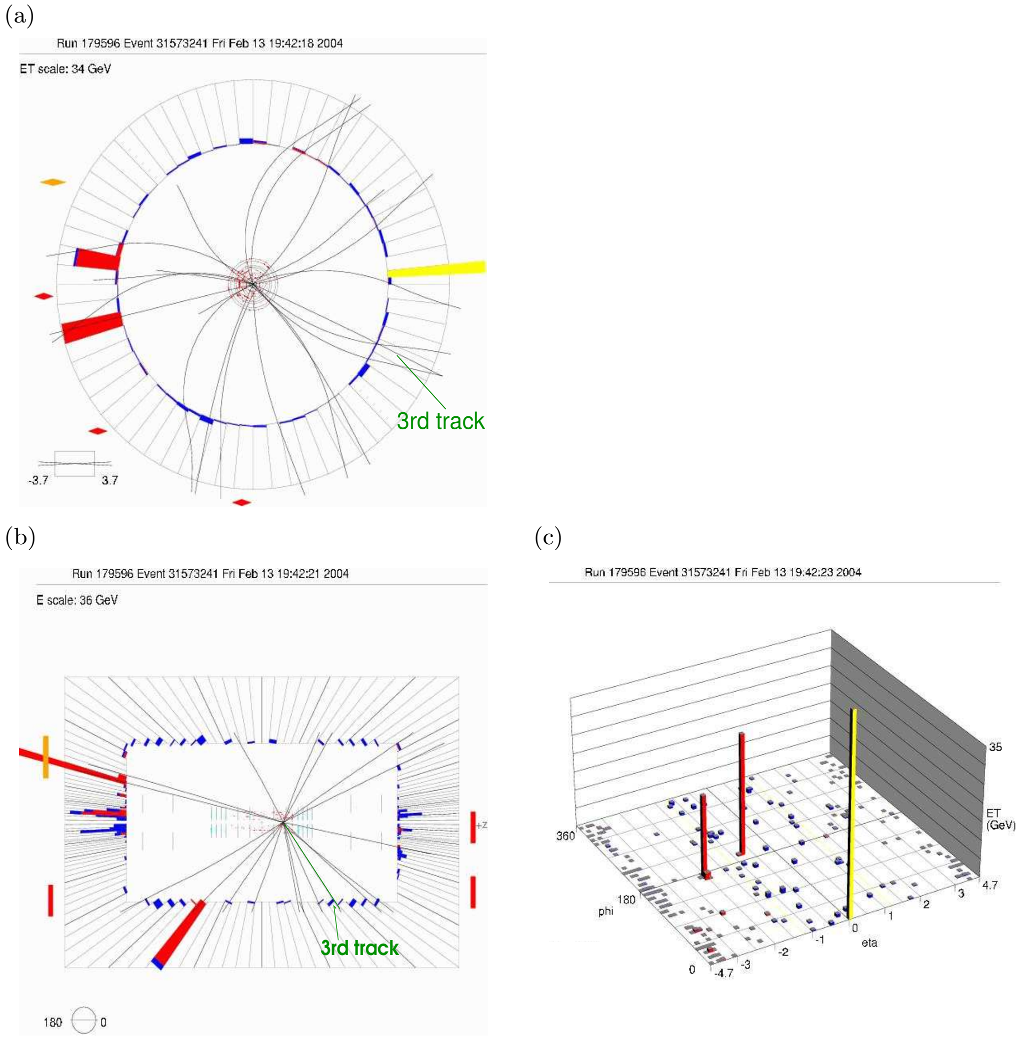

FIG. 4: (a) XY view, (b) RZ view and (c) Lego plot of the event surviving the selection cuts.