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Search for single top production in e^+e^- collisions at $\sqrt{s}$ up to 209 GeV

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Abstract

Single top production via the flavour changing neutral current reactions $e^+e^- \to \bar{t}c, \bar{t}u$ is searched for within the 214 pb^{-1} of data collected by ALEPH at centre-of-mass energies between 204 and 209 GeV. No deviation from the Standard Model expectation is observed and upper limits on the single top production cross sections are derived. The combination with data collected at lower centre-of-mass energies yields an upper limit on the branching ratio $BR(t \to Zc) + BR(t \to Zu) < 14\%$, for $BR(t \to \gamma c) + BR(t \to \gamma u) = 0$ and $m_t = 174\ GeV/c^2$.

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1. Introduction

Because of the large mass of the top quark [1], at LEP2 only single top production is possible. This could occur via flavour changing neutral currents (FCNC) in the reactions[33]

$$e^+e^- \to \bar{t}c, \bar{t}u.$$

In the Standard Model (SM) such a process is forbidden at tree level and can only proceed via loops with cross sections $\lesssim 10^{-9}$ fb [2]. Extensions of the Standard Model could lead to enhancements of FCNC single top production and to measurable effects as proposed, for example, in Refs. [3–7]. It is customary to parametrise the FCNC transitions in terms of anomalous vertices whose strengths are described by the parameters k_Z and k_γ for Z and γ exchange, respectively, using the formalism of Ref. [7].

The results of searches for single top production are presented in this Letter with the data collected by the ALEPH detector at LEP at centre-of-mass energies ranging from 204 to 209 GeV, corresponding to an integrated luminosity of 214 pb^{-1}. Previous ALEPH results obtained with lower energy data are given in Ref. [8]. The centre-of-mass energies and the integrated luminosities of the analysed data sample are listed in Table 1.

The Letter is organised as follows. The ALEPH detector is briefly reviewed in Section 2 together with the simulation samples used for the analysis. Section 3 is dedicated to the selection algorithm. In Section 4 the results of the searches are given, along with their interpretation within the theoretical framework of Ref. [7]. The conclusions of the Letter are given in Section 5.

2. ALEPH detector and the simulation samples

A thorough description of the ALEPH detector is presented in Ref. [9], and an account of its performance can be found in Ref. [10]. Only a brief overview is given here.

The tracking system consists of a silicon vertex detector (VDET), a drift chamber (ITC) and a large time projection chamber (TPC), immersed in a 1.5 T magnetic field produced by a superconducting solenoid. The VDET consists of two concentric layers of double-sided silicon microstrip detectors positioned at average radii of 6.5 cm and 11.3 cm, covering 85% and 69% of the solid angle, respectively. It is surrounded by the ITC, a multilayer axial-wire cylindrical drift chamber. The TPC provides up to 21 three-dimensional space coordinates and 338 samples of ionization loss for tracks at radii between 30 and 180 cm. Altogether, a transverse momentum resolution of $\sigma(1/p_t) = 0.6 \times 10^{-3} \oplus 0.005/p_t$ (p_t in GeV/c) is achieved.

The electromagnetic calorimeter (ECAL), a lead/proportional-wire-chamber sampling device of 22 radiation lengths, surrounds the TPC and is contained inside the superconducting coil. The energy resolution is $\sigma(E)/E = 0.18/\sqrt{E} + 0.009$ (E in GeV).

The magnetic field return yoke is a large iron structure fully instrumented to form a hadron calorimeter (HCAL), and also serves as a muon filter. The HCAL consists of 23 layers of streamer tubes for a total of 7.2 interaction lengths. The relative energy resolution is $\sigma(E)/E = 0.85/\sqrt{E}$ (E in GeV). It is surrounded by two double layers of streamer tubes to improve the muon identification.

The luminosity monitors (LCAL and SICAL) extend the calorimetric coverage down to polar angles of 34 mrad.

The measurement from the tracking detectors and calorimeters are combined into "objects", classified as electrons, muons, photons, and charged and neutral hadrons, by means of the energy flow algorithm described in [10].

The signal samples were simulated using the generator described in Ref. [8]. A sample of 2000 events was produced for each of the two final states $\bar{t}c$ and $\bar{t}u$ at $\sqrt{s}$ of 204, 206 and 209 GeV and for three values of the top mass (169, 174 and 179 GeV/c^2).

The relevant SM background processes were simulated as follows. The generators PYTHIA [11] and KORALZ [12] were both used for the $q\bar{q}$ simulation. The KORALW [13] generator was used to produce WW events, while the simulation of Weν and ZZ events was based on PYTHIA. The size of the simulated samples typically corresponds to ten times the integrated luminosity of the data. All background and

[33] Throughout this Letter, the notation $\bar{t}q$ is used for both $\bar{t}q$ and $\bar{q}t$ ($q = c, u$).

Table 1

Performance and results of the analysis. At each centre-of-mass energy the numbers of expected background events (N^{bkg}), of observed candidates (N^{obs}), the signal efficiency ε computed with respect to all W decays, and the expected and measured 95% CL upper limits on the single top production cross section ($\sigma_{95}^{\mathrm{exp}}$ and $\sigma_{95}^{\mathrm{meas}}$) are reported for both the leptonic and hadronic W decays. Systematic uncertainties are not included in these cross section upper limits. In the last row the measured 95% CL upper limits on the single top production cross section ($\sigma_{95}^{\mathrm{comb}}$), obtained by combining the leptonic and hadronic channels and including the systematic uncertainties on background and on the signal efficiencies are given

$\langle\sqrt{s}\rangle$ (GeV)	203.8		205.0		206.3		206.6		208.0	
$\mathcal{L}$ (pb^{-1})	8.3		71.6		65.6		61.0		7.3	
	lept.	hadr.	lept.	hadr.	lept.	hadr.	lept.	hadr.	lept.	hadr.
$N_{\mathrm{WW}}^{\mathrm{bkg}}$	0.1	0.4	0.6	3.4	0.6	3.1	0.5	2.9	0.1	0.4
$N_{\mathrm{4f}}^{\mathrm{bkg}}$	< 0.01	0.1	0.1	0.7	0.03	0.7	0.05	0.6	< 0.01	0.1
$N_{\mathrm{qq}}^{\mathrm{bkg}}$	< 0.01	0.2	< 0.01	1.9	< 0.01	1.7	< 0.01	1.6	< 0.01	0.2
$N_{\mathrm{tot}}^{\mathrm{bkg}}$	0.1	0.7	0.7	6.0	0.63	5.5	0.55	5.1	0.1	0.7
N^{obs}	0	1	2	6	0	7	0	7	0	1
ε (%)	3.4	13.8	3.3	13.7	3.3	13.7	3.2	13.5	3.3	13.2
$\sigma_{95}^{\mathrm{exp}}$ (pb)	11.2	3.4	1.65	0.71	1.77	0.75	1.91	0.80	13.3	4.10
$\sigma_{95}^{\mathrm{meas}}$ (pb)	10.6	3.7	2.38	0.69	1.38	0.89	1.53	1.01	12.6	4.47
$\sigma_{95}^{\mathrm{comb}}$ (pb)	2.94		0.68		0.68		0.78		4.32	

signal samples were processed through the full detector simulation.

3. Analysis

The processes $e^+e^- \to \bar{t}c, \bar{t}u(\bar{t} \to \bar{b}W^-)$ are characterised by a multijet final state with one b jet. The event properties depend significantly on the W decay mode. Two separate analyses have been designed for the leptonic and the hadronic decays of the W. The selections follow closely those described in Ref. [8]. The minor changes in the hadronic selection arise from a re-optimization of the selection criteria according to the $\overline{N}_{95}$ prescription [14], to take into account the increase in the centre-of-mass energy and of the background level:

- The lower cut on the b-jet energy was loosened to $E(\mathrm{b\ jet}) > 50$ GeV.
- The lower cut on the W boost was loosened to $P_{\mathrm{qq}}/E_{\mathrm{qq}} > 0.5$.
- The lower cut on the b-tag variable for the most b-like jet cut has been tightened to $(\mathrm{b\ tag}) > 6.4$.

There were no changes in the leptonic selection. The distributions of the b-jet energy and of the b-tag variable are shown in Fig. 1.

The signal selection efficiencies and the expected backgrounds at the various centre-of-mass energies are reported in Table 1. The efficiencies are given for a top mass of 174 GeV$/c^2$ and $\mathrm{BR}(t \to bW) = 1$.

The main sources of systematic uncertainties on the expected background and the signal efficiencies have been assessed as in Ref. [8]. In order to increase the statistical precision, the data collected by ALEPH at lower centre-of-mass energies in the years 1998 and 1999 [8] have been included in these systematic checks, except for the one on the b-tag variable which can vary from year to year. The results of these systematic studies are reported in Table 2.

4. Results

The number of candidate events are given in Table 1 for the various centre-of-mass energies. In total 24 candidates were observed in the data in agreement with 20.1 events expected from SM backgrounds. Upper limits on the signal cross section have been derived

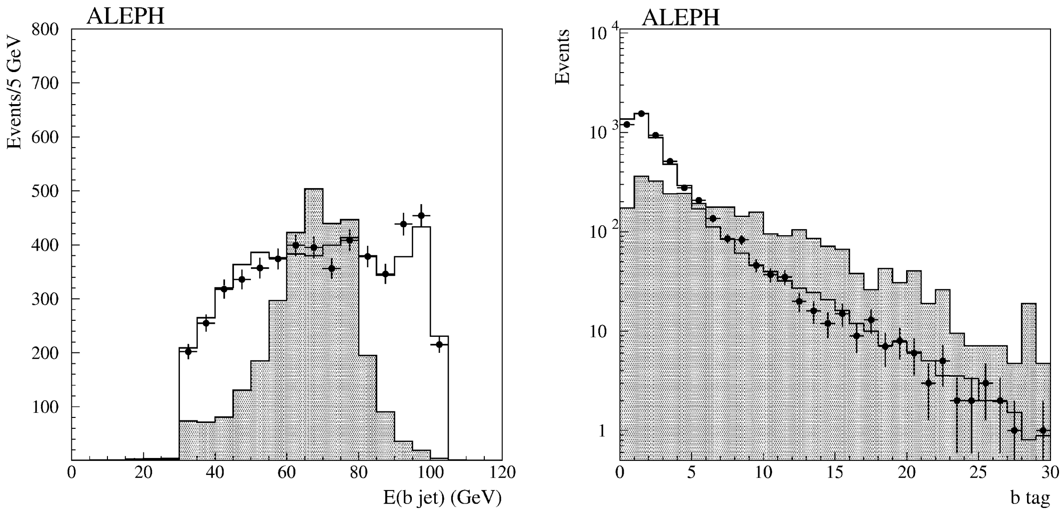

Fig. 1. Distributions for hadronic W decays for the signal (shaded histogram), the background (solid histogram) and the data (points with error bars) for $\sqrt{s}$ from 204 to 209 GeV for the b-jet energy (left) and for the b-tag variable (right).

Table 2
Relative systematic uncertainties on the background and signal efficiency for each selection variable [8], determined by applying one cut at a time in data and Monte Carlo

Leptonic W		Hadronic W	
Variable	$\frac{\varepsilon_{\text{data}}-\varepsilon_{\text{MC}}}{\varepsilon_{\text{MC}}}$ (%)	Variable	$\frac{\varepsilon_{\text{data}}-\varepsilon_{\text{MC}}}{\varepsilon_{\text{MC}}}$ (%)
Lepton ID	3.8 ± 2.9	$P_{\text{qqqq}}/E_{\text{qq}}$	1.4 ± 1.5
m_{qq}	1.0 ± 3.4	m_{qq}	-1.1 ± 1.5
E (b jet)$_{\text{tcm}}$	0.5 ± 1.1	E (b jet)	0.1 ± 0.9
$m_{\ell\nu}$	1.9 ± 2.1	Thrust	0.1 ± 0.7
m_{t}	-0.8 ± 1.4	E_{tot}	-0.1 ± 0.4
Highest jet b tag	5.1 ± 4.7	Highest jet b tag	1.3 ± 4.0

at 95% CL for the different channels and centre-of-mass energies (Table 1).

The negative result of these searches are translated into limits on the top quark couplings k_{Z} and k_γ [7]. The data collected by ALEPH at lower centre-of-mass energies in 1998 and 1999 [8] are also included to derive the exclusion region in the (k_{Z}, k_γ) plane and in the $[\text{BR}(\text{t} \to \text{Zc/u}), \text{BR}(\text{t} \to \gamma\text{c/u})]$ plane. The likelihood ratio method [15] has been used in the computation of the excluded regions. The signal selection efficiency and the background expectation were conservatively reduced by their systematic uncertainties.

The region of the (k_{Z}, k_γ) plane excluded at 95% CL is shown in Fig. 2. The excluded region in the $[\text{BR}(\text{t} \to \text{Zc/u}), \text{BR}(\text{t} \to \gamma\text{c/u})]$ plane is shown in Fig. 3. The limits are given for different choices of the top mass. The exclusion curves include the reduction in $\text{BR}(\text{t} \to \text{bW})$, computed as a function of k_{Z} and k_γ, due to possible FCNC decays of the top. The limits obtained by CDF from a search for the decays $\text{t} \to \text{Zc}, \text{Zu}$ and $\text{t} \to \gamma\text{c}, \gamma\text{u}$ [16] are also shown.

A 95% CL upper limit of 0.42 for the anomalous coupling $|k_{\text{Z}}|$ is obtained assuming $m_{\text{t}} = 174\ \text{GeV}/c^2$ and $k_\gamma = 0$. This exclusion translates into the branching ratio limit $\text{BR}(\text{t} \to \text{Zc}) + \text{BR}(\text{t} \to \text{Zu}) < 14\%$.

5. Conclusions

Single top production via flavour changing neutral currents has been searched for in 214 pb^{-1} of data collected by ALEPH at centre-of-mass energies between 204 and 209 GeV. In total, 24 events have been selected in the data in agreement with 20.1 expected from Standard Model backgrounds. Upper limits at 95% CL on single top production cross sections at $\sqrt{s} = 204$–209 GeV have been derived.

The combination with the data collected in 1998 and 1999 yields a 95% CL upper limit on the FCNC coupling for Z exchange of $|k_{\text{Z}}| < 0.42$, for $m_{\text{t}} = 174\ \text{GeV}/c^2$ and $k_\gamma = 0$. It corresponds to a branching ratio limit of $\text{BR}(\text{t} \to \text{Zc}) + \text{BR}(\text{t} \to \text{Zu}) < 14\%$. This result updates the previous ALEPH measurements at

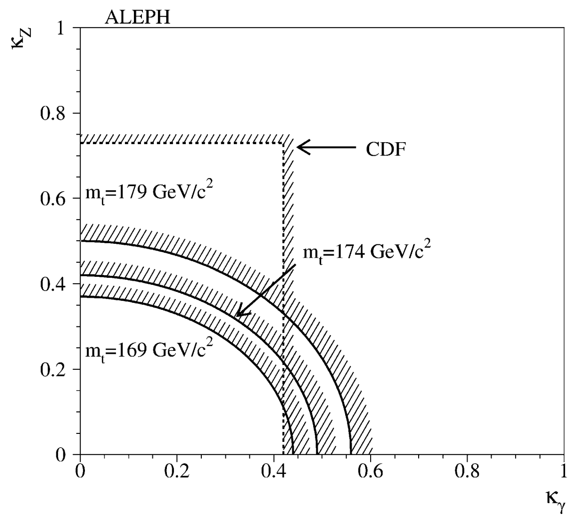

Fig. 2. Exclusion curves at 95% CL in the (k_Z, k_γ) plane for $m_t = 169, 174, 179\ \mathrm{GeV}/c^2$ (full lines). The region excluded by CDF is also shown (dotted line).

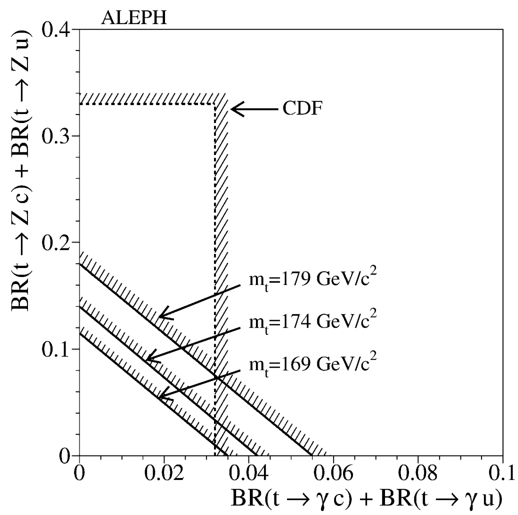

Fig. 3. Exclusion curves at 95% CL in the $[\mathrm{BR}(\mathrm{t} \to \mathrm{Zc/u}), \mathrm{BR}(\mathrm{t} \to \gamma \mathrm{c/u})]$ plane for $m_t = 169, 174, 179\ \mathrm{GeV}/c^2$ (full lines). The region excluded by CDF is also shown (dotted line).

lower centre-of-mass energies [8], and is in agreement with recent results from OPAL [17].

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