DELPHI Collaboration DELPHI 2000-032 CONF 351
March 8, 2000

Search for FCNC at $\sqrt{s} = 192 - 202$ GeV

S. Andringa, P. Gonçalves, A. Onofre,
R. Paiva, L. Peralta, M. Pimenta and B. Tomé
LIP, Lisboa, Portugal

V.Obraztsov, S.Slabospitsky and O.Yushchenko
IHEP, Protvino, Russia

Abstract

A search for Flavour Changing Neutral Currents is performed using data taken by DELPHI detector at LEP-II. The data analysed were accumulated at the centre-of-mass energies ranging from 192 to 202 GeV. A limit at 95% confidence level was obtained on the cross section of the reaction $e^+e^- \to \bar{t}c + \bar{t}u + \mathrm{CC}$.

1 Introduction

Flavour Changing Neutral Currents (FCNC) are known to be absent at tree level in the Standard Model but can naturally appear at one-loop level due to CKM mixing. The relative suppression of the loop contributions together with the smallness of the non-diagonal CKM matrix elements ensures only small contributions to FCNC from the SM [1]. On the other hand many extended models such as supersymmetry [2] and multi-Higgs doublet models [3] predict the presence of FCNC already at tree level. Some specific models [4] give rise to detectable FCNC amplitudes.

The energy of the last LEP run ($\sqrt{s} = 192 - 202$ GeV) is well above tc production threshold and gives the possibility to perform a search for FCNC in the specific process $e^+e^- \to \bar{t}q + t\bar{q}$ where q can stand either for u- or c-quark. The advantage of this specific FCNC consists in the fact that the t-quark can decay into Wb only. This can produce some distinct signatures both in leptonic and hadronic W decay modes. The numerical estimations for the expected number of events taking into account the limits on anomalous vertices recently set by the CDF collaboration [5] can be found in [6].

One can get an almost background-free signature for the decays $W \to l\nu$, while the branching ratio is relatively low. The hadronic W decays give about three times higher event rate while the background situation is less favourable.

This note is devoted to the search of FCNC processes with an intermediate t-quark and subsequent W decay into leptonic channels as well as into quarks. The data were collected with the DELPHI detector [7] at $\sqrt{s} = 192 - 202$ GeV and the statistics corresponds to the integrated luminosity of 30 pb^{-1} at 192 Gev, 77.5 pb^{-1} at 196 Gev, 84.3 pb^{-1} at 200 Gev, and 41.1 pb^{-1} at 202 Gev.

2 Semileptonic Channel

In the semileptonic channel the final state corresponding to the single top production, is characterized by having two jets and at least one well isolated lepton (from the W decay). One of the jets is energetic and the other one is of low momentum.

At the pre-selection stage the events were classified according to the number of jets and of isolated leptons and photons. Details on the pre-selection are given in reference [9]. Only small adjustments were made with respect to the previous analysis. The minimum required charged multiplicity was six and all particles (excluding the isolated charged leptons) were forced into two jets using the Durham jet algorithm [8]. The two jets were required to have at least one charged particle. No selection criteria were applied to distinguish different lepton flavours.

The following criteria were applied to the events (level 1):

- the total visible energy was required to be larger than $0.2\sqrt{s}$;
- the momentum of the most energetic jet had to be larger than 30 GeV/c;
- the momentum of the most energetic isolated charged lepton had to be greater than 5 GeV/c. The charged lepton was required to have hits on the vertex detector (VD);
- the polar angle of the missing momentum had to be between 20° and 160°.

The Figure 1 represents (at $\sqrt{s} = 202$ GeV and after the level 1 of the selection) the most energetic lepton momentum (a), the most energetic jet momentum (b) and the angle between them (c), together with the SM simulation and the expected signal behaviour. The dots show the data, the shaded region the SM simulation and the dark region the expected signal behaviour.

After this selection, more specific criteria were applied (level 2):

- The ratio between the electromagnetic energy of the most energetic jet and its total energy had to be smaller than 0.95. This removes most Bhabha events;
- the polar angle of the most energetic jet had to be between 10° and 170°;
- the polar angle of the least energetic jet (required to have charged particles) had to be between 10° and 170° and its momentum had to be lower than the centre-of-mass energy;
- events with a B hadron decay were selected by requiring the event combined b-tag variable [10] to be higher than -1.

In order to further reduce the contribution of WW and $We\nu$ background, a kinematic fit to the events was performed assuming they were compatible with a topology of two jets, one lepton and one neutrino. The overall four-momentum conservation was imposed. In Figures 2 and 3 are represented (at $\sqrt{s} = 202$ GeV) the reconstructed top mass and the mass of the two jets respectively, after the selection level 1 and with a loose χ^2 cut of 7. The dots show the data, the shaded region the SM simulation and the top right picture the expected signal behaviour.

Additional criteria (level 3) were applied in order to further reduce the contamination from background events, mostly $q\bar{q}$ and WW. These criteria were the following:

- The polar angle of the most energetic lepton had to be between 20° and 160°, and the angle between the lepton and the most energetic jet had to be lower then 170° and higher then 30°;
- the angle between the least energetic jet and the most energetic lepton had to be greater then 30° respectively;
- the angle between the two jets had to be lower then 170°;
- the value of the kinematical fit χ^2 was required to be lower then 7 and the two jet invariant mass had to be lower then 65 GeV/c^2;
- the reconstructed mass of the top quark (by taking the four-momentum of the most energetic jet, of the neutrino and the lepton) was required to be higher then 150 GeV/c^2.

In table 1 the number of events which survived the different levels of selection is shown, together with the expected SM background. The WW and $q\bar{q}$ events are the main source of background.

In the present analysis 3 events were found while the expected SM background is 5.2 ± 0.7. The detection efficiency convoluted with the W leptonic branching ratio, is $(8.\pm0.5)\%$, $(7.\pm0.5)\%$, $(5.\pm0.5)\%$ and $(5.\pm0.5)\%$ for centre-of-mass energies of 192 GeV, 196 GeV, 200 GeV, 202 GeV respectively.

$\sqrt{s}$(GeV)	selection level					
	1		2		3	
192	215	(200.5±2.9)	29	(22.1±0.9)	1	(0.6±0.2)
196	694	(600.0±8.6)	65	(66.2±2.9)	0	(1.7±0.4)
200	725	(669.3±9.6)	93	(71.9±3.2)	2	(1.9±0.5)
202	348	(324.0±4.7)	33	(34.9±1.6)	0	(0.9±0.2)

Table 1: Number of events passing the sets of cuts corresponding to the selection levels described in the text for the single top production.

3 Hadronic Channel

In this analysis the events were preselected according to the standard hadronic selections described in [11]. An additional cut was applied to suppress events with an energetic muon or electron: the events with leptons above 40 GeV identified as *standard* electrons or *loose* muons (according to the classification described in [7]) were removed.

After that the LUCLUS algorithm with $D_{join} = 6.5$ have been applied to perform the events clusterization into jets. Only events with at least 3 jets have been selected and have been forced into 4-jets topology with the same D_{join}.

The three most energetic jets have been assumed to originate from the decay $t \to bW \to bq\bar{q}$. Kinematic fits have been performed for the three possible combinations of two jets out of three that can form a W. The combination with the best χ^2 has been chosen.

As the cross-section for background process is rather high (about 100 pb) different cuts have been applied to suppress $\gamma q\bar{q}$ and WW backgrounds.

Due to the b-quark production in the studied FCNC Z/γ decays, the b-tagging algorithms provide powerful tools to suppress WW background. Two-step cuts were applied - one at the level of the whole event with the combined algorithm [10] and another one at the level of the b-jet candidate.

The suppression of $\gamma q\bar{q}$ background is also based on the observation that the initial two-quark configuration will produce after fragmentation an event with small sphericity and relatively balanced jets momenta. Figures 4 and 5 represent the distributions of the b-tagging variable and E_b/E_c the kinematic fit, at $\sqrt{s} = 196$ GeV. The solid lines show the expected background while dots represent the real data.

The full list of cuts applied was as follows (E_c stands for the energy of the softest jet in the 4-jet mode while E_b stands for the possible b-jet candidate energy):

- Standard hadronic events selection;
- Number of jets > 4;
- combined b-tag variable $> 0.$;
- $-\log$(jet b-tag probability) > 3.0;
- Sphericity > 0.2;

- $E_b/E_c > 2.5$;
- $E_{\text{vis}} > 150.$ GeV.

The signal efficiencies together with the expected and observed numbers of events for the hadronic W decay mode are summarized in table 2.

Proc.	Eff. (%)	NOE	Eff. (%)	NOE
	192 GeV		196 GeV	
WW	0.050	0.27	0.080	1.17
$\gamma q\bar{q}$	0.042	1.21	0.041	2.80
Signal	8.4		7.3	
Exp.		1.48		3.97
Obs.		1.0		4.0
	200 GeV		202 GeV	
WW	0.080	1.29	0.090	0.68
$\gamma q\bar{q}$	0.05	3.68	0.05	1.80
Signal	7.9		8.1	
Exp.		4.97		2.48
Obs.		2.0		5.0

Table 2: Number of events passing the selections

4 Conclusion

The combination of the data collected at the energies 192-202 GeV both in semileptonic and hadronic channels results in the upper limit on the cross-section for the process $e^+e^- \to Z/\gamma \to tq$ to be < 0.32 pb (95% CL) at the mean energy of 199 GeV. This number gives a straightforward input to set a limit on the branching ratio $t \to Zc(u)$ following the formulae in [6]. As the cross-section of the FCNC process strongly depends on the t-quark mass this limit should be considered as a function of this mass contrary to the CDF result [5] where this process was searched for in the direct decay channel.

The Figure 6 represents the preliminary DELPHI result on the branching ratio $t \to Zc(u)$.

Acknowledgements

We would like to thank D. Atwood, L. Reina and A. Soni for the discussions relative to the two Higgs doublet model.
We are greatly indebted to the members of the CERN-SL Division for the excellent performance of the LEP collider.
We are also grateful to the technical and engineering staffs in our laboratories and we acknowledge the support of
Austrian Federal Ministry of Science, Research and Arts,
FNRS–FWO, Belgium,
FINEP, CNPq, CAPES, FUJB and FAPERJ, Brazil,
Czech Ministry of Industry and Trade, GA CR 202/96/0450 and GA AVCR A1010521,
Danish Natural Research Council,
Commission of the European Communities (DG XII),
Direction des Sciences de la Matière, CEA, France,
Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Germany,
General Secretariat for Research and Technology, Greece,
National Science Foundation (NWO) and Foundation for Research on Matter (FOM), The Netherlands,
Norwegian Research Council,
State Committee for Scientific Research, Poland, 2P03B00108, 2P03B03311 and 628/E–78–SPUB–P03–023/97,
JNICT–Junta Nacional de Investigação Científica e Tecnológica, Portugal,
Vedecka grantova agentura MS SR, Slovakia, Nr. 95/5195/134,
Ministry of Science and Technology of the Republic of Slovenia,
CICYT, Spain, AEN96–1661 and AEN96-1681,
The Swedish Natural Science Research Council,
Particle Physics and Astronomy Research Council, UK,
Department of Energy, USA, DE–FG02–94ER40817.

References

[1] Grzadkowski B, Gunion J.F., and Krawcyk P., *Phys. Lett.* **B268** (1991) 106;
Eilam G, Hewett J.L, and Soni A., *Phys. Rev.* **D44** (1991) 1473;
Luke M. and Savage M.J., *Phys Lett.* **B307** (1993) 387.

[2] G.M.Divitiis, R.Petronzio, and L.Silvestrini, hep-ph/9704244 (1997).

[3] D.Atwood, L.Reina, and A.Soni, SLAC-PUB-95-6927 (1995).

[4] Arbuzov B.A. and Osipov M.Yu., hep-ph/9802392 (1998).

[5] CDF Coll., Abe F. et al., FERMILAB-Pub-97/270-E, 1997.

[6] Obraztsov V.F., Slabospitsky S.R. and Yushchenko O.P., *Phys. Lett.* **B426** (1998), 393.

[7] DELPHI coll., P. Aarnio et al., Nucl. Instr. Meth. **A303** (1991) 233;
DELPHI Coll., P. Abreu et al., Nucl. Instr. Meth. **A378** (1996) 57.

[8] S. Catani et al., Phys. Lett. **B269** (1991) 432.

[9] DELPHI Coll., P. Abreu et al., Phys. Lett. **B393** (1997) 245.

[10] G. Borisov, C. Mariotti, DELPHI 97-16 PHYS672; DELPHI Coll., P. Abreu et al., Nucl. Inst. Meth. **A378** (1996) 57.

[11] DELPHI Coll., P.Abreu et al., *Phys. Lett.* **B393** (1997) 245.

[12] V.Obraztsov, *Nucl. Inst. and Meth.* **A316** (1992), 388 and Erratum in *Nucl. Inst. and Meth.* **A399** (1997), 500.

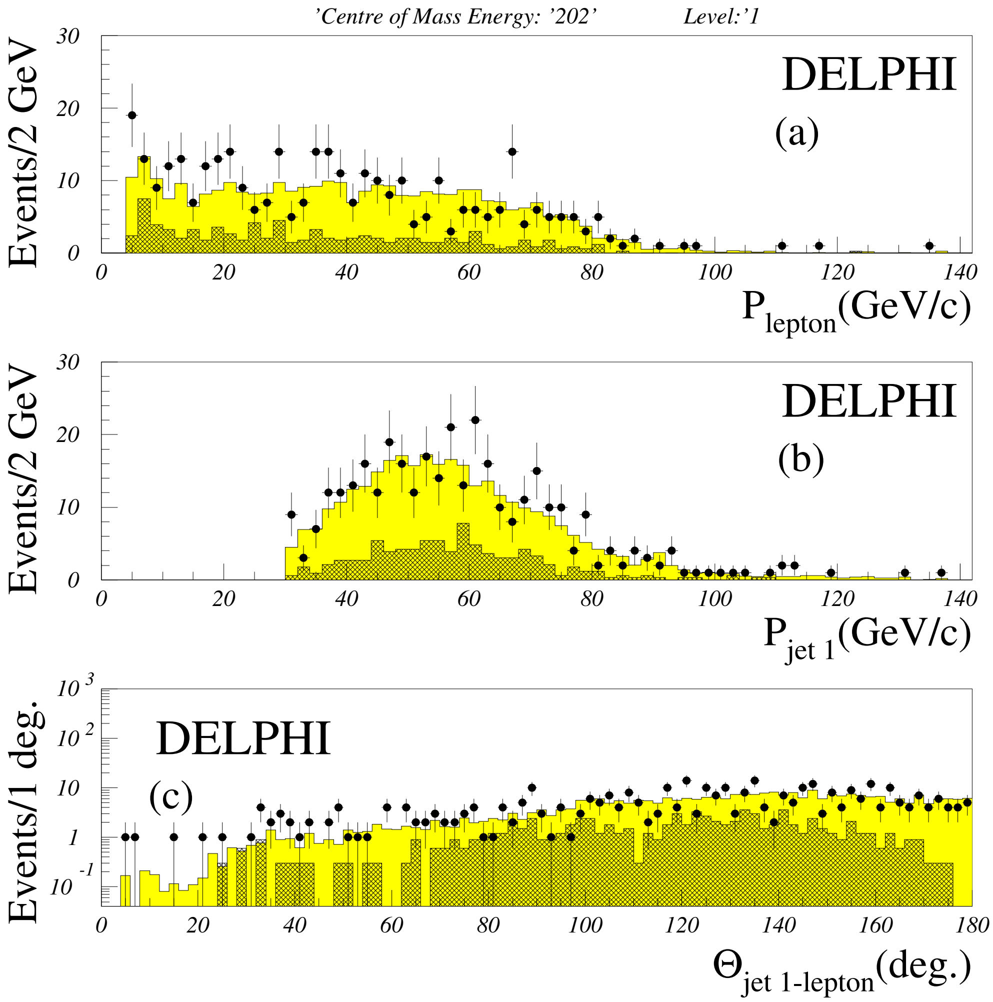

Figure 1: FCNC search after Level 1: the most energetic lepton momentum (a), the most energetic charged jet momentum (b) and the angle between them (c). The dots show the data, the shaded region shows the SM simulation and the dark region is the expected signal behaviour for a top quark mass of 175 GeV/c^2.

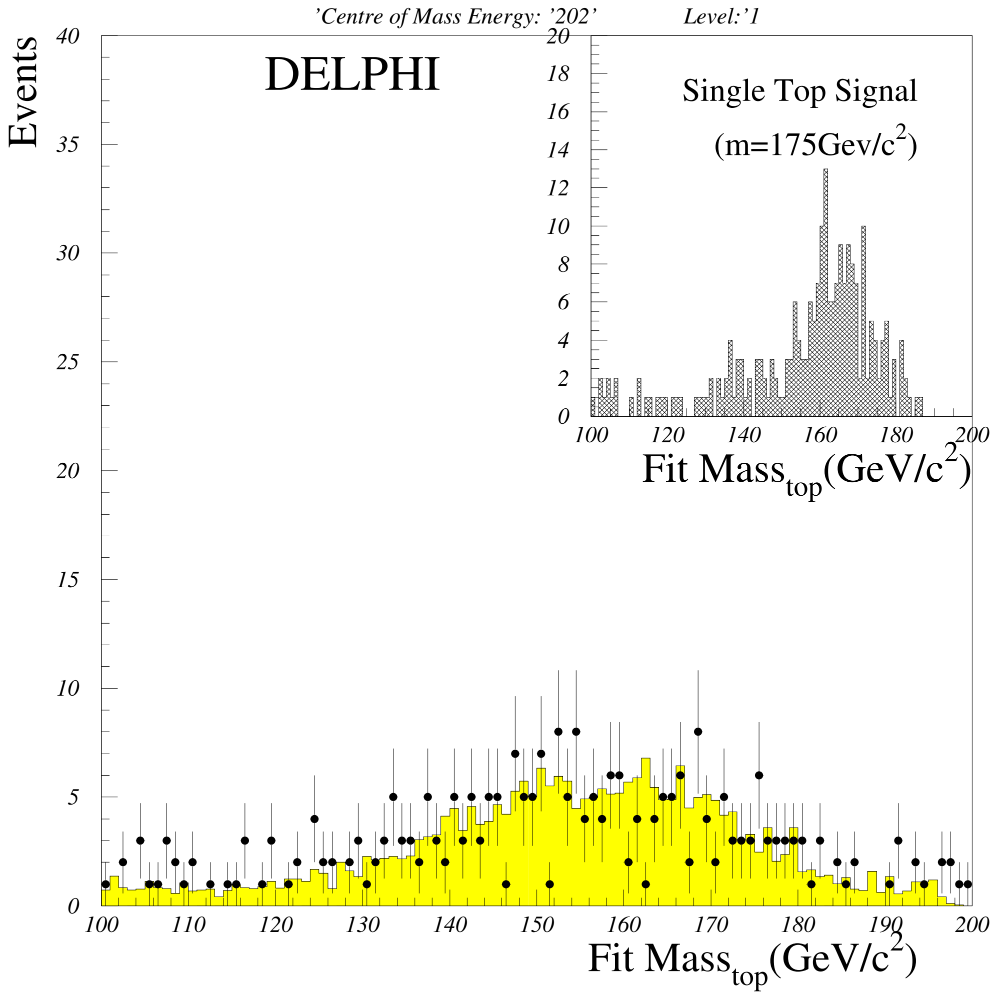

Figure 2: FCNC search after Level 1: the reconstructed top mass distribution, assuming a loose chi-squared cut of 7. The dots show the data, the shaded region shows the SM simulation and the dark region is the expected signal behaviour for a top quark mass of 175 GeV/c^2.

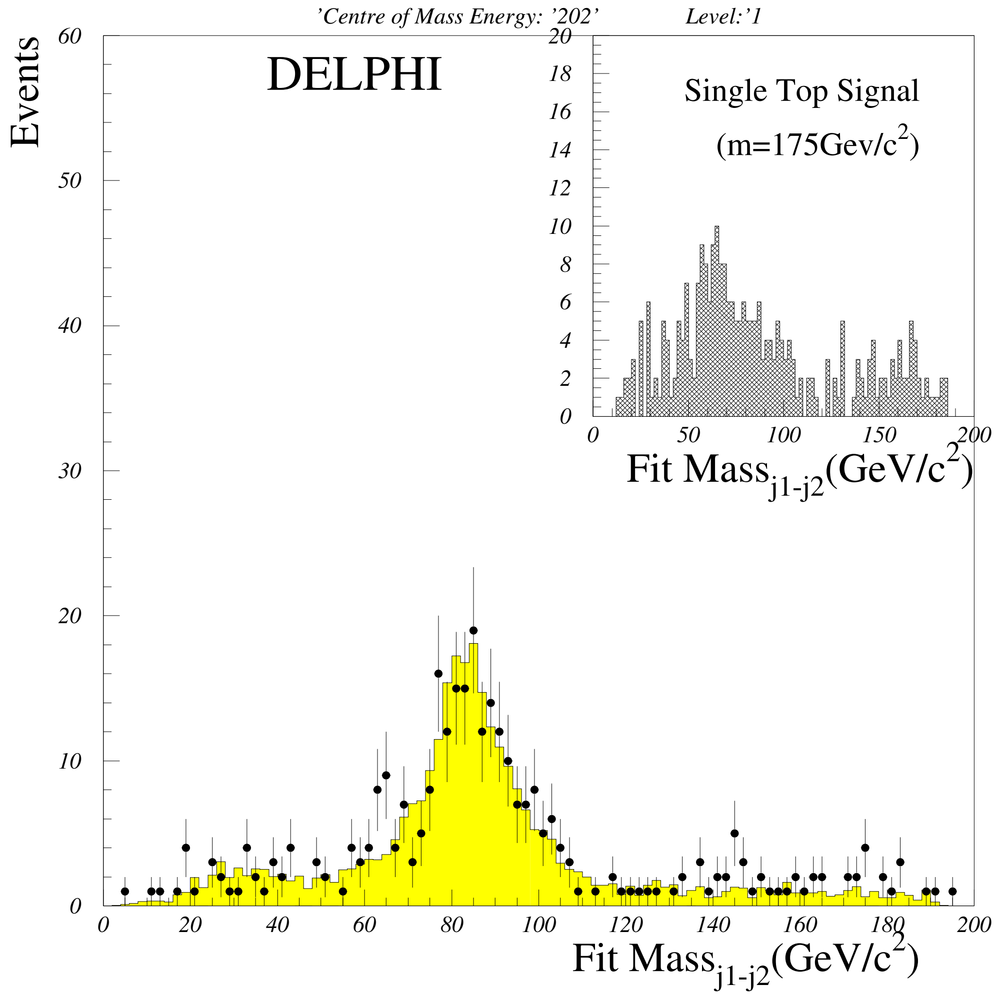

Figure 3: FCNC search after Level 1: the two jets invariant mass distribution, assuming a loose chi-squared cut of 7. The dots show the data, the shaded region shows the SM simulation and the dark region is the expected signal behaviour for a top quark mass of 175 GeV/c^2.

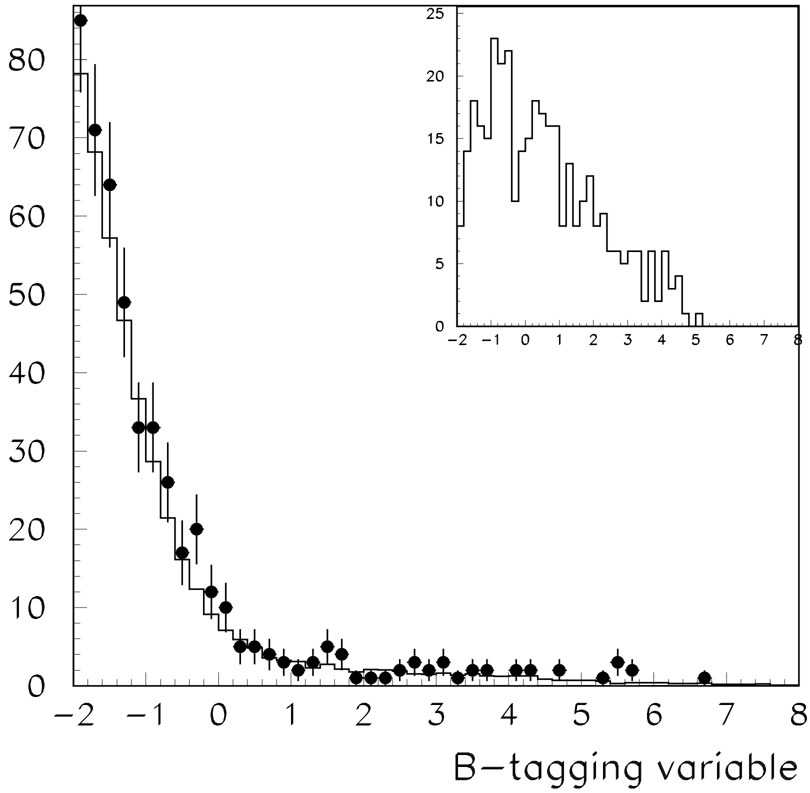

Figure.4 The combined b-tagging variable distribution. The expected signal is shown in the upper right corner.

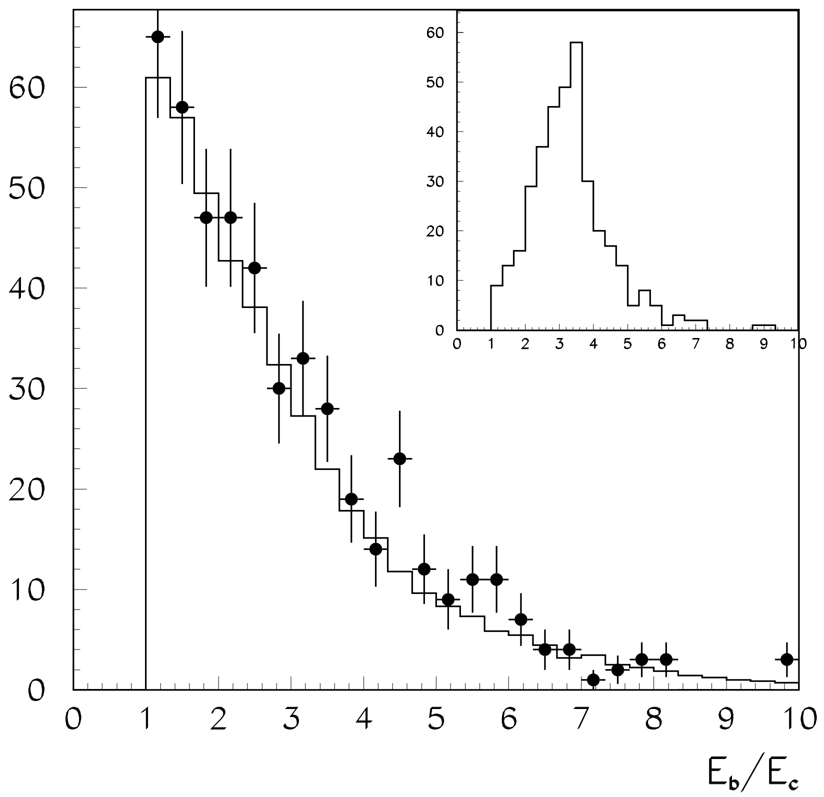

Figure.5 E_b/E_c distribution. The expected signal is shown in the upper right corner.

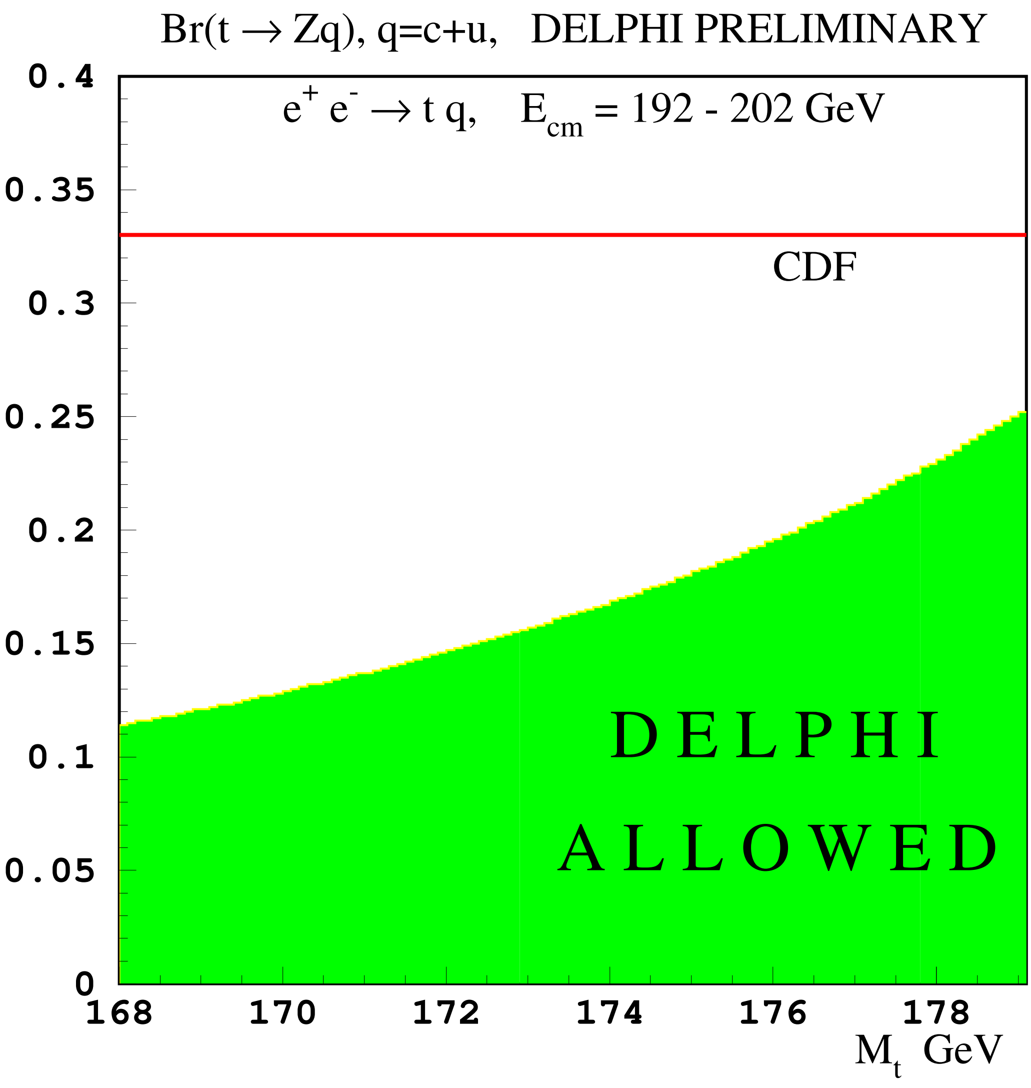

Figure.6 DELPHI upper limit on the branching ratio $Br(t \rightarrow Zc) + Br(t \rightarrow Zu)$ as a function of the t-quark mass.