Search for Single Top-quark Production at LEP2

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In the mid-1990's, the LEP collider at CERN entered a new phase of operation, LEP2, with the first e^+e^- collisions above the W^+W^- threshold. Between 1998 and 2000, with the installation of additional super-conducting radio-frequency accelerating cavities, the centre-of-mass energy of the LEP collider was further increased. The LEP2 data accumulated at centre-of-mass energies between 189 GeV and 209 GeV have opened up a new kinematic domain for particle searches.

There are stringent experimental limits on flavour changing neutral currents (FCNC) between the first two generations of quarks. This is not the case for the third generation quarks, where interesting new phenomena can occur. New physics can appear in FCNC vertices, such as $Z \to tq$. The FCNC coupling Ztq[1] is forbidden at tree level and highly suppressed at loop level in the standard model (SM). Extensions of the SM or new physics beyond the SM could allow FCNC for the top quark at tree level [1]. Any observation of such vertices would signal new physics.

At the Tevatron, the CDF Collaboration performed a search for FCNC in the top decays $t \to \gamma\, c(u)$ and $t \to Z\, c(u)$ in $p\bar{p}$ collisions at a centre-of-mass energy of 1.8 TeV. They obtained upper limits at the 95% confidence level (CL) on the branching fractions [2]: $\mathrm{Br}(t \to c\gamma) + \mathrm{Br}(t \to u\gamma) < 3.2\%$ and $\mathrm{Br}(t \to cZ) + \mathrm{Br}(t \to uZ) < 33\%$.

At LEP such FCNC vertices can appear in the single top-quark production in the process $e^+e^- \to tc(u) \to bWc(u)$ at center-of-mass energies $\sqrt{s} \geq 180$ GeV. The standard model predictions for this process are $\mathcal{O}(10^{-9})$ fb.

A FCNC transition can be described with the parameters κ_γ and κ_Z which represent the tree-level γ and Z^0 exchange contributions to $e^+e^- \to \bar{t}c(u)$ [3]. Using the published limits of CDF on FCNC and the above parametrisation one can derive the following 95% CL limits: $\kappa_\gamma^2 < 0.176$ and $\kappa_Z^2 < 0.533$. The ZEUS and H1 Collaborations also performed a search for FCNC in ep collisions at HERA. ZEUS reports $\kappa_{tu\gamma} < 0.19$ and H1 reports $\kappa_{tu\gamma} < 0.305$. It should be stressed that the HERA experiments are only sensitive to the $\gamma \to tu$ coupling.

Due to the large mass of the top quark of 174.3 ± 5.1 GeV/c^2 , it is produced at LEP2 close to its threshold ($\sqrt{s} \approx m_t$) and decays before hadronizing, thus leaving a characteristic signal signature: a high energetic b-jet, as well as a low energetic c(u)-jet have nearly fixed values of energies. The W-boson is almost mono-energetic and decays in 67% into $\bar{q}q'$ (hadronic channel) and in 33% into $l\nu$ (leptonic channel). The hadronic analysis looks for four jet events, produced by the b-, c-quark and the two quarks coming from the W-boson. The leptonic channel is characterized by one isolated lepton and some missing energy (from W-boson decay). Details about the analyses of OPAL on single top quark production are described in the OPAL publication [4].

In principle, a large FCNC coupling could not only lead to the associated production of a top plus a light quark at LEP2, but also to sizeable branching ratios of the top quark into $\gamma c(u)$ or $Zc(u)$. This analysis uses only the $t \to bW$ channel.

The combination of all the data can be used to determine limits on the anomalous coupling parameters κ_γ and κ_Z. Using additional QCD and ISR corrections modify the Born-level cross-section slightly and are taken into account. These limits are obtained with the likelihood ratio method which has been used extensively in the Higgs boson searches at LEP2. Each individual measurement at each centre-of-mass energy for the leptonic and the hadronic channel has been used as an independent channel. Taking the statistical and systematic errors into account the limit on the anomalous coupling parameters in the $\kappa_\gamma - \kappa_Z$ plane has been derived at the 95% CL. The reduction of the branching ratio $\mathrm{Br}(t \to bW)$ due to possible FCNC decays derived at each point in the $\kappa_\gamma - \kappa_Z$ plane is taken into account in this limit calculation. To compare our results with the limits from Tevatron , exclusion regions for $m_t = 169$, 174 and 179 GeV/c^2 in the $\kappa_\gamma - \kappa_Z$ plane were derived. These exclusions translate into branching fraction limits of $\mathrm{Br}(t \to Z^0c) + \mathrm{Br}(t \to Z^0u) < 9.7/13.7/20.6$ % for $m_t = 169/174/179$ GeV/c^2.

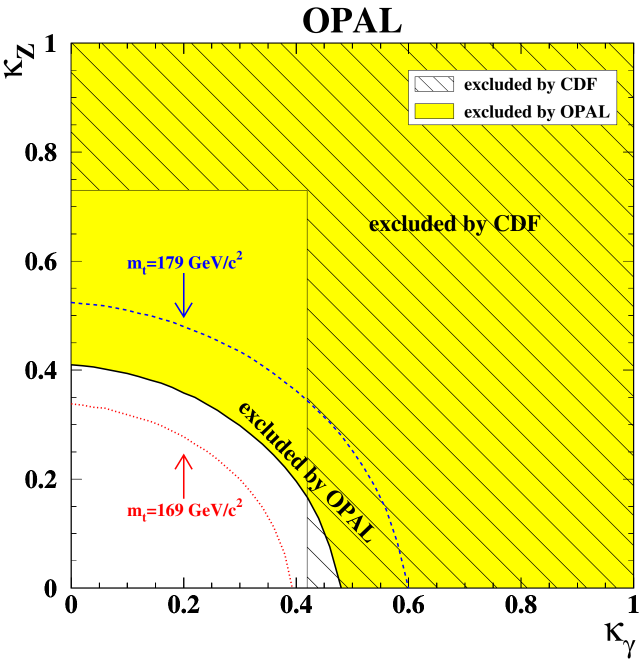

Fig. 1: The light grey region shows the OPAL exclusion region at 95% CL in the $\kappa_Z - \kappa_\gamma$ plane for $m_t = 174$ GeV/c^2 with QCD and ISR corrections. The exclusion curves for different values of top quark masses are also shown. The hatched area shows the CDF $\kappa_\gamma - \kappa_Z$ exclusion region [2].

References

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[2] CDF Collaboration, Phys. Lett. **80** (1998) 2525
[3] J.F. Obraztsov *et al.*, Phys. Lett. **B426** (1998) 393
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[1] q is a light up-type quark