Search for single top production at LEP 2

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L3 Collaboration

ALEPH CONF 2000-004, DELPHI 99-85 CONF 272, DELPHI 2000-032 CONF 351, L3 Internal Note 2506, OPAL Physics Note PN429

- Motivations.
- Theoretical framework.
- Signatures and backgrounds.
- Analysis strategies.
- LEP results at $\sqrt{s} = 189 - 202$ GeV.
- Conclusions.

- At LEP 2, top quark produced only via FCNC processes:

$$e^+e^- \longrightarrow t\,\bar{c}\,(\bar{u}) + c.c.$$

- Very small S.M. predictions for cross section [1]:

$$\sigma(e^+e^- \longrightarrow t\,\bar{c}) \simeq 1.8 \times 10^{-12}\ \text{pb} \ \text{ at } \sqrt{s} = 200\ \text{GeV}$$

- Ideal place to search for new physics.

	$BR(t \longrightarrow c\gamma, cZ^0)$
S.M. [2]	$\sim 10^{-13} - 10^{-12}$
Two Higgs Doublet [2]	$\sim 10^{-9} - 10^{-8}$
SUSY [3, 4]	$\sim 10^{-8} - 10^{-6}$
Multiple Higgs Doublet [5]	$\sim 10^{-6} - 10^{-5}$
Quark singlets [6]	$\sim 10^{-2}$
Composite top quark [7]	$\sim 10^{-2}$

- LEP 2 $\sqrt{s}$ near top threshold $\Rightarrow$ characteristic final state topologies.

References

[1] C-S. Huang et al., Phys. Lett. **B452**, 143 (1999)

[2] G. Eilam et al., Phys. Rev. **D44**, 1473 (1991)

[3] C.S. Li et al., Phys. Rev. **D49**, 293 (1994)

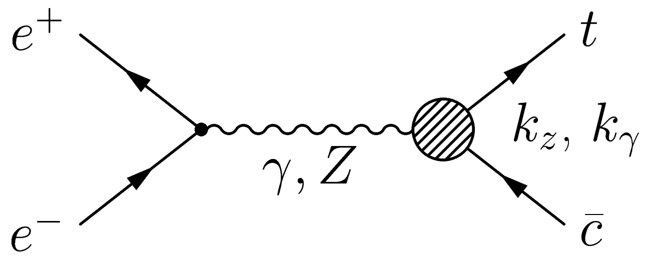
[4] J.L. Lopez et al., Phys. Rev. **D56**, 3100 (1997)

[5] M. Luke et al., Phys. Lett. **B307**, 387 (1993)

[6] V. Barger et al., Phys. Rev. **D52**, 1663 (1995)

[7] H. Georgi et al., Phys. Rev. **D51**, 3888 (1995)

- Parametrisation of FCNC transitions in terms of anomalous vertices, k_Z and k_γ parameters.



- Vertex factor:

$$\Gamma^\gamma_\mu = k_\gamma \frac{e e_q}{\Lambda} \sigma_{\mu\nu} q^\nu$$

$$\Gamma^Z_\mu = k_Z \frac{e}{\sin(2\theta_W)} \gamma_\mu$$

Λ: new physics cut-off ($= m_t$)

- Recent limits on k_Z and k_γ from CDF search for $t \to c\,\gamma(Z)$:

$$BR(t \to c(u)\,\gamma) < 3.2\% \quad \Rightarrow \quad k_\gamma^2 < 0.176$$

$$BR(t \to c(u)\,Z) < 33\% \quad \Rightarrow \quad k_Z^2 < 0.533$$

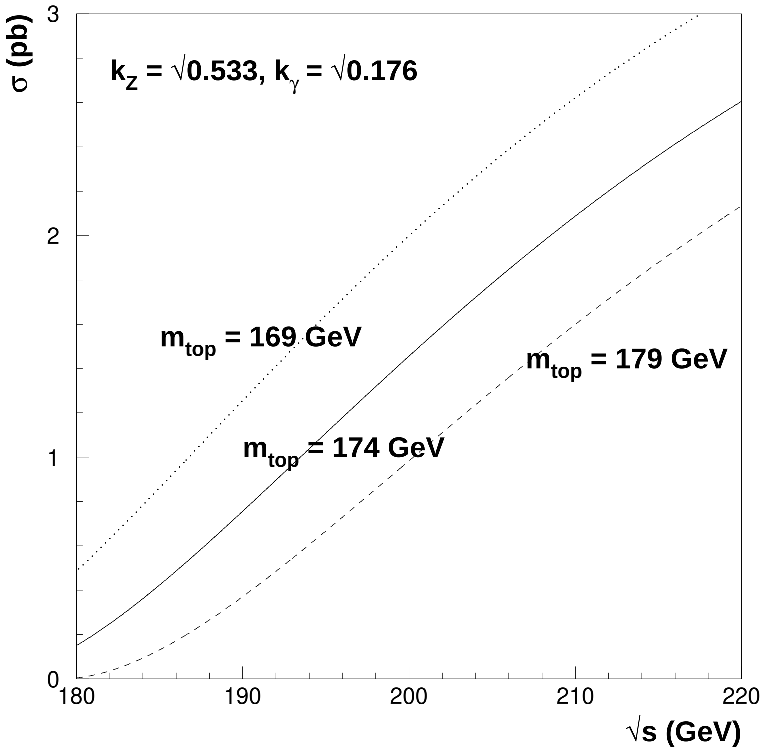
- Cross section:

$$\sigma(\mathrm{e}^+\mathrm{e}^- \to t\bar{c}) = \frac{\pi\alpha^2}{s}\left(1 - \frac{m_t^2}{s}\right)^2 \left[k_\gamma^2 e_q^2 \frac{s}{m_t^2}\left(1 - 2\frac{m_t^2}{s}\right) + \right.$$

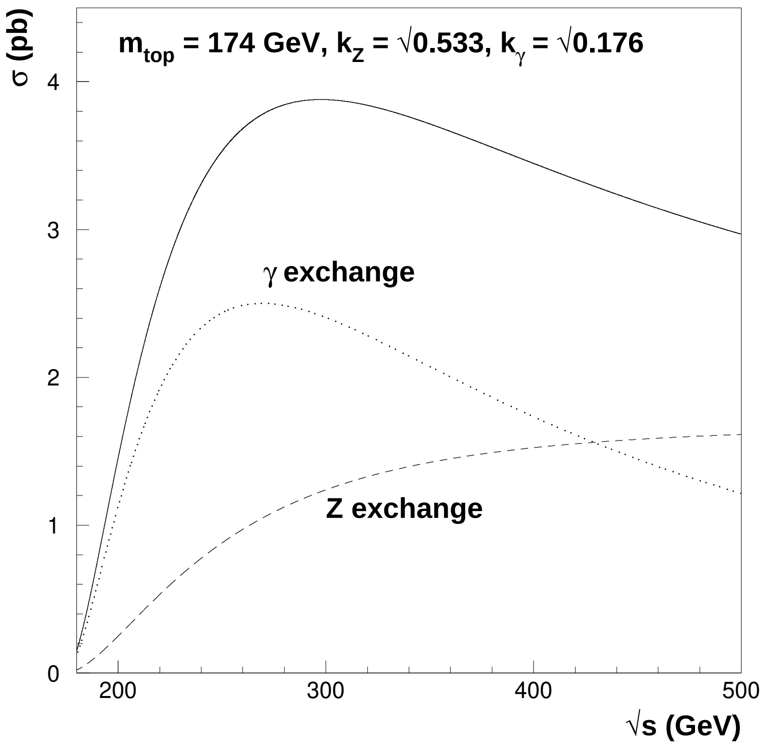
$$+ \frac{k_Z^2(1 + a_W^2)(2 + m_t^2/s)}{4\sin^4(2\theta_W)(1 - m_Z^2/s)^2} +$$

$$\left. + 3 k_z k_\gamma \frac{a_W e_q}{\sin^2(2\theta_W)(1 - m_Z^2/s)}\right]$$

where $a_W = 1 - 4\sin^2(2\theta_W)$



σ (pb)
$k_Z = \sqrt{0.533}$, $k_\gamma = \sqrt{0.176}$
m_{top} = 169 GeV
m_{top} = 179 GeV
m_{top} = 174 GeV
0
1
2
3
180
190
200
210
220
√s (GeV)



σ (pb)
m_{top} = 174 GeV, $k_Z = \sqrt{0.533}$, $k_\gamma = \sqrt{0.176}$
γ exchange
Z exchange
0
1
2
3
4
200
300
400
500
√s (GeV)

EVENT TOPOLOGY

- Top quark produced almost at rest.
- No top-flavored hadrons, top decays: $\mathrm{t} \longrightarrow \mathrm{Wb}$
- c and b quarks with fixed energies: ($\sqrt{s} = 189$ GeV):

$$E_{c(u)} \simeq \frac{\sqrt{s}}{2}\left(1 - \frac{m_t^2}{s}\right) \simeq 10 \text{ GeV}$$

$$E_b \simeq \frac{m_t}{2} - \frac{m_W^2}{2m_t} \simeq 70 \text{ GeV}$$

- Two final states:

  Leptonic: $\mathrm{W} \longrightarrow l\nu_l$
  Hadronic: $\mathrm{W} \longrightarrow \mathrm{qq}'$

SIGNAL SIGNATURE

- Fixed energy jets.
- High energetic b jet.
- Leptonic channel:

  High energetic isolated lepton.

  High missing energy.

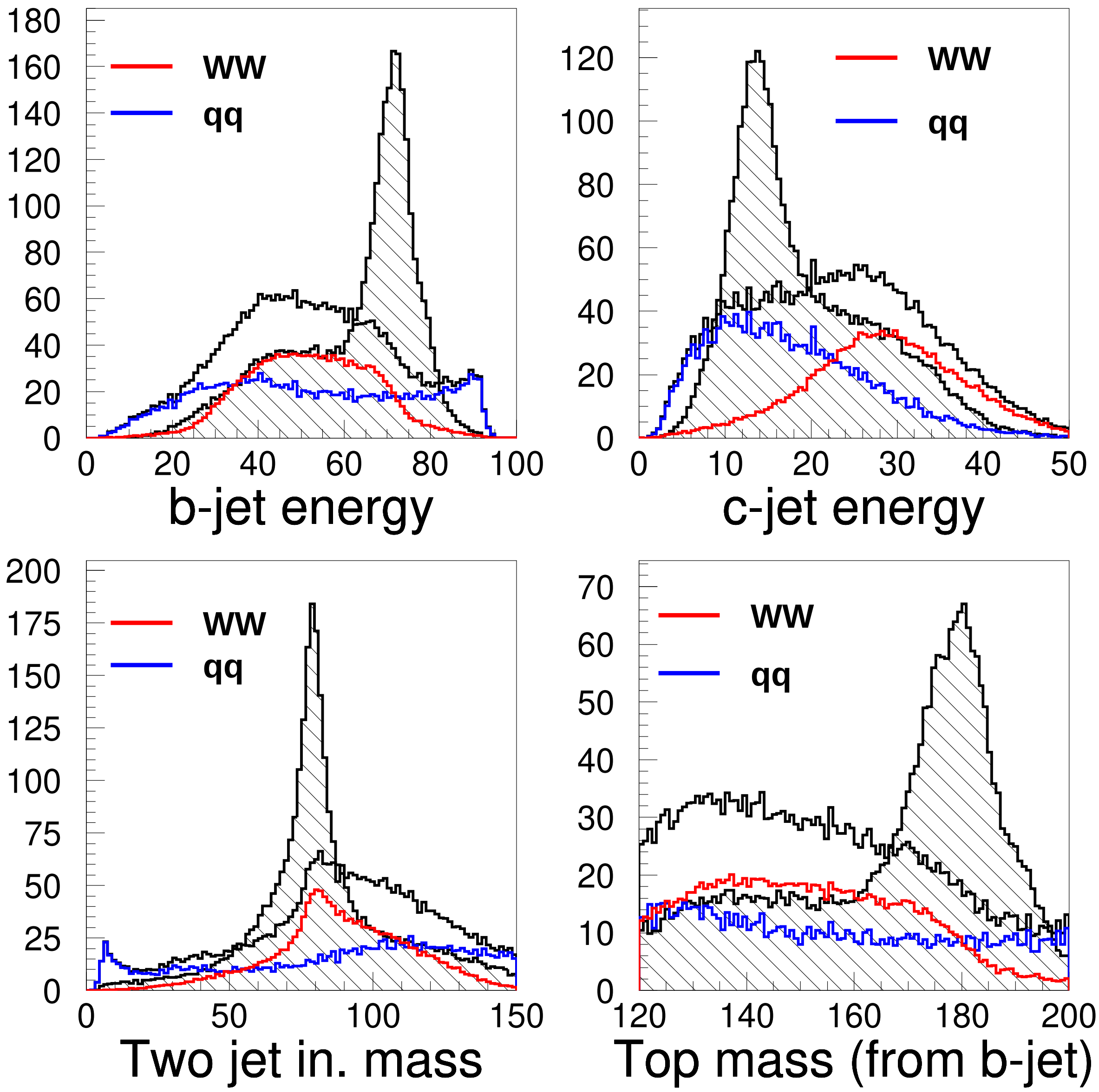
  Lepton-Missing invariant mass $\simeq m_W$
- Hadronic channel:

  4 jets.

  2 jet invariant mass $\simeq m_W$

BACKGROUNDS

- $\mathrm{e^+e^-} \longrightarrow \mathrm{W^+W^-}$
- QCD.



L3 simulation: 4-jets events for sample (modified JETSET) and main backgrounds.

ANALYSIS STRATEGIES

- Preselection Cuts:

  High multiplicity events.

  Event shapes: thrust, sphericity.

  Visible energy, momentum, mass.

- Lepton identification:

  Isolated.

  Large energy.

  Polar angle.

- Missing momentum:

  Large momentum.

  Polar angle.

- Event forced in 2 or 4 jets + kinematic fits:

  c-jet $\equiv$ least energetic jet.

  b-jet $\equiv$ highest b-tag and/or most energetic.

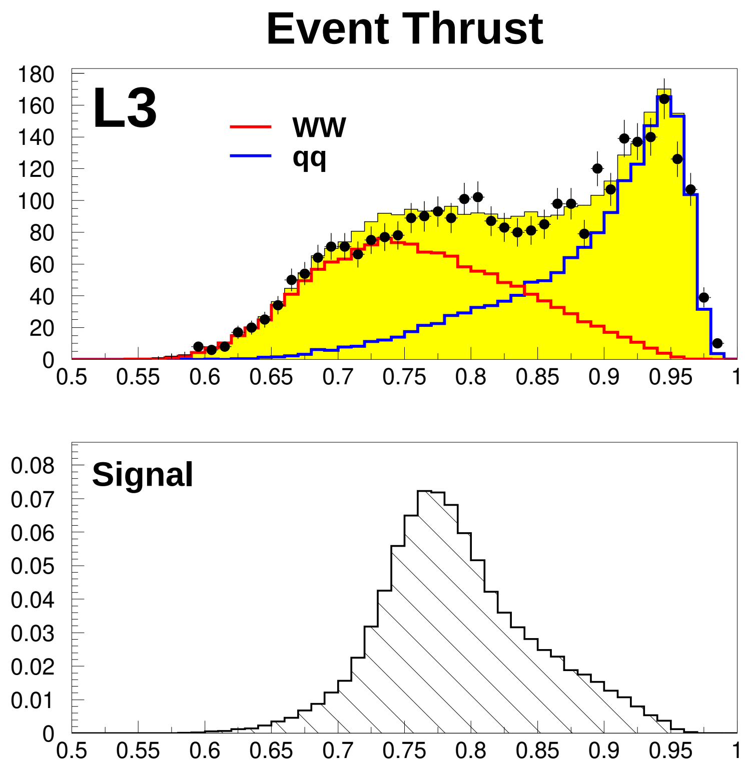
  Reconstruct W and M_{top}.

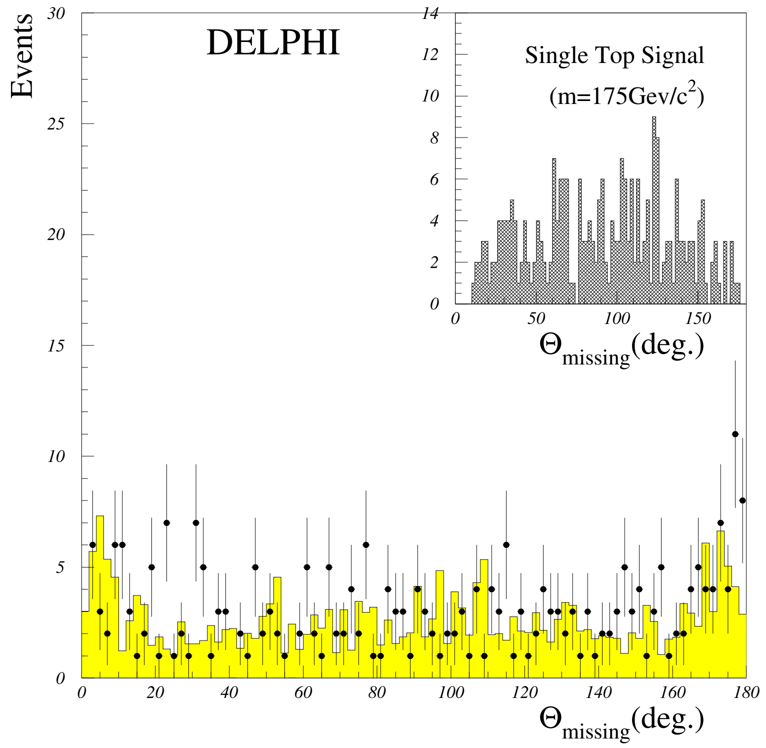
  Kinematic cuts on jets, reconstructed W and top.

- Cuts on jet (and/or event) b-tagging.

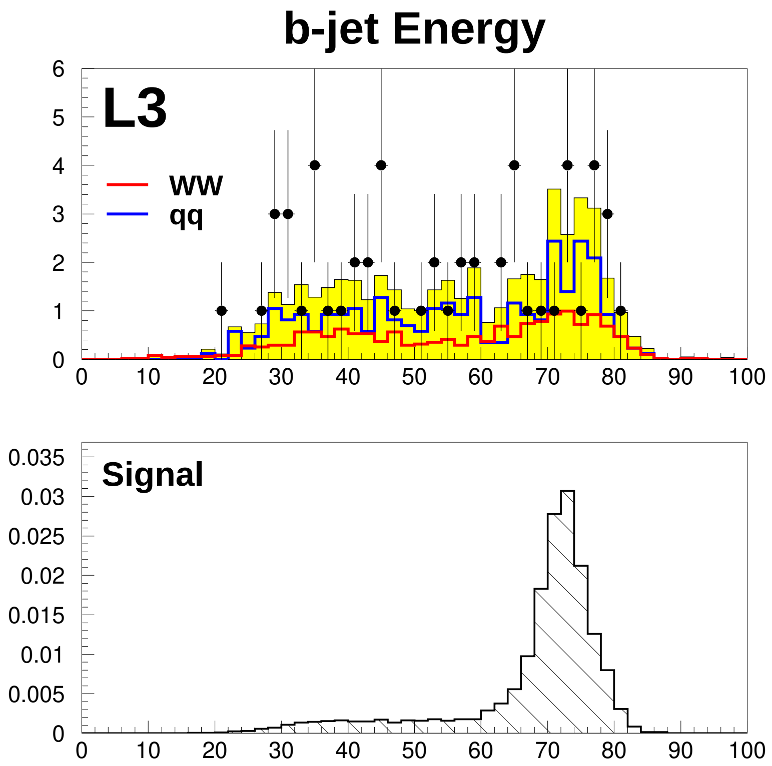
- Use of Likelihood function or Neural Network.

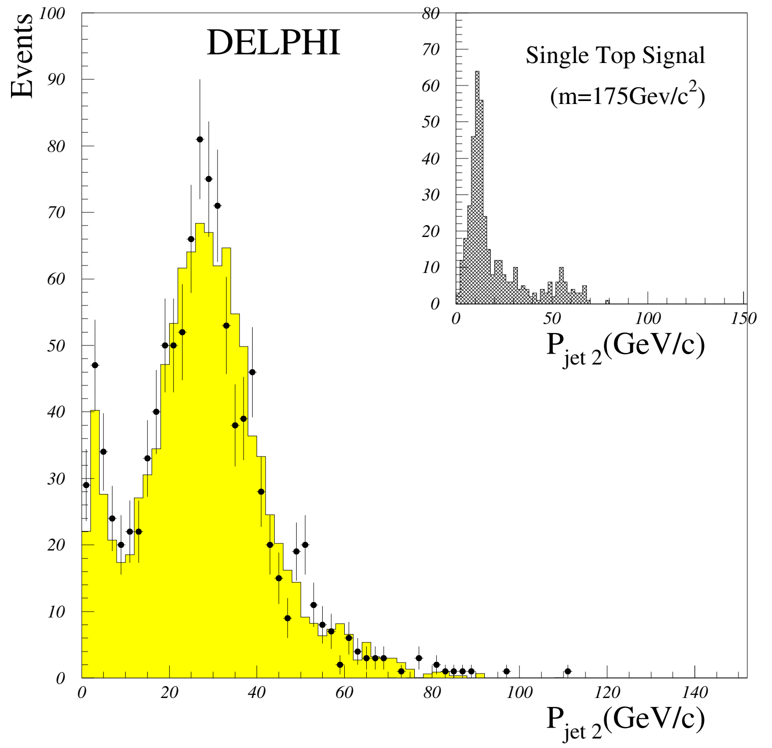
ANALYSIS STRATEGIES



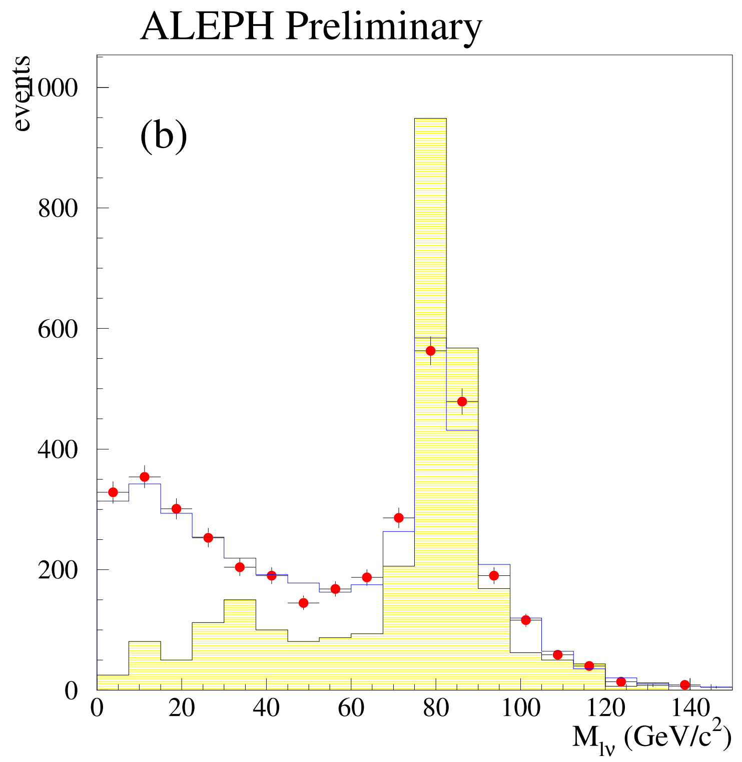


$$\theta \text{ missing } (\sqrt{s} = 189 \text{ GeV}).$$

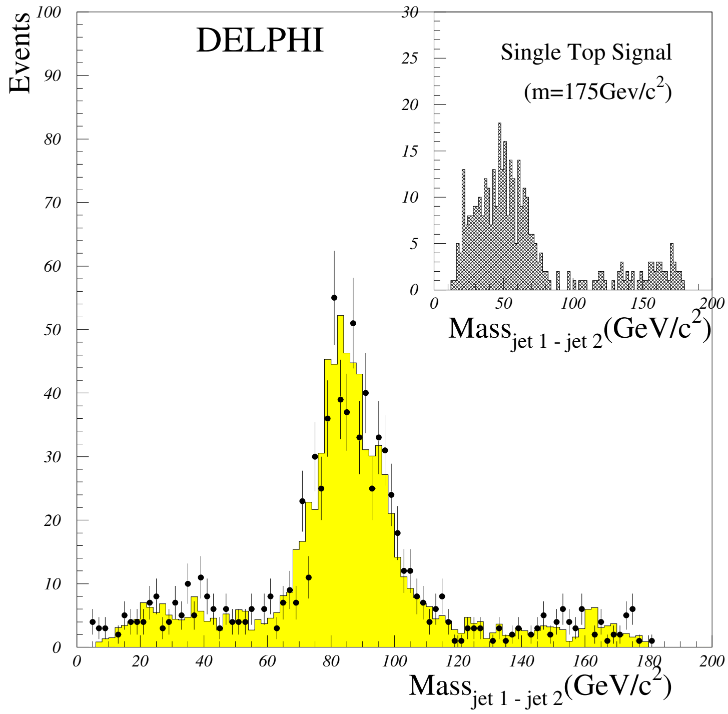




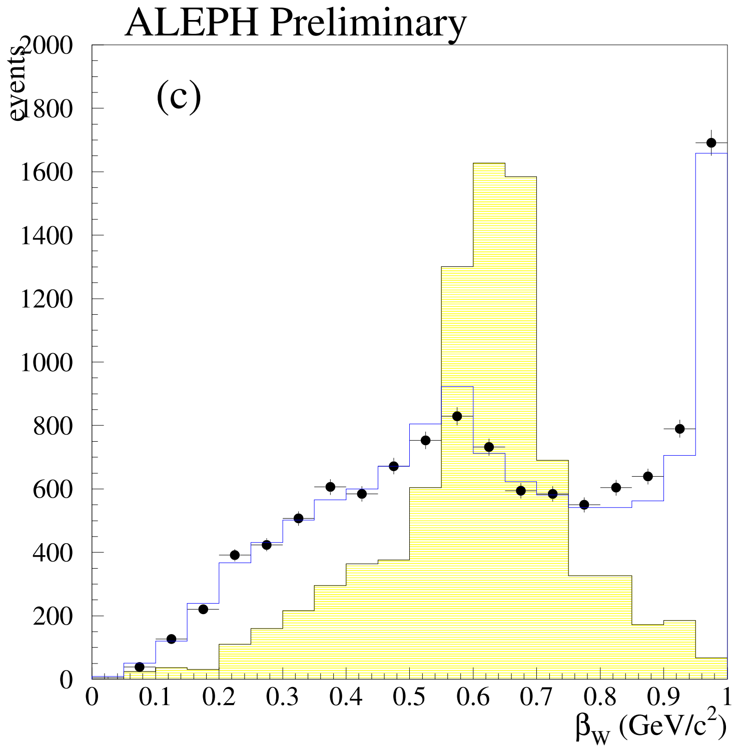
P c-jet ($\sqrt{s} = 189$ GeV).



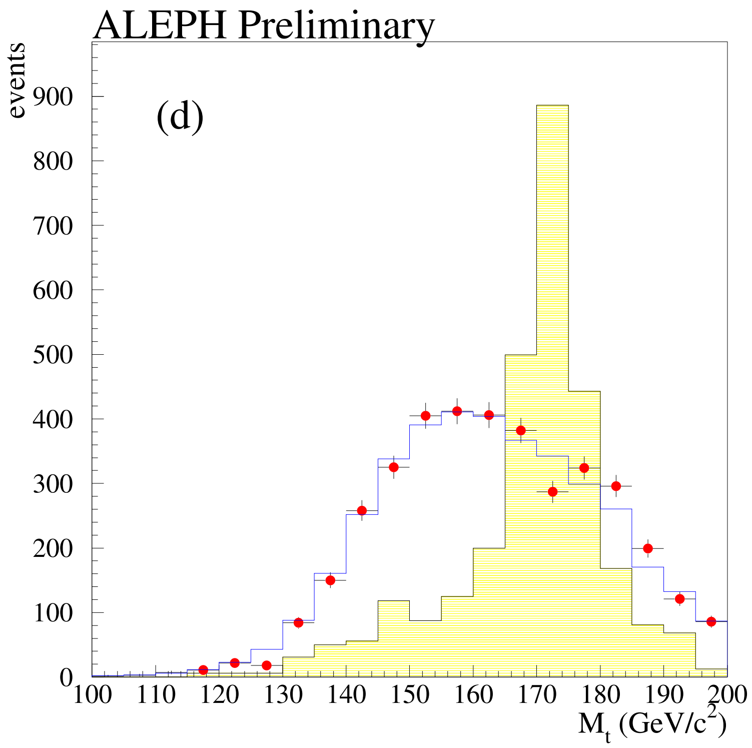
Lepton-missing invariant mass ($\sqrt{s} = 189 - 202$ GeV).



2 jets invariant mass ($\sqrt{s} = 189$ GeV).

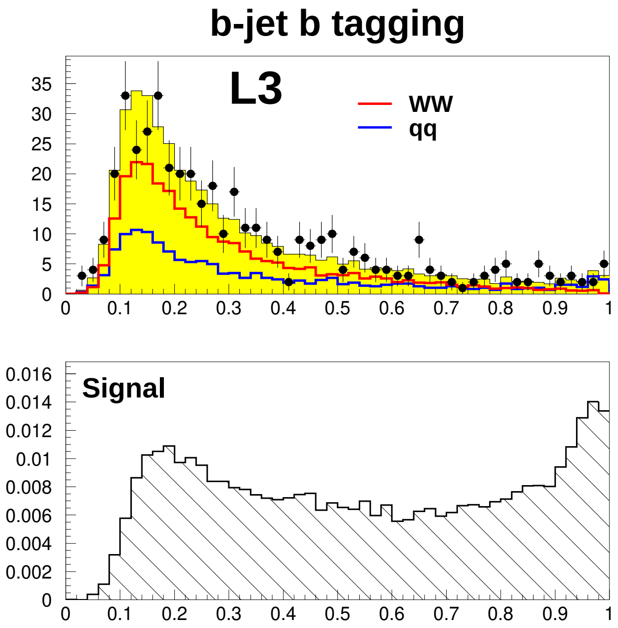


Reconstructed W: P_W/E_W ($\sqrt{s}$ = 189 GeV, 4 jets events).

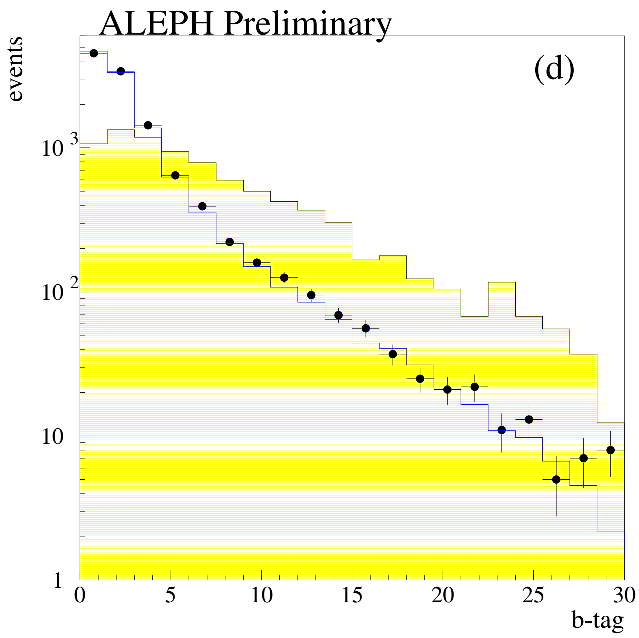


Reconstructed top mass ($\sqrt{s}$ = 189 GeV, 2 jets events).

ANALYSIS STRATEGIES

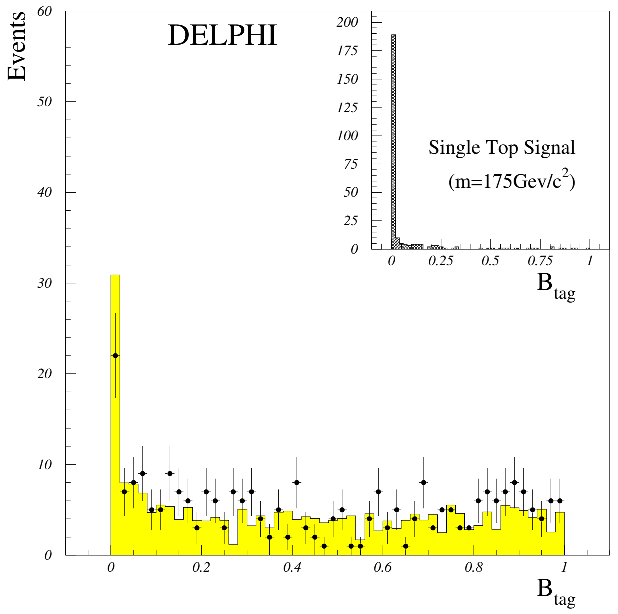


Jet b-tag

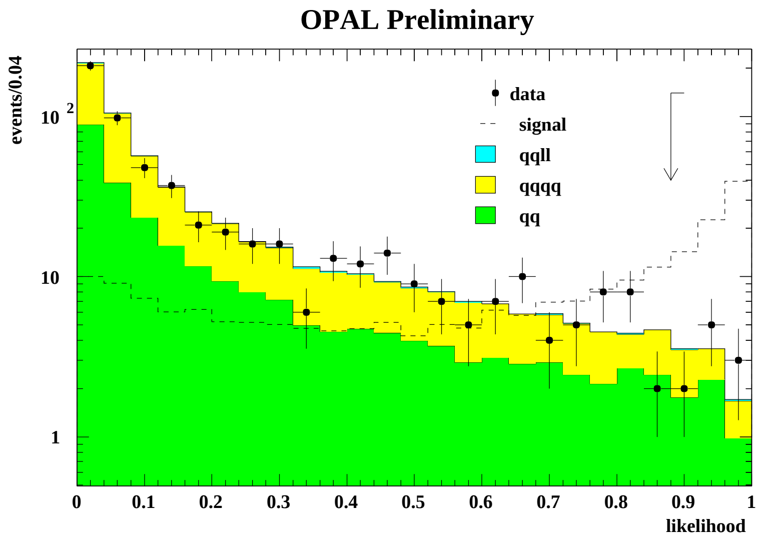


Jet b-tag

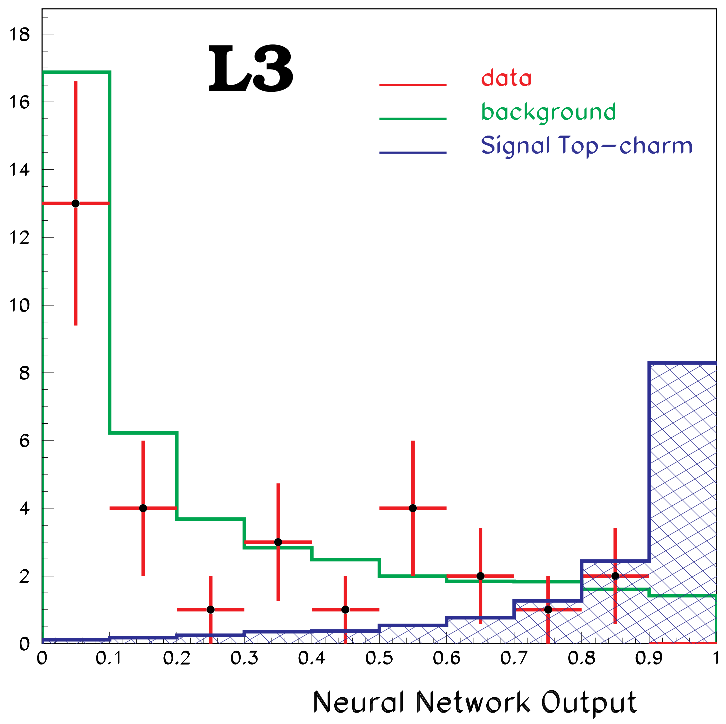
$(\sqrt{s} = 189 - 202$ GeV, 4 jets events)



Event b-tag $(\sqrt{s} = 189$ GeV)



Likelihood function.



Neural Network output (2 jets events).

LEP RESULTS

	$\sqrt{s}$ (GeV)	189		192-202	
L3	Int. Lumi.(pb^{-1})	176.7			
		Lept.	Hadr.	Lept.	Hadr.
	Data	31	22		
	Exp. Bkg.	40.8	21.6		
	Sig. eff (%) *	13.5	9.6		
ALEPH	Int. Lumi.(pb^{-1})	174		237	
		Lept.	Hadr.	Lept.	Hadr.
	Data	4	21	2	32
	Exp. Bkg.	2.2	16.3	3.5	28.2
	Sig. eff (%) *	7.0	17.0	5.0	14.5
DELPHI	Int. Lumi.(pb^{-1})	153		232.9	
		Lept.	Hadr.	Lept.	Hadr.
	Data	0		3	12
	Exp. Bkg.	1		5.1	13.0
	Sig. eff (%) *	6.7		6.2	7.9
OPAL	Int. Lumi.(pb^{-1})	172			
		Lept.	Hadr.	Lept.	Hadr.
	Data		10		
	Exp. Bkg.		9.0		
	Sig. eff (%) *		14.8		

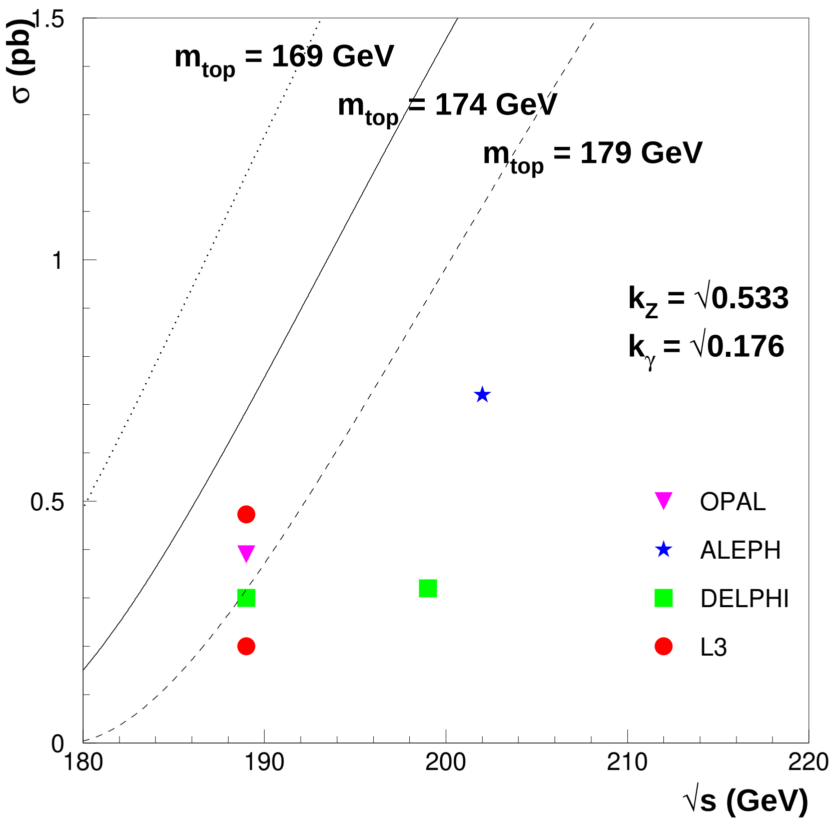
$*$ Sign. eff. $\equiv$ Sign. eff. $\times$ Br($W \rightarrow \cdots$)

NO DEVIATION FROM THE S.M. EXPECTATION.

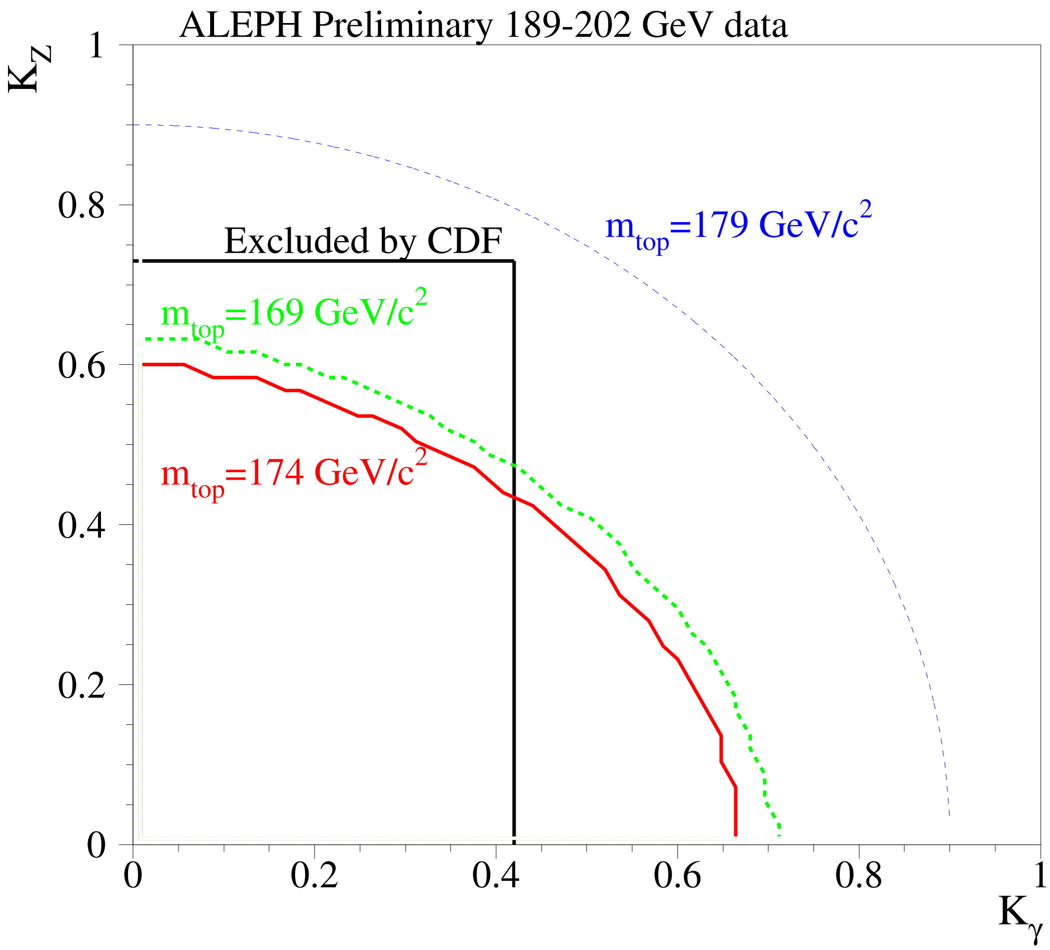
- All results are preliminary.
- No deviation from the S.M. expectation.
- 95 % CL upper limit on $\sigma(\mathrm{e}^+\mathrm{e}^- \to t\bar{c})$

	Lept.	Hadr.
L3 at 189 GeV:	0.200 pb	0.473 pb
ALEPH at 202 GeV		0.720 pb
DELPHI at 189 GeV	0.300 pb	
DELPHI at 199 GeV	0.320 pb	
OPAL at 189 GeV		0.390 pb

Assuming $BR(t \to Wb) = 100\%$



- Exclusion curves for k_Z, k_γ, from ALEPH.



- For $k_\gamma = 0, \Longrightarrow BR(t \rightarrow c(u)\, Z) < 22\%$

CONCLUSIONS

- Inclusive search for FCNC single top production performed at LEP 2 by ALEPH, DELPHI, L3 and OPAL.
- No signal has been seen.
- Set peliminary limits on cross section:

  0.200 pb at 189 GeV

  0.320 pb at 199 GeV

  0.720 pb at 202 GeV
- Using anomalous coupling parametrisation $\longrightarrow$ improvement of the CDF limit on k_Z for $m_t = 174$ and 169 GeV.
- No analysis on differential cross sections $\longleftrightarrow$ model dependence.
- Possible improvement by integrating all the L3, OPAL and year 2000 data.