Searches for single top production at LEP2

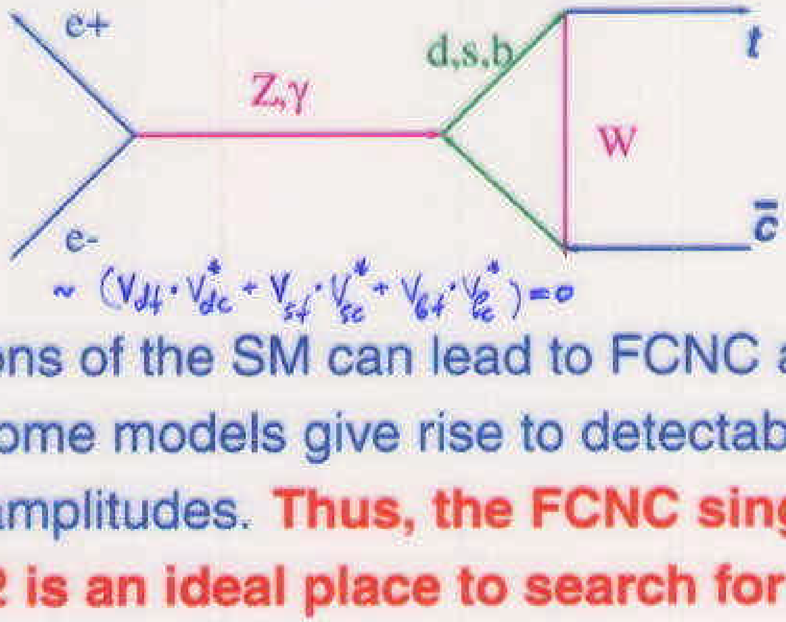
Vladimir Obraztsov, IHEP, Protvino

representing the LEP collaborations

Since the summer of 1997, the LEP-2 e^+e^- collider has been operating at the cms energy of $\sqrt{s} > 183$ GeV. At this energy the production of single top quark becomes kinematically possible:

$$e^+e^- \to Z^*(\gamma^*) \to t\bar{c}(\bar{u})$$

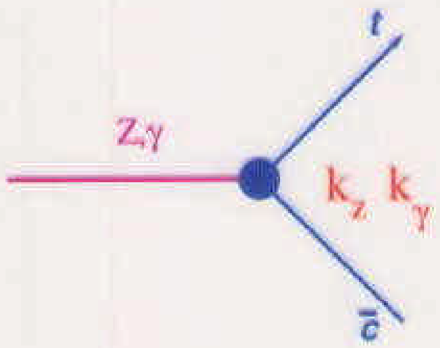
- This is FCNC process, forbidden in the SM at tree level. Can proceed via loops $\sigma \leq 10^{-9}$ fb. Another possibility is the reaction $e^+e^- \to e^-\bar{\nu}_e t\bar{b}$ $\sigma \sim 10^{-4}$ fb. for $\sqrt{s}$=200 GeV
  (K.Hagiwara, M.Tanaka Phys.Lett B325(1994)521.)



- Extentions of the SM can lead to FCNC at tree level , some models give rise to detectable FCNC amplitudes. **Thus, the FCNC single top at LEP2 is an ideal place to search for new physics.**

Another way to detect FCNC in the top sector is to search for the rare t-quark decays: $t \to \gamma(Z,g) + c(u)$
CDF searched for such decays in the process $\bar{p}p \to \bar{t}tX$ at $\sqrt{(s)} = 1.8$ TeV and set limits:

$$Br(t \to \gamma c) + Br(t \to \gamma u) < 3.2\%$$
$$Br(t \to Zc) + Br(t \to Zu) < 33\%$$



- The neutral-current verticies for $t \to c\gamma$ and $t \to cZ$ can be expressed as:

$$\Gamma^{\gamma}_{\mu} = \kappa_{\gamma} \frac{ee_q}{\Lambda} \sigma_{\mu\nu} q^{\nu};\ \Gamma^{z}_{\mu} = \kappa_{z} \frac{e}{sin2\theta_w} \gamma_{\mu};$$

$\sigma^{\mu\nu} = \frac{1}{2}(\gamma^{\mu}\gamma^{\nu} - \gamma^{\nu}\gamma^{\mu});\ \Lambda = m_t;\ \kappa_{\gamma};\ \kappa_{z}$ - anomalous coupling constants.

- Then for the decay widths:

$$\Gamma(t \to c\gamma) = \kappa^2_{\gamma} \frac{\alpha e^2_q}{4} (\frac{m^2_t}{\Lambda^2}) m_t;$$
$$\Gamma(t \to cZ) = \kappa^2_{z} \frac{\alpha}{8 sin^2 2\theta_w M^2_z} m^3_t (1 - \frac{M^2_z}{m^2_t})(1 + 2\frac{M^2_z}{m^2_t})$$

- Then from the CDF limit it is straitghforward to obtain: $\kappa^2_{\gamma} < 0.176$;$\kappa^2_{z} < 0.533$

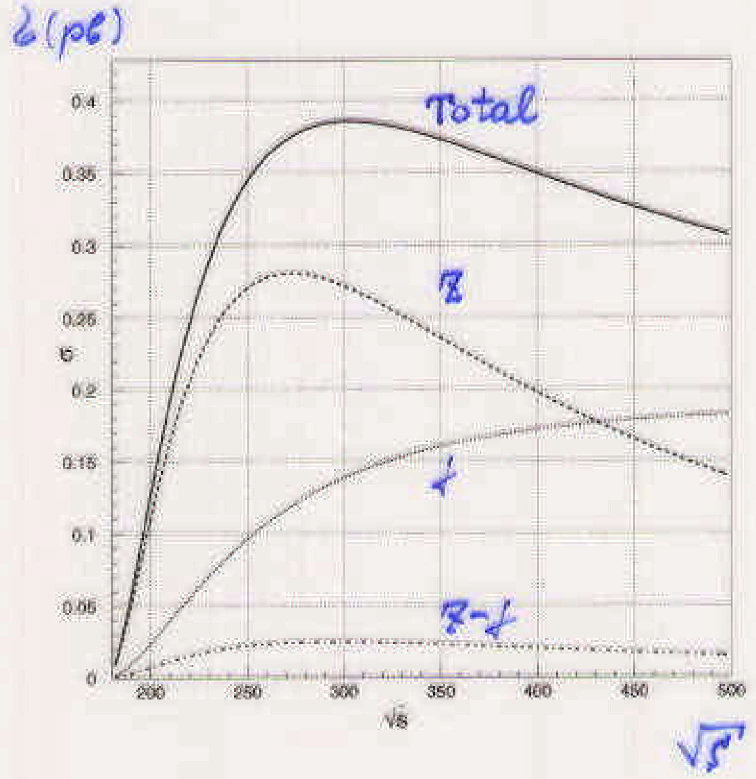
For the t production x-section:

$$\sigma(e^+e^- \to t\bar{c}) = \frac{\pi\alpha^2}{s}(1-\frac{m_t^2}{s})^2 \times [\frac{\kappa_z^2(1+\alpha_w^2)(2+m_t^2/s)}{4sin^4 2\theta_w(1-M_z^2/s)^2} + \kappa_\gamma^2\frac{m_t^2}{\Lambda^2}e_q^2\frac{s}{m_t^2}(1+\frac{2m_t^2}{s}) - 3\kappa_\gamma\kappa_z(\frac{m_t}{\Lambda})\frac{\alpha_w e_q}{sin^2 2\theta_w(1-M_z^2/s)}]$$

here $\alpha_w = 1 - 4sin^2\theta_w$

The x-section versus $\sqrt{s}$ is shown on Fig.1 for CDF

κ_z ; κ_γ :



Data presented to the conference

The first results of the search for $e^+e^- \to t\bar{c}$ at $\sqrt{s} = 183, \mathcal{L}$ 50 pb^{-1} GeV was published by DELPHI Phys.Lett.**B446**,62(1999)

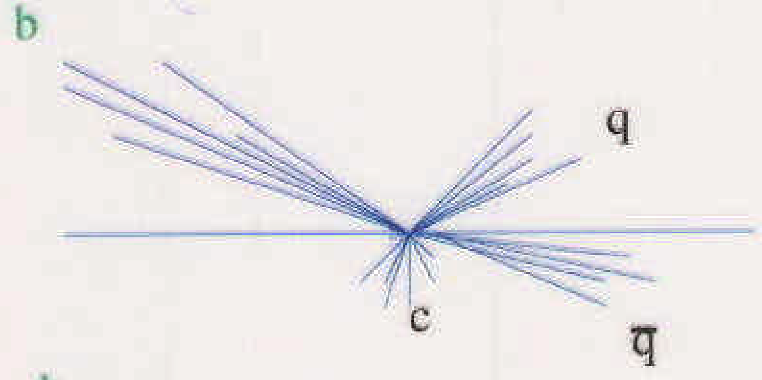
Four LEP collaborations presented the following data to Osaka conference:

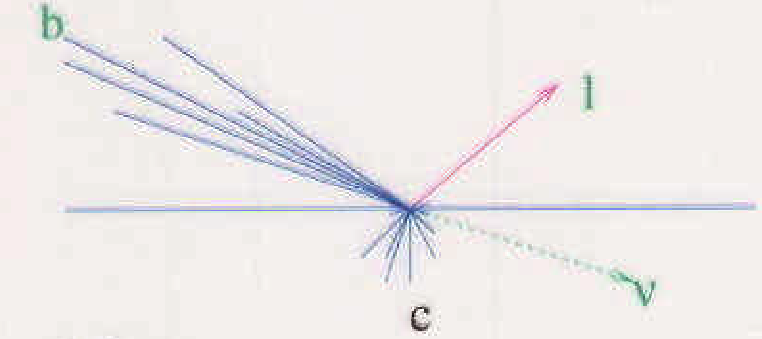
- ALEPH $\mathcal{L}$ 411 pb^{-1} $\sqrt{s} = 189 \div 202$ GeV
  (189 GeV submitted ICHEP99 Tampere)
- DELPHI $\mathcal{L}$ 391. pb^{-1} $\sqrt{s} = 189 \div 202$ GeV
  (189 GeV submitted to ICHEP99 Tampere)
- L3 $\mathcal{L}$ 410. pb^{-1} $\sqrt{s} = 189 \div 202$ GeV
  (189 GeV submitted to ICHEP99 Tampere)
- OPAL $\mathcal{L}$ 172 pb^{-1} $\sqrt{s} = 189$ GeV hadronic+ leptonic
  (189 GeV hadronic submitted to Moriond-2000)

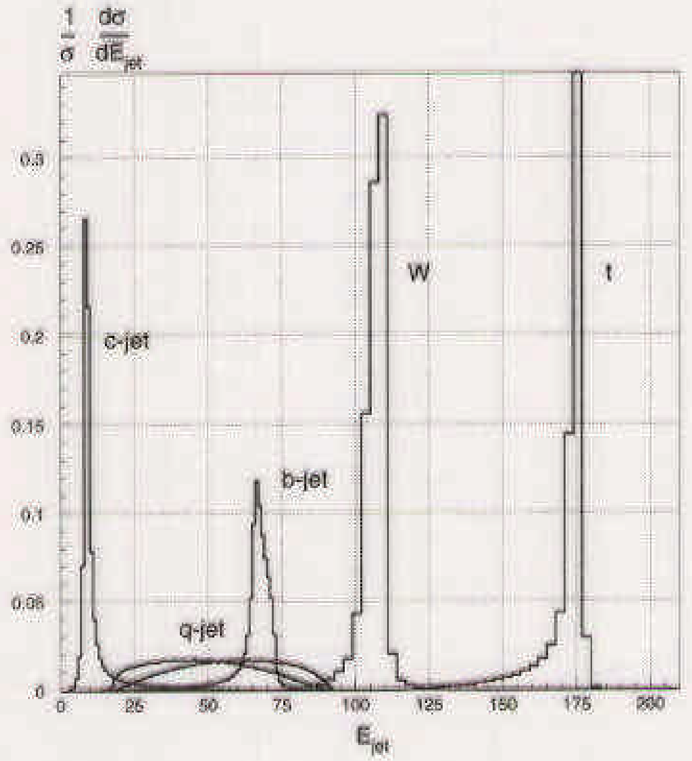
$\sqrt{s}$(GeV)	189	192	196	200	202
ALEPH$\mathcal{L}(pb^{-1})$	174	29	80	86	42
DELPHI$\mathcal{L}(pb^{-1})$	158	30	78	84	41
L3 $\mathcal{L}(pb^{-1})$	177	30	84	83	37
OPAL $\mathcal{L}(pb^{-1})$	172				

$$e^+e^- \to t\bar{c}, \quad t \to Wb$$

Event Topology & Kinematics







$\sqrt{s} = 184$ GeV

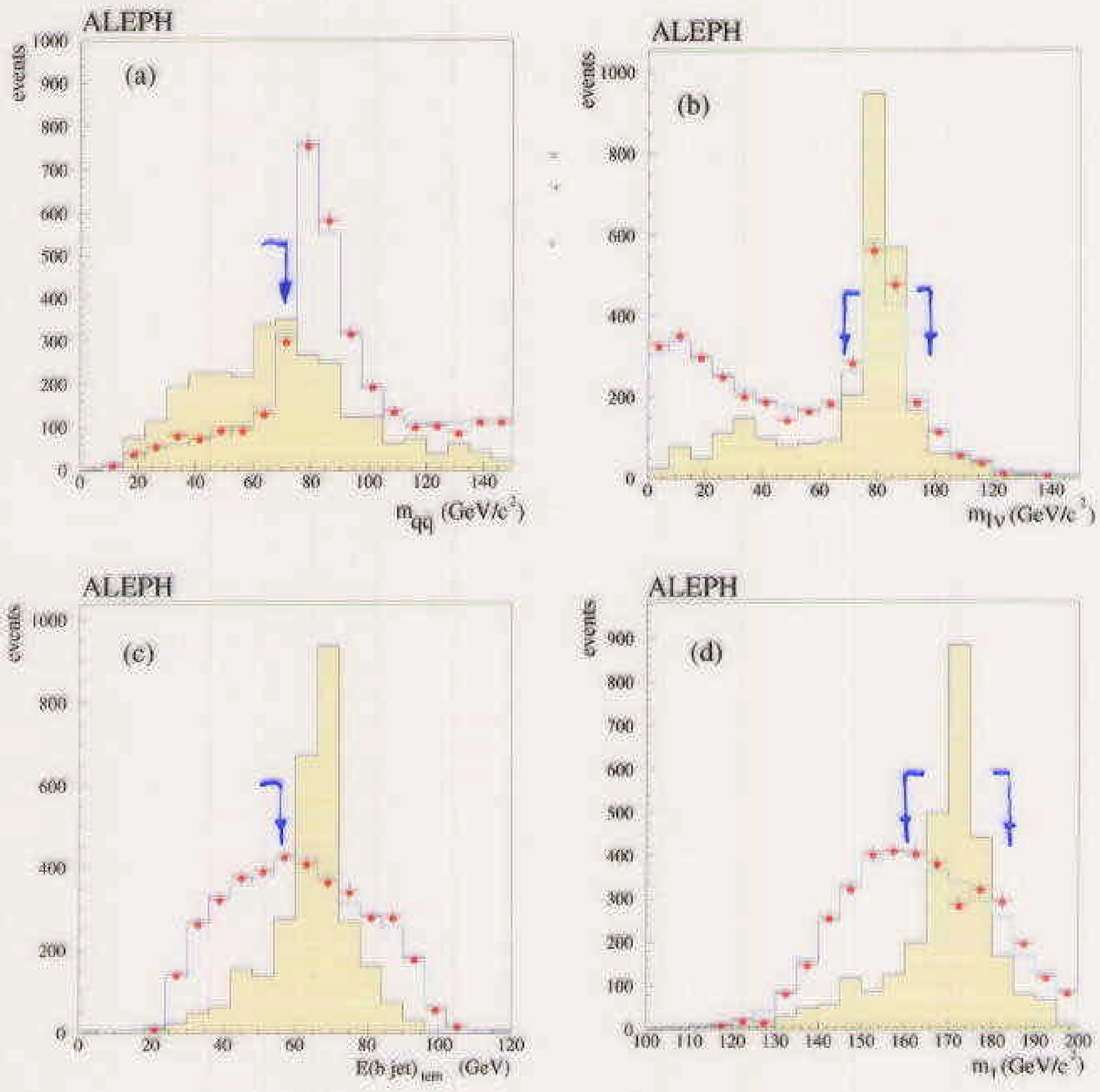
$$E_c \sim \sqrt{s} - m_t;\ E_b \sim \frac{m_t^2 - m_W^2 + m_b^2}{2m_t};\ E_W \sim \frac{m_t^2 + m_W^2 - m_b^2}{2m_t}$$

Event Selection

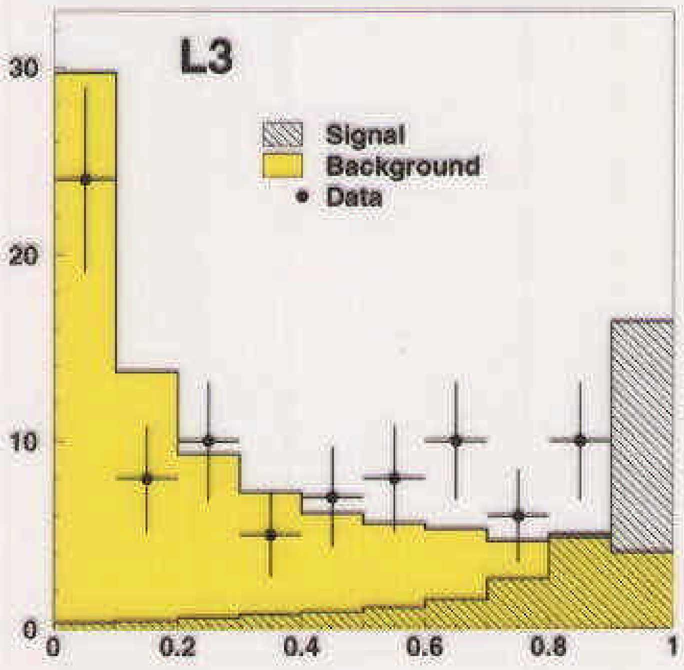
The first step of the analysis is to select $e^+e^- \to 4q$ and $e^+e^- \to l\nu q\bar{q}'$. The event selection, at first steps, is similar to that used for the WW, the main backgrounds being $Z\gamma; \gamma\gamma$:

- $l\nu$ channel Standard hadronic event selection $\Rightarrow$ $E_{vis} >\sim 0.2\sqrt{s} \Rightarrow$ isolated lepton(slim jet). Aleph - e, μ identification, Delphi- just one isolated track; L3,OPAL- e, μ, τ(1 or 3 tracks slim jet).
- Event is forced in 3 jets (one jet - lepton) $\Rightarrow$ 1-C fit ($m_\nu = 0$) $\Rightarrow m_{l\nu}; m_{qq}$ is calculated $\Rightarrow$ $m_{l\nu} \sim M_W \Rightarrow m_{qq} < 70$ GeV (anti WW cut !).
- b(c)-jets are identified as most(least) energetic $\Rightarrow E_b > 50$GeV $\Rightarrow$ b- tagging .
- ALEPH, DELPHI use sequential cuts; L3- NN 12 inputs 25 hidden nodes 3 outputs $\Rightarrow$ final variable $NN_{tc} \times (1 - NN_{WW}) \times (1 - NN_{qq})$.OPAL- binned likelyhood.

Event Selection leptonic channel



Event Selection $qql\nu$



L3

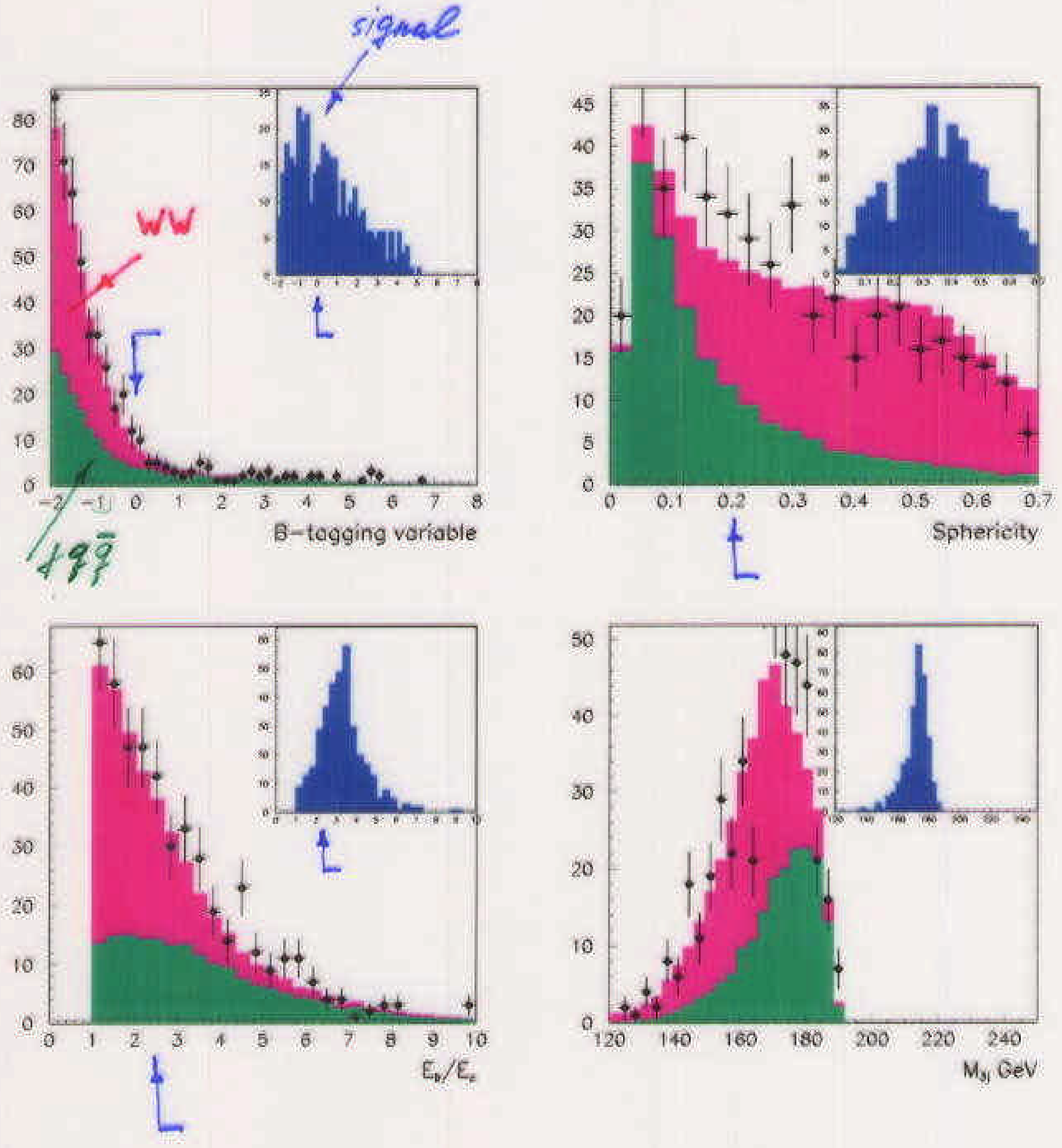
$\sqrt{s}$	189 GeV				192 GeV				196 GeV			
	A	D	L	O	A	D	L	O	A	D	L	O
$\#ev$	4	0		3	0	1			1	0		
bkg	2.2	1.0		4.0	0.3	0.6			1.4	1.7		
$\epsilon\%$	7.0	6.8		6.8	6.2	8.0			5.5	7.0		
$\sqrt{s}$	200 GeV				202 GeV				Sum_E ($\bar{E}$=193.8 GeV)			
	A	D	L	O	A	D	L	O	A	D	L	O
$\#ev$	1	2			0	0			6	3	10	
bkg	1.0	1.9			0.8	0.9			5.7	6.1	9.0	
$\epsilon\%$	4.9	5.0			3.5	5.0			5.9	6.2	7.5	

Total LEP: # ev 22 ; #*bkg* 24.8

Event Selection 4q channel

- Standard hadronic events selection $\Rightarrow$ 3-5 jets
- Global cuts: $E_{vis} > 0.7 \times \sqrt{s}$, Sph > 0.2, and/or Thrust < 0.82.
- Event forced into 4 jets $\Rightarrow$ 4-c or 5-c kinematic fit ($\sum_{i=1,4} E_i = \sqrt{s}, \sum_{i=1,4} \vec{p}_i = 0$ and $M_{i,j} = M_W$) $\Rightarrow$ the least energetic jet= c , the most energetic =b.
- b- tag for the "b" jet , cut on $E_b, E_c, E_b/E_c, \beta_W$, anti-b cut for the jet with the second b-tag value.
- ALEPH, DELPHI using sequential cuts, L3, OPAL construct combined variable (binned likelihood function).

Event Selection 4q channel
Delphi Preliminary



Results of the event selection in 4q channel

$\sqrt{s}$	189 GeV				192 GeV				196 GeV		
	A	D	L	O	A	D	L	O	A	D	L
$\#ev$	21	2		10	5	1			13	4	
bkg	16.3	6.9		9.0	2.7	1.5			10.2	4.0	
$\epsilon\%$	17.0	5.3		14.8	16.0	8.4			14.6	7.3	
$\sqrt{s}$	200 GeV				202 GeV				$\Sigma_{\bar{E}}(\bar{E}$=193.8 GeV)		
	A	D	L	O	A	D	L	O	A	D	L
$\#ev$	9	2			4	5			52	14	50
bkg	10.3	5.0			5.0	2.5			44.5	18.8	54.6
$\epsilon\%$	13.1	7.9			14.3	8.1			15.4	6.8	10.5

Total LEP: $\#$ ev 126 ; $\#bkg$ 127.0

Combined results on the x-section 95 % upper limits.

$\sqrt{s}$	189 GeV				192 GeV			
	A	D	L	O	A	D	L	O
σpb	0.33	0.2		0.35	1.18	0.99		
$\sqrt{s}$	196 GeV				200 GeV			
	A	D	L	O	A	D	L	O
σpb	0.67	0.42			0.48	0.46		
$\sqrt{s}$	202 GeV				Total($\bar{E}$=193.8 GeV)			
	A	D	L	O	A	D	L	O
σpb	0.72	1.28			0.23	0.12	0.136	

Combined LEP: $\sigma < 90$ fb $\bar{E}$ =193.8 GeV

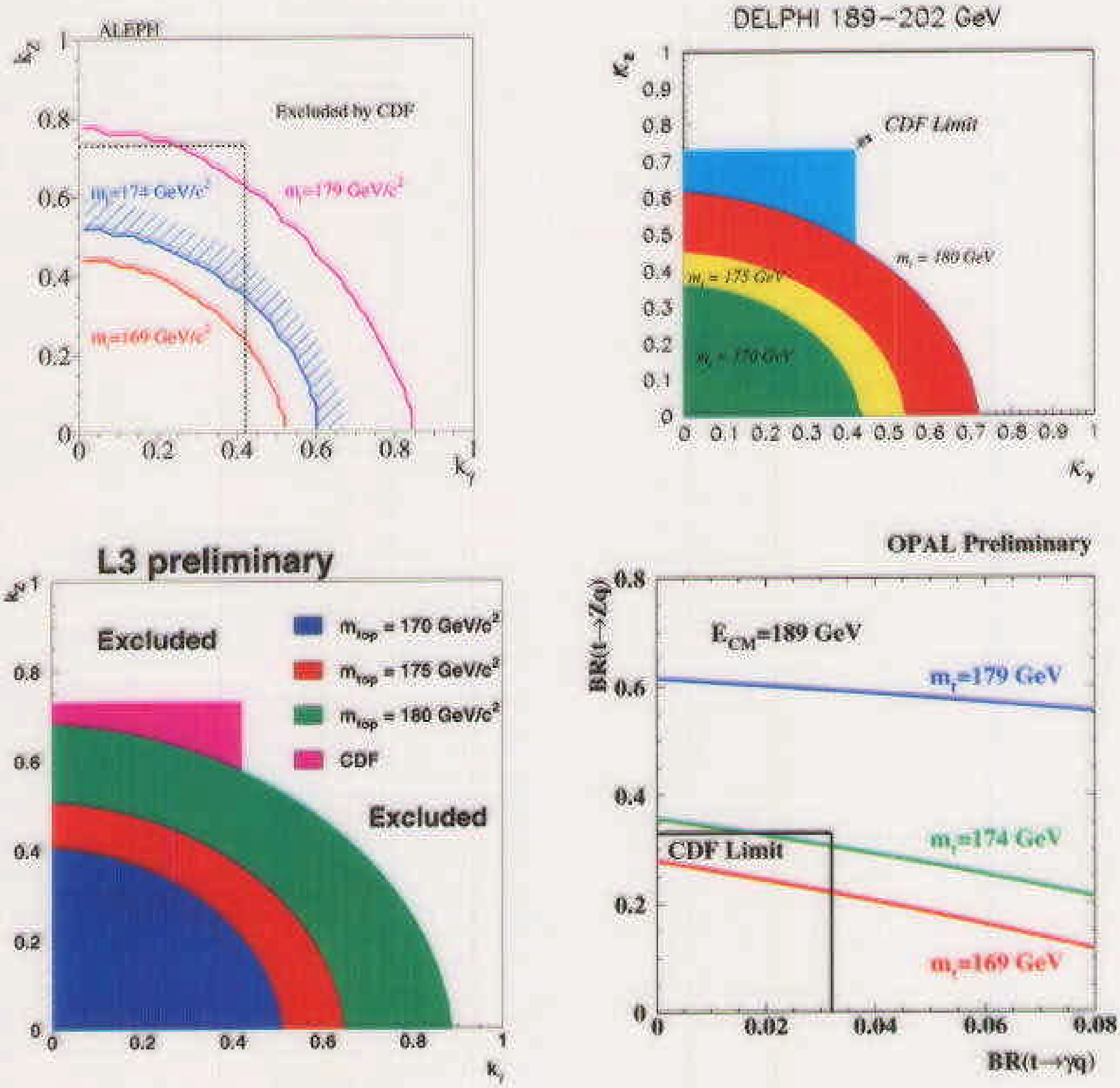
Arbuzov,Osipov Yad.Fiz. 62(1999)528 predict

$\sigma_{t\bar{c}+\bar{t}c} \sim 40$ fb $\sqrt{s}$=192 GeV.

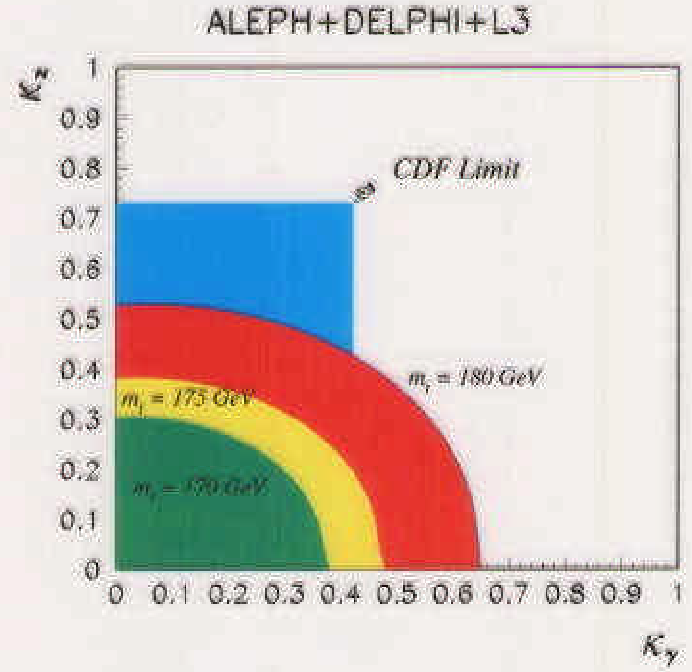
Final results

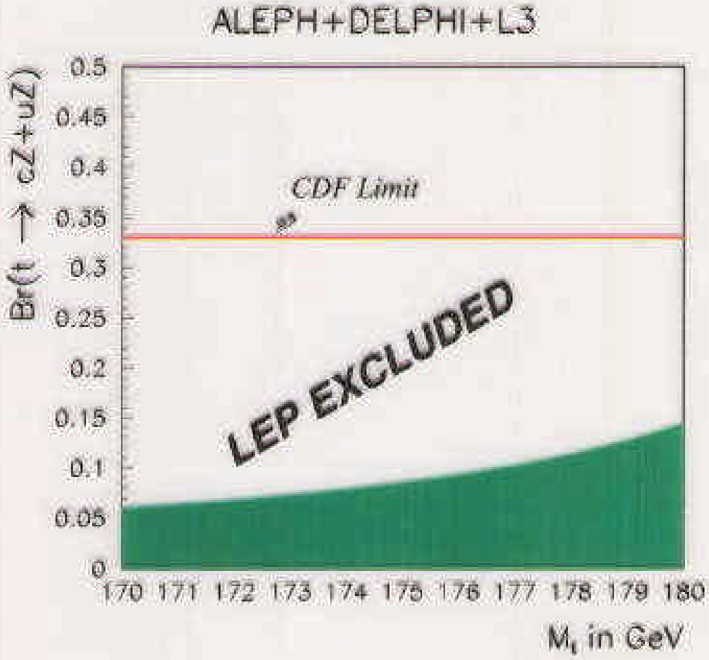
The final results are presented as 95% exclusion regions in κ_γ, κ_z plane. ALEPH,DELPHI do that by a fit which combines results at different energies, taking into account the dependence of the x-section on $\sqrt{s}$. The QCD correction for the x-section ($\sim 5\%$ increase) is taken into account as well as the dependence of Br($t \rightarrow Wb$) on κ_γ, κ_z L3 is using simplified procedure, when all the data are assigned to one average energy of $\bar{E}$=193.8 GeV. OPAL, L3 assume Br($t \rightarrow Wb$) =1

Final results



Very Preliminary! Combination of the ALEPH,DELPHI,L3 data


ALEPH+DELPHI+L3
κ_z
CDF Limit
m_t = 180 GeV
m_t = 175 GeV
m_t = 170 GeV
κ_γ
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1


ALEPH+DELPHI+L3
Br(t → cZ+uZ)
CDF Limit
LEP EXCLUDED
170 171 172 173 174 175 176 177 178 179 180
M_t in GeV

Conclusions

- An impressive progress has been achieved since Tampere conference.
- If compared with CDF measurement, the limit on the Br($t \to cZ$)is improved by factor of 3 !
- Still progress is expected in future: the Y2K ($\sim$ 100 pb^{-1}/experiment already accumulated) $\Rightarrow$ combination of the results of all 4 LEP experiments. $\mathcal{L} \simeq 1.2 fb^{-1} \Rightarrow 2.2 fb^{-1}$. As a result, it will become possible to constraint some theoretical models.