Preliminary Exotica Results at $\sqrt{s} = 189$-209 GeV from the LEP Experiments

ALEPH DELPHI L3 OPAL

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on behalf of the
LEP EXOTICA
Working Group

OUTLINE

INTRODUCTION

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Motivation and Combination Procedure

EXCITED LEPTONS

Compositeness
Topologies and Decay Modes
Limits on the Compositeness Scale versus M_{ℓ^*}

SINGLE TOP PRODUCTION

Kinematics
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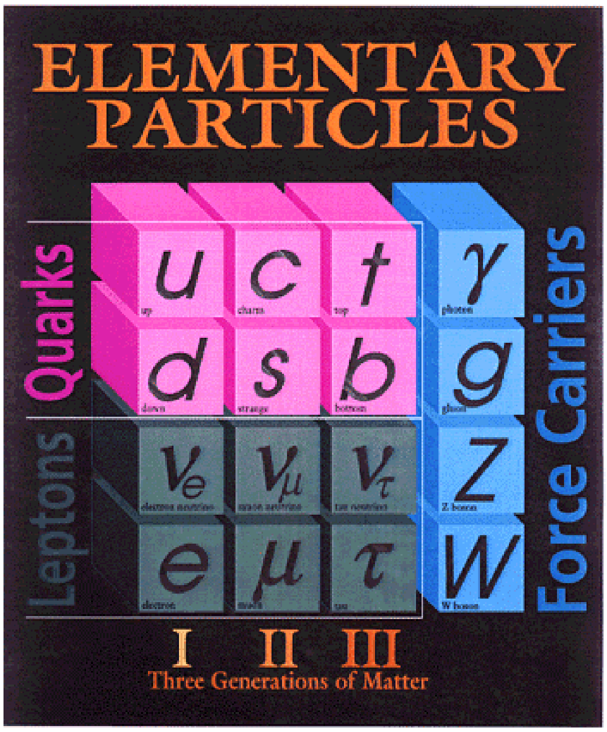
Results
Limits on FCNC

TECHNICOLOR

Toward LEP Combination

SUMMARY

Tests of the Standard Model



Extend the SM

- New Forces
- Substructure
- Anomalous Couplings
- Extra Dimensions

$\Downarrow$

Motivation For New Searches

FCNC — Compositeness

LeptoQuarks — Technicolor

Mandate of the LEP EXOTICA WG

Combination of all non-Higgs and non-SUSY searches at LEP2

Data Samples for Combinations

About 2.4 fb^{-1} ($\sim$600 pb^{-1} per experiment) at $\sqrt{s} = 189 - 209$ collected in 1998-2000.

Combination Procedure

The statistical procedure adopted for the combination of the different channels is the likelihood ratio method:

$$X = \mathcal{L}(s+b)/\mathcal{L}(b)$$

Test two hypotheses "b" and "$s+b$" and consider the ratio:

$$CL_s = \frac{CL_{s+b}}{CL_b} = \frac{P_{s+b}(X \le X_{\rm obs})}{P_b(X \le X_{\rm obs})}$$

The 95% CL lower limit is set by identifying the signal hypothesis which yields $CL_s = 0.05$.

$$X_i = \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i!} \Bigg/ \frac{e^{-b_i} b_i^{n_i}}{n_i!}$$

Easy to combine different topology, centre-of-mass energy, and experiment:

$$X = \prod_{i=1}^{N} X_i$$

Systematic errors affecting the signal and background are included with an extension of the method of Cousins and Highland.

Ref: T. Junk, Nucl. Inst. and Meth. **A434** (1999) 435.

Search for Excited Leptons at LEP2

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PRELIMINARY COMBINATION

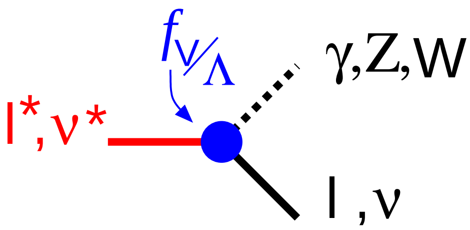
DELPHI + OPAL All the data collected in 1998-2000

D:540.9 pb^{-1} O:600.2 pb^{-1}

Compositeness

Substructure at an energy scale Λ $\Longrightarrow$ Excited leptons ℓ^* & ν^*

Decay promptly $\begin{cases} \ell^* \rightarrow \ell\gamma, \nu W, \ell Z \\ \nu^* \rightarrow \nu\gamma, \ell W, \nu Z \end{cases}$

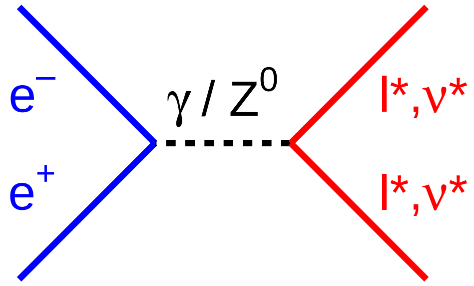


$\left.\begin{matrix} f_\gamma \\ f_Z \\ f_W \end{matrix}\right\} \Longrightarrow f\,,\,f\,'$

Control strength of weak/EM couplings

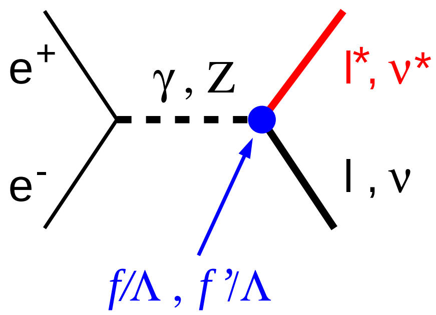
(*e.g.* f=f' no $\nu_e^* \rightarrow \nu_e\gamma$ f=-f' no $e^* \rightarrow e\gamma$)

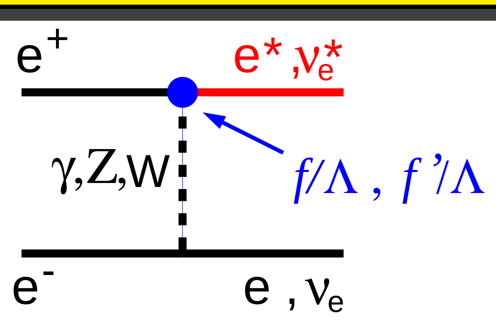
Pair production of Excited Leptons



Discovery up to $\mathrm{M}_{\ell^*} \sim \sqrt{\mathrm{s}}/2$

Single production of Excited Leptons





Discovery up to $\mathrm{M}_{\ell^*} \sim \sqrt{\mathrm{s}}$

Single Production

Direct Searches

$$\boxed{\ell^*\ell} \to \ell\ell\gamma,\quad \nu W\ell,\quad Z\ell\ell$$

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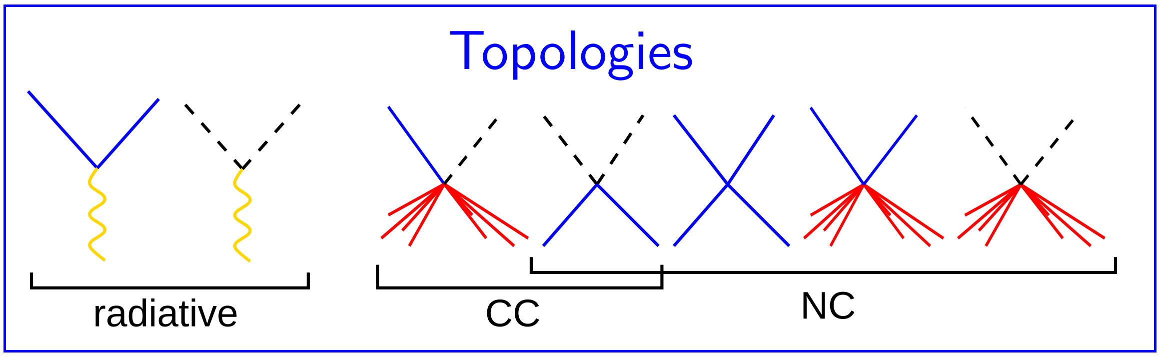
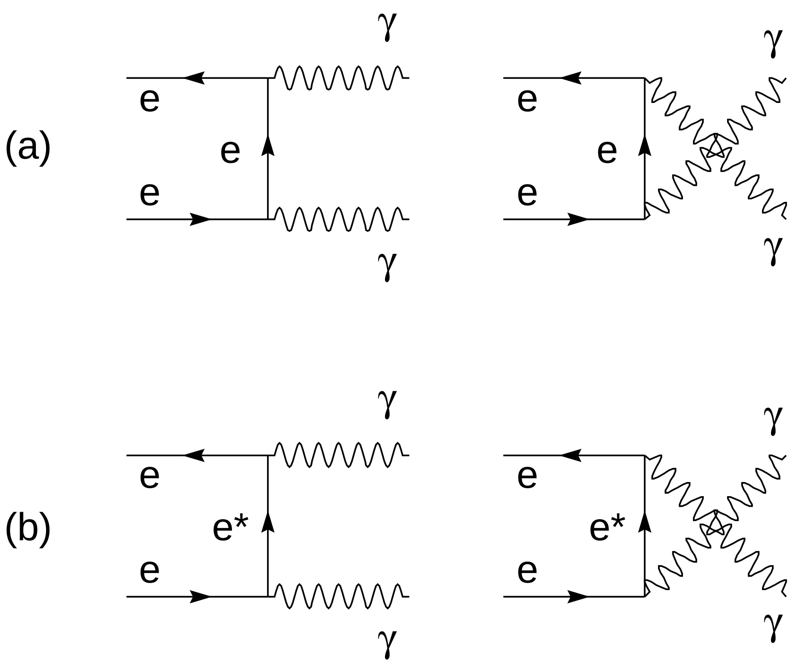


Indirect Searches



Standard Model Contributions

Excited Electron Contributions

Decay Modes: DELPHI and OPAL

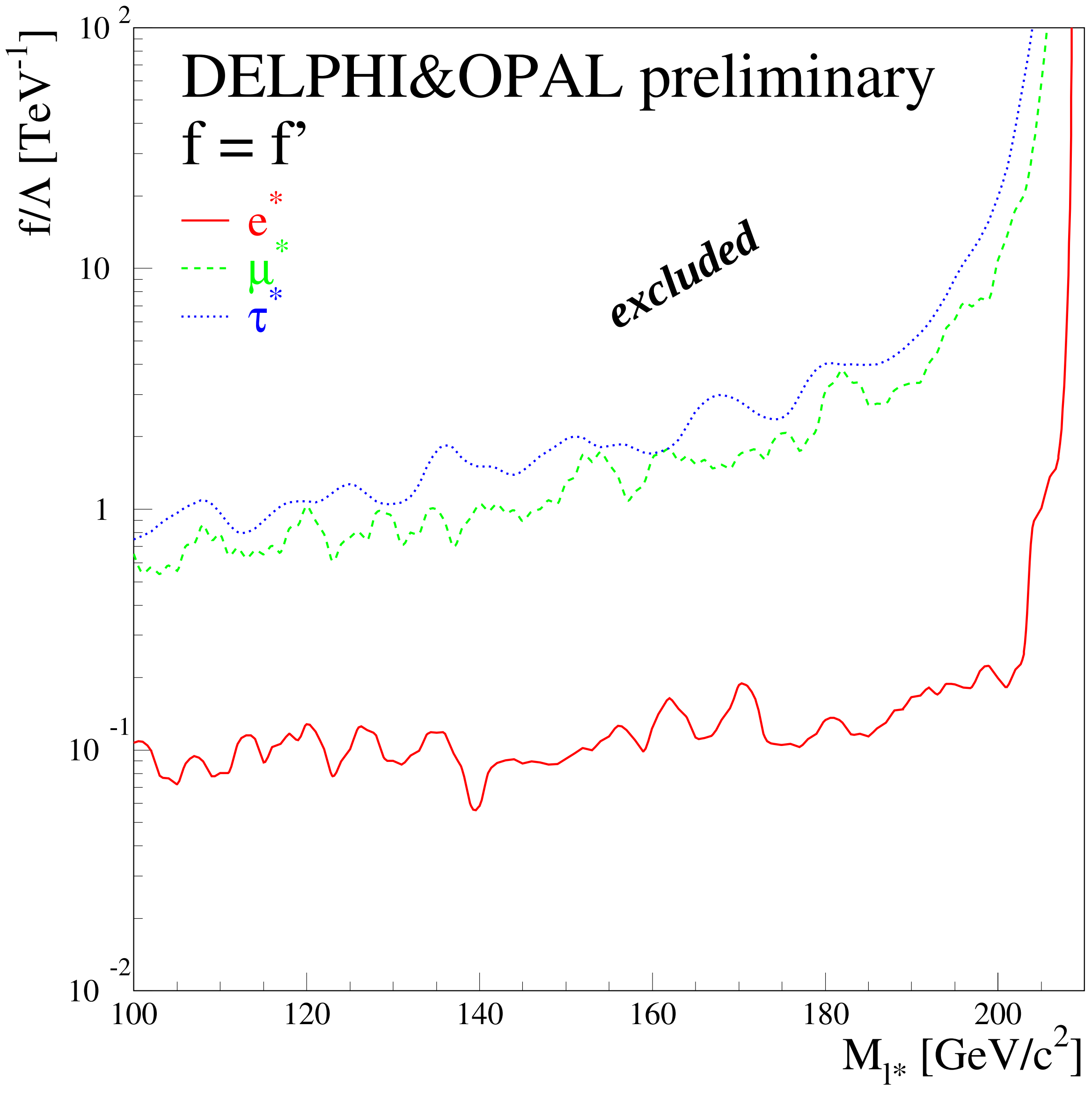
Modes	189 GeV	$192-202$ GeV	$204-208$ GeV
$e^{\star\pm} \longrightarrow e^{\pm}\gamma$	144 (128.0)	174 (172.0)	141 (127.0)
$\mu^{\star\pm} \longrightarrow \mu^{\pm}\gamma$	28 (37.0)	70 (71.0)	43 (44.0)
$\tau^{\star\pm} \longrightarrow \tau^{\pm}\gamma$	62 (49.0)	140 (113.0)	52 (45.0)
$e^{\star\pm} \longrightarrow \nu W^{\pm}$	38 (42.0)	51 (56.0)	21 (27.0)
$\mu^{\star\pm} \longrightarrow \nu W^{\pm}$	22 (21.0)	31 (32.0)	28 (26.0)
$\tau^{\star\pm} \longrightarrow \nu W^{\pm}$	12 (14.0)	18 (17.0)	10 (13.0)
$e^{\star\pm} \longrightarrow e^{\pm}Z^0$	87 (96.0)	128 (132.0)	64 (65.0)
$\mu^{\star\pm} \longrightarrow \mu^{\pm}Z^0$	52 (51.0)	74 (85.0)	58 (66.0)
$\tau^{\star\pm} \longrightarrow \tau^{\pm}Z^0$	86 (81.0)	75 (66.0)	58 (55.0)
$\nu^{\star} \longrightarrow \nu\gamma$	3 (0.7)	9 (3.7)	6 (3.9)
$\nu_e^{\star} \longrightarrow e^{\mp}W^{\pm}$	34 (38.0)	45 (50.0)	15 (22.0)
$\nu_\mu^{\star} \longrightarrow \mu^{\mp}W^{\pm}$	18 (17.0)	25 (27.0)	22 (21.0)
$\nu_\tau^{\star} \longrightarrow \tau^{\mp}W^{\pm}$	33 (30.0)	33 (32.0)	18 (21.0)
$\nu^{\star} \longrightarrow \nu Z^0$	13 (9.0)	6 (11.0)	14 (11.0)
$e^{\star\pm} \longrightarrow e^{\pm}\gamma$	828 (892.2)	914 (1009.3)	739 (899.5)
$\mu^{\star\pm} \longrightarrow \mu^{\pm}\gamma$	66 (85.8)	67 (87.0)	72 (76.1)
$\tau^{\star\pm} \longrightarrow \tau^{\pm}\gamma$	79 (91.4)	84 (88.3)	72 (78.4)

Inputs currently used for the combination

Results: Direct Searches

NO EXCESS OF EVENTS COMPARE TO THE SM EXPECTATION

Exclusion for f/Λ versus M_{ℓ^*} at $\sqrt{s} = 189 - 210\,\mathrm{GeV}$



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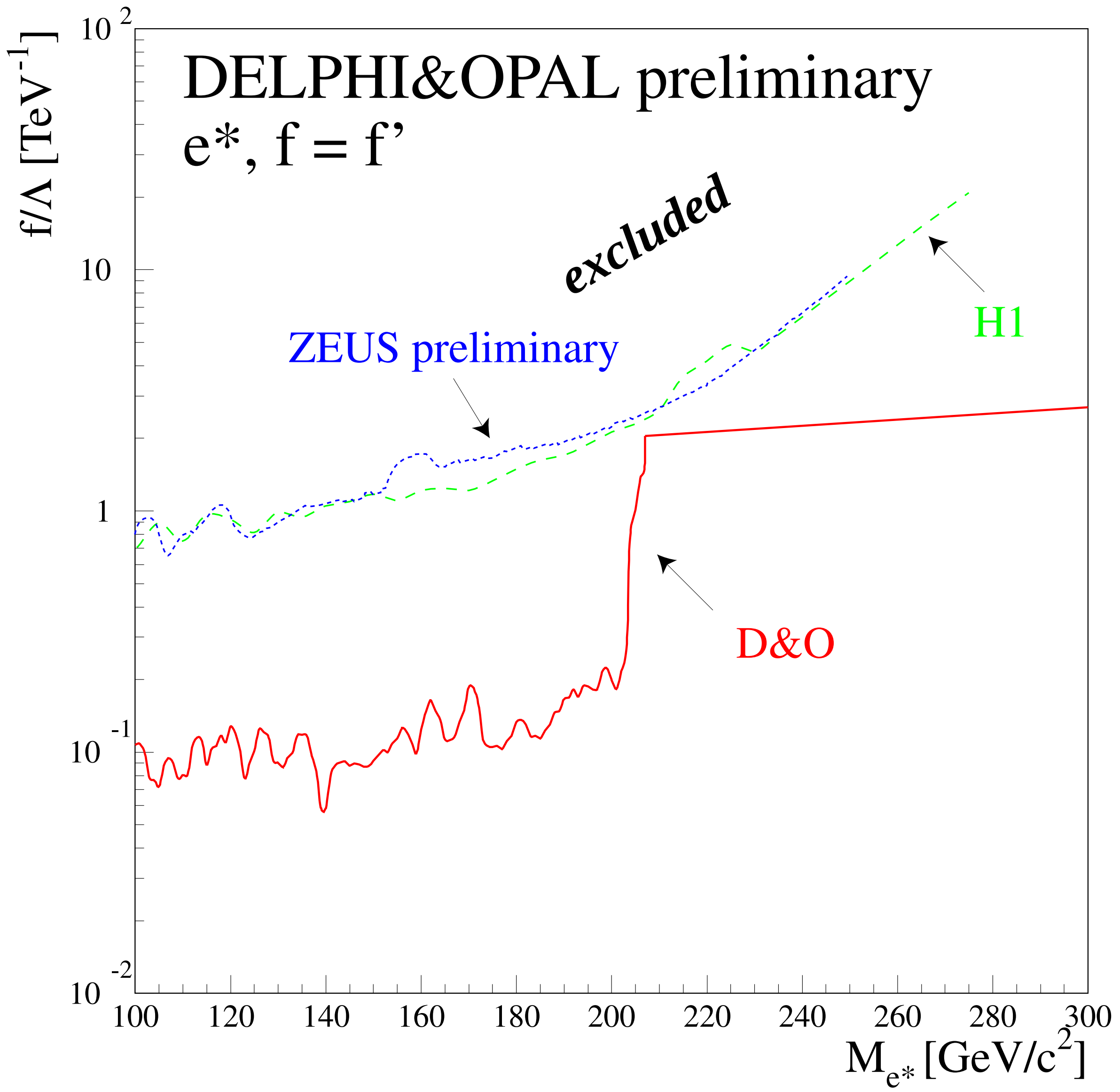


Single Top Production via Flavour Changing Neutral Currents

ALEPH DELPHI L3 OPAL

PRELIMINARY COMBINATION

ALEPH + DELPHI + L3 + OPAL

All the data collected in 1998-2000

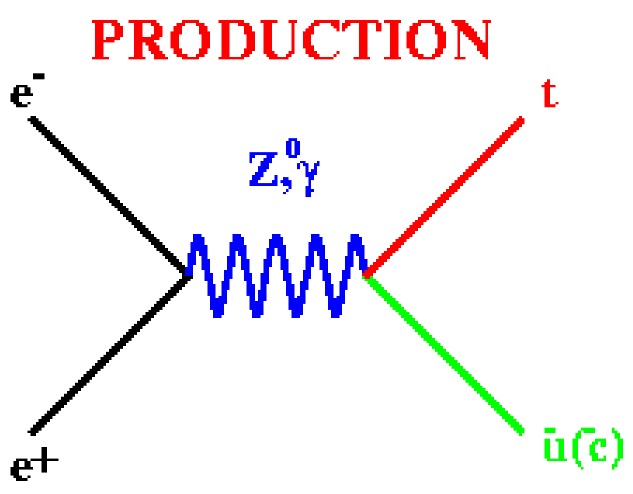
A:624.7 pb^{-1} D:540.9 pb^{-1}
L:626.2 pb^{-1} O:600.2 pb^{-1}

Introduction

Flavour-Changing-Neutral-Currents (FCNC) are known to be absent at tree level in the Standard Model. Neutral currents such as $e^+e^- \rightarrow t\bar{q}$ can be present at the one loop level, but the rates are severely suppressed.

In SM: Single Top Production is $\mathcal{O}(10^{-9})$ fb at LEP2 Energies

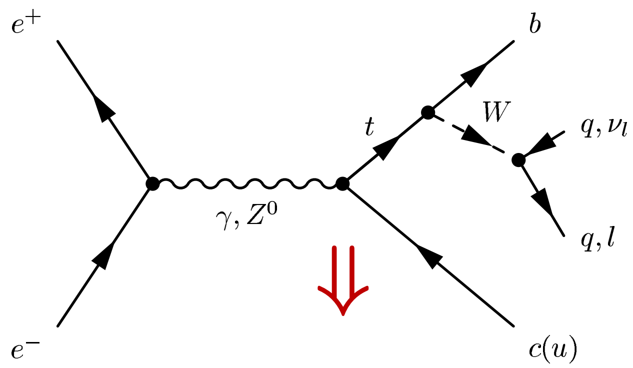
This opens the possibility of using the corresponding FCNC processes to probe for new physics !



Flavour changing vertices are present in many extensions of the SM which could enhance the production of the top quarks.

Single Top Production

At $\sqrt{s} \simeq 189$ GeV:

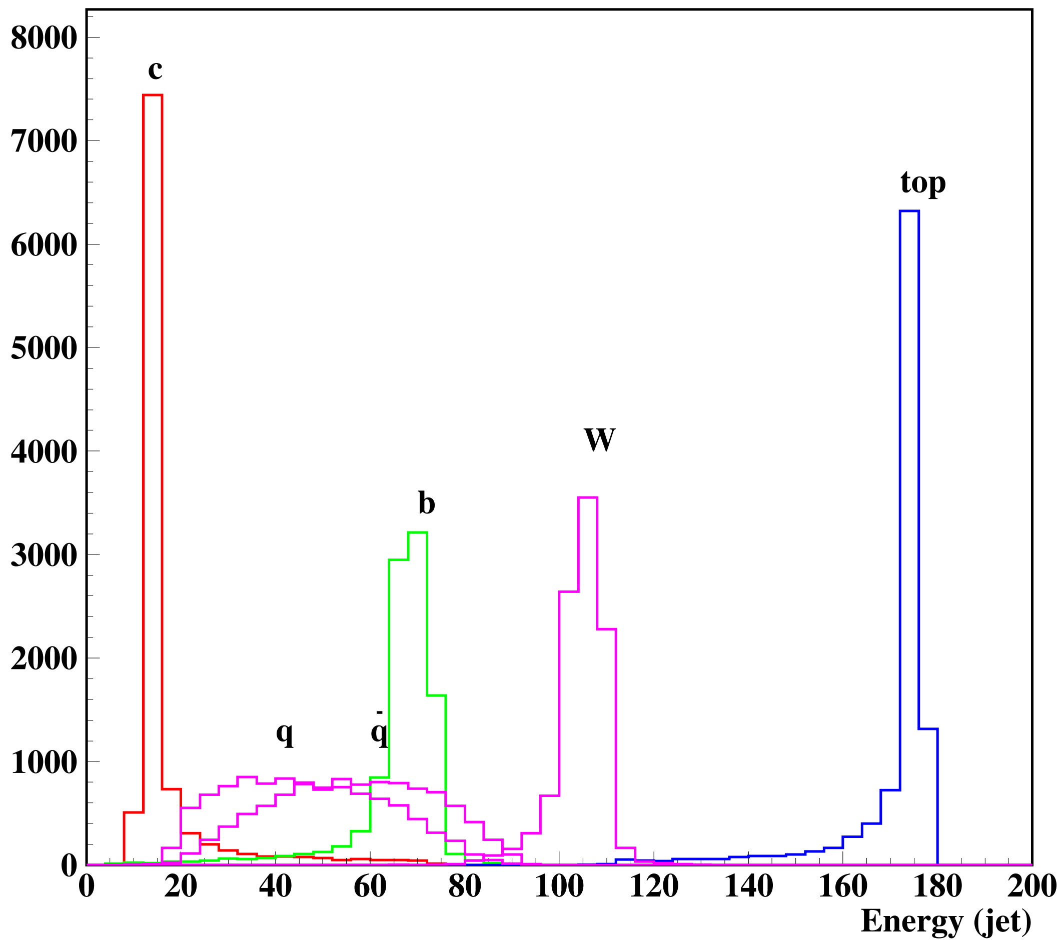


$$E_t \simeq m_t$$
$$E_W \simeq \frac{m_t^2+m_W^2-m_b^2}{2m_t}$$
$$E_b \simeq \frac{m_t^2-m_W^2+m_b^2}{2m_t}$$
$$E_{c(u)} \simeq \sqrt{s}-m_t$$

$\Downarrow$

Coupling Parameters κ_Z and κ_γ

Characteristic Kinematics



Results

Xsection limit at each C.M energy with signal efficiency ϵ and luminosity $\mathcal{L}$:

$$CL_s = \prod_{i=1}^{N} \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i!} \Big/ \prod_{i=1}^{N} \frac{e^{-b_i} b_i^{n_i}}{n_i!}$$

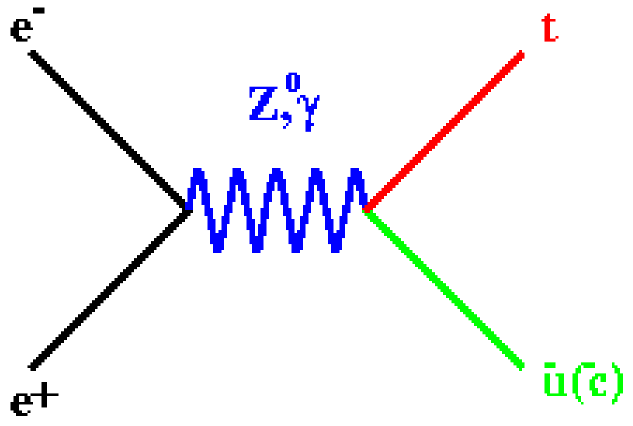
b_i: MC background events
s_i: Number of signal events
N: Number of data channels

$$\sigma_{95}^{\mathrm{obs.}} = \frac{s_{\mathrm{tot}}/\epsilon}{\mathcal{L}}$$

Combination A+D+L+O [cross-section UL in pb]						
Label	$m_{top} = 169$ GeV$/c^2$		$m_{top} = 174$ GeV$/c^2$		$m_{top} = 179$ GeV$/c^2$	
(GeV)	$\sigma_{95}^{\mathrm{obs.}}$	$\sigma_{95}^{\mathrm{exp.}}$	$\sigma_{95}^{\mathrm{obs.}}$	$\sigma_{95}^{\mathrm{exp.}}$	$\sigma_{95}^{\mathrm{obs.}}$	$\sigma_{95}^{\mathrm{exp.}}$
189	0.15	0.14	0.11	0.11	0.13	0.13
192	0.41	0.39	0.38	0.33	0.42	0.36
196	0.38	0.24	0.36	0.20	0.39	0.22
200	0.26	0.24	0.21	0.21	0.24	0.20
202	0.31	0.40	0.30	0.35	0.27	0.35
205	0.27	0.28	0.22	0.25	0.23	0.24
207	0.19	0.20	0.17	0.18	0.15	0.17

Anomalous Couplings

PRODUCTION



Born-Level Cross-Section:

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

$$\left.+\frac{\kappa_z^2(1+a_w^2)(2+\frac{m_t^2}{s})}{4\sin^4 2\vartheta_W(1-\frac{M_Z^2}{s})^2}+3\kappa_\gamma\kappa_z\left(\frac{m_t}{\Lambda}\right)\frac{a_w e_q(g_1z_1+g_2z_2)}{\sin^2 2\vartheta_W(1-\frac{M_Z^2}{s})}\right]$$

with the assumption $\Lambda = m_t$, $g_1^2+g_2^2=1$, and $z_1^2+z_2^2=1$.

Branching Ratio:

$$\Gamma(t\to c\gamma) = \kappa_\gamma^2\frac{\alpha e_q^2}{4}\left(\frac{m_t^2}{\Lambda^2}\right)m_t$$

$$\Gamma(t\to cZ) = \kappa_z^2\frac{\alpha}{8\sin^2 2\vartheta_W M_Z^2}m_t^3\left(1-\frac{M_Z^2}{m_t^2}\right)^2\left(1+2\frac{M_Z^2}{m_t^2}\right)$$

with the assumption $\Gamma(t\to c\gamma)=\Gamma(t\to u\gamma)$.

QCD and ISR Corrections:

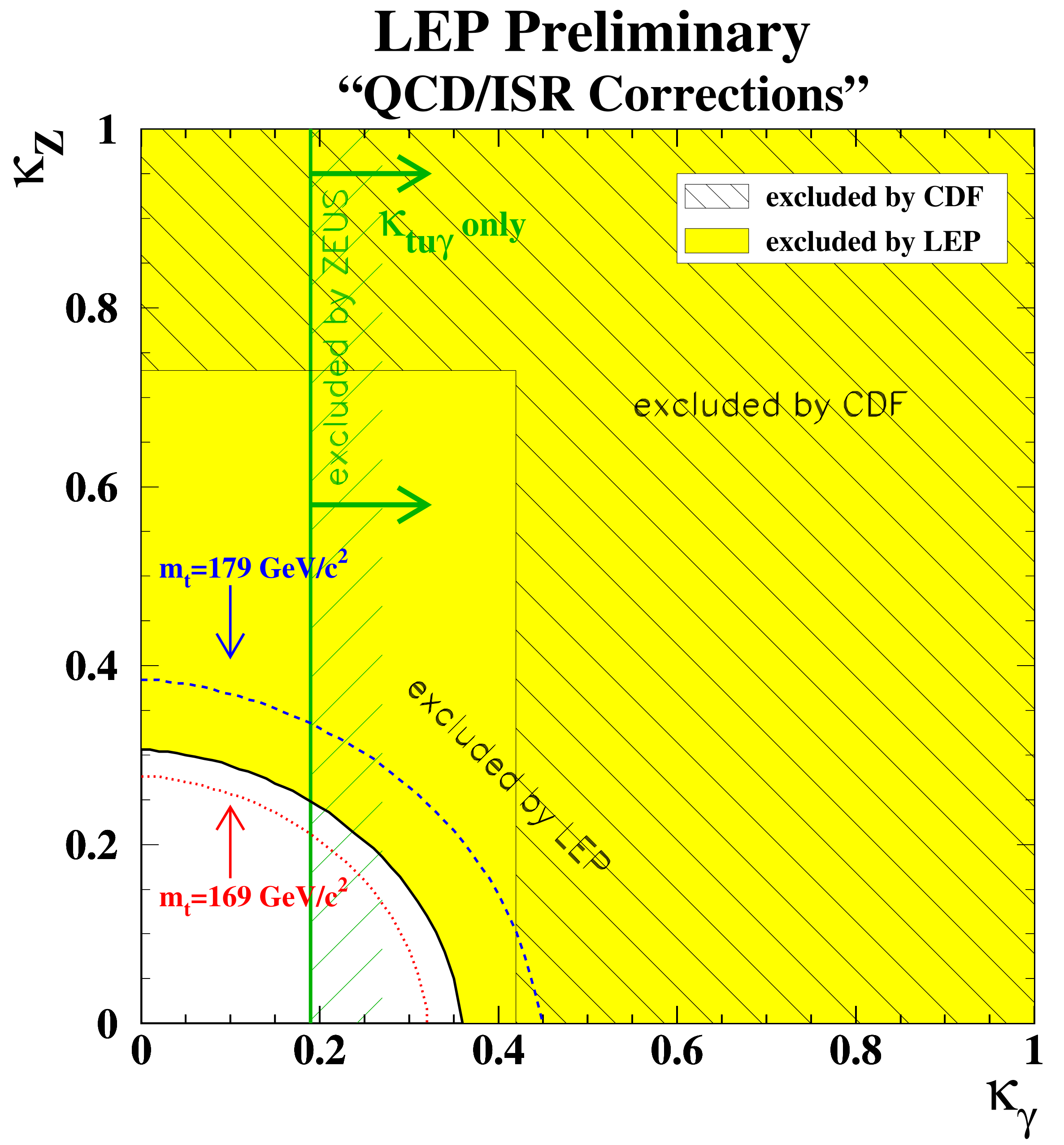
$$\sigma_{\mathrm{Born+QCD}} = \sigma_{\mathrm{Born}}[1+\frac{\delta\Pi(q^2)}{\Pi(q^2)}]$$

QCD corrections increase the σ_{Born} by $\sim 30\%$
ISR corrections suppress the QCD effects
Overall little impact on the exclusion region in $\kappa_\gamma - \kappa_Z$ plane

Results

Combine all experiments, all C.M. energies for the leptonic and hadronic modes

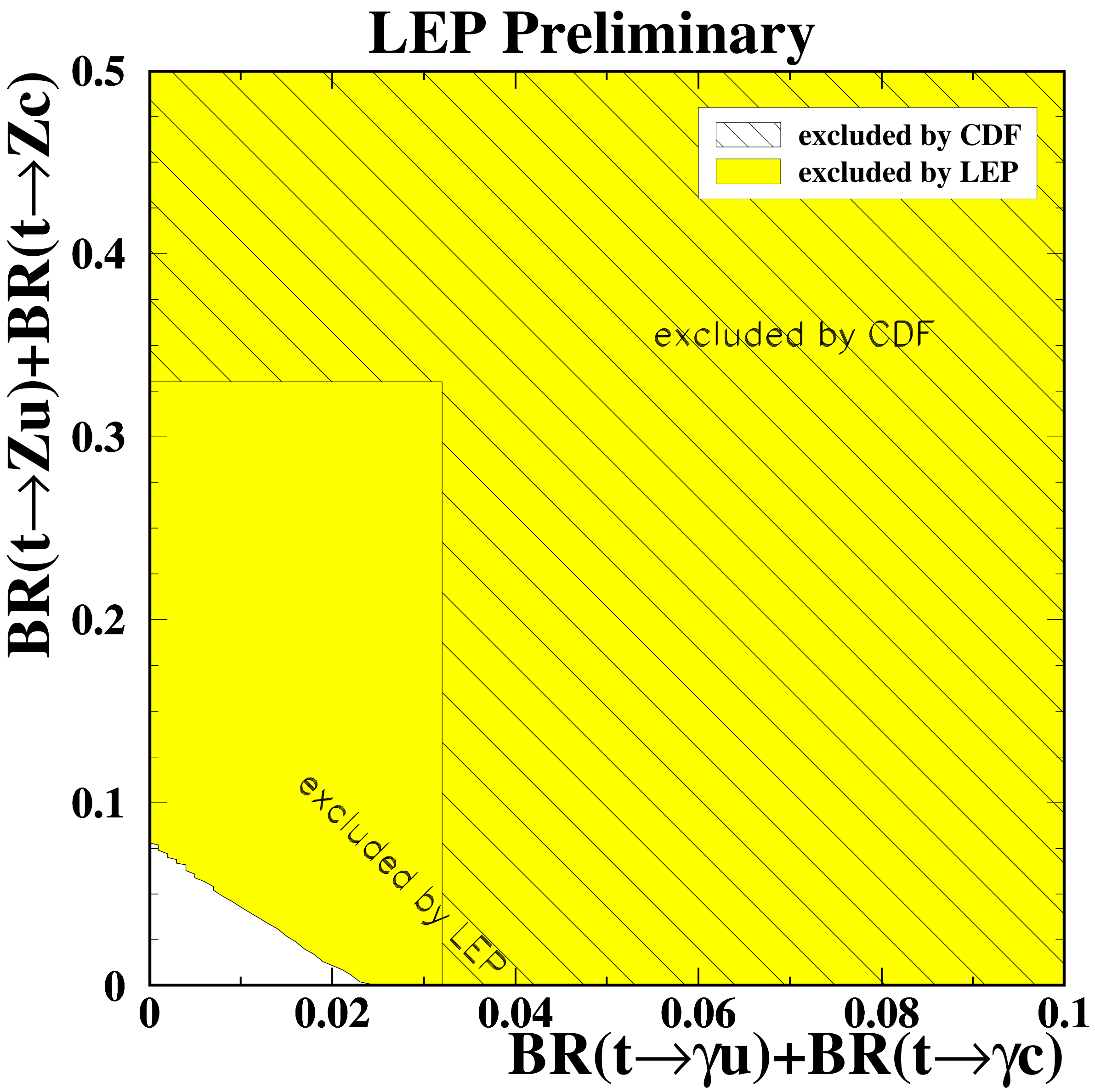
Exclusion in the Plane of the Anomalous Couplings at $\sqrt{s} = 189 - 210\,\text{GeV}$



Results

Combine all experiments, all C.M. energies for the leptonic and hadronic modes

Exclusion in the Plane of the Branching Fractions at $\sqrt{s} = 189 - 210\,\mathrm{GeV}$ ($m_t = 174\,\mathrm{GeV}/c^2$)



Search for Technicolor at LEP2

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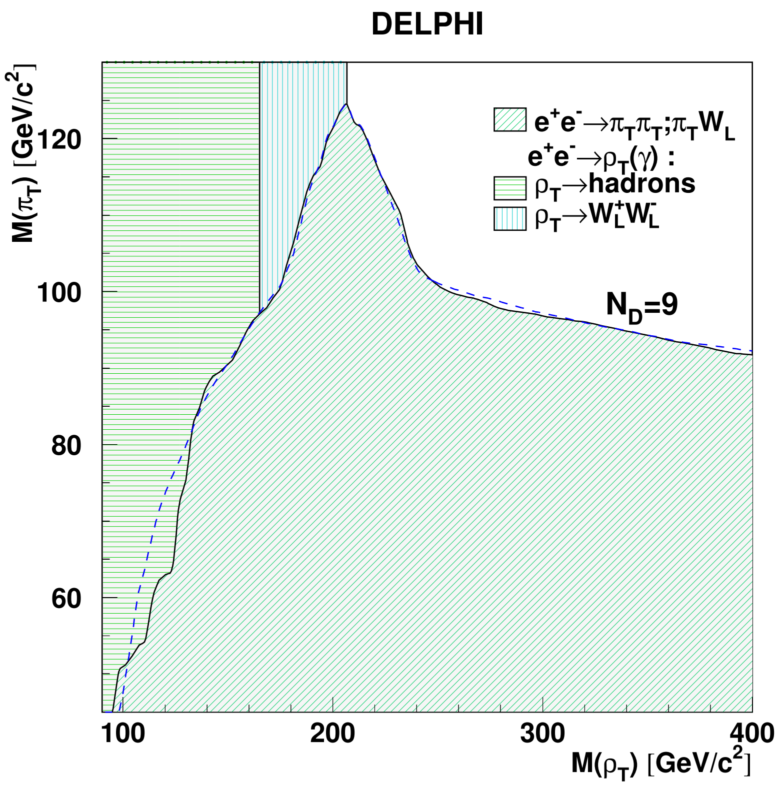
INDIVIDUAL RESULTS

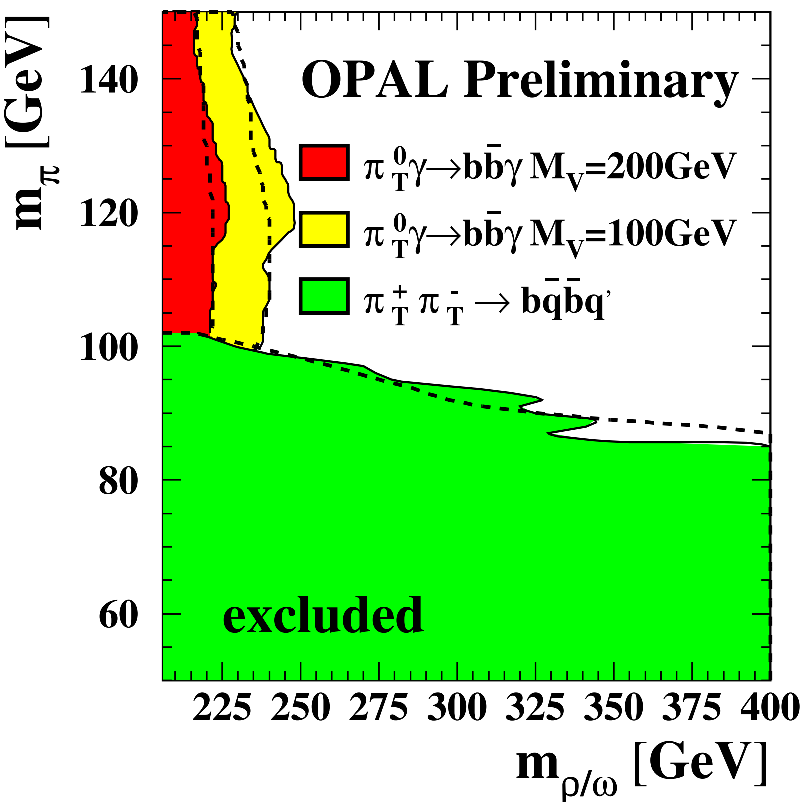
by

DELPHI and OPAL

D:452.0 pb^{-1} 192 – 208 GeV
O:209.4 pb^{-1} 200 – 208 GeV

Technicolor





Summary

- **LEP2 provides data samples with which to look for new physics beyond the Standard Model.**
- **Offers a great variety of experimental probes for the investigation of new phenomena and search for new particles.**
- **Allows a direct search for excited leptons:**

$$f/\Lambda \lesssim \begin{array}{lll} 0.1 & TeV^{-1} & (e^*) \\ 1 & TeV^{-1} & (\mu^*, \tau^*) \end{array}$$

- **Allows a direct search for single top production via FCNC:**

  κ_γ <0.36 and κ_Z <0.31 for $m_t = 174\,\mathrm{GeV}/c^2$

  $\mathrm{Br(t \to Zc) + Br(t \to Zu)} <$ 8.1% for $\kappa_\gamma = 0$

- **Allows a direct search for technicolor and leptoquarks.**
- **First LEP EXOTICA results summarised in:**
  LEP Exotica WG 2001-01
  LEP Exotica WG 2001-02
  for EPS HEP2001 and LP01
- **Forthcoming:** More excited lepton modes, combination of technicolor and leptoquarks.

See: http://lepexotica.web.cern.ch/LEPEXOTICA/