2 fermions and 2 photons production at e^+e^- colliders

The legacy of LEP and SLC

8-11 October 2001

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CIEMAT, Madrid

INDEX

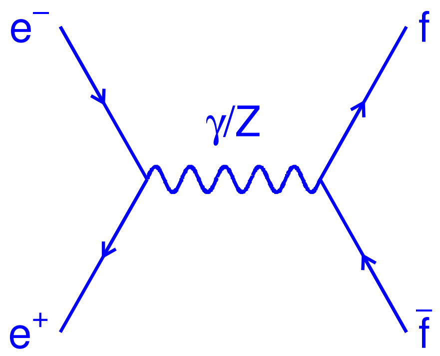
Two fermion production

Two photon production

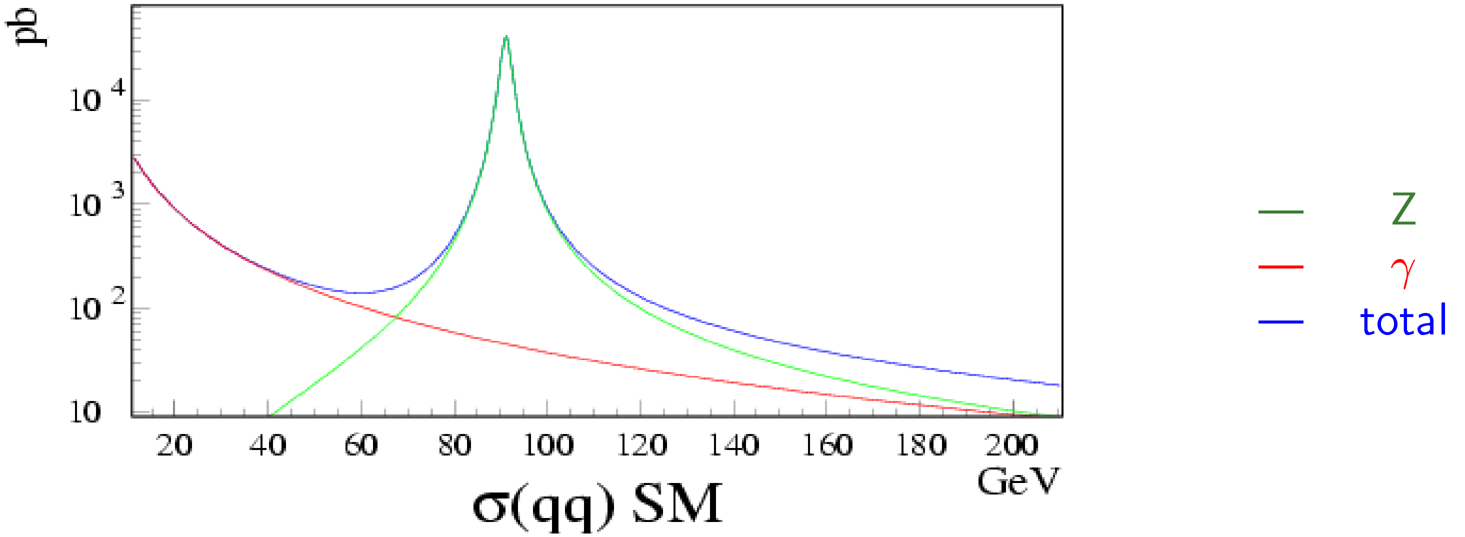
Above the Z peak

TWO FERMION PRODUCTION

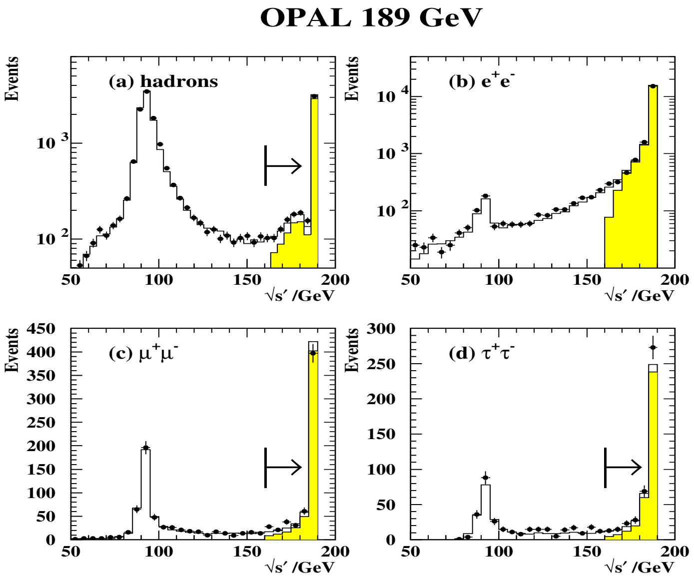
Fermion Pair Production



- γ exchange
- Z boson exchange
- Z/γ interference



SIGNAL DEFINITION



Two peaks in the distribution of the reduced mass energy $\sqrt{s}$

- radiative return peak $\sqrt{s'} \sim \mathrm{M_Z}$ (acolinear events)
- non radiative peak $\sqrt{s'} \sim \sqrt{s}$ (two fermion back-to-back)

Two signal definitions:

- Inclusive events $\sqrt{s'/s} > 0.1$
- Non radiative events $\sqrt{s'/s} > 0.85$

LEP2 $f\bar{f}$ Group

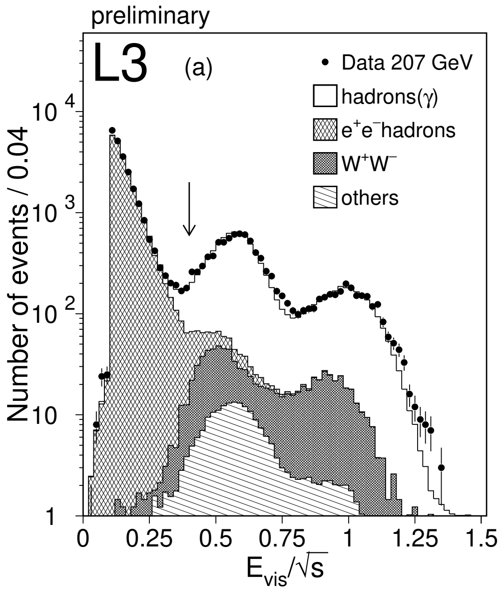
- I will present the results of LEP2 $f\bar{f}$ Group
- Group established to combine: $\sigma_{\rm tot}$, $\frac{\rm d\sigma}{\rm dcos\theta}$ $\rm A_{FB}$ $\rm R_b$, $\rm R_c$ of the process $e^+e^- \rightarrow f\bar{f}$
- Preliminary combination of the measurements of the four LEP collaborations

- Concentrate in non-radiative events $\sqrt{s'/s} > 0.85$
- $\rm e^+e^- \rightarrow e^+e^-$ not yet combined
- Corrections are applied to data before averaging $\rightarrow$ data correspond to a common signal definition

- All averages are performed using a χ^2 technique

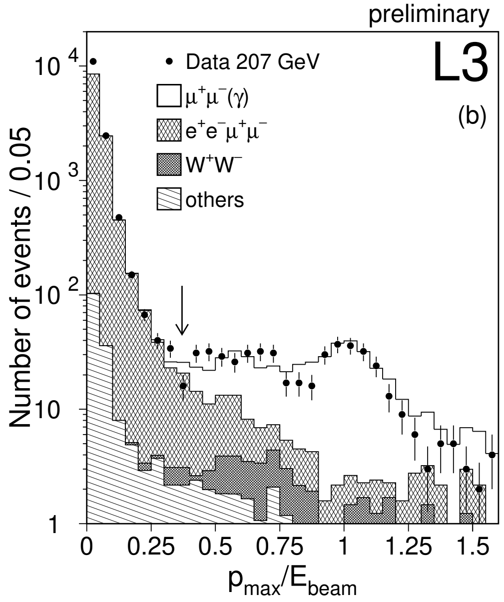
EVENT SELECTION

$e^+e^- \rightarrow q\bar{q}$



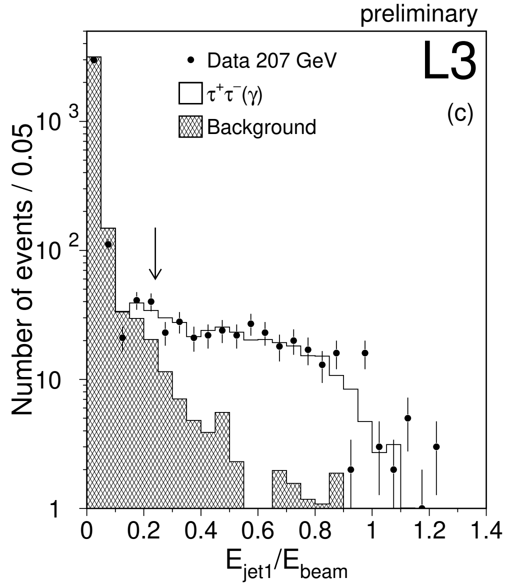
- multiplicity of tracks and electromagnetic calorimeter clusters
- total electromagnetic energy
- energy balance along the beam direction

$e^+e^- \rightarrow \mu^+\mu^-$



- muon pair events are required to have two tracks indentified as muons

$e^+e^- \rightarrow \tau^+\tau^-$

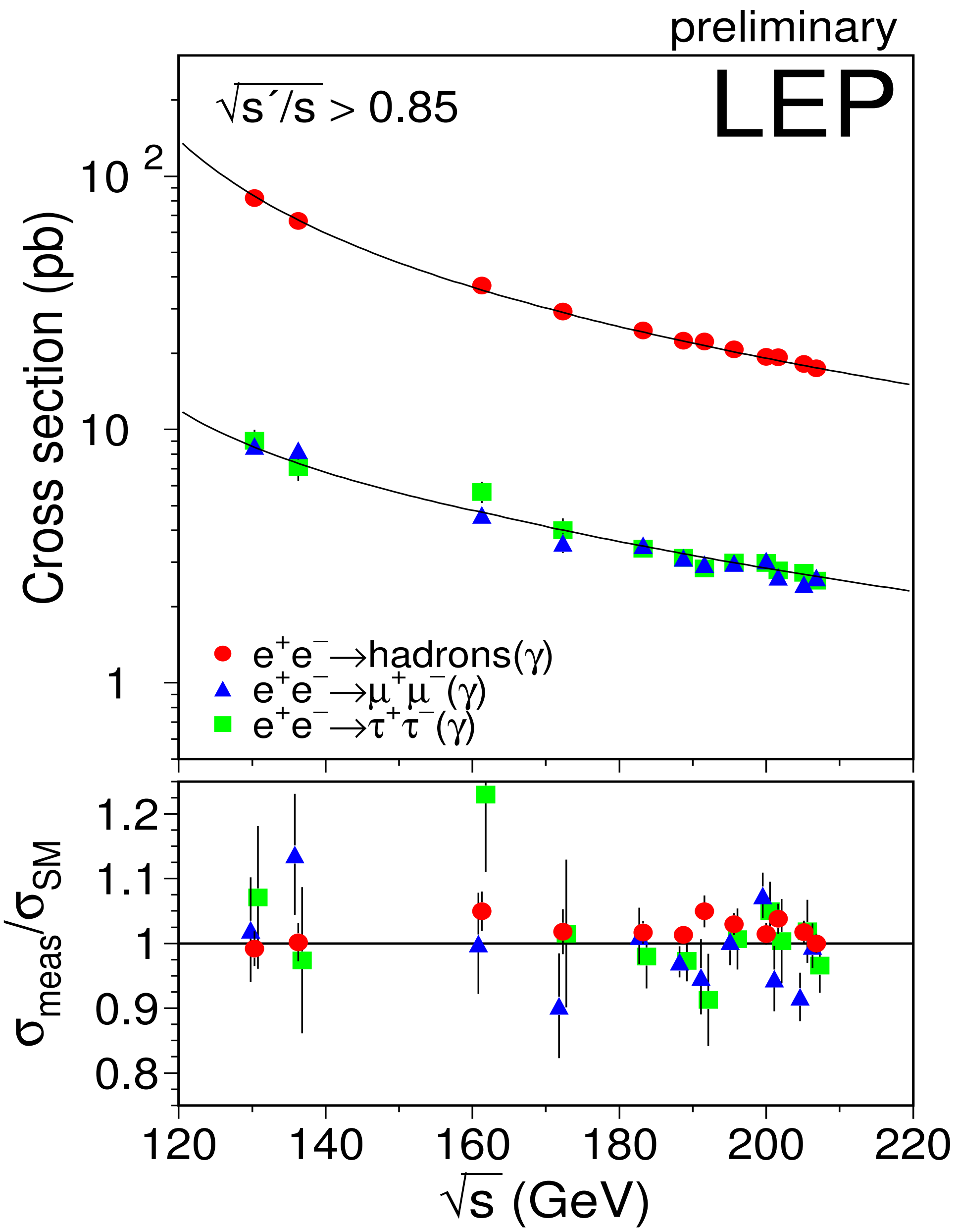


- low multiplicity jets
- ratio of jet to beam energy supresses back-grounds

CROSS SECTION MEASUREMENTS

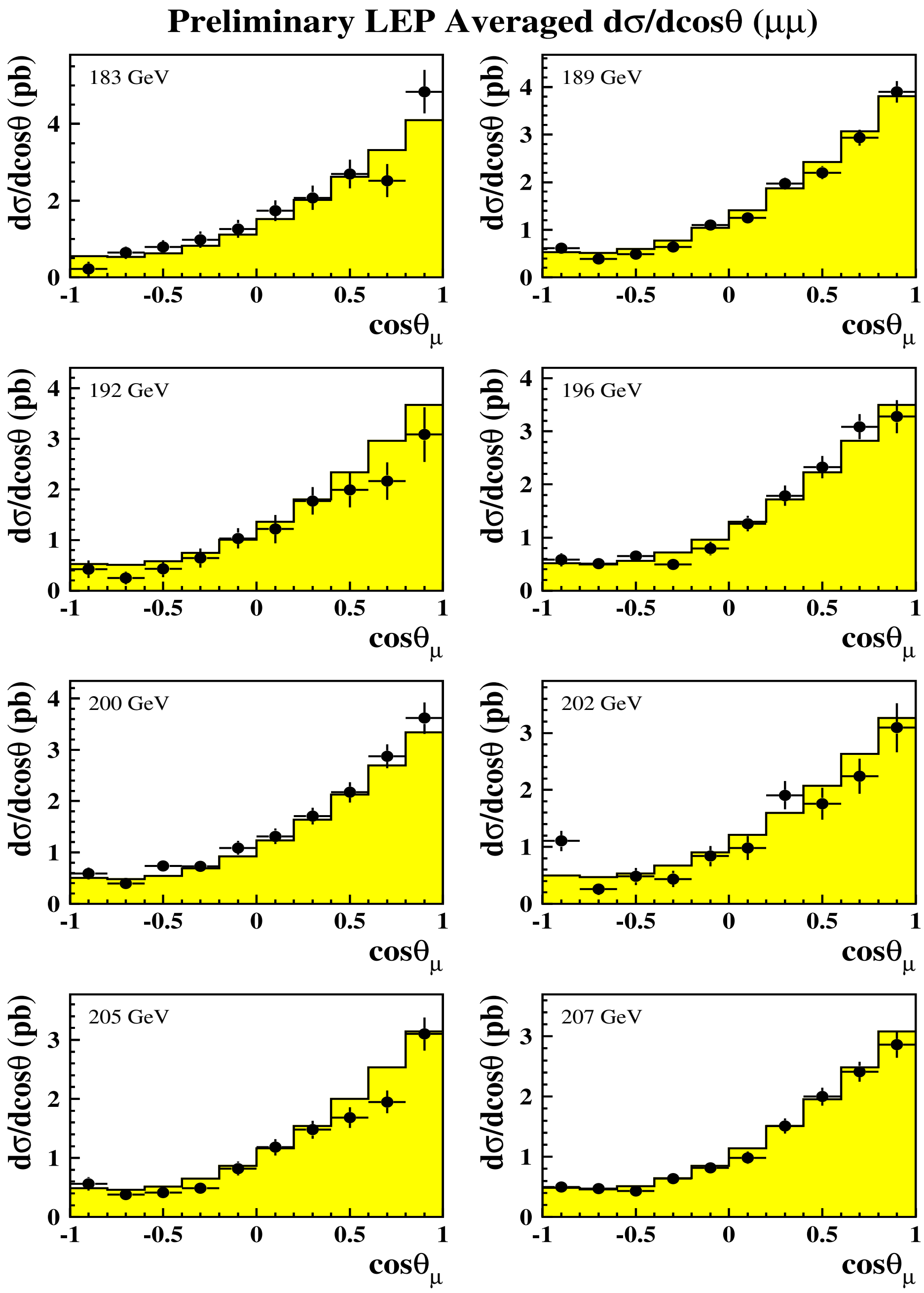
Preliminary LEP results on:

- the cross sections as a function of the center of mass energy
- the ratio between the data and the SM expectation

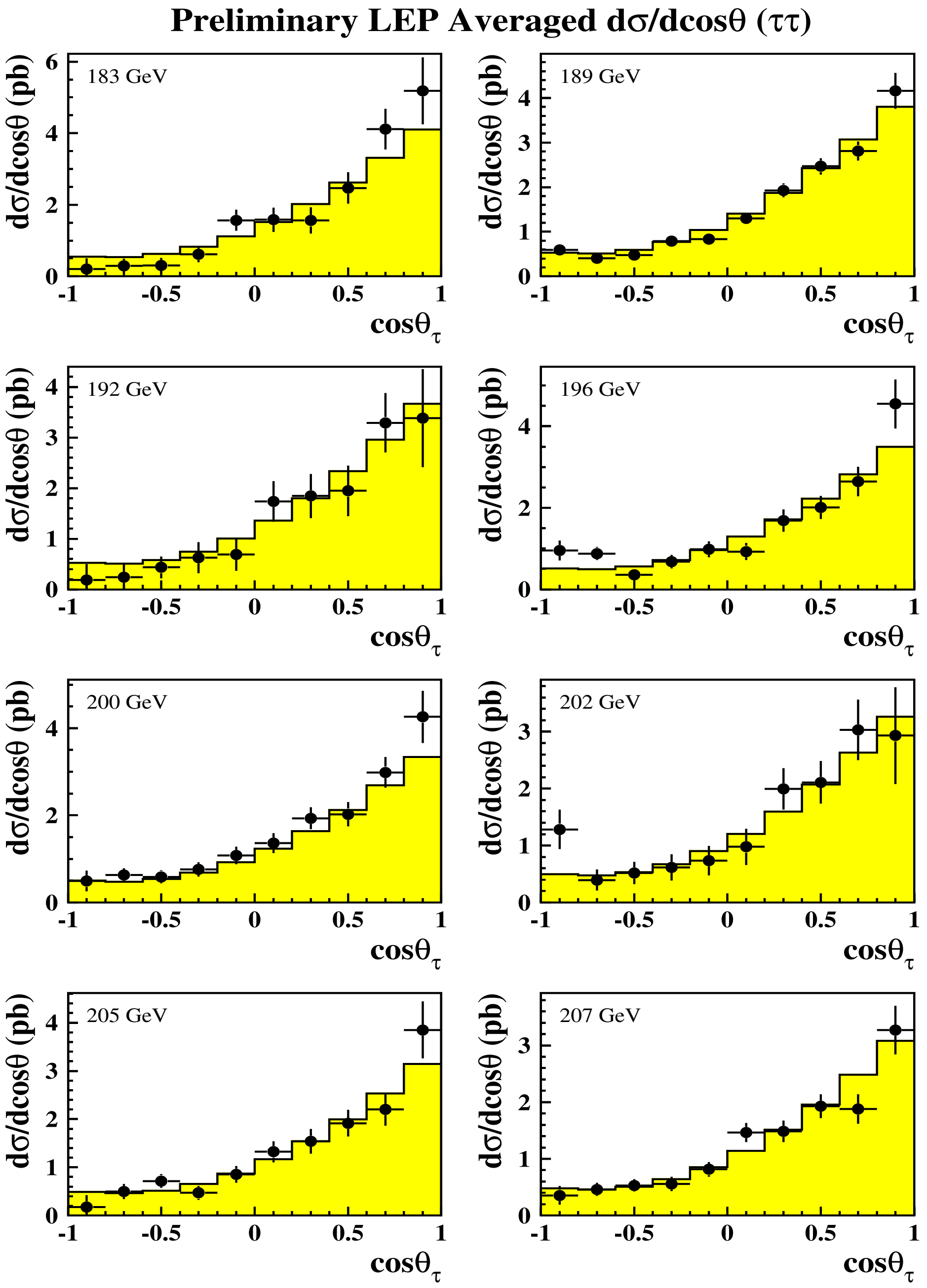


Good agreement. Hadronic excess 1.8 σ averaged over all energies

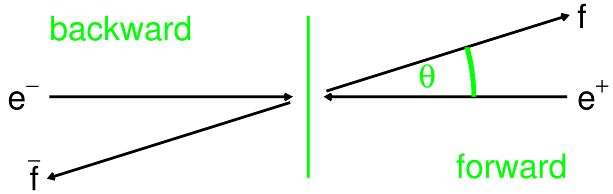
$\mu^+\mu^-$ 183 - 207 GeV



$\tau^+\tau^-$ 183 - 207 GeV

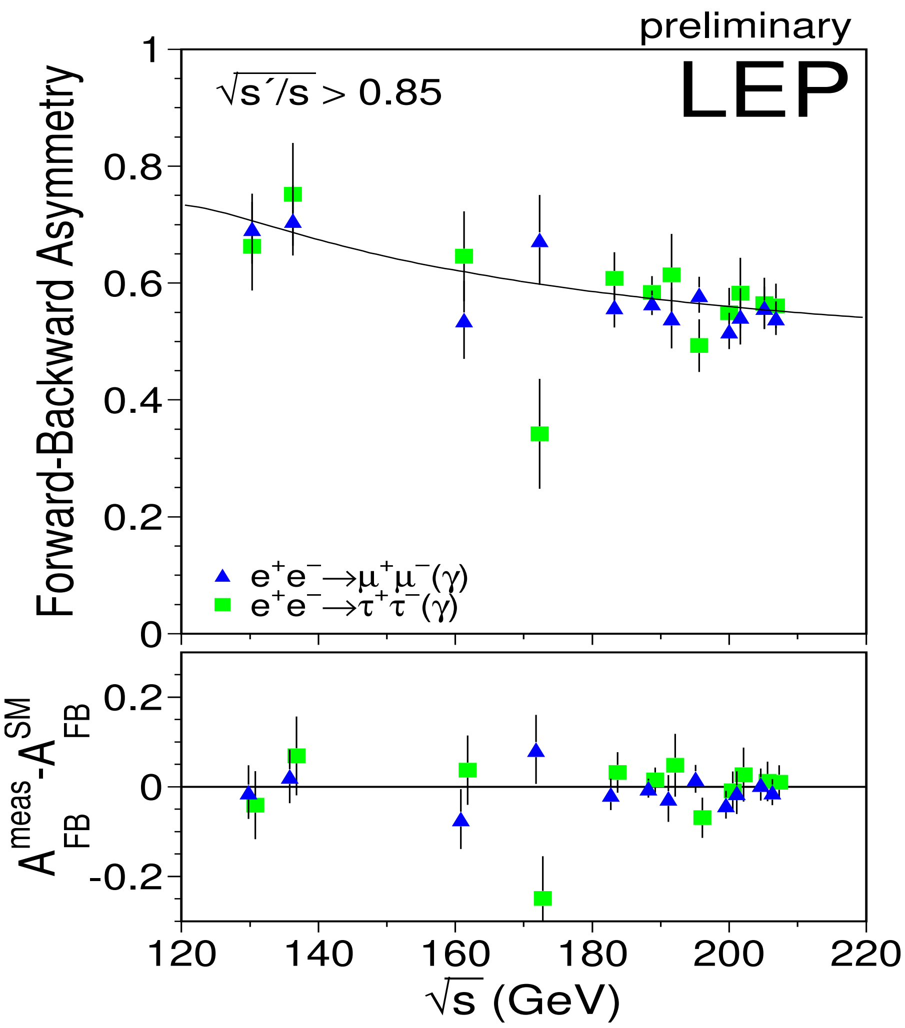


LEPTON ASYMMETRY



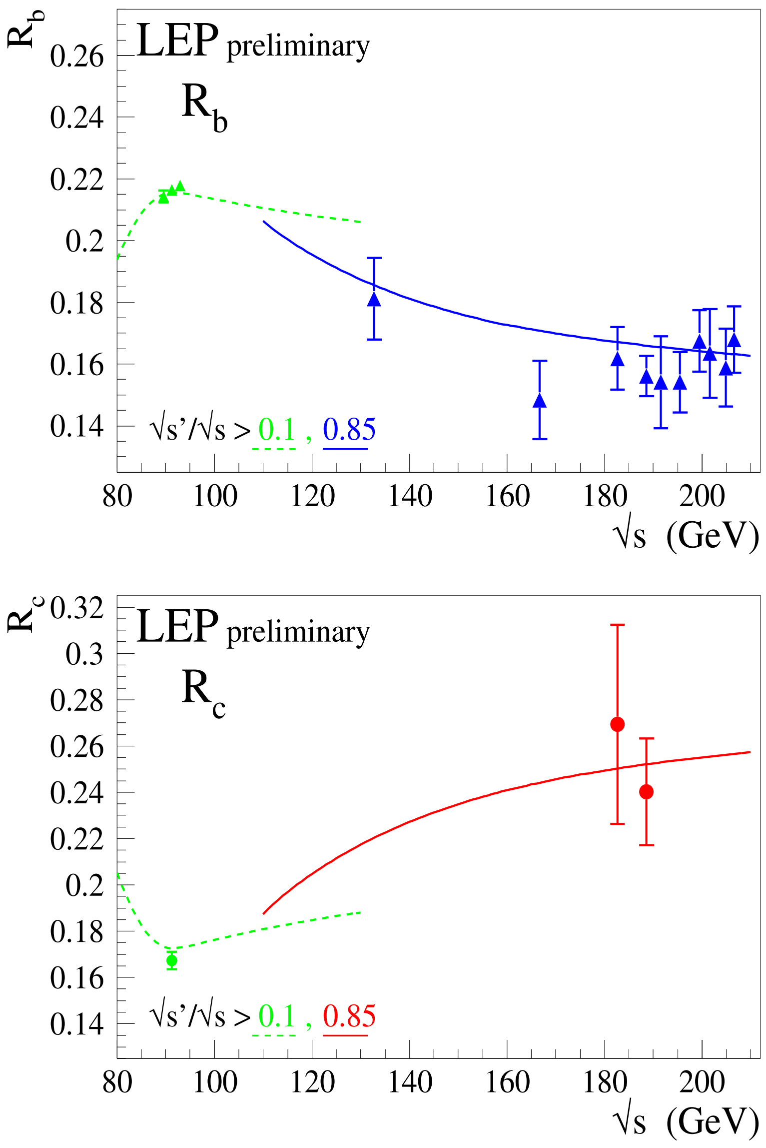
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- The lepton A_{FB} is measured from the angular distribution of the final state lepton
- Good agreement with SM expectations

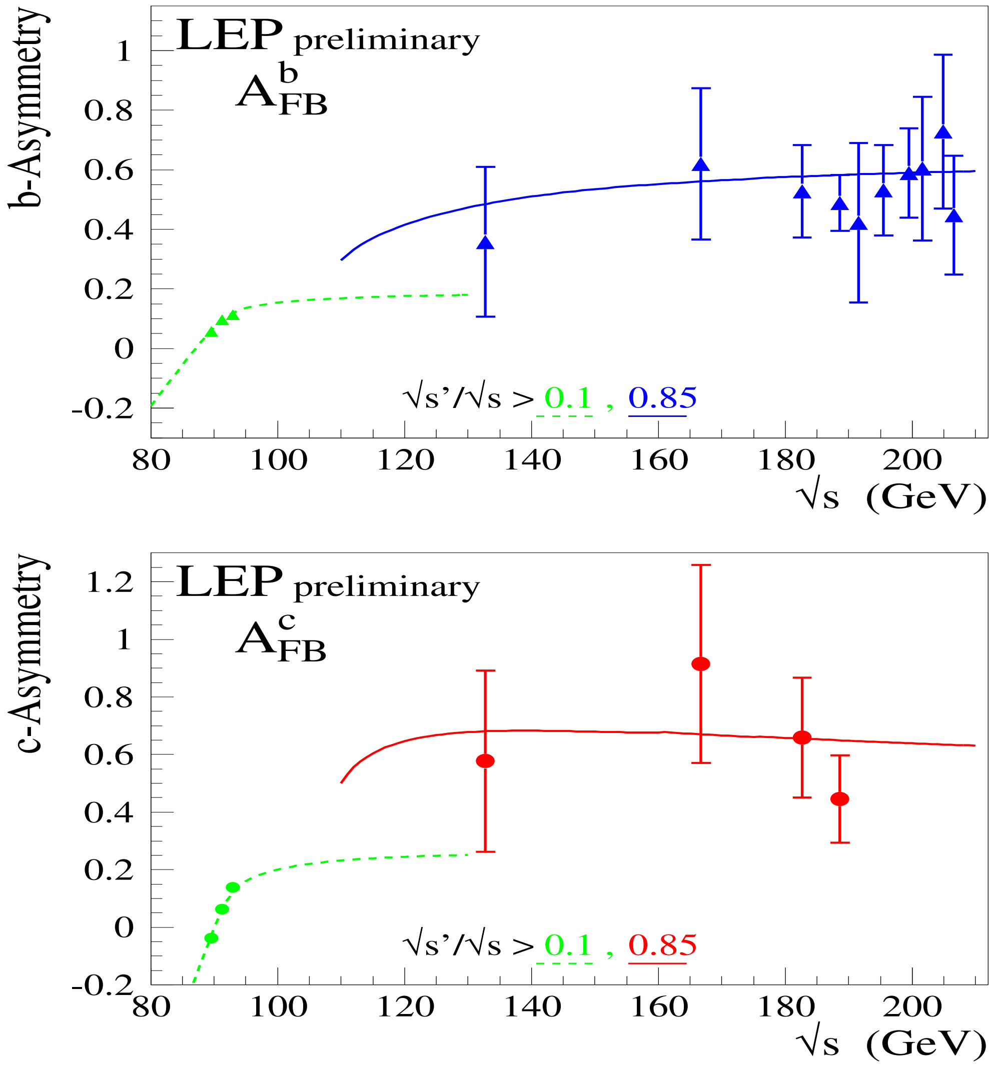


QUARK MEASUREMENTS

$$R_b = \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma(e^+e^- \to q\bar{q})} \qquad R_c = \frac{\sigma(e^+e^- \to c\bar{c})}{\sigma(e^+e^- \to q\bar{q})}$$



ASYMMETRY

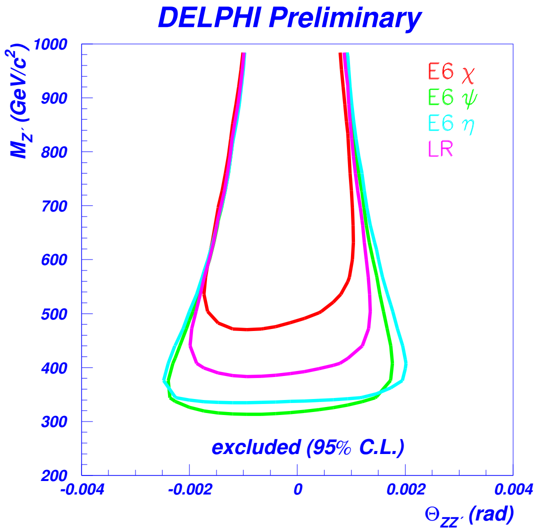


LEP preliminary
A_{FB}^{b}
b-Asymmetry
$\sqrt{s'}/\sqrt{s} >$ 0.1 , 0.85
$\sqrt{s}$ (GeV)
LEP preliminary
A_{FB}^{c}
c-Asymmetry
$\sqrt{s'}/\sqrt{s} >$ 0.1 , 0.85
$\sqrt{s}$ (GeV)

no deviations from the SM predictions → limits at 95% CL on the contributions of new physics

- Existence of Z'

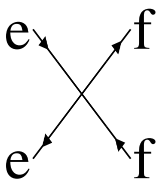
Model	χ	ψ	η	LR	SSM
$M_{Z'}$(GeV) >	678	463	436	800	1890



- Masses of leptoquarks

M > 167-1070 GeV

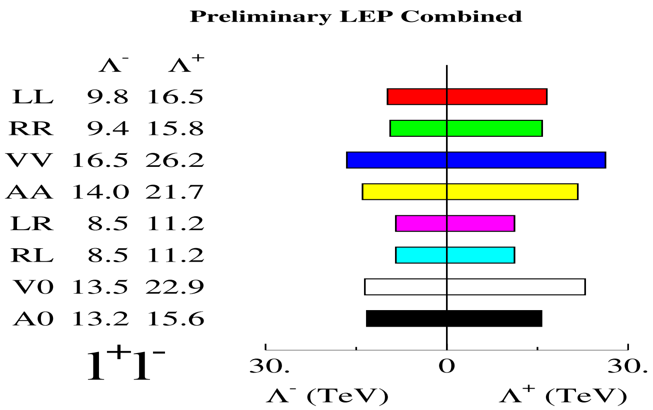
- Contact interactions



$$\mathcal{L}_{\rm eff} = \frac{g^2}{(1+\delta_{\rm f})\,\Lambda^2}\Sigma_{i,j}\eta_{ij}\bar{e}_i\gamma_\mu e_i \bar{f}_j\gamma^\mu f_j \quad i,j = {\rm L,R}$$

Model	LL	RR	LR	RL	VV	AA	V0	A0	LL-RR
η_{LL}	±1	0	0	0	±1	±1	±1	0	±1
η_{RR}	0	±1	0	0	±1	±1	±1	0	±1
η_{LR}	0	0	±1	0	±1	∓1	0	±1	0
η_{RL}	0	0	0	±1	±1	∓1	0	±1	0

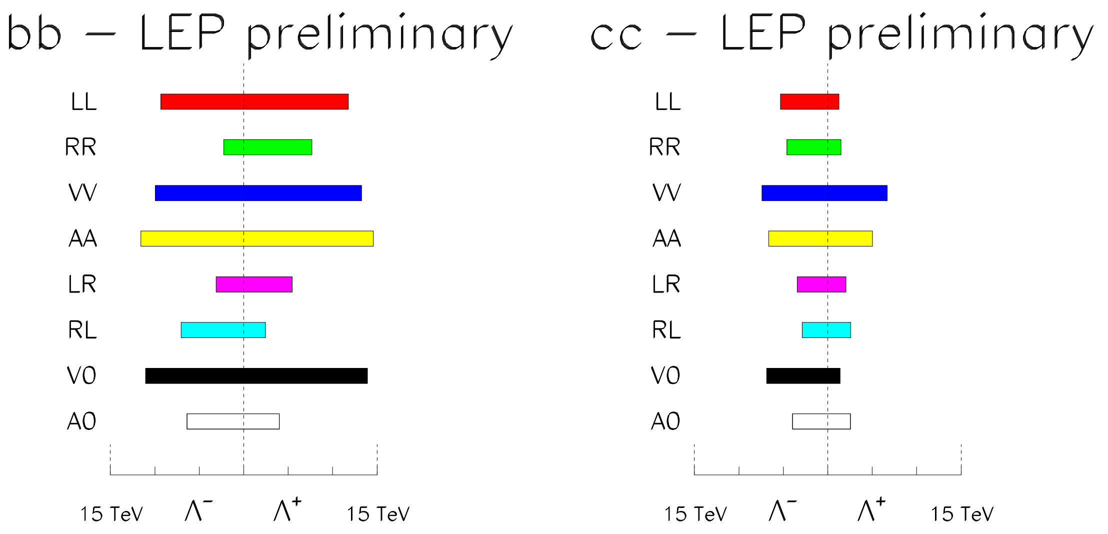
leptons



95% confidence level limits for $e^+e^- \rightarrow \ell^+\ell^-$

$\Lambda > 8.5 - 26.2$ TeV

b and c quarks

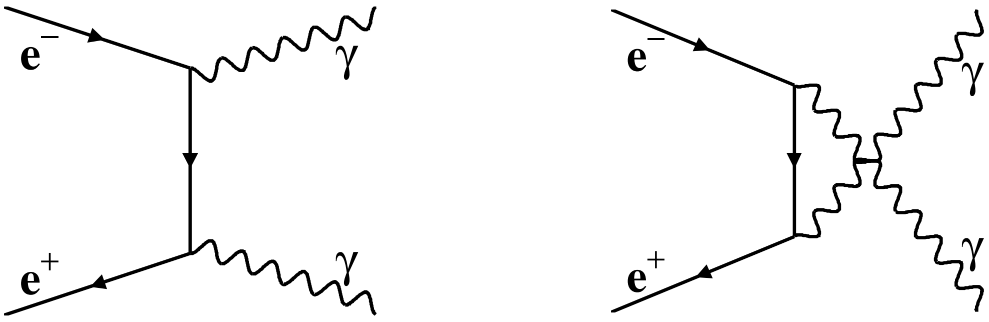


95% confidence level limits for $e^+e^- \to q\bar{q}$

$\Lambda > 2.2 - 14.6$ TeV $\Lambda > 1.3 - 7.4$ TeV

TWO PHOTON PRODUCTION

INTRODUCTION



EVENT SELECTION

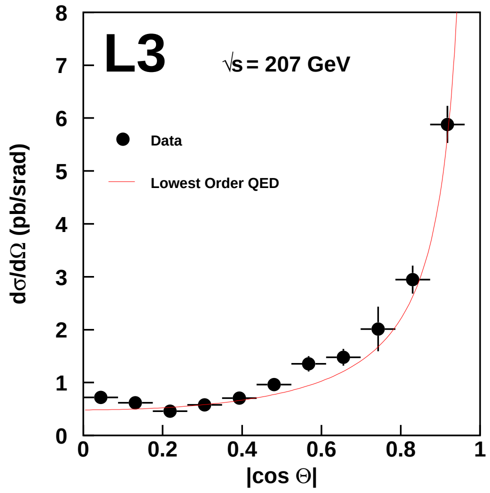
- electromagnetic energy
- absence of charged tracks

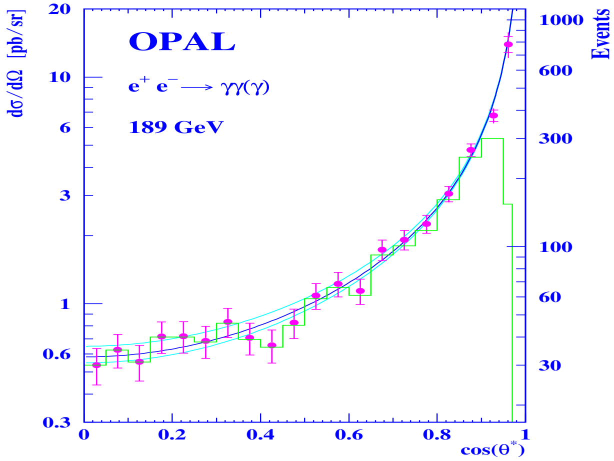
	$\lvert\cos\theta\rvert$ range
ALEPH	0.95
DELPHI	0.87
L3	0.96
OPAL	0.97

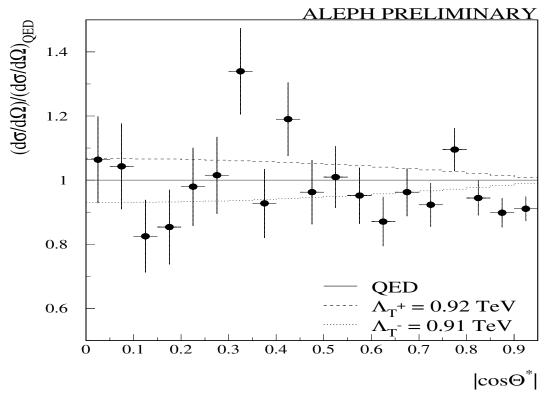
LEP2 $\gamma\gamma$ Group

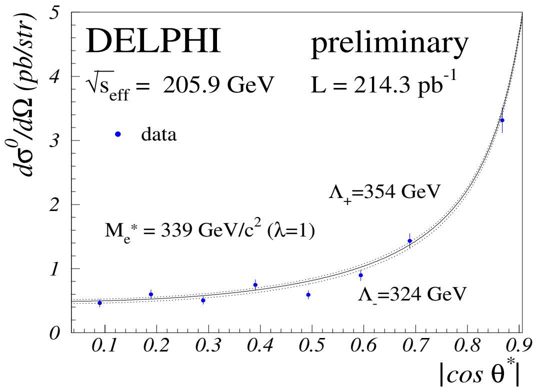
- formed in 2001 to combine the four experiment results
- the total cross sections are combined using a χ^2 average

RESULTS







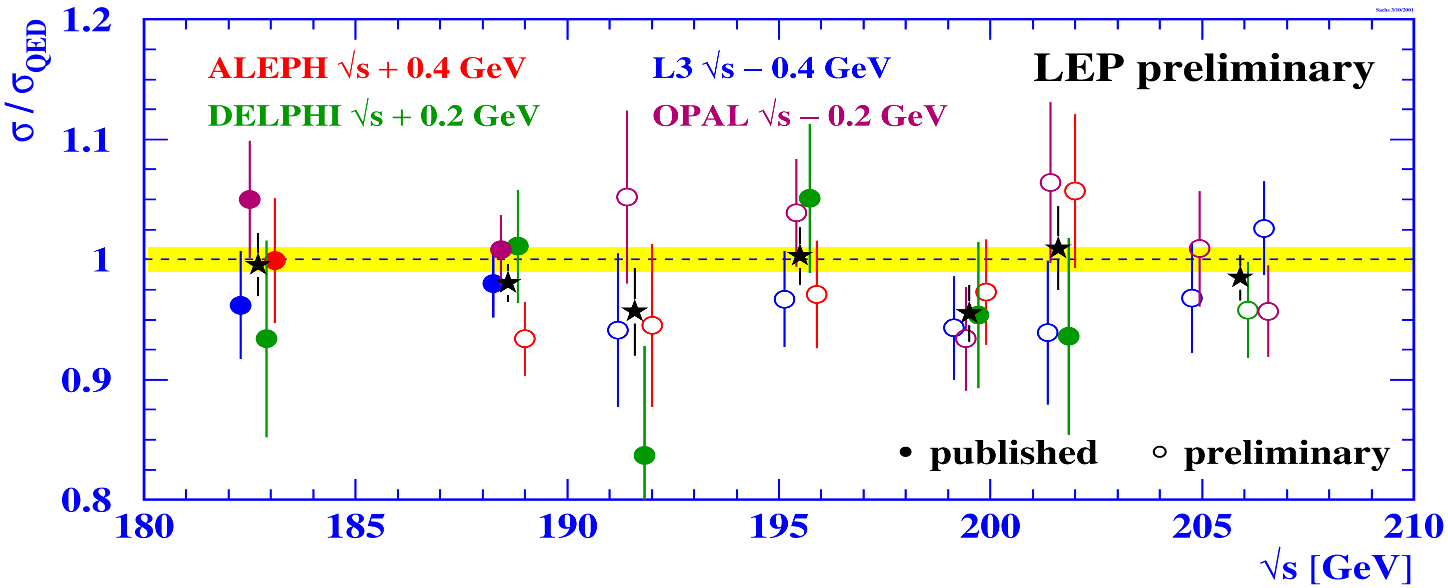


- Good agreement with the Standard Model expectation is observed

TOTAL CROSS SECTION

For the combination: measured cross section relative to the QED expectation

Per energy:



- Statistical and systematic error added in quadrature

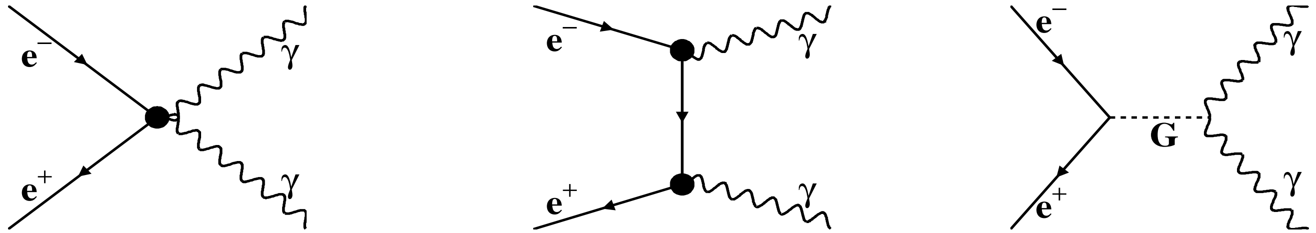
Per experiment and global value:

	cross-section ratio
ALEPH	0.963 ± 0.025
DELPHI	0.974 ± 0.032
L3	0.982 ± 0.021
OPAL	1.000 ± 0.021
LEP	0.982 ± 0.012

NEW PHYSICS CONSTRAINTS

- The angular distributions are compared to the differential cross-sections predicted by various models

Contact Interactions — Anomalous Couplings — Virtual Graviton



$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_\pm} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} \left(1 \pm \frac{s^2}{2\Lambda_\pm^4}\sin^2\theta\right)$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{7} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} \left(1 + \frac{s^3}{32\pi\alpha^2}\frac{1}{{\Lambda_7}^6}\frac{\sin^2\theta}{1+\cos^2\theta}\right)$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{M_s}} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} - \frac{\alpha\lambda s}{2\pi M_S^4}\left(1+\cos^2\theta\right) + \frac{\lambda^2 s^3}{16\pi^2 M_S^8}\left(1+\cos^2\theta\right)\left(1-\cos^2\theta\right), \lambda = \pm 1$$

NEW PHYSICS CONSTRAINTS

The global fit is based on angular distributions at energies between 183 and 207 GeV from the individual experiments

Fit parameter	Fit result	95% CL Limit [GeV]
$\Lambda_{\pm}^{-4}$	$\left(4.6\,^{+27.0}_{-26.5}\right)\cdot 10^{-12}$ GeV^{-4}	$\Lambda_{+} >$ 365 $\Lambda_{-} >$ 379 $\Lambda_{6} >$ 1484
Λ_7^{-6}	$\left(0.18\,^{+1.95}_{-1.92}\right)\cdot 10^{-18}$ GeV^{-6}	$\Lambda_7 >$ 794
λ/M_s^4	$\left(-0.106\,^{+0.609}_{-0.615}\right)\cdot 10^{-12}$ GeV^{-4}	$\lambda = +1$: $M_S >$ 972 $\lambda = -1$: $M_S >$ 940

CONCLUSIONS

Two fermions

- The combined results for the σ_{tot}, $\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}$ and for the A_{FB}, R_{b} and R_{c} above the Z resonance are shown and they agree well with the Standard Model expectations
- These measurements are used to search for effects of new physics phenomena. No manifestation of physics beyond the Standard Model is found

Two photons

- The total and differential cross sections of $\mathrm{e}^+\mathrm{e}^- \to \gamma\gamma$ are measured at $\sqrt{s}$ above the Z peak
- No significant deviation from QED is found and limits on several extensions of QED are set

Many thanks to LEP2 difermion and LEP2 diphoton groups