Electroweak Results from the Cross-Sections and Asymmetries with ALEPH at Energies from 130 to 189 GeV

Elsa MERLE

Laboratoire de Physique des Particules d'Annecy
France

For the ALEPH Collaboration

OUTLINE

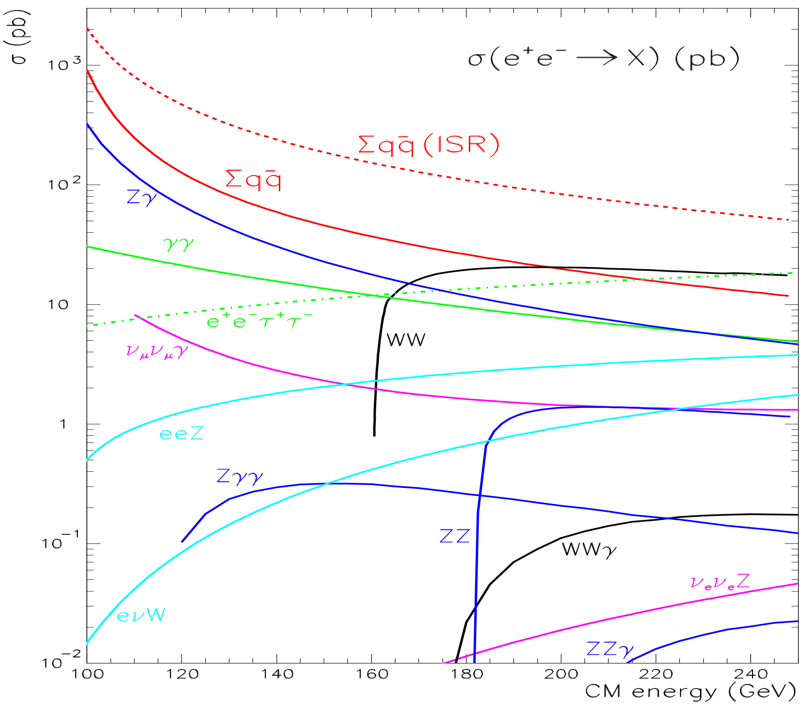
- Physics e^+e^- at LEP2 and motivation
  Electroweak tests above the Z peak

- Measurement of σ and A_{FB} in Aleph
  - Definitions and methods
  - $\mu\mu$, ee, $\tau\tau$ selections
  - Hadronic selection

- Results and interpretations
  - Comparison with Standard Model expectations
  - Deviations from Standard Model : tests of new phenomena modelisations

- Conclusion

Electroweak tests above the Z peak



Luminosity and precision (1995-1999)

- Range : 130 GeV to 189 GeV with $\int \mathrm{L}\, dt = 250\ \mathrm{pb}^{-1}$

- Experimental accuracy expected ?
  Dimuon production :
  $\rightarrow$ 3.0% on the cross-section (2.0% end of LEP2)
  $\rightarrow$ 2.0% on the asymmetry

  $q\bar{q}$ production : 1.5% on the cross-section (0.7% end of LEP2)

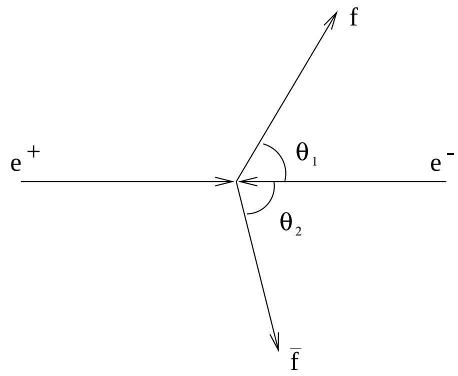
  $\Longrightarrow$ Theoretical predictions : 1 - 1.5 %
  study of the ISR-FSR interference, four-fermions processes

Selection of events sample : kinematic variable

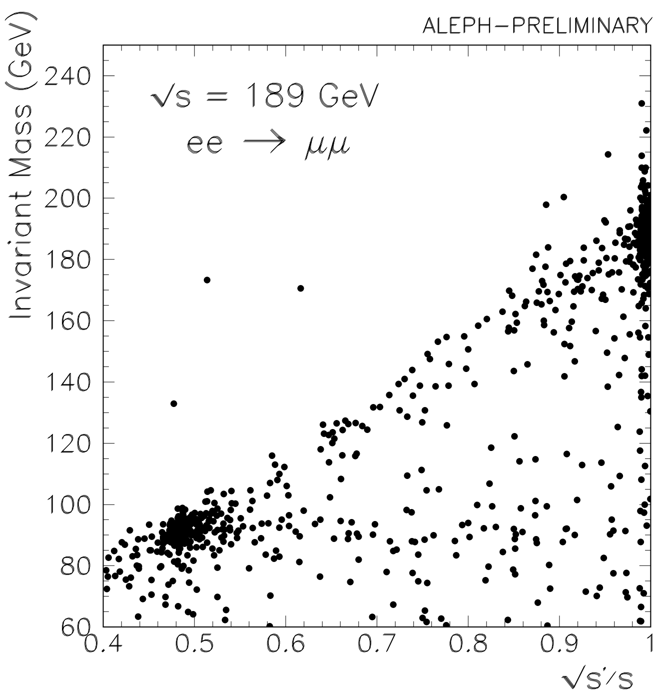
Definition of the effective energy of the collision s' in $e^+e^- \rightarrow Z, \gamma$: account for hard photons radiation (Z return)

$$\sqrt{s'} = \sqrt{s} * (1 - \frac{\Sigma E_\gamma^{ISR}}{\sqrt{s}})$$

Experimental determination of s' :



$$\Longrightarrow \quad s' = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1 + \theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1 + \theta_2)|} \times \text{s}$$



Di-fermionic measurements at LEP2

- Di-muons, di-taus and hadronic events :
  - Cross-sections with $\sqrt{s'/s} > 0.1$ (inclusive)
    $\sqrt{s'/s} > 0.9$ (exclusive)
  - Asymmetries with $\sqrt{s'/s} > 0.9$ (leptons)

- Di-electrons : cross-sections with $\sqrt{s'/s} > 0.9$

Forward-Backward asymmetry A^l_{FB} measurements

Asymmetry determination : counting method

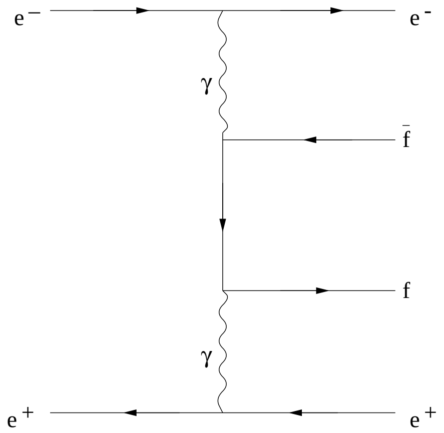
$$\mathrm{A}^l_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}}$$

$$\Rightarrow \mathrm{A}^l_{\mathrm{FB}} = \frac{\mathrm{N}(\cos\theta^* > 0) - \mathrm{N}(\cos\theta^* < 0)}{\mathrm{N}(\cos\theta^* > 0) + \mathrm{N}(\cos\theta^* < 0)}$$

(θ^* : angle between incoming e^- and outgoing l^- in $\mathrm{l}^+\mathrm{l}^-$ frame)

Expected backgrounds

- $\gamma\gamma$ processes



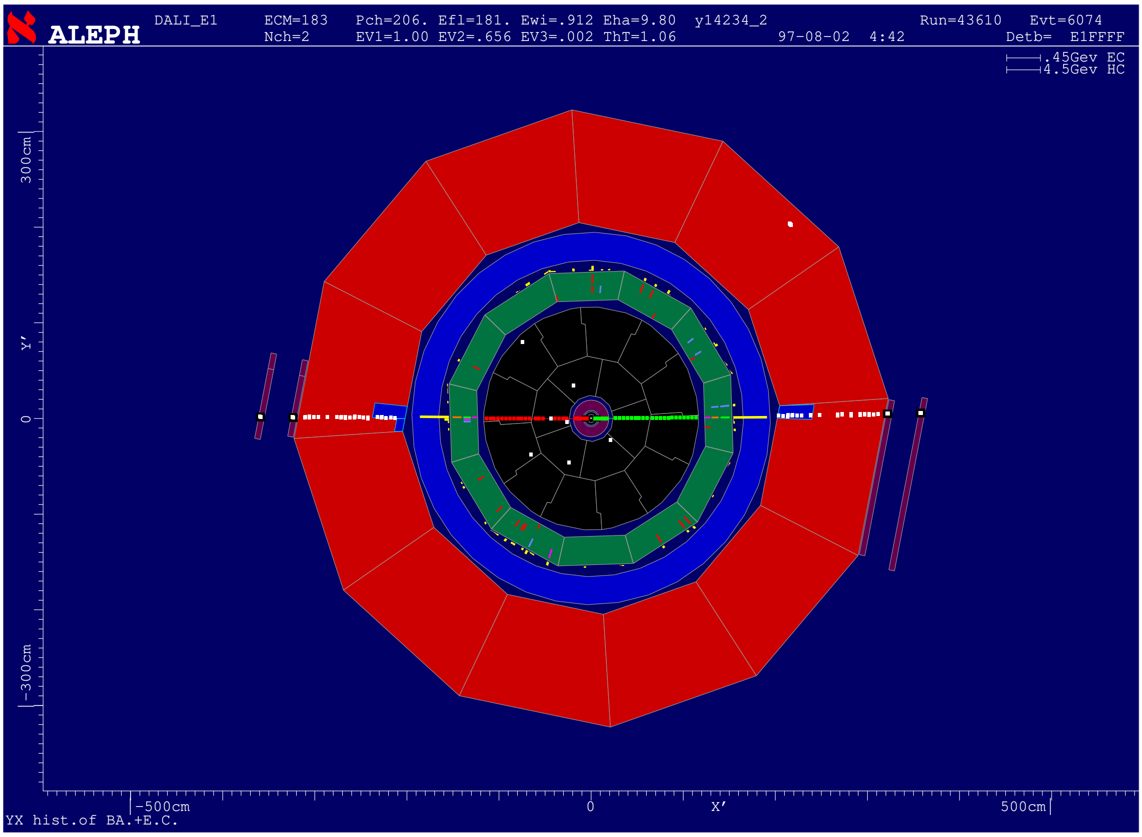
- WW, Weν, ZZ and Zee productions

- Cosmic events

- $e^+e^- \rightarrow f\bar{f}$, with other fermions

- Double radiative events : $e^+e^- \rightarrow f\bar{f}\,\gamma_1\gamma_2$

Selection algorithm



Single muon : two selections

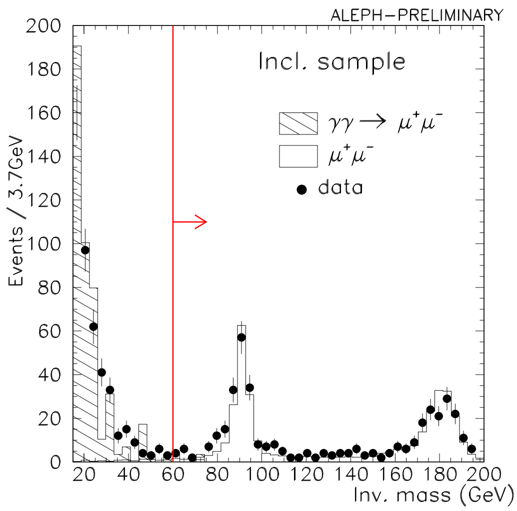
$\rightarrow$ Hits required in the last HCAL layers

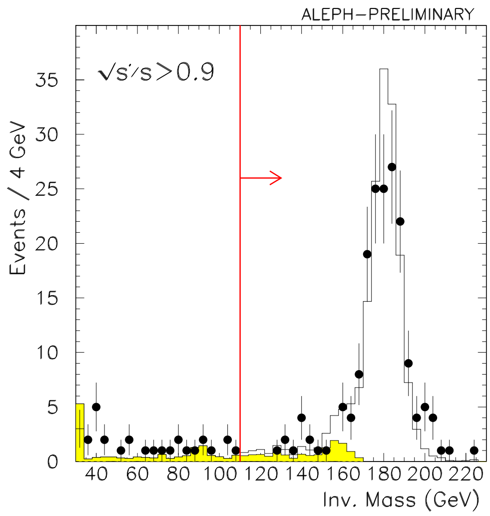
$\rightarrow$ Digital selection based on hits in HCAL planes and muon chambers

or Calorimetric selection based on energy deposits in ECAL and HCAL

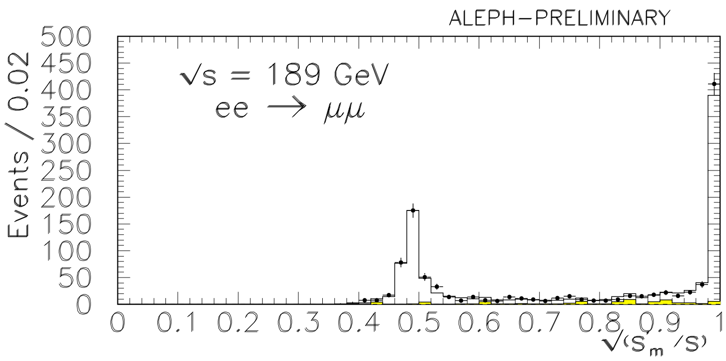
Selection algorithm (2)

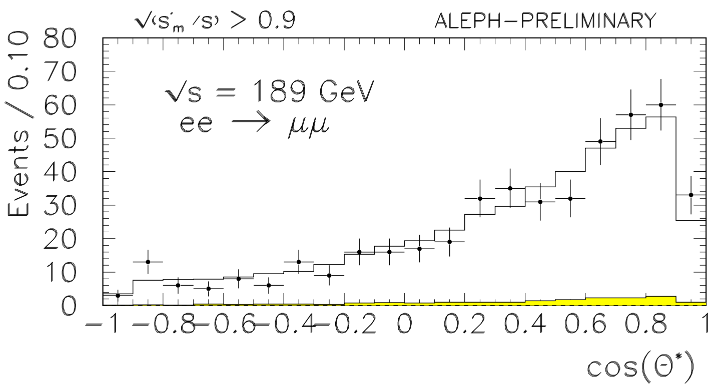
Dimuon selection : kinematic requirements



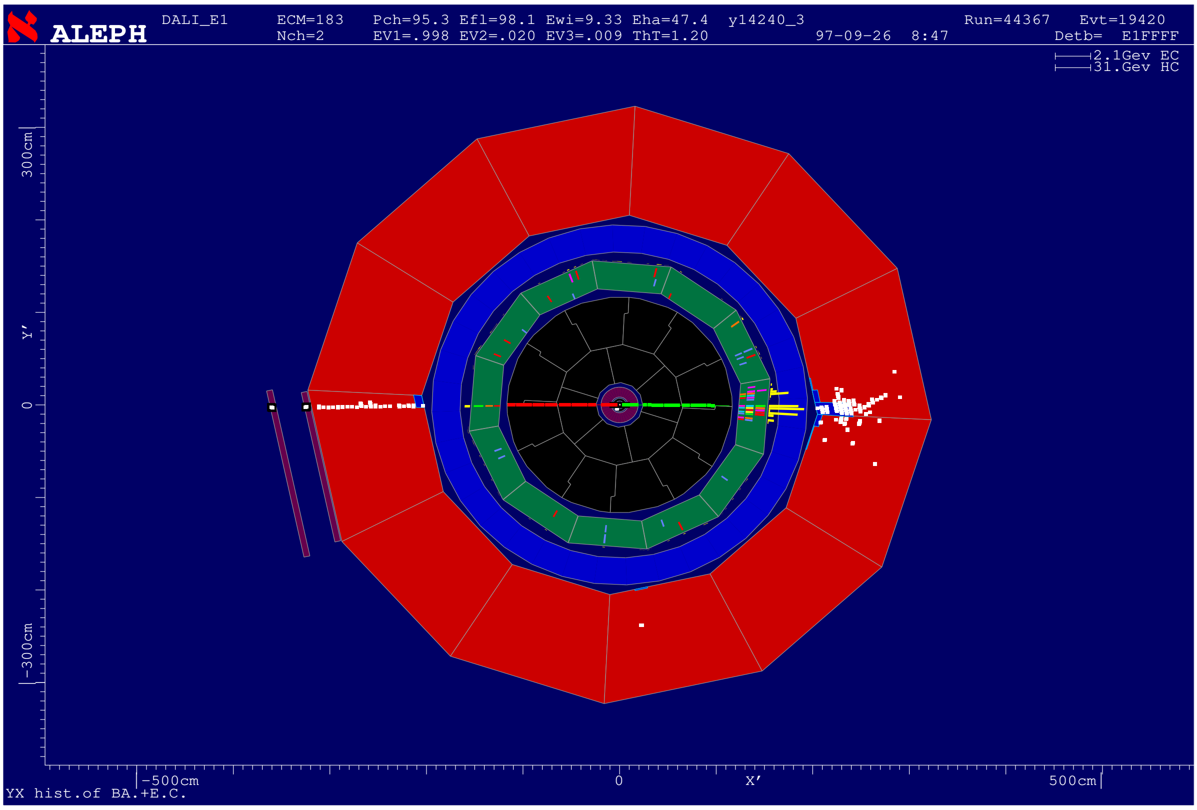


Selected data events :





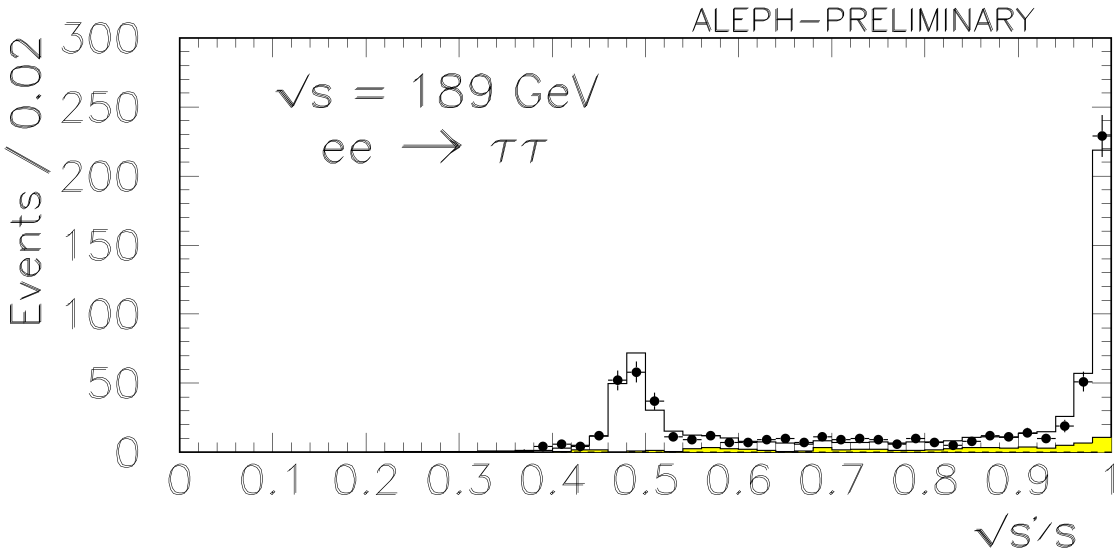
Selection algorithm

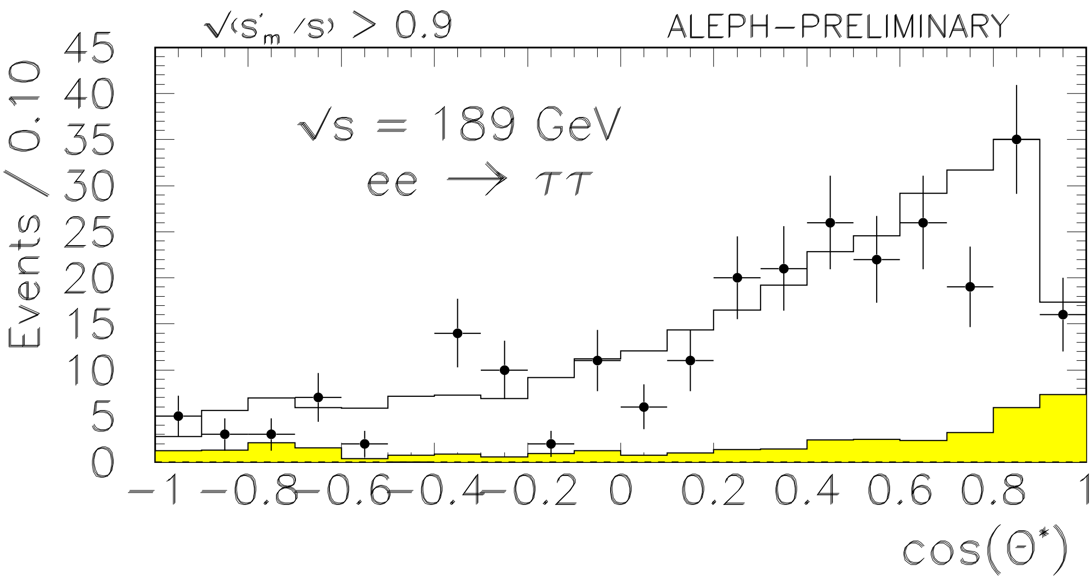


Hemisphere identified as $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau$, $\tau \rightarrow \text{hadrons} + \nu_\tau$ and $\tau \rightarrow \text{hadrons} + \nu_\tau + \pi^o$

τ_1 decay	/	τ_2 decay	$\sqrt{s'/s} > 0.1$	$\sqrt{s'/s} > 0.9$
$\mu\nu_\mu\nu_\tau$	/	$\mu\nu_\mu\nu_\tau$	veto	veto
$\mu\nu_\mu\nu_\tau$	/	hadrons ν_τ	56.3 ± 1.8 %	77.1 ± 2.5 %
$\mu\nu_\mu\nu_\tau$	/	hadrons $\pi^0\ \nu_\tau$	61.7 ± 1.3 %	87.3 ± 1.5 %
$\mu\nu_\mu\nu_\tau$	/	$e\nu_e\nu_\tau$	49.2 ± 2.1 %	74.9 ± 2.9 %
hadrons ν_τ	/	hadrons ν_τ	48.0 ± 2.2 %	67.5 ± 3.3 %
hadrons ν_τ	/	hadrons $\pi^0\ \nu_\tau$	53.6 ± 1.2 %	77.9 ± 1.6 %
hadrons ν_τ	/	$e\nu_e\nu_\tau$	31.6 ± 1.7 %	50.2 ± 2.9 %
hadrons $\pi^0\ \nu_\tau$	/	hadrons $\pi^0\ \nu_\tau$	58.7 ± 1.2 %	79.9 ± 1.6 %
hadrons $\pi^0\ \nu_\tau$	/	$e\nu_e\nu_\tau$	35.2 ± 1.3 %	48.5 ± 2.1 %
$e\nu_e\nu_\tau$	/	$e\nu_e\nu_\tau$	veto	veto

Selected data events

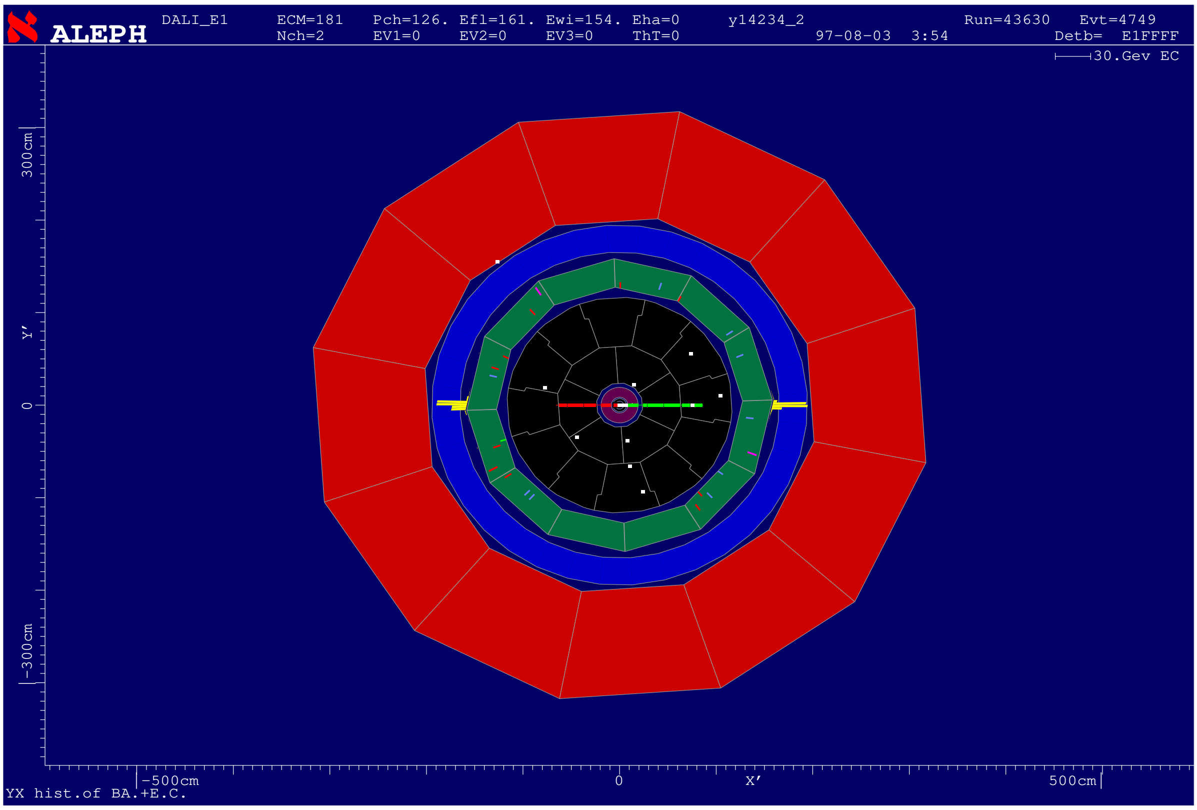




Main backgrounds : e^+e^-, $\gamma\gamma \rightarrow \tau^+\tau^-$, WW (inclusive sample)

radiative events, e^+e^- (exclusive sample)

Selection algorithm



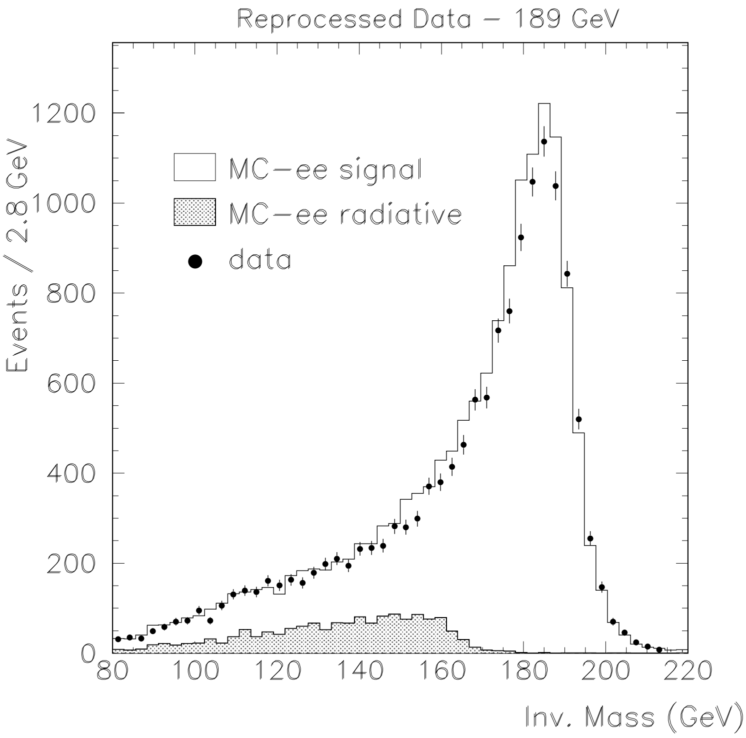
→ Two high momentum tracks with a large energy deposition in ECAL

→ Included : Bremsstrahlung photons energy
HCAL energy (crack)

→ Rejection of muon candidates

Selection algorithm (2)

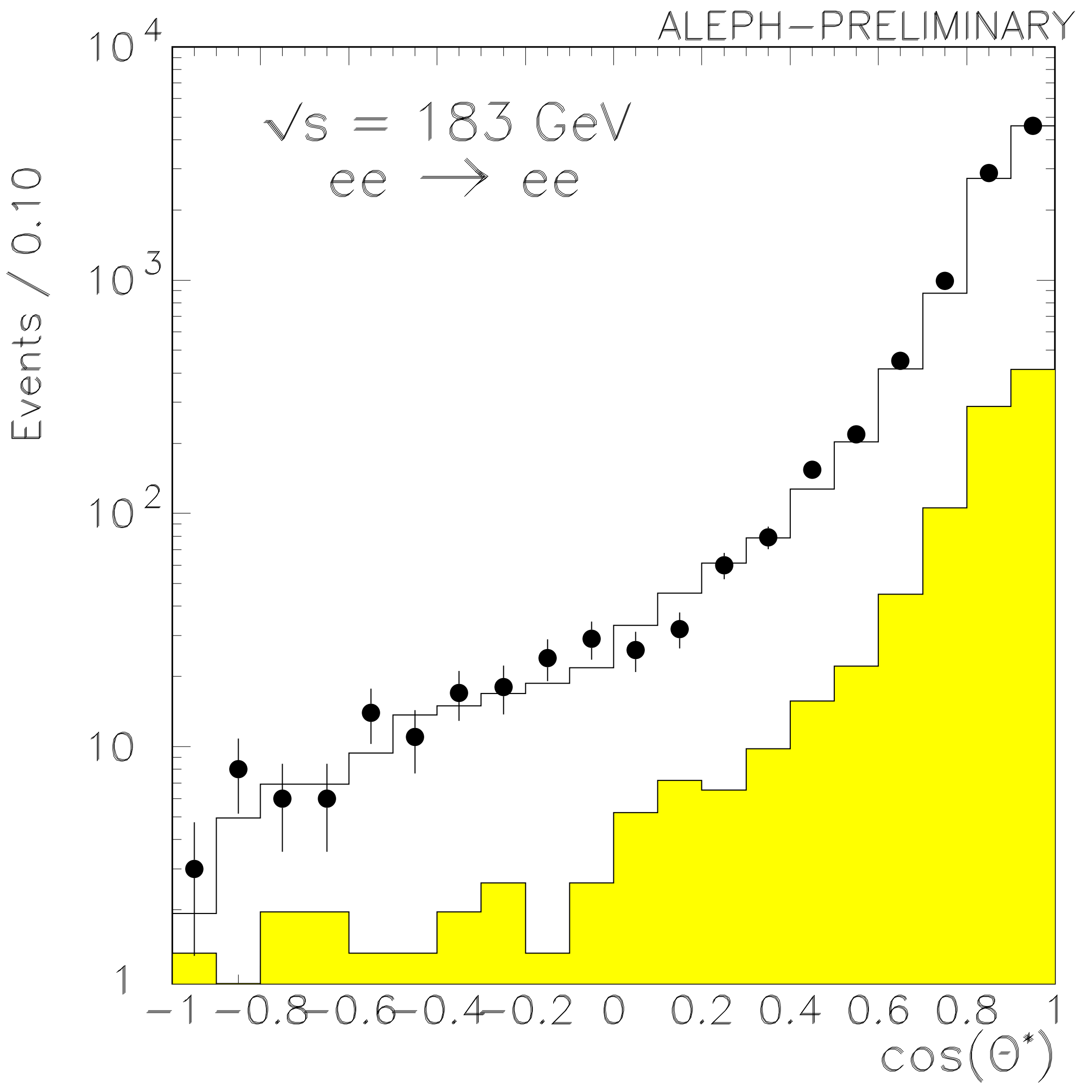
$\rightarrow$ Rejection of double radiative events (inv. mass)



$\rightarrow$ Estimation of the contamination in double radiative events :
fit of inv. mass distribution of di-electron selected events

$\Longrightarrow$ Uncertainty on the factor taken as systematic error

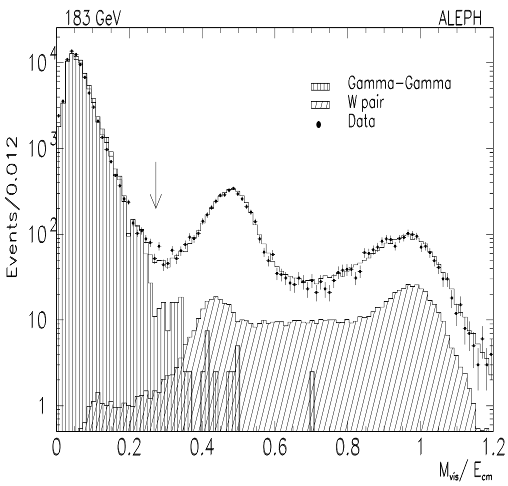
Selected data events



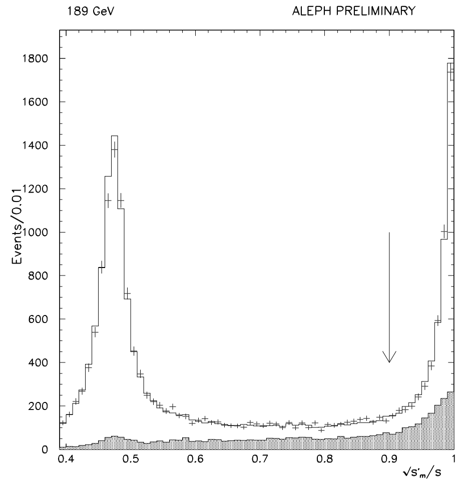
Main background : double radiative e^+e^-events

Selection algorithm

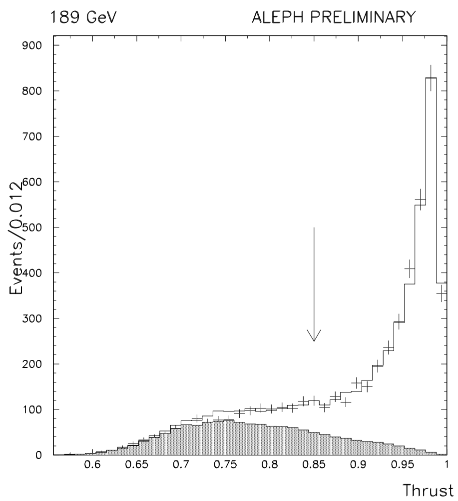
Events with ≥ 7 charged tracks



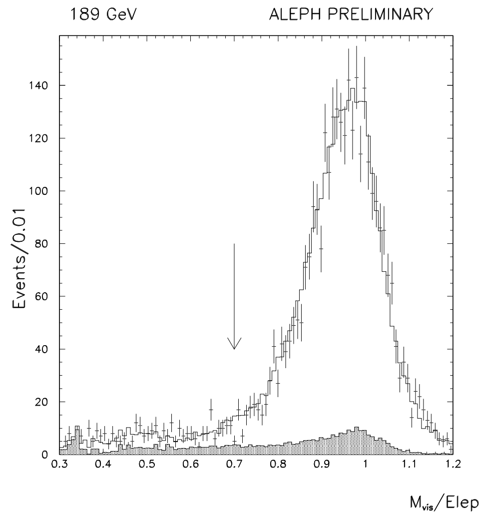
$\Longrightarrow$



High energy sample : $\sqrt{s'/s} > 0.9$



$\Longrightarrow$



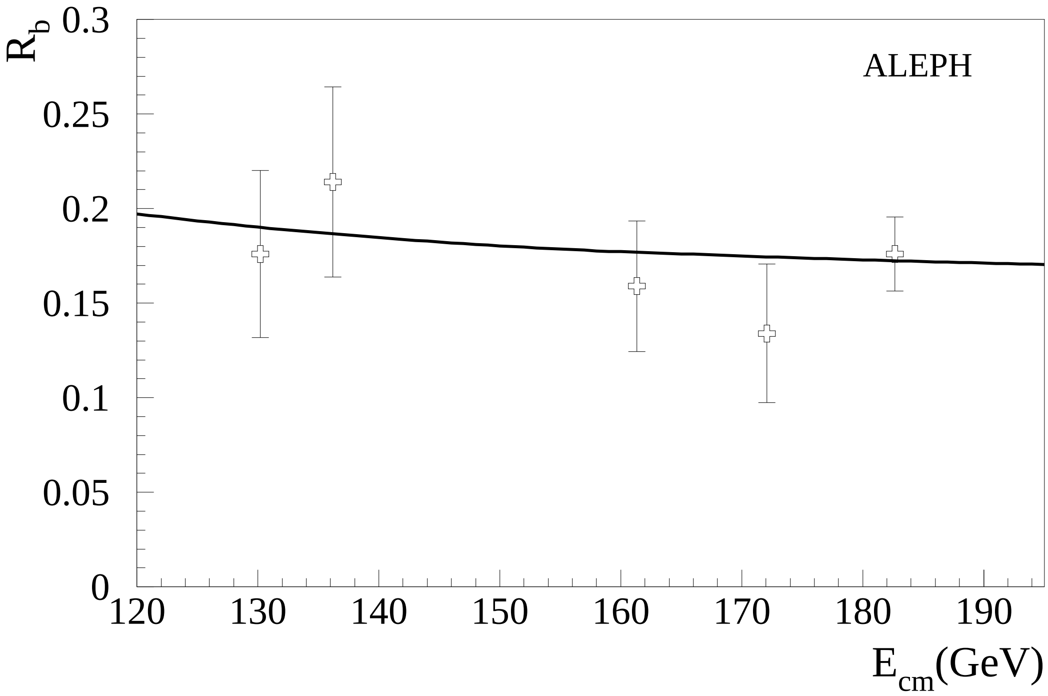
R_b measurement

- Same selection as for hadronic exclusive events

- b-tagging : based on transverse variables

  tested at the Z peak (R_b compared with world average)

  $\Rightarrow$ Main systematic error



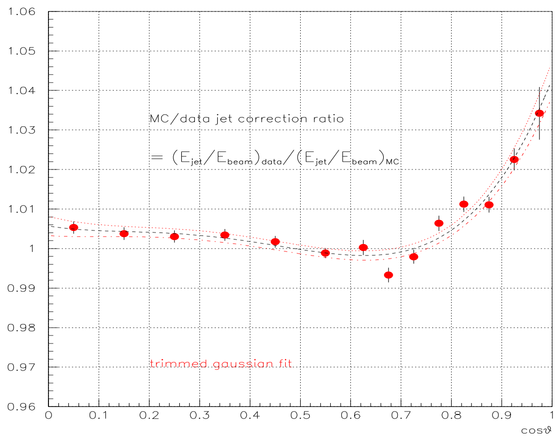
Systematic estimations

- Tracking effects :
  - Selections with/without momenta correction distortions
  - Efficiency tested on data when possible

- Calorimeters calibration :

  $\Delta E_{ECAL} = 0.7\% \times E_{ECAL}$ (calibration at 10 and 94 GeV)
  $\Delta E_{HCAL} = 2.0\% \times E_{HCAL}$ (muons)

- Detector response to jet energy f($\cos\theta$), estimated on Z peak events



- Background comtamination :
  - Experimental uncertainty on other ee$\rightarrow f\bar{f}$ cross-sections
  - Theoretical error on WW cross-section production and on W mass
  - Number of events between MC and data for the $\gamma\gamma$ processes (estimated in the low invariant mass range)

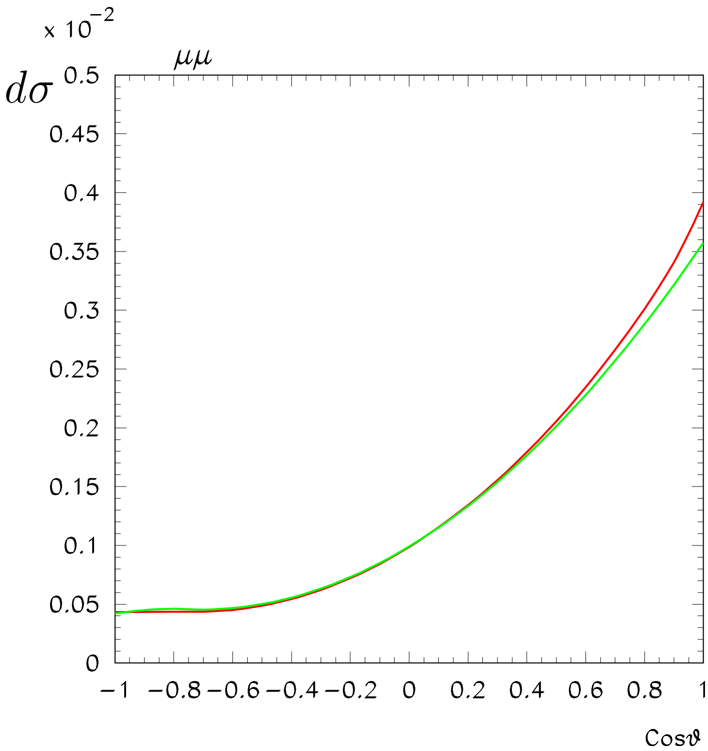
Performance and systematics

(on 183 GeV data)

$\sqrt{s'/s}$ cut	Event type	Efficiency (%)	Background (main)	Uncertainties stat./syst. (%)
0.1	$q\bar{q}$	84 %	18 % (WW)	$\pm$ 1.5 $\pm$ 0.8 (detect. resp.)
	$\mu^+\mu^-$	75 %	5 % ($\gamma\gamma$,$\tau^+\tau^-$)	$\pm$ 5.7 $\pm$ 2.3 (tracking)
	$\tau^+\tau^-$	47 %	13 % ($\gamma\gamma$,e^+e^-,WW)	$\pm$ 7.7 $\pm$ 2.5 (back.)
0.9	$q\bar{q}$	86 %	9 % (radiative,WW)	$\pm$ 3.2 $\pm$ 1.1 (detect. resp.)
	$\mu^+\mu^-$	96 %	6.5 % (radiative events)	$\pm$ 8.0 $\pm$ 2.0 (tracking)
	$\tau^+\tau^-$	68 %	13 % (radiative,e^+e^-,WW)	$\pm$ 10.3 $\pm$ 3.1 (back.)
	e^+e^-	95 %	11 % (radiative events)	$\pm$ 1.5 $\pm$ 0.8 (back.)

Theoretical uncertainty

ISR-FSR interference : Zfitter predictions at the first order only
Effect at higher orders ?

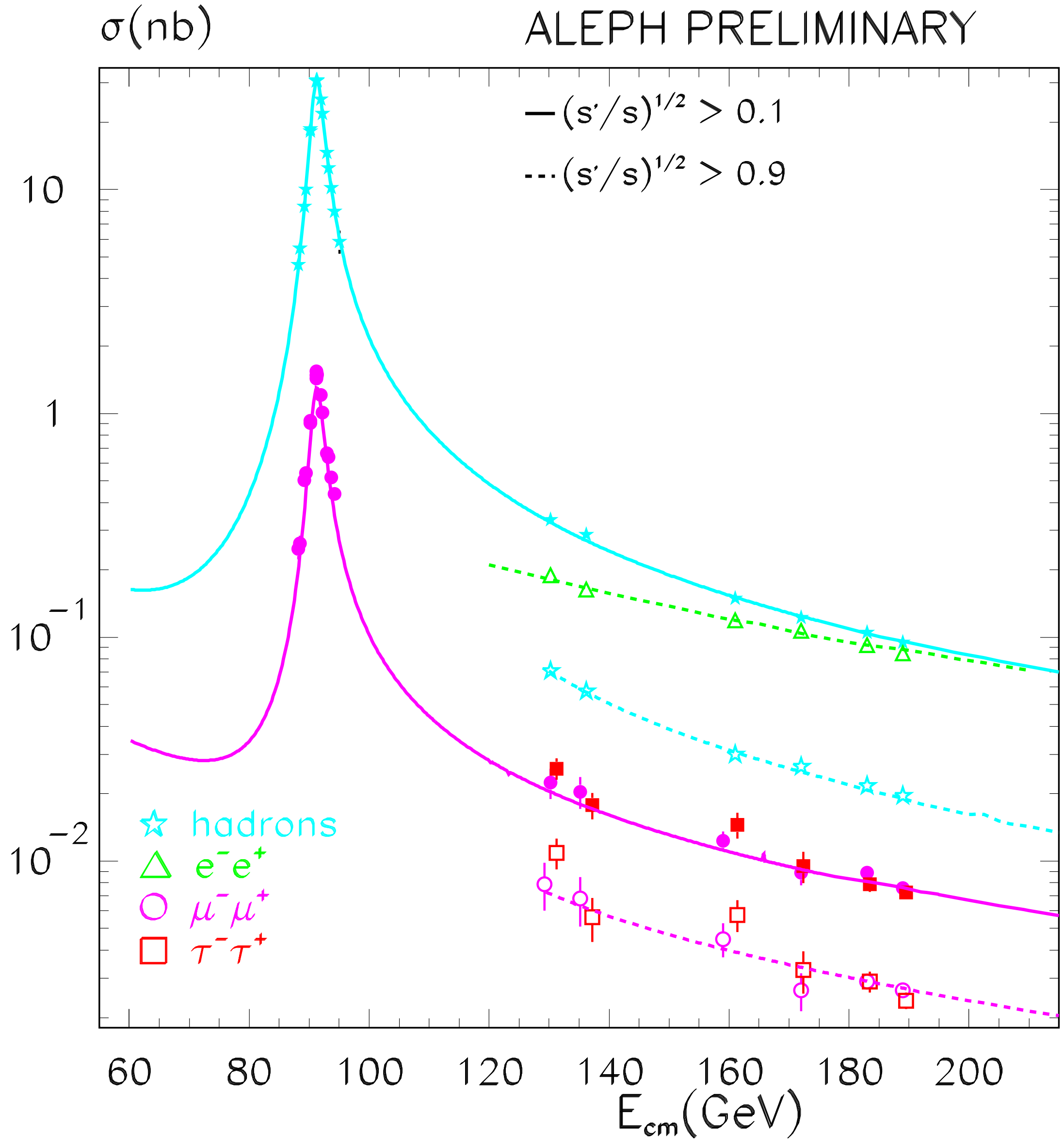


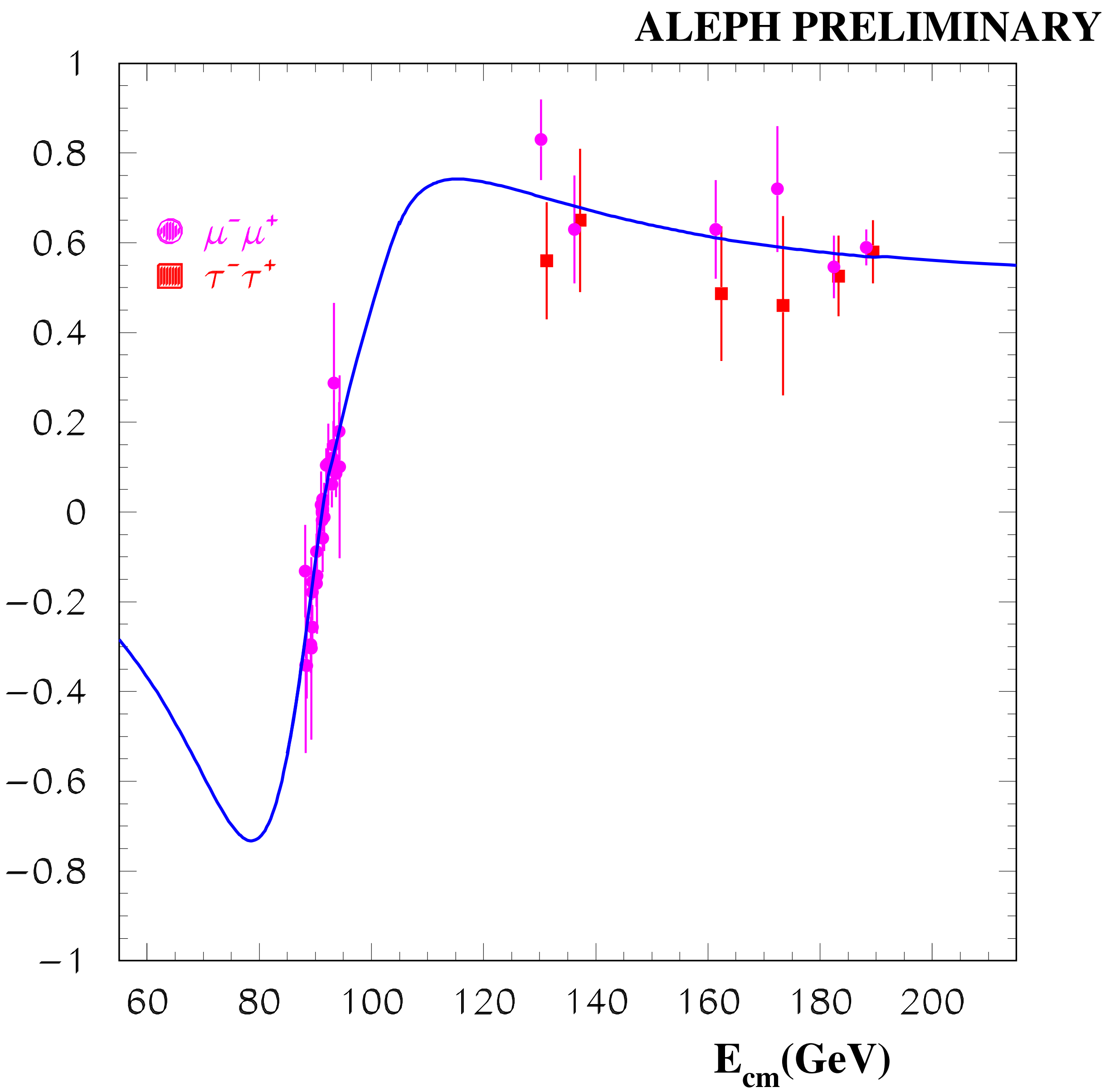
Effect of ISR-FSR interference on cross-sections from 130 to 189 GeV :

$q\bar{q}$ production : -1.5 % to -2.0 %

$\mu^+\mu^-$ events : 2.4 % to 3.0 %

$\tau^+\tau^-$ events : 2.4 % to 2.8 %


σ(nb)
ALEPH PRELIMINARY
— (s'/s)^1/2 > 0.1
--- (s'/s)^1/2 > 0.9
10
1
10^-1
10^-2
hadrons
e⁻e⁺
μ⁻μ⁺
τ⁻τ⁺
60
80
100
120
140
160
180
200
Ecm(GeV)


ALEPH PRELIMINARY
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
60
80
100
120
140
160
180
200
$\mu^-\mu^+$
$\tau^-\tau^+$
E_{cm}(GeV)

Deviations from the Standard Model predictions

- Theoretical accuracy dominated by ISR-FSR interference :

  affects the differential cross-sections at low θ (1 to 3 %)

  effect at higher orders ?

- Tests of new physics modelisations (using 130 to 183 GeV data) :

  $\rightarrow$ Contact term interactions

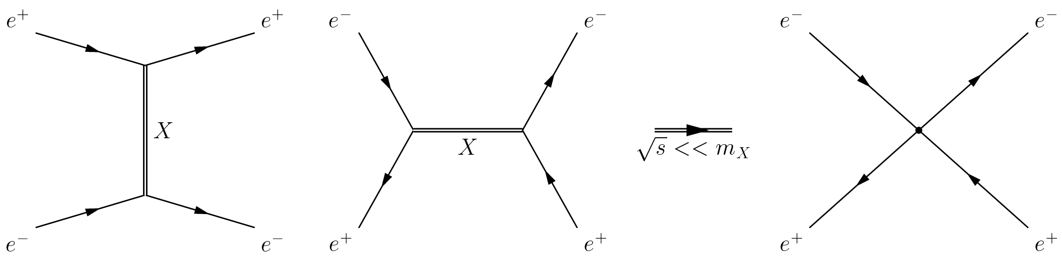
  $\rightarrow$ Leptoquarks

  $\rightarrow$ Sneutrinos with R-parity violation

  $\rightarrow$ Extra neutral Z bosons

Contact terms

Indirect test of new physics phenomena at a scale $\Lambda \gg E_{LEP2}$
Processes not seen at LEP2 energies $\Rightarrow$



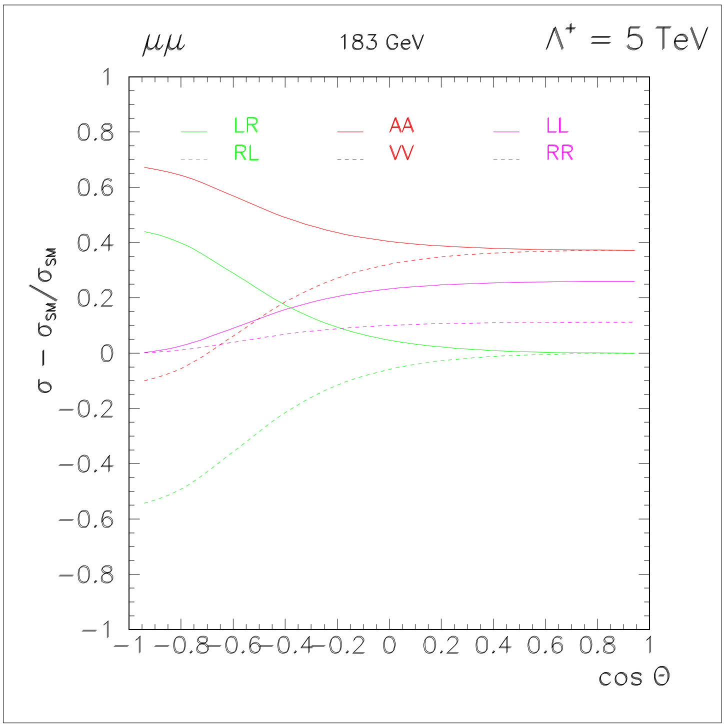
Differential cross-section :

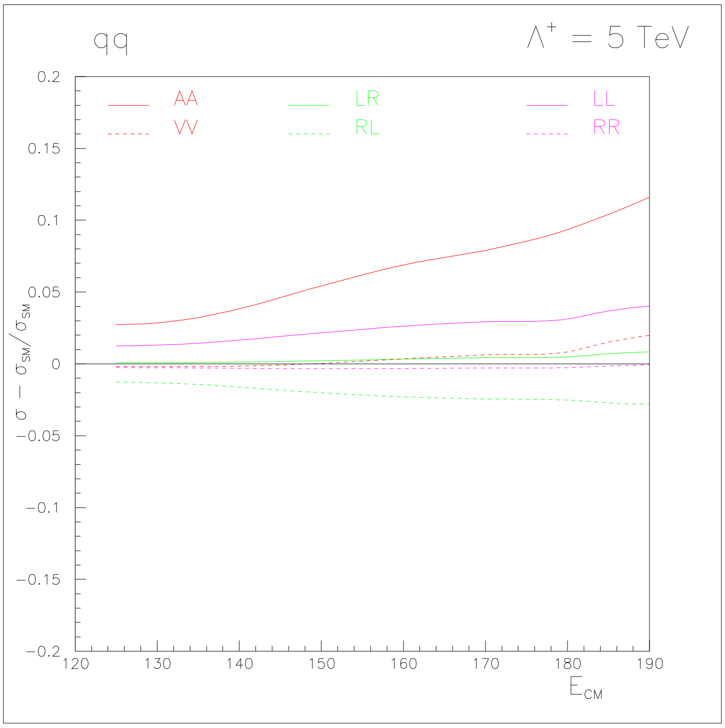
$$\frac{d\sigma}{d\cos\theta} = \mathrm{SM}^o(s,t) + \mathrm{C}_2^o(s,t)\frac{1}{\Lambda^2} + \mathrm{C}_4^o(s,t)\frac{1}{\Lambda^4}$$

Addition of a $\mathcal{L}^{contact}$ term in the Standard Model lagrangian :

$$\mathcal{L}^{contact} = \frac{g^2\eta_{sign}}{(1+\delta)\,\Lambda^2}\sum_{i,j=L,R}\eta_{ij}[\bar{e}_i\gamma^\mu e_i][\bar{f}_j\gamma_\mu f_j]$$

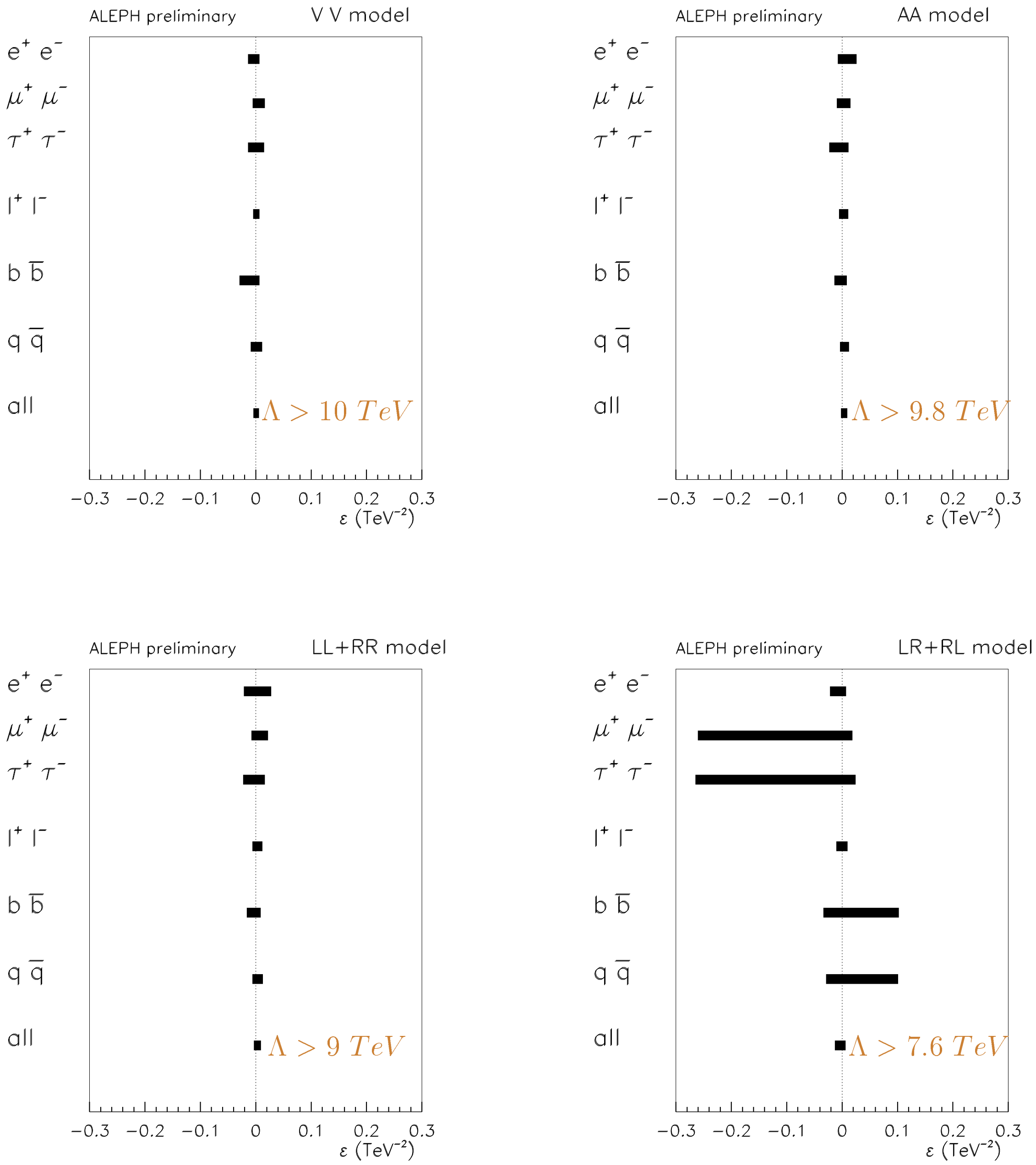
Model	η_{sign}	η_{LL}	η_{RR}	η_{LR}	η_{RL}
$\mathrm{LL}^\pm$	±1	1	0	0	0
$\mathrm{RR}^\pm$	±1	0	1	0	0
$\mathrm{VV}^\pm$	±1	1	1	1	1
$\mathrm{AA}^\pm$	±1	1	1	-1	-1
$\mathrm{LR}^\pm$	±1	0	0	1	0
$\mathrm{RL}^\pm$	±1	0	0	0	1
$\mathrm{LL+RR}^\pm$	±1	1	1	0	0
$\mathrm{LR+RL}^\pm$	±1	0	0	1	1


μμ
183 GeV
Λ⁺ = 5 TeV
LR
RL
AA
VV
LL
RR
σ − σSM/σSM
cos Θ


qq
Λ⁺ = 5 TeV
AA
VV
LR
RL
LL
RR
σ − σSM/σSM
ECM

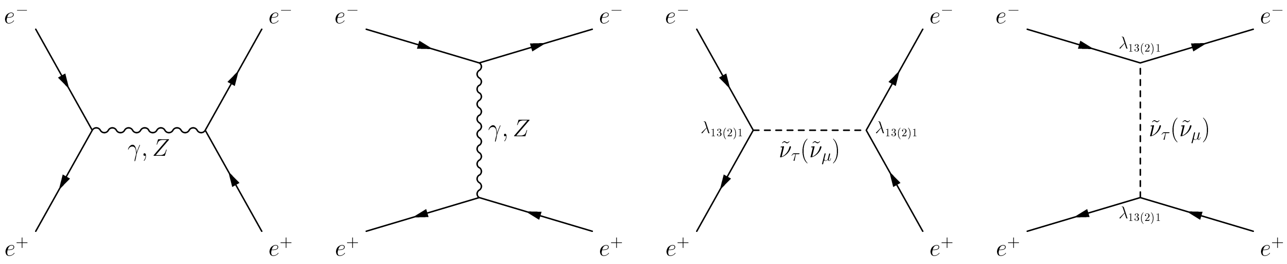
Limits on contact interactions

Maximum likelihood method : fit of electroweak measurements with composite models using the variable $\epsilon \equiv 1/\Lambda^2$



Sneutrinos with R-parity violation

Exchange of sneutrinos $\tilde{\nu}$ $(s, t$ channels$)$ in e^+e^- :



Exchange of sneutrinos in s,t channels in fermion pair production :

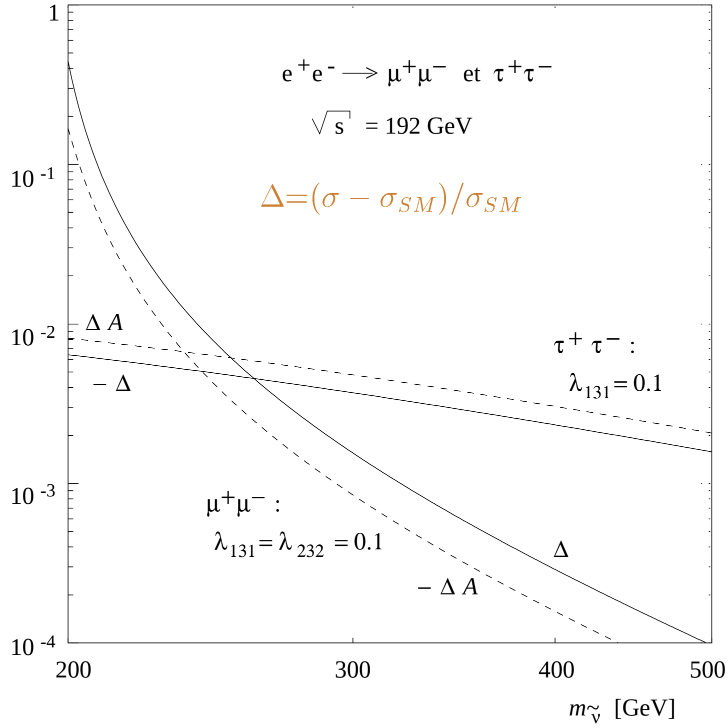
λ^2	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$
λ^2_{121}	$\tilde{\nu}_\mu$ (s,t)	$\tilde{\nu}_e$ (t)	—
λ^2_{131}	$\tilde{\nu}_\tau$ (s,t)	—	$\tilde{\nu}_e$ (t)
$\lambda_{121}\lambda_{233}$	—	—	$\tilde{\nu}_\mu$ (s)
$\lambda_{131}\lambda_{232}$	—	$\tilde{\nu}_\tau$ (s)	—

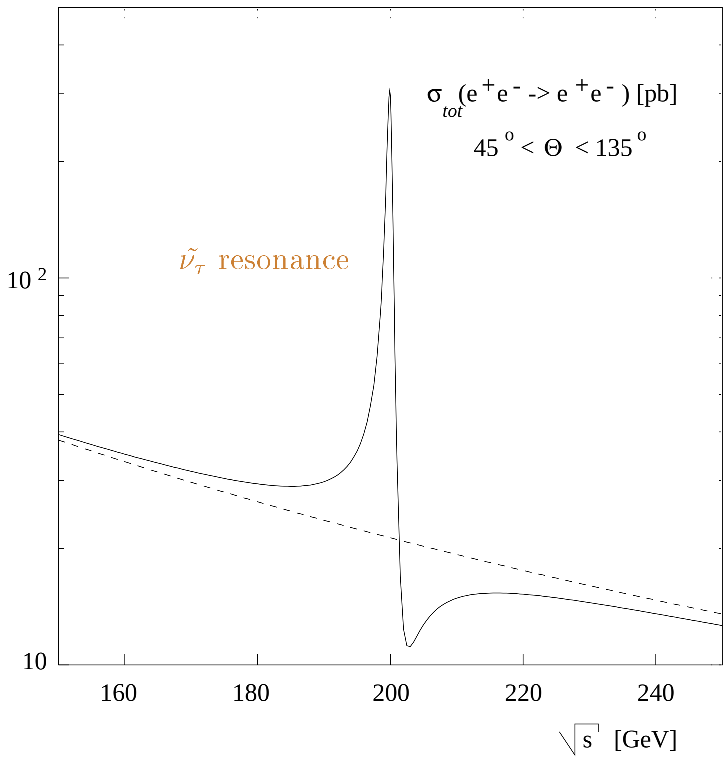
S-channel sneutrinos exchange : resonance (width 1 GeV/c^2)

Comparisons of electroweak measurements with theoretical predictions

$\Longrightarrow$ Constraints in the plane of the couplings λ_{ijk} and the masses m$_{\tilde{\nu}}$

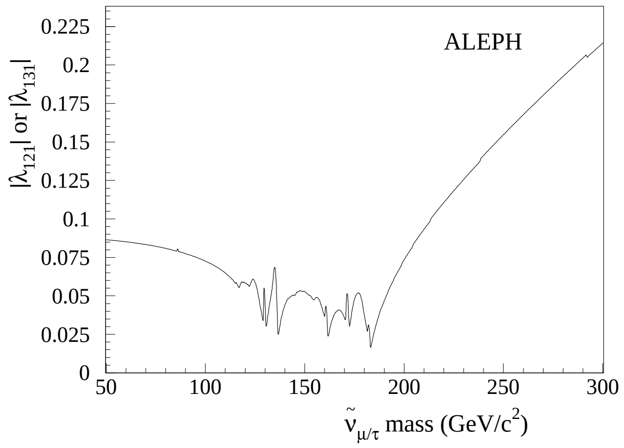
Sneutrinos exchange modelisations



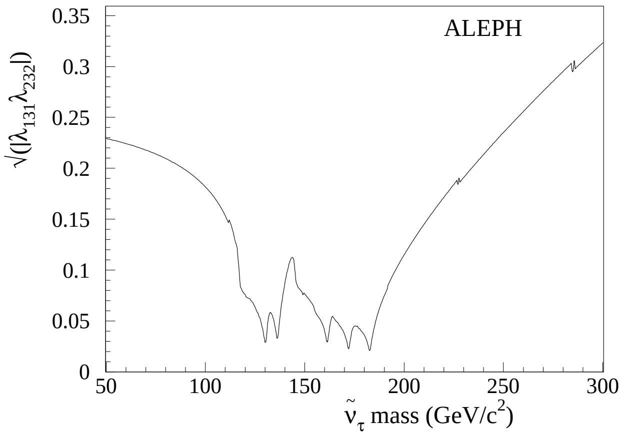


Limits on sneutrinos

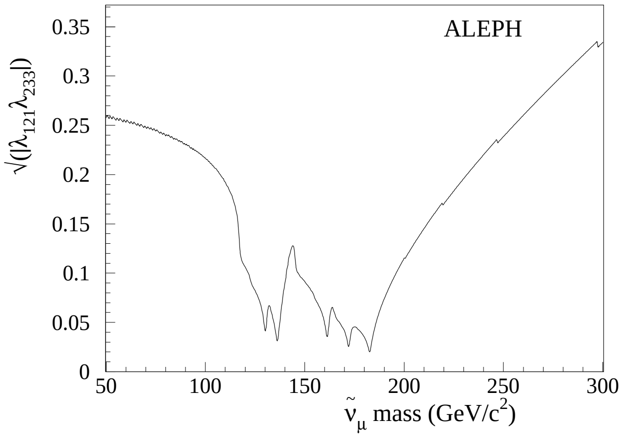
From Bhabha cross-section measurements :



From $\mu^+\mu^-$ cross-section measurements :



From $\tau^+\tau^-$ cross-section measurements :



- Results for e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$: cross-section and asymmetry measurements
  - good agreement with the Standard Model expectations ($< 2\sigma$)
  - total LEP2 statistic (4 manip.)

    $\Rightarrow$ study of higher orders for ISR-FSR interference

- Constraints upon physics beyond the Standard Model
  - Limits on the energy scale Λ of $\mathrm{e^+e^-f\bar{f}}$ contact interactions : in range from 2–10 TeV
  - Limits on R-parity violating sneutrinos : masses of a few hundred GeV/c^2 for large values of their Yukawa couplings