*** this presentation was originally a Powerpoint animation; to avoid disagreeable ***
*** superimpositions in PDF version, some slides are repeated in different aspects ***

WW production at LEP2

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L3 Collaboration

Lake Louise Winter Institute - 19/02/2002

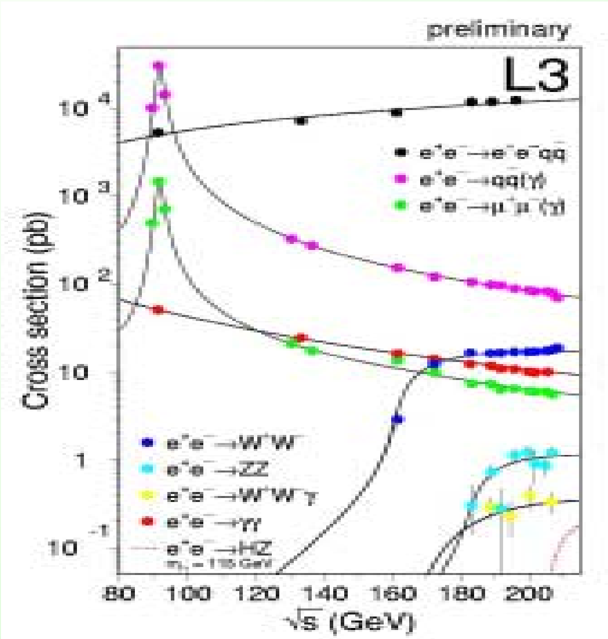
INTRODUCTION

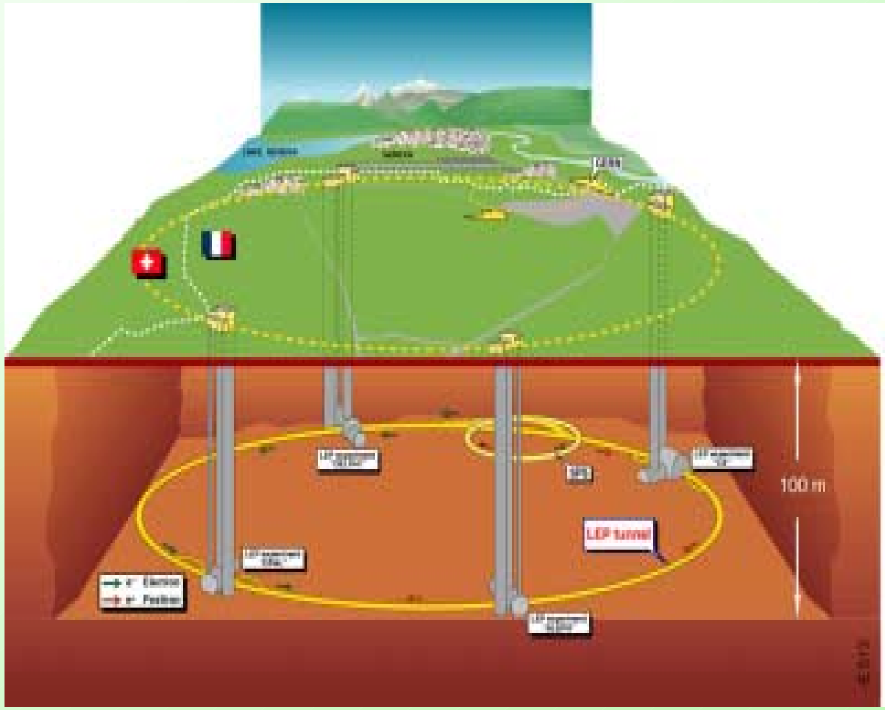
- LEP history
- $e^+e^- \rightarrow W^+W^-$ events
- Selection criteria of different decay channels
- Cross section measurements
- Branching Ratio measurements
- Conclusions

the Large Electron Positron collider

LEP is the biggest e^+e collider

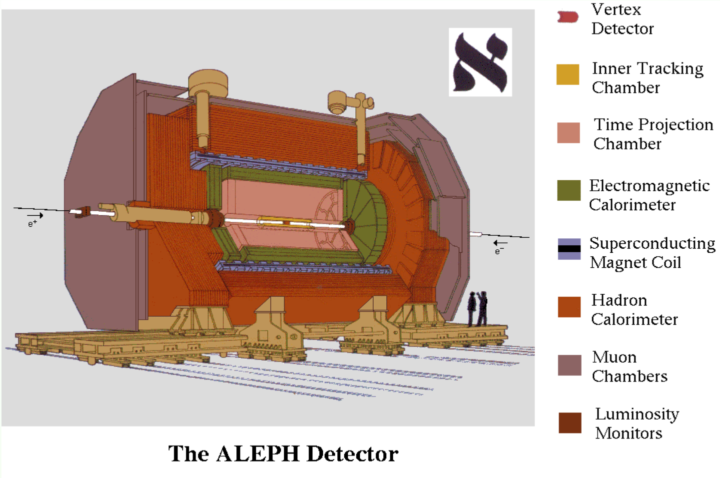
- 1975 - LEP proposal
- 1981 - CERN approves LEP
- 1983 - the tunnel excavation starts
- july 1989 - first e^+e collisions
- november 2000 - LEP end





The four experiments Aleph, Delphi, L3 and Opal collected almost 1 fb^{-1} each; the 75 % of luminosity over the W^+W^- production threshold

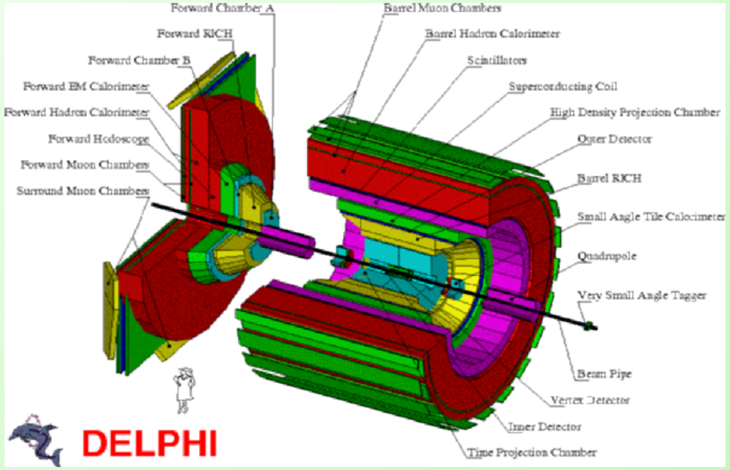
LEP experiments (ADLO)

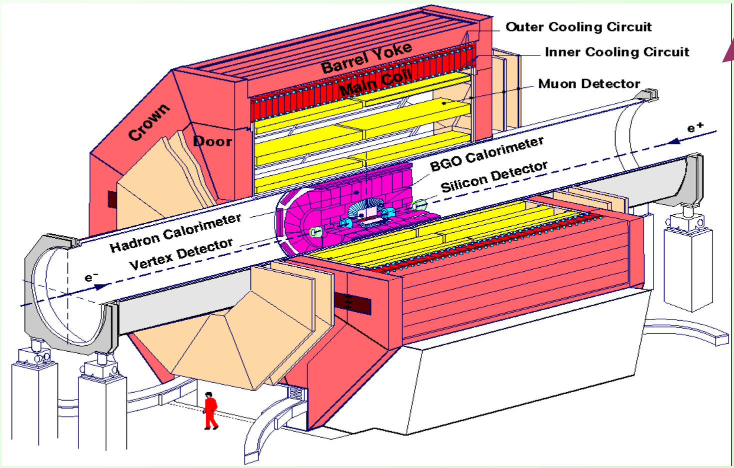


The ALEPH Detector

ALEPH

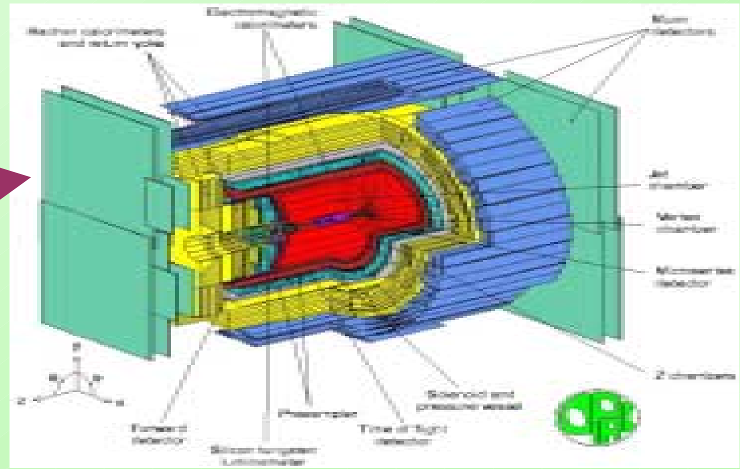
DELPHI



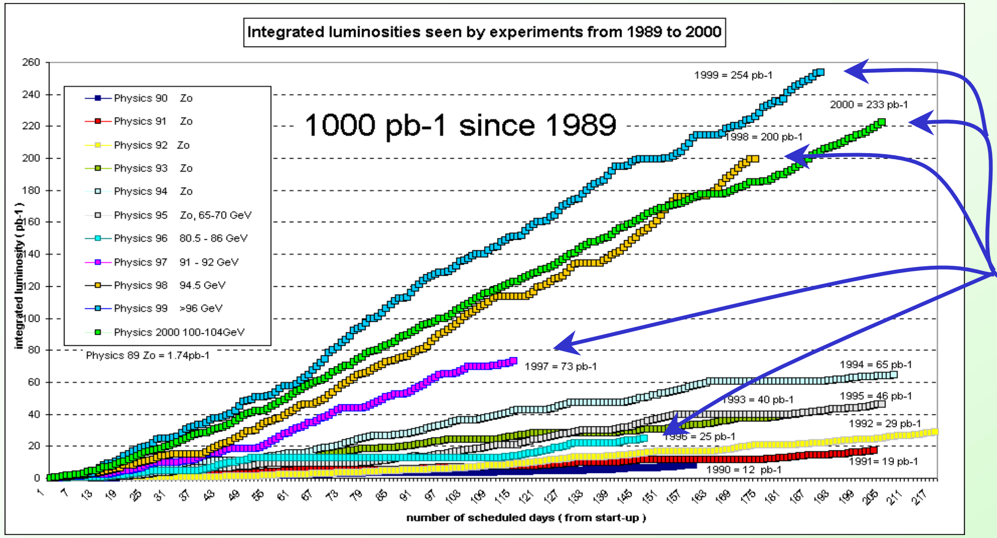


L3

OPAL



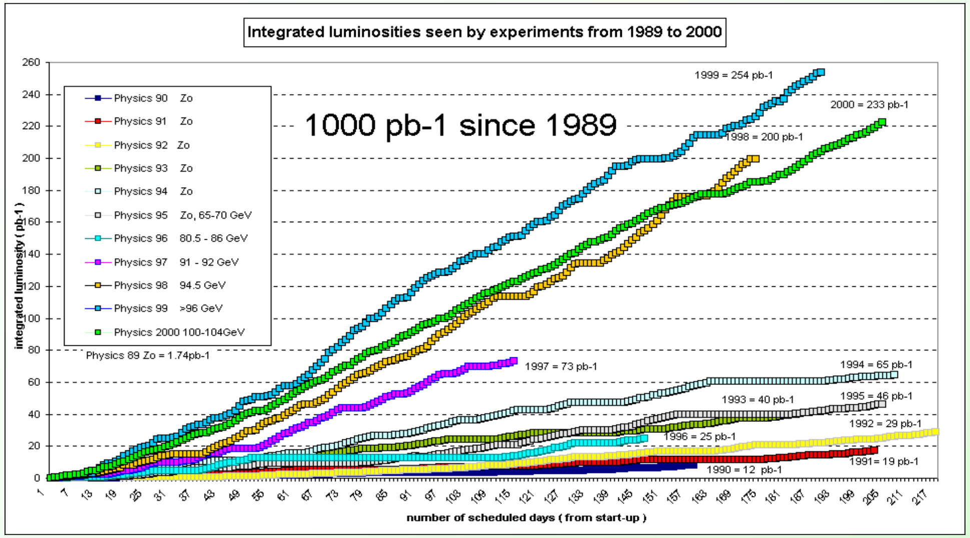
Luminosity delivered by LEP



LEP1: $\sqrt{s}$ = 88 - 94 GeV

LEP2: $\sqrt{s}$ = 161 - 209 GeV

Luminosity delivered by LEP



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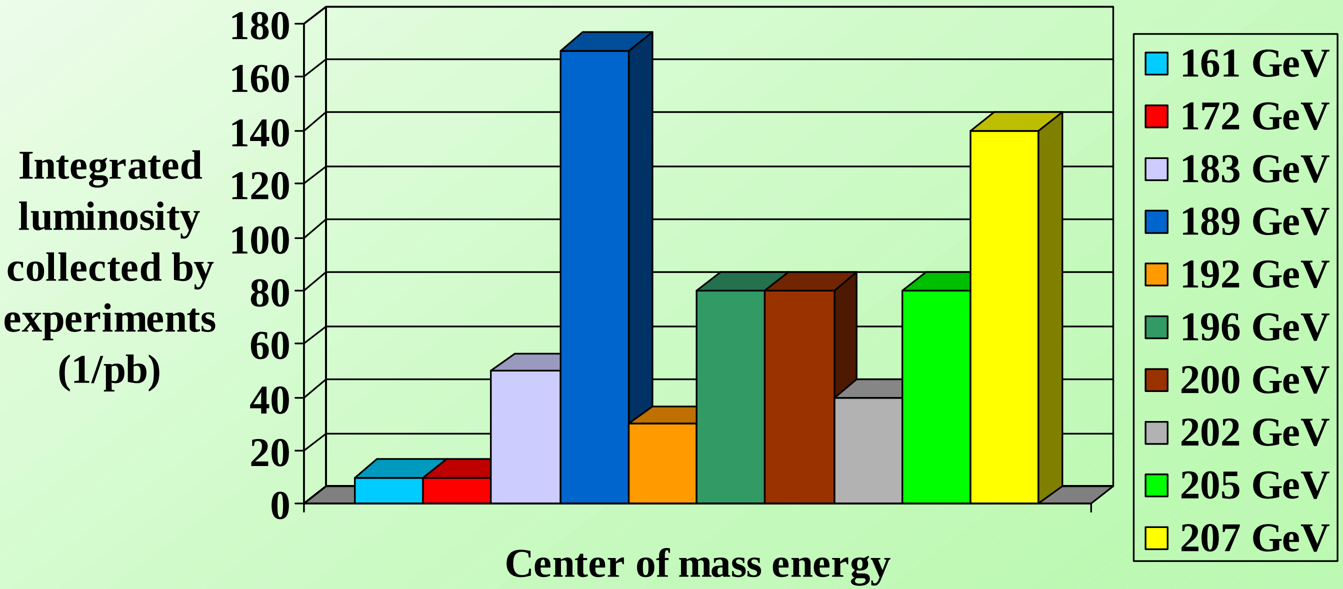
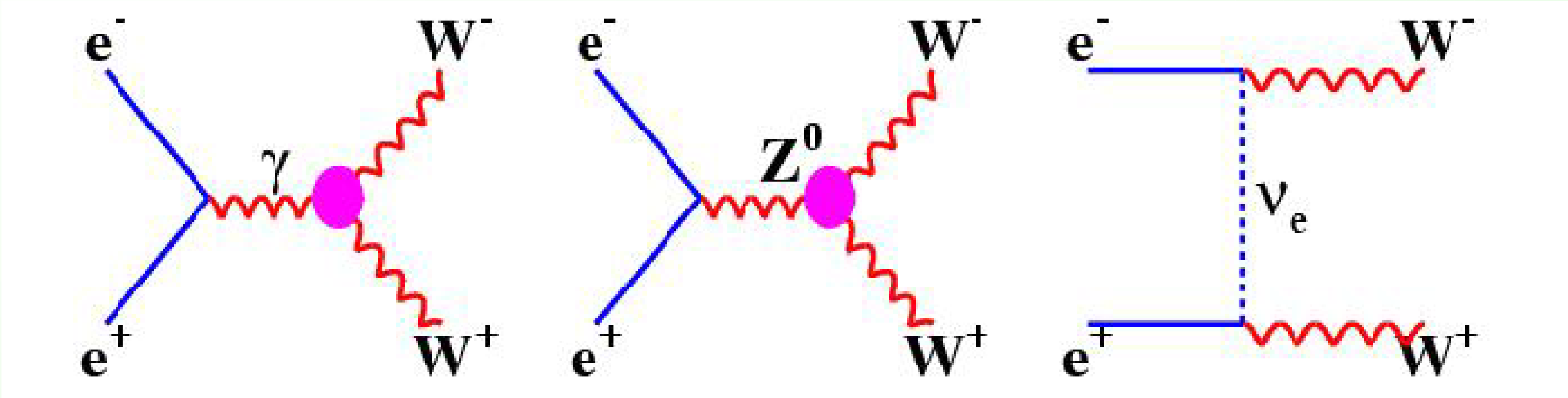


19/02/2002

W^+W^- production

the CC03 diagrams:



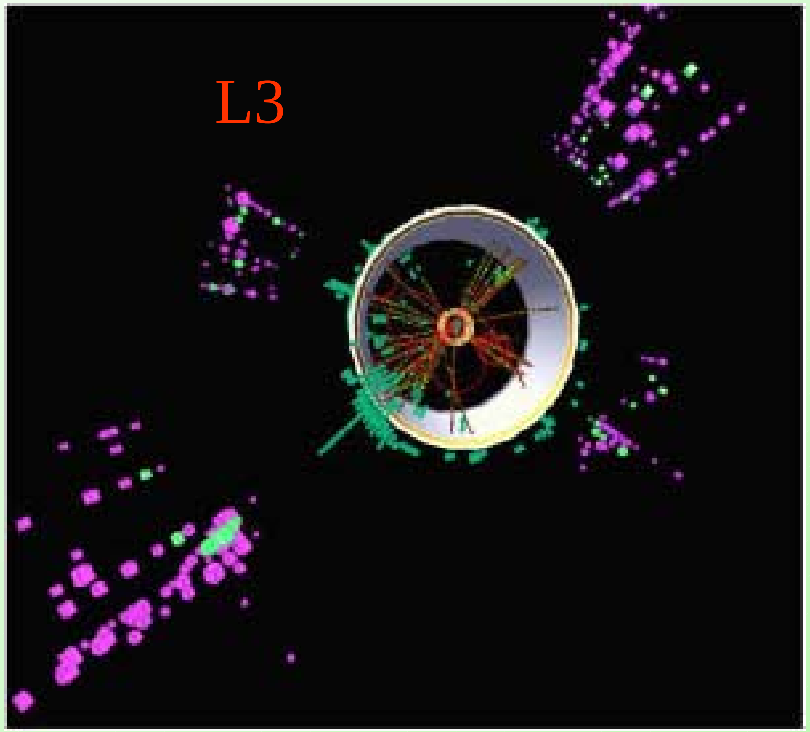
W can decay hadronically or leptonically, giving 3 final states :

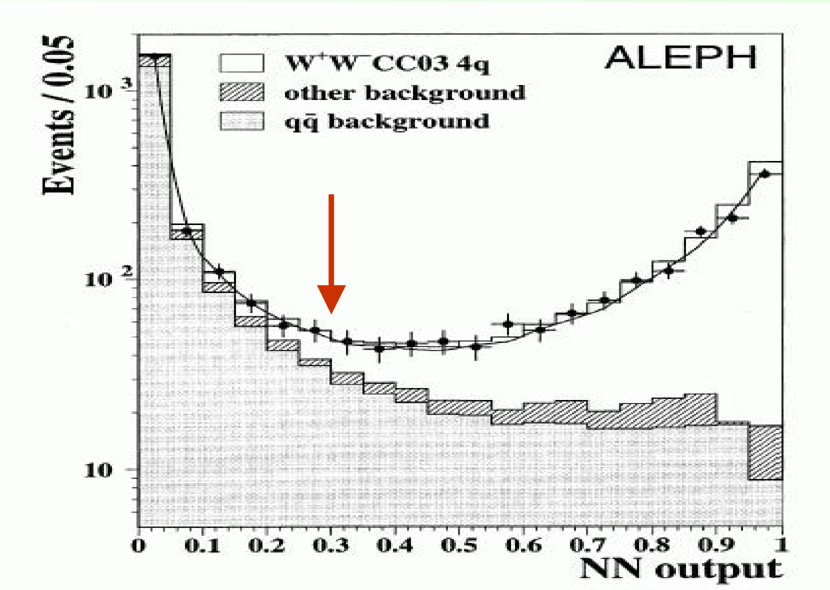
- hadronic channel - 45.6 % $W^+W^- \to q\bar{q}q\bar{q}$ $q = u, d, s, c, b$
- semileptonic channel - 43,9 % $W^+W^- \to q\bar{q}l\nu_l$ $l = e, \mu, \tau$
- pure leptonic channel - 10,5 % $W^+W^- \to l\nu l'\nu'$

$e^+e^- \rightarrow W^+W^- \rightarrow qqqq$ events

Peculiarities:

- 4 or more hadronic jets
- No missing energy
- No high energetic lepton or photon
- Huge QCD background coming from $e^+e^- \rightarrow qq$ events with radiative gluons
- Irreducible $e^+e^- \rightarrow ZZ \rightarrow qqqq$ background



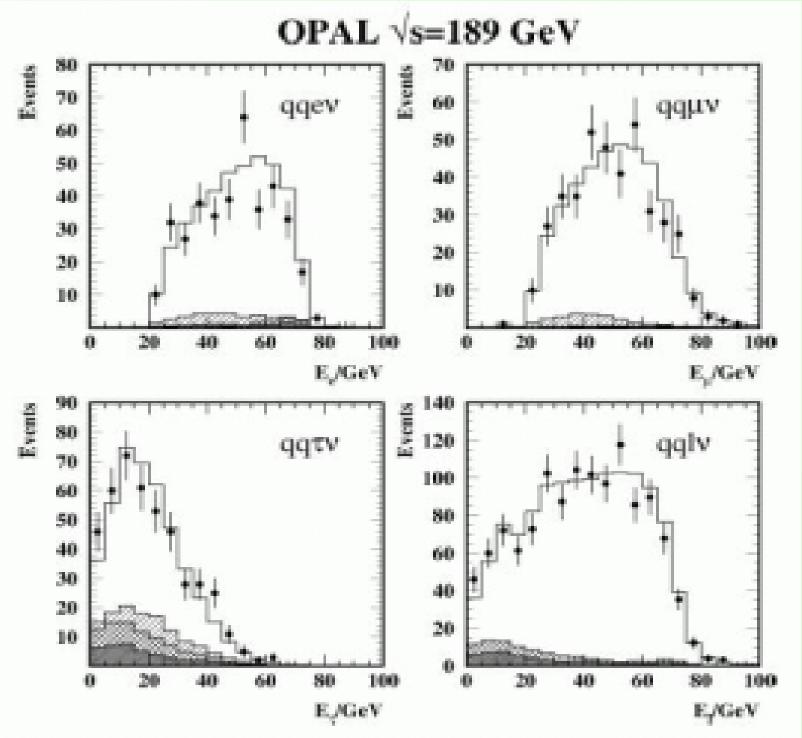


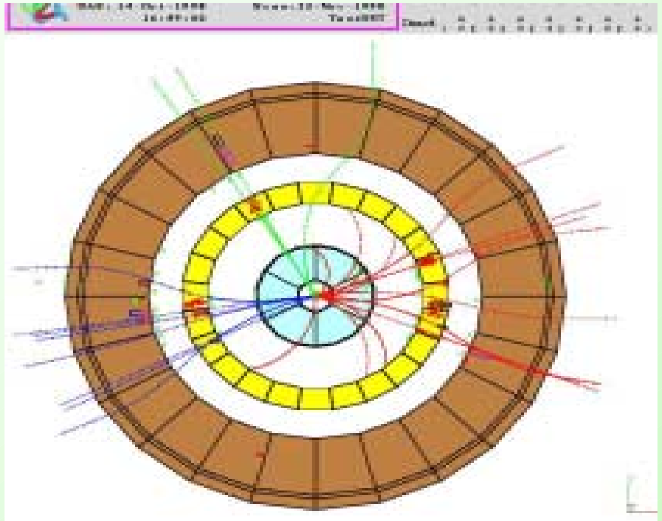
Cut based preselection and neural network application
Typical efficiencies ≅ 85-90 %
Typical purity ≅ 80 %

$e^+e^- \to W^+W^- \to qql\nu$ events

Peculiarities:

- 2 hadronic jets
- Missing energy
- One isolated lepton for $qqe\nu$, $qq\mu\nu$ and $qq\tau\nu$ with leptonic decay of τ or one low multiplicity jet for $qq\tau\nu$ with hadronic decay of τ.
- Background: $e^+e^- \to qq$ events with ISR photon and same four-fermion final states





Delphi - $qq\tau\nu$ event

Cut based analysis and/or likelihood selections

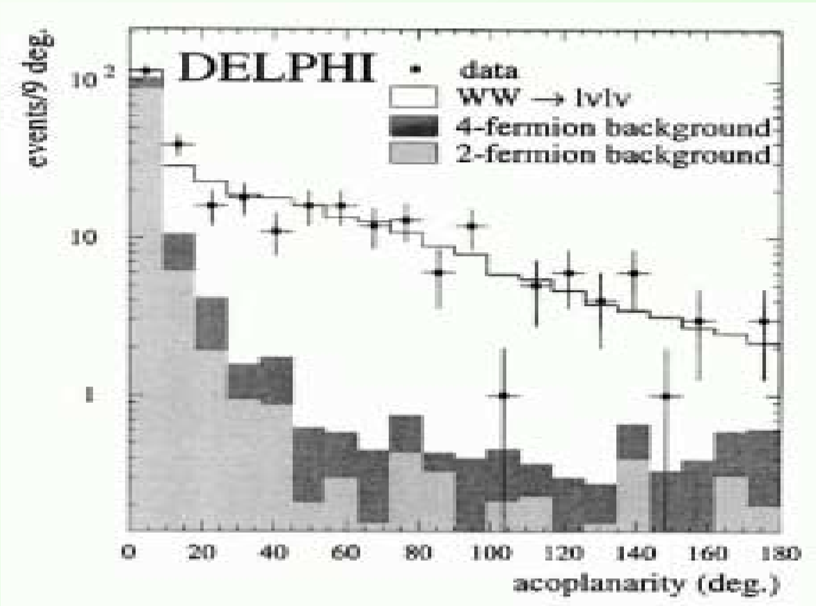
Typical efficiencies ≅ 60(τ)-90 %

Typical purity ≅ 80(τ)-95 %

$e^+e^- \rightarrow W^+W^- \rightarrow l\nu l\nu$ events

Peculiarities:

- 3 lepton flavour → 6 different final states
- 2 high energy acoplanar leptons (electron, muon)
  either 1 lepton and one low multiplicity jet
  or even 2 low multiplicity jets.
- Large missing energy
- Large number of diagrams for each final states



Delphi efficiencies @ 189 GeV

channel	$\tau\nu\tau\nu$	$\tau\nu e\nu$	$\tau\nu\mu\nu$	$e\nu e\nu$	$e\nu\mu\nu$	$\mu\nu\mu\nu$
$\tau\nu\tau\nu$	**0.252**	0.069	0.083	0.005	0.008	0.003
$\tau\nu e\nu$	0.040	**0.433**	0.012	0.044	0.057	0.
$\tau\nu\mu\nu$	0.019	0.008	**0.540**	0.0	0.043	0.047
$e\nu e\nu$	0.005	0.114	0.	**0.474**	0.	0.
$e\nu\mu\nu$	0.004	0.038	0.090	0.001	**0.589**	0.
$\mu\nu\mu\nu$	0.001	0.	0.058	0.	0.002	**0.655**

Cross section measurements

The observed numbers of events selected in the 10 signal channels $e^+e^- \rightarrow W^+W^- \rightarrow$ ffff are used in a maximum likelihood fit.

$$L_{WW} = \prod_{i=1,10} \frac{e^{-n_i} \cdot n_i^{d_i}}{d_i!}$$

$$n_i = L \cdot \sum_{j=1,10} \varepsilon_{ij} \cdot \sigma_j + n_i^{bg}$$

Taking into account correlations:

Event selection and classification

	ee	$e\mu$	$e\tau$	$\mu\mu$	$\mu\tau$	$\tau\tau$	$eq\bar{q}$	$\mu q\bar{q}$	$\tau q\bar{q}$	$q\bar{q}q\bar{q}$	all
$e\nu e\nu$	57.8	–	8.8	–	–	0.5	–	–	–	–	67.1
$e\nu\mu\nu$	–	59.0	4.7	–	4.6	0.3	–	–	–	–	68.6
$e\nu\tau\nu$	3.0	4.2	50.1	–	0.3	4.3	–	–	–	–	61.9
$\mu\nu\mu\nu$	–	–	–	61.9	8.3	0.3	–	–	–	–	70.6
$\mu\nu\tau\nu$	–	4.2	0.3	3.5	52.9	3.5	–	–	–	–	64.4
$\tau\nu\tau\nu$	0.2	0.4	7.7	0.4	6.0	36.5	–	–	–	–	51.2
$e\nu q\bar{q}$	–	–	–	–	–	–	82.4	–	5.4	0.2	88.0
$\mu\nu q\bar{q}$	–	–	–	–	–	–	–	87.5	4.1	0.2	91.9
$\tau\nu q\bar{q}$	–	–	–	–	–	–	3.7	3.8	59.0	0.9	68.0
$q\bar{q}q\bar{q}$	–	–	–	–	–	–	–	–	–	91.7	91.7

Aleph efficiencies table @ 189 GeV

$$\sigma_{q\bar{q}q\bar{q}} = \sigma_{WW} \cdot \left(BR(W \rightarrow q\bar{q})\right)^2$$

$$\sigma_{q\bar{q}l\nu} = 2 \cdot \sigma_{WW} \cdot BR(W \rightarrow q\bar{q}) \cdot BR(W \rightarrow l\nu)$$

$$\sigma_{l\nu l'\nu'} = 2 \cdot \sigma_{WW} \cdot BR(W \rightarrow l\nu) \cdot BR(W \rightarrow l'\nu')$$

The fit is performed by determining the total WW cross section and the Branching Ratios

LEP Combination

Combination take into account correlations between systematic uncertainties

global fit to 32 measurements

$\sqrt{s}$ (GeV)	WW cross section (pb) ALEPH	DELPHI	L3	OPAL	LEP	χ^2/d.o.f.
161.3	$4.23 \pm 0.75^*$	$3.67^{+0.99}_{-0.87}$ *	$2.89^{+0.82}_{-0.71}$ *	$3.62^{+0.94}_{-0.84}$ *	3.69 ± 0.45	} 1.3 / 3
172.1	11.7 ± 1.3 *	11.6 ± 1.4 *	12.3 ± 1.4 *	12.3 ± 1.3 *	12.0 ± 0.7	} 0.22/ 3
182.7	$15.57 \pm 0.68^*$	$15.86 \pm 0.74^*$	$16.53 \pm 0.72^*$	$15.43 \pm 0.66^*$	15.79 ± 0.36	27.42/24 (182.7–206.6)
188.6	$15.71 \pm 0.38^*$	$15.83 \pm 0.43^*$	$16.24 \pm 0.43^*$	$16.30 \pm 0.38^*$	16.00 ± 0.21	
191.6	17.23 ± 0.91	16.90 ± 1.02	16.39 ± 0.93	16.60 ± 0.98	16.72 ± 0.48	
195.5	17.00 ± 0.57	17.86 ± 0.63	16.67 ± 0.60	18.59 ± 0.74	17.43 ± 0.32	
199.5	16.98 ± 0.56	17.35 ± 0.60	16.94 ± 0.62	16.32 ± 0.66	16.84 ± 0.31	
201.6	16.16 ± 0.76	17.67 ± 0.84	16.95 ± 0.88	18.48 ± 0.91	17.23 ± 0.42	
204.9	16.57 ± 0.55	17.44 ± 0.64	17.35 ± 0.64	15.97 ± 0.64	16.71 ± 0.31	
206.6	17.32 ± 0.45	16.50 ± 0.48	17.96 ± 0.51	17.77 ± 0.57	17.33 ± 0.25	

Full covariance matrix built with inter-experiment and inter-energy correlations (accounting for common MonteCarlo generators to predict background cross sections and to simulate hadronisation processes, final state interactions…)

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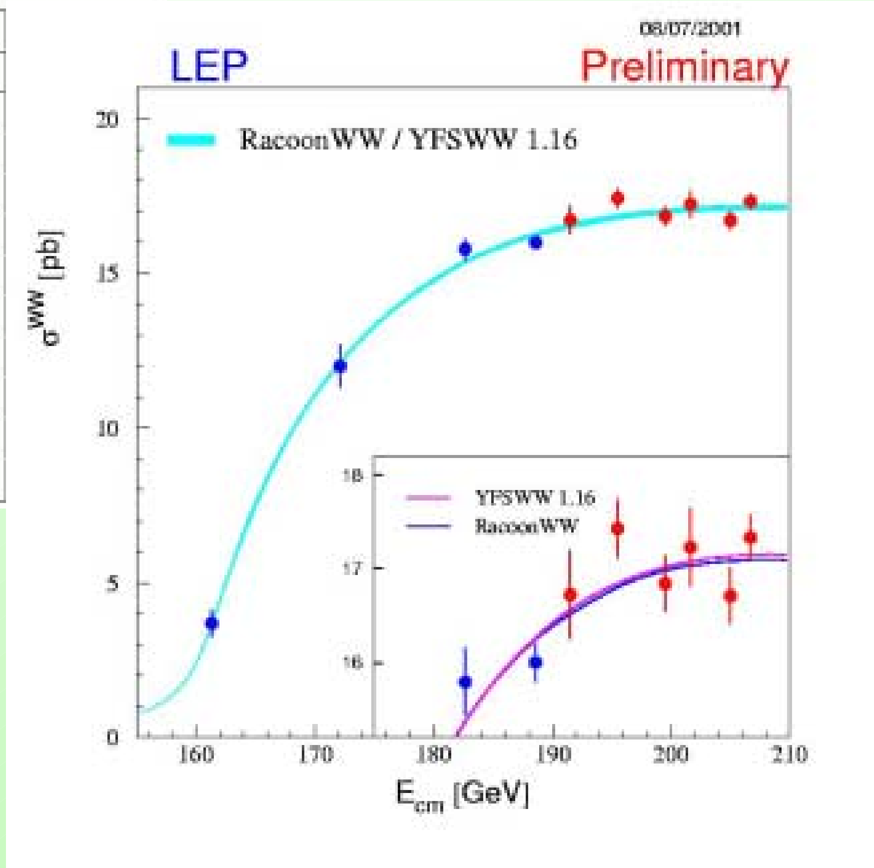

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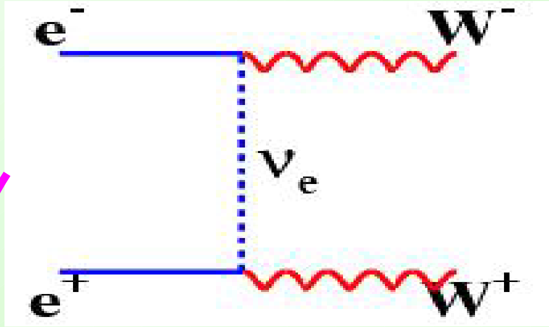
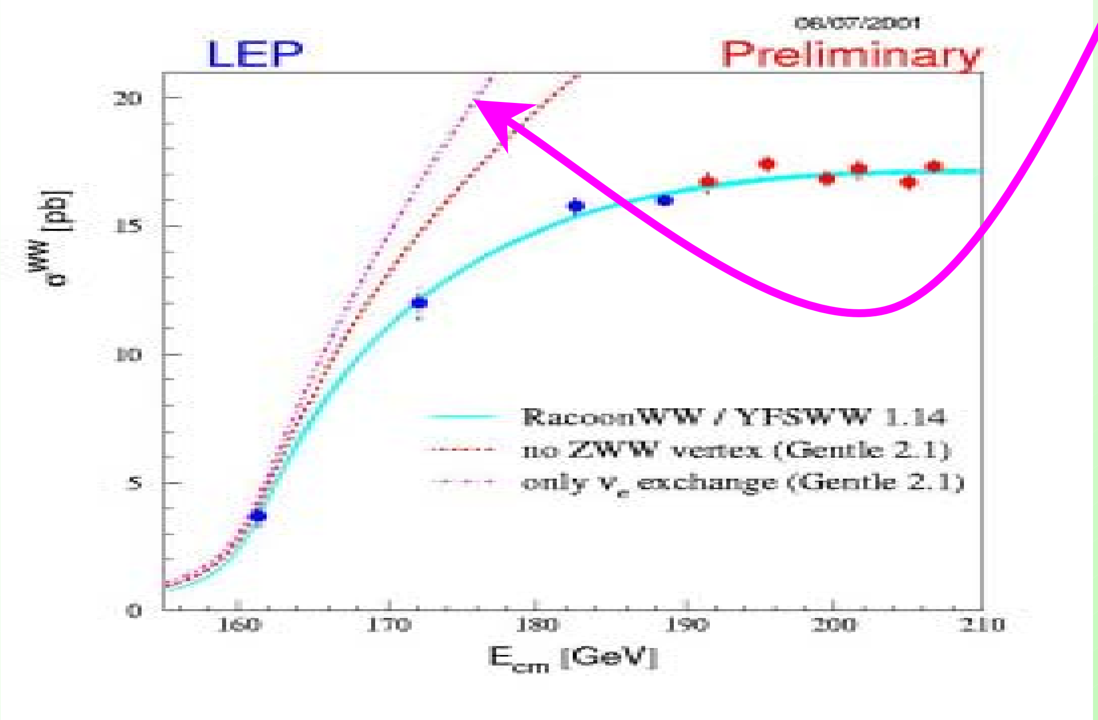
Triple gauge boson vertex

The $e^+e^- \to W^+W^-$ cross section measurement at LEP2 is in perfect agreement with the Standard Model triple gauge boson vertex $WW\gamma$ e WWZ





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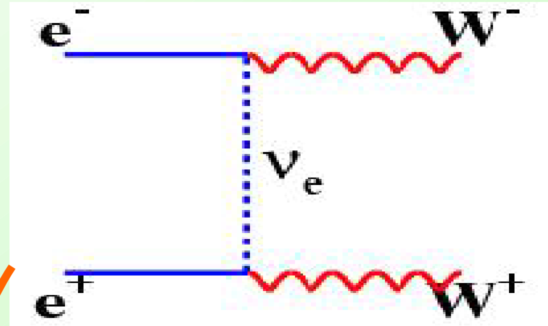

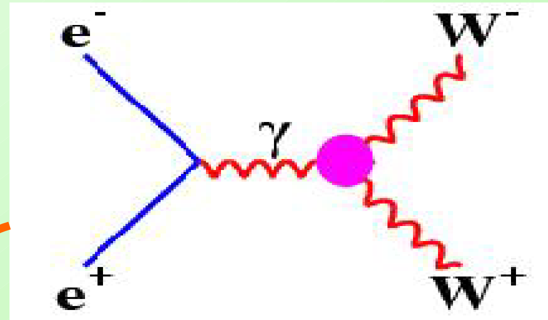

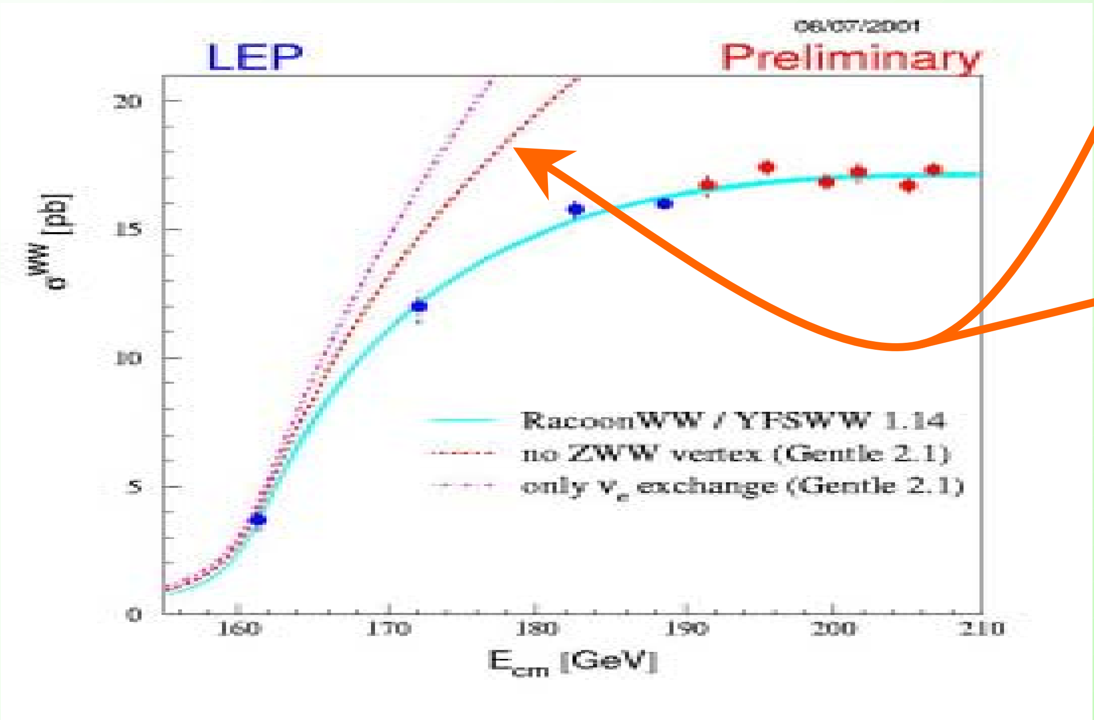

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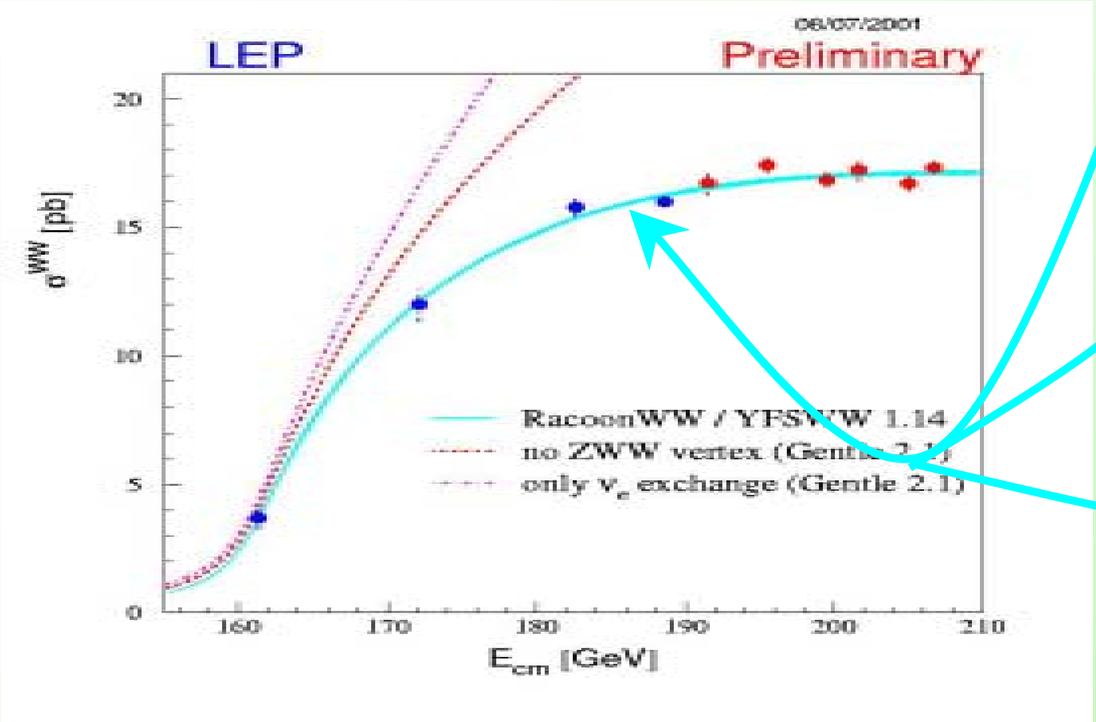
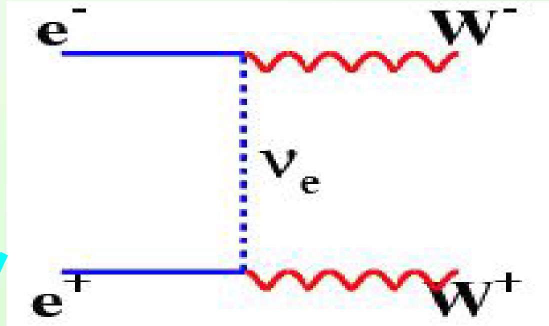
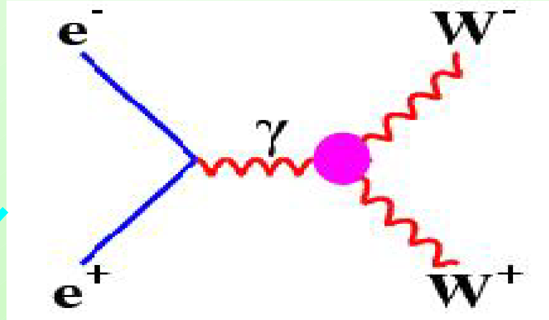
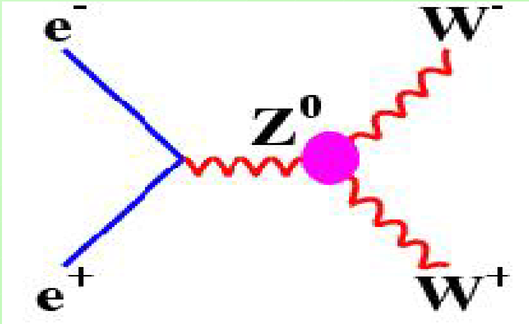
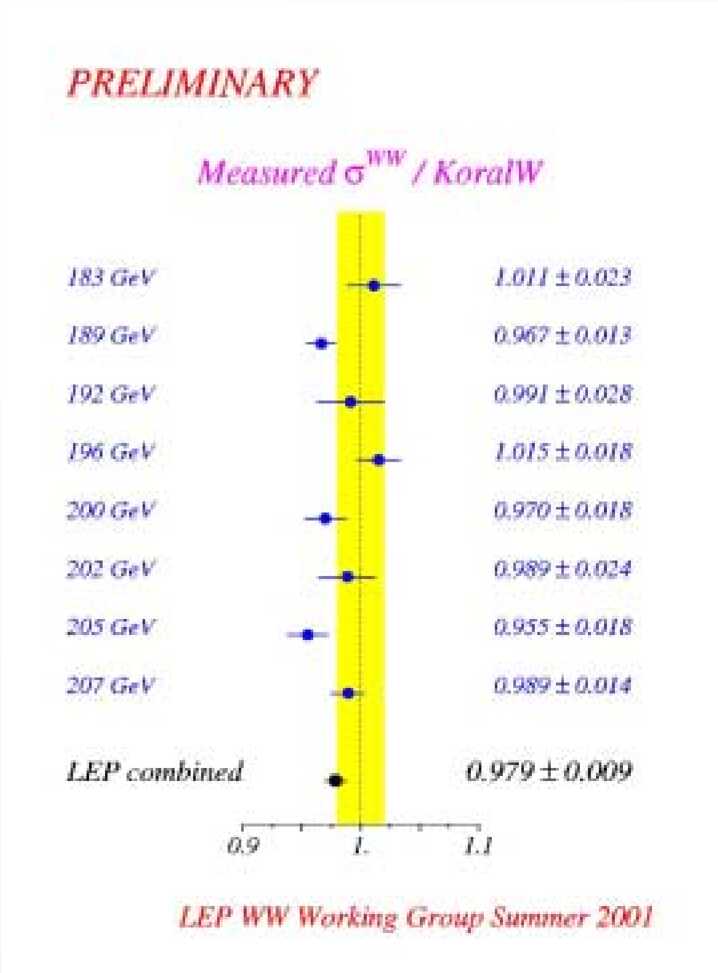






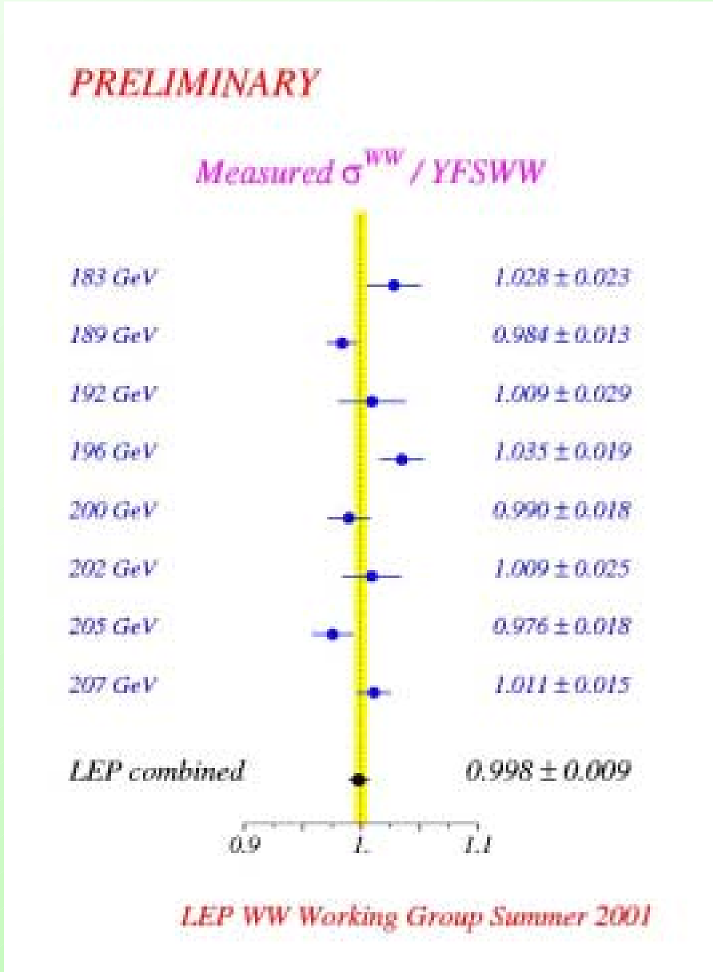


Measured/Expected Cross Section



The agreement averaged over the different energies can be expressed quantitatively by the combination of the ratios:

$$R_{WW} = \frac{\sigma_{WW}^{meas.}}{\sigma_{WW}^{theo.}}$$



The improvement in the new Montecarlo YFSWW3 comes from non-leading O(α) electroweak radiative corrections to the W-pair production process, not included in the old Montecarlo KoralW. **The uncertainty on the theoretical predictions is now ~ 0.5 %** (yellow band)

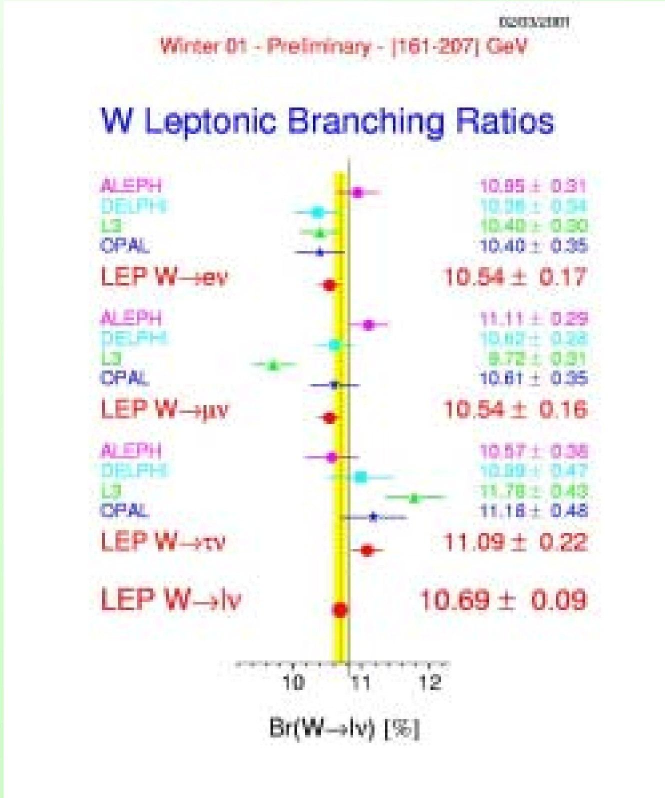
Leptonic Branching Ratio

The lepton universality in the decay of W bosons can be tested at the level of 2,9 %:

$$BR(W \to \mu\bar{\nu}_\mu) \big/ BR(W \to e\bar{\nu}_e) = 1.000 \pm 0.021$$

$$BR(W \to \tau\bar{\nu}_\tau) \big/ BR(W \to e\bar{\nu}_e) = 1.052 \pm 0.029$$

$$BR(W \to \tau\bar{\nu}_\tau) \big/ BR(W \to \mu\bar{\nu}_\mu) = 1.052 \pm 0.028$$



Assuming lepton universality:

$$BR\ (W \to l\nu) = 10{,}69\ \% \pm 0.06\ \%\ (stat.) \pm 0.07\ \%\ (syst.)$$

Standard Model expectation: 10,83%

Hadronic Branching Ratio and V_{cs}

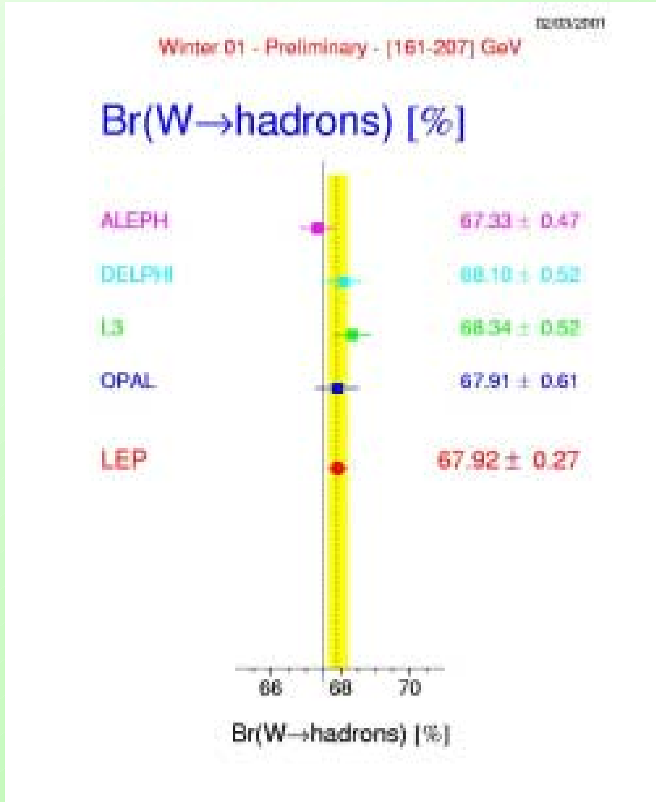
BR (W → qq) = 67.92 % ± 0.17 % (stat.) ± 0.21 % (syst.)

Standard Model expectation: 67,51 %

$$\frac{BR(W \to q\bar{q})}{1 - BR(W \to q\bar{q})} = \left[1 + \frac{\alpha_s(M_W^2)}{\pi}\right] \cdot \sum_{\substack{i=u,c \\ j=d,s,b}} |V_{ij}|^2$$

$$\alpha_s(M_W^2) = 0.121 \pm 0.002$$

$$\sum_{\substack{i=u,c \\ j=d,s,b}} |V_{ij}|^2 = 2.039 \pm 0.025$$



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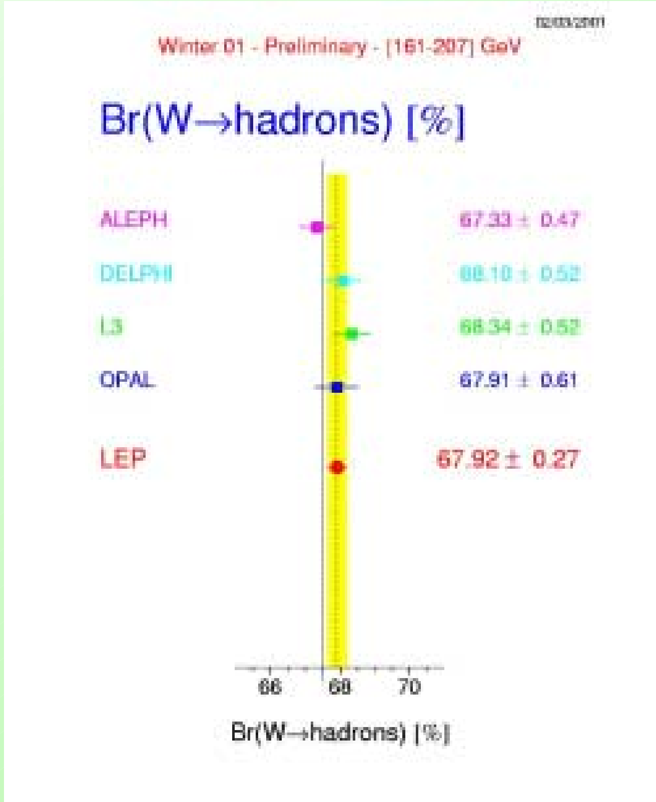
$$\alpha_s(M_W^2) = 0.121 \pm 0.002$$

$$|V_{cs}| = 0.996 \pm 0.013$$



CONCLUSIONS

- More than 40000 $e^+e^- \rightarrow W^+W^-$ events were collected by LEP experiments in 1996-2000
- Cross section measurements of different decay channels are in good agreement with the Standard Model predictions
- Lepton universality in W decay is tested at level of 2.9 %. Branching Ratios are in agreement with the Standard Model.
- LEP collaborations are working to publish final results in the next months