LEP Summary on $W \to l\nu$

T. Moulik
TIFR, Bombay, India (L3,CERN)

14-17, September, 1998
TAU 98, Santander, Spain

- **Introduction**
- **Event topology and Selection**
- **Cross-Section and Branching Fractions**
- **Conclusions**

Introduction

- W boson is the carrier of the weak charged current interaction.
- The $W \to l\nu$ vertex $\quad -i\frac{g}{\sqrt{2}}\gamma^{\mu}\frac{1}{2}(1-\gamma^{5})$
- The Study of $W \to l\nu$ events at LEP2 provides tests of lepton universality in charged current sector. Lepton Universality indicates

$$BR(W \to e\nu_e) = BR(W \to \mu\nu_\mu) = BR(W \to \tau\nu_\tau)$$

☞ W Boson decay Widths and Branching Fractions

- $\Gamma_{\mathbf{W_{\nu_i l_i}}} = \frac{\mathbf{G_\mu M_W^3}}{\mathbf{6\sqrt{2}\pi}}$
- $\Gamma_{\mathbf{W_{q_i q_j}}} = \frac{\mathbf{3G_\mu M_W^3}}{\mathbf{6\sqrt{2}\pi}} \mid \mathbf{V_{ij}} \mid^{\mathbf{2}} \left(\mathbf{1} + \frac{\alpha_\mathbf{s}(\mathbf{M_W^2})}{\pi}\right)$
- $\Gamma_{\mathbf{W}} = \frac{\mathbf{9G_\mu M_W^3}}{\mathbf{6\sqrt{2}\pi}} \left(\mathbf{1} + \frac{\mathbf{2}\alpha_\mathbf{s}(\mathbf{M_W^2})}{\mathbf{3}\pi}\right)$

$$\begin{aligned} BR(W \to l\nu) &= 10.8\%\ l = e, \mu, \tau \\ BR(W \to q\bar{q}) &= 67.5\% \end{aligned}$$

Introduction

☞ Current Status of Lepton Universality Tests

- From Neutral Current Couplings(Z decays)

Parameter	**LEP1+SLD**
g_{V_μ}/g_{V_e}	0.967 ± 0.082
g_{V_τ}/g_{V_e}	0.965 ± 0.032
g_{A_μ}/g_{A_e}	0.9997 ± 0.0014
g_{A_τ}/g_{A_e}	1.0015 ± 0.0015

- From Charged Current Couplings(τ decays)

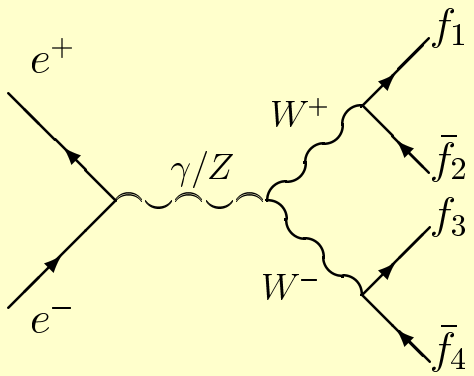
Decay Process	World Average
$\mathbf{BR}(\tau \to \mathrm{e}\nu\nu)$	$\mathbf{17.78 \pm 0.08}$
$\mathbf{BR}(\tau \to \mu\nu\nu)$	$\mathbf{17.32 \pm 0.09}$

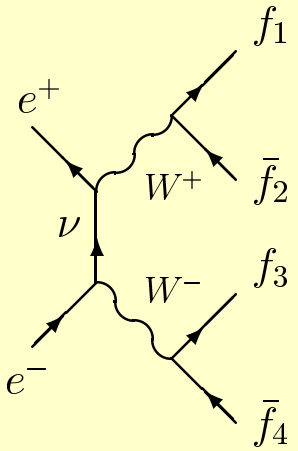
$$\frac{g_\mu}{g_e} = 1.001 \pm 0.003$$
$$\frac{g_\tau}{g_\mu} = 1.000 \pm 0.003$$

Introduction

- W production occours in various processes.
- Double resonant production of W-bosons (CC03) is dominant.

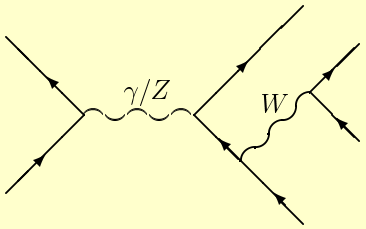
☞ Double Resonant Diagrams



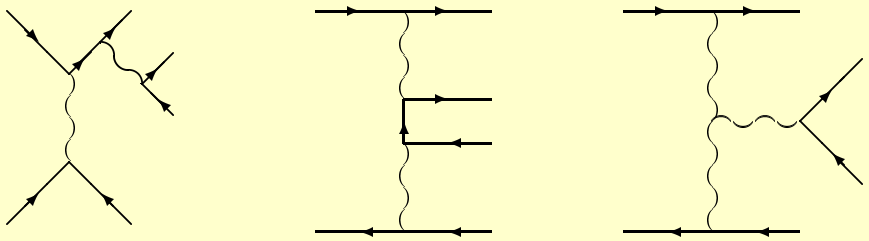


☞ Non-Resonant Diagrams

- Non-resonant contributions typically supressed by a factor $\frac{\Gamma_W}{M_W} \approx 2.5\%$.



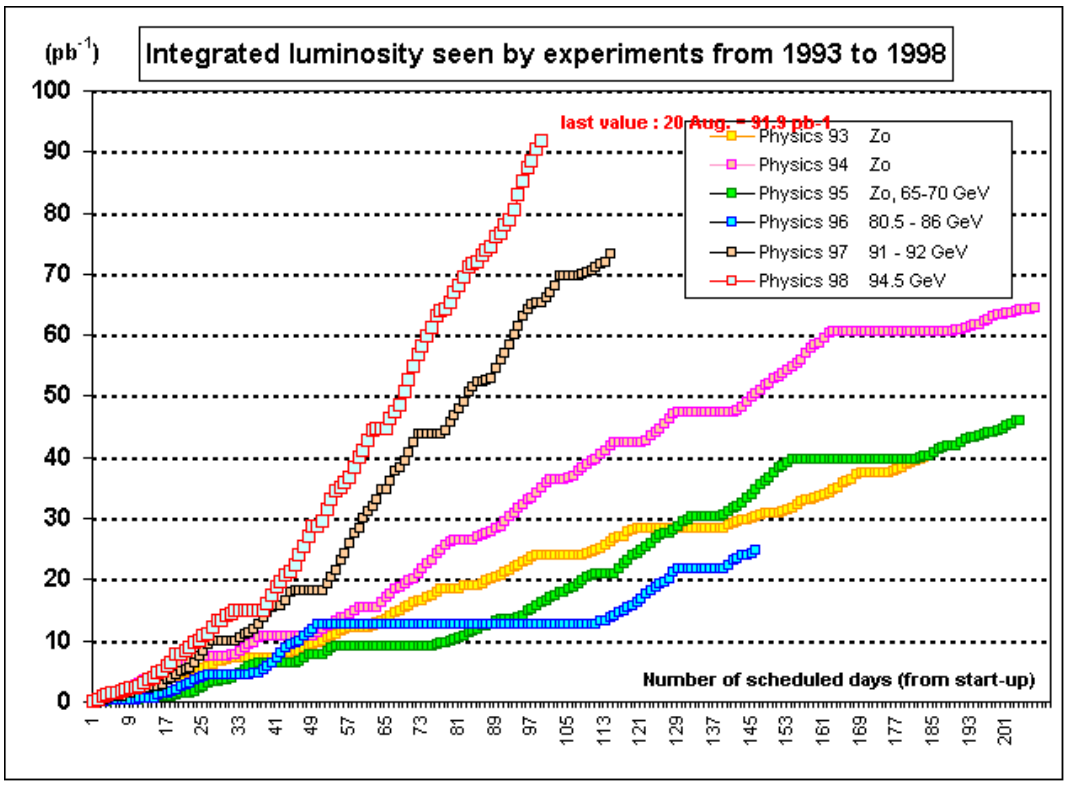
Singly-Resonant



Additional Diagrams involving e and ν_e

T. Moulik
TIFR, Bombay, India
(L3,CERN)

Introduction



☞ At 183 GeV

Experiment	**Luminosity** (pb^{-1})	$\mathrm{q\bar{q}l}\nu$	$\ell\nu\ell\nu$
ALEPH	57.0	322	60
DELPHI	50.0	288	59
L3	55.5	297	54
OPAL	57.0	362	78

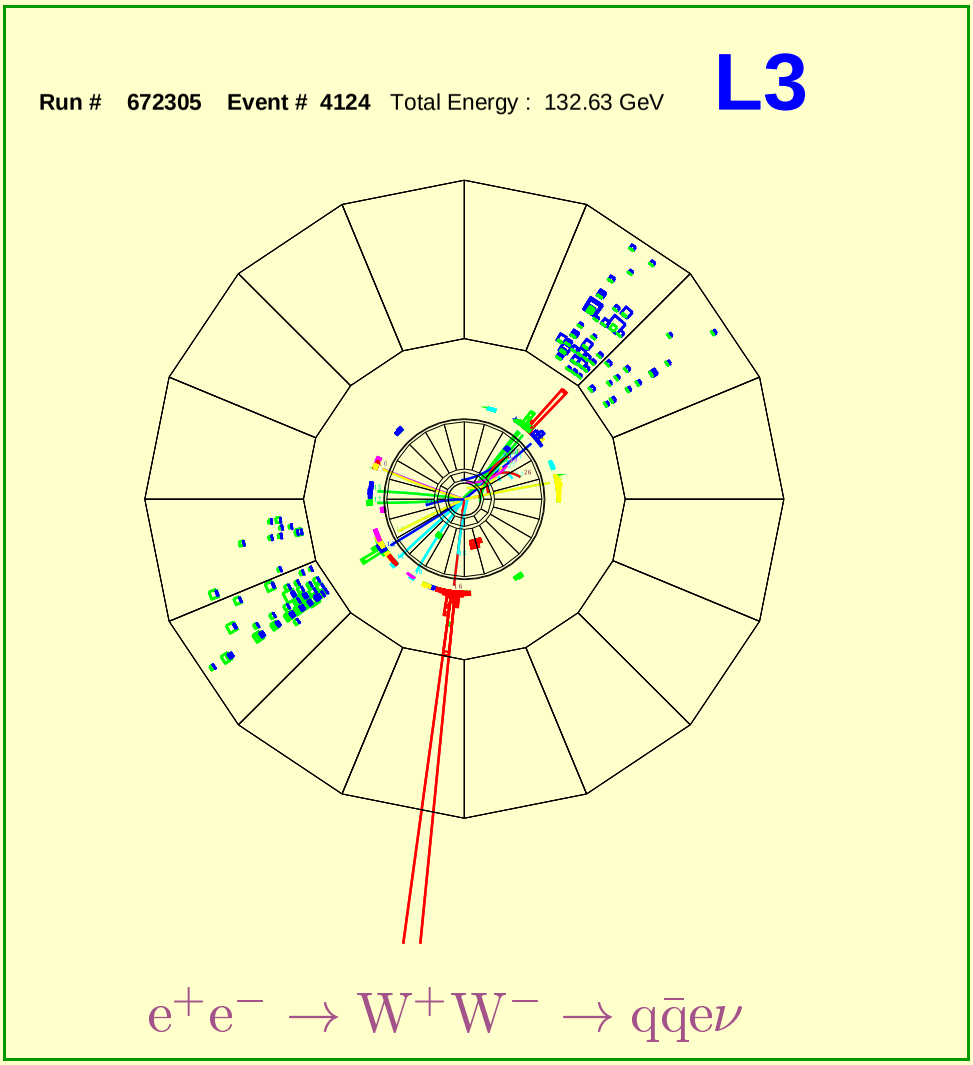
☞ At other Energies

$\sqrt{\mathrm{s}}(\mathrm{GeV})$	**Luminosity** (pb^{-1})	$\mathrm{q\bar{q}l}\nu$	$\ell\nu\ell\nu$
161	$\sim 12/\mathrm{exp}$	11-16	2-6
172	$\sim 10/\mathrm{exp}$	40-55	8-9

Topology and Selection ($\mathrm{W^+W^-} \to \mathrm{q\bar{q}l}\nu$)

Signature : 2 seperated jets, 1 energetic isolated lepton,missing momentum and energy due to neutrino.

Backgrounds: $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}(\gamma)$, $\mathrm{e^+e^-} \to q\bar{q}l^+l^-$

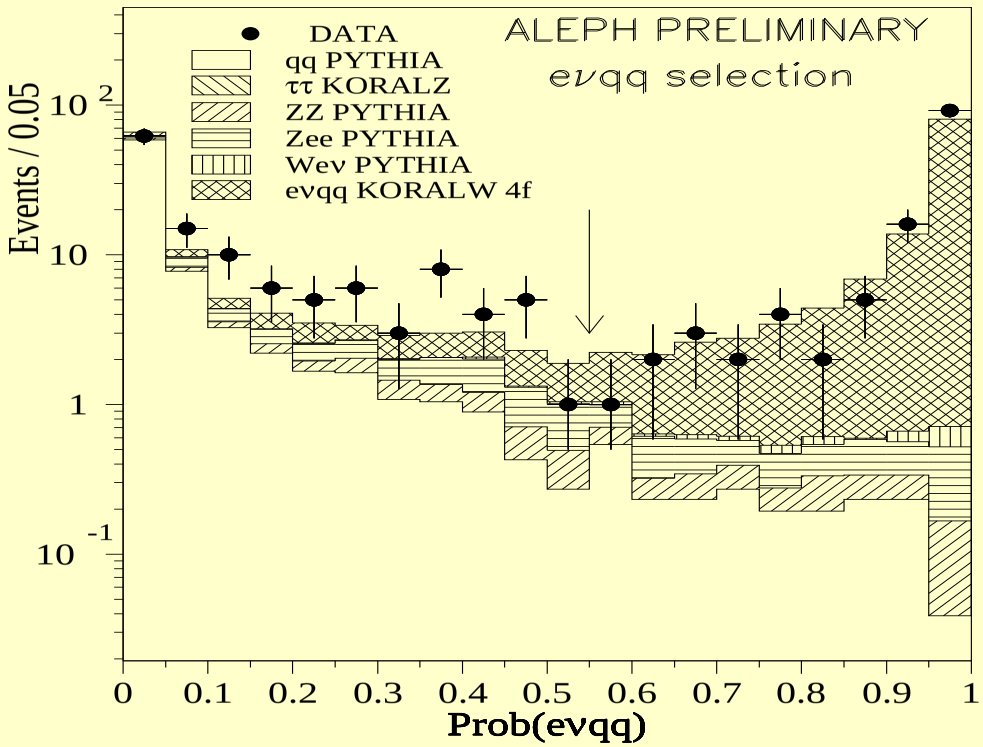


$\mathrm{e^+e^-} \to \mathrm{W^+W^-} \to \mathrm{q\bar{q}e}\nu$

Electron : identified as energy deposit in Calorimeter+Matching Track in tracking chamber

$q\bar{q}l\nu$ Selection Variables

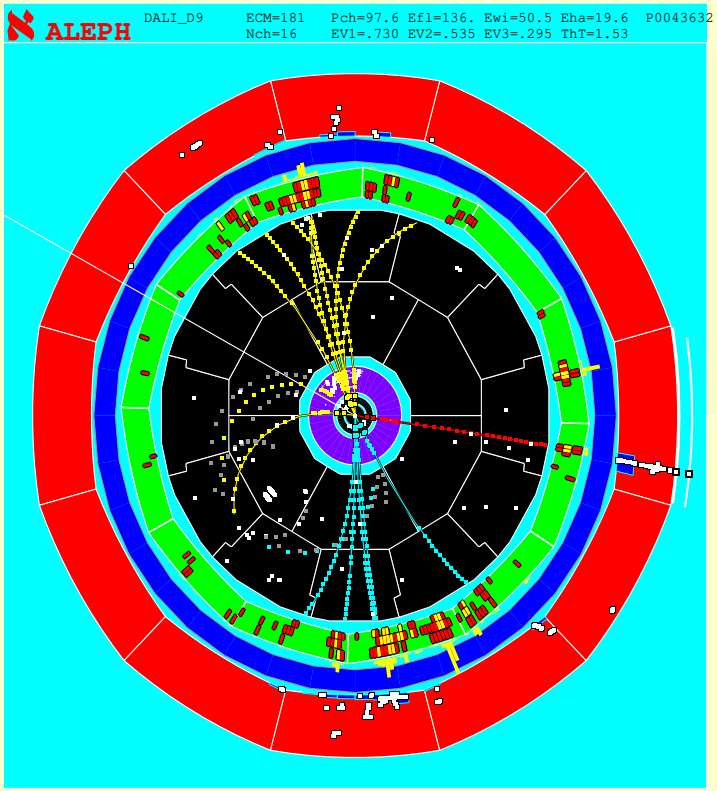
☞ 183 GeV

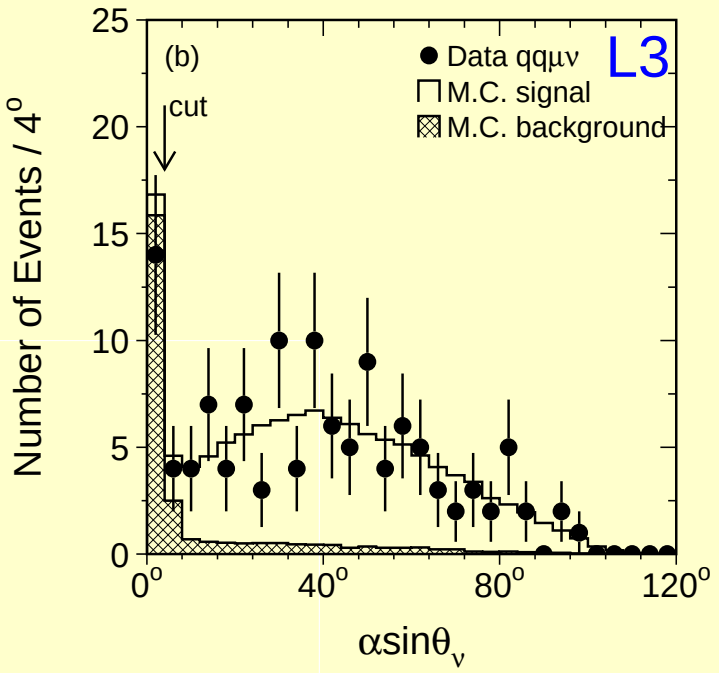


- Probability density function constructed using 3 variables
  - Lepton Energy
  - Total transverse missing momentum
  - Lepton Isolation

T. Moulik
TIFR, Bombay, India
(L3,CERN)

Topology and Selection $(W^+W^- \to q\bar{q}l\nu)$

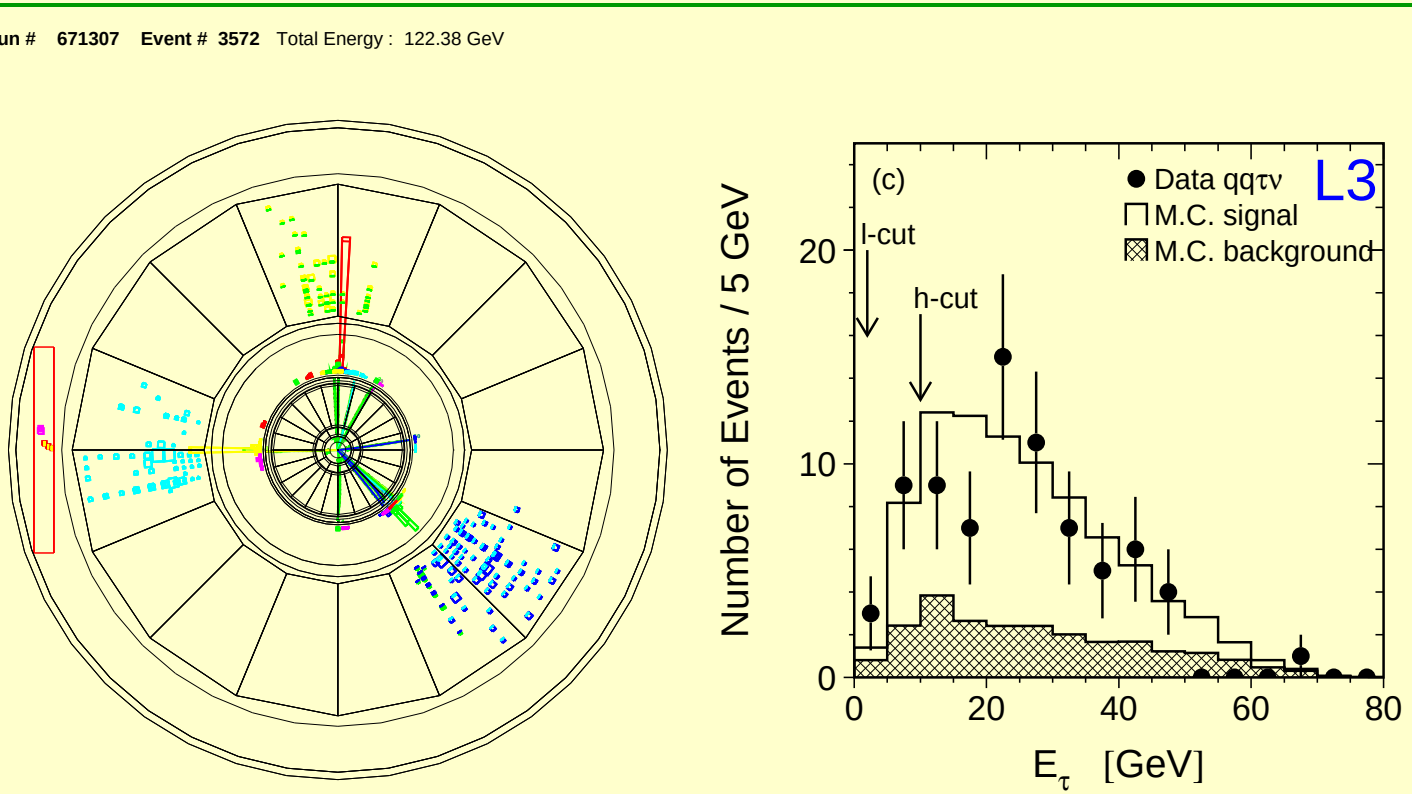




$e^+e^- \to W^+W^- \to q\bar{q}\mu\nu$

☞ **Muon**- Identified in Muon chamber or as MIP signal with matched track

Topology and Selection ($W^+W^- \to q\bar{q}l\nu$)



$e^+e^- \to W^+W^- \to q\bar{q}\tau\nu$

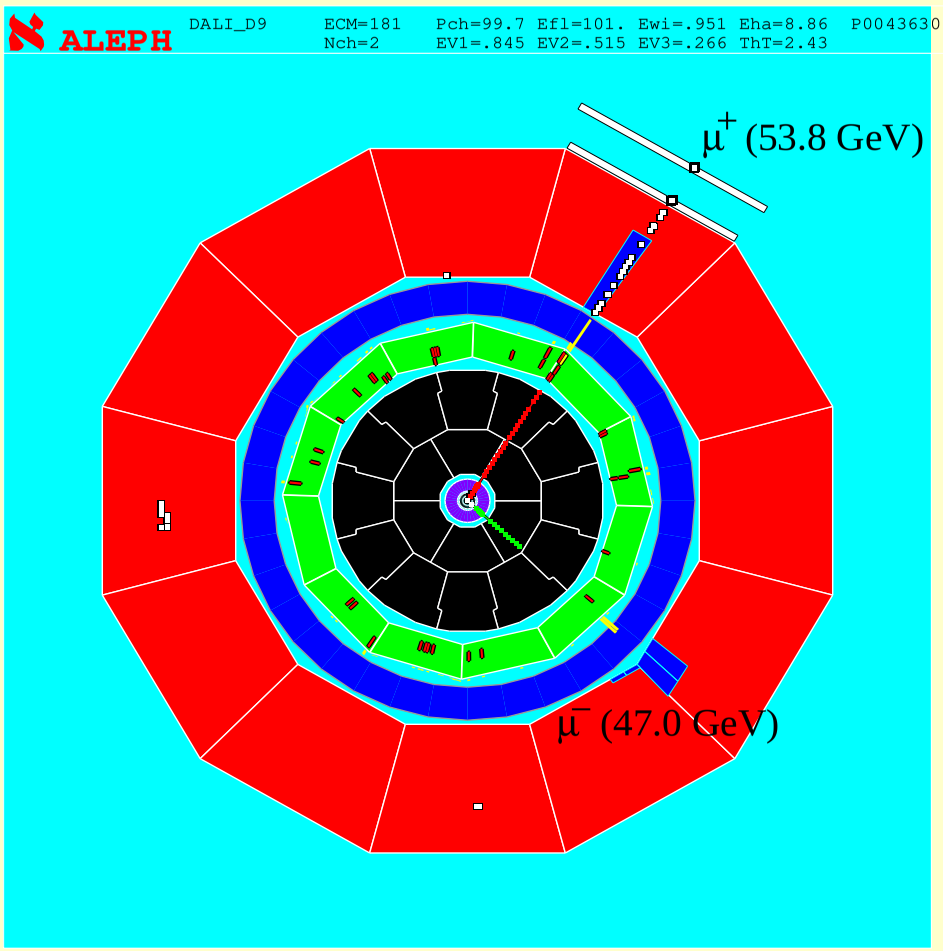
☞ **Tau**- identified from its decay into electron or muon or as narrow jet from hadronic decays.

Efficiencies and Background in $\mathrm{q\bar{q}l\nu}$ channel

Chan.	Signal Efficiency	Background (fb)	$\mathrm{N_{data}/exp(183GeV)}$
$\mathrm{q\bar{q}e\nu}$	70-85	100-200	112
$\mathrm{q\bar{q}}\mu\nu$	77-89	60-140	108
$\mathrm{q\bar{q}}\tau\nu$	30-60	114-350	77

- The efficiencies for channels involving electrons or muons have higher efficiencies $\sim$ 70-90 $\%$.
- When tau is involved efficiencies drop to $\sim$ 30-60 $\%$.

$W^+W^- \to \ell\nu\ell\nu$



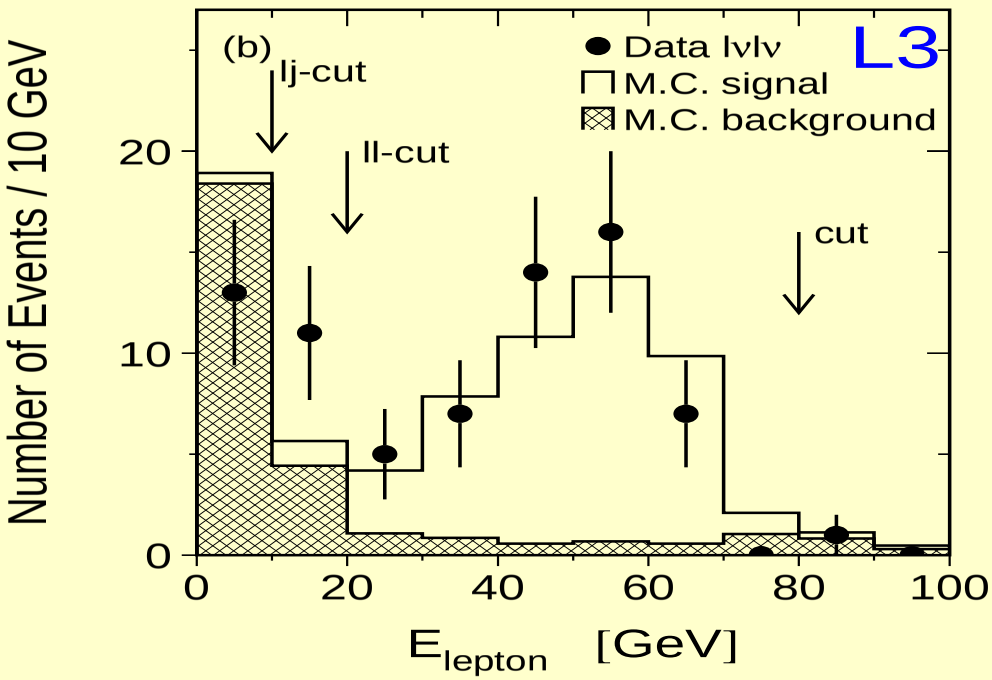
$e^+e^- \to W^+W^- \to \mu\nu\mu\nu$

Signature : 2 acoplanar energetic leptons, missing momentum not along the beam pipe.

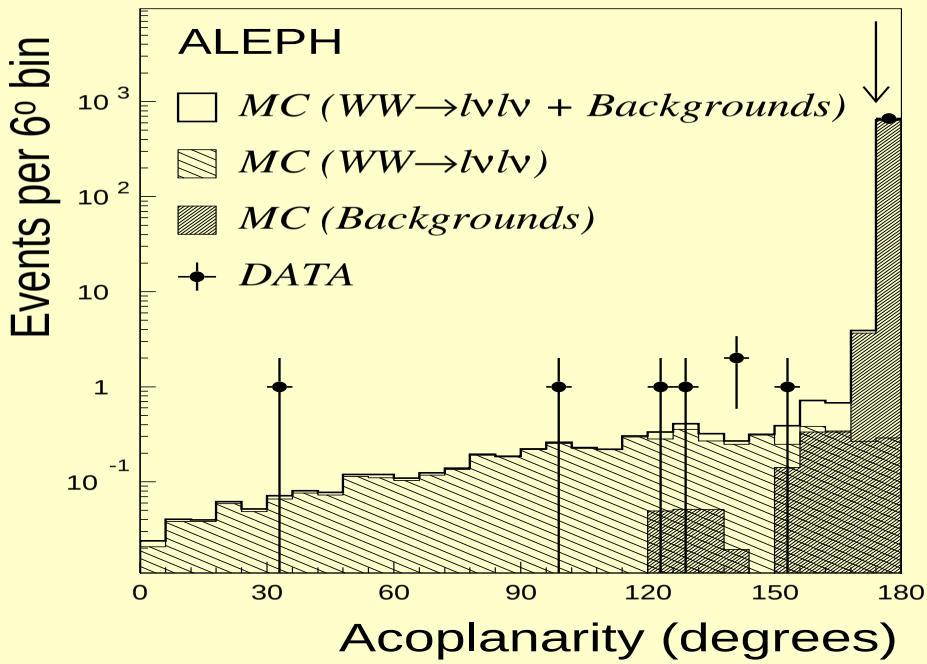
Backgrounds: $e^+e^- \to Z/\gamma \to l^+l-(\gamma)$, $e^+e^- \to e^+e^-$(Bhabha),two photon processes, $e^+e^- \to e^+e^-e^+e^-(\mu^+\mu^-)$.

$\ell\nu\ell\nu$ Selection variables

☞Energy of Selected Leptons(183 GeV)

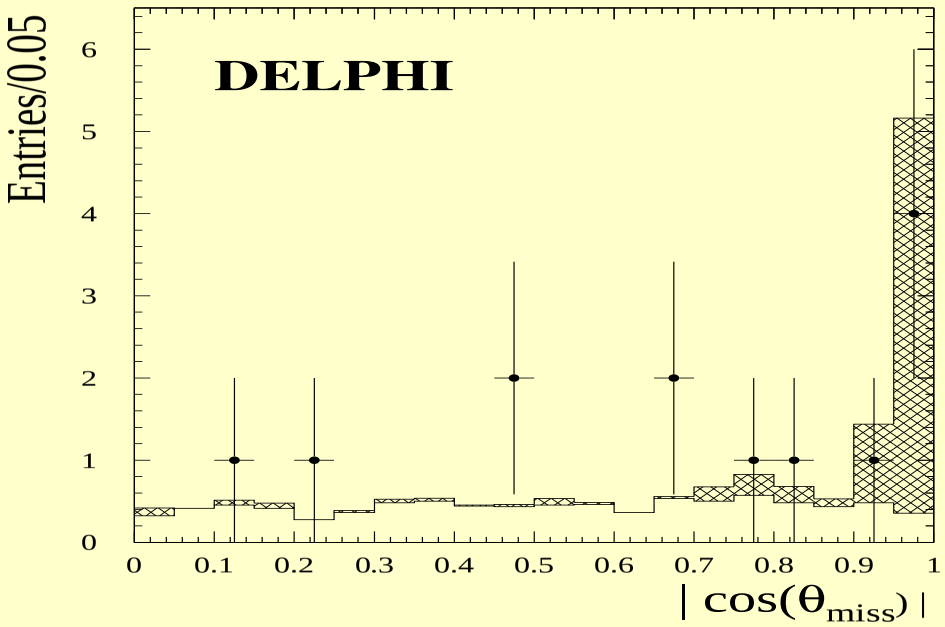


☞Acoplanarity (161 GeV)



$\ell\nu\ell\nu$ Selection variables

☞ $|\cos\theta_{\rm miss}|$ (172 GeV)



+ Other Cuts

- Cuts on Cluster Multiplicity and Tracks typically between 2-5 tracks.
- Photon Vetos to get rid of ISR where the photon is identified in the detector. e.g. DELPHI requires that any EM cluster not associated with lepton be $< 30\mathrm{GeV}$.

Efficiencies and Background in $\ell\nu\ell\nu$ channel

Chan.	Signal Efficiency	Background (fb)	$\mathrm{N_{data}/exp(183GeV)}$
$e\nu e\nu$	62-68	19	9
$e\nu\mu\nu$	62-70	7	14
$e\nu\tau\nu$	38-58	41	19
$\mu\nu\mu\nu$	63-71	12	8
$\mu\nu\tau\nu$	33-58	18	8
$\tau\nu\tau\nu$	17-45	46	5

- The efficiencies for channels involving only electrons and muons have higher efficiencies $\sim$ 62-70 %.
- When one tau is involved efficiencies are lower $\sim$ 40-58 %.
- When both leptons are taus efficiencies drop to $\sim$ 20-40 %.

Treatement of CC03 vs all 4f diagrams

Effect of 4f diagrams other than CC03 for final states involving e and ν_e has to be corrected for.

☞ ALEPH, OPAL

- **Treat interference diagrams as background.**

$$N_{4f}^{\overline{CC03}} = \mathcal{L}\left[\epsilon_{4f}\sigma_{4f}^{\mathrm{MC}} - \epsilon_{CC03}\sigma_{CC03}^{\mathrm{MC}}\right]$$

$$\sigma_{CC03} = \frac{N_{obs} - N_{back} - N_{4f}^{\overline{CC03}}}{\mathcal{L}\epsilon_{\mathrm{CC03}}}$$

☞ DELPHI, L3

- **Phase space cuts to deduce effect of interference diagrams.**

e.g. in $\mathrm{q\bar{q}e\nu}$ channel L3 used
$E_{(}e/\nu) > \ 20\ \mathrm{GeV} \ \ |\cos(\theta_{(}e/\nu)| < \ 0.95,$
$M_{qq}, M_{e\nu} > \ 45.0\ \mathrm{GeV}$

- Correction factor $f = \dfrac{\sigma_{CC03}}{\sigma_{4f}(\mathrm{within\ cuts})}$

$$\epsilon_{4f} = \frac{\mathrm{N_{sel}}}{\mathrm{N_{gen}(within\ cuts)}}, \qquad \epsilon_{CC03} = \frac{\epsilon_{4f}}{f}$$

$$f_{\mathrm{q\bar{q}e\nu}} = 1.087, \ f_{e\nu e\nu} = 1.070, \ f_{\mathrm{q\bar{q}}\mu(\tau)\nu} = 1.006$$

Cross-section Calculation

- Cross-section from Log likelihood fit.
- Total LL a product of $\mathrm{P}(\mathrm{N}_i, \mu_i)$ which is Poisson probability to observe N_i events where μ_i are expected.

$$\mu_{\mathbf{i}} = \left(\sum_{j=1}^{10} \epsilon_{ij} \sigma_j + \sigma_i^{bg} \right) \cdot \mathcal{L}_i$$

  - ϵ_{ij} efficiency for ith channel to select j.
  - σ_i^{bg} is Non-WW background.
  - $\mathcal{L}_i$ is the Luminosity.
- 6 different cross-sections are determined for the purely leptonic final states corresponding to the 6 decay modes for different lepton flavours.

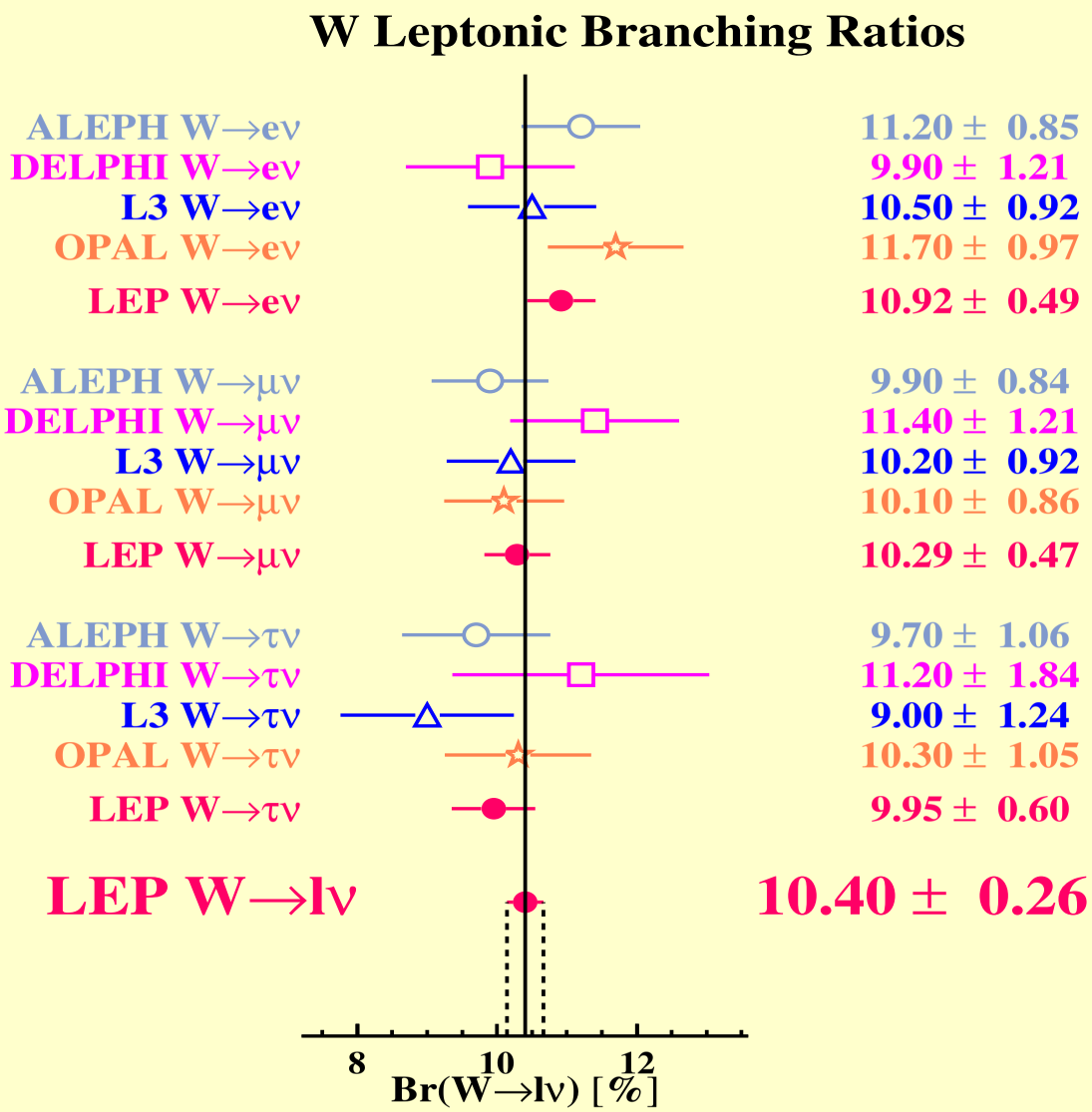
Branching Fractions

- $\sigma_{qqqq} = [B(\mathrm{W} \to qq)]^2 \times \sigma_{\mathrm{WW}}$
  $\sigma_{\mathrm{q\bar{q}l\nu}} = 2B(\mathrm{W} \to qq)B(\mathrm{W} \to l\nu) \times \sigma_{\mathrm{WW}}$
  $\sigma_{\ell\nu\ell\nu} = [B(\mathrm{W} \to e\nu) + B(\mathrm{W} \to \mu\nu) + B(\mathrm{W} \to \tau\nu)]^2 \times \sigma_{\mathrm{WW}}$
  where σ_{WW} is the total cross-section.

- Test of Lepton Universality from the ratios
  $$\frac{\mathbf{g}_\mu}{\mathbf{g}_\mathbf{e}} = \sqrt{\frac{\mathbf{BR}(\mathbf{W} \to \mu\nu)}{\mathbf{BR}(\mathbf{W} \to \mathbf{e}\nu)}}$$
  $$\frac{\mathbf{g}_\tau}{\mathbf{g}_\mathbf{e}} = \sqrt{\frac{\mathbf{BR}(\mathbf{W} \to \tau\nu)}{\mathbf{BR}(\mathbf{W} \to \mathbf{e}\nu)}}$$

- Systematic error on cross-sections is $\sim 1/5$ the statistical error. Some of the sources which contribute to the systematics is the Selection Cuts, modelling of ISR and FSR in the Monte Carlo, 4f to CC03 corrections, limited MC Statistics.

Results - Branching Fractions



Lepton Universality from W decays

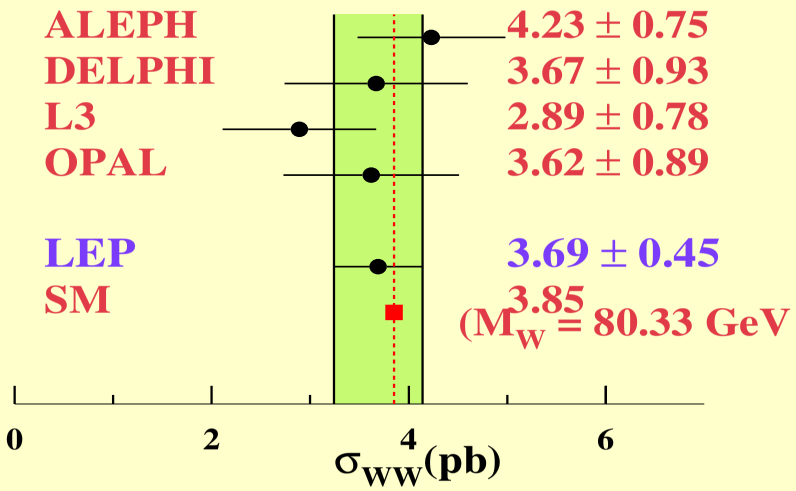
$$\frac{g_\mu}{g_e} = 0.971 \pm 0.031$$

$$\frac{g_\tau}{g_e} = 0.954 \pm 0.040$$

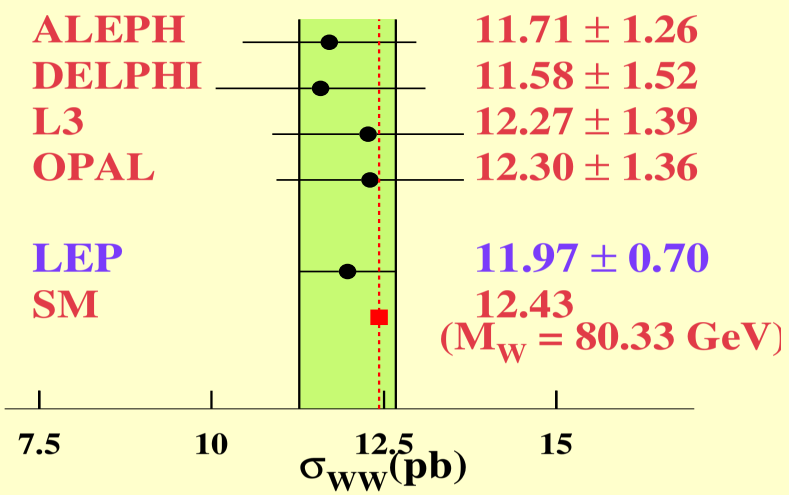
T. Moulik
TIFR, Bombay, India
(L3,CERN)

$e^+e^- \to W^+W^-$ *cross-sections*

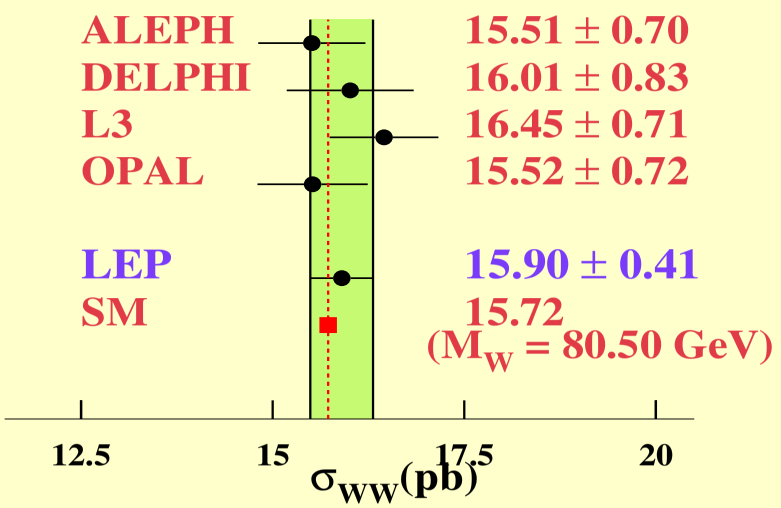
161 GeV

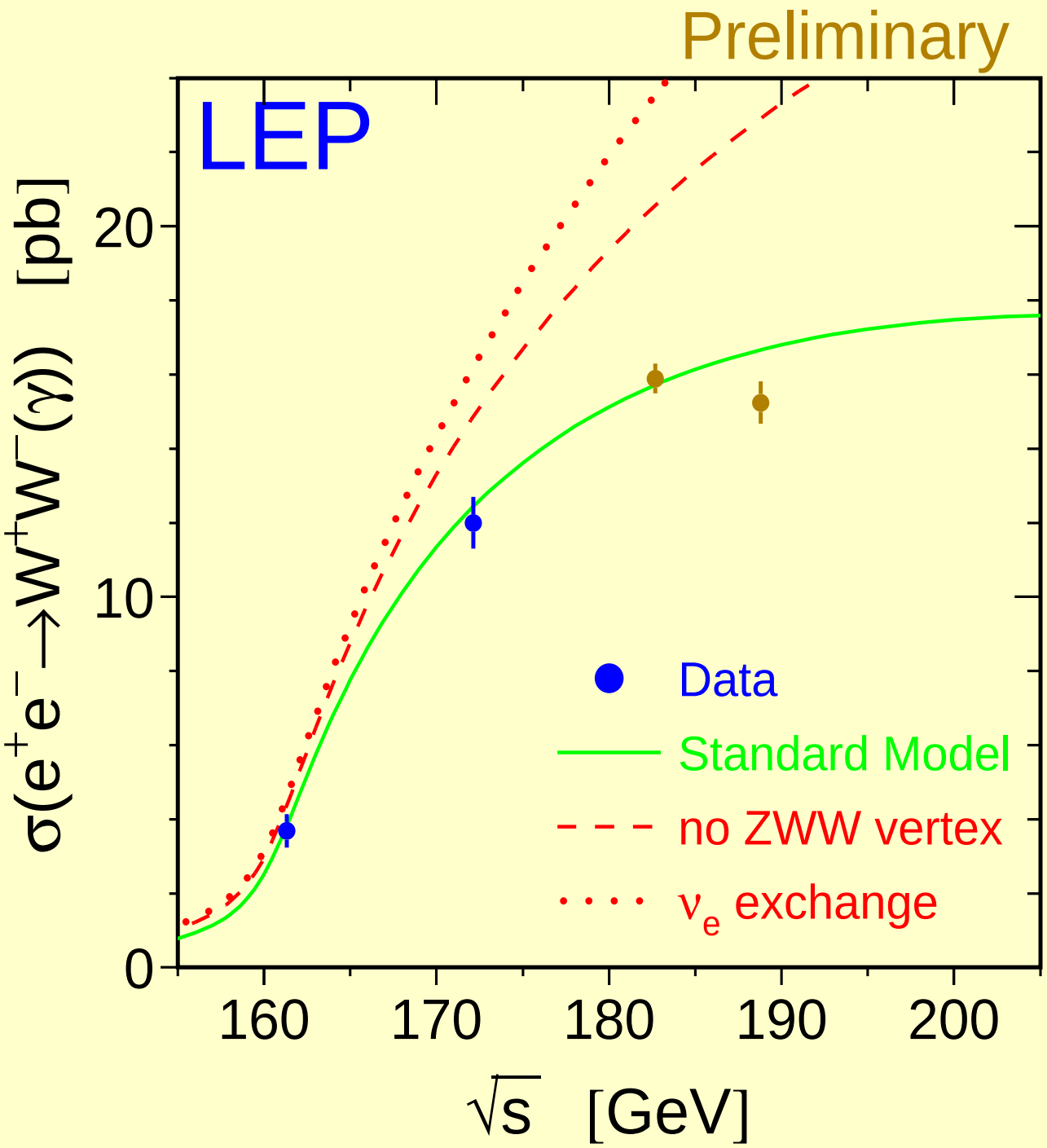


172 GeV



183 GeV




Preliminary
LEP
$\sigma(e^+e^- \to W^+W^-(\gamma))$ [pb]
20
10
0
160
170
180
190
200
$\sqrt{s}$ [GeV]
Data
Standard Model
no ZWW vertex
ν_e exchange

Conclusions

- LEP has successfully run at 161,172 and 183 GeV above W-pair production threshold.
- In these Runs ~ 4000 W-pairs have been observed.
- The current run is operating at Energy 189 GeV.
- The measured cross-section for $\mathrm{e^+e^-} \rightarrow \mathrm{W^+W^-}$ at the 3 energies consistent with Standard Model Expectation.
- The Branching Fractions for the leptonic decay Mode has been measured to be $10.46 \pm 0.26\%$ and is consistent with Standard Model expectation of 10.8 $\%$.
- W decays at LEP2 confirm lepton universality to within 3-4$\%$.