WW Cross Section and Branching Fraction Measurements at LEP

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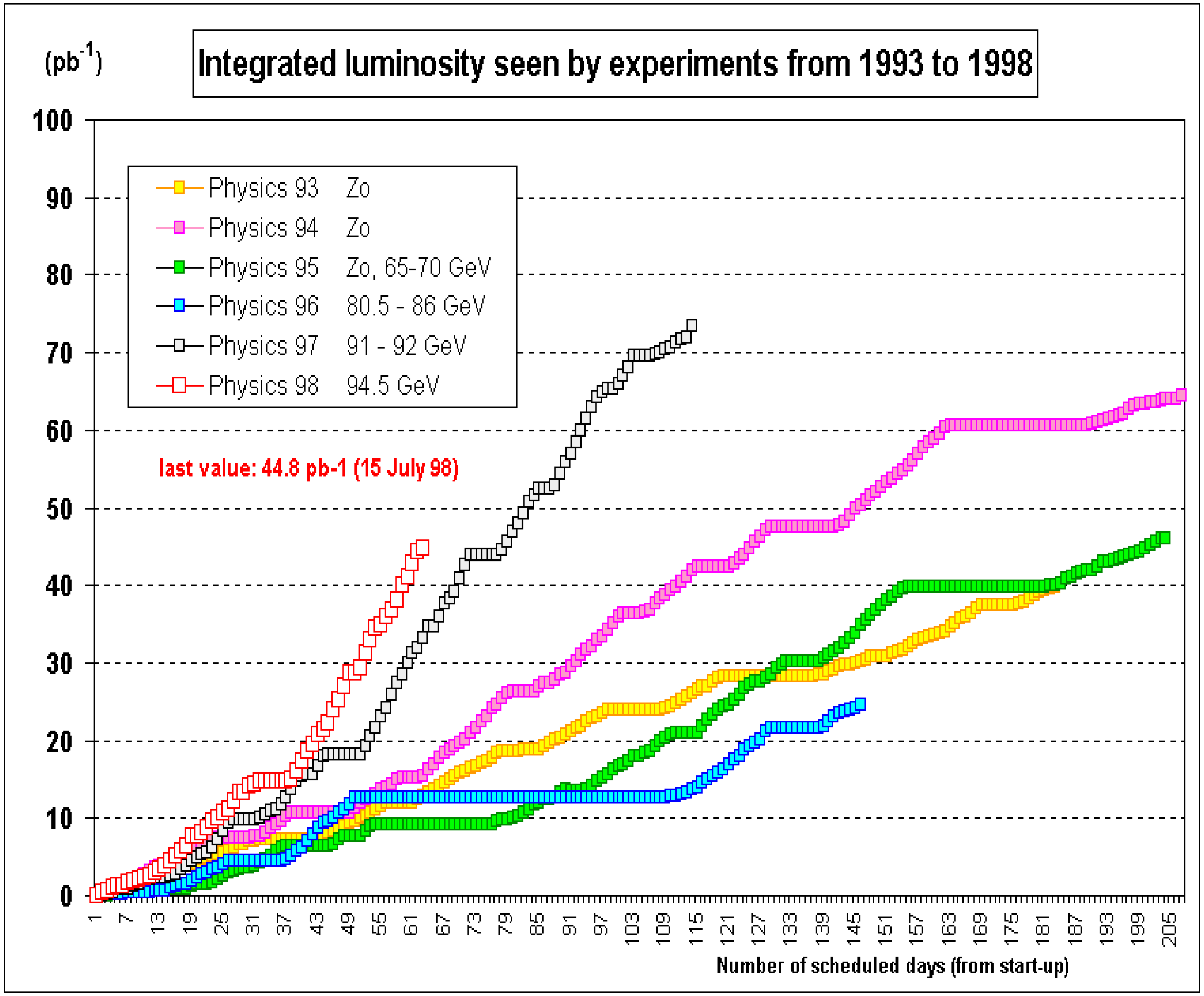
Outline

- Experiments and Theory
- Selection strategies and performances
- WW cross sections (total and channel–wise)
- Branching fractions
- Up to date results from 189 GeV run
- $|V_{cs}|$
- Γ_W^{inv}
- Conclusions and outlook

All the following results have to be considered preliminary!

LEP experiments

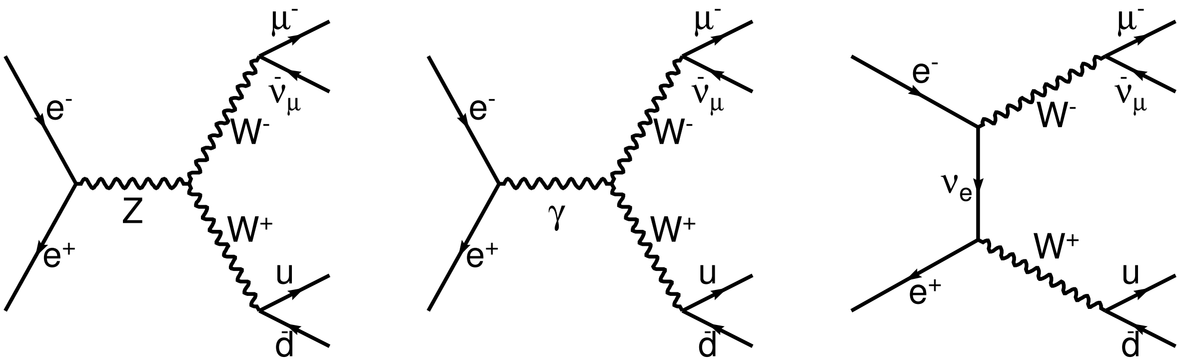
- **A**leph
- **D**elphi
- **L**3
- **O**pal



Theory

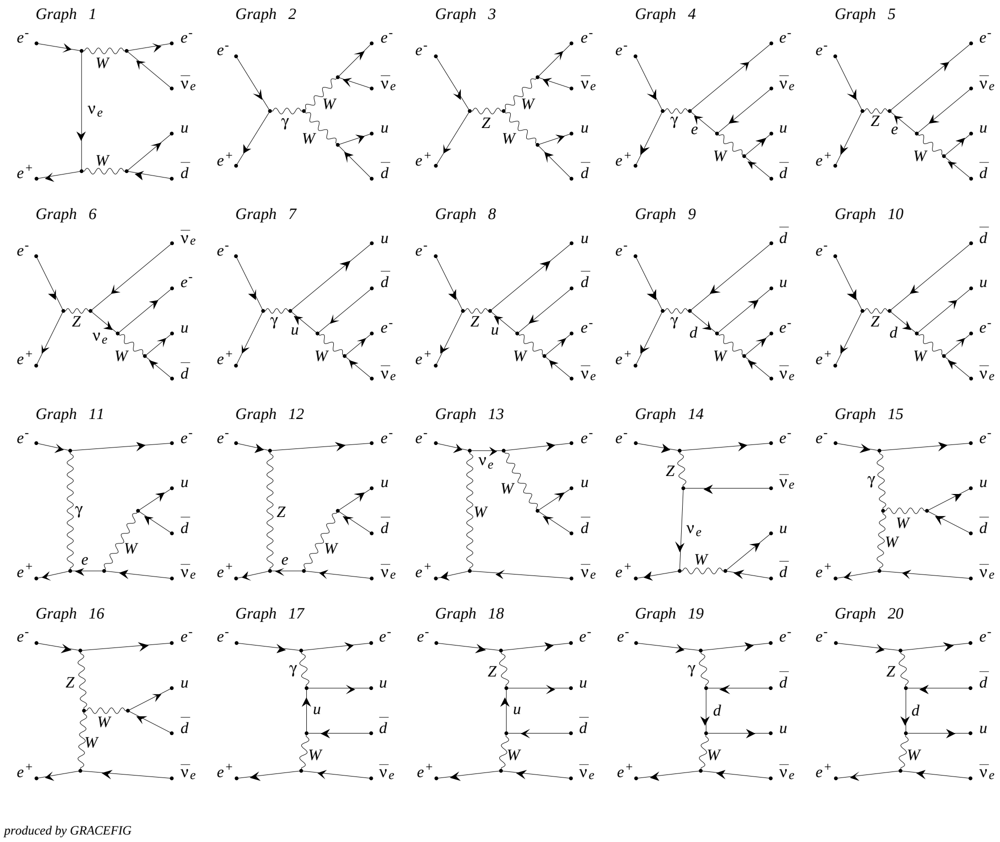
W–pairs at LEP are produced via three main diagrams:

Charged Current 03



But the SM–4 fermions final states, which interfere with CC03, are a bit more complex:

Charged Current 56 + Neutral Currents 56



Theoretical accuracy on σ_{WW} is now ~ 1 %
(Jadach, Placzek, Skrzypek, Ward and Was
UTHEP 98–0502 and this conference)

Selection Strategies

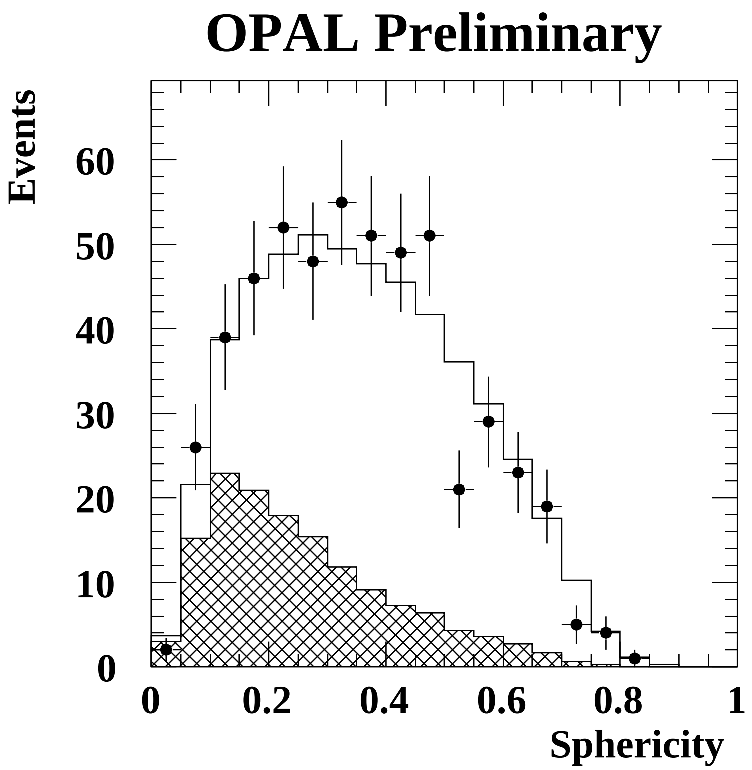
The W–pair decay topologies are classified in five main classes:

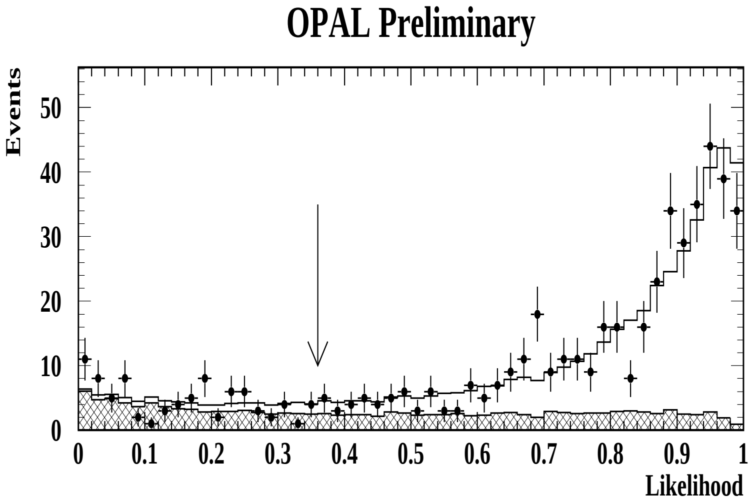
$\boldsymbol{WW \rightarrow qqqq}$	$\rightsquigarrow$ 45.6 %
‡ $\boldsymbol{WW \rightarrow qqe\nu_e}$	$\rightsquigarrow$ 14.6 %
$\boldsymbol{WW \rightarrow qq\mu\nu_\mu}$	$\rightsquigarrow$ 14.6 %
$\boldsymbol{WW \rightarrow qq\tau\nu_\tau}$	$\rightsquigarrow$ 14.6 %
‡ $\boldsymbol{WW \rightarrow \ell\nu\ell\nu}$	$\rightsquigarrow$ 10.6 %

‡ WARNING!

All the cross sections here presented are "CC03" extrapolated cross sections.
In particular for the tagged channels the corrections to be applied are not negligible (up to 10 %)

$WW \to qqqq$ Selection





- 4 jets
- no missing energy
- pairing
- highest background contamination from $q\bar{q}(\gamma)$ events

Standard cut–based analysis not highly efficient due to high background contamination:

$\to$ neural networks

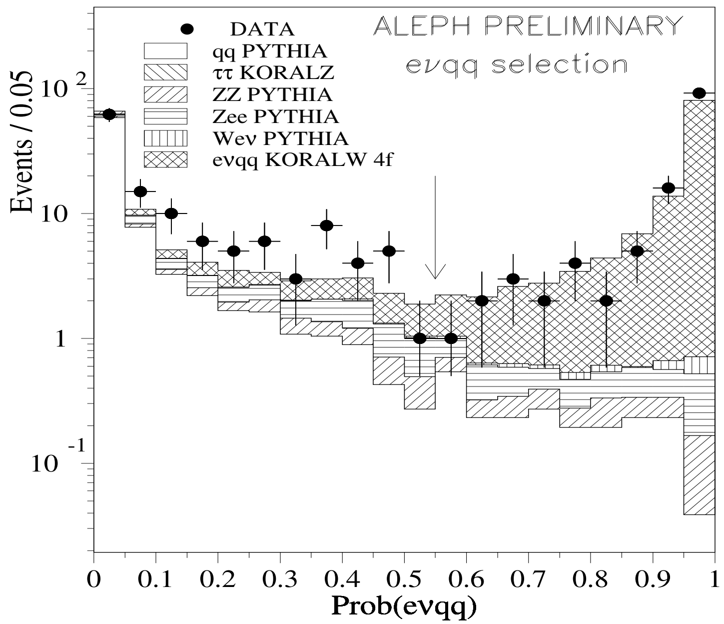
$\to$ likelihood outputs

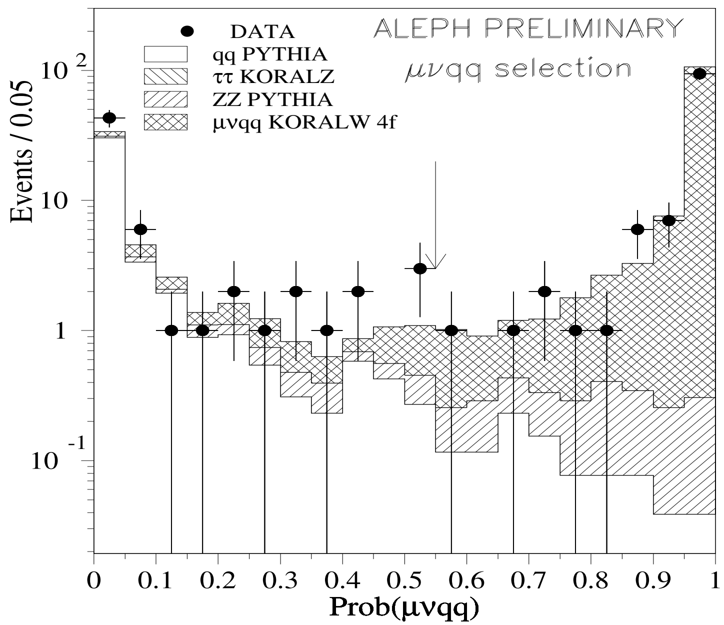
$\to$ multidimensional analysis

$\to$ fit to best discriminating distributions

Typical efficiency	$\sim$	85 %
Typical accepted bkg	$\sim$	1.5 pb
Typical # selected events/experiment	$\sim$	850

$WW \rightarrow qqe\nu_e,\ qq\mu\nu_\mu$ *Selections*

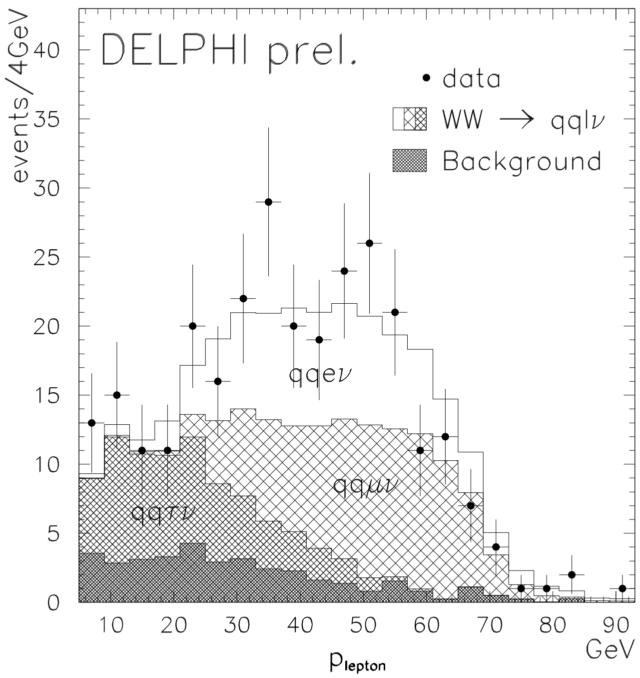


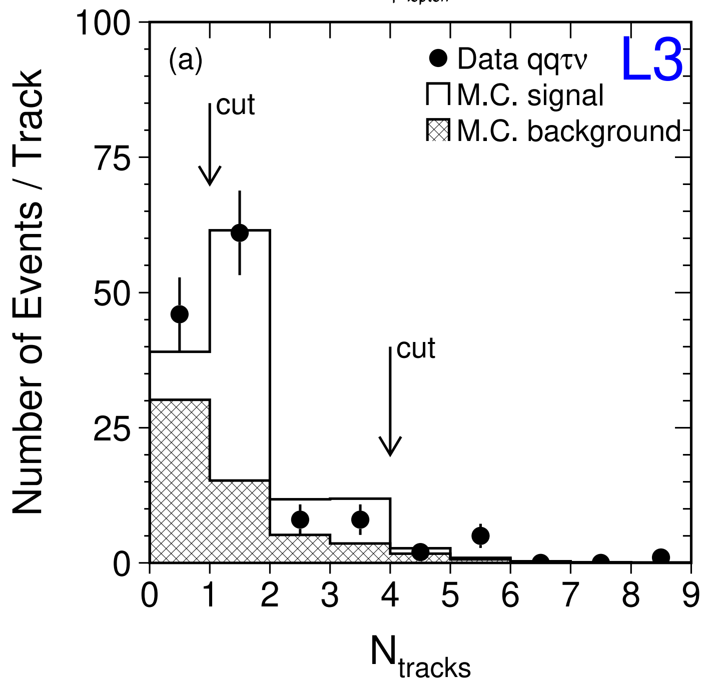


- an energetic lepton (e, μ)
- missing energy
- 2 hadronic jets
- invariant masses M_{qq}, $M_{\ell\nu}$ windows
- highest background contamination from $q\bar{q}(\gamma)$ events

Typical efficiency	$\sim$	80 %
Typical accepted bkg	$\sim$	150 fb
Typical # selected events/experiment	$\sim$	200

$WW \to qq\tau\nu_\tau$ Selection





- 2 hadronic jets +
  a low multiplicity hadronic jet or
  an electron or muon
- missing energy
- invariant masses M_{qq}, $M_{\tau\nu}$ windows
- τ jet identification (in the hadronic decay case) is crucial
- highest background contamination from $q\bar{q}(\gamma)$ events

Typical efficiency matrix in % (from L3)

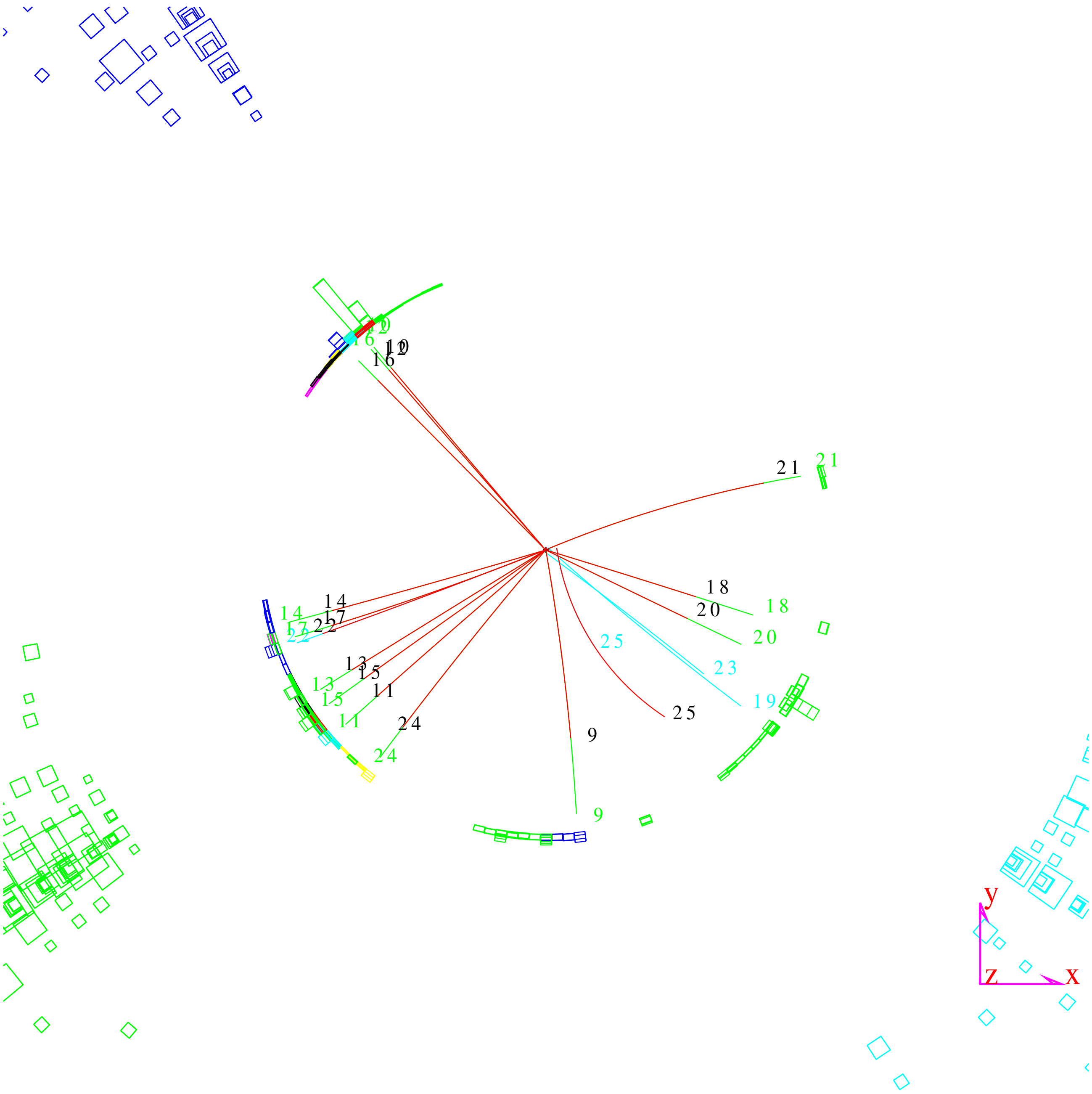
Generated		$qqe\nu_e$	$qq\mu\nu_\mu$	$qq\tau\nu_\tau$
Reconstructed	$qqe\nu_e$	85.4	0.2	2.1
	$qq\mu\nu_\mu$	0.1	77.0	4.3
	$qq\tau\nu_\tau$	4.8	6.0	50.1

Typical accepted bkg $\sim$ 250 fb

Typical # selected events/experiment $\sim$ 200

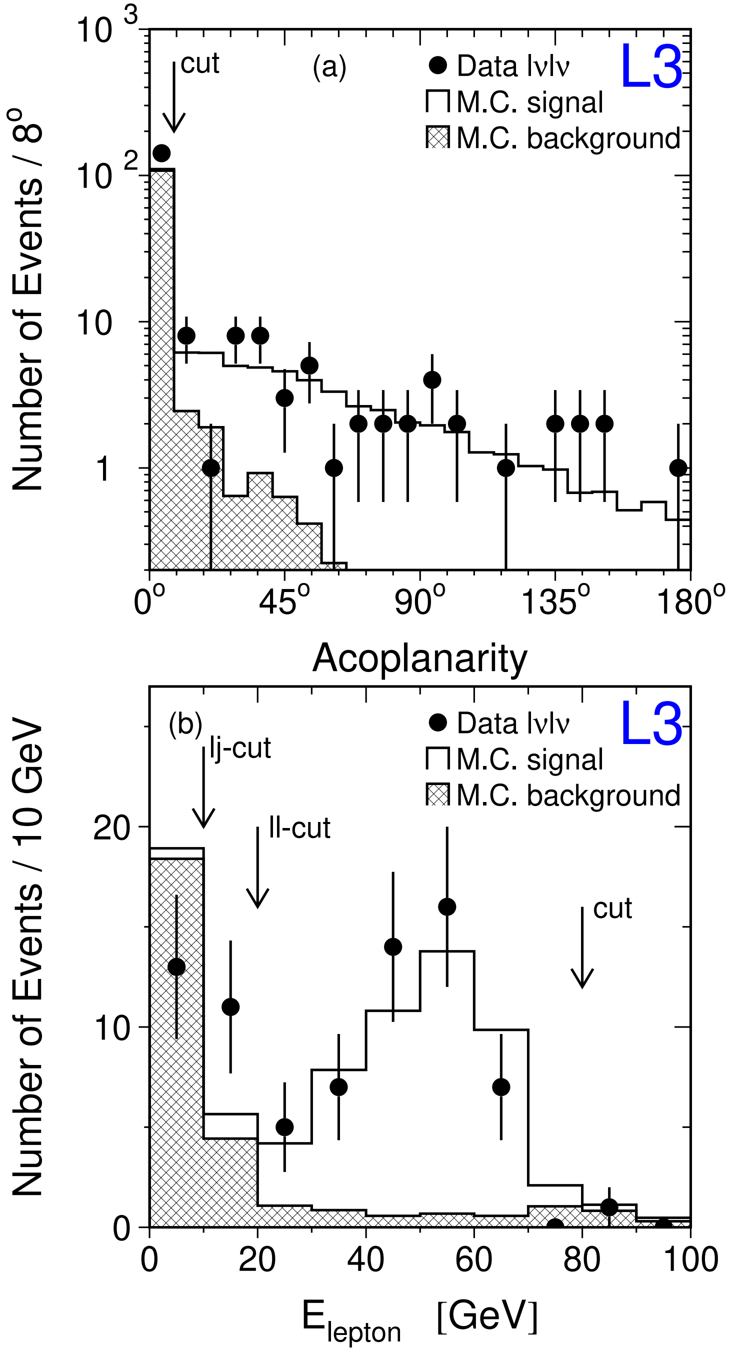
$WW \rightarrow qq\tau\nu_\tau$ *Example*

Run # **684502** **Event #** **4670** Total Energy : 130.50 GeV



Transverse Imbalance :	.4202		**Longitudinal Imbalance :**	-.0034	
Thrust :	.7969	**Major :**	.5078	**Minor :**	.1996
Event DAQ Time :	*971011 92208*				

$WW \to \ell\nu\ell\nu$ Selection



- 2 acoplanar, acollinear high energy leptons
- missing energy
- 6 different topologies:
  ee, $e\mu$, $e\tau$, $\mu\mu$, $\mu\tau$, $\tau\tau$
- 112 (CC56+NC56) diagrams contribute to the physical signal!
- highest background contaminations from 2γ and fermion pair events

Typical efficiency	$\sim$	50 – 60 %
Typical accepted bkg	$\sim$	100 – 200 fb
Typical # selected events/experiment	$\sim$	100

Cross sections measurements

A combined likelihood fit to all $WW \to ffff$ channels is performed using:

$$\mathcal{L} = \prod_i \mathcal{P}(N_i, \mu_i)$$

where:

- $\mathcal{P}$ is the poissonian probability distribution
- N_i is the number of observed events in channel i
- μ_i is the number of expected events in channel i

$$\mu_i = \left(\sum_j \varepsilon_{ij} \sigma_j + \sigma_i^{bg} \right) \cdot \mathrm{lumi}$$

where:

$$\begin{aligned} j &= \text{process} \\ \varepsilon_{ij} &= \text{efficiency matrix} \\ \sigma_j &= \text{cross section of process } j \text{ (to be measured)} \\ \sigma_i^{bg} &= \text{accepted non–WW background in process } i \\ \mathrm{lumi} &= \text{integrated luminosity} \end{aligned}$$

- All known systematics effects are taken into account
- overlap in the selected events is avoided

Fit variations

Branching fractions and σ_{WW} fits:

replace σ_j with $r_i\sigma_{WW}$ where:

$$\begin{aligned}
r_i &= \mathrm{BR}(W \to qq)^2 & \text{for } i = qqqq\\
&= 2\mathrm{BR}(W \to qq)\mathrm{BR}(W \to \ell\nu) & \text{for } i = qq\ell\nu\\
&= \mathrm{BR}(W \to \ell\nu)^2 & \text{for } i = \ell\nu\ell\nu\\
&= 2\mathrm{BR}(W \to \ell\nu)\mathrm{BR}(W \to \ell'\nu') & \text{for } i = \ell\nu\ell'\nu'
\end{aligned}$$

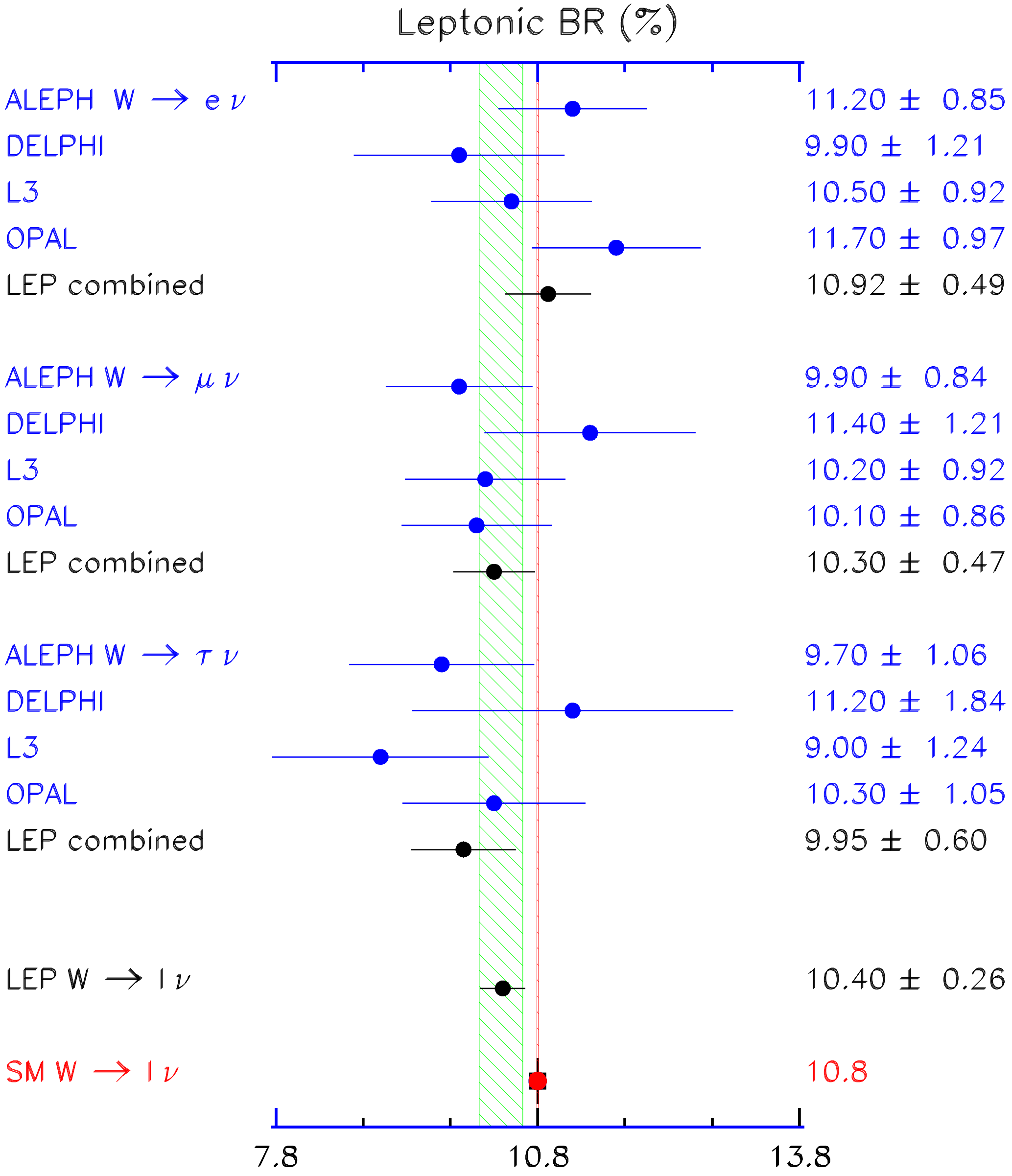
Lepton universality fits:

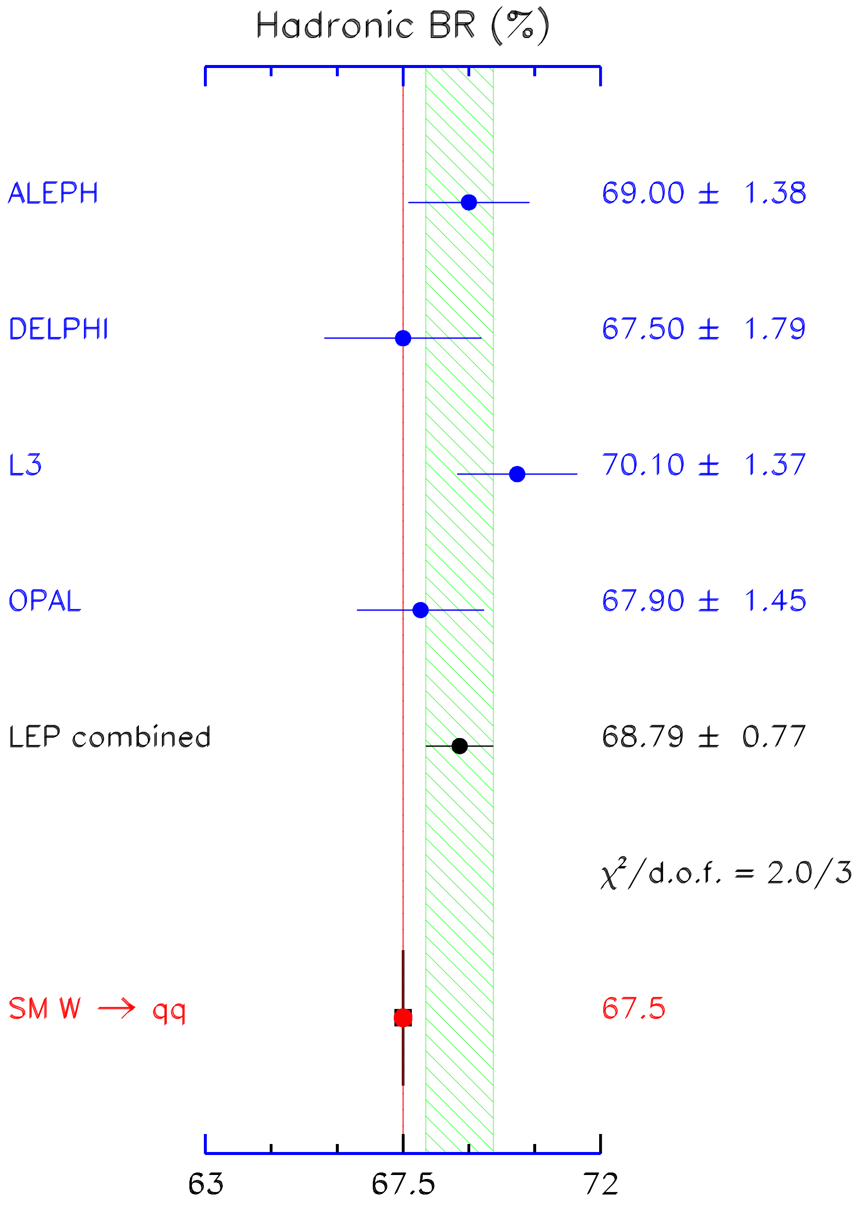
replace $\mathrm{BR}(W \to \mathrm{e}\nu_{\mathrm{e}})$, $\mathrm{BR}(W \to \mu\nu_\mu)$ and $\mathrm{BR}(W \to \tau\nu_\tau)$ by a single $\mathrm{BR}(W \to \ell\nu_\ell)$

Standard Model BR fits:

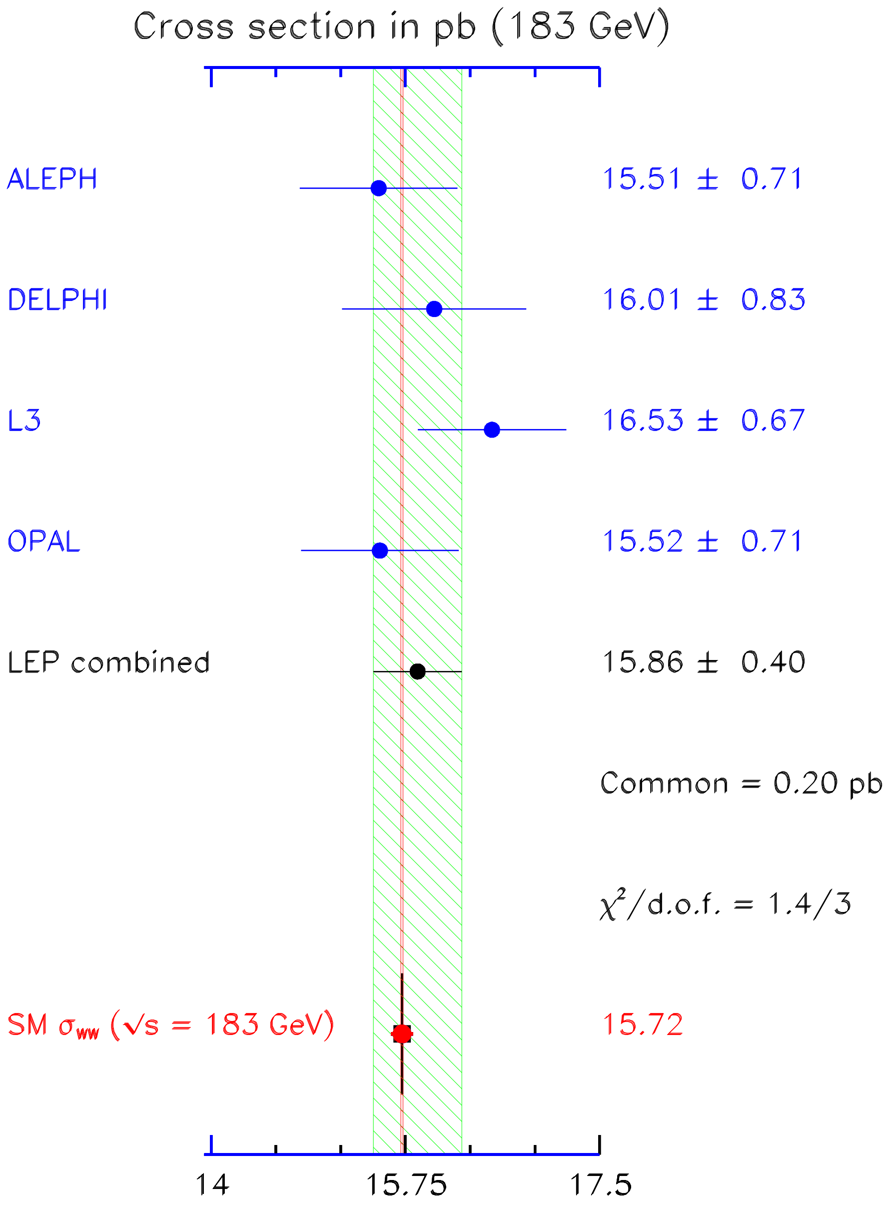
replace r_i by the Standard Model predicted values leaving only σ_{WW} as free parameter

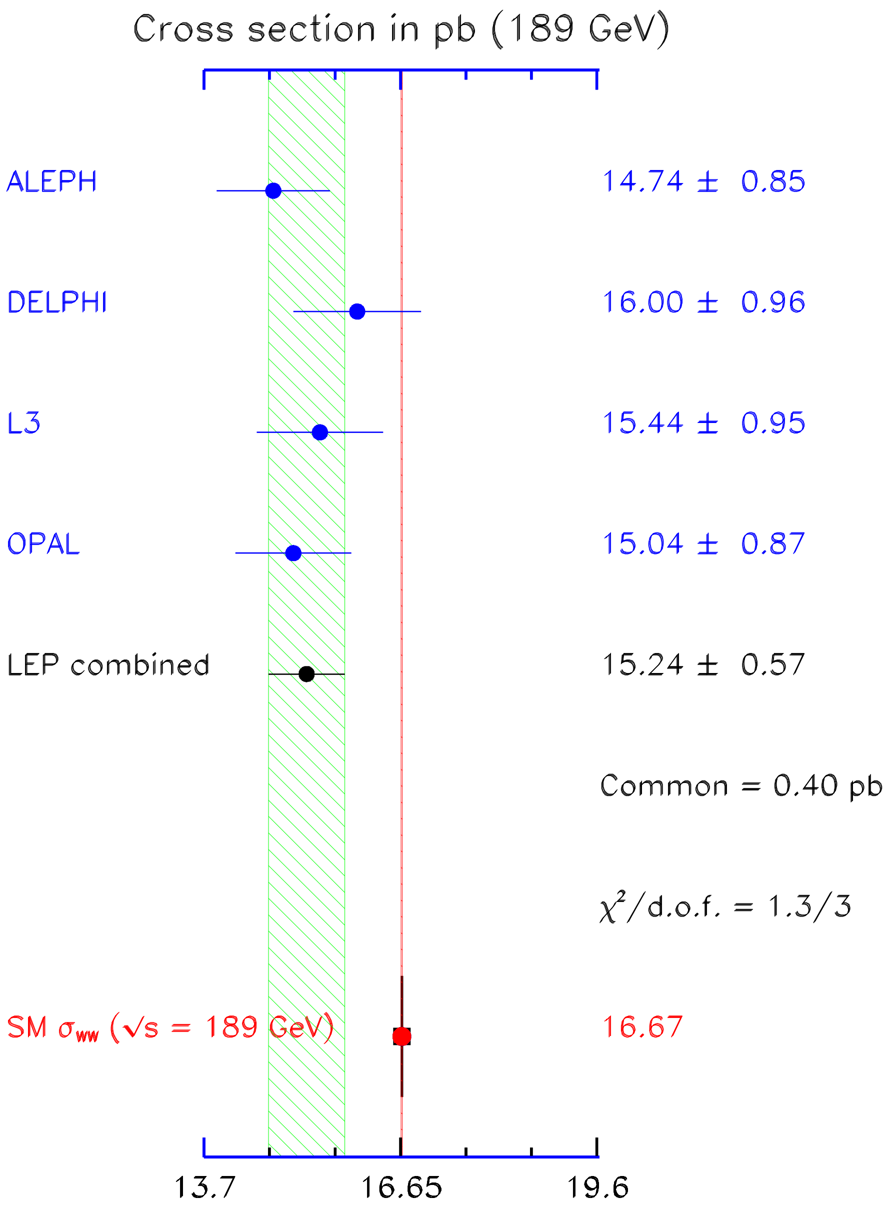
Branching Fraction Measurements





Cross Section Measurements





$|\mathrm{V_{cs}}|$ *measurement from BR's*

In first, but very good, approximation:

$$\frac{\mathrm{BR}(W \to qq)}{1 - \mathrm{BR}(W \to qq)} = \left(1 + \frac{\alpha_s(M_W^2)}{\pi}\right) \sum |\mathrm{V_{ij}^{CKM}}|^2$$

using $\mathrm{BR}(W \to qq)$ from LEP combined results and $\alpha_s = 0.118 \pm 0.003$ from current world average:

$$\sum |\mathrm{V_{ij}^{CKM}}|^2 = 2.131 \pm 0.076 \quad (\text{Unitarity} \equiv 2)$$

$|\mathrm{V_{cs}}|$ can be extracted by fixing the other CKM matrix elements to their measured values:

$$|\mathrm{V_{cs}}| = 1.04 \pm 0.04$$

without the assumption of unitarity.

Invisible Γ_W

How can W's decay invisibly?

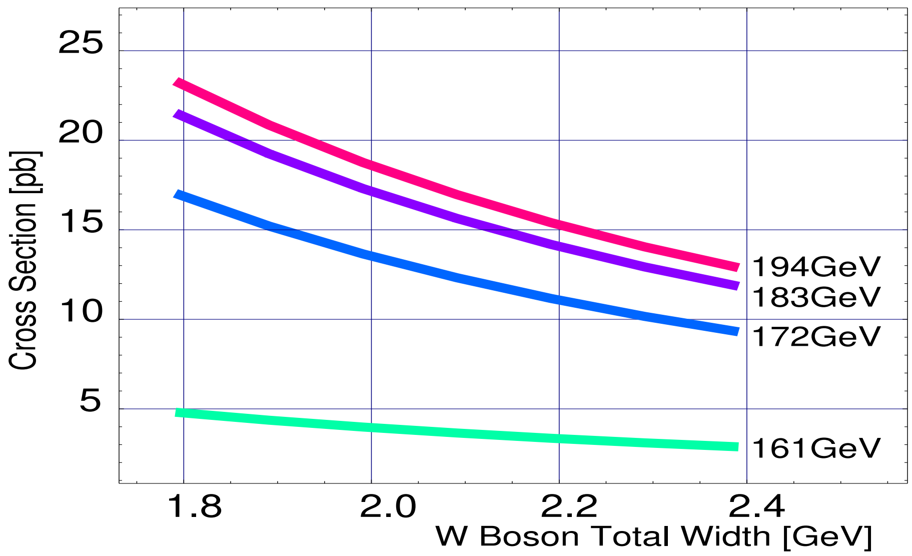
Example: SUSY scenario

$$W^+ \rightarrow \chi^+\chi^\circ \rightarrow \ell\nu\chi^\circ\chi^\circ$$

if $M_{\chi^+} - M_{\chi^\circ}$ very small $\rightsquigarrow$ E_ℓ low and probably "not visible" in the detector or affecting only a small part of the phase–space

$$\sigma_{WW} = \sigma_{WW}(\Gamma_W^{tot}) \quad \text{and} \quad \Gamma_W^{tot} = \Gamma_W^{SM}(M_W) + \Gamma_W^{inv}$$

CC03 Total Cross Section (Modified GENTLE)



using an independent measurement of:

$$\begin{aligned} M_W &= 80.33 \pm 0.15 \text{ GeV} \quad (p\bar{p} \text{ collider}) \\ \text{and} \quad \Gamma_W^{SM} &= \Gamma_W^{SM}(M_W) \end{aligned}$$

we can put stringent limits on Γ^{inv}:

$$\Gamma_W^{inv}(LEP) < 41 \text{ MeV} \qquad @\ 95\ \%\ \text{C.L.}$$

Summary table

		N. of events		σ_{CC03} in pb		BR in %	BR(SM) in %
$qqqq$	A						
	D						
	L	473	233	$8.35 \pm 0.46 \pm 0.23$	6.83 ± 0.54	$70.4 \pm 1.3 \pm 0.4$	67.5
	O	433					
$qqe\nu_e$	A					$10.5 \pm 0.9 \pm 0.2$	10.8
	D						
	L	112	74	$2.36 \pm 0.24 \pm 0.04$	2.44 ± 0.31		
	O	140					
$qq\mu\nu_\mu$	A						
	D						
	L	108	73	$2.29 \pm 0.24 \pm 0.04$	2.26 ± 0.30	$10.2 \pm 0.9 \pm 0.2$	10.8
	O						
$qq\tau\nu_\tau$	A						
	D						
	L	77	58	$1.86 \pm 0.32 \pm 0.06$	2.43 ± 0.44	$9.0 \pm 1.2 \pm 0.3$	10.8
	O						
$\ell\nu_\ell\ell\nu_\ell$	A						
	D						
	L	54	32	$1.49 \pm 0.25 \pm 0.05$	1.41 ± 0.31		
	O						
Total	A				14.74 ± 0.85		
	D				16.00 ± 0.98		
	L	824	470	$16.34 \pm 0.67 \pm 0.26$	15.44 ± 0.81		
	O				15.04 ± 0.87		

Preliminary

Black
$\sqrt{s} = 183\text{GeV}$

Blue
$\sqrt{s} = 189\text{GeV}$
(this year data)

Conclusions and outlook

- $\sim$ 1400 W pair events have been collected by each LEP experiment so far

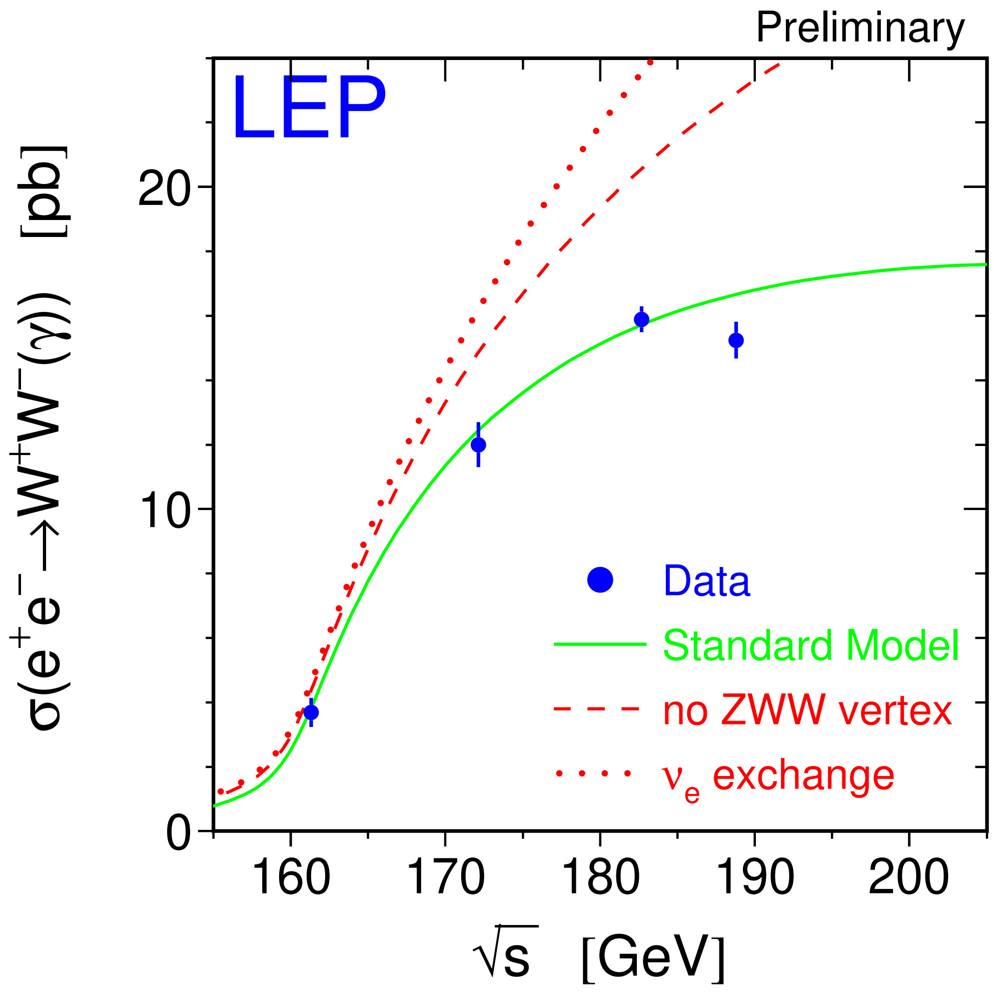
- All cross sections are in agreement with SM and between all the experiments:

$$\sigma_{WW}^{CC03}(183\mathrm{GeV}) = 15.89 \pm 0.40 \text{ pb (SM} = 15.72 \text{ pb)}$$

$$\sigma_{WW}^{CC03}(189\mathrm{GeV}) = 15.24 \pm 0.57 \text{ pb (SM} = 16.67 \text{ pb)}$$

$$\Downarrow$$

(0.3 at the end of '98 ?)



- **A combination of 161–183 GeV LEP data, under the assumption of lepton universality, gives:**

$$\mathrm{BR}(W \to qq) = 68.79 \pm 0.77\ \%\ (\mathrm{SM} = 67.5\ \%)$$

$$\mathrm{BR}(W \to \ell\nu_\ell) = 10.40 \pm 0.26\ \%\ (\mathrm{SM} = 10.8\ \%)$$

- **$|\mathbf{V_{cs}}|$ can be extracted from Branching Fractions:**

$$|\mathrm{V_{cs}}| = 1.04 \pm 0.04$$

- **A limit on the invisible W–decay width can be set:**

$$\Gamma_W^{inv} < 41\ \mathrm{MeV} \quad @\ 95\ \%\ \mathrm{C.L.}$$