W Boson Pair Production at L3

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L3 Collaboration
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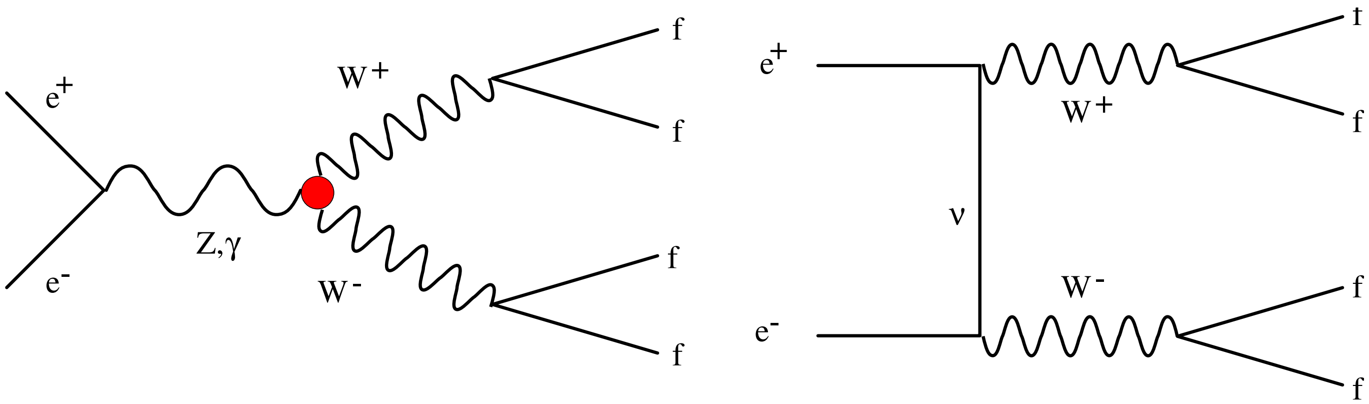
Outline

- Introduction
- Cross Sections and Branching Ratios
- W Mass Measurements
- Triple Gauge Boson Couplings
- Summary and Future Outlook

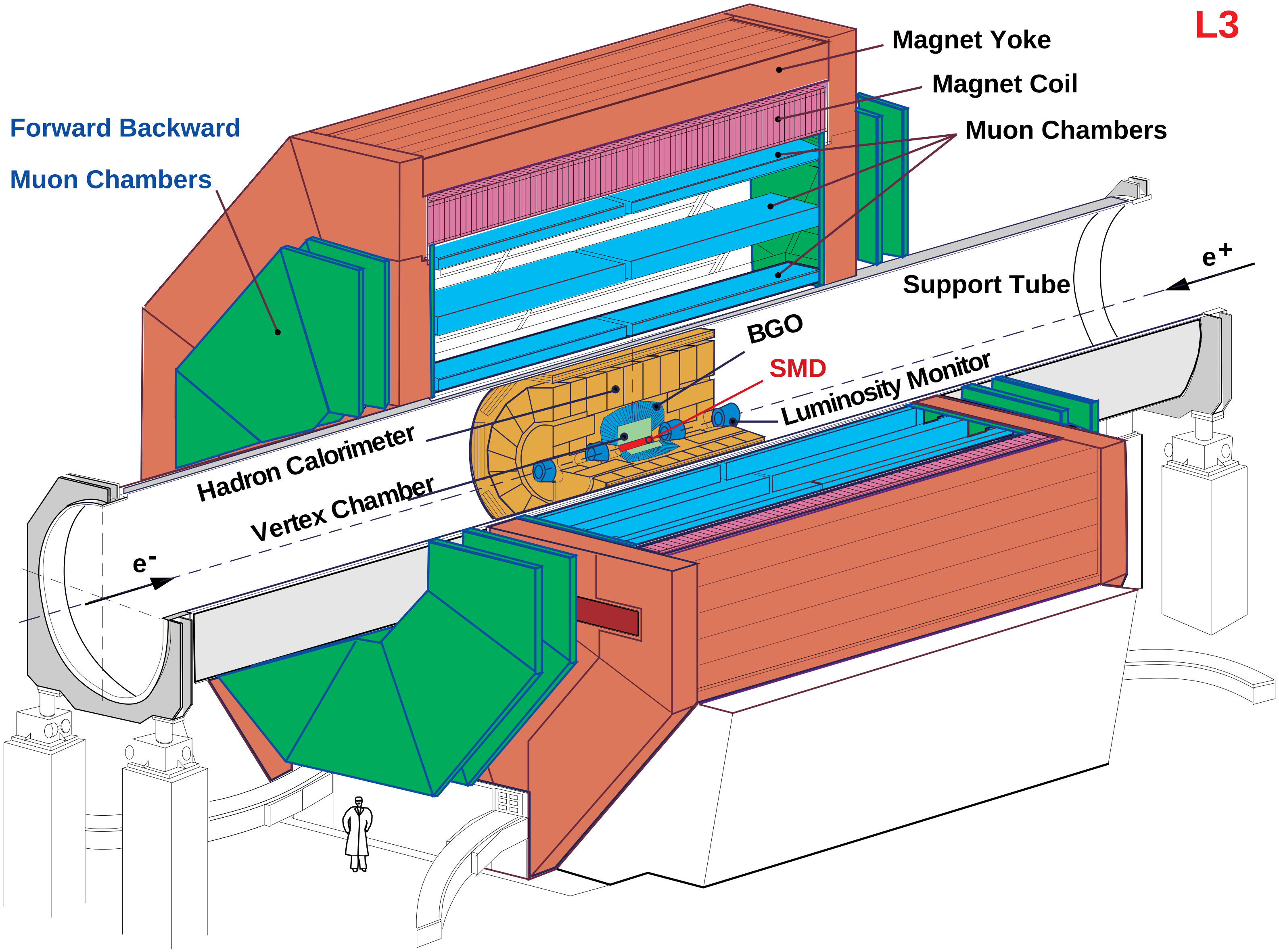
W Boson Pair Production



The "Bread and Butter" physics at LEP2

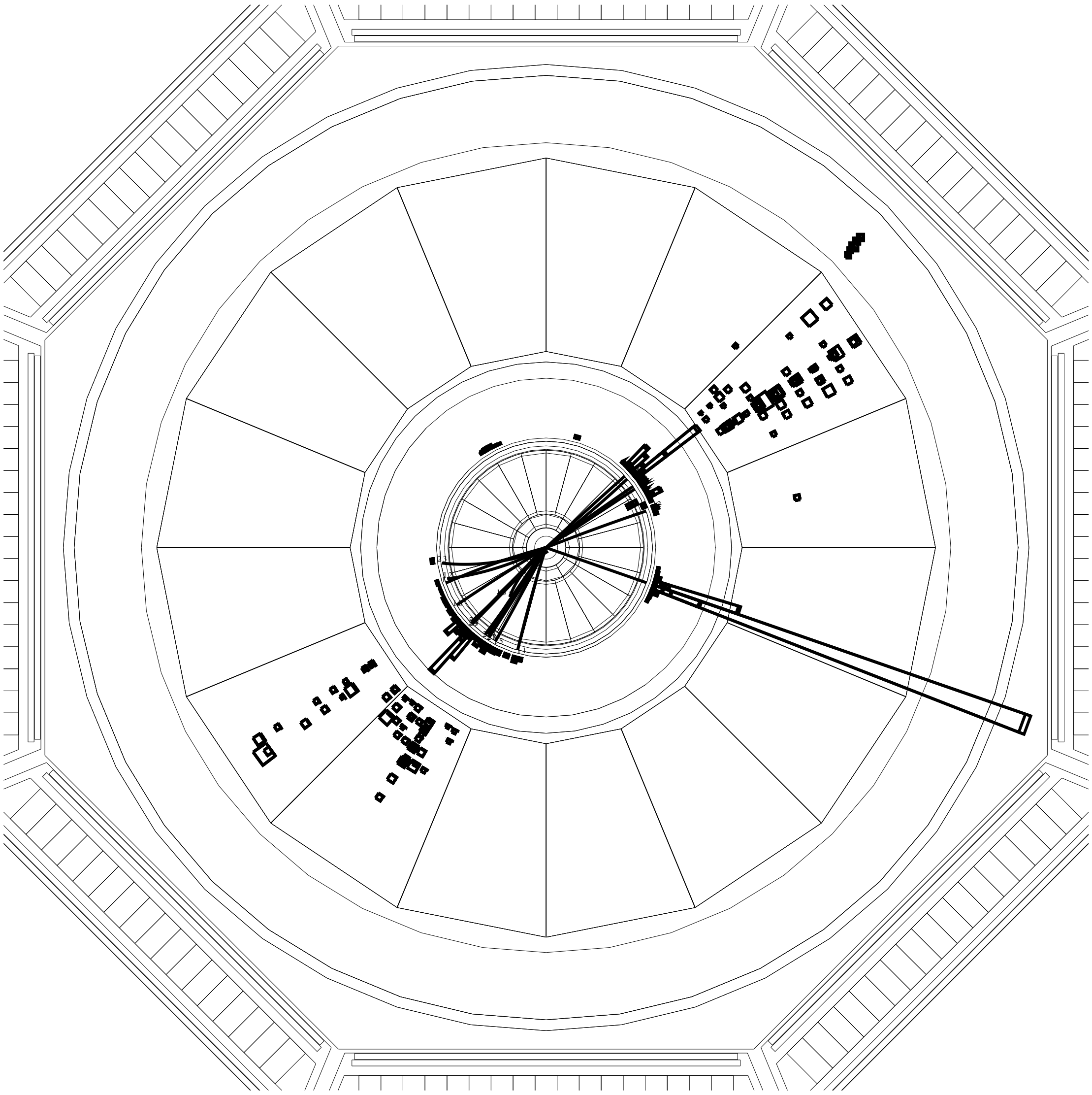
Recent timeline:

- July 9, 1996 LEP2 is born at 161 GeV
  L3 Detector recorded $\approx$ 11 pb^{-1}
  Results Submitted to *Phys. Lett. B*
- October 19, 1996 Energy increased to 172 GeV
  L3 Detector recorded $\approx$ 11 pb^{-1}
  Results are Preliminary


L3
Magnet Yoke
Magnet Coil
Muon Chambers
Forward Backward
Muon Chambers
Support Tube
e+
BGO
SMD
Luminosity Monitor
Hadron Calorimeter
Vertex Chamber
e-

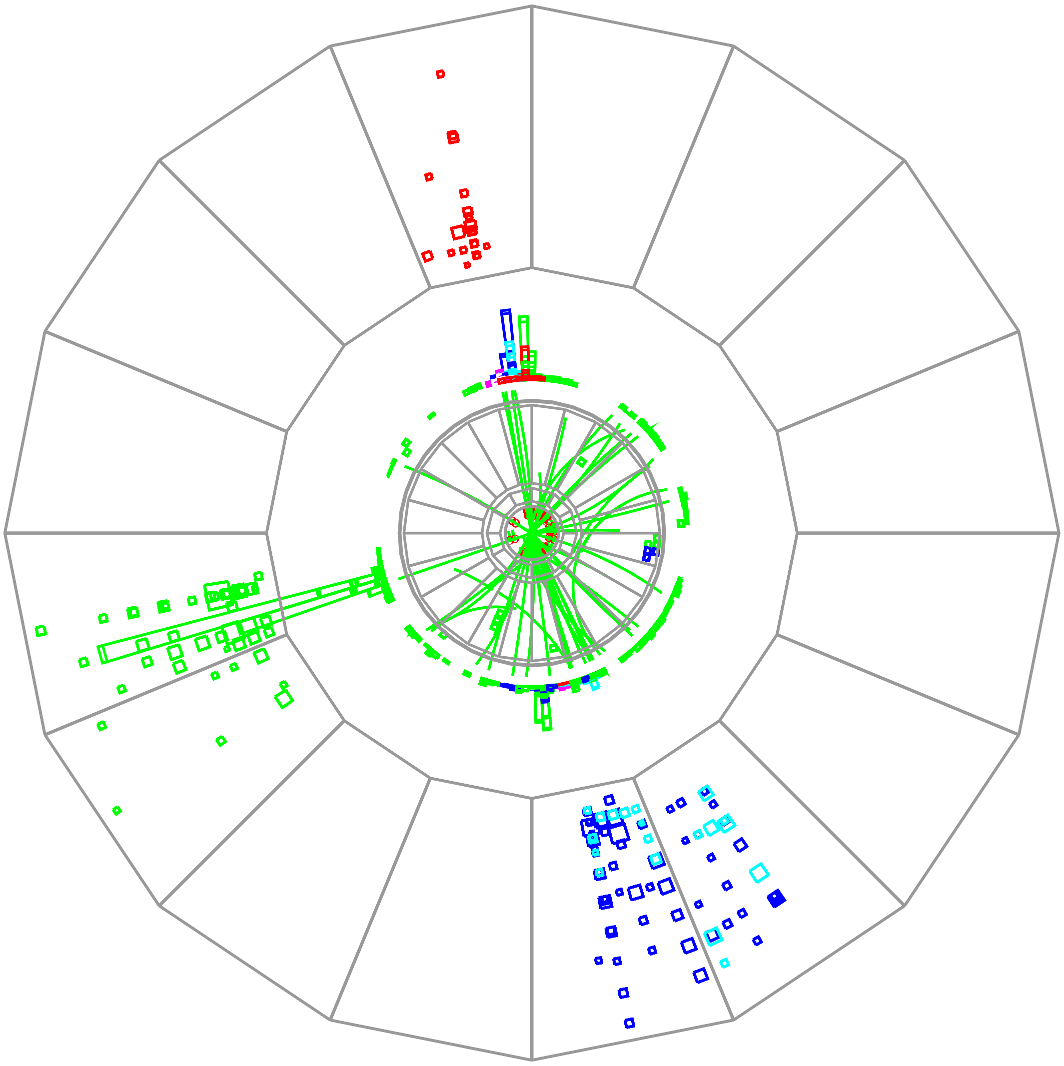
Semileptonic modes qq$\ell\nu$ where $\ell = \mu$ or e B.R. 14.6% each

- Isolated energetic $\ell \otimes$ Missing energy from $\nu \otimes$ 2 hadronic Jets
- Efficiencies $\approx 70\%$ for purities $\geq 95\%$



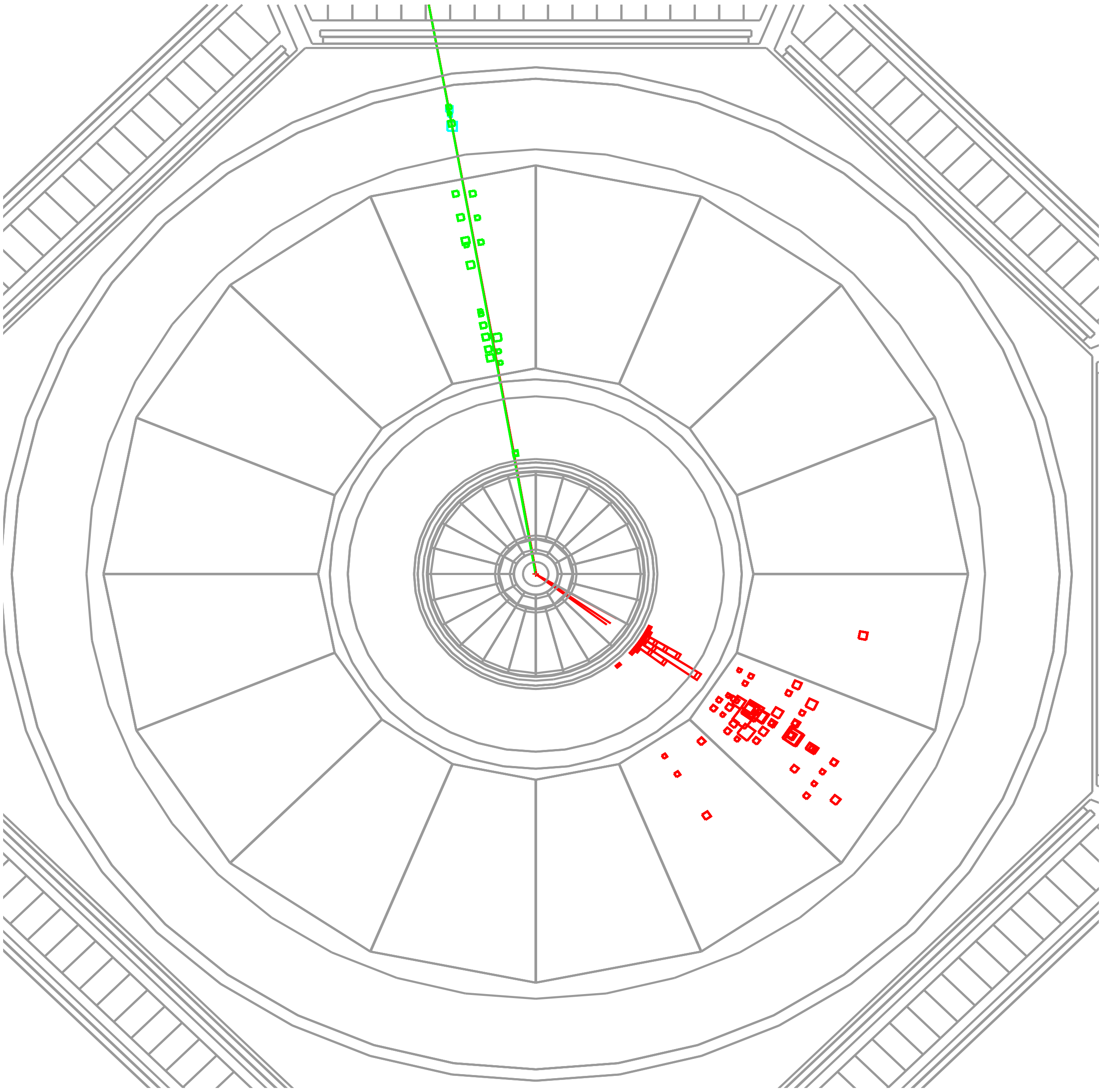
Semileptonic qq$\tau\nu$ mode B.R. 14.6%

- Missing energy (2 νs) $\otimes$ Energetic ℓ OR τ Jet $\otimes$ 2 hadronic Jets
- Efficiencies $\approx 40\%$ for purities $\approx 65\%$



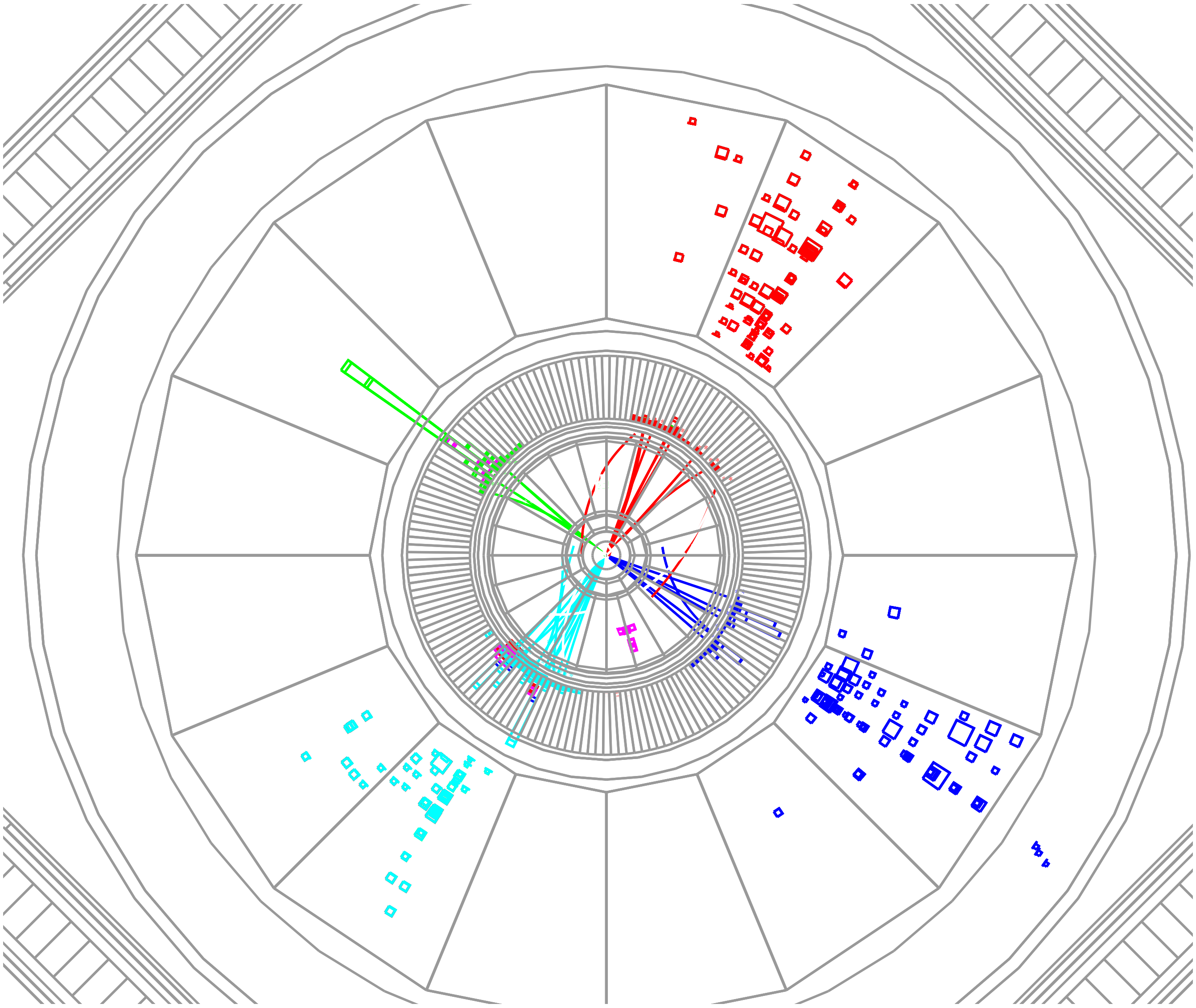
Fully Leptonic $\ell\nu\ell\nu$ mode B.R. 10.8%

- Missing energy 2 νs $\otimes$ 2 ℓ OR 1 ℓ and τ Jet $\otimes$ acoplanarity
- Efficiencies $\approx 40\%$ for purities $\approx 80\%$



Hadronic mode qqqq B.R. 45.6%

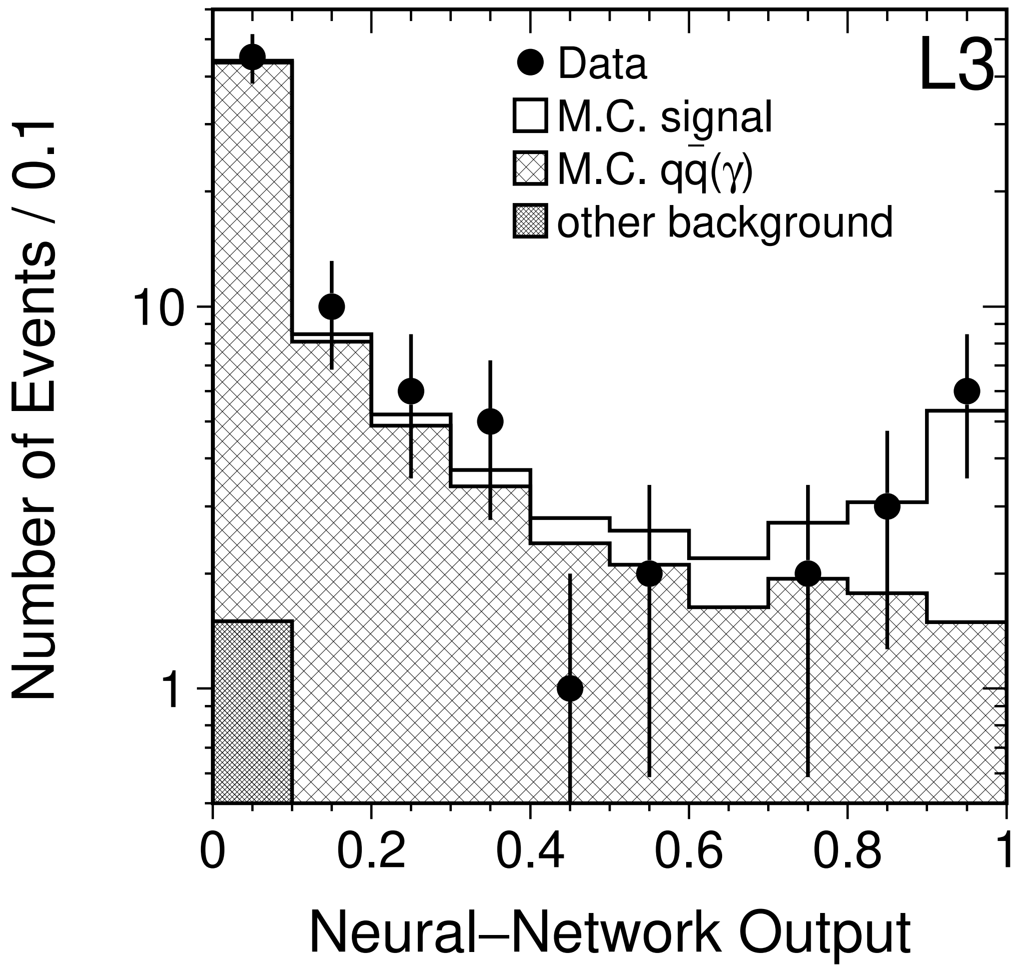
- 4 well seperated Jets
- Background: “4 Jet” events from $Z \rightarrow qq(\gamma)$ $\Rightarrow$ Same topology



161 GeV

Background $\approx 100\times$ Signal $\Rightarrow$ Preselection + Neural Net

Fit the Neural Net output distribution $\Rightarrow$ Cross section



172 GeV

Background $\approx 10\times$ Signal$\Rightarrow$ No need for complex Neural Net

Classic cut based analysis $\Rightarrow$ Efficiencies $\approx 70\%$, purities $\approx 70\%$

Results

Method: Combine all results for all WW decays in liklihood fit

161 GeV

Individual Cross sections

Mode	N_{data}	σ_i [pb]	σ_i^{SM} [pb]
qqeν	4	$0.62^{+0.38}_{-0.27}$	0.56
qq$\mu\nu$	4	$0.53^{+0.33}_{-0.24}$	0.56
qq$\tau\nu$	3	$0.22^{+0.55}_{-0.38}$	0.56
$\ell\nu\ell\nu$	2	$0.39^{+0.43}_{-0.27}$	0.41
qqqq	-	$0.98^{+0.51}_{-0.40}$	1.76

Branching Ratios and Total Cross sections

Parameter	Non-Universality	Universality	Standard Model
$B(\mathrm{W} \to \mathrm{e}\nu)$ [%]	$18^{+11}_{-\ 8}$	—	
$B(\mathrm{W} \to \mu\nu)$ [%]	$16^{+10}_{-\ 7}$	—	
$B(\mathrm{W} \to \tau\nu)$ [%]	6^{+12}_{-11}	—	
$B(\mathrm{W} \to \ell\nu)$ [%]	—	$13^{+\ 3}_{-\ 3}$	10.8
$B(\mathrm{W} \to \mathrm{qq})$ [%]	61^{+10}_{-11}	$60^{+\ 9}_{-10}$	67.5
σ_{WW} [pb]	$2.73^{+0.87}_{-0.74}$	$2.94^{+0.84}_{-0.72}$	3.85
With SM Branching Ratios			
σ_{WW} [pb]	$2.89^{+0.81}_{-0.70}$		3.85

$$\boxed{\sigma_{\mathrm{WW}} = 2.89^{+0.81}_{-0.79} \pm 0.14 \text{ pb}}$$

172 GeV **PRELIMINARY**

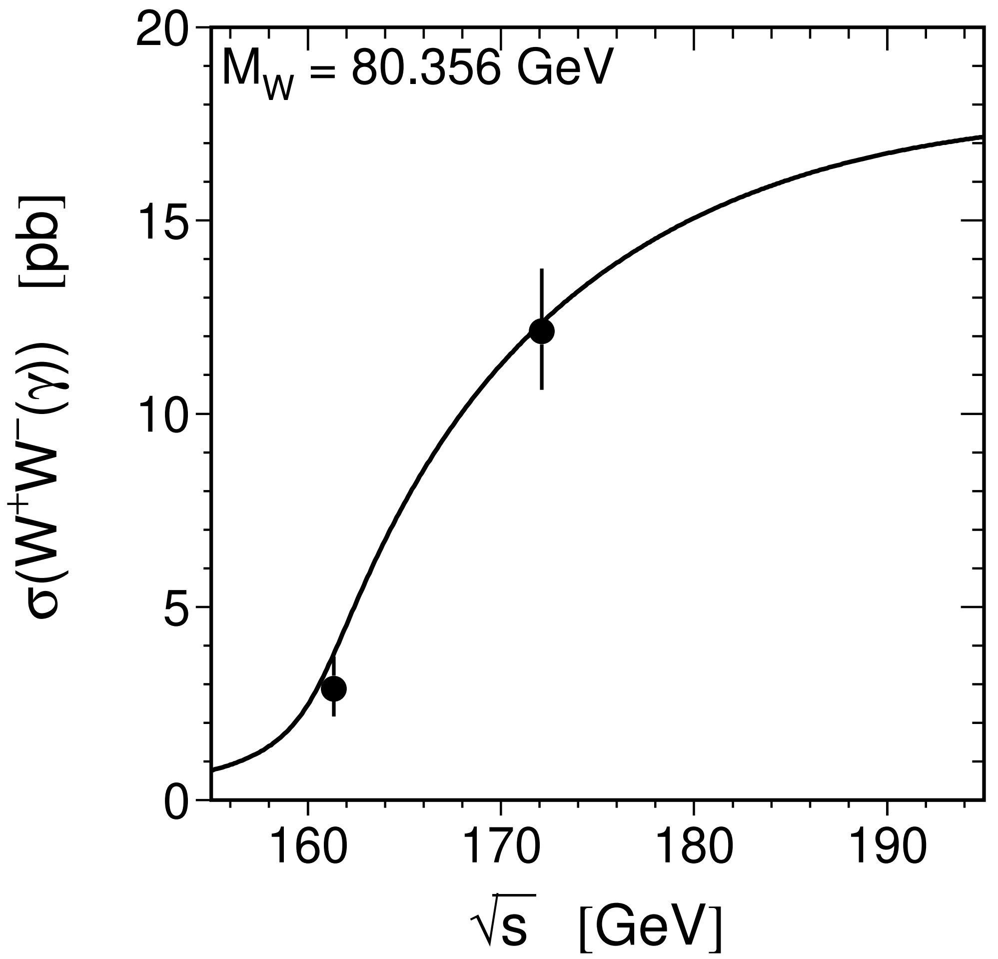
$\rightarrow$ qq$\tau\nu$ and $\ell\nu\ell\nu$ still coming

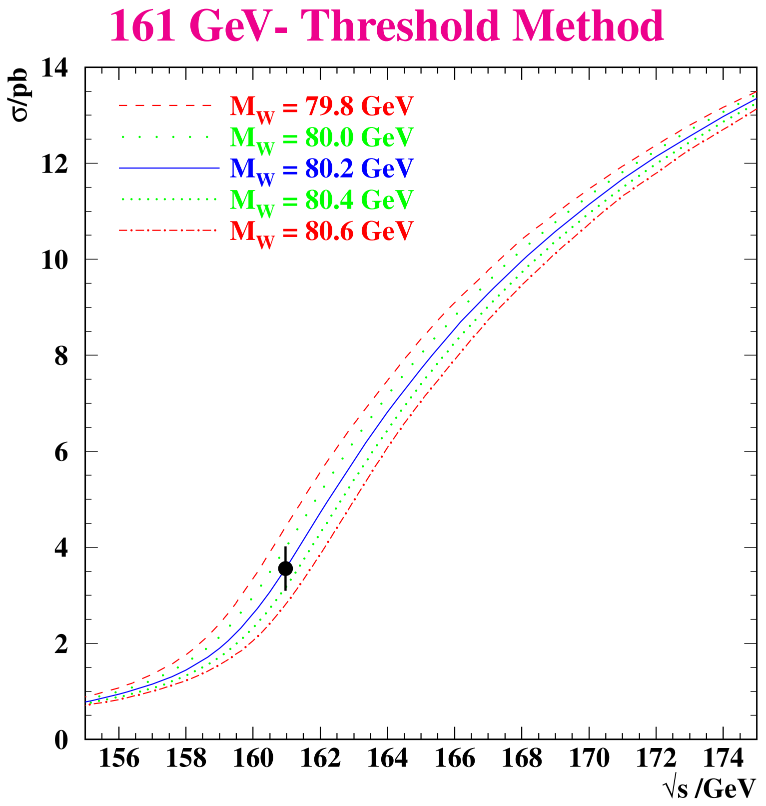
Individual Cross sections

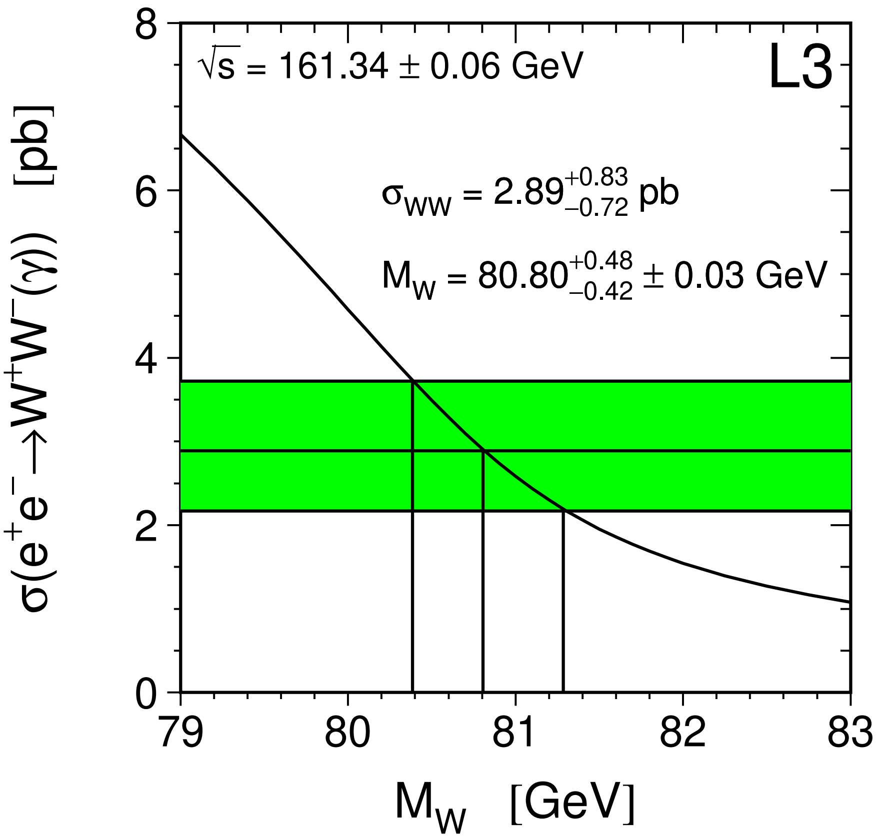
Mode	N_{data}	σ_i [pb]	σ_i^{SM} [pb]
qqeν	19	$2.63^{+0.67}_{-0.58}$	1.82
qq$\mu\nu$	11	$1.22^{+0.57}_{-0.41}$	1.82
qqqq	58	$5.31^{+0.99}_{-0.90}$	5.68

Cross Section and Branching Ratios

Parameter	Value	SM
$B(\mathrm{W}\rightarrow\ell\nu)$ [%]	$11.5^{+2.0}_{-1.3}$	10.8
$B(\mathrm{W}\rightarrow\mathrm{qq})$ [%]	$65.6^{+5.6}_{-6.1}$	67.5
σ_{WW} [pb]	$12.36^{+1.88}_{-1.66}$	12.2
With SM Branching Ratios		
σ_{WW} [pb]	$12.13^{+1.63}_{-1.51}$	12.2




161 GeV- Threshold Method
σ/pb
M_W = 79.8 GeV
M_W = 80.0 GeV
M_W = 80.2 GeV
M_W = 80.4 GeV
M_W = 80.6 GeV
√s /GeV


√s = 161.34 ± 0.06 GeV
L3
$\sigma_{WW} = 2.89^{+0.83}_{-0.72}$ pb
$M_W = 80.80^{+0.48}_{-0.42} \pm 0.03$ GeV
$\sigma(e^+e^- \to W^+W^-(\gamma))$ [pb]
M_W [GeV]

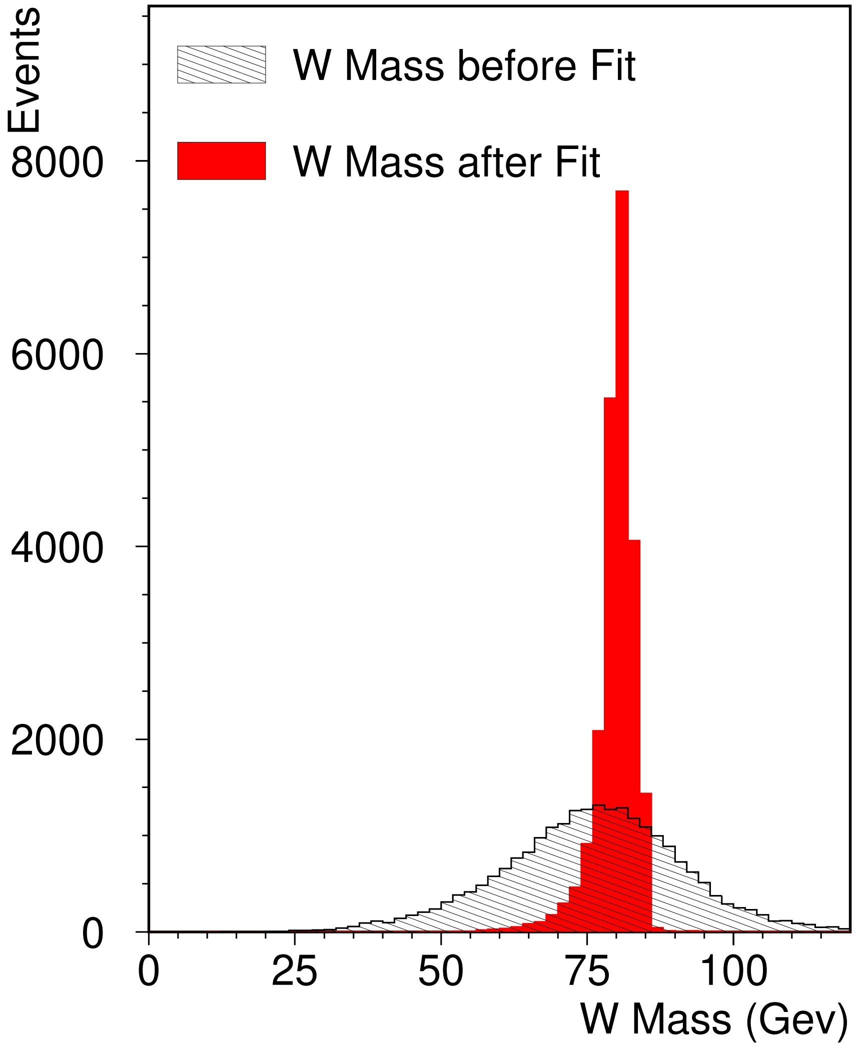
172 GeV- Direct Reconstruction

Use Kinematic fitting to improve resolution

- Measurements E,θ,ϕ for 3 (qq$\ell\nu$) or 4 (qqqq) vectors
- Constraints

$$\Sigma\, \mathrm{E}_j = \sqrt{s}$$
$$\Sigma\, \overrightarrow{p}_j = 0$$
$$\text{Equal Mass } \mathrm{M}_{12} = \mathrm{M}_{34}$$

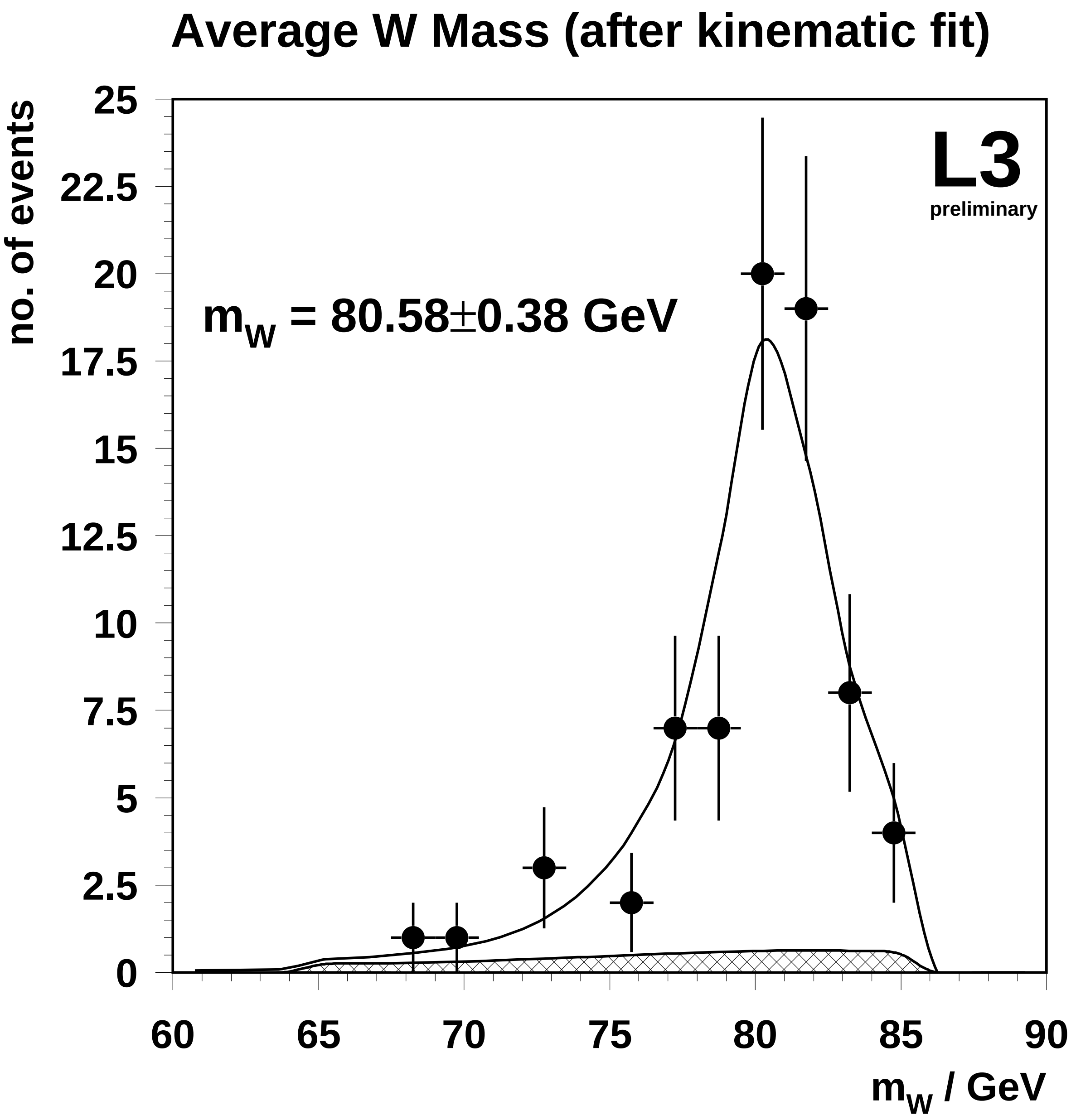
- 5 constraint fit for qqqq, 2 constraint fit for qq$\ell\nu$



Build direct Mass Spectrum and fit for m_{W} using “best estimator” function

- Detector resolution effects
- Background for qqqq
- Sensitivity to W Mass

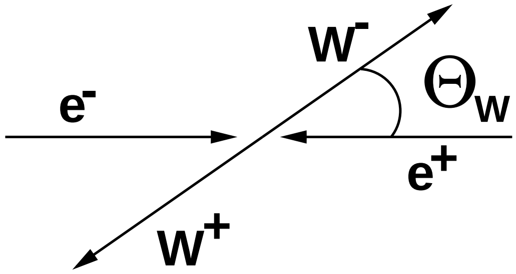
Other Systematics: Jet Pairing, Initial state radiation, Correlations

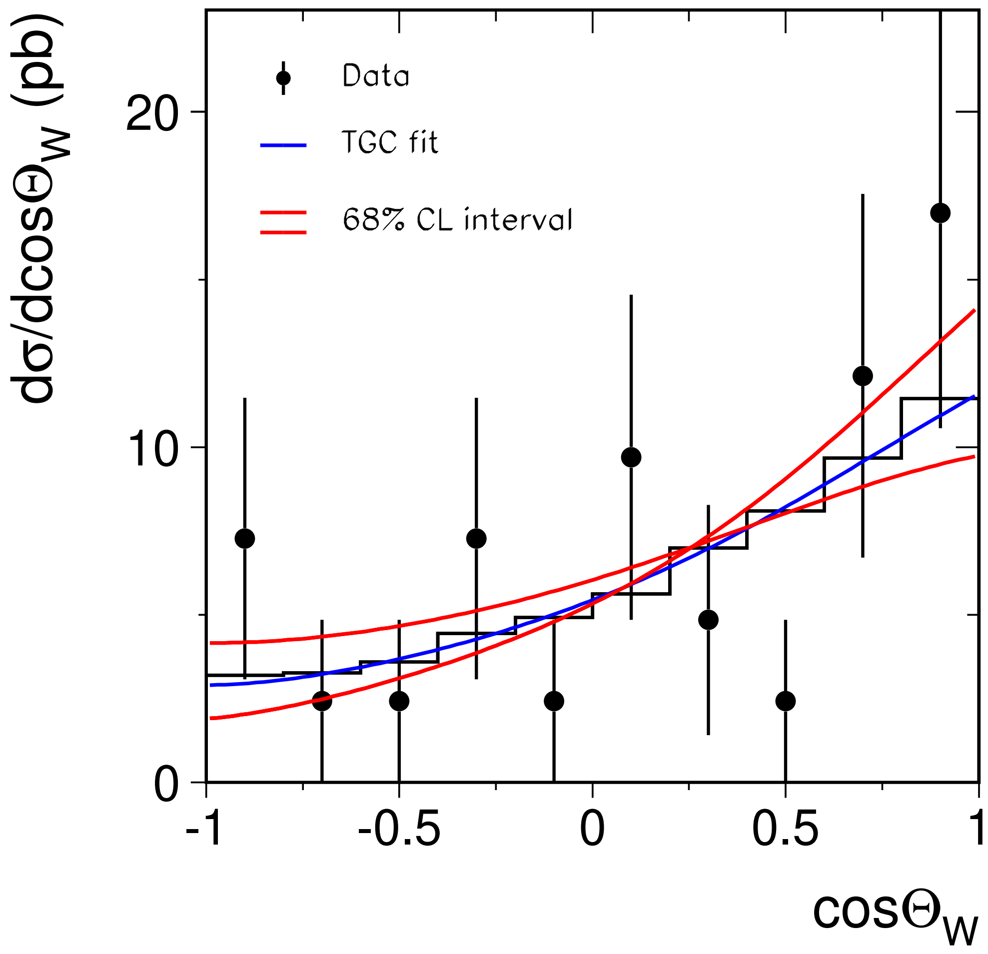


Fit cross section and angular distribution dependence on couplings

$$\delta_Z \equiv g_{ZWW} - \cot(\bar{\theta}_W)$$

	161 GeV 68% C.L.	172 GeV 68% C.L.
δ_Z	-0.1 ± 1.9	$-0.07^{+1.03}_{-0.84}$





Summary

- Cross Sections Measured

$$\sigma_{\rm WW} = 2.89^{+0.81}_{-0.79} \pm 0.14 \text{ pb at } 161 \text{ GeV}$$
$$\sigma_{\rm WW} = 12.13^{+1.63}_{-1.51} \text{ pb at } 172 \text{ GeV}$$

- W Mass Measured

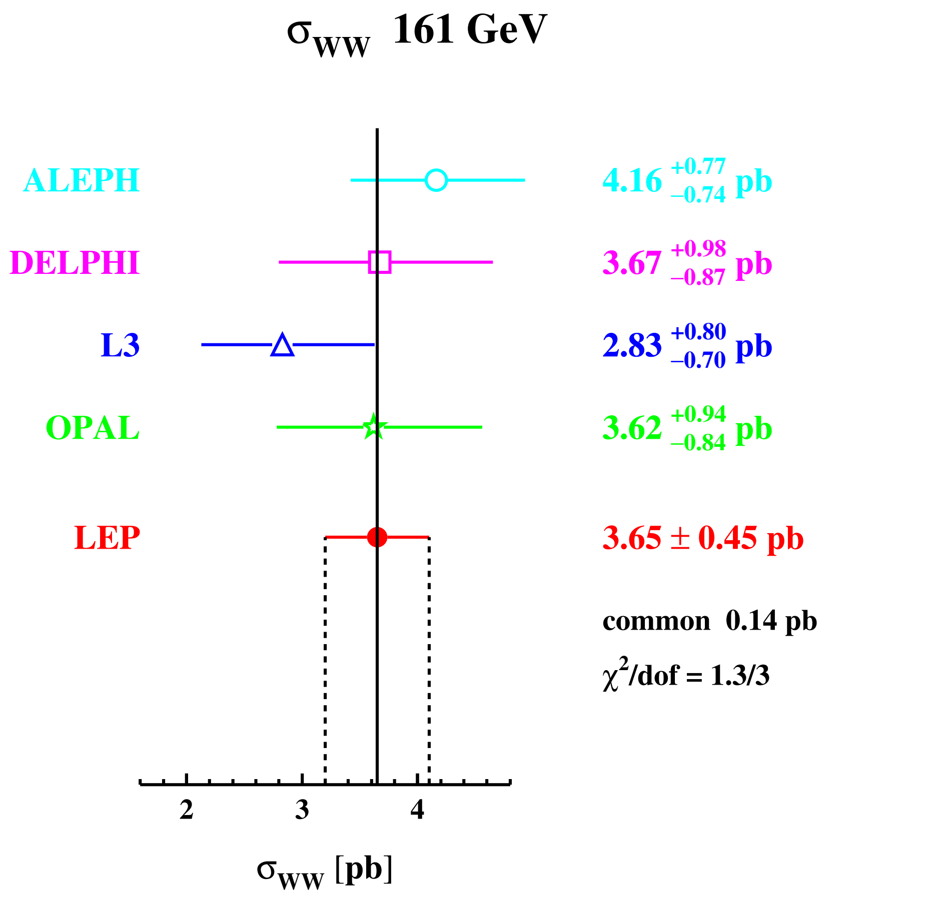
$$m_{\rm W} = 80.80^{+0.48}_{-0.42} \text{ GeV at } 161 \text{ GeV}$$
$$m_{\rm W} = 80.58 \pm 0.38 \text{ GeV at } 172 \text{ GeV}$$

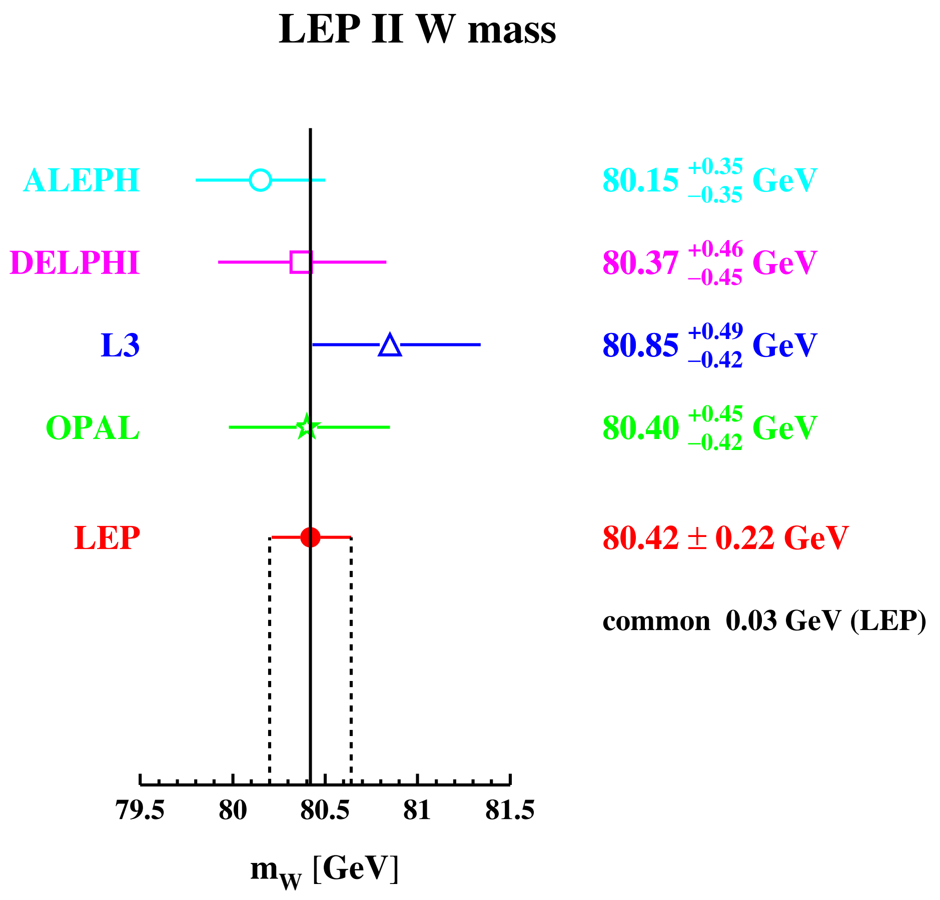
- TGC constrained

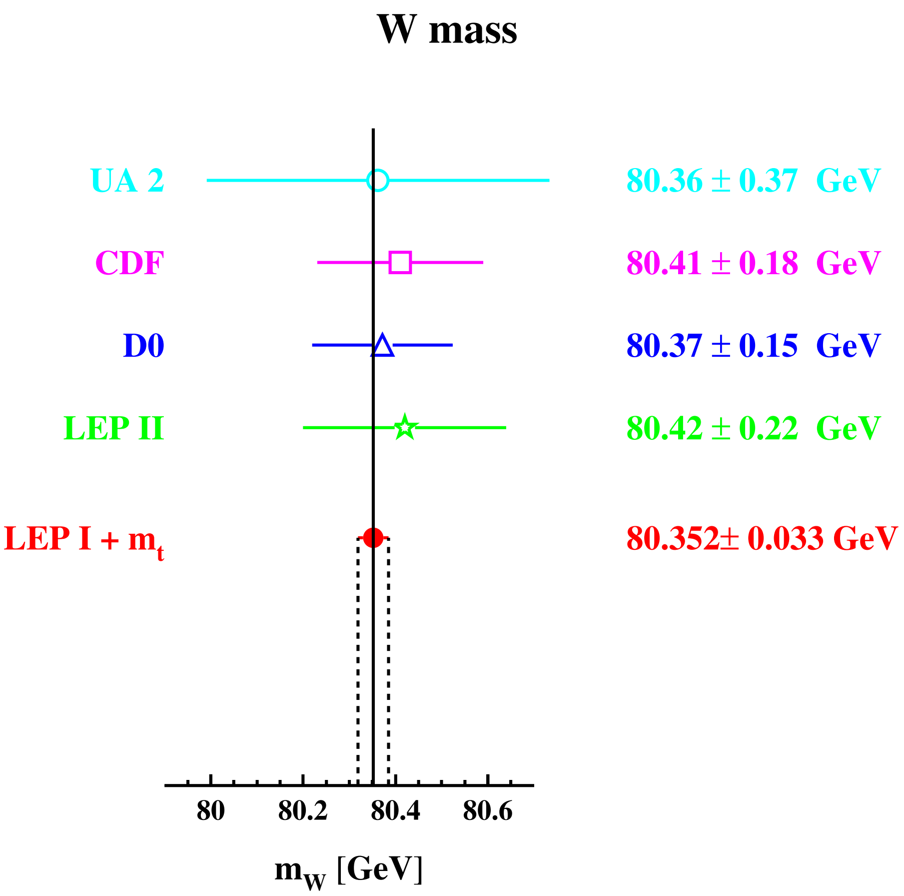
$$\delta_{\rm Z} = -0.1 \pm 1.9 \text{ (68\% C.L.) at } 161 \text{ GeV}$$
$$\delta_{\rm Z} = -0.07^{+1.03}_{-0.84} \text{ (68\%C.L.) at } 172 \text{ GeV}$$

$\Rightarrow$ Rules out $g_{\rm ZWW} = 0$ at 95% C.L.

Summary and Future





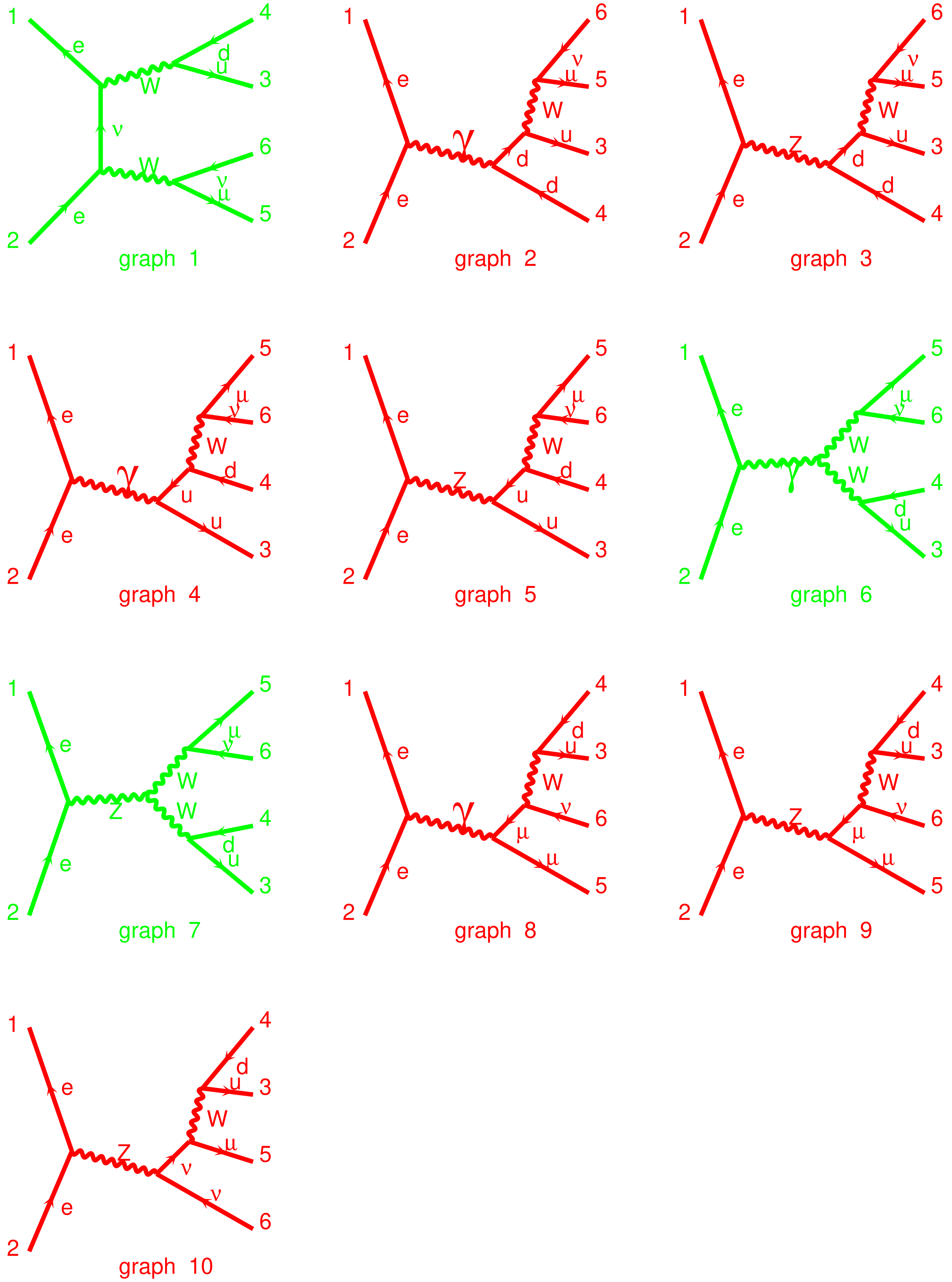


Future

- Finalize measurements for 172 GeV
- Combine 161 and 172 GeV measurements
- Looking forward to

$$100\ \mathrm{pb}^{-1}\ \text{at 184 GeV in 1997}$$
$$500\ \mathrm{pb}^{-1}\ \text{by the end of 2000}$$

Diagrams by MadGraph



Log liklihood fit for cross sections takes into account cross efficiencies
⇒WW decays are treated as signal in every selection

$$\begin{aligned}
\log \mathcal{L} &= \sum_{i=1}^{5} \log P(N_i, \mu_i) \quad P \text{ is Poisson Probability} \\
\mu_i &\equiv \mathcal{L}_i \cdot \left(\sum_{j=1}^{5} \epsilon_{ij}\omega_j + \sigma_i^{\mathrm{bg}} \right) \\
\epsilon_{ij} &= \text{Efficiency for Selection } i \text{ to select mode } j
\end{aligned}$$

$$\omega_j = \sigma_j \Rightarrow \text{Measures individual Cross sections}$$

$$\begin{aligned}
\omega_j &= r_j \sigma_{\mathrm{tot}} \Rightarrow \text{Measures total cross section and branching ratios} \\
& r_{\mathrm{qqqq}} = (B(\mathrm{W} \to \mathrm{qq}))^2 \\
& r_{\mathrm{qq}\ell\nu} = 2 \times (B(\mathrm{W} \to \mathrm{qq})(B(\mathrm{W} \to \ell\nu) \\
& r_{\ell\nu\ell\nu} = (1 - B(\mathrm{W} \to \mathrm{qq}))^2
\end{aligned}$$

$$\omega_j = r_j^{\mathrm{SM}} \sigma_{\mathrm{tot}}(\sqrt{s}, m_{\mathrm{W}}) \Rightarrow \text{Threshold method for } m_{\mathrm{W}}$$