LEP W measurements

LEP シンポジウム @ ICEPP

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佐伯 学行

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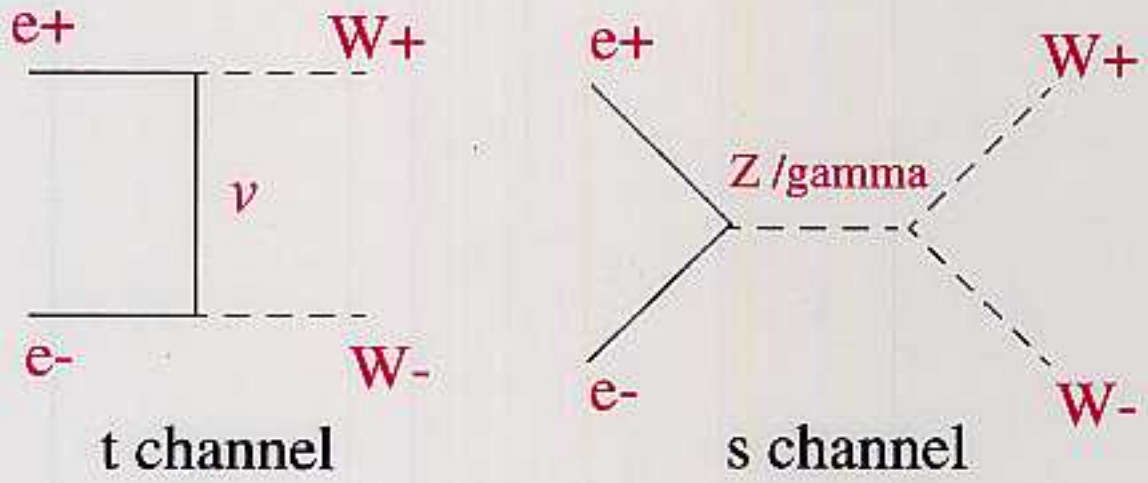
Introduction

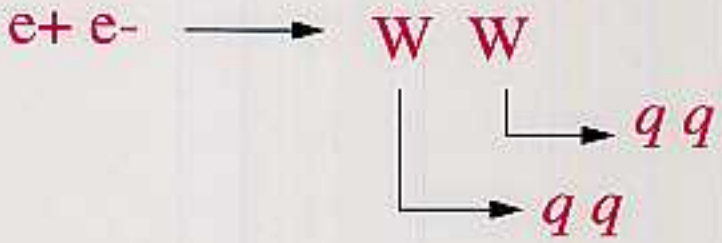
Year	ECM (GeV)	$\mathcal{L}$ (pb^{-1})/exp	σ_{WW}(pb)/exp	N_{WW}/exp
1996	161	11	3.5	40
	172	10	12	0.1k
1997	183	60	15.5	0.9k
1998	189	190	16	3k
1999	192 ~ 202	220	17	3.7k
2000	204 ~ 208	220	17	3.7k
total		710		11.4k

LEP 4 experiments $\Rightarrow$ 46k WW events produced.

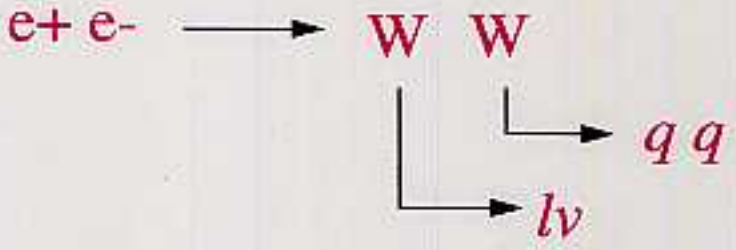
CC03 diagram



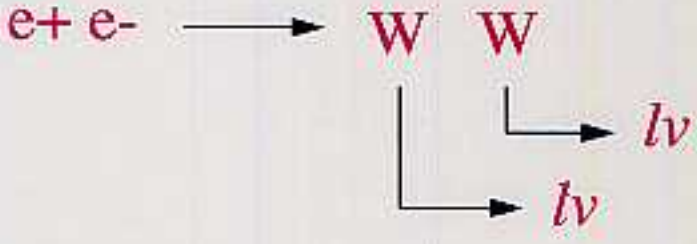
1. *qqqq* channel (46 %)



2. *qqlν* channel (44 %)

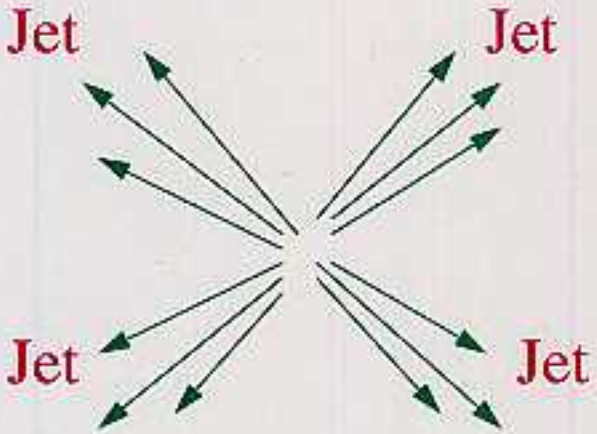


3. *lνlν* channel (10%)



Event Topology

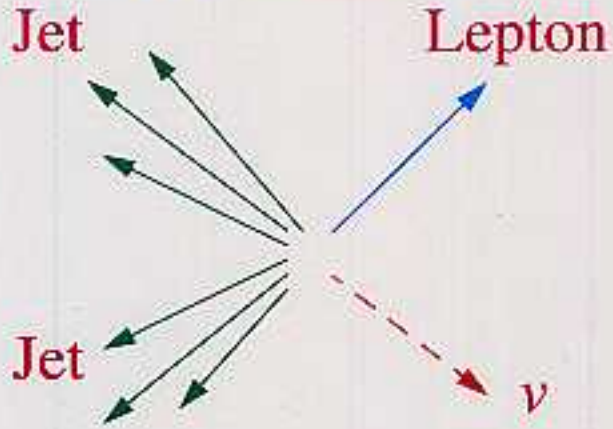
1. *qqqq* channel



4 jets
(well balanced)

Total E = sqrt(s)

2. *qqlv* channel

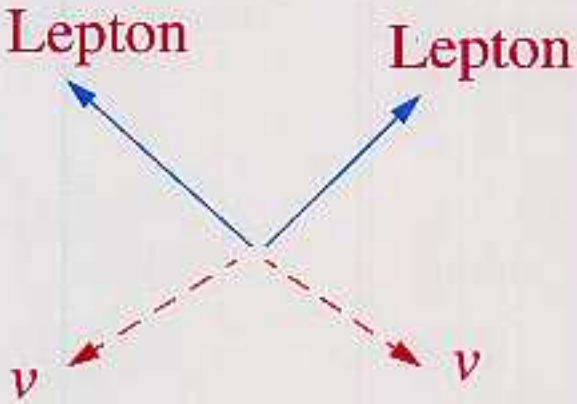


2 jets

1 energetic lepton
(well isolated)

Missing (E ,P)

3. *lvlv* channel



2 energetic leptons
(Acoplanar)

Missing (E ,P)

Selection

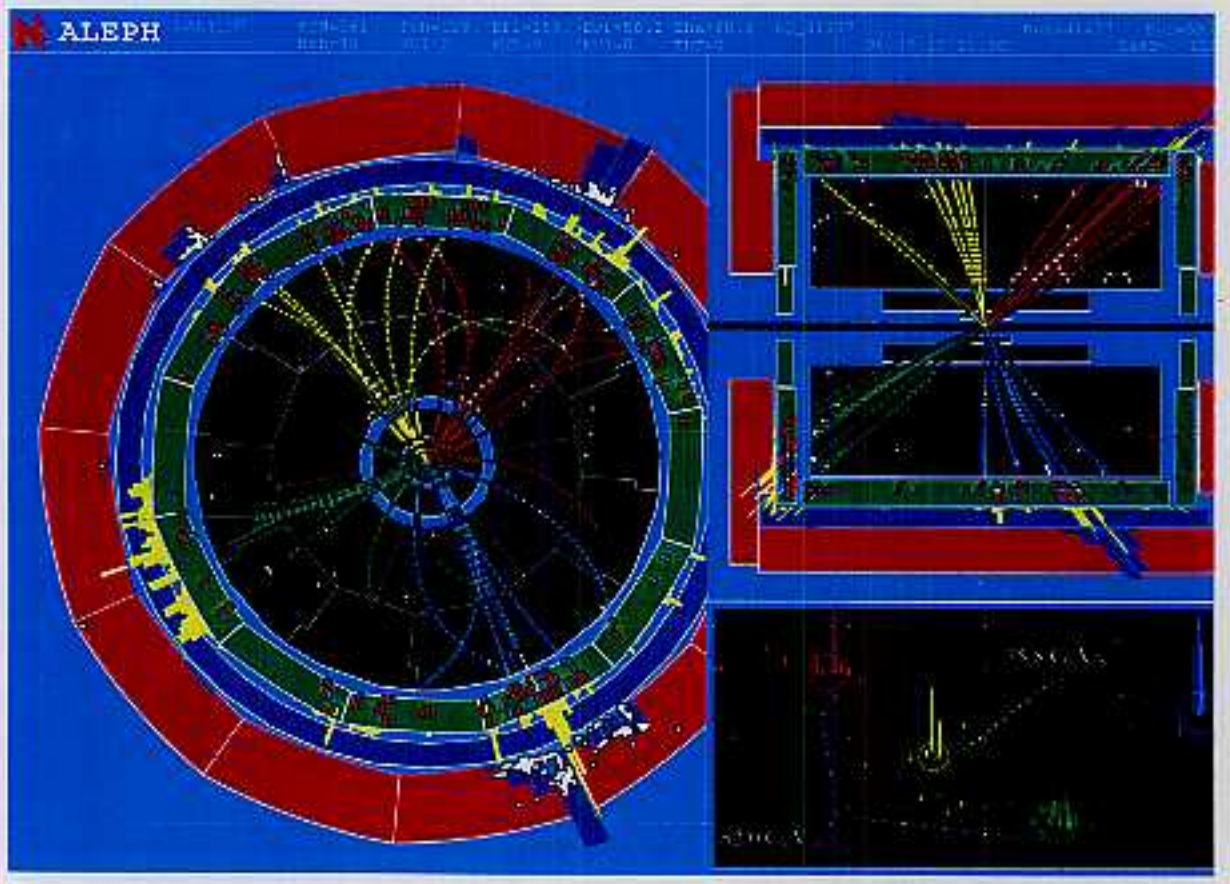
1. qqqq channel

Main Background Z/gamma ---> *qq*

Two order of magnitude larger than for the signal(161GeV)
Order of magnitude larger than for the signal(High E)

sqrt(s') cut, E_gamma cut .... ===> Preselection

Other Background ===> LH, NN selection.
qqlv, (Z/gamma)(Z/gamma), QCD(qqgg...)
ZZ BG at ECM>182 GeV



2. qqlv channel

Main Background Z/gamma ---> *qq*

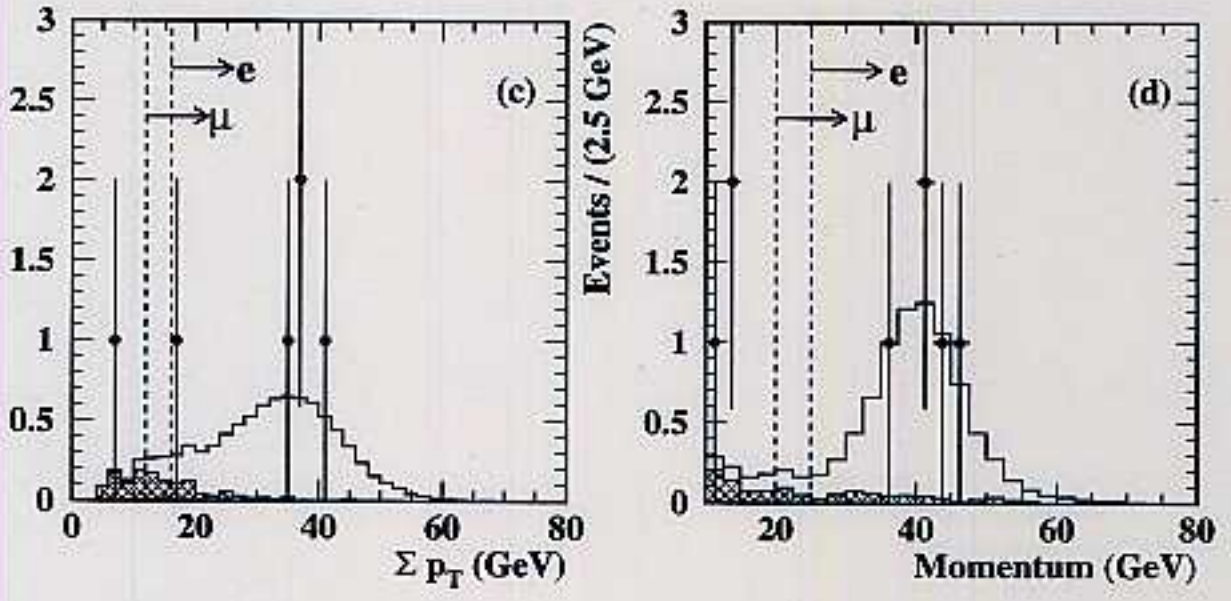
(Misidentification of ISR photon as a lepton)

Other Background : four-fermion process

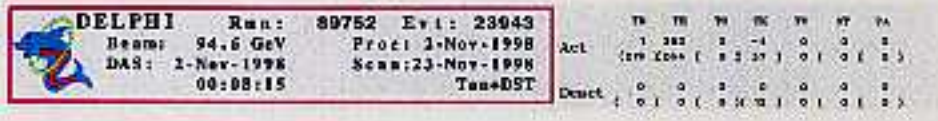
Z0 e+e-, W ev, ZZ ---> 2 jets and 1 id-lepton

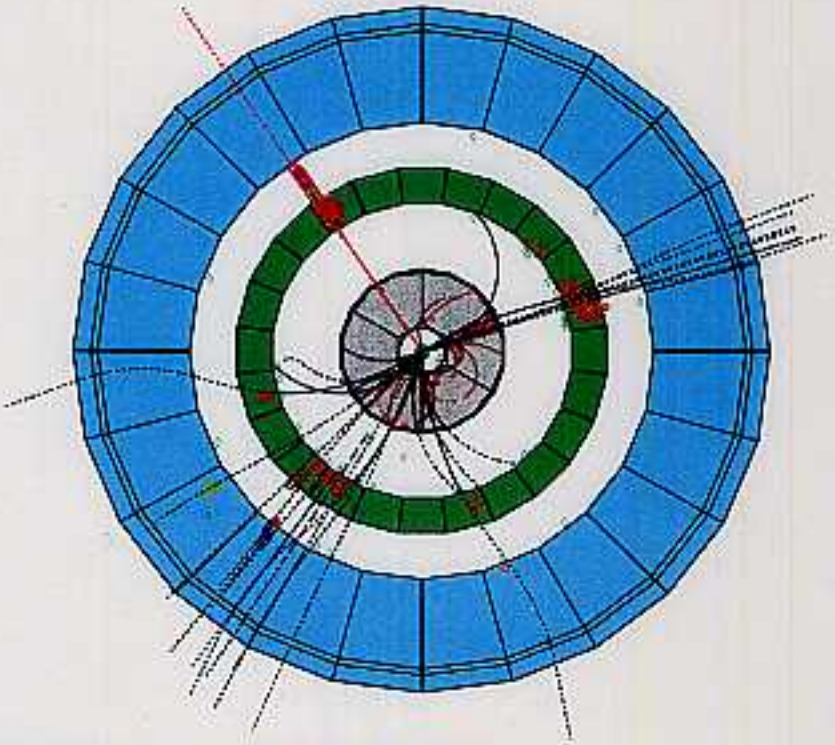
OPAL at 161 GeV

Lepton ID : E > 25 GeV (e), p > 20 GeV (muon)
Well isolated (200 mrad cone)
Large missing p, off beam direction



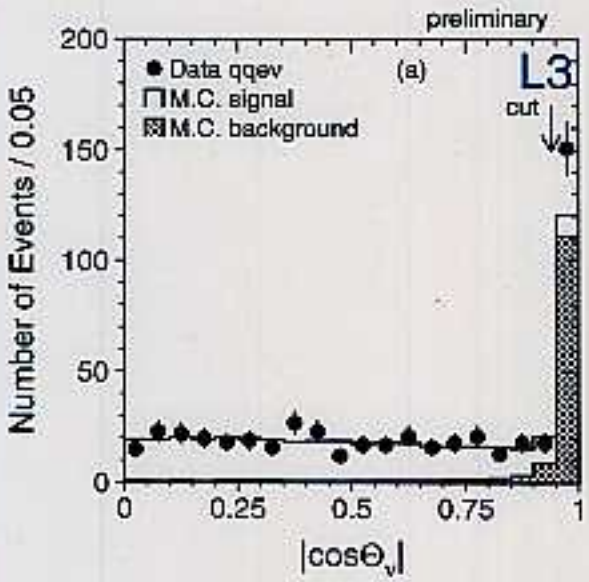
DELPHI WW --> qqev event at 189 GeV

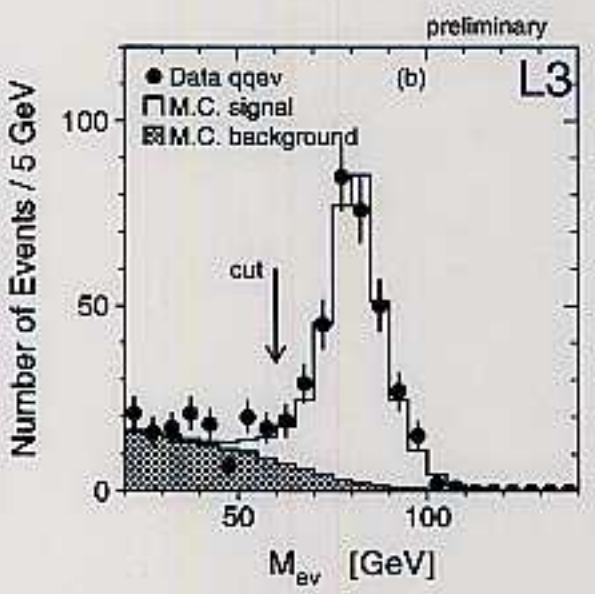




L3 selection at 189 GeV

qqev channel:





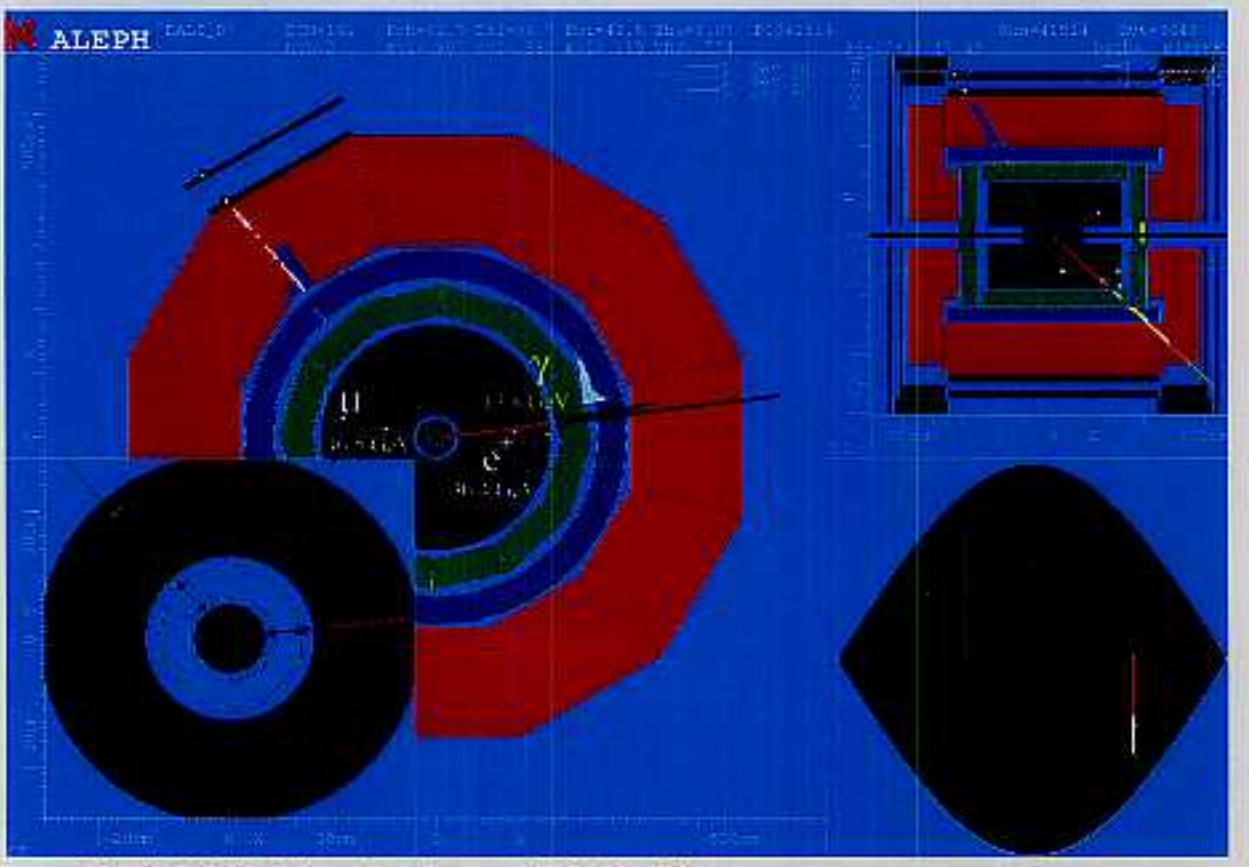
Polar angle of v

(e,v) invariant mass

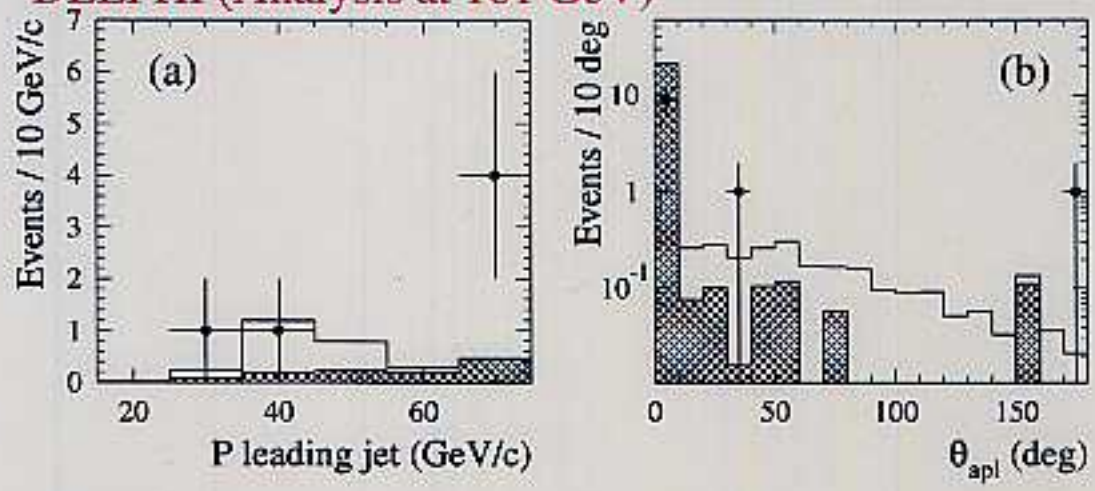
3. *lvlv* cahnnel

main background is e+e- ---> Z(g),
Bhabha scattering, and two-photon events

APLEPH



DELPHI (Analysis at 161 GeV)



All particles were clustered into 2 jets

Event selection summary

OPAL @ 189 GeV

Selected as	Observed	Total Expected	Efficiency (%)	Background
$e^+\nu_e e^-\overline{\nu}_e$	37	34.4 ± 1.1	75.5 ± 1.1	3.3 ± 1.0
$\mu^+\nu_\mu\mu^-\overline{\nu}_\mu$	34	37.1 ± 1.1	80.4 ± 1.2	3.7 ± 1.0
$\tau^+\nu_\tau\tau^-\overline{\nu}_\tau$	37	30.9 ± 1.0	46.4 ± 0.7	7.7 ± 1.0
$e^\pm\nu_e\mu^\mp\nu_\mu$	68	68.0 ± 1.3	77.8 ± 1.2	2.9 ± 1.0
$e^\pm\nu_e\tau^\mp\nu_\tau$	46	61.9 ± 1.2	63.0 ± 1.0	7.5 ± 1.0
$\mu^\pm\nu_\mu\tau^\mp\nu_\tau$	54	55.0 ± 1.2	60.6 ± 0.9	4.1 ± 1.0
$q\overline{q}e\nu_e$	389	414.3 ± 6.5	85.4 ± 0.8	25.1 ± 4.4
$q\overline{q}\mu\nu_\mu$	420	418.9 ± 4.8	89.2 ± 0.8	10.1 ± 1.1
$q\overline{q}\tau\nu_\tau$	437	423.6 ± 9.5	68.4 ± 1.4	76.3 ± 6.2
$\ell^+\nu_\ell\ell'^-\overline{\nu}_{\ell'}$	276	287.2 ± 5.0	82.1 ± 1.2	29.3 ± 2.9
$q\overline{q}\ell^\pm\nu_\ell$	1246	1256.8 ± 16.1	86.8 ± 0.9	111.5 ± 9.5
$q\overline{q}q\overline{q}$	1546	1500.0 ± 25.2	86.4 ± 0.9	325.3 ± 21.4
Weighted	1306.1 ± 31.8	1270.5 ± 19.1	72.3 ± 0.7	287.4 ± 15.4
any	3068	3044.0 ± 32.1	86.6 ± 0.6	466.1 ± 23.6

Determination of cross-section

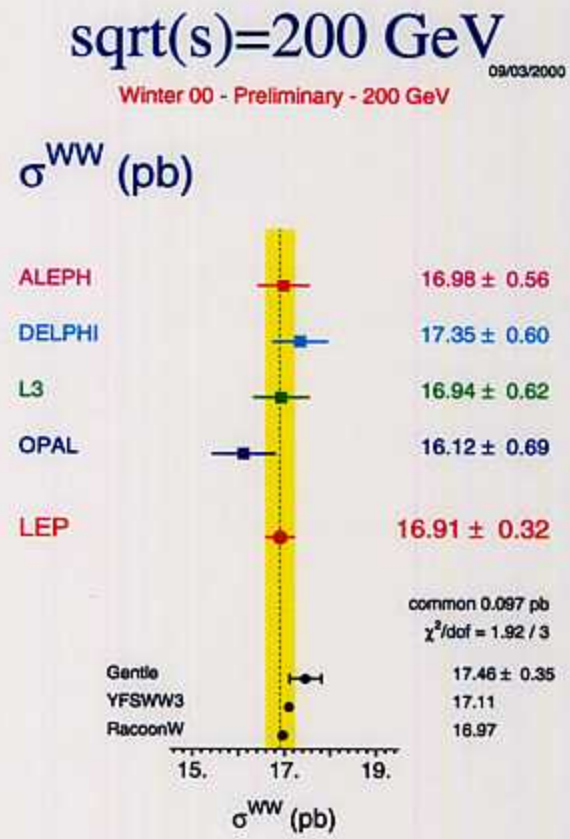
Likelihood fit using a function of WW x-sec,

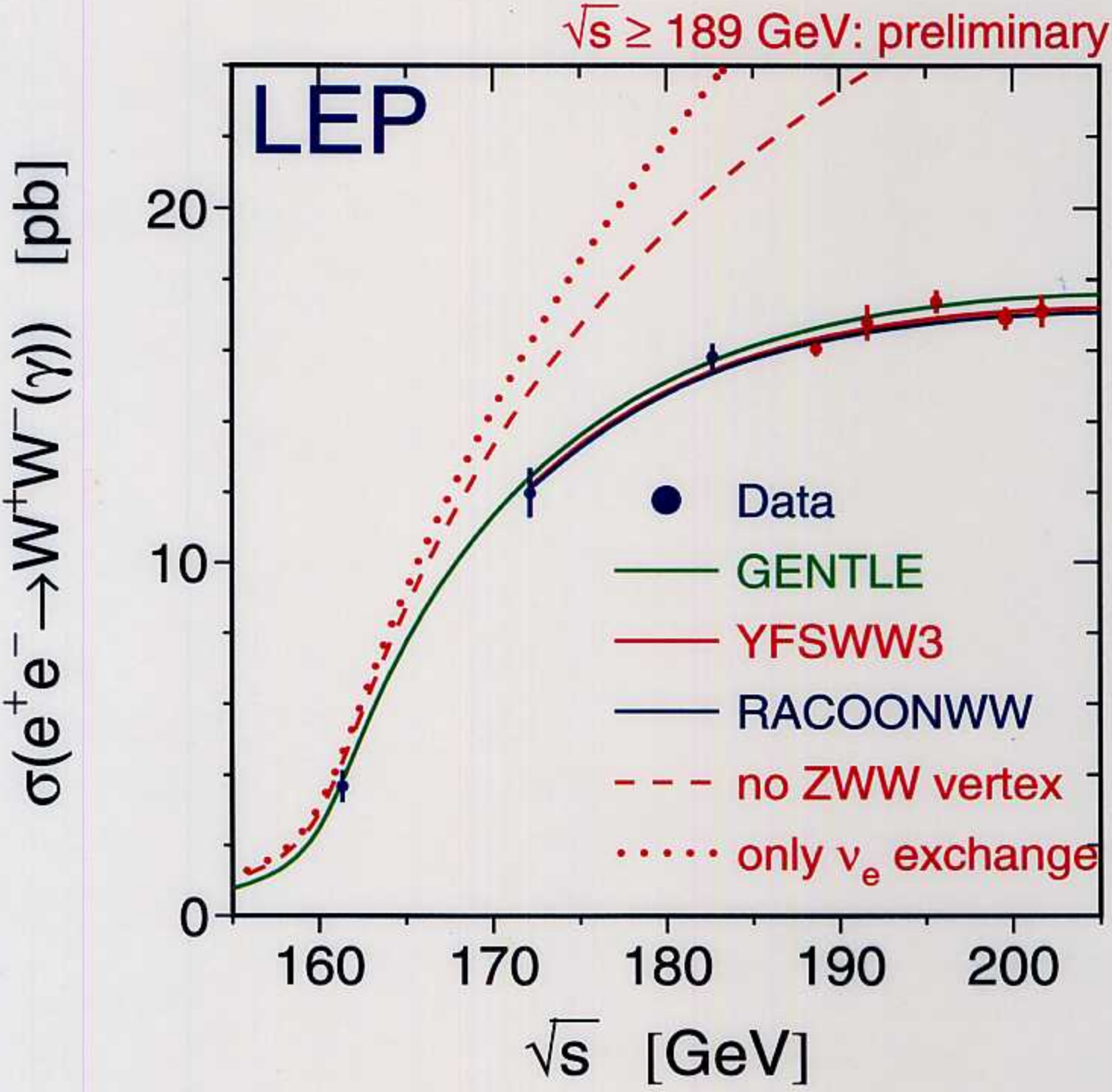
$$L = \prod_i P_i(N_i, \mu_i(\sigma_{WW})) = \prod_i \frac{\mu_i(\sigma_{WW})^{N_i} \cdot e^{-\mu_i(\sigma_{WW})}}{N_i!}$$

N_i = Observed number of events

$\mu_i(\sigma_{WW})$ = Expected number of events

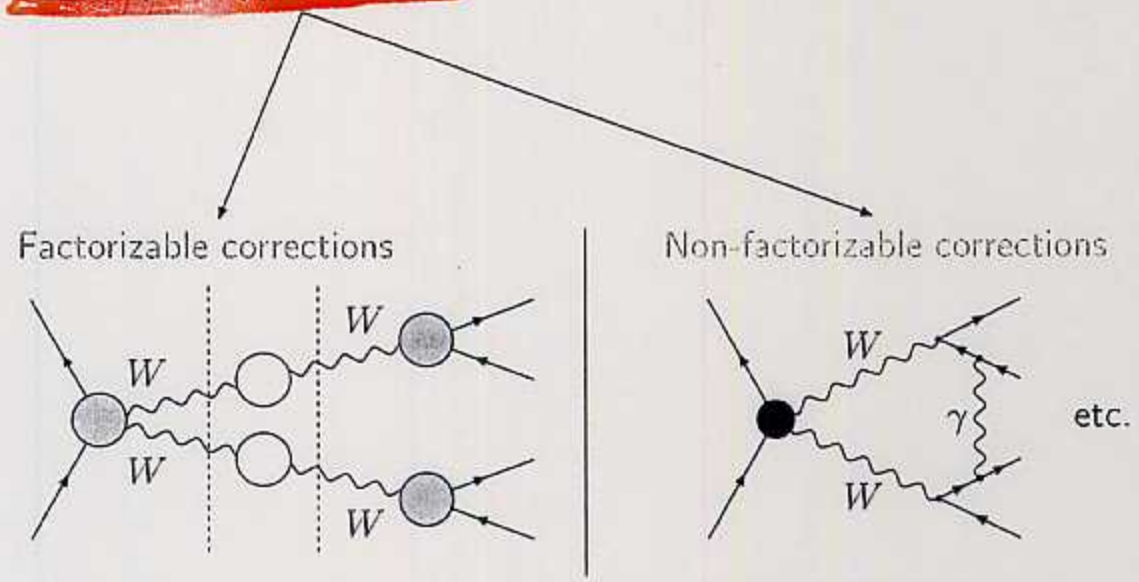
i runs over all of WW decay channels




√s ≥ 189 GeV: preliminary
LEP
σ(e⁺e⁻ → W⁺W⁻(γ)) [pb]
20
10
0
160
170
180
190
200
√s [GeV]
Data
GENTLE
YFSWW3
RACOONWW
no ZWW vertex
only ν_e exchange

$e^+e^- \to WW \to 4f$ at one loop:

Double-pole approximation



New $\mathcal{O}(\alpha)$-CC03 Calculation

- BBC (W. Beenakker, F.A. Berends, A.P. Chapovsky)
  DPA(double-pole approximation)
  ... double expansion in $\mathcal{O}(\alpha)$ and $\mathcal{O}(\Gamma_W/M_W)$.
  hep-ph/9902333, Nucl. Phys. B548(1999)3
- DDRW (A. Denner, S. Dittmaier, M. Roth, D. Wackeroth)
  DPA(double-pole approximation)
  hep-ph/9909363, hep/ph-9904472
- YFSWW (S. Jadach et al.)
  CC03/LPA(leading pole approximation) hep-ph/9907436

Expected uncertainty

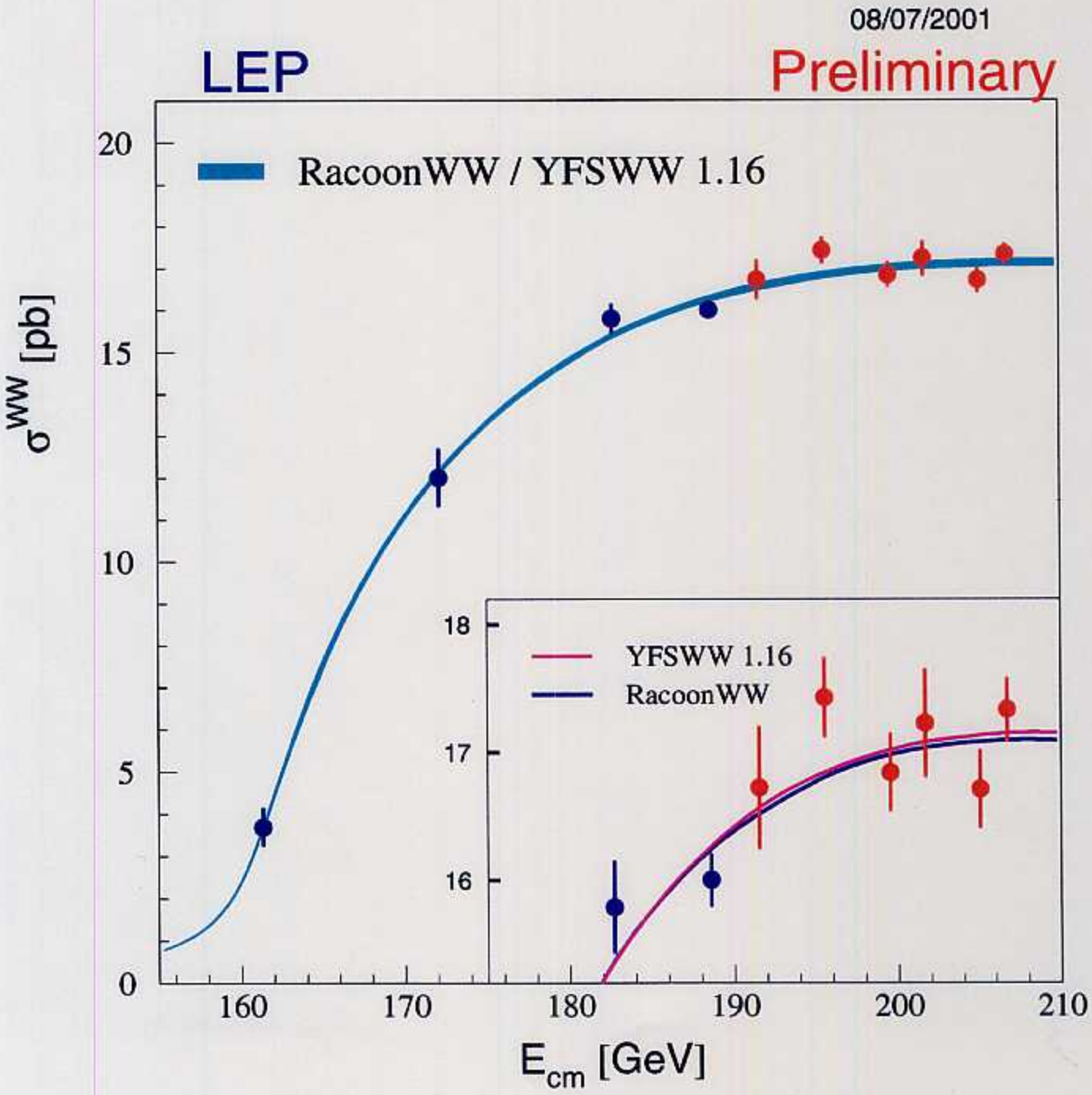
$$\mathcal{O}\left(\frac{\alpha}{\pi}\frac{\Gamma_W}{M_W}\ln(..)\right) < 0.5\,\%$$

Valid for $\sqrt{s} > 2M_W + n\Gamma_W$ $(n = 3-5)$

Theory : $O(\alpha)$ in DPA

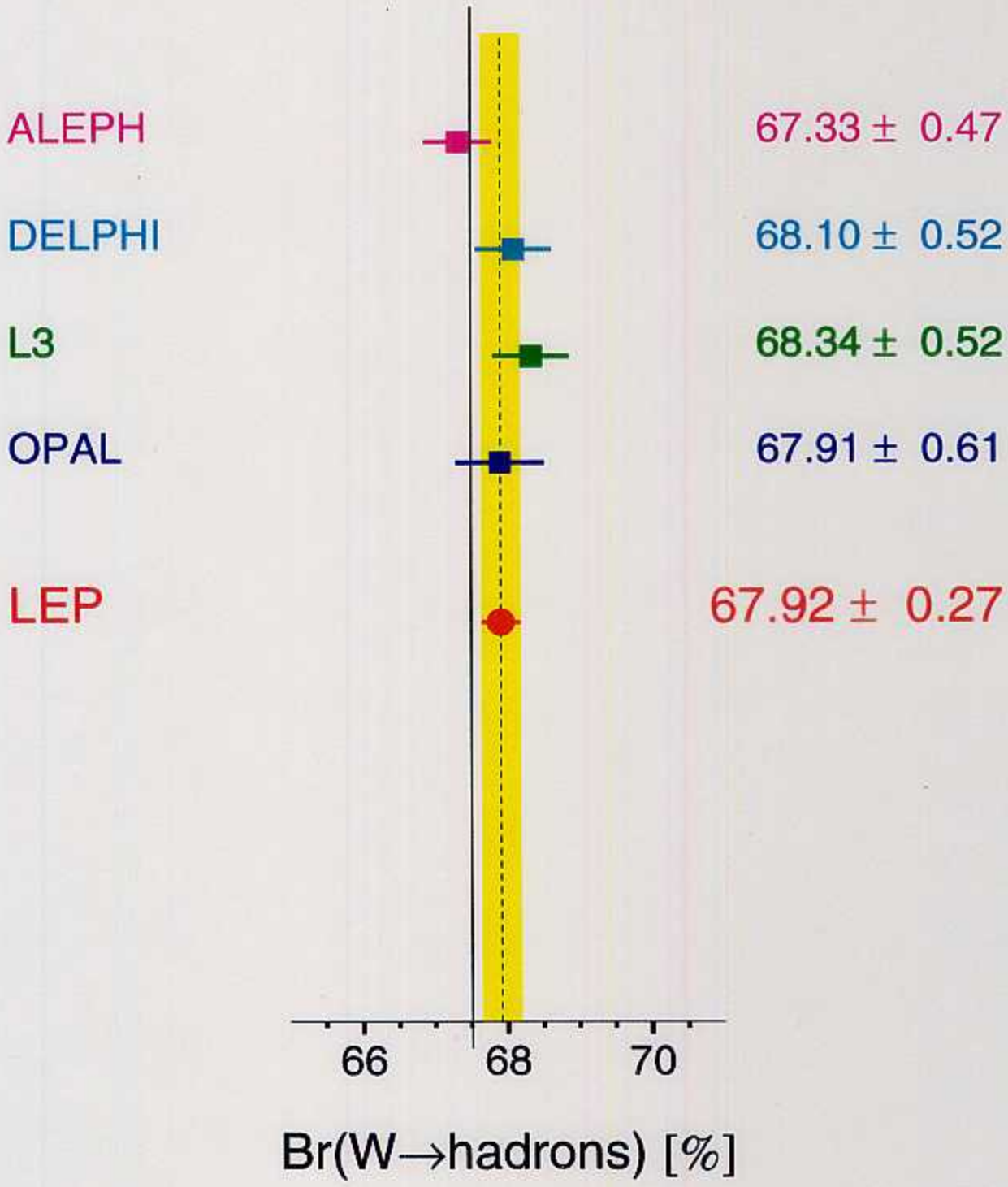
(Double Pole Approximation)

$\frac{\delta \sigma^{th}}{\sigma} \sim 0.5\%$



Winter 01 - Preliminary - [161-207] GeV

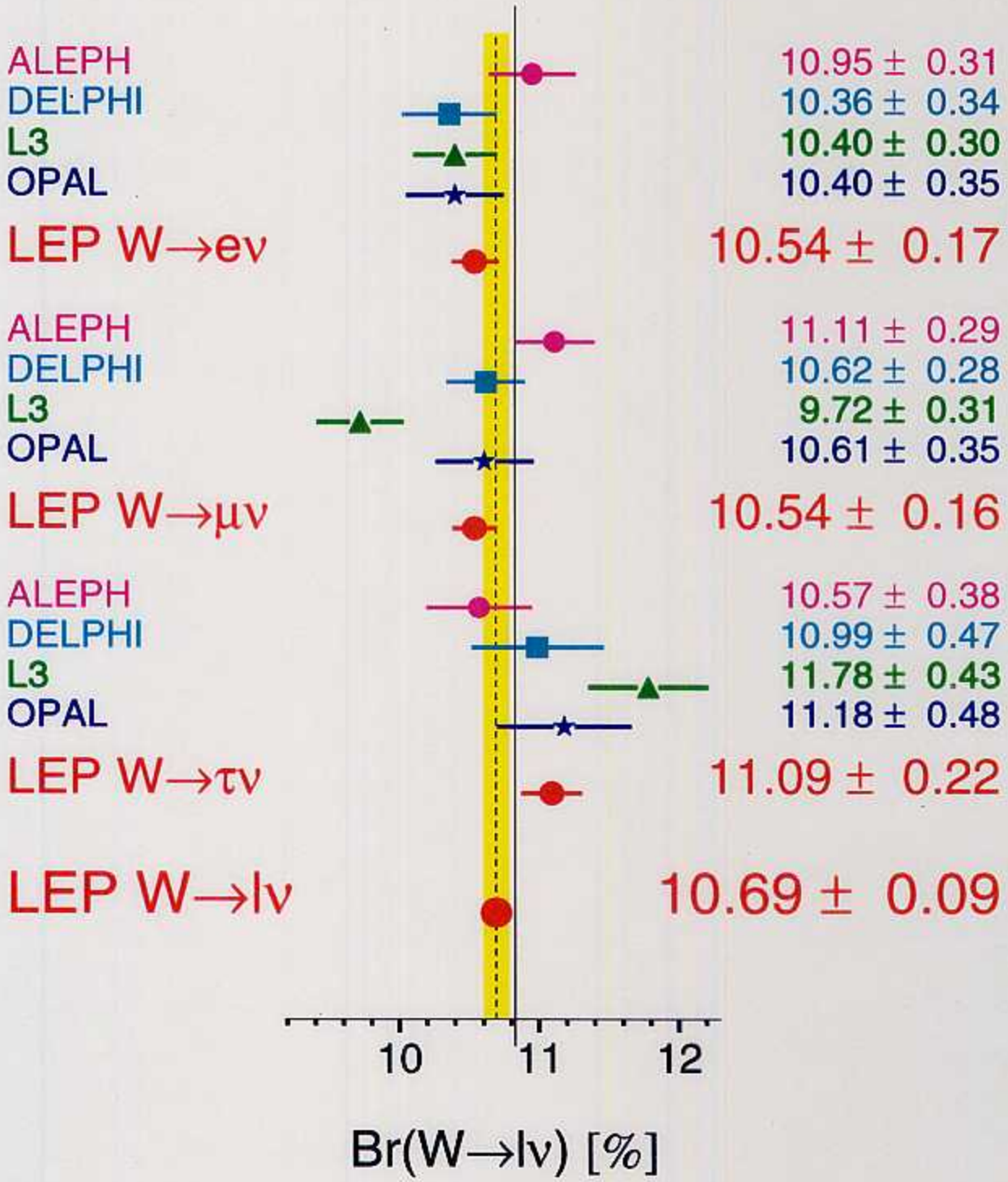
Br(W→hadrons) [%]



02/03/2001

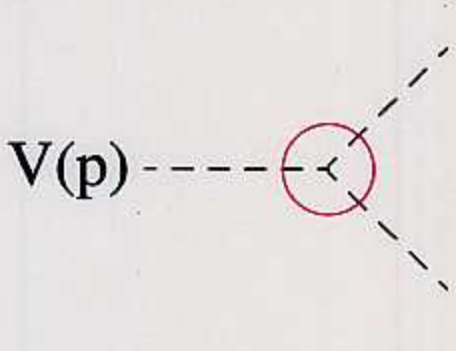
Winter 01 - Preliminary - [161-207] GeV

W Leptonic Branching Ratios



Triple gauge coupling

Parameter space



$$= - ie\, g_{VWW}\, \Gamma_V^{\alpha\beta\mu}(q, \bar{q}, p) \qquad V = \gamma, Z$$

2 x 7 complex coupling constants

Overall couplings : $g_{WW\gamma} = 1$, $g_{WWZ} = \cot\theta_W$

C,P and CP conservations reduce to five

$$g_1^Z,\ \kappa_\gamma,\ \kappa_Z,\ \lambda_\gamma,\ \lambda_Z$$

Blind directions (LEP1 data) ---> Three TGC's

$$\alpha_{W\phi} = \Delta g_1^Z \cos^2\theta_W$$

$$\alpha_W = \lambda_\gamma$$

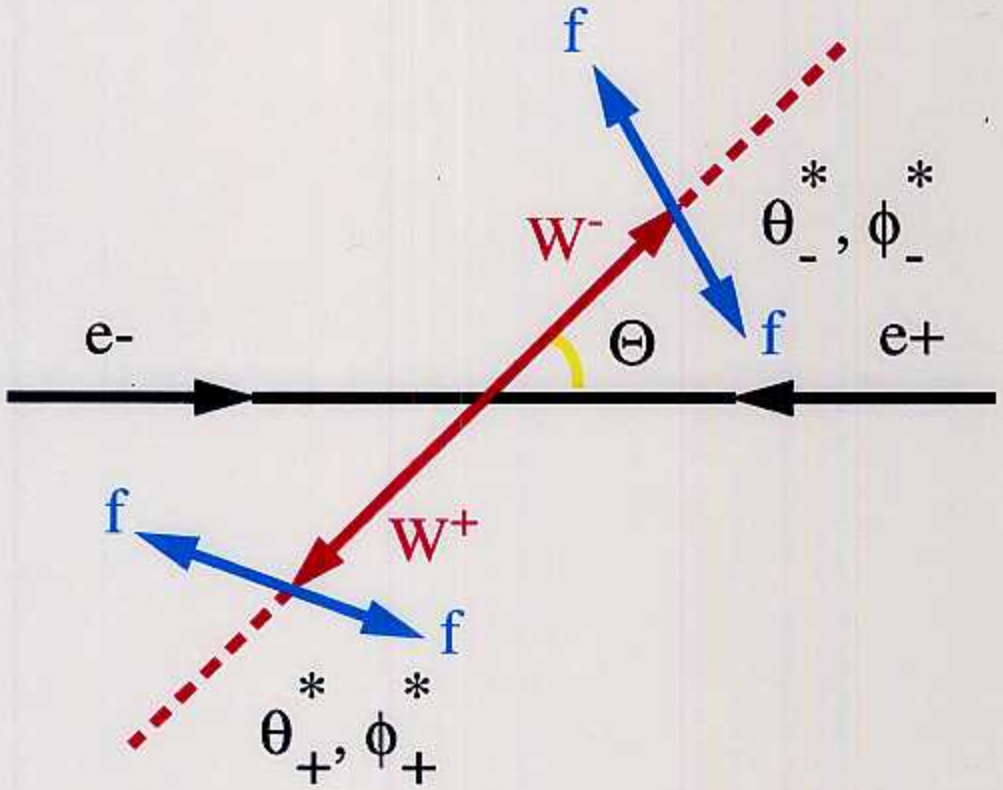
$$\alpha_{B\phi} = \Delta\kappa_\gamma - \Delta g_1^Z \cos^2\theta_W$$

with constrains

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_W \ , \quad \lambda_\gamma = \lambda_Z$$

preserve local $SU(2)_L$ x $U(1)_Y$ invariance

Experimental variables



Θ **W^- polar production angle**

θ^*_-, ϕ^*_-
θ^*_+, ϕ^*_+

Polar and azimathal W decay angle in W rest frame

- Reconstruction of 4 decay fermions
- Kinematic fit to improve resolution
- Reconstruction of 5 phase-space variables

Diffential cross section

$$d\sigma = d\sigma(\Omega, \alpha)$$

$$\Omega = (\Theta, \theta^{*}_{\pm}, \phi^{*}_{\pm})$$

- contains all possible information
- measure as many angle as possible

W --> lv decay

The sign of the charge of lepton determines unique W- decay angle: $\cos\theta^{*}, \phi^{*}$

W -->qq decay

Flavour and chrage of quak is not measured

two-fold ambiguity

$$\left(\cos\theta^{*}, \phi^{*}\right) \leftrightarrow \left(-\cos\theta^{*}, \phi^{*} + \pi\right)$$

Jet charge determines the sign of $\cos\Theta$

Correct-asignment efficiency = 70 ~ 80 %

$$\cos\Theta \leftrightarrow -\cos\Theta$$

Semileptonic channel is more sensitive

Optimal Observable

Differential cross-section is expanded as a functions of coupling α

$$\frac{d\sigma}{d\Omega}(\alpha) = C_0 + \alpha C_1 + \alpha^2 C_2$$

$$\frac{1}{C_0}\frac{d}{d\alpha}\frac{d\sigma}{d\Omega} = \frac{C_1}{C_0} + 2\alpha\frac{C_2}{C_0}$$

2-variable space (C1/C0, C2/C0)
retains
the whole infotmation of TGC's

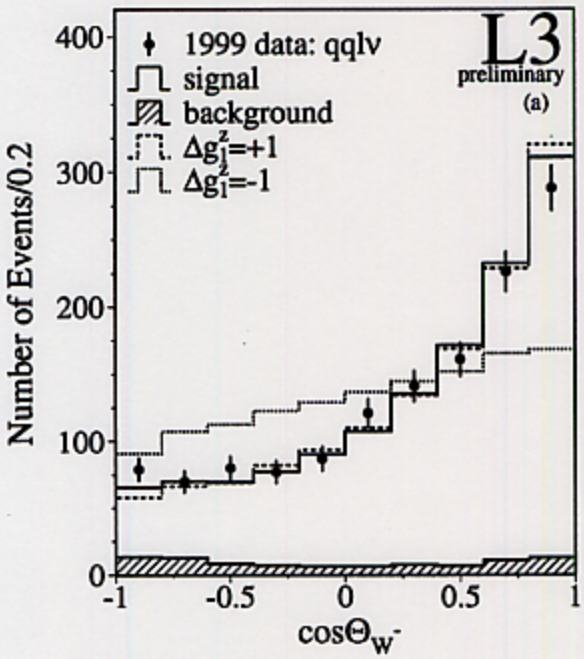
↓

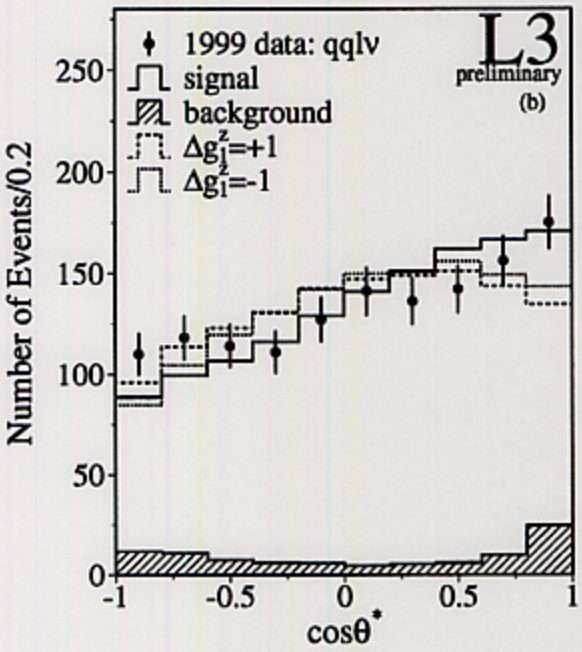
Allows determination of α
with maximum precision

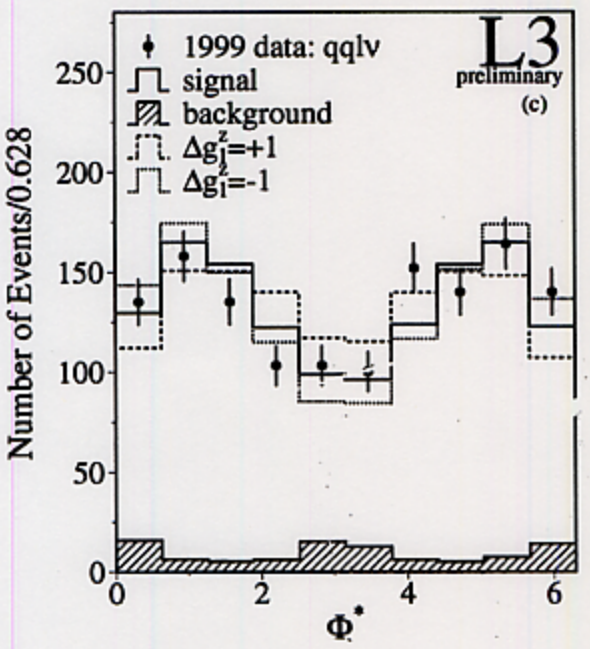
↓

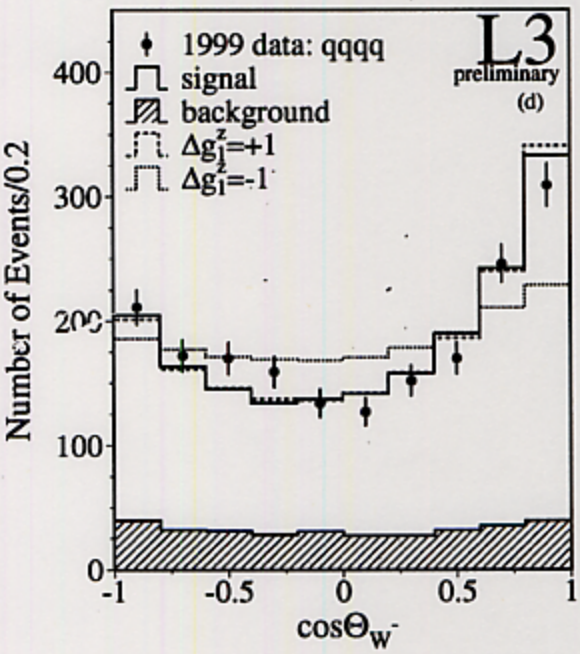
Fits (C1/C0, C2/C0), by likelihood method

Example of angular distributions





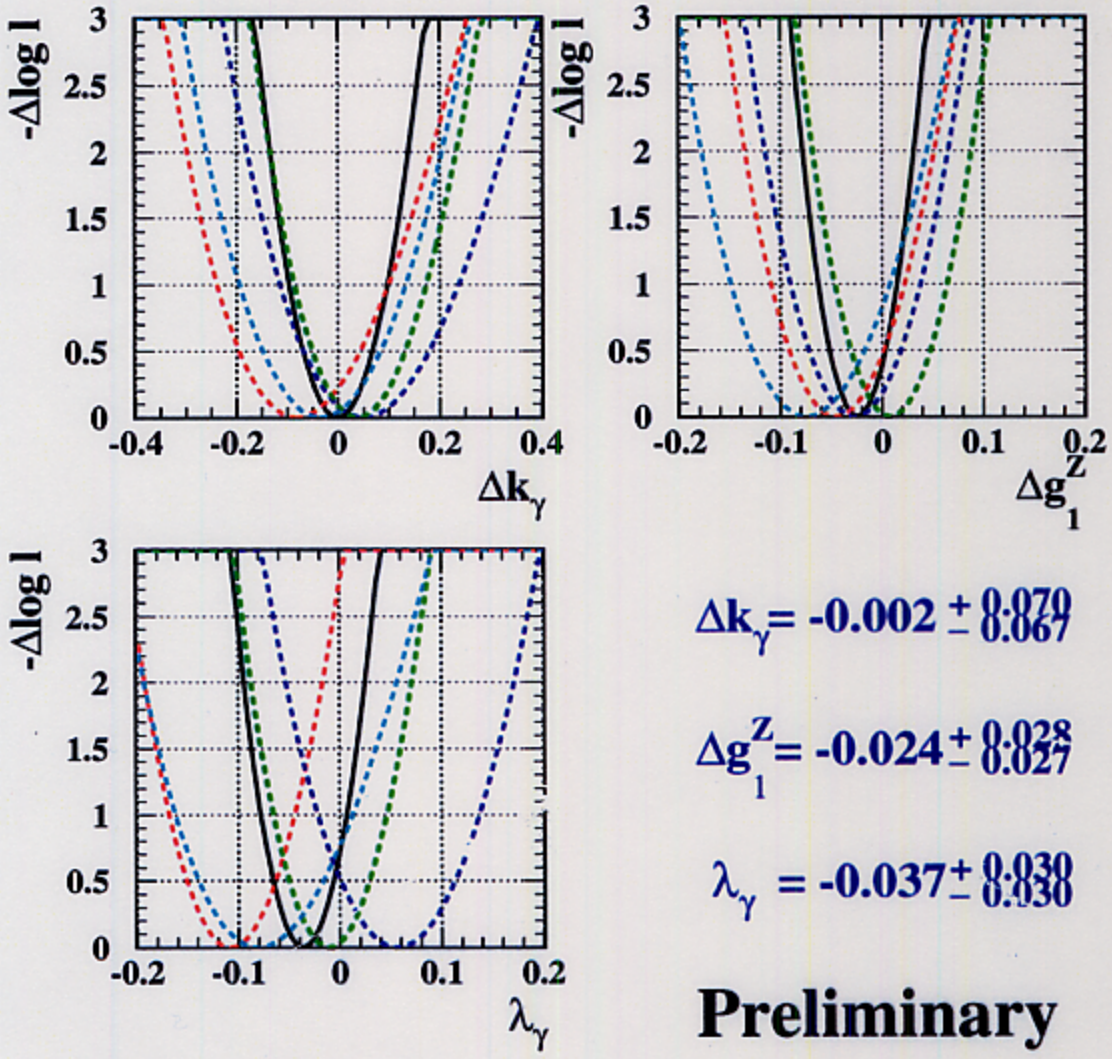




▷WW and single W (LEP2 → 202 GeV in 99)

(Except Single-W from OPAL for 192-202 GeV data)

ALEPH + DELPHI + L3 + OPAL



$\Delta k_\gamma = -0.002 \pm {}^{0.079}_{0.067}$

$\Delta g_1^Z = -0.024 \pm {}^{0.028}_{0.027}$

$\lambda_\gamma = -0.037 \pm {}^{0.030}_{0.030}$

Preliminary

Systematic source	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
σ (WW) (± 2%)	± 0.012	± 0.055	± 0.014
Fragmentation	± 0.013	± 0.051	± 0.014
Color Reconnection	± 0.003	± 0.012	± 0.005
Bose-Einstein effect	± 0.006	± 0.020	± 0.006
σ (Weν) ± 5%)	-	± 0.049	± 0.067

Mass of W

Motivation

- Precision test of Standard Model
- Higgs mass constraint

$$G_\mu = \frac{\alpha\pi}{\sqrt{2}M_W^2}\left(1-\frac{M_W^2}{M_Z^2}\right)^{-1}\frac{1}{1-\Delta r}$$

where Δr is m_t- and m_H-dependent,
when loop corrections are included

Method for Mw measurement

- WW cross-section to Mw
  at qrt(s)=161 GeV
- Direct mass reconstruction
  at sqrt(s)=172 GeV

W mass measurement by WW x-sec

Estimate of the error on the W mass

$$\Delta M_W = \sqrt{\sigma_{WW}} \left| \frac{dM_W}{d\sigma_{WW}} \right| \sqrt{\frac{1}{\varepsilon_{WW} \cdot L}}$$

ε_{WW} = Overall signal efficiency

L = Integrated luminosity

ΔM_W is changed as a function of $\sqrt{s}$

$$\sqrt{s}^{\text{Optimal}} \cong 2M_W + 0.5 \text{ GeV}$$

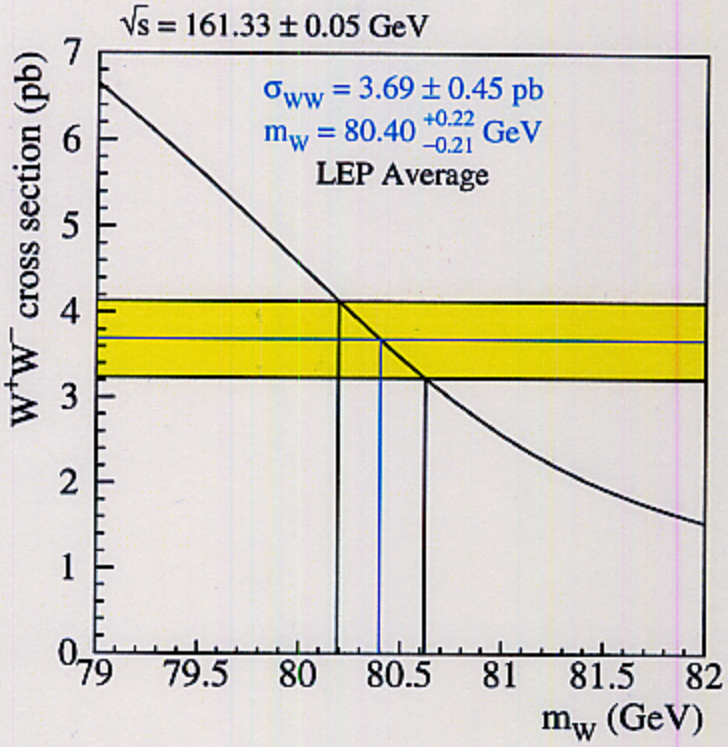
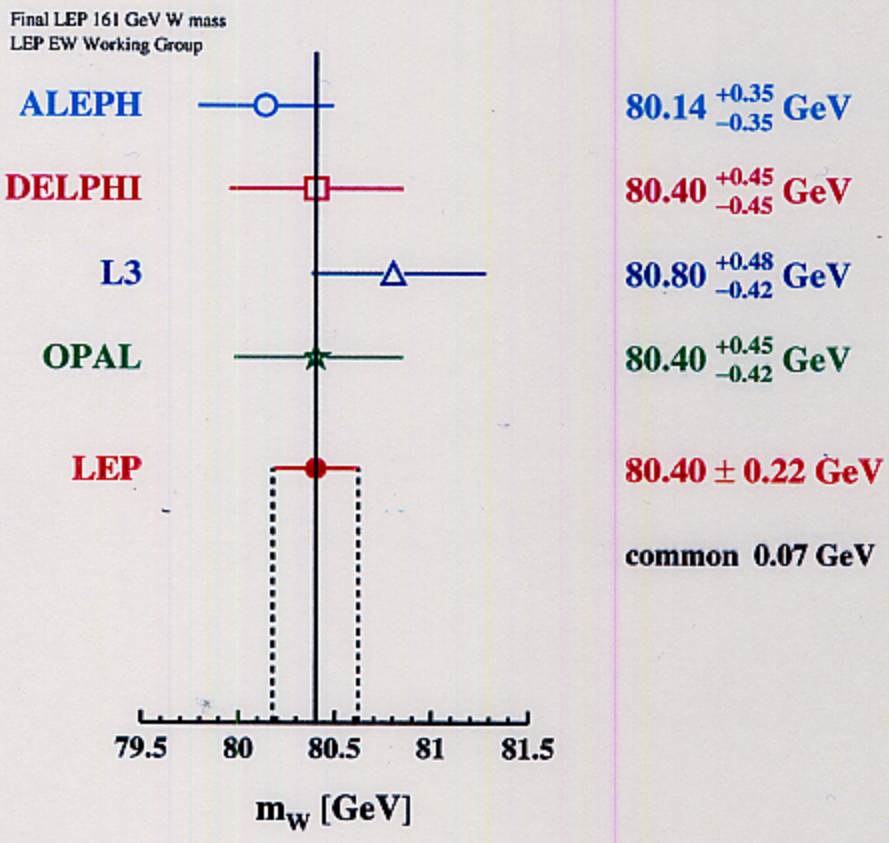
161 GeV

Likelihood fit

$$L = \prod_i P_i(N_i, \mu_i(\sigma_{WW})) = \prod_i \frac{\mu_i(\sigma_{WW})^{N_i} \cdot e^{-\mu_i(\sigma_{WW})}}{N_i!}$$

$$\mu_i(\sigma_{WW}) = \mu_i(\sigma_{WW}(M_W))$$

m_W from σ_{WW} at 161 GeV



LEP 161 GeV W mass