EPS, Jerusalem

PA8

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The cross-sections for WW and four-fermion production at LEP2

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Content:

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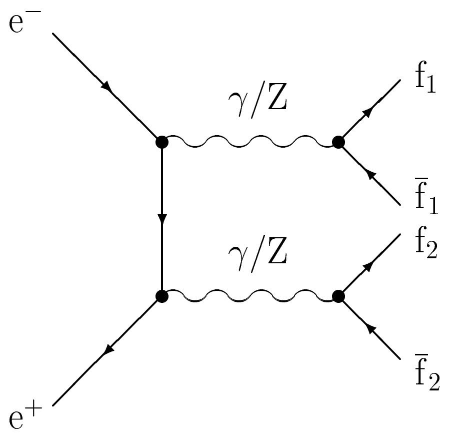
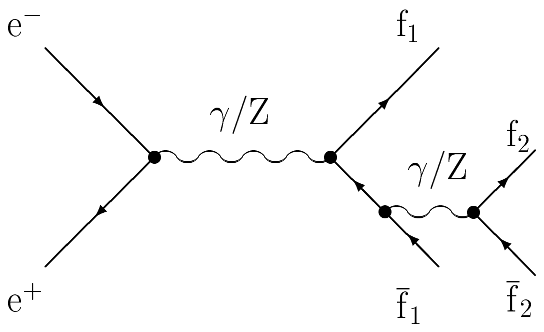
- Neutral Current 4f Production
- Single W
- WW
- Summary

		$\sqrt{s}$	int. Lumi per exp.
1989 :	LEP 1	~ 92 GeV	130 pb-1
1995	LEP 1.5	133 GeV	6 pb-1
1996	LEP 2	161 GeV	11 pb-1
1997		172 GeV	10 pb-1
:		183 GeV	running (7 pb-1 by 13.8.)

This talk concentrates on LEP 2 and some LEP 1.5 results

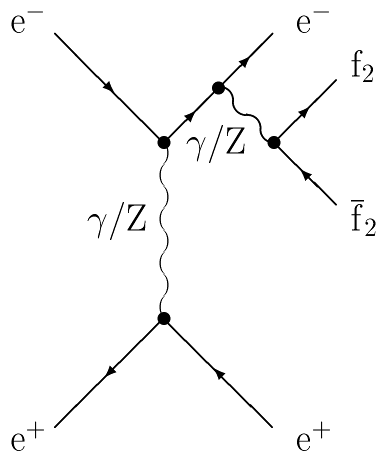
Neutral Current 4f production:

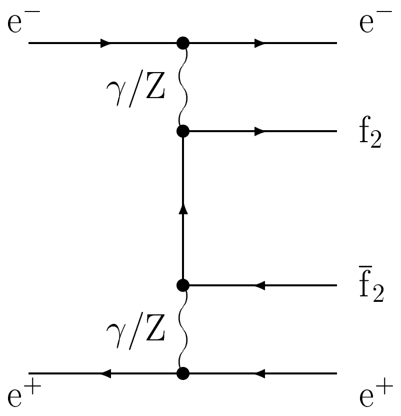




Bremsstrahlung

Multiperipheral





Main contributions (above Z^0 pole):

- ee in final state: Bremsstrahlung
- other final states: Conversion (radiat. return)

Topologies

"low multiplicity" $\ell\ell\ell'\ell'$

- 4 leptons
- large E_{vis} (in contrast to 2γ bgd)

"high multiplicity" $\ell\ell q\bar{q}$

- 2 leptons + 2 jets
- large E_{vis}
- most serious bgd: $qq\gamma$

"missing momentum " $\nu\bar{\nu}q\bar{q}$

- large missing momentum
  not pointing along the beam pipe

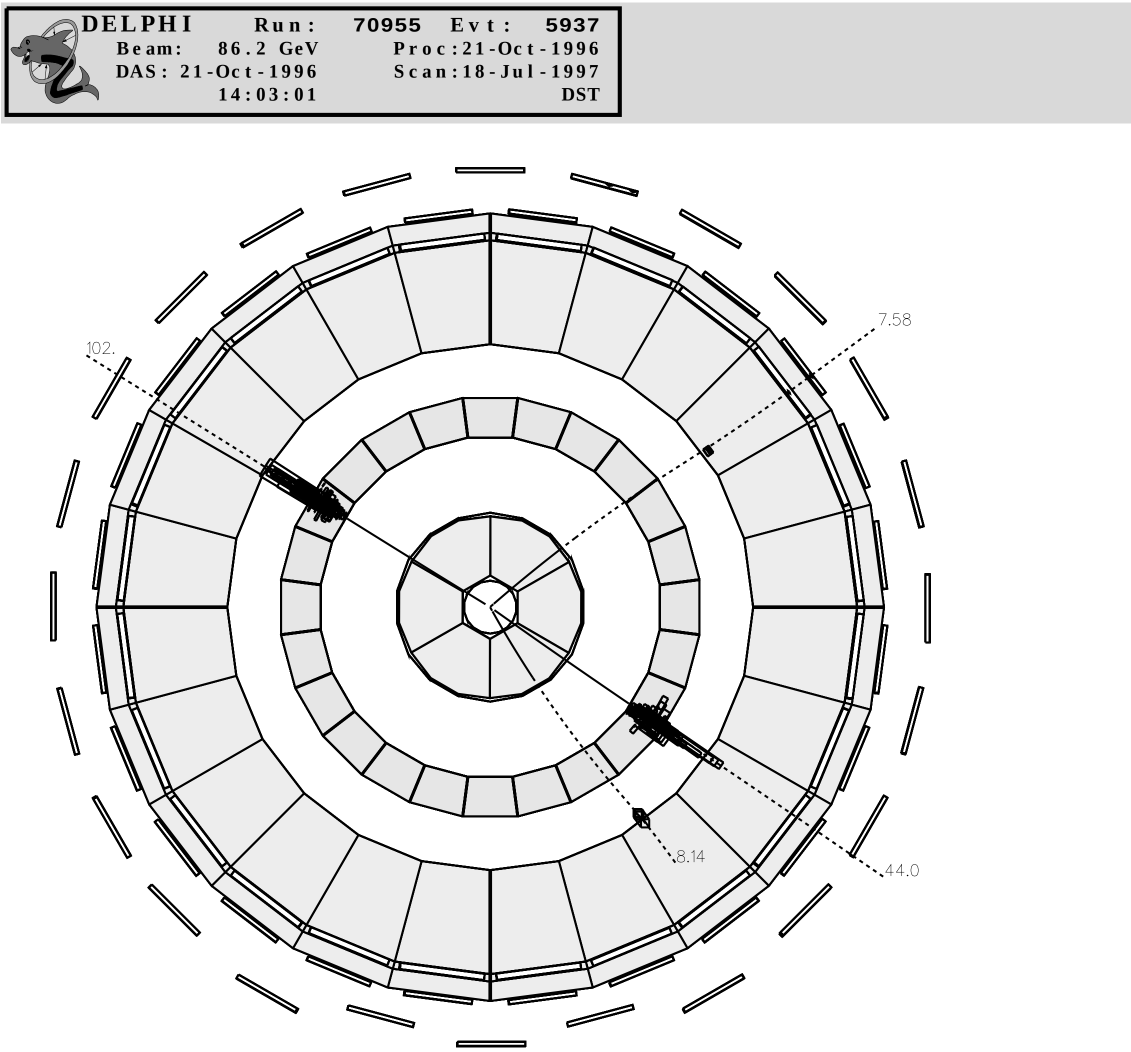
"4-jet " $q\bar{q}q\bar{q}$

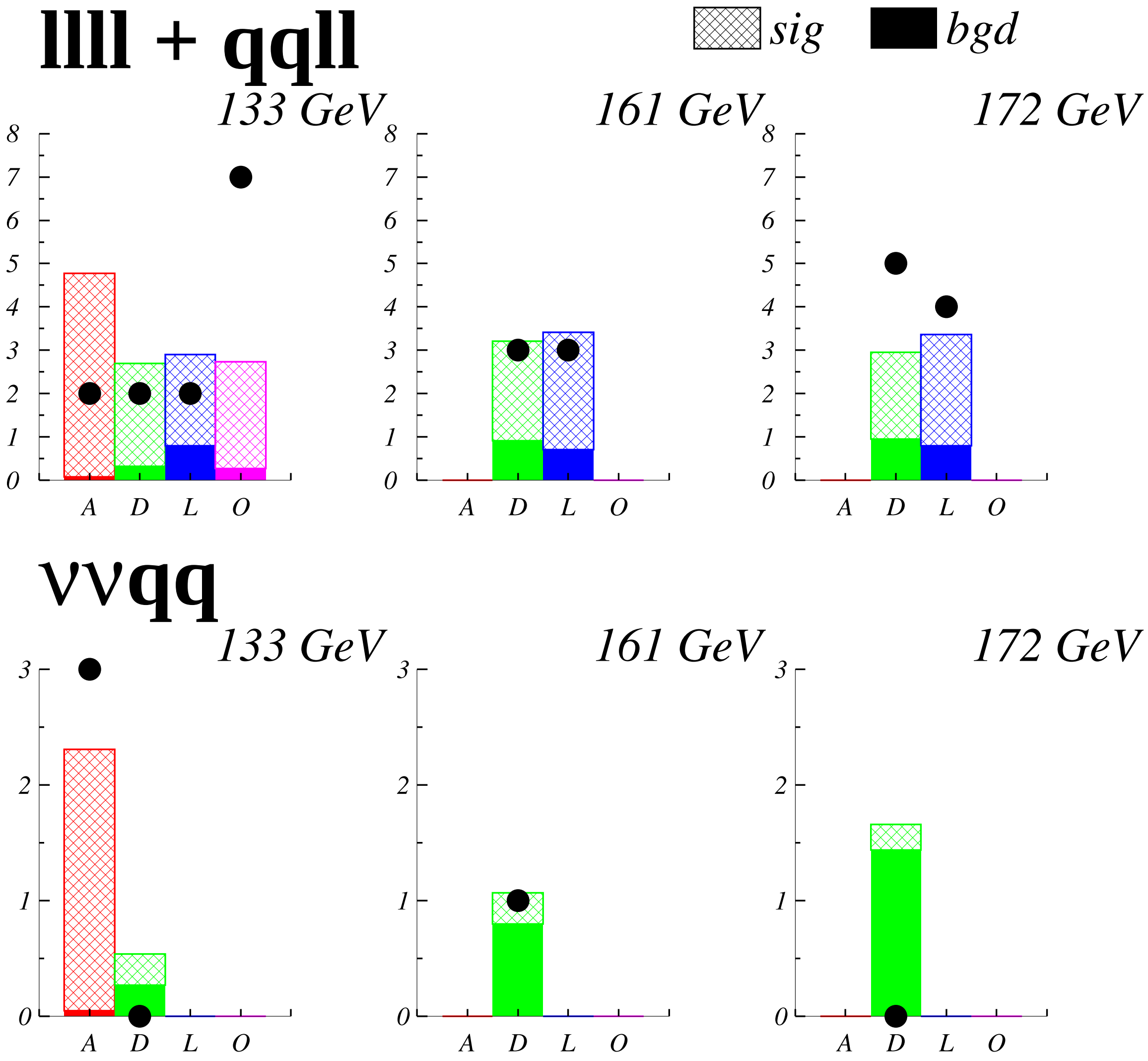
QCD dominated,

not considered here (but surely in searches talks)

$\rightarrow$ but see WW charged current later this talk

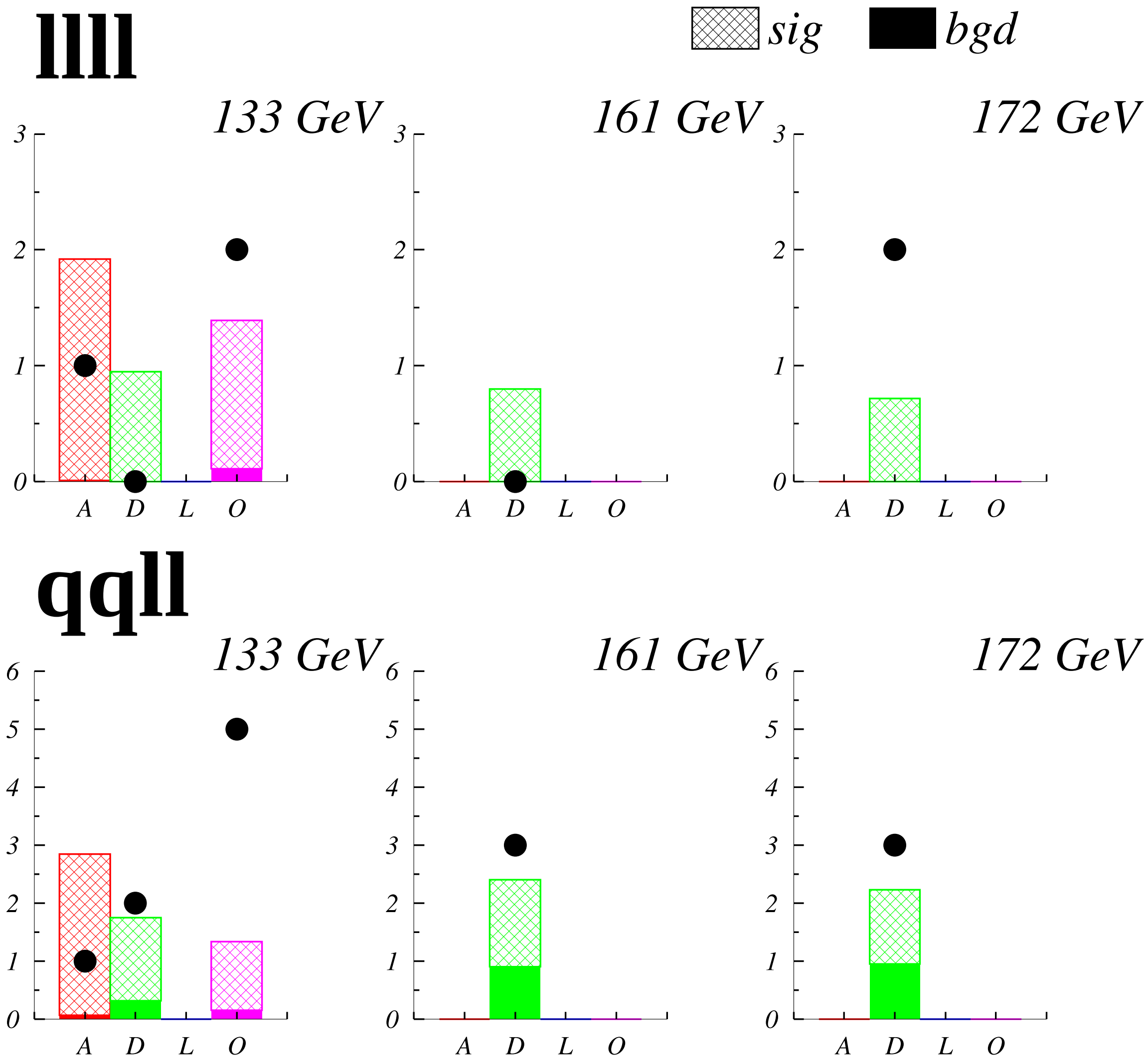
$e^+e^-\mu^+\mu^-$ candidate @ 172 GeV





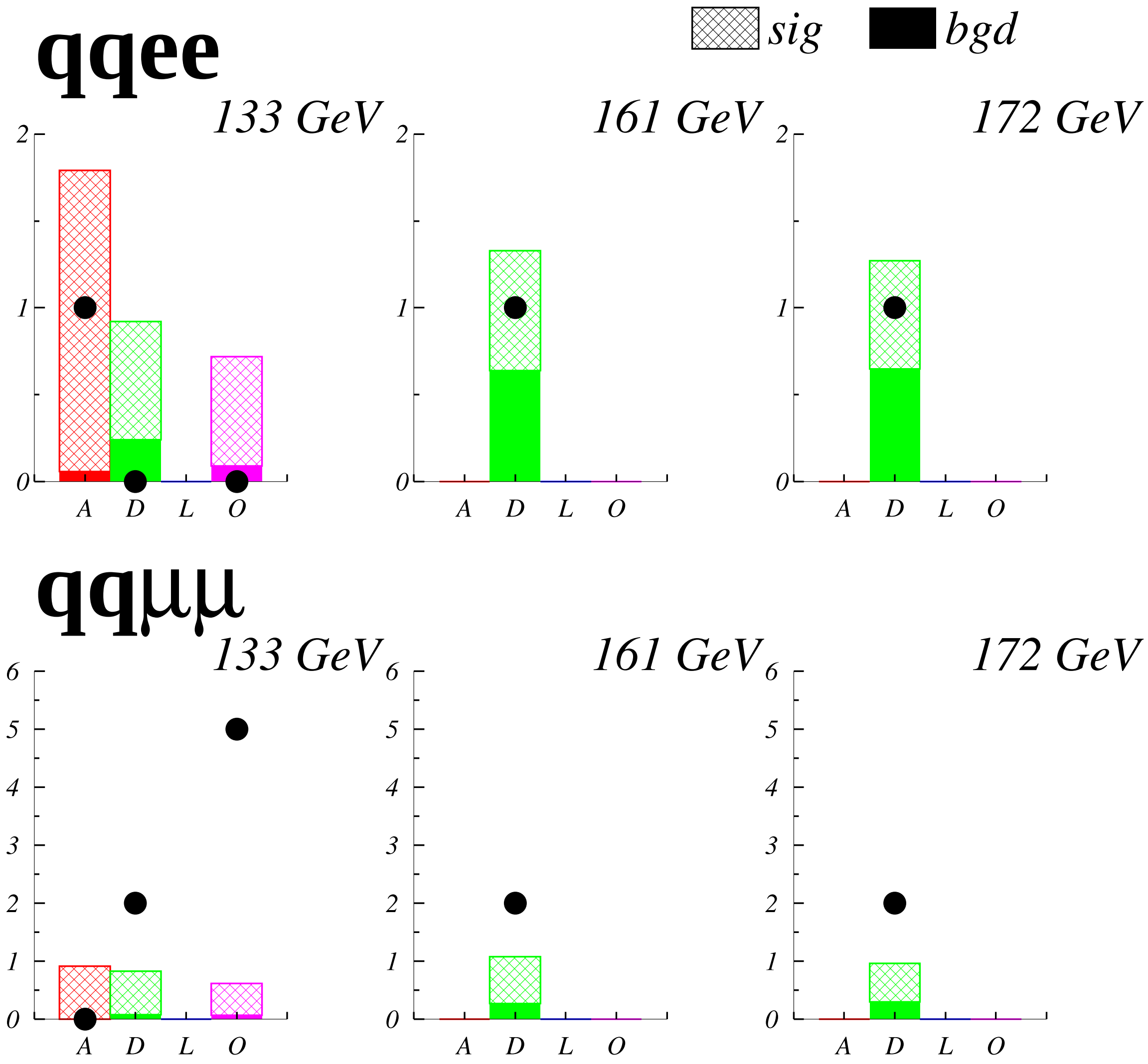
Delphi: preliminary

Opal: $\ell\ell\ell\ell$ preliminary



Delphi: preliminary

Opal: $\ell\ell\ell\ell$ preliminary

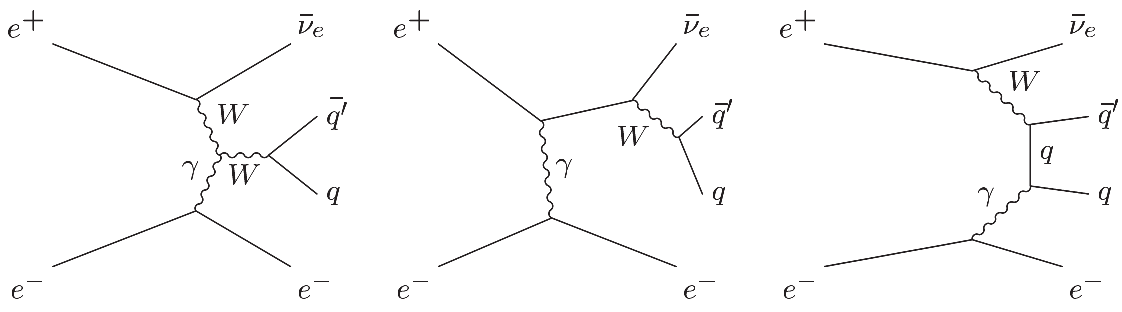


Delphi: preliminary

Neutral Current 4 fermion production

- ➢ Overall good agreement between experiment and SM
- ➢ NC 4f bgd for searches ok (within present statistics)

Single W production



(a) (b) (c)

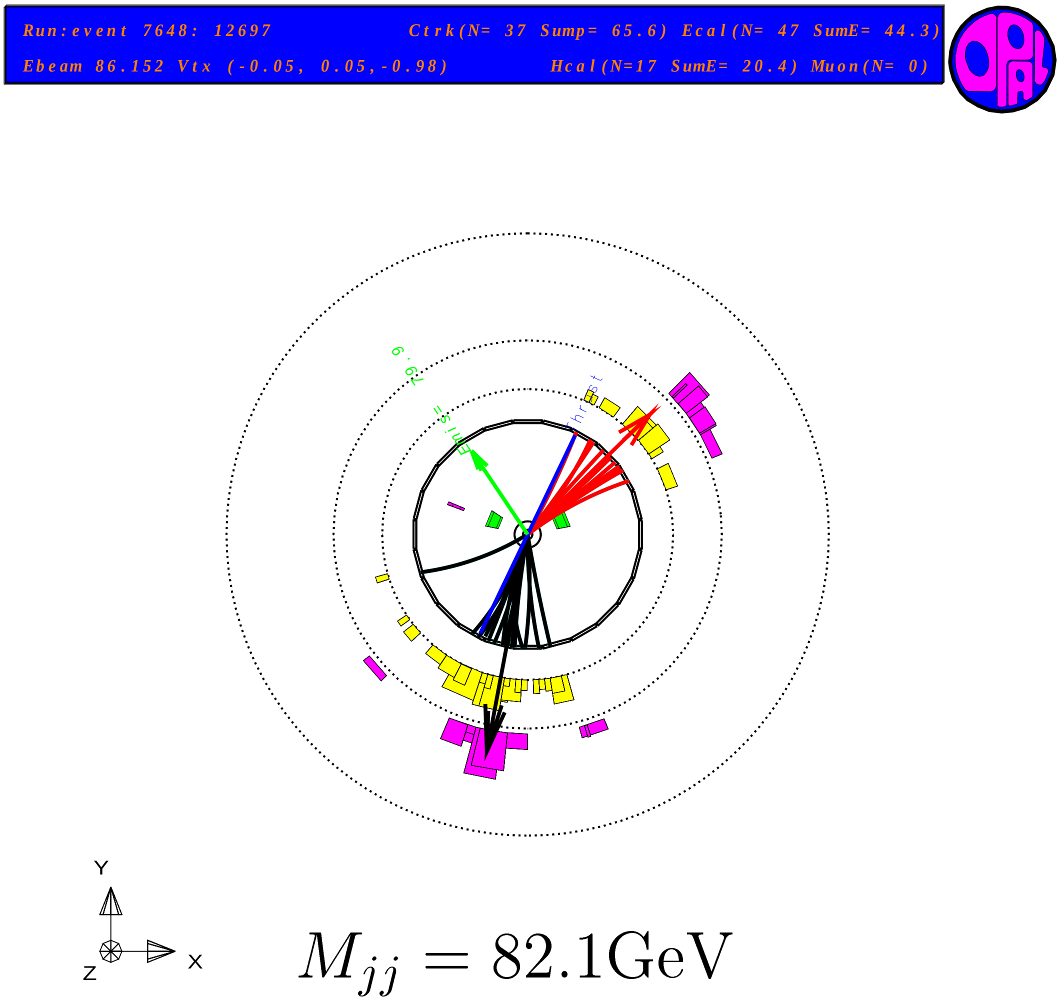
- 4f final state: $\mathrm{e}^-\bar{\nu}_\mathrm{e}\mathrm{f}\bar{\mathrm{f}}'$
- Define signal phase-space region where (a) dominates !
- e.g. L3:

$$
\begin{aligned}
|\cos\theta_{\mathrm{e}^-}| &> 0.997 \\
\min(\mathrm{E_f}, \mathrm{E}_{\bar{\mathrm{f}}'}) &> 15\ \mathrm{GeV} \\
|\cos\theta_{\mathrm{e}^+}| &< 0.75, \quad \text{for } \mathrm{e}^-\bar{\nu}_\mathrm{e}\mathrm{e}^+\nu_\mathrm{e}
\end{aligned}
$$

$\mathrm{e}^-\bar{\nu}_\mathrm{e}\mathrm{W}^+ \rightarrow \mathrm{e}^-\bar{\nu}_\mathrm{e}(\mathrm{q}\bar{\mathrm{q}})$

- 2 acoplanar jets
  - ➢ large transverse missing momentum
- main background sources:

  $\mathrm{q}\bar{\mathrm{q}}$, two-photon, other 4 fermion
- "nothing" in forward detector



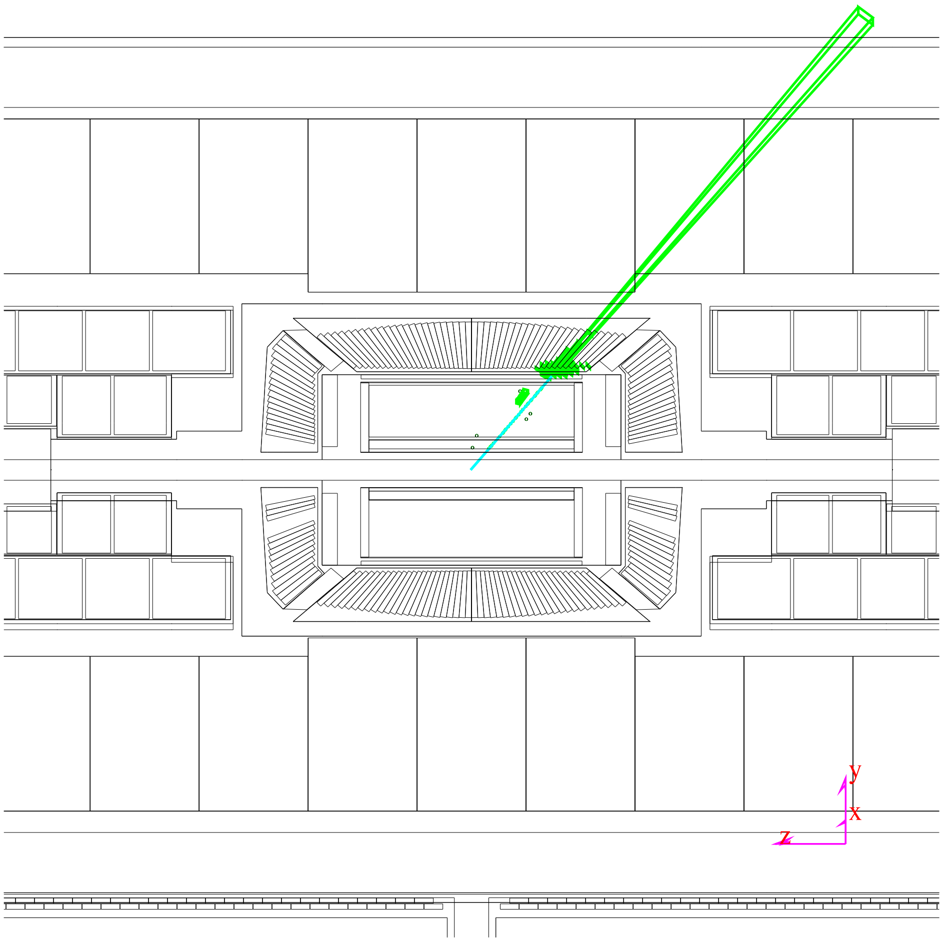
$$M_{jj} = 82.1\mathrm{GeV}$$

$e^- \bar{\nu}_e W^+ \to e^- \bar{\nu}_e (\ell^+ \nu_\ell)$

- 1 isolated energetic lepton, "nothing" else
- main background sources:

  $\ell^+\ell^-(\gamma)$, two-photon, other 4 fermion
- "nothing" in forward detector

L3 **Run # 660201 Event # 5876** $E_{e^-} = 40.5$ GeV



comb.	$e^-\bar{\nu}_e q\bar{q}$ L3	$e^-\bar{\nu}_e q\bar{q}$ OPAL	$e^-\bar{\nu}_e \ell^+\bar{\nu}_\ell$ L3	$e^-\bar{\nu}_e \ell^+\bar{\nu}_\ell$ OPAL
N^{data}	10	4	2	2
N^{sig}_{exp}	2	1.3	1	0.8
N^{bgd}_{exp}	6.2	1.1	0.5	1.2
ϵ^{sig}	41%	37%	53%	50%

161 GeV, 172 GeV combined

➢ Limits on photonic TGC (SM: $\lambda_\gamma = 0$, $\kappa_\gamma = 1$)

(more in A.Webers talk on TGC)

L3

$$-3.6 \quad < \quad \lambda_\gamma \quad < \quad 3.6$$

$$-2.6 \quad < \quad \kappa_\gamma \quad < \quad 2.5$$

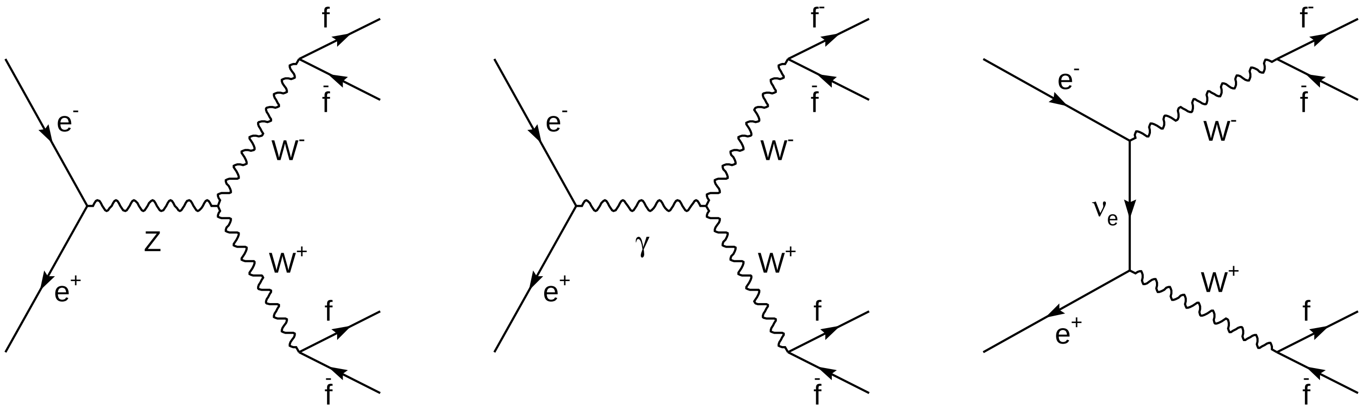
OPAL preliminary

$$3.1 \quad < \quad \lambda_\gamma \quad < \quad 3.1$$

$$2.6 \quad < \quad \kappa_\gamma \quad < \quad 2.6$$

WW cross section and BRs

WW production, lowest order: "CC03"



Interference with other 4f diagrams contributing to same final state !

- use CC03 Monte Carlo for efficiencies
- compare CC03 Monte Carlo
  with complete 4f Monte Carlo:

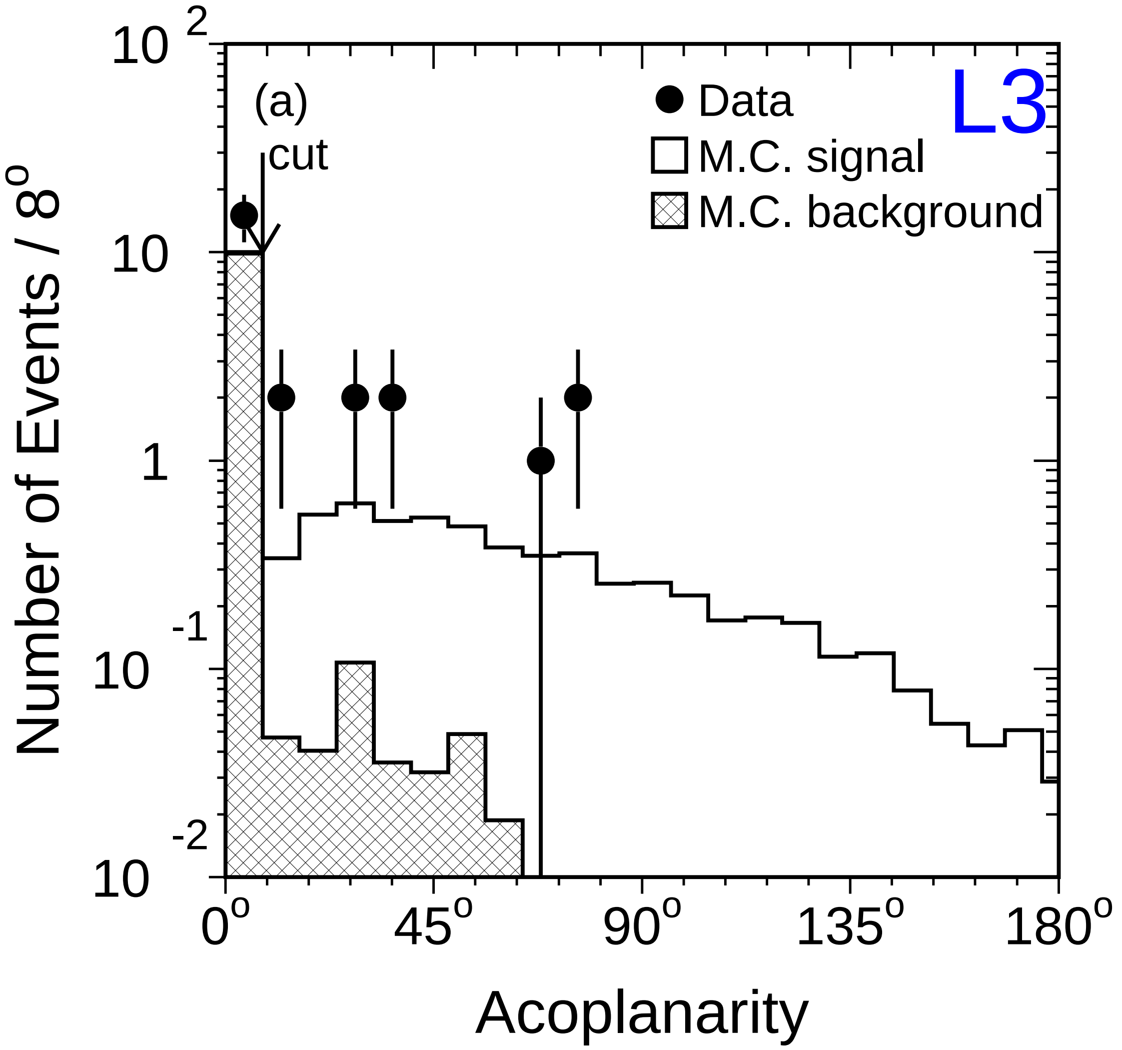
$$\epsilon^{\rm 4f}_{\rm MC} \cdot \sigma^{\rm 4f}_{\rm MC} / \epsilon^{\rm CC03} \quad \text{vs.} \quad \sigma^{\rm CC03}_{\rm MC}$$

- Correct measured cross section

$\ell^- \overline{\nu}_\ell \ell^+ \nu_\ell \quad \approx 11\%$

2 acoplanar, energetic leptons

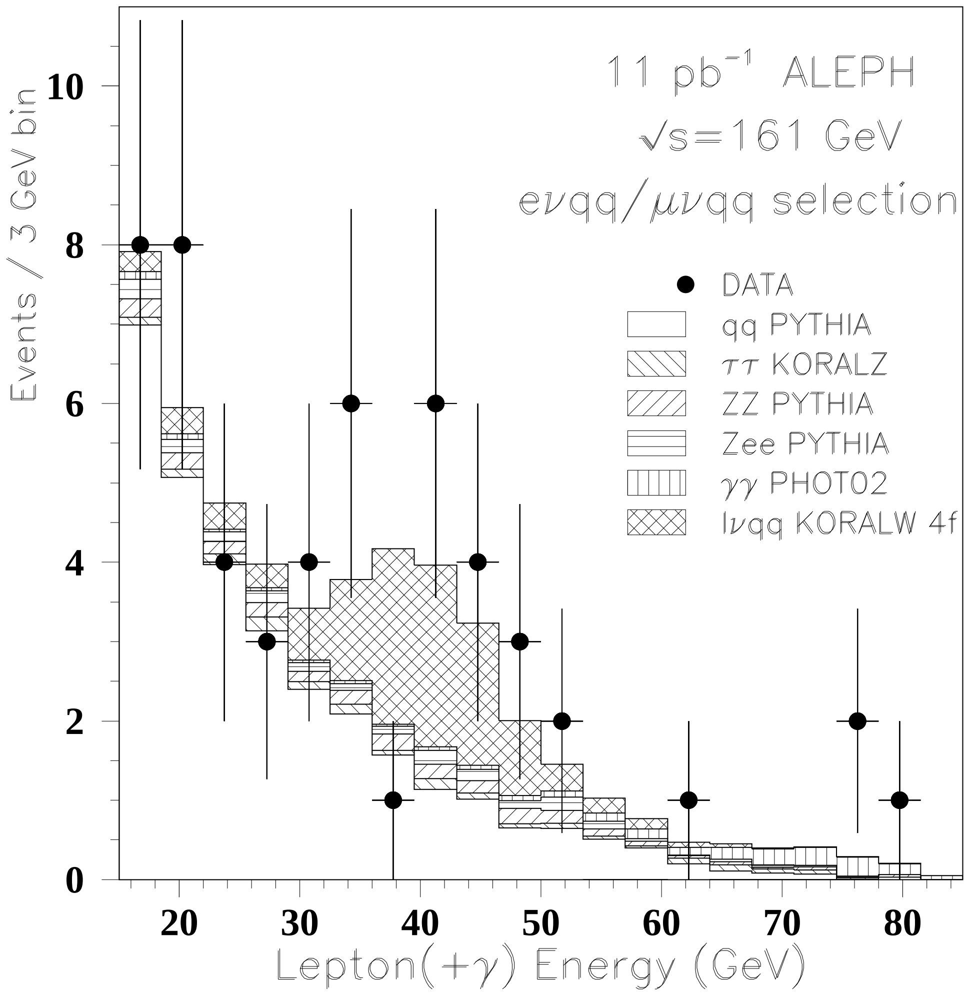
missing momentum not along the beam pipe



$q\bar{q}\ell\overline{\nu}_\ell \quad \approx 44\%$

2 well-separated jets

1 energetic, isolated lepton



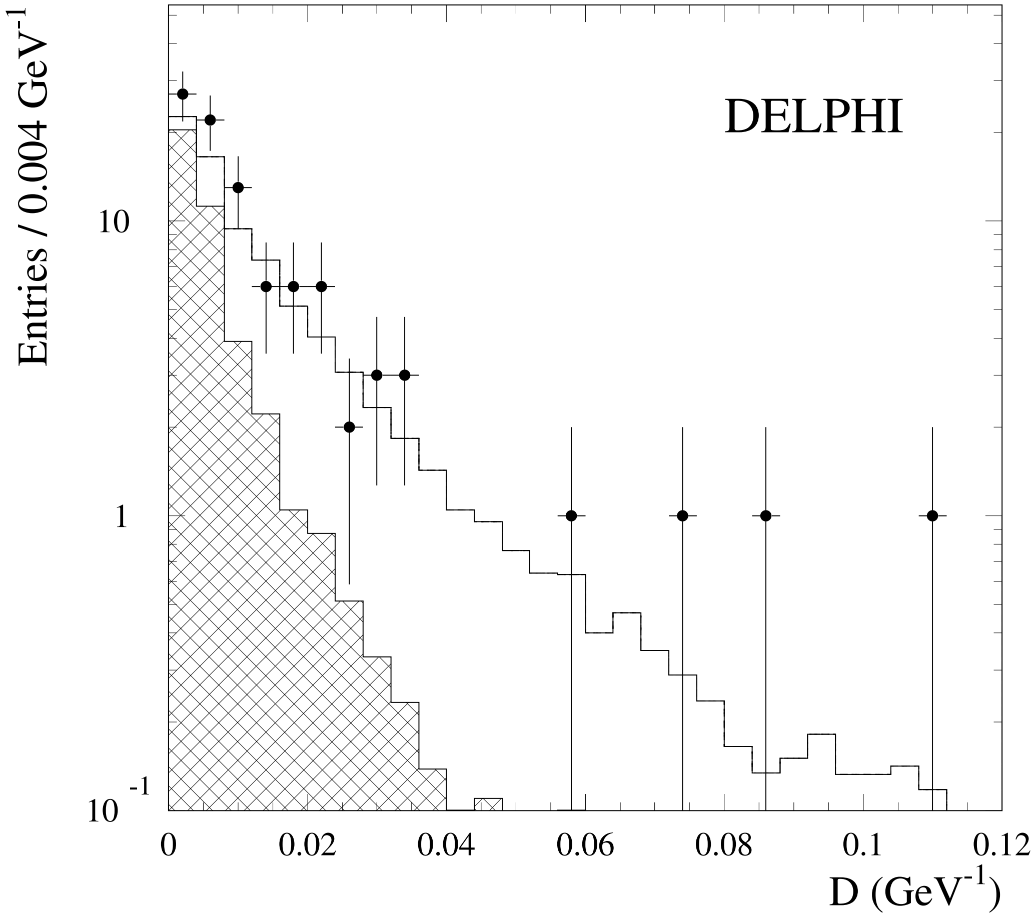
$q\bar{q}q\bar{q}$ $\approx 46\%$

4 jets of similar energies

large $q\bar{q}$ bgd (dominantly 2 or 3-jet like)

e.g. Delphi:

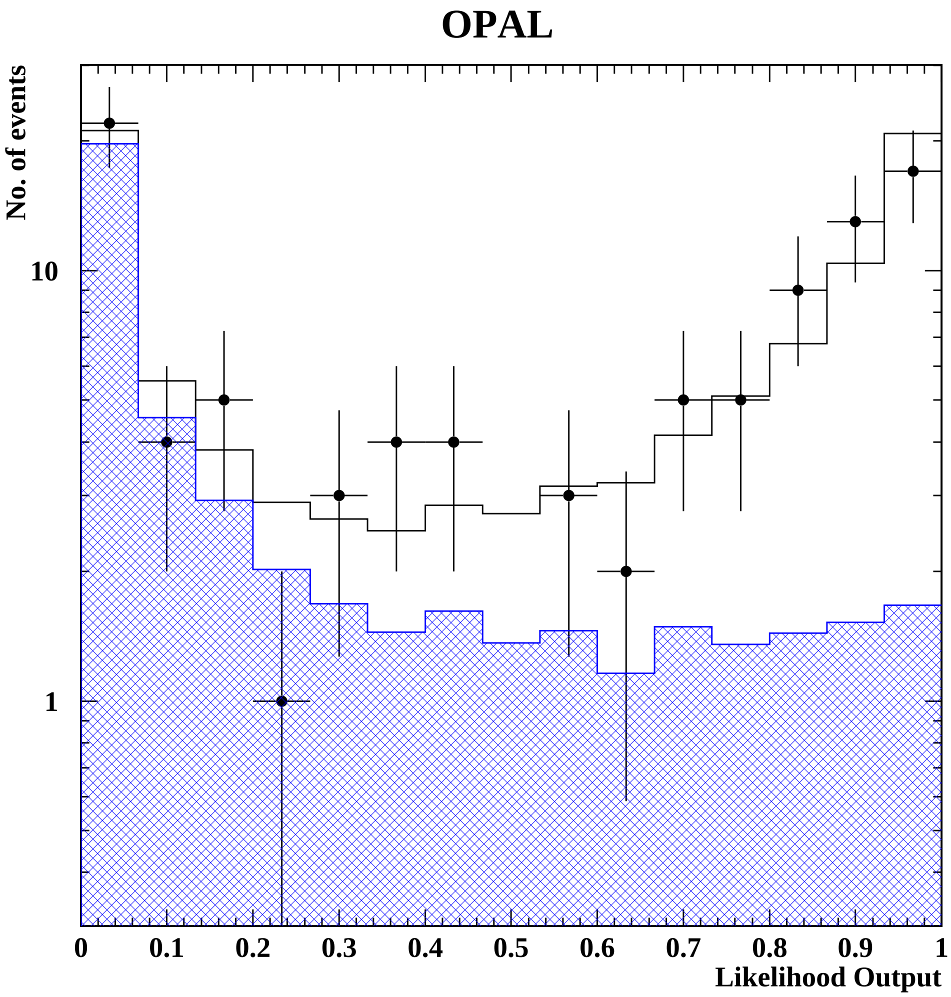
$$D = \frac{E_{min}}{E_{max}} \cdot \frac{\theta_{min}}{(E_{min} - E_{max})}$$



Sizeable background in $q\bar{q}q\bar{q}$ channel

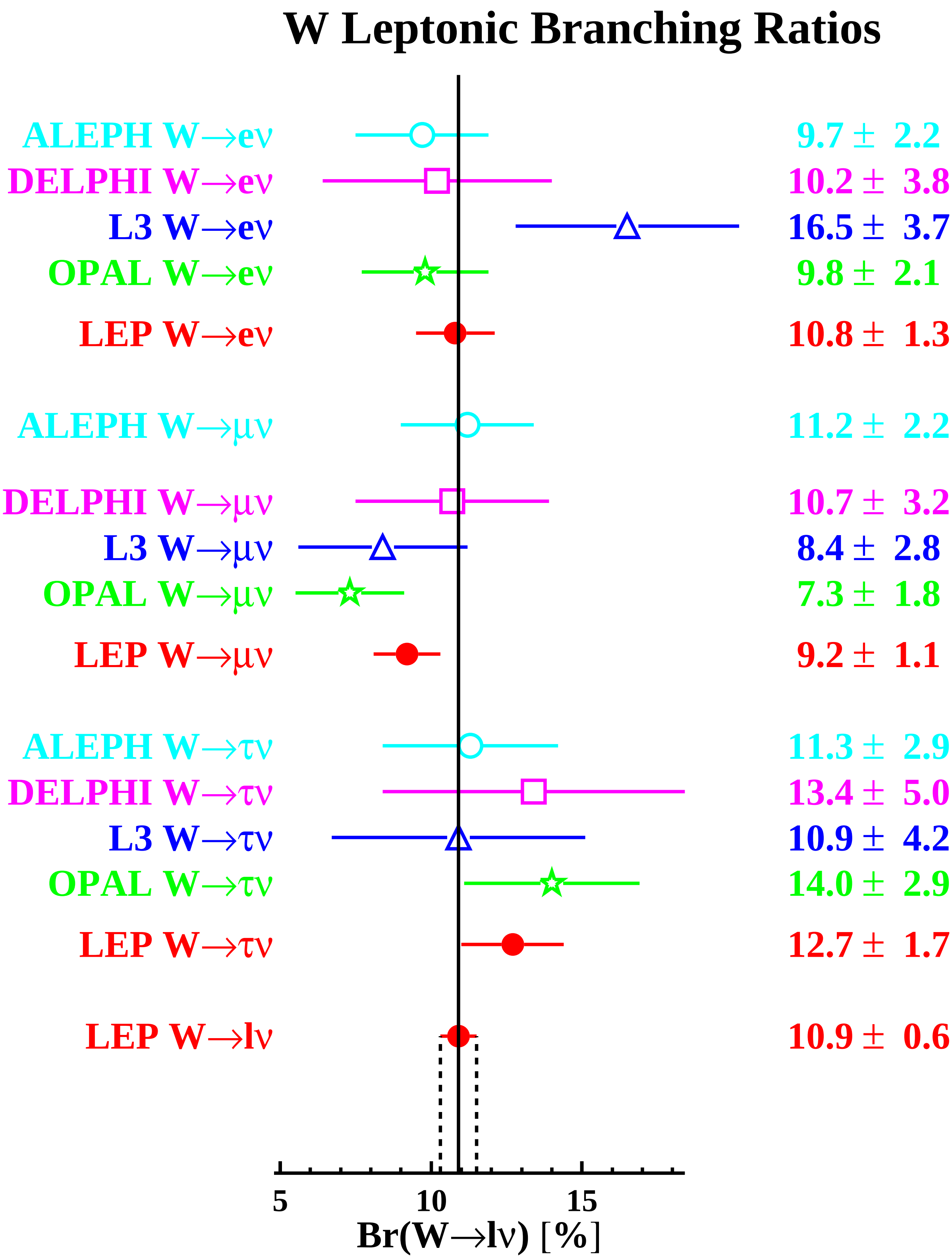
$\rightarrow$ extract N^{sig} from

- fit to
  DELPHI: D distribution
  L3: neural network output distribution
- assignement of signal weights to events using:
  ALEPH: multidimensional analysis
  OPAL: likelihood output

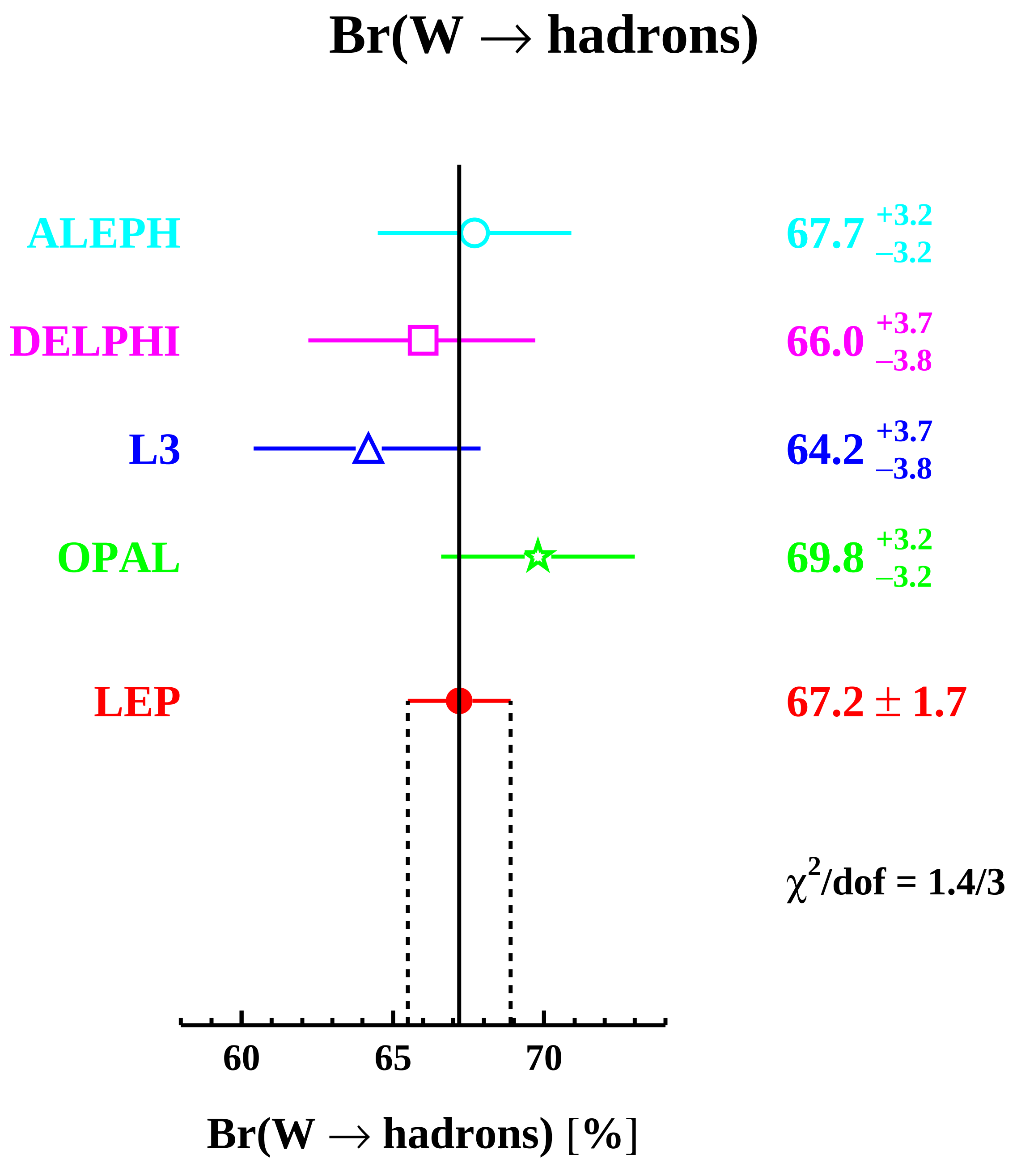


(this transparency was handwritten and nicer - but practically untexable.)

$$\mathrm{N}^{\mathrm{i}}_{\mathrm{obs}} = \mathrm{N}^{\mathrm{i}}_{\mathrm{bgd}} + \mathcal{L} \cdot \sigma_{\mathrm{WW}} \cdot \epsilon_{\mathrm{ij}} \cdot (\mathrm{Br}^{\mathrm{i}} \cdot \mathrm{Br}^{\mathrm{j}} \cdot (2 - \delta_{\mathrm{ij}}))$$



W Leptonic Branching Ratios
ALEPH W→eν
9.7 ± 2.2
DELPHI W→eν
10.2 ± 3.8
L3 W→eν
16.5 ± 3.7
OPAL W→eν
9.8 ± 2.1
LEP W→eν
10.8 ± 1.3
ALEPH W→μν
11.2 ± 2.2
DELPHI W→μν
10.7 ± 3.2
L3 W→μν
8.4 ± 2.8
OPAL W→μν
7.3 ± 1.8
LEP W→μν
9.2 ± 1.1
ALEPH W→τν
11.3 ± 2.9
DELPHI W→τν
13.4 ± 5.0
L3 W→τν
10.9 ± 4.2
OPAL W→τν
14.0 ± 2.9
LEP W→τν
12.7 ± 1.7
LEP W→lν
10.9 ± 0.6
5
10
15
Br(W→lν) [%]



Br(W → hadrons)
ALEPH
DELPHI
L3
OPAL
LEP
67.7 +3.2 −3.2
66.0 +3.7 −3.8
64.2 +3.7 −3.8
69.8 +3.2 −3.2
67.2 ± 1.7
χ²/dof = 1.4/3
60
65
70
Br(W → hadrons) [%]

Test of Unitarity

In SM and (some) possible extensions:

$$\frac{Br(\mathrm{W} \to \mathrm{q\bar{q}})}{1 - Br(\mathrm{W} \to \mathrm{q\bar{q}})} = (1 + \frac{\alpha_s}{\pi}) \sum_{i=\mathrm{u,c};\, j=\mathrm{d,s,b}} |\mathrm{V_{ij}}|^2$$

From LEP combined Br($\mathrm{W} \to \mathrm{q\bar{q}}$):

$$\sum_{i=\mathrm{u,c};\, j=\mathrm{d,s,b}} |\mathrm{V_{ij}}|^2 \;=\; 1.97 \pm 0.15$$

c.f. 2.0 in SM

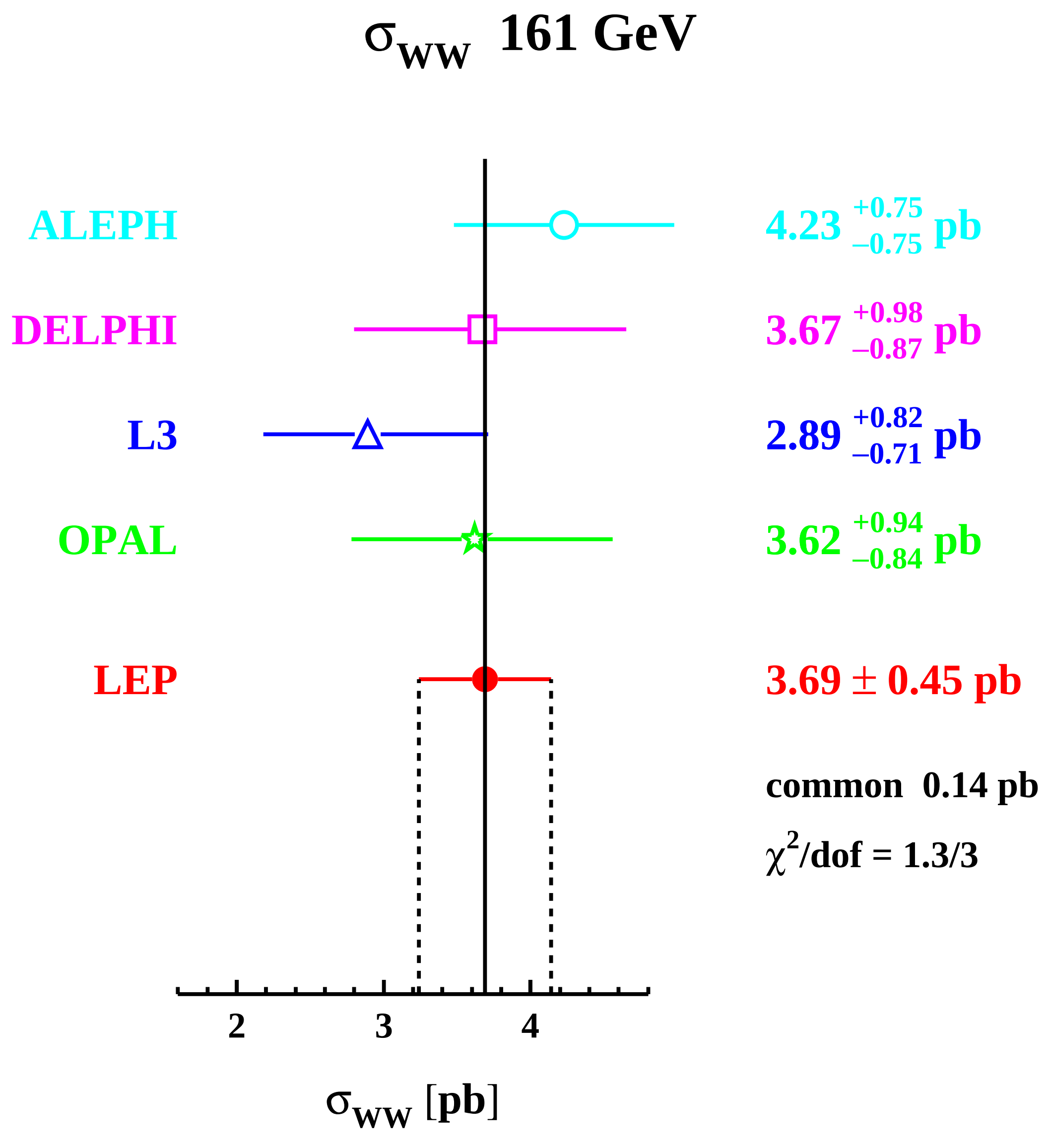
Using measured values of the other $|\mathrm{V_{ij}}|$

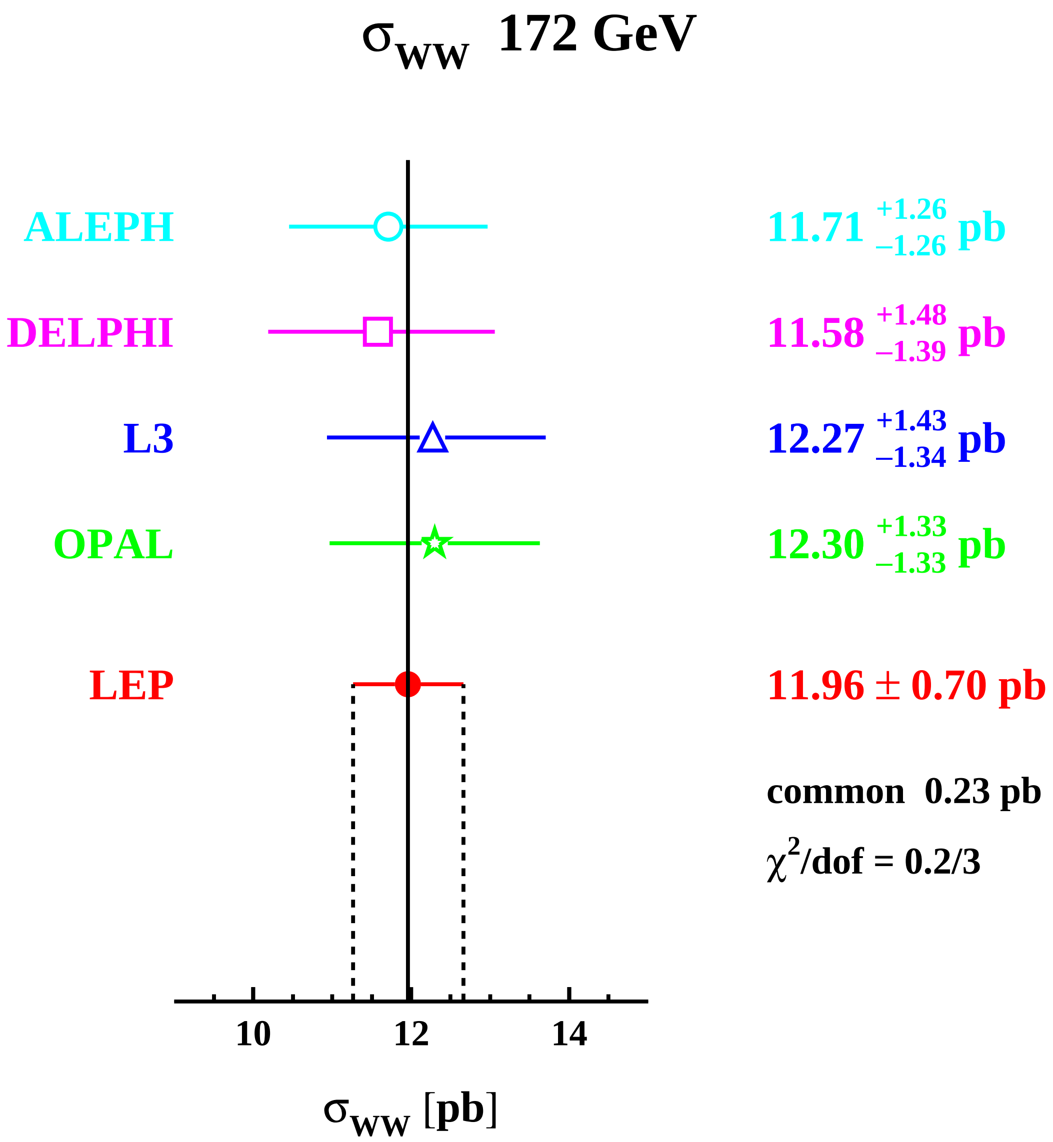
(w.o. assuming unitarity):

$$|\mathrm{V_{cs}}| \;=\; 0.96 \pm 0.08$$

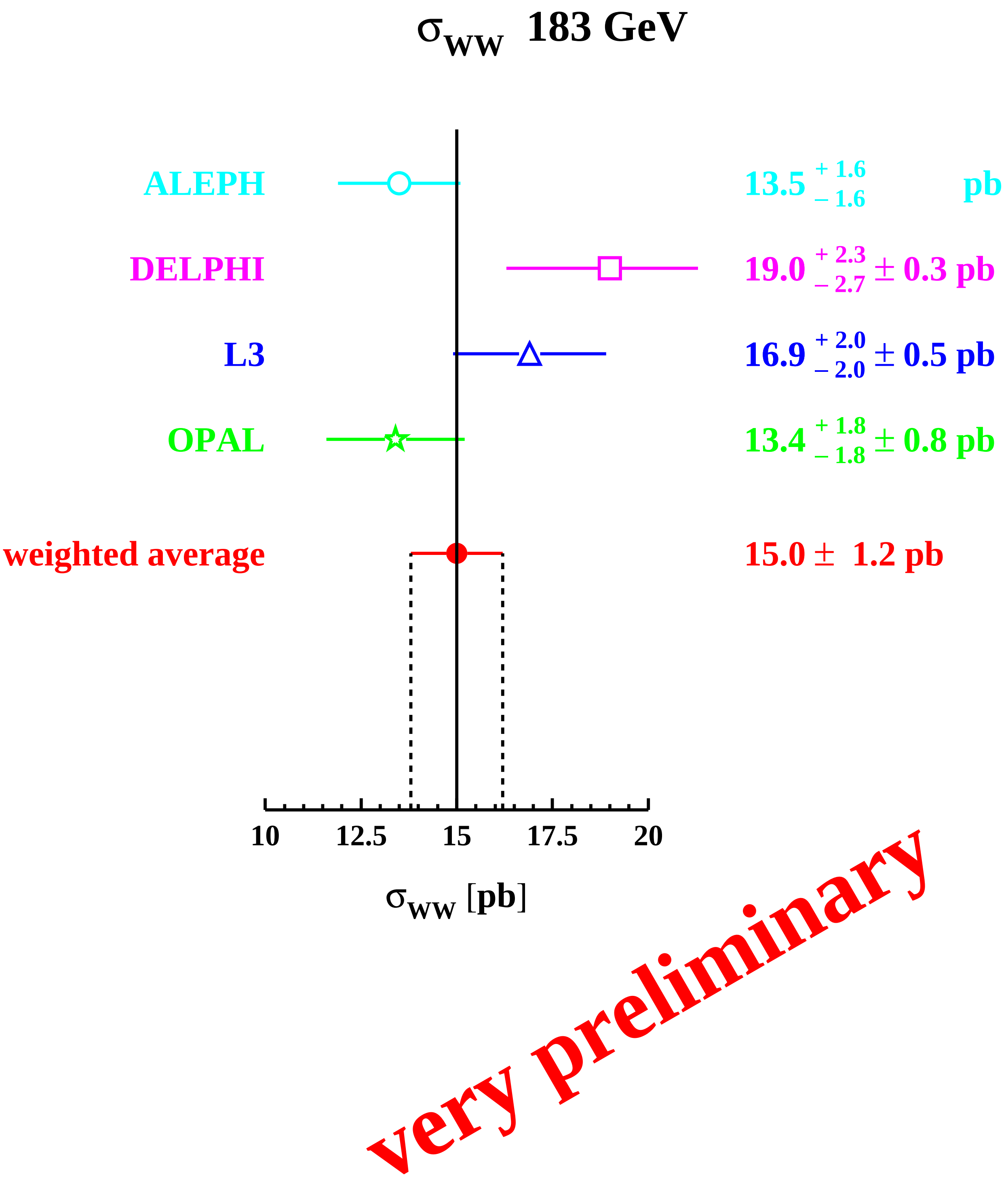
(c.f. from D decays: $|\mathrm{V_{cs}}| = 1.01 \pm 0.18$)

there are also direct determinations at LEP2
$\rightarrow$ P. Perez talk

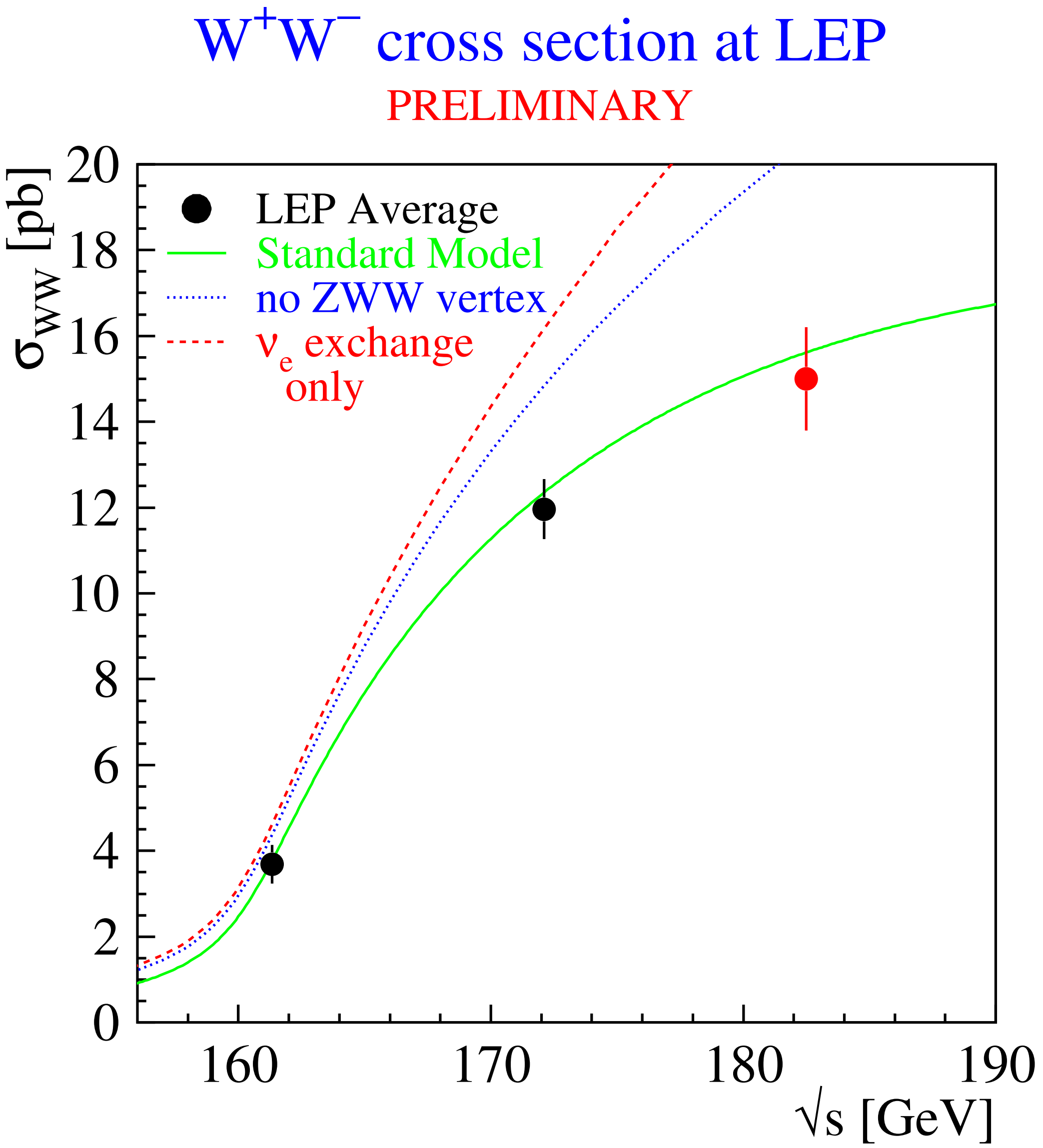

σ_{WW} 161 GeV
ALEPH
DELPHI
L3
OPAL
LEP
$4.23^{+0.75}_{-0.75}$ pb
$3.67^{+0.98}_{-0.87}$ pb
$2.89^{+0.82}_{-0.71}$ pb
$3.62^{+0.94}_{-0.84}$ pb
3.69 ± 0.45 pb
common 0.14 pb
χ^2/dof = 1.3/3
2
3
4
σ_{WW} [pb]



σ_{WW} 172 GeV
ALEPH
DELPHI
L3
OPAL
LEP
$11.71\ ^{+1.26}_{-1.26}$ pb
$11.58\ ^{+1.48}_{-1.39}$ pb
$12.27\ ^{+1.43}_{-1.34}$ pb
$12.30\ ^{+1.33}_{-1.33}$ pb
11.96 ± 0.70 pb
common 0.23 pb
χ^2/dof = 0.2/3
10
12
14
σ_{WW} [pb]



σWW 183 GeV
ALEPH
DELPHI
L3
OPAL
weighted average
13.5 +1.6 −1.6 pb
19.0 +2.3 −2.7 ± 0.3 pb
16.9 +2.0 −2.0 ± 0.5 pb
13.4 +1.8 −1.8 ± 0.8 pb
15.0 ± 1.2 pb
10
12.5
15
17.5
20
σWW [pb]
very preliminary



- clear evidence for (ZWW) TGC
- from sensitivity to M_{W} at 161 GeV (LEP combined):

$$M_{\mathrm{W}} = 80.40 \pm 0.22 \ \mathrm{GeV}$$

(to be combined with results from direct reconstruction
$\rightarrow$ D. Fassouliotis talk)

Summary

Neutral Cuurent 4f: within expectations

Single W: seen

$\rightarrow$ limits on photonic TGC's

WW pairs:

σ_{WW}:

- nice rise with $\sqrt{s}$
- sensitive to M_{W} and TGC's

BR:

- within expectations
- test of unitarity of hadronic sector