$Q\bar{Q}$, $L\bar{L}$, WW, and ZZ Cross Sections at LEP

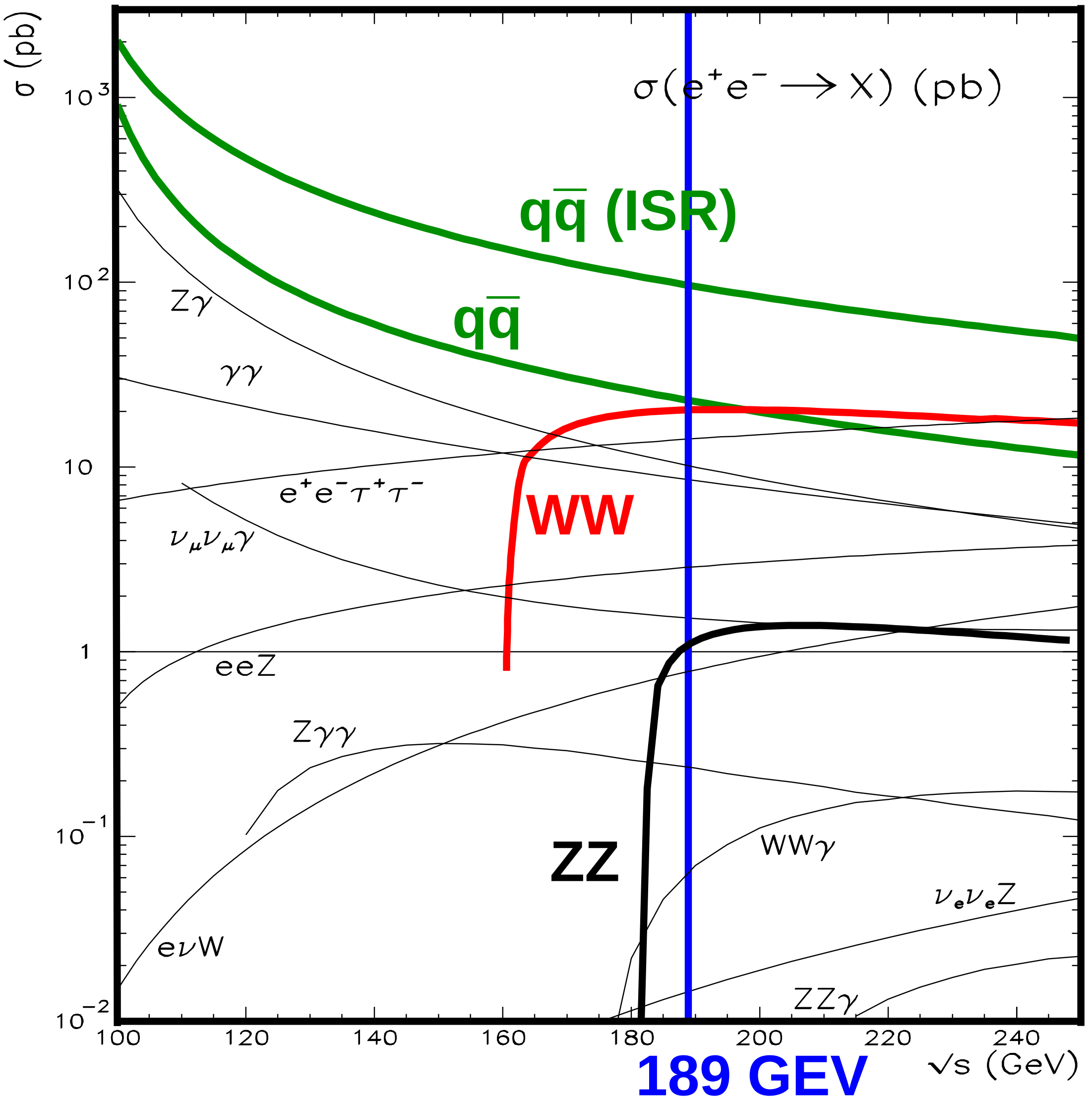
Yoshi Uchida — MIT

XXXIVth Rencontres de Moriond QCD
March 1999

- Introduction
- LEP Running
- Fermion Pair Production
- WW
- ZZ
- Conclusions

Most Results PRELIMINARY

Standard Model Cross Sections



(From Pre-LEP II CERN Report)

Significance of Cross Section Measurements

- Tests of Standard Model
- Understanding of Background for Other Processes
- Measurements of Standard Model Parameters
- New Physics Searches/Limits

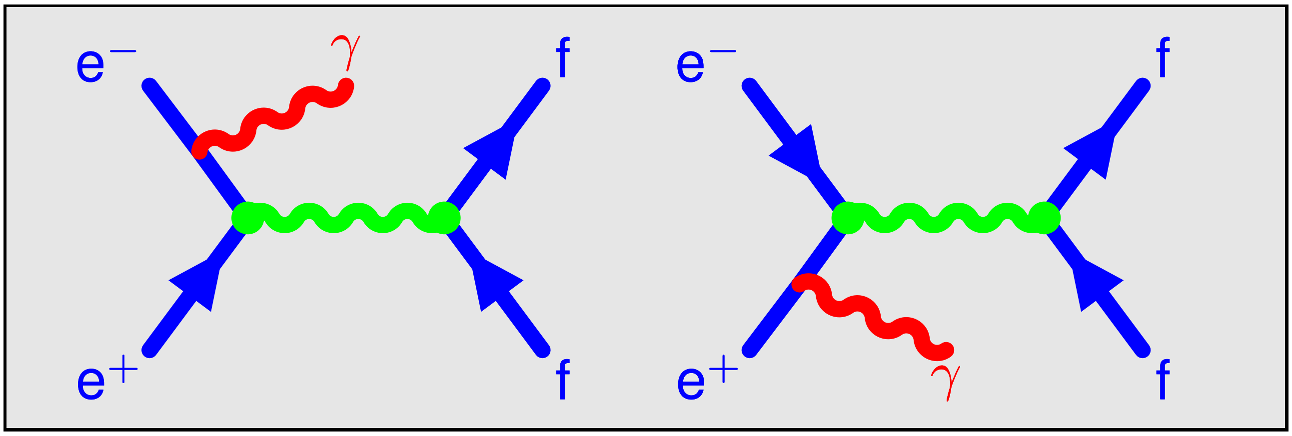
LEP High Energy Running

Year	C.M. Energy	†$\int\mathcal{L}dt$
1995	130–140 GeV	5 pb^{-1}
1996	161 GeV	11 pb^{-1}
	172 GeV	10 pb^{-1}
1997	183 GeV	55 pb^{-1}
	130, 136 GeV	7 pb^{-1}
1998	189 GeV	176 pb^{-1}
(1999)	192–196 (200) GeV	

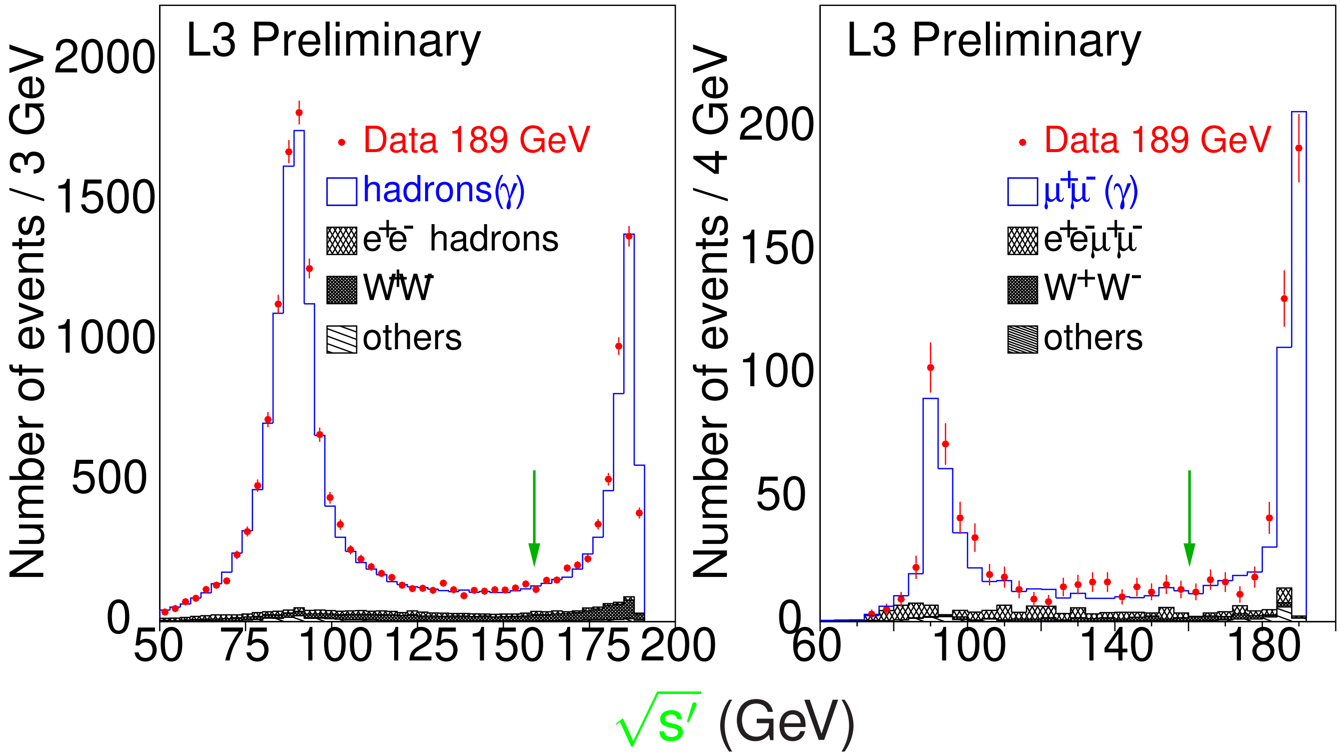
†Typical luminosity collected by experiments

Fermion Pair Production

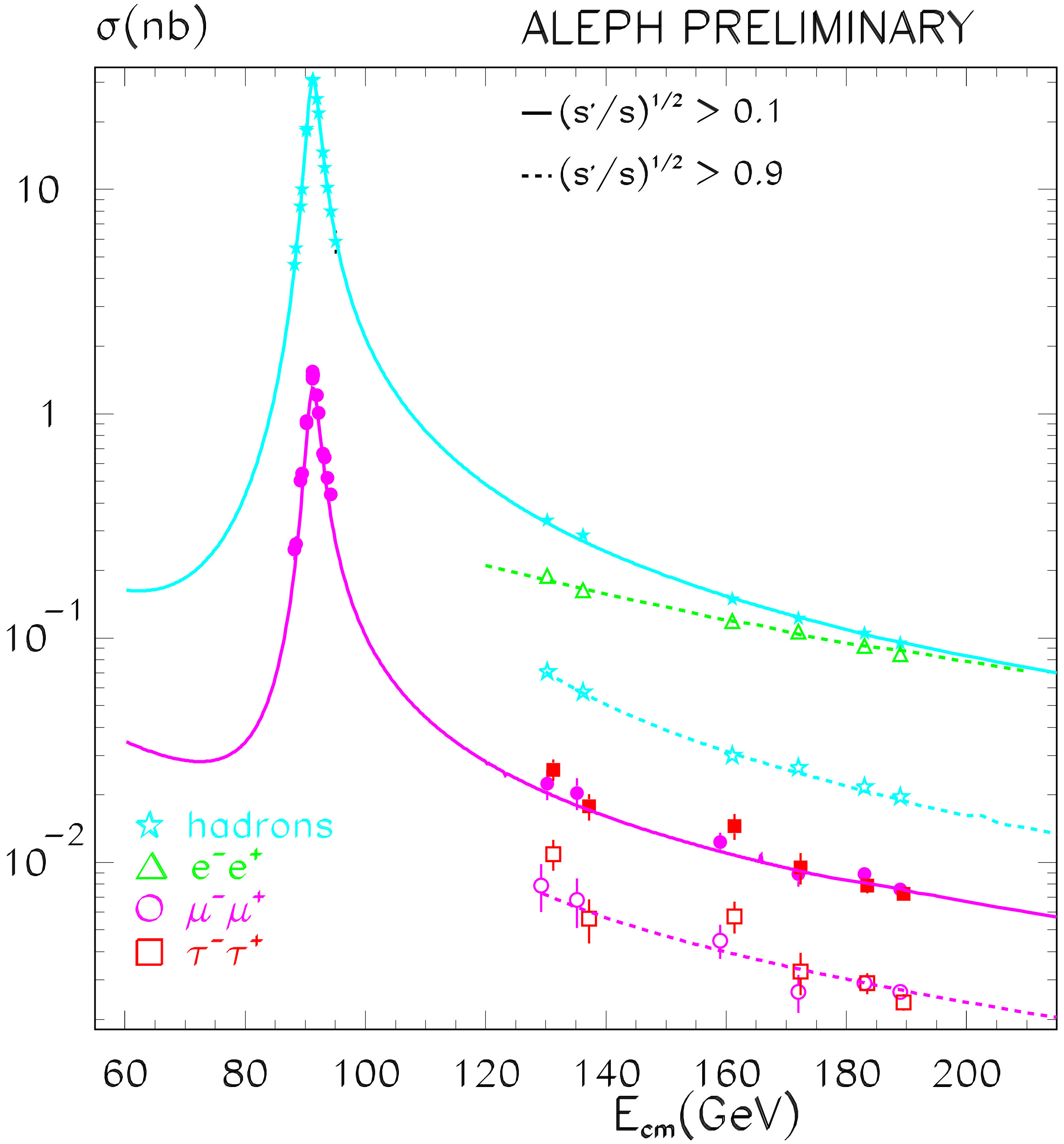
- Cut on Effective centre-of-mass "$\sqrt{s'}$"



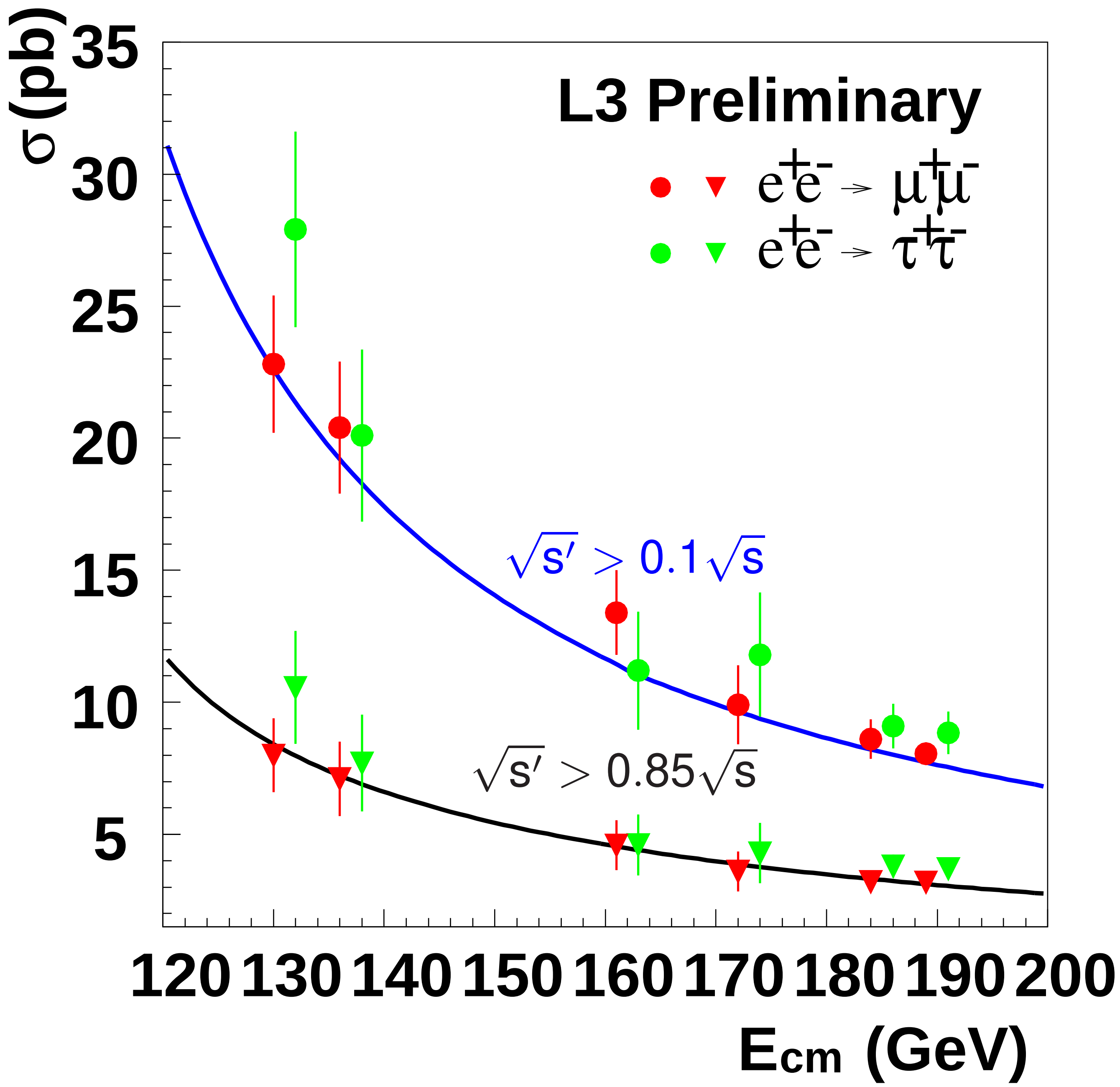
$\sqrt{s'}$: $f\bar{f}$ production centre-of-mass energy excluding initial state radiation



Fermion Pair Cross Section Results

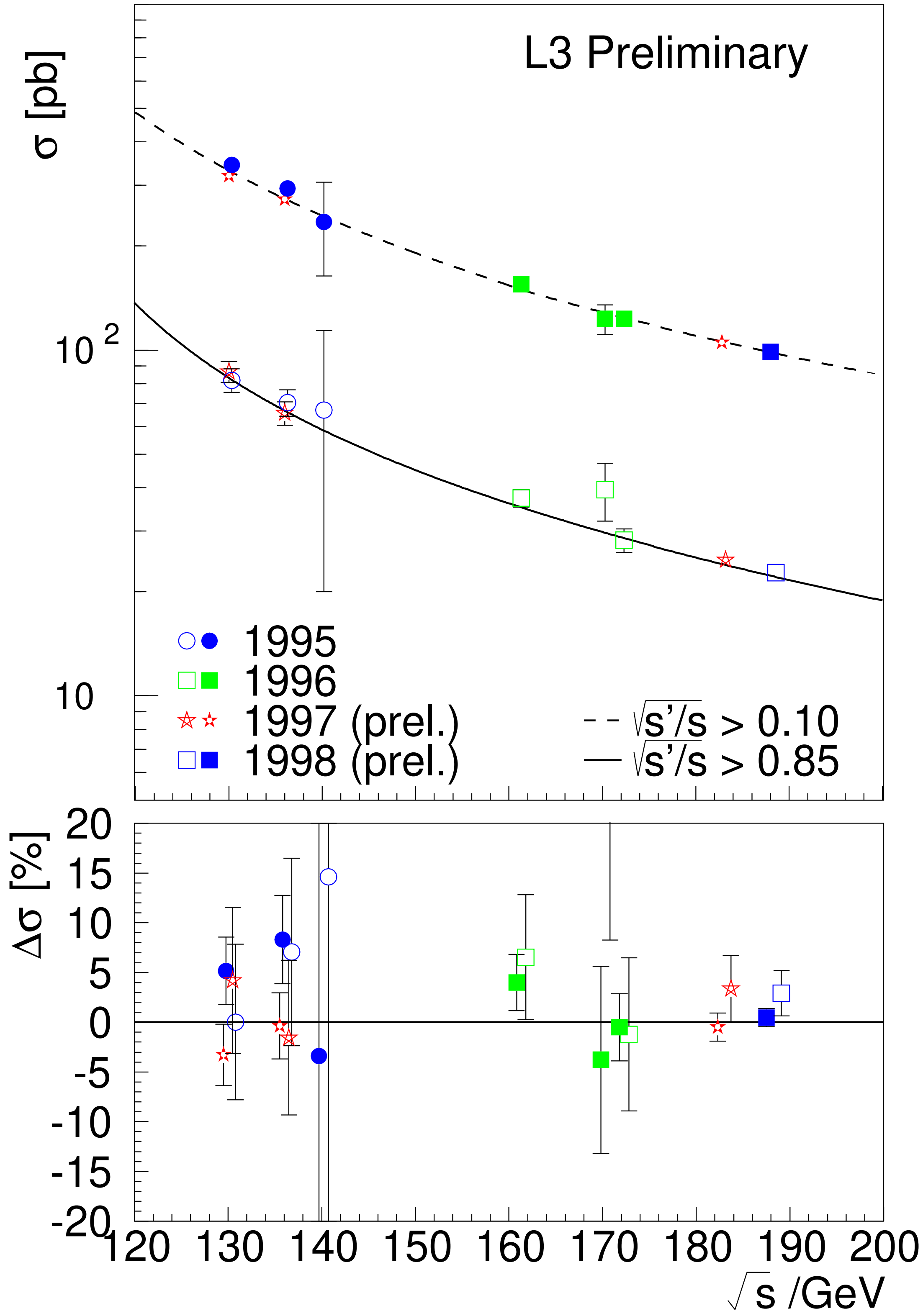


Fermion Pair Cross Section Results

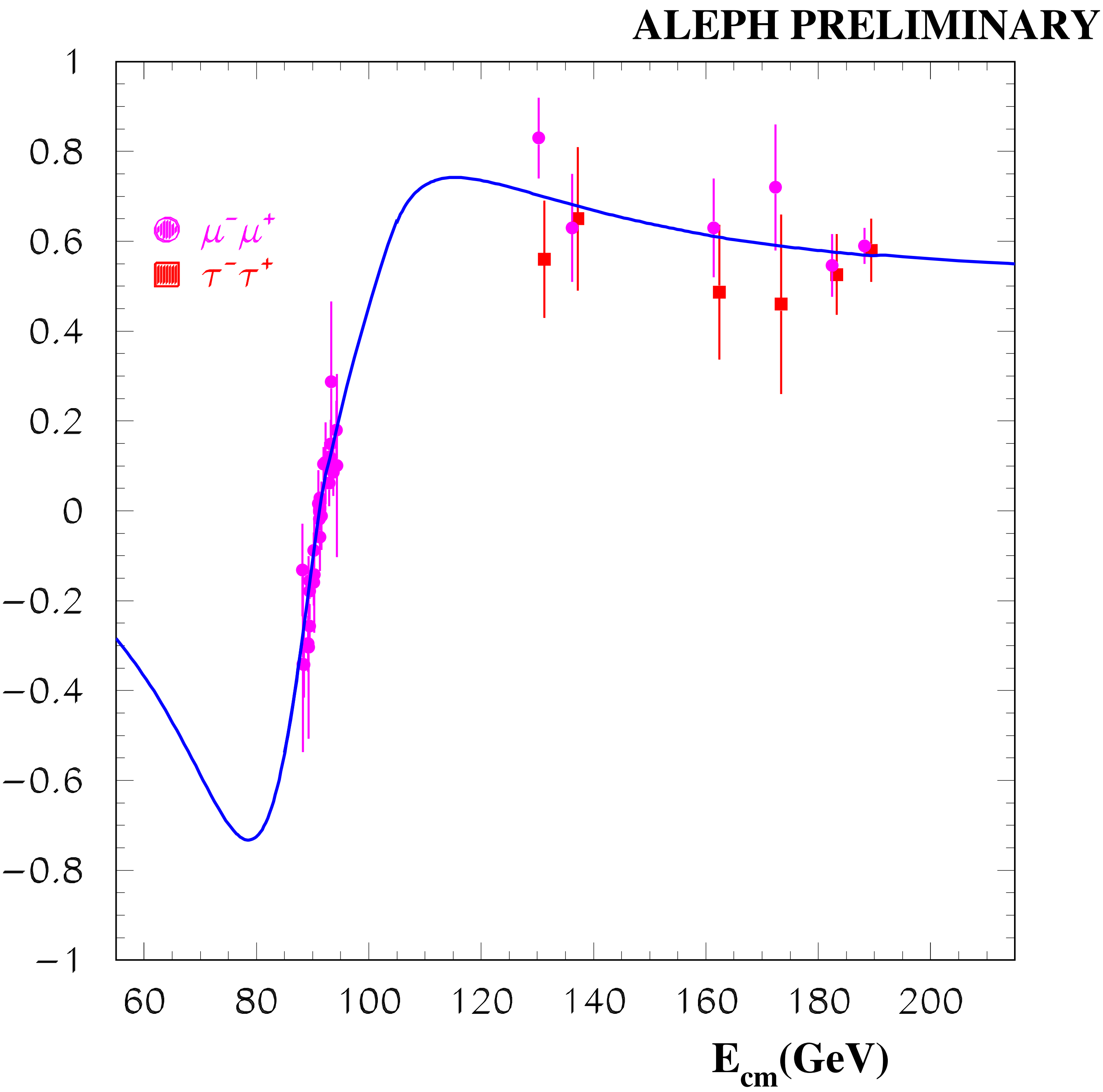


Fermion Pair Cross Section Results

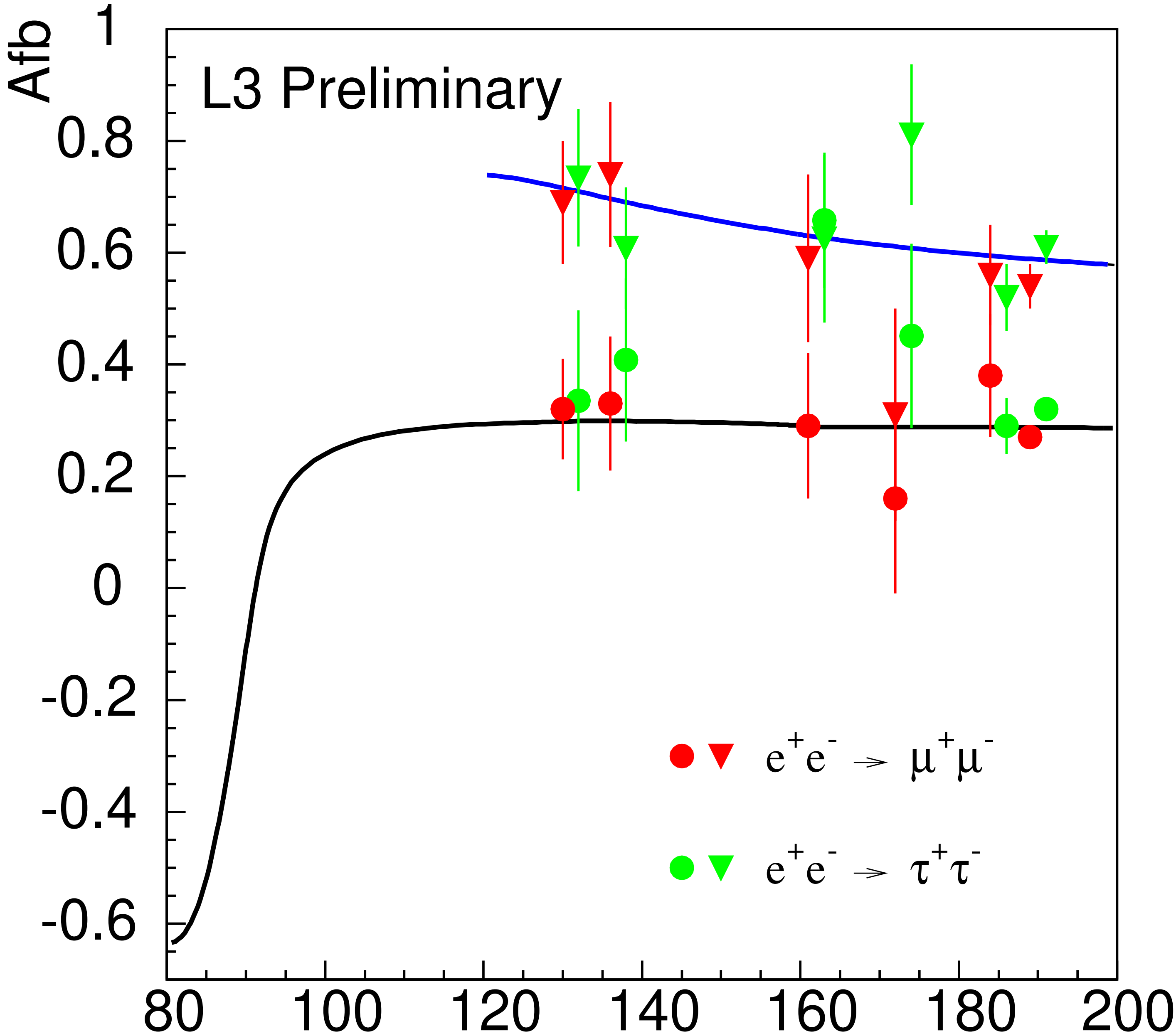
Hadronic Cross Sections above 130 GeV



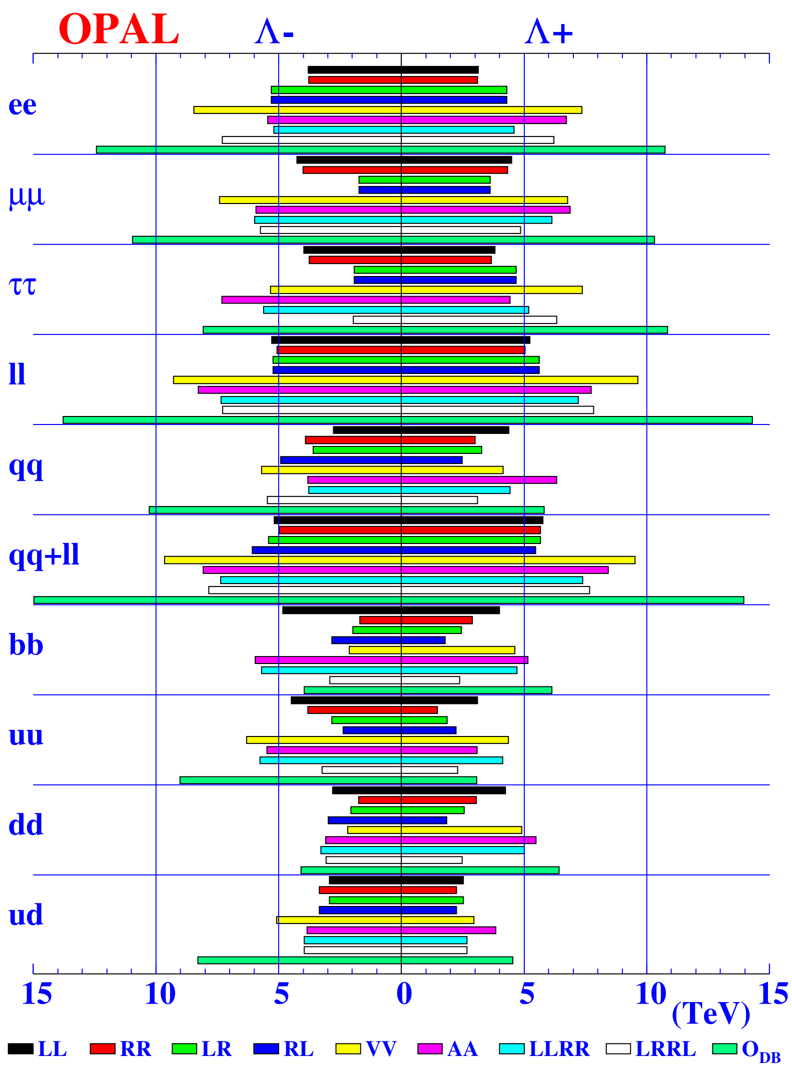
Fermion Pair Asymmetry Results



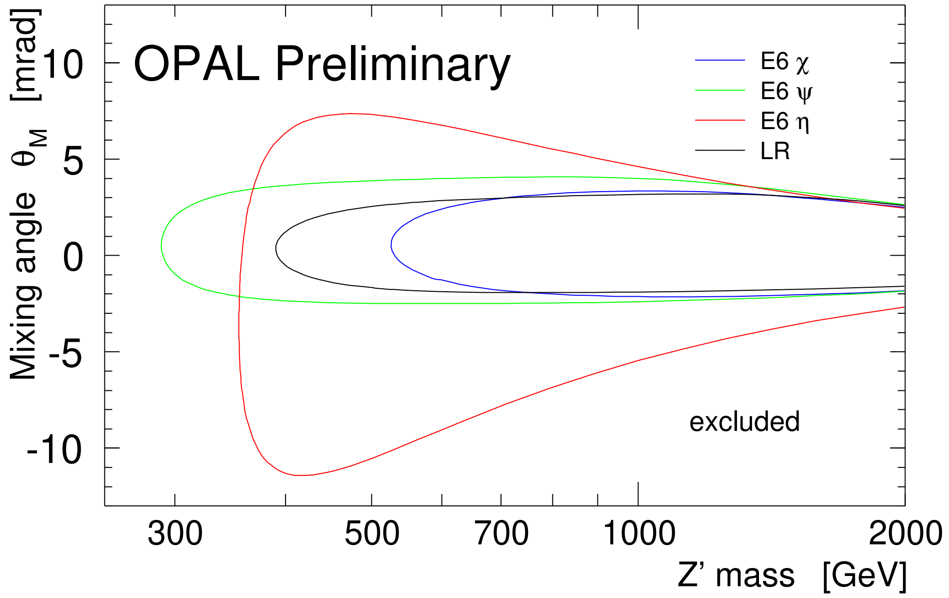
Fermion Pair Asymmetry Results



New Physics Limits



95%C.L. limits on energy scale Λ from contact interaction fits

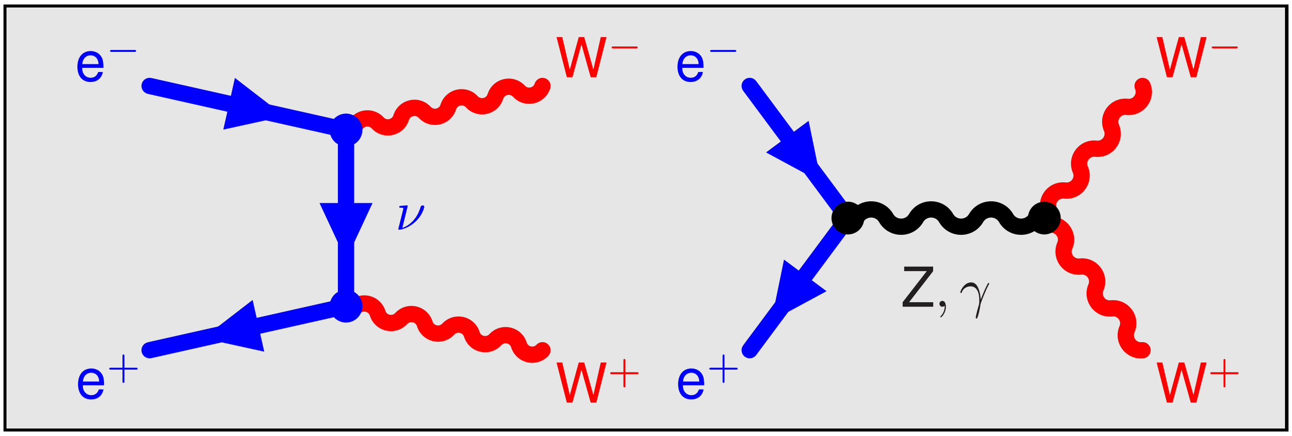


Z' Exclusion contours for four different models

W Boson Pair Production

- Subset of Four Fermion Production Processes
- $2 \times m_{\mathrm{W}}$ threshold crossed in 1996

CC03 Diagrams



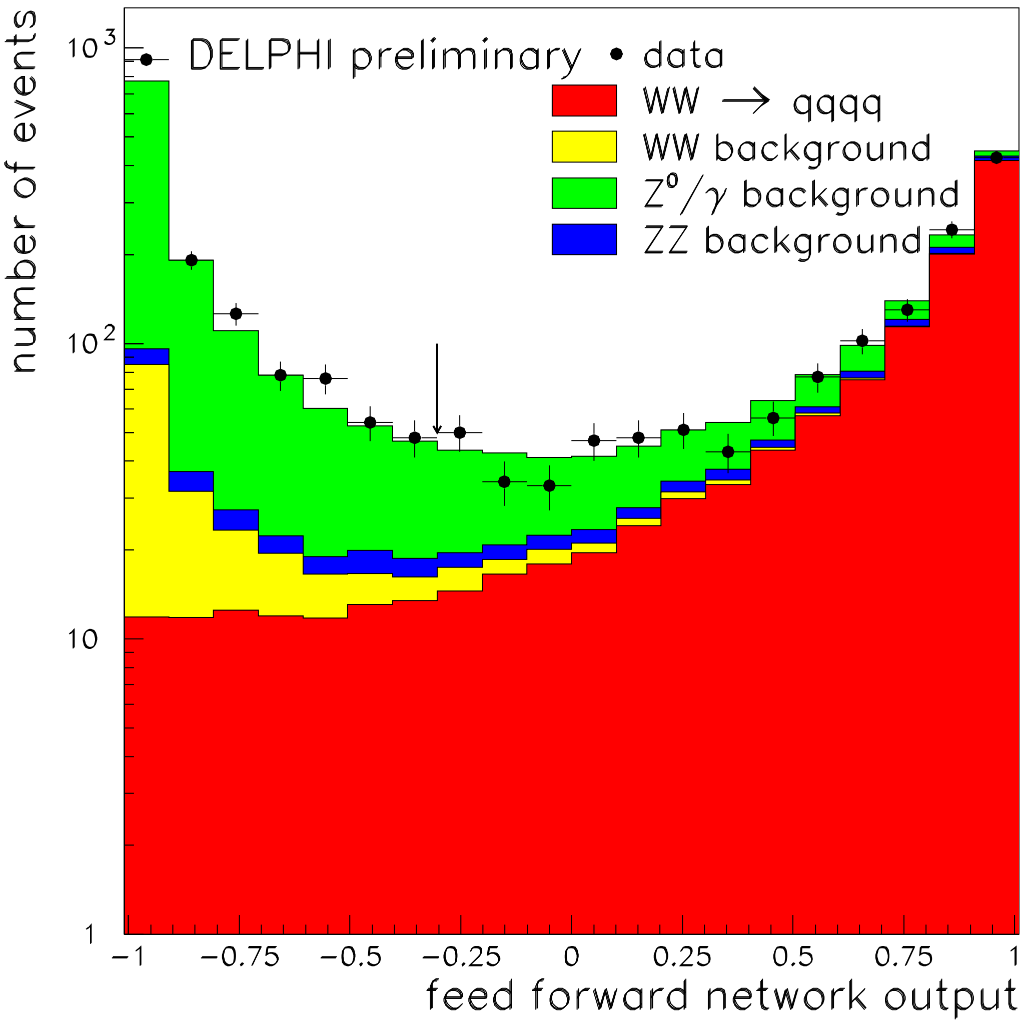
- W bosons decay into $q\bar{q}$, $l^{\pm}\nu$
- Event signatures: qqqq, qqlν, $l^{\pm}\nu l^{\mp}\nu$ ($l=e^{\pm}, \mu^{\pm}, \tau^{\pm}$)
- Many other non-double-resonant diagrams with identical four-fermion final states

Selection Results (OPAL, 189 GeV, 184 pb^{-1})

Channel	Eff.[%]	Pur. [%]	Expected	Obs.
$l^{\pm}\nu\, l^{\mp}\nu$	81.5±1.6	90.3	290.0±8.9	278
$q\bar{q}l^{\pm}\nu$	86.7±1.1	90.2	1287.2±29.5	1252
$q\bar{q}q\bar{q}$	86.3±0.8	79.4	1511.1±34.9	1546
Comb'd	86.5±0.6	85.4	3088.3±62.0	3076

→ Extract "CC03" Cross Sections for each channel

- $q\bar{q}q\bar{q}$: Fit on Neural Net/Likelihood distributions



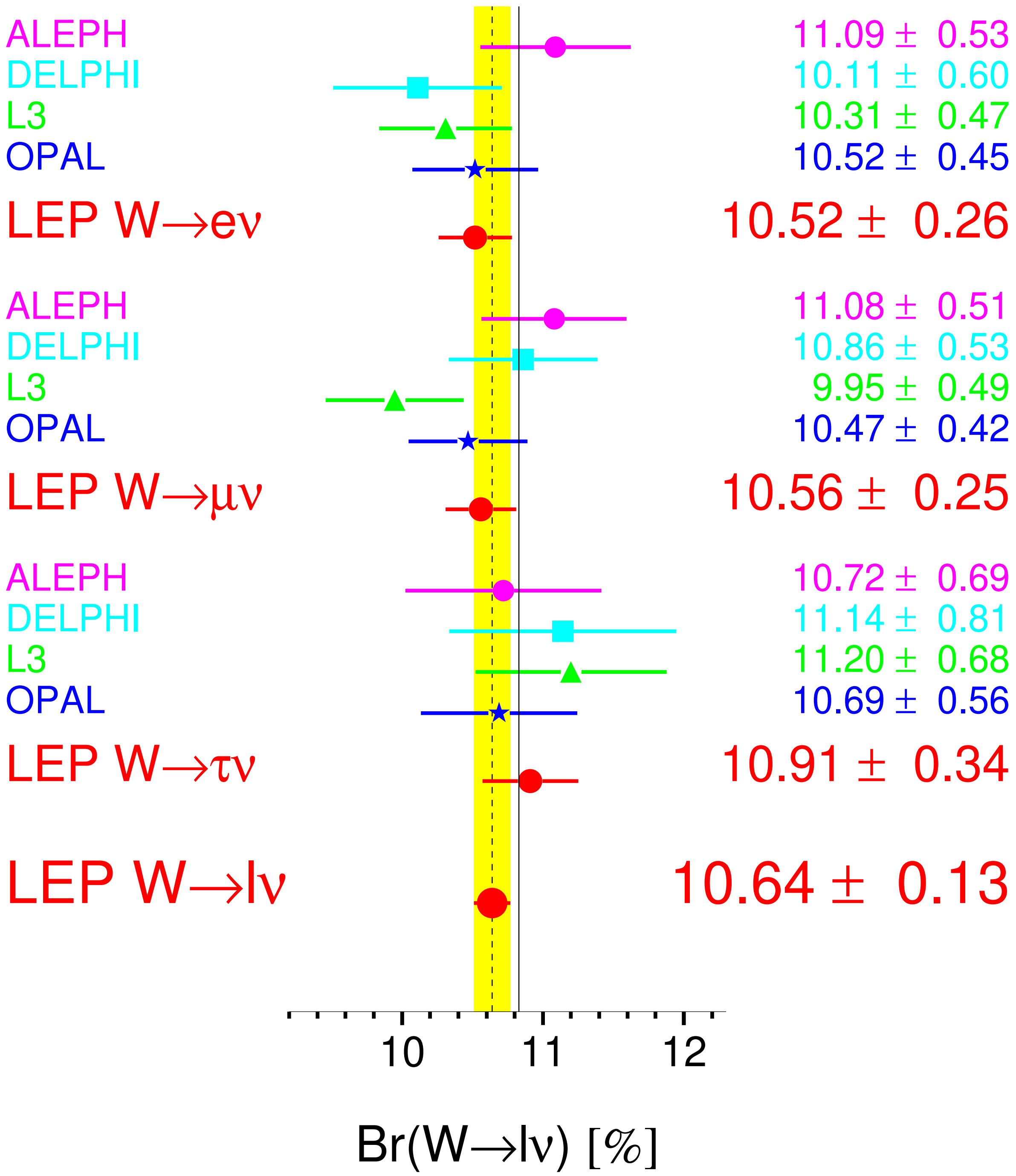
- non-$q\bar{q}q\bar{q}$: Event Counting

Branching Ratio Results

10/03/99

Moriond 99 - Preliminary - [161-189] GeV

W Leptonic Branching Ratios

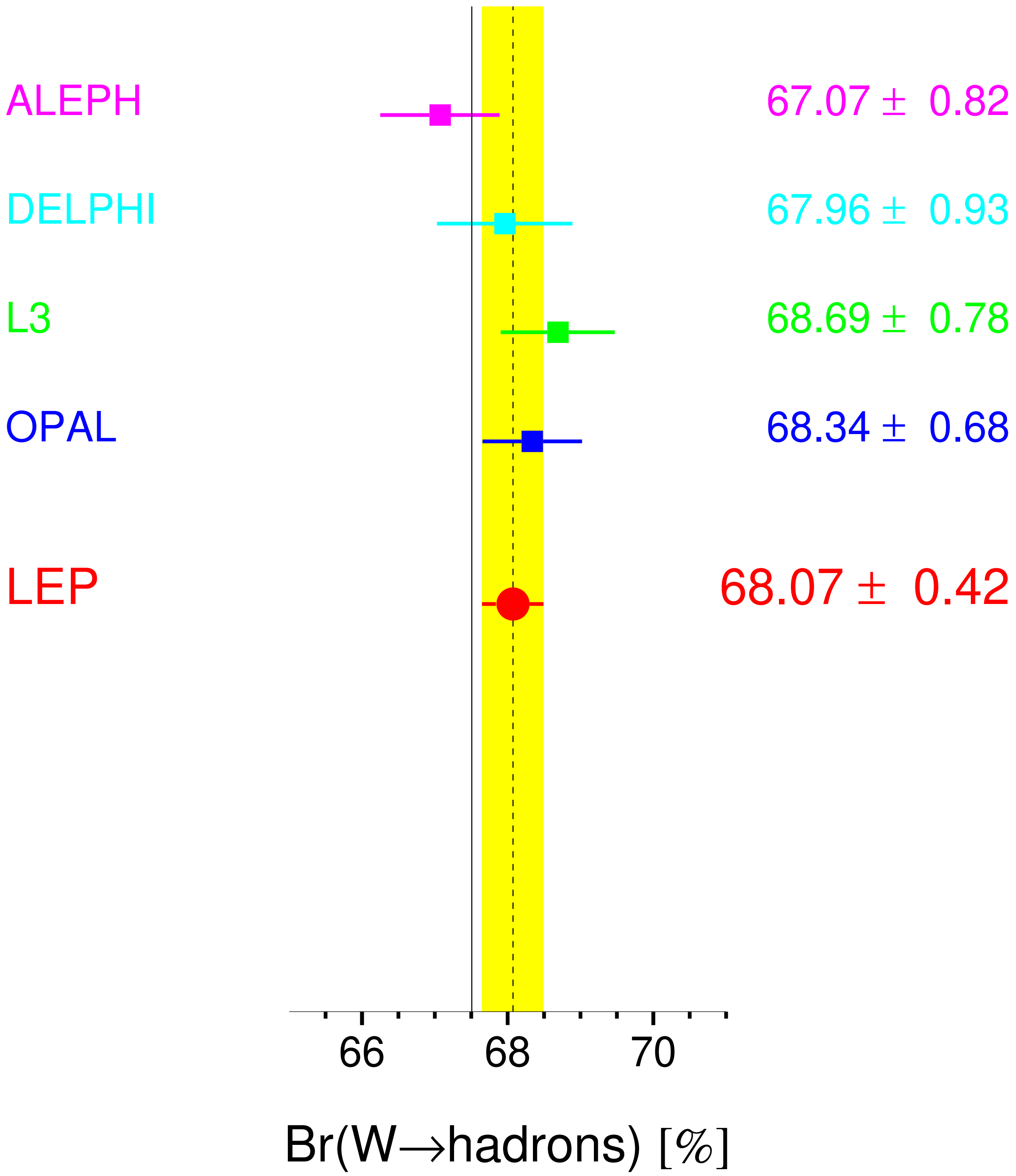


Branching Ratio Results

10/03/99

Moriond 99 - Preliminary - [161-189] GeV

Br(W→hadrons) [%]

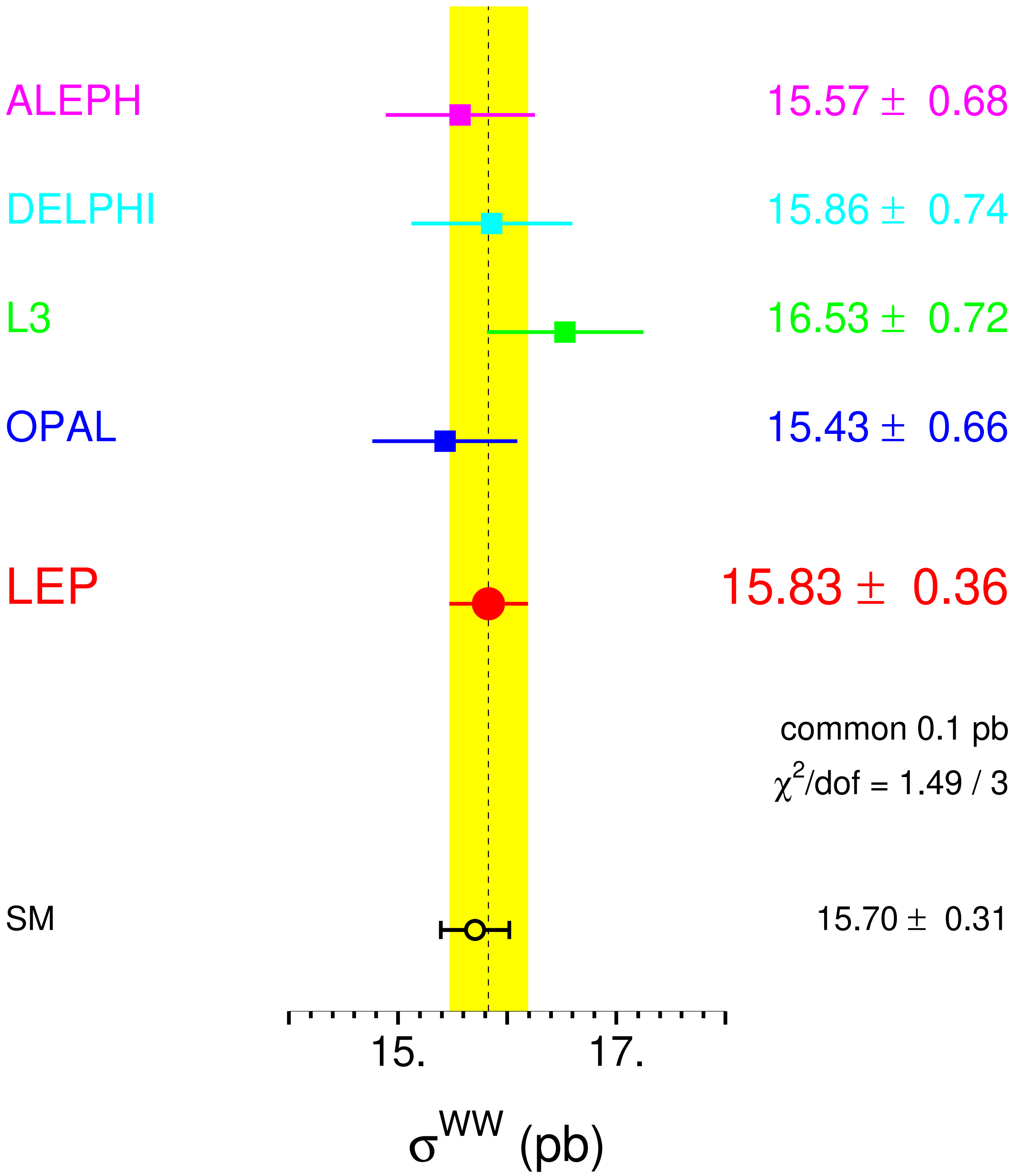


WW/CC03 Cross Section Results

10/03/99

Moriond 99 - Final - 183 GeV

σ^{WW} (pb)

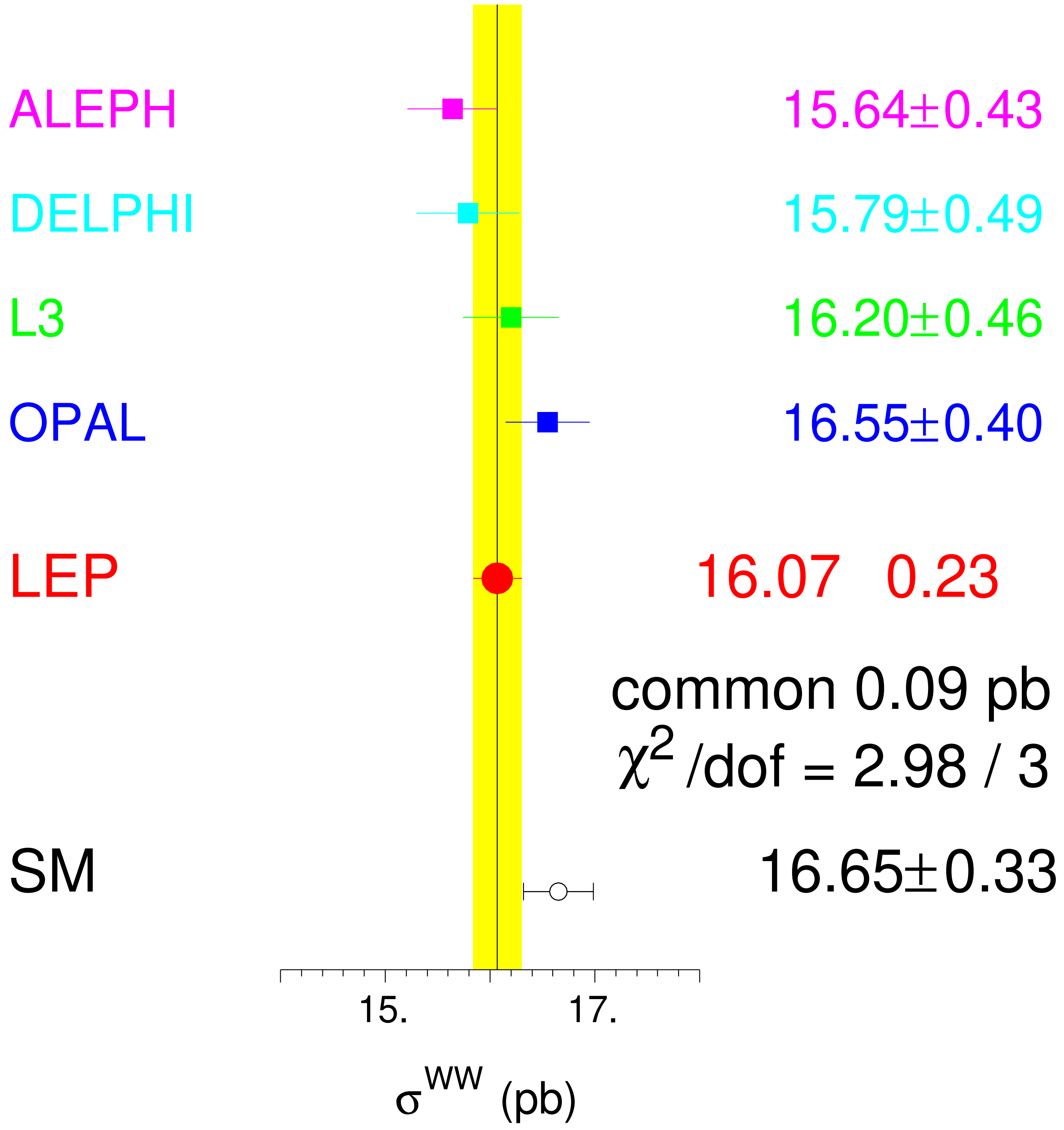


WW/CC03 Cross Section Results

10/03/99

Moriond 99 - Preliminary - 189 GeV

σ^{WW} (pb)

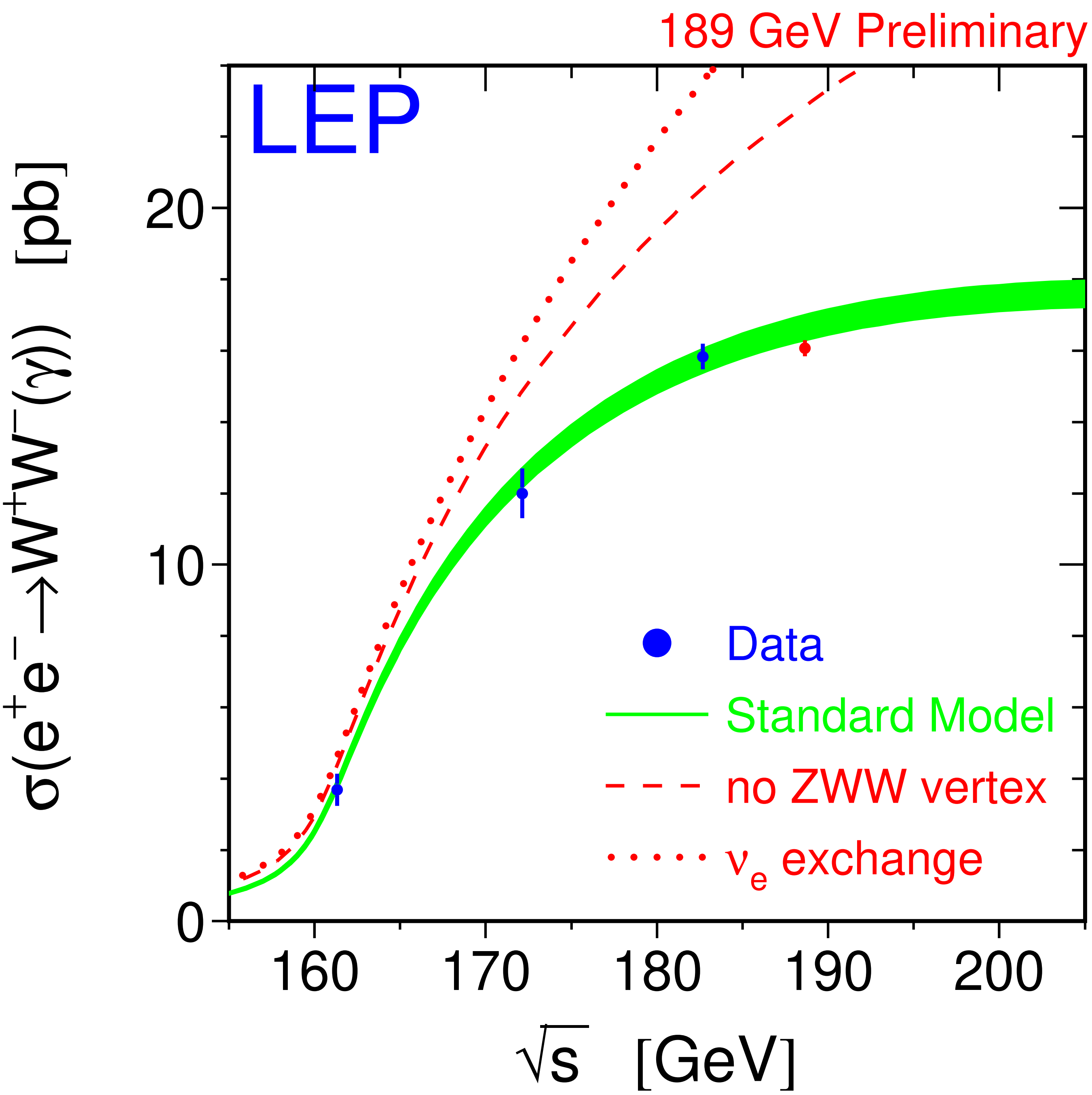


WW/CC03 Cross Section Results

	183 GeV
ALEPH	$15.57 \pm 0.62 \pm 0.29(0.09)$
DELPHI	$15.86 \pm 0.69 \pm 0.26(0.10)$
L3	$16.53 \pm 0.67 \pm 0.26(0.08)$
OPAL	$15.43 \pm 0.61 \pm 0.26(0.14)$
LEP	15.83 ± 0.36
SM	15.70 ± 0.31
	189 GeV
ALEPH	$15.64 \pm 0.34 \pm 0.26(0.07)$
DELPHI	$15.79 \pm 0.38 \pm 0.31(0.09)$
L3	$16.20 \pm 0.37 \pm 0.27(0.08)$
OPAL	$16.55 \pm 0.35 \pm 0.20(0.11)$
LEP	16.07 ± 0.23
SM	16.65 ± 0.33

- Cross sections in pb
- Correlated QCD contributions to systematic errors in brackets
- 183 GeVresults FINAL

WW/CC03 Cross Section
LEP Combined Results

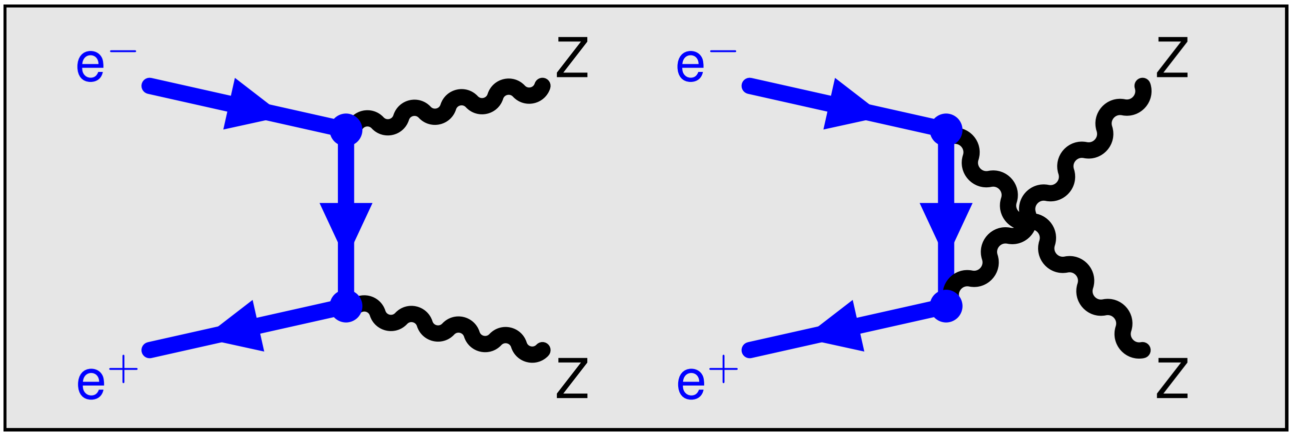


183 GeV LEP Result (Final)	15.83 ± 0.36 pb^{-1}
189 GeV LEP Result (Preliminary)	16.65 ± 0.33^{-1}

Z Boson Pair Production

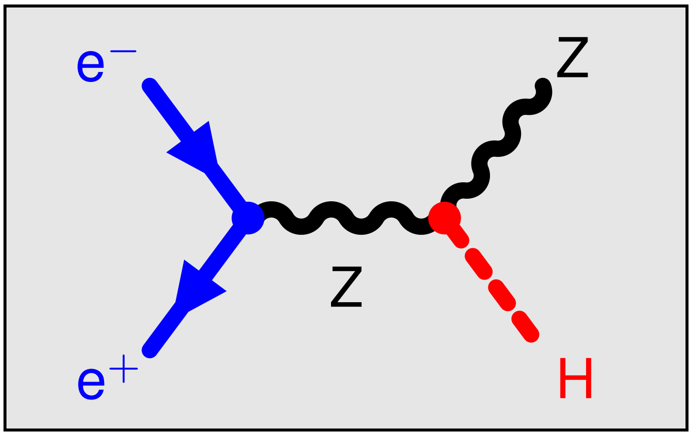
- Subset of Four Fermion Production Processes
- $2 \times m_Z$ threshold crossed in 1997

NC02 Diagrams



- NC02 diagrams dominate
- Z bosons decay into q$\bar{q}$, l$^+$l$^-$, $\nu\bar{\nu}$

  $\rightarrow$ many different four fermion final states
- q$\bar{q}$q$\bar{q}$, q$\bar{q}$ l$^+$l$^-$, l$^+$l$^-$ l$^+$l$^-$, and events with neutrino pairs
- Irreducible background to SM Higgs production searches if $m_Z \approx m_H$



Selection Results (DELPHI, 189 GeV)

Channel	data	Expected	Bkgd
$l^+l^-l^+l^-$	1	0.9	0.3
$e^+e^-q\bar{q}$	2	4.5 ± 0.4	0.8 ± 0.2
$\mu^+\mu^-q\bar{q}$	6	4.5 ± 0.4	0.5 ± 0.2
$\nu\bar{\nu}q\bar{q}$	6	7.7 ± 0.5	2.0 ± 0.4
$b\bar{b}q\bar{q}$	6	4.9	1.4
Total	21	22.5	5.0

LEP ZZ/NC02 Cross Section Results

	189 GeV
ALEPH	$0.63 \pm 0.12 \pm 0.05$
DELPHI	0.58 ± 0.17
L3	$0.71 ^{+0.16}_{-0.15}$
OPAL	$0.24 ^{+0.28}_{-0.21} {}^{+0.05}_{-0.04}$ ‡
SM	0.60 – 0.63

Cross sections in pb corrected to NC02 values

‡ July 1998

Selection Results (DELPHI, 189 GeV)

Channel	data	Expected	Bkgd
$l^+l^-l^+l^-$	1	0.9	0.3
$e^+e^-q\bar{q}$	2	4.5 ± 0.4	0.8 ± 0.2
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$\nu\bar{\nu}q\bar{q}$	6	7.7 ± 0.5	2.0 ± 0.4
$b\bar{b}q\bar{q}$	6	4.9	1.4
Total	21	22.5	5.0

LEP ZZ/NC02 Cross Section Results

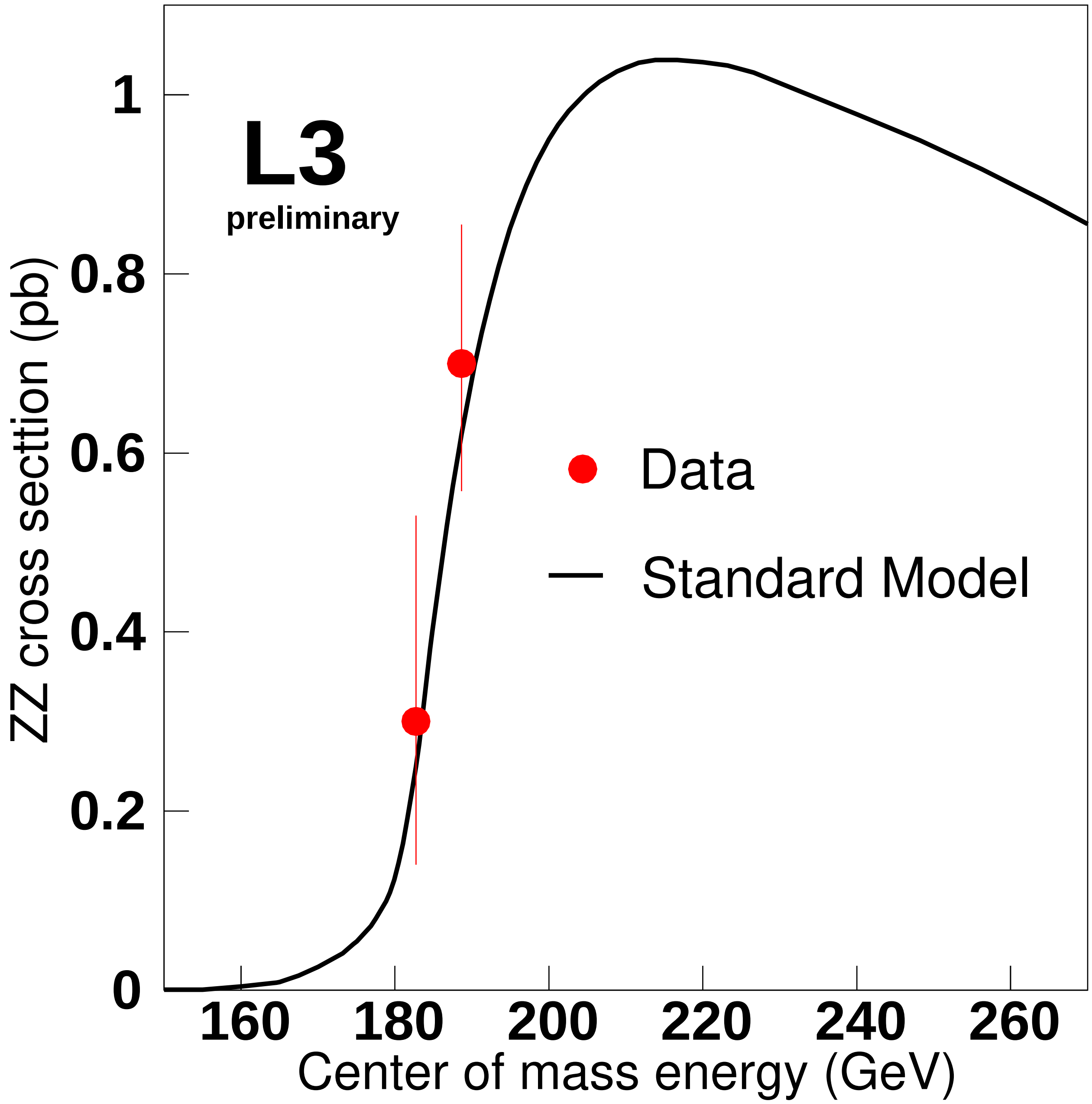
	183 GeV	189 GeV
ALEPH	$0.22\,^{+0.18}_{-0.22} \pm 0.04$	$0.63 \pm 0.12 \pm 0.05$
DELPHI		0.58 ± 0.17
L3	$0.31\,^{+0.16}_{-0.15}\,^{+0.07}_{-0.03}$	$0.71\,^{+0.16}_{-0.15}$
OPAL	$0.16\,^{+0.17}_{-0.12}\,^{+0.04}_{-0.03}$	$0.24\,^{+0.28}_{-0.21}\,^{+0.05}_{-0.04}$ ‡
SM	0.29	0.60 – 0.63

Cross sections in pb corrected to NC02 values

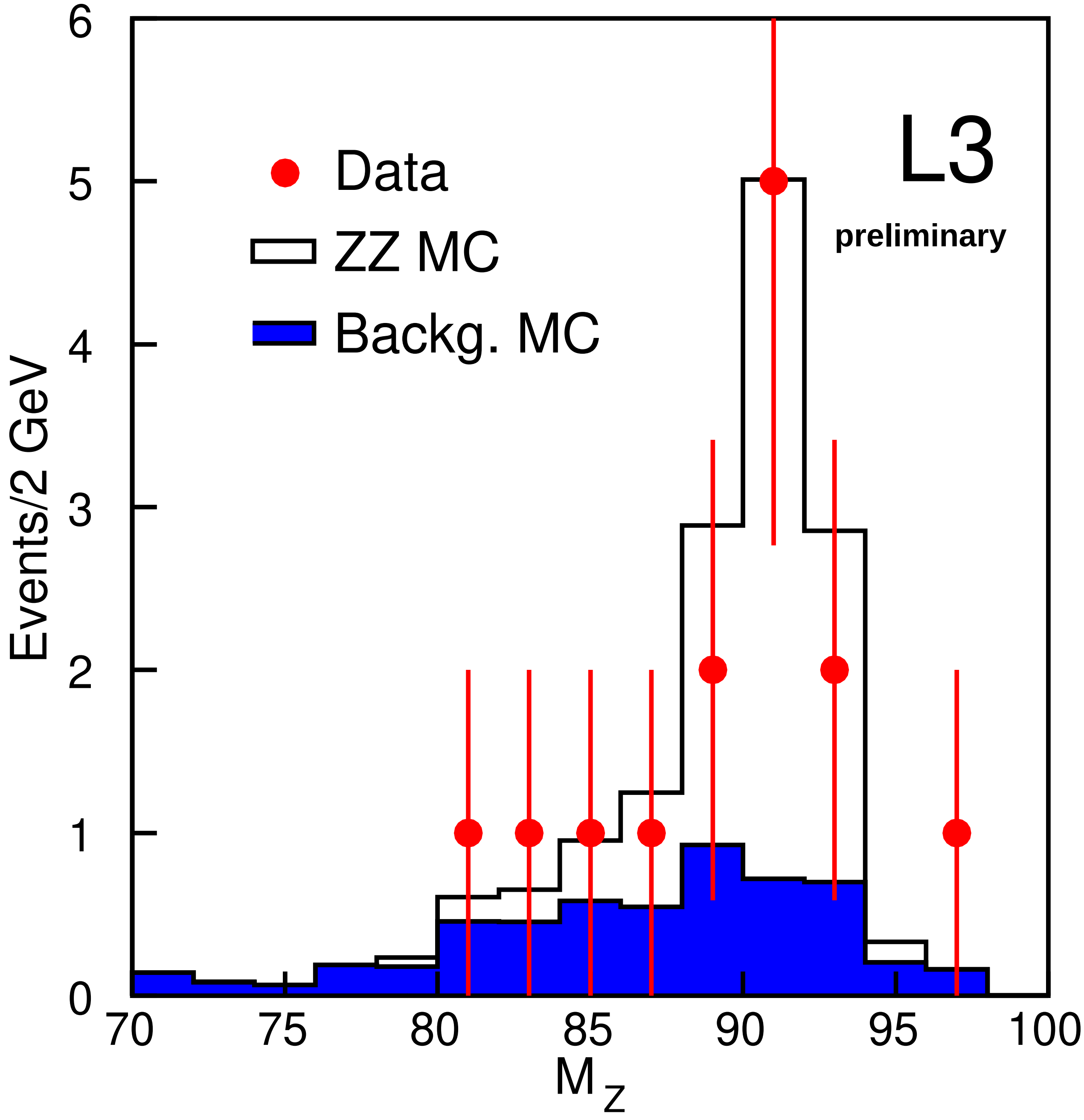
(except † measured ZZ cross section before correction)

‡ July 1998

ZZ Cross Sections at 183 & 189 GeV



Mass Distribution of ZZ Events at 189 GeV



Invariant Mass of Lepton Pair for $q\bar{q}l^+l^-$ selected events

Conclusions

- High Statistics Collected
- New Results at Highest Energies
- Results Consistent With Standard Model