Experimental Status of the Standard Model

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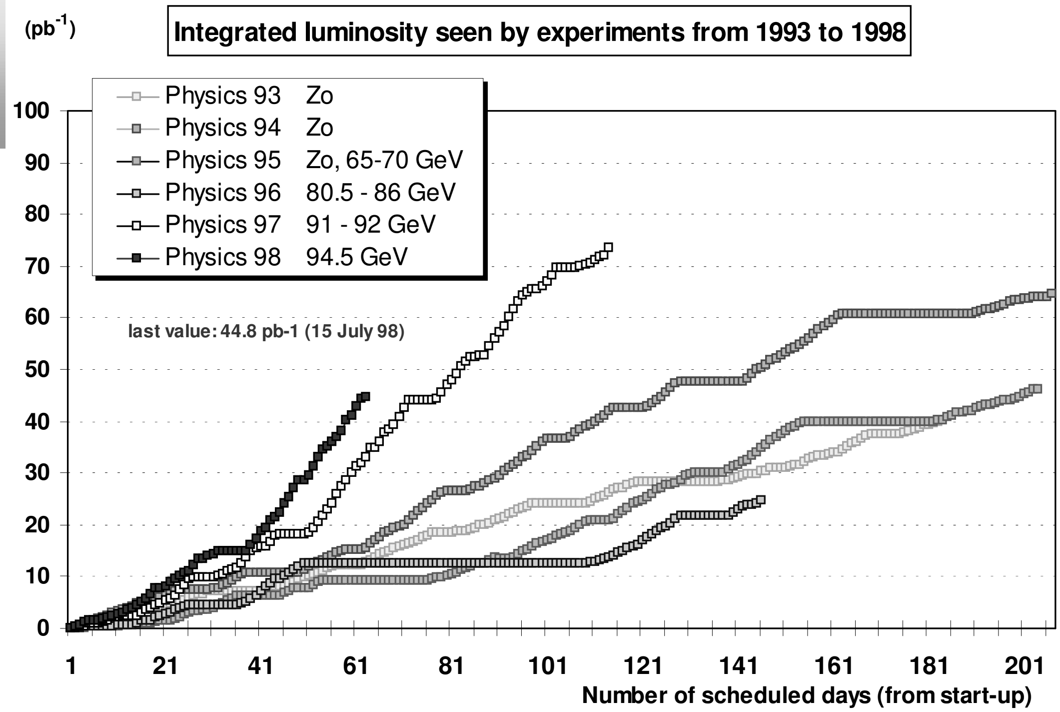
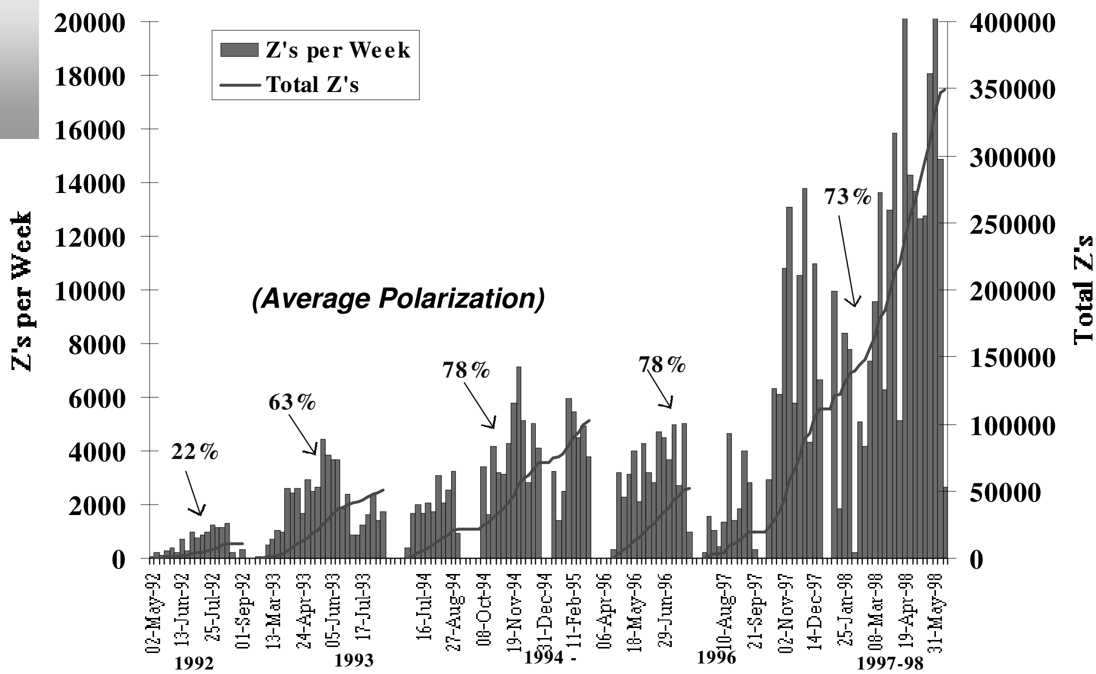
Outline

- *LEP & SLC performance 1997 - 98*
- *Updates of measurements*
  - *W properties*
  - *Z properties*
  - *Other SM processes*
  - *Note: most results presented are **preliminary***
- *Interpretation of precision data in the SM framework*
- *Summary and Outlook*

LEP performance



SLC Performance

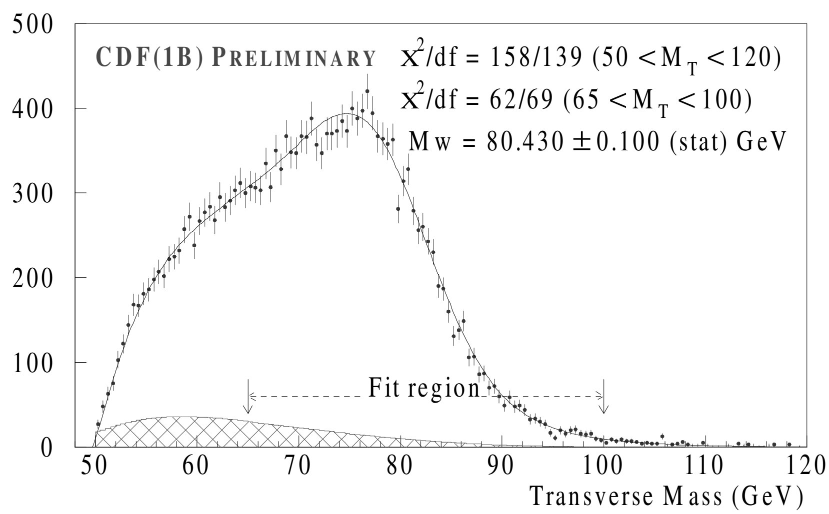


Machine energy calibration

- LEP beam energies/errors for Z^0 running now final
  - overall contributions to the LEP combined results:
    - $\Delta m_Z \cong 1.5$ MeV $\Delta\Gamma_Z \cong 1.5$ MeV
- LEP II beam energy less precisely determined
  - large extrapolation: $\Delta E_{beam} = 25$ MeV ; $\Delta m_W = 20$ MeV
  - cross check with $Z\gamma$ events demonstrated by ALEPH ('97 data)
    - $\Delta m_W = 102$ MeV (E_{cm} scale), $\Delta m_W = 139$ MeV (expt. error)
  - new project to install spectrometer in LEP
    - goal is to attain $\Delta E_{beam} \approx 10$ MeV
- SLC beam energy checked using final scan of Z^0
  - indicates shift of $+49 \pm 22$ MeV
  - correction applied to A_{LR} $(\Delta \sin^2\theta_{eff}^{lept} = -0.00011 \pm 0.00009)$

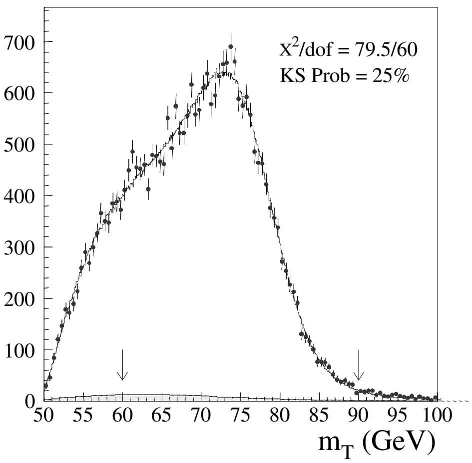
W mass from Tevatron

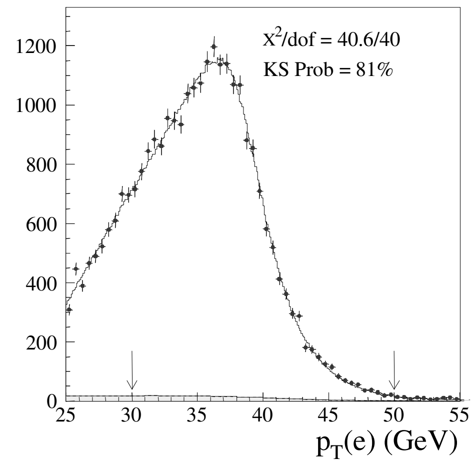
- W mass determined from $\ell\nu$ transverse mass
  - calibration from π^0, J/ψ, and Z^0



W mass from Tevatron

- DØ fits both transverse mass and electron p_t

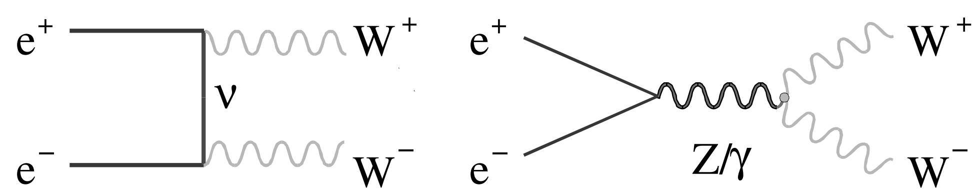




- CDF (prelim.) $M_W = 80.38 \pm 0.12$ GeV
- DØ $M_W = 80.43 \pm 0.11$ GeV

W measurements from LEP

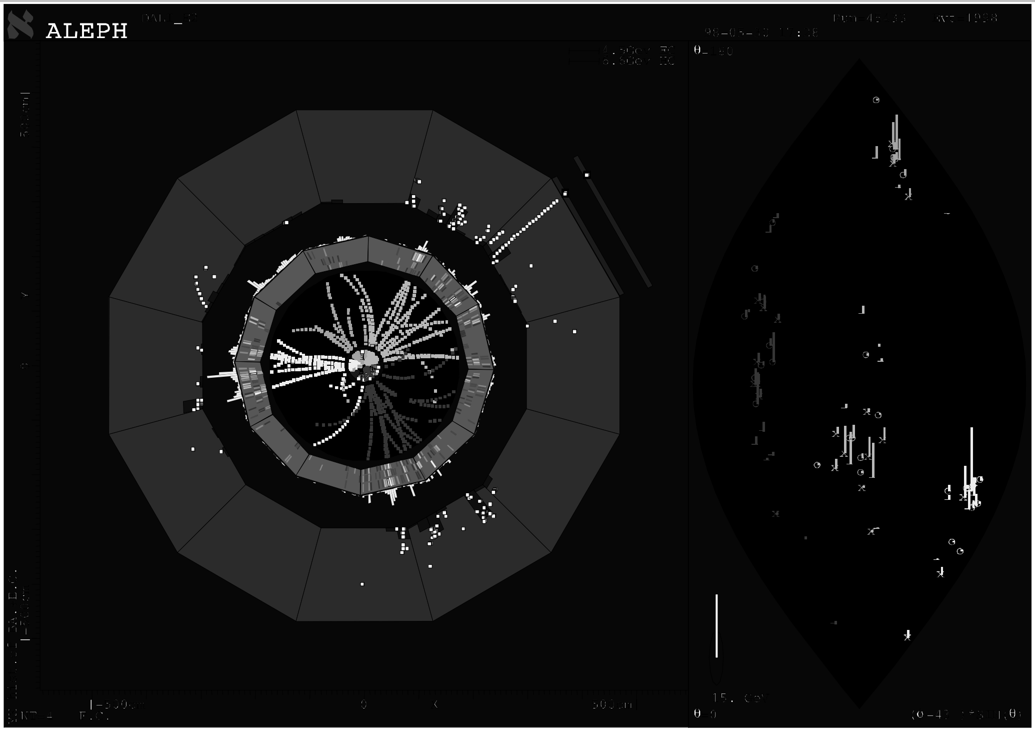
- W pair production at LEP



- events selected in all decay channels:

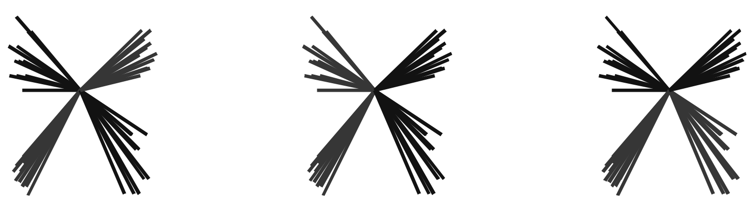
	BR (%)	Π (%)	ε (%)
$W^+W^- \to q\bar{q}'q\bar{q}'$	46	80	85
$W^+W^- \to q\bar{q}'\ell\bar{\nu}_\ell$	44	90	80
$W^+W^- \to \ell^+\nu\ \ell^-\bar{\nu}$	10	90	70

$W^+W^- \to q\bar{q}'q\bar{q}'$ event at 189 GeV



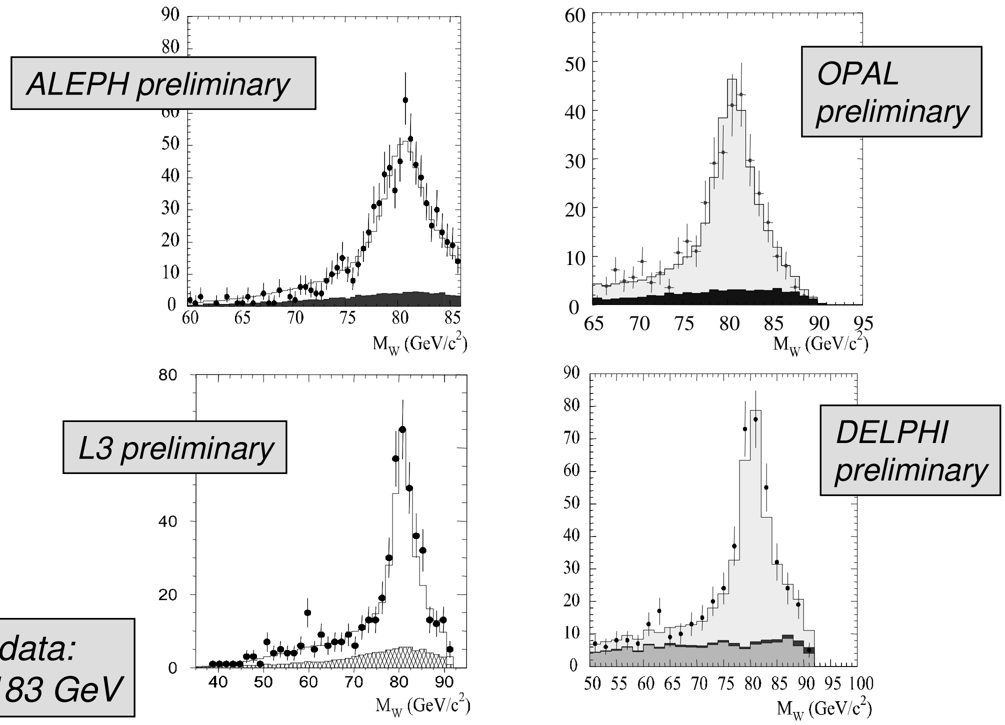
W mass from LEP

- m_W is estimated by direct reconstruction of jet-jet invariant masses
- kinematic fitting applied to improve mass resolution
- four quark final state has three jet pairings



- use kinematic fit χ^2, jet charge, and/or angles to decide

$W^+W^- \rightarrow q\bar{q}'q\bar{q}'$ mass distributions



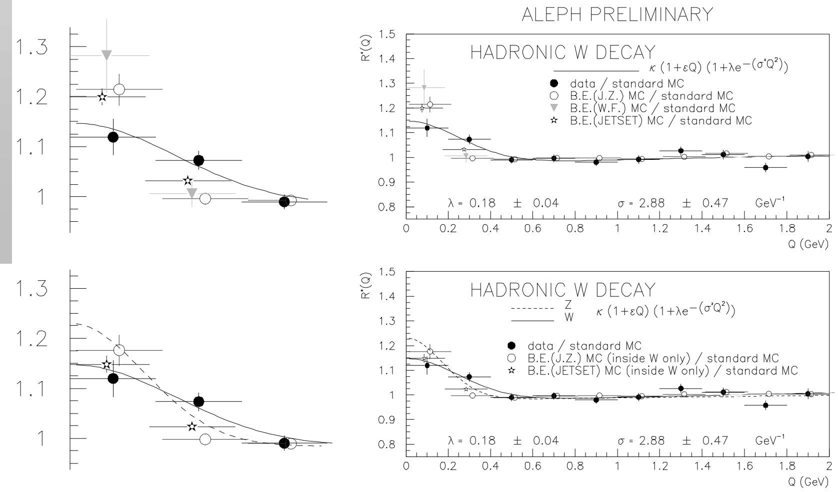
1997 data:
E_{cm}=183 GeV

Final state interactions in $W^+W^- \rightarrow q\bar{q}'q\bar{q}'$

- decays of the two W's not independent
  - decay length (0.1 fm) << hadronization scale (1 fm)
  - interconnection may affect estimation of M_W in this channel
- Bose-Einstein correlations
  - enhancement of identical bosons nearby in phase space
  - unknown whether effect exists for π's from different W bosons
- colour reconnection
  - significant interference effect possible in hadronization process, but estimates come only from models
  - models generally predict slight reduction in multiplicity, possibly enhanced at low momentum and for heavy hadrons

Bose-Einstein correlations

- a correlation function is formed, $C(Q)$, $Q = |p_1 - p_2|$
  - enhancement at low Q observed within W and Z decays but no experiment sees evidence for BEC between different W bosons



With full BEC, shift in m_W is ≈ -50 MeV

colour reconnection

- compare semileptonic and fully hadronic multiplicities:

$$\Delta n_{ch} = \left\langle n_{ch}^{4q} \right\rangle - 2\left\langle n_{ch}^{qq\ell\nu} \right\rangle$$

ALEPH	+ 1.3 ± 0.7 ± 0.4
DELPHI	− 1.6 ± 0.9 ± 1.2
L3	− 1.0 ± 0.8 ± 0.5
OPAL	+ 0.7 ± 0.8 ± 0.6

preliminary average:
+ 0.2 ± 0.5

- model investigation (OPAL)
  - *Ariadne shows largest shifts*
    - *but also predicts deficit at low p… not observed*
    - *need more data to exclude*
  - *Other models: $\Delta m_W < 40$ MeV*

model	p^{reco}	Δn_{ch}	Δm_W (MeV)
SK I	0.38	−0.3	+ 50 ± 17
SK II	0.22	−0.2	+ 17± 17
SK II′	0.20	−0.2	+ 18 ± 17
AR 2	0.52	−0.1	+ 73 ± 18
AR 3	0.63	−1.0	+ 146 ± 18

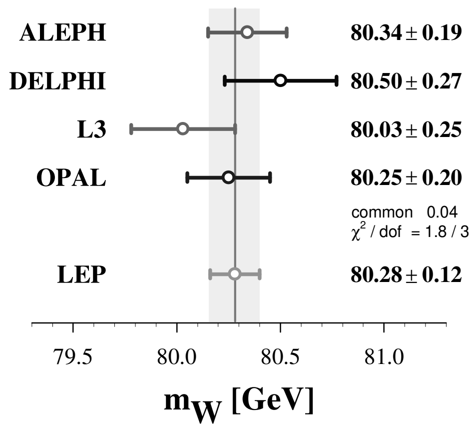
SK = Pythia (Sjöstrand / Khoze)
AR = Ariadne (Lönnblad)

- Currently assign 90 MeV systematic for BEC ⊕ CR

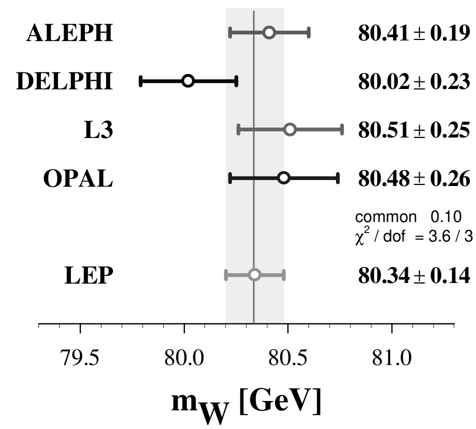
W mass from LEP (prelim.)

- *Results from 183 GeV data:*

LEP W mass from qqlν



LEP W mass from qqqq



- *with earlier LEP II measurements:* $\boxed{m_W = 80.37 \pm 0.09}$

W width

- *most precise (indirect) estimate is from hadron colliders*

$$\frac{\sigma_W \cdot BR(W \to \ell\nu)}{\sigma_Z \cdot BR(Z \to \ell\ell)} = \frac{\sigma_W \cdot \Gamma(W \to \ell\nu)}{\sigma_Z \cdot \Gamma(Z \to \ell\ell)} \frac{\Gamma_Z}{\Gamma_W}$$

  - *uses Z^0 data from LEP and BR($W \to l\nu$) from SM*
  - *$\Gamma_W = 2.06 \pm 0.06$ GeV (CDF+D0+UA1+UA2)*
- *CDF fits tail of transverse mass distribution*
  - *$\Gamma_W = 2.19 \pm 0.17 \pm 0.09$ GeV (CDF) (prelim.)*
- *LEP experiments fit mass distribution:*
  - *L3 $\Gamma_W = 2.41 \pm 0.39 \pm 0.25$ GeV (prelim.)*
  - *OPAL $\Gamma_W = 2.25 \pm 0.37 \pm 0.17$ GeV (prelim.)*
- *All results in accord with SM: 2.077 ± 0.014 GeV*

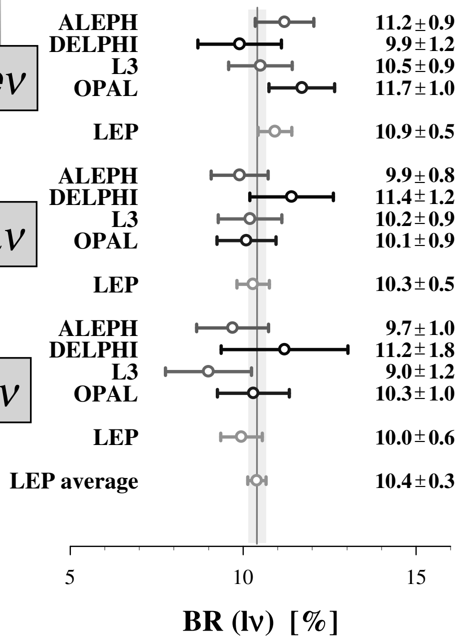
W branching ratios (prelim.)

W leptonic branching ratios

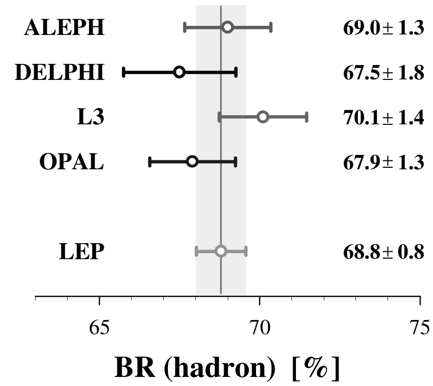
$W \rightarrow e\nu$

$W \rightarrow \mu\nu$

$W \rightarrow \tau\nu$



W hadronic branching ratio



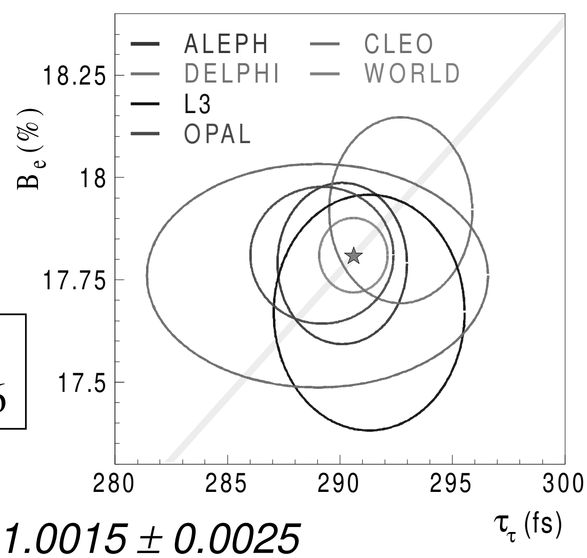
DØ measures ratios of branching ratios:

$$\frac{BR(W \rightarrow \tau\nu)}{BR(W \rightarrow e\nu)} = 1.00 \pm 0.06$$

$$\frac{BR(W \rightarrow \mu\nu)}{BR(W \rightarrow e\nu)} = 1.00 \pm 0.08$$

lepton CC universality from τ decays

- *relation between BR($\tau \rightarrow e$), τ_τ , and m_τ tests μ - τ*



combined result:
$g_\tau/g_\mu = 1.0001 \pm 0.0026$

- *from B_e,B_μ : g_μ/g_e = 1.0015 ± 0.0025*
  - *comparable precision as from π decays (0.15%)*

CKM matrix element V_{cs}

$\boxed{B_h \equiv BR(W \to \text{hadrons}) = 0.6879 \pm 0.0077}$

- *This can be related to CKM matrix elements:*

$$\frac{B_h}{1-B_h} = \sum_{\substack{i=u,c \\ j=d,s,b}} \left|V_{ij}^2\right|\left(1+\frac{\alpha_s}{\pi}\right)$$

- *V_{cs} least well known $\Rightarrow$ estimate V_{cs} from relation*

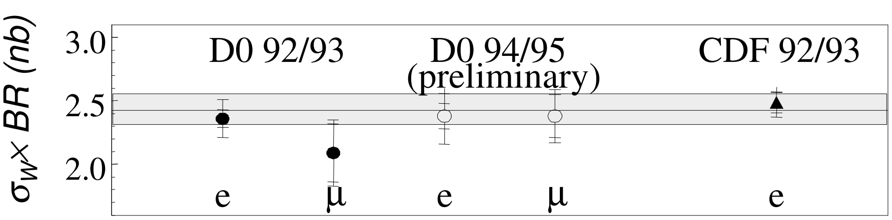
$\boxed{\text{LEP indirect average: } |V_{cs}| = 1.04 \pm 0.04}$

- *LEP experiments also measure by tagging charm*

$\boxed{\text{LEP direct average: } |V_{cs}| = 0.99 \pm 0.11}$

W production measurements

- *new (preliminary) results from DØ:*
  - $\sigma_W\, BR(W\to e\nu) = 2.38 \pm 0.01 \pm 0.09 \pm 0.20$ (lumi) nb
  - $\sigma_W\, BR(W\to \mu\nu) = 2.38 \pm 0.03 \pm 0.17 \pm 0.13$ (lumi) nb



- *HERA experiments: look for lepton and missing p_t*

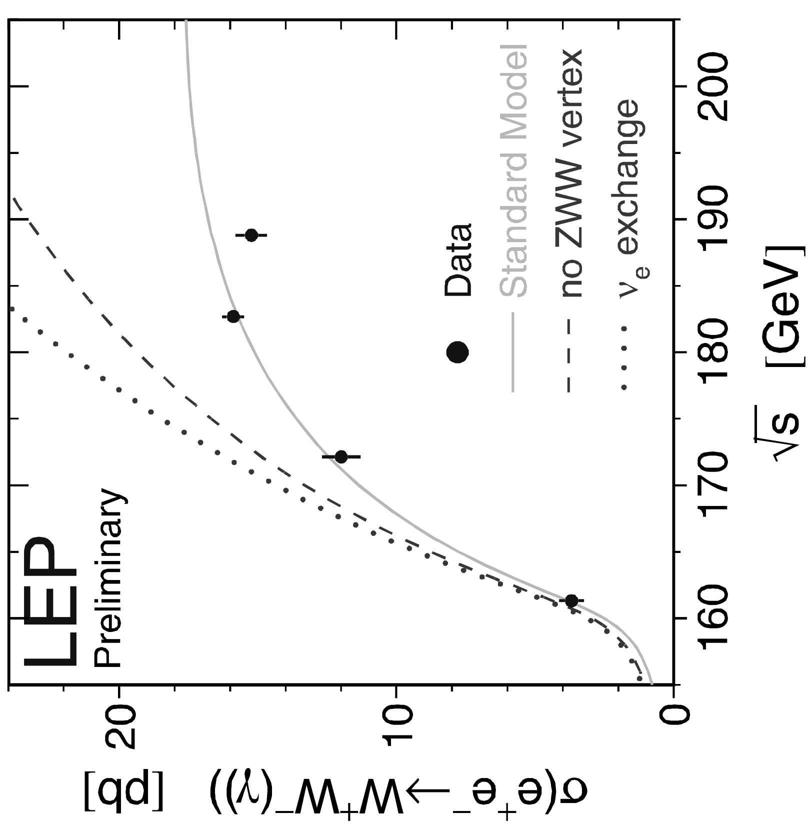
	$W \to e\nu$ selection			$W \to \mu\nu$ selection		
	obs.	$W\to e\nu$	bckgnd	obs.	$W\to\mu\nu$	bckgnd
ZEUS	3	2.0	1±0.5	0	0.6	0.6±0.2
H1	1	1.7	0.7	5	0.5	0.3

WW cross section at LEP

- *corrected to CC03 diagrams (preliminary)*

	σ_{WW} [pb] (E_{cm} = 183 GeV)	σ_{WW} [pb] (E_{cm} = 189 GeV)
ALEPH	15.51 ± 0.71	14.74 ± 0.85
DELPHI	16.01 ± 0.83	16.00 ± 0.96
L3	16.53 ± 0.67	15.44 ± 0.95
OPAL	15.52 ± 0.71	15.04 ± 0.87
LEP combined	15.86 ± 0.40	15.24 ± 0.57
	Common = 0.20 pb χ^2 / d.o.f. = 1.4 / 3	Common = 0.40 pb χ^2 / d.o.f. = 1.3 / 3
Standard Model	15.72	16.67

σ_{WW} [pb]

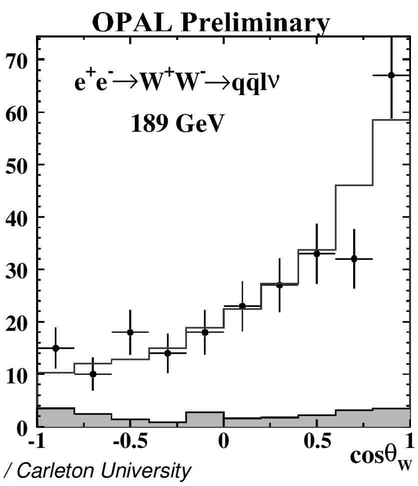


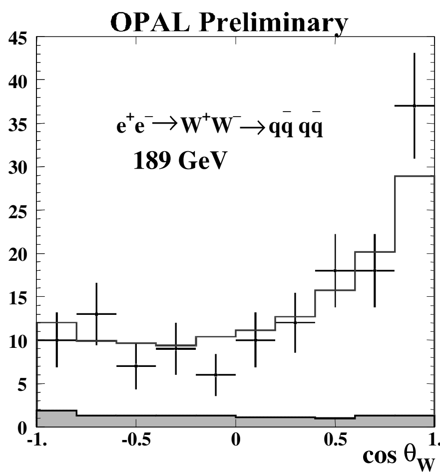
Precision of 189 GeV result should improve by factor of 2 by the end of the year…

WW at 189 GeV

$\sigma \times BR$ [pb]

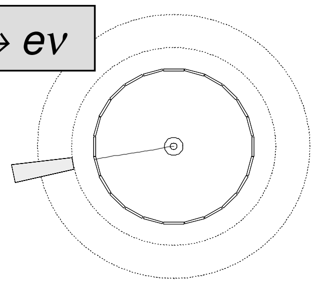
	qqqq	qqlν	lνlν
DELPHI	6.8 ± 0.6	7.6 ± 0.6	1.5 ± 0.3
L3	6.8 ± 0.5	7.1 ± 0.6	1.4 ± 0.3
OPAL	7.0 ± 0.6	6.4 ± 0.5	1.7 ± 0.3
S. M.	7.6	7.3	1.8

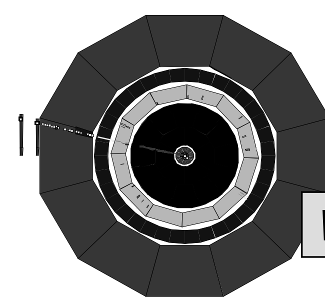




Single W production at LEP

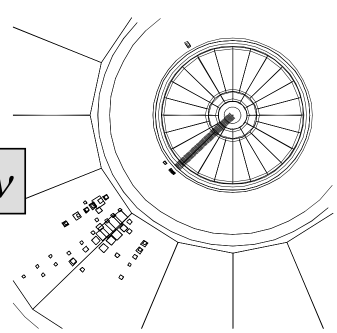
$W \rightarrow e\nu$

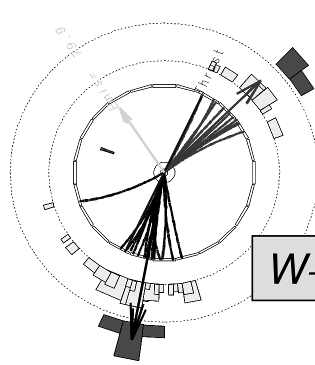




$W \rightarrow \mu\nu$

$W \rightarrow \tau\nu$





$W \rightarrow qq$

Single W production

$$\boxed{W \to \ell \nu}$$

	E_{cm} (GeV)	Lumi (pb^{-1})	N_{obs}	N_{exp}	$N_{e\nu W}$
ALEPH	161-183	78.9	11	11.1	7.3
DELPHI	161-183	73.0	9	5.4	5.2
L3	130-183	88.5	12	10.2	6.0
OPAL	161-172	20.3	2	2.0	0.8

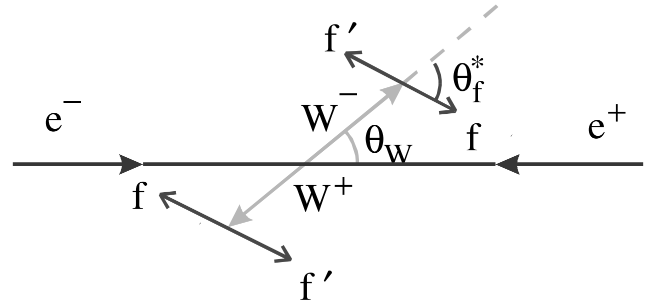
- *ALEPH uses single W cross section to determine the partial width of the W into (nearly) invisible final states*
  - *eg.* $W^+ \to \chi^+ \chi$, $\chi^+ \to \tilde{\nu} \ell$, $\left| m_{\chi^+} - m_{\tilde{\nu}} \right|$ *small*
  - *select single W events consistent with WW but only 1 W seen*
  - *result:* Γ_W*(inv) < 27 MeV at 95 % C.L.*
  - *other limits on* Γ_W*(inv) :*
    - *41 MeV from* $\sigma_{WW}(\Gamma_W)$ *; 109 MeV from* Γ_W *(indirect)*

Triple Gauge Couplings

- *testing the non-abelian nature of the Standard Model*
- *to be quantitative, consider the most general Lagrangian describing WWZ and WW*γ *interactions (Lorentz invariant)*
  - *leaves 14 terms, each with its own coupling constant*
- *use physics insight to suggest most interesting combinations of terms (ie. not already strongly excluded)*
- *this leaves 3 parameters:* $\Delta\kappa_\gamma$, Δg_1^z, λ *(all 0 in SM)*
- *the parameters related to static moments of* W^+*:*
  - *magnetic dipole moment:* $\mu_W = (e/2m_W)(2 + \Delta\kappa_\gamma + \lambda)$
  - *electric dipole moment:* $q_W = -(e/m_W^2)(1 + \Delta\kappa_\gamma - \lambda)$

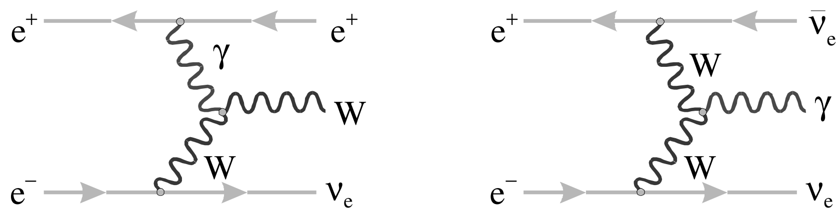
LEP measurements of TGC's

- *anomalous couplings increase σ_{WW} and modify angular distribution and helicity states (decay distributions)*

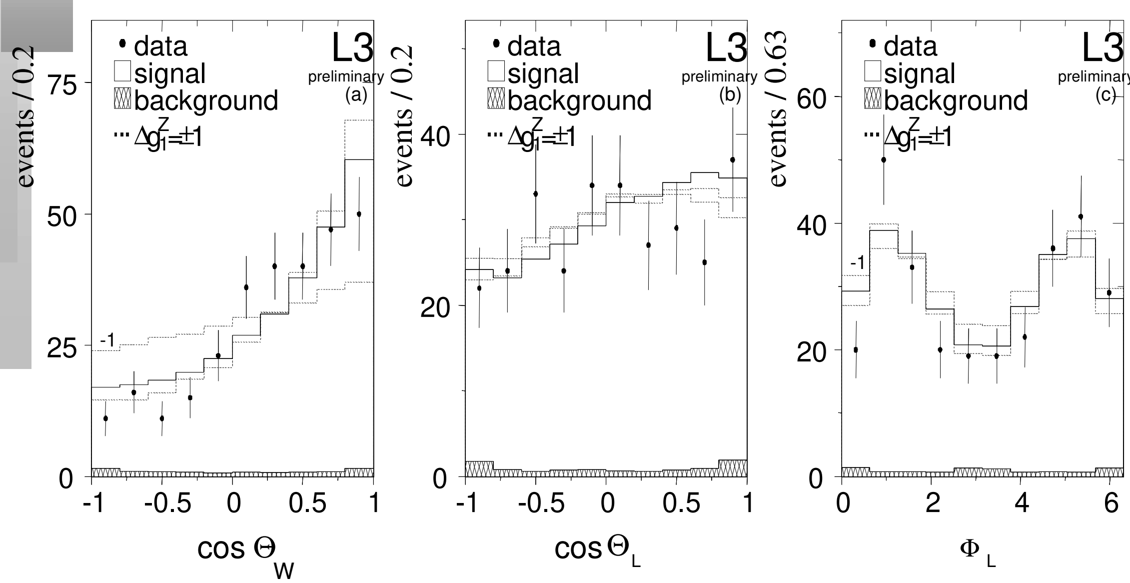


and ϕ^* : out of plane

- *single W and single γ production also sensitive to TGC*



angular distributions



Tevatron (DØ) TGC measurements

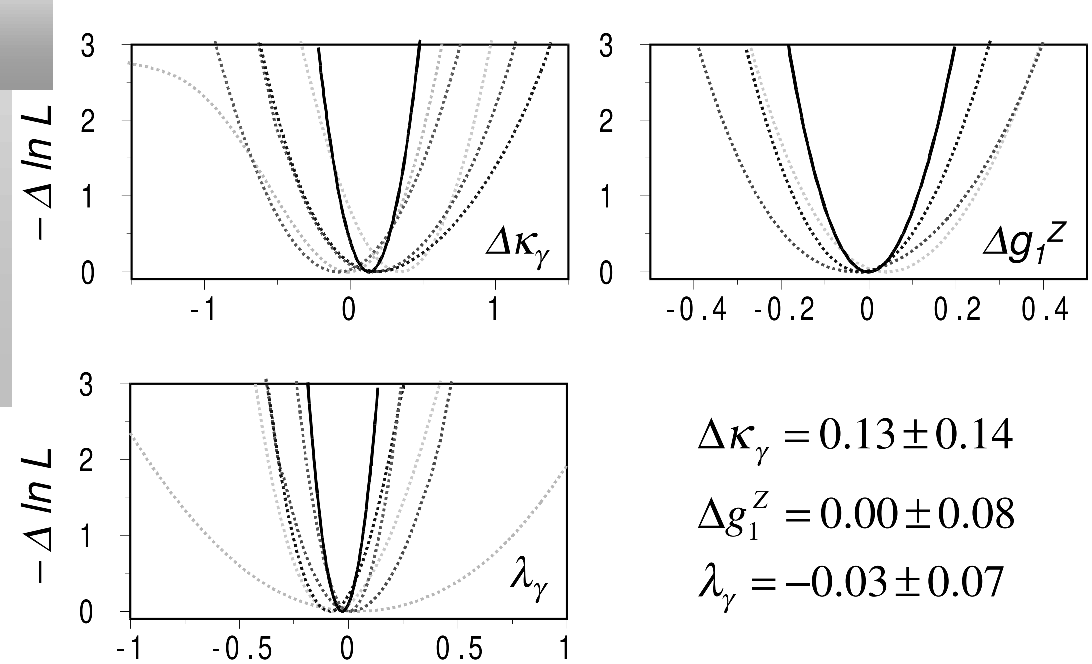
- *Measure gauge boson pair production:*

$W\gamma$	$W \quad W$	$W \quad (W/Z)$
$\hookrightarrow \ell\nu$	$\hookrightarrow \ell\nu \hookrightarrow \ell\nu$	$\hookrightarrow e\nu \hookrightarrow qq$

- *compared with LEP*
  - *enhancement of σ from anom. couplings increases with s*
  - *larger background*
  - *overall sensitivity similar to LEP*

Combined TGC results

ALEPH + DELPHI + L3 + OPAL + D0



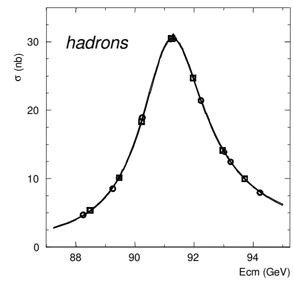
$$\Delta\kappa_\gamma = 0.13 \pm 0.14$$

$$\Delta g_1^Z = 0.00 \pm 0.08$$

$$\lambda_\gamma = -0.03 \pm 0.07$$

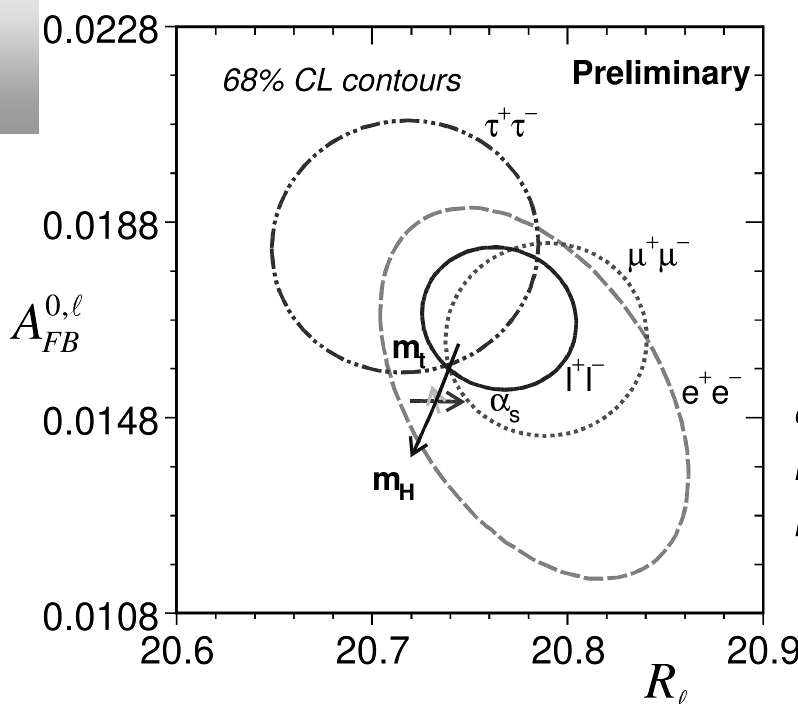
Z^0 observables

- *lineshape:*
  - $\sigma(e^+e^- \to f\bar{f})$ vs. $\sqrt{s} \;\Rightarrow\; M_Z\,,\Gamma_Z\,,\sigma^0_{had}$



- *partial widths:*
  - $\Gamma_f \equiv \Gamma(Z \to f\bar{f}) \propto (g^2_{V_f} + g^2_{A_f})$
  - $R_\ell \equiv \Gamma_{had}/\Gamma_\ell\;,\; R_b \equiv \Gamma_b/\Gamma_{had}$
- *Forward backward asymmetries:*
  - $A^{0,f}_{FB} \equiv \dfrac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4}A_e A_f \qquad A_f \equiv \dfrac{2 g_{V_f} g_{A_f}}{g^2_{V_f} + g^2_{A_f}}$ *(coupling parameter)*
- *Tau polarization*
  - $P_\tau(\cos\theta) \;\Rightarrow\; A_\tau\,, A_e \qquad \langle P_\tau \rangle = -A_\tau$
- *with polarized beams:*
  - $A^0_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e \qquad A^{0,f}_{LR/FB} = \frac{3}{4}A_f$

Z^0 lineshape and FB asymmetries



$\alpha_s(M_Z^2)=0.119\pm0.002$

$m_t = 173.8 \pm 5.0$ GeV

$m_H = 300^{+700}_{-220}$ GeV

Z^0 lineshape and A_{FB} results

- *Assuming lepton universality*

$$m_Z = 91186.7 \pm 2.1 \text{ MeV}$$
$$\Gamma_Z = 2493.9 \pm 2.4 \text{ MeV}$$
$$\sigma^0_{had} = 41.491 \pm 0.058 \text{ nb}$$
$$R_\ell = 20.765 \pm 0.026$$
$$A^{0,\ell}_{FB} = 0.01683 \pm 0.00096$$

- *strong coupling from R_l:*

$$\alpha_s(m_Z^2) = 0.124 \pm 0.004 \pm 0.002(m_H)$$

- *Partial decay widths:*

$$\Gamma_{had} = 1742.3 \pm 2.3 \text{ MeV}$$
$$\Gamma_\ell = 83.90 \pm 0.10 \text{ MeV}$$

- *Invisible decay width:*

$$\Gamma_{inv} = \Gamma_Z - \Gamma_{had} - (3 + \Delta_\tau)\Gamma_\ell$$
$$= 500.1 \pm 1.9 \text{ MeV}$$
$$\Delta\Gamma_{inv} < 2.8 \text{ MeV (95\% C.L.)}$$

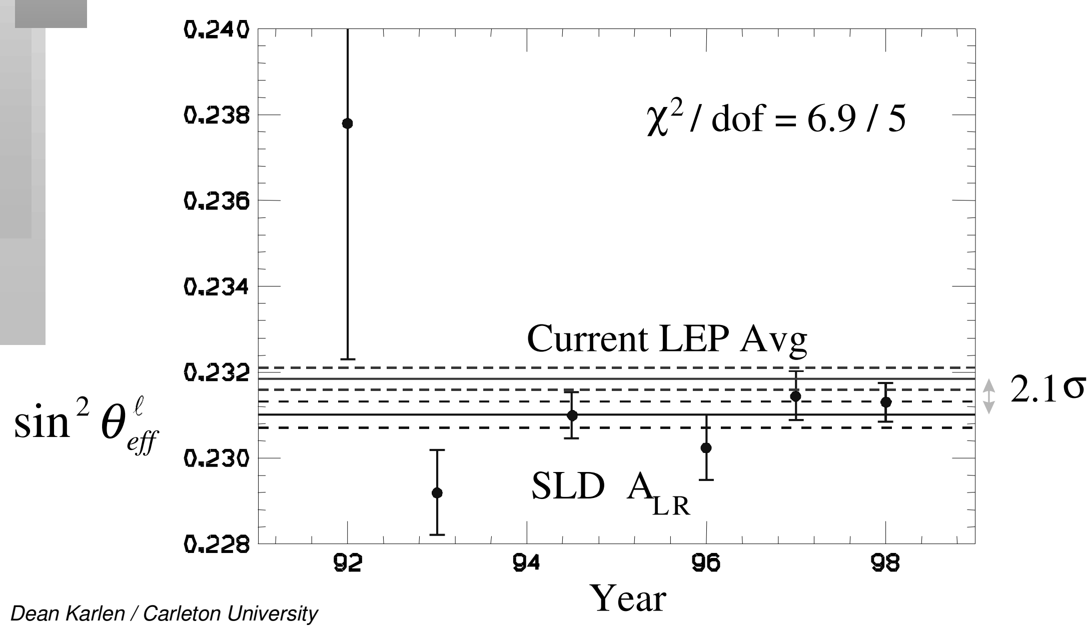
  - *will improve with reduced luminosity error*

- *number of light neutrino species*

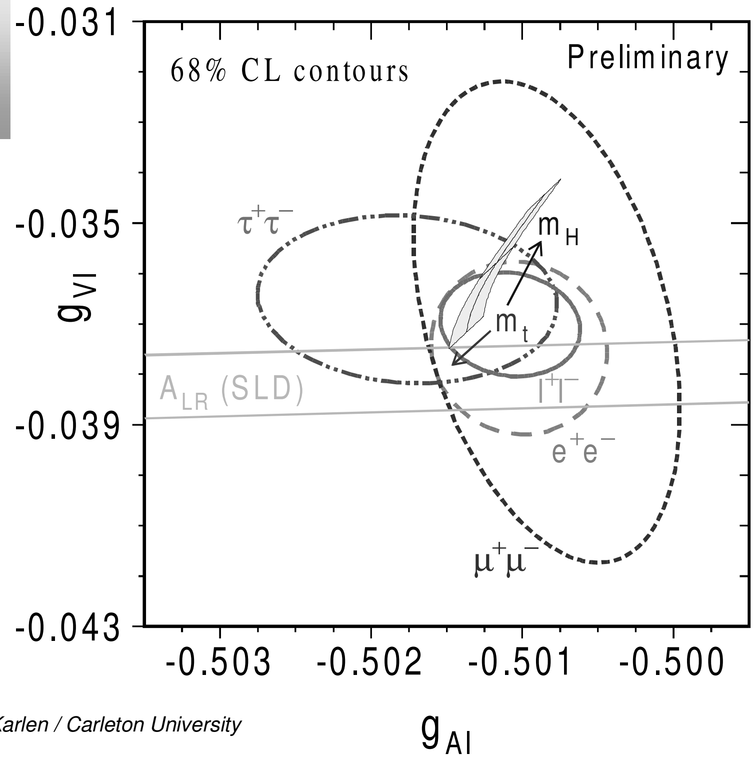
$$N_\nu = \frac{\Gamma_{inv}}{\Gamma_\ell}\left(\frac{\Gamma_\ell}{\Gamma_\nu}\right)_{SM} = 2.994 \pm 0.011$$

Polarisation asymmetries

- *large increase in statistics for SLD A_{LR} measurement*
- *two new polarimeters confirm previous measurements*



effective coupling constants



includes τ polarisation asymmetries

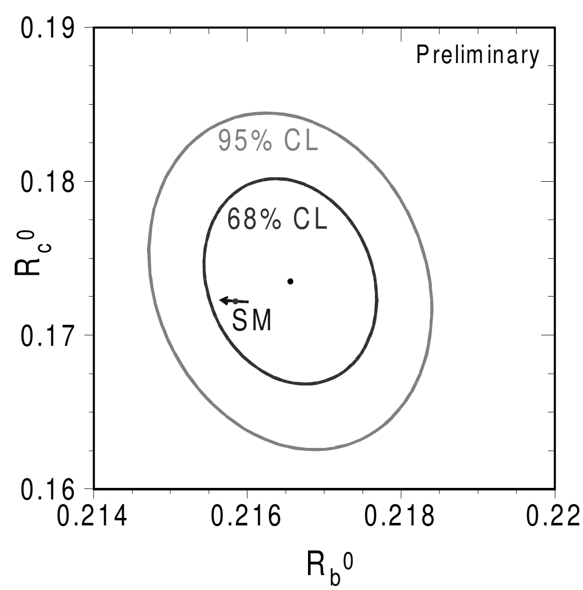
$m_t = 173.8 \pm 5.0$ GeV

$m_H = 300^{+700}_{-220}$ GeV

Heavy Flavour couplings

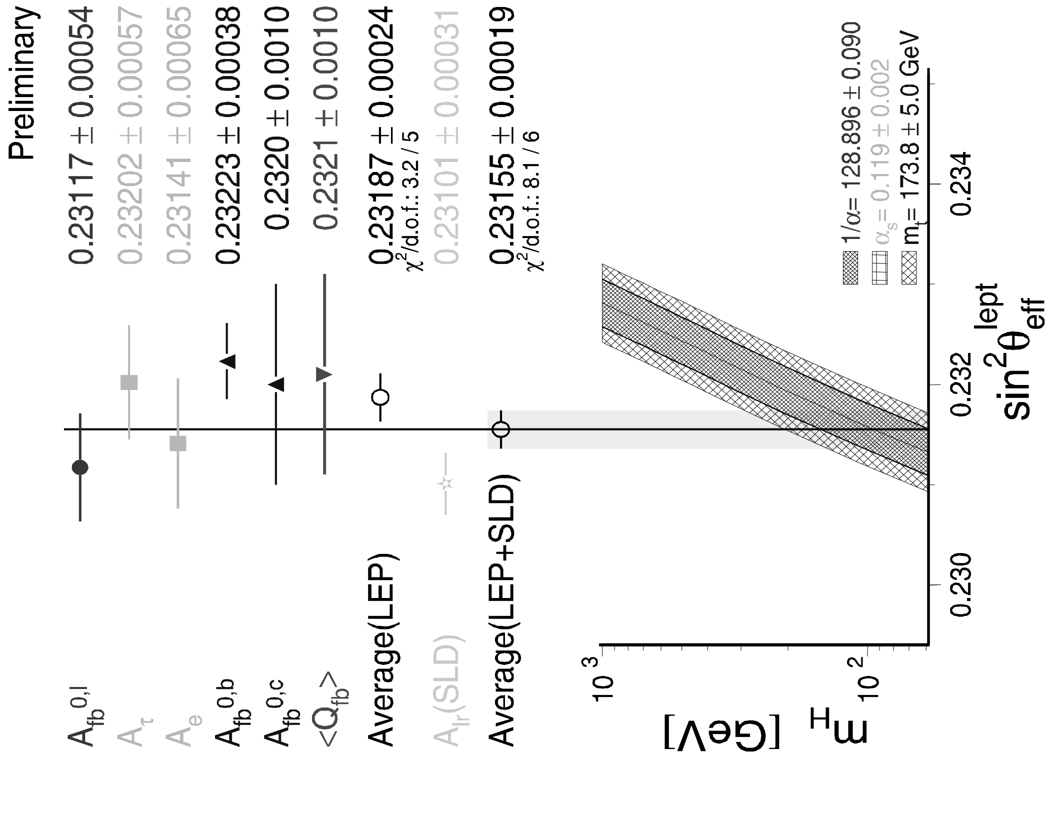
- *Results of combination:*
  - *includes late SLD results*

$$R_b = 0.21656 \pm 0.00074$$
$$R_c = 0.1735 \pm 0.0044$$
$$A_{FB}^{0,b} = 0.0990 \pm 0.0021$$
$$A_{FB}^{0,c} = 0.0709 \pm 0.0044$$
$$A_b = 0.867 \pm 0.035$$
$$A_c = 0.647 \pm 0.040$$



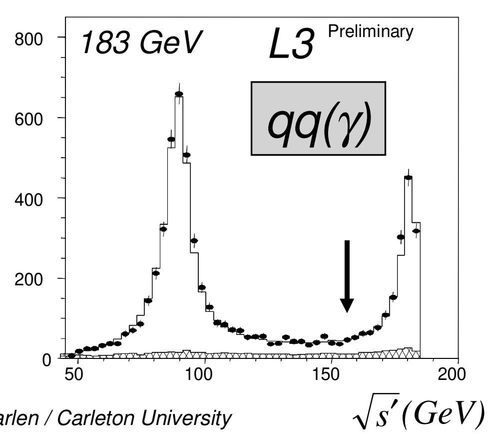
- $m_t = 173.8 \pm 5.0$ GeV

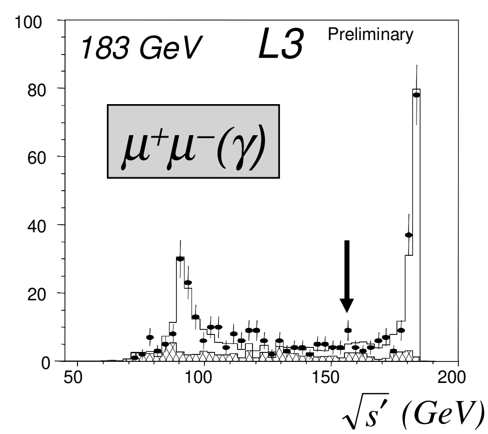
Effective electroweak mixing angle



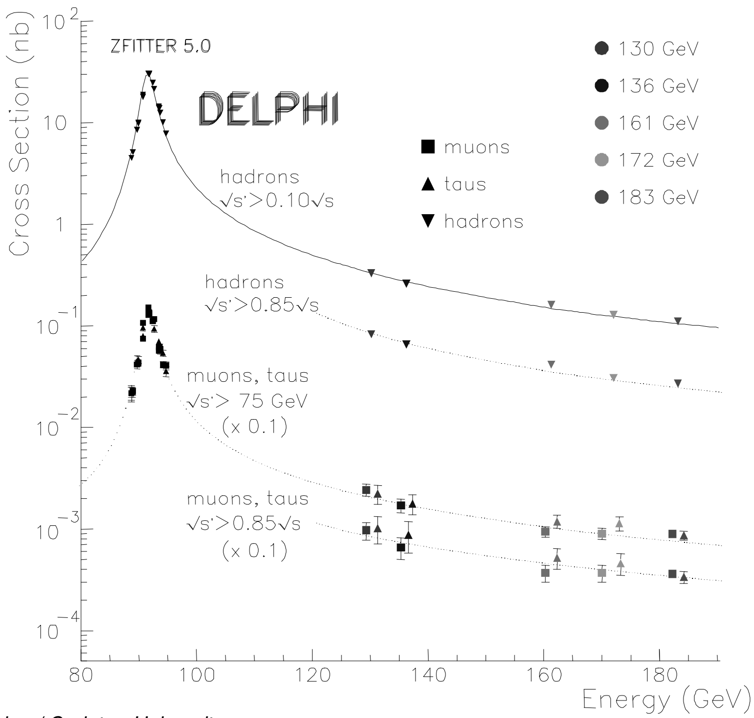
fermion pair production above Z^0

- *unlike at Z^0 peak, initial state radiation is very significant*
- *a signal for new physics above Z^0 would be diluted in an inclusive f f sample…*
  - *cut on effective centre-of-mass ($\sqrt{s'}$) as calculated from kinematic fits (hadrons) or acollinearity angles (leptons)*





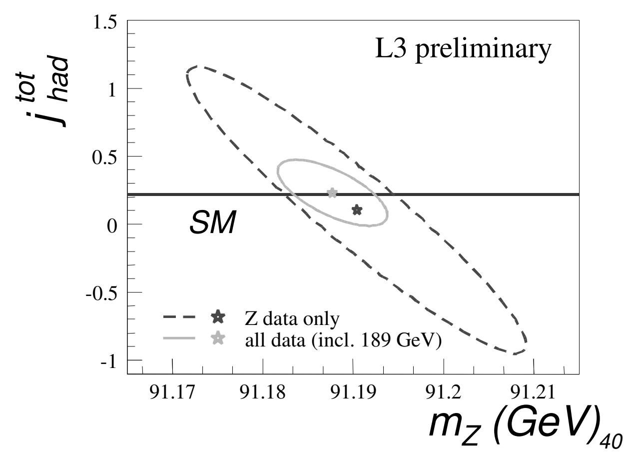
cross sections



A_{FB} above peak also in good agreement with SM expectations

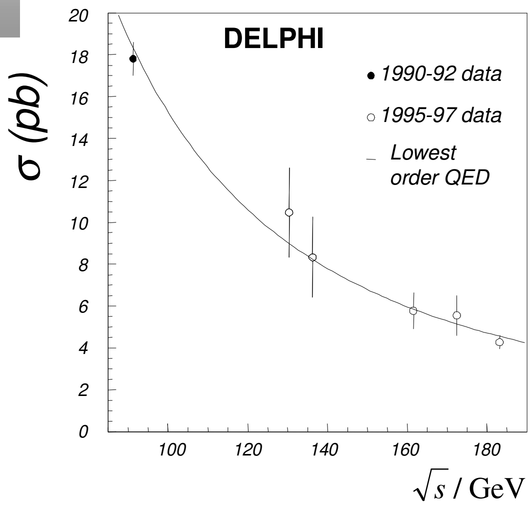
Test of γ - Z^0 interference

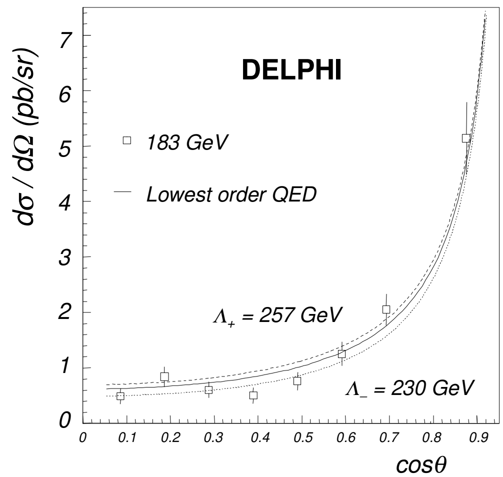
- *The standard electroweak fits fixes the γ - Z^0 interference term to the SM value (data does not constrain it well)*
  - *an alternative fit (S-matrix) includes scale factors for the interference terms*
  - *large correlation between m_Z and the hadronic γ - Z^0 interference term*
  - *uncertainty in m_Z in this fit is much reduced by including LEP 2 data*



Other SM processes

- $e^+e^- \to \gamma\gamma(\gamma)$

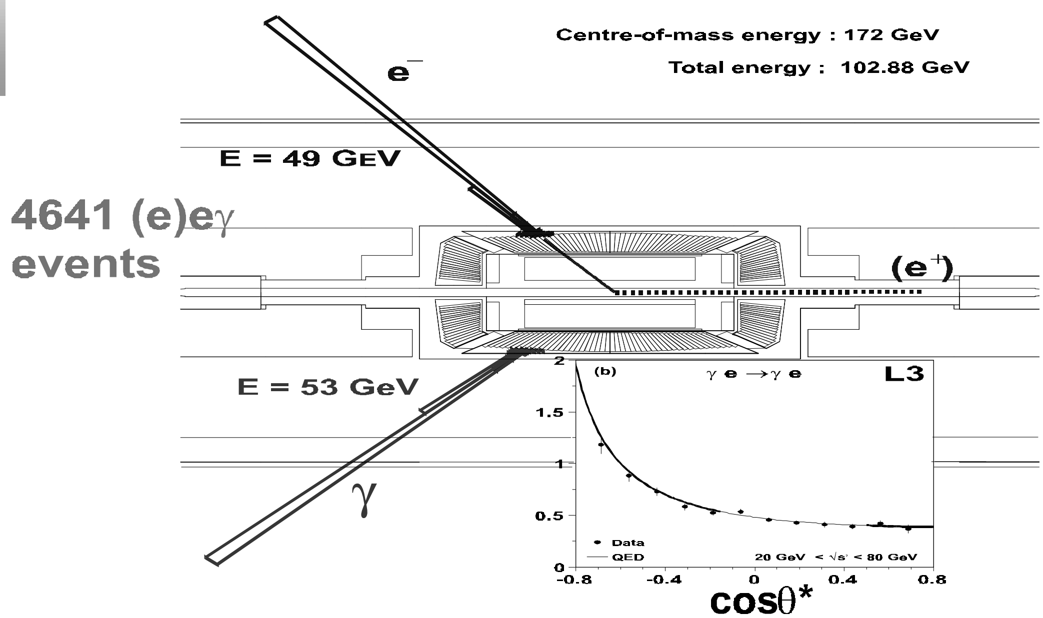




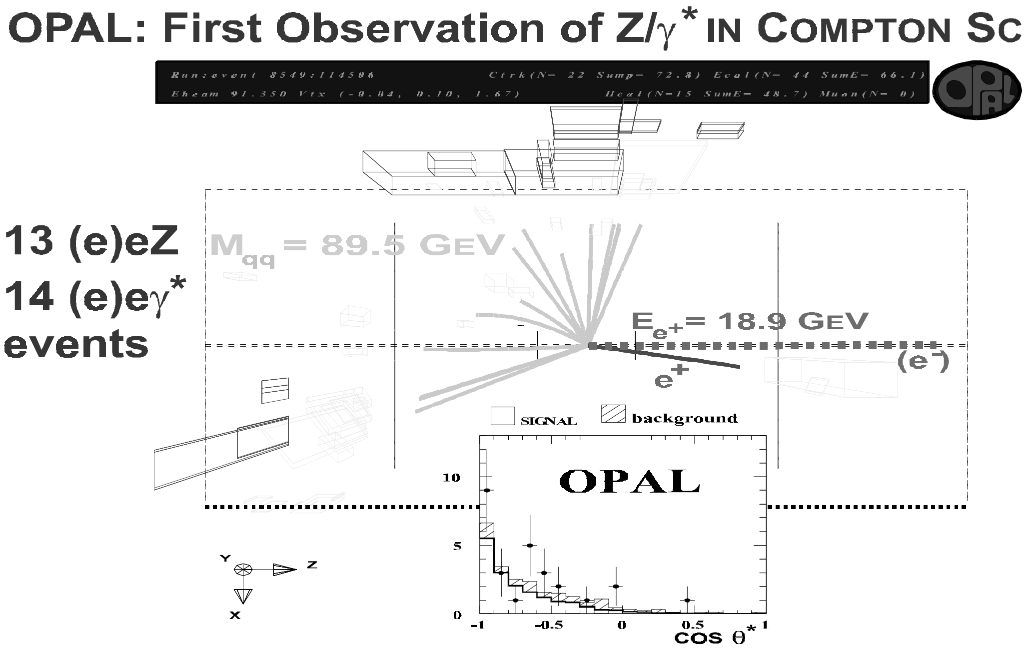
- *new measurements of virtual eγ scattering…*

Virtual Compton scattering

L3 : Highest Energy Compton Scattering



Electroweak Compton scattering

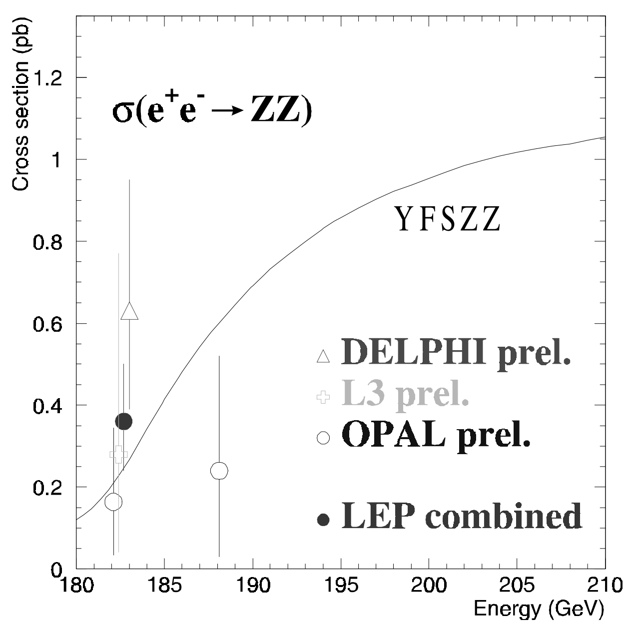


$e^+e^- \rightarrow Z^0Z^0$ cross sections

183 GeV	chan	σ_{ZZ} (pb)
DELPHI	4	$0.63^{+0.31+0.06}_{-0.24-0.02}$
L3	2(3)	$0.28^{+0.48+0.10}_{-0.24-0.02}$
OPAL	8(7)	$0.16^{+0.17+0.04}_{-0.12-0.02}$
LEP	14	$0.36^{+0.14+0.03}_{-0.12-0.02}$

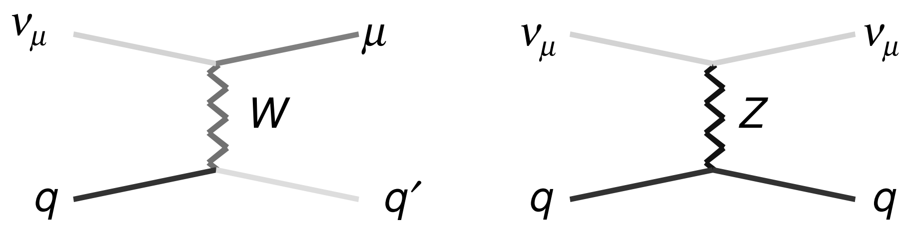
189 GeV	chan	σ_{ZZ} (pb)
OPAL	8(7)	$0.24^{+0.28+0.05}_{-0.21-0.02}$

DELPHI 189 GeV result: 11 observed
5.7 ± 0.2 signal, 4.5 ± 0.3 background



νN scattering

- NC to CC cross section ratio sensitive to $\sin^2\theta_W$



- dominant systematic: theoretical uncertainty in CC charm production from scattering off sea quarks: 0.0027
- also uncertainty in ν_e component in beam: 0.0015
- final CCFR result: $\sin^2\theta_W^{(on\text{-}shell)} = 0.2236 \pm 0.0041$

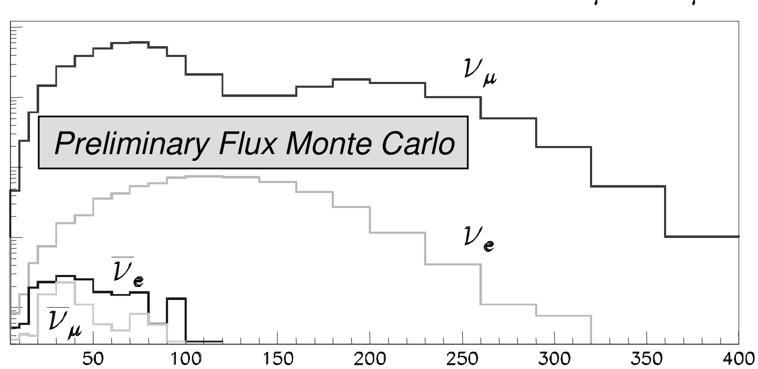
New result from NuTeV

- to reduce systematics, measure:

$$R^- = \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}}$$

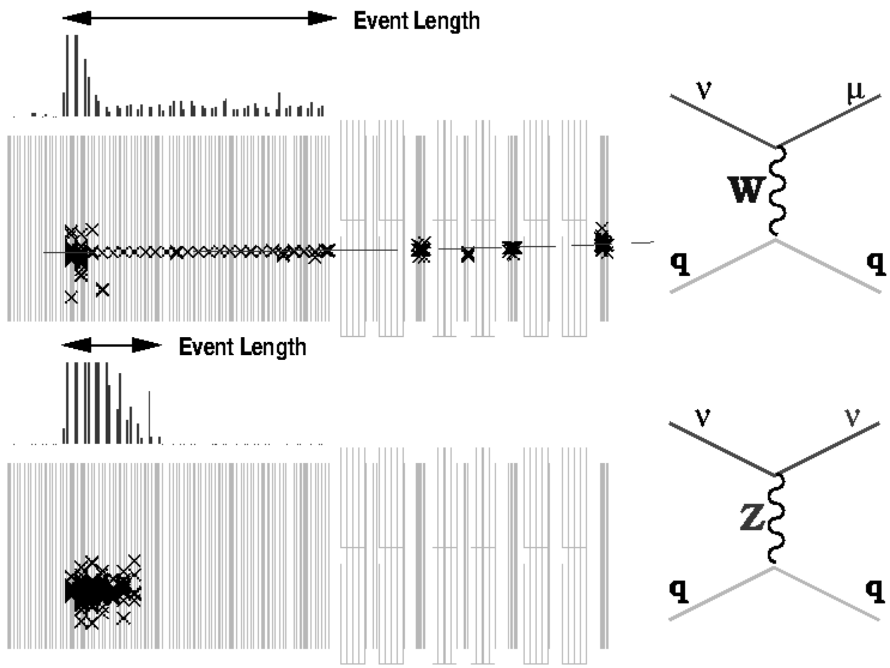
effect of scattering off sea quarks cancel

- modified beam line to select ν_μ or $\overline{\nu_\mu}$ and reduce ν_e

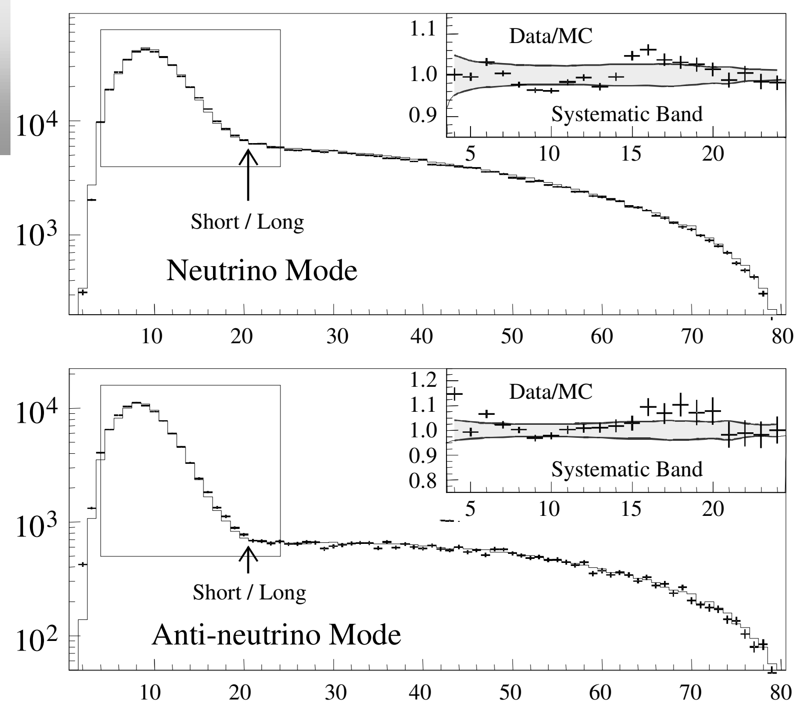


contamination	
$\bar{\nu}$ (in ν)	< 0.1 %
ν (in $\bar{\nu}$)	< 0.2 %
ν_e	≈ 1.8 %

CC / NC event separation



event length distributions



Preliminary

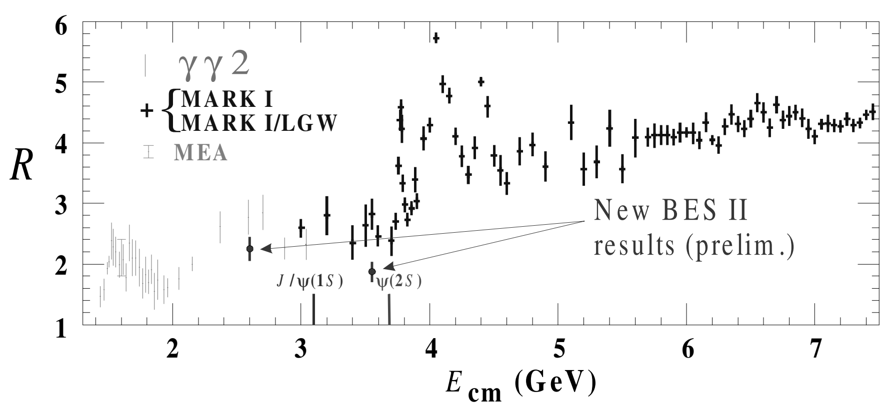
event length: (counters ≈10 cm steel)

PRELIMINARY NuTeV result

- $\sin^2\theta_W{}^{(on\text{-}shell)} = 0.2253 \pm 0.0019\ (stat) \pm\ 0.0010\ (sys)$
  - *twice as precise as best previous ν N measurement (CCFR)*
  - *change since Moriond (fix error in application of radiative corrections)*
  - *result is preliminary, work is continuing on the analysis*

R(s): improving $\alpha(m_Z^2)$

- *uncertainty on $\Delta\alpha_{had}(m_Z^2)$ important for SM interpretation*
  - *for theoretical developments, see W.H. presentation*
- *BES carrying out new scan of R(s): $\Delta R/R \rightarrow\ \approx 7\%$*



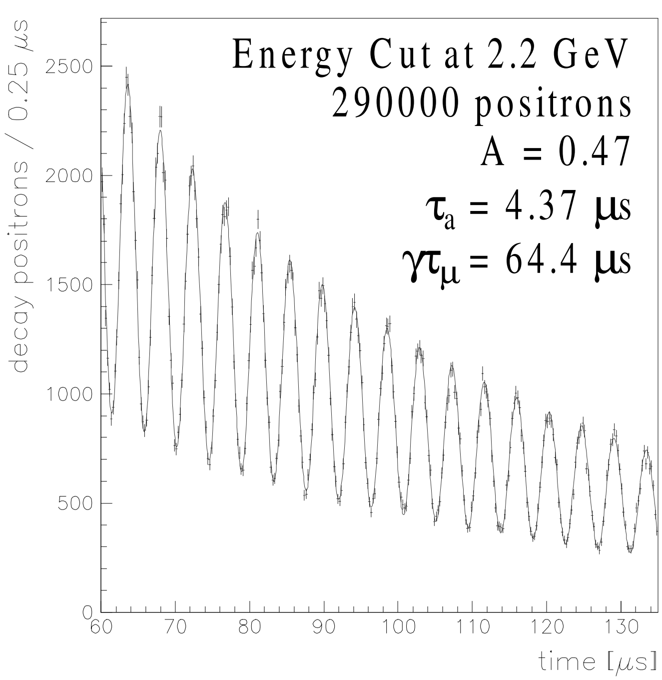
- *BES will perform fine scan in 2-5 GeV region Fall 1998*
- *hadronic vacuum polarisation also important for a_μ*

BNL:E821 a_μ

- Goal: measure $\mu^\pm$ anomalous magnetic moment to a high precision (0.35 ppm)
  - weak contribution is 1.3 ppm
- 14 m diameter ring constructed to store muons and precess their spins
  - at magic momentum $\vec{\omega}_a = -\frac{e}{m_\mu} a_\mu \vec{B}$
  - precise knowledge of average B necessary
- electrons from μ decay detected in Pb-sci-fi calorimeters
  - electrons preferentially decay along the μ spin direction
  - number of electrons above an energy cut will follow

$$N(t) = N_0 e^{-t/\gamma\tau_\mu}\left[1 - A\cos(\omega_a t + \phi)\right]$$

Results from the 1997 run



a_μ=1165925(15)×10^{-9}

previous results:

CERN μ^+
a_μ=1165910(11)×10^{-9}

CERN μ^-
a_μ=1165937(12)×10^{-9}

Expected error for 1998/1999 run:

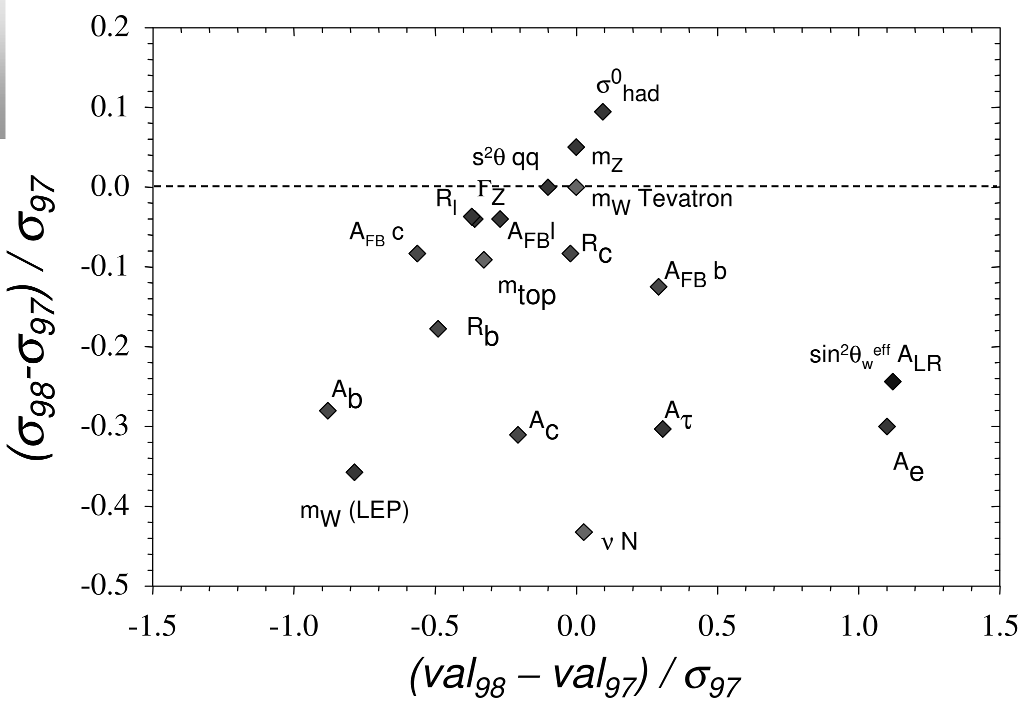
≈ 1×10^{-9}

SM interpretation of precision data

- Global electroweak fit using as input:
  - Z^0 measurements from LEP / SLC, m_W from LEP2 and Tevatron
  - $\sin^2\theta_W^{(on\text{-}shell)} = 0.2255 \pm 0.0021$ (NuTeV and CCFR)
  - $m_t = 173.8 \pm 5.0$ GeV (CDF and DØ)
  - $1/\alpha(m_Z) = 128.894 \pm 0.090$

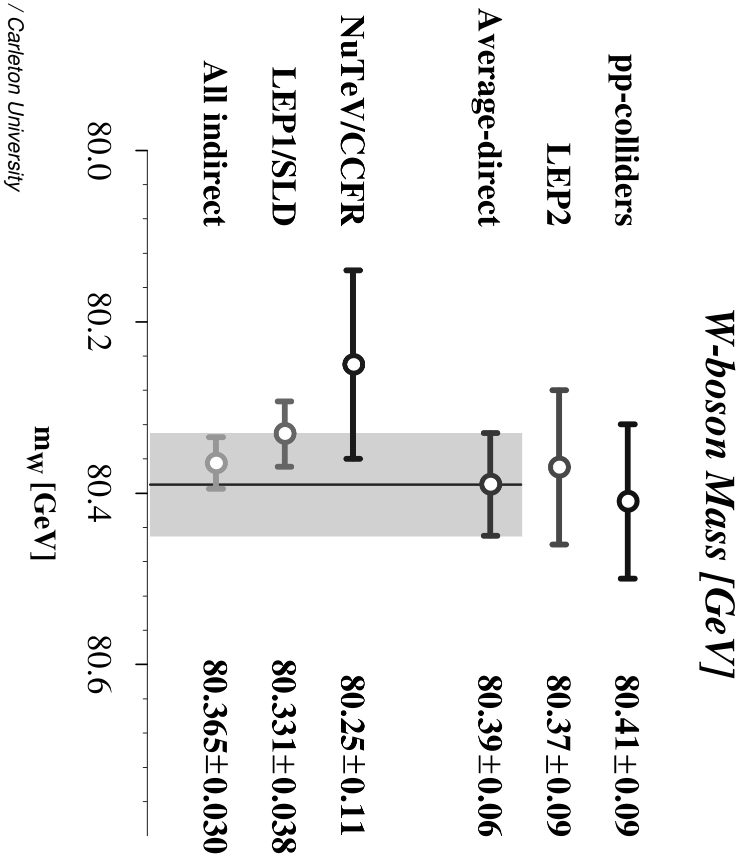
	LEP I and LEP II	all data except m_W	all data
m_t [GeV]	160^{+13}_{-10}	171.2 ± 4.9	171.3 ± 4.9
m_H [GeV]	66^{+142}_{-38}	92^{+101}_{-57}	84^{+91}_{-51}
$\alpha_s(m_Z^2)$	0.121 ± 0.003	0.120 ± 0.003	0.119 ± 0.003
χ^2 / d.o.f.	4.2 / 9	16.2 / 13	16.4 / 15
$\sin^2\theta^l_{eff}$	0.23182 ± 0.00023	0.23159 ± 0.00020	0.23156 ± 0.00019
m_W [GeV]	80.312 ± 0.038	80.365 ± 0.030	80.370 ± 0.027

Changes since Summer 1997



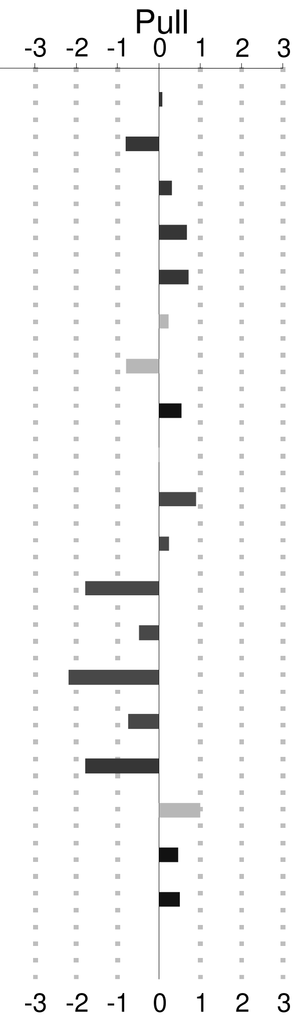
Dean Karlen / Carleton University

W mass summary



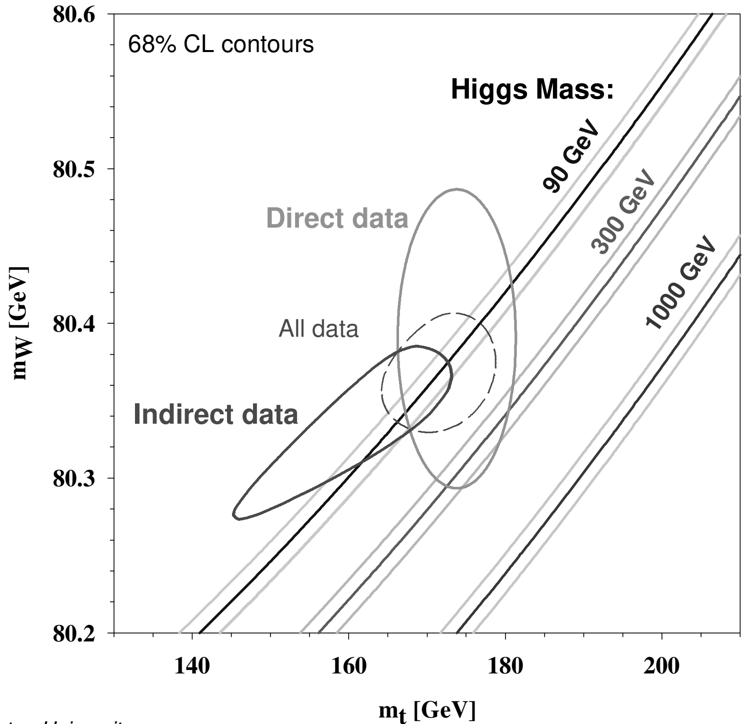
Pulls from SM fit to all data

	Measurement	Pull
m_Z (GeV)	91.1867 ± 0.0021	.08
Γ_Z (GeV)	2.4939 ± 0.0024	-.80
σ^0_{hadr} (nb)	41.491 ± 0.058	.31
R_e	20.765 ± 0.026	.66
$A^{0,e}_{fb}$	0.01683 ± 0.00096	.72
A_e	0.1479 ± 0.0051	.24
A_τ	0.1431 ± 0.0045	-.80
$\sin^2\theta^{LEPT}_{eff}$	0.2321 ± 0.0010	.54
m_W (GeV)	80.370 ± 0.090	.01
R_b	0.21656 ± 0.00074	.90
R_c	0.1733 ± 0.0044	.24
$A^{0,b}_{fb}$	0.0991 ± 0.0021	-1.78
$A^{0,c}_{fb}$	0.0714 ± 0.0044	-.47
A_b	0.856 ± 0.036	-2.18
A_c	0.638 ± 0.040	-.74
$\sin^2\theta^{LEPT}_{eff}$	0.23101 ± 0.00031	-1.78
$\sin^2\theta_W$	0.2255 ± 0.0021	1.06
m_W (GeV)	80.410 ± 0.090	.45
m_t (GeV)	173.8 ± 5.0	.50
$1/\alpha$	128.896 ± 0.090	-.04

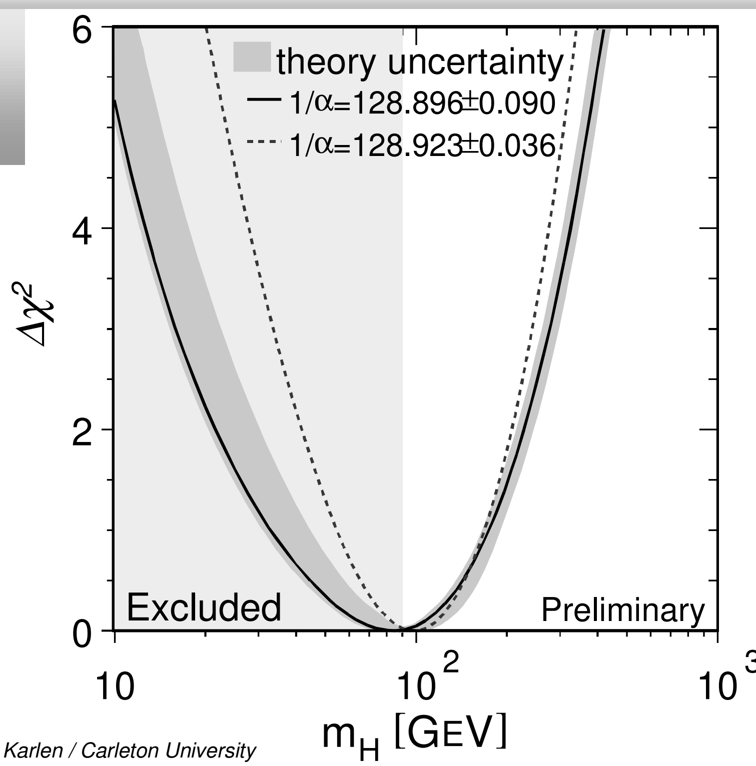


$\chi^2 / dof = 16.4 / 15$

Check indirect estimates of m_W & m_t



implications for m_H



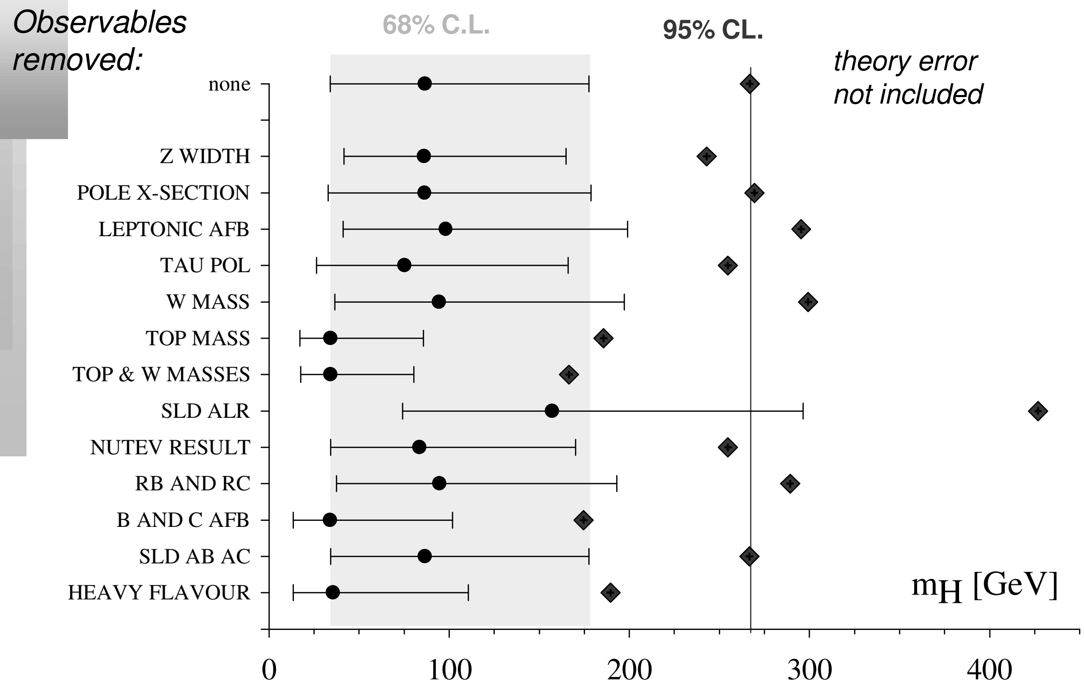
$m_H = 84^{+91}_{-51}$ GeV

m_H < 280 GeV
95% C.L.

direct search results not included in 95% CL.

mH precision depends strongly on $\alpha(m_Z)$

Influence of individual observables on m_H



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Summary and Future

- *Precision Z^0 measurements at LEP nearing completion*
  - *careful work on systematics*
  - *further data from SLD?*
- *LEP II data sample growing rapidly*
- *LEP future*
  - *year 2000 run approved*
  - *500 pb^{-1} per experiment within reach*
  - *still a chance for a direct Higgs mass measurement*
- *Tevatron future*
  - *Run II (2 fb^{-1}) $\Rightarrow$ 40 MeV precision on W mass*

The Standard Model still works!

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Special Thanks to...

- For their help, results, and many plots...
  - Bob Clare & LEP Electroweak group
  - Tom Bolton (NuTeV)
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  - Tatsuo Kawamoto, David Strom, Mark Thomson, Michael Kobel, Gideon Bella (OPAL)
  - Niels Kjaer (DELPHI)
  - Morris Swartz, Tony Johnson (SLD)
  - Fred Harris (BES)
  - Charles Timmermans (E821)