Z physics

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XX Physics in Collision Conference

Lisbon, 29 June - 1 July 2000

- Precision measurements at the Z resonance

- Fermion-pair production above the Z
- Production of Z bosons pairs: $e^+e^- \rightarrow ZZ$ and the couplings of the neutral gauge bosons
- Production of Z bosons and photons:
  $e^+e^- \rightarrow Z\gamma$
  $e^+e^- \rightarrow Z\gamma\gamma$
  and the couplings of neutral gauge bosons

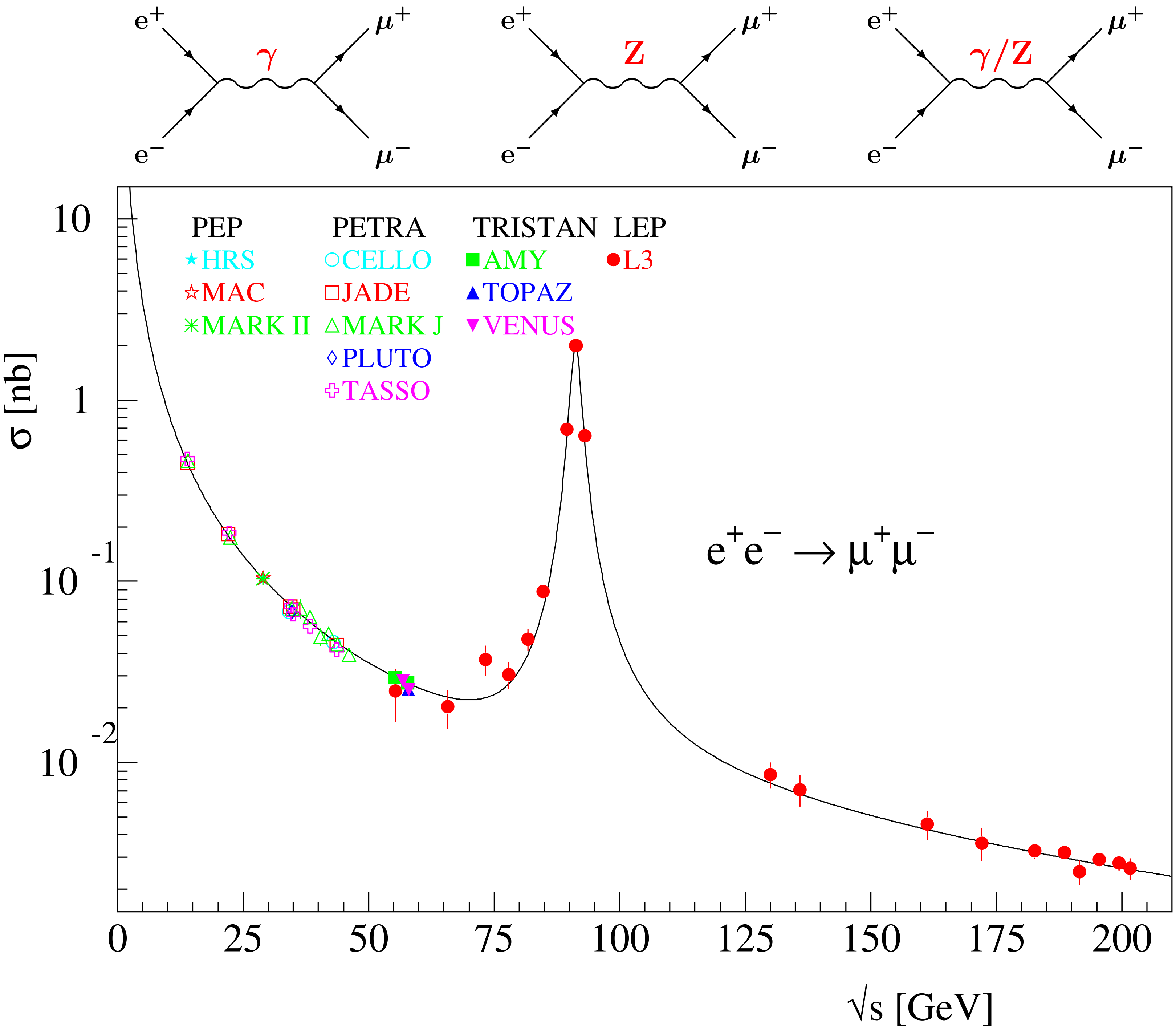
- Interpretation in the Standard Model and limits on the Higgs boson mass

New results from

- LEP up to $\sqrt{s} = 202$ GeV
- SLD

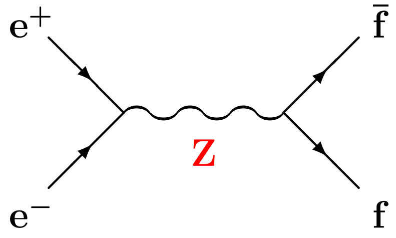
Most of the results are preliminary

S. Gentile – CERN EP



June 30^{th} 2000

Z lineshape



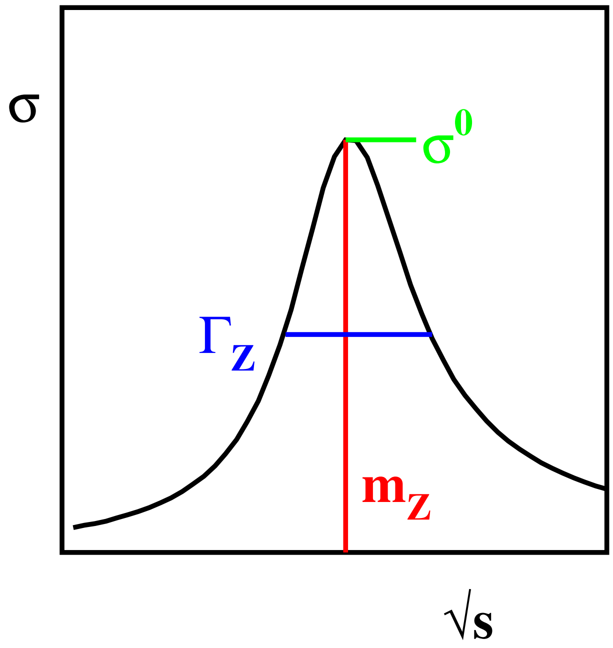
$e^+e^- \to \text{hadrons} \quad e^+e^- \to e^+e^-$

$e^+e^- \to \mu^+\mu^- \quad e^+e^- \to \tau^+\tau^-$

- 17 million Z decays observed at LEP (1989 – 1995)
- Precision measurements of total cross sections and leptonic forward-backward asymmetries at $\sqrt{s} \approx m_Z$ (LEP):

$$\sigma^0_{\text{had}} = \frac{12\pi}{m_Z^2}\frac{\Gamma_e\Gamma_{\text{had}}}{\Gamma_Z^2}, \quad R_\ell = \frac{\Gamma_{\text{had}}}{\Gamma_\ell},$$

$$A^{0,\ell}_{\text{FB}} = \frac{3}{4}A_e A_\ell, \quad A_\ell = \frac{2\bar{g}^\ell_V \bar{g}^\ell_A}{(\bar{g}^\ell_V)^2 + (\bar{g}^\ell_A)^2}$$



9 parameters:

m_Z Z mass

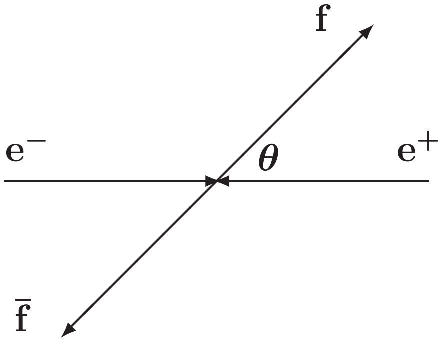
Γ_Z total width

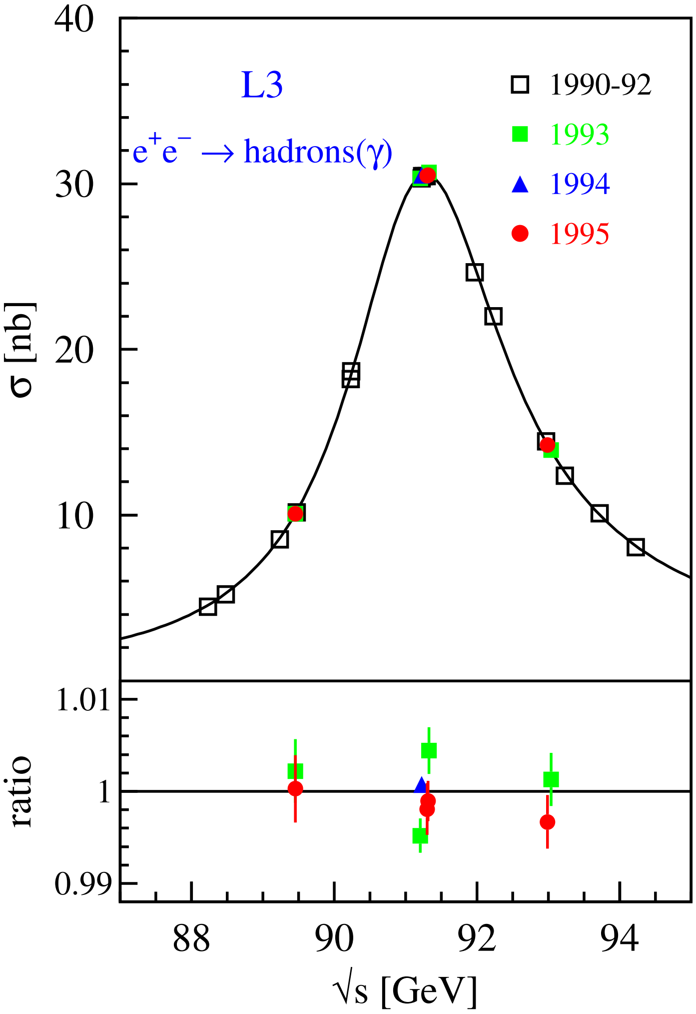
σ^0_{had} hadronic pole cross section

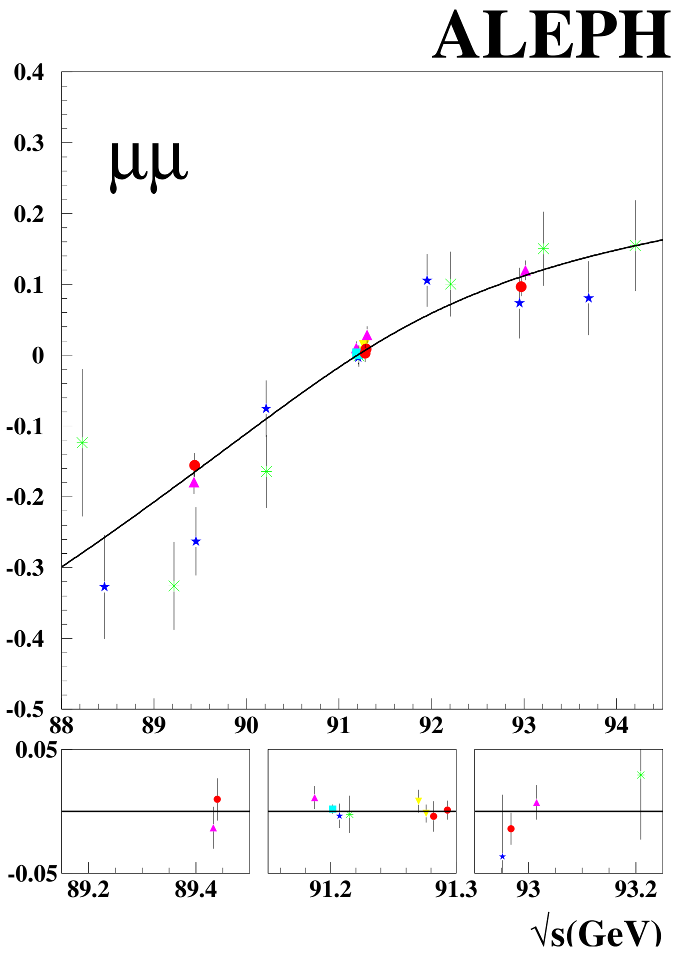
R_ℓ lepton cross sections

$A^{0,\ell}_{\text{FB}}$ lepton asymmetries

χ^2 fit to measured σ^0_{had} ,R_ℓ, $A^{0,\ell}_{\text{FB}}$







- LEP beam energy calibration: accuracy $10^{-5} \Longleftrightarrow \Delta m_Z$
- Improvement on theoretical calculations ISR: $\mathcal{O}(\alpha^2), \mathcal{O}(\alpha^3 L^3)$ $L = \ln(s/m_e^2)$ (ZFITTER 6.23,T0PAZ0 4.4)
- Finalising the experimental analyses: 3 LEP experiments have published FINAL lineshape results!

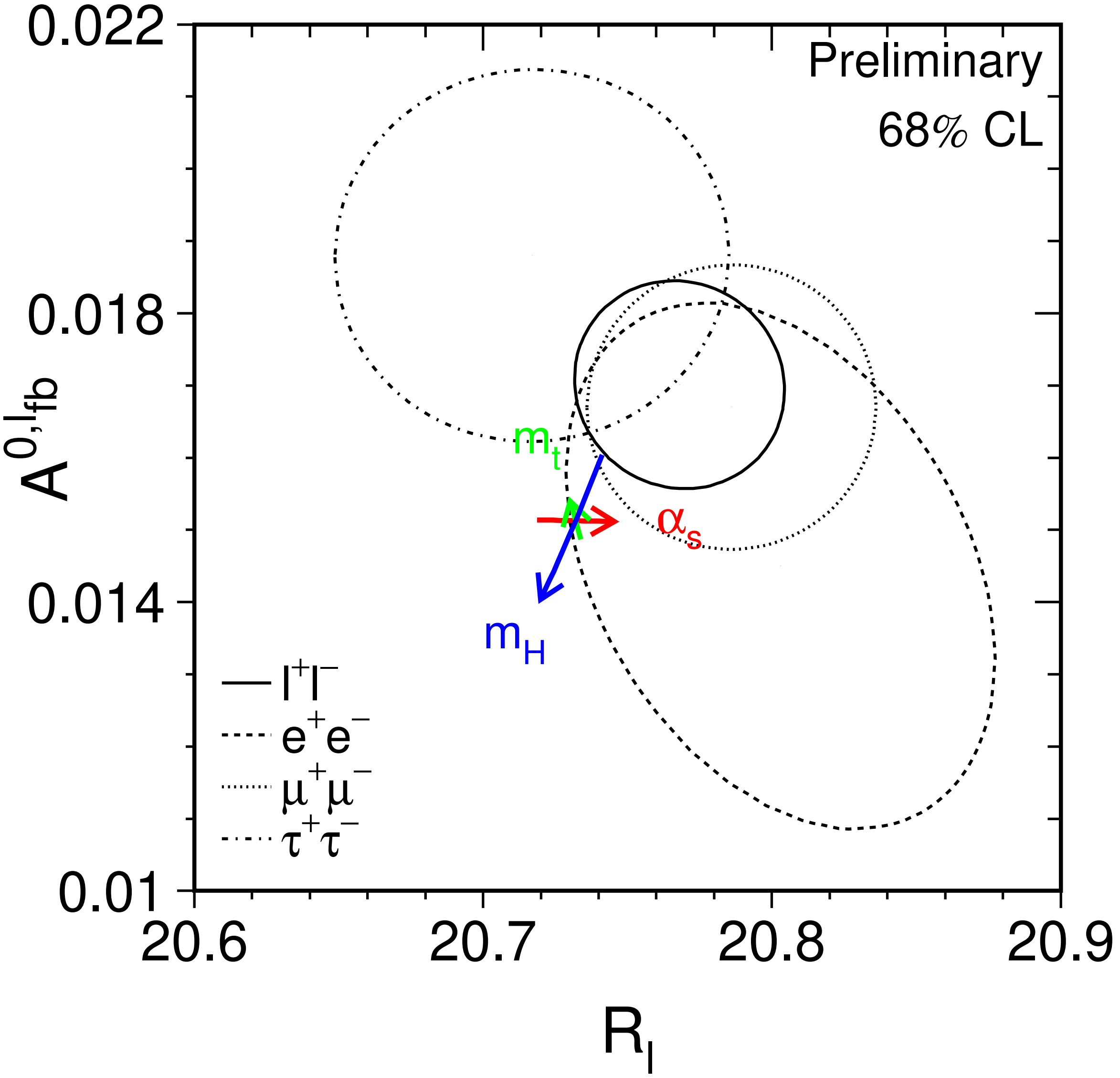
- **Experiments determine 9 parameter from total cross sections and forward-backward asymmetries**
- **Combination of the four LEP experiments:**

m_Z	$91\,187.2 \pm 2.1$ MeV
Γ_Z	$2\,499.4 \pm 2.4$ MeV
σ^0_{had}	41.544 ± 0.037 nb
R_e	20.803 ± 0.049
R_μ	20.786 ± 0.033
R_τ	20.764 ± 0.045
$A_{\mathrm{FB}}^{0,e}$	0.0145 ± 0.0024
$A_{\mathrm{FB}}^{0,\mu}$	0.0167 ± 0.0013
$A_{\mathrm{FB}}^{0,\tau}$	0.0188 ± 0.0017

- **Assuming lepton universality.**

$$R_\ell = 20.768 \pm 0.024 \qquad A_{\mathrm{FB}}^{0,\ell} = 0.01701 \pm 0.00095$$

- **Determination of α_s from R_ℓ**
  (QCD corrections $e^+e^- \to$ hadrons)
  ($\alpha_s = 0.1229 \pm 0.0036\,^{+0.0033}_{-0}(m_H)$)



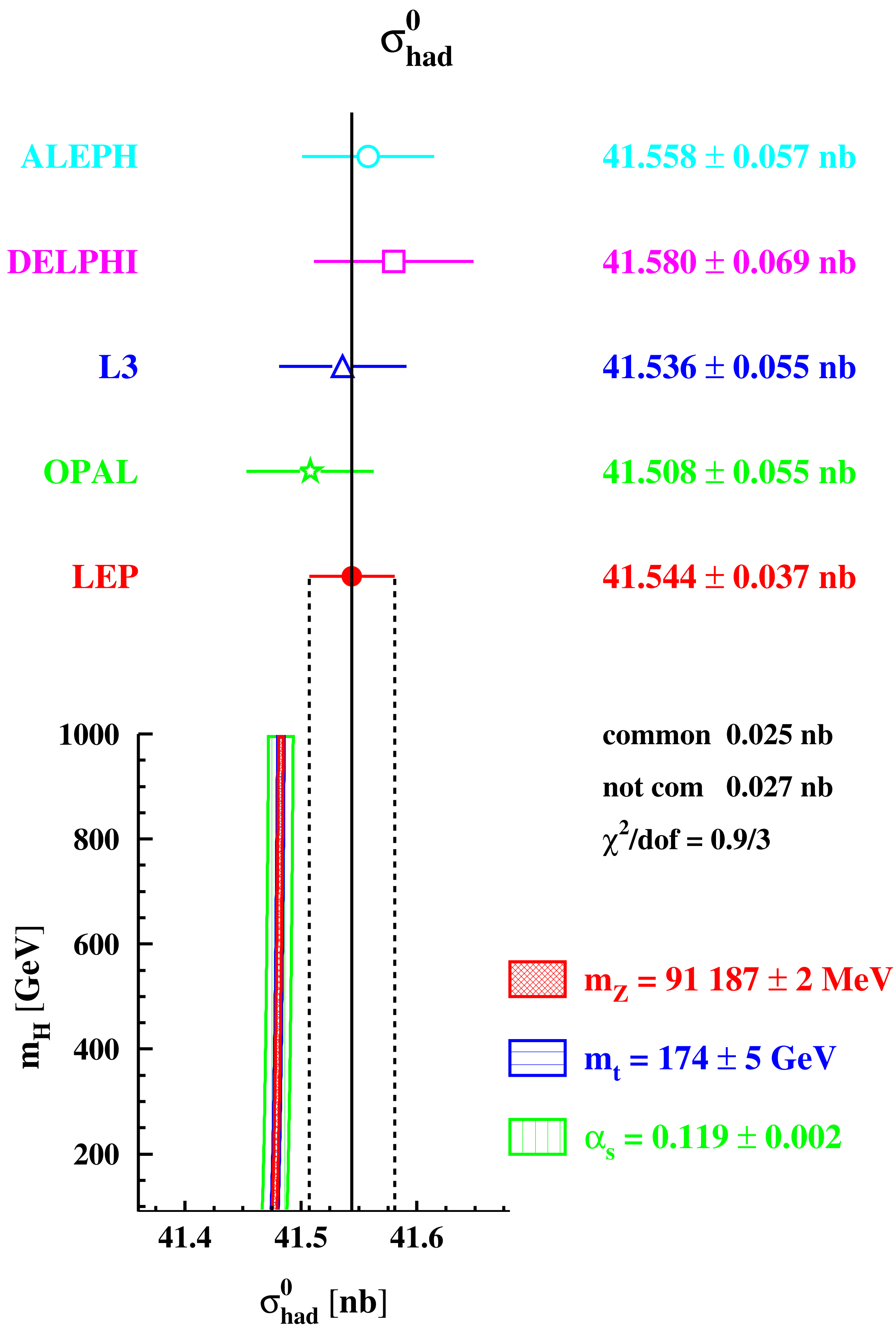
Partial decay widths:

$$\begin{aligned} \Gamma_{\rm had} &= 1743.9 \pm 2.0 \text{ MeV} \\ \Gamma_\ell &= 83.959 \pm 0.089 \text{ MeV} \\ \Gamma_{\rm inv} &= 498.80 \pm 1.5 \text{ MeV} \\ \Delta\Gamma_{\rm inv} &< 2.0 \text{ MeV} \qquad 95\% \text{ CL} \end{aligned}$$

$$\Gamma_{\rm inv} = \Gamma_Z - \Gamma_{\rm had} - 3\,\Gamma_\ell$$

Number of neutrino families:

$$N_\nu = \frac{\Gamma_{\rm inv}}{\Gamma_\ell}\left(\frac{\Gamma_\ell}{\Gamma_\nu}\right)^{\rm SM} = 2.9835 \pm 0.0083$$



σ^0_{had}
ALEPH
DELPHI
L3
OPAL
LEP
41.558 ± 0.057 nb
41.580 ± 0.069 nb
41.536 ± 0.055 nb
41.508 ± 0.055 nb
41.544 ± 0.037 nb
common 0.025 nb
not com 0.027 nb
χ^2/dof = 0.9/3
m_Z = 91 187 ± 2 MeV
m_t = 174 ± 5 GeV
α_s = 0.119 ± 0.002
m_H [GeV]
1000
800
600
400
200
41.4
41.5
41.6
σ^0_{had} [nb]

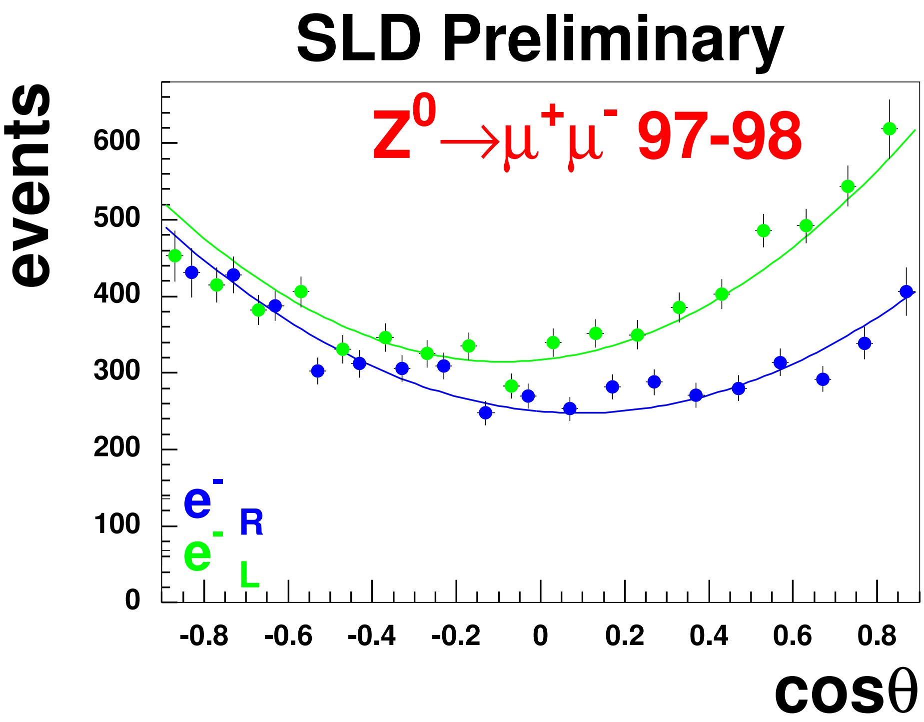
- SLD: 550k $e^+e^- \rightarrow$ hadrons(γ) events collected in total

  Polarized e^- beam

Left-right asymmetry $A_{FB}^{0,\ell}$ in $e^+e^- \rightarrow$ hadrons

$$A_{FB}^{0,\ell} = A_e = 0.1514 \pm 0.0022 \quad \text{FINAL}$$

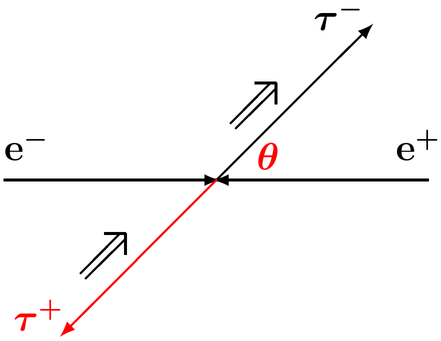
Left-right forward-backward asymmetries $e^+e^- \rightarrow \ell^+\ell^-$, improved measurement with large acceptance:

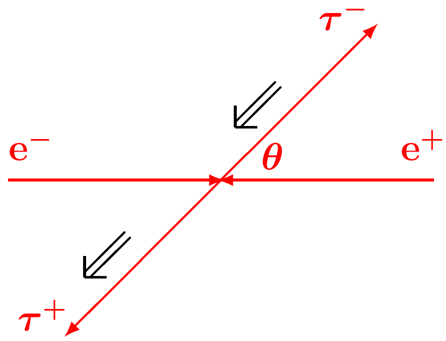


$$\begin{aligned}
A_e &= 0.1548 \pm 0.0058 \text{ (preliminary Moriond 2000)} \\
A_\mu &= 0.142 \pm 0.015 \text{ (preliminary Moriond 2000)} \\
A_\tau &= 0.140 \pm 0.015 \text{ (preliminary Moriond 2000)} \\
\hline
A_\ell &= 0.1514 \pm 0.0021 \text{ (preliminary Moriond 2000)}
\end{aligned}$$

Converted to the effective weak mixing angle. All combined in:

$$\sin^2\overline{\theta}_W = \frac{1}{4}\left(1 - \frac{\bar{g}_V^\ell}{\bar{g}_A^\ell}\right) = 0.23096 \pm 0.00026 \text{ (preliminary SLD)}$$





$$P_{\tau^-} = \frac{\sigma(\tau_R^-) - \sigma(\tau_L^-)}{\sigma(\tau_R^-) + \sigma(\tau_L^-)}$$

$$= -\frac{2\,\bar{g}_A^\tau\,\bar{g}_V^\tau}{(\bar{g}_A^\tau)^2 + (\bar{g}_V^\tau)^2} \equiv -A_\tau \quad (\sqrt{s} = m_Z)$$

Angular dependence:

$$P_{\tau^-}(\cos\theta) = \frac{(1+\cos^2\theta)\,A_\tau + 2\cos\theta\,A_e}{(1+\cos^2\theta) + 2\cos\theta\,A_\tau A_e}$$

Tau-polarization is derived from the momentum spectra of the decay products

$$\tau \longrightarrow e,\ \mu,\ \pi,\ \rho,\ a_1 \quad (+\nu)$$

Vector and axial-vector coupling constants of charged leptons

- **Partial decay widths:**

$$\Gamma_\ell \propto (\bar{g}_A^\ell)^2 + (\bar{g}_V^\ell)^2$$

- **Forward-backward asymmetry ($\sqrt{s} = m_Z$):**

$$A_{FB}^\ell = 3 \frac{\bar{g}_A^e \bar{g}_V^e}{(\bar{g}_A^e)^2 + (\bar{g}_V^e)^2} \frac{\bar{g}_A^\ell \bar{g}_V^\ell}{(\bar{g}_A^\ell)^2 + (\bar{g}_V^\ell)^2}$$

$A_{FB}(\sqrt{s} \neq m_Z)$ solves ambiguity in $\bar{g}_V$ and $\bar{g}_A$

- **Tau-polarization:**

$$A_\tau = 2 \frac{\bar{g}_A^\tau \bar{g}_V^\tau}{(\bar{g}_A^\tau)^2 + (\bar{g}_V^\tau)^2}$$
$$A_e = 2 \frac{\bar{g}_A^e \bar{g}_V^e}{(\bar{g}_A^e)^2 + (\bar{g}_V^e)^2}$$

- **From SLD left-right asymmetry**

$$A_{FB}^{0,\ell} = A_e$$

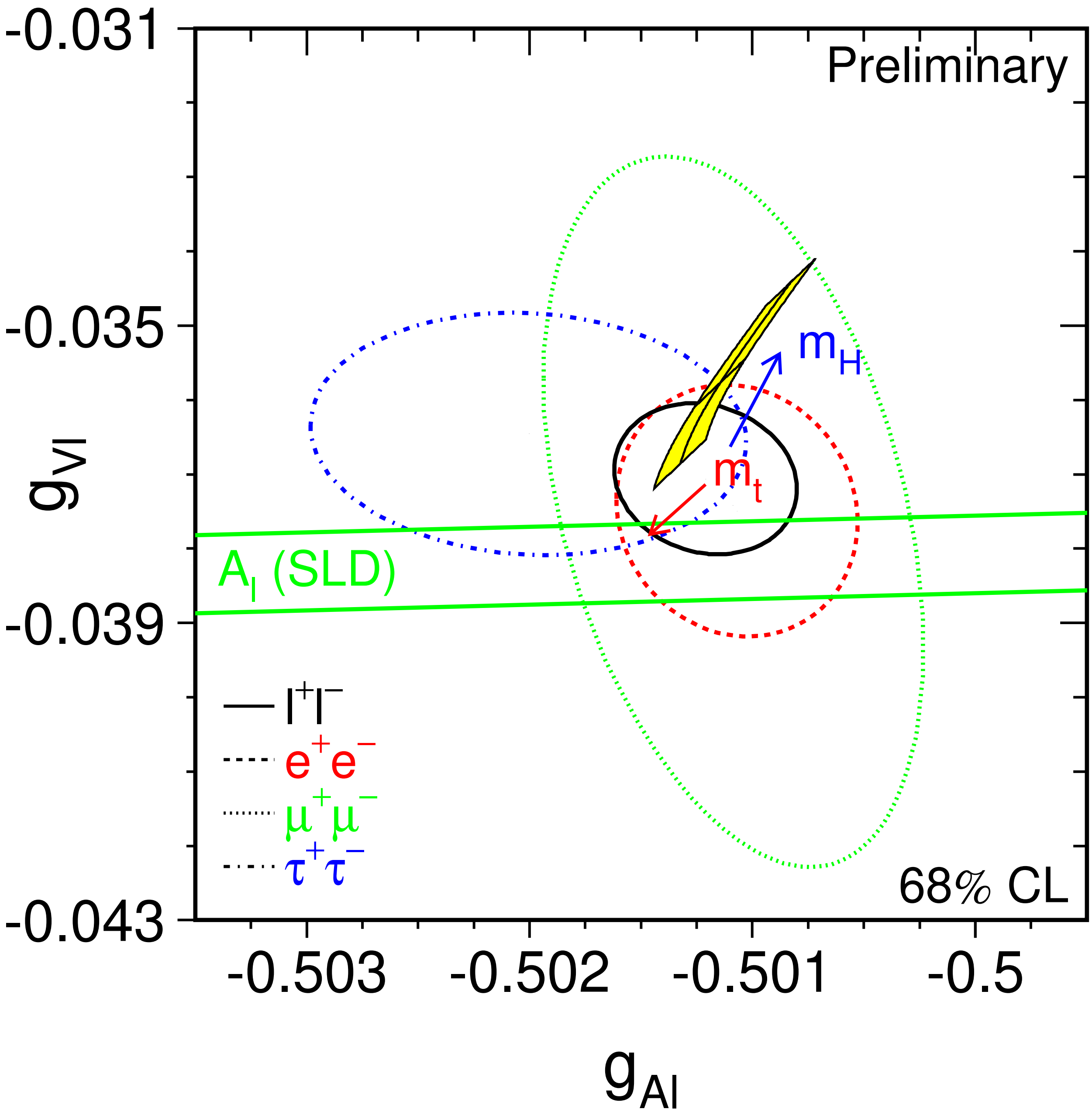
- **From SLD left-right forward-backward asymmetery**

$$A_e, A_\mu, A_\tau$$

$\Longrightarrow$ **Determination of $\bar{g}_A^\ell$ and $\bar{g}_V^\ell$**
Test of lepton universality

Include LEP tau polarization measurements:

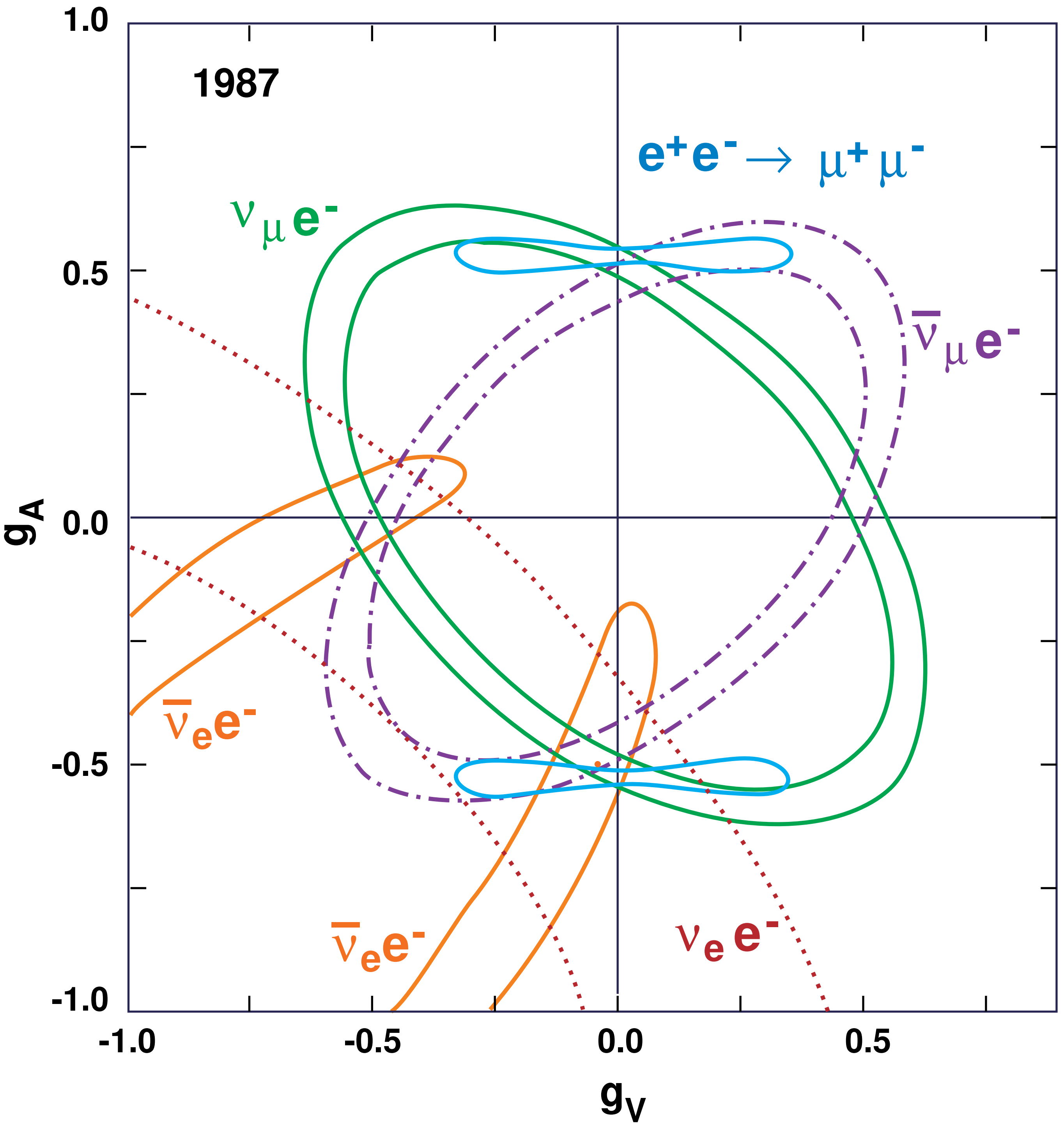
$$\mathcal{A}_{e} = 0.1483 \pm 0.0051$$
$$\mathcal{A}_{\tau} = 0.1425 \pm 0.0044$$



Ratios of neutral current coupling constants (LEP & SLD):

$$\bar{g}_A^\mu/\bar{g}_A^e = 1.0002 \pm 0.0013 \qquad \bar{g}_V^\mu/\bar{g}_V^e = 0.955 \pm 0.063$$
$$\bar{g}_A^\tau/\bar{g}_A^e = 1.0019 \pm 0.0015 \qquad \bar{g}_V^\tau/\bar{g}_V^e = 0.954 \pm 0.030$$

- Year 1987: Before LEP



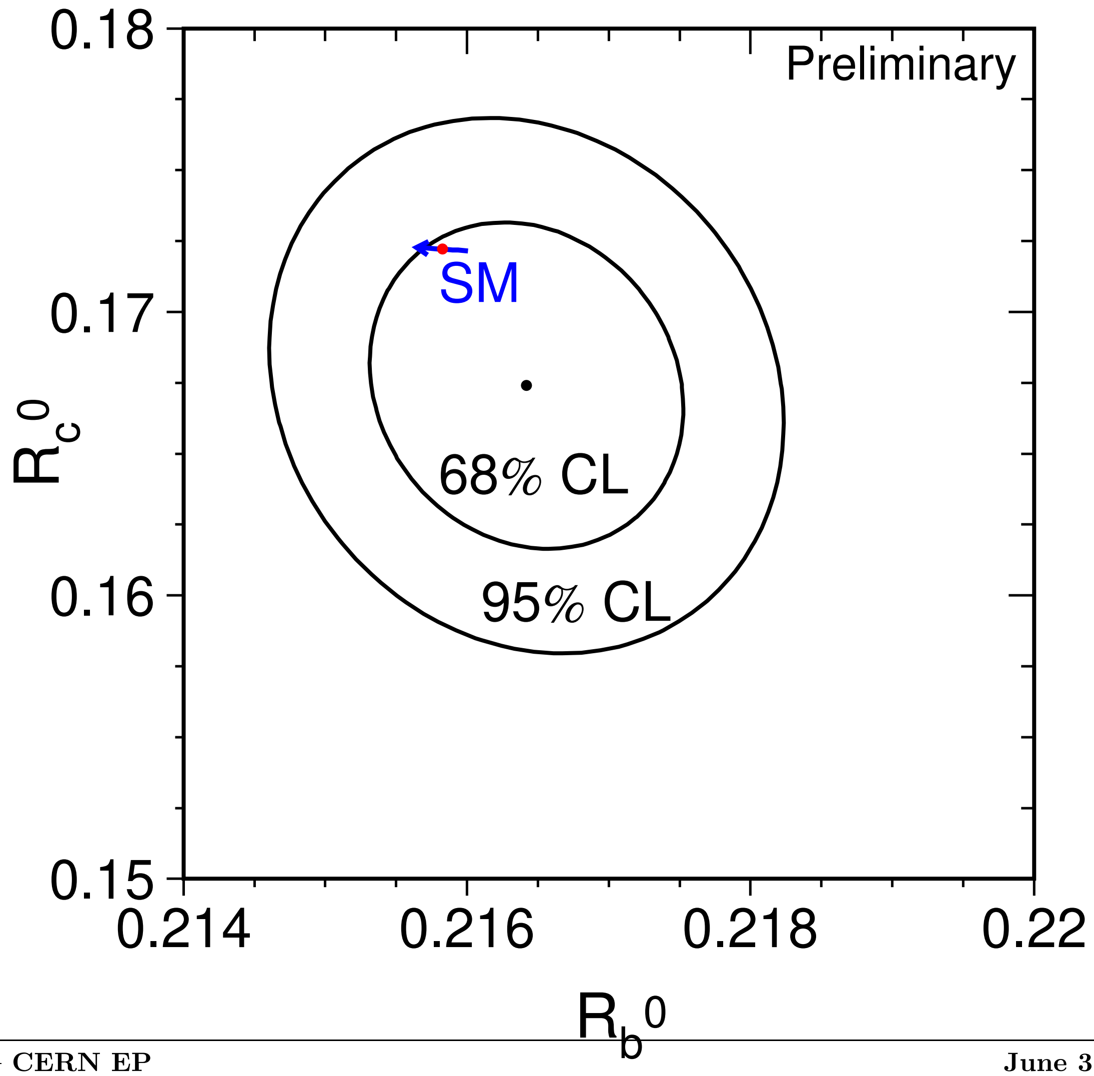
Measurements of

- Cross sections (R_{b}, R_{c}) at LEP & SLD
  $R_{\mathrm{q}} = \Gamma_{\mathrm{q}}/\Gamma_{\mathrm{had}}$ $\qquad$ $\Gamma_{\mathrm{q}} \propto (\bar{g}^{\mathrm{q}}_{\mathrm{A}})^2 + (\bar{g}^{\mathrm{q}}_{\mathrm{V}})^2$
- Forward-backward asymmetries at LEP
  $A^{0,\mathrm{b}}_{\mathrm{FB}}$, $A^{0,\mathrm{c}}_{\mathrm{FB}}$
- Left-right forward-backward asymmetries
  A_{b}, A_{c} $\qquad$ $A_{\mathrm{q}} = \frac{2\,\bar{g}^{\mathrm{q}}_{\mathrm{A}}\bar{g}^{\mathrm{q}}_{\mathrm{V}}}{(\bar{g}^{\mathrm{q}}_{\mathrm{A}})^2+(\bar{g}^{\mathrm{q}}_{\mathrm{V}})^2}$

Combined fit to LEP & SLD data:

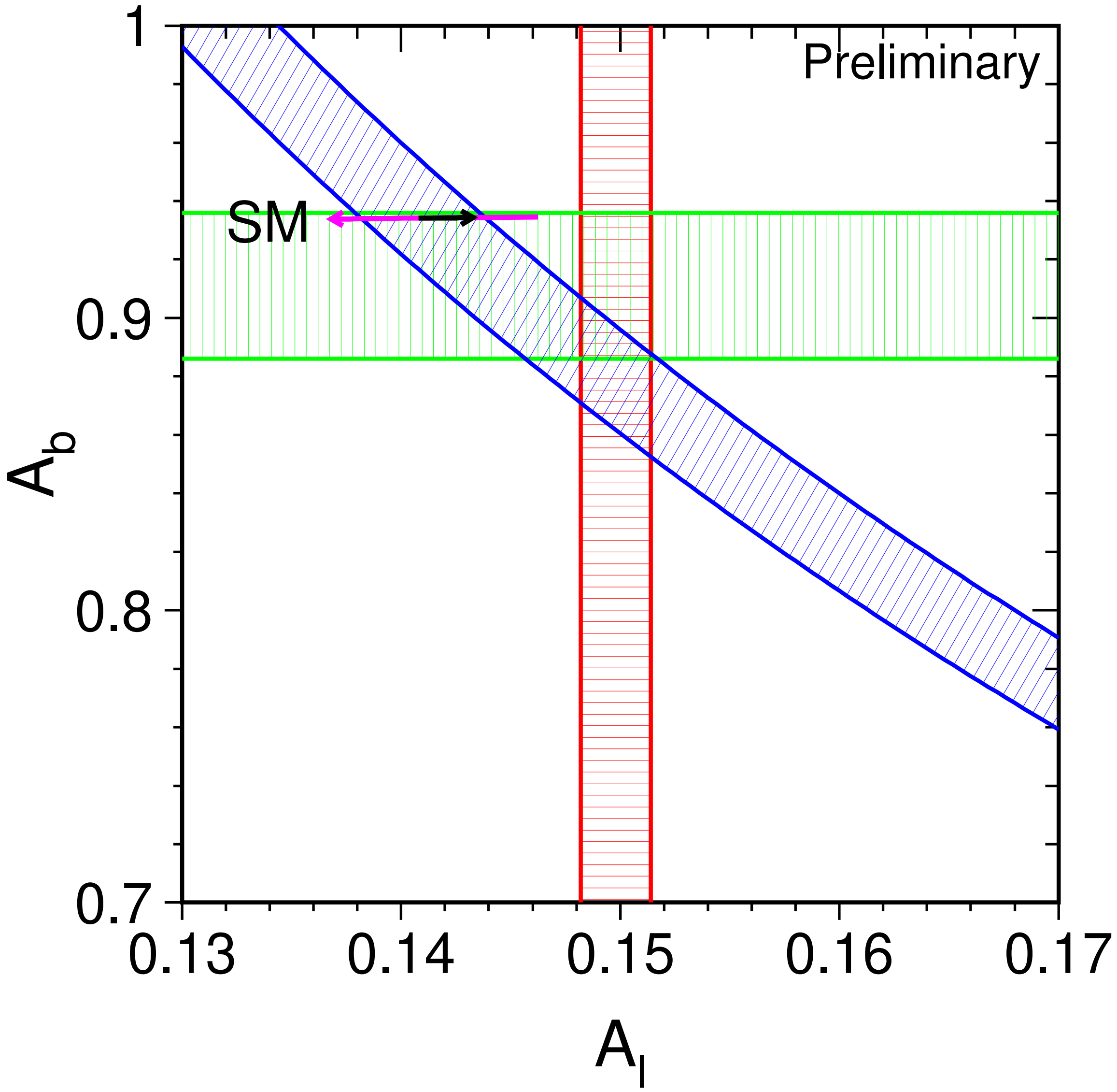
$$\begin{aligned} R_{\mathrm{b}} &= 0.21642 \pm 0.00073 & R_{\mathrm{c}} &= 0.1674 \pm 0.0038 \\ A^{0,\mathrm{b}}_{\mathrm{FB}} &= 0.0988 \pm 0.0020 & A^{0,\mathrm{c}}_{\mathrm{FB}} &= 0.0692 \pm 0.0037 \\ A_{\mathrm{b}} &= 0.911 \pm 0.025 & A_{\mathrm{c}} &= 0.630 \pm 0.026 \end{aligned}$$

most recent updates of A_{c} by SLD are not included.

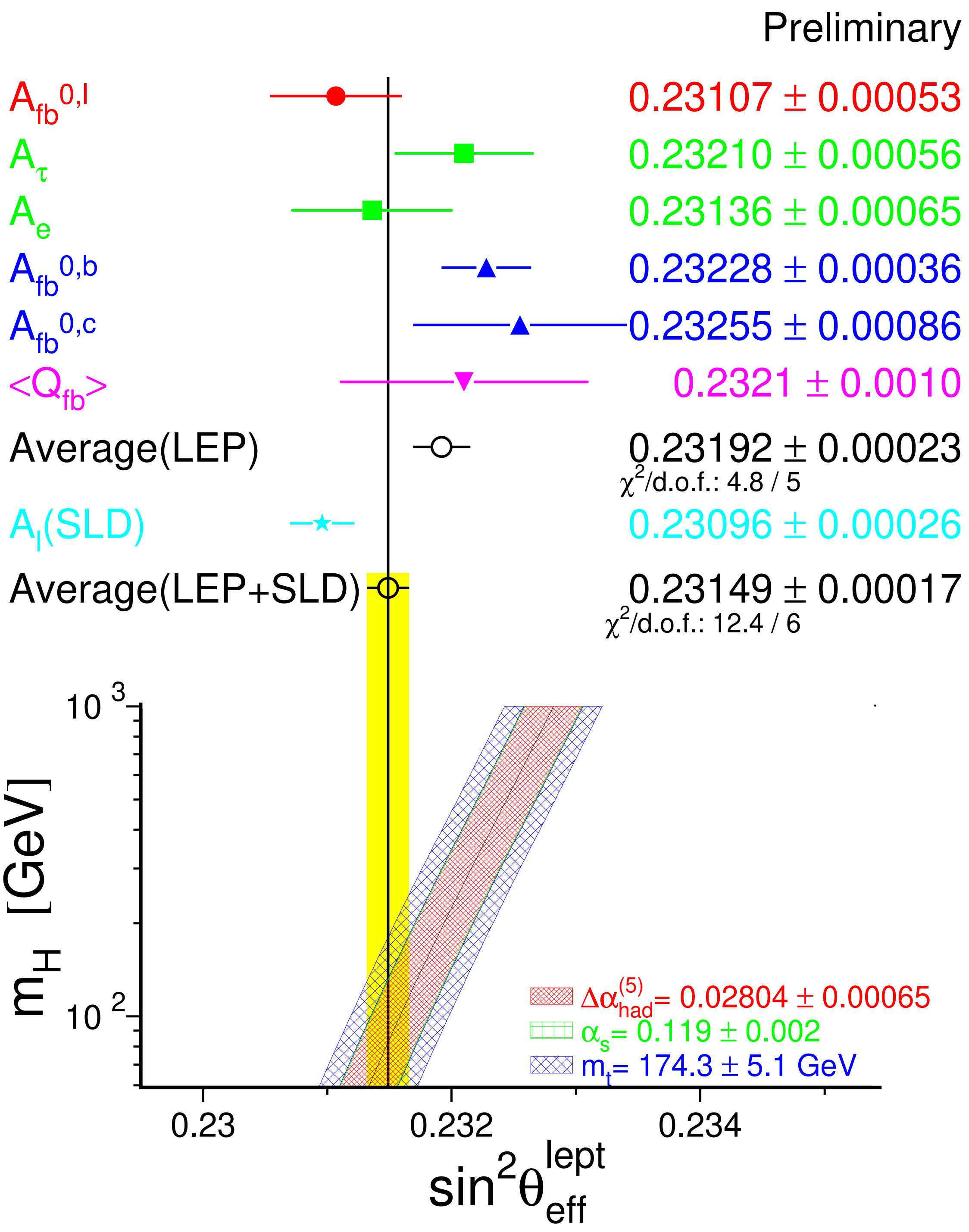


Comparison of

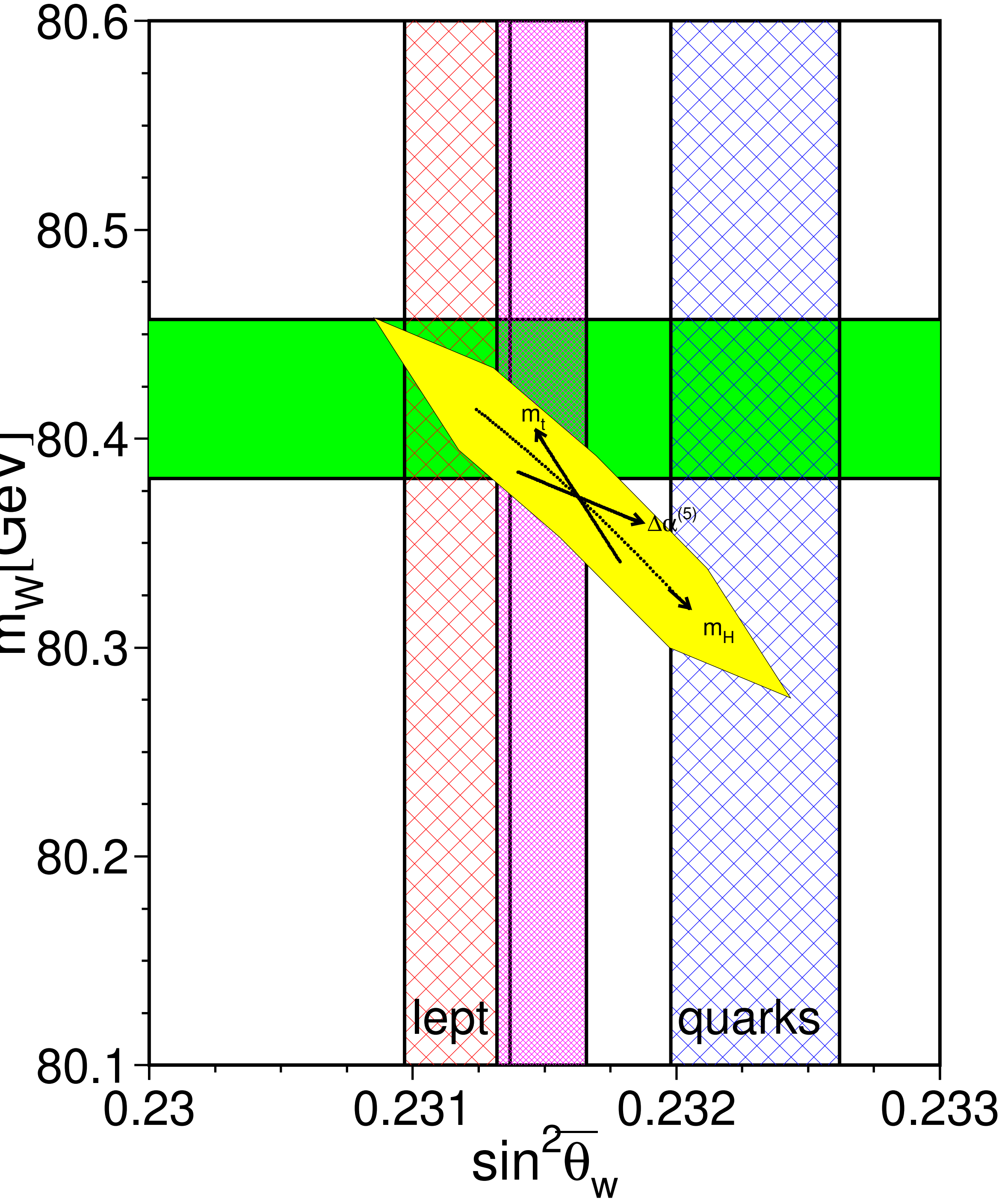
- A_{b} (left-right forward-backward asymmetry)
- A_ℓ (A_{LR}, $A_{\mathrm{FB}}^{0,\ell}$, tau-polarization)
- $A_{\mathrm{FB}}^{0,\mathrm{b}} = \frac{3}{4} A_\ell A_{\mathrm{b}}$
- SM (m_{H}, m_{t})



	LEP	SLD	LEP & SLD	SM
A_ℓ	0.1471 ± 0.0026		0.1493 ± 0.0015	
A_{b}	0.896 ± 0.024	0.911 ± 0.025	0.892 ± 0.016	0.935
A_{c}	0.625 ± 0.035	0.630 ± 0.026	0.624 ± 0.021	0.668



- **LEP and SLD averages still different**

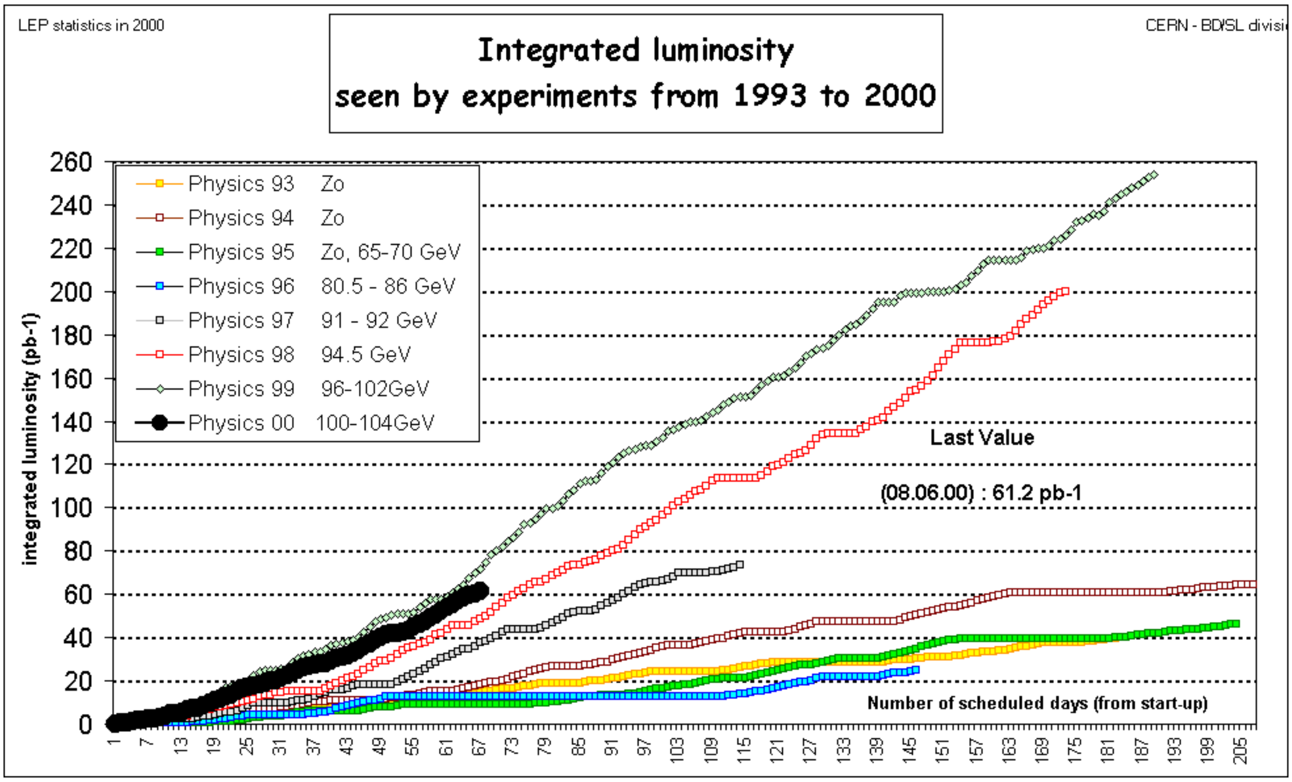


- A_ℓ and A_b still different

- **LEP II: Physics above the Z resonance**

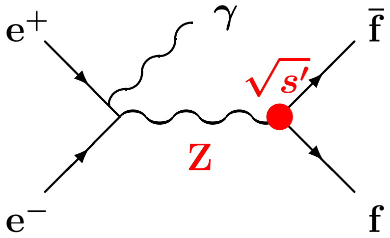
Centre-of-mass energies and approximate luminosities per experiment:

Year	$\sqrt{s}$	$\int\mathcal{L}\,dt$
1995	130 – 140 GeV	5 pb^{-1}
1996	161/172 GeV	21 pb^{-1}
1997	183 GeV	55 pb^{-1}
	130/136 GeV	7 pb^{-1}
1998	189 GeV	180 pb^{-1}
1999	192 – 202 GeV	240 pb^{-1}
2000	202 – 208 GeV	$>$ 62 pb^{-1}



$e^+e^- \to f\bar{f}$ above the Z resonance

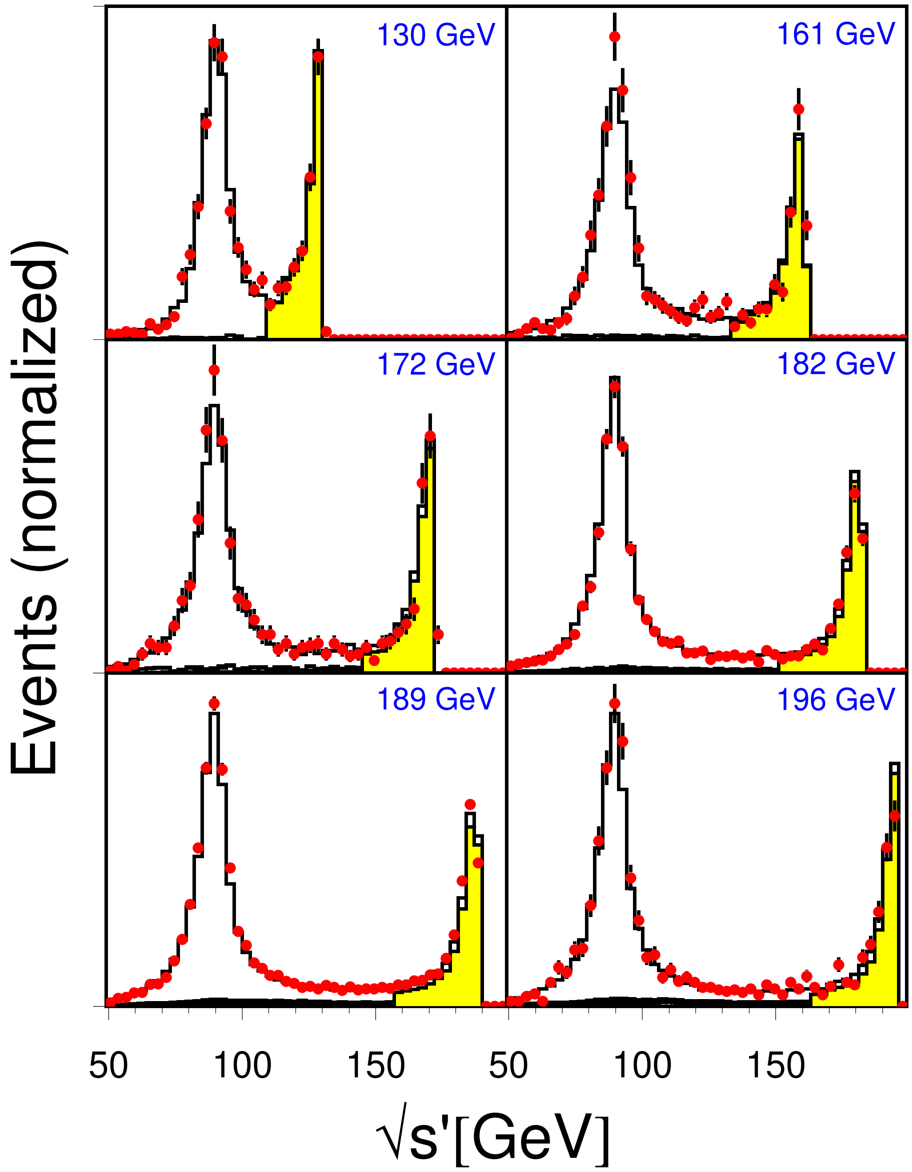
Important contribution from initial state radiation:



Return-to-the-Z

Effective cms energy $\sqrt{s'}$ in $e^+e^- \to$ hadrons(γ)

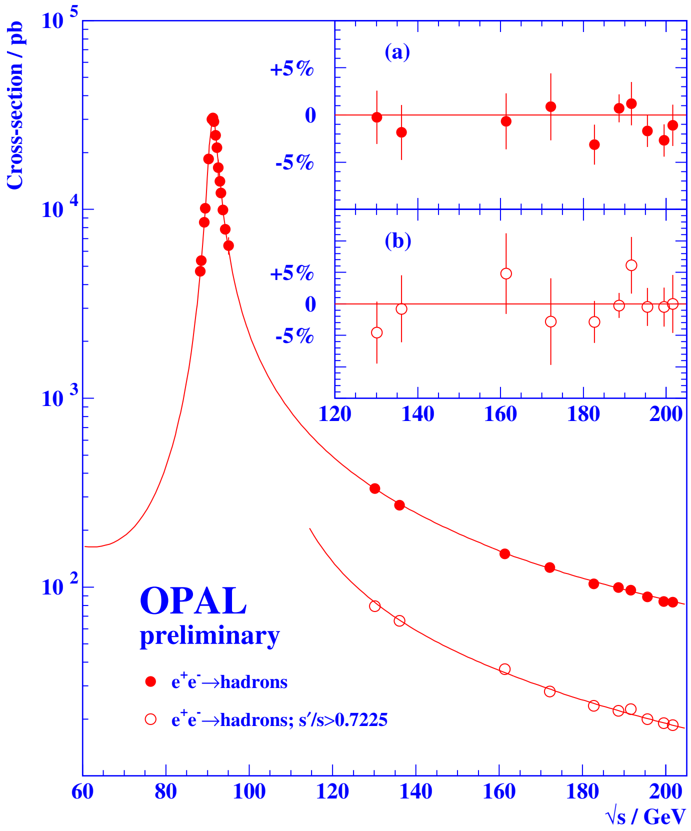
Data samples from $\sqrt{s} = 130$ GeV to $\sqrt{s} = 196$ GeV:

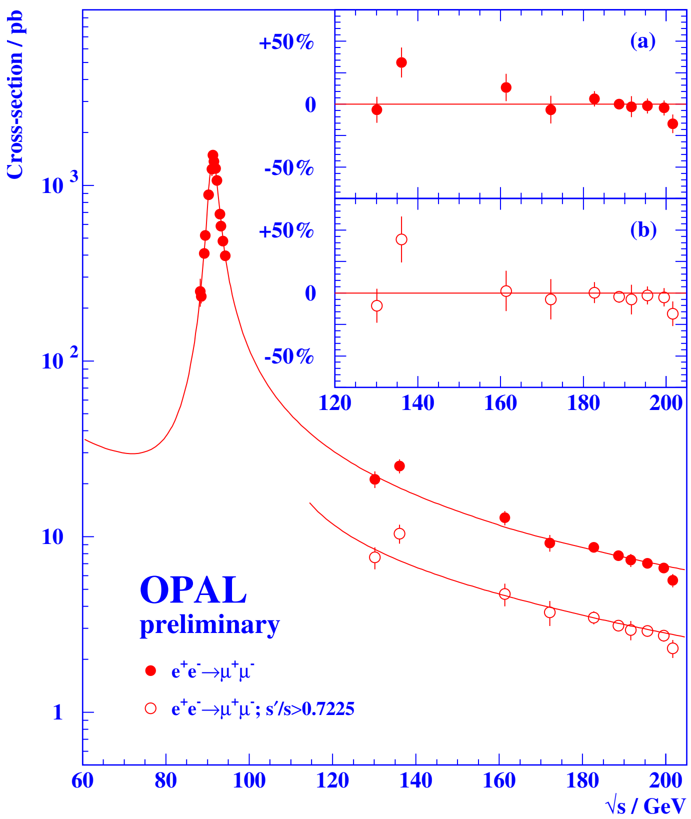


Measure cross sections and asymmetries for

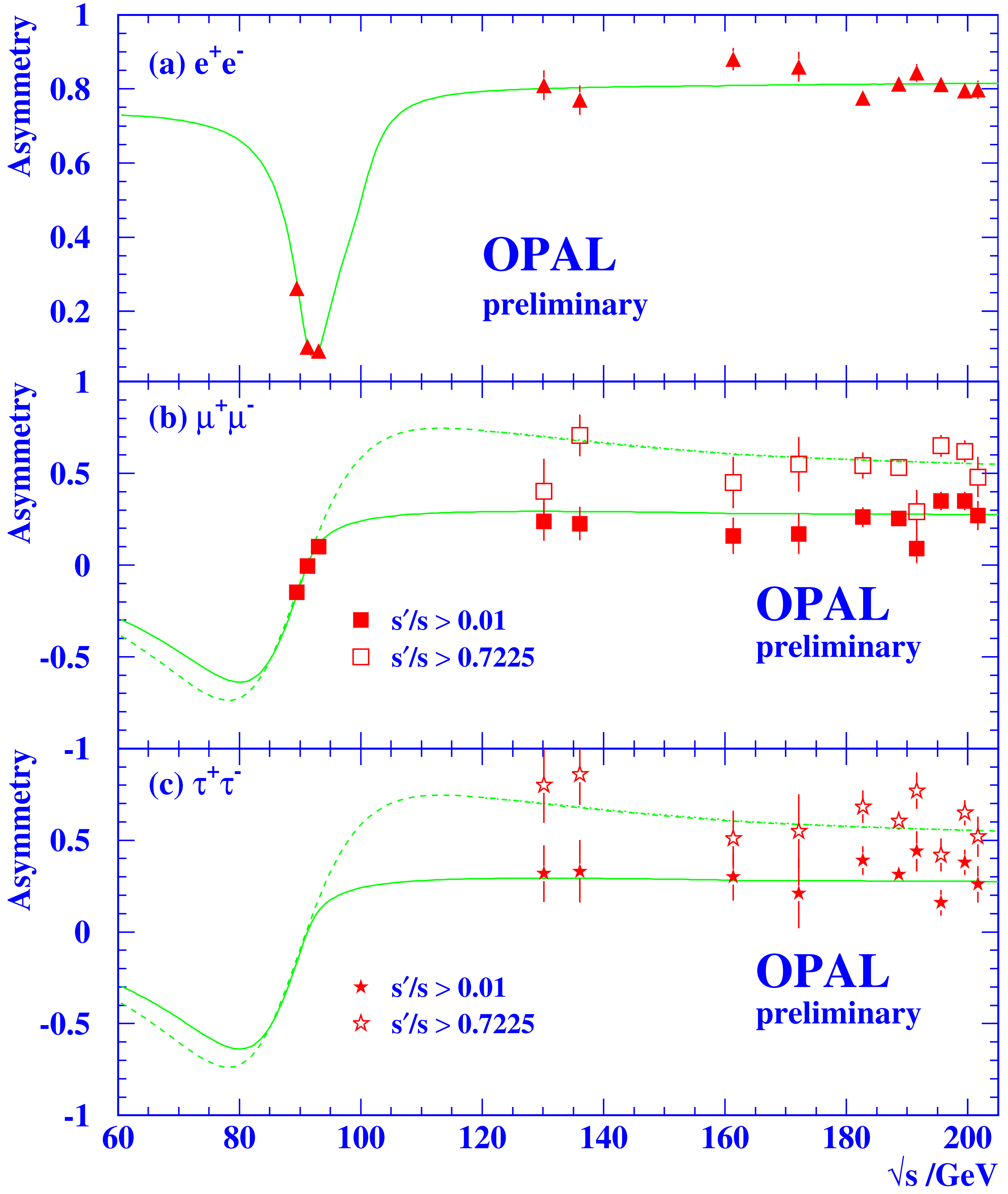
- Inclusive sample
- High energy sample $\sqrt{s'} > 0.85\sqrt{s}$

- **Quark- and lepton-pair cross sections up to $\sqrt{s} = 202$ GeV**

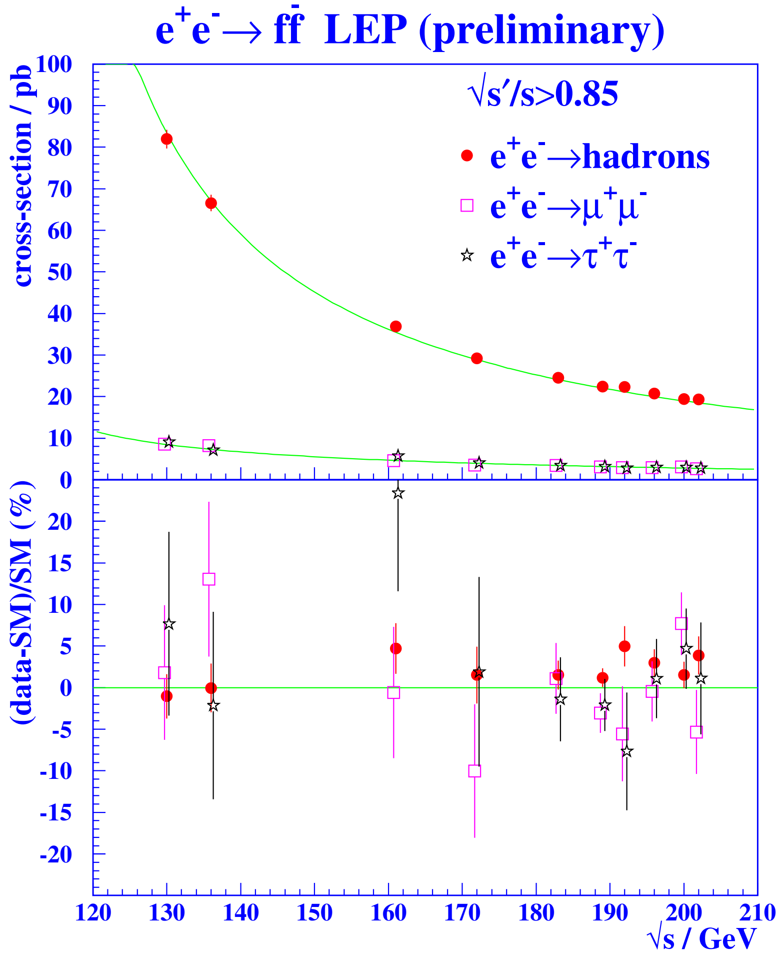




• Leptonic forward-backward asymmetries up to $\sqrt{s} = 202$ GeV



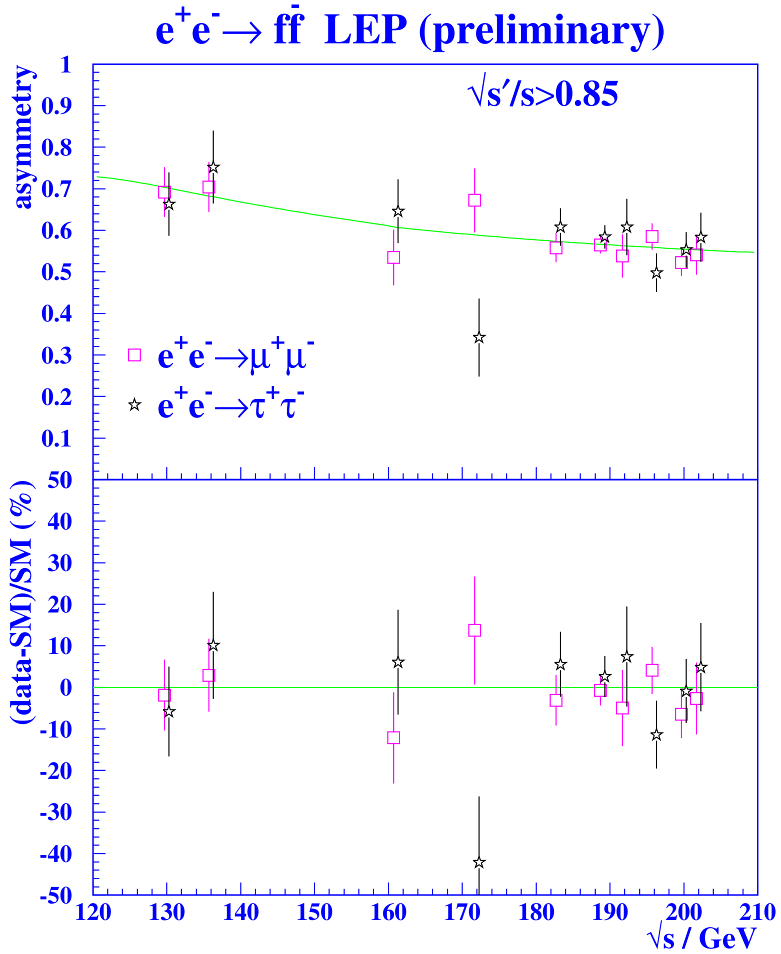
$e^+e^- \to f\bar{f}$ above the Z resonance



LEP combination

183 GeV $\leq \sqrt{s} \leq$ 202 GeV

(Difference to SM)

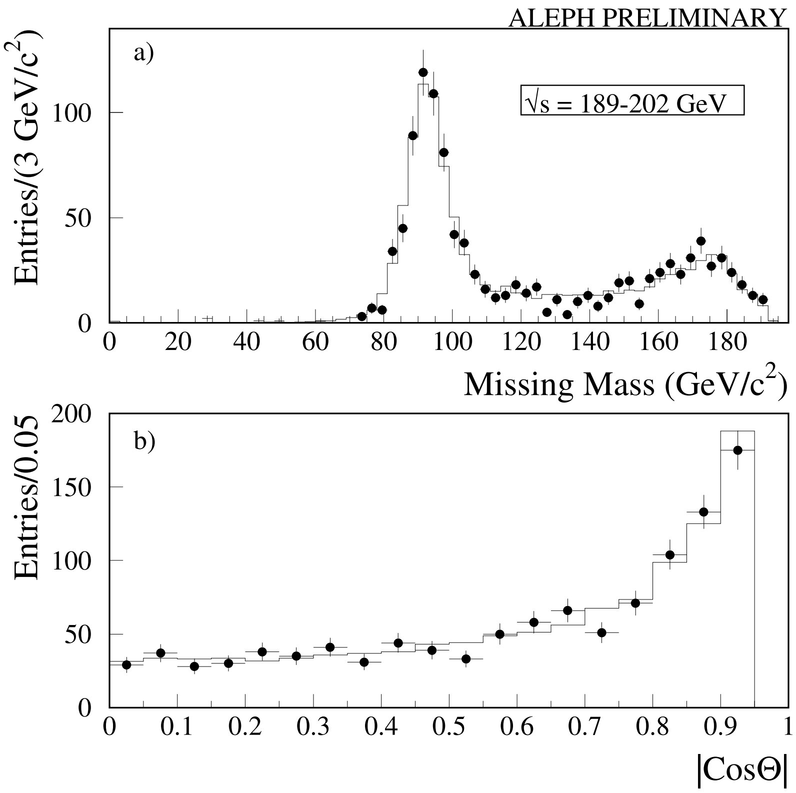


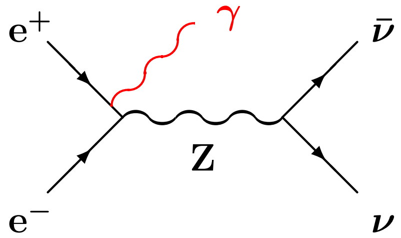
LEP combination

183 GeV $\leq \sqrt{s} \leq$ 202 GeV

(Difference to SM)

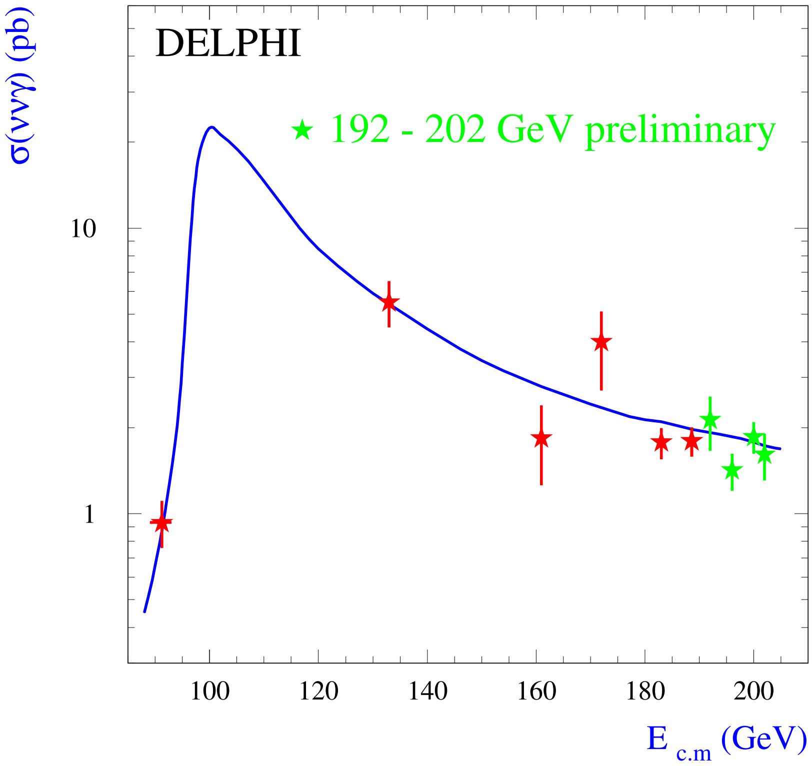
Cross section $e^+e^- \to \nu\bar{\nu}$ from single photon events





$\sqrt{s} \geq 189$ GeV

$\approx$ 1100 events per expt.



# of neutrinos

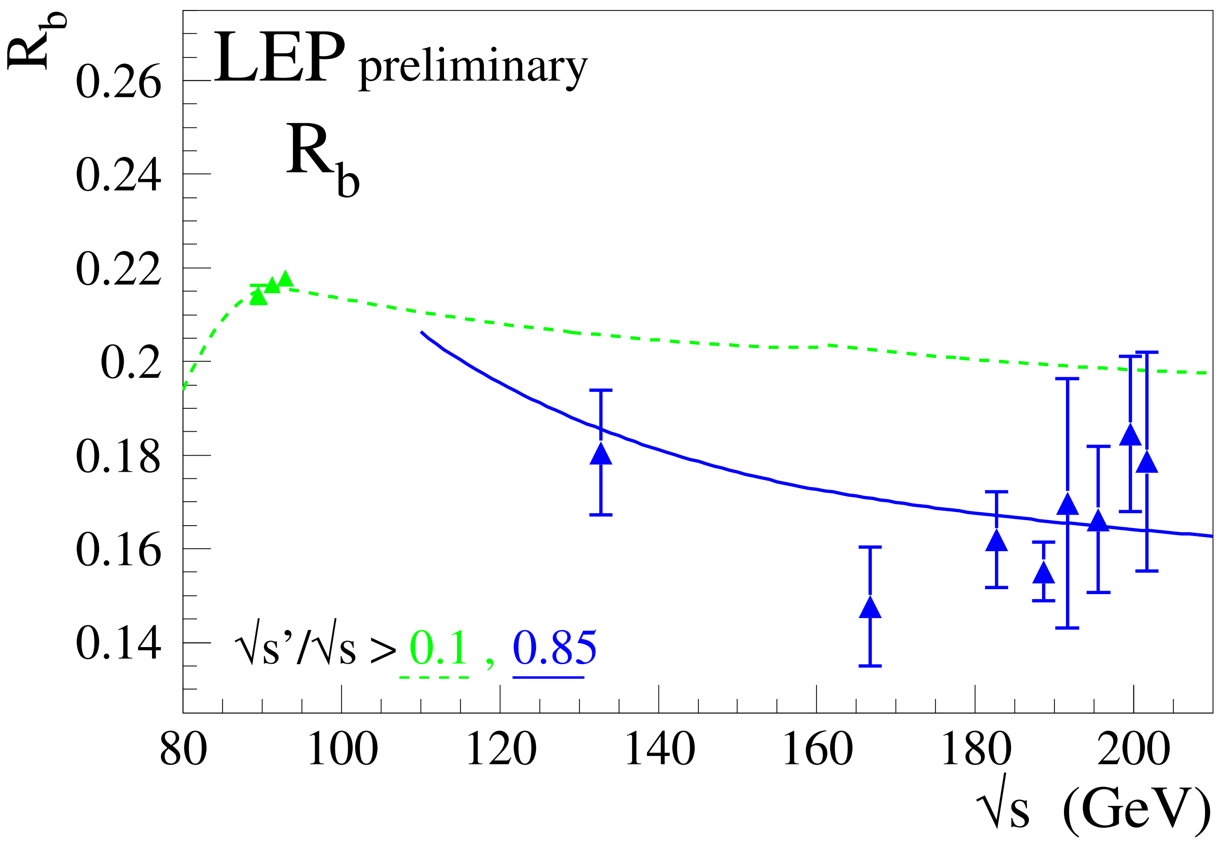
($\sqrt{s} = 189 - 202$ GeV)

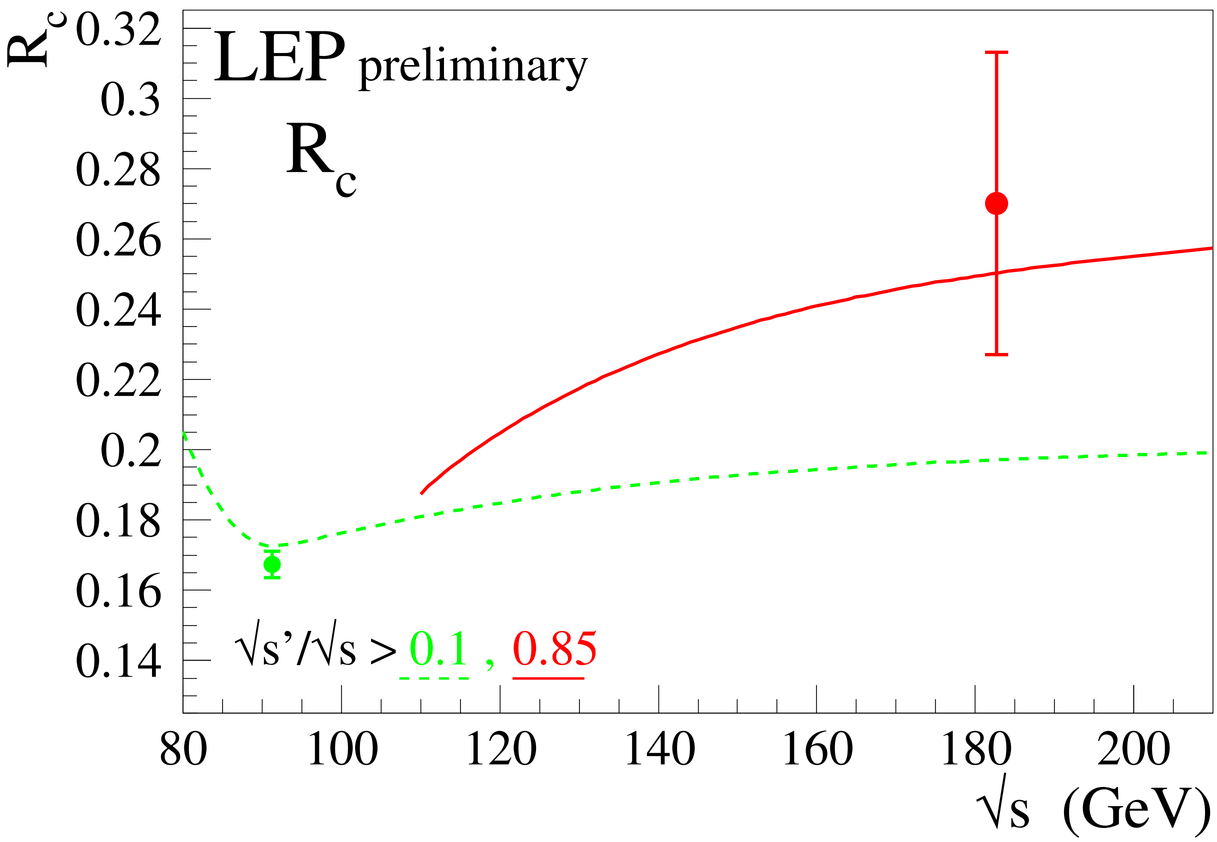
L3	**3.05 ± 0.12**
DELPHI	**2.82 ± 0.17**

LEP I

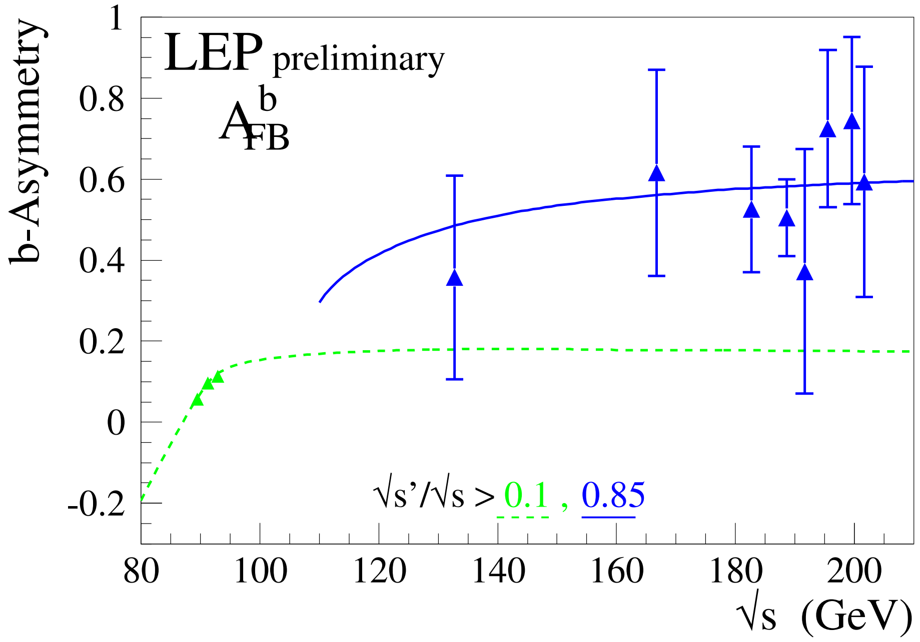
single γ	**3.00 ± 0.08**
lineshape	**2.9835 ± 0.0083**

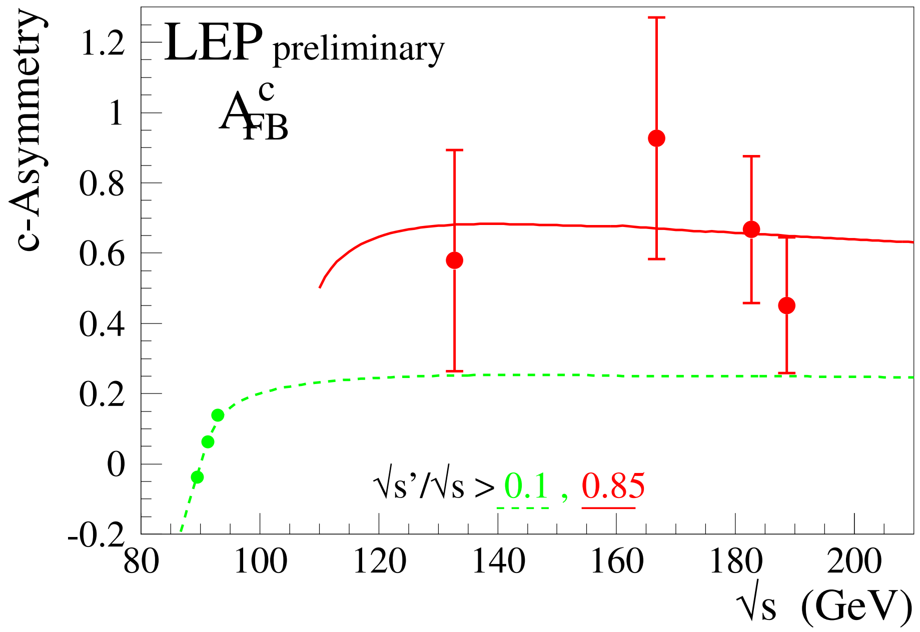
- **Measurement of** $R_b = \sigma(e^+e^- \to b\bar{b})/\sigma(e^+e^- \to q\bar{q})$





- **Measurement of forward-backward asymmetries**





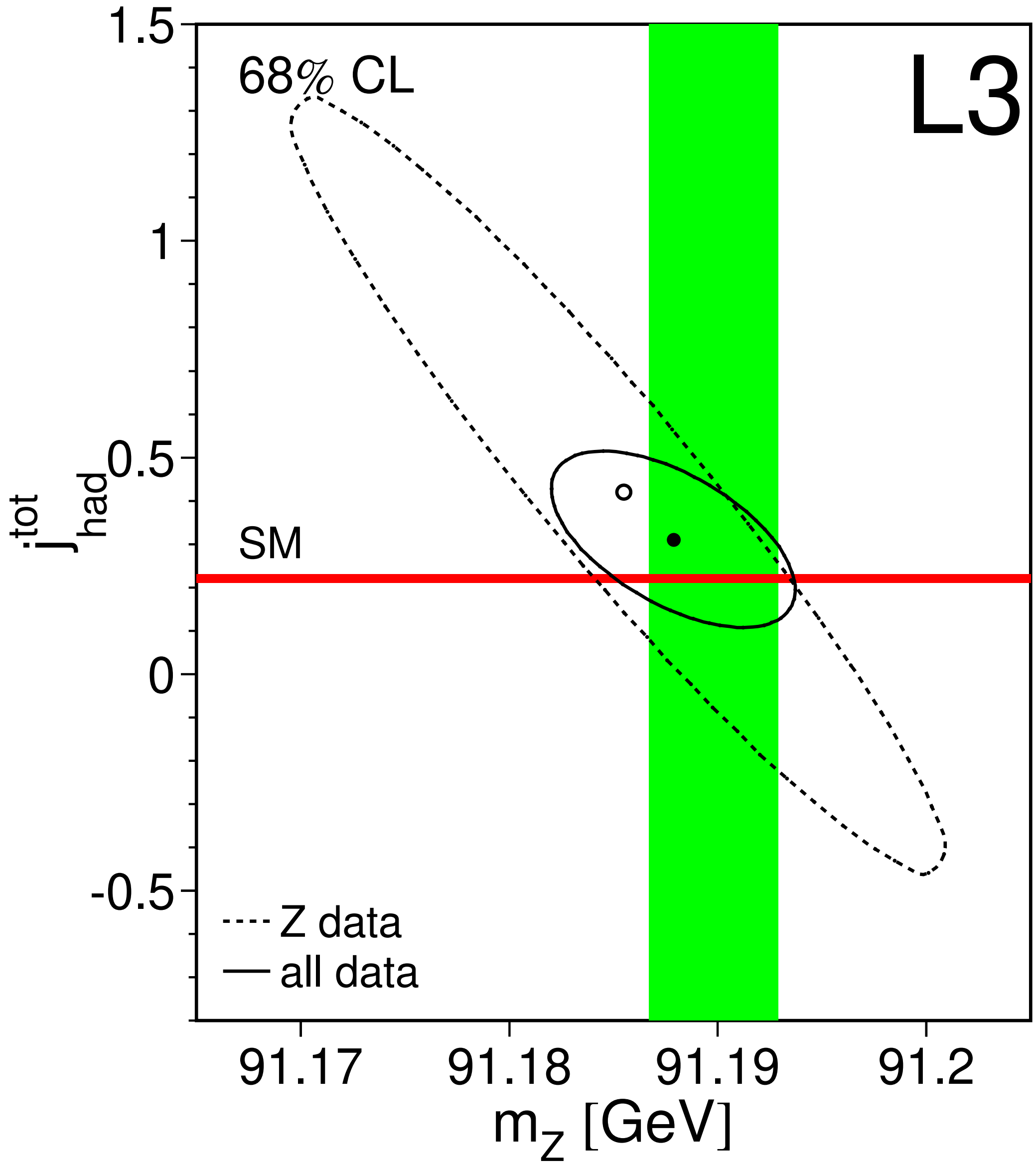
- **Photon – Z interference not well determined from Z data**
  Usually fixed to SM expectation
- **Large correlation between m_Z and hadronic $\gamma - $ Z interference**
- **Uncertainty much reduced by LEP II data:**

$$\sigma_a^0(s) = \frac{4}{3}\pi\alpha^2\left[\frac{g_f^a}{s} + \frac{j_f^a(s-\bar{M}_Z^2) + r_f^a\, s}{(s-\bar{M}_Z^2)^2 + \bar{M}_Z^2\bar{\Gamma}_Z^2}\right], \text{for } a = \text{tot}, \text{fb},$$

$$A_{\text{fb}}^0(s) = \frac{3}{4}\frac{\sigma_{\text{fb}}^0(s)}{\sigma_{\text{tot}}^0(s)}, \qquad \text{with} \qquad \sigma_{fb}^0 = \frac{4}{3}(\sigma_f - \sigma_b)\,.$$

- **Photon exchange**
- **Z-Boson exchange**
- **γ/Z interference**

"Standard" fits: fix g_f^a and j_f^a
S-Matrix fits: fix g_f^a only



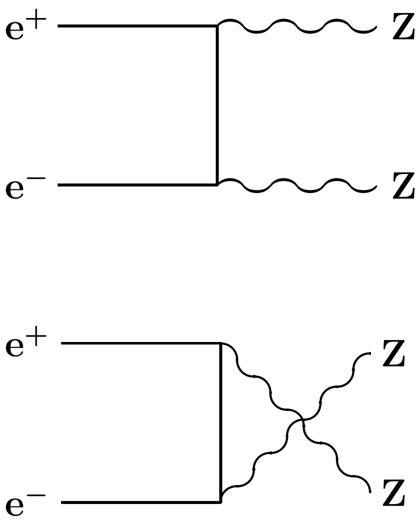
Fit for m_Z using data up to $\sqrt{s} = 189$ GeV (L3):

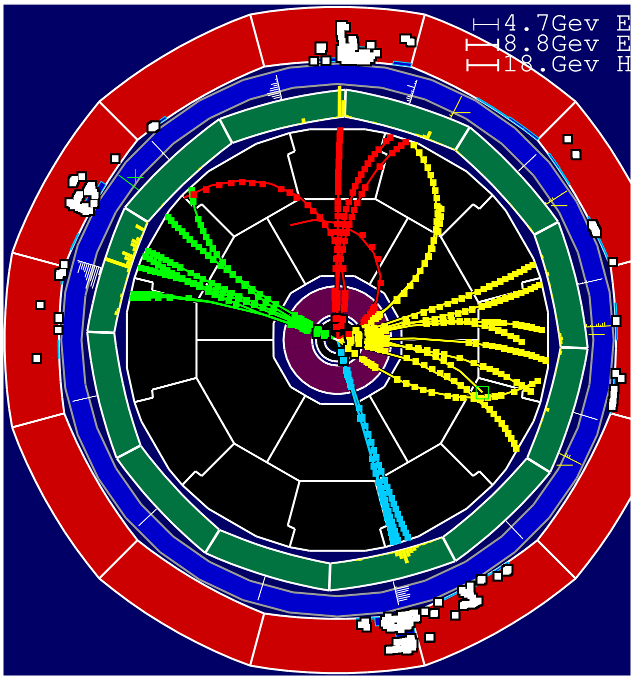
$$m_Z = 91\,185.5 \pm 3.1 \pm 2.3(j^{tot}_{had}) \pm 0.6(theory)\ \mathrm{MeV}$$

and

$$j^{tot}_{had} = 0.31 \pm 0.13 \pm 2.3(exp) \pm 0.04(theory)$$

Production of Z-boson pairs



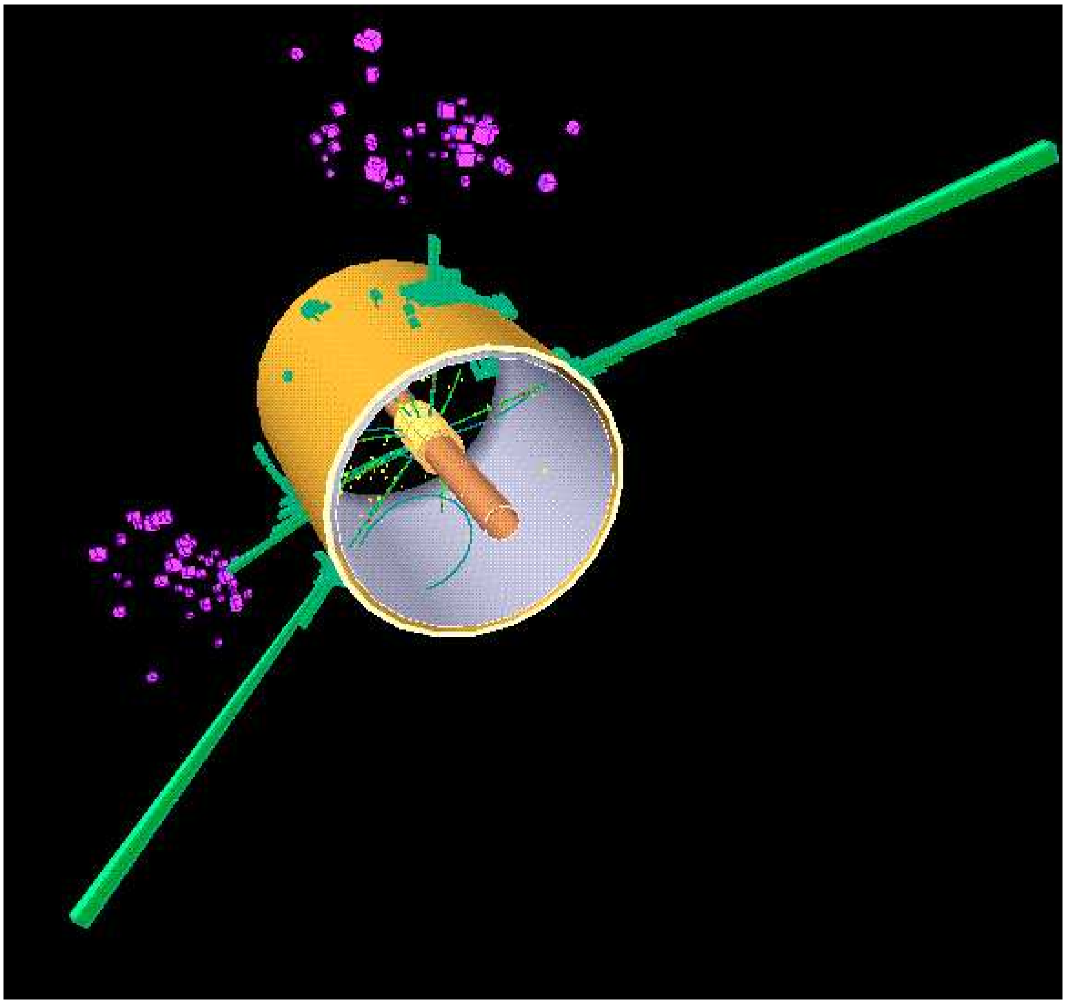


ZZ SELECTION

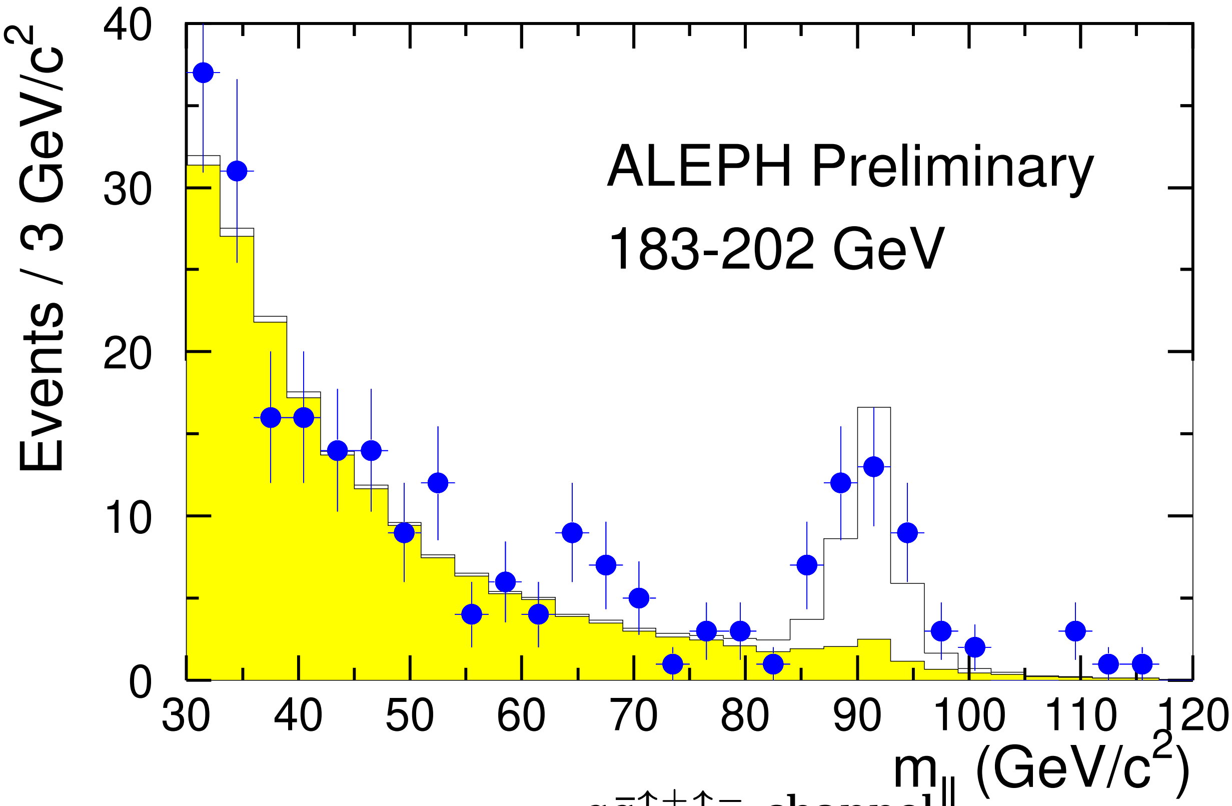
Channel	Statistics	Experimental Signature	Background
$q\bar{q}q'\bar{q}'$	Large	4 hadronic jets	Large
$q\bar{q}\nu\bar{\nu}$	Large	2 jets + missing energy	Large
$q\bar{q}l^+l^-$	Medium	2 jets + 2 leptons	Low
$l^+l^-\nu\bar{\nu}$	Low	2 leptons + missing energy	Medium
$l^+l^-l'^+l'^-$	Low	4 leptons	Medium
$\nu\bar{\nu}\nu'\bar{\nu}'$		invisible!	

L3

$\mathrm{ZZ} \to q\bar{q}e^+e^-$ at $\sqrt{s} = 200$ GeV

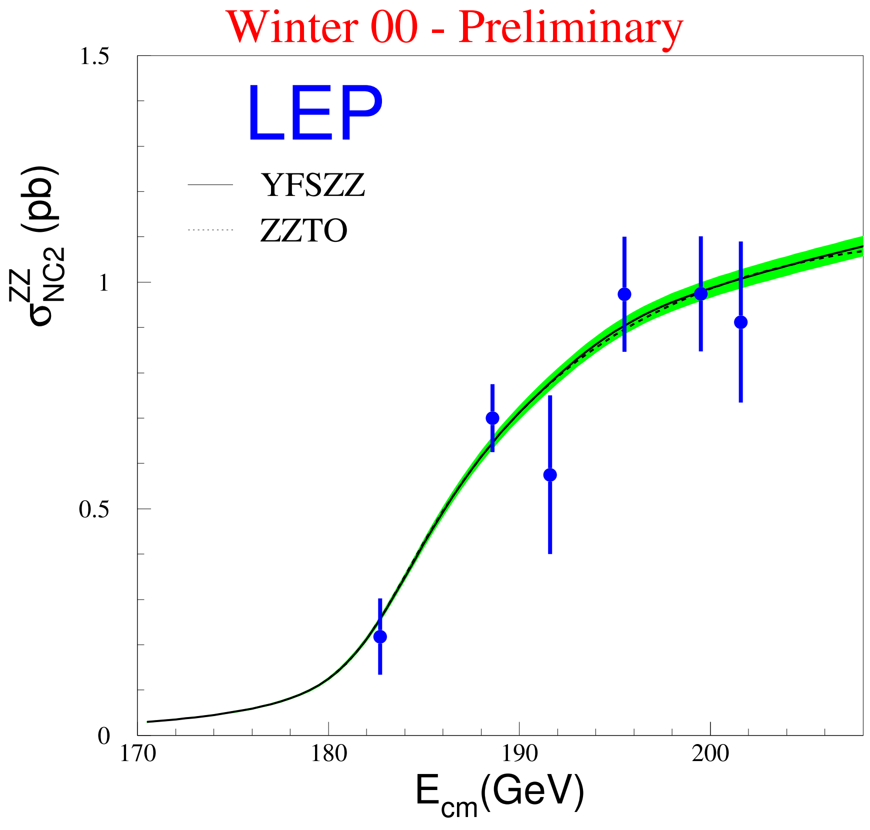


$M_{q\bar{q}} = 95.0$ GeV, $M_{e^+e^-} = 92.8$ GeV, $M_{5C} = 93.8$ GeV



$q\bar{q}\ell^+\ell^-$ channel

- **Combined LEP cross sections**



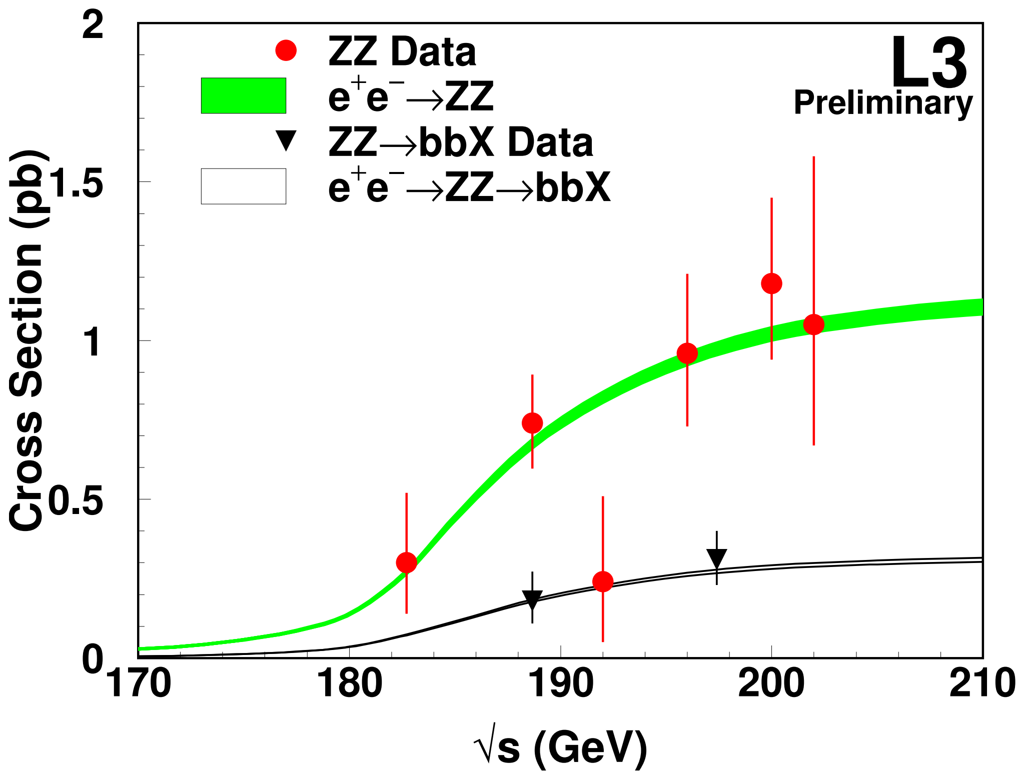
$e^+e^- \rightarrow$ ZZ probes ZZZ and ZZγ vertices

- **We are looking for Higgs production through:**

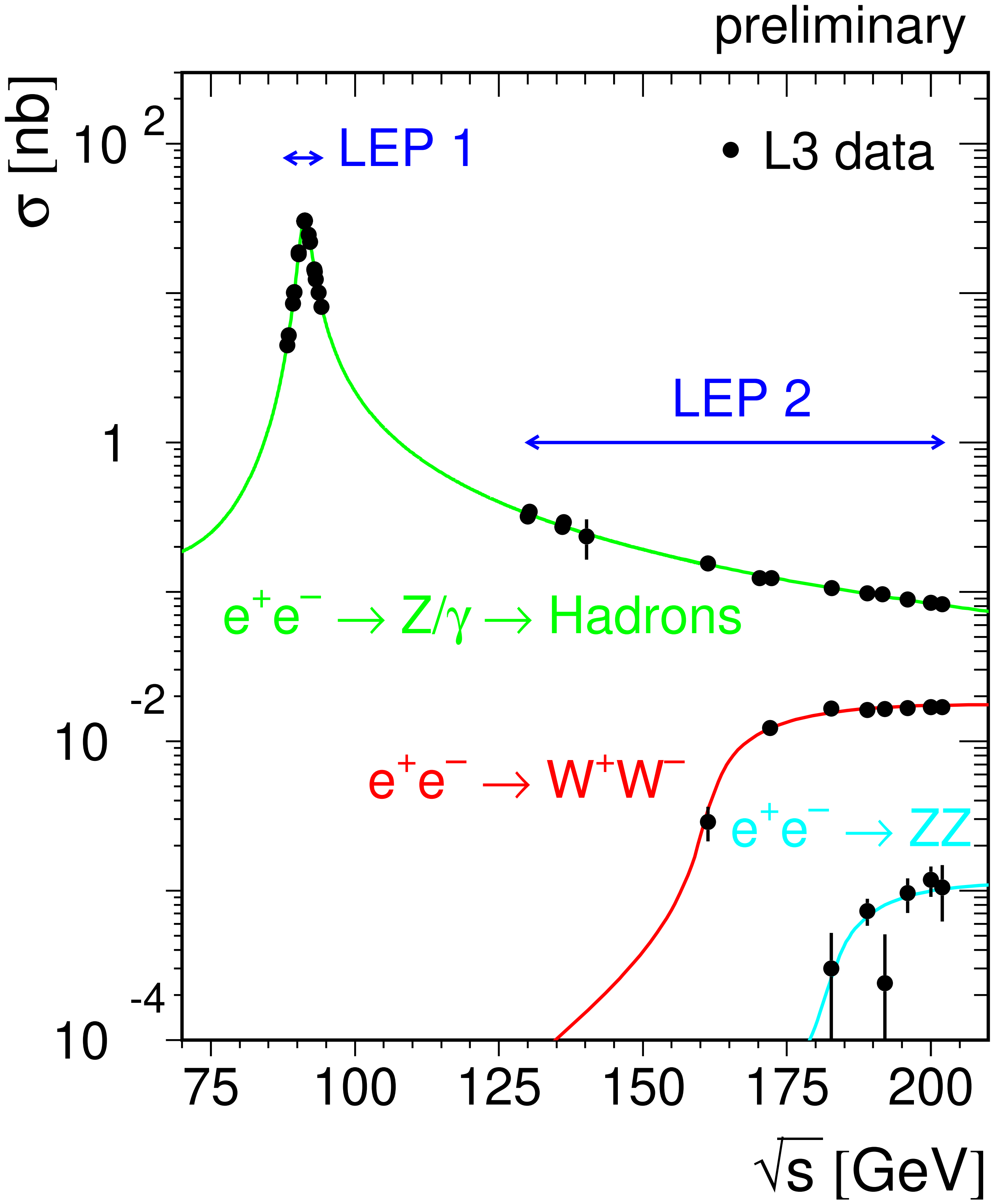
$$e^+e^- \longrightarrow HZ \longrightarrow b\bar{b}f\bar{f}$$

- **Can we see it? Yes, if we can measure:**

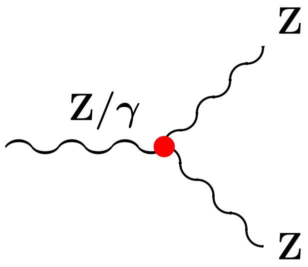
$$e^+e^- \longrightarrow ZZ \longrightarrow b\bar{b}f\bar{f}$$



Cross section measurement up to $\sqrt{s} = 202$ GeV


preliminary
σ [nb]
10^2
1
10^{-2}
10^{-4}
LEP 1
L3 data
LEP 2
$e^+e^- \to Z/\gamma \to$ Hadrons
$e^+e^- \to W^+W^-$
$e^+e^- \to ZZ$
75
100
125
150
175
200
√s [GeV]

- $e^+e^- \to$ ZZ probes ZZZ and γZZ vertices



4 coupling parameters f_i^V; $V = \gamma, Z$
$i = 4$ CP violating
$i = 5$ C & P violating, CP Conserving

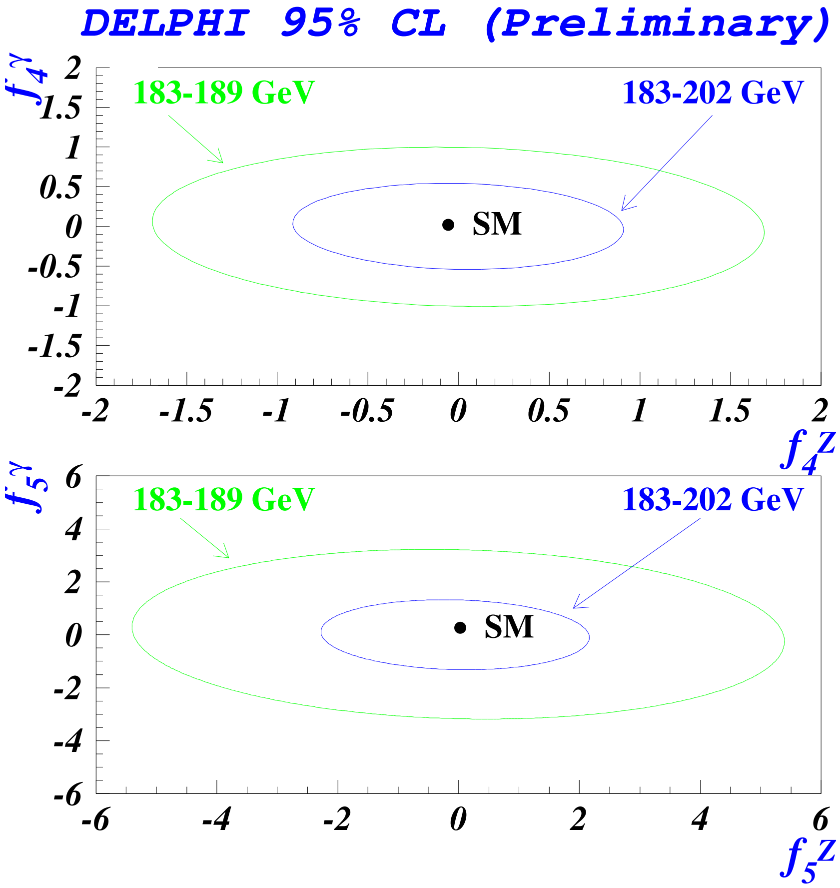
- Anomalous coupling of ZZZ, ZZγ :

  Vertex function $\Gamma_{ZZV}^{\alpha\beta\mu}$ has coupling $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$

  $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$=0 at SM tree level

- Signatures :

  deviations of σ_{ZZ} and
  angular distribution of the Z bosons
  with respect to S.M. predictions



DELPHI (up to $\sqrt{s} = 202$ GeV):

$-0.73 < f_4^Z < +0.72 \qquad -0.44 < f_4^\gamma < +0.44$

$-1.81 < f_5^Z < +1.69 \qquad -1.04 < f_5^\gamma < +1.04$

L3 (up to $\sqrt{s} = 189$ GeV):

$-0.9 < f_4^Z < +0.9 \qquad -0.5 < f_4^\gamma < +0.5$

$-1.9 < f_5^Z < +2.4 \qquad -1.2 < f_5^\gamma < +1.3$

OPAL:

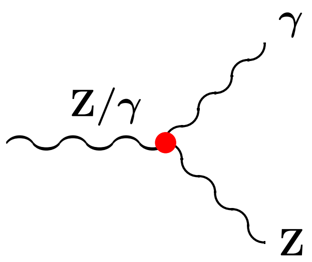
$-1.0 < \Re\{f_4^Z\} < +1.1 \qquad -0.6 < \Re\{f_4^\gamma\} < +0.6$

$-1.1 < \Re\{f_5^Z\} < +1.2 \qquad -1.4 < \Re\{f_5^\gamma\} < +1.4$

$-1.1 < \Im\{f_4^Z\} < +1.1 \qquad -0.6 < \Im\{f_4^\gamma\} < +0.6$

$-2.4 < \Im\{f_5^Z\} < +2.1 \qquad -1.4 < \Im\{f_5^\gamma\} < +1.4$

- $e^+e^- \to Z/\gamma \to f\bar{f}\gamma$ probes $ZZ\gamma$ and $Z\gamma\gamma$ vertices

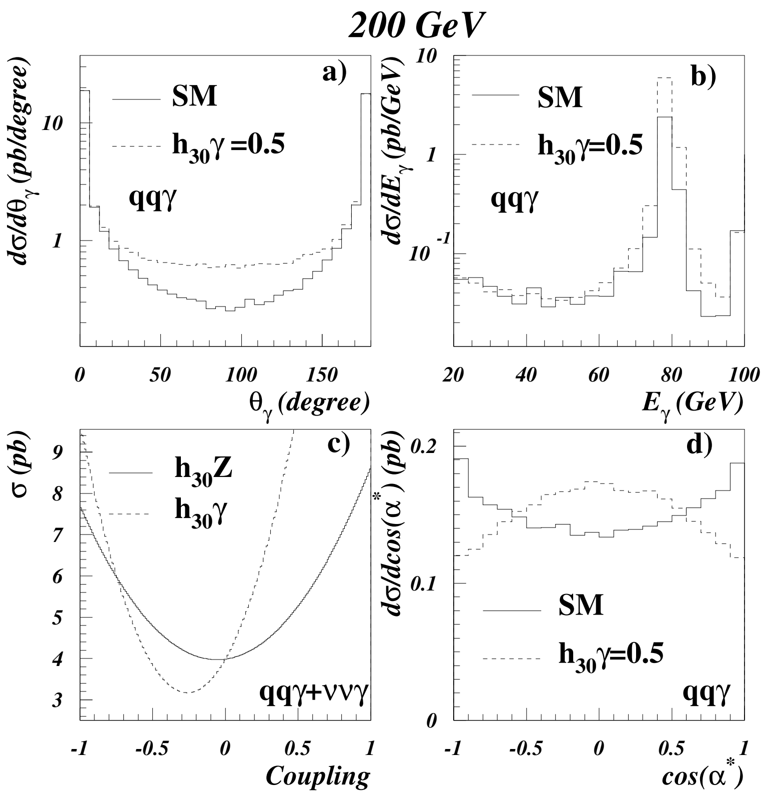


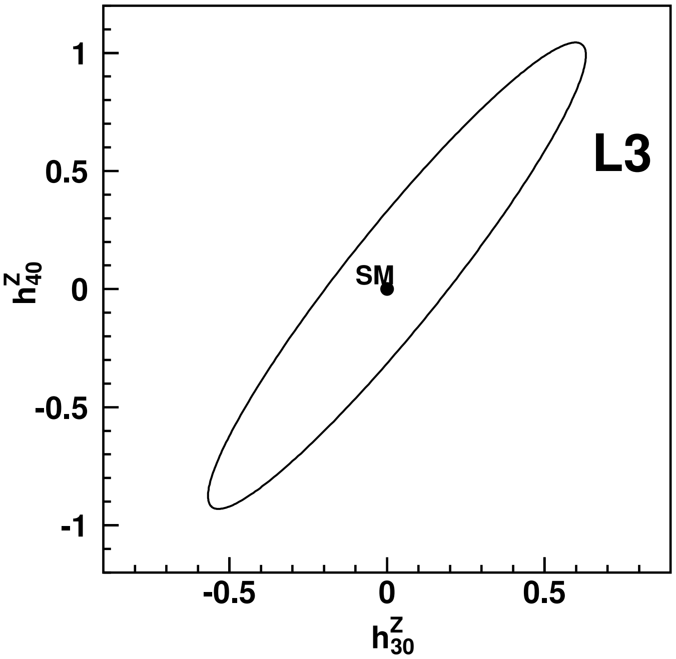
8 coupling parameters h_i^V; $V = \gamma, Z$
$i = 1, 2$ CP violating
$i = 3, 4$ CP conserving

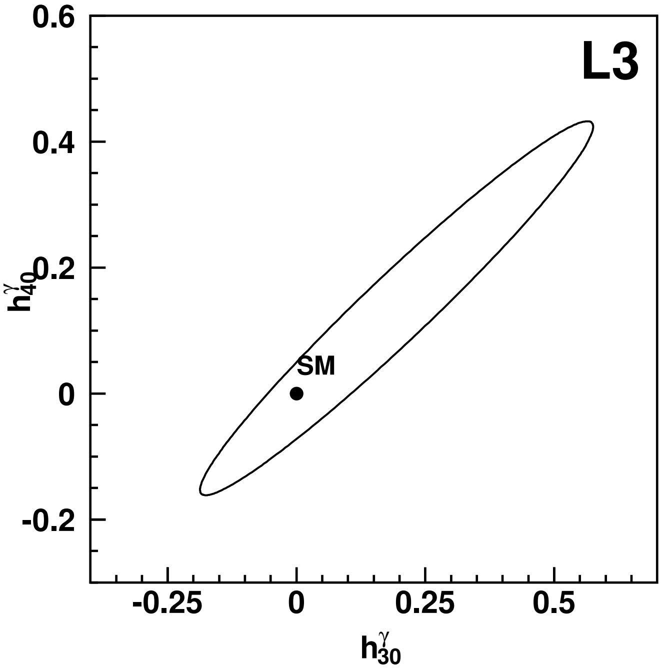
$h_1^V, h_2^V = 0$ in SM and $h_3^V, h_4^V \approx 0$

- Study of rate and differential distributions in $e^+e^- \to q\bar{q}\gamma$ and $e^+e^- \to \nu\bar{\nu}\gamma$ events

DELPHI







- $e^+e^- \to q\bar{q}\gamma$ and $e^+e^- \to \nu\bar{\nu}\gamma$

  DELPHI (up to $\sqrt{s} = 202$ GeV):

$$-0.34 < h^Z_{10} < 0.33 \qquad -0.21 < h^\gamma_{10} < 0.21$$
$$-0.20 < h^Z_{20} < 0.21 \qquad -0.13 < h^\gamma_{20} < 0.13$$
$$-0.41 < h^Z_{30} < 0.27 \qquad -0.01 < h^\gamma_{30} < 0.07$$
$$-0.18 < h^Z_{40} < 0.24 \qquad -0.05 < h^\gamma_{40} < 0.00$$

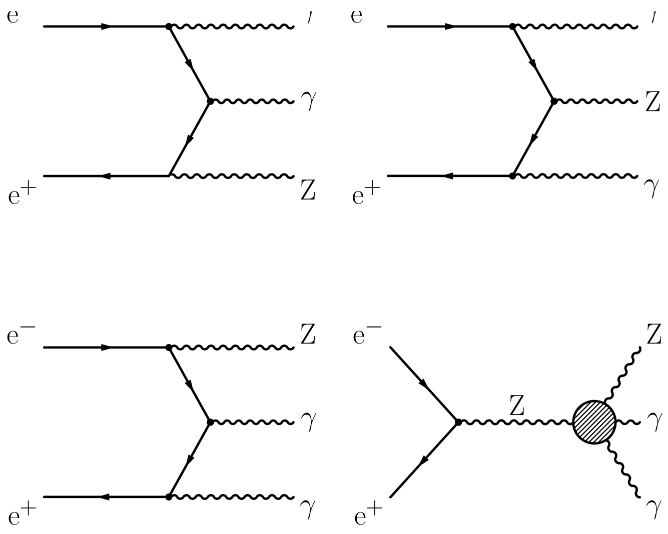
  L3(up to $\sqrt{s} = 189$ GeV):

$$-0.71 < h^Z_{10} < 0.29 \qquad -0.33 < h^\gamma_{10} < 0.23$$
$$-1.22 < h^Z_{20} < 0.21 \qquad -0.56 < h^\gamma_{20} < 0.17$$
$$-0.56 < h^Z_{30} < 0.63 \qquad -0.16 < h^\gamma_{30} < 0.43$$
$$-0.93 < h^Z_{40} < 1.04 \qquad -0.18 < h^\gamma_{40} < 0.57$$

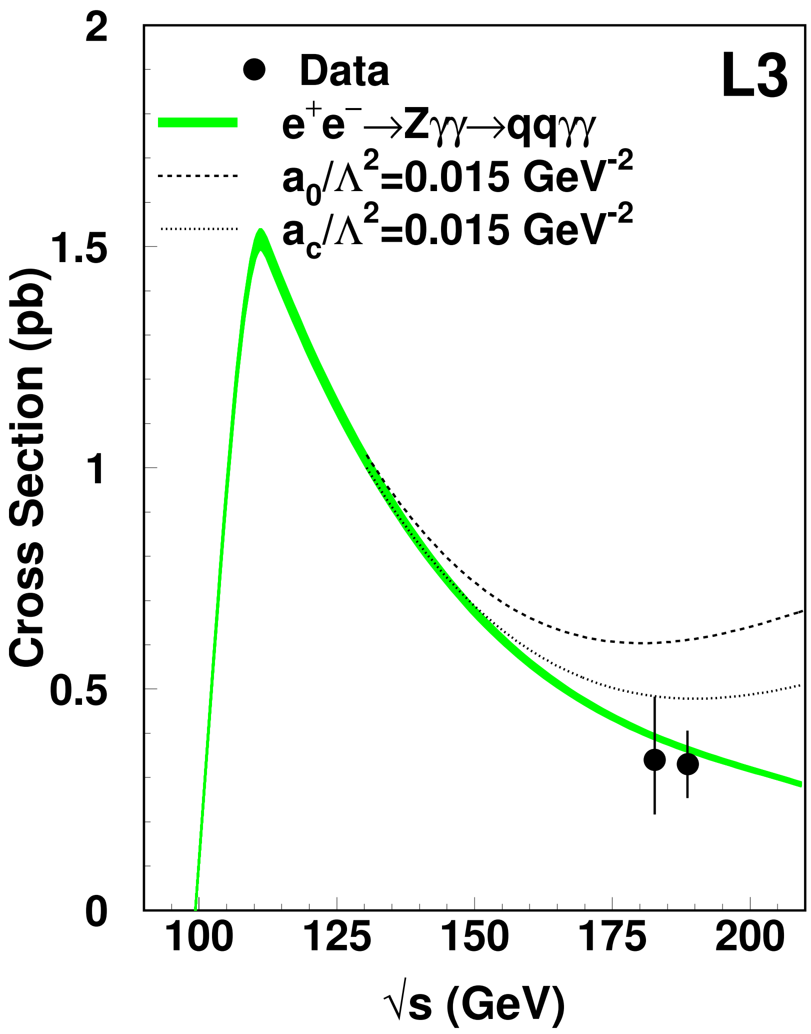
- $Z\gamma$ production at the Tevatron ($p\bar{p} \to e^+e^-\gamma,\ \mu^+\mu^-\gamma$)

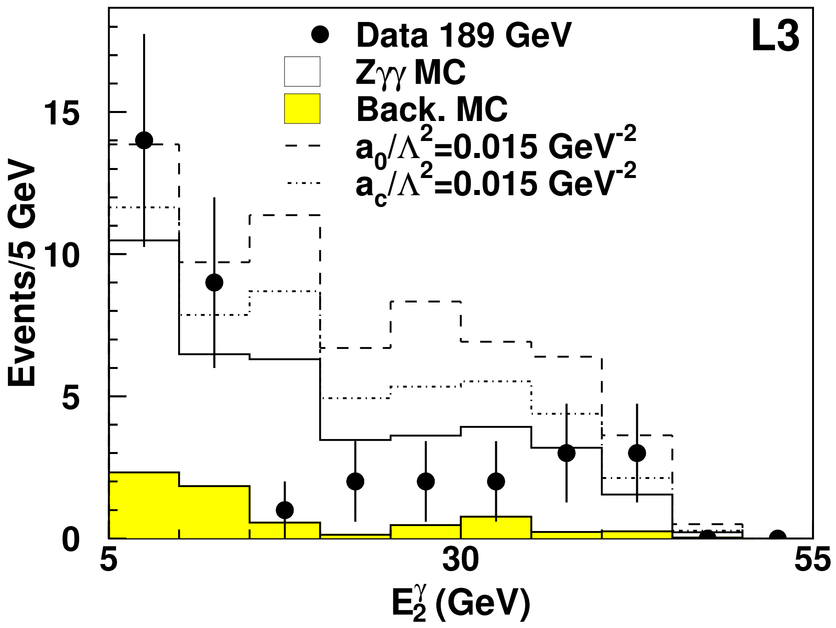
  DØ:

$$|h^Z_{30}| < 0.36 \qquad |h^\gamma_{30}| < 0.37$$
$$|h^Z_{40}| < 0.05 \qquad |h^\gamma_{40}| < 0.05 \qquad (\Lambda = 750 \text{ GeV})$$



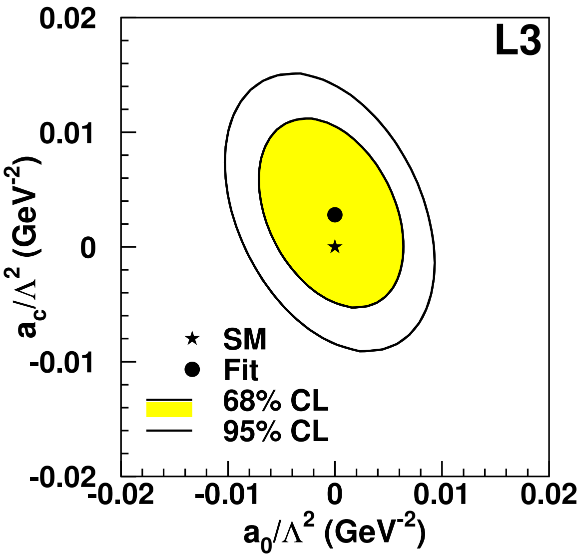
$e^+e^- \to Z\gamma(\gamma)$ channel probes anomalous quartic vertex $ZZ\gamma\gamma$ with couplings a_0/Λ^2, a_c/Λ^2





Hadronic $Z\gamma\gamma$ MC events reweighted with and fitted to the observed $E_{2\gamma}$ spectrum. Simultaneous fit gives 95% CL limits:

$$-0.009 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.008 \text{ GeV}^{-2}$$
$$-0.007 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.013 \text{ GeV}^{-2}$$



$\Longrightarrow$ Tightest limits on a_0 and a_c.

- Relevant Standard-Model parameters:

α, α_s	QED and QCD couplings
$m_{\rm Z}, m_{\rm W}, m_{\rm H}, m_{\rm t}$	Masses

I. Test of higher order

Electroweak radiative corrections Δr:

$$\frac{G_{\rm F}}{\sqrt{2}} = \frac{\pi\alpha}{2}\frac{1}{m_{\rm W}^2\,\sin^2\theta_{\rm W}}\frac{1}{1-\Delta r}$$

$$\begin{aligned}
G_{\rm F} &= (1.16639 \pm 0.00001)\cdot 10^{-5}\text{GeV (from } \mu \text{ decay)}\\
\Delta r &= \Delta\alpha - \Delta r_{\rm W} + \ldots\\
\Delta\alpha & \quad \text{running of QED coupling constant}\\
& \quad Q^2 = 0 \longrightarrow m_{\rm Z}^2\\
\Delta\alpha(m_{\rm Z}^2) & \quad \text{Uncertainty due to contribution of}\\
& \quad \text{five lightest quarks } \Delta\alpha^5_{\rm had}\\
\Delta r_{\rm W} &\approx \Delta r_{\rm W}(m_{\rm t}^2, \log m_{\rm H}) \quad \text{weak corrections}
\end{aligned}$$

II. The mass of the W boson

- $m_{\rm W}$ as parameter determining electroweak couplings ($\cos\vartheta_{\rm W} = m_{\rm W}/m_{\rm Z}$)
- Direct measurement of $m_{\rm W}$ at LEP II and in $p\bar{p}$-experiments

III. The mass of the top quark

- Direct measurement of m_t in $p\bar{p}$-experiments

♠ Higher order corrections to couplings introduce sensitivity to top quark mass and Higgs boson mass:

$$\mathrm{m_t^2} \qquad\qquad \log m_{\mathrm{H}}$$

♠ Fit to all electroweak measurements except direct measurements of m_{W} and m_{t}:

$$m_{\mathrm{W}} = 80.368 \pm 0.034 \text{ GeV} \qquad m_{\mathrm{t}} = 167.3 \pm 8.8 \text{ GeV}$$

Direct LEP II m_{W} and TEVATRON m_{t}:

$$m_{\mathrm{W}} = 80.401 \pm 0.049 \text{ GeV} \quad \text{(LEPII)}$$
$$m_{\mathrm{W}} = 80.448 \pm 0.062 \text{ GeV} \qquad m_{\mathrm{t}} = 174.3 \pm 5.1 \text{ GeV} \quad \text{(TEV)}$$

GOOD AGREEMENT between direct measurements and SM fits

♣ Next step: include all data in SM fit
(LEP I, SLD, ν N, LEP II and Tevatron) $\Longrightarrow$ to predict m_{H}

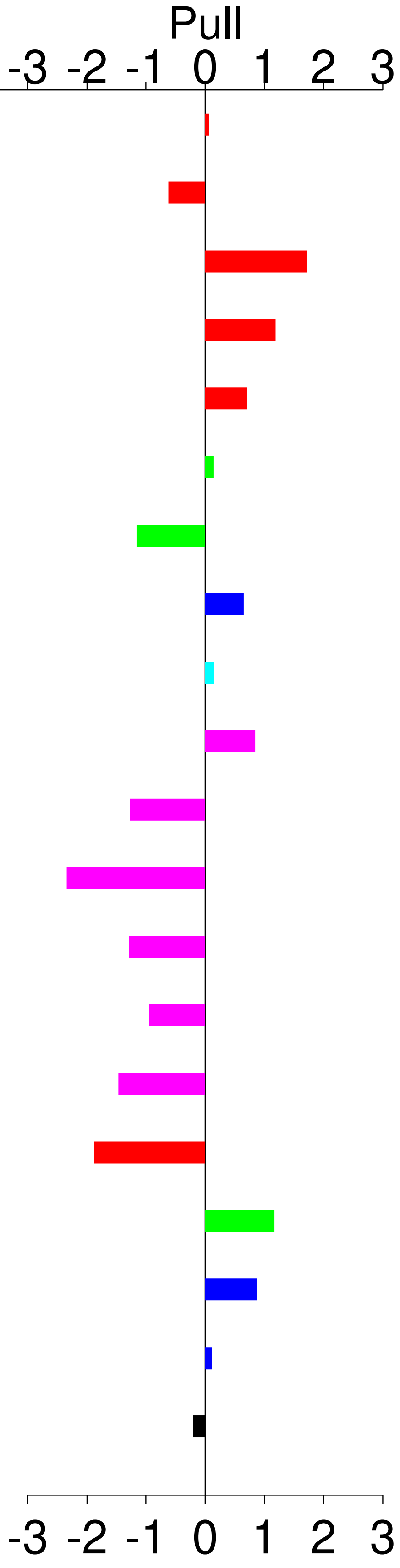
- Observables at the Z from LEP & SLC
- m_W from LEP II and CDF & DØ
- $\sin^2\theta_W$ from ν-nucleon scattering
- $m_t = 174.3 \pm 5.1$ GeV (CDF & DØ)
- Hadronic contribution to running of α: $\Delta\alpha^{(5)}_{\mathrm{had}} = 0.02804 \pm 0.00065$

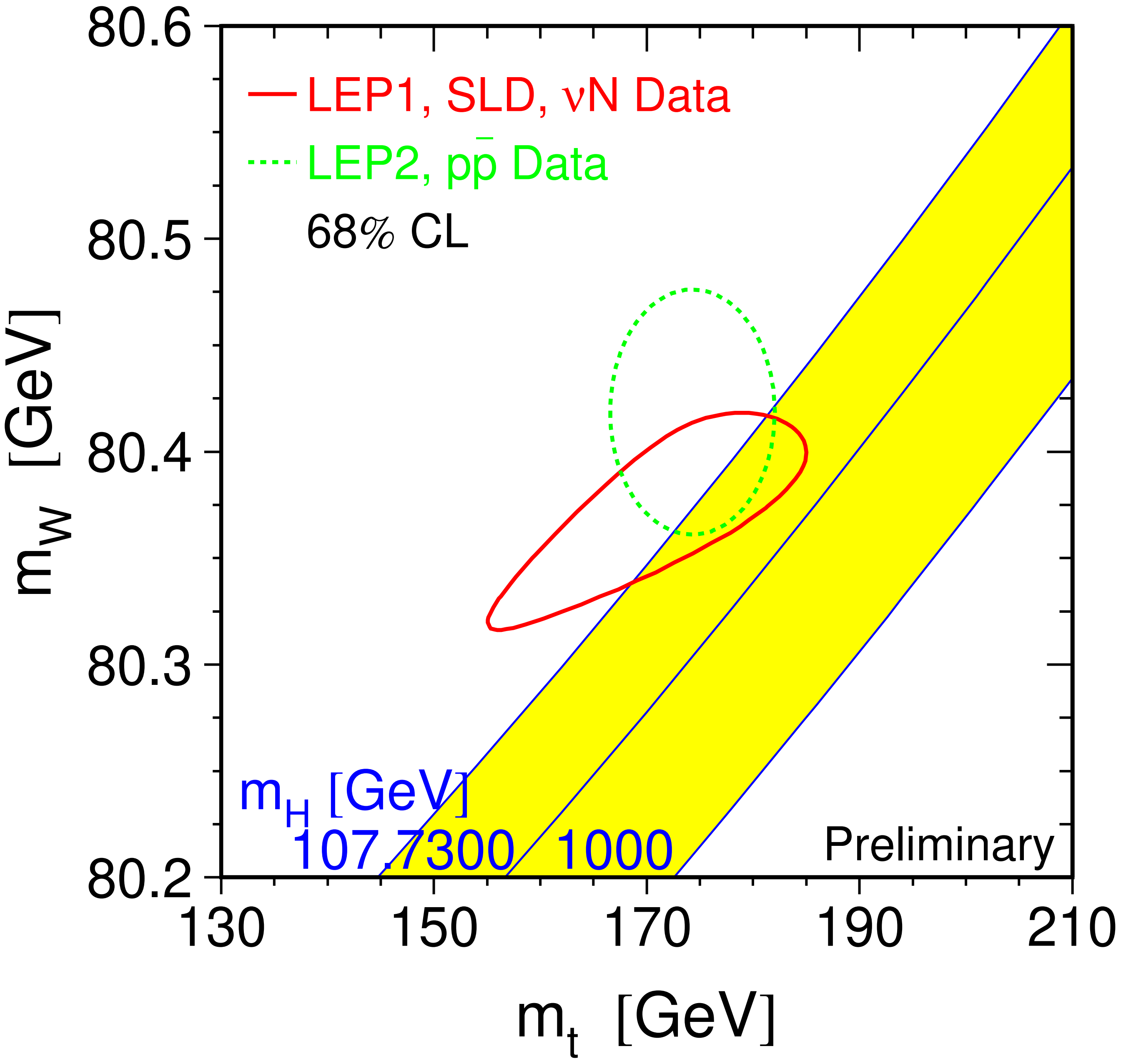
	LEP including LEP II m_W	all data except m_W and m_t	all data except m_W	all data
m_t [GeV]	176^{+14}_{-11}	167^{+10}_{-8}	172.9 ± 4.7	173.7 ± 4.4
m_H [GeV]	147^{+299}_{-92}	54^{+81}_{-27}	78^{+76}_{-41}	67^{+60}_{-33}
$\log(m_H/\mathrm{GeV})$	$2.17^{+0.48}_{-0.43}$	$1.73^{+0.40}_{-0.30}$	$1.90^{+0.29}_{-0.32}$	$1.82^{+0.28}_{-0.30}$
α_s	0.120 ± 0.003	0.118 ± 0.003	0.118 ± 0.003	0.118 ± 0.003
χ^2/d.o.f.	12/9	22/12	22/13	23/15
$\sin^2\overline{\theta}_W$	0.23187 ± 0.00021	0.23151 ± 0.00017	0.23152 ± 0.00017	0.23145 ± 0.00016
$\sin^2\theta_W$	0.2233 ± 0.0006	0.2232 ± 0.0007	0.2229 ± 0.0005	0.2227 ± 0.0004
m_W [GeV]	80.363 ± 0.030	80.368 ± 0.034	80.382 ± 0.026	80.394 ± 0.021

Pulls from data to SM fit

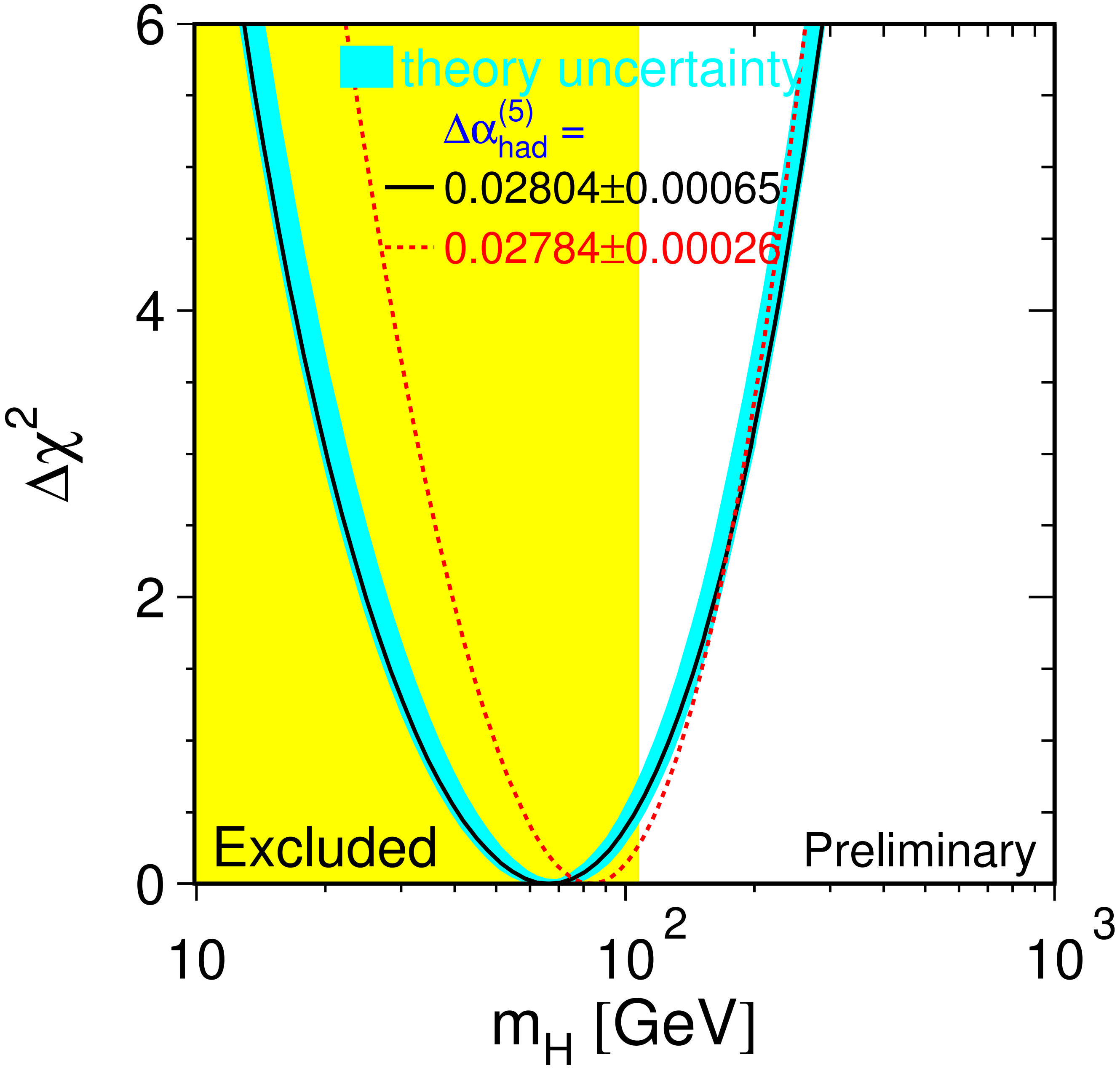
Moriond 2000

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.07
Γ_Z [GeV]	2.4944 ± 0.0024	-.62
σ^0_{hadr} [nb]	41.544 ± 0.037	1.72
R_e	20.768 ± 0.024	1.19
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.70
A_e	0.1483 ± 0.0051	.13
A_τ	0.1425 ± 0.0044	-1.16
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.65
m_W [GeV]	80.401 ± 0.048	.15
R_b	0.21642 ± 0.00073	.85
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0988 ± 0.0020	-2.34
$A^{0,c}_{fb}$	0.0692 ± 0.0037	-1.29
A_b	0.911 ± 0.025	-.95
A_c	0.630 ± 0.026	-1.47
$\sin^2\theta^{lept}_{eff}$	0.23096 ± 0.00026	-1.87
$\sin^2\theta_W$	0.2255 ± 0.0021	1.17
m_W [GeV]	80.448 ± 0.062	.88
m_t [GeV]	174.3 ± 5.1	.11
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.20





- Good agreement between direct and indirect determinations of m_{t} and m_{W}
  The SM is correct at the one-loop level
- Data prefer a light Higgs boson



Electroweak precision data :

$$m_{\mathrm{H}} < 188 \text{ GeV} \qquad 95\% \text{ CL}$$

Direct search for Higgs production at LEP:

$$m_{\mathrm{H}} > 107.7 \text{ GeV} \qquad 95\% \text{ CL}$$

10 years of Z physics completed at LEP & SLD

♠ **LEP at $\sqrt{s} = m_{\mathrm{Z}}$ (LEP1)**

- **Z parameters determined with high precision**
- **SM confirmed on 1-loop level**
- **Study of universality of lepton couplings**

♠ **LEP at $\sqrt{s} > m_{\mathrm{Z}}$ (LEP2)**

- **γ/Z interference.**
- **Study of Boson self-coupling: ZZZ,Z$\gamma\gamma$,ZZγ**
- **Futher confirmation of SM**
- **Limit on Higgs boson mass**

In this moment

- **LEP: $\sqrt{s} > 205$ GeV**

The Standard Model works better than ever

The Higgs boson is light