Precise Determination of Electroweak Parameters with the L3 Detector at LEP

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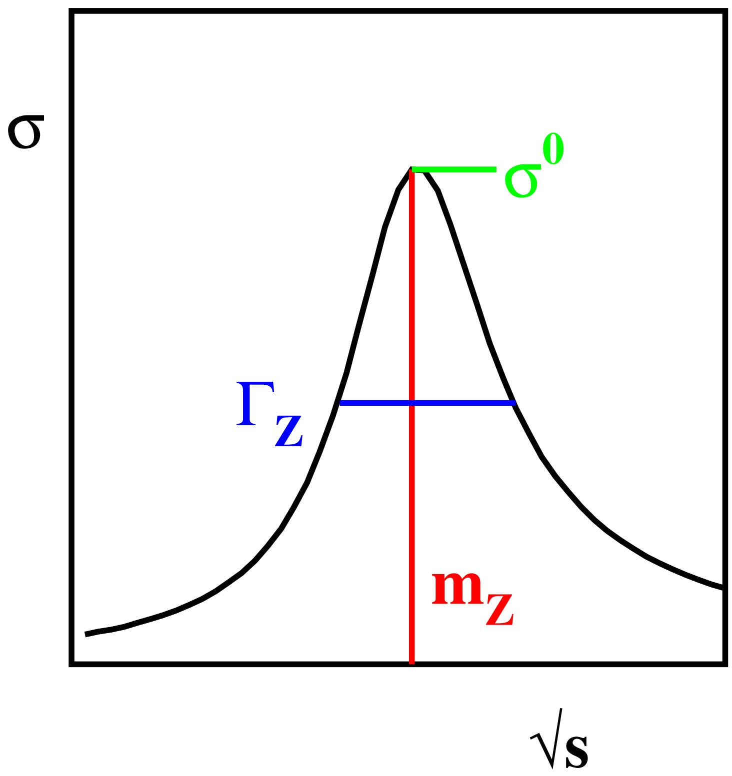
1. Introduction
2. Fit Ingredients
3. Fit Results

All numbers are preliminary!

Introduction

Fit Z parameters to cross sections:



In practice, use:

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

Sensitivity to LEP energies:

$$\Delta m_Z = \frac{1}{2}\Delta(E_+ + E_-), \quad \Delta\Gamma_Z \approx 0.71\Delta(E_+ - E_-)$$

Introduction

Measurement of coupling constants:

Include asymmetry measurements

$$A_{\mathrm{FB}}^{0,\ell} = \frac{3}{4}\mathcal{A}_{\mathrm{e}}\mathcal{A}_{\ell}, \text{ with } \mathcal{A}_{\ell} = \frac{2\bar{g}_{\mathrm{V}}^{\ell}\bar{g}_{\mathrm{A}}^{\ell}}{(\bar{g}_{\mathrm{V}}^{\ell})^2 + (\bar{g}_{\mathrm{A}}^{\ell})^2}$$

S-Matrix Framework:

Assumption of unitary S matrix:

$$\mathcal{M}^{fi}(s) = \frac{A_{\gamma}}{s} + \frac{B_{\mathrm{Z}}}{s - s_{\mathrm{Z}}} + \ldots, \text{ where } s_{\mathrm{Z}} = \bar{m}_{\mathrm{Z}}^2 - i\bar{m}_{\mathrm{Z}}\bar{\Gamma}_{\mathrm{Z}}$$

leading to explicit hadronic γ/Z interference term: fit term

$$\frac{4\pi\alpha^2}{3} \jmath_{\mathrm{had}}^{\mathrm{tot}} \frac{s - \bar{m}_{\mathrm{Z}}^2}{(s - \bar{m}_{\mathrm{Z}}^2)^2 + \bar{m}_{\mathrm{Z}}^2\bar{\Gamma}_{\mathrm{Z}}^2}$$

Standard Model Fits:

Fit $\alpha_{\mathrm{s}}(m_{\mathrm{Z}}),\ m_{\mathrm{Z}},\ m_{\mathrm{t}},\ m_{\mathrm{H}}$

Fit Ingredients

4M events (135pb^{-1}) collected from 1990 to 1995

	1990/91	1992	1993	1994	1995
N_{ECMS}	7+7	1	3	1	3
$\mathcal{L}$ (pb^{-1})	18.4	22.4	31.7	43.2	19.4
hadrons	416	678	646	1307	311
bhabhas	16	22	23	43	12
muons	14	21	21	42	9
taus	10	15	20	42	7

LEP Energies (see talk by T. Camporesi)

- TGV Effects: revision of energies & errors:
  6×6 energy matrix for 1993/1995 Scan periods
  (errors typically ~ 3 MeV for 1993 scan, ~ 2 MeV for 1995 scan, and bigger for other periods)
- Beam Spread: 55 ± 5 MeV $\rightarrow 55 \pm 1$ MeV
  reduces corresponding error on Γ_Z from 1 to 0.2 MeV.

$$\Delta m_Z(\mathrm{LEP}) = 1.5 \text{ MeV}, \quad \Delta\Gamma_Z(\mathrm{LEP}) = 1.4 \text{ MeV}$$

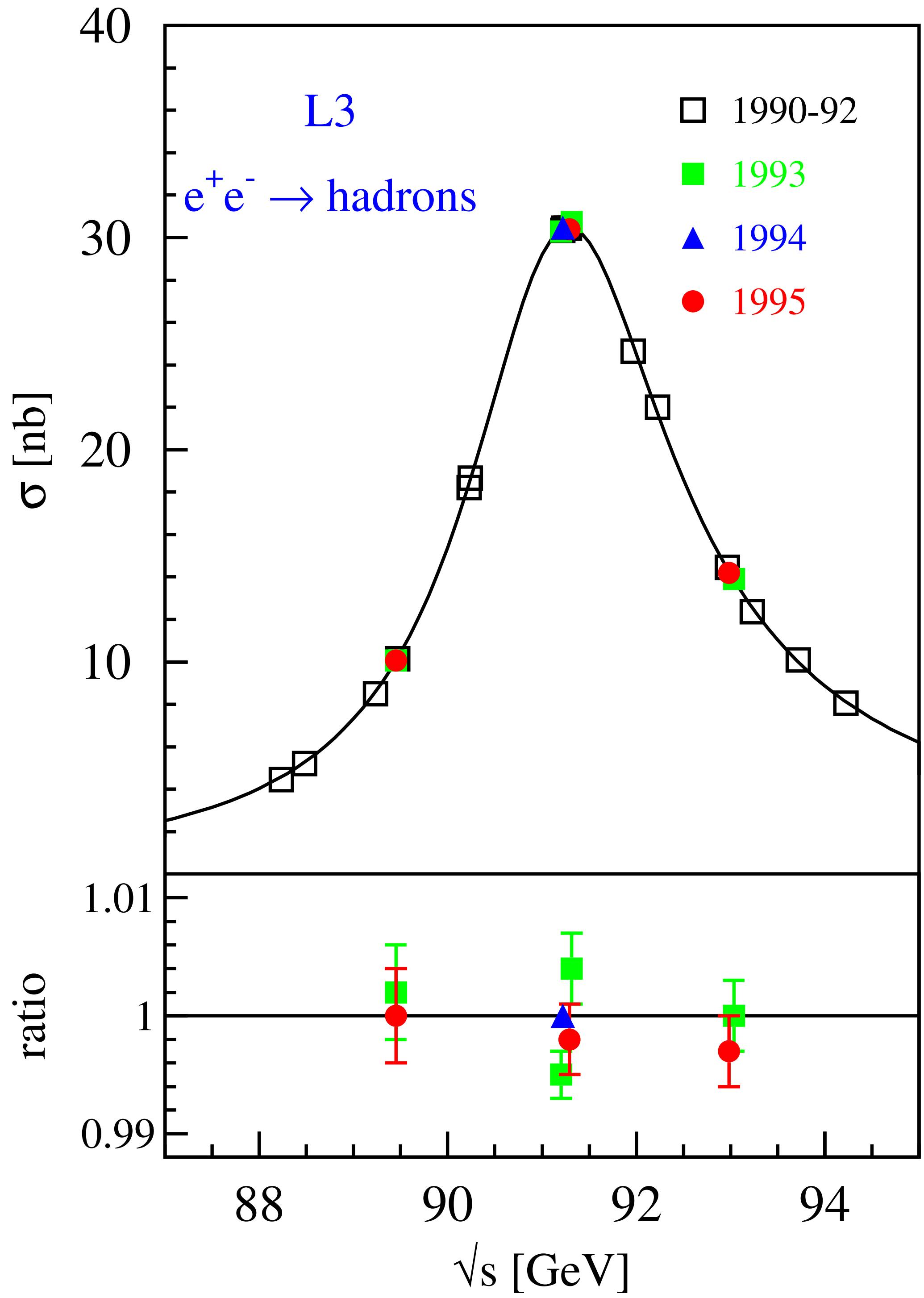
Luminosity Error

LEP2 Workshop: $\Delta\mathcal{L}^{\mathrm{th}}$ $0.16\% \rightarrow 0.11\%$
(total error: $\Delta\mathcal{L}$ $0.20\% \rightarrow 0.15\%$)

Vacuum Polarization Convergence?

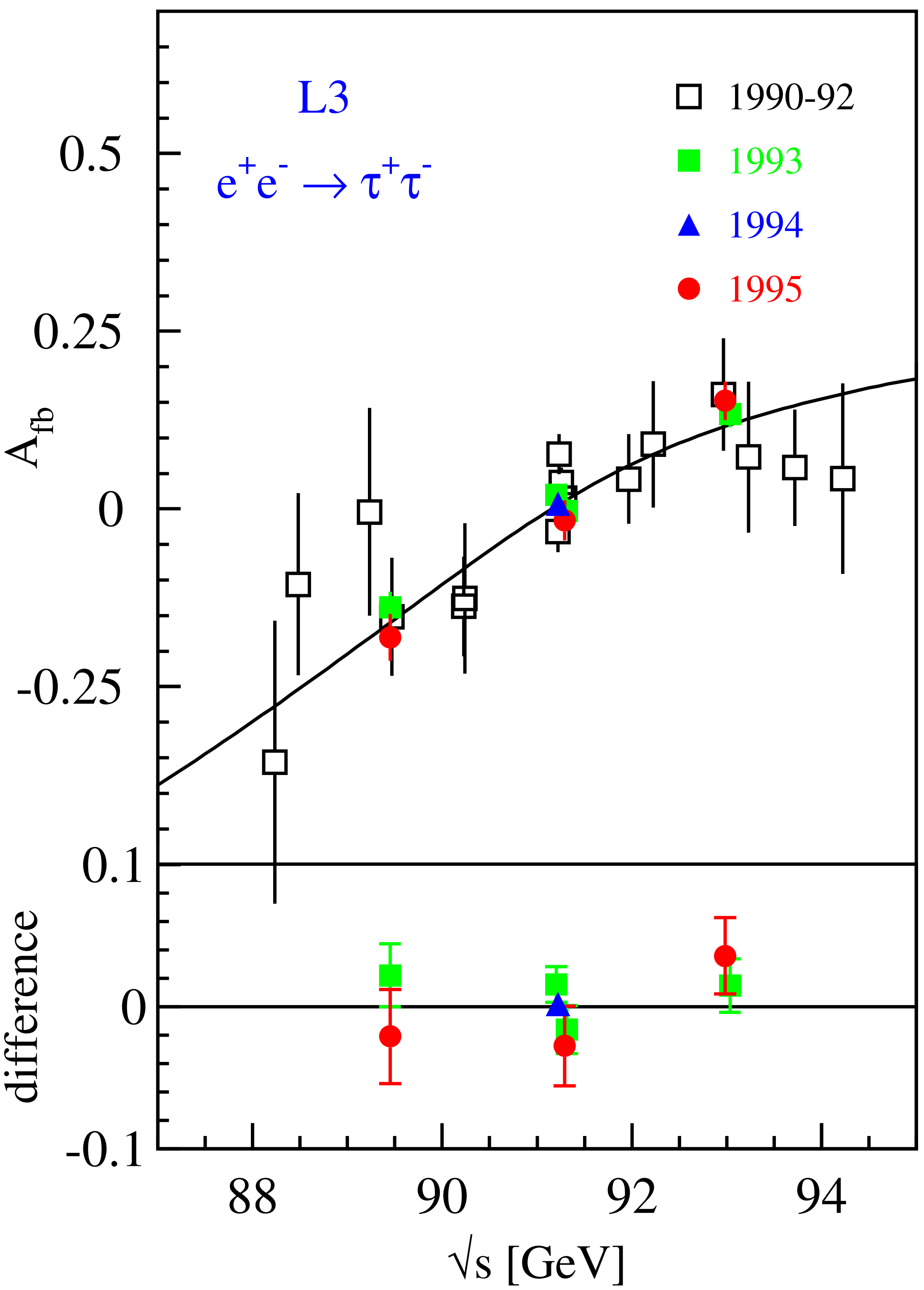
$\alpha^{-1}(m_Z) = 128.896 \pm 0.090$

Cross Sections



Parameter	1995 prel.	1996 prel.
m_Z (MeV)	$91\,193.6 \pm 3.6$	$91\,188.1 \pm 2.9$
Γ_Z (MeV)	$2\,502.0 \pm 5.4$	$2\,499.8 \pm 4.3$

$$N_\nu = 3.001 \pm 0.017$$


L3
$e^+e^- \to \tau^+\tau^-$
1990-92
1993
1994
1995
0.5
0.25
0
-0.25
A_{fb}
0.1
0
-0.1
difference
88
90
92
94
$\sqrt{s}$ [GeV]

Asymmetries

Fit results:

Parameter	Treatment of Charged Leptons non-universality	universality	Standard Model
m_Z (MeV)	91 188.3±2.9	91 188.3±2.9	—
Γ_Z (MeV)	2 499.6±4.3	2 499.6±4.3	2 495.9
σ^0_{had} (nb)	41.411±0.074	41.411±0.074	41.452
R_e	20.78±0.11	—	
R_μ	20.84±0.10	—	
R_τ	20.75±0.14	—	
R_ℓ	—	20.788±0.066	20.768
$A^{0,e}_{\mathrm{FB}}$	0.0148±0.0063	—	
$A^{0,\mu}_{\mathrm{FB}}$	0.0176±0.0035	—	
$A^{0,\tau}_{\mathrm{FB}}$	0.0233±0.0049	—	
$A^{0,\ell}_{\mathrm{FB}}$	—	0.0187±0.0026	0.0154

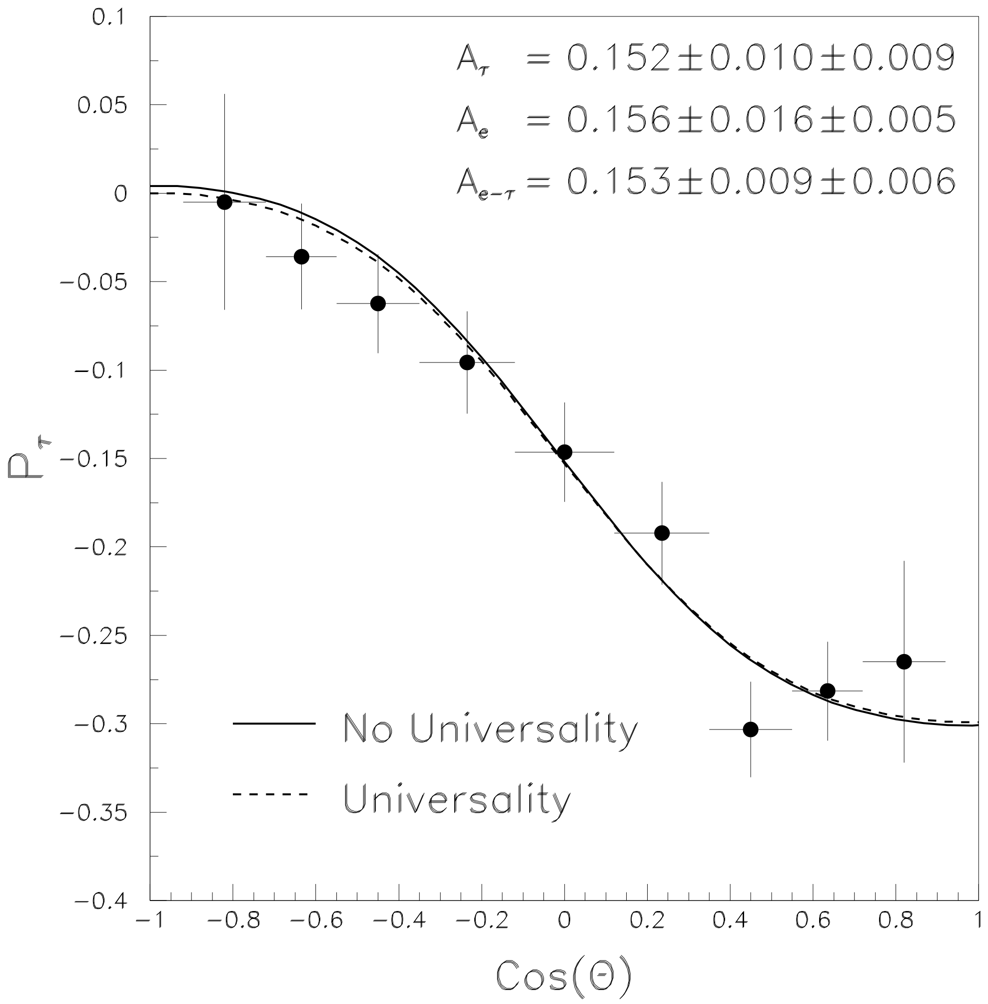
Correlation matrix assuming universality:

	m_Z	Γ_Z	σ^0_{had}	R_ℓ	$A^{0,\ell}_{\mathrm{FB}}$
m_Z	1.000	0.115	−0.059	−0.005	0.077
Γ_Z		1.000	−0.258	−0.015	0.001
σ^0_{had}			1.000	0.125	0.009
R_ℓ				1.000	−0.007
$A^{0,\ell}_{\mathrm{FB}}$					1.000

Asymmetries

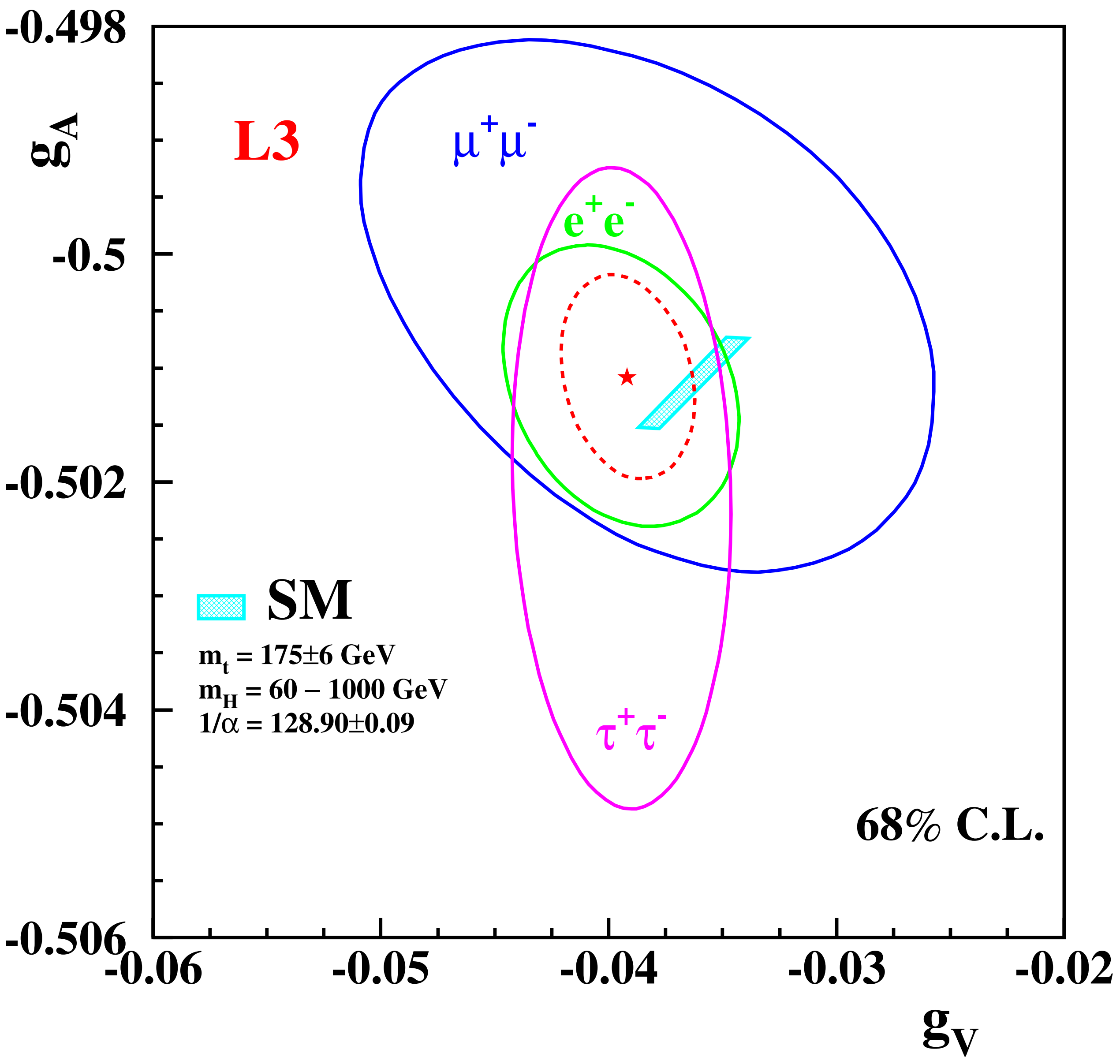
Use also τ polarization numbers:

Allows extraction of both $\mathcal{A}_e$ and $\mathcal{A}_\tau$



$$\mathcal{A}_e = 0.156 \pm 0.017, \quad \mathcal{A}_\tau = 0.152 \pm 0.013$$

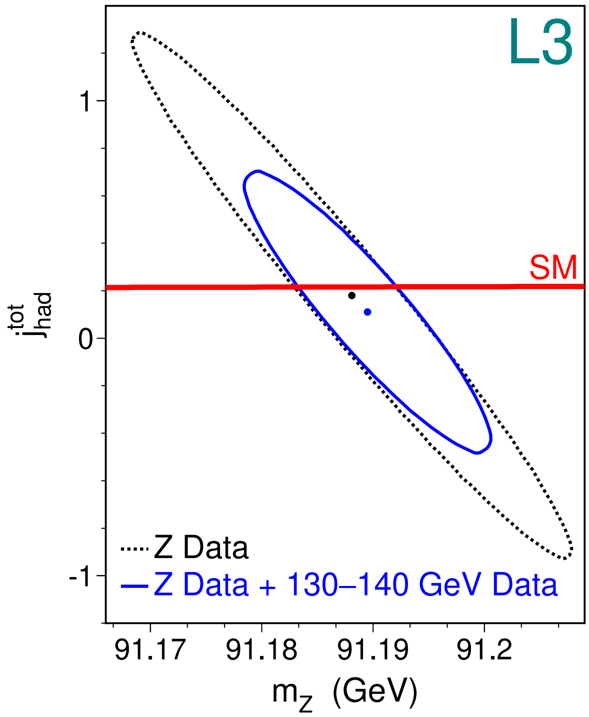
See talk by D. Kim



-0.498
-0.5
-0.502
-0.504
-0.506
g_A
L3
$\mu^+\mu^-$
e^+e^-
$\tau^+\tau^-$
SM
m_t = 175±6 GeV
m_H = 60 – 1000 GeV
1/α = 128.90±0.09
68% C.L.
-0.06
-0.05
-0.04
-0.03
-0.02
g_V

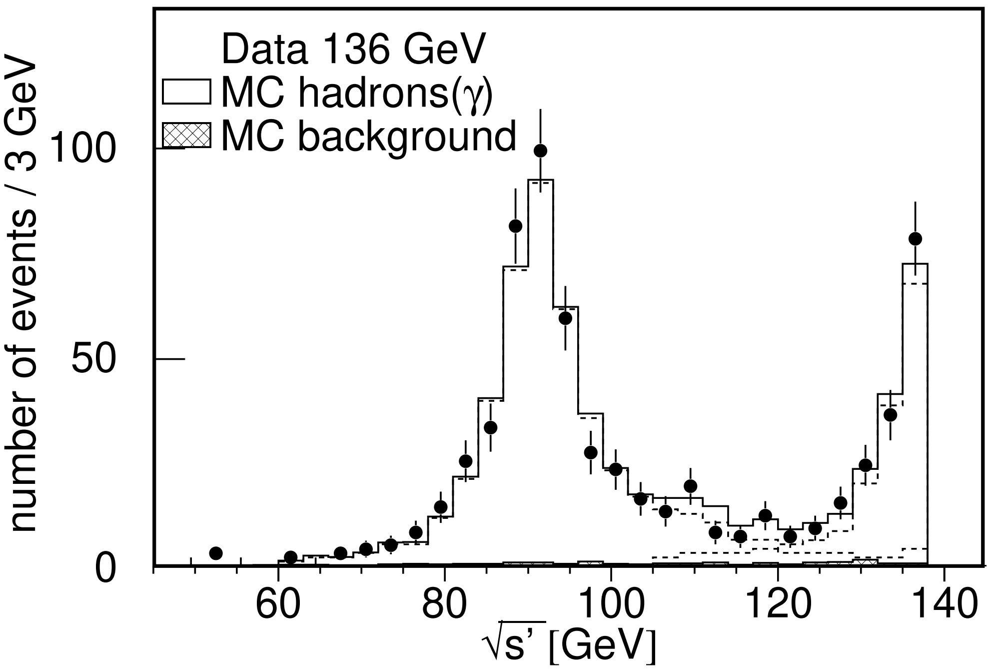
S Matrix

130-140 GeV data (5 pb^{-1}) has proven useful!



$$
\begin{aligned}
m_Z &= 91189.6 \pm 7.3\ \text{MeV} \\
\Gamma_Z &= 2499.3 \pm 4.4\ \text{MeV} \\
j^{tot}_{had} &= 0.11 \pm 0.39
\end{aligned}
$$

…but harder to measure ⇒ see talk by S. Wynhoff



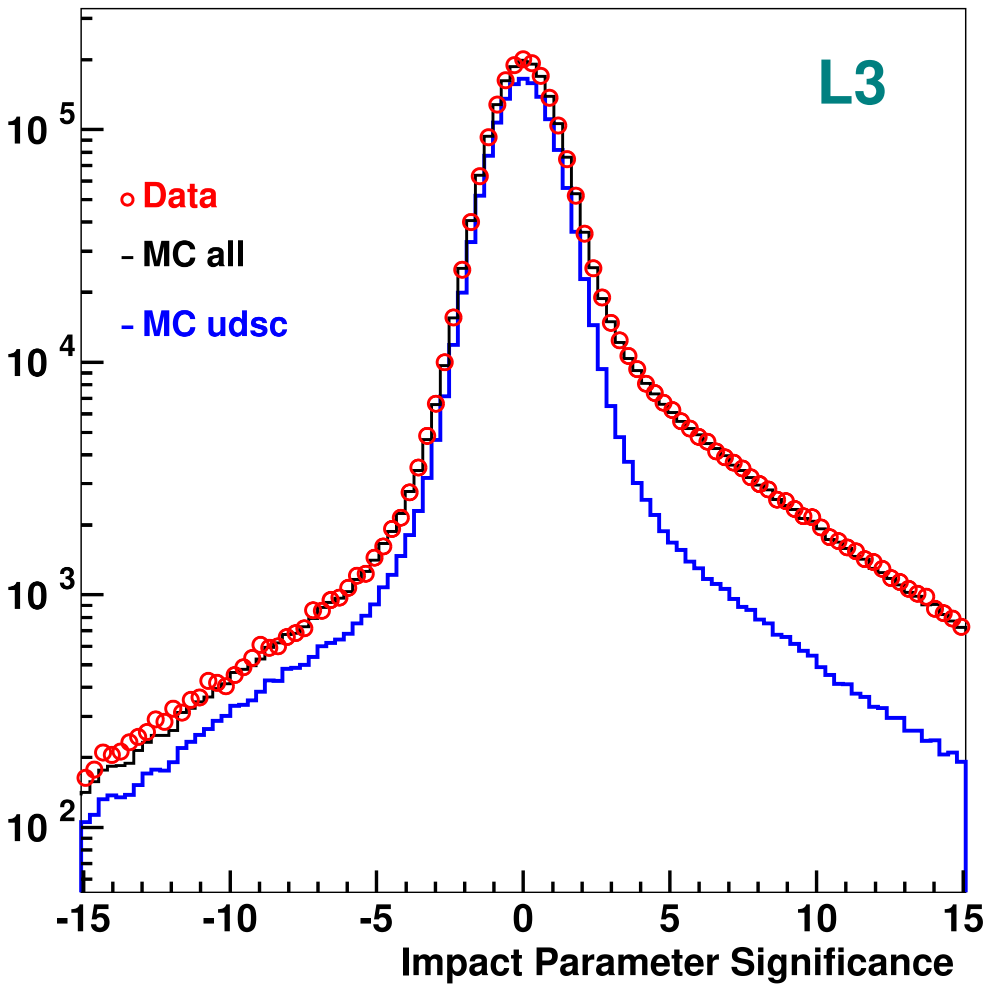
Standard Model fits

Fit m_Z, m_t, $\alpha_s(m_Z)$, m_H, $\alpha(m_Z)$

constrain $\alpha^{-1}(m_Z) = 128.896 \pm 0.090$

(introduces $\Delta(\sin^2\overline{\theta}_W) = 0.00023$, $\Delta m_t = 4$ GeV)

Use also $A_{FB}^{0,b} = 0.107 \pm 0.011$, τ polarization results,
$\alpha_s(m_Z) = 0.123 \pm 0.006$, $R_b \equiv \Gamma_b/\Gamma_{had} = 0.2185 \pm 0.0043$
(see talk by S. Easo)



Standard Model fits

Fit with m_{H} fixed to 60 GeV, 300 GeV, 1000 GeV:

$$\alpha_s(m_Z) \text{ fitted: } \alpha_s(m_Z) = 0.126 \pm 0.007 \pm 0.002(m_{\mathrm{H}})$$

Fitted m_{t} compatible with CDF, D0:

$$m_{\mathrm{t}} = 191^{+13}_{-14} \pm 17(m_{\mathrm{H}}) \text{ GeV}$$

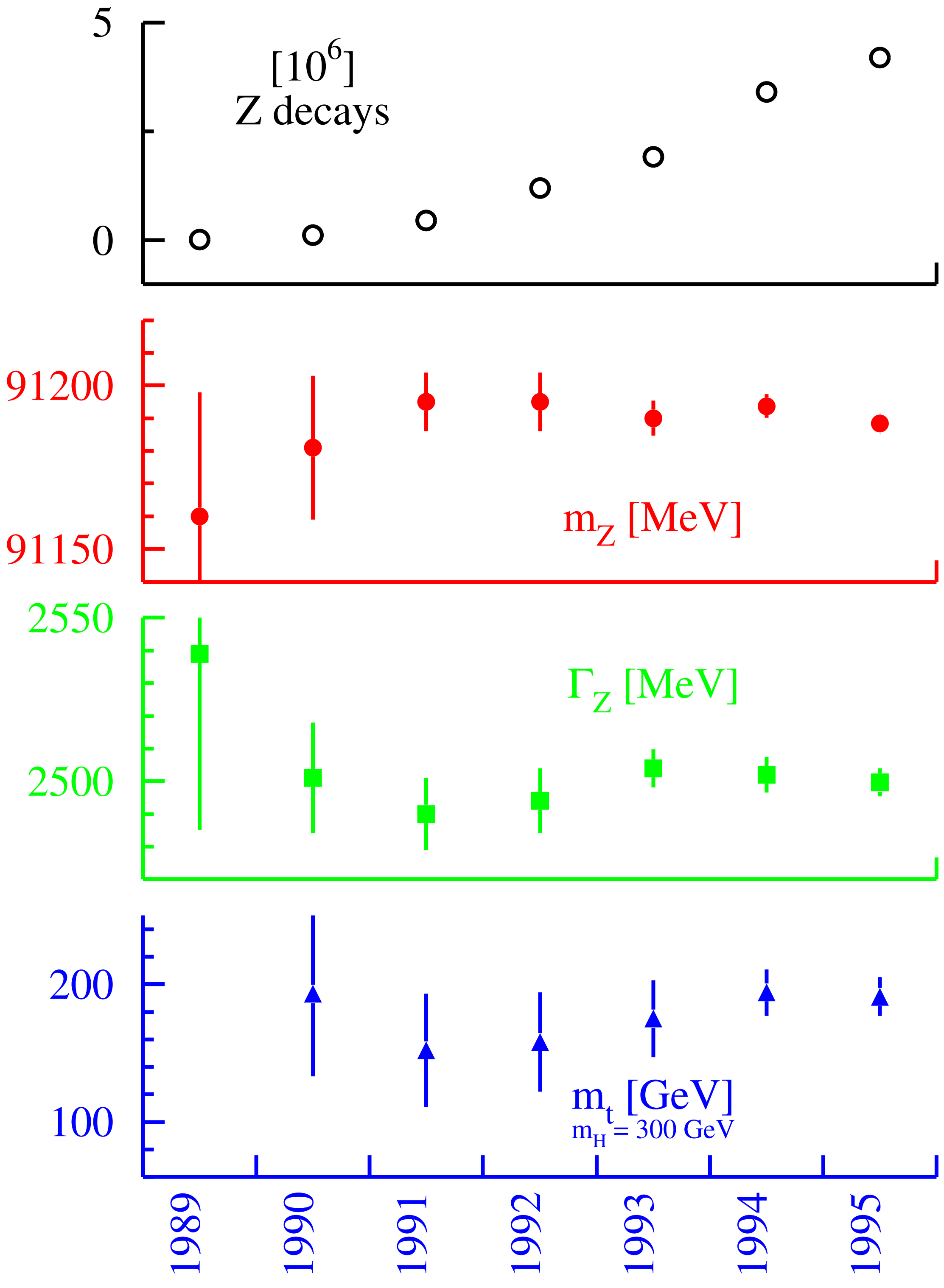
Derive:

$$\begin{aligned} m_{\mathrm{W}} &= 80.42 \pm 0.09 \pm 0.01 \text{ GeV} \\ \sin^2\theta_{\mathrm{W}} &= 0.2222^{+0.0018}_{-0.0017}{}^{+0.0001}_{-0.0002} \\ \sin^2\overline{\theta}_{\mathrm{W}} &= 0.2314 \pm 0.0005\,^{+0.0001}_{-0.0003} \end{aligned}$$

Constrain $m_{\mathrm{t}} = 175 \pm 6$ GeV:

$$m_{\mathrm{H}} = 14^{+90}_{-8} \text{ GeV} \quad (m_{\mathrm{H}} < 350 \text{ GeV} \quad 95\%\text{CL})$$

Standard Model fits



Tables

Systematic uncertainties:

	1990	1991	1992	1993	1994	1995
$\delta\mathcal{L}$ [%]	0.6	0.6	0.6	0.15	0.14	0.17
$\delta\sigma$ (had) [%]	0.3	0.15	0.15	0.052	0.051	0.1
$\delta\sigma$ (e) [%]	0.4	0.3	0.3	0.27-0.32	0.23	1.0
$\delta\sigma$ (μ) [%]	0.8	0.5	0.5	0.31-0.32	0.31	1.0
$\delta\sigma$ (τ) [%]	0.9	0.7	0.7	0.64-0.71	0.65	0.6
δA_{FB} (e)	0.004	0.004	0.002	0.003	0.003	0.01
δA_{FB} (μ)	0.005	0.002	0.002	0.0008	0.0008	0.005
δA_{FB} (τ)	0.005	0.005	0.003	0.003	0.003	0.003

LEP Energy covariance matrix (all numbers in MeV^2):

		1993			1995		
		peak−2	peak	peak+2	peak−2	peak	peak+2
1993	peak−2	8.38	4.39	4.27	0.43	0.03	−0.01
	peak		39.95	6.87	0.15	1.74	0.67
	peak+2			9.38	0.15	1.45	1.32
1995	peak−2				2.56	1.43	1.23
	peak					22.18	2.11
	peak+2						5.40