A Model Independent Analysis

of the Z Lineshape

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XXIX Rencontres de Moriond

March 12-19, 1994

There are several model independent approaches to describe the process

$$e^- e^+ \longrightarrow f^- f^+$$

- partial width
- effective couplings
- S-matrix

The S-Matrix Approach

$\Rightarrow$ Z, γ are described by poles in the complex energy plane

$$\mathcal{M}^i = \frac{R_\gamma}{s} + \frac{R^i_Z}{s - s_z}$$

$$s_z = \overline{m}_Z^2 + i\overline{m}_Z\overline{\Gamma}_Z$$

$$\begin{aligned} R_z^0 &= R_z(e_L^- e_R^+ \longrightarrow f_L^- f_R^+) \\ R_z^1 &= R_z(e_L^- e_R^+ \longrightarrow f_R^- f_L^+) \\ R_z^2 &= R_z(e_R^- e_L^+ \longrightarrow f_R^- f_L^+) \\ R_z^3 &= R_z(e_R^- e_L^+ \longrightarrow f_L^- f_R^+) \end{aligned}$$

$\Rightarrow$ the cross section is given by:

$$\sigma_A(s) = \frac{4}{3}\pi\alpha^2 \left[\frac{r_A^\gamma}{s} + \frac{s r_A + (s - \overline{m}_Z^2) j_A}{(s - \overline{m}_Z^2)^2 + \overline{m}_Z^2 \overline{\Gamma}_Z^2}\right]$$

$$A = tot,\ fb,\ pol,\ fb - pol$$

The S-Matrix Approach

$$r_A^\gamma = \begin{cases} |R_\gamma|^2 & \text{if } A = tot \\ 0 & \text{if } A \neq tot \end{cases}$$

$$\begin{aligned} r_A &= \frac{1}{4}\sum_{i=1}^{4}\{\pm 1\}\left|R_Z^i\right|^2 + 2\frac{\overline{\Gamma}_Z}{\overline{m}_Z}\Im\mathrm{m}C_A \\ j_A &= 2\Re\mathrm{e}C_A \\ C_A &= R_\gamma^*\left(\frac{1}{4}\sum_{i=1}^{4}\{\pm 1\}R_Z^i\right), \end{aligned}$$

$\Rightarrow$ asymmetries :

$$\mathcal{A}_A = \frac{\sigma_A}{\sigma_{tot}};\ A = fb,\ pol,\ fp - pol$$

$\Rightarrow$ free parameter: $\overline{m}_Z$, $\overline{\Gamma}_Z$, r_γ^{tot}, (R_Z^{0-3} or j_A, r_A)

$\Rightarrow$ Γ_Z is not s dependent in the S-Matrix approach

$$\begin{aligned} \overline{m}_Z &= m_\mathrm{Z} - 34\ \mathrm{MeV} \\ \overline{\Gamma}_Z &= \Gamma_\mathrm{Z} - 1\ \mathrm{MeV} \end{aligned}$$

Other Model Independent Ansatzes

Partial Width Approach

$$r_{tot}^{\gamma} = \mid \frac{\alpha(s)}{\alpha} \mid^2 Q_e^2 Q_f^2; \quad \alpha(s = m_{\mathrm{Z}}^2)^{-1} = 128.8$$
$$r_{tot} \sim \Gamma_e \Gamma_f$$

$\Rightarrow j_{tot}$ usually fixed to the Standard Model (ZFITTER,MIZA)

Effective Couplings Approach

$$r_{tot} \sim (a_{\mathrm{e}}^2 + v_{\mathrm{e}}^2)(a_f^2 + v_f^2)$$
$$j_{tot} \sim v_{\mathrm{e}} v_f$$
$$r_{fb} \sim a_{\mathrm{e}} v_{\mathrm{e}} a_f v_f$$
$$j_{fb} \sim a_{\mathrm{e}} a_f$$

$\Rightarrow j_{tot}^{lep}$ can be constrained for leptons using $\mathcal{A}_{fb}$

L3 Results

⇒ fit to σ_{tot}, $\mathcal{A}_{fb}$ (90-92) and P_τ (90-91) with ZFITTER and SMATASY

⇒ r_{tot}^{γ} fixed ($\alpha(s = m_{\mathrm{Z}}^2)^{-1} = 128.8$)

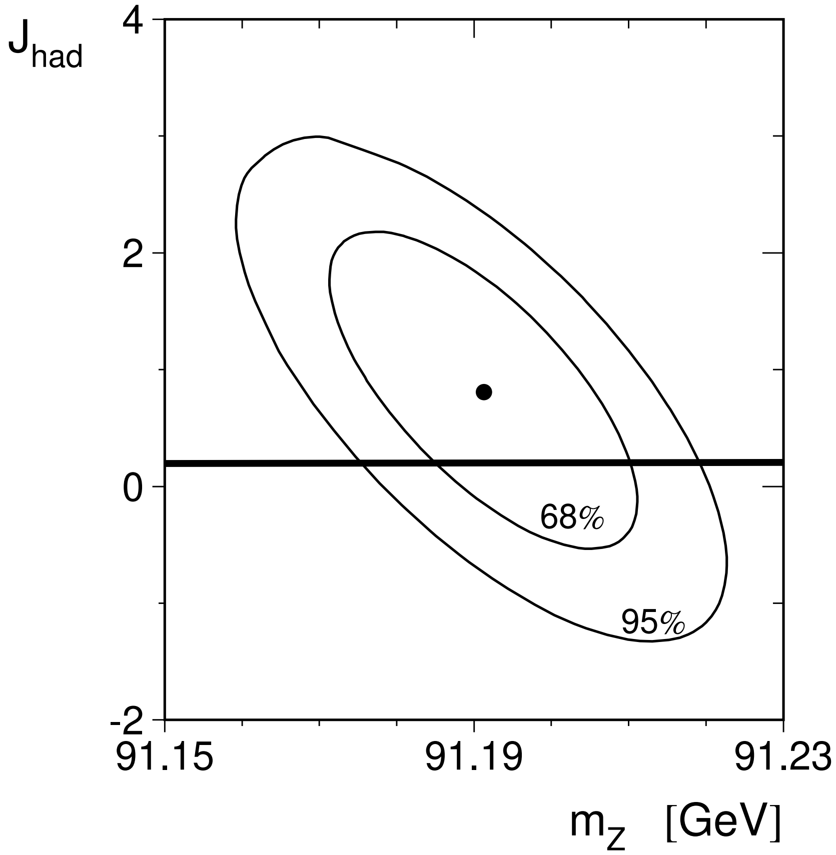
⇒ lepton universality

⇒ CP invariance $\rightarrow R_Z^1 = R_Z^3$

⇒ j_{tot}^{lep} is constrained by R_Z^i

Parameter	j_{tot}^{had} free	j_{tot}^{had} fixed to SM
$\overline{m}_Z$ (GeV)	91.157 ± 0.013	91.161 ± 0.009
$\overline{\Gamma}_Z$ (GeV)	2.496 ± 0.011	2.495 ± 0.011
R_Z^0	0.427 ± 0.012	0.427 ± 0.012
R_Z^1	-0.372 ± 0.002	-0.372 ± 0.002
R_Z^2	0.326 ± 0.015	0.326 ± 0.015
r_{tot}^{had}	2.862 ± 0.030	2.860 ± 0.029
j_{tot}^{had}	0.467 ± 0.628	fixed to 0.219

L3 Results



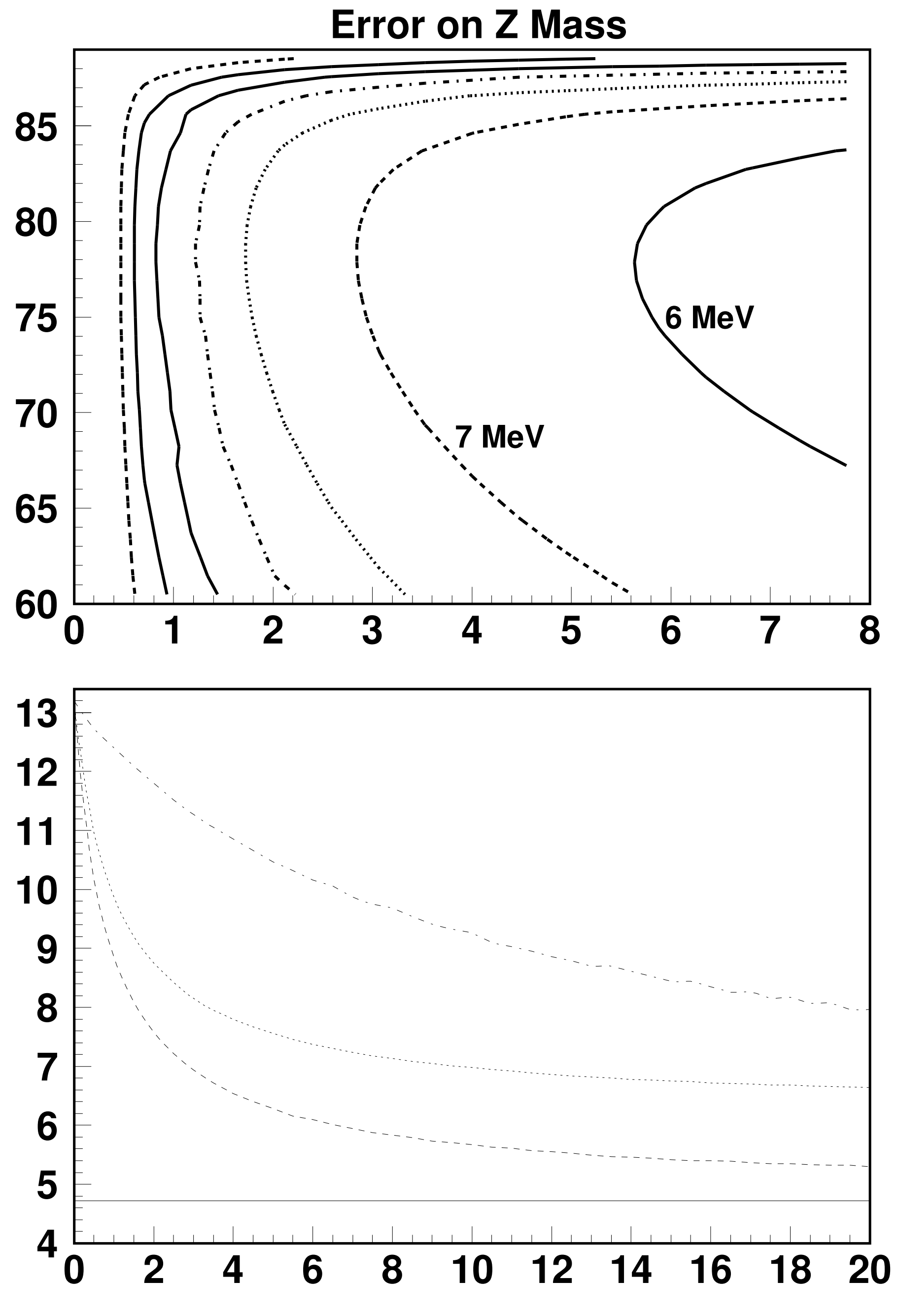
$\Rightarrow$ correlation between m_Z and j_{tot}^{had} is neglected if j_{tot}^{had} is fixed

$\Rightarrow$ leads to an underestimation of the error on m_Z

$$\Delta m_Z = \pm 6 \text{ MeV} \pm 7 \text{ MeV}(LEP) \pm 9 \text{ MeV}(j_{tot}^{had})(90-92)$$
$$\Delta m_Z = \pm 3 \text{ MeV} \pm 3 \text{ MeV}(LEP) \pm 8 \text{ MeV}(j_{tot}^{had})(90-93)$$

$\Rightarrow$ How to improve Δm_Z ?

Energy Point far from the Peak



Conclusion

- S-matrix approach truly model independent

- identical treatment of parameters in S-matrix and effective couplings + partial width approach give same results

- the correlation of m_{Z} and j_{tot}^{had} is neglected in partial width approach

- uncertainty in j_{tot}^{had} is the dominant error for m_{Z}

$$\Delta m_{\mathrm{Z}}(j_{tot}^{had}) = \pm 9 \text{ MeV}$$

- error on j_{tot}^{had} can be improved substantially by running at 80 GeV

S-Matrix Fit to XS

Parameter	j free	j fixed to SM
$\overline{m}_Z$ (GeV)	91.157 ± 0.014	91.161 ± 0.009
$\overline{\Gamma}_Z$ (GeV)	2.497 ± 0.011	2.496 ± 0.011
r_{tot}^{lep}	0.1415 ± 0.0016	0.1414 ± 0.0016
j_{tot}^{lep}	0.0082 ± 0.0647	fixed to 0.0058
r_{had}^{lep}	2.864 ± 0.030	2.861 ± 0.029
j_{had}^{lep}	0.523 ± 0.706	fixed to 0.219

S-Matrix Fit to XS, $\mathcal{A}_{fb}$

Parameter	j free	j fixed to SM
$\overline{m}_Z$ (GeV)	91.157 ± 0.014	91.161 ± 0.009
$\overline{\Gamma}_Z$ (GeV)	2.496 ± 0.011	2.496 ± 0.011
r_{tot}^{lep}	0.141 ± 0.002	0.141 ± 0.002
j_{tot}^{lep}	0.0194 ± 0.0636	fixed to 0.0058
r_{fb}^{lep}	0.003 ± 0.001	0.003 ± 0.001
j_{fb}^{lep}	0.691 ± 0.088	0.6917 ± 0.088
r_{had}^{lep}	2.862 ± 0.030	2.861 ± 0.029
j_{had}^{lep}	0.541 ± 0.703	fixed to 0.219

S-Matrix Fit to XS, $\mathcal{A}_{fb}$, P_τ

Parameter	j_{had} free	j_{had} fixed to SM
m_Z (GeV)	91.191 ± 0.013	91.195 ± 0.009
Γ_Z (GeV)	2.497 ± 0.011	2.496 ± 0.011
r_{had}^{lep}	2.862 ± 0.030	2.860 ± 0.029
j_{had}^{lep}	0.467 ± 0.628	fixed to 0.219
v_l	-0.0338 ± 0.0055	-0.0337 ± 0.0055
a_l	-0.5001 ± 0.0016	-0.5002 ± 0.0016
$\sin^2 \theta_W^{\mathrm{eff}}$	0.2331 ± 0.0027	0.2331 ± 0.0027

Effective Couplings, Partial Width Fit to XS, $\mathcal{A}_{fb}$, P_τ

Parameter	j_{had} free	j_{had} fixed to SM
m_{Z} (GeV)	91.190 ± 0.013	91.195 ± 0.009
Γ_{Z} (GeV)	2.496 ± 0.011	2.495 ± 0.011
v_l	-0.0374 ± 0.0045	-0.0378 ± 0.0045
a_l	-0.5000 ± 0.0015	-0.4999 ± 0.0014
Γ_{had}	1.749 ± 0.010	1.748 ± 0.010
j_{had}^{lep}	0.803 ± 0.872	fixed to 0.219
$\sin^2\theta_W^{\mathrm{eff}}$	0.2314 ± 0.0022	0.2312 ± 0.0022