Preliminary L3 Results on Fermion-Pair Production in 1999-2000

Jessica Hirschfelder, Carnegie Mellon University
For the L3 Collaboration

APS Meeting 20-23 April 2002

Measurements at 7 CM energies from 192 – 208 GeV
Total luminosity 450 pb^{-1}

Cross Sections, Differential Cross Sections and
Forward-Backward Asymmetries

$$\mathrm{e}^+\,\mathrm{e}^- \rightarrow \mathrm{e}^+\,\mathrm{e}^-\;(\gamma)$$
$$\mathrm{e}^+\,\mathrm{e}^- \rightarrow \mu^+\,\mu^-\;(\gamma)$$
$$\mathrm{e}^+\,\mathrm{e}^- \rightarrow \tau^+\,\tau^-\;(\gamma)$$

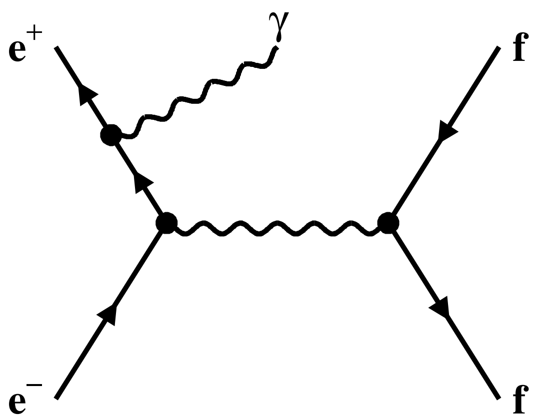
Cross Sections

$$\mathrm{e}^+\,\mathrm{e}^- \rightarrow \mathrm{q}\,\overline{\mathrm{q}}\;(\gamma)$$

Results used for:

- S-Matrix interpretation
- Four-Fermion Contact interactions
- Quantum gravity in extra dimensions
- Fermion sizes

Effective Center of Mass Energy $\sqrt{s'}$



Most ISR photons escape in beampipe.

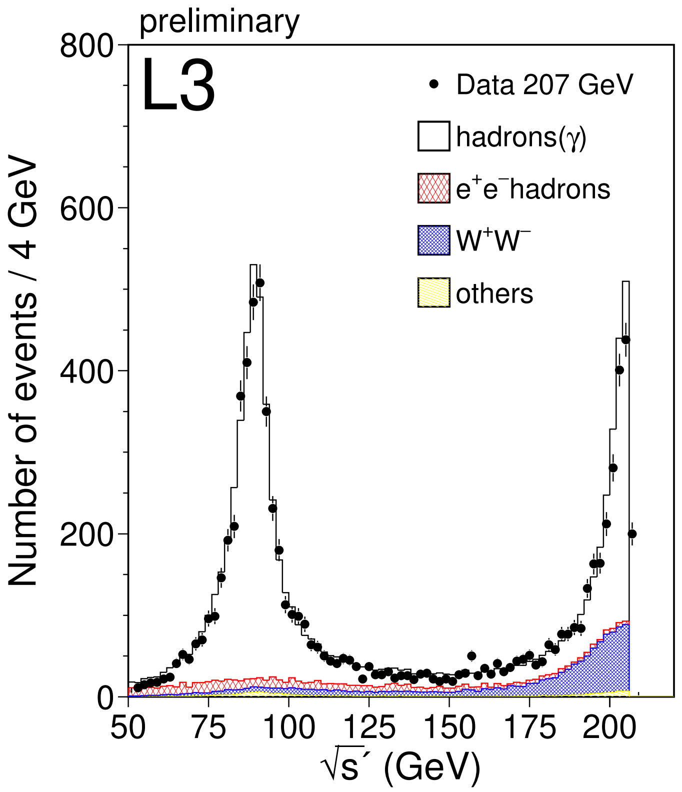
$\sqrt{s'}$: mass of outgoing lepton pair or γ^*/Z propagator

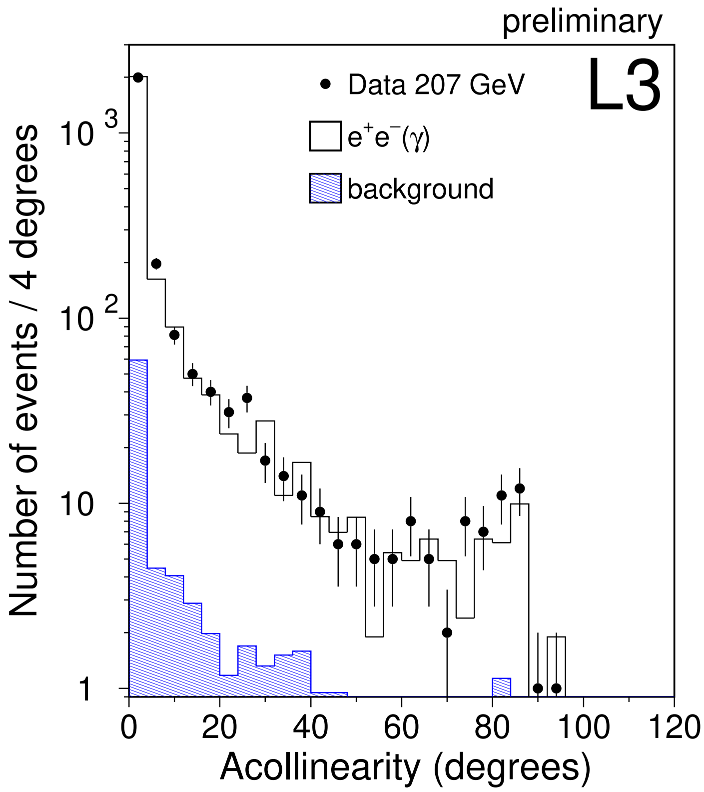
High energy events: $\sqrt{s'} > 0.85\ \sqrt{s}$

Bhabha scattering: large t-channel contribution

$\rightarrow$ acolinearity $\zeta < 25\ ^\circ$ for high energy sample

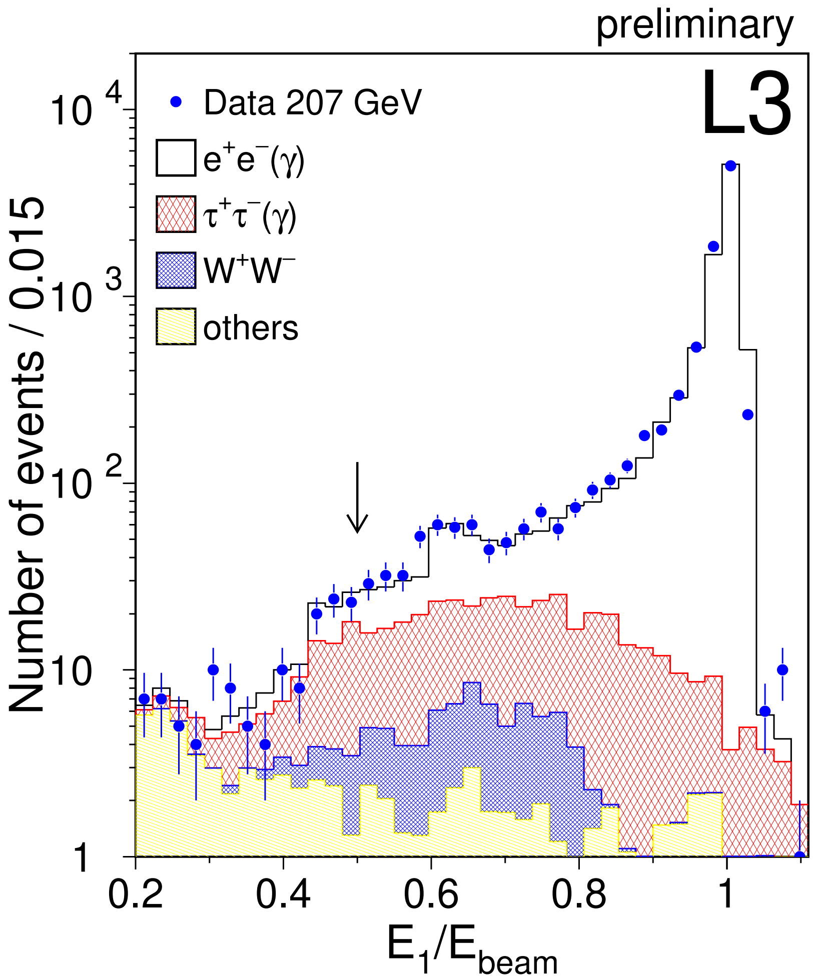
Reconstruction of $\sqrt{s'}$ with polar angles or with kinematic fit

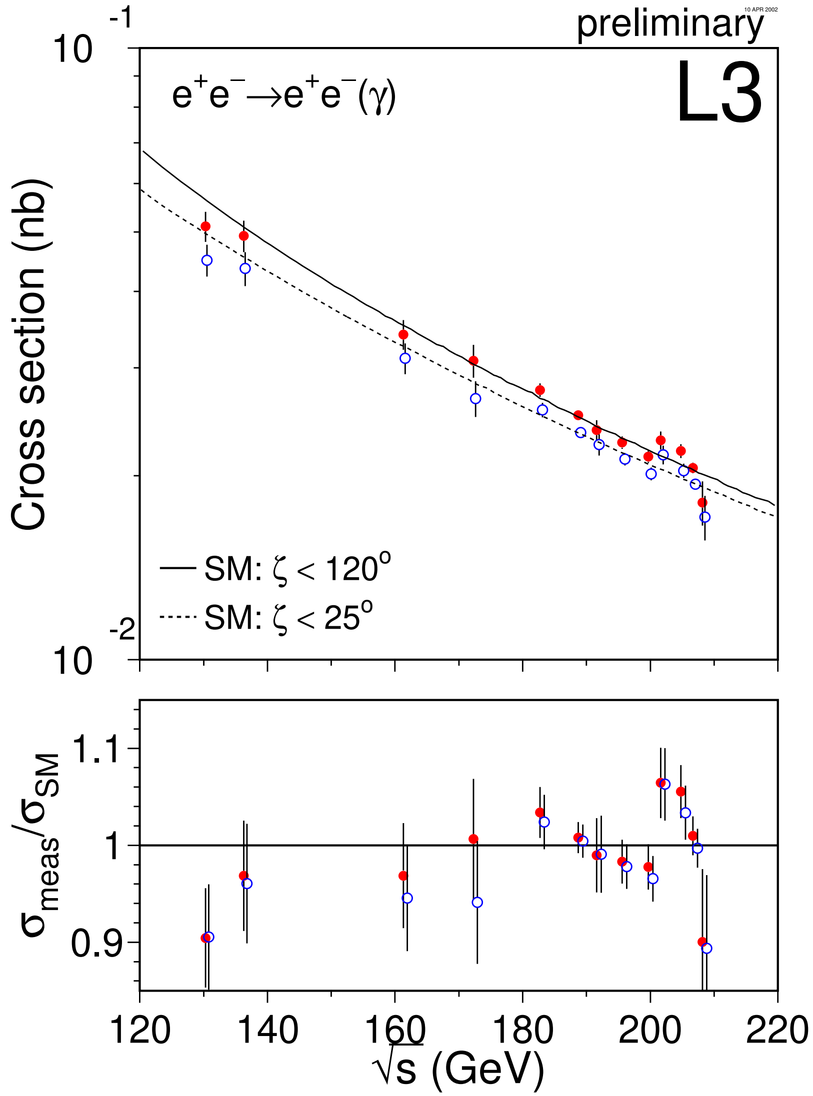




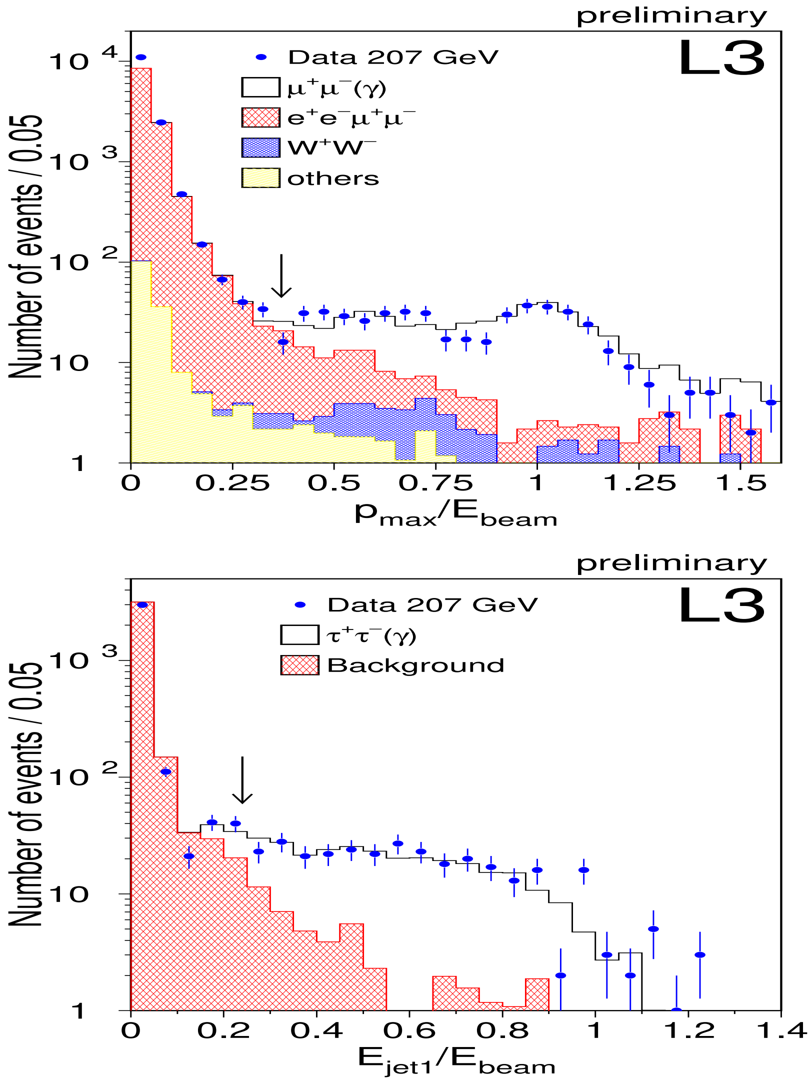
Cross Section Results for Bhabha Scattering

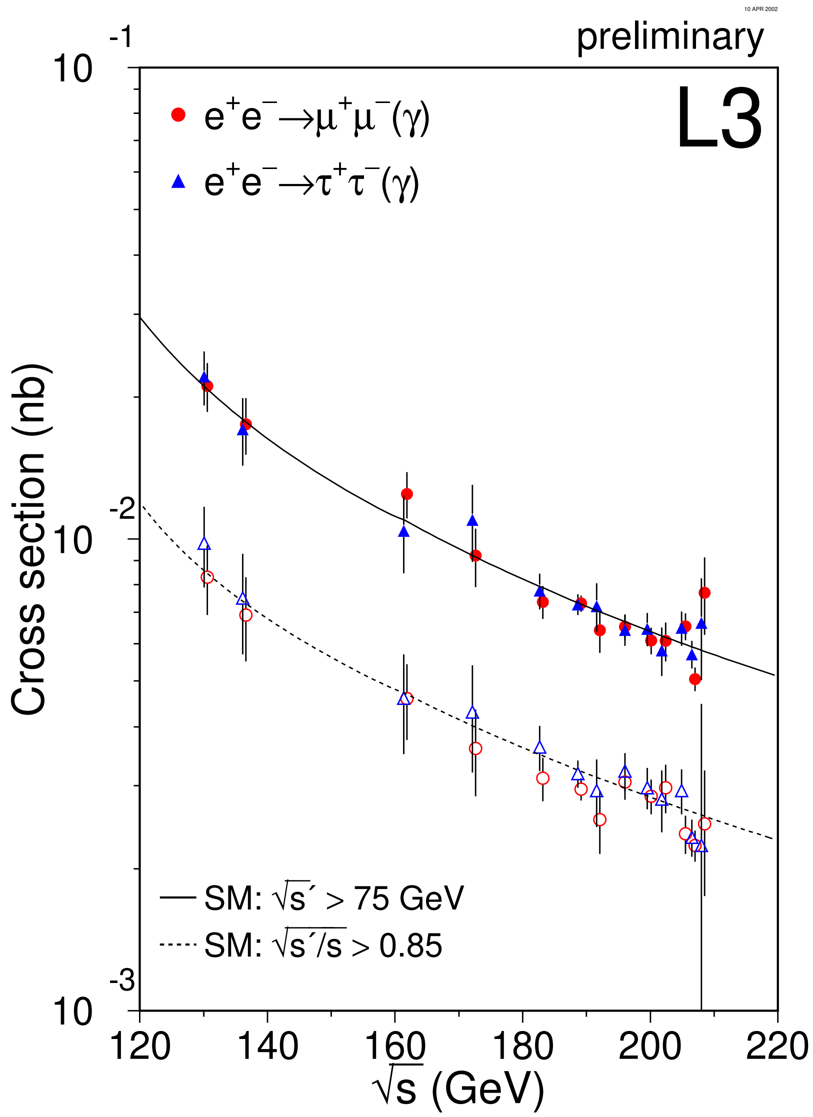
Signal definition:
Both leptons must have polar angle
$44^\circ < \theta < 136^\circ$



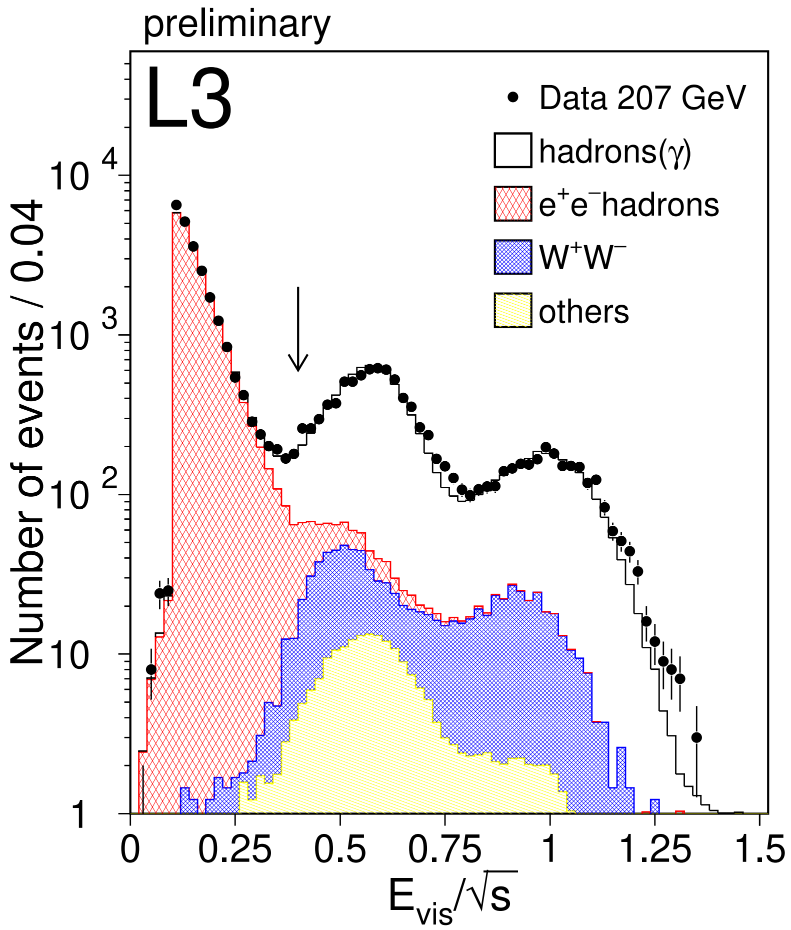


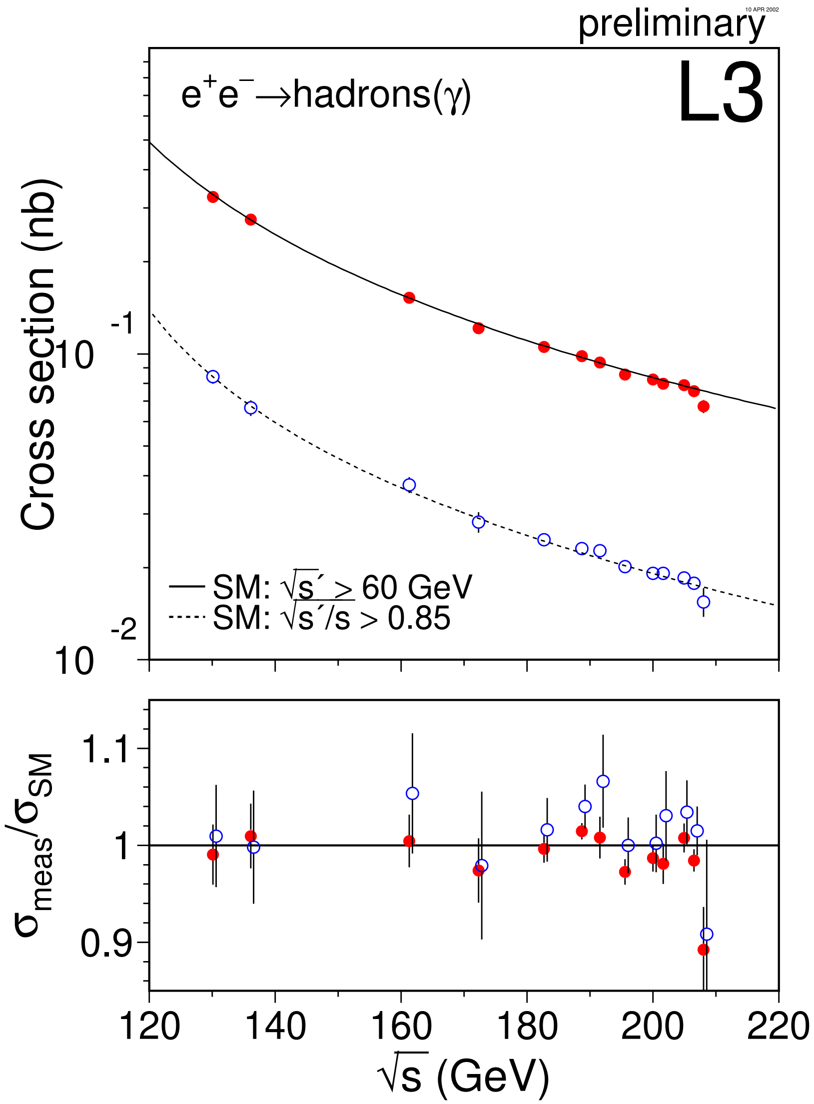
Cross Section Results for Muons and Taus



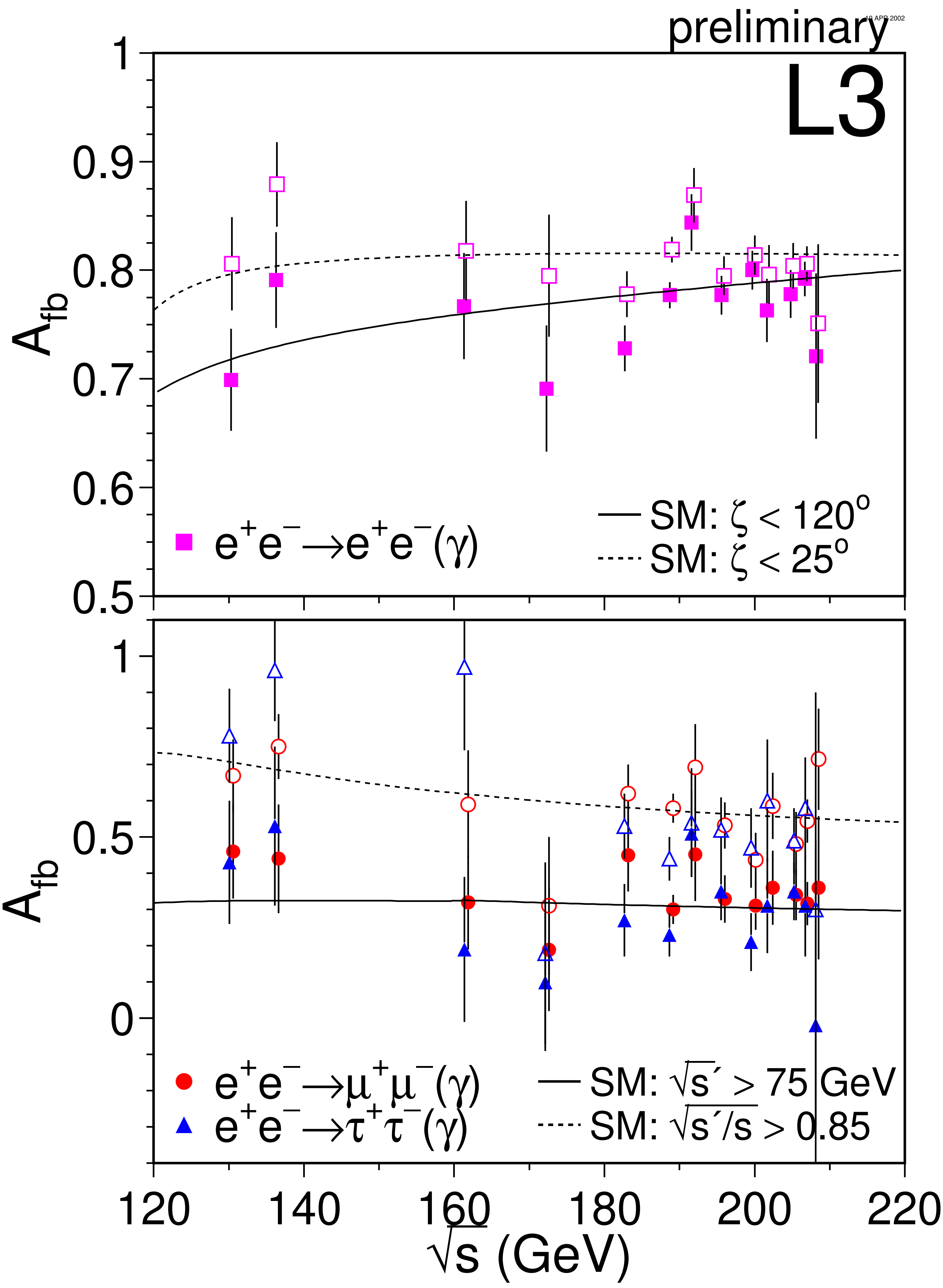


Cross Section Results for Hadrons





Lepton Asymmetry Results



S-Matrix Interpretation

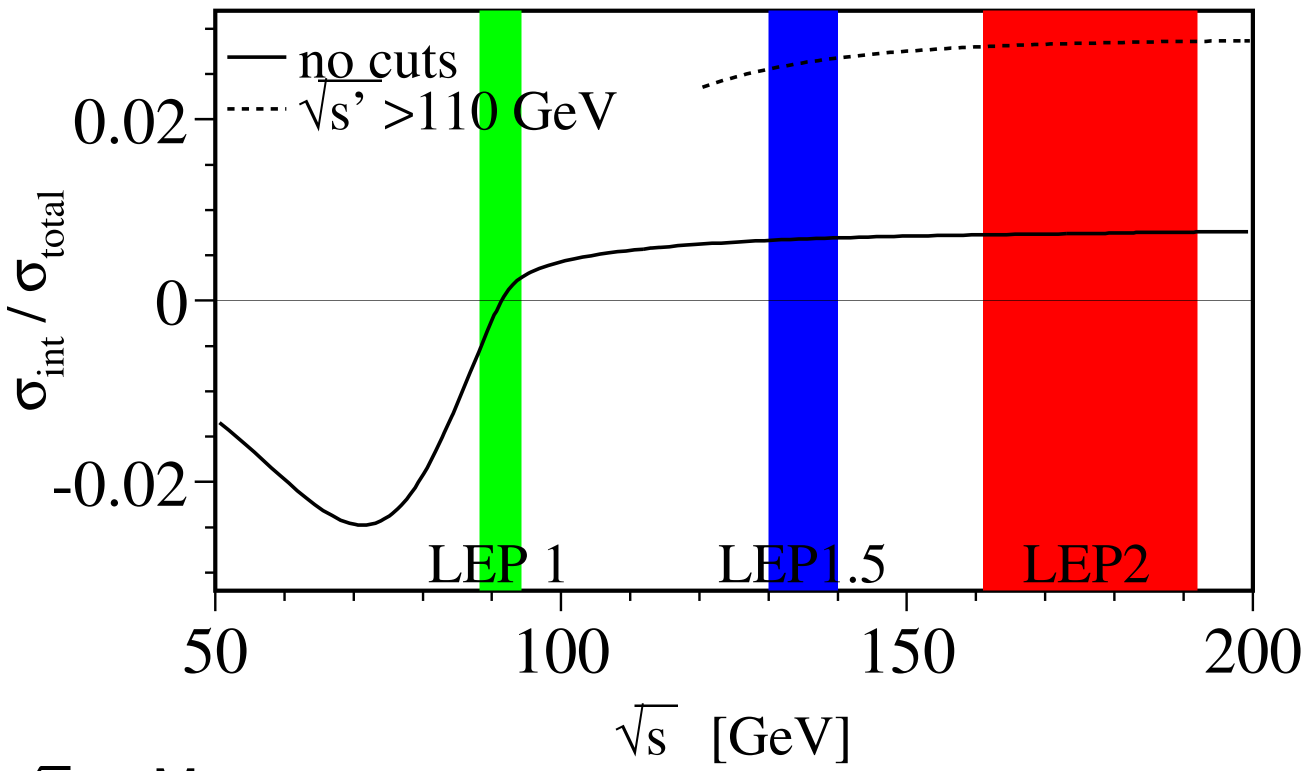
Model-independent: only unitary S-matrix and QED
Definition of the S-Matrix parameters:

$$\sigma_a^0(s) = \frac{4}{3}\pi\alpha^2 \left[\frac{\mathrm{g}_\mathrm{f}^a}{s} + \frac{\mathrm{j}_\mathrm{f}^a(s-\overline{\mathrm{m}}_\mathrm{Z}^2) + \mathrm{r}_\mathrm{f}^a\, s}{(s-\overline{\mathrm{m}}_\mathrm{Z}^2)^2 + \overline{\mathrm{m}}_\mathrm{Z}^2\overline{\Gamma}_\mathrm{Z}^2}\right] \quad \text{for } a = \text{tot, fb}$$

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

g_f Photon exchange fixed to QED value
r_f Z-Boson exchange
j_f γ/Z interference

16(8) parameters without(with) lepton universality



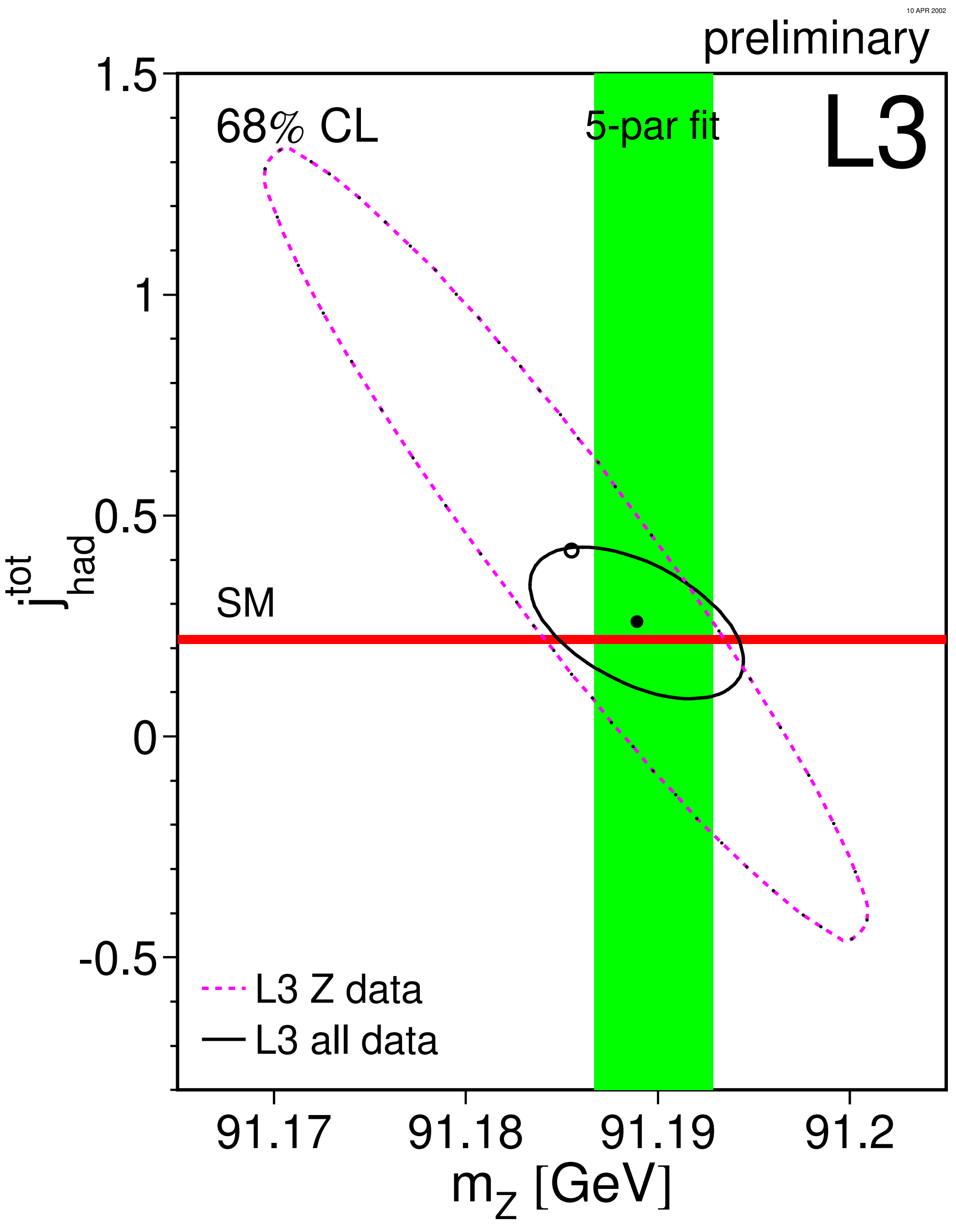
At $\sqrt{s} > \mathrm{M_Z}$:

- sensitivity to j_f higher
- further enhanced by cut on $\sqrt{s'} > 0.85\sqrt{s}$

S-Matrix Results

Assuming lepton universality

	M_Z [MeV]	j_{had}^{tot}
LEP1	91 185.2 $\pm$ 10.3	0.44 $\pm$ 0.59
LEP1+2	91 189.4 $\pm$ 3.7	0.25 $\pm$ 0.11



Also performed at Z Pole Only:

5-parameter fit with g_f^a and j_f^a fixed to SM values

Four-Fermion Contact Interactions

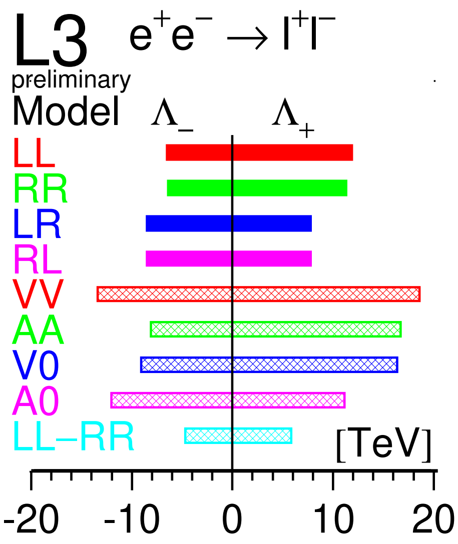
At energies much lower than Λ, exchange of virtual new particles is described by an effective Lagrangian

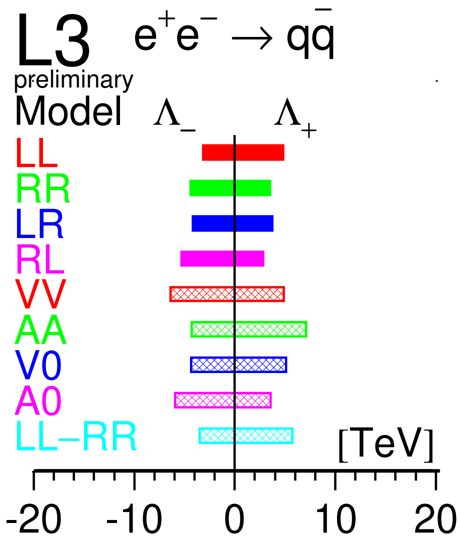
$$\mathcal{L} = \frac{1}{1+\delta_{ef}} \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\bar{e}_i \gamma^\mu e_i)(\bar{f}_j \gamma_\mu f_j)$$

g coupling, fixed to $g^2 = 4\pi$
η_{ij} helicity amplitudes, $|\eta_{ij}| = 0, 1$
Λ energy scale

Choice of η_{ij} defines the model

Obtain lower limits on energy scale Λ for 9 different models:

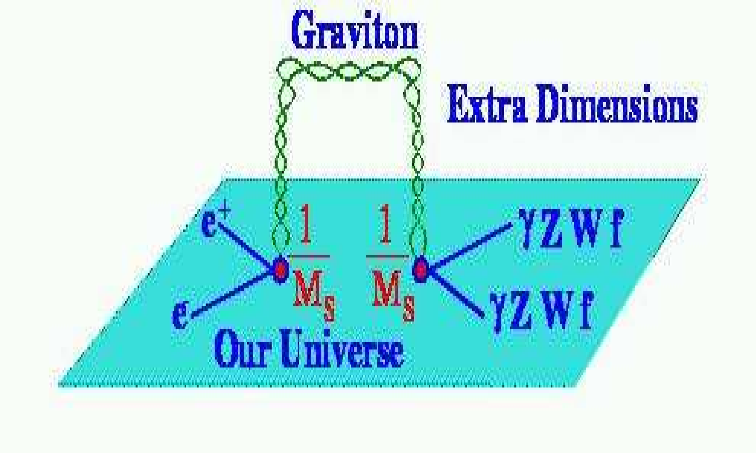




L3 all channels: $\Lambda > 4 - 20$ TeV
Preliminary LEP combined leptons: $\Lambda > 10 - 20$ TeV

Quantum Gravity in Extra Dimensions

Model proposed to overcome the hierarchy problem:
relative weakness of the gravitational force
Electroweak $M_W \simeq 10^2$ GeV, Planck $M_{PL} \simeq 10^{19}$ GeV



Graviton travels in compactified higher dimensions.

SM particles confined to normal 3+1 dimensions.

Quantum gravity scale M_S in N dimensions is related to the Planck mass in the 4-dimensional world:

$M_{PL}{}^2 \simeq R^\delta\ M_S^{2+\delta}$
$\delta = N - 4$ number of extra dimensions
R size of the extra dimensions

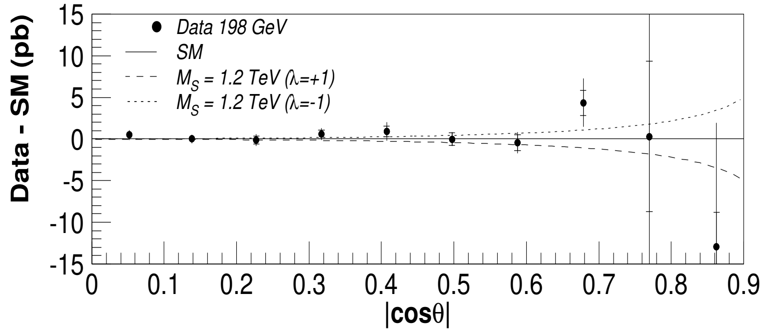
Cross sections depend on M_S and coupling $\lambda = \pm 1$

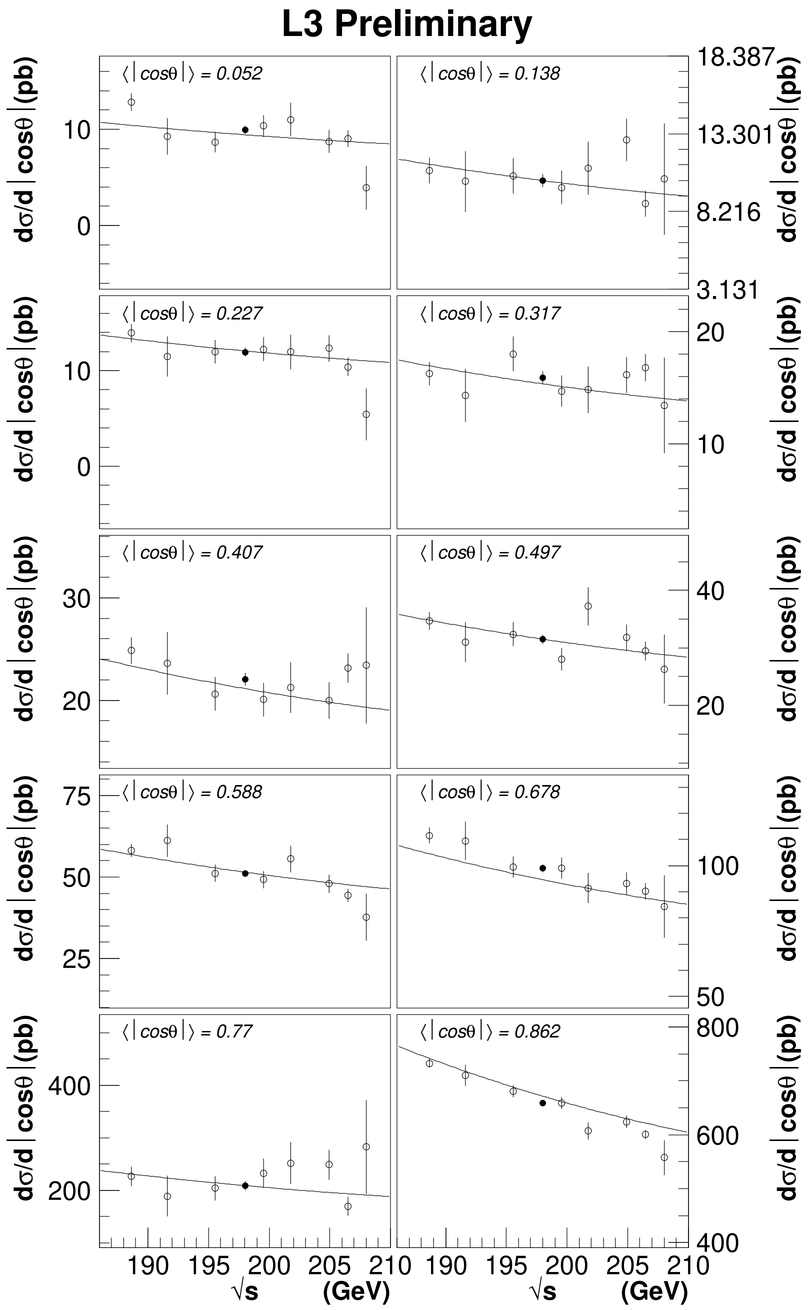
$$\left(\frac{d\sigma}{dcos(\theta)}\right)^{SM} - \mathcal{O}\left(\frac{\lambda}{M_S^4}\right)\ (intf) + \mathcal{O}\left(\frac{\lambda^2}{M_S^8}\right)\ (graviton\ exch)$$

Interference term disappears for total cross section
$\longrightarrow$ differential Bhabha scattering, with t-channel contribution, is most sensitive channel

Quantum Gravity Results from Bhabha Differential Cross Sections

8 energies 189 – 208 GeV (1998 – 2000)
10 bins in $|cos(\theta)|$





Limits:

$M_S > 1.16$ TeV for $\lambda = +1$
$M_S > 1.23$ TeV for $\lambda = -1$

Comparison:

Previous L3	$M_S > 1.06$ TeV for $\lambda = +1$
	$M_S > 0.98$ TeV for $\lambda = -1$
Tevatron	$M_S > 1.1$ TeV for $\lambda = +1$
	$M_S > 1.0$ TeV for $\lambda = -1$

Fermion Sizes

Nonzero fermion sizes introduce corrections to the cross sections, which can be described by form factors:

$$\frac{d\sigma}{dq^2} = \left(\frac{d\sigma}{dq^2}\right)^{\text{SM}} F_e^2(q^2) F_f^2(q^2)$$

Assume Dirac form factor

$$F(q^2) = 1 + \frac{1}{6} q^2 R^2$$

Obtain upper limits on fermion radii using all measurements above the Z pole

$e^+ e^- \longrightarrow e^+ e^-$	$2.9 \cdot 10^{-19}$ m
$e^+ e^- \longrightarrow \mu^+ \mu^-$	$2.1 \cdot 10^{-19}$ m
$e^+ e^- \longrightarrow \tau^+ \tau^-$	$3.0 \cdot 10^{-19}$ m
$e^+ e^- \longrightarrow \ell\, \ell$	$1.9 \cdot 10^{-19}$ m
$e^+ e^- \longrightarrow q\, \bar{q}$	$2.8 \cdot 10^{-19}$ m

Summary

Precise measurements of cross sections and asymmetries at 192 – 208 GeV

Measurements in good agreement with Standard Model

S-matrix approach confirms SM values of Z mass and interference term j_f

Addition of high-energy data reduces error on Z mass in the S-matrix approach

Measurements used to set limits on:

- Contact interactions: $\mathbf{\Lambda > 4 - 20}$ TeV
- Quantum gravity: $M_S > \mathbf{1.2}$ TeV
- Fermion sizes: leptons $< \mathbf{1.9 \cdot 10^{-19}}$ m
  quarks $< \mathbf{2.8 \cdot 10^{-19}}$ m