Measurement and Interpretation of Lepton–Pair Production at LEP2 energies

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- Introduction, Features of LEP2
- Measurement of Cross–Sections and $A_{fb}$
- Interpretations of the Results
Lepton-Pair Production at LEP2

- Motivation: Test of the Standard Model
  ⇒ deviations may be a hint for new physics, indirect search
- observed channels: $f = e, \mu, \tau$
- at LEP2 many events undergo Initial State Radiation
  ⇒ reduction of the effective centre-of-mass energy $\sqrt{s'}$
  Z returns: $\sqrt{s'} \approx M_Z$ (acollinear events)

$$\sqrt{s'} = \sqrt{s_{ll}}$$, invariant Mass of the final Lepton-Pair
after ISR and FSR (initial and final state radiation)

- calculation of cross-section and $A_{fb}$ for 2 event samples
  - inclusive sample (including radiative events)
  - non-radiative sample
- non-radiative sample most sensitive to new physics effects
Determination of $\sqrt{s'}$

Computation of $\sqrt{s'}$ using the following information:

- $E_{\text{Beam}}$
- directions and momentum of the final state leptons
- deposited energy of isolated photons in the calorimeters

1. **Angular Method**

   $s' = s - 2E_\gamma \sqrt{s}$ with energy of the ISR-Photon:

   $$E_\gamma(\text{ISR}) = \frac{|\sin(\theta_1 + \theta_2)| \sqrt{s}}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1 + \theta_2)|}$$

2. **Kinematic Fit**

   (a) different topology assumptions ($\mu\mu, \mu\mu + \gamma, ....$)
   (b) fitted parameters: ($|\vec{p}|$, $\theta$, $\phi$)
   (c) constraints: energy and momentum conservation
   (d) cut on $P(\chi^2)$
   (e) $\sqrt{s'}$ set accordingly to fitted parameters

   $\Rightarrow$ improves the $\sqrt{s'}$ resolution ($\Delta \sqrt{s'}/\sqrt{s'} \sim 5\%$)
Distributions of $\sqrt{s'}$

\[ e^+ e^- \rightarrow \mu^+ \mu^- (\gamma) \]

\[ \sqrt{s} = 192 + 196 \text{ GeV} \]

\[ e^+ e^- \rightarrow \tau^+ \tau^- (\gamma) \]

\[ \sqrt{s} = 192 + 196 \text{ GeV} \]

Preliminary Data

Expected signal + background

Background
Event Selection

Different cuts for each channel on:

- charged multiplicity
- impact to interaction point
- polarangle ($|\cos \theta| \leq 0.97/0.94$ for $\mu/\tau$)
  $44° \leq \theta \leq 136°$ for electrons
- acollinearity
- inclusive class: $\sqrt{s'} > 75$ GeV ($\mu, \tau$)
- non-radiative class $\sqrt{s'/\sqrt{s}} > 0.85$ ($\mu, \tau$)
  ($e^+e^- \rightarrow$ acollinearity $< 20°$)

Remaining Backgrounds:

- 4–fermion–events ($WW, ZZ, Ze^+e^-, We\nu...$)
- 2–photon–events ($e^+e^- \rightarrow e^+e^- f\bar{f}$)
- Cosmics
- Feed through from radiative events
### Results for Lepton–Pair Selection

<table>
<thead>
<tr>
<th>Year</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>130/136</td>
<td>161/172</td>
<td>183</td>
<td>189</td>
<td>192-202</td>
</tr>
<tr>
<td>$\int \mathcal{L} dt$ (pb)$^{-1}$</td>
<td>$\sim$6</td>
<td>$\sim$20</td>
<td>$\sim$54</td>
<td>$\sim$155</td>
<td>$\sim$225</td>
</tr>
<tr>
<td>number of events</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e^+e^- \rightarrow e^+e^- (\gamma)$</td>
<td>129/152</td>
<td>276/312</td>
<td>1109</td>
<td>2804</td>
<td>4446</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow \mu^+\mu^- (\gamma)$</td>
<td>56/40</td>
<td>72/70</td>
<td>354</td>
<td>880</td>
<td>1256</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow \tau^+\tau^- (\gamma)$</td>
<td>33/29</td>
<td>58/54</td>
<td>232</td>
<td>682</td>
<td>640</td>
</tr>
</tbody>
</table>

Errors on $\sigma$ and $A_{fb}$ dominated by statistics

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![Histogram of collision energy with a peak near 205.5 GeV](image)

$\sim 90$ (pb)$^{-1}$ running in Y2K:

- 204 - 208 GeV
- →preliminary results

for 2 energy bins:

- $\sqrt{s} < 205.5$ GeV
- $\sqrt{s} \geq 205.5$ GeV

A.Behrmann, DPF 2000 in Columbus, Ohio, 9-13 August 2000
Lepton Cross–Sections at LEP2

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Typical Systematic Errors: \( \mu \sim 3\%, \tau \sim 5\%, e \sim 1\% \)
Lepton Asymmetries at LEP2

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Typical Systematic Errors: $\mu \sim 10^{-3}$, $\tau \sim 10^{-2}$, $e \sim 10^{-3}$
All results in a reasonable agreement with the SM Prediction!
Differential Cross Sections

**DELPHI PRELIMINARY**

\[ e^+ e^- \rightarrow \mu^+ \mu^- (\gamma) \]

\[ \frac{d\sigma}{d \cos(\theta)} \; (\text{pb}) \]

\( s \sim 197.7 \text{ GeV} \)

\( |L dt| = 223.7 \text{ pb}^{-1} \)

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**DELPHI PRELIMINARY**

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$Z'$–Models

Several theories predict an additional heavy gauge boson $Z'$ parameters: mass $m_{Z'}$, $Z Z'$ mixing $\theta_M$, couplings to fermions

$\Rightarrow$ Sensitivity above $Z$ resonanz: mass $m_{Z'}$

Fits to measured $\sigma_{ll,qq}$, $A_{FB_{ll}}$ (LEP1+2) with 2 different approaches:

- Model independent: $a'_f$, $\nu'_f$ free

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**DELPHI Preliminary**

\[ a'_f, \nu'_f \text{ free} \]
Z’–Models

- Model dependent (E6-models, L-R model, sequential SM): $m_{Z'}, \theta_{Z'Z}$ free

### DELPHI Preliminary

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi$</th>
<th>$\psi$</th>
<th>$\eta$</th>
<th>L-R</th>
<th>SSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{Z'}^{\text{limit}}$ (GeV/c$^2$)</td>
<td>468</td>
<td>345</td>
<td>330</td>
<td>397</td>
<td>676</td>
</tr>
</tbody>
</table>

$\Rightarrow m_Z$ compatible with SM, $\theta_{Z'Z}$ with 0
Contact Interactions

New physics with a high characteristic energy scale \( m \gg \sqrt{s} \) parameterized by the effective Lagrangian:

\[
\mathcal{L}_{\text{eff}} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} \bar{e}_i \gamma_{\mu} e_i \bar{f}_j \gamma^\mu f_j, \text{ assume } g^2 = 4\pi
\]

- \( \Lambda \) is the scale of C.I, \( \epsilon = 1/\Lambda^2 \) the fitted parameter,
- input: \( \sigma_{ll}, A_{fb} \), assuming lepton universality

lower limits of the scale \( \Lambda \) (at 95\% C.L)

**DELPHI Preliminary**

<table>
<thead>
<tr>
<th></th>
<th>( \Lambda^- ) (TeV)</th>
<th>( \Lambda^+ ) (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>6.9</td>
<td>9.7</td>
</tr>
<tr>
<td>RL</td>
<td>6.9</td>
<td>9.7</td>
</tr>
<tr>
<td>AA</td>
<td>13.7</td>
<td>10.3</td>
</tr>
<tr>
<td>VV</td>
<td>12.7</td>
<td>19.0</td>
</tr>
<tr>
<td>RR</td>
<td>7.8</td>
<td>9.6</td>
</tr>
<tr>
<td>LL</td>
<td>8.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

\( \epsilon \) compatible with SM \( \epsilon = 0 \) at 2 \( \sigma \)-level
Gravity in extra Dimensions

- Process $e^+ e^- \rightarrow G \rightarrow f \bar{f}$
  \[ \frac{d\sigma}{dz} = A(z) + B(z)\left[\frac{\lambda}{M_S}\right] + C(z)\left[\frac{\lambda}{M_S}\right]^2, \quad z = \cos(\theta) \]
- Parameter is $\epsilon = \frac{\lambda}{M_S}$
- Fit the measured differential cross-sections $(\mu^+ \mu^-, \tau^+ \tau^-)$
- Biggest effect at large $|\cos \theta|$
Conclusions

- Lepton-pair production above the $Z$ resonanz still a good process to test the SM

- Results for the cross-sections and asymmetries at 130-202 GeV in a good agreement with the SM expectations

- Preliminary results at 205-206 GeV also consistent with the SM

- Interpretations in terms of possible new interactions gave no evidence for the existence of new physics, but limits on the energy scales (95% C.L.) were derived
  
  ($Z'$ boson $> 350$ GeV, Contact Interaction energy scale above 10-20 TeV, Gravity in extra Dimensions $M_S > 600$ GeV)

- Last chance to find something new at LEP THIS YEAR!