Far Forward
Linear Collider Physics
(mostly γγ)

\[
d \frac{d \mathcal{P}(x, Q^2)}{dx \ d \ln Q^2} = \frac{\alpha}{2 \pi} \ \frac{1 + (1-x)^2}{x}
\]

\[Q^2 = 2 E_e E_e' (1 - \cos \theta) \approx E_e E_e' \theta^2 \sim (E_e \theta^2)
\]

\[\theta \sim \frac{Q}{E_e}
\]

Flat in \( \ln Q^2 \) from \( \ln M^2 \rightarrow \ln Q^2 \)
TOPICS

(I) $\gamma \gamma \to WW$ as \underline{background to $e^+e^\to \nu \nu WW$ (strong electroweak sym. breaking studies)}

(II) $\gamma \gamma \to e^+e^-$ as \underline{background to SUSY parameter determinations}:

$$e^+e^- \to \bar{e}^+\bar{e}^- \to e^+\chi^0 e^-\chi^0$$

(III) $\gamma^*\gamma^* \to$ hadrons \underline{total cross-section as test of the "perturbative pomeron" (BFKL)}

(IV) $\gamma^*\gamma \to$ hadrons: \underline{DIS structure of the photon}

(V) \underline{Soft $\gamma\gamma$ physics: e.g. total cross-section}

$\gamma\gamma \to \rho + X$

$\gamma\gamma \to \rho + \rho$

$\gamma\gamma \to \delta/4 + X$

...
(I) At $E_{cm} = 1.5$ TeV, $e^+e^- \rightarrow \bar{\nu}\nu W^+W^+$ probes scattering of longitudinal $W$s at sufficiently high scale to see possible signs of strongly-interacting Higgs sector.

Large background from $e^+e^- \rightarrow e^+e^- W^+W^-$

Q: What $E_{c}^{tag}$ do we need to suppress this background?

→ Barger, Cheung, Han, Phillips, Phys. Rev. D52, 3815 (1995)

• Key is that $e^+\frac{E}{W}p_T$ has $p_T \sim M_W$

$\Rightarrow$ signal WW pair has higher typical $p_T(WW)$ than background.

A: $E_{c}^{tag} \geq 150 \text{ MeV}$ is sufficient.
FIG. 4. SEWS signal and background cross sections versus diboson invariant mass at $\sqrt{s} = 1.5$ TeV, after the first-level cuts of Eqs. (21) and (22), in the channels (a)
(II) LC & precision SUSY measurements, e.g.

\[ e^+e^- \rightarrow \tilde{e}^+\tilde{e}^- \rightarrow e^+e^- \chi^0\chi^0 \]

Studied by N. Danielson & L. Goodman

http://hep-www.colorado.edu/NLC/grpwk.html

"Point 2 Selectrons..." 

\[
\begin{align*}
    m_{\tilde{e}_R} &= 157 \text{ GeV} \\
    m_{\tilde{e}_L} &= 238 \text{ GeV} \\
    m_{\chi^0} &= 129 \text{ GeV}
\end{align*}
\]

- For \( m_{\tilde{e}_R} \approx m_{\chi^0} \), \( E_{e^+} \) can be small
  - Large off background from \( e^+e^- \rightarrow \tilde{e}^+\tilde{e}^- e^+e^- \)
Cross sections (in fb) for selectron events and for Standard Model Background production modes at $E_{cm} = 500$ GeV, 80% right polarization

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cross Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{e}_L^+ \tilde{e}_L^-$</td>
<td>2</td>
</tr>
<tr>
<td>$\tilde{e}_R^+ \tilde{e}_R^-$</td>
<td>317</td>
</tr>
<tr>
<td>$\tilde{e}_L^+ \tilde{e}_R^-$</td>
<td>146</td>
</tr>
<tr>
<td>$W^+W^-$</td>
<td>1461</td>
</tr>
<tr>
<td>$\gamma + \gamma$</td>
<td>6840</td>
</tr>
<tr>
<td>$\gamma^* or Z^0$</td>
<td>5380</td>
</tr>
<tr>
<td>$\gamma + \gamma^* or Z^0$</td>
<td>5200</td>
</tr>
<tr>
<td>$Z^0 + Z^0$</td>
<td>427</td>
</tr>
<tr>
<td>$\gamma^<em>\gamma^</em>$</td>
<td>$4.42 \times 10^7$</td>
</tr>
</tbody>
</table>
A summary of the cuts:

The three “standard cuts”:

- Limit events to those with exactly two visible particles: one electron and one positron.

- Limit events to those with less than 1 GeV visible energy between 451 and 100 mrad.

- Limit events to those with energy in the forward direction less than 0.4 E,.

  \[ \text{AND} \]

- The total transverse momentum $p_t$ must be greater than 40 GeV/c.

  \[ \text{OR} \]

- The total $p_t$ must be greater than 15 GeV/c.

- Cut events with electrons with an angle between 40 mrad and 100 mrad. This cut amounts to assuming that the detector can see down to 40 mrad.
$E_{e^+, e^-}$ for Supersymmetric signal (red) and Standard Model background (blue) following cut to limit events to those with energy in the forward direction less than 0.4 $E_{\gamma}$, 80% right polarization.

with "3 standard cuts"
The total transverse momentum of $\gamma^*\gamma^*$ events (blue) and selectron events (red for 80% right polarized data, green for 80% left polarized data).
The energy of electrons and positrons as the cut on total transverse momentum is varied. The 80% right polarized selectron data is red, the 80% left polarized data is green, and the $\gamma^*\gamma^*$ data is blue. When the total $p_t$ cut is set at 40 GeV/c, most of the $\gamma^*\gamma^*$ background is removed.
Almost all the background can be eliminated if our detector can see down to 40 mrad and if we make a $p_t$ cut of 15 GeV/c.
LC can study $\gamma^* \gamma^* \rightarrow$ hadrons

for $S_{yy} \gg Q^2 \gg \Lambda_{QCD}^2$

$\rightarrow$ HE scattering of small color dipoles

$\Rightarrow$ "perturbative QCD pomeron" or "BFKL dynamics"

Leading log predictions: Large enhancement over $1$-gluon exchange

Brodsky et al., hep-ph/9610260, 9706427, 9707444

Bartels et al., 9609401, 9710566

But:

- Next-to-leading corrections may be large + negative
- LEP II apparently doesn't see at leading-log level.

- Studies have not yet looked at QED $Y\gamma$
  background, requirement for hadronic activity...

$\Rightarrow \frac{e^+ e^- \rightarrow \ell \nu}{e^+ e^- \rightarrow \ell \ell}$ would be good to shoot for here
Table 1: Total event rates per $1000 \text{ pb}^{-1}$ for different values of $\theta_{\text{tag,min}}$. We have chosen $E_{\text{tag}} > 20 \text{ GeV}, \log s/s_0 > 2, 2.5 < Q^2 < 200 \text{ GeV}^2$.

<table>
<thead>
<tr>
<th>$\theta_{\text{tag,min}}$</th>
<th>BFKL</th>
<th>2-gluon</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mrad</td>
<td>2724</td>
<td>46</td>
</tr>
<tr>
<td>30 mrad</td>
<td>324</td>
<td>12</td>
</tr>
<tr>
<td>40 mrad</td>
<td>67</td>
<td>3.6</td>
</tr>
<tr>
<td>50 mrad</td>
<td>19</td>
<td>1.1</td>
</tr>
<tr>
<td>60 mrad</td>
<td>4.8</td>
<td>0.24</td>
</tr>
<tr>
<td>70 mrad</td>
<td>1.3</td>
<td>0.059</td>
</tr>
<tr>
<td>80 mrad</td>
<td>0.46</td>
<td>0.020</td>
</tr>
<tr>
<td>90 mrad</td>
<td>0.17</td>
<td>0.0074</td>
</tr>
<tr>
<td>100 mrad</td>
<td>0.063</td>
<td>0.0029</td>
</tr>
</tbody>
</table>

Table 2: Total event rates for $1000 \text{ pb}^{-1}$ and different values of $E_{\text{tag}}$ and $p$. We have chosen $\theta_{\text{tag}} > 30 \text{ mrad}$, the other cuts are as above. Given are numbers of events for BFKL and for 2-gluon exchange (in brackets).

$$\frac{1}{p} < Q_2^2 < \rho$$

$$\rho = \infty |324 (12), 159 (9), 72 (6) |
\rho = 3 |188 (9), 122 (7), 63 (5) |
\rho = 2 |122 (6), 87 (5), 47 (4) |
\rho = 1.5 |65 (4), 51 (3), 31 (3) |
(IV) Deep Inel. Scattering off Photon

\[ F_2^\gamma(x, Q^2) \]

\[ e^- \rightarrow \text{tag} \rightarrow E_e, \theta_e \]

\[ e^- \overline{q} \rightarrow q, q' \]

\[ q^2 = D \]

\[ q \rightarrow \text{down beam pipe, } E \approx 1 \text{ mrad} \]

- **SLAC ep DIS:** \( E_e, \theta_e \rightarrow x, Q^2 \)
  - but that's because \( E_p \) was known!

- Here, to get \( x = \frac{Q^2}{W_{\text{had}}} \), need either
  1. \( E_e, \text{beampipe} \)
  2. reconstruct hadron 4-momentum \( W_{\text{had}} \)

- Also want small enough \( \theta_e^{\text{tag}} \)
  - so \( Q^2 \) is not too large to overlap with LEP2
  - want some \( Q^2 \lesssim 100 \text{ GeV}^2 \)
  - \( \theta_e^{\text{tag}} = 40 \text{ mrad} \) will permit this
The \( W - W_{\text{vis}} \) correlation at \( \text{LEP200} \)

![Graphs showing correlation between \( W \) and \( W_{\text{vis}} \)]

The correlation based on \textbf{F2GEN} is much stronger. The inclusion of the \textbf{Forward Region} significantly improves the correlation.
GUINEA PIG: Disrupted 500 GeV beam

\[ Q^2 > (150 \text{ MeV})^2 \]
# Quick & Dirty Summary Table

<table>
<thead>
<tr>
<th>Physics Topic</th>
<th>$E_\text{tag}^{\text{min}}$ (meV)</th>
<th>hadrons at $\Theta \leq 200$ meV?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I) WW</td>
<td>$15C$</td>
<td>no</td>
</tr>
<tr>
<td>(II) SUSY (some topics)</td>
<td>$4C$</td>
<td>no</td>
</tr>
<tr>
<td>(III) $\gamma^<em>\gamma^</em>$ (BFKL)</td>
<td>$41$</td>
<td>detect</td>
</tr>
<tr>
<td>(IV) $\gamma^*\gamma$ ($F_2\gamma$)</td>
<td>$41$</td>
<td>try to measure $E$</td>
</tr>
<tr>
<td>(V) soft $\gamma\gamma$</td>
<td>$-1$</td>
<td>try to measure $E$</td>
</tr>
</tbody>
</table>