Where Machine and Detector Meet

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Special thanks to Tom Markiewicz

http://physics.uoregon.edu/~torrence/talks/
High Luminosity

- Stability
- Instrumentation
- Crossing angle (NLC/JLC)

Background Protection

- Collimation
- Shielding from collision products
- Extraction to dump

Collision Properties

- Polarization
- Beam Energy
- Luminosity

Large overlap between traditional detector, accelerator, and analysis camps...
• Short focal length ($L^* \sim 3-5$ m)
• Large conical mask ($\sim 50$ mRad)
• Integrated instrumentation
Beams strongly attracted to each other!

<table>
<thead>
<tr>
<th></th>
<th>Tesla 500</th>
<th>NLC/JLC 500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>$2.0 \times 10^{10}$</td>
<td>$0.75 \times 10^{10}$</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>550 nm</td>
<td>250 nm</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>5 nm</td>
<td>3 nm</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>300 $\mu$m</td>
<td>110 $\mu$m</td>
</tr>
</tbody>
</table>

⇒ Beams strongly attracted to each other!

- Spot size reduced \((\text{higher lumi} \sim x2)\)
- Outgoing beam highly disrupted
- Pinch produces ‘beamstrahlung’ photons
Beamstrahlung Photons

- $N_\gamma/N_e \sim 1.5$
- $E_\gamma/E_{beam} \sim$ few percent
- confined to 1 mRad cone
- secondary $e^+e^-$ pairs

Charged Particles

- Long E tail after IP
- Radiative Bhabhas
- Beam-beam pairs

77 kW $E < 50\% E_{nom}$
4 kW lost (.25%) to dump (NLC 1 TeV)
IP Backgrounds

- Disrupted primary beam
- Beamstrahlung (BSL) photons
- $e^+e^-$ pairs from BSL $\gamma$s
- Hadrons from BSL or $\gamma\gamma$
- Neutrons from $e^+e^-$ pairs
- Radiative Bhabhas

These scale with Luminosity (Good)
Shield from detectors

Machine Backgrounds

- Neutron back-shine from dump
- Synchrotron radiation
- Muon production
- Collimator scraping

These don’t scale with Lumi (Bad)
Avoid near IP
**e^+e^- Pairs**

Pairs ‘curl up’ in large solenoid field

**P_T from opposing bunch**

must absorb without scattering into detector...

NLC Simulation

Eric Torrence  8/29  April 2003
~ $1 \times 10^9$ per second (1 Watt)

Pairs also make good monitor of luminosity and collision parameters...
~ 0.5 $\gamma\gamma$ hadron events/NLC train
average 6 GeV in barrel + endcap, 10 tracks
~ 30 GeV in forward mask...

Neutrons

- Expect $0.5 \times 10^9$ n/cm$^2$/yr at VXD (NLC SD)
- Dominated by beam-beam pairs
- Small backshine from dump

Tolerate $3 \times 10^9$ n/cm$^2$/yr for pixel detector
- $m_Z$, $\Gamma_Z$ (LEP I) Energy Lumi
- $m_W$ (LEP II) Energy
- $\sin^2\theta_w$ (SLC) Polarization

Dependent upon Beam Instrumentation
Beam Energy

- Absolute energy scale
- Beam energy width

Polarization

- Electron polarization scale
- Positron polarization (if available)

Luminosity

- $\frac{dL}{dE}$ (luminosity spectrum)
- $\int Ldt$ (total integrated luminosity)

⇒ Ensure instrumentation for physics needs!

Combination of beam-based and physics-based measurements!
Production Threshold

Kinematic Fits

Common Scale Uncertainty

$$\frac{\delta M_W}{M_W} \approx \frac{\delta E_{Beam}}{E_{Beam}}$$
Energy Needs

• Target 200 ppm from $2m_t < \sqrt{s} < 1\text{TeV}$
  $$\Delta m_t, \Delta m_H \sim 50\text{MeV}$$

• Recognize desire for < 50 ppm at $2m_W$

⇒ Improved precision always welcome...

Energy Proposal

• BPM-style at upstream 1mRad bend
  RT monitor, possible absolute scale

• WISRD-style at post-IP chicane
  RT monitor, possible absolute scale

  Energy width?

• Forward tracking 200-500 mRad

  Lumi-weighted absolute scale ($\mu^+\mu^-\gamma$)
LEP II Spectrometer

- 4.8 mRad Bend ⇒ 1 μm BPM resolution
- Stability maintained for less than 8 hours
- ~200 ppm achieved (relative)

RF Spectrometer

- 200 μRad Bend ⇒ < 100 nm BPM resolution
- Move the BPMs to the beam
- In situ alignment

⇒ Upstream of IP only!
Operated for 8 years ⇒ ~250 ppm achieved

NLC Questions

- Improved detector?
- Downstream operation?
- Energy distribution?
Radiative Returns at LEP

Statistics

- **Channel** $\Delta E_{\text{beam}}$
  - $q\bar{q}\gamma \sim 18$ MeV
  - $\mu\mu\gamma \sim 40$ MeV
  - $ee\gamma \sim 70$ MeV

- **LEP Potential**
  - **Statistics Only**
  - 2.7 fb$^{-1}$

Systematics

- Theoretical Description
- Hadronization Uncertainties
- Detector Understanding

Need absolute $\theta$ measurement!

Opal Estimates

- $q\bar{q}\gamma \Delta E_{\text{beam}} \sim 70$ MeV
- $\mu\mu\gamma \Delta E_{\text{beam}} \sim 20$ MeV
- $ee\gamma \Delta E_{\text{beam}} \sim 80$ MeV

\[
\frac{s'}{s} = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1 + \theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1 + \theta_2)|}
\]
Symmetric production: $s' = m_Z^2$, $\Theta_1 = \Theta_2$

<table>
<thead>
<tr>
<th>Collision Energy</th>
<th>$\cos \Theta$</th>
<th>$\Theta$ (mRad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 , m_W$</td>
<td>0.522</td>
<td>1000</td>
</tr>
<tr>
<td>$2 , m_t$</td>
<td>0.875</td>
<td>500</td>
</tr>
<tr>
<td>500 GeV</td>
<td>0.937</td>
<td>360</td>
</tr>
<tr>
<td>1 TeV</td>
<td>0.984</td>
<td>180</td>
</tr>
</tbody>
</table>

Need precision and accuracy at small $\Theta$

$\delta \Theta \approx 0.1\%$ per event ($\Gamma_Z$ limit)

100ppm accuracy (20 µm @ 2 meters)
Also WW background suppression, SUSY, new physics, etc.

<table>
<thead>
<tr>
<th>Process</th>
<th>Events per 80 fb^{-1}</th>
<th>$A_{LR}$</th>
<th>$dA/A$ (stat) in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>560 k</td>
<td>99%</td>
<td>0.07</td>
</tr>
<tr>
<td>qq</td>
<td>250 k</td>
<td>45%</td>
<td>0.5</td>
</tr>
<tr>
<td>ll</td>
<td>120 k</td>
<td>10%</td>
<td>3.2</td>
</tr>
</tbody>
</table>

⇒ Also WW background suppression, SUSY, new physics, etc.
Slepton Production

\[ e^- \rightarrow Z/\gamma \rightarrow \tilde{e} \]
\[ e^+ \rightarrow \tilde{e}^* \]

s-channel: \( \tilde{e}_L \tilde{e}_L^* \) or \( \tilde{e}_R \tilde{e}_R^* \) only

\[ \tilde{e}_L \tilde{e}_R^* \) and \( \tilde{e}_R \tilde{e}_L^* \) also

\[ \sqrt{s} = 500 \text{ GeV} \]

\[ P_{e^-} = -80\% \]

\[ P_{e^-} = +80\% \]

[G. Moortgat-Pick, H. Steiner, 2000]

⇒ Unique manipulation of helicity states
Multiple Detectors

- Çerenkov counter - scattered $e^-$ asymmetry
- Photon counter - integral $\gamma E$ asymmetry
- Quartz fiber calorimeter - transverse $\gamma$ asym.

Unique systematics help reduce errors

$\delta P / P = 0.5\%$ achieved at SLD
Electron polarization only

- absolute scale limiting factor
- IP depolarization significant

Lum Weighted $\neq$ Polarimeter

0.25% per beam possible (not proven)

Positron polarization also

$$ P_{eff} = (P^+ + P^-)/(1 + P^+P^-) $$

$\Rightarrow$ 0.1% precision achievable

Blondel scheme gives lumi-weighted $P^+$, $P^-$

- Lose some luminosity (or don’t gain as much)
- Still need $\Delta = |P_L| - |P_R|$, relative Lumi
- Precision depends upon $P^+$ reversal freq.
Direct Polarization

\[ \sigma = 7 \text{ pb at } \sqrt{s} = 500 \text{ GeV} \]

\[ \sqrt{s} = 800 \text{ GeV} \]

\[ \kappa_\gamma = 1.007 \]

\[ \kappa_Z = 1.01 \]

\[ \text{SM} \]

\[ \delta P / P < 0.15\% \text{ for } 500 \text{ fb}^{-1} \text{ at } 500 \text{ GeV (9/1 L ratio)} \]

⇒ Similar with e\(^{-}\) pol only

[K. Mönerg, Snowmass 2001]
Highly dynamic distribution...

Linac energy spread

\[ \frac{dn}{dE} \]
Flat tail + Gaussian core $R = \frac{A_{\text{tail}}}{A_{\text{core}}}$

$\frac{d\Gamma_t}{dR} = 40 \text{ MeV} / 1\%$

$\frac{d\Gamma_t}{dR} = 100 \text{ MeV} / 1\%$

Comparable to other systematics
The Uncertainty of it all

Key Reactions

- Threshold scans (top mass)
- Mass reconstruction (Higgs mass)

⇒ Plus many, many more...

Highly dynamic distribution

- Variance: increased statistical errors
- Uncertainty: increased systematic errors

Both need consideration

Rough physics needs

- Scans mostly need shape (tails to 1%)
- Mass analyses need mean $\sqrt{s'}$ (200 ppm)

⇒ New instrumentation problem for e$^+e^-$
Bhabha rates

- Forward (180-300 mRad) ~ 200 R
- Intermediate (300-800 mRad) ~ 100 R
- Barrel (> 800 mRad) ~ 8 R

Need rates from forward events, but not too far forward...

Forward Tracker (Tesla design)

Silicon planes 100 - 400 mRad
Acolinearity Limitations

- Bhabha analysis measures boost not $\sqrt{s}$
- Other inputs (e.g. energy width, asymmetry)
- Detector alignment systematics

⇒ Area of active study...

Beamstrahlung Correlations

- Dispersion effects
- Early-late correlations
- Banana tail effects

⇒ Can’t trust simulation alone...

Need data-tuned models integrated into generators
The Linear Collider Interaction Region must be carefully planned between accelerator, detector, and analysis-minded people.

New challenges exist for the LC environment

- Nanometer-sized beams, IP stability
- Large beam disruption
- Large $e^+e^-$ pair background
- Uncertain luminosity spectrum

Old challenges for $e^+e^-$ also exist

- Beam energy/width
- Beam polarization
- Absolute luminosity scale

Lots of interesting work going on NOW!

Plenty of work still to be done...