Pursuing New Theoretical Ideas that are Available at High Energy and High Luminosity Linear Collider.

- Reinforcing the LC Physics Case - new diagnostics tests aimed at model differentiation;
- Compare New Physics opportunities at LC with those elsewhere: relations to LHC: Uniqueness, Impact on Programs;
- Implementation of new Theoretical Models in physics generators;
- Identify Reactions that are best suited or unique for LC;
- Examine the Impact of this Physics on the Machine Parameters, Beam Options and Detector characteristic.
Studies of New Phenomena

- Include new developments in the theory: extra gauge bosons, extra dimensions, KK towers, composite higgs, higgsless models;

- Open list of topics...

- Common experimental signatures:
  \[ e^+e^- \rightarrow f\bar{f}: (b\bar{b}, c\bar{c}, \tau^+\tau^-, \ldots) \]
  \[ e^+e^- \rightarrow \gamma\bar{f}: (\gamma G, \gamma\nu\bar{\nu}) \]

- New Phenomena can show up EITHER through direct production of new particles OR through deviations from the precision measurements of the SM predictions. \( \implies \) sensitivity to new physics at energies \( \geq \sqrt{s} \)

- Measurements of many observables constructed from analyses of specific fermions in the final state: total cross section and forward-backward and left-right asymmetries, \( \tau \) polarization, heavy flavors, etc.

- Study of systematics effects, angular coverage, lepton ID, flavor tagging in measurements of New Phenomena

- Link to an LC detector performance specifications.
New Phenomena - Experimental Aspects

- Attempt to quantify the following Detector and Machine requirements:
  - $b$- and $c$-quark tagging - $b/c$ rejection; $c \sim 35\%$, $b \sim 60\%$
  - $\tau$ identification and polarization
  - EM and HAD calo resolution
  - Angular coverage - small angle $\gamma$'s
  - Hermeticity
  - $\Delta L/L$ - error $< 1\%$
  - Polarization of the beams - $e^- \sim 90\%$, $e^+ \sim 0 - 60\%$; error $< 1\%$
  - Beam Energy and Luminosity
  - Machine Options - $e^+e^-$, $e^-e^-$, $\gamma\gamma$, $e\gamma$
Determination of Lumi Spectrum

- Wide angle Bhabha scattering a key process for constraining new physics cross sections (contact interactions, extra dimensions)
- Acollinearity of Small Angle Bhabha’s - an essential measurement for understanding the luminosity spectrum.

S. Boogert, D. J. Miller, hep-ex/0211021.
G. Wilson, D. Strom, K. Moenig

- Presence of missing energy complicates determination of $s'$.  
- Minimal angular reconstruction biases, angle determination and good energy resolution.  
- Beam energy peak- nongaussian, with jitter and time walk.  
- More work on bunch fluctuations and simulations of outgoing particles in actual design.
Determination of Lumi Spectrum
Experimental Limitations

Open Questions - David Strom
- How does the calo pad geometry affect the position resolution?
- How large is the correlated beamstrahlung effect in the NLC type machine?
- How does correlated beamstrahlung depend on beam alignment?
- Can ECAL measure the correlated beamstrahlung? (How big are the tails in the calo energy spectrum?)

Precision luminosity measurement requires understanding of the interaction region of the machine, mask designs, and their instrumentations, inputs from loop verein group, calorimeter and tracking detector groups, ... quite convoluted logistics for such an important issue.
Hooman Davoudiasl, Tom Rizzo, and Joanne Hewett have looked at the signatures of localized gravity models (hep-ph/0006041).

Many SM particles can propagate in other dimensions.

Simultaneous production of graviton and gauge boson KK excitations.
In LED models, production of a KK tower of gravitons in the process $e^+e^- \rightarrow G\gamma$ used to determine the number of extra dimensions. Polarization of both beams crucial to suppress the SM $e^+e^- \rightarrow \nu\nu\gamma$ process in the s- and t-channels.

Fermion pair production is used to search for virtual effects from new gauge bosons or contact interactions at large scales.
Benefits from Beam Polarization

- Many types of new physics can lead to Contact type Interactions below the direct production threshold. T.G. Rizzo hep-ph/0303056
- Increase in reach for fixed luminosity and energy as a function of the degree of positron polarization.

![Graph showing fractional gain in reach vs. positron polarization.]

- Compositeness searches in Bhabha scattering.
- LL, RR case
- LR, VV, AA case
- Z' models
- ADD model (dashed)
CI Benefits from Beam Parameters

- Parameters trade-offs for the search reaches
- dim-8 CI (dashed)
- dim-6 CI (solid)
Properties of New Bosons

\[ e^+ e^- \rightarrow f \bar{f} \]

L=1 ab\(^{-1}\), \(P_-=0.8, P_+=0.6\)

\(\sqrt{s}=0.5\) TeV:
- case A
- case B

\(\sqrt{s}=0.8\) TeV:
- LHC: observation of \(Z'\);
- LC: measurement of couplings.

\(\sqrt{s}=1.0\) TeV:
- LHC: direct reach 4 TeV

S. Riemann, LC-TH-2001-007.

LC: High indirect mass reach;
LHC: direct reach 4 TeV
Extra Dimensions

- Each ED scenario predicts a distinct set of signatures at $\sqrt{s} \sim 1 \ TeV$
- The precise control of SM reactions achievable at the LC makes these measurements possible.
- Future Accelerators can test these ideas and possibly yield information on the geometry of the extra dimensions of the universe (number, size, curvature,...)

Phenomenological implications of ED:
- KK excitations of the Gravitons, SM gauge bosons and other particles;
- techniques for discovering and studying the radion field, impact of mixing between the radion and the Higgs sector.

If deviations from the SM are observed, how do we know which one it is?
- try to fit to various hypotheses
- or look for something unique (Graviton exchange at a single $\sqrt{s}$)
Indirect Tests of New Physics

- Angular distributions and polarization asymmetries become sensitive probes of the spin of new particles.
- e.g. Differential cross section for the process $e^+e^- \rightarrow f\bar{f}$ for spin-2 Graviton exchanges contains both cubic and quartic terms in $z = \cos(\theta)$
  
  JL Hewett

- Combined fit of angular distributions of kinematically accessible $f\bar{f}$ states, as well as $\tau$ polarization
- Deviations induced by Spin-2 Graviton exchanges can be distinguished, up to a discovery limit $\sim 5\sqrt{s}$, from those due to lower spins, such as new vector bosons ($Z'$) or scalar-$\nu$ in R-parity violating models.
A method proposed that uses specific modifications in angular distributions induced by new exchanges and quickly identifies basic features about certain model classes. T.G.Rizzo hep-ph/0208027

Used as a way to uniquely identify Graviton KK-tower exchange or any possible spin-0 exchange.

various models are discriminated by the analysis of moments of the normalized xsection with respect to the Legendre polynomials ($P_n$)

Though a rather simple test of the exchange of graviton KK-towers, but can it be as powerful in the realistic detector simulation?

$$ (5 - 6) \sqrt{s} - \text{ID reach} \quad (9) \sqrt{s} - \text{search reach} $$
Spin Rotators with high efficiency can take longitudinally polarized beams and make them transversely polarized. T.G.Rizzo hep-ph/0211374

Transverse polarization helps to identify Graviton KK-tower exchange in the $e^+e^- \rightarrow f\bar{f}$.

<table>
<thead>
<tr>
<th>$E_{CM}$ (GeV)</th>
<th>Search Reach (TeV)</th>
<th>ID Reach (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>10.2</td>
<td>5.4</td>
</tr>
<tr>
<td>800</td>
<td>17.0</td>
<td>8.8</td>
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<tr>
<td>1000</td>
<td>21.5</td>
<td>11.1</td>
</tr>
<tr>
<td>1200</td>
<td>26.0</td>
<td>13.3</td>
</tr>
<tr>
<td>1500</td>
<td>32.7</td>
<td>16.7</td>
</tr>
</tbody>
</table>

Search Reach for Graviton exchanges with Transverse Polarization of beams can be as high as $20\sqrt{s}$.

Graviton and $Z'$ exchanges can be distinguished up to $10\sqrt{s}$.

The bounds are systematically dominated and should be carefully carefully examined in a more detailed detector simulation.
- Radion and the Higgs have same quantum numbers, and thus can mix.
- Mixing effects can lead to shifts in the Higgs couplings, $g_{HVV}$ and $g_{Hff}$ and BF's for certain parameter values.
- Higgs search reach at colliders can be significantly influenced by mixing contributions.

\[ M_H \] from LEP searches including the mixing effects.
Deviations in Higgs BR and Width

$$m_r = 300, 500, 300$$

- Observation of these shifts will require the accurate determination of the Higgs BR from which constraints on the Radion param space can be extracted (obtainable at a LC).

$$v/\Lambda = 0.2, 0.2, 0.1$$
In the context of LED, KK excitations can be produced: directly at LHC in the Drell-Yan channel and indirectly at LC as contact interactions in processes $e^+e^- \rightarrow f\bar{f}$. 

T.G. Rizzo hep-ph/0305077
KK/Z' differentiation possible at both machines, with the LC analysis relying on the resonance mass determination at LHC.

\( M_c = 4, 5, 6, \ldots \text{ TeV} \)
New Phenomena - Conclusions

- Watch for effects of New Phenomena and be prepared for the Unexpected ones!
- New Phenomena program is an integral part of physics justification for an LC!

- Issues being addressed:
  - Discovery - fill in the gaps from hadron colliders
  - Elucidation - LC strong point
  - Impact on the machine and detector designs

- We would like to thank all New Phenomena Working Group members and visitors for their dedication and contributions.