Some Thoughts on the Luminosity Spectrum

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SLAC

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• What do we need
• Simple fits
• Goals for Paris
What motivates the need to know dL/dE to high precision?

- Direct Reconstruction - \( m_H \)
- Threshold Scans - \( m_t \)

Bias to \( \langle s' \rangle \) which counts
(same motivation for beam energy)

Others less important (i.e.: SUSY endpoints)
due to lower event rates

Beware of thinking you know the answer before you begin! Nature may have surprises...
Reconstruct recoil mass from Z decay products

\[ m_R^2 \approx (E_{CM} - E_Z)^2 - |\vec{p}_Z|^2 \]

\[ = E_{CM}^2 - 2E_{CM}E_Z + M_Z^2 \]
LEP II Example

W Boson Mass

Substantial bias due to ISR

Can correct to high accuracy using precision MC generator

\[ m_W = 80.330 \text{ GeV} \]

\[ \Gamma_W = 2.093 \text{ GeV} \]
Must plug measured beam-beam effects directly into precision MC description

Bootstrap using some other physics process (akin to Parton Density Functions...)

MC tools for extraction of luminosity spectra at LC,
S. Jadach, SLAC, 24th Oct. 2002

http://home.cern.ch/jadach/public/LumLCslac.ps.gz
What do we want?

4-vector producing physics

\[
d^4L/dp'
\]

Note: s-channel bias...

Assume transverse components small...

Two parameters: \( E', p'_z \) or \( s', \beta \) or \( E^+, E^- \)

We talk about \( dL/dE, \)
but at minimum we need \( \frac{d^2L}{ds'd\beta} \)
What’s the problem with acolinearity?

\[ \sigma \sqrt{s} \sim \sigma_{\Delta \theta} E_b / \sin \theta_0 \]

\[ \frac{s'}{s} = \frac{\sin \theta_1 + \sin \theta_2 - |\sin(\theta_1 + \theta_2)|}{\sin \theta_1 + \sin \theta_2 + |\sin(\theta_1 + \theta_2)|} \]

First-order approximation!

\[ \Delta \theta = f(\beta) \text{ where } \beta \approx \frac{E^+ - E^-}{E^+ + E^-} \]

Physics actually depends more on \( \frac{dL}{ds'} \) than \( \frac{dL}{d\beta} \)
Strategy #1

‘Measure’ \( \frac{d^2L}{ds'd\beta} \) (or at least \( \frac{dL}{ds'} \)) from observable \( \frac{dL}{d\beta} \)

Implicitly assumes \( \frac{dL}{dE^+} = \frac{dL}{dE^-} \) (or at least that the relation is known)

Further assumes that the correlations are understood:

\[
\frac{d^2L}{dE^+dE^-} = f\left(\frac{dL}{dE^+}, \frac{dL}{dE^-}, \rho(E^+, E^-)\right)
\]

Mike has shown that these are potentially large and variable, must be measured

Don’t trust simulations too much...
Guinea Pig using A. Seyri ‘realistic’ inputs
Guinea Pig using A. Seyri ‘realistic’ inputs
Strategy #2

Use all information available in $e^+e^- \rightarrow e^+e^-$

$E^+, E^-, \theta^+, \theta^-, \phi^+, \phi^-$ or $E_0, \Delta E, \theta_0, \Delta \theta, \phi_0, \Delta \phi$

(ignore transverse info in $\phi$ for now)

Using $\frac{d\sigma}{d\theta_0}$ probably hopeless...

⇒ 3 observables

$\Delta E$, $\Delta \theta$ redundant: cross-check!

Comparing $\frac{d^2L}{dE^+dE^-}$ vs. $\frac{dL}{dE^+}$ or $\frac{dL}{dE^-}$

is a direct measure of correlations!

(comment by Klaus Monig)

Only way to get what we truly want!
Conventional wisdom is that calorimeters can’t do better than ~ 1% on E

For the spectrum we want relative energy from the peak, not absolute energy from zero.

Easier?

Relative E
Montpellier

Talks by S. Bogart and E. Poirer about ‘unfolding’ $dL/dE$ spectrum

Really want a ‘simple’ function with few (<100) parameters to plug into MC

Take one step backwards

How bad do you do by fitting Gaussian convoluted with Circe if you had perfect data?

Tools

- A. Seyri ‘realistic beam’ files (NLC 500)
- Guinea Pig
- RooFit

$$P(E) = g(E; E_0, \sigma) + a_0 \int_E x^{a_1}(1 - x)^{a_2} g(E')dE'$$

where $x = E/E'$

5 parameters!
Good Fit?
Does it matter?

NLC500
File #1

2 GeV bias in 15 GeV window!

Need to understand < 50 MeV or 1%
NLC500
File #1

Total bias ~ 15 Gev, includes ISR
One more parameter might do it.

What about variation?

### Results

<table>
<thead>
<tr>
<th>$\sqrt{s'}$ above</th>
<th>$\Delta &lt;\sqrt{s'}&gt;$ (in MeV) for file</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Gev</td>
<td>1       2       3       5       6</td>
</tr>
<tr>
<td>250 GeV</td>
<td>-41     -4      -143    -130    -25</td>
</tr>
<tr>
<td>350 GeV</td>
<td>-300    -140    -305    -320    -198</td>
</tr>
<tr>
<td>450 GeV</td>
<td>-35     +90     +15     -61     -154</td>
</tr>
<tr>
<td>475 GeV</td>
<td>+77     +60     +97     +63     124</td>
</tr>
</tbody>
</table>

Errors range from 30 to 120 MeV

Bias in $\Delta <\sqrt{s'}>$ from direct fit to data varies significantly (100s MeV)

Simple function not adequate to track ‘realistic’ variations!
(and not just core, but tails also)
Peak-region looks problematic for warm machine
Detector resolution will tend to wash this out

Need proper study with Guinea Pig, detector simulation, and realistic analysis method

Cold machine isn’t off the hook, either!
Vertical offsets lead to uncomfortable numbers

Only way to show there isn’t a problem is to measure it to sufficient precision...

Quantify warm/cold difference for Paris?
Repeat under different machine assumptions (failure modes?) to get variation of extracted result.
Luminosity spectrum and beam energy are two sides of the same problem

Need full “cradle-to-grave” analysis pulling all the pieces together!

The way ahead?