Breit-Wigners for masses of each top

1 = \int \delta(m^2 - m_R^2) \, dm^2 \to \int \frac{1}{\pi} \frac{m_R \Gamma_R}{(m^2 - m_R^2)^2 + m_R^2 \Gamma_R^2} \, dm^2

\beta_{34}(\bar{s}, \bar{m}^2, \bar{m}^2) = \beta_{34}(\bar{s}, m_3^2, m_4^2) \Rightarrow \bar{m}^2 = \frac{m_3^2 + m_4^2}{2} - \frac{(m_3^2 - m_4^2)^2}{4\bar{s}}.

S-matrix approach to the Z

While practically all experimental analyses of LEP/SLC data have followed the 'Breit-Wigner' approach described above, an alternative S-matrix-based analysis is also possible. The Z, like all unstable particles, is associated with a complex pole in the S matrix. The pole position is process independent and gauge invariant. The mass, \( \bar{M}_Z \), and width, \( \bar{\Gamma}_Z \), can be defined in terms of the pole in the energy plane via [11–14]

\[ \bar{s} = \bar{M}_Z^2 - i\bar{M}_Z \bar{\Gamma}_Z \]

leading to the relations

\[ \bar{M}_Z = M_Z / \sqrt{1 + \bar{\Gamma}_Z^2 / M_Z^2} \approx M_Z - 34.1 \text{ MeV} \]

\[ \bar{\Gamma}_Z = \Gamma_Z / \sqrt{1 + \bar{\Gamma}_Z^2 / M_Z^2} \approx \Gamma_Z - 0.9 \text{ MeV} \]

Some authors [15] choose to define the Z mass and width via

\[ \bar{s} = (\bar{M}_Z - \frac{\bar{\Gamma}_Z}{2})^2 \]

which yields \( \bar{M}_Z \approx M_Z - 26 \text{ MeV}, \bar{\Gamma}_Z \approx \Gamma_Z - 1.2 \text{ MeV} \).

\[ \approx 100 \text{ MeV} \]

Adjust kinematics in equal mass formulae
Stephen Mrenna (CD)

Changes kinematics of top pair

\[ E_{t2} = \frac{s + m_{t2}^2 - m_{t1}^2}{2 \sqrt{s}} \]

Showering of the top before decay

Recoils against partner radiation

\[ Q^2 = p_T^2 + m_t^2 \]
Stephen Mrenna (CD)

The Top Mass in Pythia

- Top decays including NLO gluon radiation
- W decays including NLO gluon radiation
- No top-top spin correlations (HERWIG, yes)
The Top Mass in Pythia

The top mass is conserved in the final state shower. The equation for the recoiling W boson is given as:

$$E_w = \frac{m_t^2 + M_w^2 - m_{bg}^2}{2m_t}$$
Remnant does NOT have to be simple diquark

For gg process, color can flow from OTHER beam

b quark color connected to remnant with gluons as kinks on string

Stephen Mrenna (CD) The Top Mass in Pythia
Stephen Mrenna (CD)

The Top Mass in Pythia

String can pull b towards beam line

Hadron momentum comes from string fragmentation with a given $f(z)$ (which one?)

Hadron multiplicity can depend on beam-b angle
Stephen Mrenna (CD)

The Top Mass in Pythia

Initial State radiation

Causes confusion in top mass reconstruction

Underlying Event

Changes color connections, hence fragmentation

Tune A showed that color re-connections are important

Causes confusion in top mass reconstruction

Changes color connections, hence fragmentation
Stephen Mrenna (CD)
The Top Mass in Pythia

Color Recombinations affect fragmentation, momentum of reconstructed objects

Leading Systematic in W mass @ LEP 
~ 100 MeV

Magnitude of effect in hadronic environment not well known
### Uncertainties on $M_W$

#### NEW!
- **Main Sum05** → **Winter 2006**

<table>
<thead>
<tr>
<th>Source</th>
<th>Systematic Error on $M_W$ (MeV)</th>
<th>$qq\nu$</th>
<th>$qq\bar{q}$</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>QED(ISR/FSR,etc)</td>
<td></td>
<td>9</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Hadronisation</td>
<td></td>
<td>14</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Detector Syst.</td>
<td></td>
<td>14</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>LEP Beam Energy</td>
<td></td>
<td>9 (14)</td>
<td>9 (11)</td>
<td>9</td>
</tr>
<tr>
<td>Colour Reconnection</td>
<td></td>
<td>-</td>
<td>31 (49)</td>
<td>7</td>
</tr>
<tr>
<td>Bose-Einstein Corr.</td>
<td></td>
<td>-</td>
<td>13 (22)</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>3</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total Systematic</strong></td>
<td></td>
<td>22 (28)</td>
<td>43 (63)</td>
<td>24 (28)</td>
</tr>
<tr>
<td><strong>Statistical</strong></td>
<td></td>
<td>31</td>
<td>43 (48)</td>
<td>26 (27)</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td>38 (42)</td>
<td>61 (79)</td>
<td>35 (39)</td>
</tr>
</tbody>
</table>

- **O:** EPJ C45 307 (2006)
- **L:** EPJ C45 569 (2006)
- **A:** submitted to EPJC

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**14th March 2006 - Recontres de Moriond (La Thuile)**

**Standard Model at LEP - F. Spano'**
Final State Interactions

- $1/\Gamma_W \sim 0.1 \text{ fm} < l_{\text{had}} \sim 1 \text{ fm} \rightarrow \text{two (colour singlet) with significant space-time overlap} \rightarrow \text{possible interaction of final products}$
- Effect not simulated in Monte Carlo $\rightarrow$ possible mass/width bias only in $qqqq$ channel

Colour Reconnection

- Colour cross-talk between Ws: bias in $qqqq$ but not $qqlv$.

The Top Mass in Pythia

- Bose-Einstein Correlations
  - QM interference $\rightarrow$ Momentum space correlation of bosons pairs from different W (inter-W) decays: bias $qqqq$ only

- Established in $Z^0$ decays

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Standard Model at LEP - F. Spanò
Colour Reconnection

$\delta M_W, \delta \Gamma_W =$ largest (CR - no CR) shift in different models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\delta M_W^{4q}$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herwig</td>
<td>~40</td>
</tr>
<tr>
<td>Ariadne</td>
<td>~60</td>
</tr>
<tr>
<td>SKI</td>
<td>up to 200</td>
</tr>
</tbody>
</table>

$p_{\text{rec}} =$ CR prob $\Leftrightarrow$ CR strength

Particle Flow technique

Measure ratio of particle densities in intra- and inter-W planes: sensitive to CR

Intra-W $q_{11}, w_1, q_{12}$ Inter-W $q_{21}, w_2, q_{22}$

Find Observable for CR

Final Step
Desensitize analysis to CR effects

Preliminary LEP PF analysis 68% CL upper limit on CR strength in SKI model ($p_{\text{rec}} < 56\%$) → Data Driven $\delta M_W$ for SKI

Future: need A,D final results for final comb

Stephen Mrenna (CD)

The Top Mass in Pythia
MSTP(115):

(D=0) (C) choice of colour rearrangement scenario for process 25, pair production, when both 's decay hadronically. (Also works for process 22, production, except when the 's are allowed to fluctuate to very small masses.)

= 0 : no reconnection.

= 1 : scenario I, reconnection inspired by a type I superconductor, with the reconnection probability related to the overlap volume in space and time between the and strings. Related parameters are found in PARP(115) - PARP(119), with PARP(117) of special interest.

= 2 : scenario II, reconnection inspired by a type II superconductor, with reconnection possible when two string cores cross. Related parameter in PARP(115).

= 3 : scenario II', as model II but with the additional requirement that a reconnection will only occur if the total string length is reduced by it.

= 5 : the GH scenario, where the reconnection can occur that reduces the total string length (measure) most. PARP(120) gives the fraction of such event where a reconnection is actually made; since almost all events could allow a reconnection that would reduce the string length, PARP(120) is almost the same as the reconnection probability.

= 11 : the intermediate scenario, where a reconnection is made at the `origin' of events, based on the subdivision of all radiation of a system as coming either from the or the . PARP(120) gives the assumed probability that a reconnection will occur. A somewhat simpleminded model, but not quite unrealistic.

= 12 : the instantaneous scenario, where a reconnection is allowed to occur before the parton showers, and showering is performed inside the reconnected systems with maximum virtuality set by the mass of the reconnected systems. PARP(120) gives the assumed probability that a reconnection will occur. Is completely unrealistic, but useful as an extreme example with very large effects.
Colour Reconnection (cont)

CR affects mostly soft particles between jets \( \Rightarrow \) changes jet direction
Re-calculate jet dir. from particles:
1. with momentum \( P \) larger than \( P_{\text{thr}} \)
2. by weighted momentum vector sum (weight = \( |P|^{\kappa} \))
3. within cone of radius \( R \)

Use \( P_{\text{thr}}(\text{GeV}) = 3 \ (A), 2.5 (O), 2 (L) \) for \( M_w \) (best stat-syst compr). \( \Gamma_w \) is obtained with standard analysis (O,A) or using \( P_{\text{thr}}(L) \).

**W mass stability vs jet dir**

\[ \delta M_W \text{ (stat)} : \text{worse by 15-35\%} \]
\[ \delta M_W \text{ (had)} : \text{worse by } \sim 30-100 \% \]
\[ \delta M_W \text{ (CR)} : \text{reduced by factor 2-3} \]
Total \( \delta M_W \) improves:
79 MeV \( \rightarrow \) 61 MeV

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**Difference between Breit-Wigner and Pole-mass**
small $\sim 100$ MeV

**Gluons from top radiation**
$E \sim 1.5$ GeV
$???$ MeV

b fragmentation not necessarily the same as @ LEP $???$ MeV

**Magnitude of color re-connections**
needs to be studied

**Experiments need to provide people for even simple studies**