Simulation Study on Top Physics

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LC Physics Study Group Kick-off Meeting
Introduction

There are a number of interesting analysis & feasibility studies on the measurements of top quark properties.

They can be classified into 2 categories,

- **Near $t\bar{t}$ threshold**
  - Mainly focused on physics contained in the threshold enhancement factor.

- **Open top region**
  - Searching for anomalies in production & decay vertices (Form factor measurements & CP violation in top-sector).
Realistic simulation study is need to clarify feasibility of precise measurements of top form factor at the $t\bar{t}$ threshold.

- In view of the energy upgrading scenario of the LC, study of Top-physics is expected to commence in the $t\bar{t}$ threshold region.

- Form factor measurements in the $t\bar{t}$ threshold have many theoretical & experimental advantages.

☆ We need a sophisticated method to kinematically reconstruct events as efficiently, as precisely & as bias-freely as possible.
Framework of analysis

Our simulation studies also aim at developing new analysis tools.

Event generator

- **Physsim** (using BASES/SPRING + HELAS)
  - ISR & Beamstrahlung as well as S- & P-wave QCD corrections to the $t\bar{t}$ system are taken into account.

Hadronizer

- **JETSET 7.4** with tau leptons treated by TAUOLA

Detector simulator (w/ ACFA-JLC study parameters)

- **JSF Quick Simulator**
  - Track-cluster matching was performed to achieve the best energy-flow measurements.

Data analysis framework

- **JSF** (ROOT based) + **Anlib** (C++ analysis library)
Strategy for reconstruction

- Lepton charge = $W$ charge -> $t, \bar{t}$ ID & $b, \bar{b}$ ID
- Small combinatorial BG & No process BG
- $b$-$W$ system: back-to-back decay near threshold
**Assumption**

- Jet directions fixed to output from jet finder
- No initial transverse momentum

The $t\bar{t}$ system produced via $e^+e^-$ annihilation is a heavily constrained system.

**Unknown : 10 parameters**

$$E_{j1}, E_{j2}, E_{j3}, E_{j4}, p_\nu(E_\nu, \vec{p}_\nu),$$

$$E_{e-}, E_{e+}$$

\[ \sum p_{cm} = 0 \]

\[ m_\nu = 0 \]

**Free : 5 parameters**

$$E_{j1}, E_{j2}, E_{j3}, E_{j4}, (E_{e-} - E_{e+})$$
Likelihood function

\[ L = \left( \prod_{f=1}^{4} P_{E_f}^f \left( E_{f \text{measured}}, E_f \right) \right) \cdot P_{\Gamma W^+} \cdot P_{\Gamma W^-} \cdot P_{\Gamma t\bar{t}} \cdot P_{\sqrt{s}} \]

\[ P_{E_f(f; q, \bar{q})} = \frac{1}{\sqrt{2\pi}\sigma_E} \exp\left(-\frac{(E_{f \text{meas}} - E_f)^2}{2\sigma_E}\right) \]

\[ P_{\Gamma t\bar{t}} \] cannot be simultaneously on-shell below threshold

\[ P_{\sqrt{s}} = \frac{1}{L} \frac{dL}{d\sqrt{s}} \]
Constraints on top mass

- Rconst’d
- Fitted
- Generator level
Effects on $b$-jets & $W$s

$\sigma E_{\bar{b}}$

$\sigma E_W(jj)$

$\sigma E_W(\ell\nu)$

$\sigma \theta_W(\ell\nu)$
A possible application

Form factor at tbW vertex

\[ \Gamma_{Wtb}^\mu = -\frac{g_W}{\sqrt{2}} V_{tb} \bar{u}(p_b) \left[ \gamma_\mu \, f_1^L \, P_L - \frac{i \sigma^{\mu\nu} p_W \nu}{M_W} \, P_R \right] u(p_t) \]

Standard Model (tree)

\[ f_1^L = 1 ; \quad f_2^R = 0 \]

Variation of \( f_1^L \)
- changes only the normalization of the differential cross section

Variation of \( f_2^R \)
- changes both the normalization and the shape of the decay dist.
Example of observable

★ Double differential decay width

\[
\frac{d\Gamma(t \to bW \to b\ell\nu)}{d\cos \theta_W(\ell\nu) \; d\cos \theta_\ell} \quad \text{W (in the rest frame of top)}
\]

\[
\text{lepton (in the rest frame of W)}
\]

\[
N^{-1} \frac{d\Gamma(t_\uparrow \to b\ell\nu)}{(d\cos \theta_W d\cos \theta_\ell)} \quad \text{for } f_2^R = 0
\]

\[
N = \Gamma_t \times \text{Br}(W \to \ell\nu) \quad \text{for } f_2^R = 0
\]

\[
\text{Difference of } N^{-1} d\Gamma/(d\cos \theta_W d\cos \theta_\ell) \quad \text{for } f_2^R = 0.1 \text{ and for } f_2^R = 0
\]
Effects on form factor meas.

• Kinematical fit almost completely removes bias in form factor measurement.

Rconst'd / Generated

Fitted / Generated
To make maximum use of LC’s potential, the top quark reconstruction in lepton + 4-jet mode has been studied under realistic experimental conditions in the $\bar{t}t$ threshold.

As a new technique to fully reconstruct $\bar{t}t$ final state, we have developed a kinematical fitting algorithm.

The remarkable improvements of the energy resolution of b-jets and the angular and energy resolution of $W(ln)$’s have been achieved by the kinematical fitting.

These improvements should benefit the form factor measurements in general.

As possible application, we considered measurements of decay form factors, on which correct reconstruction of the $W(ln)$ may have a large impact.