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.

    m_t, Γ_t, α_s

- Open top region
  - Searching for anomalies in production & decay vertices (Form factor measurements & CP violation in top-sector).

Introduction (cont'd)

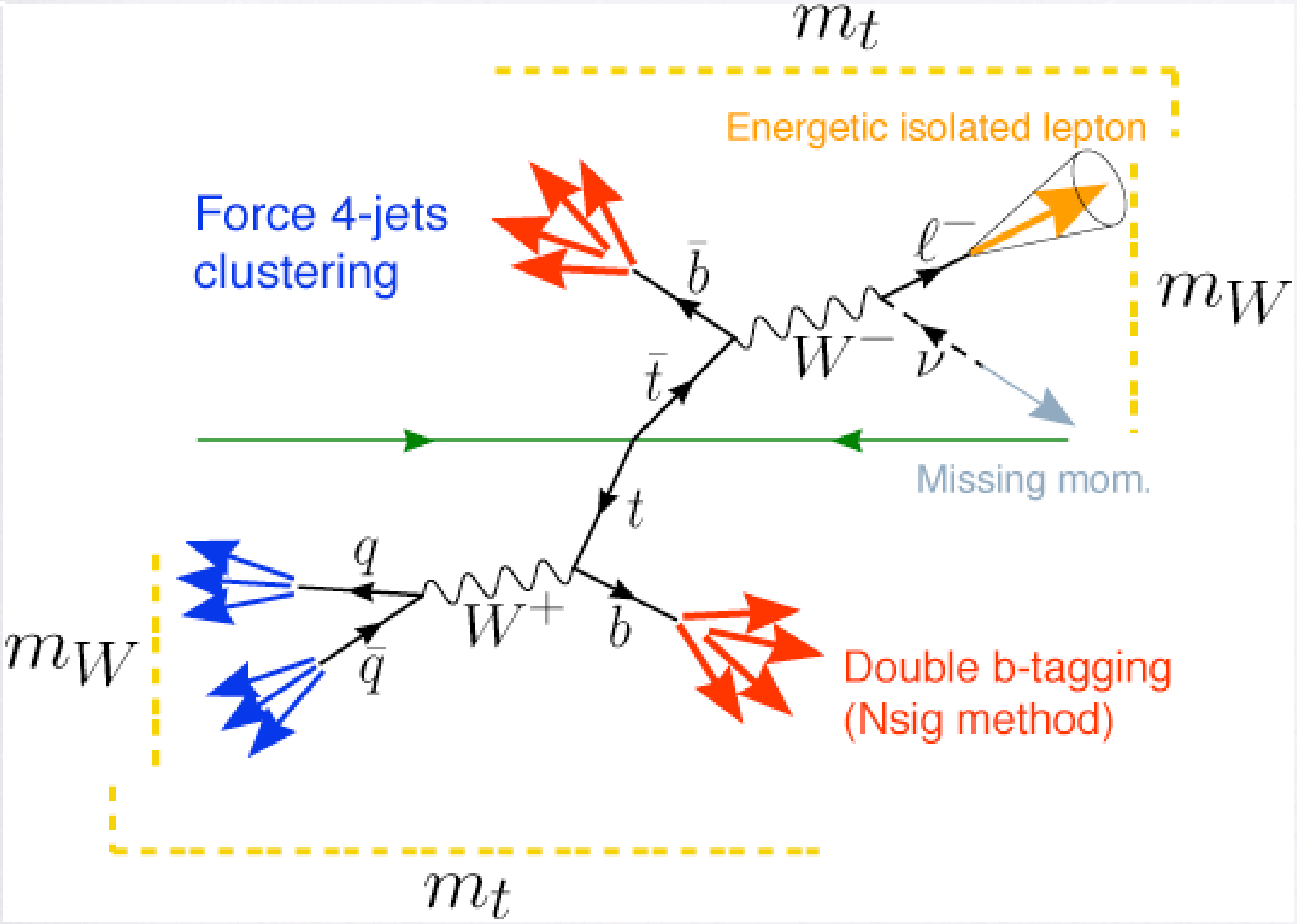
- Realistic simulation study is need to clarify feasibility of precise measurements of top form factor at the $t\bar{t}$ threshold.
  - In view of the energy upgrading scenario of the LC, study of Top-physics is expected to commence in the $t\bar{t}$ threshold region.
  - Form factor measurements in 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.

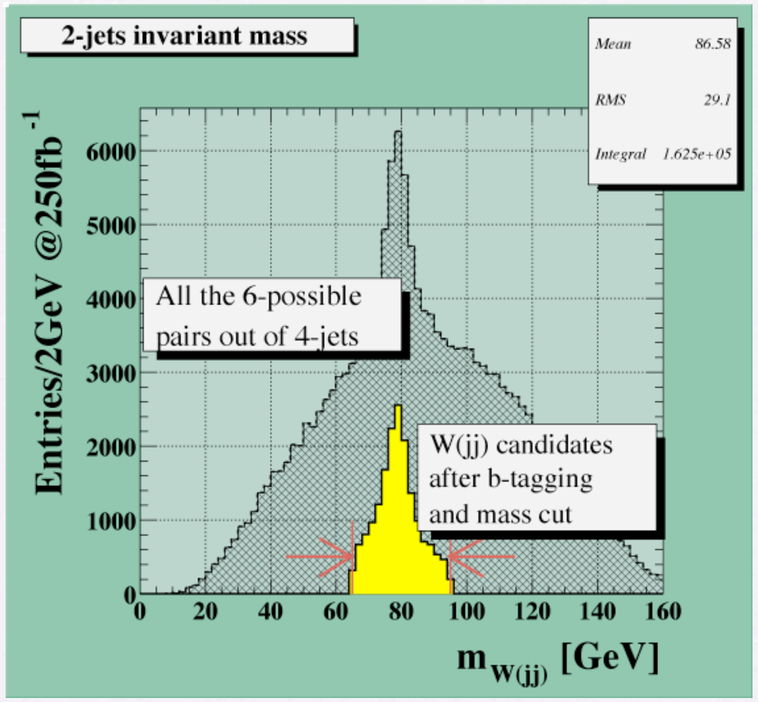
Framework of analysis

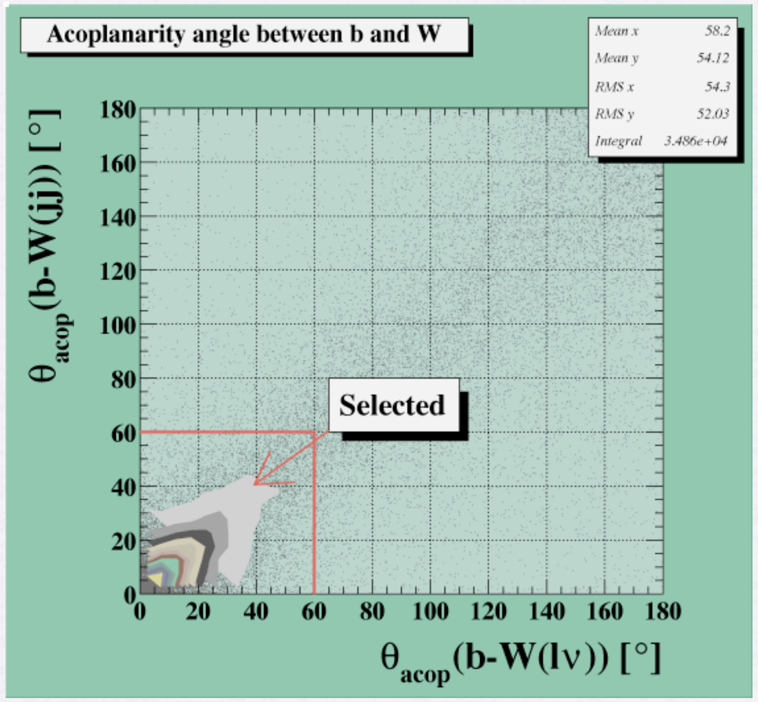
Our simulation studies also aim at developing new analysis tools.

- 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

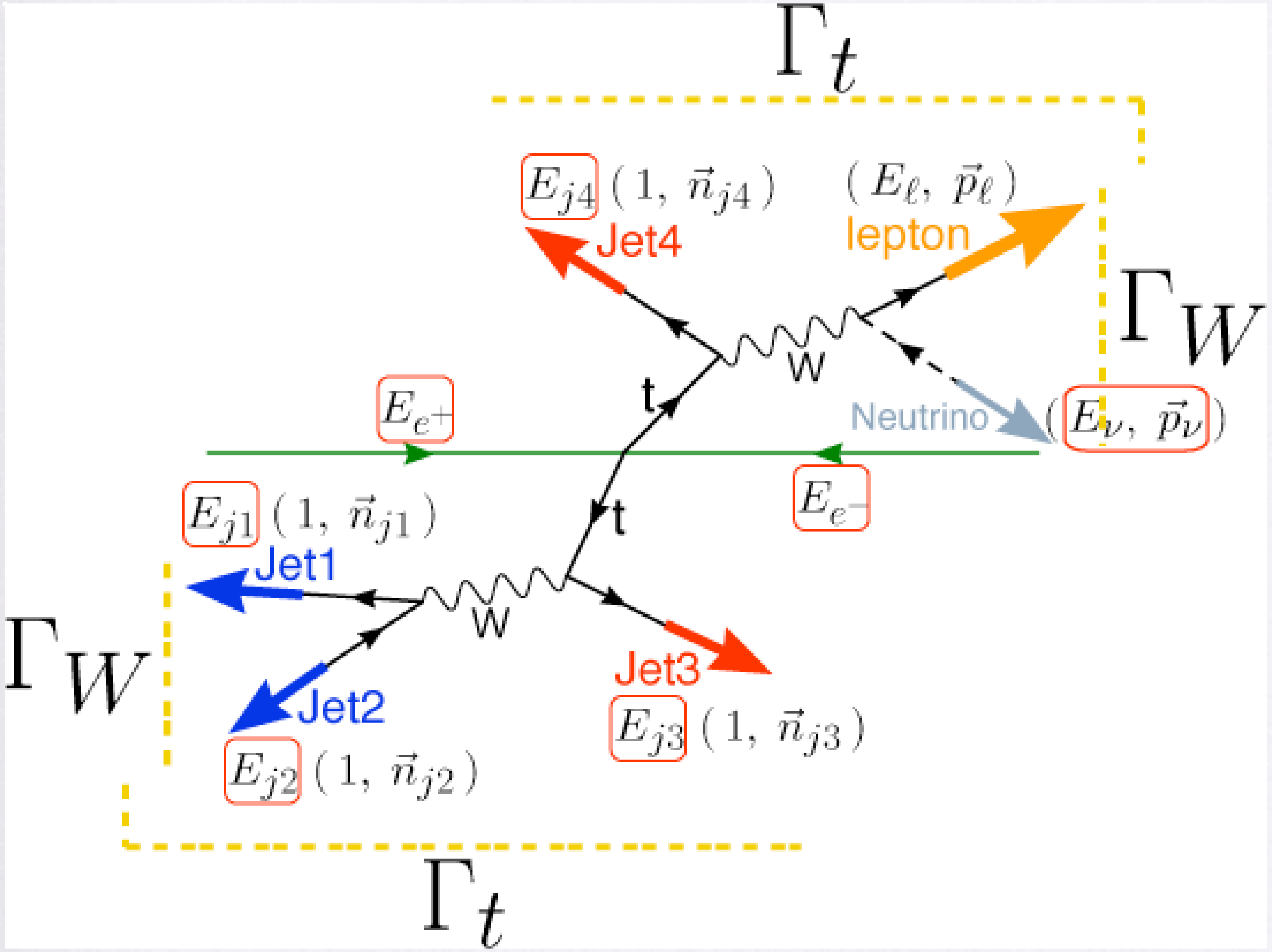






- Lepton charge = W charge -> $t, \bar{t}$ ID & $b, \bar{b}$ ID
- Small combinatorial BG & No process BG
- b-W system : back-to-back decay near threshold

Kinematical reconstruction



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

$$E_{j1},\ E_{j2},\ E_{j3},\ E_{j4},$$
$$(E_{e^-} - E_{e^+})$$

☆ Assumption

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

Likelihood function

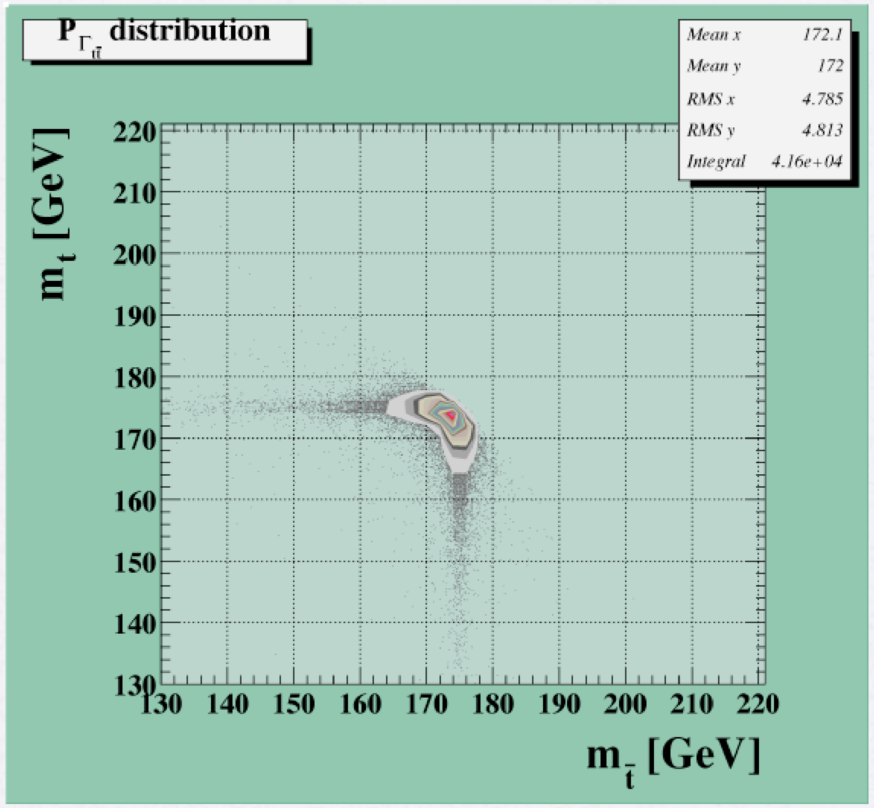
$$L = (\prod_{f=1}^{4} P_{E_f}^{f}(E_f^{measured}, E_f)) \cdot P_{\Gamma_{W+}} \cdot P_{\Gamma_{W-}} \cdot P_{\Gamma_{t\bar{t}}} \cdot P_{\sqrt{s}}$$

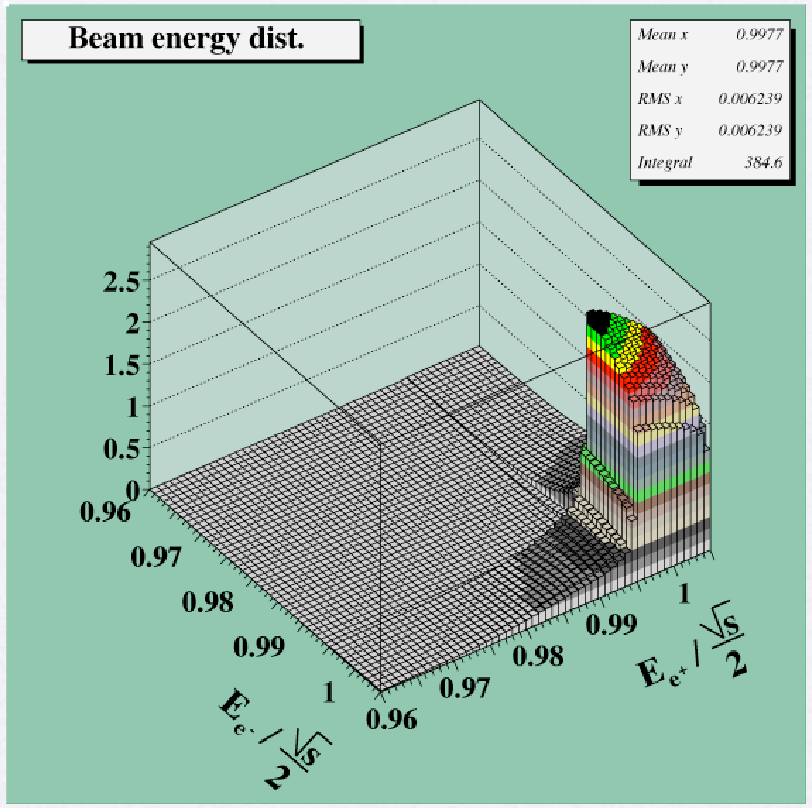
$$P_{E_f(f;q,\bar{q})} = \frac{1}{\sqrt{2\pi}\sigma_E} \exp(-\frac{(E_f^{meas} - E_f)^2}{2\sigma_E})$$

$f = \text{jet1} \rightarrow \text{jet4}$

$P_{\Gamma_{t\bar{t}}}$ t & t̄ cannot be simultaneously on-shell below threshold

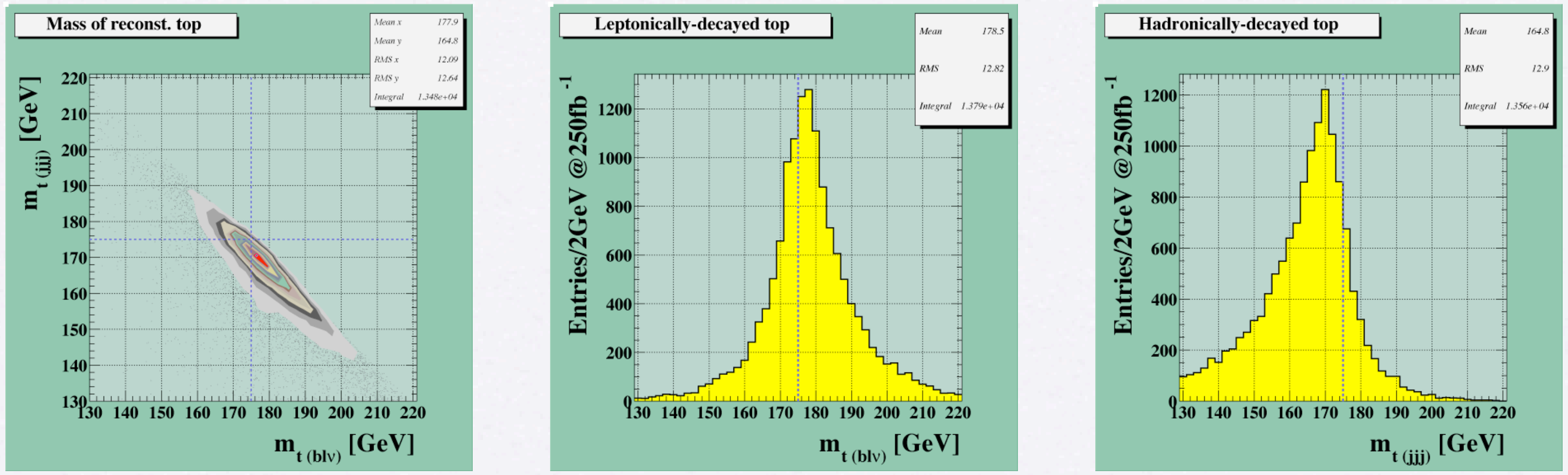
$$P_{\sqrt{s}} = \frac{1}{L}\frac{dL}{d\sqrt{s}}$$





Constraints on top mass

Rconst'd



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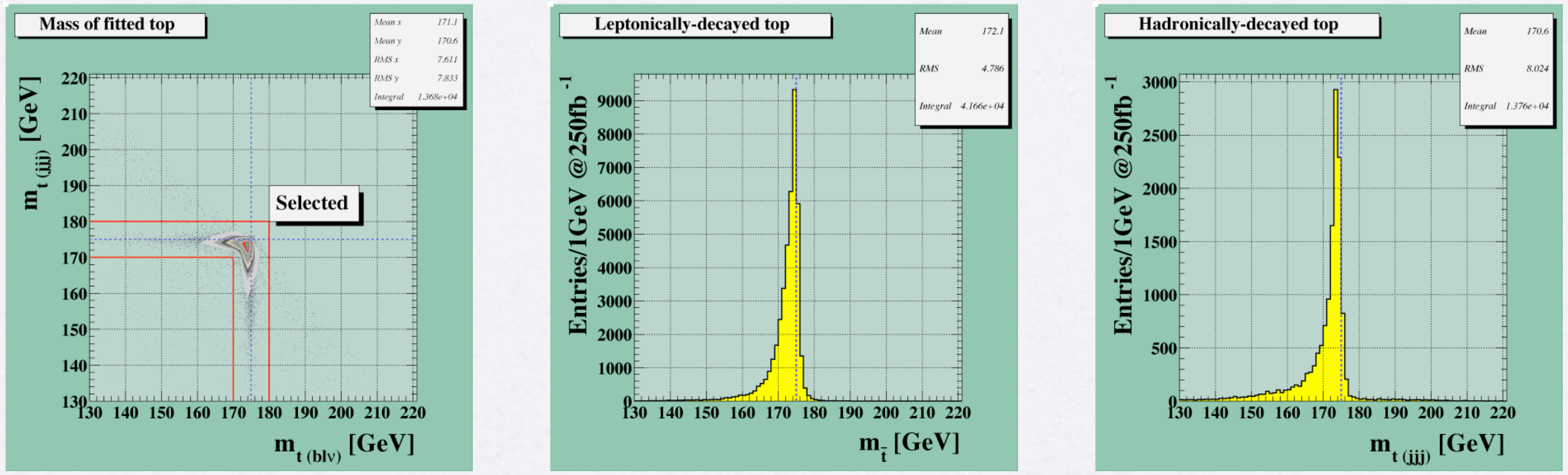
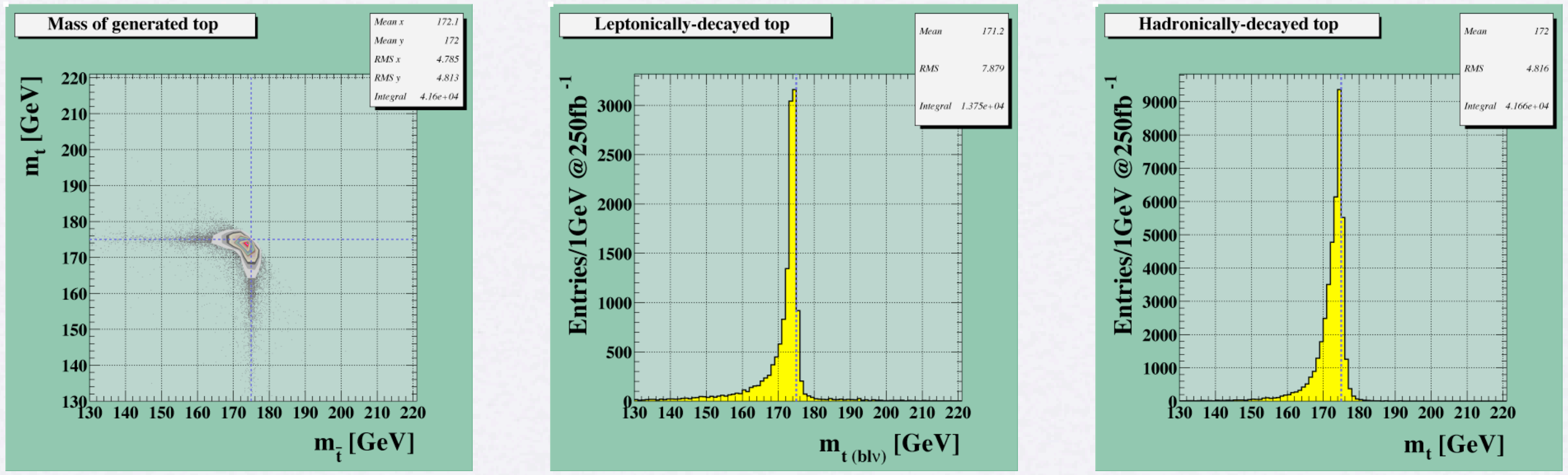
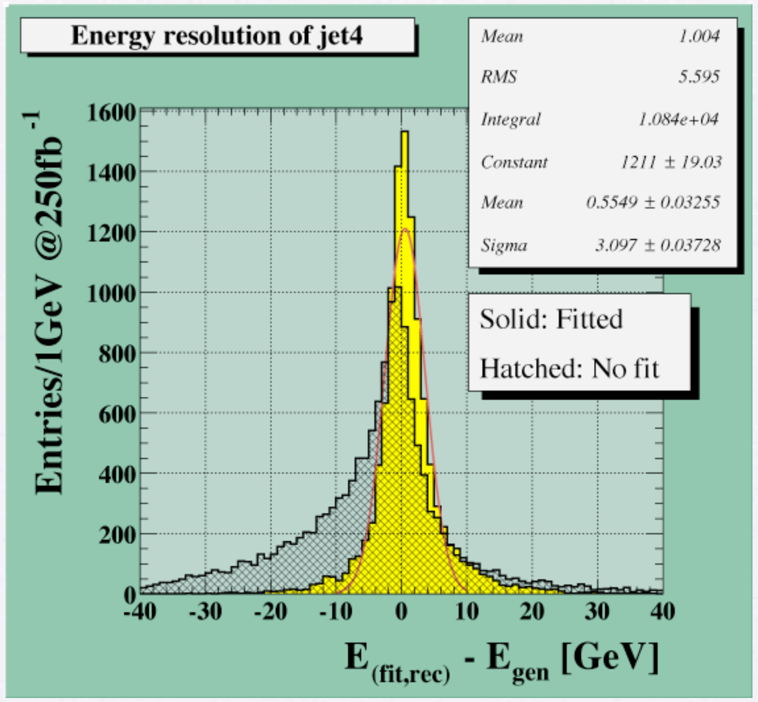


Generator level

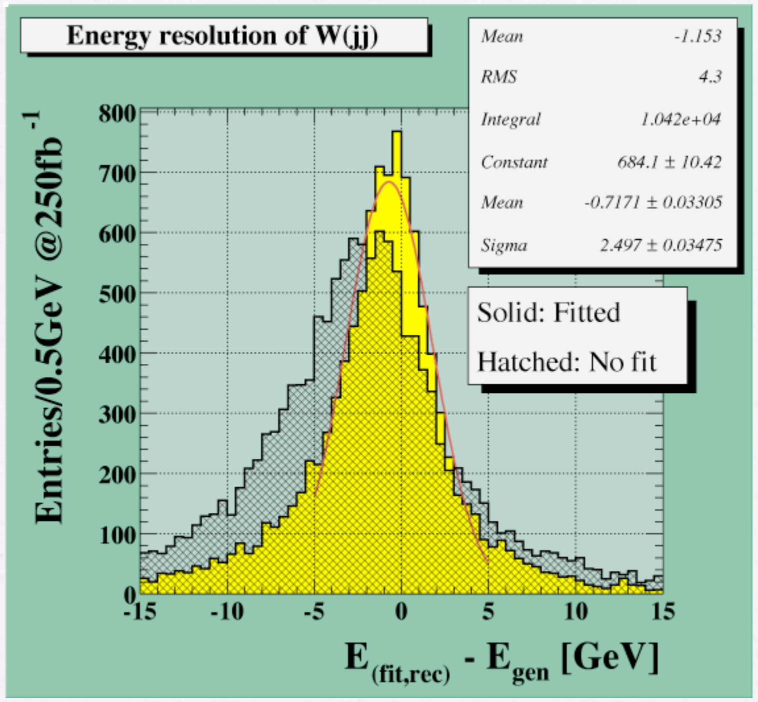


Effects on b-jets & Ws

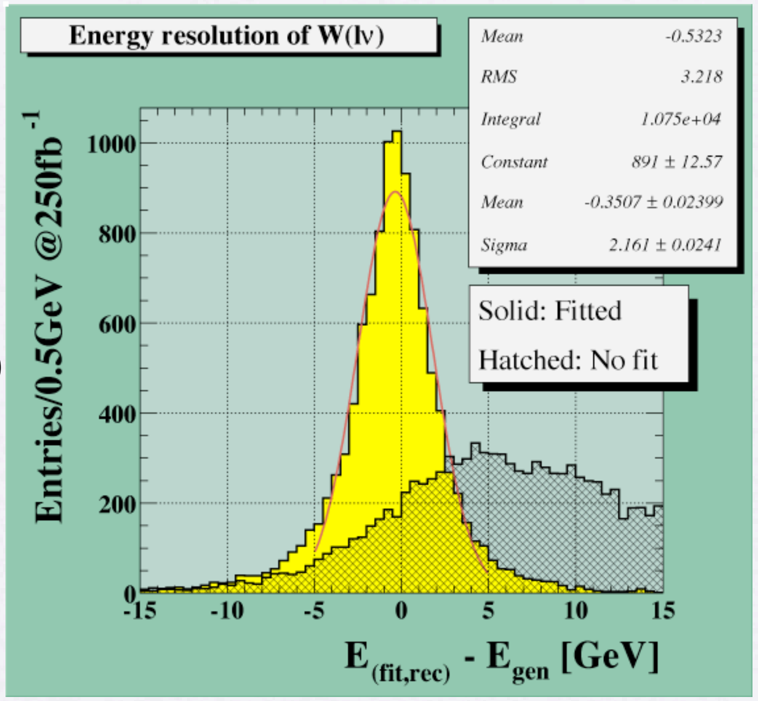
$\sigma_{E_{\bar{b}}}$



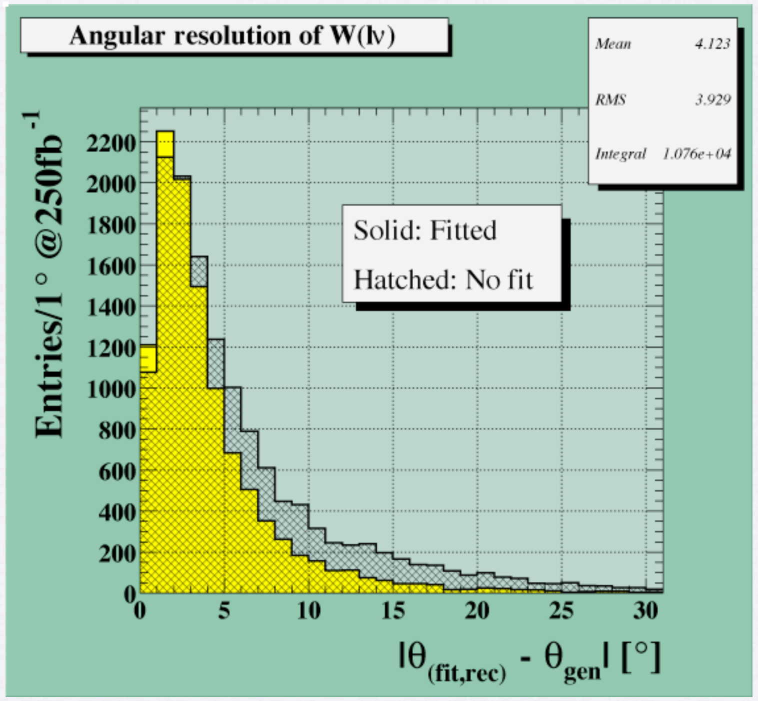
$\sigma_{E_{W(jj)}}$



$\sigma_{E_{W(\ell\nu)}}$



$\sigma_{\theta_{W(\ell\nu)}}$



A possible application

Form factor at tbW vertex

$$\Gamma^{\mu}_{Wtb} = -\frac{g_W}{\sqrt{2}} V_{tb}\, \bar{u}(p_b) \left[\gamma^{\mu} f_1^L P_L - \frac{i\sigma^{\mu\nu} p_{W\nu}}{M_W} f_2^R P_R \right] u(p_t)$$

$$P_{L/R} = (1 \mp \gamma_5)/\,2$$

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.

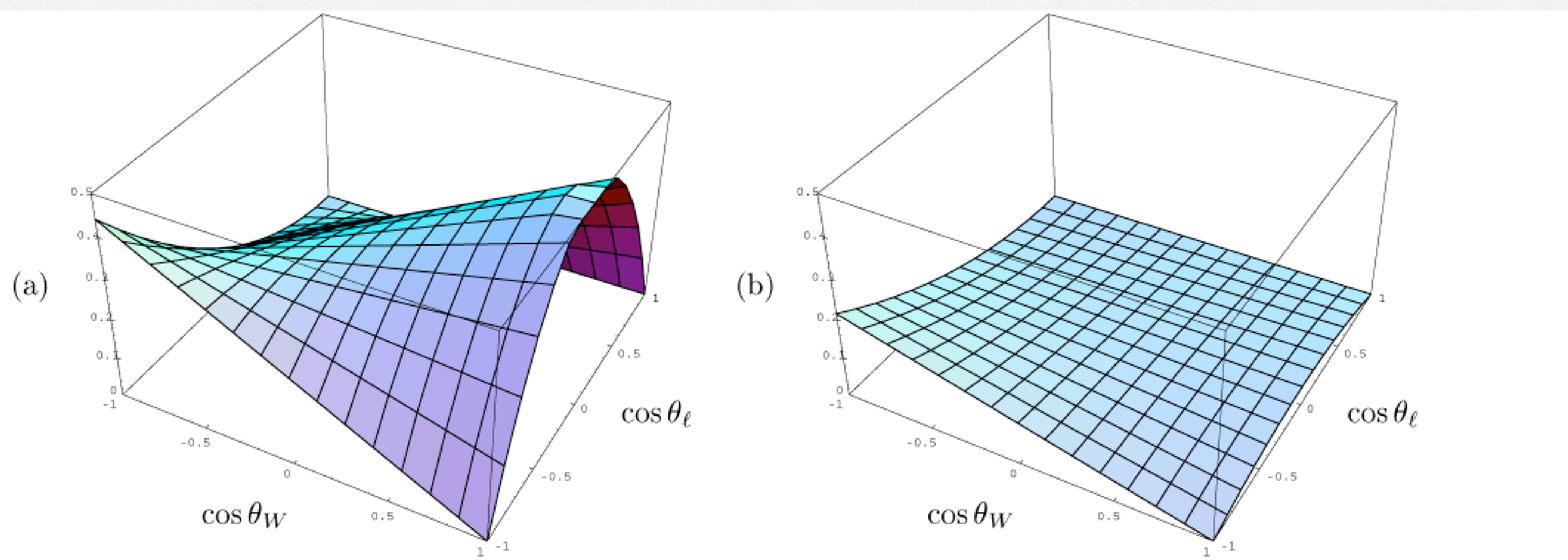
Example of observable

- Double differential decay width

$$\frac{d\Gamma(t \to bW \to b\ell\nu)}{d\cos\theta_{W(\ell\nu)}\; d\cos\theta_\ell}$$

W (in the rest frame of top)

lepton (in the rest frame of W)



$\mathcal{N}^{-1}\, d\Gamma(t_\uparrow \to b\ell\nu)/(d\cos\theta_W d\cos\theta_\ell)$ for $f_2^R = 0$

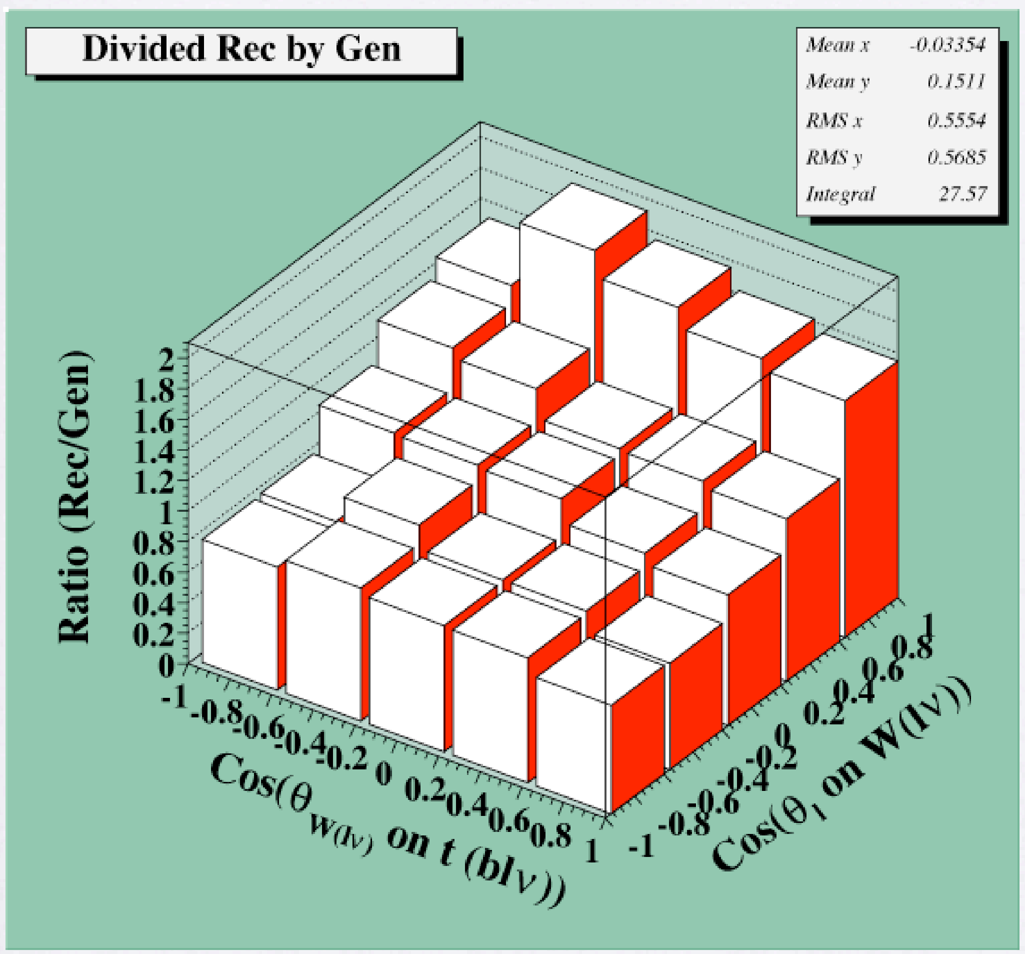
$\mathcal{N} = \Gamma_t \times \mathrm{Br}(W \to \ell\nu)$ for $f_2^R = 0$

Defference of $\mathcal{N}^{-1}\, d\Gamma/(d\cos\theta_W d\cos\theta_\ell)$

for $f_2^R = 0.1$ and for $f_2^R = 0$

Effects on form factor meas.

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



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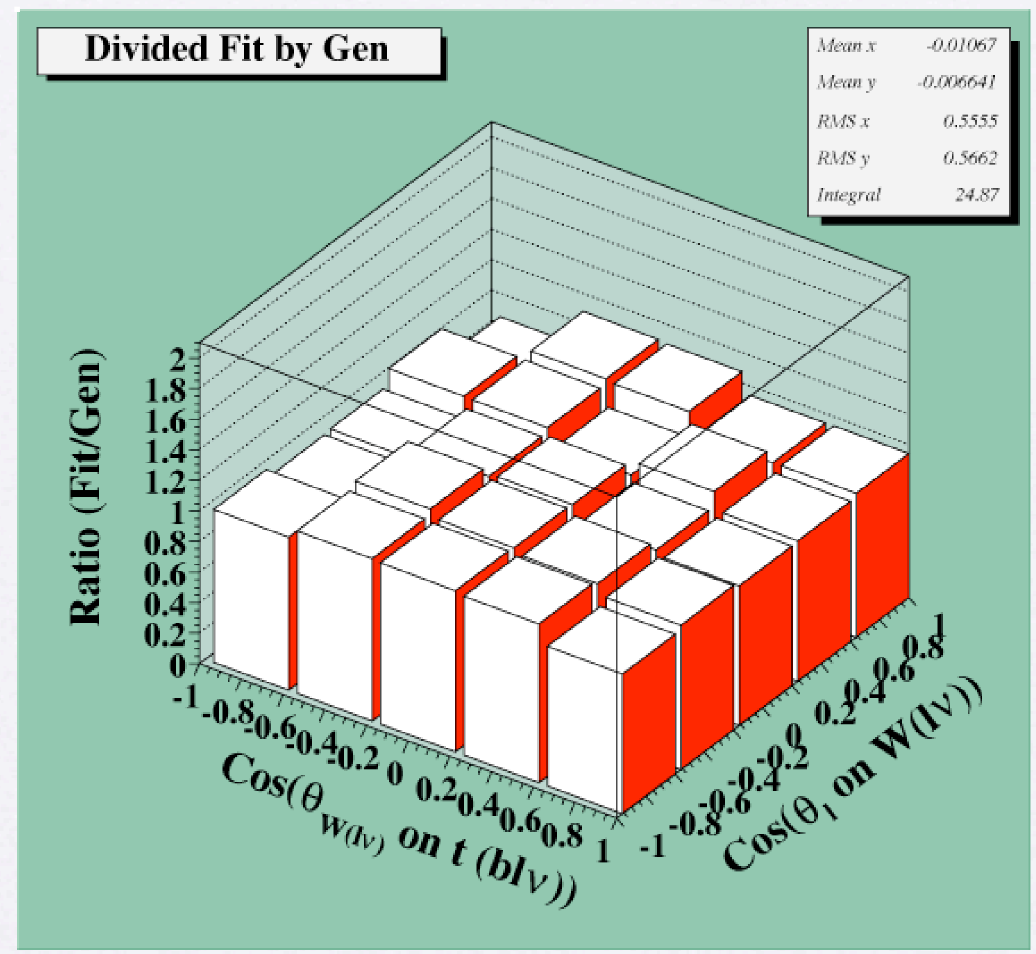

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Summary

- 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 $t\bar{t}$ threshold.
- As a new technique to fully reconstruct $t\bar{t}$ 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.