

Top couplings to gauge and Higgs bosons at linear colliders: 6 and 8 fermion final states

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- **Single Top Production** $e^+e^- \rightarrow e^- \bar{\nu}_\mu t \bar{b}$:
6 fermion final states, finite width effects, gauge invariance
- **Associated Top-Higgs production**: $e^+e^- \rightarrow t \bar{t} H$
Electroweak contributions to $e^+e^- \rightarrow b \bar{b} b \bar{b} W^+ W^-$,
8 fermion final states
- Calculation using **O'Mega/WHIZARD**

O'Mega: an Optimizing Matrix Element Generator for tree level matrix elements (T.Ohl, J.Reuter, CS)

- Algorithm eliminates redundancies by construction (M.Moretti, T.Ohl, J.Reuter, hep-ph/0102195)
- Arbitrary (massive, polarized) particles as external states
- Ward Identities as consistency checks
- QCD vertices implemented, color factors in preparation (T.Ohl)

WHIZARD : Phase space integration and event generation (W.Kilian)

What's new?

- Complete EW Standard Model in R_ξ gauge, CKM mixing (CS)
- Finite widths: Complex mass, effective vertices (CS)
- Complete MSSM (J.Reuter)
- Cascade Decays, Diagram selection (T.Ohl)

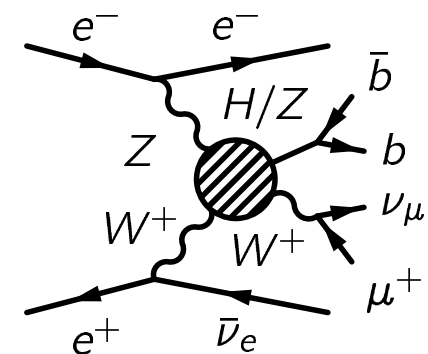
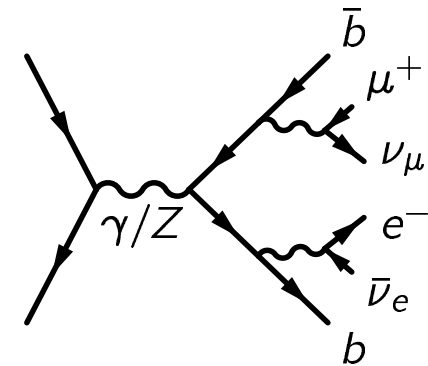
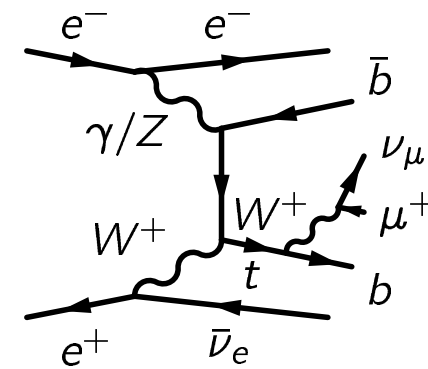
Single top production $e^+e^- \rightarrow e^-\bar{\nu}_e t \bar{b}$

- Measurement of V_{tb}
- Top pair production contributes to same final state \Rightarrow
 - Mass cut $|m_{\bar{b},e^-\bar{\nu}_e} - m_t| > 20 \text{ GeV}$
 - Right-handed polarized e^\pm .

(Boos et.al. EPJ.C21:81, hep-ph/0104279)

Six fermion final states

- Background from $W^+Z \rightarrow W^+Z/H$
- Selecting diagrams not gauge invariant
- Cuts on invariant mass of $b\bar{b}$ pair:
 - $|m_{\bar{b}b} - m_Z| > 20 \text{ GeV}$
 - $|m_{\bar{b}b} - m_H| > 1 \text{ GeV}$



Cross sections (fb) for $\theta_e > 5^\circ$

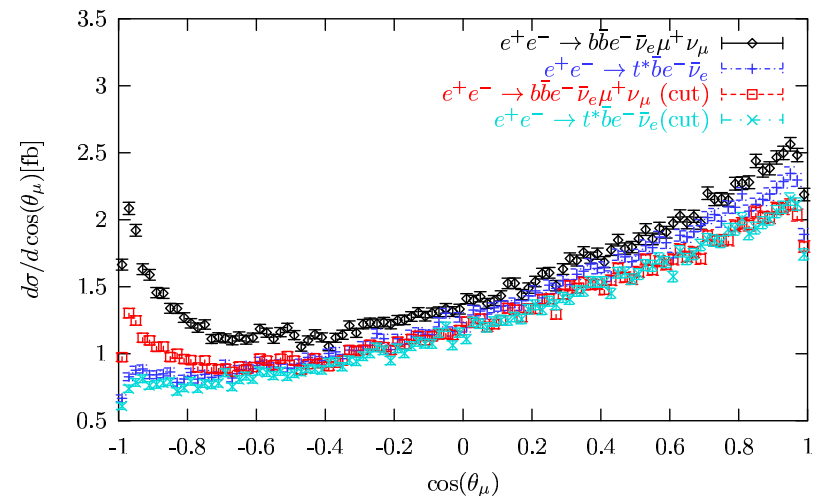
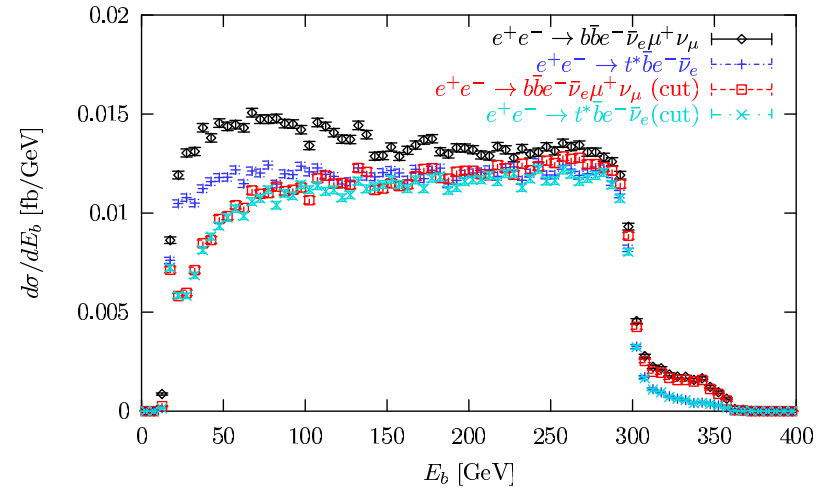
\sqrt{s}	$b\bar{b}e^- \bar{\nu}_e \mu^+ \nu_\mu$	$t^* \bar{b}e^- \bar{\nu}_e$
500	5.83(1)	5.56(1)
800	3.150(6)	2.719(4)
2000	1.461(5)	0.693(2)

(Cuts and input parameters as in:
Gleisberg *et.al*, EPJ.C34:173, hep-
ph/0311273)

Cuts on $m_{\bar{b}b}$ around m_Z, m_H :

\sqrt{s}	$b\bar{b}e^- \bar{\nu}_e \mu^+ \nu_\mu$	$t^* \bar{b}e^- \bar{\nu}_e$
500	4.71(1)	4.60(1)
800	2.639(7)	2.508(7)
2000	0.691(4)	0.667(4)

($\sqrt{s} = 800$ GeV):



Treatment of finite widths

$$\text{Replace } m_t \rightarrow \sqrt{m_t^2 - im_t\Gamma_t}$$

- in top propagator: **Constant width scheme**
(Kauer, Zeppenfeld, PRD65:014021,2002,hep-ph/0107181)
- also in Feynman rules: **Complex mass scheme**
(Denner *et al* Nucl.Phys.B560:33, hep-ph/9904472)

Inconsistent for external top!

Numerical comparison:

$$\sigma(e^+e^- \rightarrow b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu)(fb) \text{ with } \theta(e^-) > 0.01^\circ$$

\sqrt{s}	Fixed Width	Complex Mass	Fudge Factor	Step Width
500	5.91 (1)	5.92 (2)	5.83 (1)	9.3 (1.9)
800	3.541 (8)	3.549 (8)	3.528 (8)	4.5 (3)
2000	3.62 (2)	3.64 (1)	3.62 (2)	98.0 (4)

Inconsistency of diagram selection

($\theta_e > 0.1^\circ$, $\sqrt{s} = 800$ GeV):

$b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu$	$t^*\bar{b}e^-\bar{\nu}_e$	$b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu(RR)$	$t^*\bar{b}e^-\bar{\nu}_e(RR)$
3.400(7)	6.62 (2)	0.641(2)	7.77(2)

Single Top Cross Section

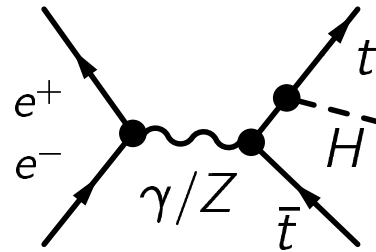
$\sigma(e^+e^- \rightarrow b\bar{b}e^-\bar{\nu}_e\mu^+\nu_\mu)(\text{fb})$

\sqrt{s}	θ_e	Unpolarized	RR
500	5°	0.200(2)	0.0068(4)
500	0.01°	0.203(11)	0.0368 (9)
800	5°	0.250(2)	0.0335(8)
800	0.01°	0.321 (11)	0.168 (4)
2000	5°	0.223(2)	0.135 (5)
2000	0.01°	0.558(14)	0.694 (17)

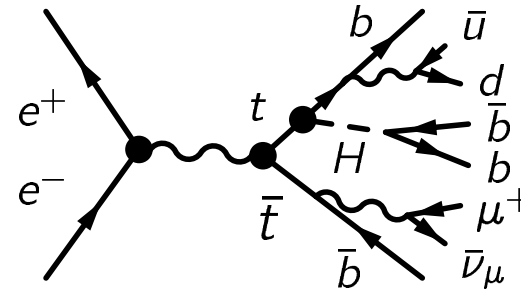
Complex mass scheme

Cuts: $|m_{\bar{b},e^-\bar{\nu}_e} - m_t| > 20$ GeV $|m_{\bar{b}b} - m_Z| > 20$ GeV $|m_{\bar{b}b} - m_H| > 1$ GeV

- Measurement of top-Yukawa coupling
- 8 fermion final state:



5 Diagrams



21908 Diagrams (EW)

- Background studies:
 - $e^+ e^- \rightarrow b\bar{b} W^+ W^- H/Z/g$ (S. Moretti, PLB452,338, hep-ph/9902214)
 - $e^+ e^- \rightarrow t\bar{t} b\bar{b}$ (Baer, Dawson, Reina PRD61:013002, hep-ph/9906419)
 - Experimental studies: (Juste, Merino, hep-ph/9910301; Besson, Gay, Winter)
- EW+QCD radiative corrections $\sim 10\%$ for 800 GeV
(You *et al* PLB571,85, hep-ph/0306036, Belanger *et al* PLB571,163, hep-ph/0307029, Denner *et al* PLB575,290, hep-ph/0307193)

Six particle final state

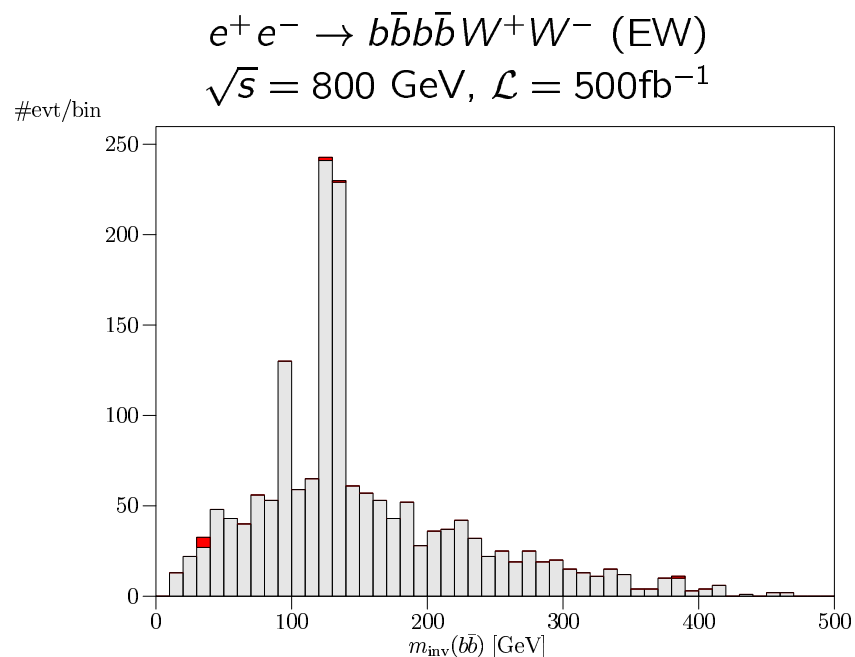
$$\sigma(e^+e^- \rightarrow b\bar{b}b\bar{b}W^+W^-)(\text{fb})$$

\sqrt{s}	$H^* \bar{b}bW^+W^-$	$Z^* \bar{b}bW^+W^-$	$b\bar{b}t^* \bar{t}^*$ (EW)	$b\bar{b}b\bar{b}W^+W^-$ (EW)	$g^* \bar{b}bW^+W^-$
500	0.1521 (4)	0.1590 (6)	0.319 (1)	0.3231 (5)	1.923 (7)
800	2.639 (9)	0.758 (3)	3.357 (8)	3.417 (3)	2.62 (1)
2000	0.989 (8)	0.588 (5)	1.513 (6)	1.600 (8)	1.59 (1)

($m_H = 130$ GeV, $m_t = 175$ GeV)

8 fermion final states (EW only)

	$\sigma(\text{fb}), 800\text{GeV}$
$b\bar{b}b\bar{b}\mu^- \bar{\nu}_\mu \tau^+ \bar{\nu}_\tau$	$3.81 (1) \times 10^{-2}$
$b\bar{b}b\bar{b}W^{-*}W^{+*}$	$3.82 (1) \times 10^{-2}$
$b\bar{b}\bar{t}^* t^*$	$3.74 (2) \times 10^{-2}$
$b\bar{b}b\bar{b}\mu^- \bar{\nu}_\mu \bar{u}d$	0.1144 (5)
$b\bar{b}b\bar{b}W^{-*}W^{+*}$	0.1148 (4)
$b\bar{b}\bar{t}^* t^*$	0.1120 (4)



Single Top Production

- Six fermion final states necessary for stable results for small electron scattering angle
- Background $\sim 5\%$ after $m_{\bar{b}b}$ cuts to reduce $W^+Z \rightarrow W^+Z/H$

Associated Top-Higgs production

- Six particle final state $b\bar{b}b\bar{b}W^+W^-$: $\sim 3\%$
- Eight fermion final states considered: small effect.
Identical particles?

Outlook

- Variation of top and Higgs masses
- Anomalous couplings
- Better QCD treatment
- Single Top: Realistic polarization