Single W Production at Linear Colliders

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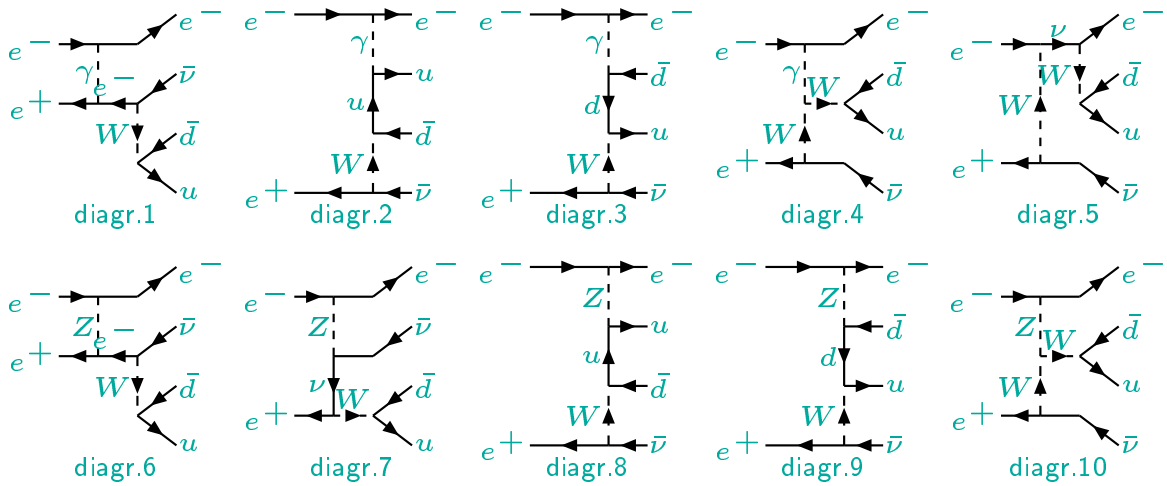
Outline

- Motivation
- Comparison of results from different programs, gauge cancellation and W width treatment, distributions
- Contributions from the gauge invariant classes
- A rate dependence on masses
- Conclusions and Comments

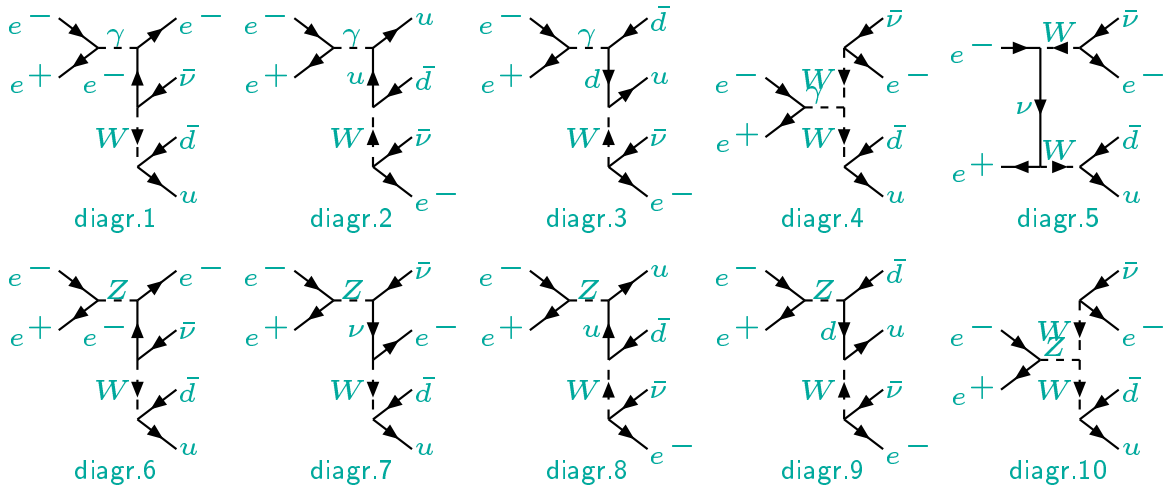
The CC20 process has been considered several times

- see D.Bardin et al. Report on Event Generators for WW Physics at LEP2, G.Altarelli et al., CERN-96-01.
- Y.Kurihara, D.Perret-Gallix, and Y.Shimizu, Phys.Lett. B349 (1995) 367.
- W.Beenakker et al. Nucl. Phys. B500 (1997) 255
- G. Passarino hep-ph/9810416
  - Motivation
    * At high energies single W has a large rate
    * Important information on anomalous couplings
    * Important source of a background to various new physics
    * Interesting theoretically as an example with huge gauge cancellation, for a treatment of the width, for an understanding of a role of different singularities etc

t-channel Feynman diagrams for the process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$:



s-channel Feynman diagrams for the process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$:



CC10-t and CC10-s are two exactly gauge invariant classes. CC10-s represents also a contribution from other lepton final states

	CompHEP	grc4f	KORALW	WPHACT
$\sqrt{s}$ = 350 GeV				
q cuts, no ISR	**1076(1)**	**1080(2)**		**1074(1)**
q cuts, with ISR	**1039(1)**	**1040(1)**		**1038(2)**
q, e cuts, no ISR	**520(1)**	**521(1)**		**512(1)**
q, e cuts, with ISR	**478(1)**	**480(1)**		**479(2)**
$\sqrt{s}$ = 500 GeV				
q cuts, no ISR	**1417(2)**	**1419(2)**	**1395(6)**	**1416(1)**
q cuts, with ISR	**1357(5)**	**1359(2)**	**1336(6)**	**1358(2)**
q, e cuts, no ISR	**939(3)**	**939(1)**	**909(5)**	**936(1)**
q, e cuts, with ISR	**864(9)**	**874(1)**	**840(5)**	**847(2)**
$\sqrt{s}$ = 800 GeV				
q cuts, no ISR	**2140(4)**	**2146(3)**		**2138(3)**
q cuts, with ISR	**2048(4)**	**2046(3)**		**2042(2)**
q, e cuts, no ISR	**1687(4)**	**1697(2)**		**1692(3)**
q, e cuts, with ISR	**1597(3)**	**1597(2)**		**1593(2)**

CompHEP, grc4f, KORALW and WPHACT results for the total cross section of the process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$ (fb) at $\sqrt{s} = 350$, 500 and 800 GeV. The notation 'q cuts' means partonic level quark cuts $E_q \geq 3$ GeV, $M_{u\,d} \geq 5$ GeV, 'l cuts' corresponds to $\cos\theta_e \geq 0.997$ One standard deviation error of the last digit is indicated in brackets.

[a]

[a] An agreement at LEP2 energies $\sqrt{s} = 183$, 190 GeV has been found to be reasonable between different codes. (See talk by A.Ballestrero at LEP2 Miniworkshop).

Two ways of gauge invariant width treatment have been used in calculations

t-channel resonant + nonresonant

(1) "overall prescription" or "preserved gauge scheme"

(CompHEP, Wphact)

First take the sum

$$\frac{a_\mu}{k^2 - m_W^2} + b_\mu$$

then square and multiply by

$$\frac{(k^2 - m_W^2)^2}{(k^2 - m_W^2)^2 + m_W^2 \Gamma_W^2}$$

(2) Redifinition of leptonic tensor (GRACE, KORALW)

see for details *Y.Kurihara, D.Perret-Gallix, Y.Shimizu, Phys.Lett. B349 (1995) 367*

$$M \sim \frac{1}{q^2} L_\mu W^\mu \qquad\qquad q_\mu W^\mu = 0$$

$$M \sim \frac{1}{q^2} L_\mu W^\mu = \frac{1}{q^2} L_\mu \left[\frac{a_\mu}{k^2 - m_W^2 + i m_W \Gamma_W} + b_\mu\right]$$

$$|M|^2 \sim \frac{1}{q^4} \frac{L_{\mu\nu} \left[d_\mu d_\nu^* + m_W^2 \Gamma_W^2 b_\mu b_\nu^*\right]}{(k^2 - m_W^2)^2 + m_W^2 \Gamma_W^2}$$

$$L_{\mu\nu} = 2(p_\mu p'_\nu + p_\nu p'_\mu) + q^2 g_{\mu\nu}; \quad d_\mu = a_\mu + (k^2 - m_W^2) b_\mu$$

$$L'_{\mu\nu} = 4(p_\mu - \frac{p_0}{q_0} q_\mu)(p_\nu - \frac{p_0}{q_0} q_\nu) + q^2 g_{\mu\nu} = 4 P_\mu P_\nu + q^2 g_{\mu\nu}$$

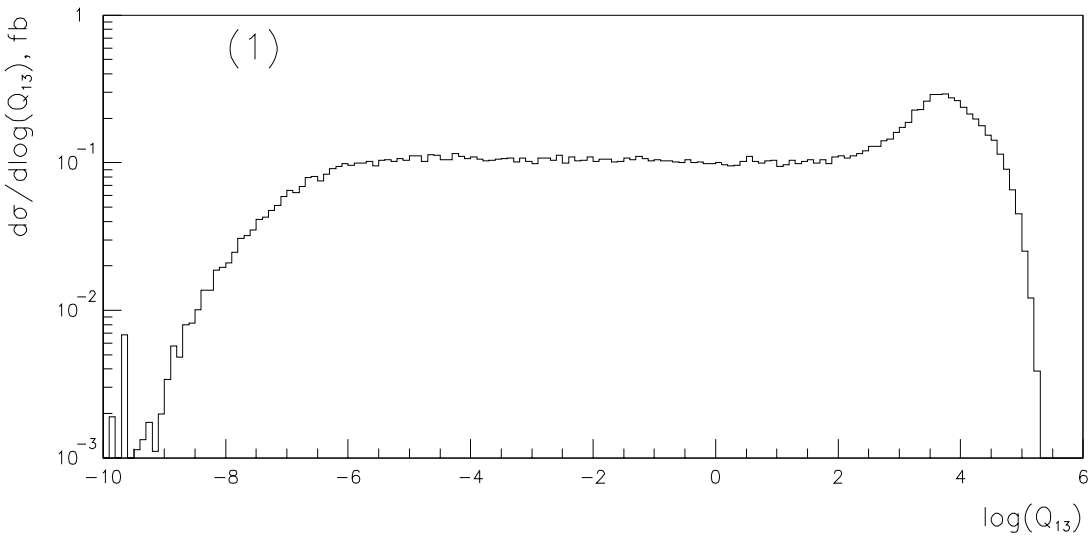
$$L_{\mu\nu} \to L'_{\mu\nu}$$

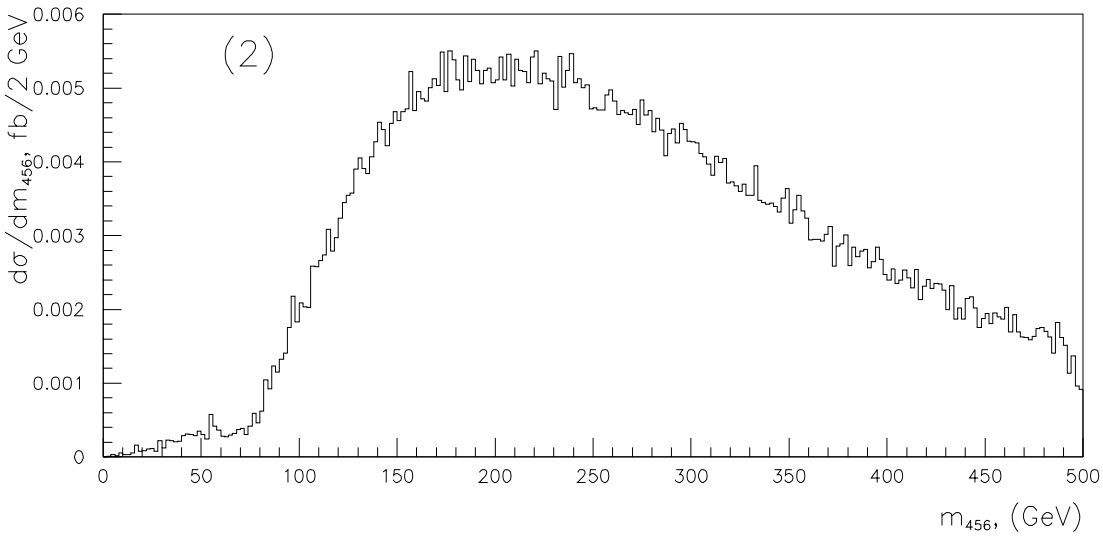
Energy component of P_μ is equal to zero. P_3 component behaves as $\bigcirc(q^2)$ up to terms of order m_e^2. {*F.Gutbrod, Z.Rek, Z.Phys C1 (1979) 171*} Important for the unitary behaviour of the amplitudes with Breit-Wigner propagators.

(1)- The distribution of $\log_{(}\frac{Q^2}{1GeV^2})$

(2) - The $M_{\nu u\bar{d}}$ invariant mass distribution

$$\sqrt{s} = 500\mathrm{GeV}$$





Plato reflects a gauge cancellation

$\frac{1}{t^2} \to \frac{1}{t}$

$\sqrt{s}$	$\sigma(CC10-t)$	$\sigma(CC10-s)$	$\sigma(t-s\ interf.)$	σ_{tot}
quark phase space cuts, no ISR				
183	**130(0)**	**655(1)**	**0.2(0)**	**785(1)**
190	**147(0)**	**680(1)**	**5(0)**	**832(1)**
350	**635(1)**	**420(1)**	**21(0)**	**1076(1)**
500	**1127(2)**	**270(0)**	**19(0)**	**1417(2)**
800	**1981(4)**	**143(0)**	**16(0)**	**2140(4)**
quark phase space cuts, with ISR				
183	**117(0)**	**566(1)**	**0.2(0)**	**683(1)**
190	**132(0)**	**603(1)**	**5(0)**	**739(1)**
350	**587(1)**	**432(1)**	**20(0)**	**1039(1)**
500	**1049(5)**	**289(0)**	**19(0)**	**1357(5)**
850	**1873(4)**	**159(0)**	**16(1)**	**2048(4)**
lepton and quark phase space cuts, no ISR				
183	**102(0)**	**2(0)**	**0.0(0)**	**104(0)**
190	**116(0)**	**2(0)**	**0.0(0)**	**118(0)**
350	**513(1)**	**7(0)**	**0.2(0)**	**520(1)**
500	**928(2)**	**10(0)**	**0.3(0)**	**938(2)**
800	**1671(4)**	**15(0)**	**0.4(0)**	**1686(4)**
lepton and quark phase space cuts, with ISR				
183	**92(1)**	**2(0)**	**0.0(0)**	**94(1)**
190	**103(1)**	**2(0)**	**0.0(0)**	**105(1)**
350	**472(1)**	**6(0)**	**0.0(0)**	**478(1)**
500	**854(9)**	**10(0)**	**0.3(0)**	**864(9)**
800	**1581(3)**	**15(0)**	**0.4(0)**	**1596(3)**

Contributions to the total cross section (in fb) of the CC20 process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$ from the gauge invariant subsets of t-channel and s-channel diagrams and their interference at the energies of LEP2 and NLC. One standard deviation error of the last digit is indicated in brackets.

$\sqrt{s}$	$\sigma(CC10-t)$	$\sigma(CC10-s)$	$\sigma(t-s\ interf.)$	σ_{tot}
no cuts, no ISR				
183	**141(0)**	**655(1)**	**0.2(0)**	**796(1)**
190	**158(0)**	**680(1)**	**5(0)**	**843(1)**
500	**1141(2)**	**271(0)**	**19(0)**	**1431(2)**
800	**2000(6)**	**143(0)**	**16(0)**	**2159(6)**

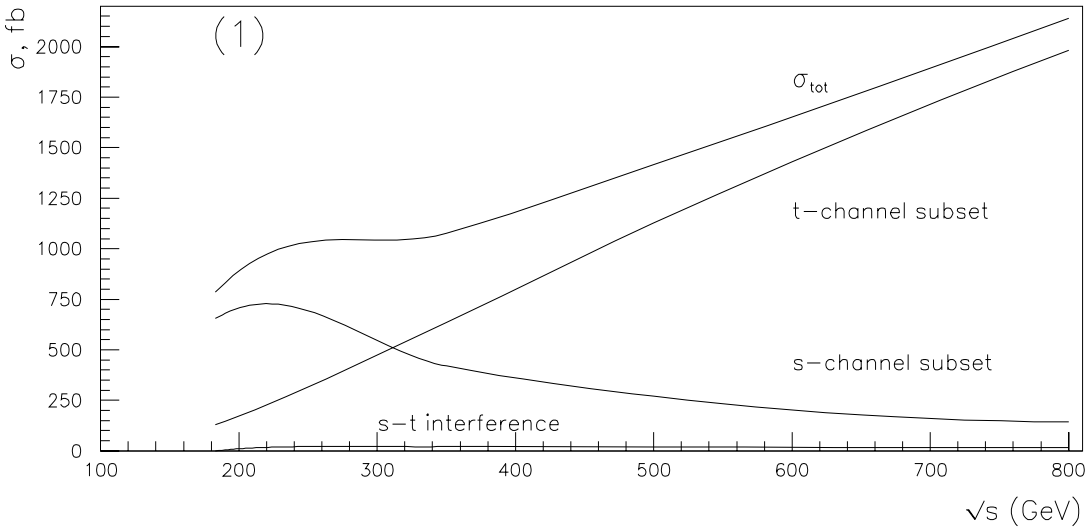
Contributions to the total cross section (in fb) of the CC20 process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$ from the gauge invariant subsets of t-channel and s-channel diagrams and their interference at the energies of LEP2 and NLC. Phase space cuts are not imposed. One standard deviation error of the last digit is indicated in brackets.

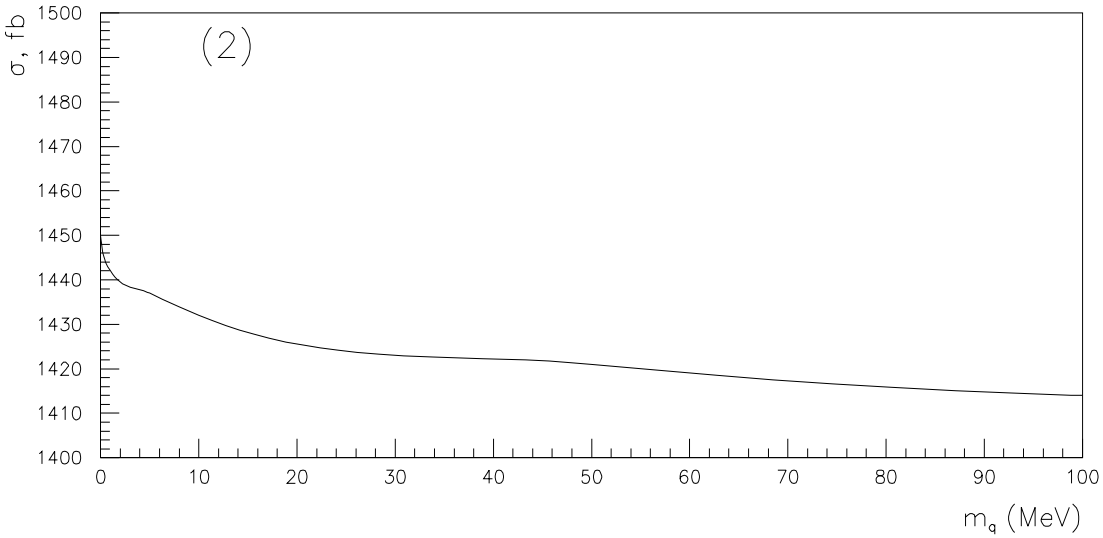
m_q (MeV)	$\sigma(CC10-t)$	$\sigma(CC10-s)$	$\sigma(t-s\ interf.)$	σ_{tot}
0	**1160(4)**	**270(0)**	**20(0)**	**1450(4)**
0.5	**1154(3)**	**270(0)**	**20(0)**	**1444(3)**
1	**1152(3)**	**270(0)**	**20(0)**	**1442(3)**
5	**1147(2)**	**270(0)**	**20(0)**	**1437(3)**
10	**1142(2)**	**270(0)**	**20(0)**	**1432(3)**
50	**1131(2)**	**270(0)**	**20(0)**	**1421(2)**
100	**1124(2)**	**270(0)**	**20(0)**	**1414(2)**

The total rate for the process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$ (fb) at various quark masses.

The mass dependence is weak. The contribution from multiperipheral diagrams is rather small, compare rates at 500 GeV for CC10-t part $1140fb$ and $\sigma(e^+e^- \to e^-\bar{\nu}_e W^+) * Br(W \to u\bar{d}) = 1060fb$. Therefoe one should not expect an important contribution from a resolved photon. A situation at LC is different from HERA where single W comes from quark fusion directly.

(1)- s and t channel subset contributions to σ_{tot}
(2) - total cross section dependence on the quark mass





$$q^2_{min} = -m_e^2 \frac{x^2_{min}}{1-x_{min}}, \quad x_{min} = \frac{(2m_q+m_e)^2}{S}$$

$$q^2_{min} < 0 \text{ at } m_q = 0$$

$\Rightarrow$ The rate is finite even for $m_q = 0$

Conclusions and Comments

- The CC20 rate without ISR in the range $cos(\theta_e) > 0.997, M_W - 10\ GeV\ < M_{u\,d} < M_W + 10\ GeV$ with $V_{u\,d} = 0.9496$ and all other parameters as for LEP2 Mini-workshop is lagre:
  - $\sqrt{s} = 350 GeV \qquad \sigma = 439(1) fb$
  - $\sqrt{s} = 500 GeV \qquad \sigma = 783(1) fb$
  - $\sqrt{s} = 800 GeV \qquad \sigma = 1426(3) fb$
- CC10-t channel part grows rapidly with energy in the interval from 200 to 800 GeV while CC10-s channel falls down. They are equal at about 300 GeV. Interference contribution is about 1-1.5 %
- The W width should be treated in a gauge invariant manner in order not to violate huge gauge cancellations. Results of grc4f, Wphact and CompHEP for CC20 rate agree better than 0.4 %
- The cross section for CC20 is finite even for zero quark masses, and the quark mass dependence is weak. If a quark mass varies in the range from 0 to 100 MeV the CC20 cross section changes on about 2.5 % only
- A use of the ISR needs a special care. Seems one should use two different Q^2 scales for t-channel and s-channel parts. In case of $Q^2 = s$ for s-channel and $Q^2 = 0$ for t-channel one should simply sum up the contributions from the table with ISR for s-channel and without ISR for t-channel