May 2004

$e^- e^+ \to e^- e^+ t\bar{t}$

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Outline

- $e^-e^+ \to \gamma\gamma$ (CompHEP)

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- $e^-e^+ \to e^-e^-e^+e^+$ (CompHEP)

- $e^-e^+ \to e^-e^+t\bar{t}$ (CompHEP)

- M_{rec} cut suppression of $e^-e^+ \to e^-e^+t\bar{t} + e^-e^+ \to \gamma t\bar{t}$ (Pythia)

- "Discovery of the week"

$\boxed{e^- e^+ \to \gamma\gamma \text{ (} \frac{1}{m_e^2} \text{ peak in t-channel)}}$

Old CompHEP at 1500 GeV:

Simpson: $\sigma = 1.667$ pb

VegaS: no C, no R, $5 \times 10^4 + 5 \times 10^5 + 5 \times 10^6$

$\sigma = 1.667$ pb, Error $\sim 10^{-4}$ %

CompHEP4.4.0 at 1500 GeV:

Simpson: ? pb (warning 'constraints cannot be calculated')

VegaS: no C, no R, $5 \times 10^4 + 5 \times 10^5 + 5 \times 10^6$

$\sigma = 1.667$ pb, Error $\sim 10^{-4}$ % Bad Precision $\sim 30\%$ warnings

$\boxed{e^- e^+ \to e^- e^+ \text{ (} \infty \text{ in t-channel)}}$

CompHEP both old and 4.4.0 at 1500 GeV:

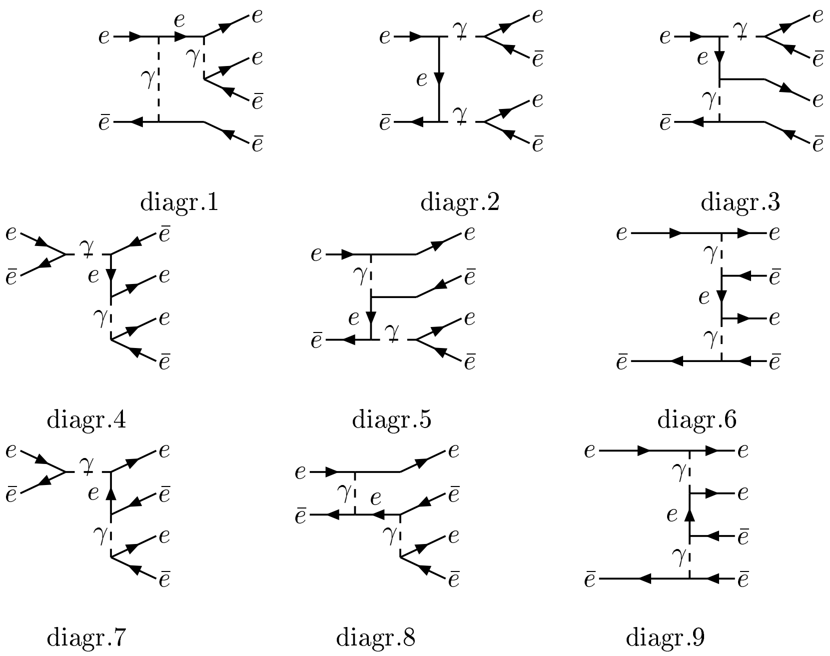
VegaS: $C : -0.9 < C13 < 0.9$, no R, 5×10^4

$\sigma = 1.754$ pb

VegaS: $C : -0.99 < C13 < 0.99$, no R, 5×10^4

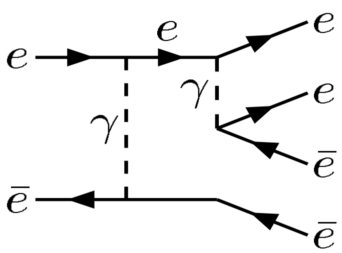
$\sigma = 22.09$ pb

$$\boxed{e^- e^+ \rightarrow e^- e^- e^+ e^+}$$



Propagators in $e^-e^+ \to e^-e^-e^+e^+$, 1st diagram

$(12 \to 3456)$



diagr.1

(exchange of identical particles gives 4 amplitudes in diagr. 1)

Mathematica :(note 1st power propagators in green)

denominator =prop[-p2+p5,0,0]^2*prop[-p1-p2+p5,Me,0]^2
prop[p4+ p6,0,0]^2

denominator =prop[-p2+p5,0,0]*prop[-p1-p2+p5,Me,0]
prop[p4+p6,0,0] *prop[-p2+p6,0,0]*prop[-p1-p2+p6,Me,0]
prop[p4+p5,0,0]

denominator =prop[-p2+p5,0,0]^2*prop[-p1-p2+p5,Me,0]^2
prop[p4+ p6,0,0]*prop[p3+p6,0,0]

denominator =prop[-p2+p5,0,0]*prop[-p1-p2+p5,Me,0]

prop[p4+p6,0,0] *prop[-p2+p6,0,0]*prop[-p1-p2+p6,Me,0]

prop[p3+p5,0,0]

Peaks in t-channel photon propagator

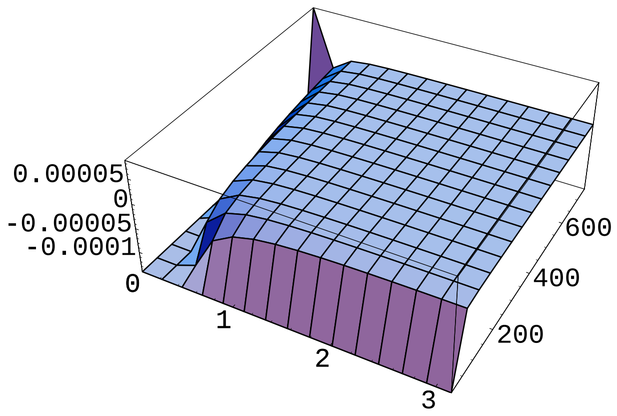
$$\mathrm{prop}[-\mathrm{p2}+\mathrm{p6},0,0]^2 = (p_2 - p_6)^2 = 2m_e^2 - 2(E_2E_6 - \sqrt{E_2^2 - m_e^2}\sqrt{E_6^2 - m_e^2}\cos\theta_{26})$$

Propagator (the inverse of $\mathrm{prop}[-\mathrm{p2}+\mathrm{p6},0,0]^2$) is plotted with Mathematica (for details see /melo/FYZIKA/MATHEMATICA/E-E-E+E+):

Prop1.nb 1

```
In[1]:= me = 0.000511;
        e2 = 750.;
        p2 = Sqrt[e2^2-me^2];
        p6 = Sqrt[e6^2-me^2];
        h1 = e2*e6 - p2*p6*Cos[theta26];
        Propagator = 1/(2*me^2 - 2*h1);

        Plot3D[Propagator,{theta26,0,Pi},{e6,me,750-me}]
```



Positive and negative peaks seem to be found at $\theta_{26} \to 0$ and $E_6 \to m_e$.

$$\boxed{\text{Propagator} = 2m_e^2 - 2(E_2 E_6 - \sqrt{E_2^2 - m_e^2}\sqrt{E_6^2 - m_e^2}\cos\theta_{26})}$$

estimate: Propagator $\sim 1/E_2 E_6 \sim 1/10^2 10^2 \text{GeV}^{-2} = 10^{-4}\text{GeV}^{-2}$

$E_6 \to m_e$:

Propagator $= (\text{prop}[-\text{p2} + \text{p6}, 0, 0]^2])^{-1} = (2m_e^2 - 2m_e E_2)^{-1}$

$\doteq -(m_e\sqrt{s})^{-1} \doteq -1.33$ GeV^{-2} for any θ_{26} (no problem)

$\theta_{26} \to 0$:

From $E_6 = m_e$ (see above) the inverse of $\text{prop}[-\text{p2} + \text{p6}, 0, 0]^2$ falls with E_6 reaching $\doteq -\frac{s}{4m_e^4} \doteq -8.25 \times 10^{18}$ GeV^{-2} (!!!) at upper kinematic limit $E_6 = \sqrt{s}/2 - m_e$ (real problem).

For $E_6 = E_2 = \sqrt{s}/2$ (not allowed kinematically) we would recover the divergency known from $e^- e^+ \to e^- e^+$. Thus, m_e cuts off divergency but nevertheless the peak at $\theta_{26} \to 0$ and $E_6 = \sqrt{s}/2 - m_e$ is terrible.

Peaks in 2nd photon propagator

$$\begin{aligned}\mathsf{prop[p3+p5,0,0]}^2 &= (p_3 - p_5)^2 \\ &= 2m_e^2 + 2(E_3E_5 - \sqrt{E_3^2 - m_e^2}\sqrt{E_5^2 - m_e^2}\cos\theta_{35})\end{aligned}$$

$E_3 \to m_e, E_5 \to m_e$:

Propagator $= \frac{1}{4m_e^2} = 957411\ \mathrm{GeV}^{-2}$ (problem)

$\theta_{35} = 0$:

Propagator's maximum $= \frac{1}{4m_e^2}$ for $E_3 = E_5$ (problem)

$\theta_{35} = \pi$:

Propagator's maximum $= \frac{1}{4m_e^2}$ for $E_3 \to m_e, E_5 \to m_e$ (problem)

Peaks in electron propagator

$$\begin{aligned} \mathsf{prop}[-\mathsf{p1}-\mathsf{p2}+\mathsf{p6}, Me, 0]^2 &= (p_1+p_2-p_6)^2 - m_e^2 \\ &= s - 2\sqrt{s}E_6 \end{aligned}$$

Propagator reaches maximum for $E_6 = \sqrt{s}/2 - m_e$:

Propagator $= (s - 2\sqrt{s}\ E_6)^{-1} = (2\sqrt{s}\ m_e)^{-1} = 0.65\ \mathrm{GeV}^{-2}$ (no problem)

Peaks in 1 st diagram (summary)

$\theta_{26}, \theta_{25} \to 0$

$\theta_{35}, \theta_{36}, \theta_{45}, \theta_{46} \to 0, \pi$

New angles above were obtained by exchange of identical particles in the final state

I do not show separately peaks in energy since those are included in the angles above

$e^-e^+ \to e^-e^-e^+e^+$, CompHEP (QED), 1st diagr.

C ... cuts, R ... regularization, C26 $= \cos\theta_{26}$

Standard C: $-0.9 < C26, C25, C35, C36, C45, C46 < 0.9$

Standard R: $125(Me, 0, 2); 25, 46(0, 0, 2); 126(Me, 0, 1); 45, 36, 35(0, 0, 1)$

1st value of σ and Error (the worst out of 5 or 10) is ignored

1) No C, no R, 5×10^4, $\boxed{\sigma = 2.49 - 338.93 \text{ pb}}$

2) Stand. C, stand. R, 10×10^6

$\boxed{\sigma = 5.00 - 5.20 \times 10^{-5} \text{ pb}}$, Error $= 1.03 - 1.35\%$

3) Stand. C, stand. R with all powers $= 2$, 10×10^6

$\boxed{\sigma = 5.04 - 5.31 \times 10^{-5} \text{ pb}}$, Error $= 0.96 - 1.34\%$

4) Stand. C, no R, 10×10^6

$\boxed{\sigma = 5.14 - 5.42 \times 10^{-5} \text{ pb}}$, Error $= 0.86 - 6.10\%$

5) C: $-0.9 < C26, C25 < 0.9$, $-0.99 < C35, C36, C45, C46 < 0.99$, stand. R, 10×10^6

$\boxed{\sigma = 1.51 - 1.65 \times 10^{-3} \text{ pb}}$, Error $= 2.03 - 4.28\%$, Bad Precision 5E-05 % in 1 of 10

6) C: $-0.9 < C26, C25 < 0.9$, stand. R, 10×10^6

$\boxed{\sigma = 6.78 - 6.96 \times 10^{+5} \text{ pb}}$, Error $= 1.04 - 1.82\%$, Bad Precision 60% in 10 of 10

CompHEP run of $e^-e^+ \to e^-e^-e^+e^+$, all diagrams

Stand. C: $-0.9 < C26, C25, C13, C14, C35, C36, C45, C46 < 0.9$

Stand. R: $125, 126, 135, 136, 145, 146, 124, 123(Me, 0, 2)$;

$25, 26, 35, 36, 45, 46, 34, 56, 12, 13, 14(0, 0, 2)$ no check of Mathematica amplitudes for R - 1st powers missing

1) No C, no R, 5×10^4, $\boxed{\sigma = 0.079 - 74.025 \text{ pb}}$

2) Stand. C, stand. R, 5×10^5,

$\boxed{\sigma = 1.48 - 1.69 \times 10^{-5} \text{ pb}}$, Error $= 2.54 - 7.85\%$

3) Stand. C, no R, 5×10^5,

$\boxed{\sigma = 1.51 - 1.59 \times 10^{-5} \text{ pb}}$, Error $= 1.07 - 2.28\%$ 'no R' better than 'stand. R' !

$e^- e^+ \to e^- e^+ t\bar{t}$

CompHEP (SM,FG),all diagrams

Stand. C: $500 < M56 < 1500, -0.8 < C15, C16 < 0.8, 0 < E5, E6 < 700, 50 < T5, T6 < 1500, 30 < T56 < 600, 200 < M34 < 1500$

Stand. R: $24, 56, 34, 12, 13, (MZ, wZ, 2)$;
$24, 56, 34, 12, 13(0, 0, 2); 56(MH, wH, 2)$

$m_e = 0$

0) no C, no R, 5×10^4,
$\boxed{\sigma = 1.50 - 4.17 \times 10^{-3} \text{ pb}}$, Error $= 18.7 - 67.6\%$

1) Stand. C, stand. R, 5×10^4,
$\boxed{\sigma = negative 3.56 - positive 5.67 \times 10^{-3} \text{ pb}}$, Error $= 30 - 113\%$,
Bad Precision up to 300 %

$m_e = 0.511$ GeV

2) no C, no R, 5×10^4,
$\boxed{\sigma = 1.25 - 2.62 \times 10^{-3} \text{ pb}}$, Error $= 9.98 - 50.7\%$

3) Stand. C, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$,
$\boxed{\sigma = 3.03 - 3.06 \times 10^{-4} \text{ pb}}$, Error $= 0.49 - 0.52\%$

4) Stand. C, stand. R: 24,13 (MZ,0,2) + e,t propagators, $5 \times 10^4 + 5 \times 10^5$,
$\boxed{\sigma = 3.04 - 3.08 \times 10^{-4} \text{ pb}}$, Error $= 0.80 - 0.93\%$

$m_e = 0.0511$ GeV

5) Stand. C, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$,

$\boxed{\sigma = 4.17 - 4.20 \times 10^{-4} \text{ pb}}$, Error $= 0.56 - 0.65\%$

$m_e = 0.00511$ GeV

6) Stand. C, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$,

$\boxed{\sigma = 5.23 - 5.39 \times 10^{-4} \text{ pb}}$, Error $= 0.76 - 0.95\%$, Bad Precision 0.2 % 5 in 5

$m_e = 0.000511$ GeV

7a) Stand. C, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$

$\boxed{\sigma = 5.40 - 6.44 \times 10^{-4} \text{ pb}}$ (Pythia: 1.6×10^{-4} pb),

Error $= 0.80 - 6.42\%$, Bad Precision 5-7 % 5 in 5

7b) Same as above but $5 \times 10^4 + 5 \times 10^5 + 5 \times 10^6$ (Beata)

$\boxed{\sigma = 6.42 - 6.51 \times 10^{-4} \text{ pb}}$ (Pythia: 1.6×10^{-4} pb),

Error $= 0.29 - 0.73\%$, Bad Precision 7 % 5 in 5

No electron at $\theta > 10 - 20$ degrees

$m_e = 0.000511$ GeV

8a) Stand. C no e cuts $0.94 < C13, C24 < 1$, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$

$\boxed{\sigma = 4.37 - 4.40 \times 10^{-4} \text{ pb}}$, Error = 0.89–2.39%, Bad Precision

8-9 % 5 in 5

8b) Same as above but $5 \times 10^4 + 5 \times 10^5 + 5 \times 10^6$ (Beata)

$\boxed{\sigma = 4.26 - 4.49 \times 10^{-4} \text{ pb}}$, Error = 0.41–2.70%, Bad Precision

8 % 5 in 5

9a) Stand. C no e cuts $0.98 < C13, C24 < 1$, stand. R: 24,13 (MZ,0,2), $5 \times 10^4 + 5 \times 10^5$

$\boxed{\sigma = 2.76 - 2.95 \times 10^{-4} \text{ pb}}$, Error = 1.03–4.72%, Bad Precision

9-10 % 5 in 5

9b) Same as above but $5 \times 10^4 + 5 \times 10^5 + 5 \times 10^6$ (Beata)

$\boxed{\sigma = 2.71 - 2.83 \times 10^{-4} \text{ pb}}$, Error = 0.38–0.90%, Bad Precision

10 % 5 in 5

Backgrounds - M_{rec} cut

$e^+e^- \to t\bar{t}\gamma \quad + \quad e^+e^- \to e^+e^- t\bar{t}$

Pythia (1500 GeV):

$M_{rec} >$ 200 GeV

S($M_\rho = 1$ TeV, $\Gamma_\rho = 10.1$ GeV) $= 692$ events
$\sigma = 2.475$ fb $\to$ 0.76fb

B $=$ 659 events
$\sigma = 99.4 + 5.2$ fb $\to$ 0.71 fb

$M_{rec} >$ 400 GeV

S($M_\rho = 1$ TeV, $\Gamma_\rho = 10.1$ GeV) $= 646$ events
$\sigma = 2.475$ fb $\to$ 0.70fb

B $=$ 341 events
$\sigma = 99.4 + 5.2$ fb $\to$ 0.37 fb

"Discovery of the Week"

Pythia ISR (initial state radiation) generates n = 1 to 4 photons
hence $e^-e^+ \to (n\gamma)\ t\bar{t}$ does indeed have $M_{rec} \neq$ 0 for $n > 1$!