Top Quarks at Photon Linear Colliders

Edward Boos
Theory Division of the Institute of Nuclear Physics
Moscow State University

Outline

- Introduction
- Top pair production in $\gamma\gamma$ collisions
- Top pair production in $\gamma\gamma$ close to the threshold
- Probe for anomalous couplings from pair production
- Single top in $\gamma\gamma$ and γe
- Concluding Remarks and Problems

Top quark has been found by the Fermilab CDF and D0 collaborations. Some last RUN1 results:

- $M_t = 174.3 \pm 3.2(stat) \pm 4.0(syst)$
- $\sigma_{t\bar{t}}(CDF M_t = 175 GeV) = 6.5^{+1.7}_{-1.4} pb$
  $\sigma_{t\bar{t}}(D0 M_t = 172 GeV) = 5.9 \pm 1.7 pb$
- $\lambda_t(M_t) = 1.00 \pm 0.03$
- $|V_{tb}| = 0.96^{+0.16}_{-0.13}$ or $|V_{tb}| > 0.78$ (90% CL)
- The 95% Confidence Level Limit on single top production cross section (CDF): 13.5 pb
  Extracted cross section of single top production by the likelihood fit (CDF):
  $\sigma = 5.2^{+4.9}_{-3.4}$ pb
  SM prediction: $\sigma_{SM} = 2.43 \pm 0.32$ pb

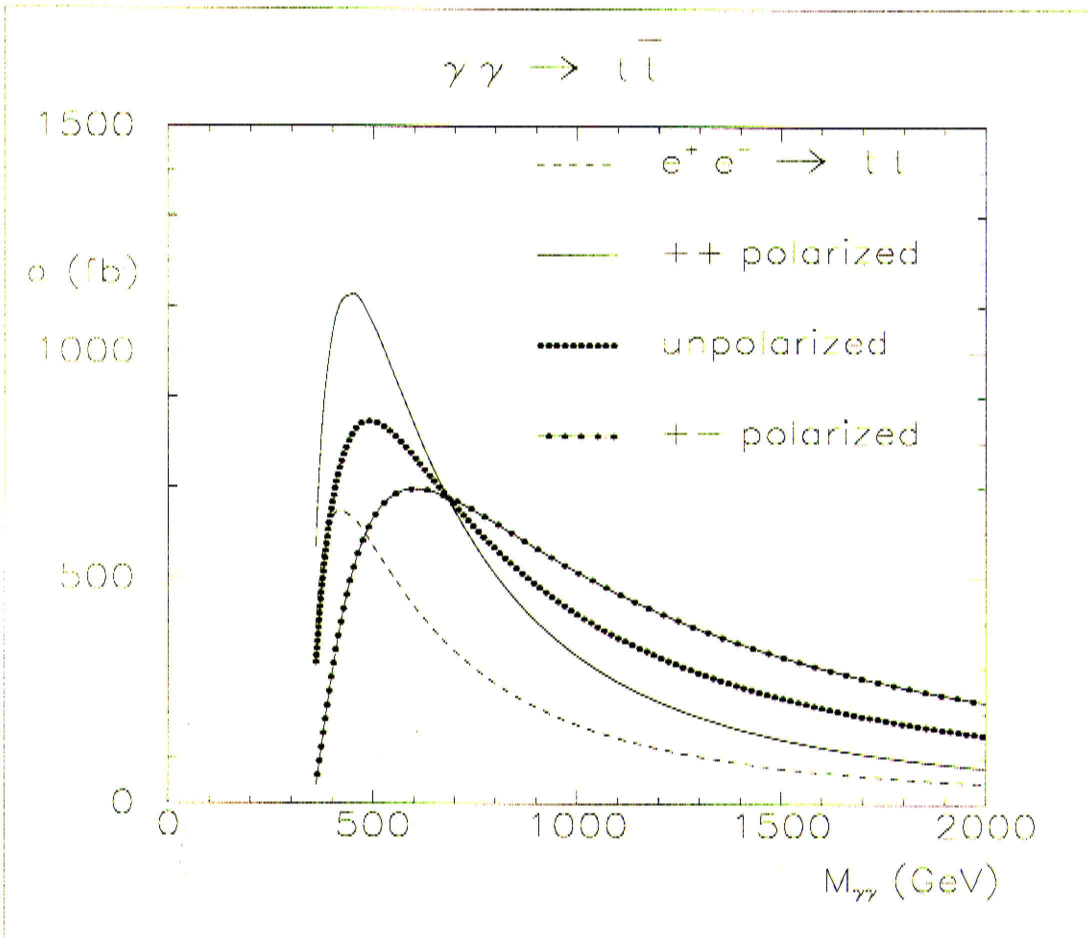
Top quark is the heaviest found so far elementary particle with the mass slightly less than the mass of the gold nucleus.

- Top decays much faster than a typical time-scale for a formation of the strong bound states. So, top provides, in principle, a very clean source for a fundamental information.
- Top is so heavy and point like (up to now) at the same time. So, one might expect a possible deviations from the SM predictions more likely in the top sector.
- Top Yukawa coupling $\lambda_t = 2^{3/4} G_F^{1/2} m_t$ is very close to unit. Studies of top may shed a light on an origin of the mechanism of the EW symmetry breaking.

Top quark physics will be a very important part of research programs for all future hadron and lepton colliders. The $\gamma\gamma$ collider is of a special interest because of a very clean electromagnetic production mechanism with large enough rate.

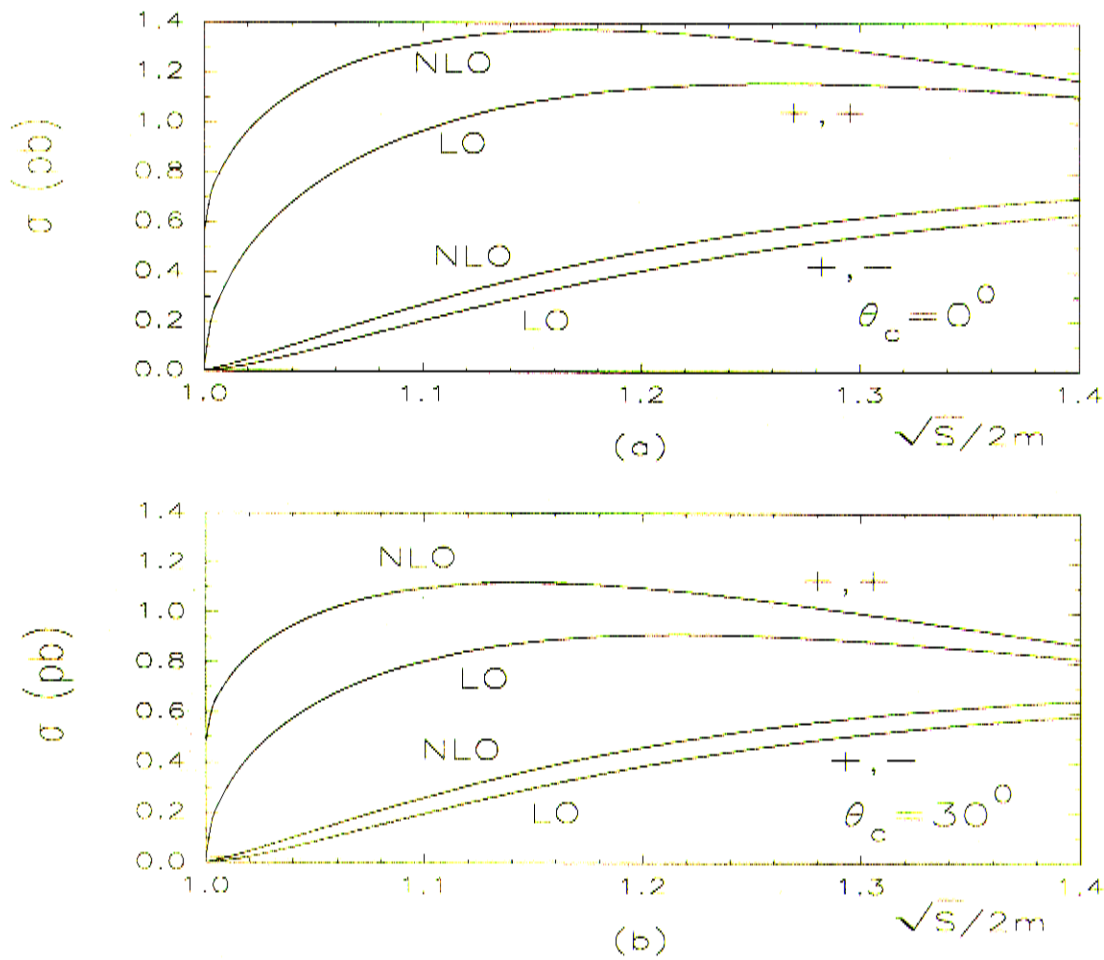
The leading order $\gamma\gamma \to t\bar{t}$ cross section has a maximum at about 420 (++), 450 (Unpolarize) and 550 (+−) GeV. The cross section is larger than the corresponding e^+e^- cross section.

CompHEP



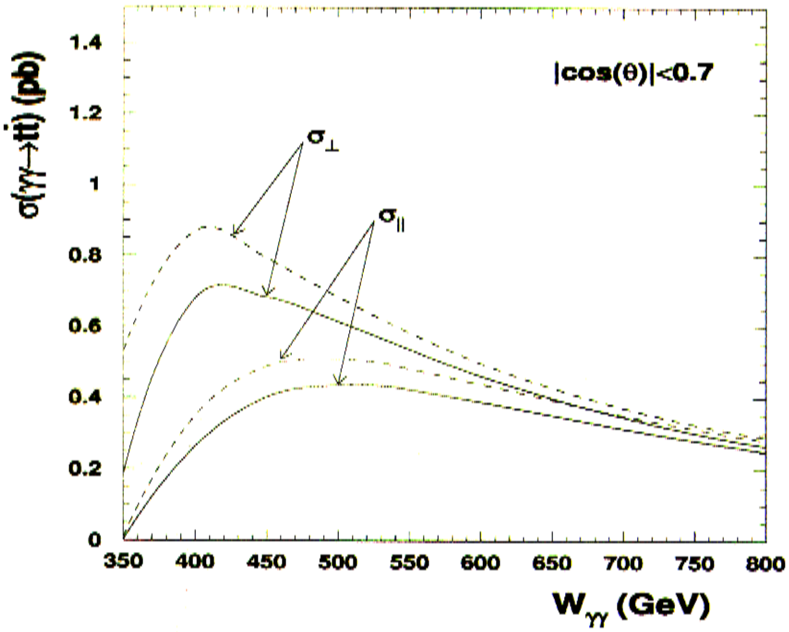
The (++) = (−−) helicity configuration ($J_z = 0$) dominates at energies less than about 680 GeV while the (+−) = (−+) or $J_z = 2$ configuration starts to dominate at higher energies.

The strong NLO corrections are large and important in the region above the threshold up to about 500 GeV. They lead to a significant increase of the rate in (++) mode. The angular cuts do not make a big difference. B.Kamal, Z.Merebashvili, A.P.Contogouris



The Electroweek corrections are also known (A.Denner, S.Dittmaier, M.Strobel) to be of the order of 0 - (-10)% up to 1TeV energies. In the region close to the threshold they are about -10 % for $J_z = 0$ case. The EW corrections are important in order to get high level accuracy predictions.

The corrections for the linear polarizations of initial photons have been computed recently (G. Jikia, A.Tkabladze (2000))



The results are given for $\Delta\gamma = 0$ and $\pi/2$ where $\Delta\gamma$ is the angle between polarization vectors of colliding photons. The calculation could be important for a measurement of CP parity of SUSY Higgses H and A.

In the threshold region in order to get a reliable answer it is very important to resum the Coulomd corrections due to the final state interactions. In this sense a situation is similar to e^+e^- case (J.Kühn; I.Bigi, Y.Dokshitzer, V.Khoze, J.Kühn, P.Zerwas; V.Fadin, V.Khoze; M.Strassler, M.Peskin; last review A.Hoang et al hep-ph/0001286).

After resummation the cross section close to the threshold is increasing several times. The effect is specially pronounced for the (++)mode of colliding photons.
(A.Penin, A.Pivovarov)

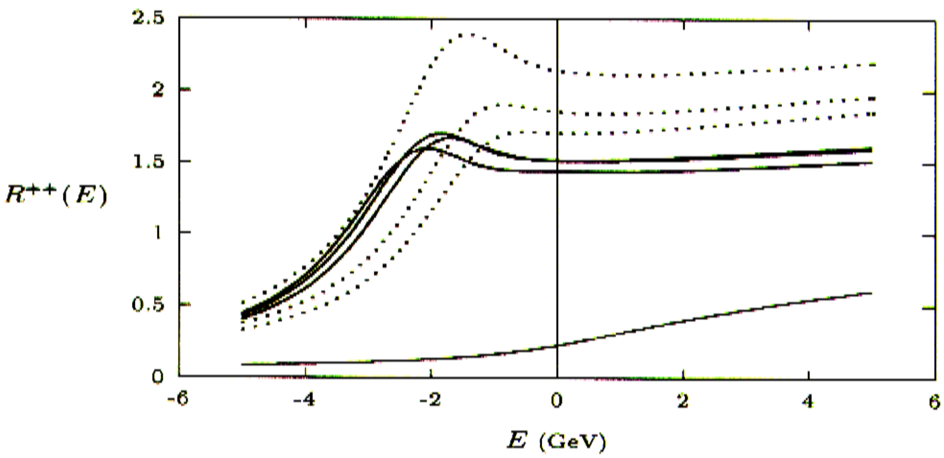


Fig. 2.

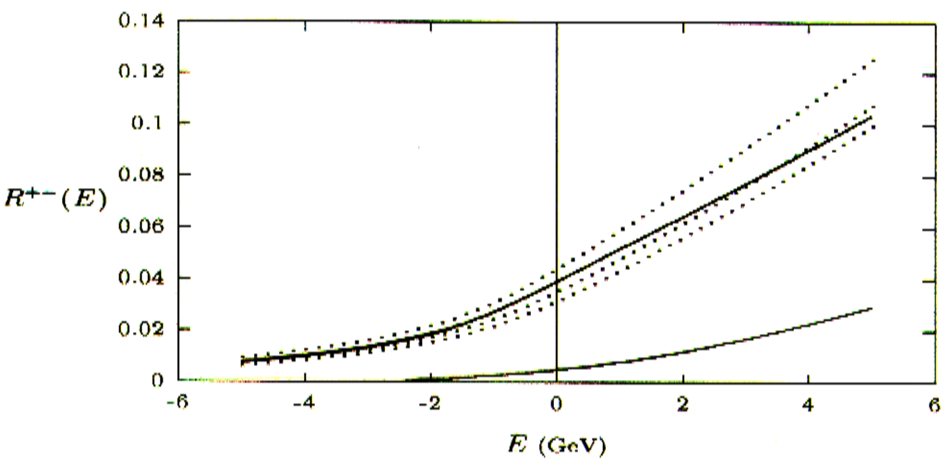


Fig. 3.

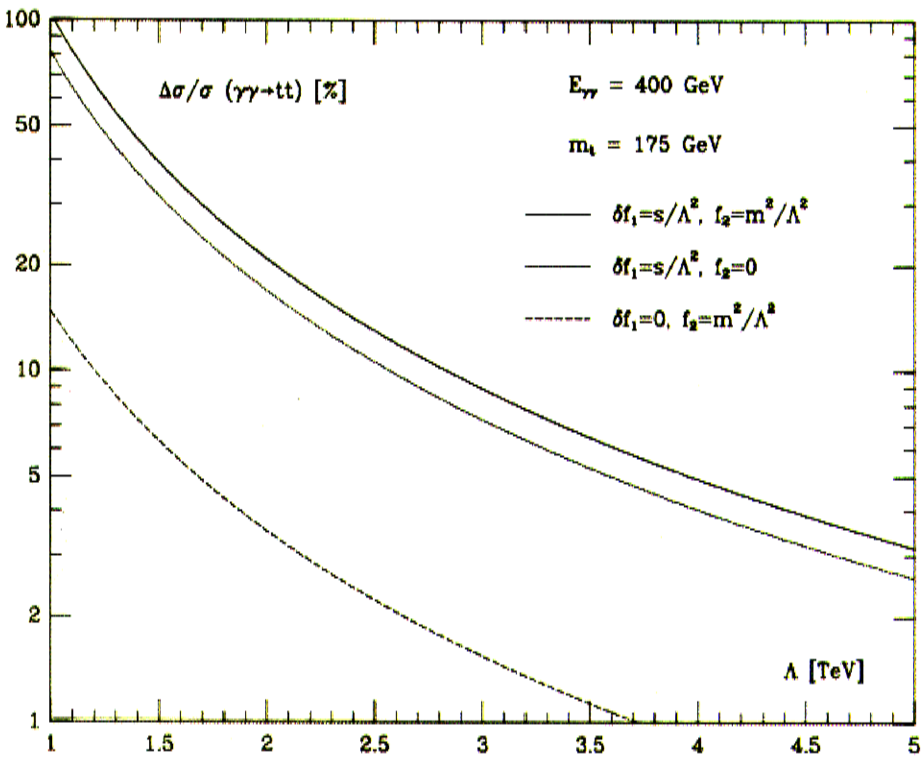
$\gamma\gamma \to \tilde{t}\bar{\tilde{t}} \to$ Stop $\to$ { gg; hh if kinemat. possible

(V. Ilyin, D. Gorbunov)

There are two points which are different for $\gamma\gamma$ and e^+e^- collisions with respect to the couplings:

- the $\gamma t\bar{t}$ coupling is involved in the 4th power
- the $\gamma t\bar{t}$ coupling is separated from $Zt\bar{t}$ coupling

If one can measure the cross section with 2% accuracy one will be able to probe Λ upto 10 TeV (formfactors reexpressed through Λ) (A.Djouadi et al)



$$L_{eff} = ie_0(f_1^\alpha \gamma_\mu + \frac{i}{2m_t} f_2^\alpha \sigma_{\mu\nu} q^\nu + f_3^\alpha \gamma_\mu \gamma_5$$

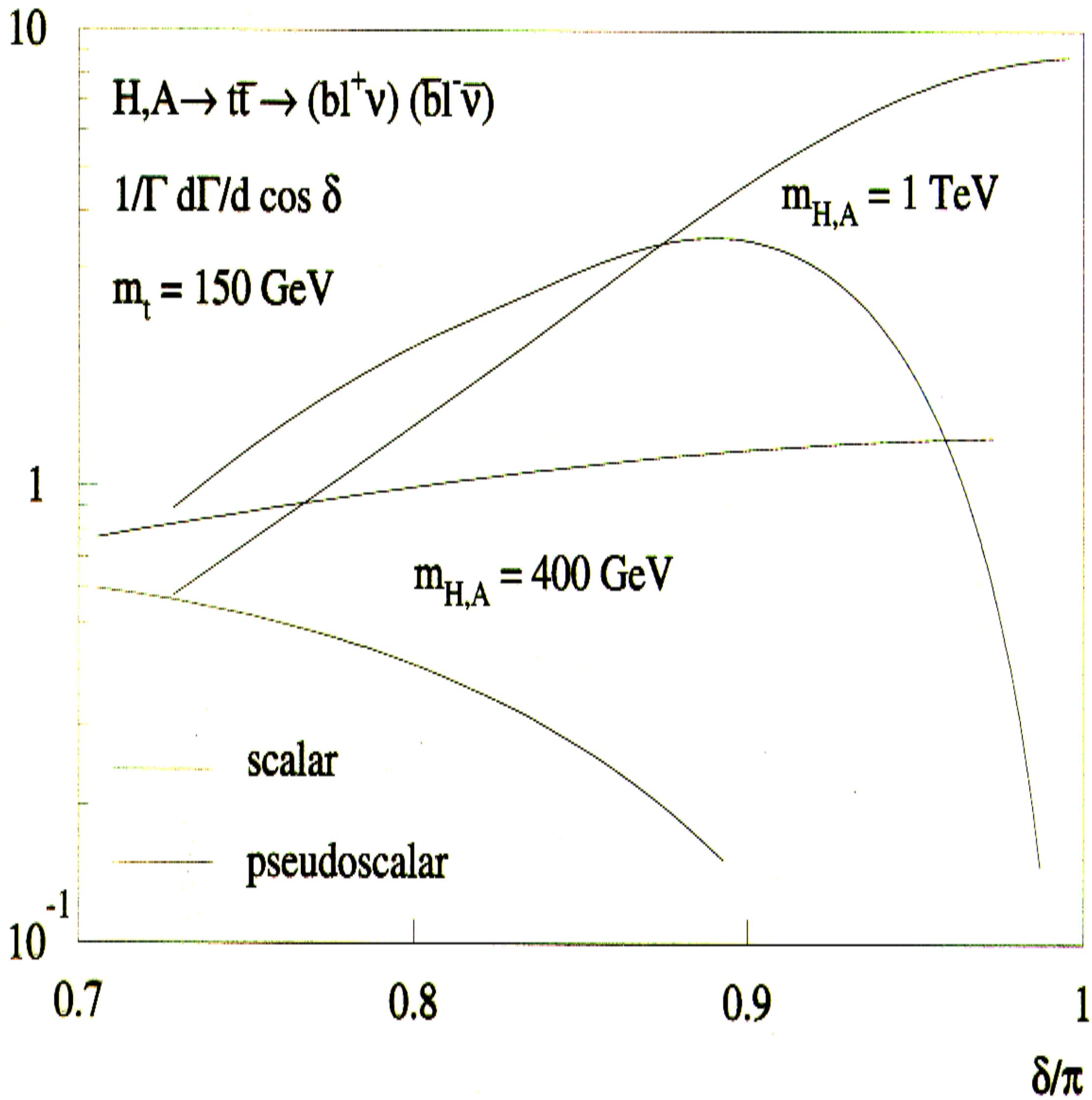
$$+ \frac{i}{2m_t} f_4^\alpha \sigma_{\mu\nu} \gamma_5 q^\nu)$$

, where $\alpha = \gamma, Z$

The f_4^α is the CP violating term. The best limit on the imaginary part of the electric dipole moment $Im(f_4^\gamma)$ is about 2.310^{-17} (P.Poulose and S.D.Rindani). It comes from A_{fb} with the initial-beam helicities of electron and laser beams $\lambda_e^1 = \lambda_e^2$ and $\lambda_l^1 = -\lambda_l^2$. The limit for the real part of the dipole moment is also of the order of 10^{-17} obtained from the linear polarization asymmetries (S.Choi and K.Hagiwara; M.Baek, S.Choi, C.Kim). One should stress the limit is better by an order of magnitude than that from 500 GeV e^+e^- collisions.

The top quark pair production in $\gamma\gamma$ collisions provide a very interesting option to study parity properties of the Higgs boson and CP violating effects

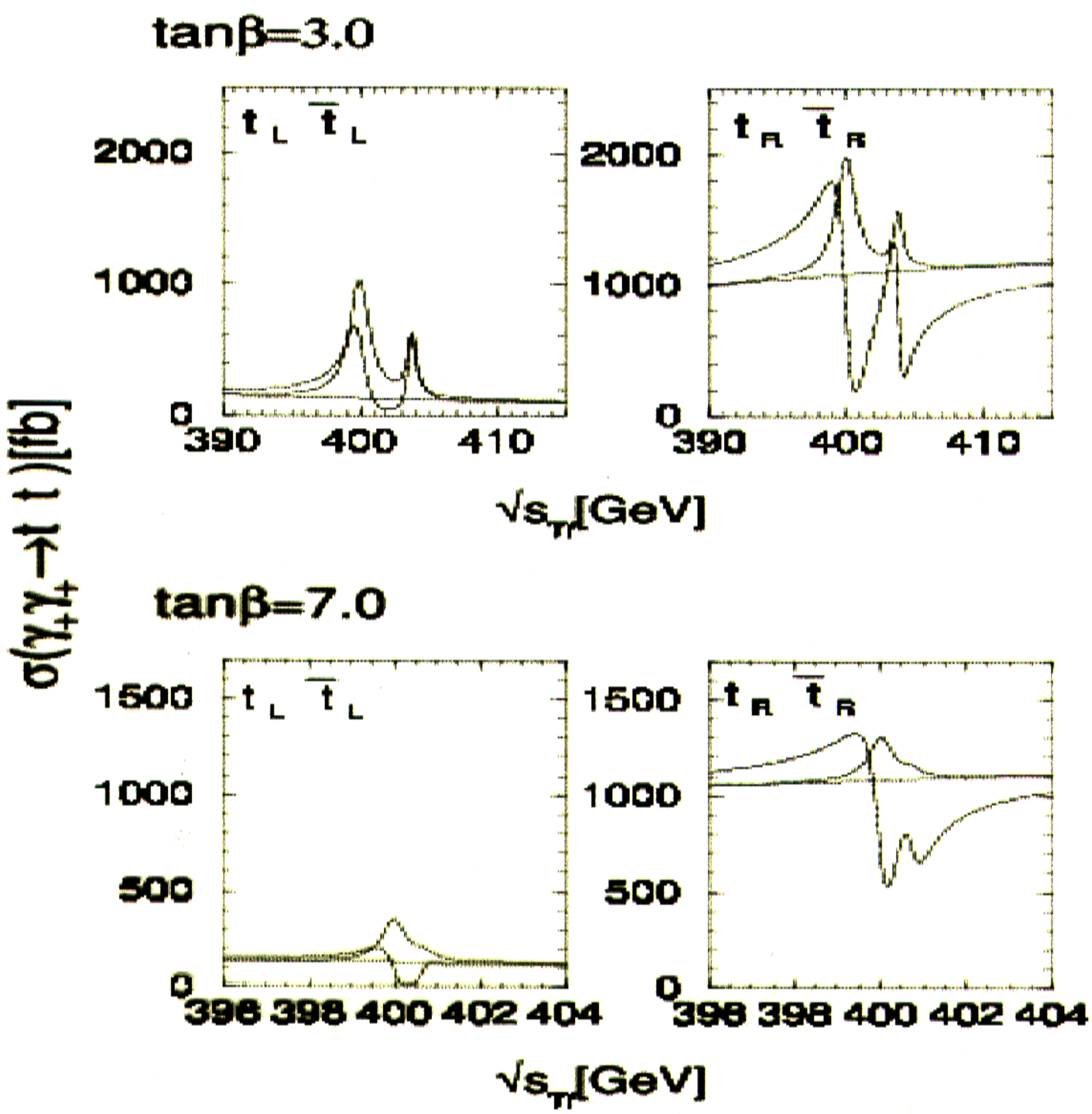
(M.Krämer, J.Kühn, M.Stong, P.Zerwas)



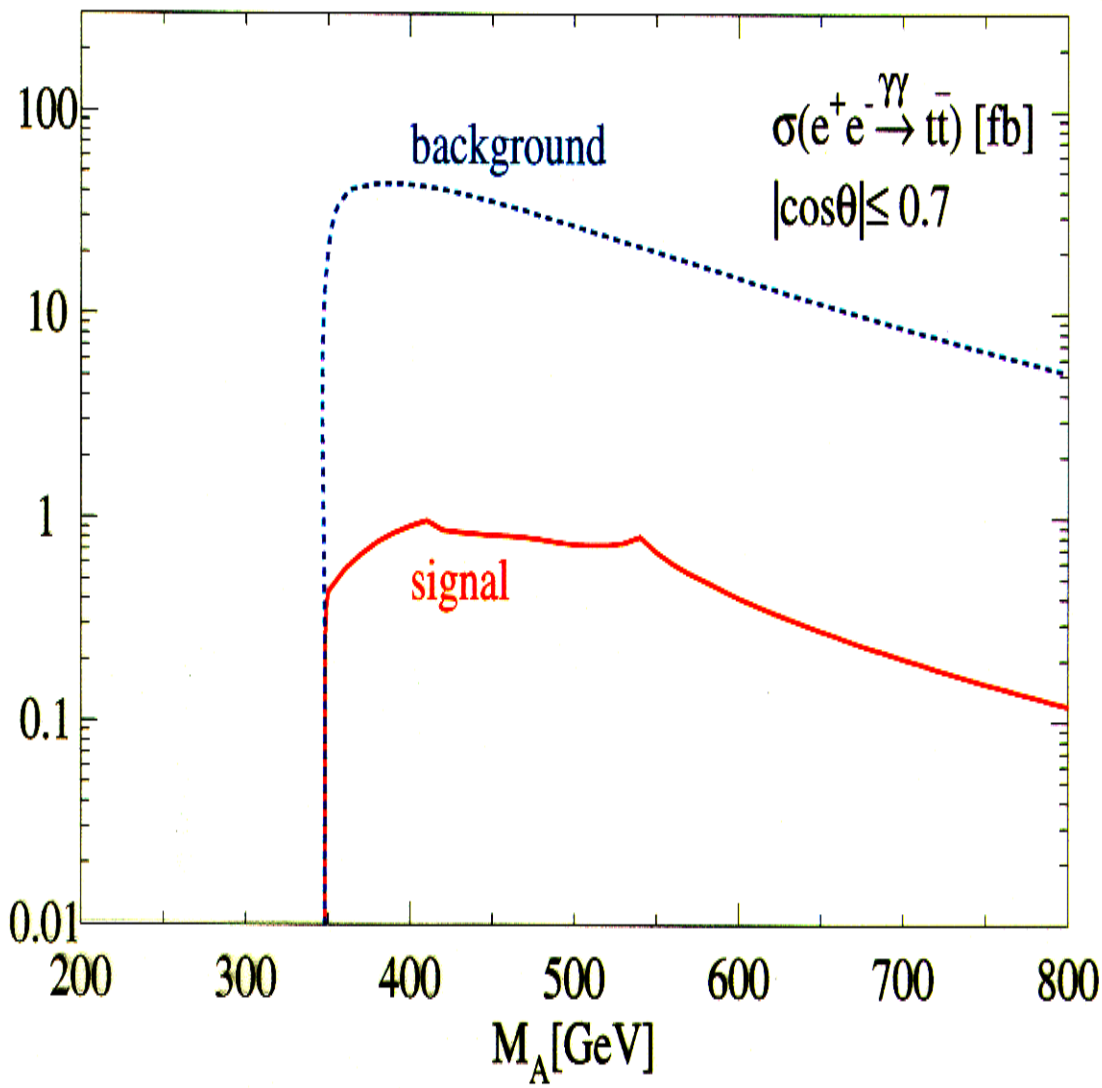
δ is the angle between charged leptons.

It was shown for the two-Higgs doublet model that there are several asymmetries which are sensitive for probing CP violation in the Higgs sector. (H.Anlauf, W.Bernreuter, A.Brandenburg; W.Bernreuter, A.Brandenburg, P.Overmann)

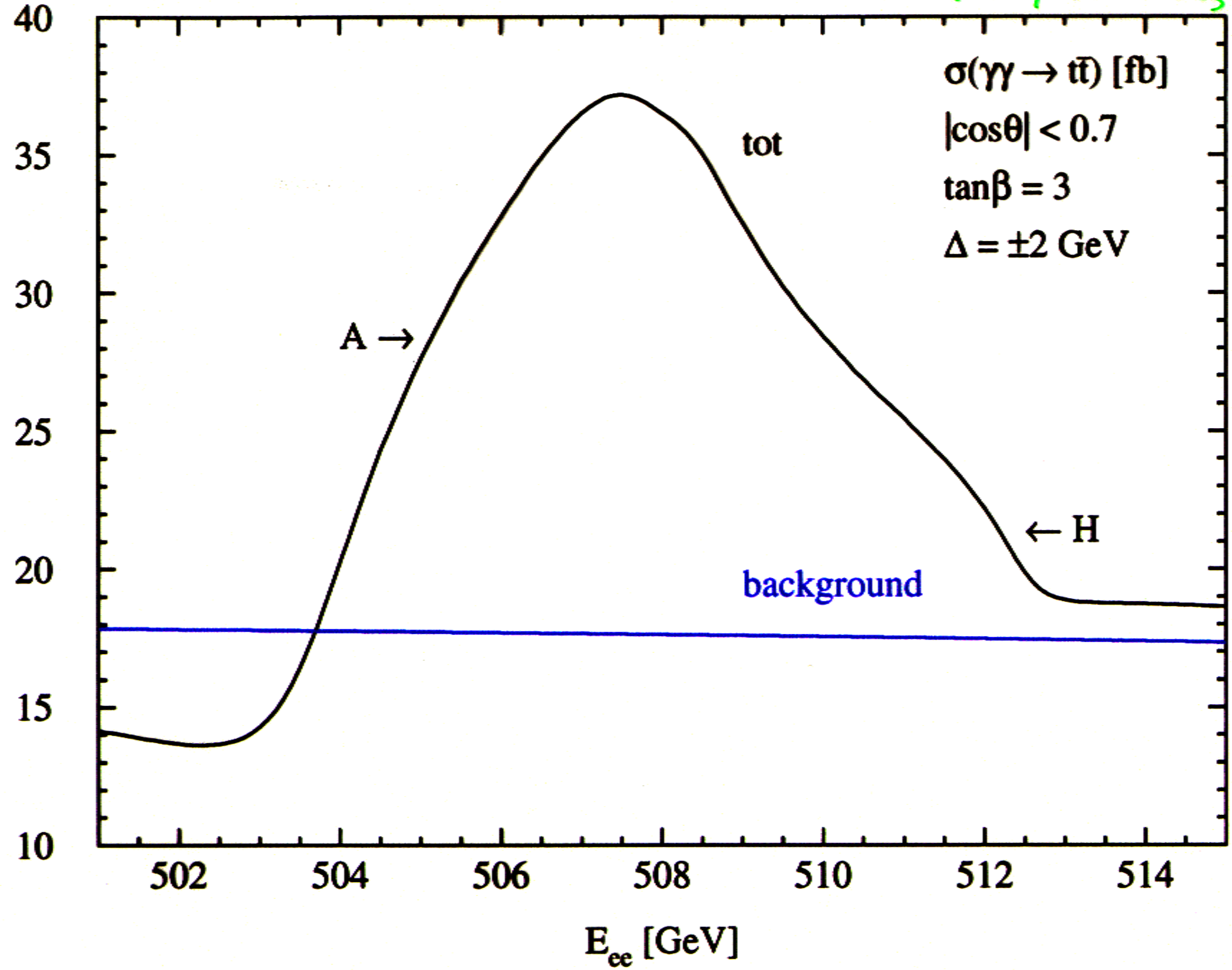
The problem is that there is an interference between H and A with a small mass gap. The recent obtained results on the subject (E.Asakawa, J.Kamoshita, A.Sugamoto)



The effect is less pronounce if the $tan(\beta)$ is increaing. An example for the case $tan(\beta)$=7 and a resolution for the $b\bar{b}$ invariant mass 10 GeV: (M.Muehlleitner, M.Spira, P.Zerwas)

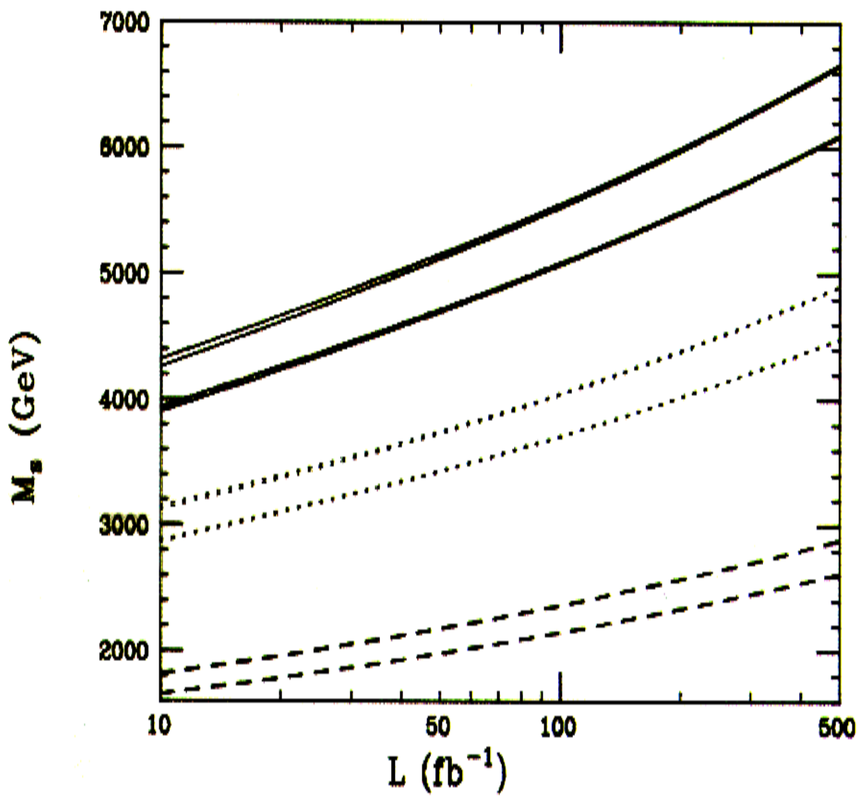


M. Kraemer, M. Mühlleitner,
M. Spira, P. Zerwas

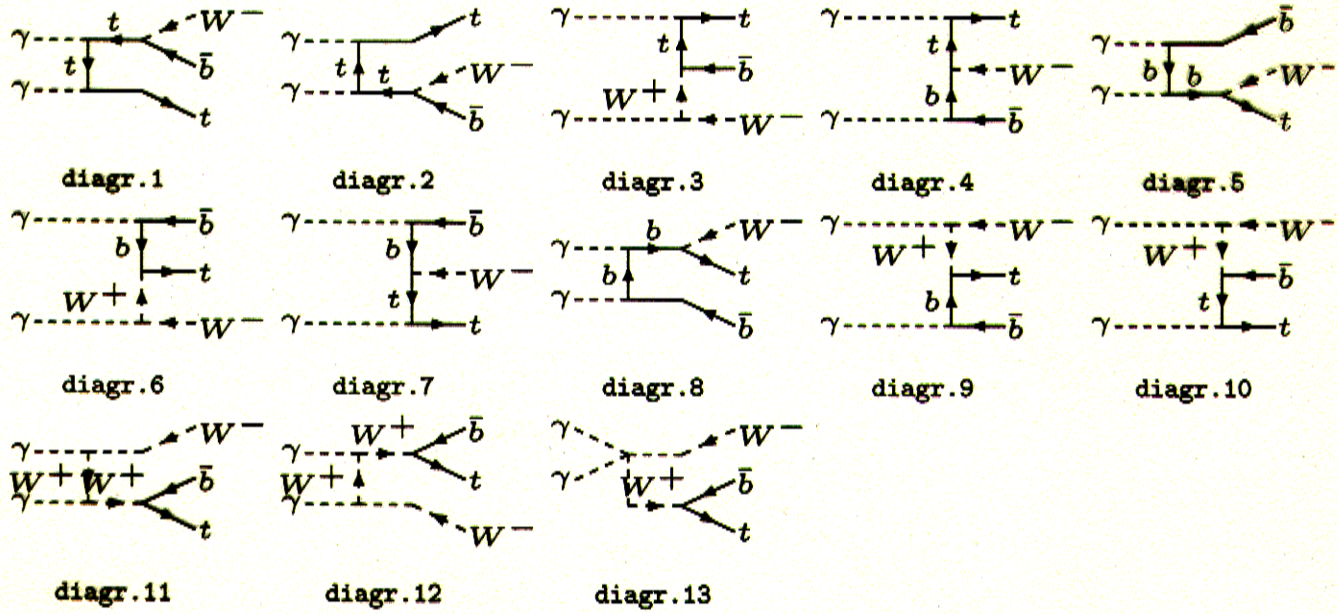


The $\gamma\gamma$ colliders will be comparable to the e^+e^- and e^-e^- in the search reach for large extra dimensions.

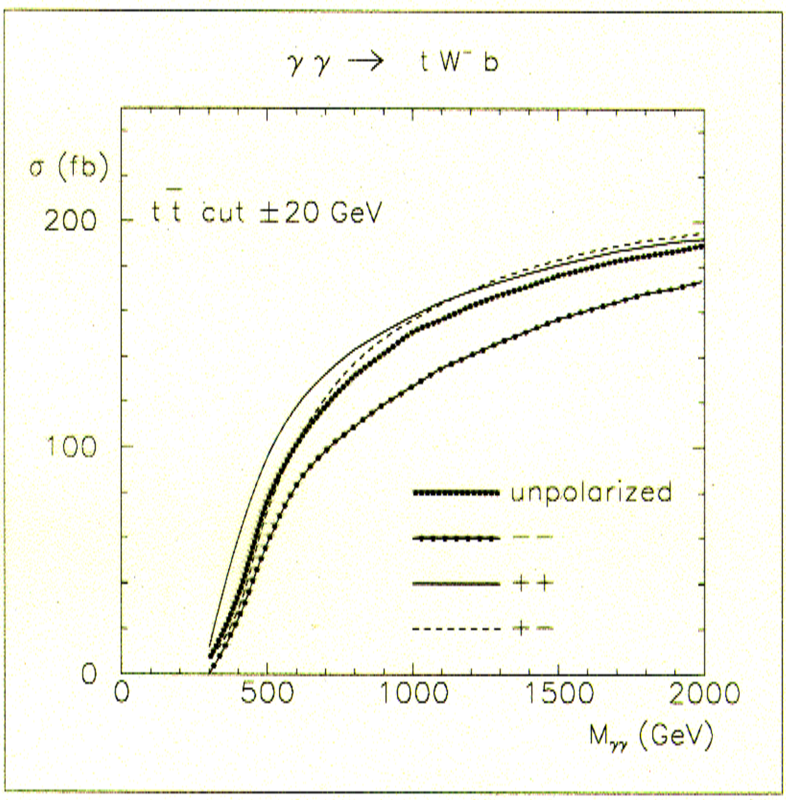
(T.Rizzo)



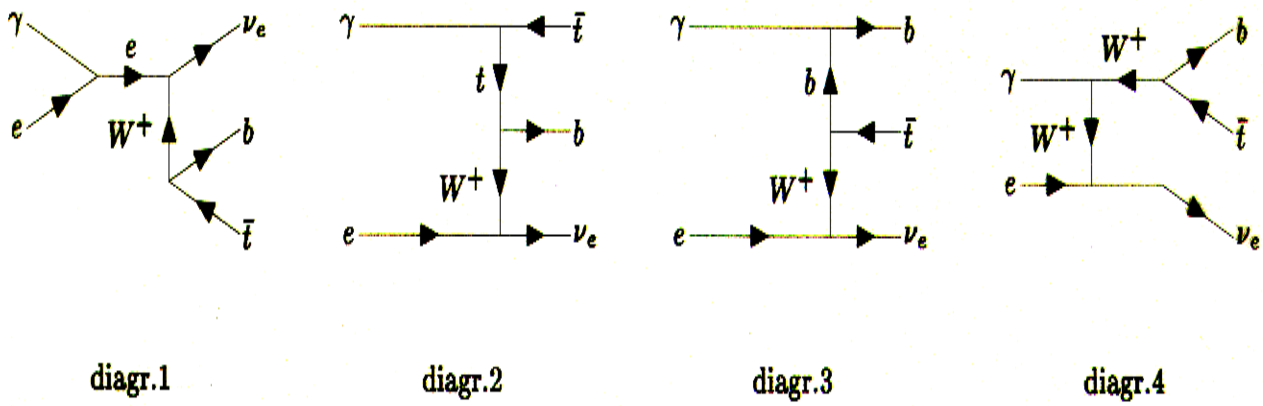
Single top in $\gamma\gamma$ collisions has the same final state like the top pair production. (Here a situation is similar to single top at the LHC in Wt mode (A.Belyaev, E.Boos)). The top pair rate has to be removed in order to get the correct single top rate.



(E.Boos, M.Dubinin, A.Pukhov, M.Sachwitz, H.J.Schreiber)

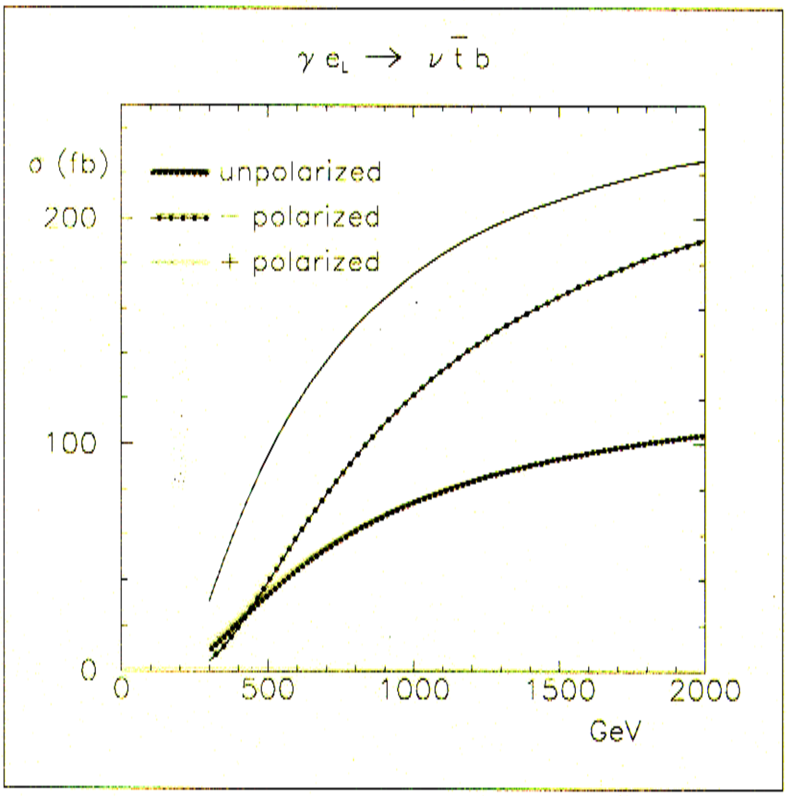


Single top in γe collisions



(E.Boos, A.Pukhov, M.Sachwitz, H.J.Schreiber; B.Young, X.Zhang et al)

(E.Boos, M.Dubinin, A.Pukhov, M.Sachwitz, H.J.Schreiber)



In contrast to the top pair production the single top rate is directly proportional to the Wtb coupling and therefore the process is very sinsitive to its structure.

$$\mathcal{L} = \frac{g}{\sqrt{2}}\Big[W_\mu^- \bar{b}(\gamma_\mu f_{1L} P_- + \gamma_\mu f_{1R} P_+)t - \frac{1}{2M_W} W_{\mu\nu}\bar{b}\sigma^{\mu\nu}(f_{2R}P_- + f_{2L}P_+)t\Big] + \text{h.c.} \quad (1)$$

where $W_{\mu\nu} = D_\mu W_\nu - D_\nu W_\mu, D_\mu = \partial_\mu - ieA_\mu, P_\pm = 1/2(1 \pm \gamma_5)$ and $\sigma^{\mu\nu} = i/2(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$.

$$f_{2L(R)} = \frac{C_{t(b)W\Phi}}{\Lambda^2}\frac{v\sqrt{2}m_W}{g}, \quad (2)$$

where Λ is the scale of new physics.

	F_2^L	F_2^R
Tevatron ($\Delta_{sys.} \approx 10\%$)	$-0.18 \div +0.55$	$-0.24 \div +0.25$
LHC ($\Delta_{sys.} \approx 5\%$)	$-0.052 \div +0.097$	$-0.12 \div +0.13$
γe ($\sqrt{s_{e^+e^-}} = 0.5$ TeV)	$-0.1 \div +0.1$	$-0.1 \div +0.1$
γe ($\sqrt{s_{e^+e^-}} = 2.0$ TeV)	$-0.008 \div +0.035$	$-0.016 \div +0.016$

Uncorrelated limits on anomalous couplings from measurements at different machines.

Single top quark production in $\gamma\gamma$ and γe collisions provides interesting possibilities to test FCNC radiative couplings and to study various predictions of Technicolor models.

$$L_{eff} = \frac{e}{\Lambda}(k_c \bar{t} \sigma \mu\nu c) F^{\mu\nu} + h.c.$$

k/Λ is expected to be constrained at the level of 0.12/TeV at the Tevatron with with 10 fb^{-1} and 0.01/TeV at the LHC with 100 fb^{-1}. At 500 GeV $\gamma\gamma$ collider one expects a limit for k/Λ about 0.05/TeV with 10 fb^{-1} luminosity. (K.Abraham, K.Whisnant, B.Young)

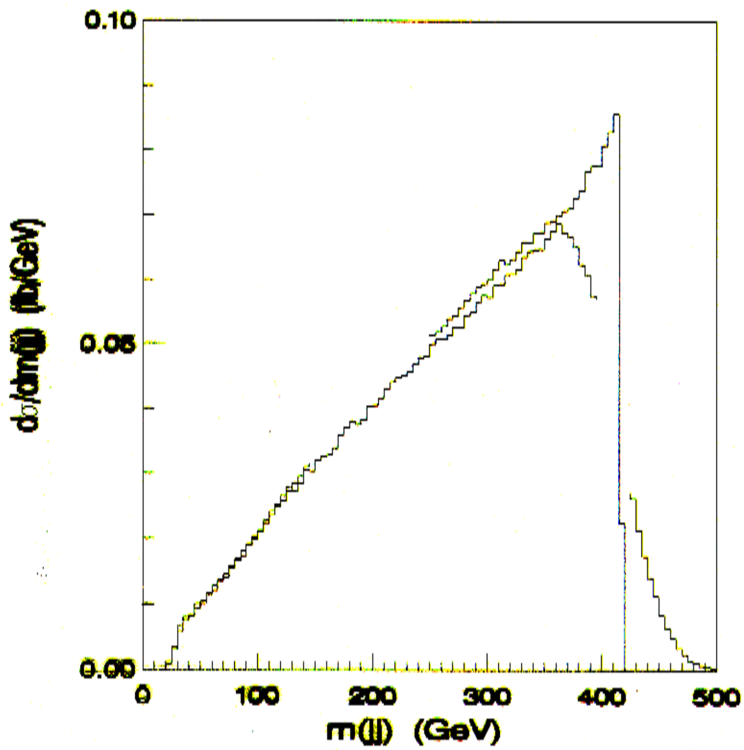
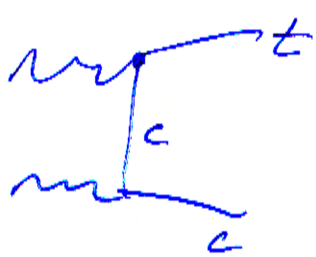


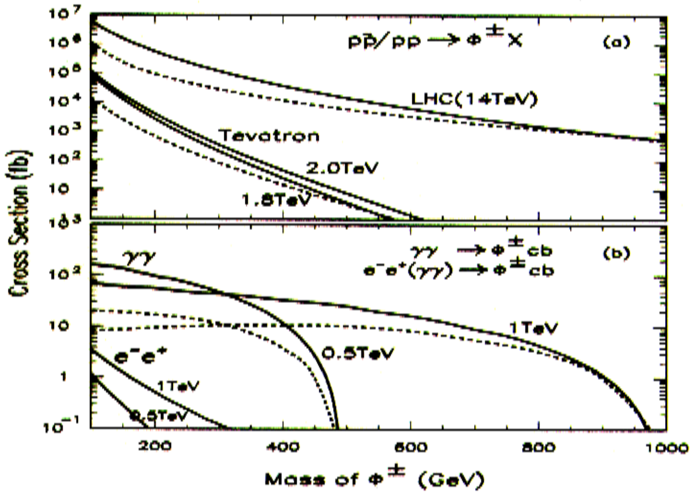
Fig. 1

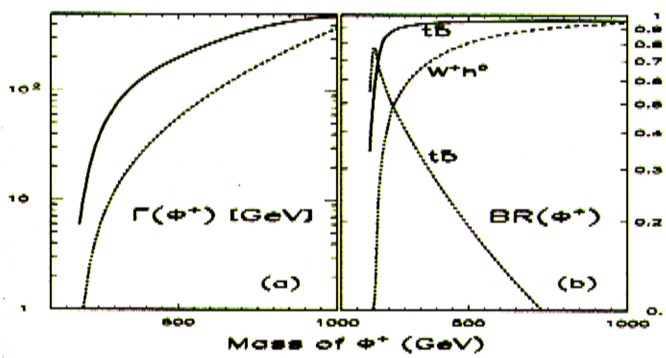


There are many variants on technicolor models. The detail predictions are normally model dependent. However, there are predictions like an existence of Charged (Pseudo-)Scalars which is sort of model independent. Several studies of that have been done for photon colliders. (X.Wang, Y.Kuang et al)

(H.-J.He, C.-P.Yuan)

Charm-Bottom Fusion at Colliders:
Production and Decay of Charged Scalar $\phi^{\pm}$





If there is a large flavor mixing between the right-handed top and charm quarks it leads to a a large Yukawa couplings of a charged (pseudo-)scalar with charm and bottom quarks. The domination decay mode in Topcolor models is $\phi^+ \to t\bar{b}$. So it gives the contribution to the single top production in $\gamma\gamma$ and γe collisions.

Concluding Remarks and Problems

- Top quarks could be produced all photon colliders in the top pair mode or singly. The production SM mechanisms are clean and simple. The SM cross section and distributions are known to the LO and in several cases to the NLO level.
- The Photon Linear Colliders provide a number of interesting options for a study of top quark physics which are comparable and in some cases even better than those at other colliders.
  - Top pair production rate is proportional to the coupling of top quark with photon in 4th power and therefore it is very sensitive to its structure and possible deviations from the SM.
  - Using various asymmetries one can uniquely study CP properties of the Higgs bosons and CP violating effective operators.
  - Single top quark production at high energy γe collider is the best collision option to study of a structure of the Wtb coupling.
  - Single top at photon colliders allows to study various effects predicted by technicolor models
- However one should stress that in general simulations of effects at photon colliders with top quarks are much less developed than for e^+e^- LC and for the hadron colliders Tevatron and LHC. Usually subsequent decays, jet fragmentation, a possible detector response as well as various background have been not included into simulations. An important point is to simulate correctly an influence of a real photon spectra. Much work is still needed to be done.