FEASIBILITY OF OBSERVING $\eta_t \rightarrow \gamma\gamma$ AT THE CERN $p\bar{p}$ COLLIDER

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ABSTRACT

In a recent paper the rate of η_t production by two-gluon fusion at the CERN $p\bar{p}$ Collider has been calculated. We find that the production cross-section has been overestimated by a factor of 64. For a top quark mass of $30 \text{ GeV}/c^2$ the revised calculation gives $\sigma \cdot B(\eta_t \rightarrow \gamma\gamma)$ in the range 0.038 to 0.146 pb.

This suggests that observation of the η_t decaying into two photons at the Collider is unlikely in the coming 1984/1985 data-taking periods.

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Observation of the two-photon decay mode of the 0^{-+} toponium state ($\eta_t \rightarrow \gamma\gamma$) would provide a clean way of confirming the existence of the top quark and measuring its mass. In the 1983 data-taking period the experiments at the CERN $p\bar{p}$ Collider received an integrated luminosity of $\sim 100 \text{ nb}^{-1}$. No event containing two energetic photons has been reported by the experiments. In the coming collider runs of 1984/1985, the experiments expect to receive a factor of ~ 10 more integrated luminosity. Furthermore, the recent evidence for the existence of events in which an isolated lepton has been produced in association with two hadronic jets [1] suggests the possible existence of a top quark in the mass range $30 \text{ GeV}/c^2$ to $50 \text{ GeV}/c^2$. It is therefore interesting to ask whether the increase in integrated luminosity expected in the near future will enable a few $\eta_t \rightarrow \gamma\gamma$ events to be recorded by the UA1 and UA2 experiments. A recent paper by Inazawa et al. [2] has computed the expected rate of $\eta_t \rightarrow \gamma\gamma$ events from gluon-gluon fusion for η_t masses of $60 \text{ GeV}/c^2$ and $80 \text{ GeV}/c^2$. At $\sqrt{s} = 540 \text{ GeV}$ and an η_t mass of $60 \text{ GeV}/c^2$, they predict a $\sigma \cdot B(\eta_t \rightarrow \gamma\gamma)$ in the range 1.54–6.98 pb. For a top quark mass of $30 \text{ GeV}/c^2$ this would imply the occurrence of several $\eta_t \rightarrow \gamma\gamma$ decays in each of the Collider experiments in the near future. However, the authors have made a normalization error in their calculation of the production cross-section, resulting in an overestimate of this cross-section by a factor of 64. Their calculation follows closely that of Einhorn and Ellis [3] for the production of the η_c in a colour singlet state by the fusion of two gluons. The basic expression they use is

$$\sigma = 8\pi^2 \frac{\Gamma(\eta_t \rightarrow gg)}{M_{\eta_t}^3} \tau \int_{\tau}^1 \frac{dx}{x} f(x) f(\tau/x) , \quad (1)$$

where $f(x)$ is the gluon structure function of the proton, and $\tau = M_{\eta_t}^2/s$. The width $\Gamma(\eta_t \rightarrow gg)$ is given by

$$\Gamma(\eta_t \rightarrow gg) = \left(\frac{8}{3} \alpha_s^2 / M_{\eta_t}^2 \right) 4\pi |\psi(0)|^2 , \quad (2)$$

where α_s is the strong coupling constant and $|\psi(0)|^2$ is the wave function at the origin of the η_t state. The width, which is for the decay of a colour singlet η_t

state, includes a sum over all gluon colours in the final state. Bearing this in mind, the appropriate normalization to use for the gluon structure functions for the production of a colour singlet state is

$$\int_0^1 xf(x) dx = \frac{g}{8} , \quad (3)$$

where g is the fraction of the momentum of the proton carried by the gluons ($g \sim 0.5$). The factor of 8 reflects the existence of 8 gluon species. The structure functions used by Inazawa et al. [2] are

$$\begin{aligned} xf(x) &= 3.30(1-x)^5 && \text{Ref. [4]} \\ xf(x) &= 0.74(1-x)^5/\sqrt{x} && \text{Ref. [5]} \\ xf(x) &= 1.10(1+9x)(1-x)^4 && \text{Ref. [6].} \end{aligned}$$

These structure functions are normalized such that

$$\int_0^1 xf(x) dx = 0.55 ,$$

i.e. a factor of 8 too large. This results in an overestimate of the η_t production cross-section by a factor of 64.

In the coming data-taking runs at the CERN $p\bar{p}$ Collider a modest increase in beam energy is anticipated. The centre-of-mass energy is expected to increase from $\sqrt{s} = 540$ GeV to $\sqrt{s} = 620$ GeV. We have therefore corrected the normalization error in the calculation of Ref. [2] and have redone the calculation for $\sqrt{s} = 620$ GeV. The results are given in table 1 for the three structure functions considered in ref. [2] and also for the UA1 parametrization⁹⁾ of the gluon structure function extracted from two-jet data at a Q^2 of ~ 2000 GeV²;

$$xf(x) = 0.87(1-x)^{11.6} .$$

Expression (3) has been used to give the normalization (taking $g = 0.55$), which is consistent (within 1 standard deviation) with the experimentally determined normalization of the structure function. We feel that it is appropriate to use the UA1 parametrization of the gluon structure function, not only because it is extracted from the experimental data, but also because the Q^2 scale for which it has been

determined is $O(m_t^2)$ for the range of η_t masses under consideration. We have calculated $\sigma \cdot B(\eta_t \rightarrow \gamma\gamma)$ for three top quark masses ($m_t = 30 \text{ GeV}/c^2$, $40 \text{ GeV}/c^2$, and $50 \text{ GeV}/c^2$) spanning the range indicated by the collider data. In addition to results for $\sqrt{s} = 620 \text{ GeV}$, we also present in table 1 predictions for $\sqrt{s} = 2000 \text{ GeV}$.

In conclusion, the gluon-gluon fusion cross-section for η_t production and subsequent decay into two photons does not appear to be large enough to be observable in the coming collider run with an expected integrated luminosity of $\sim 1000 \text{ nb}^{-1}$.

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Table 1

The total cross-section $\sigma \cdot B(\eta_t \rightarrow \gamma\gamma)$ for η_t production
by gluon-gluon fusion in $p\bar{p}$ collisions
for top quark masses $m_t = 30, 40$, and $50 \text{ GeV}/c^2$

f(x) from ref.	Values of $ \psi(0) ^2$ from*)	$\sigma \cdot B(\eta_t \rightarrow \gamma\gamma)$ (pb)					
		$\sqrt{s} = 620 \text{ GeV}$			$\sqrt{s} = 2000 \text{ GeV}$		
		$m_t = 30^{**})$	$m_t = 40$	$m_t = 50$	$m_t = 30$	$m_t = 40$	$m_t = 50$
[4]	case (a)	0.116	0.027	0.008	0.401	0.128	0.051
	case (b)	0.071	0.018	0.006	0.248	0.085	0.038
	case (c)	0.146	0.040	0.013	0.504	0.186	0.083
[5]	case (a)	0.061	0.011	0.003	0.686	0.163	0.052
	case (b)	0.038	0.007	0.002	0.422	0.109	0.039
	case (c)	0.077	0.016	0.004	0.861	0.238	0.084
[6]	case (a)	0.069	0.022	0.009	0.112	0.041	0.018
	case (b)	0.043	0.015	0.007	0.069	0.027	0.014
	case (c)	0.087	0.033	0.014	0.140	0.059	0.030
[9]	case (a)	0.097	0.014	0.002	0.874	0.240	0.083
	case (b)	0.059	0.009	0.002	0.539	0.160	0.062
	case (c)	0.121	0.021	0.004	1.099	0.350	0.135

*) The results are presented, for $m_t = 30 \text{ GeV}/c^2$, $(40 \text{ GeV}/c^2)$, and $[50 \text{ GeV}/c^2]$,
using the following values of M_{η_t} and $4\pi|\psi(0)|^2$ from refs. [7] and [8]:

case (a)	$M_{\eta_t} = 58.759 (78.597) [98.462] \text{ GeV}/c^2$ $4\pi \psi(0) ^2 = 164.18 (280.20) [424.69] \text{ GeV}^3$	From ref. [7]
case (b)	$M_{\eta_t} = 59.026 (78.899) [98.793] \text{ GeV}/c^2$ $4\pi \psi(0) ^2 = 104.15 (191.35) [322.69] \text{ GeV}^3$	From ref. [8] with $\Lambda_{\overline{\text{MS}}} = 0.2 \text{ GeV}$
case (c)	$M_{\eta_t} = 58.818 (78.610) [98.428] \text{ GeV}/c^2$ $4\pi \psi(0) ^2 = 207.57 (408.62) [684.62] \text{ GeV}^3$	From ref. [8] with $\Lambda_{\overline{\text{MS}}} = 0.5 \text{ GeV}$

**) Top quark mass in GeV/c^2 .