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τ PAIR PHOTOPRODUCTION CROSS SECTION*

Yung Su Tsai
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

The τ pair photoproduction cross sections from proton and Be targets are tabulated. The charm photoproduction cross section is also estimated.

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In this note we present the results of the calculation for the total τ pair photoproduction cross section from proton and Be targets as a function of incident photon energy. This note is an addendum to my Review of Modern Physics paper[1] entitled "Pair Production and Bremsstrahlung of Charged Leptons" in which I presented the calculation of the cross section for photo pair production of leptons with masses $M_L = 0.5, 1.0, 2.0, 4.0, 6.0, 10.0, 15.0$ and 20.0 GeV. Since the existence of τ is well established now[2] and its mass is now known to be[3] $M_\tau = 1.782 \pm {}^{3}_{4}$ GeV, we calculate the cross section using the correct mass.[4]

Smith, Soni and Vermaseren[5] have computed the τ photoproduction in the energy range from $E_\gamma = 50$ to 200 GeV using $M_\tau = 1.8$ GeV. The energy range covered in this note is from 20 GeV to 10^4 GeV. As will be shown later the charm production cross section is four order of magnitude higher than the τ production cross section and hence the photoproduction of τ is essentially only of academic interest. The purpose of this note is to give experimentalists something to refer to about this fact when they design an experiment to search for charm, bottom, top, $W^\pm$ or Z particles.

In Table I, we tabulate the numerical values of the cross sections for the following four processes:

1. $\gamma + p \rightarrow \tau^+ + \tau^- + p$ Labeled proton elastic
2. $\gamma + p \rightarrow \tau^+ + \tau^- + X\ (\neq p)$ Labeled proton inelastic
3. $\gamma + n \rightarrow \tau^+ + \tau^- + n$ Labeled neutron elastic
4. $\gamma + n \rightarrow \tau^+ + \tau^- + X\ (\neq n)$ Labeled neutron inelastic .

In Fig. 1, the curve labeled σ $(\gamma + p \rightarrow \tau^+ + \tau^- + \text{anything})$ represents the sum of the first two cross sections and the curve labeled σ $(\gamma + n \rightarrow \tau^+ + \tau^- + \text{anything})$ represents the sum of the last two cross sections. In Table II, we tabulate the cross sections for photo pair production of τ from the Be target. The total cross section given in the last column is the sum of three sub cross sections shown in the same table. The total cross section from Be is also plotted in Fig. 1. The basic formula used for the calculation is given by Eq. (2.7) of Ref. 1. The target form factors used in each subprocess are as follows:

1. Proton Elastic $(\gamma + p \rightarrow \tau^+ + \tau^- + p)$ and Neutron Elastic $(\gamma + n \rightarrow \tau^+ + \tau^- + n)$. The target form factors used for these two processes are given by Eq. (B.44) of Ref. 1.

2. Proton Inelastic $(\gamma + p \rightarrow \tau^+ + \tau^- + X\ (\neq p))$ and Neutron Inelastic $(\gamma + n \rightarrow \tau^+ + \tau^- + X\ (\neq n))$. Instead of the parametrization of Suri and Yennie used in Ref. 1, we used the following parametrizations.[6] For the inelastic proton form factors we used

$$W_{2p} = (1-x)^3\left[0.6453 + 1.902(1-x) - 2.343(1-x)^2\right]/\nu \quad ,$$

where $\nu = (m_f^2 - m_p^2 - q^2)/2$, $x = q^2/(q^2 - m_f^2)$ and m_f is the invariant mass of the final state of the target system (see Ref. 1), and $W_{1p} = 0.2W_{2p}$. For the inelastic neutron form factor we use

$$W_{2n} = \left[0.45 + 0.55 \exp(-6.5x)\right] W_{2p}$$

and

$$W_{1n} = 0.2W_{2n} \quad .$$

3. Be Coherent $(\gamma + \text{Be} \rightarrow \tau^+ + \tau^- + \text{Be})$. We use Eq. (B.49) of Ref. 1 as the elastic form factor of the Be nucleus.

4. Be Quasielastic ($\gamma + Be \rightarrow \tau^+ + \tau^- + \text{nuclei}\ (\neq Be)$). For quasielastic form factors we use Eqs. (B.52) and (B.53) of Ref. 1 in which the Be nucleus was approximated by a free Fermi gas of nucleons. In general this cross section is somewhat smaller than $Z\sigma(\gamma + p \rightarrow \tau^+ + \tau^- + p) + (A-Z)\sigma(\gamma + n \rightarrow \tau^+ + \tau^- + n)$ because of the suppression due to the Pauli principle. For Be, Z is 4 and A is 9.

5. Be Mesonic Final States ($\gamma + Be \rightarrow \tau^+ + \tau^- + \text{mesons} + \text{baryons}$). This cross section was obtained by Z × "proton inelastic" + (A-Z) × "neutron inelastic".

The total cross section for $\gamma + p \rightarrow \tau^+ + \tau^- + \text{anything}$ is around 10^{-35} to 10^{-33} cm^2 depending upon the energy as shown in Fig. 1. This cross section is roughly four order of magnitude smaller than the photoproduction of charm particles from a proton. The latter cross section can be estimated[7] from the former by observing the following: (i) τ particle and charmed particles (D, F, and Λ_c, etc.) have roughly the same mass hence the phase spaces for the two reactions are roughly equal, and (ii) one photon exchange between τ and the proton target can be replaced by one gluon exchange in the charm production. Using these two observations the ratio of the two cross section can be estimated to be

$$R = \frac{\sigma(\gamma + p \rightarrow \text{charm})}{\sigma(\gamma + p \rightarrow \tau^+ + \tau^- + \text{anything})} = \frac{22}{27}\left(\frac{\alpha_s(\overline{q^2})}{\alpha}\right)^2$$

where $\alpha \sim 1/137$ is the electromagnetic coupling constant and $\alpha_s(\overline{q^2})$ is the similar constant for gluon-quark coupling evaluated at some mean momentum transfer $\overline{q^2}$. The factor 22/27 comes from a product of three factors: $22/27 = (2/3)^2 \times 3 \times (11/18)$, where 2/3 is the charge of c quark, 3 is the number of quarks inside a proton and 11/18 is due to color degree of freedom.[8] Assuming $\alpha_s \approx 1$ we obtain $R = 1.5 \times 10^4$ and thus the cross section for $\gamma + p \rightarrow$ charm is ~0.9 μb at $k = 80$ GeV and 2.1 μb at $k = 160$ GeV according to Fig. 1. We have gone into photoproduction of charmed particles in some detail because the lifetime of τ is expected to be[9] 2.5×10^{-13} sec and its existence can be ascertained only through the properties of its decay products and they are usually overwhelmed by the decay products of charmed particles according to our calculation.

Note added in the revised version:

The cross section for the process $\gamma + N \rightarrow D^o + \bar{D}^o +$ anything has been reported by M. S. Atiya *et al.*[10] recently. They gave the cross section $\sigma(\gamma N \rightarrow D^o\bar{D}^o$ + anything) = 720 ± 290 nb using the wide band photon spectrum of FNAL which has roughly the shape $dN_\gamma/dE_\gamma \propto \exp(-E_\gamma/52\ \mathrm{GeV})$ with the maximum photon energy of around 250 GeV. This can be translated into $\sigma(\gamma N \rightarrow \mathrm{charm}) \approx 1.5$ μb at $E_\gamma = 100$ GeV, which agrees with our estimate.

ACKNOWLEDGEMENT

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REFERENCES

1. Y. S. Tsai, Rev. Mod. Phys. 46, 815 (1974), Erratum 49, 421 (1977).

2. See for example: M. L. Perl, Nature 275, 273 (1978), and G. J. Feldman, Proc. of the 19th International Conference on High Energy Physics in Tokyo (1978).

3. W. Bacino et al., Phys. Rev. Lett. 41, 13 (1978).

4. We use $M_\tau = 1.8$ GeV in our calculation.

5. J. Smith, A. Soni and J. A. M. Vermaseren, Phys. Rev. 15D, 648 (1977).

6. W. Atwood, private communication.

7. Two different methods have been used previously to estimate the cross section for the photoproduction of charmed particles. One uses the vector dominance model and the other gluon-photon annihilation model. Our method is a variation of the latter. The references on this subject can be found in the review article: T. Applequist, R. M. Barnett and K. Lane, Annu. Rev. Nucl. Part. Sci. 28, 387 (1978).

8. Let the gluon quark-quark coupling be $gA^a_\mu \bar{q}_i \gamma_\mu T^a_{ik} q_k$, where $a = 1,\ldots,8$ and $i,k = 1,2,3$ and $g^2/4\pi \equiv \alpha_s$. Then in the reaction $\gamma + q \to \bar{c} + c + q$ the averaging over the initial color and summing over the final color yield $(1/3)\sum_{i=1}^{3}\sum_{k=1}^{3}\left(\sum_{a=1}^{8} T^a_{ik}\, T^a_{ki}\right)^2 = 11/18$.

9. Y. S. Tsai, Phys. Rev. 4D, 2821 (1971), also Y. S. Tsai SLAC-PUB-2105 (1978) (unpublished).

10. M. S. Atiya et al., Phys. Rev. Lett. 43, 414 (1979).

Table I. Cross sections for photo pair production of τ from proton and

γ Energy (GeV) in Lab System	Proton Elastic $\gamma + p \to \tau^+ + \tau^- + p$	Proton Inelastic $\gamma + p \to \tau^+ + \tau^- + X$ ($\neq p$)	Neutron Elastic $\gamma + n \to \tau^+ + \tau^- + n$
20	1.46 D-36*	1.33 D-37	5.96 D-37
40	1.27 D-35	3.76 D-36	3.70 D-36
80	4.11 D-35	1.95 D-35	7.66 D-36
160	9.00 D-35	5.17 D-35	1.08 D-35
320	1.58 D-34	9.57 D-35	1.29 D-35
640	2.39 D-34	1.44 D-34	1.42 D-35
1000	2.96 D-34	1.73 D-34	1.47 D-35
10000	5.98 D-34	2.63 D-34	1.55 D-35

* D-36 means 10^{-36}

Table II. Cross sections for photo pair production of τ from Be.

γ Energy (GeV) in Lab System	Be Coherent $\gamma + Be \rightarrow \tau^+ + \tau^- + Be$	Be Quasielastic (No Mesons) $\gamma + Be \rightarrow \tau^+ + \tau^- +$ nuclei ($\neq$ Be)	Be Mesoni Final Stat $\gamma + Be \rightarrow \tau^+ +$ mesons + bar
20	1.03 D-36	8.83 D-36	9.05 D-37
40	1.32 D-35	6.60 D-35	2.54 D-35
80	9.14 D-35	1.72 D-34	1.35 D-34
160	3.58 D-34	3.02 D-34	3.64 D-34
320	9.21 D-34	4.29 D-34	6.91 D-34
640	1.79 D-33	5.36 D-34	1.06 D-33
1000	2.50 D-33	5.91 D-34	1.30 D-33
10000	5.81 D-33	7.28 D-34	2.14 D-33

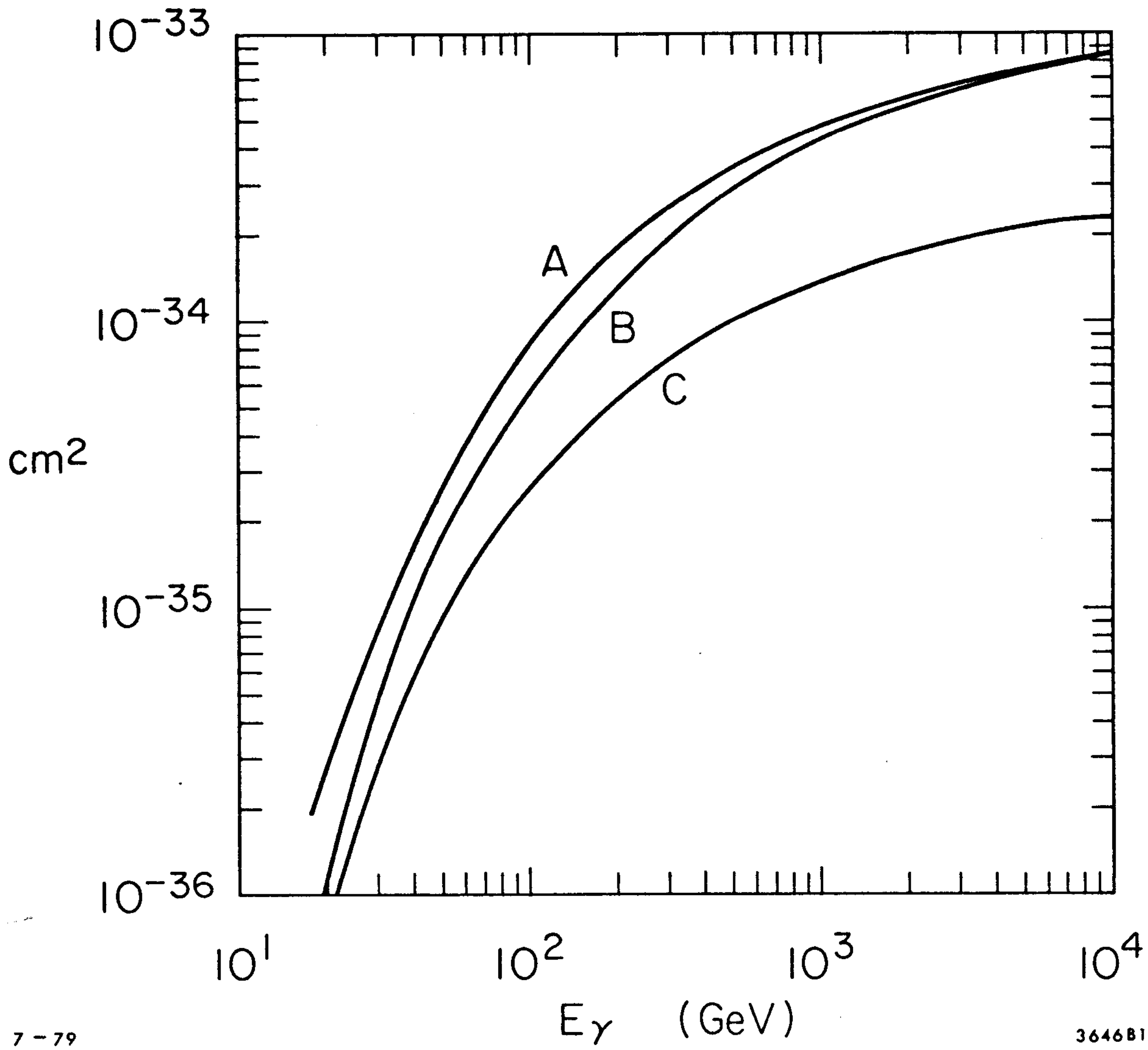
FIGURE CAPTION

Fig. 1. Total cross sections for the photo pair production of τ.

Curve A: $\sigma(\gamma + p \to \tau^+ + \tau^- + \text{anything})$.

Curve B: $0.1 \times \sigma(\gamma + \text{Be} \to \tau^+ + \tau^- + \text{anything})$.

Curve C: $\sigma(\gamma + n \to \tau^+ + \tau^- + \text{anything})$.



10^{-33}
10^{-34}
10^{-35}
10^{-36}
cm^2
A
B
C
10^1
10^2
10^3
10^4
E_γ (GeV)
7 - 79
3646B1

Fig. 1