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Heavy Quark Photoproduction in Ultra-peripheral Heavy Ion Collisions*

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In ultra-peripheral heavy ion collisions, heavy quarks can be produced in electromagnetic or hadronic interactions. Electromagnetic production occurs through strong electromagnetic fields which can interact with a target nucleus in the opposing beam (photoproduction) or with the electromagnetic field of the opposing beam (two-photon reactions) and produce hadronic final states, including heavy quark pairs. Hadroproduction of heavy quark pairs is also possible in grazing interactions. Since photon emission is coherent over the entire nucleus and because the photon is colorless, the three channels can be distinguished by the presence of zero, one or two rapidity gaps in the events and by whether or not the nuclei dissociate.

Photoproduction of heavy quarks occurs when a photon emitted from one nucleus fuses with a gluon from the other nucleus, "direct" production. The photon can also fluctuate into a state with multiple $q\overline{q}$ pairs and gluons, *i.e.* $|n(q\overline{q})m(g)\rangle$, which can interact with a quark or gluon from the target nucleus, "resolved" production. Direct photoproduction proceeds by

$$\gamma(k) + N(P_2) \to Q(p_1) + \overline{Q}(p_2) + X \tag{1}$$

where k is the photon 4-mometum, P_2 is the nucleon 4-momentum and p_1 and p_2 are the 4-momenta of the produced heavy quarks. On the parton level, the leading order (LO) reaction is

$$\gamma(k) + g(x_2P_2) \to Q(p_1) + \overline{Q}(p_2) \tag{2}$$

where x_2 is the fraction of the target momentum carried by the gluon. On the parton level, the resolved LO reactions are

$$\begin{aligned} g(xk) + g(x_2P_2) &\to Q(p_1) + \overline{Q}(p_2) & (3)\\ q(xk) + \overline{q}(x_2P_2) &\to Q(p_1) + \overline{Q}(p_2)\ , & (4) \end{aligned}$$

where x is the fraction of the photon momentum carried by the partons in the photon. The photon flux is exponentially suppressed for $k > \gamma_L \hbar c/R_A$. The maximum γN center of mass energy, $\sqrt{S_{\gamma N}}$, is then much lower than the hadronic $\sqrt{S}$.

Hadroproduction of heavy quarks in heavy ion collisions has been considered previously. Heavy quarks are produced via the reaction

$$N(P_1) + N(P_2) \to Q(p_1) + \overline{Q}(p_2) + X\ . \tag{5}$$

The LO parton reactions are

$$\begin{aligned} g(x_1P_1) + g(x_2P_2) &\to Q(p_1) + \overline{Q}(p_2) & (6)\\ q(x_1P_1) + \overline{q}(x_2P_2) &\to Q(p_1) + \overline{Q}(p_2)\ . & (7) \end{aligned}$$

Heavy quark pairs can also be produced in purely electromagnetic photon-photon collisions. In ion colliders the cross sections are enhanced since the $\gamma\gamma$ luminosity increases as Z^4. The two-photon center of mass energy, $\sqrt{S_{\gamma\gamma}}$, is a factor of $(\hbar c/m_p R_A)^2$ smaller than $\sqrt{S}$, a factor of 10^{-3} for gold or lead. Thus the rates in the $\gamma\gamma$ channel will be much lower than the other channels. As in photoproduction, there are also direct,

$$\gamma(k_1) + \gamma(k_2) \to Q(p_1) + \overline{Q}(p_2)\ , \tag{8}$$

and resolved contributions. Either one,

$$\gamma(k_1) + g(xk_2) \to Q(p_1) + \overline{Q}(p_2)\ , \tag{9}$$

or both

$$\begin{aligned} g(x_1k_1) + g(x_2k_2) &\to Q(p_1) + \overline{Q}(p_2) & (10)\\ q(x_1k_1) + \overline{q}(x_2k_2) &\to Q(p_1) + \overline{Q}(p_2)\ , & (11) \end{aligned}$$

of the photons can resolve itself into partons.

To study ultra-peripheral heavy quark production, it is necessary to be able to disentangle the three channels. Photoproduction, hadroproduction, and two-photon interactions may be separated on the basis of overall event characteristics. The signatures that can be used to distinguish between production processes are whether there are rapidity gaps in the event and whether the nuclei break up. Nuclear breakup can be measured with downstream ZDCs.

The hadroproduction cross section is the largest, followed by photoproduction and two-photon interactions: $\sigma_{AA\to Q\overline{Q}} \geq \sigma_{\gamma A\to Q\overline{Q}} \gg \sigma_{\gamma\gamma\to Q\overline{Q}}$. Using the characteristics of rapidity gaps and nuclear breakup, photoproduction and two-photon processes may be experimentally separable.

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