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Peripheral Production of Fermion Pairs in Heavy-Ion Collisions

Recently several groups have made estimates of the Higgs-boson production rate in heavy-ion collisions in which there is no strong interaction, but rather the heavy ions emit a pair of virtual photons which collide and materialize as the Higgs boson.[1, 2, 3, 4, 5, 6, 7] Such processes were first considered by Landau and Lifshitz in 1934.[8] The cross section varies as Z^4, so the rates can be quite large for heavy ions.

Here we estimate the rates for the production of various fermion-antifermion pairs, which were considered only as backgrounds in Refs. [1-7] (except for Ref. [4]). Such pairs would be produced in a collision in which the heavy ions remain intact, and go down the beam pipes. That is, pair production by virtual photons in heavy-ion collision is as clean as pair production in an e^+e^- collider. One would devise a veto on any forward tracks outside the beam pipes to reject the unwanted hadronic interactions. If the rates are high enough, a heavy-ion collider could be the most favored source of heavy-quark pairs in the future.

The Landau and Lifshitz cross section, as improved by Racah,[9] for production of a pair of fermions each of charge q and mass m in a collision of a pair of heavy ions each of charge Z and γ per nucleon in the center-of-mass frame is

$$\sigma_{\rm LL} = \frac{28}{27\pi} Z^4 q^4 \alpha^2 r_e^2 \left(\frac{m_e}{m}\right)^2 (A^3 - 6.36A^2 + 15.7A - 13.8),$$

where r_e is the classical electron radius, and $A = \ln 4\gamma^2$. From this expression, rather large rates are predicted at RHIC and the SSC, where $\gamma = 100$ and 8000 per nucleon, respectively. However, the Landau-Lifshitz calculation is based on a model of nuclei as point charges, which overestimates the actual effect for large masses of the produced particles.

Here we follow the prescription of Ref. [3] to include a model of the nuclear eleastic form factor:

$$\sigma_{ZZ\to ZZf\bar f} = Z^4 \int dx_1 dx_2 F(x_1) F(x_2) \sigma_{\gamma\gamma\to f\bar f}(x_1 x_2 s).$$

In this, s is the square of the center-of-mass energy of the heavy ion collision, and x is the fraction of the energy of a heavy ion that is taken by the virtual photon. The equivalent-photon spectrum of the field of a Pb_{82}^{206} nucleus is taken from [3] as

$$F(x) = \frac{\alpha}{\pi}\left[-\frac{\exp(-x^2M^2/Q_0^2)}{x} + \left(\frac{1}{x} + \frac{x^2M^2}{Q_0^2}\right)\mathrm{Ei}(x^2M^2/Q_0^2)\right],$$

where M is the mass of the nucleus, $Q_0 \approx 60$ MeV, and $\mathrm{Ei}(x)$ is the exponential integral $\int_x^\infty (e^{-t}/t)dt$. The spectrum $F(x)$ falls rapidly with increasing x to 10^{-4} of its peak value at $x = 4 \times 10^{-4}$, beyond which F falls extremely rapidly.

The cross section for fermion-pair production by light was first calculated by Breit and Wheeler.[10] We take the cross section from eq. (13-40) of Ref. [11] as

$$\sigma_{\gamma\gamma\to f\bar{f}} = \frac{\pi}{2} q^4 r_e^2 \left(\frac{m_e}{m}\right)^2 \frac{1}{\gamma_f^2} \left[(3-\beta_f^4)\ln\left(\gamma_f^2(1+\beta_f)^2\right) - 2\beta_f\left(1+\frac{1}{\gamma_f^2}\right)\right].$$

In this, $\gamma_f^2 = s/4m^2$ where s is the square of the center-of-mass energy of the photon-photon collision.

The results of a numerical integration of these expressions are given in Table 1.

Table 1: The cross sections for fermion-antifermion production via virtual photons in Pb-Pb collisions at RHIC and the SSC. We suppose that the γ per nucleon is 100 at RHIC, and 8000 at the SSC. Also shown are the estimates of Landau and Lifshitz. The total hadronic interaction rates are a few barns.

Fermion	Mass	$\sigma_{ZZ\to ZZf\bar{f}}$		$\sigma_{\rm LL}$	
	(GeV/c^2)	(mb)	(mb)	(mb)	(mb)
		RHIC	SSC	RHIC	SSC
e	0.000511	1.4×10^8	3.5×10^8	4.0×10^7	3.3×10^8
μ	0.105	226	2468	940	7716
τ	1.784	3.2×10^{-3}	2.6	3.3	26.7
u	0.333	1.0	32.5	18.5	152
d	0.333	0.065	2.0	1.1	9.4
s	0.5	0.014	0.76	0.51	4.2
c	1.5	1.7×10^{-3}	0.79	0.91	7.48
b	5.0	1.3×10^{-8}	1.9×10^{-3}	5.1×10^{-3}	0.042

The rate for $b\bar{b}$ production at RHIC is too low to be of interest, but the rate at the SSC, some 10^{-7} of the ($\approx$ 10 b) total hadronic cross section, is almost high enough. If one ran with 10^7 hadronic interactions/sec, there would be about 1 clean $b\bar{b}$ pairs/sec from the virtual photons. This is equivalent to a luminosity of 10^{33} at an e^+e^- collider. However, a luminosity of 10^{28} for heavy-ion collisions at the SSC is already quite ambitious. This would yield only 1 $b\bar{b}$ event every 100 seconds.

1 References

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