SYNCHROTRON RADIATION FROM RUNAWAY ELECTRONS AND POSITRONS IN LORENTZIAN PLASMAS

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1. INTRODUCTION

Runaway electron avalanches are frequently observed during large tokamak disruptions. In post-disruption plasmas in large tokamaks, the energy of runaway electrons typically ranges between 10 and 20 MeV. Consequently, the average runaway energy exceeds the threshold for electron-positron pair production. Therefore, positrons are expected to be present in significant quantities in magnetized tokamak plasmas during disruption events [1]. At birth, these positrons are highly relativistic. Moreover, they experience further acceleration due to the electric field, causing a significant fraction of them to run away. Detecting the annihilation radiation from runaway positrons in tokamak plasmas is challenging because it is masked by the Bremsstrahlung radiation generated by the electron population. However, the synchrotron radiation emitted by runaway positrons is directional and peaks in the opposite direction of the runaway electrons, making detection potentially feasible. Additionally, it has been demonstrated that electron-positron pair production is expected to occur in post-disruption plasmas in large tokamaks, such as the Joint European Torus (JET) [2] and JT-60U [3-4]. Under these conditions, up to approximately 10^{14} positrons may be generated during collisions between multi-MeV runaway electrons and thermal particles [1].

2. METHODS

In this work, the formulas from [5] were used to determine the distribution function of relativistic runaway electrons, with the kappa distribution applied for electrons [6]. Based on this distribution, the differential positron production rate [5] was investigated. The positron distribution function was calculated using the kinetic equation from [1]. An analysis was also conducted on the fraction of positrons that annihilate before thermalization, depending on their birth energy. Diagnostics using synchrotron radiation is a powerful tool for observing and studying runaway electrons in tokamak plasma. The spectrum of synchrotron radiation for runaway electrons and positrons was calculated using the formulas from [5], taking into account the Coulomb logarithm [6] with a kappa distribution. The results obtained show good agreement with data presented by other authors.

3. RESULTS

In this work, the distribution function of positrons generated by runaway electrons was determined, and the average energy of positrons was calculated. First, we investigated how the distribution of electrons in Lorentzian plasma changes concerning momenta $\rho_{\perp}$ and $\rho_{\parallel}$ (where $\perp$ represents the perpendicular and $\parallel$ the parallel component relative to the magnetic field). It is known that in Lorentzian plasma with the so-called kappa-distribution of electrons, a decrease in the spectral index (κ) leads to a reduction in the Coulomb logarithm (as shown in the work [6]). This decrease in the Coulomb logarithm leads to an increase in the distribution of runaway electrons along the parallel momentum and a decrease in the distribution along the perpendicular momentum since the lower Coulomb collision cross-section results in stronger confinement of electrons by the magnetic field. This effect is illustrated in Figure 1, which shows the distribution of electrons concerning parallel momentum at a fixed perpendicular momentum value. Additionally, the process of positron generation by runaway electrons was investigated. Figure 2 shows the differential birth rate of positrons produced by runaway electrons.

ACKNOWLEDGEMENTS

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP19679536).

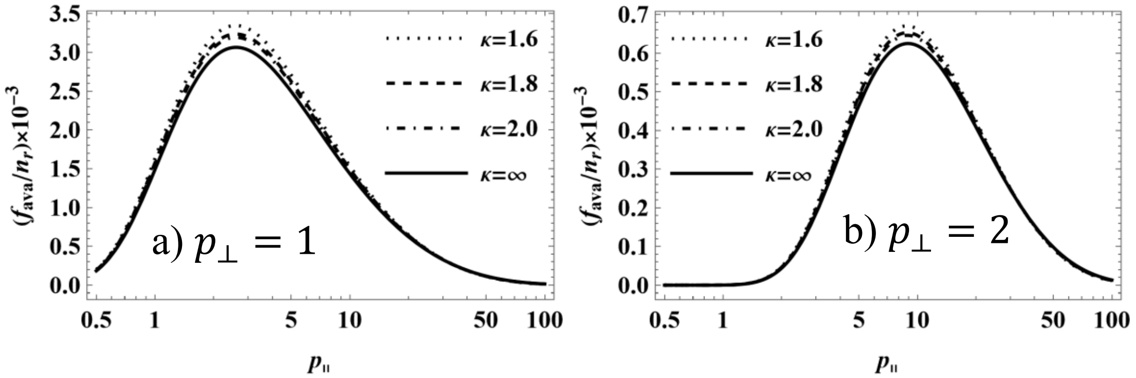

Figure 1. Dependence of the distribution function of runaway electrons on $p_\parallel$ in Lorentzian plasma ($\kappa = 1.6; 1.8; 2.0$) and Maxwellian plasma ($\kappa = \infty$) at $T_e = 1$ кэВ, $n_e = 1 \cdot 10^{20}$ м^3, $Z_{eff} = 1.5$ и $E/E_c = 15$.

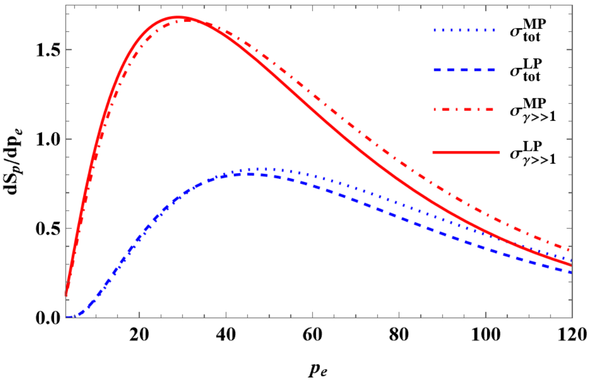

Figure 2. Differential production rate normalized to $n_i n_r c/c_z$, as function of runaway energy of electrons. The red line represents the ultra-relativistic approximation, while the blue line corresponds to the numerically calculated cross-section. MP (Maxwellian plasma) corresponds to $\kappa = \infty$ [5], while LP (Lorentzian plasma) corresponds to $\kappa = 1.6$ (present works).

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