Particle Acceleration at Relativistic Shocks

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Relativistic shocks find natural application in astrophysics in active galaxies and gamma-ray bursts. While modest to moderate Lorentz factors are associated with the former environment, it is probable that extremely high values of 100-1000 are attained in bursts. Studies of diffusive acceleration at such relativistic shocks are more sparse than those pertaining to their non-relativistic counterparts. This is in part due to the inapplicability of the diffusion approximation to relativistic shocks, where particle isotropy is never realized. This paper presents results of acceleration properties of such relativistic shocks over a wide range of Lorentz factors of the upstream flow. Our tool is a well-known and successful Monte Carlo simulation that possesses versatility to probe a variety of scattering properties, and determine acceleration spectra, anisotropies, spatial gradients and acceleration times. Here we present results from our simulation of quasi-parallel shocks that relate to these various quantities, demonstrating close agreement with semi-analytic convection-diffusion equation results in the limit of pitch angle diffusion. We also explore the spectral flattening that arises when scattering angles are finite. Furthermore, it is determined that acceleration times can never become arbitrarily short in ultrarelativistic shocks, but are dominated by diffusion in the downstream region and couple to the particle's gyroperiod.