Uncertainty quantification and statistical analysis of Monte Carlo particle simulations

Background

There is a considerable amount of evidence from experimental wortk, numerical kinetic and fluid simulations that indicate that plasma turbulent transport in tokamaks is, under some conditions, non-diffusive. There are several reasons for the possible breakdown of the standard diffusion paradigm which is based on restrictive assumptions including locality, Gaussianity, lack of long-range correlations, and linearity. Different physical mechanisms can generate situations where, e.g., locality and Gaussianity may be incorrect assumptions for understanding transport. For example, interactions with external fluctuations may introduce long-range correlations and/or anomalously large particle displacements.

The emergence of such strange kinetics has been studied previously, e.g., References 1–16 using different modelling strategies where it may be generated by accelerated or sticky motions along the trajectory of a random walk. Recent evaluations of experimental data have revealed the degree of fractality of the system, characterized by the fractional index α, a novel approach to define the fractional index α, of the heat flux in tokamak plasma experiments through a power balance analysis of the steady state profiles over the whole plasma region have been proposed. The findings show that the average fractional degree of the heat flux over the database for electrons is $\alpha \sim 0.8$, suggesting a global scaling between the net heating and the pressure profile in the plasma. A Monte Carlo (MC) code have recently been developed to investigate this phenomenon [16] where the statistics of charged particle motion in the presence of a-stable Lévy fluctuations in an external magnetic field and linear friction can be investigated. The Lévy noise is introduced to model the effect of non-Gaussian, intermittent electrostatic fluctuations. The statistical properties of the velocity moments and energy for various values of the fractional index can e.g. be investigated

Proposed work

The work is expected to span 30 ECTS credits during the first half of 2019 and it will focus on statistical analysis of data produced by the MC code and optimizing the code. One of the main interests is to investigate the dynamics of the particles around the experimentally found fractional index. Here it is proposed to make an uncertainty quantification (UQ) on fractional index (mean + St. Dev.) and other parameters of interest to better align the simulations to the experimental situation. The UQ can be performed using various methods such as factorial design or constructing a surrogate model using the Polynomial Chaos Expansion. Measuring differences/distances between PDFs and use propagation of moments of α. From a computational point of view it is most interesting in optimizing the code to be able to handle more particles (recode into C) and from a physics point of view it would be most interesting to add aspects of magnetic field geometry such as toroidicity.

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