Self modulated dynamics of relativistic charged particle beam in plasma wake field excitation

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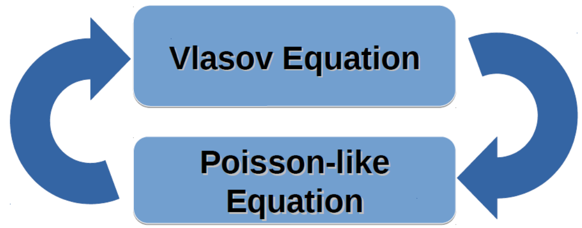
We have described the self-modulated dynamics of a long, relativistic charged-particle beam while experiencing the self consistent plasma wake field (PWF) excitation. The *beam+plasma* system is governed by the Vlasov-Poisson-type pair of equations that is obtained in the quasi-static approximation from the Vlasov-Maxwell sytem of equations



- We have deepen the PWF mechanism and provided the extension of its description to more general physical conditions experienced by the beam+plasma system. In the overdense regime and in a nonrelativistic plasma, we have found a generalized Poisson-like equations which accounts for the presence of a longitudinal magnetic field, longitudinal and transverse plasma pressure terms, the sharpness of the beam

$$\left[\left(\frac{\partial^2}{\partial\xi^2}+k_{uh}^2-\alpha_z\frac{\partial^2}{\partial\xi^2}-\alpha_\perp\nabla_\perp^2-\alpha_z k_{ce}^2\right)\left(\frac{1}{\gamma_0^2}\frac{\partial^2}{\partial\xi^2}+\nabla_\perp^2-k_p^2\right)+(1-\alpha_z)k_{pe}^2k_{ce}^2\right]\Omega$$
$$= k_{pe}^2\frac{qm_0c^2}{e^2}\left[\frac{1}{\gamma_0^2}\left(\frac{\partial^2}{\partial\xi^2}+k_{ce}^2-\alpha_z\frac{\partial^2}{\partial\xi^2}-\alpha_\perp\nabla_\perp^2-\alpha_z k_{ce}^2\right)-(1-\alpha_z)k_{pe}^2\right]\frac{\rho_b}{n_0}$$

$$\frac{\partial f}{\partial t}+\mathbf{p}\cdot\nabla_r f+\nabla_r\Omega\cdot\nabla_p f=0$$
$$\mathbf{r}=\hat{z}\xi+\mathbf{r}_\perp,\ \nabla_r=\hat{z}\frac{\partial}{\partial\xi}+\nabla_\perp,\ \nabla_p=\hat{z}\frac{\partial}{\partial p_z}+\nabla_{p\perp}$$

- In the regime of a fully relativistic cold plasma, we have described the PWF excitation in a 1D longitudinal dynamics for physical conditions that include both the overdense and the underdense regimes and found the related Poisson-like equations

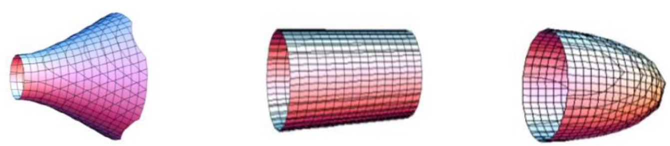
$$\frac{d^2\Omega}{d\xi^2} + \frac{k_p^2}{\alpha}\left(\frac{\beta^2 + \alpha\Omega\left(\alpha\Omega - 2\right) \mp \beta\sqrt{\left(\alpha\Omega - 1\right)^2\left[\beta^2 + \alpha\Omega\left(\alpha\Omega - 2\right)\right]}}{\left(\beta^2 - 1\right)\left[\beta^2 + \alpha\Omega\left(\alpha\Omega - 2\right)\right]}\right) = -\frac{k_p^2}{\alpha}\frac{q}{e}\frac{n_b}{n_0}\frac{u - u_b}{\beta - u}$$

- We have used our theory to describe simple physical situation in both local and nonlocal regimes

$$\frac{d^2\sigma_\perp^2}{d\xi^2} + 4K\sigma_\perp^2 = \begin{cases} 4\mathcal{C} + 2\langle U_w\rangle \;\; \text{(NLC)}: \begin{cases} |\nabla_\perp| \approx k_s & \text{(moderately NLC)} \\ |\nabla_\perp| \gg k_s & \text{(strongly NLC)} \end{cases} \\ 4\mathcal{C} \;\; \text{(LC)}: \;\; |\nabla_\perp| \ll k_s \end{cases}$$

Stability analysis in **purely local regime**

$$\sigma_\perp^2(\xi) = \sigma_{0\perp}^2 + 2\mathcal{C}(\xi - \xi_0)^2$$

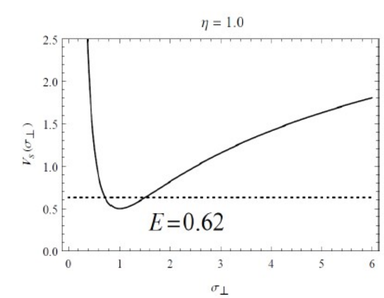


self-defocusing *stationary* *self-focusing*

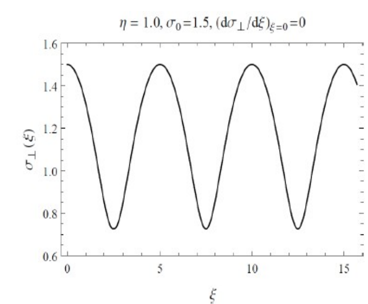
Stability analysis in **strongly nonlocal regime**

$$\frac{d^2\sigma_\perp}{d\xi^2} + \frac{\eta}{\sigma_\perp} - \frac{\epsilon^2}{\sigma_\perp^3} = 0 \;\; \Rightarrow \;\; \frac{d^2\sigma_\perp}{d\xi^2} = -\frac{\partial V_s(\sigma_\perp)}{\partial\sigma_\perp}$$

Sagdeev Potential: $V_s = \frac{1}{2}\eta\ln\sigma_\perp^2 + \frac{1}{2\sigma_\perp^2}$ $\qquad \eta = k_s^2\lambda_0/2\pi$



Sagdeev Potential



Corresponding self modulated oscillation of spot size

- Finally, we used the related results to describe the beam envelope self-modulation that included also the prediction of the self-modulation instability