BUMP FORMATION

IN THE RUNAWAY ELECTRON TAIL

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SYNCHROTRON REACTION FORCE

- **Abraham-Lorentz-Dirac force in reaction to the synchrotron emission**

$$\mathbf{F}_{\mathrm{ALD}} \simeq -\frac{m}{\tau_r}\left[\mathbf{v}_{\perp} + \frac{\gamma^2 v_{\perp}^2}{c^2}\mathbf{v}\right] \qquad \tau_r^{-1} = \frac{e^4 B^2}{6\pi\varepsilon_0 (mc)^3}$$

- **Guiding center electron kinetic equation**

$$\frac{\partial f}{\partial t} + \boldsymbol{\nabla}_{p,\xi} \cdot \mathbf{S}_{p,\xi}\left[f\right] = I_{\mathrm{FP}}[f]$$

$$\mathbf{S}_{p,\xi}\left[f\right] = \left(\mathbf{K}_{\mathrm{FP}} + \mathbf{K}_{\mathrm{E}} + \mathbf{K}_{\mathrm{ALD}}\right) f - \mathbb{D}_{\mathrm{FP}} \cdot \boldsymbol{\nabla}_{p,\xi} f$$

CONVECTION COEFFICIENTS

- **Fokker-Planck collisions drag**

$$K_{\perp,\mathrm{FP}} = -\frac{p_\perp}{p} F_{\mathrm{FP}}$$
$$K_{\parallel,\mathrm{FP}} = -\frac{p_\parallel}{p} F_{\mathrm{FP}}$$

$$F_{\mathrm{FP}}(p) = \frac{1}{v^2}$$

- **Electric field force**

$$K^{\mathrm{C}}_{\perp,\mathrm{E}} = 0$$
$$K^{\mathrm{C}}_{\parallel,\mathrm{E}} = E_\parallel$$

- **Synchrotron emission reaction force**

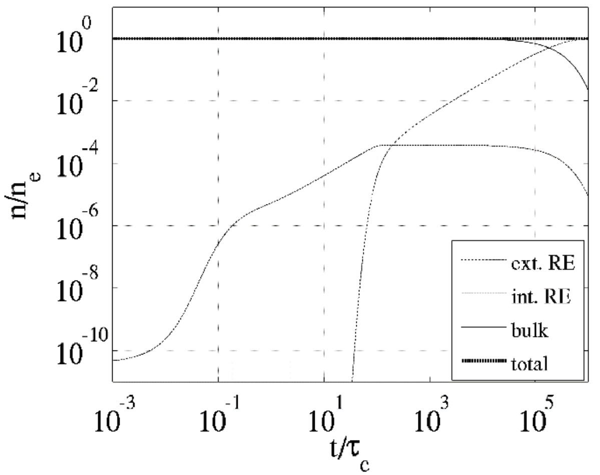
$$K^{\mathrm{C}}_{\perp,\mathrm{ALD}} = -\sigma_r \frac{p_\perp}{\gamma}\left(1 + p_\perp^2\right)$$
$$K^{\mathrm{C}}_{\parallel,\mathrm{ALD}} = -\sigma_r \frac{p_\parallel}{\gamma} p_\perp^2$$

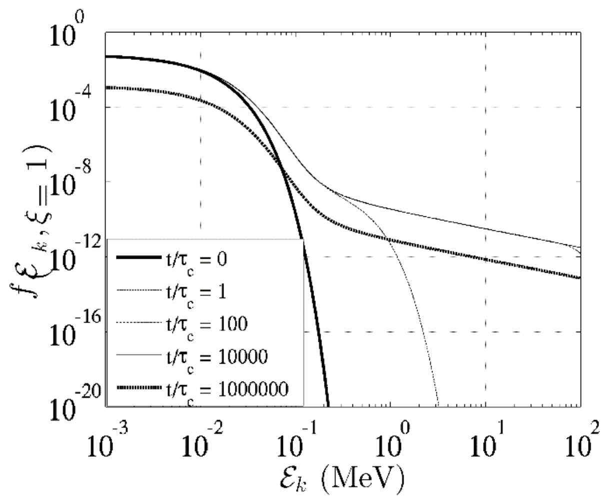
$$\sigma_r = \frac{2}{3}\frac{1}{\ln\Lambda}\frac{\omega_c^2}{\omega_p^2}$$

EVOLUTION OF THE ELECTRON DISTRIBUTION

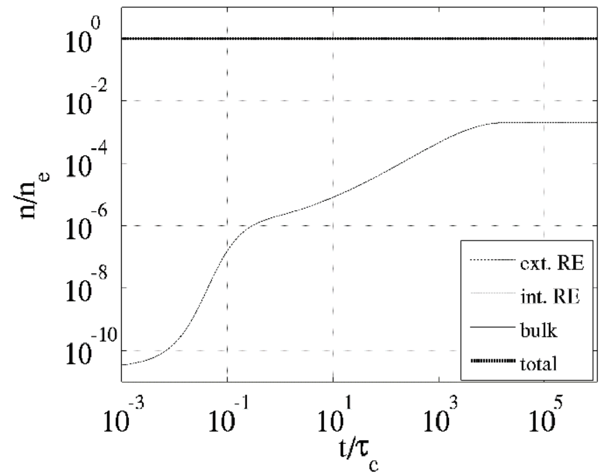
J. Decker, et al.,to be submitted to PoP (2015)

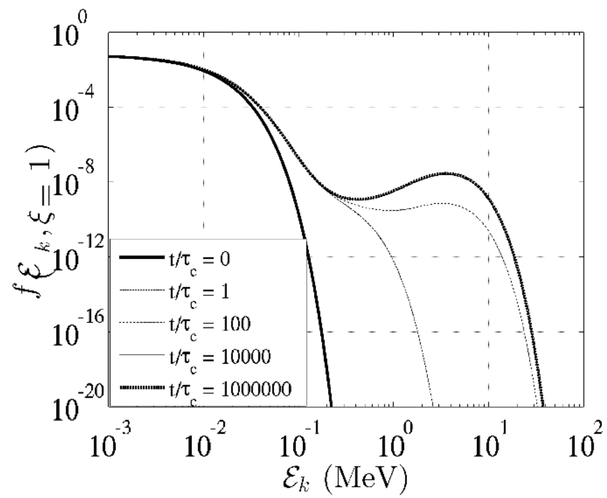
NO ALD FORCE





WITH ALD FORCE





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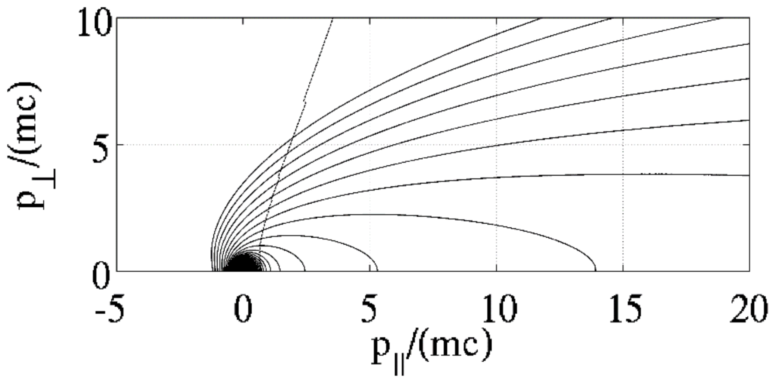
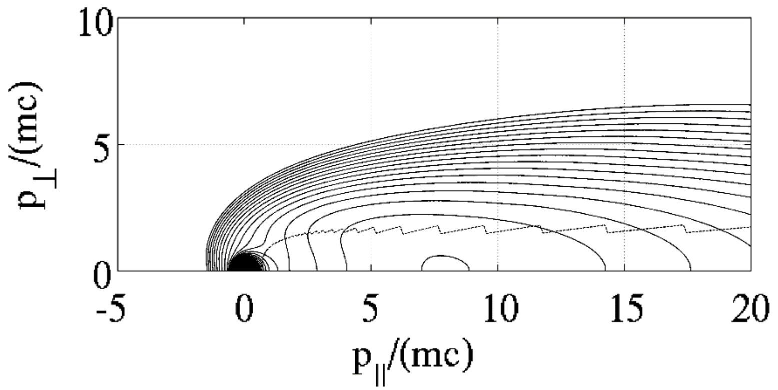


WITH ALD FORCE

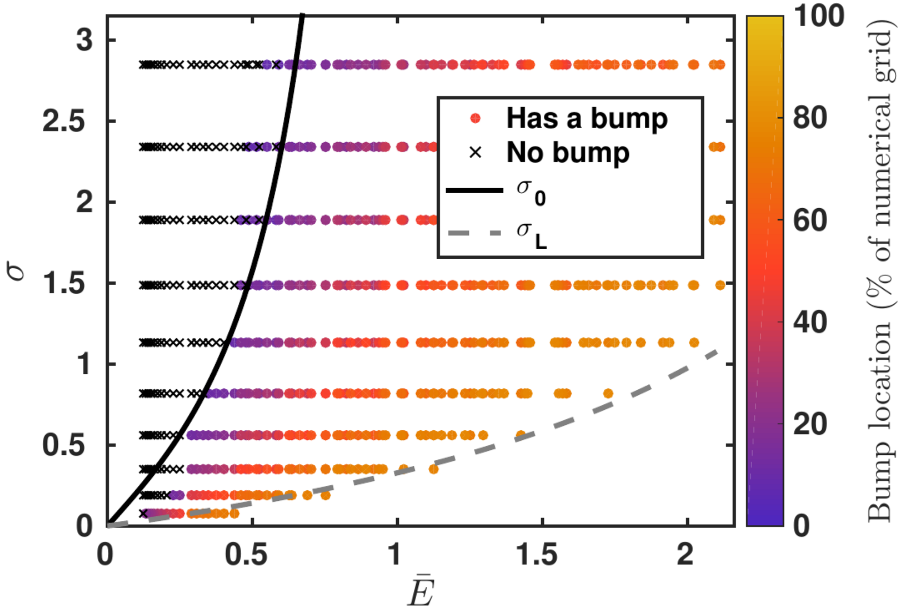


THRESHOLD CONDITION FOR BUMP

E. Hirvijoki, et al., submitted to JPP (2015)

$$\sigma_0 = \frac{3\kappa/\bar{E} + \sqrt{8 + \kappa^2/\bar{E}^2}}{2\left(\kappa^2/\bar{E}^2 - 1\right)} \approx 2\bar{E}/\kappa \quad \underline{(\bar{E} \ll 1)}$$

$$\bar{E} = (\hat{E} - 1)/[2(1 + Z_{\text{eff}})]$$



CONCLUSIONS AND PERSPECTIVES

- The ALD force in reaction to the synchrotron emission **limits the maximum energy** of runaway electrons
- If the electric field is sufficiently large compared to the ALD force, **a bump can appear in the runaway tail**
- The threshold on E for bump appearance increases with the effective charge

- The bump can give rise to **plasma-beam** type of **instabilities**
- The ALD force also increases the perpendicular gradient, possibly reducing the threshold for kinetic instabilities such as the **EXEL or Whistler wave**
- Any drag force increasing with the electron energy could play a similar role as the ALD force