CHERENKOV RADIATION in ELECTRODYNAMIC STRUCTURES and its APPLICATIONS

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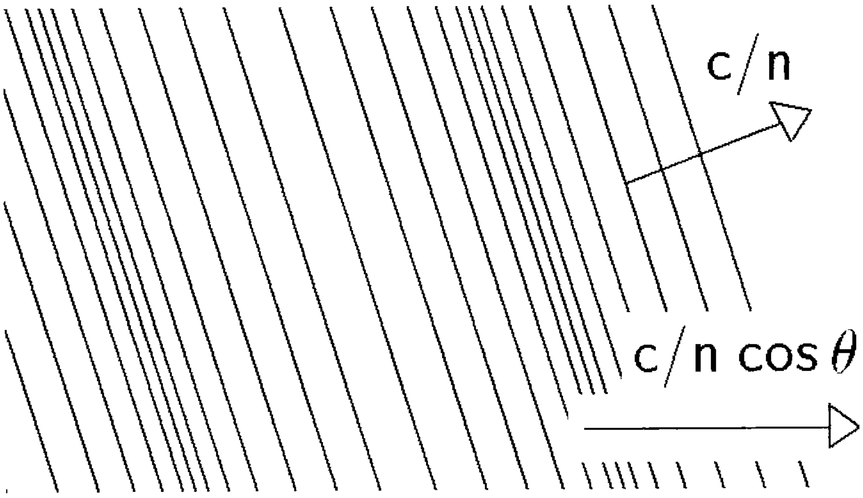
- Long-term wave-particle interaction (synchronism).
- Reversibility of V.-Ch. effect (phase relations)
- Oscillator in the Ch. domain. Anomalous Doppler effect.
- Structures of interest:
  - Magnetized plasma
  - Periodic waveguides and lattices
  - Smith-Purcell effect and resonant transition radiation
  - Ultralight bunches in regular waveguides
- Coherent Ch. radiation. Limits of coherency
- Induced Ch. radiation and UHF sources

$\Delta\mathcal{E} \gg \hbar\omega$ – classical radiation

$l \gg \lambda$ – long-term interaction



necessary and sufficient:

$$\boxed{\omega/k_{\mathrm{Z}} = \beta c; \quad \vec{E}\vec{\beta} \neq 0}$$

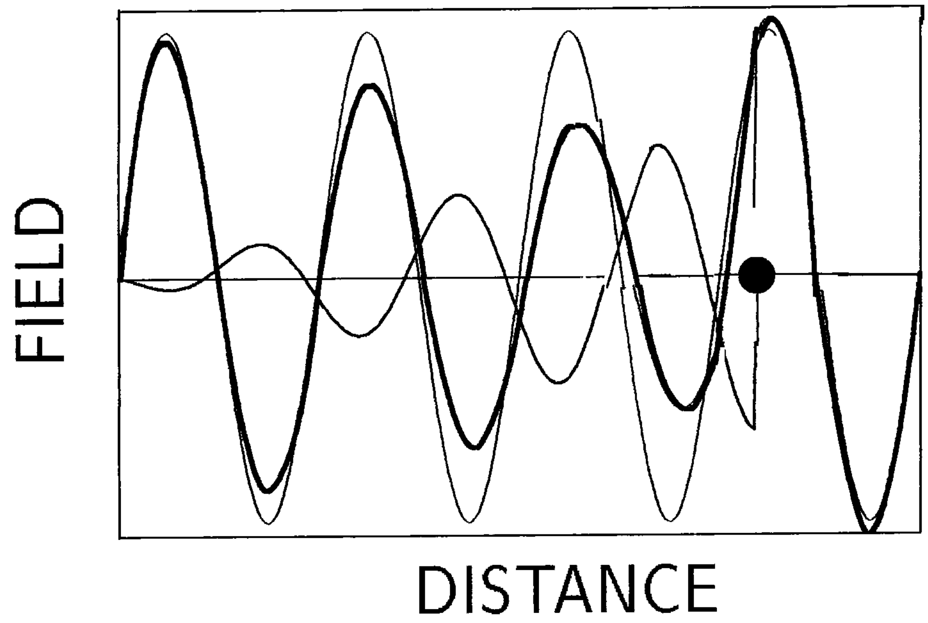
In free space $k_{\mathrm{Z}} = \frac{\omega}{c}\sqrt{\epsilon}\cos\theta$ and

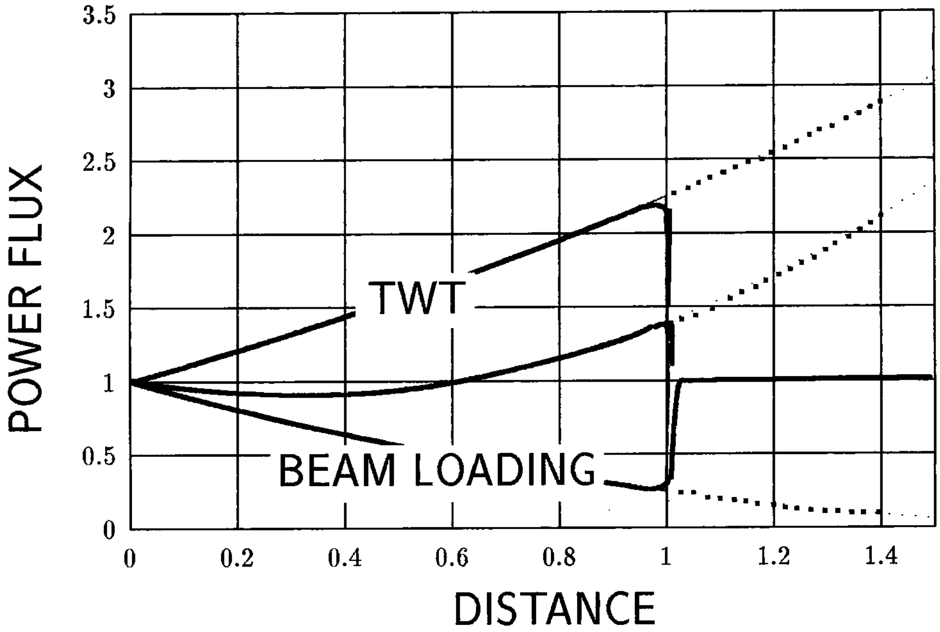
$$\cos\theta = \frac{1}{\beta\sqrt{\epsilon(\omega)}}$$

For the n-th E-mode in a waveguide

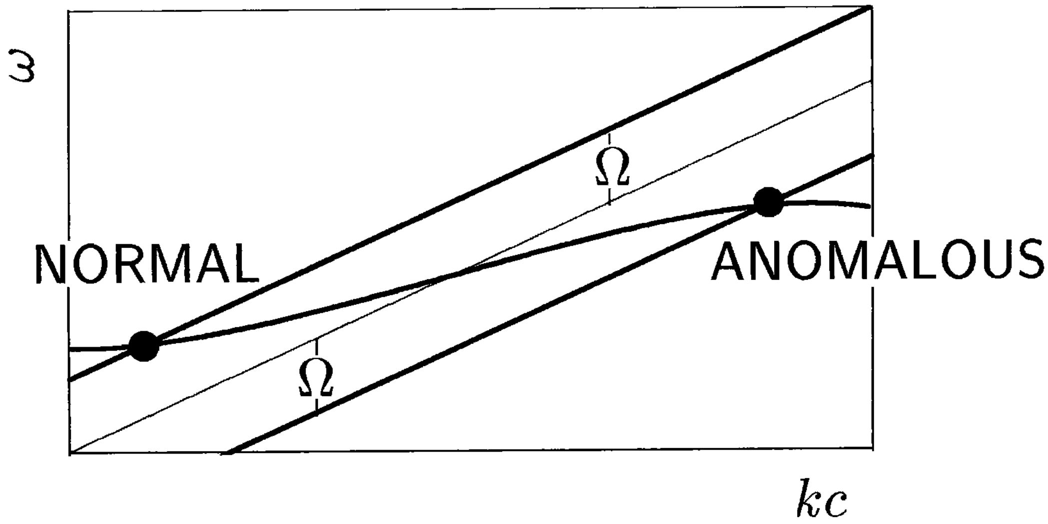
$$\beta_n = \beta$$

CHERENKOV RADIATION IN A COHERENT EM WAVE





ULTRALIGHT OSCILLATOR DOPPLER EFFECT



The wave outstrips (lags behind) the particle by λ per osc. period

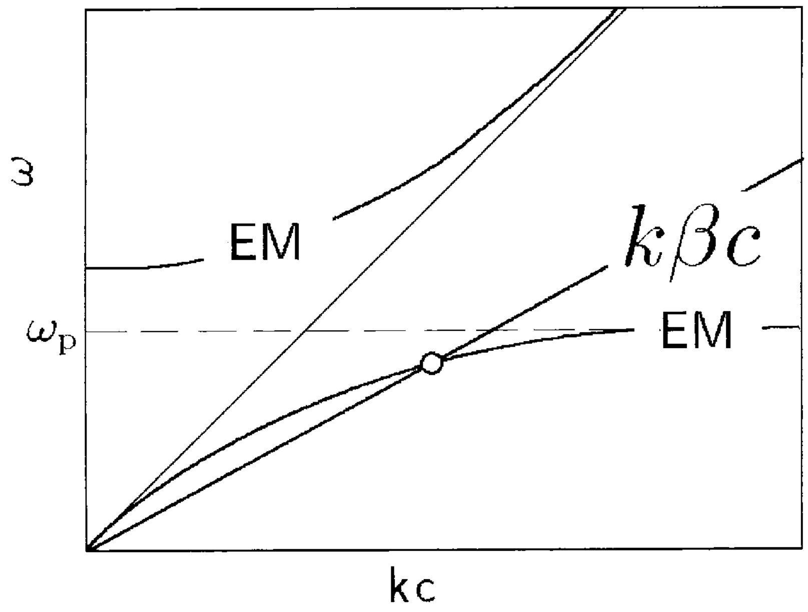
$$\omega - k\beta c = \pm\Omega \qquad k = \omega/\beta_{\rm p} c$$

Conservation laws yield the change in internal osc. energy:

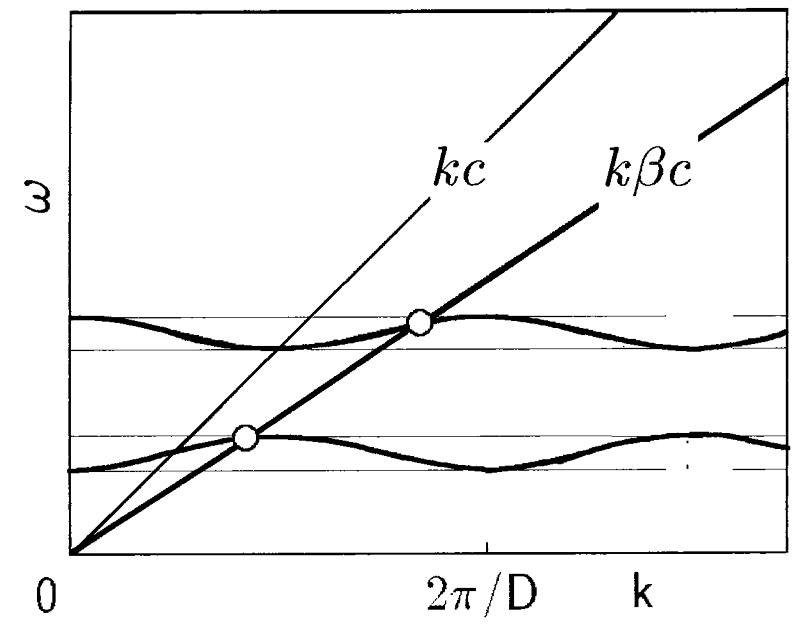
$$\Delta W = \Delta E\,(1 - \beta/\beta_{\rm p})$$

Radiation in Cherenkov domain excites oscillations at longitudinal retardation expence

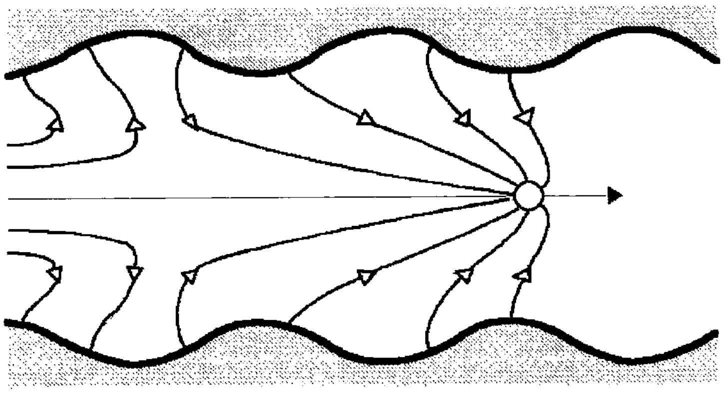
MAGNETIZED PLASMA



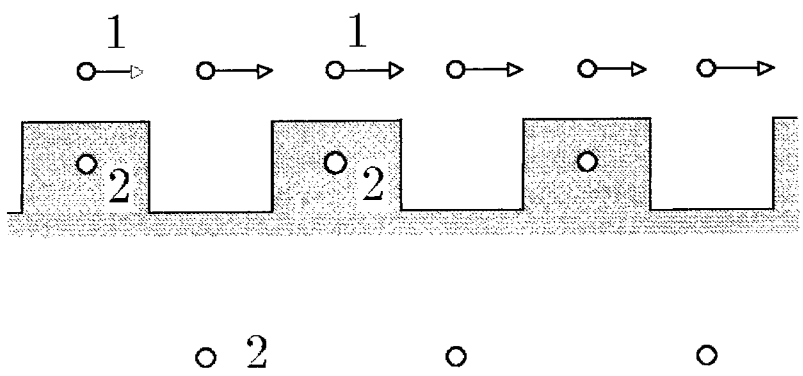
PERIODIC STRUCTURE



CORRUGATED WAVEGUIDE

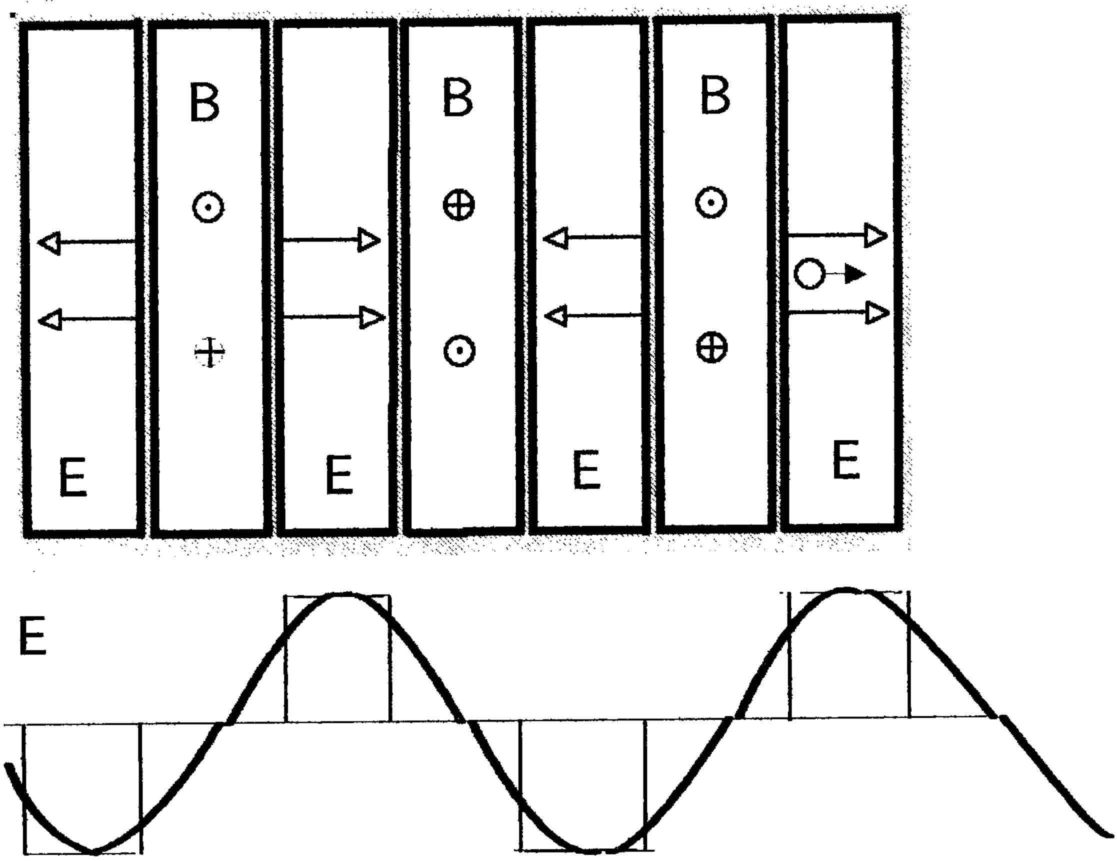


SMITH-PURCELL EFFECT
(Cherenkov radiation of a slow surface wave)



1 – particles; 2 – images

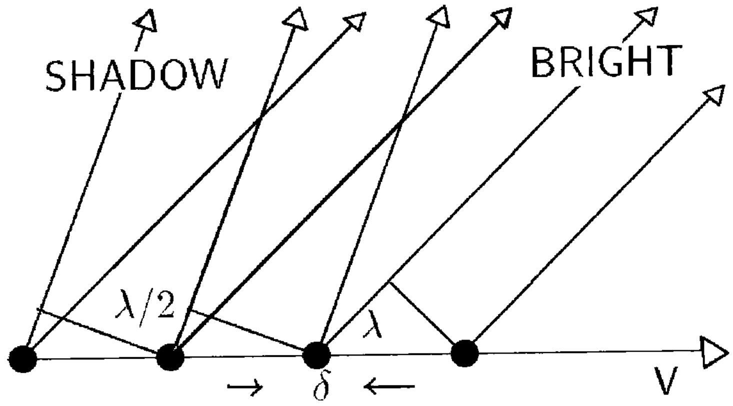
RESONANT TRANSITION RADIATION



The proper cavity frequency ω_c and the time of light τ are matched for $\omega_c\tau = \pi/2$. For smaller ω_c the wavelength is larger to keep the synchronism.

The group velocity is zero.

COHERENCY $P_{\mathrm{coh}}(\omega) = CP(\omega)$



FREE SPACE:
synchronism defines $\theta(\omega)$, then coherency define θ and ω

WAVEGUIDE:
synchronism defines a set of ω_n, then coherency is compatible for a particular L_{b} only (if at all)

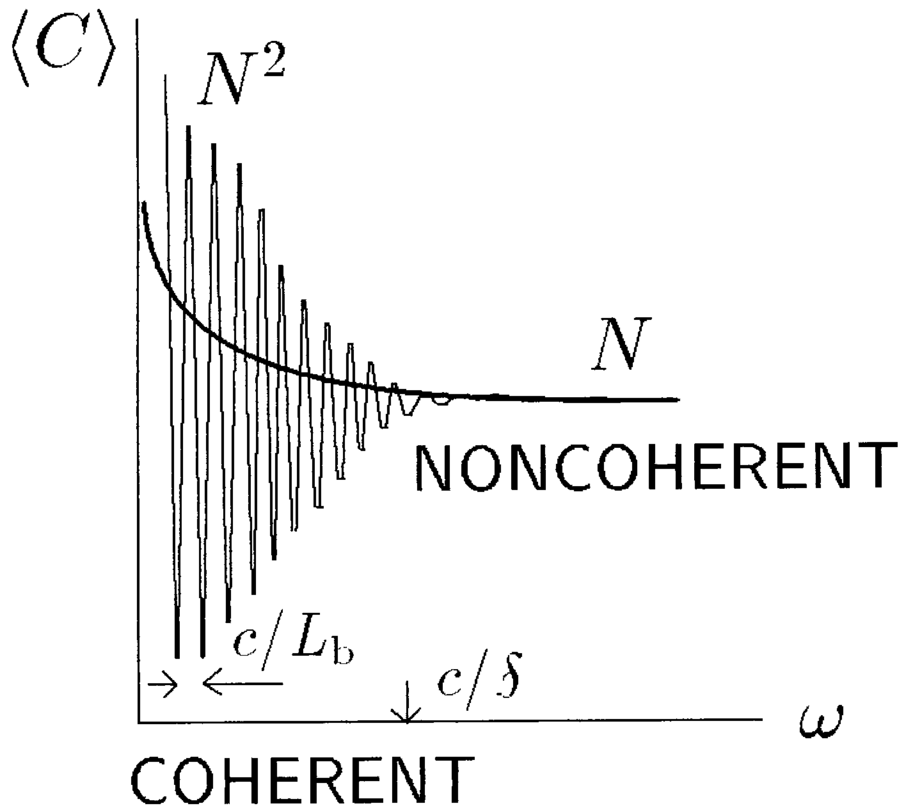
NOT ANY TRAIN OF PARTICLES RADIATES COHERENTLY

LIMITS OF COHERENCY

$P_N = N^2 P_1$ **requires** $\lambda \gg a$ **and** $\omega_\mathrm{p} a \ll c$

Can be fulfilled for $\lambda \gg a \gg N r_0$ **only. A "pointlike" bunch** $\neq$ **an elementary particle because of internal degrees of freedom.**

For a train of particles (bunches) with uncertaintity in position δ



Beeng averaged over a finite frequency interval the coherency factor $< N^2$**.**

INDUCED RADIATION IN CLASSICAL APPROACH

kinetic equation for photons:

$$\frac{\partial n_{\rm k}}{\partial t} = \int w_{\rm k} \left\{ f(E)\,(1+n_{\rm k}) - f\,(E-\hbar\omega)\,n_{\rm k} \right\} \mathbf{d}E$$

radiation **absorption**

For $\hbar \to 0$:

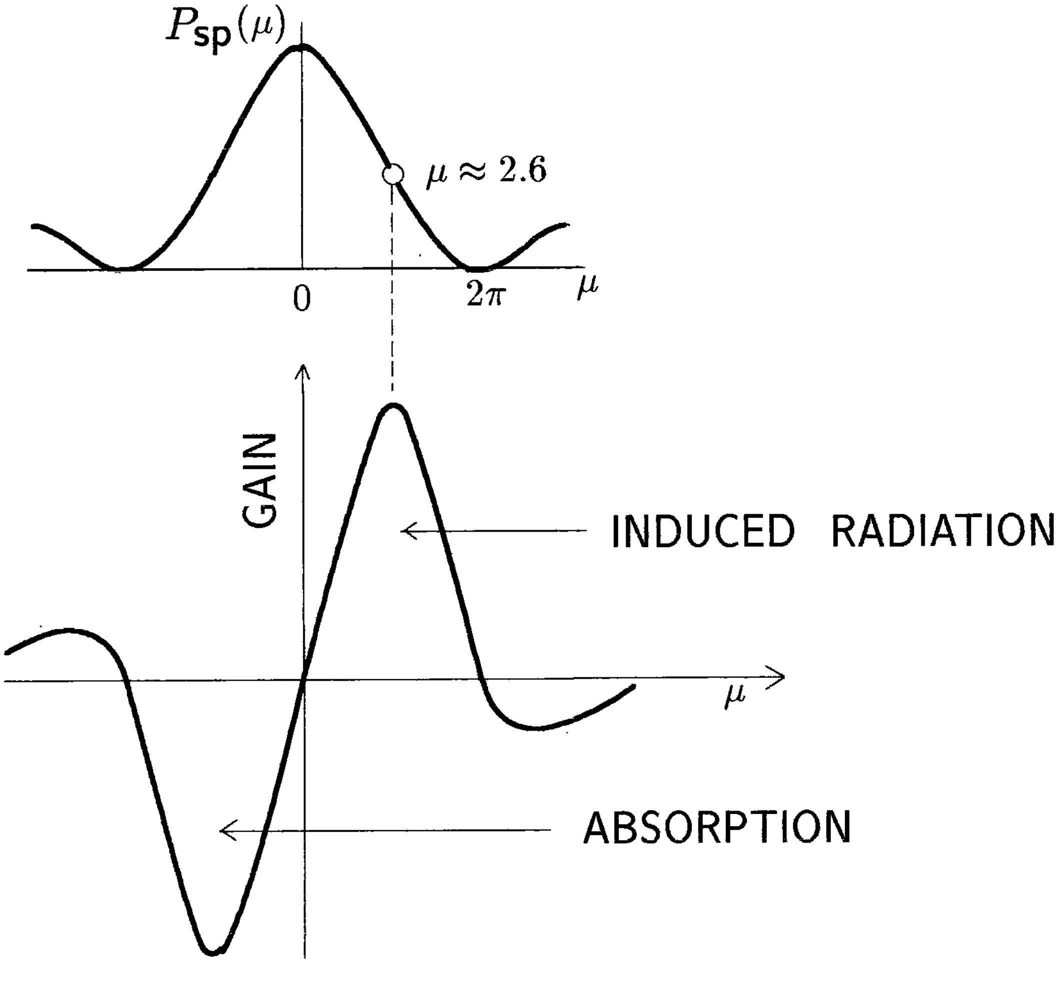
$$\boxed{\frac{\partial W_{\rm k}}{\partial t} = -W_{\rm k} \frac{\partial P_{\rm sp}}{\partial E}}$$

The difference between absorption and radiation due to the energy dependence of $P_{\rm sp}$

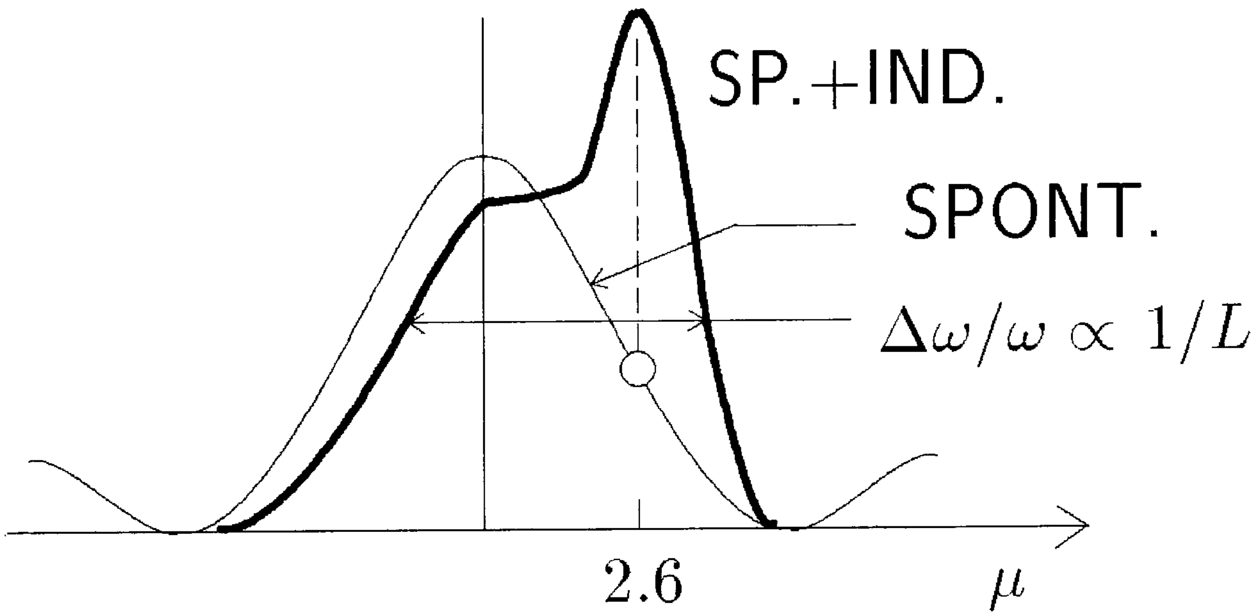
PROVIDES INDUCED RADIATION.

A SHARP ENERGY DEPENDENT LINE OF SPONTANEOUS RADIATION IS REQUIRED.

INDUCED RADIATION/ABSORPTION LINES

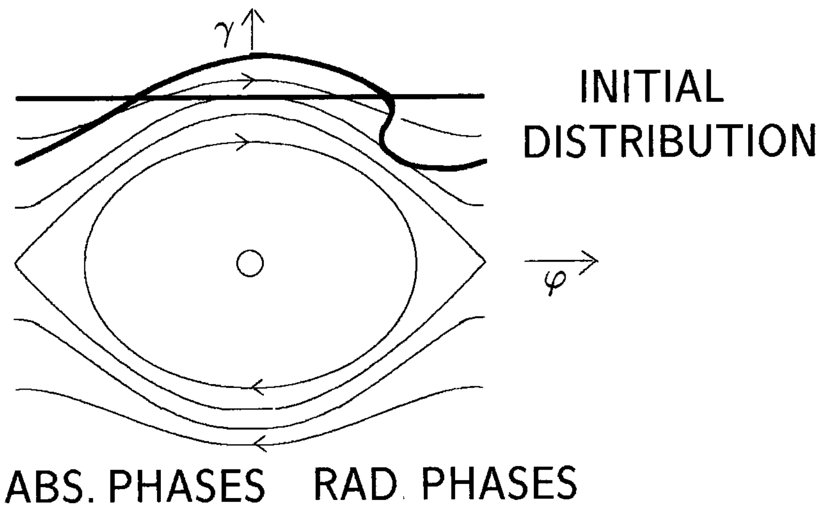


RADIATION SPECTRUM

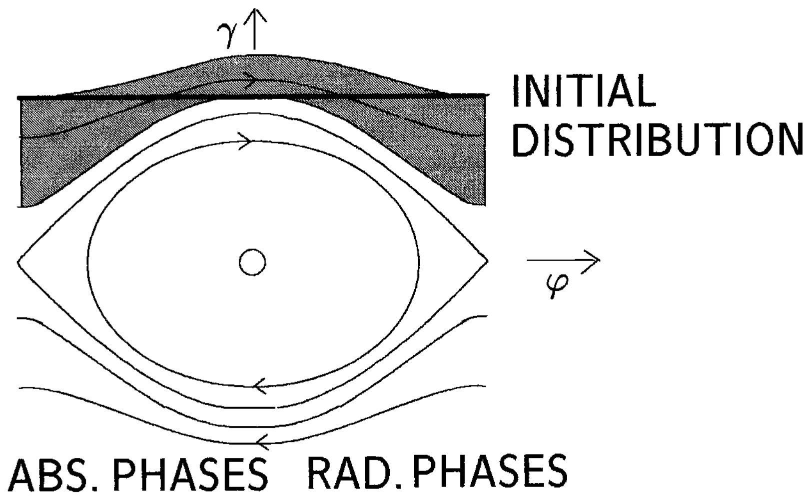


The linewidth of sp. radiation is determined, at least, by the limited interaction length L. The preferential mode with $\mu = 2.6$ grows exponentially causing narrowing of the spectral line (lasing).

PHASING



SATURATION



Due to radiation reaction ultralight particles bunch in the decelerating field providing coherent radiation. This process comes to saturation

BEAM – PLASMA INTERACTION