High Harmonic Generation

Basic Techniques & Challenges

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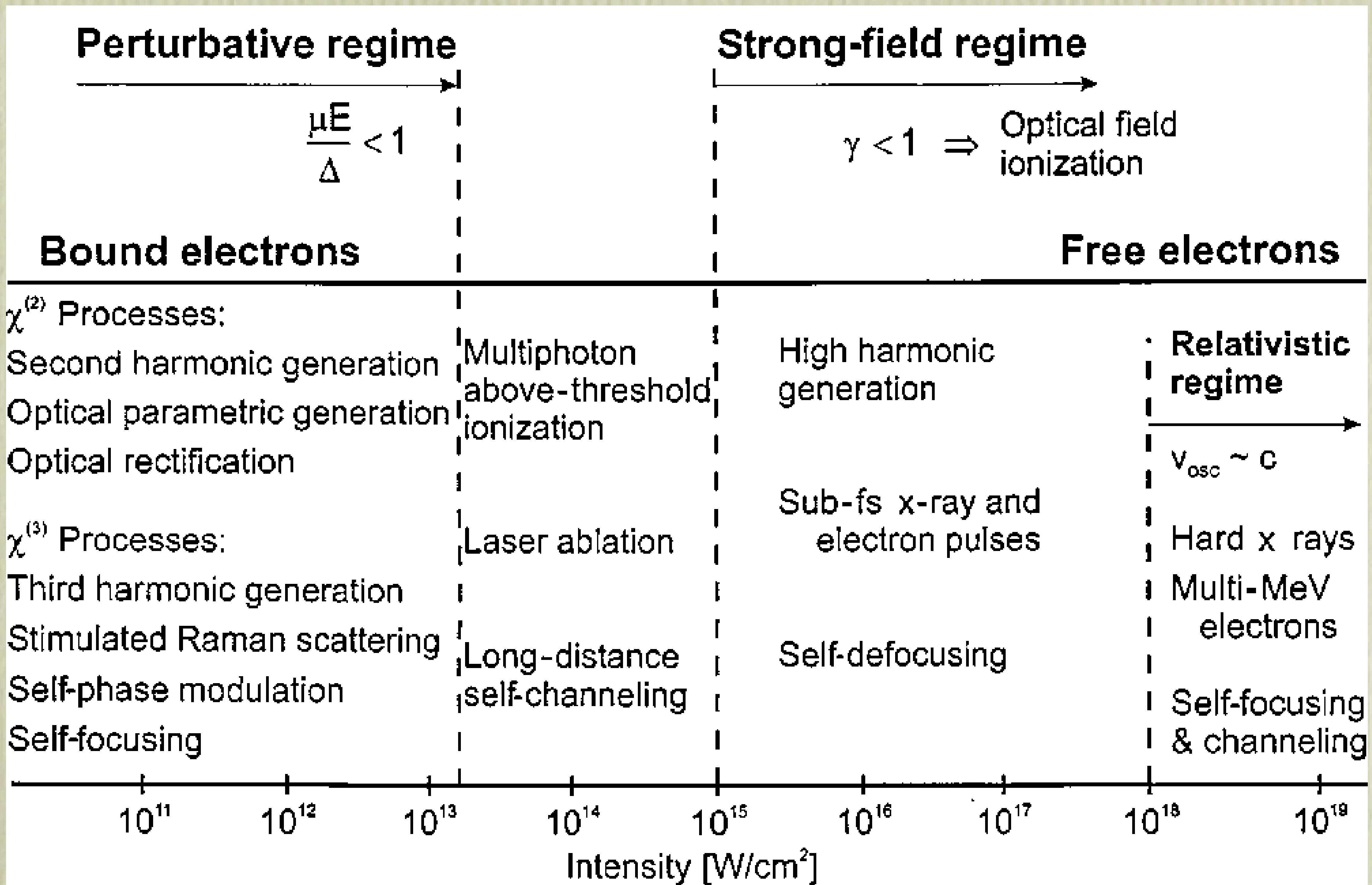
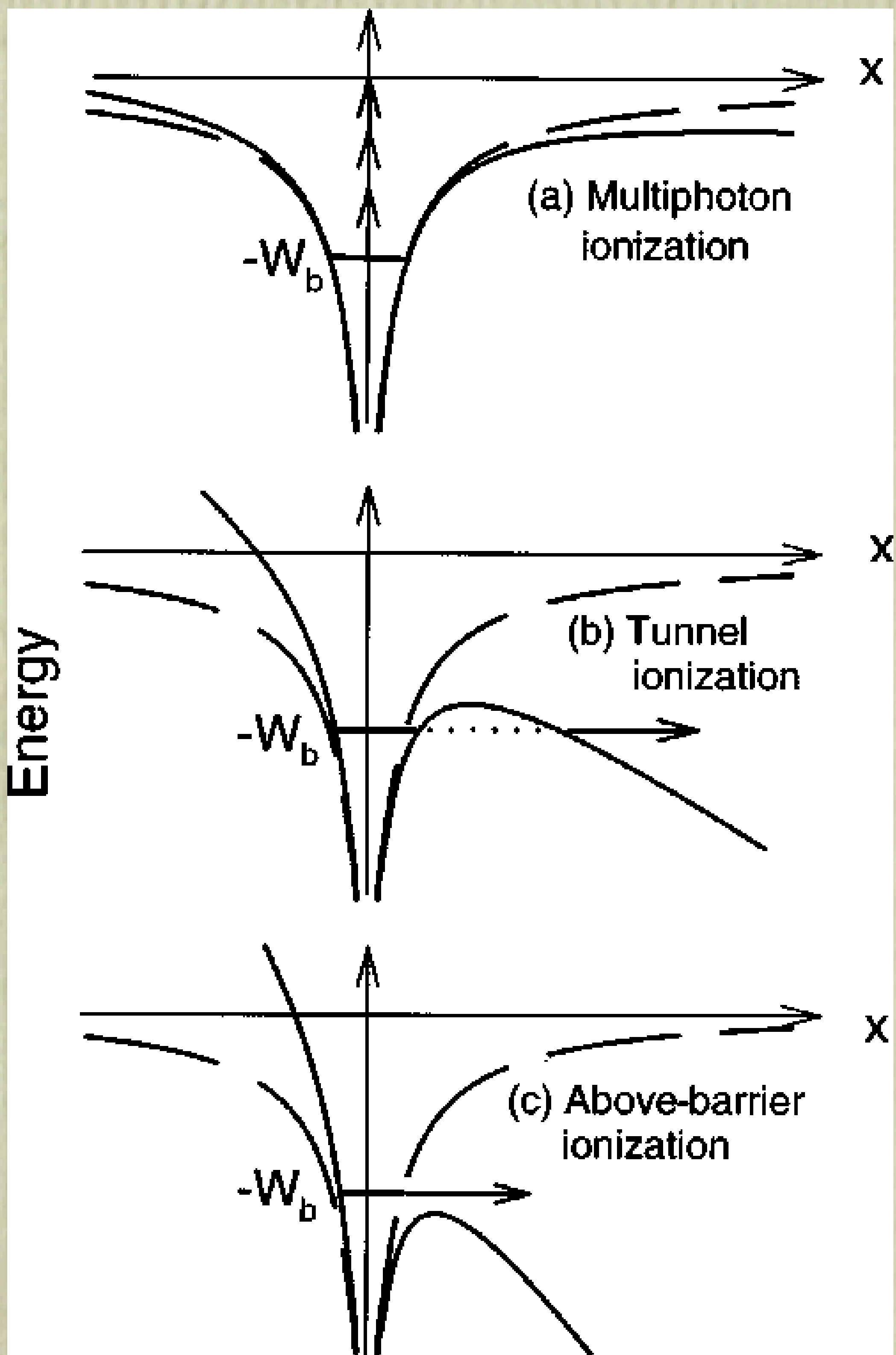
Regimes of Nonlinear Optics



Outline

- Optical Field Atomic Ionization
- High Harmonic Generation (HHG)
  - Microscopic Description
  - Macroscopic Description
- Techniques for Phase Matched Generation of Coherent Soft X-rays
- References

Optical Field Atomic Ionization



- Harmonics are generated by the tunneling, transport and recombination of electrons
- Atomic ionization proceeds by perturbation of the Coulomb potential in the presence of the electric field of the driving laser pulse
- Ionization rate by the Quasistatic Approximation

Strong Field Regime

- Measure of field strength is given by Keldysh scale parameter:

$$\frac{1}{\gamma} = \frac{eE_a}{\omega_0\sqrt{2mW_b}}$$

- $\frac{1}{\gamma} > 1$ defines the **strong field regime**
- Coulomb potential is suppressed
- Electron can tunnel through the potential barrier
- Corkum model: Classical description of the electron evolution after ionization

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HHG Microscopic Analysis

- HHG photon radiation dependent on the acceleration of the electron

$$\frac{\partial^2}{\partial t^2} < \psi_e | r | \psi_e >$$

- Two simplifying assumptions:
  1. Electron is a free particle in continuum states
  2. Only ground state interactions are considered

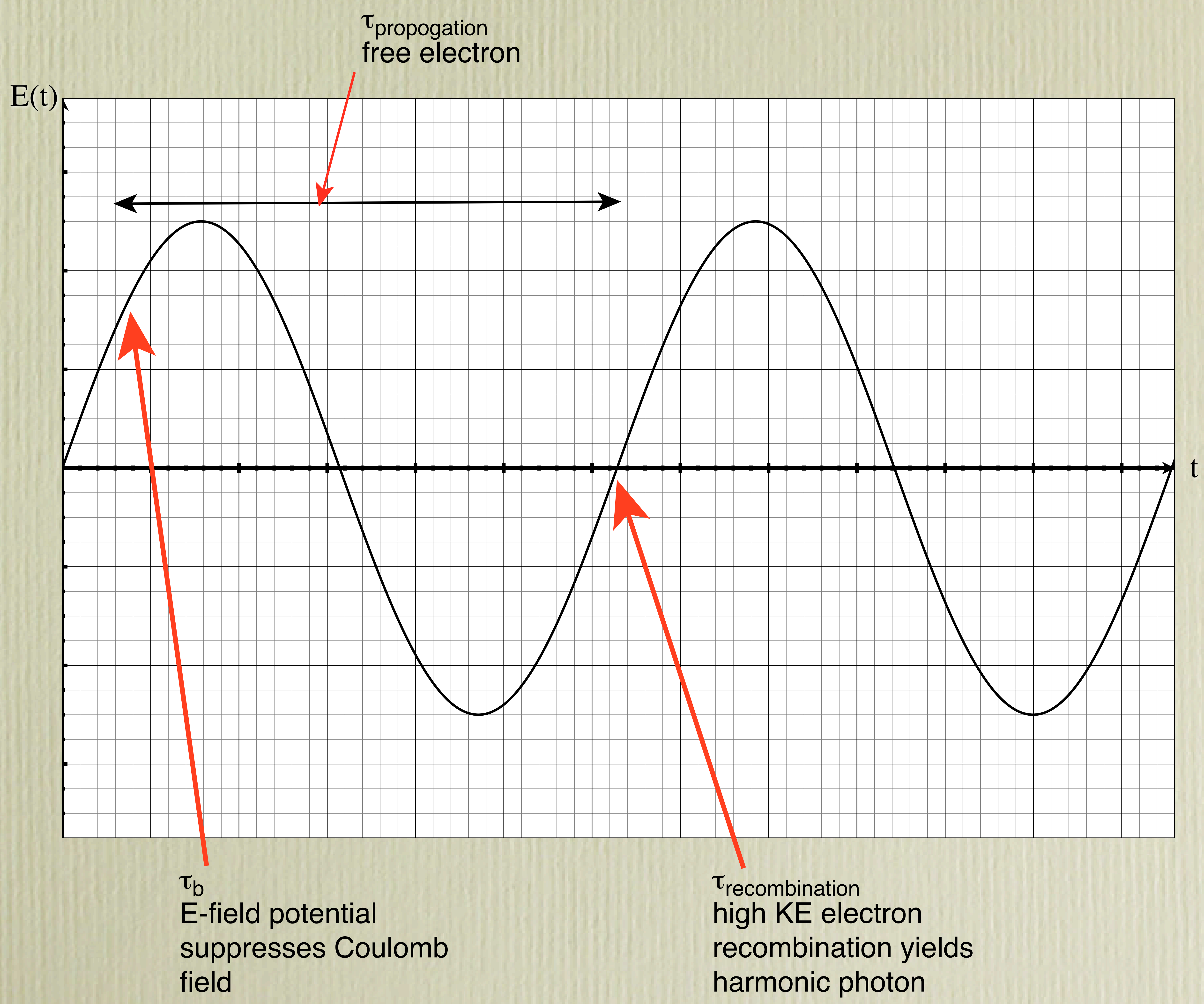
- Under these assumptions:

$$d_n(\tau) = \sum_{\tau_b} \frac{1}{\sqrt{i}} a_{ion}(\tau_b) a_{propogation}(\tau_b, \tau) a_{recombination}(\tau)$$

Microscopic II

- Model valid for linearly polarized light
  - Elliptically polarized light is less efficient
- $a_{propogation}$ time is on the order of the oscillation period of the electric field
- Photon emission occurs upon recombination with the ground state

Microscopic III



Microscopic IV

$$(\hbar\omega)_{max} = I_p + 3.2U_p$$

$$U_p = \frac{2\pi c a_0 I_L}{\omega^2}$$

- Periodic process yields <u>odd</u> harmonics of the laser field

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Macroscopic Analysis (Propagation)

- Macroscopic effects reduce HHG efficiency

1. Absorption - excitation of core atomic states by harmonic photon
2. Dephasing - difference in propagating velocities of laser and harmonic photon
3. Defocusing - distribution in electron density profile due to laser focus

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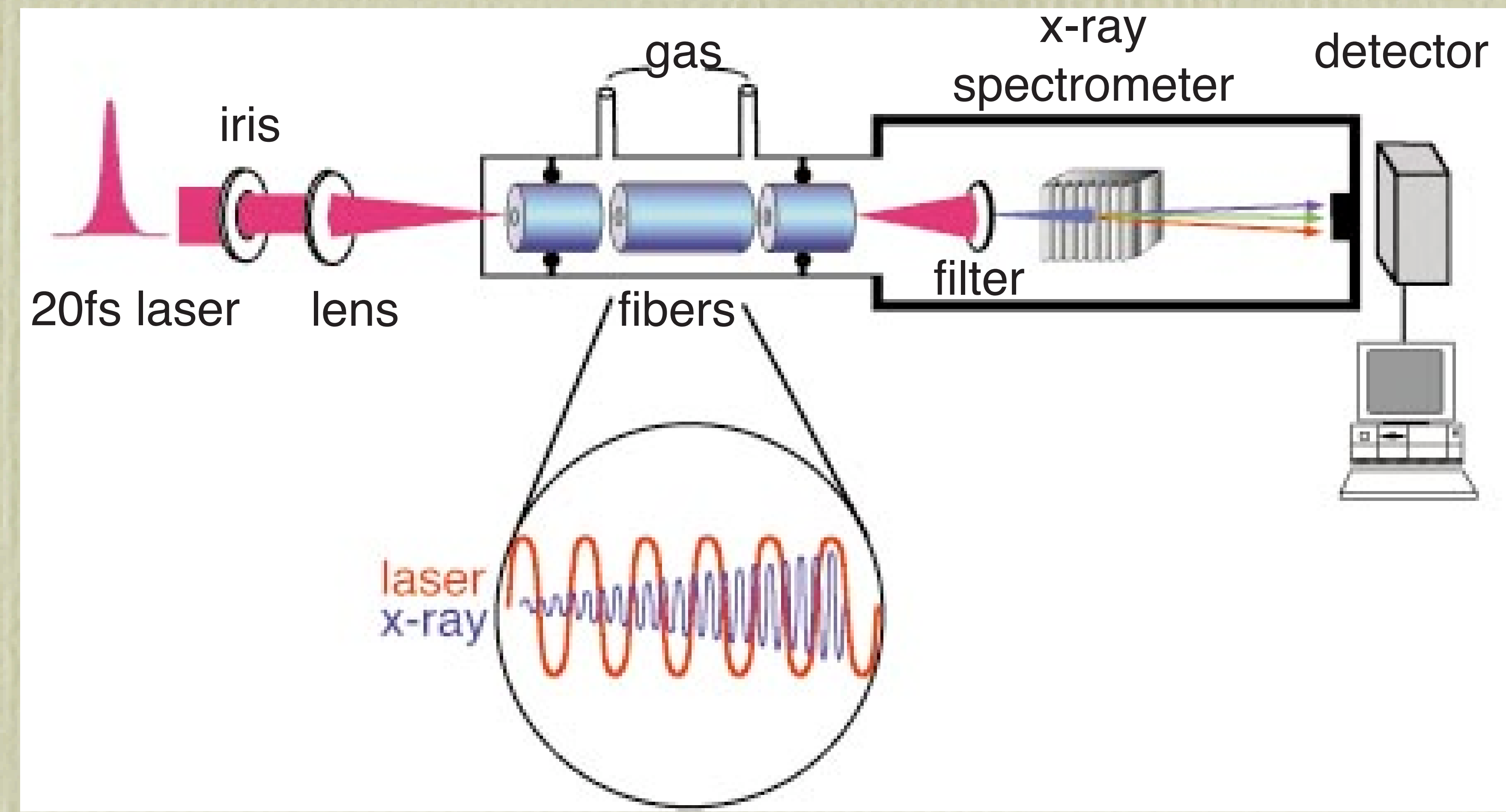
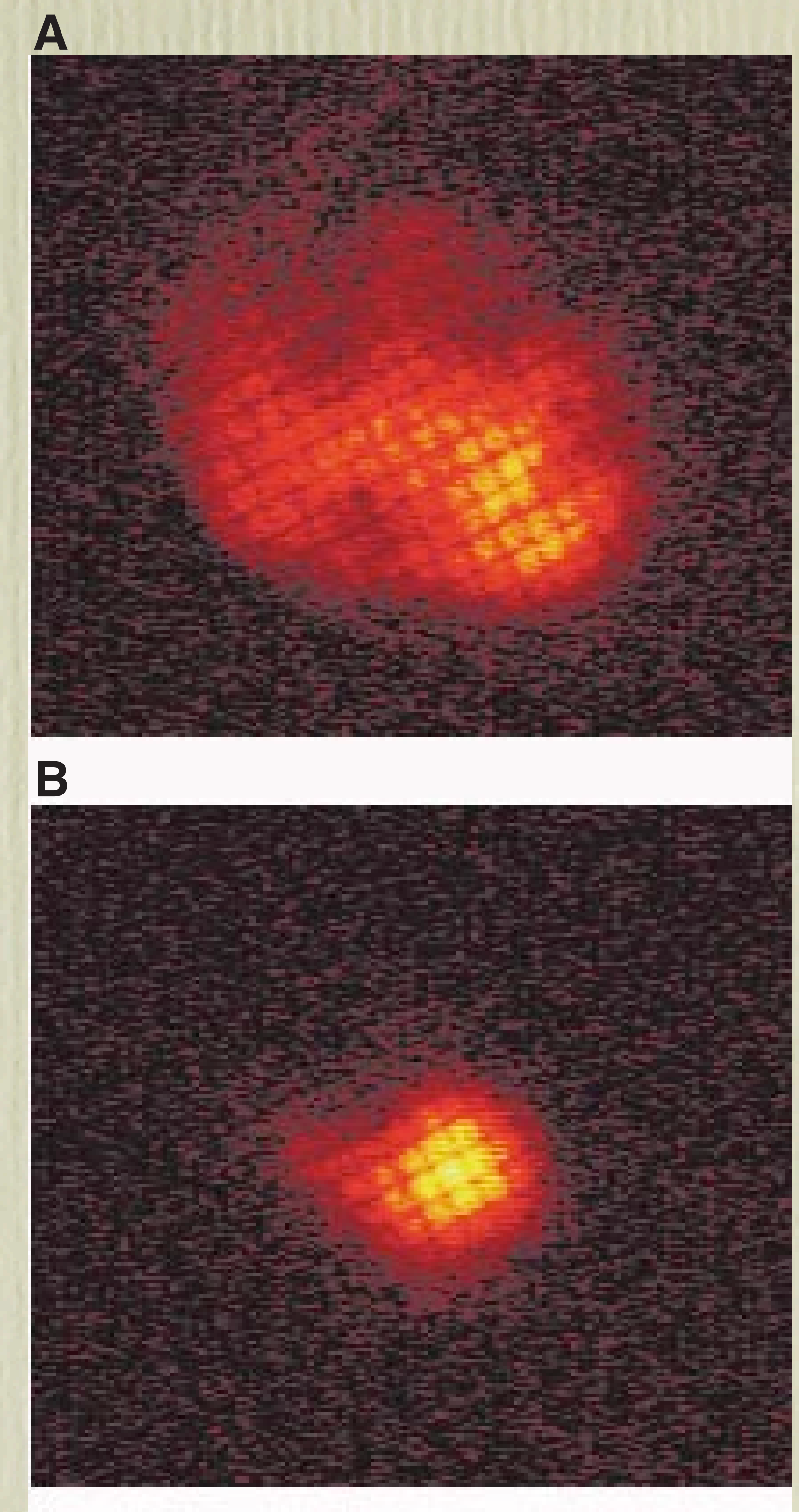
Phase Matching

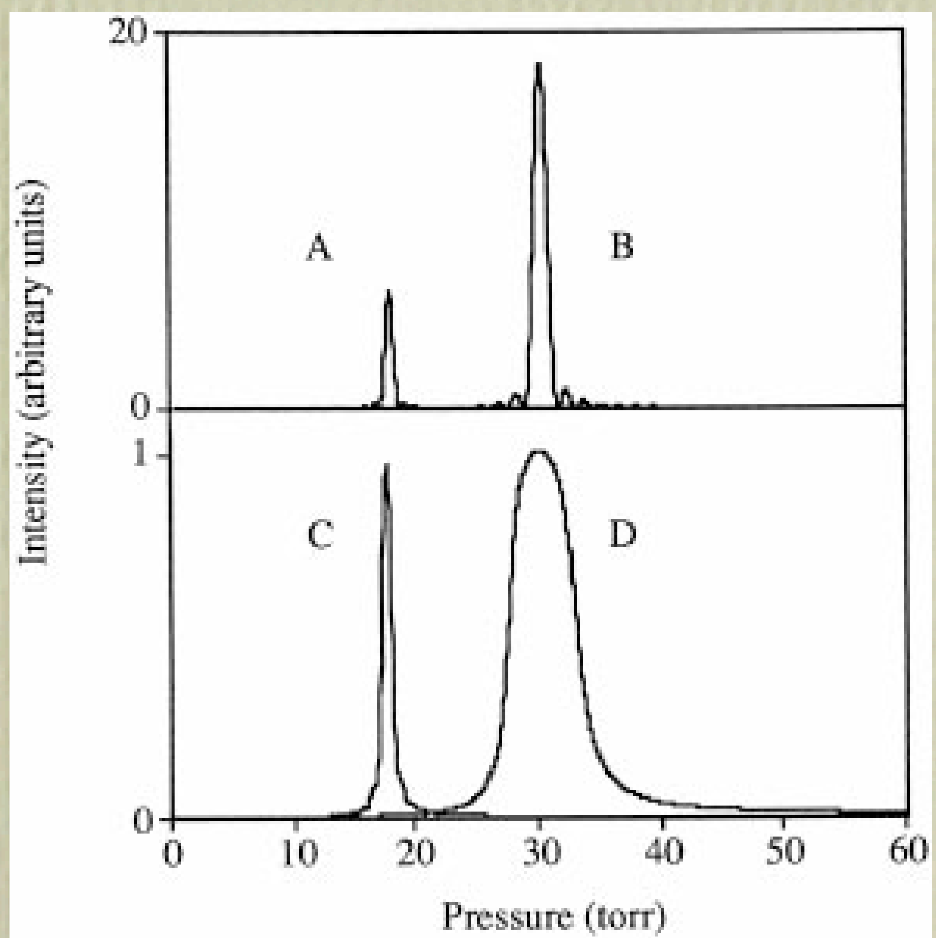
- Goal: Increase the coherence length of the harmonic beam and the driving laser pulse for a given harmonic order
- Phase match condition: $\Delta k = qk_{laser} - k_{x-ray} = 0$
- Use fiber to increase path length of laser relative to harmonic beam

$$k_{laser} \approx \frac{2\pi}{\lambda} + \frac{2\pi N_a \delta(\lambda)}{\lambda} - N_e r_e \lambda - \frac{u_{nm}^2 \lambda}{4\pi a^2}$$

Phase Matching II







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