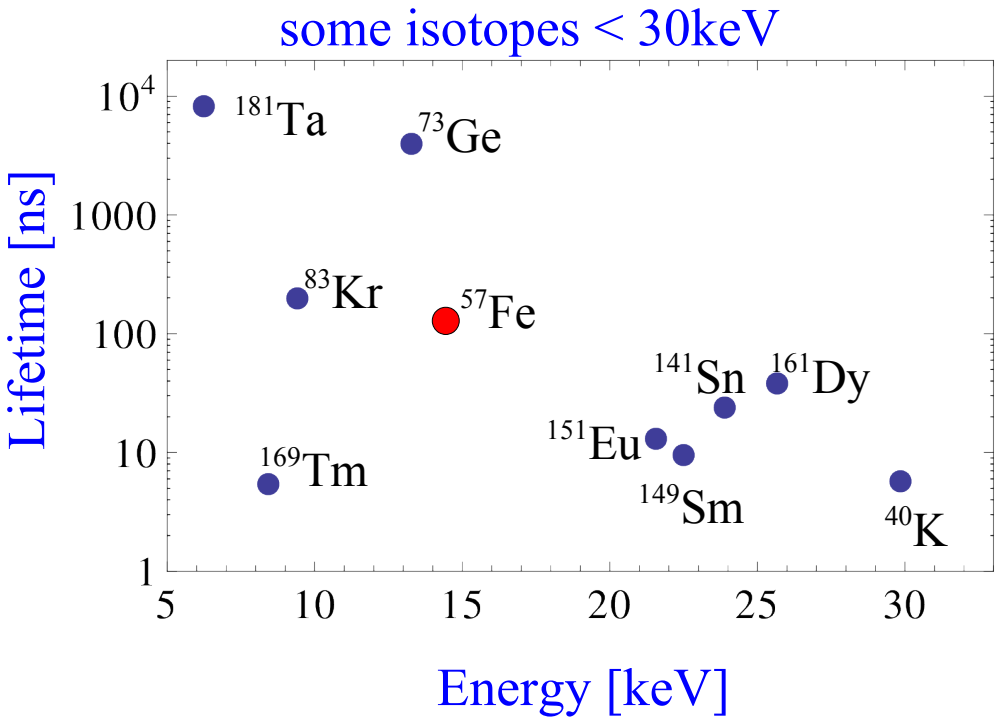
Nuclear quantum optics

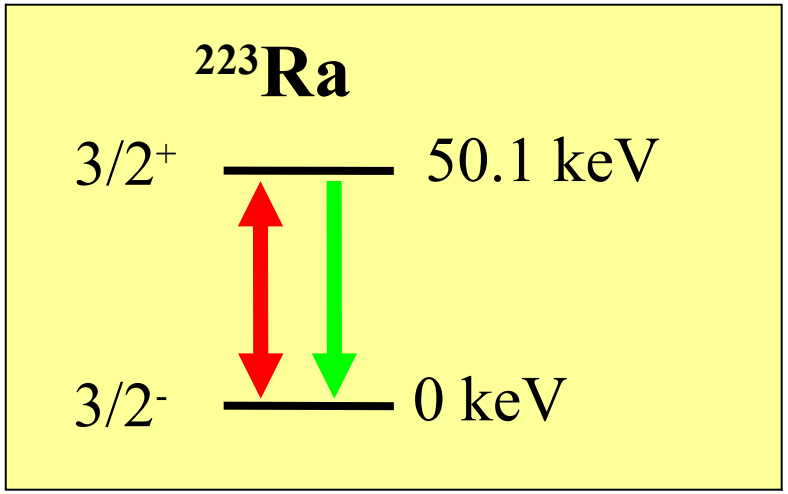
Nuclear transition energies



but many more with higher energies – use target acceleration!

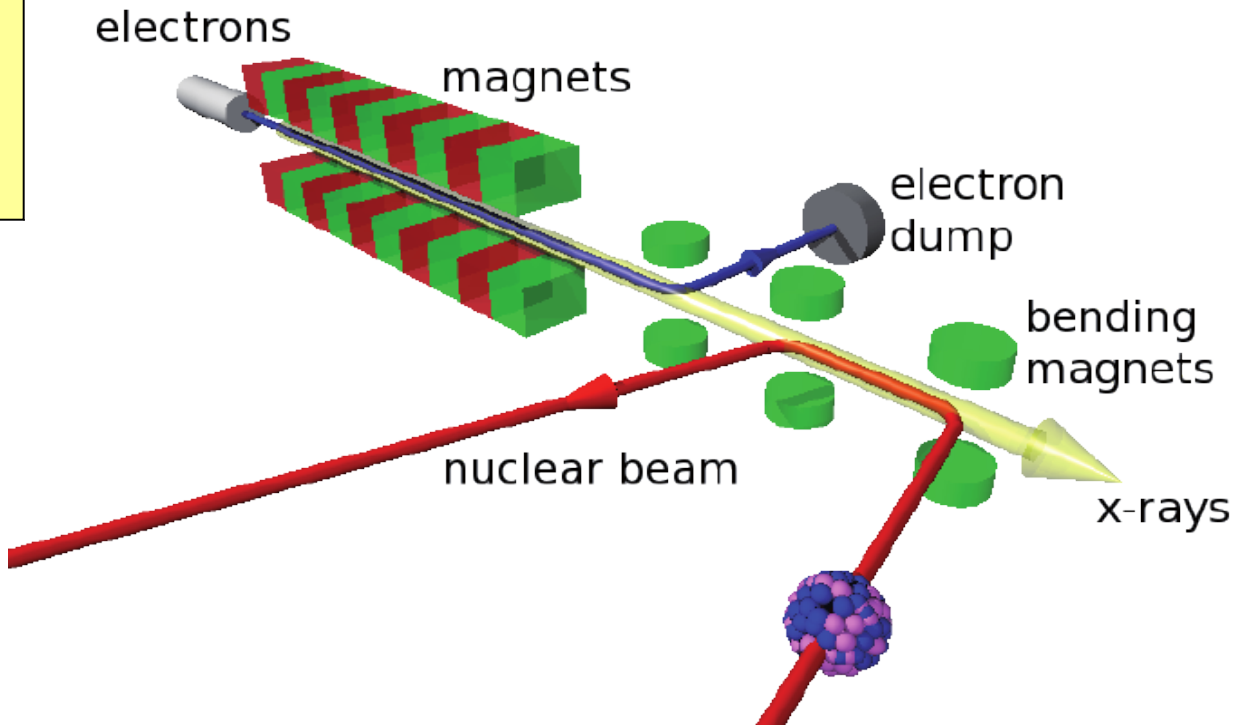
Accelerated nuclei as targets

bridge the gap between nuclear excitation and photon energies...



Doppler shift

$$E_n = (1+\beta)\gamma E_L$$



T. Bürvenich, J. Evers and C. H. Keitel, **PRL 96, 142501 (2006)**

Accelerated nuclei as targets

bridge the gap between nuclear excitation and photon energies...

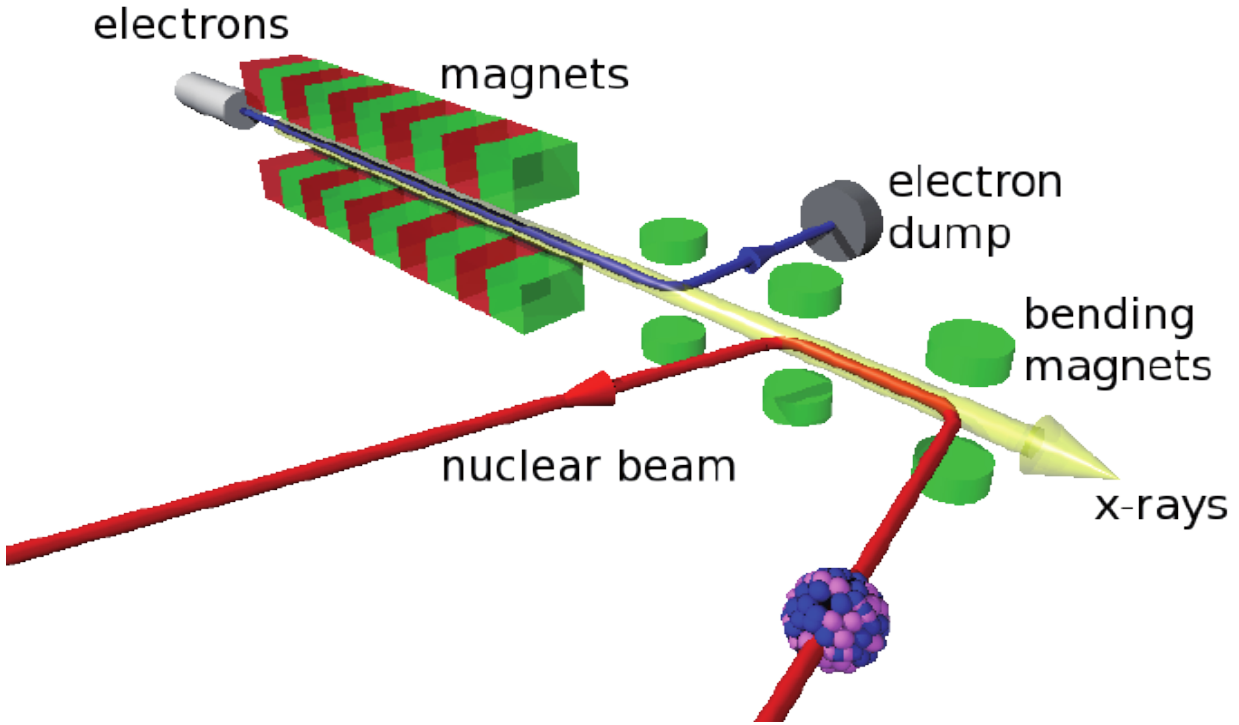
Doppler shift

$$\beta = \frac{v}{c} \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$t_b = \frac{t_l}{(1+\beta)\gamma}$$

$$I_b = I_l(1+\beta)\gamma$$

$$E_b = E_n = (1+\beta)\gamma E_l$$



T. Bürvenich, J. Evers and C. H. Keitel, **PRL 96, 142501 (2006)**

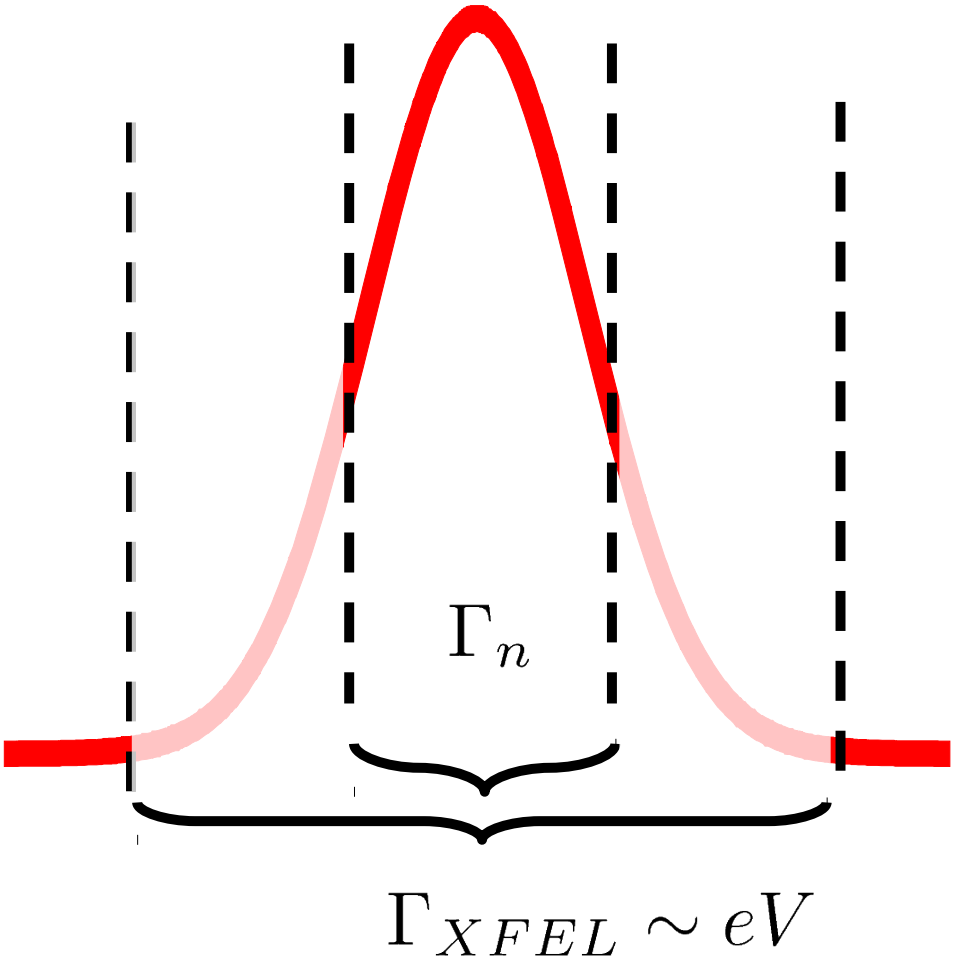
Nuclear transition widths

Nuclear widths are very narrow!

$$\Gamma_n \sim 10^{-8} - 10^{-5}\ eV$$

$$I_{eff} = I \frac{\Gamma_n}{\Gamma_{XFEL}}$$

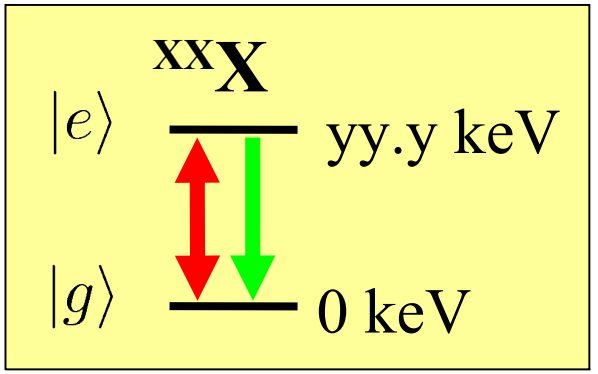
effective intensity!



Quantum optics approach

Density matrix formalism

$$\rho = |\Psi\rangle\langle\Psi| \qquad |\Psi\rangle = c_g|g\rangle + c_e|e\rangle$$



→ so-called Bloch equations

$$\frac{\partial \rho}{\partial t} = -\frac{i}{\hbar}[H_0, \rho] - \underbrace{\frac{\gamma_{SE}}{2}\left(A_{eg}A_{ge}\rho + \rho A_{eg}A_{ge} - 2A_{ge}\rho A_{eg}\right)}_{spontaneous \quad emission}$$

$$A_{ij} = |i\rangle\langle j|, \quad i,j \in \{e,g\}$$

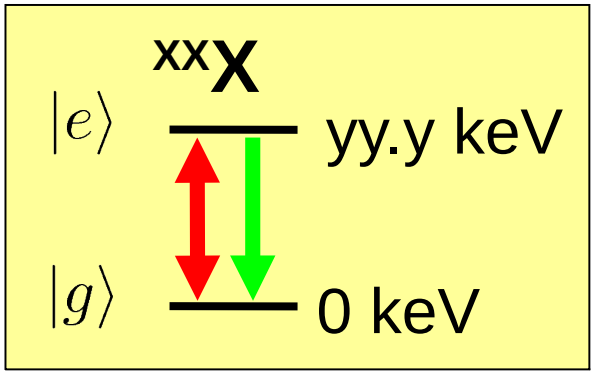
$$H_0 = -\frac{1}{c}\int d^3r \; \vec{j}(\vec{r}) \cdot \vec{A}(\vec{r},t)$$

AP, J. Evers and C. H. Keitel, **PRC 77, 044602 (2008)**

Nuclear transition might be “forbidden”

Atomic quantum optics – electric dipole E1 transitions

Low-lying nuclear transitions - M1, E2, rarely E1



$$\frac{\partial \rho}{\partial t} = -\frac{i}{\hbar}[H_0, \rho] - \underbrace{\frac{\gamma_{SE}}{2}\left(A_{eg}A_{ge}\rho + \rho A_{eg}A_{ge} - 2A_{ge}\rho A_{eg}\right)}_{spontaneous \quad emission}$$

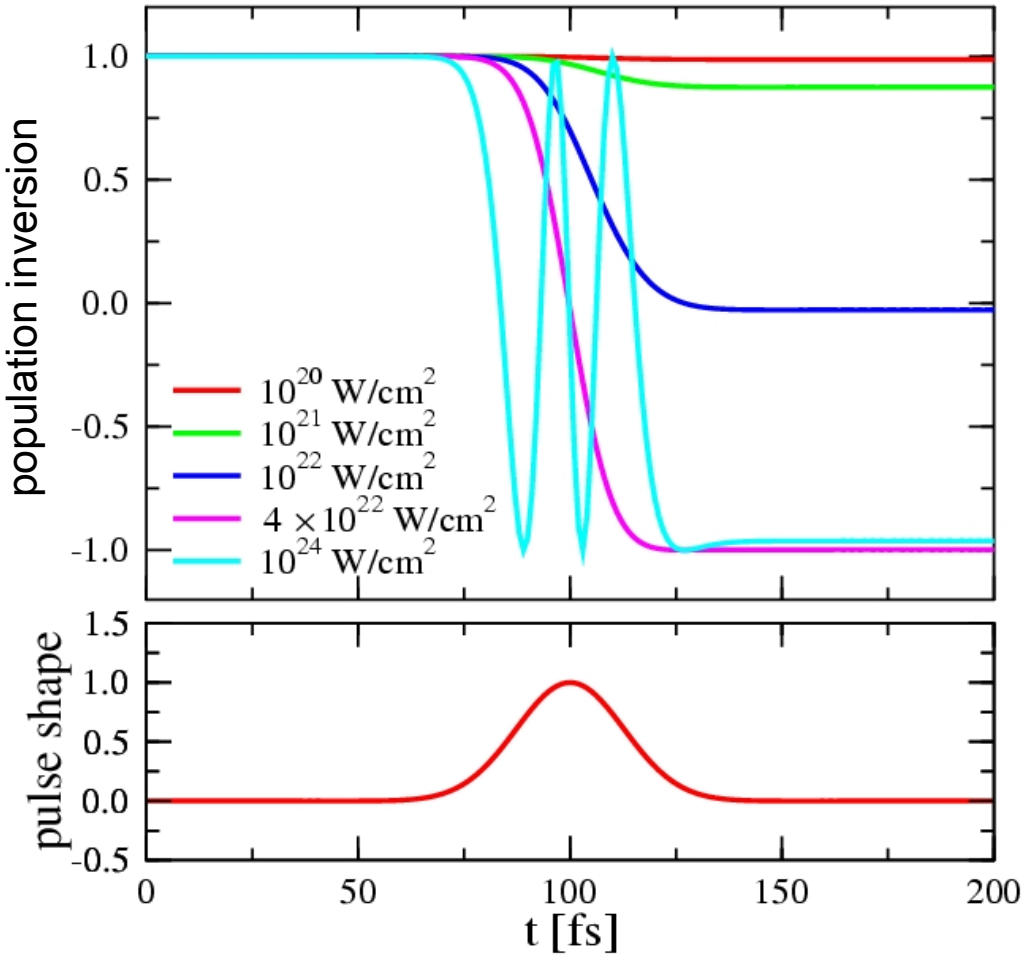
Beyond the dipole approximation!

$$A_{ij} = |i\rangle\langle j|, \quad i,j \in \{e,g\}$$

$$H_0 = -\frac{1}{c}\int d^3r \; \vec{j}(\vec{r}) \cdot \vec{A}(\vec{r},t) \propto \mathfrak{M}_{LM} \neq -e\vec{r}\cdot\vec{E}$$

AP, J. Evers and C. H. Keitel, **PRC 77, 044602 (2008)**

Nuclear Rabi flopping



Population inversion in ^{223}Ra

Population inversion ~

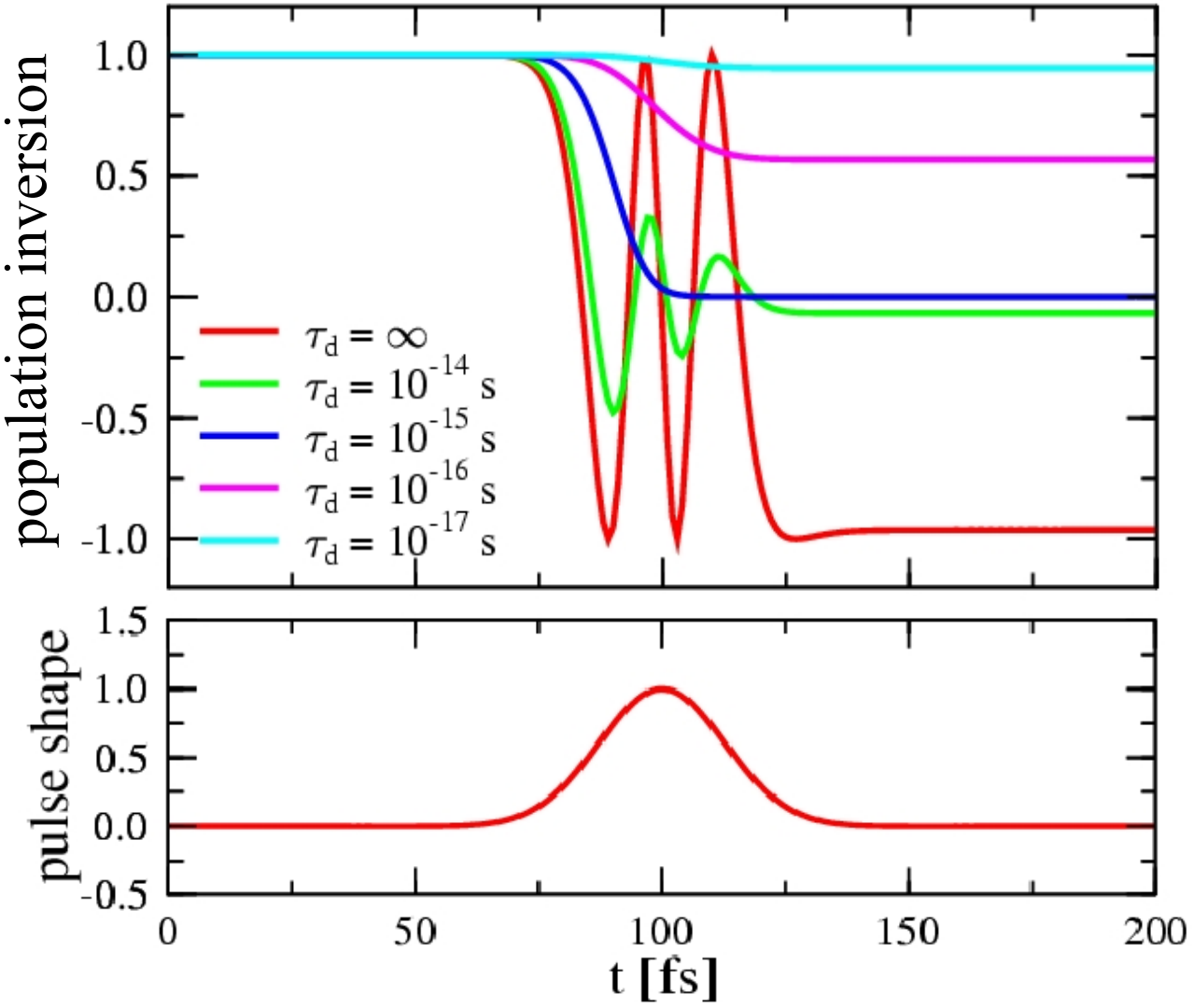
$$\langle g|\rho|g\rangle - \langle e|\rho|e\rangle$$

- resonant laser-nucleus interaction allows to induce Rabi flopping of nuclear population
- detection e.g. via scattered light, state-selective measurements
- potential application: model-free determination of nuclear parameters

T. Bürvenich, J. Evers and C. H. Keitel, Phys. Rev. Lett. 96, 142501 (2006)

Coherence in nuclear Rabi floping

coherence ⟷ intensity



strongly incoherent

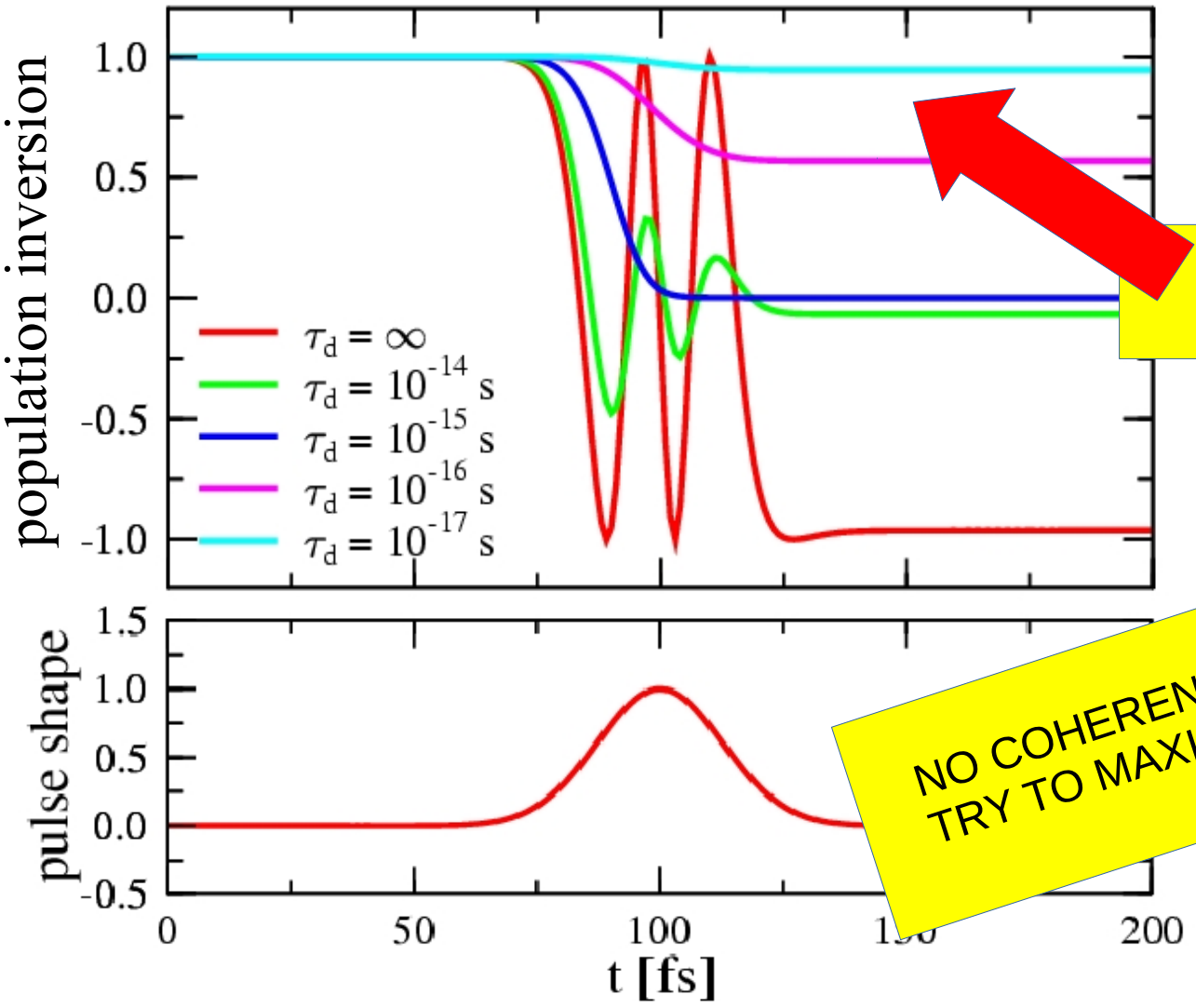
partially coherent

coherent

T. Bürvenich, J. Evers and C. H. Keitel, Phys. Rev. Lett. 96, 142501 (2006)

Coherence in nuclear Rabi floping

coherence ⟷ intensity



strongly incoherent

WE ARE HERE!

coherent

NO COHERENT EFFECTS YET
TRY TO MAXIMIZE EXCITATION

T. Bürvenich, J. Evers and C. H. Keitel, Phys. Rev. Lett. 96, 142501 (2006)