High Energy Density Electron Beam Production by Laser Longitudinal Electric Field

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Contents

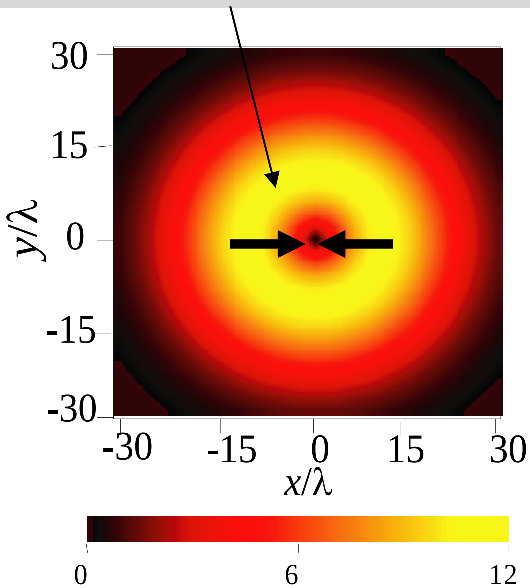
- High-energy and high-density electron beam generation by intense short pulse laser
- Electron acceleration by longitudinal laser electric field
- Scaling law of maximum electron energy

Laser field distribution

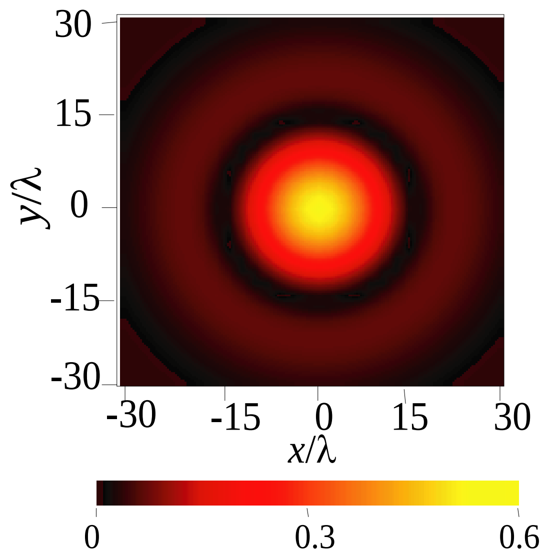
- **Field distribution of TEM_{10} + TEM_{01} mode laser**

Electron confinement by transverse ponderomotive force

Electron acceleration by longitudinal electric field



Transverse electric field $|E_r|$ normalized by $m_e \omega c/e$



Longitudinal electric field $|E_z|$ normalized by $m_e \omega c/e$

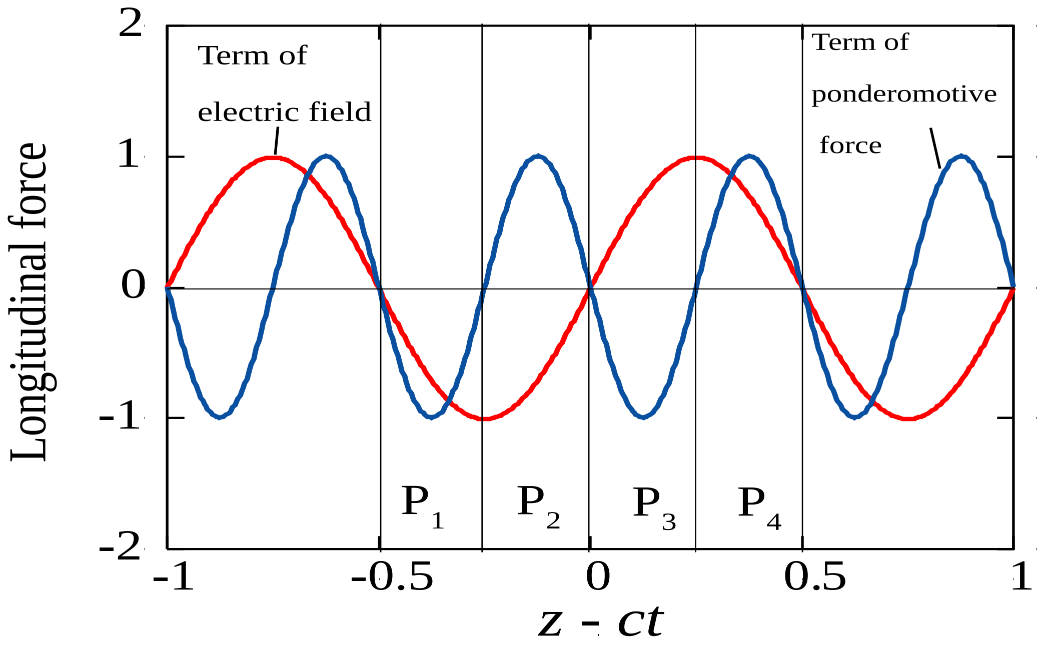
a_0=9, λ=0.8 μm, w_0=15λ

Acceleration mechanism

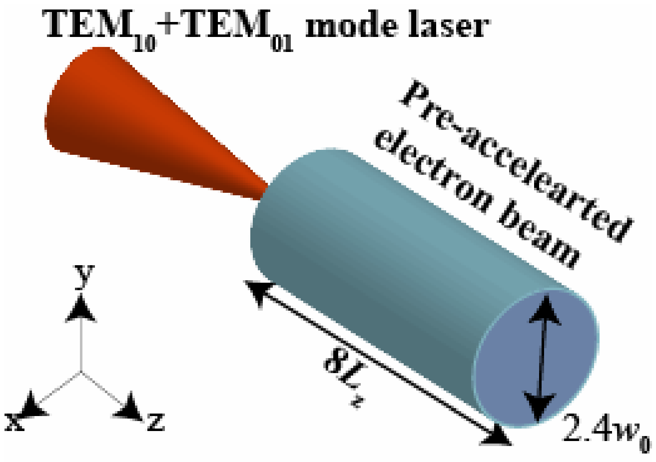
- **Phases of acceleration and deceleration**

Ponderomotive force: ~exp[2i(kz-ωt)]

Longitudinal electric field: ~$i$exp[i(kz-wt)]



Simulation model & Parameter values



- **Pre-accelerated electron beam parameter values**

  Initial density: $n_i = 10^{12}$ (cm^{-3})

  Initial energy: $\gamma_i \sim 6$

- **Laser parameter values**

  Intensity: $a_0 = eE_0 / (m_e \omega c) \sim 5$

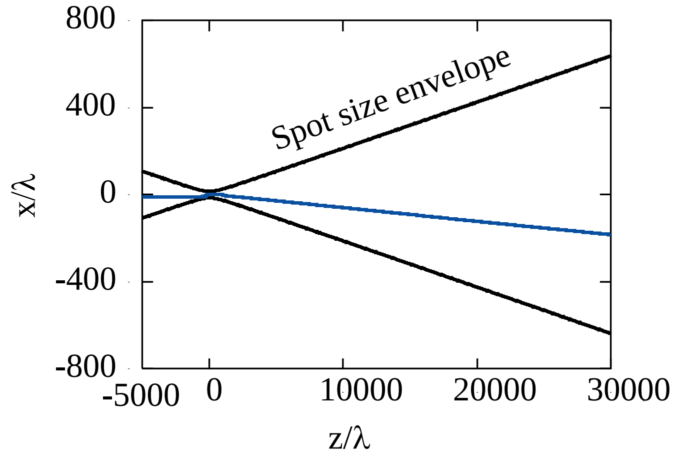
  Wavelength: $\lambda = 0.8$ (μm)

  Spot size: $w_0 = 15\lambda$ (FWHM)

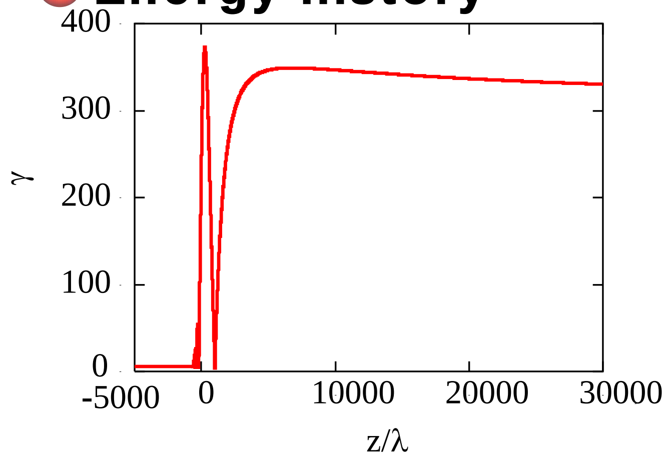
  Pulse length: $L_z = 5\lambda$ (FWHM)

Single electron acceleration

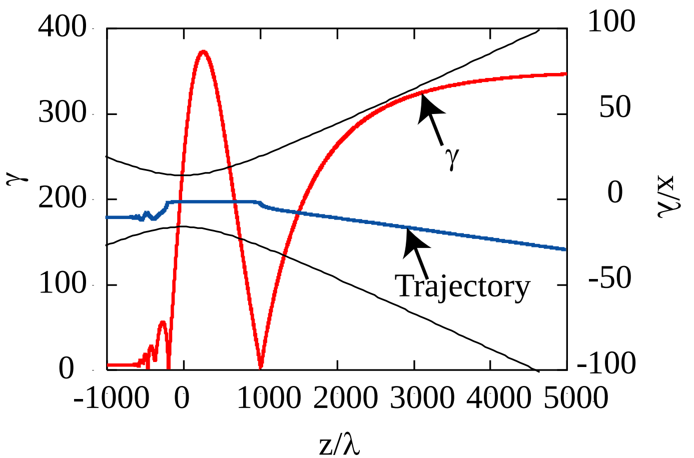
- **Electron trajectory**



- **Energy history**



- **Enlarged figure**

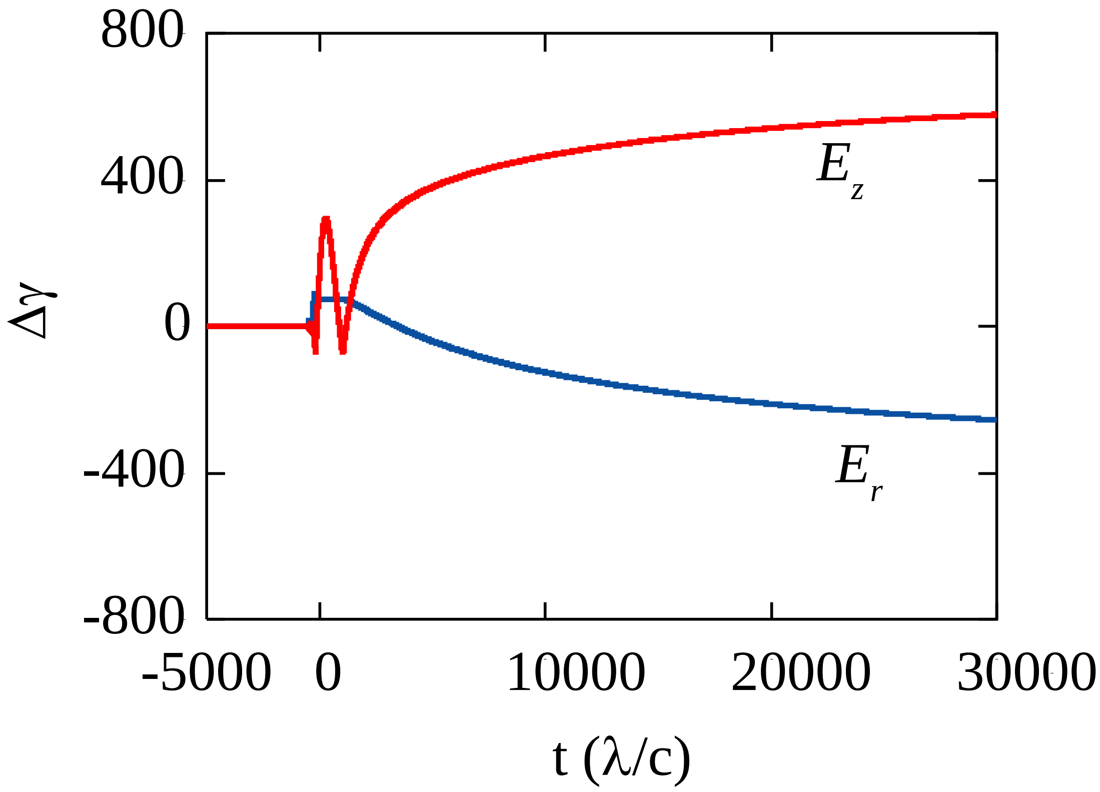


Maximum electron energy: ~160 (MeV)

Single electron acceleration

- **Energy equation**

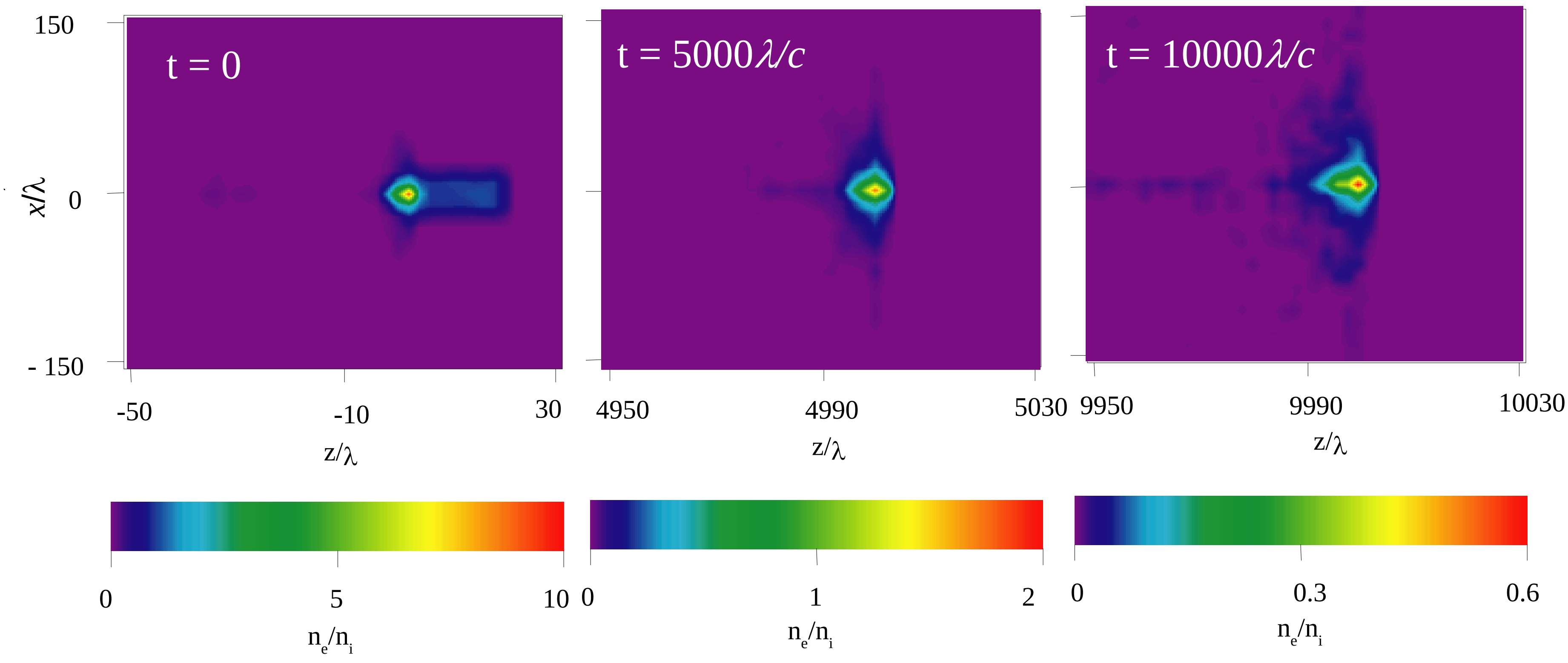
$$\Delta\gamma \sim \int_{-\infty}^{\infty} v \cdot E dt$$



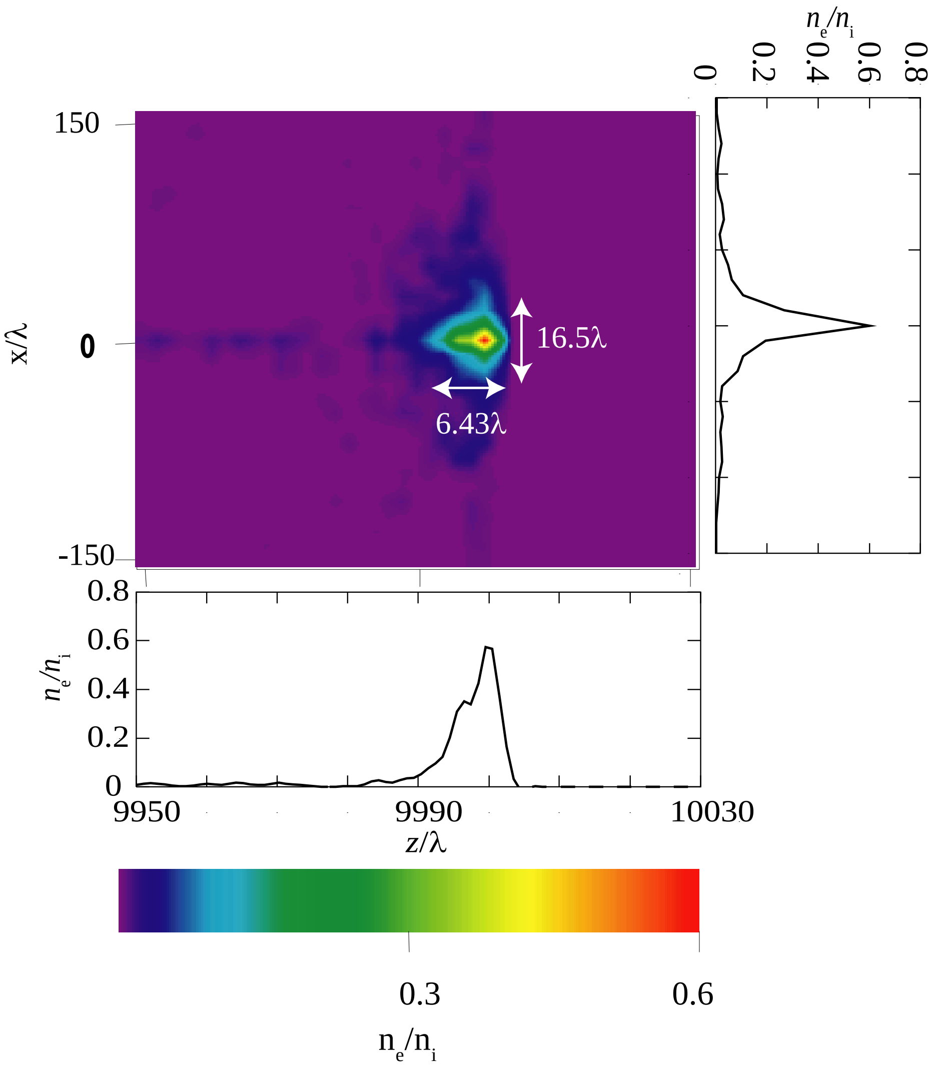
Acceleration by longitudinal electric field

Electron bunch acceleration

- **Electron density distributions**



Electron bunch acceleration



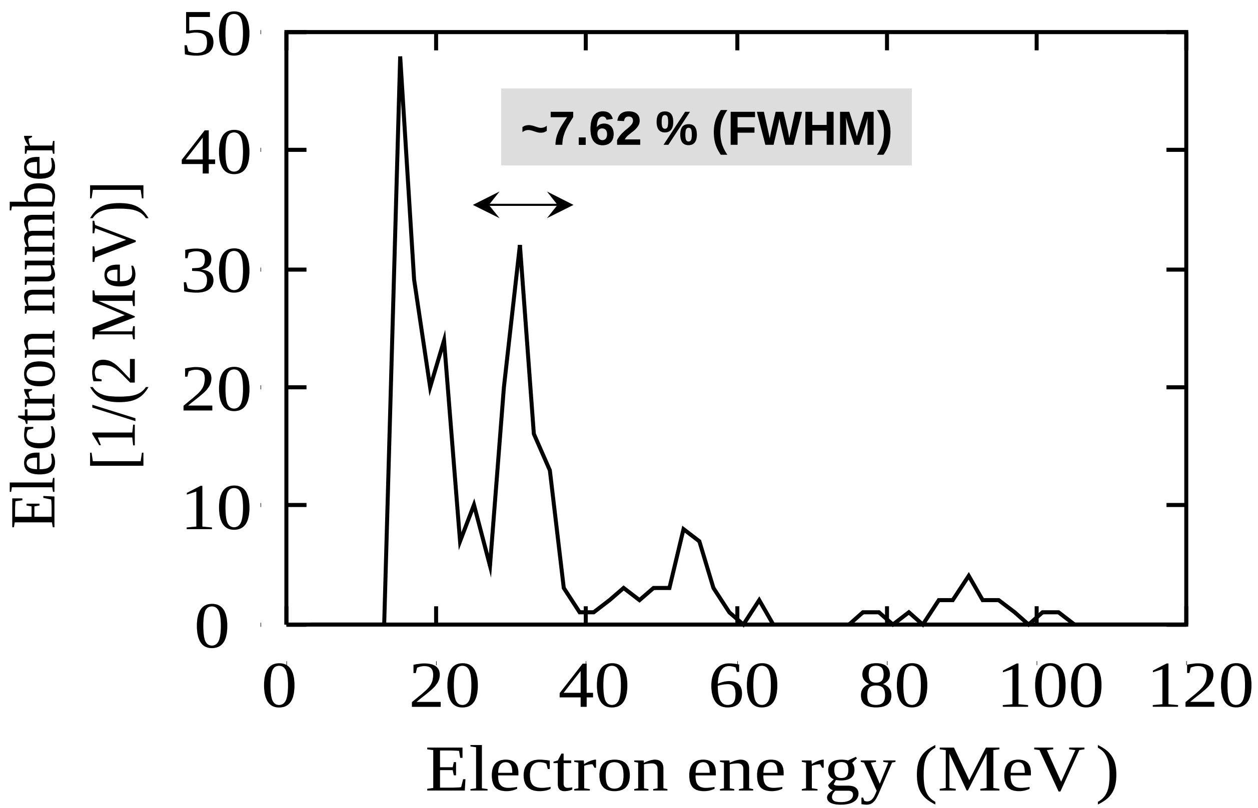
Bunch size
Transverse: 16.5λ
Longitudinal: 6.43λ

Averaged energy: ~31.7 (MeV)

Normalized transverse rms emittance: 0.472 (π mm mrad)

Electron bunch acceleration

- **Energy spectrum of electrons accelerated**



Electron energy estimation

- **Longitudinal electric field at the central axis**

$$E_z \sim \frac{4\sqrt{2}w_0}{kw(z)^2}E_0$$

- **Interaction length and electron energy gain in phase P_4**

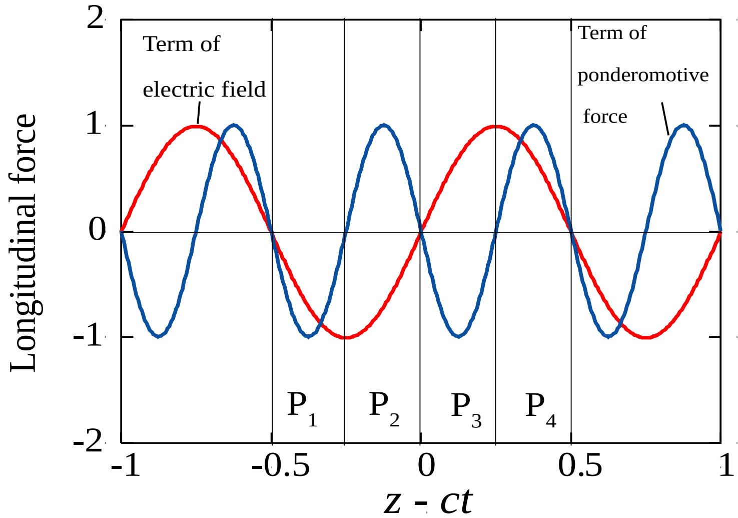
$$l_1 \sim \lambda/[4(1-\sqrt{1-1/\gamma_i^{\ 2}})]$$

$$\gamma_1 \sim \gamma_0 + 2(1+e^{-1/2})\pi a_0 w_0 \tan^{-1}\left[l_1/z_R\right]$$

- **Interaction length and electron energy gain in phase P_3**

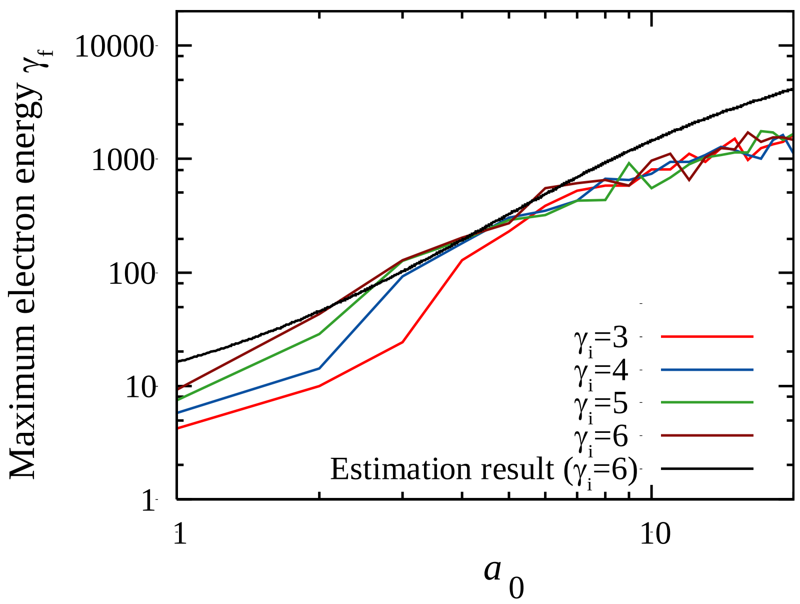
$$l_2 \sim \lambda/[4(1-\sqrt{1-1/\gamma_1^{\ 2}})]$$

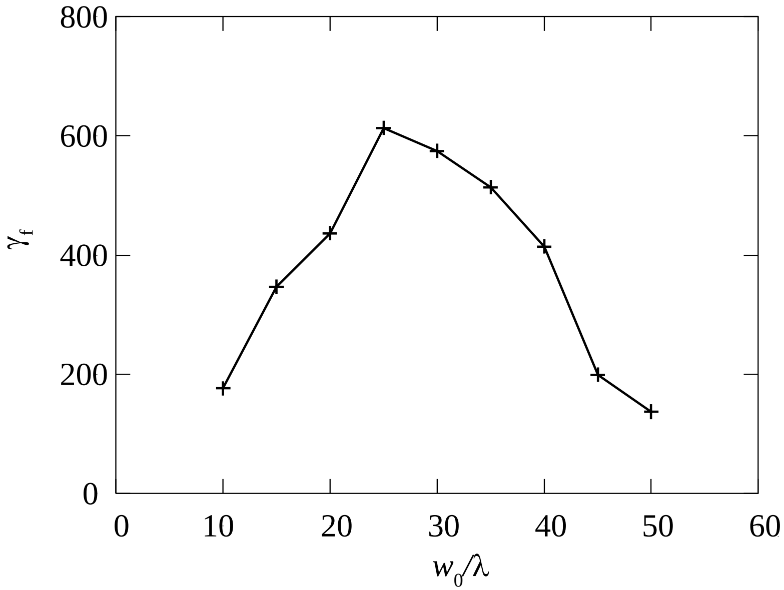
$$\gamma_1 \sim \gamma_0 + 2(1+e^{-1/2})\pi a_0 w_0 \tan^{-1}\left[l_2/z_R\right]$$

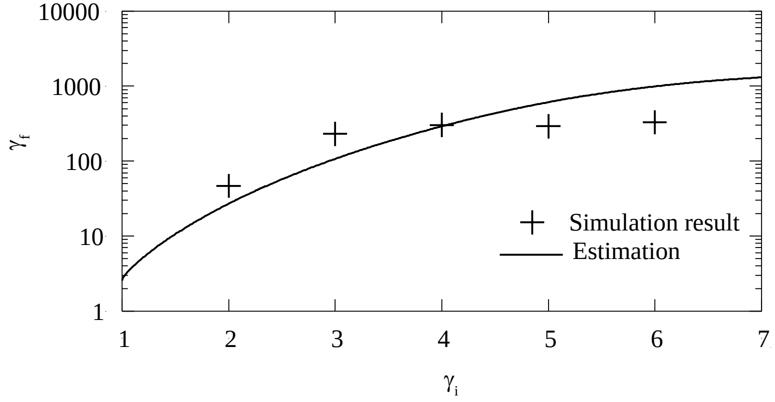


Acceleration in Phases P_3 and P_4

Electron energy estimation and parameter study







The maximum electron energy decreases with the increase of the laser spot size

Conclusions

- **High energy density electron beam generation by intense short pulse laser**
  - Electron confinement by transverse ponderomotive force
  - Electron acceleration by longitudinal electric field
  - Generation of high-energy & high-density electron bunch
  - Low energy spread (<10 %)
  - Scaling law of maximum electron energy