MOOT06

レーザー駆動誘電体加速器の設計

DESIGNING OF THE LASER DRIVEN DIELECTRIC ACCELERATOR

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A)KEK,　B)東大原子力,　C)コッククロフト研

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第10回日本加速器学会年会

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Low-dose Radiation Risk

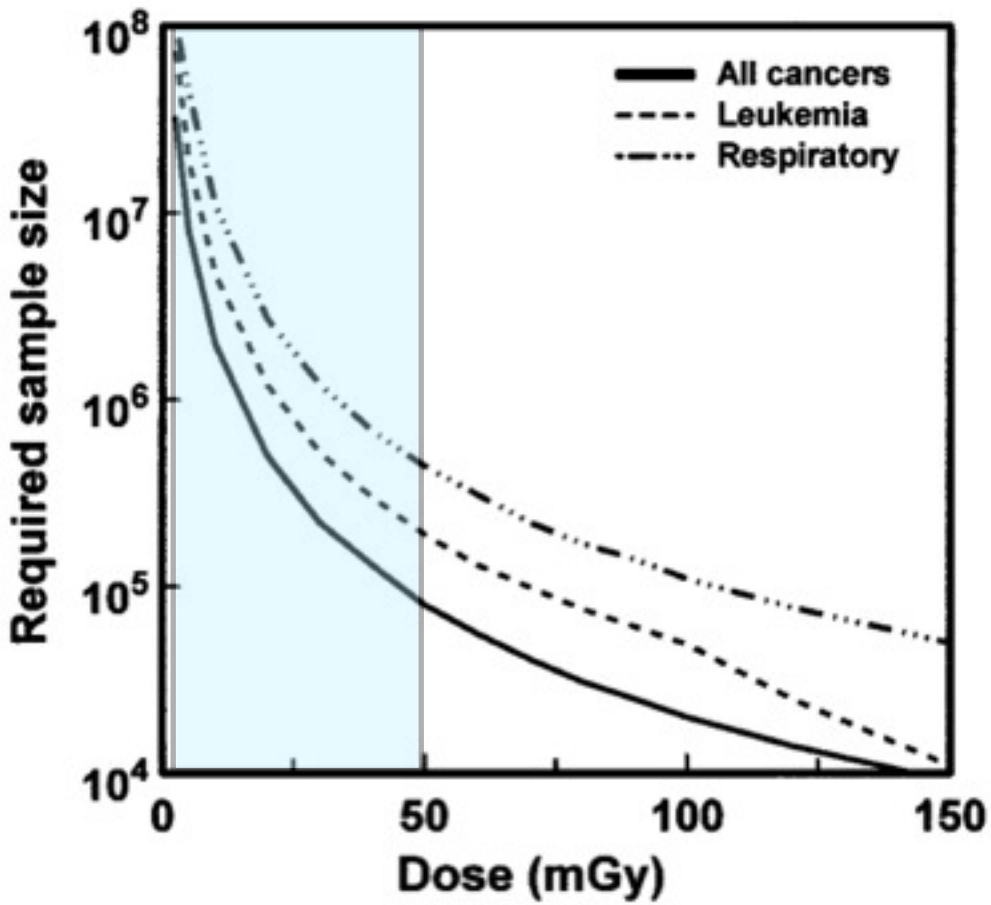


Fig. 1. Size of a cohort exposed to different radiation doses, which would be required to detect a significant increase in cancer mortality in that cohort, assuming lifetime follow-up (9).

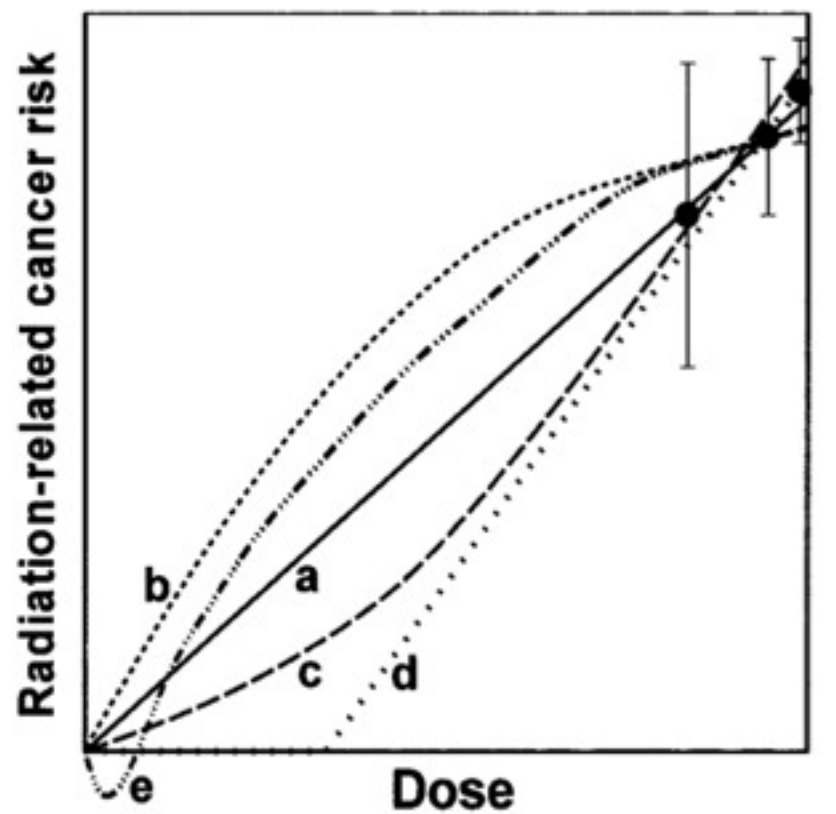


Fig. 3. Schematic representation of different possible extrapolati measured radiation risks down to very low doses, all of which co principle, be consistent with higher-dose epidemiological data. Curve a, extrapolation; curve b, downwardly curving (decreasing slope); curve wardly curving (increasing slope); curve d, threshold; curve e, hormeti

Brenner, D. J. ,et al., "Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know", PNAS **100**, 13765 (2003).

Requirements

Electron / X-ray is much easier to make the compact source.

Energy deposition ; LET(linear energy transfer) e/x < ion

LET(keV/μm) <1 ; >100

The beam size (irradiation area) is smaller than 1 μm.

The charge is 0.01 fC to 0.1 fC. (≈ 10^2 - 10^3 electrons/μm^2)

The beam energy is several tens keV to 1 MeV.

The pulse width is sub fs. (μ^3-bunch)

The exit of the accelerator and specimen are observed through the transparent window.

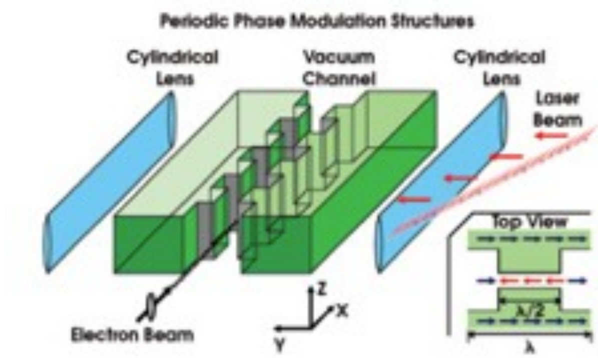
A laser-driven dielectric accelerator, i.e. photonic crystal accelerators, makes it possible to realize a tabletop/mobile system.

Structures of PCA

Phase Modulation Masked Structure

Silica, λ=800nm, *Ez=830 MV/m*

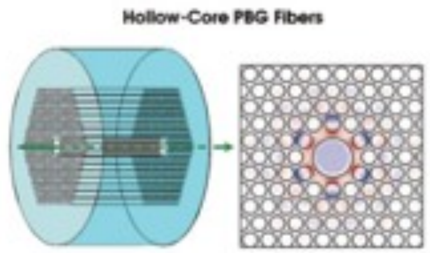
T. Plettner, *et al, PRST−AB,* **9**, 111301 *(2006).*



Wave Guiding Structures

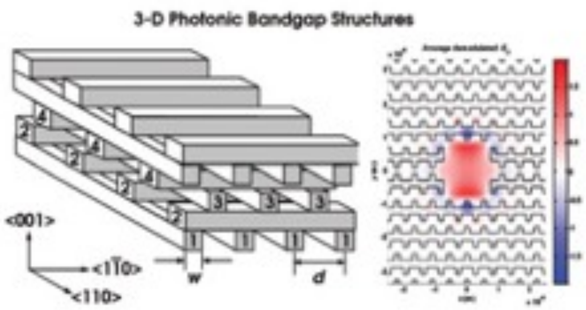
Silica, λ=1890 nm, *E =400 MV/m*

X. Lin, *PRST−AB,* **4**, 051301 (2001).

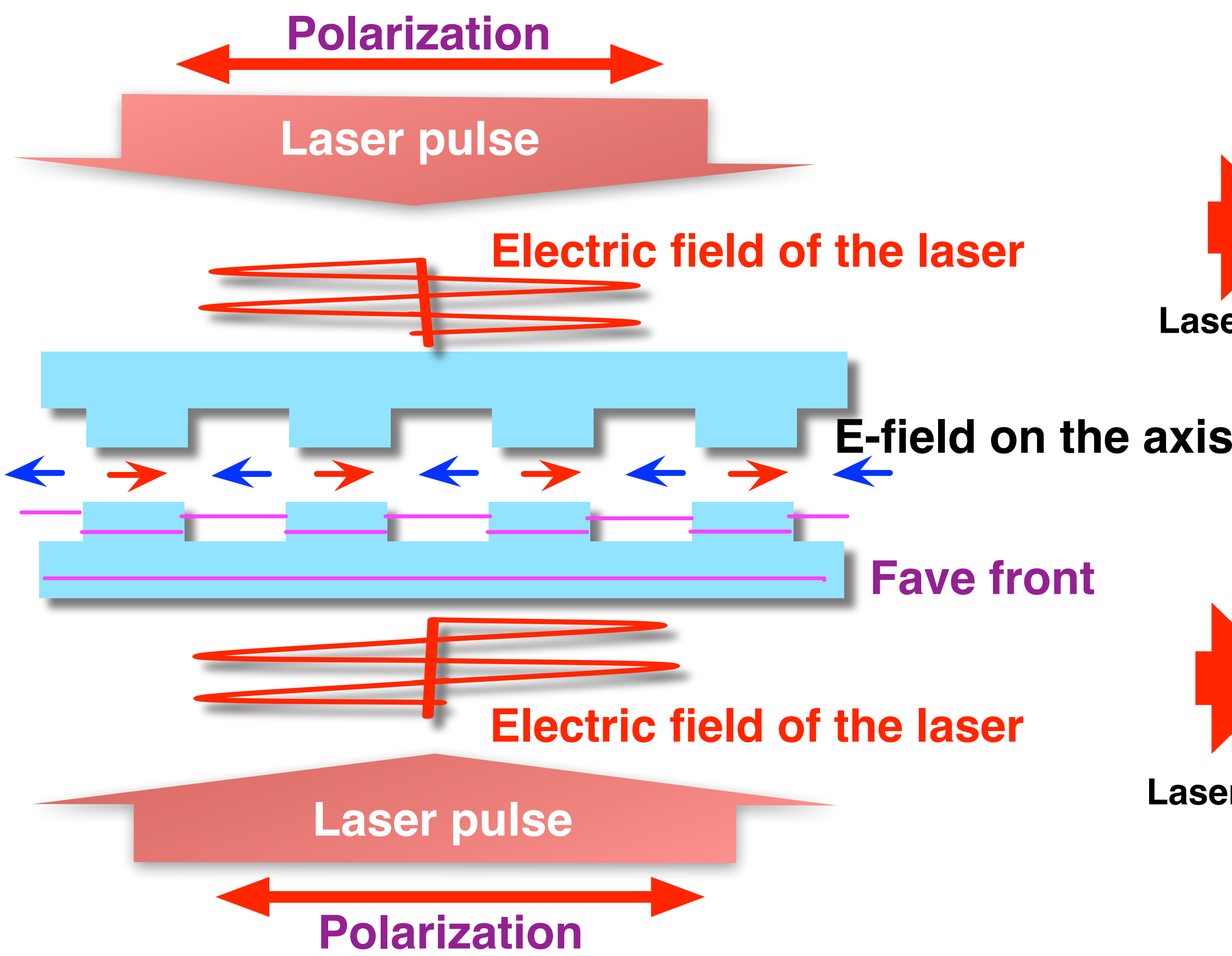


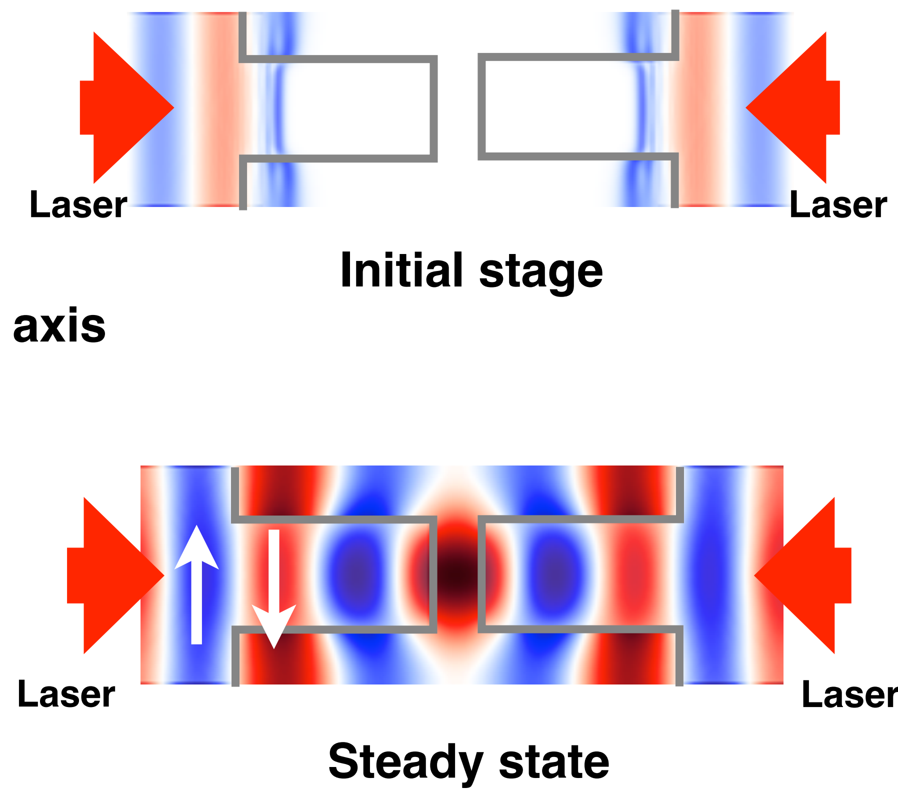
Silicon, λ=2200nm, *Ez=400 MV/m*

B. Cowan, *et al*, *PRST−AB,* **11**, 011301 (2008).



Alternate Direction of the Field is Produced by the Optical Path-difference



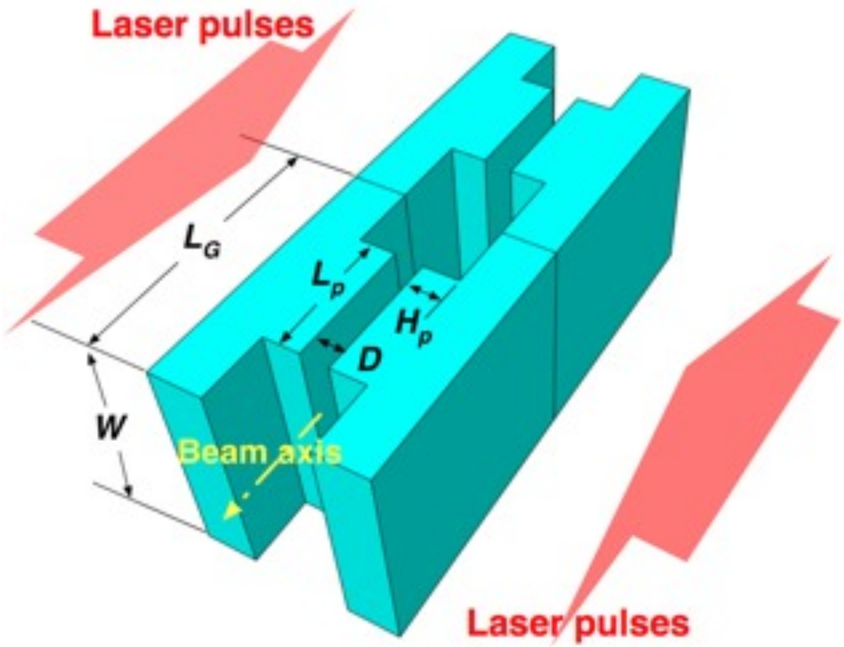


Summary of Analytical Consideration

$$L_G = 2L_P$$

$$\frac{H_P}{\lambda_L} = \frac{1}{2(n-1)}$$

$$D \leq \frac{2L_P^2}{N\lambda_L}$$



$$L_G \leq \lambda_L$$

$$v_0/c = L_G/\lambda_L$$

If the initial electron is non-relativistic, the grating constant must be gradually changed from small value to the laser wavelength.

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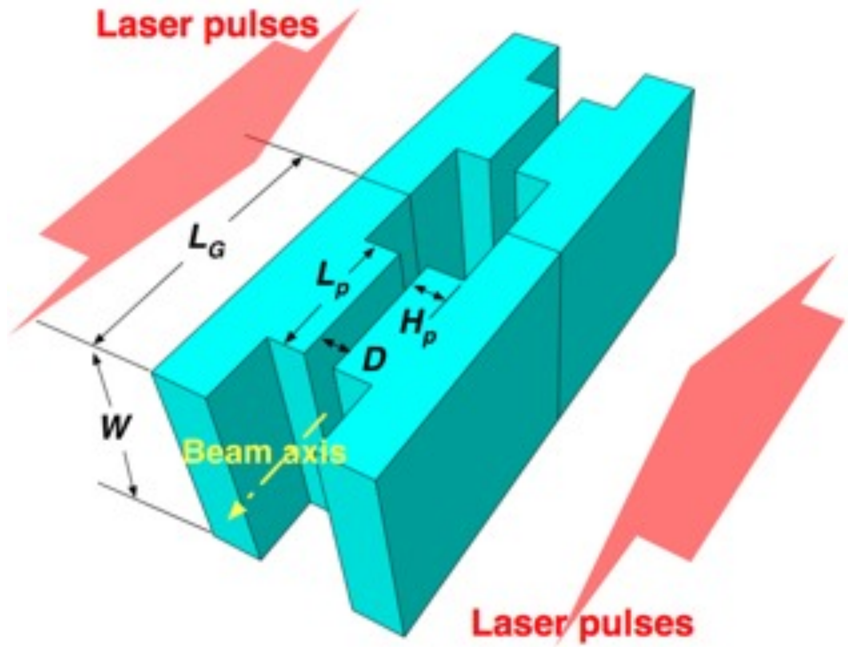


If the initial electron is non-relativistic, the grating constant must be gradually changed from small value to the laser wavelength.

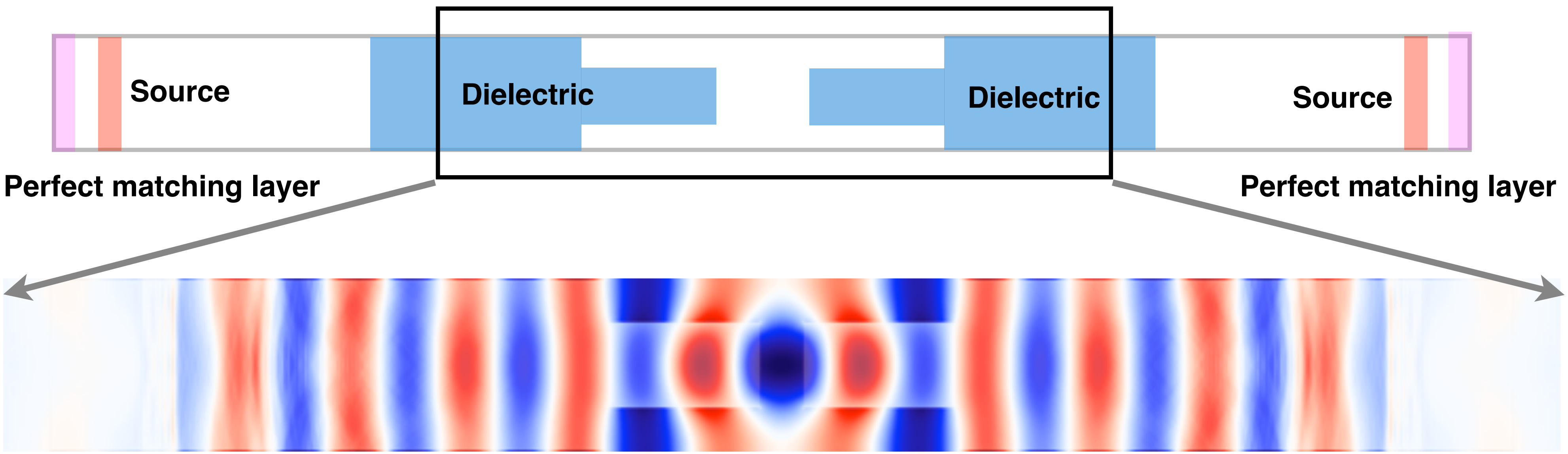
In a real situation, the refractive and interference effects deform the field structure.
The asymmetry of the field, higher harmonics of the field relaxes the matching condition. → **Numerical simulation**

FDTD-simulation

FDTD (Finite-Difference Time-Domain method)

simulation software package developed at MIT to model electromagnetic systems.

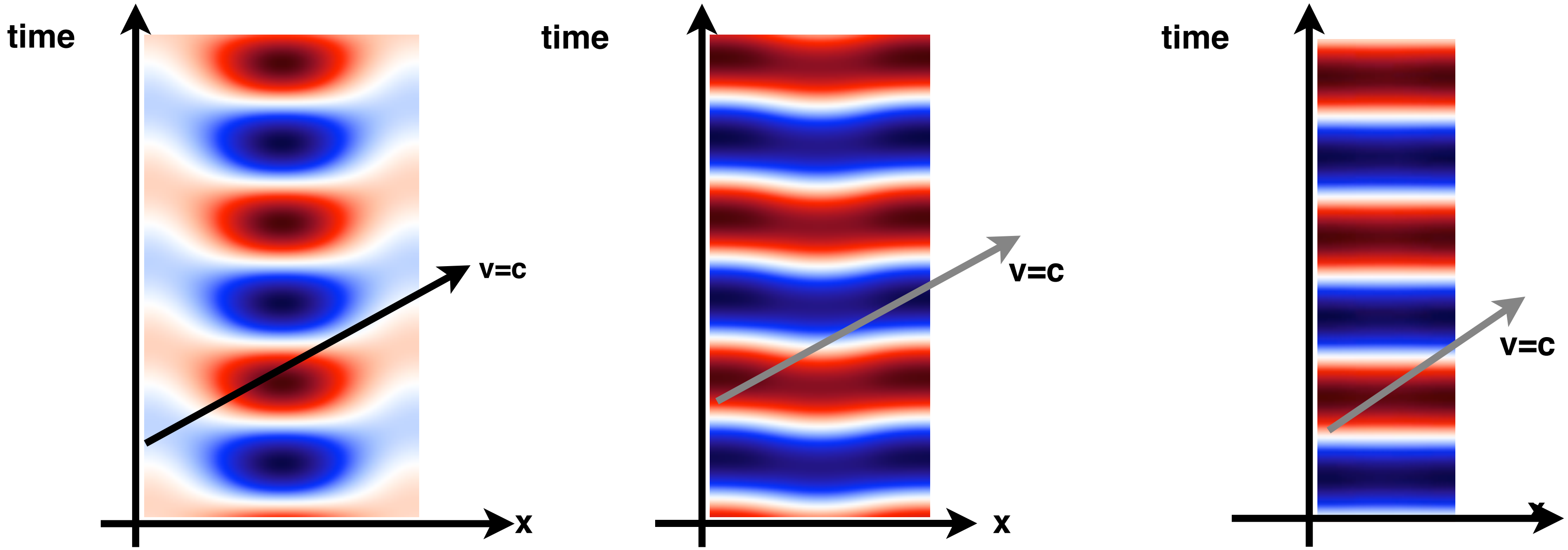
http://ab-initio.mit.edu/wiki/index.php/Meep



Intensity of the laser pulse ; $I_L = 10^{13} W/cm^2$ (8.7GV/m) on entrance surfaces of dielectric.
Laser wavelength ; $\lambda_L = 1.55\ \mu m$.
Channel width ; $D = \lambda/4 = 0.39 \mu m$
Pillar hight ; ($Hp = 0.9\lambda = 1.5 \mu m$) varied.

Acceleration field along the axis

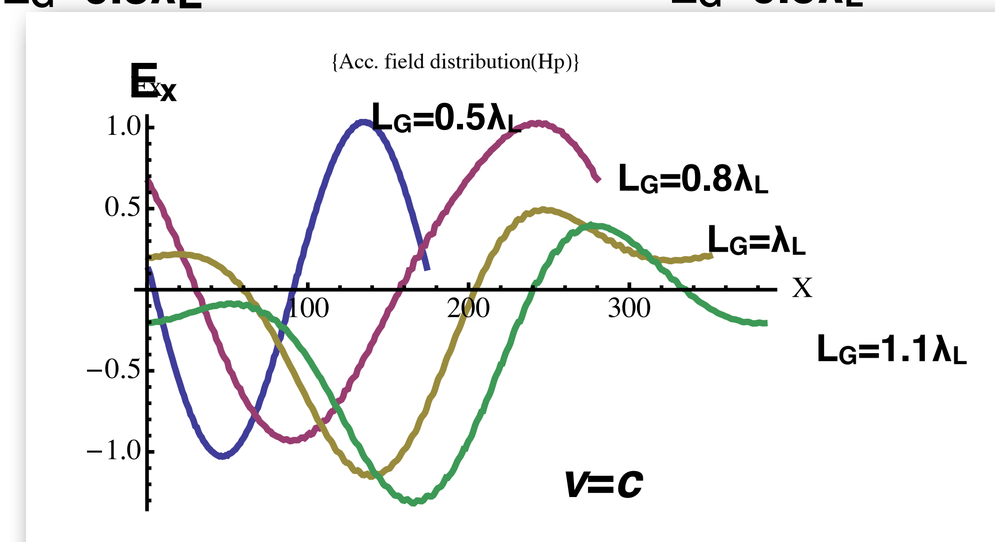
Field strengths in *xt*-space for different grating constants



$L_G=\lambda_L$ $L_G=0.8\lambda_L$ $L_G=0.5\lambda_L$

$$E_{acc} = \frac{1}{L}\int_0^L E_x\left(x,t\right)dx$$

$$x = vt + x_0$$



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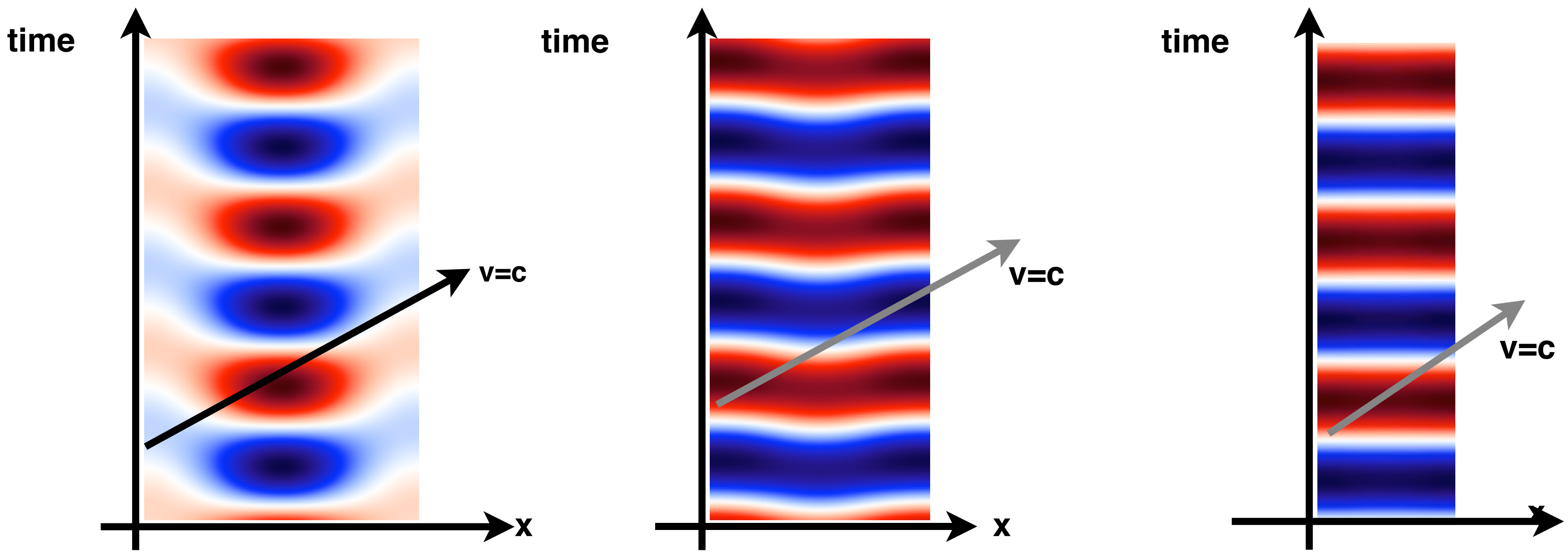

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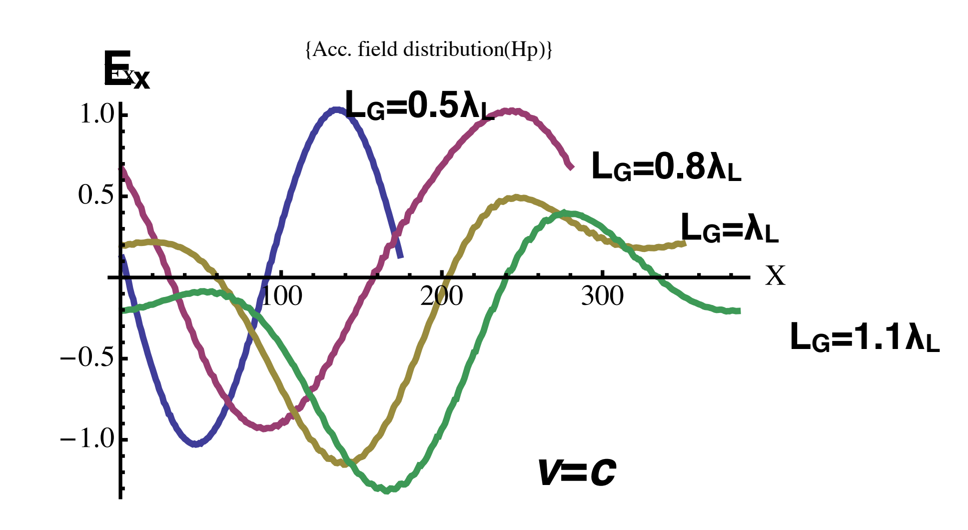
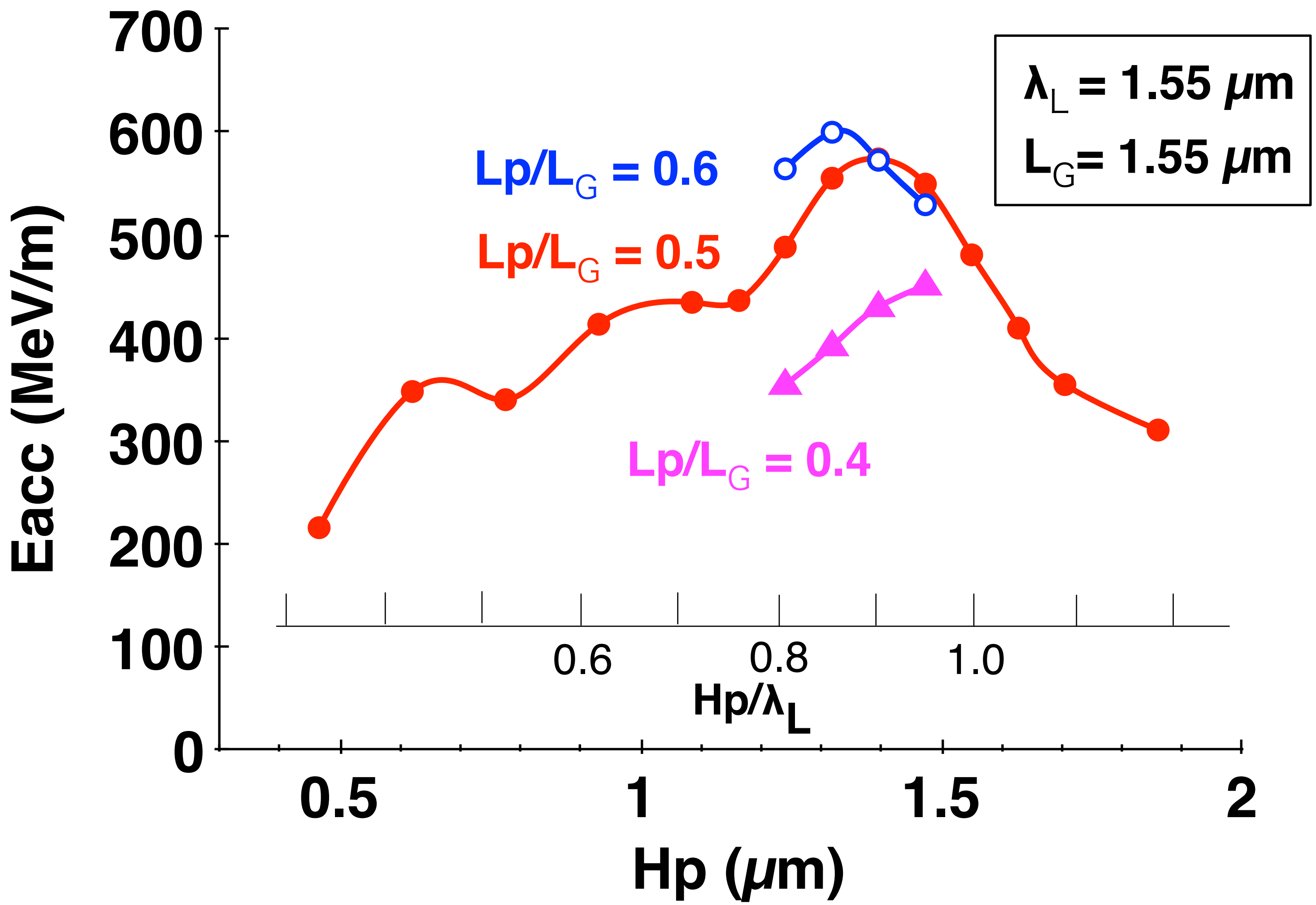
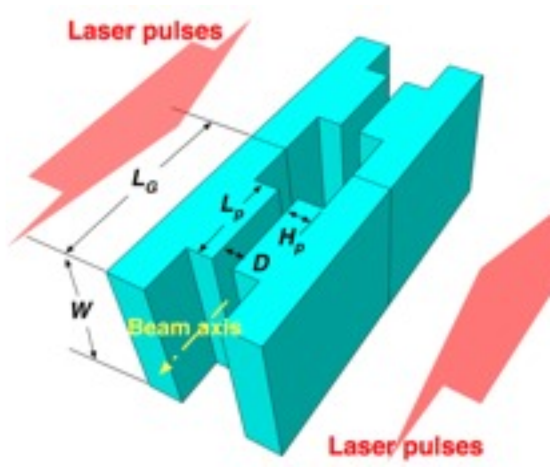


very sensitive to the initial phase of the injection

Optimum Pillar Hight

$I_{th}=10^{13}$ W/cm^2 (1 J/cm @ 100fs) ; E_{th}= 8.7 GV/m is assumed.





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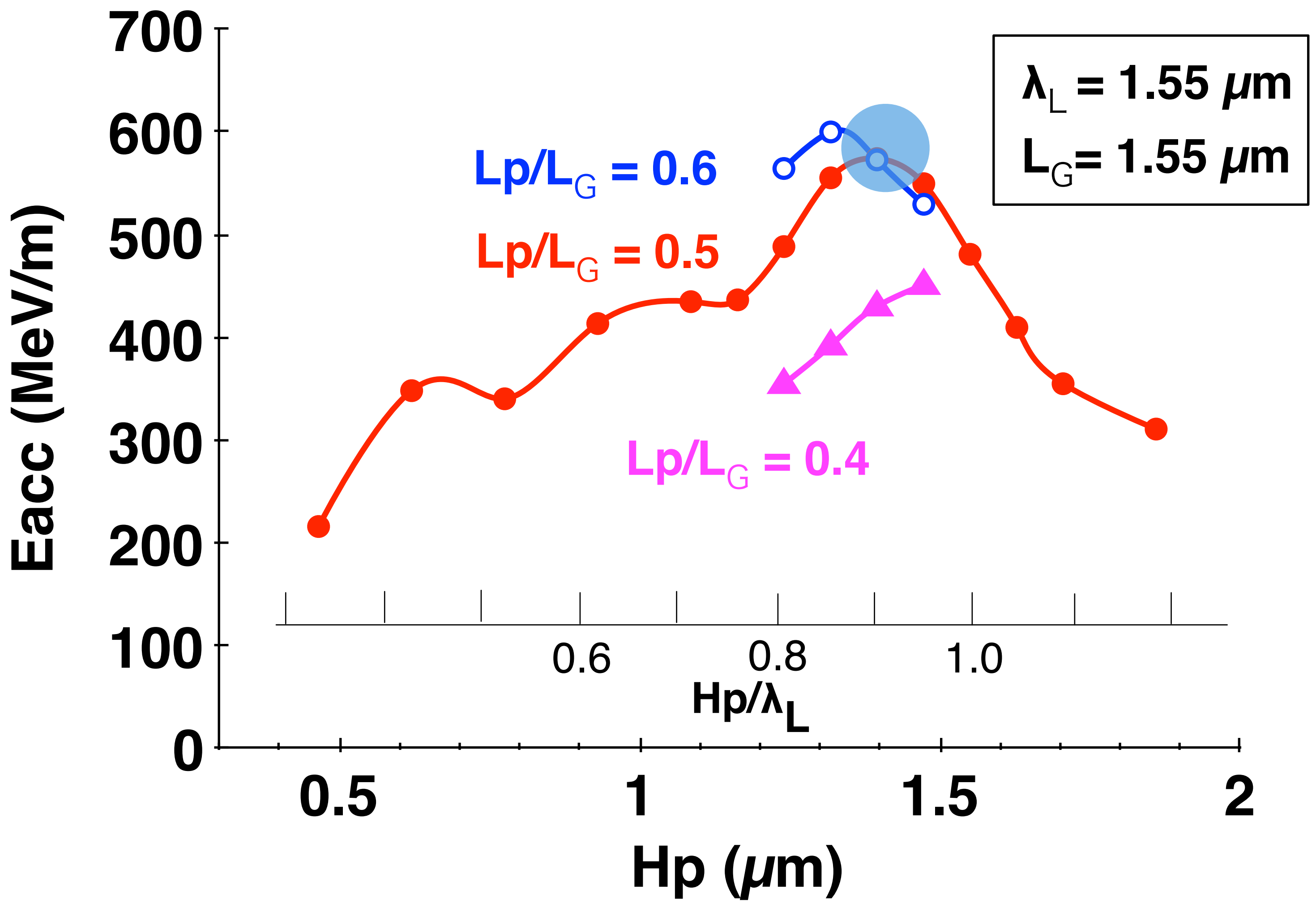
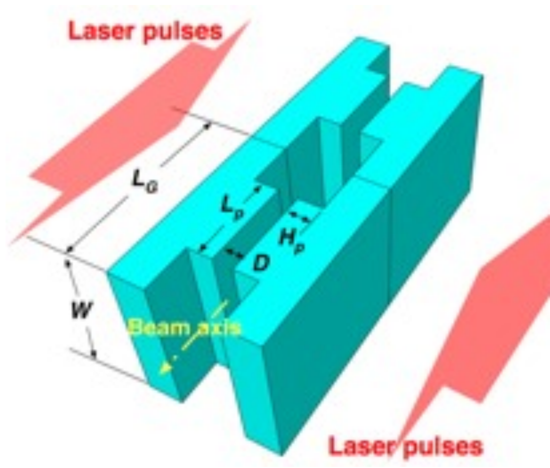
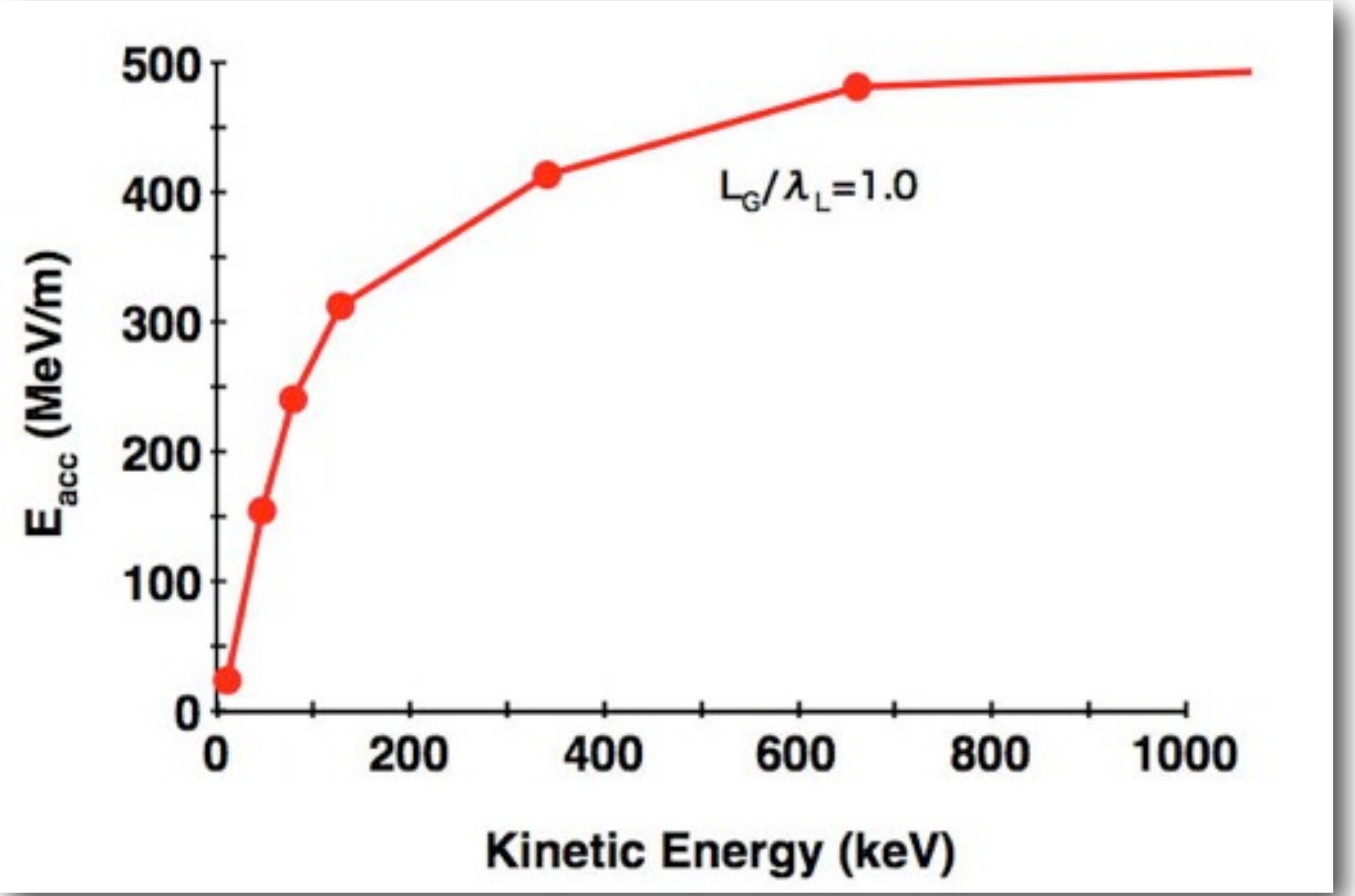




Optimum parameters of the structure are
$L_p/L_G \approx 0.5$ and $H_p/\lambda_L \approx 0.9$.

Acceleration from the low energy in the constant grating period



K. KOYAMA, *et al.* The 10 th Annual Meeting of Particle Accelerator Society of Japan, Nagoya University, 3-5, Aug. 2013

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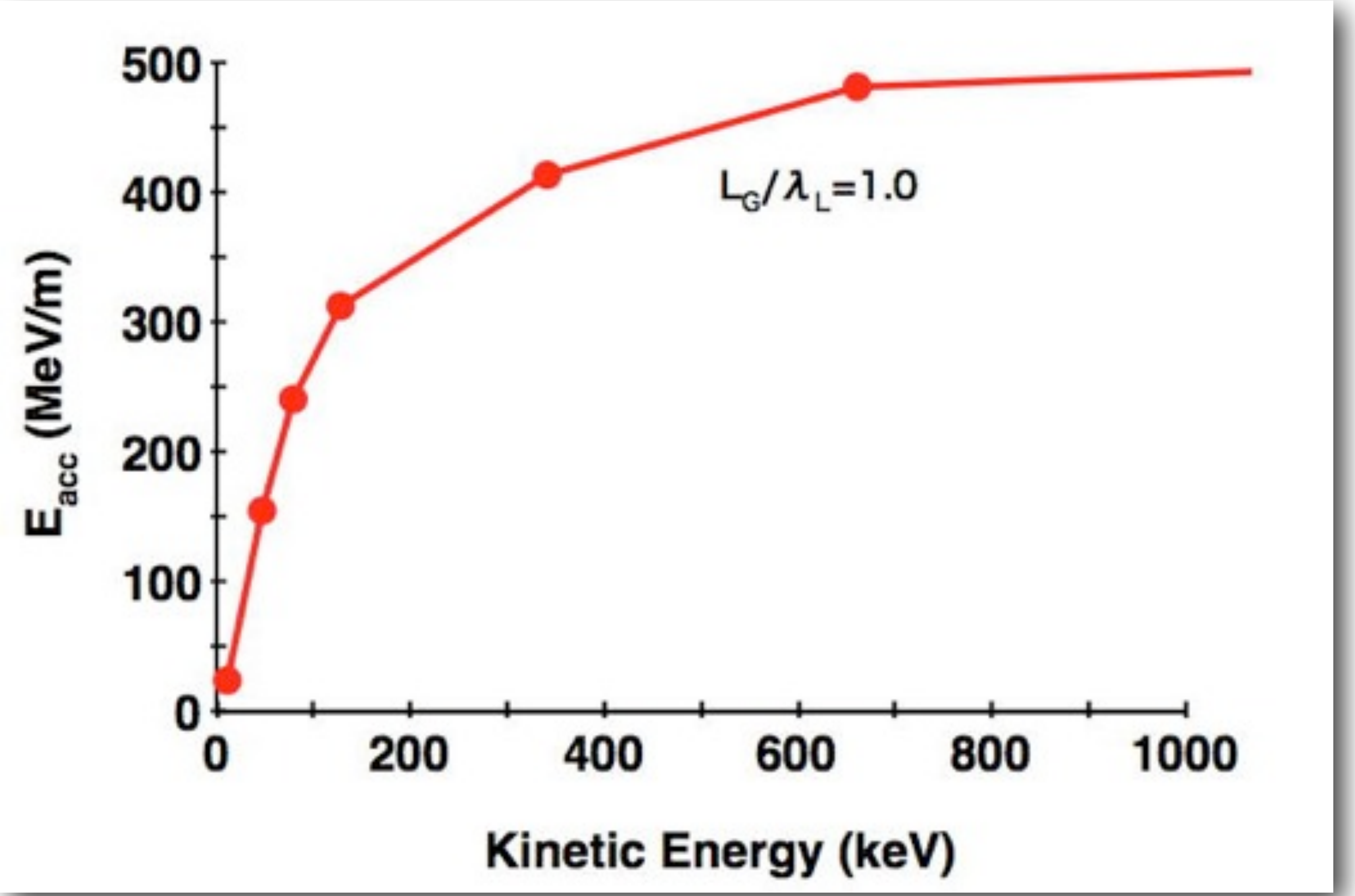

Slow electron can be accelerated even if the period is constant.

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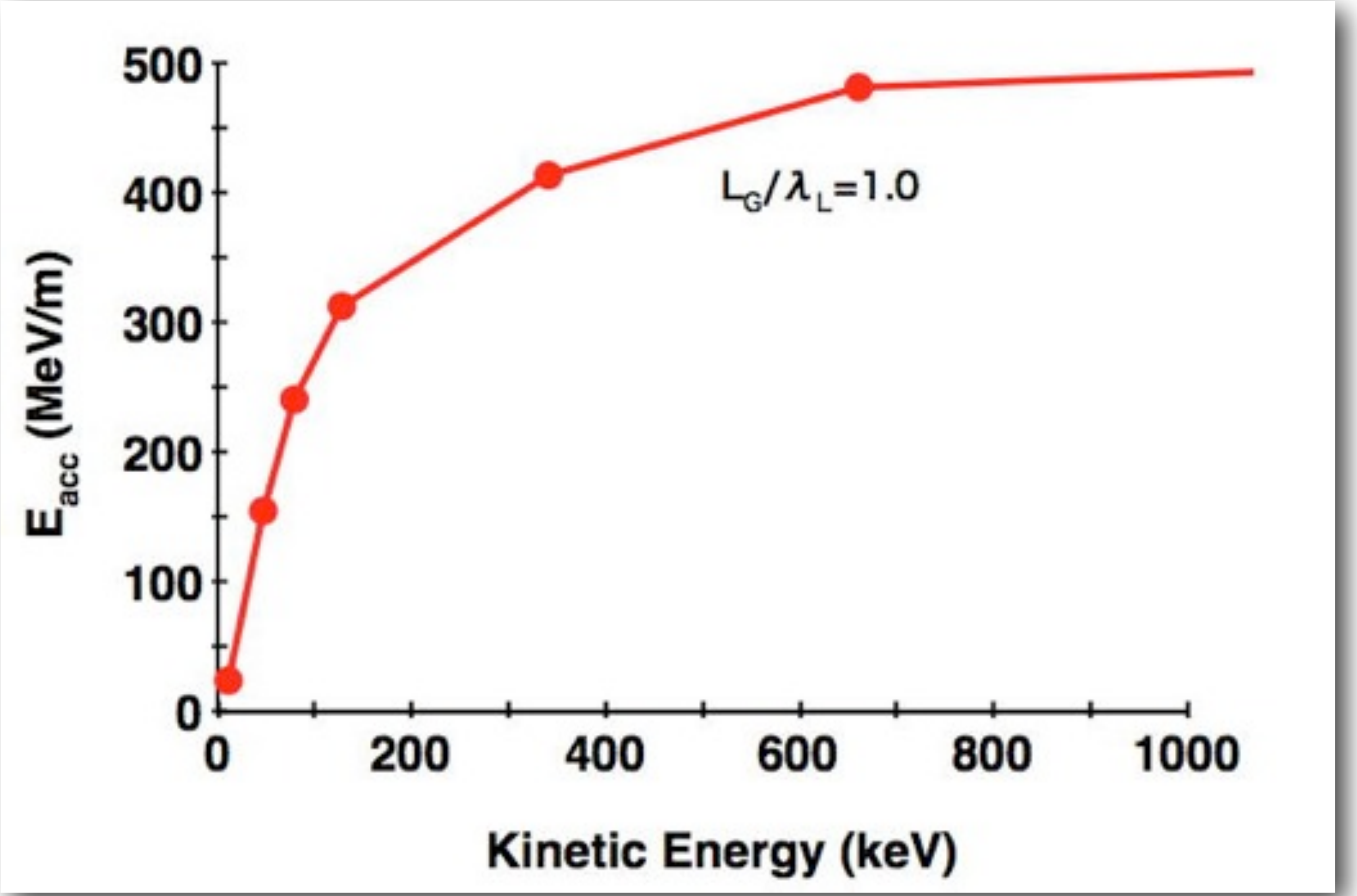


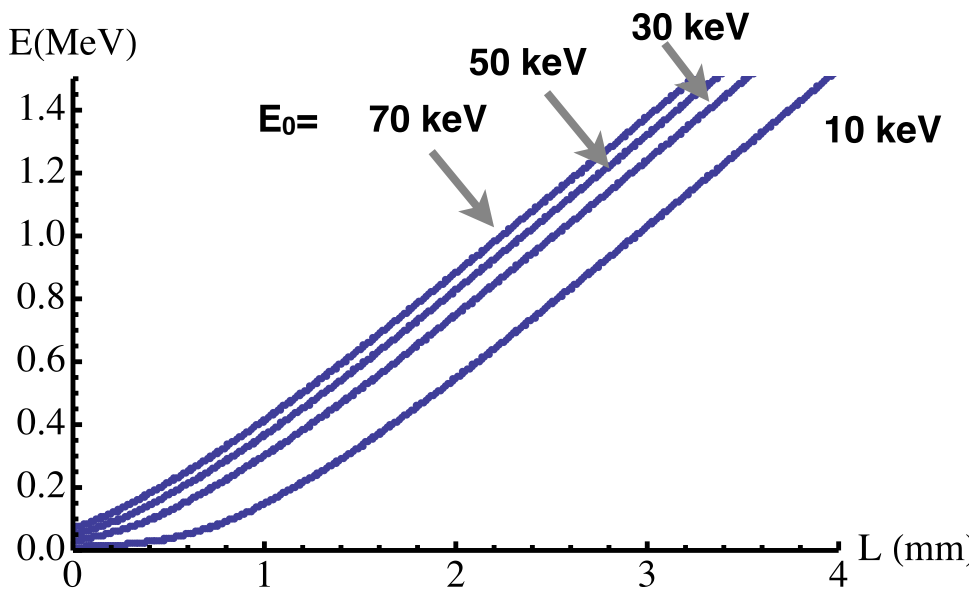
Slow electron can be accelerated even if the period is constant.

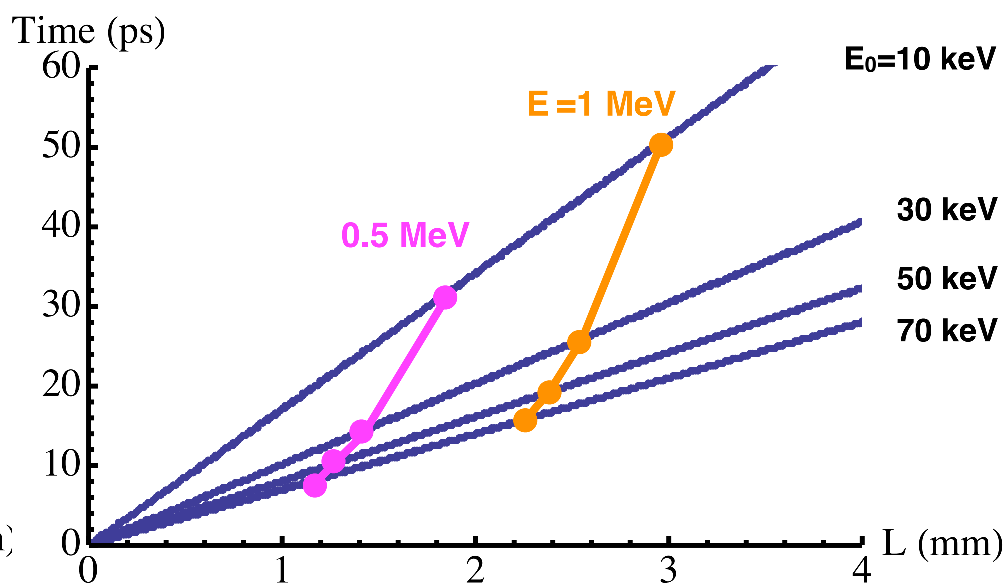
Acceleration field is very sensitive to the injection phase.

K. KOYAMA, *et al.* The 10 th Annual Meeting of Particle Accelerator Society of Japan, Nagoya University, 3-5, Aug. 2013

Acceleration Length and Time

Laser intensity = 10^{13} W/cm^2 (E = 8.7 GV/m)





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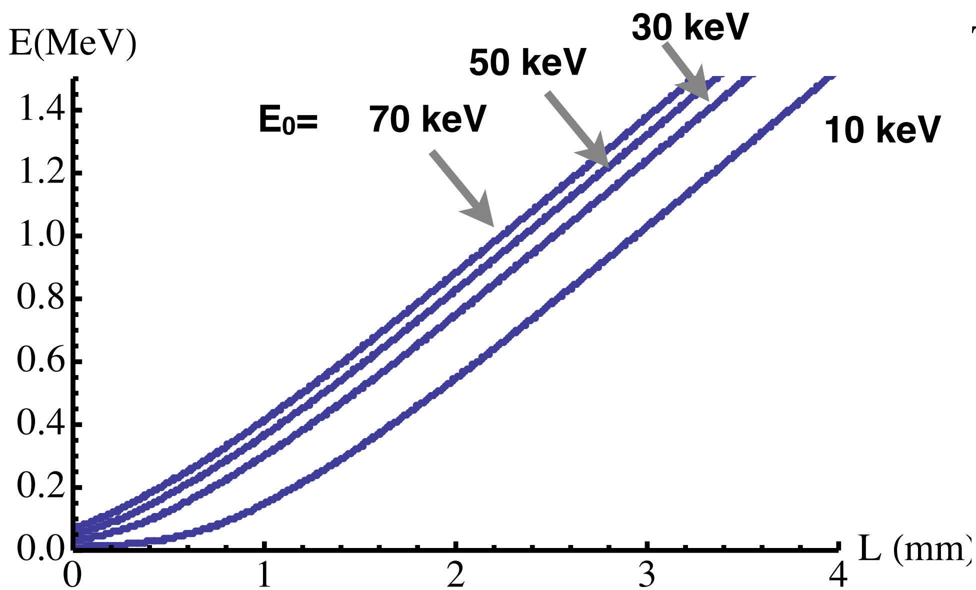

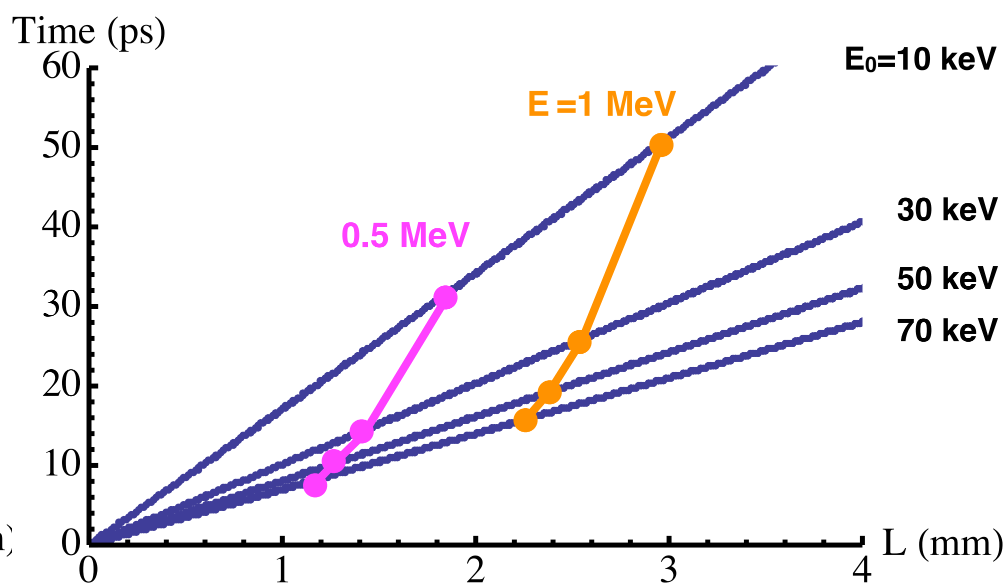

Accel. length to get 1 MeV,
3 mm for E_0= 10 keV
2.2 mm 70 keV

Accelerator and Laser Parameters

			1 MeV
Accelerator Length		L_A	3 mm
Channel width		W	0.1 mm
Irradiation Area (per side)		$A = W\ L_A$	$3x10^{-3}cm^2$
Laser Intensity (damage threshold)		I_{th}	10^{13} W/cm^2
Two sides irradiation	Laser Power (total)	$P_L = 2P_{th}A$	60 GW
	Pulse width	$\tau_L = L_A/v_{eff}$	50 ps
	Energy （total energy)	$E_L = P_L\tau_L$	3 J

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In order to decrease the laser energy, the laser pulse must locally irradiate around the electron bunch.

Accelerator and Laser Parameters

			1 MeV
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Channel width		W	0.1 mm
Irradiation Area (per side)		$A = W\ L_A$	$3 \times 10^{-3} cm^2$
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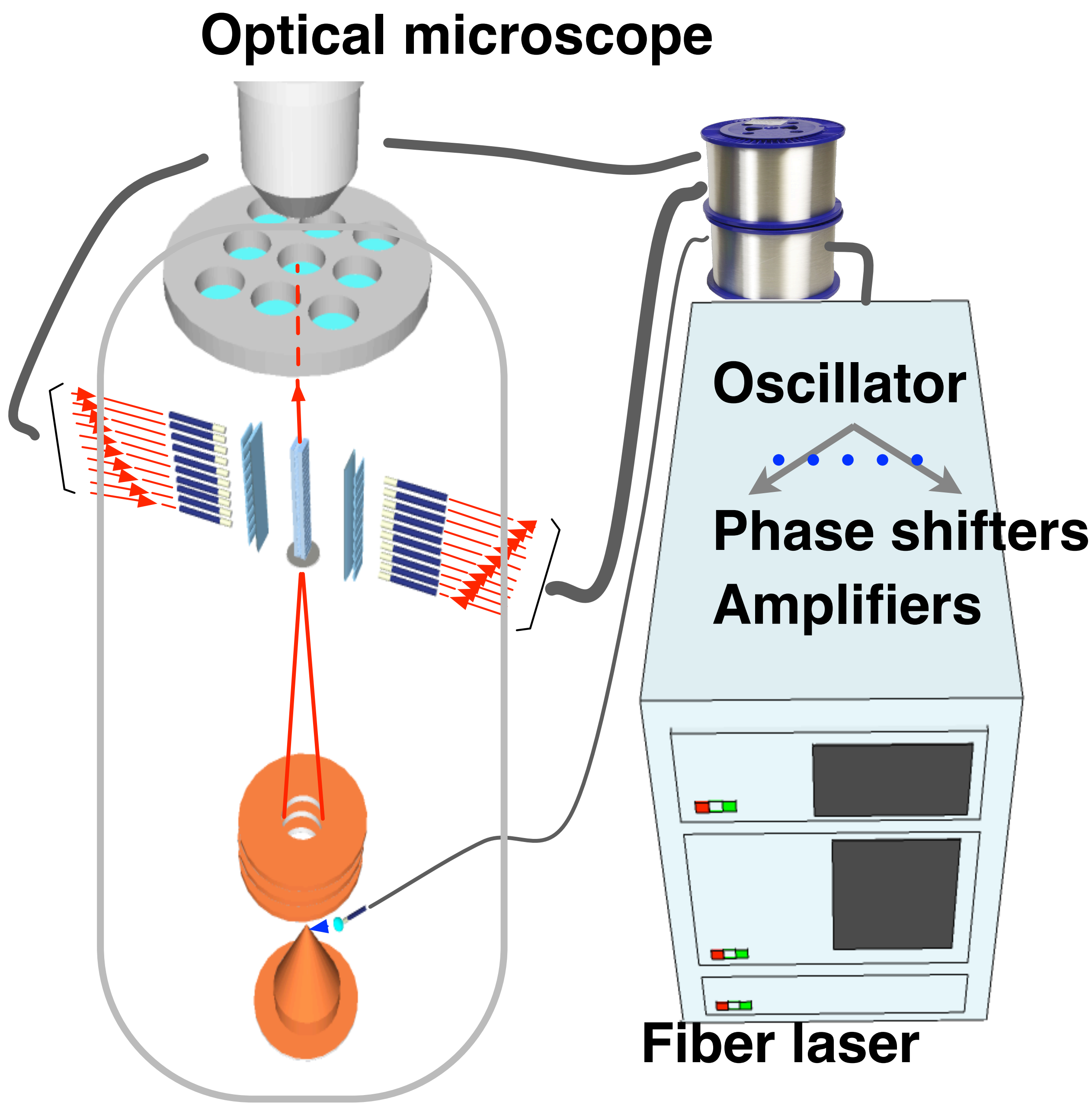
Two sides irradiation	Laser Power (total)	$P_L = 2P_{th}A$	60 GW
	Pulse width	$\tau_L = L_A/v_{eff}$	50 ps
	Energy (total energy)	$E_L = P_L \tau_L$	3 J
Divided irradiation	Number of Pulses (one side)	N	10
	Laser Power per Pulse	$P_{L,N} = P_L/N$	3 GW
	Pulse Width	$\tau_{L,N} = \tau_L/N$	5 ps
	Energy (total)	$E_{L,N} = E_L/N$	30 mJ
	(per pulse)	$E_{p,N} = E_L/2N^2$	1.5 mJ

Sketch of a fiber-laser-pumped accelerator



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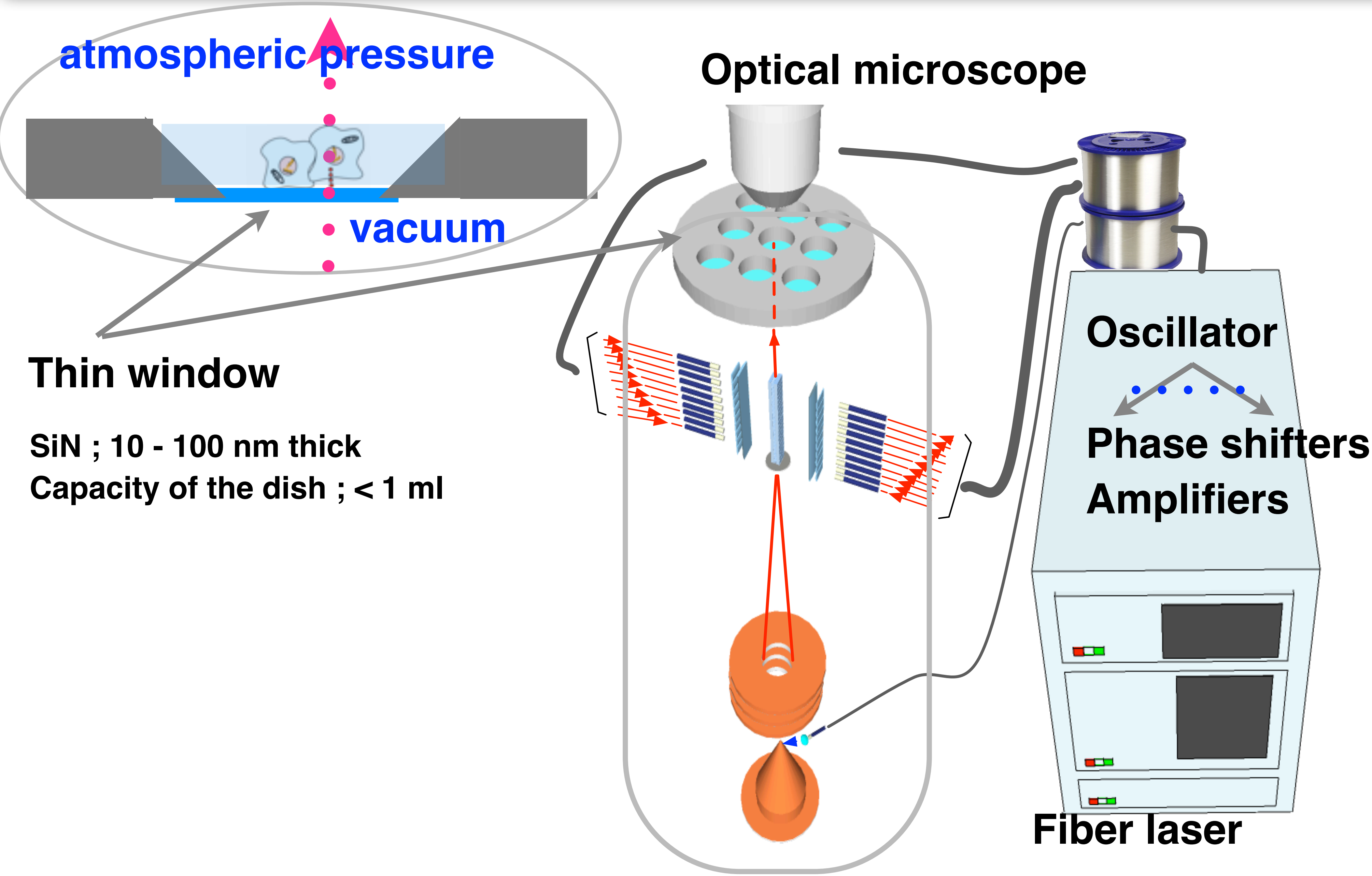

SiN ; 10 - 100 nm thick
Capacity of the dish ; < 1 ml

Summary

1. **The deformation of the wavefront in the phase-modulation-masked-type accelerator relaxed the matching condition. The slow electron to be accelerated even under the geometry of $L_G=\lambda_L$.**

2. **The electron initially at the low energy of 20 keV felt the acceleration field strength of 20 MV/m and gradually felt higher field as the speed was increased. The ultra relativistic electron felt the field strength of 600 MV/m.**

3. **Restrictions on the laser is relaxed by adopting sequential laser pulses. The required laser power is estimated to be 3 GW/pulse when ten pairs of sequential laser pulse is irradiated.**