Constraints on Structure Based Optical Accelerators

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Outline

- *Optical structures – short overview*
- *Efficiency & Luminosity*
- *Non-linear phase-shift*
- *Heat dissipation*
- *Stress considerations*

Constraints & Assumptions

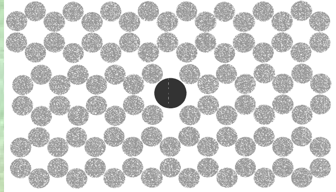
- ***Gradient***: order of 1[GV/m] or higher.
- ***Efficiency***: limited by radiation source and acceleration scheme
  - # Lasers anticipated efficiency of wall-plug to light 10% → 30%?!
  - # Efficiency of acceleration scheme – major ***difficulty***
- ***Breakdown***: at optical wavelengths ***dielectrics*** sustain higher fields comparing to metals → ***non-linear effects***
- ***Manufacturing*** constraints favor planar structures – consistent with luminosity constraints.
- ***Single Mode***: width of vacuum tunnel 0.3λ - 0.8λ → ***position***
- ***Machining tolerance***: 1μm at 3 cm wavelength. Four orders of magnitude difference are difficult to preserve at λ=1μm.

S. Banna, D. Schieber and L. Schächter; App. Phys. Lett., Vol.**84**(5) 723-5 (2004).
S. Banna, D. Schieber and L. Schächter; J. of Appl. Phys. **95**(8) 4415-4426 (2004).

Structure parameters

$$Z_{\text{int}} \equiv \left(E_0\lambda\right)^2/2P$$

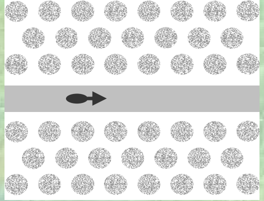
Transverse PBG



$$\underbrace{\frac{R_{\text{int}}}{\lambda}\simeq 0.68}_{\varepsilon=2.1,\ \lambda\simeq 1[\mu\text{m}]} \Rightarrow \begin{cases} Z_{\text{int}} \simeq 19.5[\Omega] \\ \beta_{gr} \simeq 0.58 \\ \dfrac{E_{\text{acc}}}{E_{\max}} \simeq 0.5 \end{cases}$$

E. Lin, PR STAB, 2000

Longitudinal PBG

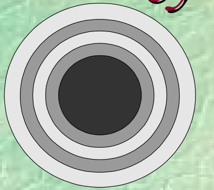


$$\underbrace{\frac{D_{\text{int}}}{\lambda}=0.55\div 1.25}_{\varepsilon=2.1,\ \lambda\simeq 1.5[\mu m]} \Rightarrow \begin{cases} Z_{\text{int}}\dfrac{\Delta_y}{\lambda} \simeq 250\div 20[\Omega] \\ \beta_{\text{gr}} \simeq 0.2\div 0.6 \\ \dfrac{E_{\text{acc}}}{E_{\max}} \simeq 0.35\div 0.15 \end{cases}$$

B. Cowan, PR STAB, 2003

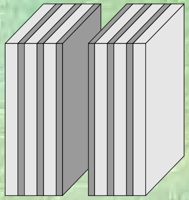
LEAP

Cylindrical Bragg Structure



$$\underbrace{\frac{R_{\text{int}}}{\lambda}\simeq 0.3\div 0.8}_{\varepsilon_1=2.1,\ \varepsilon_2=4,\ \lambda=1[\mu m]} \Rightarrow \begin{cases} Z_{\text{int}} \simeq 268\div 37[\Omega] \\ \beta_{gr} \simeq 0.41\div 0.48 \\ \dfrac{E_{\text{acc}}}{E_{\max}} \simeq 0.73\div 0.37 \end{cases}$$

Planar Bragg Structure



$$\underbrace{\frac{D_{\text{int}}}{\lambda}=0.3\div 0.8}_{\varepsilon_1=2.1,\ \varepsilon_2=4,\ \lambda=1[\mu m]} \Rightarrow \begin{cases} Z_{\text{int}}\dfrac{\Delta_y}{\lambda} \simeq 147\div 25.7[\Omega] \\ \beta_{\text{gr}} \simeq 0.42\div 0.53 \\ \dfrac{E_{\text{acc}}}{E_{\max}} \simeq 0.47\div 0.20 \end{cases}$$

A. Mizrahi & L. Schachter, Phys. Rev. E, 2004

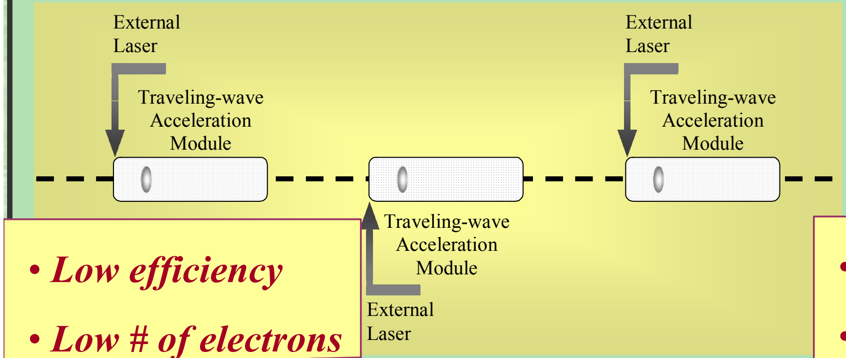
Outline

- *Optical structures*
- *Efficiency & Luminosity*
- *Non-linear phase-shift*
- *Heat dissipation*
- *Stress considerations*

Configurations

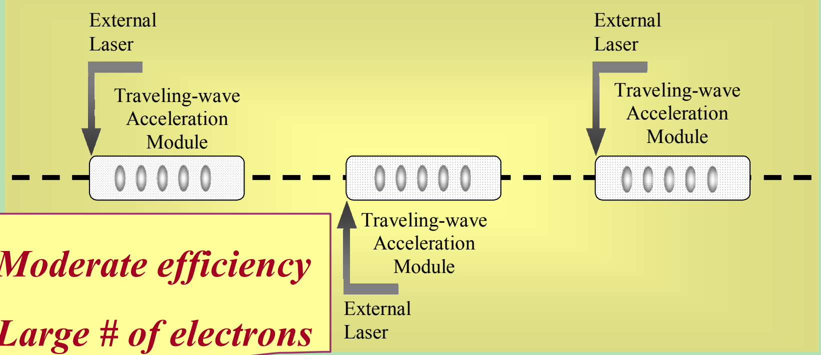
L. Schächter; *Energy Recovery in an Optical Linear Collider,* Physical Review E **70**, 016504 (2004)

Single bunch & no feedback



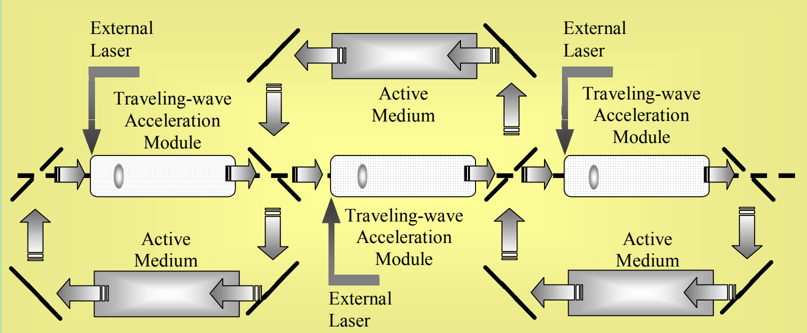
- ***Low efficiency***
- ***Low # of electrons***

Train of micro-bunches & no feedback



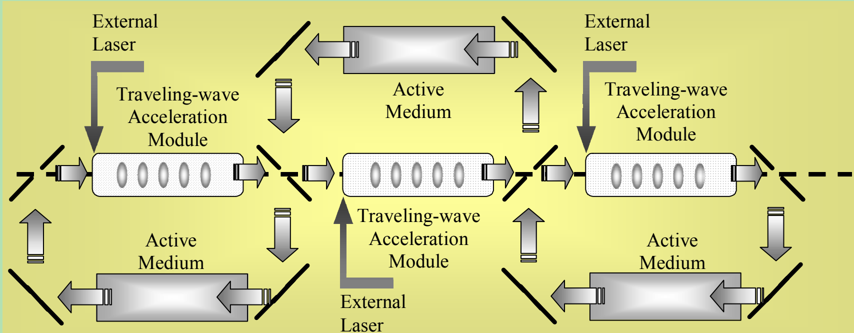
- ***Moderate efficiency***
- ***Large # of electrons***

Single bunch & feedback



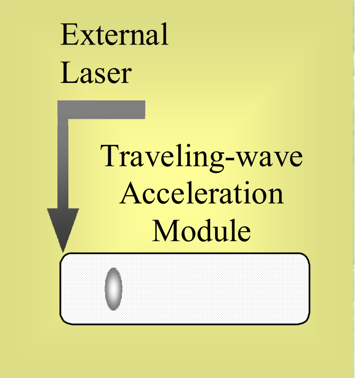
- ***High efficiency***
- ***Low # of electrons***

Train of micro-bunches & feedback



- ***High efficiency***
- ***Large # of electrons***

Single bunch & no feedback



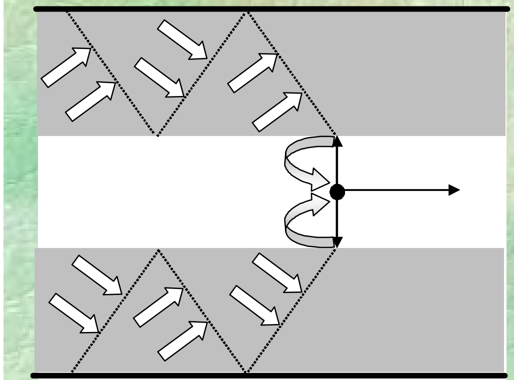
- ***Wake parameter:***

Decelerating field for a given charge ………… $E_{\text{dec}} \equiv \kappa q$

$$\kappa = 2/4\pi\varepsilon_0 R^2$$

- ***Beam-loading parameter:***

Beam-loading of the accelerating mode ……….. $E_{\text{dec}}^{(F)} \equiv \kappa_1 q$



$$E_z(r=0,\tau=t-z/c) \simeq q\kappa\sum_{n=1}^{\infty} W_n \cos(\omega_n\tau)\,2h(\tau)$$

$$\sum_{n=1}^{\infty} W_n = 1$$

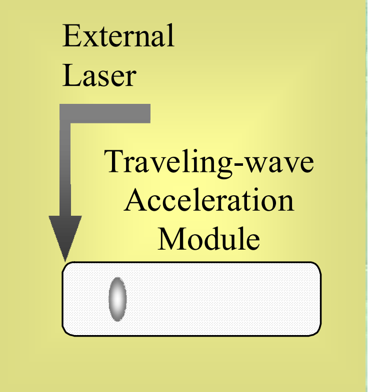
$$\kappa_1 \equiv \kappa W_1$$

Contribution of the fundamental to the total deceleration

$$\kappa_1 = \frac{\beta_{\text{gr}}}{1-\beta_{\text{gr}}}\,\frac{Z_{\text{int}}}{\sqrt{\mu_0/\varepsilon_0}}\,\frac{\pi}{4\pi\varepsilon_0\lambda^2}$$

Stupakov & Bane, PR STAB, 2003

Single bunch & no feedback



- Loaded gradient: $E_{\text{eff}} \equiv E_{\text{acc}} - E_{\text{dec}} = E_{\text{acc}} - \kappa q$
- Kinetic energy: $\Delta U_{\text{KIN}} \equiv q E_{\text{eff}} d$
- EM energy: $U_{\text{EM}} \equiv P_{\text{Laser}} \frac{d}{V_{\text{gr}}}(1 - V_{\text{gr}}/c)$

Zero force charge

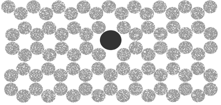
$$\boxed{\eta \equiv \frac{\Delta U_{\text{KIN}}}{U_{\text{EM}}} = \eta_{\max} \frac{4q\left(q_0 - q\right)}{q_0^2}} \Rightarrow q_{\text{opt}} = \frac{1}{2} q_0 \equiv \frac{1}{2} \frac{E_{\text{acc}}}{\kappa}$$

$$\boxed{\eta_{\max} = \frac{\kappa_1}{\kappa}}$$

Maximum efficiency is set by the projection of the total deceleration on the fundamental !!

Single bunch & no feedback

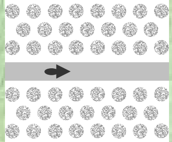
Transverse PBG



$$\left.\begin{aligned} R_{\text{int}} &\simeq 0.68\lambda \\ \varepsilon = 2.1,\ \lambda &\simeq 1.0[\mu\text{m}] \\ Z_{\text{int}} &\simeq 19.5[\Omega] \\ \beta_{gr} &\simeq 0.58 \\ E_{\max} &\simeq 2[\text{GV/m}] \end{aligned}\right\} \Rightarrow \begin{aligned} P_{\text{Laser}} &\simeq 50\left[\text{kW}\right] \\ \eta &\simeq 6\% \\ q_{\text{opt}} &\simeq 7\times 10^{4} e \\ E_{\text{acc}} &\simeq 1\left[\text{GV/m}\right] \end{aligned}$$

E. Lin, PR STAB, 2000

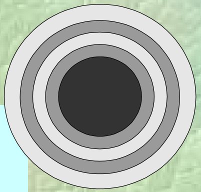
Longitudinal PBG



$$\left.\begin{aligned} D_{\text{int}} &\simeq 0.55\lambda \\ \varepsilon &= 2.1 \\ \lambda &\simeq 1.5[\mu\text{m}] \\ Z_{\text{int}}\Delta_y/\lambda &\simeq 250[\Omega] \\ \beta_{gr} &\simeq 0.2 \\ E_{\max} &\simeq 2[\text{GV/m}] \end{aligned}\right\} \Rightarrow \begin{aligned} \bar{P}_{\text{Laser}} &\simeq 2.3\left[\text{kW}/\mu\text{m}\right] \\ \eta &\simeq 36\% \\ \bar{q}_{\text{opt}} &\simeq 5\times 10^{4}\left[e/\mu\text{m}\right] \\ E_{\text{acc}} &\simeq 0.6\left[\text{GV/m}\right] \end{aligned}$$

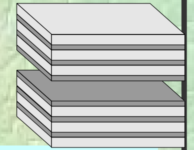
B. Cowan, PR STAB, 2003

Cylindrical Bragg Structure



$$\left.\begin{aligned} R_{\text{int}} &\simeq 0.68\lambda \\ \varepsilon_1 = 2.1, \varepsilon_2 &= 4 \\ \lambda &\simeq 1[\mu\text{m}] \\ Z_{\text{int}} &\simeq 56.4[\Omega] \\ \beta_{gr} &\simeq 0.58 \\ E_{\max} &\simeq 2[\text{GV/m}] \end{aligned}\right\} \Rightarrow \begin{aligned} P_{\text{Laser}} &\simeq 18\left[\text{kW}\right] \\ \eta &\simeq 9\% \\ q_{\text{opt}} &\simeq 7\times 10^{4} e \\ E_{\text{acc}} &\simeq 1\left[\text{GV/m}\right] \end{aligned}$$

Planar Bragg Structure

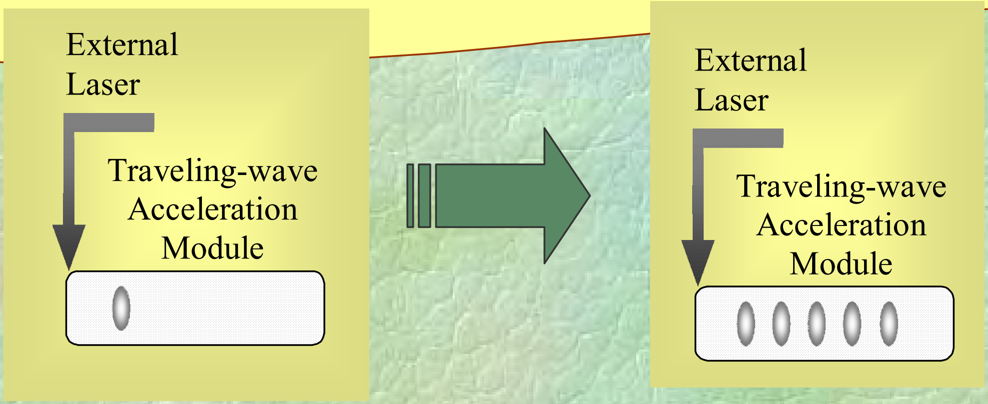


$$\left.\begin{aligned} D_{\text{int}} &\simeq 0.55\lambda \\ \varepsilon_1 = 2.1,\ \varepsilon_2 &= 4 \\ \lambda &\simeq 1[\mu\text{m}] \\ Z_{\text{int}}\Delta_y/\lambda &\simeq 57[\Omega] \\ \beta_{gr} &\simeq 0.48 \\ E_{\max} &\simeq 2[\text{GV/m}] \end{aligned}\right\} \Rightarrow \begin{aligned} P_{\text{Laser}} &\simeq 5.3\left[\text{kW}/\mu\text{m}\right] \\ \eta &\simeq 8\% \\ q_{\text{opt}} &\simeq 3.3\times 10^{4}[e/\mu\text{m}] \\ E_{\text{acc}} &\simeq 0.56\left[\text{GV/m}\right] \end{aligned}$$

A. Mizrahi & L. Schachter, Phys. Rev. E, 2004

Single bunch & no feedback

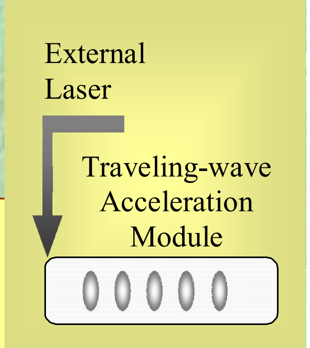
By splitting the bunch into a train of micro-bunches, the projection of the wake on the fundamental remains the same, but higher frequencies are suppressed



$$\eta_{\max} = \frac{\kappa_1}{\bar{\kappa}(M)} = \frac{\kappa_1}{\kappa_1 + \kappa_2(M) + \ldots}$$

$$P(M) = q^2 c \underbrace{\kappa \sum_{n=1}^{\infty} W_n \left[\frac{\operatorname{sinc}\left(\pi M \frac{\omega_n}{\omega_1}\right)}{\operatorname{sinc}\left(\pi \frac{\omega_n}{\omega_1}\right)} \right]^2}_{\bar{\kappa}(M)}$$

Train of bunches & no feedback

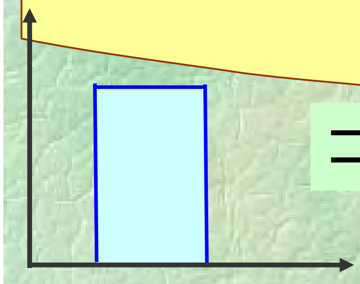

External Laser

Traveling-wave Acceleration Module

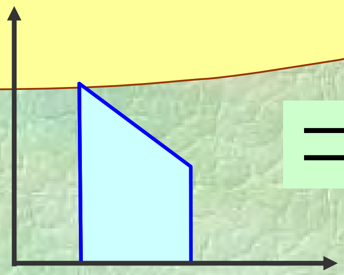
What is the efficiency in case of a train of micro-bunches?

For an answer, one needs to make two observations:

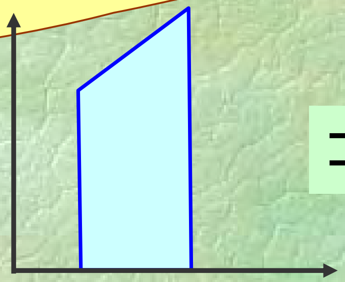
- *a) The laser pulse duration ought to be longer in order to account for the macro-bunch length.*
- *b) The envelope of the laser pulse must be tapered, in order to compensate for beam loading.*


Uniform laser pulse

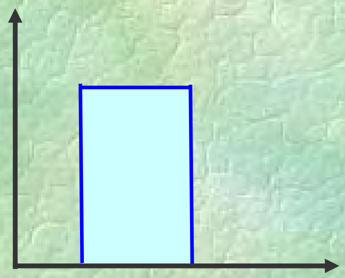
⇒


Uniform & loading

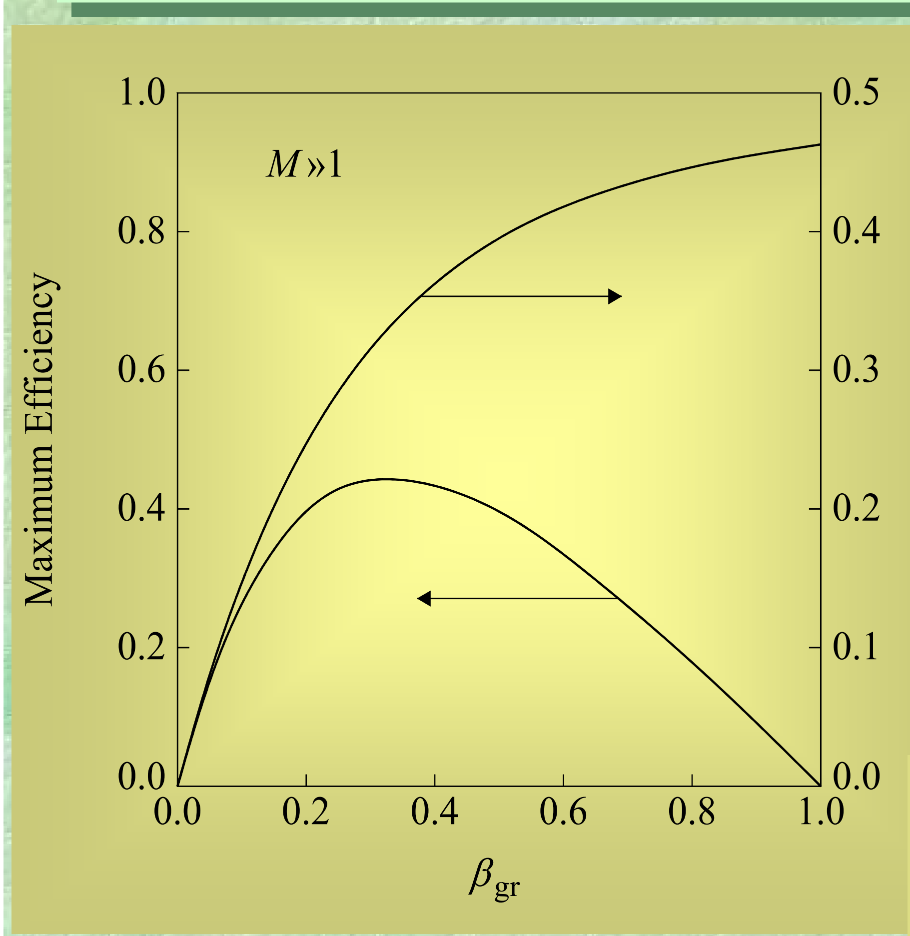
⇒

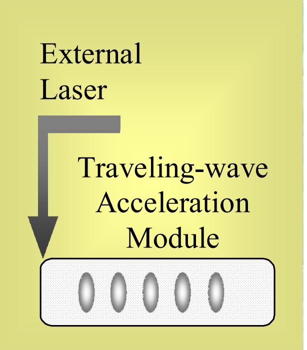

Tapered laser pulse

⇒

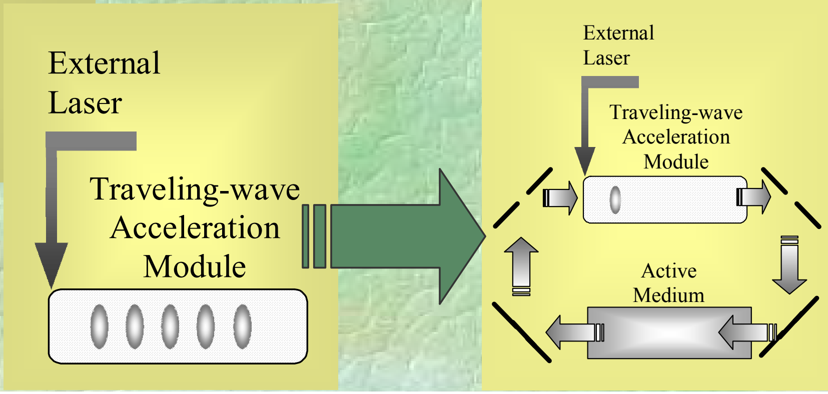

Tapered & loading

Train of bunches & no feedback

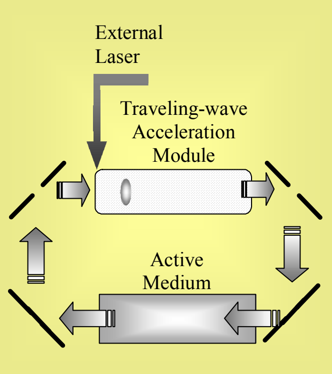




In spite of splitting the macro-bunch, there still is 50% waste of the laser energy → feedback loop.



Single bunch & feedback



$$\eta = \frac{\Delta U_{KIN}}{U_{LASER}+U_{ACTIVE}} = \frac{\Delta U_{KIN}}{\Delta U_{KIN}+U_{LOSS}} = \frac{1}{1+\frac{1}{Q}\frac{U_{OUT}}{\Delta U_{KIN}}}$$

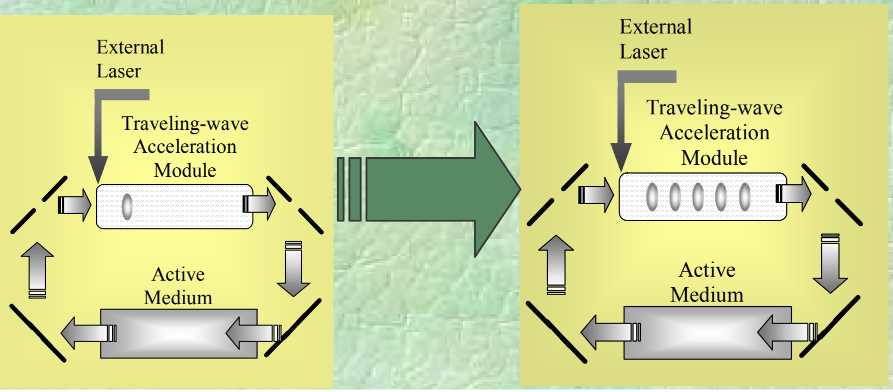
$$q_{\rm opt} = \frac{1}{2} q_0$$

$$\eta_{\max} \simeq \frac{1}{1+\frac{1}{Q\frac{\kappa_1}{\kappa}}} \simeq \begin{cases} 1 & Q \gg 1 \\ \frac{\kappa_1}{\kappa} & Q \to 1 \end{cases}$$

High efficiency but,

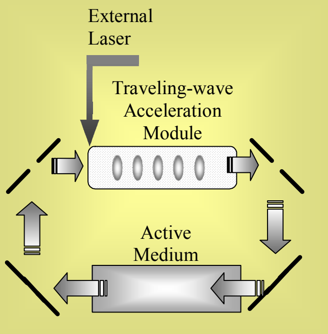
small number of electrons →

train of bunches and feedback loop



Ensure that output & feedback are consistent with the necessary input !!

Train of bunches & feedback



Conditions for self-consistent field:

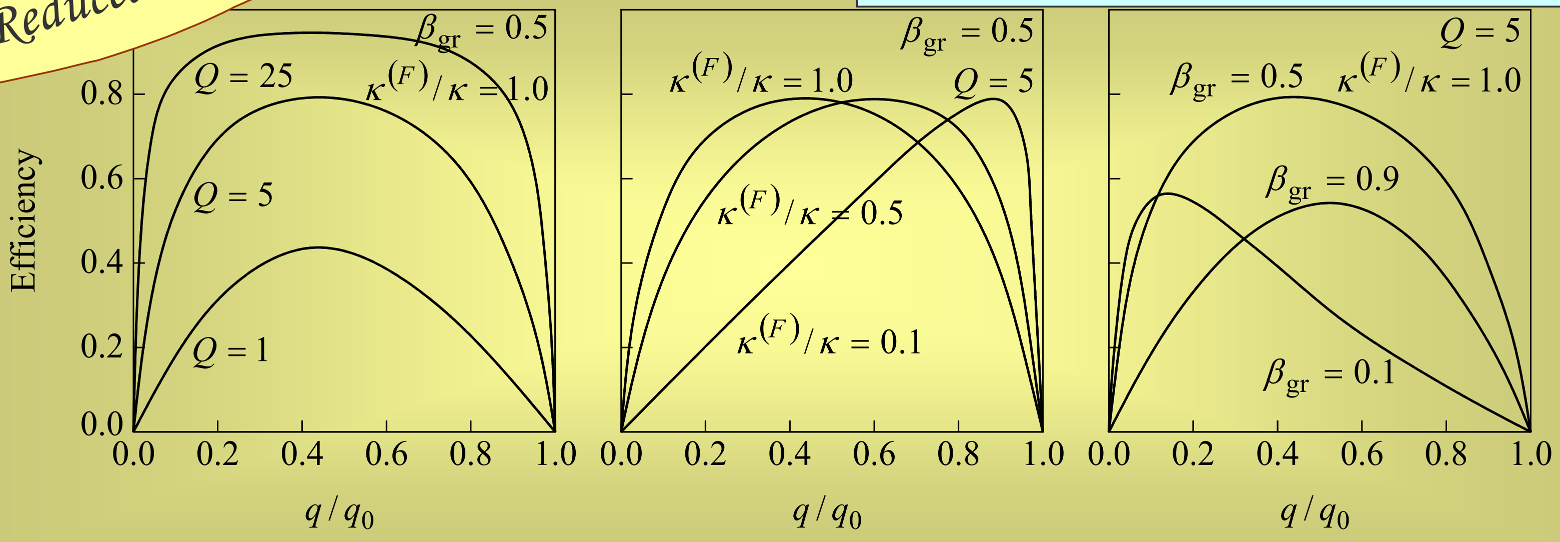
(I) Amplifier compensates for all ***radiation loss***

(II) External laser compensates for ***beam-loading***

Active enhancement of the quality factor

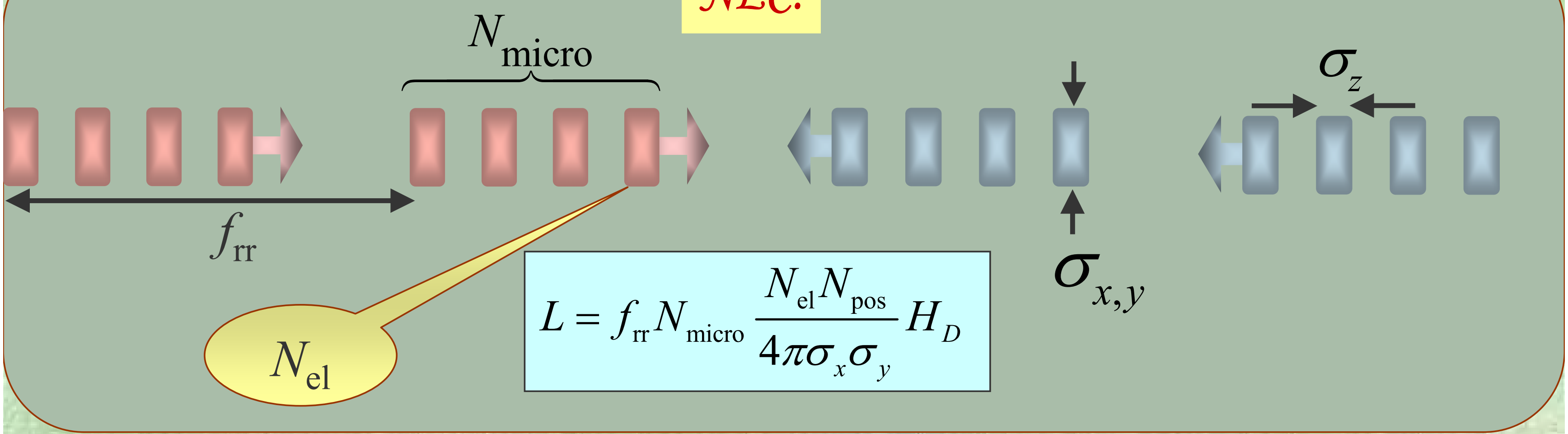
High efficiency
Reduced sensitivity

$$\eta = \frac{\Delta U_{KIN}}{U_{LASER}+U_{ACTIVE}} = \frac{1}{1+\frac{1}{Q}\frac{U_{OUT}}{\Delta U_{KIN}}}$$



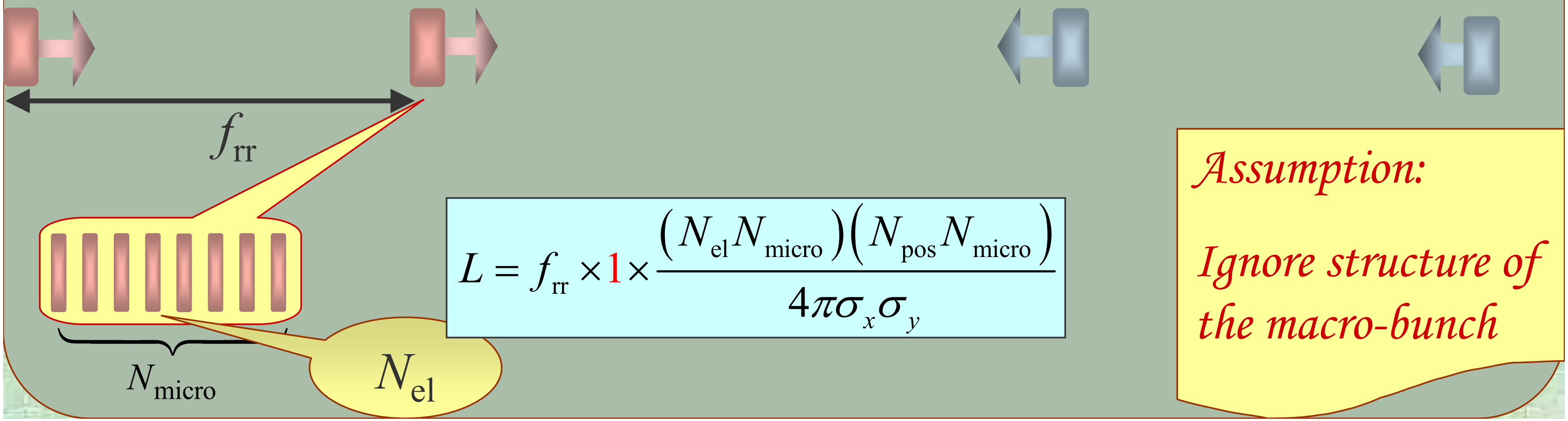
Luminosity

NLC:



$$L = f_{\mathrm{rr}} N_{\mathrm{micro}} \frac{N_{\mathrm{el}} N_{\mathrm{pos}}}{4\pi\sigma_x\sigma_y} H_D$$

Optical Acc.:



$$L = f_{\mathrm{rr}} \times 1 \times \frac{\left(N_{\mathrm{el}} N_{\mathrm{micro}}\right)\left(N_{\mathrm{pos}} N_{\mathrm{micro}}\right)}{4\pi\sigma_x\sigma_y}$$

Assumption:

Ignore structure of the macro-bunch

Luminosity

	NLC	Single no FB	Single no FB	Train & FB	Train & FB
f_{rr} [Hz]	120	1(6)	1(9)	1(6)	1(6)
N_{micro}	190	1	1	1(3)	1(3)
N_{el}	0.75(10)	5(4)	5(4)	1(6)	1(6)
σ_z [nm]	0.11(6)	4	4	4	4
σ_x [nm]	245	245	24.5	245	24.5
σ_y [nm]	2.7	2.7	0.27	2.7	0.27
$n^{-1/3}$ [Å]	2.1	3.8	0.8	1.4	0.3
H_D	1.4	1.0	1.0	1.0	1.0
L[cm^{-2}sec^{-1}]	*2(34)*	*3(25)*	*3(30)*	*1.2(34)*	*1.2(36)*
Beam power [MW]	*13.7*	*4(-3)*	*4*	*80*	*80*

Fluence

Density !

Outline

- Optical structures
- Efficiency & Luminosity
- Non-linear phase-shift
- Heat dissipation
- Stress considerations

Polarization non-linearity

- ***Breakdown & Nonlinearity***: In dielectrics at optical wavelengths breakdown threshold is ***higher*** than that required to excite nonlinear effects.

- ***Main Nonlinear Effect***: laser affects dielectric coefficient → phase shift.

$$\vec{P} = \varepsilon_0 \left[\chi^{(1)} \vec{E} + \chi^{(2)} \vec{E}\vec{E} + \chi^{(3)} \vec{E}\vec{E}\vec{E} + \dots \right]$$

- ***Third harmonic generation***
- ***Four wave mixing***
- ***Nonlinear refraction***

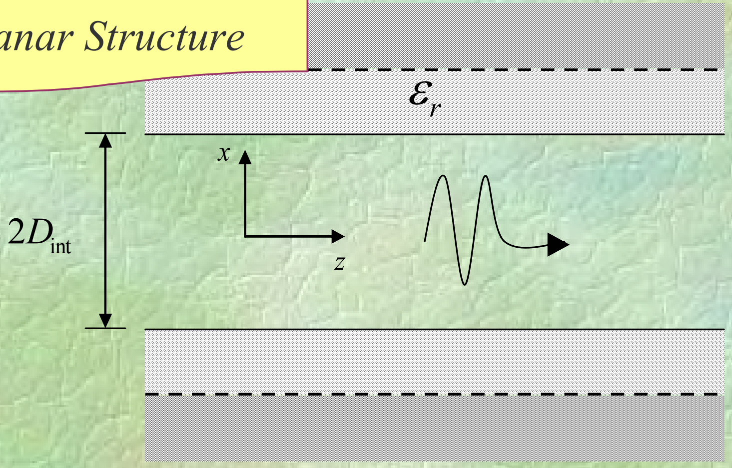
- ***Second harmonic generation***
- ***Sum-frequency generation***

Nonlinear Phase-shift

$$n = n_0 + n_2 I$$

$$\Delta\phi_{NL} = 2\pi n_2 I \frac{L}{\lambda}$$

Planar Structure

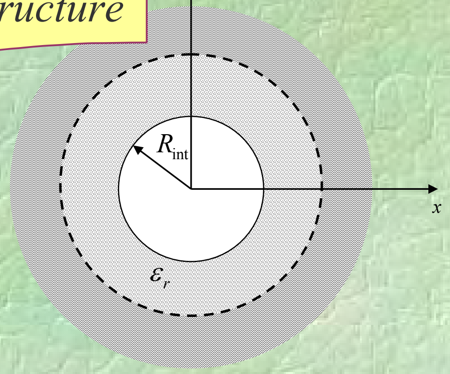


$$E_z = E_0 \exp\left(-j\frac{\omega}{c}z\right), \quad E_x = \left(j\frac{\omega}{c}x\right)E_0 \exp\left(-j\frac{\omega}{c}z\right)$$

$$E_{\max}^{incident} = E_{acc}\frac{2\pi D_{\text{int}}}{\lambda}$$

$$\Delta\phi_{NL}^{\max} = \frac{\pi L}{\eta_0 \lambda} n_0 n_2 E_{acc}^2 \left(\frac{2\pi D_{\text{int}}}{\lambda}\right)^2$$

Cylindrical Structure



$$E_z = E_0 \exp\left(-j\frac{\omega}{c}z\right), \quad E_r = j\frac{\omega}{c}\frac{r}{2}E_0 \exp\left(-j\frac{\omega}{c}z\right)$$

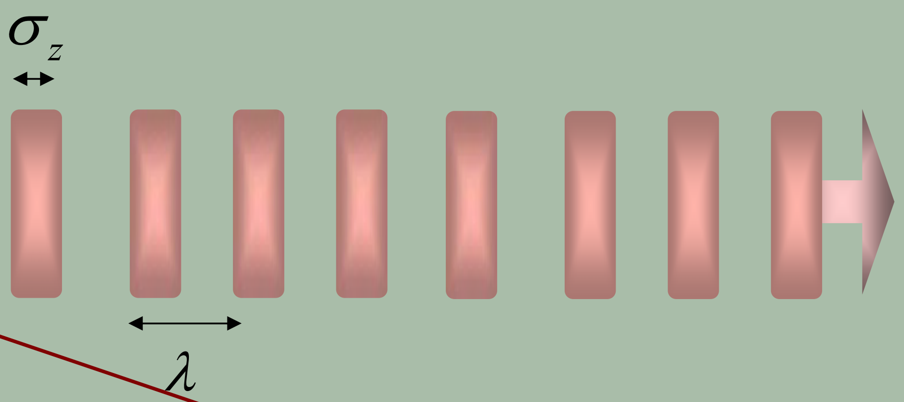
$$E_{\max}^{incident} = E_{acc}\frac{1}{2}\frac{2\pi R_{\text{int}}}{\lambda}$$

$$\Delta\phi_{NL}^{\max} = \frac{\pi L}{\eta_0 \lambda} n_0 n_2 E_{acc}^2 \left(\frac{1}{2}\frac{2\pi R_{\text{int}}}{\lambda}\right)^2$$

Non-linear Phase-shift criterion

$$\sigma_z = \frac{\alpha}{2\pi}\lambda$$

$$0 < \alpha < \frac{2\pi}{12}$$



Efficient acceleration

Synchronization

Condition

Phase-shift less than 10%

$$\Delta\phi_{NL} < \frac{2\pi}{120}$$

Non-linear Phase-shift

Ti:Sapphire laser

Fused Silica

$n_0 = 1.45$

$n_2 = 2.55 \times 10^{-20} \frac{m^2}{W}$

$R_{\text{int}} = \lambda = 800nm;\ L = 1mm$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times \boxed{0.72} \ @\ E_{acc} = 0.1\frac{GV}{m}$$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times 72.60 \ @\ E_{acc} = 1.0\frac{GV}{m}$$

$R_{\text{int}} = 0.5\lambda = 400nm;\ L = 1mm$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times \boxed{0.18} \ @\ E_{acc} = 0.1\frac{GV}{m}$$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times 18.15 \ @\ E_{acc} = 1.0\frac{GV}{m}$$

Zirconia

$n_0 = 2$

$n_2 = 5.23 \times 10^{-20} \frac{m^2}{W}$

$R_{\text{int}} = \lambda = 800nm;\ L = 1mm$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times 2.05 \ @\ E_0 = 0.1\frac{GV}{m}$$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times 85.32 \ @\ E_0 = 1.0\frac{GV}{m}$$

$R_{\text{int}} = 0.5\lambda = 400nm;\ L = 1mm$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times \boxed{0.51} \ @\ E_0 = 0.1\frac{GV}{m}$$

$$\Delta\phi_{NL}^{\max} = \frac{2\pi}{120} \times 51.34 \ @\ E_0 = 1.0\frac{GV}{m}$$

Solution: Redesigning the structure to (initially) have a phase velocity larger than *c*.

Outline

- *Optical structures*
- *Efficiency & luminosity*
- *Non-linear phase-shift*
- *Heat dissipation*
- *Stress considerations*

Heat flow – single pulse operation

$$\Delta T(r=D_{\mathrm{ext}})=\frac{1}{h}\left(\frac{\partial}{\partial x}\Delta T\right]_{x=D_{\mathrm{ext}}}$$

$$\left[\frac{\partial}{\partial t}-\frac{1}{D}\nabla^2\right]\Delta T=\frac{1}{D\sigma_T}\,p_{\mathrm{loss}}(r,z,t)$$

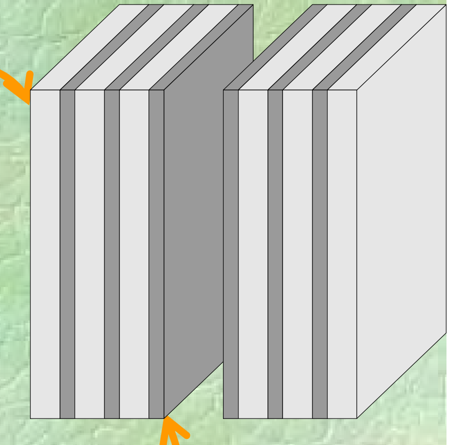
Diffusion Coefficient

$D[\mathrm{sec/m^2}]$

Heat Conductivity

$\sigma_{\mathrm{T}}\,[\mathrm{J/sec\,m\,^{o}K}]$

Dissipated EM Power Density



$$\left(\frac{\partial}{\partial x}\Delta T\right]_{x=D_{\mathrm{int}}}=0$$

$$p_{\mathrm{loss}}(r,z,t)\simeq\varepsilon\tan\delta\,\frac{\omega_0}{c}\left\langle S_z(r,z,t)\right\rangle$$

Heat Flow – Train of Pulses

$T_{rr} > 10[\mathrm{nsec}]$

$T_p \sim 1[\mathrm{psec}]$

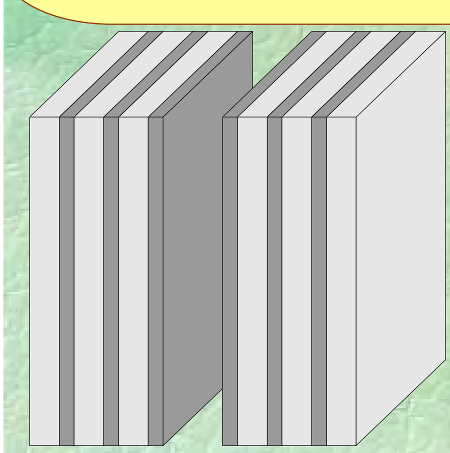
$$\Delta T(x,z;t)=\frac{P_0}{\sigma_T}\frac{T_p}{T_{rr}}\sum_{\nu=-\infty}^{\infty}\mathrm{sinc}\left(\pi\nu\frac{T_p}{T_{rr}}\right)\exp\left(j2\pi\nu\frac{t-z/V_{gr}}{T_{rr}}\right)$$

$$\times\sum_{m=0}^{\infty}\cos\left[\frac{\pi(m+1/2)}{D_{\mathrm{ext}}-D_{\mathrm{int}}}(x-D_{\mathrm{int}})\right]$$

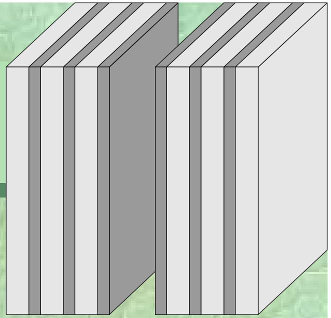
$$\times\frac{2}{D_{\mathrm{ext}}-D_{\mathrm{int}}}\frac{\displaystyle\int_{D_{\mathrm{int}}}^{D_{\mathrm{ext}}}dx'\,X_0(x')\cos\left[\frac{\pi(m+1/2)}{D_{\mathrm{ext}}-D_{\mathrm{int}}}(x'-D_{\mathrm{int}})\right]}{\left[j\dfrac{2\pi\nu}{T_{rr}}D+\left(\dfrac{2\pi\nu}{T_{rr}}\dfrac{1}{V_{gr}}\right)^2+\dfrac{\pi^2(m+1/2)^2}{\left(D_{\mathrm{ext}}-D_{\mathrm{int}}\right)^2}\right]}$$

Power profile

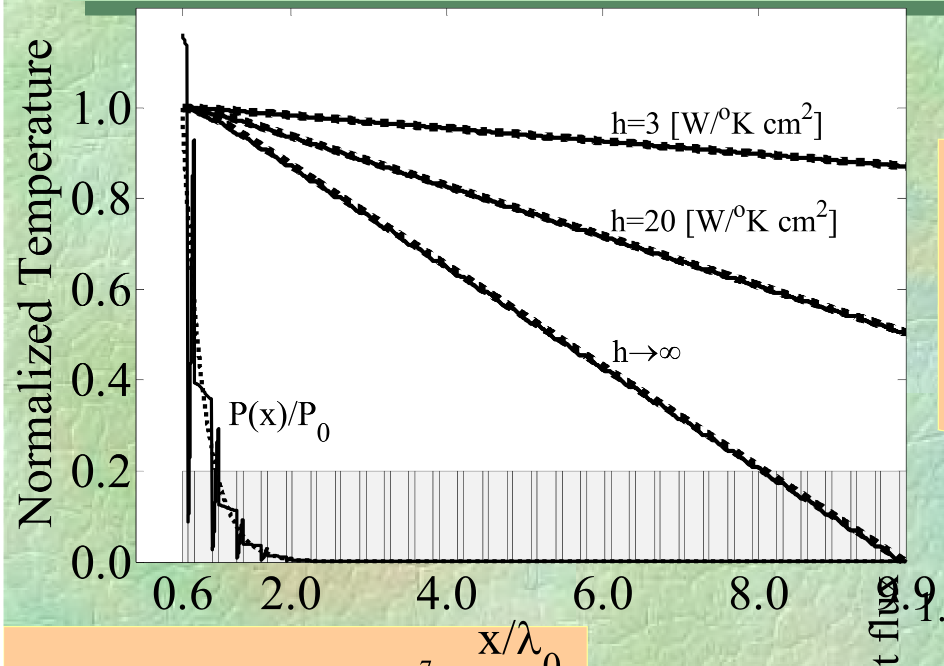
For the parameters of interest, the deviation from average ΔT *is negligible !!*



Heat Flow – Average Quantities



Silica - Silicon



$$\Delta T_{AV} \sim \left[\frac{P_0}{\sigma_T}\frac{x_c}{2}\left(D_{\text{ext}} - D_{\text{int}}\right)\right]\frac{T_p}{T_{rr}}$$

$$Q_{AV} \sim \left(P_0\frac{x_c}{2}\right)\frac{T_p}{T_{rr}}$$

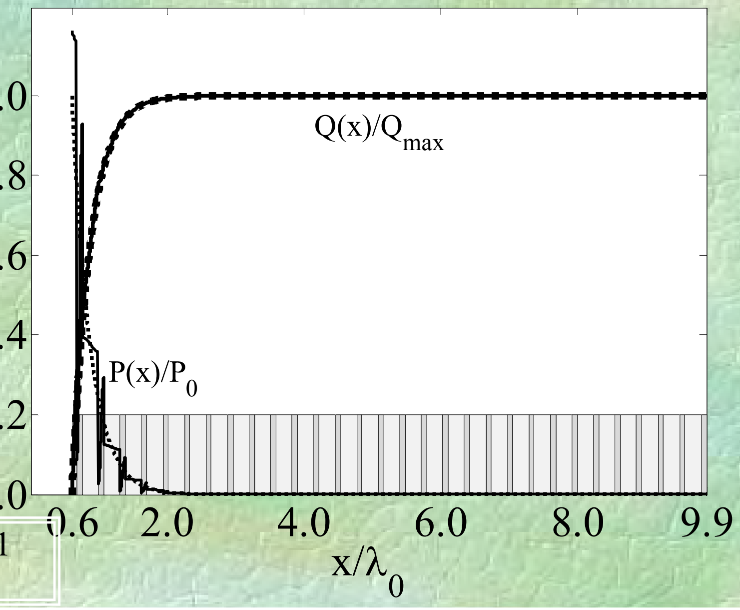
$$T_{\max}(h=3) = 66.4\times10^7 \tan\delta_1$$

$$T_{\max}(h=20) = 17.2\times10^7 \tan\delta_1$$

$$T_{\max}(h\to\infty) = 8.49\times10^7 \tan\delta_1$$

$$Q_{\max} = 1.74\times10^9 \tan\delta_1[\text{W/cm}^2]$$

Limit: 1500 [W/cm²]

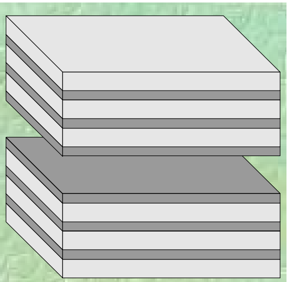


Optical Fibers: $\tan\delta\left(\alpha = 1[\text{dB/km}]\right) = 5\times10^{-11}$

Outline

- *Optical structures*
- *Efficiency & Luminosity*
- *Non-linear phase-shift*
- *Heat dissipation*
- *Stress considerations*

EM Stress on a Planar Accelerator



Total repelling Laser Pressure – Time-averaged Maxwell stress-tensor component

$$\langle T_{xx} \rangle = \frac{1}{4}\varepsilon_0 |E_x|^2 - \frac{1}{4}\varepsilon_0 |E_z|^2 - \frac{1}{4}\mu_0 |H_y|^2$$
$$= -\frac{1}{4}\varepsilon_0 |E_0|^2$$

$$E_0 = 1\left[\frac{\mathrm{GV}}{\mathrm{m}}\right] \Rightarrow |\langle T_{xx} \rangle| \cong 2.1\left[\frac{\mu\mathrm{N}}{\mu\mathrm{m}^2}\right]$$
$$\simeq 2[\mathrm{MP}]$$
$$\ll 1[\mathrm{GP}]$$

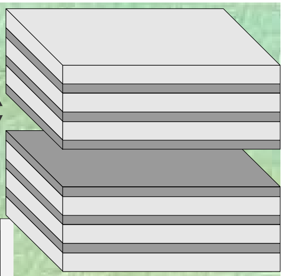
Time-averaged Lorentz force density inside the v'th layer is due to the polarization current

$$f_x = \frac{1}{2}\mathrm{Re}\left\{ j\omega\varepsilon_0 (\varepsilon_\nu - 1) E_z^* \mu_0 H_y \right\}$$

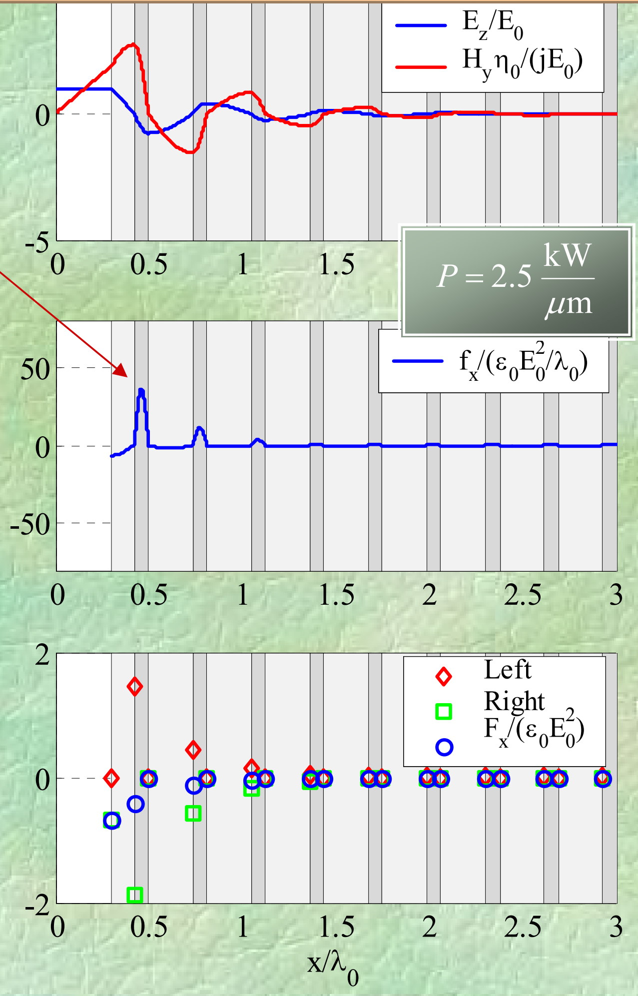
Total time-averaged boundary stress between the v'th and the v+1'th layer is due to polarization surface charge

$$F_x = \frac{1}{4}\varepsilon_0 |E_{x,\nu}^2| \left[\frac{\varepsilon_\nu^2}{\varepsilon_{\nu+1}^2} - 1\right]$$

EM Stress – $D_{int}=0.3\lambda_0$

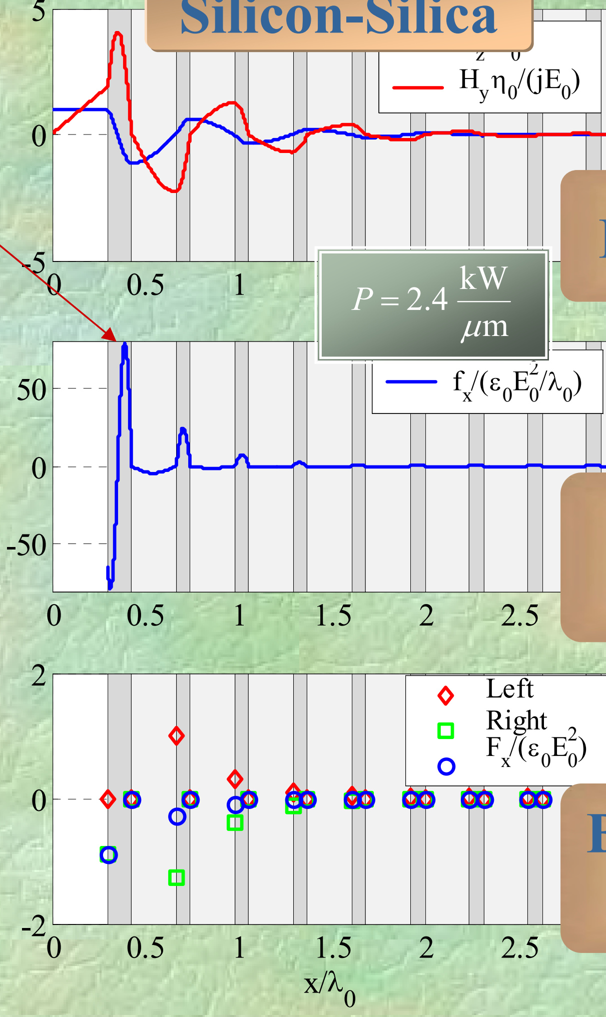


Silica(ε=2.1)-Silicon(ε=11.9)



$$P = 2.5\,\frac{\mathrm{kW}}{\mu\mathrm{m}}$$

Silicon-Silica



$$P = 2.4\,\frac{\mathrm{kW}}{\mu\mathrm{m}}$$

EM Field

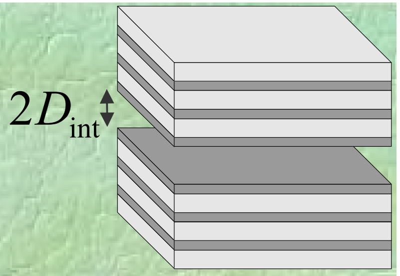
Force Density

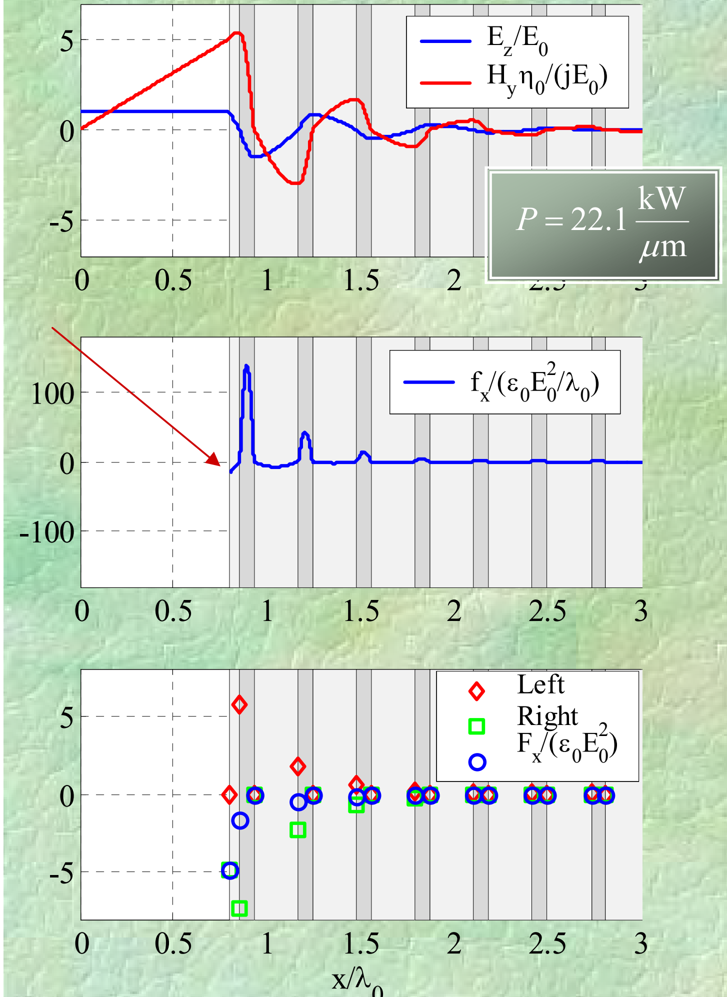
Boundary Stress

EM Stress – $D_{int}=0.8\lambda_0$

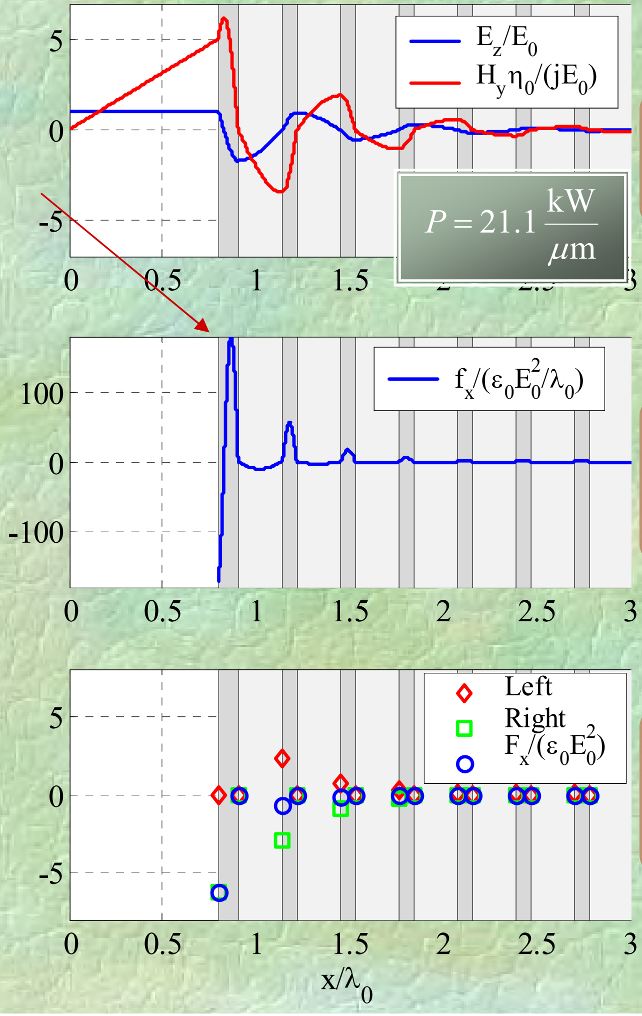
Silica(ε=2.1)-Silicon(ε=11.9)

Silicon-Silica





$P = 22.1 \frac{\text{kW}}{\mu m}$



$P = 21.1 \frac{\text{kW}}{\mu m}$

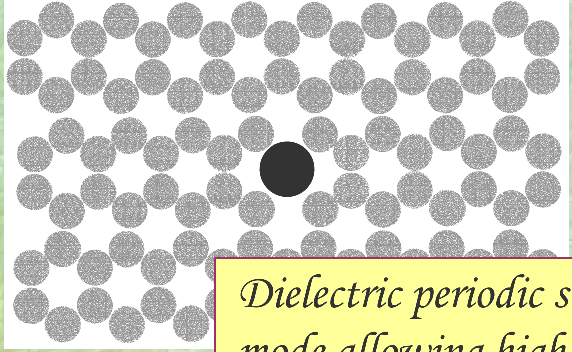
EM Field

Force Density

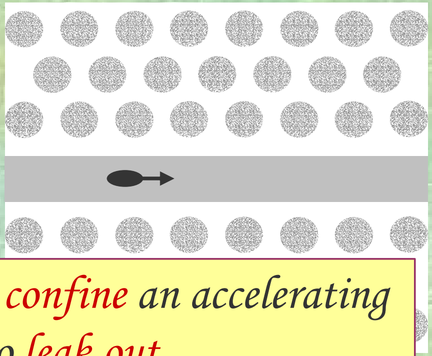
Boundary Stress

Summary: Dielectric Structures

Transverse PBG

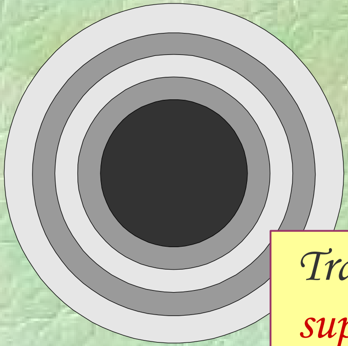


Longitudinal PBG

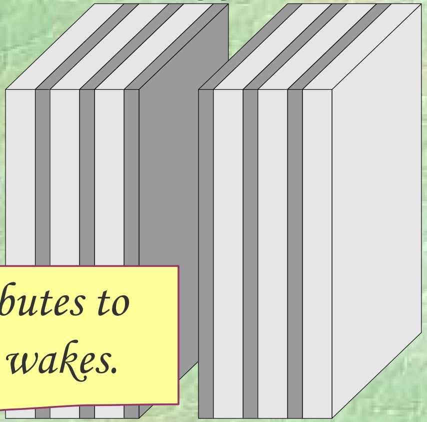


Dielectric periodic structures may confine an accelerating mode allowing high order modes to leak out.

Cylindrical Bragg Structure



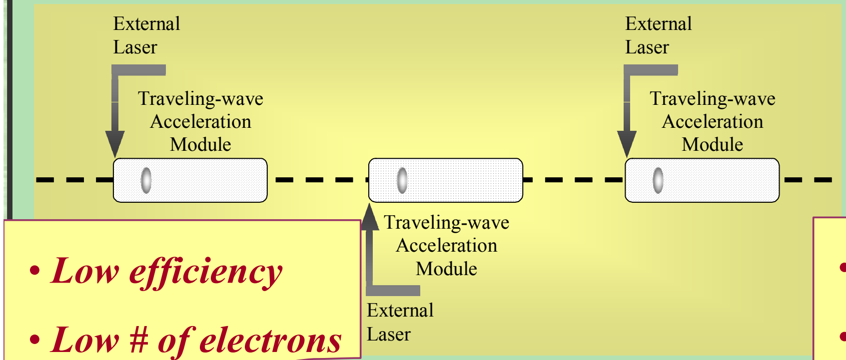
Planar Bragg Structure



Train of micro-bunches contributes to suppression of high frequency wakes.

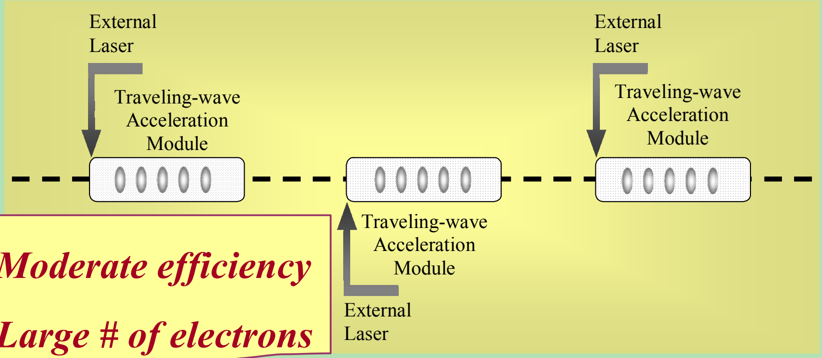
Summary: Configurations

Single bunch & no feedback



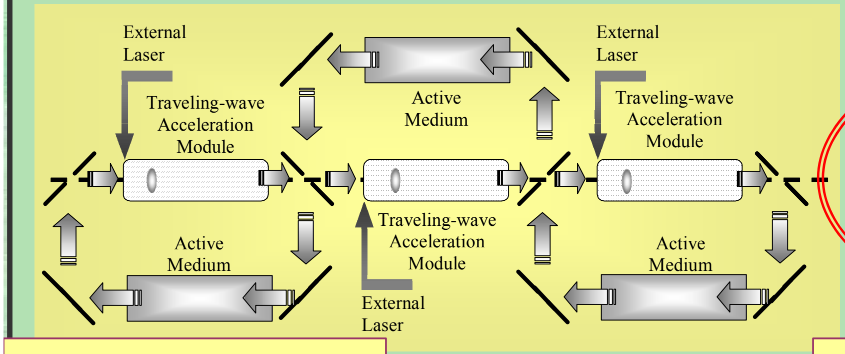
- Low efficiency
- Low # of electrons

Train of micro-bunches & no feedback



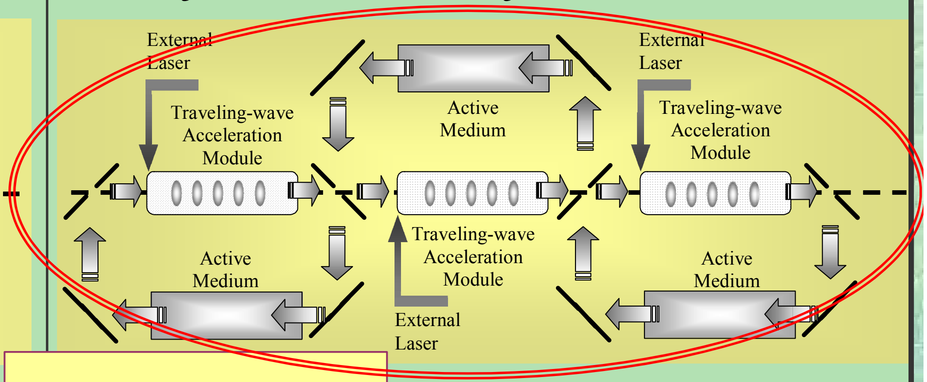
- Moderate efficiency
- Large # of electrons

Single bunch & feedback



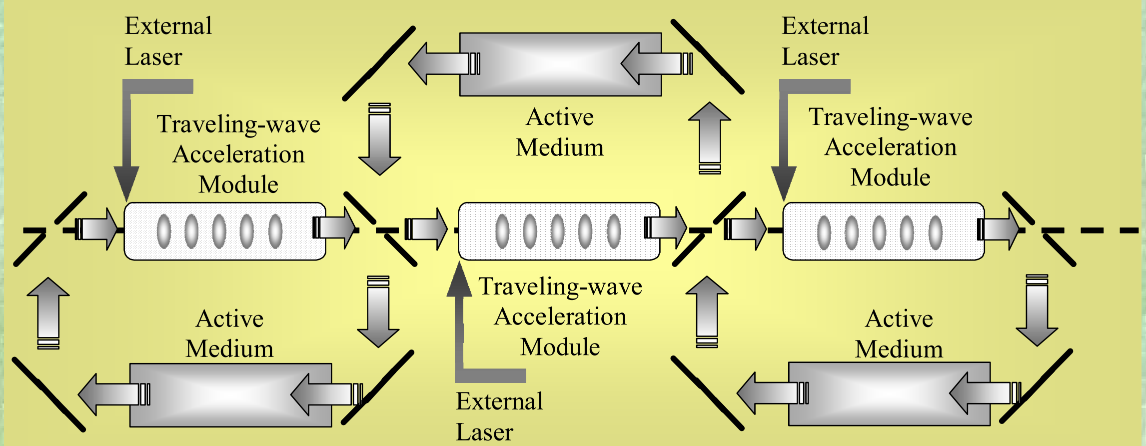
- High efficiency
- Low # of electrons

Train of micro-bunches & feedback



- High efficiency
- Large # of electrons

Summary: Efficiency & Luminosity



(I) *Amplifier compensates for all* ***radiation loss*** *(active enhancement of the Q—factor) facilitated by the wake being "quasi-coherent"*

(II) *External laser compensates for* ***beam-loading*** *(tapered pulse)*

(III) *Luminosity*

Summary

(I) With commonly used materials Kerr effect may become a problem. By accounting for the local increase in the dielectric coefficient, it is possible to compensate for the phase velocity reduction.

(II) Preliminary estimates indicate that heat dissipation needs close attention because the high repetition rate dictated by the luminosity constraint. Employing optical fiber technology may eliminate the problem although the latter works well in homogeneous medium, implications on multi-layered structure are unclear as yet.

(III) The typical stress is evaluated to be of the order of 1[MPascal] which is three orders of magnitude below typical critical values at μm scale.