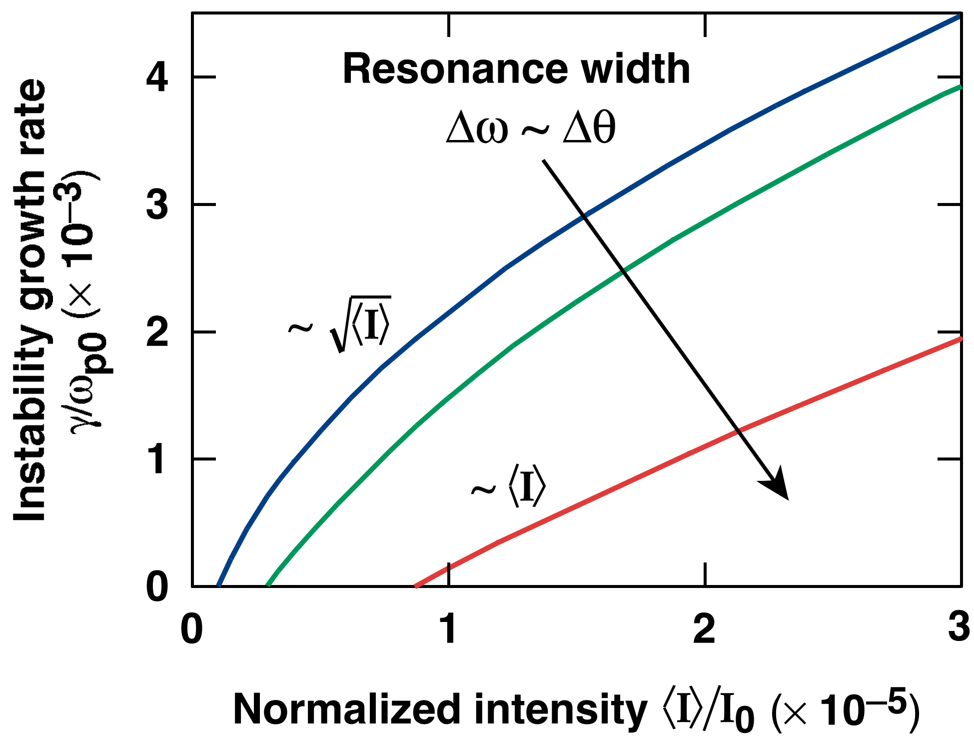
Modeling of Two-Plasmon-Decay Instability in Direct-Drive ICF Plasmas



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Summary

A model of the two-plasmon-decay (TPD) instability near quarter-critical density has been developed for irradiation by incoherent laser beams

- In OMEGA experiments, TPD scales with the overlapped intensity of crossing laser beams.
- The dispersion relation of TPD driven by incoherent laser beams describes both the regimes where the growth rate is proportional to laser intensity, and to the square root of laser intensity.
- TPD has a regime where the instability growth rate depends on the overlapped intensity of the crossing laser beams.
- The effect of density inhomogeneity on TPD in OMEGA plasmas is limited due to a large density scale length.

Outline

- Motivation
  - Experiments on OMEGA study TPD and electron preheat from multiple beams.
- Dispersion relation of TPD driven by incoherent beams
- TPD instability under irradiation by crossing beams
- Numerical modeling of TPD in inhomogeneous plasmas

In planar experiments TPD scales with overlapped intensity and saturates above 10^{15} W/cm^2

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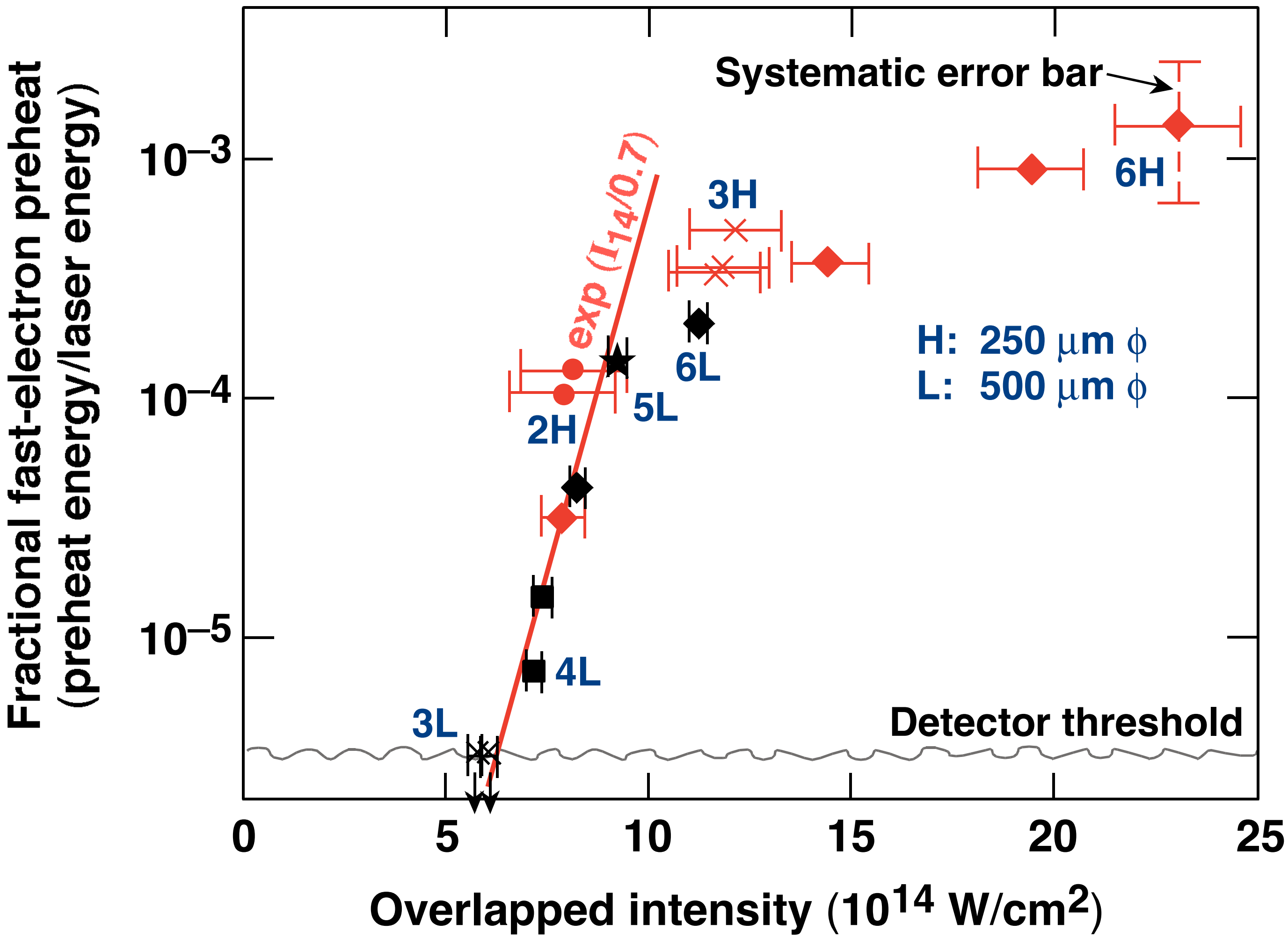
- Planar CH targets, 100 μm thick, multiple-overlapping beams



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The effect of density inhomogeneity on TPD can be limited in OMEGA plasmas

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- **Different studies* have shown that for TPD in inhomogeneous plasmas the absolute growth rate**

$$(\gamma/\omega_{p0})_{inhom} = (\gamma/\omega_{p0})_{hom} - \Delta_{inhom}$$
$$\Delta_{inhom} \sim 1/K_0 L_N$$

- **for OMEGA plasmas the density scale length near quarter-critical density**

$$L_N = 200 - 400\ \mu m,$$

$$\text{and } \Delta_{inhom} \sim 10^{-4}$$

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* Liu and Rosenbluth, Phys. Fluids 19, 967 (1976).
Lasinski and Langdon, UCRL-50021-77, 4–49 (1977).
Simon, Short *et al.*, Phys. Fluids 26, 3107 (1983).

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The assumption of a small correlation angle for the incident light allows the derivation of the dispersion relation for the TPD instability

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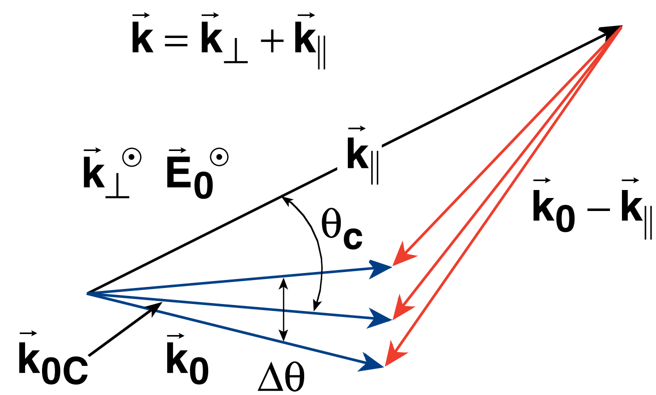
Consider a plasmon $\Psi_\alpha(\vec{k})$ in a homogeneous plasma model

Standard frequency-matching conditions for TPD instability:

$$\omega^2 = \omega_{p0}^2 + 3k^2 v_{Te}^2,$$

$$(\omega_0 - \omega)^2 = \omega_{p0}^2 + 3(\vec{k}_{0C} - \vec{k})^2 v_{Te}^2$$



The following correlation properties are assumed: $\left\langle \Psi_\alpha(\vec{k}_1)\Psi_\alpha^*(\vec{k}_2)v_0(\vec{k}_{01})v_0^*(\vec{k}_{02})\right\rangle = \left\langle \Psi_\alpha(\vec{k}_1)\Psi_\alpha^*(\vec{k}_2)\right\rangle\left\langle v_0(\vec{k}_{01})v_0^*(\vec{k}_{02})\right\rangle,$

where $\left\langle v_0(\vec{k}_{01})v_0^*(\vec{k}_{02})\right\rangle \sim \dfrac{\left\langle |v_0|^2\right\rangle \delta(\vec{k}_{01} - \vec{k}_{02})}{k_0\Delta\theta}$ **for light smoothed with DPP.**

The growth rate of the TPD instability can be proportional to the average laser intensity

Equation for the instability growth rate γ:

$$\frac{2(\gamma+\gamma_e)}{\omega_{p0}} = -\mathrm{Im}\int \frac{d\vec{k}_0}{k_0\Delta\theta}\,\frac{\left\langle |v_0|^2 \right\rangle F(\vec{k}_0,\vec{k})}{2i(\gamma+\gamma_e)\omega_{p0} - 3v_{Te}^2\left[(\vec{k}_0-\vec{k})^2 - (\vec{k}_{0C}-\vec{k})^2\right]},$$

where $F(\vec{k}_0,\vec{k}) = \frac{\left(k_0^2 - 2\vec{k}_0\vec{k}\right)^2}{4\left[(\vec{k}_0-\vec{k})^2 k^2\right]} k_\perp^2$

γ_e – damping coefficient,

resonance width $\Delta\omega = 3k_{||}k_0\lambda_{De}^2 |\sin\theta_c| \Delta\theta\,\omega_{p0}$

$\int d\vec{k}_0 \rightarrow \int d\theta$: to integrate over the resonant denominator in the integrand

- Small angular width $\Delta\theta$: $(\gamma+\gamma_e) >> \Delta\omega$ $\quad \gamma+\gamma_e = \sqrt{\left\langle |v_0|^2 \right\rangle F(\vec{k}_{0C},\vec{k})/4}$

- Large angular width $\Delta\theta$: $(\gamma+\gamma_e) << \Delta\omega$ $\quad \gamma+\gamma_e = \frac{\pi}{4}\frac{\left\langle |v_0|^2 \right\rangle F(\vec{k}_{0C},\vec{k})}{\Delta\omega}$

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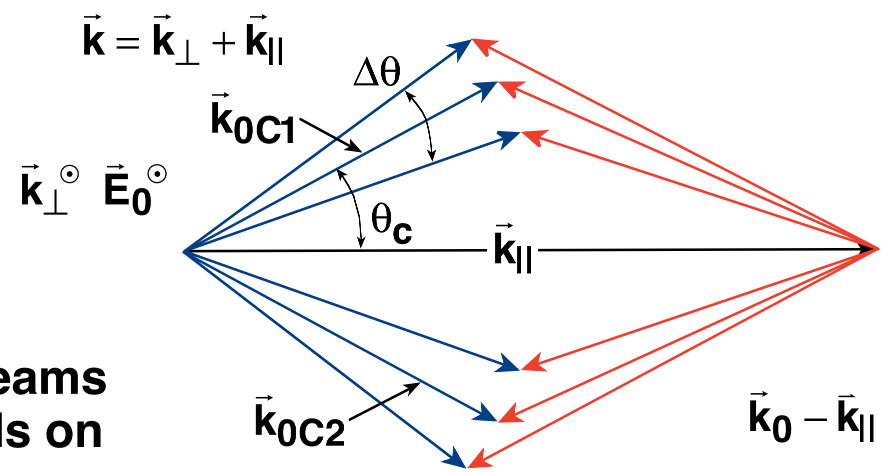
The growth rate of the TPD instability can be determined by the overlapped beam intensity of crossing incoherent beams

For certain orientations of a plasmon k-vector:

$$\left(\vec{k}\ \vec{k}_{0C1}\right) \approx \left(\vec{k}\ \vec{k}_{0C2}\right)$$



TPD resonance conditions for two beams are similar, and growth rate γ depends on the overlapped beam intensity.

For the parameters:

$$k_0\lambda_{De} = 0.15,\ k_{||} = 1.3\ k_0,\ k_{\perp} = k_0,$$
$$\Delta\theta = 0.2,\ \theta_c \approx 0.5,\ \gamma_e/\omega_{p0} = 2 \times 10^{-3}$$

the threshold intensity

$$\langle I \rangle = 4 \times 10^{14}\ W/cm^2.$$

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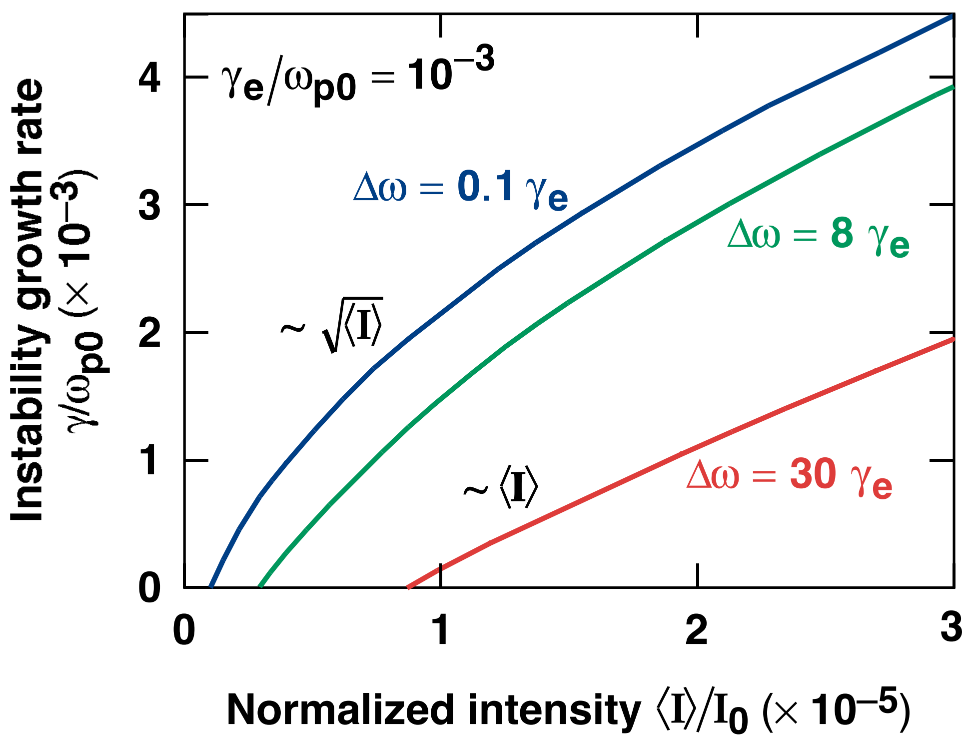
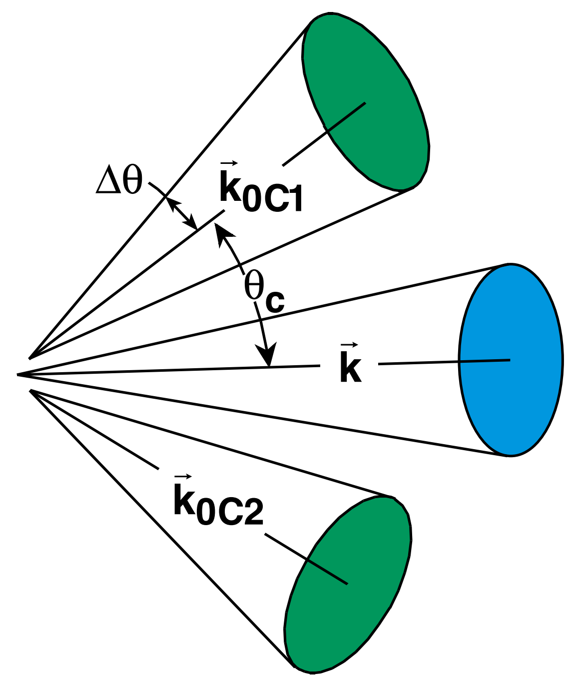
The increase of the angular width of an incoherent laser beam leads to the decrease of TPD growth rate and to the increase of the threshold



Incoherent beams (circular polarization) in 3-D



$(\gamma + \gamma_e)/\omega_{p0} \equiv \sqrt{\langle I \rangle / I_0}$ at $\Delta\omega = 0$

Resonance width $\Delta\omega/\omega_{p0} = 3\,k\ k_0 \lambda_{De}^2 \,|\sin\theta_c|\,\Delta\theta$

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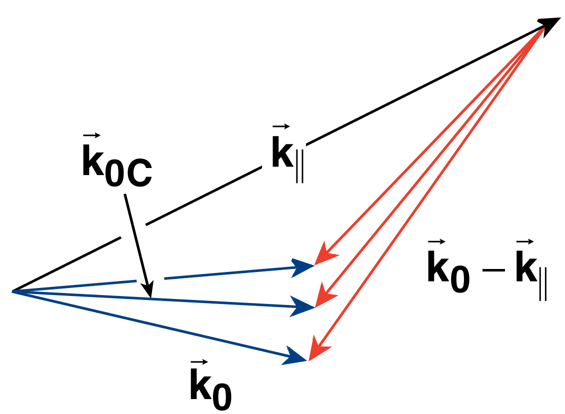
A new code is being developed to model the TPD instability driven by incoherent laser beams

- The code is based on fluid-type description.
- It runs in two spatial dimensions.
- Equations for plasma waves are enveloped around $\omega_0/2$.
- The solver for plasma waves is nonparaxial.
- The grid allows to resolve scales few times smaller than the laser wavelength.
- The code has been tested in a linear instability regime.

$$\vec{k} = \vec{k}_\perp + \vec{k}_\parallel$$

$$\vec{k}_\perp^{\odot} \quad \vec{E}_0^{\odot}$$



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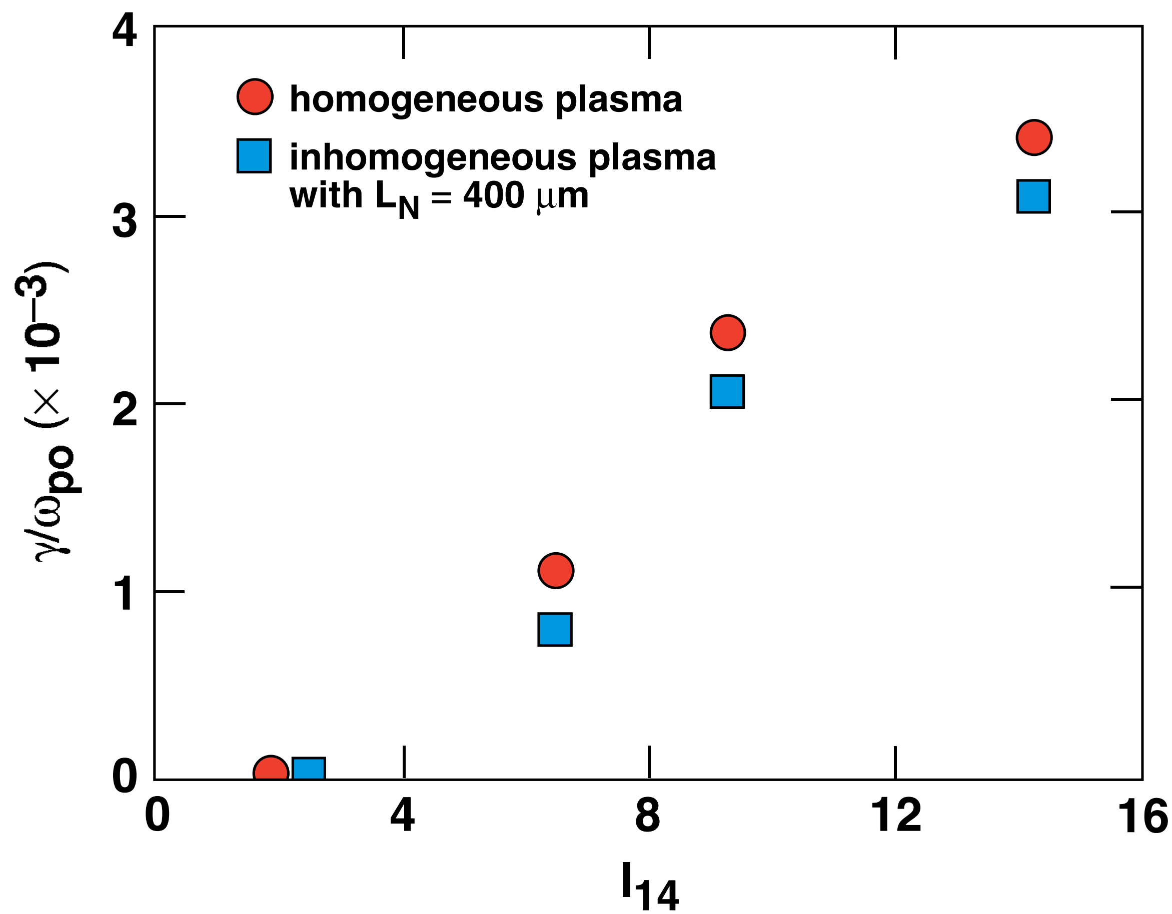
For the parameters of OMEGA plasmas, the plasma inhomogeneity decreases moderately the absolute growth rate of TPD



Simulation region

$200\ \lambda_0 \times 200\ \lambda_0$

$\Delta\theta = 0.15$

$\Delta\omega > \gamma_e$

$k_0 \lambda_{De} = 0.15$,

$k_\perp = 0.3\ k_0$,

$\gamma_e/\omega_{p0} = 10^{-3}$

When $\Delta\theta\uparrow$, $\gamma\downarrow$
$\Delta\theta\downarrow$, $\gamma\uparrow$

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