Use of Optical Phase Conjugation for Laser Irradiation on Laser Fusion Fuel Pellets

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Outline

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- Why optical phase conjugation technique?
  - Precise and automatic targeting of laser radiation
  - Compensate turbulence inside the fusion reactor
- What is Optical Phase Conjugation?
- Experiments
  - Efficiency
  - Compensation
  - Tracking
- How can it be used to irradiate ICF targets

Wave Front Distortion Compensation
Effect of Optical Phase Conjugation

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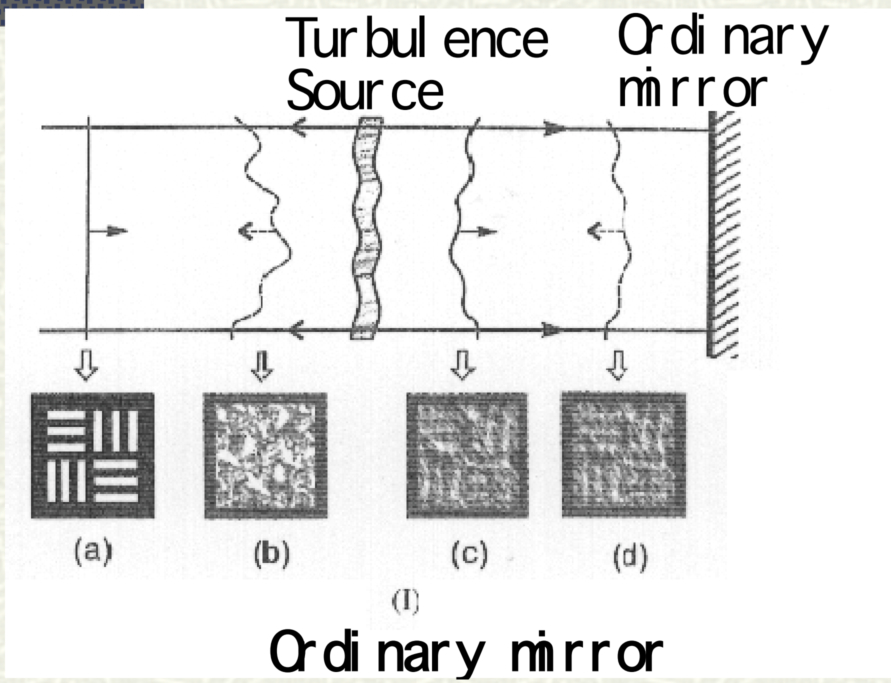
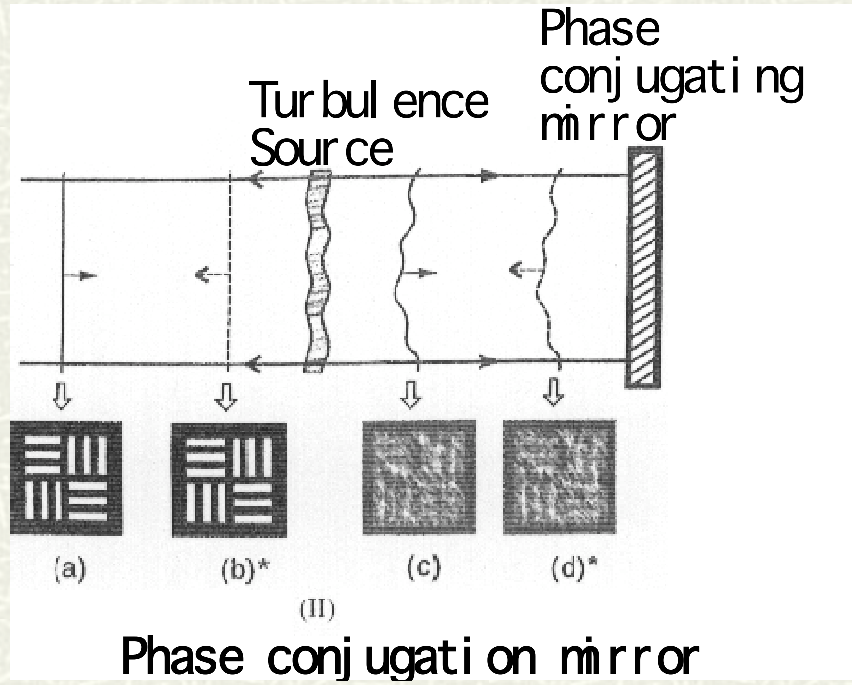
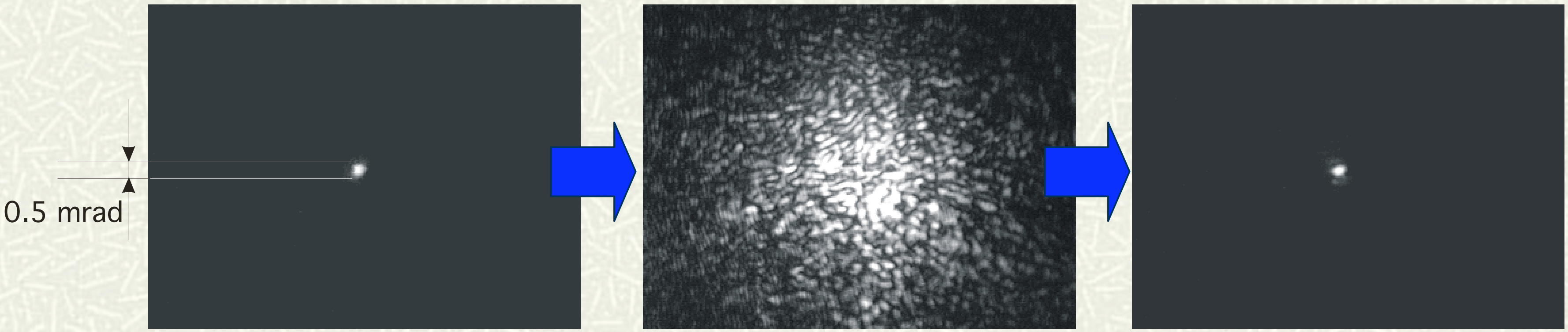




- **Phase conjugated waves share identical wave front shape with its original wave while their wave vectors are in opposite direction**
- **→Can be used for automatic compensation / targeting**

Phase conjugated wave can restore severe distortion

Initial signal **Distorted signal** **Corrected signal**



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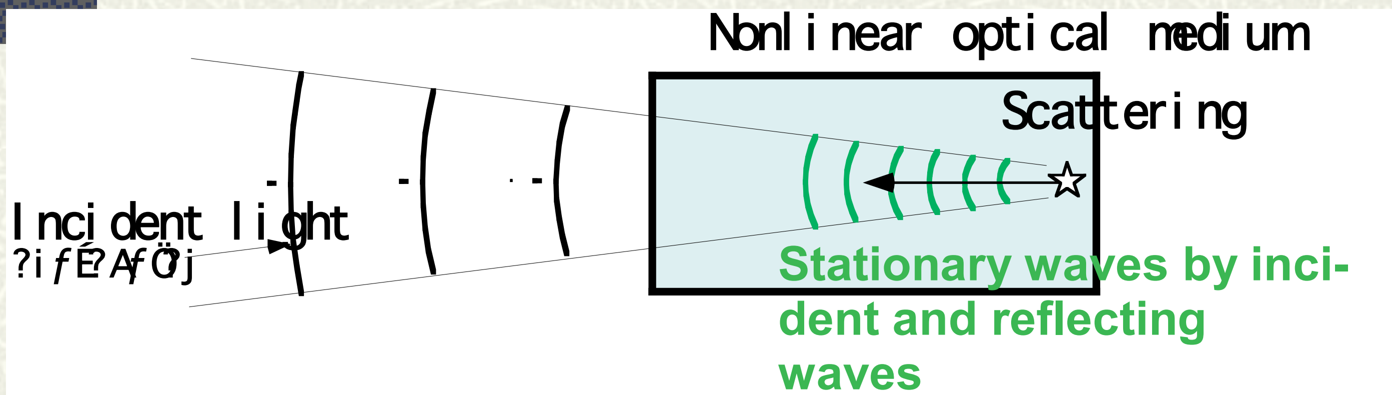
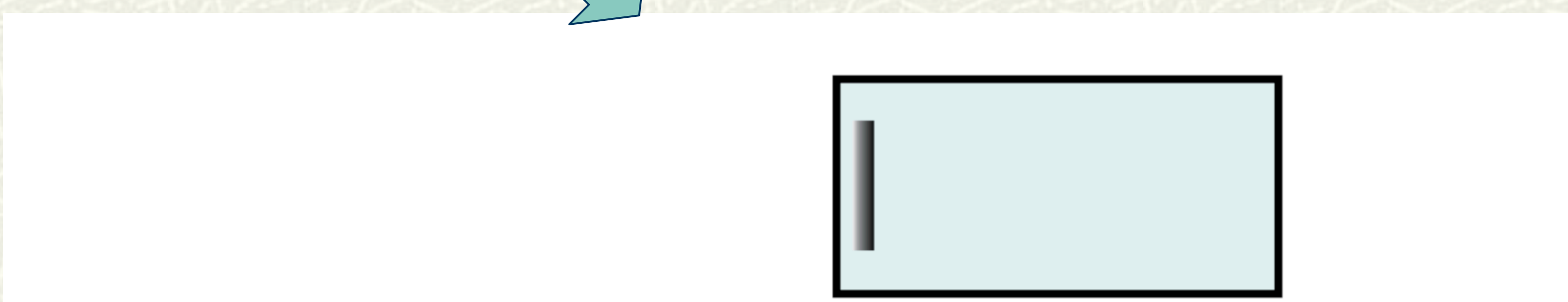
Making Optical Phase Conjugating Waves

- Use diffraction gratings to recode and recover information of optical wave fronts
- Ways to make gratings (modulation of refractive index)
  - Brillouin nonlinearity (acoustic waves)
  - Photorefractive effects (electron excitation in semiconductors)
- For high power applications, Brillouin effects are suitable
  - Stimulated Brillouin Scattering (SBS)
  - Degenerate Four Wave Mixing
  - Brilluoin Enhanced Four Wave Mixing

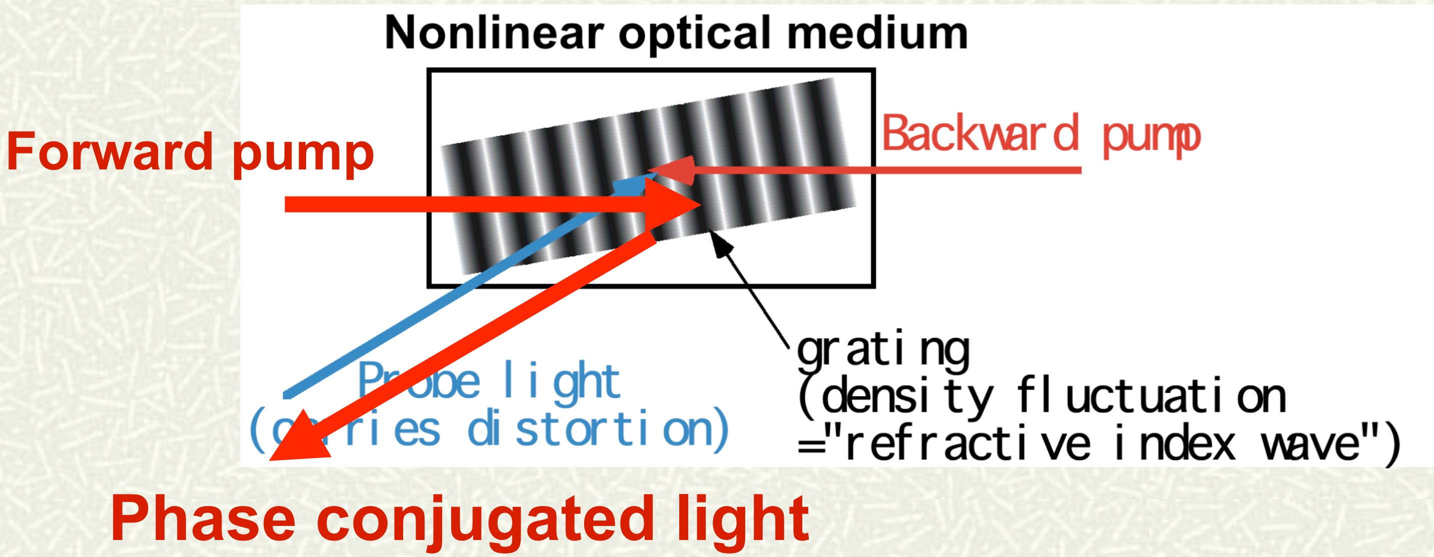
Phase Conjugation by SBS





- Need certain incident power to overcome SBS threshold

Phase Conjugation by Four Wave Mixing (degenerate)



- Amplification with phase conjugation
- No high intensity focus to the medium
  - (compared to SBS)

Further improvement is possible by Brillouin Enhanced Four Wave Mixing

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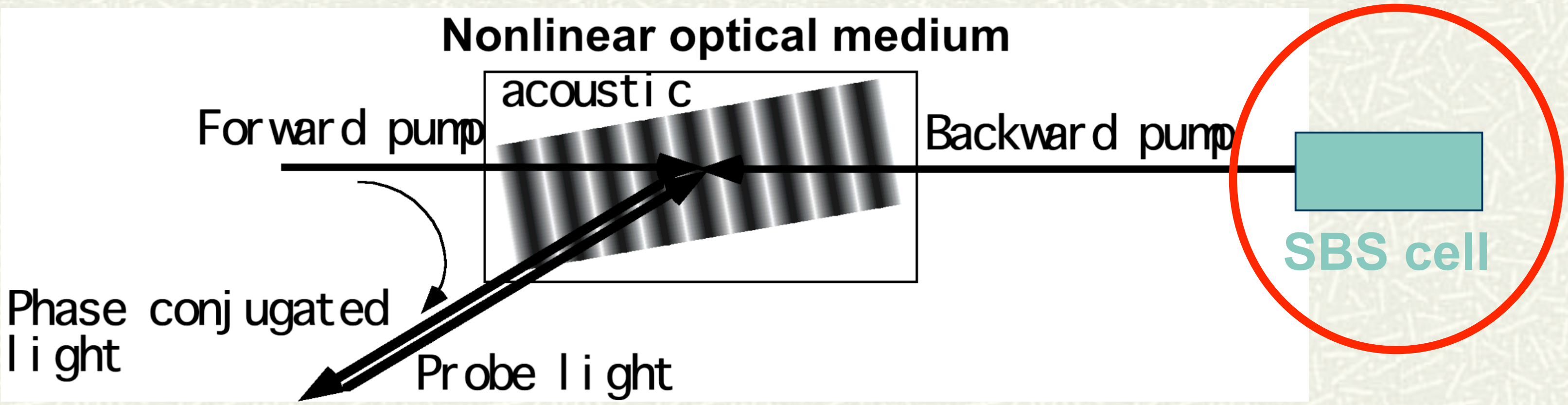

- The SBS cell provides frequency shift so that the motion of interference and acoustic wave matches resulting in the energy transfer enhancement
- Helps the two pump beams counter-propagate by themselves

What is good Phase Conjugation Material?

- Broad Brilluoin resonance
  - A few hundreds of MHz
- Low linear & nonlinear absorption
  - $\alpha<10^{-5}$ cm^{-1}, $\alpha_{NL}<10^{-5}$ cm^{-1}GW^{-1}
- High optical breakdown threshold
  - >100 GWcm^{-2}

Materials for Phase Conjugation

- Gases
  - Inert, diatomic, heavy molecular
  - Need to be high pressure
- Transparent solids
  - Silica
  - Damage
- Inorganic liquids
  - Metal tetrachlorides, Freon-113 ($C_2Cl_3F_3$)
  - Toxic, carcinogen, ozone layer hazardous

Fluorocarbon liquids for Phase Conjugation

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- F_6C_{16} (FC72), F_8C_{18} (FC75)
- Preferred properties
  - Low absorption from UV to IR region
  - High damage threshold
    - >100 GW/cm^{-2} at 1m and 1-ns pulse width
- Chemically stable
  - Environmentally harmless
  - No interaction with optical surfaces

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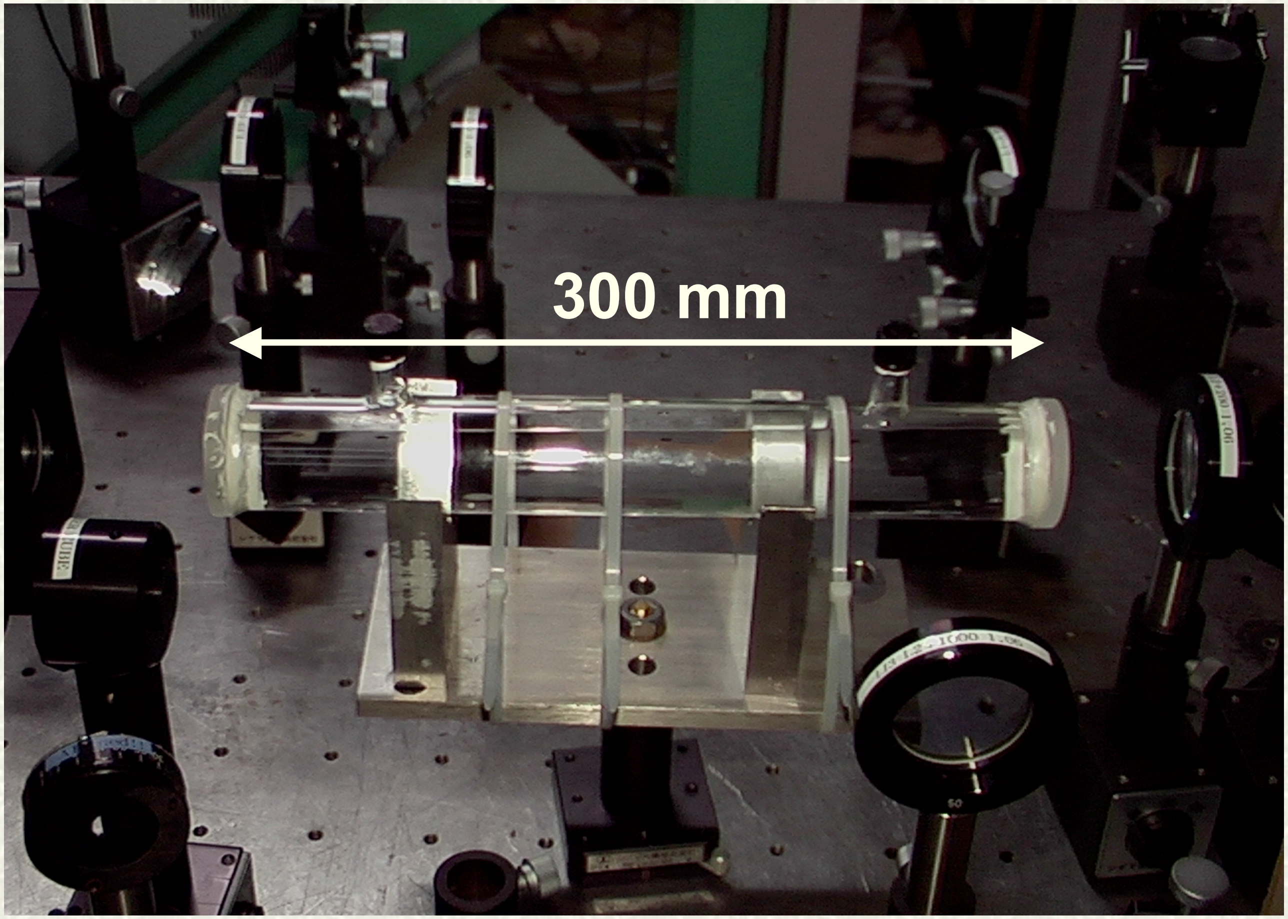
The phase conjugater cell



- **Liquid: FC72 (C_6F_{16})**

Experimental setup for BEFWM characteristics

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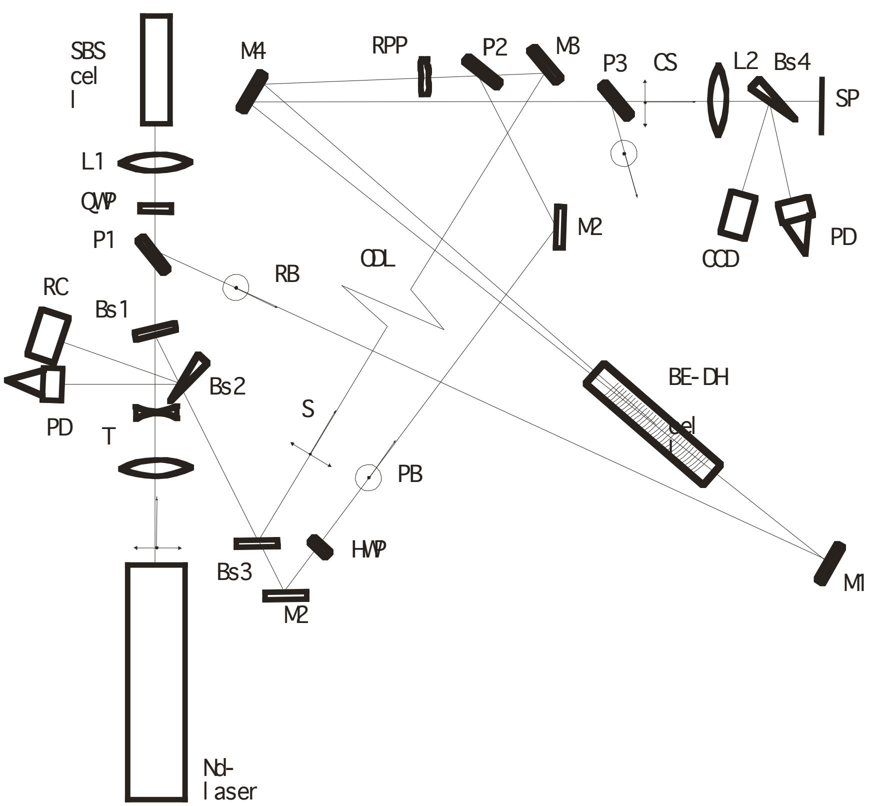

Equipment:

Nd-laser: MOPA,
E = 1 J, t = 20 ns, d = 15 mm
SBS cell - Stimulated Brillouin Scattering cell
BE-DH cell - Brillouin Enhanced Dynamic Hologram cell
Nonlinear medium - liquid fluorocarbon
Flourinert FC-72 refractive index n = 1.248
sound velocity vs = 512 m/sec
Brillouin frequency DnB = 1.2 GHz
QWP - Quarter Wave Plate
HWP - Half Wave Plate
T - Telescope, M = 0.4
P - Polarizer
L - Lens
BS - Beamsplitter
M - Mirror
RC - Reference Calorimeter
PD - Pin-diode
CCD - Video camera
SP - Sensitive paper
RPP - Random Phase Plate
ODL - Optical Delay Line

Signals and energy:

S - Signal to be corrected 40 mJ
PB - Probe Beam 120 mJ
RB - Reference Beam 500 mJ
CS - Corrected Signal 20 mJ

Diffraction efficiency strongly depends on probe intensity

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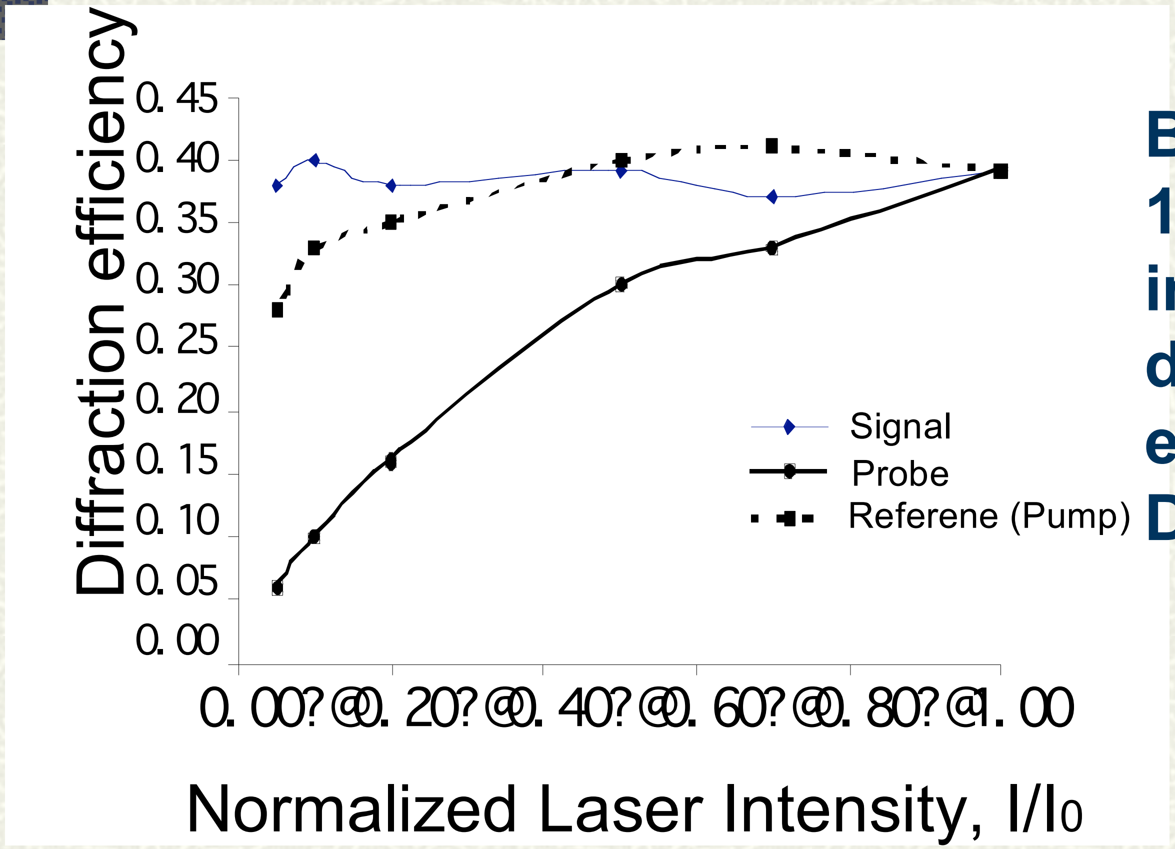

BEFWM exhibits 10 times improvement in diffraction efficiency from DFWM

- **All intensities are normalized to their optimum intensity**

Interaction length of FWM is 30 cm

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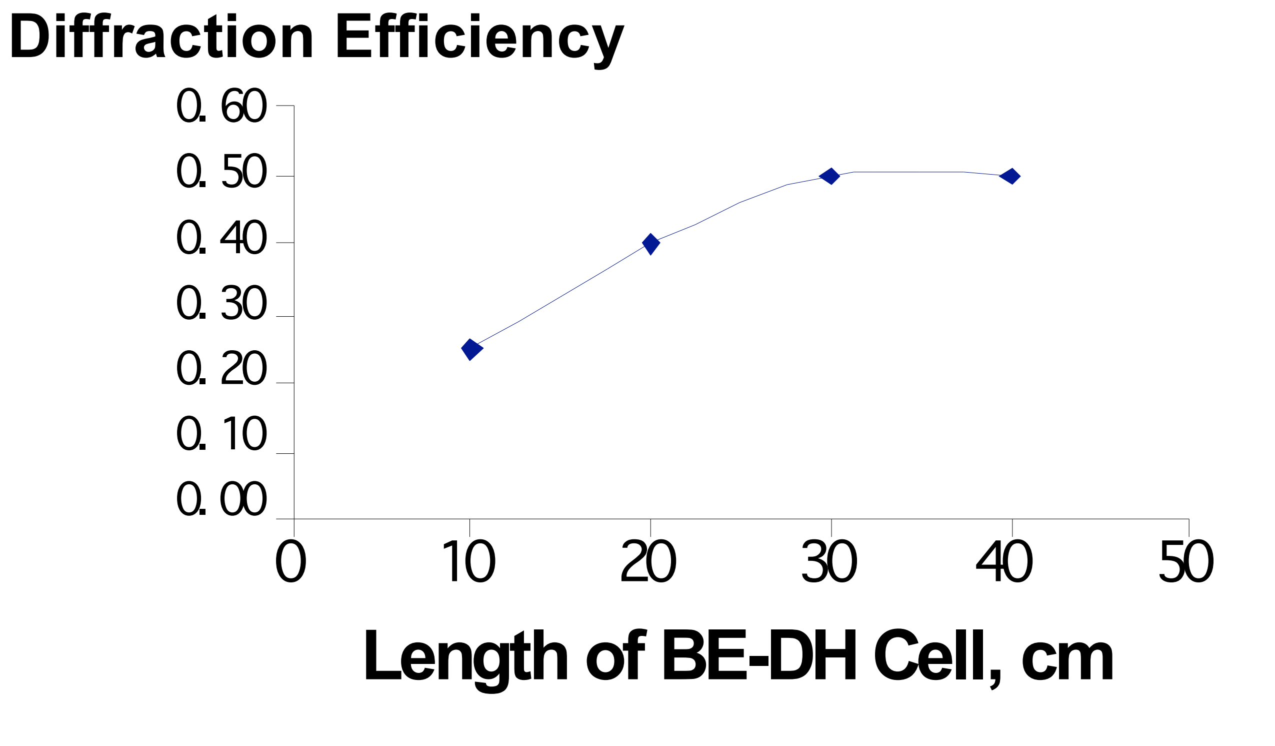

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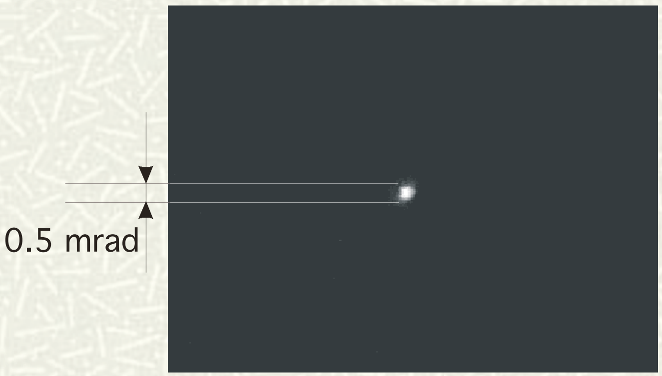
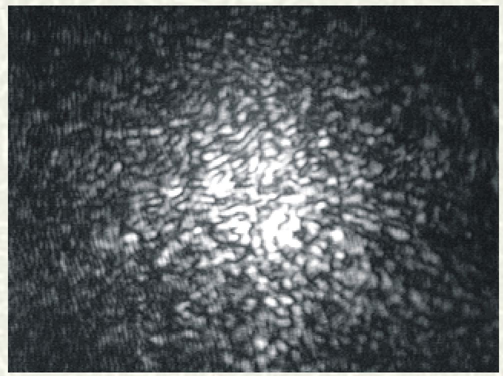
The degree of wavefront distortion recovery

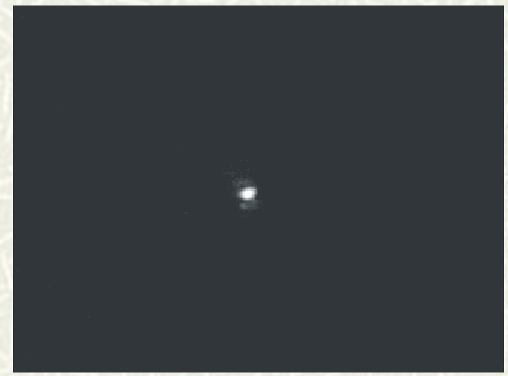
Initial signal



Distorted signal



Corrected signal



Laser Beam Divergence = 0.78

Laser Beam Divergence = 0.71

- **Laser beam divergence = energy in diffraction limited solid angle / total energy**
- **Fidelity of PC = 0.71 / 0.78 = 90 %**

Experimental Setup for targeting

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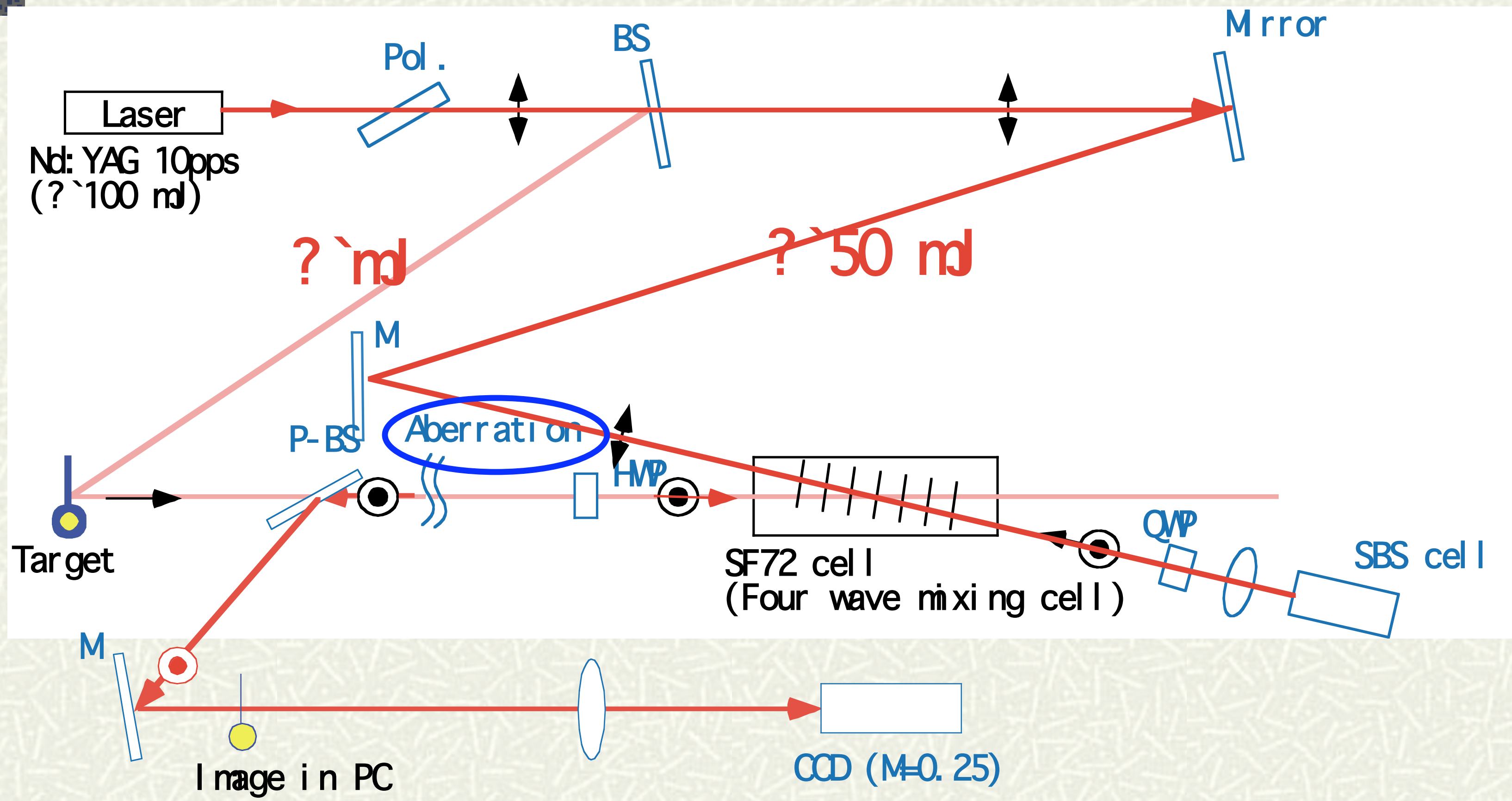

Al plane target

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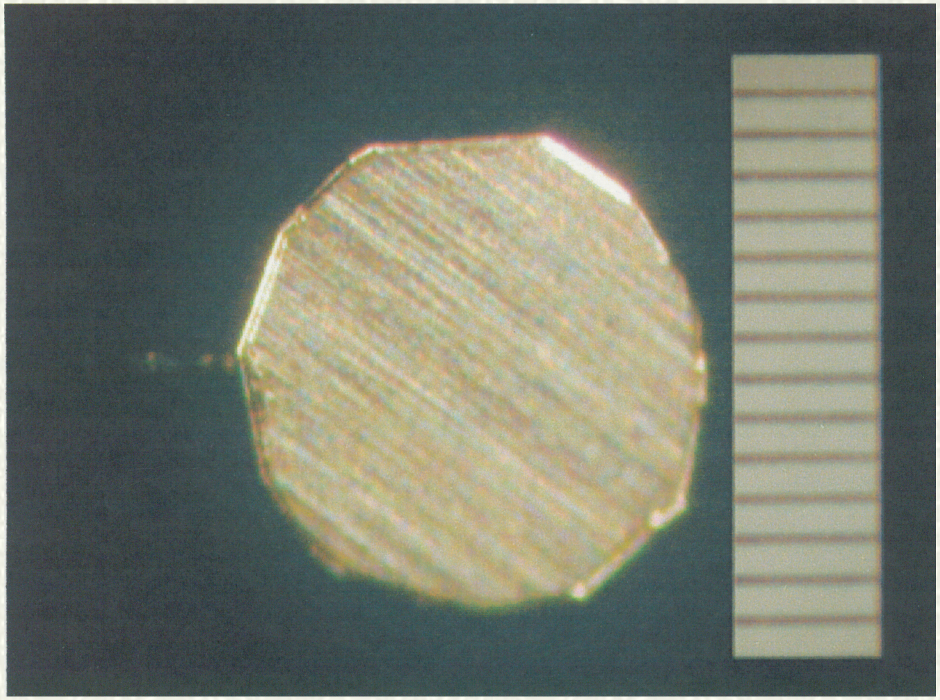

- Diameter : 1 mm

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Light from target seen through turbulent media and the compensation effect of phase conjugation

Without PC

With PC

- **Turbulence compensation and tracking function**

How will PC be implemented to ICF target irradiation system

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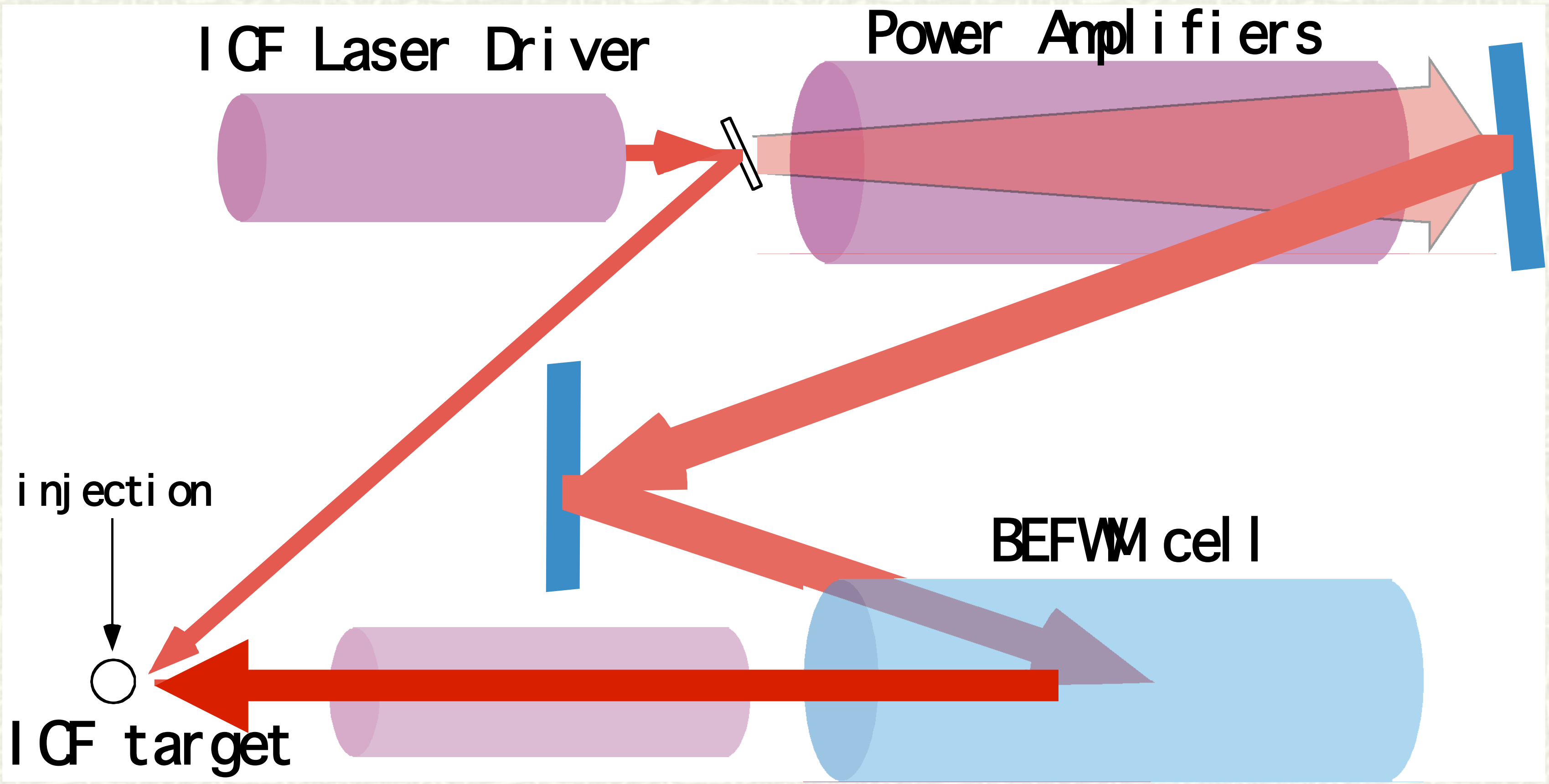

Summary

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- Use of optical phase conjugation technique is proposed for ICF target beaming
- Brillouin Enhanced Four Wave Mixing is a promising technique for the purpose
- Preliminary experiments show the technique exhibits sufficient wavefront compensation and beaming capability
- Improvement for increase energy usage through the system will be one of the future tasks