Feasibility study on Scalable Self-Phase Locking of two beam combination using stimulated Brillouin scattering phase conjugate mirrors

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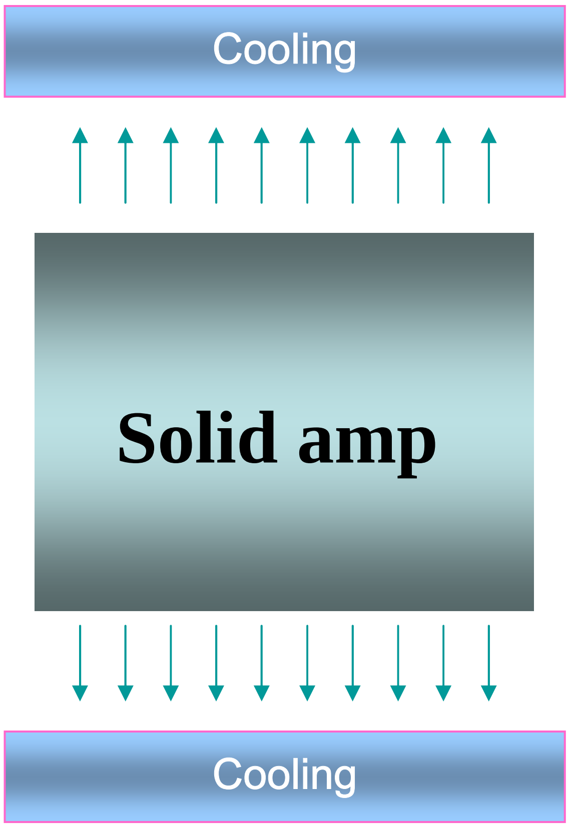
Motivation

- Laser IFE Program has the bottle neck mainly due to the laser driver with high rep. rate over 10 Hz. (NIF operates at 1 shot per several hours)

Why bottleneck?



- For high power and high energy output,
- big size of laser amplifier to reduce the optical damage and gain saturation is necessary.
- But, it gives very high thermal load so that
- it takes too much time to cool down .

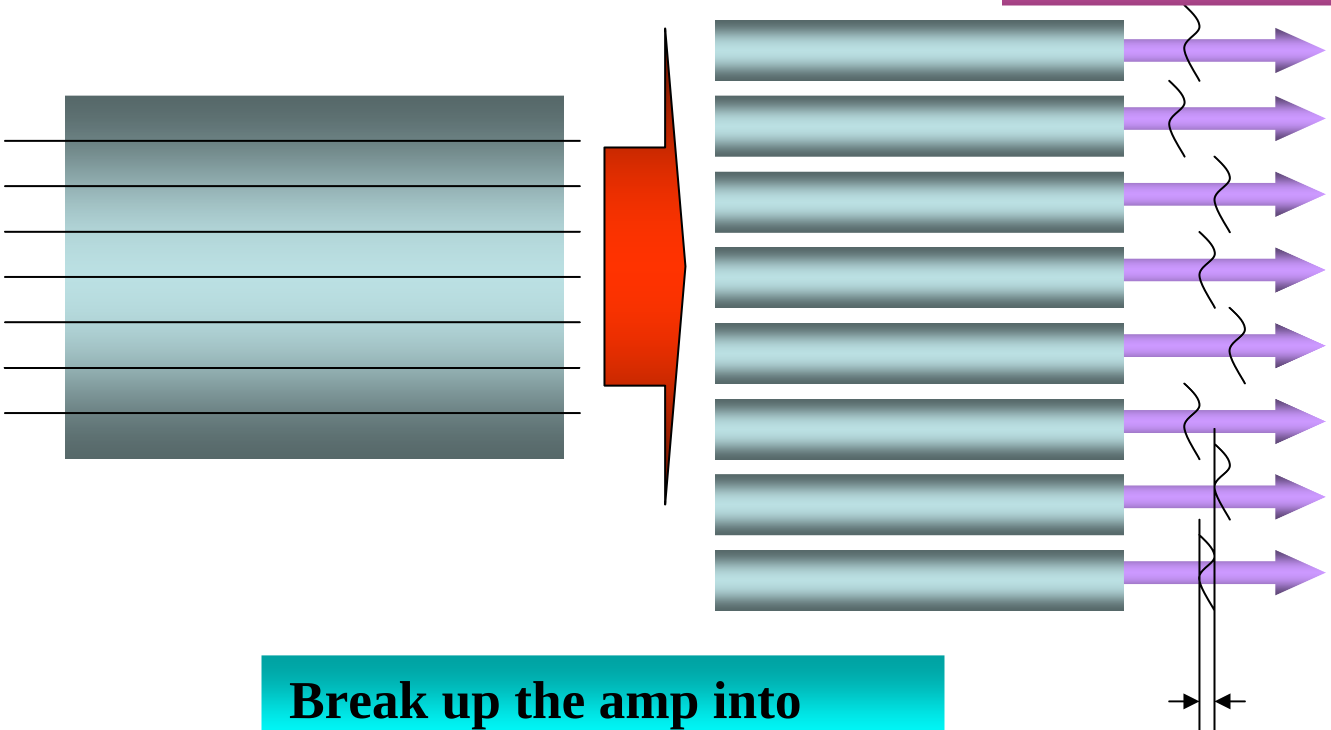
How to solve the thermal load?

- Use the pumping source with LD (Mercury, LLNL)
- Use the high thermal conductivity laser materials such as ceramic crystals (K.Ueda)
- Break down the amplifier with small size to reduce the size of the amplifier (H.Kong)

⇨ Beam combination

Beam combination

Phase distortion



Easy to cool down the sliced amps

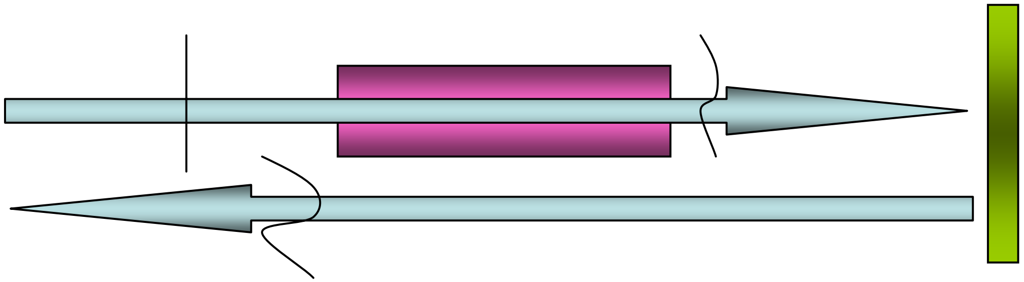
Each beam has different phases and distorted by the amp’s nonlinearities such as thermal lensing effect and thermal birefringence, different gain profiles and so on.

Break up the amp into small size amp to reduce the thermal load

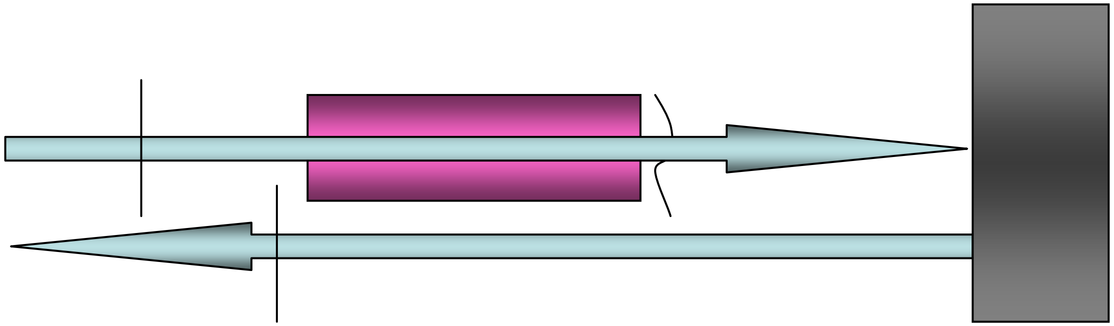
Piston error

How to combine the beams together in phase? (to fix the piston error)

Phase conjugation mirror (PCM)



Conventional mirror



Phase conjugation mirror

Types of PCM

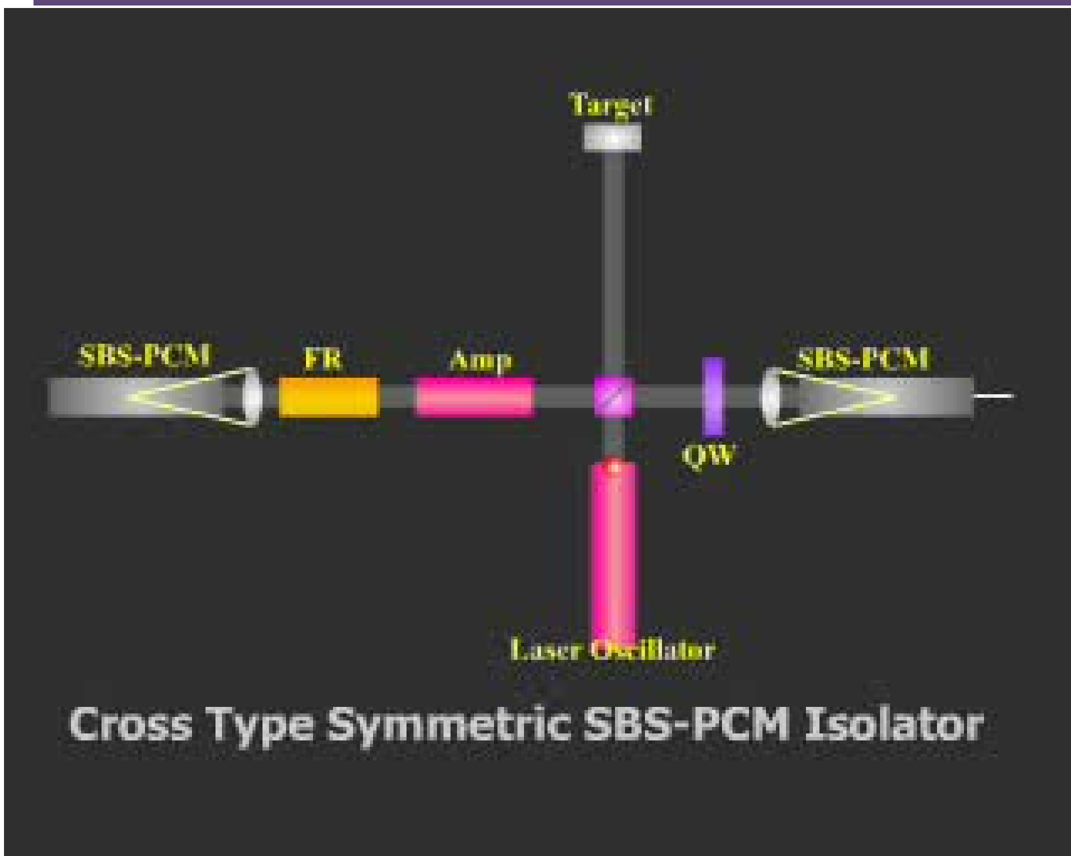
- 4 wave mixing PCM (complicated, phase controllable)
- Stimulated Brillouin Scattering PCM (SBS PCM) (most simple, random phase piston error)

Stimulated Brillouin Scattering PCM (SBS-PCM)

- Backward scattering – high reflectivity more than 90 %
- Phase conjugate wave – high fidelity
- Scattering by acoustic phonon induced by laser field
- Frequency down shift –negligible; ~1 GHz for liquids
  < 1 GHz for gases

Cross-type PCM amplifier : Perfect Optical Isolator with PCMs

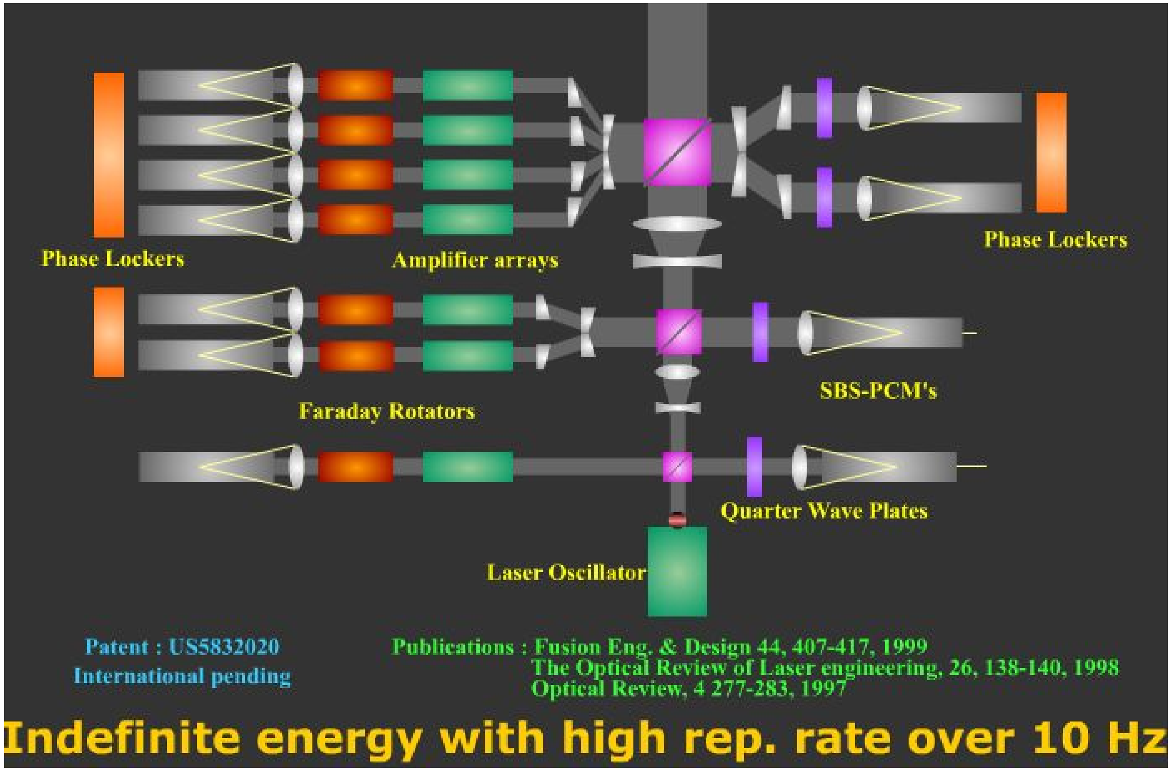
Proposed by Kong (will be submitted, patent pending)



- Compensate the phase distortions experienced passing through the amplifier by PCM
- Perfect optical isolation
- Insensitive to misalignment: Fixed beam pointing

Beam combination using SBS-PCM for highly repetitive high power and high energy laser

Proposed by H.J.Kong
Optical Review 4, 277-283(1997)
Fusion Eng. & Design 44, 407-417(1999)



- Interference between the beams at their boundaries in beam combination gives *spatial spiking* if their phases are not matched.
- Phase difference between the beams *should be less than $\lambda/4$* for constructive interference at the boundary of the combination not give spatial spiking.

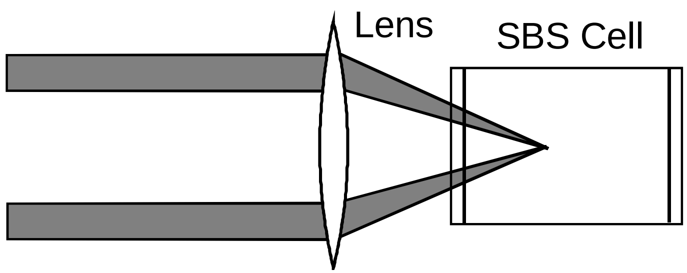
Phase locking between beams

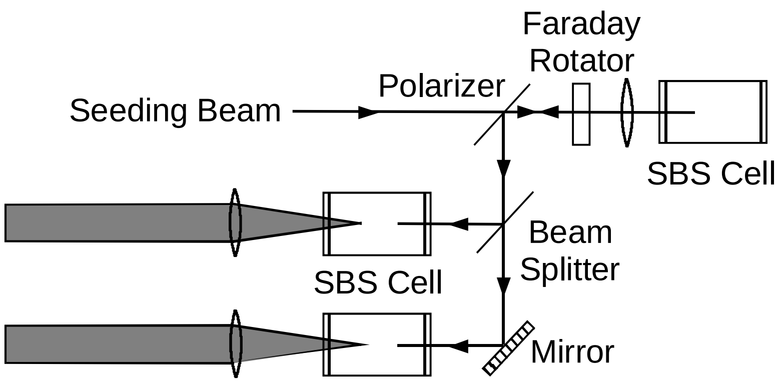
- Interference between the beams at their boundaries in beam combination gives ***spatial spiking*** if their phases are not matched.
- Phase difference between the beams ***should be less than λ/4*** for constructive interference at the boundary of the combination not give spatial spiking.

Previous works for phase locking

1. **Overlapping the SBS focal points locks the phases of the beams.**

2. **Phase locking by back seeding the Stokes shifted beam, which locks the phase of the PC wave.**





a) Overlap of two focal points

D.A.Rockwell and C.R.Giuliano, Opt. Lett. 11, 147 (1986)

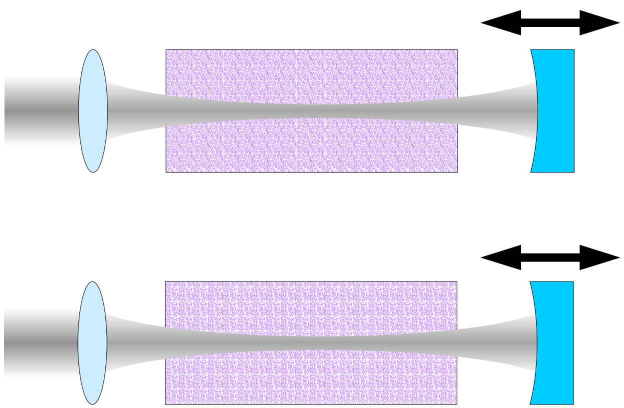
b) Back-seeding of Stokes wave

T.R.Loree, et. al., Opt. Lett. 12, 178 (1987)

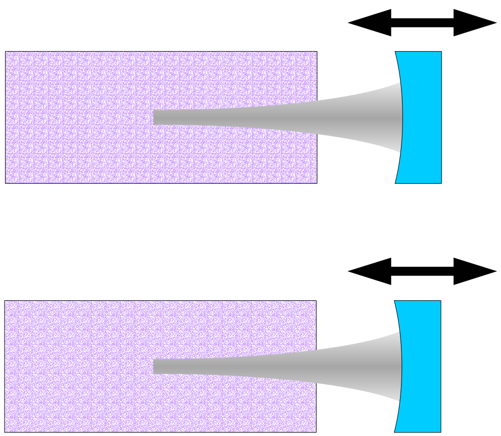
Proposed *"Self-Phase locking"*

1. Interference between the counter-propagating beams generates a very weak standing wave, which ignites the phonon and locks the phase of the moving grating (phonon).

2. This phonon locks the phase of the SBS wave.



(a) Self-seeding

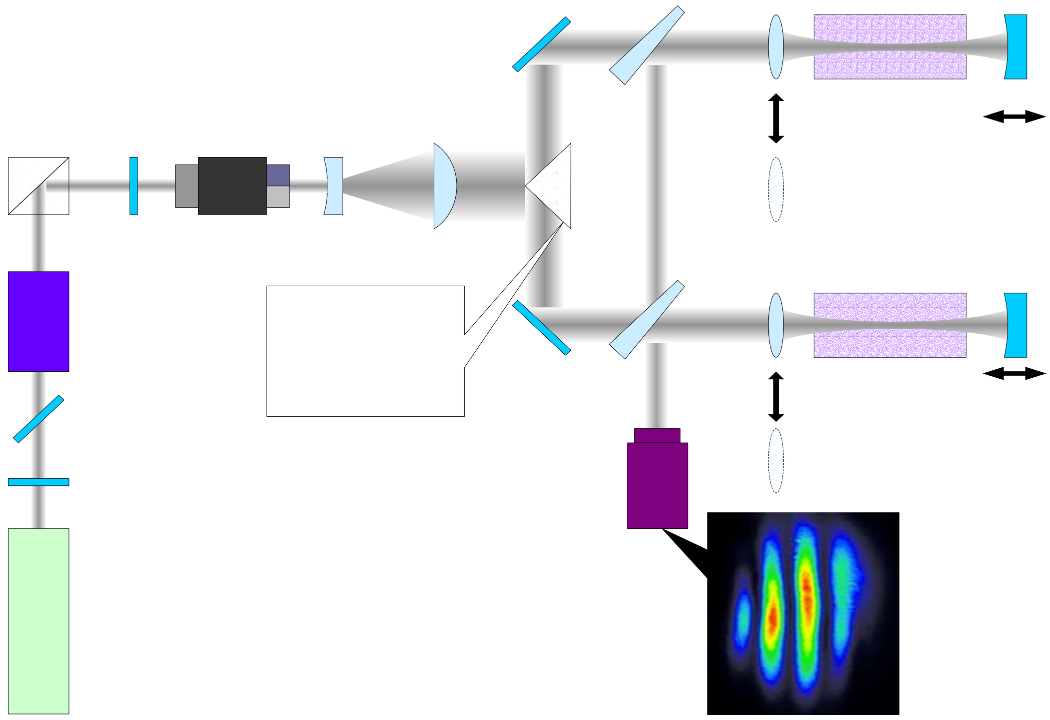


(b) Backward focusing SBS

Basic concept of a new phase locking

Stop Play

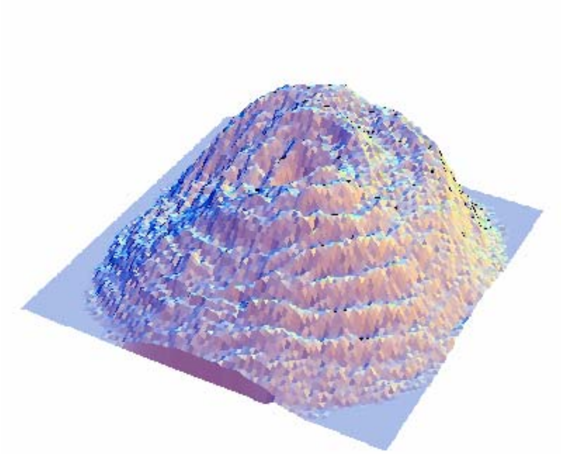
Experimental setup for self-phase locking of two beams

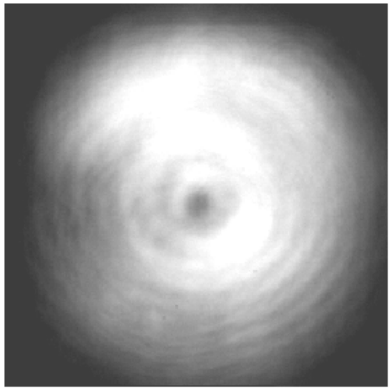


M1&M2, mirror; W1&W2, wedge; L1&L2, cylindrical lens: L3&L4, focusing lens, CM1&CM2, concave mirror; HWP1&HWP2, half wave-plate; P1, polarizer; PBS, polarization beam splitter

Properties of the pumping laser

- Nd^{3+}:YAG laser (1064 nm)
- Repetition rate: 10 Hz
- Single longitudinal mode
  Line-width: ~120MHz
- Pulse width: 6-8 ns
- Beam diameter : 8 mm

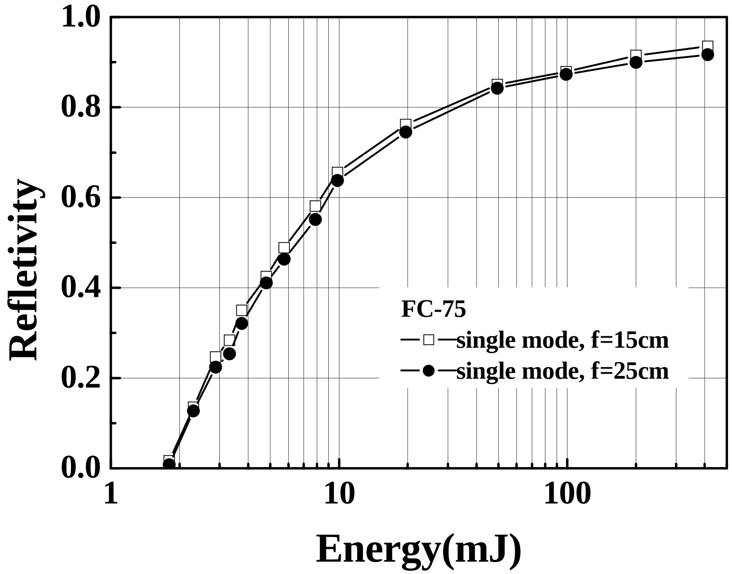




Beam profile

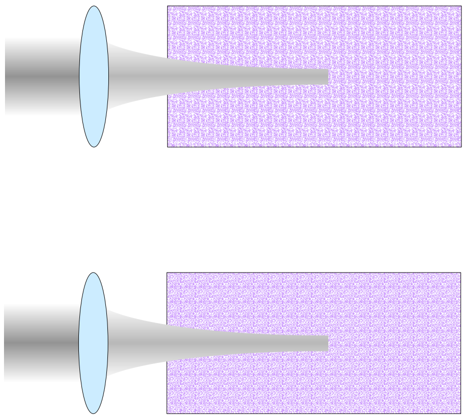
Properties of SBS medium (FC-75)

Main component	C_8F_{18}
Absorption coefficient	$<10^{-5}$(cm^{-1})
Optical breakdown threshold	100~130GW/cm^2
Brillouin frequency shift	1.34 GHz
Hyper sound velocity V	563 m/sec
SBS gain coefficient g	4.5~5 cm/GW
Brillouin bandwidth	350 ~ 400 (MHz)
Hyper sound decay time	0.8 ns

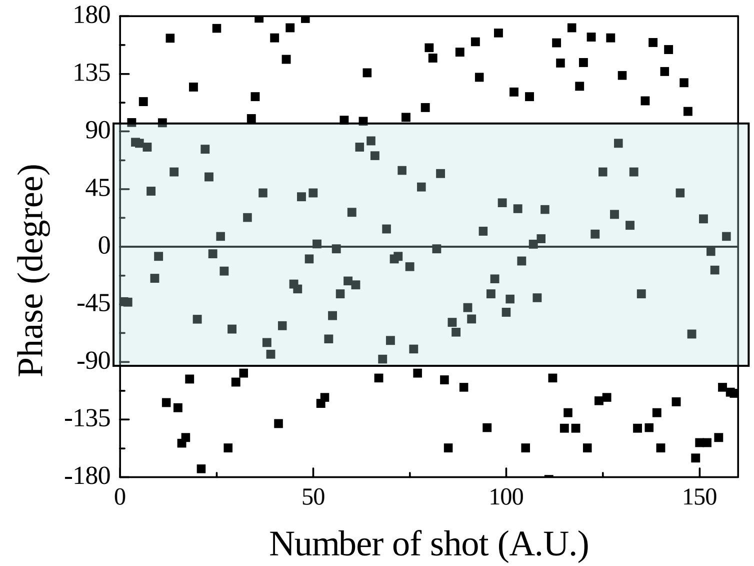


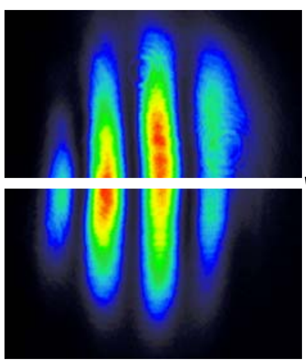
Reflectivity vs. pump energy

Normal case: No locking

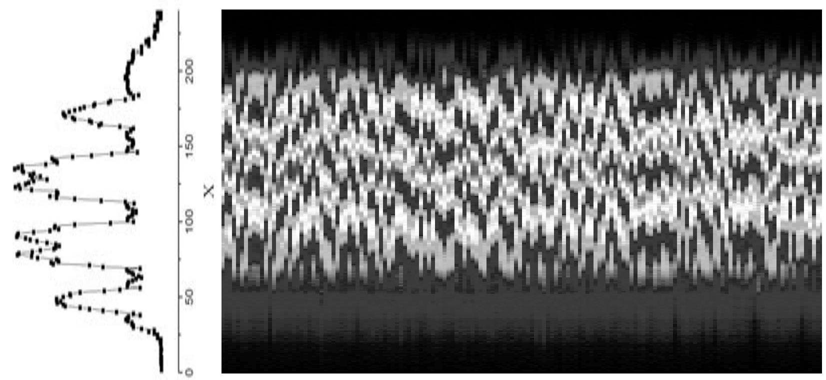


Average fluctuation ≈ ±0.6 λ



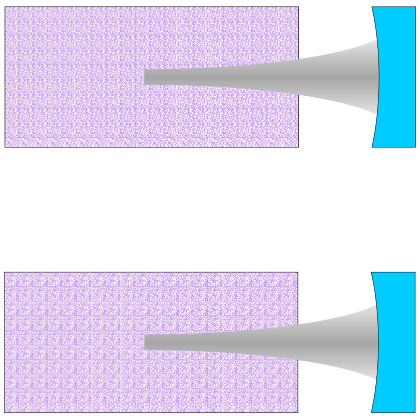


Intensity profile of interference



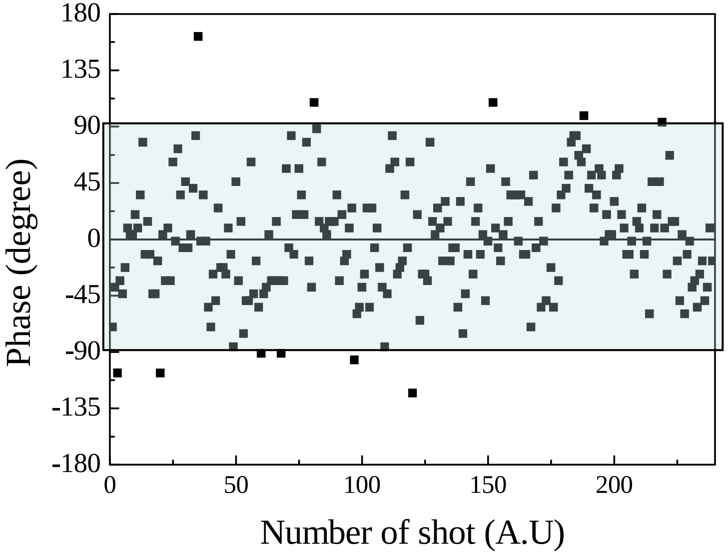
Intensity profile of interference for 160 shots

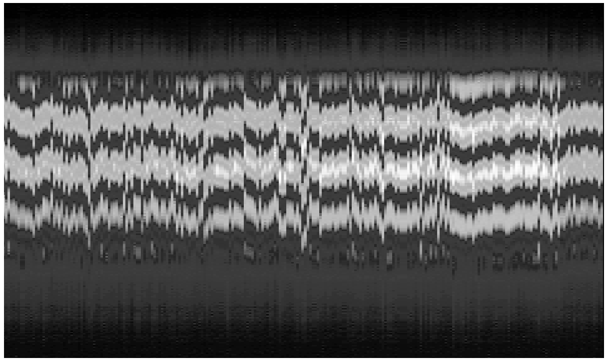
Backward focusing SBS



228/238 : success (96%)

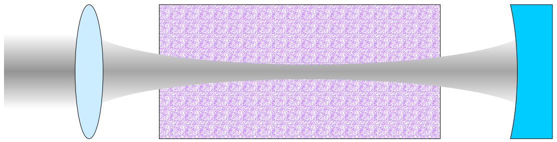
Average fluctuation ≈ ±0.27 λ

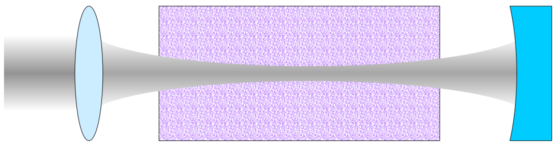




Intensity profile of interference for 238 shots

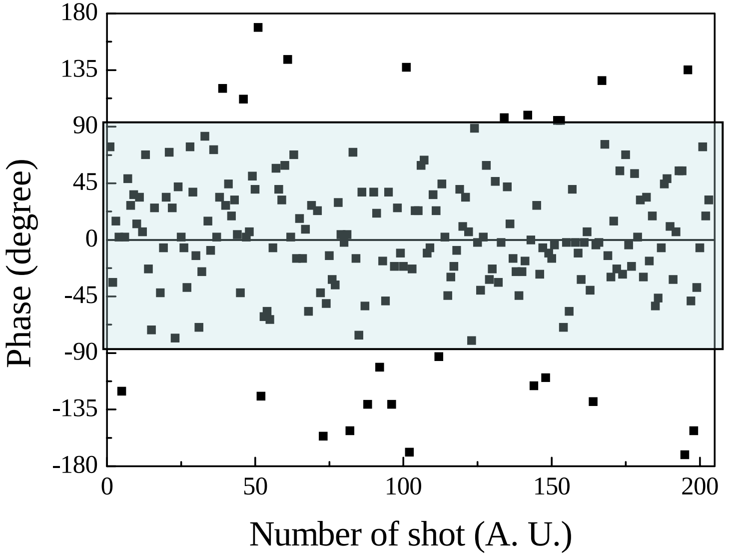
Concentric seeding beam case #1

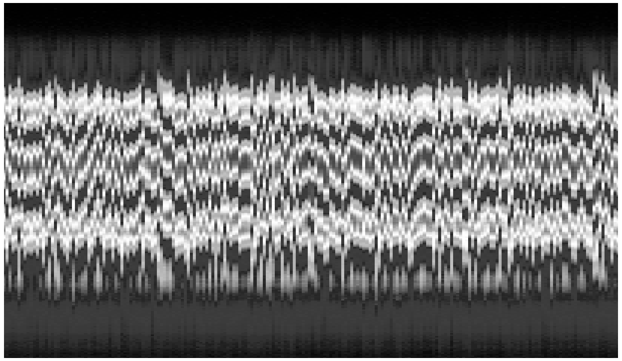




178/203 : success (88%)

Average fluctuation ≈ ±0.33 λ

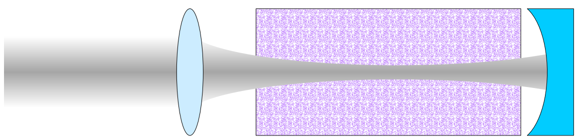


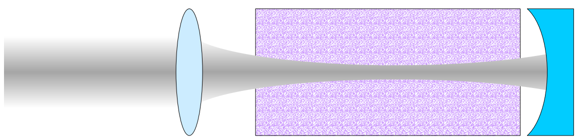


Intensity profile of interference for 203 shots

Confocal seeding beam

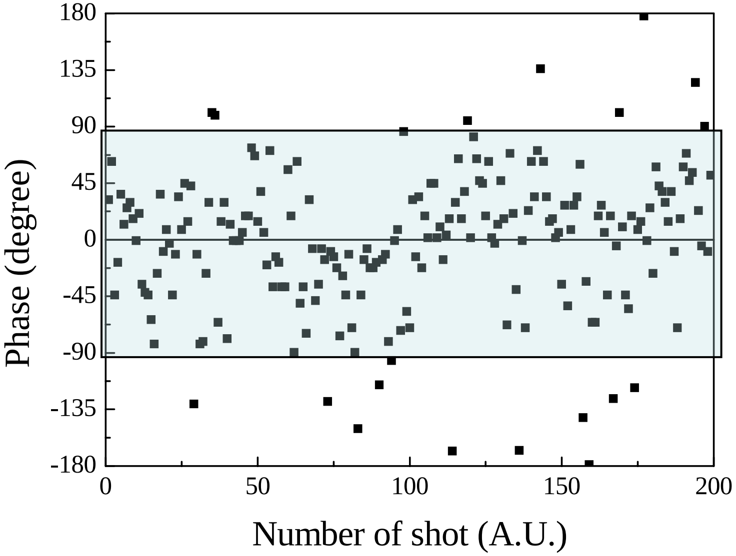
case #2

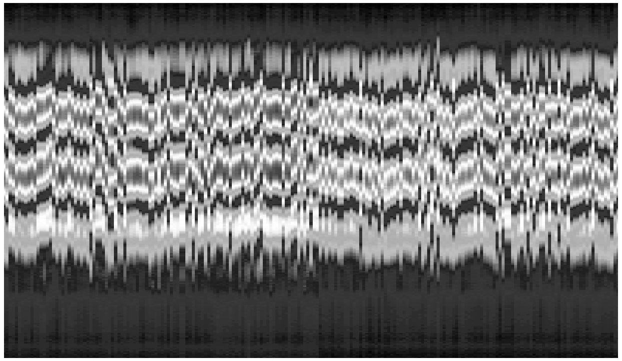




181/199 : success (91%)

Average fluctuation ≈ ± 0.31 λ

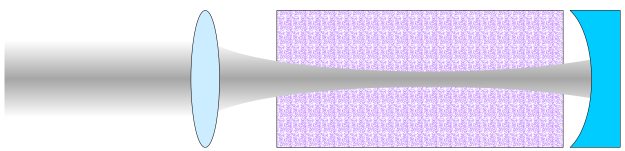


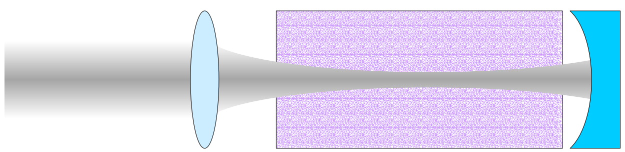


Intensity profile of interference for 199 shots

Confocal seeding beam

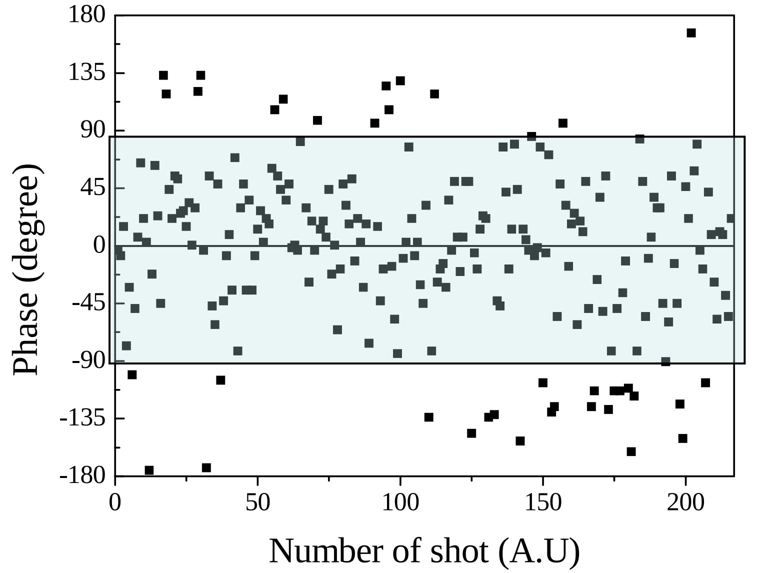
case #3

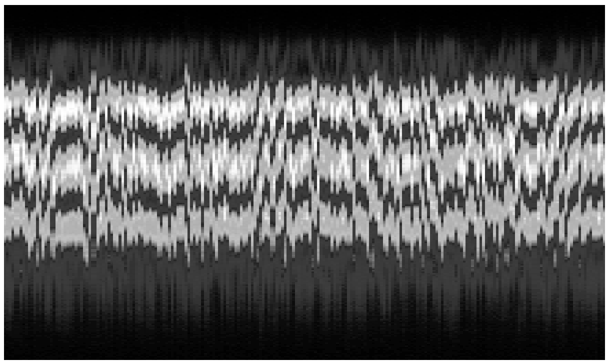




178/216 : success (82%)

Average fluctuation ~ ±0.38 λ

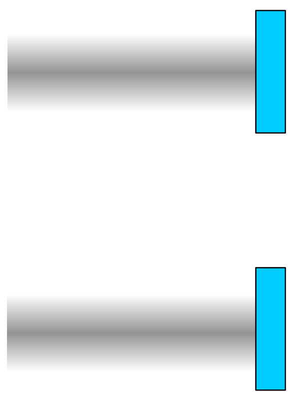


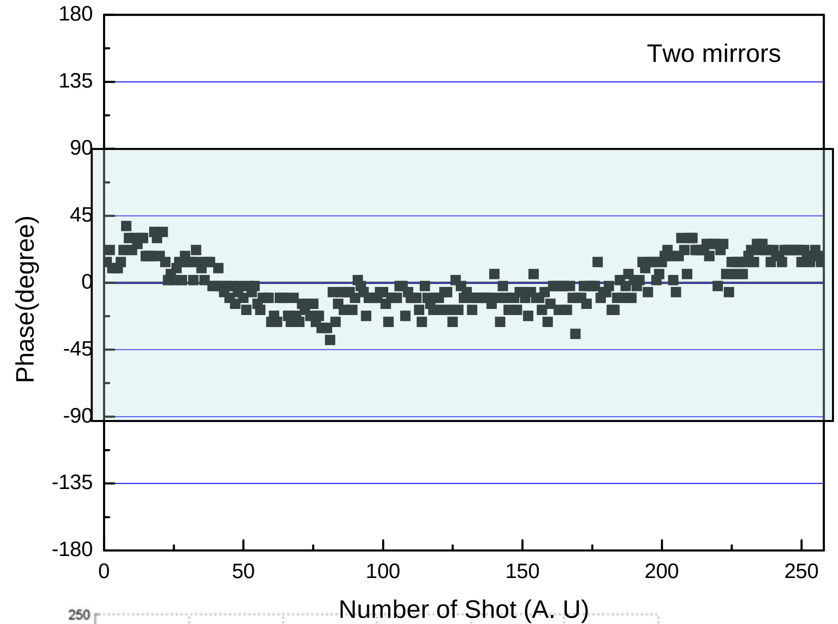


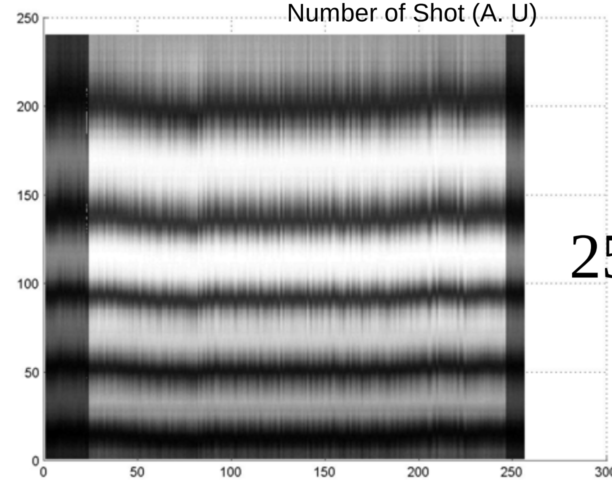
Intensity profile of interference for 216 shots

Average fluctuation ≈ ±0.09 λ

Two mirrors

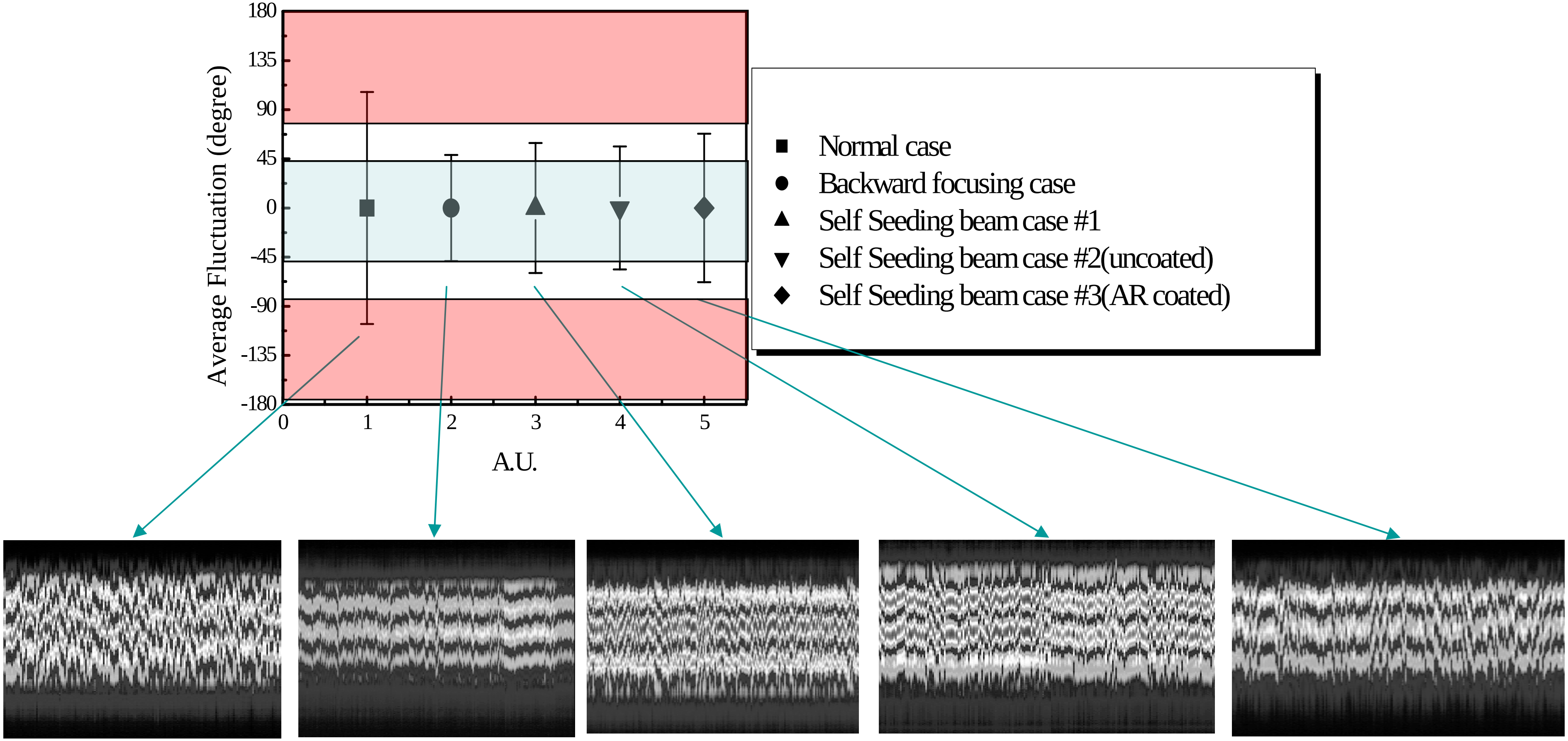






256 shots

Average fluctuations for each case



Summary

- We have proposed a new scalable phase locking method, **"*the self-phase locking*"**.
- **For the case of the backward focusing, the average fluctuation of phases between two beams is $\approx \pm 0.27\lambda$ *(96% success)*.**
- **Further works are necessary to reduce the phase locking fluctuation $< 0.25\lambda$ *with* 100% success.**
- **This new method can easily scaled up to a number of beams to get a high power and high energy laser output for IFE or other applications.**
- **With or without LD pumped ceramic laser materials developed by K. Ueda, this new technique is expected to advance the Laser Fusion Program, IFE, and also expand the high power laser application area including laser machining.**