Conceptual Design of Sub-Exa-Watts OPCPA System

GEKKO – EXA

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Lake Tahoe, California
10th September 2012

Outline

1. Conceptural design of sub-exa-watts laser -“GEKKO – EXA”-

1-1 Concept of Sub-EW Laser

2. Pump source of OPCPA

2-1 Repeatable DPSSL at 100 J

2-2 Single shot glass laser at 10 kJ

3. Broadband OPCPA in kilo-joule

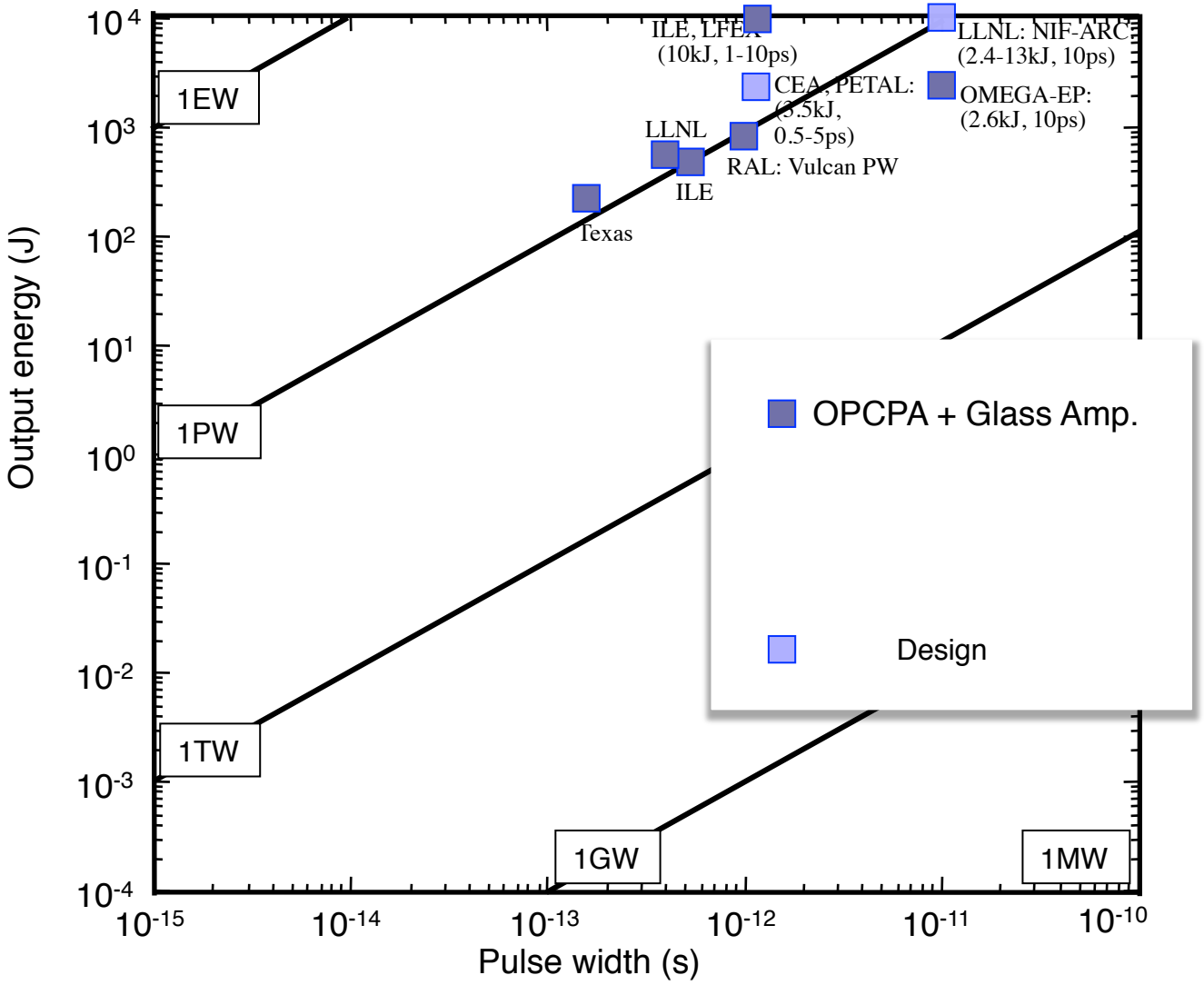
3-1 Randam-phase pumped OPCPA

3-2 Partially-deuterated DKDP

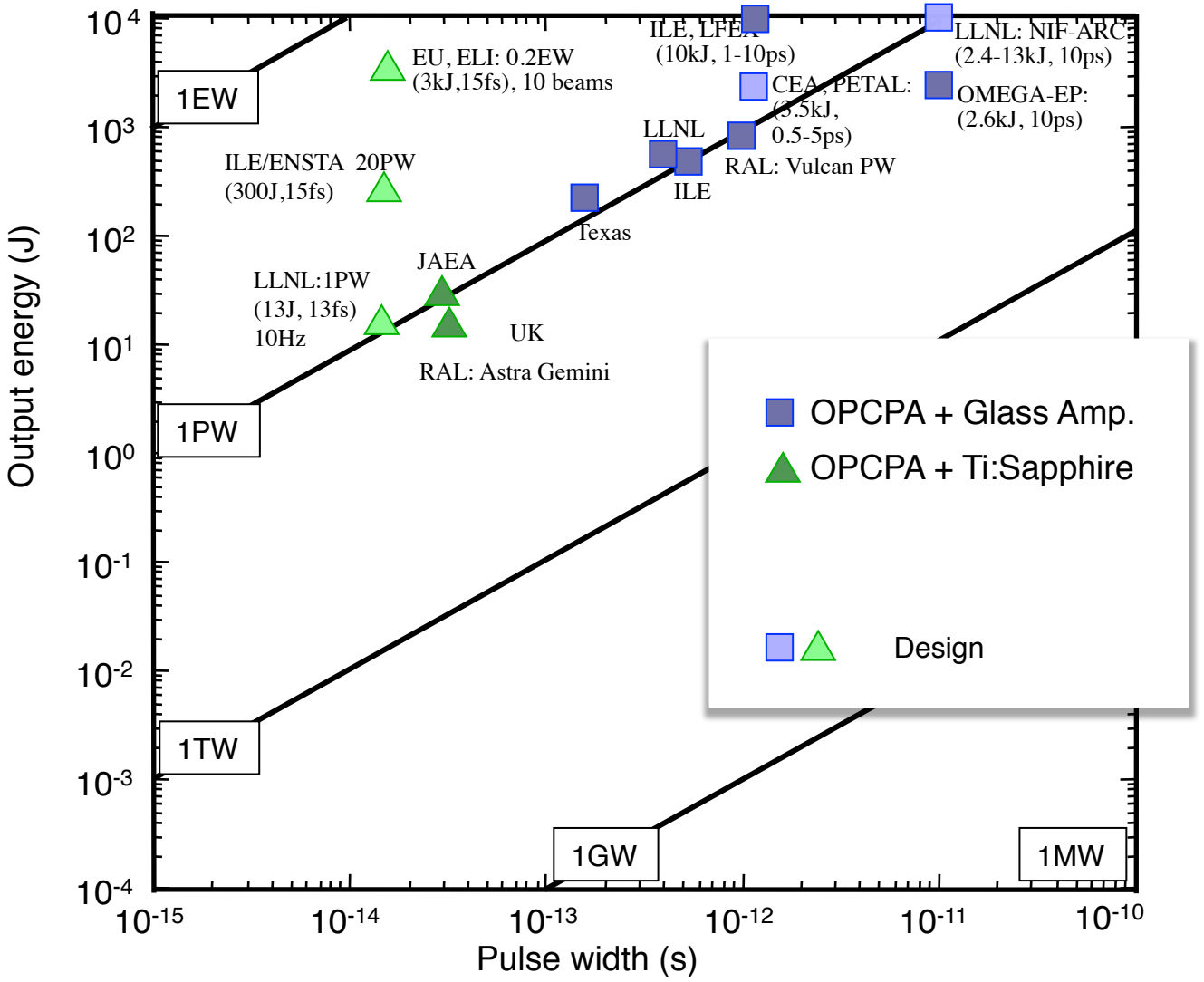
4. Summary

Conceptual Design of Sub-Exa-Watts Laser -GEKKO-EXA-

Ultra-intense lasers over the world



Ultra-intense lasers over the world



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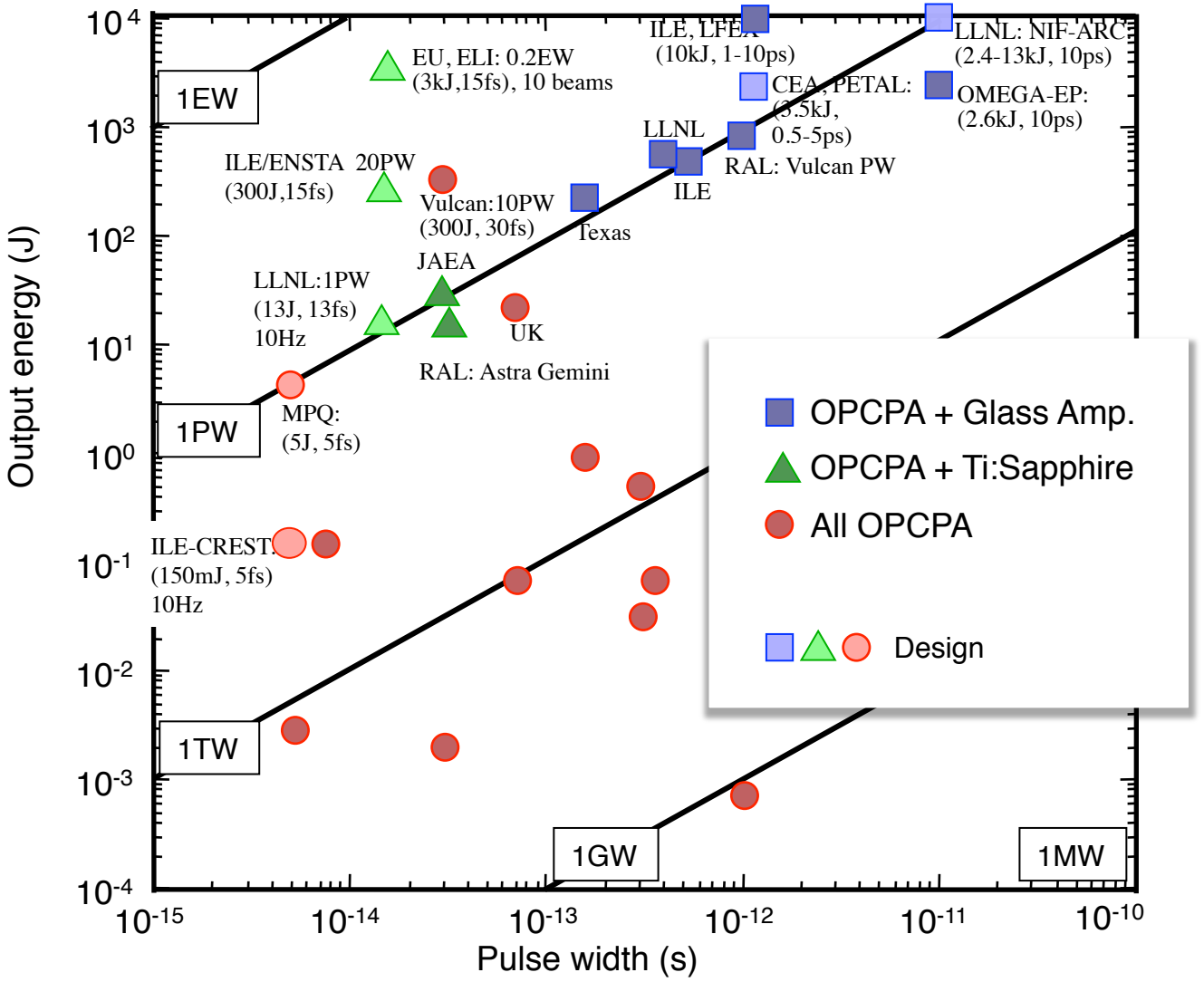
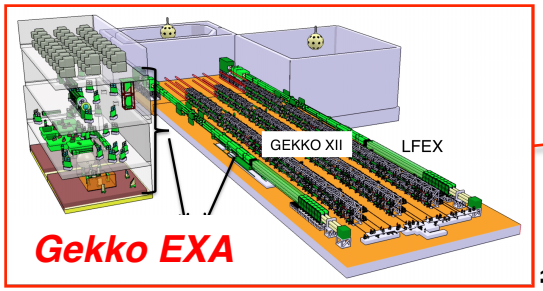
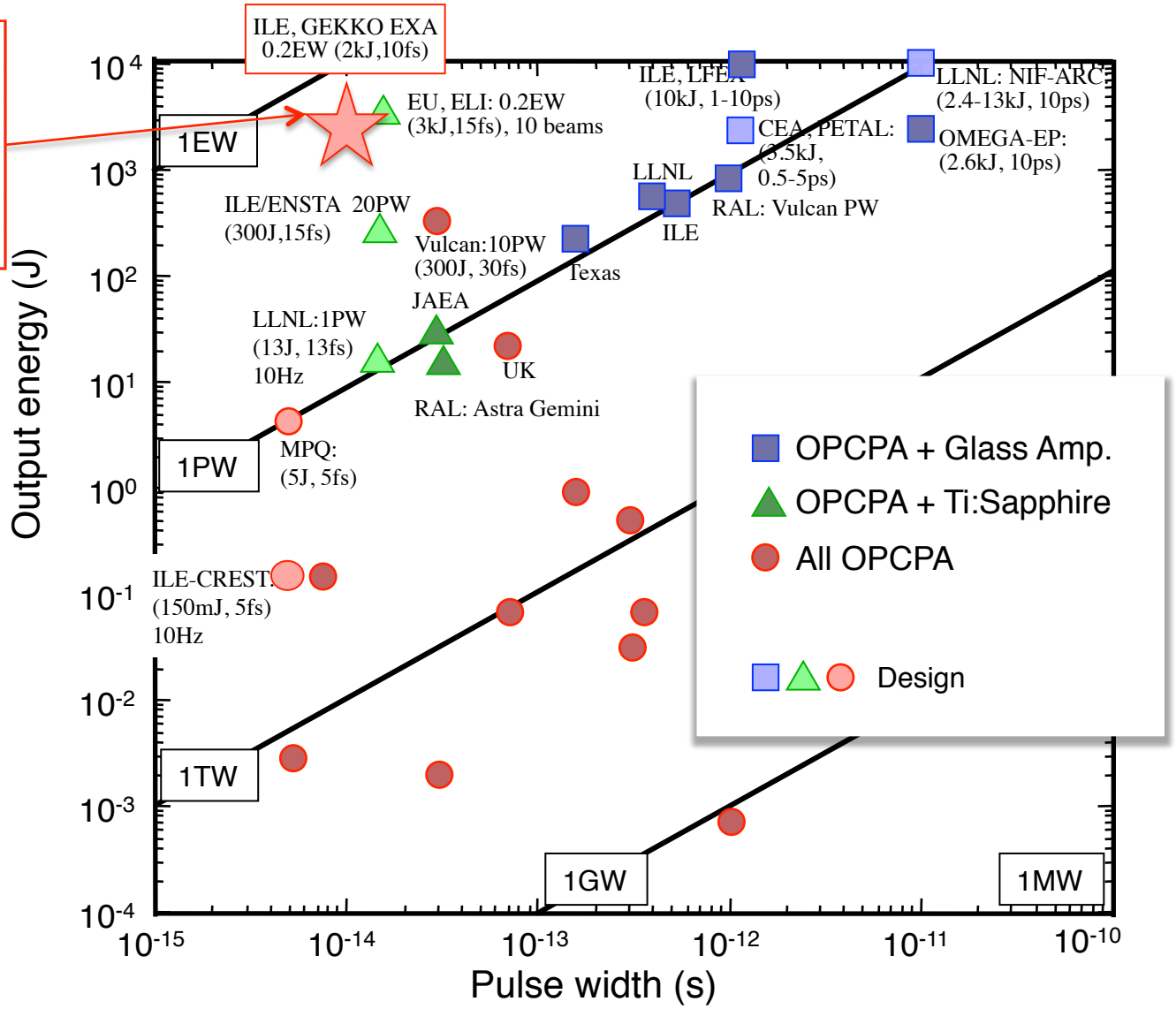


Ultra-intense lasers over the world



- ✓ Sub-EW
- ✓ Few cycle



Basic concept of sub-EW laser

Key technologies

- All **OPCPA** System

Front End + **DPSSL-pumped OPCPA** + Glass-laser-pumped OPCPA → OPA pump source

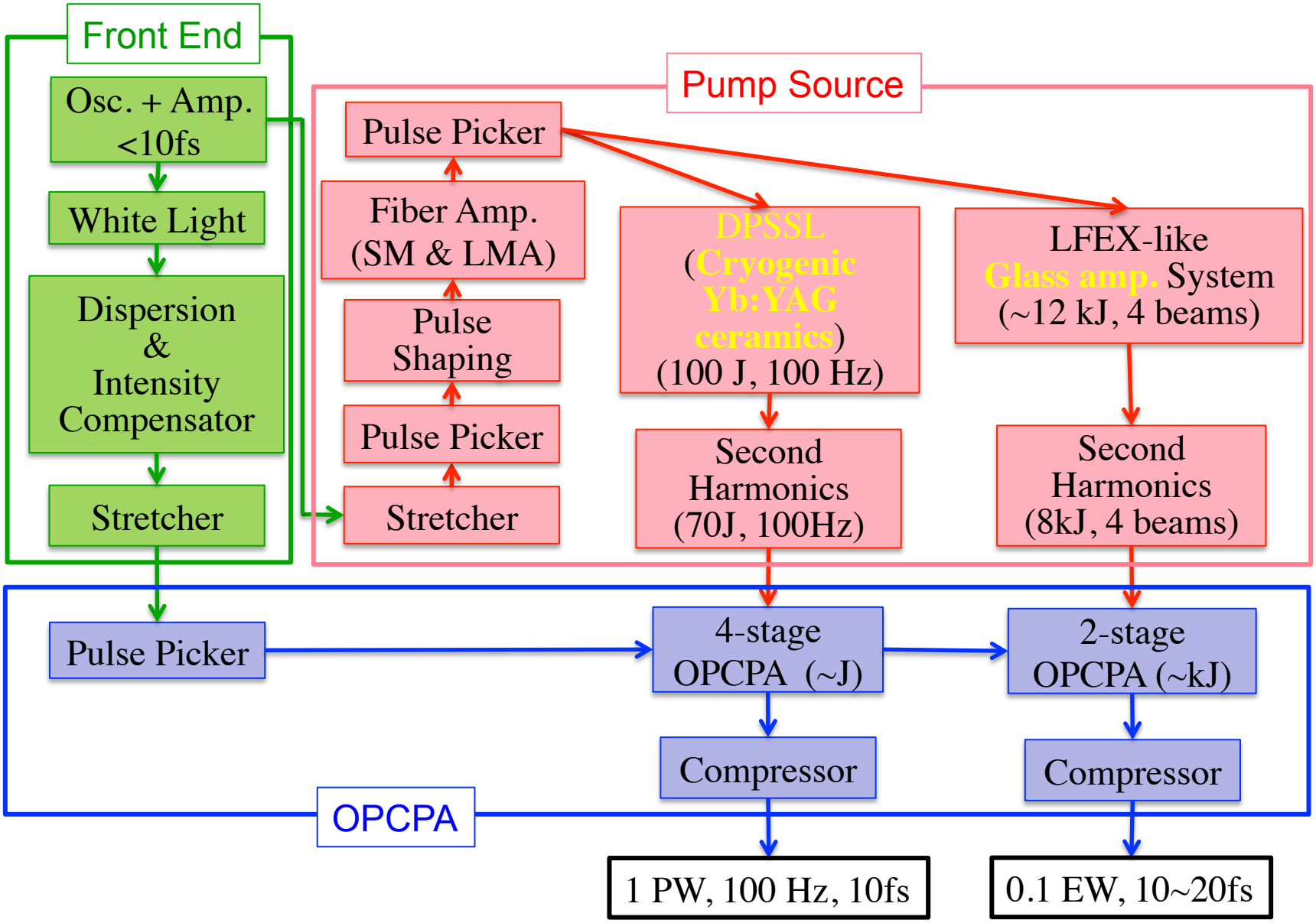
- Specification

Peak power	: > 1 PW	0.1 EW / beam
Beam size	: 30 x 30 mm^2	300 x 300 mm^2
Rep. rate	: 100 Hz	Single shot
Beams	: 1 beam	1~2 beams
Bandwidth	: 750 ~ 1250 nm	
Pulse duration	: ~ 10 fs (CEP stabilied)	

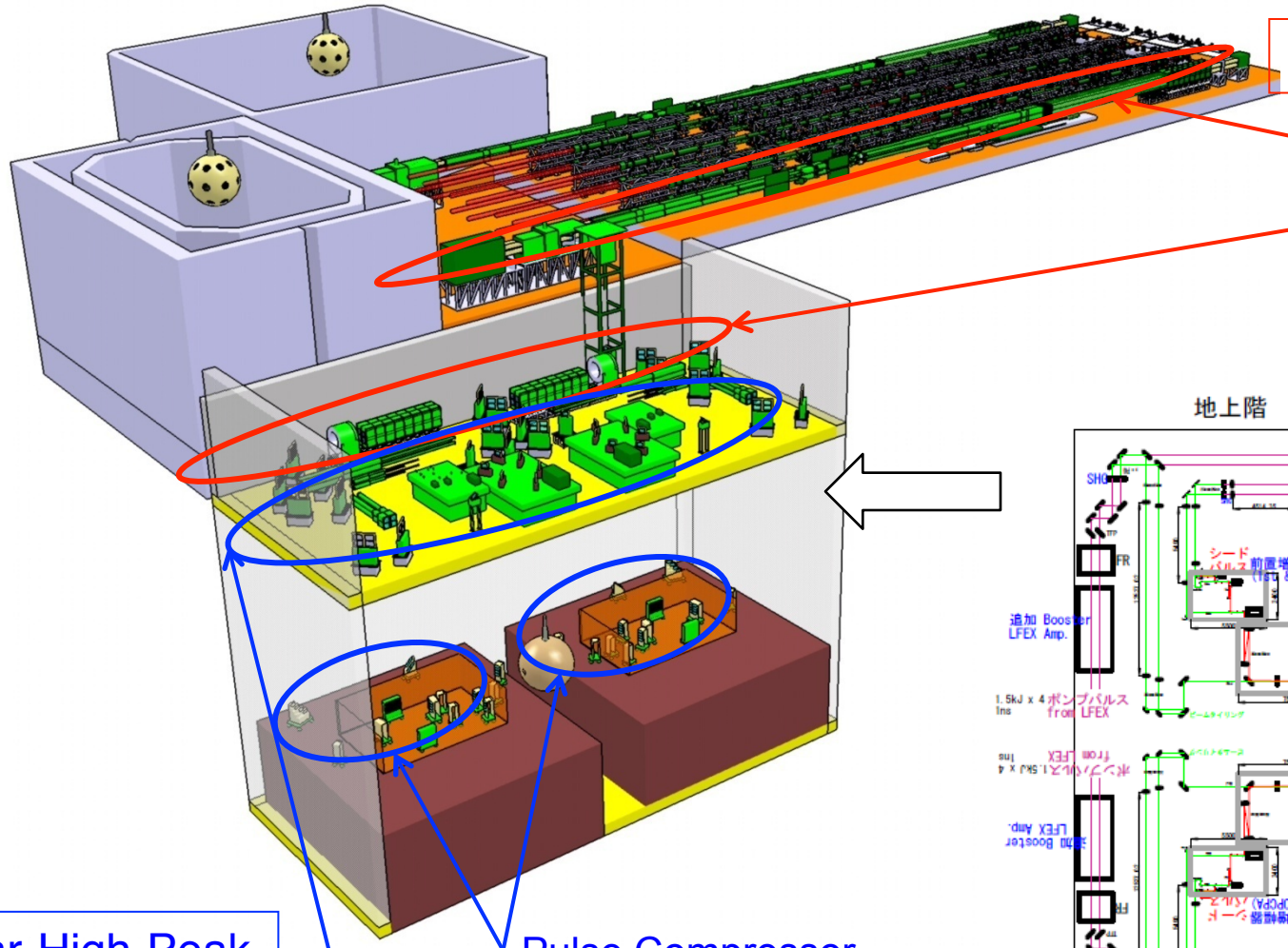
→ Large-aperture, ultra-broad-band crystal

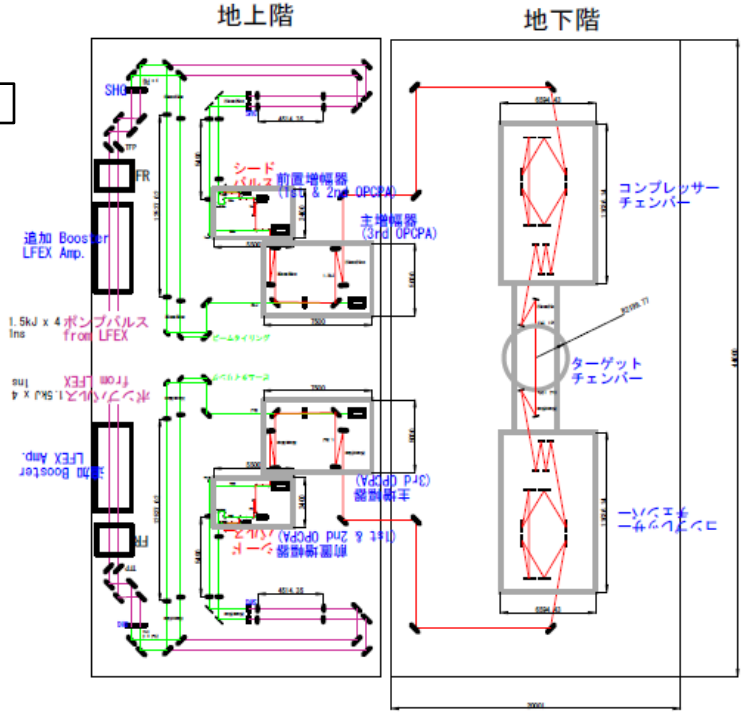
→ CEP and Dispersion control

Block diagram of GEKKO - EXA



GEKKO – EXA Layout





Pump Source of OPCPA

Cryogenic Yb:YAG as an repeatable amplifier material

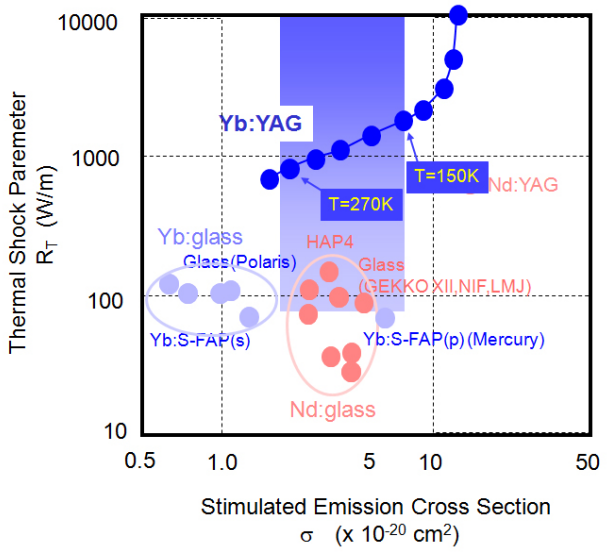
Advantages

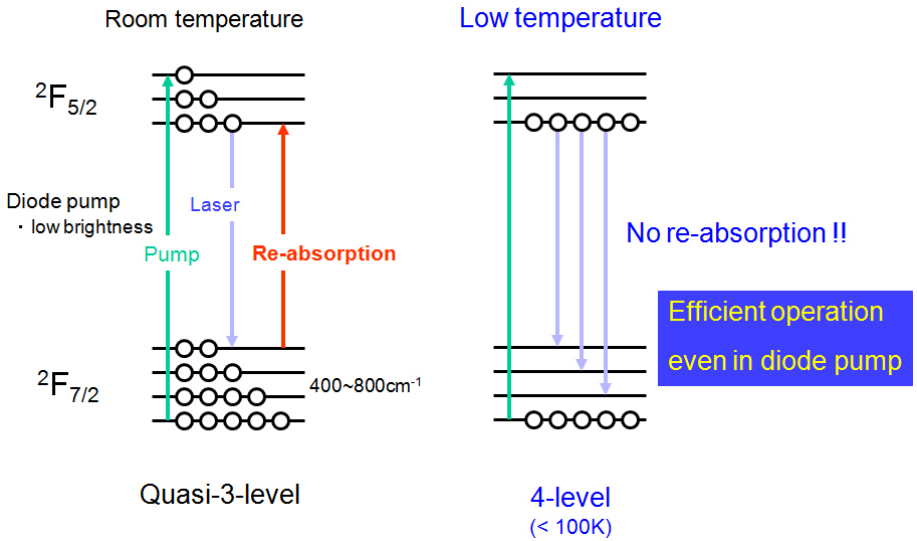
1. Wide Tunability of Stimulated Emission Cross Section

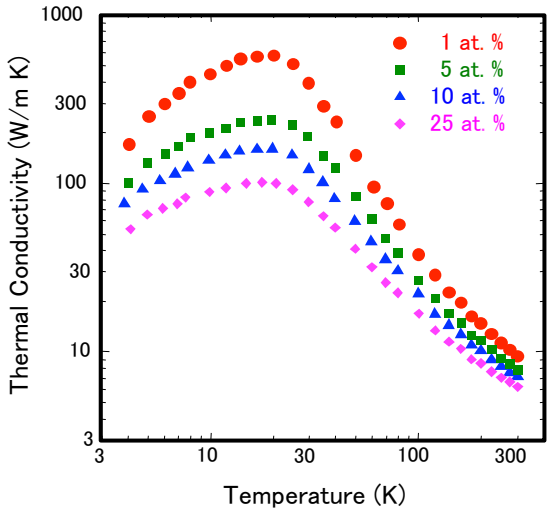
2. Improved Thermal Strength

Thermal conductivity	κ,
Thermal expanstion	1/L(dL/dT),
Thermal refrative index	dn/dT

3. Efficient Laser Operation without Re-absorption

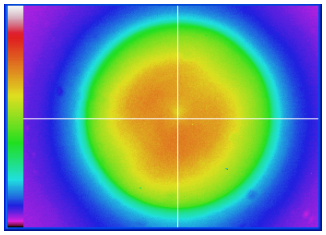


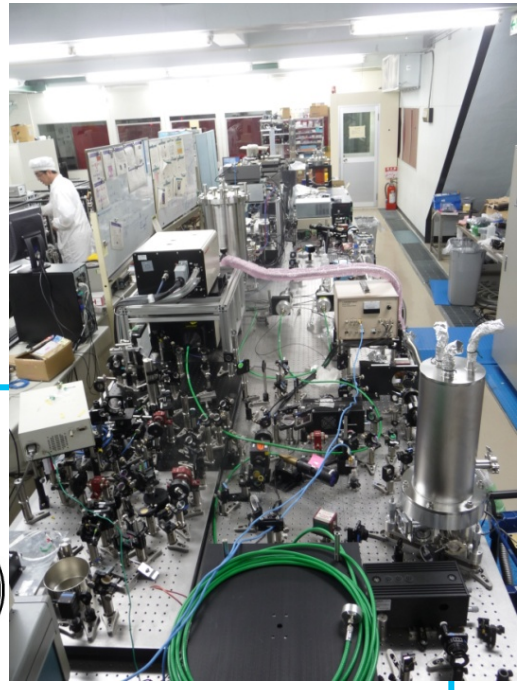




J. Kawanaka et. al, Laser Physics 15, pp. 1306-1312 (2005).

1J x 100Hz laser system as a test bench of pre-amp



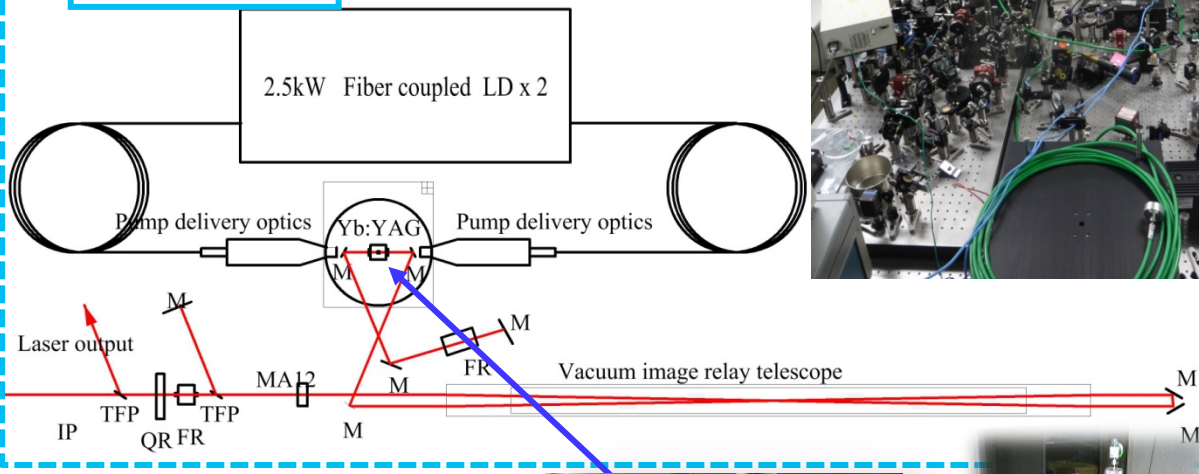


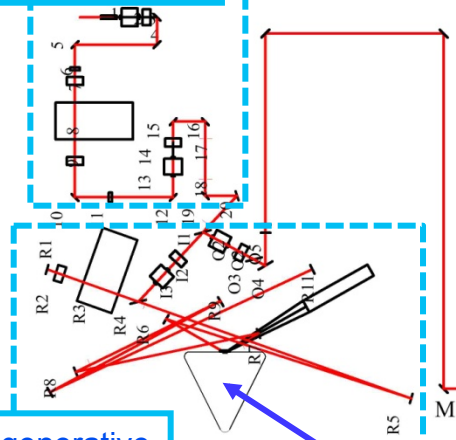
J-class

CW Fiber Oscillator & Pulse Slicer

10ns, pJ-class

4-pass Amplifier

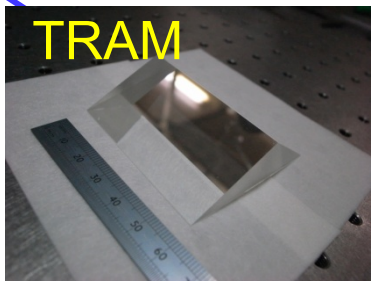




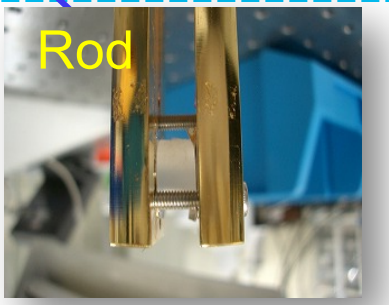
Regenerative Amplifier

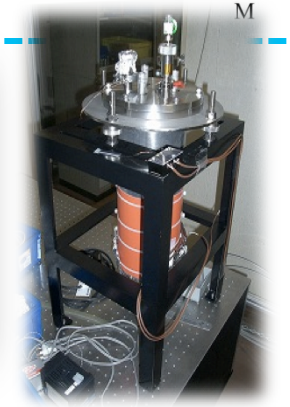
mJ-class

TRAM

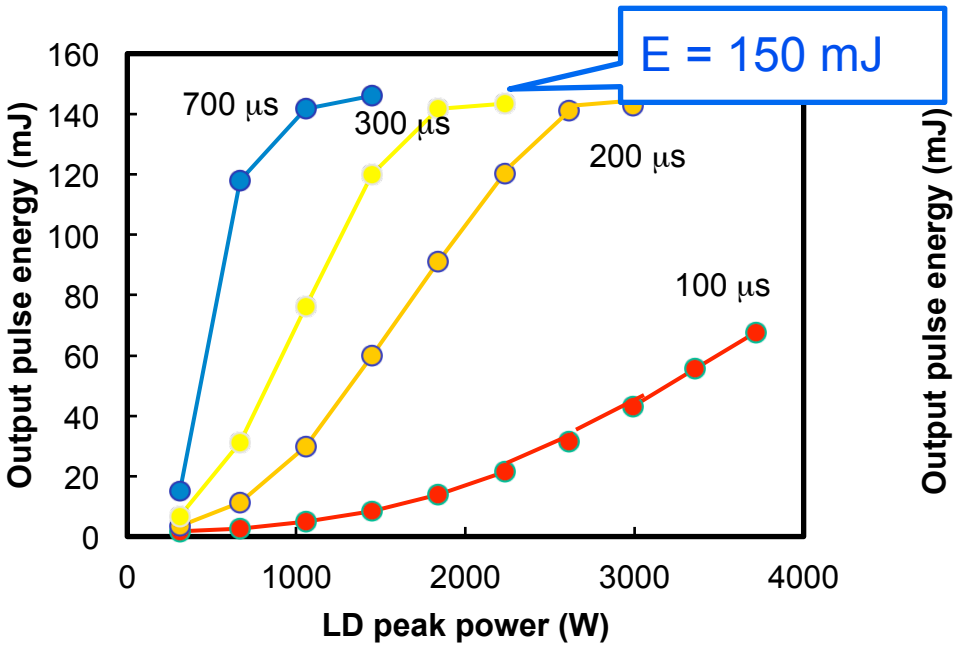


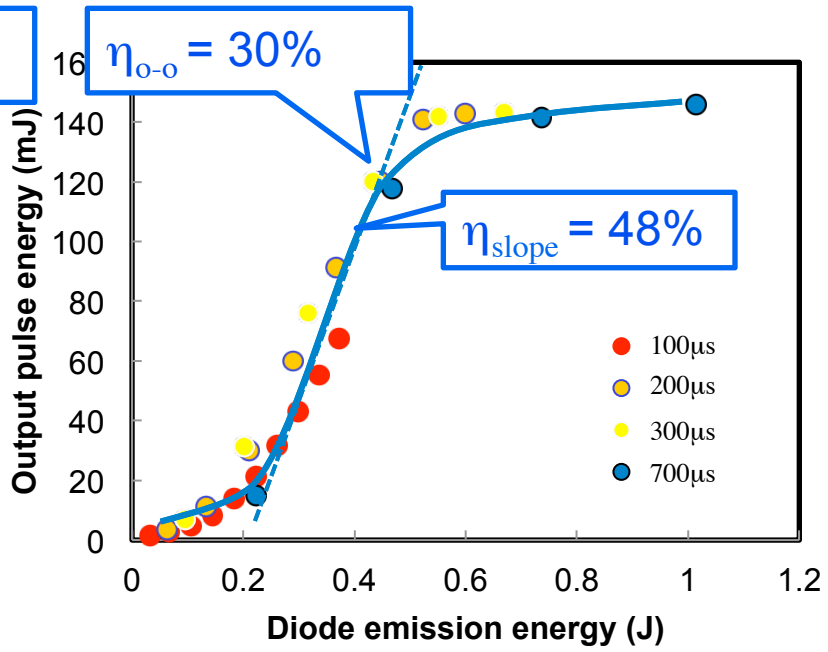
Rod

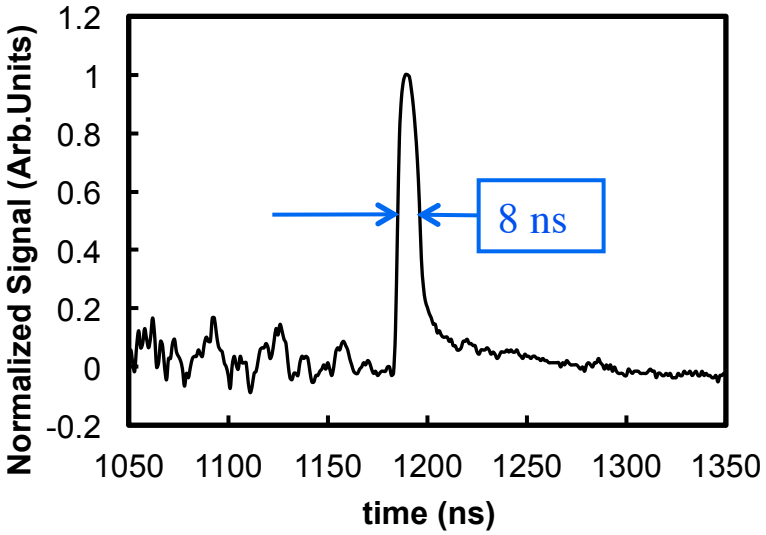




Output pulse energy and temporal waveform at 100Hz





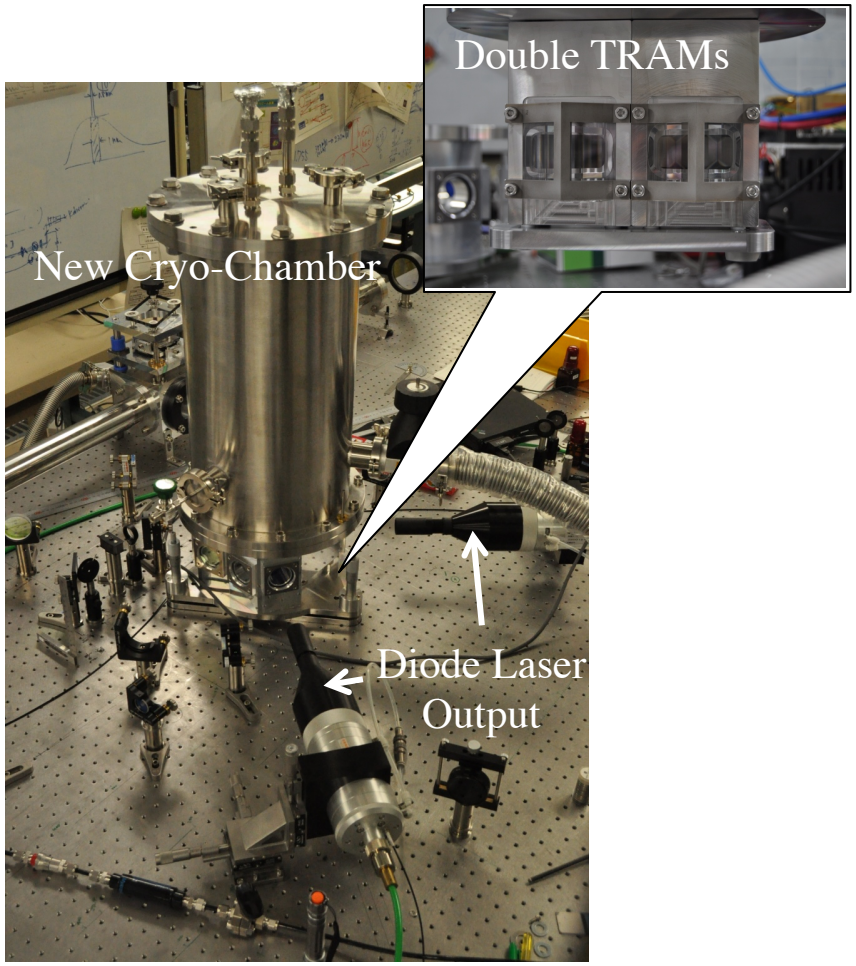


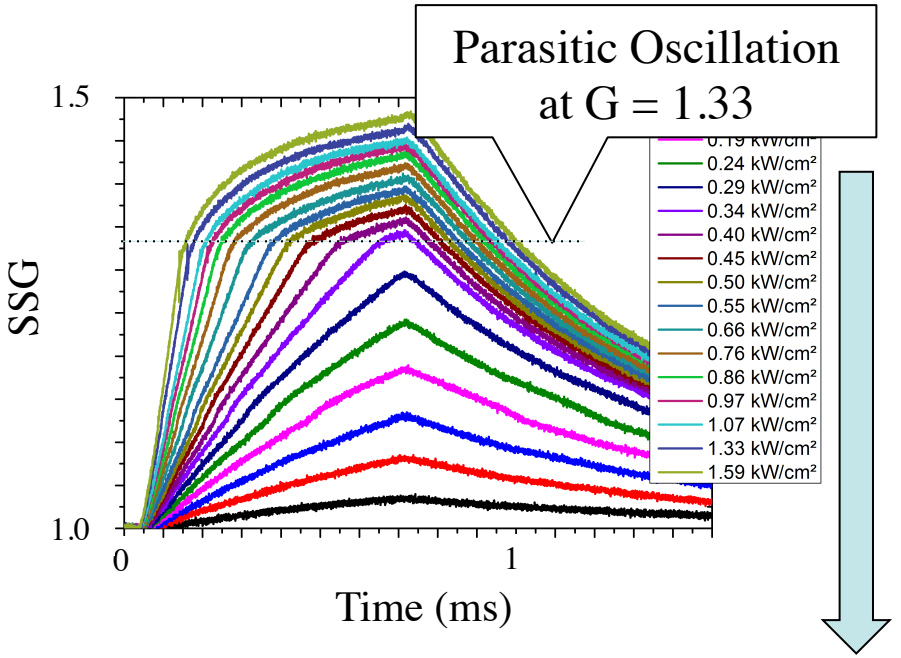
G_0 = 13/pass
I = 7.8 kW/cm^2 @700μs (5.5 J/cm^2)
Transmission loss = 0.3/pass

We need more TRAMs for higher pulse energy.
Pump source power is enough high for 1 J.

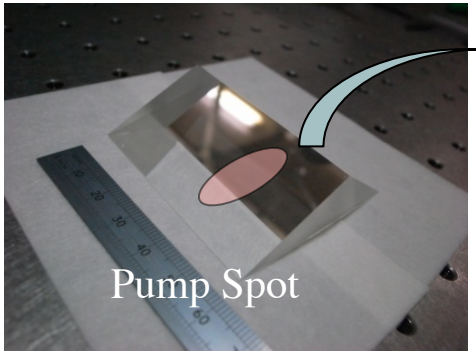
S. Pearce, et. al., *Optics Communications* **282** 2199 (2009).

Small signal measurements of TRAM in the main amp.





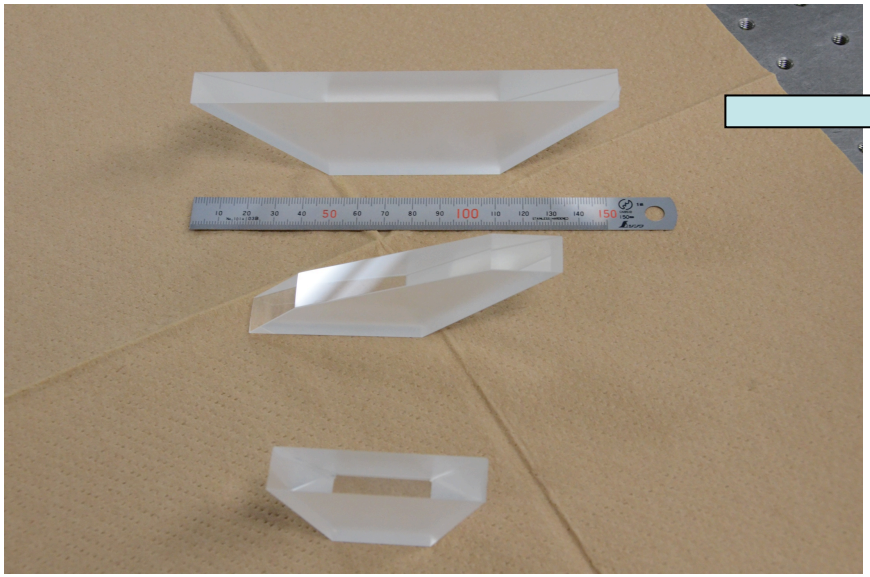
- Estimated $E_{storate}$ ~ 100 mJ / TRAM
- $g_0 l_{PARA} = 3.5$

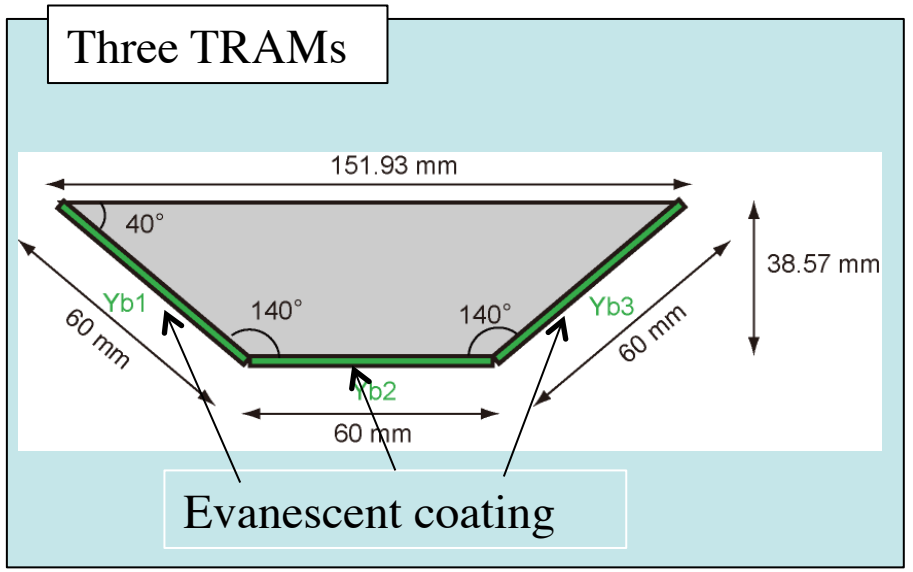


Direction of P.O.
$g_0 l_{PARA} = 3.5$

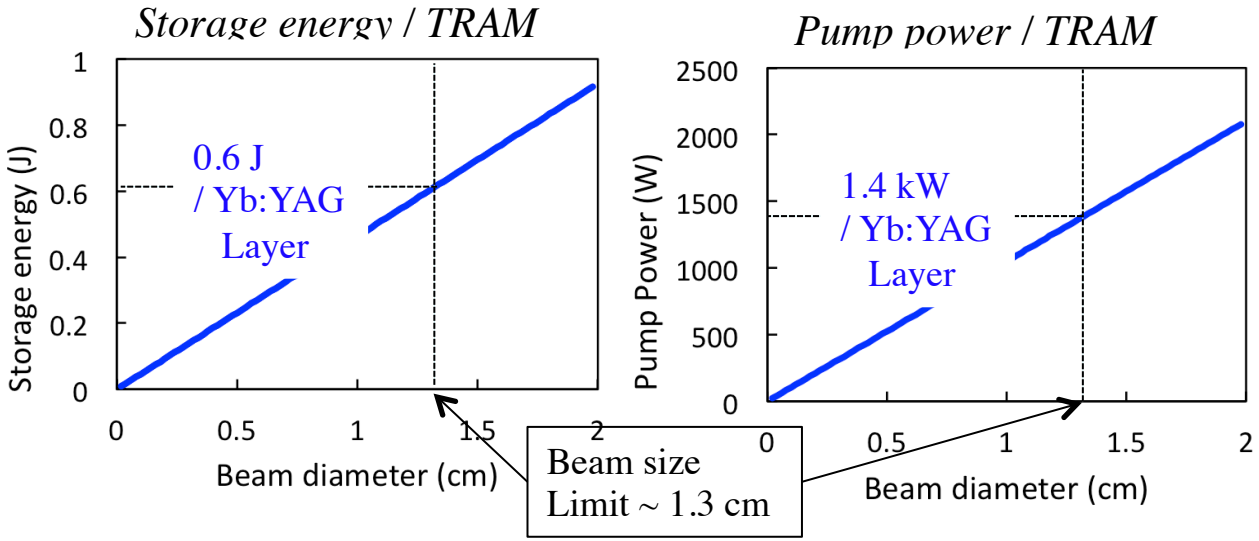
In addition, contaminations in LN were attached to the back surface of the TRAM.

Output Pulse Energy and Temporal Waveform at 100Hz





Numerical calculation

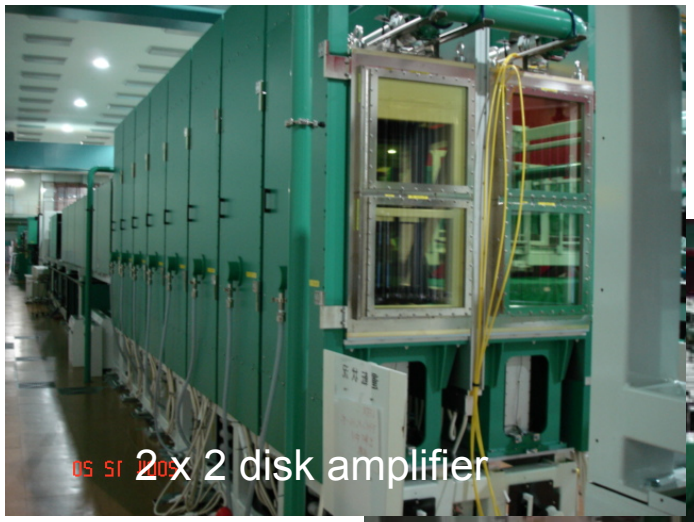


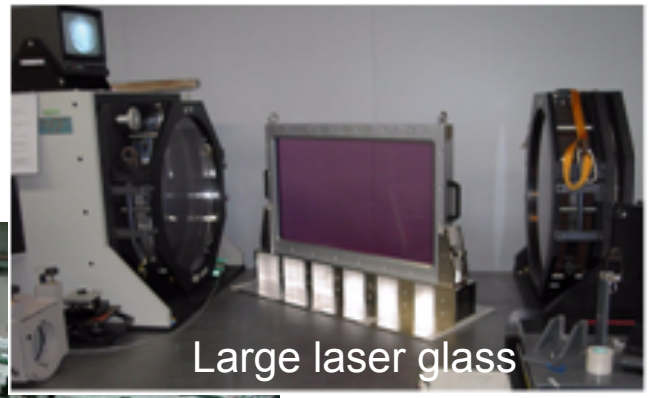
Storage energy
0.6 x 3 = 1.8 J

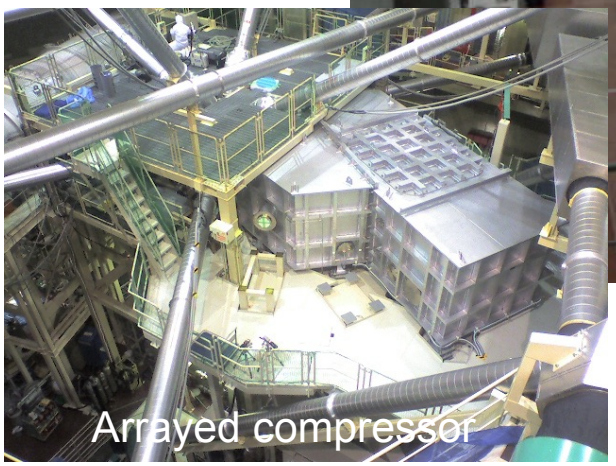
Required pump power
1.4 kW x 3 = 4.2 kW < 5 kW

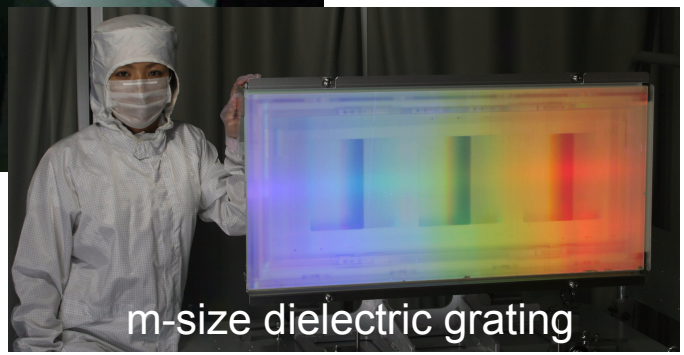
1 J, 100Hz
ps pulses

kJ-pump source based on LFEX-Laser technologies



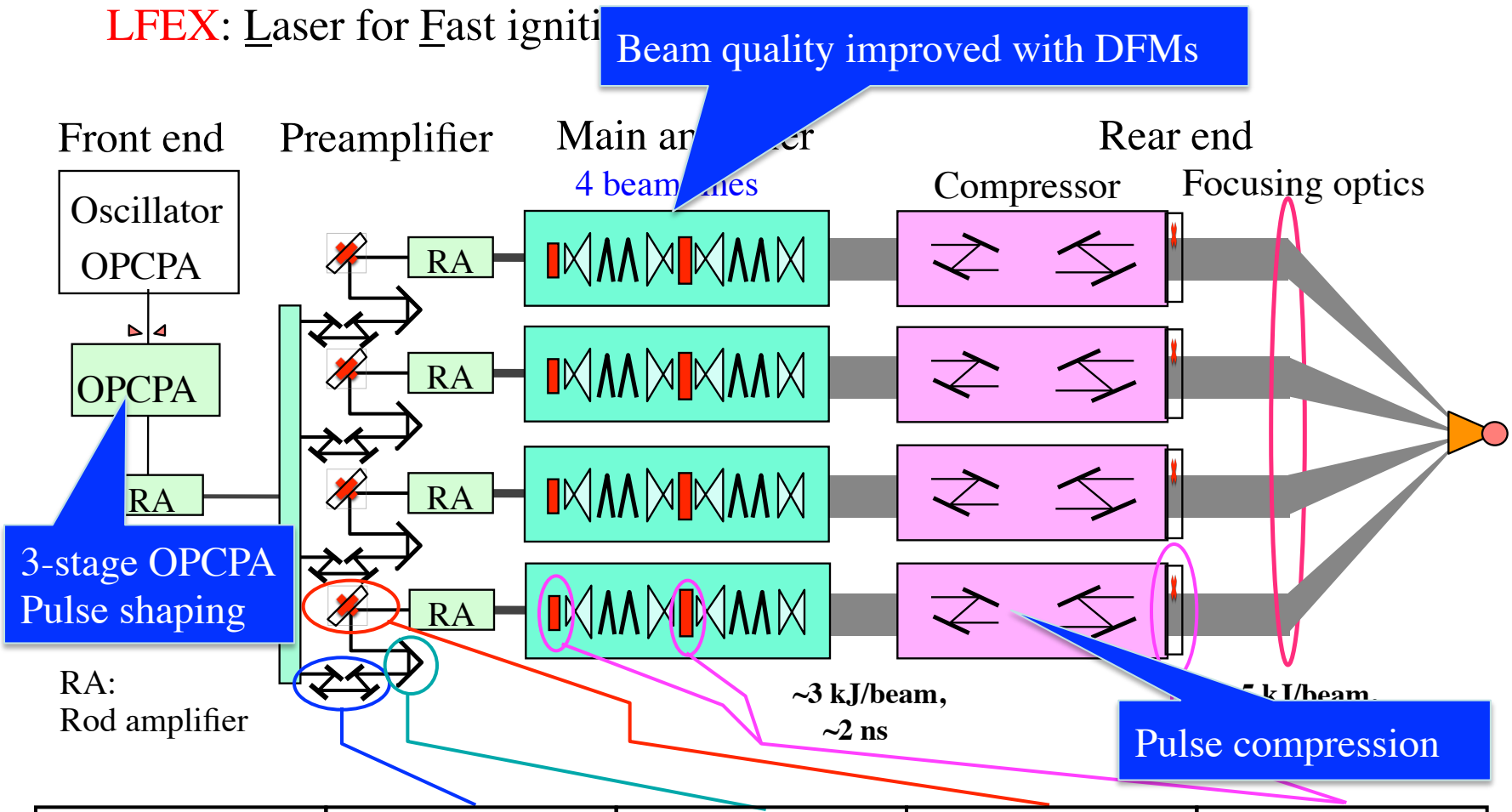






Block dagram of LFEX-Laser

LFEX: Laser for Fast igniti

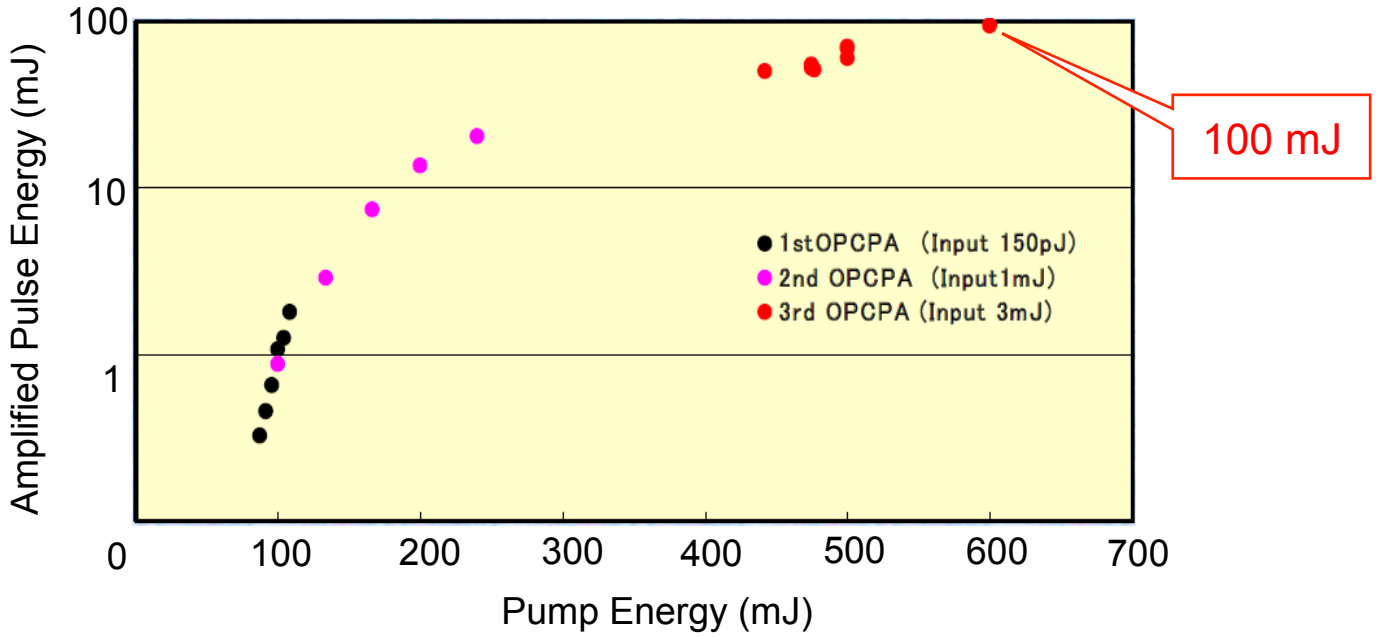


Beam control	GVD adjustment	Beam synchronization	Bam-to-beam phase locking	Wavefront correction
Tool	Grating pair	Precision stage	Fast tip/tilt mirror	Deformable mirror

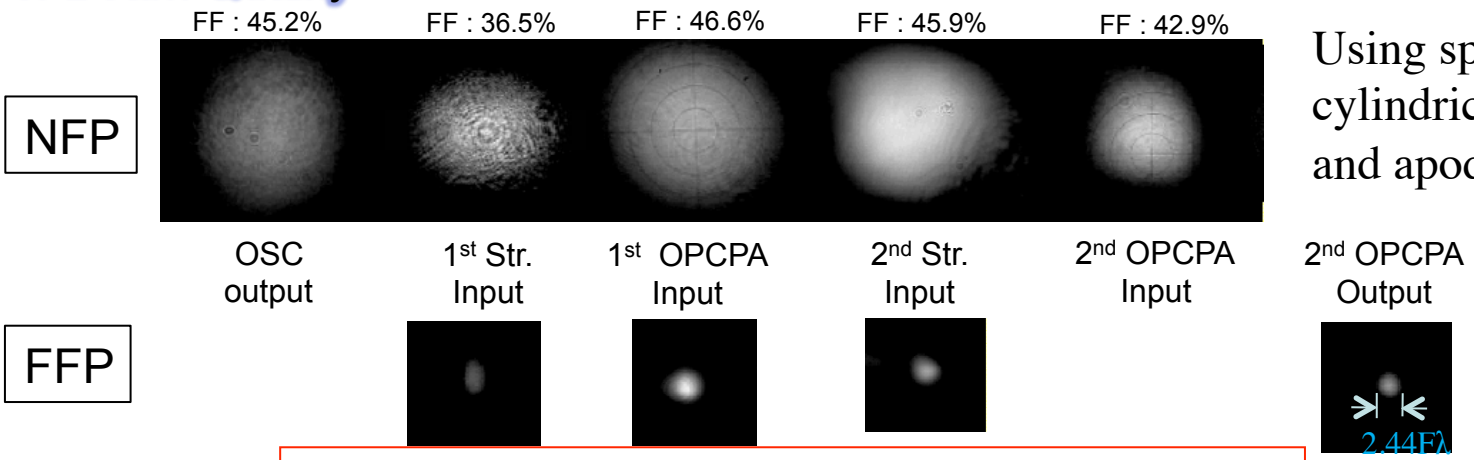
3-stage OPCPA

Output pulse energy and beam quality

Pulse Energy



Transfer of Beam Quality



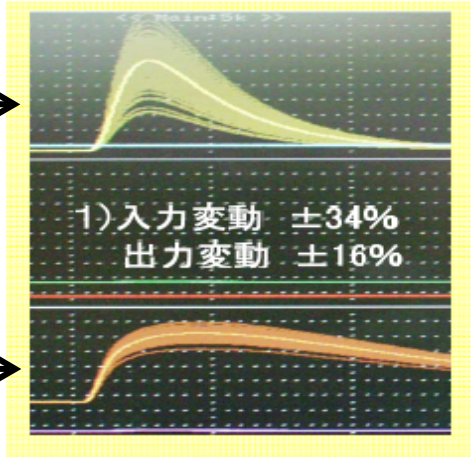
Using spatial filter, cylindrical lens pair and apodizer

Pointing Stability 50 μrad (< 0.2 μrad on target)

Pulse stabilities improved by gain saturation at 3rd OPCPA

Energy

Seed before 3rd OPCPA →

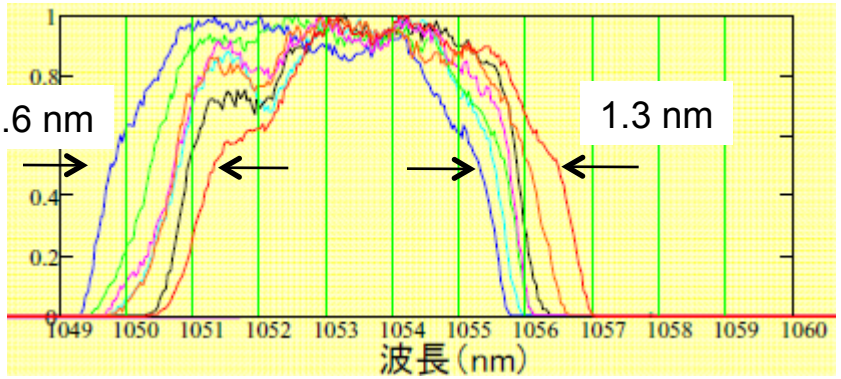


After 3rd OPCPA →

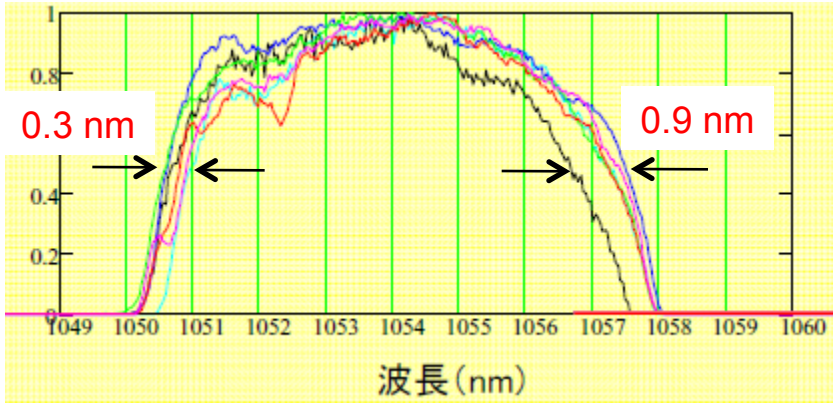
Make energy fluctuation less than half.

Spectrum

Small Signal Gain

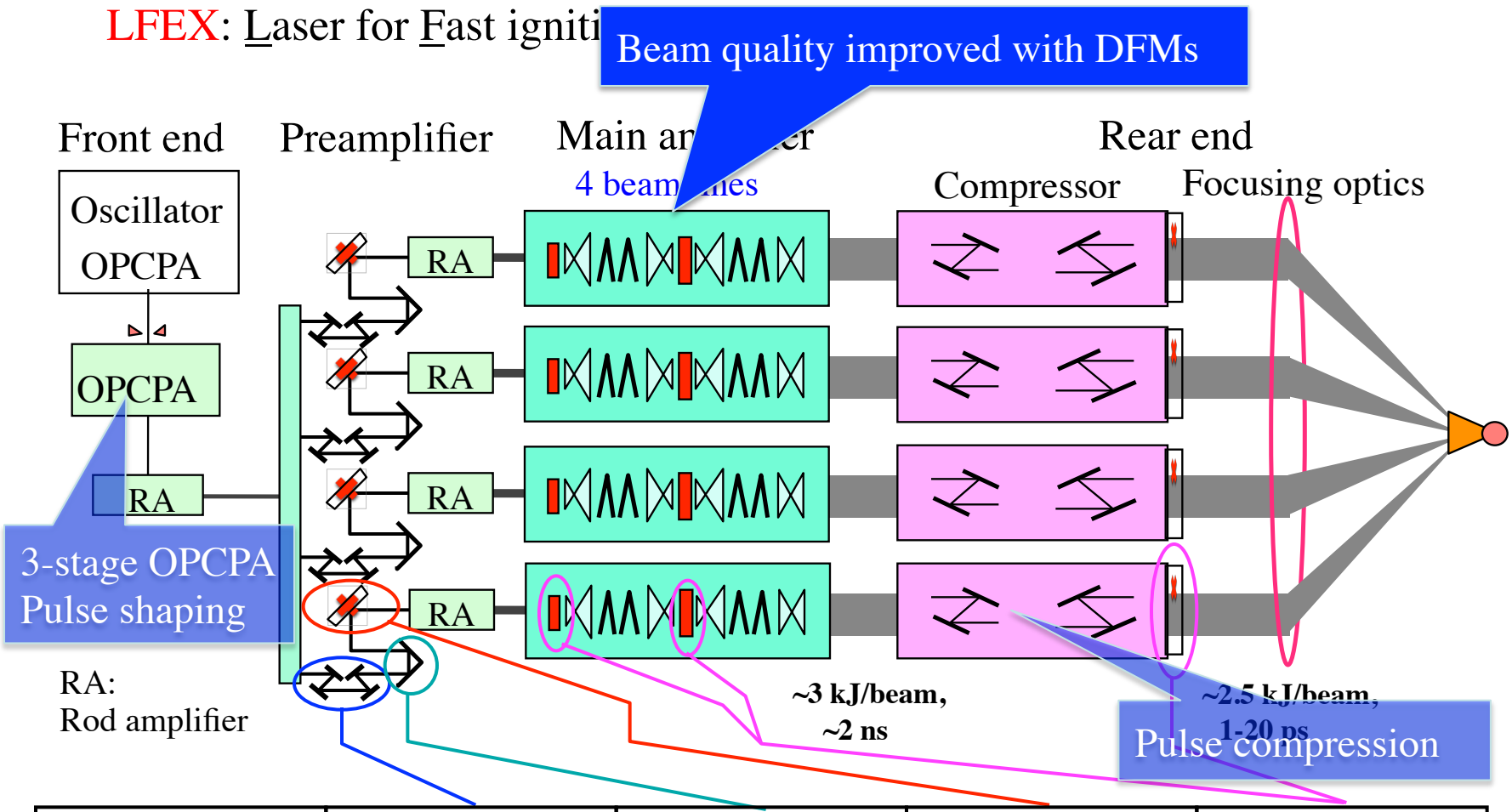


Gain Saturation



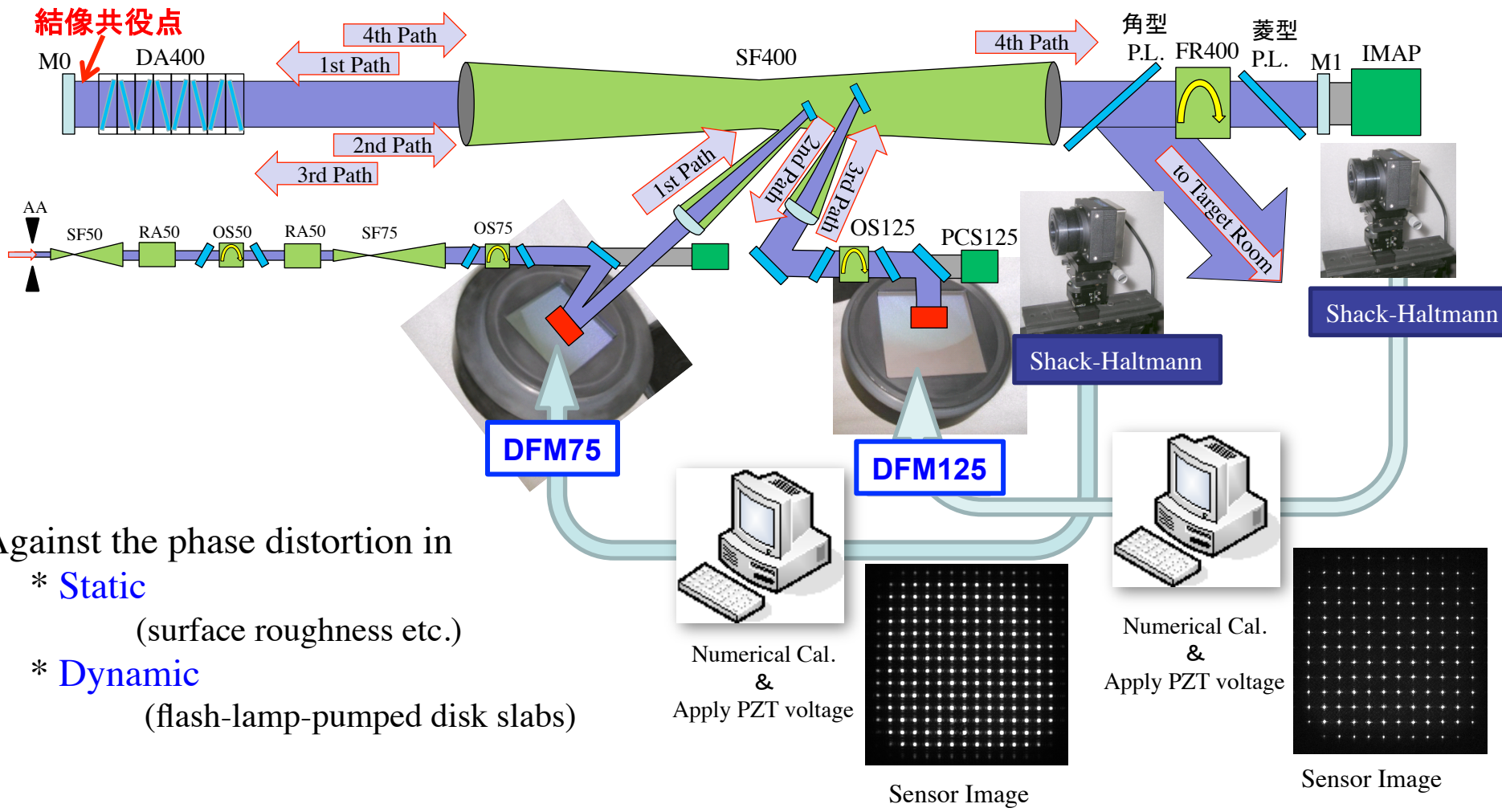
To improve more, a new fiber oscillator should be used instead of 10-years-old Ti:sapphire.

Block dagram of LFEX-Laser



Beam control	GVD adjustment	Beam synchronization	Bam-to-beam phase locking	Wavefront correction
Tool	Grating pair	Precision stage	Fast tip/tilt mirror	Deformable mirror

Phase pre-compensation with deformable mirrors



Against the phase distortion in

* Static

(surface roughness etc.)

* Dynamic

(flash-lamp-pumped disk slabs)

DFM 75 (DFM125) pre-compensates a spatial phase of the laser pulse for 1st and 2nd (3rd and 4th) pass through the disk slabs.

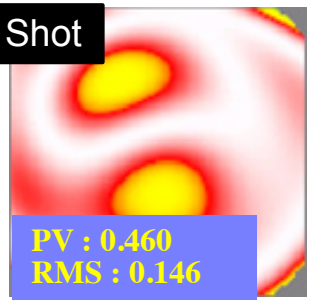
Experimental results of phase pre-compensation

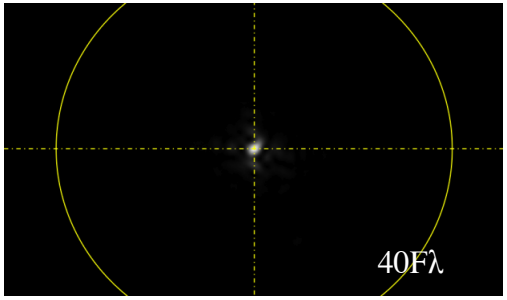
Wavefront on SH sensor

FFP

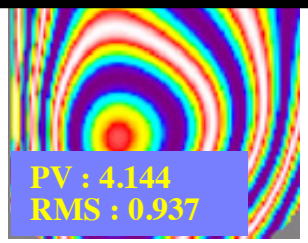
Pointing Stability

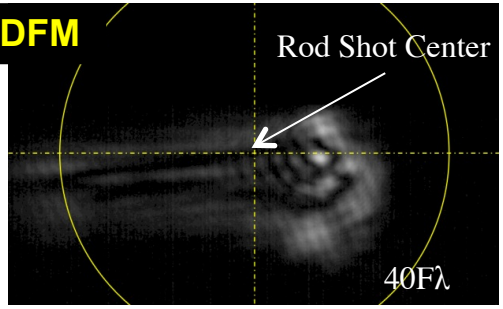
Rod Shot



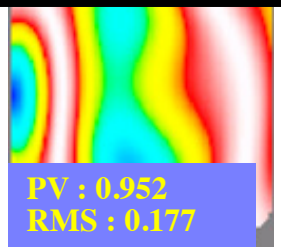


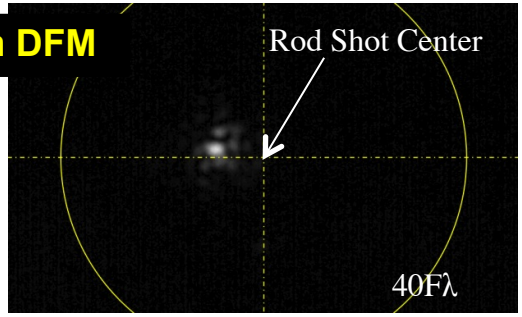
Rod and Disk Shot **w/o DFM**

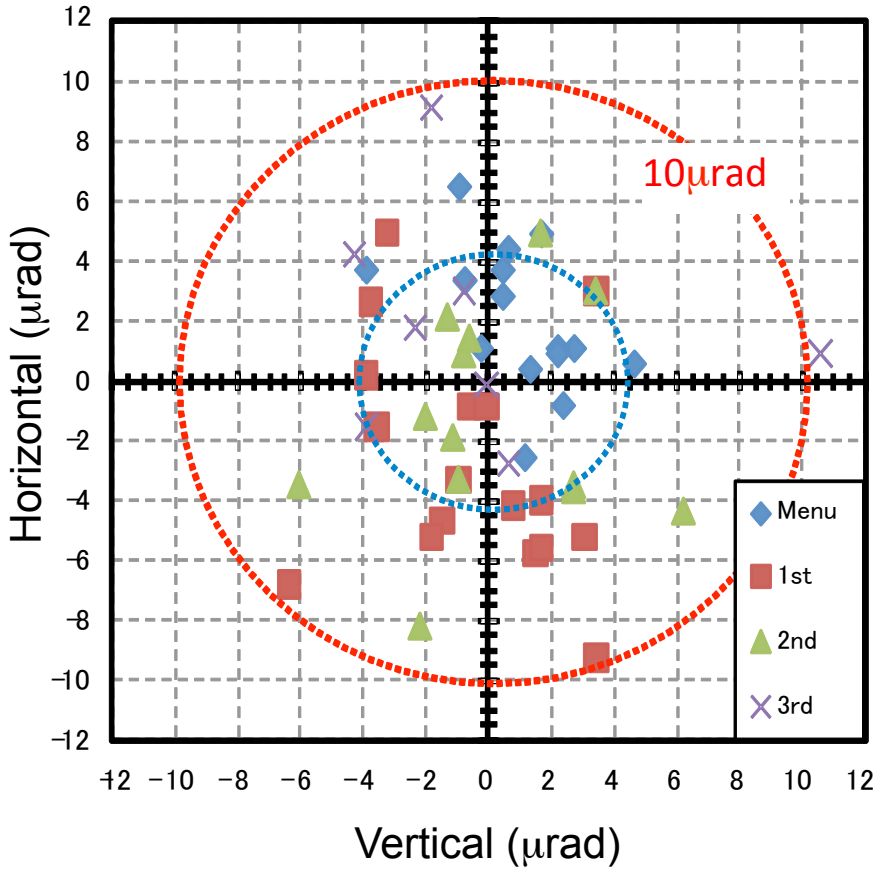




Rod and Disk Shot **with DFM**

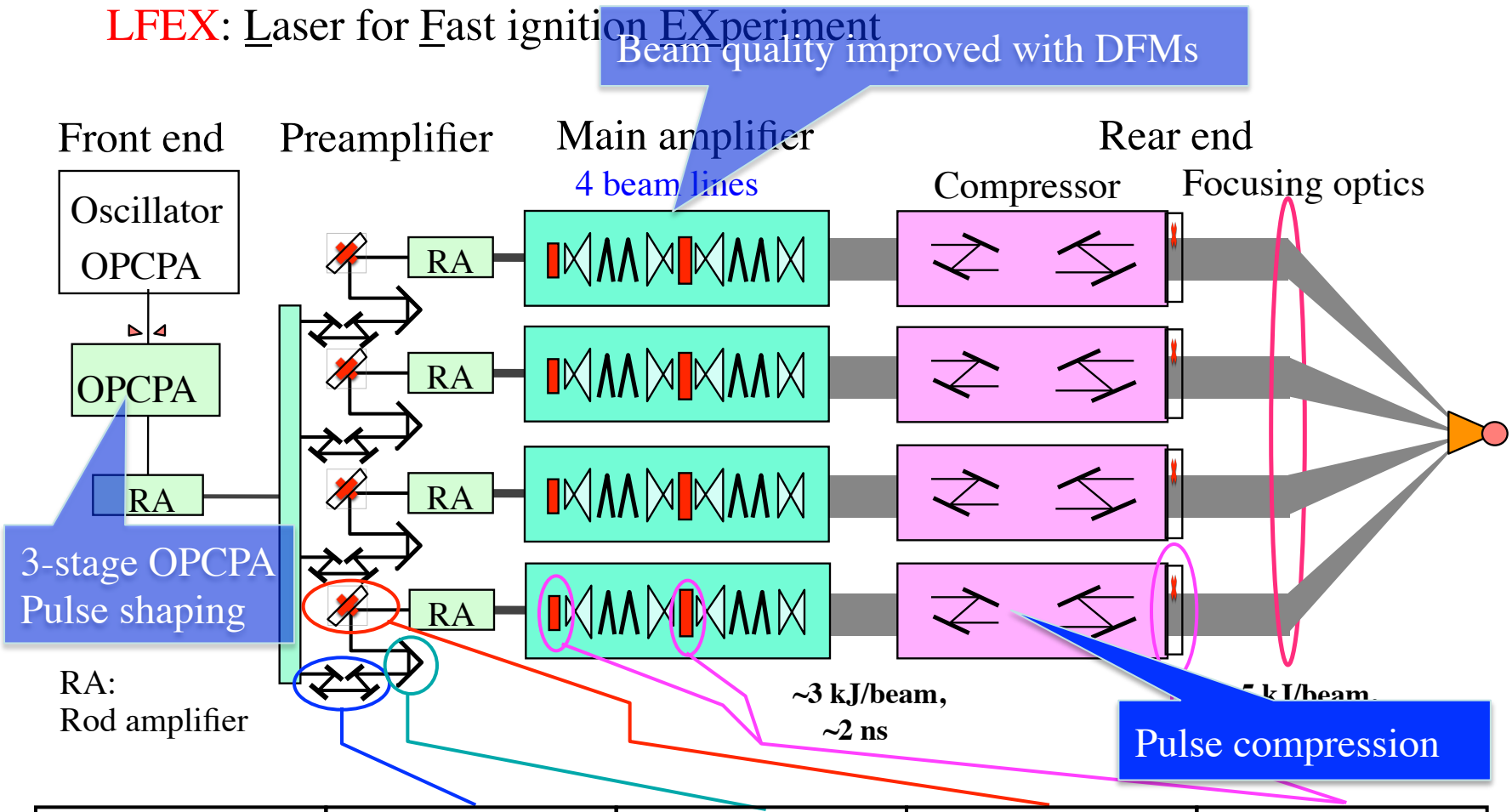






Block dagram of LFEX-Laser

LFEX: Laser for Fast ignition EXperiment



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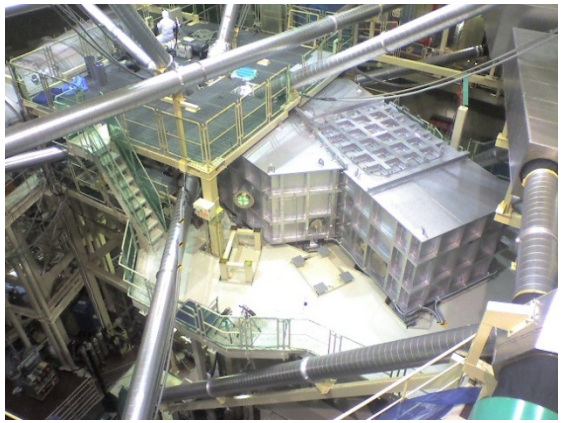
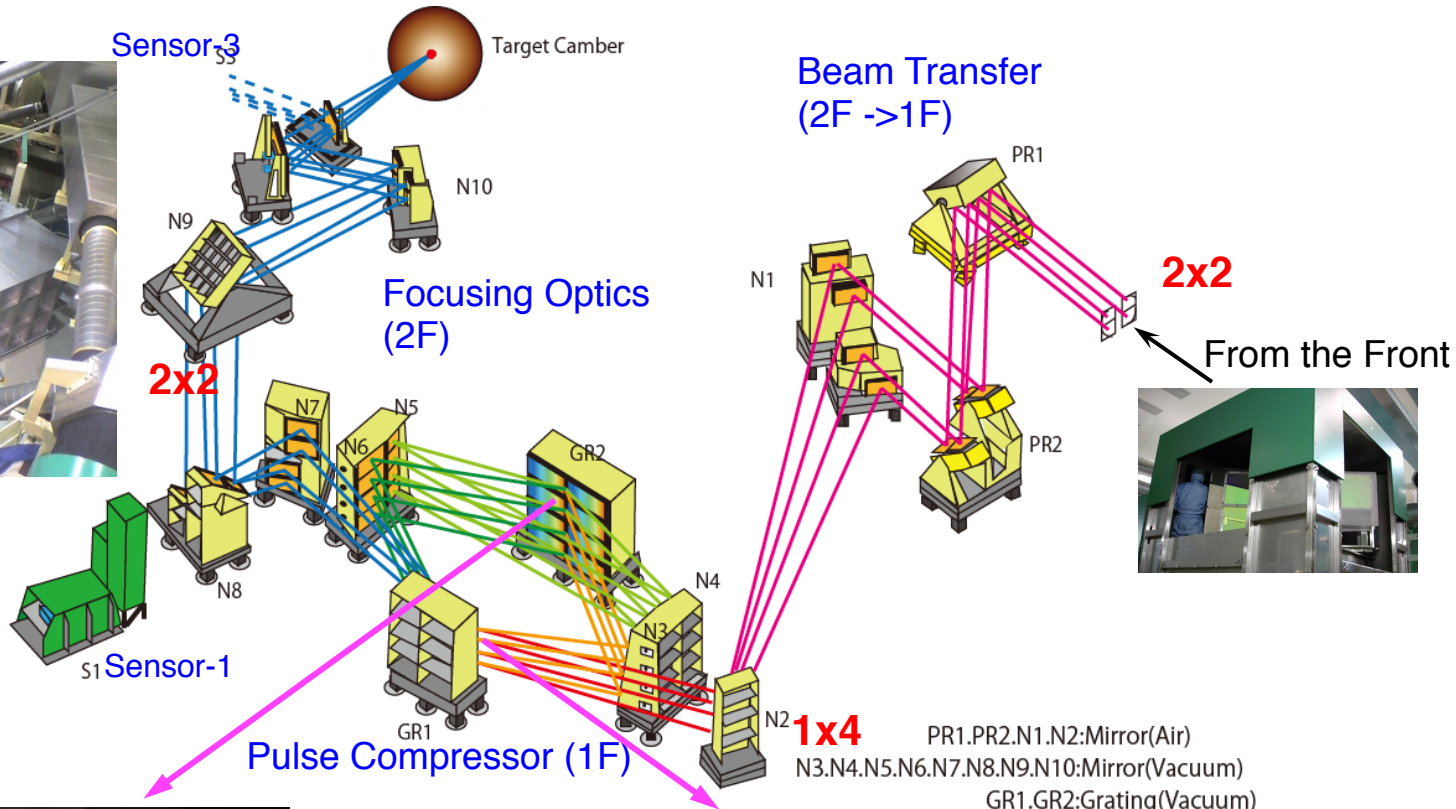
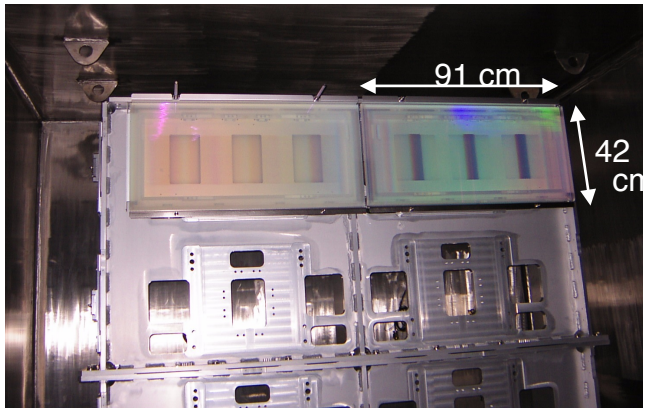
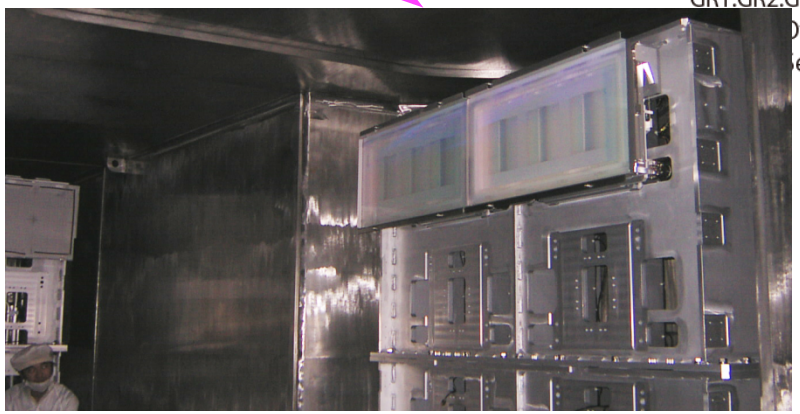
Tool	Grating pair	Precision stage	Fast tip/tilt mirror	Deformable mirror

Optical Layout of Rear-End

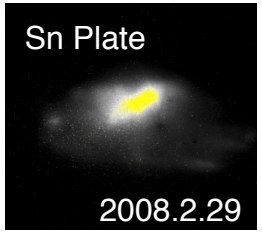






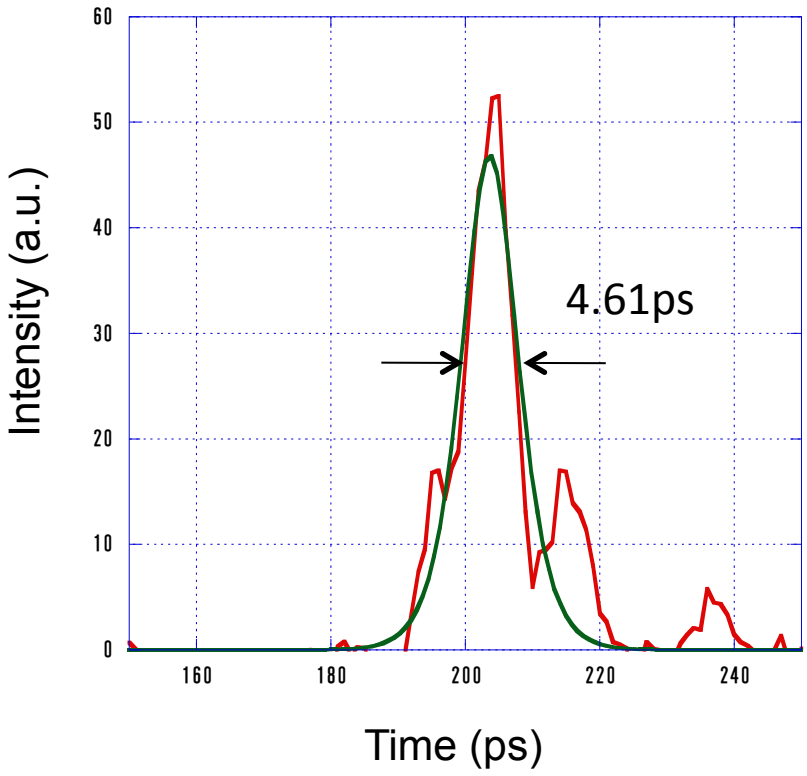


First light

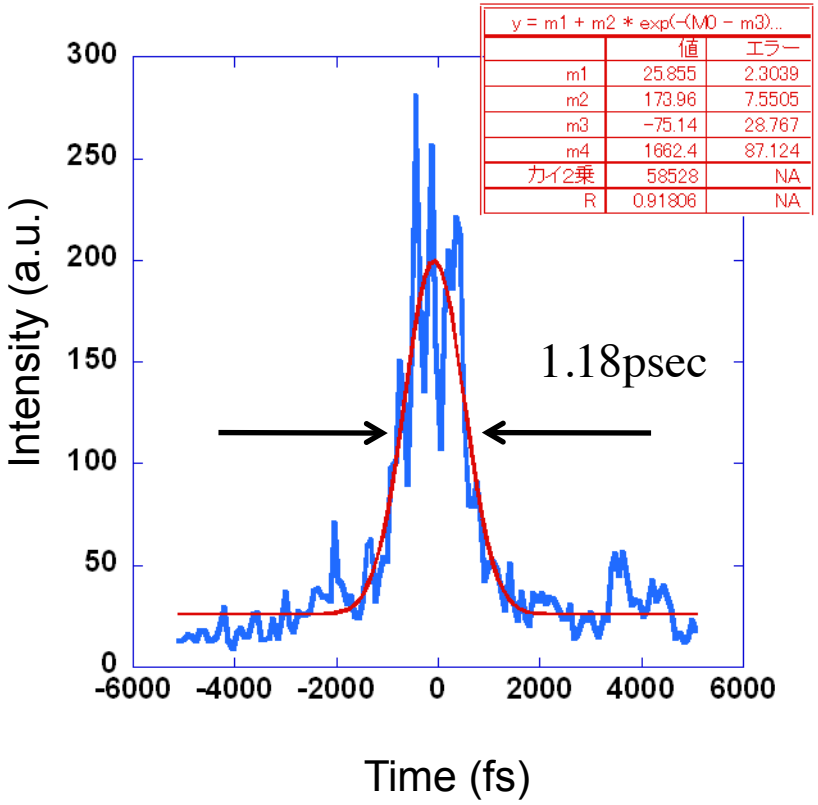


Pulse Duration of LFEX-Laser

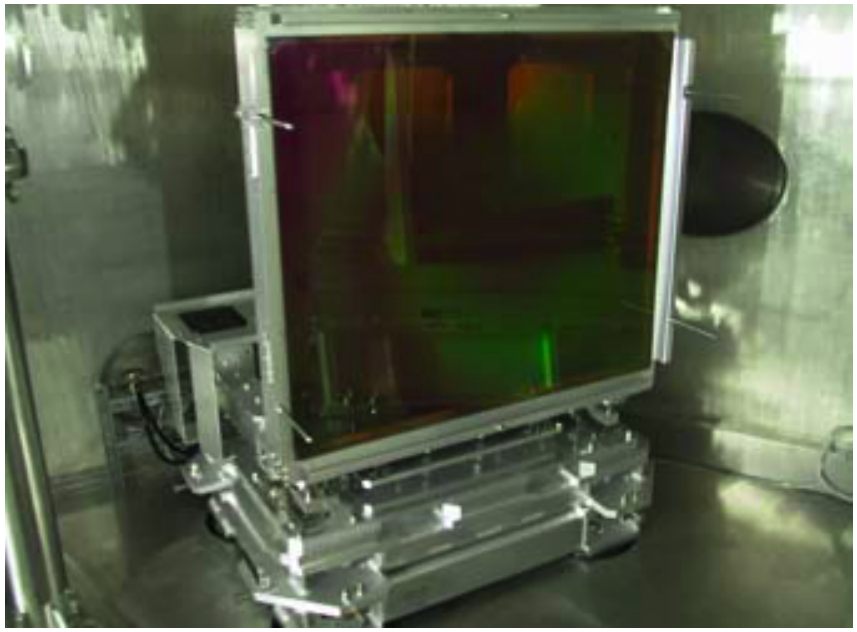
Streak Camera



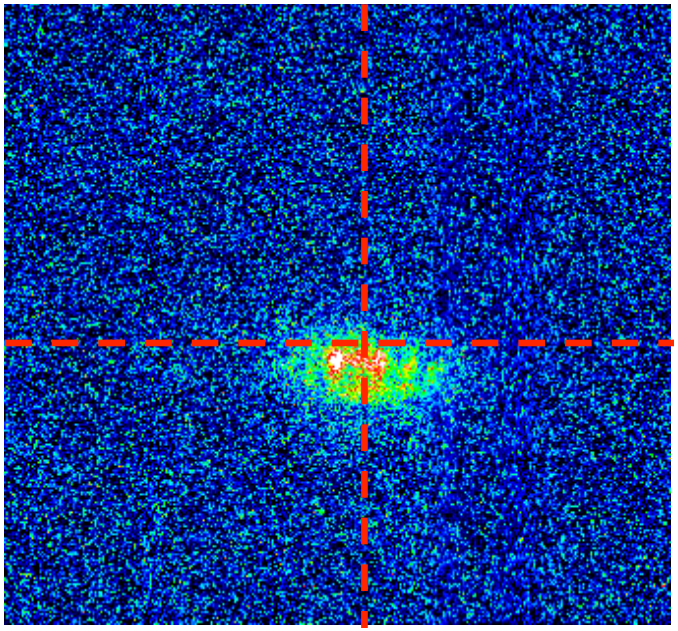
Autocorrelation



Focusing Beam Spot Size of LFEX-Laser



Off-axis parabola mirror installed into chamber

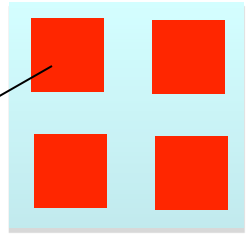


X-ray image of focal spot
30 (V) x 60 (H) μm 1.5 - 2.5 XDL

A square shaped beam was focused with an off-axis parabola mirror (*f* = 4000 mm).

Broadband OPCPA in kilo-joule

Large-aperture OPCPA pumped by arrayed beams in kJ



λ = 1053 nm

ω

KDP

2ω

ω

λ = 527 nm

OPCPA preamp.へ

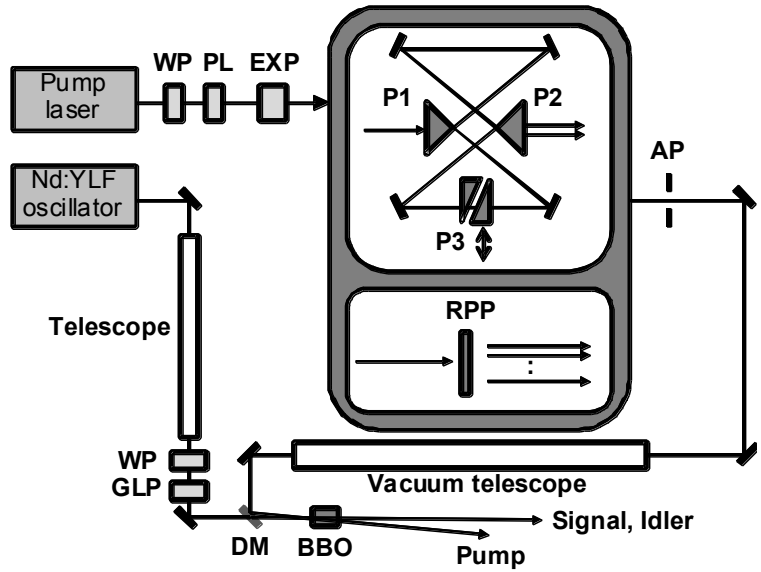
Signal

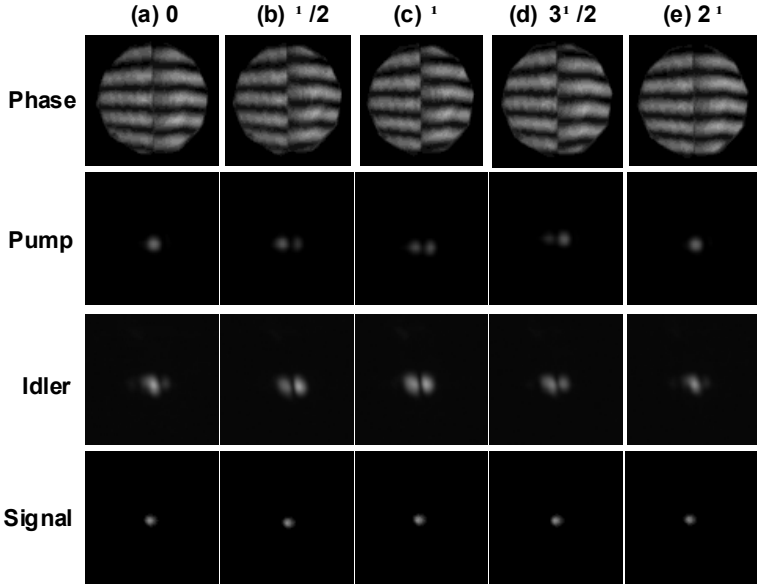
Pump

Nonlinear crystal

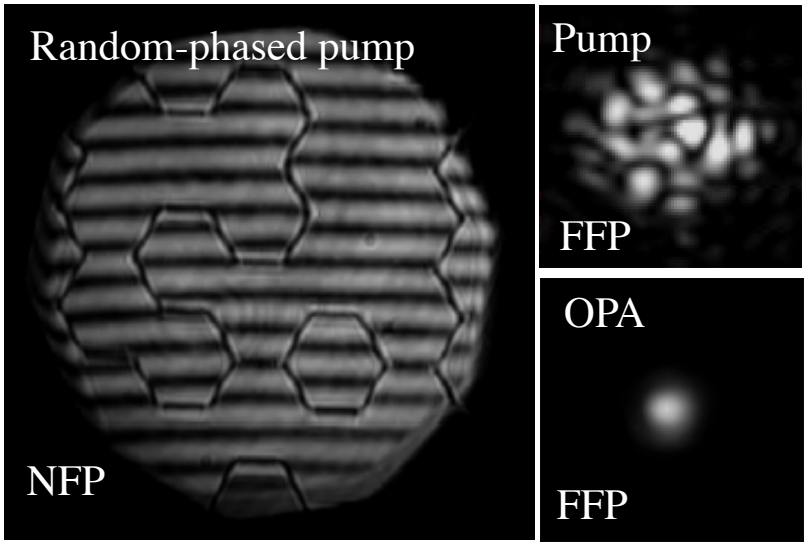
30cm

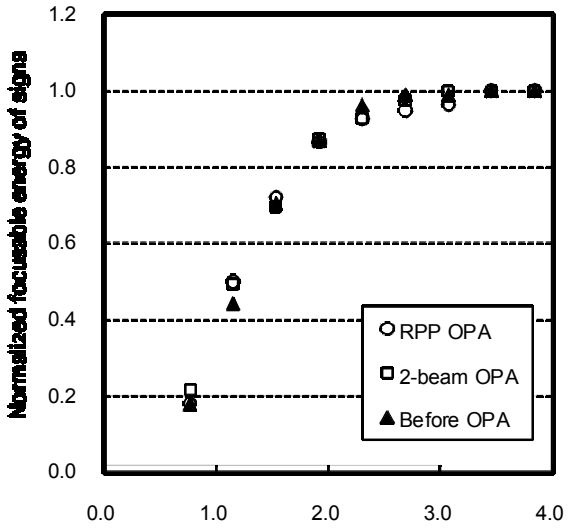
Proof-of-principle experiment of arrayed beam pumped OPA



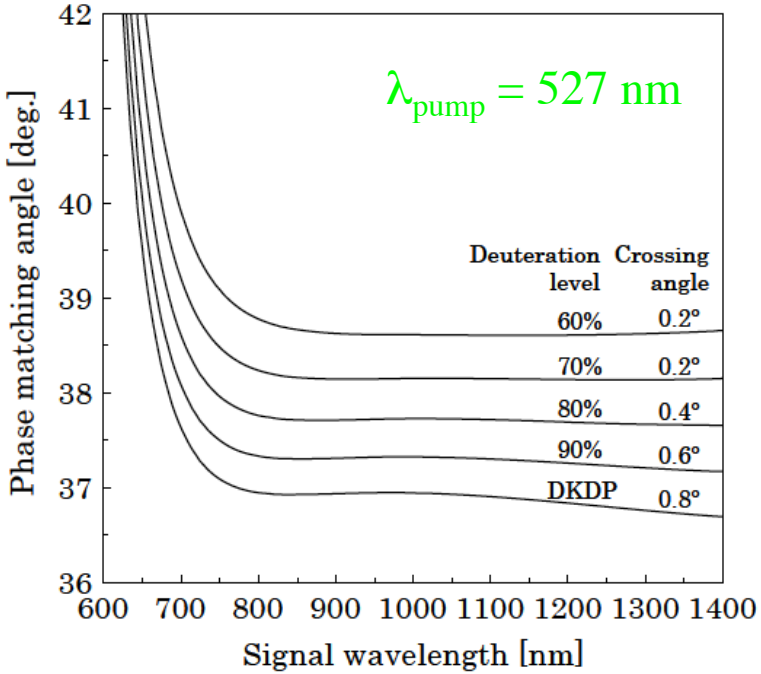


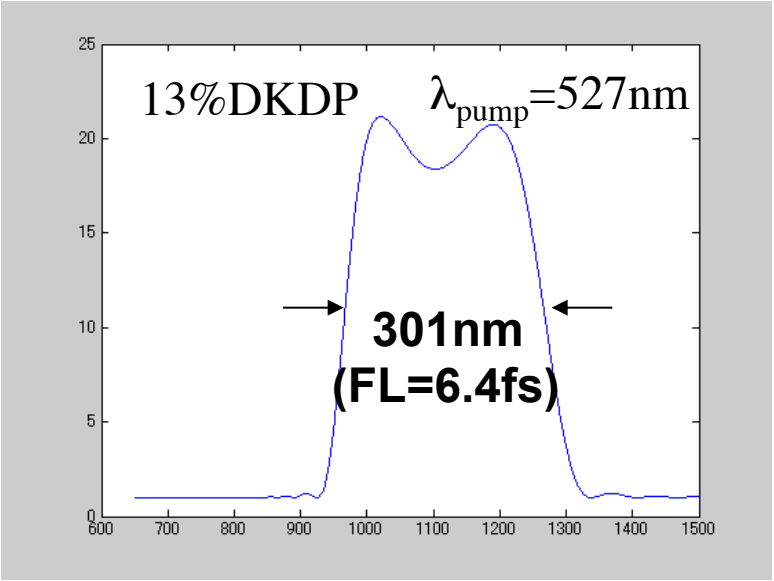
Virtually alignment free for beam combination

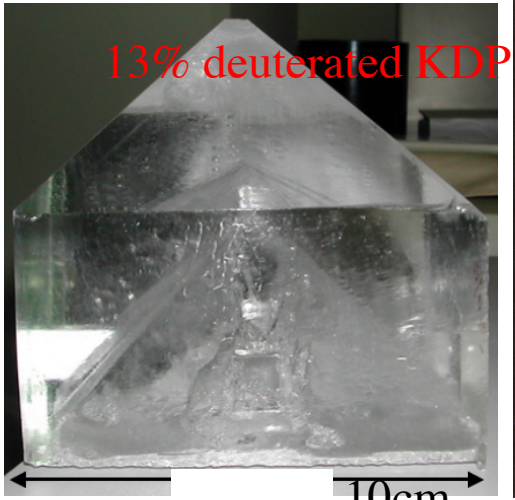


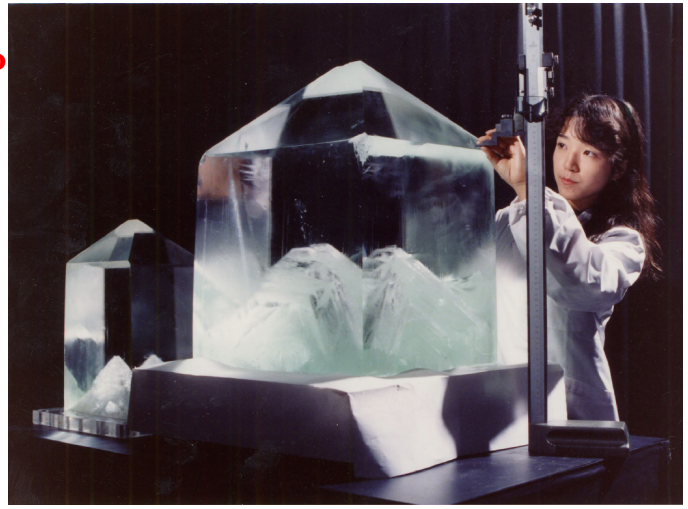


Partially deuterated KDP crystal for broadband OPA









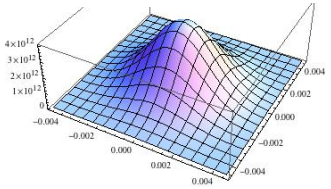
Pumping
- Energy: 8.4 kJ
- Pulse width: 1 ns
- Beam size: 32 cm
- Energy fluence: 10 J/cm^2

OPCPA output
- Energy: ~1.2 kJ
- Pulse width: 0.5 ns

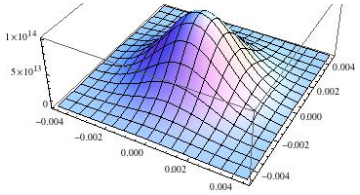
How about Non-collinear ? pDKDP(40%) + Gain Saturation

pDKDP(40%)

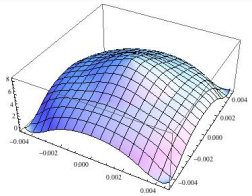
Signal 6 GW/cm^2



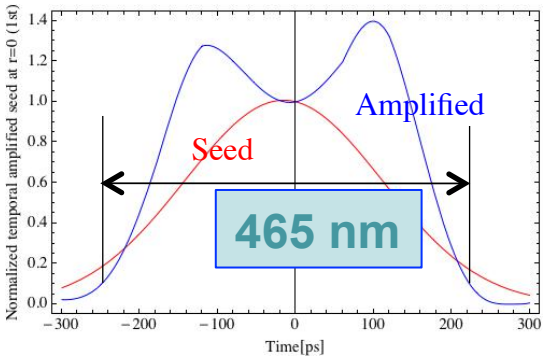
Pump 150 GW/cm^2



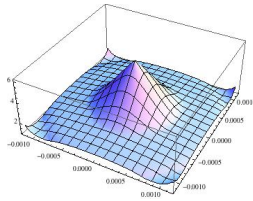
Collinear



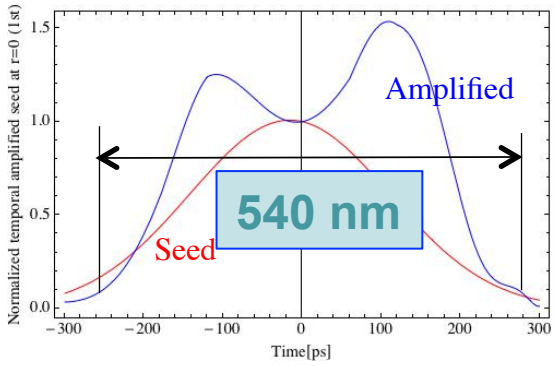
Con. eff. 18.8%



Non-Collinear



Con. eff. 8.0%



1) N-CL shows a broader gain band width than CL.
2) Need higher pump intensity in N-CL to recover the reduced gain. Also, need to take much care of the optically induced damage.

Summary

We are starting to design “Gekko – EXA” laser system conceptually.

1. OPCPA –based sub-EW laser

・Pre – Amp.	*DPSSL-pumped OPCPA*	~1 PW @100 Hz
・Main Amp.	*Nd:glass-pumped OPCPA*	0.1 EW @ single shot

2. Pump source

・DPSSL	*Cryogenic Yb:YAG ceramic*	150 mJ @ 100Hz $\eta_{o\text{-}o}$=30% Upgrade to joule-class
・Nd:glass	*Arrayed-beam of “LFEX” technology*	3 kJ/beam ps~ns 0.177λ(RMS)

3. Broadband OPCPA in kilo-joule

・p-DKDP	*40%-deuteration*	540 nm
	Non-collinear OPCPA	8%
	Gain saturation	

・Randam-phase pumped OPCPA

Research members

HAMAMATSU

Osaka PhoPs

SOC

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