Core Key Technologies of Multi-Kilojoule Repeatable Laser System

J. Kawanaka, S. Tokita, J. Ogino, H. Yoshida, K. Tsubakimoto, K. Fujioka, Z. Li, S. Motokoshi[*1], N. Morio, S. Matsuo, K. Kawabata, K. Takahashi, K. Matsumoto, Y. Kawakami, K. Sawai, K. Tsuji, M. Ishida, K. Matsushita, Y. Hirose, K. Fuwa, K. Shigemori, H. Matsuo, S. Oketani, T. Sezaki, T. Yanagida, N. Miyanaga[*1], M. Fujita, K. Ueda[*2], and R. Kodama

Institute of Laser Engineering, Osaka University
[1)] Institute for Laser Technology
[2)] Institute for Laser Science, UEC

Outline

1. **Repeatable kJ-class** laser system for fast-ignition-based fusion reactor engineering

2. **Core key technologies and experimental results**
   - Repeatable kJ-class implosion laser
     - 2-1 Cryogenic laser material
     - 2-2 Active-mirror amplifier
   - High-contrast heating laser
     - 2-3 Spectrum-resolved pulse cleaner
     - 2-4 Large-aperture Dielectric grating

3. **Conceptual design of laser system for high energy density plasma**

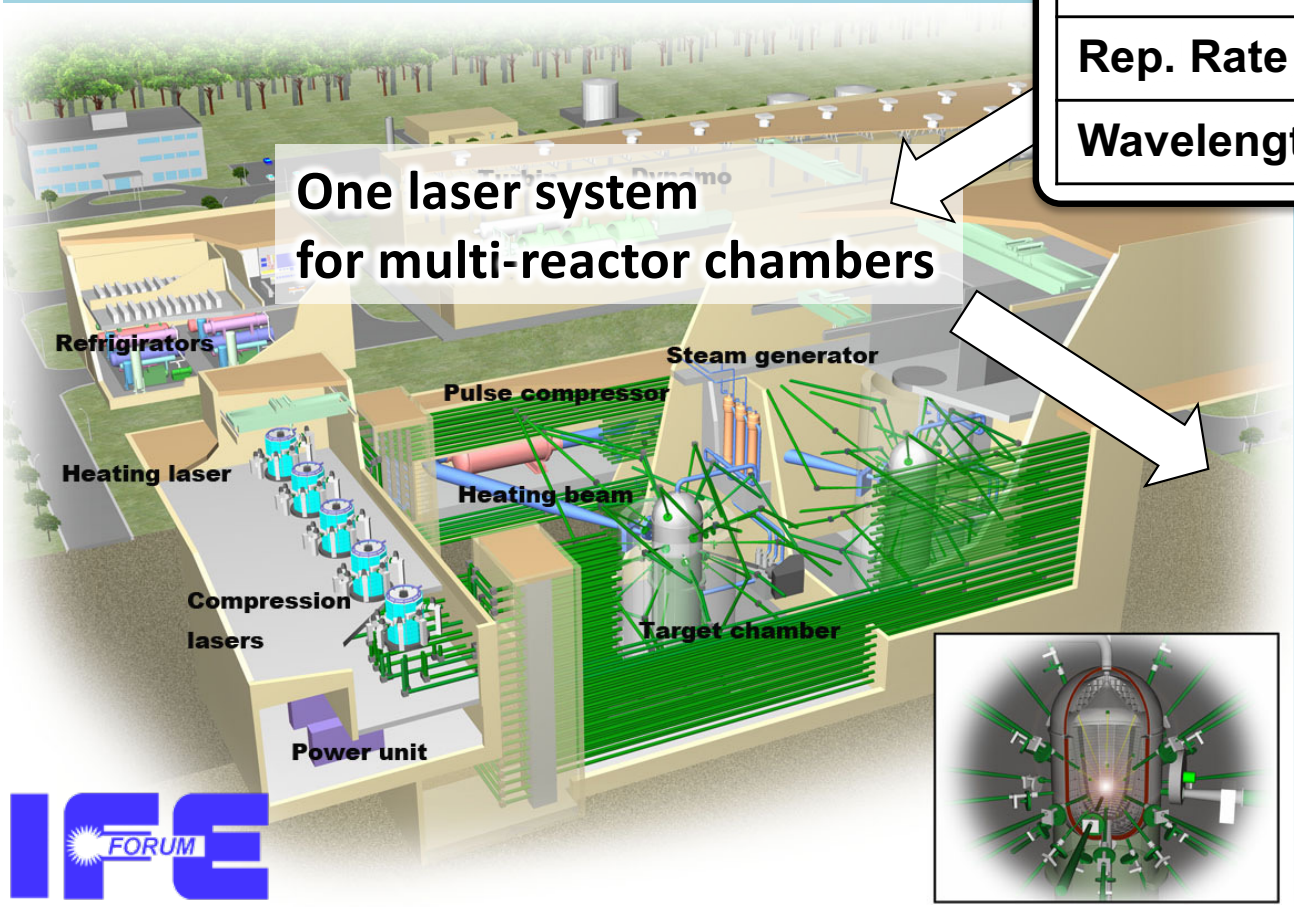
4. **Summary**

Laser system for fast-ignition based fusion reactor

Implosion by multiple beams → Fast heating by Intense laser → Ignition and burn

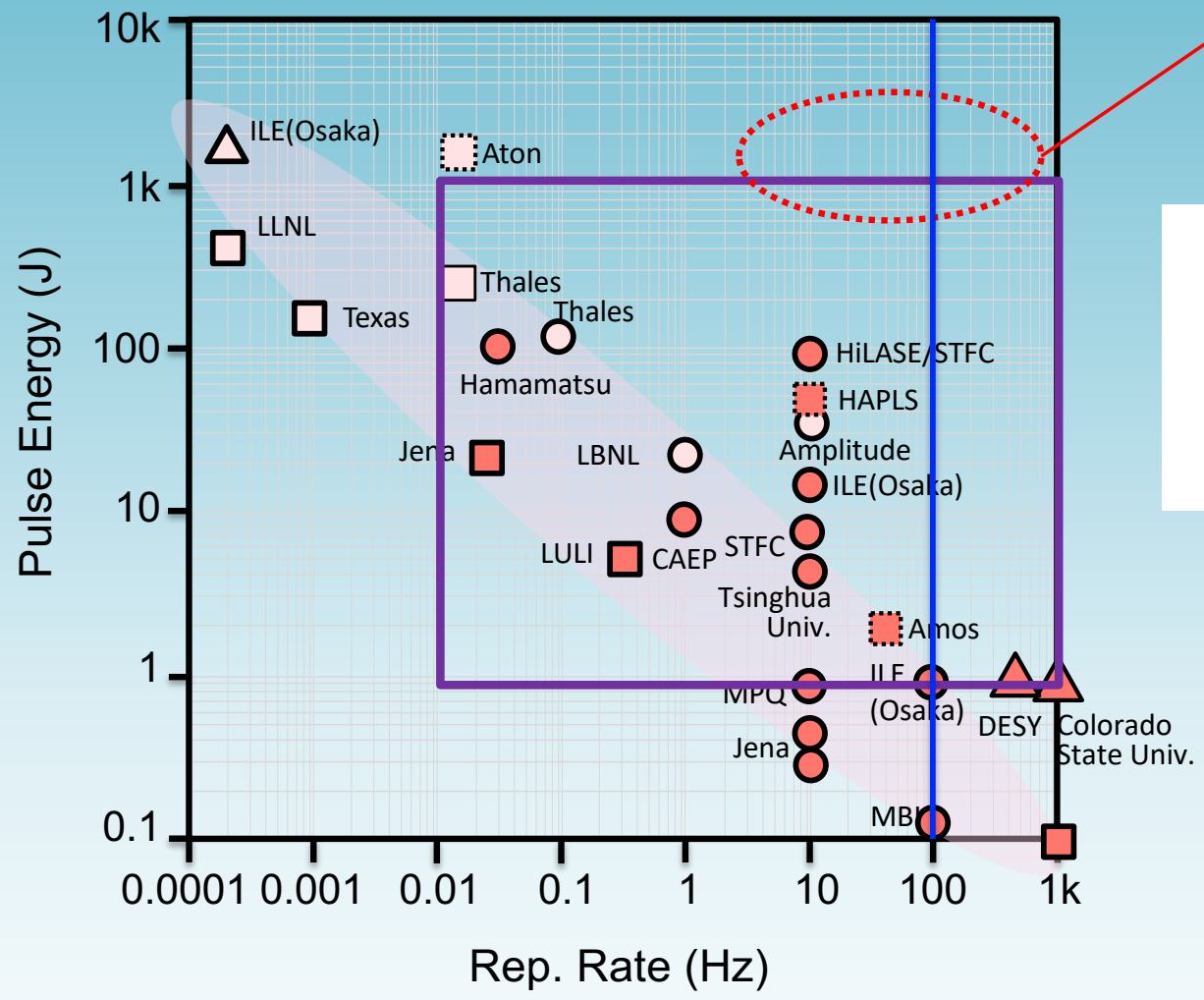
Core plasma
- Fusion output : > 50 MJ/pulse
- Target gain : > 100

	Implosion	Fast heating
Energy	896- kJ (ω) 500 kJ (3ω)	500 kJ (ω) 200 kJ (2ω)
Duration	30 ns (Tailored)	20ps (Rise:1 ps)
Rep. Rate	4 Hz	4 Hz
Wavelength	0.35 um	0.53 um



100 Hz operation

Advanced power laser over the world



No repeatable laser in kilo-joule !!

Repeatable DPSSL in kilo-joule

- High efficiency (less heat generation)
- Compact size

Thermal control of much heat at 100 Hz is inevitable.

Flash lamp ○ ns △ ps □ fs

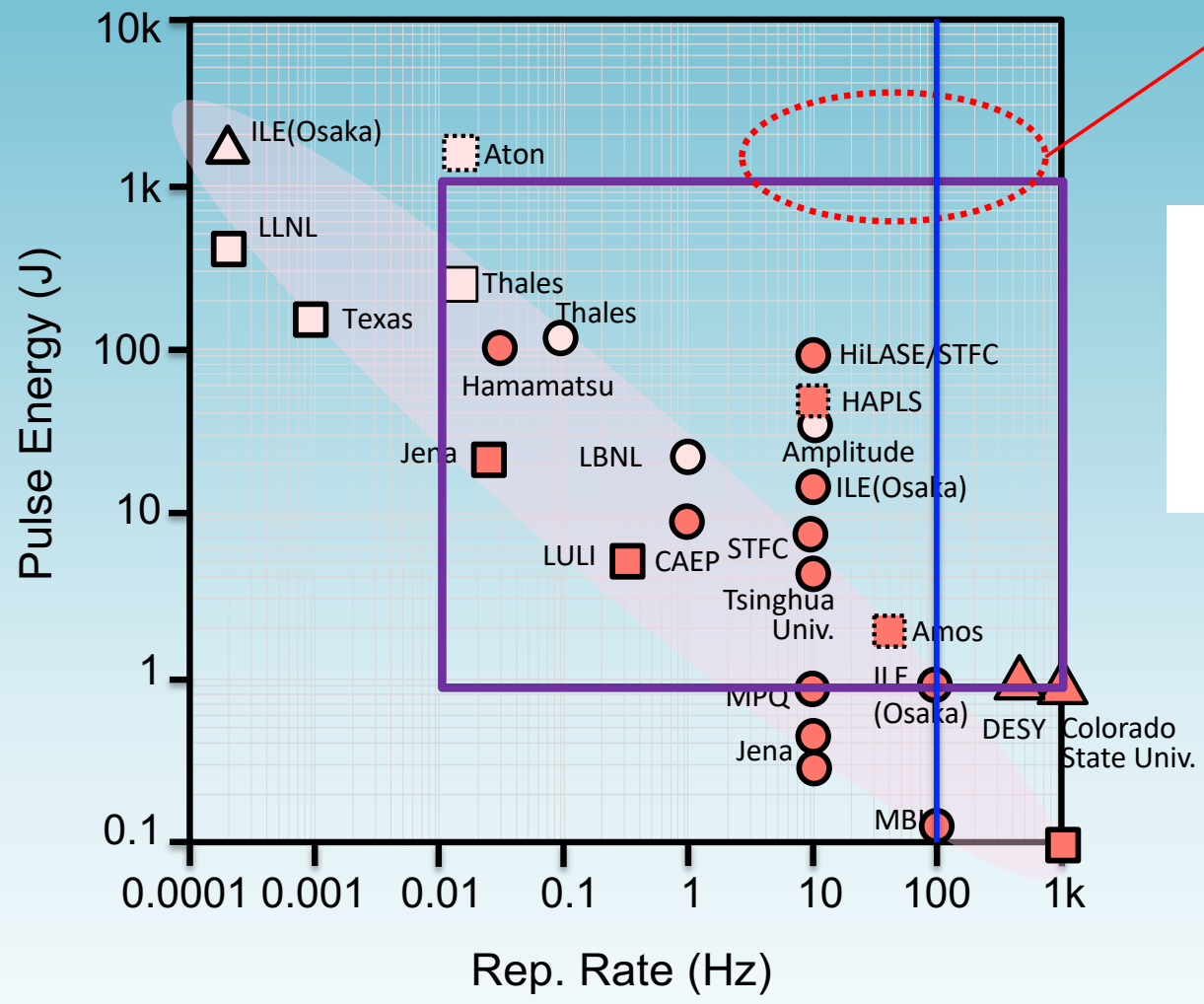
Diode ● ns ▲ ps ■ fs

Core Key Tech. for kJ-class repeatable laser

2-1 Cryogenic laser material

2-2 Active-mirror amplifier

Advanced power laser over the world



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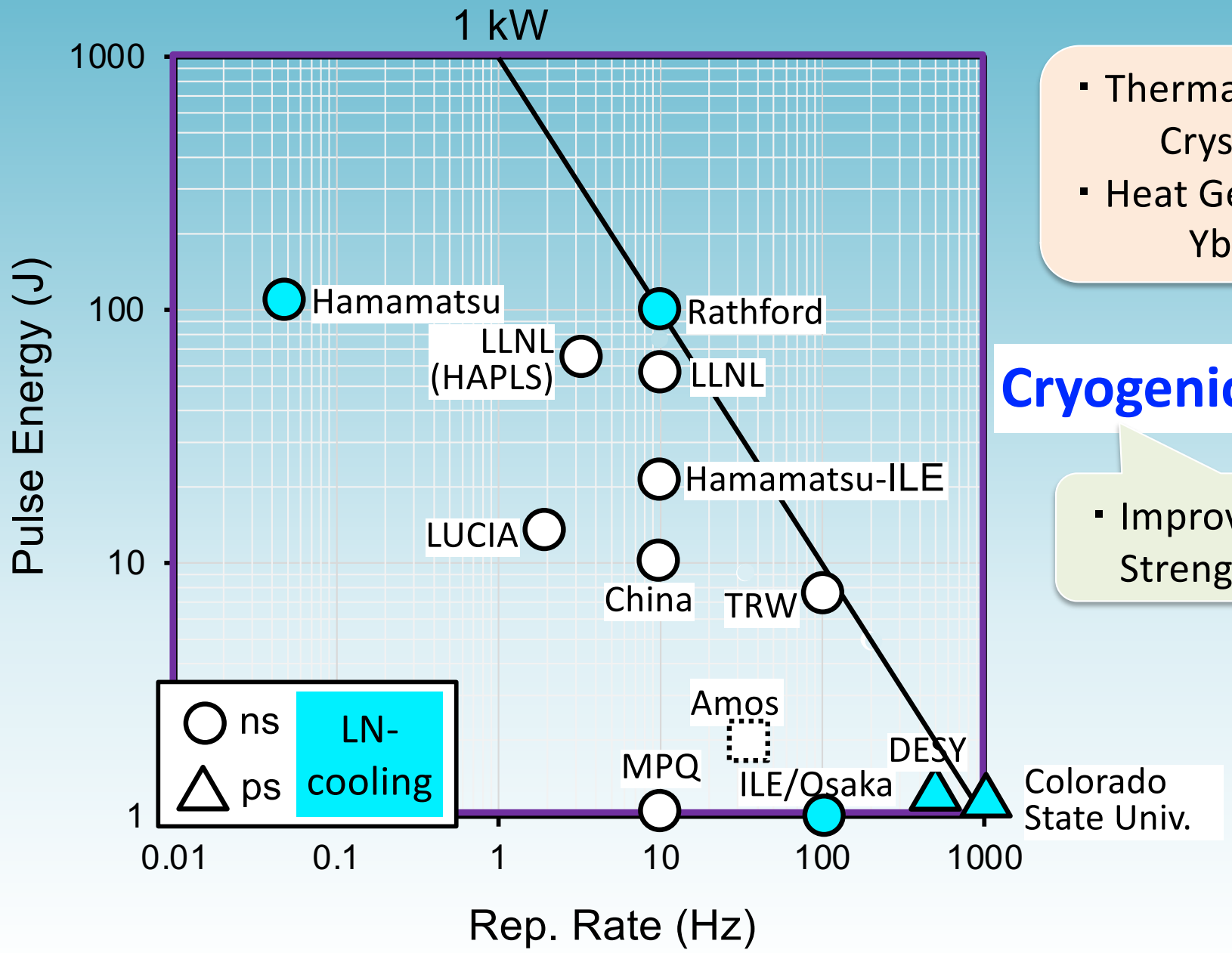
Repeatable DPSSL



- Thermal Strength
  Crystal > Glass
- Heat Generation
  Yb < Nd

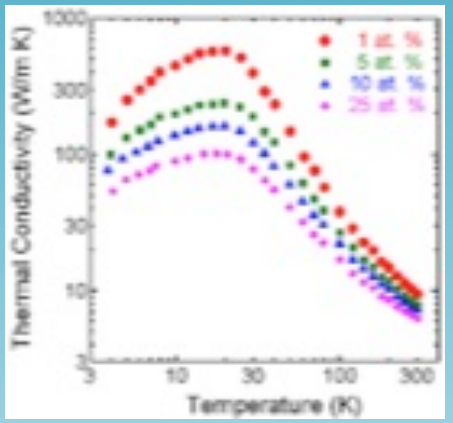
Cryogenic Yb:YAG

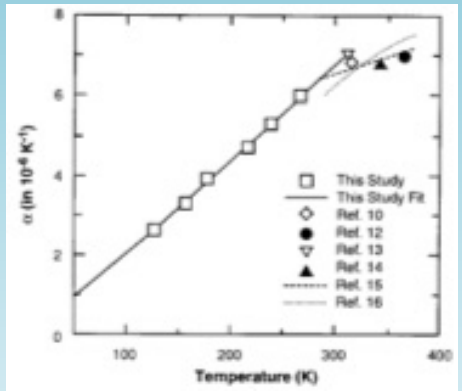
- Improve Thermal Strength

Thermal improvement of cryogenic Yb:YAG

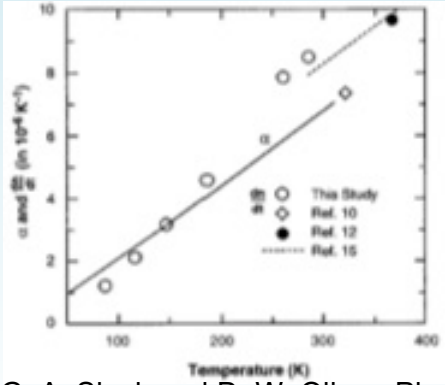
	Nd-glass	Yb:YAG	**Cryogenic Yb:YAG** (@77K)
Thermal Conductivity (w/mK)	0.5~1	**11.7**	**70**
		x 7	
Thermo-Optic ($x10^{-6}$)	-5 (Phosphate) 3 (Silicate)	6.5	**1**
		x 1/7	
Thermal Expansion ($x10^{-6}$)	7～14	8	**2**
		x 1/4	

Thermal effect is dramatically reduced!!



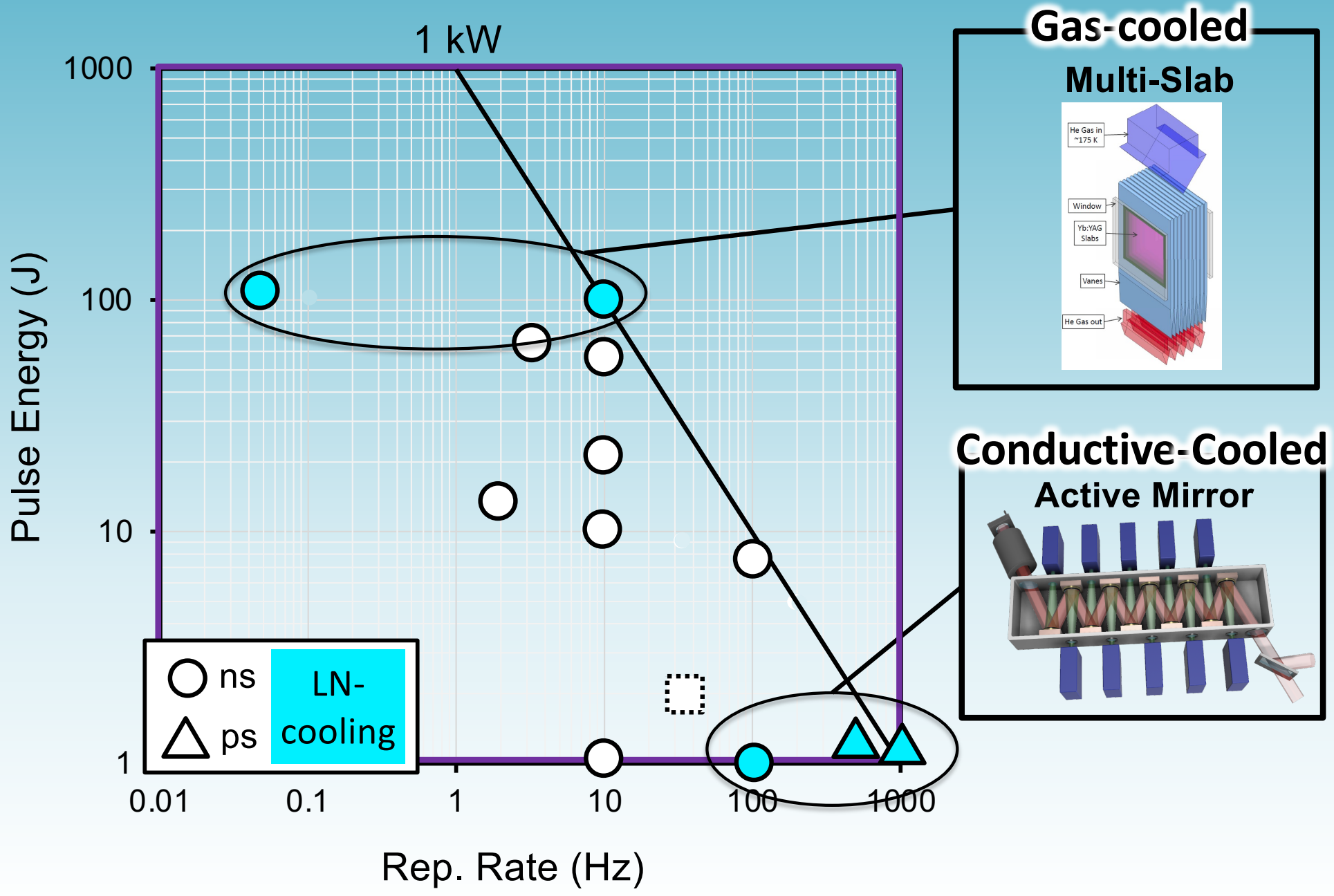


R. Wynne, J. L. Daneu, and T. Y. Fan, Appl. Opt. **38,** 3282-3284 (1999).



G. A. Slack and D. W. Oliver, Phys. Rev. B **4,** 592-609 (1971).

Repeatable DPSSL

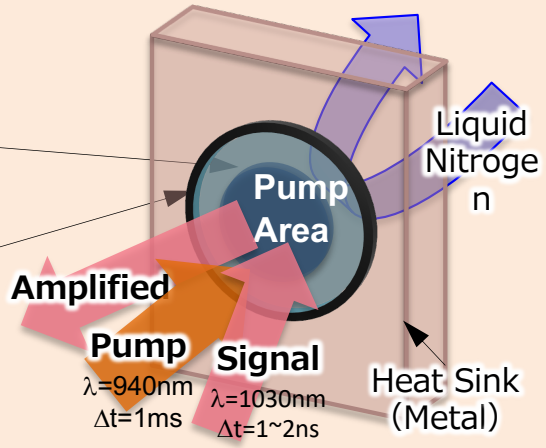


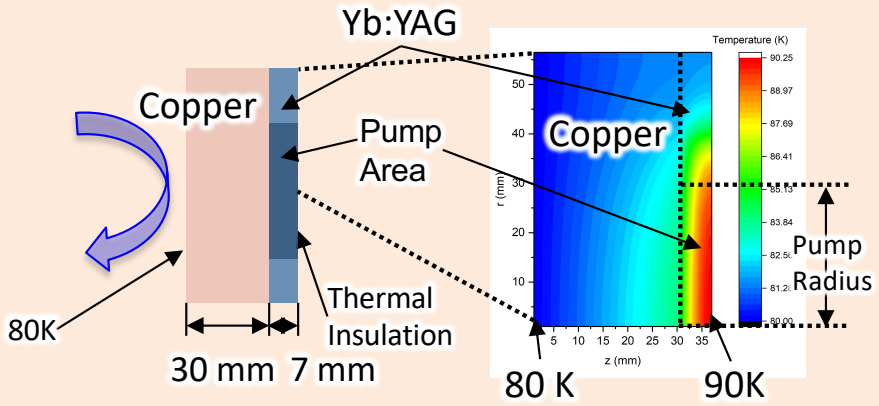
Active Mirror Amplifier

Conductive-Cooled Active Mirror

Laser Material

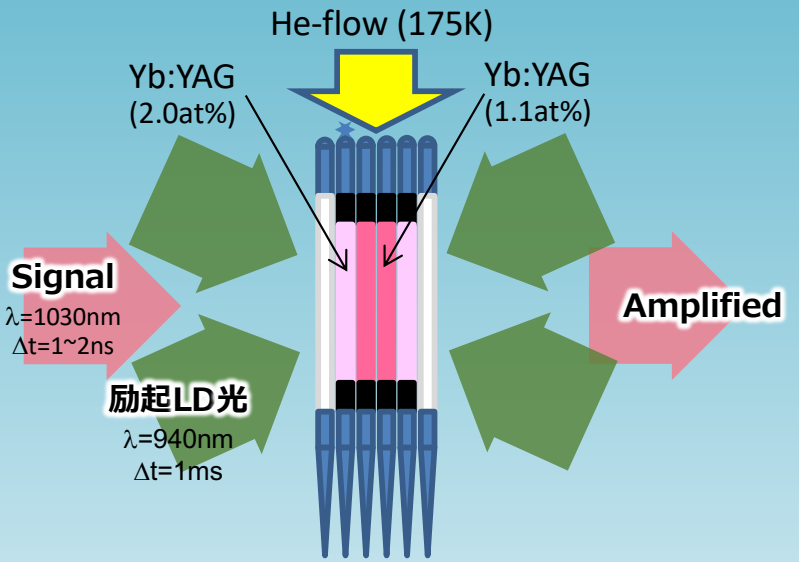
Yb:YAG
Front Surface:AR
Rear Surface:HR
+
Cr^{4+}:YAG
As edge-cladding

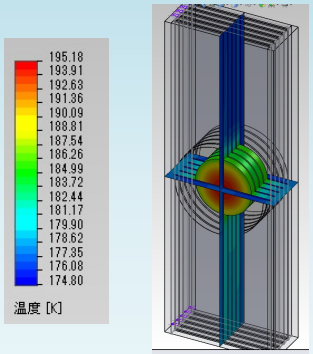




・Small temperature rise。**6K（@100Hz）**

Gas-Cooled Slab



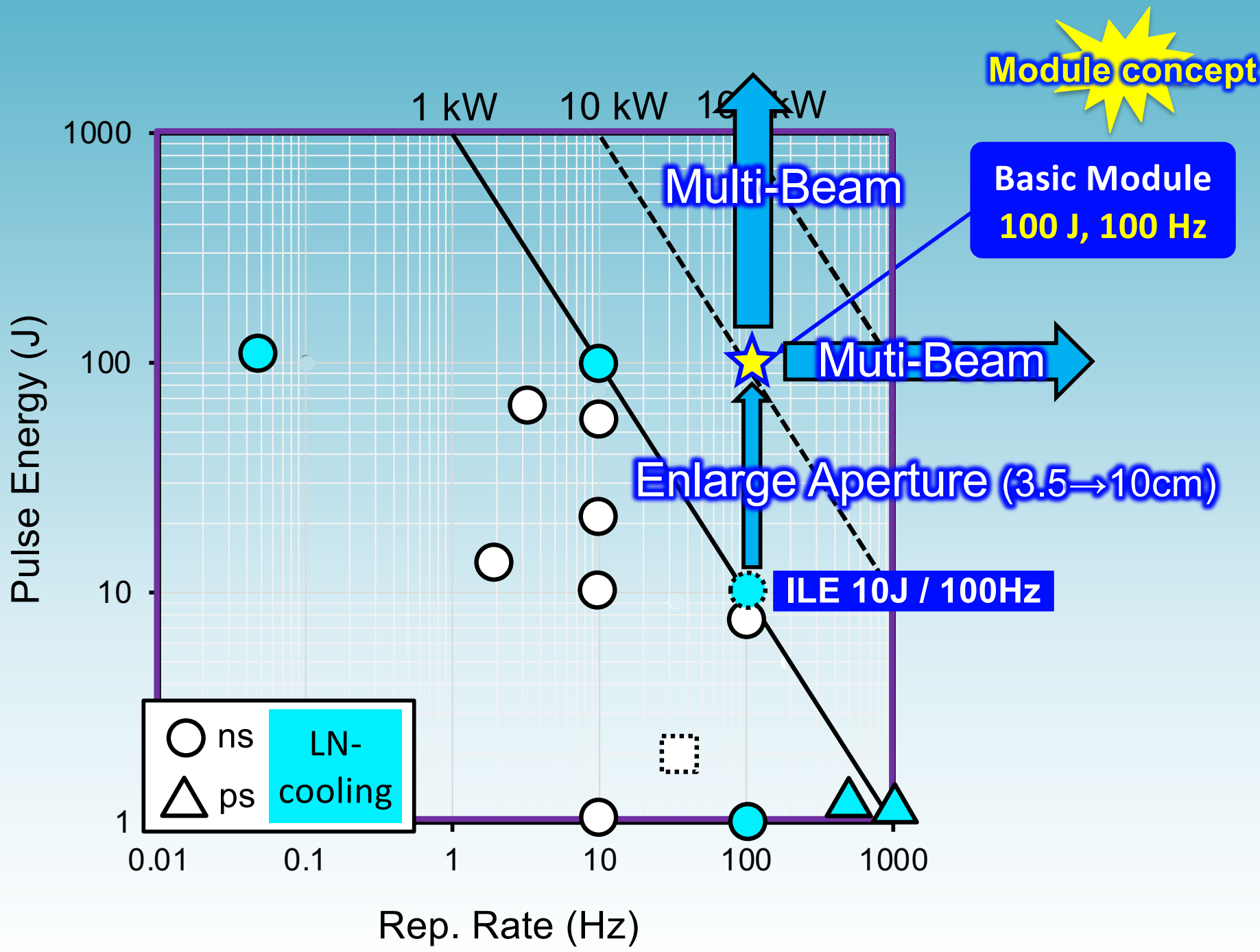


ELI HiLASE(Czech)
DiPOLE(UK)

・Large temperature rise。10K (@10Hz)

・Thermal gradient is parallel to laser axis. ⇨ **Easy energy scaling**

Strategy for kilo-Joule

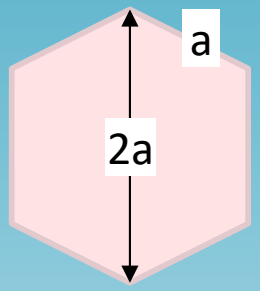


Core Key Tech. for kJ-class repeatable laser

2-1 Cryogenic laser material

2-2 Active-mirror amplifier

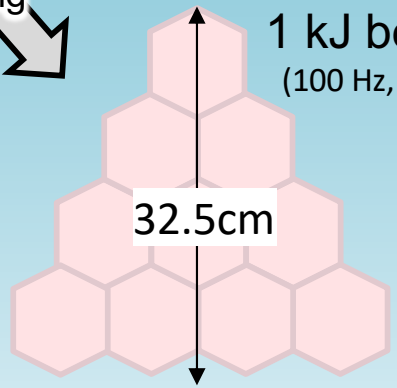
Yb:YAG disk size for 100 J



Hexagon

$S = 6\,(a\,(a/2)\tan 60^\circ\ \ (1/2))$
$= (3/2)\,3^{1/2}\,a^2$

Tiling



1 kJ beamlet
(100 Hz, 100 kW)

Limitting Factor

Pulse duration : 10 ns

2a (cm)	S (cm^2)	Optical Damage Threshold (J/cm^2)	Pulse energy (J)
1	0.65	1.6	1.0
3	5.8	1.6	9.4
7	32	1.6	51
10	65	1.6	**104**

Commercially obtainable maximum size

Limitting Factor

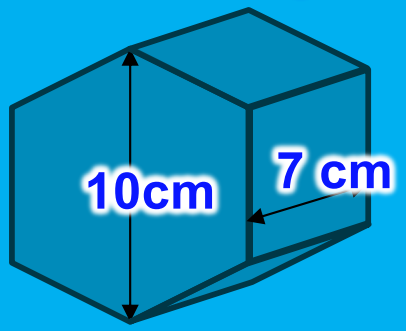
2a (cm)	Parsitic oscillation g_0L	Maximum SSG coefficient g_0 (cm^{-1})	Maximum SSG G_0
10	2.5	0.25	1.284

Storage Energy Density (J/disk)

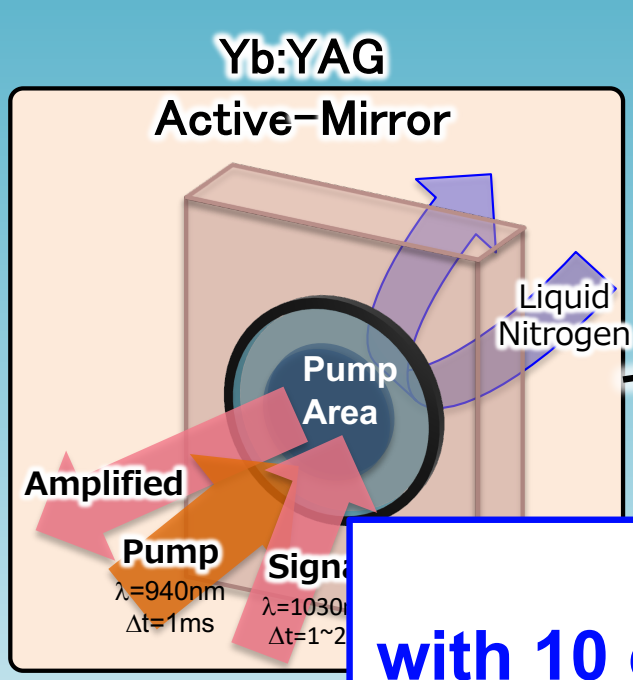
$E_{st} = g_0 E_s V$
$= 0.25 \times 1.5 \times (62.5 \times 0.7)$
$= 24.4$ J/disk at t=10mm

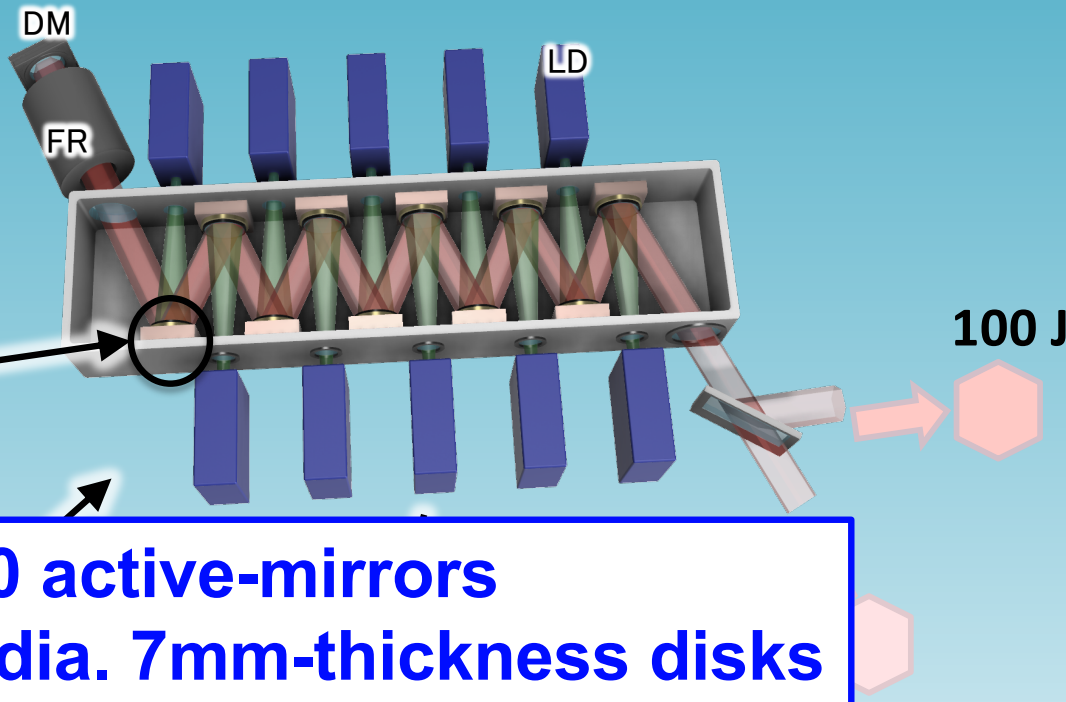
Extraction efficiency : 0.6
Amplified Energy : **100 J**
→ Required Storage Energy : 167 J

Yb:YAG Total Volume For 100 J output



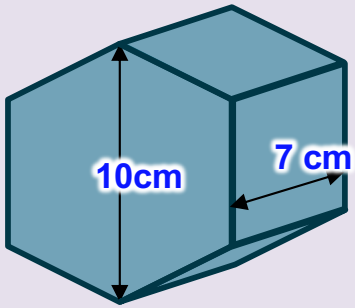
100 J, 100 Hz Amplifier Module





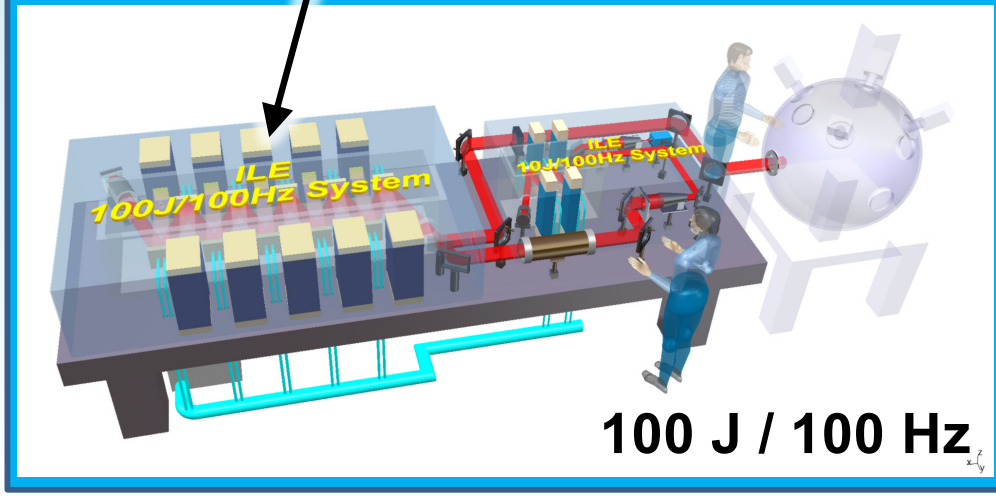
10 active-mirrors
with 10 cm-dia. 7mm-thickness disks

Required Volume of Yb:YAG



t7mm x 10 disks

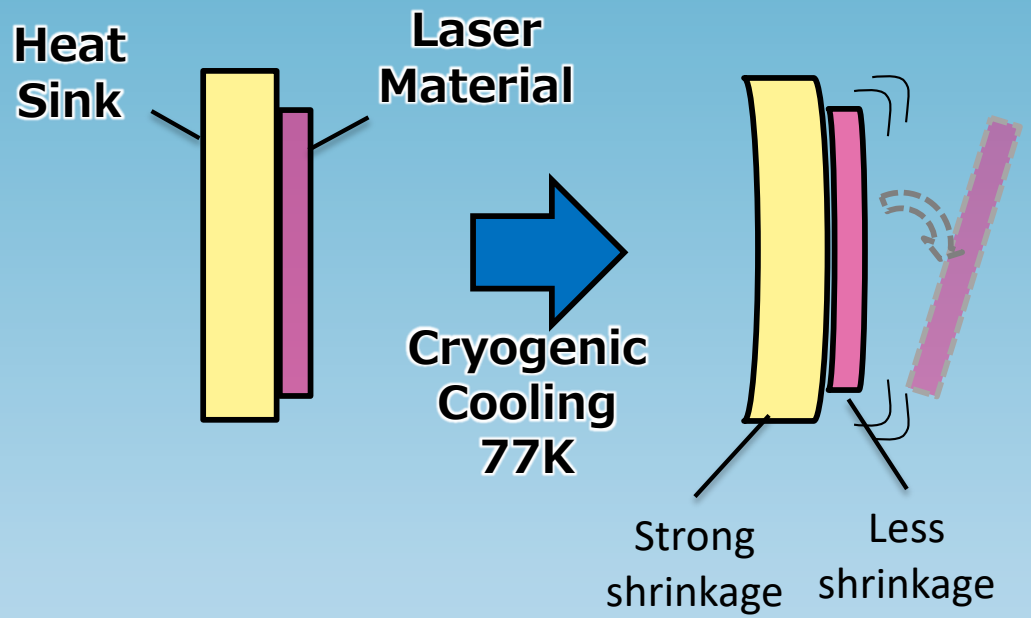
SENJU
Super-Energetic Joint Unit



100 J / 100 Hz

Significant problem of large-aperture active-mirror

- Large difference of thermal expansion between heat sink and Yb:YAG



Expanding Aperture size,

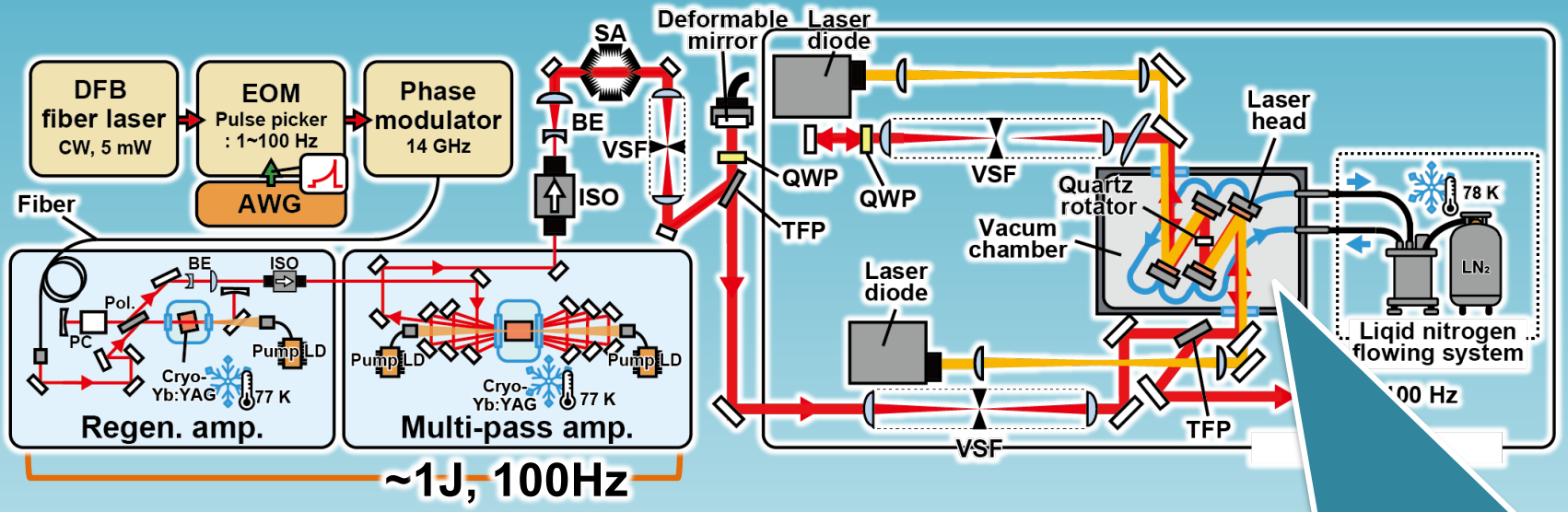
Strong internal stress
- Distortion of wave front
- Birefringence

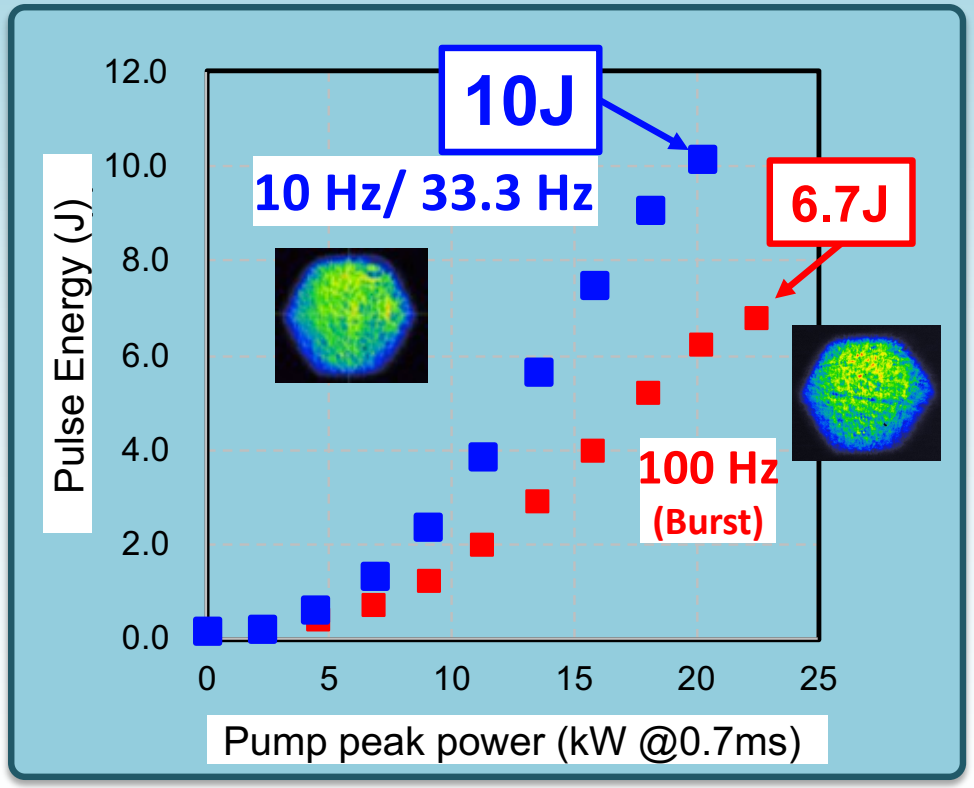
or

Peeling off

- **Bonding technology** : Reduced internal stress

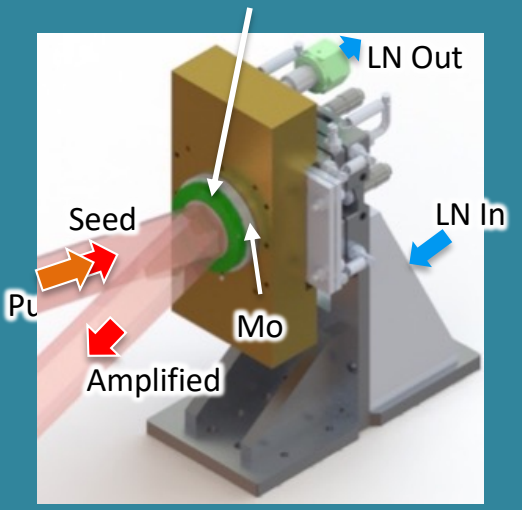
10J, 100Hz Active-mirror laser system





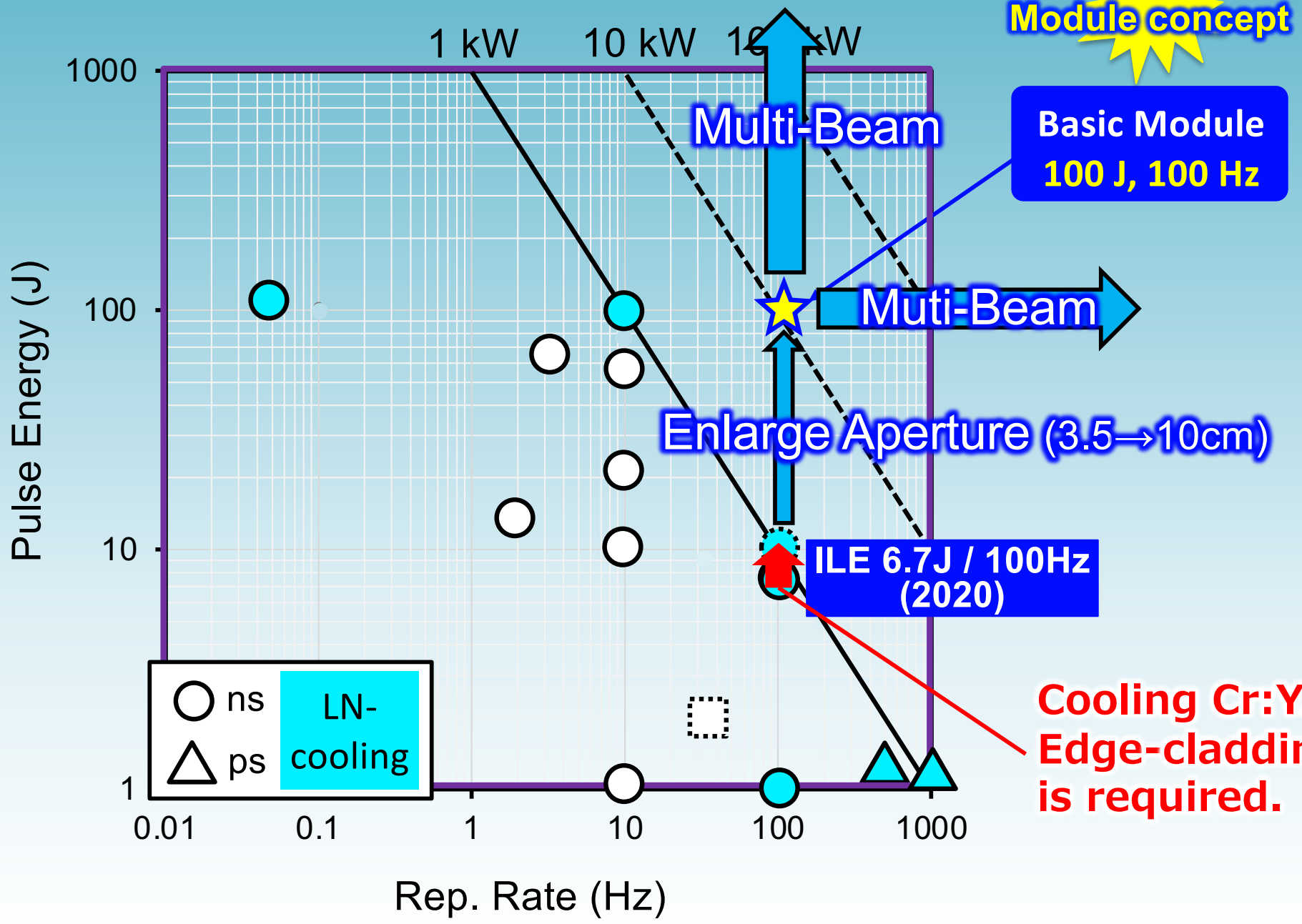
10 J, 100 Hz amplifier

Yb:YAG dia. : 70 mm



30cm x 35 cm x 40 cm

We are here.


1 kW
10 kW
1000
100
10
1
Pulse Energy (J)
0.01
0.1
1
10
100
1000
Rep. Rate (Hz)
ns
ps
LN-cooling
Multi-Beam
Muti-Beam
Enlarge Aperture (3.5→10cm)
ILE 6.7J / 100Hz (2020)
Module concept
Basic Module
100 J, 100 Hz
Cooling Cr:YAG
Edge-cladding
is required.

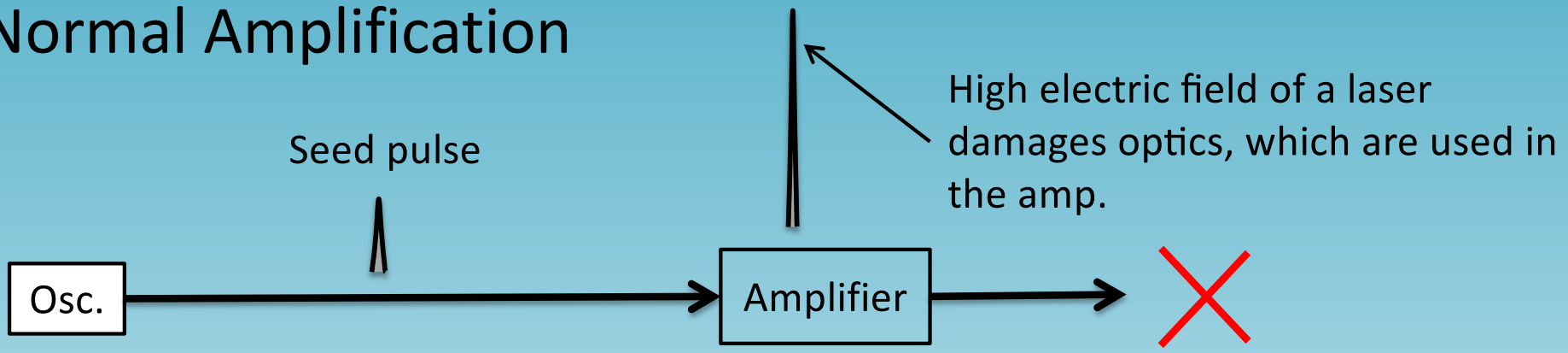
Core Key Tech. for High-contrast heating laser

2-3 Large-aperture Dielectric grating

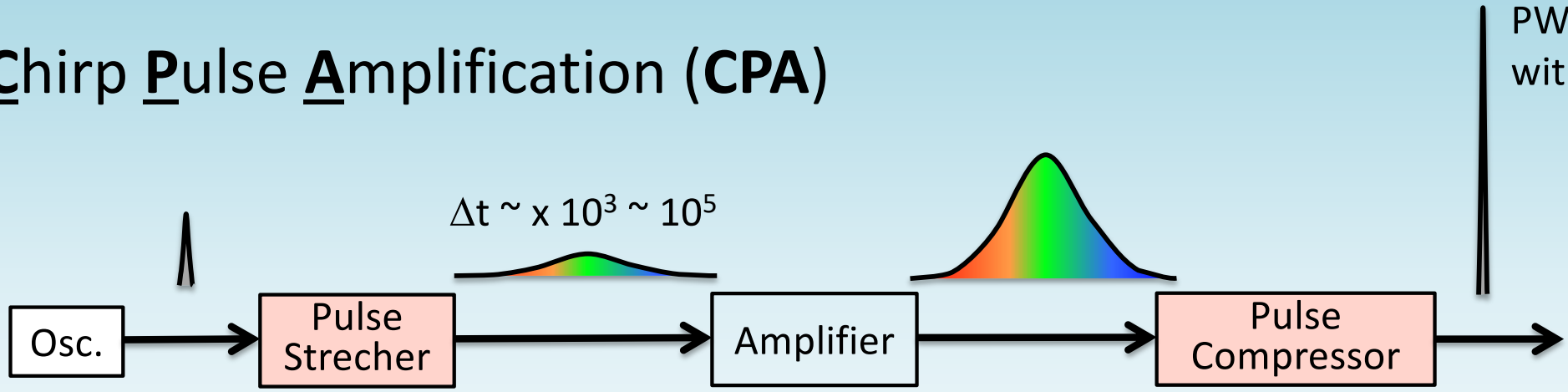
2-4 Spectrum-resolved pulse cleaner

How can we generate PW peak power?

Normal Amplification



Chirp Pulse Amplification (CPA)

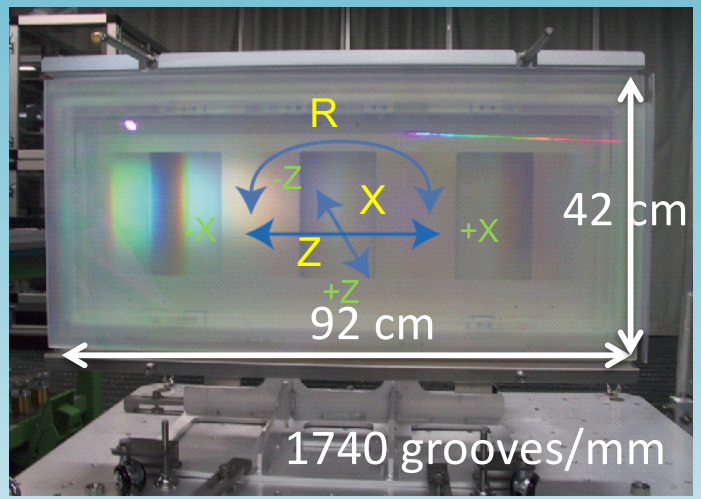


Large-aperture Grating

- Dielectric grating
- Meter-size large aperture

All large aperture dielectric gratings are fully installed.

The world's largest dielectric gratings



Difficulties

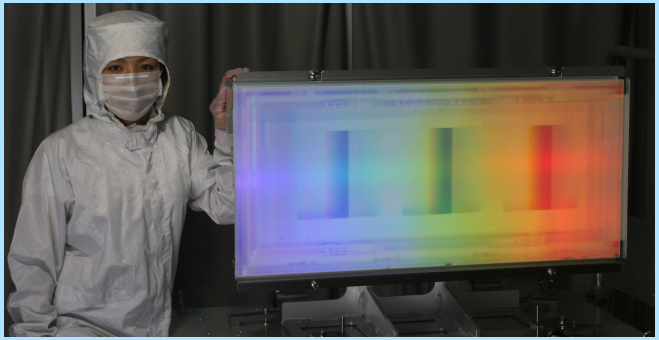
- Dielectric coating on large aperture silica glass
- Extremely precise grooving (0.05ppm)

Okamoto Optics (Japan)
Plymouth Grating Laboratory (U.S.)
Osaka Univeristy (Japan)

Development & manufacturing system of large-aperture, high perfomance dielectric gratings

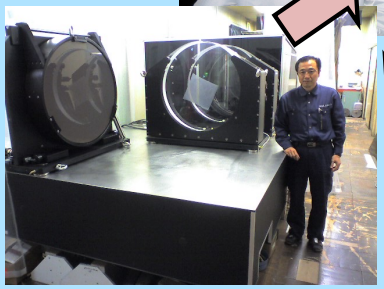
Japan

ILE, Osaka Univ.



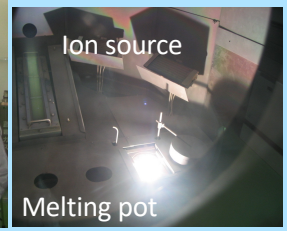
Quartz material (Tosoh Co.)

Polishing



Wavefront Inspection

2m-size Coating machine



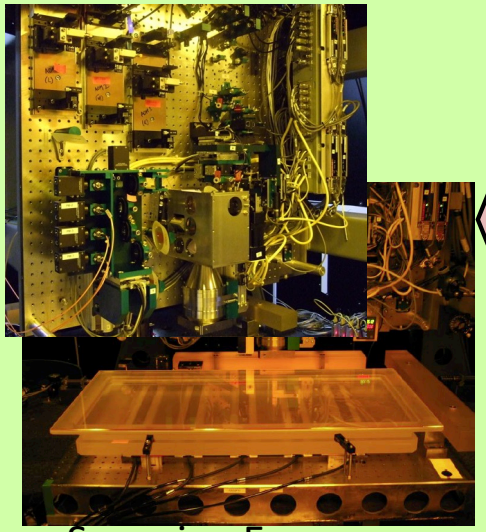
Dielectirc coating

Okamoto Optics Works (Yokohama)

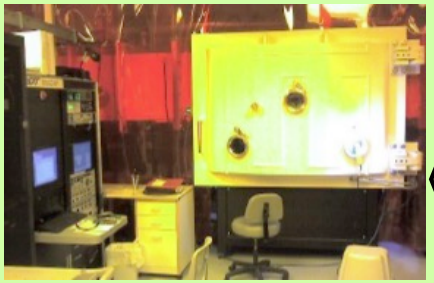
Resist coating

Plymouth Grating Laboratory

PGL, Massachusetts

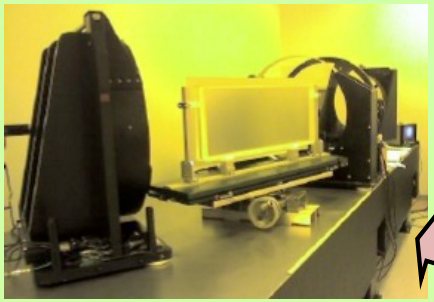


Scanning Exposure (1.3-m stage)



Ion Etching

Cleaning



Wavefront Inspection

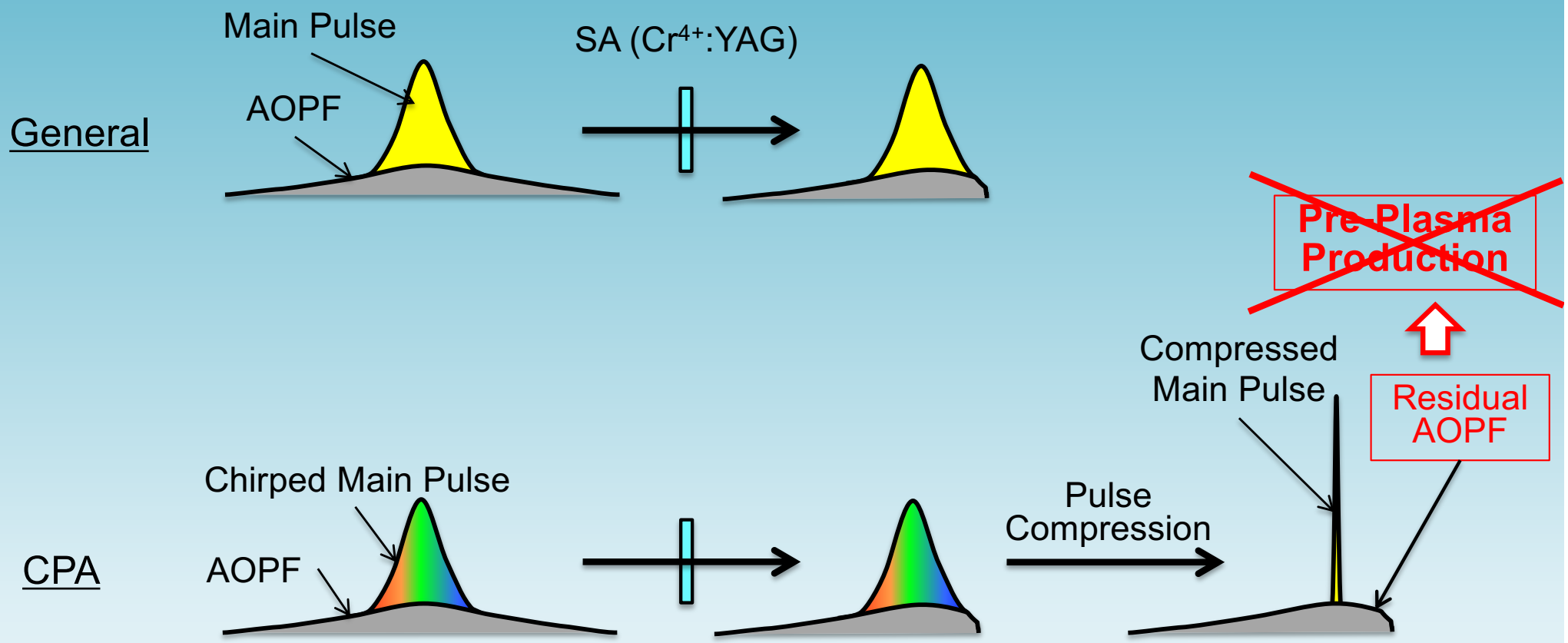
U.S.

Core Key Tech. for High-contrast heating laser

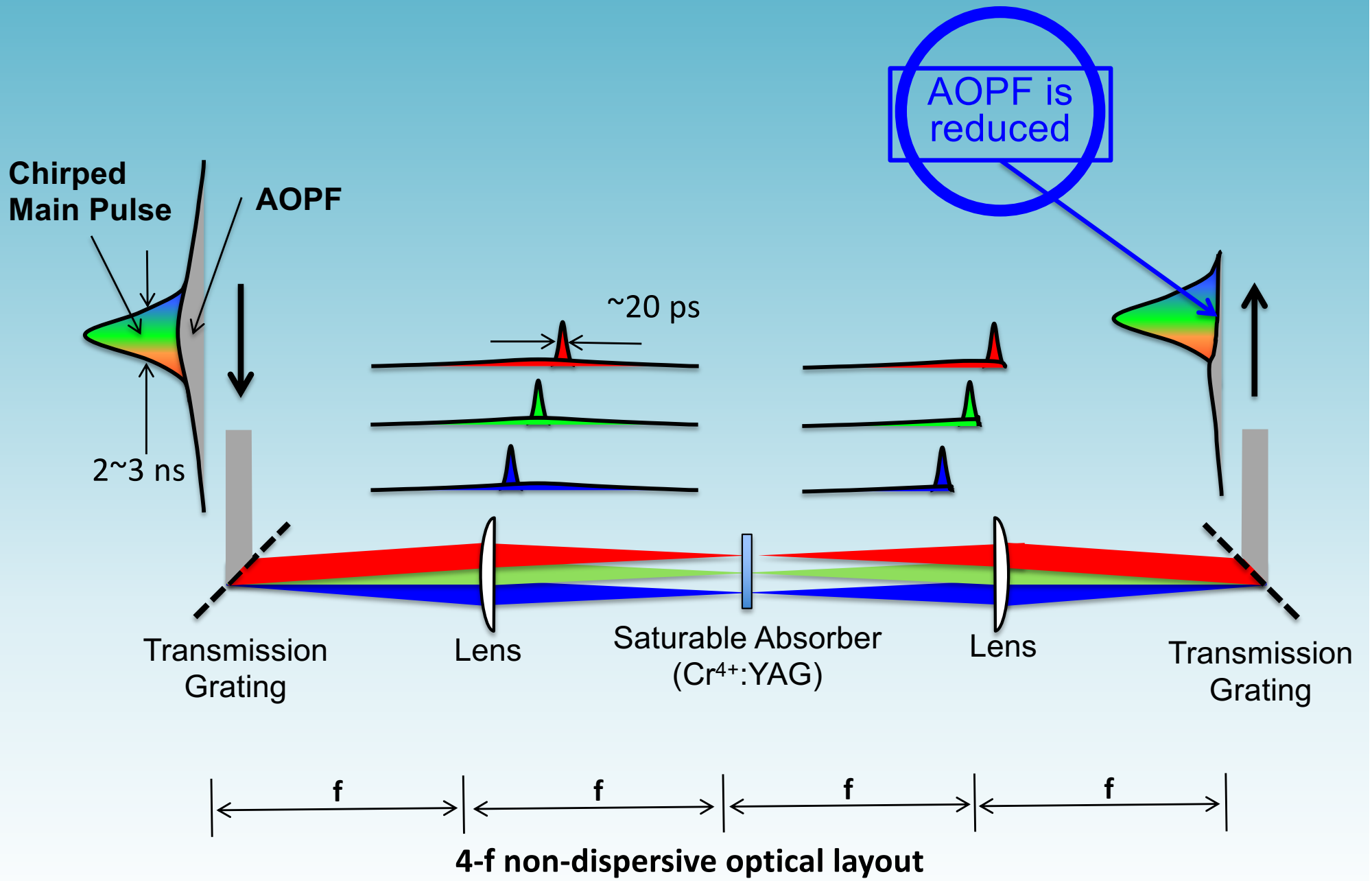
2-3 Large-aperture Dielectric grating

2-4 Spectrum-resolved pulse cleaner

Saturable absorber as pulse cleaner

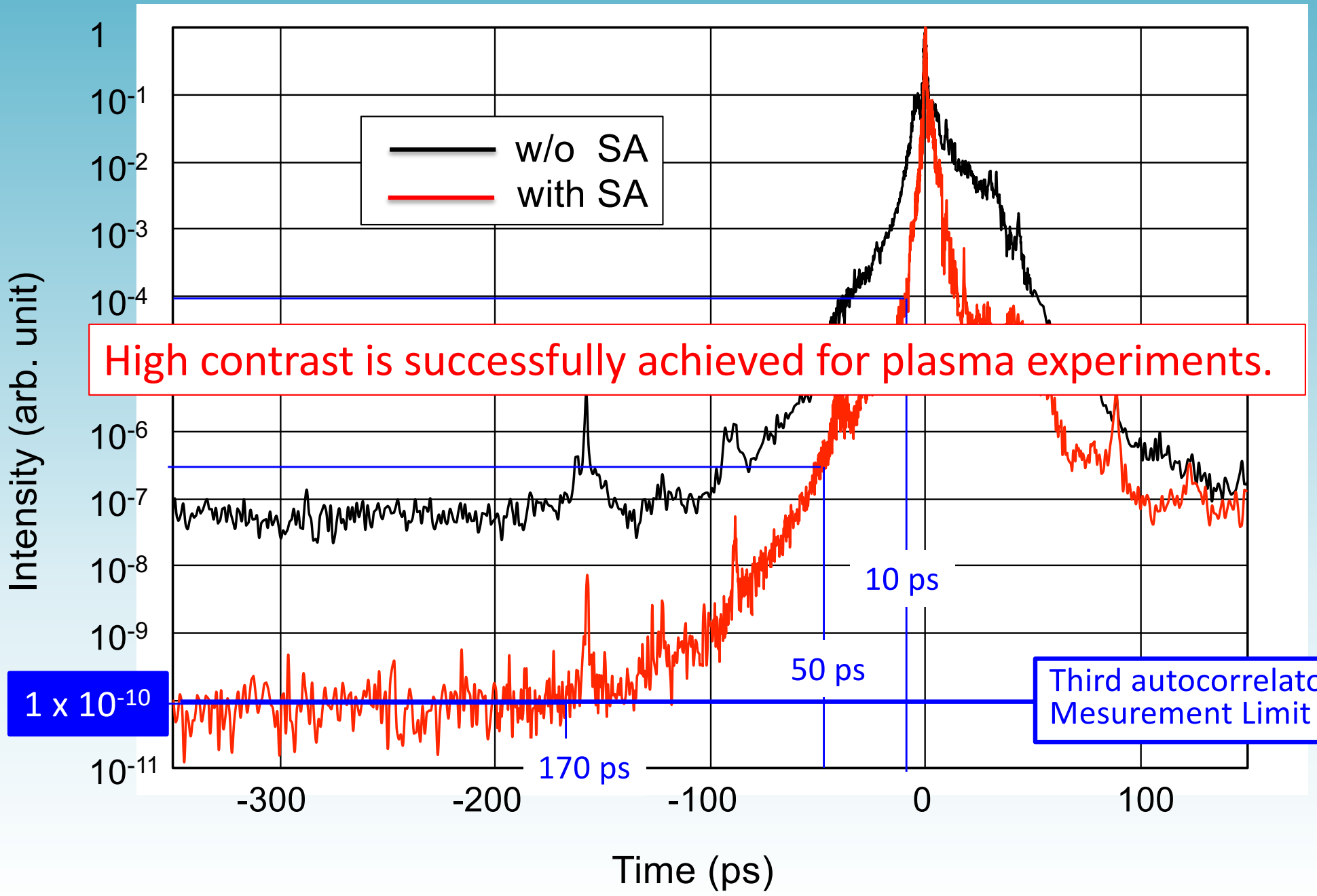


Original Spectrally Resolved Pulse Cleaner

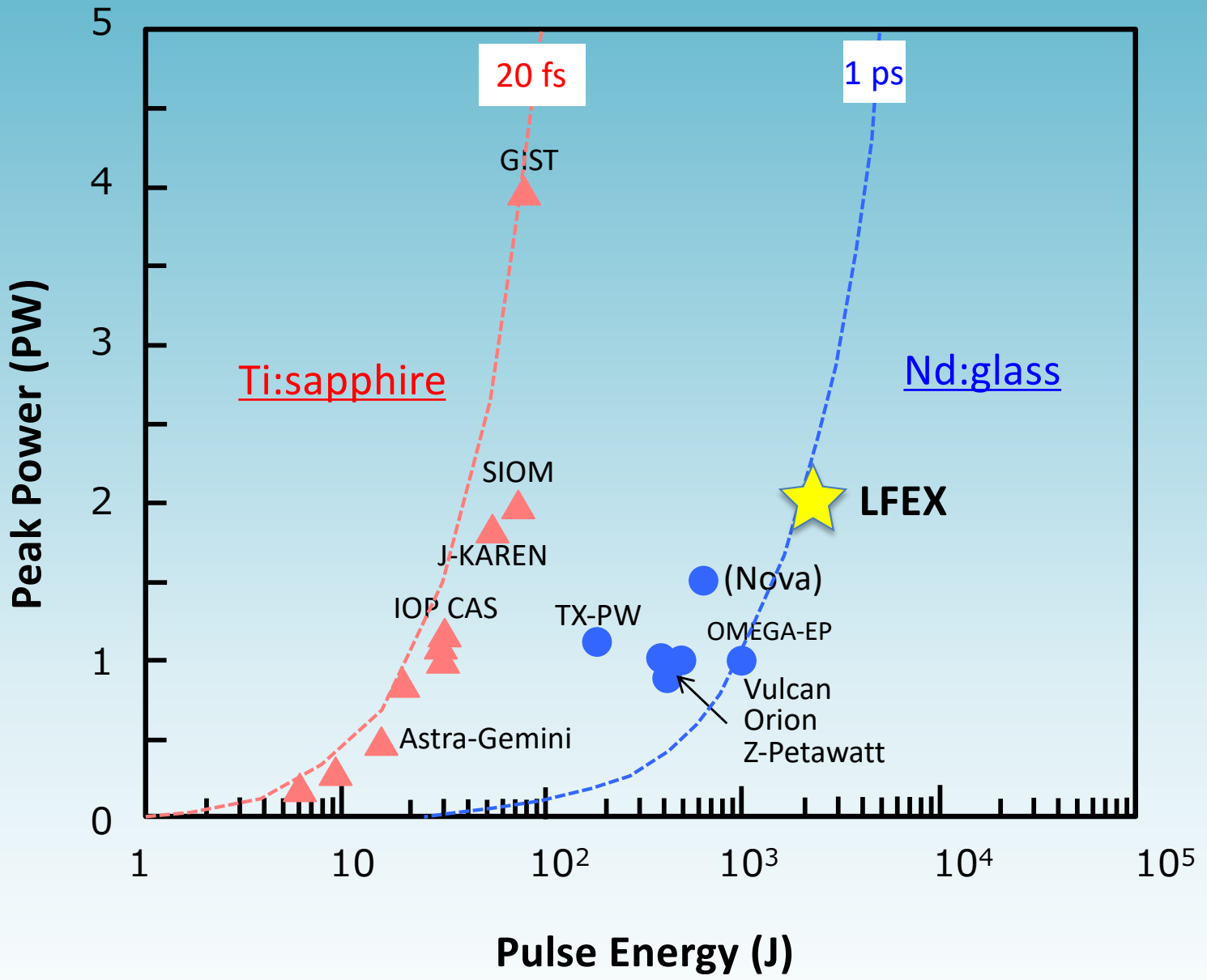


4-f non-dispersive optical layout

Pulse intensity contrast after OPCPA



LFEX -The first CPA laser at multi-kilojoules

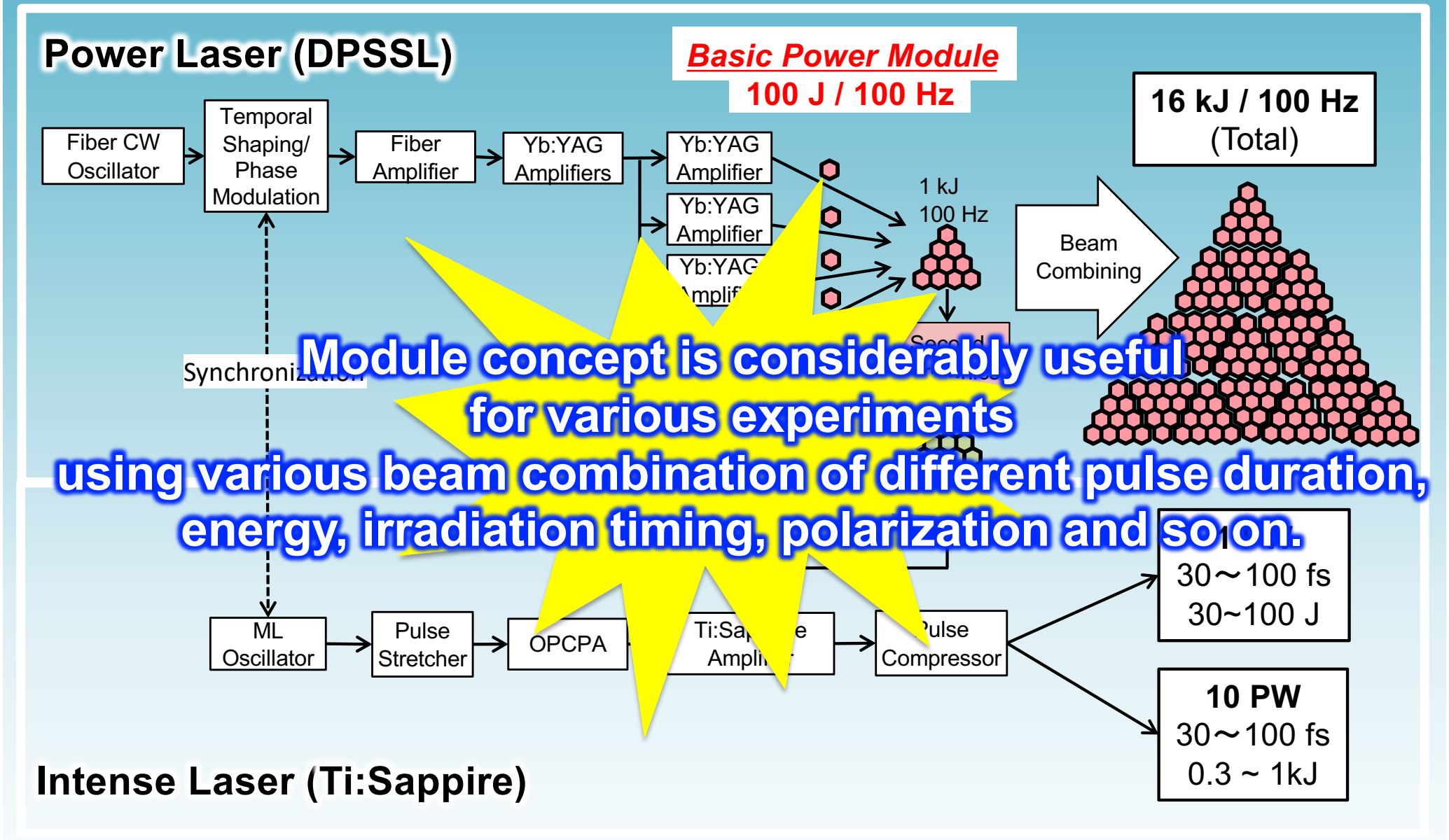


Core Key Tech. for kJ-class repeatable laser

2-1 Cryogenic laser material

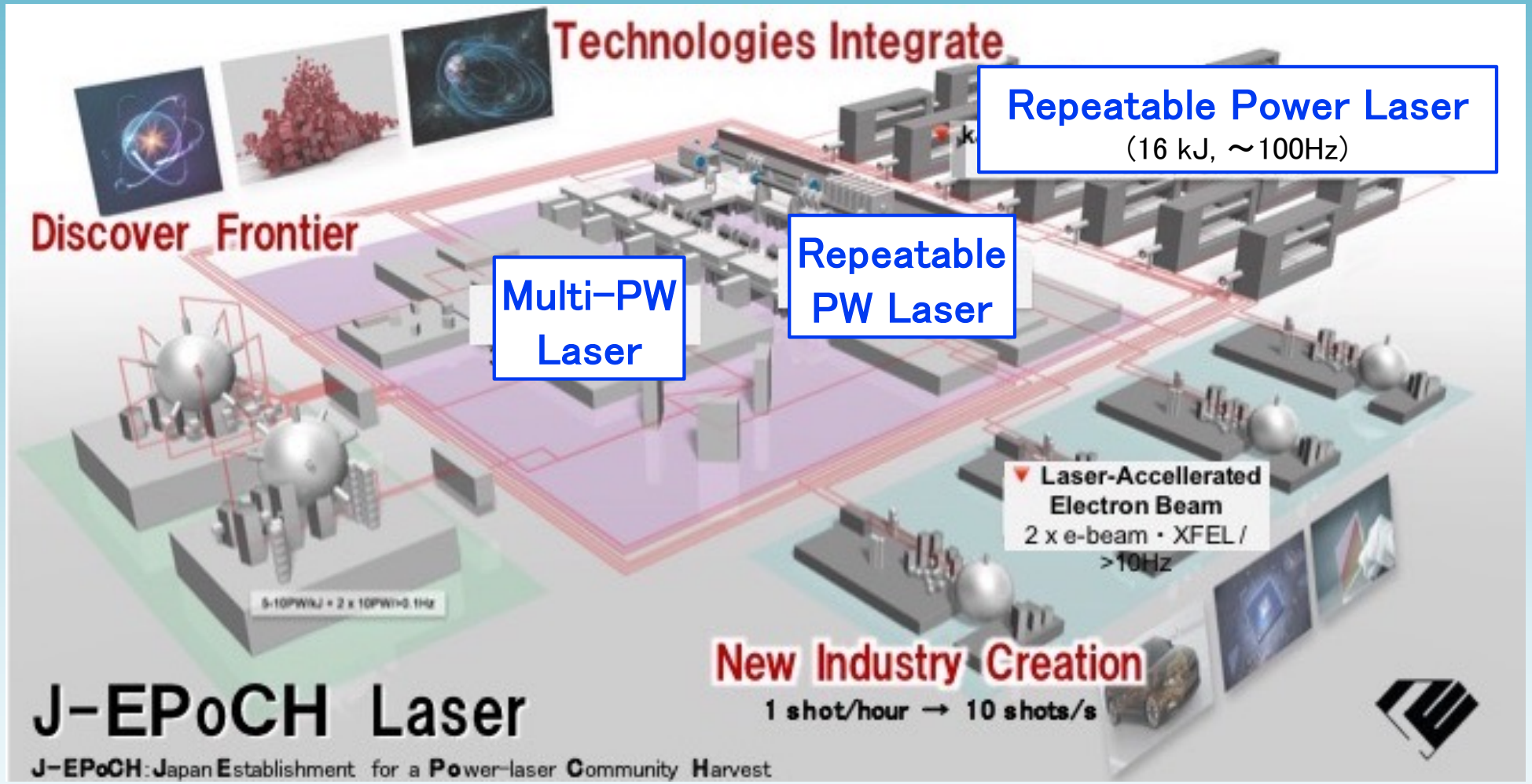
2-2 Active-mirror amplifier

Concept of repeatable power laser for HEDP



J-EPoCH

Innovative high-power-laser application platform



Innovative application platform with AI, Big Data in Cyber Physical System

J-EPoCH

Summary

Repeatable Power Laser

Key technologies
- **70 mm bonding technology** has been demonstrated.
- **Large-Aperture Active-Mirror** has been developed for 100 J.

Results **10 J @ 10 ~ 33.3 Hz** or **6.7 J @ 100 Hz** has been demonstrated.

High Contrast Intense Laser

Key technologies
- **Meter-size dielectric grating** has been successfully developed.
- **Original pulse cleaner for CPA** improved the intensity contrast.

Results **The world's highest peak-power laser in kilojoule, LFEX** has been successfully demonstrated with **a high contrast**.
2 kJ, 1~2ps, ~ 2 PW, $<10^{-10}$ (@ -170ps)

In future,

Innovative high-power repeatable laser system based on **module concept** for application platform has been conceptually designed in nano- ~ femto-second region.
And
high energy density plasma physics including the fast-ignition-based reactor will be actively researched using **various beam combination**.