Petawatt OPCPA Lasers: Status and Perspectives

V.V.Lozhkarev, G.I.Freidman, V.N.Ginzburg, E.V.Katin, E.A.Khazanov, A.V.Kirsanov, G.A.Luchinin, A.N.Mal'shakov, M.A.Martyanov, O.V.Palashov, A.K.Poteomkin, A.M.Sergeev, A.A.Shaykin and I.V.Yakovlev

Institute of Applied Physics Russian Academy of Science

Introduction

- Compact 0.56 PW laser system
- Scalability to multi-petawatt power

Conclusion

Introduction. OPCPA vs CPA

Advantages of OPCPA:

+ broad gain bandwidth
+ high aperture
+ considerable decrease in thermal loading
+ significantly lower level of ASE
+ very high gain
+ no self-lasing
+ no backscattering from a target

Disadvantages of OPCPA:

– high precision synchronization
– high quality of a pump beam
– short (1ns) pump pulse duration

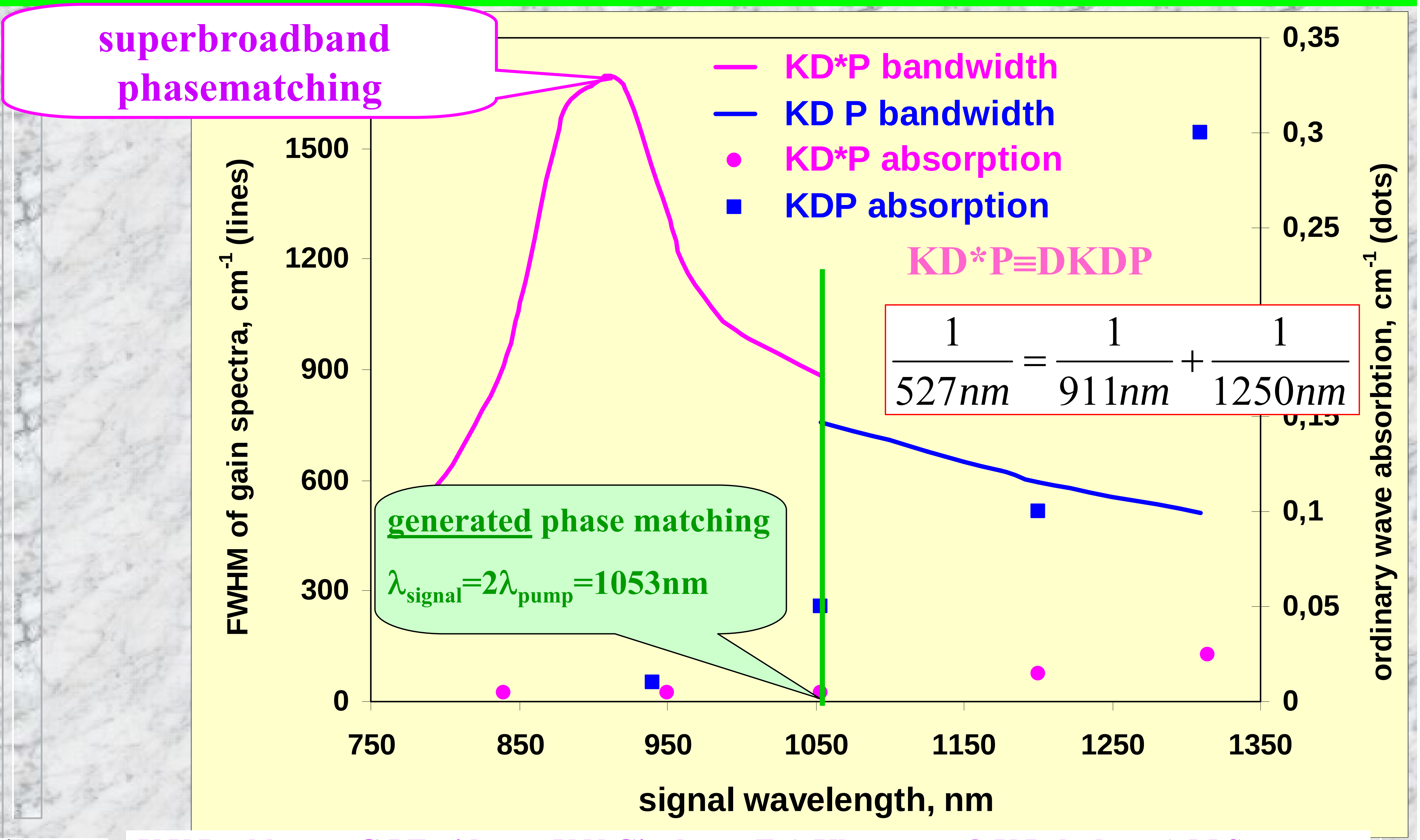
Introduction. Petawatt laser systems

	type I	type II	type III
Gain medium	Nd:glass	Ti:sapphire	KD*P
Energy source	Nd:glass	Nd:glass	Nd:glass
Pump	no	2ω Nd	2ω Nd
Pump duration, ns	no	<30	1
Amplifier aperture, cm	40x40	10	40x40
Minimum duration, fs	150	20	20
Efficiency (1ω Nd →фс), %	80	15	10
Number of PWs from 1 kJ 1ω Nd	~~4~~ (5)	~~8~~ (1.5)	4
Maximum power obtained, PW	1.3 PW LLNL, 1997	0.85 PW JAEA 2004	0.56 PW IAP 2006

Diffraction grating damage threshold

Ti:sapphire damage threshold

Physics of OPCPA. KD*P vs KDP.



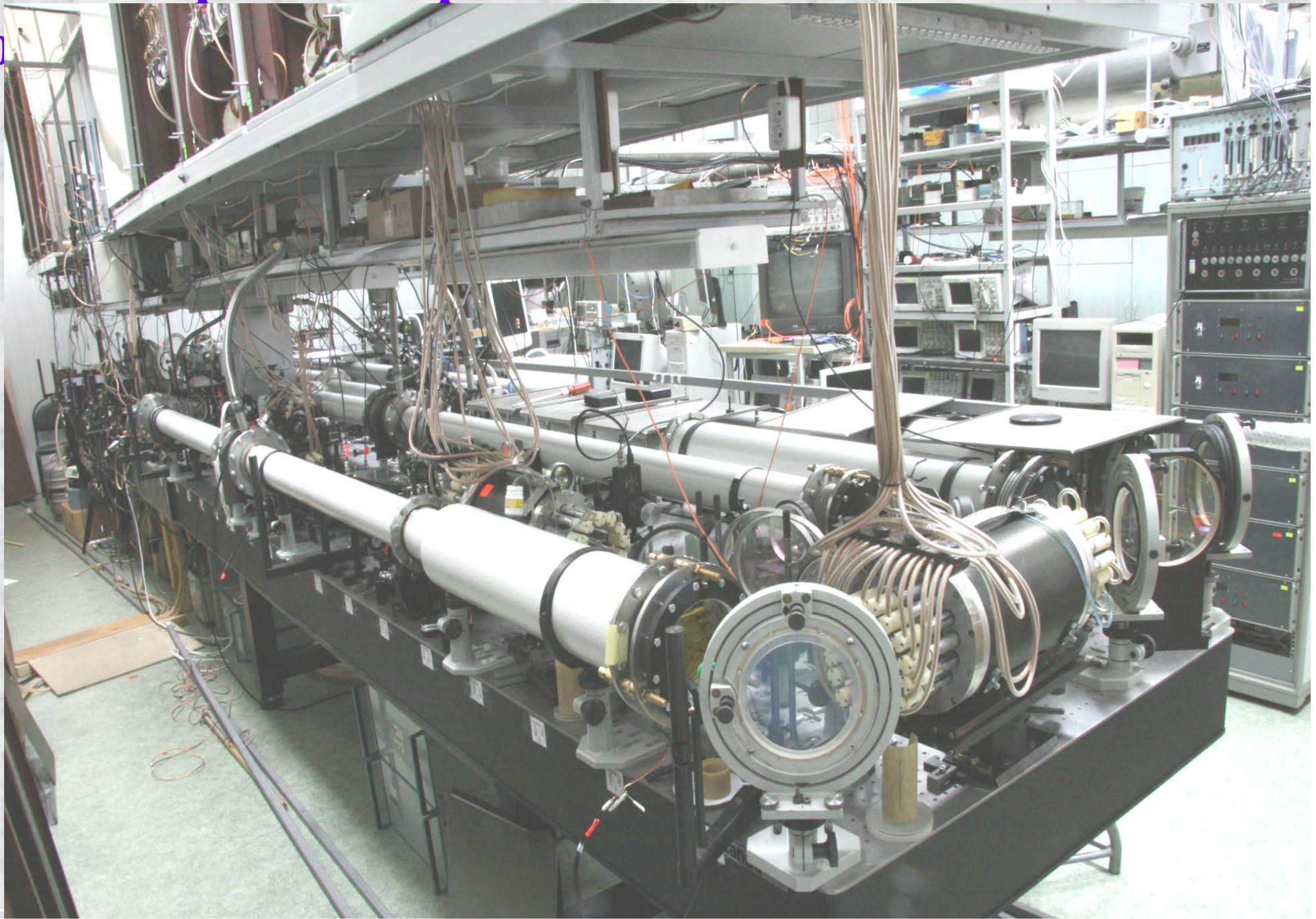
$$\frac{1}{527nm}=\frac{1}{911nm}+\frac{1}{1250nm}$$

V.V.Lozhkarev, G.I.Freidman, V.N.Ginzburg, E.A.Khazanov, O.V.Palashov, A.M.Sergeev, I.V.Yakovlev. Laser Physics, 15, 1319 (2005).

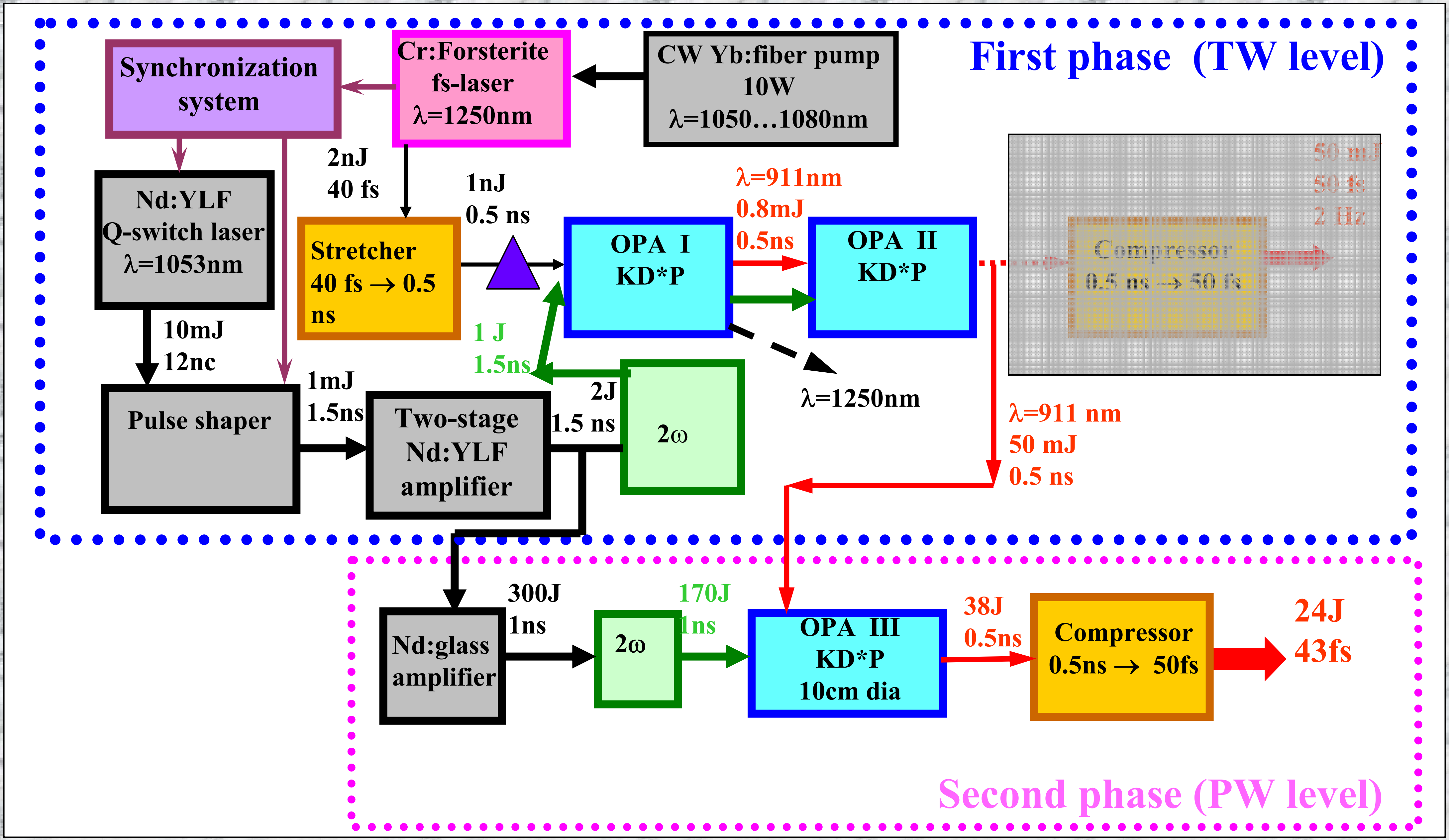
Petawatt OPCPA Lasers: Status and Perspectives

Introduction to PW lasers
- Compact 0.56 PW laser system
- Scalability to multi-petawatt power

Conclusio



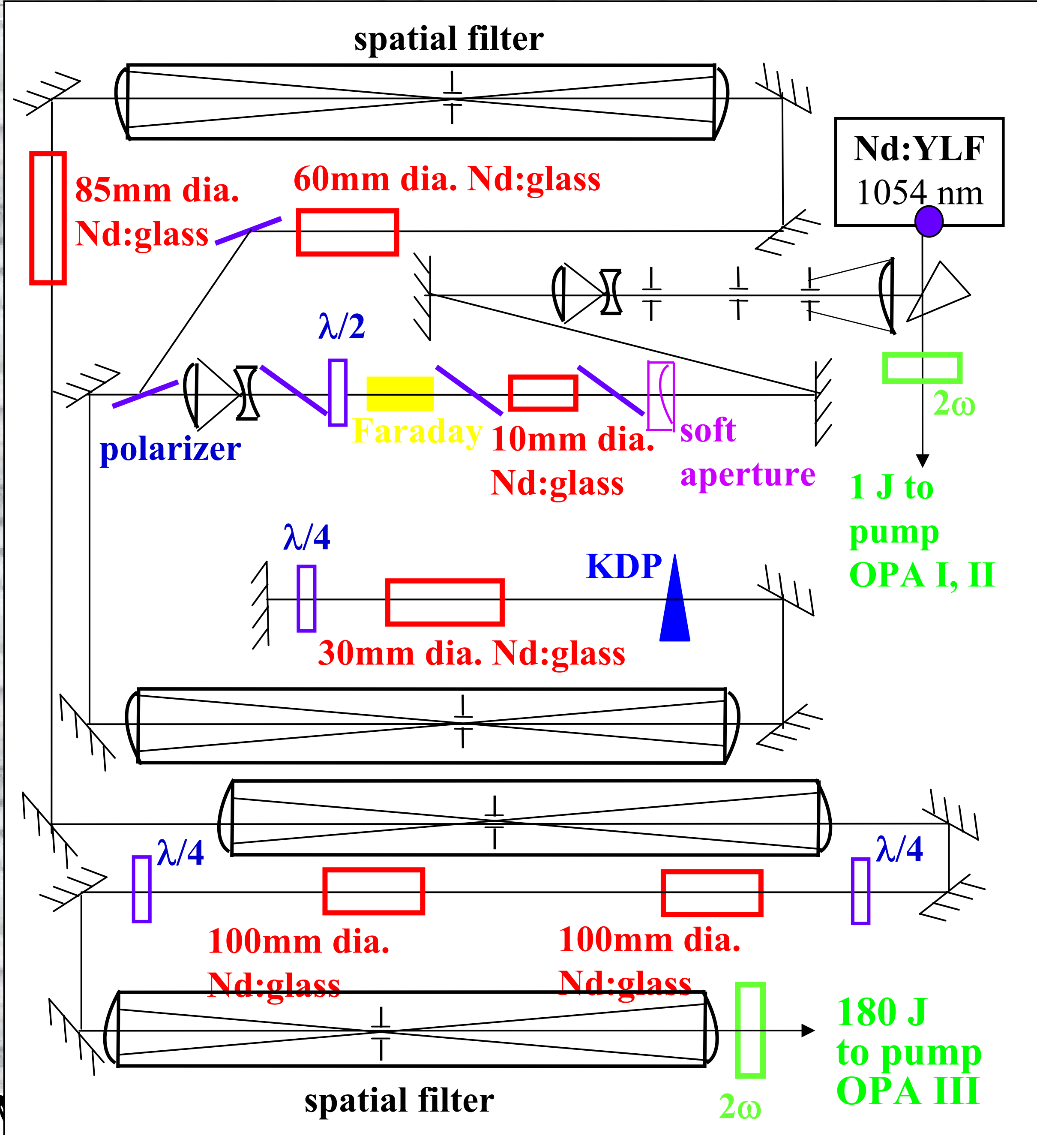
Compact 0.56 PW laser system. Architecture



Freidman G., Andreev N., Ginzburg V., Katin E., Khazanov E., Lozhkarev V., Palashov O.,

Compact 0.56 PW laser system.

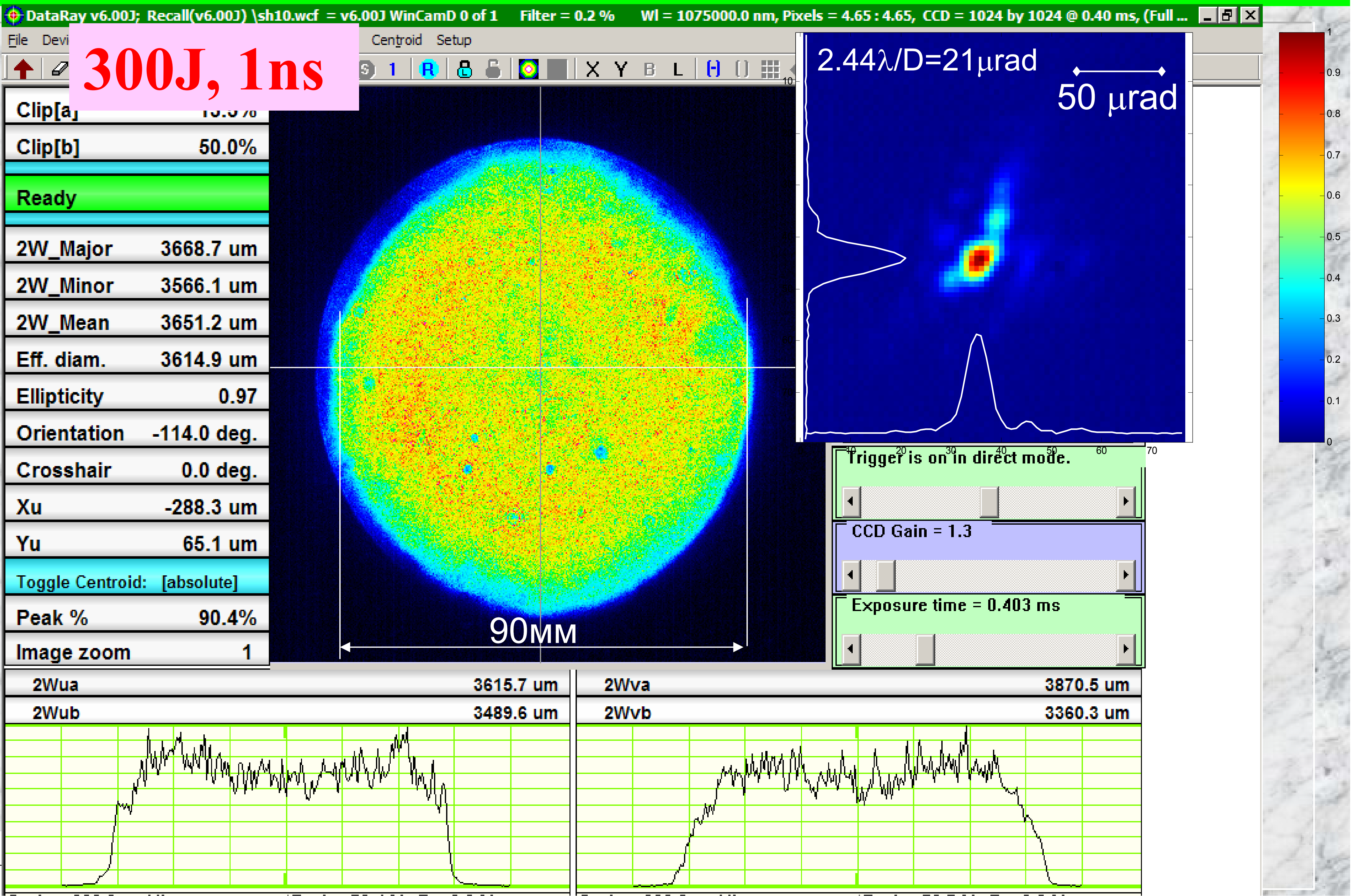
Key elements of tabletop 300 J Nd:glass laser



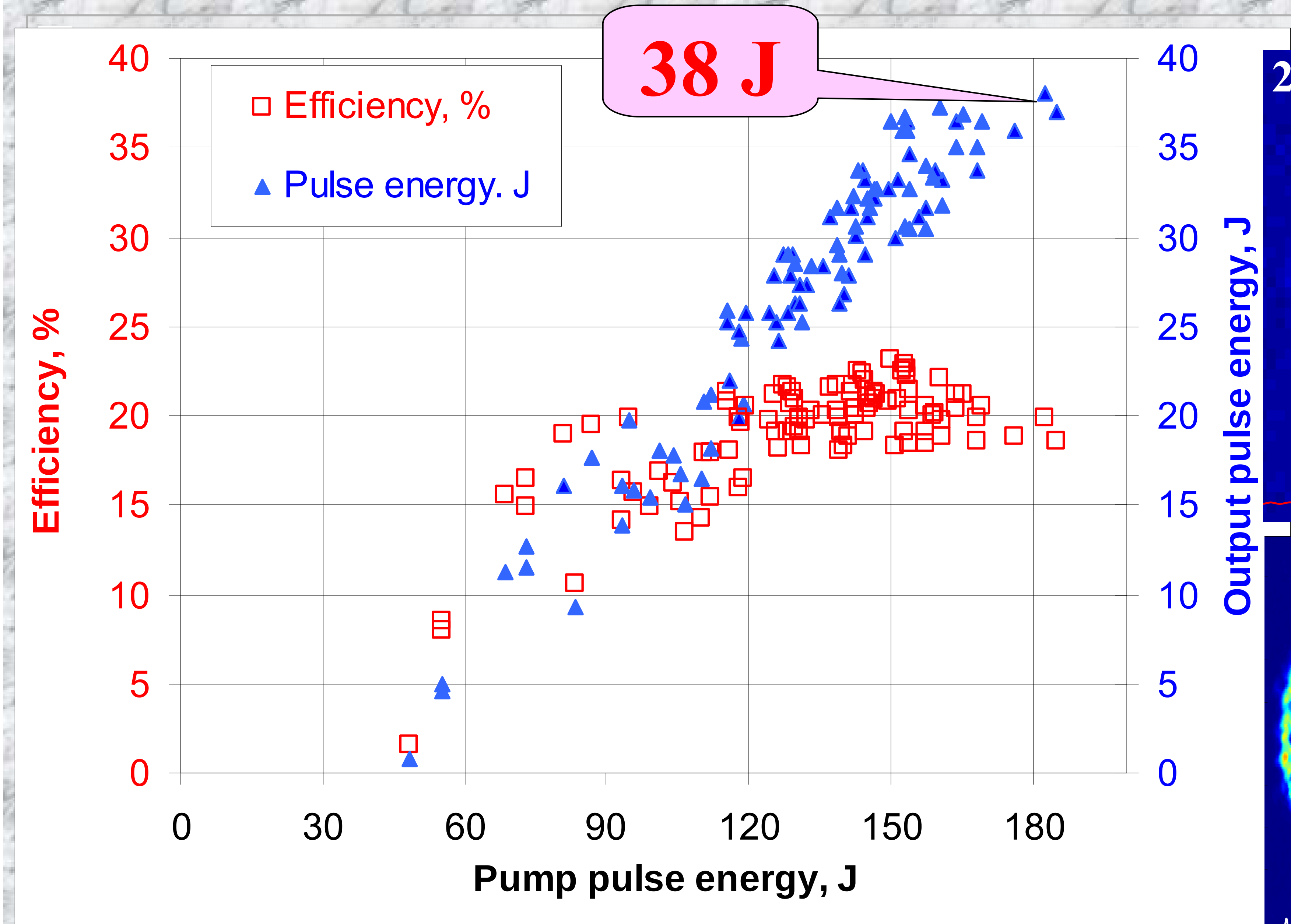
- input beam shaping
- spatial filters
- self-focusing suppression
- laser heads
- self-excitation suppression
- second harmonic generation

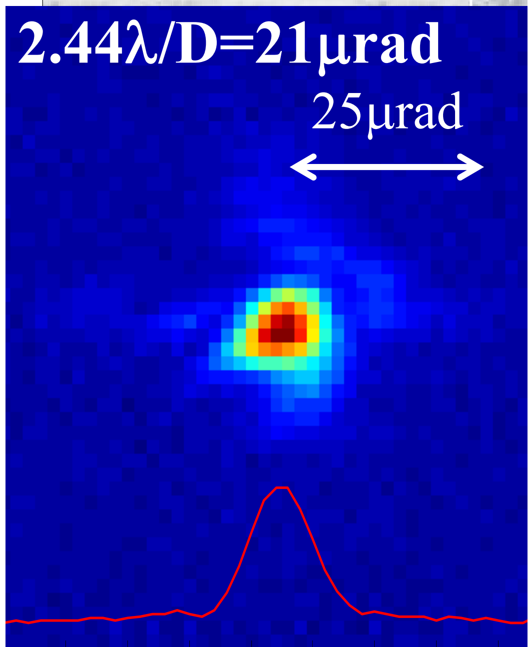
Martyanov M. A., Khazanov E.A. , Poteomkin A. K.,

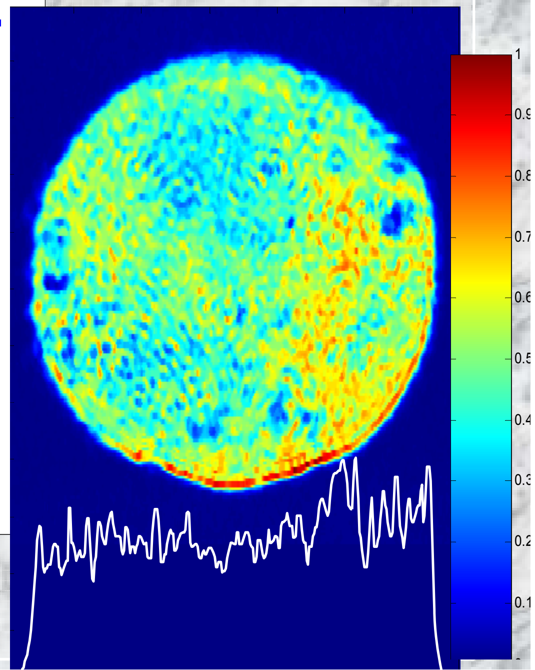
Compact 0.56 PW laser system.
Nd:glass laser output beam



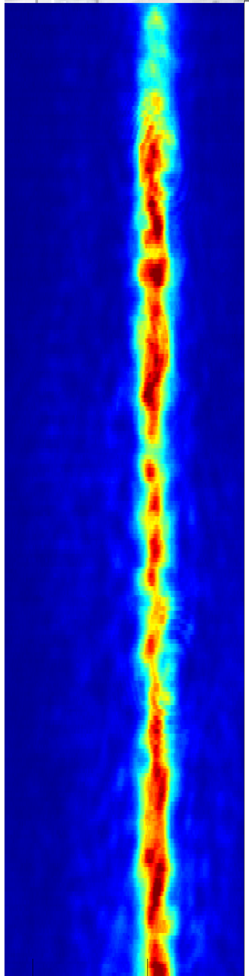
Compact 0.56 PW laser system.
Energy characteristics of final OPCPA

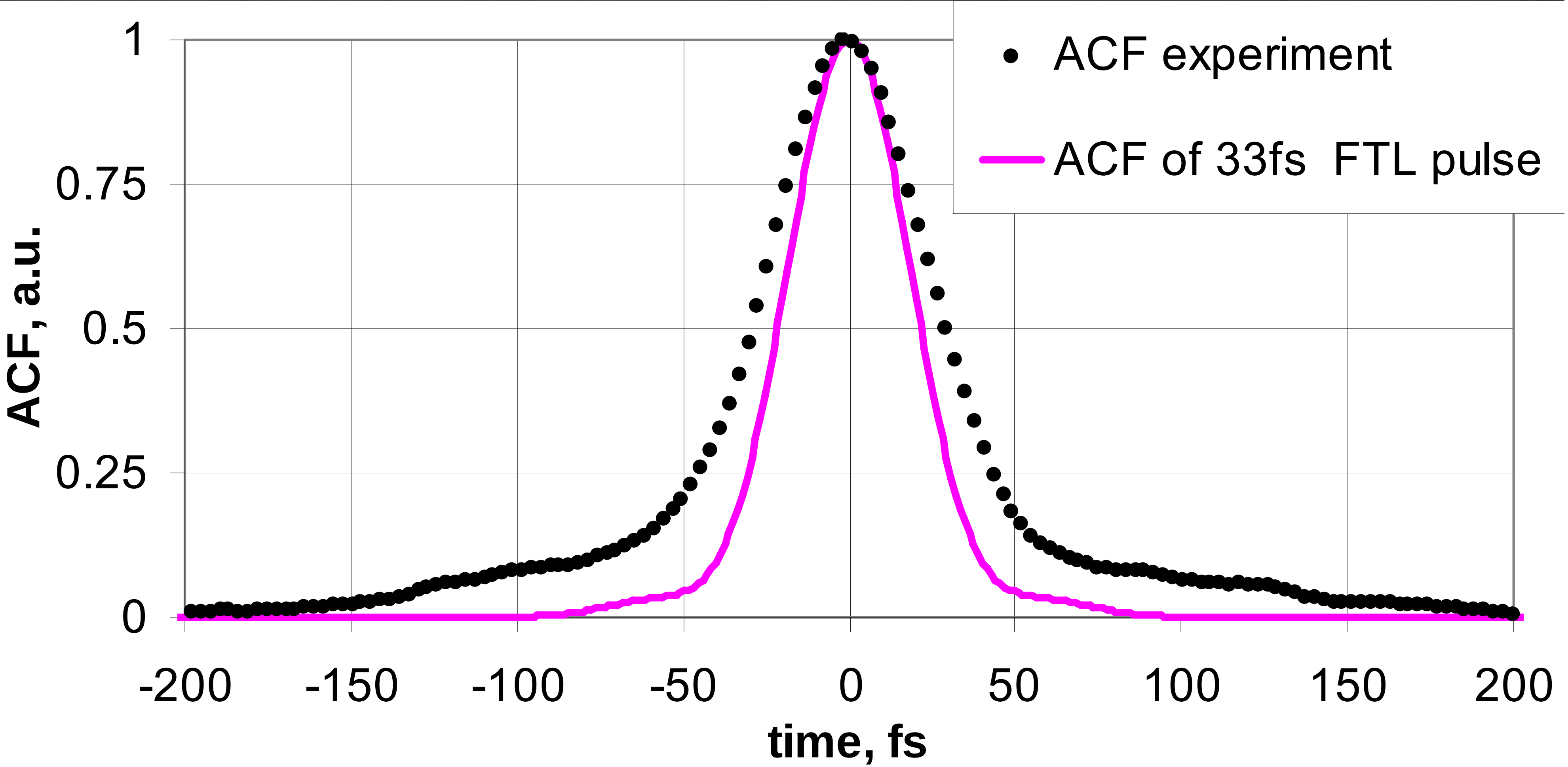






Compact 0.56 PW laser system.
Compressed pulse

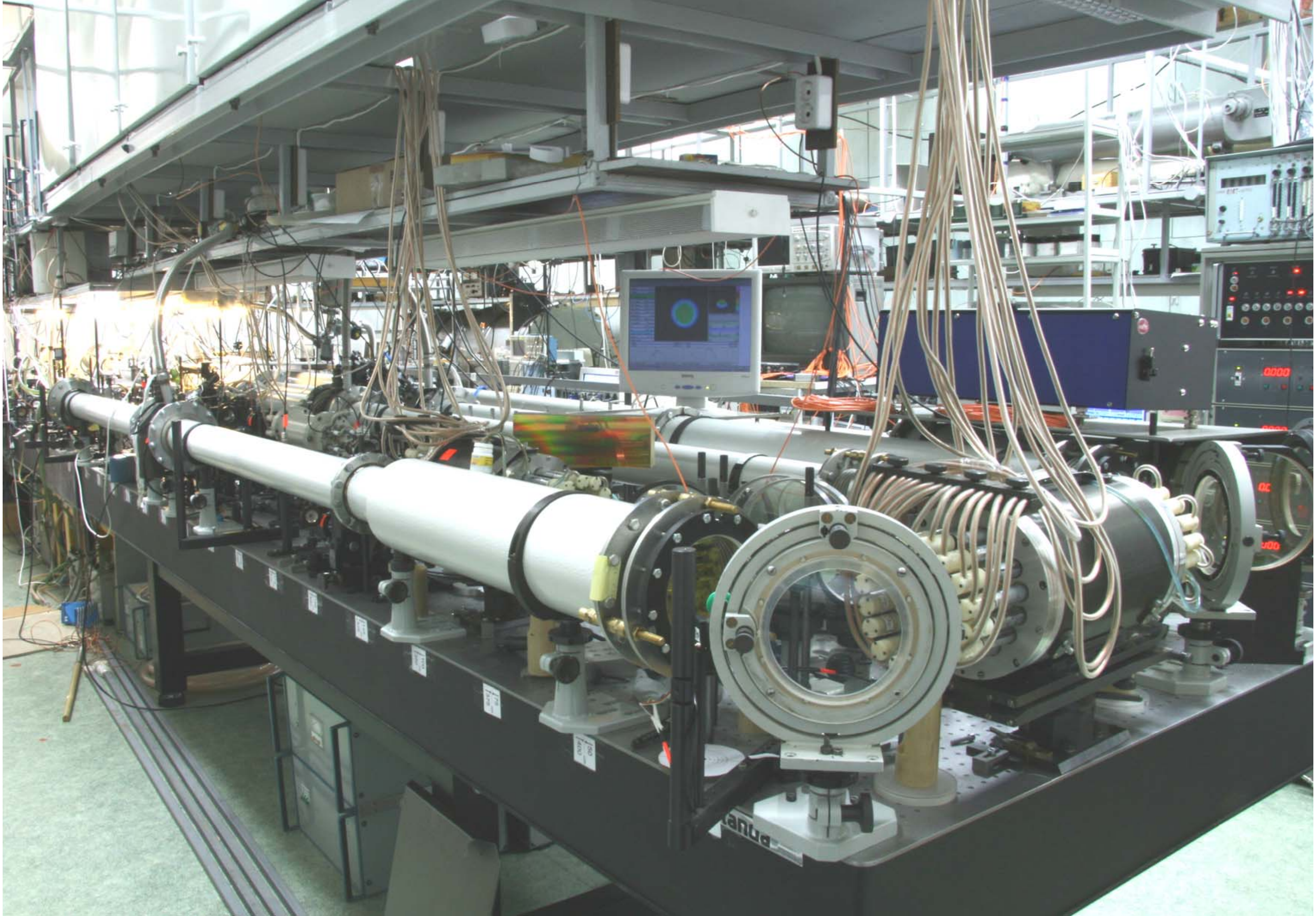




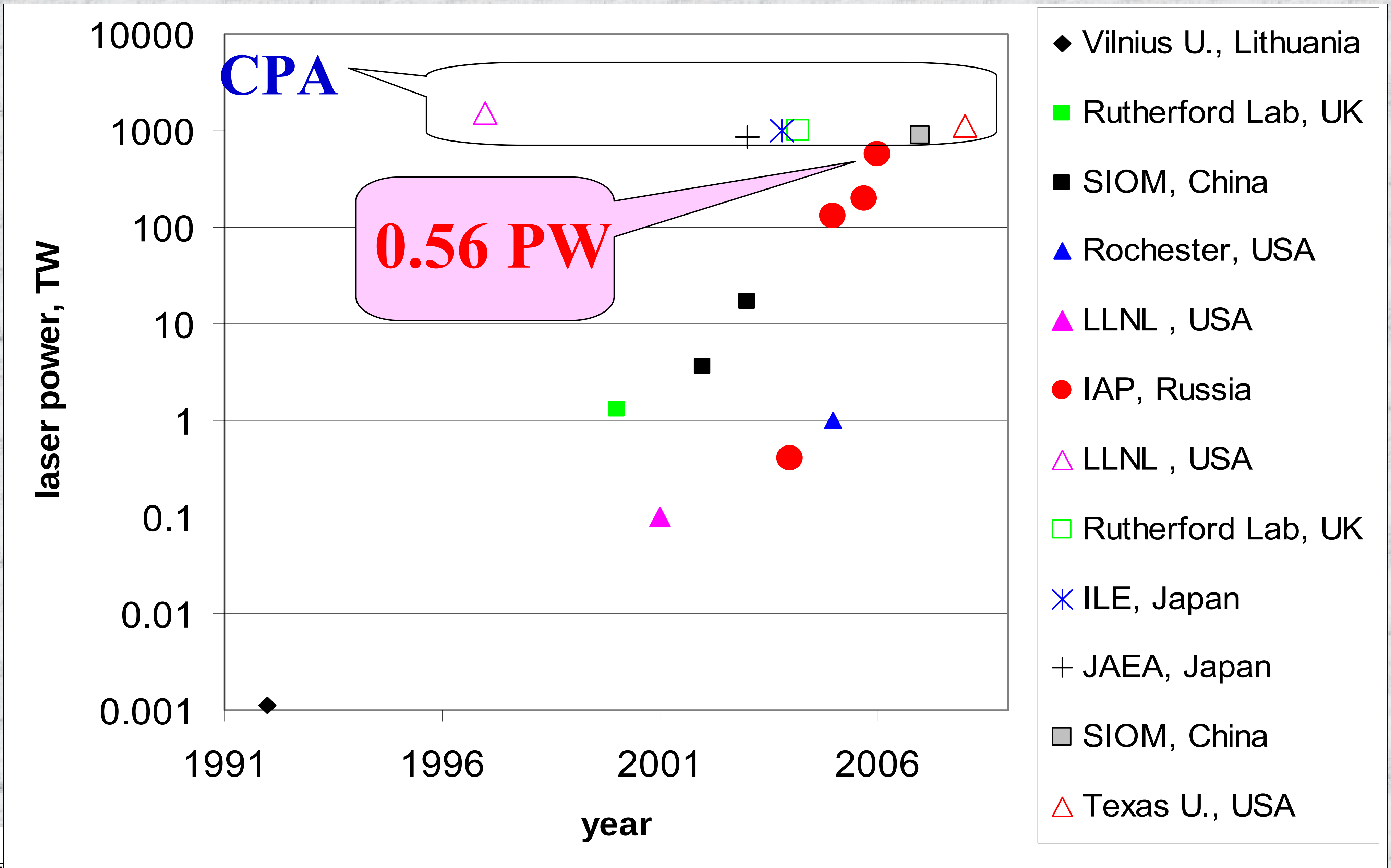
24 J /43 fs=0.56 PW

Contrast: 10^8 (0.5ns window)
10^4 (1ps window)

Lozhkarev V.V., Freidman G.I., Ginzburg V.N., Katin E.V., Khazanov E.A., Kirsanov A.V., Luchinin G.A., Mal'shakov A.N., Martyanov M.A., Palashov O.V., Poteomkin A.K., Sergeev A.M., Shaykin A.A., Yakovlev I.V.
Laser Physics Letters, 4, 421-427 (2007)



Compact 0.56 PW laser system. Compressed pulse

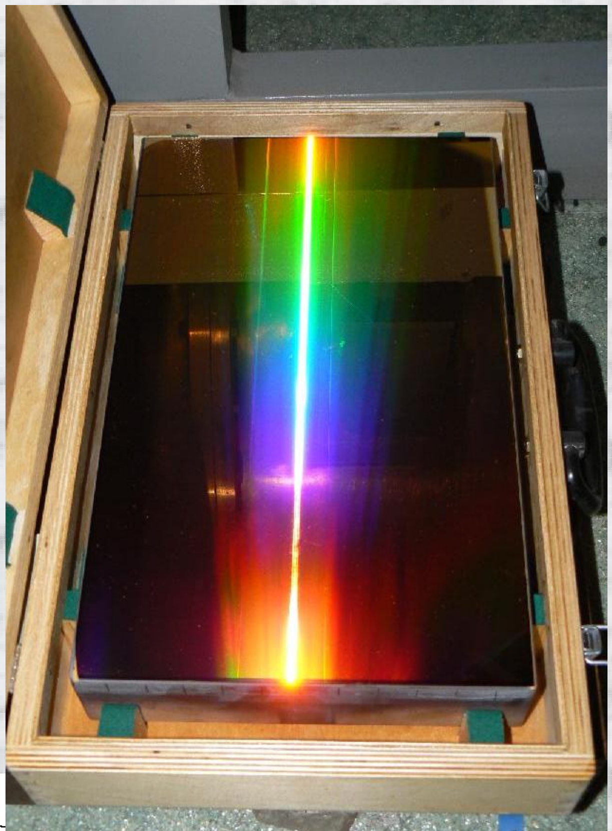


Petawatt OPCPA Lasers: Status and Perspectives

Introduction to PW lasers

- Compact 0.56 PW laser system
- Scalability to multi-petawatt power

Conclusion



Scalability to multi-petawatt power. Routes to increase power and contrast

POWER:

+ Pulse duration: x3 (15fs instead of 45fs)

+ OPCPA efficiency: x2 (40% instead of 20%)

+ Pump power x1.3: (230J instead of 180J)

+ Compressor efficiency x1.2 (79% instead of 66%)

TOTAL: x11 (6PW instead of 0.56PW)

CONTRAST:

Second harmonic generation in KDP crystal

- theory (includes self-focusing) predicts high efficiency
- crystal <u>100mm diameter and 0.5mm</u> thickness was grown
- experiments are coming soon

Scalability to multi-petawatt power:
Four started projects.

VNIIEF (Sarov) + IAP , Russia, 2005-2008, 3PW OPCPA

Rutherford Lab, UK, 2007-2011, 10PW OPCPA

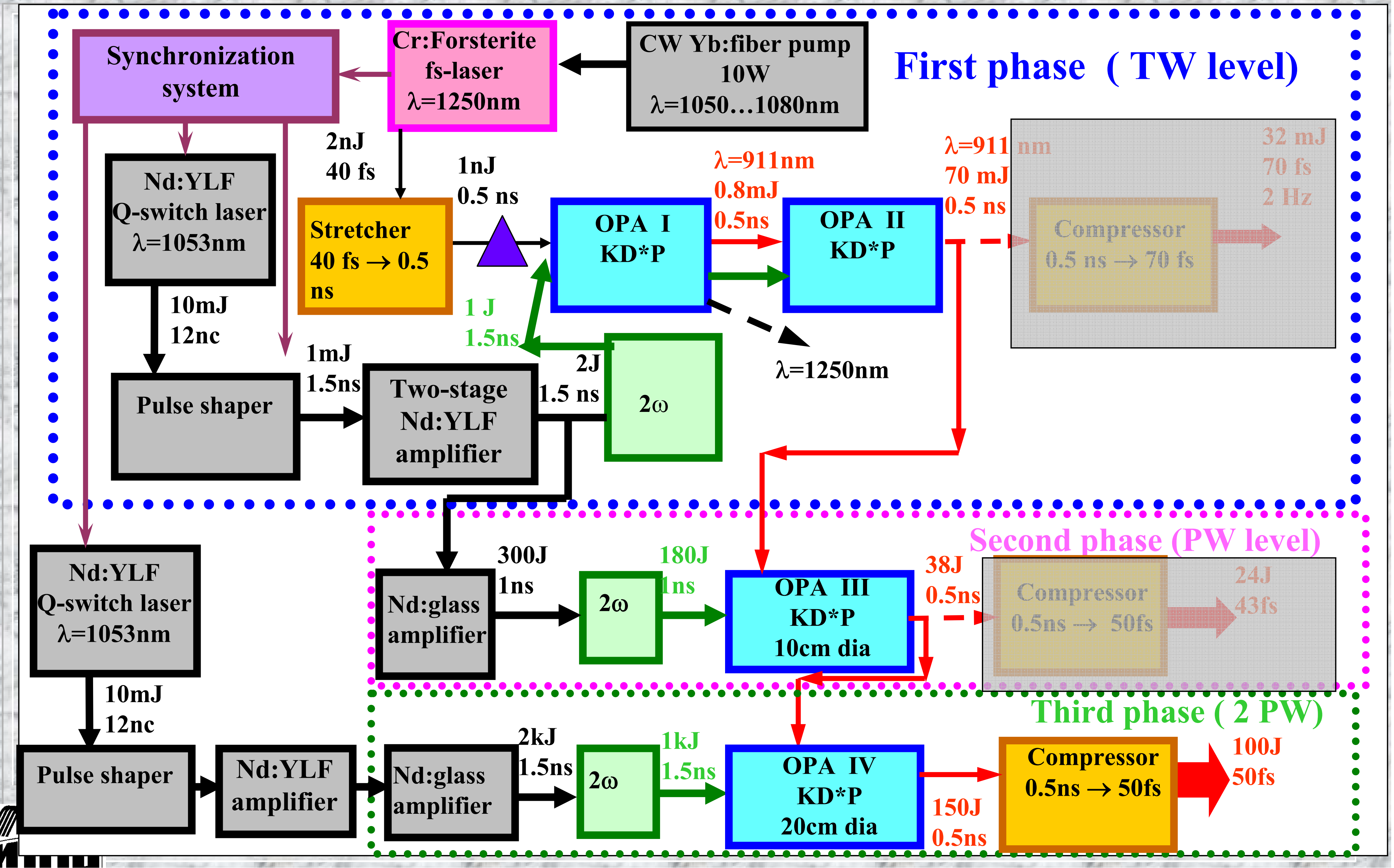
HiPER, pan-European, 2008-2018, 150PW / 2000PW OPCPA

ELI, pan-European, 2008-2020 200PW OPCPA or Ti:sapphire

The Extreme Light Infrastructure European Project

Scalability to multi-petawatt power

Sarov – N.Novgorod.



Scalability to multi petawatt power?

Sarov – N.Novgorod.

I.A. Belov, O.A. et al. *Petawatt laser system of the "Luch" facility*
International Conference X Khariton's Scientific Reading, p.145 (2008)

Conclusion

#1. OPCPA at 910 nm in DKDP is the best.

No question.

#2. There is only one question.

Q.: The best *or* one of the best?

A1: See message #1.

A2: Will live and see.

After conclusion…
Let's think about laser ceramics!

Cr:YAG ceramics

- very wide **aperture** to amplify chirped pulses to the multikilojoule level,
- high conversion **efficiency** of narrow band Nd:glass laser pulses into chirped pulses,
- large gain **bandwidth** to amplify chirped pulses with less than 20 fs durations

E.A.Khazanov, A.M.Sergeev. Laser Physics, 2007.

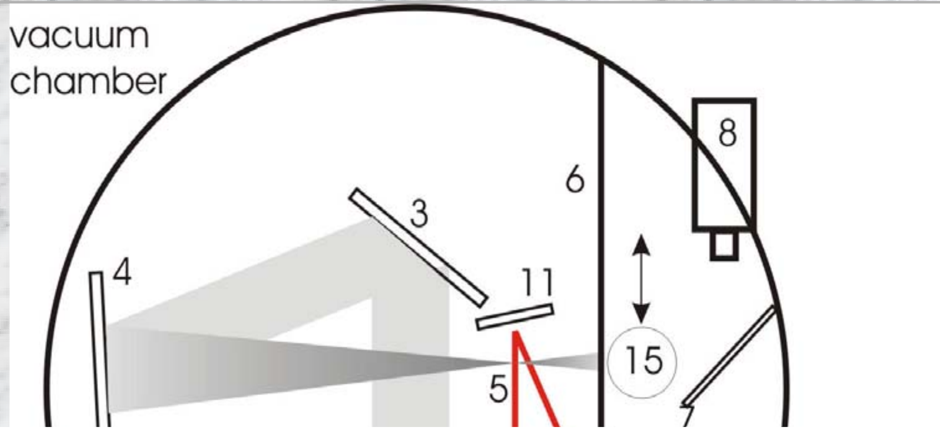
Nd,Yb:Re_2O_3 ceramics (Re=Y,Lu,Sc)

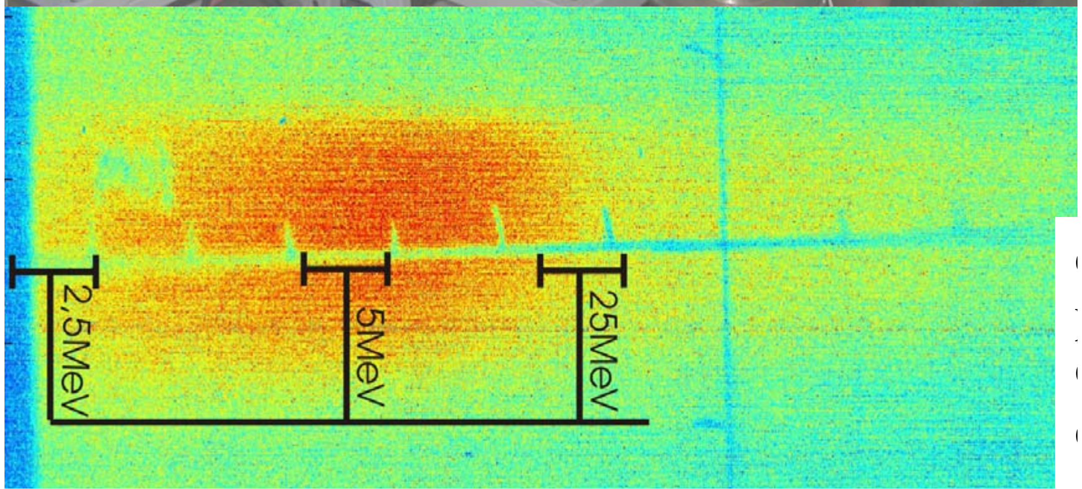
1. Very wide **aperture** to amplify chirped pulses to the multikilojoule level
2. Large gain **bandwidth** to amplify chirped pulses with less than **50 fs** durations
3. High conversion **efficiency** due to direct lamp pumping (lamps pump Nd and excitation transfers to Yb)

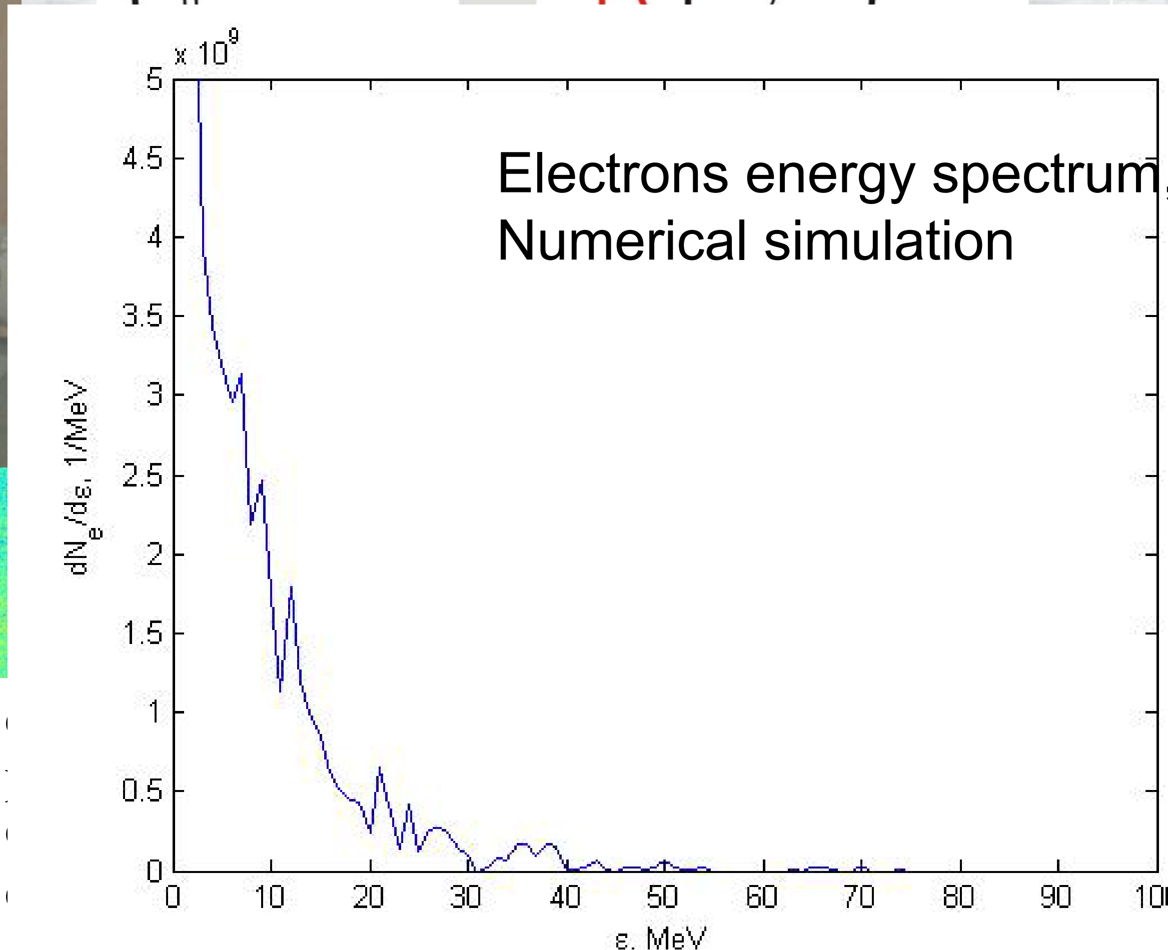
E.A.Khazanov, A.M.Sergeev. UFN, 2008.

ИПФ

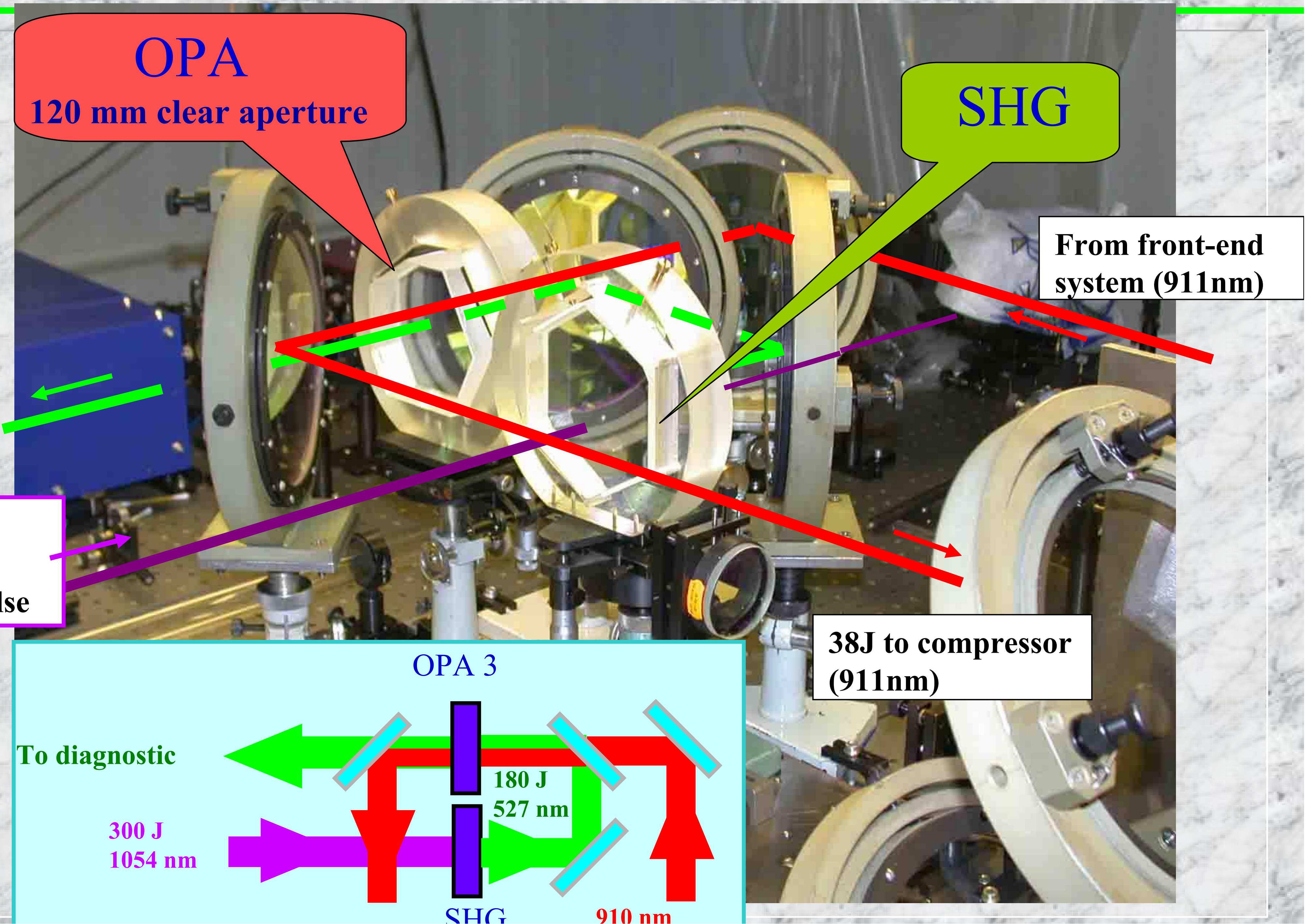
Compact 0.56 PW laser system.
Electon acceleration (preliminary results)







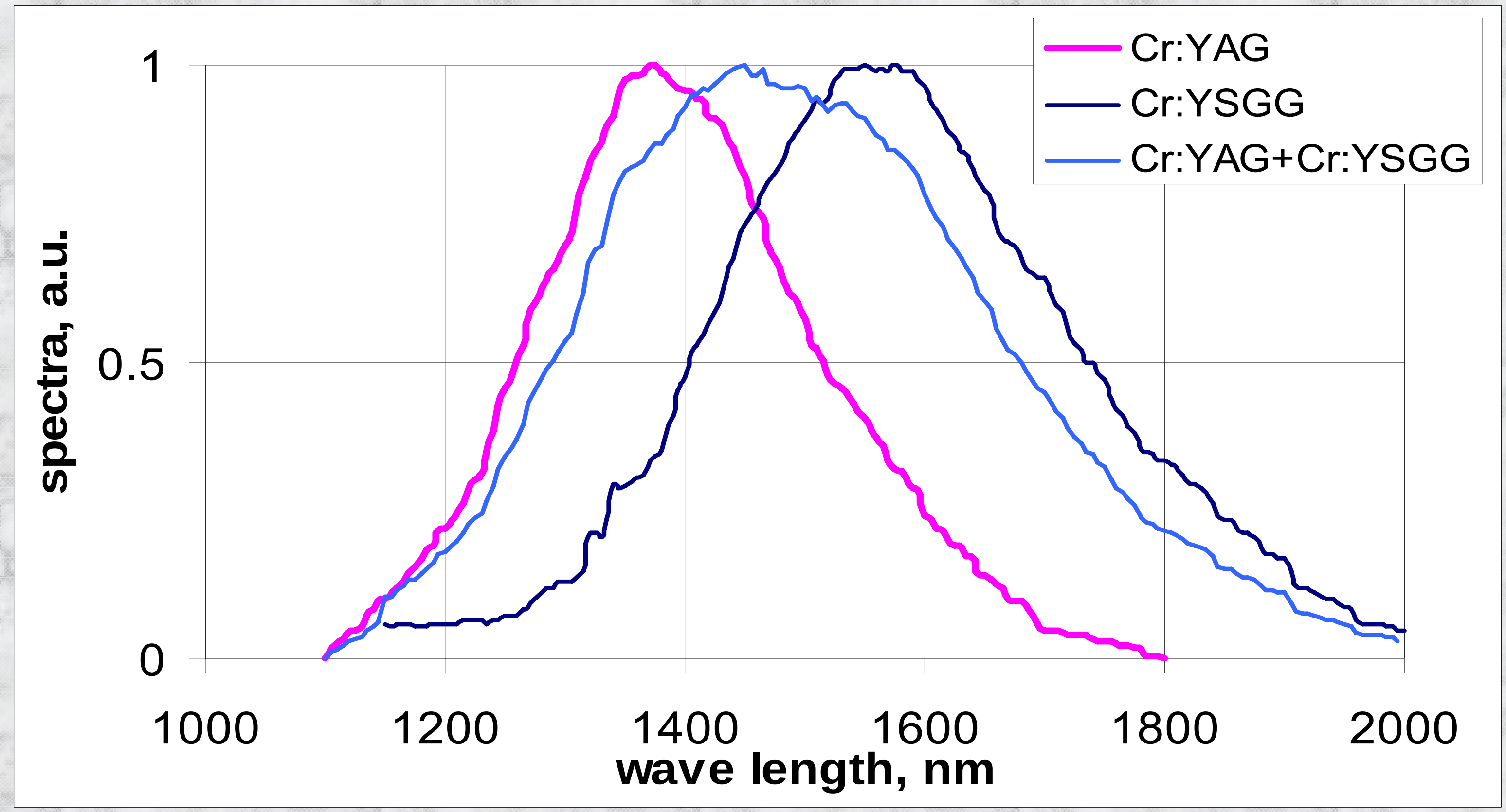
Compact 0.56 PW laser system:
120mm clear aperture OPA



Scalability to 100(s) petawatt power

Crazy ideas are welcome!

Cr^{4+}:YAG ceramics (CPA)



18 fs pulse: Ripin D.J., Chudoba C., Gopinath J.T., Fujimoto J.G., Ippen E.P., Morgner U., Kartner F.X., Scheuer V., Angelow G., Tschudi T. // Optics Letters, 27, 61-63, 2002.

Scalability to multi-petawatt power.

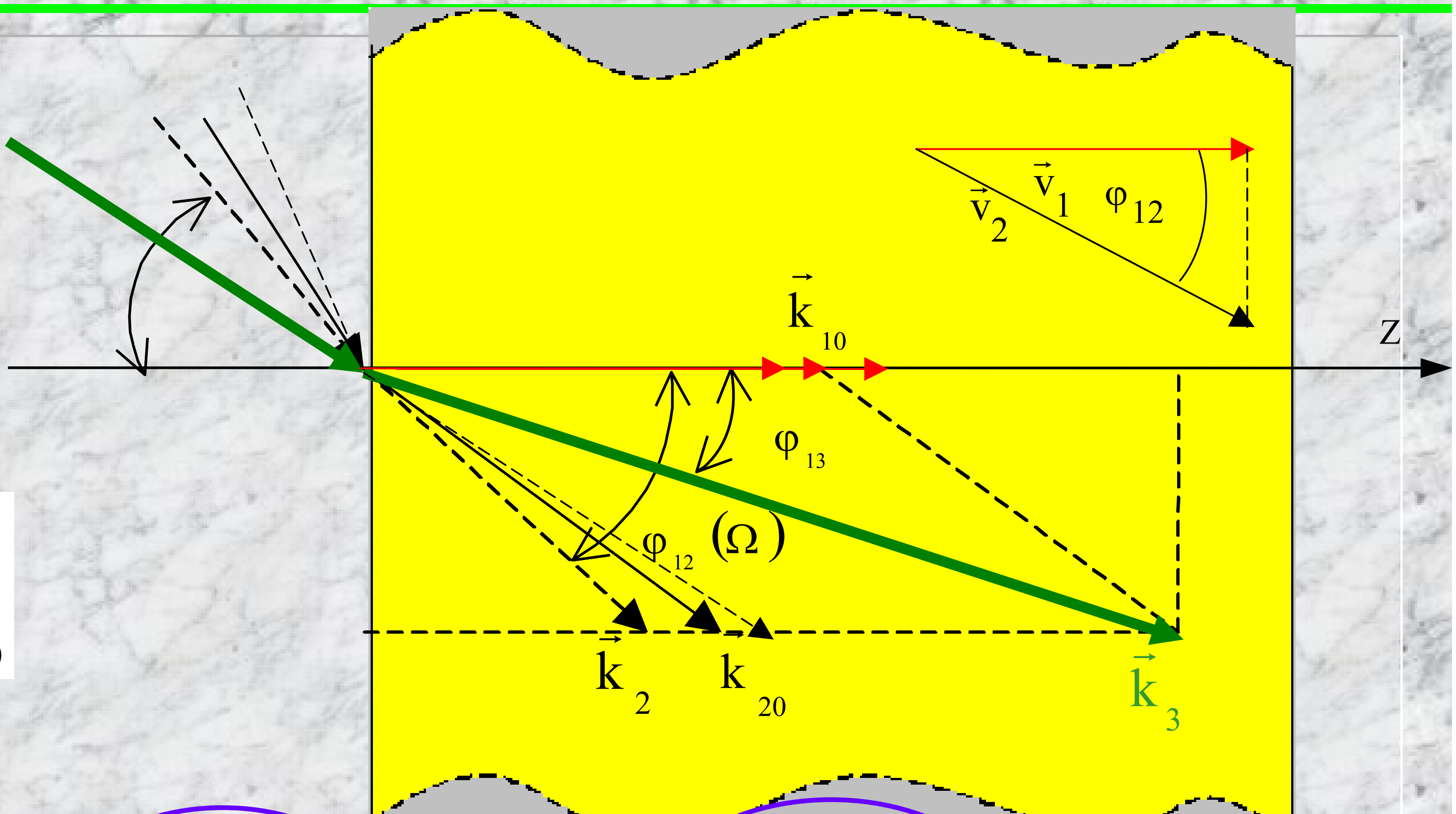
Crazy ideas are welcome!

	type I	type II	type III	type IV
Gain medium	Nd:glass	Ti:saphire	DKDP	Cr:YAG ceramics
Energy source	Nd:glass	Nd:glass	Nd:glass	Nd:glass
Pump	no	2ω Nd	2ω Nd	1ω Nd
Pump duration, ns	no	<30	1	<30
Amplifier aperture, cm	40x40	8	40x40	>50
Minimum duration, fs	150	20	20	20
Efficiency (1ω Nd →φc), %	80	15	10	25
Number of PWs from 1 kJ 1ω Nd	~~4.5~~ (5)	~~8~~ (1.5)	4	10
Maximum power obtained, PW	1.3 LLNL, 1997	0.85 JAEA 2004	0.56 IAP 2006	

Physics of OPCPA. Wideband phase-matching

$$\omega_3 = \omega_1 + \omega_2$$

$$\omega_1 = \omega_{10} + \Omega(t)$$
$$\omega_2 = \omega_{20} - \Omega(t)$$



$$k_{2x}(\omega_2) = k_{3x}$$
$$\Delta\vec{k}(\Omega) = \Delta k(\Omega) \cdot \vec{z}_0$$

$$\Delta k(\Omega) \equiv \Delta k(0) - \left(\frac{dk_1}{d\omega} + \frac{dk_{2z}}{d\omega}\right)\Omega - \frac{1}{2}\left(\frac{d^2k_1}{d\omega^2} + \frac{d^2k_{2z}}{d\omega^2}\right)\Omega^2 - 0(\Omega^3)$$

0= phase-matching

$$k_3 = k_1(0) + k_2(0)$$

=0 wideband phase-matching

$$V_{1g} = V_{2g} \cdot \cos\varphi_{12}$$

=0 super-wideband phase-matching