Optical Parametrical Chirped Pulse Amplification for Petawatt Lasers

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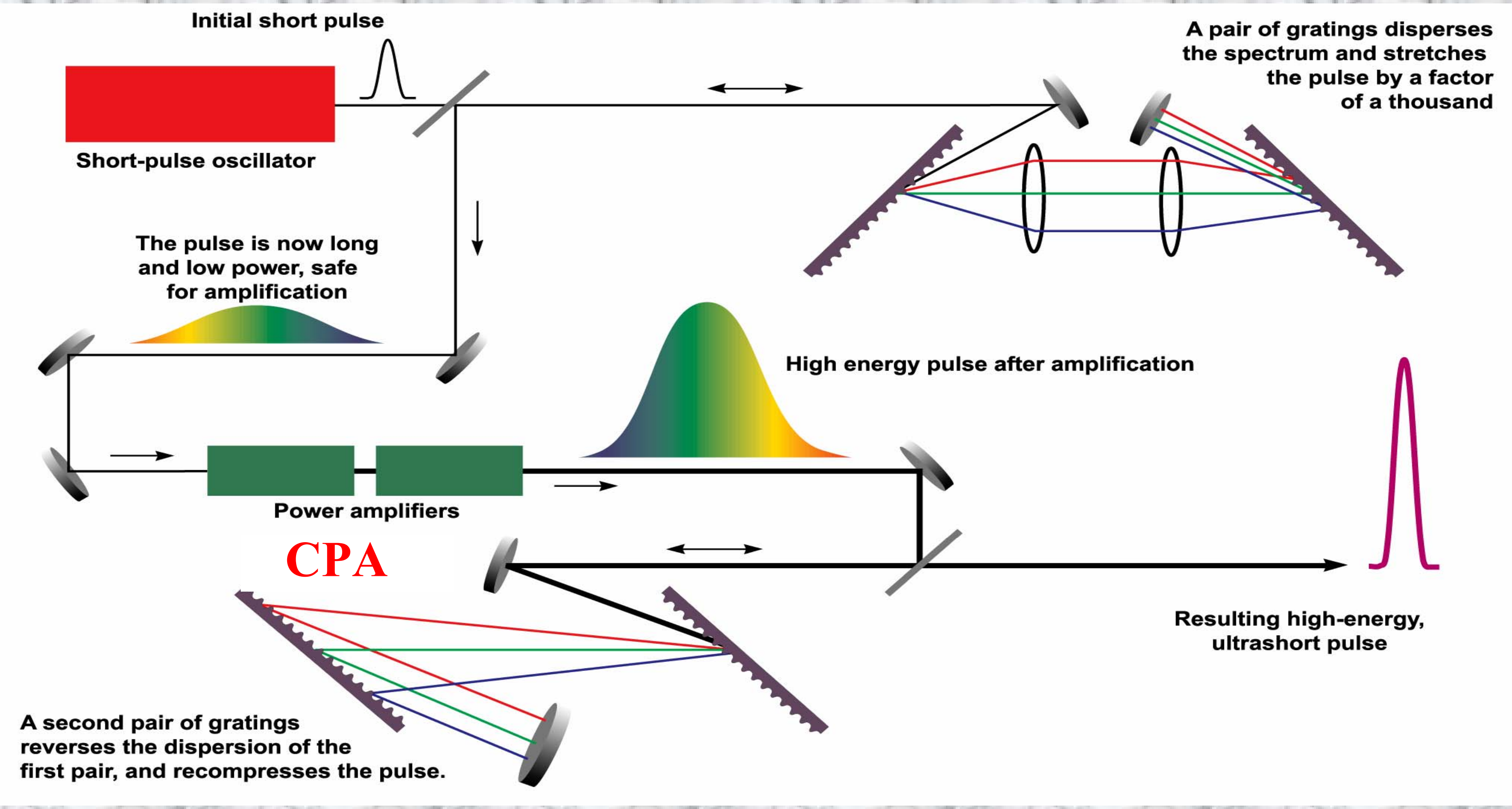
Introduction
- **Physics of OPCPA**
- **Compact 0.56 PW laser system - PEARL**
- **Scalability to multi-petawatt power**

Conclusion

Introduction. CPA invention

D. Strickland and G. Mourou, "Compression of Amplified Chirped Optical Pulses," Opt. Commun. 56, 219 (1985).

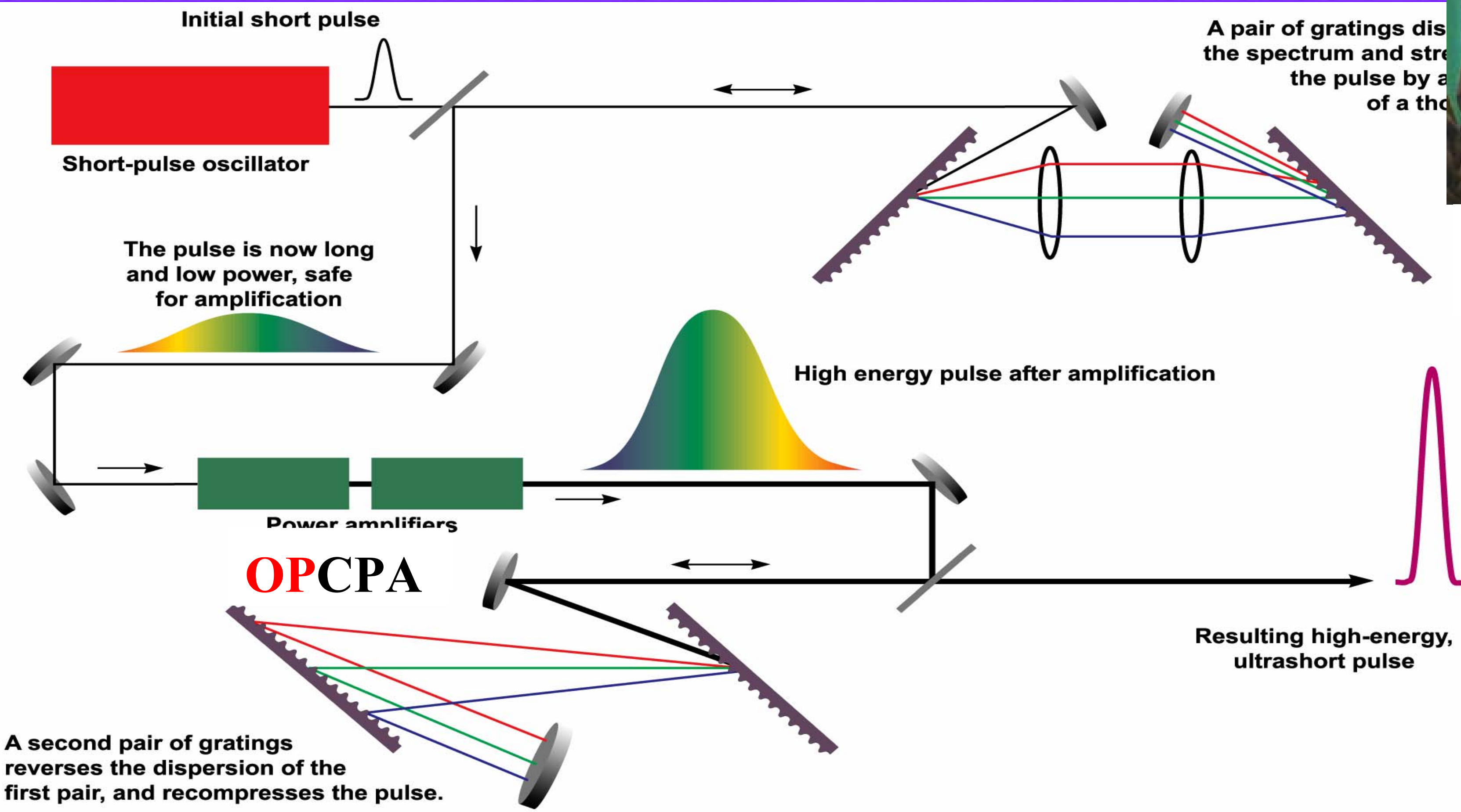


Introduction. OPCPA invention

A. Piskarskas, A. Stabinis, and A. Yankauskas, "Phase effects in optical parametric amplifiers and oscillators of ultrashort optical pulses," Sov. Phys. Ups, 29, 969 (1986).

A.Dubietis, G.Jonusauskas, A.Piskarskas, "Powerful femtosecond pulse generation by chirped and stretched pulse parametric amplification in BBO crystal" Opt. Commun. 88, 437 (1992)

A.Piskarskas
Vilnius University



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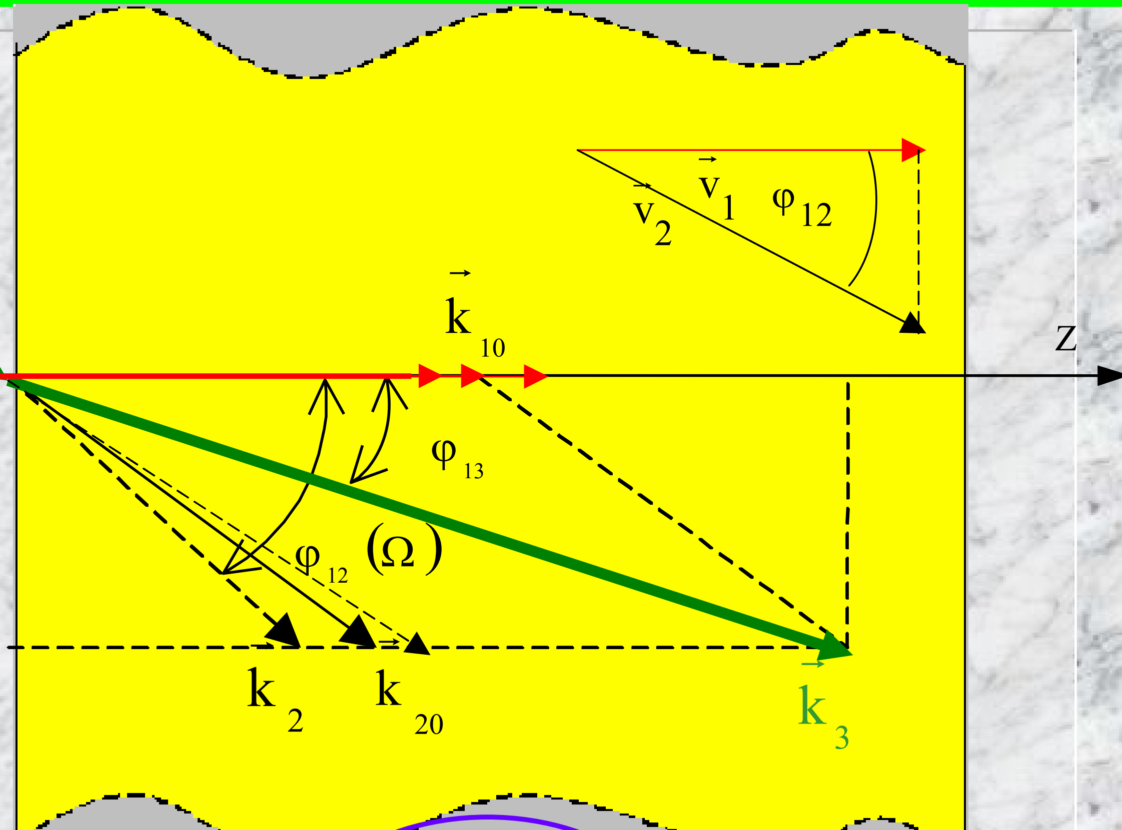
Physics of OPCPA. Wideband phase-matching

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

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

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



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

phase-matching

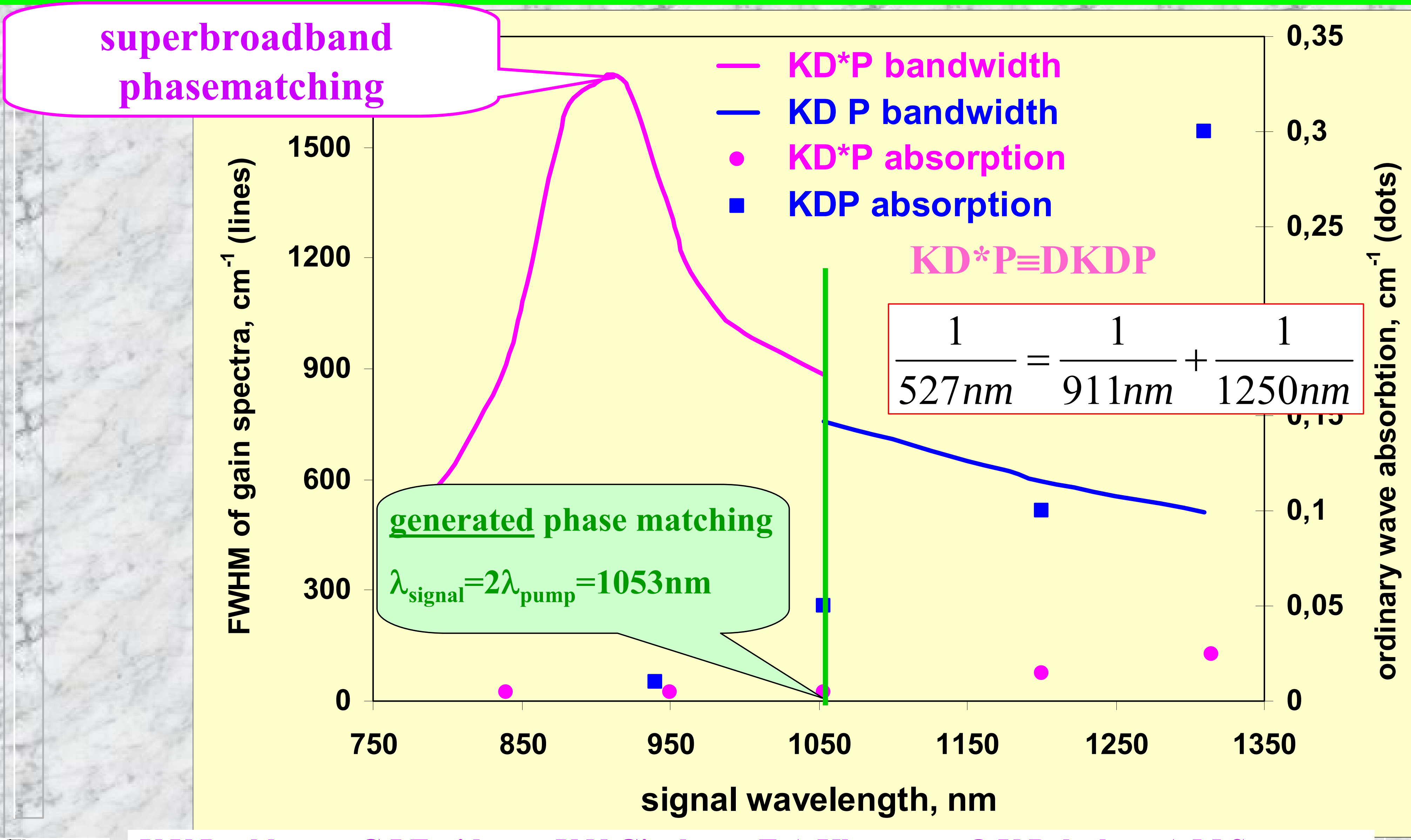
$$k_3 = k_1(0) + k_2(0)$$

wideband phase-matching

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

super-wideband phase-matching

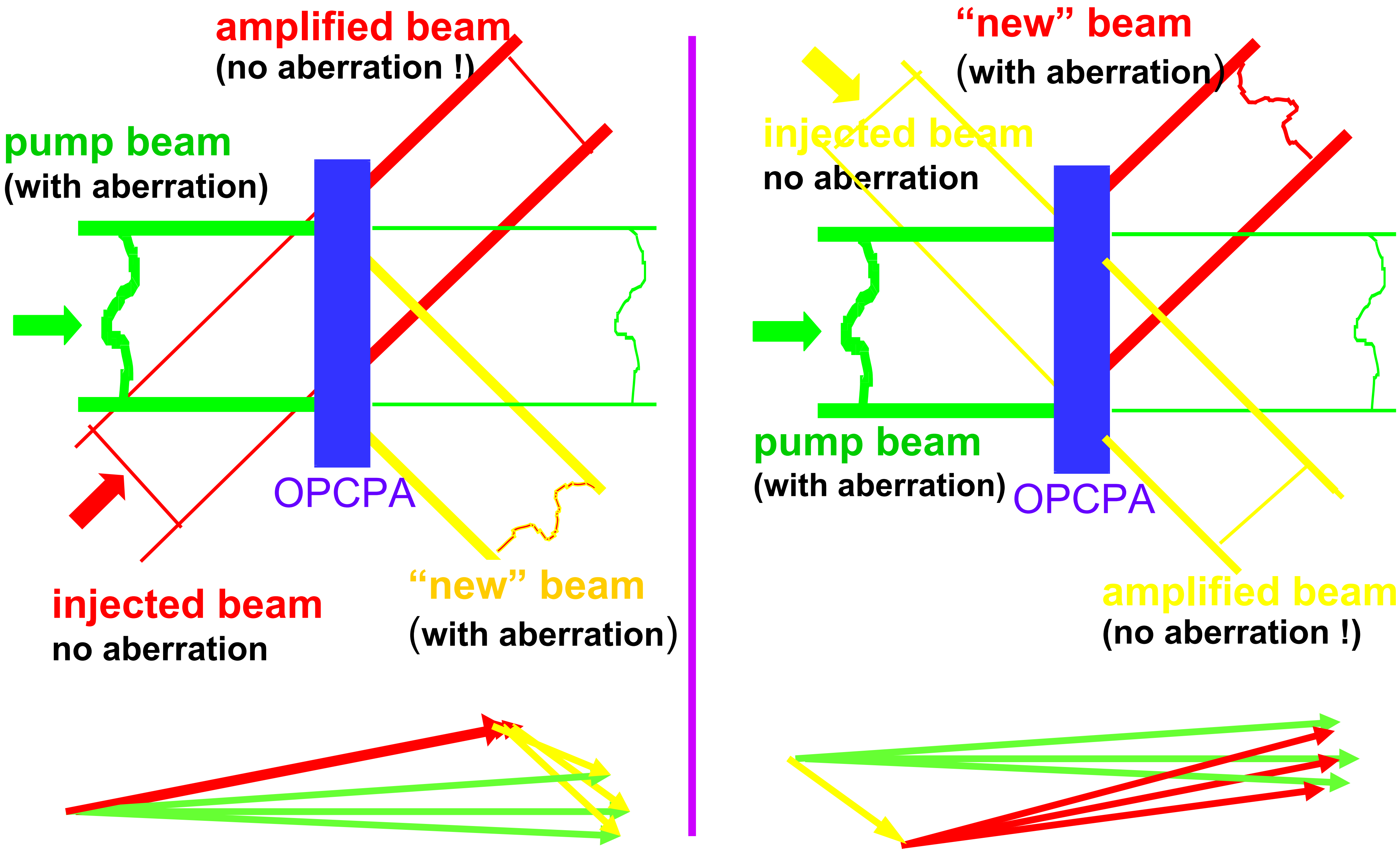
Physics of OPCPA. KD*P vs KDP.



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

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).

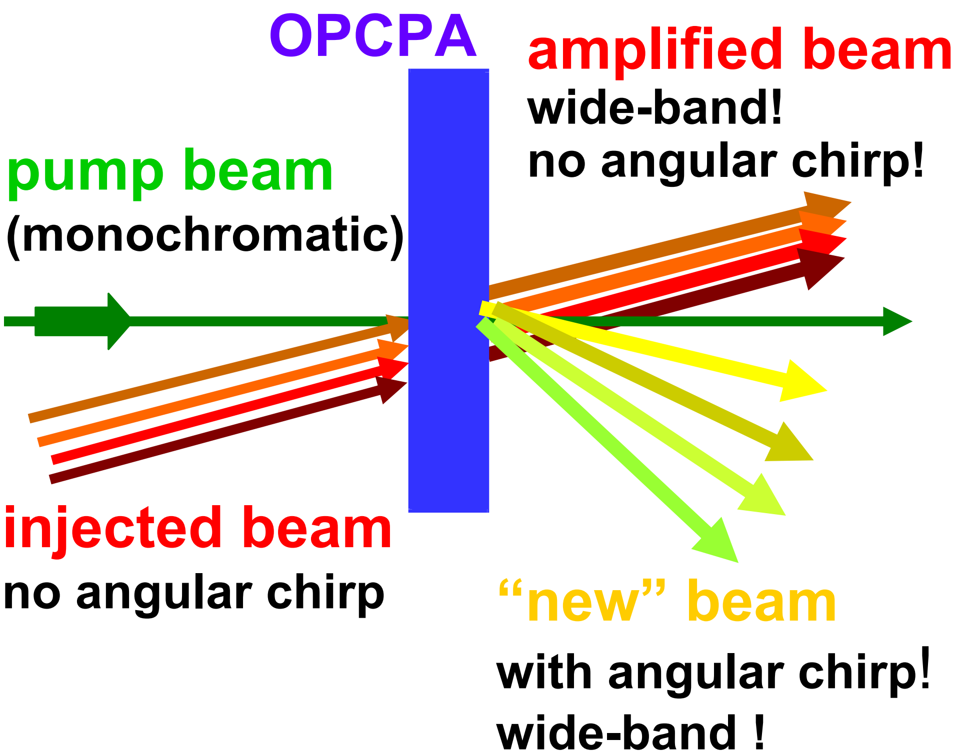
Physics of OPCPA. Monochromatic case.
Pump beam aberration are transferred to new wave



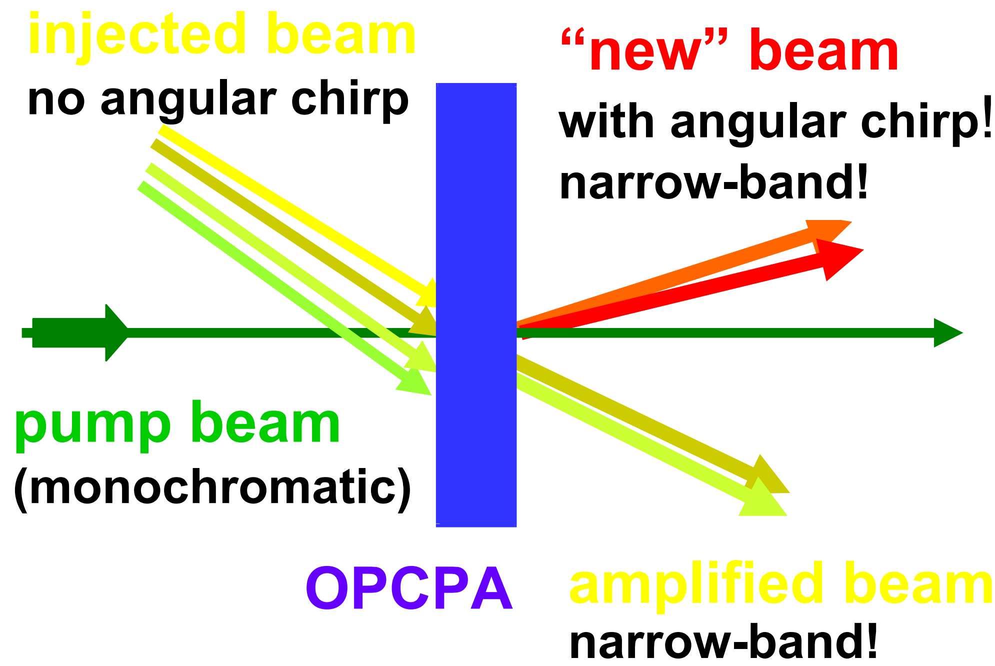
Injected beam keeps its (plane) wavefront at any pump wavefront

Physics of OPCPA. Wide-band case.
Defenition of signal and idler waves.

Signal beam is injected



Idler beam is injected

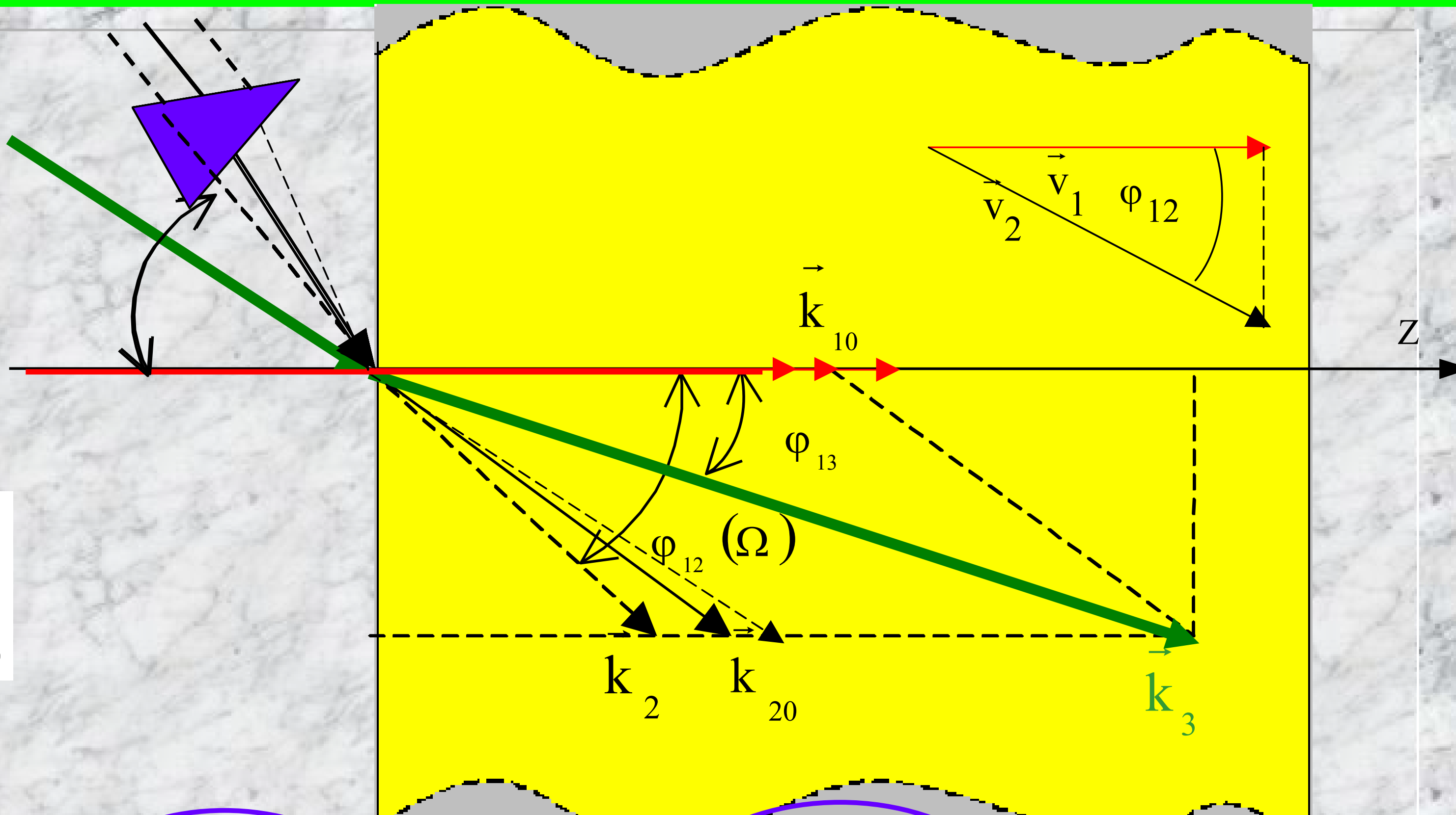


Signal beam must be injected. Not idler.
Idler may be injected with angular chirp.

Physics of OPCPA. Wideband phase-matching

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

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



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

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

phase-matching

$$\boxed{k_3 = k_1(0) + k_2(0)}$$

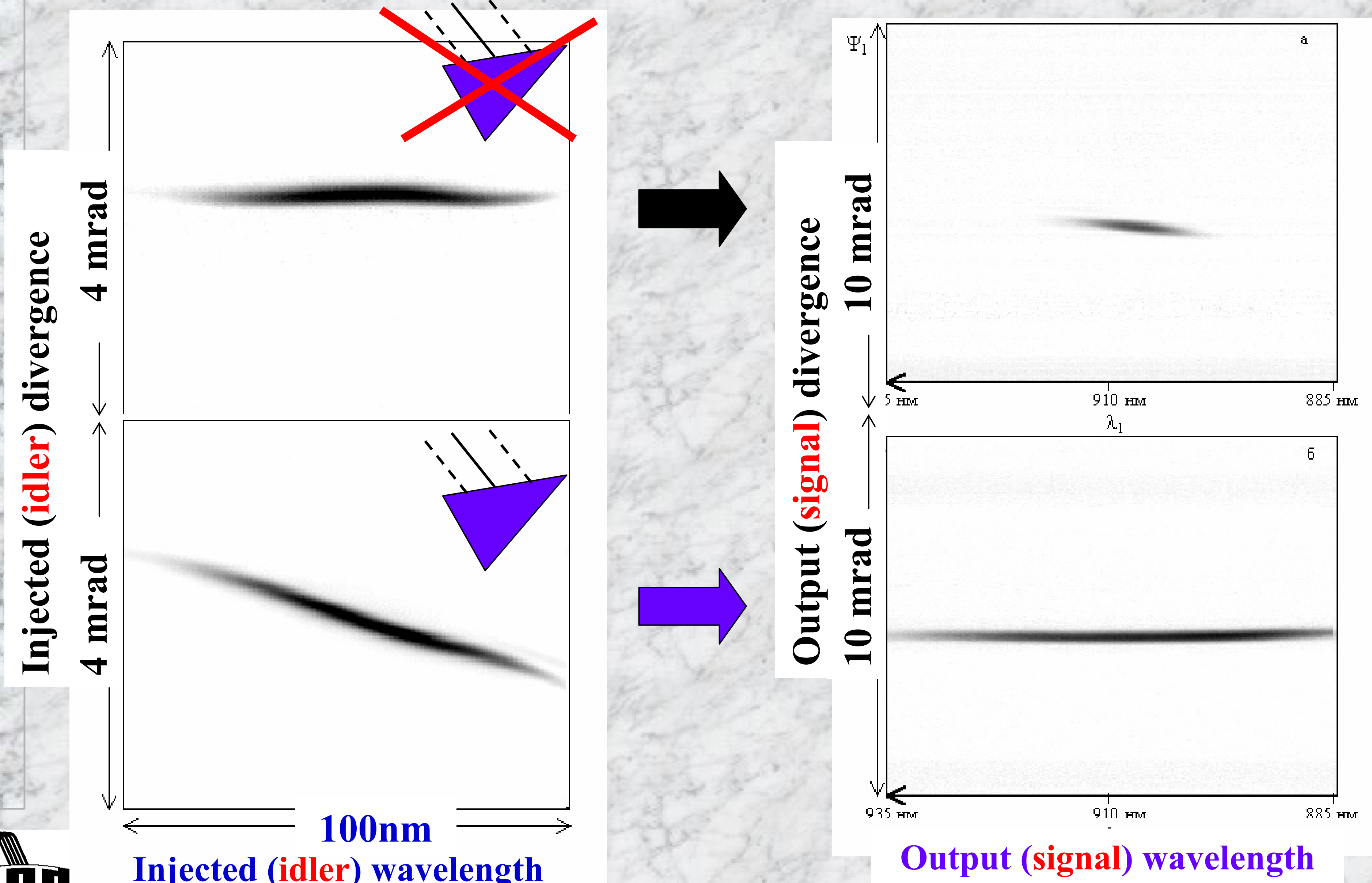
=0 wideband phase-matching

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

super-wideband phase-matching

Non-degenerated broadband phase-matching in KD*P.

Experiments with injection of idler angular-chirped wave.



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

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Introduction

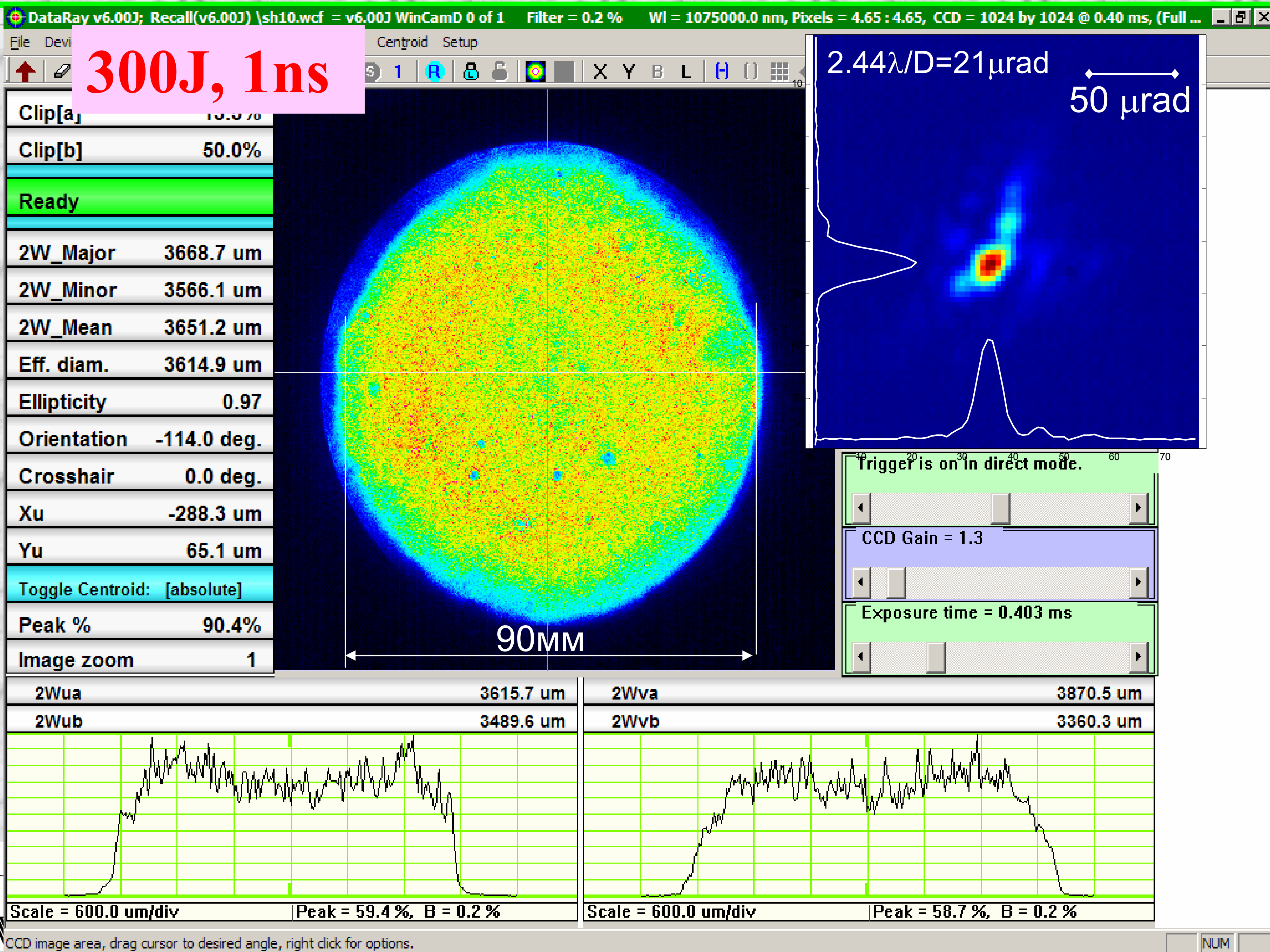
- **Physics of OPCPA**
- **Compact 0.56 PW laser system - PEARL**
- **Scalability to multi-petawatt power**

Conclusion

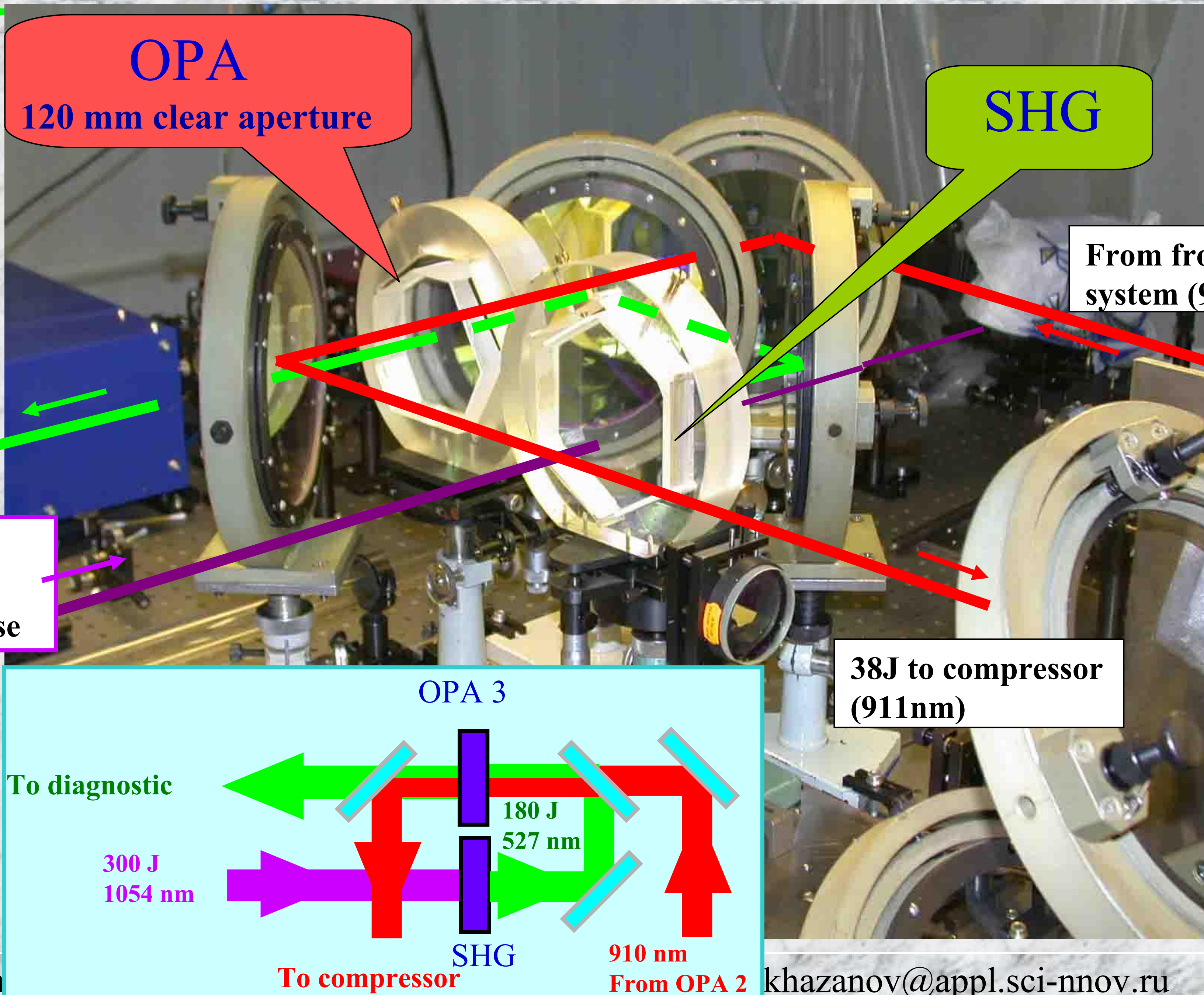
PEtawatt pARametric Laser (PEARL).
Architecture

Freidman G., Andreev N., Ginzburg V., Katin E., Khazanov E., Lozhkarev V., Palashov O., Sergeev A., Yakovlev I. Proc. SPIE, v.4630, p.135-146, 2002.

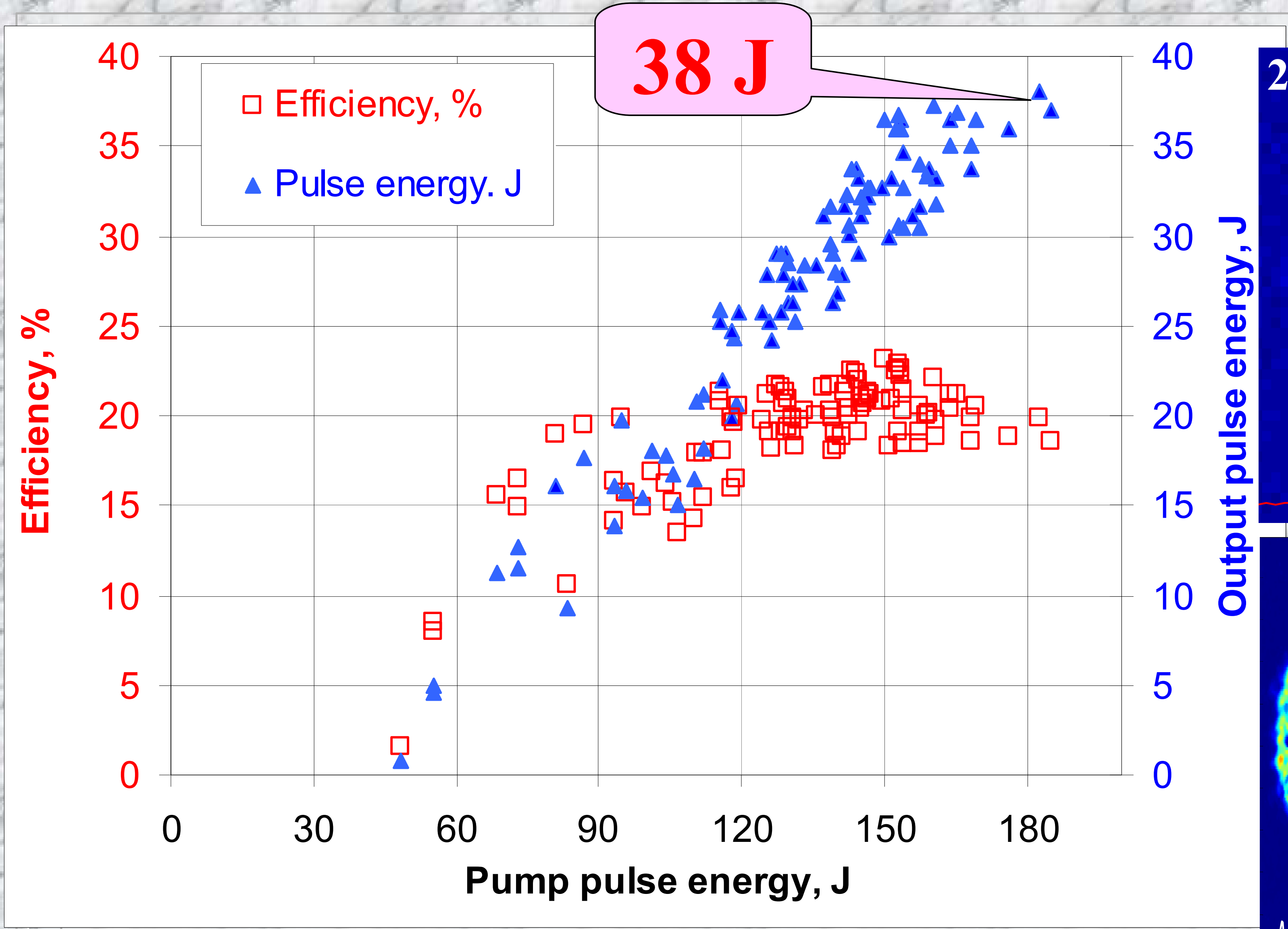
PEtawatt pARametric Laser (PEARL).
Nd:glass laser output beam

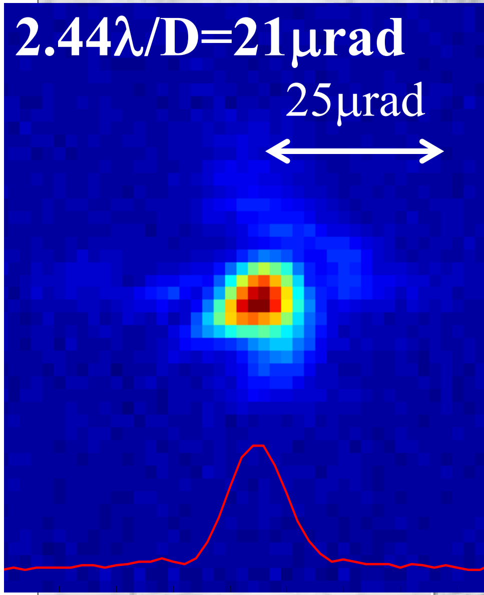


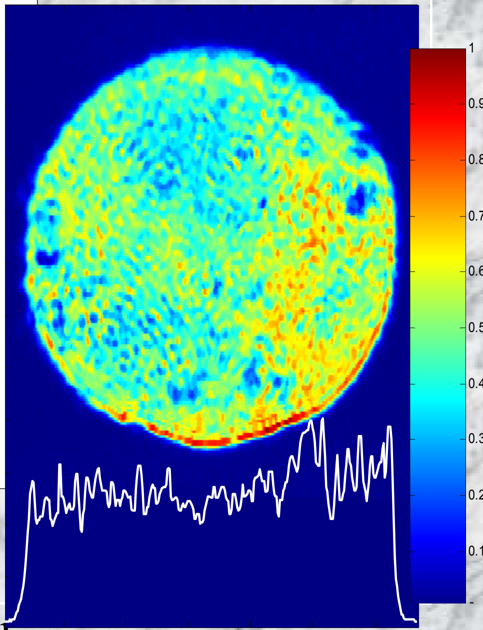
PEtawatt pARametric Laser (PEARL).
110mm clear aperture OPA



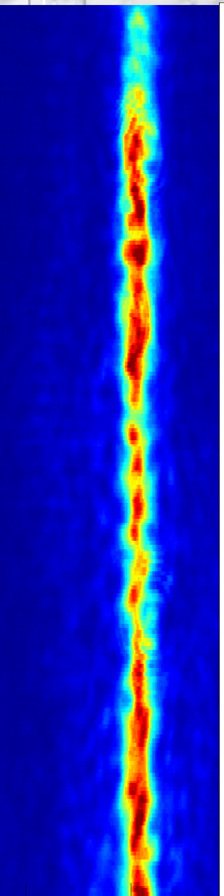
PEtawatt pARametric Laser (PEARL).
Energy characteristics of final OPCPA

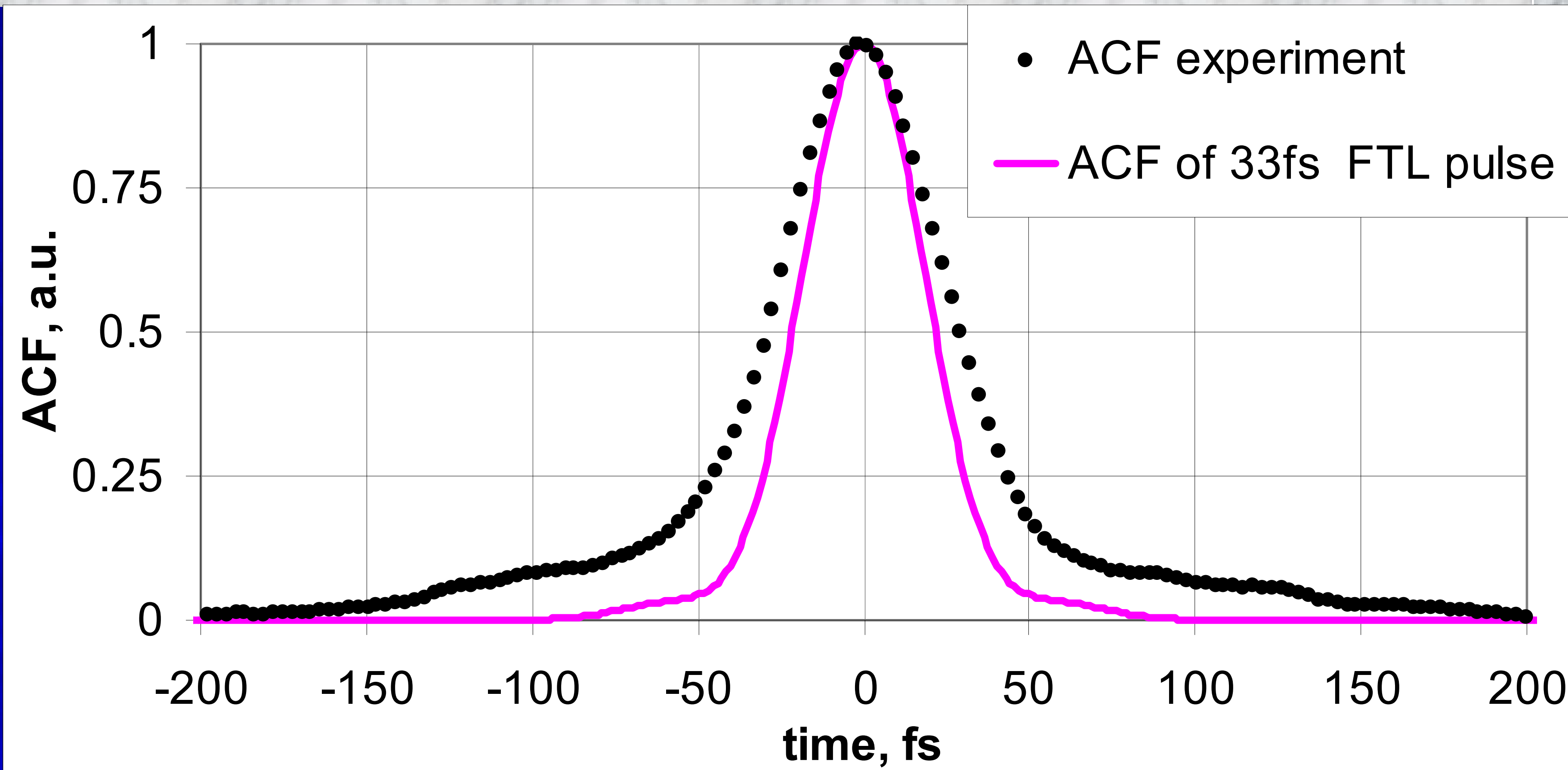






PEtawatt pArametric Laser (PEARL).
Compressed 0.56 PW pulse

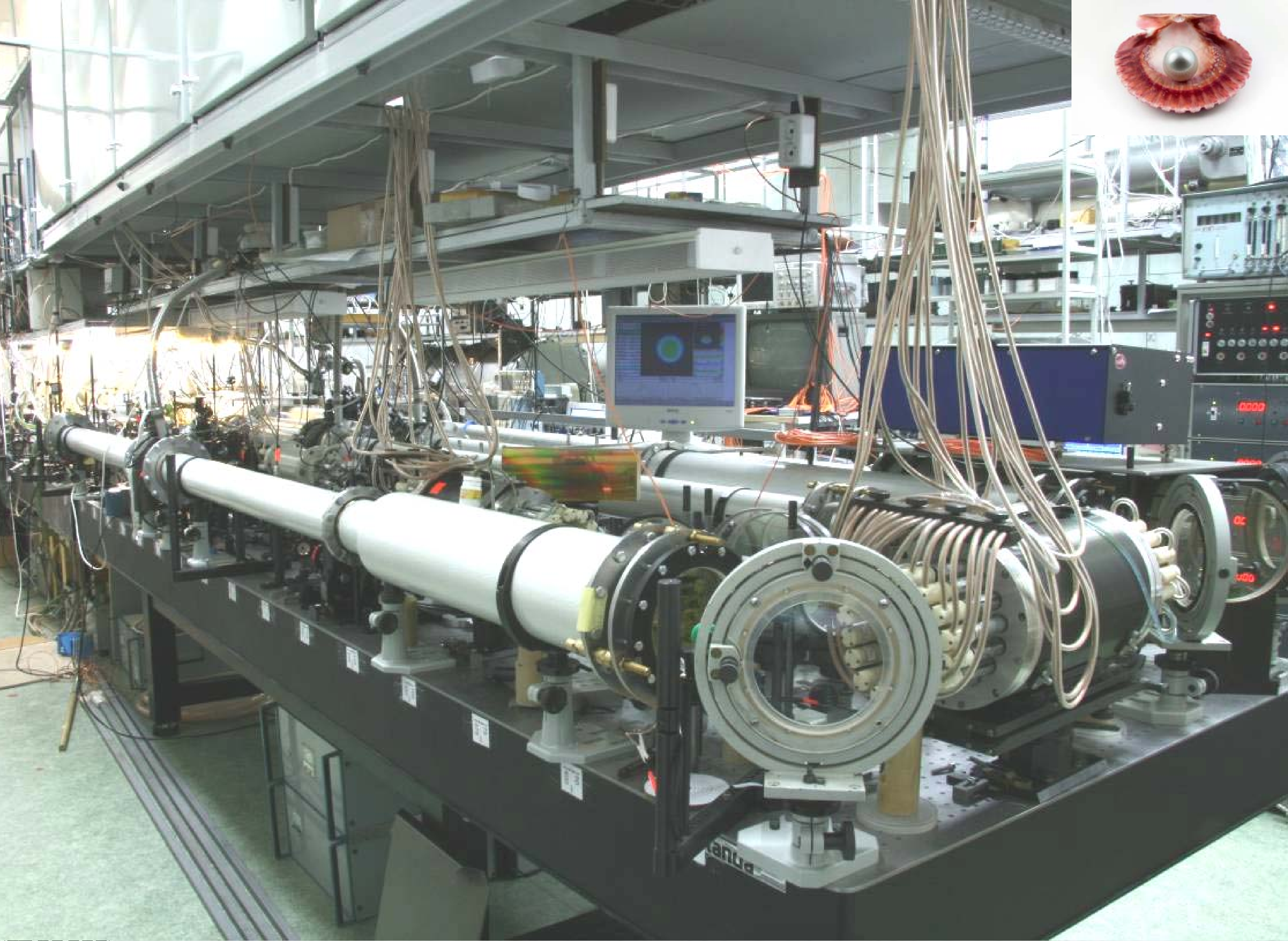




24 J /43 fs=0.56 PW

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).



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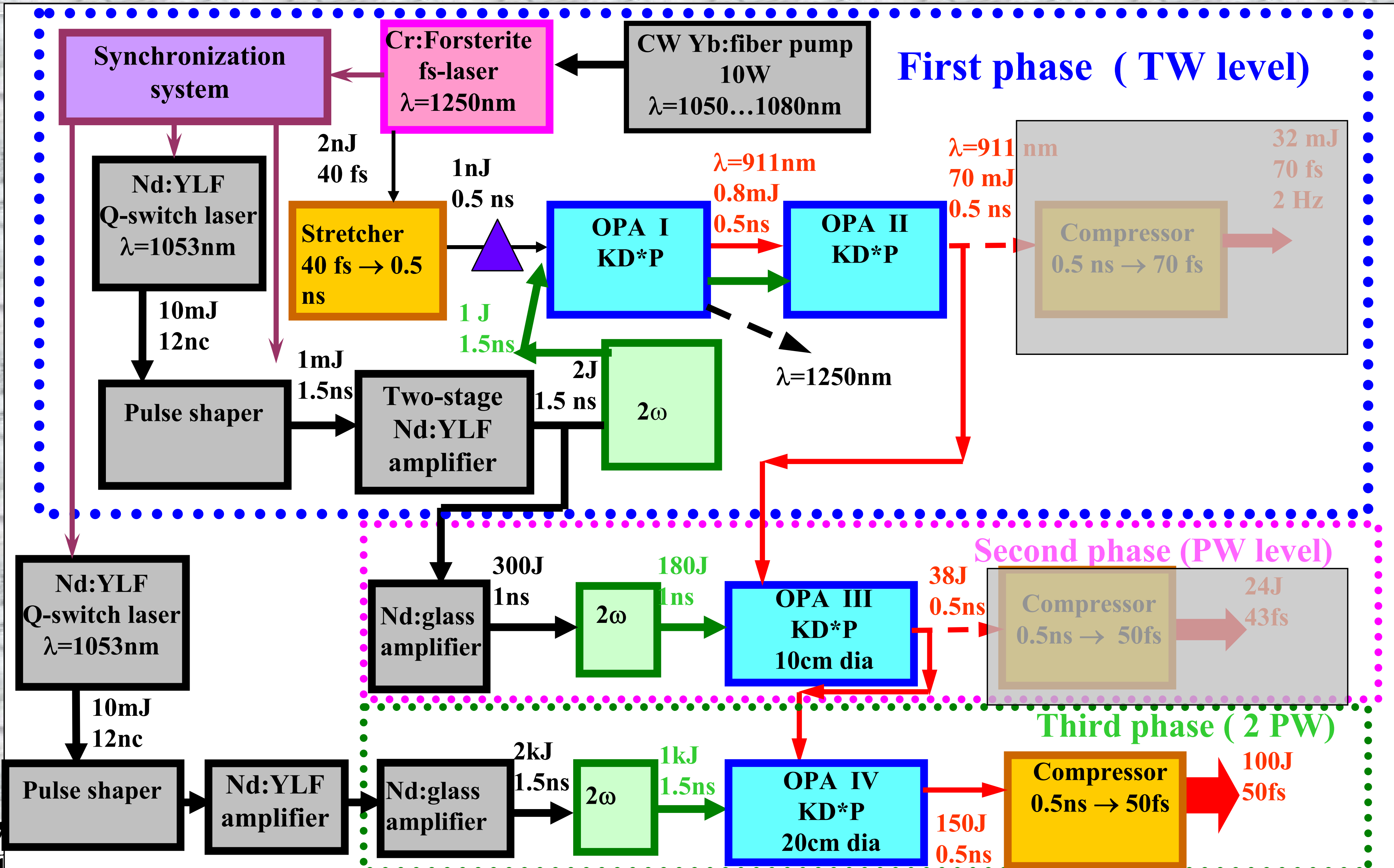
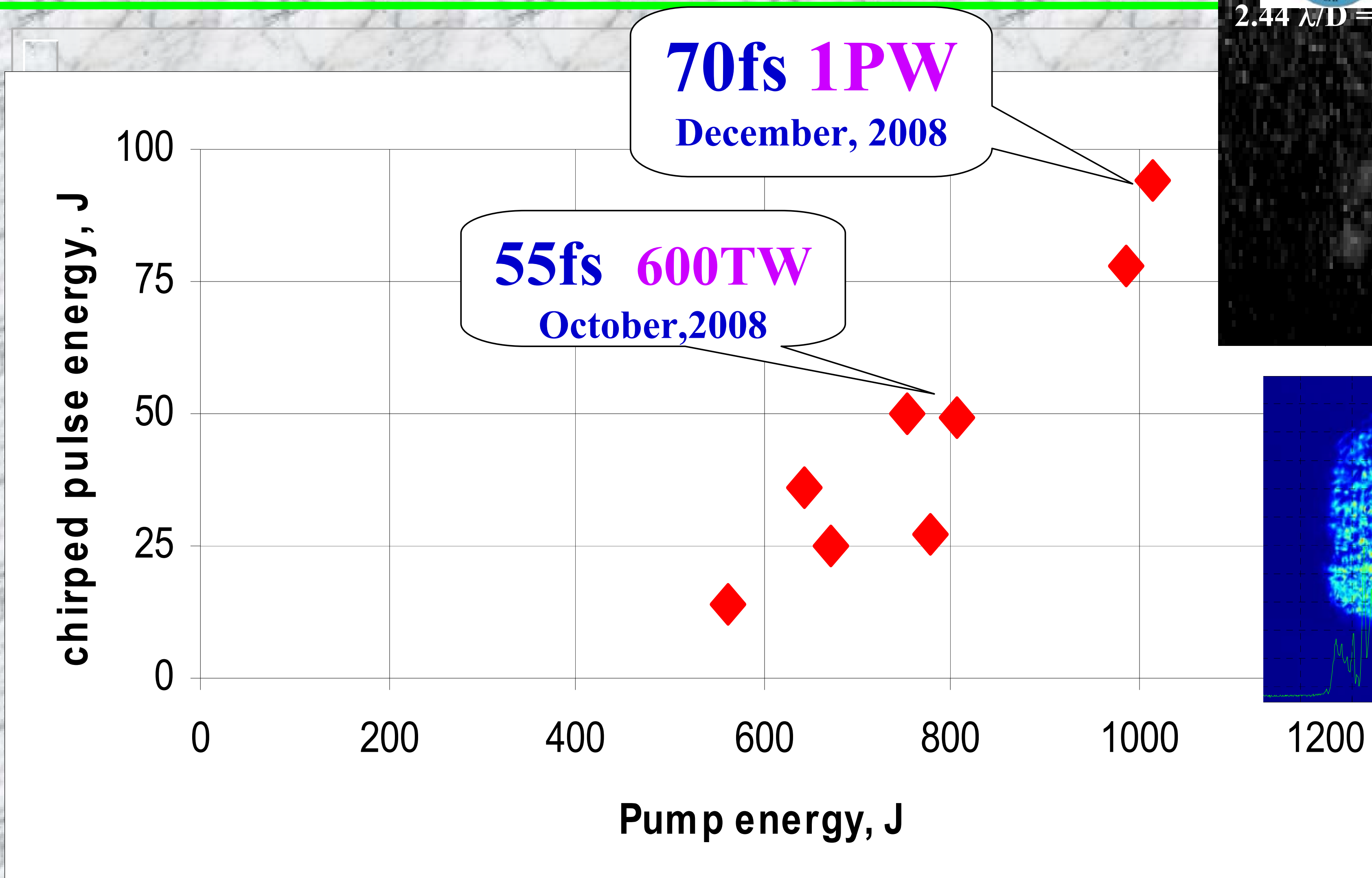
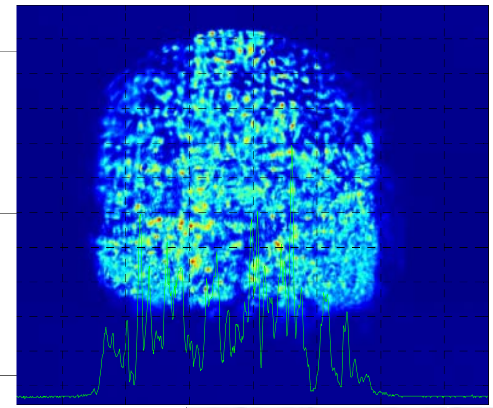
Scalability to multi-petawatt power.

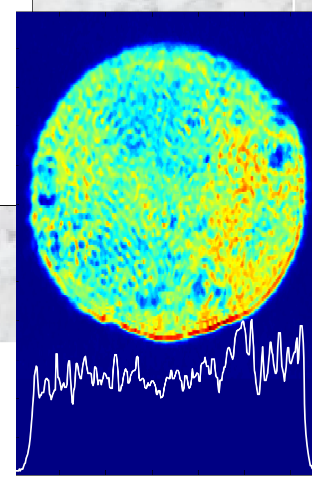
Sarov – N.Novgorod.



Scalability to multi-petawatt power.
Projects overview.

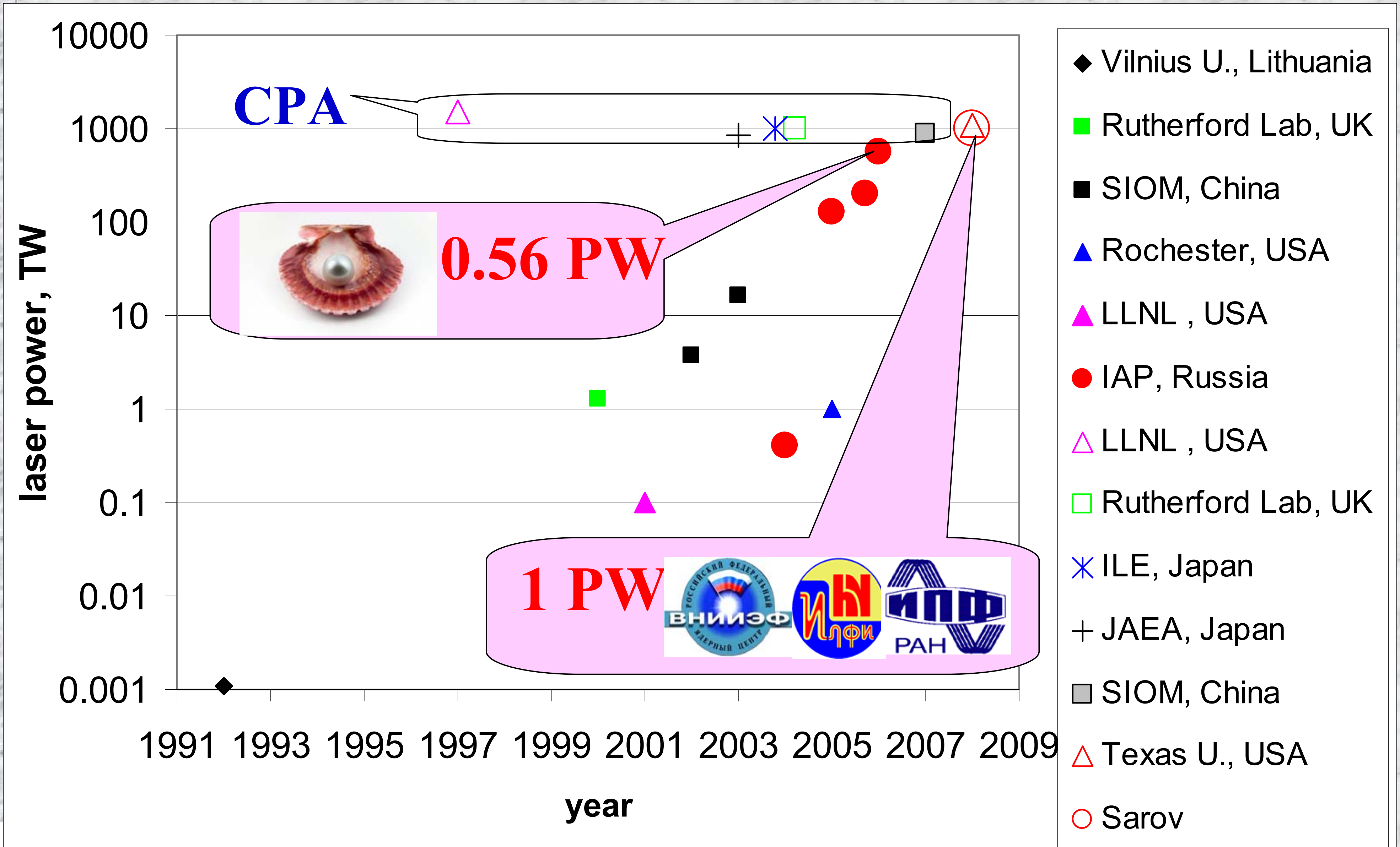






I.A. Belov, O.A. et al. *Petawatt laser system of the "Luch" facility*
International Conference X Khariton's Scientific Reading. p.145 (2008).

Scalability to multi-petawatt power.
State of the art.



Scalability to multi-petawatt power.
Projects overview.

PEARL-10, IAP, Russia, 2008-2013, 10PW

Rutherford Lab, UK, 2007-2014, 10PW

ELI, pan-European, 2008-2020 200PW (may be CPA or OPCPA)

International Center for Extreme Light Study, Russia, 2012-2018, 200PW

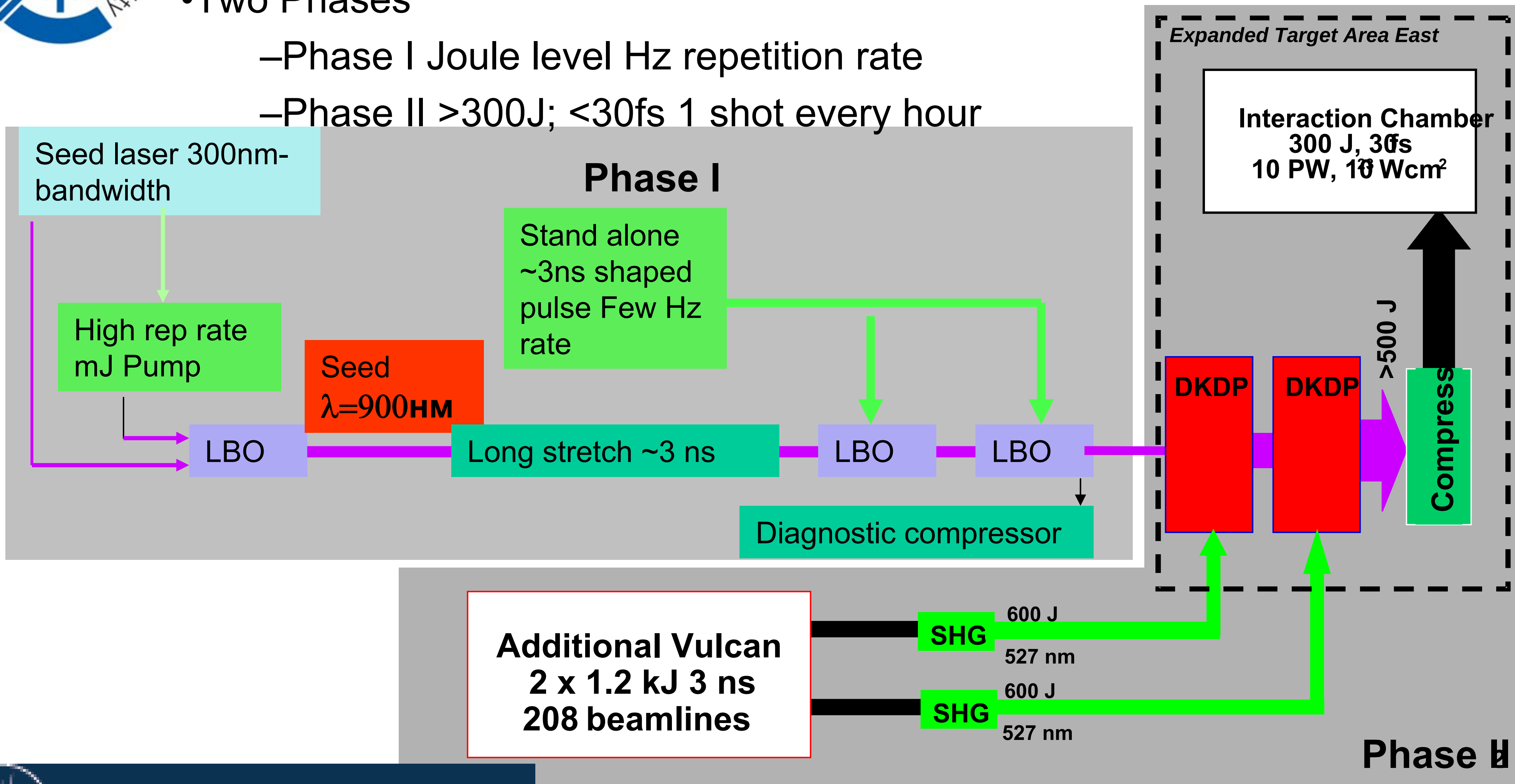
(under consideration in the Russian Government)

Scalability to multi-petawatt power.

Rutherford Lab, UK, 2007-2013, 10PW

10PW Project Schematic

- Two Phases
  - –Phase I Joule level Hz repetition rate
  - –Phase II >300J; <30fs 1 shot every hour

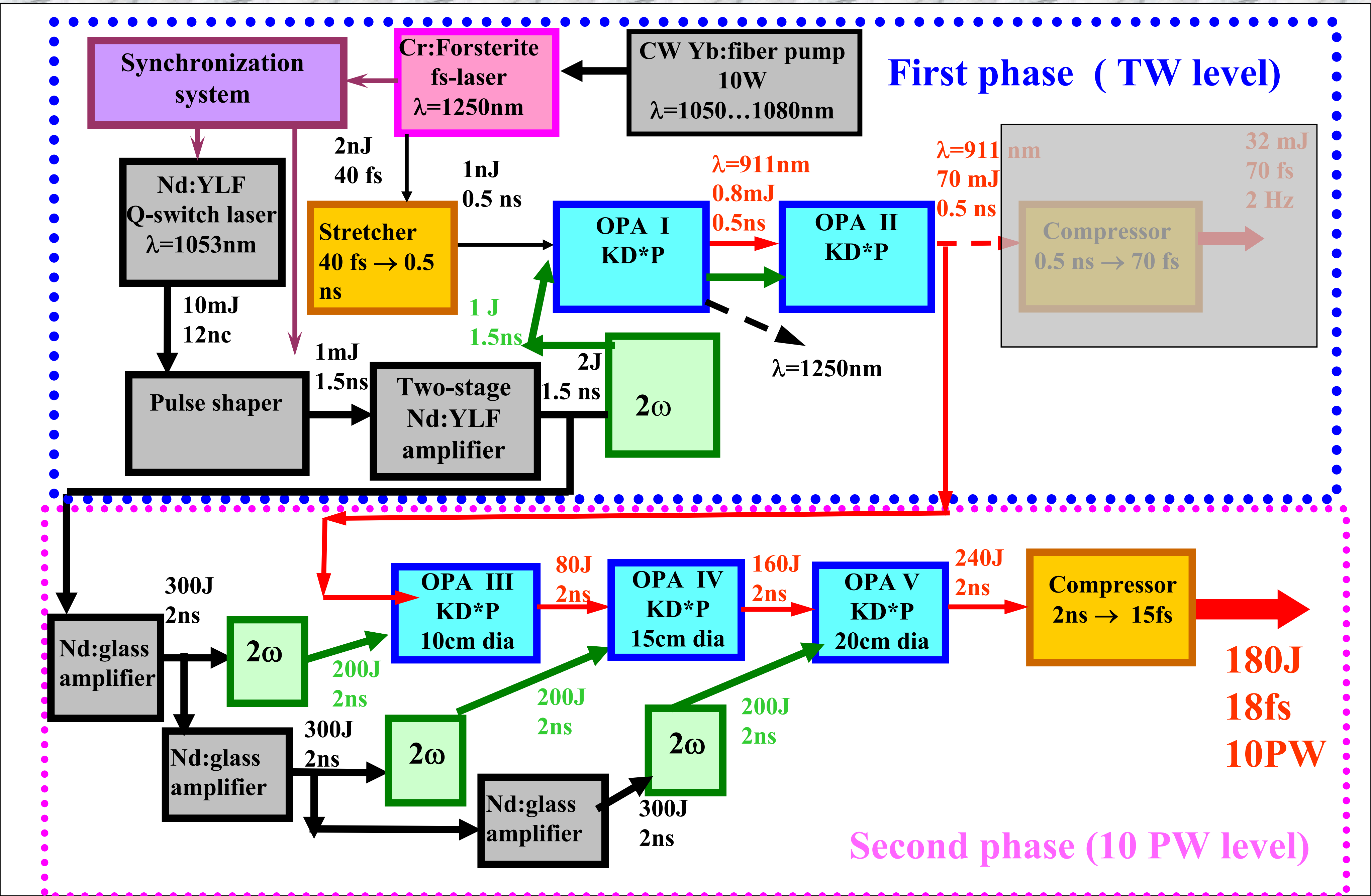


OPCPA scalability to multi-petawatt power.
Estimation for laboratory scale option

+ **Pulse duration: x2.5** (18fs instead of 45fs)
+ **OPCPA efficiency: x2** (40% instead of 20%)
+ **Pump power x3.3:** (600J instead of 180J)
+ **Compressor efficiency x1.2** (76% instead of 66%)

TOTAL: x20 (10PW instead of 0.56PW)

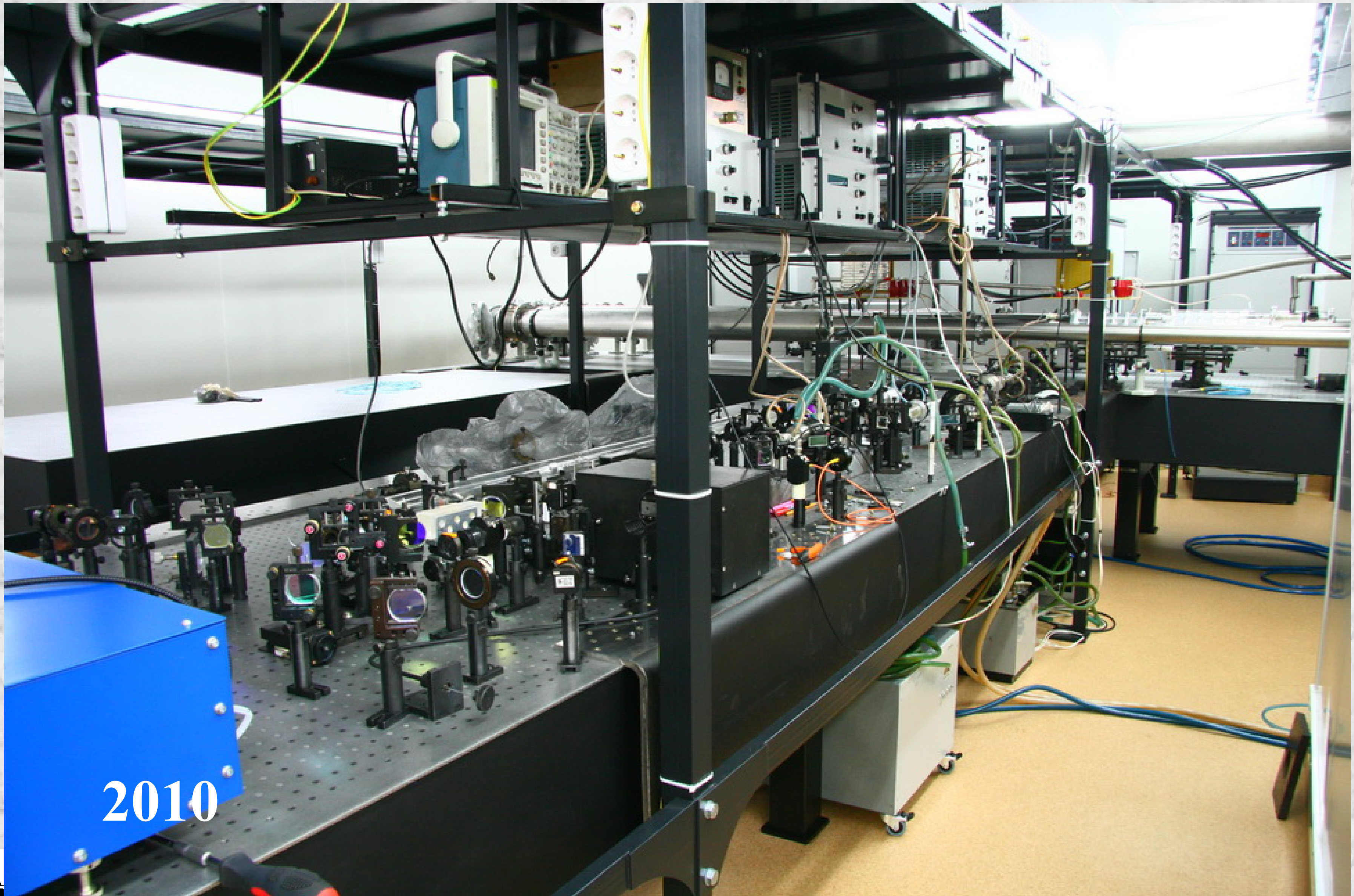
OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW



OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW

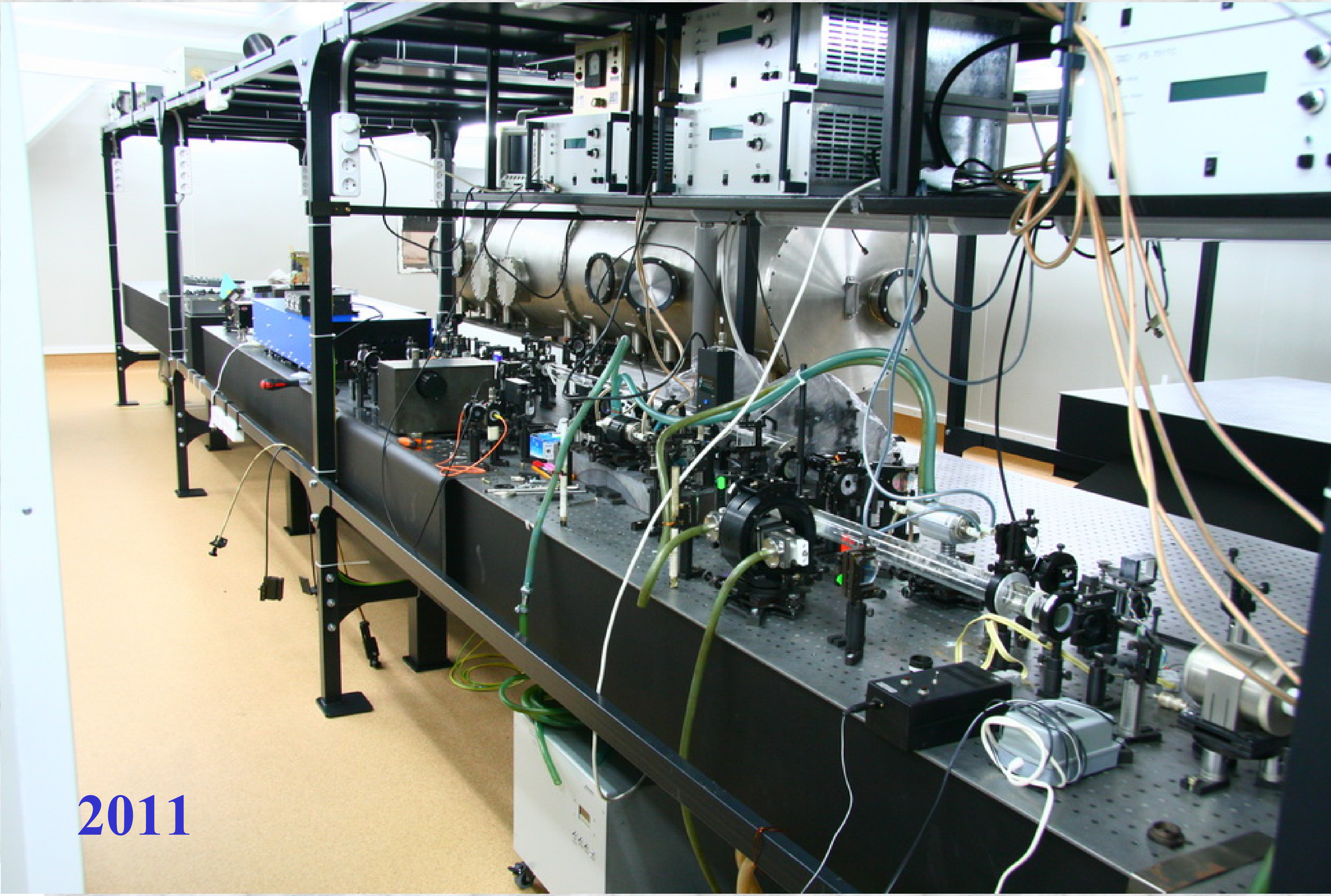
OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW

OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW



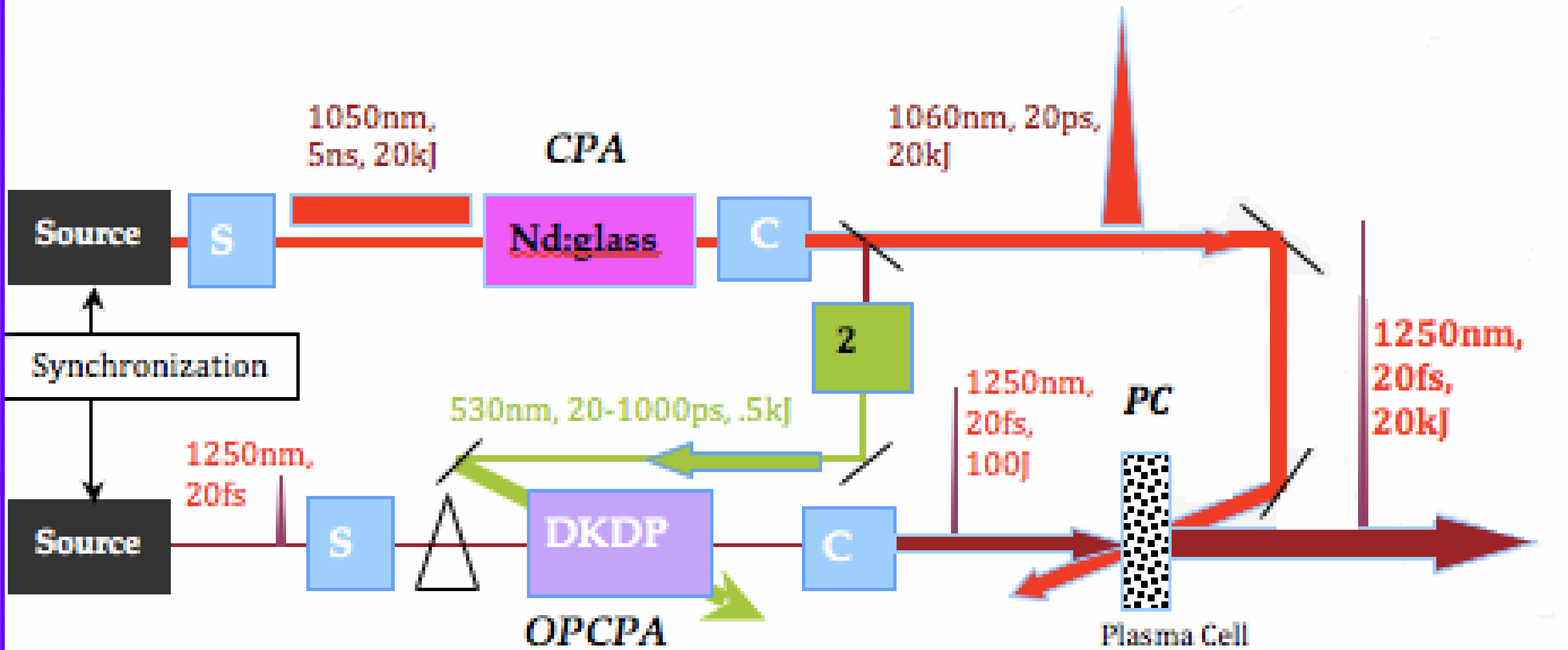
OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW

OPCPA scalability to multi-petawatt power.
PEARL-10, IAP, Russia, 2008-2013, 10PW



2011

Before conclusion. Another mission of OPCPA



The CPA technique compresses 5ns, 20kJ into a ~20ps pulse. This pulse is used after frequency doubling, to pump an OPCPA. A strong idler wave is produced at 1250nm. The latter seeds, the plasma compression cell where by interfering with the 20ps pump pulse at 1050nm converts and transfers the pump into the seed pulse at 1250 nm. To preserve the pulse shortness, a prism in the OPCPA is used to produce the necessary angular chirp.

G. A. Mourou, N. J. Fisch, V.M.Malkin, Z.Toroker, E.A.Khazanov, A.M.Sergeev, T.Tajima *Exawatt-Zettawatt Pulse Generation and Applications submitted to Optics Communications*

PAH

Before conclusion. Another mission of OPCPA

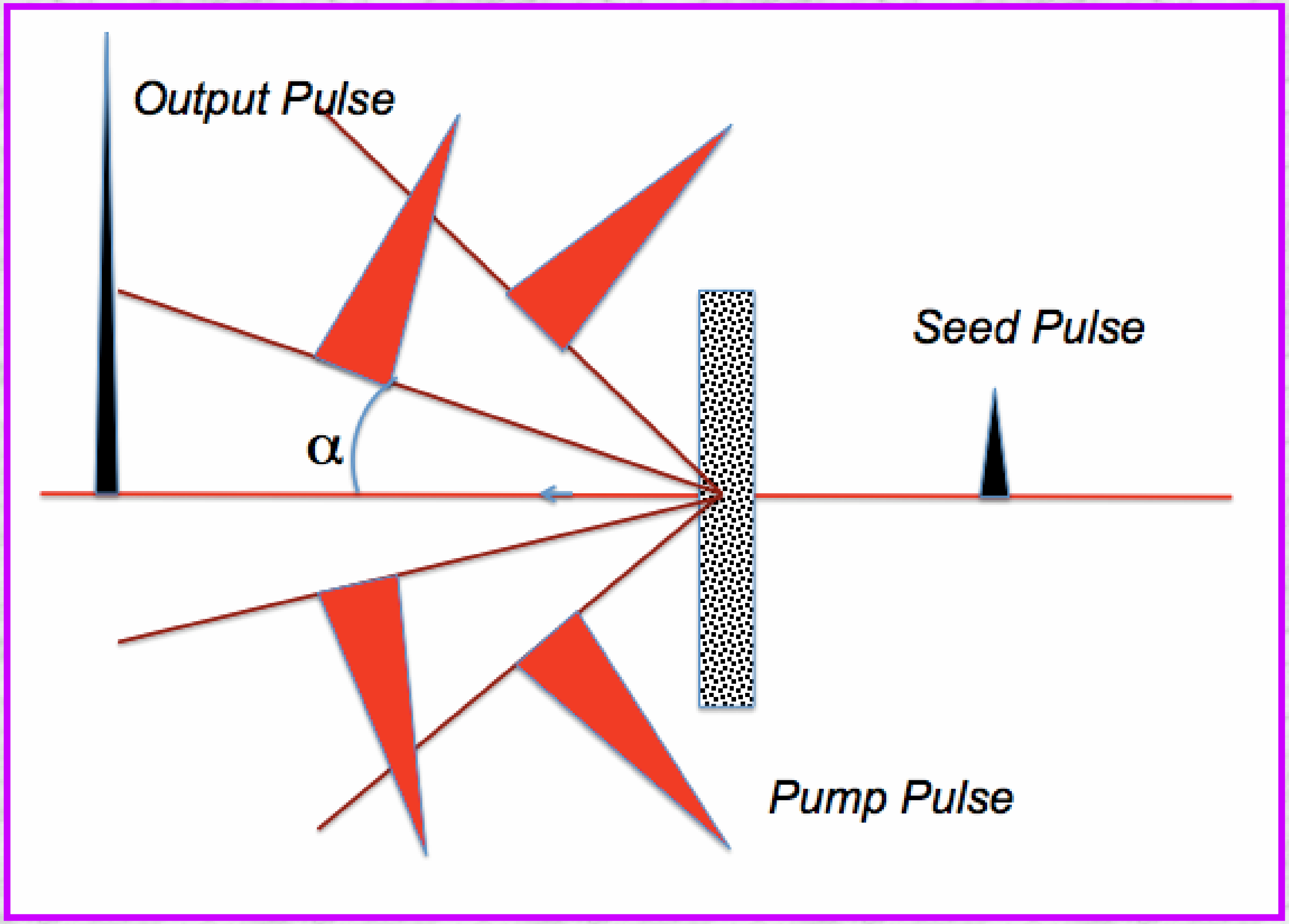


Diagram displaying the concept of Multiple-Beam-Pumping showing that the energy from several beams can be transferred to one signal seed pulse.

Before conclusion. Another mission of OPCPA

Chirped Pulse Amplification

+

Optical Parametric Chirped Pulse Amplification

+

Plasma Compression by Raman Amplification

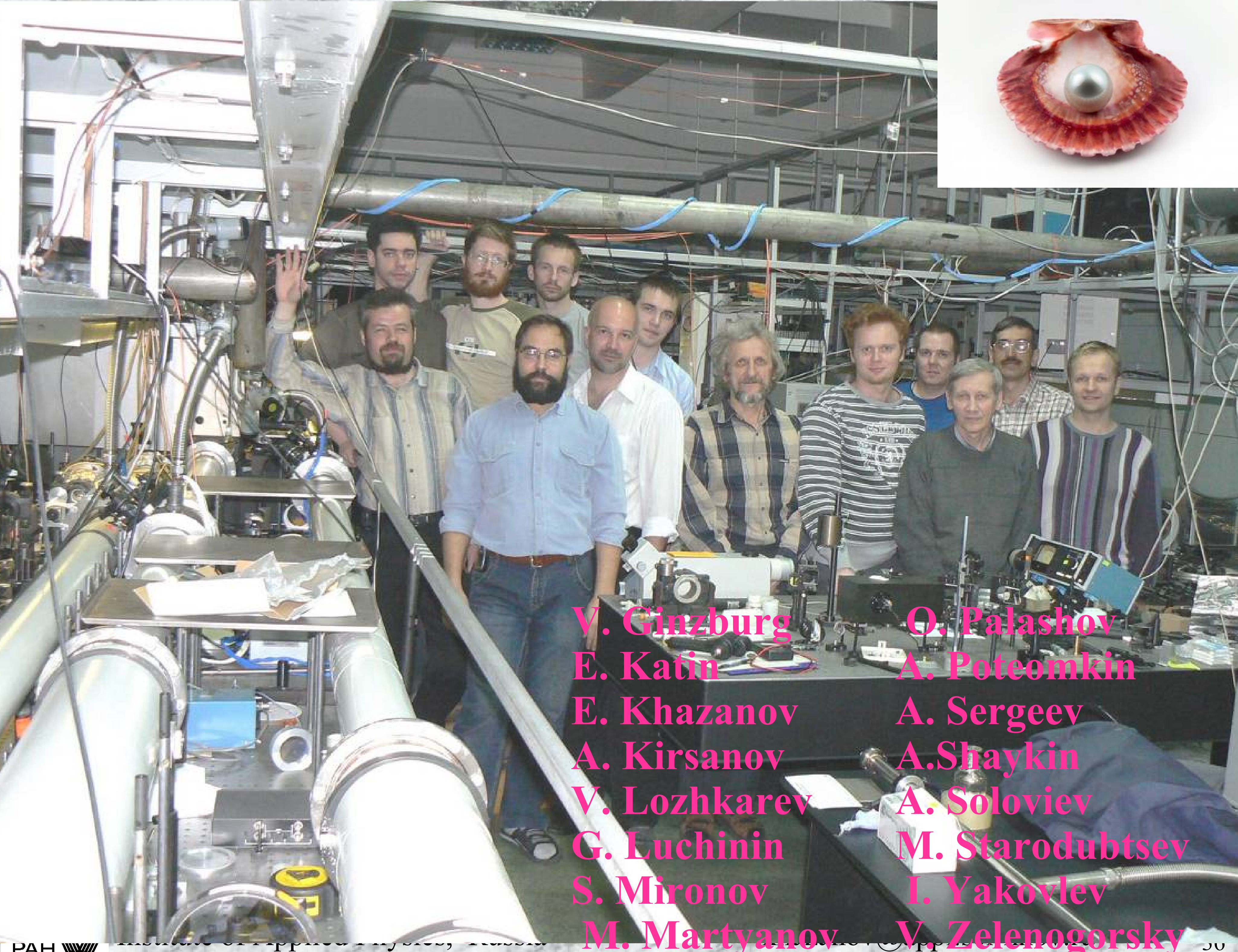
=

Cascaded Conversion Compression = C^3

Conclusion

OPCPA will keep a major role on the route(s) to 10+ PW laser.

Let's keep going.


V. Ginzburg
E. Katin
E. Khazanov
A. Kirsanov
V. Lozhkarev
G. Luchinin
S. Mironov
M. Martyanov
O. Palashov
A. Poteomkin
A. Sergeev
A.Shaykin
A. Soloviev
M. Starodubtsev
I. Yakovlev
V. Zelenogorsky

Instead of Conclusion

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

No question.

#2. There is only one question.

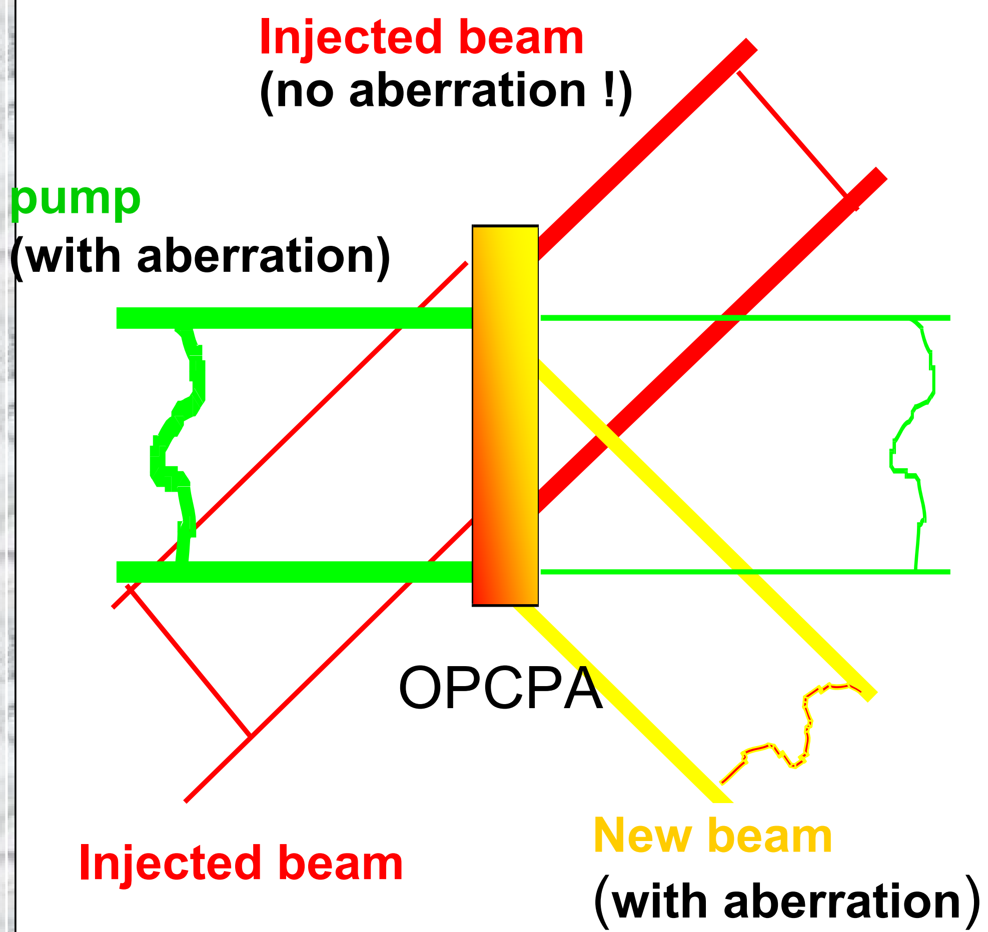
Q.: The best *or* one of the best?

A1: See message #1.

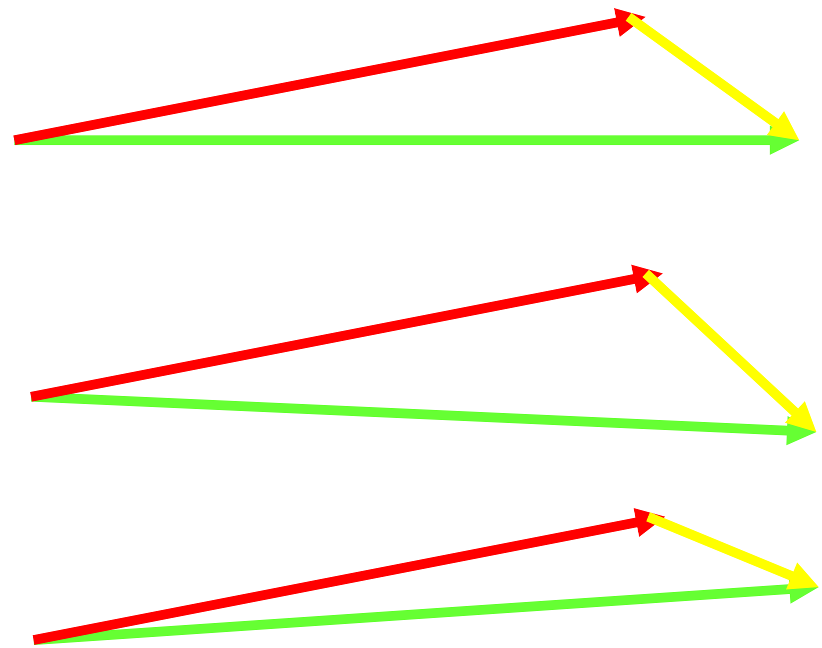
A2: Will live and see.

Physics of OPCPA. Wavefront distortions.

Pump beam aberration transfers to new wave



Pump beam deviation transfers to new wave



Injected beam keeps its wavefront at any pump wavefront

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	15	40x40
Minimum duration, fs	250	20	20
Efficiency (1ω Nd →φc), %	80	15	10
Number of PWs from 1 kJ 1ω Nd	~~4~~ (3)	~~8~~ (5)	4
First PW-level power	1.3 PW LLNL, 1997	0.85 PW JAEA 2004	0.56 PW IAP 2006

Diffraction grating damage threshold

Ti:sapphire damage threshold