DE LA RECHERCHE À L'INDUSTRIE

CREMLIN: CONNECTING RUSSIAN AND EUROPEAN MEASURES FOR LARGE-SCALE RESEARCH INFRASRUCTURES

Catalin MIRON

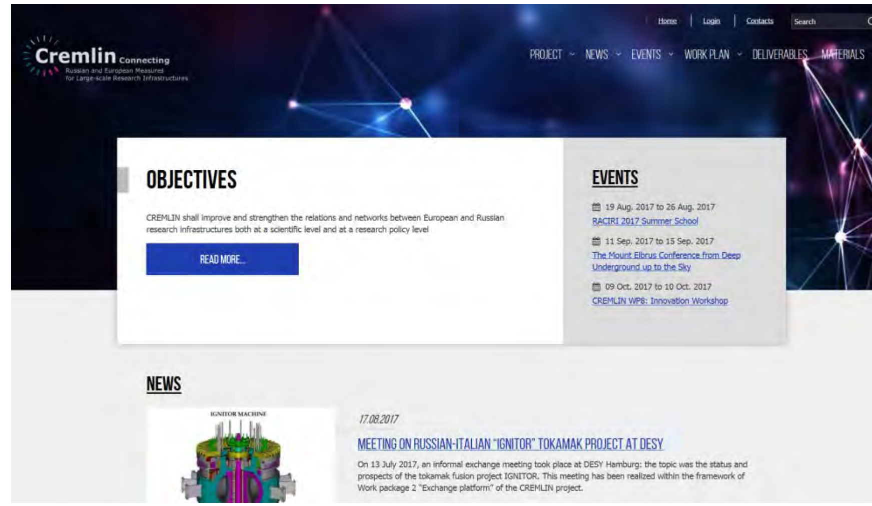
WP6 – Science cooperation with XCELS in the field of high power laser research

Involvement of European Industry in the XCELS project
11-12 December 2017, Paris, Institut Hneri Poincaré

Cremlin Connecting Russian and European Measures for Large-scale Research Infrastructures

CREMLIN Facts

- CREMLIN: www.cremlin.eu
  - Horizon 2020 project
  - European-Russian project on collaboration in megascience
  - *Connecting Russian and European Measures for Large-scale Research Infrastructures*
- Duration: 1 September 2015 – 31 August 2018
- Budget: ~€1.7M
- Coordinator: DESY
- Key Partner: NRC “Kurchatov Institute”
- Consortium: 19 European and Russian RIs



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CREMLIN Consortium: 19 partners

13 European beneficiaries	6 Russian beneficiaries
DESY (Coordinator)	NRC KI
Jülich	PNPI
FAIR	JINR
HZG	IAP RAS
TUM	BINP
European XFEL	IC RAS
ILL	
ESS	
ESRF	
ELI-DC	
CEA LIDyL	
CERN	
MAX IV Lab	

Cremlin Connecting Russian and European Measures for Large-scale Research Infrastructures

Focus: 6 Russian projects

- CREMLIN targets at **all 6 Russian megascience projects**:
  - Powerful Research Reactor **PIK,** PNPI Gatchina
  - Ion Collider Facility **NICA,** JINR Dubna
  - Fourth Generation SR Source **SSRS-4,** NRC KI Moscow
  - High power laser **XCELS**, IAP Nizhniy Novgorod
  - Lepton collider **STC**, BINP Novosibirsk
  - (Fusion project **IGNITOR**, NRC KI Moscow)

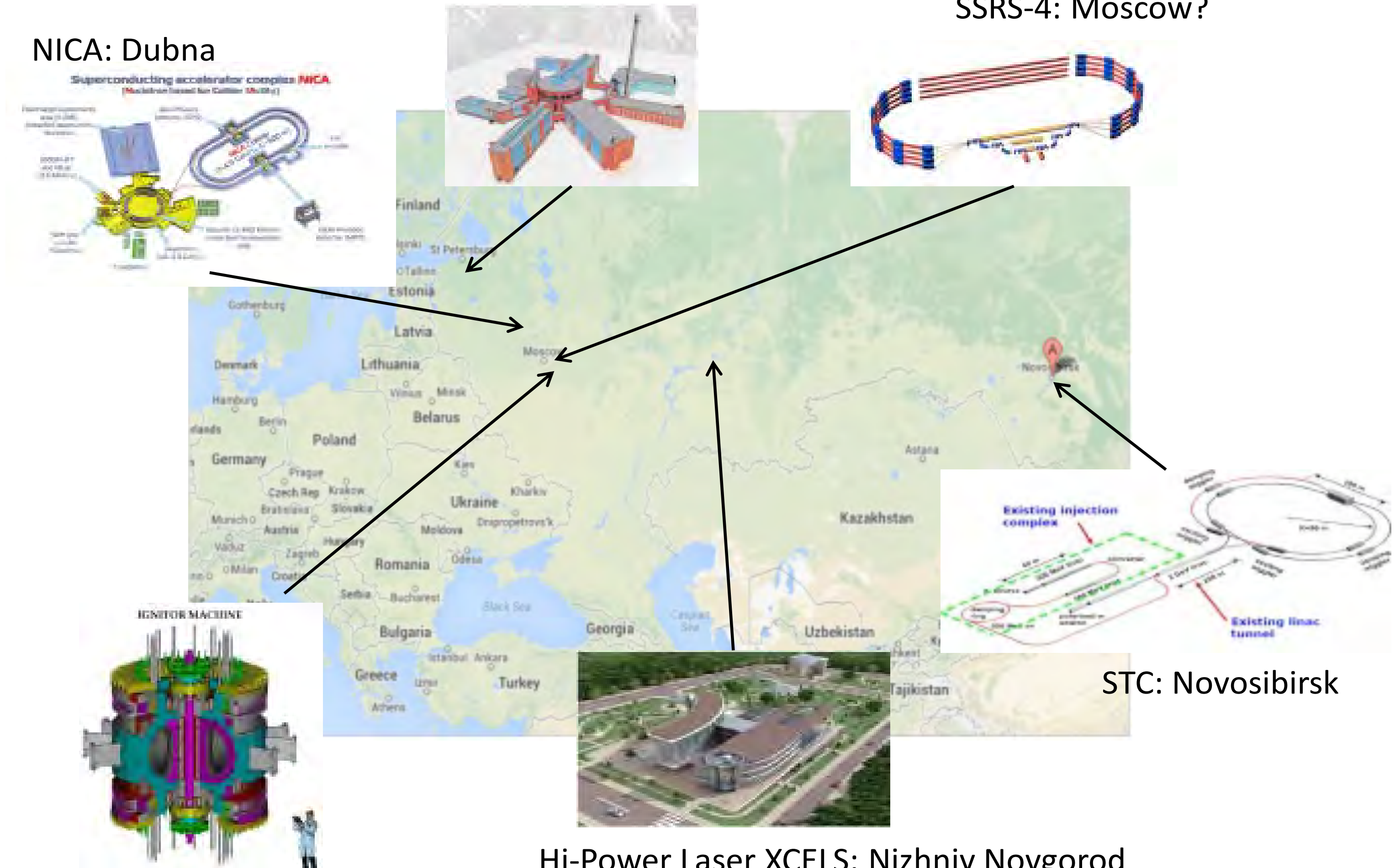
- Very different status of implementation
- PIK; NICA; IGNITOR: receiving national funding; called „international“ megascience projects;
- SSRS4 funding expected soon

Focus: 6 Russian projects

PIK: Gatchina

SSRS-4: Moscow?

NICA: Dubna



STC: Novosibirsk

Hi-Power Laser XCELS: Nizhniy Novgorod

Fusion IGNITOR: Troitsk, Moscow

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CREMLIN: Key objectives

- CREMLIN is a truly pathfinding project
- Aims at improving and strengthening the collaboration between Russian and European research infrastructures (RI), and at a better integration of both research areas

The three key objectives for CREMLIN are:

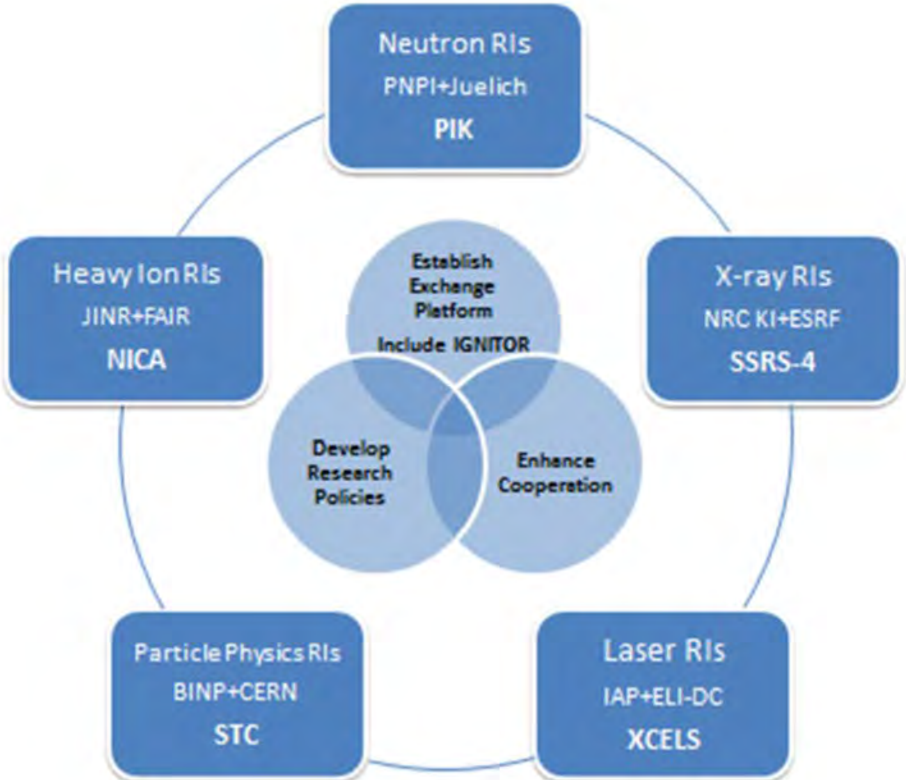
1. Enhance European-Russian science cooperation along the megascience facilities
2. Develop recommendations, strategies and perspectives for an enhanced European-Russian cooperation
3. Establish an exchange platform for mutual learning across the various science disciplines and communities

WP Structure

Two-way-approach:

5 Thematic WPs (Russian projects)

2 Horizontal WPs
(cross-topical issues)



5 Thematic WPs

WP#	Title	Beneficiaries
WP3	Science cooperation with the NICA collider facility in the field of ion beams and heavy ion physics	FAIR; JINR
WP4	Science Cooperation with the PIK research reactor in the field of neutron sources	Jülich; PNPI plus: HZG; TUM; ILL; ESS
WP5	Science cooperation with the SSRS-4 synchrotron radiation source in the field of photon science	ESRF; NRC KI plus DESY; EU.XFEL; IC RAS; Lund MAX IV
WP6	Science cooperation with XCELS in the field of high power laser research	CEA; IAP RAS plus ELI-DC
WP7	Science cooperation with the Super tau-charm factory STC in the field of lepton colliders	CERN; BINP

2 Horizontal WPs

WP#	Title	Beneficiaries
WP2	• Provide a mutual learning platform • Invite IGNITOR to benefit from findings • Support science-to-policy interface • Promote exchange on data access and big data management • Establish links to other EU-Russian STI cooperation frameworks	DESY; NRC KI
WP8	• Provide a project website • Journalists´ trip to NICA and PIK facilities • Explore potentials for innovation, industrial use and technology transfer around the Russian projects • **Organise thematic summer schools such as RACIRI!**	NRC KI; DESY plus: ILL; ESS

Examples of activities WP6

- WP6: 100 PW High Power Laser Project XCELS at the Institute of Applied Physics RAS, Nizhniy Novgorod
- Partners: CEA (France), IAP-RAS, ELI-DC AISBL
- Recent events:
  - WS “Novel applications of Exawatt laser sources”: as satellite event to International Conference "Frontiers of Nonlinear Physics", held from 17 July 2016 to 23 July 2016 at Nizhny Novgorod-St. Petersburg (River cruise boat "Nizhny Novgorod“) http://www.fnp.sci-nnov.ru/workshop.html
  - Workshop on “Key technological issues in construction and exploitation of 100PW-class lasers I” organized 4-7 October 2016 by CEA, in Cassis / France, within the ISUIL Conference on Lasers
  - Workshop "Key technological issues in construction and exploitation of 100 PW class lasers II“, July 22 through July 28, 2017, on board the river boat cruising from Moscow to St.-Petersburg, Russia
  - **Round Table on “Internationalization of XCELS”, organized by the CEA at ELI-NP, 7-8 December 2017, Bucharest, Romania**

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Involvement of European Industry in the XCELS project

Monday, 11 December 2017, Institut Henri Poincaré, Salle 314	
14:00-14:55	*Participants Registration* - **Lobby**
	Session I
14:55-15:00	*Welcome (**Philippe Martin & Catalin Miron, CEA Paris-Saclay**)*
15:00-15:15	*CREMLIN: connecting Russian and European Measures for Large-Scale RIs* **Catalin Miron – CEA Paris-Saclay – WPL – Cooperation with CREMLIN**
15:15-15:45	*XCELS project: from inception to implementation* **Alexander Sergeev – IAP – President of the Russian Academy of Sciences**
15:45-16:15	*XCELS laser requirements* **Andrey Shaykin – IAP**
16:15-16:45	*Coffee break* **Cafeteria**
	Session II
16:45-17:15	*Experiments at XCELS: opportunities and challenges* **Igor Kostyukov – IAP**
17:15-18:00	*Discussion – Q&A session*
19:30-22:00	**Workshop dinner downtown Paris** *Location: Chez Lena & Mimile, 32, rue Tournefort, 75005 Paris*

Cremlin Connecting Russian and European Measures for Large-scale Research Infrastructures

Involvement of European Industry in the XCELS project

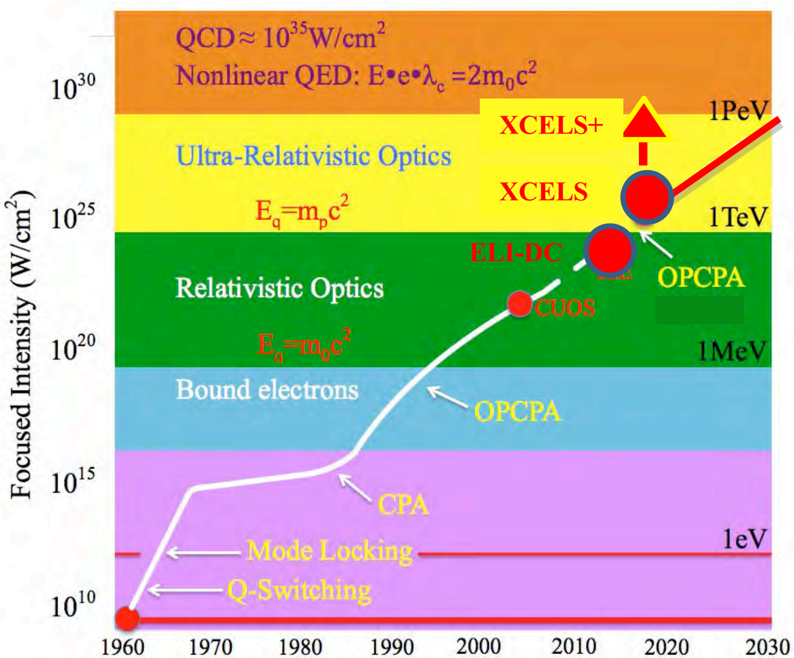
Tuesday, 12 December 2017, Institut Henri Poincaré, Salle 314	
Session III	
09-00-09:40	*Welcome coffee* **Cafeteria**
09:40-10:00	*PetaWatt Laser Systems : Current status and perspectives* **Christophe SIMON-BOISSON – THALES Optronique**
10:00-10:20	*SourceLAB : laser plasma supplier for physics and applications* **François SYLLA – SourceLAB**
10:20-10:40	*Advanced wavefront sensing solution for laser testing and optics metrology applications* **Yu LU – PHASICS**
10:40-11:00	*Title TBA* **Andrejus MICHAILOVAS – EKSPLA**
11:00-11:20	*Title TBA* **Franck FALCOZ – Amplitude Technologies**
11:20-11:50	**Coffee Break and group picture**
	Session IV
11:50-12:10	*Meter-Size Gratings for XCELS laser pulse compressors* **Arnaud COTEL – HORIBA Jobin-Yvon**
12:10-12:30	*Innovative deformable mirrors and beam transport systems for intense lasers* **Laurent ROPERT – ISP SYSTEM**
12:30-13:00	*General Discussion / Wrap-up* **Philippe Martin – CEA Paris-Saclay**
13:00	**End of workshop**

Involvement of European Industry in the XCELS project

THANK YOU FOR YOUR ATTENTION

Megaproject XCELS

XCELS - world most powerful laser infrastructure that will be built at
the Institute of Applied Physics in Nizhny Novgorod
to study the properties of matter and vacuum in the presence of extreme light

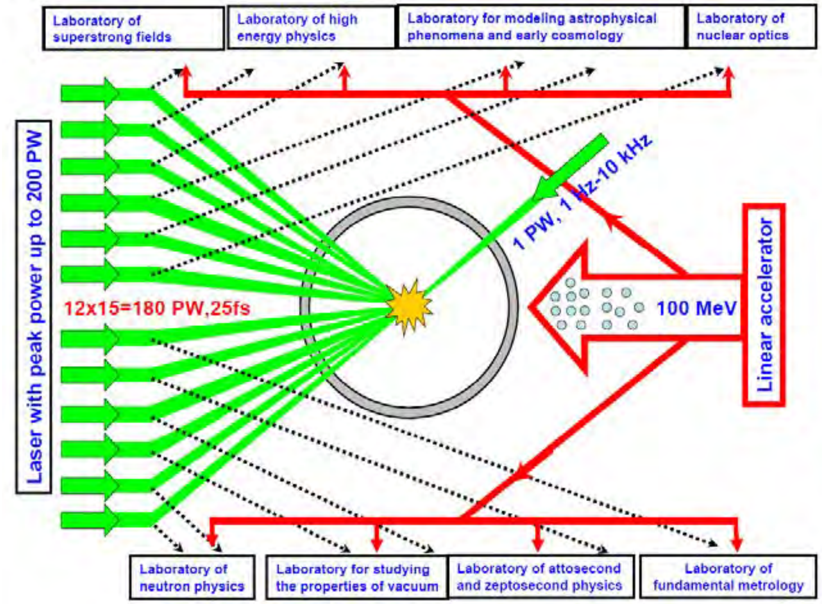


Ascent to the highest intensity of light,
"the Extreme Light"

XCELS - Exawatt Center for Extreme Light Studies

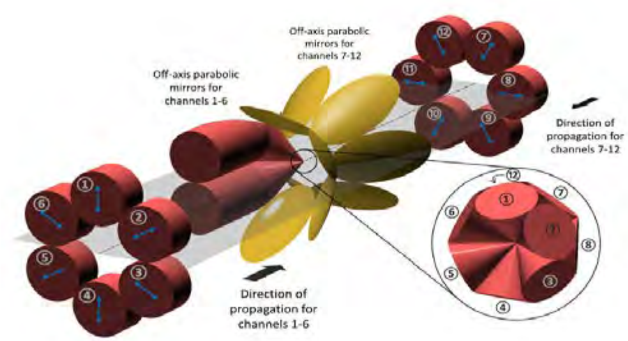
Megaproject XCELS

Laser source for XCELS



XCELS is based on the 200 Petawatt (2×10^{17} Watt) laser facility that exceeds the current record power level by 100 times. It comprises 12 amplification channels, each producing a laser pulse with 400 J energy and 25 femtosecond pulse duration.

A specially designed focusing system provides the ascent to the highest intensity level of 10^{25} - 10^{26} W/cm^2 by combining 12 laser beams. The resulting energy density in the focal area attains 10^{16} J/cm^3, several orders of magnitude higher than in the center of the Sun.



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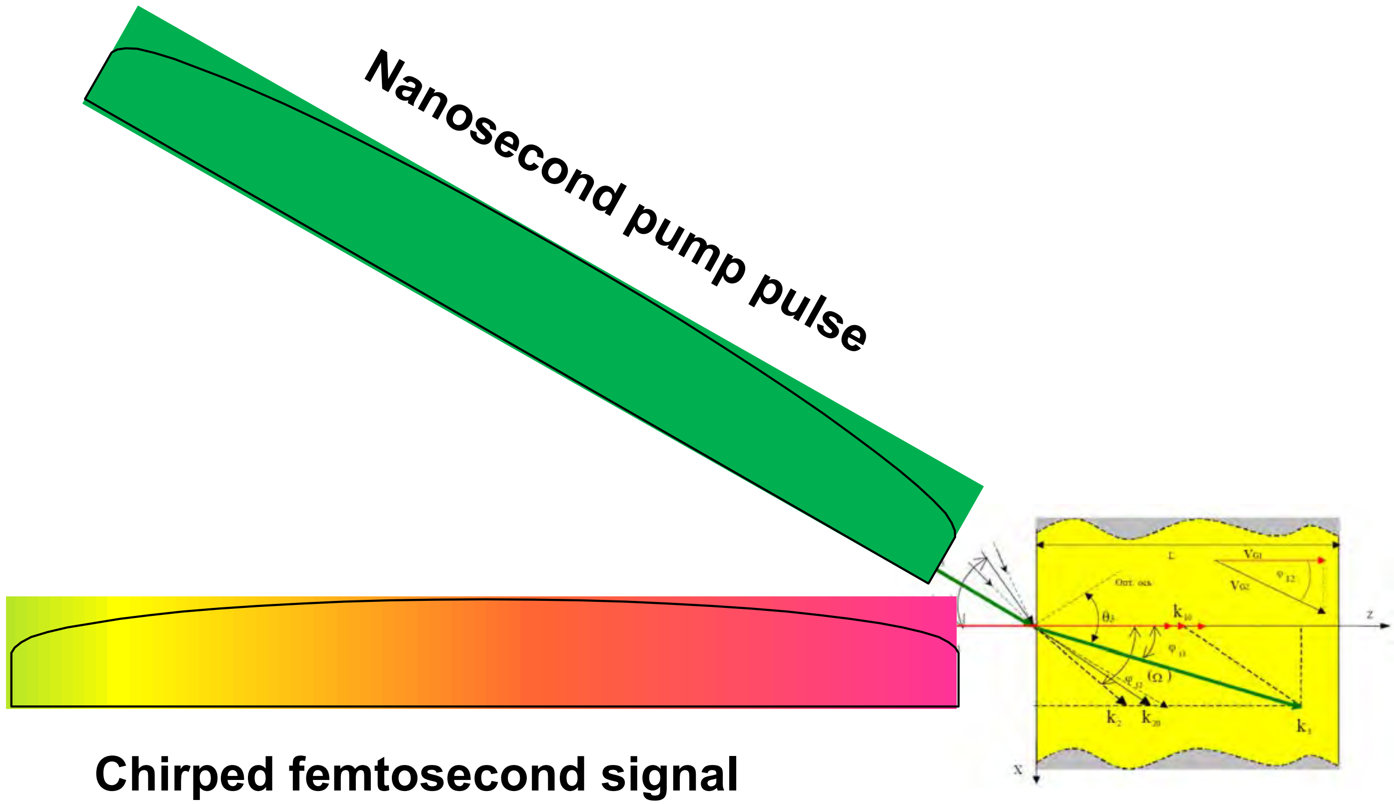
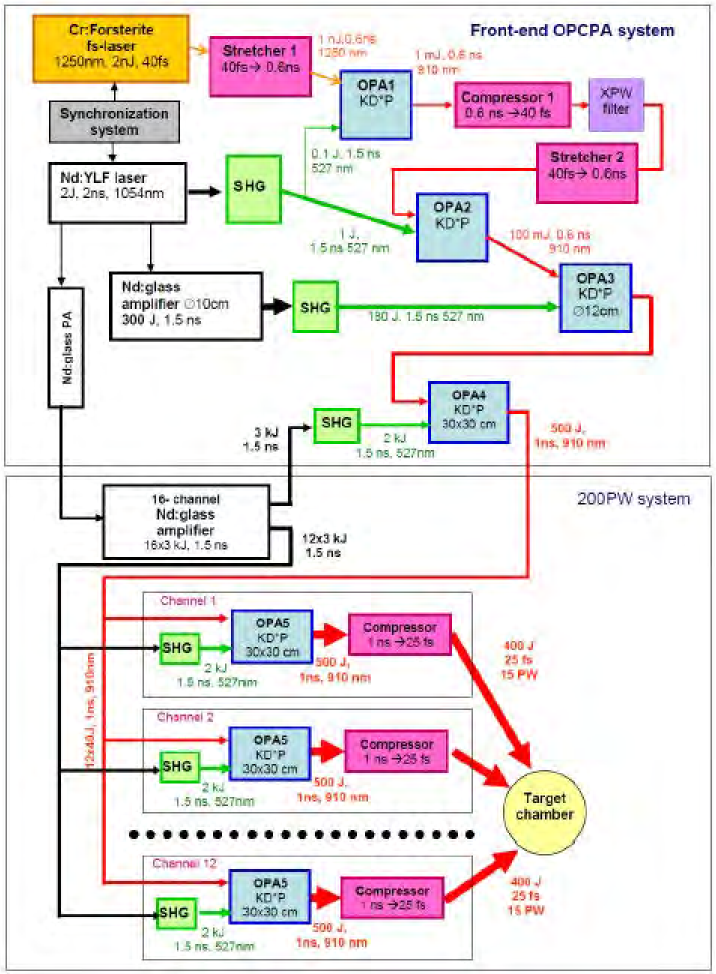
XCELS – OPCPA scheme



Megaproject XCELS

XCELS – layout



Key technologies for XCELS facility:

1. OPCPA technique
2. 3 kJ, 1.5 ns Nd: glass pump lasers
3. 30x30 cm^2 KD*P crystals
4. 50x100 cm^2, broad band (25 fs), 0.2 J/cm^2 damage threshold gratings with 910 nm central wavelength
5. Tight focusing optical system

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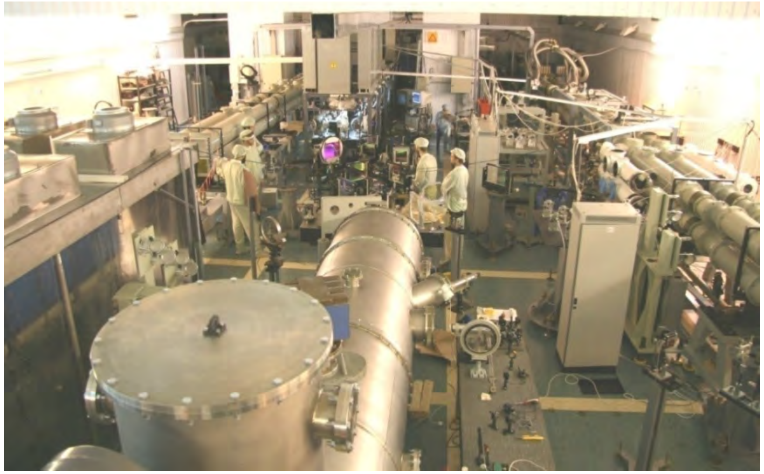
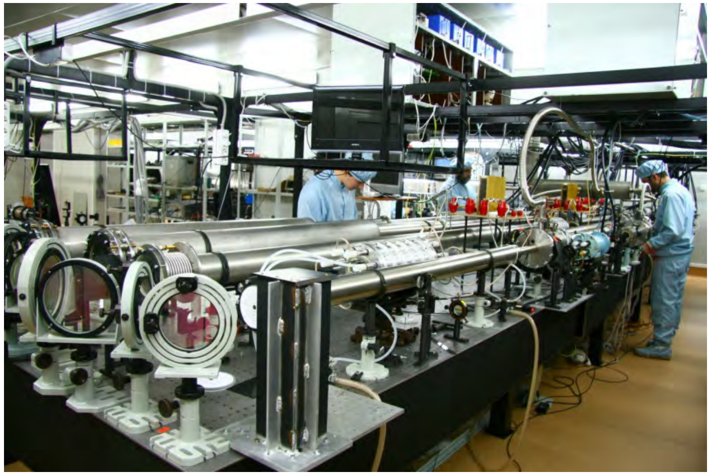
Key technologies behind XCELS laser facility

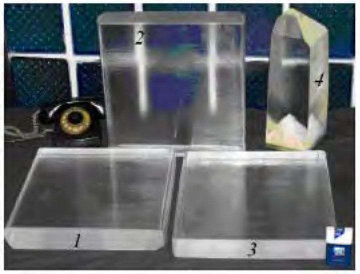
The XCELS laser facility is based on the technologies developed at the Institute of Applied Physics in Nizhny Novgorod and the Russian Federal Nuclear Center in Sarov and implemented in PEARL and FEMTA, the world's first petawatt parametric lasers

FEMTA

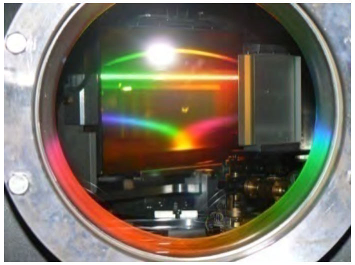


PEARL-10





Large aperture nonlinear crystals and optical gratings provide amplification and compression of laser pulses to multipetawatt level



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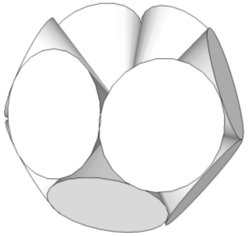
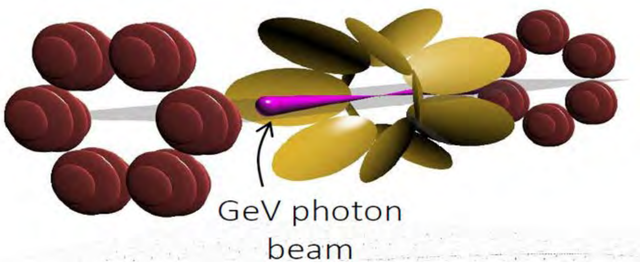
XCELS – Coherent combining to mimic converging dipole wave

Geometry	Power per channel	Intensity, $\times 10^{25} W/cm^2$	I/I(f=1.2)	Equivalent power (f=1.2)
Single beam (f=1.2)	P_0=10 PW	0.06	1	10 PW
Single beam (f=1.2)	P_0=200 PW	1.2	1	200 PW
Dipole-Wave	P_0=200 PW	16.7	13.9	2800 PW
Double-Belt-12 12× (f=0.96)	P_0/12	13.4	11.2	2200 PW





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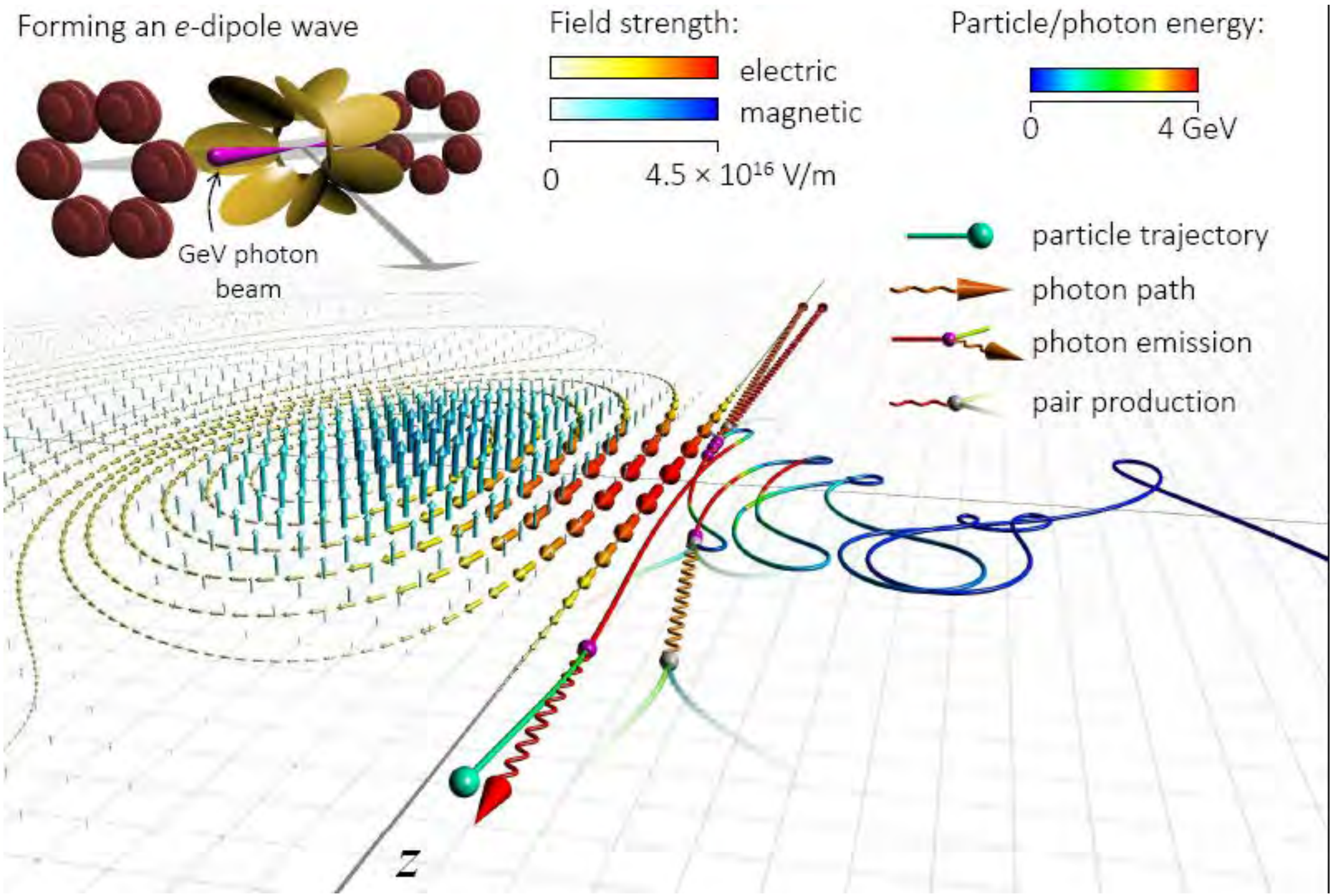
XCELS – boiling vacuum



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New science with XCELS

With XCELS we will enter a new realm of physics

Exawatt-scale laser will bring particle dynamics in the radiation dominated regime

- **QED cascades and radiation trapping of particles produce ultrarelativistic, ultradense e-e+ plasma that efficiently convert optical energy to gamma rays**

- **Controllable directed gamma ray sources of GeV photons with extreme brilliance will be soon available as a new instrument to study nuclear matter and vacuum physics**

- **Laboratory astrophysics will be provided with Gigagauss and Teragauss magnetc fields on the Earth**

- **By energy conversion from femtosecond to attosecond pulses, the Schwinger field can be approached and time-space structure of vacuum can be studied**

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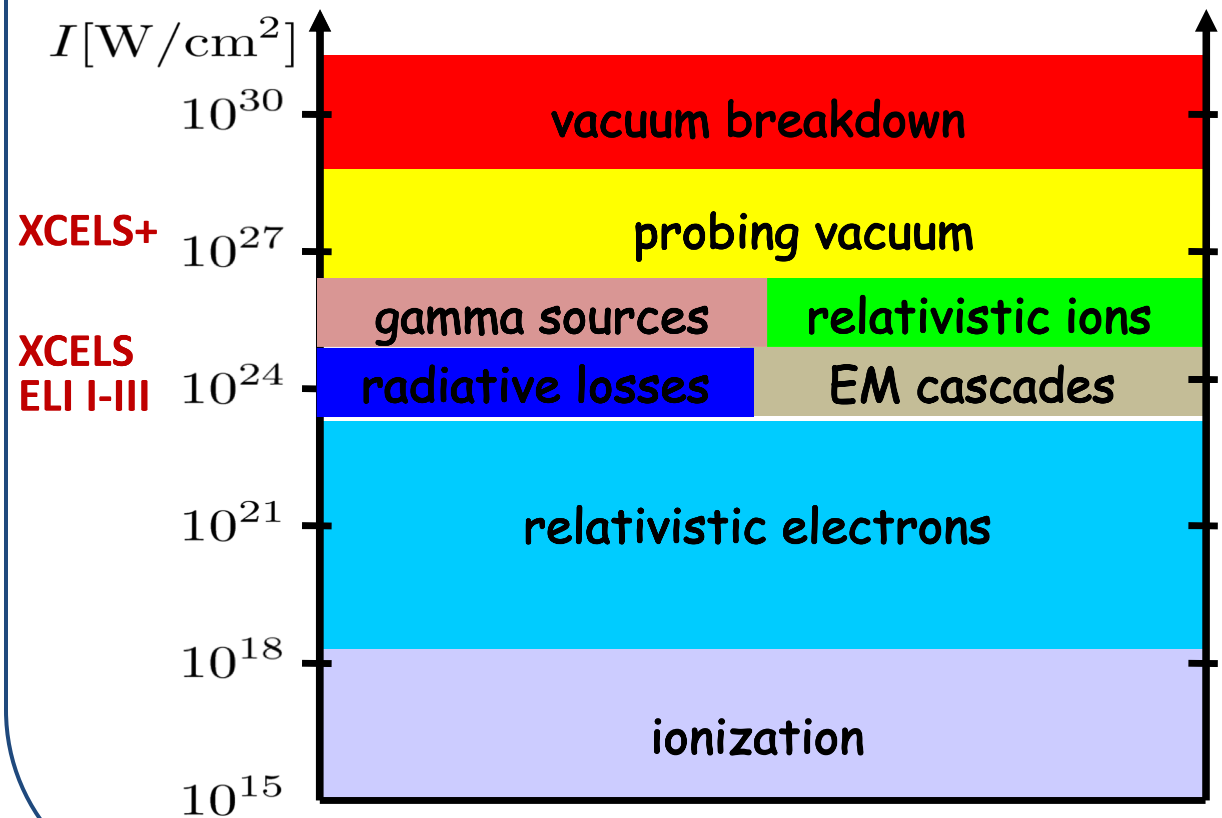
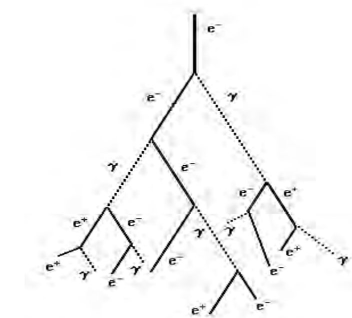
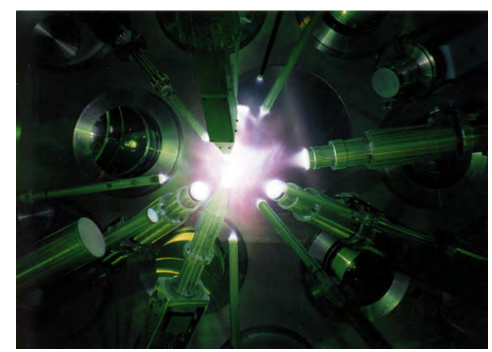
Megaproject XCELS

New science with XCELS

The main goal of XCELS is to study new science and applications at the emerging interface **between high-field physics and high-energy physics**







Electromagnetic cascades in vacuum can be produced by laser light

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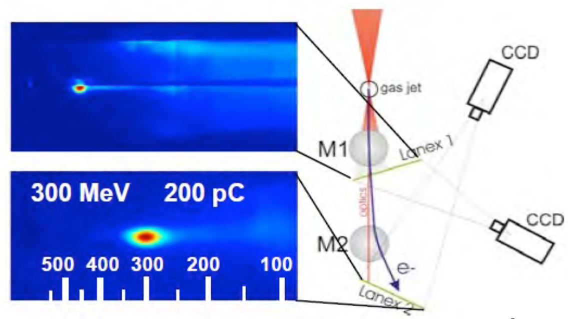
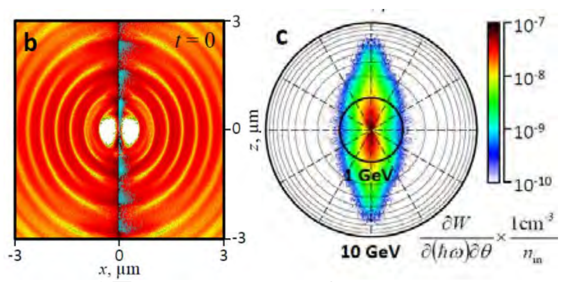
Prospects for fundamental research and applications

- Ultrarelativisitic laser-matter interaction
- Exotic states of matter with ultrahigh energy density, laboratory astrophysics
- Phenomena of nonlinear quantum electrodynamics in the presence of ultraintense laser fields; ultradense electron-positron plasma
- Study of space-time structure of vacuum
- Nuclear optics

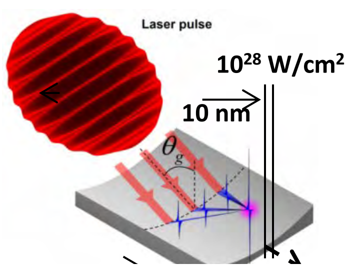


Electron acceleration with rate 1 GeV/cm

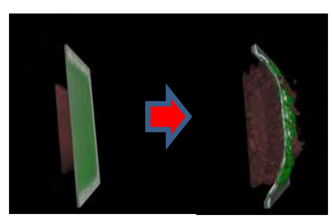


Directed Γ-ray source with 10 GeV quanta

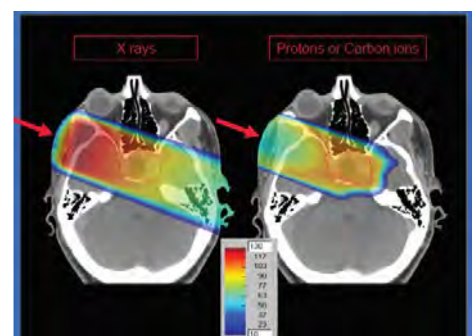
- Ultracompact particle acceleration
- Directed brilliant gamma-ray sources
- Material diagnostics and metrology with picometer spatial and subfemtosecond temporal resolution
- Advanced particle and radiation sources for medicine, pharmacology, radiography, nuclear inspection and processing



Generation of giant attosecond pulses for probing of quantum vacuum



300 MeV protons from thin foils for hadron therapy



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International Collaboration

The main contribution of foreign partners is supposed in the form of high-tech research equipment for the laser complex and research laboratories

Interest to collaborate from:

- The Ministry of Education and Science of France
- The Commissariat of Atomic Energy of France
- Thales (France)
- The Nuclear Energy Agency of Japan
- High Energy Accelerator Research Organization KEK (Japan)
- Center for Antiproton and Ion Research- FAIR (Germany)
- Extreme Light Infrastructure - ELI (Europe)
- Lawrence Livermore National Laboratory (USA)
- Los Alamos National Laboratory (USA)
- Fermi National Accelerator Laboratory (USA)
- Rutherford Appleton Laboratory (UK)
- The John Adams Institute for Accelerator Science (UK)

XCELS International Advisory Committee was founded in December 2011

T.Tajima, Chair of ICUIL

G.Mourou, Chair of XCELS IAC

Gérard Mourou – Chair, Ecole Polytechnique, France
Christian Barty – Lawrence Livermore National Laboratory ,USA
Paul Bolton – Kansai Photon Science Institute, Japan
Maria Douka – European Commission
Bjorn Manuel Hegelich – University of Texas at Austin, USA
Dino Jaroszynski – SCAPA ,University of Strathclyde, UK
Kazuoshi Koyama – KEK, Japan
Thomas Kuehl – GSI Helmholtzzentrum, Germany
Thierry Massard – Commissariat of Atomic Energy, France
Toshiki Tajima – International Committee for Ultraintense Lasers, ICUIL

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Megaproject XCELS

International Expertise

Report on XCELS
by the
International Advisory Committee

Gérard Mourou, Paul Bolton, Maria Douka, Dino Jaroszynski, Bjorn Manuel Hegelich, Thierry Massard, Wolfgang Sandner, Toshiki Tajima, Thomas Kuehl, Kazuoshi Koyama

Conclusion

Based on the description of the conceptual design, the scientific committee is convinced of the quality and timeliness of the XCELS project. XCELS is ambitious and designed to introduce a new paradigm in High Energy Physics where high-energy particles are replaced by an ultrahigh laser field. XCELS could be the premiere laser-based High Energy Physics platform in the world occupying a prominent scientific position. The committee is of the opinion that the XCELS conceptual design phase has been completed and recommends advancement to the prototyping phase. The appropriate funding should be allocated. During this phase, which would last two to three years, we recommend that the current team works in concert with the international community as early as possible. This, includes, in particular the ELI Consortium.

During this phase the design will be finalized. It should include specification of the laser, the beamline configuration and experimental halls. An early integration with the international community will facilitate and encourage other countries to join and help to fund the project.

Gérard Mourou
Chair of the International Advisory Committee

EUROPEAN COMMISSION

DIRECTORATE-GENERAL FOR RESEARCH & INNOVATION

REPORT OF THE EXPERT GROUP ON THE ASSESSMENT OF EU COOPERATION WITH SIX RUSSIAN FEDERATION MEGASCIENCE PROJECTS

"The expert group encourages the Russian authorities to timely implement the first stages of the XCELS project, in order to demonstrate the feasibility of the project to the potential partners and to keep up with the dynamic international evolution of high-power lasers. "
Dec. 20, 2013

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Collaboration - Recent MoUs

China (Shanghai Institute of Optics and Fine Mechanics (SIOM) of the Chinese Academy of Sciences): IAP RAS and SIOM signed a MoU on collaboration in the field of ultra-high intensity lasers in August 2017.

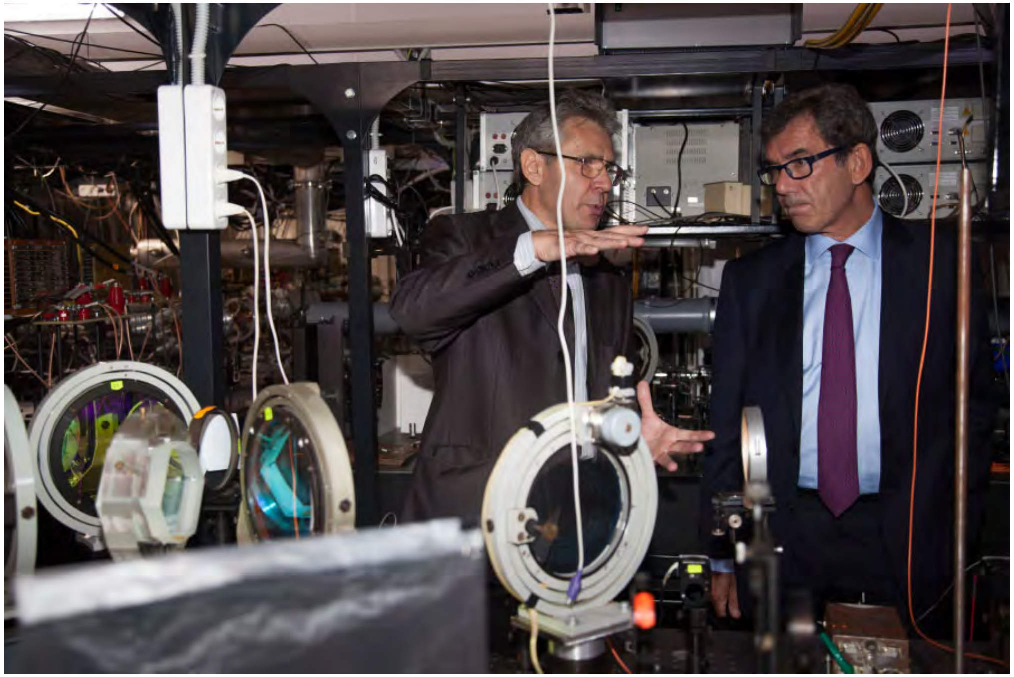
India (Tata Institute of Fundamental Research (TIFR) of the Department of Atomic Energy): IAP RAS and TIFR signed a MoU on collaboration within the framework of XCELS.

Greece (Ministry of Science, Education and Religious Affairs (MSERA) of the Republic of Greece): IAP RAS and MSERA signed a MoU on collaboration in the field of development and exploitation of Petawatt and Exawatt power laser facilities in 2016.

France (Thales Optronique): IAP RAS and Thales Optronique signed a MoU on collaboration within the framework of XCELS.

Megaproject XCELS

Visits to XCELS prototype at IAP



Jean-Maurice Ripert,
Ambassador Extraordinary and Plenipotentiary
of France in the Russian Federation

Megaproject XCELS

ELI

ELI will comprise 4 branches:

• **Attosecond Laser Science**, which will capitalize on new regimes of time resolution (*ELI-ALPS*, Szeged, HU)

• **High-Energy Beam Facility**, responsible for development and use of ultra-short pulses of high-energy particles and radiation stemming from the ultra-relativistic interaction (*ELI-Beamlines*, Prague, CZ)

• **Nuclear Physics Facility** with ultra-intense laser and brilliant gamma beams (up to 19 MeV) enabling also brilliant neutron beam generation with a largely controlled variety of energies (*ELI-NP*, Magurele, RO)

• **Ultra-High-Field Science** centred on direct physics of the unprecedented laser field strength (*ELI 4*, to be decided)

W. Sandner, ELI 2013-01

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Megaproject XCELS

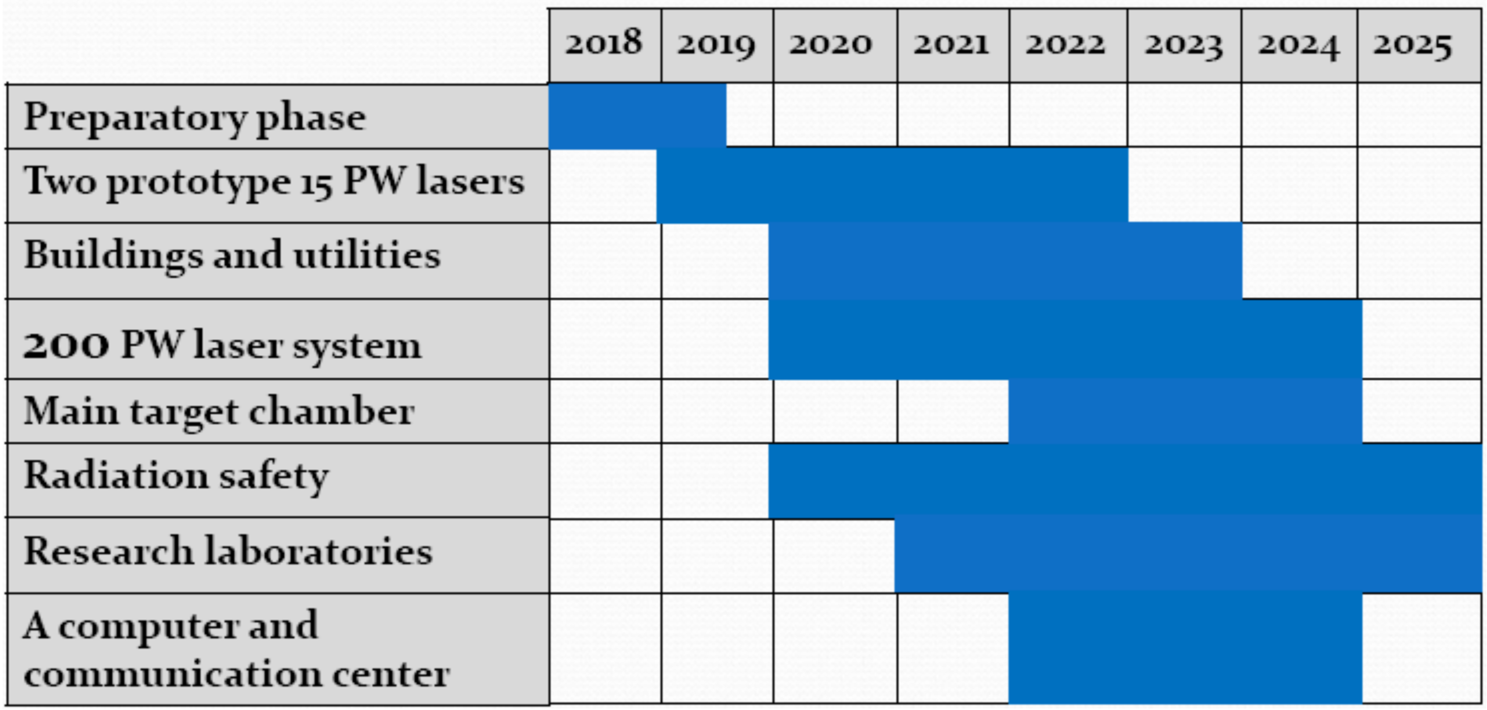
Progress in China

Shanghai Institute of Optics and Fine Mechanics (SIOM)
Qiangguang 10 PW laser under construction.
In 2015, the world highest peak power 5 PW (150 J in 30 fs) performance was demonstrated

Ruxin Li, Director of SIOM

Megaproject XCELS

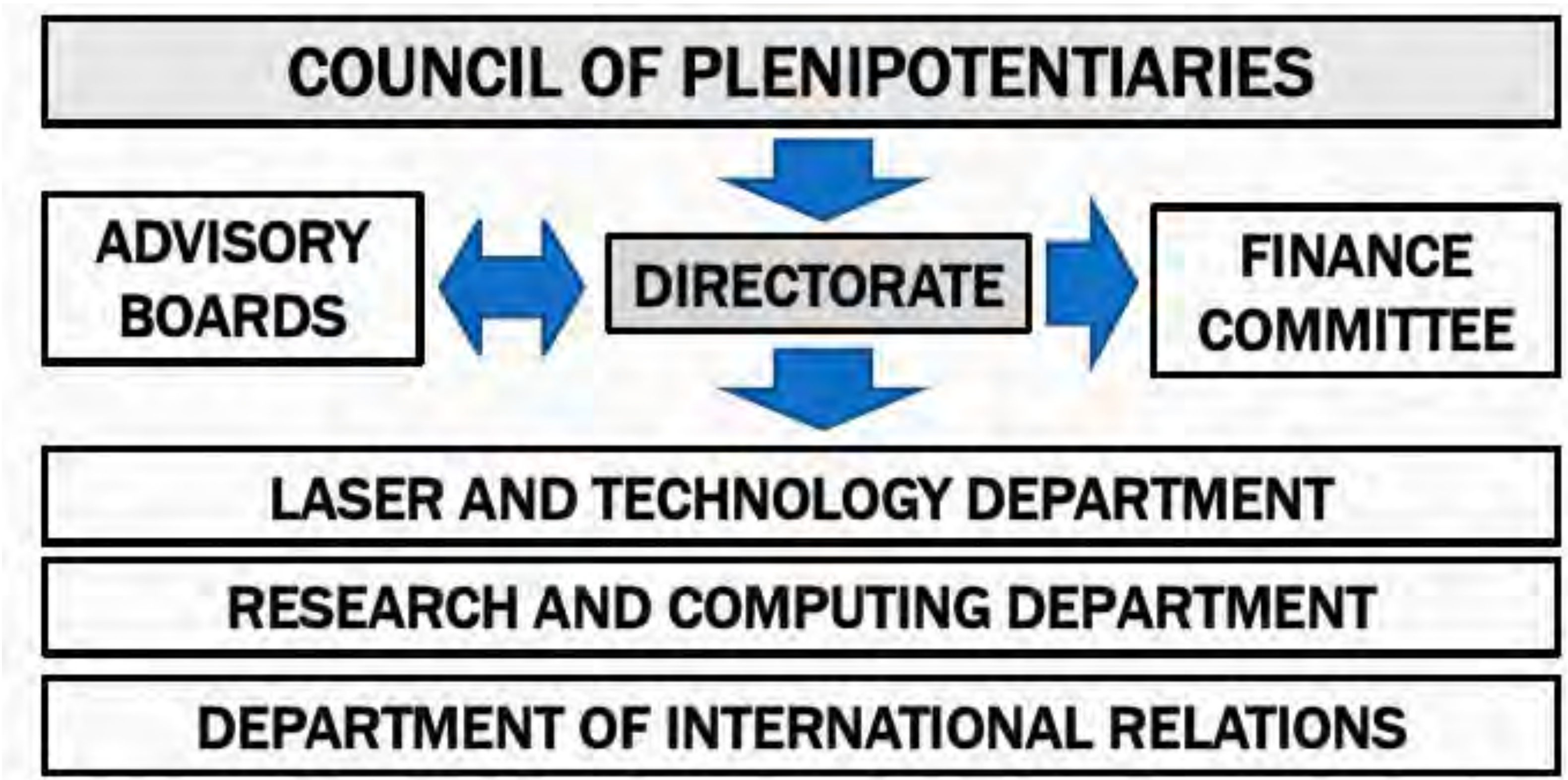
XCELS - roadmap



XCELS - Exawatt Center for Extreme Light Studies

Megaproject XCELS

XCELS - Project management



XCELS - Exawatt Center for Extreme Light Studies

Megaproject XCELS

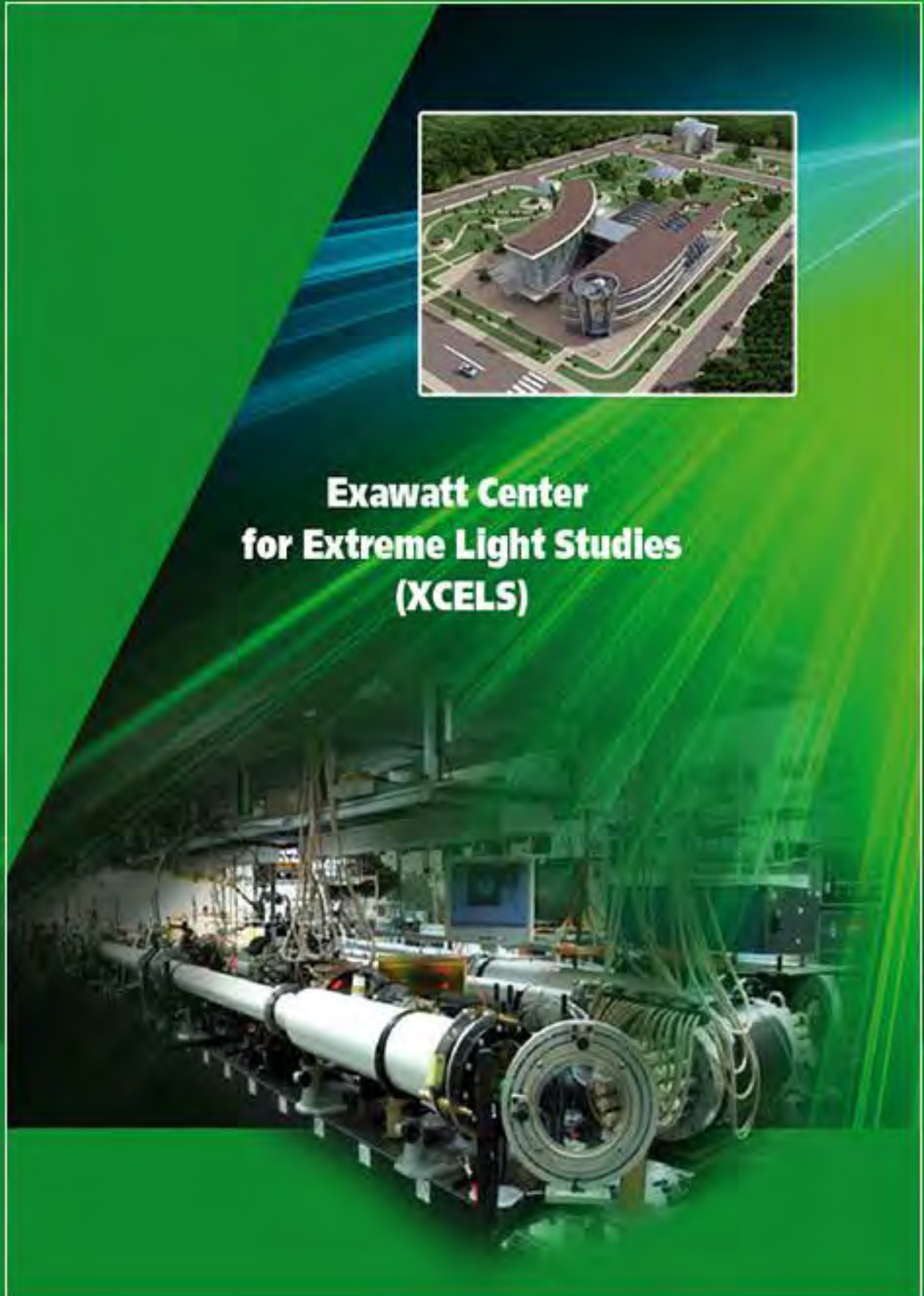
XCELS - Project management

The construction and operation of the XCELS shall be entrusted to a Limited Liability Company, which shall be subject to the Russian Federation law. The Supreme governing body of XCELS could be the Council of Plenipotentiaries of the governments of all Member States. The organs of the Company shall be the Council of Plenipotentiaries, and the Management Board. The Company exclusively and directly pursues nonprofit objectives in the field of science and research. The Management Board of the Company is composed of Managing Directors Scientific/Technical Directors. The division of responsibilities of the Directors shall be established by the Council. The Directors shall be appointed for a period not exceeding five years. Appointment, employment and termination of the appointment of the Directors as well as any amendment or enlargement of their contracts of employment shall be subject to the approval by the Council. The Council shall appoint the members of the Scientific Advisory Committee and Machine Advisory Committee by qualified majority.

Megaproject XCELS

XCELS – building design

XCELS - Exawatt Center for Extreme Light Studies

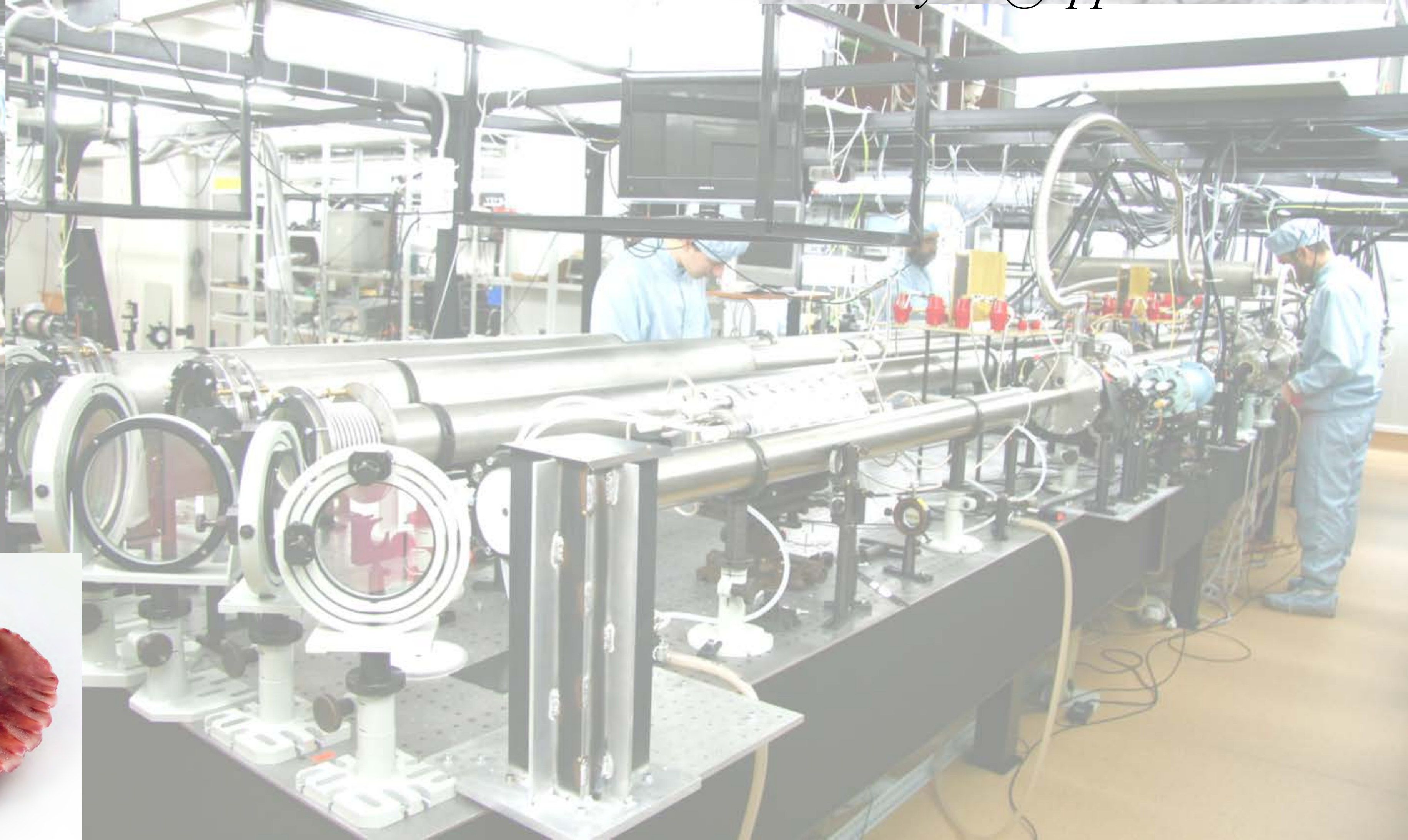


Exawatt Center
for Extreme Light Studies
(XCELS)

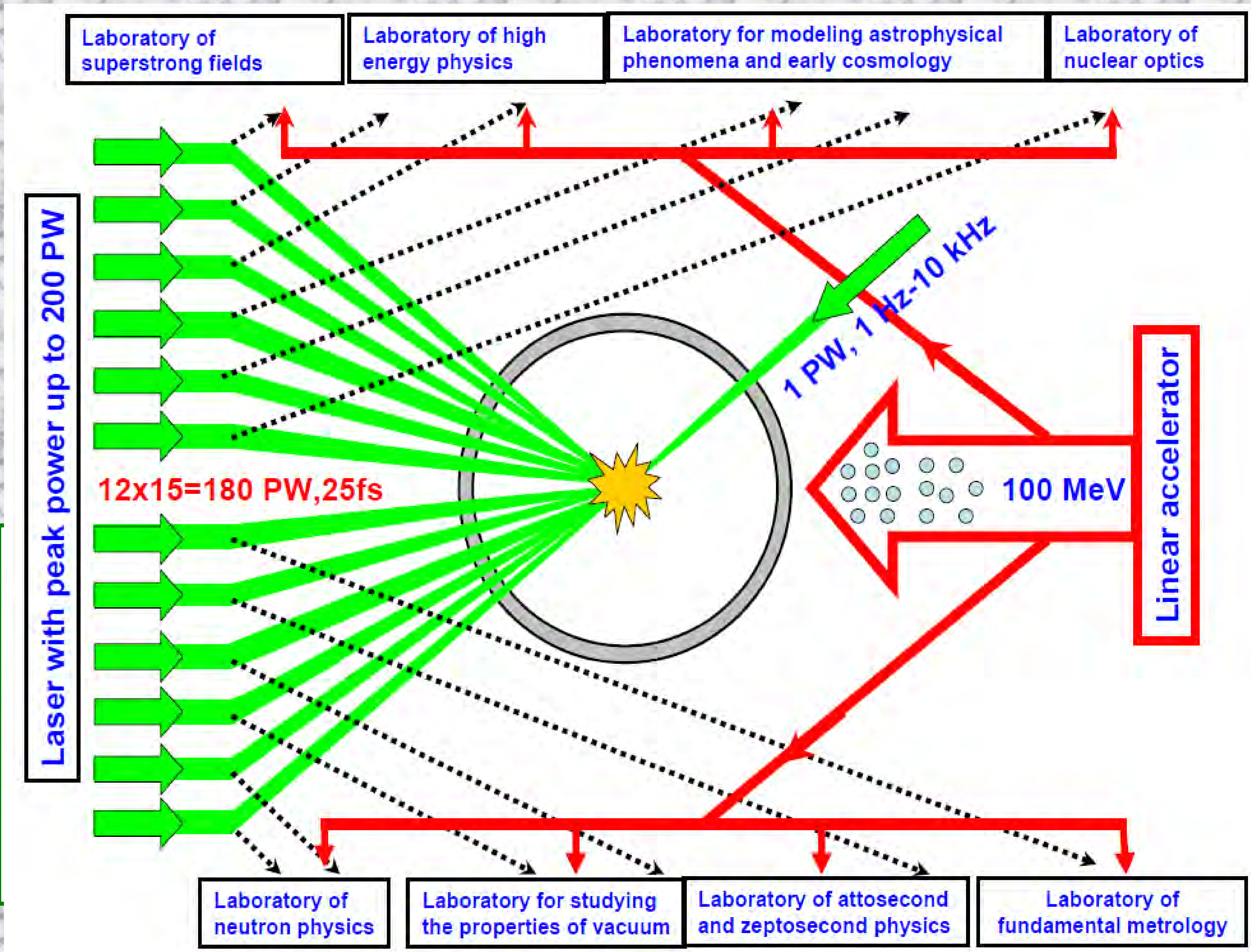
XCELS laser requirements

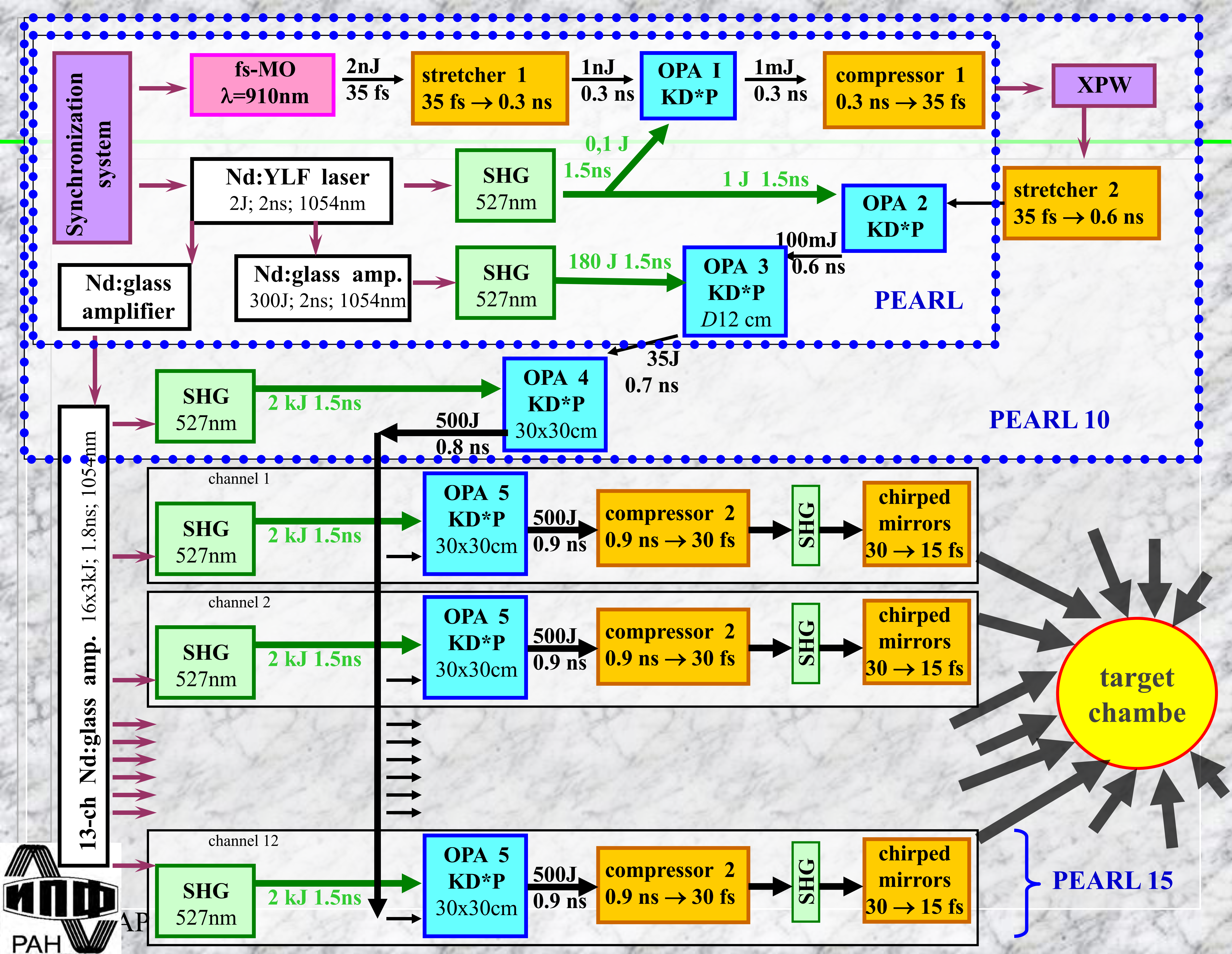
A. Shaykin

Institute of Applied Physics, Russian Academy of Science, Nizhny Novgorod, Russia, shaykin@appl.sci-nnov.ru



XCELS laser requirements




Synchronization system
fs-MO
λ=910nm
2nJ
35 fs
stretcher 1
35 fs → 0.3 ns
1nJ
0.3 ns
OPA I
KD*P
1mJ
0.3 ns
compressor 1
0.3 ns → 35 fs
XPW
stretcher 2
35 fs → 0.6 ns
Nd:YLF laser
2J; 2ns; 1054nm
SHG
527nm
0,1 J
1.5ns
1 J 1.5ns
OPA 2
KD*P
100mJ
0.6 ns
Nd:glass amplifier
Nd:glass amp.
300J; 2ns; 1054nm
SHG
527nm
180 J 1.5ns
OPA 3
KD*P
D12 cm
PEARL
35J
0.7 ns
SHG
527nm
2 kJ 1.5ns
OPA 4
KD*P
30x30cm
500J
0.8 ns
PEARL 10
13-ch Nd:glass amp. 16x3kJ; 1.8ns; 1054nm
channel 1
SHG
527nm
2 kJ 1.5ns
OPA 5
KD*P
30x30cm
500J
0.9 ns
compressor 2
0.9 ns → 30 fs
SHG
chirped mirrors
30 → 15 fs
channel 2
SHG
527nm
2 kJ 1.5ns
OPA 5
KD*P
30x30cm
500J
0.9 ns
compressor 2
0.9 ns → 30 fs
SHG
chirped mirrors
30 → 15 fs
channel 12
SHG
527nm
2 kJ 1.5ns
OPA 5
KD*P
30x30cm
500J
0.9 ns
compressor 2
0.9 ns → 30 fs
SHG
chirped mirrors
30 → 15 fs
PEARL 15
target chambe
ИПФ
РАН

200 PW laser for XCELS.

DKDP crystal growing

Installations for growing large-aperture nonlinear optical crystals in IAP RAS (left) and element for frequency conversion of superintense optical radiation

XCELS laser requirements.

PUMP lasers.

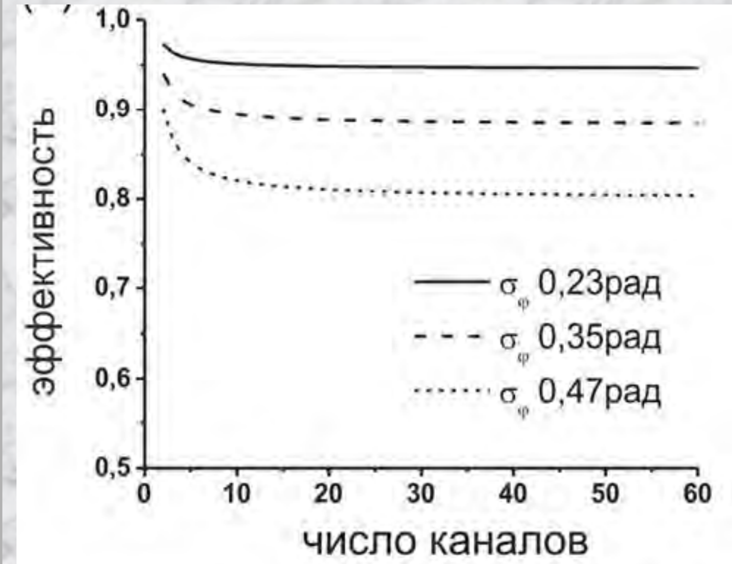
16 chanals aperture 30 x 30 cm;
3 kJ @ 1054 nm (2 kJ @ 527 nm) 1.5ns

XCELS laser requirements

Grating

XCELS laser requirements

coherent combining



Combining by parabolic mirror.
W~1mJ; t~28fs.
Doublestage sinhronization
(up to 170as).
Combining effisiency ~83%

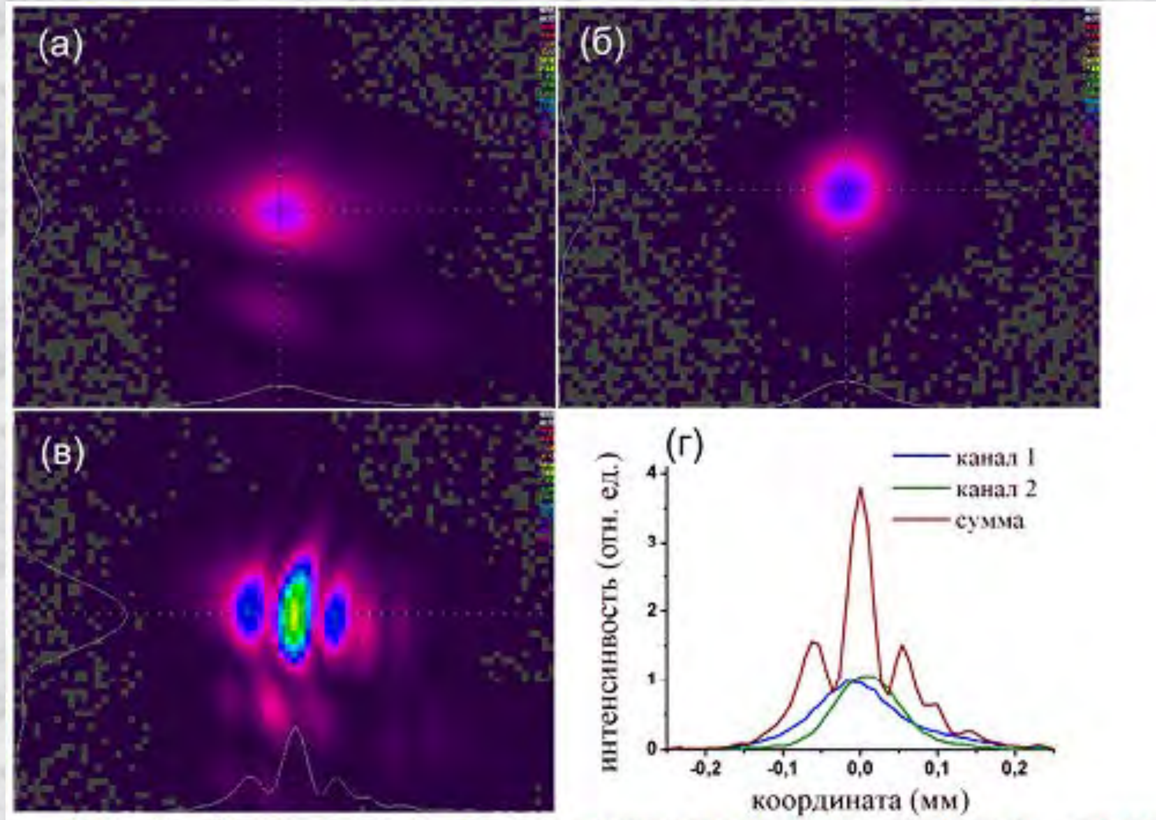


Рис. 7. Когерентное сложение мультитераваттных усиленных сжатых
пульсов: профили в первом канале (а), втором канале (б), суммарного пучка (в) и
ризонтальная проекция данных (г).

High-intensity femtosecond laser systems based on coherent combining of optical fields **Bagayev S.N., Trunov V.I., Pestryakov E.V., Leschenko V.E., Frolov S.A., Vasiliev V.A.** Optics and Spectroscopy**. 2013. T. 115.** № 3**. C. 311-319.**

Goodno G. D., Shih C., and Rothenberg J. E. Perturbative analysis of coherent combining efficiency with mismatched lasers // Opt. Express. 2010. V. 18, № 24. P. 25403–25414.

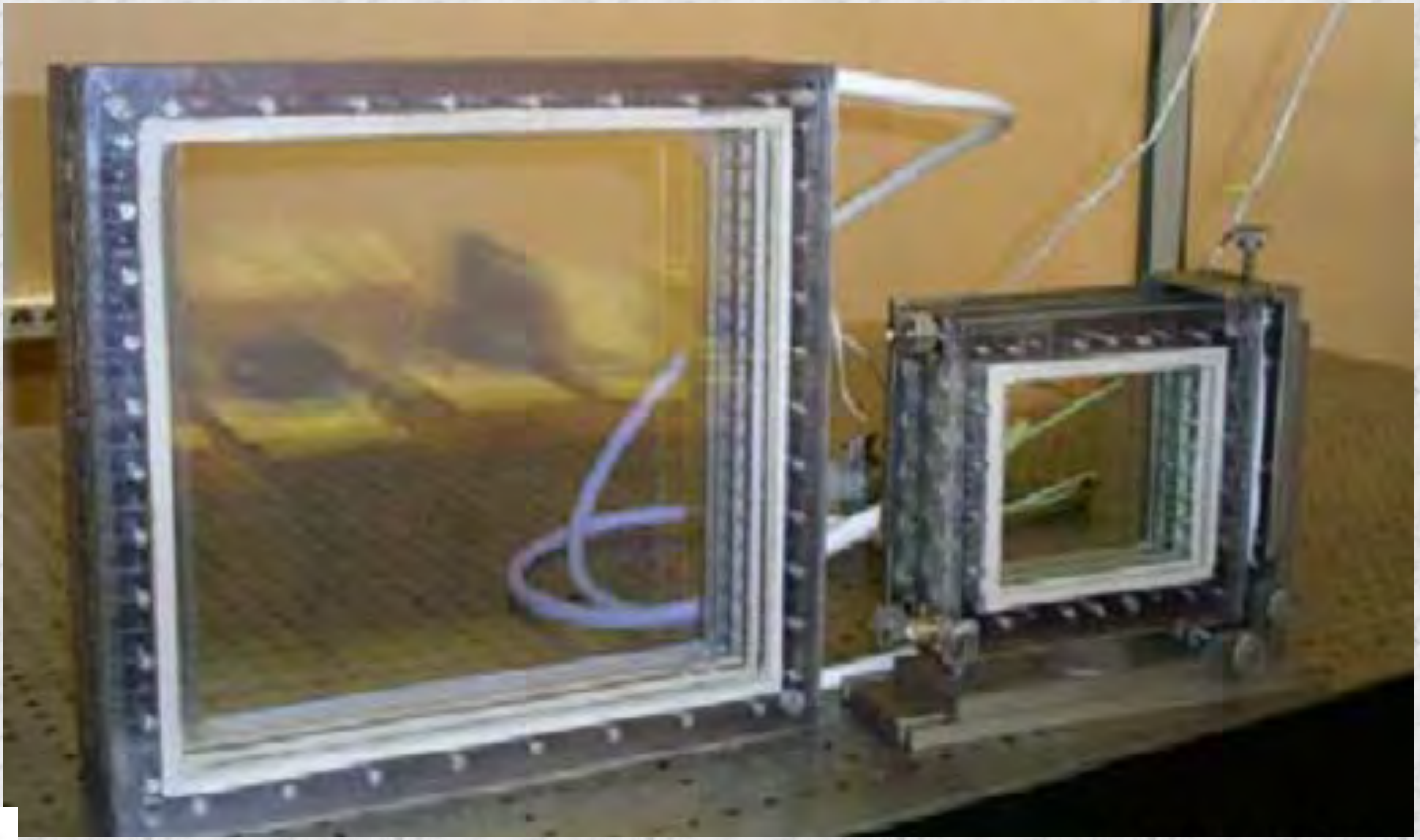
Klenke A., Seise Y., Limpert J., and Tünnermann A. Basic considerations on coherent combining of ultra-short laser pulses // Opt. Express. 2011. V. 19, № 25. P. 25379–25387.

Siiman L. A., Chang W., Zhou T., and Galvanauskas A. Coherent femtosecond pulse combining of multiple parallel chirped pulse fiber amplifiers // Opt. Express. V. 20, № 16. P. 18097–18116.

ИПФ РАН IAP RAS

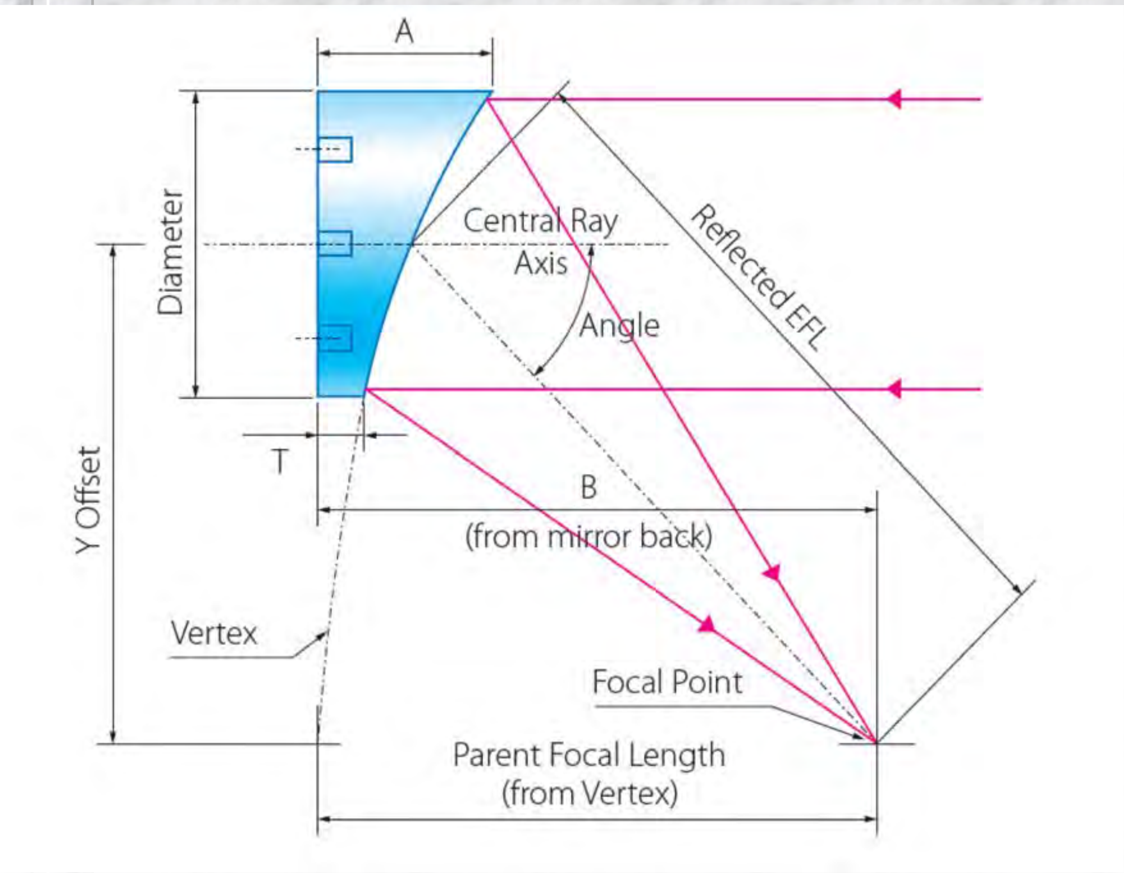
200 PW laser for XCELS.

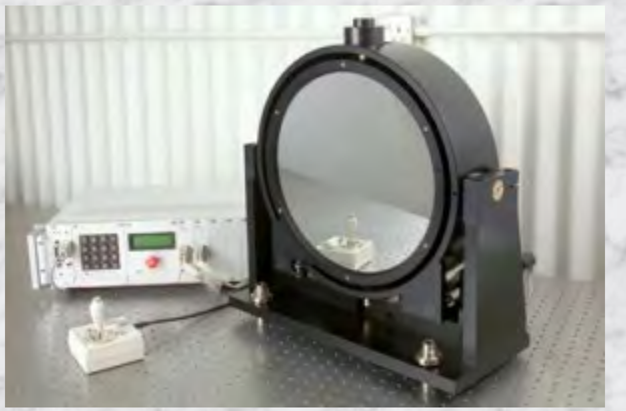
Pokkels Cell

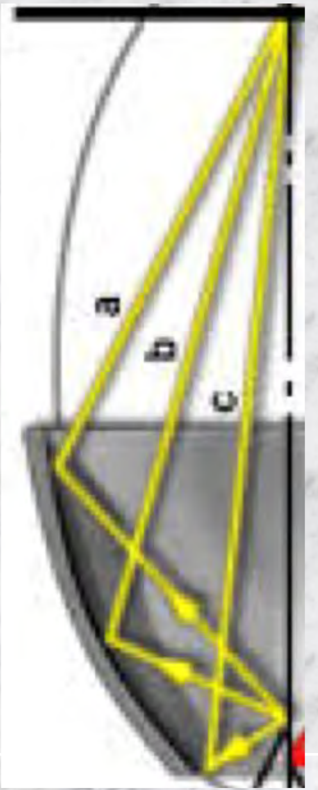


XCELS laser requirements

parabolic, plasma mirror, and adaptive optics

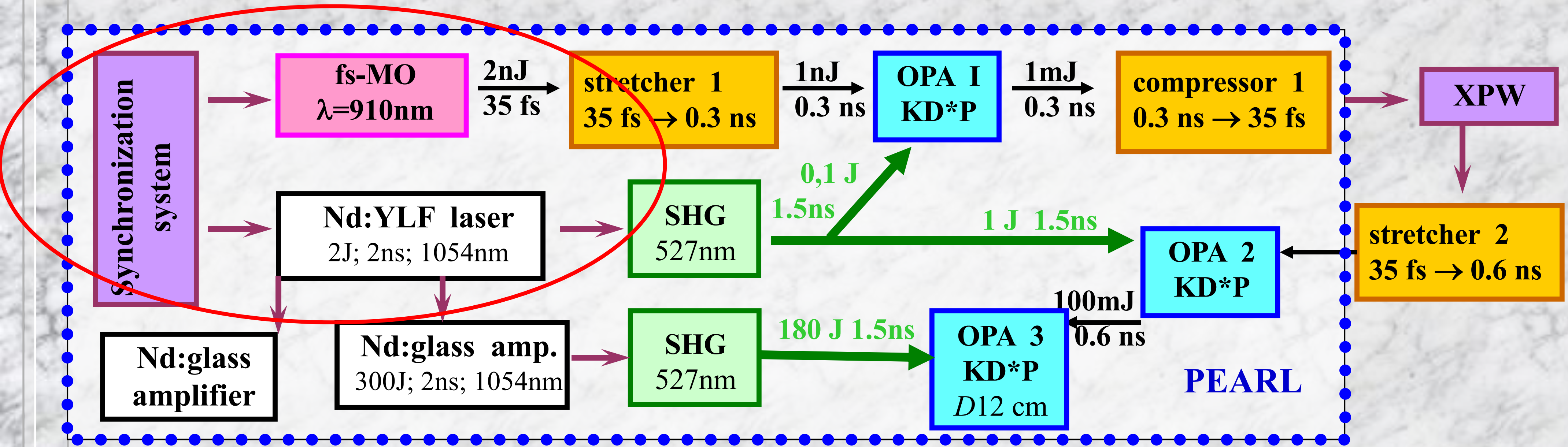






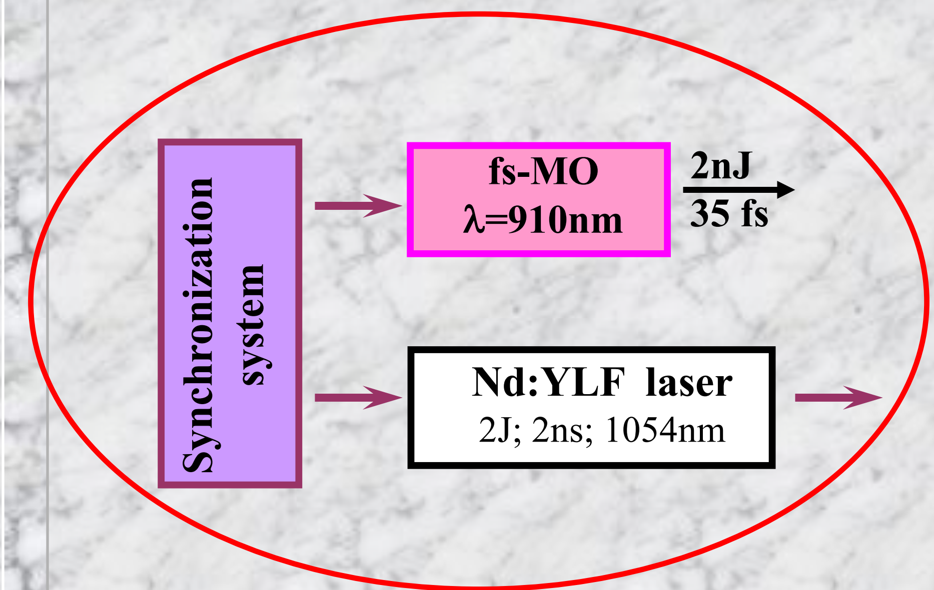
XCELS laser requirements.

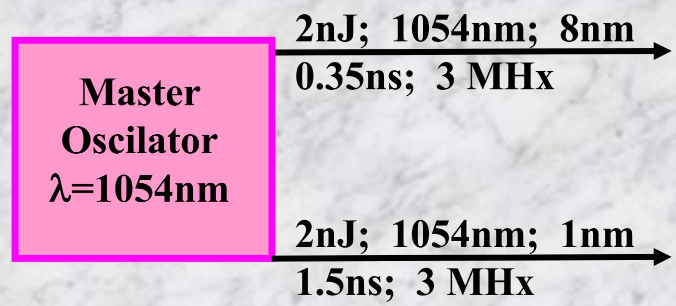
Seed. Optical synchronization.

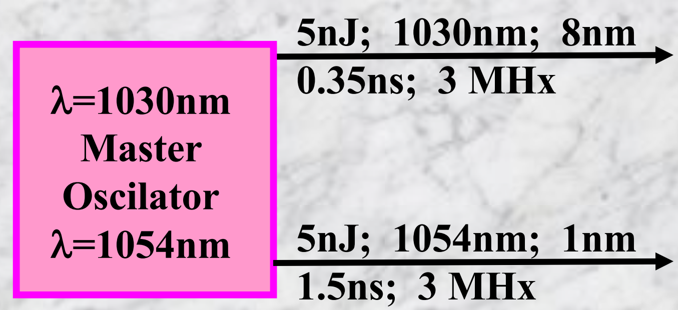


XCELS laser requirements.

Seed. Optical synchronization.







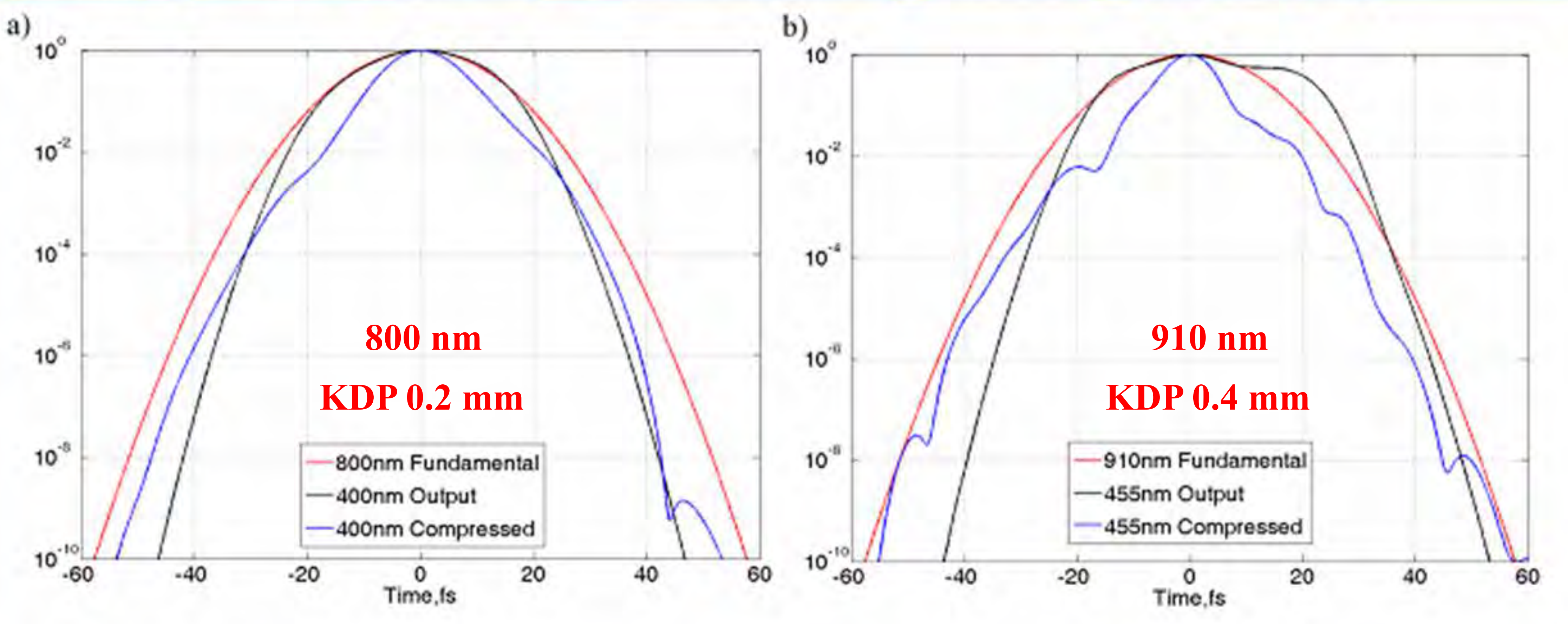
XCELS laser requirements. Sumary.

	Russia	Europe
Pump laser: 3kJ; 2ns @ 1054nm	V	?
DKDP crystals 30 x 30 cm	V	?
Gratings 500 x 1000 mm	-	V
Pokkels Cell	V	
Parabolic mirror	V	V
Plasma mirror		V
Deformable mirror	V	V
“double channel seed”	V	?
Chirped mirror	-	V
Thin film SHG	?	V
Diode pumping amplifiers for Nd:YAG (D5; D6; D15mm)	V	V

XCELS laser requirements

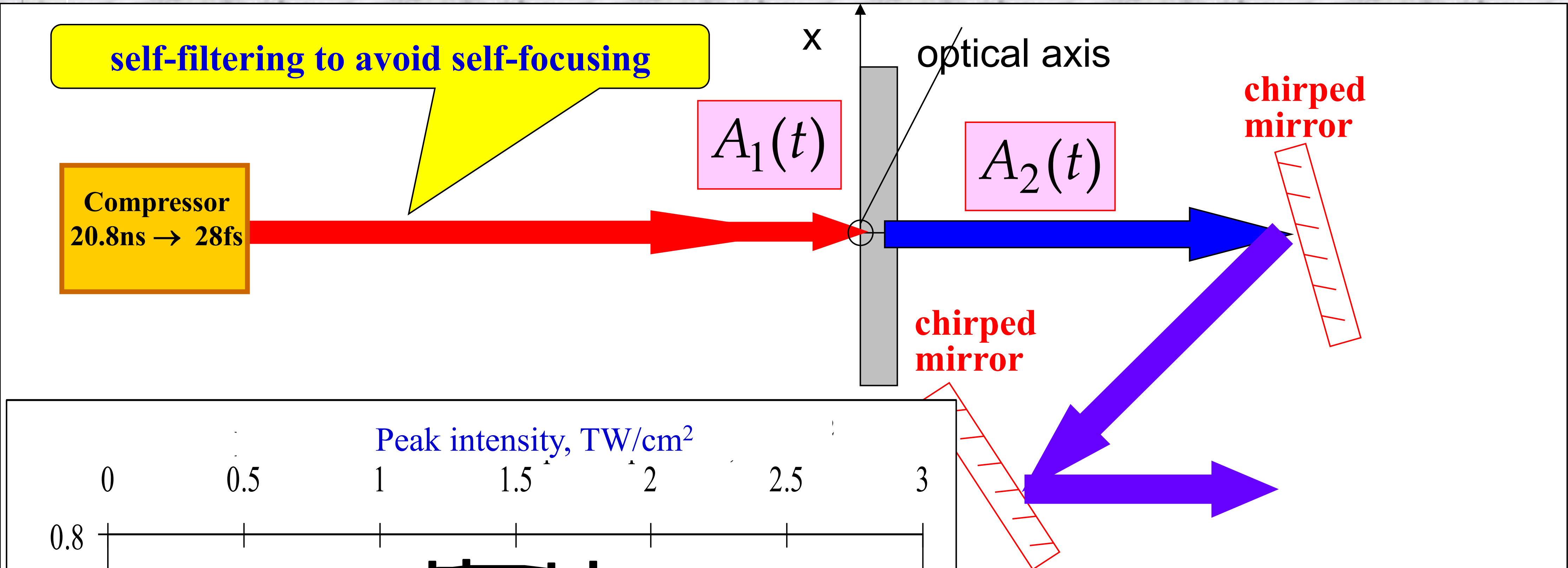
200 PW laser for XCELS.

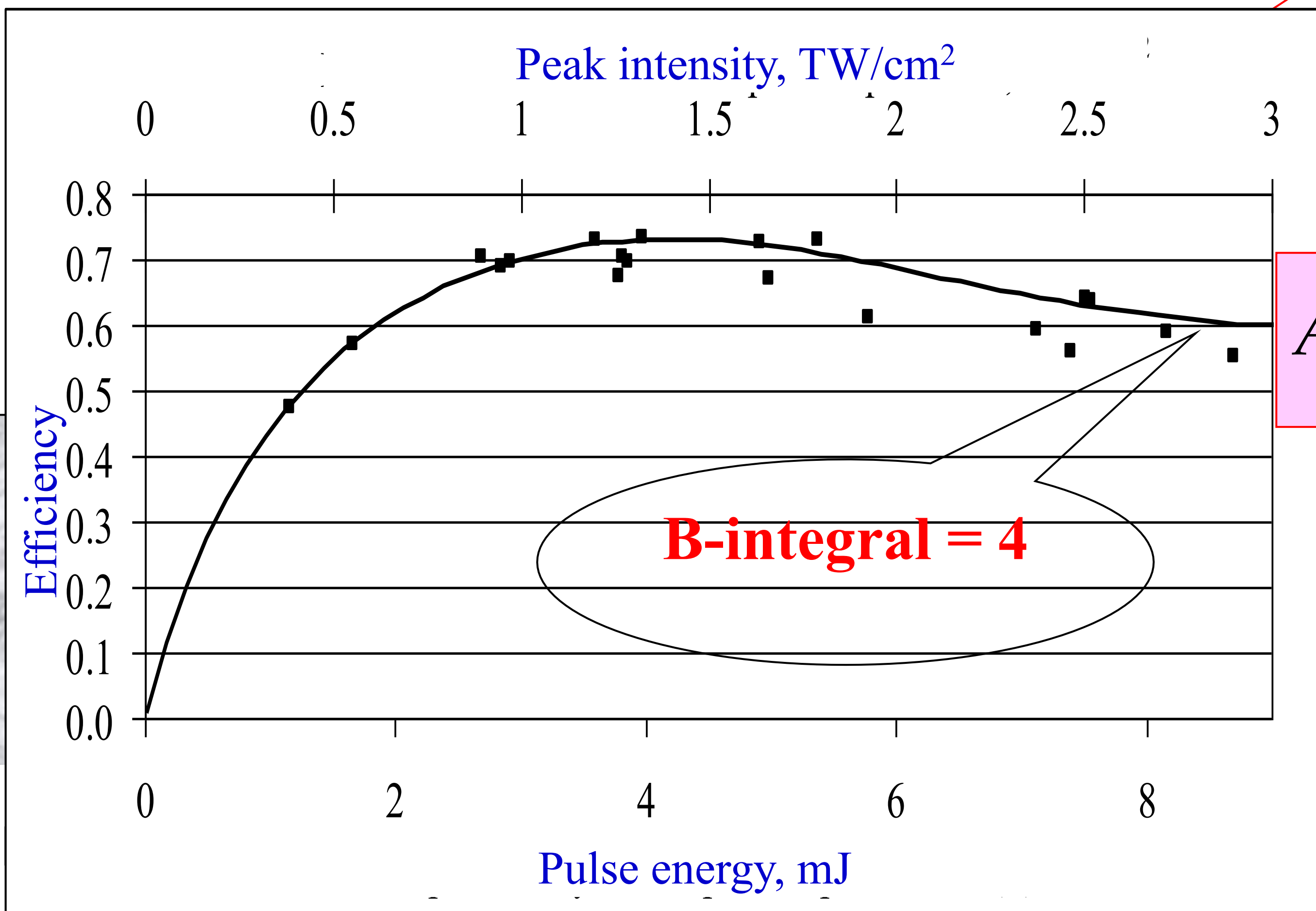
Pulse shortening and contrast enhancement.



Only linear chirp reduces pulse duration by factor of 3

Pulse shortening and contrast enhancement.



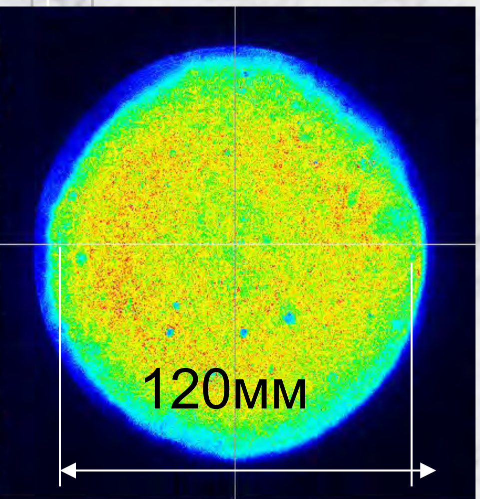


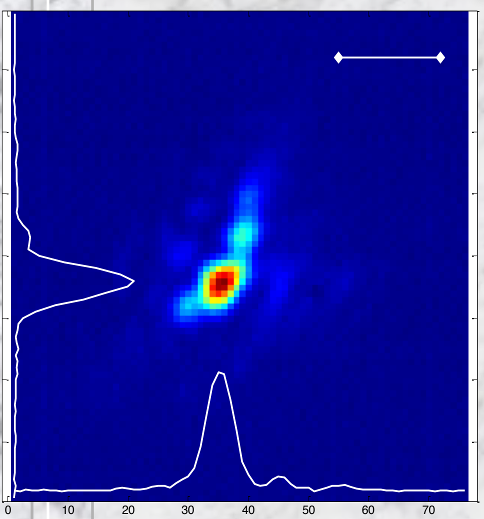
$$A_{2comp}(t) = F\left[e^{i\alpha\omega^2} \cdot F^{-1}\left[A_2(t)\right]\right]$$

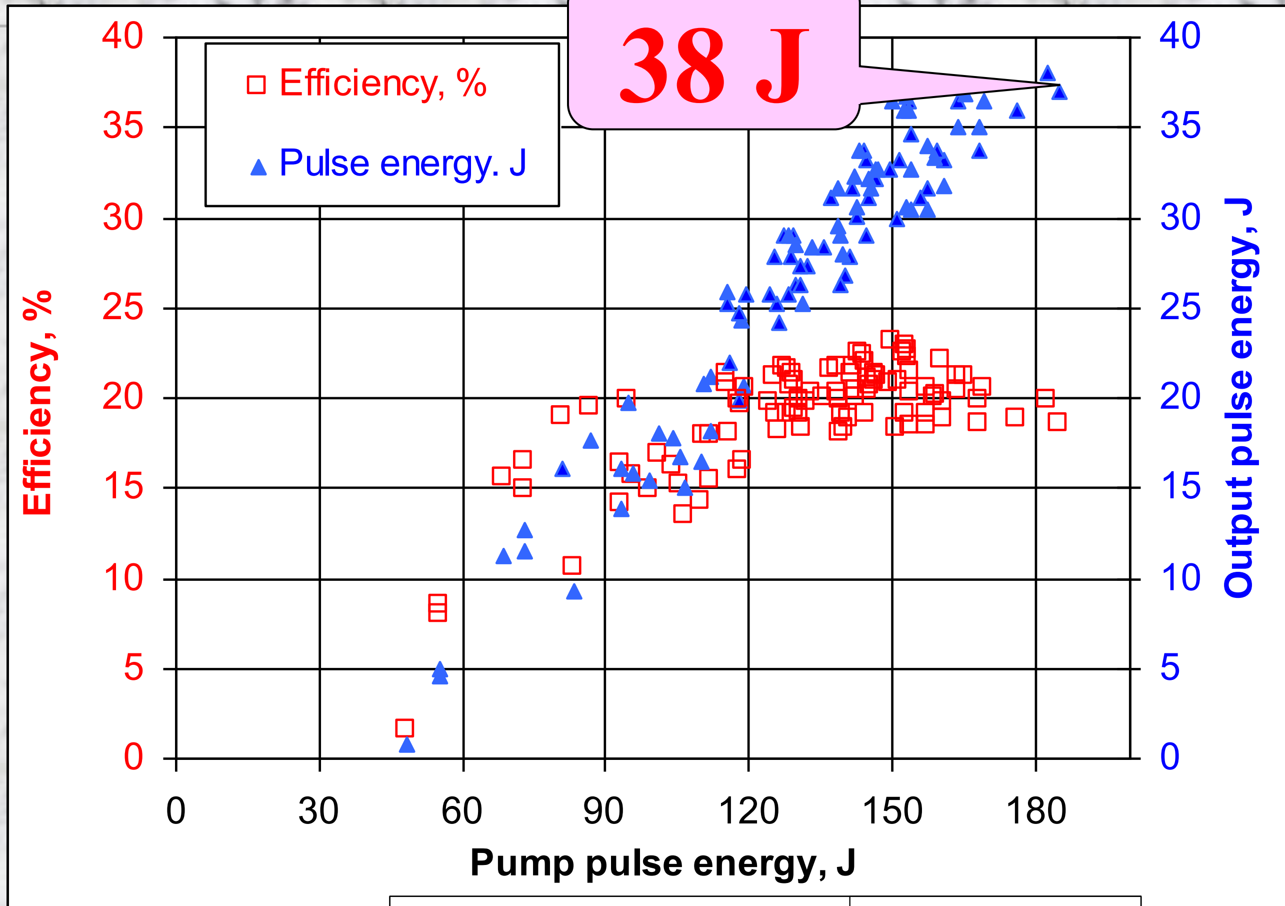
only linear chirp

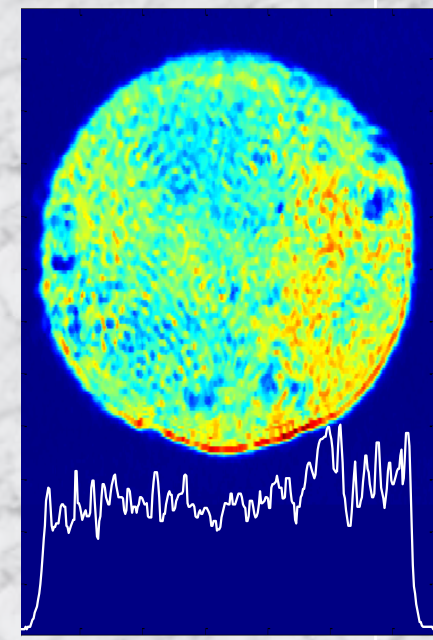
PEtawatt pARametric Laser (PEARL).

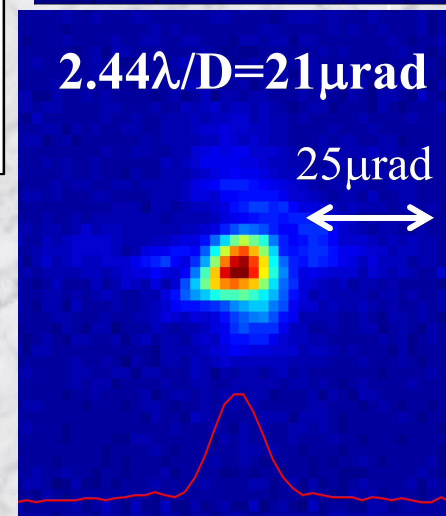
300J, 1ns

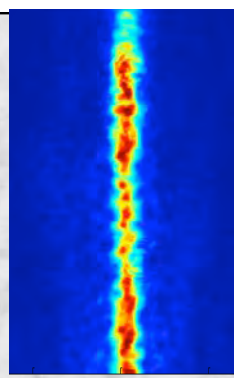


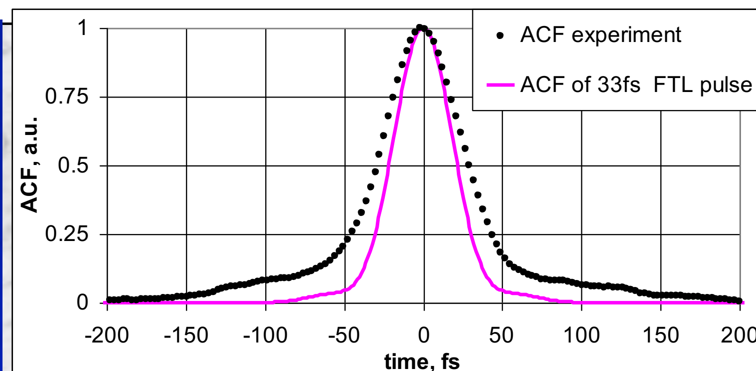






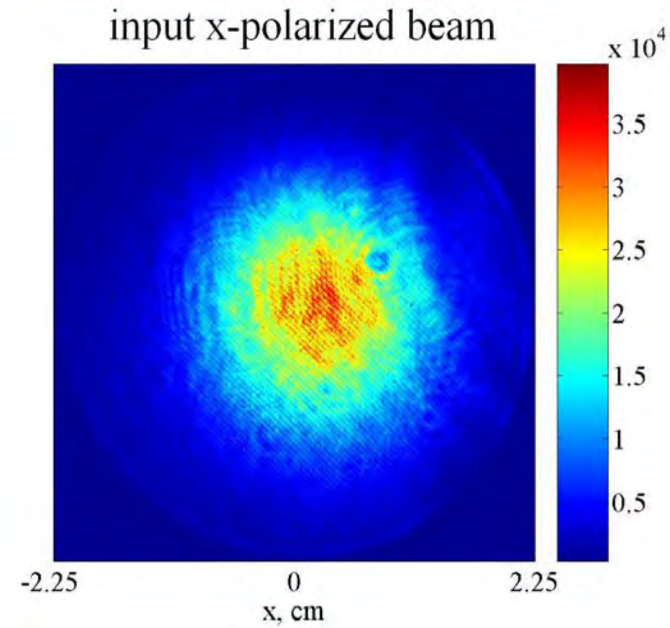






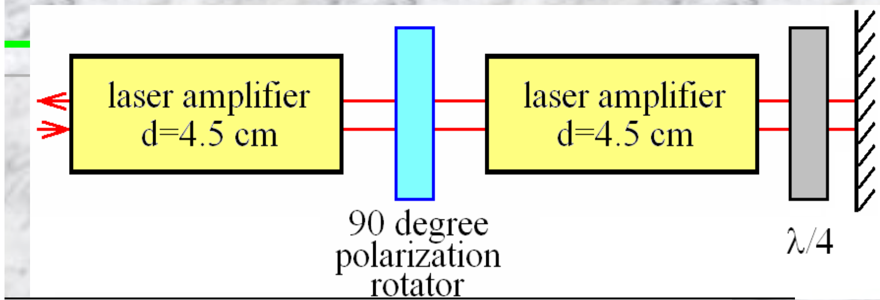
24 J /43 fs=0.56 PW

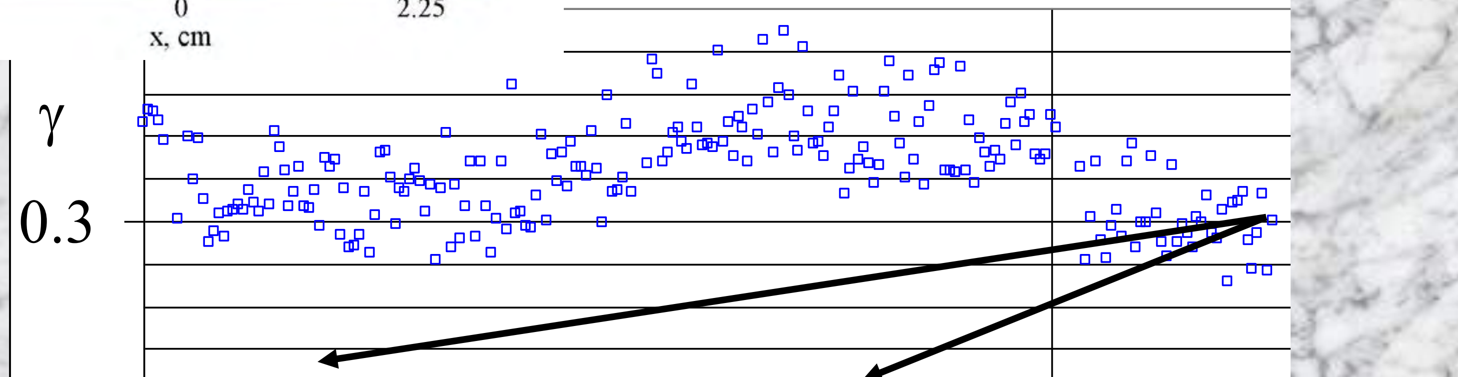
Contrast: 10^8 (0.5ns window)
10^4 (1ps window)

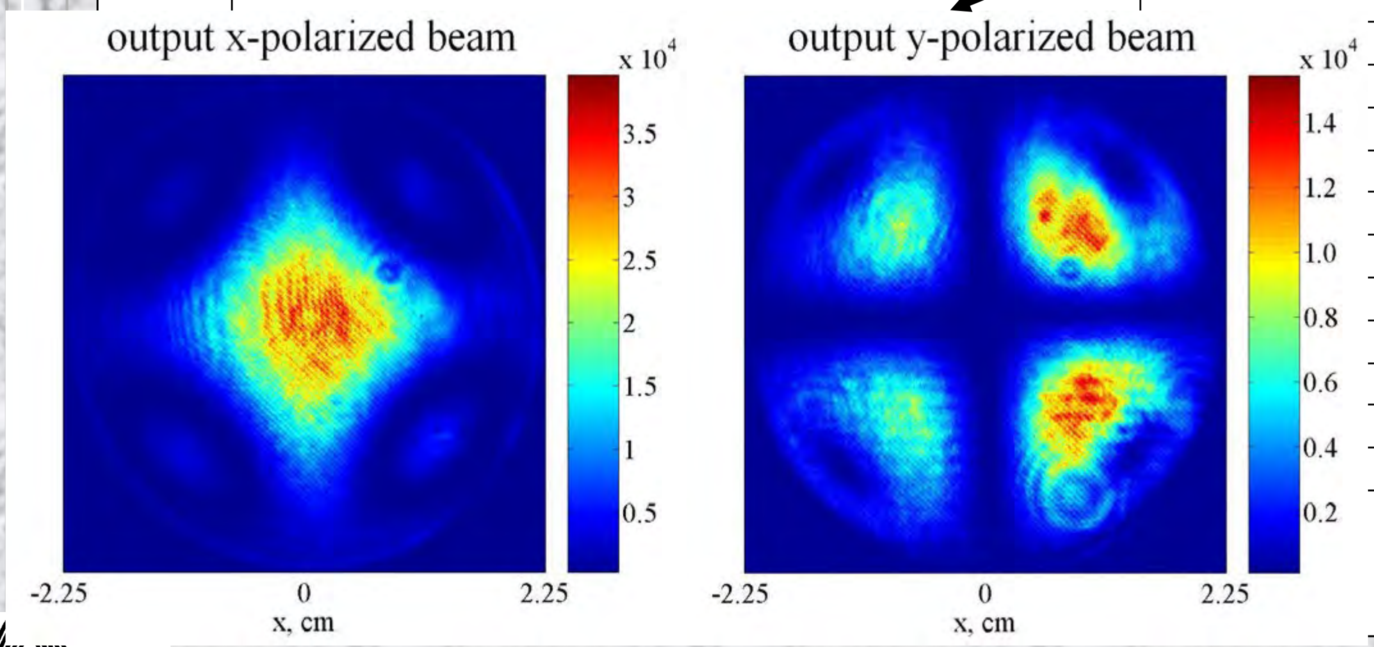


PEARL to multi-petawatt power.

depolarization compensation







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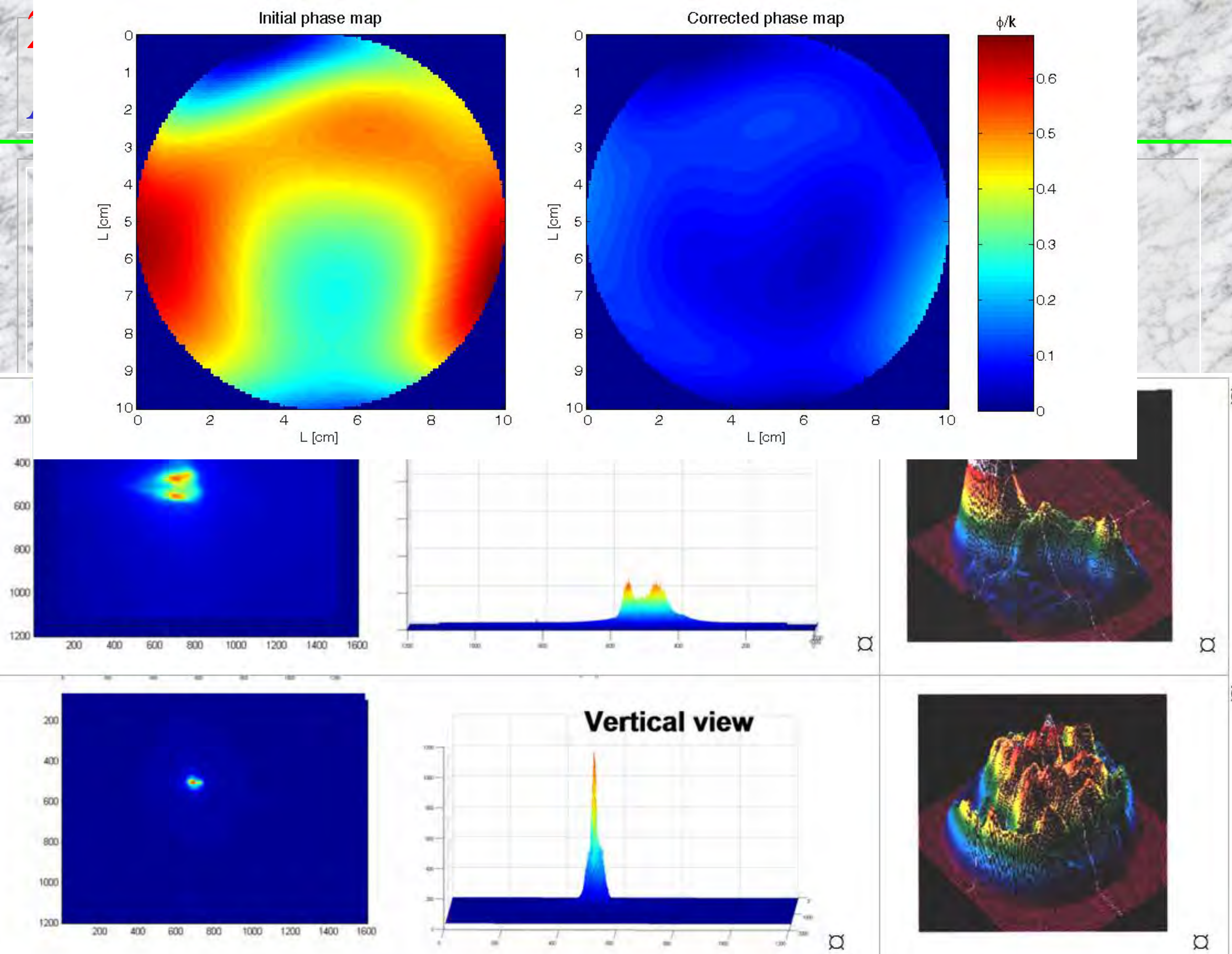
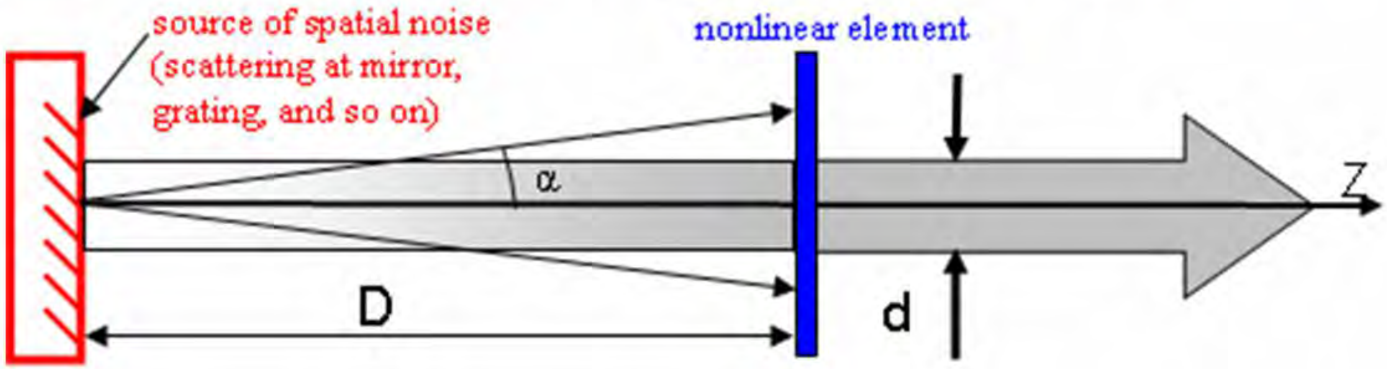
W_{pump} = 14.6 kJ + 14.6 kJ = 29.2 kJ, Δt = 3 min.


Initial phase map
Corrected phase map
ϕ/k
0.6
0.5
0.4
0.3
0.2
0.1
0
L [cm]
L [cm]
L [cm]
L [cm]
Vertical view

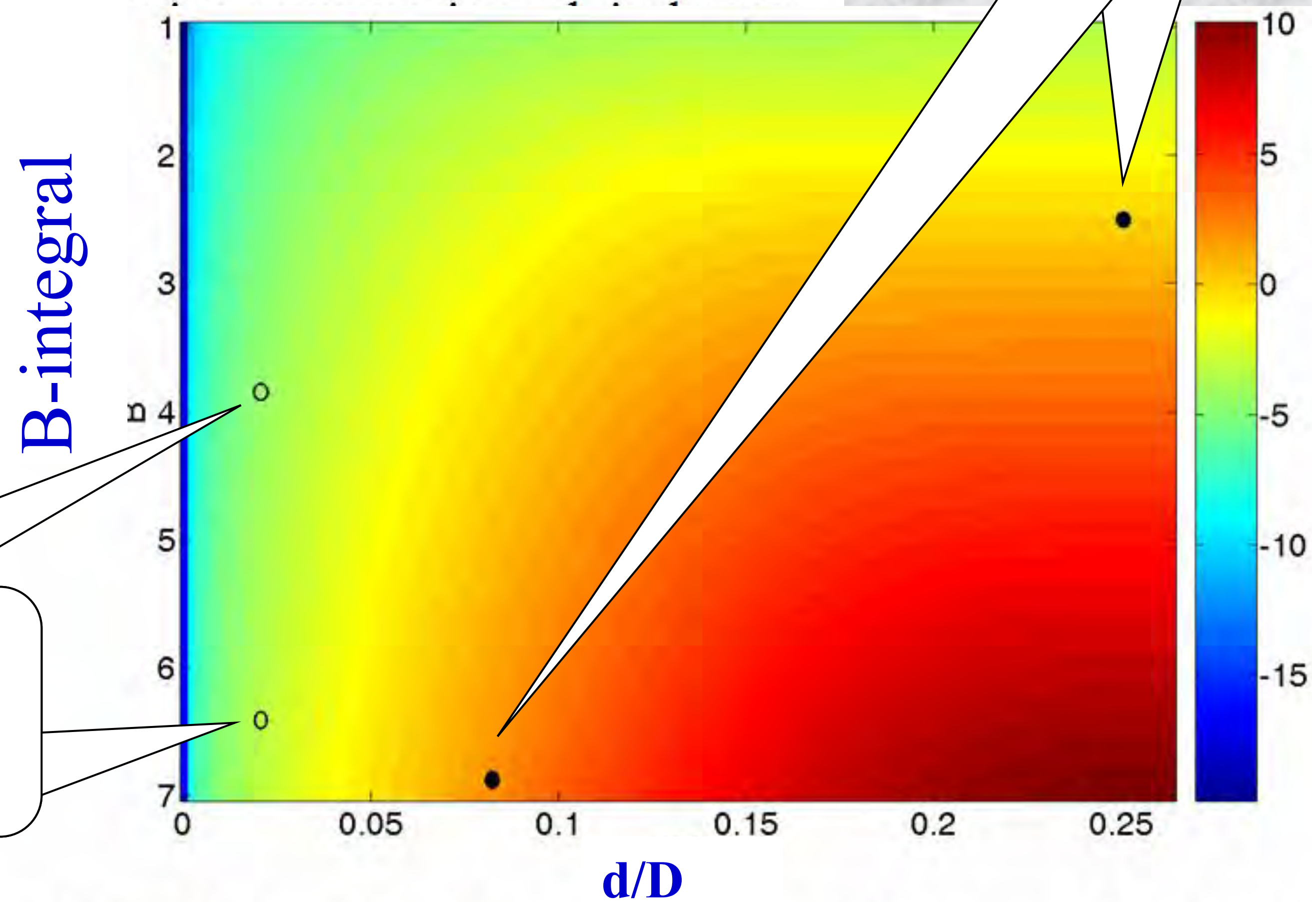
Small-scale self-focusing.
Angular distribution of instability gain.



The· idea· of· small-sc…
diameter,· D· is· free-spa…
propagation·of·noise·wav…

self-focusing breakdown

no self-focusing breakdown !!!



Logarithm·of·normalized·power·of·noise·*ln(F)*·versus·B-integral·and·angle·of·view·d/D·at·intensity·5TW/cm^2.·¶

IAP RAS

scalability PEARL to multi-petawatt power.

Contrast enhancement.

Second harmonic generation of multi-PW pulse

Motivations

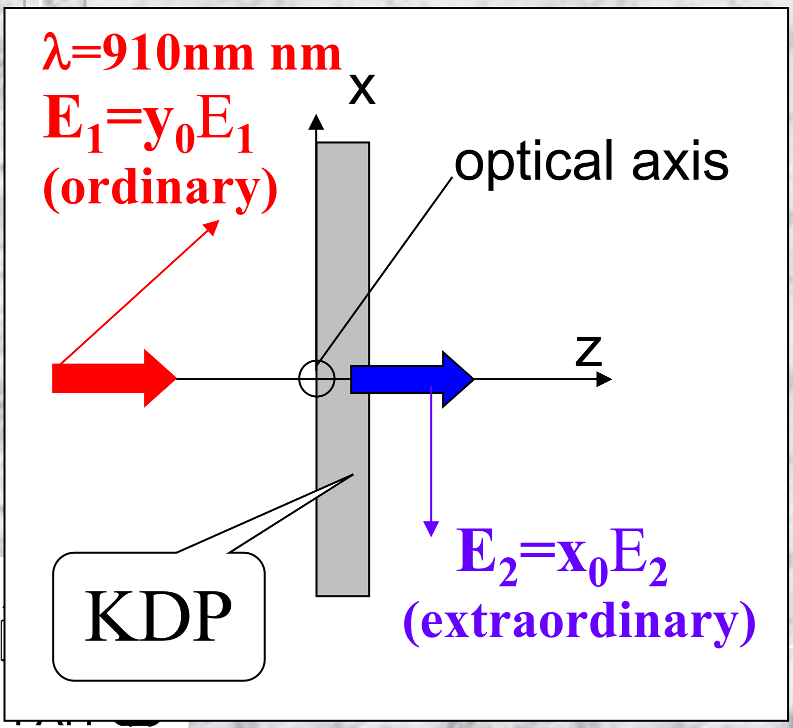
Drastic increase of pulse contract
Decrease of focus beam diameter by factor of 2
Possibility to shorten pulse duration due to spectral broadening

Challenges

Very thin AND high-aperture crystal
Parasitic third-order nonlinearity (both in space and time!)

Intensity

$5\text{-}20 TW/cm^2$
(up to 10PW at 20cm aperture)
KDP crystal



EXPERIMENTS AT XCELS: OPPORTUNITIES AND CHALLENGES

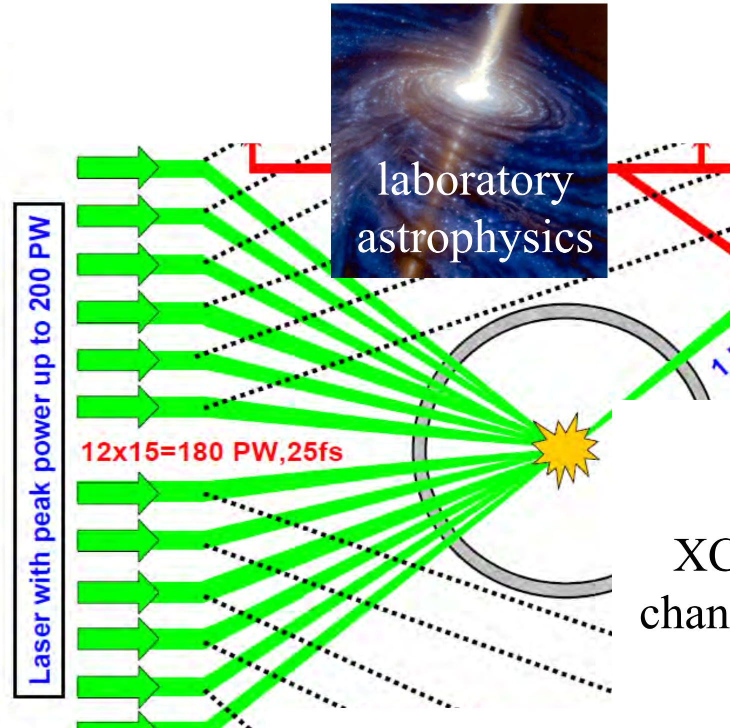
I. Kostyukov, IAP RAS

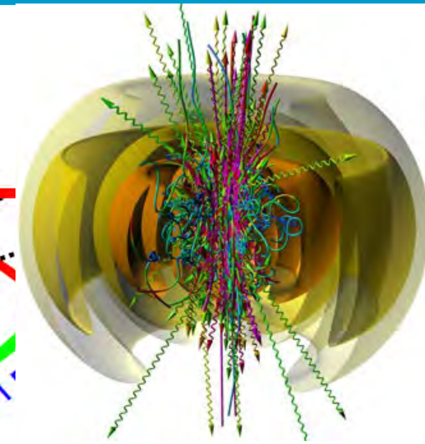
CREMLIN Workshop, 11-12 December 2017, Paris, France

Outline

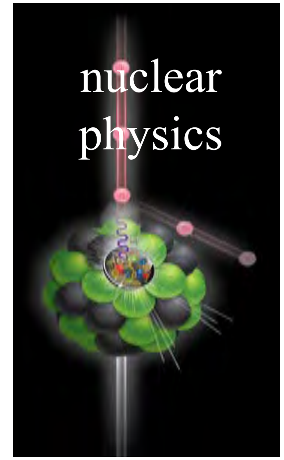
- Introduction. XCELS project
- Opportunities for science and technology
  - QED cascades. Non-perturbative QED far beyond Schwinger limit
  - Probing vacuum structure
  - Nuclear photonics
  - Laboratory astrophysics
  - High-gradient particle accelerators
  - Radiation sources
  - Neutron and isotope sources
- Challenges of laboratory high-field science
  - Laser-matter interaction at extremely high intensity
  - Diagnostic issues
  - Issues according to ELI technical design report
  - Laser targets
  - Gas cell
- Conclusions

New Science and Technology with XCELS

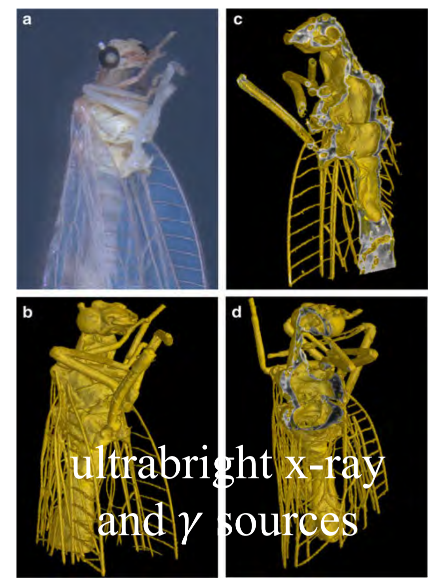


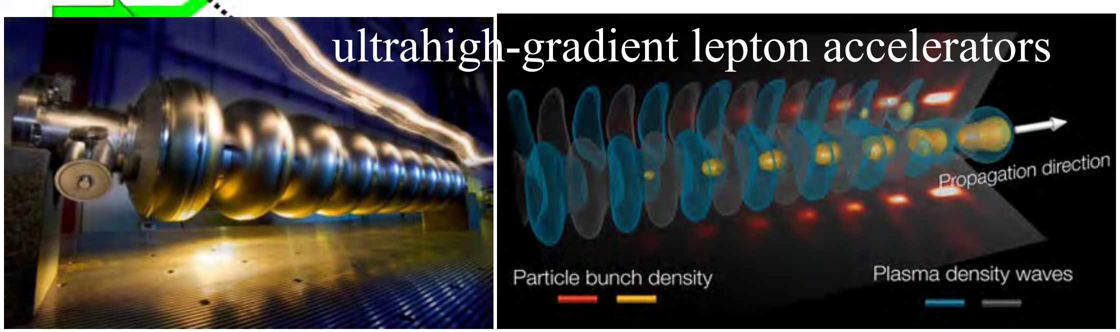


high-field physics,



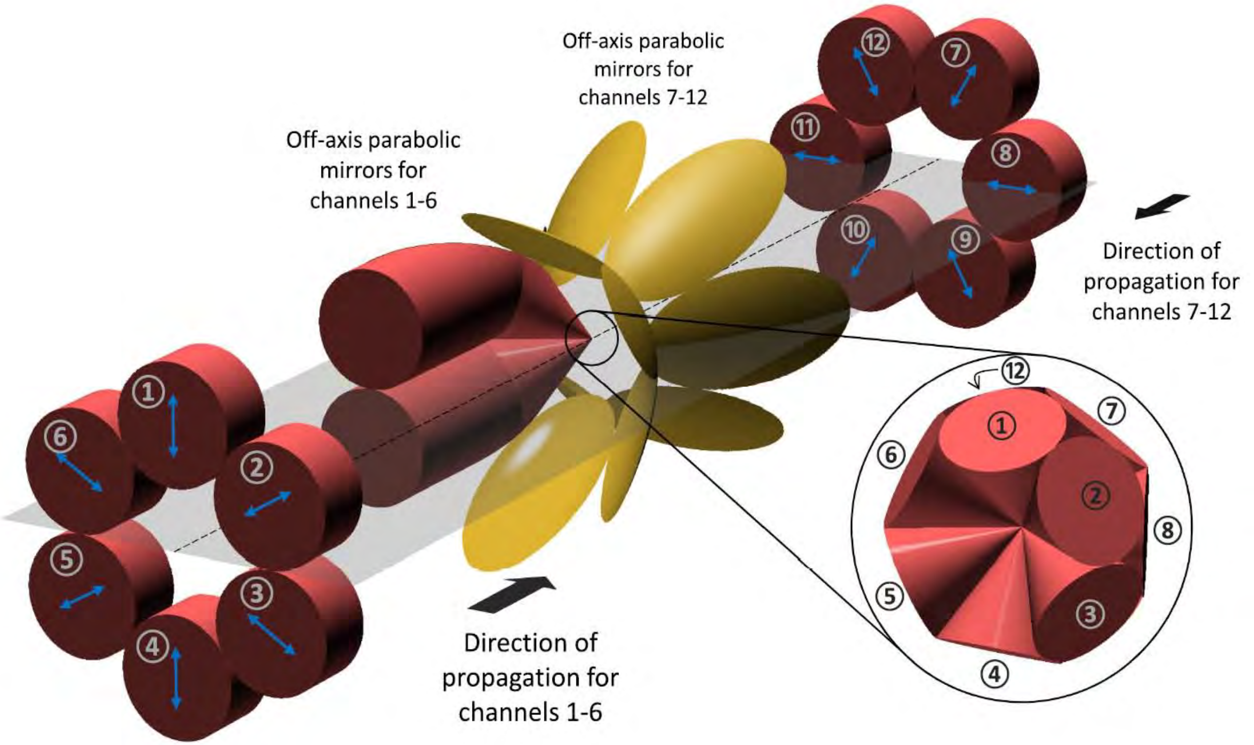
XCELS will comprise 12 channels with total power up to 200 PW.





The principal research task of XCELS is a study of fundamental processes in laser-matter interaction at extremely high intensities. Besides the basic research XCELS is also focused on developing novel technologies, related to particle and radiation sources, nuclear physics, medicine and others.

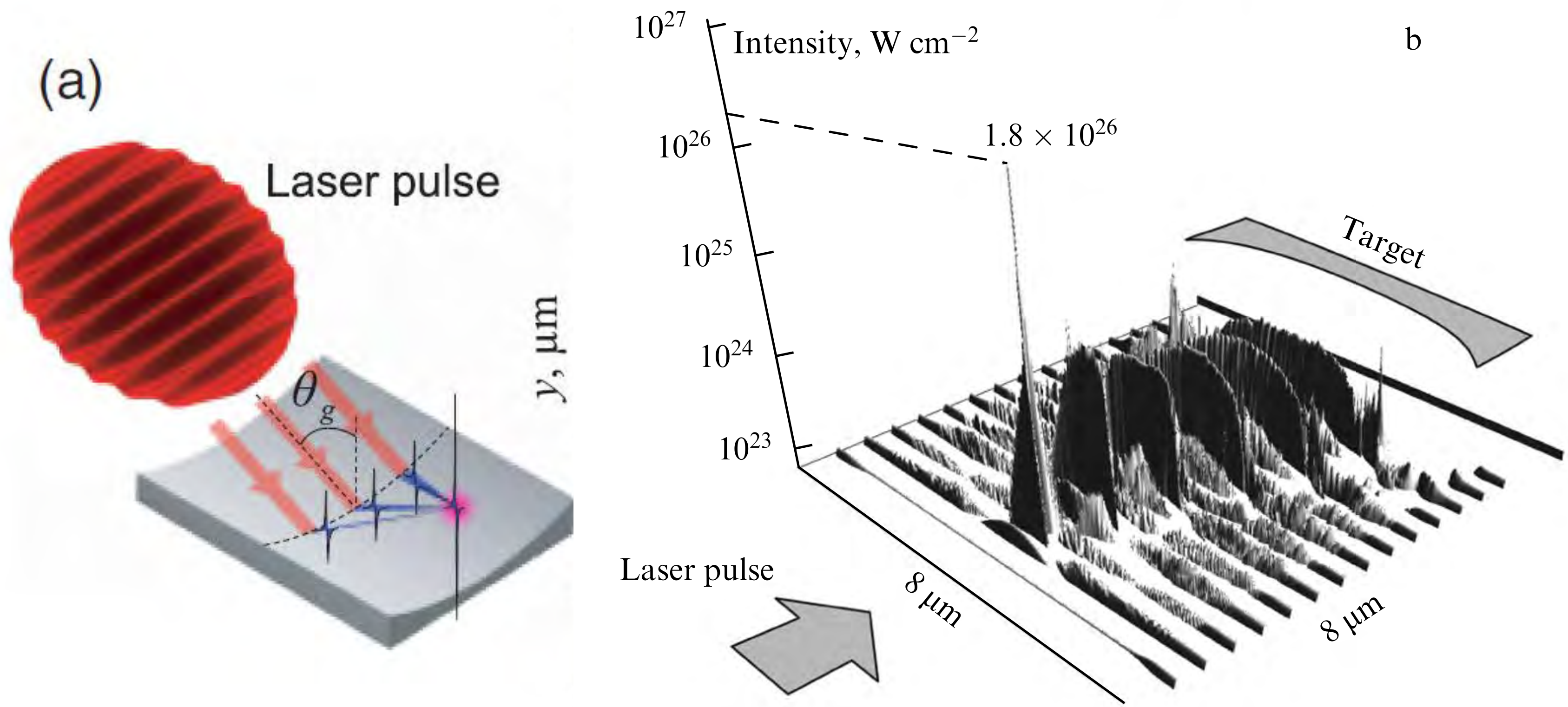
Secondary Sources of Extreme Light with XCELS



It is proposed in the project that the 12 beams will be combined in smart way in order to maximize the electric field at focusing point. To do this, the beams should reproduce the radiation of the point dipole at infinity. Such dipole wave configuration made of 12 beams provides much higher field at focal spot than that at focal spot of the single laser beam of the same total power.

A.V. Korzhimanov, A.A. Gonoskov, E.A. Khazanov, A.M. Sergeev, Horizons of petawatt laser technology, Physics-Uspekhi 54, 9 (2011); A. Gonoskov et al., Phys. Rev. Lett. 113, 014801 (2014).

Secondary Sources of Extreme Light with XCELS



Even higher intensity can be achieved by the secondary radiation source based on XCELS radiation.

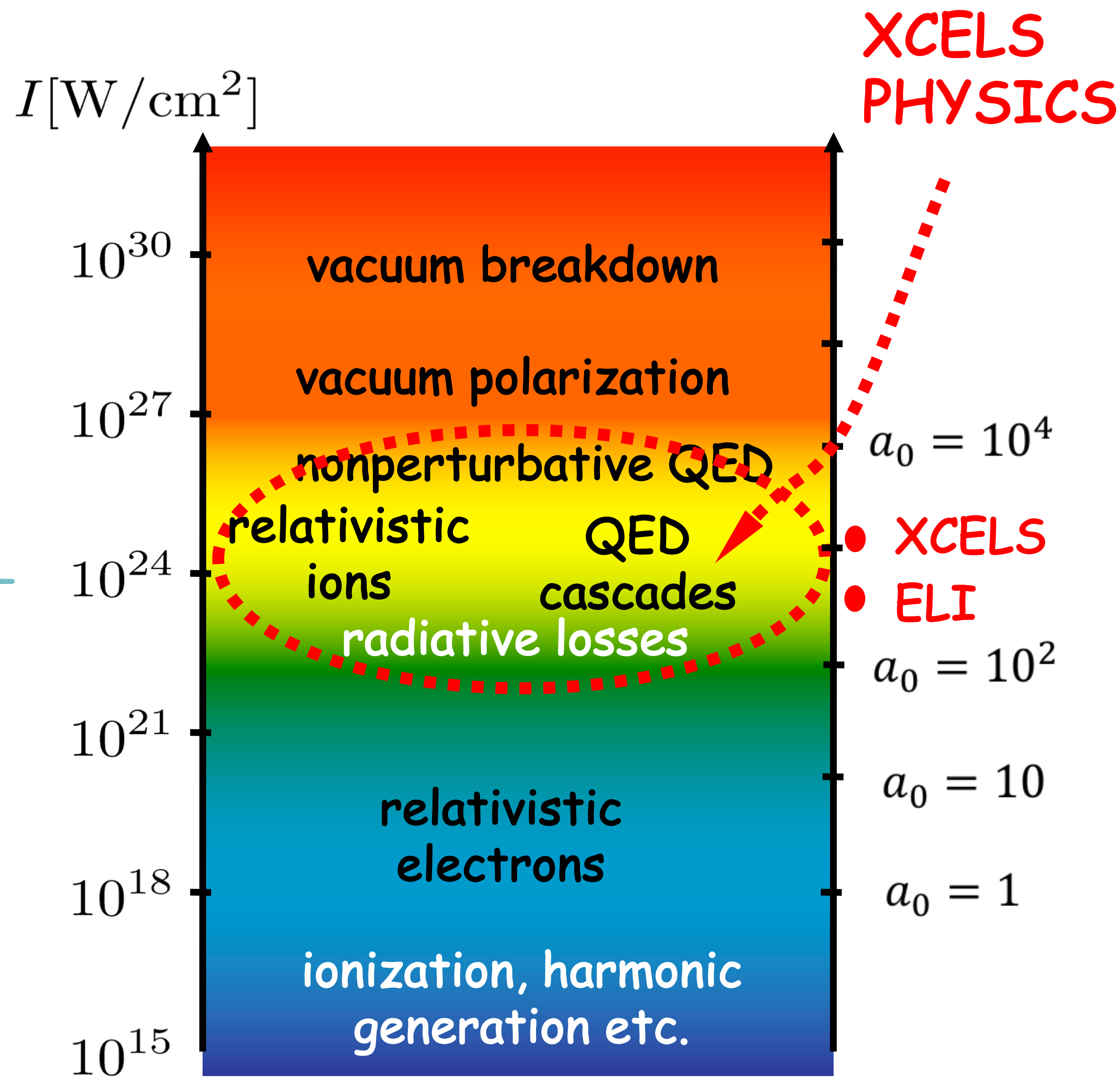
A.V. Korzhimanov, A.A. Gonoskov, E.A. Khazanov, A.M. Sergeev, Horizons of petawatt laser technology, Physics-Uspekhi 54, 9 (2011).

OPPORTUNITIES WITH XCELS IN SCIENCE AND APPLICATIONS

Physics with XCELS

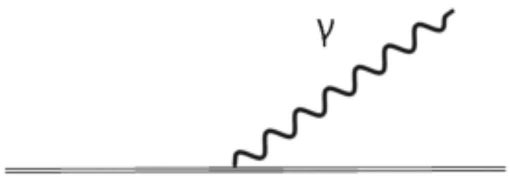
APPLICATIONS

- high energy density physics
- laboratory astrophysics
- particle acceleration
- radiation sources

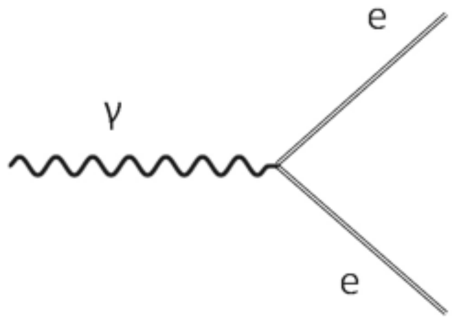


Physics with XCELS

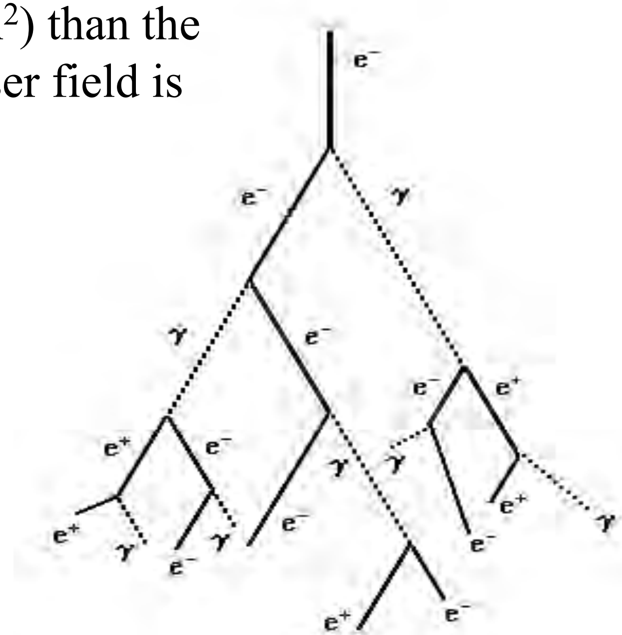
field strength $a = \dfrac{eE}{mc\omega}$ If a>1 (I>10^{18} W/ cm^2) than the particle motion in laser field is relativistic.



photon emission
(Compton scattering)



pair photoproduction
(Breit-Wheeler processes)



quantum-electrodynamic
(QED) cascade

quantum dynamic parameter

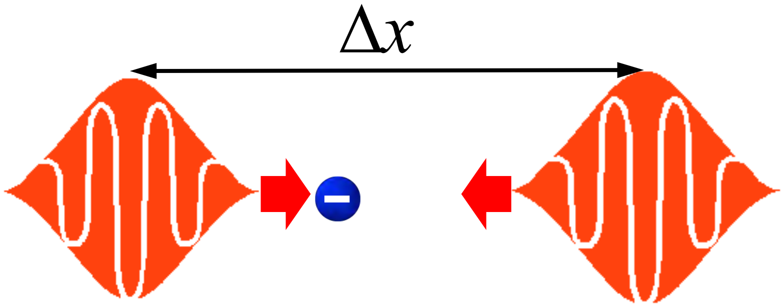
$$\chi_{e,ph} = \frac{1}{a_S}\sqrt{(\varepsilon_{e,ph}\mathbf{E} + \mathbf{p}_{e,ph}\times\mathbf{B})^2 - (\mathbf{p}_{e,ph}\cdot\mathbf{E})^2} \sim \frac{\gamma E_\perp^*}{E_{cr}} \qquad E_{cr} = \frac{mc^2}{e\lambda_C} = \frac{m^2c^3}{e\hbar} \approx 1.3\times10^{16}\,\mathrm{V/cm}$$

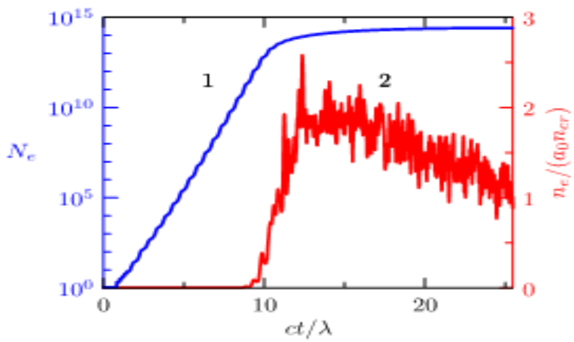
$$\boxed{\omega_{pe} \lesseqgtr \omega_L}$$

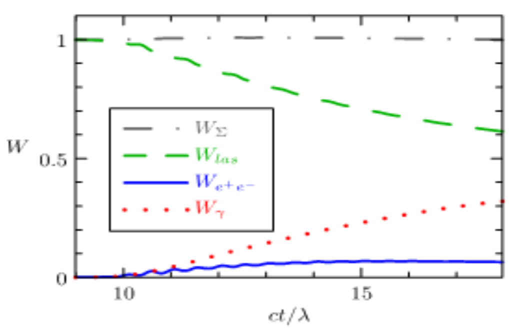
$\omega_{pe}^2 = \dfrac{4\pi e^2 n}{m a_0}$ - relativistic plasma frequency

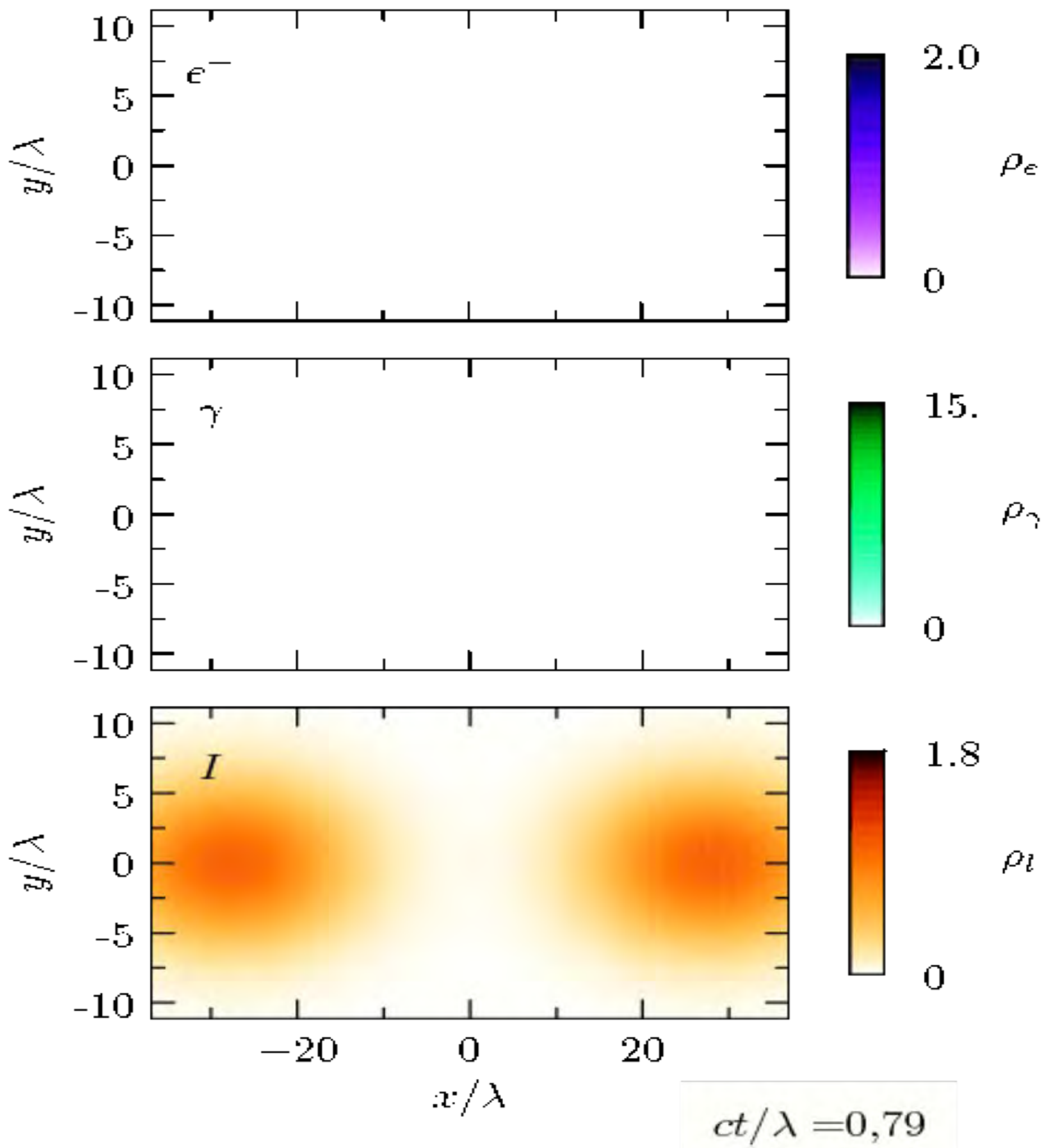
QED cascades

$I = 3\times10^{24}\,\mathrm{W/cm^2}\ (a = 1.2\times10^3)\quad \lambda = 0.8\ \mu\mathrm{m}\quad \sigma_x = 19\lambda_L\quad \sigma_y = 8\lambda_L\quad \Delta x = 2\sigma_x$



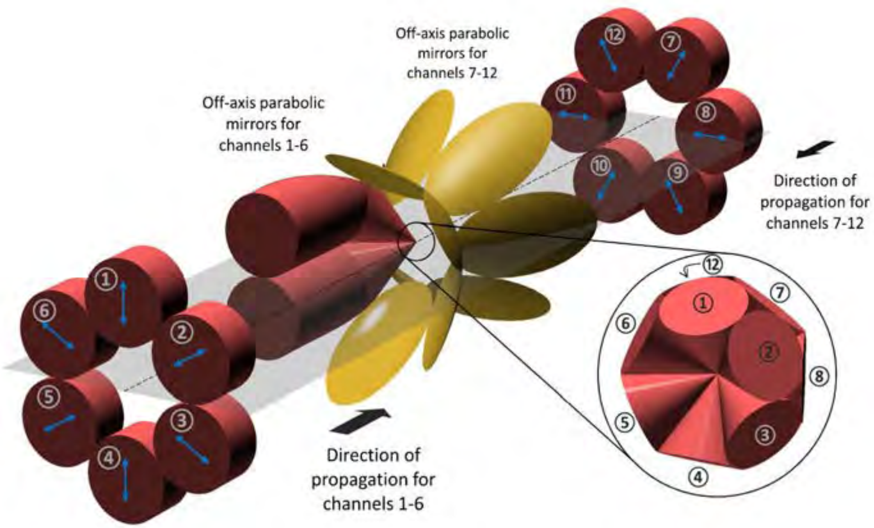


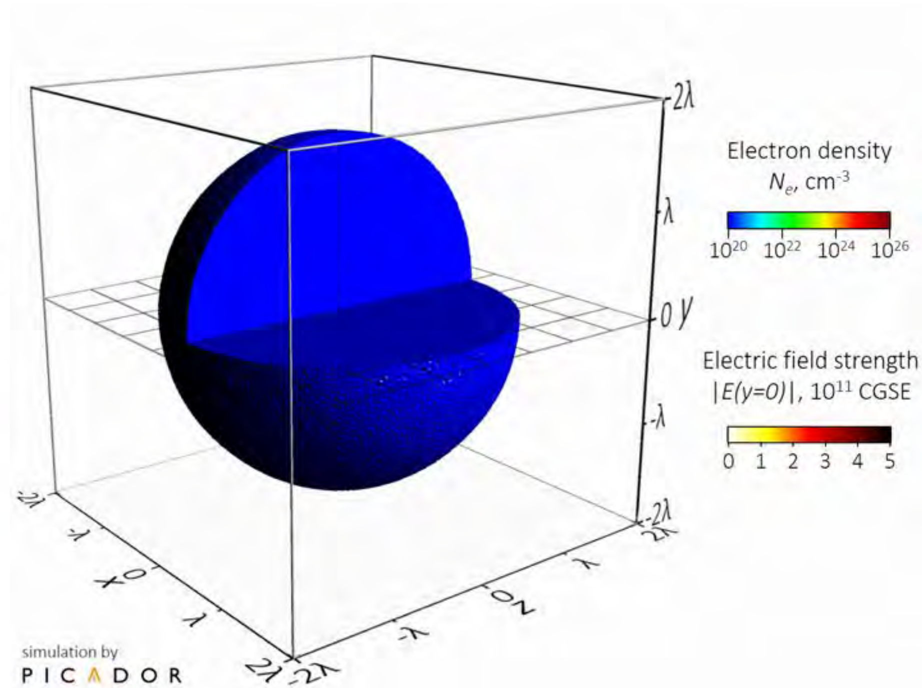




E.N. Nerush *et al.*, PRL (2011).

QED cascades

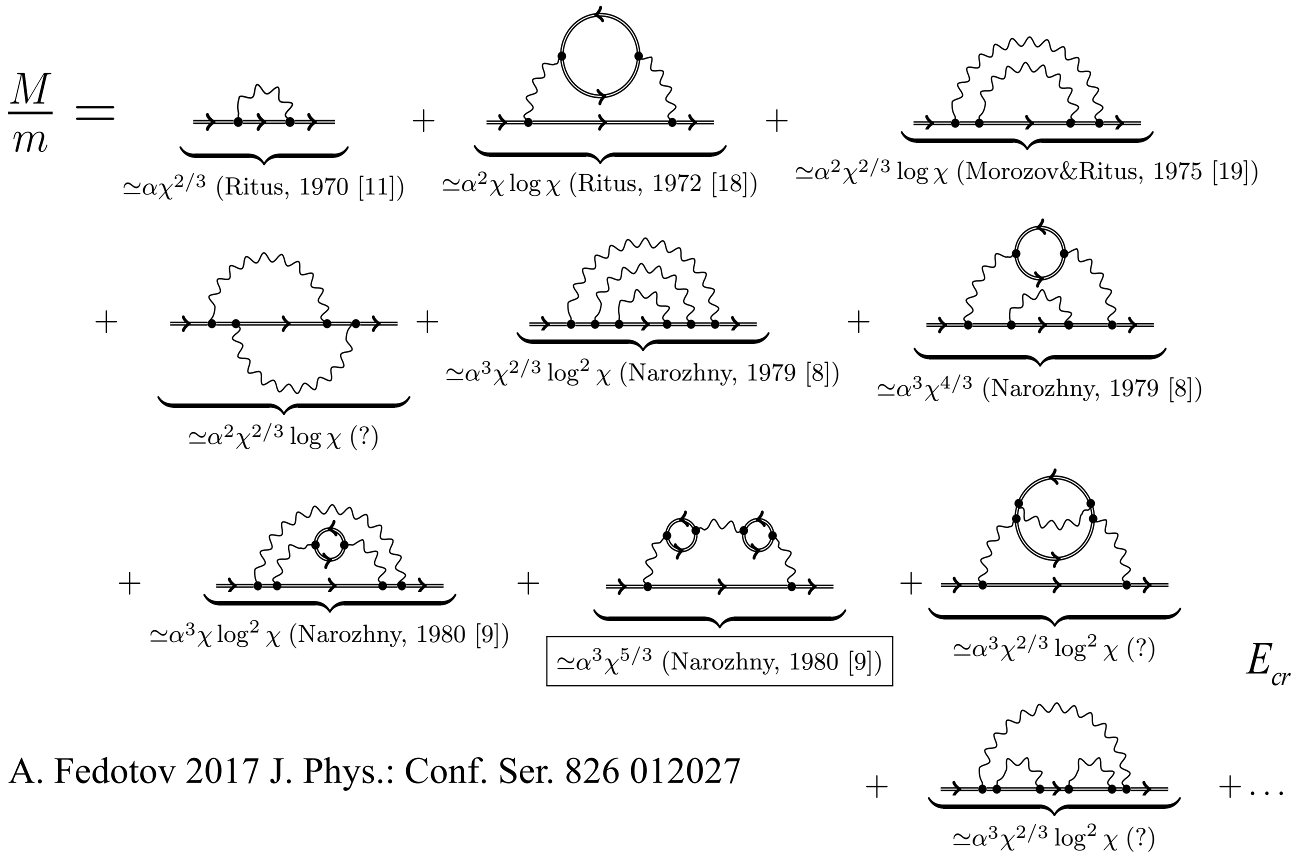




QED cascade in the dipole wave field.
Number of secondary particles can be greater than the number of the target particles.

A. Gonoskov et al., Phys. Rev. Lett. 113, 014801 (2014).

Non-perturbative QED far beyond Schwinger Limit



A. Fedotov 2017 J. Phys.: Conf. Ser. 826 012027

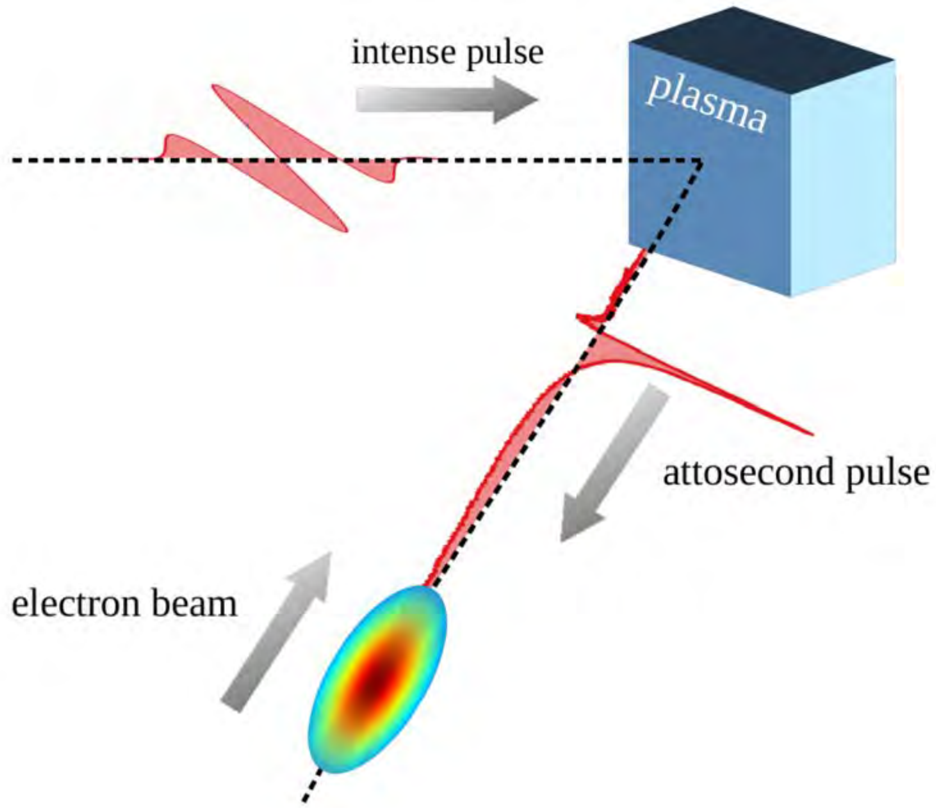
$\alpha\chi^{2/3}$ - small parameter of expansion,

$\alpha = e^2/\hbar c = 1/137$ is the fine structure constant

$$E_{cr} = \frac{mc^2}{e\lambda_C} = \frac{m^2c^3}{e\hbar} \approx 1.3\times 10^{16}\ \text{V/cm}$$

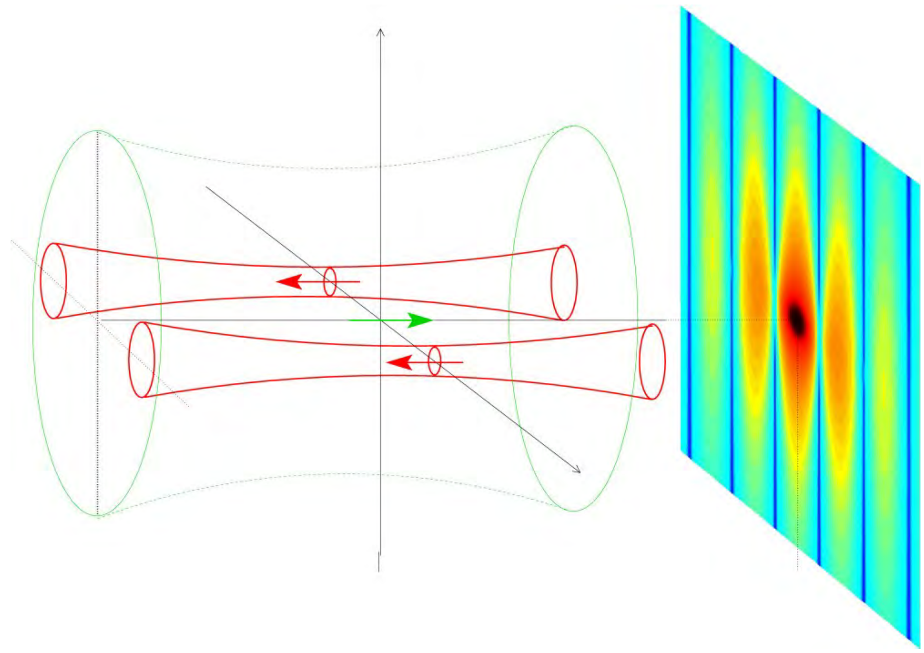
In electromagnetic fields so strong that the strength in a proper reference frame of an ulrarelativistic particle exceeds the critical (Schwinger) value by factor of about 1600 ($\chi >$ 1600), the radiative corrections become dominant, resulting in the IFQED perturbation theory breakdown. Therefore, the relevant experiments would be a significant advance and would solve one of the fundamental problems relevant to completeness of perturbative quantum field theory.

Non-perturbative IFQED far beyond Schwinger Limit



Non-perturbative IFQED effects can be explored at interaction of high-energy electron bunches with attosecond electromagnetic pulses obtained as a result of reflection of laser pulses from dense plasma targets in the relativistic oscillating mirror regime.

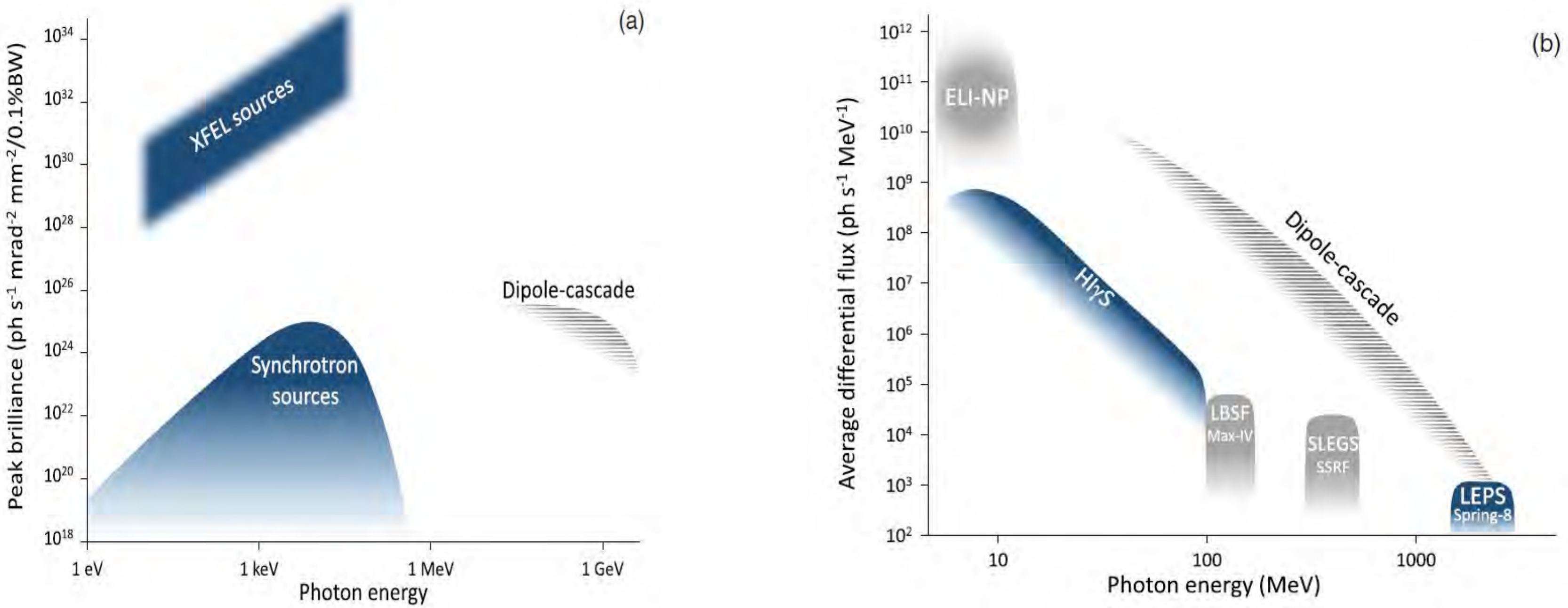
Probing vacuum structure. Light-light interaction



A possible matterless double-slit experiment: a wider probe laser beam counter-propagates antiparallel to two, tightly-focused, separated, ultra-intense laser beams, generating a specific diffraction pattern due to vacuum polarization.

B. King, A. Di Piazza, and C. H. Keitel, Nature Photon. 4, 92 (2010).

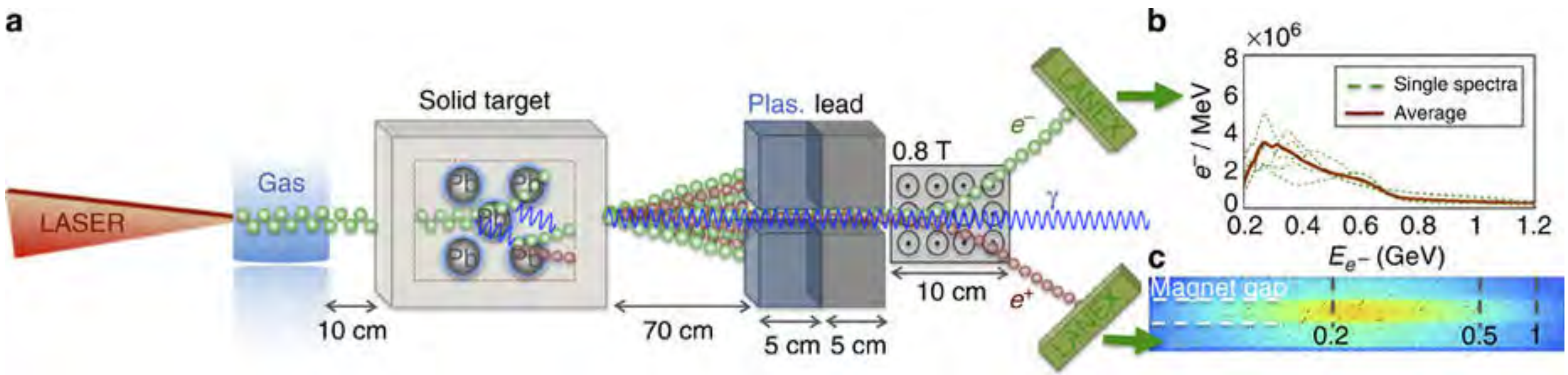
Nuclear Photonics

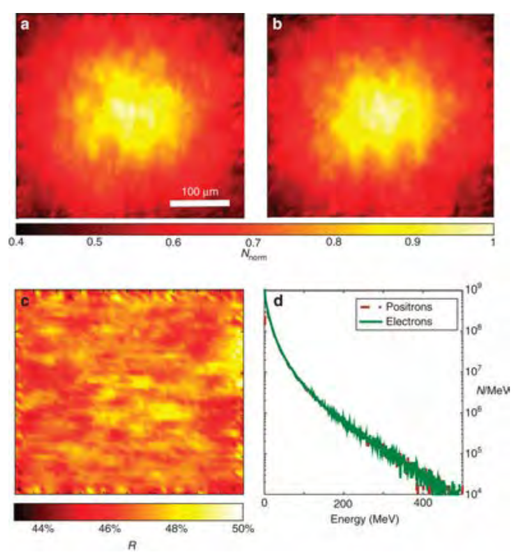


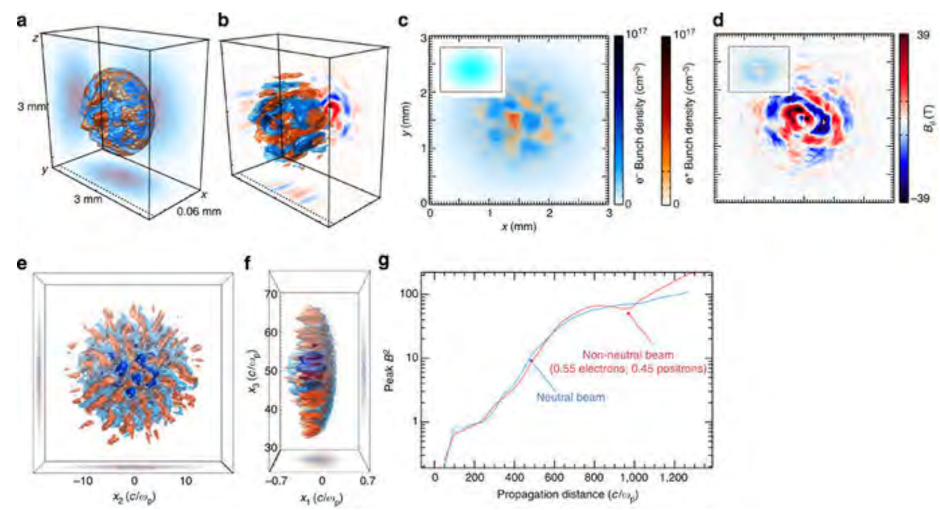
Such a source, with extraordinary high flux of GeV photons with a broad spectrum will open qualitatively new possibilities for studying photonuclear processes. This is also the main task of ELI-NP project at lower laser intensity.

A. Gonoskov et al., Physical Review X 7 (4), 041003 (2017).

Laboratory Astrophysics

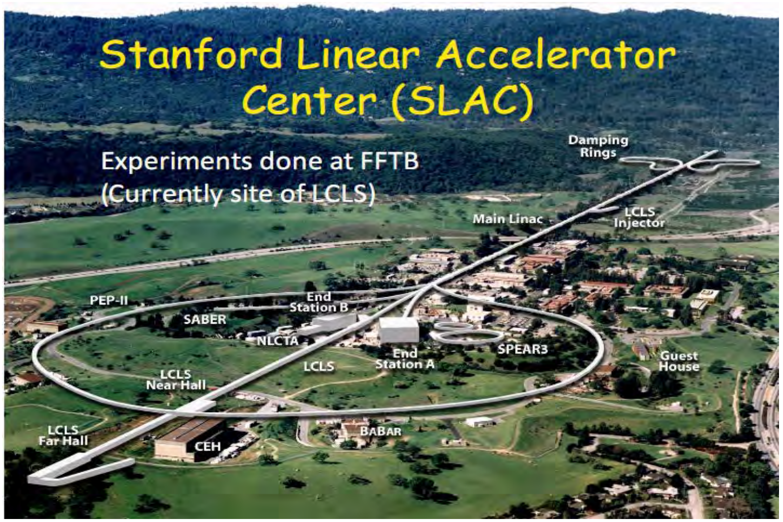


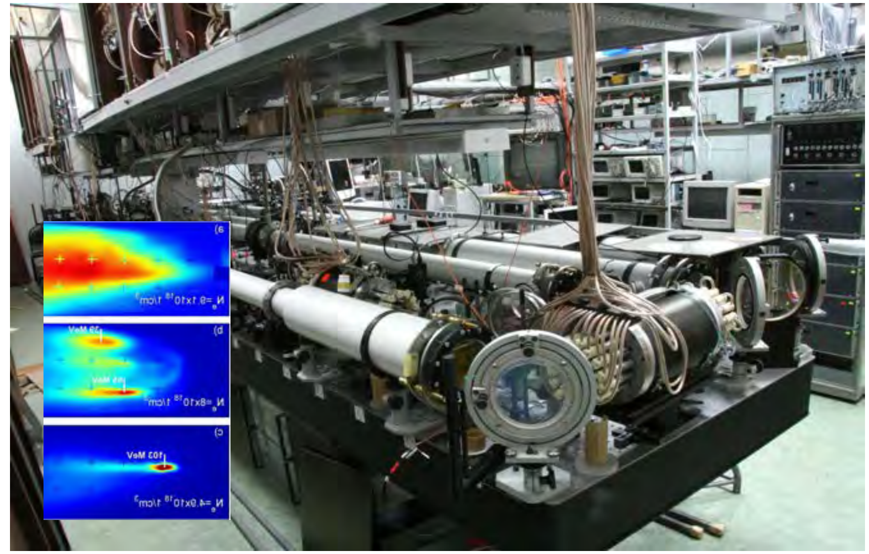




G. Sarri et al., Generation of neutral and high-density electron–positron pair plasmas in the laboratory, Nature Communications 6, 6747 (2015).

Laser-Plasma Electron Accelerators





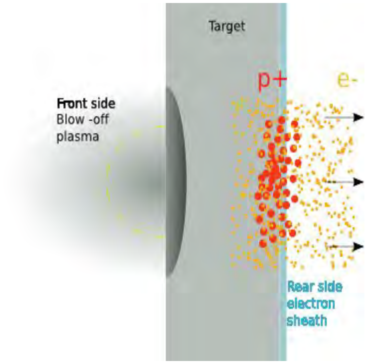
A.A. Soloviev et al., NIMA 653, 35 (2011).

High-energy electron accelerators are very large and costly machines. This limits their wide use in various areas of human activity. At the same time, the laser fields and the plasma fields, generated by laser pulses, are several orders of magnitude stronger than the accelerating fields in conventional accelerators. The plasma accelerating structure can be several orders of magnitude shorter than the conventional metallic accelerating structure.

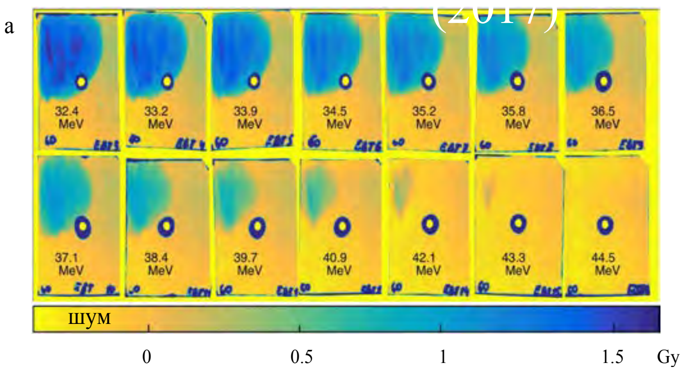
Now the quasi-monoenergetic bunches of electrons accelerated in laser plasma can be routinely produced in laboratory. Laser-plasma acceleration of electrons has been studied in our institute. In LBNL experiments, the energy of electrons has reached 8 GeV

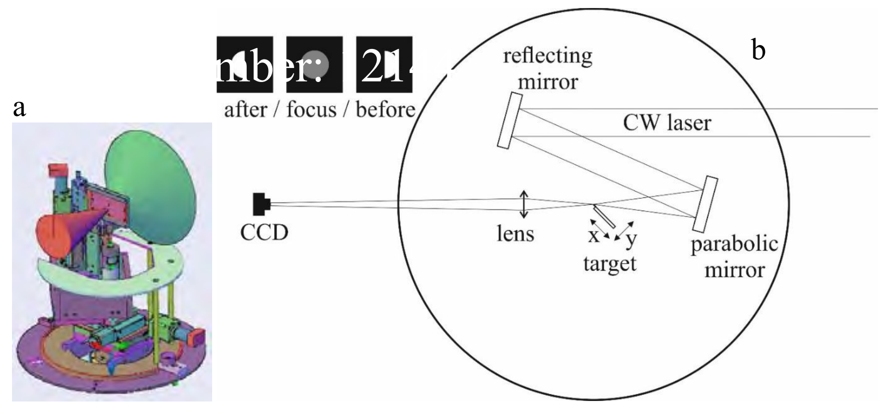
Laser-Accelerated Protons

The laser-matter interaction can be also used for efficient generation of high-energy protons and ions in very small volume.



Hegelich B. M. et al.. 160 MeV laser-accelerated protons from CH2 nano-targets for proton cancer therapy. arXiv 1310.8650 (2013).





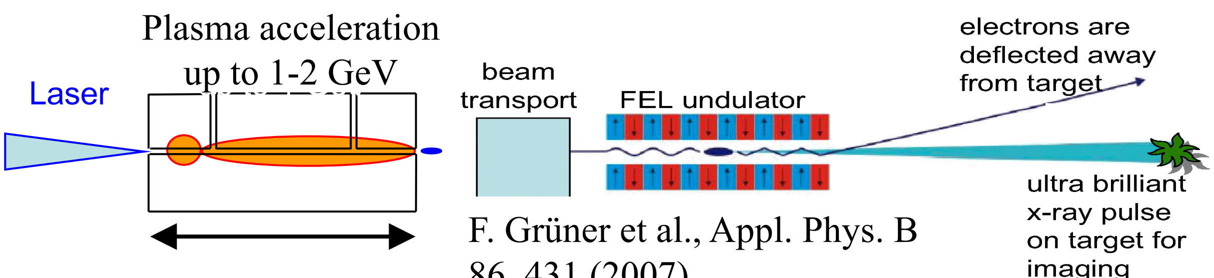
Experimental stand for study of the impact of 25 MeV laser-accelerated protons on biological objects. It is demonstrated the doses up to 10 Gy to the object can be transferred in a single shot. The technique of irradiating the cell culture HeLa Kyoto and measuring the fraction of survived cells is developed.

A. Soloviev et al., Scientific Reports 7, 12144 (2017)

Radiation Sources (x-ray, γ-ray)

As a relativistic laser-plasma interaction is accompanied by the intense flows of high-energy particles and radiation and can be used to reduce the size of radiation sources.

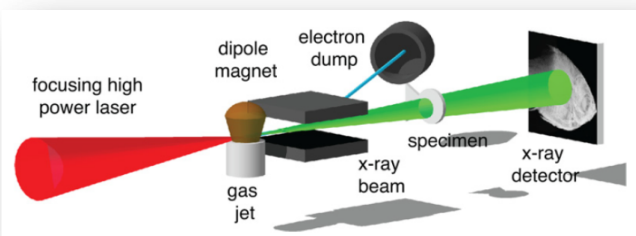
Magnetic scheme: laser-plasma XFEL

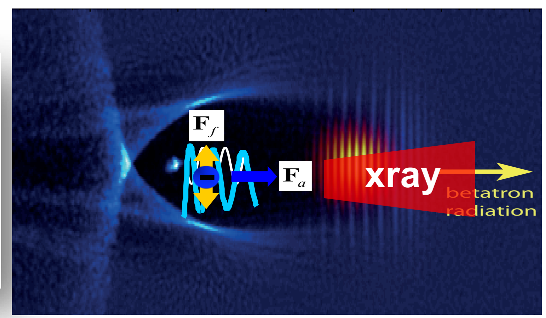


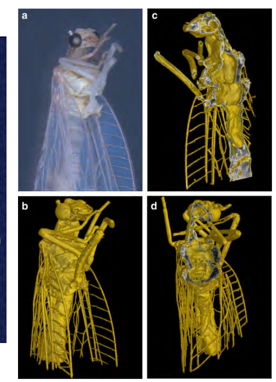
F. Grüner et al., Appl. Phys. B 86, 431 (2007).

Ultra-compact XFEL

Plasma scheme: betatron radiation source

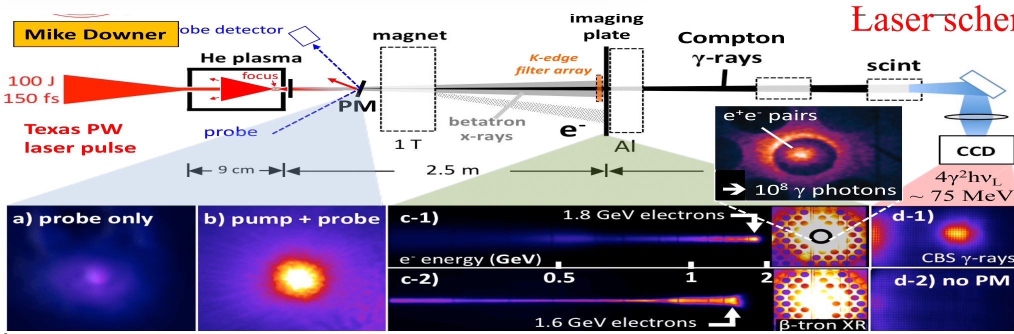




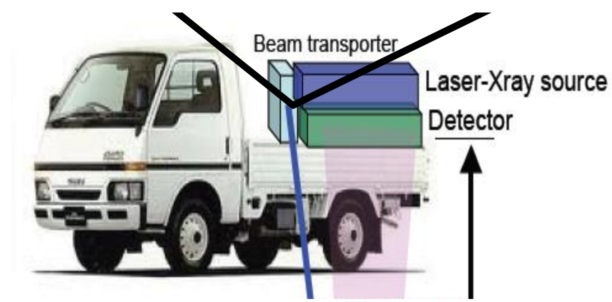


S. Corde et al., Rev. Mod. Phys. 85, 1 (2013).

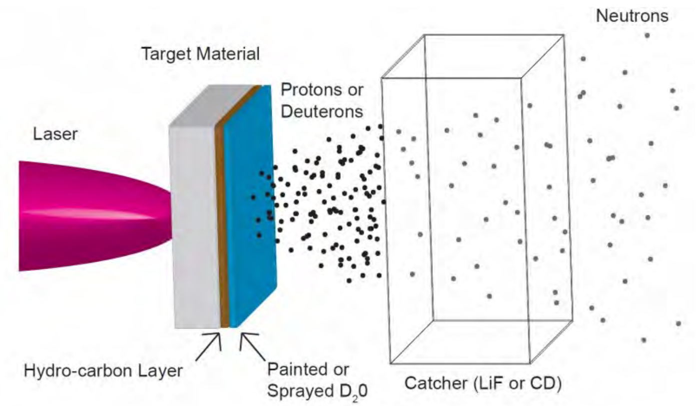
Laser scheme: Compton source

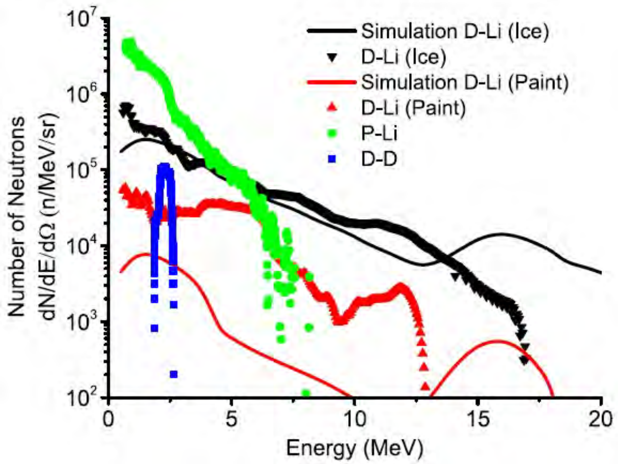


Hai-En Tsai et al., Phys. Plasmas 22, 023106 (2015).



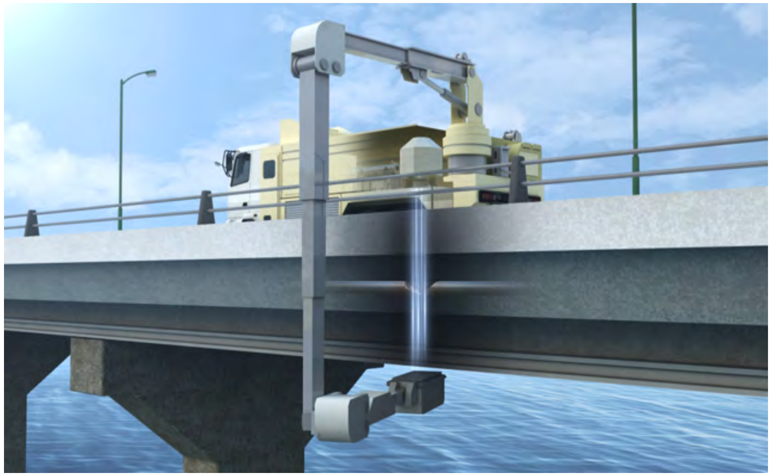
Neutron Sources





B. Hou et al., Phys. Plasmas 4, 040702 (2011).

A number of an infrastructures had been built in 1960s-70s. These structures will soon exceed their life-time of about sixty years. There is a strong need for non-destructive inspection of infrastructures which are mainly formed of concrete. High energy neutrons penetrate thick concrete and can be used to detect, for example, water in concrete nondestructively.

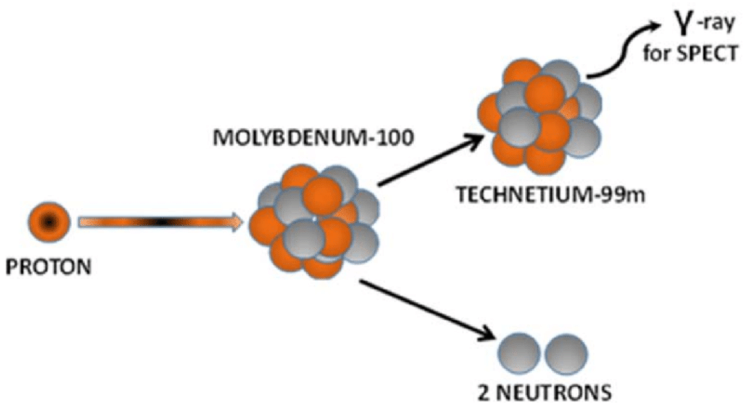


Laser-based neutron sources can produce higher neutron flux than the radio isotope sources and, thus, can provide more accurate analysis for very large concrete objects.

The world-highest neutron number in single shot, ~4 x 10^{11} (ILE, Osaka).
M. Kando, ANAR2017 (CERN, 2017).

Laser-Based Nuclear Pharmacology

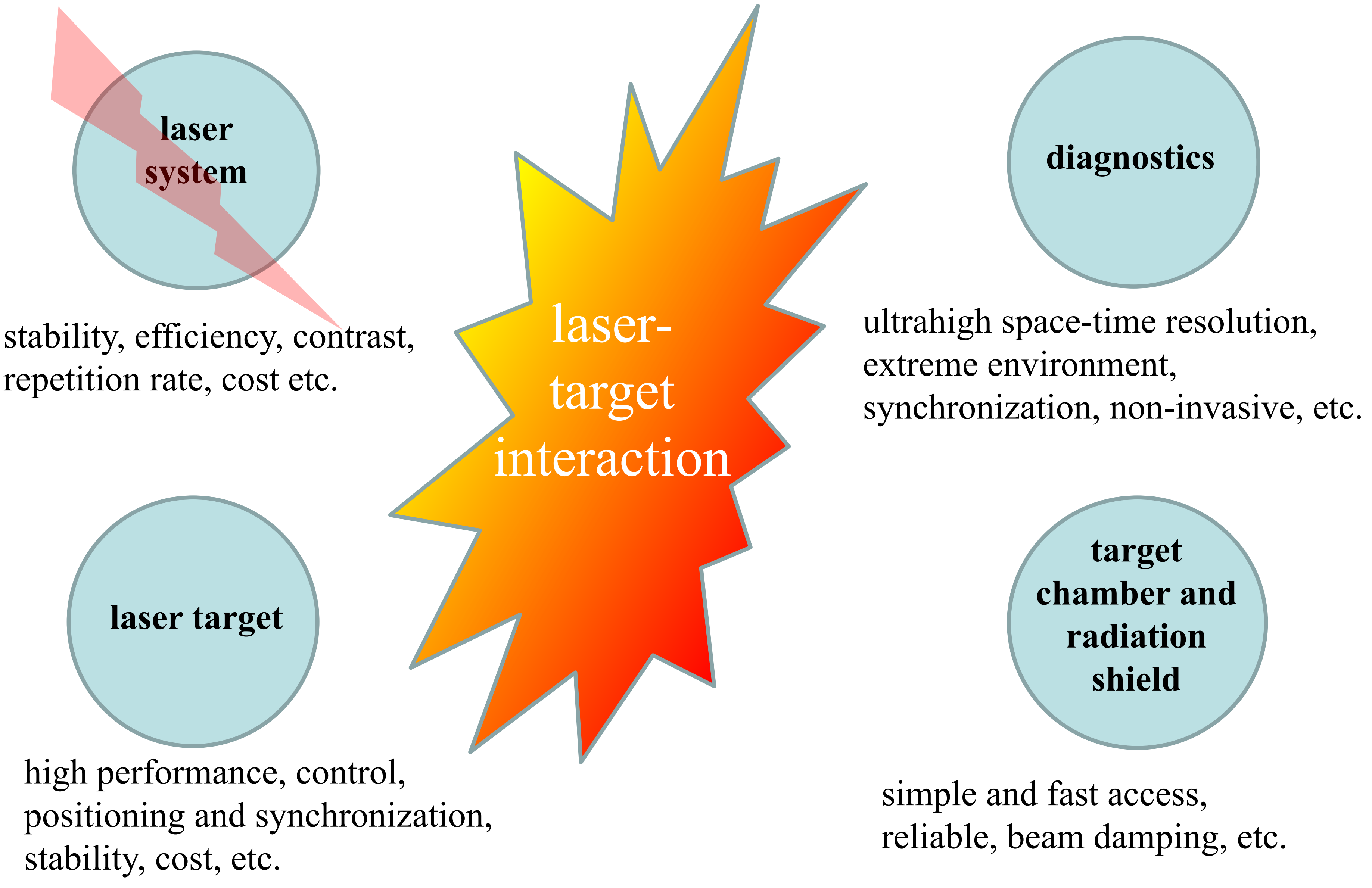
Laser-based proton sources can also facilitate isotope production. Isotope plays now an indispensable role in medicine, for example, for single-photon emission computer tomography (Tc-99m), for positron-emission tomography (for example, the carbon isotope C-11). It should be noted that the leading world suppliers of technetium-99m, the most widely used isotope in nuclear medicine (up to 80% of all diagnostic procedures) are two reactors in Canada and the Netherlands, which are planned for closing in the coming years. To initiate nuclear reactions, it is necessary to obtain the maximum number of protons/deuterons with the energy exceeding the threshold (for example, above 8 MeV for the Mo-100(p,2n) and Tc-99m reaction).



V.Yu. Bychenkov et al., Phys.-Uspekhi 58, 71 (2015).

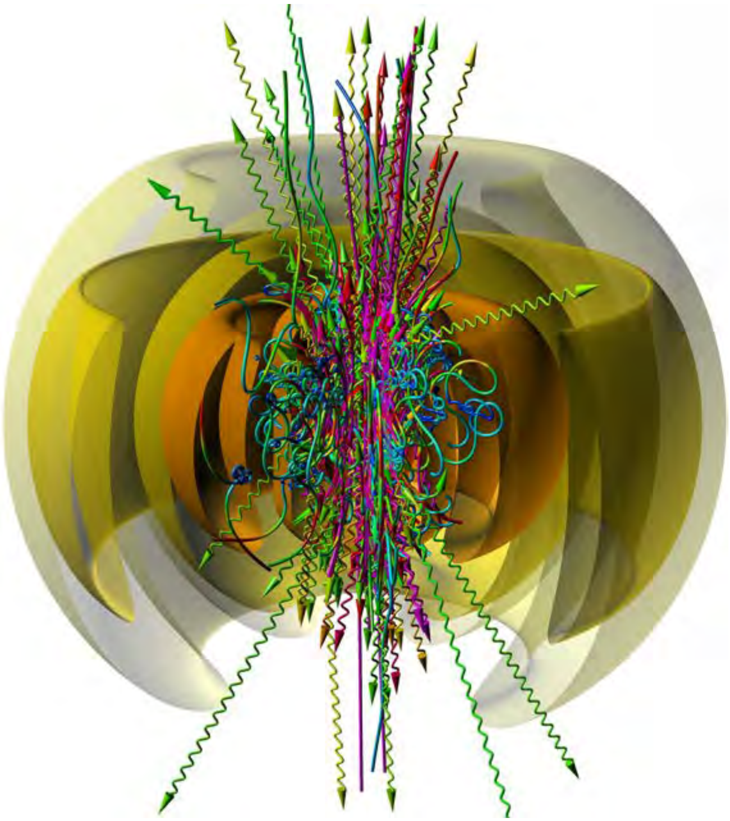
CHALLENGES OF EXPERIMENTAL HIGH-FIELD PHYSICS

Laboratory Study of Extremely High Intensity Laser-Matter Interaction



Laser-Matter Interaction with XCELS

“**Every advantage has its disadvantage**”.

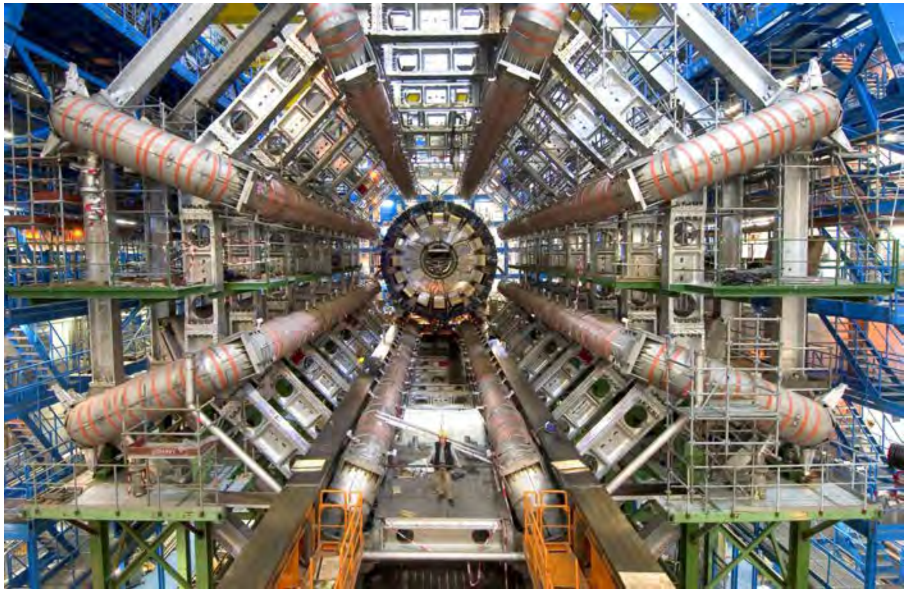


The interaction of ultra-intense laser pulses with the targets will generate:

- very strong electromagnetic fields across the entire electromagnetic spectrum, from the radiofrequency and THz (with the wavelength of the order of the laser pulse length) to gamma-rays (with the wavelength of radiation emitted by GeV electrons)
- multi GV electrons and ions
- other energetic particles (positrons, neutrons, muons etc.)
- QED cascades when the number of secondary particles can exceed the number of the target particles.

Diagnostics for High-Field Laboratory Physics

- Interaction is very short and localized in very small volume.
- It is difficult to control interaction process (the reason of uncertainties can be fluctuations in laser system, target performance, probabilistic nature of quantum processes etc).
- Detectors must be able to work with high efficiency in extremely severe environmental conditions in the laser-matter interaction area and with good discrimination between different sorts of the particles. Strong filtering and shielding are needed.
- Detectors should not be very large.
- Single shot methods are preferable.



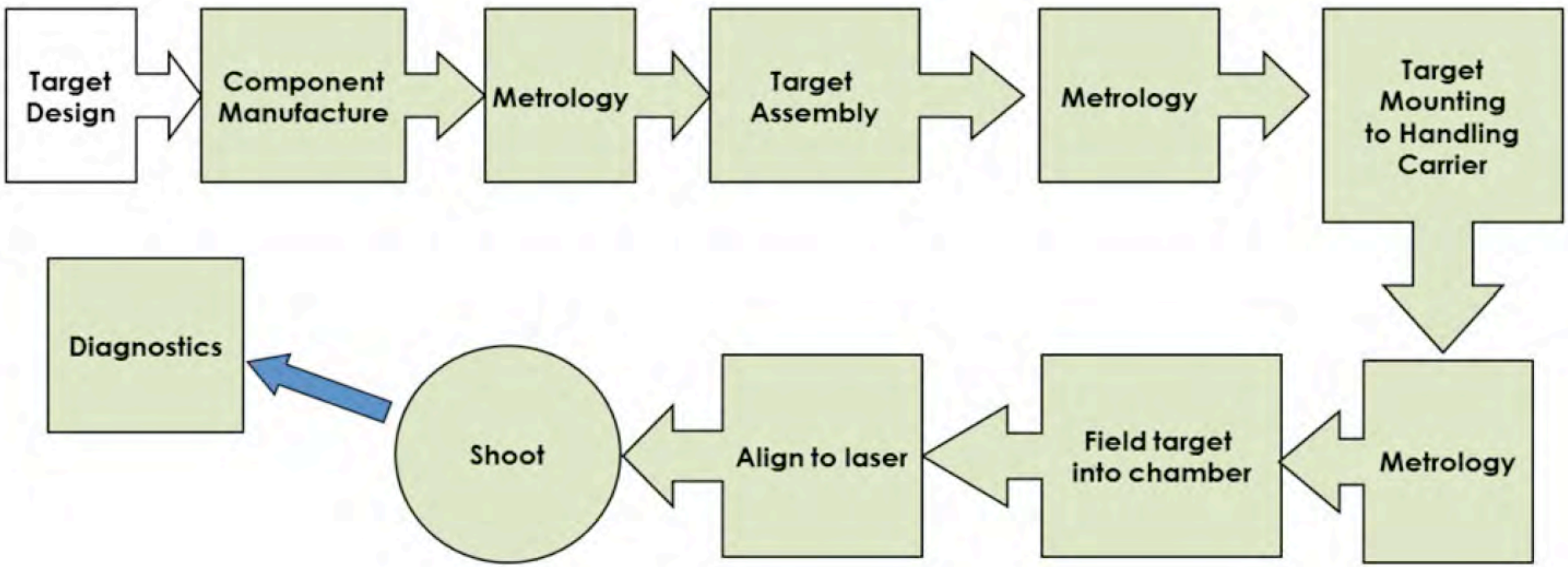
ATATLAS is one of the seven particle detector experiments constructed at the Large Hadron Collider at CERN.

ELI-NP Technical Design Report

- Up to now there are no simple and reliable methods to measure the laser intensity beyond 10^{22} W/cm^2.
- The broad spectrum and large divergence of the particles requires several specific and complementary methods for diagnostics.
- Detectors should be protected from target debris, strong electromagnetic fields, and undesirable fluxes of particles and radiation but should efficiently register and measure needed fluxes.
- Detectors should provide access to the time (fs) and the spatial (μm) scale of the laser plasma interaction and provide real-time information on the relevant mechanisms responsible for the generation of the ion/electron beams.
- Up 30% (50% for XCELS) of the laser radiation can be converted into gamma-rays. The challenge for detectors is the discriminating against the gamma - ray background.
- For some experiments the detectors contaminating with fission fragments and maybe even with long lifetime actinides is possible. It may require very long cooling time (days) before being accessible.
- High resolution microscope optics are required in-situ within the chamber for accurate positioning of targets in the laser focus. A target insertion and extraction device may be required, possibly involving robotics. This may be important for the handling of activated (post shot) target holders.
- Dump mass for Gev protons should be up to 2000 tons.

ELI-NP Technical Design Report, Rom. Rep. Phys., Vol. 68, Supplement I,II (2016). www.rrp.infim.ro.

Laser Targets



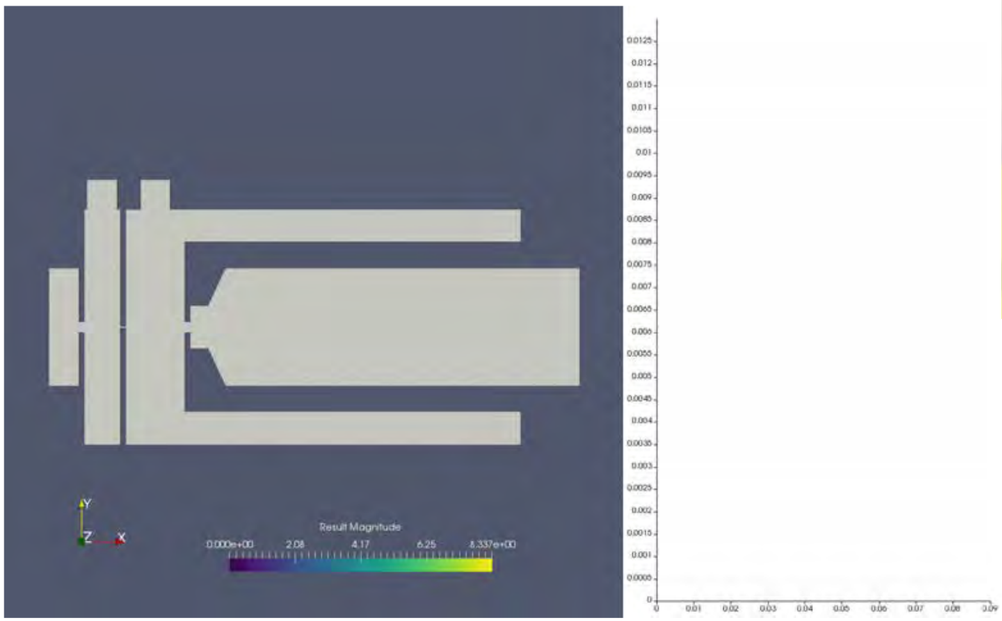
Some target challenges

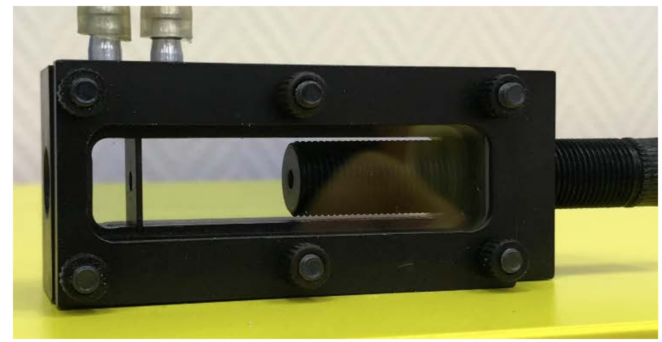
- Protection from debris and neighboring target damage
- Target positioning and alignment
- Strong electromagnetic pulses
- Back-reflection of laser light in the laser chain

I. Prencipe et al., Targets for high repetition rate laser facilities: needs, challenges and perspectives, High Power Laser Science and Engineering, 5, e17 , (2017).

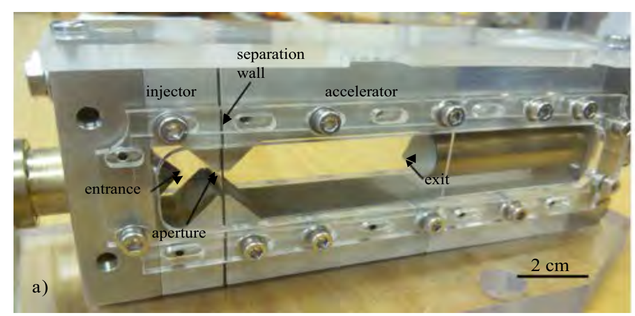
Laser Targets: Gas cell

The gas targets with controllable gas density profile are needed for laser-plasma acceleration. It is still a challenge to produce a stable gas target with arbitrary density profile.





IAP RAS gas cell



O. Kononenko et al., NIMA 829, 125 (2016).

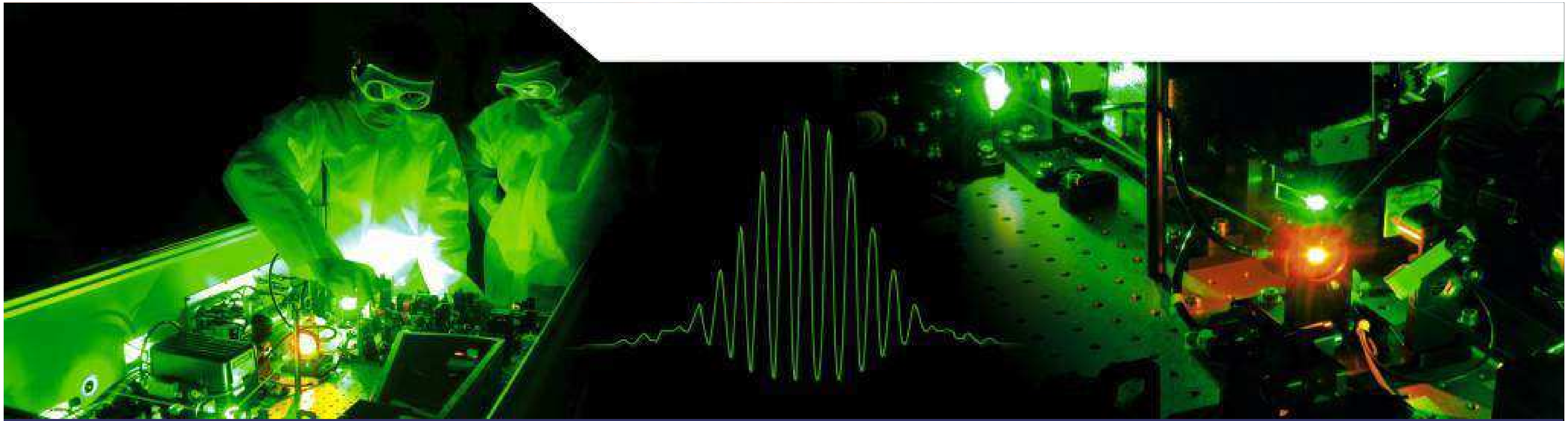
Summary

- **XCELS will open up opportunities for exploring new phenomena at the interface of the high-energy physics and high-field physics as well as for developing new technologies (like sources of radiation and particles with unprecedented parameters for scientific, industrial and medical applications).**

- **The project implementation will face many challenges. Some of possible problems are already evident at the design stage. However many issues may not be predicted before implementation since theoretical description of laser-matter interaction in XCELS regime is essentially incomplete.**

- **However the challenges are strong motivation for developing new approaches and methods that may lead to breakthrough in science and technology.**

Thank for attention!



www.thalesgroup.com

PetaWatt Laser Systems: current status & perspectives

Christophe SIMON-BOISSON

XCELS Workshop – Paris – 12th December 2017

THALES

Table of contents

- Introduction
- BELLA PetaWatt
- ELI-NP
  - Front End
  - High Energy Pump Lasers
  - First results & Integration
- Conclusion

THALES

Some of Thales large projects

1 PW 1 Hz (BELLA 2012)

200 TW 5 Hz (DESY 2013)

1 PW 0.1 Hz (CETAL 2013)

2x500 TW 1 Hz (Riken 2015)

350 TW 5Hz (Strathclyde University 2017)

200 TW 5 Hz (Peking University 2016)

- Under progress
  - 2x10 PW 1 shot/min (ELI-NP, Romania) 2018-2019
  - 90 J amplifier for 3 PW (LMU, Germany) 2017
  - 200 TW 1Hz (SW Jiao Tong University, China) 2018
  - 2x100 TW 1Hz (Weizmann Institute, Israel) 2018
  - 1 PW 0,1Hz (RRCAT, India), 2018

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Recent achievements

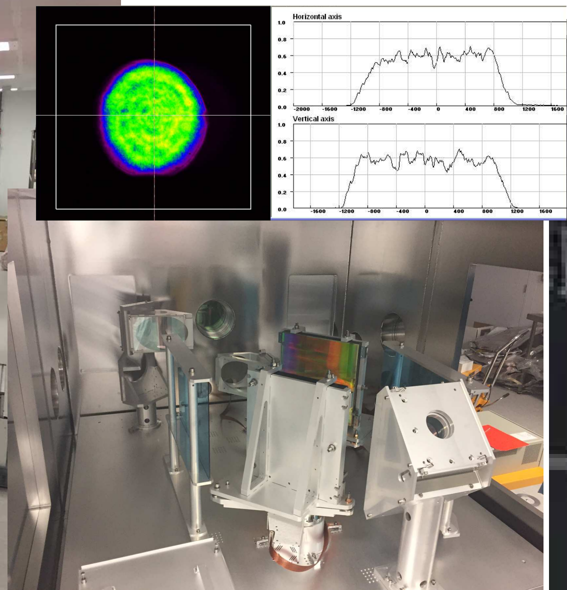
SCAPA laser at STRATHCLYDE Univ.

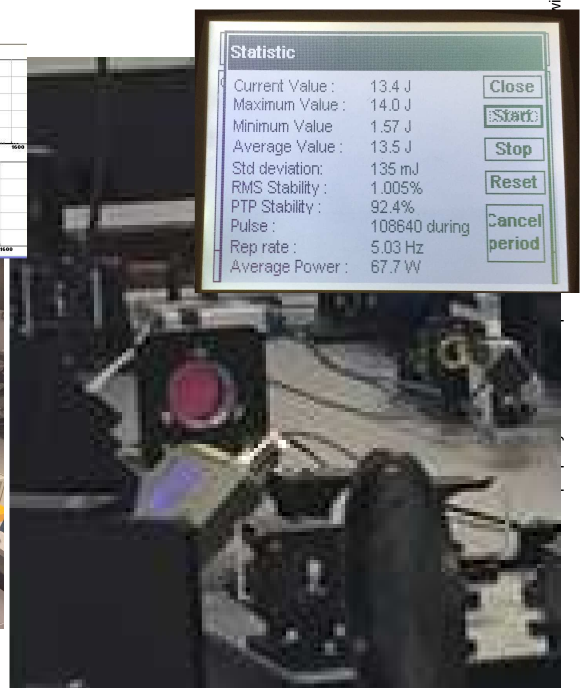
- **350TW at 5Hz => 8.75J/25fs/5Hz**

  => ≈44W average output power

  => >60W average power on first grating

Highest average power demonstrated at 5Hz using **water cooling** and with **compressor under vacuum**





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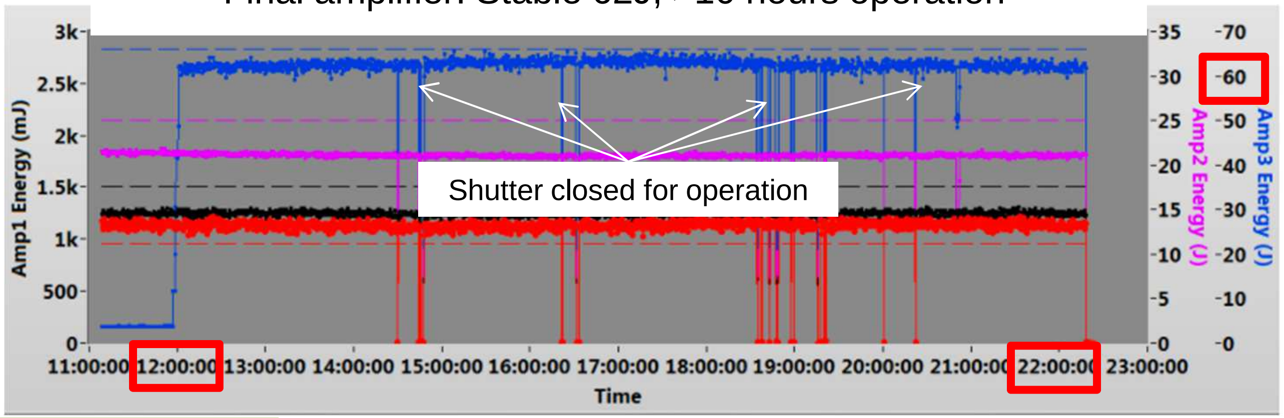
BELLA

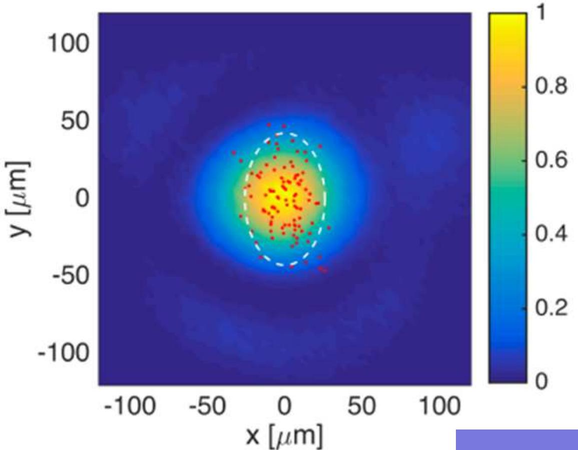
THALES

BELLA Petawatt Laser: 1 Hz, 1.3 PW to Realize 10 GeV Class LPA

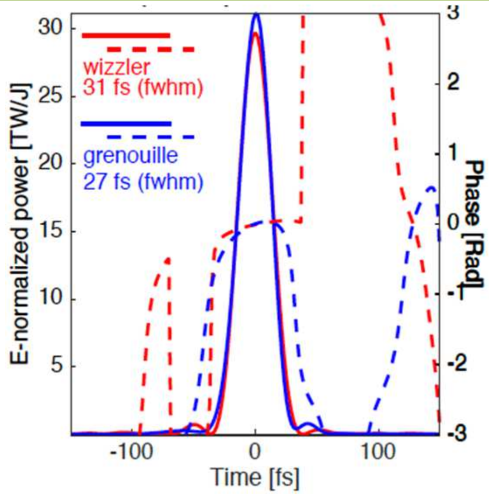
Final amplifier: Stable 62J, >10 hours operation



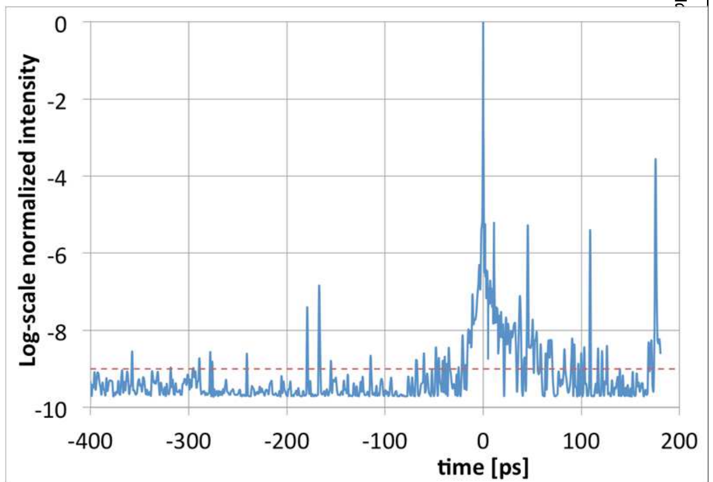
High quality spatial profile
Low pointing jitter



High quality temporal profile



High temporal contrast



49 [J on target] x 25 [TW/J] = 1.2 PW

* K. Nakamura et al., IEEE QE **53** (2017).

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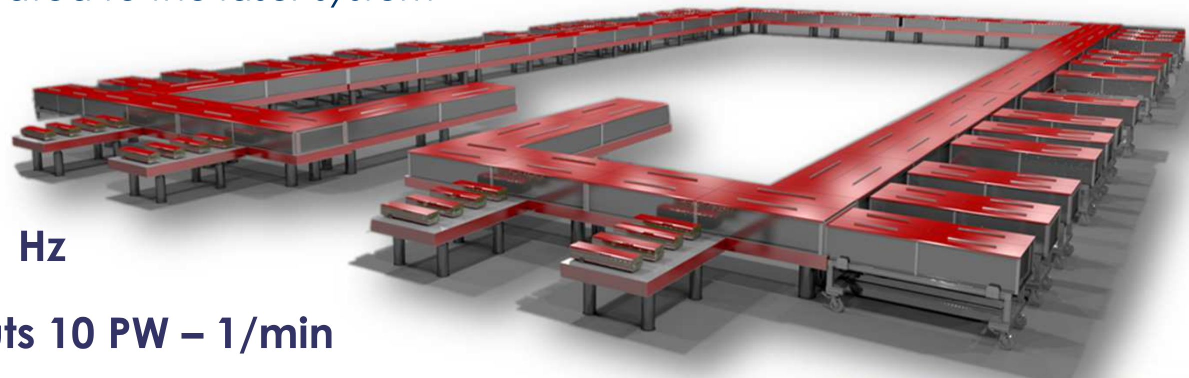
HPLS for ELI-NP

ELI-NP building with 1500m² allocated to the laser system

Contract awarded the 11th of July 2013



- **2 outputs 100 TW - 10 Hz**
- **2 outputs 1 PW - 1 Hz**
- **2 outputs 10 PW – 1/min**

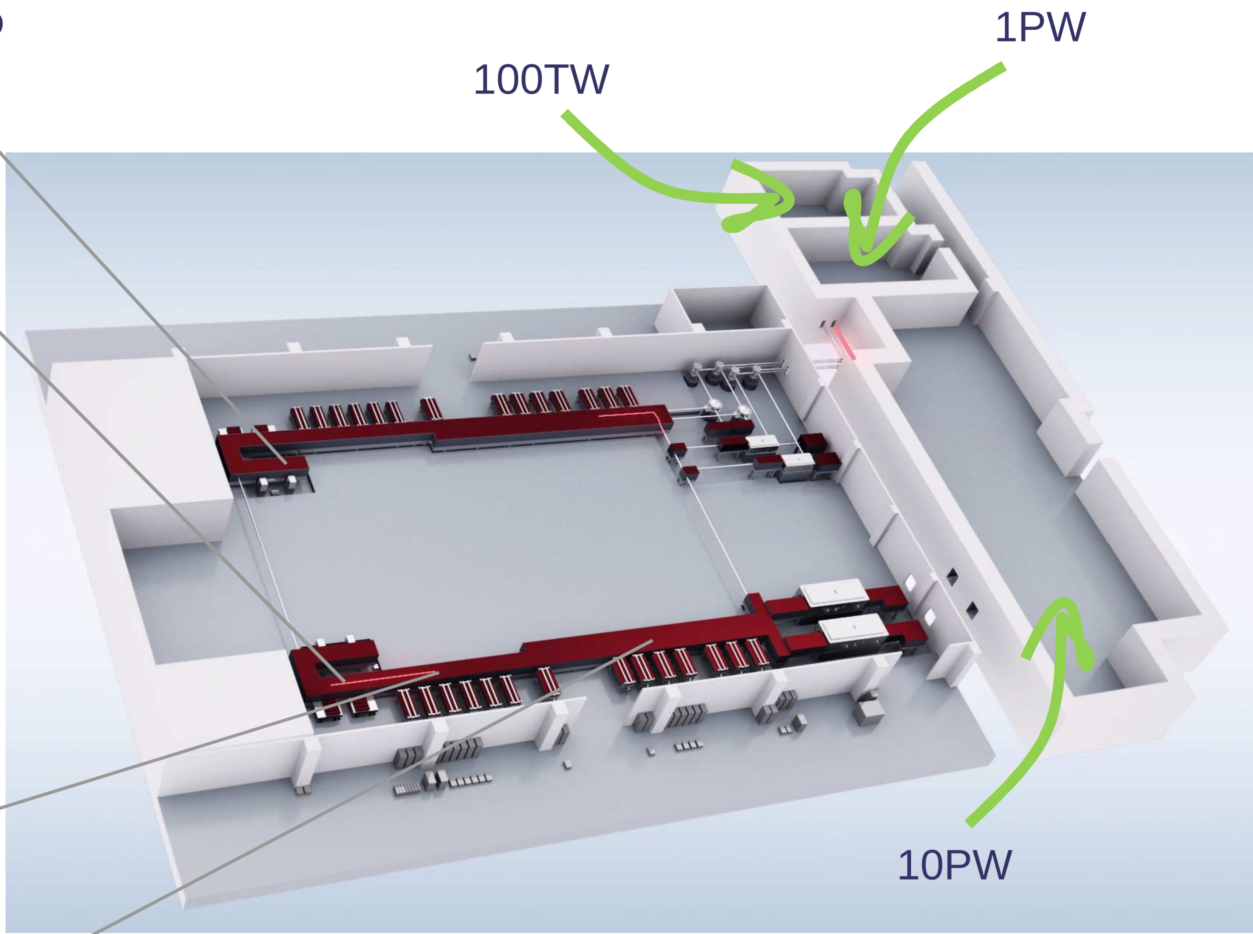
THALES

Based on a hybrid double CPA configuration

HIGH CONTRAST FRONTEND

**CPA 1 - TiSa regen amplifier
XPW for contrast and spectrum enhancement
OPCPA for contrast enhancement**

**CPA 2 for energy and energy stability – TiSa multipass amplifiers
100 TW @10Hz**



**CPA 2 for energy and energy stability – TiSa multipass amplifiers
1PW @1Hz**

**CPA 2 for energy and energy stability – TiSa multipass amplifiers
10 PW @ 1 shot/min**

Standard set-up of multi-TW systems

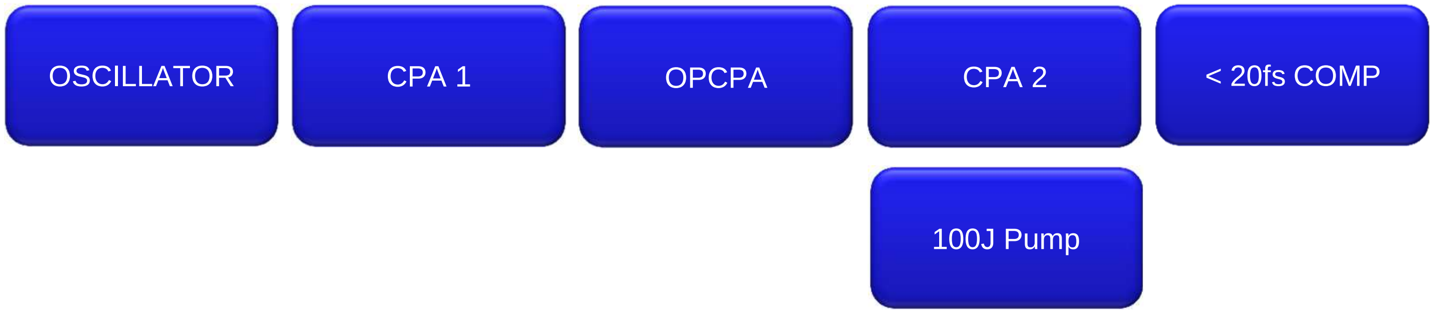
The double CPA configuration

- CPA 1 for beam stability
- XPW for contrast and spectrum enhancement
- CPA 2 for energy and energy stability

The High Power Laser Architecture

Hybrid double CPA configuration

- CPA 1 for beam stability
- XPW for contrast and spectrum enhancement
- OPCPA for contrast enhancement
- New high energy pump laser
- CPA 2 for energy and energy stability



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The High Power Laser Architecture

Based on a hybrid double CPA configuration

- **CPA 1 for beam stability** – *Ti:Sa regenerative amplifier*
- **XPW for contrast and spectrum enhancement**
- **OPCPA for contrast enhancement**
- **CPA 2 for energy and energy stability** – *Ti:Sa multipass amplifiers*
  - 100 TW @10Hz pump lasers energy > 12 J
  - 1 PW @1Hz pump lasers energy > 90 J
  - 10 PW @1shot/min pump lasers energy > 800 J

THALES

The High Power Laser Architecture

Based on a hybrid double CPA configuration

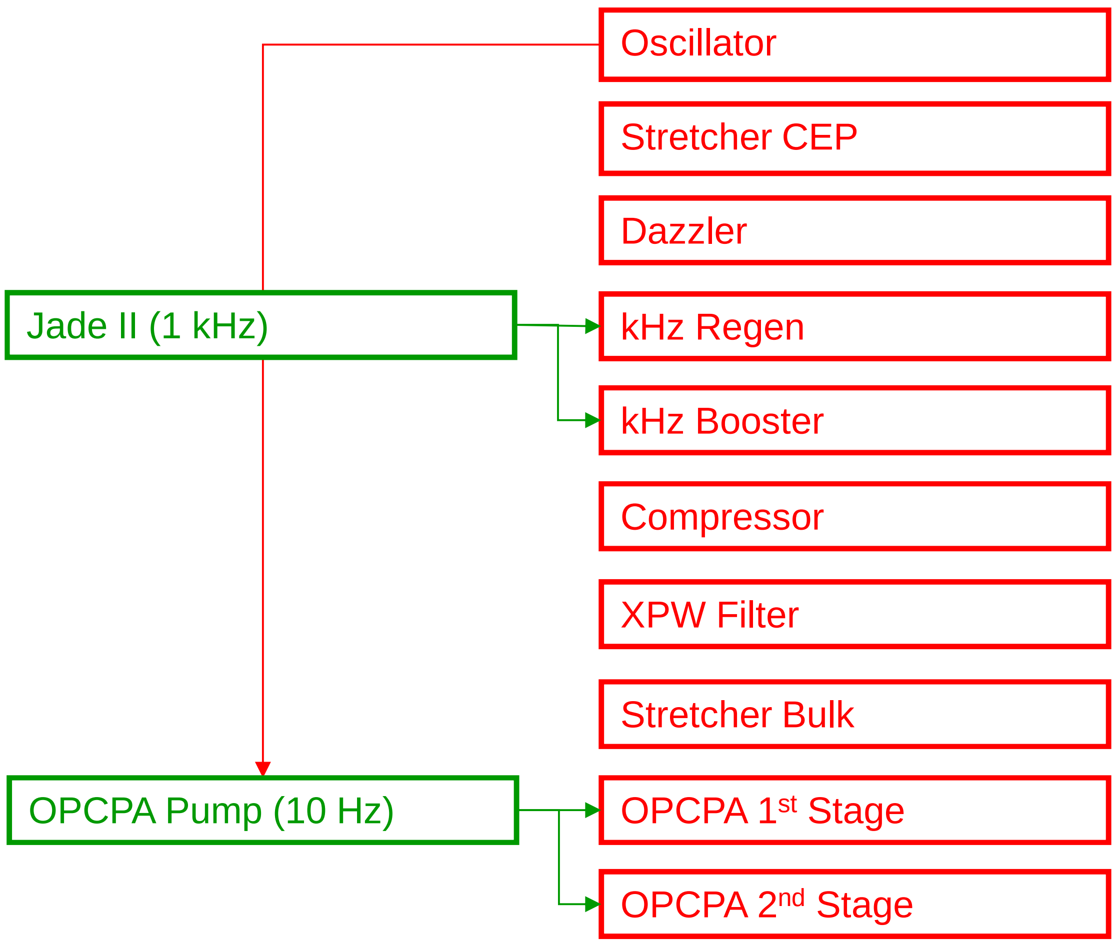
- **CPA 1 for beam stability** – *Ti:Sa regenerative amplifier*
- **XPW for contrast and spectrum enhancement**
- **OPCPA for contrast enhancement**

High Contrast FrontEnd

- **CPA 2 for energy and energy stability** – *Ti:Sa multipass amplifiers*
  - 100 TW @10Hz pump lasers energy > 12 J
  - 1 PW @1Hz pump lasers energy > 90 J
  - 10 PW @1shot/min pump lasers energy > 800 J

NIR architecture (1/3)

Frontend ELI-NP



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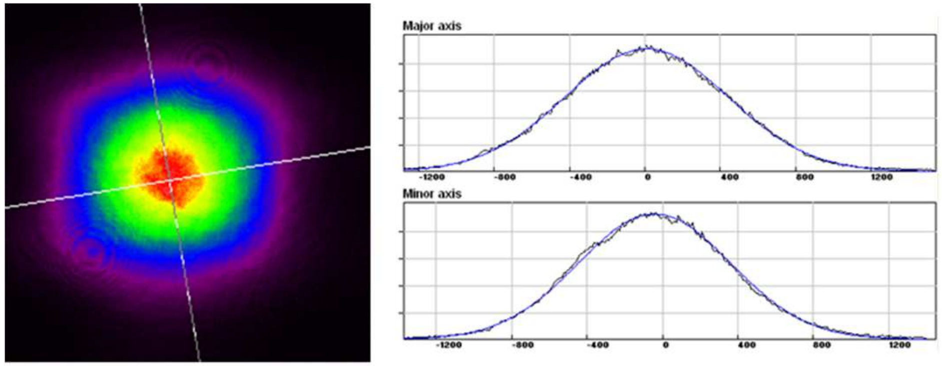
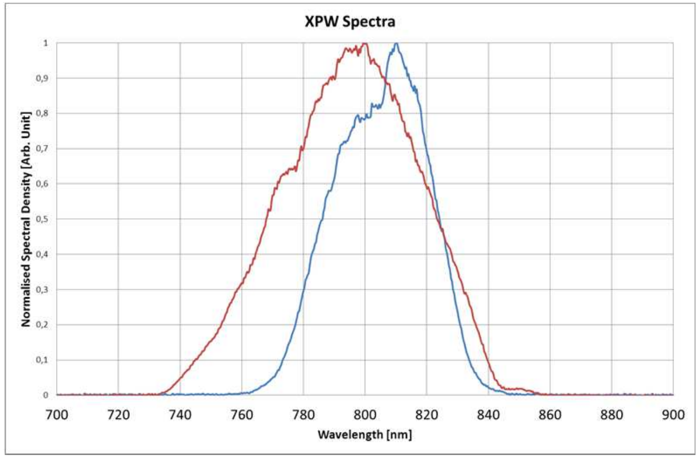
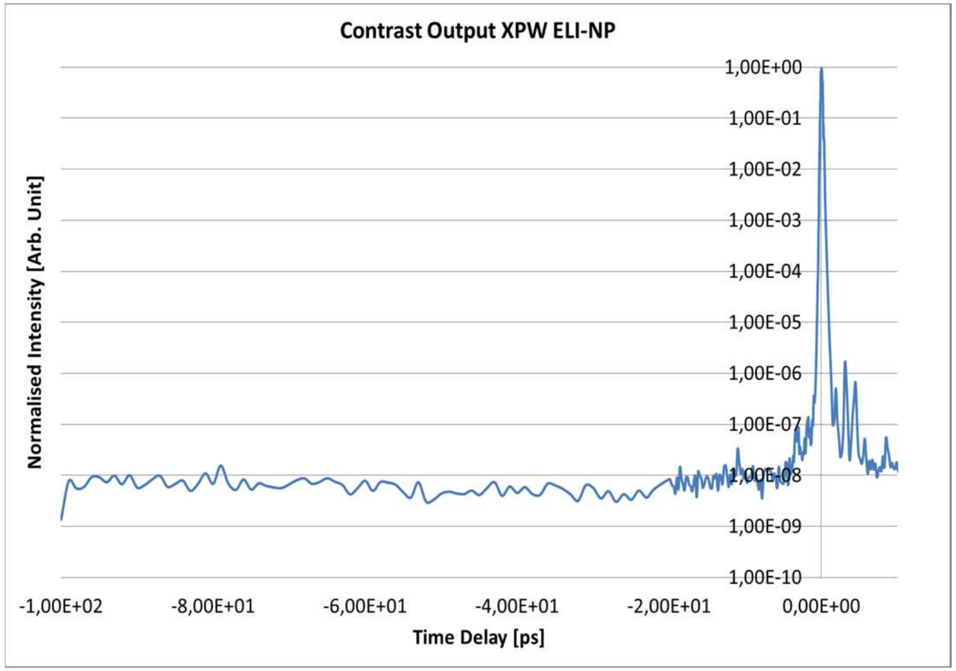
NIR architecture (2/3)

XPW Output results







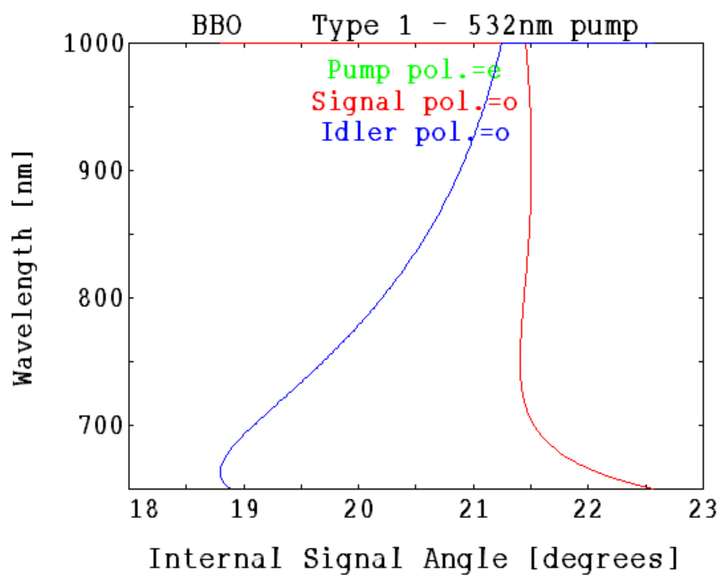
Contrast enhancement > 10^4
Output energy > 30 µJ
Bandwidth > 70 nm (FWHM)

THALES

NIR architecture (3/3)

OPCPA

- Energy >10mJ
- Pulse duration ~20ps
- Bandwidth FWHM >63nm
- Repetition rate: 10 Hz
- Pulse contrast (100ps): > 10^{12}:1
- Short term stability < 3% rms over 500 shots



THALES

Simulation and Results

- **Simulation Input Parameter:**
  - 10µJ
  - gaussian spectrum 65nm FWHM
  - 2 stage OPCPA pumped with 30mJ and 50mJ
- **Experimental Input Parameter**
  - 10µJ
  - Slightly super gaussian 63nm FWHM
  - 2 stage OPCPA pumped with 25mJ and 30mJ

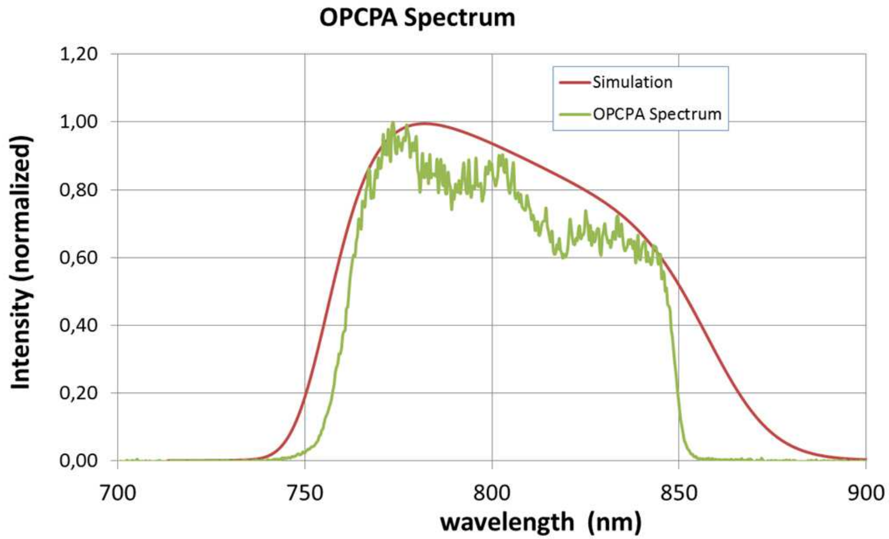
Simulation done with full 3D of the coupled wave equation including walkoff, parasitic SHG and dispersion.

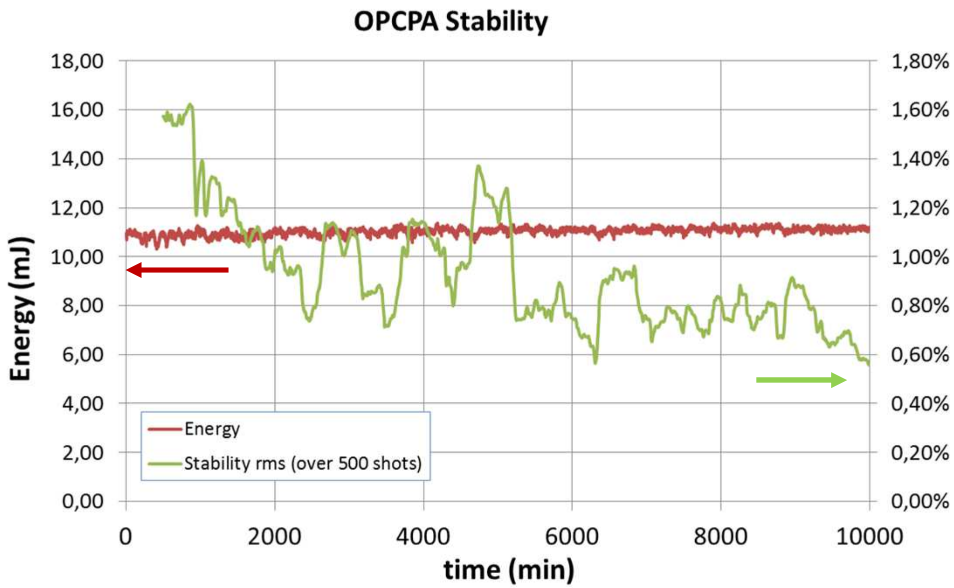
G. Arisholm J. Opt. Soc. Am. B 16, 117–127 (1999)

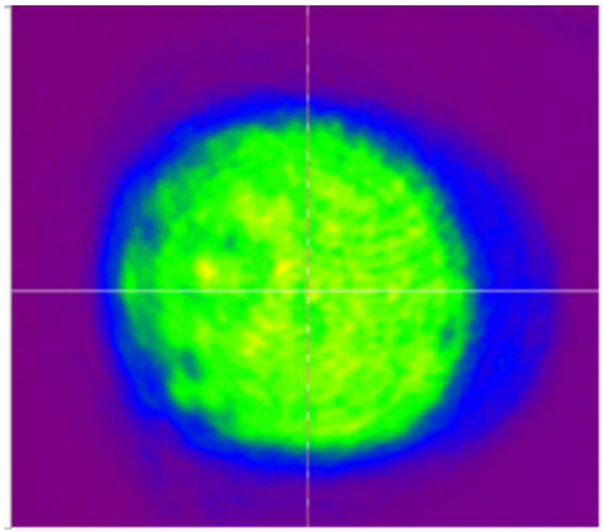
Experimental Results

Simulation and Results

- **Simulation result:**
  - 16mJ
  - 77nm FWHM
- **Experimental result:**
  - 11,6mJ (< 1,6% rms over 500 shots)





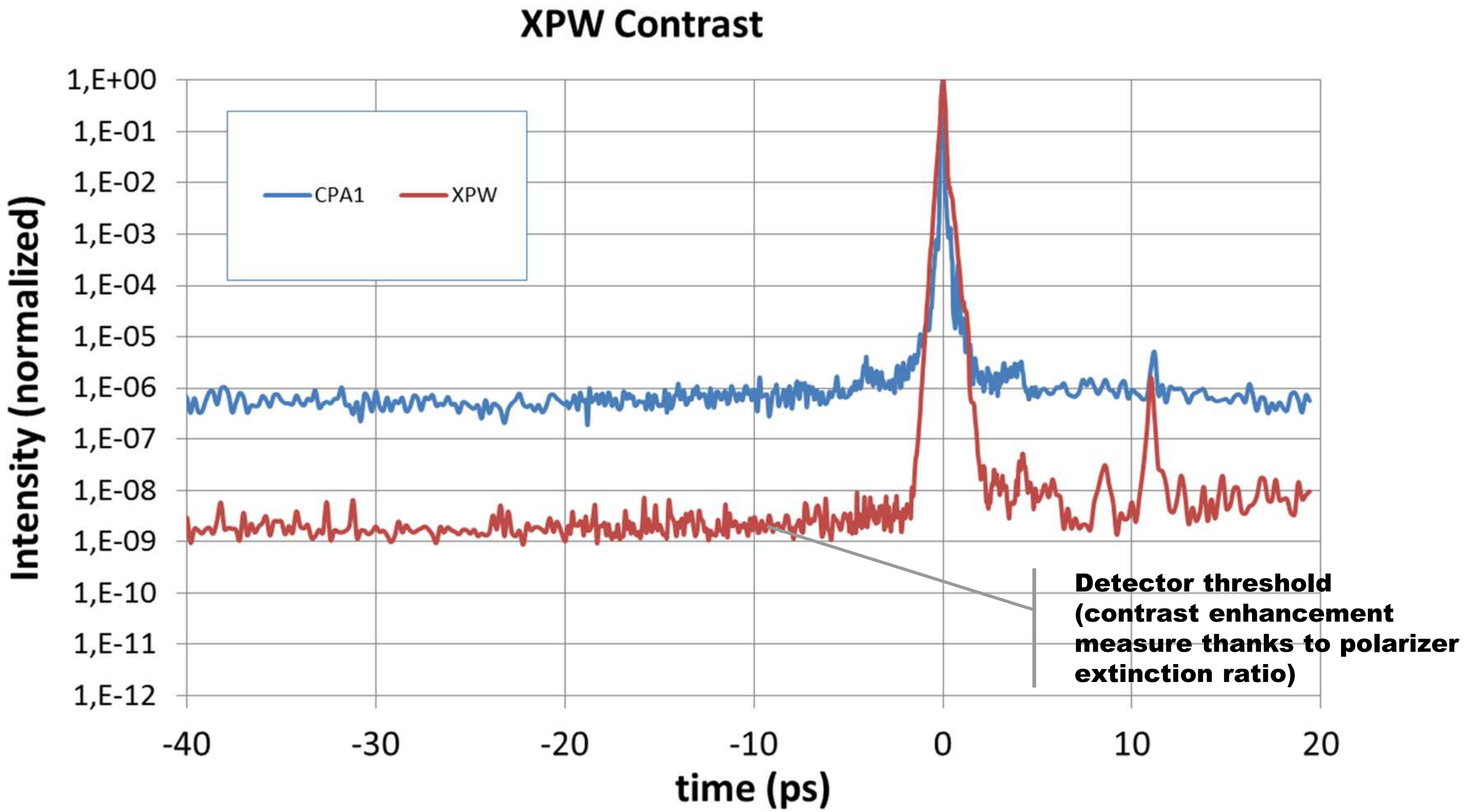


ICFO The Institute of Photonic Sciences

THALES

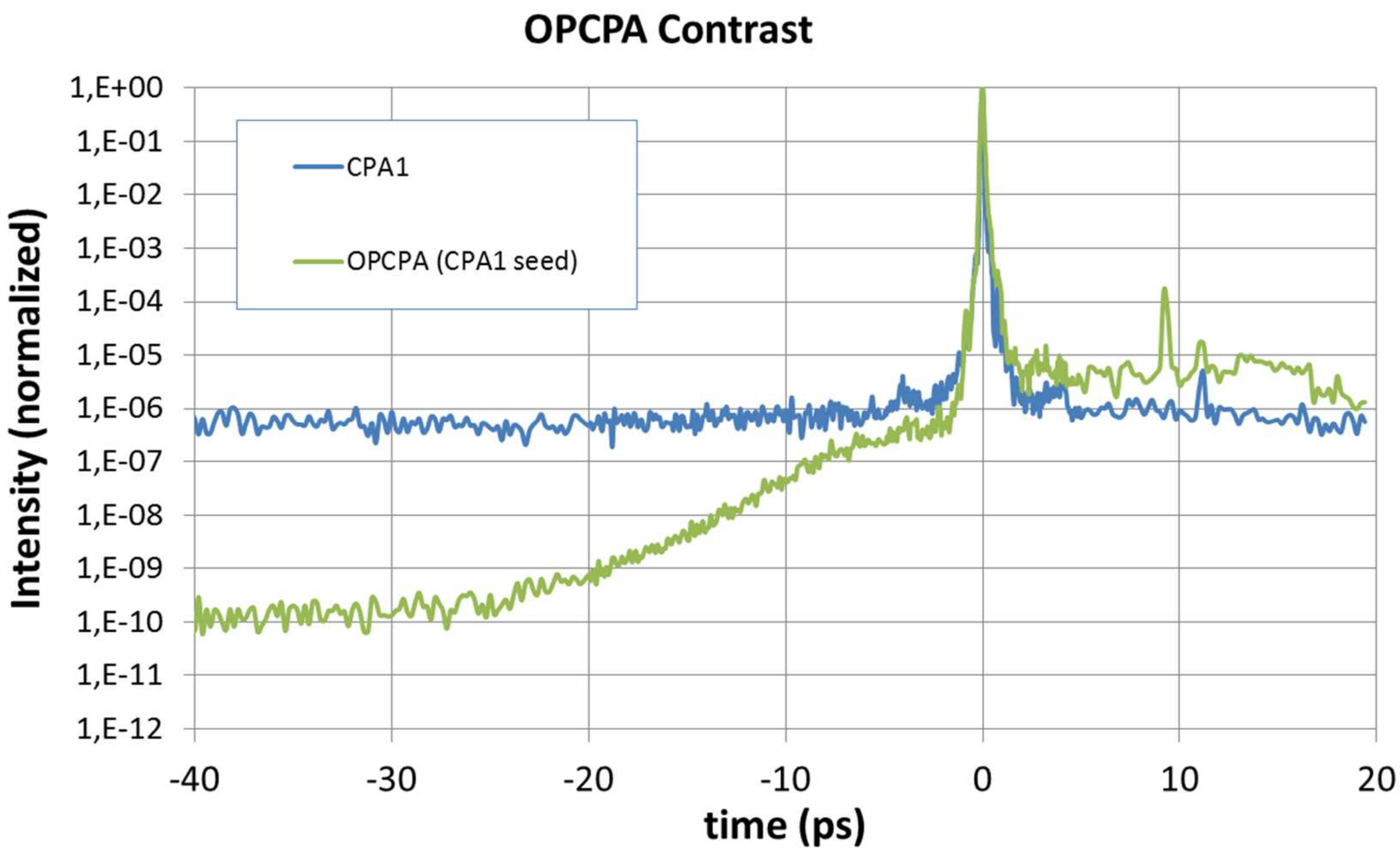
Contrast consideration

- Typical Contrast on pure Ti:Sapphire system equipped with XPW filter leads to a contrast improvement of 10^4 (10^3 measured



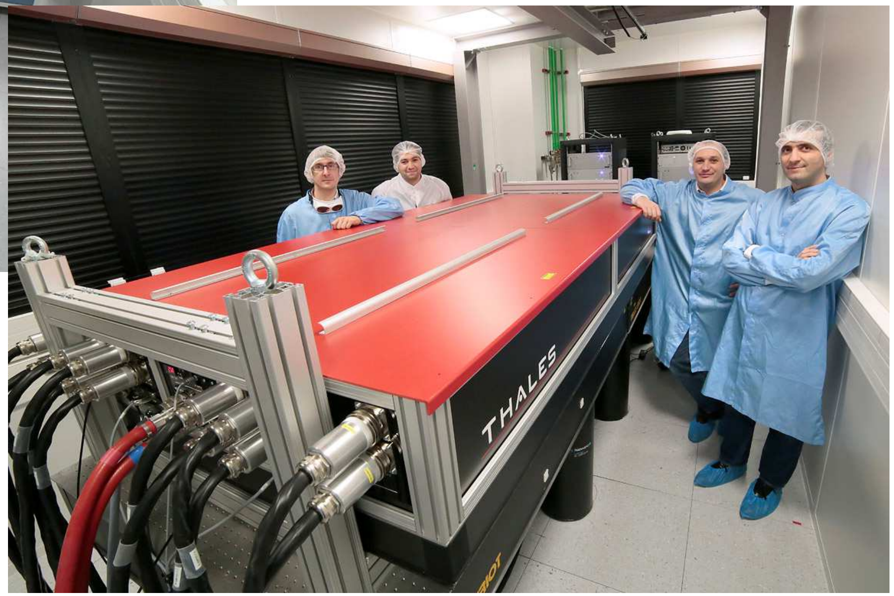
Contrast consideration

- Gain of 4 orders of magnitude measured on OPCPA on time scale of 25ps



ATLAS 100: High Energy laser system

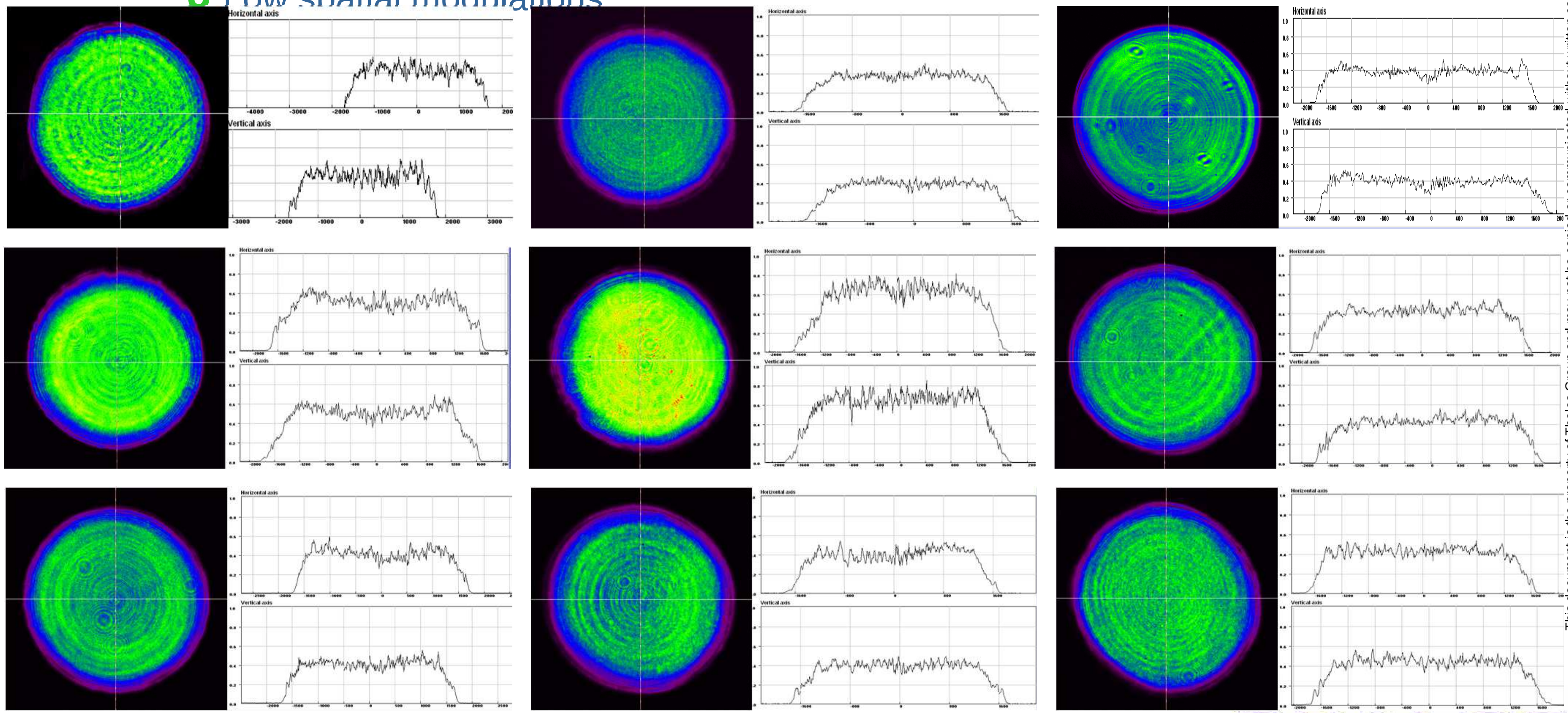
Performances demonstration in November 2014



THALES

Fourteen units already manufactured (out of 16)

- **Beam profile of the first nine units**
  - Round and supergaussian beam profile
  - Low spatial modulations

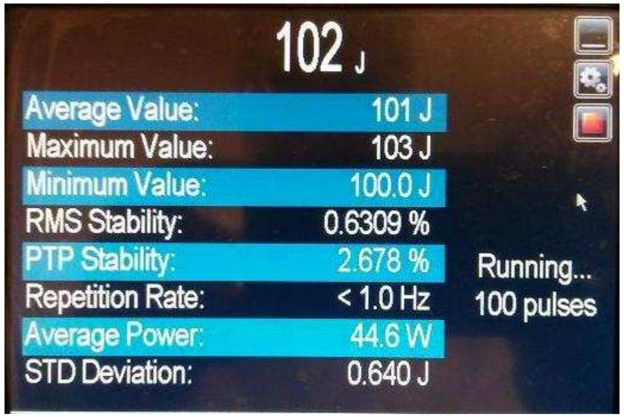


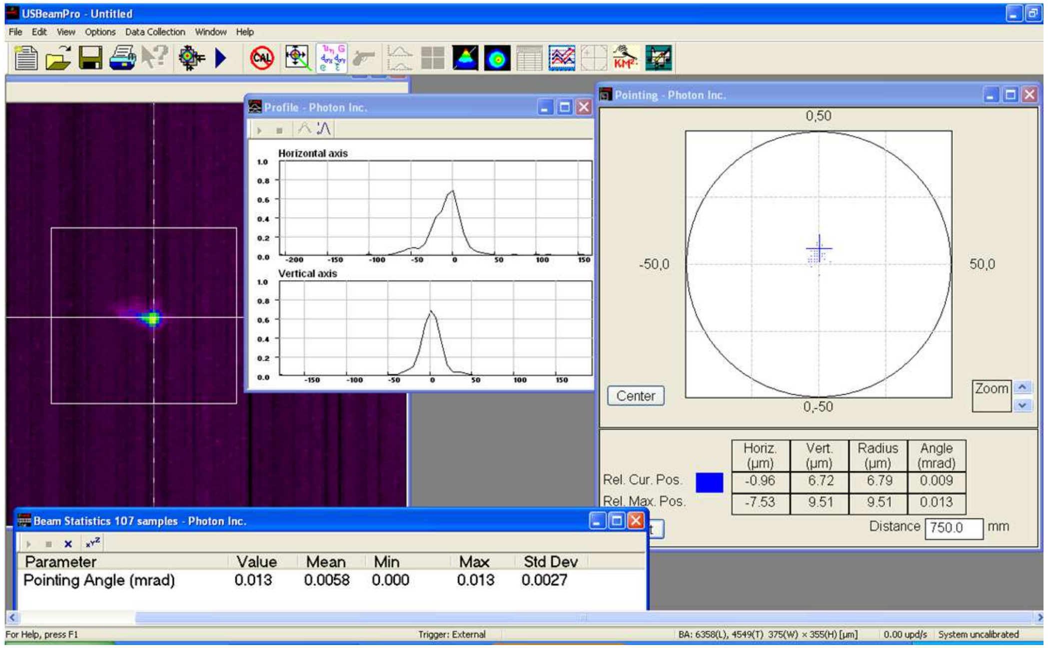
THALES

Stability measurements

- **Energy stability**
  - 0.6% RMS recorded over 100 pulses

- **Pointing stability**
  - < 20 µrad peak-to-valley over 100 shots

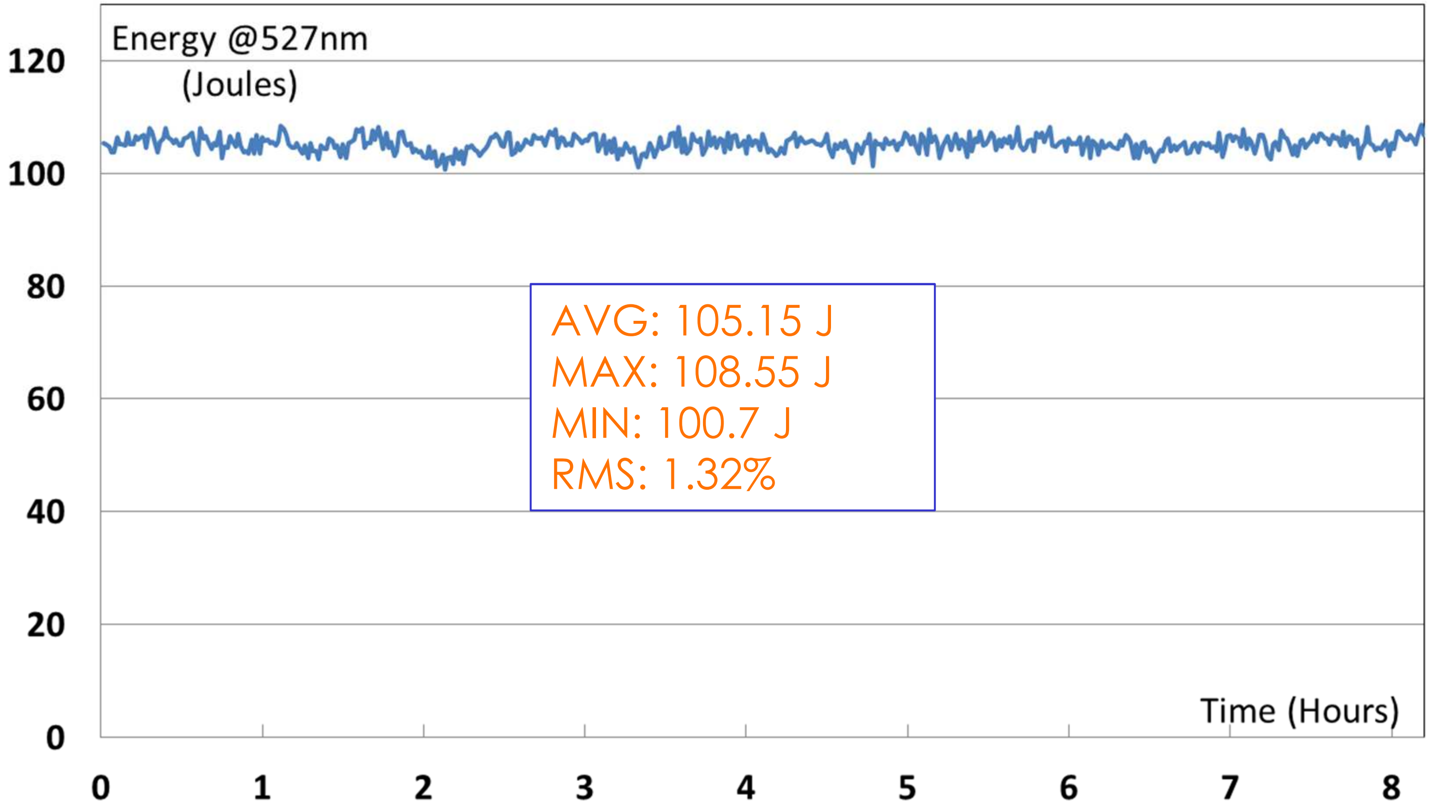




THALES

Long term stability measurements

- No drift
- No Warm-Up time



THALES

Size and integration (Picture from ELI-NP systems at TOSA)

ELI-NP System in operation at Thales

Integration up to 1PW amplifier within Thales premises

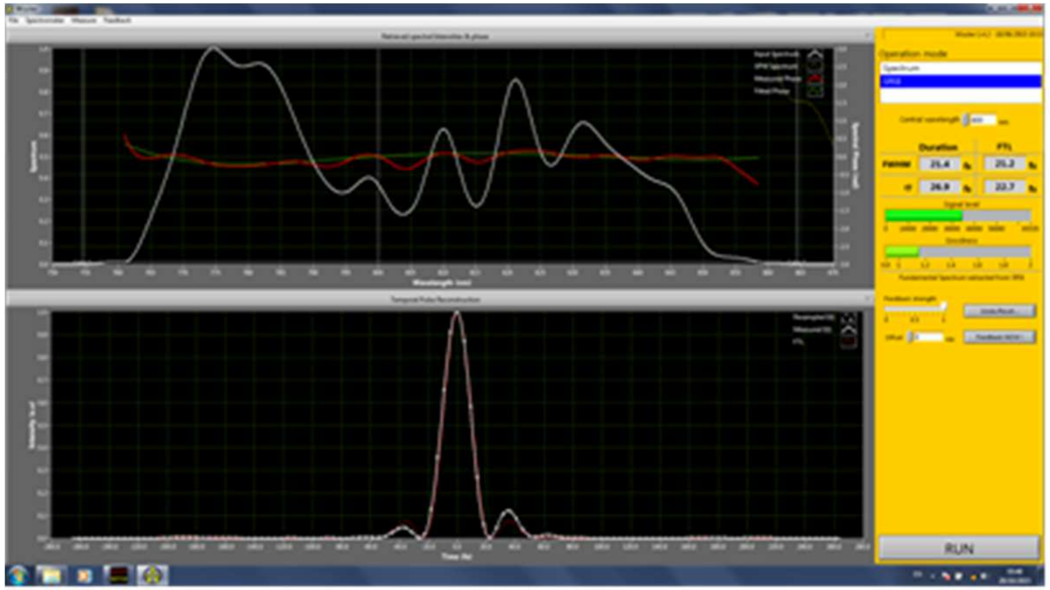
- 1PW amplifier including spectral filter (> 39 J with 75 nm FWHM bandwidth demonstrated)
- 100TW compressor

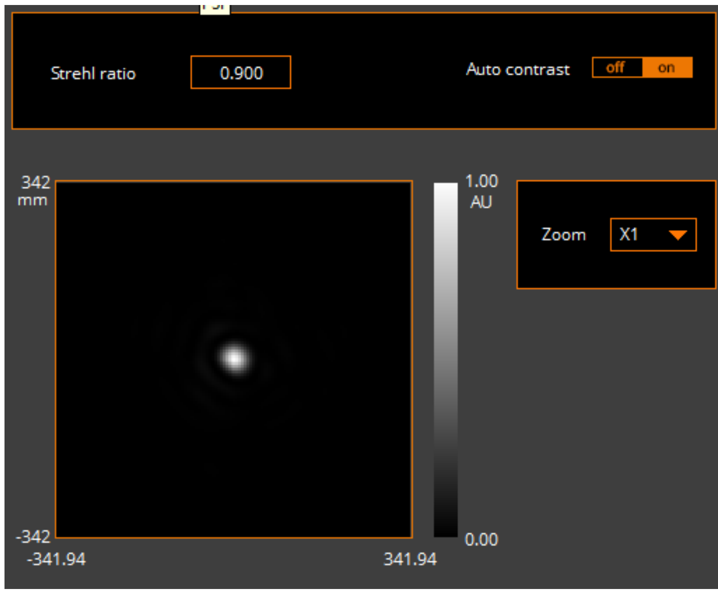
AMP2 Ti:Sa amplifier with 6 high energy GAÏA HP pump laser

100TW compressor

Compression at 100TW level

- Injected energy > 4J
- Compressor efficiency ~70%
- Pulse duration 21fs
- Strehl ratio 0.9

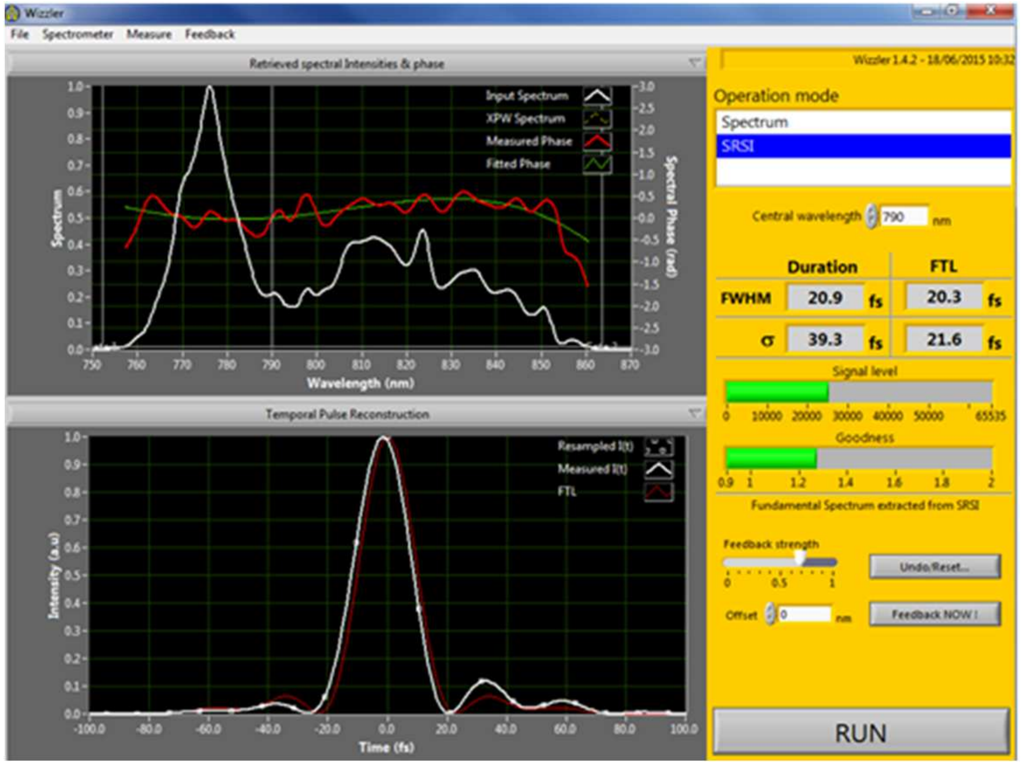


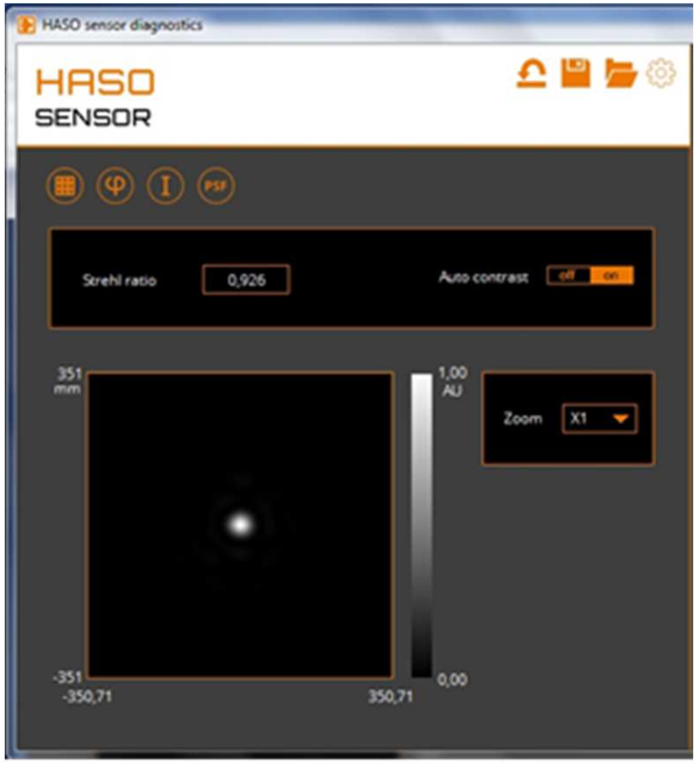


THALES

Compression at 1PW level

- Injected energy ~ 40J (attenuated before compressor)
- Compressor efficiency ~70%
- Pulse duration 21fs
- Strehl ratio 0.9





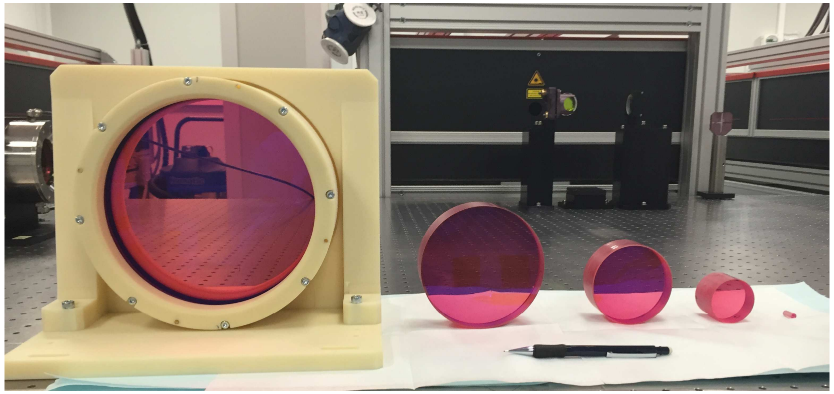
THALES

ELI-NP installation has now started in ELI-NP building @ Magurele

2 Front Ends now operational

Next main steps

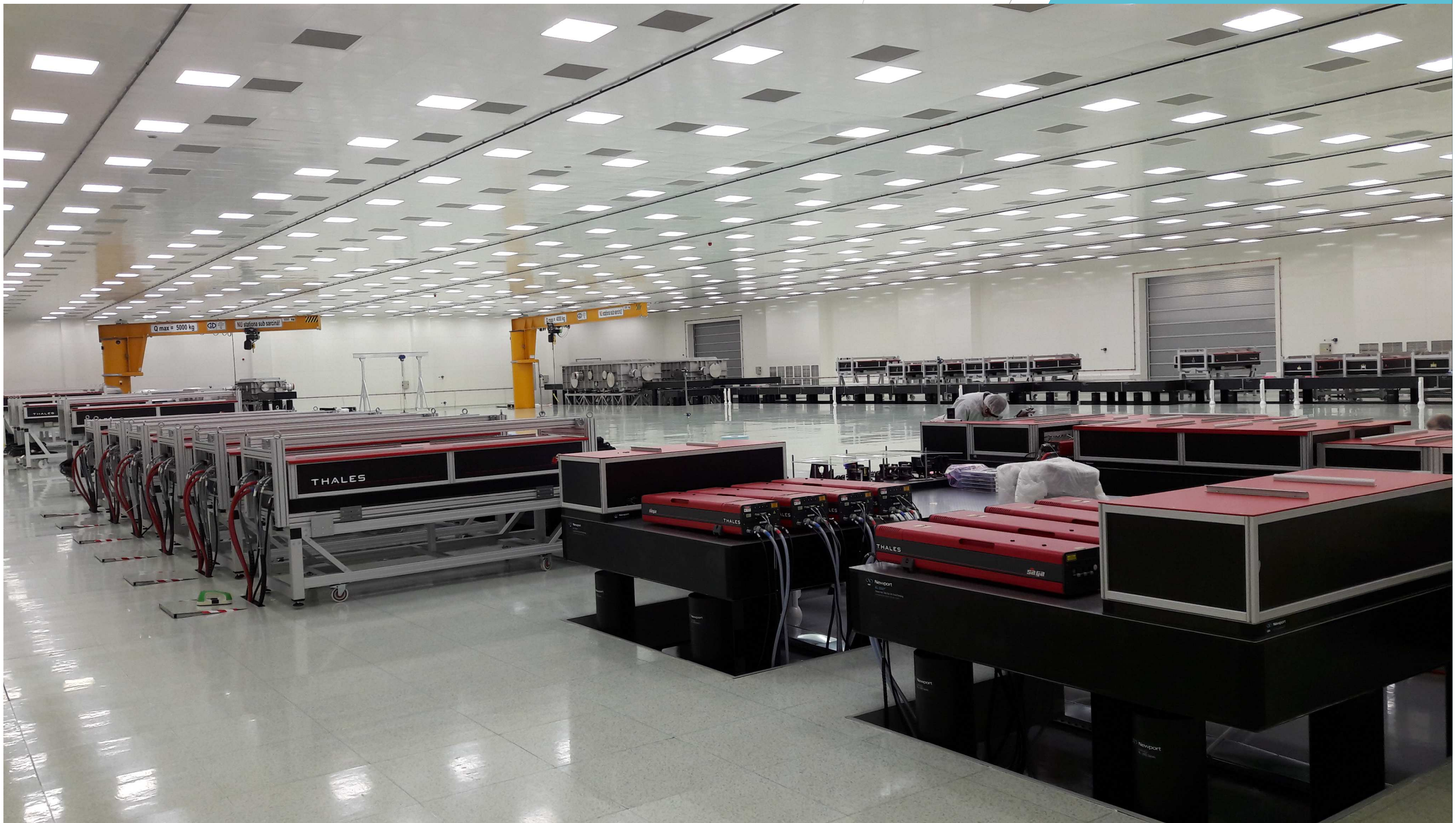
- **Integration in Romania of the full system including critical component as the largest with high quality Ti:Sa crystal ever achieved … and already available !**



Ti:Sa crystal family for ELI-NP from 6 to 200mm in diameter

First 1m scale optical grating manufactured by HJY team at Palaiseau facility (France)

Now in IFINHH premises



Supervision room @ ELI-NP

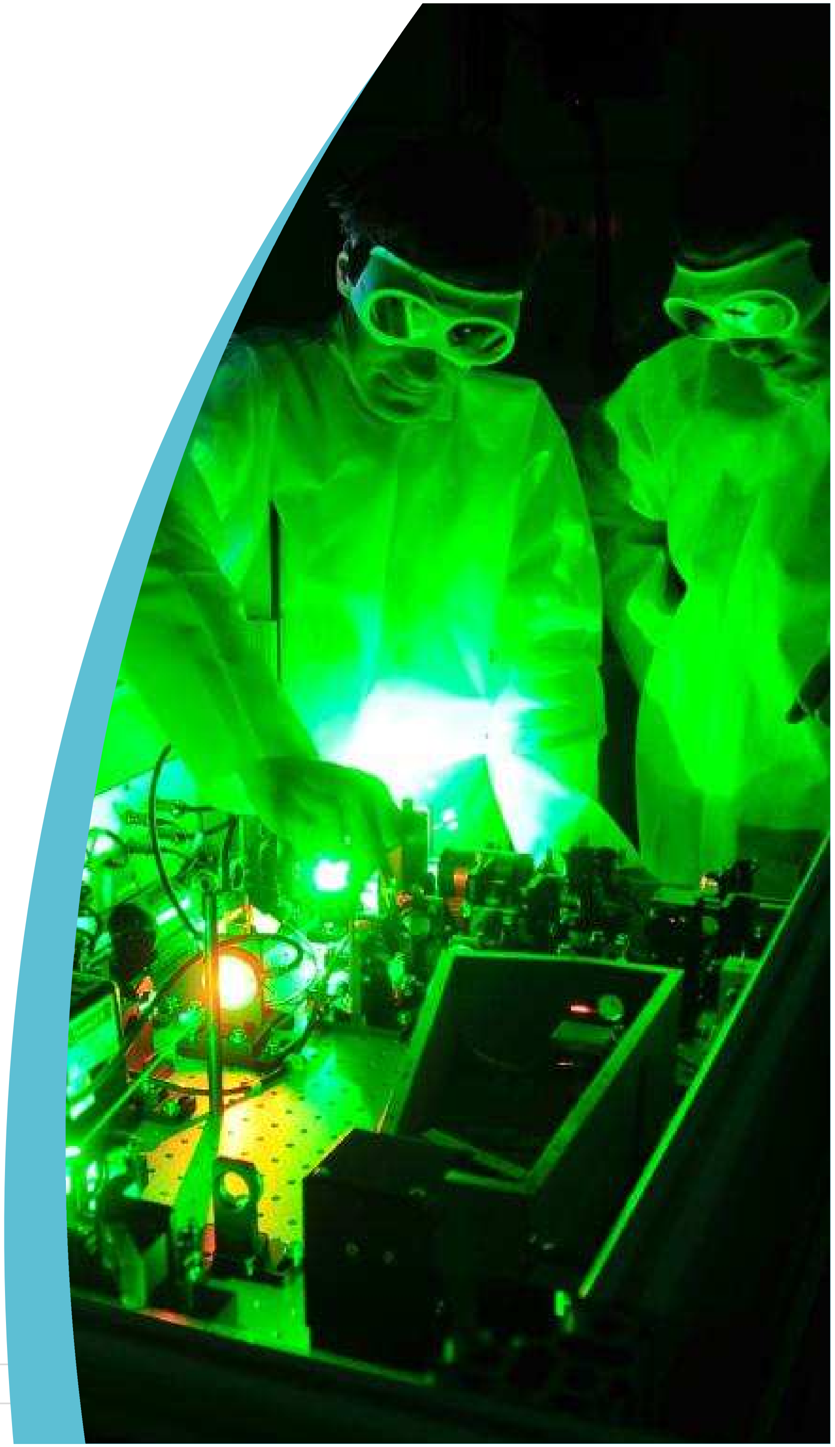
Conclusion & Perspectives

- **TiSa based PetaWatt lasers have been now introduced in few labs and start to produce science (BELLA, GIST)**
- **4 systems of 10 PW (of which 3 TiSa-based) are in construction and expected for delivery in 2018-2020 period (APOLLON, ELI-NP, ELI-BL, SULF@SIOM)**
- **Enabling technologies for TiSa-based 10 PW have been validated and are now available (large TiSa crystals, meter size gratings, industrial grade pump lasers, ultra high contrast)**
- **Next generation at 100 PW & more must follow a multi-beam approach (at least at compression stage) and investigate new technologies (beam combination, few cycle pulses for TiSa)**

THALES

Thank you for your attention

www.thalesgroup.com



SourceLAB

Laser Plasma Technologies

Laser Plasma Technologies for and beyond laboratories

December 12, 2017, CREMLIN WP6
Institut Henri Poincaré, Paris

François Sylla, PhD

SourceLAB was created in 2013 as a spin-off of the Laboratoire d'Optique Appliquée

Before SourceLAB

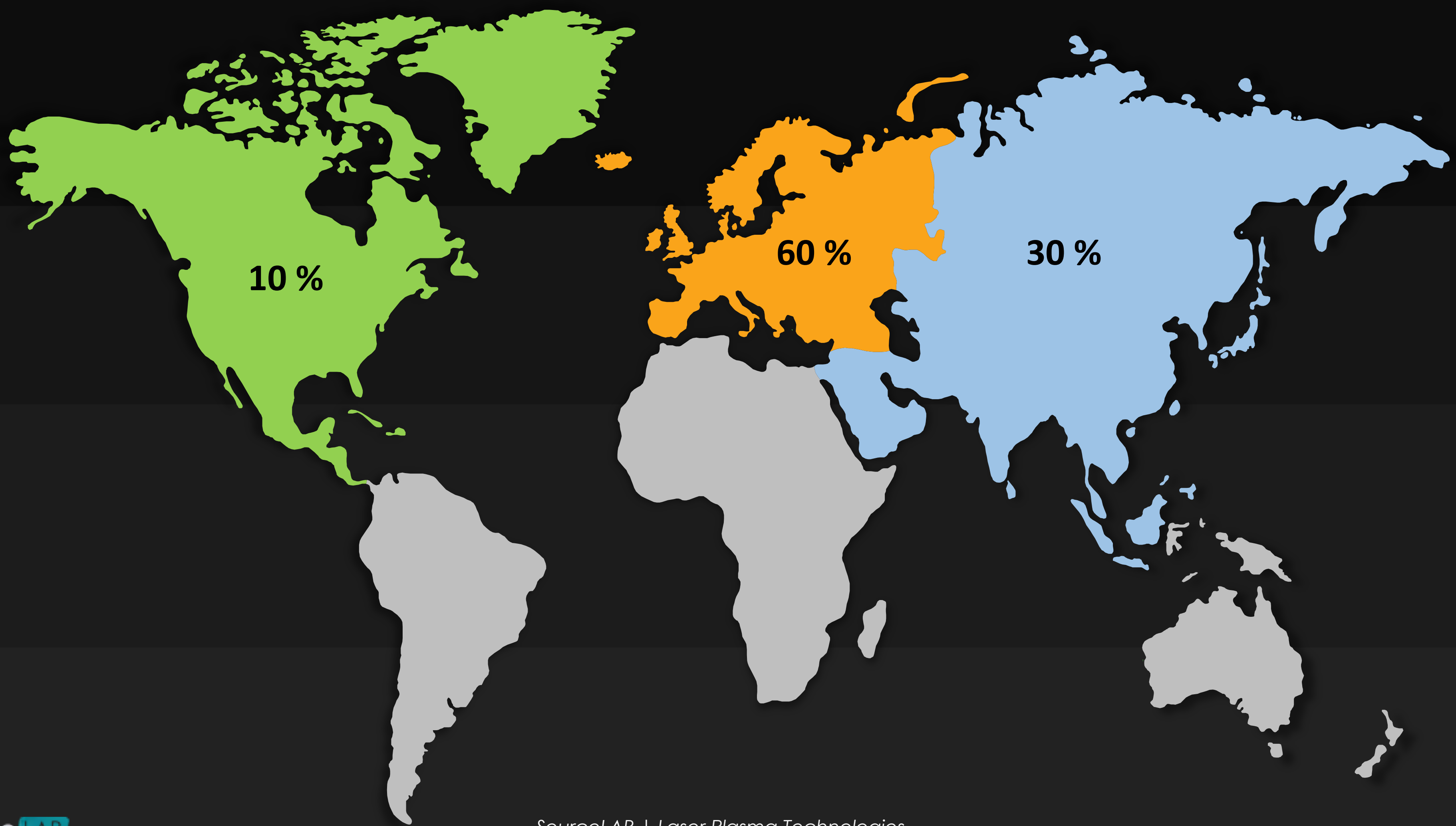
- 2 PhD thesis at the Laboratoire d'Optique Appliquée
- Different systems for laser-plasma interaction developed during thesis:
    - Novel results
    - Innovative targetry for laser plasma science
    - Pre-industrialized prototypes
- Joined by a business developer

SourceLAB

- SourceLAB founded in July 2013 via ERC-PoC initiative (Malka)
- Located in the premises of the Laboratoire d'Optique Appliquée
- Strong support of CNRS, ENSTA, Ecole Polytechnique and BPIFrance
- Initial mission: to commercialize the results of the thesis works of the founders
- Final objectives: to commercialize Laser Plasma Accelerators for industrial and medical markets

During the first years of activity, we commercialized our systems, mainly in Europe and Asia

From July 2013 to December 2017 (> 2 MEUR Revenue, >20 % CAGR)



Some references

apri ADVANCED PHOTONICS RESEARCH INSTITUTE

FEMTO LASERS
www.femtolasers.com

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

AREVA
l'avenir pour énergie

SHANGHAI JIAO TONG UNIVERSITY 1896

DESY

THALES

DE LA RECHERCHE À L'INDUSTRIE
cea

tifr

Science & Technology Facilities Council

QST

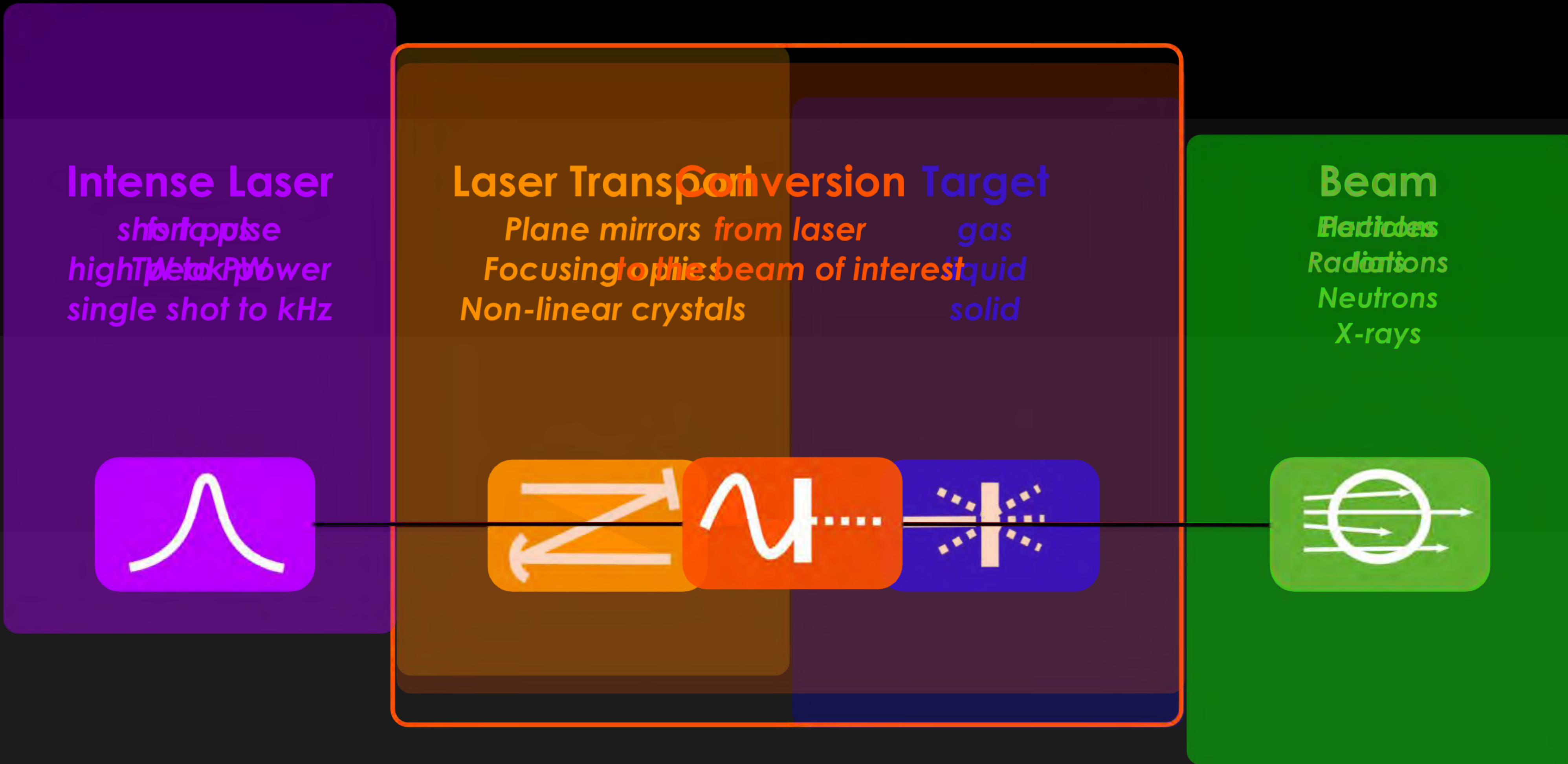
eli attosecond

INFLPR

loa

RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY, INDORE

Our fields of expertise



Contrast cleaning
Plasma mirror
XPW

Beam engineering
Design
Shaping
Stabilization

Precision targetry
Gas cell
Gas jet
Solid target positioner

Characterization
Ion analysis
X-ray radiography

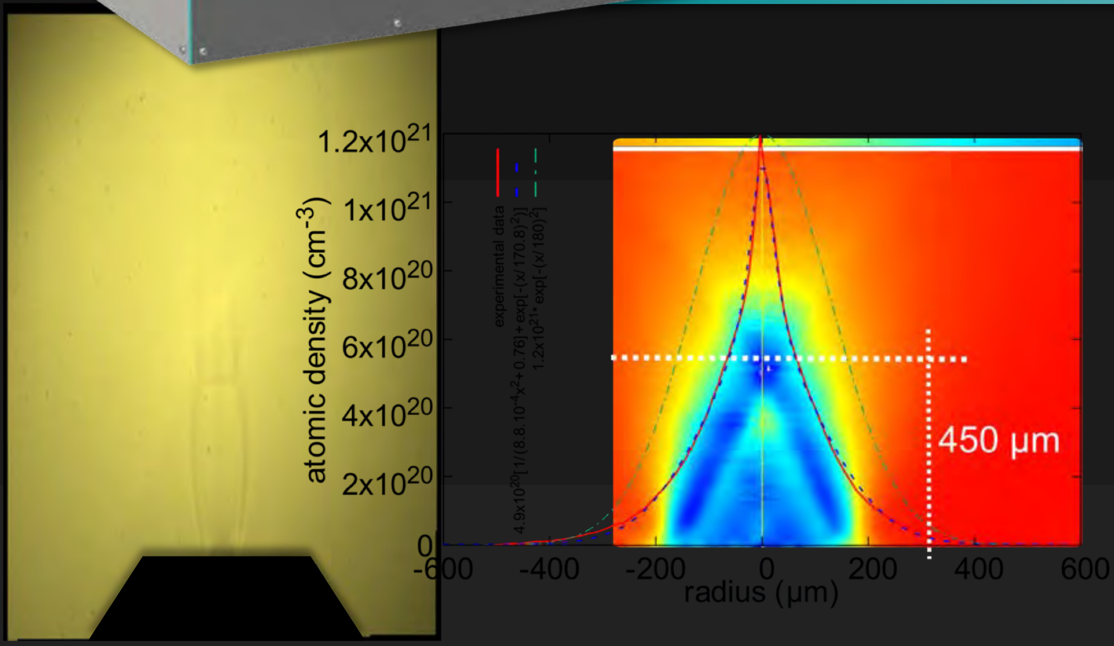
Ultrathin high density gas jet for near-critical plasma

Over-critical gas jet

Fully characterized

Tunable output gas flow

Sub-100 µm thickness



Peak density (He, Ar, Ne)	> 1.2×10^{21} atoms/cm^3
Thickness (FHWM)	< 100 µm
Open/close time	< 10 ms
Repetition rate	0.1 Hz
Nozzle materials	SS, Brass Al, Ceramic
Options	• Phasics SID4 Density • Nozzles design

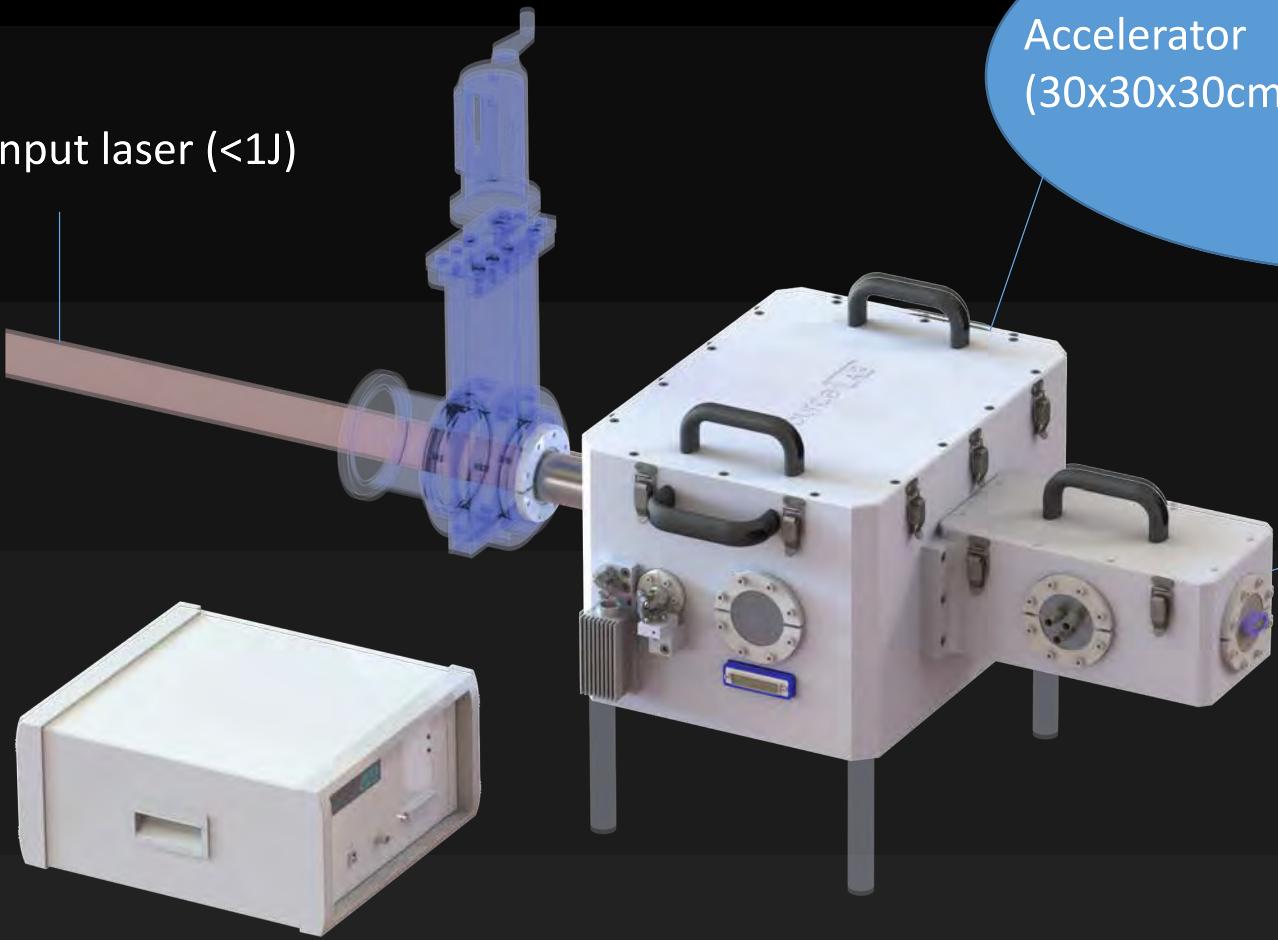
References

- Depresseux et al, **Nat Phot.** 9, 817 (2015)
- Flacco et al, **Nat. Phys**. 11, 409 (2015)
- Sylla et al, **PRL**, 110, 085001 (2013)
- Sylla et al, **PRL**, 108, 115003 (2012)

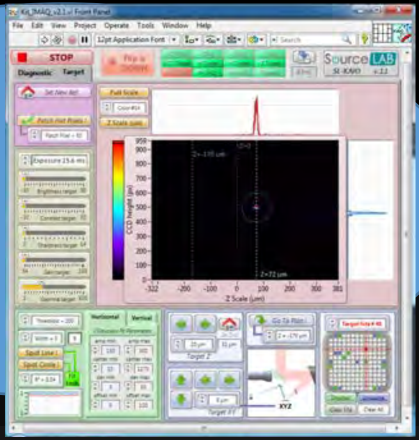
All-in-One compact source

Smart Ion Accelerator KAIO

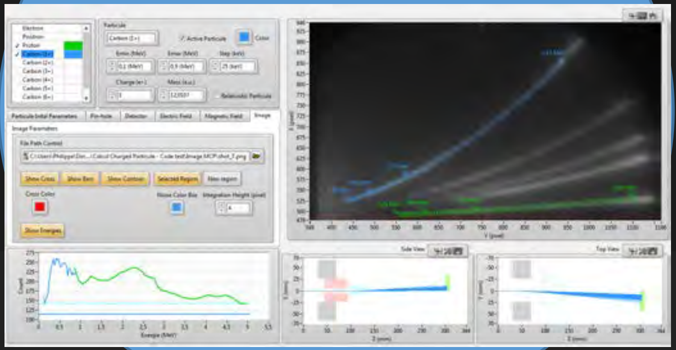
Input laser (<1J)



Accelerator
(30x30x30cm3)

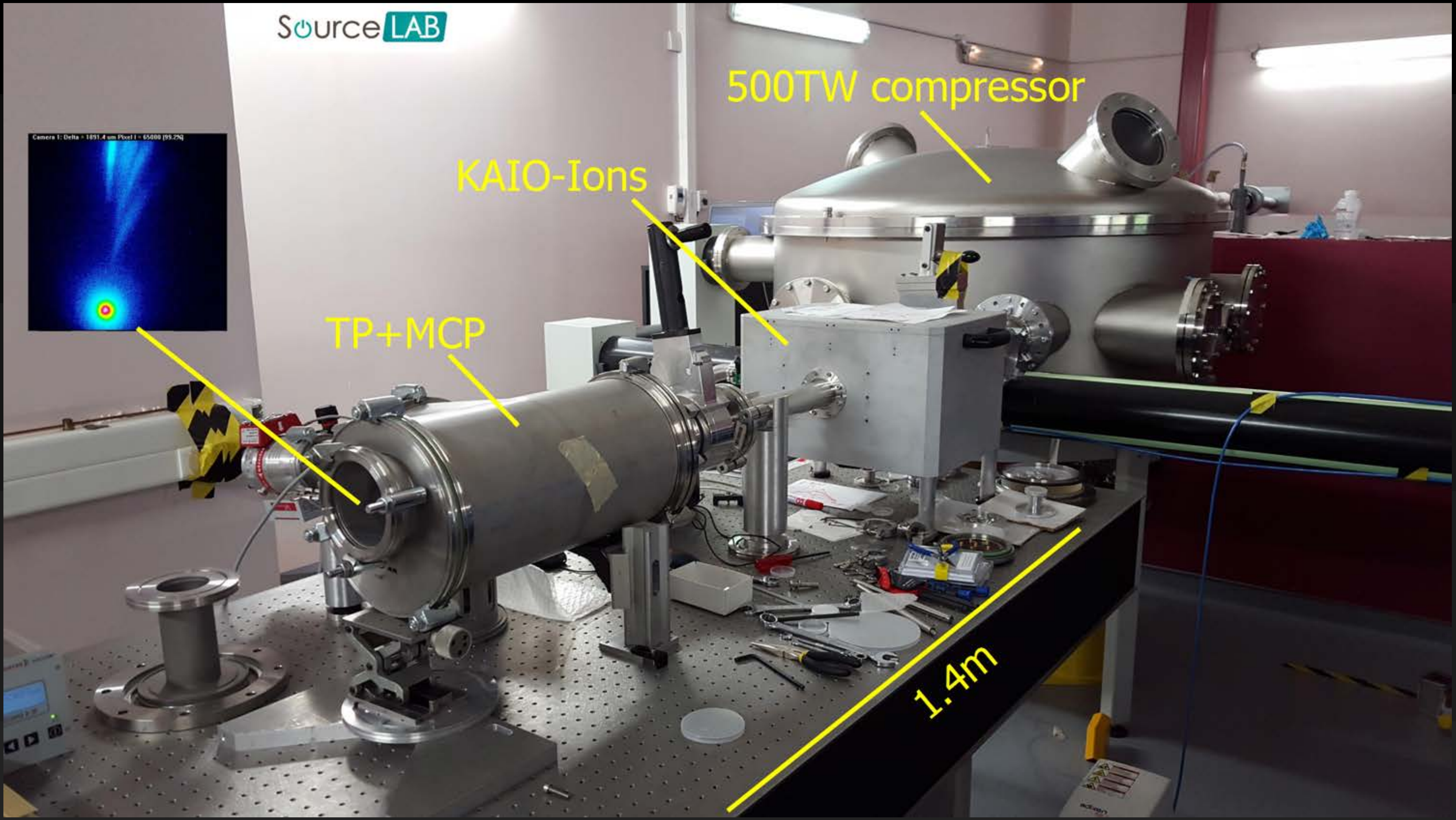


Detector
(TP + Scintillator)



KAIO tests at LOA

Conversion

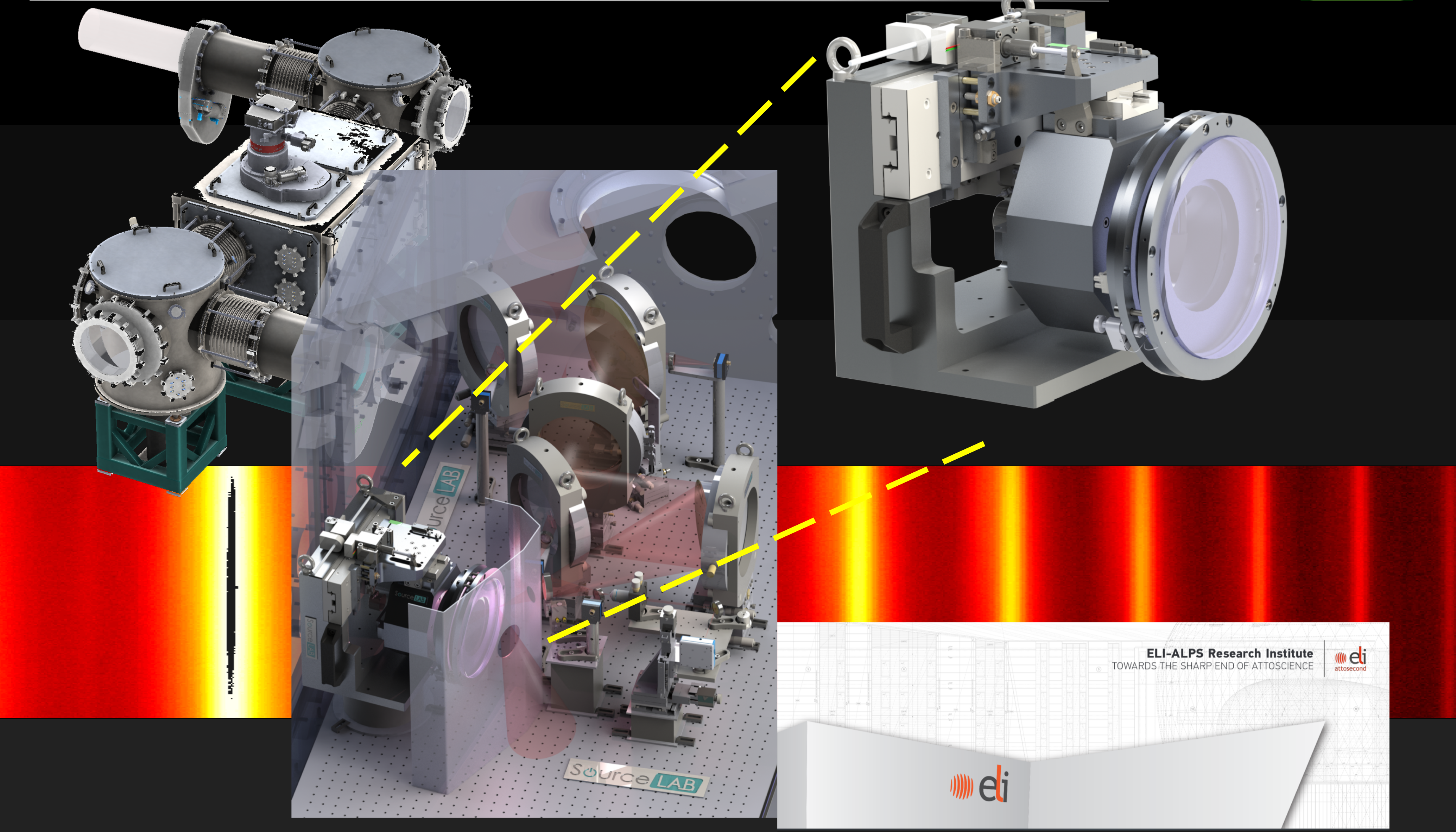


ELI-ALPS SHHG PW Beamline construction
In collaboration with LIDyL (CEA-Saclay)

Beam

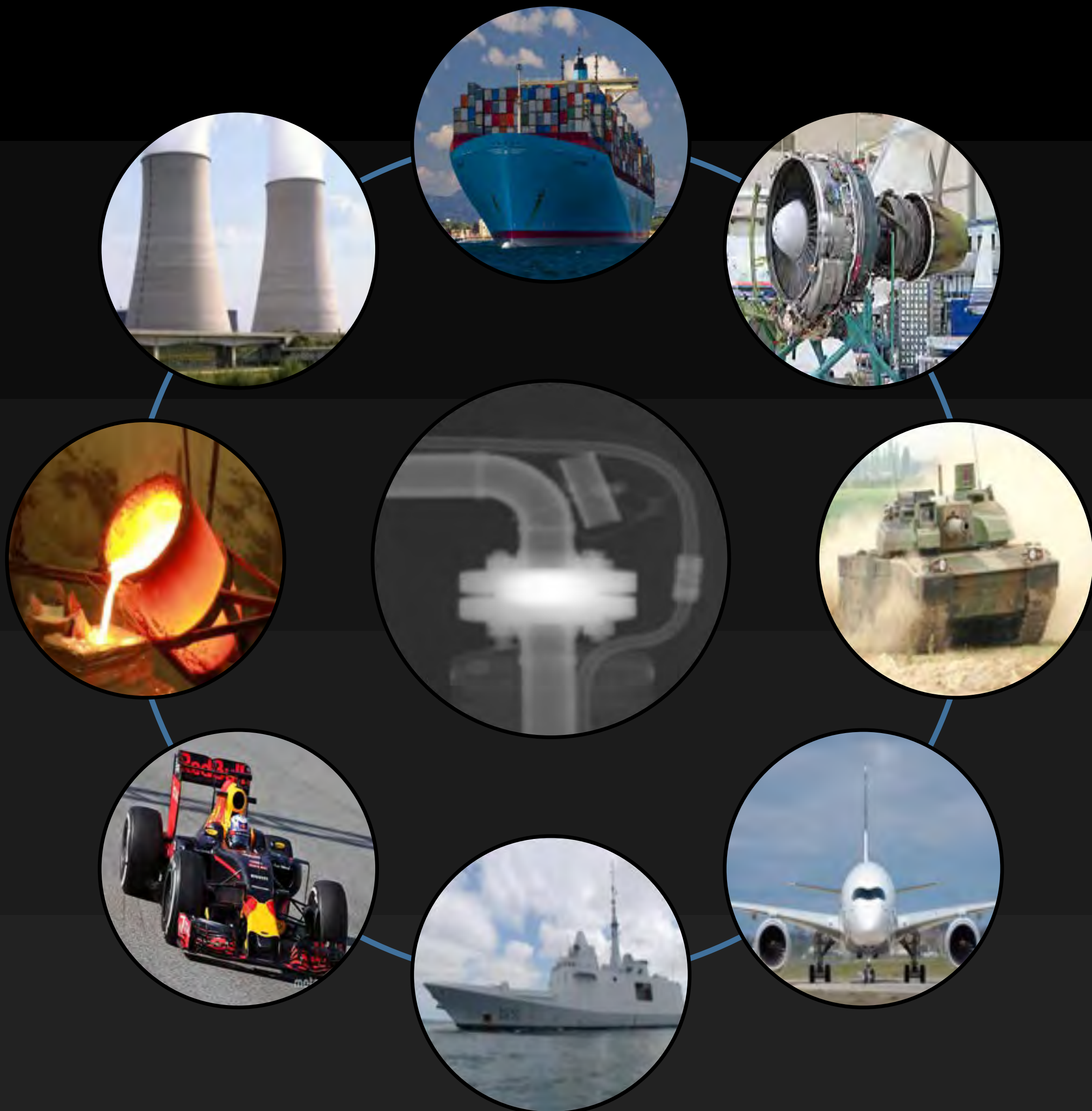
ELI-ALPS SHHG PW Beamline construction
In collaboration with LIDyL (CEA-Saclay)

Beam



Industrial NDT by X-ray radiography
The market

Beam



1500 installed sources

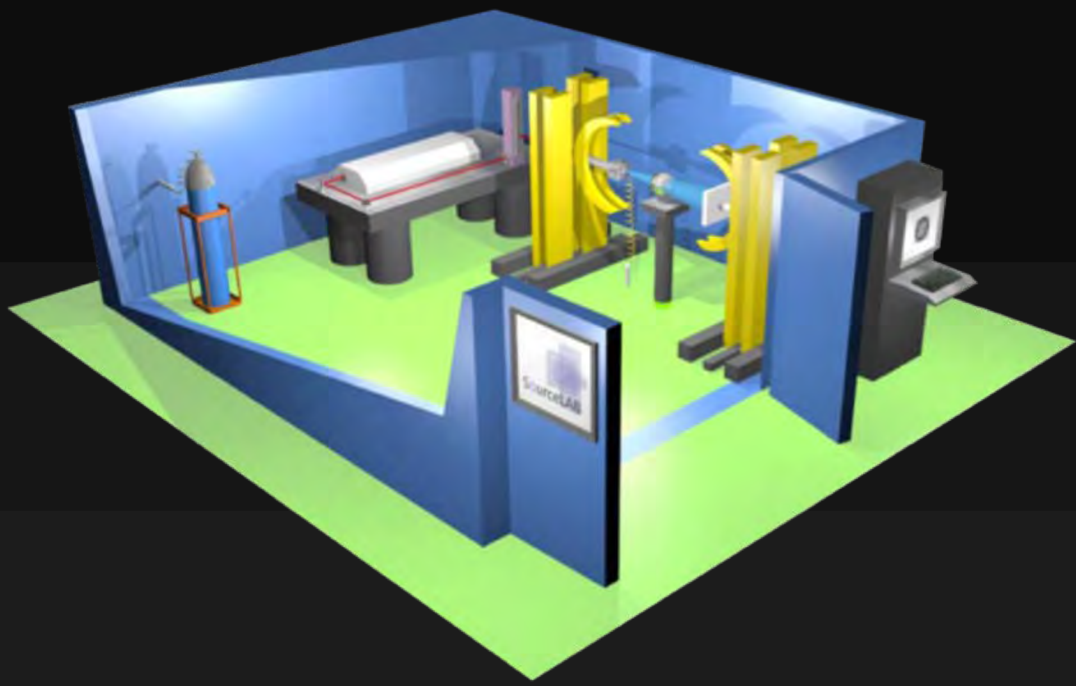
~100 new each year

~100 M€ market for sources

covered by 3 technologies

Beam

Our response to the market needs
A breakthrough source for industrial NDT by X-Ray tomography



- R&D program launched in 2015
- Prototype : 2018
- Commercialization : 2020
- SourceLAB as source manufacturer
- Tier one to final integrator

SourceLAB

PEI
Pinette Emidecau Industries

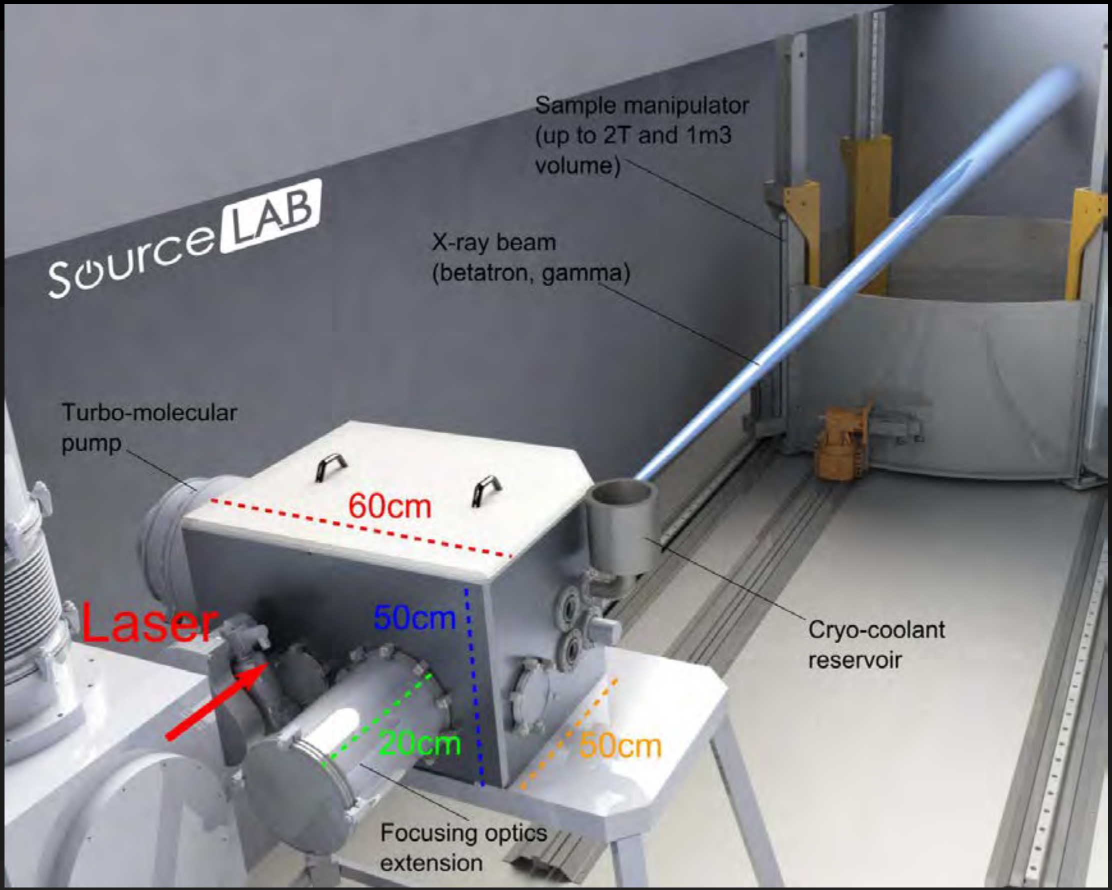
loa

rapid

DGA

Beam

Our response to the market needs
A breakthrough source for industrial NDT by X-Ray tomography



Why SourceLAB as a partner for a laser plasma beamline ?

- **SL assets** : already a key player in the laser plasma world…
  - ✓ Deep understanding of laser plasma interaction : from very underdense to very overdense regime
  - ✓ Solid expertise in R&D, integration in laser plasma technologies
  - ✓ Effective partnerships with major labs and companies in the field : LOA, CEA, CoReLS, Phasics, Thales
  - ✓ Founding member of Targetry Supplier Network : http://www.targetsuppliers.com/

- **SL trends** : …leading game-changing projects
  - ✓ Development of the first laser-based accelerator for X-ray NDT market (French DOD contract)
  - ✓ Development of the first Hub of laser-based particle and radiation dedicated to industry
  - ✓ Development of the first SHHG-PW beamline with CEA-LiDyl for ELI-ALPS.

SourceLAB

Laser Plasma Technologies

Advanced wavefront sensing solution for laser testing and optics metrology applications

PHASICS
The phase control company

Yu LU
12/12/2017

Outline

- About PHASICS
- Product range
- Technology principle and advantages
- Applications for laser testing and optics metrology

About PHASICS

PHASICS
The phase control company

F
A
C
T
S

- **2003:** creation - Spin-off from LULI laboratory (Ecole Polytechnique - CNRS)
- Patent technology developed by ONERA (French National Aerospace lab)
- HQ in France - Saint Aubin (Paris area): 200m² clean room for production and calibration
- Office in the USA – San Francisco – CA
- **Strong R&D** to introduce new features
- ISO 9001 Certification

More than **600 systems** sold

Worldwide presence :

80 % export turnover

French & US offices, distributors in China, Japan…

About PHASICS

PHASICS
The phase control company

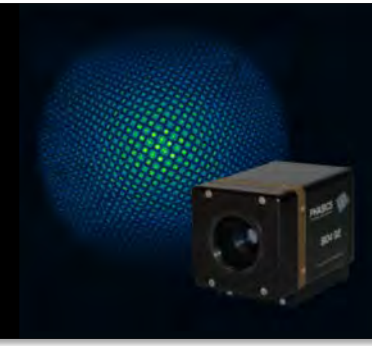
OUR CORE COMPETENCY

WAVEFRONT

ACQUISITION & ANALYSIS

Innovative patented
wavefront sensing technology

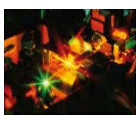
« 4-Wave Lateral Shearing Interferometry »



APPLICATIONS

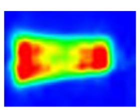
Wavefront measures how the light deforms when propagating through the specimen of interest. It enables characterizing:

LASER



Laser Beam testing
Phase, beam profile, M², Waist, Reileigh length Zernike…

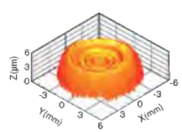
Adaptive Optics
Focal spot correction, Beam shaping



Plasma density measurement
Gas & plasma density

OPTICS

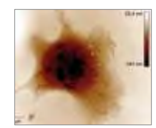
Lens Quality Control
MTF & aberrations
Off axis & broadband



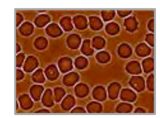
Surface testing
3D surface quality,
Radius of curvature

Intraocular lens ISO standard control
Toric, aspheric, bifocal

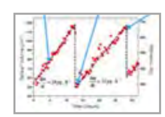
BIOLOGY



Quantitative Phase Microscope
Label-free imaging & cell parameter measurement



Population assays



Time lapse assays & cell monitoring

Product range

*All products are **based on our patented technology***

ONE TECHNOLOGY

▶ High resolution wavefront sensors

SID4

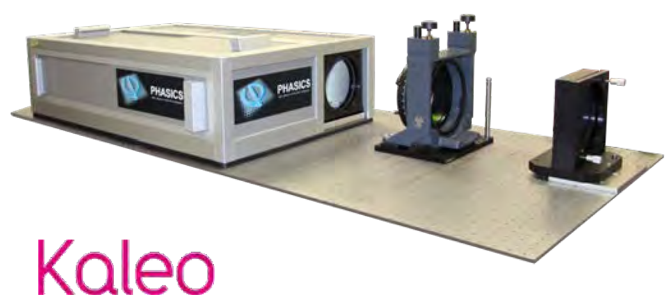
From UV to far IR

***Customized hardware** and **software** for each application:*

LASER

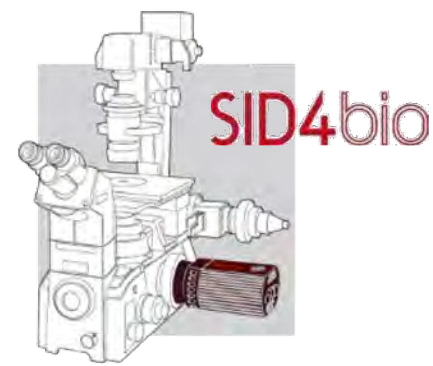
Wavefront sensor + deformable mirror

OPTICS METROLOGY



OEM solution & integrated bench

BIOLOGY



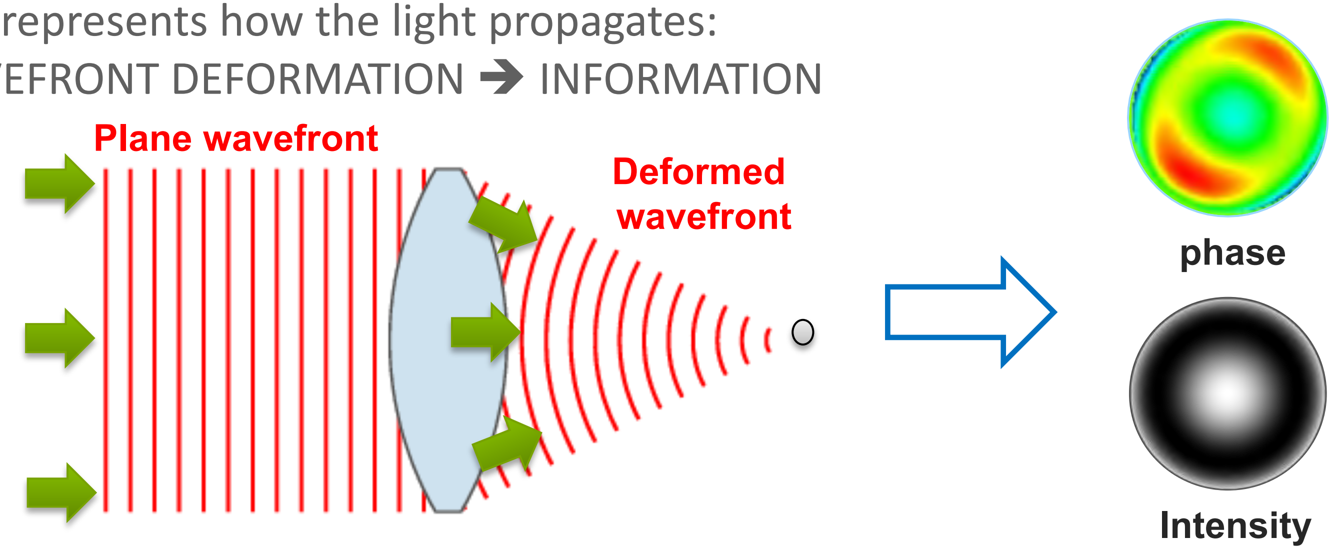
Plug & play camera

Wavefront Sensor Technology

PHASICS
The phase control company

Wavefront represents how the light propagates:

WAVEFRONT DEFORMATION ➔ INFORMATION



PHASICS patented technology: 4-Wave Lateral Shearing Interferometry

- Developed to overcome Shack-Hartmann sensor limitations

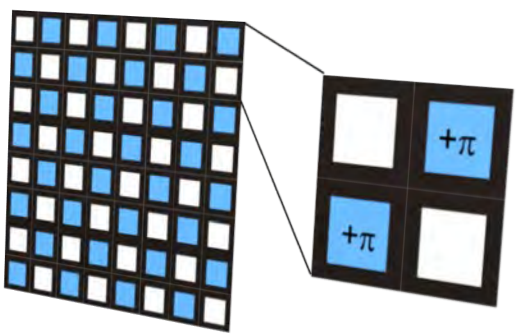
1900
Hartmann Mask

Holes

1970
Shack Hartmann Mask

Micro lenses array

2000
Modified Hartmann Mask



Diffractive grating

PHASICS

- Improves it and opens the path to new applications

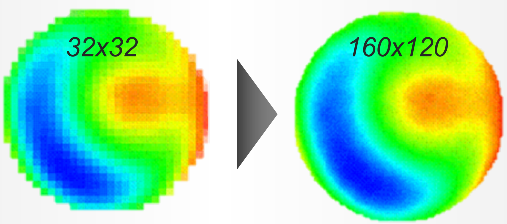
Technology advantages

PHASICS
The phase control company

✓ HIGH RESOLUTION

Robust calculation

Shack Hartmann: *Phasics:*

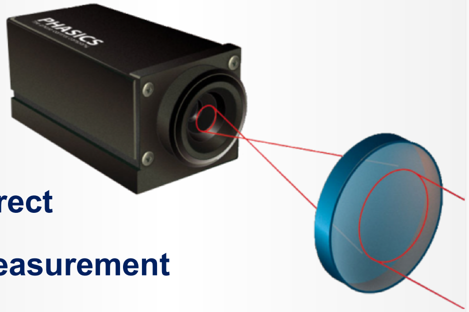


Improved sampling:

Up to 300x400 phase pixels

✓ FLEXIBILITY

Easy & fast set-up



Direct measurement

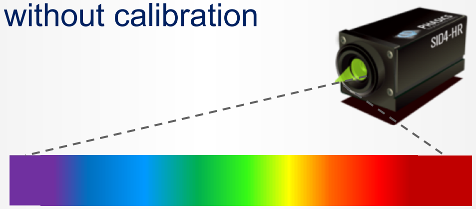
for non-collimated beam

✓ ACHROMATIC

Versatile use

1 sensor for 400-1100 nm

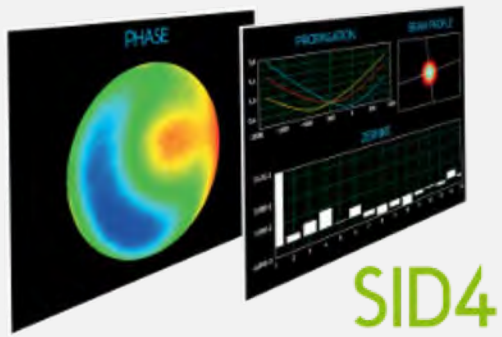
without calibration



Solutions for laser testing

PHASICS
The phase control company

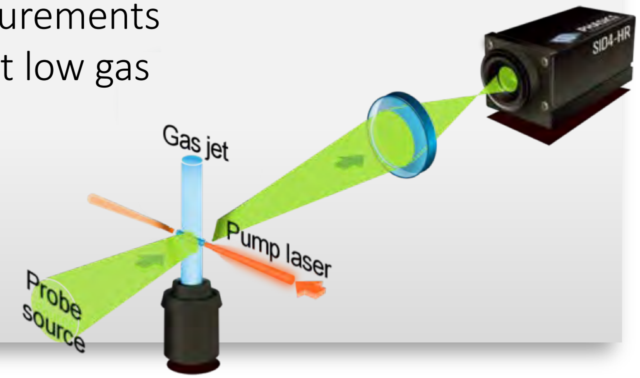
BEAM TESTING



- ✓ M², Strehl ratio, Zernike, PSF
- ✓ Waist position and size
- ✓ Beam profiler

GAS & PLASMA DENSITY

- ▶ High **sensitivity**
- ▶ **Repeatable** shot-to-shot measurements
- ▶ **Accurate** at low gas pressure
- ▶ **No reference arm**
- ▶ Any probe source



ADAPTIVE OPTICS

- ▶ With **any deformable mirror**
- ▶ **Direct control through software**
- ▶ **Correction after the last parabola** without an additional device

Adaptive optics

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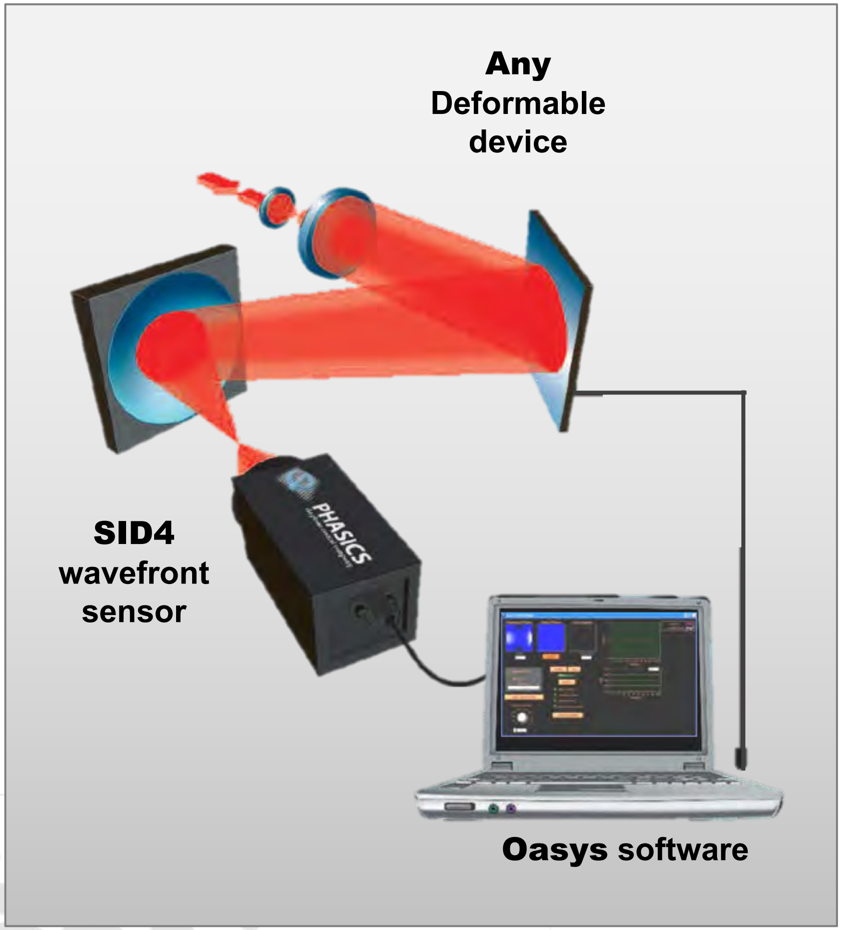
The phase control company



Advanced correction after focus

✓ **Up to Petawatts**

Some references:

eli

European XFEL

SIOM

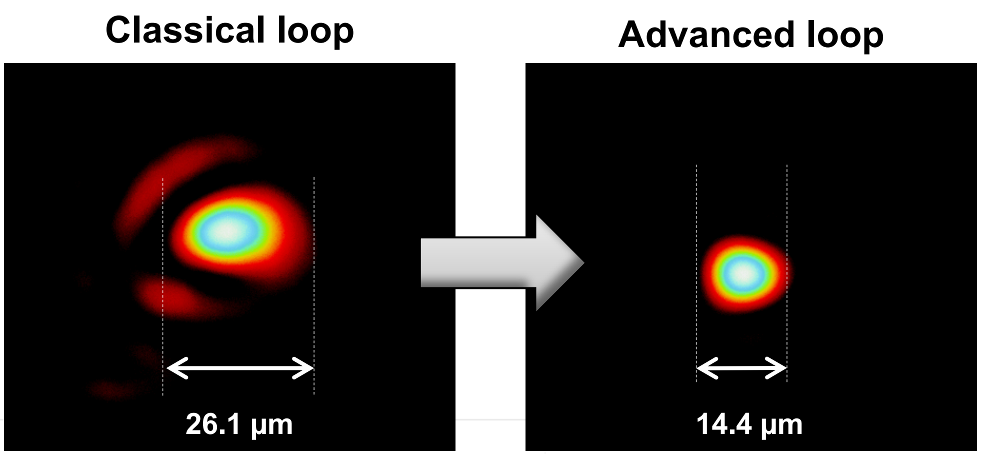
Science & Technology Facilities Council
Rutherford Appleton Laboratory

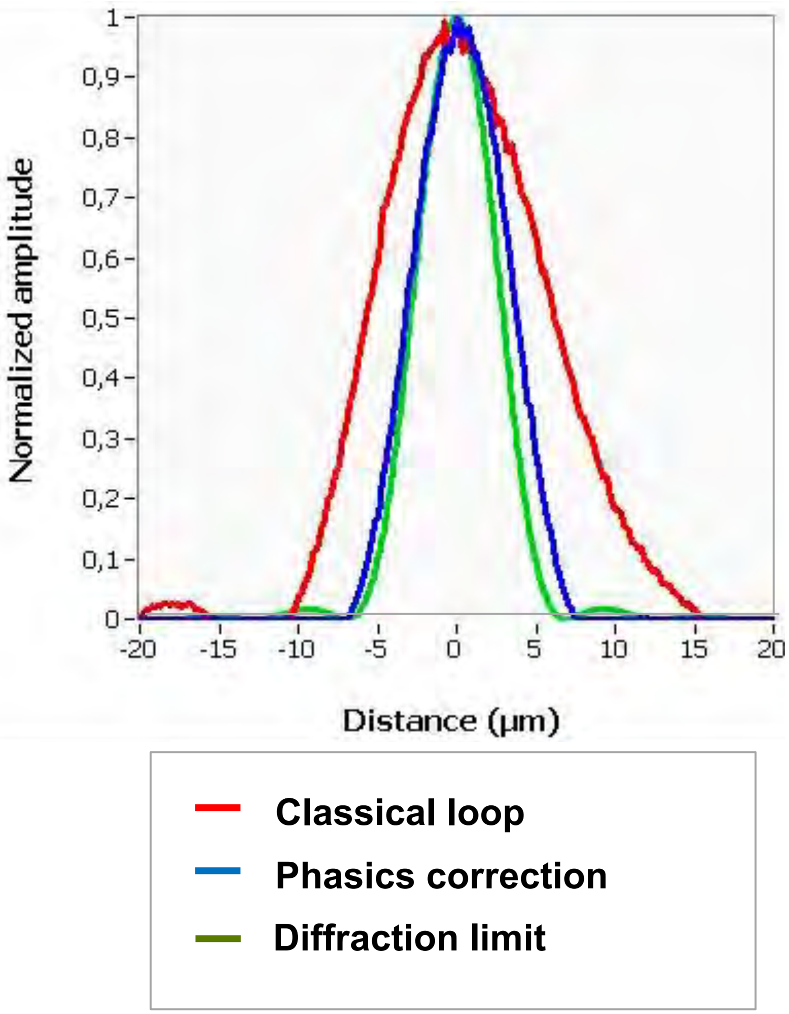
Advanced correction loop

PHASICS
The phase control company

After-focus correction loop for laser chain, thanks to the capacity of measuring directly non-collimated beams :

Example with a f/5 beam





Solutions for optics metrology

PHASICS
The phase control company

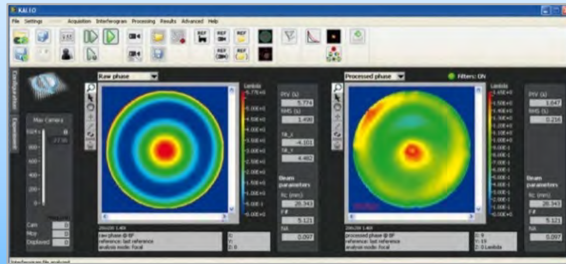
CHARACTERIZATION & ALIGNMENT OF LENS, MIRROR, SUBASSEMBLY AND ASSEMBLY

▶ Combination of our **unique technology** and **dedicated software**

WAVEFRONT SENSOR

From UV to far IR

\+



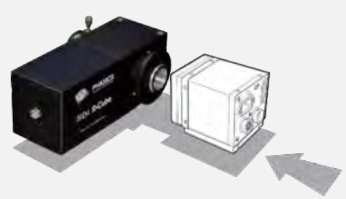
KALEO SOFTWARE

Advanced measurement interpretation

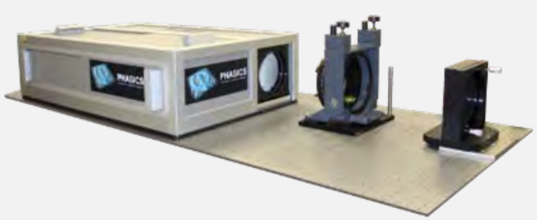
▶ Strong **expertise** in bench design

- OEM or Integrated bench
- Single or double pass set-up
- Multiple wavelengths on the same bench
- Customized set-up and software

Large diameter lens/ mirror characterization



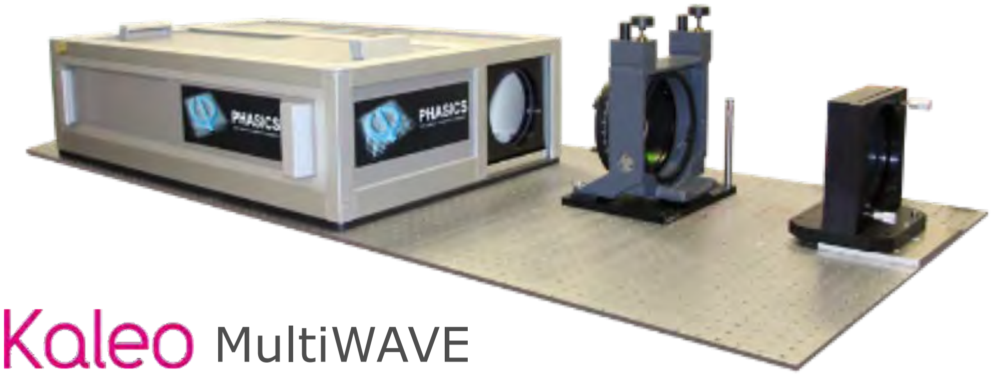
Illumination unit for double-pass test



Kaleo MultiWAVE bench

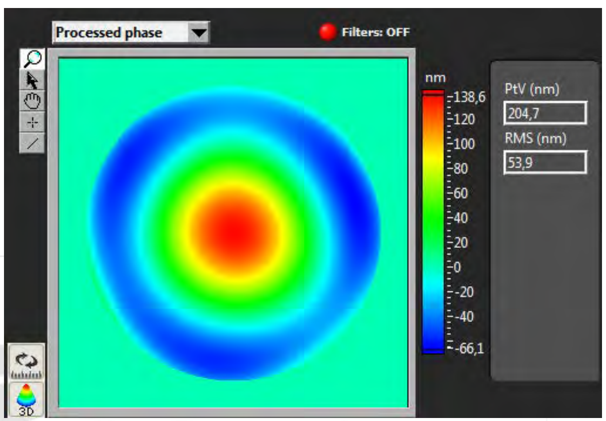
Solutions for optics metrology

PHASICS
The phase control company

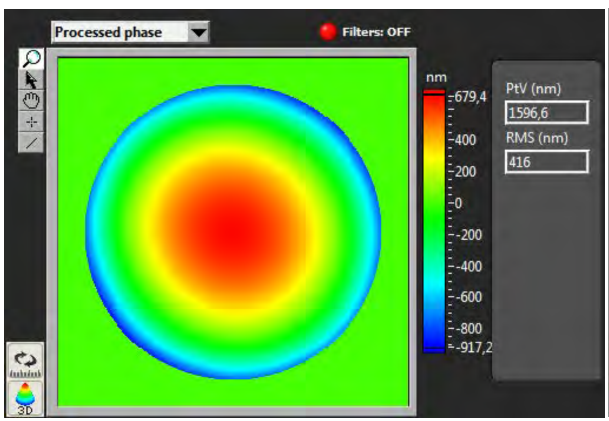


Kaleo MultiWAVE

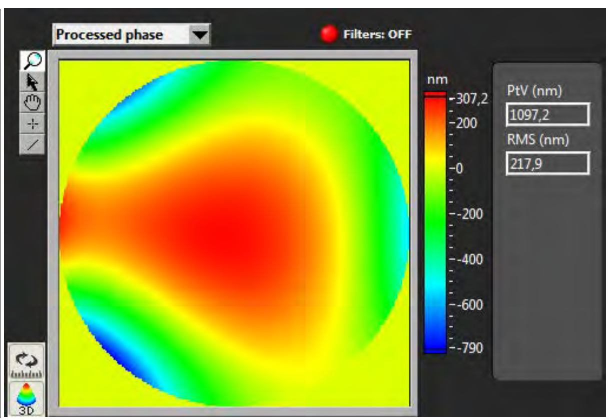
- ✓ Coated Optics and filters testing at operating wavelengths
- ✓ High dynamics surface testing



6'' WBF-633 FILTER TESTING IN TRANSMISSION AT 633 NM



6'' NBP-780 FILTER TESTING IN REFLECTION AT 780 NM



4'' PLANE MIRROR TESTING

PHASICS

The phase control company

PHASICS
HEADQUARTER

Bâtiment EXPLORER
Espace technologique
Route de l'orme des Merisiers
91190 Saint-Aubin, FRANCE

Mail: contact@phasics.fr
Tel : +33 1 80 75 06 33

PHASICS CORP
USA OFFICE

169, 11th Street
San Francisco, CA 94103
USA

Contact : Yoann Priol
priol@phasics.com
Tel : +1 415 610 9741

www.phasics.fr

EKSPLA

CREMLIN WP6 Workshop

Involvement of European Industry in the XCELS project

“Technologies for high intensity laser systems”

Dr Andrejus Michailovas

12 December 2017

Ekspla – Who we are

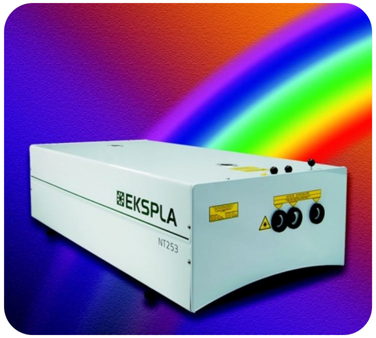
Ekspla is…

- Private company producing lasers, laser systems and laser related components
- Established in 1992.11.11
- Laser department of EKSMA - established in 1983

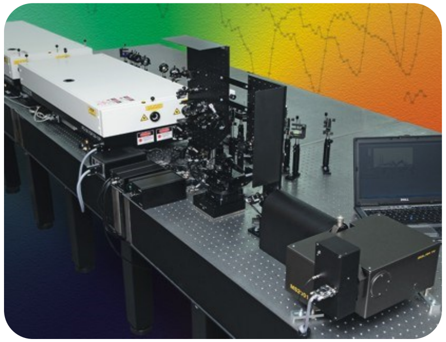
25 years

EKSPLA

Products



Lasers & laser systems for basic and applied research
(For "Science")



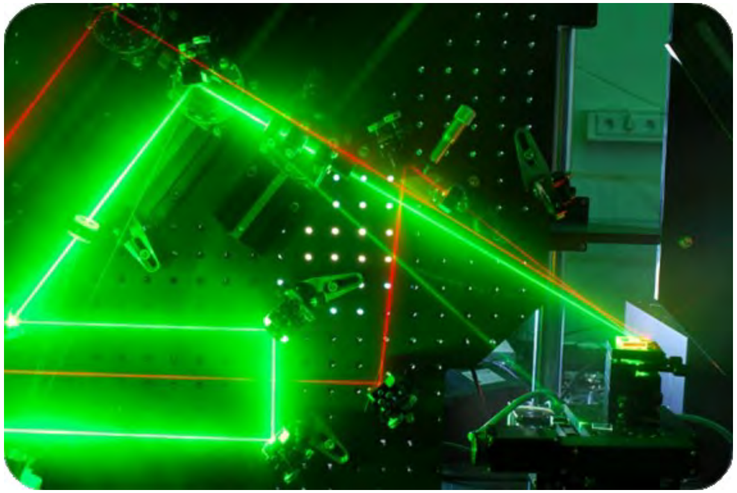
Systems for spectroscopy

Lasers for OEM customers
(For "Industry")

Laser & Optoelectronics components

Core competencies

- **High peak power laser systems**
- **Short pulse generation and amplification**
- Tunable nonlinear devices (OPO, OPA, etc.)
- Nonlinear spectroscopy
- Fast high voltage electronics
- High power electronics

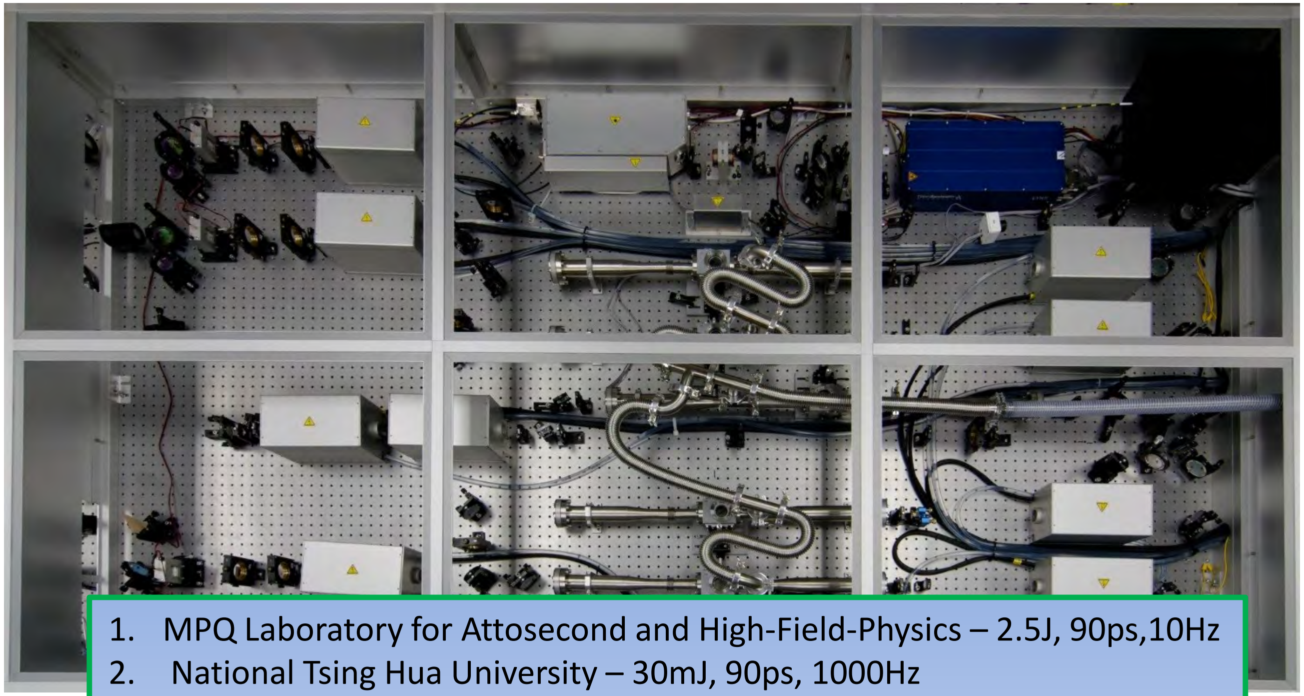


Technologies for high peak power lasers

CREMLIN WP6 Workshop

A.Michailovas 2017.12.12

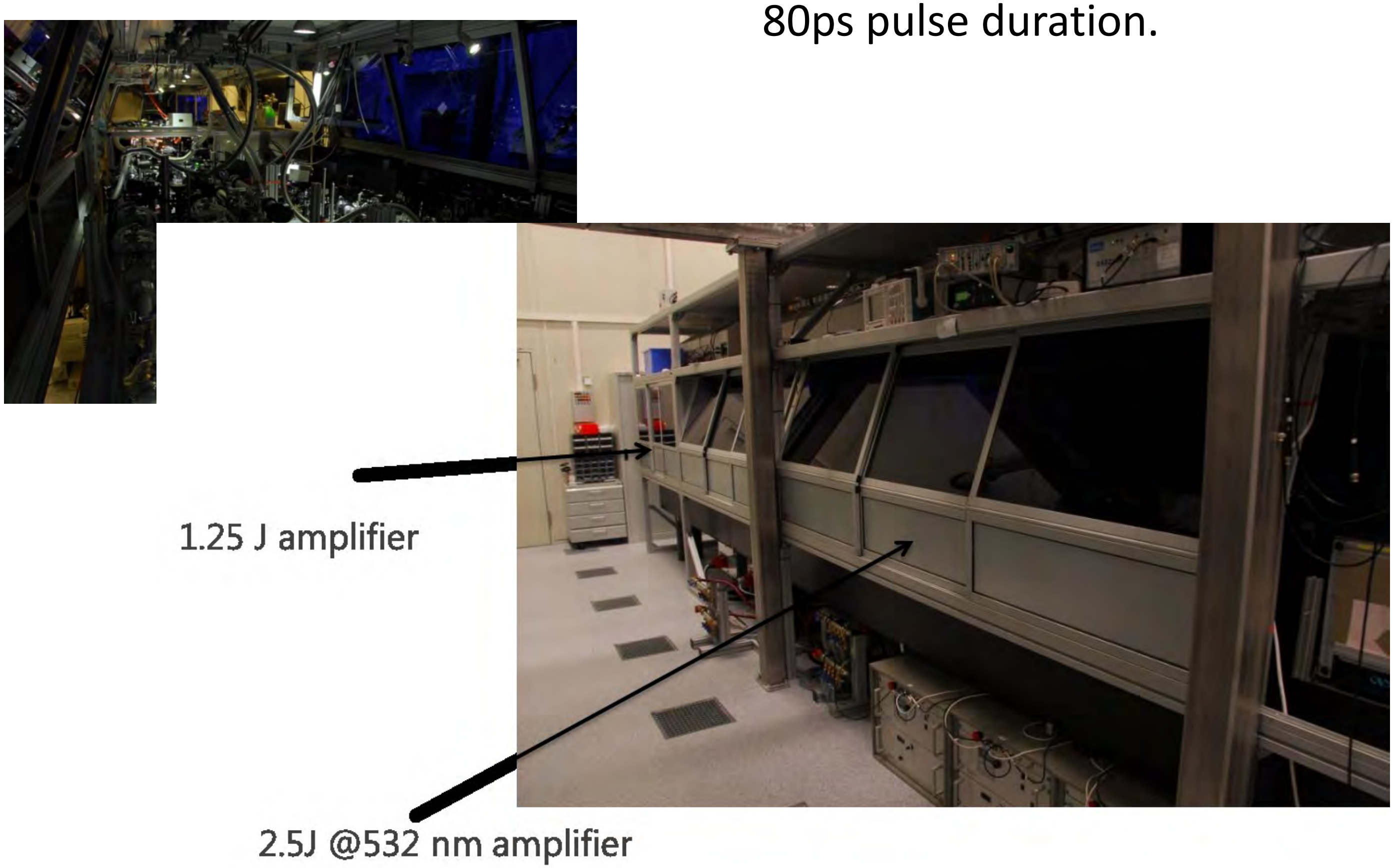
Ekspla experience in making pump laser For OPCPA



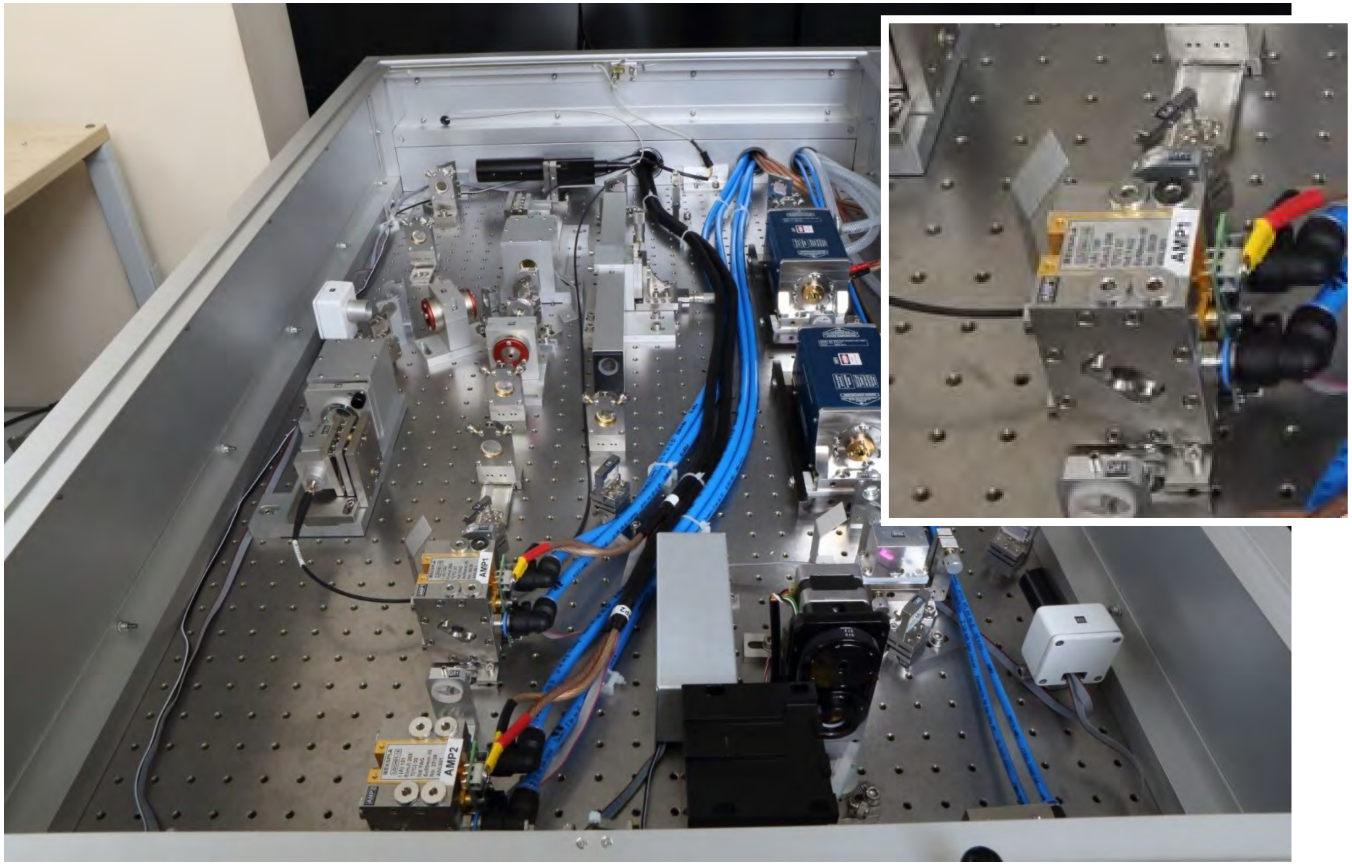
1. MPQ Laboratory for Attosecond and High-Field-Physics – 2.5J, 90ps,10Hz
2. National Tsing Hua University – 30mJ, 90ps, 1000Hz
3. AmpLight KG, Austria – 1J, 100ps, 20Hz
4. Novosibirsk University – 2.5J, 90ps,10Hz
5. Vilnius University – 0.6J, 80ps, 10Hz
6. WAT - 10 J @1064nm, 2-10 ns, 10Hz
7. Warsaw University - 4 J @ 532 nm, 4 ns, 10Hz
8. National Energetics - 4 J @ 532 nm, 3 ns, 10Hz
9. Vilnius University – 90mJ, 80ps, 1000Hz
10. Lasers for ELI projects
11. And other lasers from 160J pulse energy up to 50W mean power (NDA)

Picosecond high energy system example

10 Hz repetition rate;
80ps pulse duration.



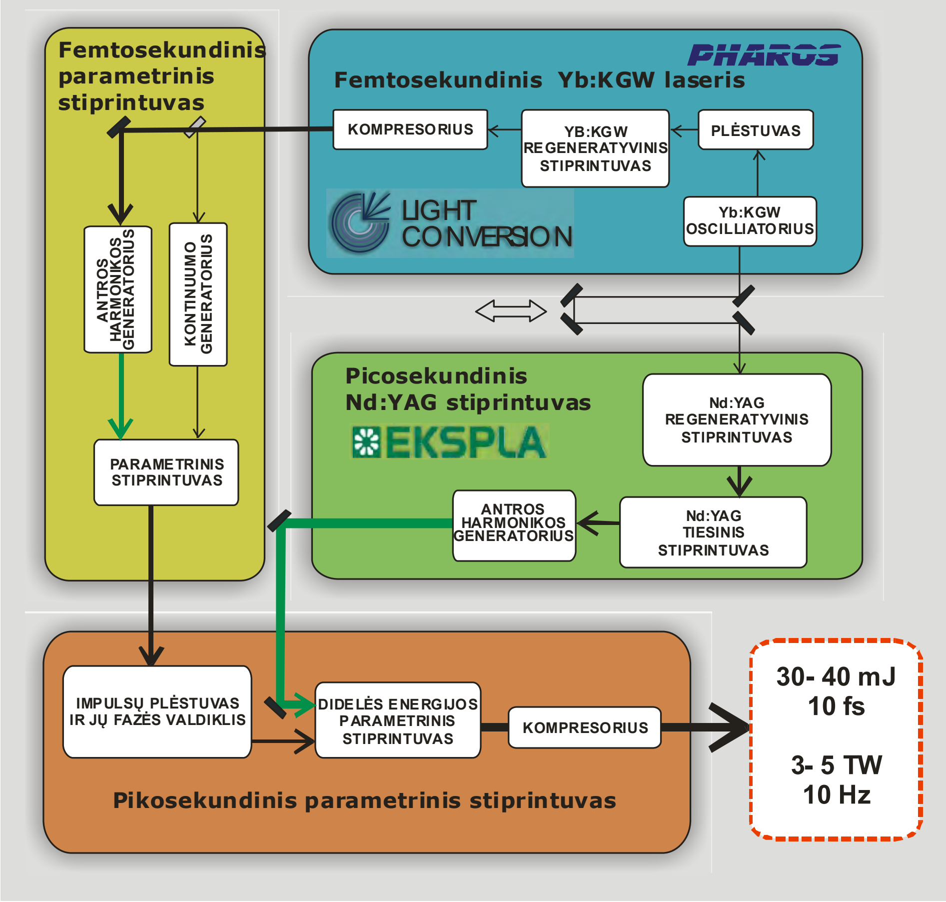
Up to 100Hz we are using modules of own design



High energy and >100Hz repetition rate
modules from Northrop-Grummann

EKSPLA

"Vilnius" OPCPA Architecture



The first Lithuanian OPCPA layout

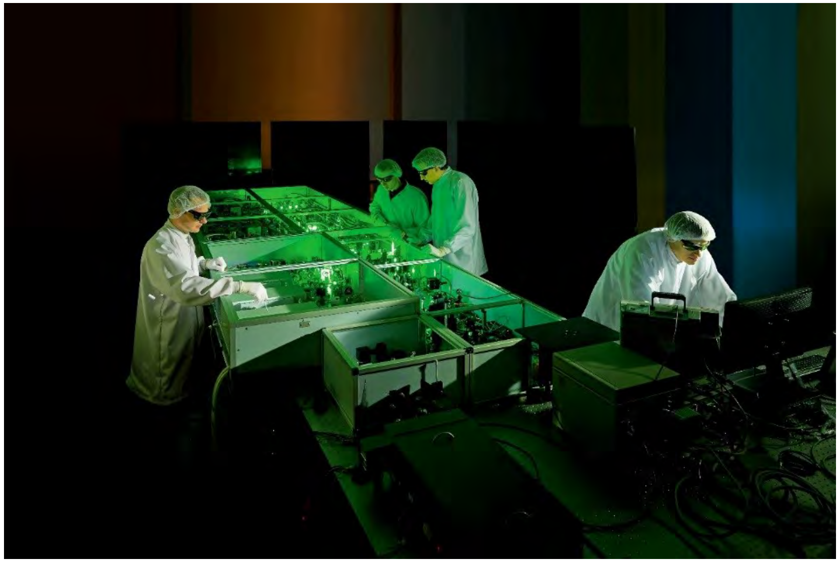
We have initiated and supported Lithuanian OPCPA projects

1. Femtosecond Yb:KGW and pikosecond Nd:YAG pump lasers
   - *Optical synchronizacion*
   - *Diode pumping*

2. Multistage fs&ps Parametrical amplifiers

- *Broad spectra*
- *High pulse contrast*

ELI SYLOS-1 laser system



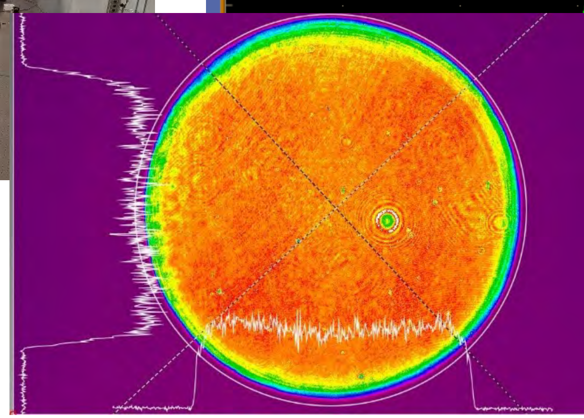
Specs:

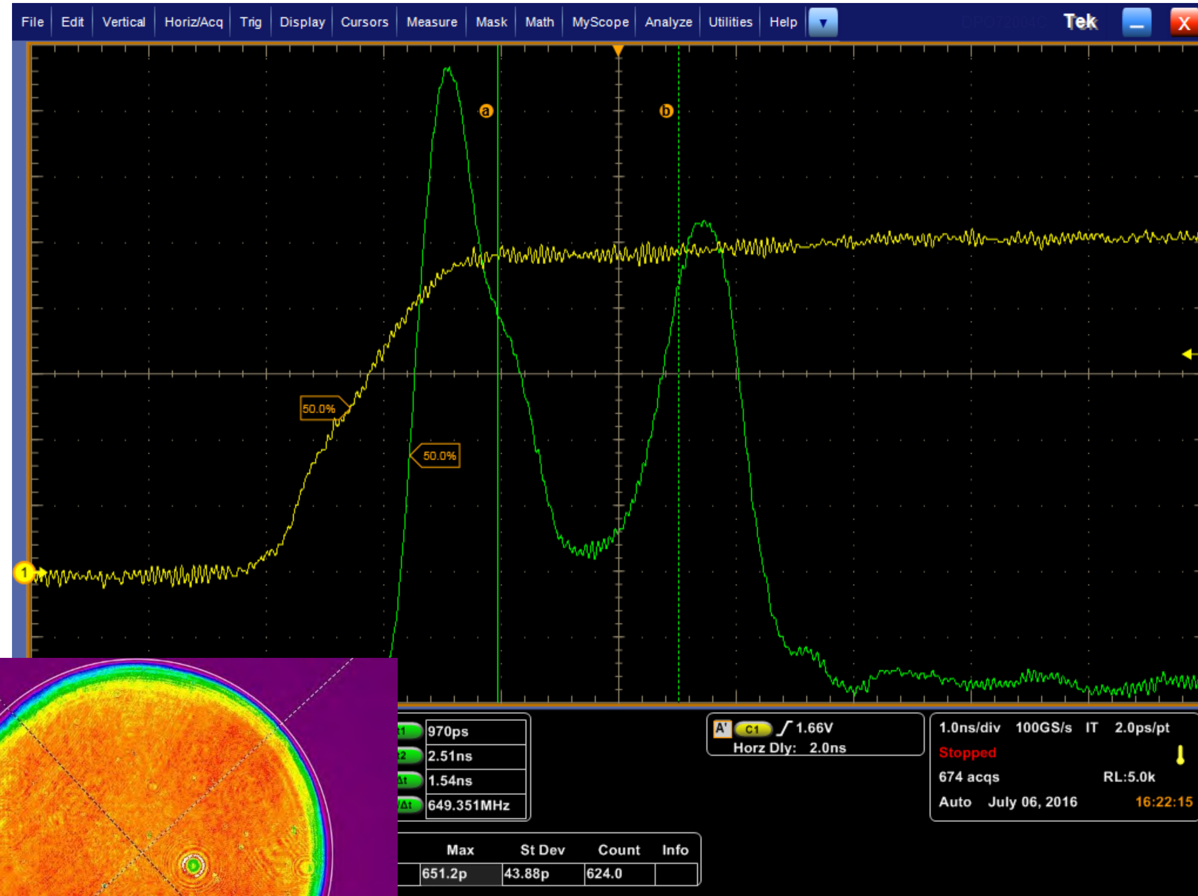
Pulse duration	<10fs;
Pulse energy	>50mJ±0,75%
Repetition rate	1kHz;
Strehl factor	>0.8;
Contrast	$>10^{-11}$;
CEP	sub 220 mrad

LIGHT CONVERSION

EKSPLA

OPCPA ns pump for ELI Beamlines



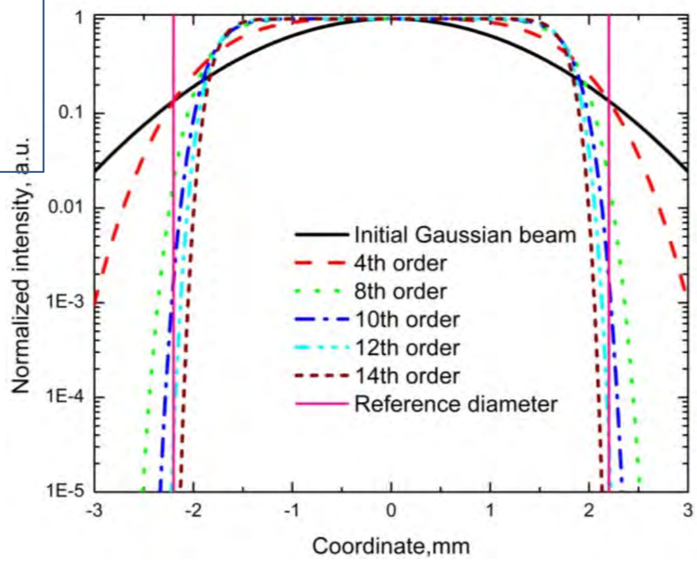


E>5J
λ=532nm
5Hz (10Hz)

We can propose….
There are many technologies beyond these projects.

Example: Flexible Beam Shaping

High amplifier fill factor = high system efficiency!
When dealing with high intensity – modulation is enemy.

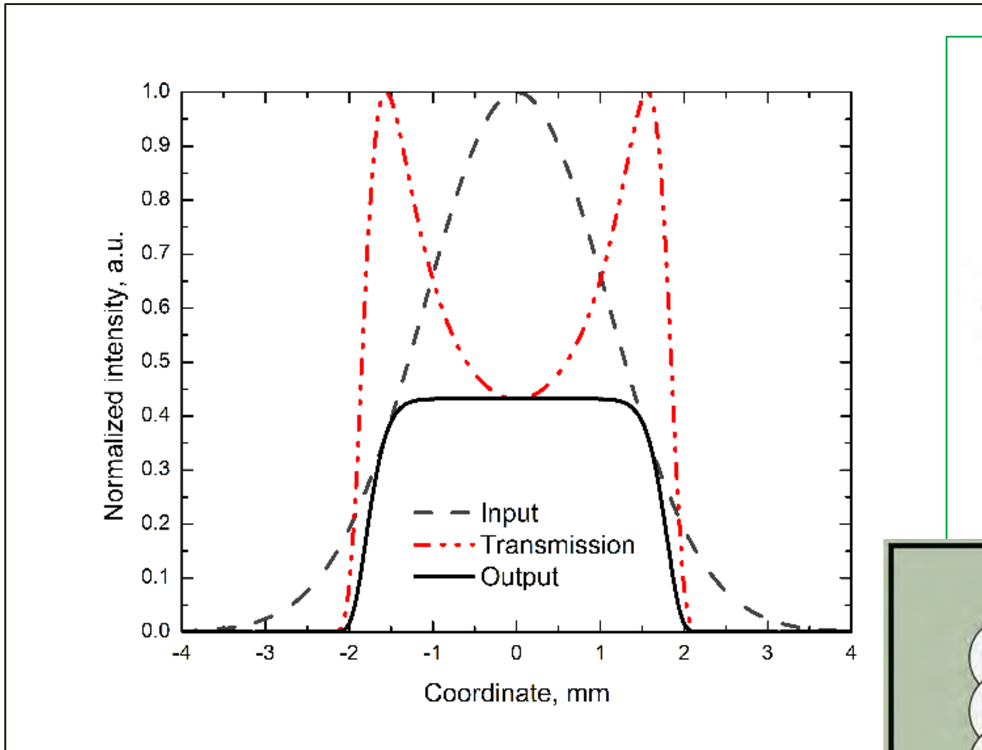


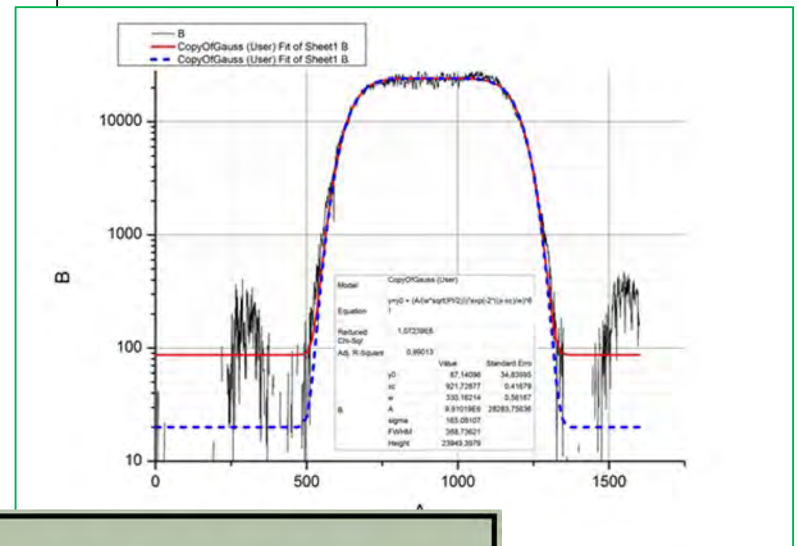
- Example Initial Gaussian beam of fixed diameter – 4.4 mm ($1/e^2$ level)
- Diameter ratio of the beam shaper (input/output) chosen for maximum efficiency for all the orders of the super Gaussian function
- Reference diameter is 4.4 mm ($1/e^2$ level):
  - **1st stage amplifier with active medium of 5 mm in diameter**
  - **0.2 mm chamfer**
  - **0.4 mm for alignment precision**
- Order of super Gaussian chosen to pass through the reference diameter at 10^{-3} level to minimize modulation

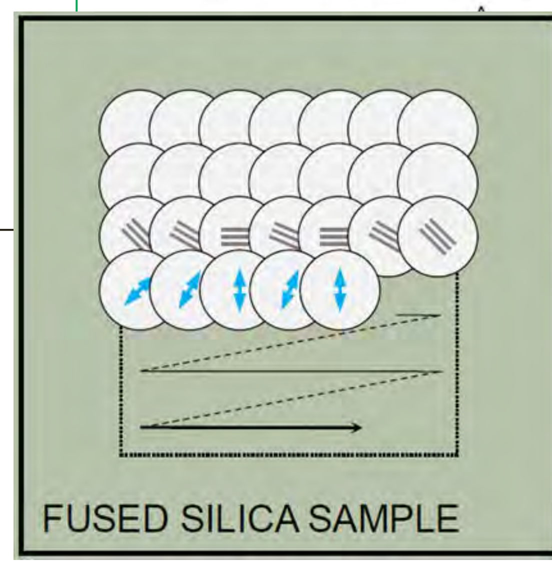
How to shape beam so precisely?

17th International Conference "Laser Optics 2016"

Beam shaping principle





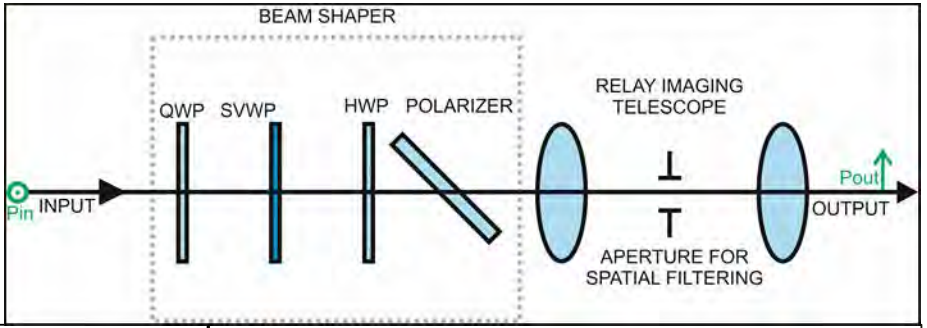


How realized flexibility?

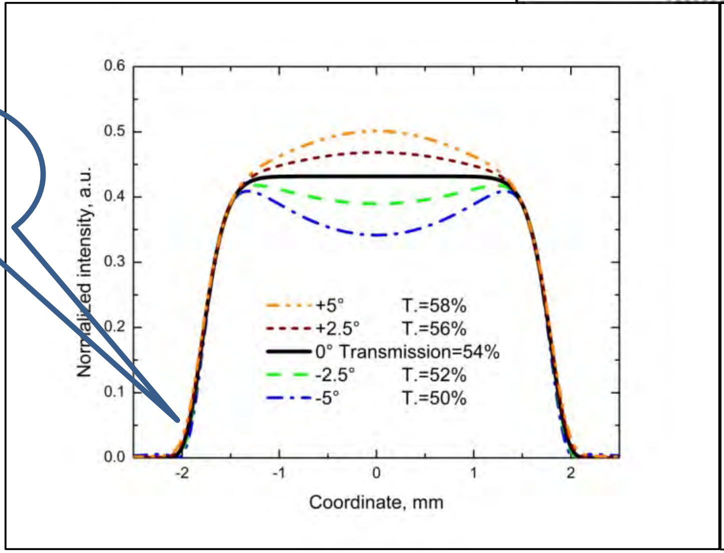
- Based on what we call Spatially Variable Wave Plate (SVWP)
- Consists of the following necessary components: a quarter-wave plate, the spatially variable wave plate with an inscribed retardance of a quarter of wave (QW-SVWP) and a polarizer
- A supplementary half-wave plate inserted between the SVWP and the polarizer makes the beam shaper easy to align and allows for additional adjustments of the output beam profile.

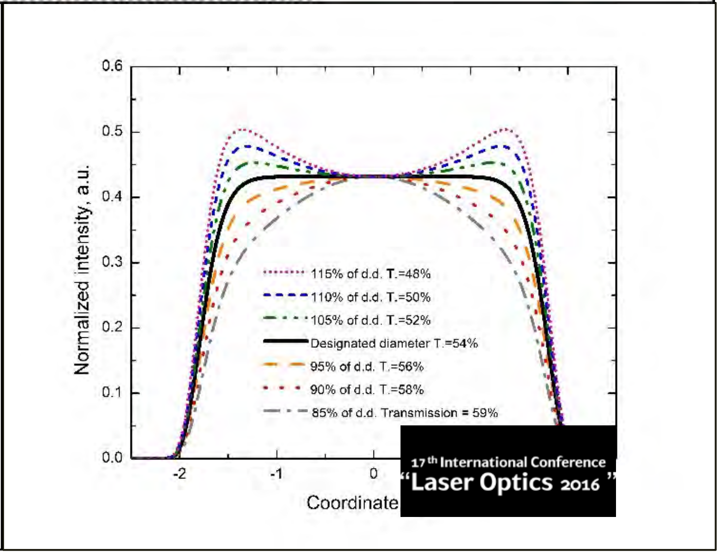
Advantages of SVWP based beam shaping

- Relatively high efficiency (~50% for 14th order)
- Easy alignment
- Adjustable output profile

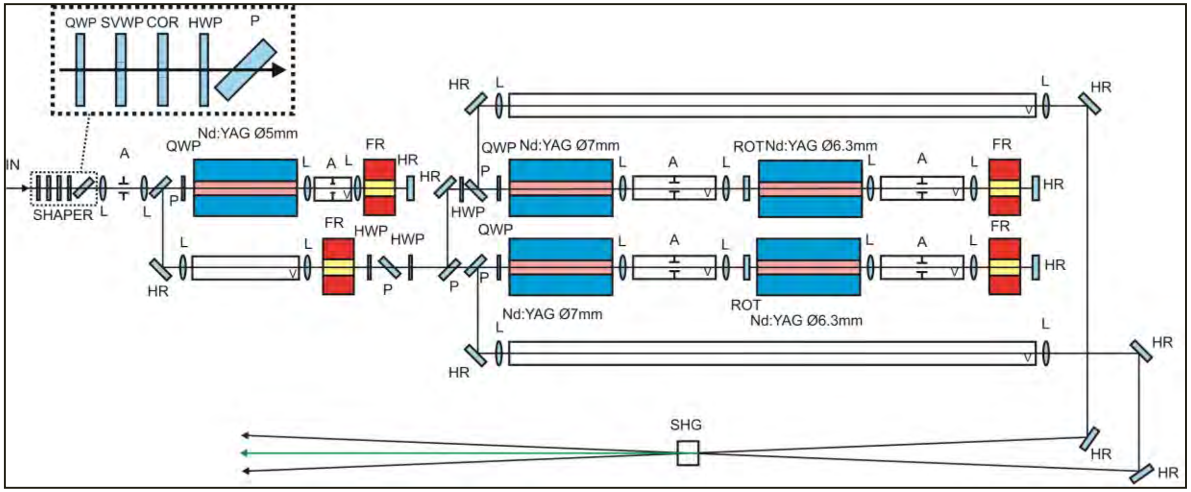


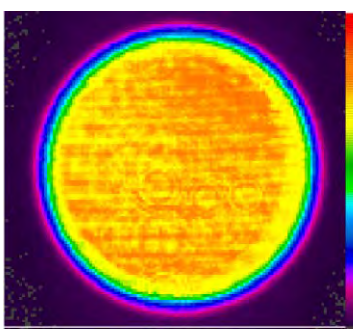
No change of diameter at 10^{-3}

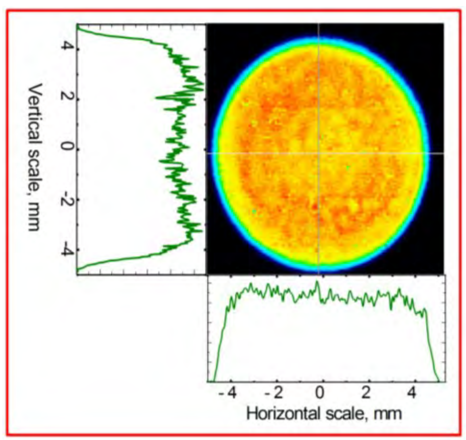


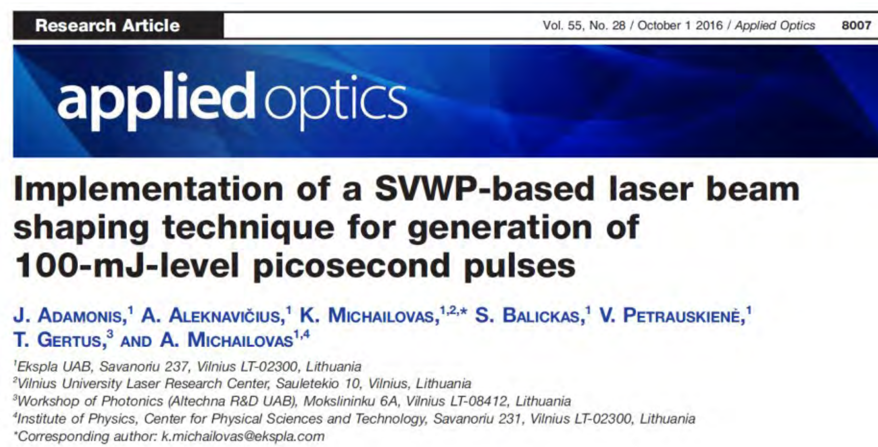


Example:Amplifier system for ps pulses








Research Article Vol. 55, No. 28 / October 1 2016 / Applied Optics 8007

applied optics

Implementation of a SVWP-based laser beam shaping technique for generation of 100-mJ-level picosecond pulses

J. Adamonis,[1] A. Aleknavičius,[1] K. Michailovas,[1,2,*] S. Balickas,[1] V. Petrauskienė,[1] T. Gertus,[3] and A. Michailovas[1,4]

[1]Ekspla UAB, Savanoriu 237, Vilnius LT-02300, Lithuania
[2]Vilnius University Laser Research Center, Sauletekio 10, Vilnius, Lithuania
[3]Workshop of Photonics (Altechna R&D UAB), Mokslininku 6A, Vilnius LT-08412, Lithuania
[4]Institute of Physics, Center for Physical Sciences and Technology, Savanoriu 231, Vilnius LT-02300, Lithuania
*Corresponding author: k.michailovas@ekspla.com

Portfolio: Laser components & Lasers

- Beam shaping;
- Flash-lamp power supplies and cooling units;
- LD power supplies;
- HV drivers;
- LD and flash – pumped amplifier modules;
- Broadband seed sources for frontends;
- OPCPA high contrast frontend;
- Multi-Joule ns pump lasers;
- Hundreds of mJ picosecond lasers;

Duo-fiber

Research Article
Vol. 24, No. 19 | 19 Sep 2016 | OPTICS EXPRESS 22261
Optics EXPRESS

Combined Yb/Nd driver for optical parametric chirped pulse amplifiers

KIRILAS MICHAILOVAS,[1,2,*] ANDRIUS BALTUSKA,[3,4] AUDRIUS PUGZLYS,[3,4] VALERIJUS SMILGEVICIUS,[2] ANDREJUS MICHAILOVAS,[1,4] AUDRIUS ZAUKEVICIUS,[1,4] ROKA
RUSTEIKA[1,4]

[1]EKSPLA, Savanoriu Av. 237, L

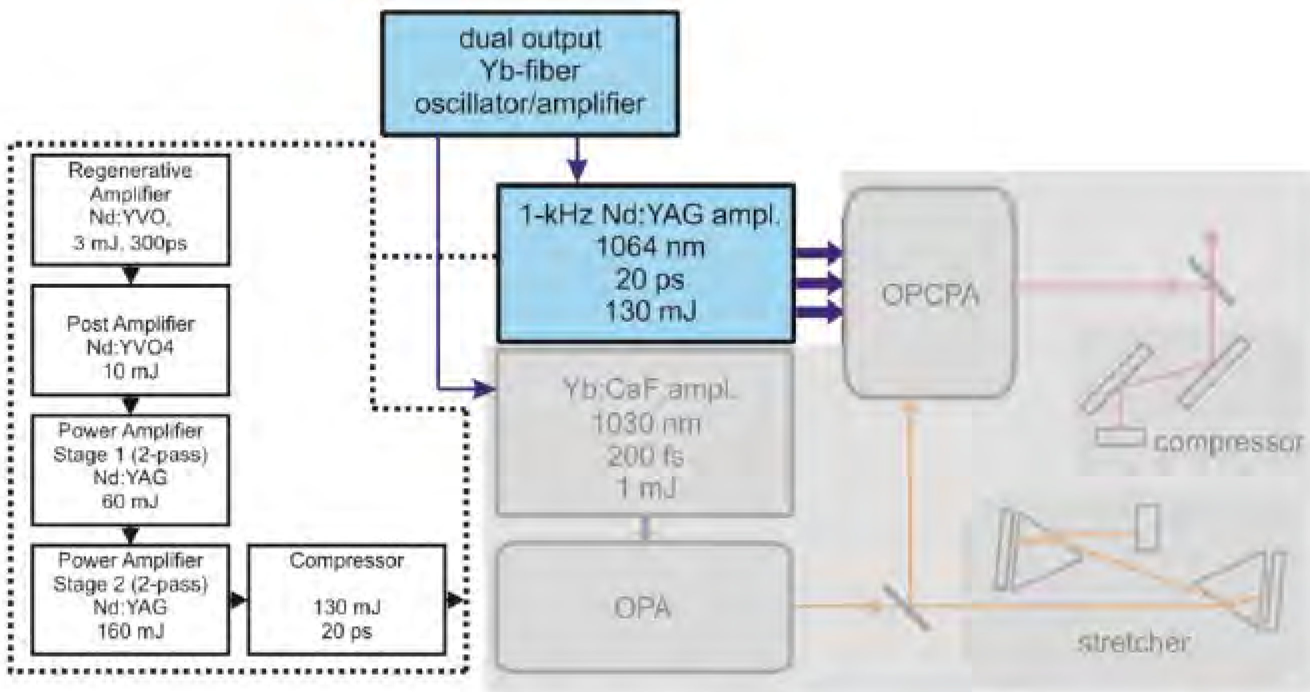


Fig. 1. Conceptual layout of an OPCPA system relevant to the one published in [17]. Related

Duo fiber in 10fs OPCPA

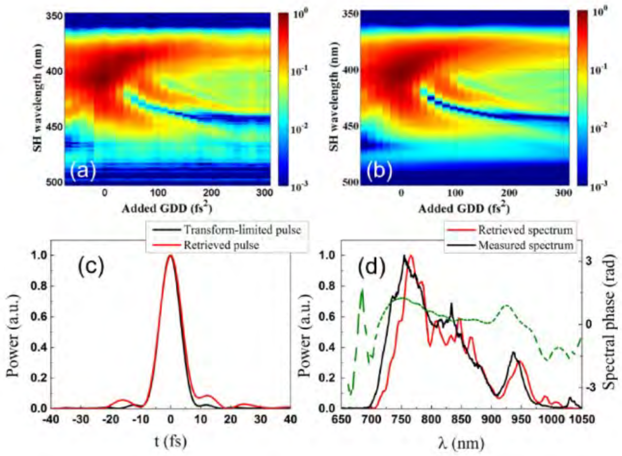
Research Article Vol. 24, No. 15 | 25 Jul 2016 | OPTICS EXPRESS 17532

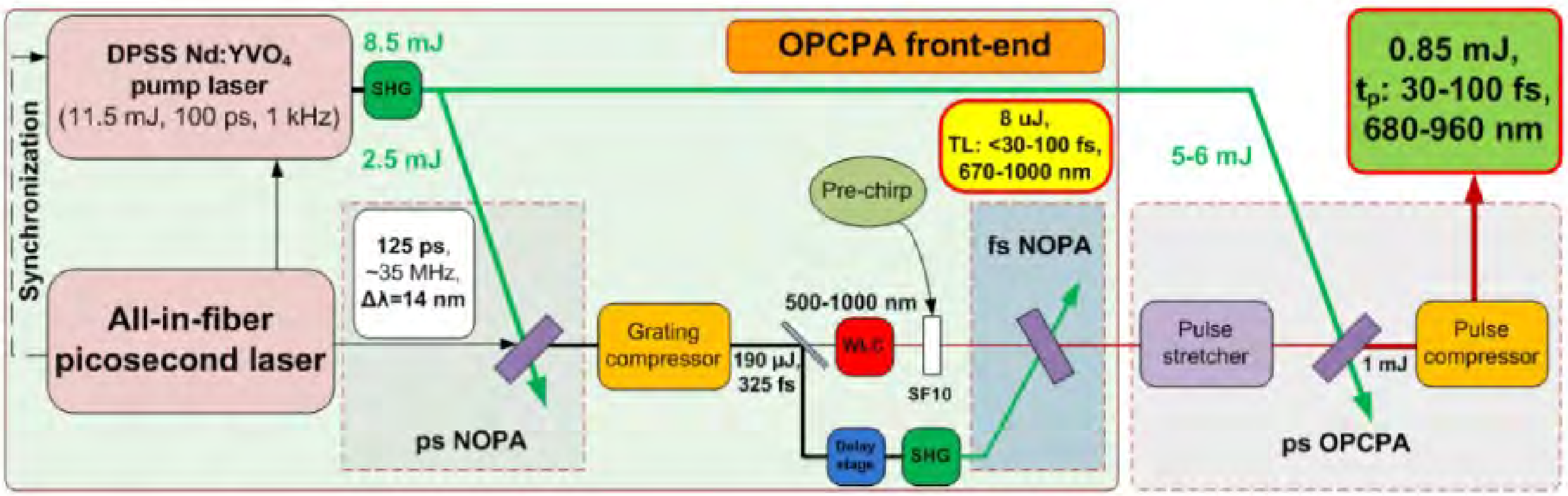
Optics EXPRESS

Femtosecond wavelength-tunable OPCPA system based on picosecond fiber laser seed and picosecond DPSS laser pump

R. DANILEVIČIUS,[1,2,*] A. ZAUKEVIČIUS,[1] R. BUDRIŪNAS,[3] A. MICHAILOVAS,[1,2] AND N. RUSTEIKA[1,2]

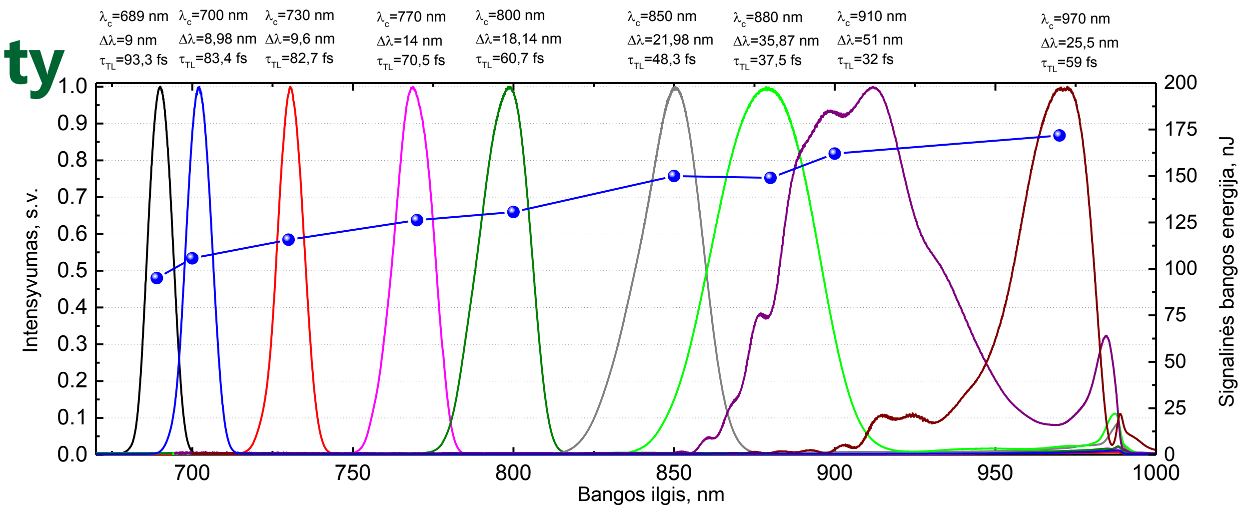
[1]Ekspla Ltd., Savanoriu ave. 237, LT-02300 Vilnius, Lithuania
[2]Department of Laser Technology, Center for Physical Sciences & Technology, Savanoriu ave. 231, LT-02300, Vilnius, Lithuania



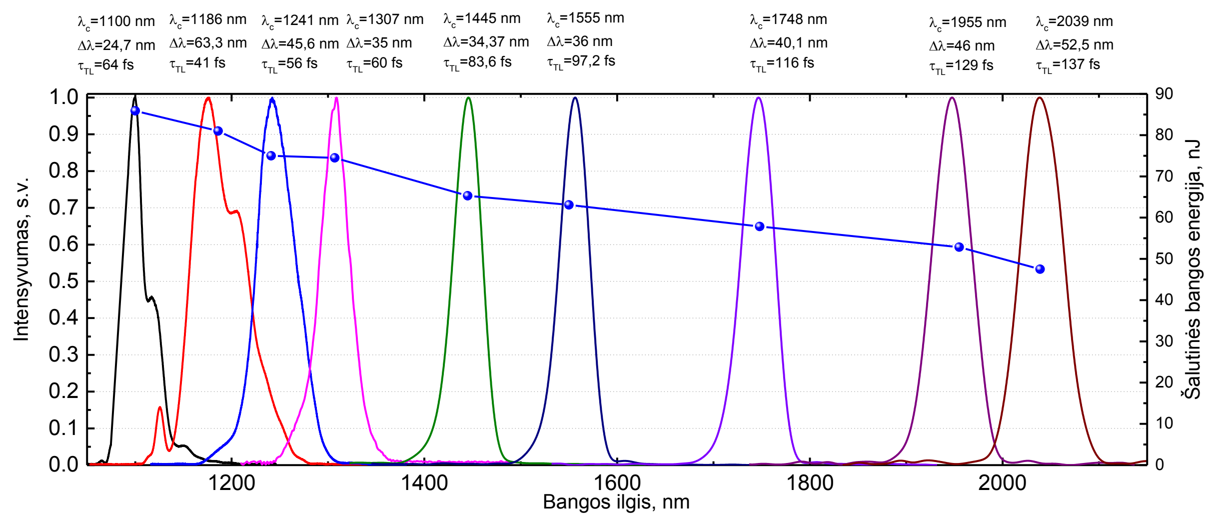


EKSPLA

OPA tunability



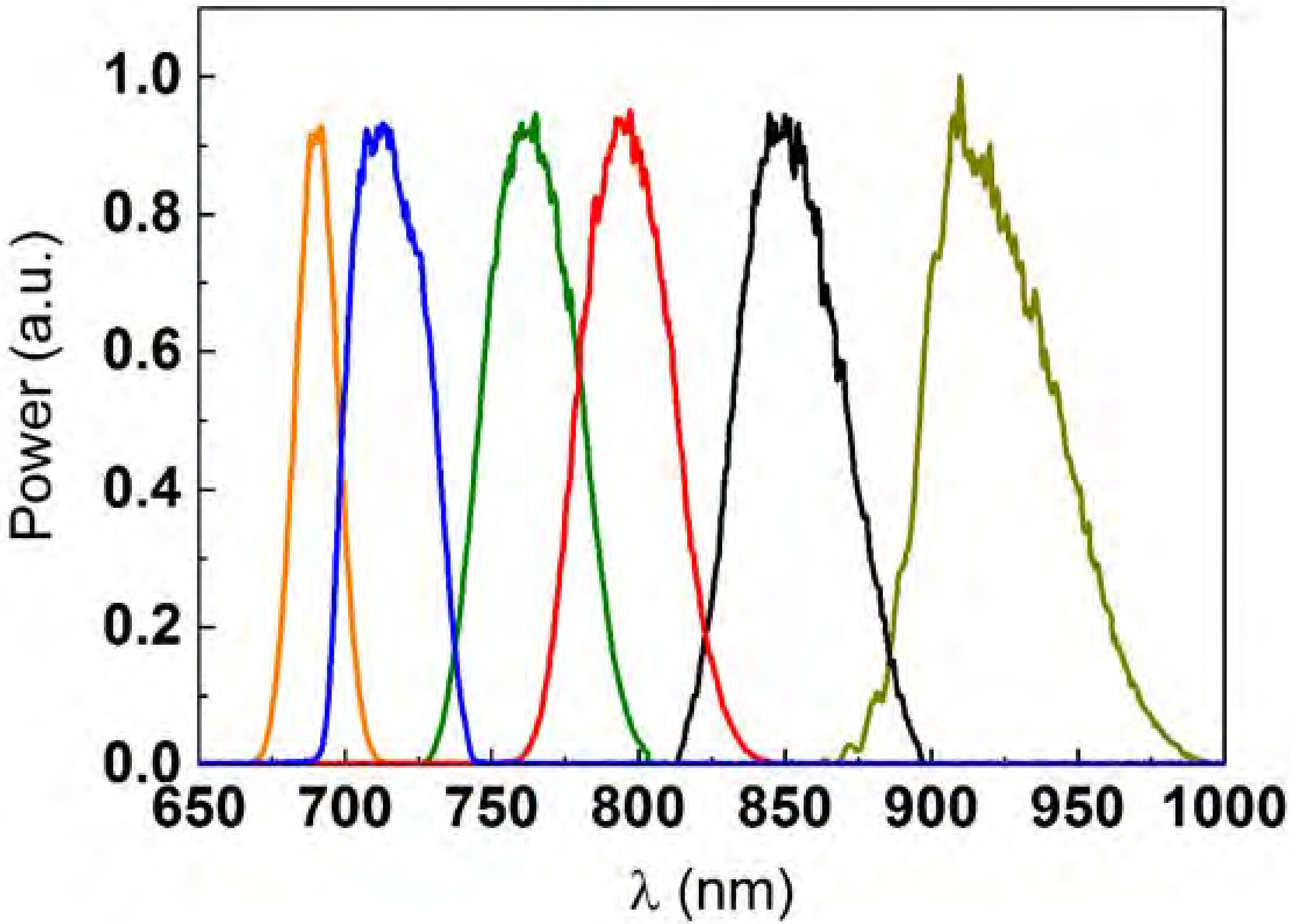
Pav.X.15a



Pav.x.15b Impulsų spektrai femtosekundinės sistemos išėjime derinant bangos ilgį.

EKSPLA

NOPA tunability



As conclusion:
We are company which supports our customers and partners in overcoming challenges.
We are good partners.

EKSPLA

Thank you

Questions

sales@ekspla.com

a.michailovas@ekspla.com

www.ekspla.com

Amplitude Laser Group

HIGH ENERGY AND ULTRAFAST LASERS

Amplitude TECHNOLOGIES

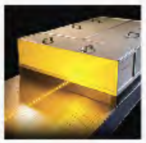
Continuum®
The High Energy Laser Company™

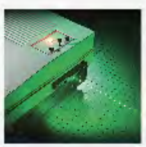
Amplitude SYSTEMES

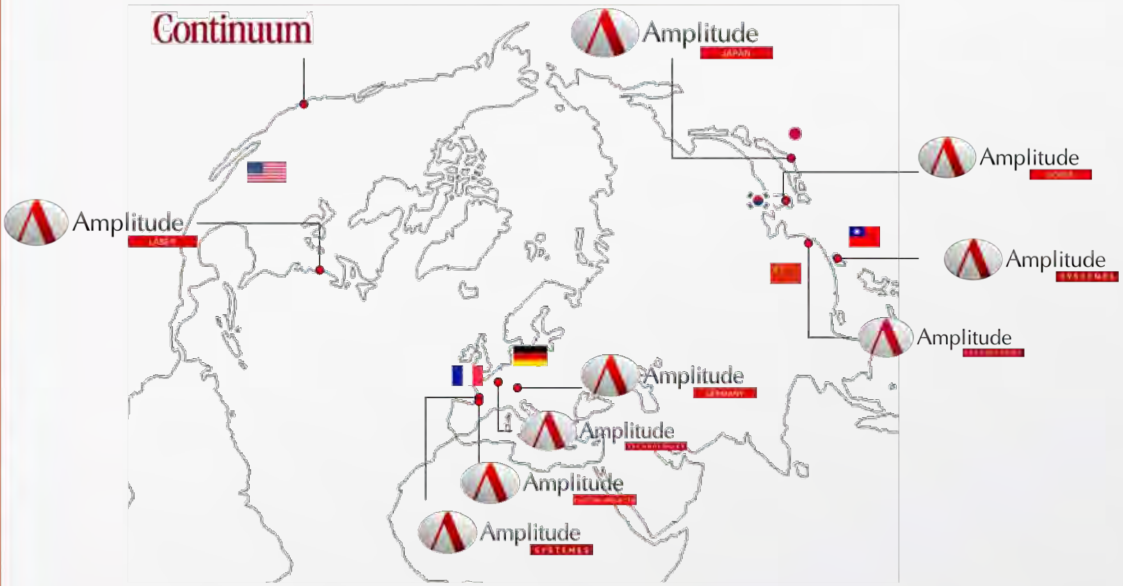
Continuum
The High Energy Laser Company™

Amplitude Laser Group worlwide







Amplitude in figures

- 290 co-workers
- 62 M€ turnover
- Presence in Europe, America and Asia

Pioneer in ultrafast and high pulsed energy laser solutions for industrial & scientific applications

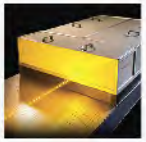
Manufacturing facilities

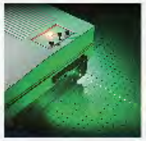
- Amplitude Technologies (Evry, France)
- Amplitude Systèmes (Pessac, France)
- Amplitude Custom Projects (Pessac, France)
- Continuum (San José, USA)

Sales & After-Sales offices

- Amplitude Technologies China (Shanghai)
- Amplitude Laser (Boston, USA)
- Amplitude Germany
- Amplitude Japan
- Amplitude Korea
- Amplitude Taiwan



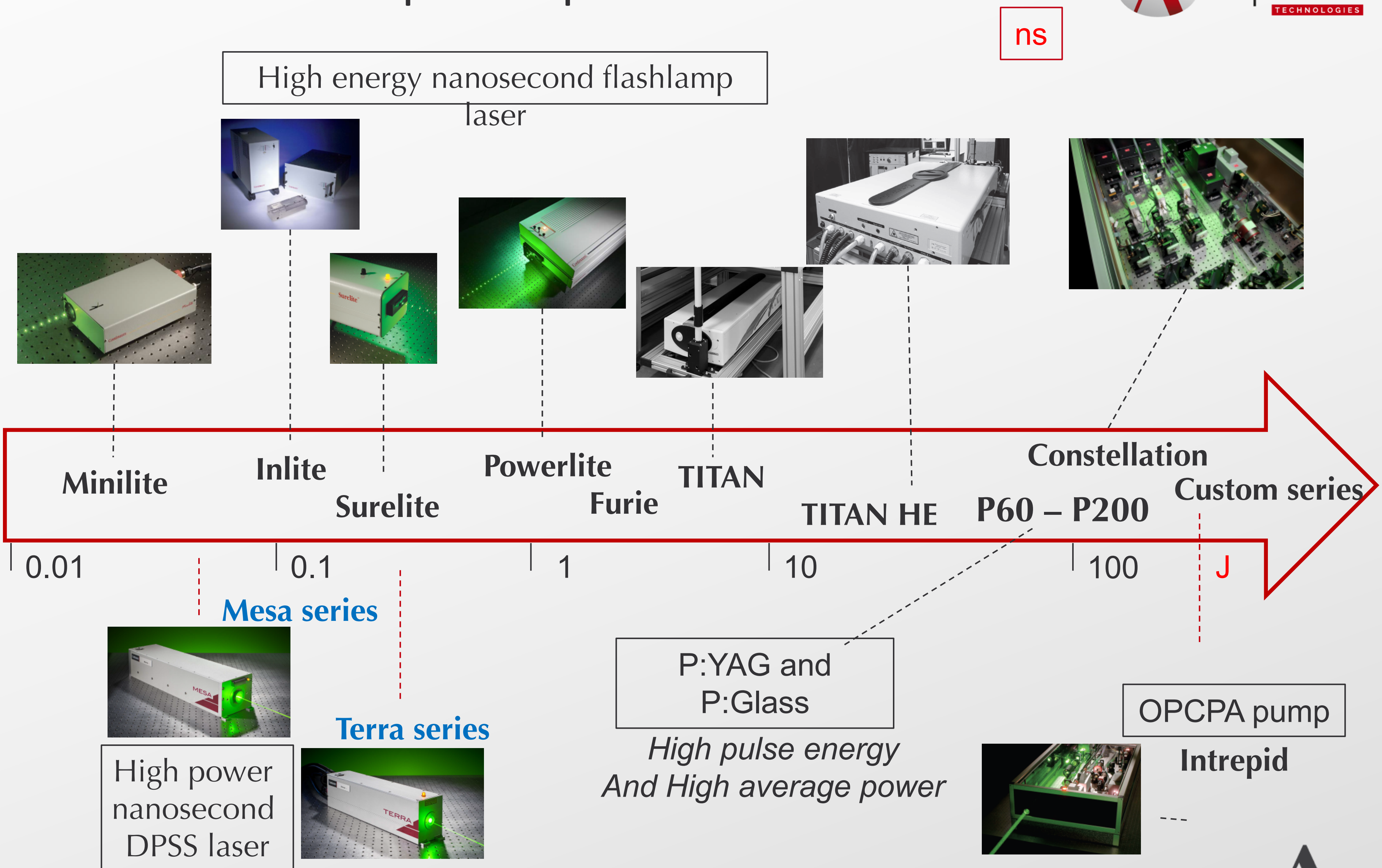





Amplitude Laser Group
Scientific Business

- **Amplitude Technologies** – *Ti:Sa CPA laser systems*
  - High peak power laser systems
  - High average power ultrafast laser systems
  - High pulsed energy lasers
- **Amplitude Systèmes** – *diode-pumped Yb-based lasers*
  - Diode-pumped ultrafast oscillators
  - Diode-pumped solid state ultrafast amplifiers
  - Diode-pumped fiber ultrafast amplifiers
- **Amplitude Custom Projects (ACP)**
  - High pulsed energy Yb:YAG laser solutions
- **Continuum**
  - High energy nanosecond lasers
  - Tunable lasers sources
  - Diode-pumped Nd:YLF or Nd:YAG lasers

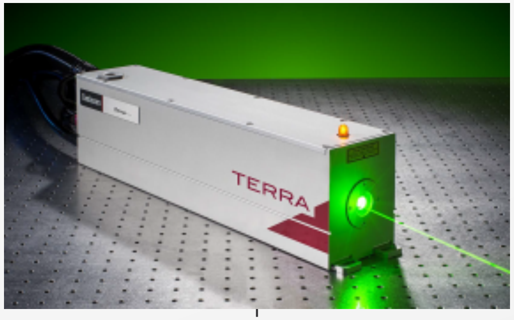
Nanosecond Pump laser portfolio



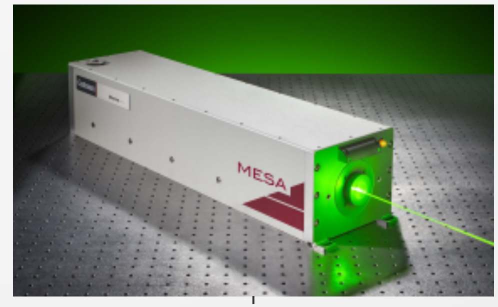
kHz Ti:Sa femtosecond portfolio

Amplitude TECHNOLOGIES

800 nm | KHz



Terra Pump



Mesa Pump

Integra-C

1 or 3,5 mJ | 130 fs | 1-3 kHz

100 fs

Fiber oscillator – All in one box

TRIDENT kHz

3- 5 mJ | 40 fs | 1-3 kHz

40 fs

Ti-Sa oscillator- 2 boxes

AURORA

Up to 20 W | 20 fs | 10 kHz

20 fs

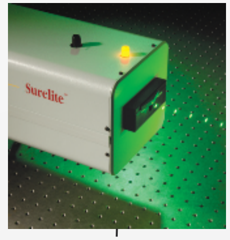
Ti-Sa oscillator
CEP

TableTop femtosecond laser portfolio

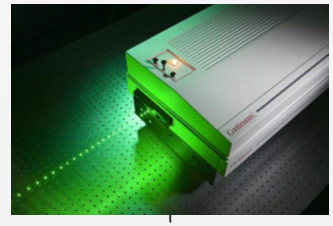
Amplitude TECHNOLOGIES

40 or 100 fs | 10 Hz

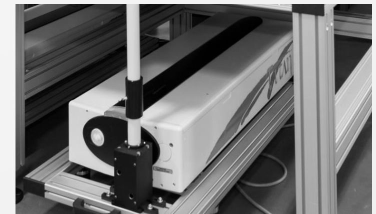
Inlite pump



Surelite pump



Powerlite pump
or



TITAN pump

TRIDENT

15 mJ | 10 Hz

LEIDA

100 mJ | 10 Hz

CENTAURUS

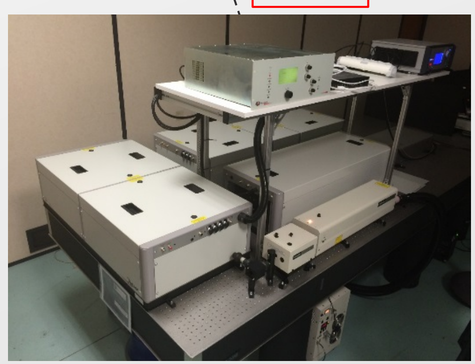
> 250 mJ | 10 Hz

1 J | 5 Hz

10 | 100 | 250 | 1 000

100 GW

1 TW



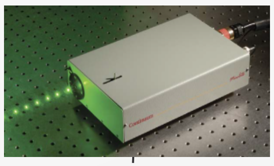
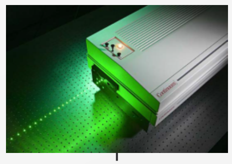
10 TW

nothing but ultrafast

Pulsar portfolio – PetaWatt Class

Amplitude TECHNOLOGIES

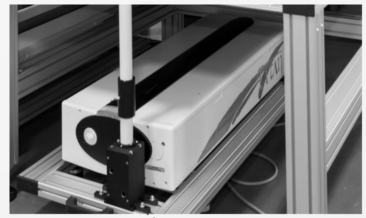
25 fs | 10 Hz

Inlite pump

Minilite pump

Powerlite pump




TITAN pump or TITAN HE pump

NOVA | NOVA UHC

15 mJ | 10 Hz

Front End

20 TW-class

450 mJ | 10 Hz

Institute of physics Beijing | CHINA
Terrawatt facility Nevada | USA
Osaka university | JAPAN

40 TW-class

1 J | 10 Hz

200 TW-class

5 J | 10 Hz

INFN Frascati Roma | ITALY
ETRI Daejong | KOREA
Jiaotong University Shangai | CHINA

500 TW-class

12,5 J | 1 Hz

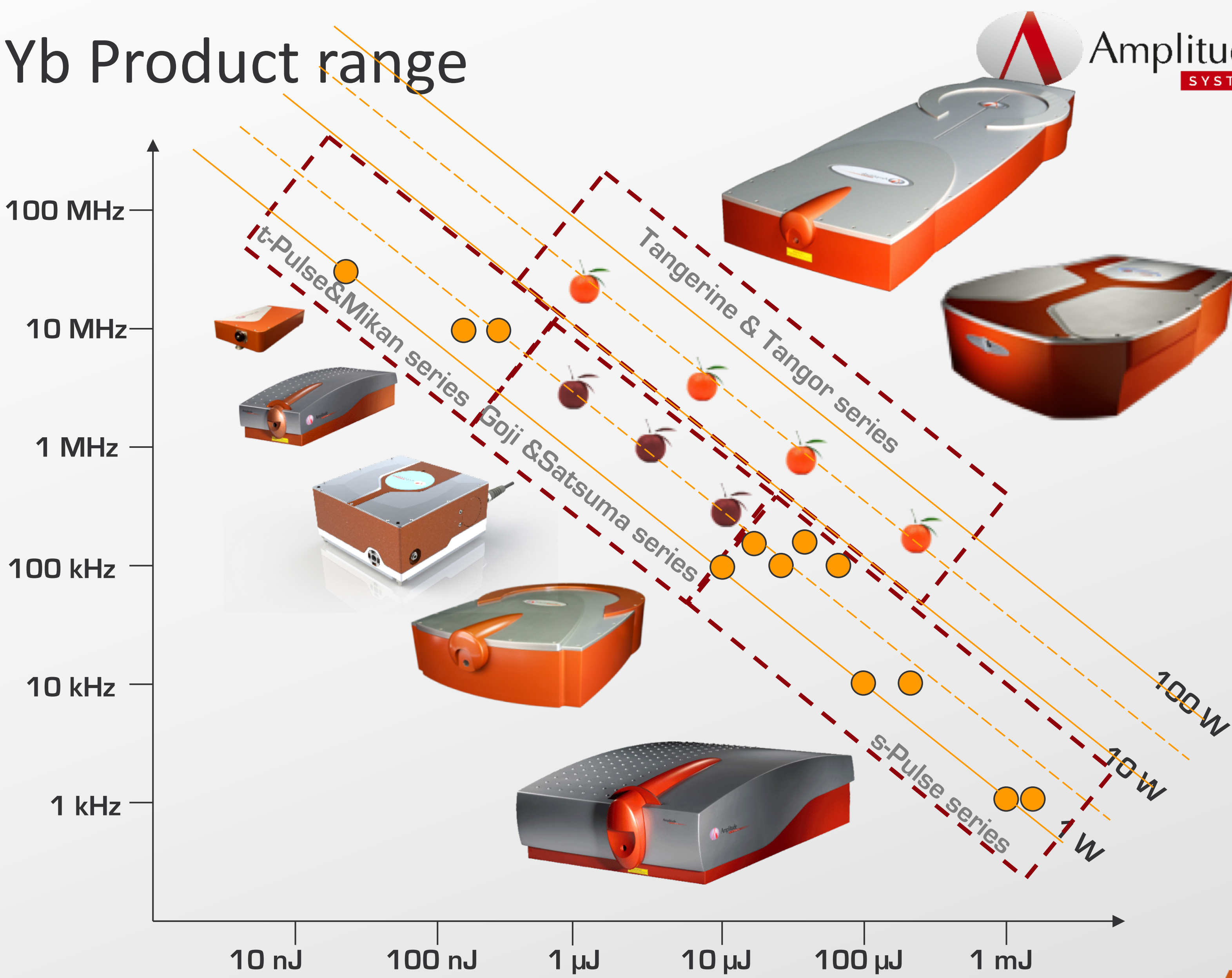
700 TW
under installation

PW-class

25 J | 0,1 - 1 Hz

CLPU Salamanca | SPAIN
HZDR Dresden | GERMANY
ELI ALPS under construction

Yb Product range



nothing but ultrafast

TOWARDS HIGH AVERAGE POWER PW LASER

Presentation of the P60 – High Energy, High repetition rate pump.

Concept of the P60

- Seeder can be adapted on demand: diode pumped, pulse shaped …
- Followed by 1 to 6 identical Nd:YAG amplifiers: high versatility for upgrade from P20 to P60.
- The philosophy is :
  → Enhanced and simple thermal management (no cryo) → Longitudinal liquid cooling in gain/heat load distributed disks.

  → Same class of average power:
  - as HAPLS (diode pumped Nd:Glass – cryo gas cooled by LLNL)
  - and Dipole (diode pumped Yb:YAG - cryo gas cooled by SFTC)

  → Compatible with diode pumping

  → ''Compact'' Laser: footprint 1.5 x 4.8 m²

  → Applications: OPCPA pumping, Ti:Sa pumping, Laser shot peening …

P-serie: 1 concept but 2 offers

1 concept

2 possible offers

Flashlamp pumping

- 'Low cost' of acquisition (~1/4 of competitors) per Joule
- Larger market can be adressed
- Similar rep-rate and specs as diode-pumped competitors thanks to efficient heat management

Diode pumping

- High cost of acquisition but similar to competitors (same per Joule as competitors)
- Small market can be adressed
- More than ~5 times higher rep-rate as competitors with same heat load as managed today → **> 3.5kW average power: 75J, 50Hz @ 1064nm**

'Serie P': Nd:YAG – 10Hz flash version

	P30	P40	P50	P60
Amount of DAH	3	4	5	6
Pulse duration, ns	Compatible 4ns and more*			
Rep-rate, Hz	**Up to 10 Hz**			
Energy @ 1.06 µm, J	40	52	64	75
Beam profile @ 1.06µm	Round, Top Hat, diam. 55mm			
Energy @ 532nm, J	30	40	50	60
Beam profile @ 532nm	Round, Top Hat, diam. 45mm		Round, Top Hat, diam. 55mm	

'Serie P': Nd:YAG – up to100Hz diode version

	P30	P40	P50	P60
Amount of DAH	3	4	5	6
Pulse duration, ns**	Compatible 4ns and more*			
Rep-rate, Hz	**Up to 100 Hz**			
Energy @ 1.06 µm, J	36	48	60	70
Beam profile @ 1.06µm	Round, Top Hat, diam. 55mm			
Energy @ 532nm, J	25	30	40	50
Beam profile @ 532nm	Round, Top Hat, diam. 45mm		Round, Top Hat, diam. 55mm	

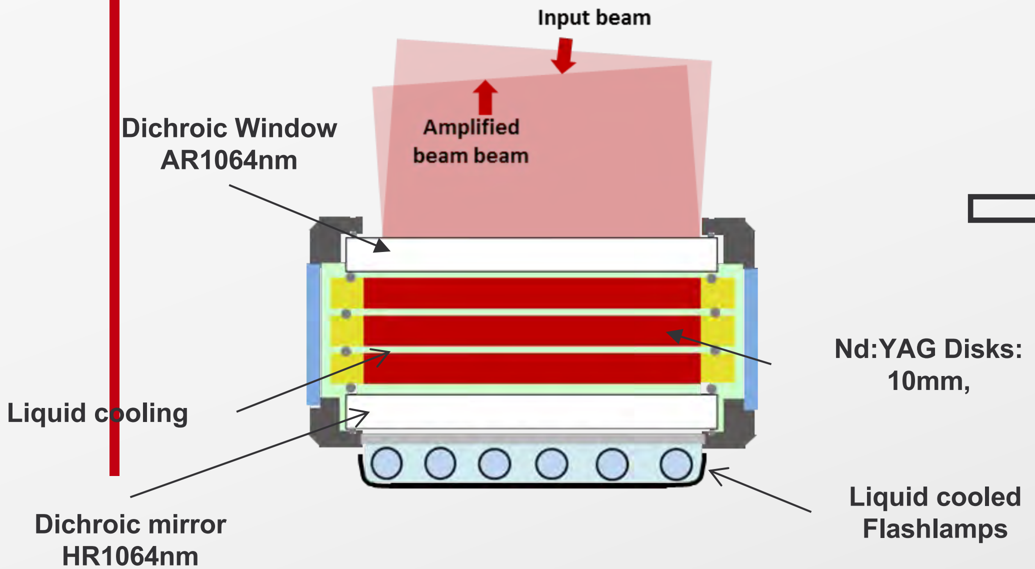
*Shorter duration available with derated energy.

Amplifiers core technology: the Disk Amplifier Head

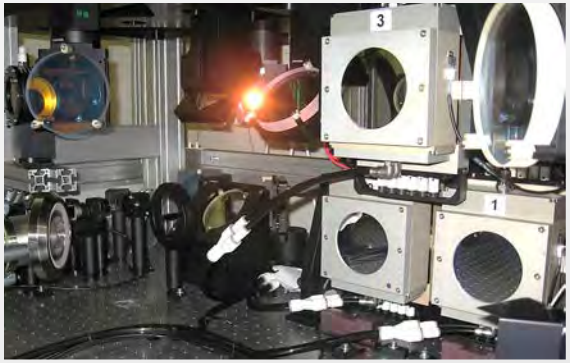
Design of Disk Amplifier Head (DAH)

- Improved ‘Active mirror’ configuration
- Nd-doped materials

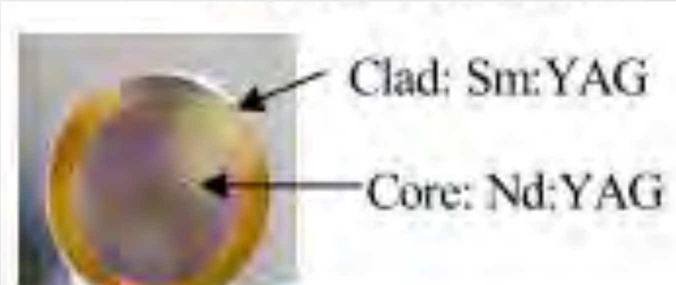
- Low cost → Flashlamps pumping
- High capacity of heat load extraction
- Limiting thermal effects: longitud. cooling



Principle of DAH



Triplets of DAH



D80-100 Nd:YAG disk

Advantages of our concept

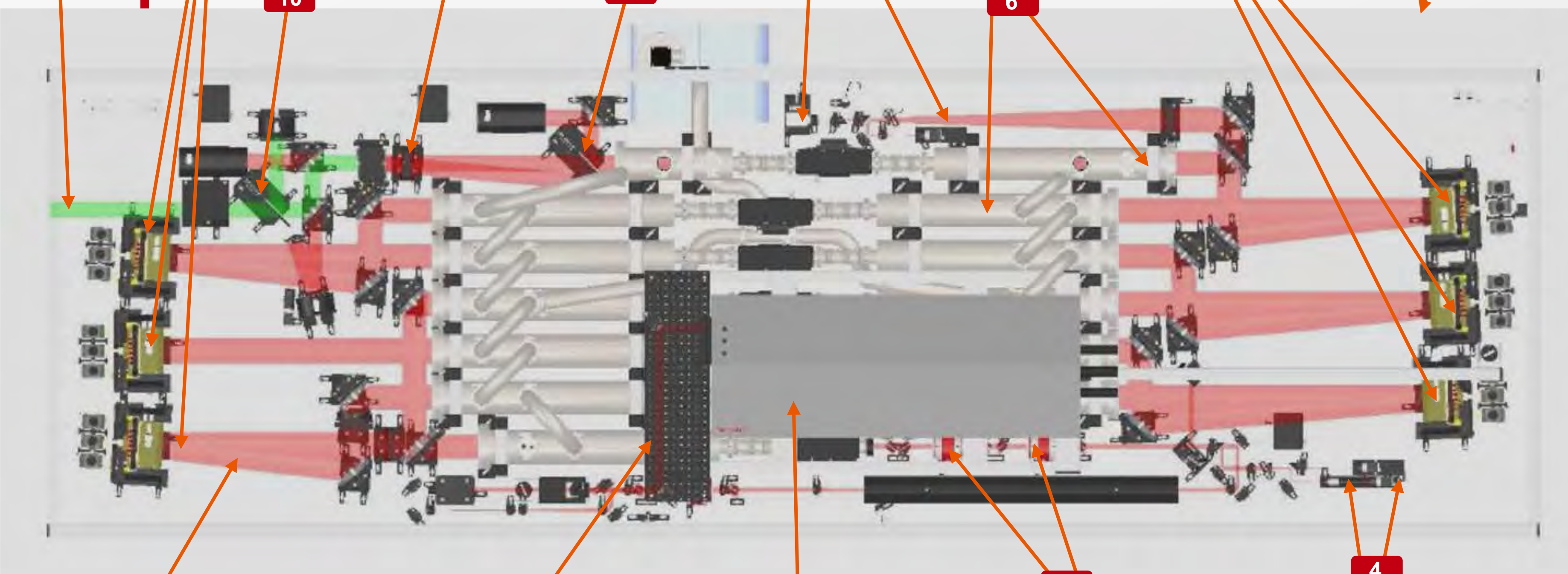
- High efficiency: optical % electrical stored energy is 2% with flashlamps pumping.
  And ~11% electrical-optical efficiency with diodes pumping.
- High gain per pass
- Almost 0° incidence → loss insensitive to polarization
- Almost perfect overlap of incident & reflected beam → high filling factor for efficient energy extraction
- Amplification possible in vertical & horizontal polarization or circular polarization → birefringence compensation with quartz rotator is possible
- Double pass configuration with $\lambda/4$ or Faraday rotator possible
- No angular multiplexing → compact and versatile configuration, low fluence on every optics (1.7J/cm²)
- Diode pumping possible
- 100Hz diode pumping with Nd = 2% cycle ratio
  = max cycle ratio in QCW
  ~ same stored energy as Yb

Diode package for HAPLS:
800kW peak power @ 888nm
@ 10Hz – 10kW/cm² peak power

6-7kW/cm² required for Nd:YAG

- Damage threshold validated up to 9J/cm² incident @ 15ns
- Low residual birefringence (few % depolarization only at full thermal load)
- Low thermal focal length (-1000 meters)
- Low cost for flashlamps pumped version

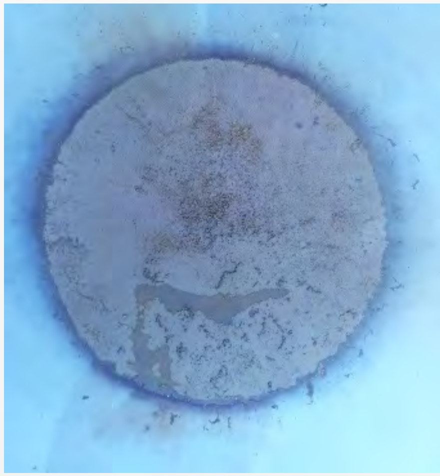
P60 flashlamps pumped version



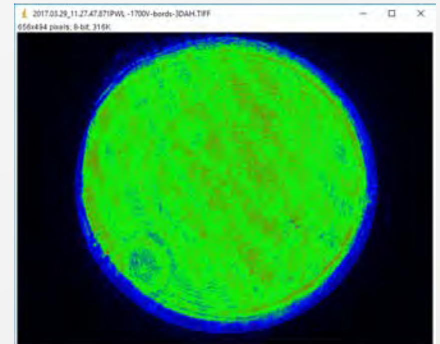
Demonstrated performances of the Laser P60

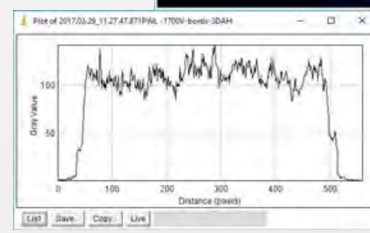
Demonstrated beam profile at 1064nm (no DOE) @ 5HZ

Amplitude TECHNOLOGIES

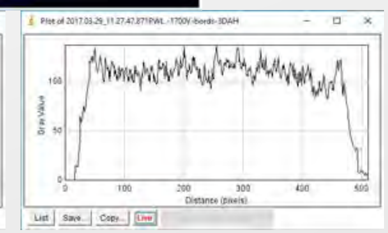


Burn paper at 78J level at 1064nm: beam diameter is 80mm

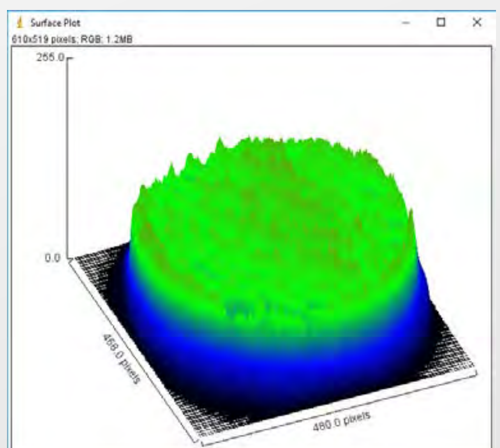




Horizontal beam profile



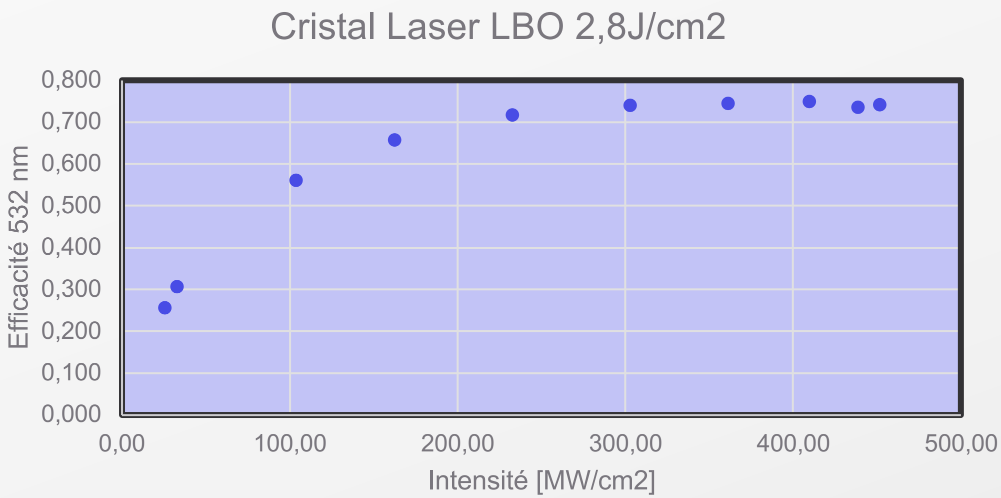
Vertical beam profile



3D view

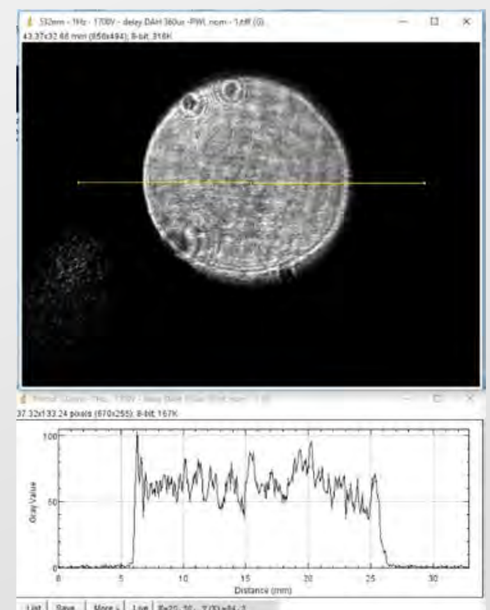
Demonstrated performances at 532nm (no DOE) @5Hz

Demonstration of 58J at 532nm at in LBO type I, diam. 65 thick. 18



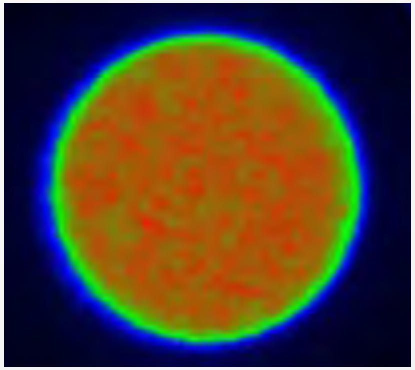
75% SHG efficiency demonstrated with 5-6ns gaussian temporal pulse @ 2.8J/cm² incident fluence

Beam profile in the green @ 75% SHG efficiency

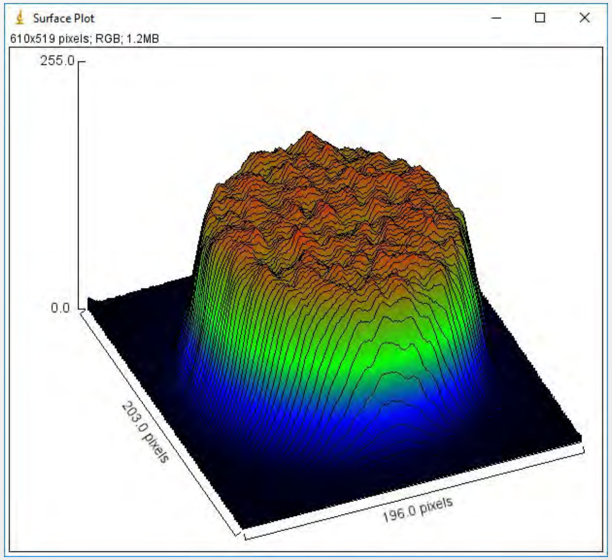


nothing but ultrafast

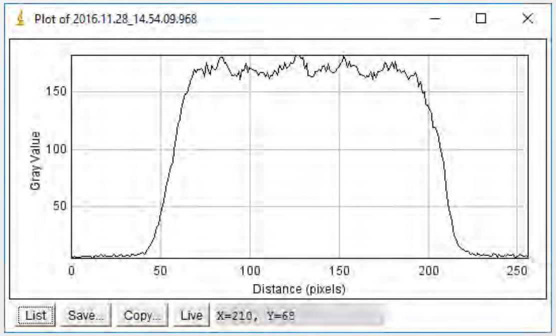
Demonstrated beam profile at 532nm
Once homogenized with DOE



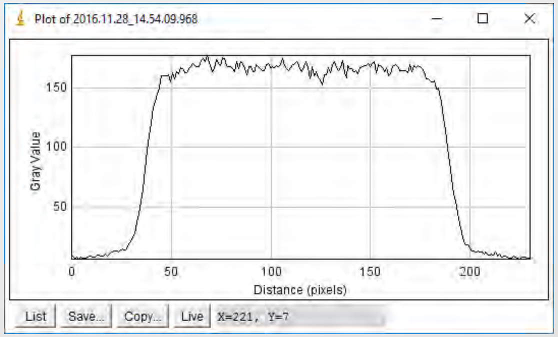
2D beam profile @ 532nm with 8mrad full angle DOE



3D beam profile @ 532nm

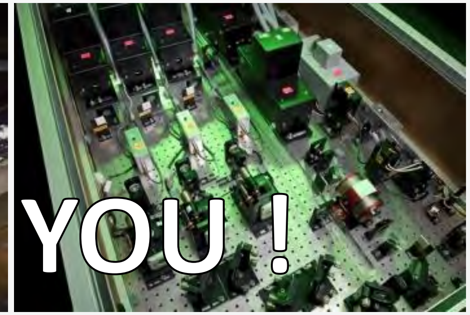


Horizontal



Vertical

The P60 in the lab.



THANK YOU !

Meter-Size Gratings for XCELS Laser Pulse Compressors

Dr. Arnaud COTEL – HORIBA France SAS
arnaud.cotel@horiba.com

CREMLIN WP6 Workshop - Paris
12th December 2017

Outline

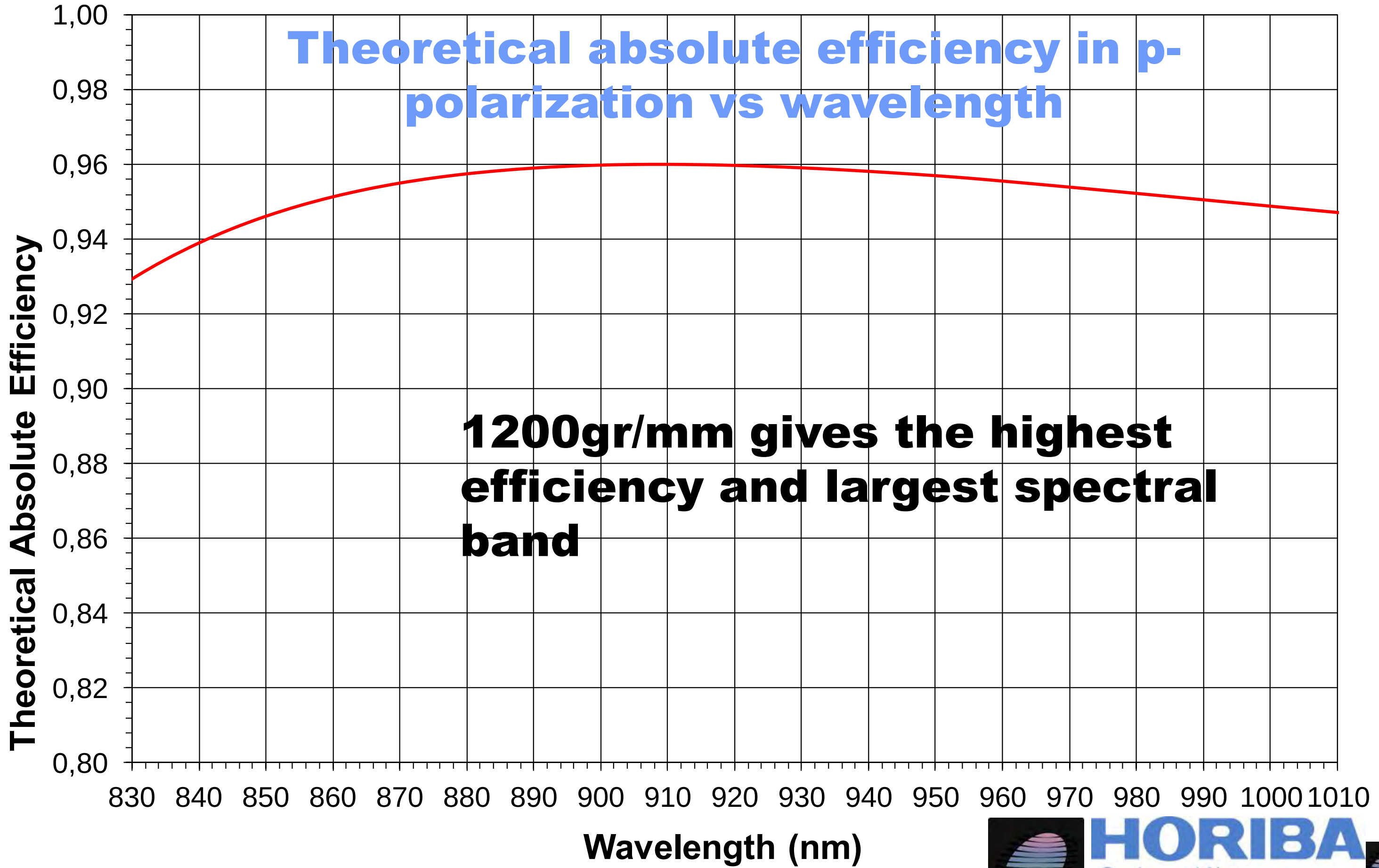
- Gratings design for OPCPA laser at 910nm
- Meter-size Gratings NANOLAM facility overview
- Latest results on Meter-size gratings performances

Outline

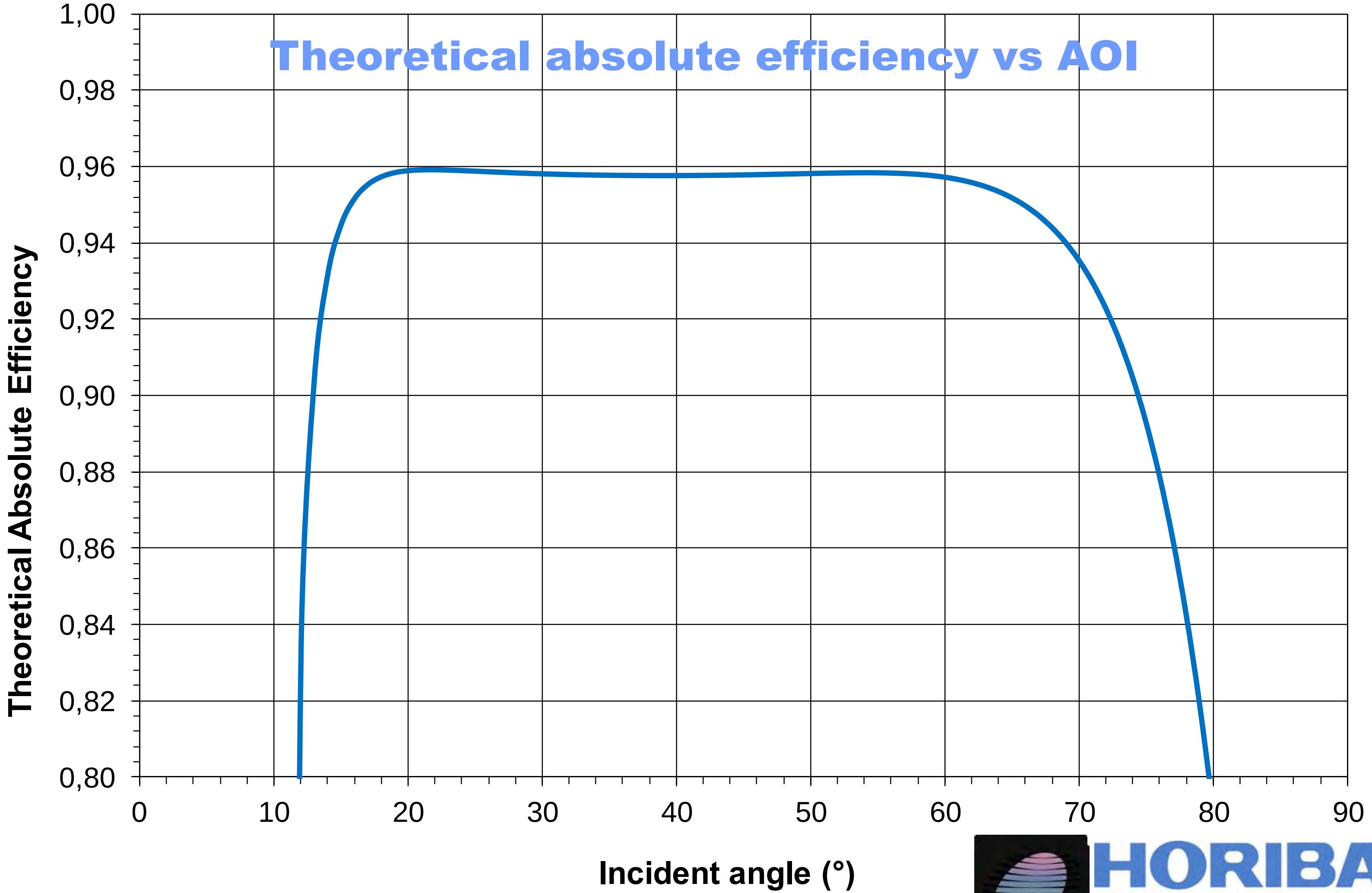
- **Gratings design for OPCPA laser at 910nm**
- **Meter-size Gratings NANOLAM facility overview**
- **Latest results on Meter-size gratings performances**

Gold-coated Gratings design for XCELS OPCPA at 910nm : 1200gr/mm

- Existing Gold-coated grating design at 800nm and 1µm with 1200 / 1480 / 1740gr/mm => at 910nm ?



Gold-coated Gratings design for XCELS OPCPA at 910nm : 1200gr/mm

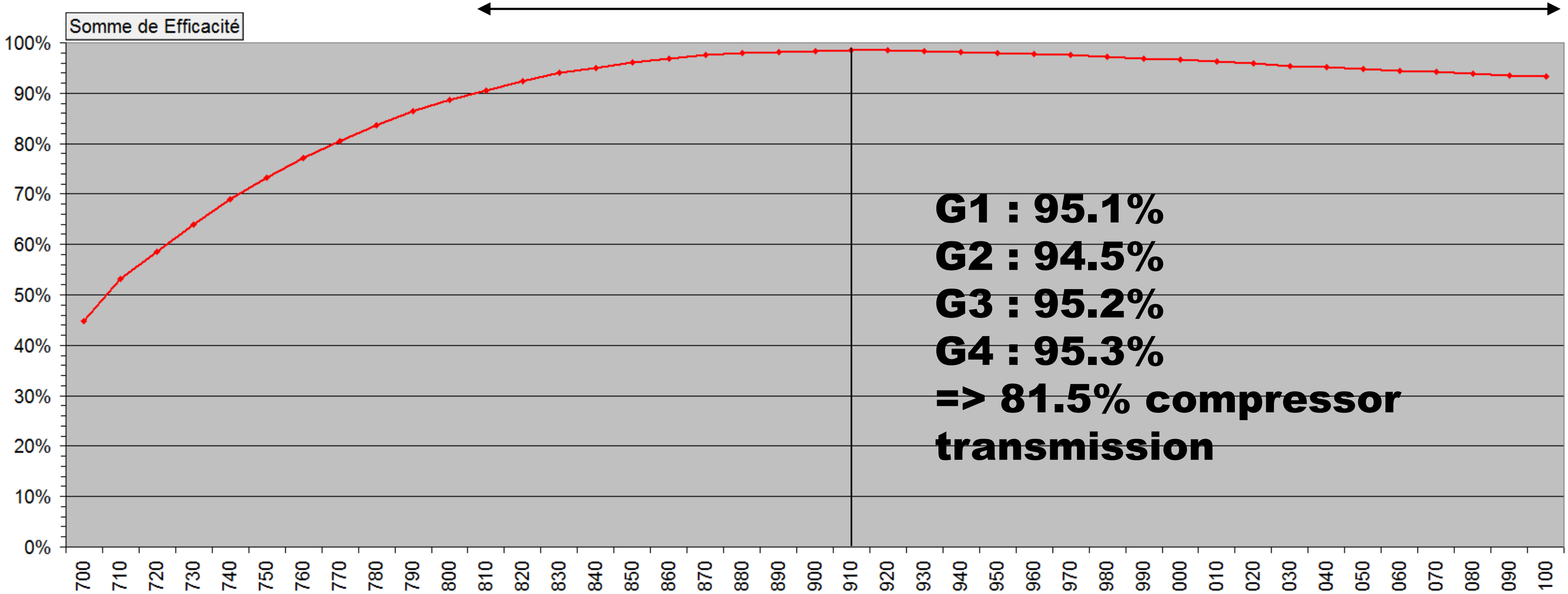


Gold-coated 1200gr @910nm Gratings results

- **4 gratings (1200gr @ 910nm) in size 210x420mm have been manufactured and characterized.**

Relative Efficiency

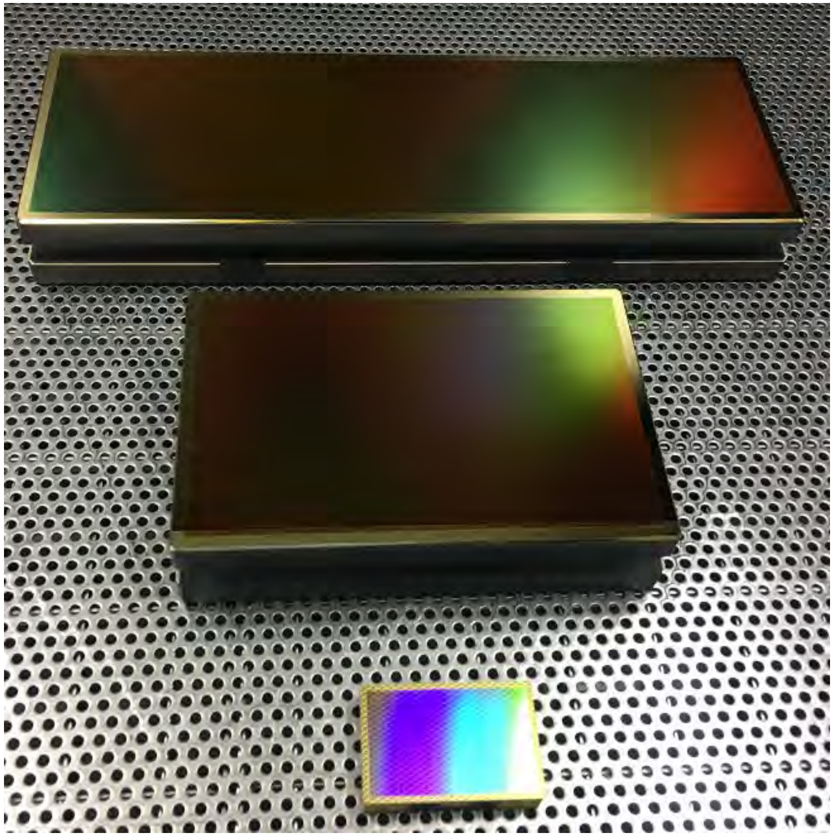
> 300nm spectral bandpass

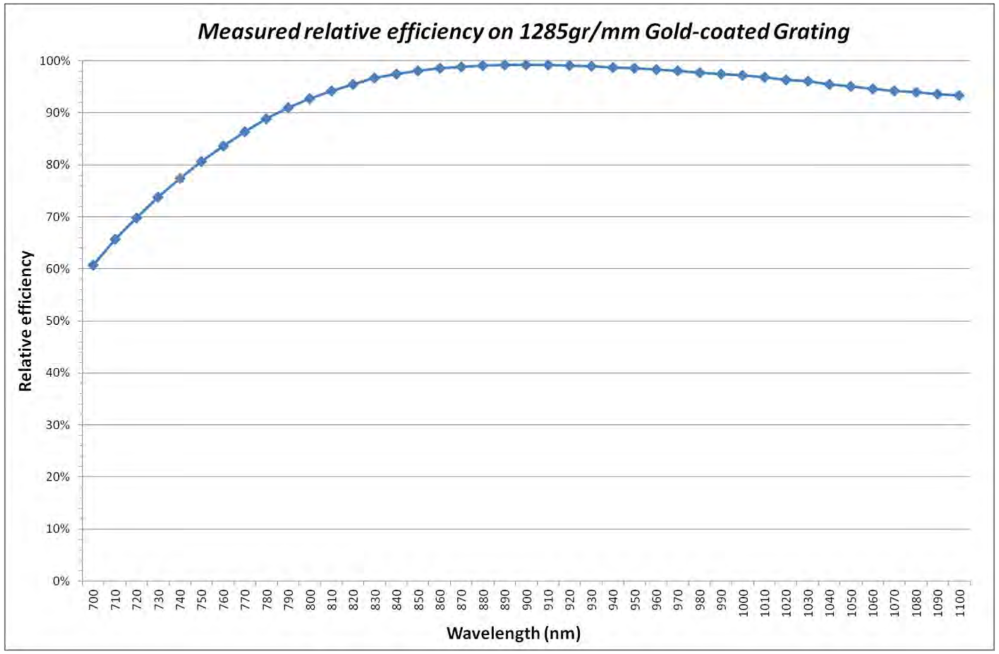


Wavelength (nm)

Gold-coated Gratings design for OPCPA at 910nm : 1285gr/mm

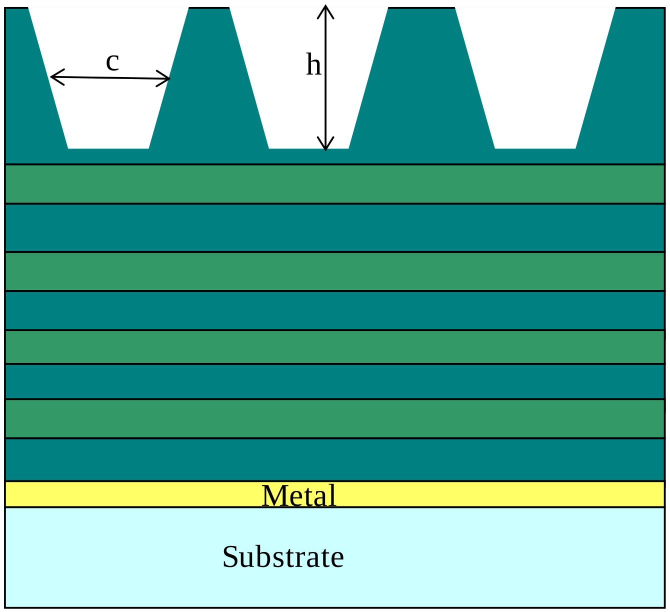
- **Other groove density close to 1200gr/mm are also possible 1285gr/mm at 910nm.**

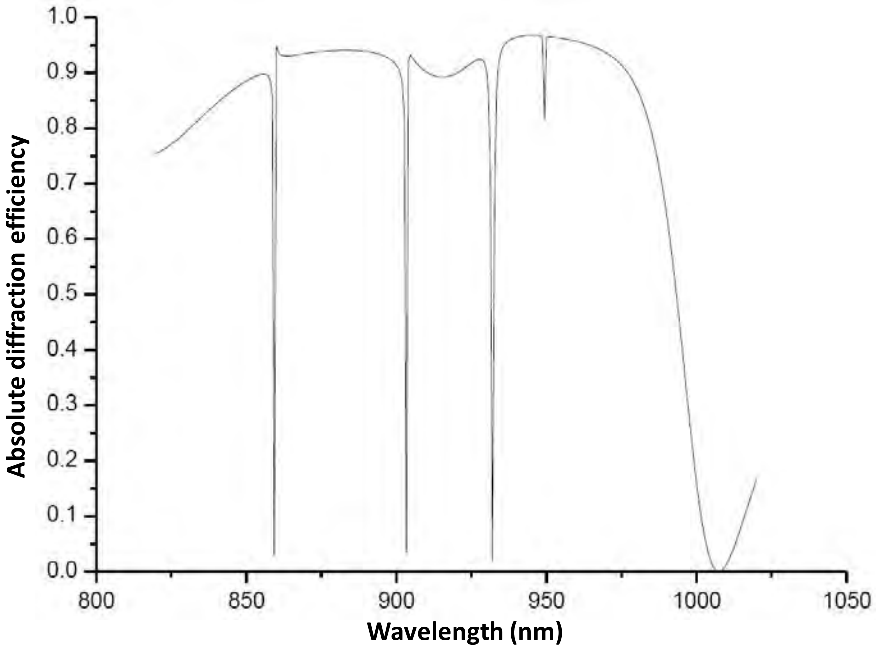




Hybrid Metal-Dielectric Gratings design for OPCPA at 910nm ??

Metal Multi-Layer Dielectric (MMLD) Grating type :



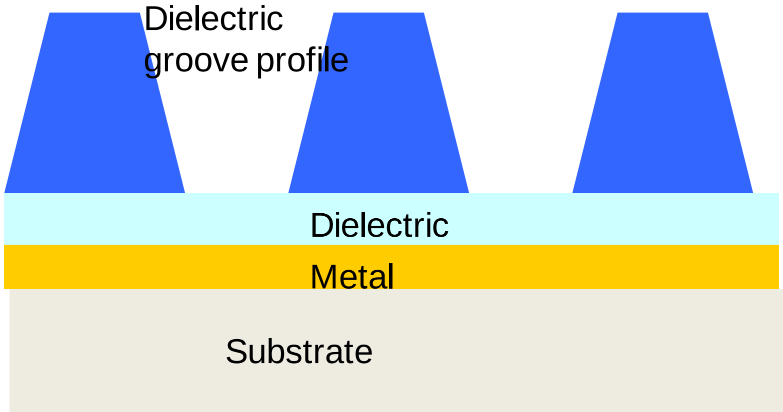


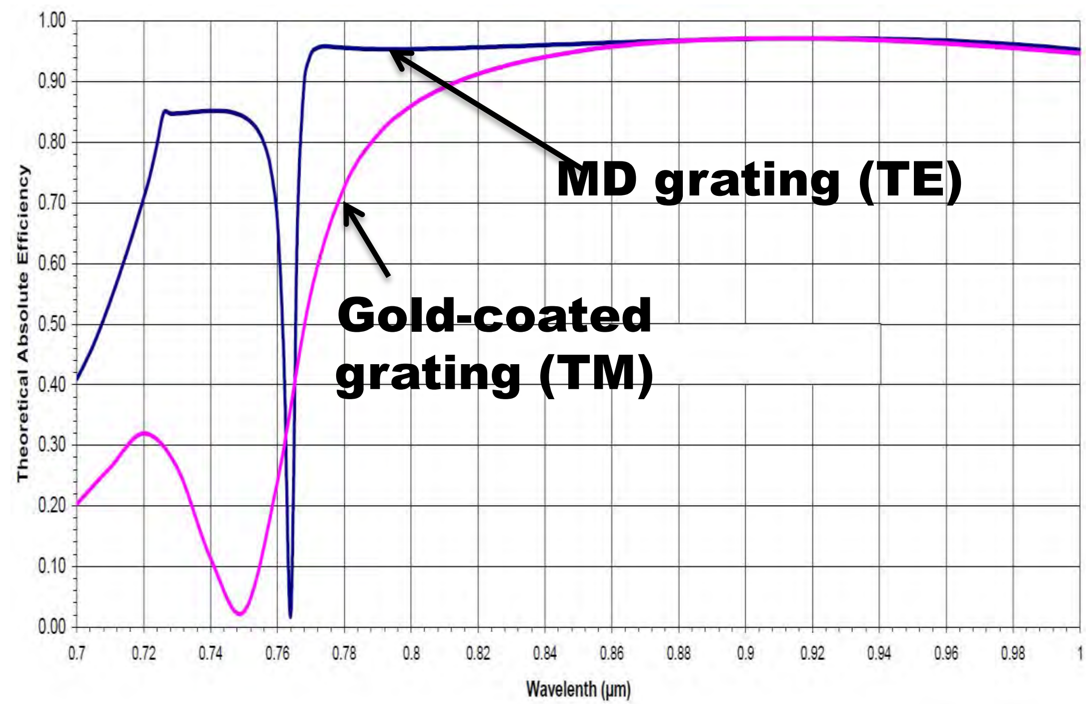
⇒ Average calculated efficiency is ~89.6% in s-polarization with 3 absorption peaks in the spectrum.

⇒ Despite a working design of MMLD grating for 1480gr @ 800nm, there is NO design found for 1200gr @ 910nm.

Hybrid Metal-Dielectric Gratings design for OPCPA at 910nm ??

Metal Dielectric (MD) Grating type :





⇒ Average calculated efficiency >95% with broaden spectral bandwidth (absorption peak at ~764nm).

⇒ NO working design of MMLD grating for 1480gr @ 800nm, BUT a design found for 1200gr @ 910nm.

Outline

- Gratings design for OPCPA laser at 910nm
- **Meter-size Gratings NANOLAM facility overview**
- Latest results on Meter-size gratings performances

NANO-structures Large Area Master (NANOLAM) New Facility

HORIBA
Scientific

Holography* : ~1000m²
ISO5 clean room

KEY FEATURES :

- **New automated grating production line** (Paris Saclay - FRANCE).
- **Largest size : up to 1500mm grating.**
- Compatible with Multi-PW laser projects and other markets.
- Flexible in grating size, groove density, …

***Jobin Yvon Patent : « Optical diffraction grating scanning device », Flamand J, Labeyrie A, Pieuchard G, 1970, US 3721487 A.**

HJY involved in ELI-NP project

Meter-Size Gratings for 2 x 10PW pulse compressors

- **EU-funded ELI-NP project (Romania) :**

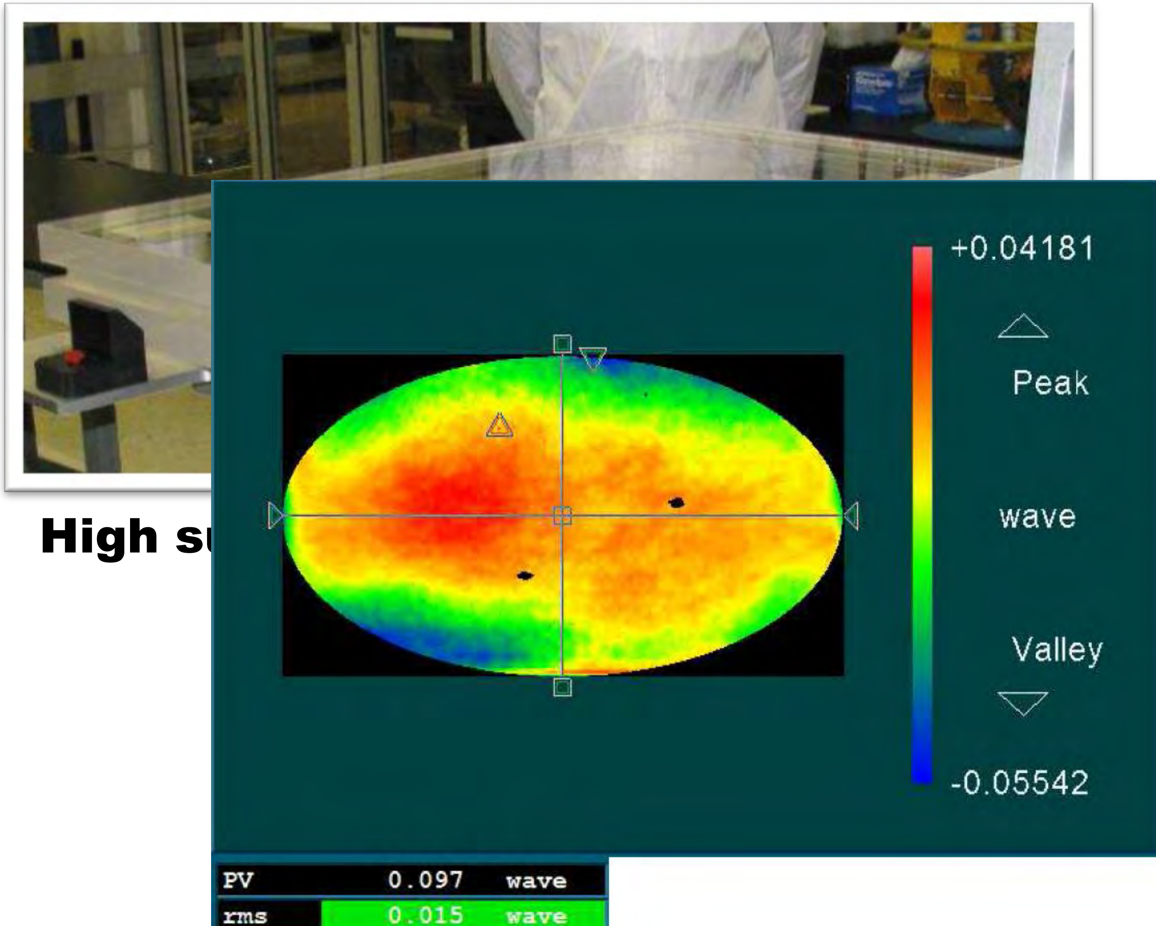
  HORIBA Jobin Yvon has been awarded in 2013 to produce ~30pcs pulse compression gratings (2x 100TW-1PW-10PW).

extreme light infrastructure

THALES

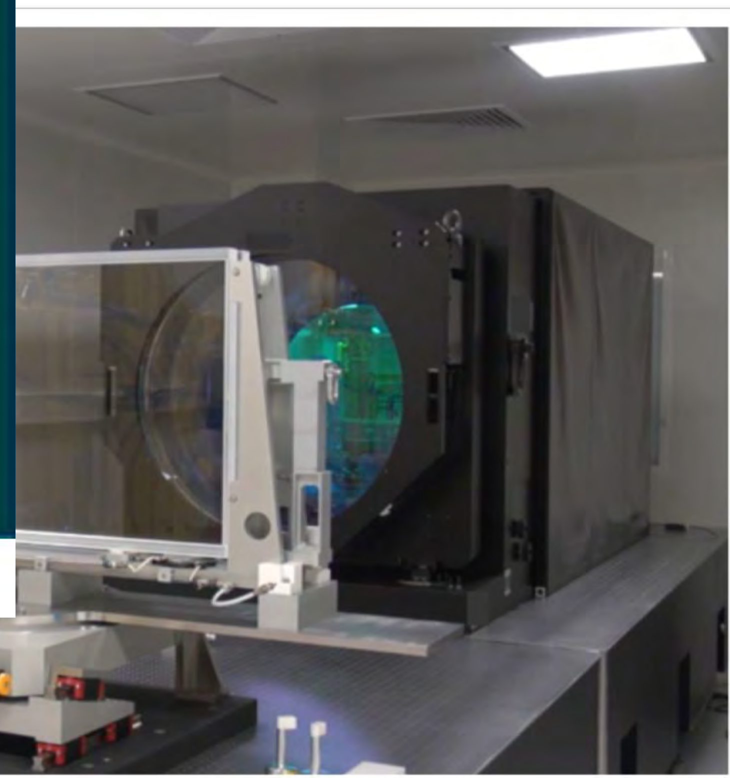
JOBIN YVON Technology

Meter-Size Gratings : Substrates



High s

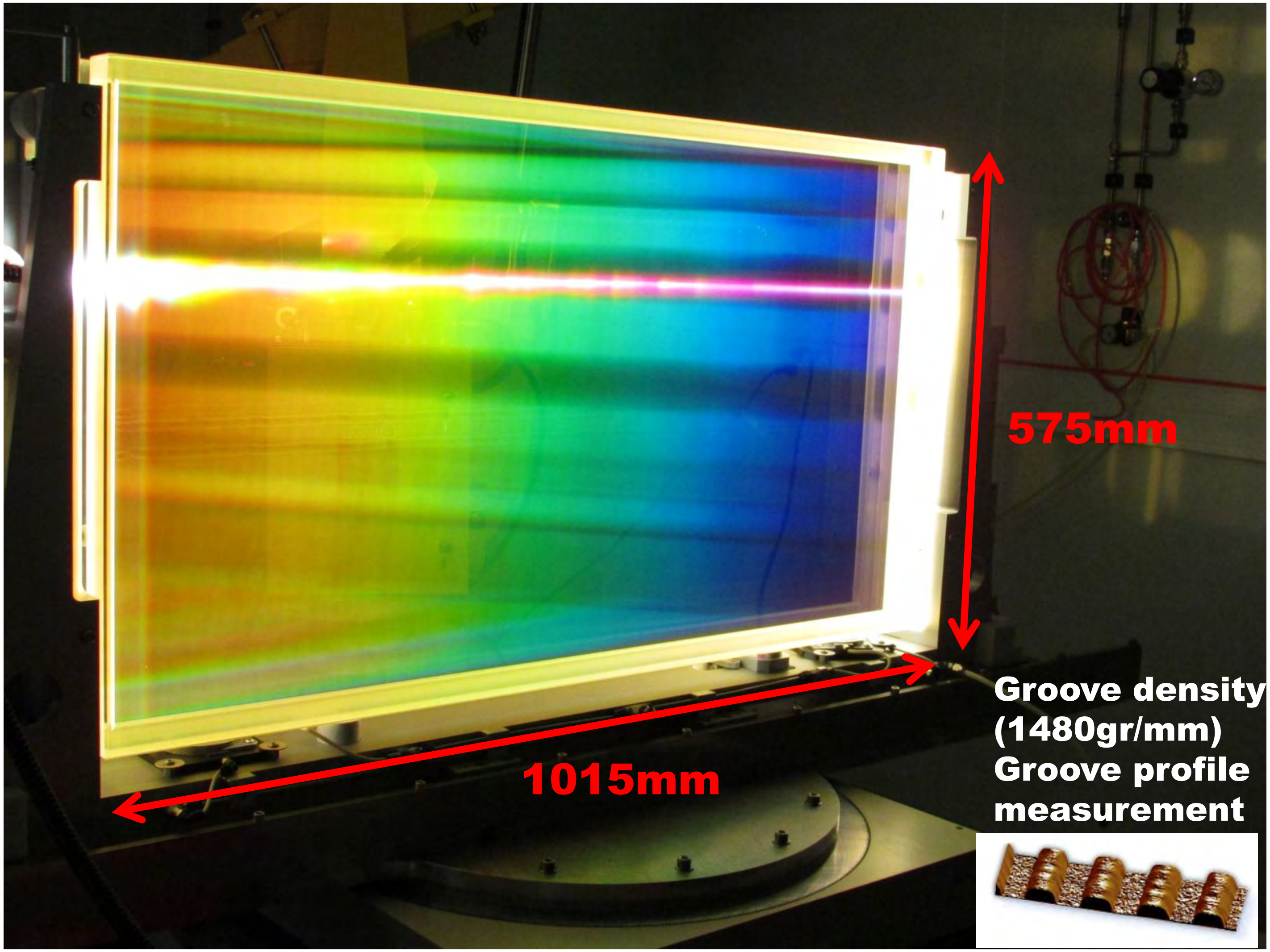
HJY heritage on large optics design and support of key Astronomy polishers.



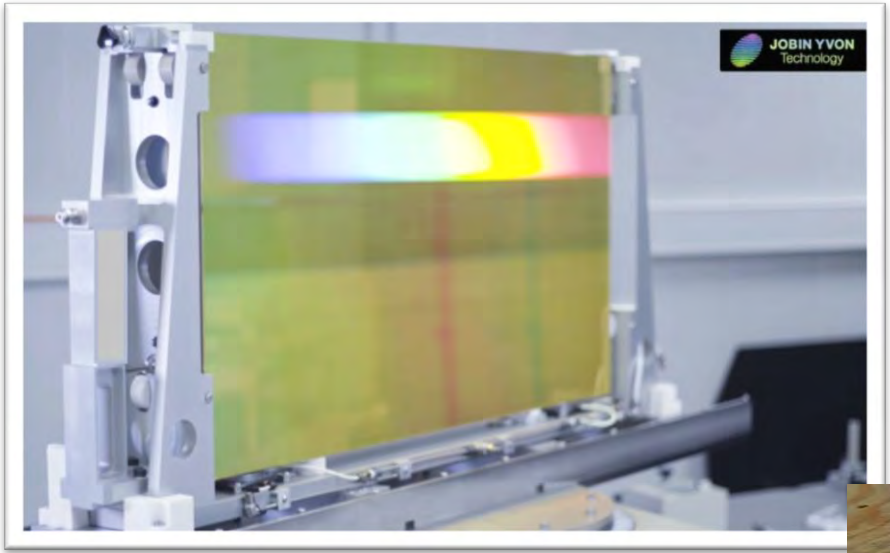
Meter-Size Gratings : Handling

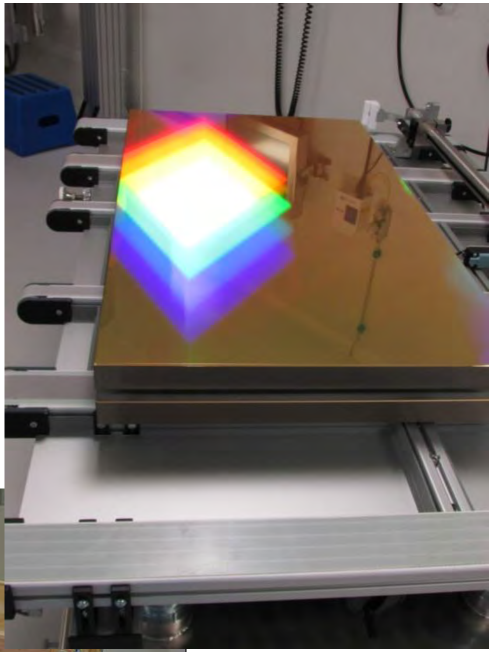
Complex handling systems were developed to manage >150kg componant.

WORLD RECORD – Meter-Size Grating holographically recorded



10PW laser pulse compressor gratings manufactured for ELI-NP





eli
extreme light infrastructure

THALES

Outline

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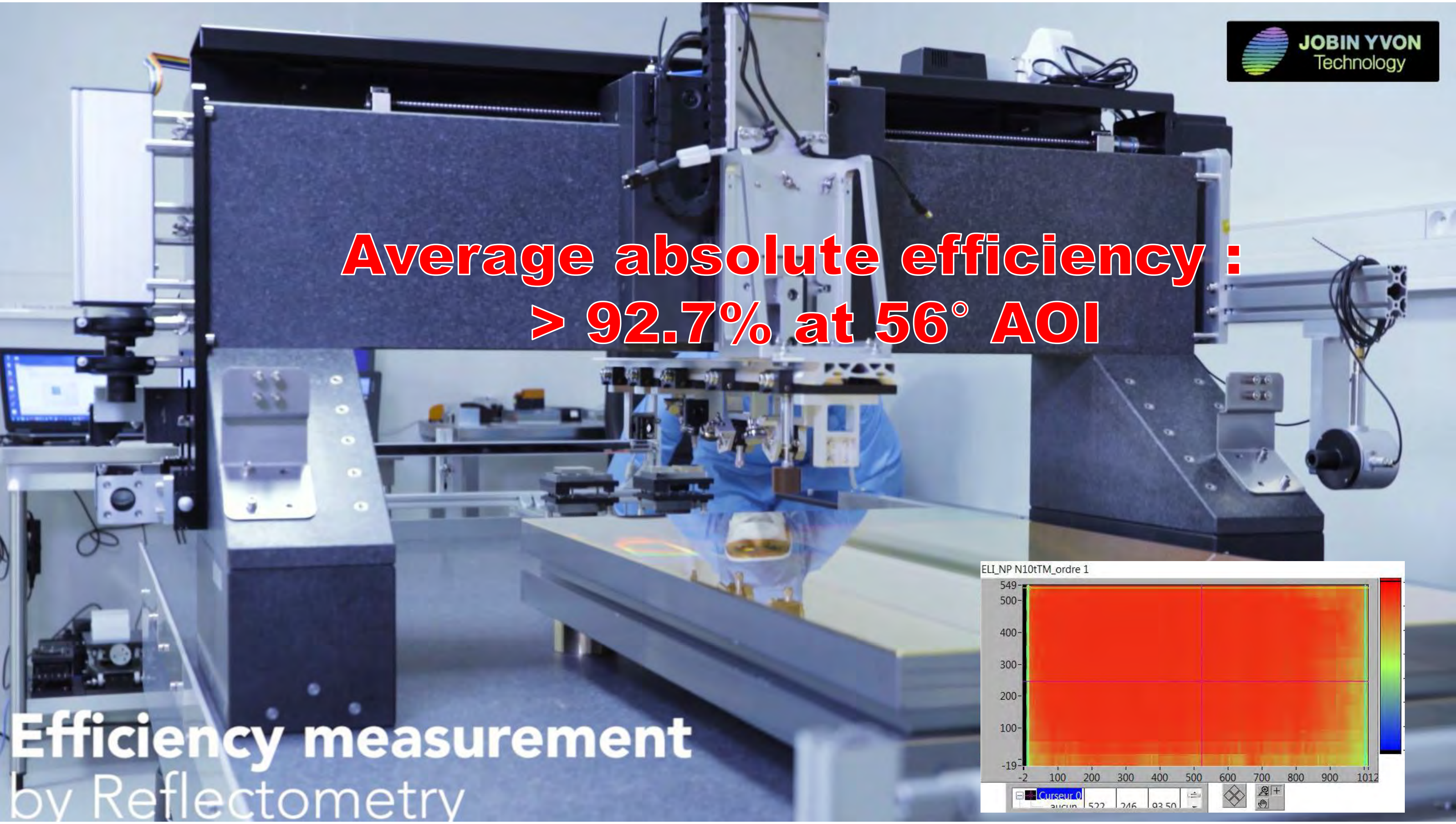
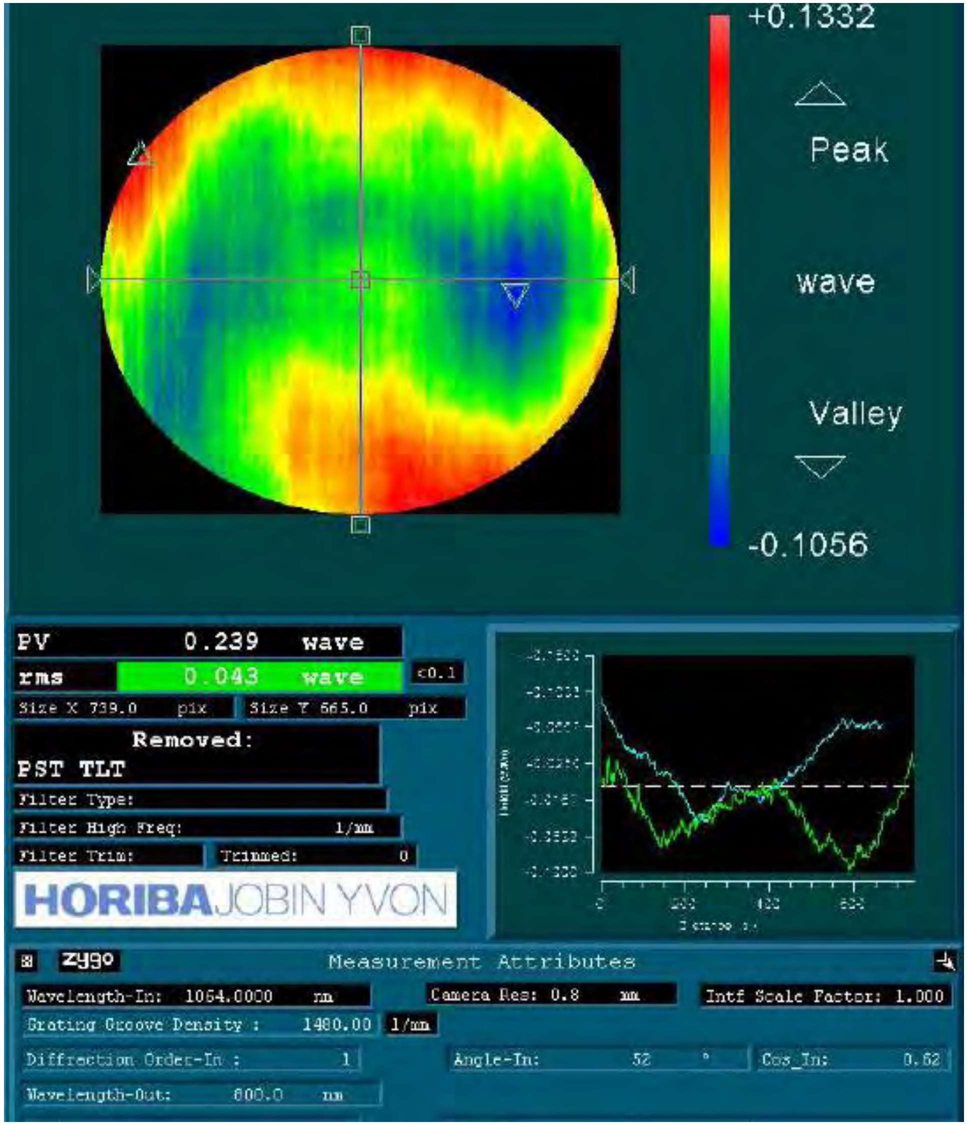
- **Latest results on Meter-size gratings performances**

High-efficiency Meter-Size Grating



Diffracted Wavefront optimization



- Meter-size grating Wavefront has been strongly improved with optimized holographic recording.
- < lambda/23 RMS at 800nm in the 1st order.

Conclusion

- **New automated Meter-size Gratings production facility is fully operational (> 10 gratings already produced).**
- **Grating Designs (Gold and MD) developed for XCELS compressors (1200gr @ 910nm)**
- **Up to 1500mm gratings are now commercially available at HJY.**

Thanks for your attention