High Power Ultrafast Lasers

Eric Mottay

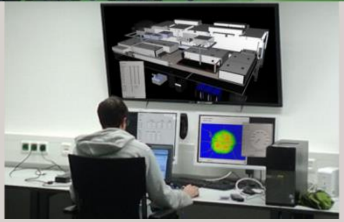
Outline

- *Industrial ultrafast lasers*
- Future roadmap
- Ultrafast lasers and high energy physics
  - Accelerators
  - ELI
  - ICANN

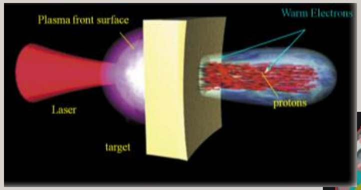
Not in the Outline

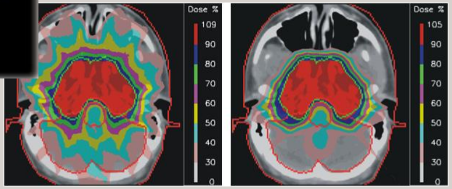
- PetaWatt Ti Sapphire Lasers

Amplitude TECHNOLOGIES



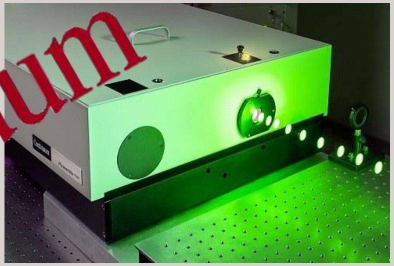
- Medical applications and Protontherapy



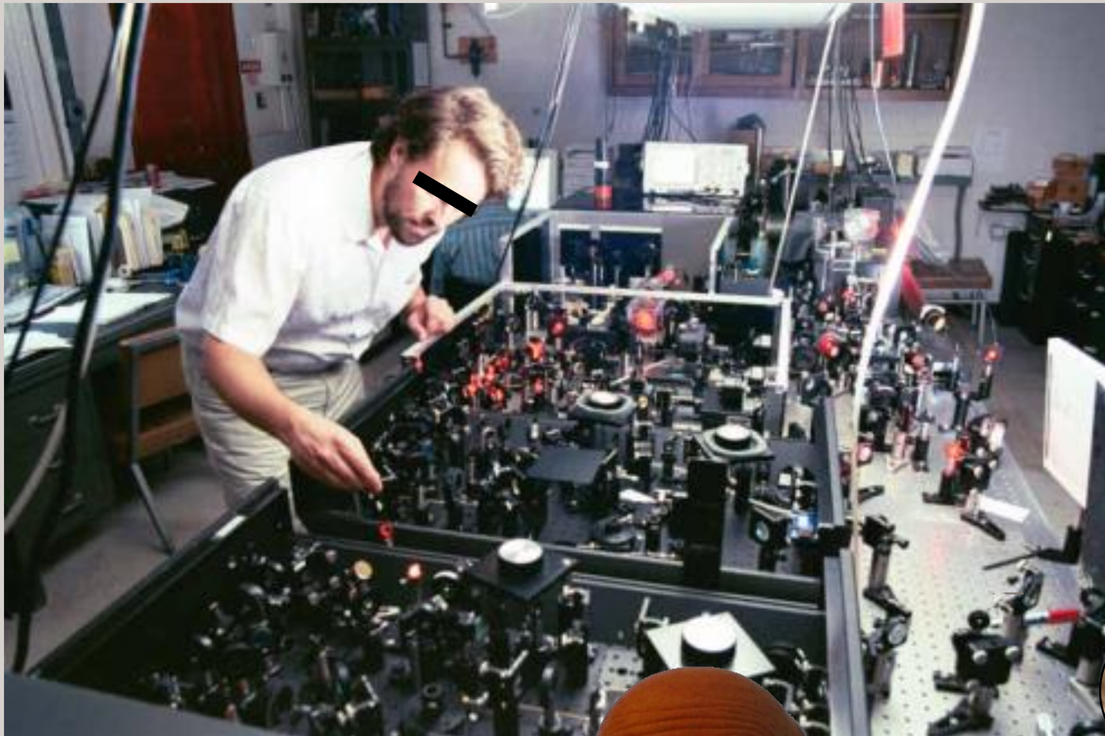


- High power ns lasers

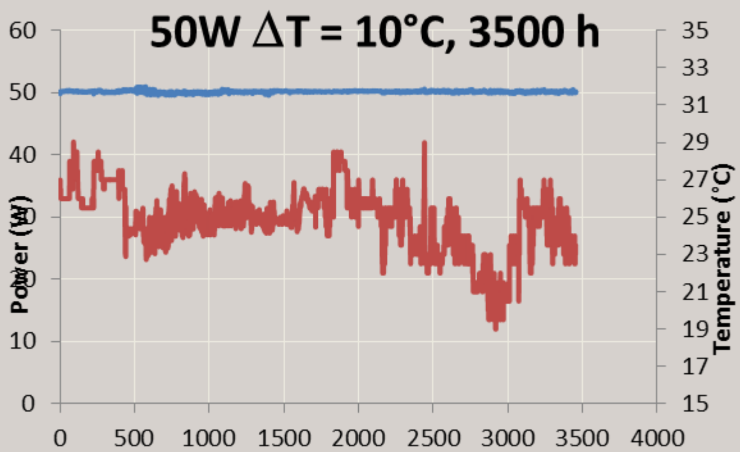
Continuum



Ultrafast lasers, 2000s



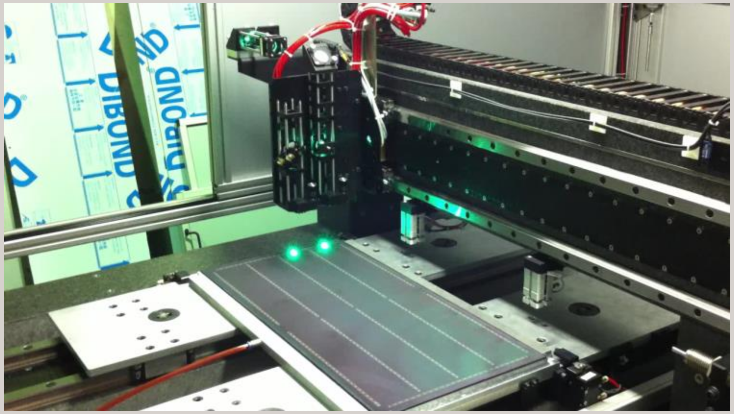
Ultrafast lasers, today



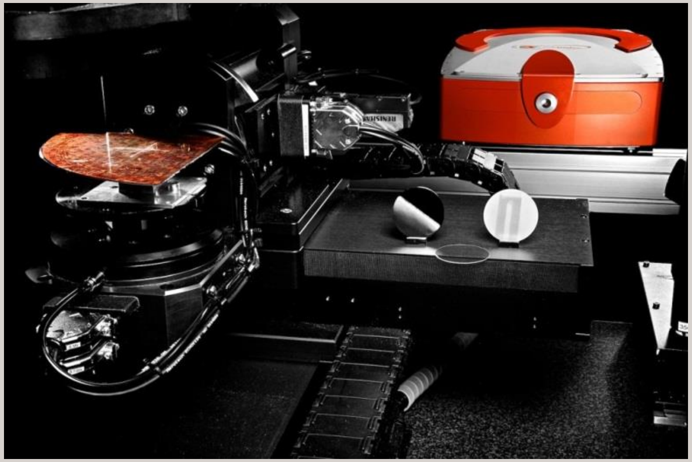
EMC and vibration testing

ISO 9001
BUREAU VERITAS
Certification

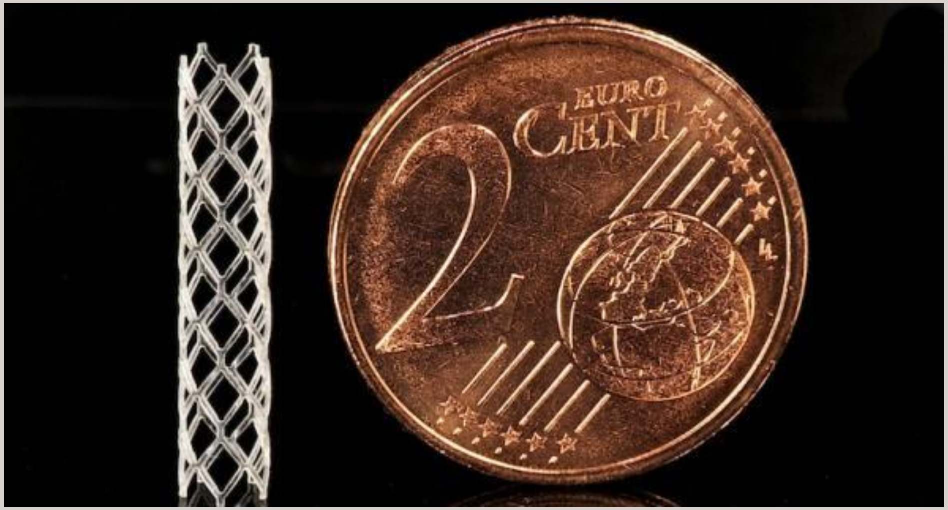
Ultrafast lasers, today



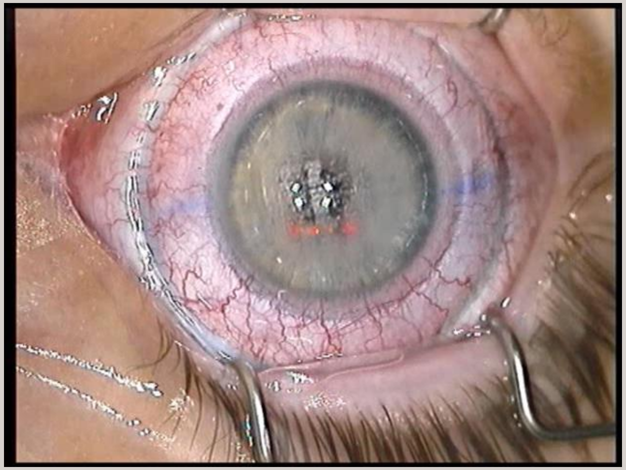
Photovoltaics



Semi-conductor



Medical device manufacturing



Opthalmology

Outline

- *Industrial ultrafast lasers*
- **Future roadmap**
- Ultrafast lasers and high energy physics
    - Accelerators
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Roadmap

Mehr Licht !

Applications

- Ophtalmology
  - FemtoLasik
  - Cataract surgery
  - Corneal Graft
  - Presbyopia
- Bio-imaging
  - Multiphoton microscopy
  - Cars Imaging
  - SHG-THG imaging
  - Intracellular ablation
  - Cell transfection
- R&D
  - Time resolved spectroscopy
  - THz spectroscopy and imaging
  - Frequency combs
  - High energy physics
- Instrumentation
  - femtoLIBS
  - Analytical chemistry
  - Atom Probe Tomography
- Material Processing
  - Medical device manufacturing
    - Stents
    - Catheters
    - Cochlear implants
    - Intra-ocular implants
- Semi-conductor, PV, display
    - Dicing, scribing, etching
    - Selective ablation
    - Pixel repair
    - Precision drilling
- Automotive
  - Drilling, cutting, engraving,
  - Texturing, tribology
  - Texturing, hydrophobic
- Glass processing
  - Cutting, texturing
  - Micro-welding
  - Waveguide generation
  - Microfluidic channels
  - Internal engraving
- Tool and mold manufacturing
  - Embossing
  - Texturing
- Emerging applications
  - 3D nanofabrication
  - Tissue engineering
  - X-ray imaging
  - Laser protontherapy




Amplitude SYSTEMES

Applications

- Ophtalmology
  - FemtoLasik
  - Cataract surgery
  - Corneal Graft
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- Bio-imaging
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  - Cars Imaging
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Applications

Medical

- Ophtalmology
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  - Frequency combs
  - High energy physics

R&D

- Instrumentation
  - femtoLIBS
  - Analytical chemistry
  - Atom Probe Tomography
- Emerging applications
  - 3D nanofabrication
  - Tissue engineering
  - X-ray imaging
  - Laser protontherapy

Industry

- Medical device manufacturing
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  - Intra-ocular implants
- Semi-conductor, PV, display
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  - Texturing



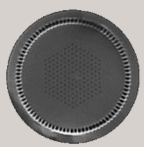

Applications

- High energy physics

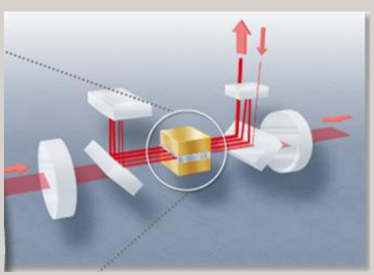
Towards high average power

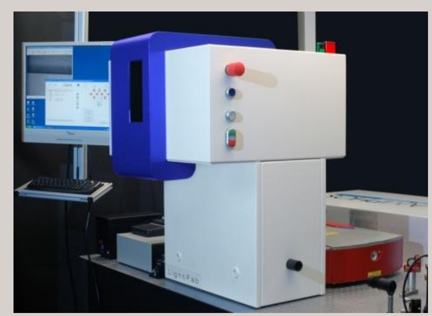
- Thin disk

- Photonics crystal fiber



- Slab





Ytterbium

December 15, 2010 / Vol. 35, No. 24 / OPTICS LETTERS

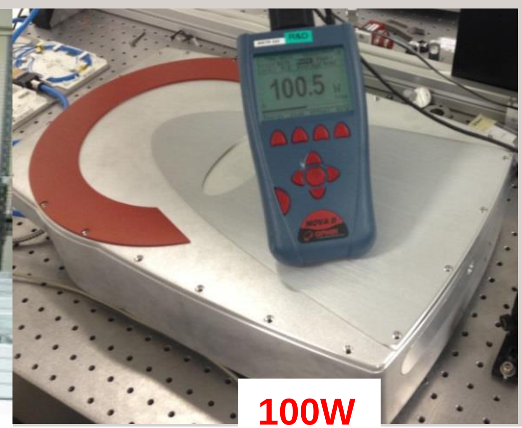
Compact diode-pumped 1.1 kW Yb:YAG Innoslab femtosecond amplifier

P. Russbueldt,[1,*] T. Mans,[2] J. Weitenberg,[2] H. D. Hof
[1]*Fraunhofer Institute for Laser Technology, Steinbachstrass*
[2]*Chair for Laser Technology RWTH Aachen, Steinbachstras*
**Corresponding author: peter.russbueldt@il*

OPTICS LETTERS / Vol. 35, No. 2 / January 15, 2010

Femtosecond fiber CPA system emitting 830 W average output power

Tino Eidam,[1,*] Stefan Hanf,[1] Enrico Seise,[1] Thomas V. Andersen,[2] Thomas Gabler,[3] Christian Wirth,[4] Thomas Schreiber,[4] Jens Limpert,[1] and Andreas Tünnermann[1,4]
[1]*Friedrich-Schiller-University Jena, Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany*
[2]*NKT Photonics, Blokken 84, DK-3460 Birkeroed, Denmark*
[3]*JT Optical Engine, Prüssingstr. 41, 07745 Jena, Germany*
[4]*Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 7, 07745 Jena, Germany*
**Corresponding author: eidam@iap.uni-jena.de*



100W

8:00 am: **Fiber amplifier with <300-fs pulses, ~~55 W~~ average power, and >50 µJ pulse energy**, Clemens Hoenninger, Franck Morin, Yoann Zaouter, Eric P. Mottay, Amplitude Systèmes (France) . . . . [8611-21]

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- *Industrial ultrafast lasers*
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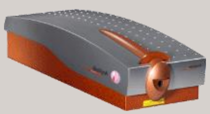
  - **Accelerators**
  - ELI
  - ICANN

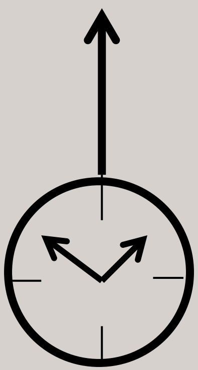
Particule accelerators

- Photocathode
- Laser heater
- Laser wire
- Pump probe experiments
  - Tim resolved X-ray spectroscopy
  - Time-resolved photo-emission spectroscopy
  - Time-resolved X-ray diffraction
- FEL seeding (low order harmonics or HHG)
- Inverse compton scattering
- Slicing
- Direct particule (e-, proton, ion…) acceleration

Laser architecture

Synchrolocked Oscillator



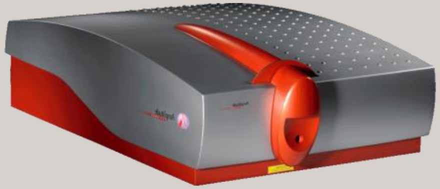


Optional Timing

Residual jitter < 10 fs rms

+

Choose your amplifier

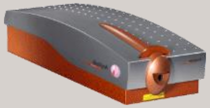


Amplitude SYSTEMES

Laser architecture

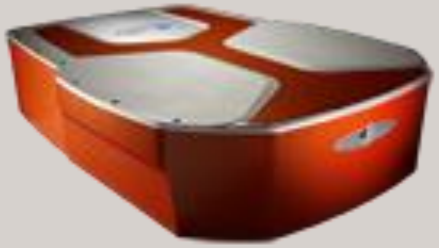
Synchrolocked Oscillator

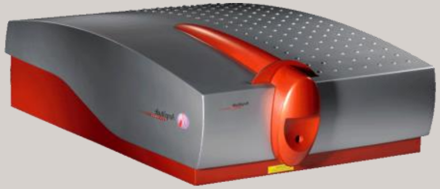
Choose your amplifier



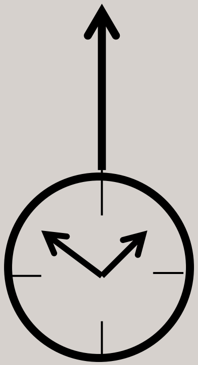
+

High repetition rate (up to 10’s MHz)





High energy (up to multi-mJ)

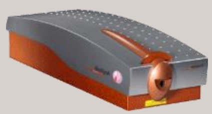


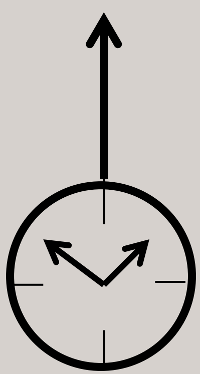
Optional Timing

Residual jitter < 10 fs rms

Laser architecture

Synchrolocked Oscillator





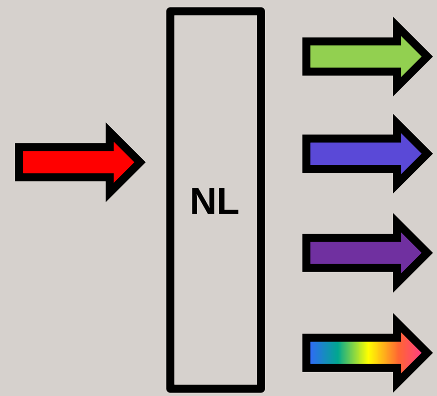
Optional Timing

+

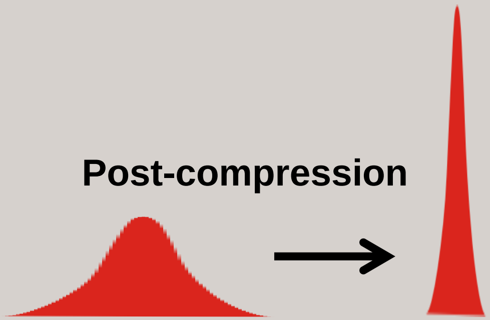
Choose your amplifier

+

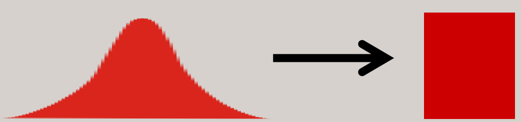
Choose your Options



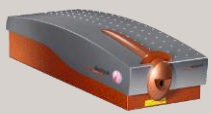
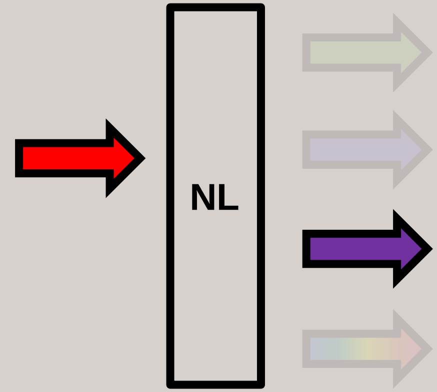
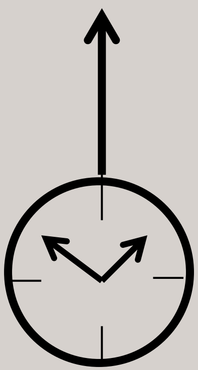
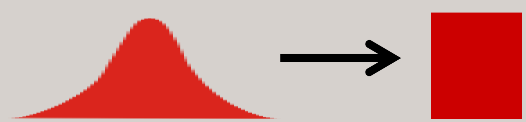
Post-compression



Temporal and spatial Shaping



Photocathode (ex: Cu)

Synchrolocked Oscillator		*Choose your amplifier*		*Choose your Options*
	+		+	
				
Optional Timing				**Temporal and spatial Shaping**
				

Amplitude SYSTEMES

Photocathode

Synchrolocked Oscillator

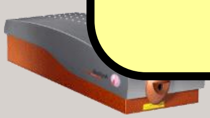
Choose your amplifier

Choose your Options

PAUL SCHERRER INSTITUT

PSI

CANDLE



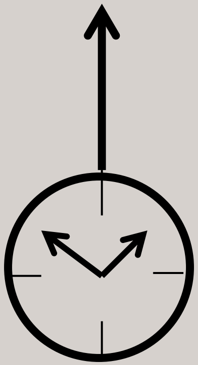
NL

SHG

THG

FHG

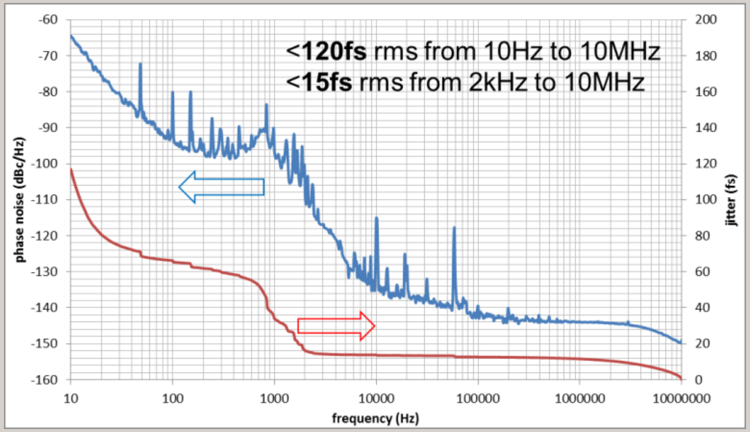
OPA



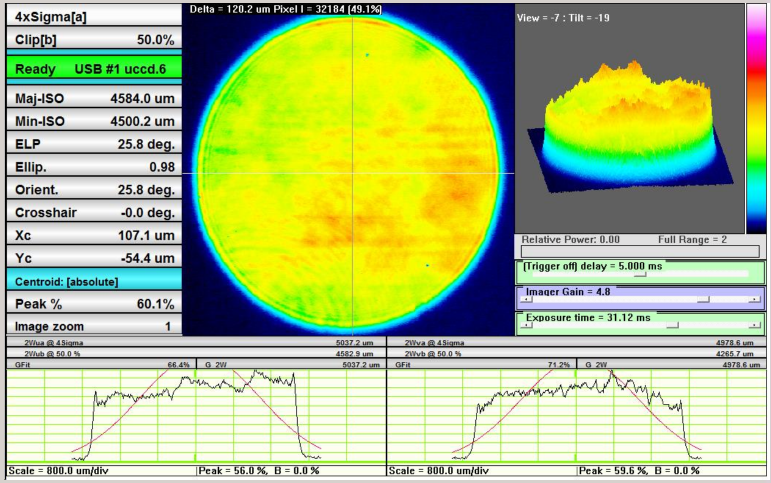
Optional Timing

ial Shaping

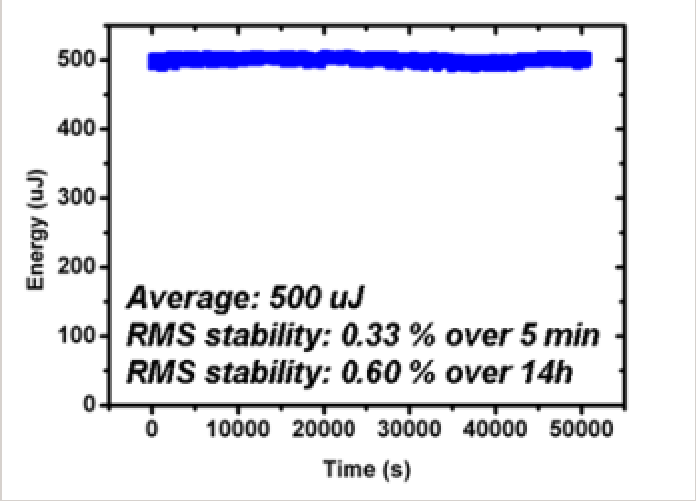
Performances



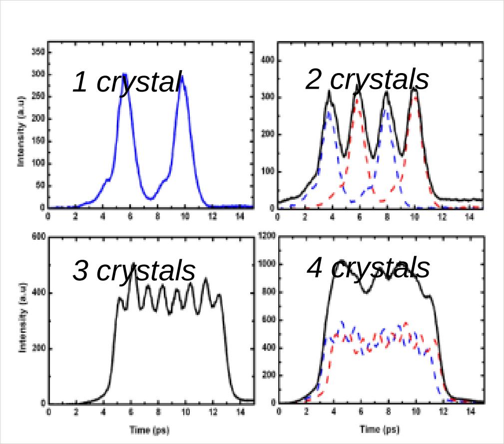
Timing jitter



UV beam shaping



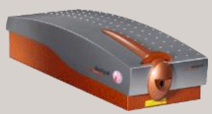
UV stability

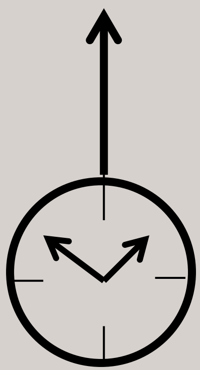


UV temporal shaping

X-ray pump probe

Synchrolocked Oscillator





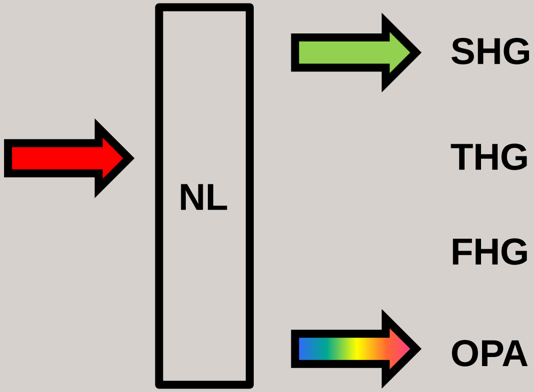
Optional Timing

+

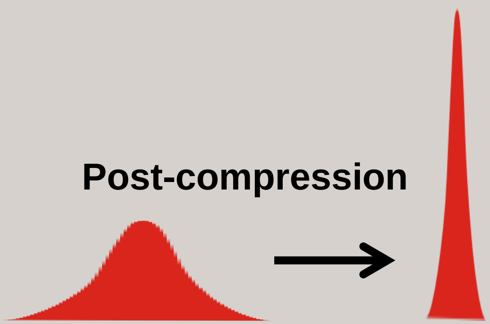
Choose your amplifier

+

Choose your Options

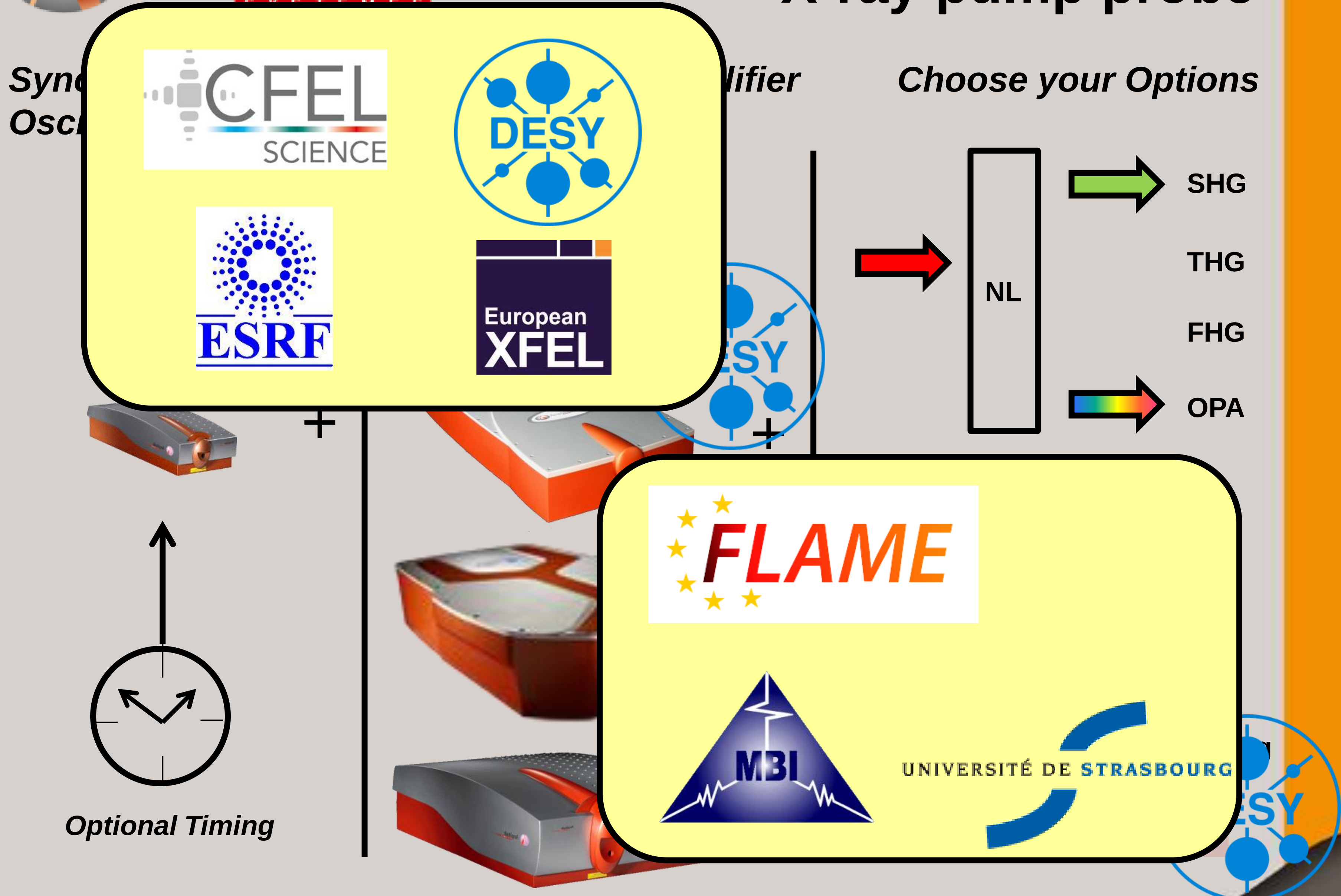


Post-compression



Temporal and spatial Shaping

X-ray pump probe



XFEL - ESRF

First MHz laser installation at XFEL-ESRF Synchrotron

And also…

BESSY

DESY

European XFEL

ESRF

John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

MBI

CFEL SCIENCE

SLAC

INFN Istituto Nazionale di Fisica Nucleare

CANDLE

PAUL SCHERRER INSTITUT PSI

Lawrence Livermore National Laboratory

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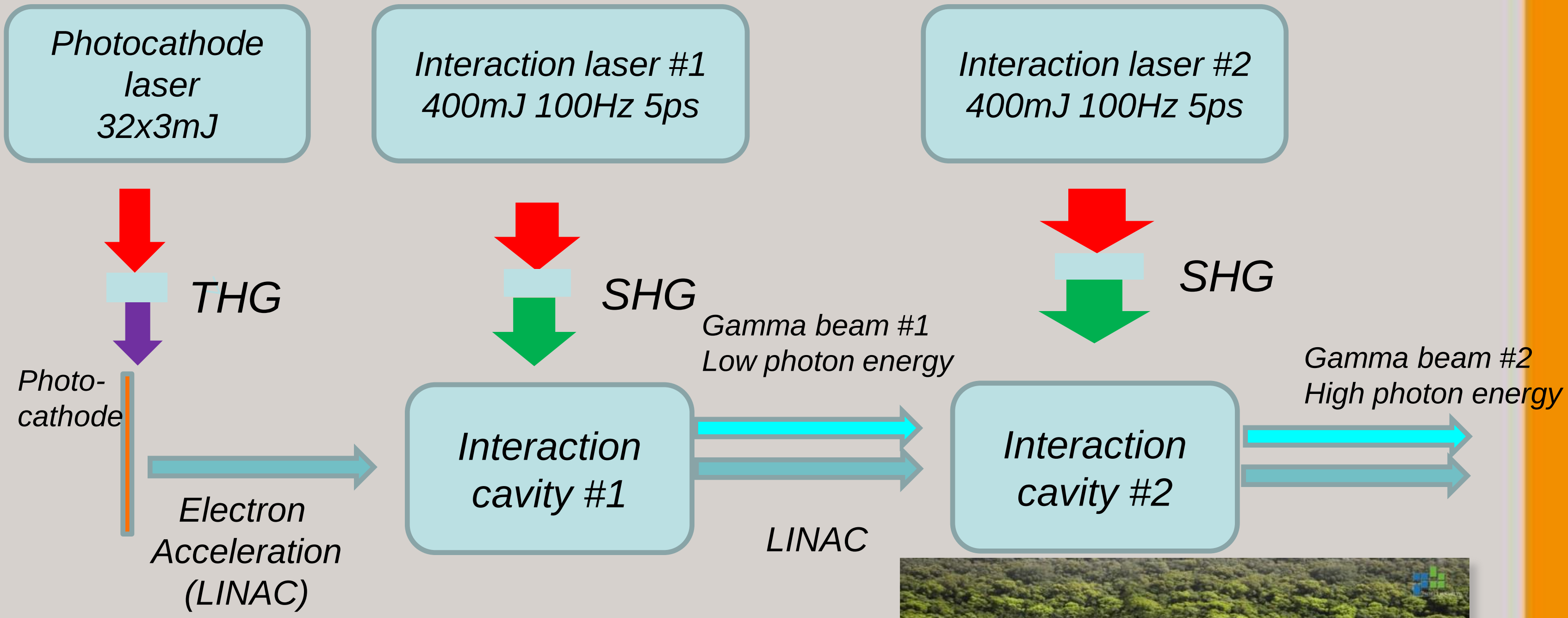
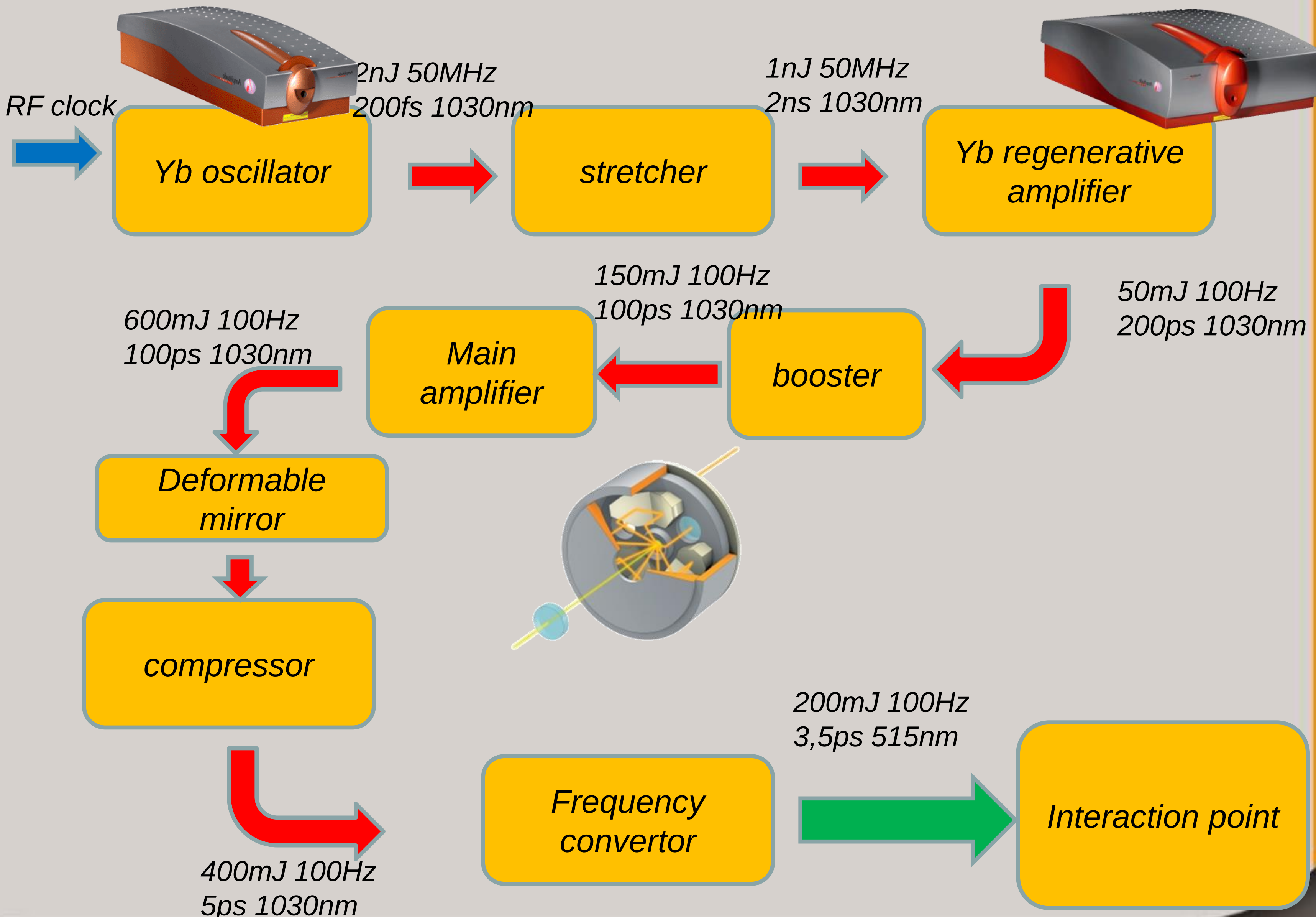
Laser for Gamma source

ELI-NP High Intensity Gamma Source

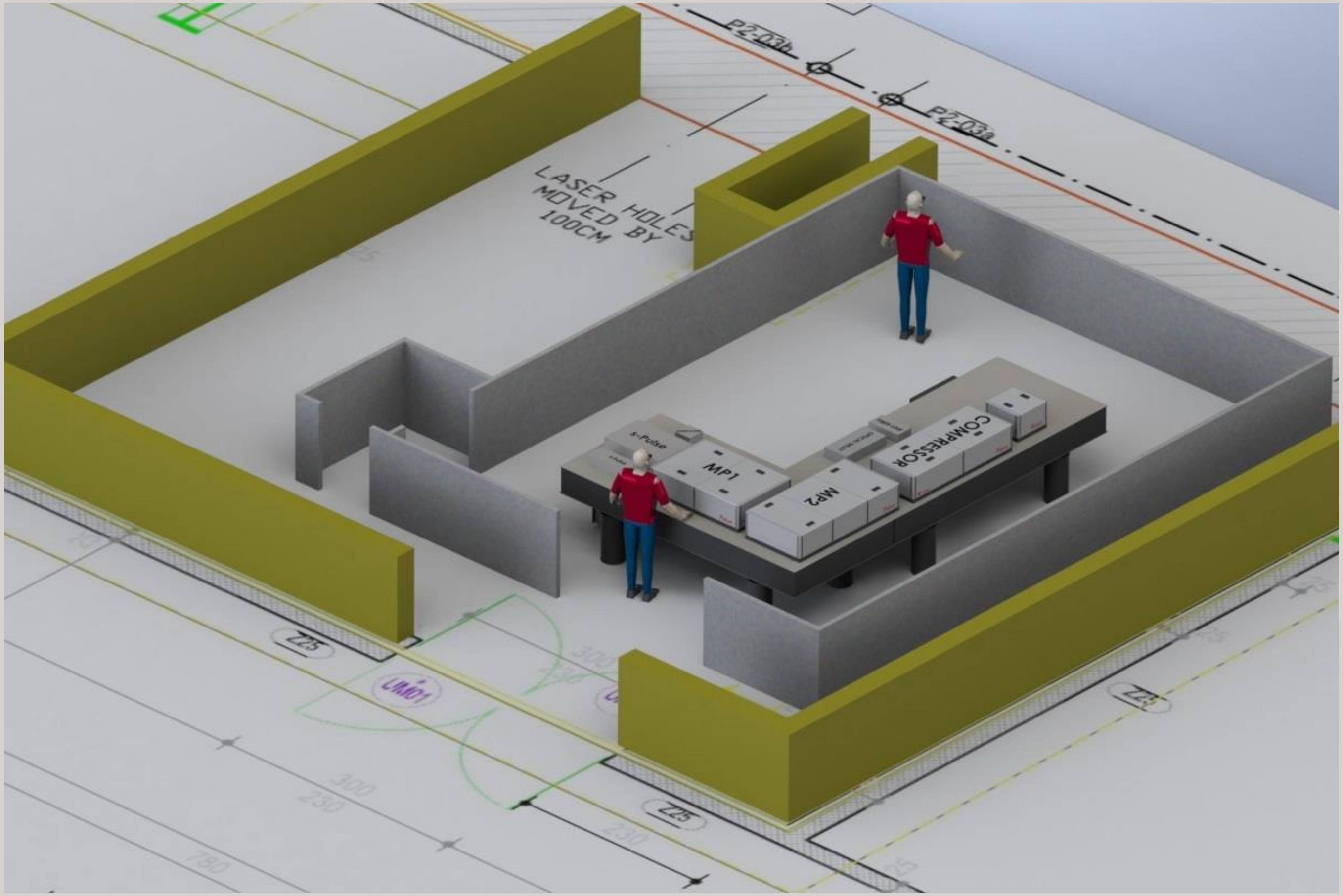
To be commissioned in Magurele (Romania) in 2018



Interaction laser architecture



Interaction laser layout



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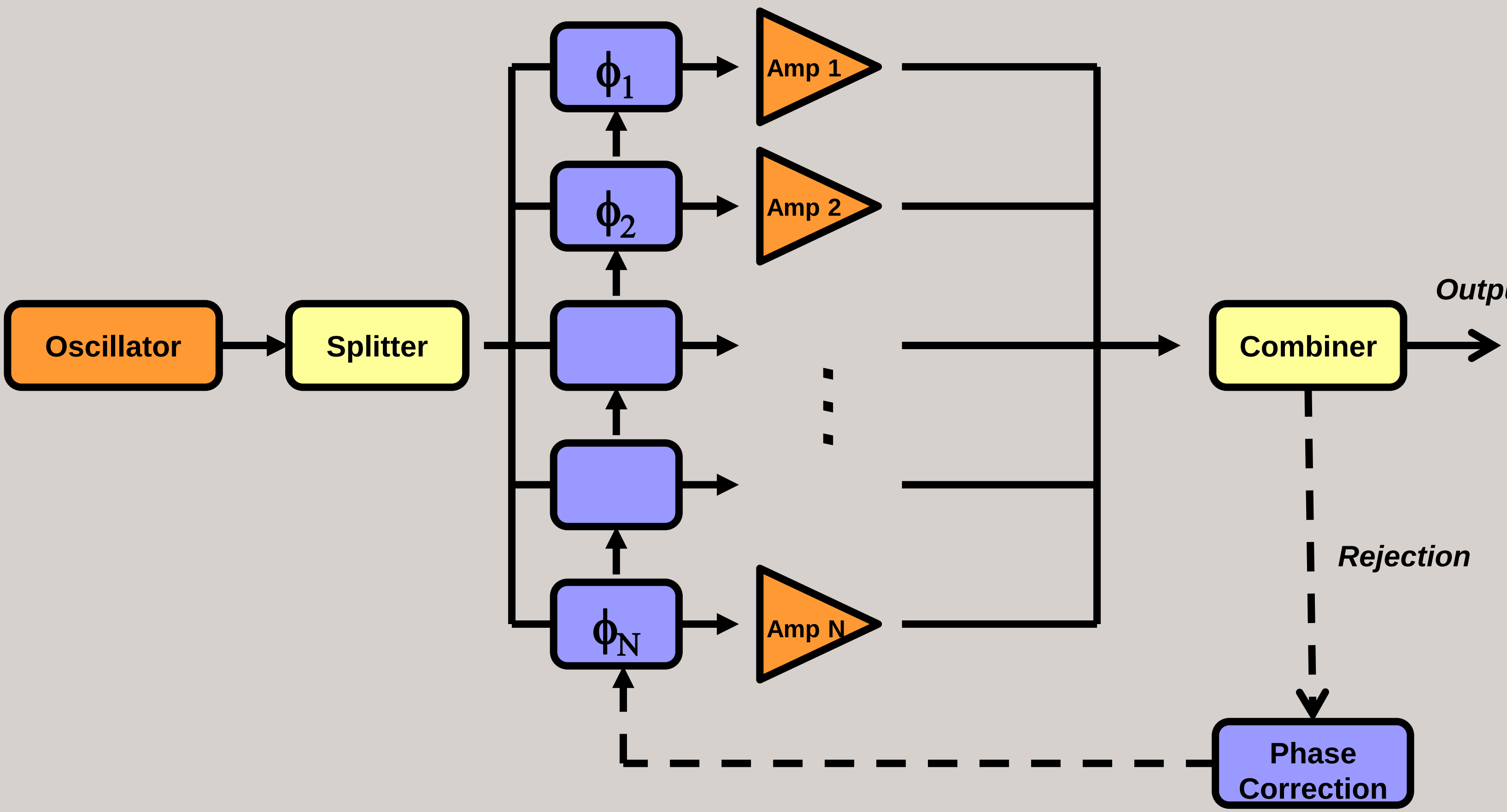
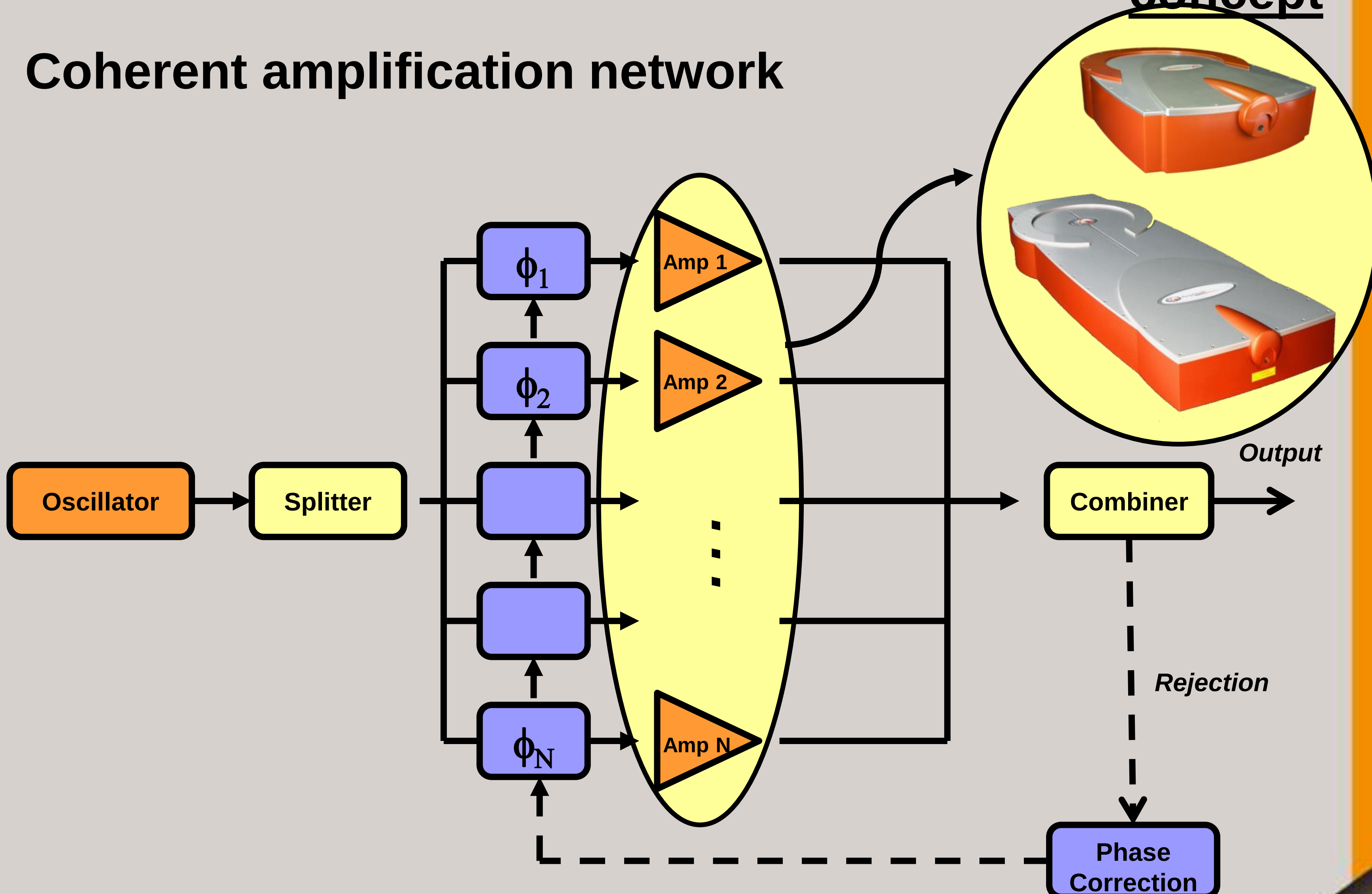
Coherent Amplification Network



Coherent combining as next generation particule accelerator concept

Coherent amplification network



Coherent Combining

Joint DEFI R&D laboratory with Institut d'Optique

INSTITUT d'OPTIQUE GRADUATE SCHOOL

> 10 publications since 2011 in high energy coherent combining

March 1, 2011 / Vol. 36, No. 5 / OPTICS LETTERS

Coherent beam combining of two femtosecond fiber chirped-pulse amplifiers

L. Dania…
D.…

OPTICS LETTERS / Vol. 37, No. 9 / May 1, 2012

Passive coherent combination of two ultrafast rod type fiber chirped pulse amplifiers

0 OPTICS LETTERS / Vol. 38, No. 24 / December 15, 2013

Two-channel pulse synthesis to overcome gain narrowing in femtosecond fiber amplifiers

Fl…

OPTICS LETTERS / Vol. 38, No. 2 / January 15, 2013

Femtosecond fiber chirped- and divided-pulse amplification system

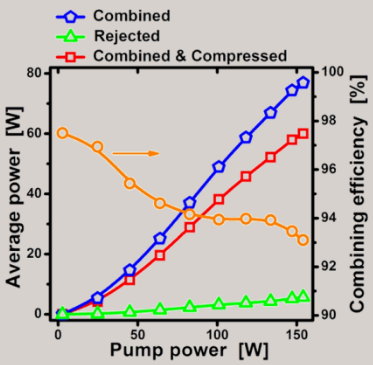
Yoann Zaouter,[1,*] Florent Guichard,[1,2] Louis Daniault,[2] Marc Hanna,[2] Franck Morin,[1] Clemens Hönninger,[1] Eric Mottay,[1] Frédéric Druon,[2] and Patrick Georges[2]

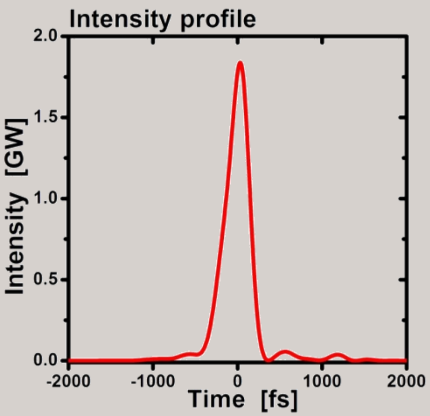
Amplitude SYSTEMES

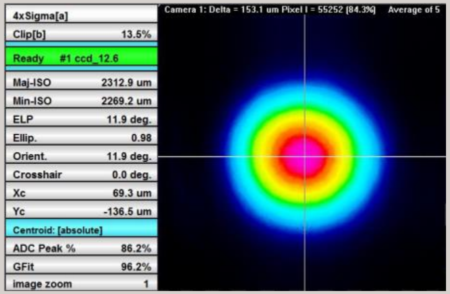
High average power DPA

100 kHz, 0.6 mJ, 60W, 300 fs

Rep. Rate [kHz]	100 kHz
Max pump power (W)	155
Combined average power (W)	77 W
Combining efficiency [%]	> 93
Compressed & combined average power [W]	60 W
Max energy [µJ]	600 µJ
Autocorrelation (fs)	450
Spectral width (nm)	4.5
Duration [fs]	310
M^2	< 1.2







ICANN

- Coherent combining of multiple fiber amplifiers
- Lower channel counts
  - *Higher efficiency*
  - *Reduced complexity*
  - *Lower overall cost / exploitation cost*
  - *Higher reliability*
- The technology already exists and is at an industrial stage today!
- Amplitude Systemes in the context of CAN
  - *Co-authored ~50 % of scientific publications*
  - *Is already offering coherent combining solutions*
  - *Natural partner for large scale project*
  - *Amplitude Technologies : Leader in high intensity infrastructures*
  - *Amplitude Systemes : Largest manufacturer of high energy fiber amplifiers*

Conclusion

- Ultrafast lasers are today at the heart of many industrial processes.
- The scientific community stands to benefit from a decade of industrial ultrafast laser development.
- High average power, high repetition rate, tunability, short pulses
- Accelerators, ELI, ICANN
- Amplitude Group as an ideal partner for this next frontier

Thank you for your attention!