

ULTRAFAST LASERS FOR ACCELERATORS

Antoine Courjaud

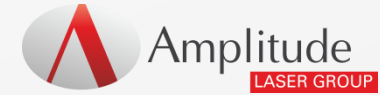
Global leader in ultrafast laser systems
nothing but ultrafast



Compact femtosecond lasers
Global production



High power femtosecond lasers
Global production



Asia sales and support



Continuum®

U.S. sales and support

San José, USA



Boston, USA
Evy, France
Munich, Germany
Bordeaux, France

RUSSIA

ASIA

Daejeon, South Korea
Shanghai, China

Taipei, Taiwan



Asia sales and support



GREENLAND

NORTH AMERICA

SOUTH AMERICA

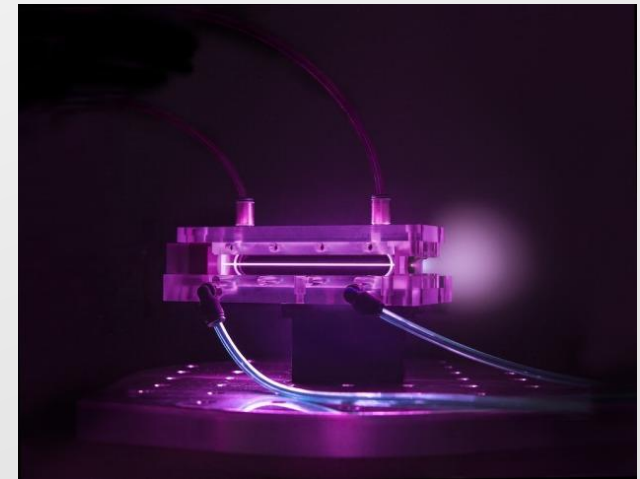
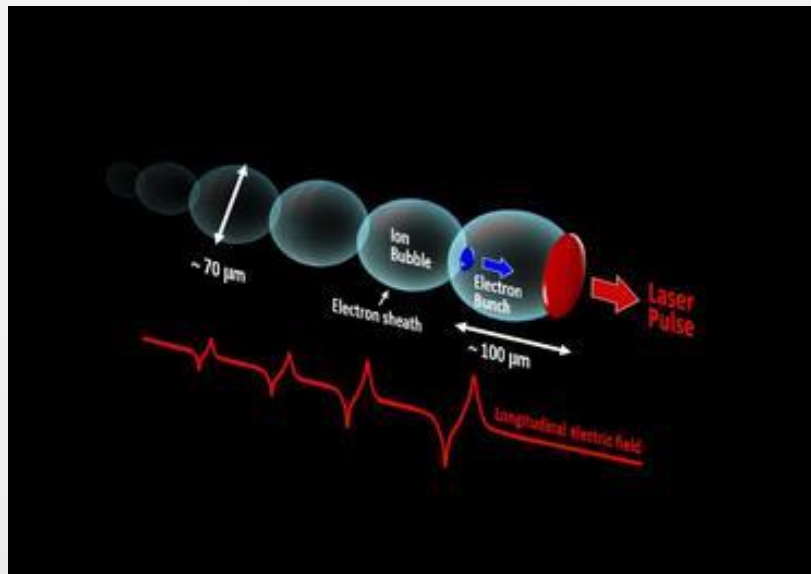
AFRICA

AUST

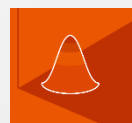
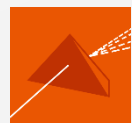
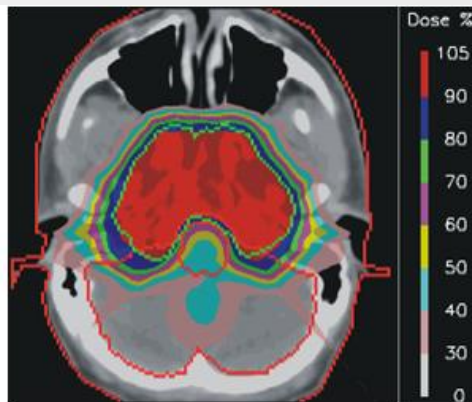
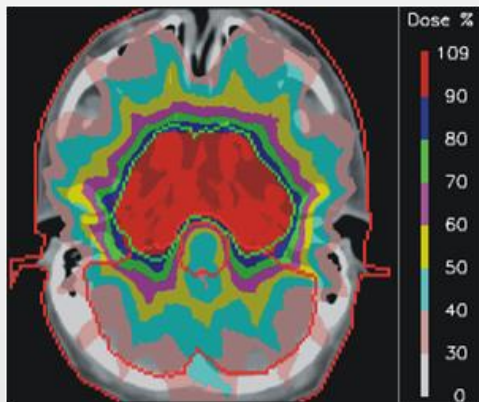
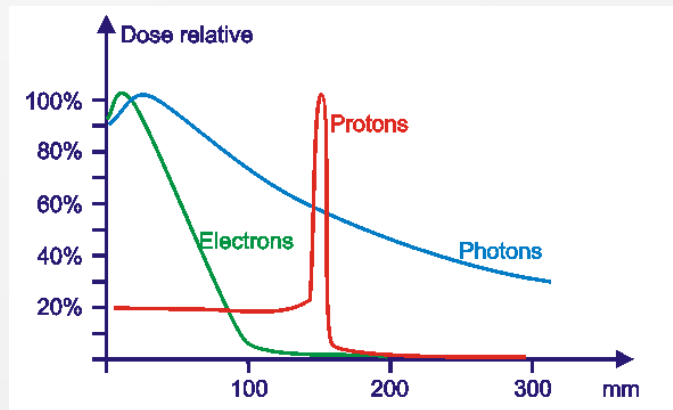
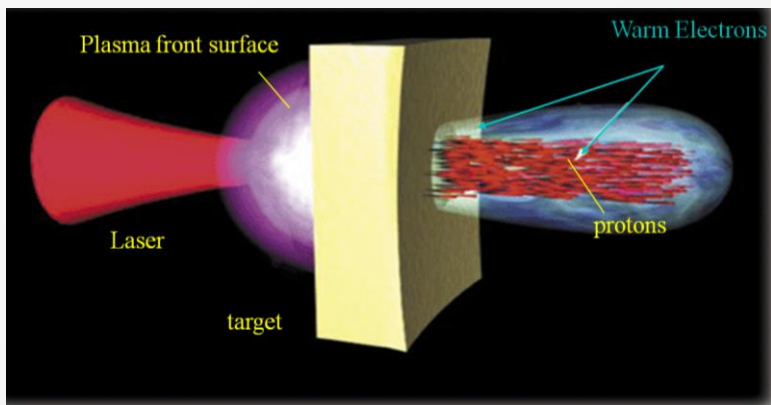


Laser Plasma Wakefield Acceleration

- Based on Ti:Sa technology
- Typically 2 to 25J @25fs @800nm (100TW-1PW)
- Allows compact electron acceleration (100GV/m)

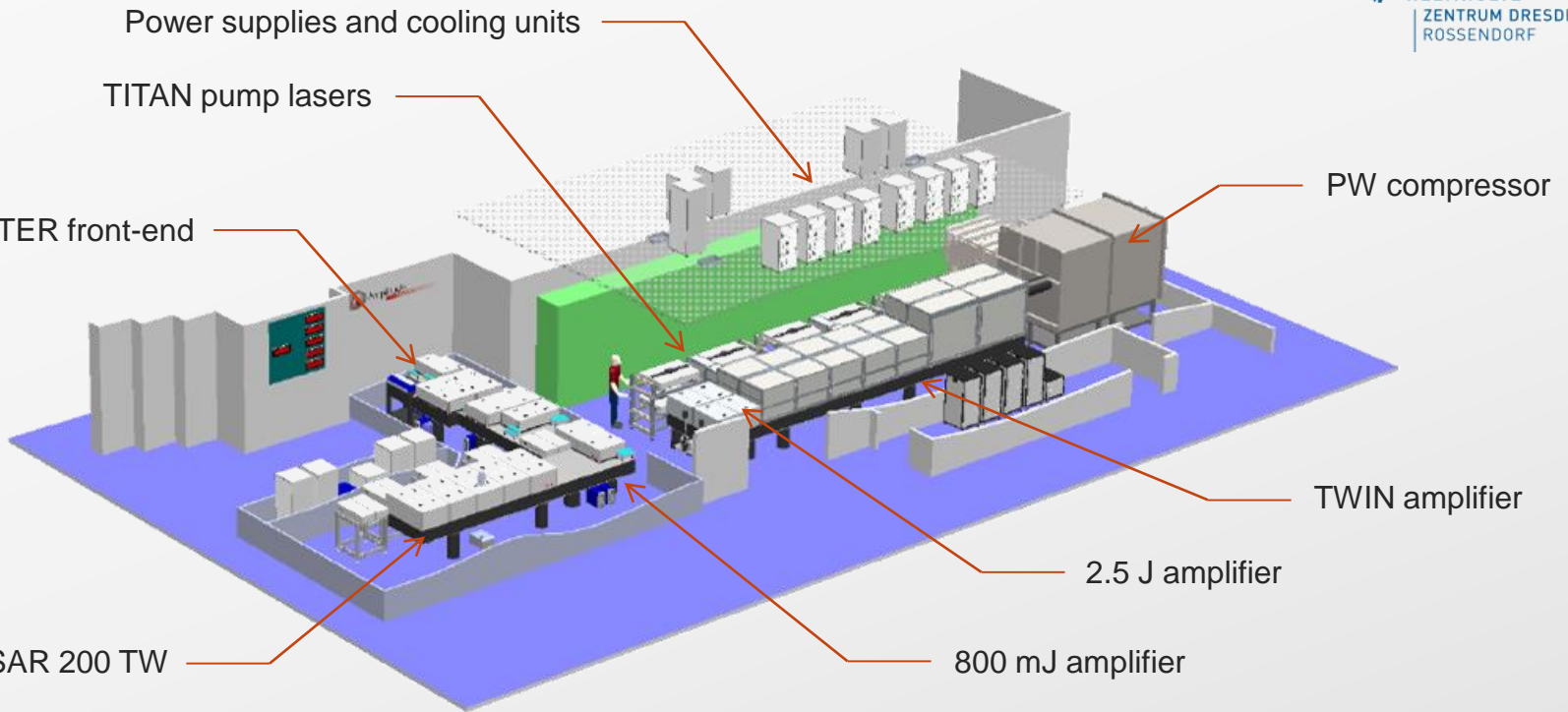
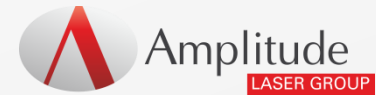


Laser-based Proton Acceleration



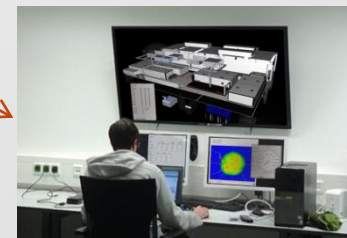
PULSAR PW laser system

25J 25fs 1-10Hz

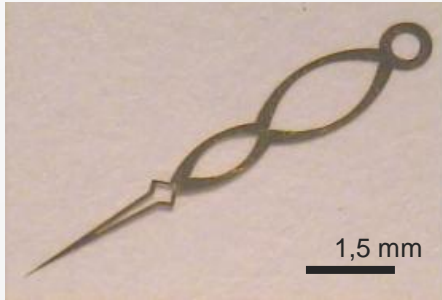


Metrology and diagnostics

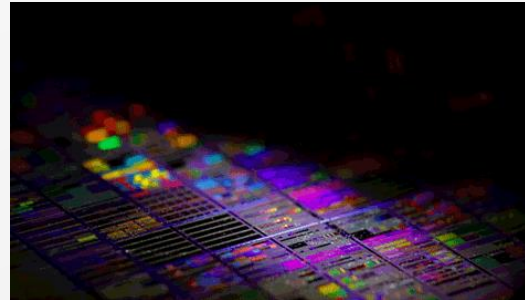
CONTROL / COMMAND



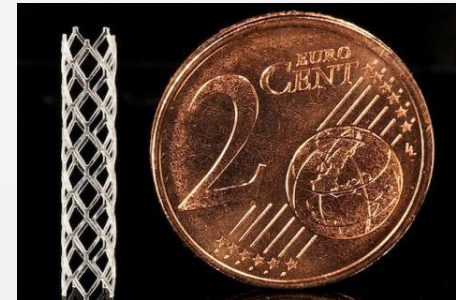
Industrial applications



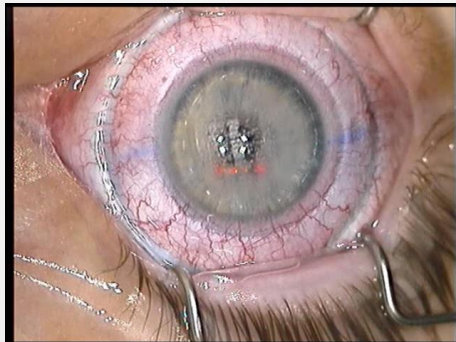
MICROMACHINING



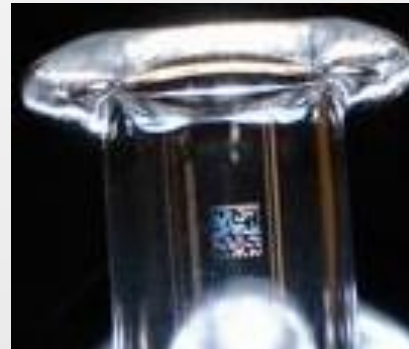
SEMI-CONDUCTOR



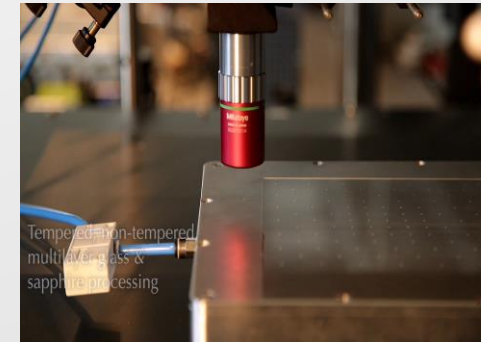
MEDICAL DEVICES
MANUFACTURING



OPHTHALMOLOGY



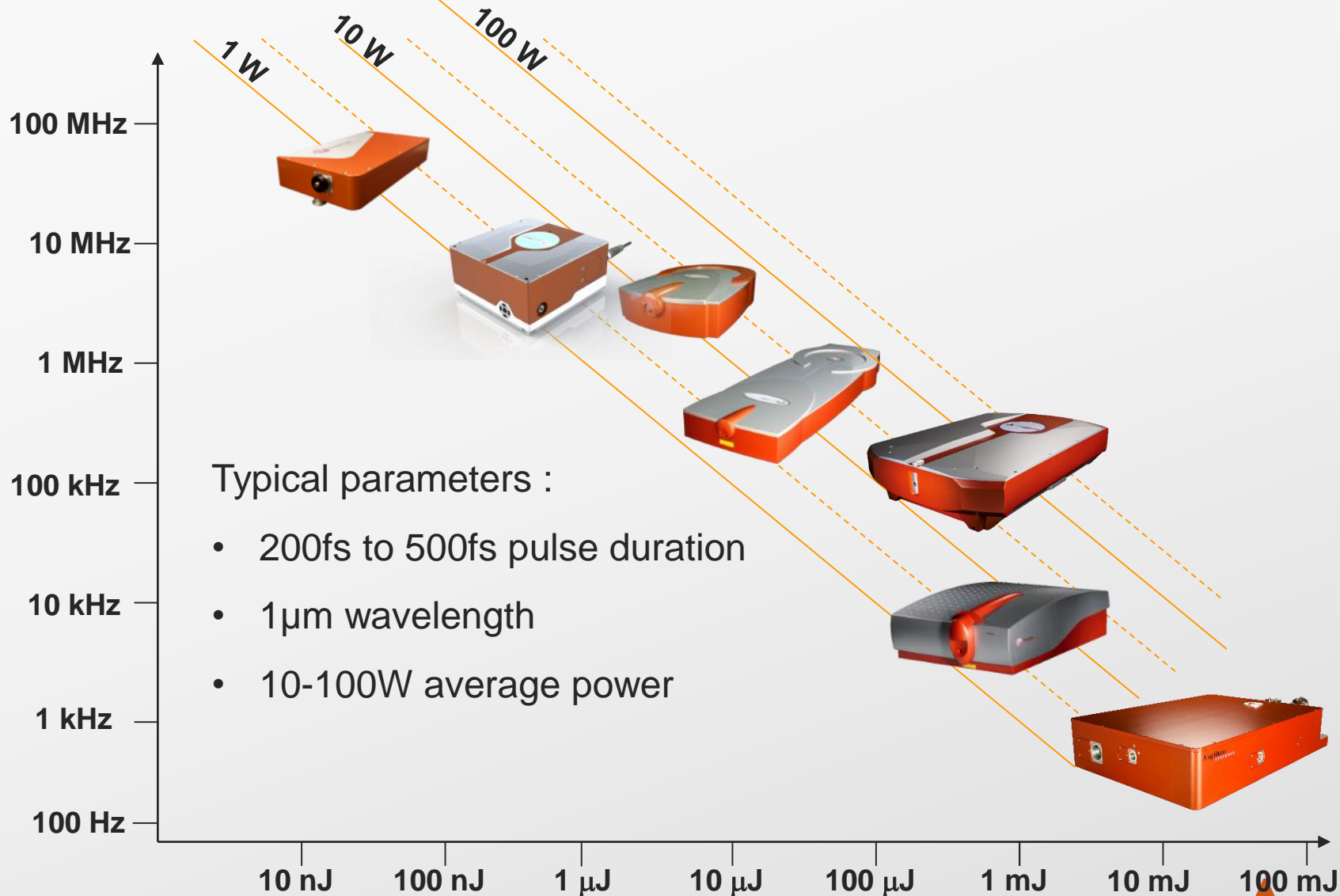
INTERNAL ENGRAVING



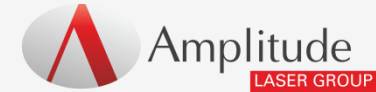
GLASS CUTTING



Diode-pumped product range



Driving reliability & innovation



- **2000 m²** of clean room production, from mechanical assembly to quality control
- **> 500 lasers / year**
- **ISO 9001** and **ISO 13485** certified



- **Picosecond and femtosecond lasers**
- High quality laser systems : **reliability, robustness, specification and compact footprint**

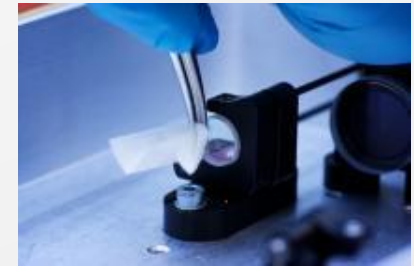


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3 levels of quality control for continuous improvement

1. In line manufacturing quality control

- Analytics and Lean manufacturing
- MRP production process
- Over 700 individual control points



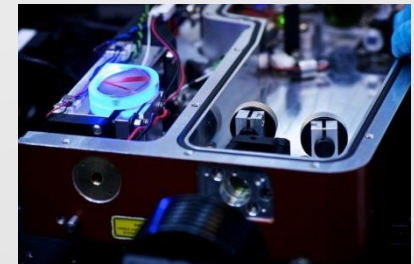
2. Before shipping product quality control

- Quality Test Report over several days
- Extensive Shock/Vibration/Temperature control



3. On the field quality feedback

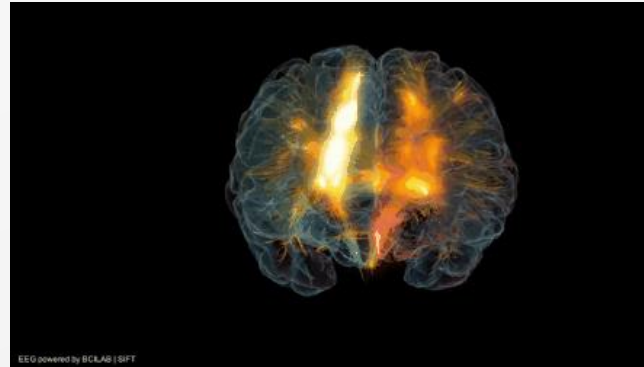
- 15000 reports database
- Feedback to production and product development teams



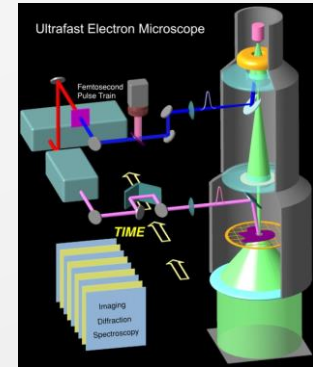
Scientific applications



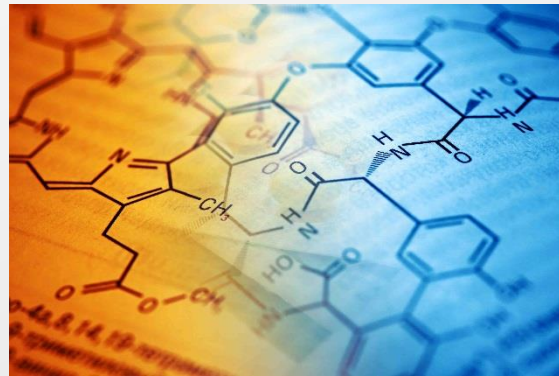
MICROSCOPY



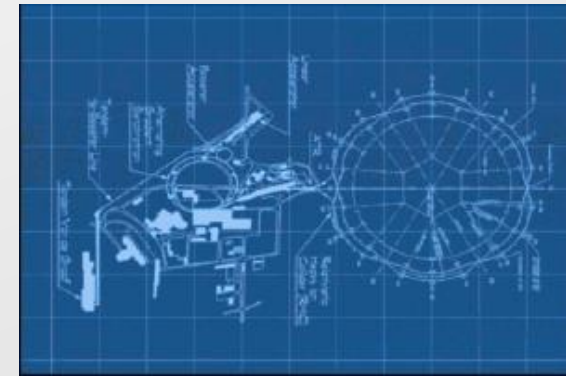
NEUROSCIENCE



UEM



ULTRAFAST
SPECTROSCOPY / DYNAMICS



ACCELERATOR

Custom solutions for science

Pulse-on-demand:

- External pulse picker
- Burst mode

Pulse duration:

- User adjustable
- Sub-100 fs option

Harmonic modules:

- SHG / THG / FHG

Synchronisation ext. RF:

- Synchro-lock

Wavelength tunability:

- OPA

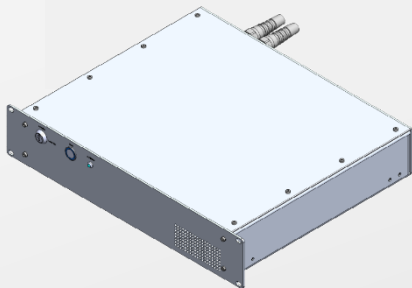
Synchronization technology

Oscillator locked to RF or optical reference

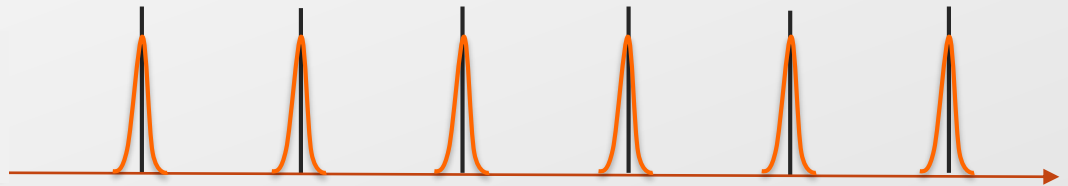
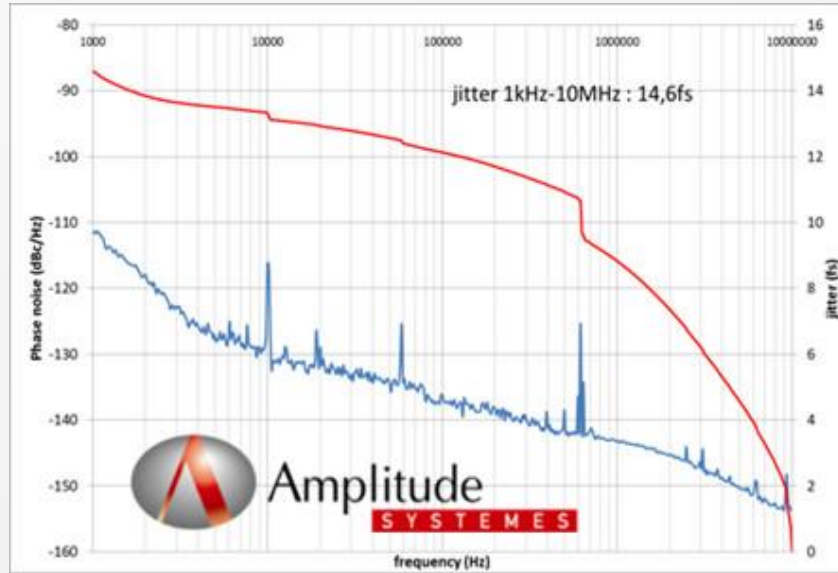
Optional Timing



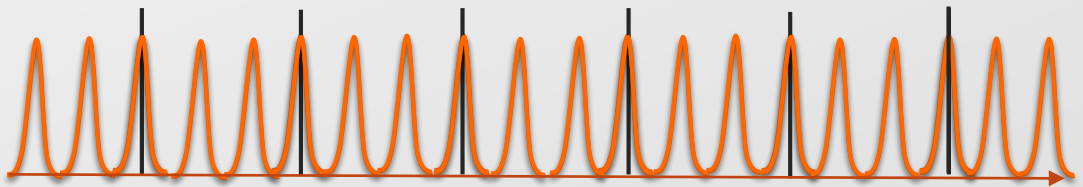
+



Jitter < 250 fs rms [100 Hz – 10 MHz]



Frequency shift



Phase shift

nothing but ultrafast

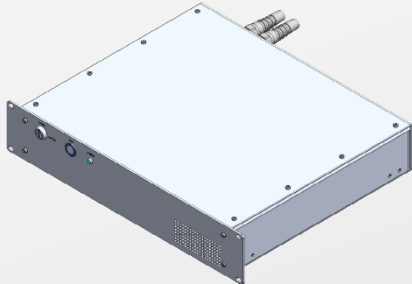
Custom solutions for science

Synchrolocked Oscillator

Optional Timing



+



Choose your amplifier



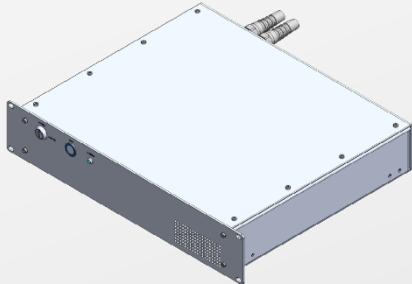
Custom solutions for science

Synchrolocked Oscillator

Optional Timing



+

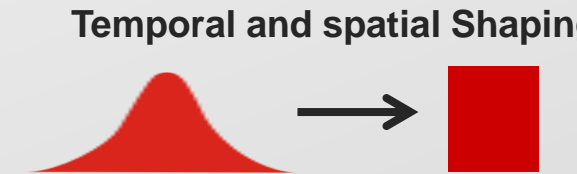
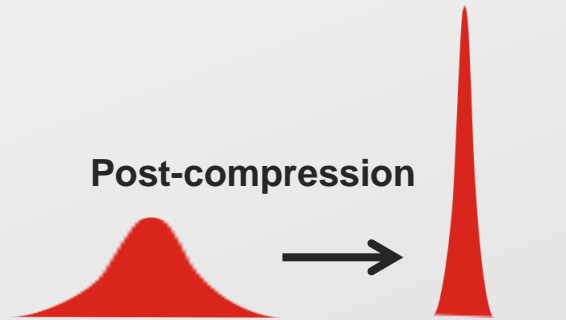
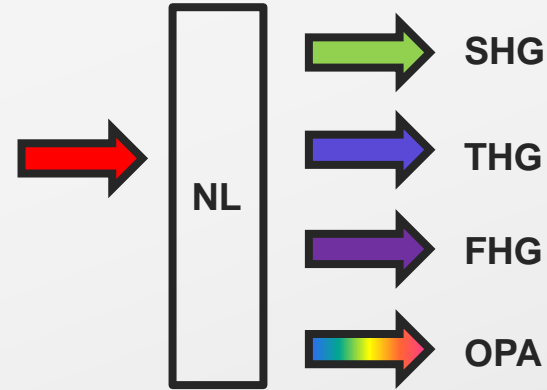


Choose your amplifier



+

Choose your Options

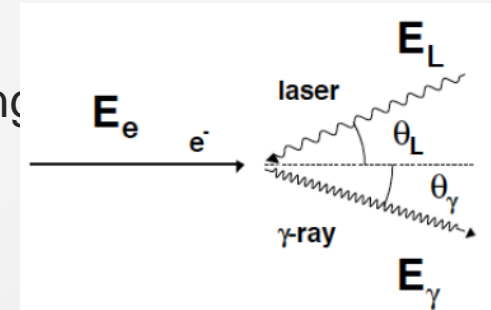


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Lasers for X / γ ICS sources

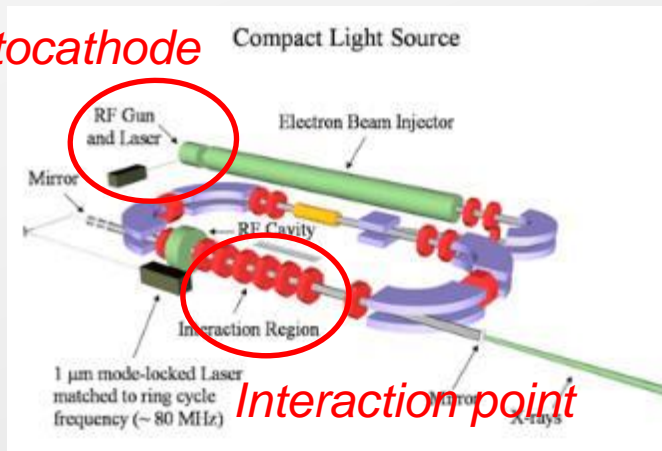
- Compton interaction between photons and relativistic electrons
- Architecture based on
 - 1 electron accelerator (LINAC / storage ring)
 - 1 photocathode laser
 - 1 interaction laser



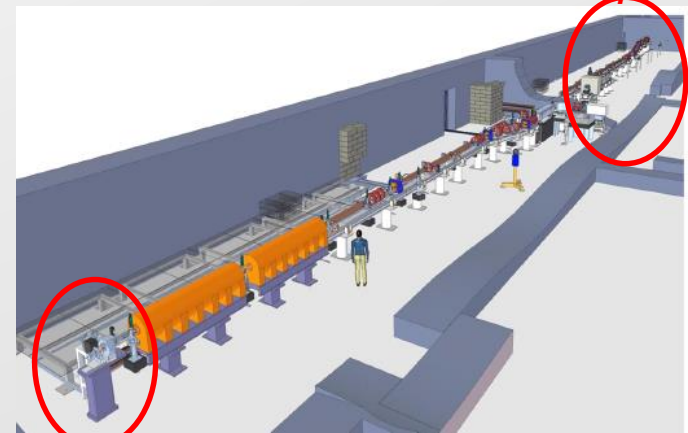
X-ray source ~2-5m long

Gamma source ~100m long

photocathode



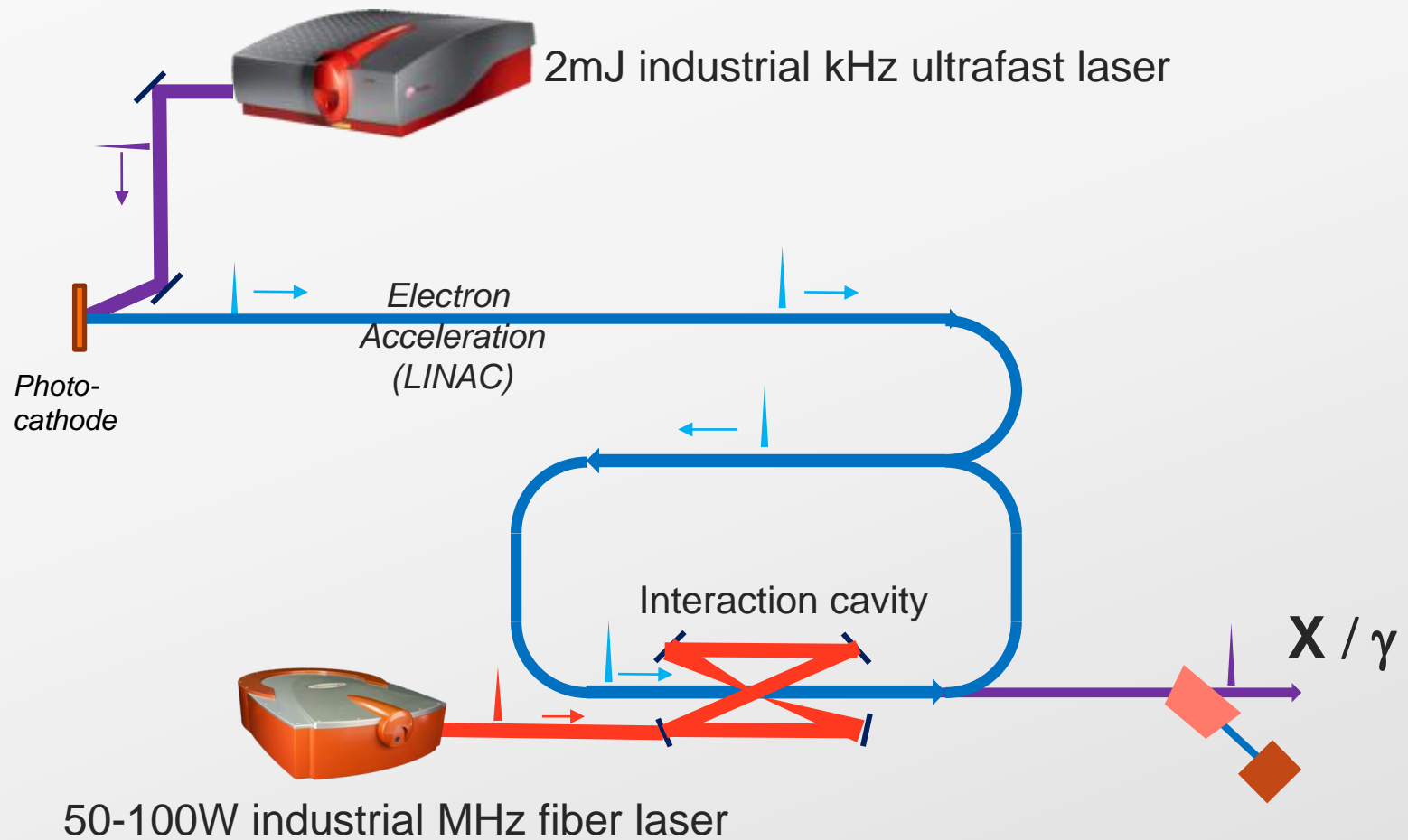
Interaction point



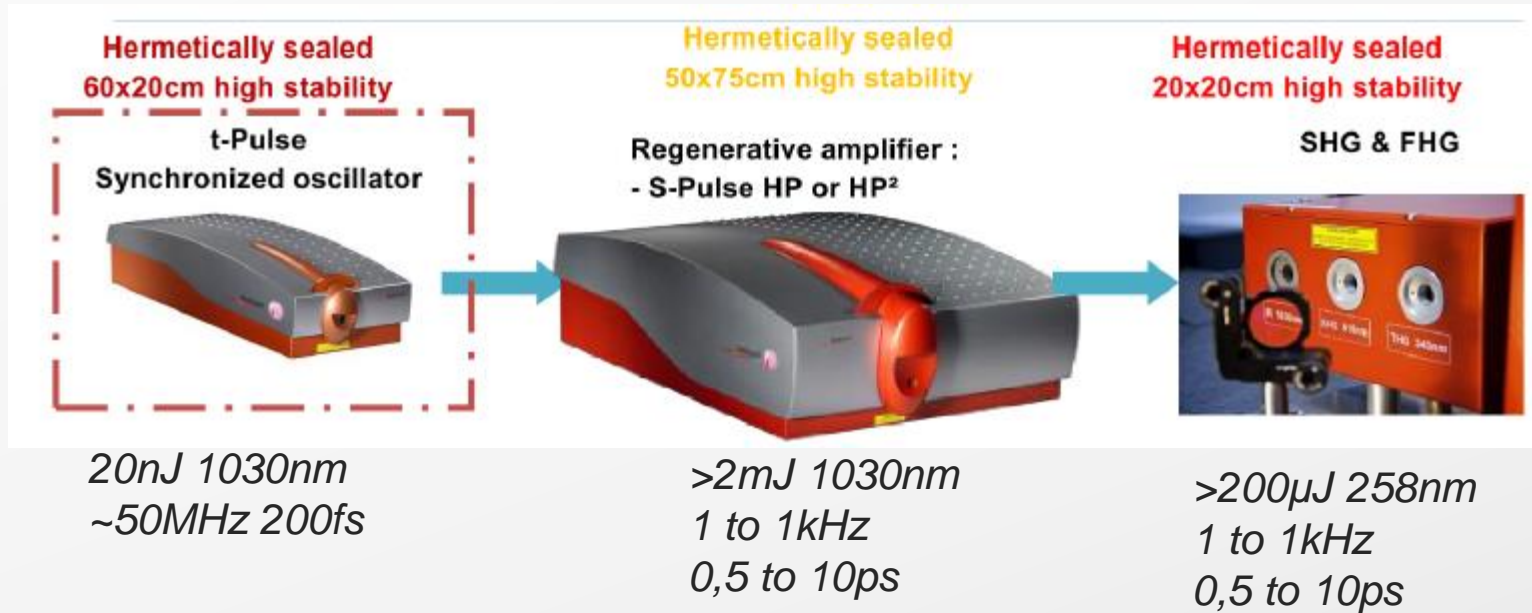
photocathode

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Storage ring ICS architecture



Typical layout for a diode-pumped photocathode laser



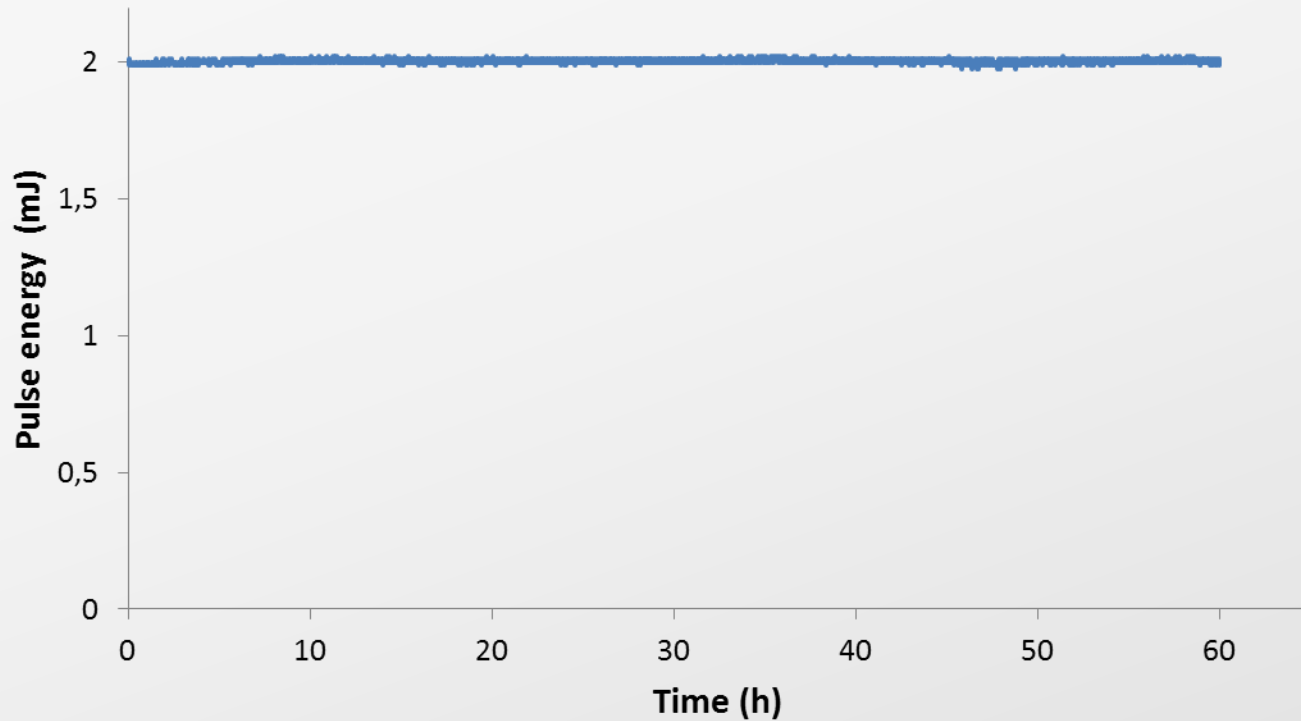
PAUL SCHERRER INSTITUT



Swissfel IR Long-term stability

Repetition rate : 100Hz

IR pulse energy stability (averaged) : 0,34% rms over 60h

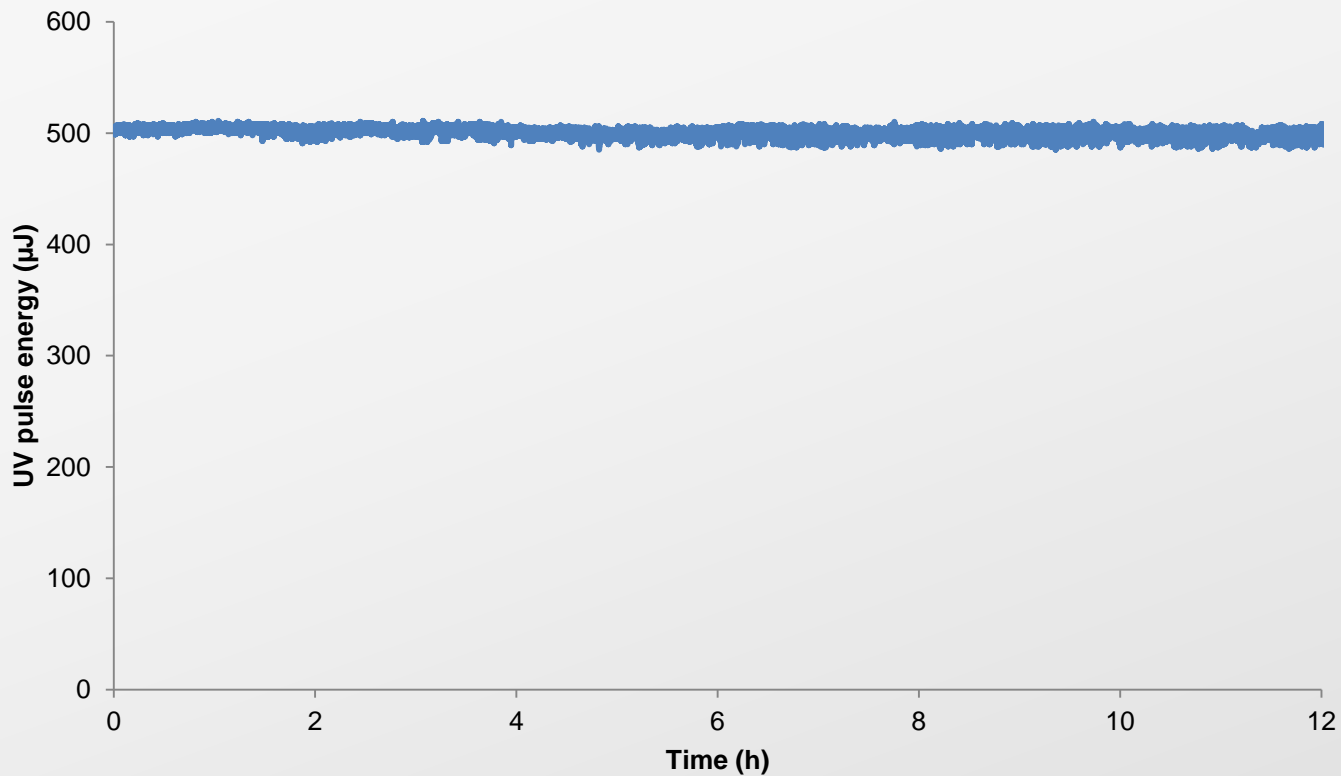


Swissfel DUV long-term stability

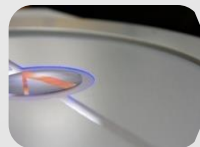
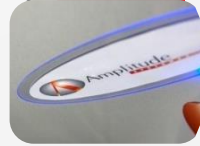
Pulse energy after FHG conversion : 500 μ J @500fs

Pulse-pulse stability :

- 0,36% rms on 1hour
- 0,78% rms on 12 hours

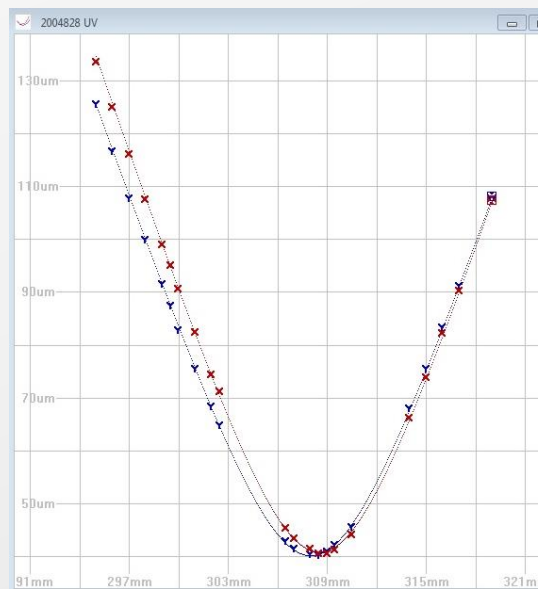
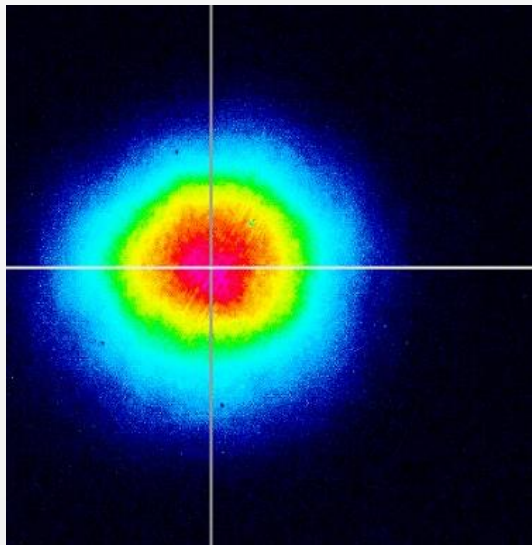


Amplitude



DUV beam quality

$$M^2 = 1,15 \times 1,08$$

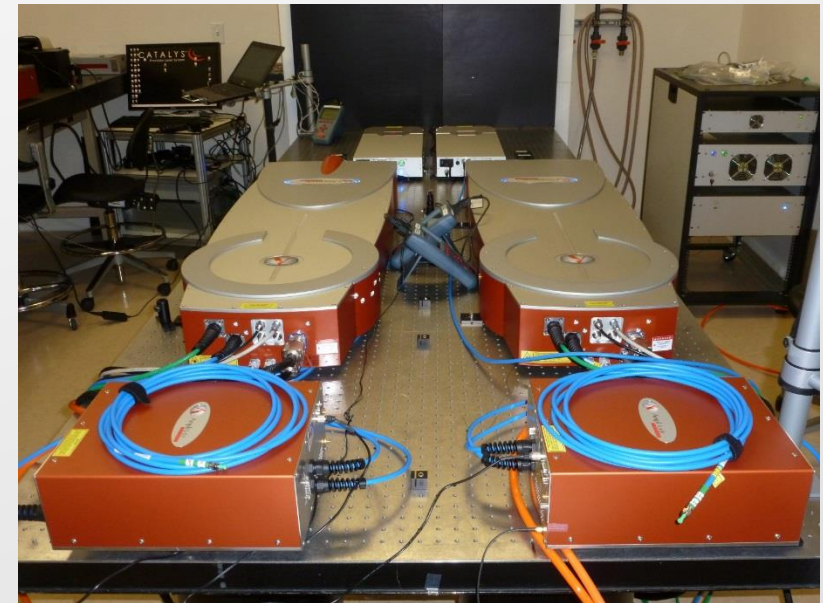


LCLS-II - Photocathode and Laser heater

- 2 x Tangerine HP2
 - Synchrolock oscillator
 - Phase shaping capability

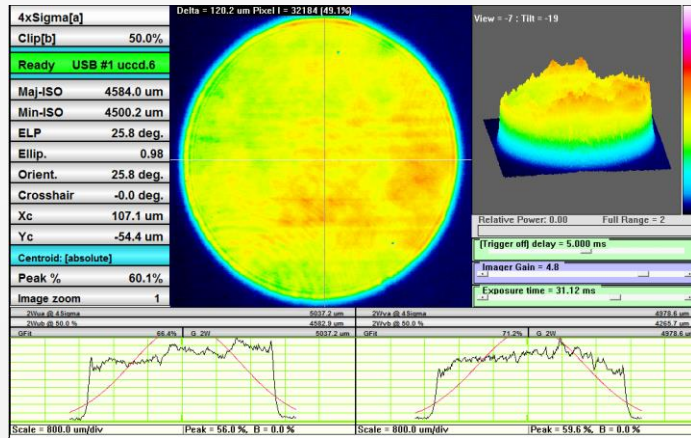


	Tangerine HP2
Pulse duration	< 350 fs
Average power	50 W
Pulse energy	50 μ J
Repetition rate	1 MHz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	120 x 40 cm
Cooling	Water

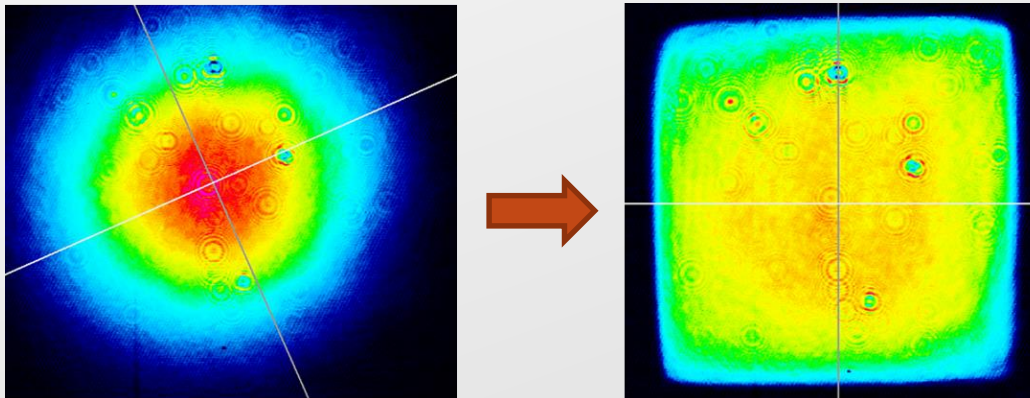


Beam shaping

Spatial shaping in UV

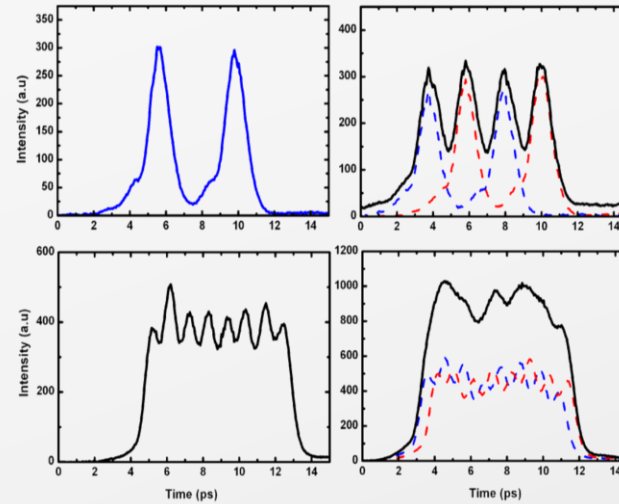
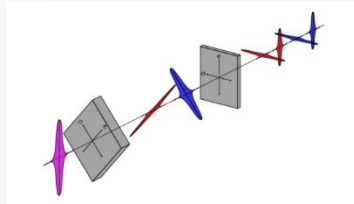


Spatial shaping in IR with phaseplate

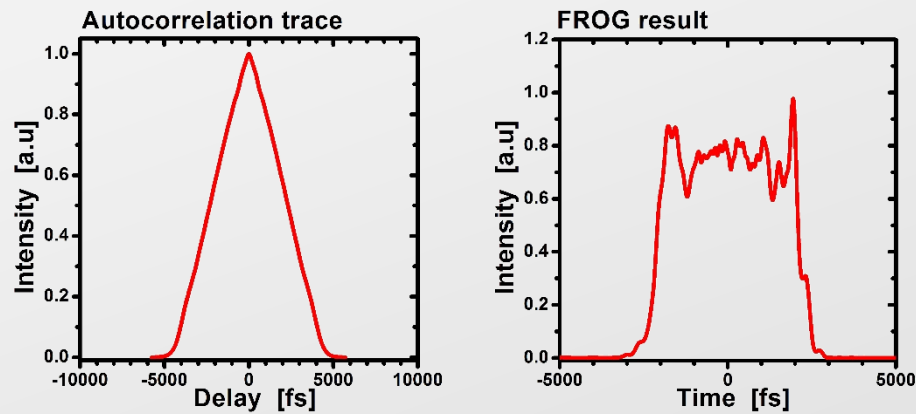


Temporal shaping

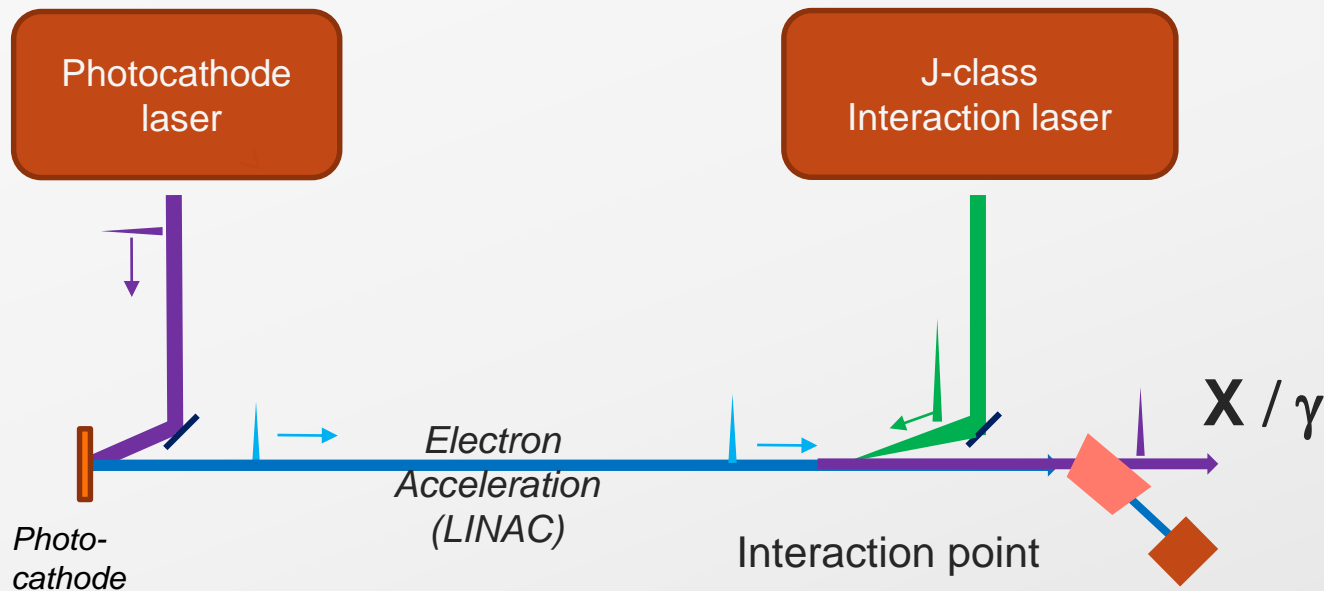
Temporal shaping with birefringent crystals



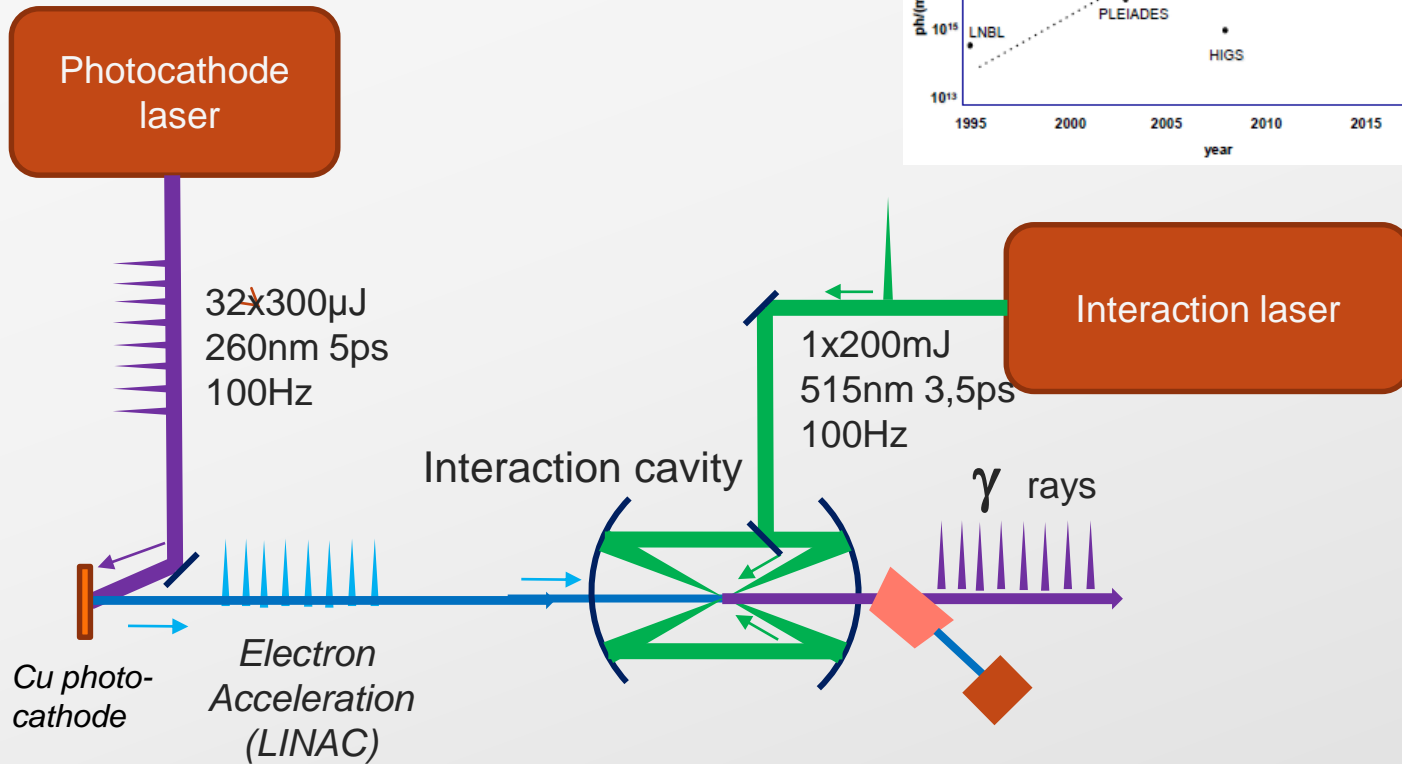
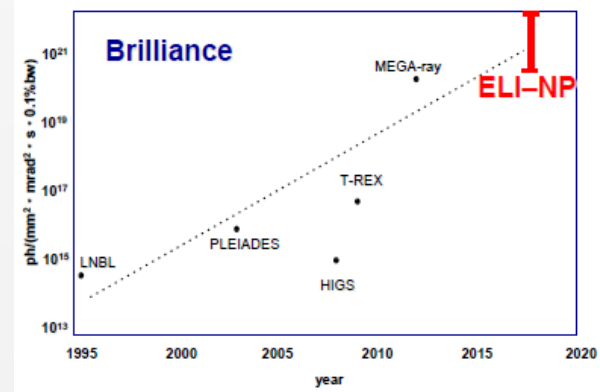
Directly from the amplifier



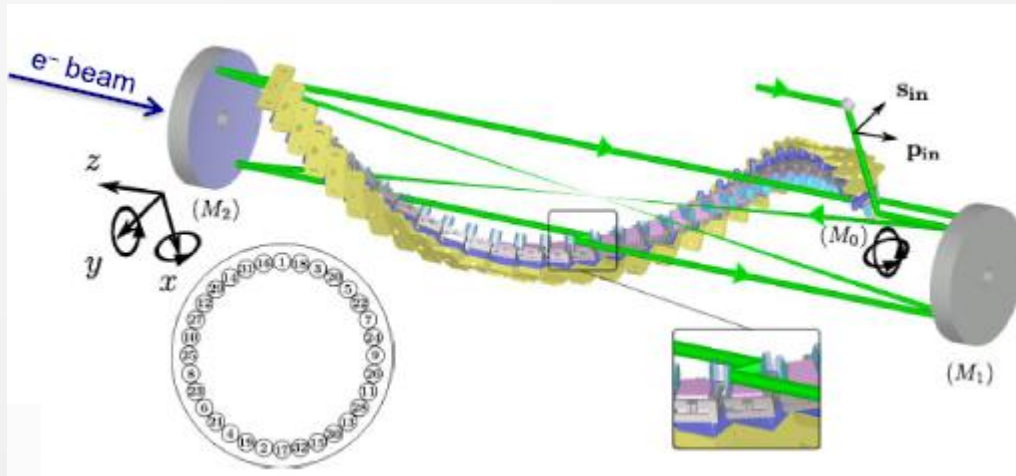
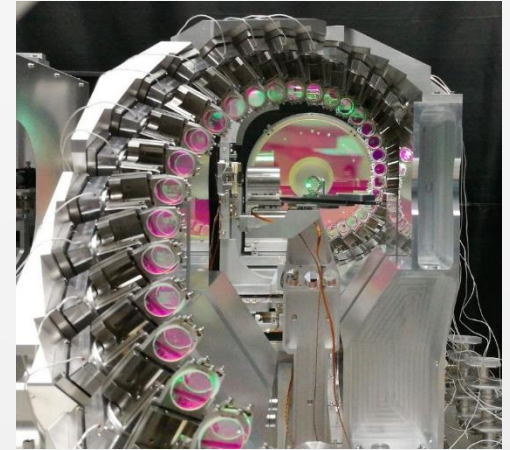
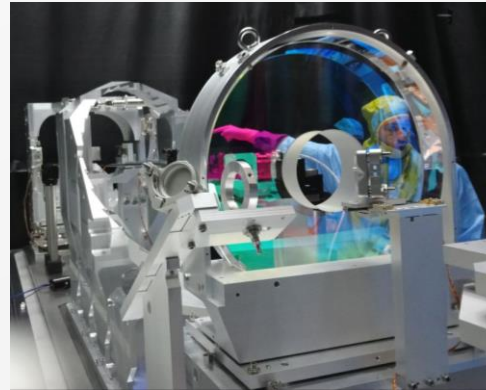
Linear ICS configuration



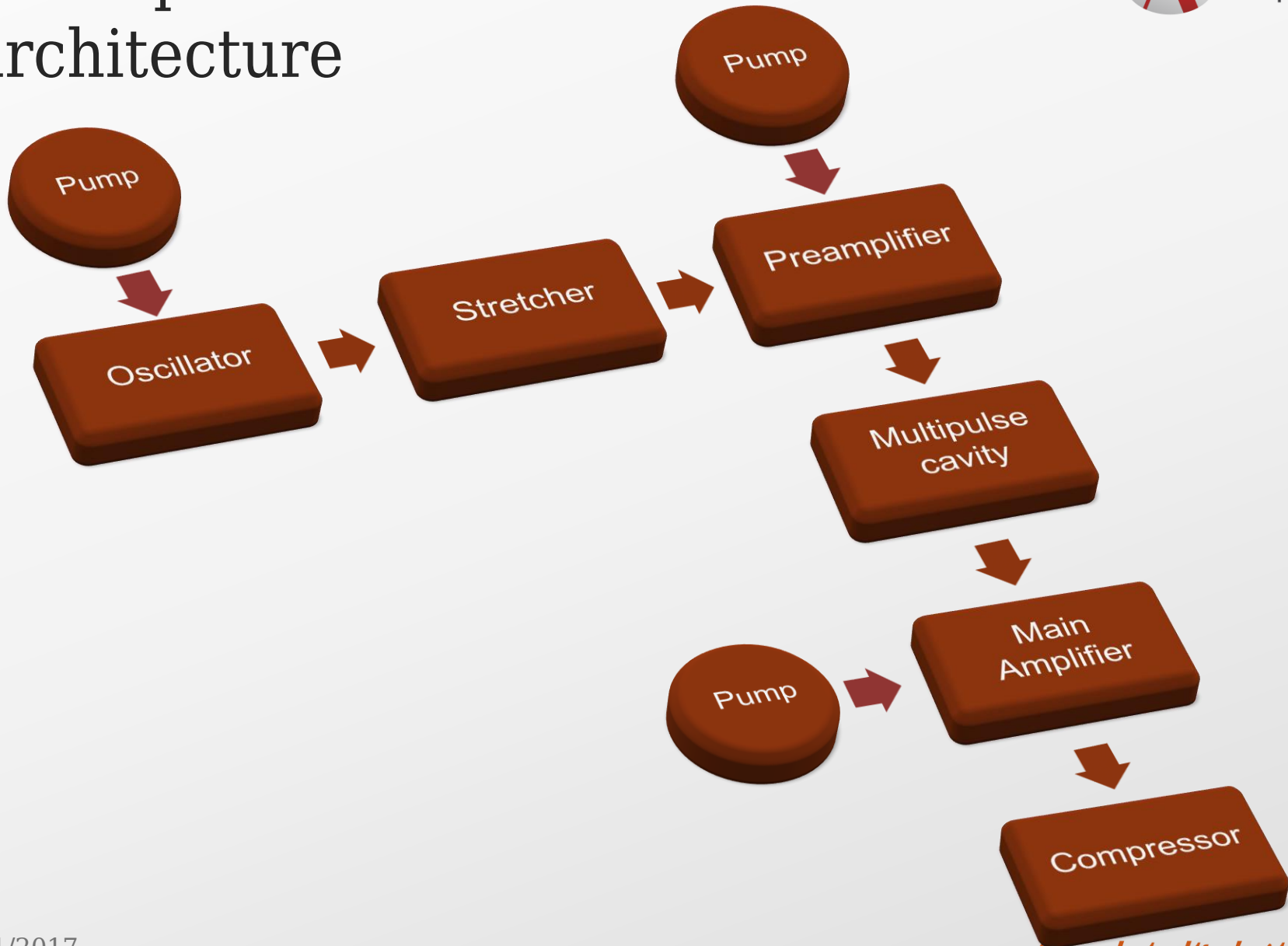
Increasing flux with recirculator : ELI-NP



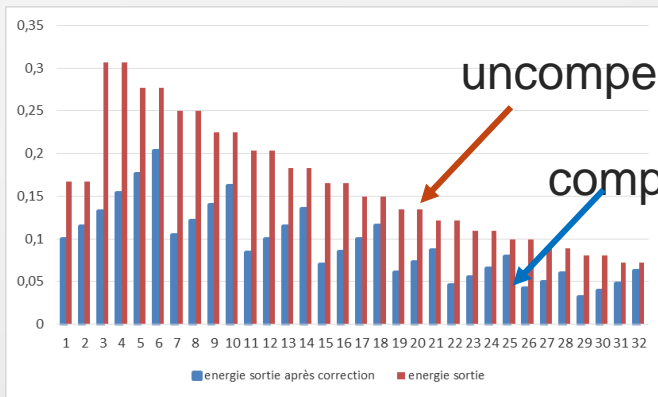
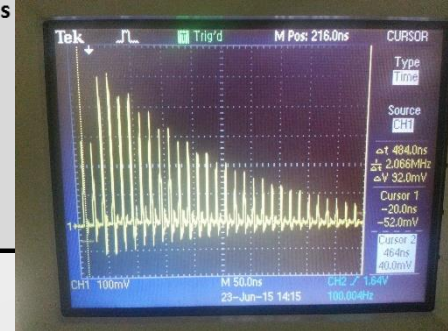
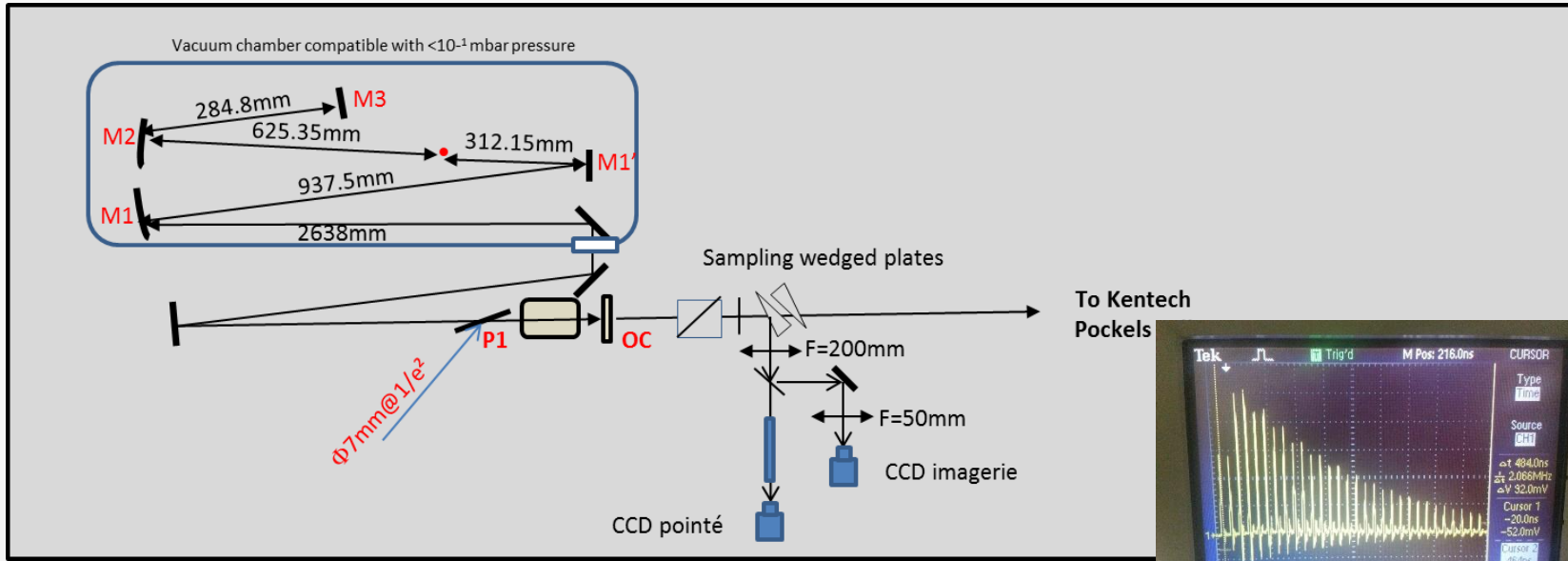
Recirculator



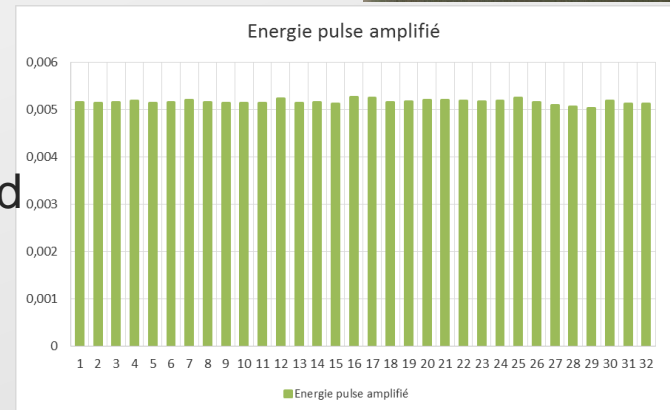
Burst photocathode laser architecture



Multipulse cavity

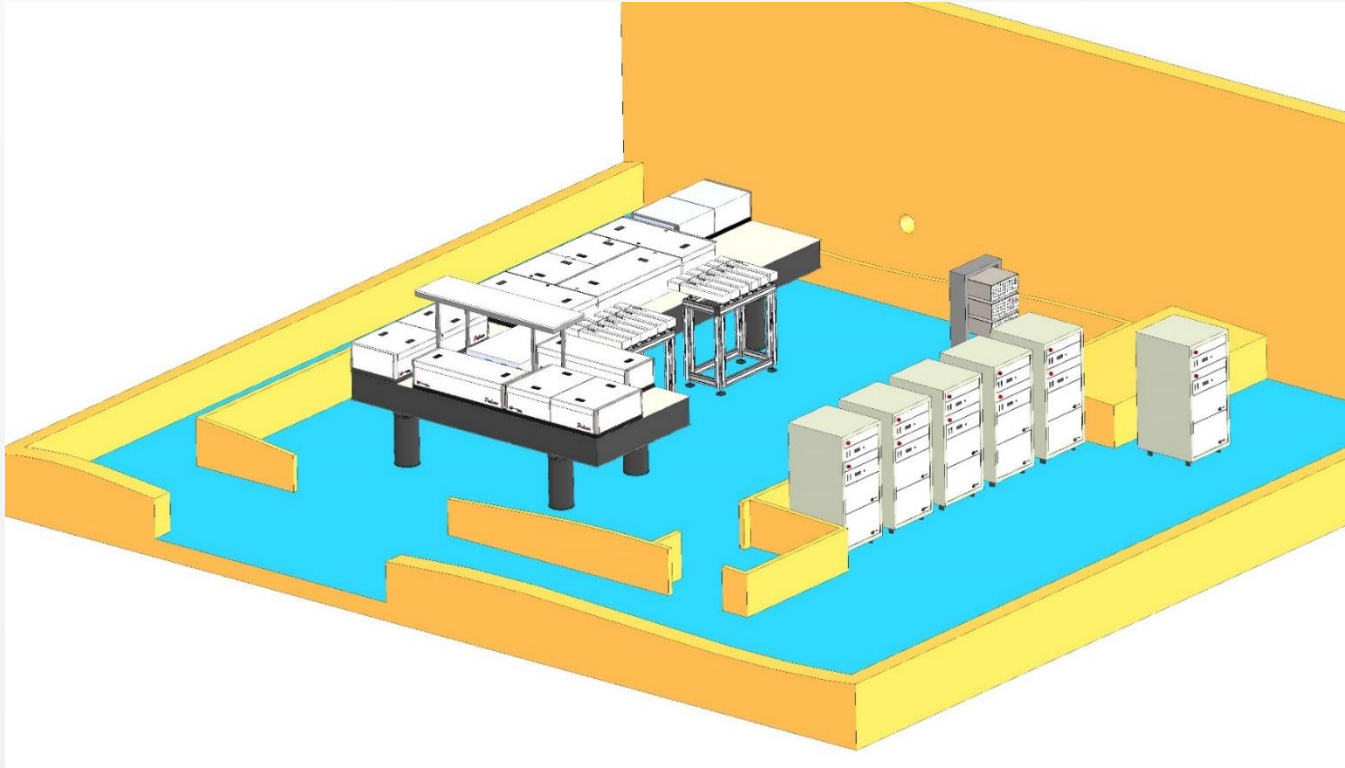


Output of the multipulse cavity



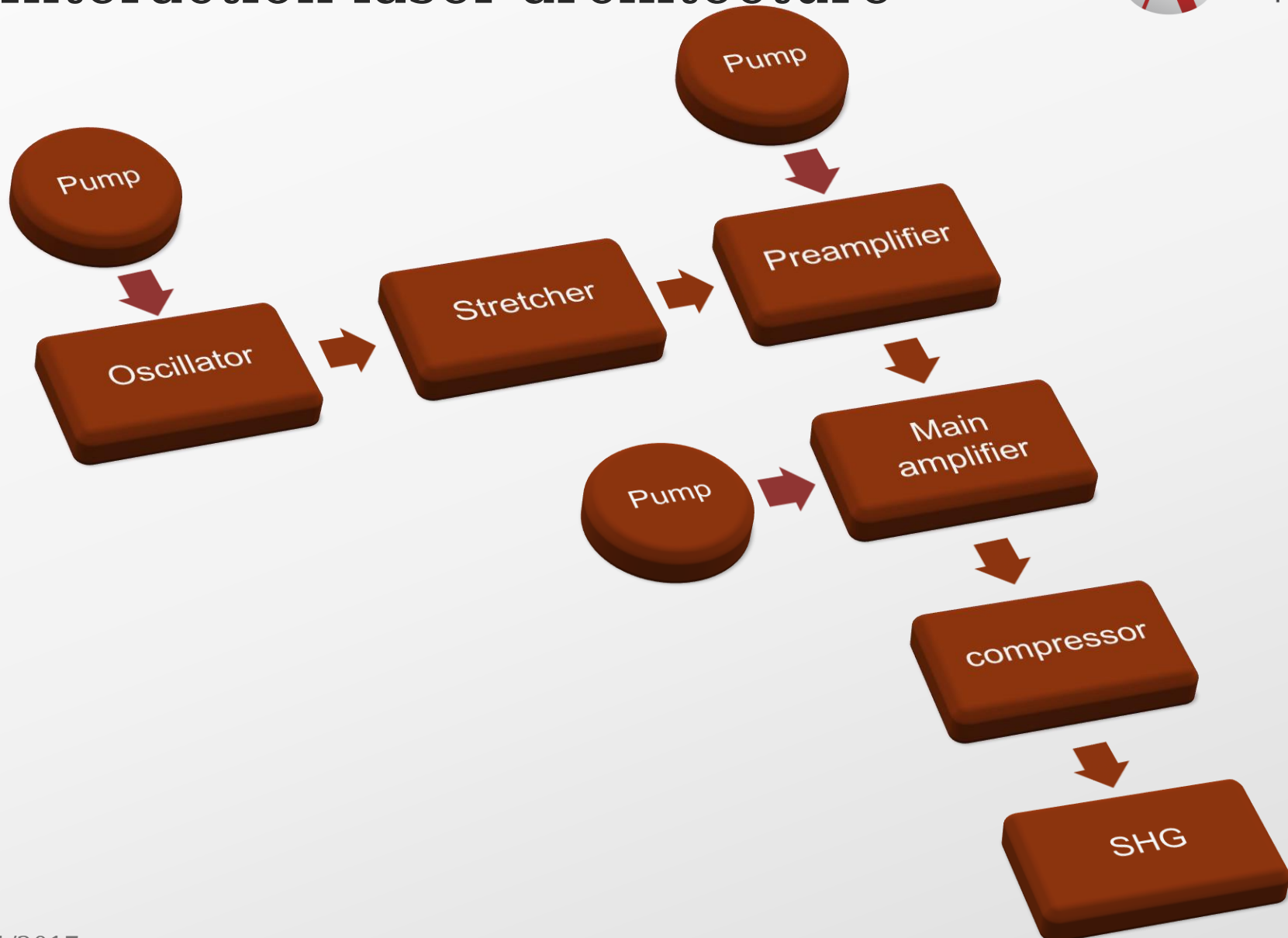
Output of the Cryo amplifier

Photocathode laser layout



Burst 32 x 350 μ J @ 258nm
100Hz repetition rate

Interaction laser architecture

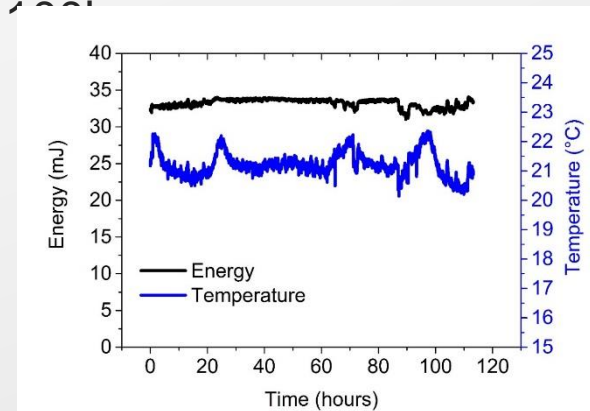


Narrowband preamplifier



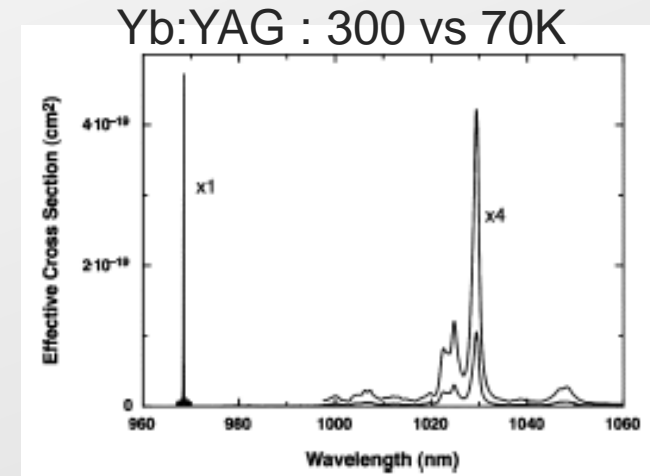
- 33mJ@100Hz before compression
- 0,3% rms short term stability
- 1,9% rms long-term stability over 100h

	Magma 25
Pulse duration	< 2 ps
Average power	2,5 W
Pulse energy	25 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Water



Cryo cooling technology

- Technology of choice for high power Ti:Sa lasers
- Closed-loop technology
- Low vibration (minimize jitter)
- Advantages :
 - Higher gain
 - Higher thermal conductivity
- Price to pay : narrow spectrum
 - Adapted to picosecond applications



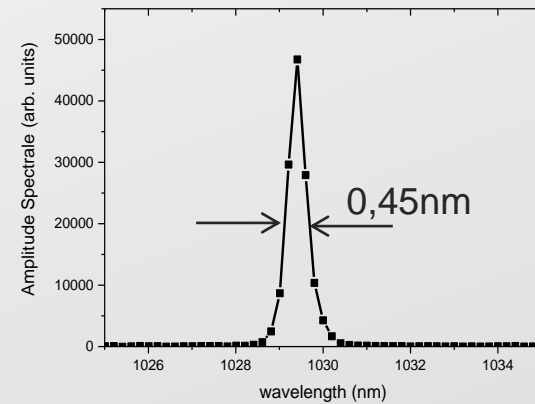
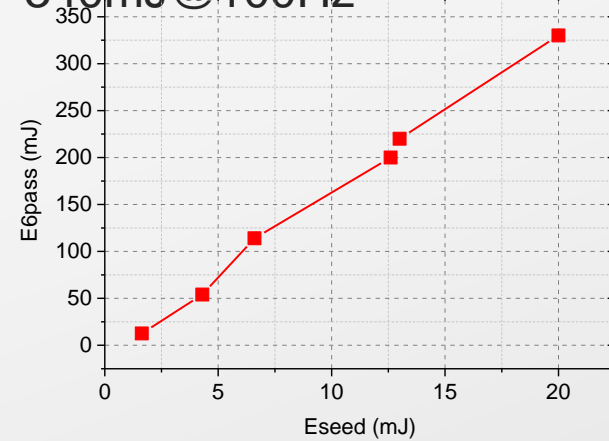
Narrowband power amplifier



	Magma 300
Pulse duration	< 5 ps
Average power	30 W
Pulse energy	300 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Cryo

- Extracted energy :

340mJ@100Hz

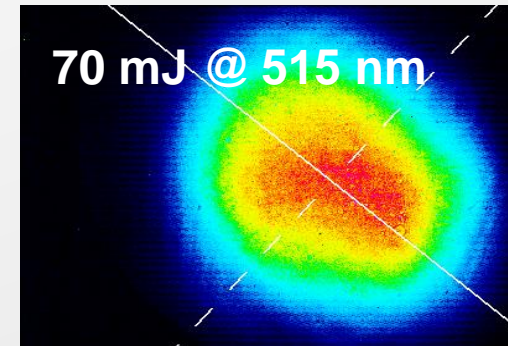


Frequency conversion

- Pulse compression : $\sim 4\text{ps}$
- SHG : 70mJ achieved with 100mJ incident



SHG profile

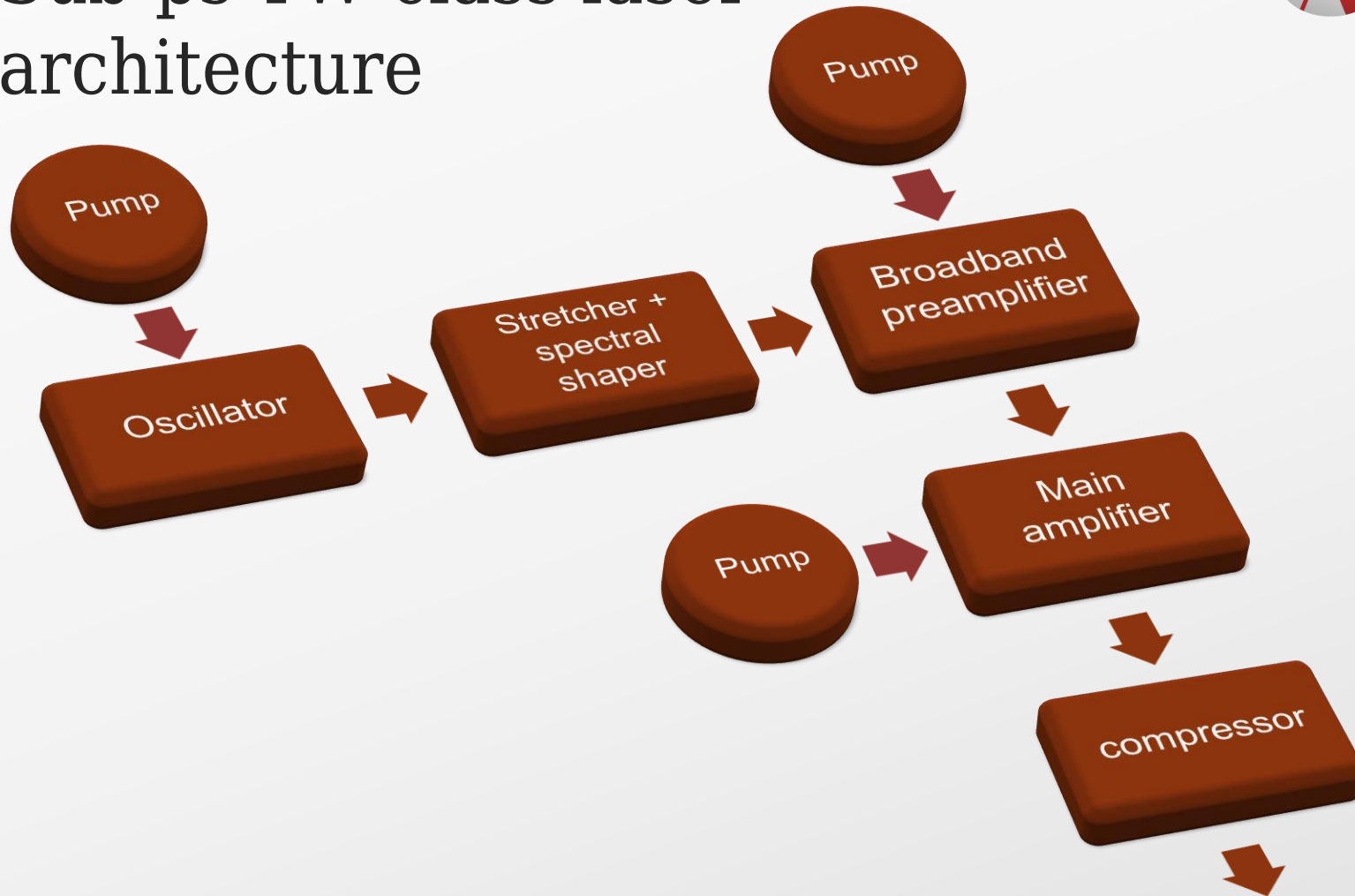


Ongoing work

- Frequency doubling at 300mJ to achieve 200mJ in green (515nm)
- To achieve 400mJ, 2 options :
 - Combining 2 IR pulses in SFG crystal
 - Boost IR energy to 600mJ, then SHG



Sub-ps TW class laser architecture

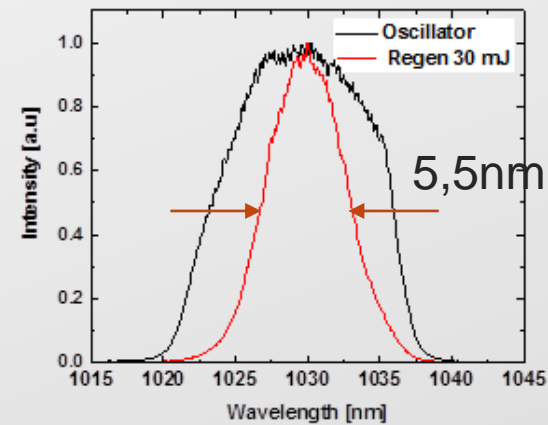
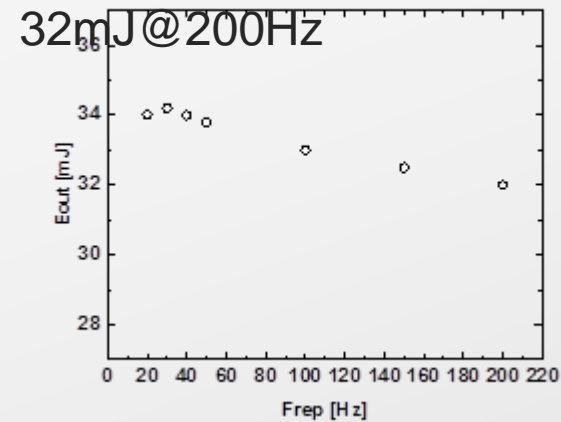


Broad band preamplifier



	Magma 25
Pulse duration	< 500 fs
Average power	2,5 W
Pulse energy	25 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Water

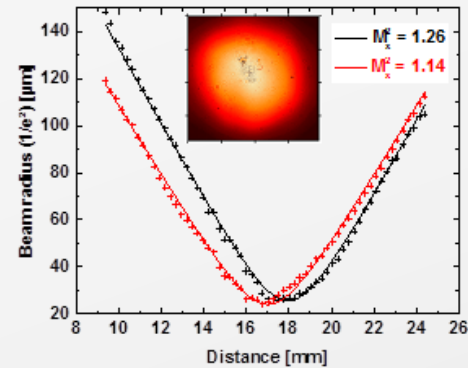
- Extracted energy :



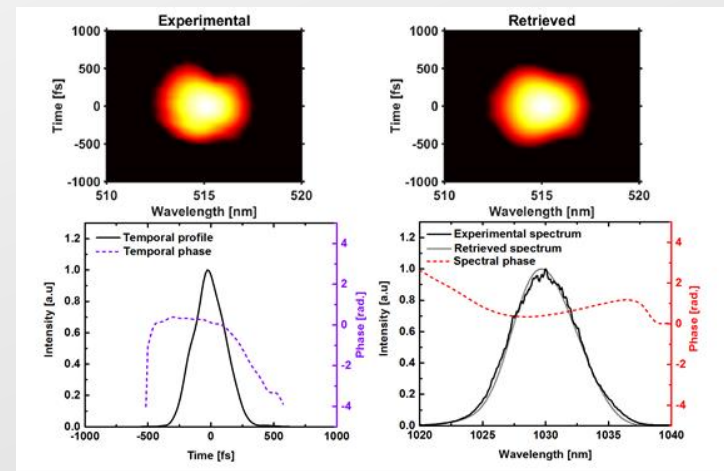
Broad band preamplifier



	Magma 25
Pulse duration	< 500 fs
Average power	2,5 W
Pulse energy	25 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Water



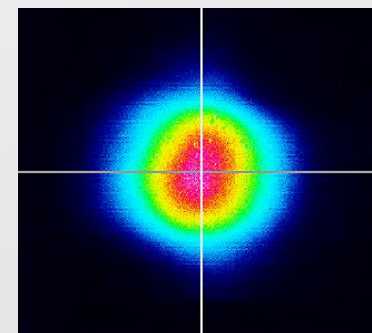
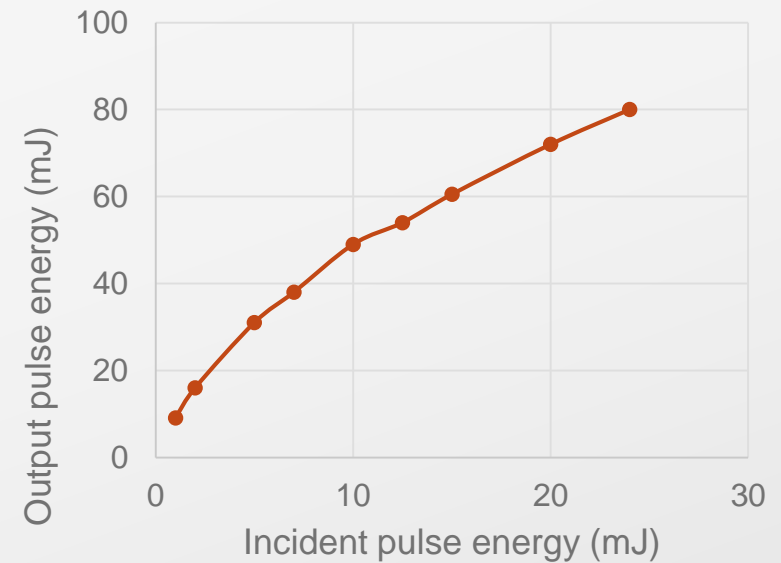
Compressed pulse duration : 300 fs @29,5m



Power amplifier



	Magma 75
Pulse duration	< 500 fs
Average power	7,5 W
Pulse energy	75 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Water

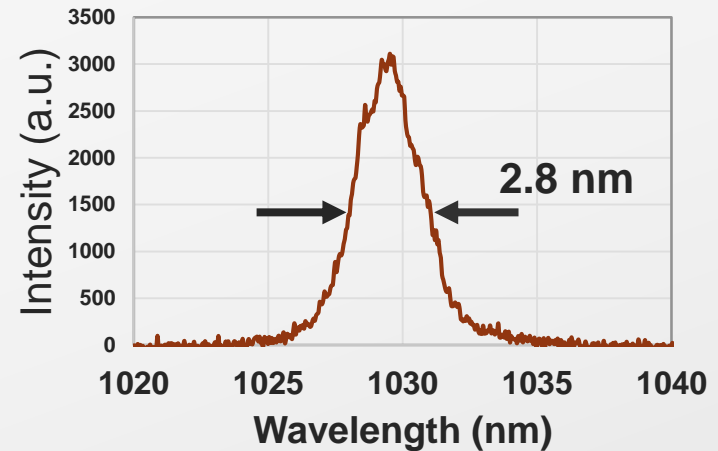


Ellips : 0,97

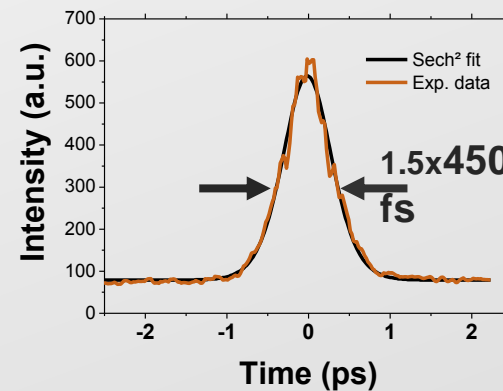
Power amplifier



	Magma 75
Pulse duration	< 500 fs
Average power	7,5 W
Pulse energy	75 mJ
Repetition rate	100Hz
Wavelength	1030 nm
Beam quality	$M^2 < 1.3$ - TEM ₀₀
Footprint	75 x 50 cm
Cooling	Water



Compressed pulse duration : 450 fs @74mJ

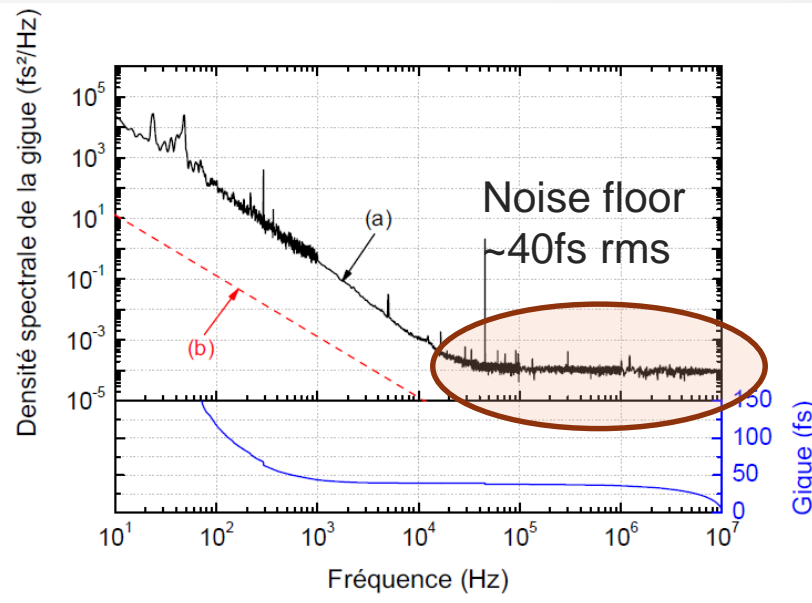


Reducing laser jitter

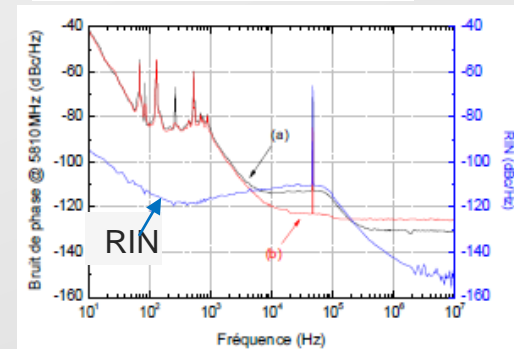
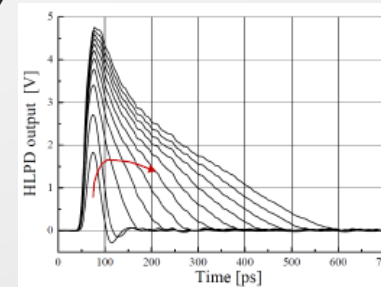
- Microwave based feedback & out-of-loop measurement (SSA)
- Typical absolute jitter ~ 100 fs rms using standard industrial fiber
 - Depends on RF reference < 100 Hz
 - Limited by noise floor > 100 kHz
 - AM-PM possible artifacts



1) Measurement noise floor

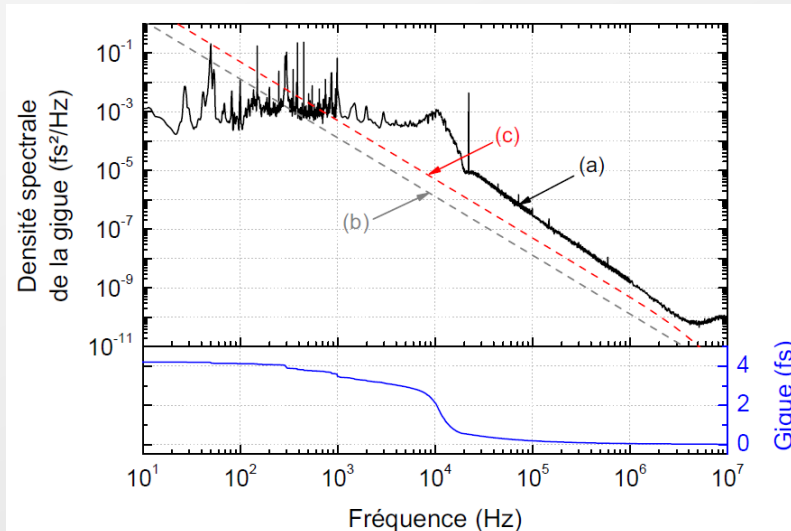
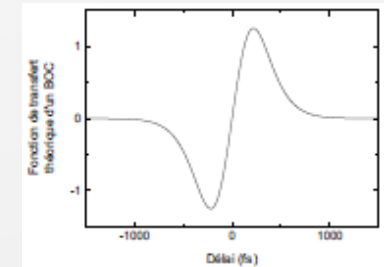
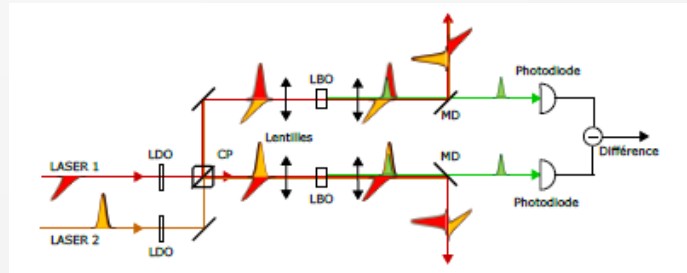


2) AM-PM induced by photodiode



Reducing laser jitter

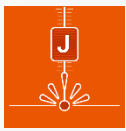
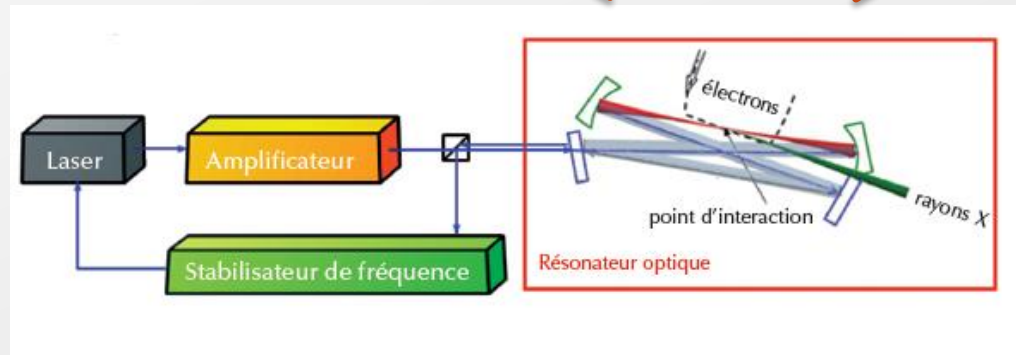
- Improved detection technique : balanced optical cross-correlation (BOC)
 - High sensivity
 - No AM-PM effect
- Optical reference to lock our oscillator with BOC
- Measure phase noise with out-of-loop BOC
 - < 4 fs rms from 10Hz to 10MHz



Increasing flux : stacking cavity



<1m >100 interactions



Perspectives

- Towards 1J 100Hz picosecond solutions
- Towards TW-class lasers @100Hz
- Combining lasers in burst mode with enhancing cavities opens new perspectives



Conclusion

- Industrial lasers become extremely attractive for science, especially in accelerator field for secondary sources
- Today both laser and accelerator communities are joining their efforts to build hybrid solutions for :
 - Light sources
 - Particle sources
 - Combined techniques

Thank you !

