

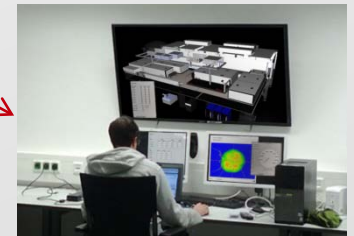
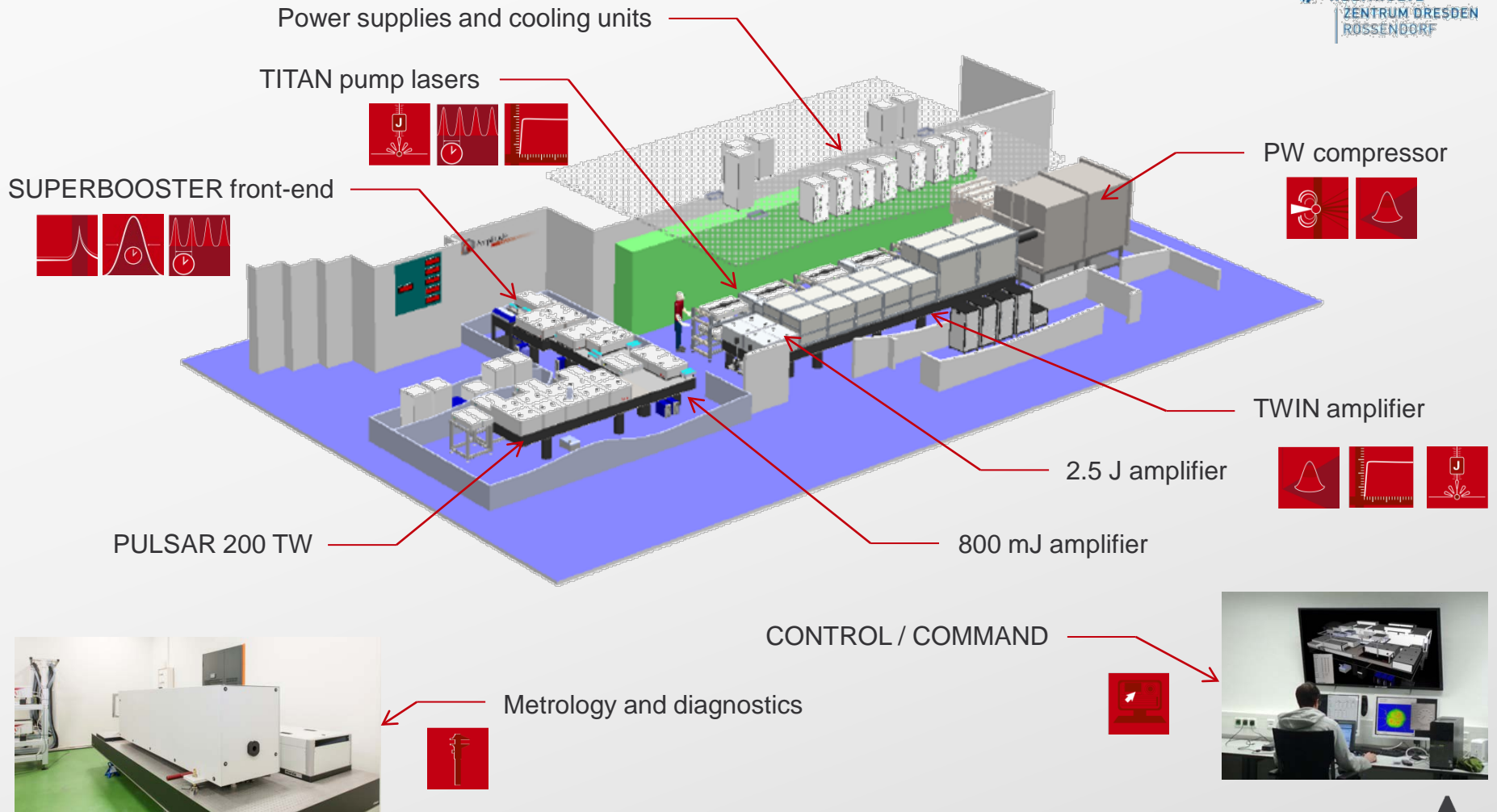
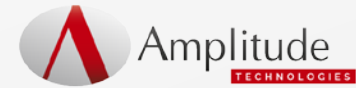
Pioneer in ultrafast
high energy lasers
laser solutions for scientific applications

LATEST DEVELOPMENTS ON PW CLASS LASERS

LA3NET SCHOOL - SALAMANCA

nothing but ultrafast

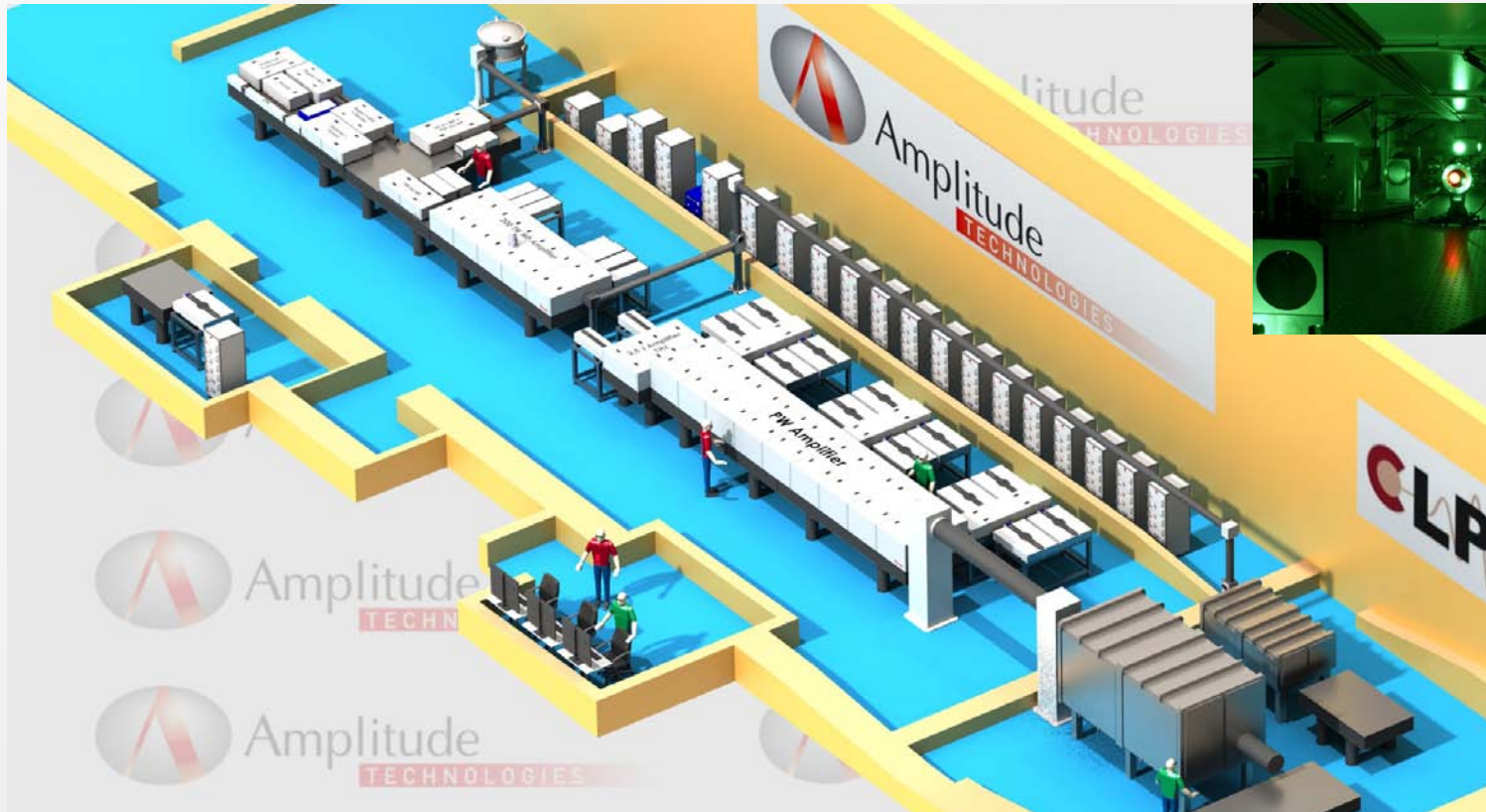
PULSAR PW laser system / DRACO



nothing but ultrafast

VEGA LASER SOURCE

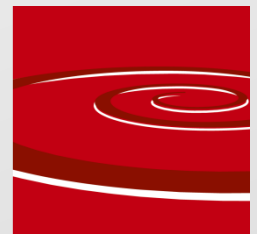
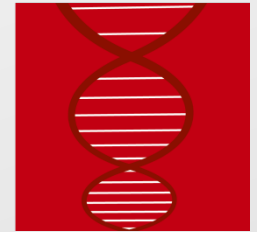
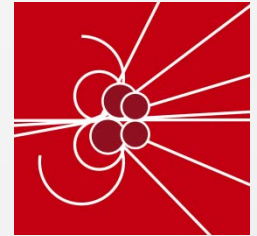
Centro de Laseros Pulsados / Prof. Dr. Luis Roso



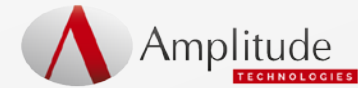
PULSAR PW – 1 Hz – < 25 fs – Temporal contrast 10^{12}
Multiple high peak power laser outputs

Multi-100's TW and PW lasers applications

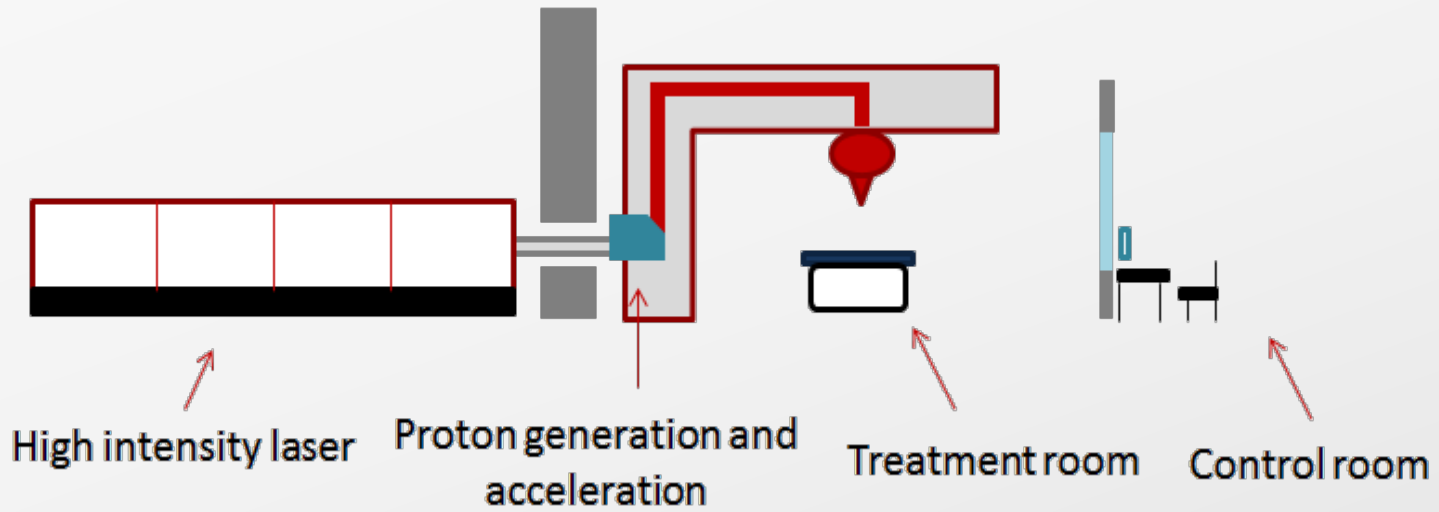
- ▲ **Proton acceleration** (European project Saphir)
- ▲ **Electron acceleration** (*Easarey et al 2009*)
- ▲ **Ion acceleration** (*Borghesi et al 2006*)
- ▲ **Laser-pumped x-ray lasers** (*Daido 2002*)
- ▲ **High-order harmonic generation** (attosecond science)
(*Corkum and Krausz 2007*)
- ▲ **Fast ignition in laser-driven fusion**
(*Tabak et al 1994, Sentoku et al 2000, Patel et al 2003*).



SAPHIR PROJECT: LASER-BASED PROTON THERAPY R&D

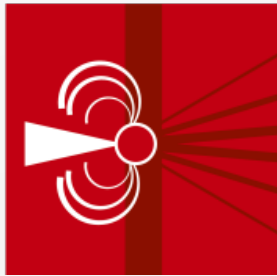


Idea of laser-based protontherapy installation

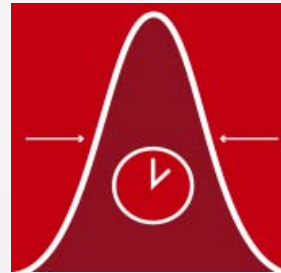


nothing but ultrafast

LASER SYSTEMS DEDICATED FOR PROTON ACCELERATION



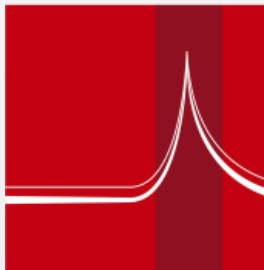
**High pulse energy
on the target**



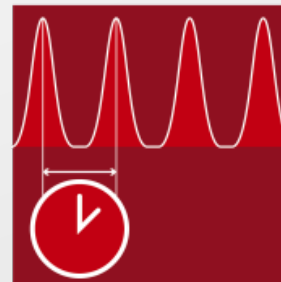
**Ultra-short pulse
duration**



High quality wavefront



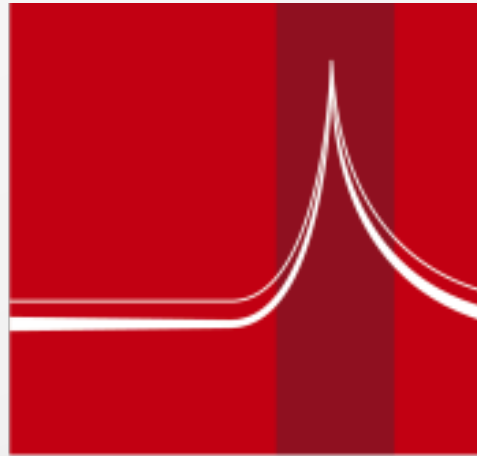
High temporal contrast



High repetition rate



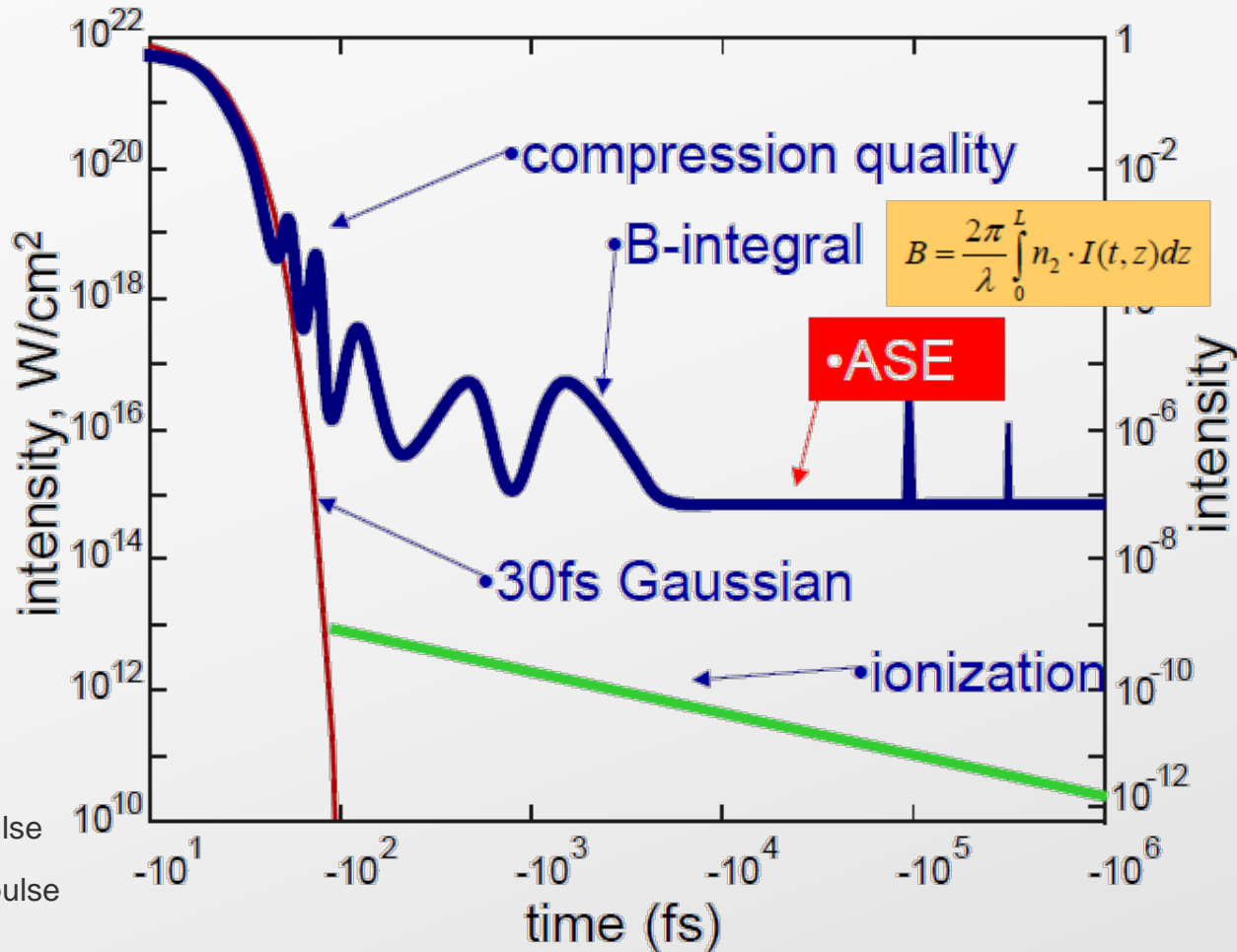
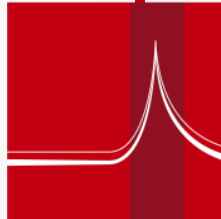
**User-friendly control /
command interface**



High temporal contrast



TEMPORAL CONTRAST

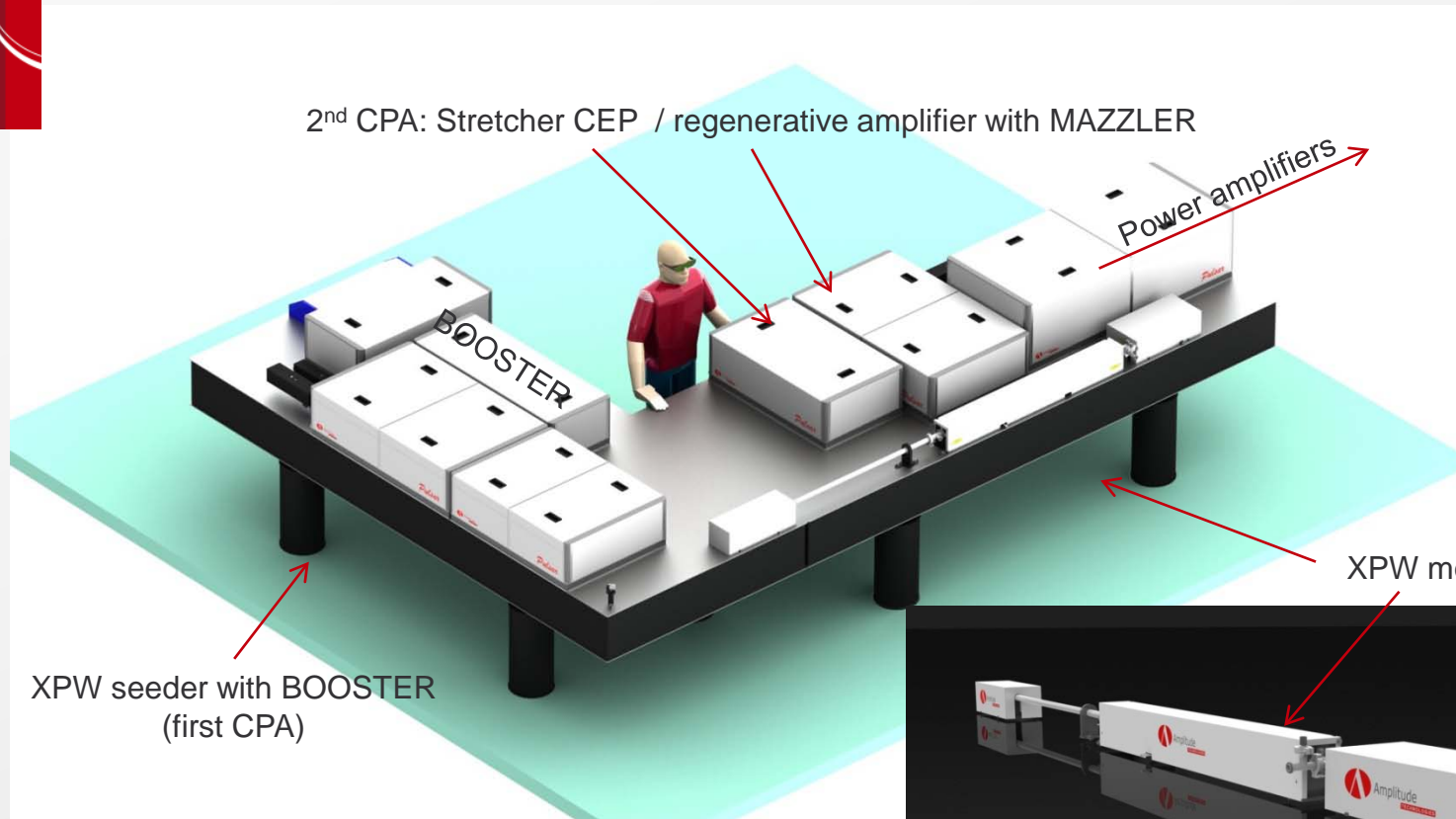
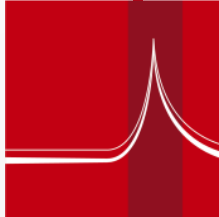


— Theoretical pulse
 — experimental pulse

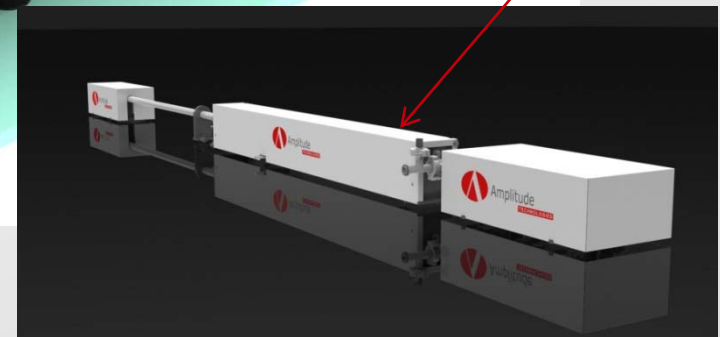
Coherent contrast
 incoherent contrast
 Pulses replicas

nothing but ultrafast

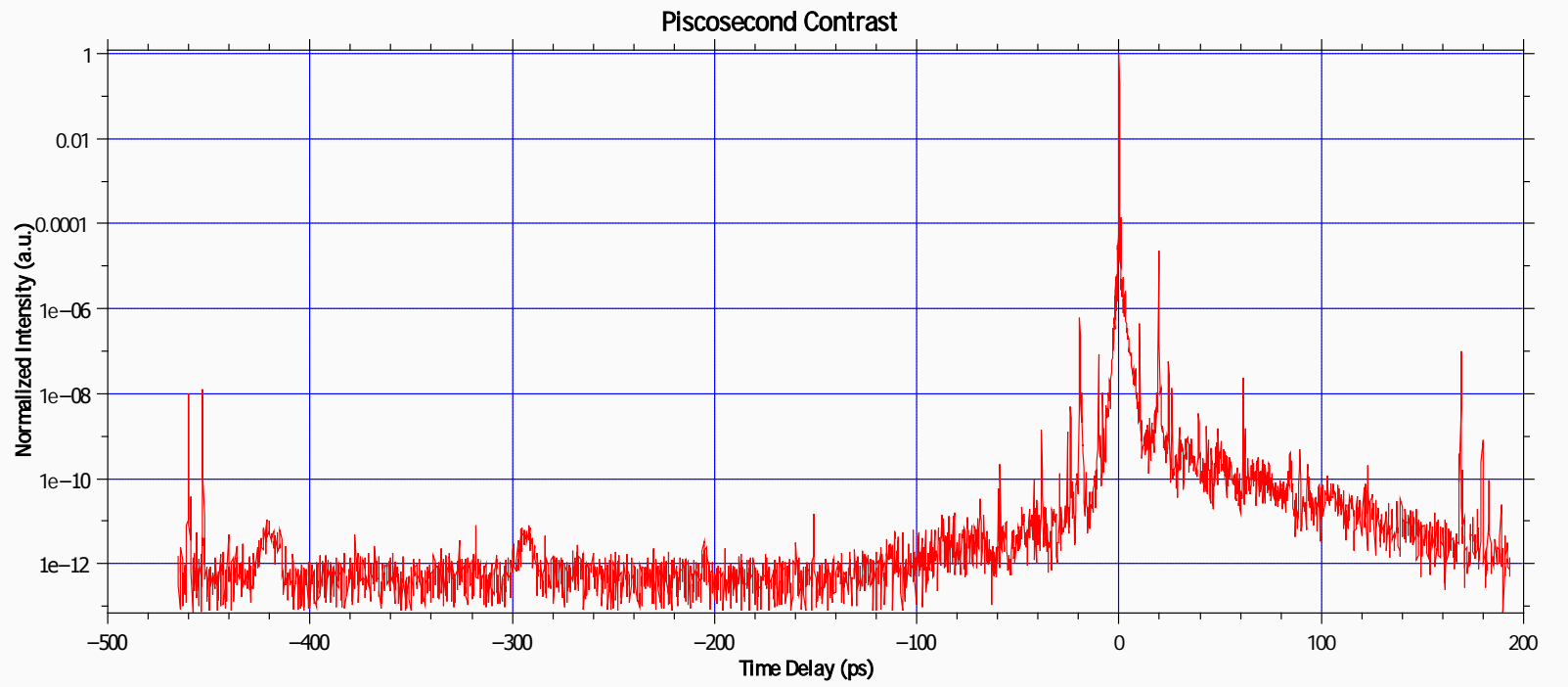
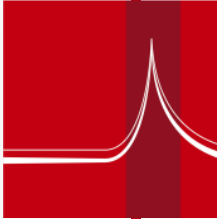
SUPERBOOSTER FRONT-END



Double CPA configuration with XPW module between both

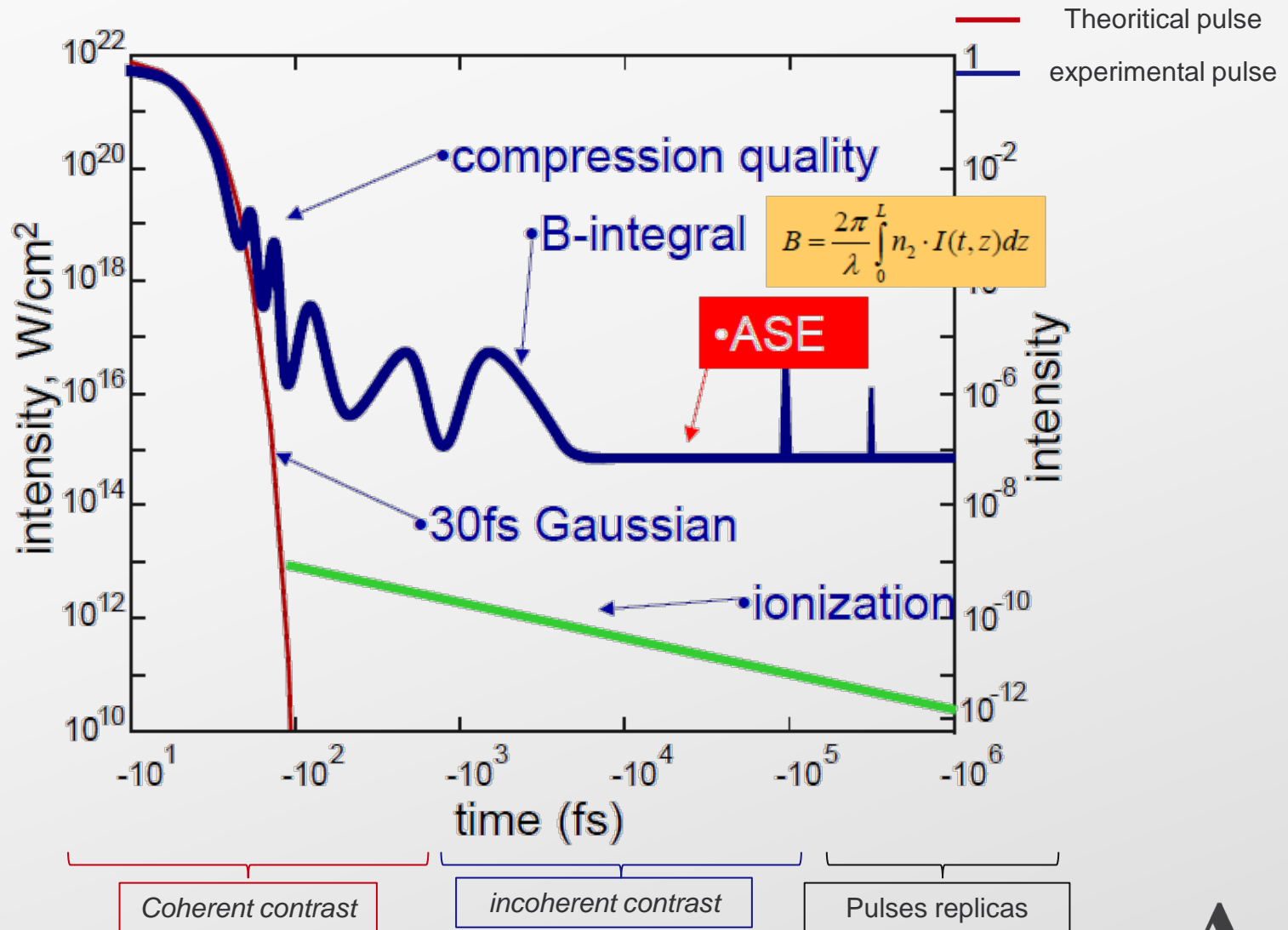
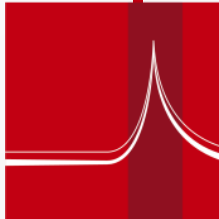


JETI100



Ultra-short high peak power laser
16 fs as temporal duration at 250 TW (4 J)
5 Hz - Temporal contrast 10^{12}

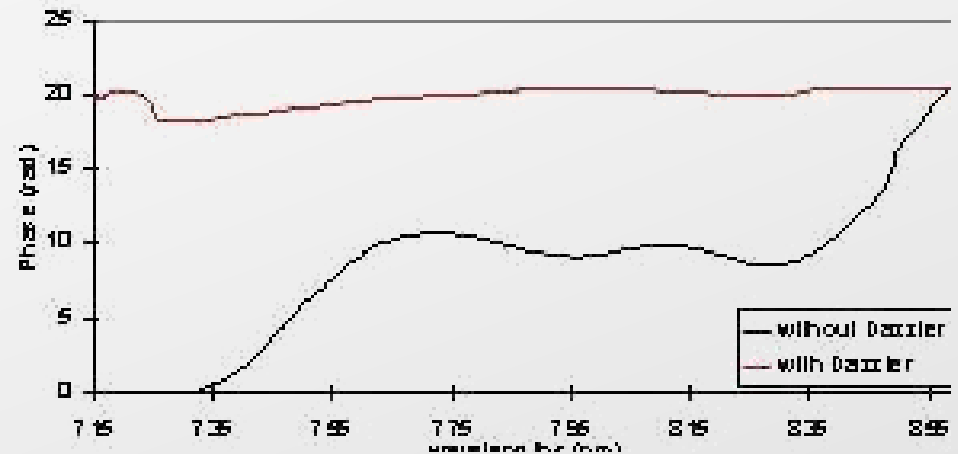
TEMPORAL CONTRAST



nothing but ultrafast

DAZZLER

Acousto-Optic Programmable Dispersive Filter



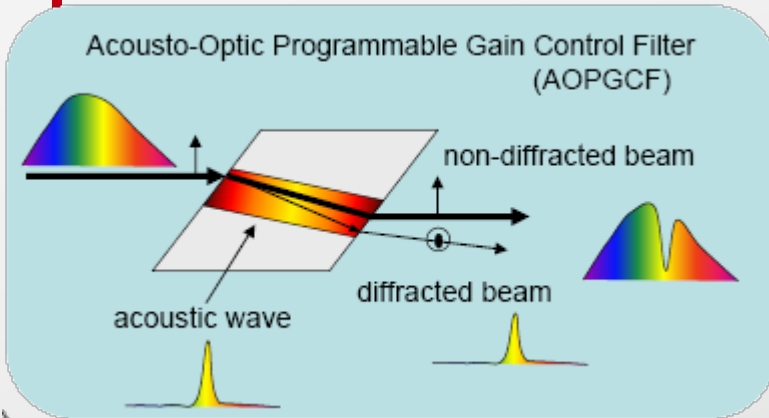
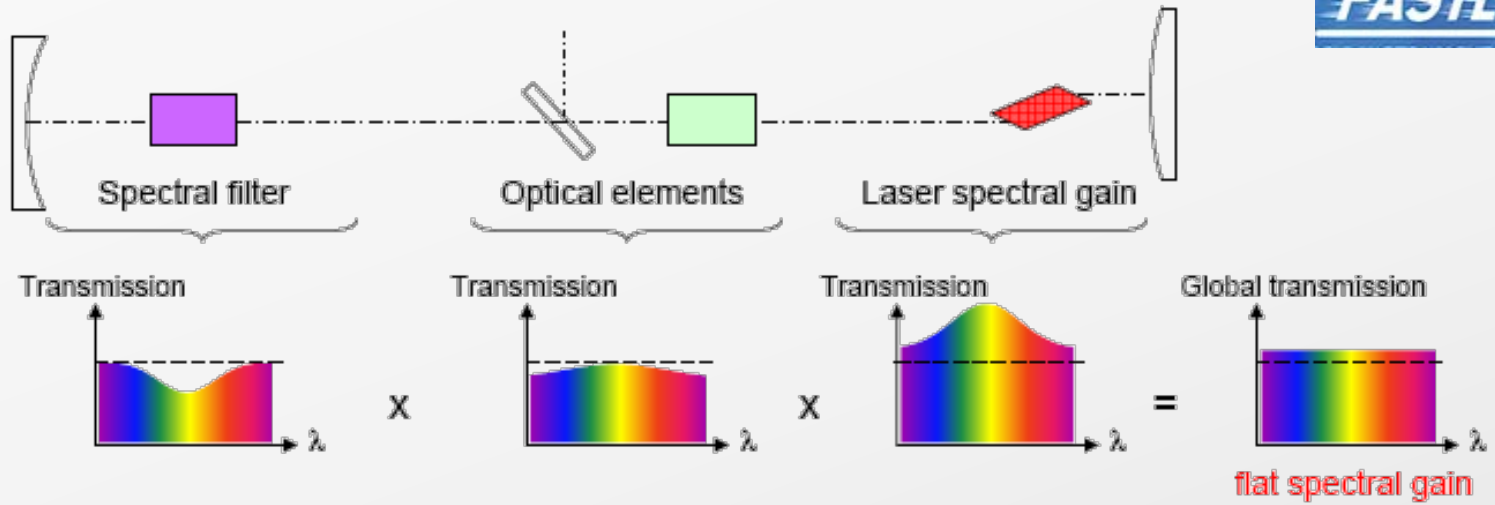
Phase compensation

FASTLITE

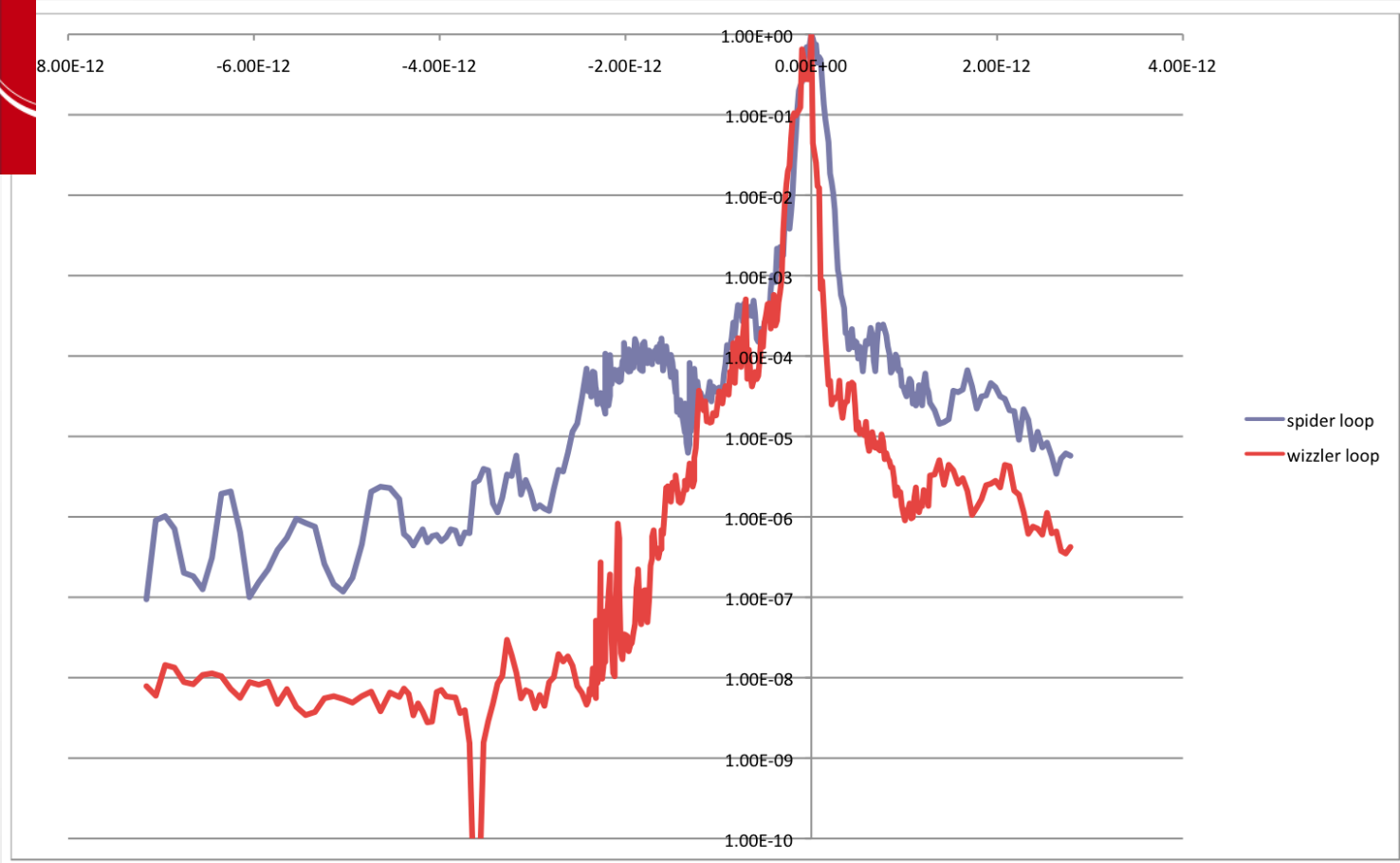
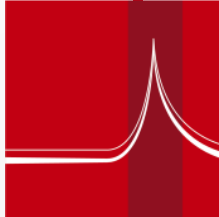
nothing but ultrafast

MAZZLER™

FASTLITE



COHERENT CONTRAST ENHANCEMENT:

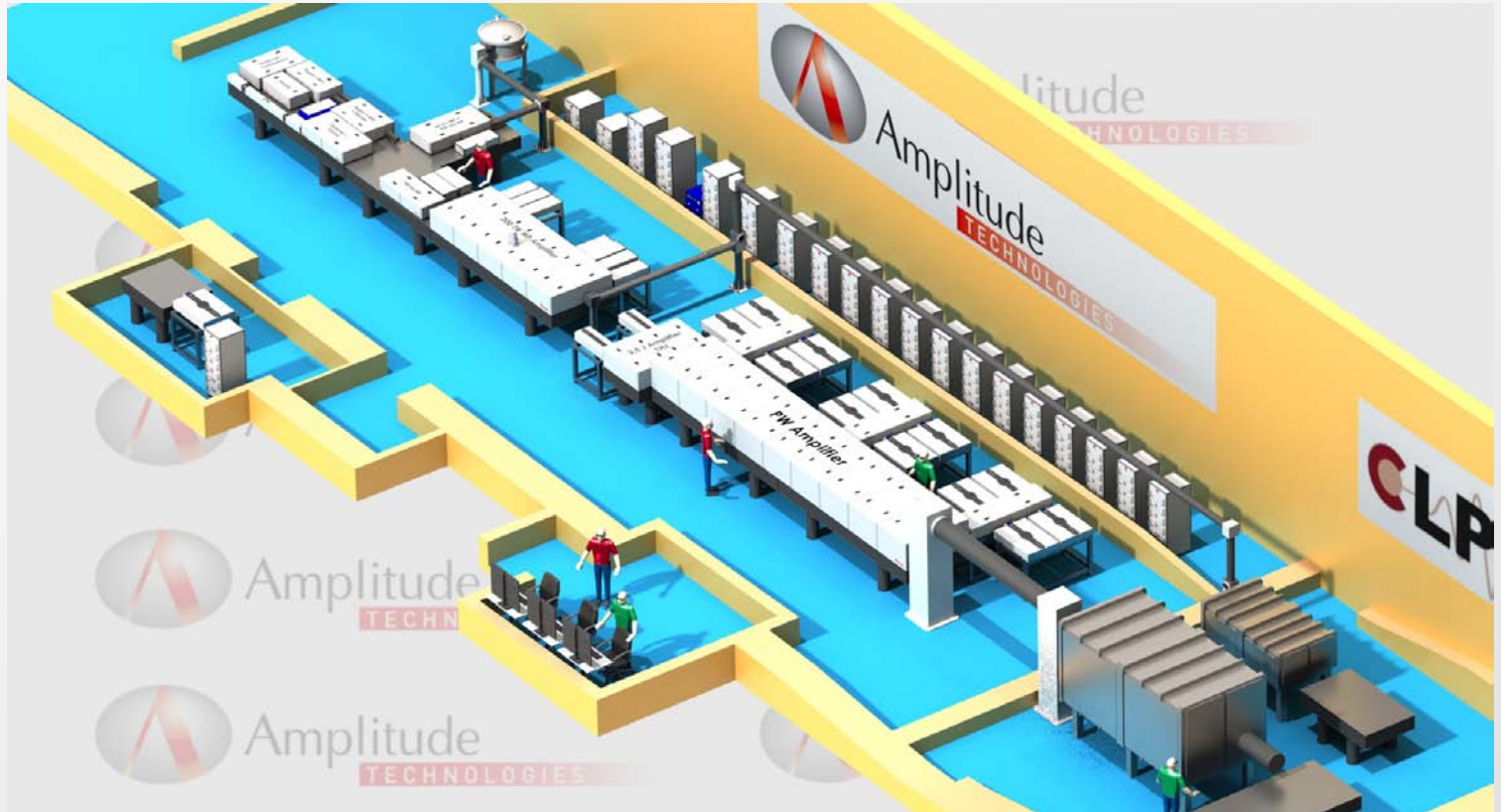


Measures realized by FASTLITE on DRACO system (HZDR):

We observe a better coherent contrast where the dispersion is compensated !

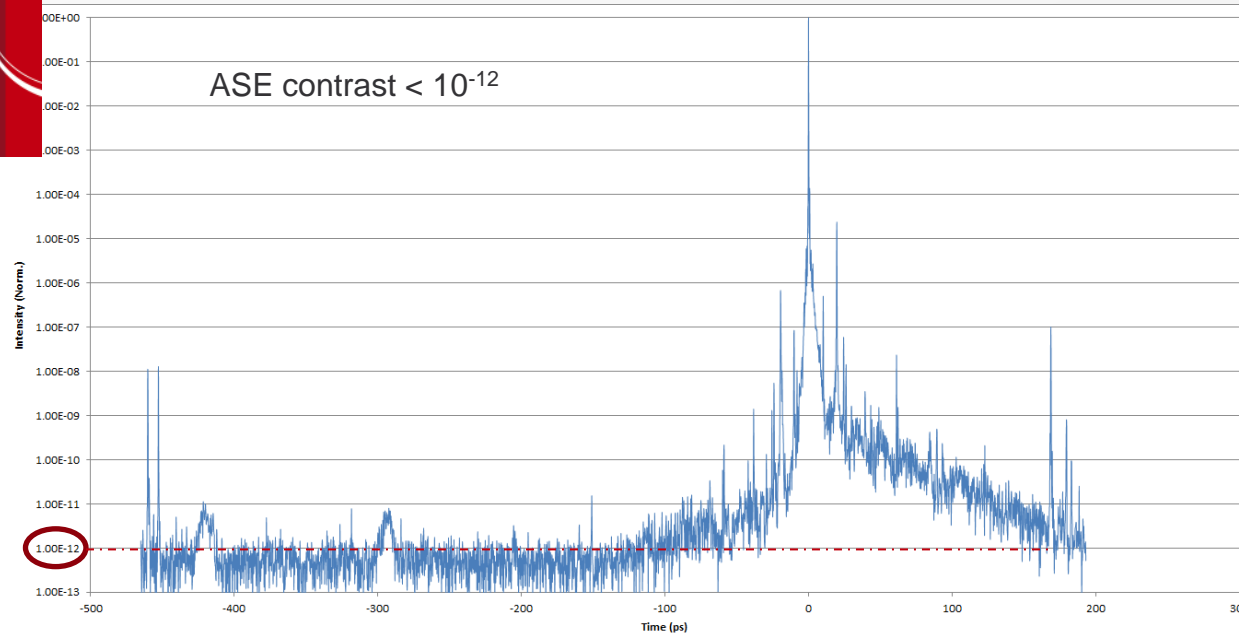
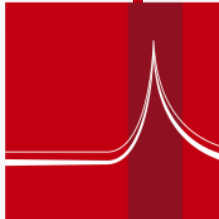
SYNCHRONIZATION

Centro de Laseros Pulsados / Prof. Dr. Luis Roso



PULSAR PW – 1 Hz – < 25 fs – Temporal contrast 10^{12}
Multiple high peak power laser outputs

SUPERBOOSTER / PERFORMANCES

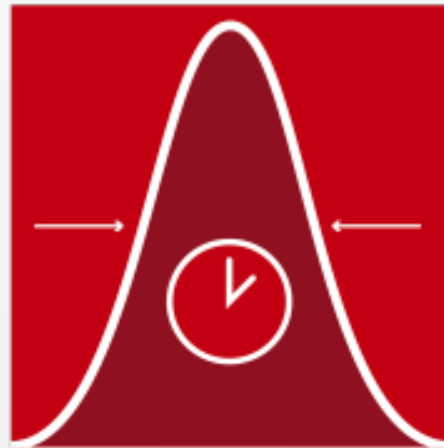


PULSAR 250 TW, 5 Hz
JET1100

Typical SEQUOIA HD for PULSAR multi-TW-class laser system with SUPERBOOSTER front-end

- ns guaranteed $< 10^{-8}$
- 1 ps guaranteed $< 10^{-3}$
- 2 ps guaranteed $< 10^{-4}$
- 5 ps guaranteed $< 10^{-6}$
- 30 ps guaranteed $< 10^{-11}$
- > 50 ps guaranteed $< 5 \cdot 10^{-12}$

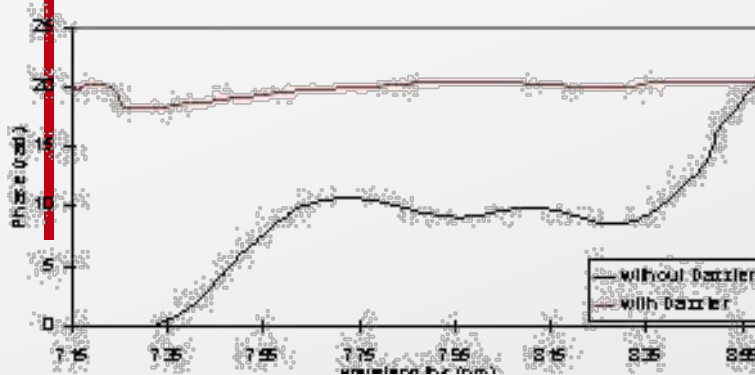
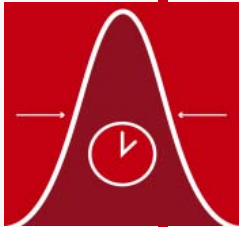
- ns measured at FAT $< 10^{-8}$
- 1 ps measured at FAT $< 10^{-5}$
- 2 ps measured at FAT $< 10^{-5}$
- 5 ps measured at FAT $< 10^{-7}$
- 30 ps measured at FAT $< 10^{-11}$
- > 50 ps measured at FAT 10^{-12}



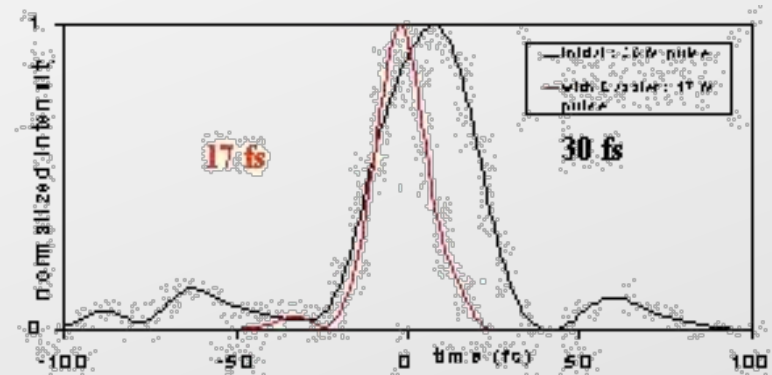
Ultrashort pulse duration

DAZZLER

Acousto-Optic Programmable Dispersive Filter



Phase compensation

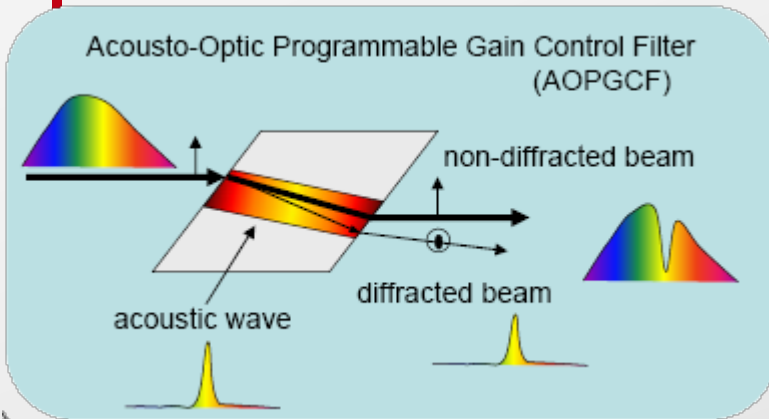
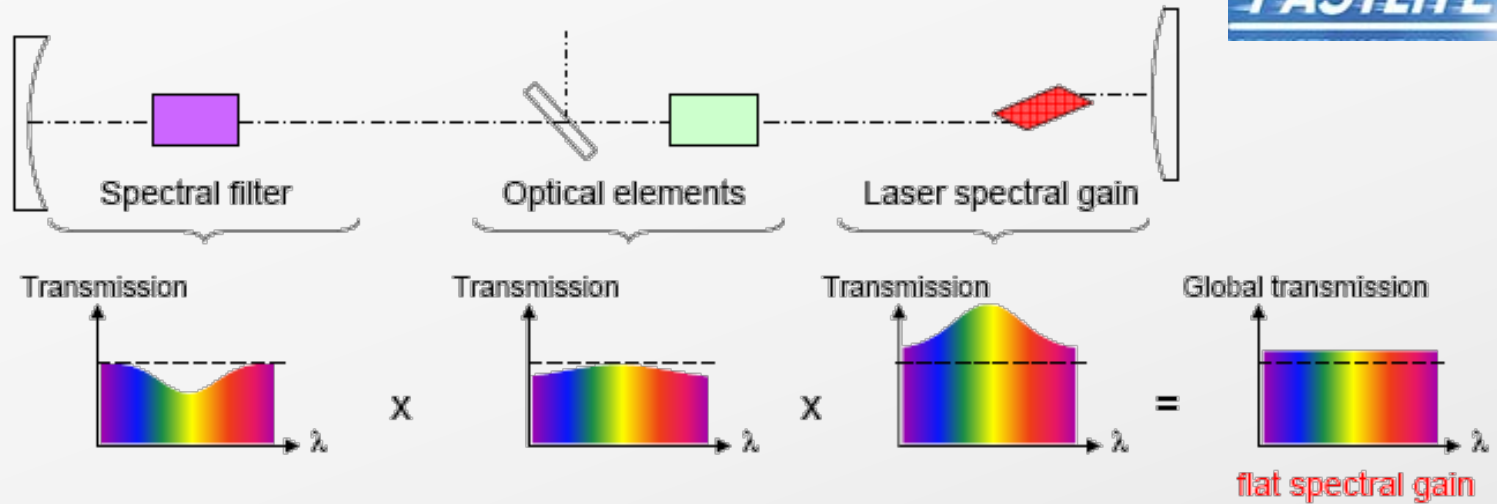
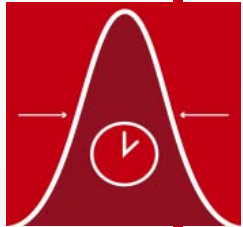


Pulse duration optimization



MAZZLER™

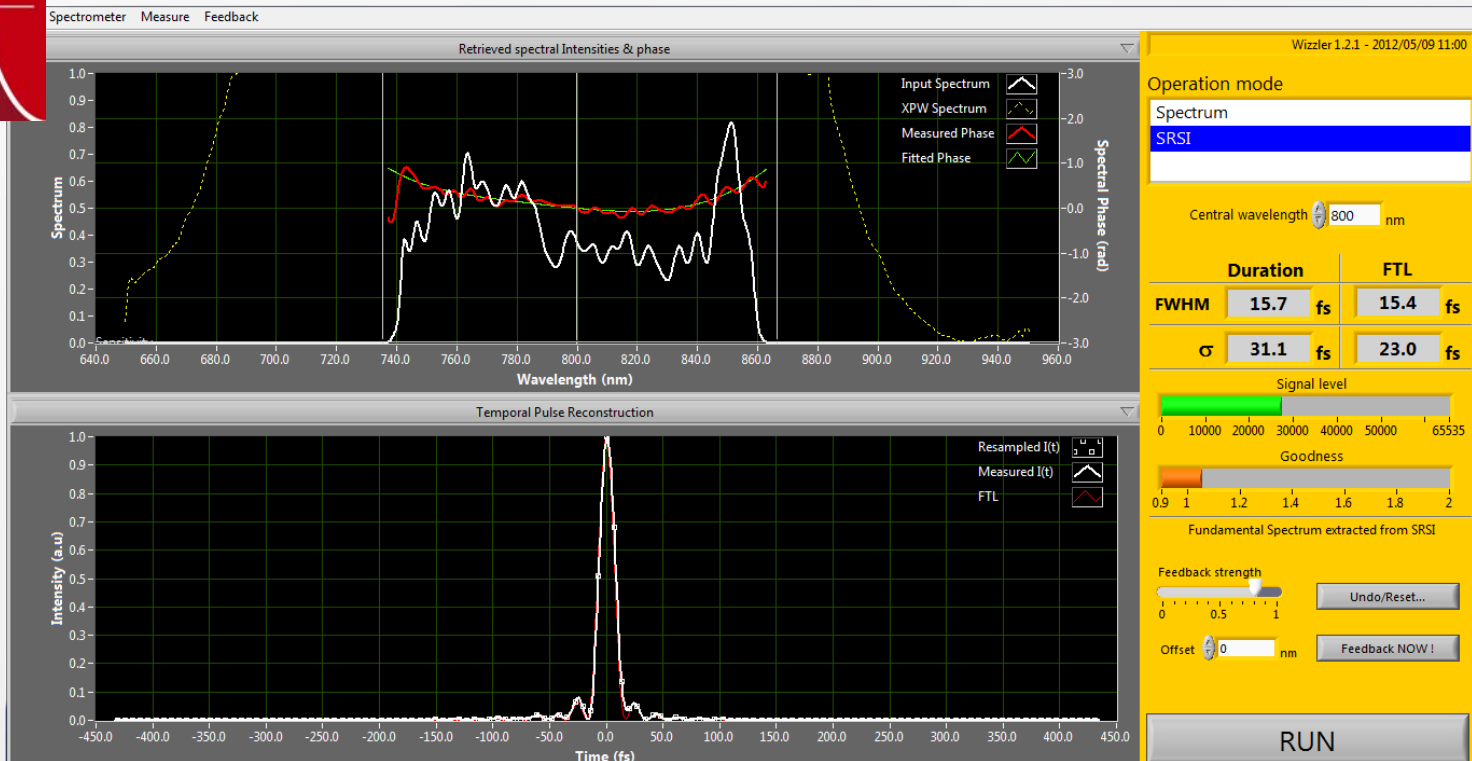
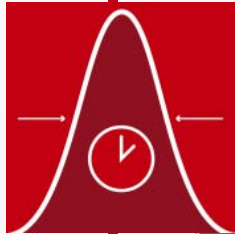
FASTLITE



The larger the pulse spectrum, the shorter the compressed pulse duration can be.

Limit the gain narrowing

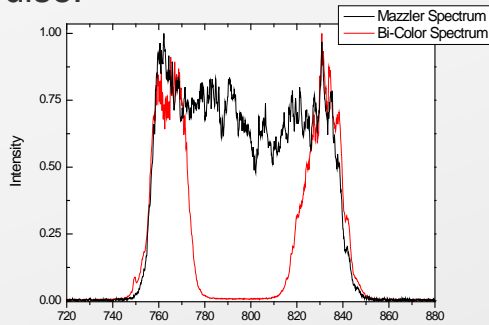
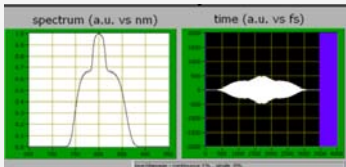
JETI100



Ultra-short high peak power laser
16 fs as temporal duration at 250 TW (4 J)
5 Hz - Temporal contrast 10^{12}

Spectrum tunability

- ^ The **MAZZLER - DAZZLER configuration** allows controlling completely the spectrum over more than 150 nm without any realignment of the system.
 - > Spectrum tunability: a square 15-30 nm spectrum can be tuned over a 55 nm spectral range
 - > Two-colors: 2 different parts of the spectrum can be amplified in the same time, allowing a “two-color” pulse.



Two-colors spectrum

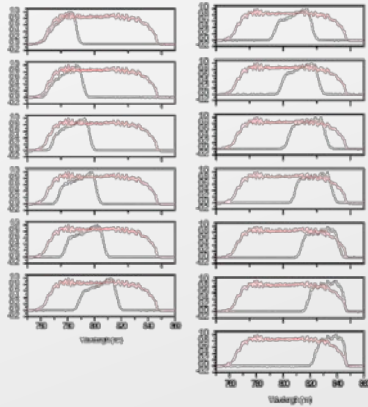
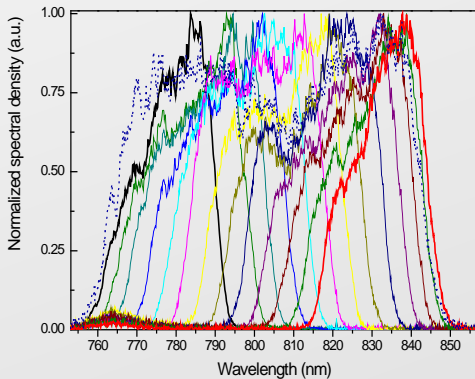
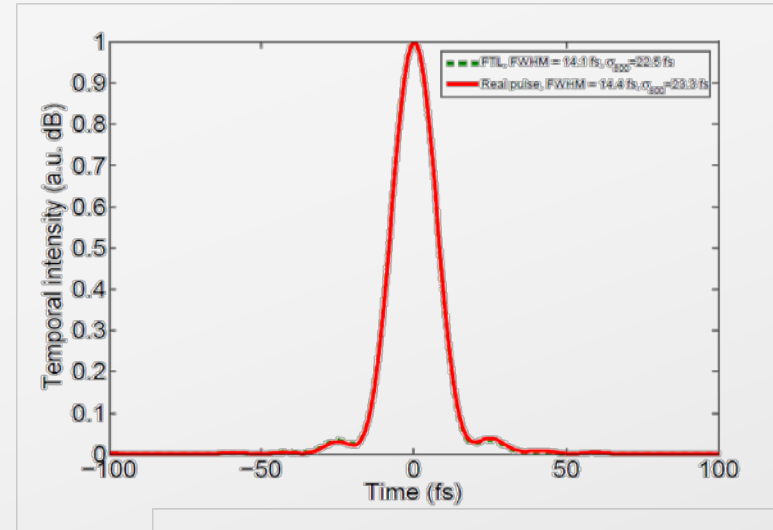
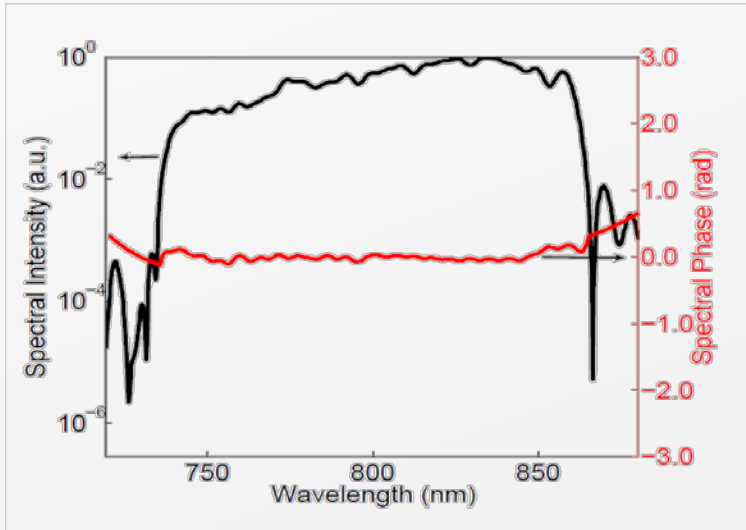


Figure 2: (a) and (b) show the spectrum and the pulse, respectively, for the Mazzler and Dazzler configurations.



Spectrum tunability

Results: Ultra Broadband Amplifier TW-class (15 fs, 20 mJ, 100 Hz)



Ultrabroadband TW-class Ti:sapphire laser system with adjustable central wavelength, bandwidth and multi-color operation

Alexandre Trisorio,^{1,*} Pierre M. Paul,³ Fabien Ple,³ Clemens Ruchert,¹ Carlo Vicario,¹ and Christoph P. Hauri^{1,2,4}

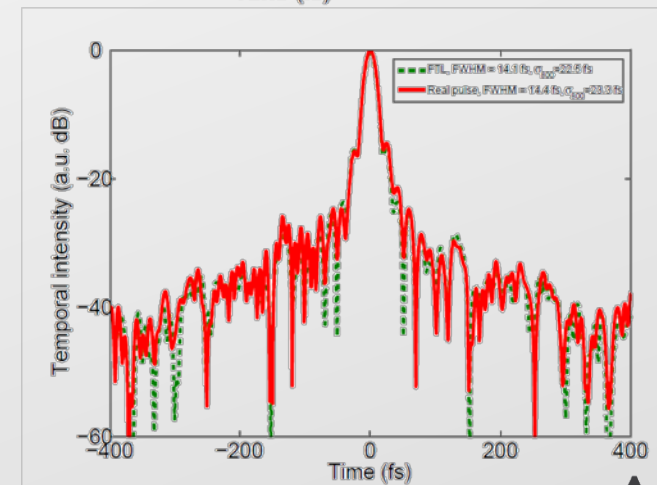
¹Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

²Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

³Amplitude Technologies, 2-4 rue du bois chaland, 91029 Evry, France

⁴christoph.hauri@psi.ch

*alexandre.trisorio@psi.ch



FIRST CONCLUSION

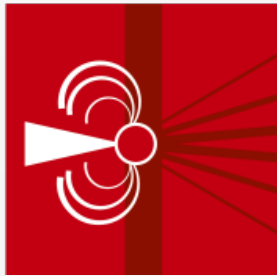
^ Contrast enhancement :

- > RGA leaks : Pockels cells
- > ASE contrast : BOOSTER and SUPERBOOSTER
- > Coherent contrast : Spectral phase and amplitude shaping

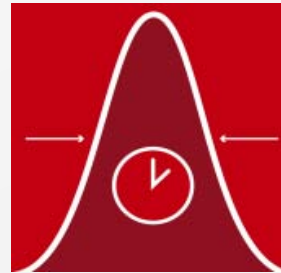
^ Pulse duration:

- > Dazzler/Mazzler

LASER SYSTEMS DEDICATED FOR PROTON ACCELERATION



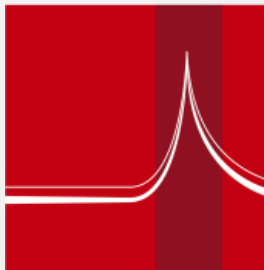
**High pulse energy
on the target**



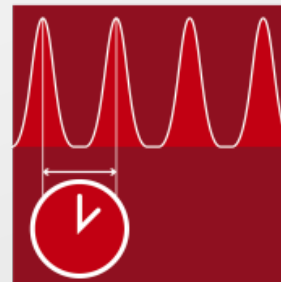
**Ultra-short pulse
duration**



High quality wavefront



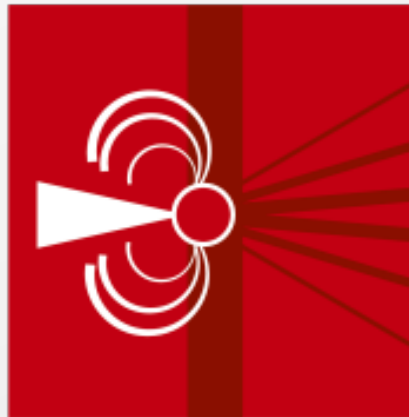
High temporal contrast



High repetition rate



**User-friendly control /
command interface**



High Pulse Energy



Ti:Sa amplification chain



Dresden laser acceleration source / DRACO

Prof. Dr. Ulrich Schramm

Laser Particle Acceleration Division / Institute for Radiation Physics



TWIN amplifier

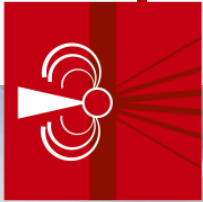
2.5 J amplifier

TITAN pump lasers

PULSAR PW – 1 Hz – < 25 fs – ASE $< 10^{-12}$

2.5 J amplifier

- ▲ This amplifier boosts the pulse energy from 800 mJ up to 2.5 J with a pulse to pulse stability of 0.6 % RMS



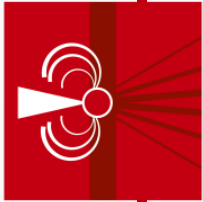
> Features

Integrated diode laser to independently align the TWIN amplifier from the front-end.

Diagnostics: beam pointing and beam profile.

Active electro-optic back scattering or reflected light protection.

TWIN amplifier (version up to < 50 J)



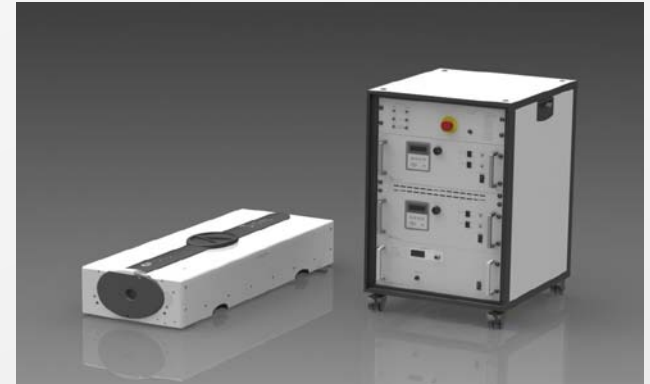
- ▲ This amplifier boosts pulse energy from 2.5 J up to 38 J with a pulse to pulse stability of 0.4 % RMS



Nd:YAG pump family



PROPULSE +



TITAN 6



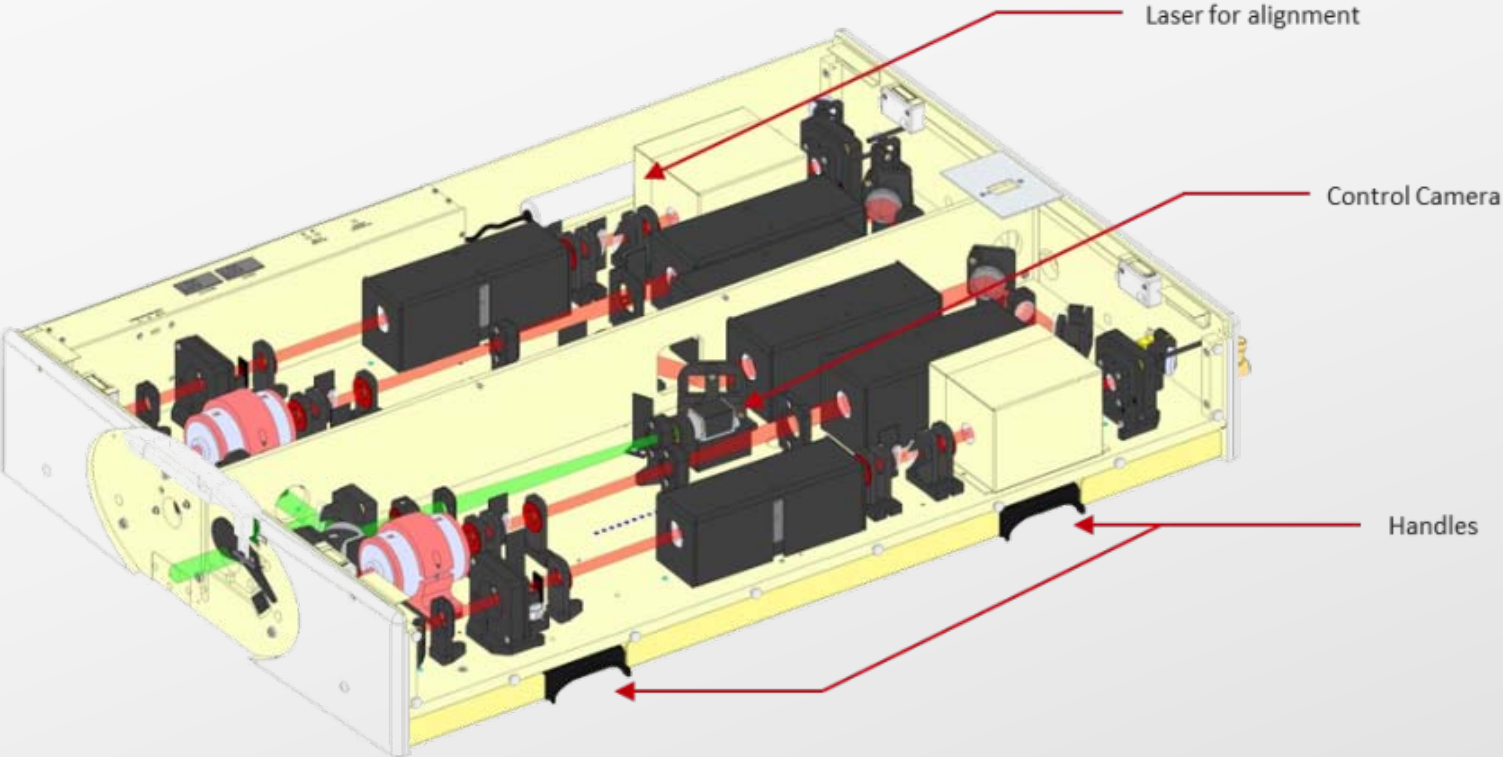
TITAN HE

NOBODY BUT US

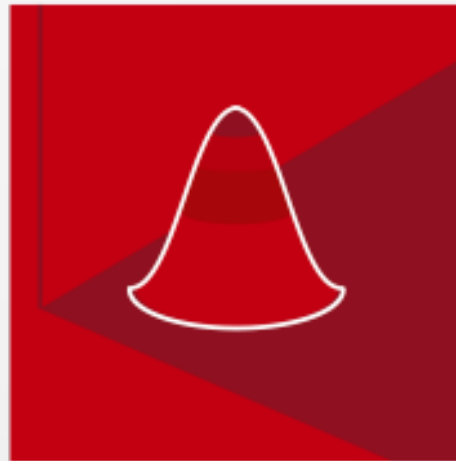
PROPULSE series : up to 2.5J at 532nm,
10Hz for TW class lasers

TITAN series : up to 10J at 532nm, 5Hz
for PW class lasers

Nd:YAG pump laser family



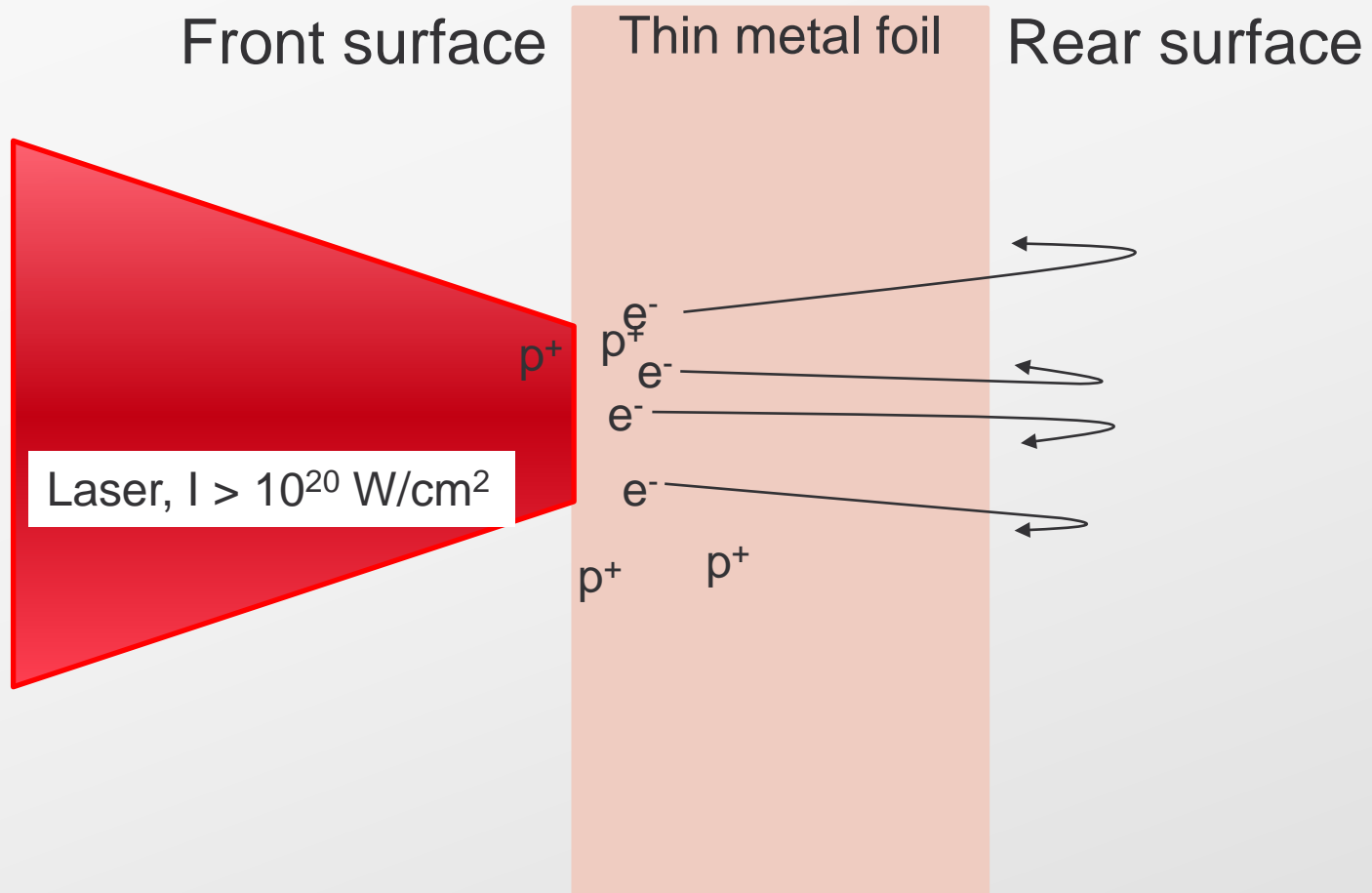
TITAN HE LAYOUT



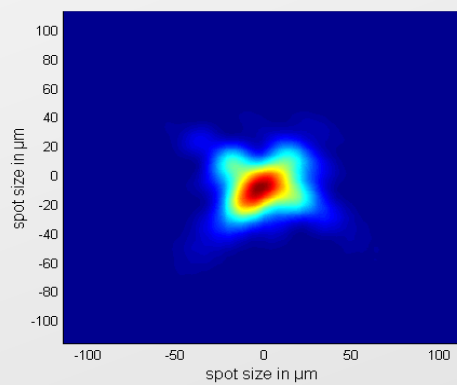
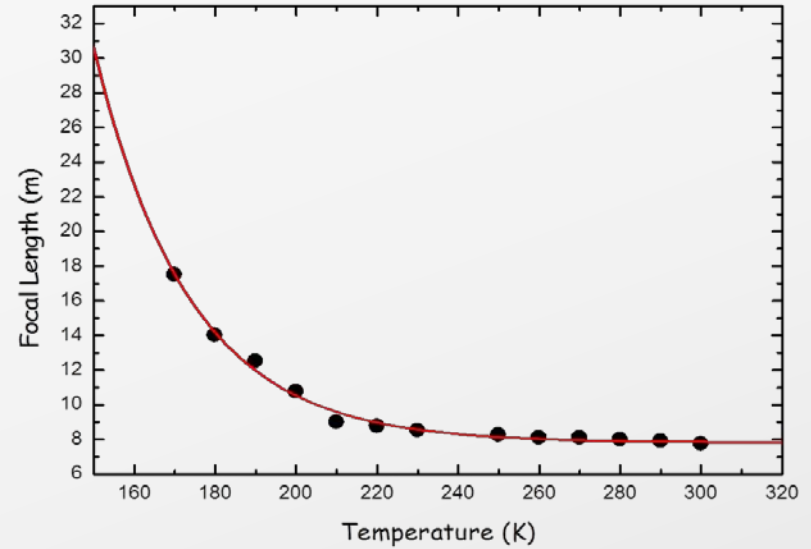
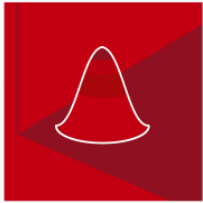
High Quality Wavefront



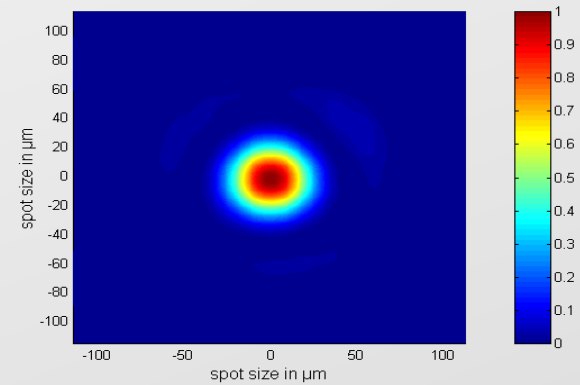
FOCUSSING STABILITY



CRYOSTAR V2.0

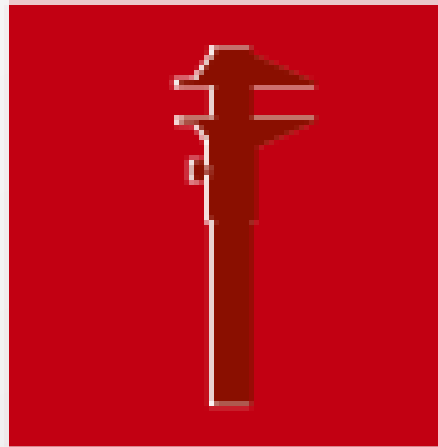


Water cooling



Cryo cooling

nothing but ultrafast



Metrology



SEQUOIA

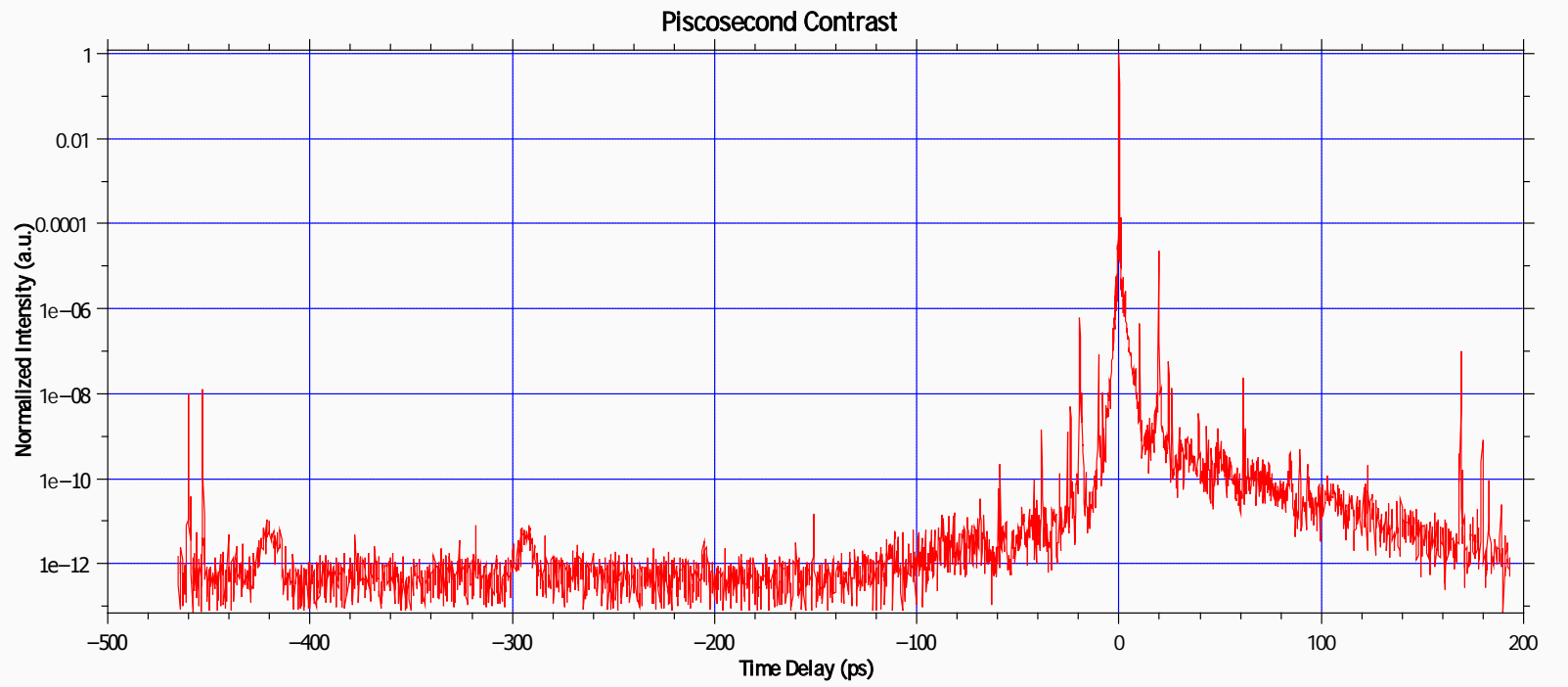
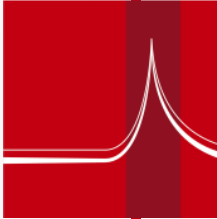
Reference product in temporal contrast measurement

- ^ Developed by Amplitude Technologies under license from the French Atomic Energy Commission, the CEA.
- ^ Ultra-high dynamic range ($> 10^{12}$) to permit characterization of high peak power laser systems
- ^ Robust and standardized measurement tool suitable for daily use



HD version
Commercially available soon

JETI100



Ultra-short high peak power laser
16 fs as temporal duration at 250 TW (4 J)
5 Hz - Temporal contrast 10^{12}

PULSAR PW metrology bench

- ▲ Compatible for beams up to 250 mm

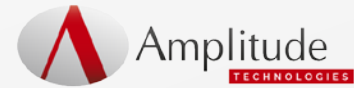
Demagnifying telescope



Metrology bench:
wavefront, beam profile, energy,
contrast (SEQUOIA), pulse duration &
spectral phase (WIZZLER, SPIDER),

ABOUT AMPLITUDE TECHNOLOGIES



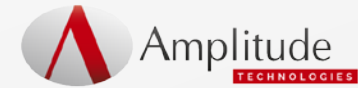


AMPLITUDE GROUP



nothing but ultrafast

Continuum[®]



Minilite

Inlite

Surelite

Powerlite

Custom



25 - 50 mJ

- Cadence 1 -15 Hz
- 1 oscillateur

250 - 450 mJ

- 1-20 Hz
- 1 oscillateur
- Cavité replier
- Modèle industriel

450 – 650 – 850 mJ

- 10 Hz
- 20 et 30 Hz en options
- 1 oscillateur

1.2 -1.6-2-3J

- 10 Hz
- 20 30 et 50 Hz en options
- 1 oscillateur
- 1 ou 2 amplificateurs

>100 J

- Plusieurs amplificateurs
- 1 tir / minute
- 1 tir / heure

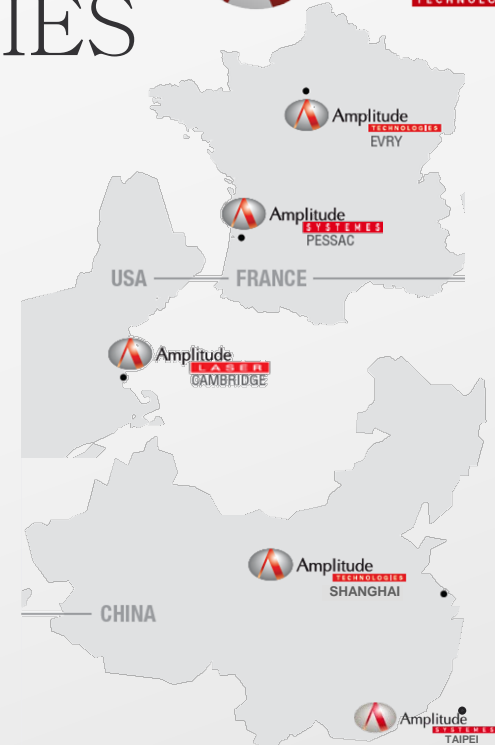
nothing but ultrafast

AMPLITUDE TECHNOLOGIES



Amplitude Technologies in figures...

- ▲ 25 x 100 TW-class laser system installed
- ▲ > 50 femtosecond Ti:Sa lasers installed
- ▲ > 200 nanosecond Nd:YAG lasers installed



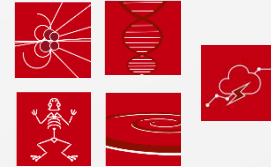
nothing but ultrafast

Organization & expertise



Realization of femtosecond high intensity laser systems for scientific applications

Design *User support*
Manufacturing *Training*
Installation



R&D

Femtosecond
 Nanosecond
 Metrology
 Applications

Engineering

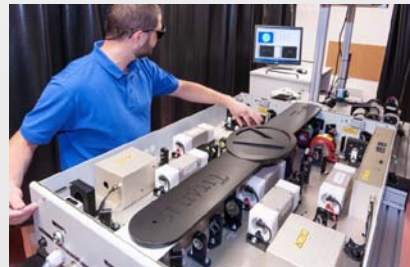
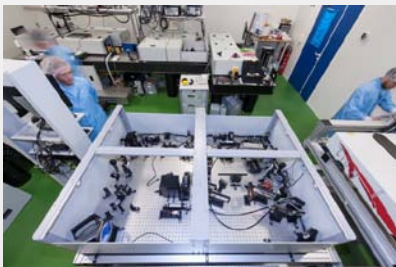
Optics
 Mechanics
 Electronic
 Computer engineering
 Process & Quality

Production

Mechanics workshop
 Electronic workshop
 Femtosecond department (Ti:Sa)
 Nanosecond department (Nd:YAG)
 Project management

Supply chain

Purchasing
 Stocks management
 Qualification



Product family

^ Femtosecond laser systems

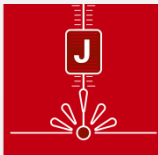
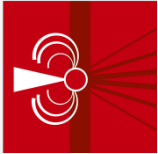
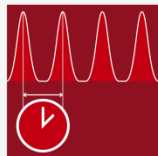
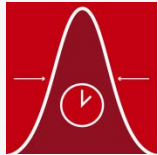
- > TRIDENT
- > CENTAURUS
- > TT-MOBILE
- > PULSAR
- > AURORA

^ Nd:YAG high energy pulsed lasers

- > PROPULSE+
- > TITAN

^ Metrology

- > BONSAI
- > SEQUOIA



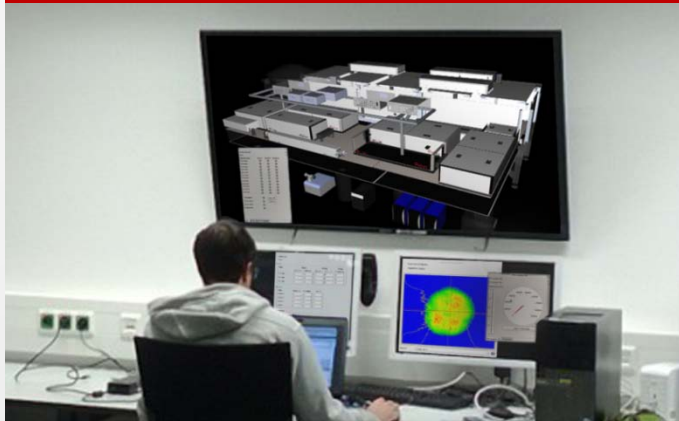
PULSAR PW laser system



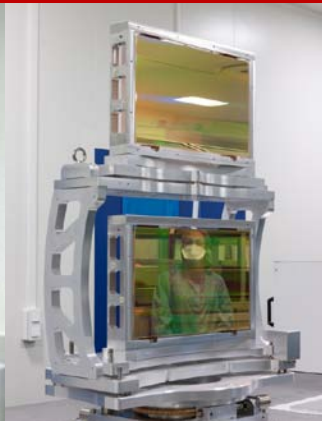
TWIN amplifier and TITAN pump lasers



TWIN amplifier



CONTROL / COMMAND



Compressor and vacuum chamber

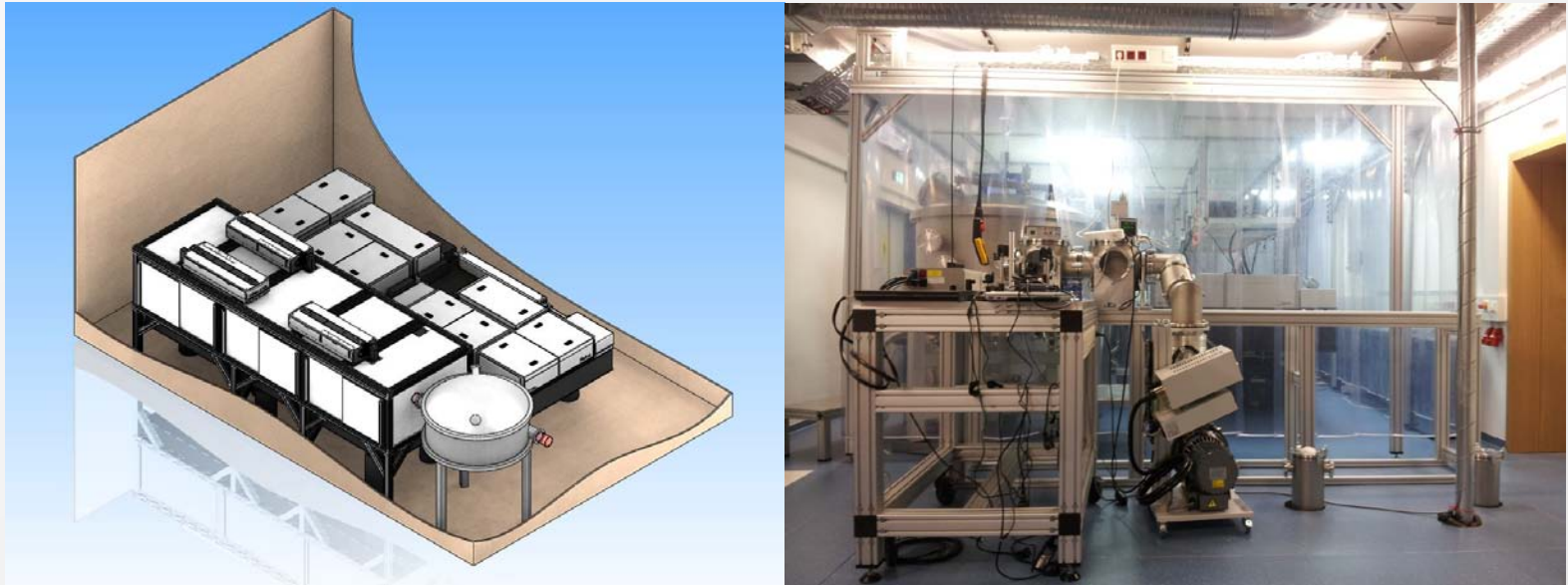
Laser in a container



TT-MOBILE version

JETI100

Prof. Dr. Gerhard Paulus / ultra-compact high peak power laser system



Ultra-short high peak power laser
16 fs as temporal duration at 250 TW (4 J)
5 Hz - Temporal contrast 10^{12}



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Area sales engineer

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AMPLITUDE TECHNOLOGIES

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CE 2926 Lisses
91029 Evry - France

AMPLITUDE LASER

One broadway, floor 14
Cambridge, MA 02142
USA

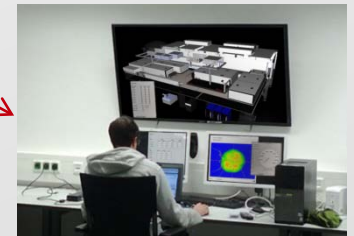
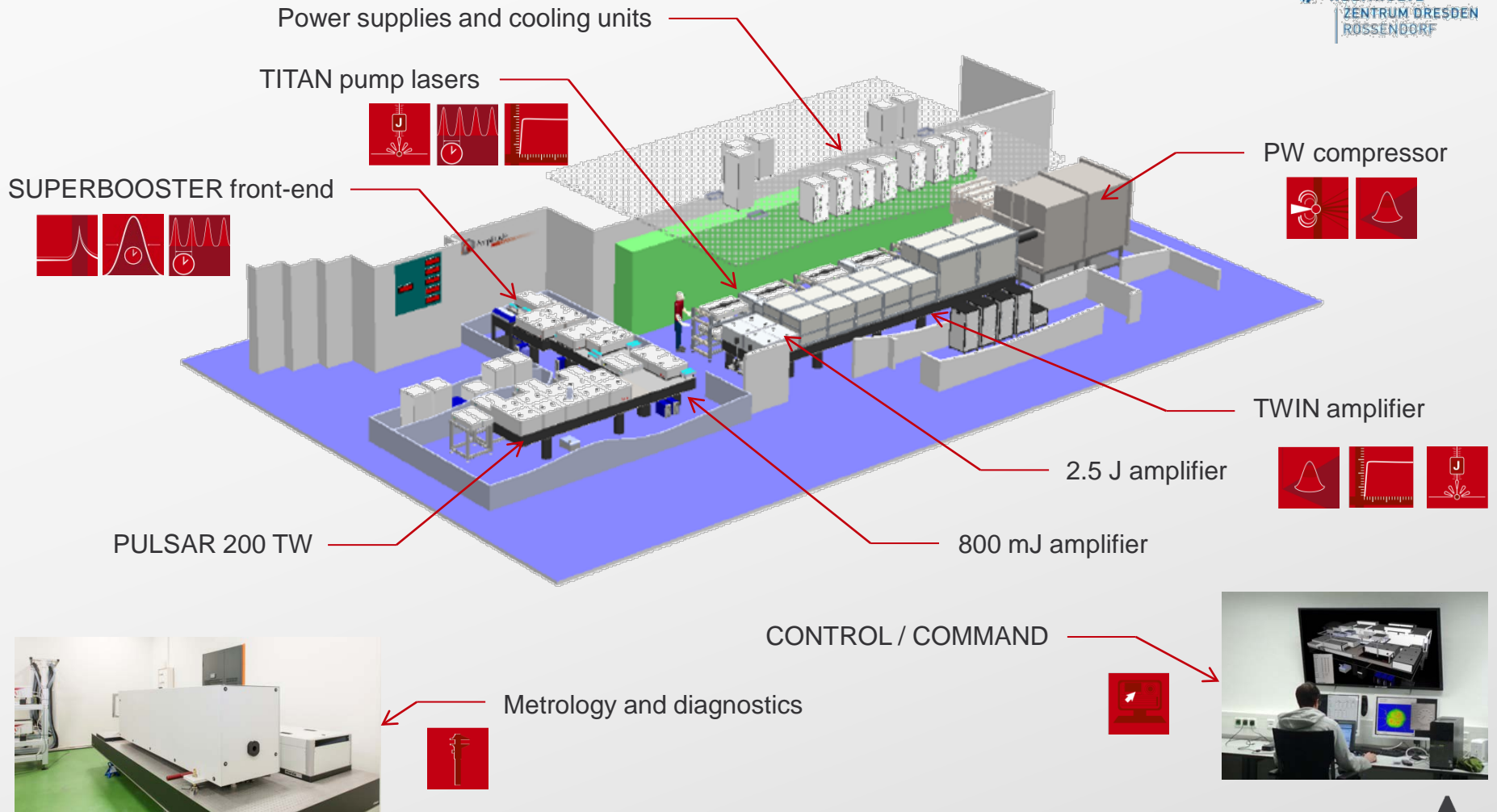
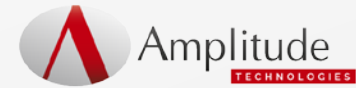
AMPLITUDE TECHNOLOGIES

Pythagore Optical Business Center
323 Guo Ging rd, bld 3, 9th floor,
Yangpu district
200 433 Shanghai - China

AMPLITUDE SYSTEMES

11, avenue de Canteranne
Cité de la Photonique
33600 Pessac - France

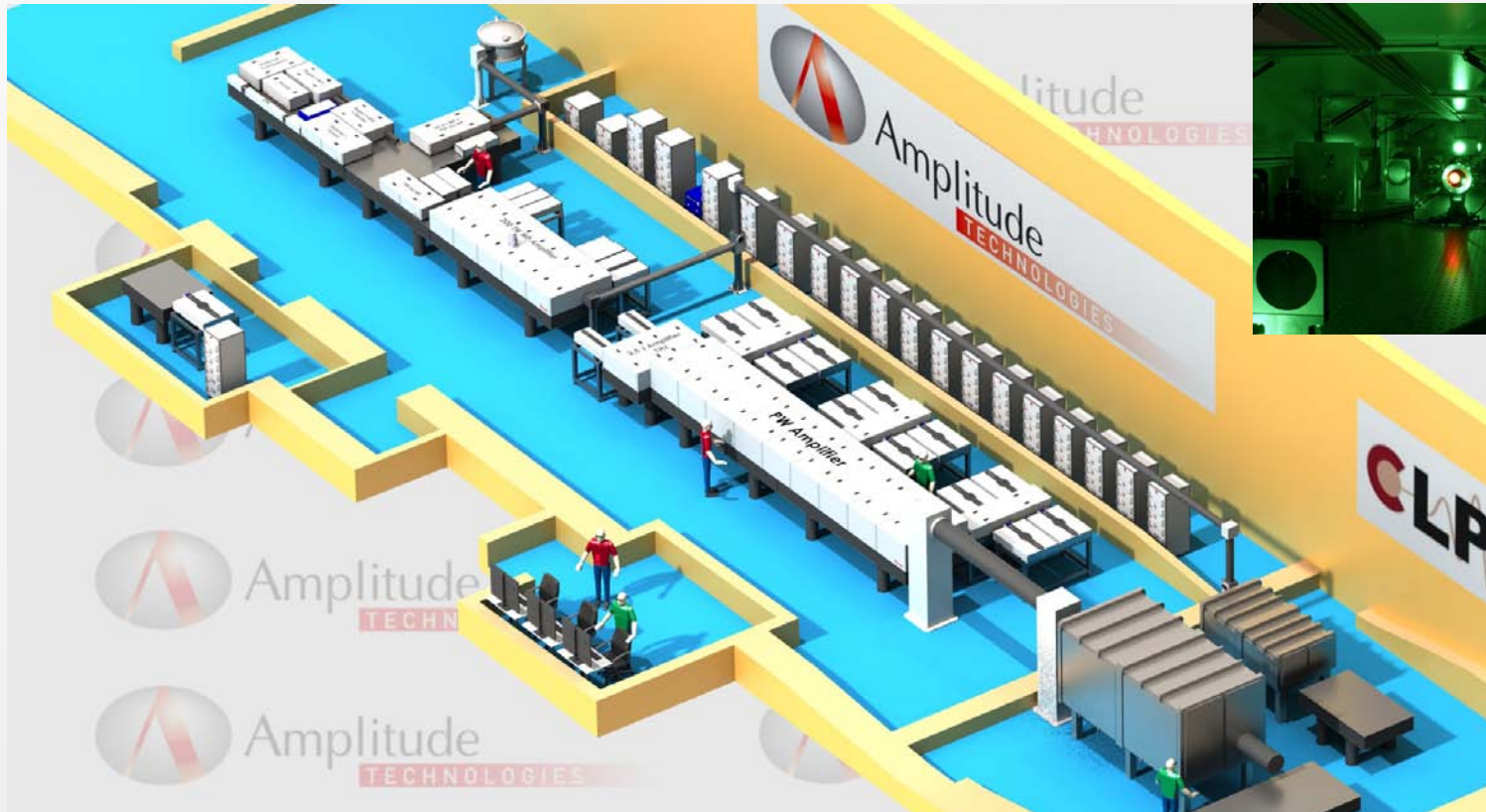
PULSAR PW laser system / DRACO



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VEGA LASER SOURCE

Centro de Laseros Pulsados / Prof. Dr. Luis Roso



PULSAR PW – 1 Hz – < 25 fs – Temporal contrast 10^{12}
Multiple high peak power laser outputs

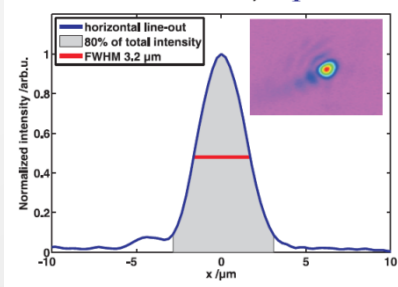
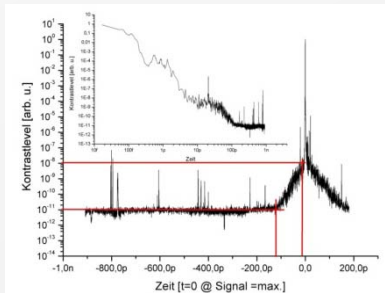
DRACO

Courtesy of

Dresden laser acceleration source (since 2008) / DRACO

Prof. Dr. Ulrich Schramm

Laser Particle Acceleration Division / Institute for Radiation Physics



PULSAR 200 TW – 10 Hz – 25 fs – ASE < 10⁻⁹

DRACO

Courtesy of

Dresden laser acceleration source / DRACO

Prof. Dr. Ulrich Schramm

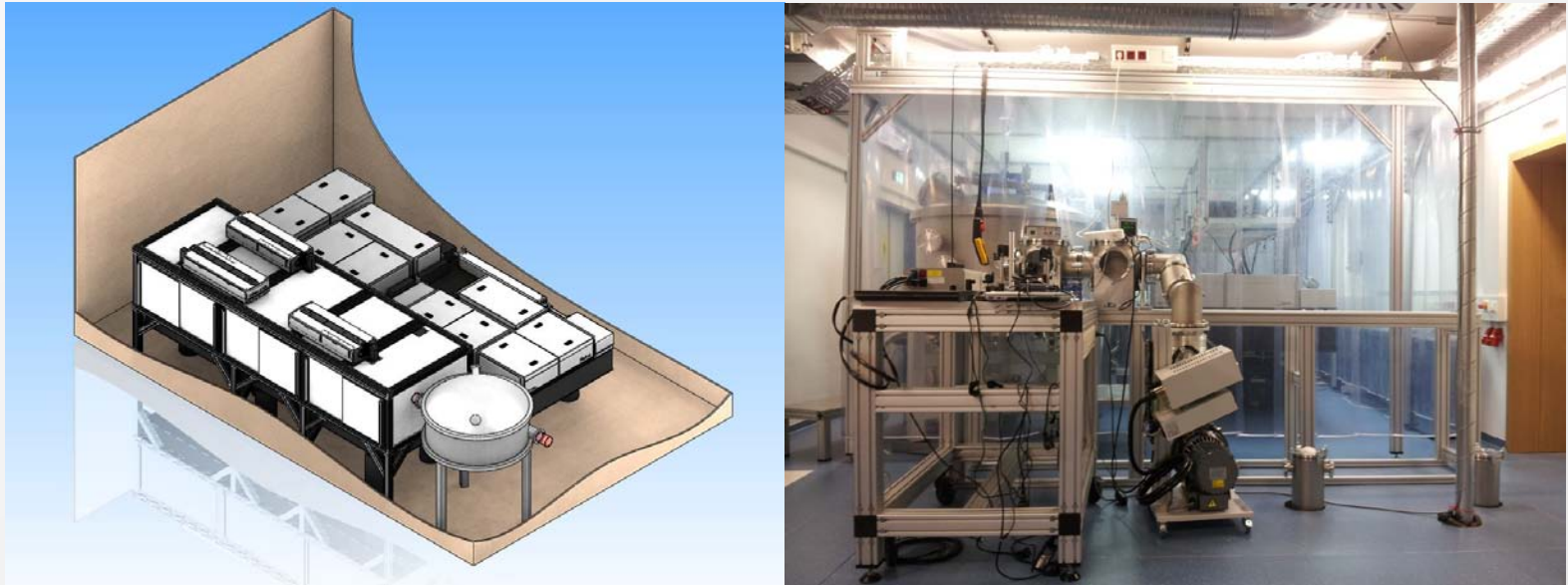
Laser Particle Acceleration Division / Institute for Radiation Physics



PULSAR PW – 1 Hz – < 25 fs – ASE $< 10^{-12}$

JETI100

Prof. Dr. Gerhard Paulus / ultra-compact high peak power laser system



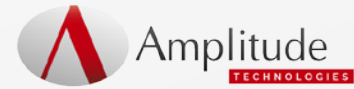
Ultra-short high peak power laser
16 fs as temporal duration at 250 TW (4 J)
5 Hz - Temporal contrast 10^{12}

TECHNOLOGICAL AND TECHNICAL CHALLENGES





PW lasers... unique tools for high intensity physics



 **Performances**

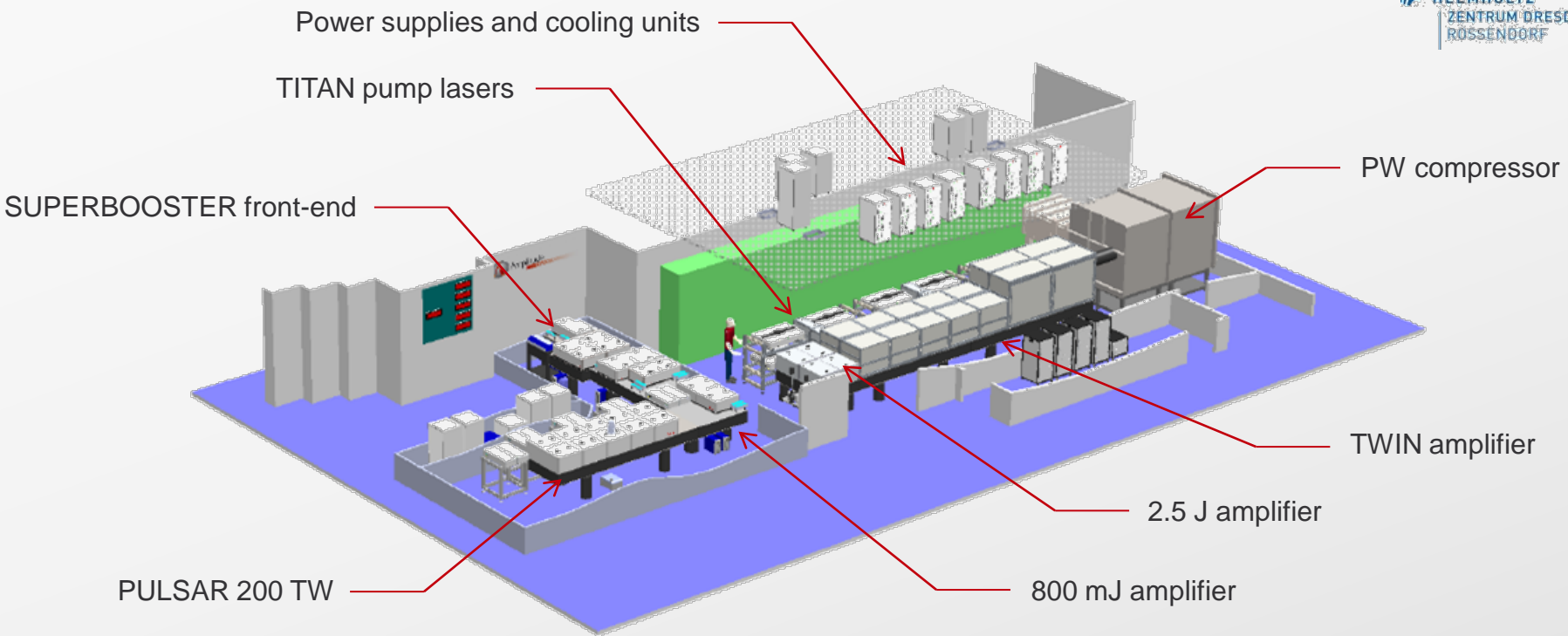
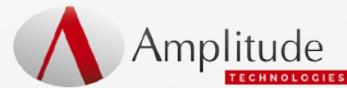
 **Quality**

 **Human engineering**

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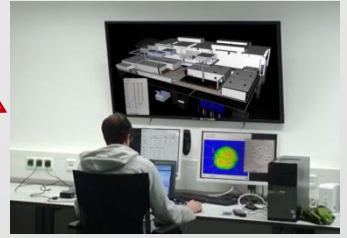


PULSAR PW laser system



Metrology and diagnostics

CONTROL / COMMAND

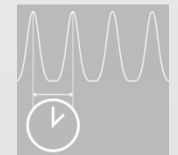
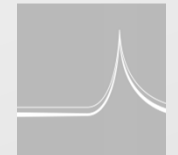
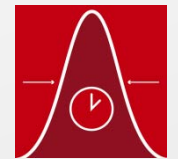


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Laser systems dedicated for high field physics

Demands for experimentations

- ▲ **High pulse energy on the target**
high photon/particles conversion
- ▲ **Ultra-short and tunable pulse duration**
high electric field (high ionization of the material)
- ▲ **High quality wavefront**
best focalization on the target
- ▲ **High temporal contrast**
Best quality of the process and of the generated plasma
- ▲ **High repetition rate**
high repeatability of the experimentations
- ▲ **User-friendly control / command interface**
to ease the use of the laser system



Focus on pulse duration optimization for high intensity physics

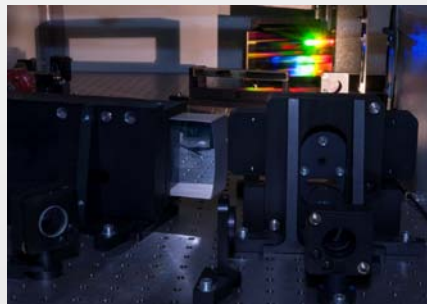
▲ **Ultra-short and tunable pulse duration**

high electric field (high ionization of the material)

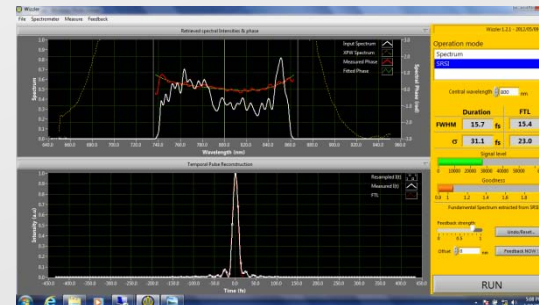


- > Sub-20 fs laser pulse
- > Tunable pulse duration
- > CEP stabilized front-end

- ▲ Active control of the spectrum to allow the possibility to have **ultra-short pulse duration** (≤ 25 fs) and **optimum pulse duration quality** for high field physics. It also enables to vary the pulse duration from 25 fs to 50 fs FT without any changes in the laser systems.



CEP PW Stretcher



Sub-20 fs 100's TW laser

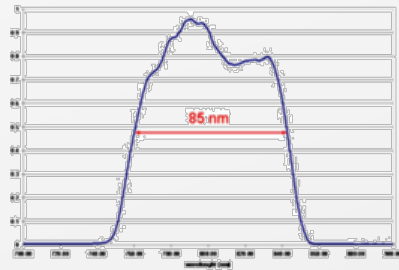
Broad spectrum and femtosecond pulse duration control

^ Typical optical and mechanical engineering

- > Strengthened quality process for the selection of broad bandwidth optical component

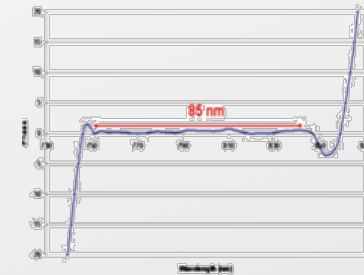


^ Laser pulse spectrum management

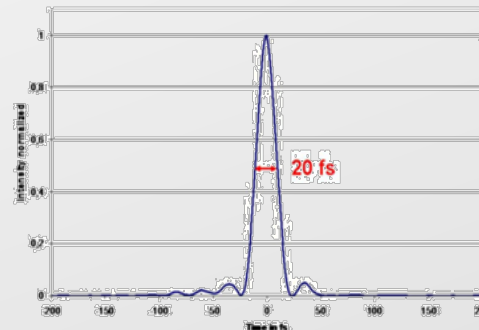


Spectral amplitude monitoring

Independent control and optimization

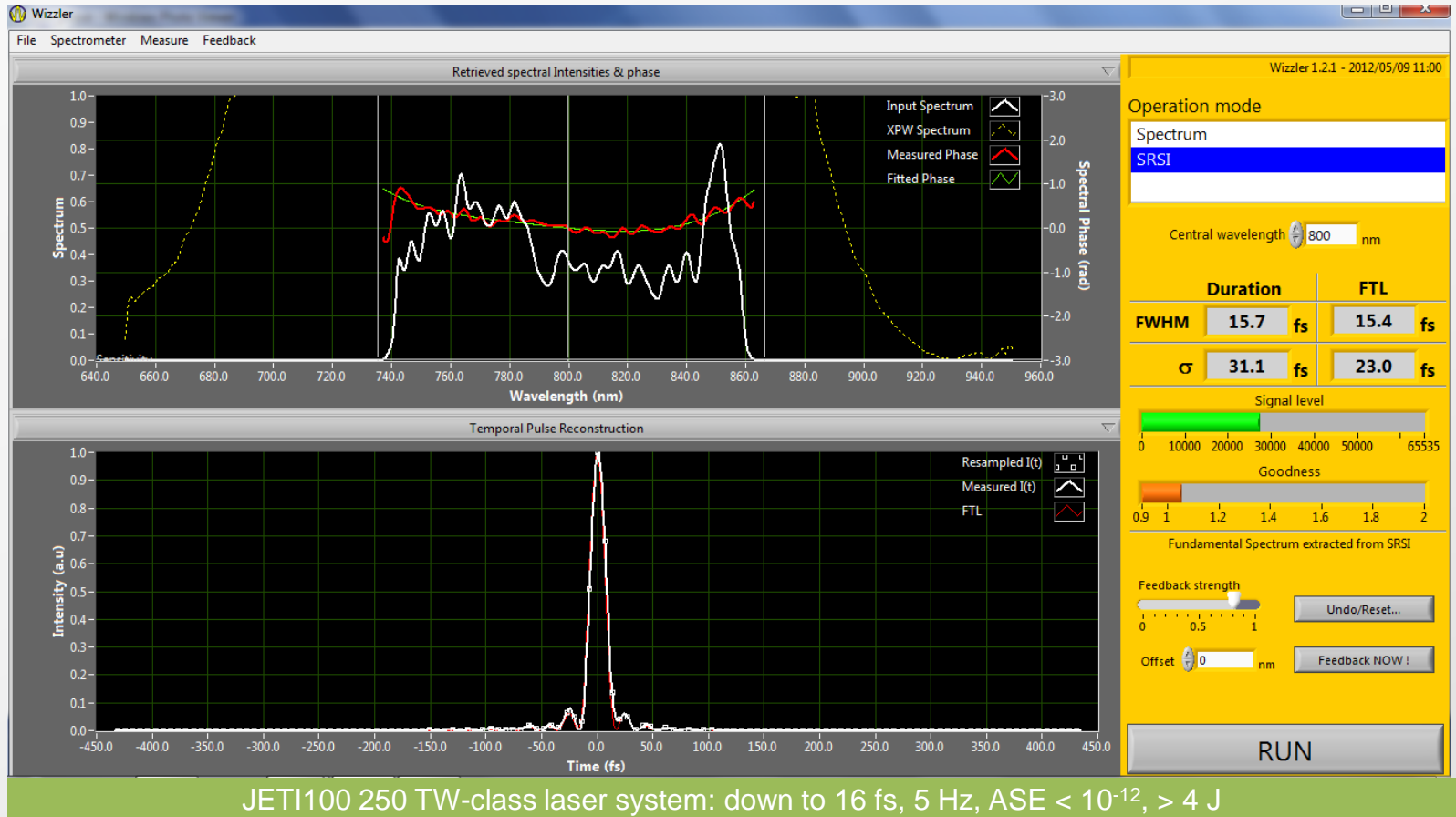


Spectral phase monitoring



Ultra-short pulse duration

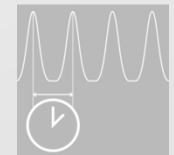
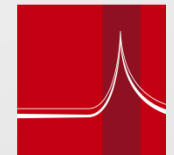
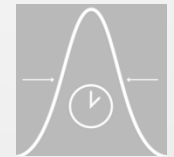
Results: ultra-short high peak power laser



Laser systems dedicated for high field physics

Demands for experimentations

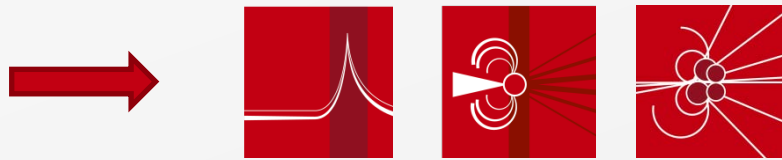
- ▲ **High pulse energy on the target**
high photon/particles conversion
- ▲ **Ultra-short and tunable pulse duration**
high electric field (high ionization of the material)
- ▲ **High quality wavefront**
best focalization on the target
- ▲ **High temporal contrast**
Best quality of the process and of the generated plasma
- ▲ **High repetition rate**
high repeatability of the experimentations
- ▲ **User-friendly control / command interface**
to ease the use of the laser system



Focus on contrast enhancement

^ High temporal contrast

Best quality of the process and of the generated plasma



- > Temporal contrast management
- > Reproducible experimentations
- > Full peak power inside the laser pulse

- ^ 1 PW laser means $> 10^{22} \text{ Wcm}^{-2}$ on the target [cf. references]
- ^ **Contrast** = $I_{\text{femtoseconde}} / I_{\text{ASE}}$
- ^ **Laser-matter interaction** (solid target) experimentations sensitive to the ASE contrast.
- ^ **Proton generation** => laser-interaction with thin metallic target.
- ^ The **ASE pedestal** could ionized the matter and destroy the solid target, if it is above the **ionization threshold** ($\sim 10^{10}$).
- ^ Contrast $> 10^{10}$ is needed

Contrast cleaning approach

Unique process thanks to combination of techniques

- ^ **Femtosecond coherent contrast**
 - > Active control loop of the pulse duration

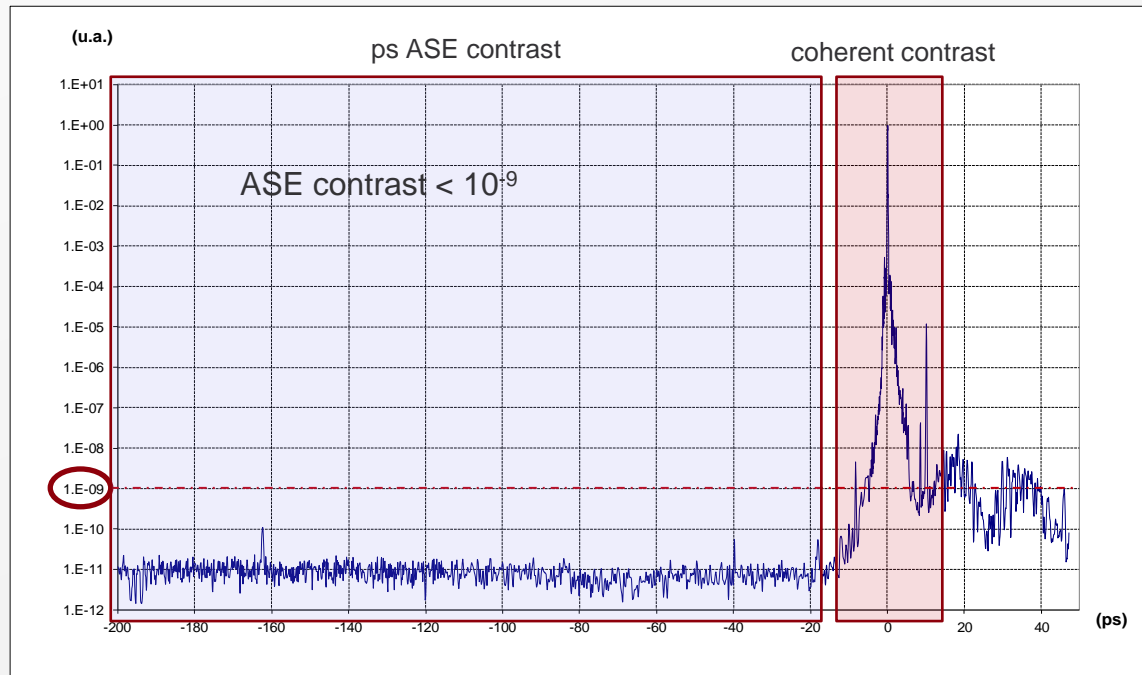
- ^ **Picosecond contrast**
 - > Non linear modules

- ^ **ASE contrast**
 - > (SUPER)BOOSTER

- ^ **Nanosecond contrast**
 - > Electro-optics and pump lasers delays management

- ^ **Dedicated metrology with SEQUOIA**
 - > To monitor on a daily basis the temporal contrast

BOOSTER module results



Typical SEQUOIA measure at full energy for a 100's TW-class PULSAR

- ns guaranteed $< 10^{-6}$
- 1 ps guaranteed $< 10^{-3}$
- 5 ps guaranteed $< 10^{-5}$
- 20 ps guaranteed $< 5 \cdot 10^{-6}$
- ASE guaranteed $< 10^{-9}$

- ns measured at FAT $9 \cdot 10^{-8}$
- 1 ps measured at FAT $2 \cdot 10^{-5}$
- 5 ps measured at FAT $5 \cdot 10^{-8}$
- 20 ps measured at FAT 10^{-9}
- ASE measured at FAT 10^{-10}

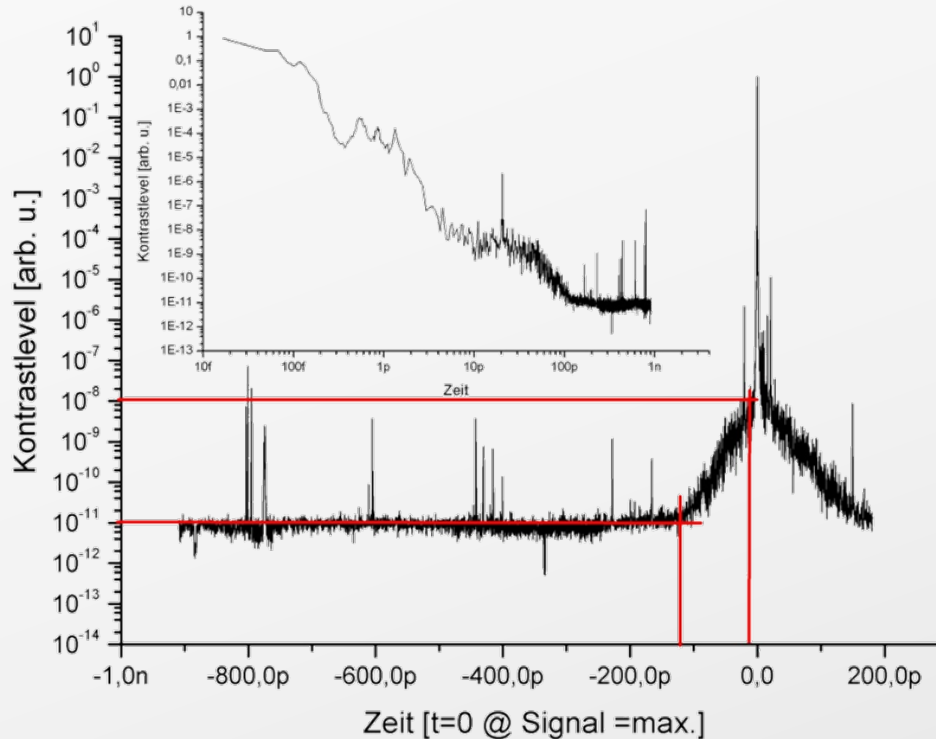


VNIVERSIDAD
D SALAMANCA



PULSAR 20 TW, 10 Hz
VEGA I laser source

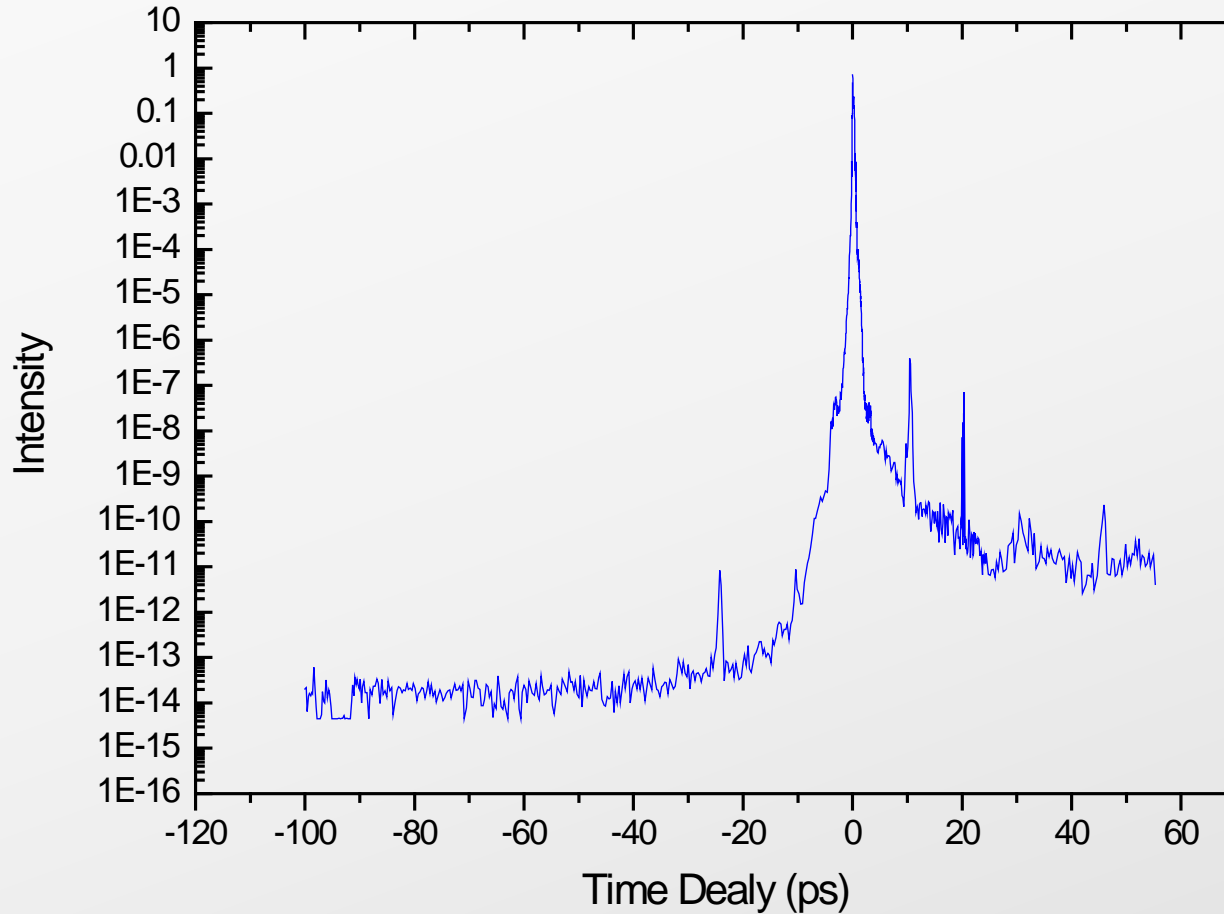
BOOSTER module results



PULSAR 150 TW, 10 Hz
DRACO laser source

Typical SEQUOIA measure at full energy for a 100's TW-class PULSAR

High ASE temporal contrast



R&D
Measured by
SEQUOIA HD

With **SUPERBOOSTER** module:
Contrast up to 10^{14} !

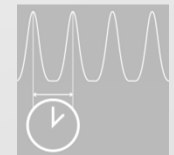
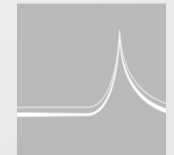
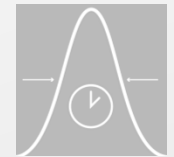
Temporal contrast comparison

<i>Orders of magnitude of contrast</i>		BOOSTER	XPW-seeder	SUPERBOOSTER	DAZZLER - WIZZLER
Coherent contrast	1ps	3	3	3	5
	5ps	5	5	5	7
ASE contrast	20ps	7	7	9	7
	50ps	9	9	11	9
	>50ps	9	10	12	9

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high repeatability of the experimentations
- ▲ **User-friendly control / command interface**
to ease the use of the laser system




AMPLITUDE TECHNOLOGIES DEVELOPMENT





2001  Creation of Amplitude Technologies

HAMAMATSU


2004  PULSAR 100 TW (3 J, 30 fs , 10 Hz, ASE <math>< 10^{-6}</math>)



2006  PULSAR 200 TW (5 J, 25 fs , 10 Hz, ASE <math>< 10^{-9}</math>)

2012  PULSAR UltraShort (> 4 J, <math>< 20</math> fs , 5 Hz, ASE <math>< 10^{-12}</math>)



2013  PULSAR PW (> 25 J, <math>< 25</math> fs , 1 Hz, ASE <math>< 10^{-12}</math>)



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