LEADER
IN ULTRA SHORT
HIGH ENERGY
LASER SYSTEM
INNOVATION & PERFORMANCE

Novel ultra-fast, high repetition rate light sources based on Ti:Sapphire :
the impact of pump sources on reliability and stability

➢Federico CANOVA, Ph.D
VP, Global Sales Manager

> PSI, Villigen

> AMPLITUDE GROUP

- > Created in 2001
- > 25 M€ in 2011
- > 170 employees

Companies

- > AMPLITUDE TECHNOLOGIES
  - ❖ Leader in Ti:SA technology
- > AMPLITUDE SYSTÈMES
  - ❖ Leader in Yb technology

Service and sales offices

- > AMPLITUDE LASER (subsidiary)
  - ❖ MA, USA
- > AMPLITUDE TECHNOLOGIES China (business incubator)
  - ❖ SHANGHAI, CHINA

PYTHAGORE
OPTICAL BUSINESS IN CHINA

> PULSAR PW : *the flagship*

PW UPGRADE

3 UNDER MANUFACTURING !

HZDR

Performances	
Rep. rate	1 Hz
Pulse duration	< 25 fs
Temporal contrast	> 10^{12}
PW output energy after compression	≈ 1 PW (30J)

> 20 laser of 200W-class laser installed

> Our experience on high energy, Ti:Sa lasers for light sources

- > SOLEIL Synchrotron / France
  - ❖ *Design of a* 5 kHz, 50 W
- > Paul Scherrer Institut - SwissFEL / Switzerland
  - ❖ 100Hz, 20/40mJ, <20fs (Hauri 1 and 2)
- > High Energy Accelerator Research Organization (KEK) / Japan
  - ❖ 10/100Hz, 10mJ, FHG and THG
- > Lawrence Livermore National Laboratory / USA
  - ❖ 500mJ, 100fs, 10Hz, THG
- > ELYSE, LCP laboratory / France
  - ❖ 1 kHz / 100 Hz, 25mJ, THG
- > FLAME project, INFN / Italy
  - ❖ 5J, <25fs, 10Hz - 200TW
- > Photon Pioneers Center in Osaka University
  - ❖ 1J, <25fs, 10Hz - 45 TW

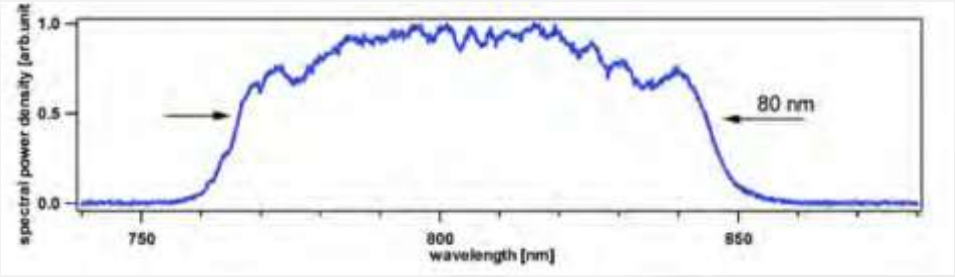
Ytterbium

> Paul Scherrer Institut – SwissFEL – HAURI1

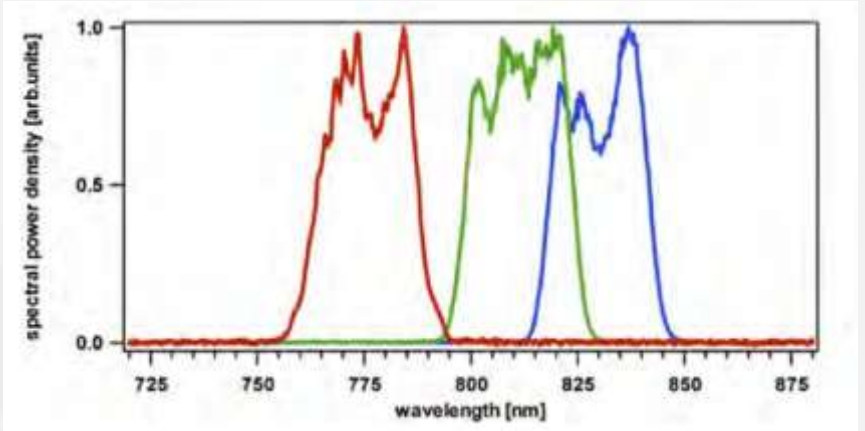
SwissFEL Injector Conceptual Design Report, PSI Bericht r. 10-05, Juil. 2010, pp. 25-28
http://www.psi.ch/swissfel/CurrentSwissFELPublicationsEN/SwissFEL_Injector_CDR_310810.pdf

λ central (nm)	785	805	835	805
bandwidth (nm)	25	25	25	90
stability (%, rms)	0.39	0.36	0.39	0.35
stability (%, P2P)	2.2	2	1.7	2.8
duration (min)	2	2	2	2
pulse energy (mJ)	18.2	18	17.9	18.2

IR stability for individual spectral slices.



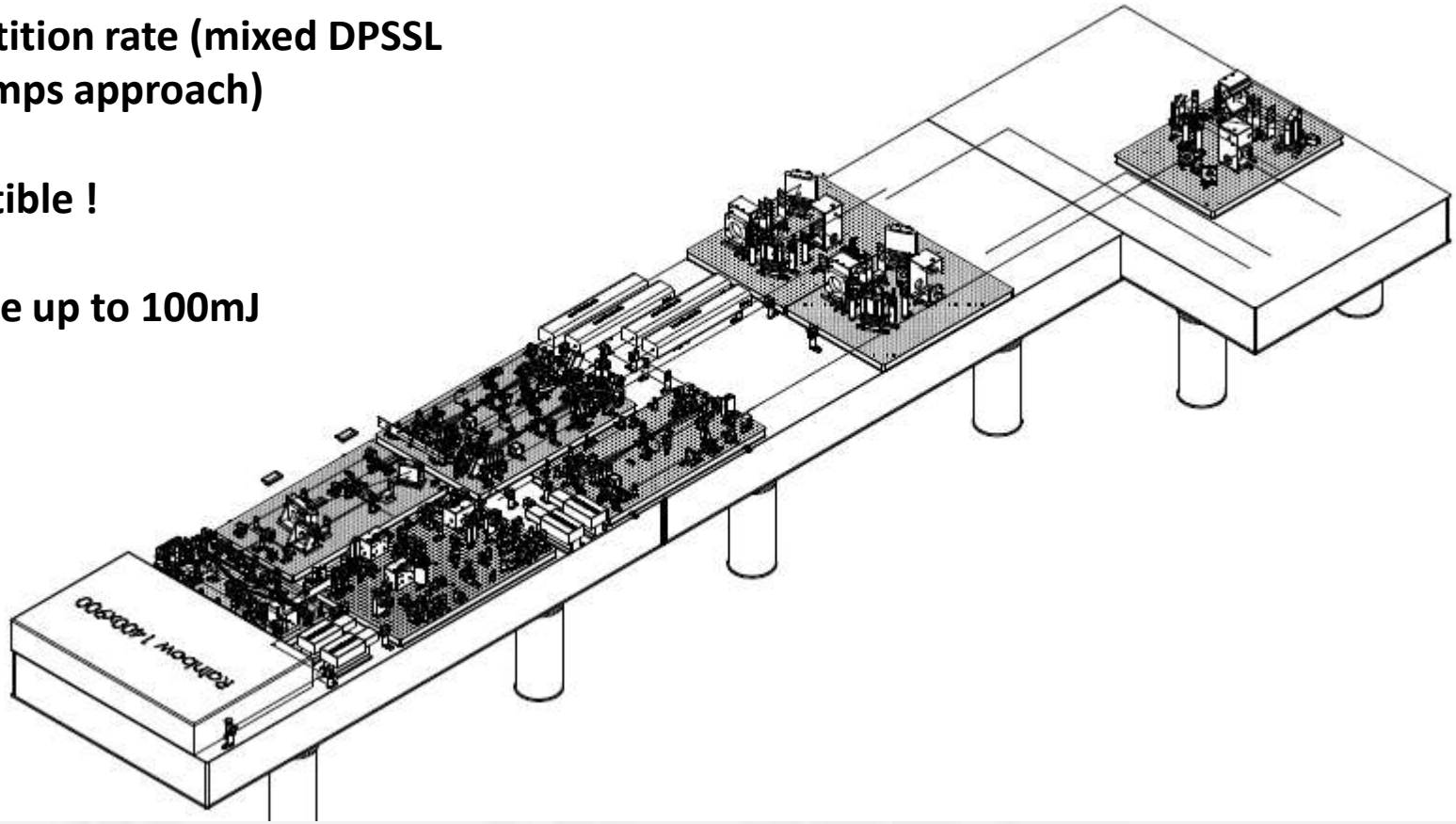
Broadband amplification in Ti:sapphire thanks to acousto-optical gain control.



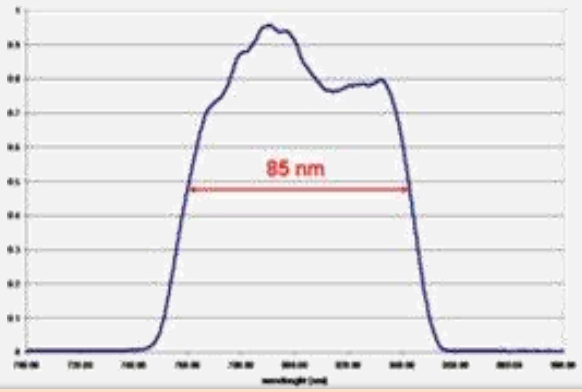
Wavelength-selected narrow-band amplification.

Project HAURI 2 – bigger, stronger and *ultra*-faster !

- **2 X outputs : 1TW, <20fs**
- **1 X output : 2,5TW, down to 15fs**
- **100Hz repetition rate (mixed DPSSL and flash-lamps approach)**
- **CEP compatible !**
- **Upgradeable up to 100mJ**



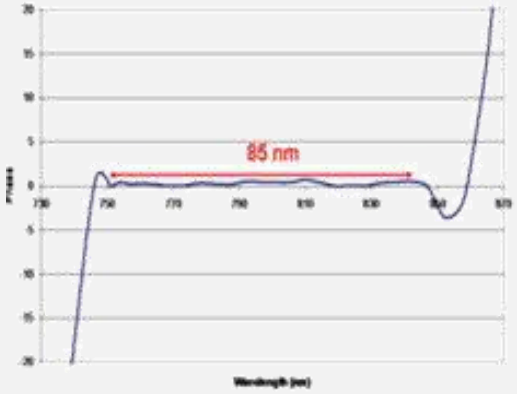
> Control femtosecond pulses duration



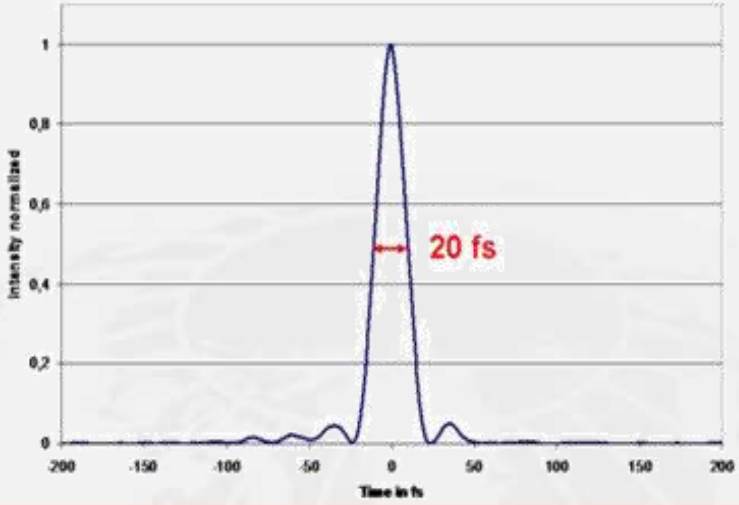
MAZZLER - **Spectral amplitude**

Independent optimizations

+



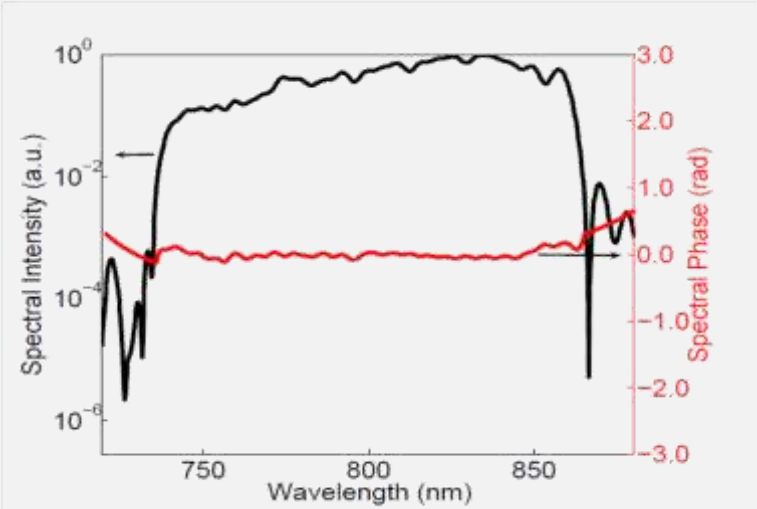
DAZZLER - **Spectral phase**

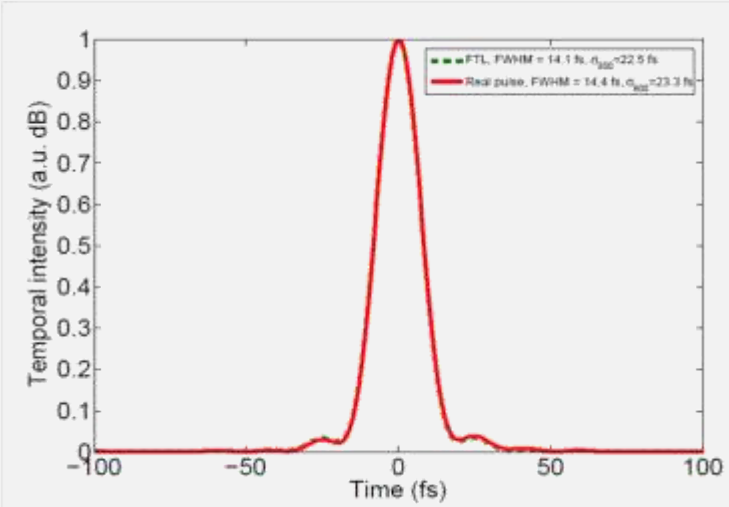


> Ultra Broadband Amplifier TW-class (**15fs**, 20mJ, 100Hz)

PAUL SCHERRER INSTITUT

PSI





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

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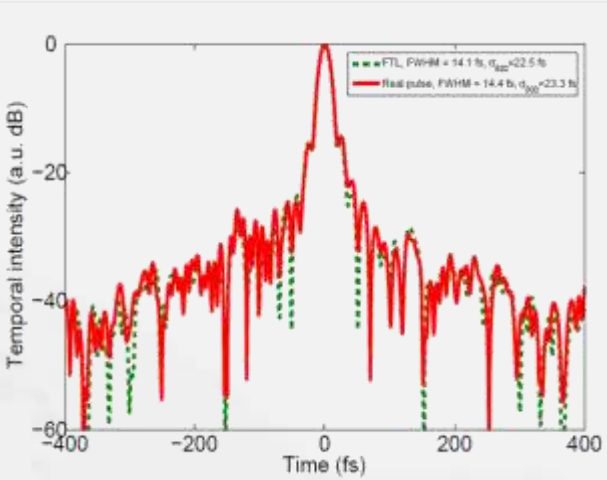

Carrier-envelope phase stabilization of a terawatt level chirped pulse amplifier for generation of intense isolated attosecond pulses

Georg Gademann,[1,*] Fabien Plé,[2] Pierre-Mary Paul, [2] and Marc J.J. Vrakking[1,3]

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[2] *Amplitude Technologies, 2-4 rue du Bois Chaland, CE 2926, 91029 Evry, France*
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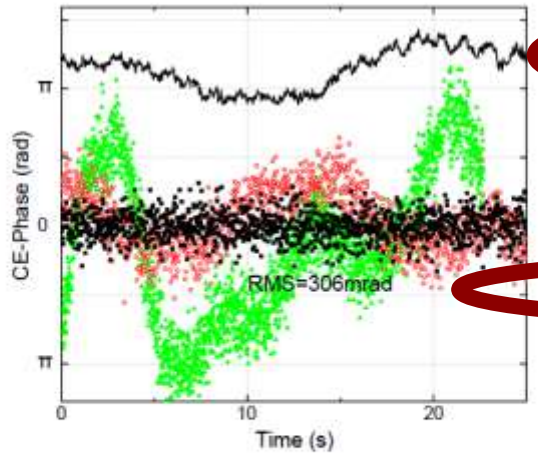


Fig. 3. Short term CEP measurements showing the stabilized (black dots) phase and the necessary compensating phase (black line) that is introduced in the grating compressor. For comparison typical cases of the free-running CEP evolution in the kHz arm (green triangles) and in the 50 Hz arm (red circles) are depicted as well. These measurements were not taken simultaneously and therefore one cannot draw any conclusions on correlation between the free running evolution in the two arms.

energies [illegible] compression. After compression the pulse energy is 35mJ at a pulse duration of 32 fs, [illegible]gnifying a peak power of 1.1 [illegible] should easily be achievable by improving the efficiency of the grating compressor. The CEP-stability of the terawatt system is demonstrated by single shot measurements of the residual CEP jitter at the full repetition rate and show an excellent root-mean-square value of 315 mrad.

CEP and amplifier jitter control are strongly linked…

> Pump lasers mixing

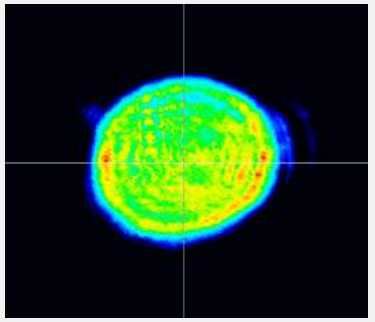
Nd:YAG pump stability:

σ_{pump} =1,2 % RMS

Mixing of N pumps :

$\sigma_{N\ pump} = \sigma_{pump} / N^{1/2}$

CALCULATED VALUES	
Number of LASER	Shot to shot stability
1	1,2 % RMS
4	0,6 % RMS
6	0,5 % RMS
8	0,4 % RMS



For 8 pump lasers mixed

Total pump energy: 15 Joules

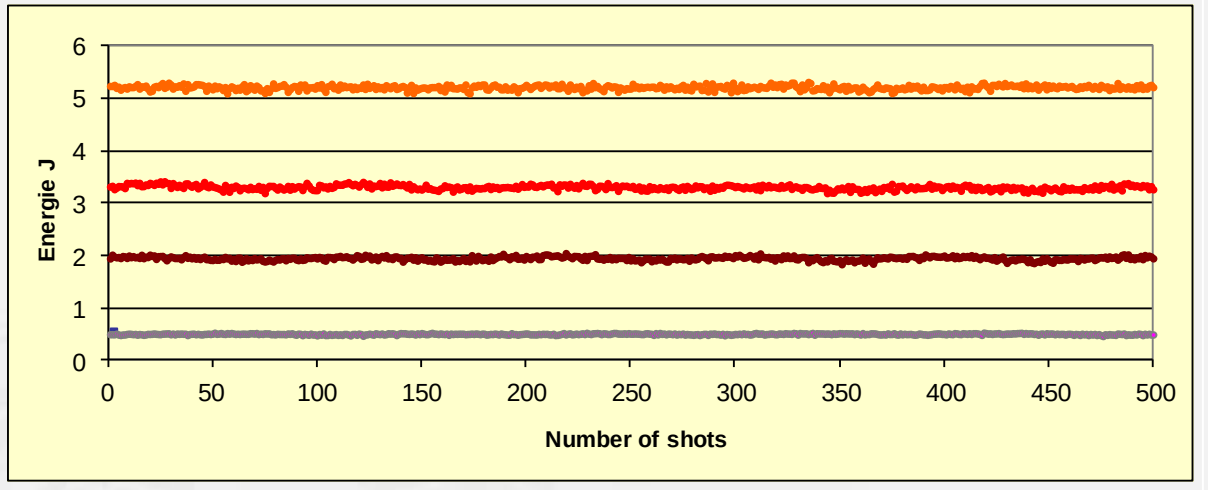
Output energy stability: 0,78% RMS

Output energy : 5,2 Joules

Measurement of energy over 500 shots.

Input energy stability: 1,9 % RMS

Input energy: 500 mJ



We are all pump lasers customers !
How we took the decision for HAURI 2… TW-class laser source

Criteria for selecting the right laser solutions dedicated to an accelerator can be:

- *1) Development, manufacturing, test and integration of the laser source versus **time** (mitigation of risks involved)*

- *2) Development, manufacturing, test and integration versus **budget***

- *3) Development, manufacturing, tests and integration versus **running costs***

Project HAURI 2 – Pump lasers strategy

Front end (RGA, pre-amp) pumps : CENTURION (Big Sky), DPSSL

High energy amplifiers (TW level) : NANO TRL LITRON), flash-lamps

Front-end pump lasers: diode pumping…

CENTURION (Big Sky)

- compact Nd :YAG with DPSSL pumping QCW
- Energy 20 mJ, at 532 nm
- Average power low (2 Watt at 532 nm max)
- beam profile Gaussian (good for far field pumping)
- Air or water cooling

With multiples CENTURION HAURI 1 had output energy stability of 0,4%RMS

- **Diode lifetime** warranty 1 Billion shots (2800 hours)
  typical 1,5 to 2 Billion shots
  That makes 175 days of operation (~6 months)

- Diode replacement cost : 40% of the purchase price , twice a year…

High energy amplifiers : flash-lamp pumping

NANO TRL (Litron)

- compact Nd :YAG with flash-lamp pumping
  (1 oscillator, 2 flash-lamps)
- energy 100 mJ, at 532 nm
- average power high (10 Watt at 532 nm max)
- beam profile super-Gaussian (good for intermediate field pumping)
- water cooling

With single pump amplifer HAURI 2 had output energy stability of <1,5%RMS

- **Flashlamp lifetime** warranty 100 Million shots
  typical 250 Million shots (700 hours)
  That makes 30 days of 24 hours operation

- Flash-lamp replacement cost : 2% of the purchase price, every month…

To resume our analysis…

DPSSL

- **Hands free operation** : OK
- **Energy**: 10mJ to 100mJ
- **Repetiton rate**: 100Hz or higher,
- **Diode lifetime** : OK ?
- **Purchase price per mJ**: medium to high ?
- **Operation cost ratio** (to purchase price) : high

Flash-lamps

- **Hands free operation**: NO
- **Energy**: 100mJ
- **Repetiton rate**: 100Hz is the maximum
- **Flash-lamp lifetime** : short !
- **Purchase price per mJ** : low
- **Operation cost ratio** (to purchase price) : low

The perfect pump laser for high repetion rate – high energy systems ?

- **High reliability** : sealed operation
- **High energy**: 1J of green,
- **High repetiton rate**: 100-300 Hz,
- ***A diode life-time equal to the instrument life-time***
- ***Purchase price per mJ as the flash-lamp sources***
- ***Operation cost ratio as the flash-lamp sources***

Are we trying to catch an unicorn?

A good candidate…**Ytterbium pumped by CW diodes**

PROS :

CW diodes for Ytterbium are TLC technology, warranty 10 000 hours, typical 30 000 hours (expected up to 50 000 hours)

30 000 hours = 1250 days = 42 months = 3,5 years…

just at the right time for the system upgrade !

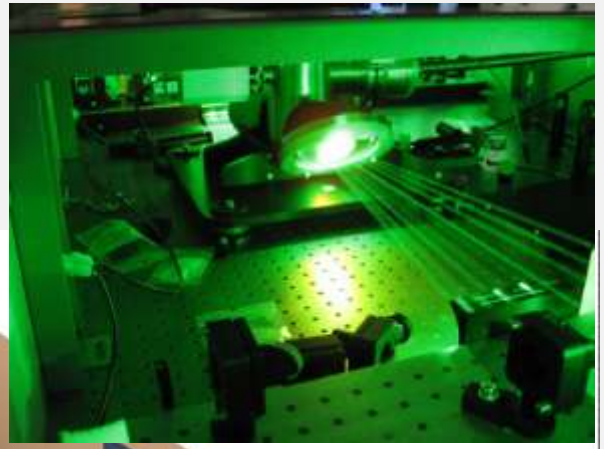
RISKS :

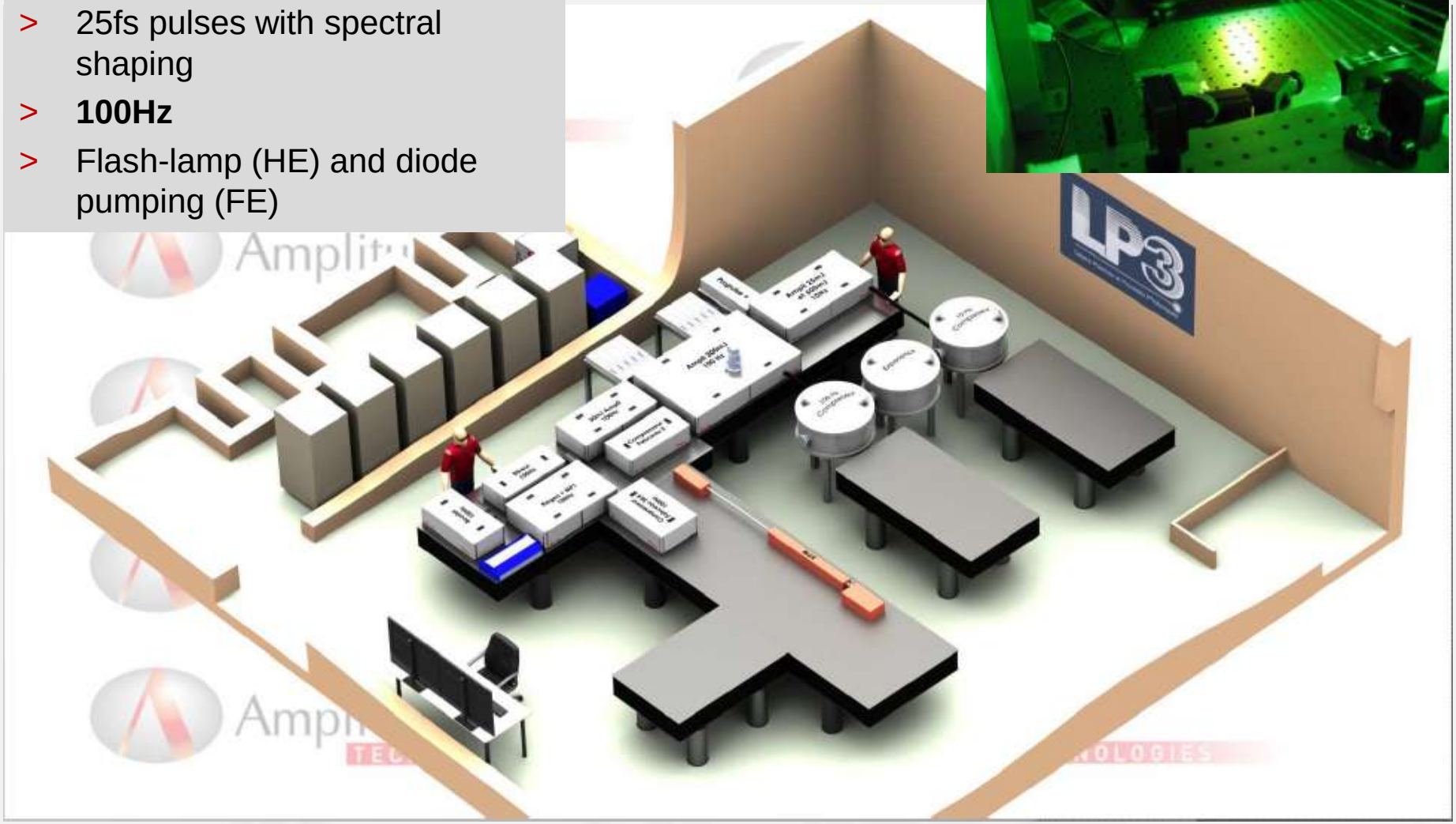
Ybb what (CaF2, YAG)? Laser architecture ? Currently a hot R&D topic…

And we know where to search for the unicorn…

ASUR: 10TW, 100Hz (*LP3, Marseille*)

- 250 mJ@800nm (compressed)
- 25fs pulses with spectral shaping
- **100Hz**
- Flash-lamp (HE) and diode pumping (FE)





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