Intense lasers: high peak power
Part 2: Propagation

Bruno Le Garrec

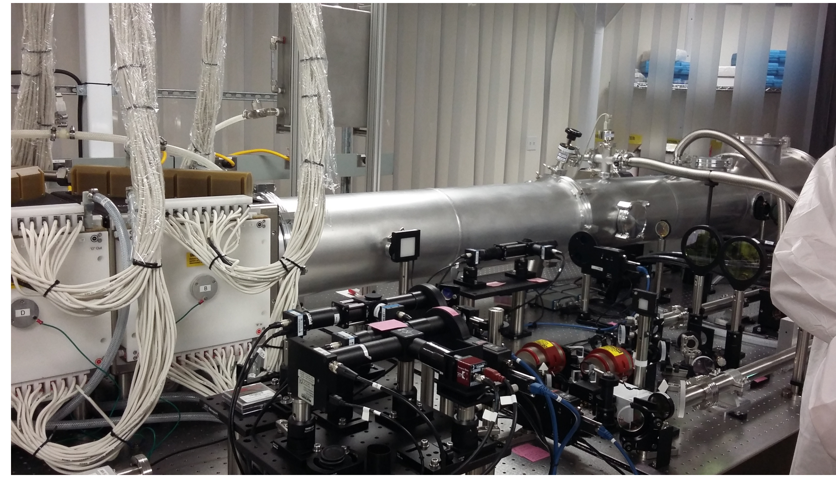
Directeur des Technologies Lasers du LULI

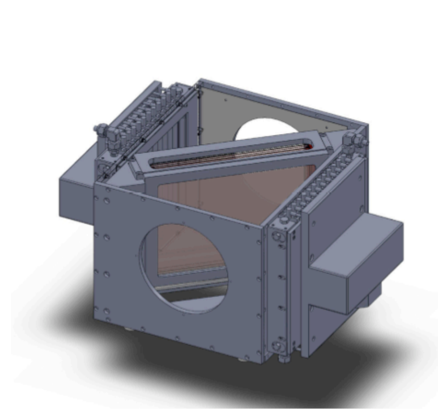
LULI/Ecole Polytechnique, route de Saclay

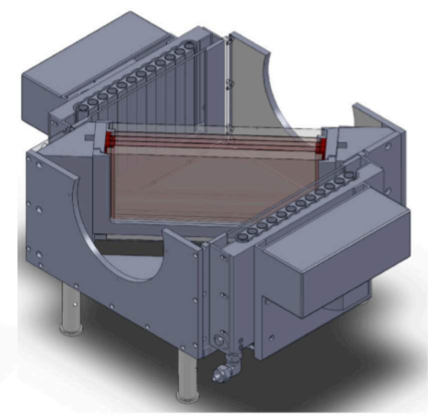
91128 Palaiseau cedex, France

bruno.le-garrec@polytechnique.edu

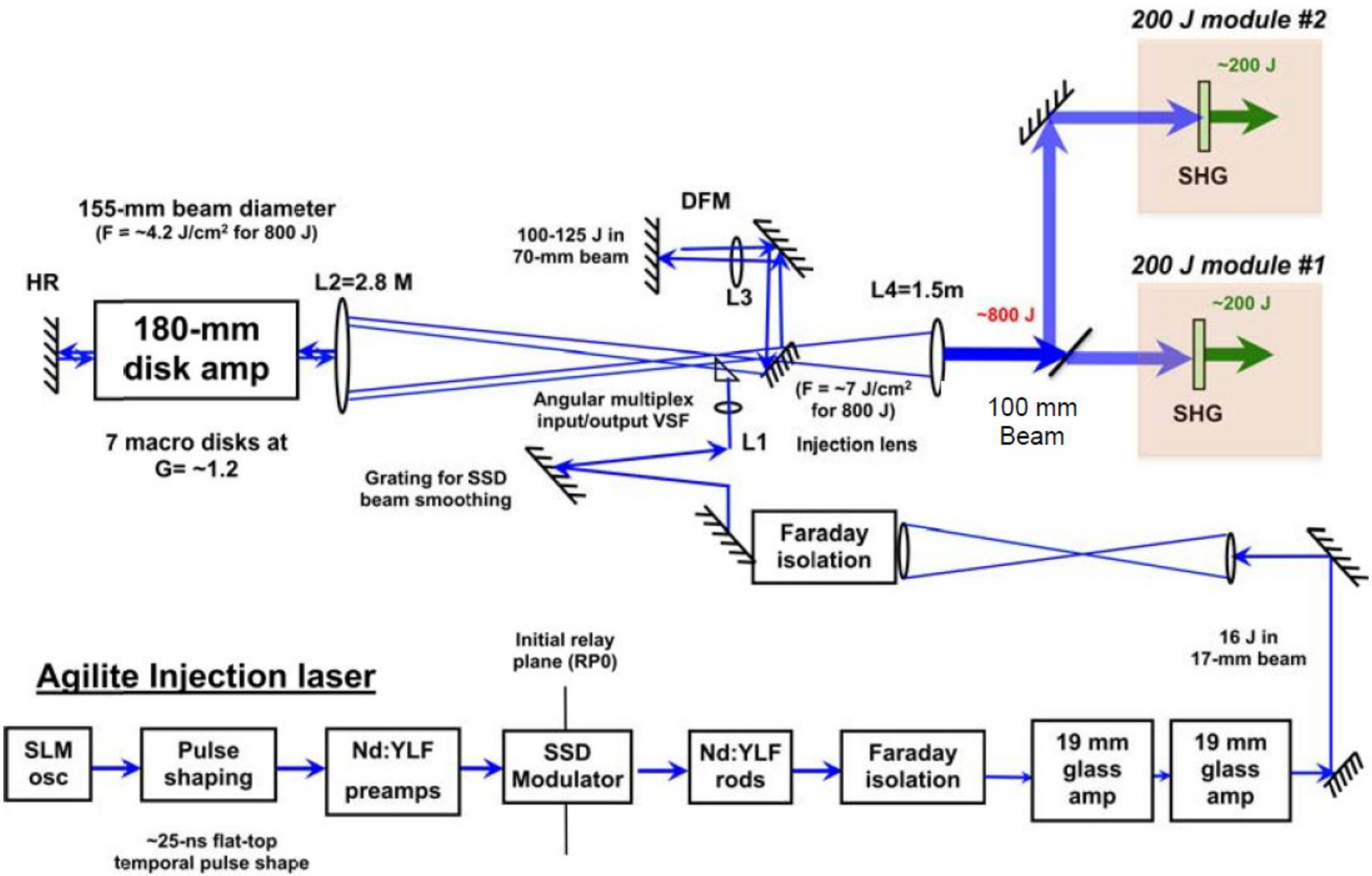
CNE400 : half kilojoule laser
Continuum - National Energetics







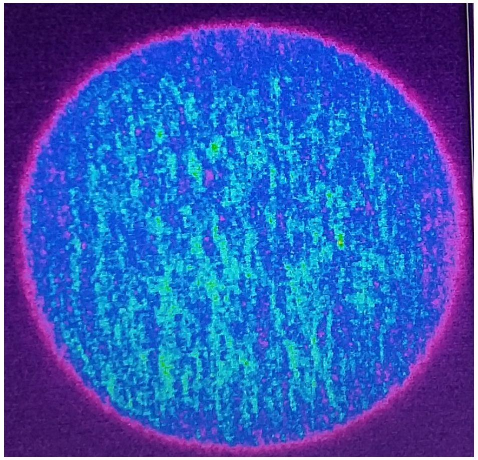
CNE400: 1.5 m x 6 m

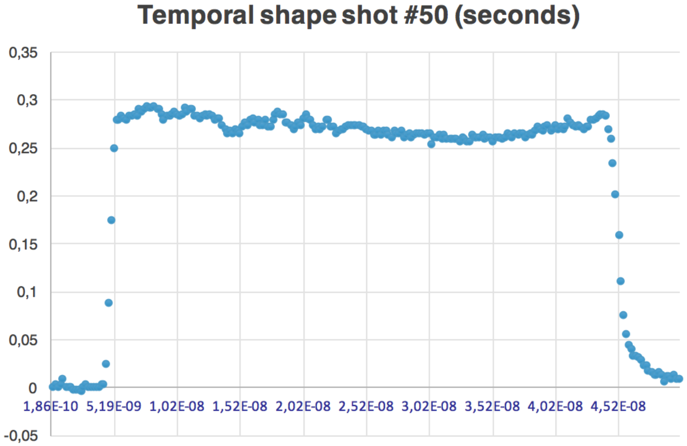


CNE400

CNE400 is delivering 200 J @ 527 nm @ 1 shot/mn rep-rate (and 300J IR)

- Beam diameter 60 mm, low divergence (< 0,2 mrad) and poynting stability =22 microrads RMS)
- Pulse shaping capability: 40 ns
- Phase modulation for smoothing purpose (« SSD »)
- Deformable mirror

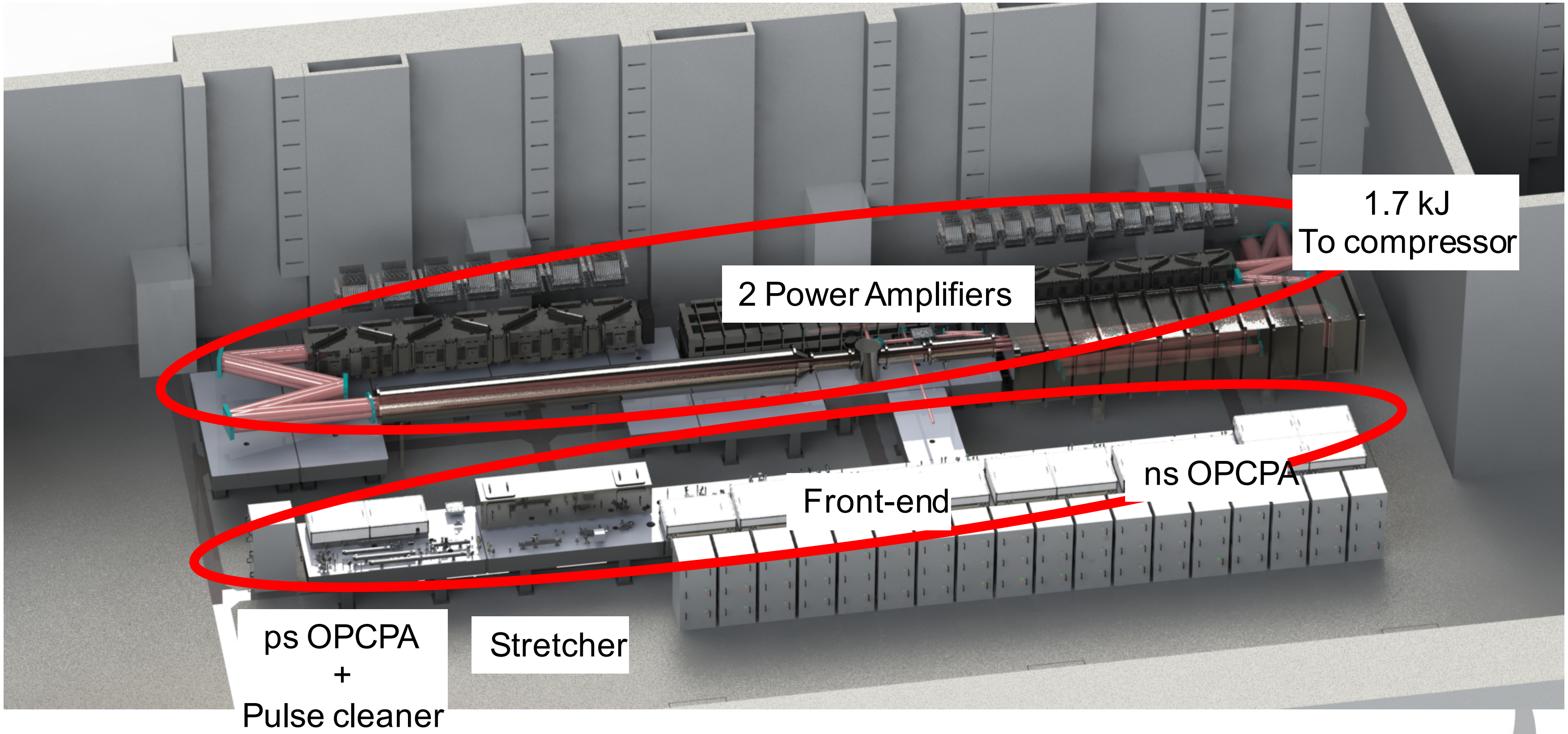




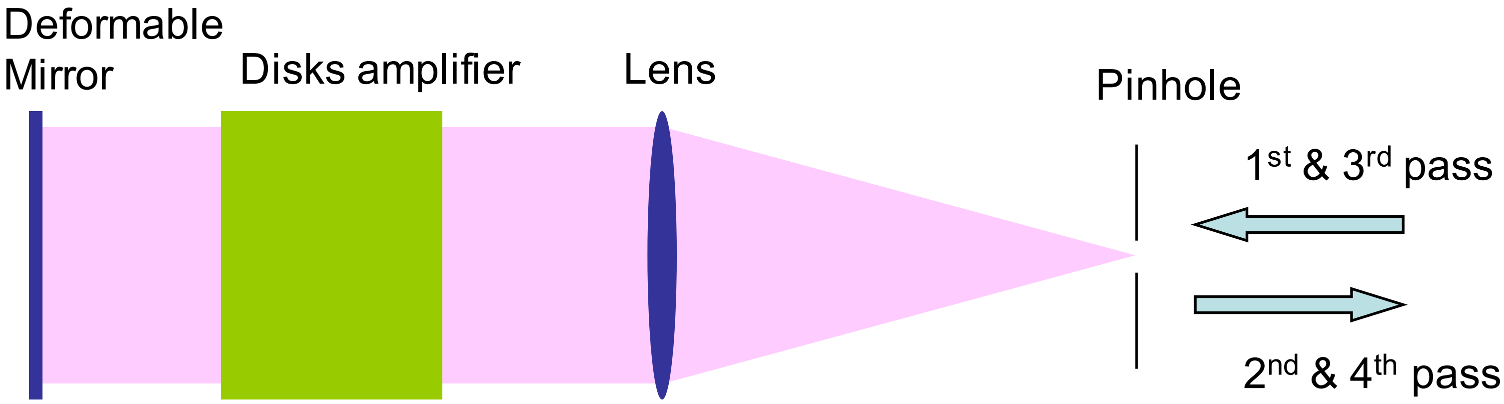
- T. Ditmire et al (2014), CLEO 2014, Technologies for high intensity (STU3F), doi:10.1364/CLEO_SI.2014.STu3F.1

Next step: L4 for ELI-Beamlines

- 2 main amps : 1 multipass 180 mm + 1 booster 300 mm
- Mixed silicate and phosphate laser glasses
- Expected up to 2 kJ stretched – 1.5 kJ compressed to 150 fs



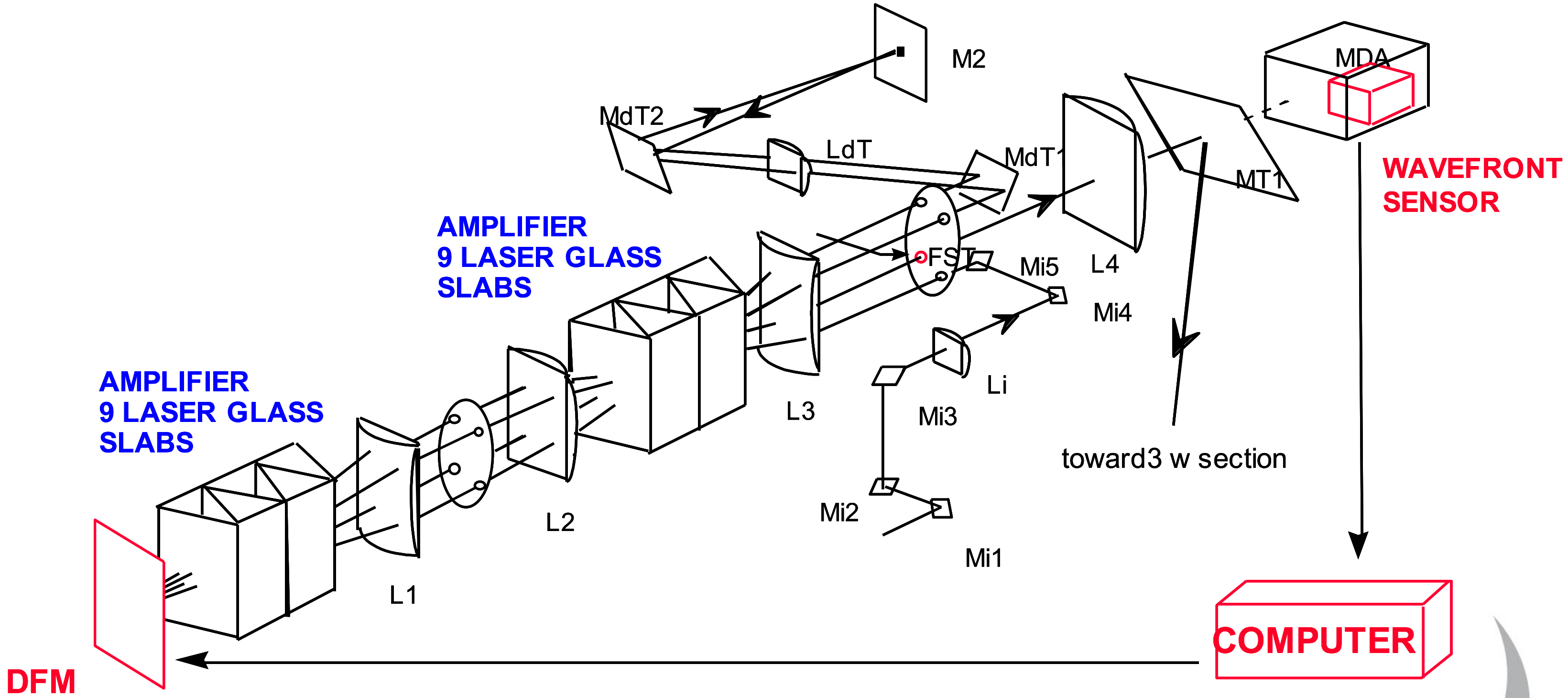
Multiple pass amplifier with adaptive optic



- It can be shown that this configuration is the best one for correcting the wave front
- Both NIF and LMJ prototype (LIL facility) have achieved more than 85% THG efficiency
- Both NIF and LMJ prototype (LIL facility) can fire every 2 hours (amplifier slabs are not cooled)
- LLE (OMEGA EP) while using this type of amplifier with water cooled lamps (but still un-cooled slabs) can fire every hour.

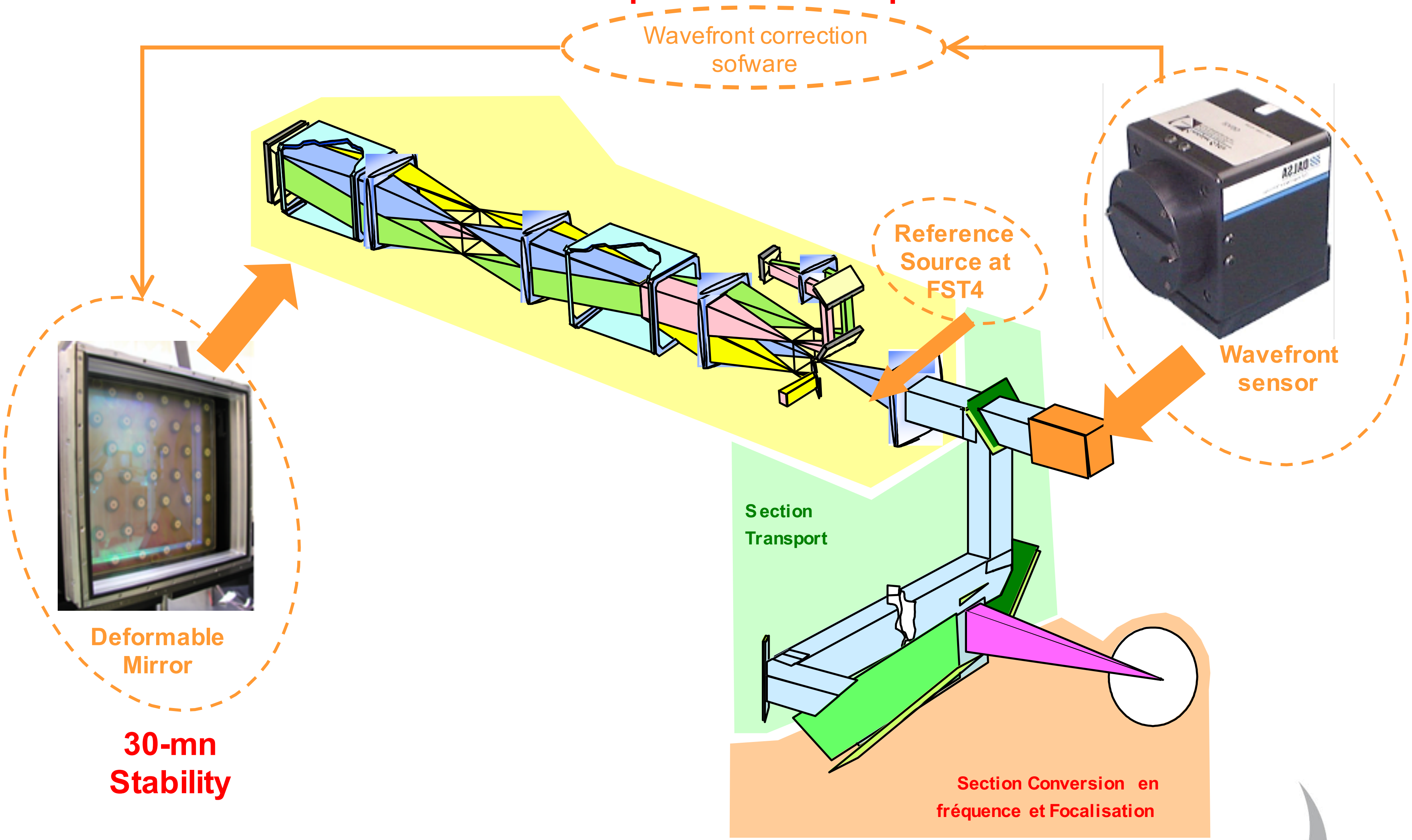
Wavefront Correction

- Wavefront distortions are coming from:
  - Dynamic aberrations from thermal effects in the amplifiers
  - Static aberrations from optical components
- Deformable mirror & spatial filtering



Wavefront correction loop

Open or close Loop



30-mn Stability

Wavefront Correction

FST1 = Ab_{INJ}

FST2 = $Ab_{INJ} + 2\ Ab_{AMPLI}$

FST3 = $Ab_{INJ} + 2\ Ab_{AMPLI} + 2\ Ab_{DT}$

FST4 = $Ab_{INJ} + 4\ Ab_{AMPLI} + 2\ Ab_{DT}$

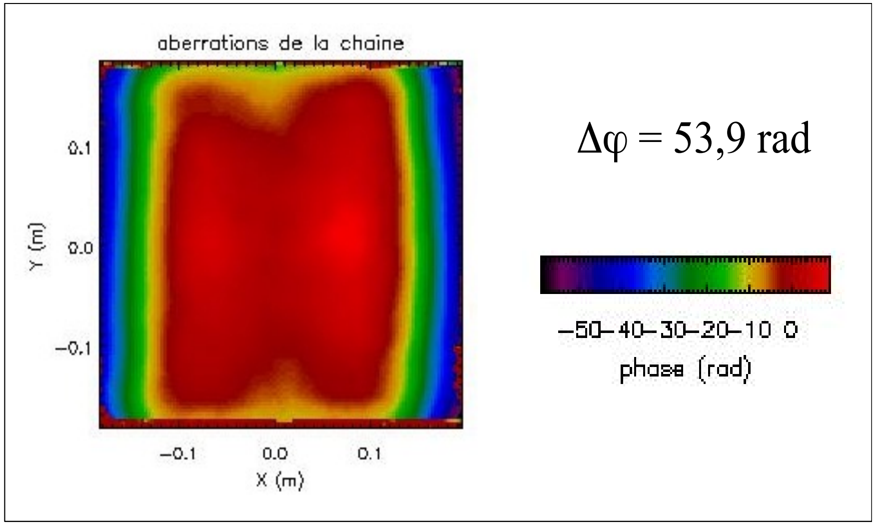
When applying the correction **- (** $Ab_{INJ} + 4\ Ab_{AMPLI} + 2\ Ab_{DT}$)/2 to the deformable mirror, one gets:

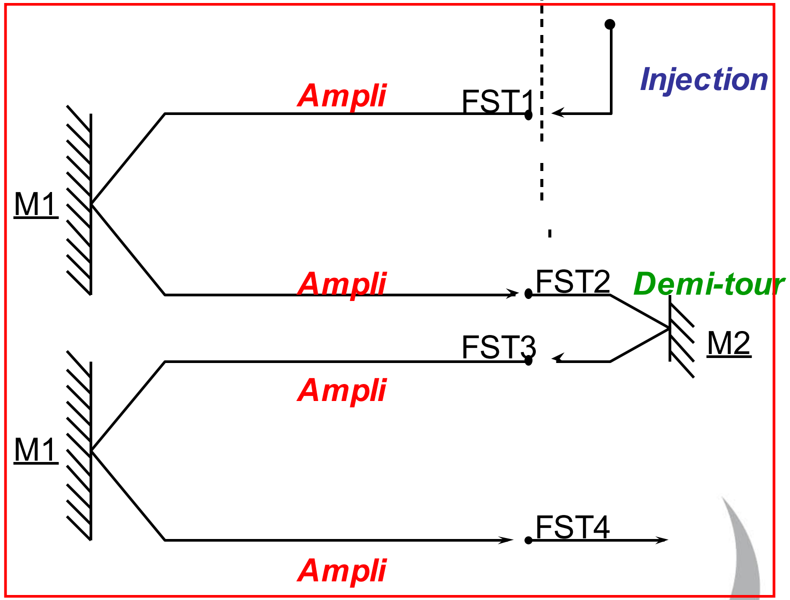
FST1 = Ab_{INJ}

FST2 = $\frac{1}{2}\ Ab_{INJ} - Ab_{DT}$

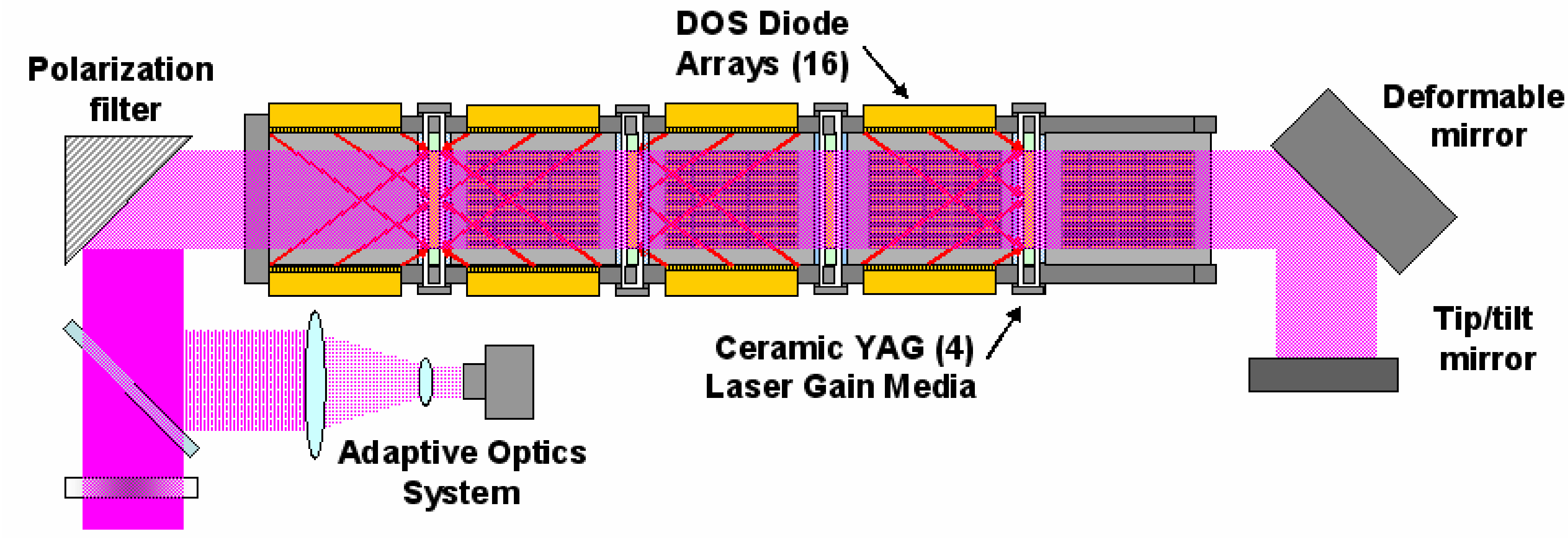
FST3 = $\frac{1}{2}\ Ab_{INJ} + Ab_{DT}$

FST4 = 0.





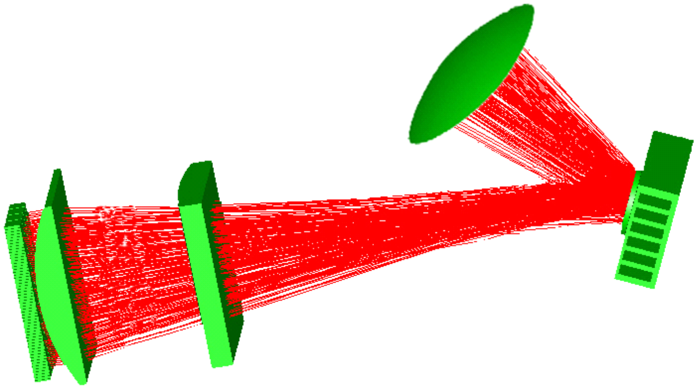
Solid State Heat Capacity Laser*

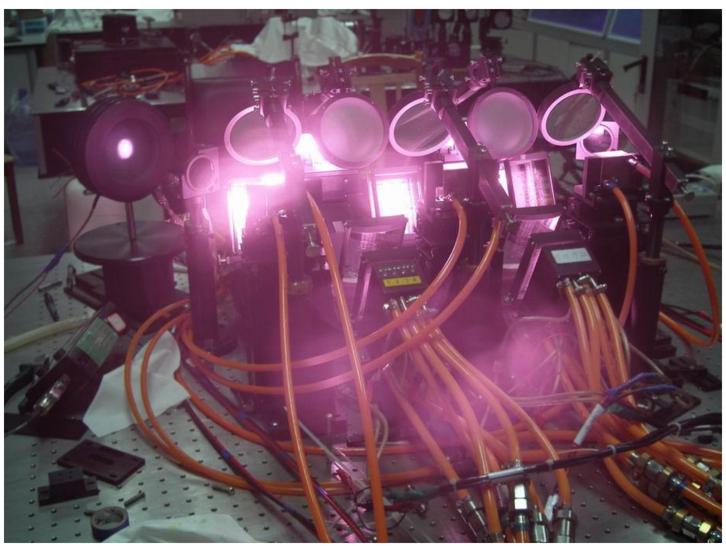


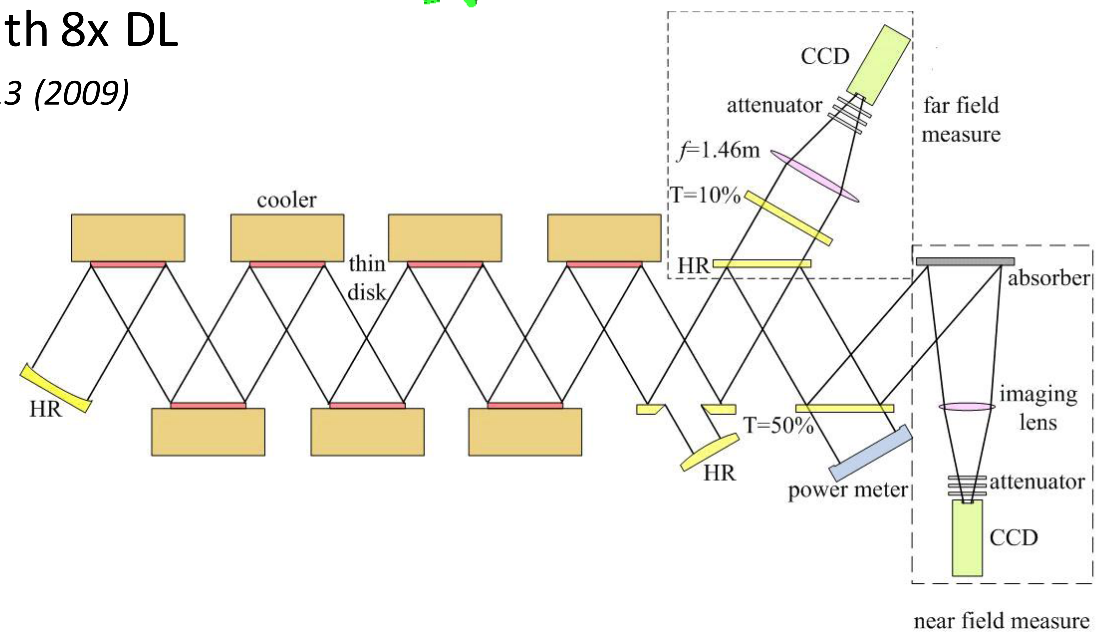
- 2006 : **67 kW** using 5 ceramic Nd:YAG slabs, 10 cm aperture
- average output power in a ½ second burst mode, 500 microsecond pulse width, 200 Hz
- Efficiency not known
- Beam quality not known but 2 x DL at 10 kW. How much at 67 kW ?
- Main trouble : pump uniformity of the diode arrays
- **R.YAMAMOTO SPIE, 6552, 655205 (2007)*

Disk Laser Face-pumped by 2D-stack Diode Arrays*

- 27 kW pump power per disk (6.75 J) at 400 Hz (10% duty cycle) => 2.7 kW average power
- Diode efficiency at 120 A = 50%
- 1 to 5 disks : 40 mm Nd:YAG
- Typical 26% optical efficiency at 3.24 kW output (5 disks) with 8x DL
- *C. TANG et al, SPIE, **7131**, 713113 (2009)*







实验光路布局图

Conclusion /1

- None of the diode-pumped solid-state lasers have been able to reach the kW level (100 J @ 10 Hz)
- DPSSL nearby the kW level have a moderate efficiency (<5 %) lower than expected
- Flash lamp pumped fusion lasers are still in the run with a low efficiency (0.5 to 1%)
  - But can access > 85% SHG/THG
- A flash lamp pumped amplifier with flow-cooled plates can run at 1 shot/mn
  - At low efficiency
  - 200J frequency doubled flash lamp pumped laser
- High average power is an engineering problem :
  - Solve the thermal problem at first
  - Optimize the heat exchange coefficient
  - Work at low temperature

Conclusion /2

- Use adaptive optics (deformable mirrors associated with pinholes) => better M^2 factors
- Cool the amplifier medium to cryogenic temperature => increase optical efficiency and thermo-mechanical properties
  - Cryogenic temperature : at 77 K, the thermal conductivity of un-doped YAG is greater than 70 W/m.K (almost 7 times the 300 K value). Some early data were close to 100 W/m.K
  - According to D. Brown, the extractable power can be increased by a factor 4 to 5 between 300 and 77 K but the typical heat flux coefficient h fall in the range 1-10 $W/cm^2.K$ for water cooling at room temperature and is a little bit less for liquid N_2 at 77K.

- Use wide angular acceptance crystals => access high frequency conversion with moderate M^2 factors

References

J. EMMETT et al, "The potential of high-average-power solid state lasers", UCRL 53571, LLNL (1984)

D.C. BROWN, "Ultrahigh-average_power diode-pumped Nd:YAG and Yb:YAG Lasers," *IEEE J. Quantum Electron.*, **33**, no.5 (1997)

W. KOECHNER, *Solid-state laser engineering*, 5th ed., Springer, Ed., (1999).

T. NUMAZAWA, O. ARAI, Q. Hu and T. Noda, "Thermal Conductivity Measurements for Evaluation of Crystal Perfection at Low Temperatures," *Meas. Sci. Technol.* **12**, 2089-2094 (2001)

D.C. BROWN, "The Promise of Cryogenic Solid-State Lasers," *IEEE J. Sel. Topics Quantum Electron.*, **11**, no.3 (2005)

R.M. YAMAMOTO et al, "Evolution of a Solid State Laser," *Proc. of SPIE,* vol. 6552, 655205 (2007)

T.Y. FAN et al, "Cryogenic Yb^{3+}-Doped Solid-State Lasers," *IEEE J. Sel. Topics Quantum Electron.*, **13**, no.3 (2007)

D.C. BROWN et al, "Kilowatt Class High-Power CW Yb:YAG Cryogenic Laser," *Proc. of SPIE,* vol. 6952, 69520K (2008)

C. TANG et al, "High-Average Power Disk Laser Face-pumped by 2D-stack Diode Arrays", *Proc. of SPIE,* vol. 7131, 713113 (2009)

S.G. GRECHIN and P.P. NIKOLAEV, "Diode-side-pumped laser heads for solid-state lasers", *Quantum Electronics* **39** (1) 1-17 (2009)

B. Le Garrec (2014) High Power Laser Science and Engineering, volume 2, e28 doi:10.1017/hpl.2014.33

T. Ditmire et al (2014), CLEO 2014, Technologies for high intensity (STU3F), doi:10.1364/CLEO_SI.2014.STu3F.1