LASER SYSTEMS FOR NEXT GENERATION LIGHT SOURCES

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OUTLINE

- *Introduction*
- *Main laser systems in the FEL light sources under development*
- *General requirements*
- *Specific issues*

A. *Photoinjector laser*

B. *Laser Heater*

C. *Seed Lasers*

- *New laser developments*

(high rep rate /average power, VUV-soft tuneable X-ray seed)

- *Jitter and drift problems:strategies for reduction*

Main laser systems in the FEL light sources under development

- *Photoinjector laser*
- *Seed laser*
- *User lasers*
- *Laser Heater*
- *Optical master oscillator*
- *Electro-optical sampling laser*
- *Short pulse 'chirping laser'*
- *…more to come!*

GENERAL REQUIREMENTS

- Wavelength: mostly UV, IR in LH; tuneable in SL
- Rep rate 10 Hz-120 Hz normal conducting ; up to MHz superconducting
- Synchronization to external reference with jitter 20-200fs RMS; no phase (CEP) stabilization requested sofar
- Pulse duration: 50fs- 15 ps FWHM (risetime<1 ps)
- Pulse energy: 10 -500 μJ
- Pulse shaping: flat-top , increasing quadratic ramp , very short gaussian with low TBWP
- Beam shaping: flat-top ; gaussian ; well-behaving in propagation
- Pulse-to-pulse stability : < 4% RMS, goal <2% -> diode-pumping!
- High reliability (>99% uptime)-> must be based on a mature technology
- Commercial units available
- Easy to integrate in a facility ->Remote control/diagnostics

In general: no commercial system meeting all !

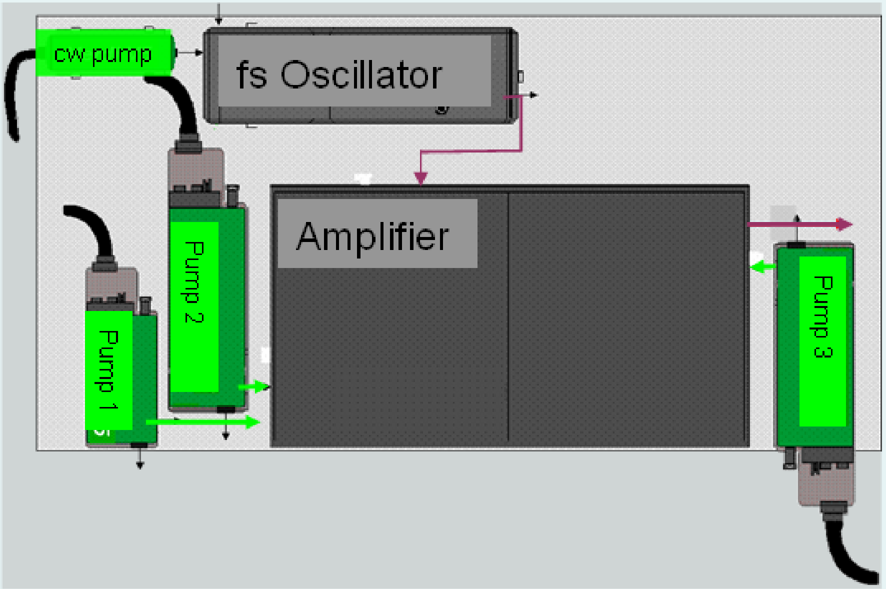
PHOTOINJECTOR LASER

- Pulse energy equirements depend on the type of gun

1. Cu-based gun on normal conducting machines

- 0.4 mJ at 260 nm on cathode -> >15 mJ in IR (12% THG efficiency, 25% transmission pulse/beam shaping and beam transport)
- Bandwidth at least 4 nm in IR to allow <1 ps rise/fall times
- Commercially available units

At present only choice Ti:Sapphire based femtosecond oscillator+regenerative amplifier +2 stage multipass amplifier , pumped by diode-pumped Nd:YLF Q-switched lasers



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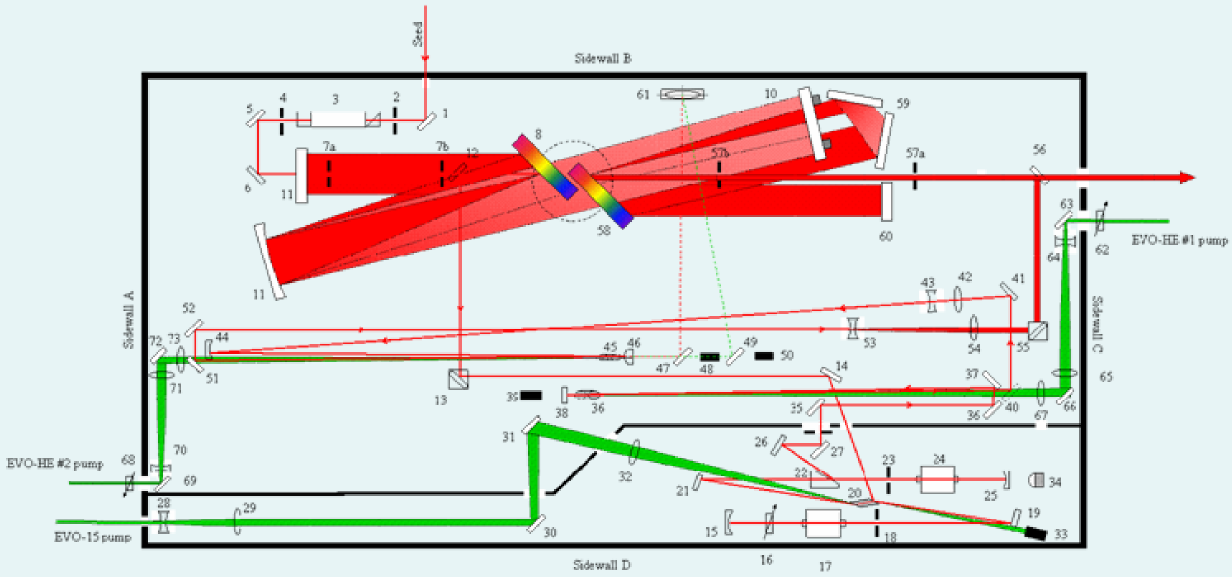


PIL PULSE SHAPING

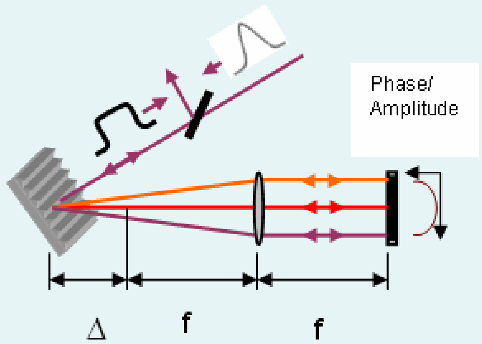
1. PULSE SHAPING SCHEMES

   FREQUENCY DOMAIN:

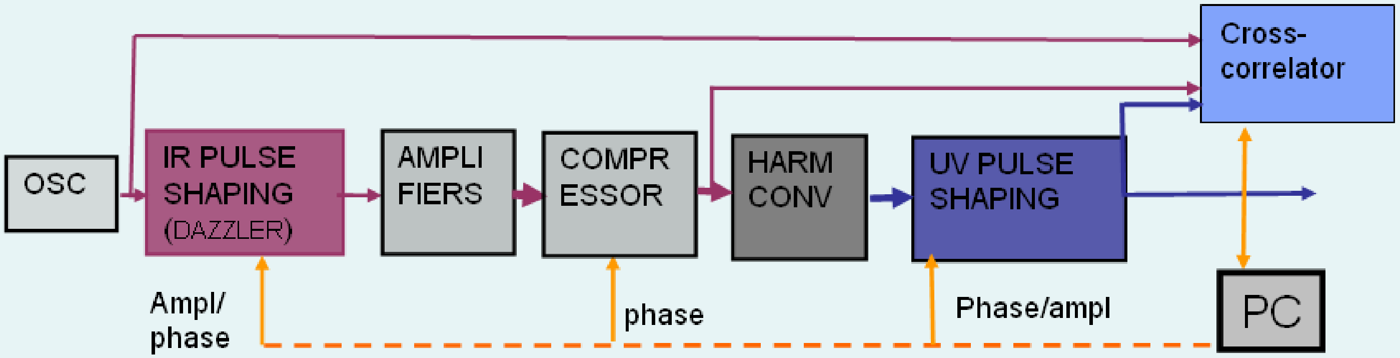
- 4-f dispersive system (or other geometries)
- DAZZLER (acousto-optic dispersive Filter), Fastlite

   TIME DOMAIN

- Pulse stacking



2. TWO STAGE SETUP FOR FERMI



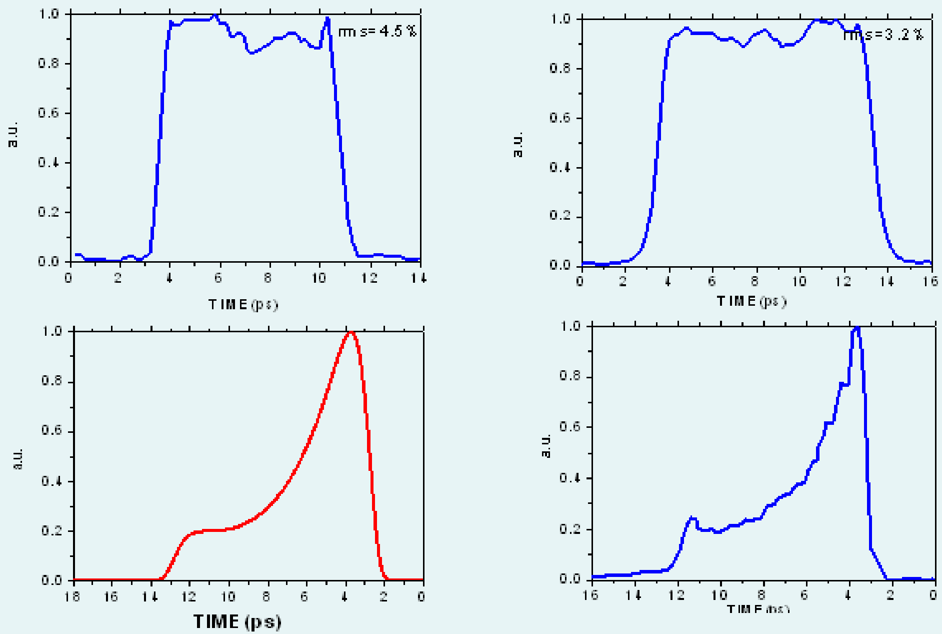
UV PULSE SHAPING

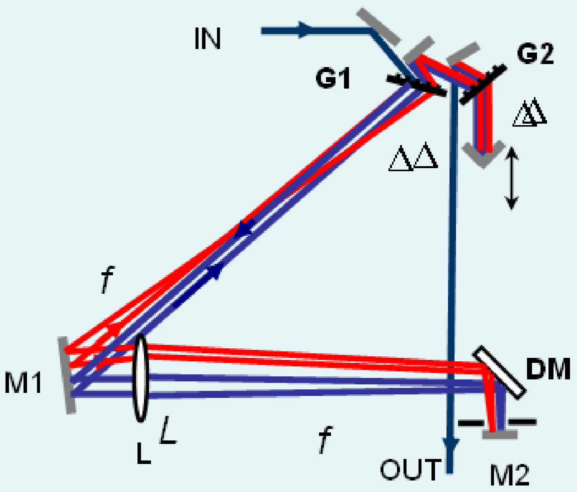
MAIN ISSUES:

a. High UV energy/peak power ->aging and damage gratings and other optics

Solution: use large beam diameter, transmission gratings, multilayer deformable mirror and CaF2 optics,

b. Narrow spectrum: long focal length lenses in the 4-f system





- Development of genetic algorithm for pulse shape optimization
- Aging of the deformable mirror

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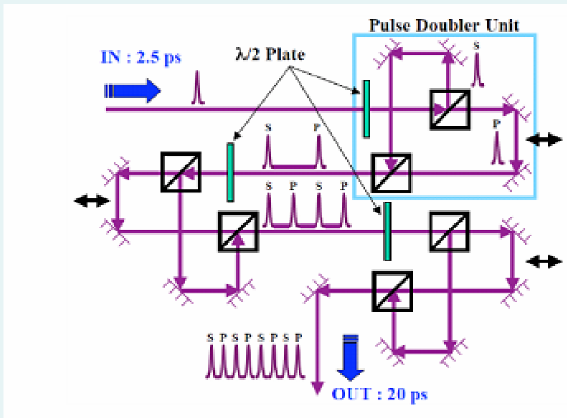
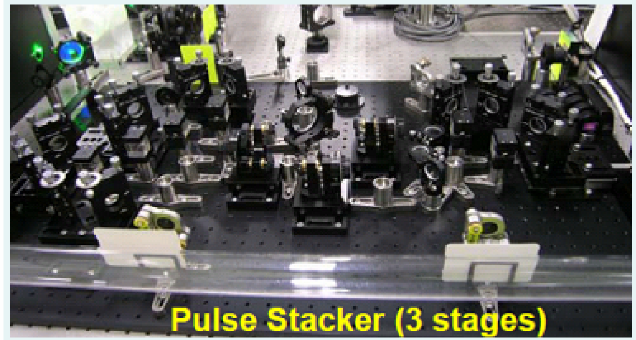
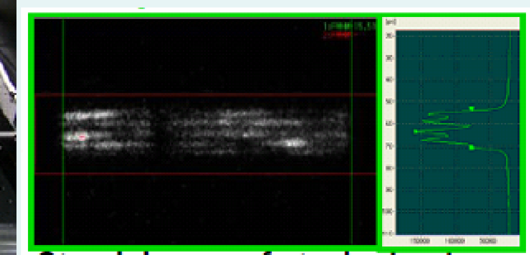
UV PULSE SHAPING

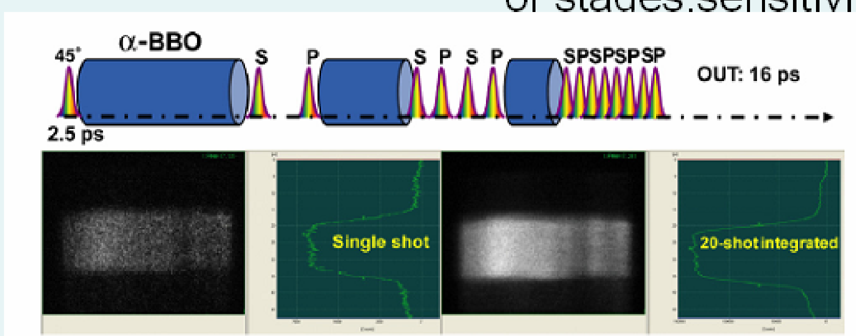
2. Pulse stacking : in UV the final shape is obtained by the addition of a number of delayed pulses; polarisation splitting used to avoid interference effects






Streak Image of stacked pulses

Issues: complexity increases with number of stages:sensitivity to alignement



Courtesy: H.Tomizawa

New scheme based on birefringent crystals
Dispersion compensation needed

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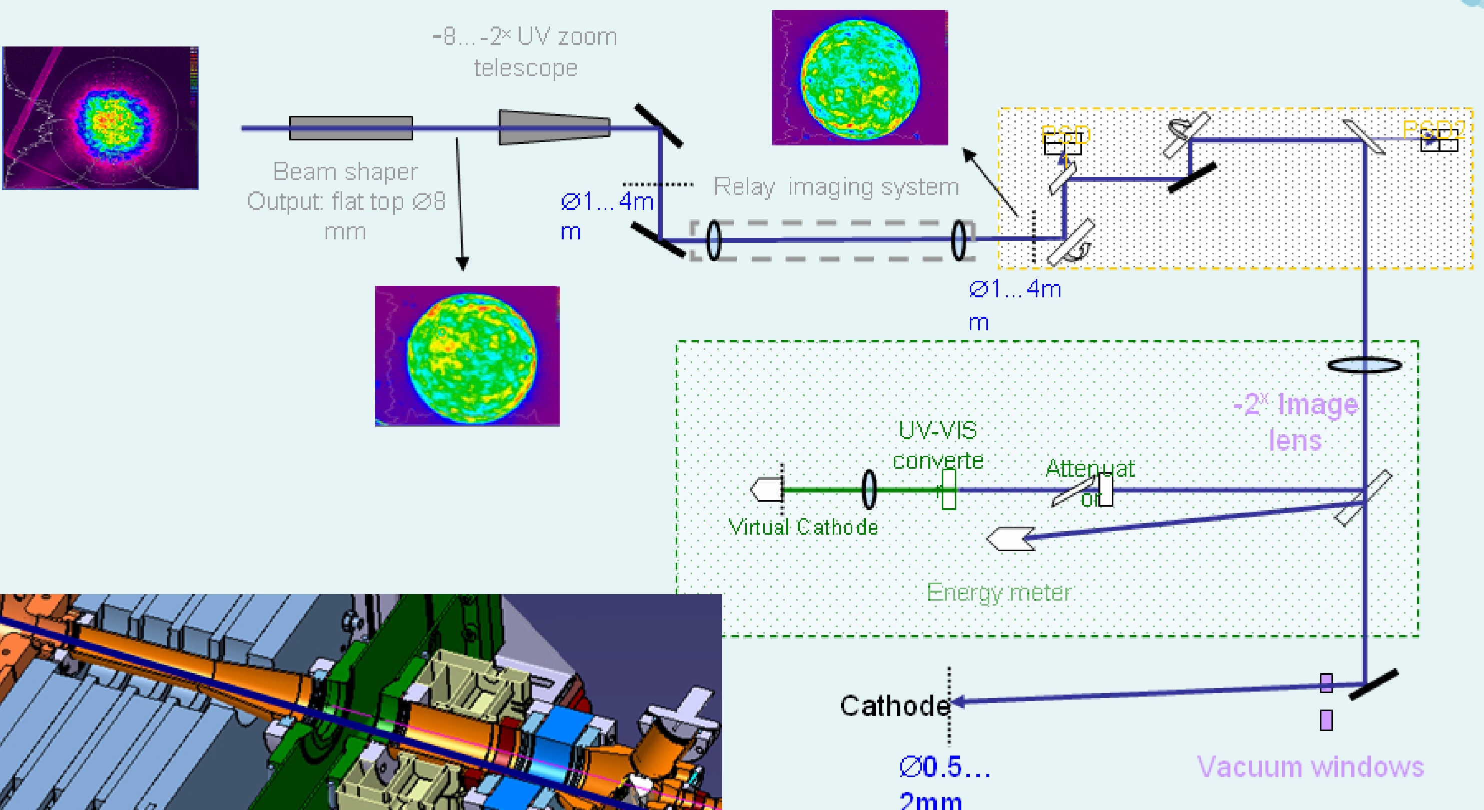
PIL Beam Shaping

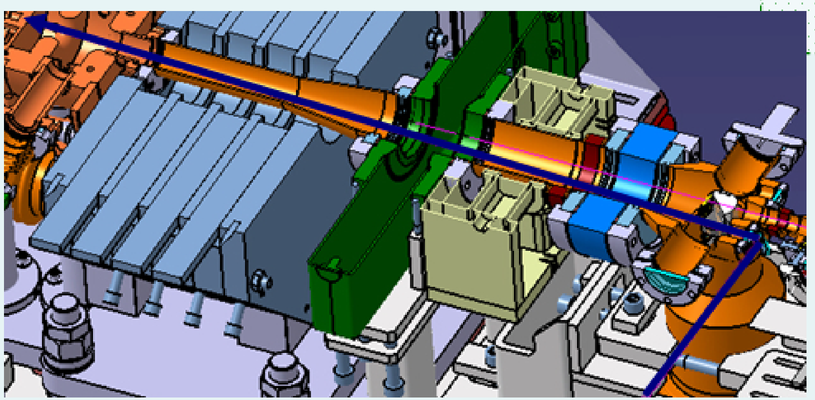
- Transformation of gaussian into flat-top beam in UV
- Aspheric shaper Newport (used at SLAC)
- Optimized aspheric shaper MBI (less sensitive to alignment)
- Shaper MOLTECH (based on spherical lenses) Elettra
- Circular aperture to select only the central part of the beam SLAC, SPARC
- Adaptive shaper (e.g. deformable mirror , Tomizawa, SPring8)
- Why not producing the flat-top in IR ?

Advantages: better HG efficiency and no spatial chirp

Problems: very large size needed to avoid nonlinear effects; the flat-top develops a modulation which would be a problem for the 4-f system

PIL BEAM TRANSPORT/INSERTION



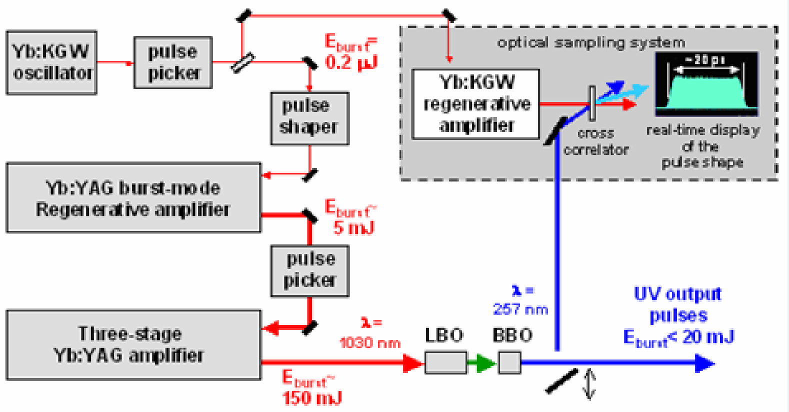


Important: in the FERMI PI design last mirror is outside the vacuum

PI Lasers for high rep rate machines

- MBI scheme, used at FLASH , to be used for the European XFEL (low rep rate macrobunches, up to 800 micropulses)

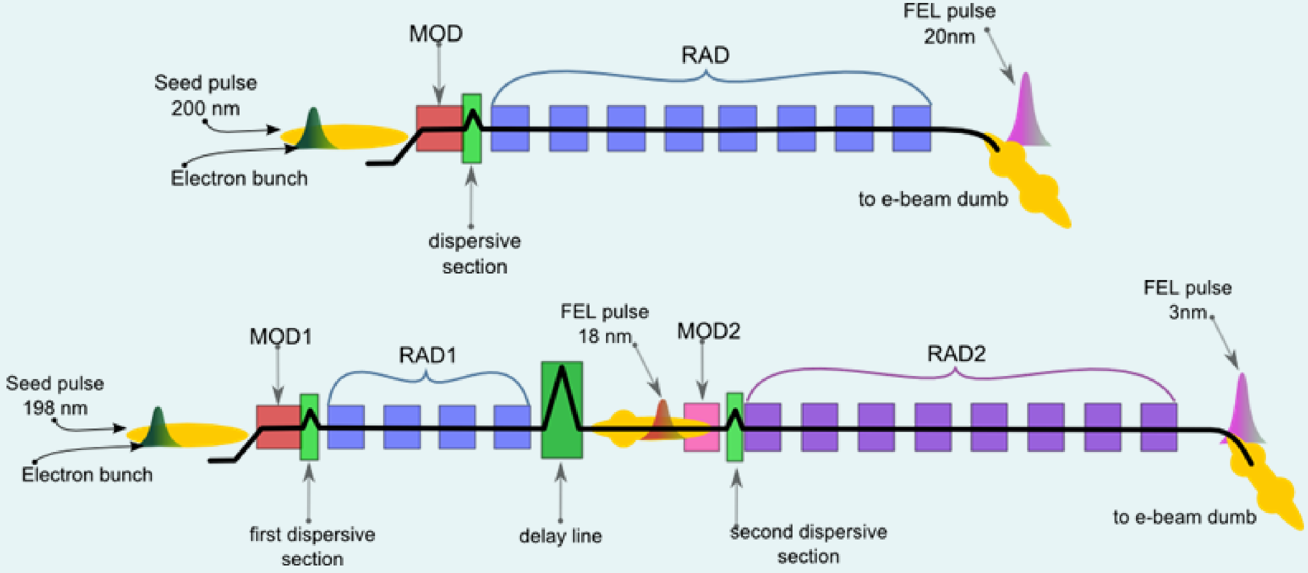
First version: Nd:YLF linear amplifier Chain; upgraded recently to diode Pumping
Next generation: Yb:YAG based



•Lasers for true CW operation
Cu-based 1 nC machine: at least 3 mJ needed in the IR
-Ti:Sapphire - > based on existing technology good to 10-20 KHz
(50 W level systems are available, based on crio-cooling and downchirped amplification)
-If pulse rise-time requirement is decreased to 2 ps, Nd:YLF could be used
-Yb:KYW ; Yb:Lu2O3 promising, literature reports 10µJ, MHz range
- Yb-fibre based systems - 100 µJ

SEED LASER

- In general, a laser pulse interacting with the e-bunch in an undulator to create bunching at a (short) wavelength
- FERMI is the first FEL entirely based on seeding, with two FEL lines having configurations based on a single seed laser operating in the 200-300 nm range

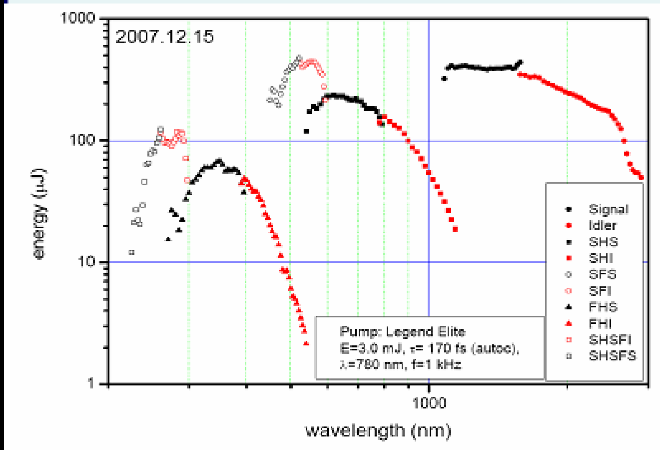


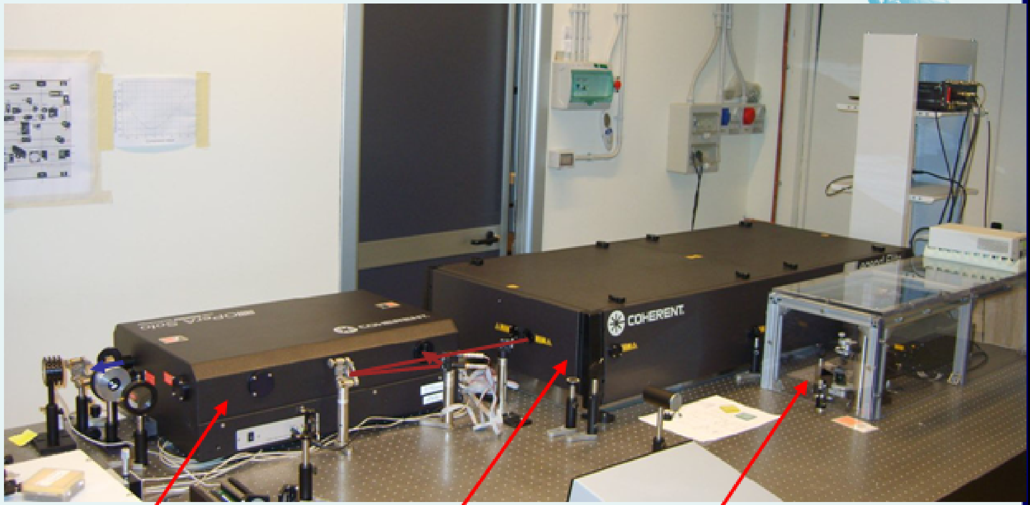
Courtesy E.Allaria

UV seed: FERMI SEED LASER

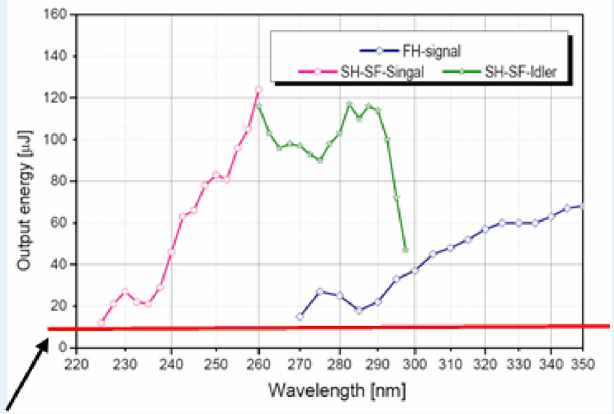
Parameter	Specs	Measured
Tunability range (nm)	240-360	195-350
Peak power (MW)	100	>100
Pulse duration (fs)	100	<100
Pulse Energy Stability RMS 5000 shots	<4%	<2%
Timing jitter (fs RMS)	<100 fs	TBM
Pointing stab. (**μrad)**	<20 (goal 10)	<20
Wavelength stab.	10^{-4}	$<10^{-4}$
Beam quality (M^{2})	<1.5	TBM

FERMI SEED LASER PERFORMANCE

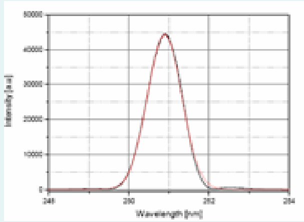


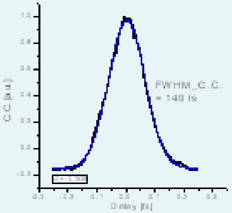


TOPAS Regen Amp Seed fibre laser

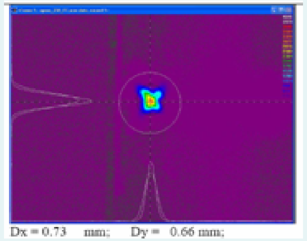


100MW level Tuning curve in UV





Typical Spectrum and crosscorelation with short Visible pulse



Spatial distribution at focus

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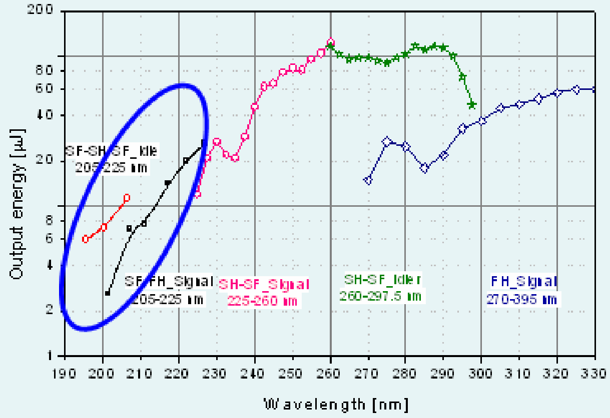
FERMI SEED LASER PERFORMANCE

Recent upgrade to shorter wavelength

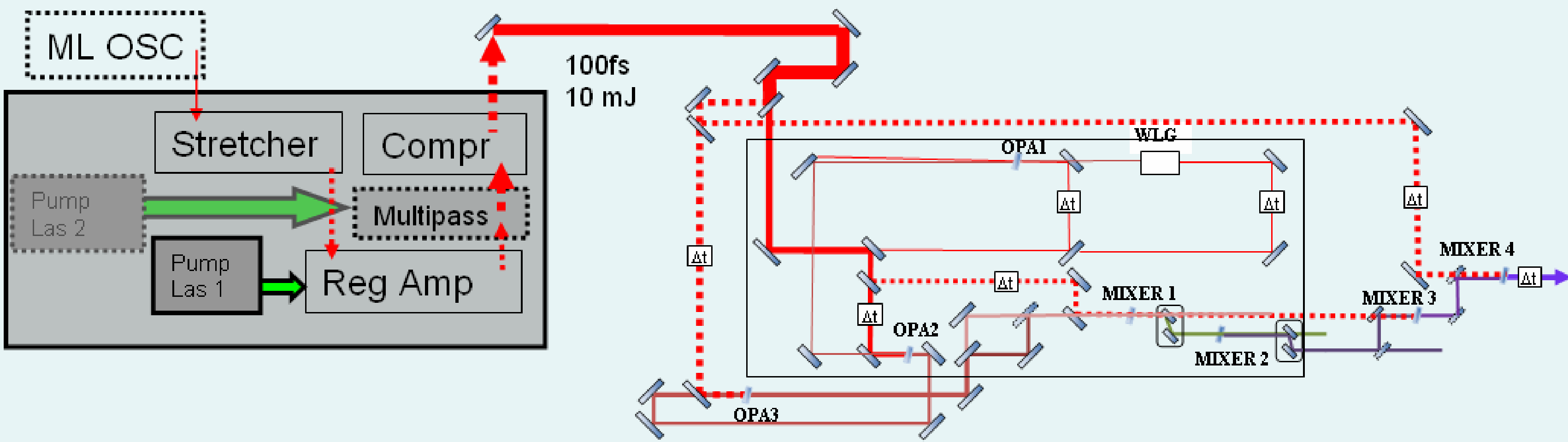


Near future Upgrade :

-Extension to 165-195 nm region by using KBBF (Mixer 4)

-Upgrade of the pump laser to 8-10 mJ range by adding one multi-pass stage

- Controlled pulse delay at the exit with wavelength tuning



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VUV/EUV UPGRADE UNDER STUDY

SEED BY HG IN GASES

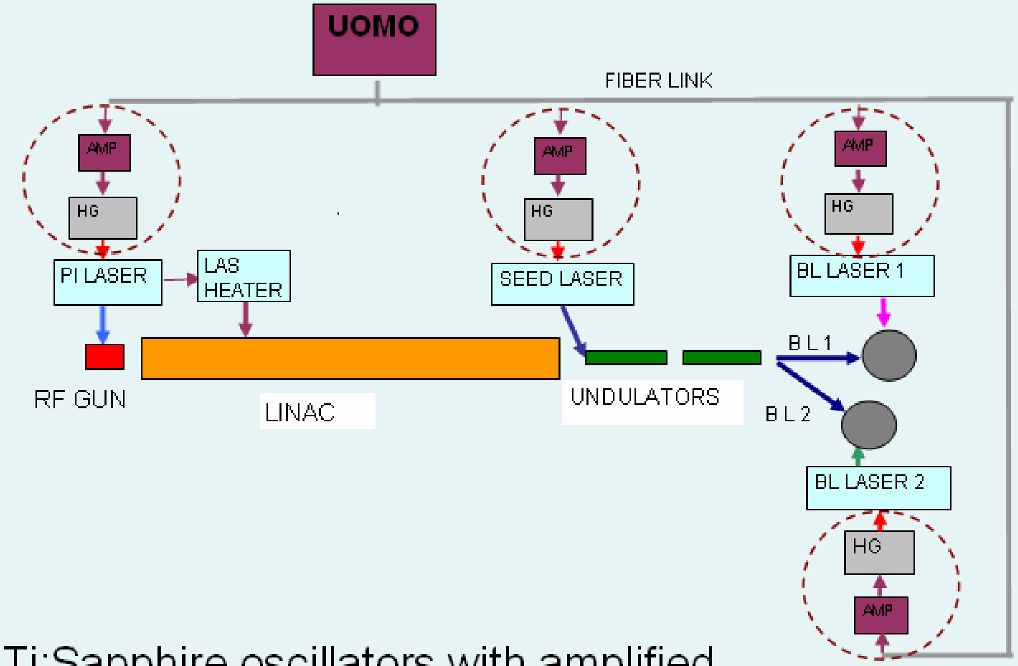
Required:

- Tunability in the range 40-70 nm (by full tunability between two harmonics);
- Peak power in the 1MW range pulse energy : 150 nJ range if HHG chamber is in the laser room, 50 nJ range with HHG chamber close to the undulator entrance and aligned;
- Pulse duration 25-30 fs

Main options for the pump laser under consideration

- Use of UV or VIS pulses from an upgraded version of the present parametric amplifier/HG system: expected 200 µJ, 80 fs in UV and 800 µJ, 50 fs in VIS
- Use of a comercially available tuneable Ti:Sapphire amplifer , tuning range ±30 nm around 790 nm, pulse duration:50 fs; pulse energy 10 mJ
- Use of fixed wavelength pump and tuning of the HG output by controlling other parameters

Direct seeding concept



Main idea: replace Ti:Sapphire oscillators with amplified frequency doubled timing pulses for seeding the regen amplifiers

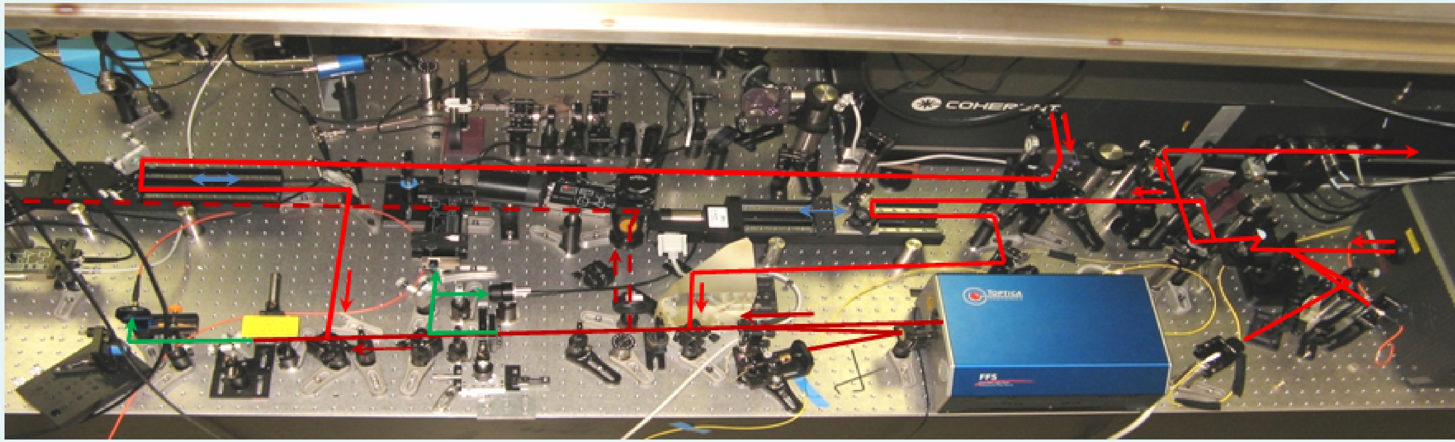
Main issues:

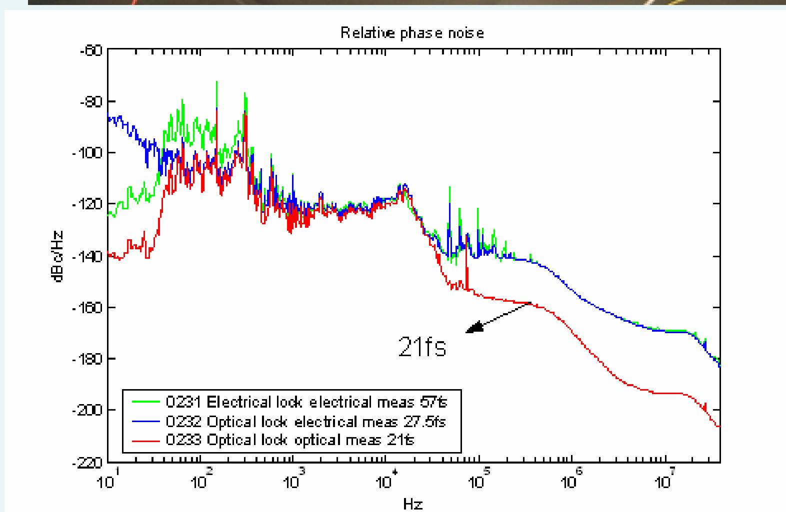
-Power (>0.5 nJ at 780 needed)

- Bandwidth (>8 nm for a 100 fs system, >20 nm for seeding a 50 fs range amp)

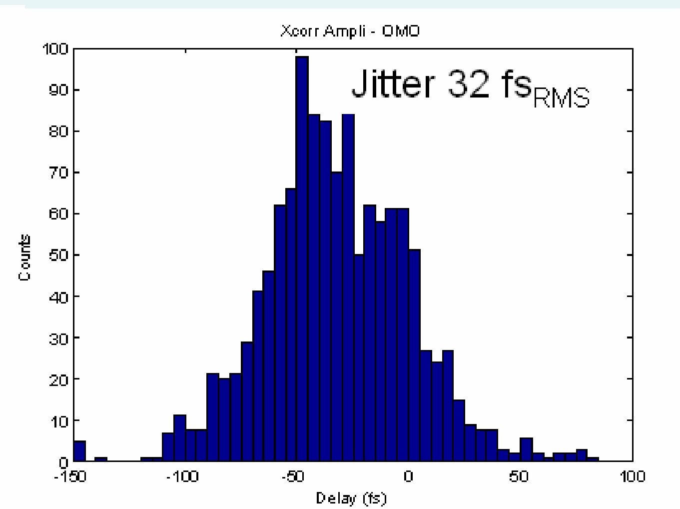
TESTS LASER JITTER

Test of PIL locking to an external fbre laser by optical cross-correlation





Phase noise measurement



Distribution of arrival time at the second x-corr

CONCLUSIONS

- Ultrafast lasers are becoming crucialy important part of new VUV and X-ray FELS
- Ti:Saphire based systems will continue to be the most popular for up to 10 kHz rate
- Higher rep rate facilities will most probably need an alternative technology. Promising candidate Yb-doped thin-disk media and especially fiber based oscillators and amplifiers
- Tunable seeding with HHG in the 40 nm range feasible
- Dedicated R&D on ultrafast lasers applied to FEL technology may substantially improve the performance

THANK YOU FOR THE ATTENTION

BACKUP SLIDES

HHG SEED BASED ON TUNABLE Ti:SAPPHIRE AMPLIFIER

PROPOSED APPROACH FOR REACHING THE PARAMETERS REQUIRED FOR FEL SEEDING

- HHG in Xe in the 45-75 nm range
- Use of Tunable Ti:Sapphire based regen+multipass amplifier with the following parameters:

Tunability ±25 nm around 800 nm

Use of bi-chromatic pump (800 nm +400 nm) for production of odd+even harmonics

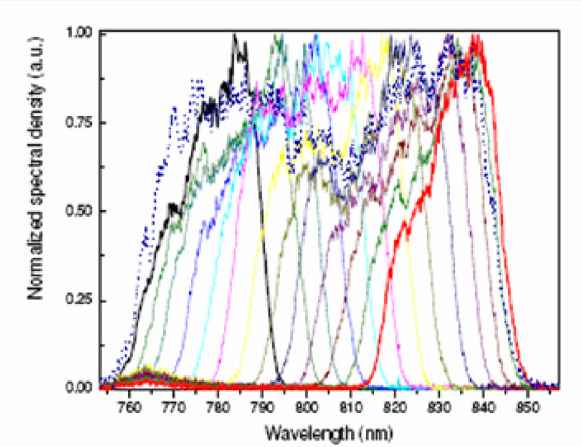
Pulse duration 50 fs

Pulse energy : 10 mJ (up to 15 mJ) at 800 nm /2 mJ at 400 nm

Approach for obtaining the amplifier tunability developed by *Amplitude Technologies*:

Broadband seed oscillator (>100 nm)

- Spectral phase shaping before Regenerative Amplifier (Dazzler)
- Spectral amplitude shaping in the Regenerative amplifier (Mazzler)
- Pulse/spectrum measurement after multipass amplifier and closed loop control of the Dazzler/Mazzler for remote controlled wavelength tuning



Tunability curve demonstrated by *Amplitude Technologies* (courtesy F.Canova , G.Riboulet)

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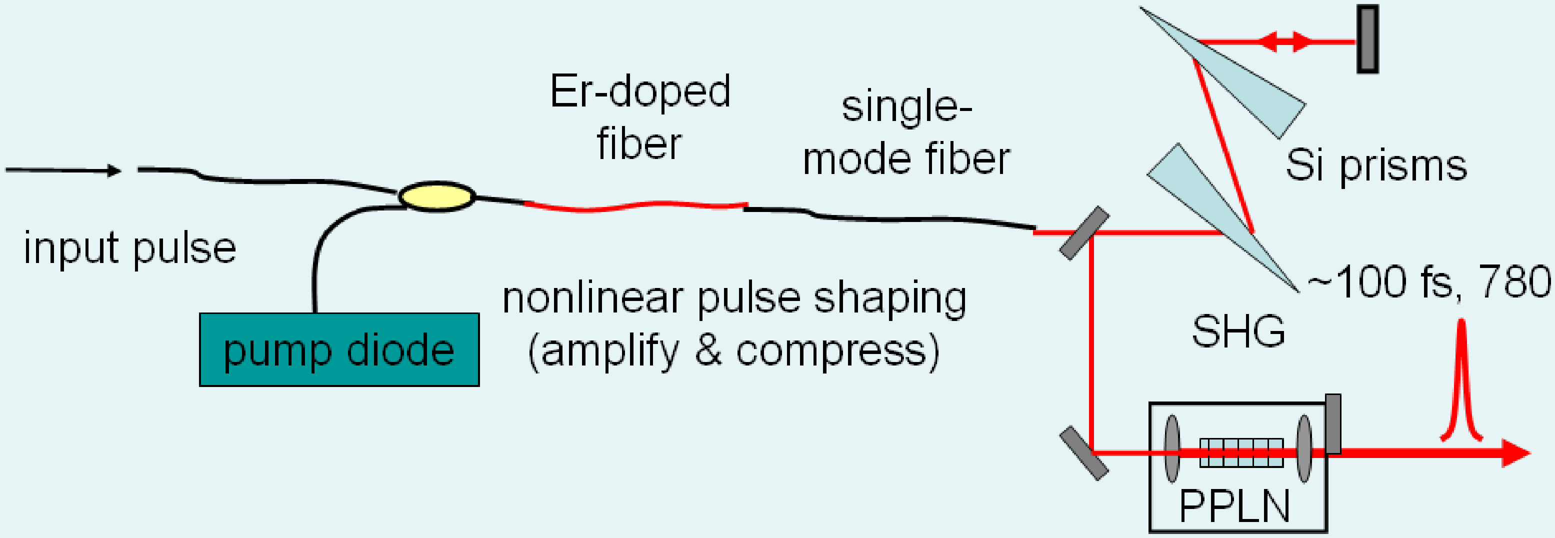
JITTER REDUCTION - DIRECT SEEDING

Seed a Ti:sapphire amplifier after pulse shaping/amplification:

~100 fs (~3 nJ @ 1550 nm & ~1 nJ @ 775 nm)



Where we are:
- SHG unit based on chirped PPLN developed
- tests of the amplifier setup started

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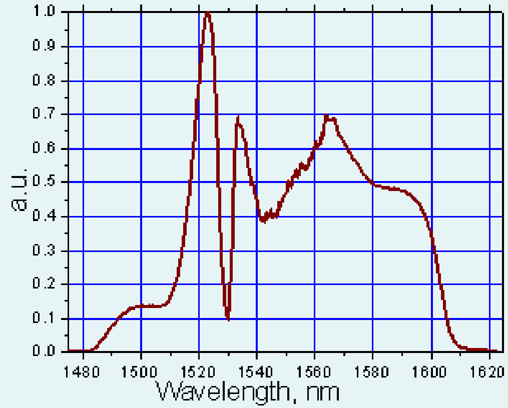
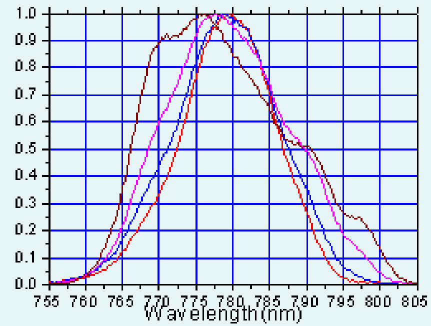
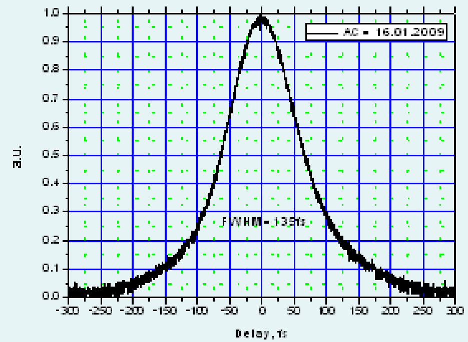
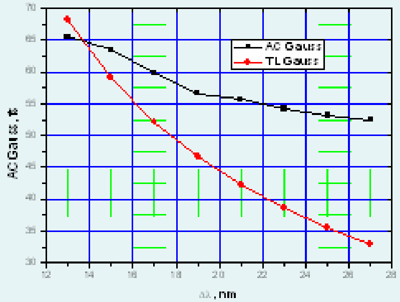
SHG results



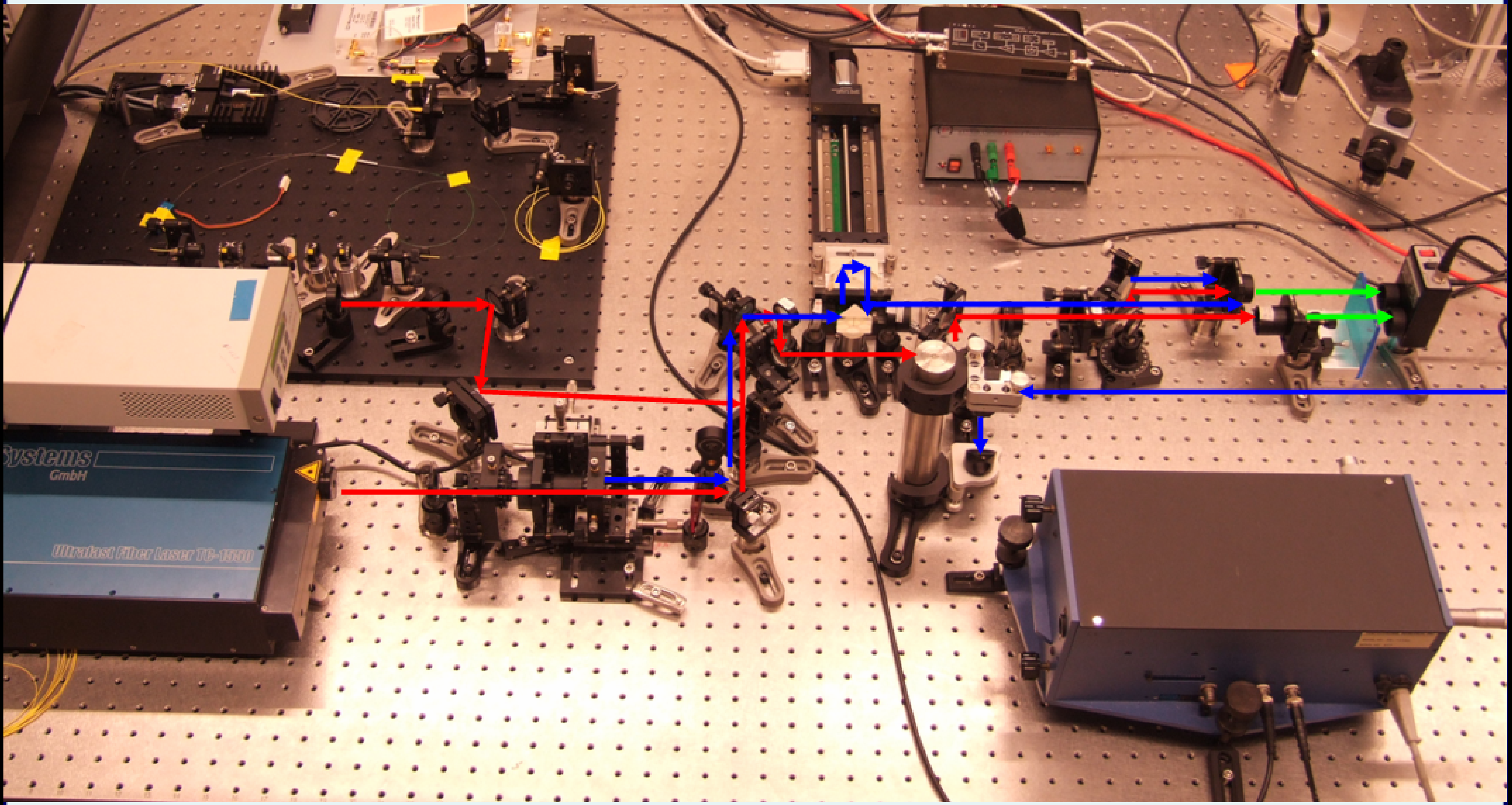


Input spectrum (Menlo TC1550)

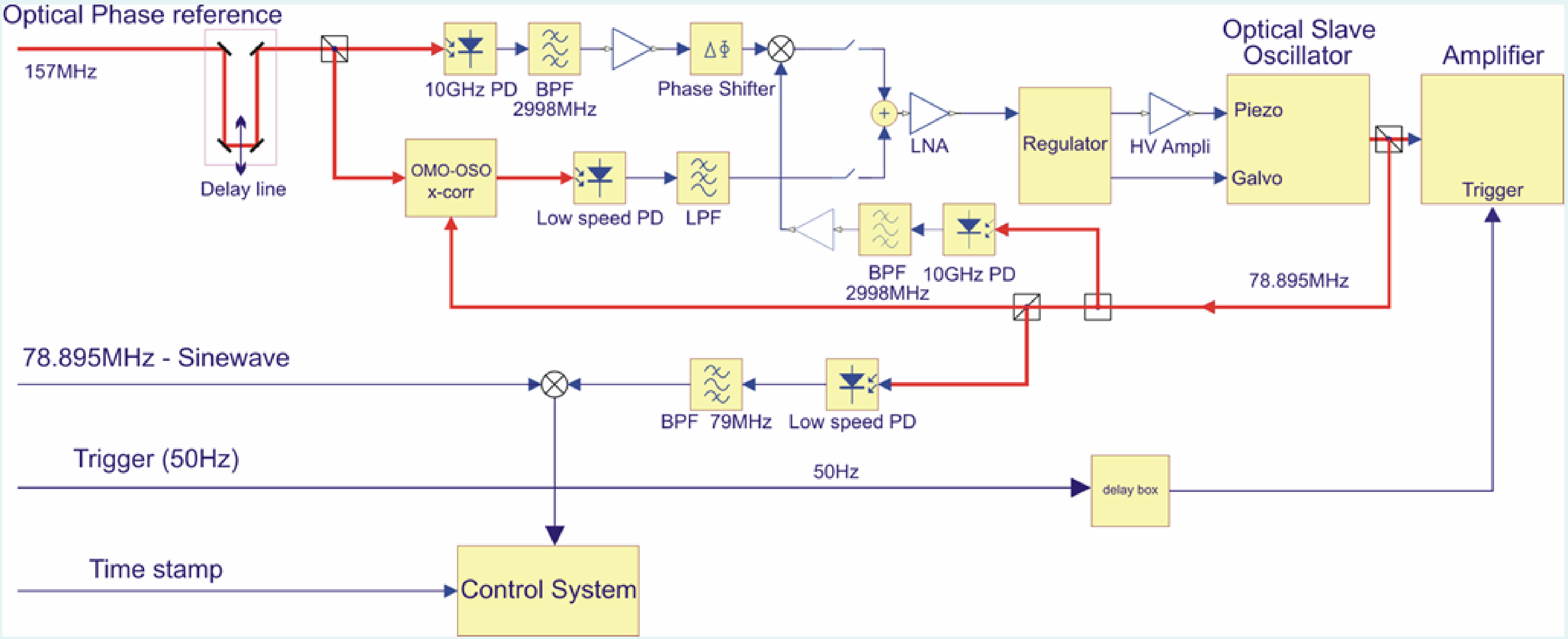




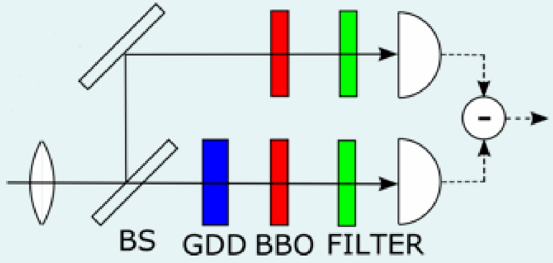
CrossCorrelator Test Bed

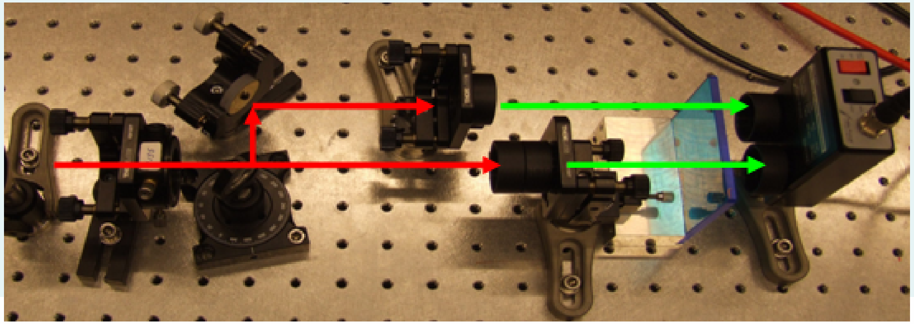


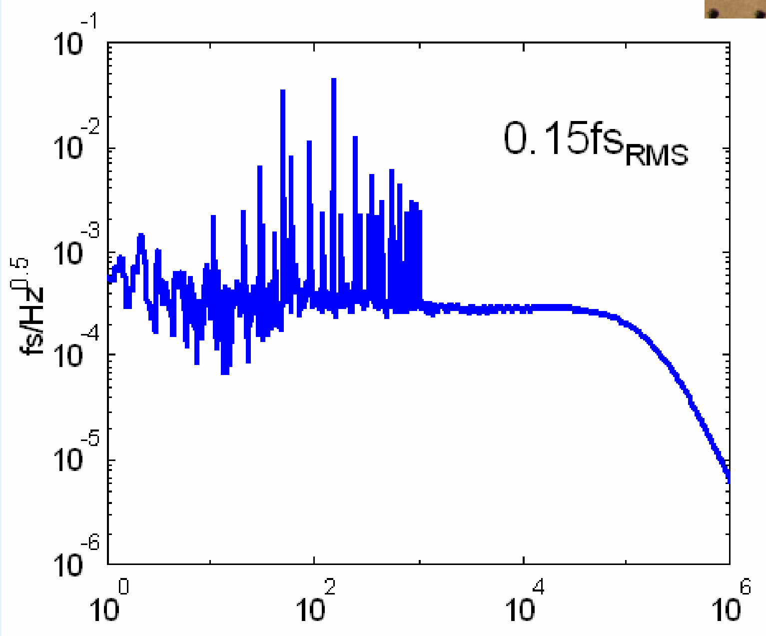
Locking setup

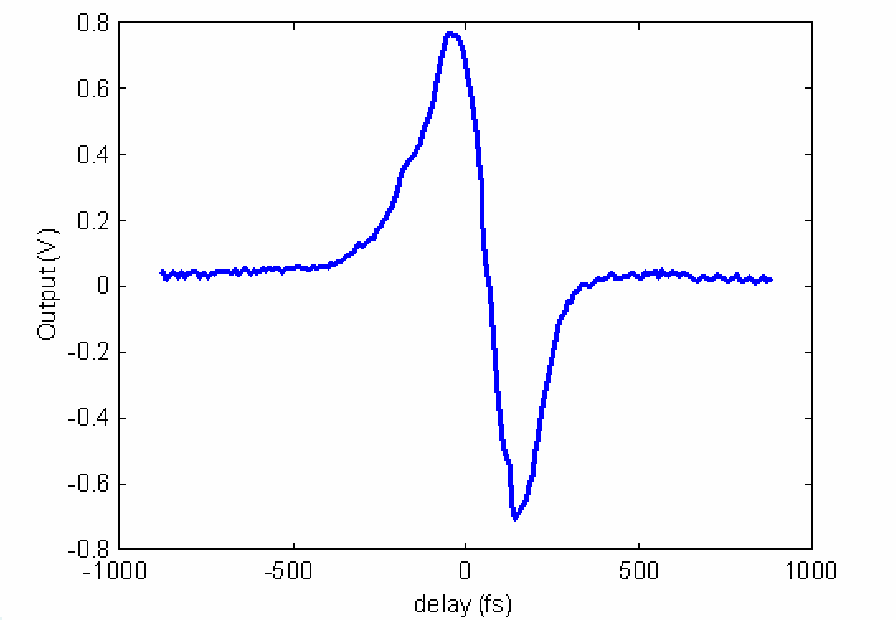


Balanced Crosscorrelator









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