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School on Synchrotron and FEL Based Methods and their Multi-Disciplinary Applications

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SEEDED FELs AND POSSIBILITIES FOR TWO COLOR EXPERIMENTS

M.B. Danailov
Sincrotrone-Trieste

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OUTLINE

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Pump-probe with FELs: main issues

Laser Systems in FEL facilities

Synchronization of Ultrafast lasers to external references: timing jitter and drifts

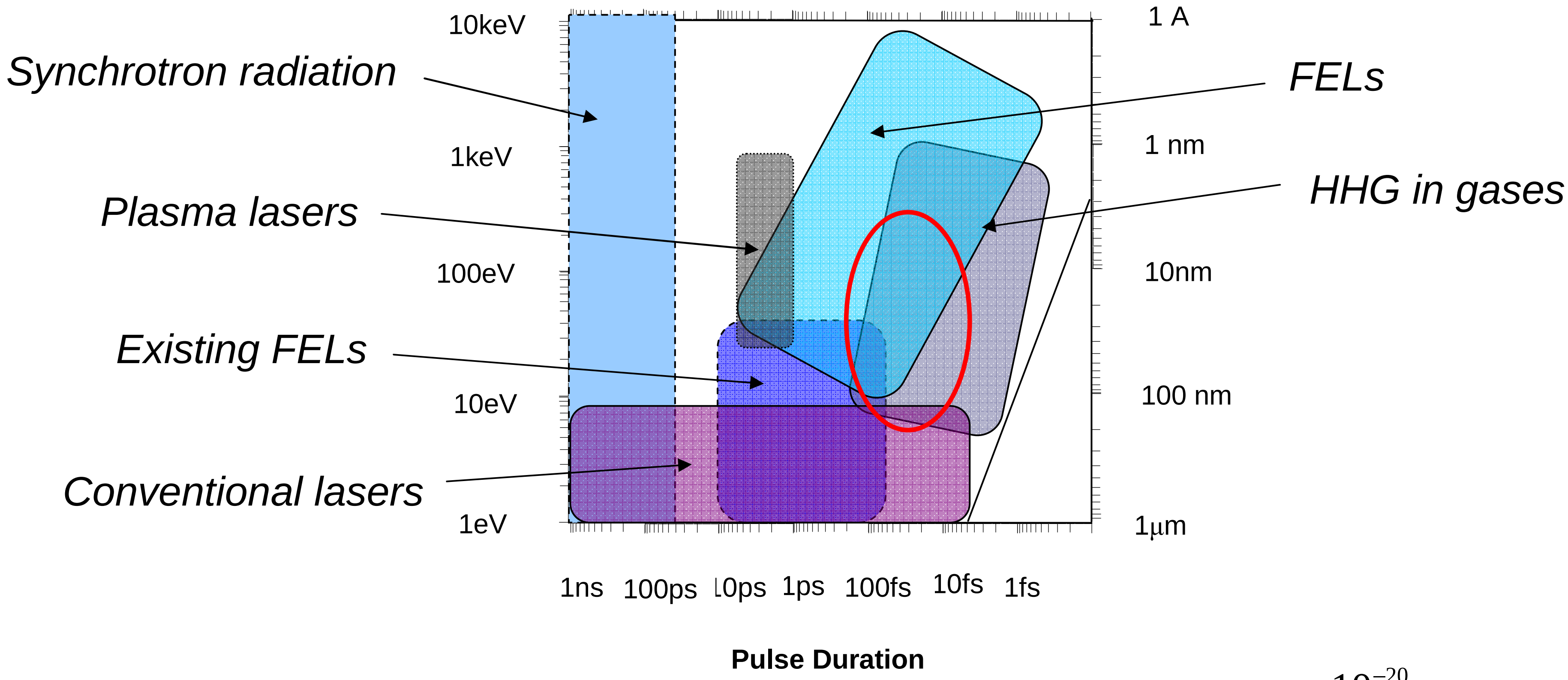
Balanced Optical Cross-correlators

Results at FERMI

Trends and new ideas

INTRODUCTION

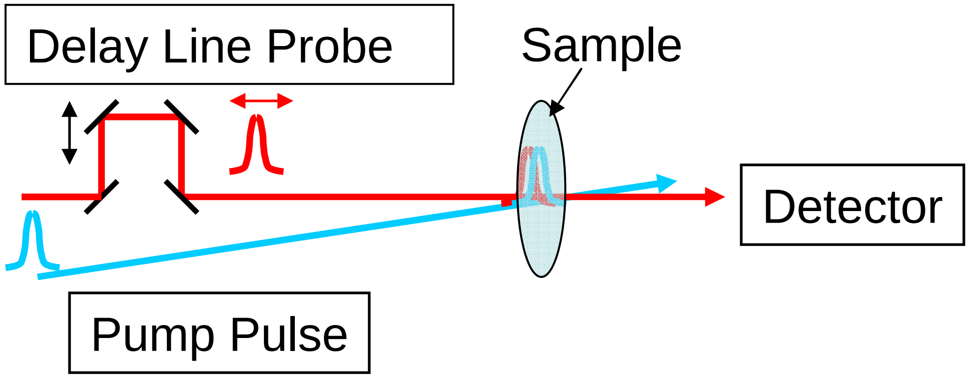
Main sources of laser-like beams/pulses in the 180-3 nm range



$$\frac{pump-power}{m^3} \sim \frac{10^{-20}}{\lambda^4 L}$$

BASIC GEOMETRIES

Two-colour /pump-probe experiment



OBSERVABLES:
- Transmission/Reflectivity
-Refractive index
-Fluorescence yield
-Dichroism/birefringence
-Photoelectron yield/energy
-…

Variations in the scheme:
-Single or multicolor
-Single shot: strongly chirped or tilted pulse
-Multiple beams (transient grating, multiwave mixing, etc)
-Single or separate sources of the pump and probe beams

In case of separate sources the stability of timing of the two sources limits the accuracy/resolution of the measurements

BASIC GEOMETRIES

Possible modalities of Pump-Probe at FELs:

-Two pulses derived from the FEL : 2 Xray pulses; Xray + THz ;

Advantage: naturaly synchronised

Problem: very limited wavelength choice(limited to FEL harmonics for SASE, may be extended for seeded FELs)

- One or more pulses derived from external laser synchronised

to the FEL

Advantage: freedom to choose wavelength and pulse duration

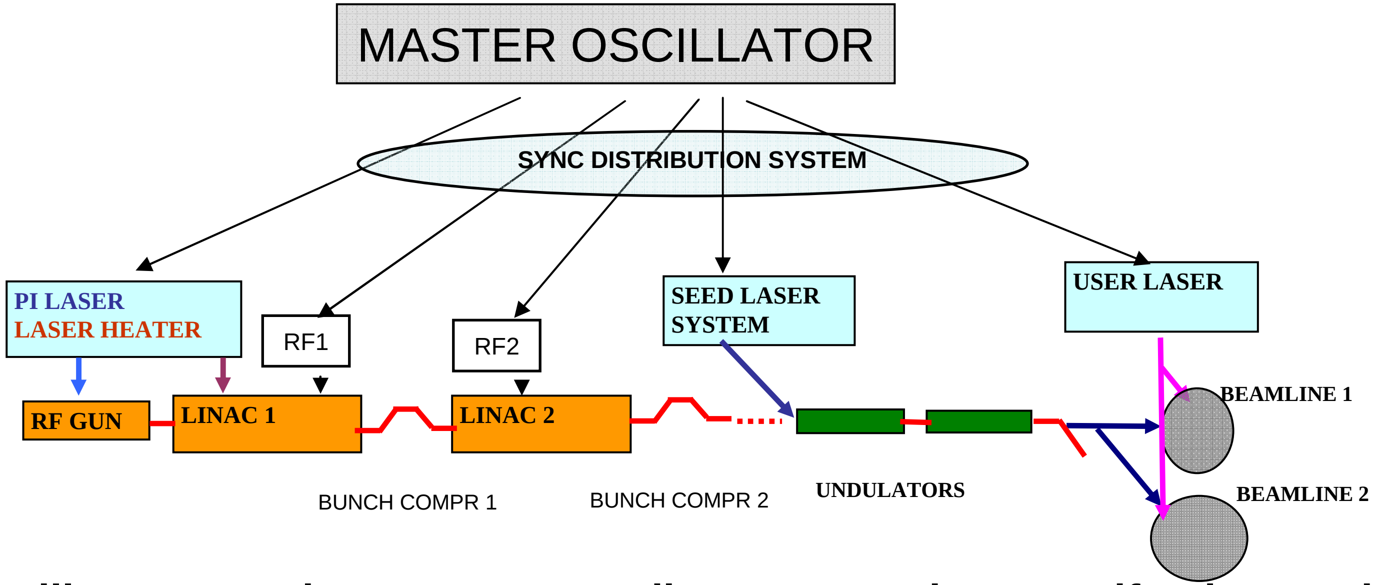
Main problem: accuracy/resolution limited by the relative jitter FEL/External Laser

- Only for Seeded FELs: Propagate a portion of the seed laser light to the user stations

Advantage: potentially very low jitter

Note: need well designed vacuum beam transport and feedbacks for compensation of pointing/timing drifts

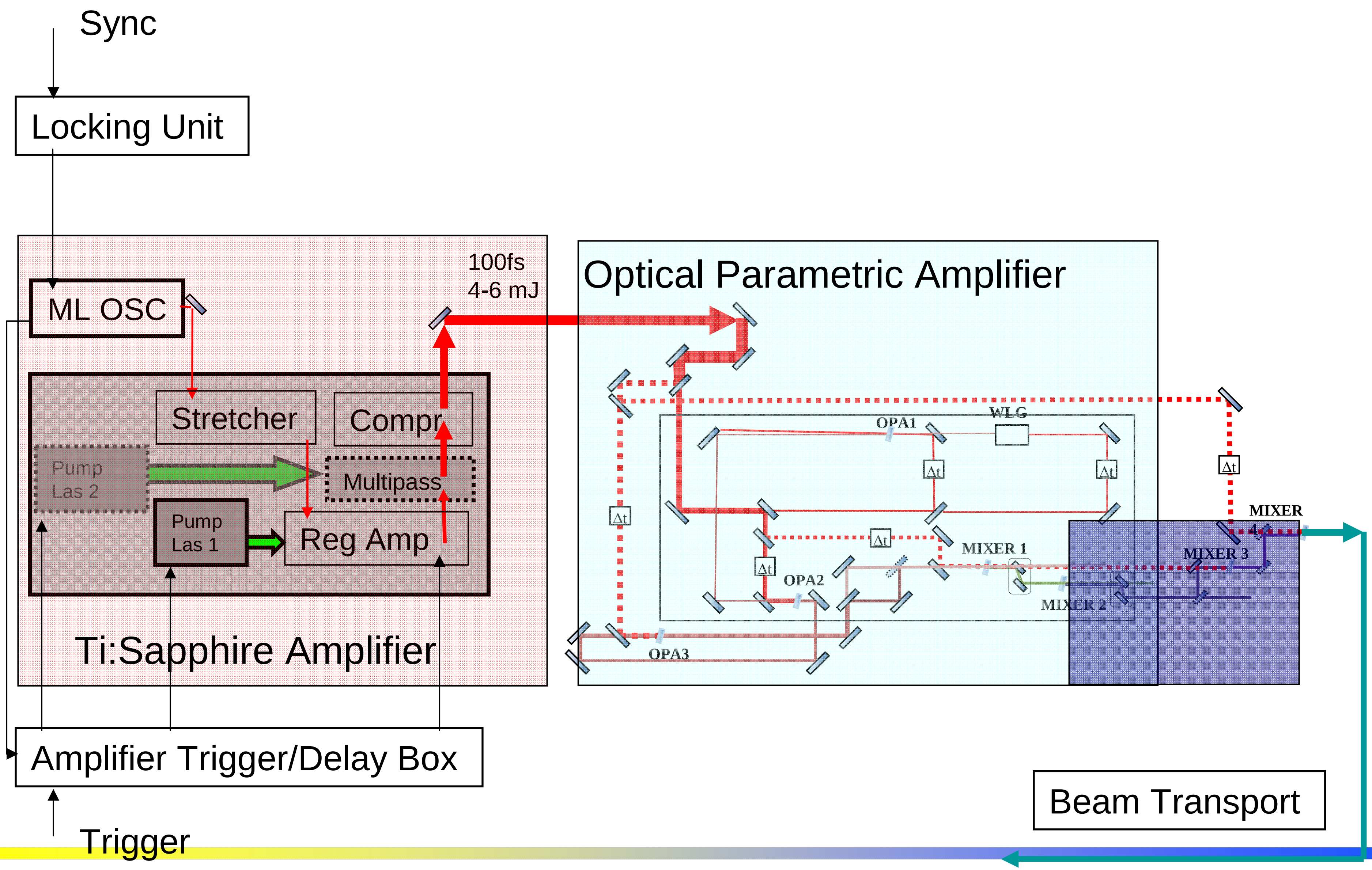
SOURCES OF TIMING ERROR BETWEEN THE FEL AND EXTERNAL LASER



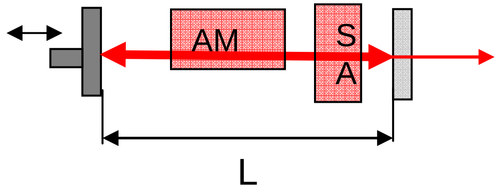
1. Master oscillator – very important, not a direct source, however if noisy can induce locking errors in the local locking systems; can be a high stability microwave oscillator (CW) or a ML laser locked to a microwave or optical standard
2. SYNC (phase) distribution system: in the optical version can be drift free, source of jitter (low in the advanced systems)
3. Locking of the Local Laser systems: crucial, both jitter and drifts, the influence of PIL is smaller due to compression
4. LINAC : jitter and drifts induced by the RF , by trajectory length changes

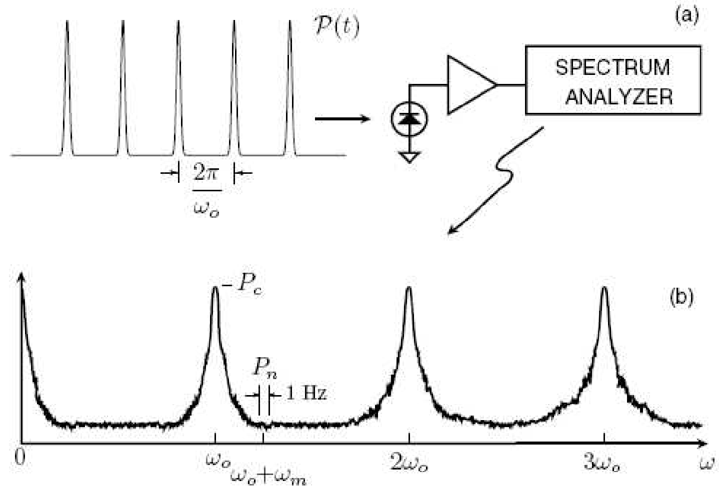
In SEEDED FELs the LINAC jitter introduces only amplitude/spectral instabilities however FEL pulse timing is fixed by the SEED LASER

EXAMPLE OF A TUNABLE ULTRAFST LASER SYSTEM: SEED/USER LASER



TIMING OF MODE LOCKED LASER OSCILLATORS





ML Lasers generate train of pulses with rep rate ***w_o=c/2L***

Typical RR 40 -200 MHz

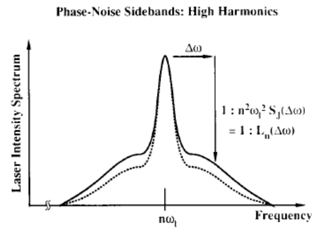
Instabilities of P(t):

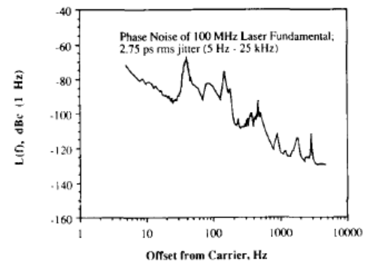
-***Amplitude noise***

-***Phase noise :***

10 Hz-10 MHz -> timing jitter

Slow phase changes->timing drifts





$$L_n(\omega) = n^2 \omega_l^2 S_J(\omega)$$

Timing jitter: $$\sigma_J \equiv \sqrt{\langle J(t)^2 \rangle} = \sqrt{\frac{1}{\pi} \int_{\omega_{low}}^{\omega_{high}} S_J(\omega)\, d\omega}.$$

-H. A. Haus and A. Mecozzi, “Noise of mode-locked lasers,” *IEEE J. Quantum Electron.*, vol. 29, pp. 983–996,
-L.-P. Chen et al , “Spectral measurement of the noise in continuous-wave mode-locked laser pulses,” *IEEE J. Quantu Electron.*, vol. 32 (1996) , pp. 1817–1825, Oct. 1996.
-D. Eliyahu et al “Noise characterization of a pulse train generated by actively mode-locked lasers,” *J. Opt. Soc. Amer. B*,vol. 13 (1996) , pp. 1619–1626.
-M.Rodwell et al, *IEEE J.Quantum Electron.*, vol. 25 (1989), pp. 983–996

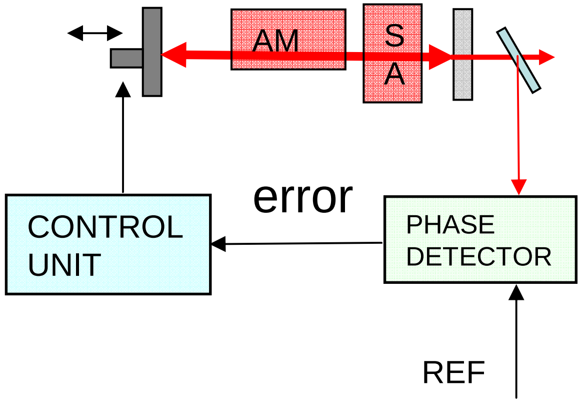
Mode-Locked Oscillators for Amplifier Seeding

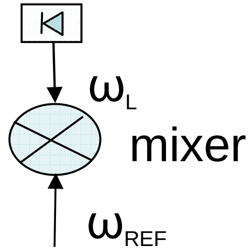
Ti:Sapphire oscillators

- **Central wavelength 800 nm region**
- **Kerr-lens mode locking, typically not self-starting**
- **Pulse-length anywhere in the 10fs-1 ps range, bandwidth up to 100 nm**
- **Average power: typical 500 mW**
- **Rep-rate 80 MHz - 100 MHz range**
- **Commercial systems with hardware prepared for timing stabilization available**
- **May require frequent interventions**
- **Pump-diode lifetime 12000-15000 hours, replacement costly**
- **Commercial systems not optimised for low jitter**

Er-doped fibre lasers

- Wavelength in the 1560 nm window (low dispersion in fibre propagation, SH coincides with Ti:Sa wavelength)
- Low intrinsic phase noise and higher long term stability
- Exceptional pointing stability
- Rep-rate 50 MHz - 3 GHz range
- Pulse-length in the few-100 fs range
- Low-power and narrow bandwidth of the second harmonic





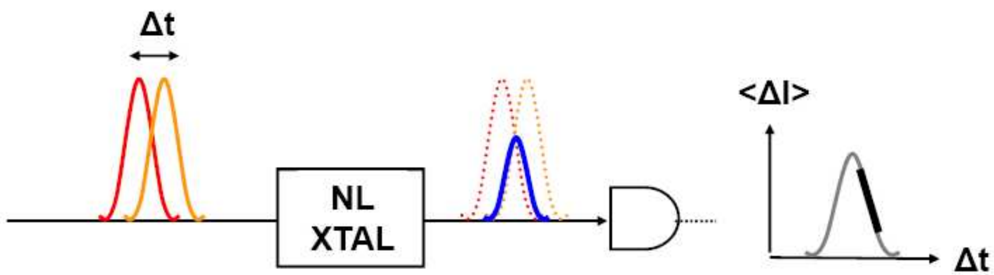
Phase Locking Loop for Laser timing stabilisation (left) and an RF balanced mixer based phase detector

NOTES:

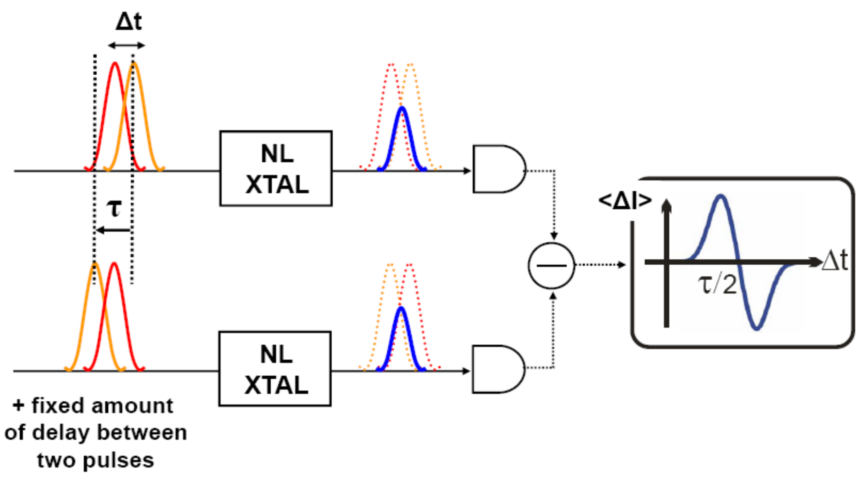
1. Phase detection can be RF, optical or hybrid
2. In most cases the laser cavity contains at least 2 (or even 3) actuators for fast and slow cavity length control
3. Typicallly only phase noise with frequency below few KHz is well cancelled by such loops due to limitations by the actuators-> much attention should be paid when choosing the laser oscillator and for isolation from external noise
4. Most commercial systems have only RF based options and specify above 200fs RMS jitter (10Hz-10MHz).

OPTICAL PHASE DETECTION

Optical Crosscorrelator:
-high sensitivity (sub fs
If 100 fs long pulses are
used
Problem:
sensitive to amplitude
changes



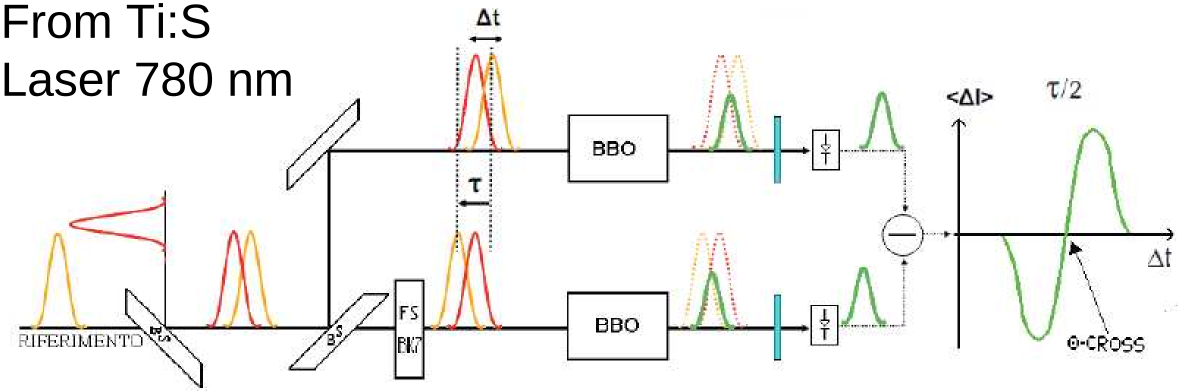
Balanced optical cross-correlator
(BOCC):
Immune to amplitude changes

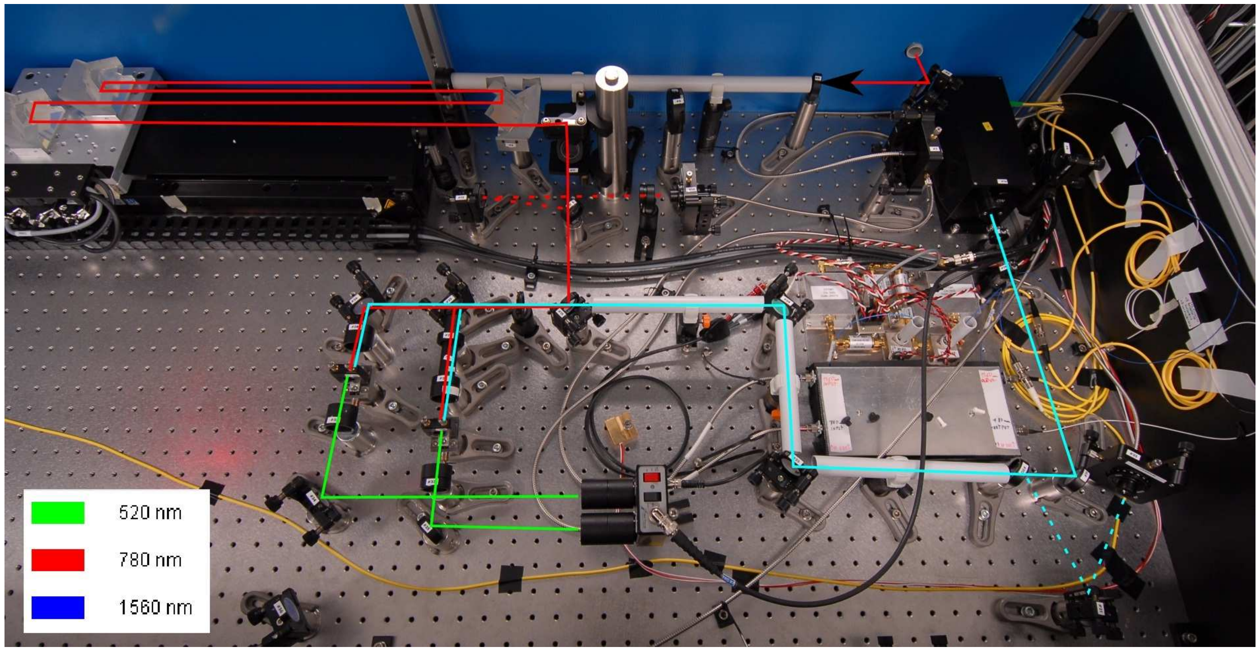


BOCC DEVELOPED FOR FERMI

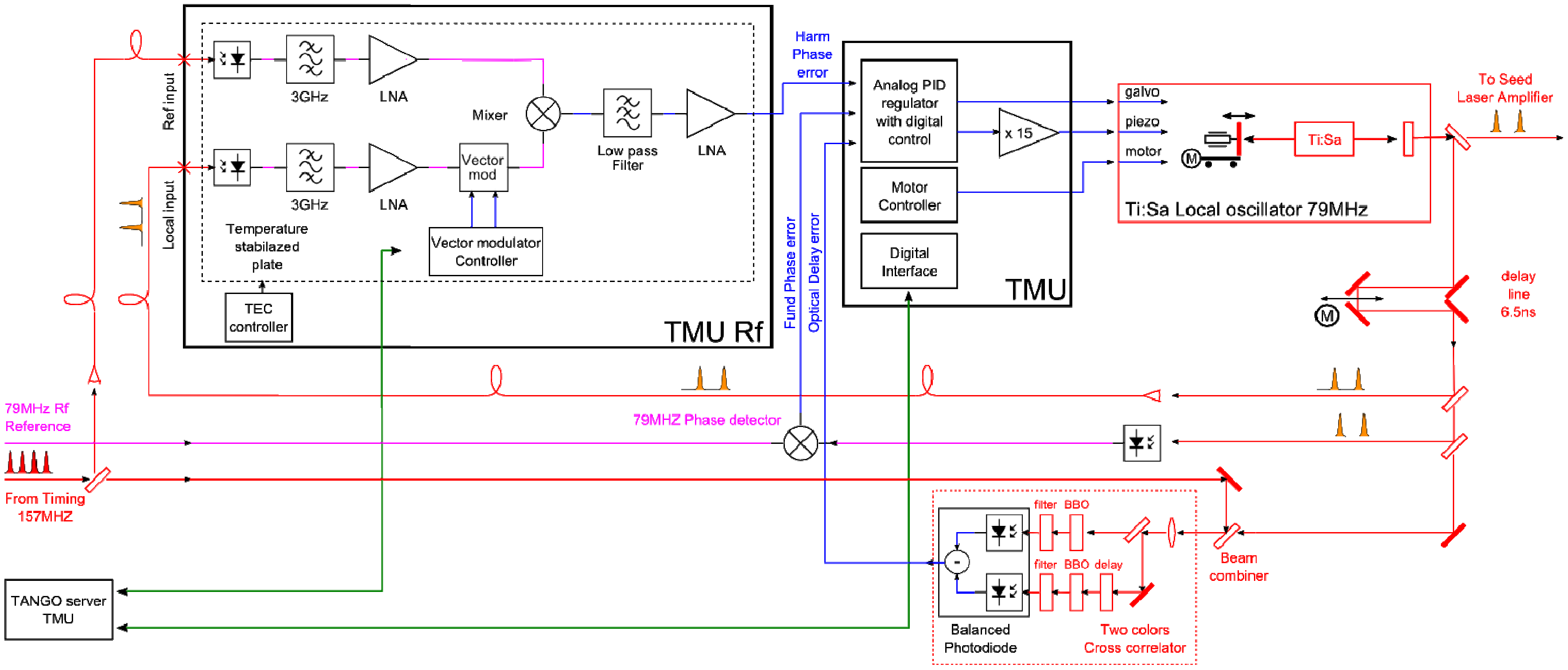
From Ti:S
Laser 780 nm

From Reference
(Fibre link), 1560 nm



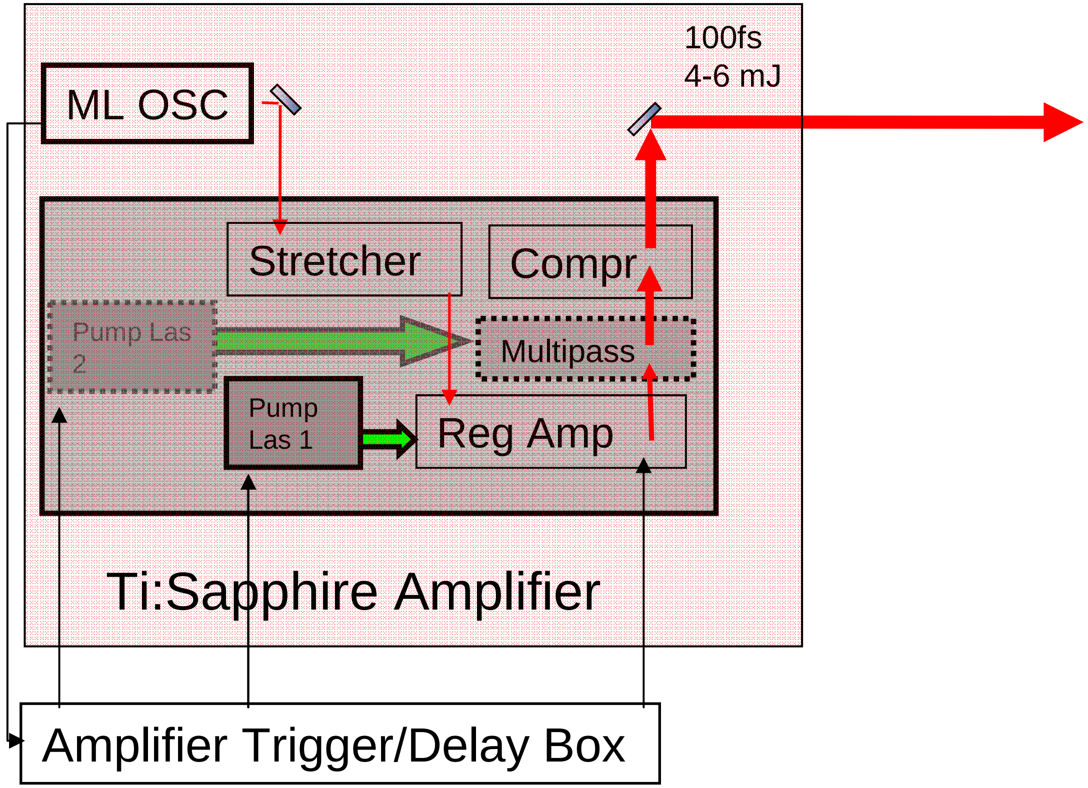


THE TIMING STABILIZATION ELECTRONICS DEVELOPED FOR FERMI



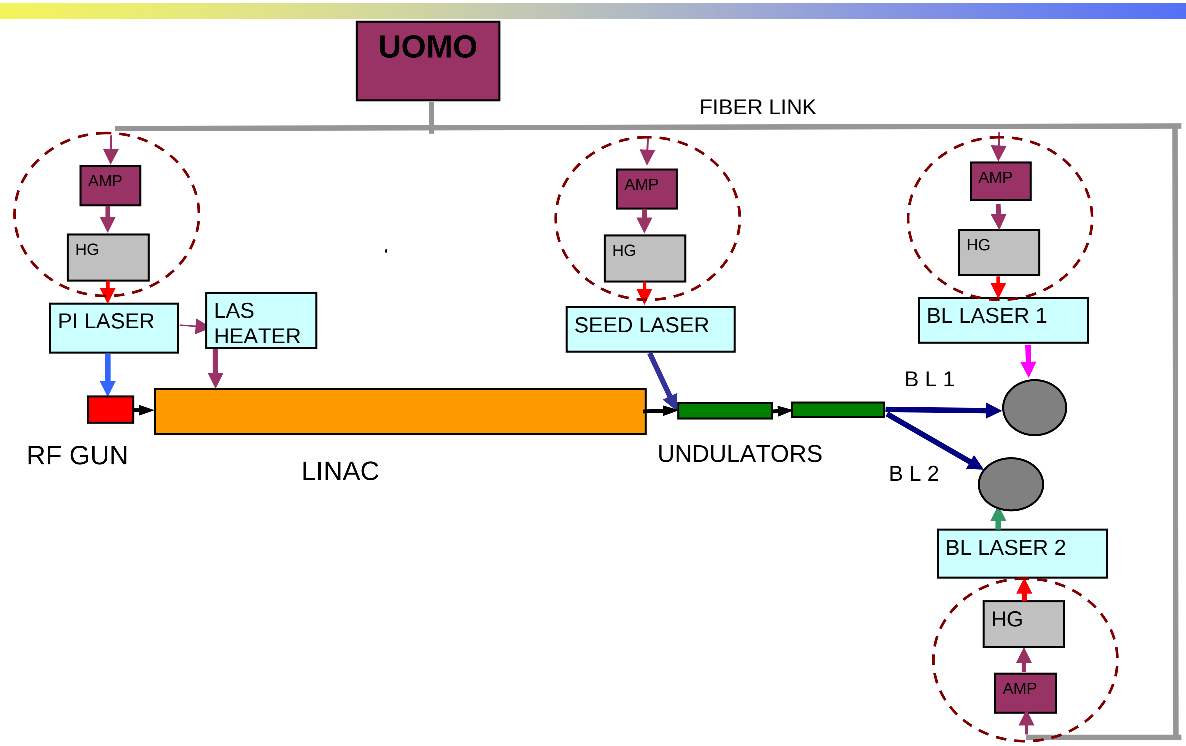
OPTICAL AMPLIFIERS CONTRIBUTION TO TIMING PROBLEMS

Timing jitter: negligible for well engineered systems (e.g. <20 fs RMS measured for some commercial systems)
Timing drift: can be a problem!
Causes:
-due to the long optical path (typically >30 m) even small temperature changes lead to Important time drifts
-Oscillator beam pointing changes: lead to path changes in stretcher/ compressor
Similar situation with parametric amplifiers and long beam transport



WAYS TO SOLVE:
-temperature stabilization
- Feedbacks for pointing/delay compensation

Direct seeding concept



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

Main issues:

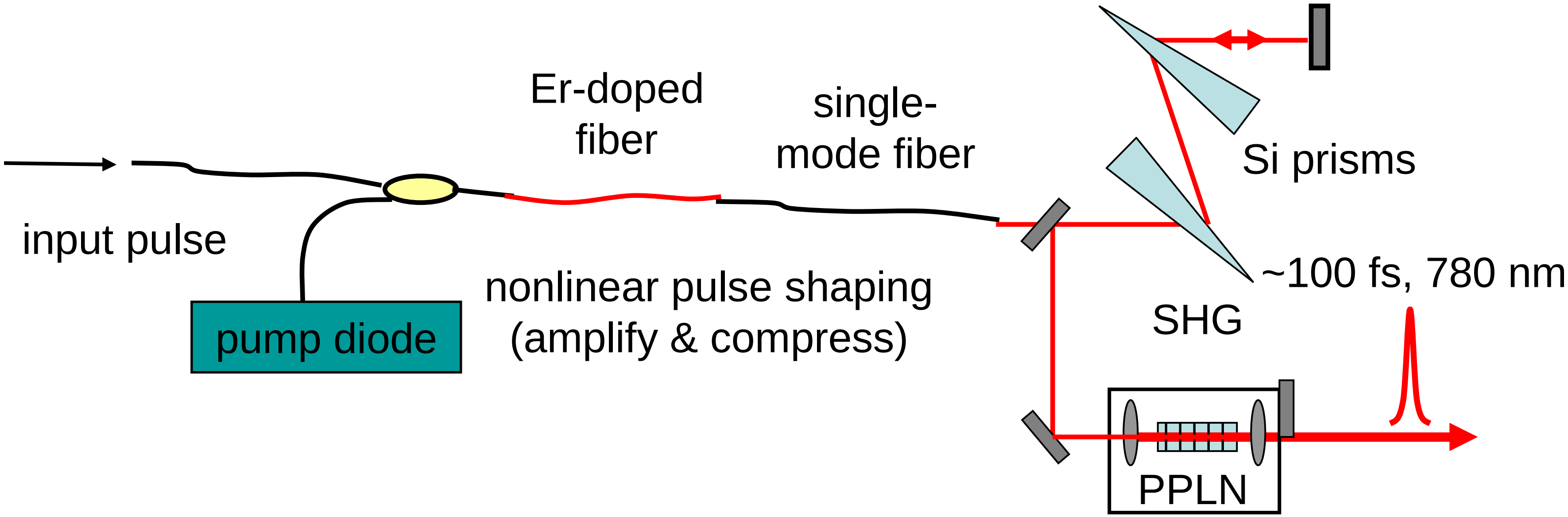
-Power (>0.5 nJ at 780 needed)

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

DIRECT SEEDING CONCEPT

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

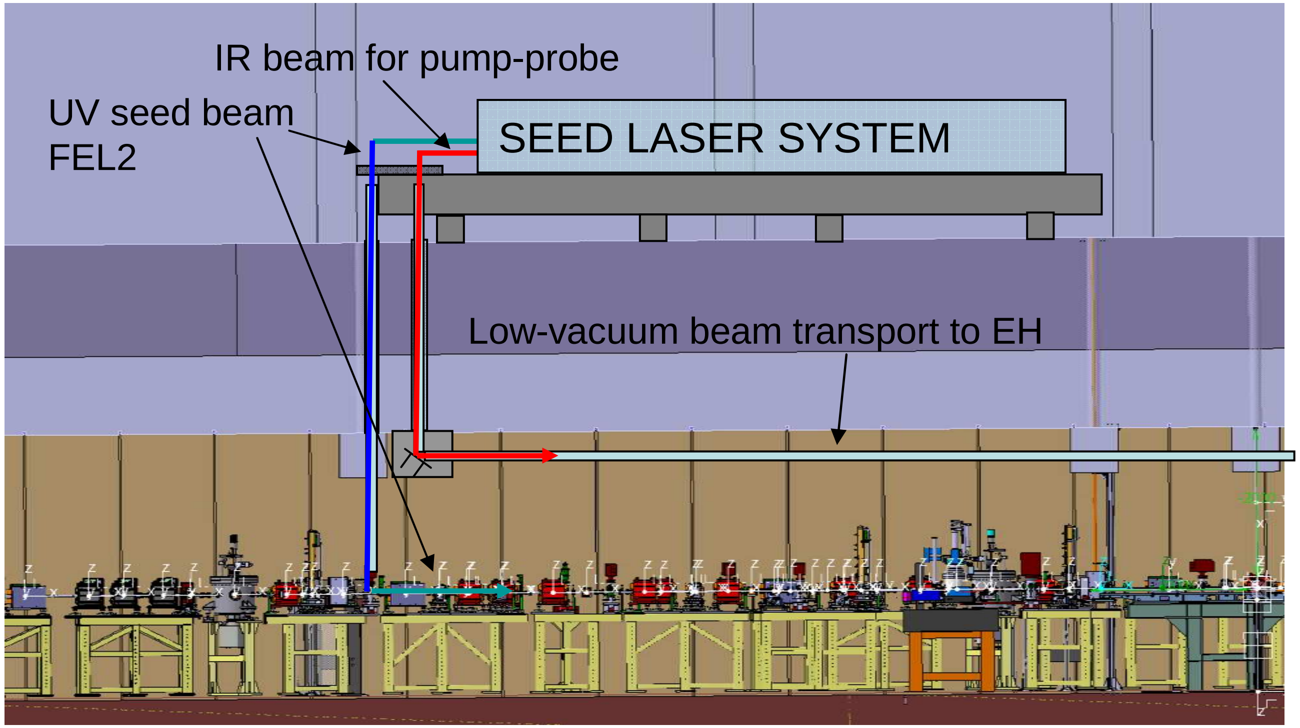
~100 fs (~3 nJ @ 1550 nm & ~1 nJ @ 775 nm)



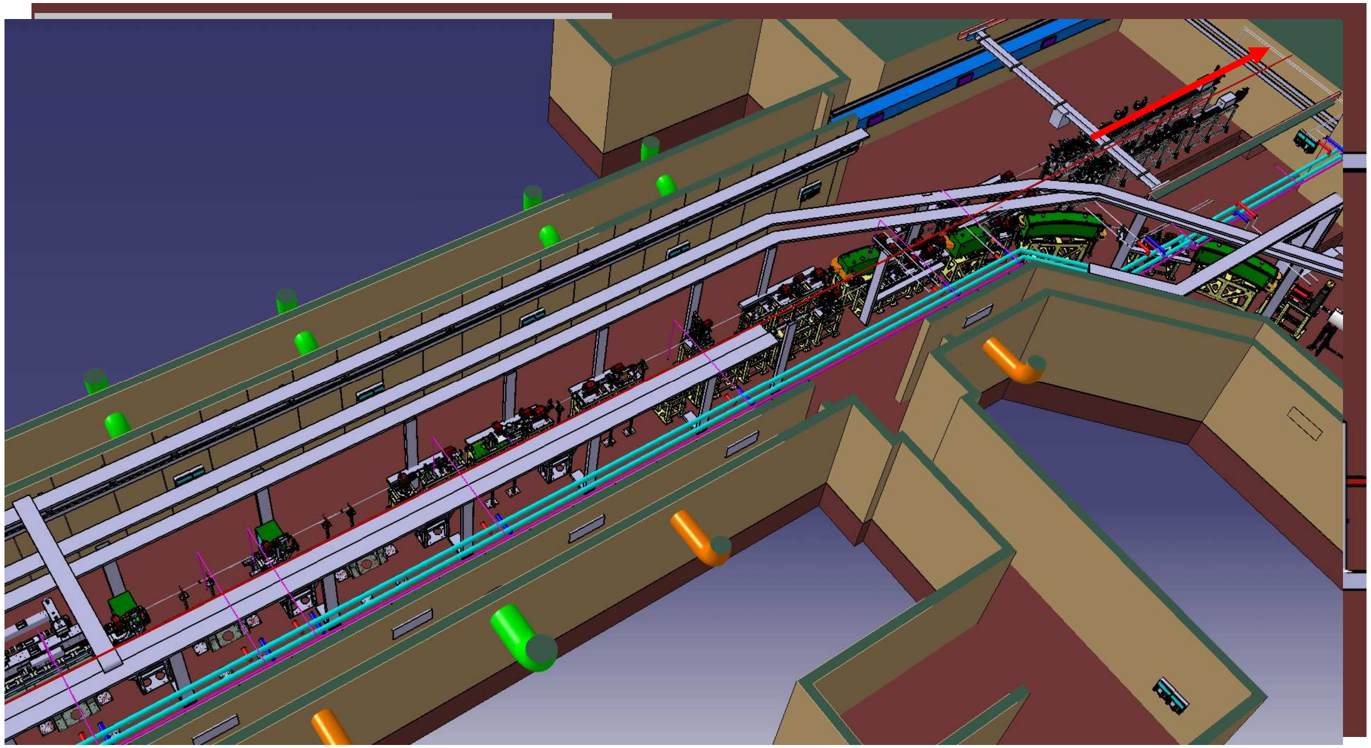
Where we are:
-SHG unit based on chirped PPLN developed
-tests of the amplifier setup

USE OF THE FERMI SEED LASER FOR LOW JITTER PUMP PROBE EXPERIMENTS WITH FERMI

- **MAIN IDEA: The FERMI FEL pulse timing is determined by the seed: this opens up the opportunity of jitter-free pump-probe measurements if a part of the seed laser pulse is propagated to the beamlines**
- **PROPOSED SCHEME**



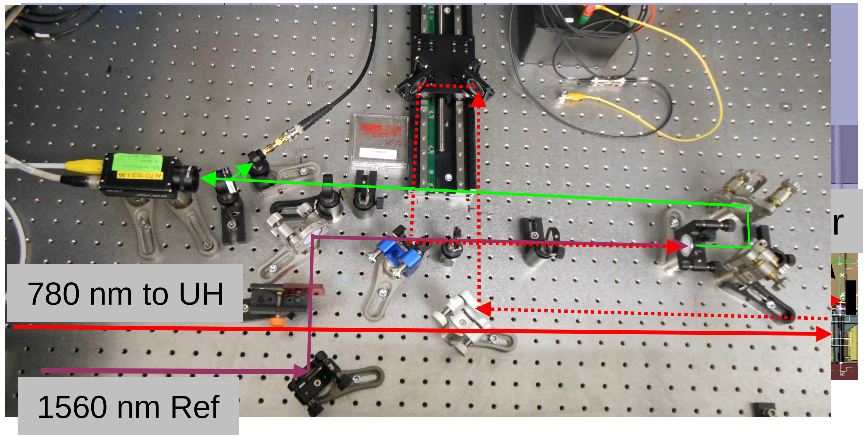
USE OF THE FERMI SEED LASER FOR LOW JITTER PUMP PROBE EXPERIMENTS WITH FERMI

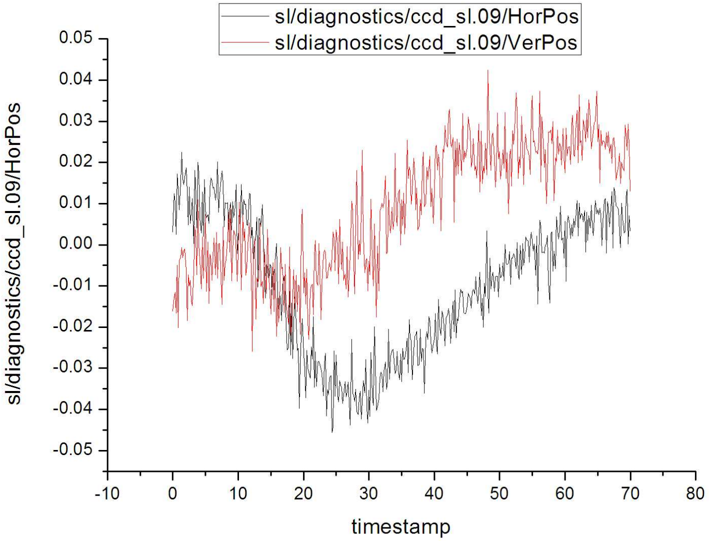


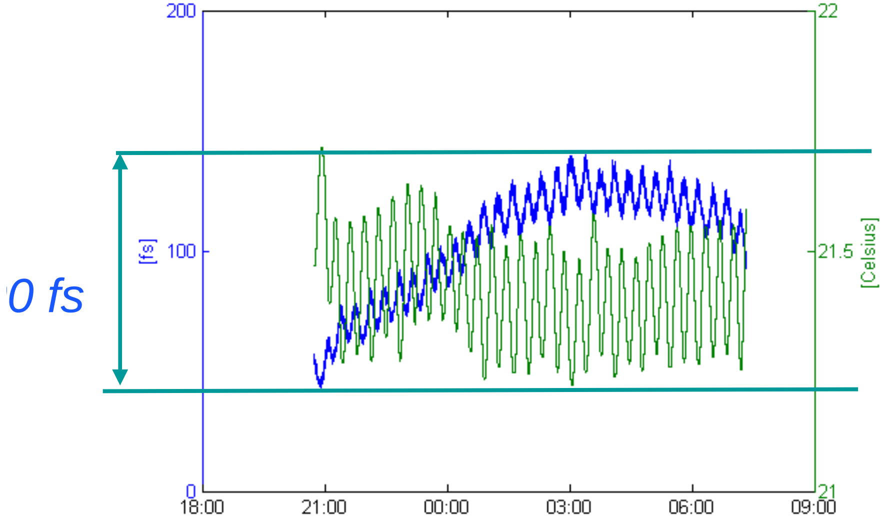
Trajectory of the Seed laser low vaccum beam transport in the FERMI Undulator Hall (left) and Experimental Hall (right). Mechanical design of the low vacuum chambers and high stability steering mirror mounts is ongoing

RESULTS FROM FEASIBILITY TESTS

Mesurement of the timing jitter, drifts and pointing stability of IR pulses from the oscillator propagated at 46 m from the Seed Laser table to UH as shown on the Figure on the right.







Crosscorrelator measurement of the propagated pulse timing jitter (left) and drift (right)