Elettra Sincrotrone Trieste

Elettra
Sincrotrone
Trieste

# The FERMI Optical Timing system: operating experience and latest developments

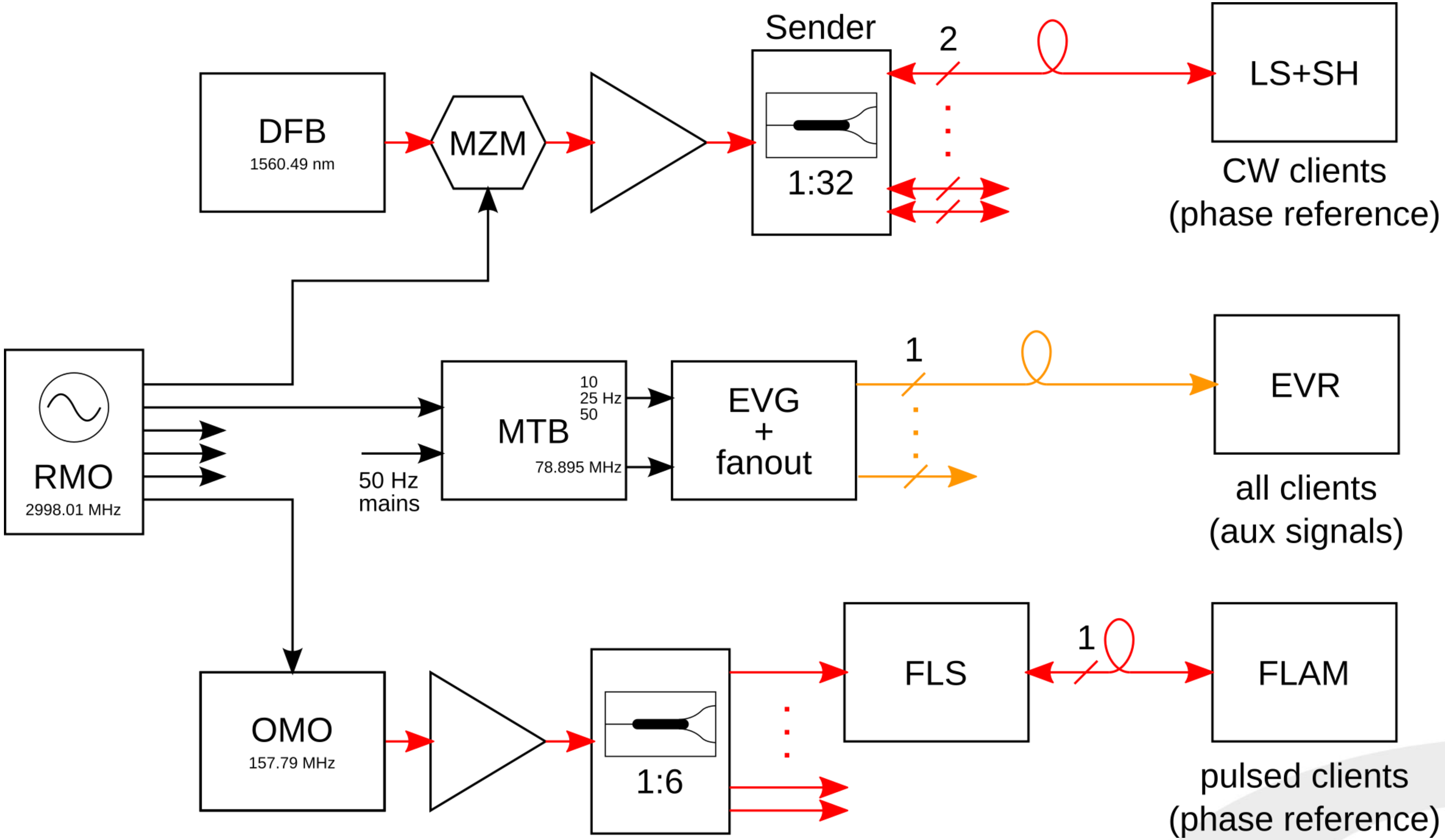
**F. Rossi**, M. Predonzani, M. Ferianis

Elettra Sincrotrone Trieste

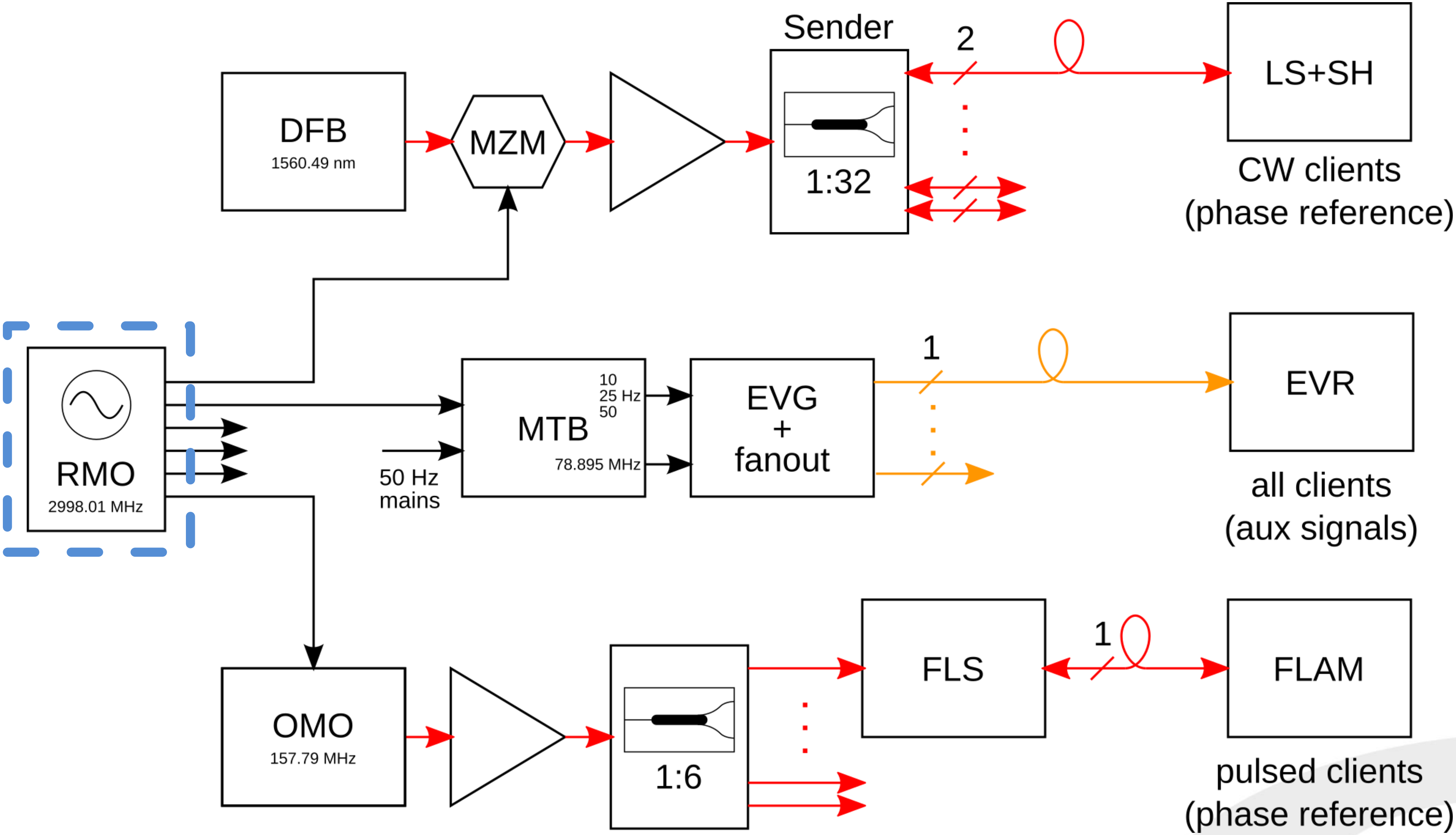
# Outline

- system overview
- operating experience
- current and future activities

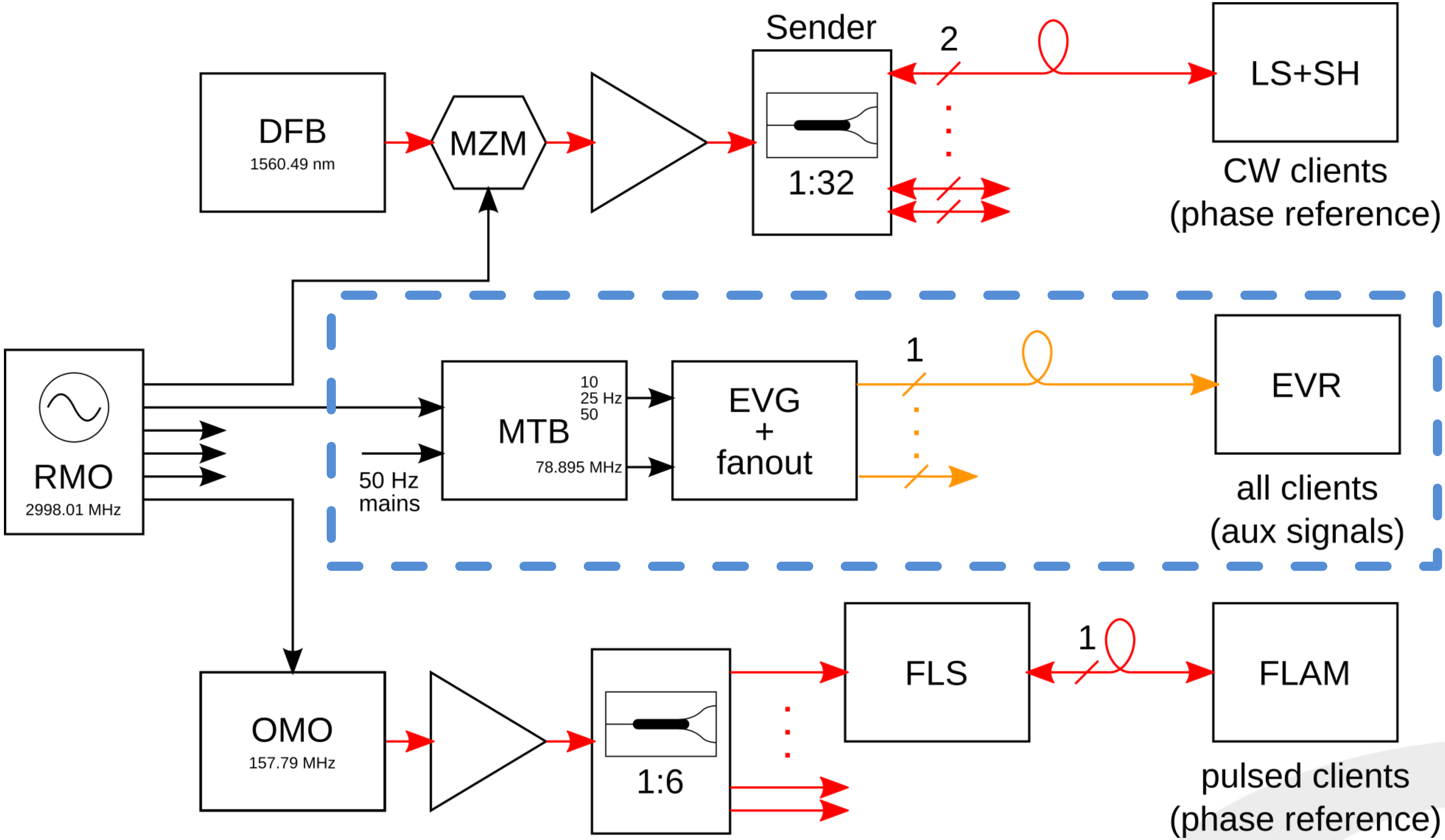
# System overview



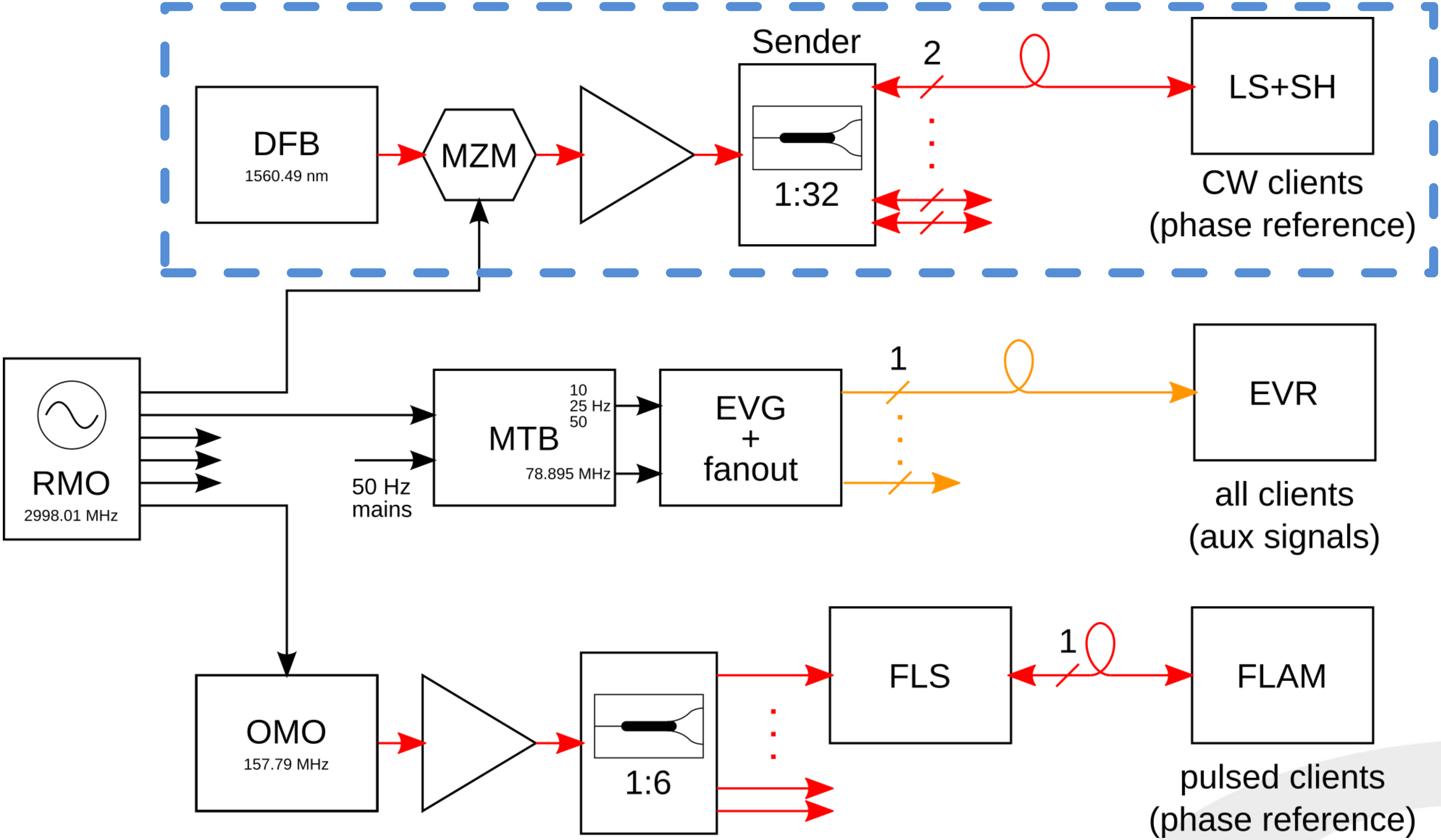
# System overview



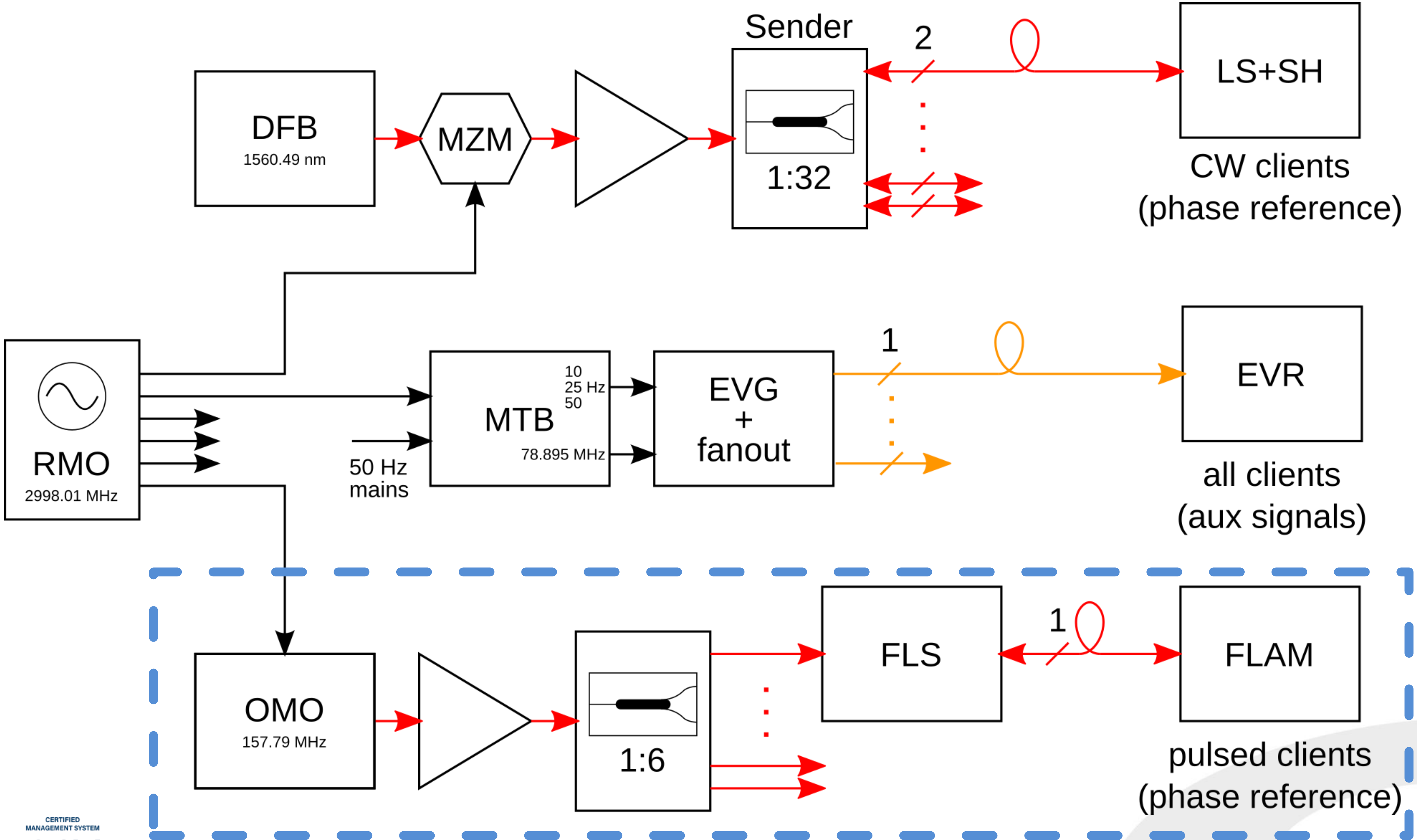
# System overview



# System overview



# System overview



Elettra Sincrotrone Trieste

# Operating experience

- how critical is the start-up of the system?
  - it requires at least a day starting from scratch (to reach an effective stabilization)
  - a procedure based on checklist  is used to verify the system
  - the pulsed subsystem is more tricky due to the care needed to find and optimize (not deterministic process) the OMO mode-locking
    → we prefer to leave the laser always on (even during machine shutdown periods)
  - the CW subsystem is a turnkey solution
- how much effort is needed to operate the system?
  - up to now the fault rate has been quite low (a few events per year)
  - it is important to provide prompt support to control room
    → data analysis is quite important to find the source of a problem
  - system optimization as needed

Elettra Sincrotrone Trieste

# Operating experience

- which is our fault statistics?

Classification of the faults based on the impact on machine operations:

- negligible – all kind of blocking situations that can be solved quickly by generic operators (e.g. relocks, power cycling, etc)
- medium – all the faults that require some servicing by specialized people
- severe – servicing + long recovery time (in particular, the faults affecting the centre of the star topology)

On the basis of our experience, the most common faults belong to the first category.

No faults due to radiations effects in the machine tunnels have been observed.

In 2009, one of the open issues was whether optical technologies for timing applications were reliable for 24/7 operations. An over ten-year experience confirms they are.

# Operating experience

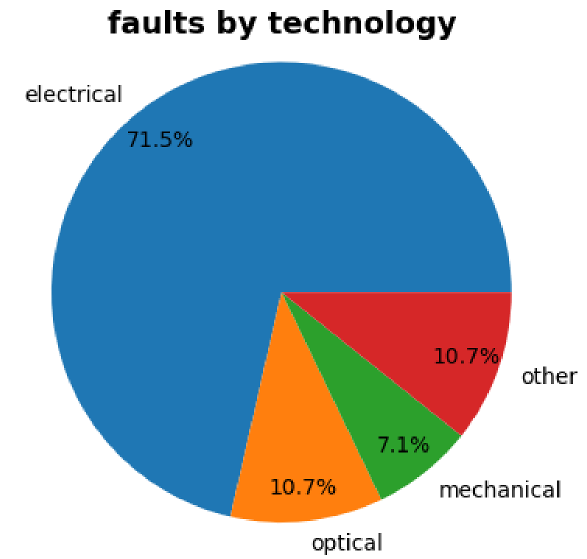
## fault statistics requiring specialized service

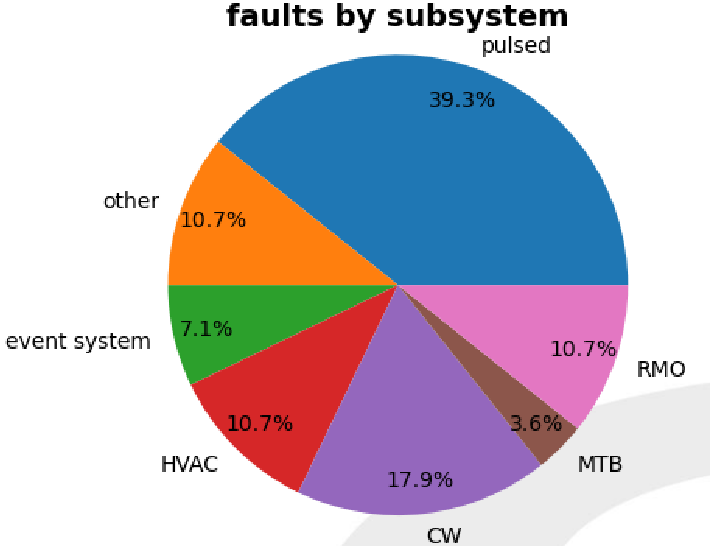
fs lab | FERMI timing config | FERMI timing faults

FERMI timing faults, all entries — Logged in as "Fabio Rossi" — ELOG

New | Find | Select | Import | Config | Logout | Last day | Help

| Edit | Delete | RUN | Date of fault | Subsystem | Technology | Text |
|---|---|---|---|---|---|---|
| | | 50 | Fri - 2023 Oct 27 | pulsed | electrical | RE306 chiller found off, replaced with spare part |
| | | 50 | Mon - 2023 Sep 11 | other | electrical | electrical power outage, complete switch-off full system |
| | | 49 | Mon - 2023 Jul 03 | event system | electrical | replaced EVR module K11 |
| | | 48 | Mon - 2023 Mar 20 | other | electrical | dead thermograph LT KG05.01 |
| | | 48 | Mon - 2023 Mar 20 | event system | optical | replace two SFP modules (one in the central fanout) |
| | | 45 | Wed - 2022 Jun 08 | HVAC | mechanical | problems with the HVAC timing room due to 3-state valve |
| | | 44 | Tue - 2021 May 04 | BAM | mechanical | dead delay line BAM frontend |
| | | 40 | Sun - 2020 Dec 06 | HVAC | electrical | unstability of HVAC timing room |
| | | 36 | Thu - 2019 Jun 13 | pulsed | electrical | problems with power supply chiller RE306, replaced |
| | | 35 | Thu - 2019 Mar 28 | CW | electrical | fixed RF power supplies of K3 and K6 link stabilizers |
| | | 33 | Mon - 2018 Apr 30 | pulsed | mechanical | problem with pump of chiller RE306, replaced |
| | | 31 | Fri - 2017 Nov 03 | pulsed | optical | dead pump diode LFC SL |
| | | 31 | Sun - 2017 Oct 29 | pulsed | other | many unlock events OMO due to wrong configuration of the software |
| | | 31 | Mon - 2017 Oct 23 | other | electrical | replaced thermograph L4 |
| | | 17 | Sat - 2017 Sep 30 | pulsed | electrical | fault power supply AC1550 |
| | | 31 | Thu - 2017 Sep 28 | CW | electrical | fixed power supply link stabilizer K9 |
| | | 29 | Mon - 2017 Jan 23 | pulsed | optical | burnt connector LFC amplifier EOS-link |
| | | 25 | Tue - 2015 Nov 03 | pulsed | other | recentering of FLS motor which reached end-of-travel |
| | | 17 | Fri - 2013 Sep 13 | CW | electrical | replaces synchead on K9 |
| | | 16 | Tue - 2013 Jul 16 | pulsed | electrical | power supply LFC PIL |
| | | 15 | Thu - 2013 Mar 14 | CW | electrical | replaced synchead on K8 (RF amplifier) |
| | | 14 | Sat - 2012 Dec 08 | pulsed | other | OMO lost modelocking |
| | | 13 | Wed - 2012 Oct 17 | pulsed | electrical | power supply LFC BC1 |
| | | 12 | Fri - 2012 Jul 27 | HVAC | electrical | problems with temperature sensor used by the loop |
| | | 12 | Fri - 2012 Jul 27 | MTB | electrical | unstable 78 MHz reference |
| | | 12 | Fri - 2012 Jun 15 | RMO | electrical | unstable RMO due to jumps in the frequency (OCXOs) |
| | | 10 | Fri - 2012 Mar 16 | RMO | electrical | unstable RMO, no lockable to Rb |
| | | 10 | Tue - 2012 Feb 07 | CW | electrical | replaced link stabilizer K3 |
| | | 7 | Wed - 2011 May 25 | RMO | electrical | replaced because of failure of internal multiplier |



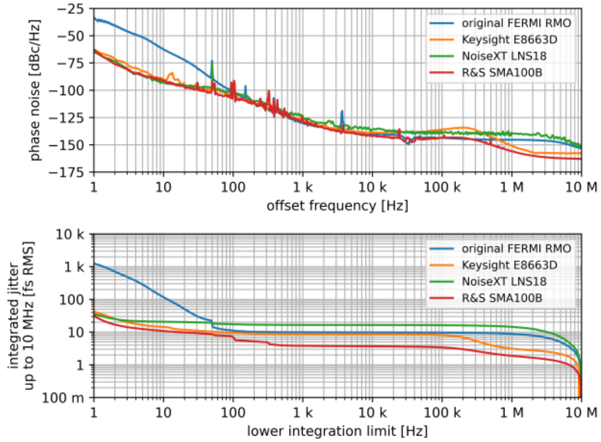



# Operating experience

- which is our strategy to maximize the up-time?
  - an on-call 24/7 service is mandatory
  - a close integration of the hardware in the machine control system
    - remote control and system automation
    - data logging (important for failure analysis)
    - continuous monitoring of the system parameters (key to implement an alarm system)
  - to predict instabilities or future problems by automatic analysis of system parameters
  - to exploit the periodic slots scheduled for machine maintenance for the optimization/tuning of the system (if needed)
  - the OMO has a redundant pump diode, it can be activated on demand without removing the laser from the system (never used this possibility!)
  - to use as much as possible standard products

# Operating experience

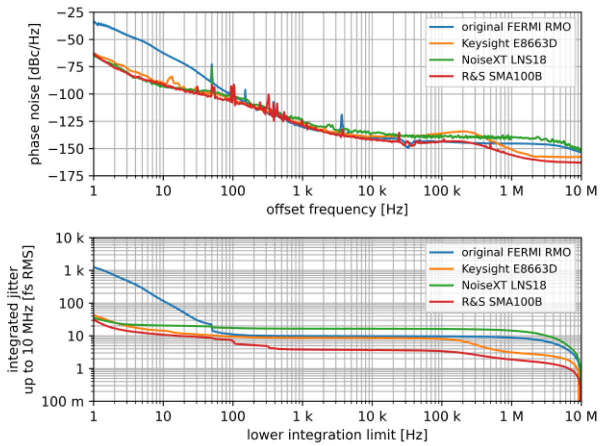
- which improvements were a real turning point?
  - Upgrade of our custom RMO to a commercial product (SMA100B)




- better phase noise
- reliability: no more faults related to RMO

# Operating experience

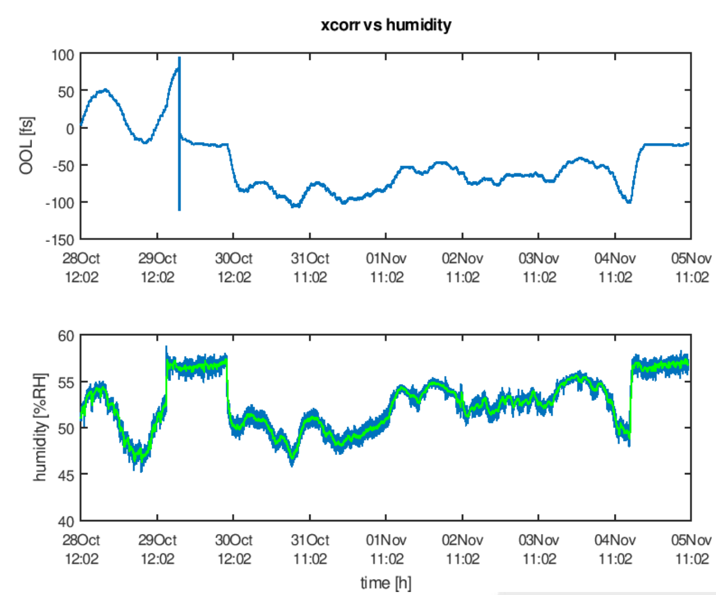
- which improvements were a real turning point?
  - Upgrade of our custom RMO to a commercial product (SMA100B)




- better phase noise
- reliability: no more faults related to RMO

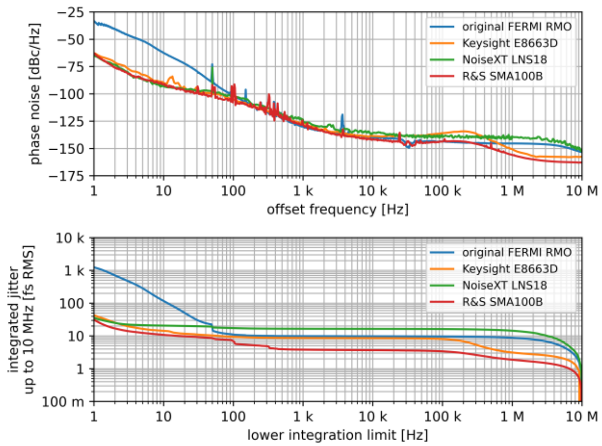
- Installation of an additional temporary machine to achieve a better control of the humidity in the timing room

  Hopefully moving to a new integrated HVAC in 2024
  - 0.25 degC p2p over 24 hours
  - 2%RH p2p over 24 hours

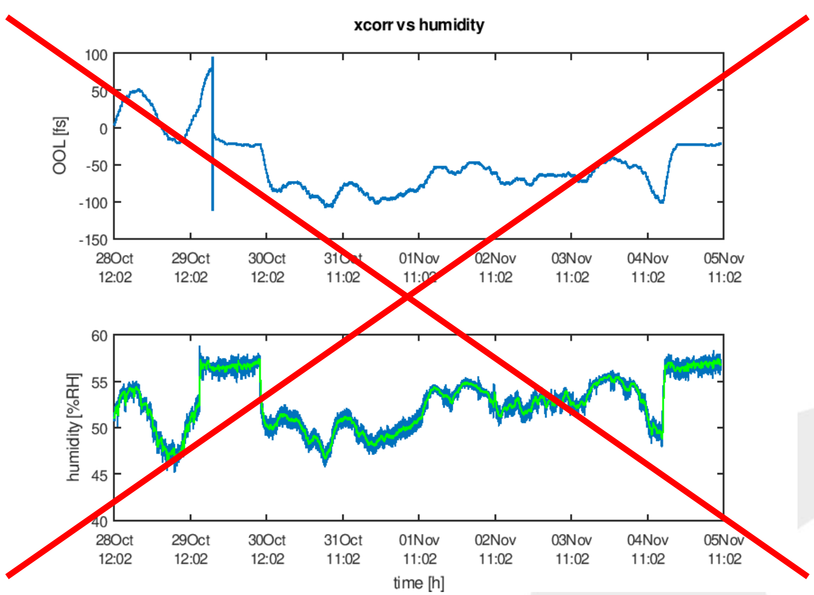


# Operating experience

- which improvements were a real turning point?
  - Upgrade of our custom RMO to a commercial product (SMA100B)




- better phase noise
- reliability: no more faults related to RMO




- Installation of an additional temporary machine to achieve a better control of the humidity in the timing room

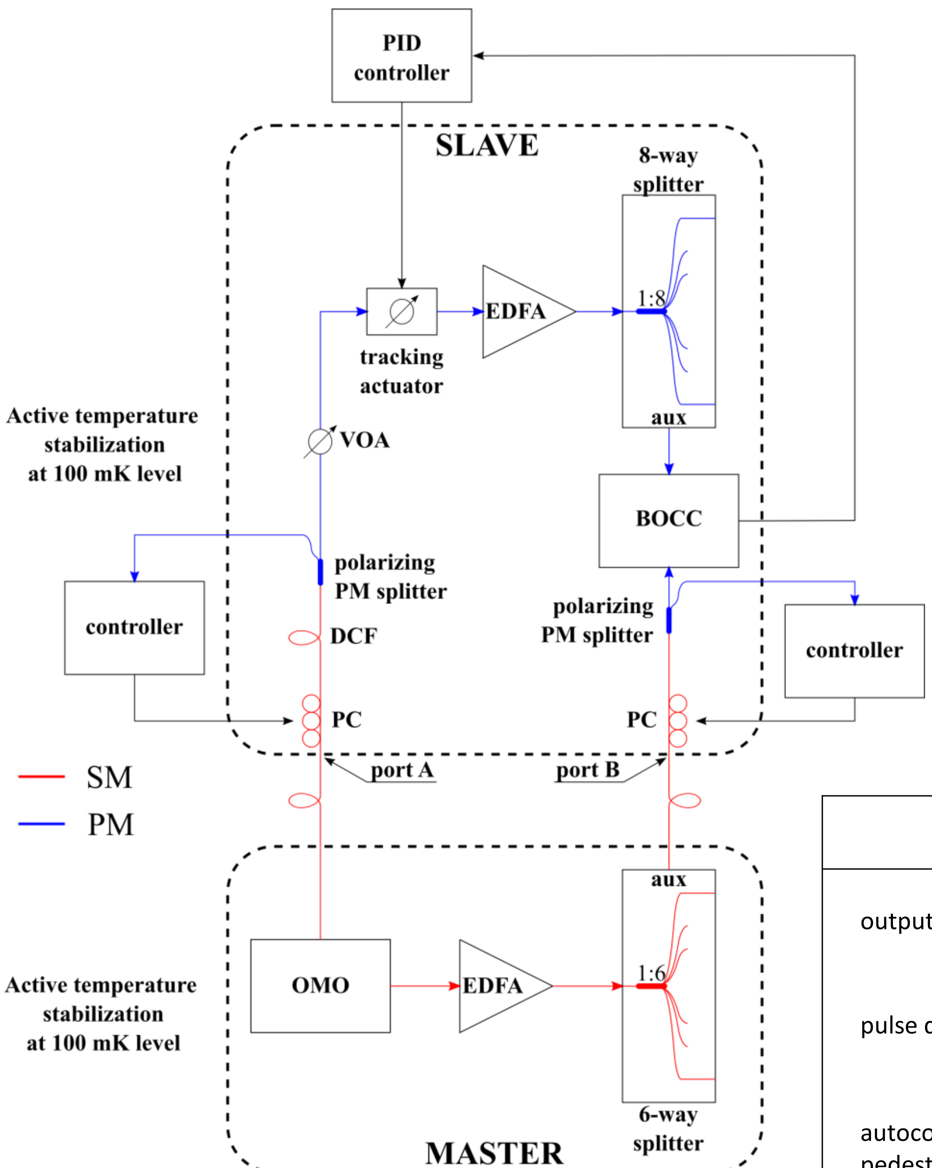
  Hopefully moving to a new integrated HVAC in 2024
  - 0.25 degC p2p over 24 hours
  - 2%RH p2p over 24 hours

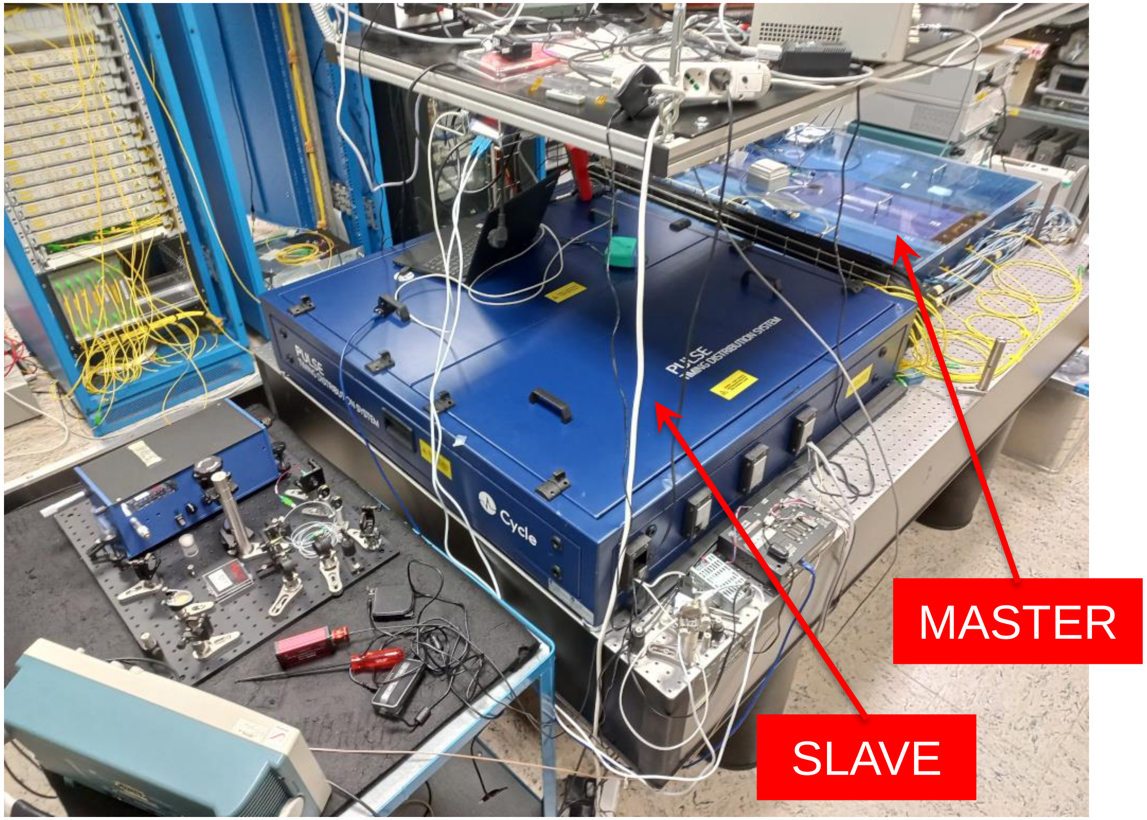
# Operating experience

- which are the drawbacks of our system?
  - the pulsed system is not based on a polarization maintaining architecture
    - → long-term stability < 1fs RMS is hard to achieve
    - → polarization drifts out of the links
    - → this poses a limit for future FEL requirements with shorter pulses
    - → how much is possible to improve the current architecture by squeezing the best performance out of it?
  - the OMO doesn't have a unique mode-locking condition
    - → the recovery time in case of failure is not deterministic
    - → the phase noise profile depends on the random combination of four waveplates
  - the CW distribution is "memory-less" due to the missing active stabilization of the link (in case of a power cycle the phase of the RF clients must be realigned, a software workaround is available)

Elettra Sincrotrone Trieste

# Current and future activities

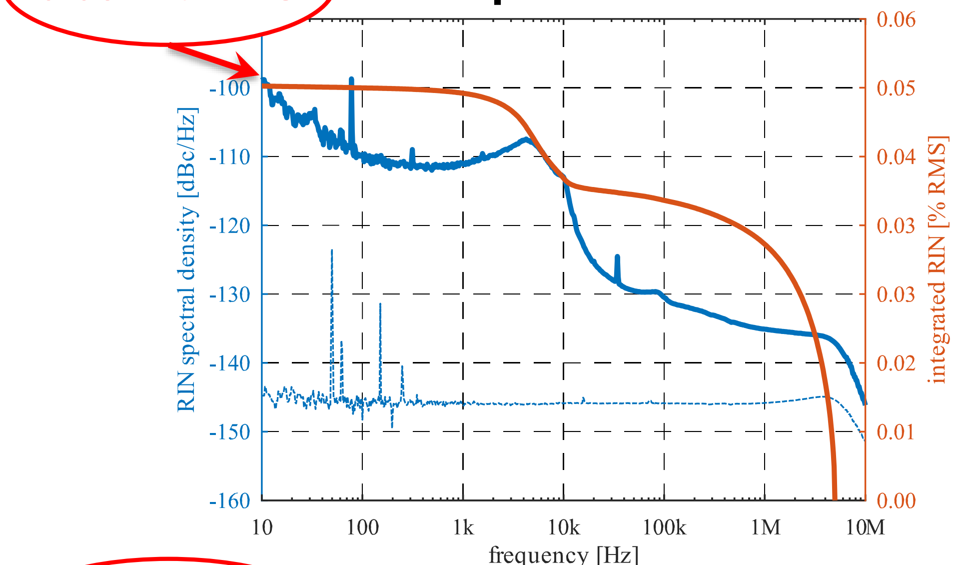


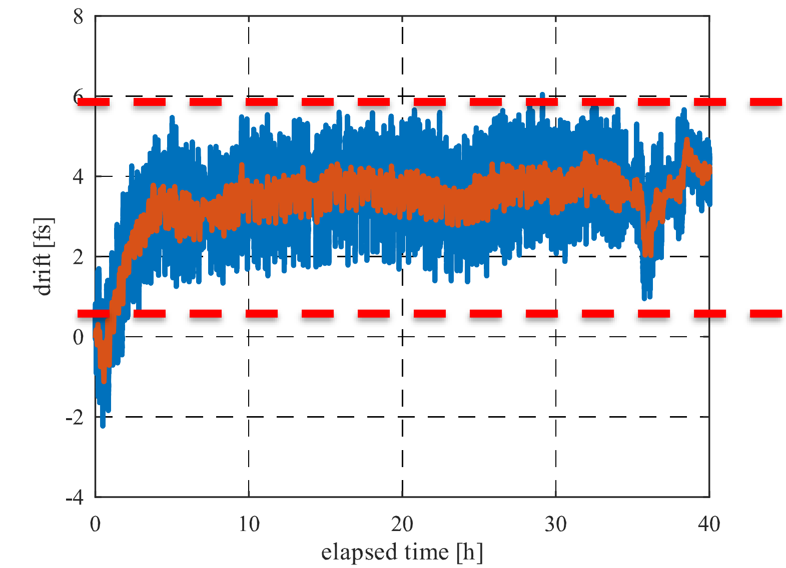

| the most relevant specifications | | | |
|---|---|---|---|
| output ports | 8 | amplitude noise | < 0.1 % RMS [10 Hz - 10 MHz] |
| pulse duration | < 200 fs FWHM | additive jitter | < 10 fs RMS [10 Hz - 10 MHz] |
| autocorrelation pedestal height | < 0.15% | splitter stability | < 25 fs p2p over 24-hour interval |
| average power | > 45 mW | tracker stability | < 25 fs p2p over 24-hour interval |

# Current and future activities

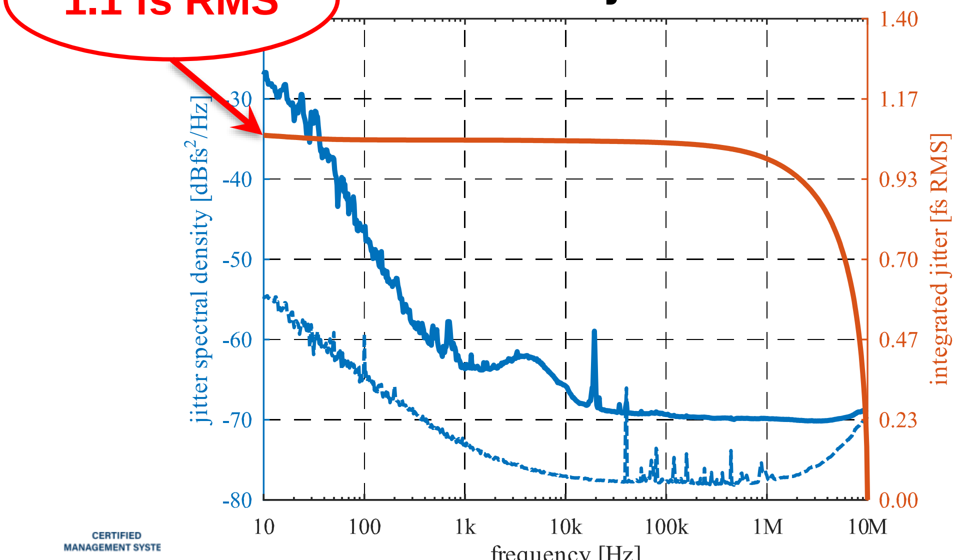
## amplitude noise



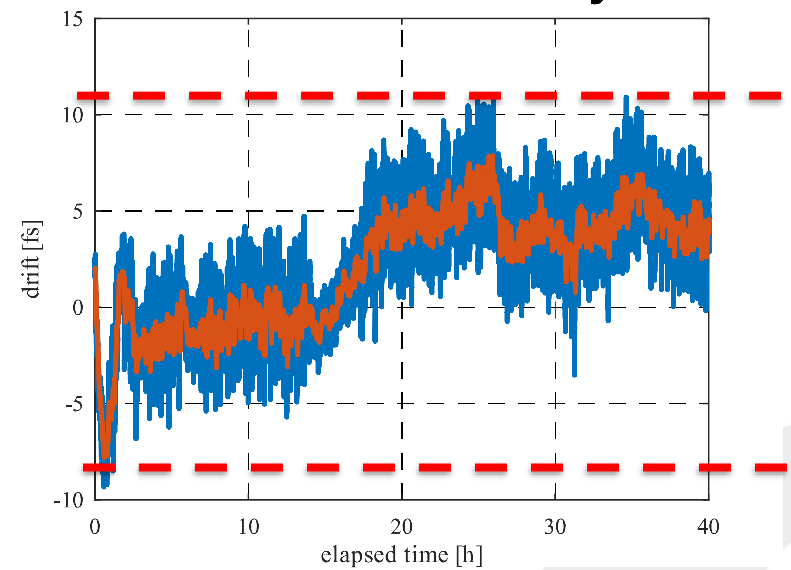

## splitter stability




## additive jitter

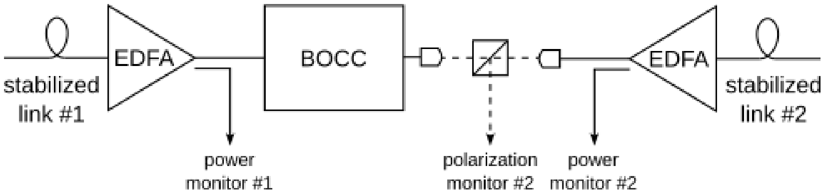


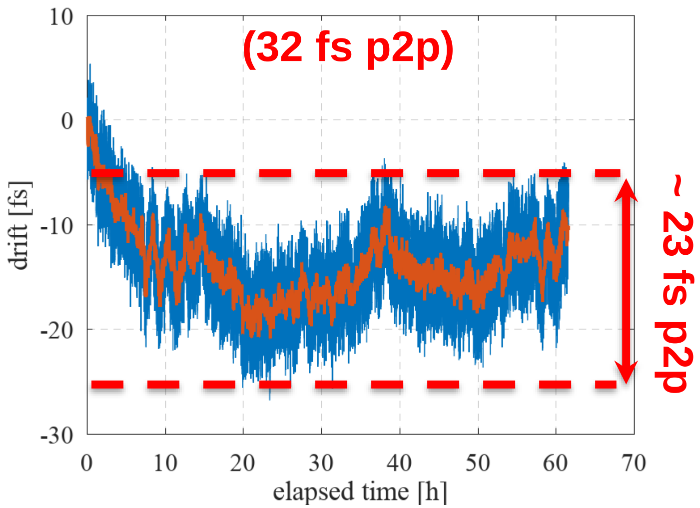

## tracker stability



# Current and future activities

## OOL drift measurement (preliminary)



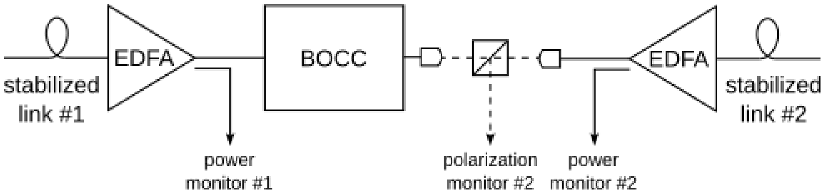



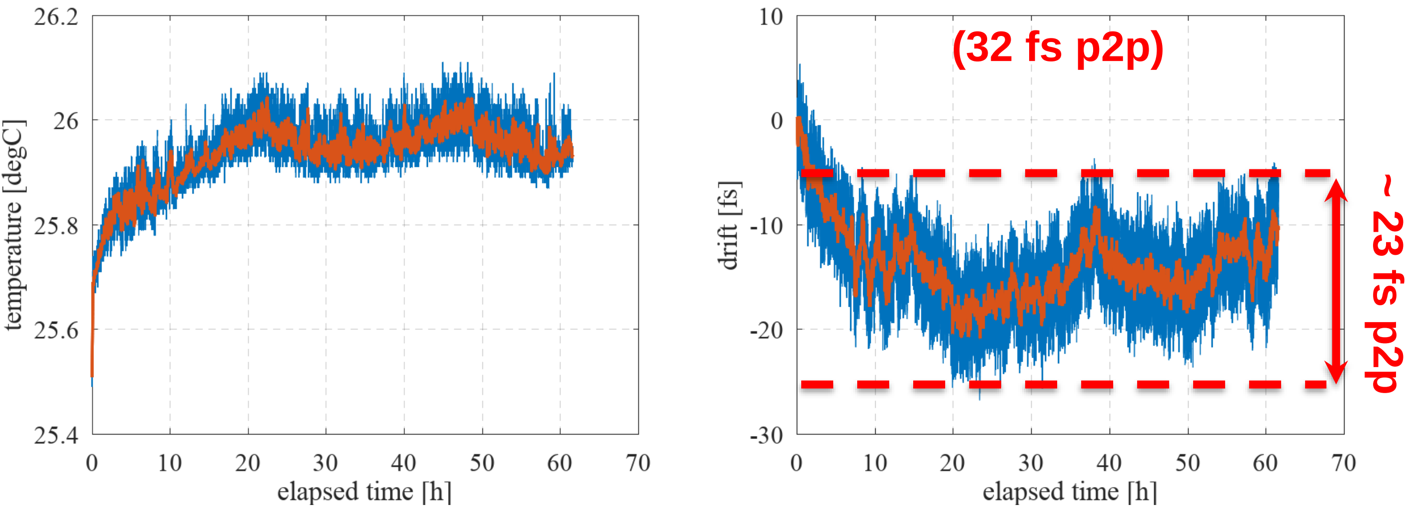

Thanks to P. Cinquegrana for support

Elettra Sincrotrone Trieste

# Current and future activities

## OOL drift measurement (preliminary)

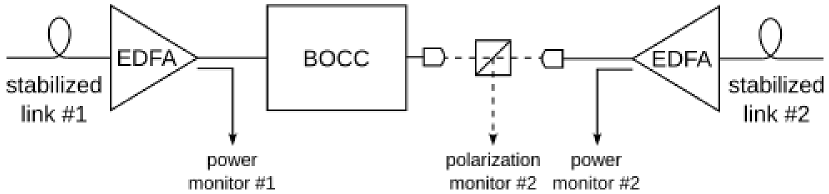


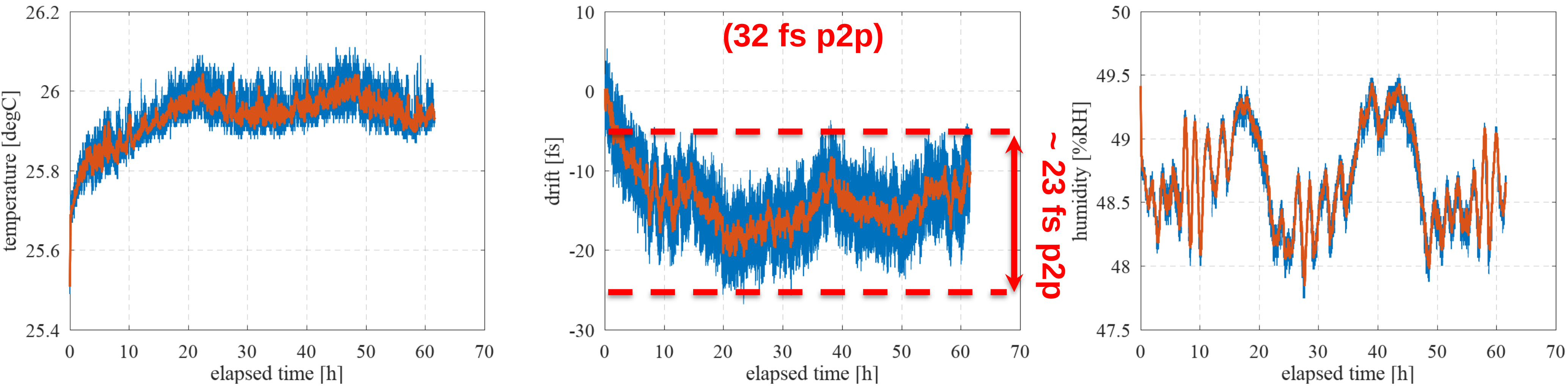




Thanks to P. Cinquegrana for support

# Current and future activities

## OOL drift measurement (preliminary)



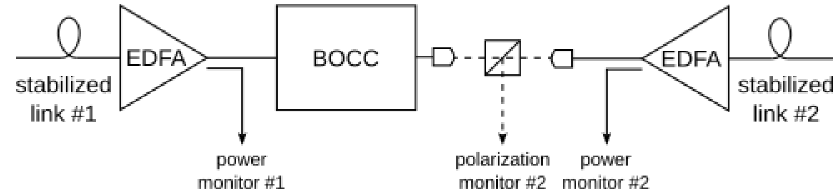



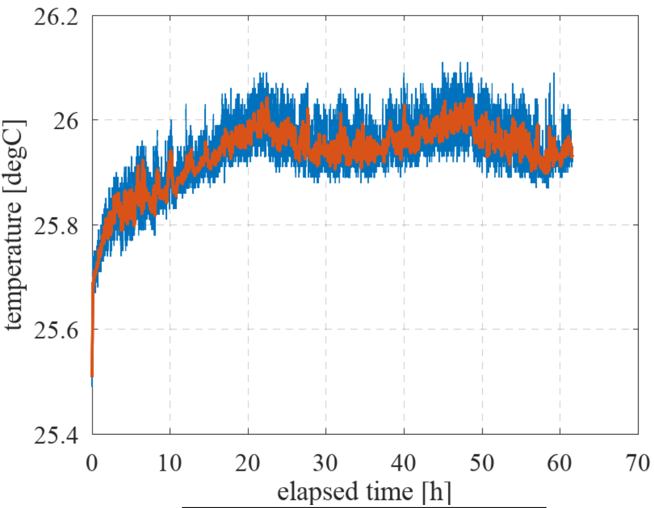

Thanks to P. Cinquegrana for support

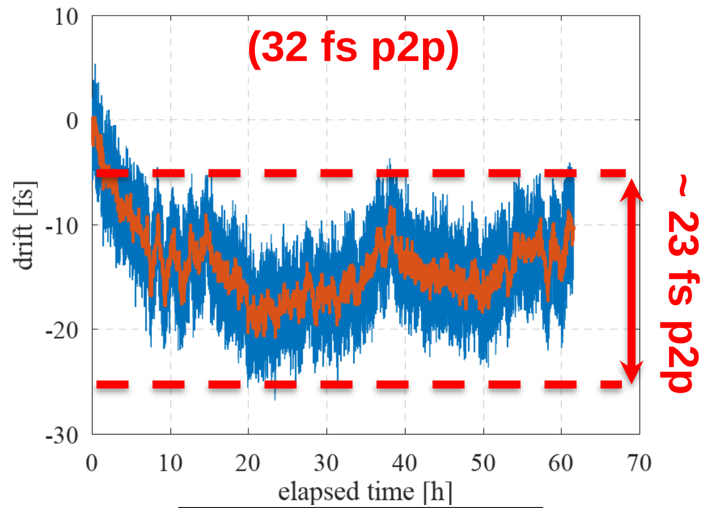
Elettra Sincrotrone Trieste

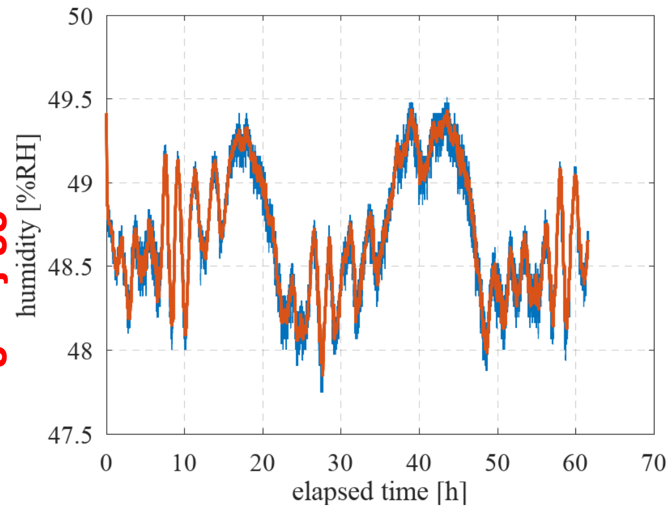
# Current and future activities

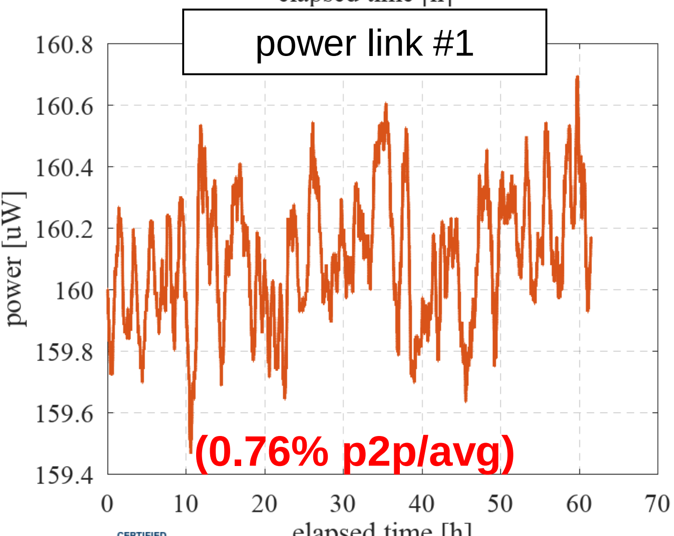
## OOL drift measurement (preliminary)

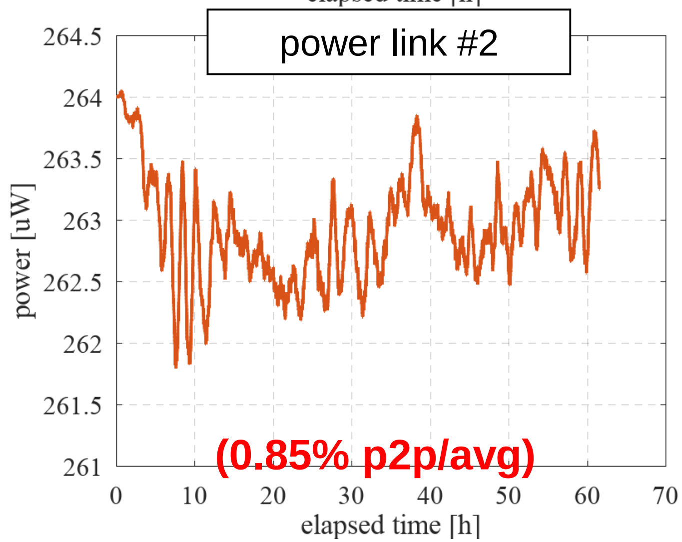


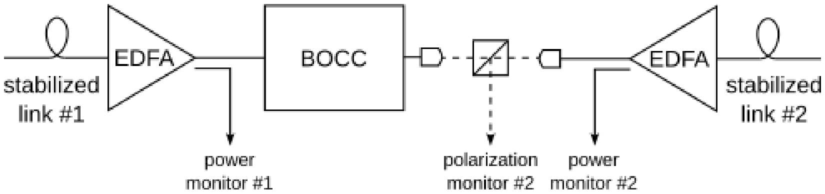



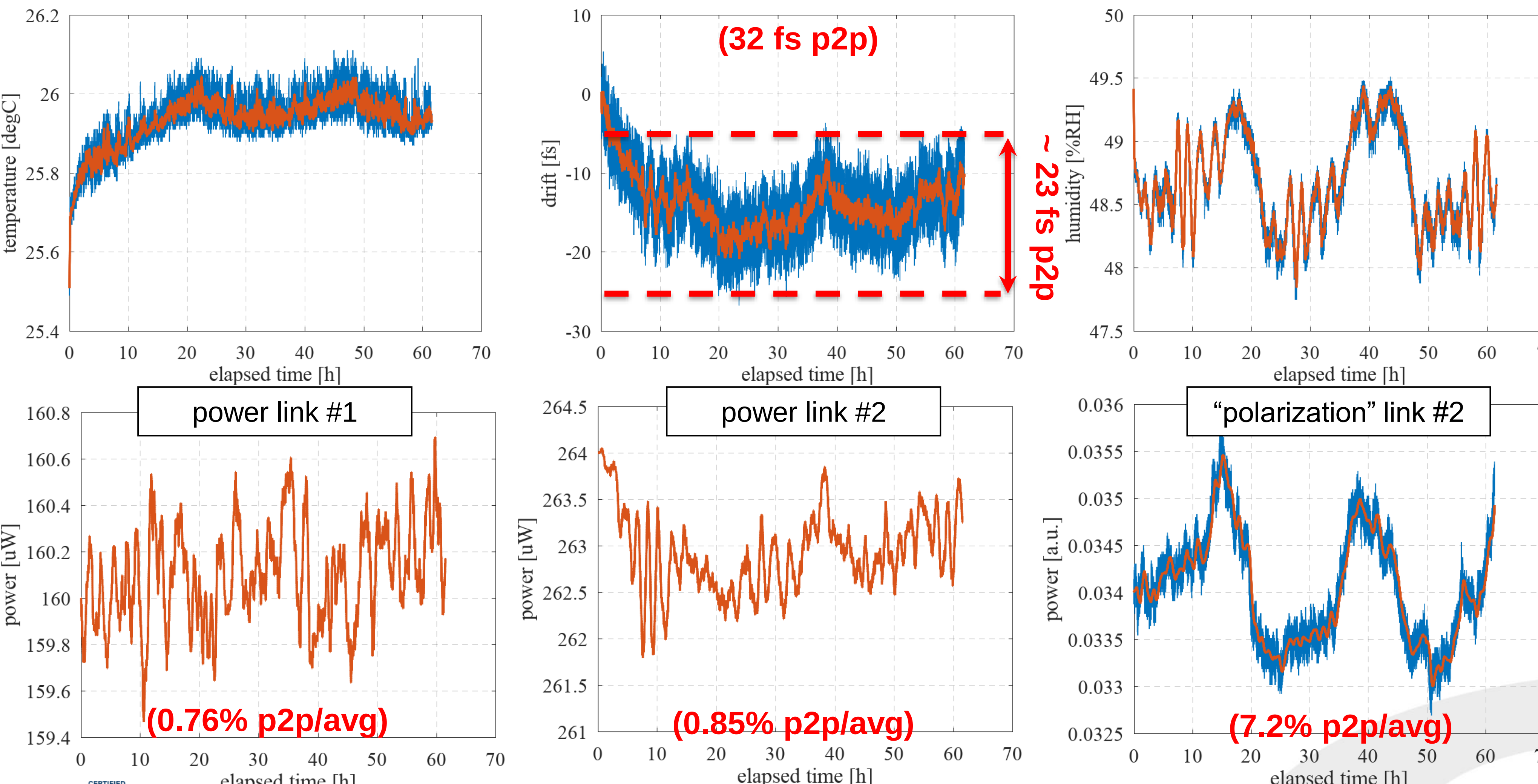

Thanks to P. Cinquegrana for support

Elettra Sincrotrone Trieste

# Current and future activities

## OOL drift measurement (preliminary)




Thanks to P. Cinquegrana for support

# Current and future activities

## OOL drift measurement (preliminary)

developed a model of measurement doing a multivariate linear regression analysis (a possible time lag effect due to the humidity is not considered)

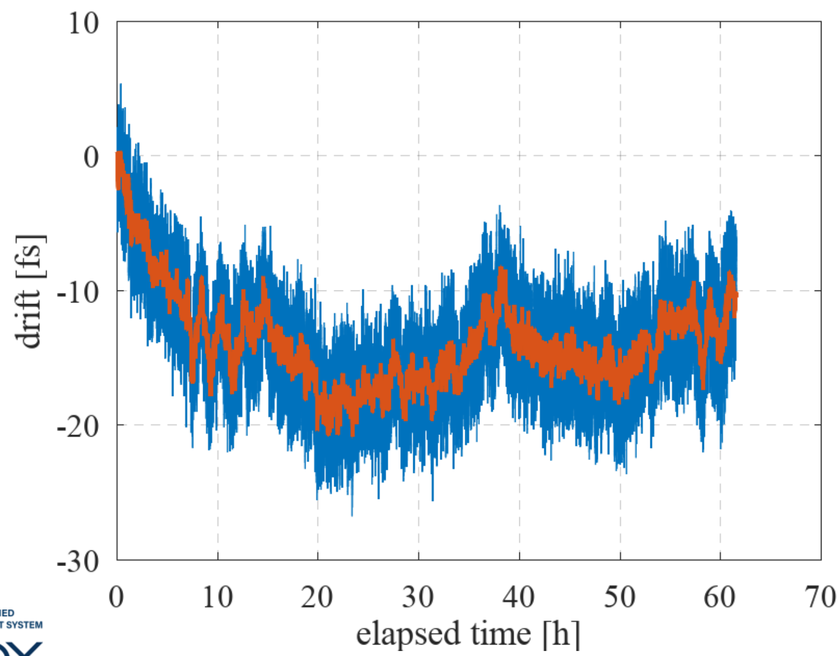
*normalized_drift =*

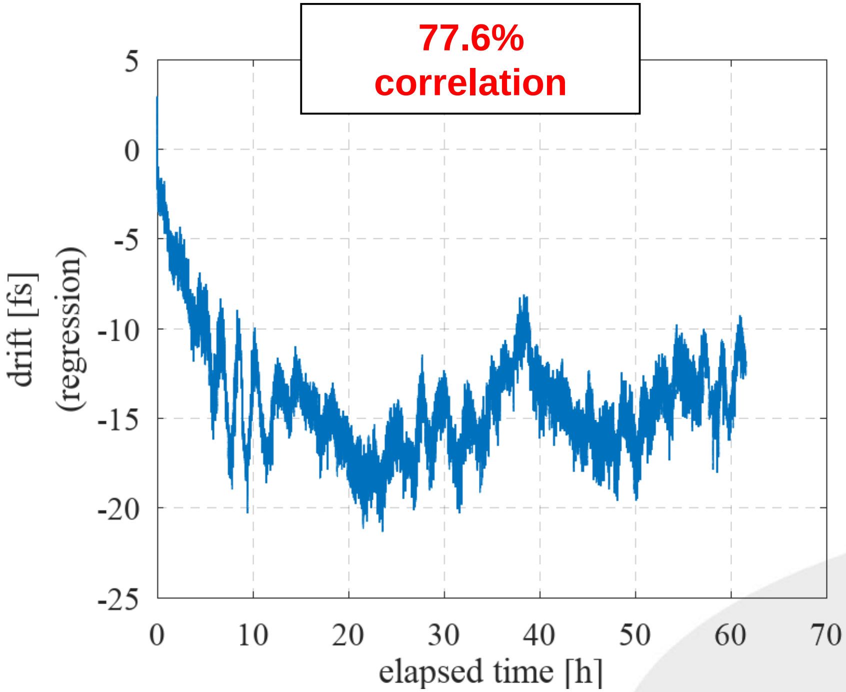
*-0.039 * normalized_power_avg_contrib_link1*

*+0.566 * normalized_power_avg_contrib_link2*

*+0.095 * normalized_humidity_contrib*

*-0.373 * normalized_temperature_contrib*



# Current and future activities

- activities on the pulsed subsystem extension
  - ongoing drift measurements between two stabilized links
  - integration in the control system
  - polarization stabilization at the input of extension
- new HVAC system for the timing room
  - integrated temperature and humidity control with better stability
  - reduction of the environmental acoustic noise
  - decoupling from the building air conditioning
- investigations about possible replacement of the OMO
  - it has been running for more than 13 years
  - outdated architecture (out of production, limited support)
  - wishing for a laser with a unique mode-locking condition
  - need to seed a PM system (pulsed extension)

Elettra Sincrotrone Trieste

# Thank you!

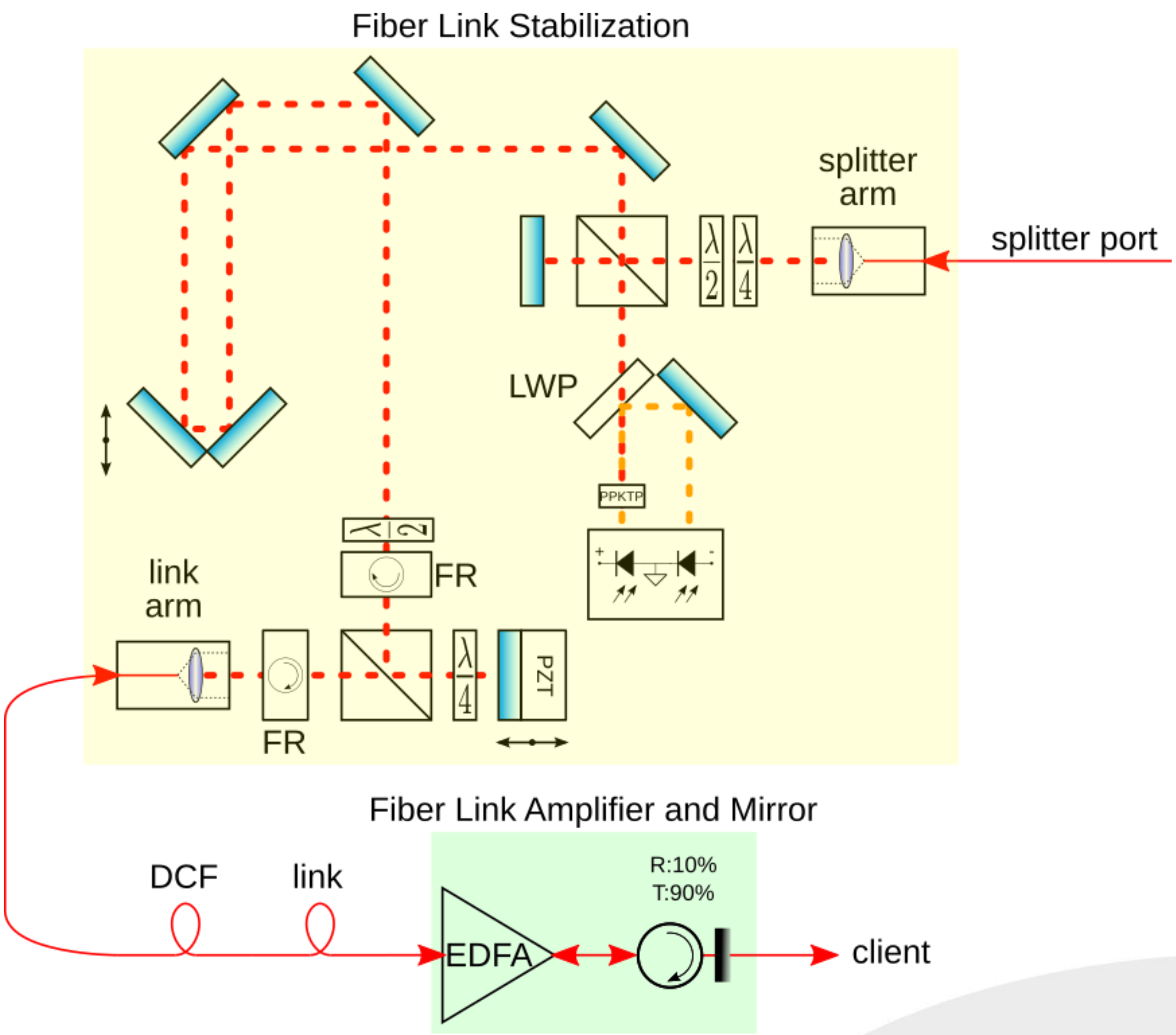

www.elettra.eu

Elettra Sincrotrone Trieste

# BACKUP SLIDES

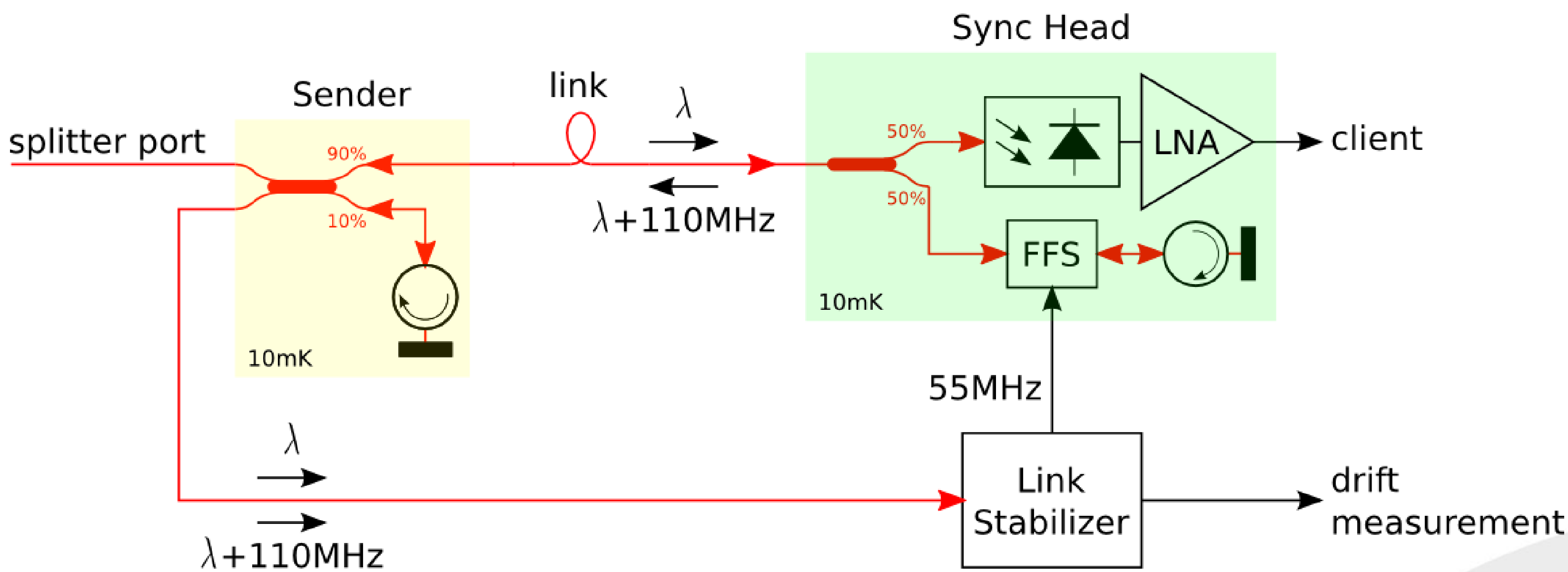
# System overview: pulsed stabilization

- a link is actively stabilized
- based on the balanced cross-correlation scheme proposed for the first time at MIT
- “natural” choice to lock pulsed lasers

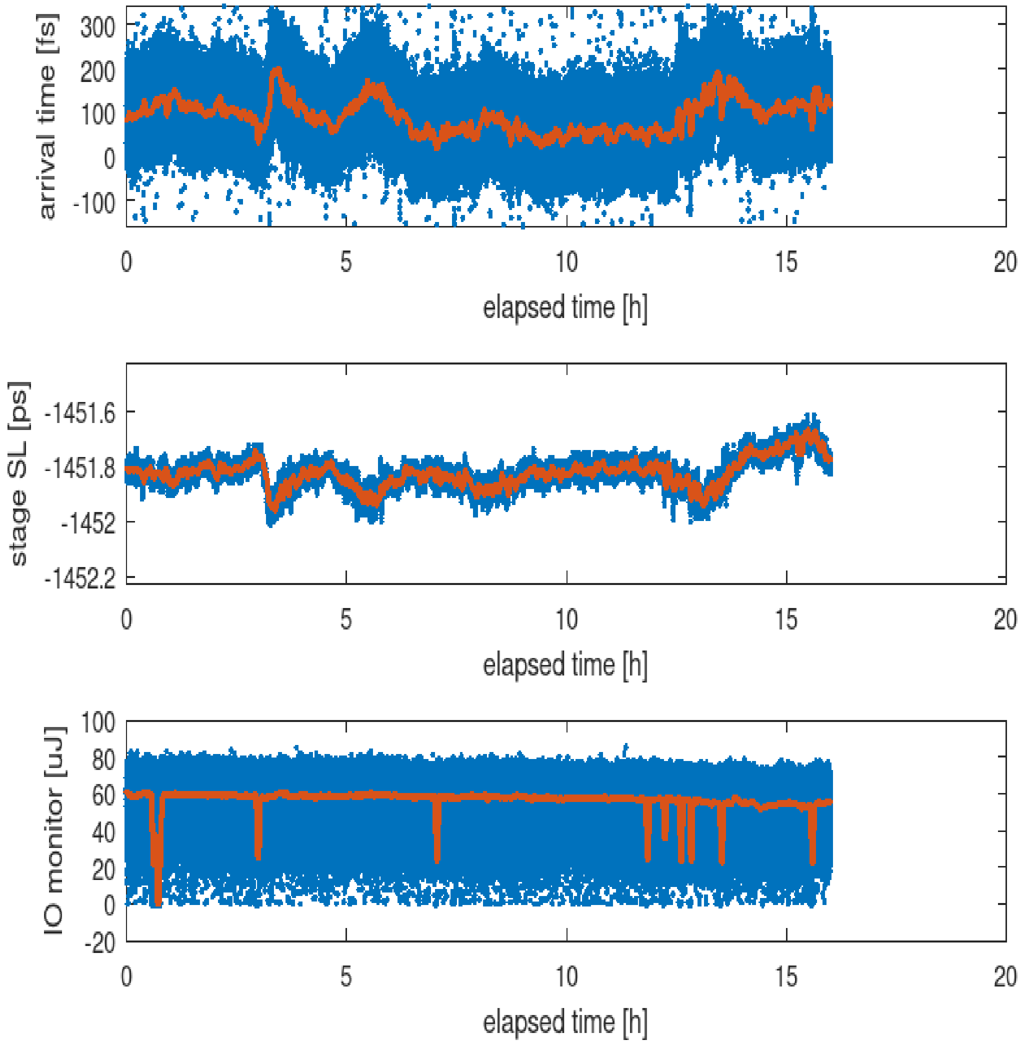


# System overview: CW distribution

- a link is not actively stabilized
- heterodyne detection for the measurement of the optical phase with a Michelson interferometer, the original scheme was developed at LBNL
- tightly integrated with the LLRF controller to compensate for group delay drifts (stable RF to the plant)



# Long-term FEL stability




Long-term longitudinal instabilities are controlled by a beam-based feed-forward compensation scheme.

We have implemented an optimization tool

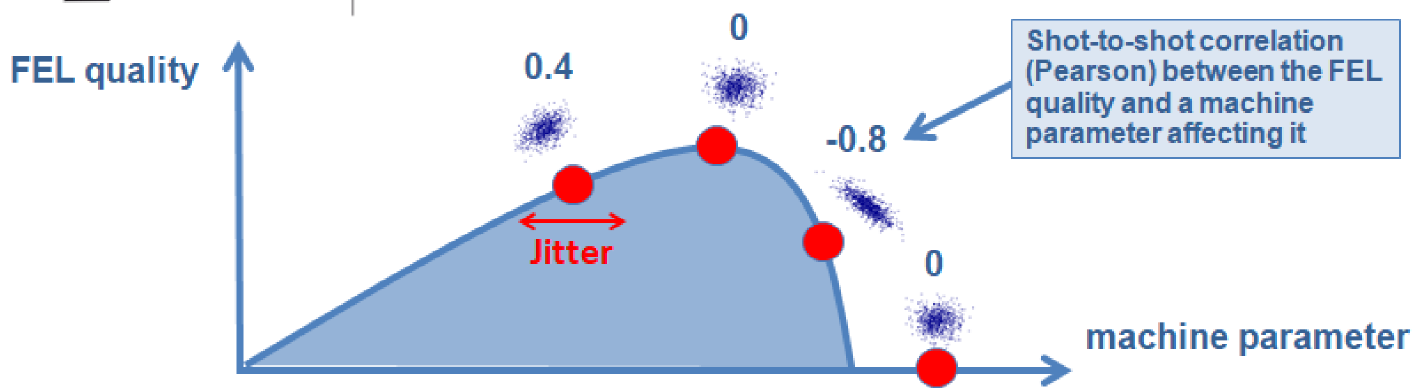
- **target**: the minimization of the correlation between the BAM and IO monitors
- **sensor**: bunch arrival monitor
- **actuator**: motorized piezo stage controlling the relative delay between the seed laser and the electrons.

# Long-term FEL stability

Elettra Sincrotrone Trieste

## Optimization Through Correlation Minimization

Elettra Sincrotrone Trieste




Courtesy of Giulio Gaio

- The function "**FEL quality vs. parameter**" (unknown) is supposed to have a maximum
- If the variable is affected by jitter, it is easy to measure the shot-to-shot correlation, which can be positive (left side), zero (top) or negative (right side)
- Based on the correlation sign, we know in which direction to move the variable by means of the actuator in order to restore the optimum working conditions
- **This optimizer is run continuously during machine operations**; the FEL performance is restored or kept optimal with almost no disruption for the beamline experiments
- This optimizer is generic; for each implementation the following variables have to be identified:
  - o **Target**: the objective function to maximize, which is usually the FEL energy or a combination of FEL parameters
  - o **Sensor**: the variable whose correlation with the target has to be minimized
  - o **Actuator**: the variable used to change the sensor value

"Advances in Automatic Performance Optimization at FERMI", ICALEPCS 2017
http://icalepcs2017.vrws.de/papers/tumpa07.pdf