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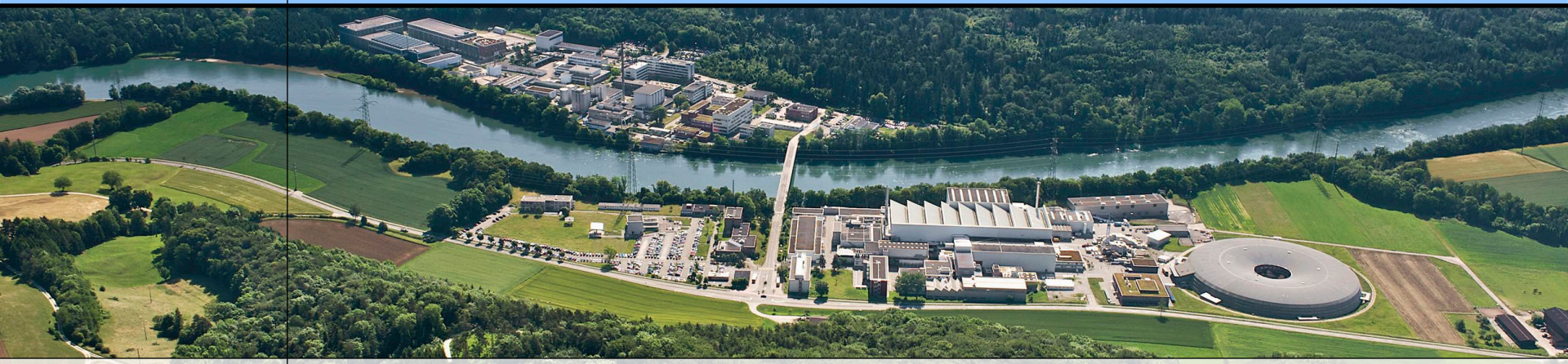
PSI



Wir schaffen Wissen – heute für morgen

# Reference Distribution and Synchronization System for SwissFEL: Concept and First Results

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# Outline

1. SwissFEL Reference Distribution Clients
2. Concept of SwissFEL Reference Distribution
3. CW Optical Link for RF Reference Distribution
4. Laser Sync
5. Status & Outlook

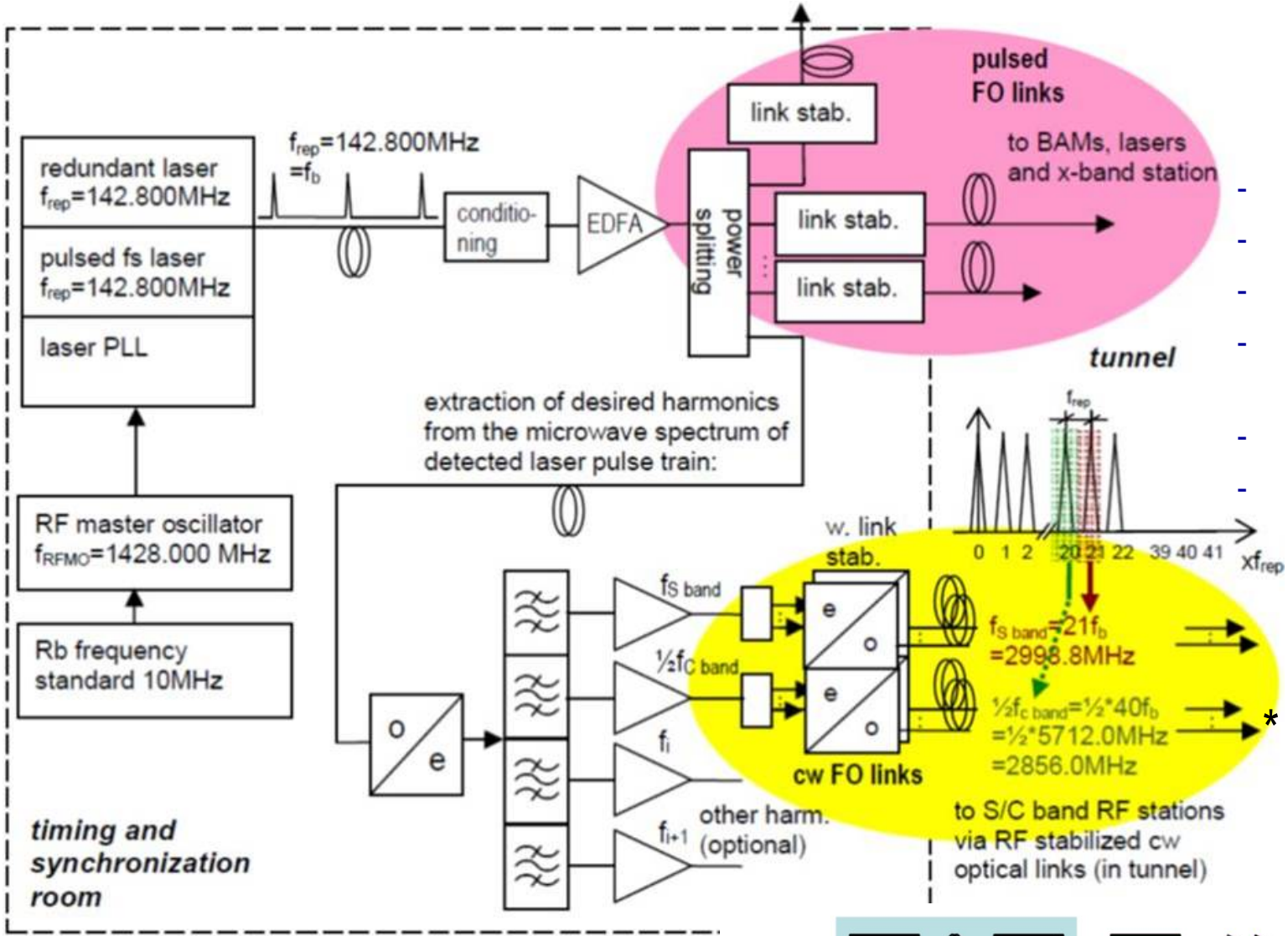
# 1. SwissFEL Reference Distribution Clients

- **SwissFEL uses US and (slightly detuned) European RF frequencies**
  **→ highest common subharmonic from which all reference signals can be derived is as low as 142.8MHz**
- **reference distribution system is based on pulsed OMO laser ($f_{rep}$=142.8MHz), from which mutually stable ref. signals are derived**

| Client,# | reference signal at client | distribution (link type) | stability goal jitter[1]/drift[2] ()[3] | remark |
|---|---|---|---|---|
| BAM,4 (later 6) | 142.8MHz optical fs pulses | stabilized pulsed optical | few $fs_{rms}$/<10$fs_{p-p}$ (<1$fs_{rms}$/few $fs_{p-p}$) | BAM modulates ref. pulse intensity |
| gun & exp. lasers ,2 | 142.8MHz optical fs pulses | stabilized pulsed optical | few $fs_{rms}$/<10$fs_{p-p}$ (<1$fs_{rms}$/few $fs_{p-p}$) | laser locked to ref. w. opt. cross corr. |
| S band RF,6 | 2998.8MHz RF (21$f_{rep}$) | stabilized cw opt. | <10$fs_{rms}$/<30$fs_{p-p}$ (<3$fs_{rms}$/<20$fs_{p-p}$) | - |
| C band RF,27 | 5712MHz RF (40$f_{rep}$) | stabilized cw opt. | <10$fs_{rms}$/≈40$fs_{p-p}$[4] | 2856MHz *over S band link*, doubled at RX |
| X band RF (S band front end),1 | 2998.8MHz RF (ref.)<br>8996.4MHz RF (DWC)<br>11'995.2MHz RF (ref.) | stabilized pulsed optical | <10$fs_{rms}$/<30$fs_{p-p}$ (<3$fs_{rms}$/<10$fs_{p-p}$) | 1st IF, RF extracted from opt. pulses<br>RF extracted from opt. pulses<br>RF VCO locked to (RF extr. from) opt. pulses |
| BPM,46 | 142.8MHs RF | VHF cw opt.,coax | uncrit. | 8 non-stab. opt. low cost links, coax subdistr. |
| event syst.,1 | 1428MHz RF | coax | uncrit. | uncritical |

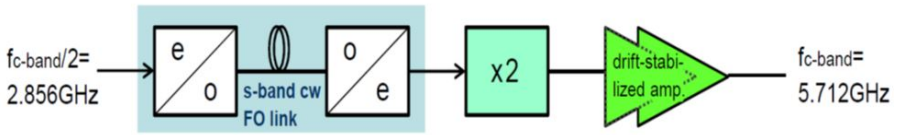
[1] 10Hz..10MHz offset freqency range; [2] per half day .. day; [3] potential of technology; [4] up to 500$fs_{p-p}$ (depends on station)

# 2. Concept of SwissFEL Reference Distribution




- high performance
- high flexibility
- high availability
- relatively "easy" to operate
- reasonable cost
- limited manpower

*) Frequency doubler at C band RX:

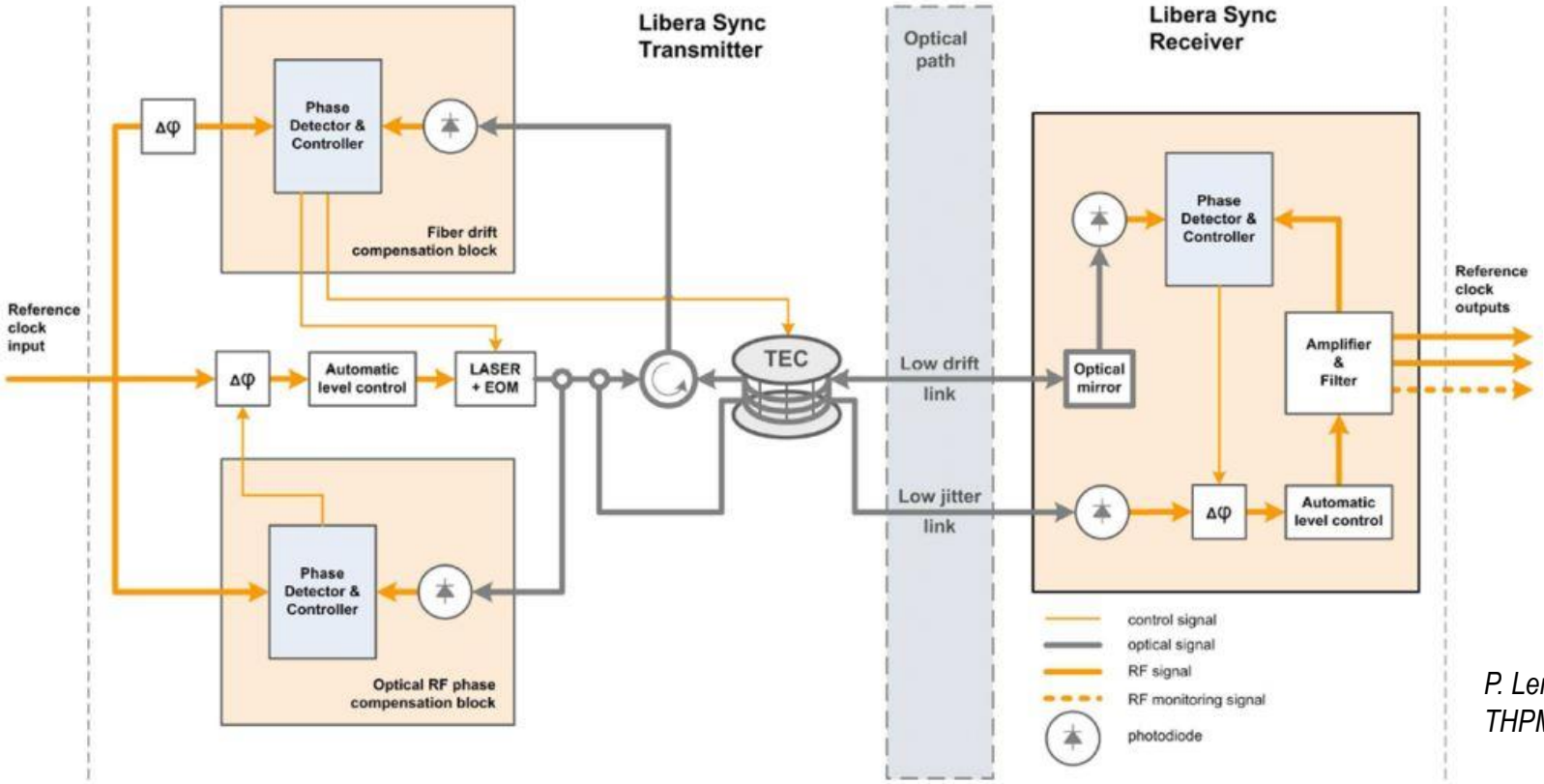


# 3. CW Optical Link for RF Reference Distribution

## Libera Sync 3 cw optical link (3GHz): PSI - I-Tech collaboration

- intensity modulation, cw laser diode ("radio-over-fiber")
- stabilization of RF phase of reflected light, Rayleigh scattering
  → low-noise unidir. link locked to low-drift link
- laser wavelength variation (temp.) & fiber dispersion used for delay variation compensation (BW≈1Hz)
- temp. controlled fiber spool for coarse delay correction

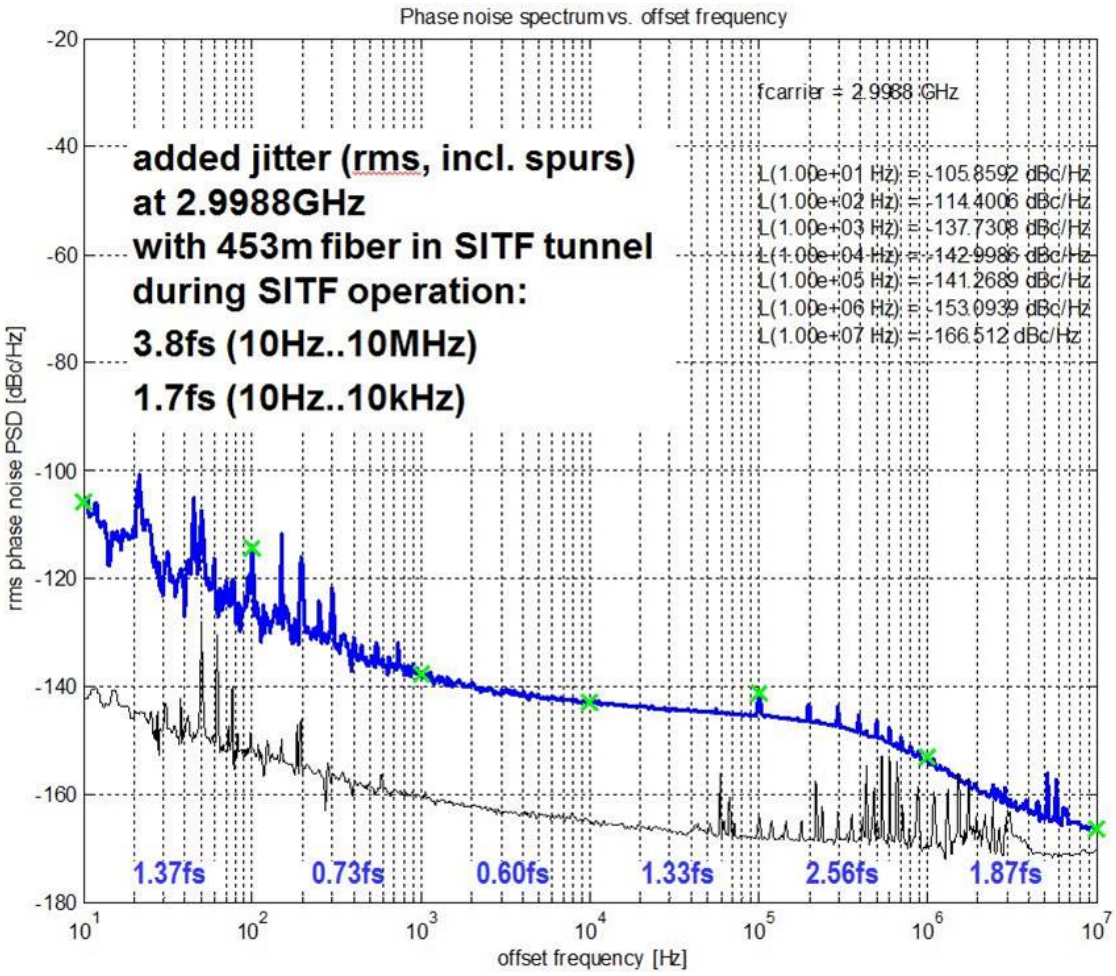

*Instrumentation Technologies*



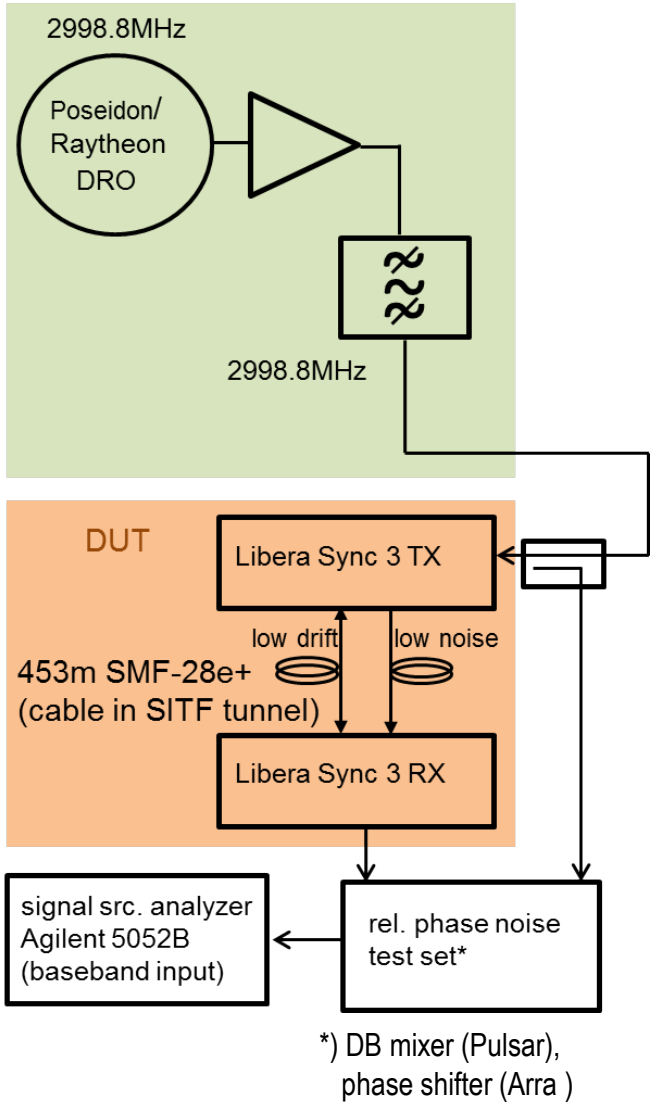

*P. Lemut et al., NA-PAC, THPMA04, 2013.*

# 3. CW Optical Link for RF Reference Distribution (contd.)

## Libera Sync 3 prototype (2998.8MHz): Added phase noise and jitter measurement



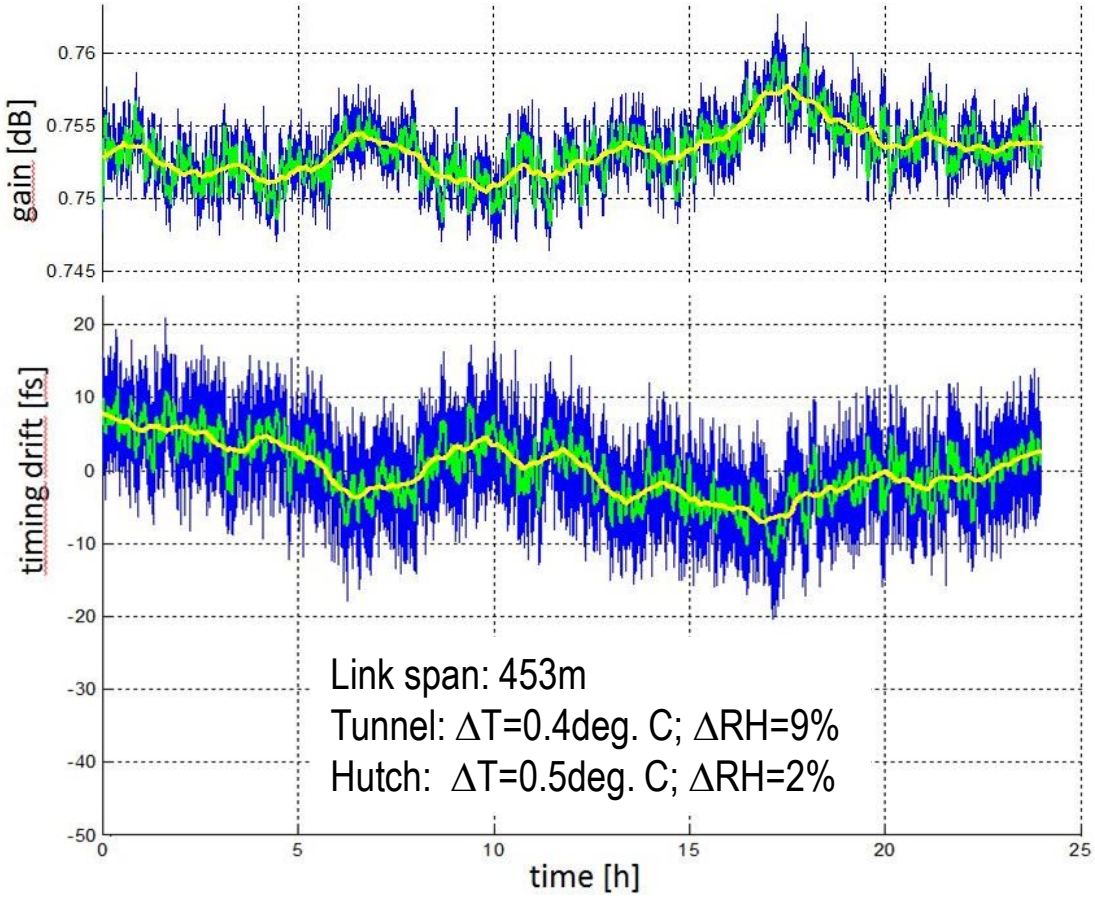

Setup located in SwissFEL Test Injector Facility gun laser hutch (vibration isoled rack)



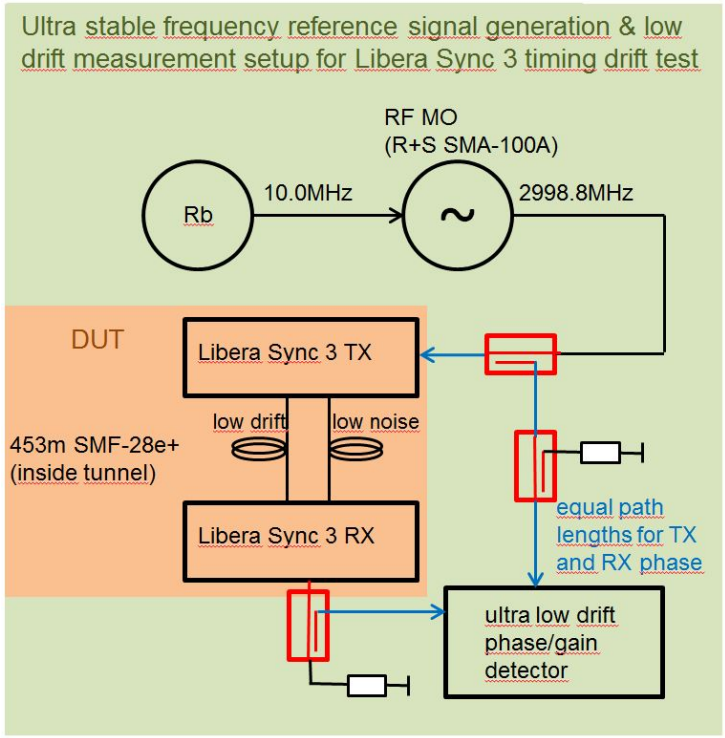

*) DB mixer (Pulsar), phase shifter (Arra )

# 3. CW Optical Link for RF Reference Distribution (contd.)

## Libera Sync 3 prototype (2998.8MHz): Typ. link group delay and gain drift measurement




Setup located in SwissFEL Test Injector Facility gun laser hutch (vibration isolated rack)

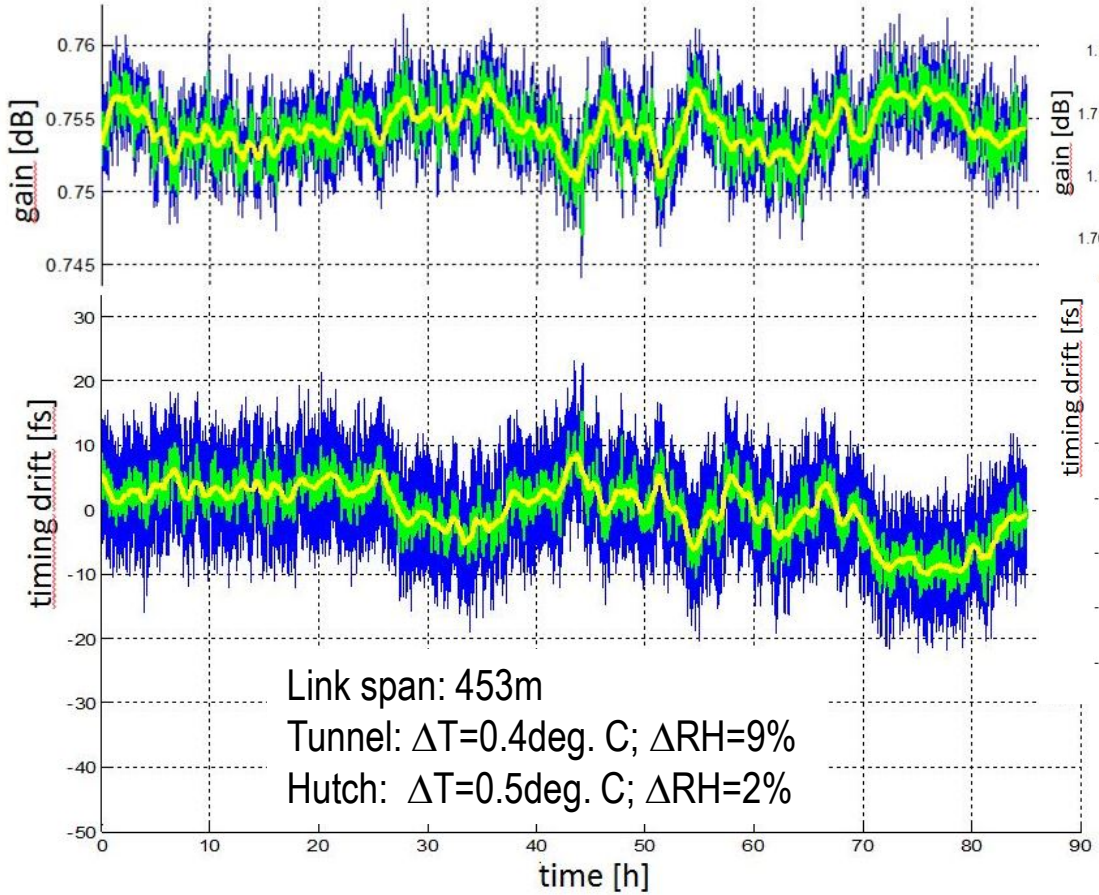



Stabilized link gain variation over 24h: $0.012dB_{p-p}$ (2.2min avg.), $0.007dB_{p-p}$ (1h avg.)

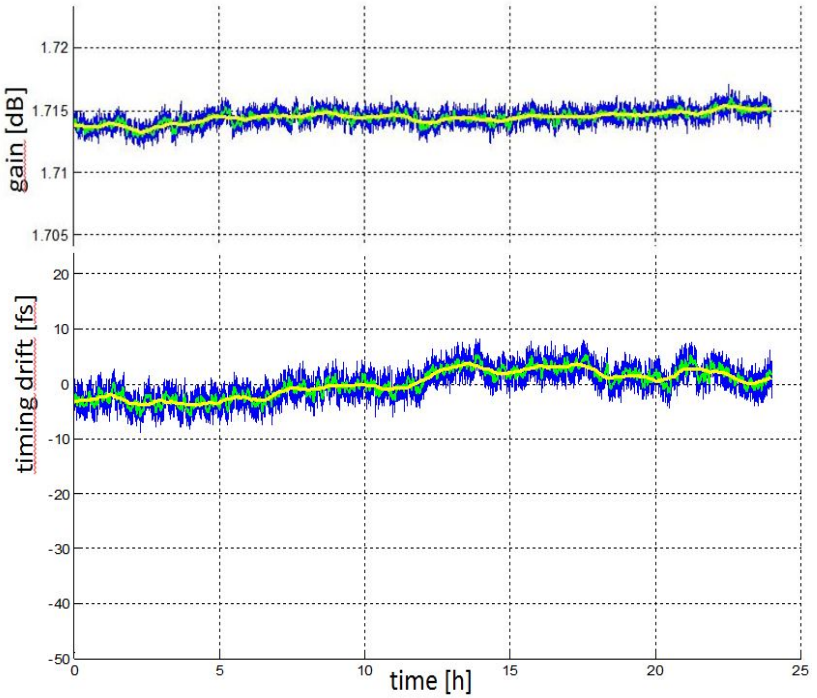
Stabilized link group delay variation over 24h: $23.7fs_{p-p}$ (2.2min avg.), $15.0fs_{p-p}$ (1h avg.)

# 3. CW Optical Link for RF Reference Distribution (contd.)

## Libera Sync 3 prototype (2998.8MHz):
## Typ. link group delay and gain drift measurement (cont.)




Link span: 453m
Tunnel: ΔT=0.4deg. C; ΔRH=9%
Hutch: ΔT=0.5deg. C; ΔRH=2%

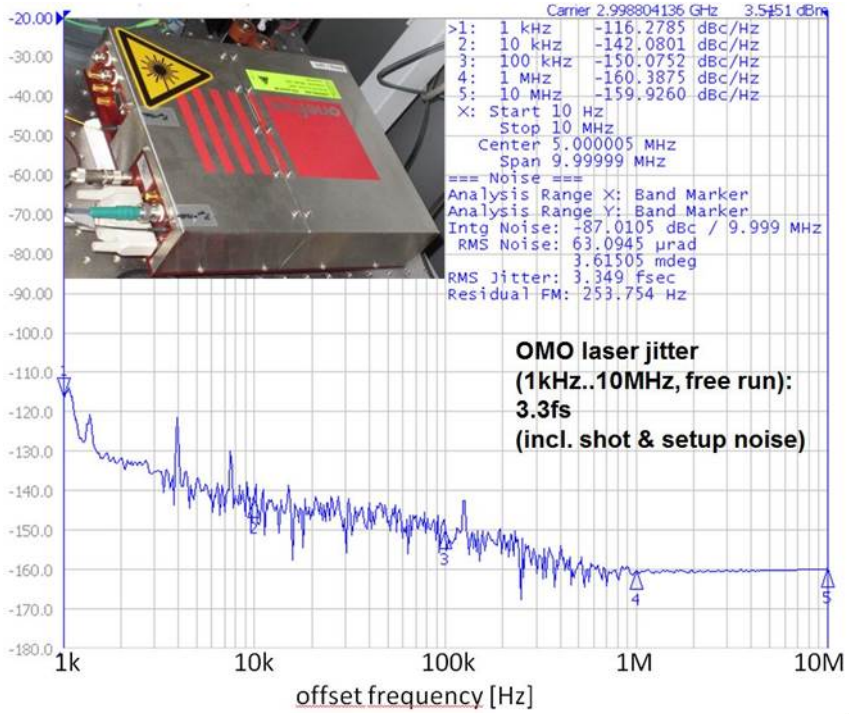



Phase detector drift (24h):
$0.003dB_{p-p}$ (2.2min avg.), $0.002dB_{p-p}$ (1h avg.)
$11.4fs_{rms}$ (2.2min avg.), $7.6fs_{rms}$ (1h avg.)

Stabilized link gain variation over 85h: $0.013dB_{p-p}$ (2.2min avg.), $0.007dB_{p-p}$ (1h avg.)
Stabilized link group delay variation over 85h: $29.5fs_{rms}$ (2.2min avg.), $18.6fs_{rms}$ (1h avg.)

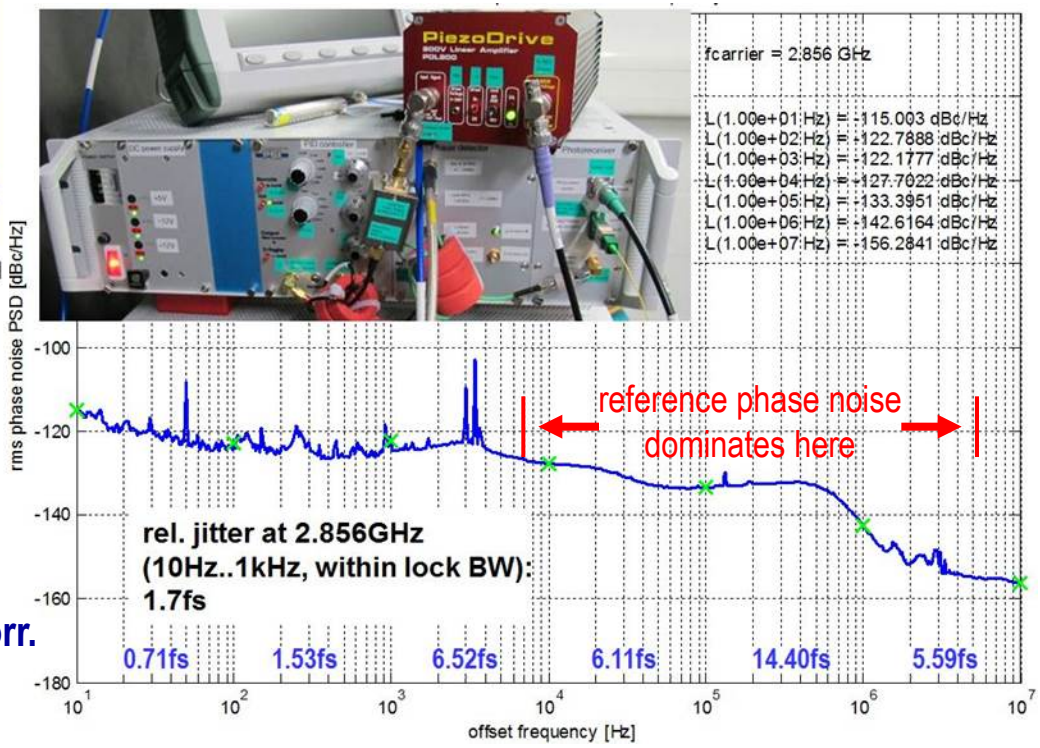
# 4. Laser Sync

## Mode-locked laser OMO, laser sync




- Onefive Origami (1560nm, frep=142.8MHz,FWHM≈100fs)
- very low free running phase noise, delivers ultra-low jitter S band and C band RF reference RF signals*
- used as OMO in SwissFEL (redundant)

*) Measured with Discovery DSC50 photodiode




- low noise PLL reduces laser phase noise
- SwissFEL RF MO R+S SMA 100A as reference
- digital PLL with superperiod, RF and opt. x-corr. under development (avail. Q2/2016)

# 5. Status & Outlook

- **important SwissFEL deadlines**
  - → T+S installation starting Q1/2015
  - → injector commissioning starting Q1/2016
  - → Linac commissioning starting Q1/2017
  - → Experimental station commissioning starting Q3/2017

- **stable reference signal generation**
  - → RF MO (Rb locked), OMO (redundant) OK
  - → stabilized RF power amplifiers (3GHz): under development
  - → stable harmonic extraction from opt. pulse train: under development
  - → OMO laser PLL OK
  - → ready by end of 2015

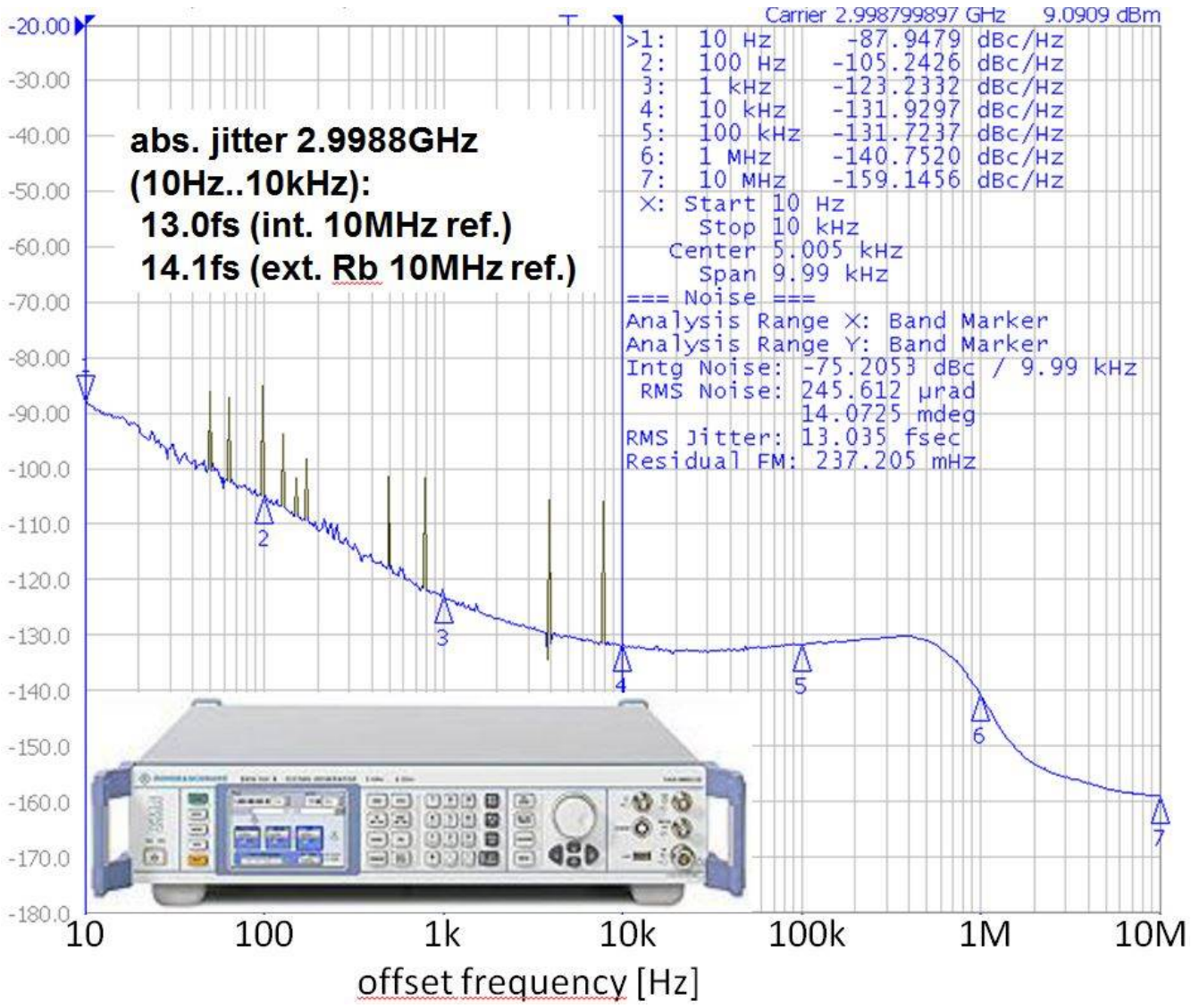
- **RF reference distribution**
  - → S & C band cw optical links developed & successfully tested OK
    series production starting Q4/2014, avail. from Q1/2015..Q2/2016
  - → freq. doubler & stabilized RF amplifier (6GHz):
    under development & ready by end of 2015

- **Pulsed optical reference distribution**
  - → WTO call for tender for optical amplifier and pulsed links in preparation
  - → system ready by end of 2015

- **BPM reference distribution**
  - → non-stabilized low-cost low-noise optical links (142.8MHz):
    developed in house & currently in production OK

# Backup slides

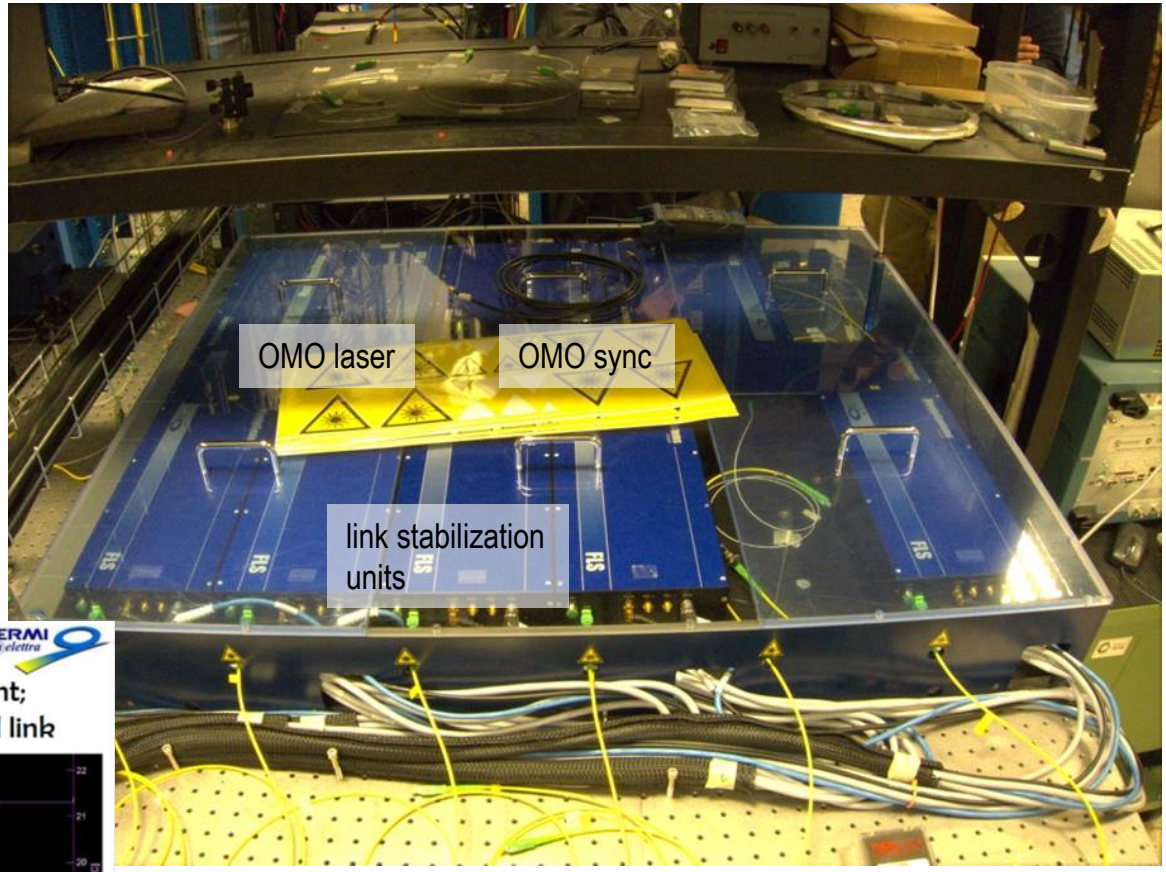
# RF Master Oscillator



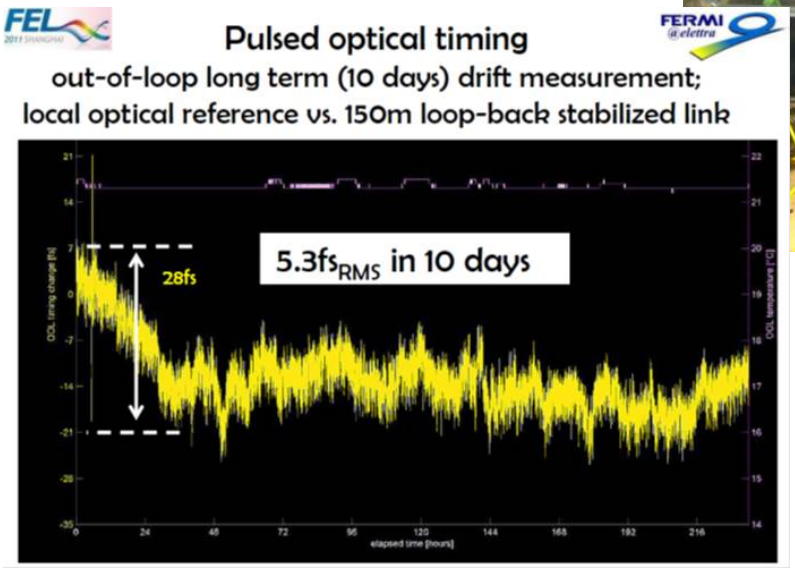
# Pulsed Optical Links

**Measured performance (Elettra, $f_{rep}$=157.79MHz)**

Jitter: <3.5$fs_{rms}$ (10Hz..10MHz)
Drift: <10$fs_{pp}$/d (typ.)



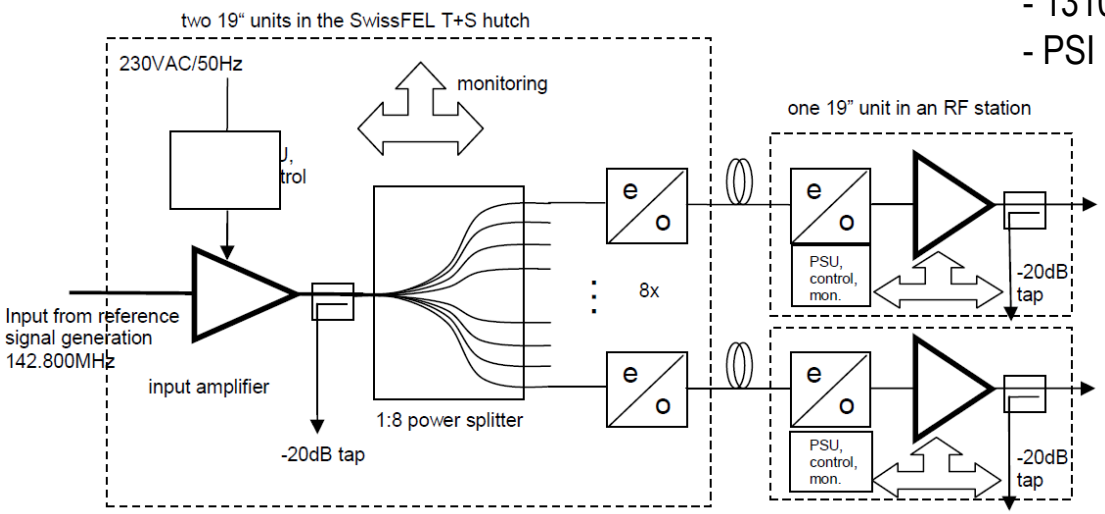

*Elettra*



# BPM Reference Distribution

***FO links and amplifiers***

- 1310nm, 142.8MHz, added jitter (10Hz..10MHz) 73fs
- PSI design, manufactured by Sintec Microwave (D)




totally 46 racks that need reference signal