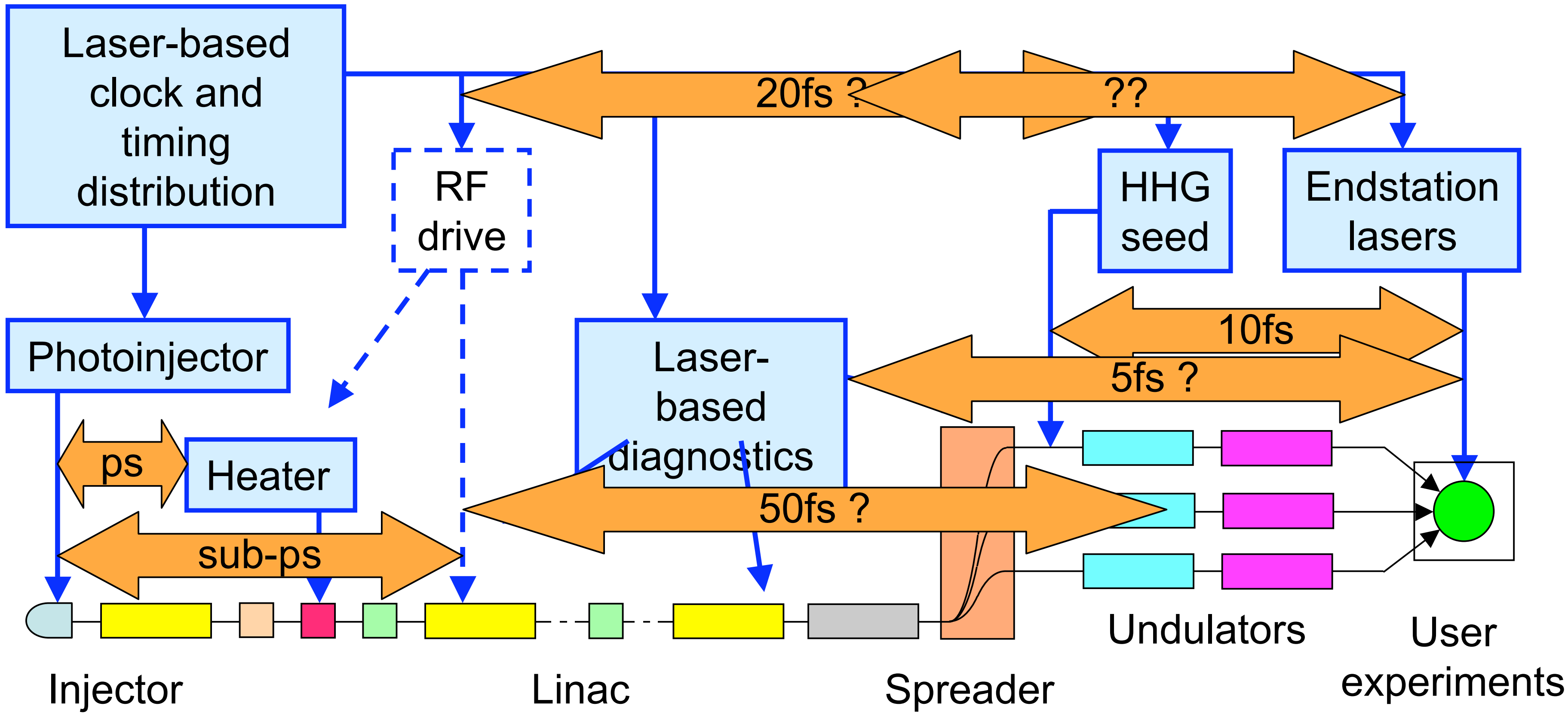
HELMHOLTZ ZENTRUM BERLIN
für Materialien und Energie

II. Timing and Synchronization Workshop - Summary Report

Torsten Quast, 10.3.2009

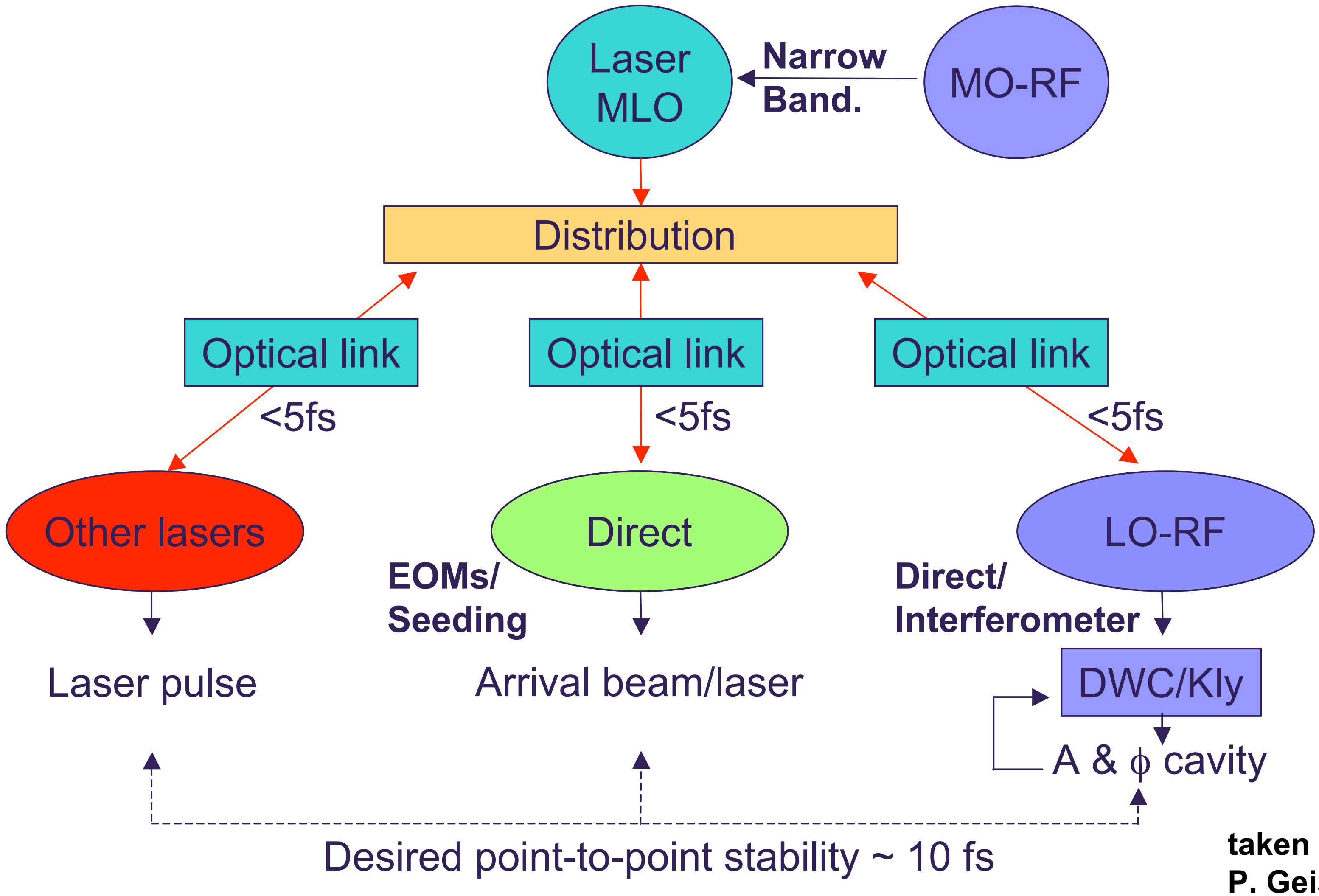
Synchronisation Requirements



Jitters to be "as low as possible", ranging from <10fs to ps

G. Hirst, STFC

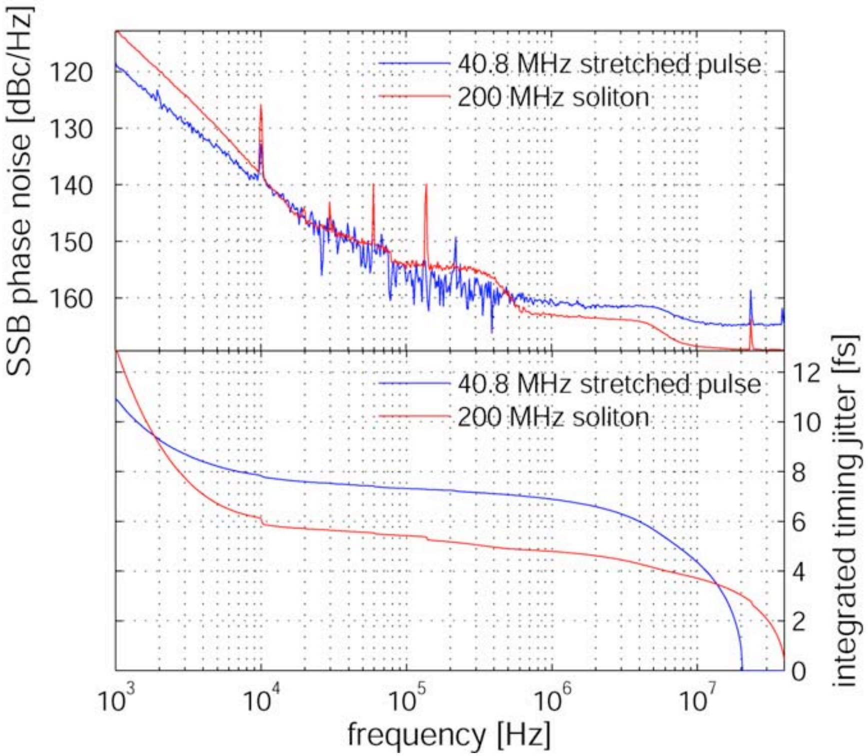
Overview of a Synchronization System

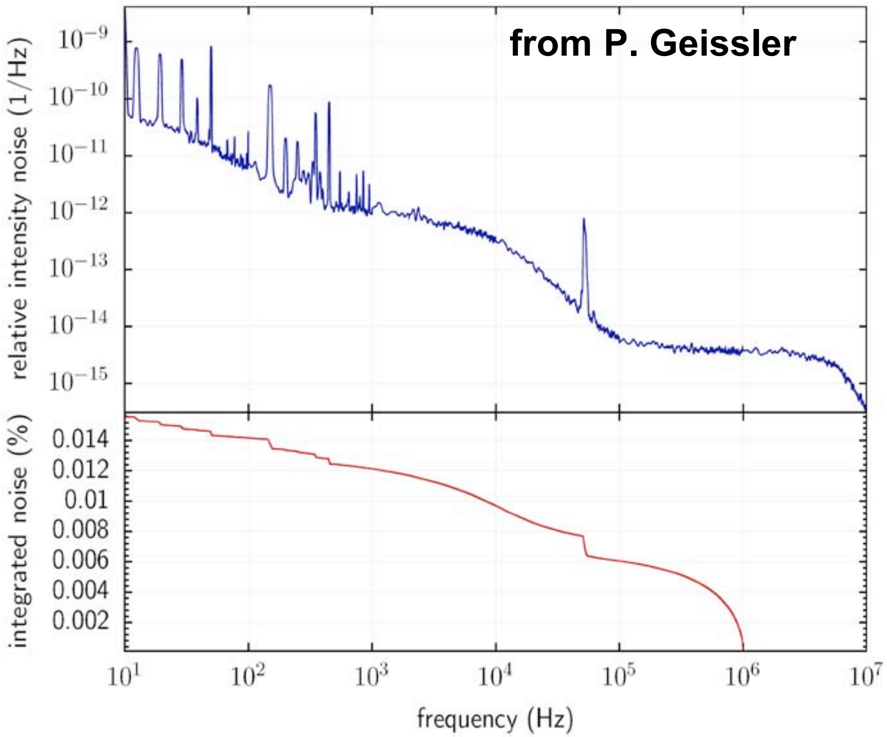


taken from P. Geissler

Performance of the Optical Master Oscillator (OMO)

Measurements – Noise and Jitter (DESY)

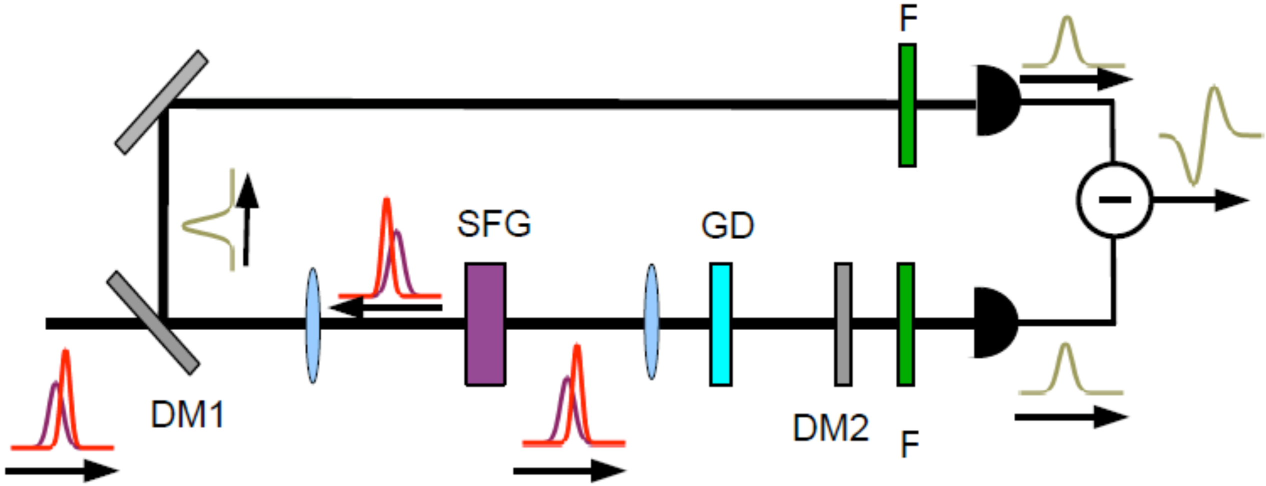




Integrated timing jitter:
< 6 fs [10kHz – 40 MHz]

relative intensity noise:
0.016 % [10 Hz – 1MHz]

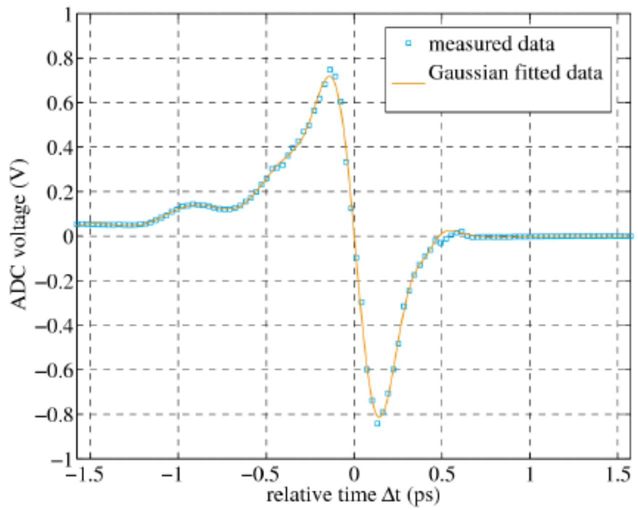
Synchronization of a Ti:Sa Laser to the optical reference system



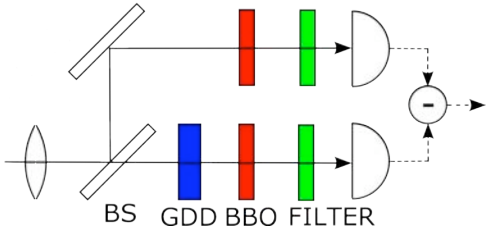
V. Arsov, DESY

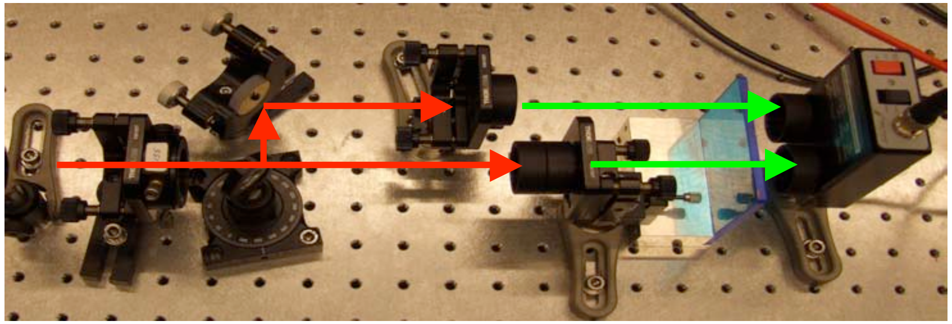
- **Balanced Optical Cross Correlator is working**

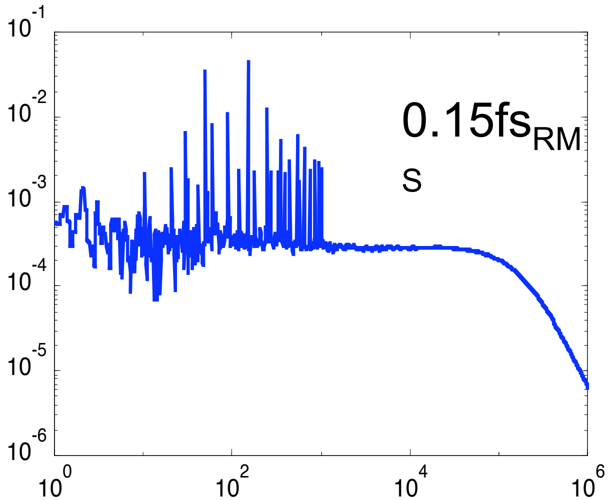
Final sync measurements to follow

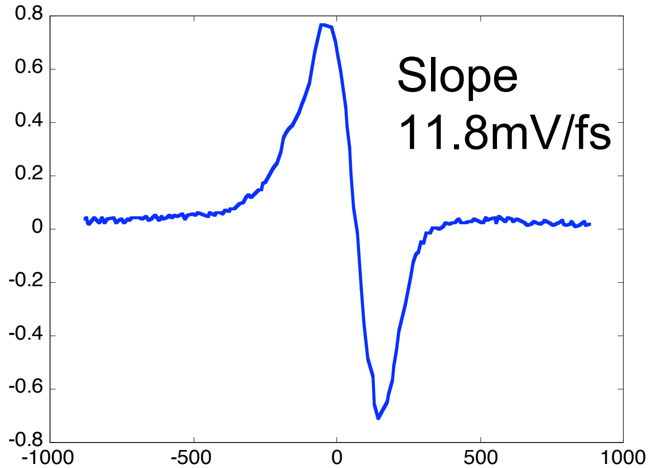


Performance limit of an a Balanced Crosscorrelator









First results on noise floor measurement

Direct Seeding of a (regenerative) TiSa Amplifier

- Nice and straight (easy) scheme
- probabely not for shortest pulses

Problems to be solved:

- ‘Blue’ shift during amplification,
- Spectrum too narrow
- Phase not linear -> TB product of compressed pulses too large

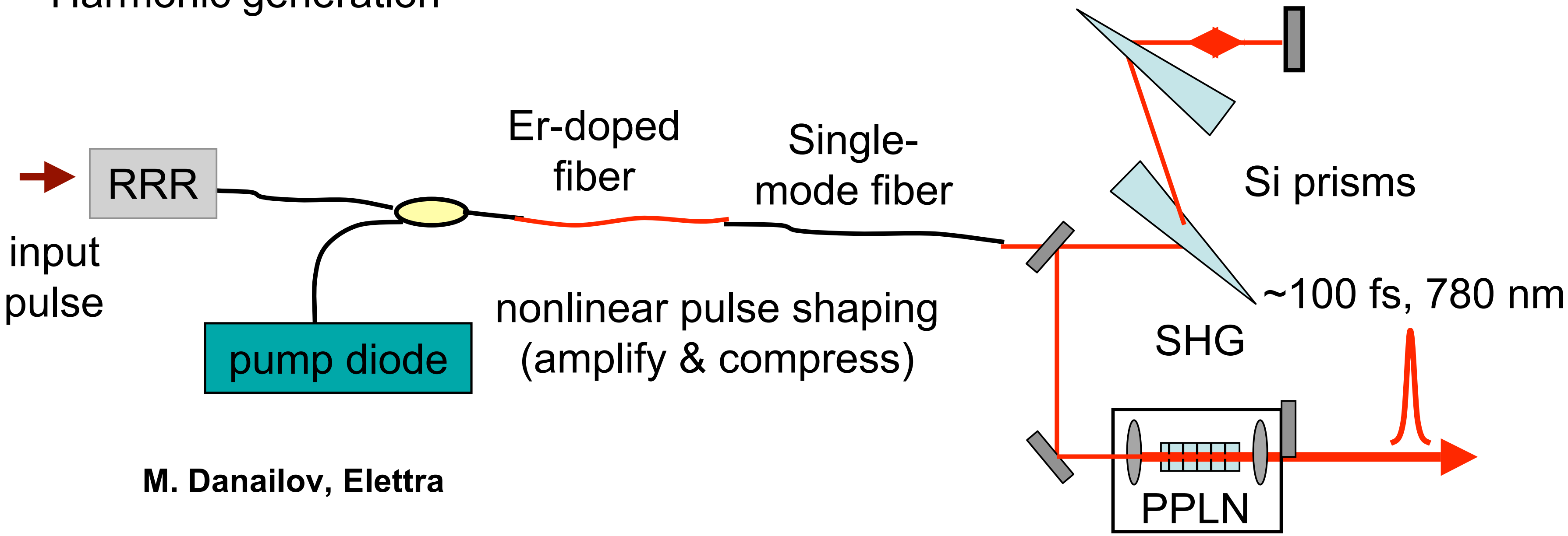
Direct Seeding Implementation

Timing pulses: 15-20 nm bandwidth @ 1560 nm, pulse energy <0.1 nJ, rep rate 157 MHz

-Repetition rate reduction ; - Amplification to 5 (better 10) nJ range

-Bandwidth broadening to 30 (better 40) nm; - Compression (fibre+prism or grating compressor) to <100 fs

-Harmonic generation

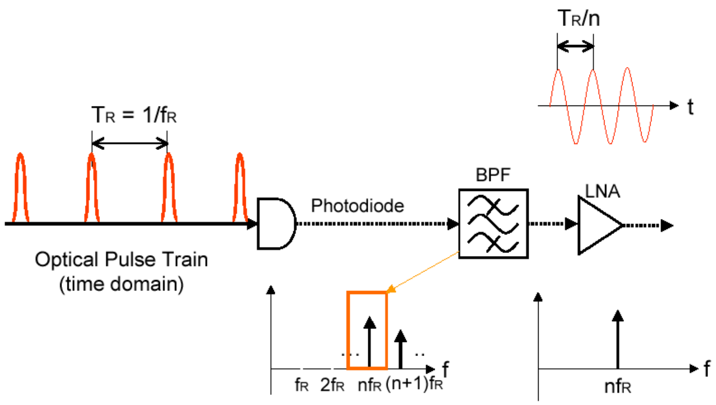


M. Danailov, Elettra

Laser to RF Conversion: Direct Extraction

<u>Direct extraction of RF from a pulse train</u>:

- Simple and cheap
- larger drift compared to sagnag loop type
- Not too bad if done correctly
- Optimized packaging (low drift components) and correct laser power can enhance performance



F. Ludwig, DESY

Short-term and long-term performance (measured):

- 10fs-25fs(rms) jitter [1kHz-10MHz] @ 1.3GHz
- 80fs peak-to-peak long-term phase drifts
- AM to PM limitation (might be overcome)
  (Typical AM to PM conversion 1-10ps/mW)

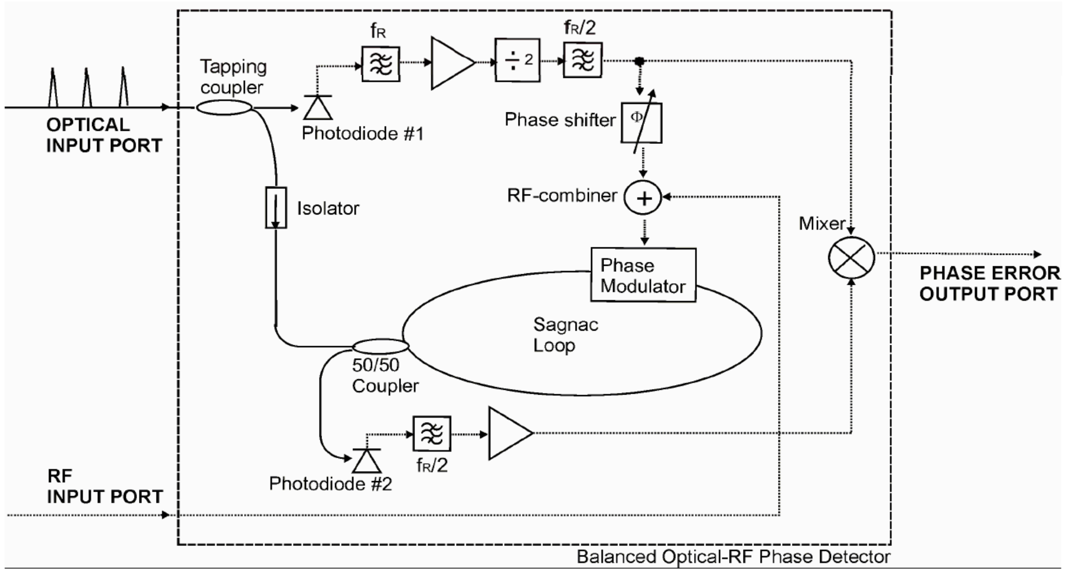
Laser to RF Conversion with Sagnac Loop

<u>Optical to RF phase detector (sagnac -loop)</u>:

• circumventing the photodiode problems
• complicated setup – many parts
• low drift and lowest noise floor
• mandatory for best jitter/ drift performance

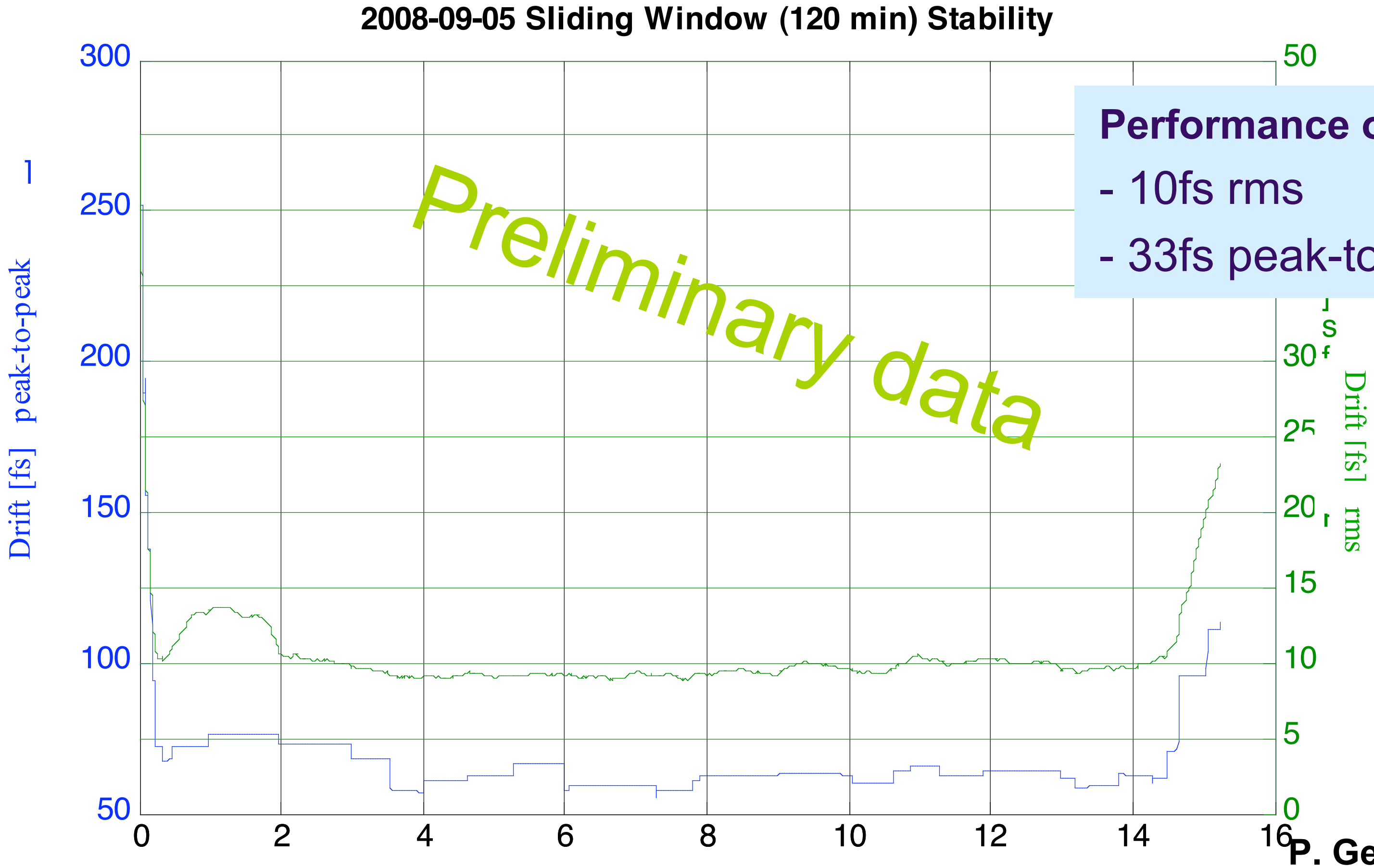
• commercial developed by <u>Menlo Systems</u>

- **Optical to RF phase detector : (Sagnac-loop scheme)**



F. Ludwig, DESY

Long term stability: Sagnac Looop vs. Direct Photodiode detection



Performance over 12h:

- 10fs rms
- 33fs peak-to-peak

P. Geissler, DESY

→ Next step: Beat 2 good Sagnac loops against each other

Is a pulsed optical synchronization the only way ?

- Pulsed Optical Synchronization systems are very complex systems with extremely tight constraints on:
  - Temperature stability
  - EMI
  - vibrations

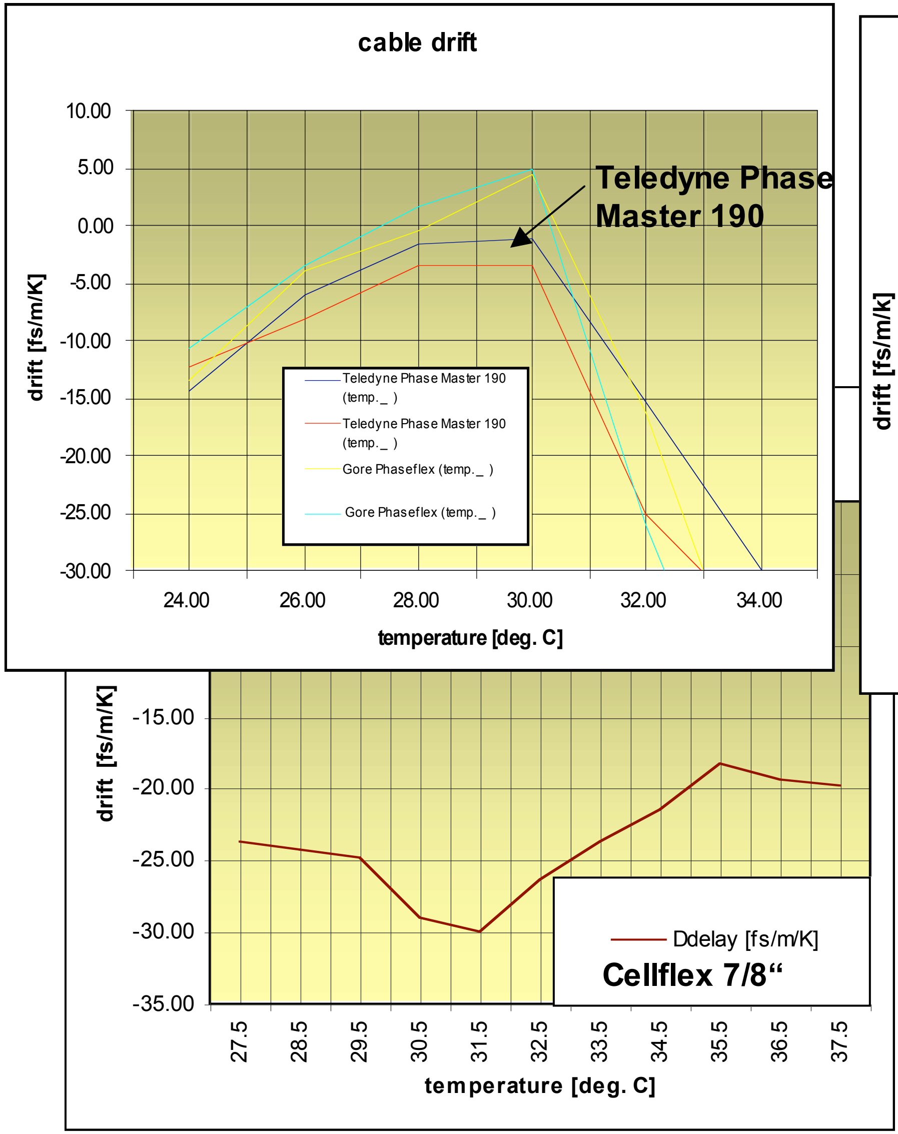
- but also require state of the art electronics:
  - High dynamic range fast ADC‘s (12 bit, ~500 MSPS)
  - High performance digital regulation systems

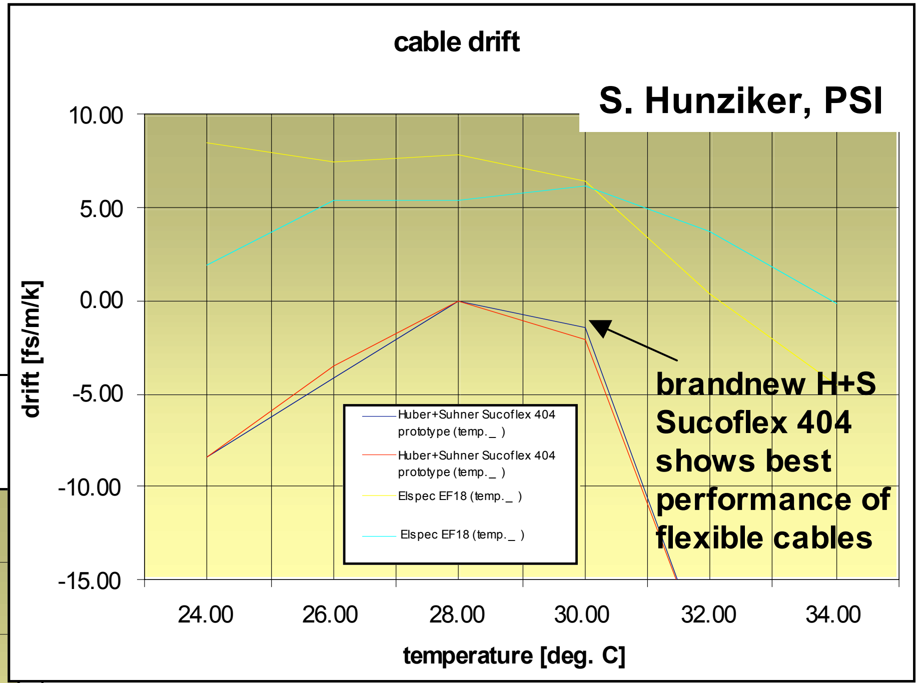
- State of the art Test & Measurement equipment required (~500 kEUR)

Optical synchronization system is very complex (reliability), cost and labor intensive

H. Schlarb, DESY – A. Winter, ITER

Electrical Reference Distribution: Cable Drifts

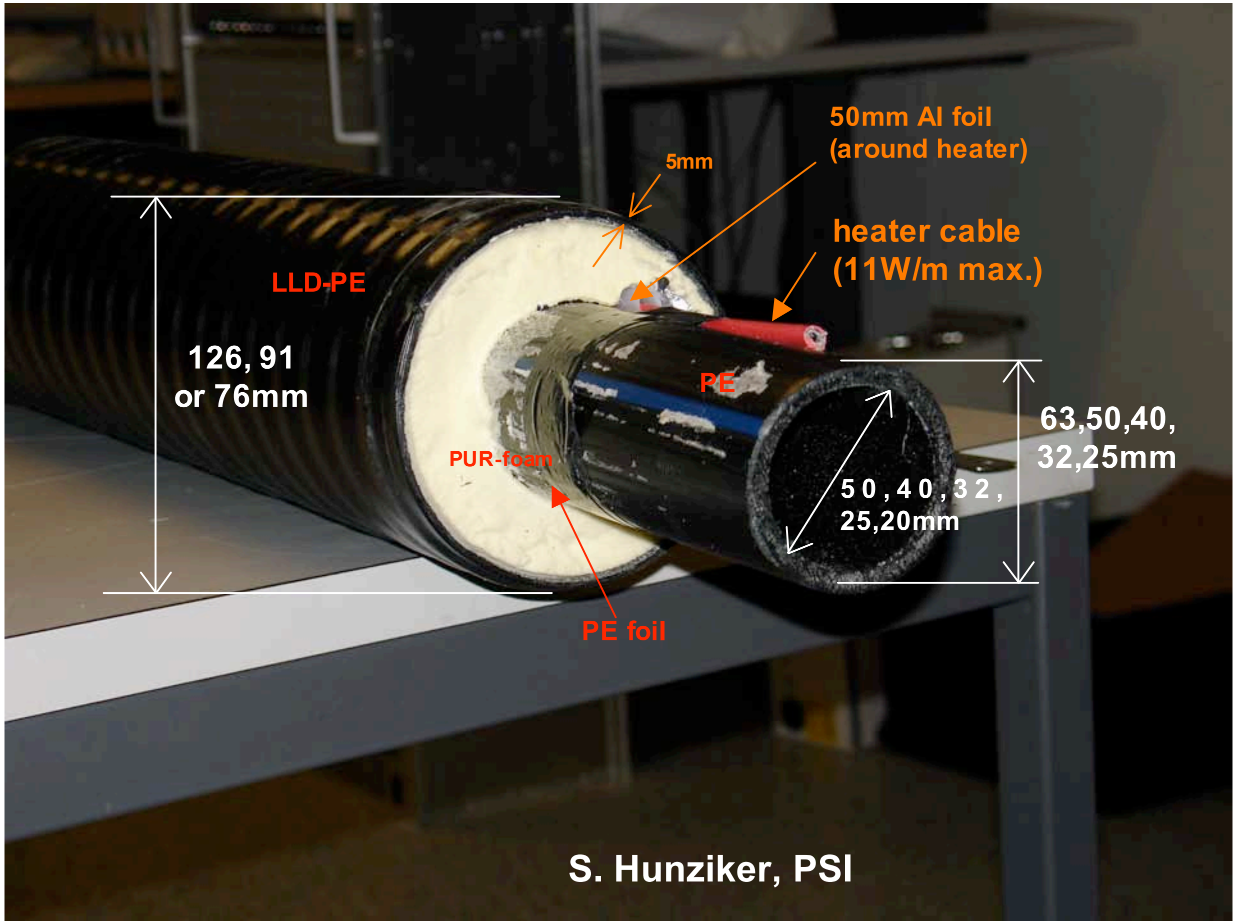




25m of <u>REAL</u> Cellflex 7/8" in a stable thermal environment (0.1..0.2°C stability): 50..100fs drift (factor 10 higher than with datasheet values)!

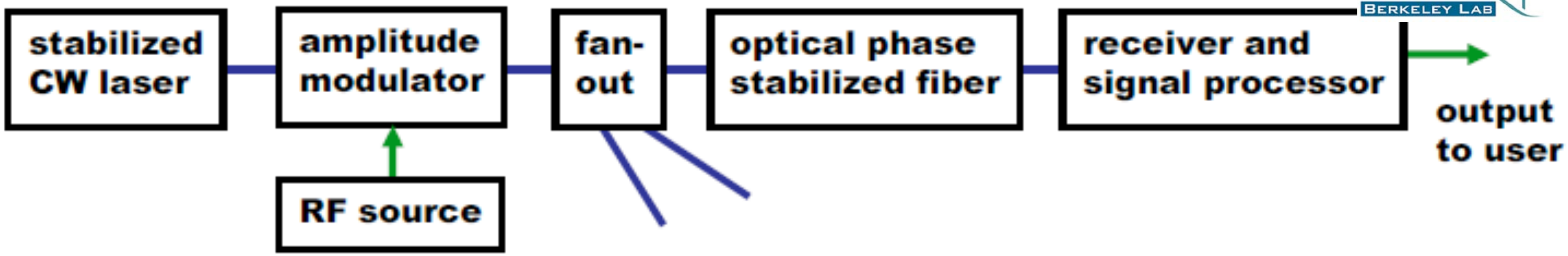
3/8" Heliax could be an alternative (tests in March 2009). 3dB higher loss over whole injector. All other low loss cables do not even have the potential for low drift.

Electrical Reference Distribution : Cable Temperature Stabilization



- provides stable thermal environment for cables (as long and medium term th. stability of tunnel is unknown, also during machine build-up)
- smearing out temp. inhomogeneities
- temperature sensors located on the inner tube
- heater control loop
- ≈45€/m

Interferometric optical stabilization of RF transmission



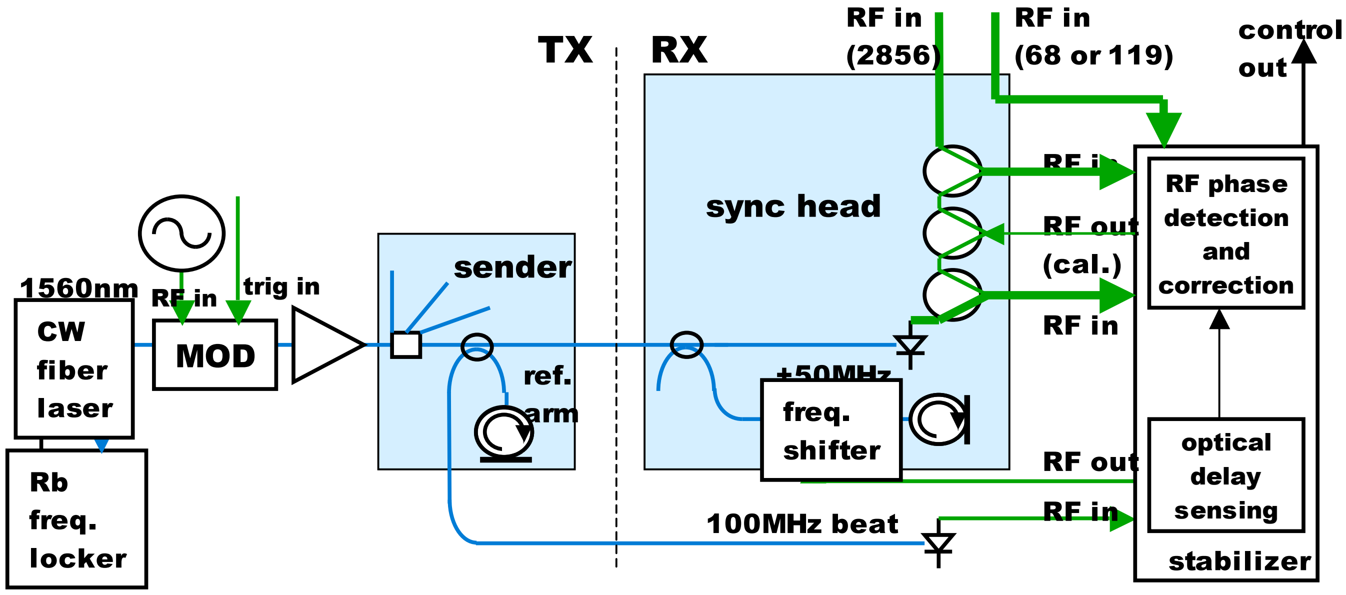
- Interferometer stabilizes optical phase in a fiber transmission line
  – Requires stable laser frequency
- Transmit RF by amplitude modulation of CW signal
  – Like cable TV transmission

- Correct for <u>different temperature coefficients of group and phase velocity</u> by feeding forward an additional phase correction to RF
- Receive <u>using photodiodes, characterized for AM/PM conversion</u>
  – High power diodes have a favorable characteristic

- Process RF signal using FPGA controller
  – Powerful processor can implement averaging and filter functions
  – Ready for integration into accelerator systems

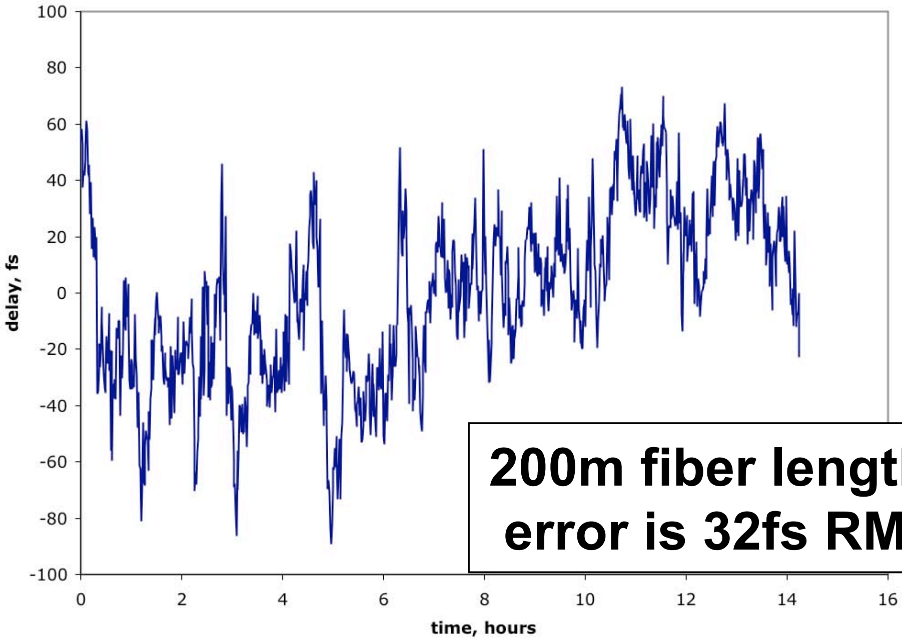
R. Wilcox, J. Byrd, LBNL

The cw system of LBNL



- ➢ Changes in line length are sensed by interferometer, signal sent to receiver
- ➢ Receiver applies phase shift to frequency shifter RF, stabilizing optical phase at end
- ➢ Optical phase correction is used to calculate RF phase shift, including group/phase correction

Performance of the cw system



**200m fiber length:
error is 32fs RMS over 14h**

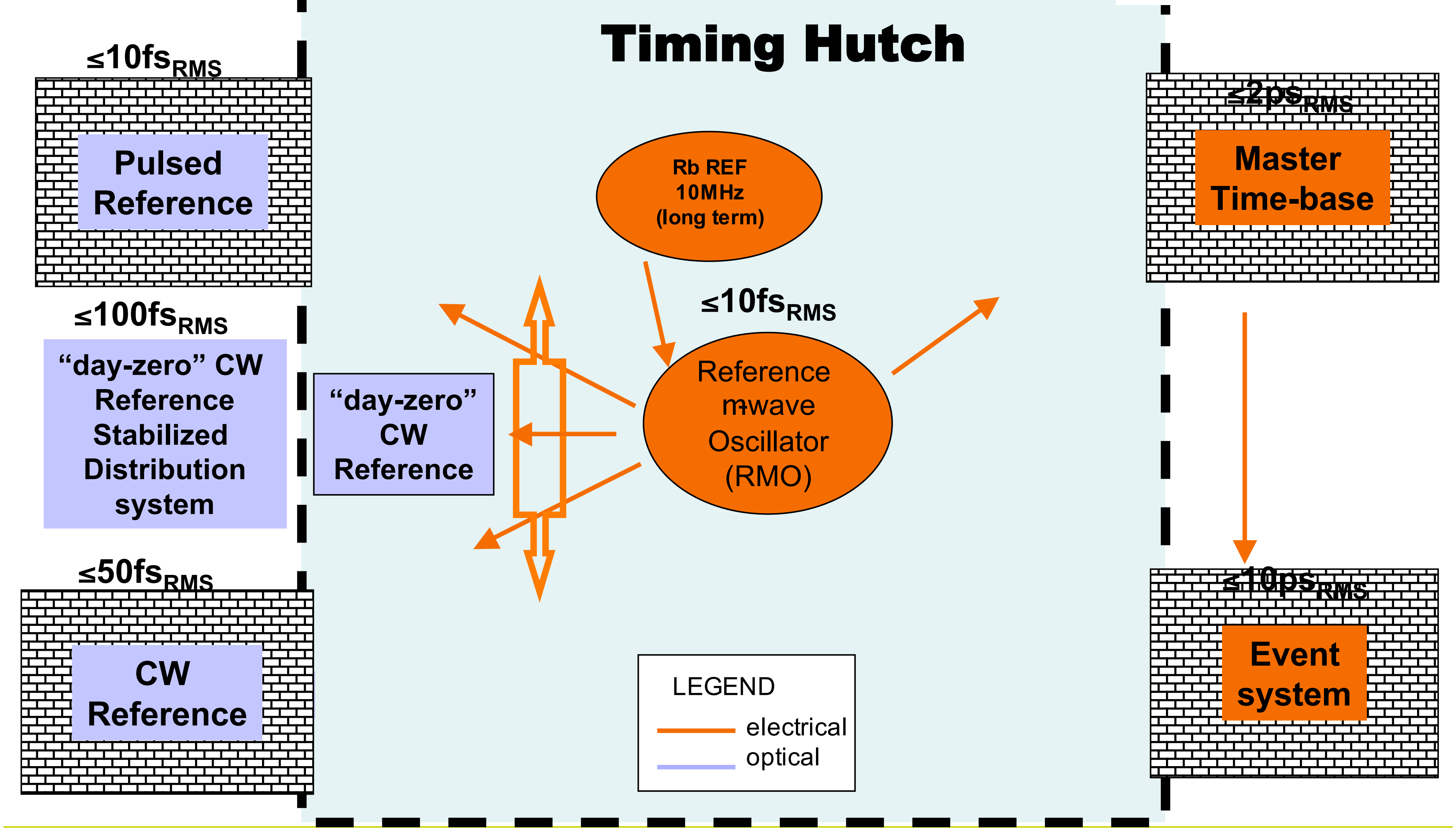
- also good performance
- sufficient for many applications
- easier implementation into RF system

R. Wilcox, J. Byrd, LBNL

- This result indicates the performance of the near term LCLS and Fermi systems
- Installation of 3 links at Fermi in 2010

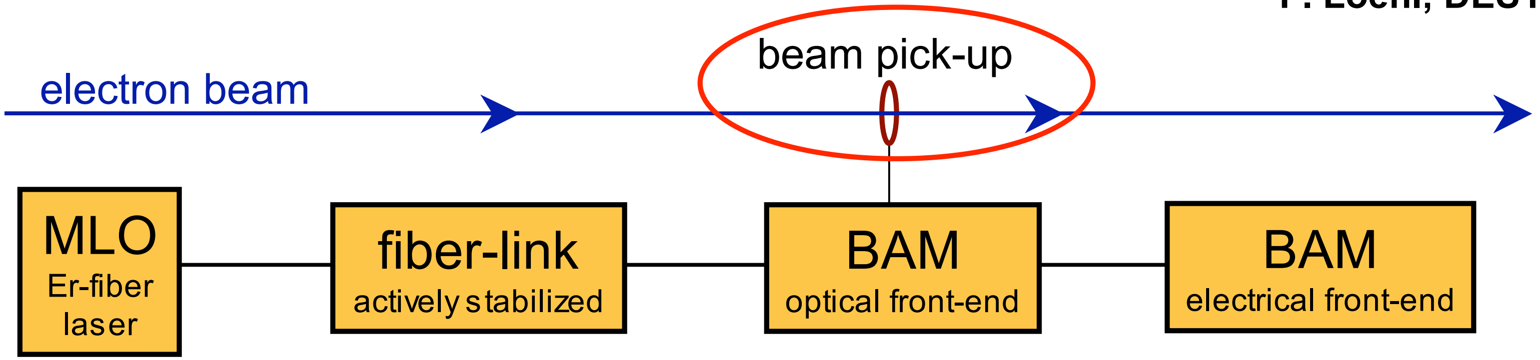
The FERMI@Elettra optical hybrid timing system

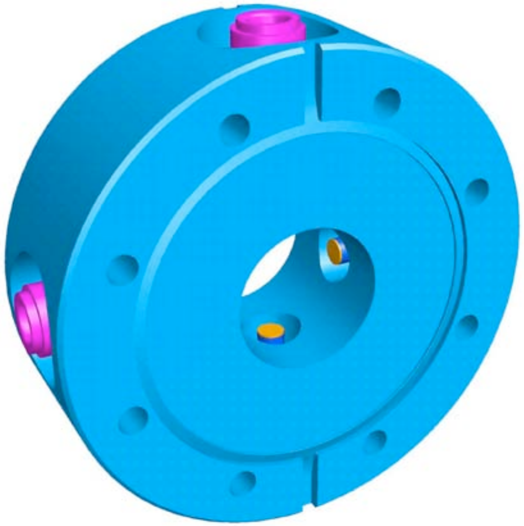
M. Ferrianis, Elettra



The Bunch Arrival Time Monitor (BAM)

F. Loehl, DESY





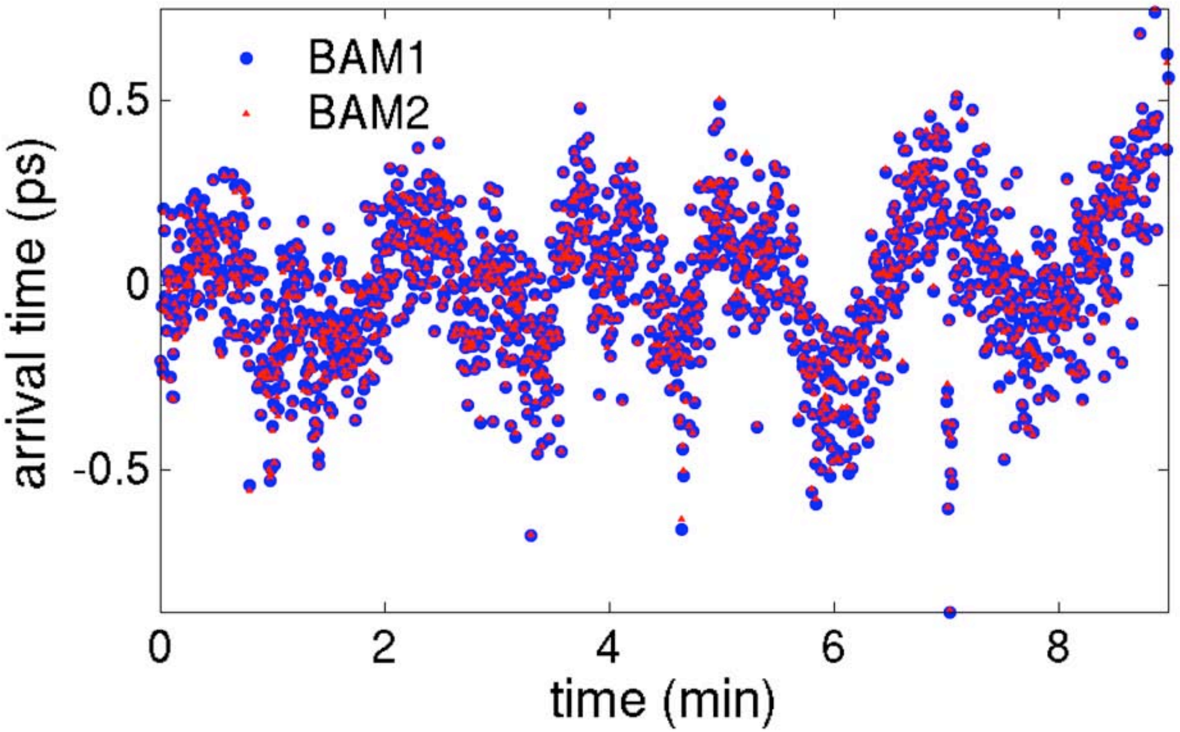
Beam pick-up experience: button-type

- opposite outputs are combined
- optimized for steep zero-crossing slope and low peak voltage

Design: K. Hacker

Arrival time correlation between two BAMs

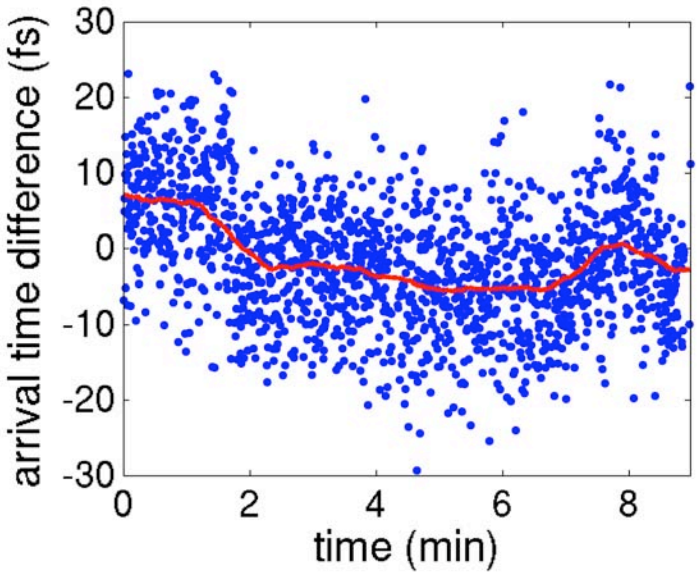
F. Loehl, DESY

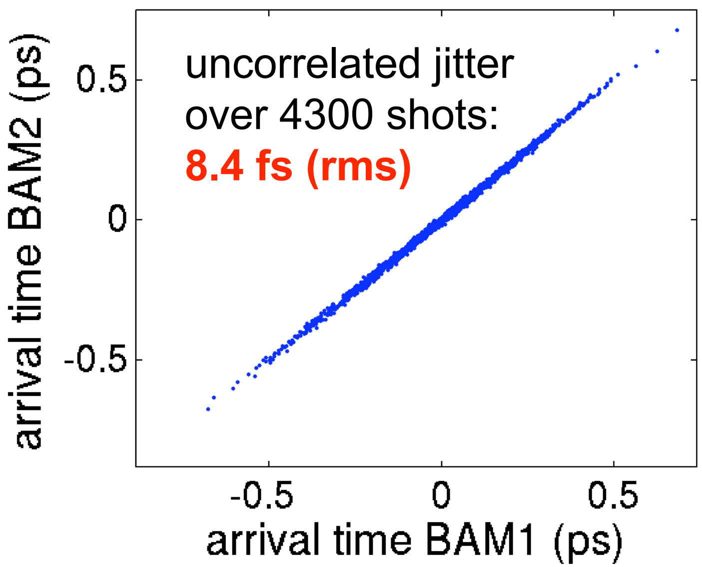


BAMs located at different positions of the accelerator

Arrival time correlation between two BAMs

F. Loehl, DESY





Arrival time difference contains:

- high frequency laser noise (~3 MHz – 108 MHz)
- stability of two fiber links
- two BAMs

Single bunch resolution of entire measurement chain: **< 6 fs (rms)**

Overview – Status of the Facilities

	Timing System	Status
DESY (Flash/XFel)	pulsed	Self developed key components have shown proof, many prototypes, further iteration steps in progress
FERMI@Elettra	Hybrid (pulsed + cw)	Ordered pulsed system from „Menlo Systems“ Cw system from Berkely Will be installed within 2009/10
SPARC-X	pulsed	Commercial OMO from „Onefive“
STFC (NLS)	pulsed	Proposed, preliminary experiments Commercial OMO from „Toptica“, DESY Type OMO
LBNL	cw	Key components demonstrated its performance, Experiments performed under lab and accellerator environment
PSI	Coax + pulsed	Commercial OMO from „Onefive“ Commercial RMO from „Inwave“ Start with RF system (Carefully choosing the RF components)

Thank you for your attention