All-optical femtosecond timing system for the Fermi@Elettra FEL

Mario Ferianis, Sincrotrone Trieste, Italy

Abstract

FERMI@ELETTRA, a 4th generation light source under commissioning at Sincrotrone Trieste, is the first FEL facility to use an all-optical system for femto-second timing and synchronization over the entire facility ranging from the photo injector, linac, FEL and beam-line end stations. The system is a unique combination of state-of-the-art femto second timing distribution based on pulsed and CW stabilized optical fiber links. We describe the details of this unique system and present the performance to date.

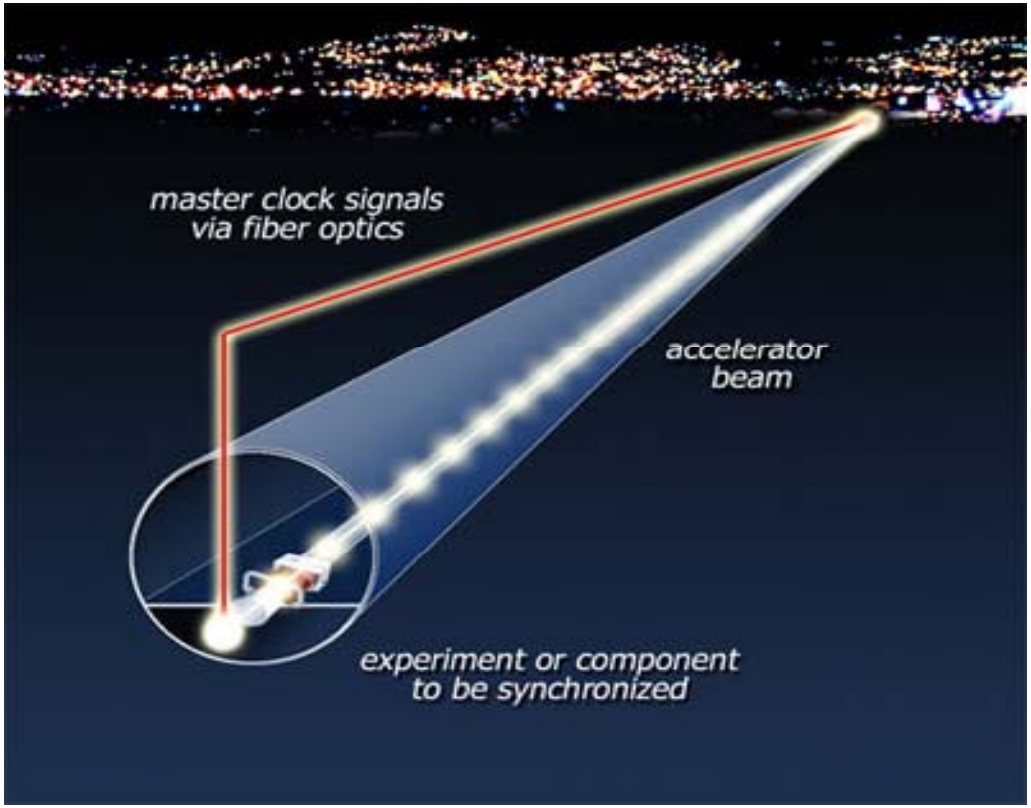
Asian Particle Accelerators...

http://www.aaplaza.org/c5.html

Fourth generation light source (4GLS) timing systems

Goal of a timing system for a 4th gen. Light Source:

to generate and to distribute, with fs accuracy over stabilized links, the phase reference signal to synchronize all time-critical accelerator components, down to the beamlines



http://www.lbl.gov/Science-Articles/Archive/sabl/2007/Jun/nSync.html

FERMI@Elettra & timing system development timeline

2002 Initial discussions about FERMI@Elettra

2004 Kick-off events for timing system design:
BIW 2004 and **ICFA XFEL2004** mini-workshop

2006 Conceptual Design Report (CDR), pub. Jan 07

2006/07 **Technical Optimization Study** (TOS),
design review of initial timing system schemes

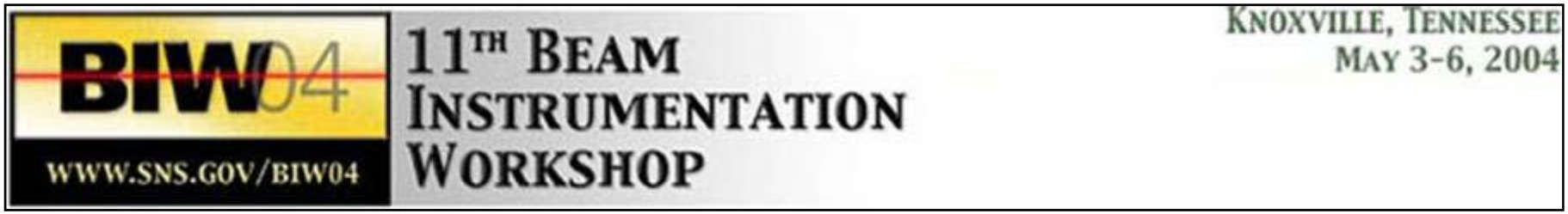
2006/09 Specific collaboration agreements signed with:
- MIT/RLE pulsed optical timing: demonstration at Elettra
- LBNL digital LLRF system with CW optical timing

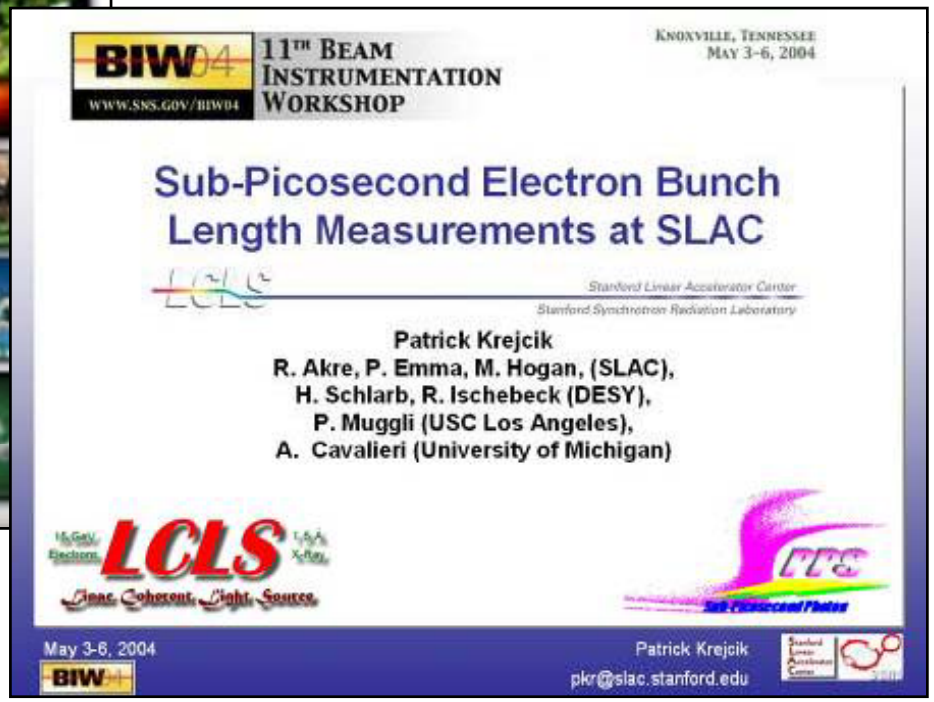
2005/07 EUROFEL FP7 project; many intercations, DESY group

2008/09 final design review;
outsourcing for final engineering and construction;
installation

2009, AUG start of FERMI commissioning; 1st timing system set-up

Kick-off events in 2004





http://neutrons.ornl.gov/workshops/20040503_biw04/

and shortly after …

XFEL 2004

Home | Agenda | Registration | Payment | Housing | Social Program | Tourism | First Announcement | Attendee List | Photos

ICFA

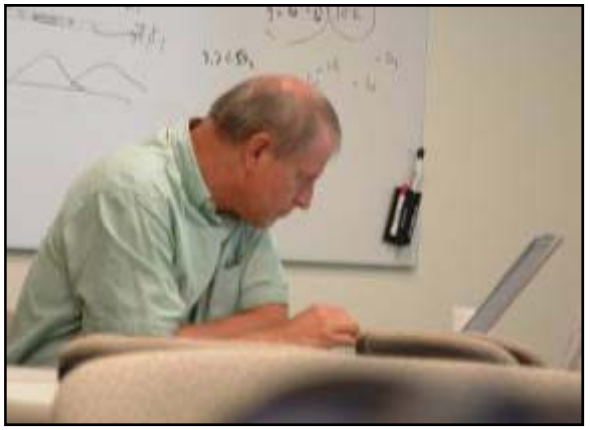
ICFA Future Light Sources Subpanel
Miniworkshop on XFEL Short Bunch Measurement and Timing
Stanford Linear Accelerator Center, July 26 - 30, 2004

Jerry Hastings SSRL
jbh@slac.stanford.edu

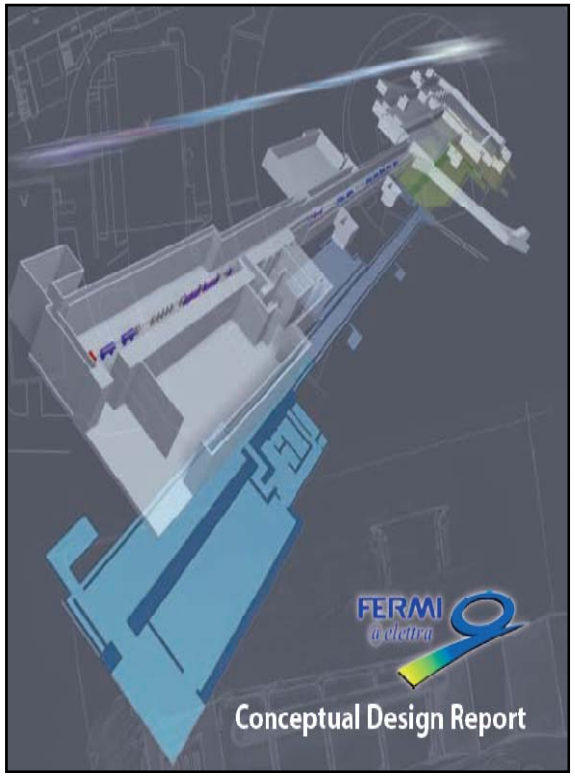
Patrick Krejcik SLAC
pkr@slac.stanford.edu

Holger Schlarb DESY
holger.schlarb@desy.de

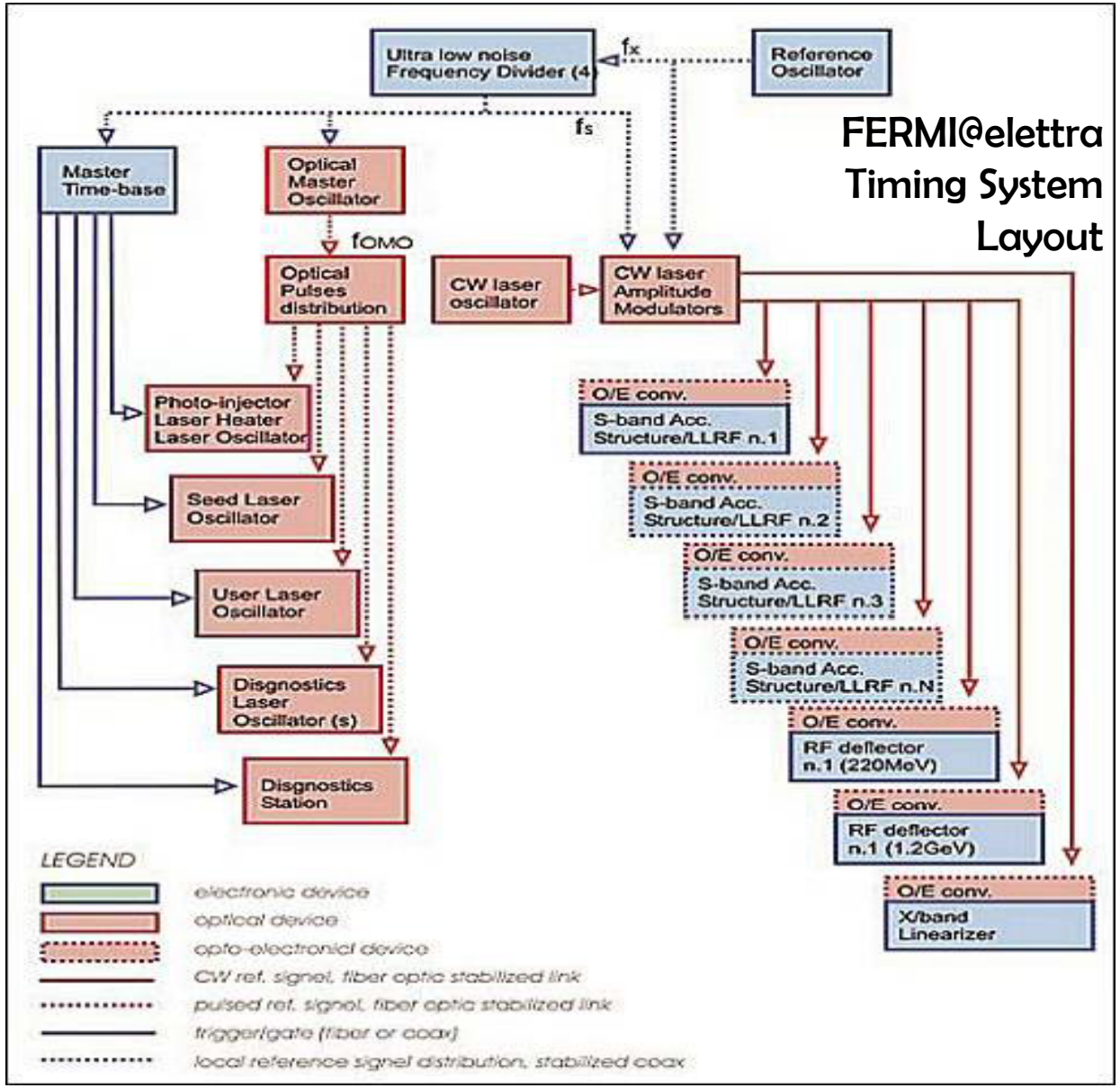
http://ssrl.slac.stanford.edu/lcls/xtel2004/



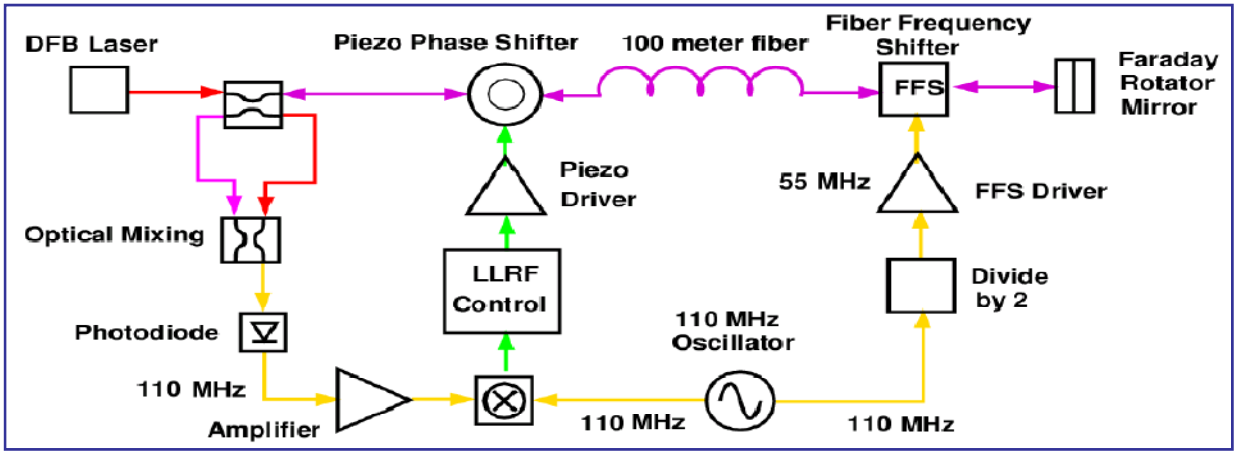
FERMI@Elettra timing system



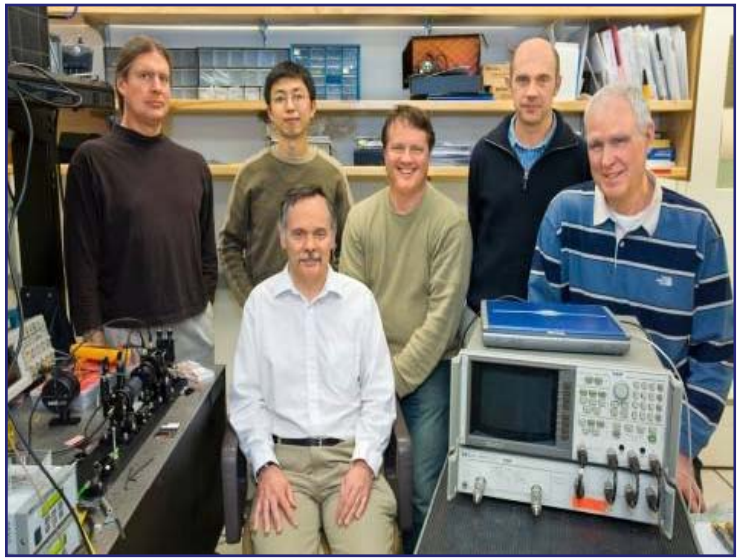
January 2007



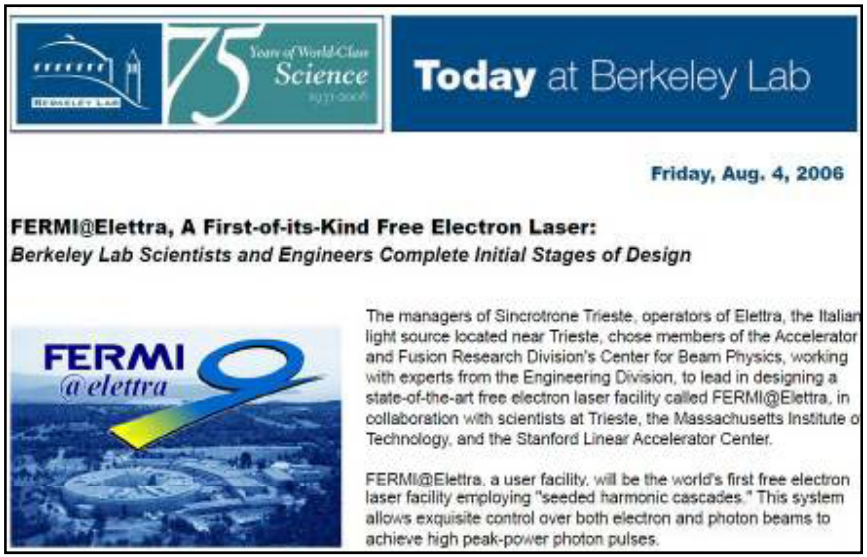
Successful collaboration with LBNL



Development of a digital LLRF system for the FERMI Linac with embedded CW optical femtosecond timing



J.M. Byrd
J. Staples
R. Wilcox
L. Doolittle
A.Ratti
G. Huang



Today at Berkeley Lab

Friday, Aug. 4, 2006

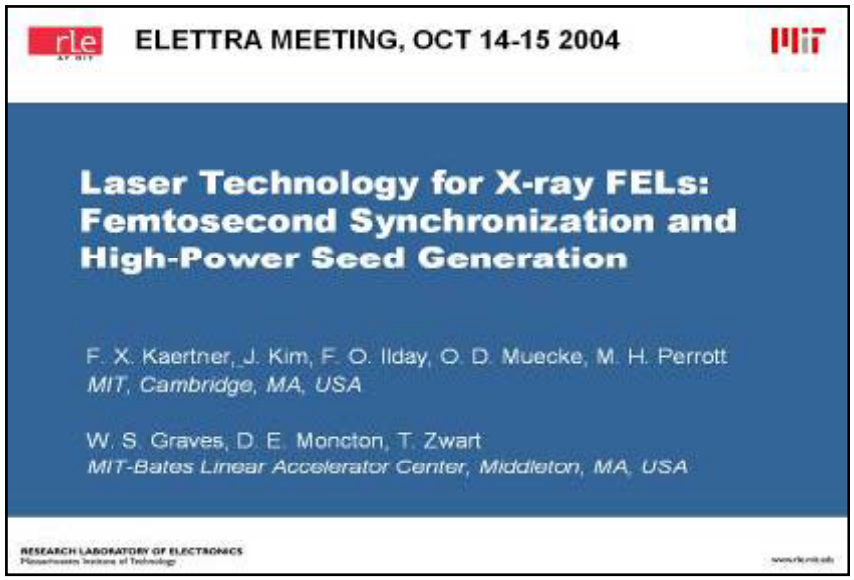
FERMI@Elettra, A First-of-its-Kind Free Electron Laser:
Berkeley Lab Scientists and Engineers Complete Initial Stages of Design

The managers of Sincrotrone Trieste, operators of Elettra, the Italian light source located near Trieste, chose members of the Accelerator and Fusion Research Division's Center for Beam Physics, working with experts from the Engineering Division, to lead in designing a state-of-the-art free electron laser facility called FERMI@Elettra, in collaboration with scientists at Trieste, the Massachusetts Institute o Technology, and the Stanford Linear Accelerator Center.

FERMI@Elettra, a user facility, will be the world's first free electron laser facility employing "seeded harmonic cascades." This system allows exquisite control over both electron and photon beams to achieve high peak-power photon pulses.

http://www.lbl.gov/today/2006/Aug/04-Fri/Elettra_pdf_FINAL.pdf

...and with with RLE@MIT


rle ELETTRA MEETING, OCT 14-15 2004 MIT

Laser Technology for X-ray FELs: Femtosecond Synchronization and High-Power Seed Generation

F. X. Kaertner, J. Kim, F. O. Ilday, O. D. Muecke, M. H. Perrott
MIT, Cambridge, MA, USA

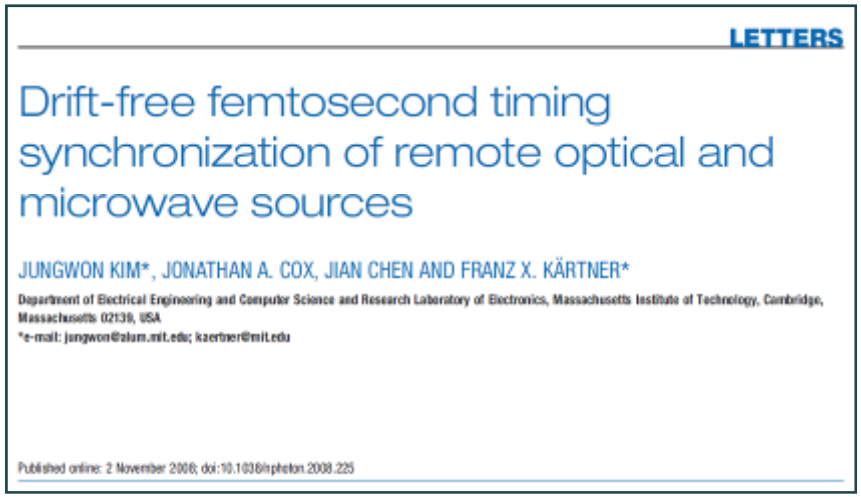
W. S. Graves, D. E. Moncton, T. Zwart
MIT-Bates Linear Accelerator Center, Middleton, MA, USA

RESEARCH LABORATORY OF ELECTRONICS
Massachusetts Institute of Technology

www.rle.mit.edu

prof. F. X. Kaertner, J. Kim,
F.O. Ilday, J. Cox, J. Chen

Demonstrate at Elettra a two stabilized link system with OMO including long term issues

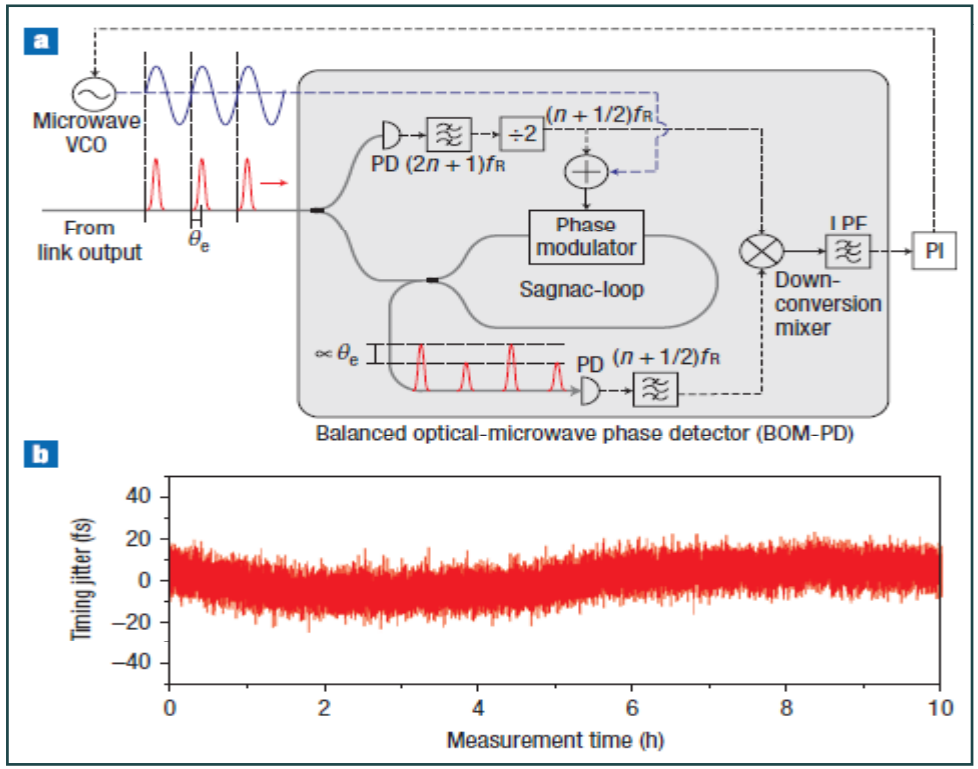

LETTERS

Drift-free femtosecond timing synchronization of remote optical and microwave sources

JUNGWON KIM*, JONATHAN A. COX, JIAN CHEN AND FRANZ X. KÄRTNER*

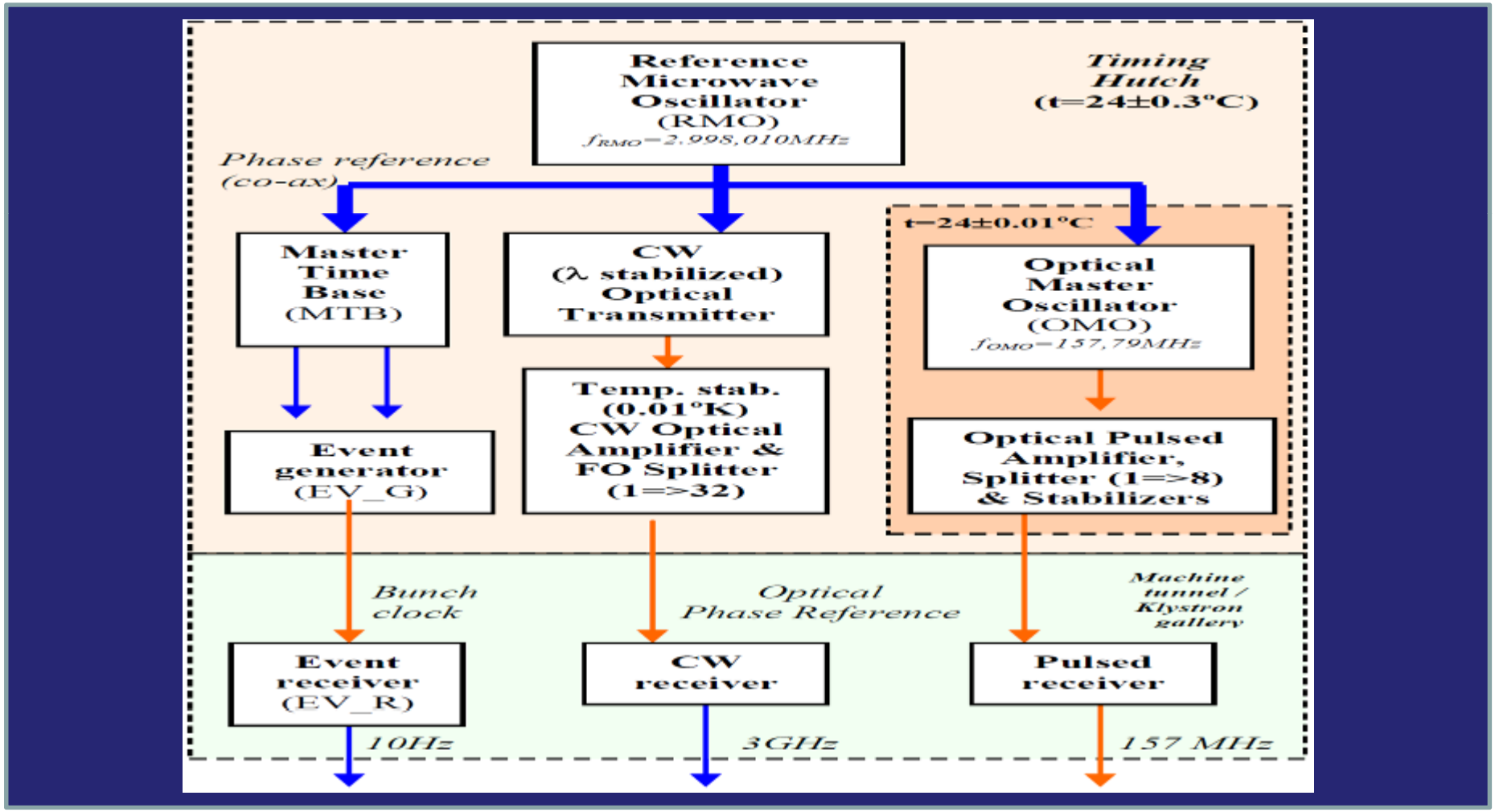
Department of Electrical Engineering and Computer Science and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
*e-mail: jungwon@alum.mit.edu; kaertner@mit.edu

Published online: 2 November 2008; doi:10.1038/nphoton.2008.225

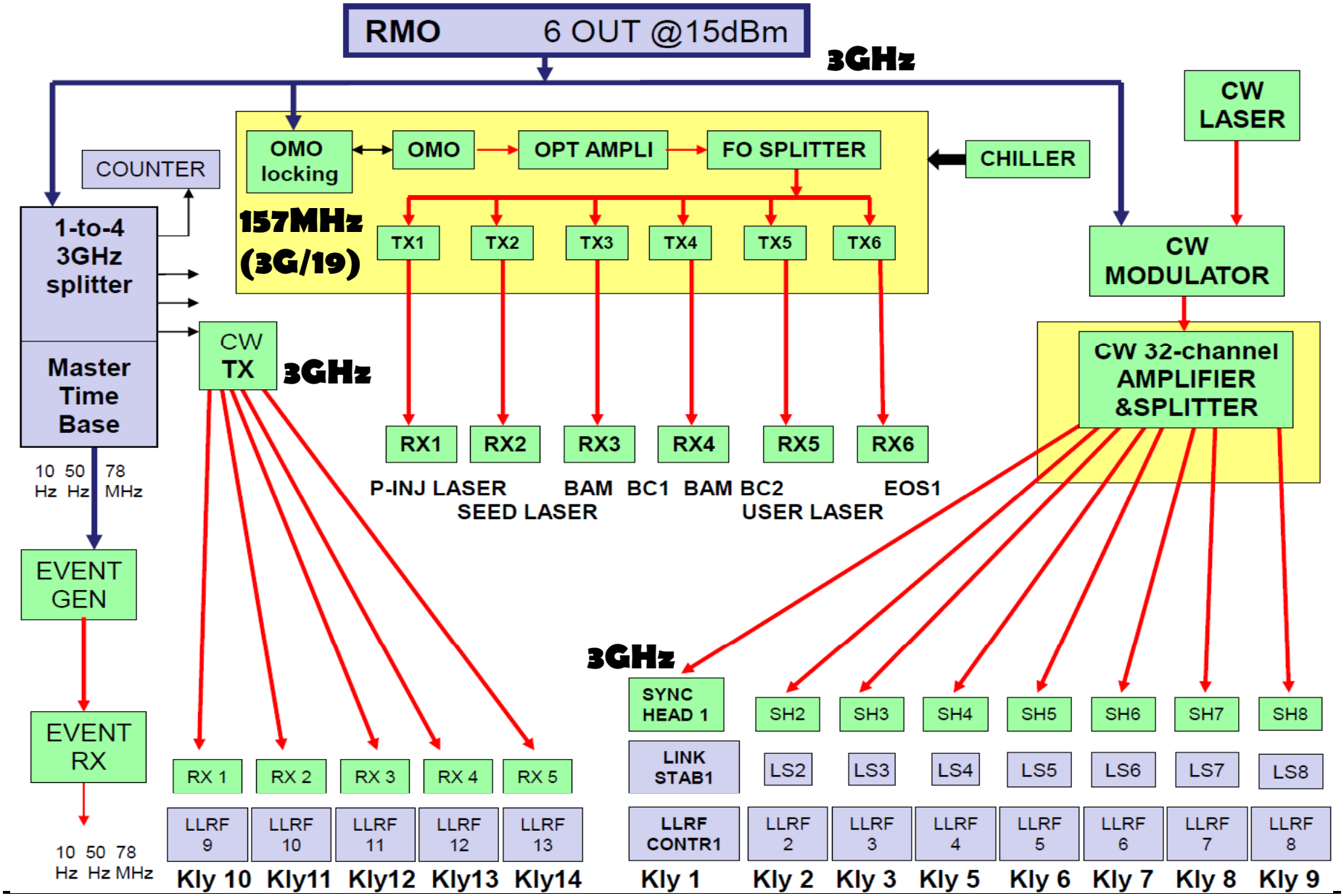


FERMI@Elettra hybrid timing system

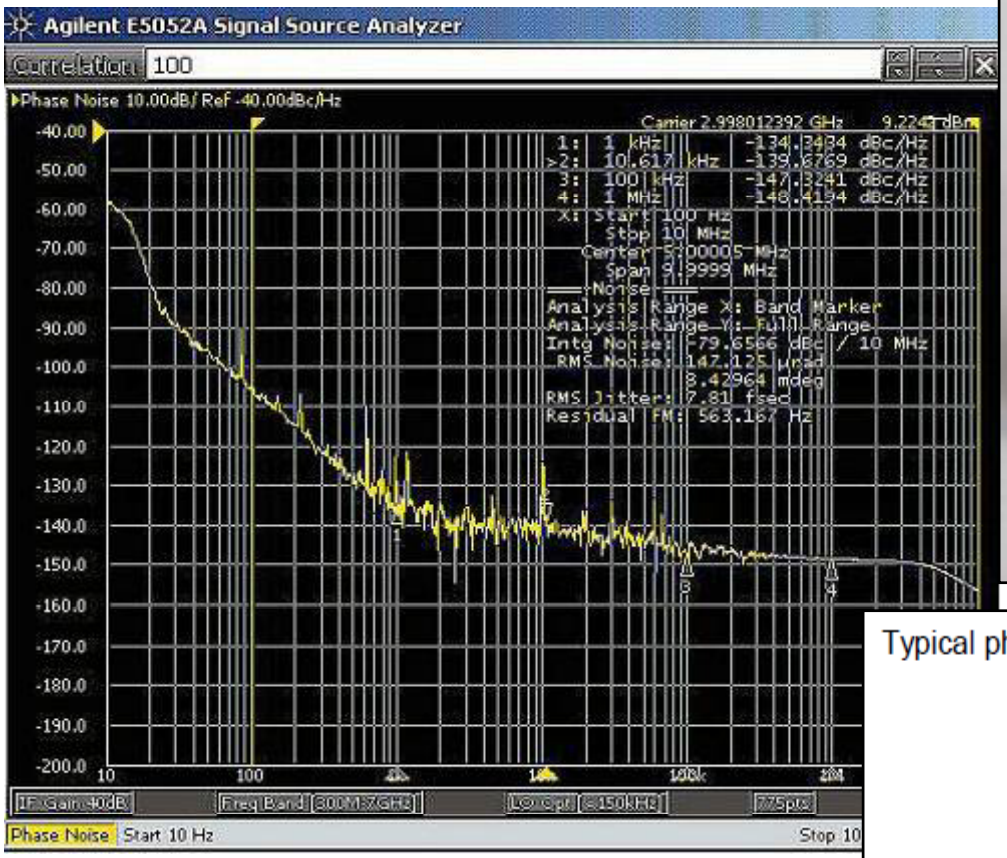
At the end of our desing effort, both pulsed and CW technologies have been engineered and integrated into a single timing system

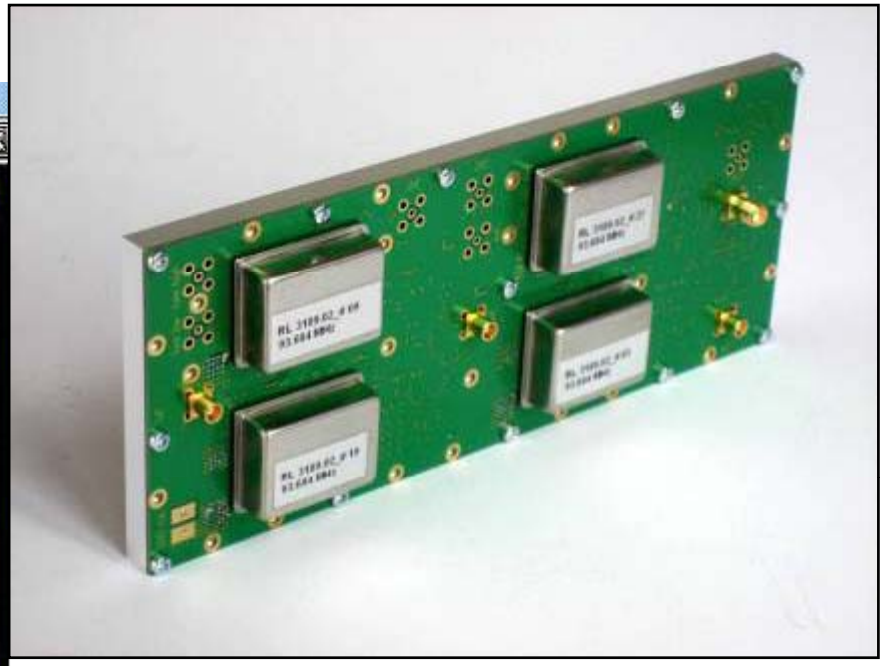


FERMI@Elettra timing system: current status



Reference Microwave Oscillator Generation II





Measured phase noise@3GHz:

7,8 fs_{RMS} [100Hz, 10MHz]

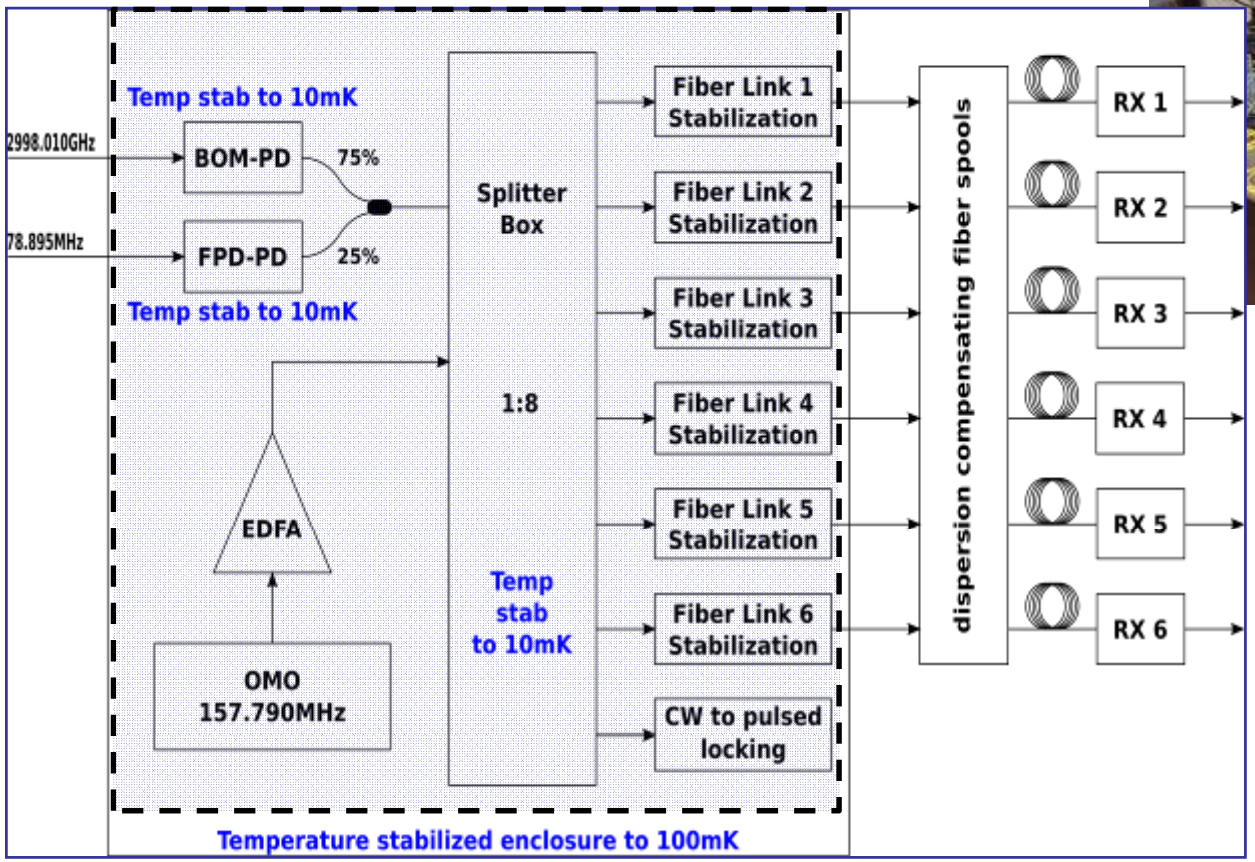
Typical phase noise @ 1 GHz (8 N)	< -85dBc @ 10 Hz offset
	< -115dBc @ 100 Hz offset
	< -137dBc @ 1 kHz offset
	< -149dBc @ 10 kHz offset
	< -153dBc @ 100 kHz offset
	< -155dBc @ 1 MHz offset
	< -160dBc @ 10 MHz offset
RMS jitter [100 Hz – 10 MHz]	<10 fsec
Multiplied output frequencies	N, 2N, 4N, 8N, 24N

INWAVE AG (CH) & RALAB AG (Liechtenstein) / Mr. E. Salow

Pulsed optical timing

Pulsed optical timing system has been engineered and built by MENLO Systems, Gmbh

A 2 year project, with on-site installation and testing included

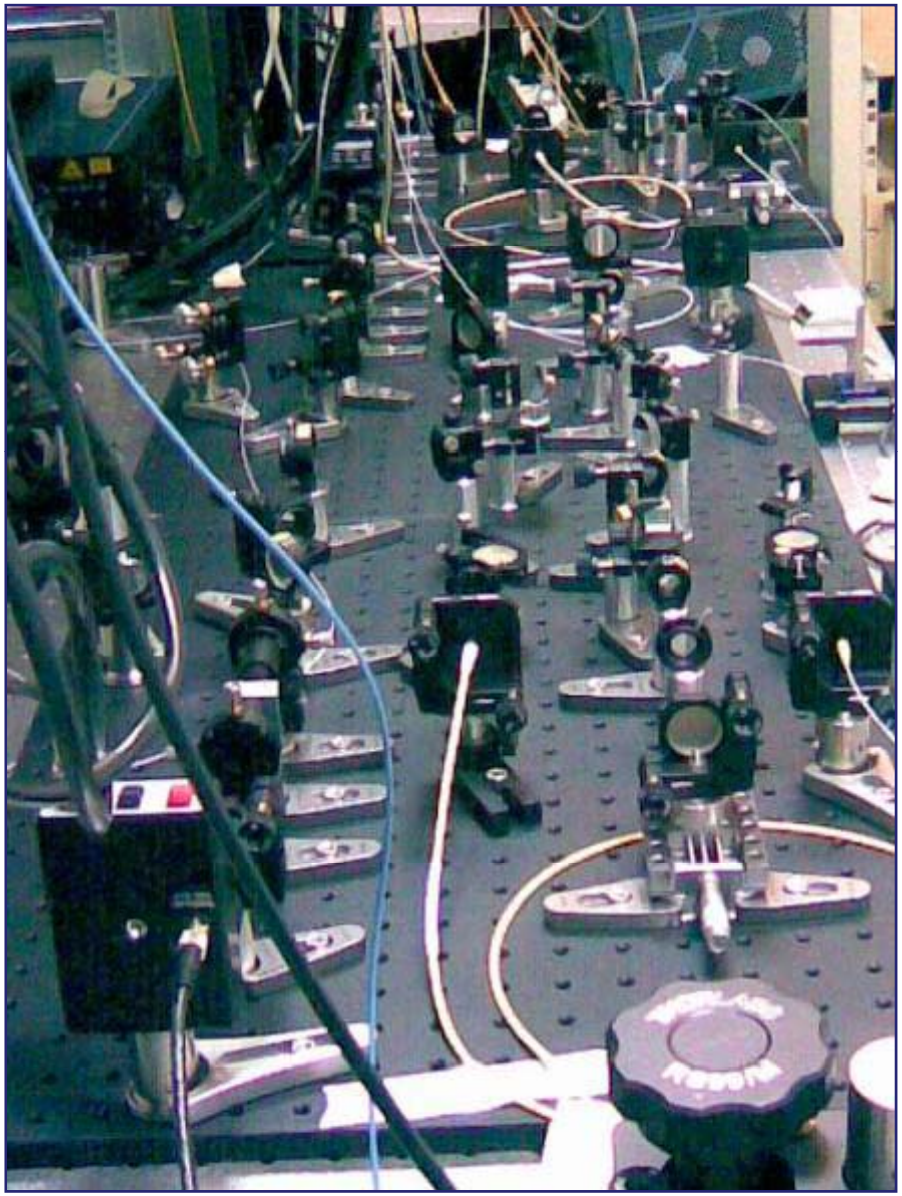


Pulsed optical timing system components installed in the FERMI timing hutch

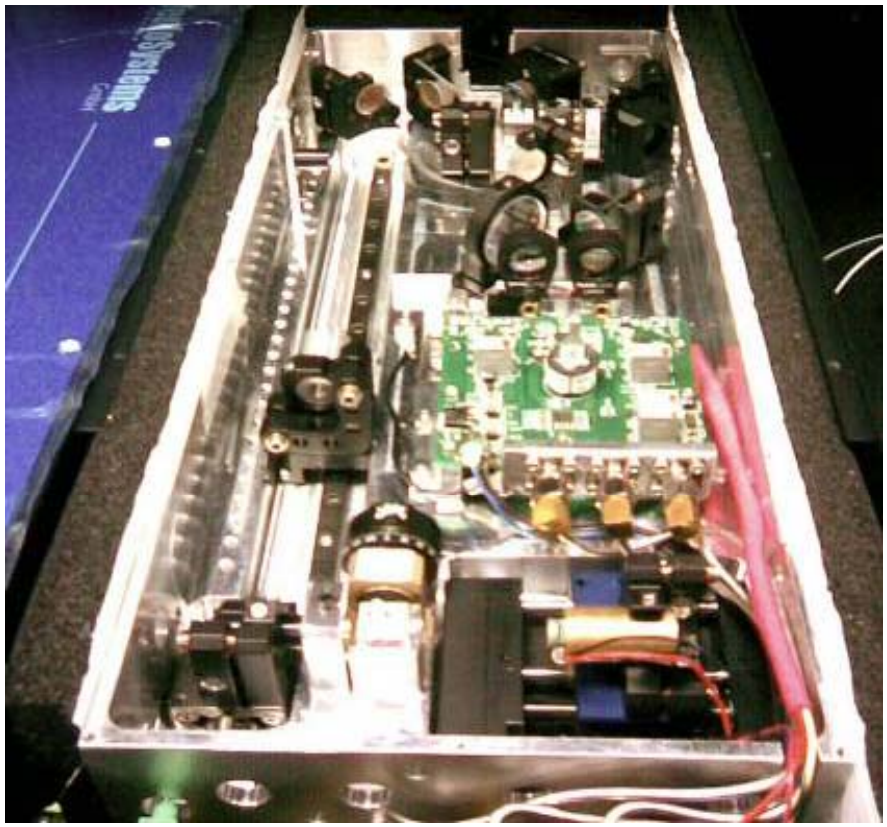
Optical Master Oscillator (OMO) & 6 Stabilized Links (transmit side)

The fibre optic **splitter** and the six **cross-correlators** for link stabilization share the same temp. controlled box of the **OMO**

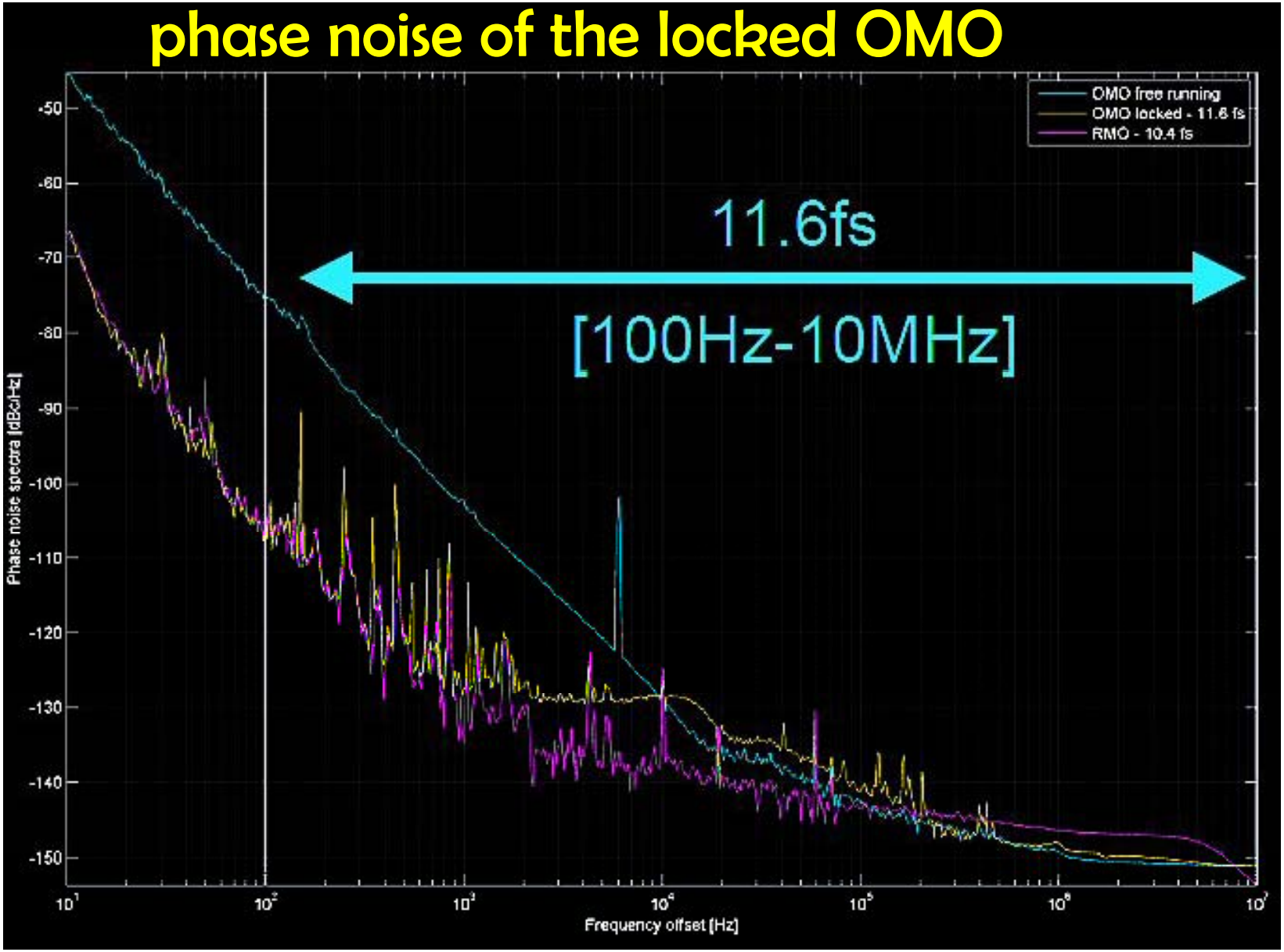
...tough engineering work



2-link table-top demonstrator (left, 2007) &
the engineered cross correlator (below, 2009)

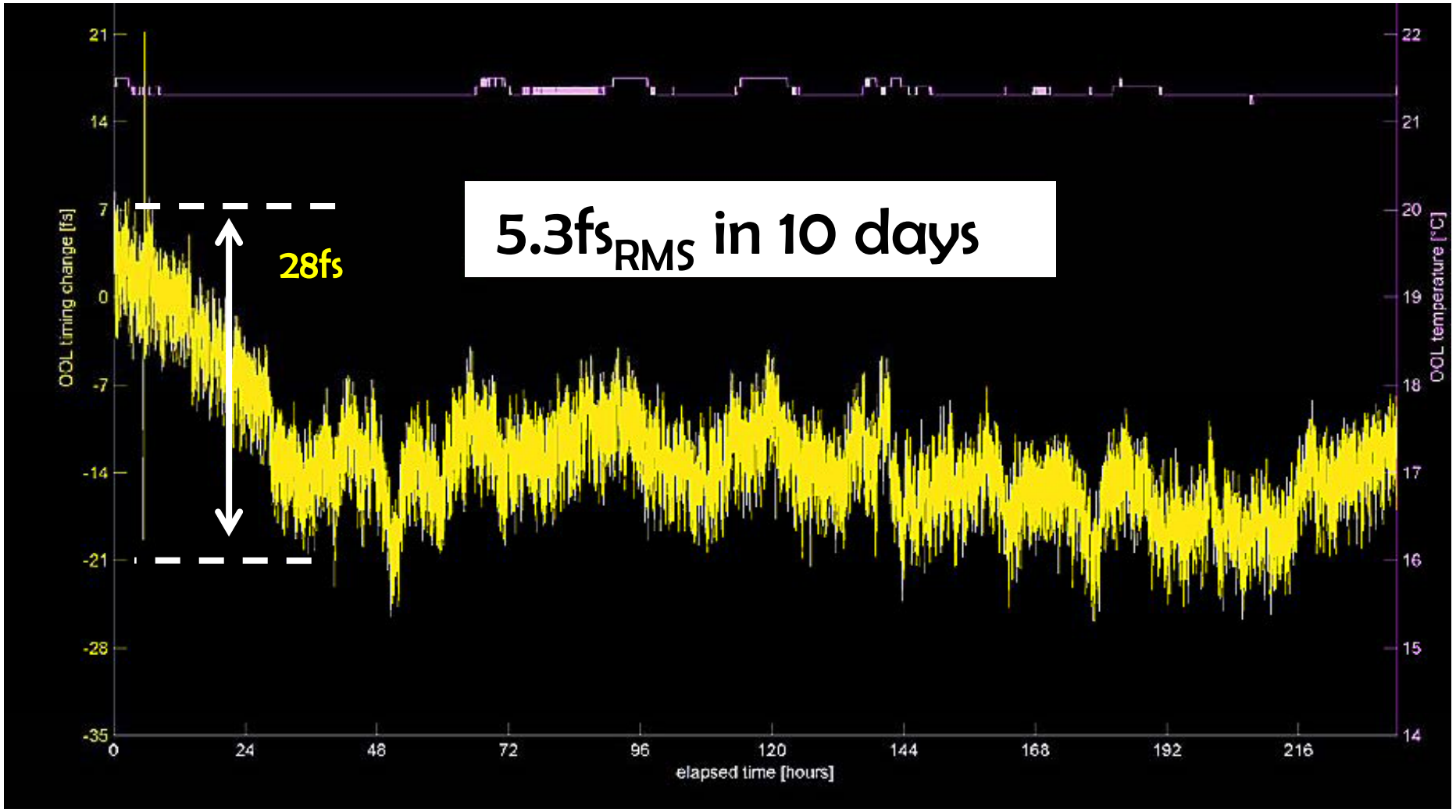


Pulsed optical timing

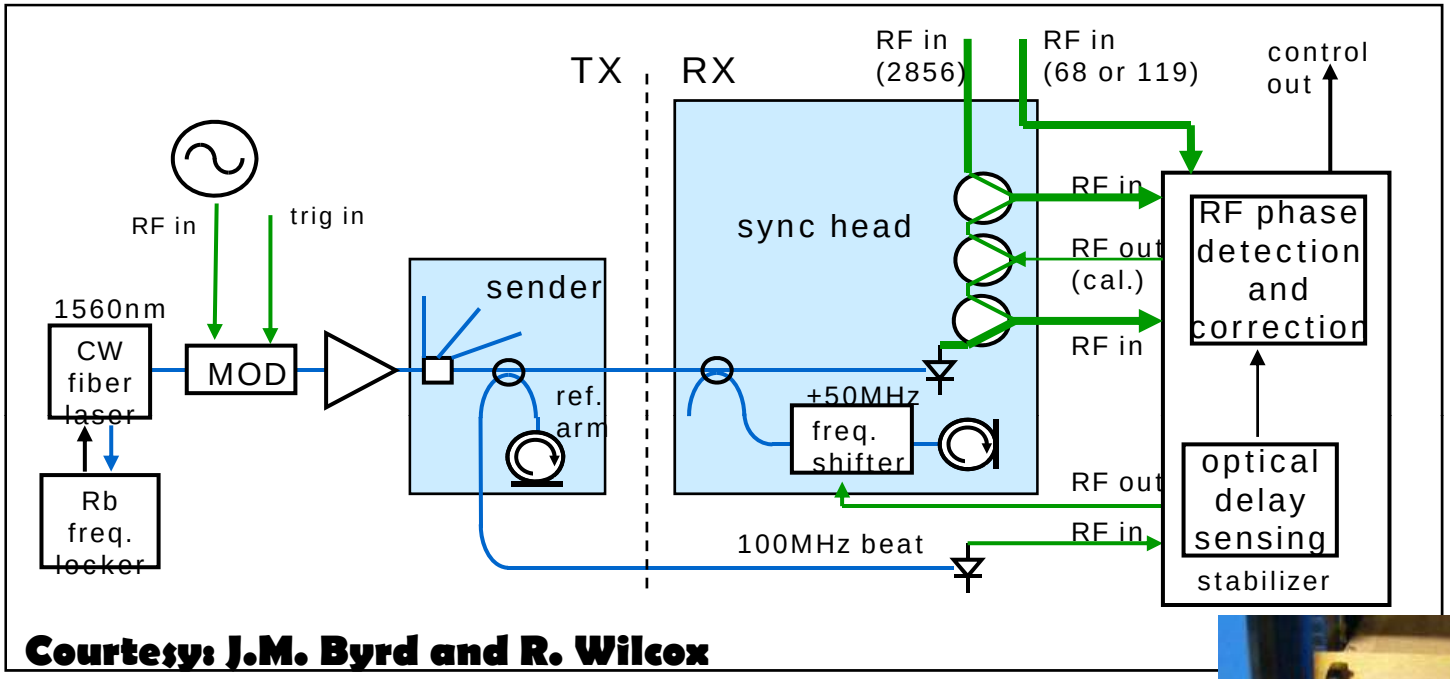


Pulsed optical timing

out-of-loop long term (10 days) drift measurement; local optical reference vs. 150m loop-back stabilized link



CW optical link:
Sync Head & Link Stabilizer



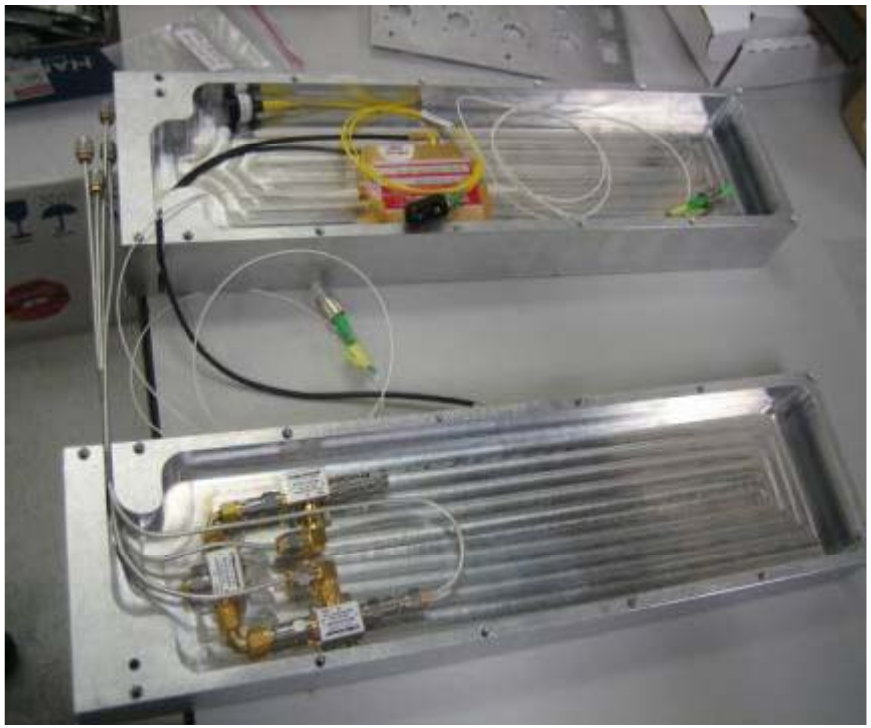
Courtesy: J.M. Byrd and R. Wilcox

No active compensation of link delay; Delay sensing and correction in the LLRF controller

CW laser (Koheras) @1560nm & amplitude modulator, by 3GHz phase ref. signal (R. Wilcox, LBNL)

CW optical timing

Assembly of the Sync Head

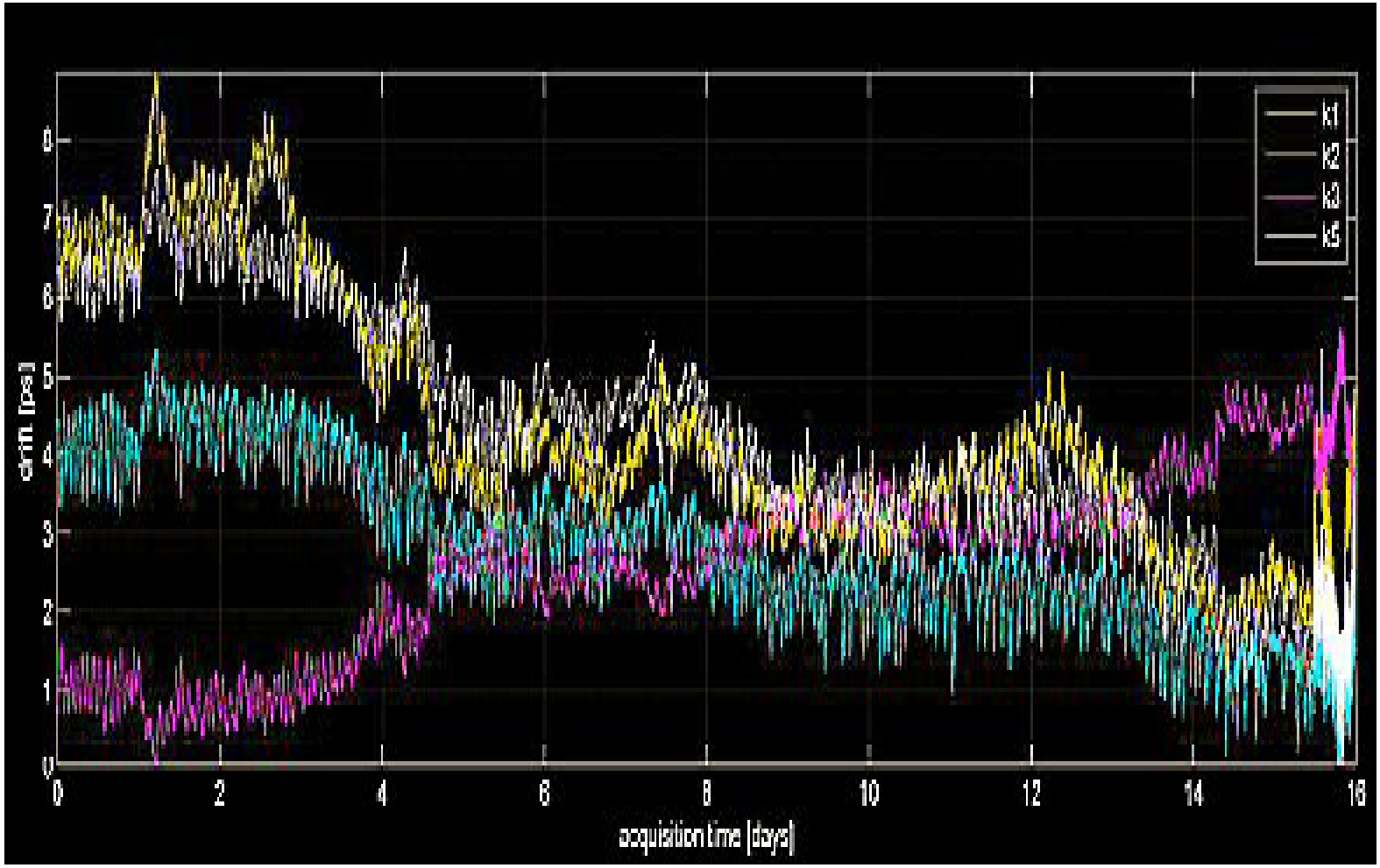


MagiQ Technologies,
Sommerville, MA - USA

Top view of the Link Stabilizer

YY-Labs,
Fremont, CA - USA

CW optical timing:
two week acquisition of the drifts of four independent links feeding:
Kly1, Kly2, Kly3 (sign rev.) and Kly5



CW optical timing…

Stabilizing down to few 10s of a femtosecond is not the toughest task… (Clearing Customs in Trieste!)

LBNL Demonstrator hardware approaching Sincrotrone Trieste

March 2010

Fiber optics cabling:
based on blown fibre system

Numbers on the FERMI ***Copper Free*** *timing cabling*:

- 36 delivery points (end-stations) installed;
- 68 fiber bundles blown as:
  - ~4.5km of 8 S-M fiber bundles
  - ~1.5km of 4 S-M fiber bundles

A total of:

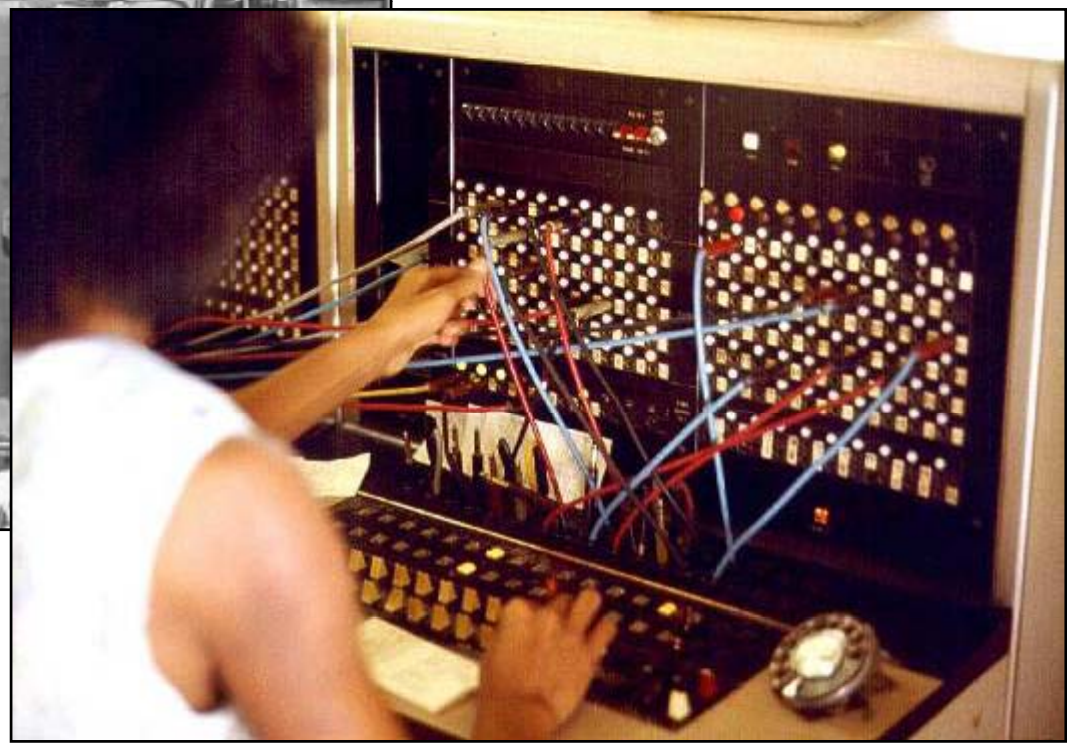
- **42km** of S-M fibers
- **6km** of M-M fibers

http://www.prysmian.com/

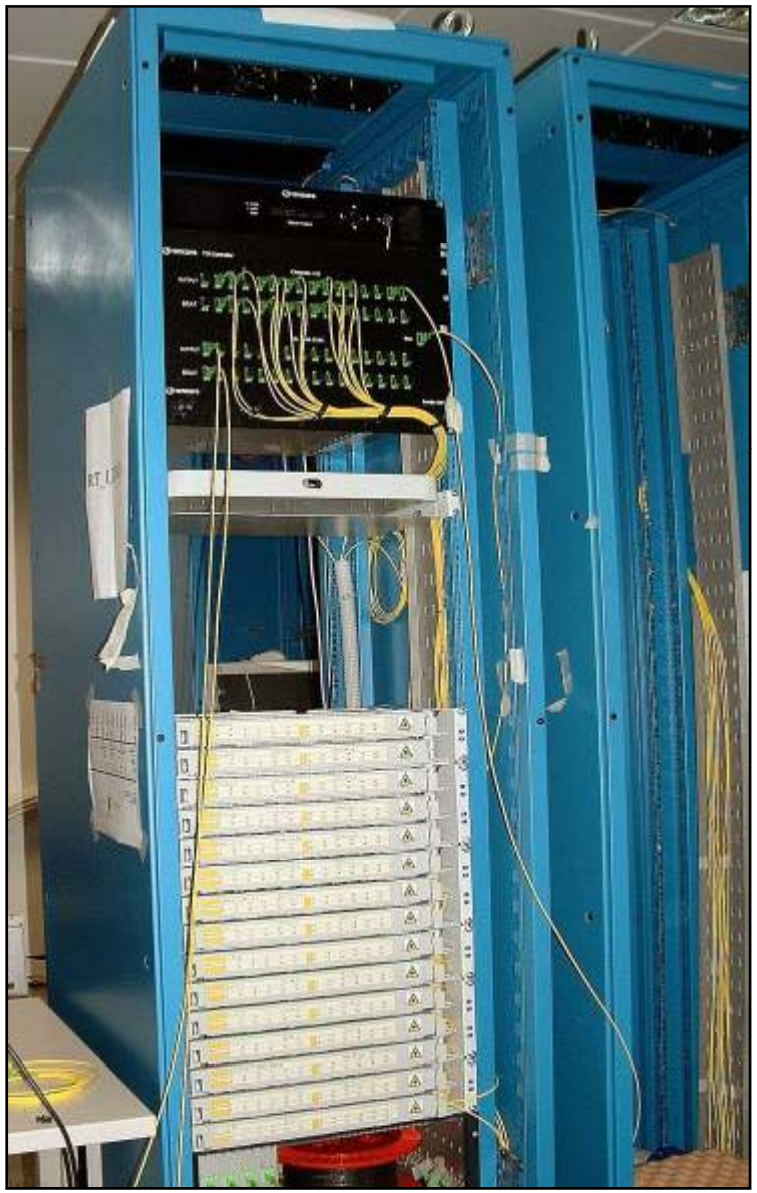
Optical cabling:

like the telephone switchboard from the 40s

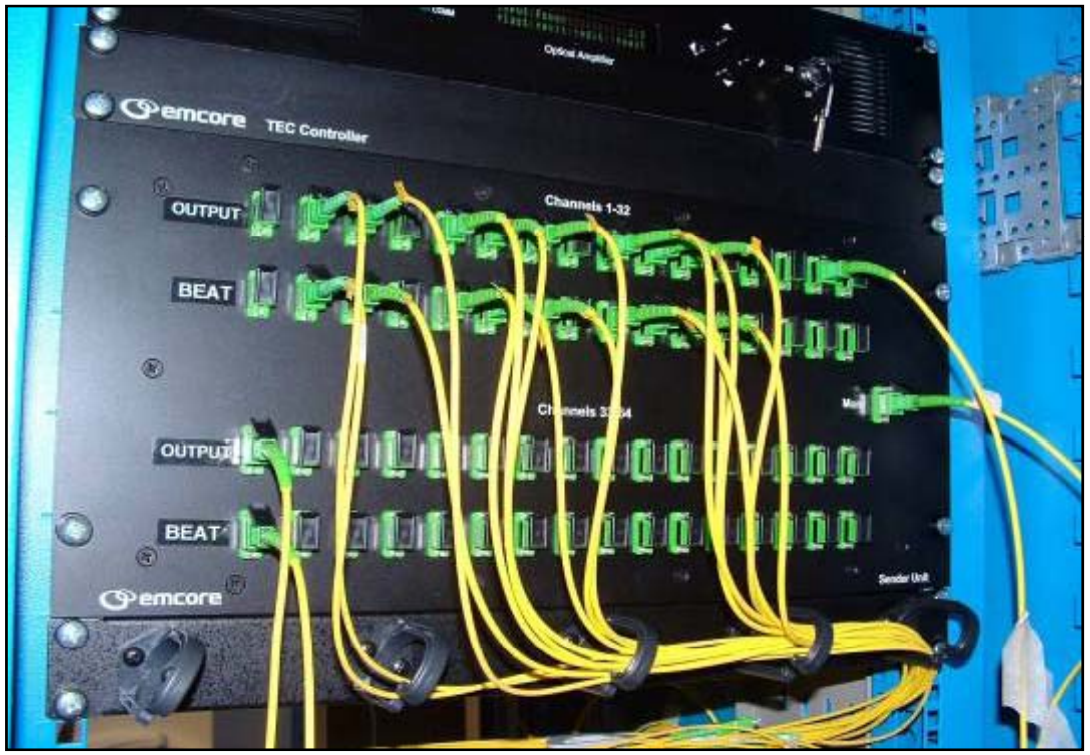
In the old telephone centrals, phone calls were manually routed from calling to the destination circuit...



Optical cabling => optical switchboard



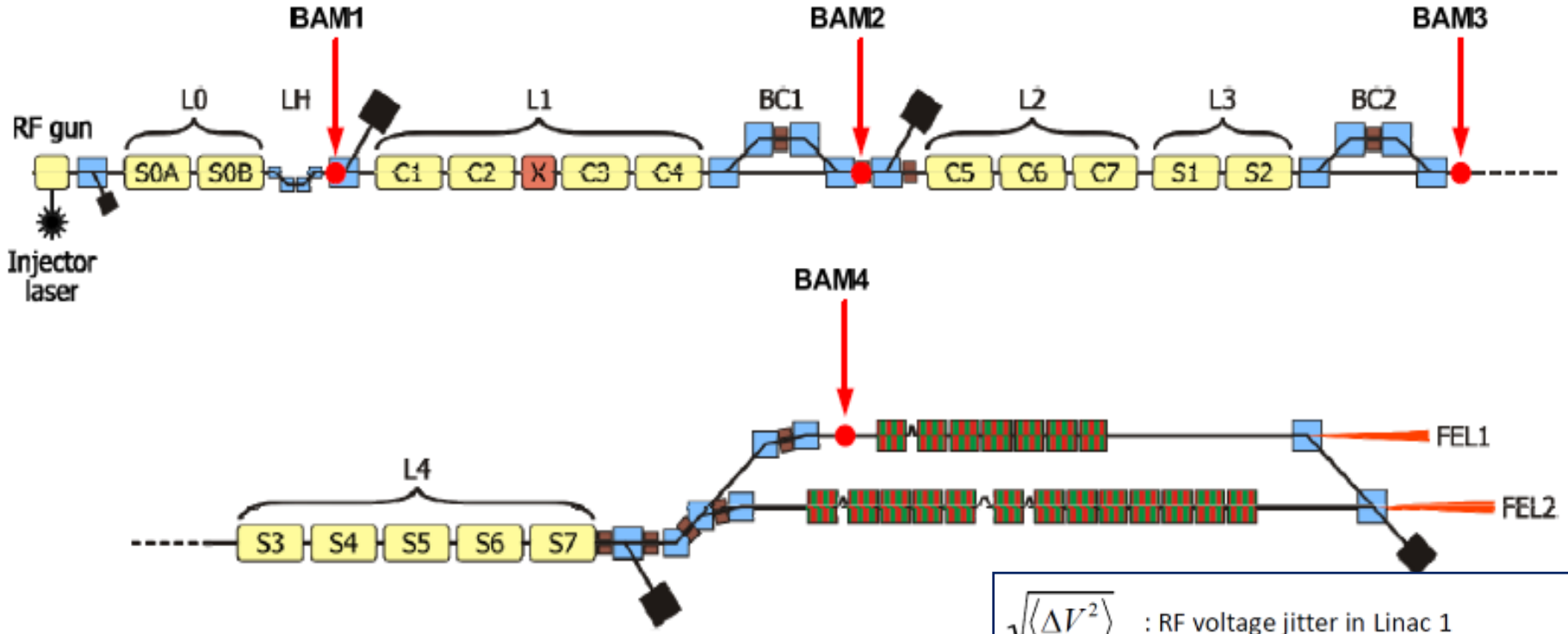
With a redundant star topology, in principle we can send any optical signal to any remote end station...



32 channel temp. stabilized optical amplifier & splitter

EMCORE Corporation, Alhambra, CA - USA

FERMI@Elettra
Bunch Arrival Monitor (BAM)



$$\sqrt{\langle \Delta t^2 \rangle} \approx \frac{R_{56}}{c}\sqrt{\left(\left.\frac{\partial \delta}{\partial V}\right|_{\phi=\phi_0}\right)^2 \langle \Delta V^2 \rangle + \left(\left.\frac{\partial \delta}{\partial \phi}\right|_{V=V_0}\right)^2 \langle \Delta \phi^2 \rangle + \frac{\langle \Delta B^2 \rangle}{B_0^2} + \frac{\langle \Delta t_{in}^2 \rangle}{C^2}}$$

$\sqrt{\langle \Delta V^2 \rangle}$: RF voltage jitter in Linac 1

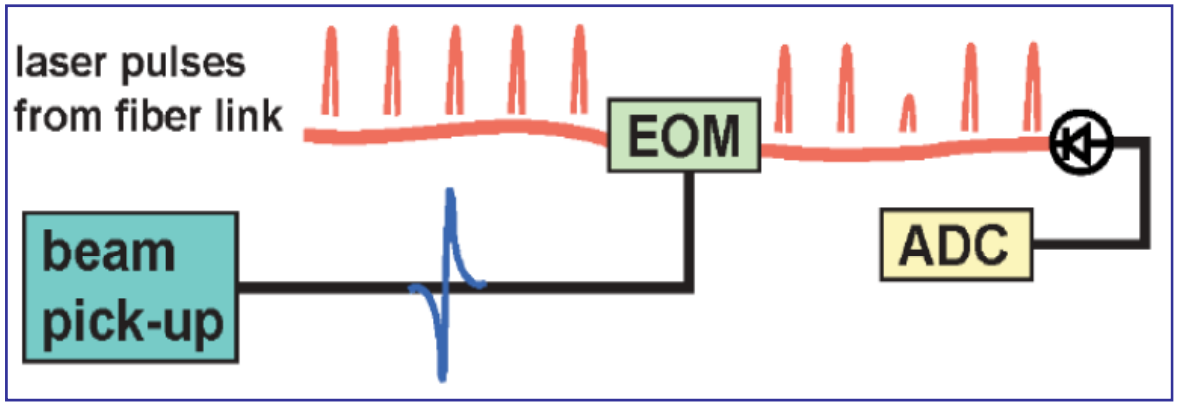
$\sqrt{\langle \Delta \phi^2 \rangle}$: RF phase jitter in Linac 1

$\sqrt{\langle \Delta B^2 \rangle}$: dipole power supply jitter

$\sqrt{\langle \Delta t_{in}^2 \rangle}$: initial time jitter (from photoinjector

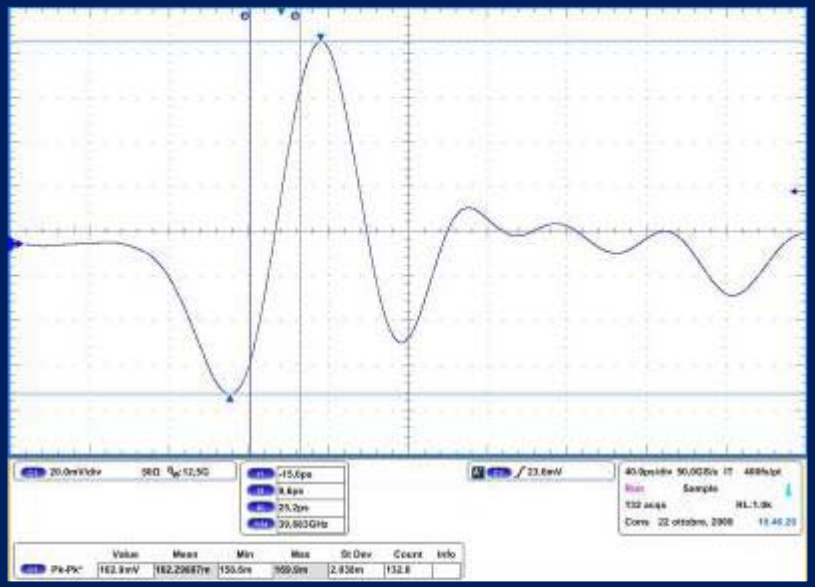
Paolo Craievich

FERMI@Elettra BAM

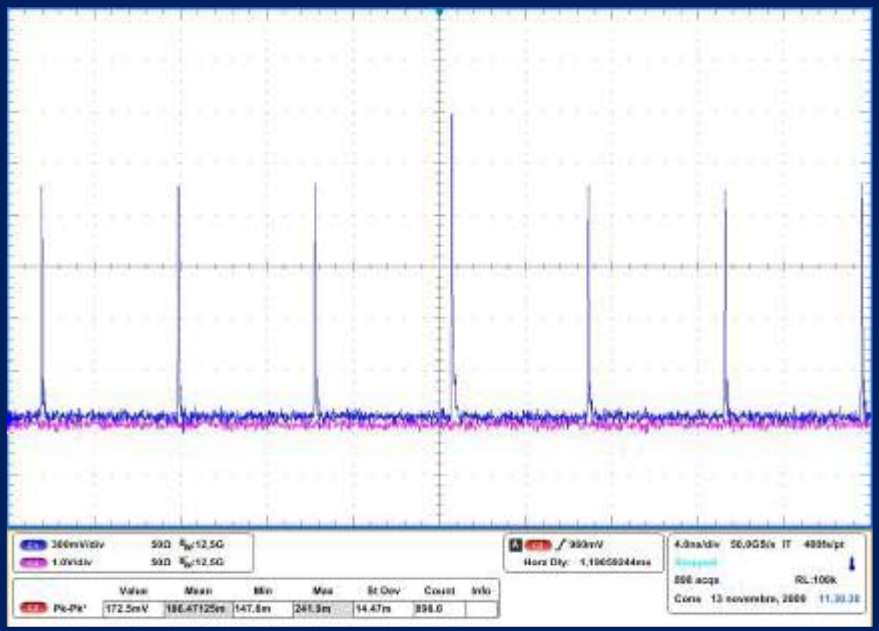


H. Schlarb, DESY;
F. Loehl, PhD Thesis,
Uni. Hamburg 2009

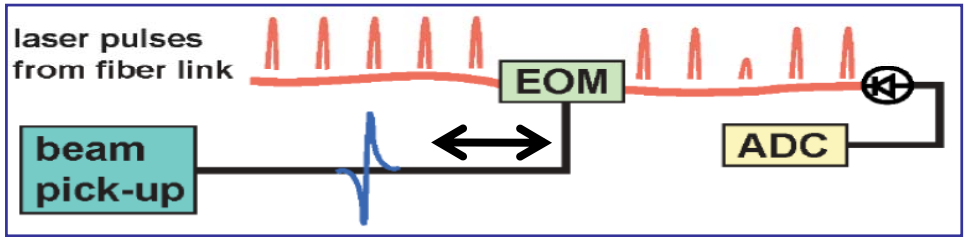
BAM pick-up pulse on FERMI



OMO amplitude modulated pulse



Bunch Arrival Monitor alignment



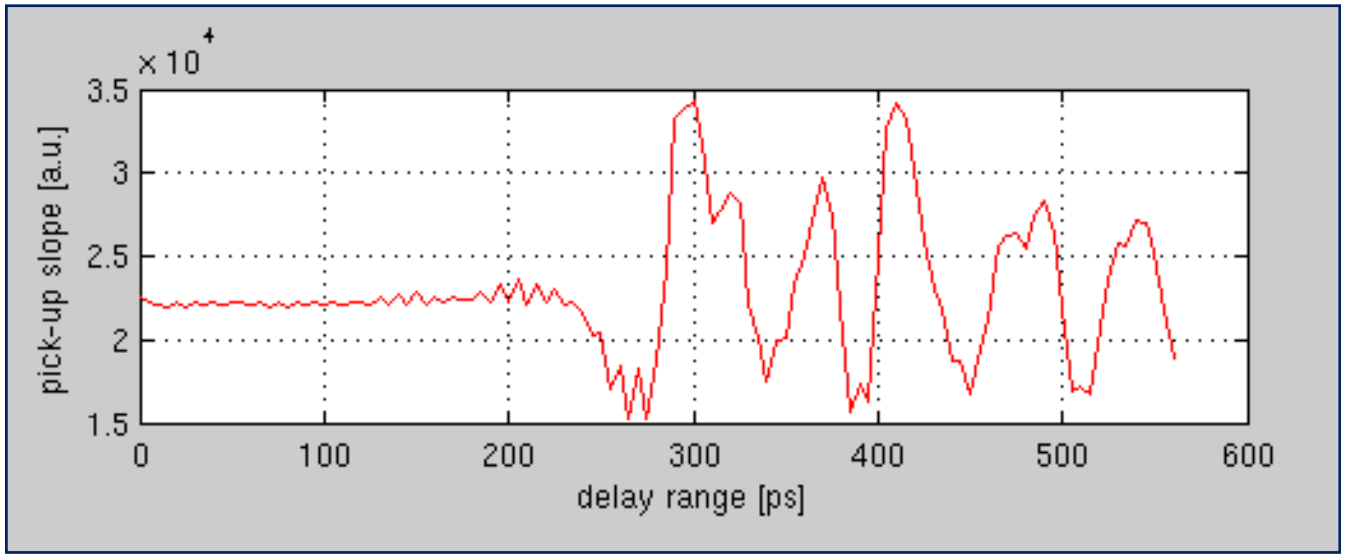
OMO pulses to the bunch signal at the M-Z modulator inputs

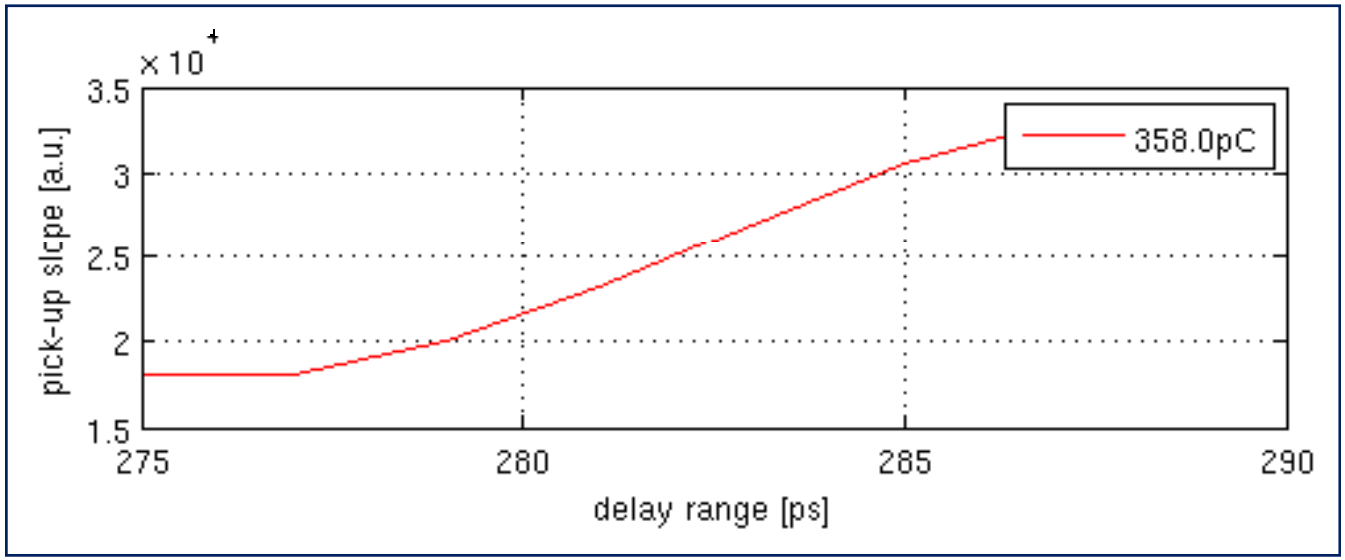
Coarse alignment *SPAGHETTI BOX!!!* Remotely controlled, broadband (12GHz) coaxial delay unit; 12 delays in 600ps steps to cope with the OMO period (f_{OMO}=157MHz)

Fine alignment: optical delay line housed in the BAM front-end; ±300ps

Leon Pavlovic

Bunch Arrival Monitor calibration

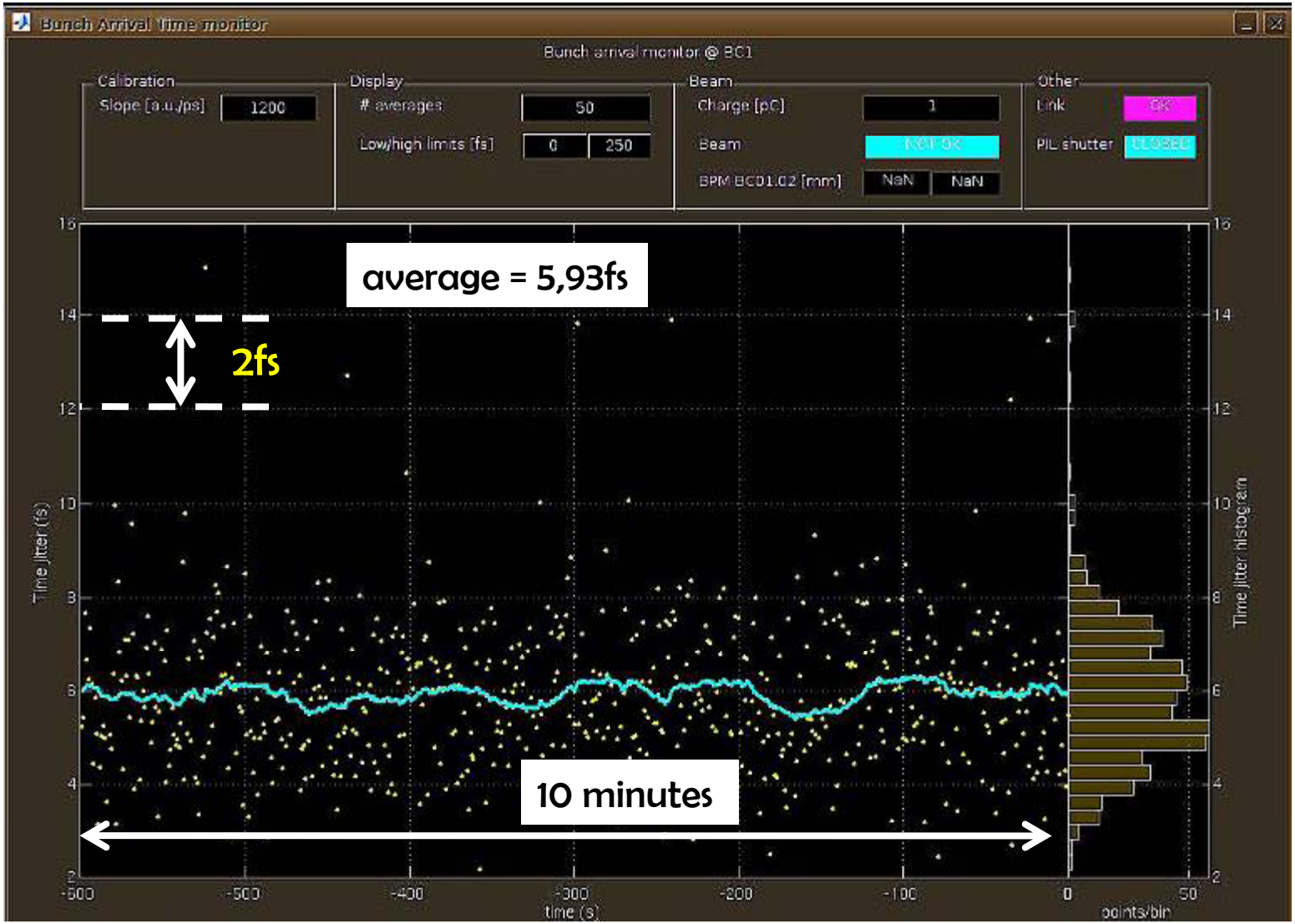




Scanning the OMO pulse over the BAM pick–up waveform, by changing the setting of the optical delay line fitted to the BAM front-end (±300ps)

10ps of linear slope
1200 counts/ps

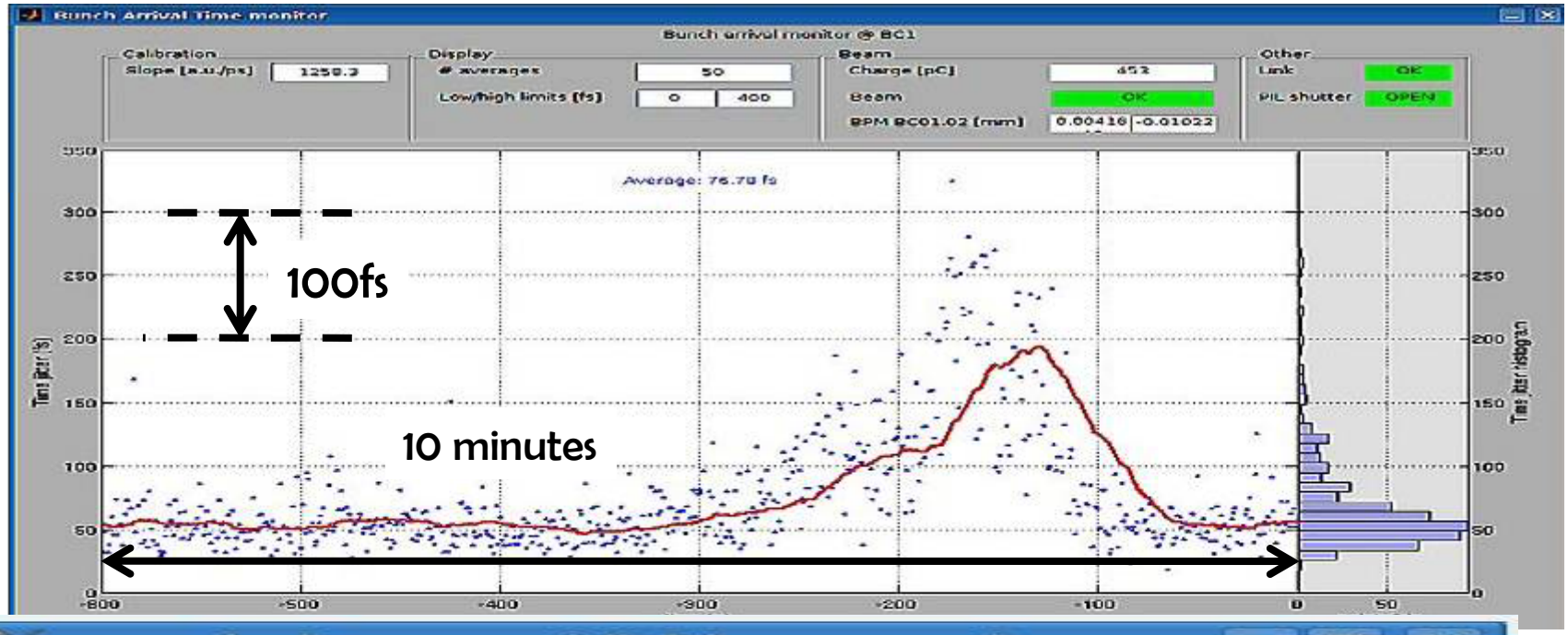
FERMI@Elettra BAM acquisition noise <15fs$_{RMS}$



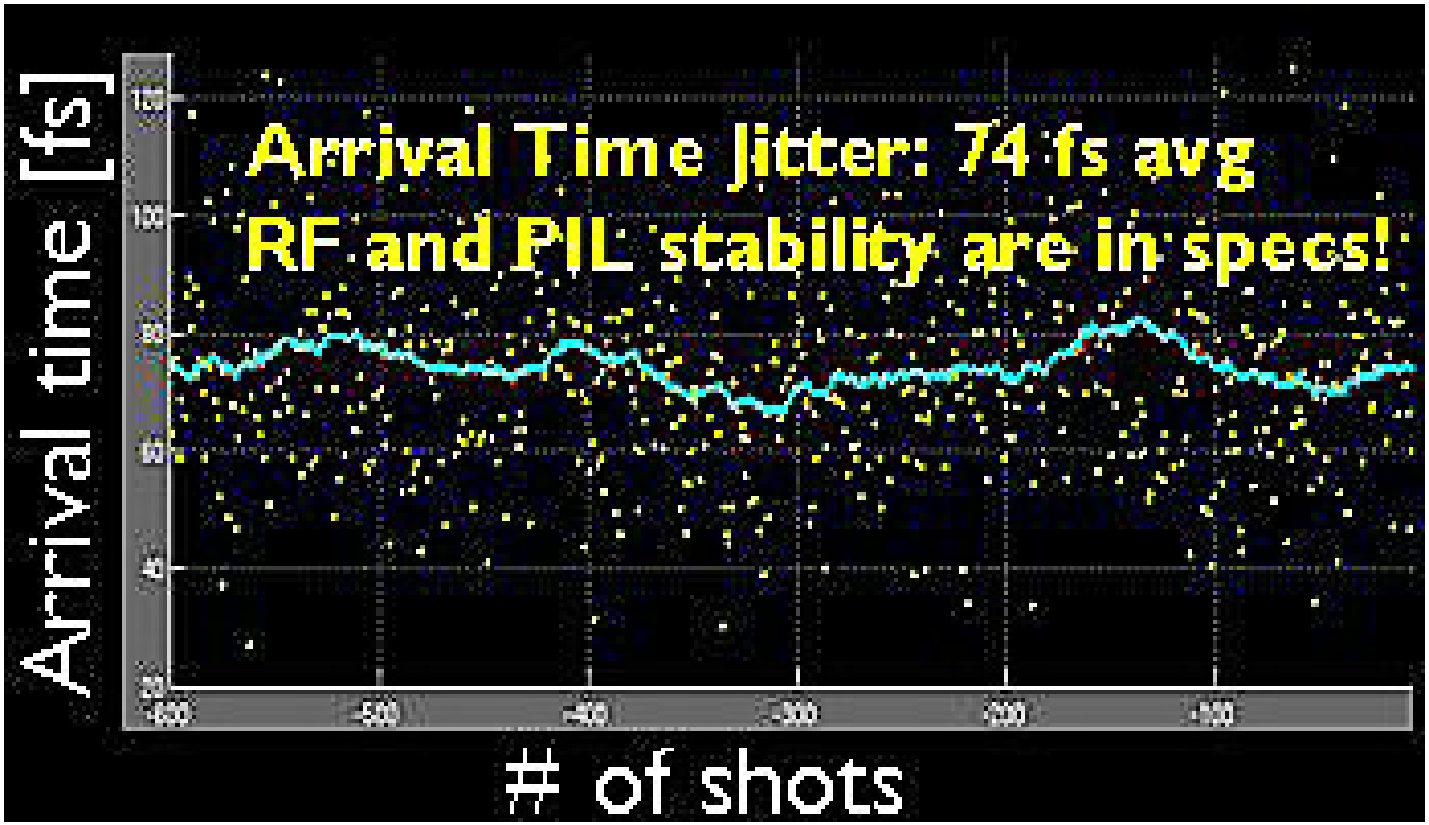
P-INJ laser = OFF;
Sampling **Unmodul.** OMO pulses;

One DOT represents 50 single shot acq. at 10Hz;

FERMI@Elettra BAM: measurement of the beam jitter increase due to KLY3 going unstable



FERMI@Elettra timing system: it's working!



courtesy of Simone Di Mitri:

Commissioning and Initial Operation of FERMI@Elettra FEL

FERMI@Elettra timing system

My acknowledgments go to the Colleagues at Elettra:

Andrea Borga
Andrea Bucconi
Paolo Craievich
Giulio Gaio
Giovanni Mian
Leon Pavlovic (Uni. LJ SLO)
Mauro Predonzani
Fabio Rossi
the LBNL Team
and many others (thank you all!!!)

and S. V. Milton and M. Svandrlik for their support


FEL
2011 SHANGHAI
33rd International
Free Electron Laser
Conference
22-26 AUGUST 2011 SHANGHAI, CHINA
Organized by SINAP, China http://www.sinap.ac.cn/fel2011
International Executive Committee
Local Organizing Committee
All-optical femtosecond timing system for the Fermi@Elettra FEL
Thank you for your attention