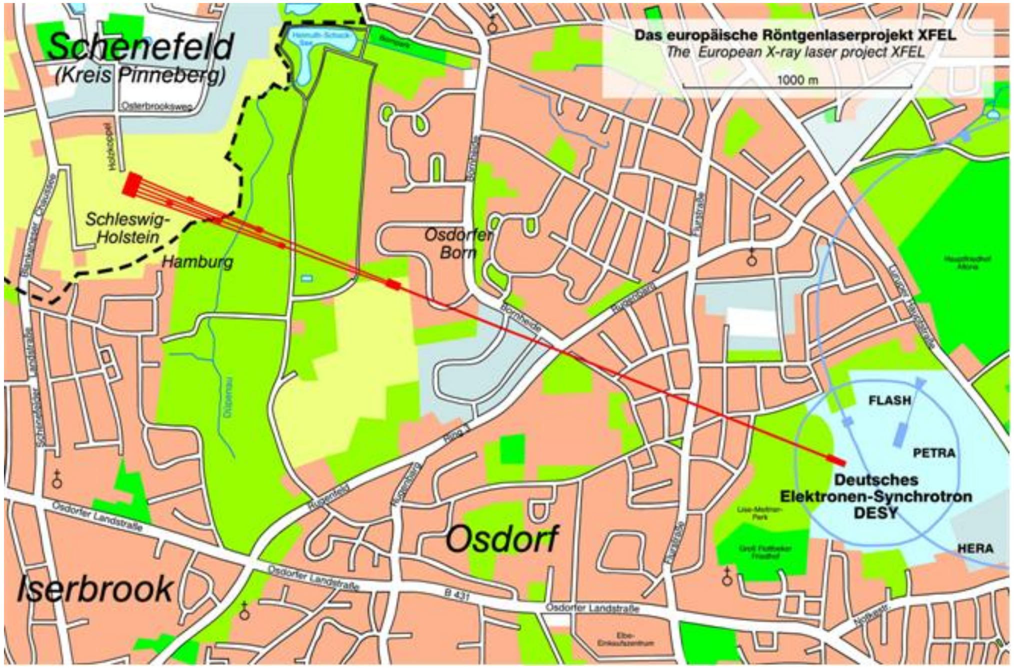
RF Synchronization System Plans for the European XFEL

LLRF 2011

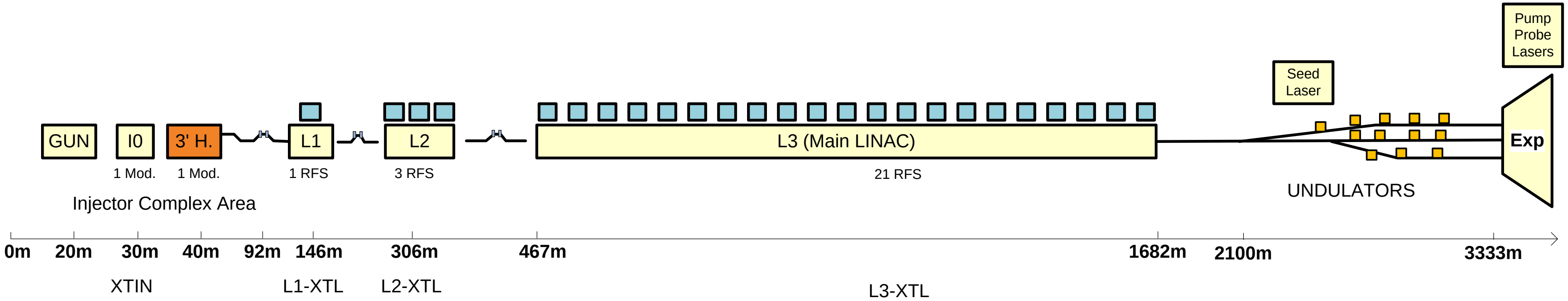
DESY, Hamburg, 18.10.2011

Krzysztof Czuba
ISE/WUT
On behalf of DESY LLRF and ISE teams

Introduction – XFEL



- 3.3km long machine
- Several thousands of digital, RF and optical devices to synchronize
- Most critical subsystems located in injector area
- Installation will start in 2013
- Commissioning planned for 2015



Field Stability Requirements for Accelerating Sections

Accelerator Section	RF Station	Amplitude Stability [%]	Phase Stability [deg]
I1 (GUN)	1300 MHz	0.01	**0.01**
I2 (Injector)	1300 MHz	0.003	**0.005**
I3 (3rd-Harmonic)	3900 MHz	0.005	**0.03**
L1 (Injector Linac)	1300 MHz	0.03	**0.03**
L2 (Booster)	3 x 1300 MHz	0.03	**0.03**
L3 (Main Linac)	20 x 1300 MHz	0.1	**0.1**

- Numbers in the last column indicate the required synchronization accuracy
  - Not straightforward! (contribution of control system components and feedback loops) but can give a good approximation
- 0.01 deg @ 1.3 GHz corresponds to roughly 20 fs of jitter

Overview of Required RF Synchronization Signals and Frequencies

WP18
10 devices, 1300MHz

Foresee RF distribution extension for upgrade linac by 5 RF stations (optional)

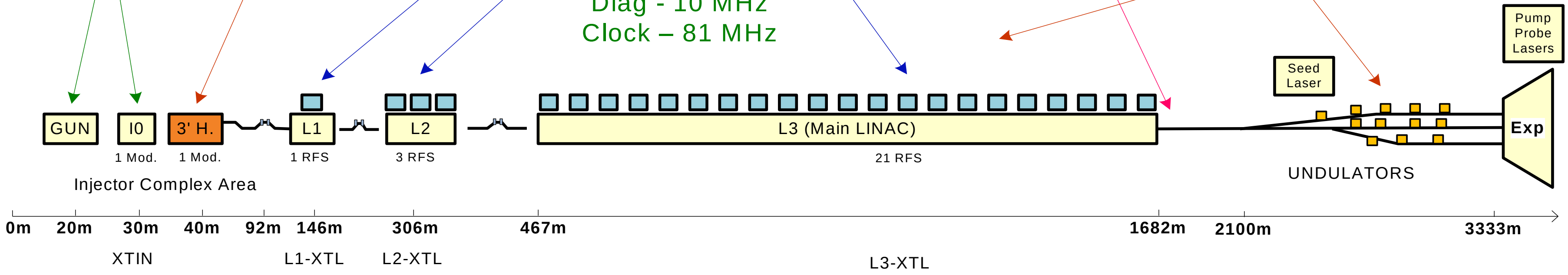
Cavity-BPM's (mostly 216 MHz)
- 4 laser heater at injector
- 6 at BC1 and BC2
- 15 between last ACC and 1st undulator
- 2 for intra bunch feedback\

216/108? MHz, +5 dBm
- 117 between undulators
- 3 after undulators

Injector
REF - 1300 MHz
LO - 1354 MHz
Diag - 10 MHz
Clock – 81 MHz

3.9 GHz system
REF – 3900 MHz
LO – 3954 MHz
Diag – 10 MHz
Clock – 81 MHz?

1 + 3 + 21 RF Stations
(semi-distributed = 50 tap points)
Frequencies @ each tap point:
REF - 1300 MHz
LO - 1354 MHz
BPMs - 216 MHz
BPM's - 108 MHz
Diag - 10 MHz
Clock – 81 MHz



LO signals will be generated within the LLRF system (F. Ludwig and cooperators)

Short Summary of Required Tap Points

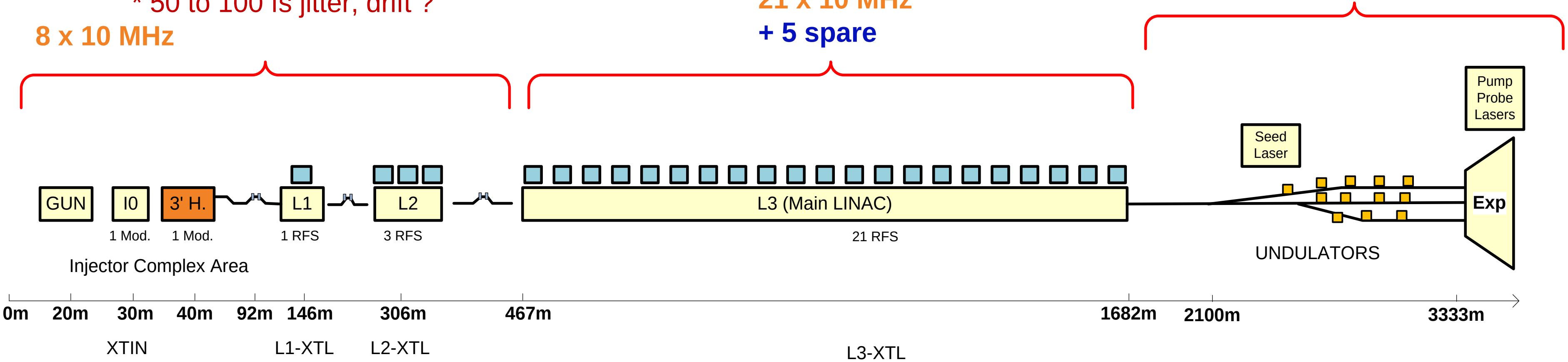
LO, precise clocks and other locally generated and distributed signals not included here but also of concern for the RF distribution

1300 MHz @ injector (timing, MLO, ….)

20 x1300 MHz, +10 dBm
* 10 to 100fs jitter
* 100 fs drift
10 x 108 MHz and 216 MHz,
* 50 to 100 fs jitter, drift ?
8 x 10 MHz

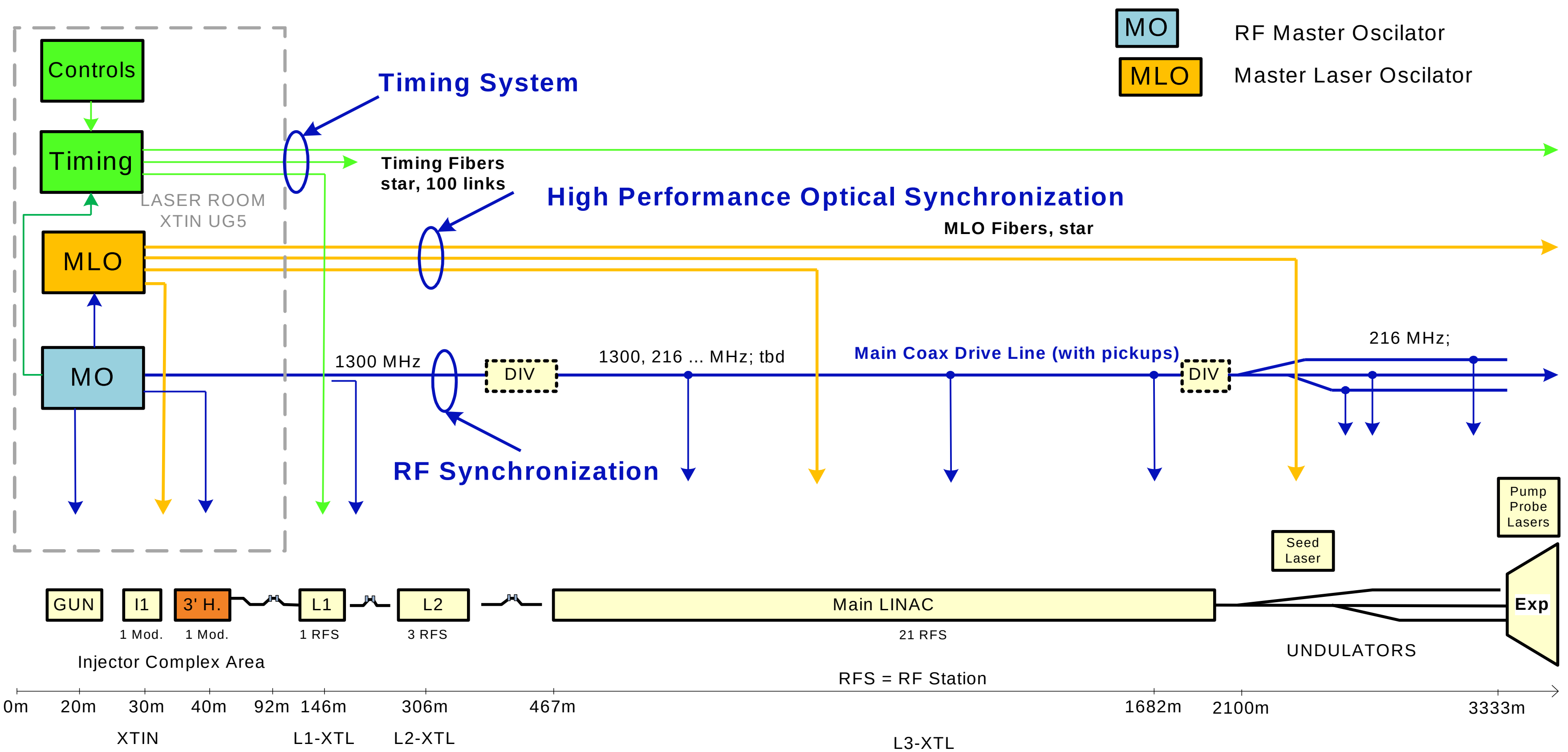
21 x1300 MHz,+10 dBm
* 50 to 100fs jitter
* 5 ps drift
21 x 10 MHz
+ 5 spare

5 x1300 MHz +10 dBm
* 100 fs to 1ps jitter
* 10 ps drift
137 x 216 MHz,
*** 100 fs to 100 ps jitter and drifts**



Together more than 220 tap points of various frequencies

XFEL Synchronization System Layout (General)

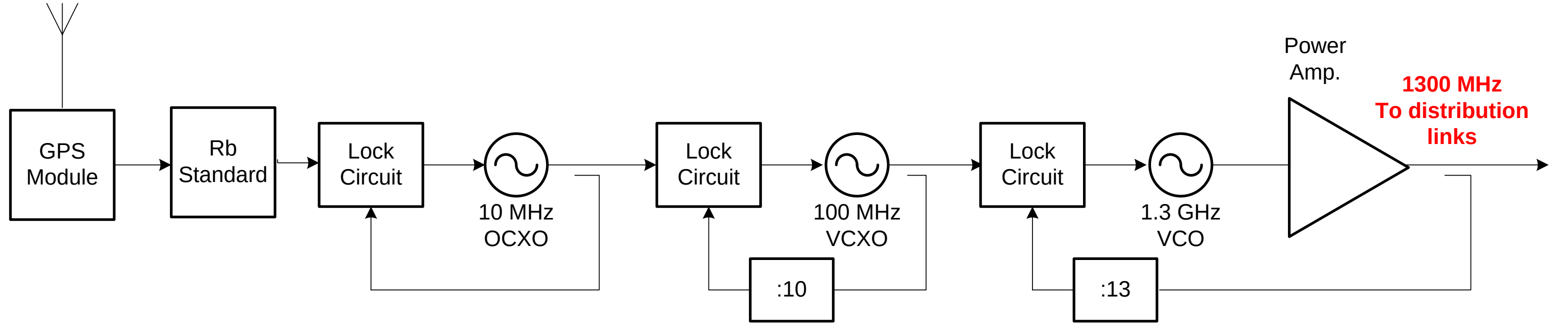


Objectives for the RF Synchronization at XFEL

- Master Oscillator design and installation
- Generation and distribution of harmonic RF signals
  - Locally at RF stations and other devices
  - Along the entire machine for high availability and diagnostic purposes
- Synchronization accuracy 50 fs to 100 fs (jitter), 100 fs to 100 ps (drift)
- Be complementary to optical synchronization and timing systems (also for system cost optimization)
- Provide backup for high performance optical links

Master Oscillator

- MO will be a single frequency 1300 MHz highly phase stable RF source
- GPS locked
- Redundant
- Introducing high power amplifier (>44 dBm) and diagnostics
- Power splitter at MO output will be the very reference for the entire XFEL (including MLO and timing system)

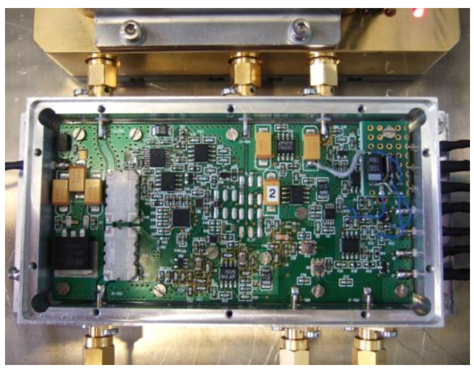


Rugh operating principle. Detailed design to be published within months

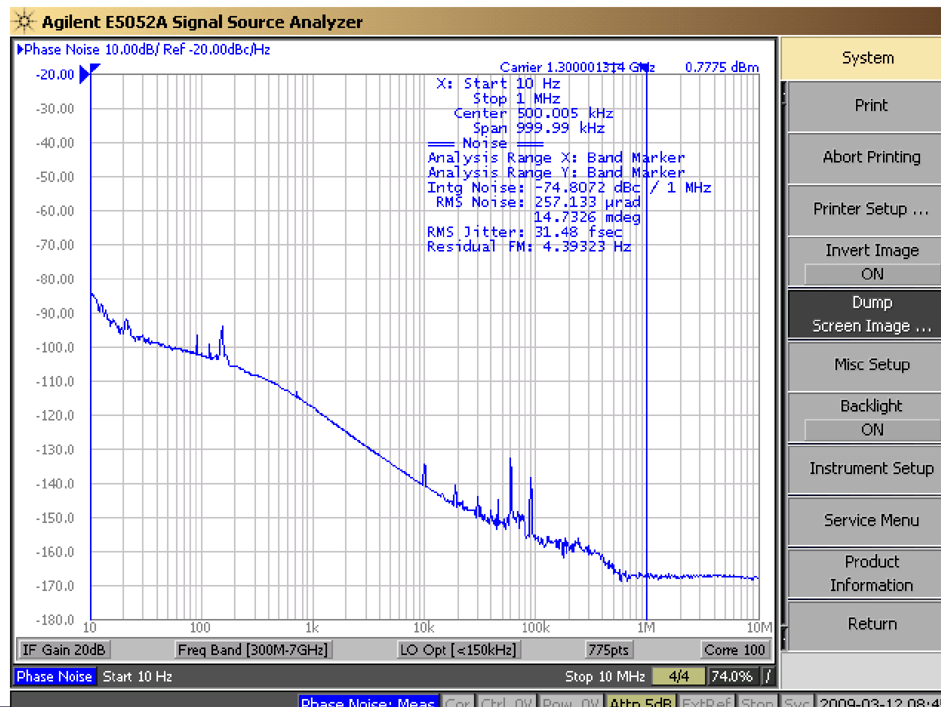
Master Oscillator – Experience

- Experience gained during design of the FLASH MO (with. H. Weddig)
- Demonstrated 31fs jitter (@ 1.3GHz, 10Hz – 1MHz BW)
- Demonstrated drift performance (~2ps/K) - not an issue for MO

FLASH MO

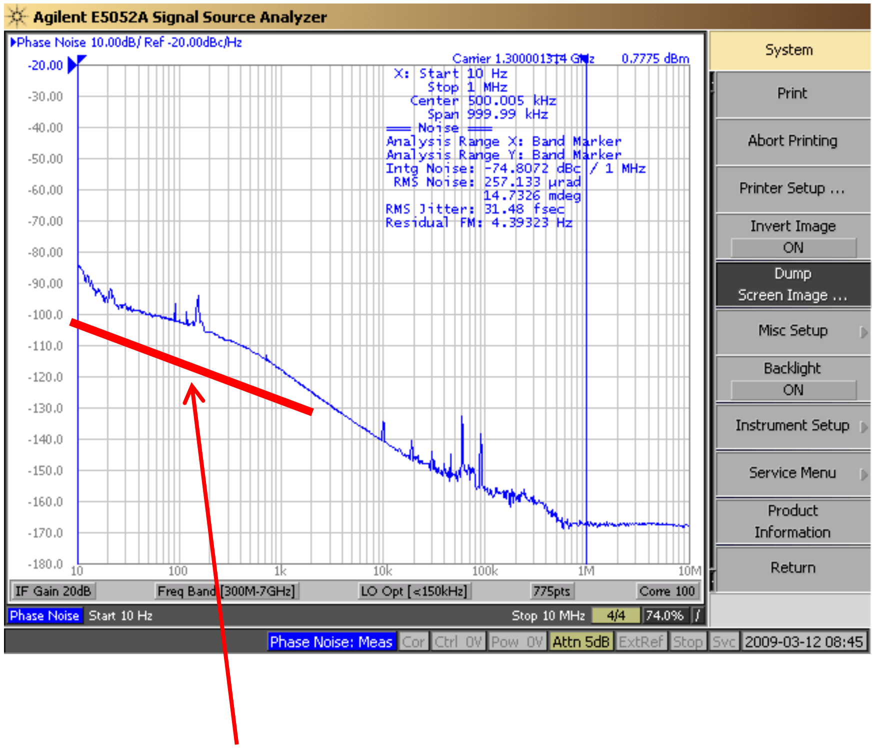


Low noise and low drift PLL by L. Zembala and H. Weddig



Master Oscillator – Status and Plans

- New version of a PLL module under development
- New components available on the market. Should help to reduce jitter by ~10fs. To be demonstrated in Febr./March 2011
- Characterized power amplifiers, switches and many passive components
- Redundancy scheme under development
- Prototype to be demonstrated in Spring 2012



Possible phase noise reduction by 6 to 14 dB

Frequency Distribution – Main Drive Line

- Assumed coax cable as a main distribution media:
- Advantages:
  - Simple, robust, highly reliable
  - Passive distribution (no additional sources of jitter), therefore low cost comparing to complex optical links
  - Radiation immune
  - Passive tap points along the line
- Disadvantages (main problems):
  - High loss, increasing with frequency
  - Phase drifts relatively difficult to compensate (but still comparable to optical fibers)

Coax Cable Parameters

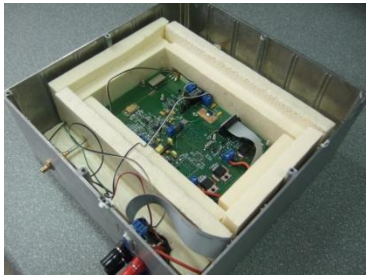
Cable	Timing drift [fs/m/K]	Loss@216MHz [dB/100m]	Loss@1.3GHz [dB/100m]
coaxial cable 3/8" (Andrew, Heliax)*	0..25 (opt. at ≈25°C to 36°C)*	5	14.2
coaxial cable 7/8" (RFS, Cellflex)*	0..35*	1.7	4.8

For local distribution

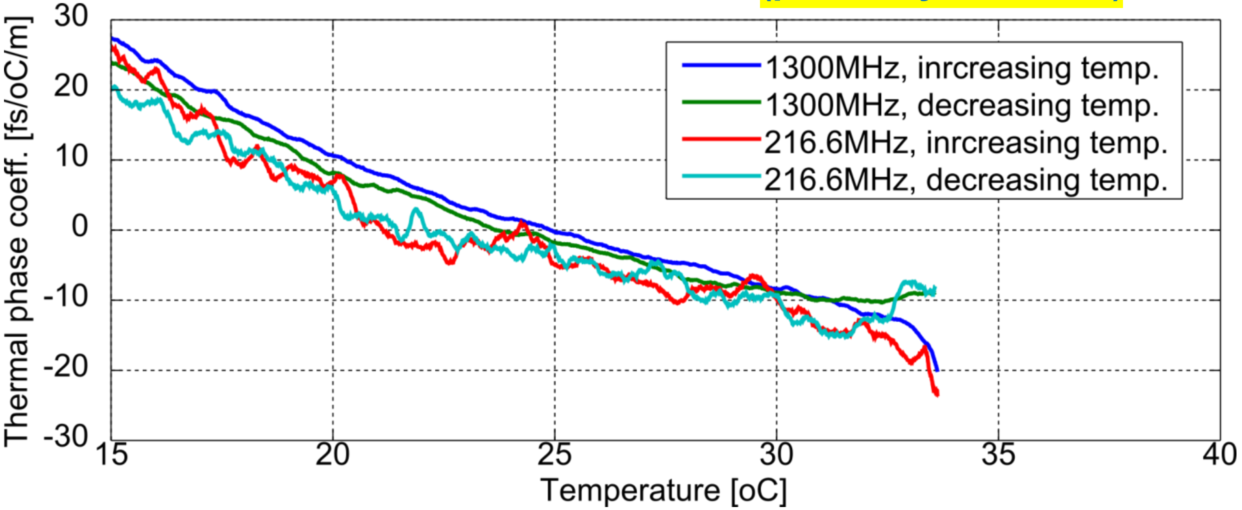
For long distance distribution

*Depends on production lot

- The 3/8" cable was selected for local distribution
- Plans to characterize low loss cables (e.g. 1 5/8") for long distance distribution
- Reflectometer scheme under development (poster by P. Kownacki), tests by G. Moeller

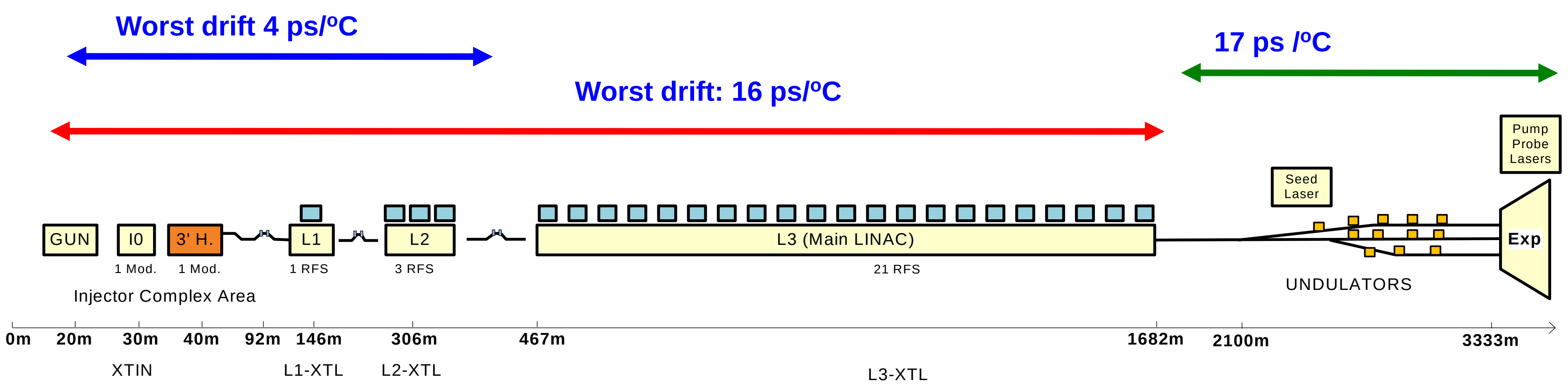


Drift measurements of 3/8" cable (poster by D. Sikora)



Phase Drift Estimation

Data for 7/8” heliax cable



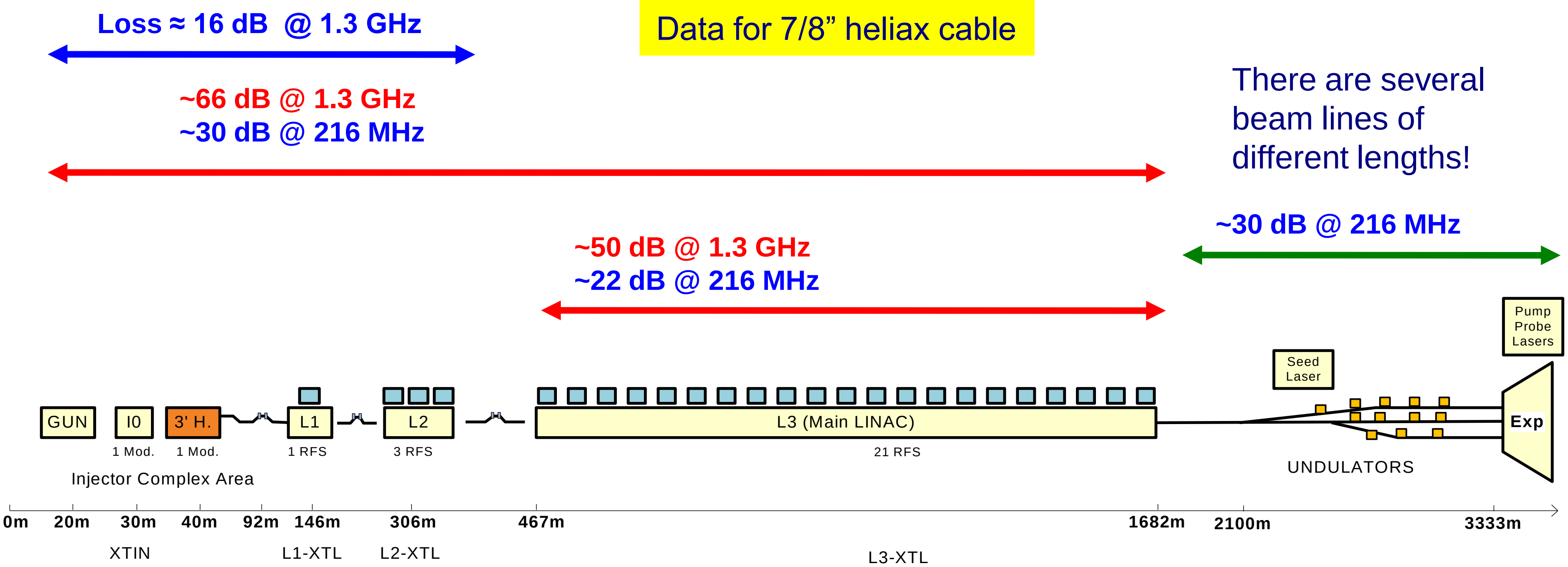
- During stable machine operation tunnel temperature can be kept within 2 ºC (Joerg Eckoldt) but temperature profile is quite complex and it is difficult to estimate drifts more precisely
- Both reflectometer scheme and temperature stabilization are considered for critical locations (Injector area and maybe L1, L2)

European XFEL

Estimated RF Loss in Cables

Data for 7/8” heliax cable

There are several beam lines of different lengths!

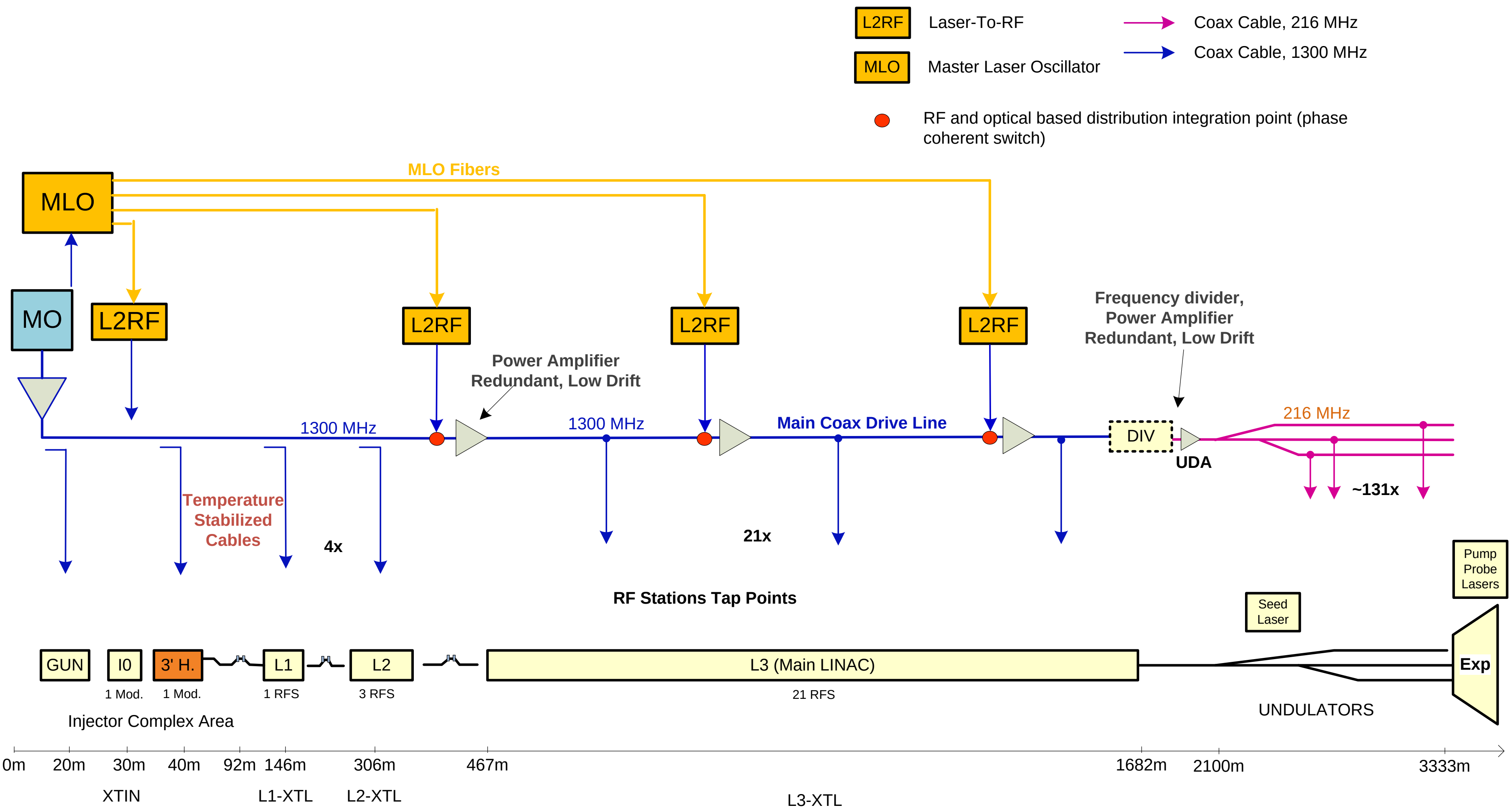


There will be 1300 MHz distribution up to L2 and 216 MHz after Main LINAC
Two scenarios considered for Main LINAC:

1. Distribution of 1300 MHz with amplifier repeaters
2. Distribution of 1300 MHz by low-loss cable

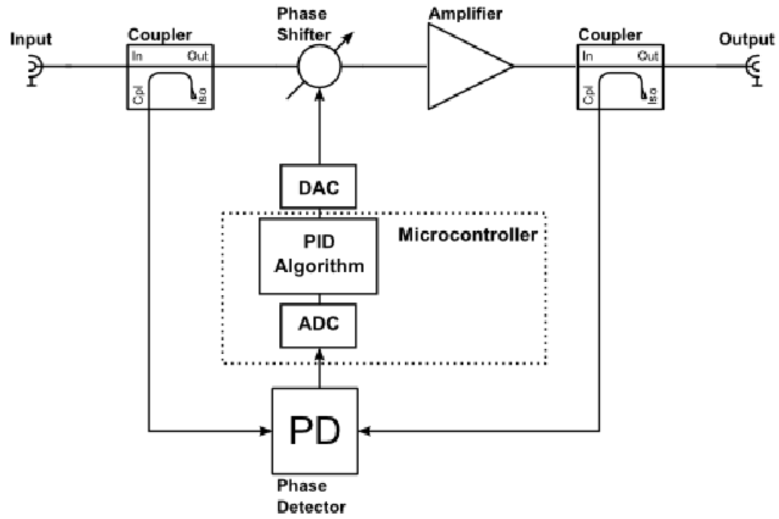
Low loss cables (diameter >1”) must be investigated, (D. Sikora) and amplifier repeaters (S. Jabłoński) to make it possible to take furhter decisions.

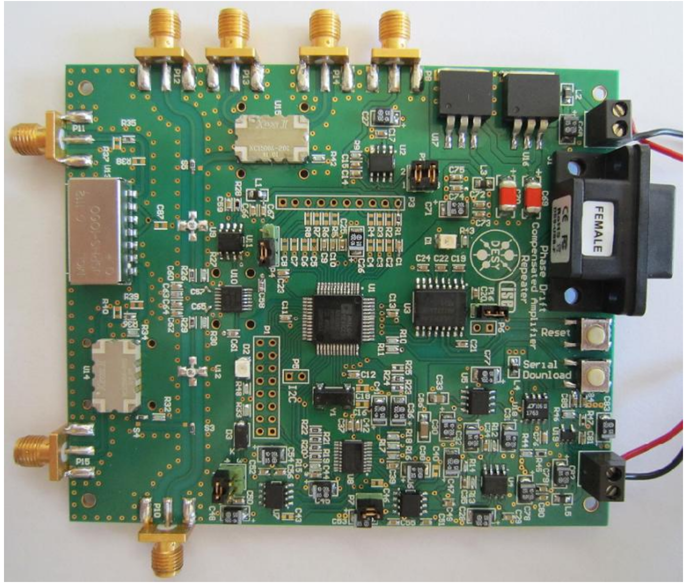
Main RF MO Distribution Scheme



Phase Drift Compensated Amplifier Repeater

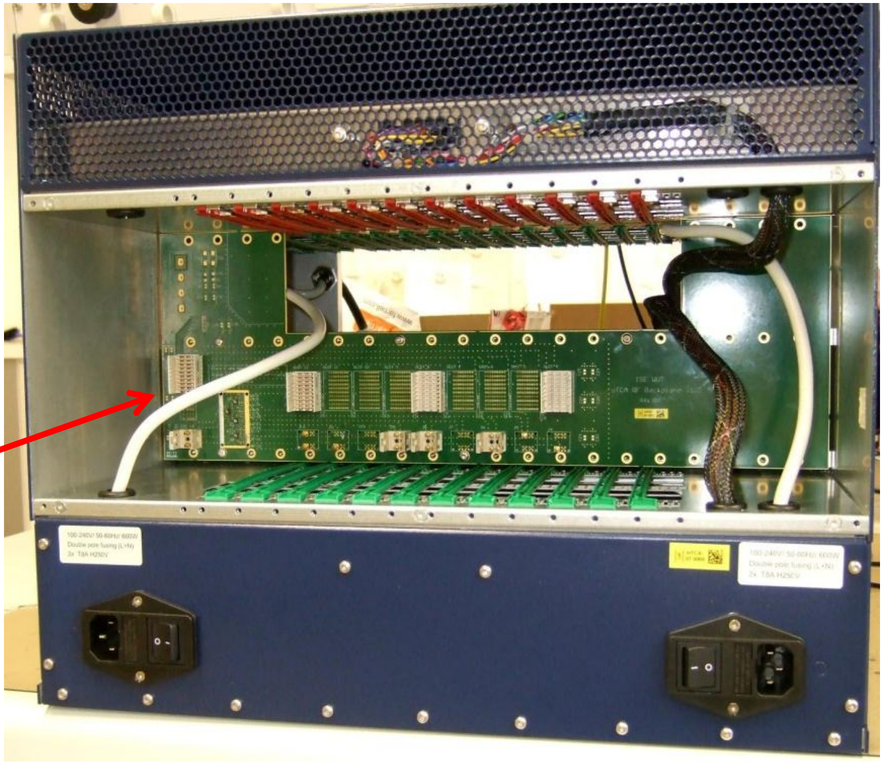
- Various power amplifier types characterized
- **Measured drifts between 0.3 ps/K and 10 ps/K**
- Active phase compensation module developed by S. Jablonski
- First prototype measurements demonstrated drift reduction from 350 fs/K to 34 fs/K
- There is still room for improvements





RF Backplane Distribution over the uTCA Crate

- The RF Backplane is the last component of the distribution chain
- Distribution of MO, LO and CLK signals inside of the crate. Eliminates cables and connectors around the crate
- Preliminary tests demonstrated almost no jitter degradation of the MO signal
  - Phase drift performance to be studied soon



Place for uLOG module (by Instrumentation Technologies) for LO generation and MO signal entry

Backplane design: P. Przybylski, K. Czuba

Summary

- System in advanced conceptual design stage
- User requirements collected, main problems identified and solutions confirmed by experiments and device characterization
- MO concept established. New version of hardware under development. System prototype to be demonstrated in spring 2012
- Drift and RF loss problem in distribution line to be overcome: reflectometer under development, cables characterized and selected, active power amplifier compensation circuit under development
- Characterized drifts of many basic components of the distribution chain (selected power splitters, directional couplers, switches)
- Open issues:
  - Phase coherent integration of optical and RF distribution
  - 7/8” or thicker cable for long distance distribution
  - Redundant phase stable amplifier
  - Drifts over the RF Backplane

Thank you for attention!