TIMING AND LLRF SYSTEM FOR JAPANESE XFEL TO REALIZE FEMTO-SECOND STABILITY

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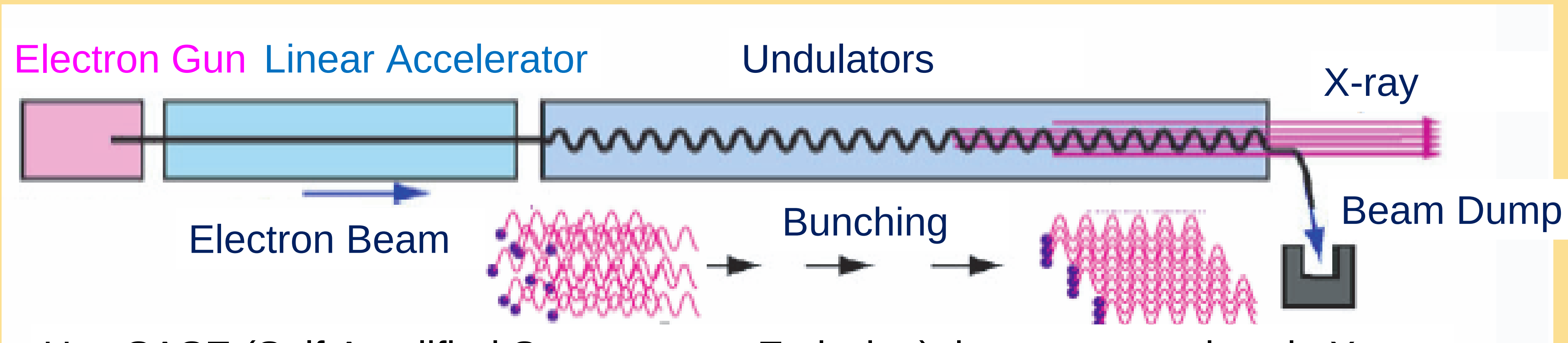
C) Institute of Laser Science, Univ. of Electro-communications

D) Optical Comb Inc.

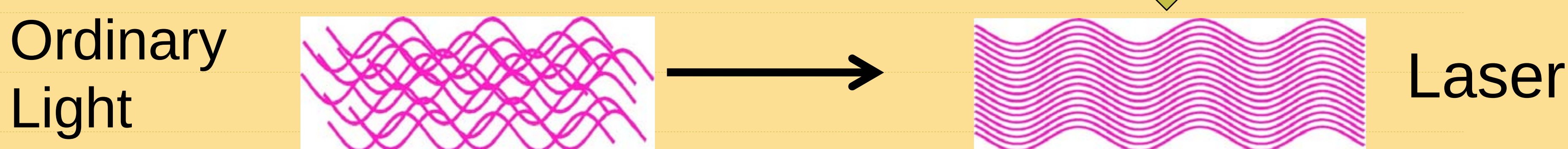
RIKEN + JASRI

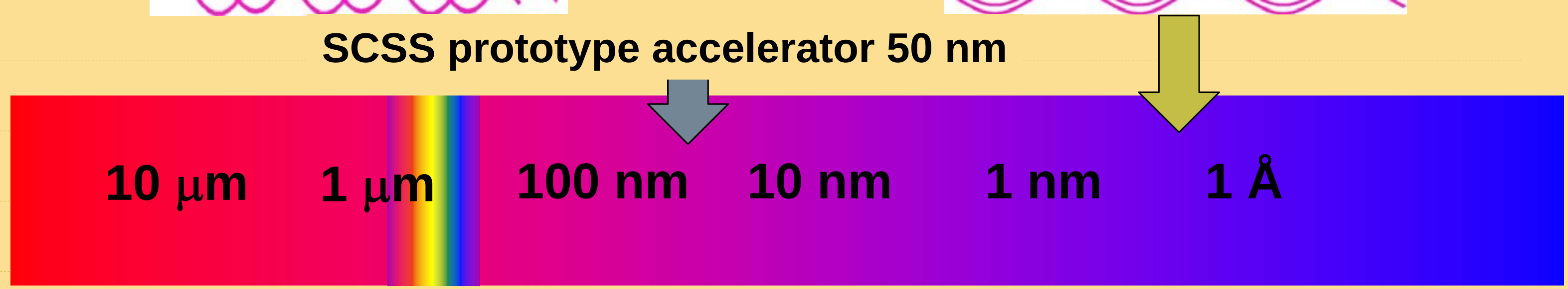
What is our XFEL ?

8GeV, 0.3 nc, 20-30 fs width, 60 pps, 0.1 nm light



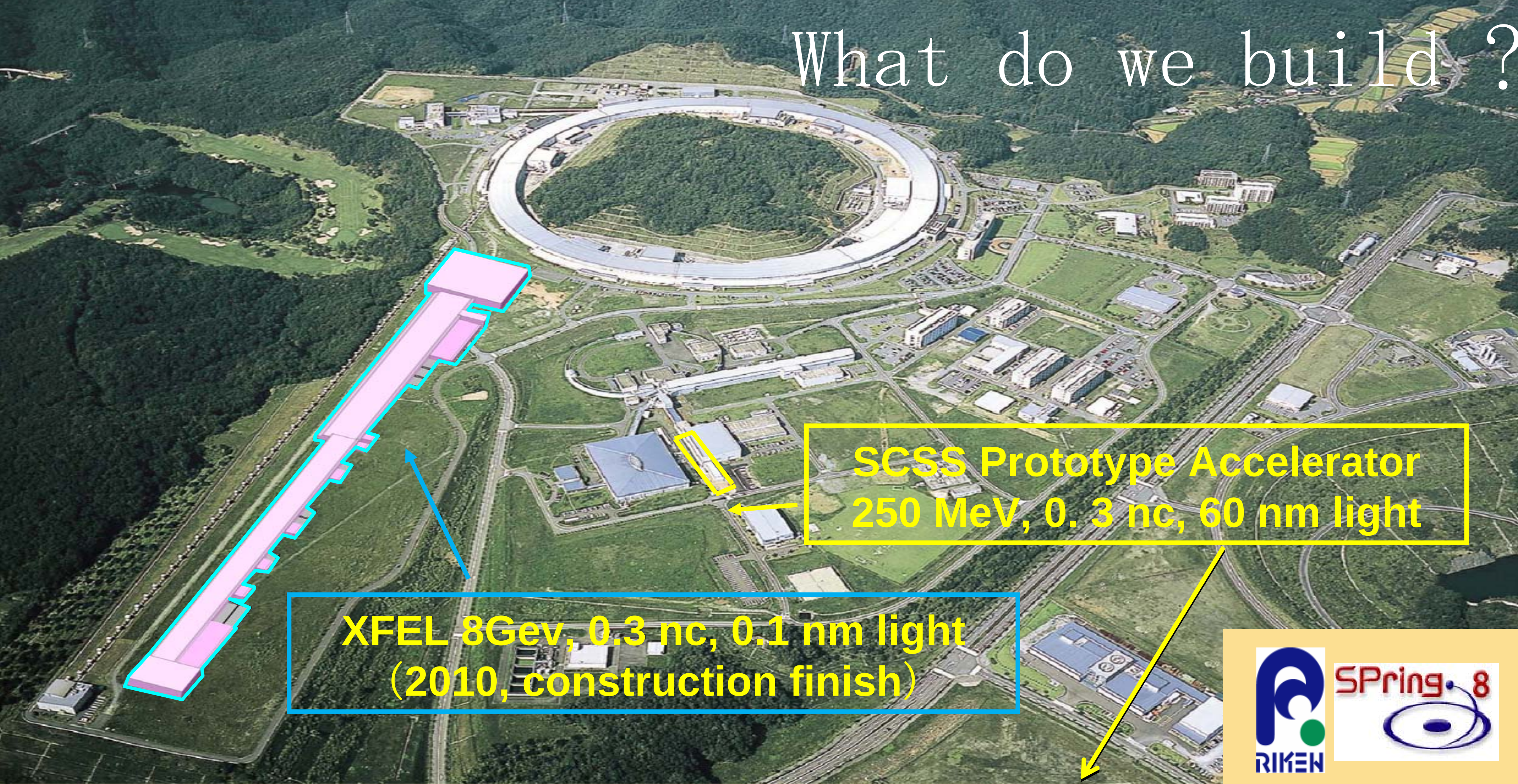
Use SASE (Self Amplified Spontaneous Emission), because no mirror in X-ray





Light Wave Length

What do we build ?



RIKEN SPring-8

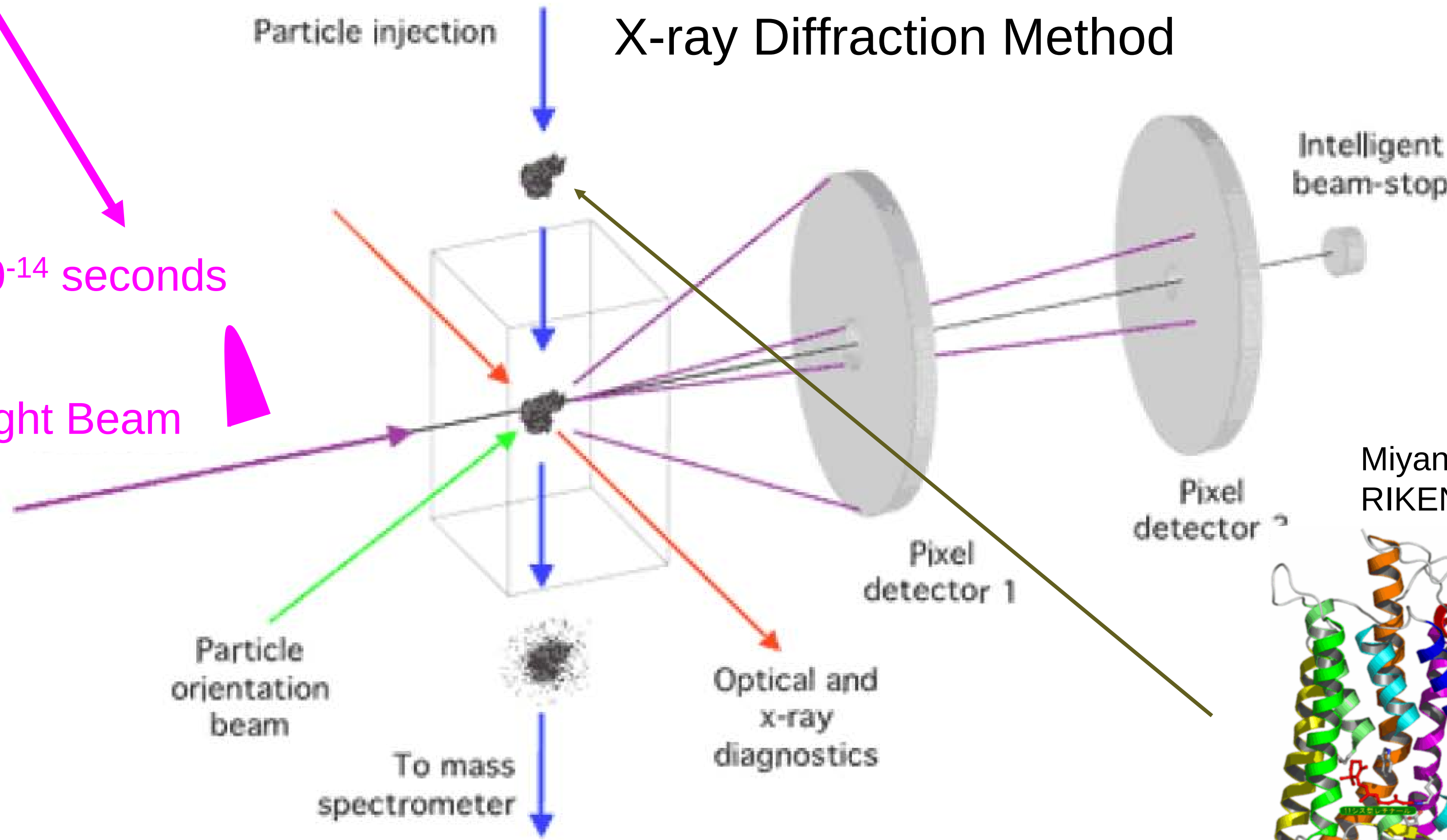
The most impressive experiment of XFEL

Like Flash Light

Protein Solution Jet
X-ray Diffraction Method

10^{-14} seconds

XFEL Light Beam



Miyano Lab in RIKEN Hrima

Cow Rhodopsin

We do not need crystallization of protein.

Requirements

- **Beams with1 kA peak current and a several tens fs pulse width for generating SASE is necessary.**
- **Required beam energy variation of less than 10^{-4} in the whole accelerator system to generate stable X ray SASE.**

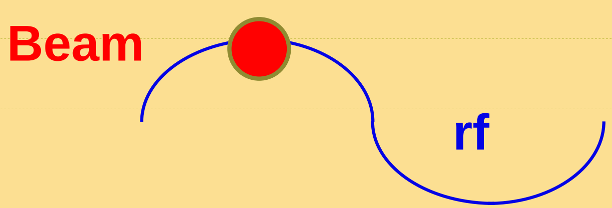
There are two parts of a LLRF & timing system for XFEL.

A. The crest acceleration part which correspond to the regular section using the 5712 MHz accelerator guides, and for

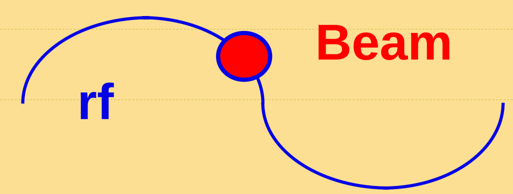
B. Velocity bunching and magnetic bunching which corresponds to off-crest acceleration part.

To realize 5712 MHz amplitude stability and resolution of less than 10^{-4}, the 5712 MHz phase stability and resolution of less than +/-0.5 deg. (less than 500 fs) are necessary.

Several tens fs time stability should be necessary for bunch compressing by the magnetic chicane.

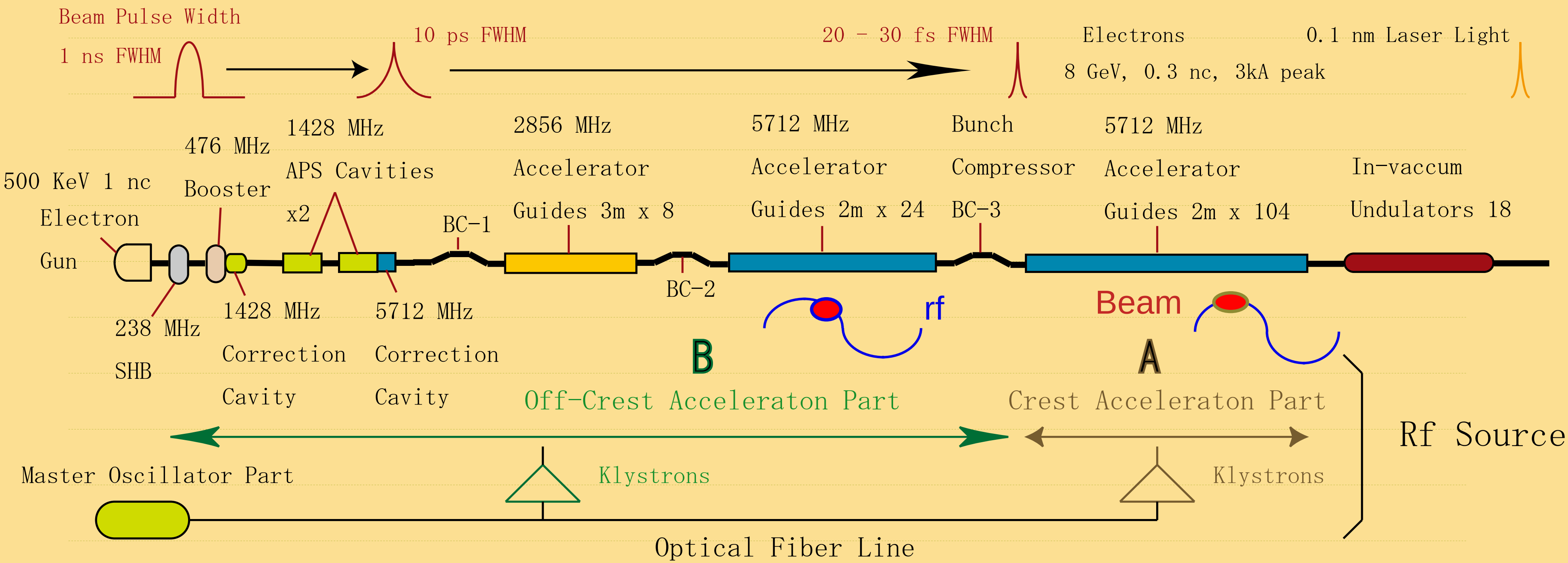


The Crest acceleration Part



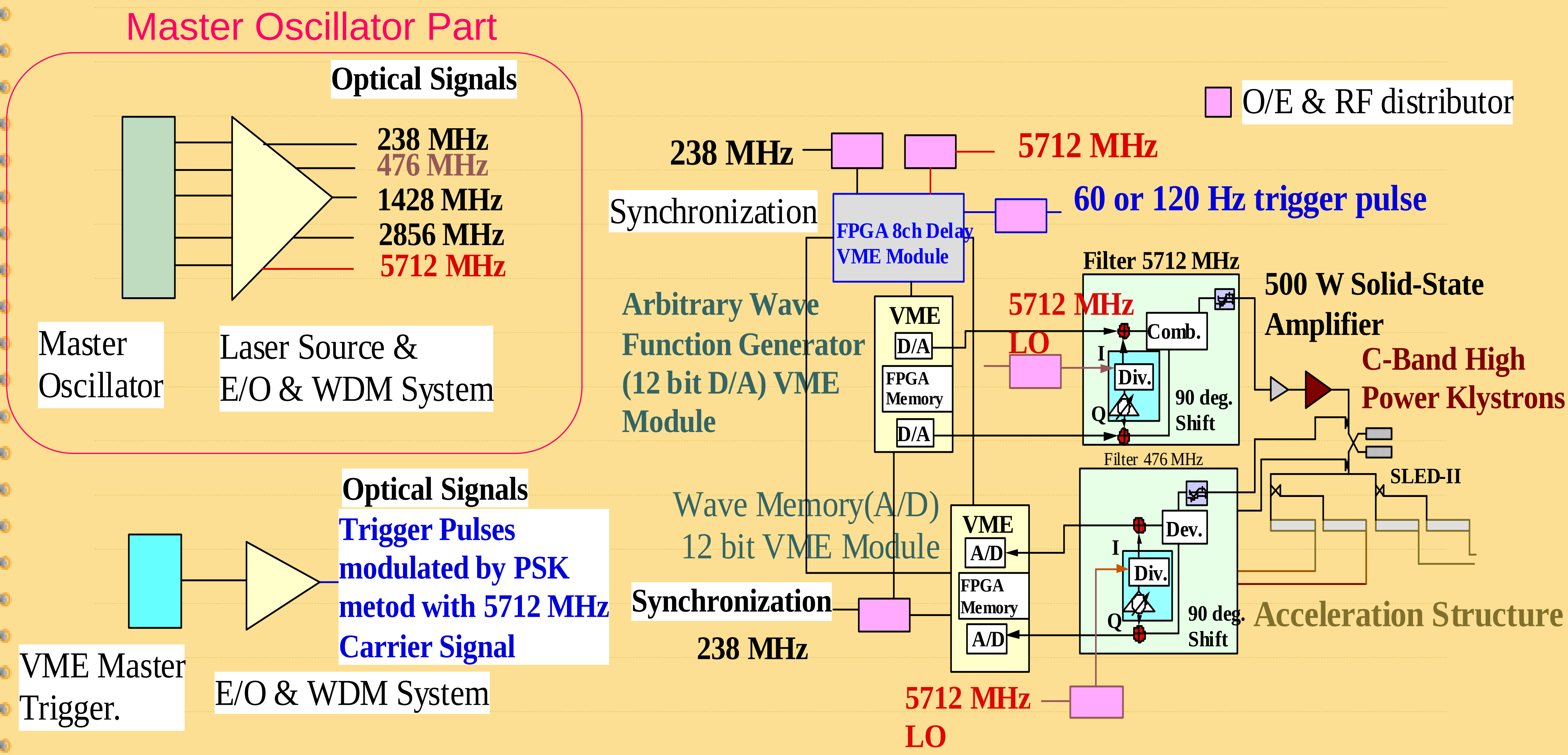
Off-crest acceleration Part

Tolerance of the phase stability of each cavity



Cavity	ΔV/V(%rms)	Δϕ (deg. rms)	Δt (ps rms)
238 MHz SHB	± 0.01	± 0.01	± 0.12
476 MHz Booster	± 0.01	± 0.02	± 0.12
L-band Cor. Cavity	± 0.03	± 0.06	± 0.12
L-band APS Cavity	± 0.01	± 0.06	± 0.12
C-band Cor. Cavity	± 0.1	± 0.06	± 0.049
S-band Accelerator	± 0.01	± 0.1	± 0.097
24 C-band Accelerator (up-stream)	± 0.01	± 0.2	± 0.097
104 C-band Accelerator (Down-stream)	± 0.01	± 0.5	± 0.24

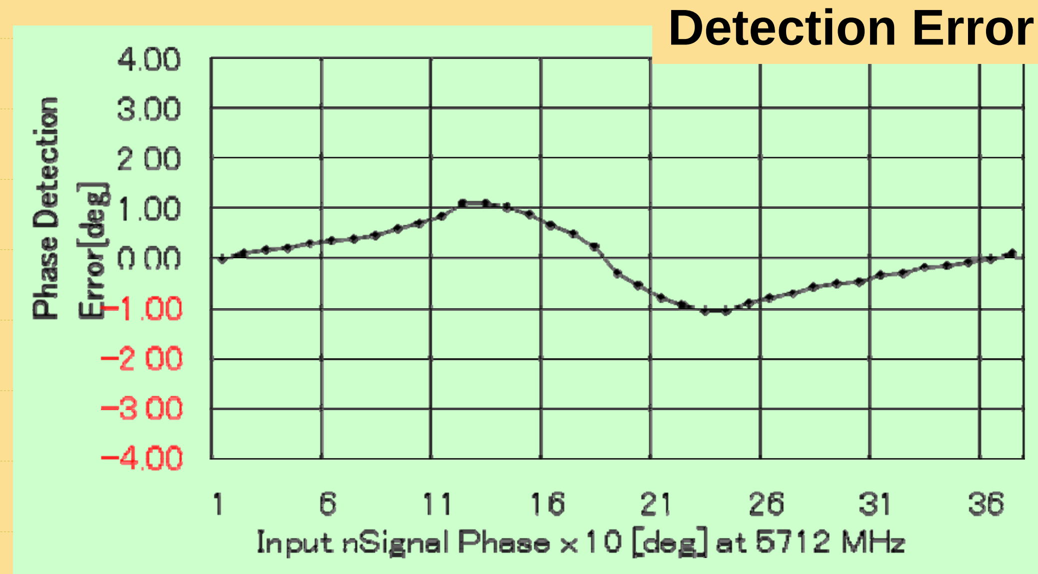
LLRF & Timing System of the crest acceleration part

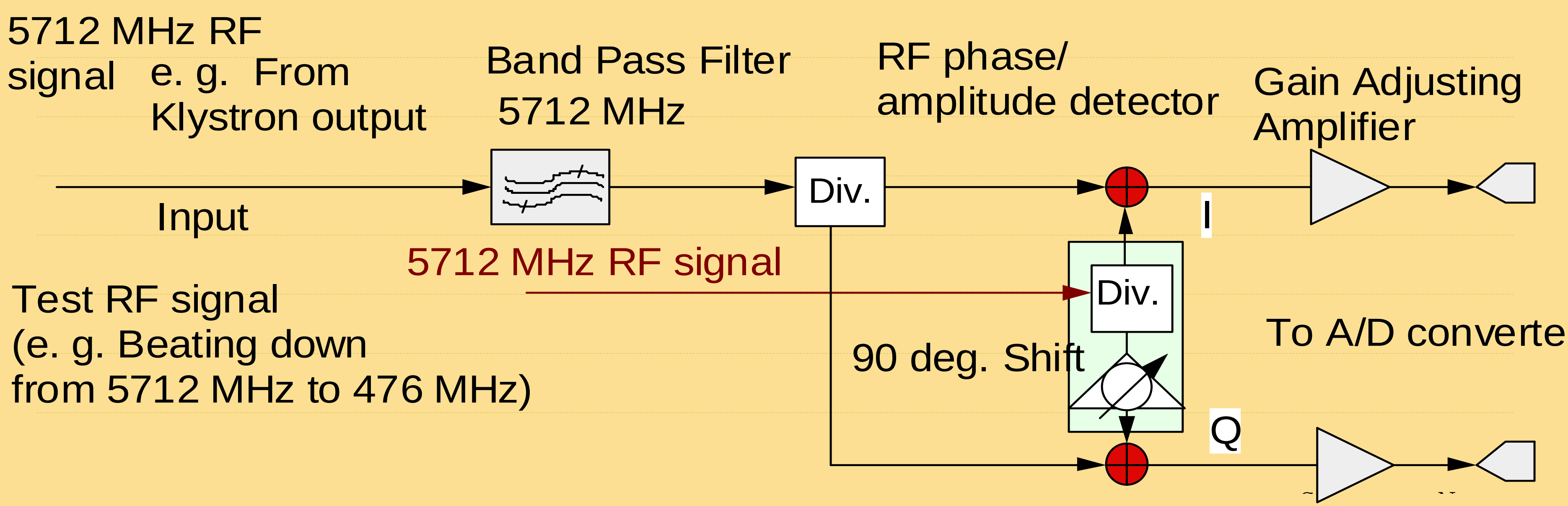


This part mainly consist of the electrical instruments.

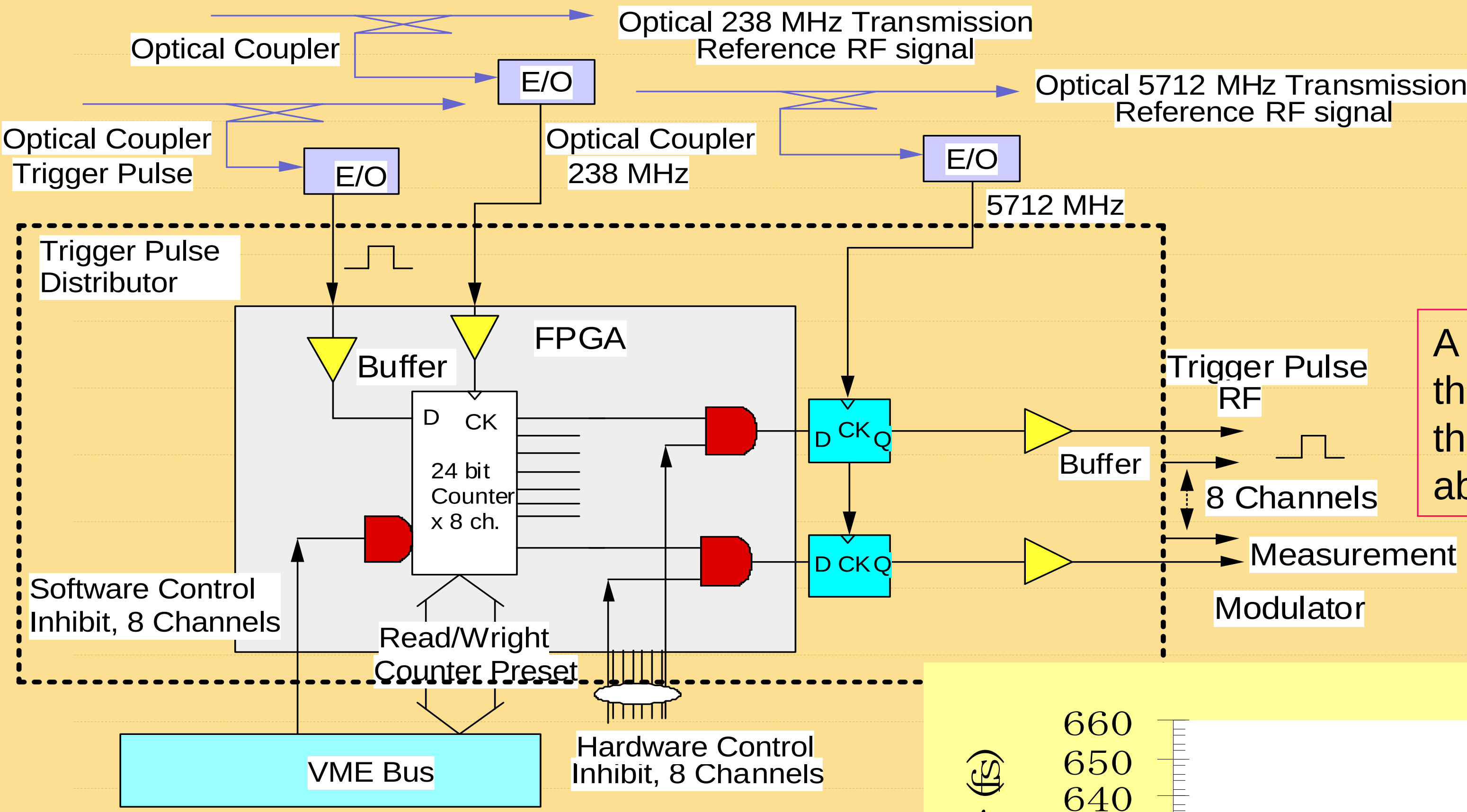
IQ-Demodulator

Demodulator uses direct conversion from 5712 MHz rf to base band by IQ detection.

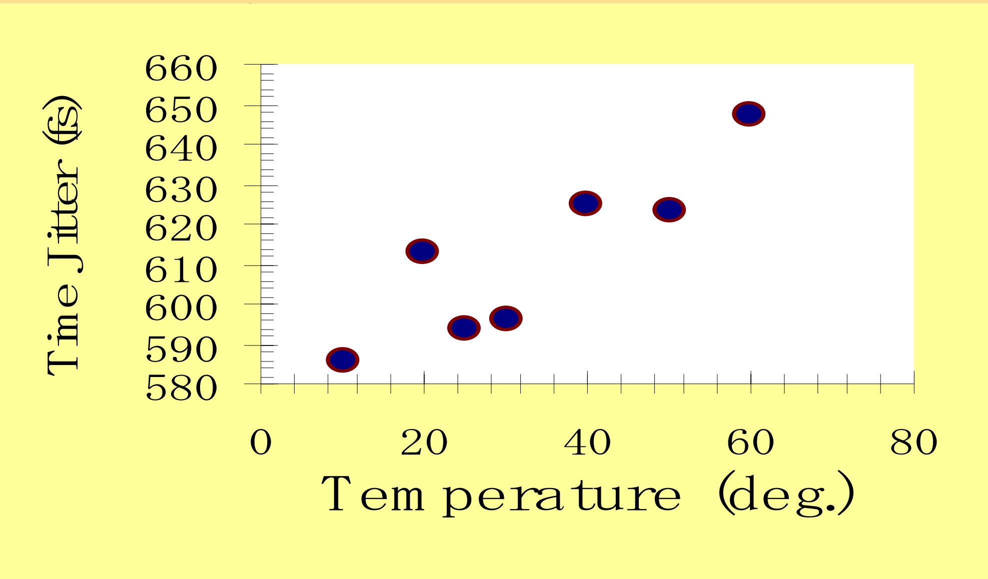




Trigger Delay

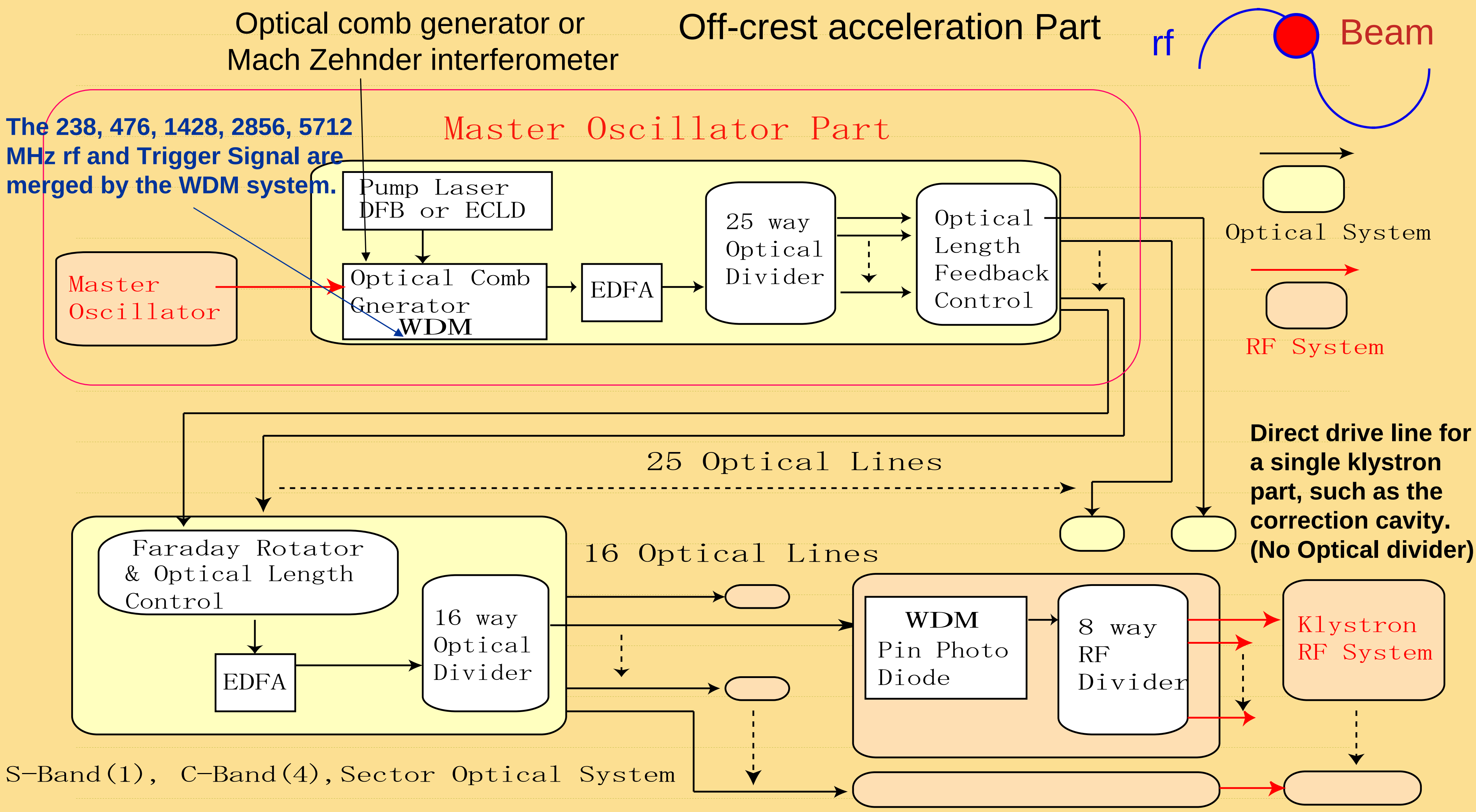


A delay time change of the unit dependent on the temperature was about 10 fs/K.



The jitters are less than 1ps that satisfies our requirement.
The temperature dependence of the jitter is very low.

Optical LLRF & Timing System



Wavelength Division Multiplex (WDM)

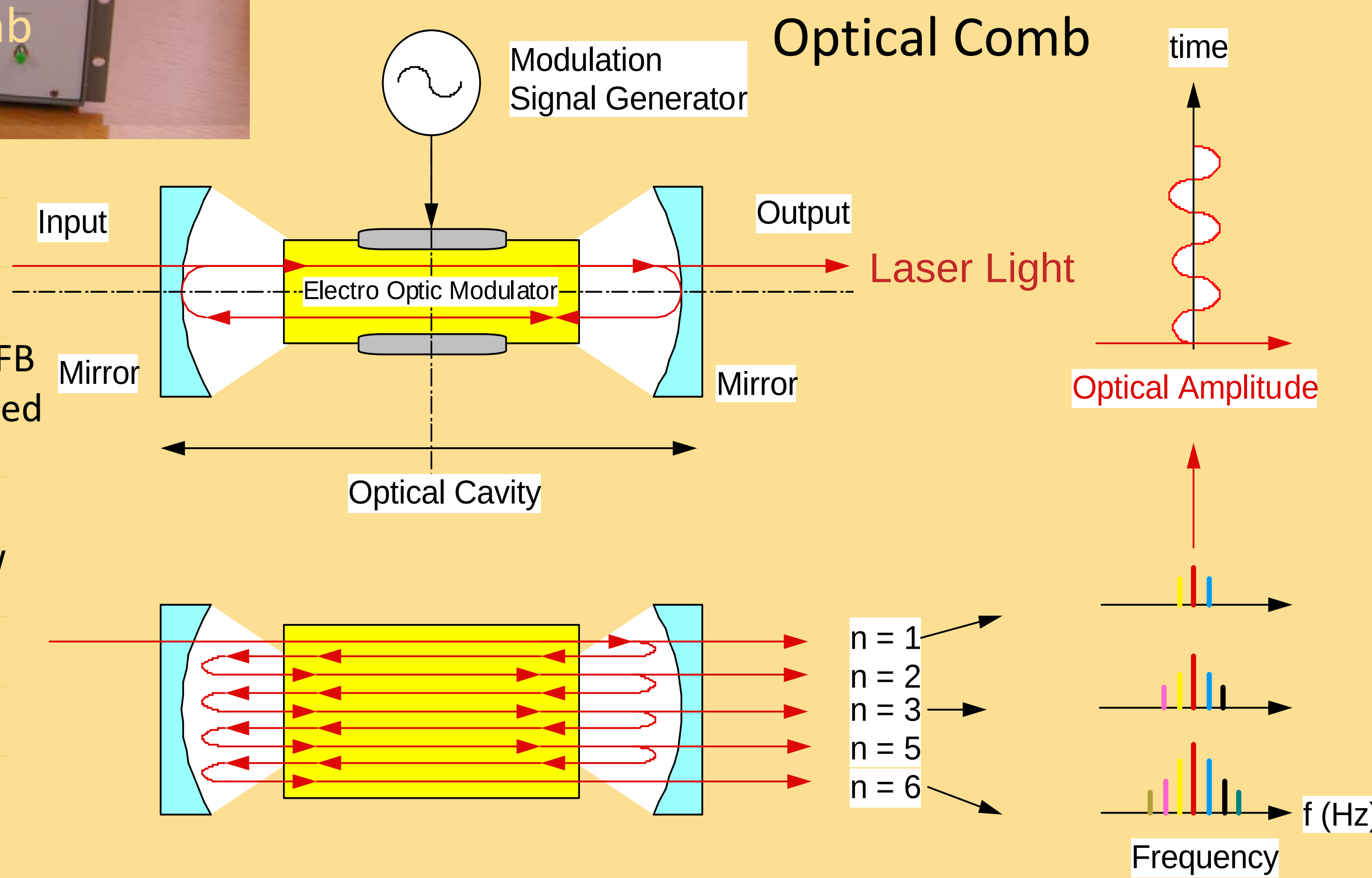
This part mainly consist of the optical instruments.

Frequency Stabilized Laser & Optical Comb

Exterior

In the optical comb generator, an electro-optic (E/O, LN) crystal is inserted into an optical Fabriot-Periot cavity.

The output rf signal of the master oscillator is added into the E/O crystal to generate the comb pulse having a period of the rf signal.

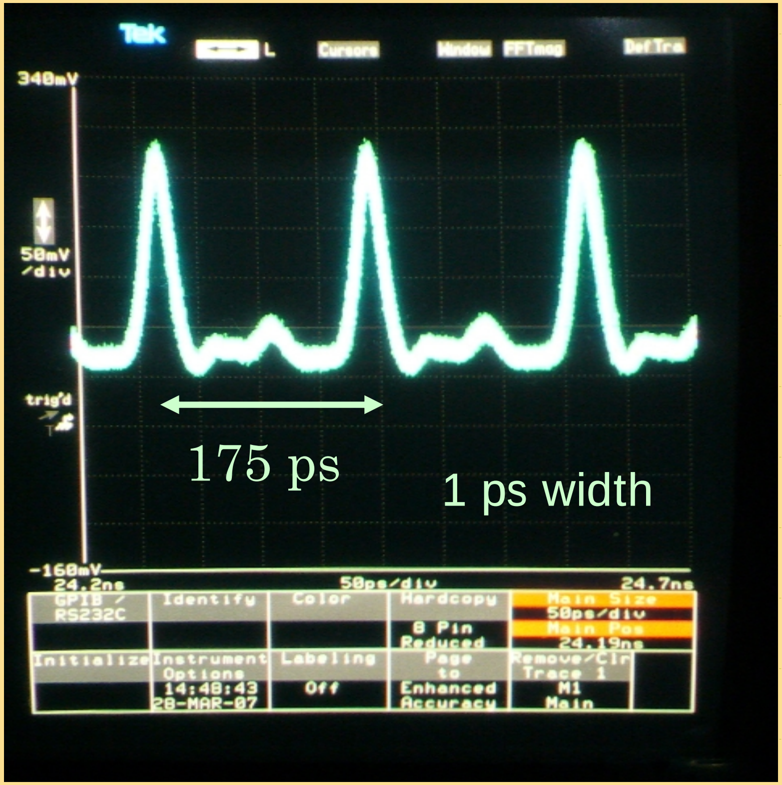


The laser source (1538 nm) using DFB laser diode in which the light is locked to acetylene absorption spectrum. The frequency stability is almost 10^{-11} in a frequency region below 10 Hz.

Output characteristic of Optical Comb Generator

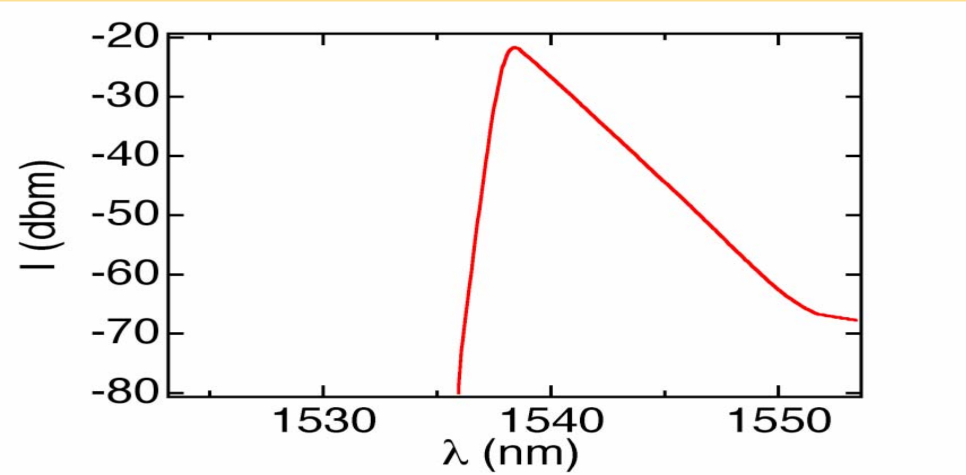
E/O driven by the 5712 MHz generated with the master oscillator.

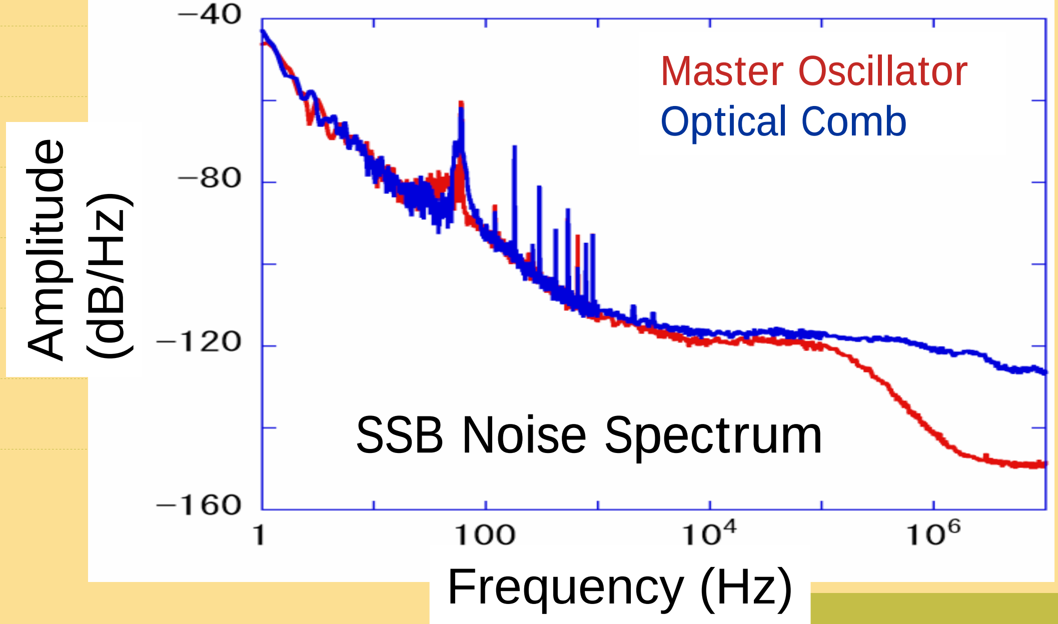
Dull rise time of the pulse by the bund width of the oscilloscope.



Wave Form of Optical Comb Generator

Spectrum envelope of the comb generator.

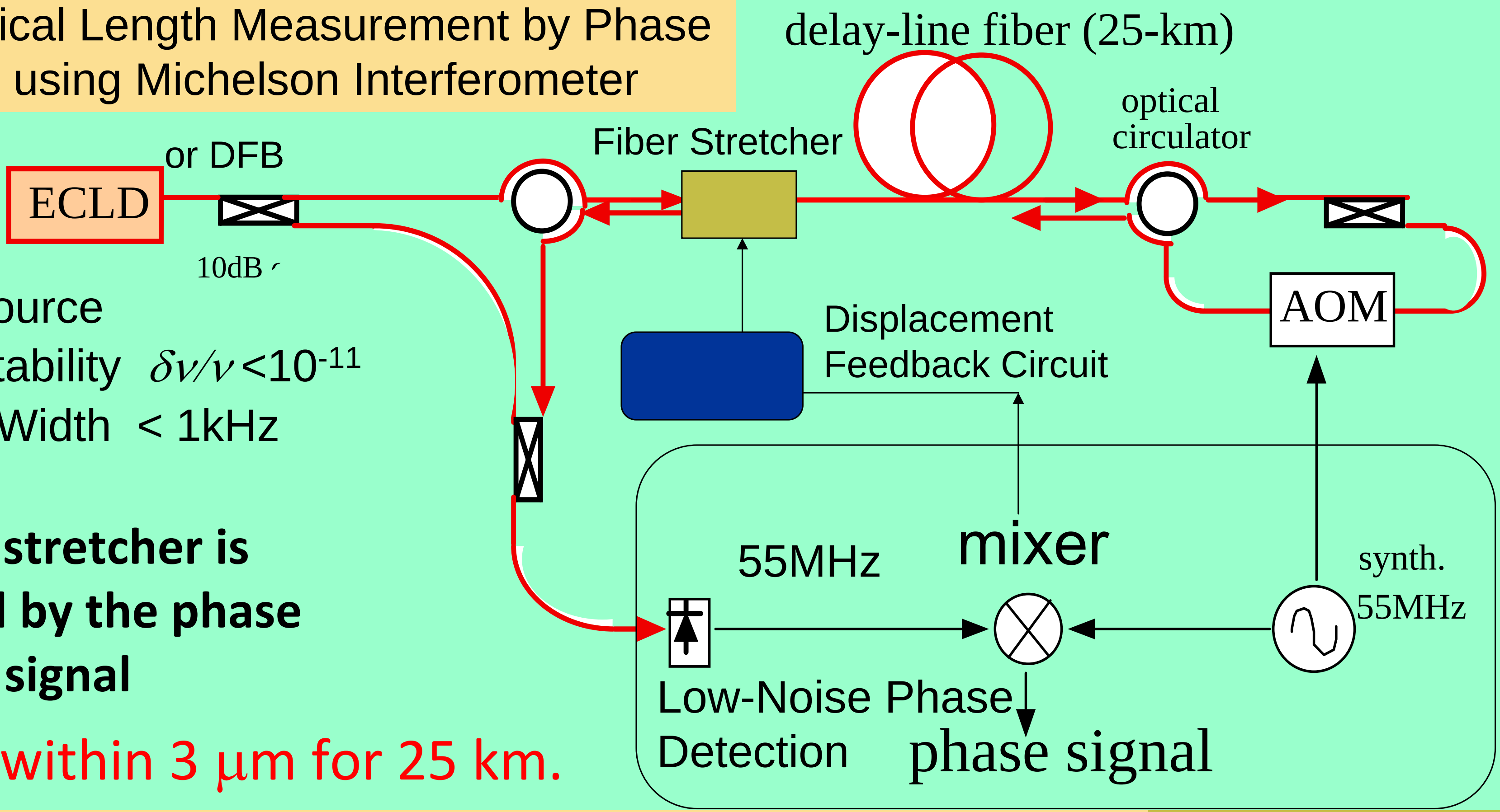




Fiber Optical Length Control (Michelson Interferometer)

Phase-stabilized optical fiber has a thermal optical length coefficient of 2 ppm/K. The optical length of the fiber moves 1.6 μm/K for 800m. This values corresponds to a phase shift of 1 deg./K and 500 fs/K at 5712 MHz, and is not acceptable to employ this method for the X-FEL.

Fiber Optical Length Measurement by Phase Detection using Michelson Interferometer

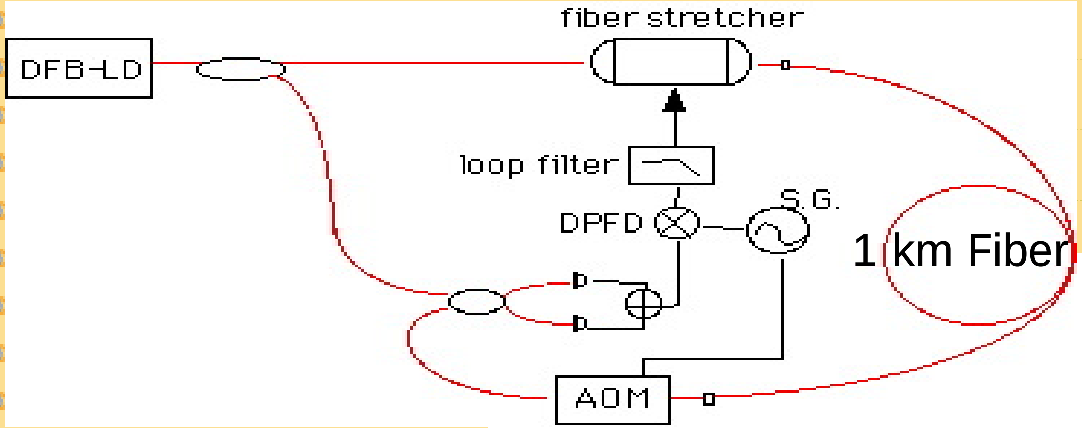


Light Source
Frequency Stability $\delta\nu/\nu < 10^{-11}$
Spectrum Width < 1kHz

The fiber stretcher is controlled by the phase detection signal

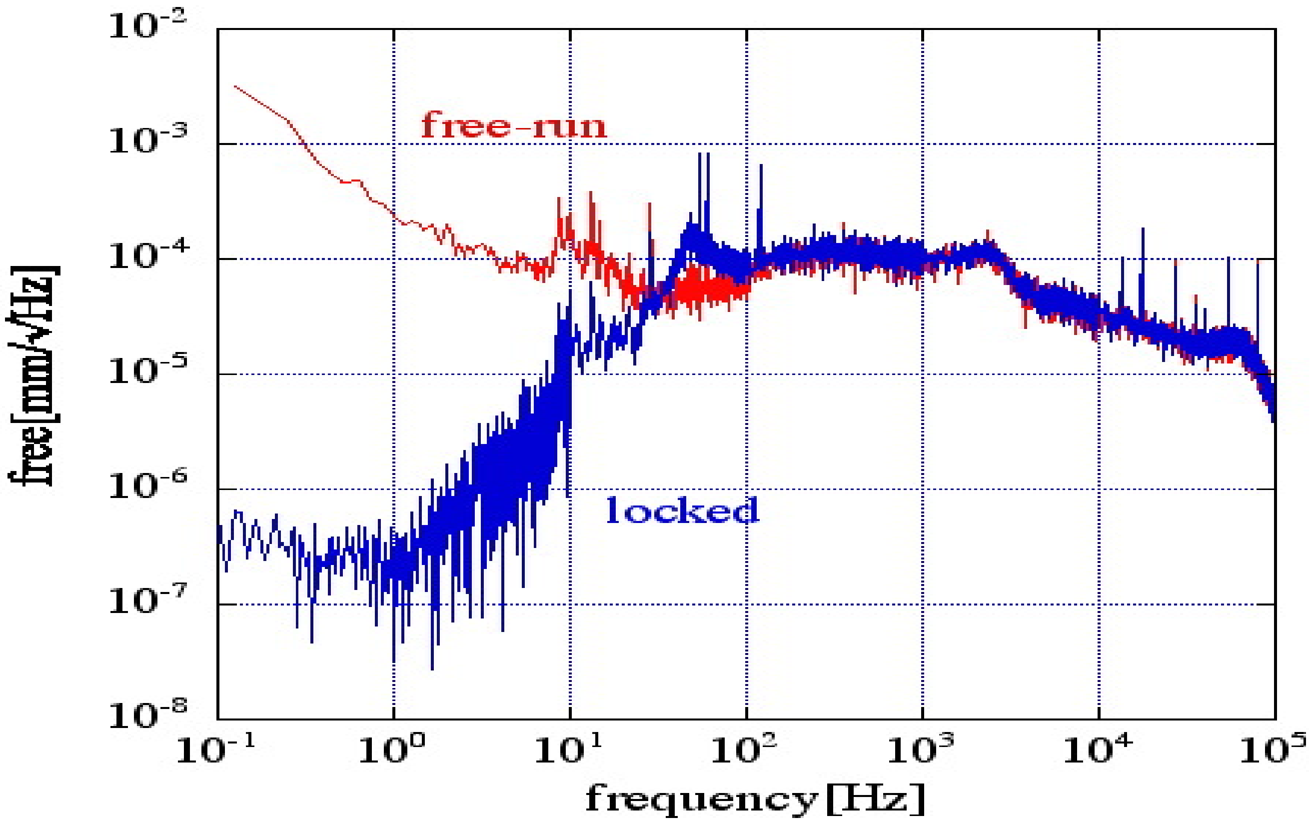
within 3 μm for 25 km.

Experiment of Fiber Optical Length Control



Satisfy the original system performance developed for ALMA. （Controlled it optical length within 3 μm for 25 km.)

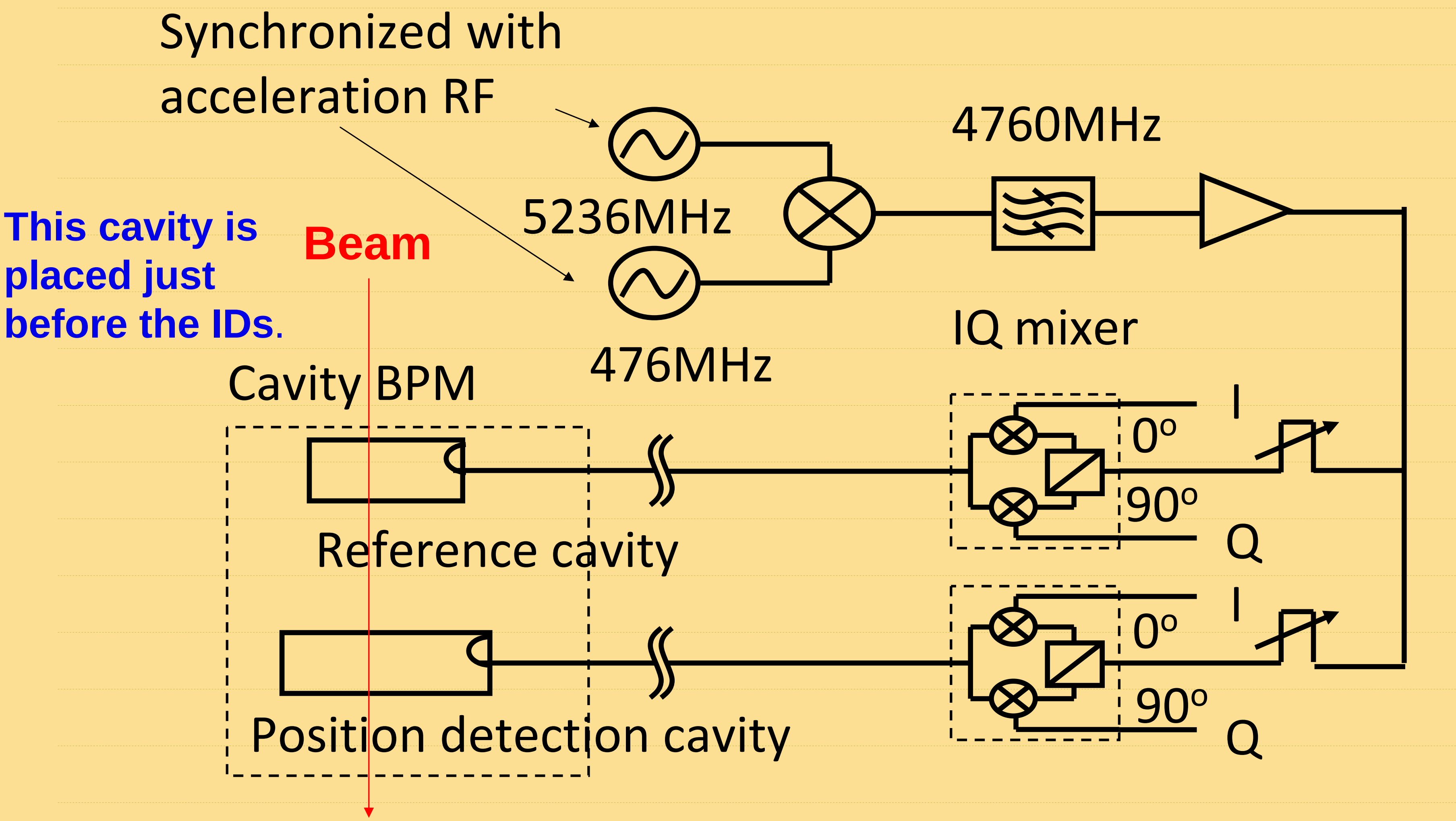
Error Length Spectrum of Control



Experimental Apparatus

Use the 1 km phase stabilized optical fiber cable settled along the circumference of the Spring-8 ring

Method of Beam Arrival Time Jitter Measurement



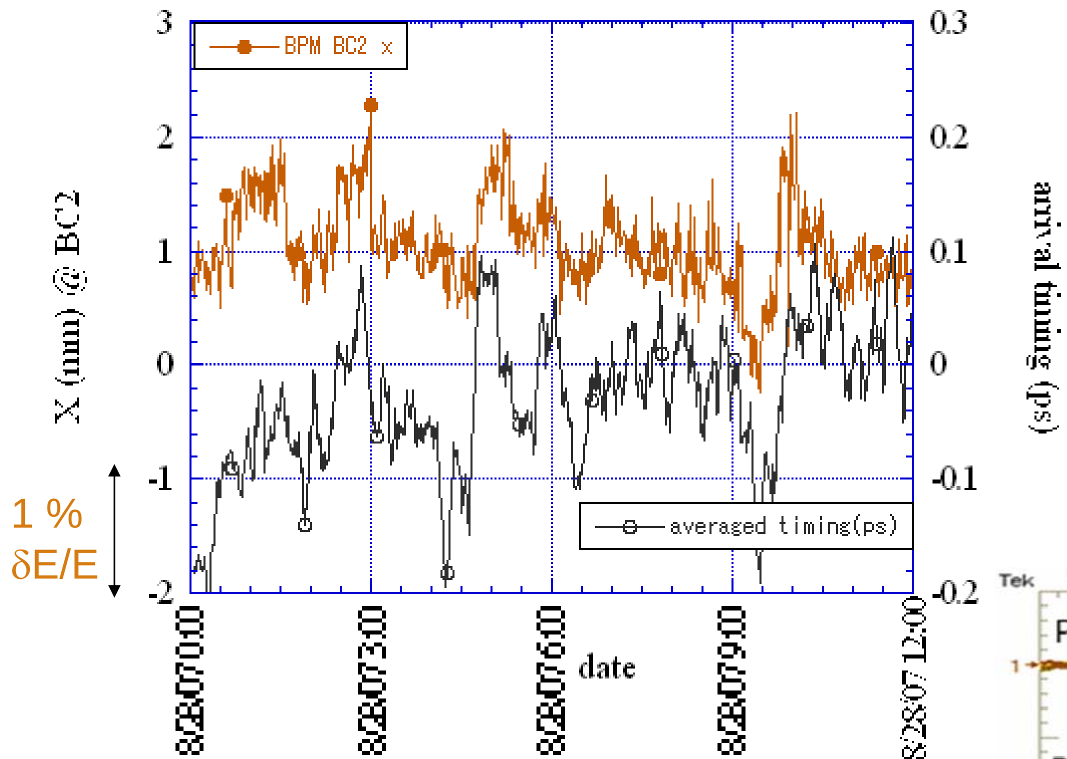
This frequency to prevent the dark current generated by the 5712 MHz accelerator guides.

Use the 4760 MHz BPM intensity detection cavity

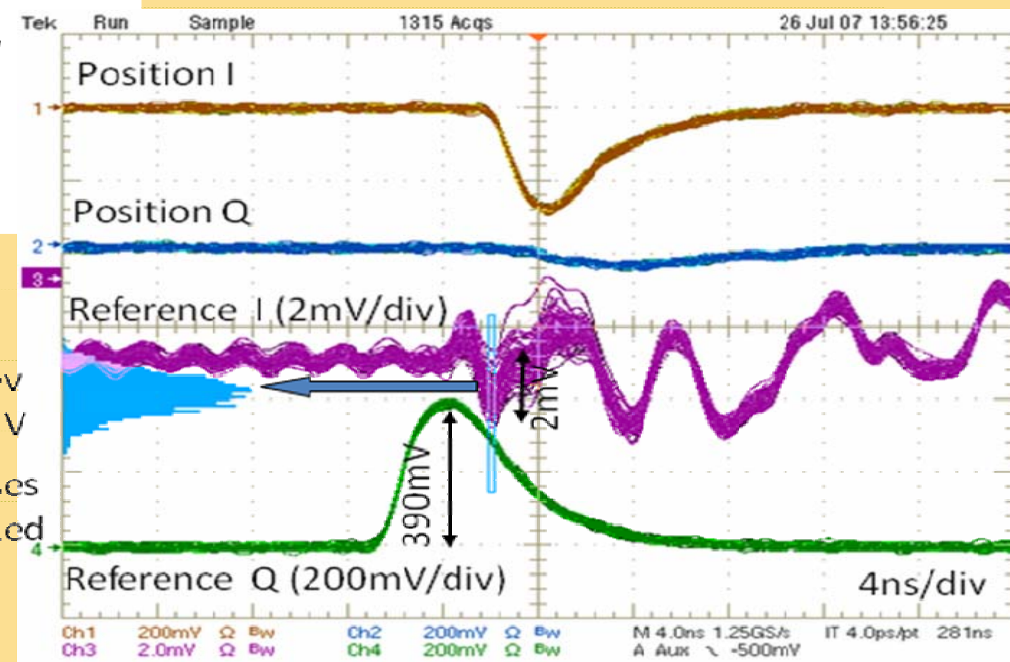
Results of Beam Arrival Time Jitter Measurement

Now, the beam energy stability was improve less than 0.1 % (rms) in the long term (more than half day) by the rf phase feedback control of the cavities (238, 476, 2856 MHz).

R56, 20 mm (BC)
Beam energy jitter value about 0.06 % (rms)



12 hours



Std Dev
0.54mV
~1300pulses
accumulated

Beam Time jitter is 46 fs
0.54 mV Standard Deviation.
Horizontal Scale. 4 ns/div.
10 pps Beam Reptation.

Summary

- The basic design of the LLRF & timing system for the 8 GeV XFEL machine was finished.
- We achieved non-linear amplification of a 50 nm VUV laser with 10 % fluctuation (saturation) in the SCSS prototype accelerator.

  This fact shows great possibility to realize XFEL.
- The master oscillator has a sufficient SSB noise level to realize the beam energy stability of 10^{-4}.
- The trigger jitter of the delay module is less than 700 fs. It is enough for the requirement of the crest acceleration part.
- The phase resolutions of the IQ-demodulator and the modulator were within +/- 1 deg. It is satisfy our requirement to realize the 10^{-4}energy stability.
- The optical comb generator were successfully developed with the pulse train having 1ps width and 175 ps time interval. The output of this instrument almost dose not increase the SSB noise of the master oscillator.
- The laser source using the DFB laser diode, with which light is locked to acetylene absorption spectrum, has the frequency stability of 10^{-11}.
- The 2 km fiber optical length control worked well within the several micro-meter length error.