Femtosource synchronization issues

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Advanced Light Source

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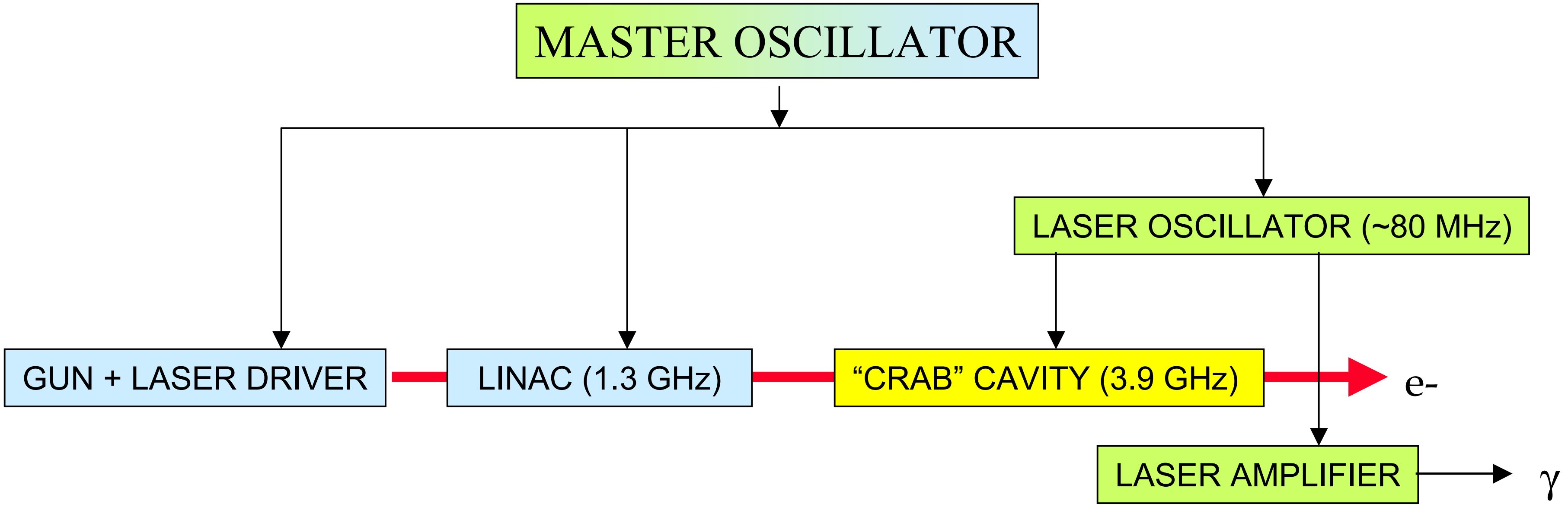
Synchronization goals

> The very diverse and confusing aspects of these phenomena are, so far as I can see at present, completely explicable on the assumption of a psychically relative space-time continuum. As soon as a psychic content crosses the threshold of consciousness, the synchronistic marginal phenomena disappear, time and space resume their accustomed sway, and consciousness is once more isolated in its subjectivity. . . . Conversely, synchronistic phenomena can be evoked by putting the subject into an unconscious state.
>
> Carl Jung, On the Nature of the Psyche

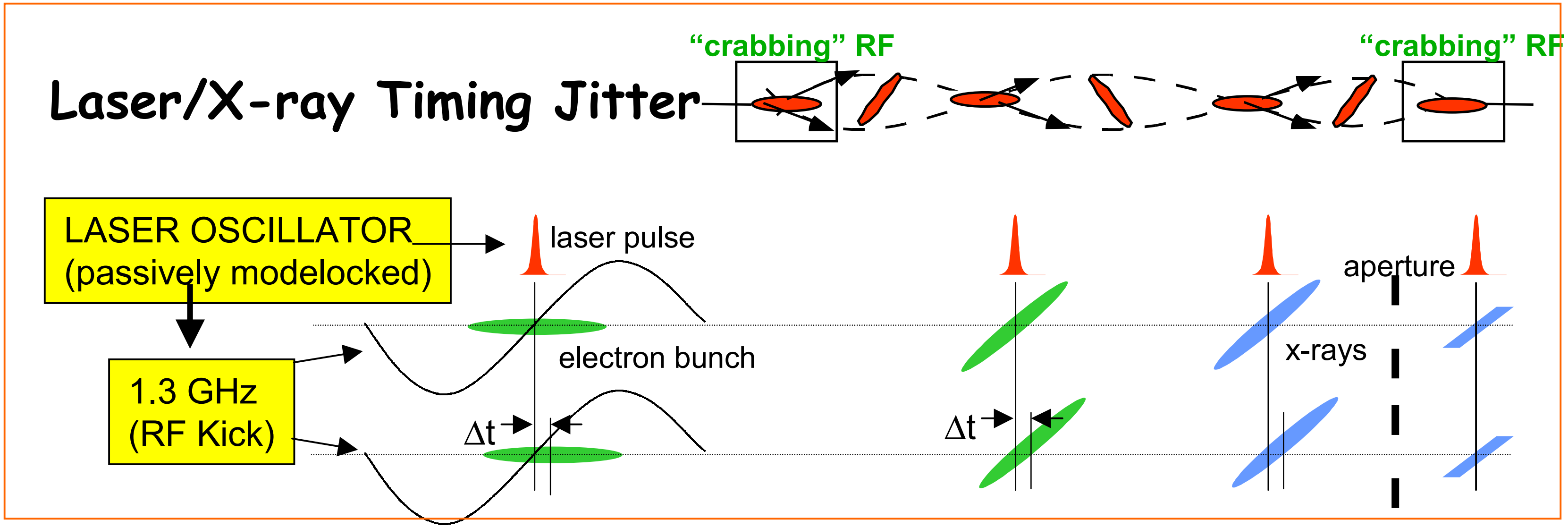
- Synchronize compressed x-ray pulse with external laser to <10 fsec (3 micron)
- Synchronize electron beam with deflecting cavity to < 1 psec (300 micron)

Overall timing strategy

- lock deflecting cavity to laser oscillator with BW of ~100 Hz
- lock laser oscillator, deflecting cavity to master oscillator with BW of < 1 Hz
- lock linac with MO with BW<1 Hz
- control linac/gun phase/energy jitter with BW~100 Hz



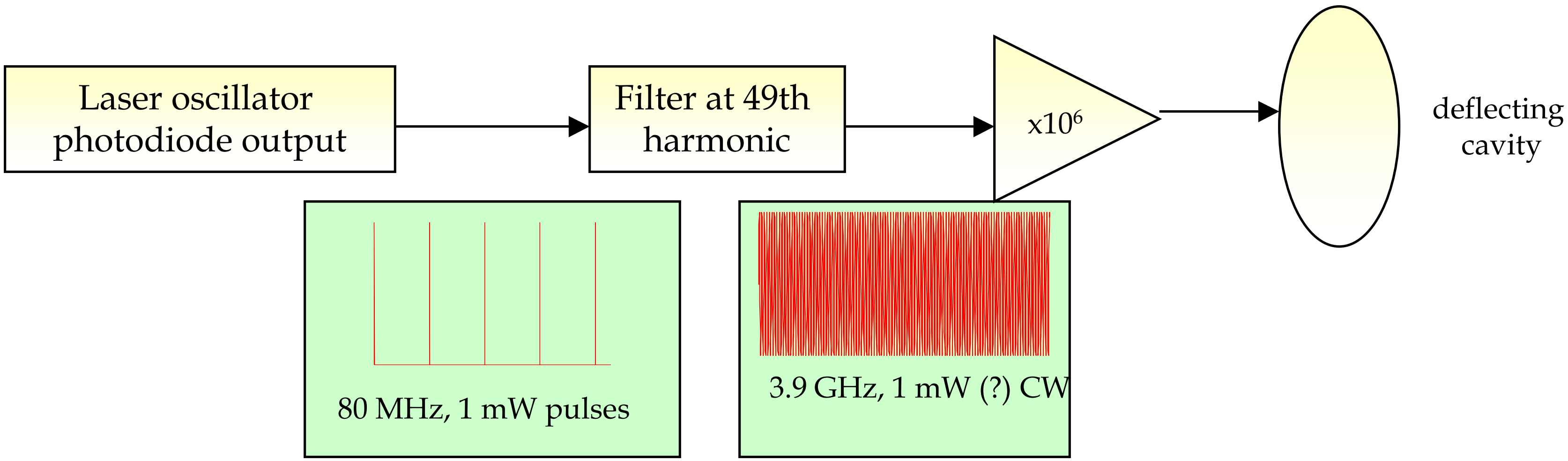
Relaxed timing for "crabbing"



Arrival jitter of the electron beam at the deflecting cavity changes the relative position of the laser and electron beam. It will also excite vertical betatron oscillations . However, the x-ray aperture will select only a fraction of the bunch which will remain synchronous with the laser. This scheme works if:

- the arrival jitter is < 1 psec
- vertical betatron oscillation within x-ray aperture
- no strong requirement on x-ray amplitude stability
- additional electron timing jitter not introduced on "user" arc (i.e. due to CSR effects)

Laser as a MO



- Issues:
  - large frequency difference (factor 50 at 3.9 GHz)
  - low signal level requires large gain
  - amplitude stability
  - limited bandwidth response of the cavity. Enough?
  - long term frequency stability of laser and cavity
  - effects of modulated beam loading?
- Possible solution: locking 3.9 GHz MO to laser (Kiewiet, et. al) ~20 fsec phase-jitter achieved

Effect of photodiode/amplifier noise

Noise in either the photodiode or amplifier stage can introduce uncorrelated noise. Try a crude estimate of the effect.

Assume source is matched to load. Phase noise is given by

$$\Delta\phi_{rms} = \frac{\sqrt{P_n R}}{V_c} = \frac{\sqrt{\eta \Delta f R}}{V_c}$$

V_c = *cavity voltage*

P_n = *noise power*

R = *load resistance*

Δf = *bandwidth*

η = *powerspectral density*

Example:
P_{pd}=1 mW
P_c=1 kW
f_c=3.9 GHz
Δf=100 Hz
use two stages of 30 dB gain

1st stage, amplifier with 3 dB NF
P_n=100 Hz*8e-21 W/Hz*1e3
=8e-16 W

Second stage noise amplifier has little contribution
$\Delta t_{rms}=\Delta\phi_{rms}/\omega_c$~1 attosecond

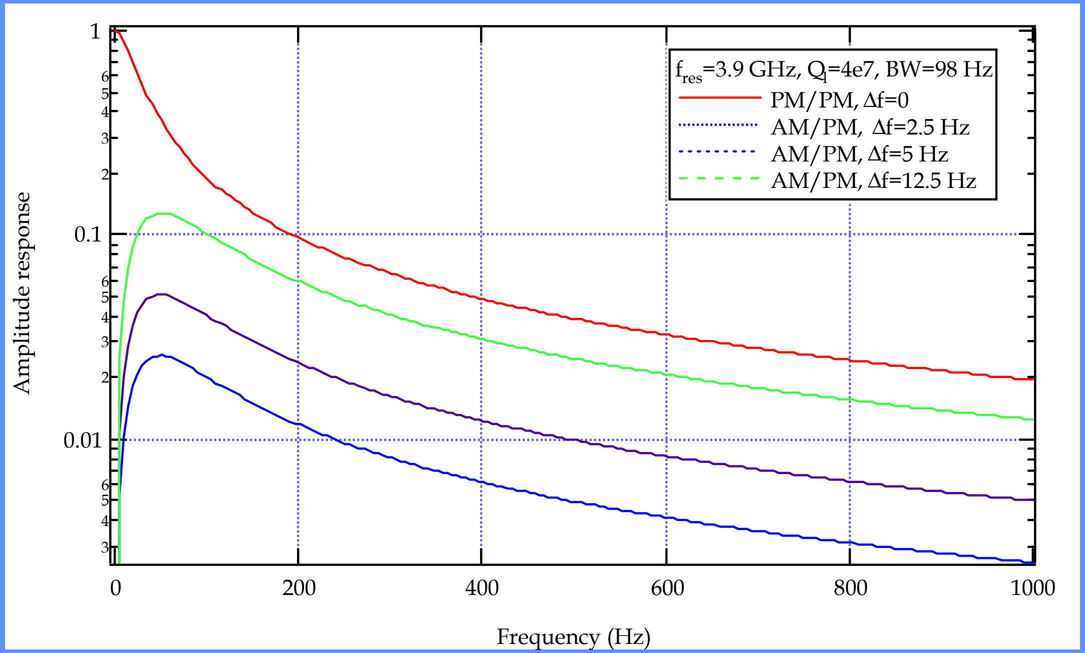
1.4 deg=25 mrad @3.9 GHz=1 psec
0.1 deg=1.7 mrad@3.9 GHz=70 fsec

Cavity response to AM/PM

The deflecting cavity phase responds to laser phase jitter within 100 Hz
Is the laser integrated phase jitter >100 Hz acceptably small?

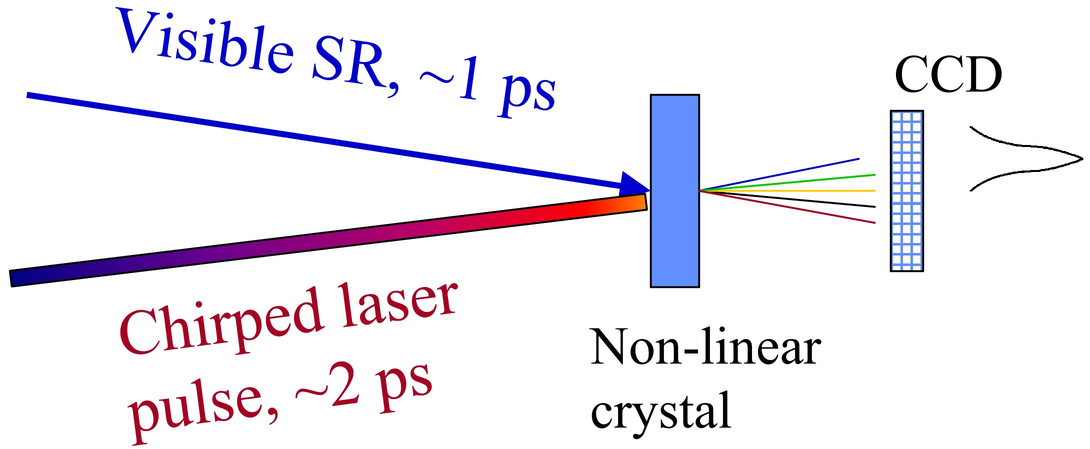
- off-resonance excitation can convert AM to PM
- high-Q structures particularly sensitive
- Laser AM can be converted into PM which is not correlated with laser PM.
- Jlab studies show RMS drift of a few Hz. Could be improved.

Transfer functions of cavity PM response to laser PM and AM



Coincidence measurements

•Jitter of the laser pulse relative to the SR from electron bunch can be measured with accuracy down to $\delta t \sim (10 - 50)$ fs. 10^7-10^8 visible photons are required in a single shot.



Main linac/laser timing

- timing budget: ~1 psec
- Major effects:
  - phase jitter in linac via klystron phase noise
  - phase jitter via cavity tuning variations (microphonics)
  - energy jitter in linac cause path length variations in the arcs: ~0.1 psec/arc/0.1% energy offset
  - timing of gun pulse
- Much work to do in this area!

Summary and future plans

Summary

- Locking of laser/deflecting cavity at 10 fsec level does not appear impossible
- Aperturing of x-ray pulse allows lax timing requirement of 1 psec from main linac to laser
- Jitter due to main linac needs to be studied in much more detail.

Future plans

- study actual phase and amplitude noise at high harmonics of mode-locked laser as well as noise from amplifier
- develop techniques for measuring jitter at 10 fsec level
- work out detailed jitter contributions in main linac