CLIC Beam Instrumentation workshop

Femtosecond phase measurement

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Energy and phase stability requirements in CLIC

- Drive beam phase jitter leads to luminosity drop.
- $\Delta\varphi$ at 1 GHz causes 12 $\Delta\varphi$ at 12 GHz!
- Requirement at 1GHz (order of magnitude):
  drive beam phase jitter <0.02° (3.5E-4, 50 fs)
  drive beam energy jitter <$\mathcal{O}$(1E-4)

  (With a feed-forward, this may be relaxed by a factor 10!)
- Requirement at 12GHz (order of magnitude):
  drive beam phase jitter <0.2° (3.5E-3, 50 fs)
  drive beam energy jitter <$\mathcal{O}$(1E-4)

See: Erk Jensen, 4th CLIC Advisory Committee (CLIC-ACE)

Sources of phase errors in CLIC

- Drive beam gun
  - Beam current changes acceleration! $\frac{\delta V}{V} = -\frac{R}{V_0/I - R}\frac{\delta I}{I}$

    at full loading: $\frac{\delta V}{V} = -2\frac{\delta I}{I}$
  - Phase jitter from the source
- Sub-harmonic buncher
  - Flips phase every 244ns. Creates also systematic error at 2.05 MHz
- via klystron:
  - Voltage $\delta\varphi = -\frac{L}{\lambda}\left(V\left(2+V\right)\right)^{-3/2}\delta V$
  - Klystron body temperature: $\delta\varphi \approx 1° \frac{\delta T}{K}$
  - Drive power $\delta\varphi \approx 2.3° \frac{\log \delta P_{in}}{\mathrm{dB}}$
  - ... filament current, magnet current, waveguides...
  - ...

See: Erk Jensen, 4th CLIC Advisory Committee (CLIC-ACE)

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Phase monitor development

Task 5. Drive Beam Phase Control

1. Design, build and test a low-impedance RF beam phase monitor with a resolution of 20 fs
2. Design, build and test an electro-optical phase monitor with a resolution of 20 fs

Sub-task 1: CERN will determine the specifications and will produce a conceptual design report of the RF monitor. CERN and INFN will attend together to the electromagnetic design and then they will produce a building design of the monitor. CERN will develop and realize the related electronics. INFN will build prototypes of the monitor that will be measured and tested in lab. A final version of the monitor will be built and the performances of the system will be tested in CTF3.
Sub-task 2: The electro-optical monitor will be designed by PSI. PSI will implement prototypes of the system, which includes pick-up, laser, electro optical detector and electronics. The performances of the system will be tested in the existing facilities at PSI.

Ready for beam tests in 2012

See: Fabio Marcellini; NCLinac Kick-Off Meeting --Presentation task 5;
http://indico.cern.ch/conferenceDisplay.py?confId=55146

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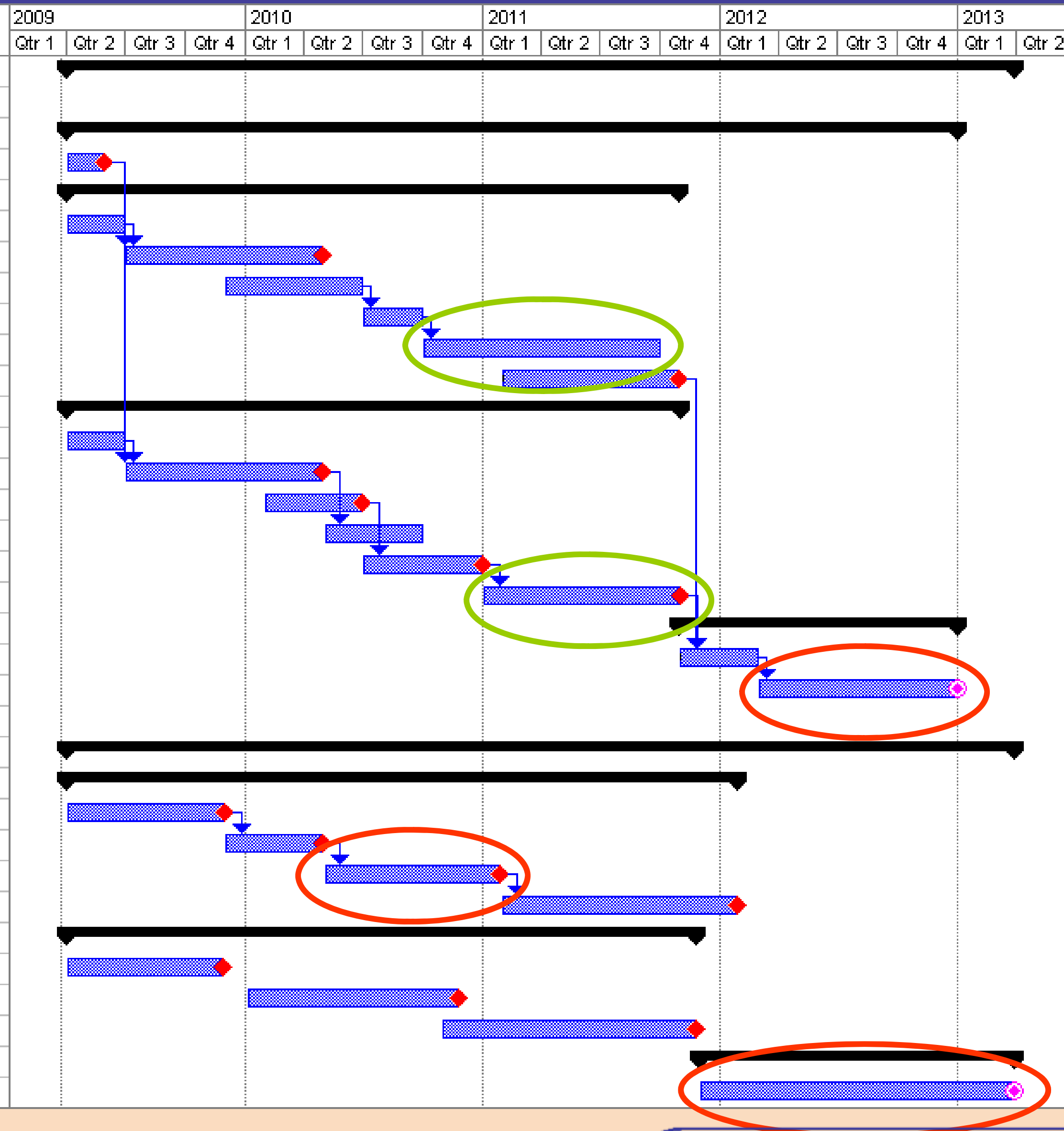
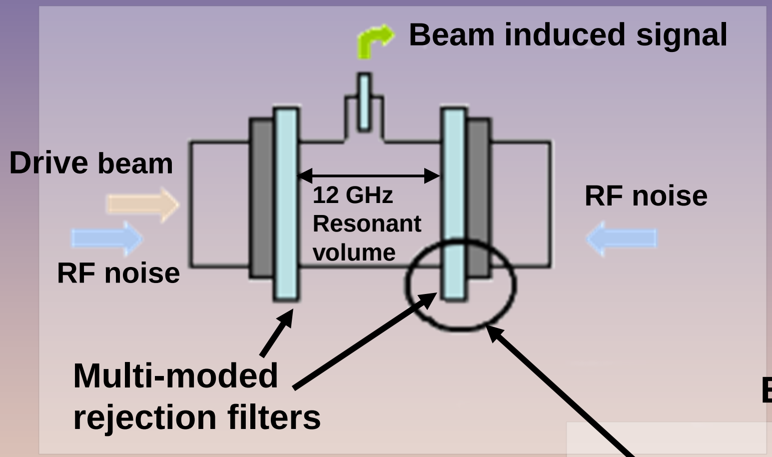
ID	Task Name
1	**drive beam phase control**
2	
3	**RF phase monitor**
4	define specs
5	**electronics**
6	study
7	design
8	component procurement
9	assembly
10	test
11	revision
12	**monitor pickup**
13	study
14	e.m. design
15	mechanical design
16	feedthrough procurement
17	mechanical realization
18	RF test/lab measurements
19	**full system test**
20	electronics and monitor integration and test
21	beam measurement at CTF3
22	
23	**electro-optical phase monitor**
24	**bunch phase pickup**
25	electrical/mechanical design
26	fabrication
27	beam test
28	revision
29	**optical system**
30	lab test optical link and stabilization
31	test lockin laser
32	setup prototype with readout system
33	**full system test**
34	beam meas, refine and adapt to CLIC specs



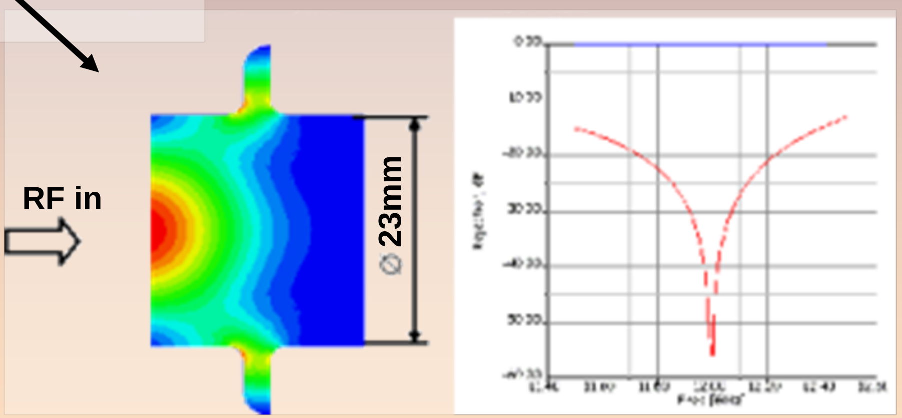
12 GHz low impedance noise-free pick-up concept by Igor Syratchev (via EuCARD kickoff meeting)



Considerations:

1. We have to keep big aperture of the pick up (I used 23 mm – similar to one in the PETS).
2. Low Impedance!
3. The sensitivity of the device will depend on the RF noise rejection level
4. We need a resonant volume anyway (Q loaded to be defined)

Example: TM01 choke-type rejection filer



Continuation: Fabio Marcellini (INFN/LNF)

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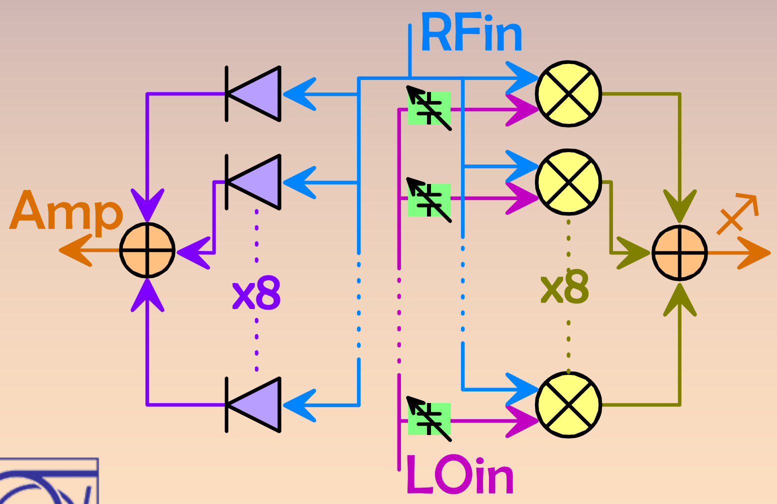
12 GHz Electronics

Concept: use mixers directly at 12 GHz

Advantage: Short device chain → less signal distortion by electronics

Problem: Amplitude to phase conversion, especially at DC

- **Solution:** Operate devices at lower RF input → less AMPM
  - **Problem:** Too much noise from devises
    - **Solution:** Use an array of many devices, sum their outputs for a reduction in noise



Same idea that was successfully implemented with 30 GHz electronics. The lower frequency allows us to contemplate a direct detection rather than down-mixing as was done there.

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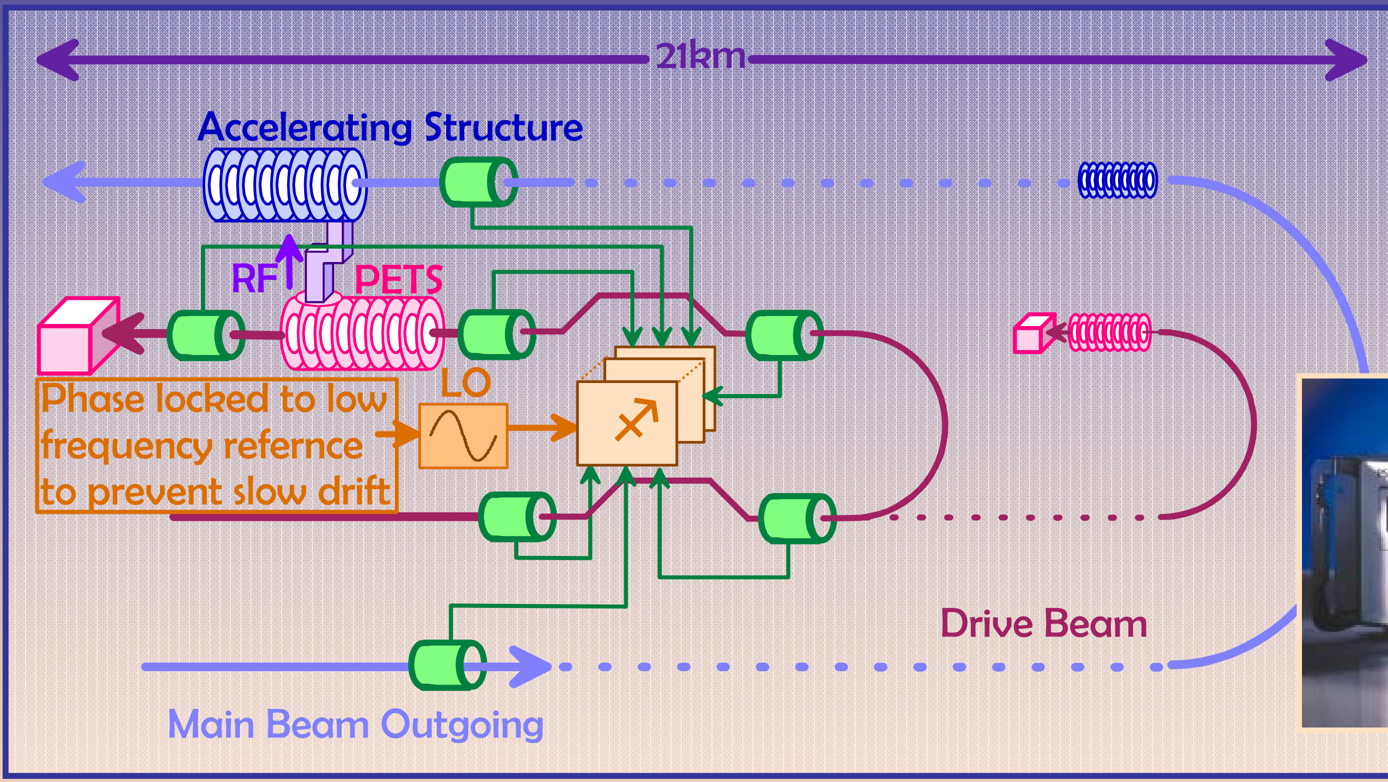
Timing distribution



Commercially available **Sapphire Loaded Cavity Oscillator** with ~2 fs integrated phase noise.

Requires:

- •Stable distribution of low frequency reference for long term stability
- •Low noise local oscillator at each turnaround

Now available:

PLL with 12GHz VCO, <5fs IPN

~€10000 -- 1 prototype

~€3000 -- 20 devices

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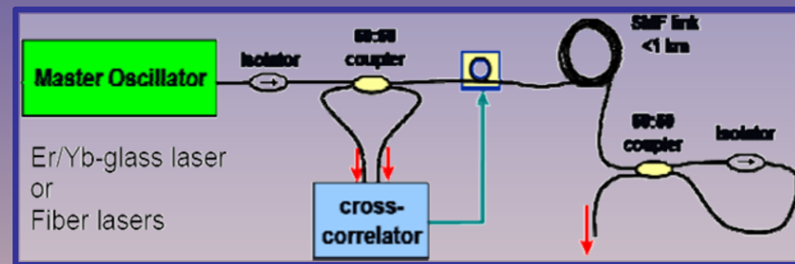
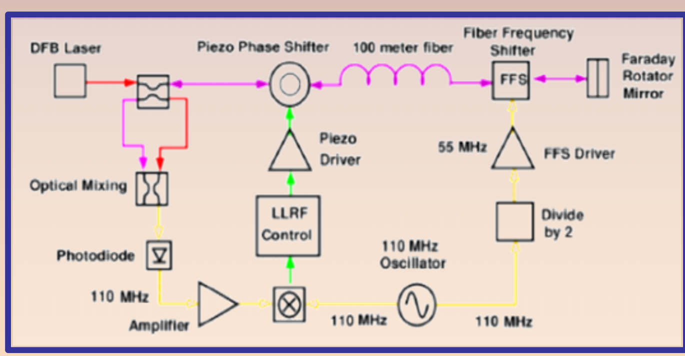
Global timing reference?

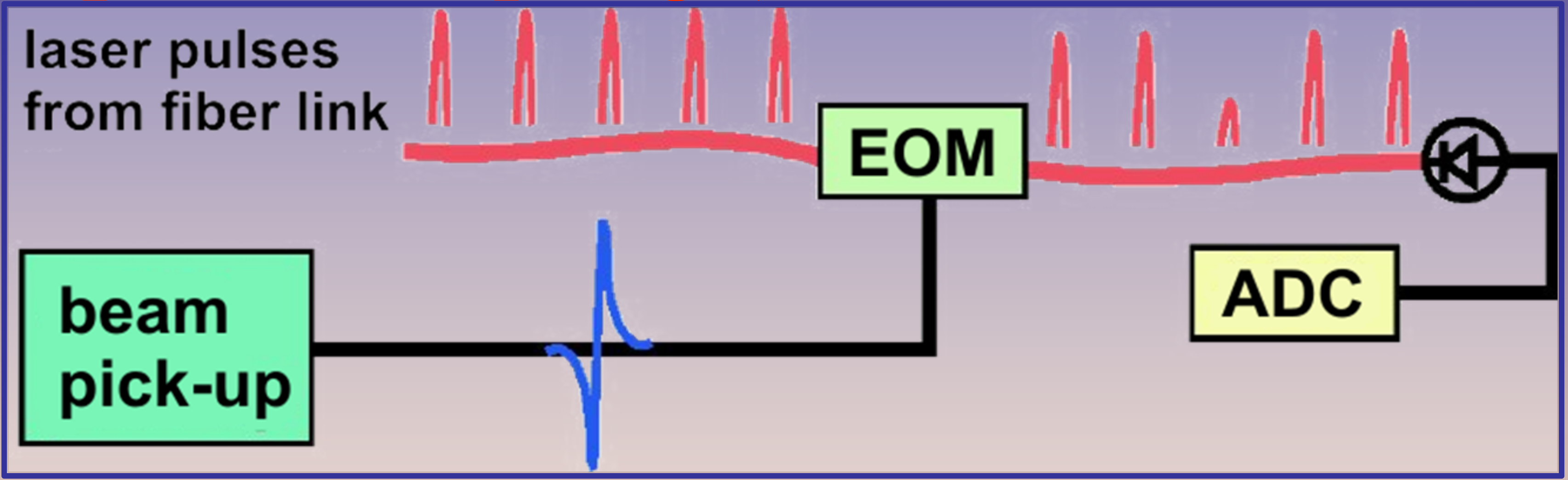
Two major R&D efforts are ongoing on the development of optical clock systems:
...
Both systems are fully consistent: each of them fulfils the requirements for a complete fs timing system.
[M. Ferianis, "Timing and Synchronization in Large Scale Linear Accelerators", LINAC 2006, Knoxville, Tennessee USA]





The distribution of ultrafast optical pulse trains across **300 meters** of fiber with **sub-femtosecond timing jitter** and 83 fs of drift over 25 hours, as measured between the outputs from two independent links, is demonstrated.
[J. A. Cox et. al, "Sub-femtosecond Timing Distribution of an Ultrafast Optical Pulse Train over Multiple Fiber Links", OSA / CLEO/QELS 2008]

Bunch phase monitoring using Electro optical sampling (Micha Dehler, PSI)



- Original idea from DESY:
- Use periodic train of laser pulses to sample signal from wide bandwidth beam pickup
- Sampling near zero crossing – variations in the bunch phase get converted to amplitude changes
- Electro optical sampling allows direct use of high precision signals from fiber laser based timing / synchronization system

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Pros and Cons

- Single bunch measurement
- High resolution: 50 fs demonstrated by DESY
- Optional use of multiple EOS modules to obtain intra bunch charge distribution for longer bunches
- Need wide bandwidth pickup: Deterioration of resolution due to beam echoes/wake fields in the beam chamber?

R&D

- Pickup:
  - Optimize bandwidth and slew rate of output signal to increase resolution
  - Minimize spurious signals from beam echos and wakes by adequate chamber design
- Make Electronics, Laser system 'real time feedback' ready:
  - Bunch rep rate
  - Minimum measurement latency
  - Reliability and stability of system

CERN

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Conclusion – The Table

2.3.5 Turn around and bunch compressor e+

Beam phase	Pick-up +electronics	Reference distribution
Accuracy	0.1	
Resolution	0.1	<5fs (noise)
Bandwidth	30-50 MHz	narrow
Beam tube aperture	23mm?	N/A
Stability		
Non-intercepting device?	Yes	N/A
How many?	168/336	24/48

Table 46: Beam Instrumentation requirements for the Drive Beams turn around for e+