Synchronization system for CLIC crab cavities

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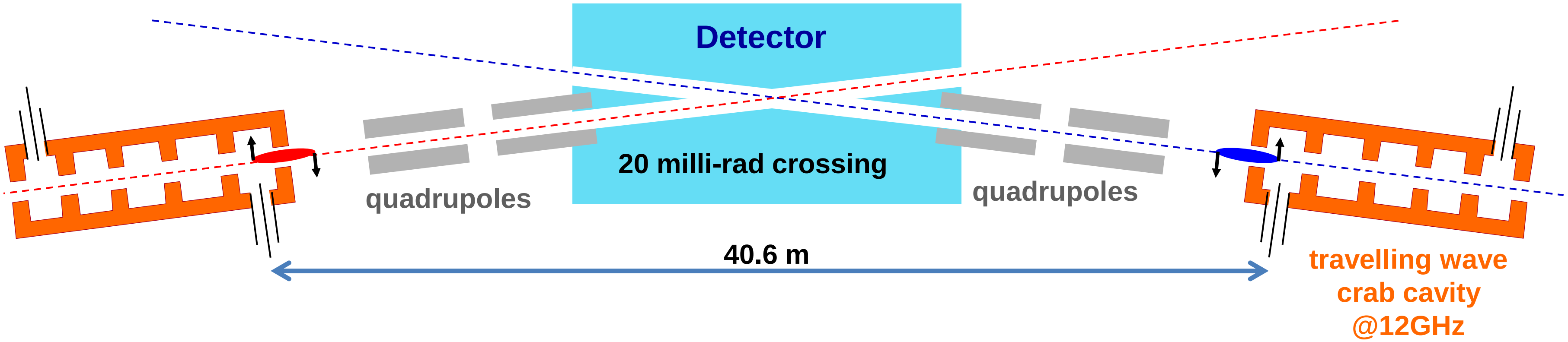
Crab cavity action

Without a correctly functioning crab cavity CLIC looses 90% of its luminosity

The crab cavity system cannot be compromised.



Bunches pass through deflecting cavities phased to give zero kick for bunch centres

A deflecting cavity phased in this way is called a crab cavity

For a bunch with length

- **The crab cavity kicks the bunch front to start rotating away from the other beamline**
- **The crab cavity kicks the bunch rear to start rotating towards the other beamline**

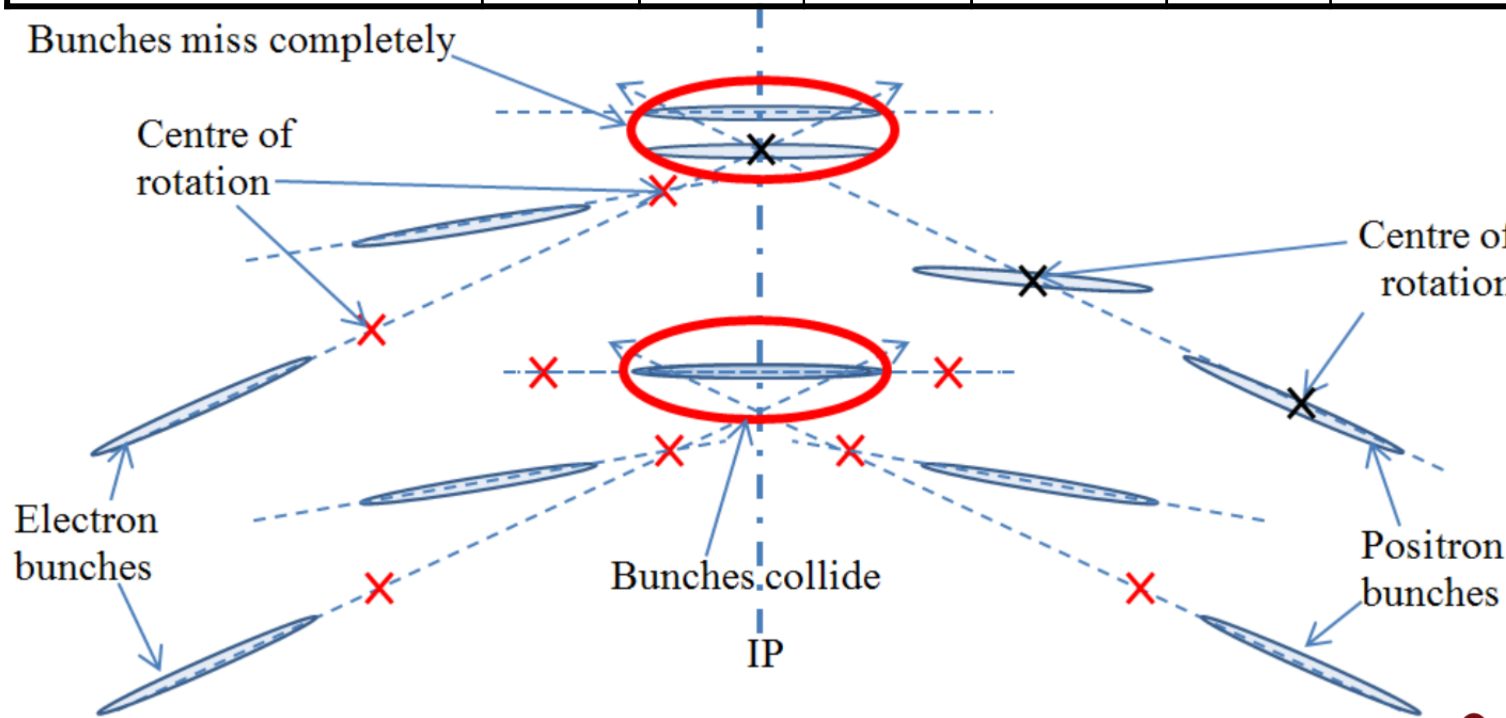
Perfect alignment of bunches occurs only at the IP

Synchronisation Requirement

Cavity to Cavity Phase synchronisation requirement

$$= \frac{720\,\sigma_x f}{c\theta_c}\sqrt{\frac{1}{S_{rms}^4} - 1} \quad \text{degrees}$$

Target max. luminosity loss fraction S	f (GHz)	σ_x (nm)	θ_c (rads)	ϕ_{rms} (deg)	Δt (fs)	Pulse Length (μs)
0.98	12.0	45	0.020	0.0188	4.4	0.156



Estimate RF to beam synchronisation ~ 100 fs (0.43 degrees)

RF Distribution

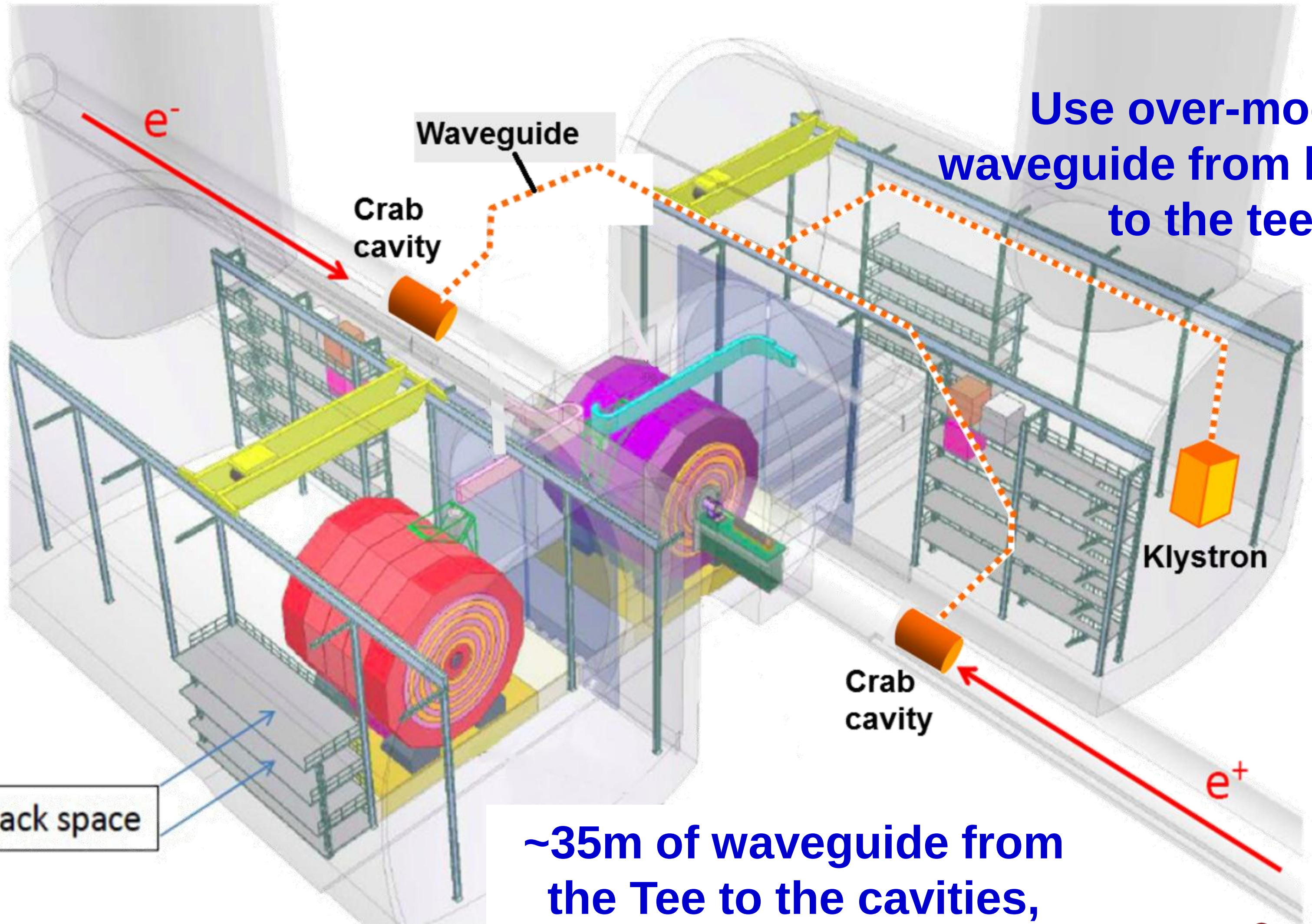
1: A single klystron with high level RF distribution to the two cavities.

- Klystron phase jitter gets sent to both cavities for identical path length. $\Delta\phi=0$.
- Will require RF path lengths to be stabilised to within 1 micron over 40m.

2: A klystron for each cavity synchronised using LLRF/optical distribution.

- Femtosecond level stabilized optical distribution systems have been demonstrated (XFELs).
- Requires klystron output with integrated phase jitter <4.4 fs.

Integration



Use over-moded waveguide from klystron to the tee

~35m of waveguide from the Tee to the cavities, 20.3m from cavities to IP

Waveguide Choice

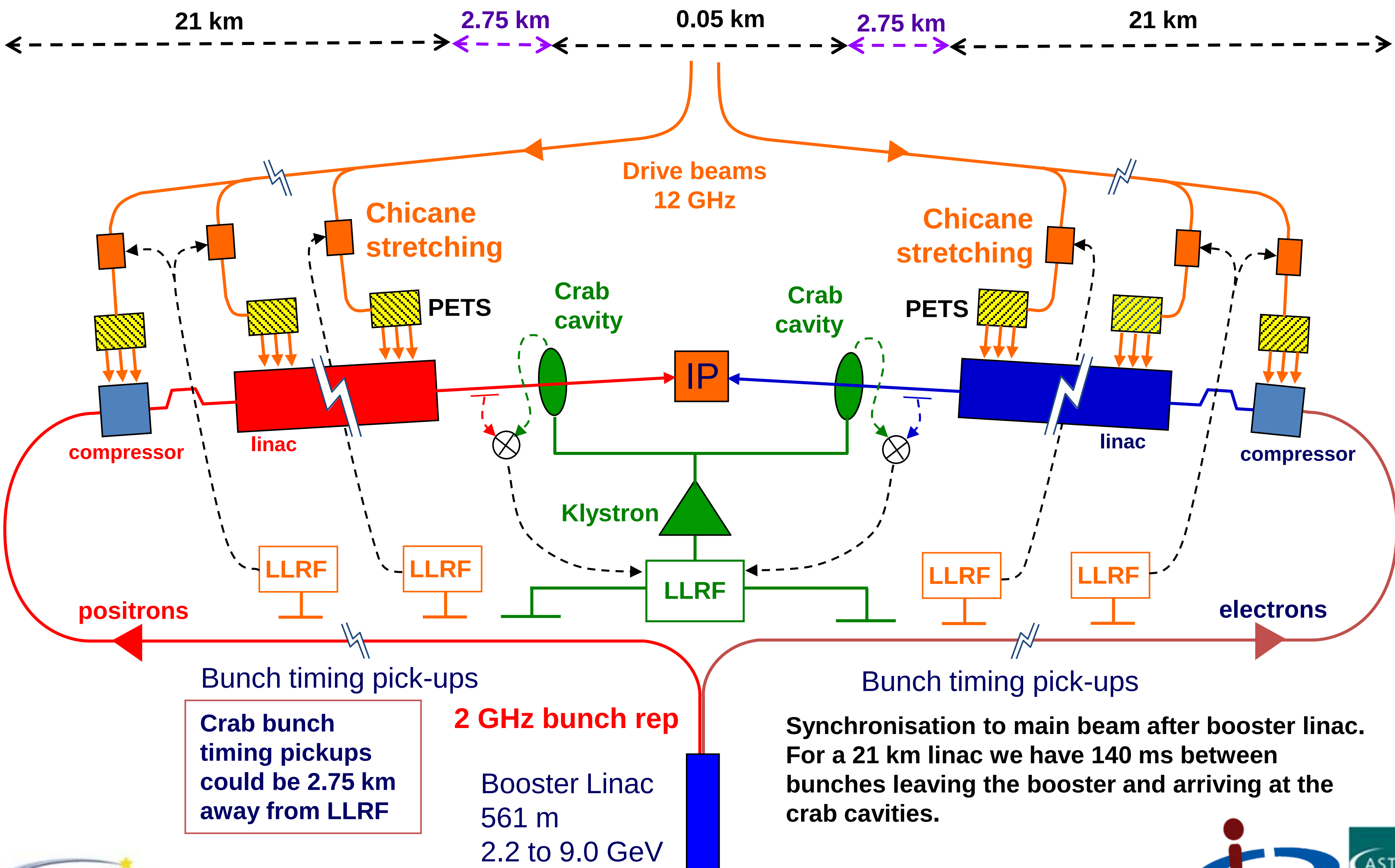
Waveguide type 35 meters COPPER Expansion = 17 ppm/K	*Mode*	*Transmission*	*Timing error/0.3°C Width*	*Timing error/0.3°C length*	*Nº of modes*
WR90(22.86x10.16mm)	TE10	45.4%	210.5 fs	498.9 fs	1
Large Rectangular (25x14.5mm)	TE10	57.9%	189.3 fs	507.8 fs	2
Cylindrical r =18mm	TE01	66.9%	804.9 fs	315.9 fs	7
Cylindrical r =25mm	TE01	90.4%	279.6 fs	471.4 fs	17

Copper coated extra pure INVAR 35 meters Expansion = 0.65 ppm/K	*Mode*	*Transmission*	*Timing error/0.3°C Width*	*Timing error/0.3°C length*	*Nº of modes*
WR90(22.86x10.16mm)	TE10	45.4%	8.13 fs	19.04 fs	1
Large Rectangular (25x14.5mm)	TE10	57.9%	6.57 fs	19.69 fs	2
Cylindrical r =18mm	TE01	66.9%	30.8 fs	12.1 fs	7
Cylindrical r =25mm	TE01	90.4%	10.7 fs	18.02 fs	17

Rectangular invar is the best choice as it offers much better temperature stability->

Expands 2.3 microns for 35 m of waveguide per 0.1 °C.

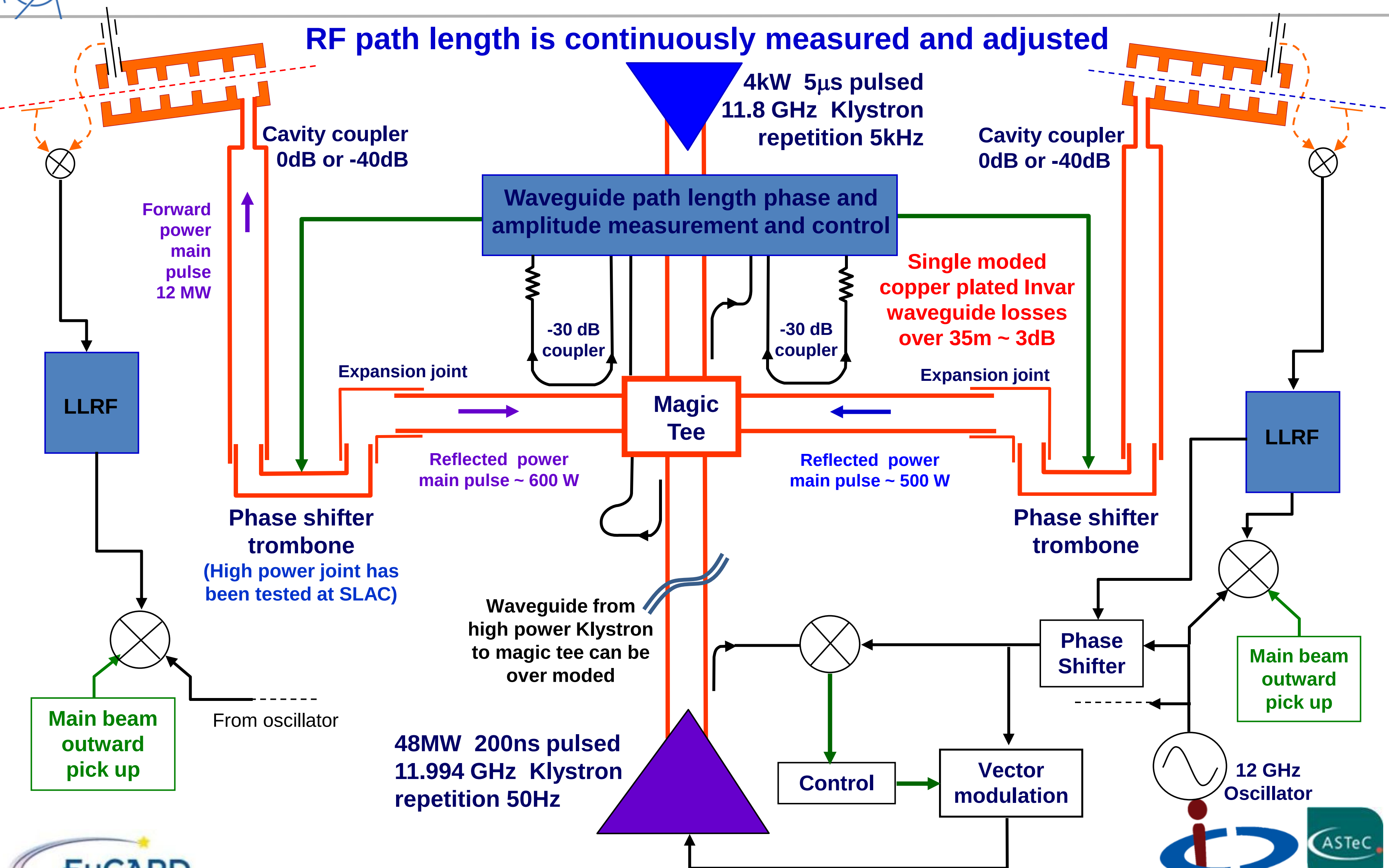
CLIC LLRF Timing



Crab bunch timing pickups could be 2.75 km away from LLRF

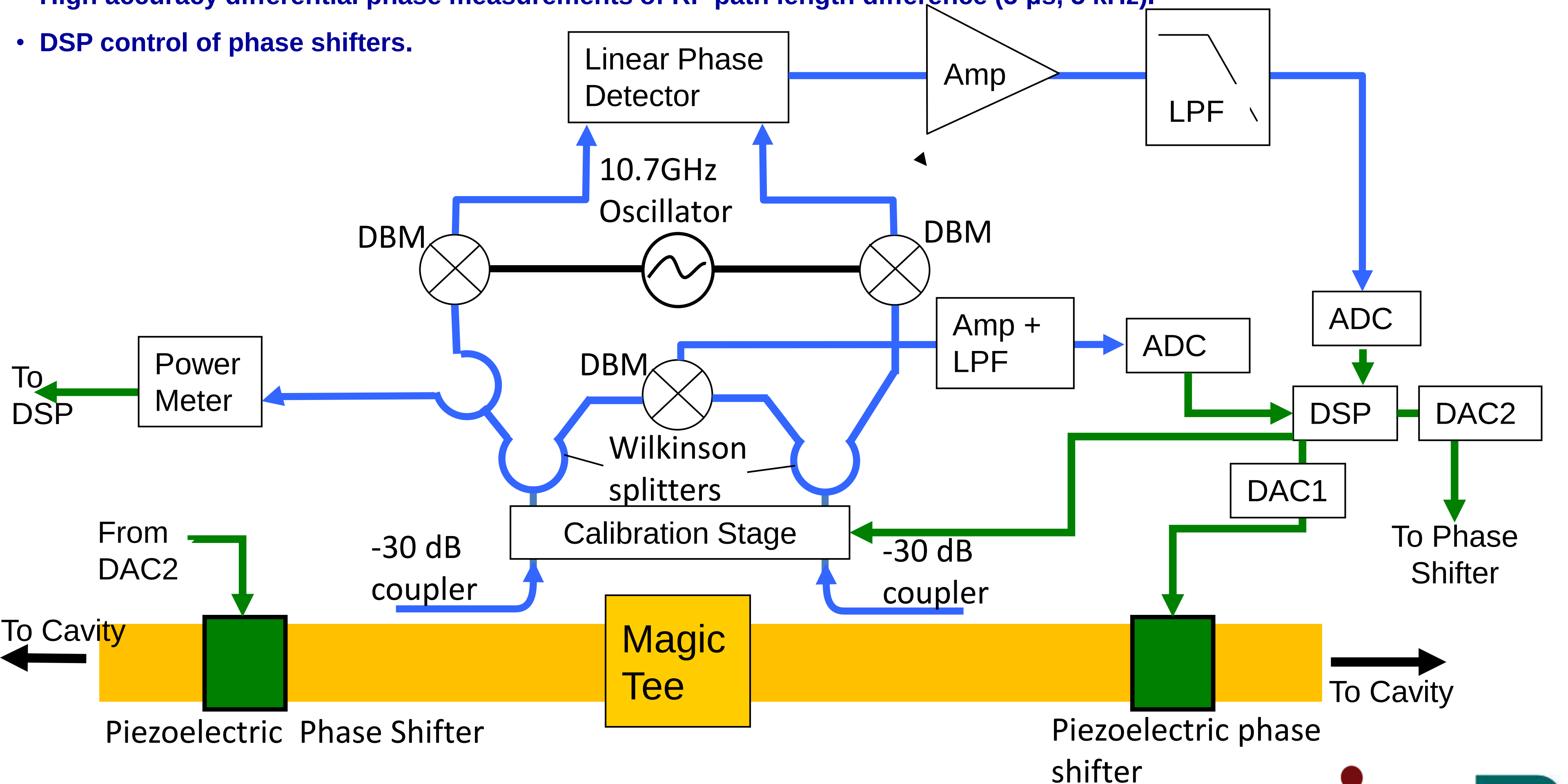
Synchronisation to main beam after booster linac. For a 21 km linac we have 140 ms between bunches leaving the booster and arriving at the crab cavities.

RF path length measurement



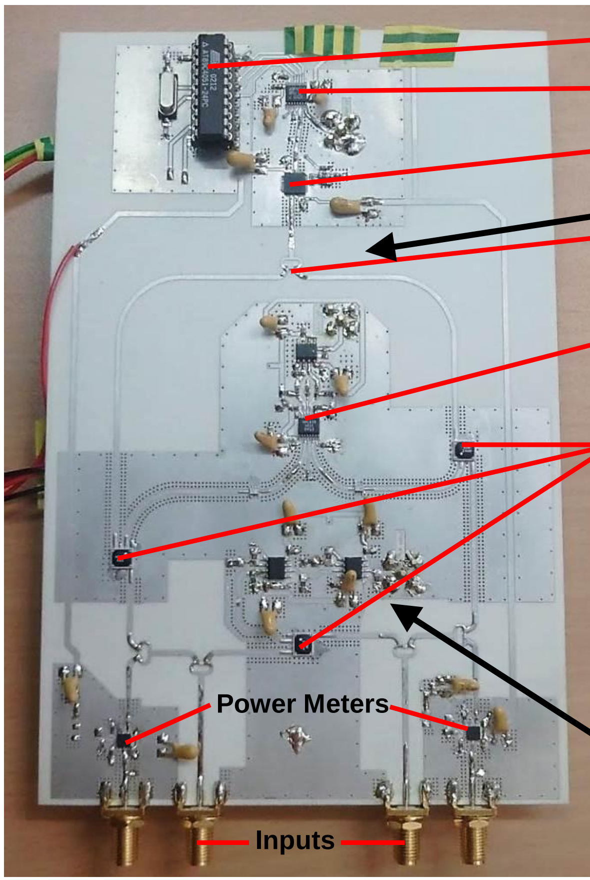
LLRF Hardware Layout

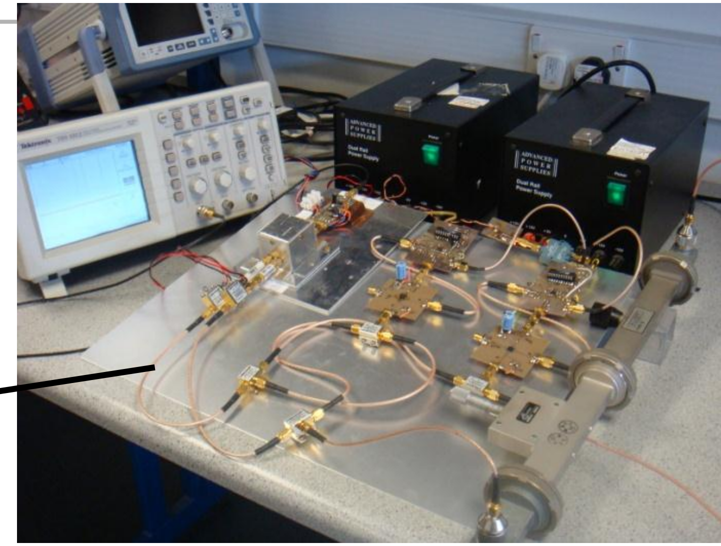
- **Fast phase measurements during the pulse (20-30 ns).**
- **Full scale linear phase measurements to centre mixers and for calibration.**
- **High accuracy differential phase measurements of RF path length difference (5 μs, 5 kHz).**
- **DSP control of phase shifters.**

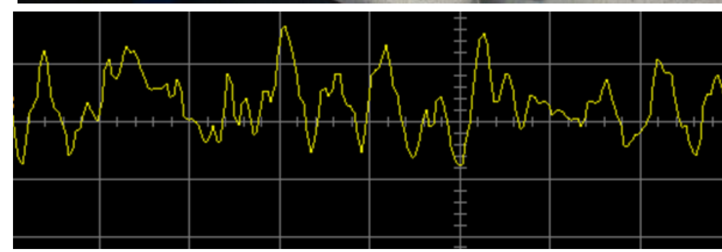


Analogue Board Development

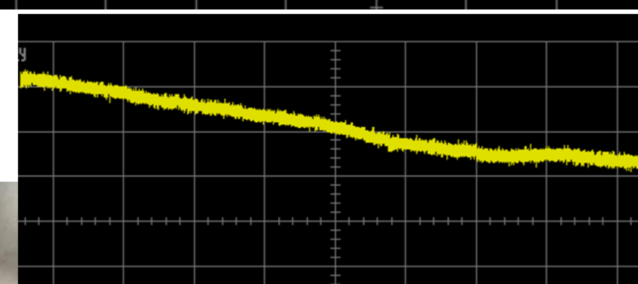
Front end electronics to enable phase to be measure during the short pulses to an accuracy of 2 milli-degrees has been prototyped and dedicated boards are being developed.





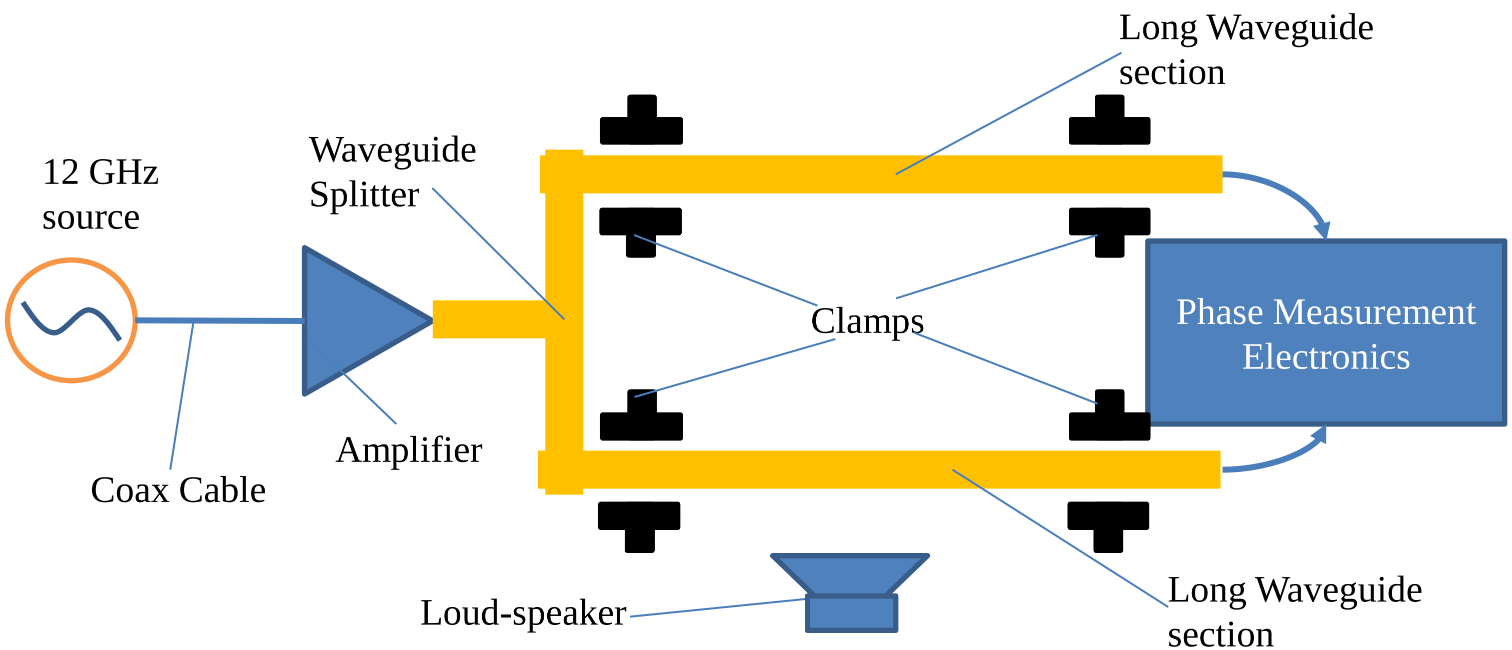


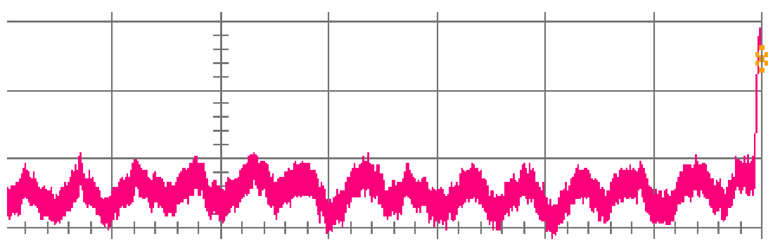
400 ns span:
RMS: 1.8 mdeg
Pk-Pk: 8.5 mdeg



90 s span:
Drift rate : 8.7 mdeg/10s
Total drift: 80 mdeg

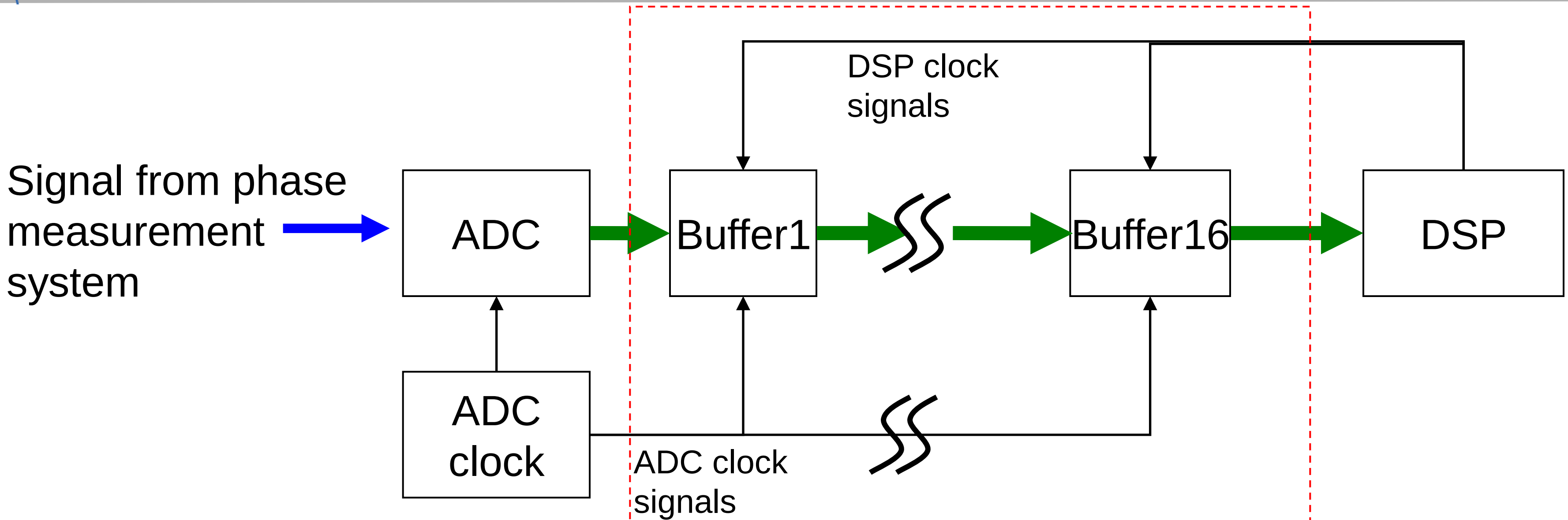
Waveguide Stability Experiments

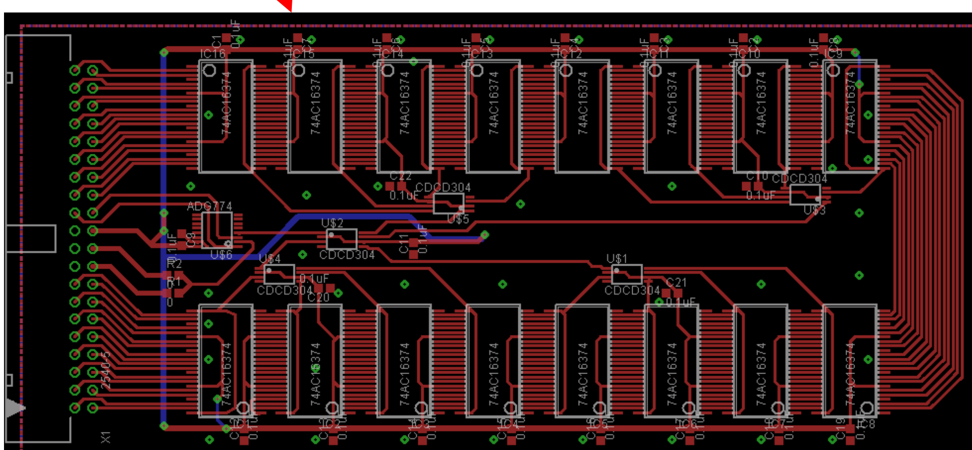




1 kHz sine wave from 1 W RMS speaker detected as a 25 milli-degree pk-pk phase variation.

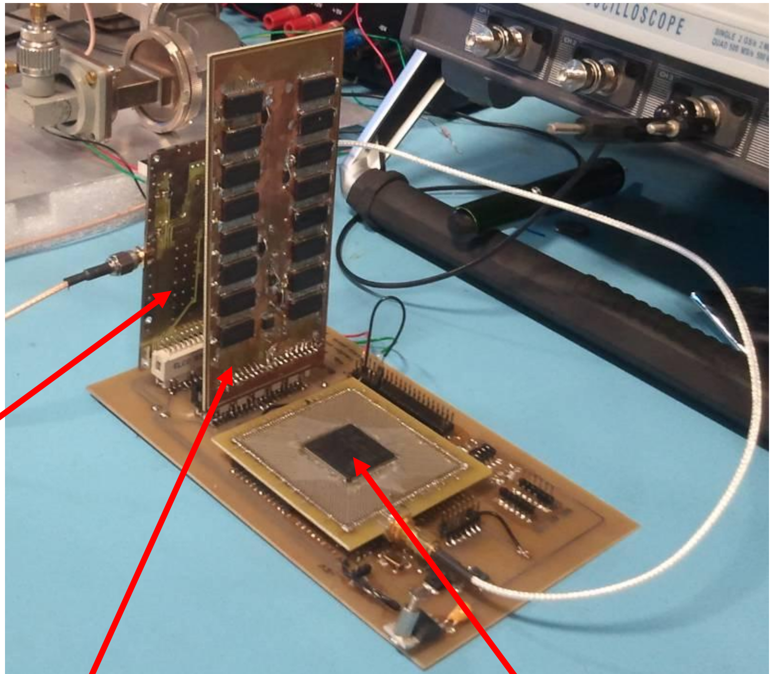
ADC+DSP scheme

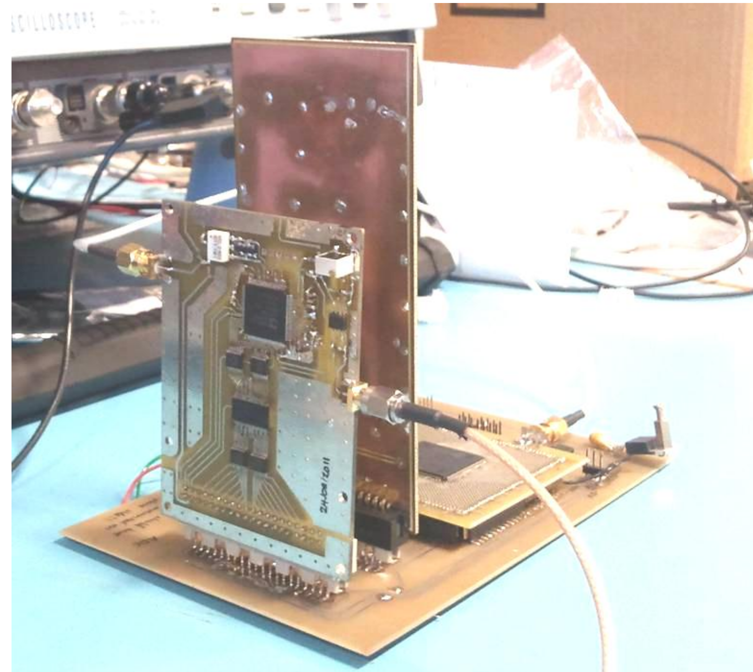




- Use DSP as opposed to FPGA for increased flexibility, due to low duty cycle DSP is fast enough.
- Sixteen, 16-bit D flip-flops store data coming from a single ADC controlled by the ADC's clock. The system then uses pulses from the DSP to shift the data once it has been read and processed.

Sampling Boards





System has been manufactured and implemented with 13 noise free bits. Multiplexer is available for increased I/O.

Future

- Comprehensive investigation into phase stability of X-band klystrons using the 12 GHz stand alone test stand at CERN. (50MW XL5, Scandinova Modulator)
- Development of feed-forward and/or feedback system to stabilise the klystron's output.

- Continued development of electronics to obtain stand alone phase measurement/correction system.
- Design/procurement of the waveguide components needed.
- Demonstration RF distribution system, with phase stability measurements. Stand alone or parasitic on CTF-3 dog leg?

- Measure phase noise across the prototype cavity during a high power test.

Summary

- Requirements for synchronisation have been established
- Synchronisation scheme(s) to meet specification has been formulated
- Prototyping of electronics for necessary phase measurements/correction
- Co-ordinated effort on the synchronisation scheme with CERN
- Future high power experiments outlined

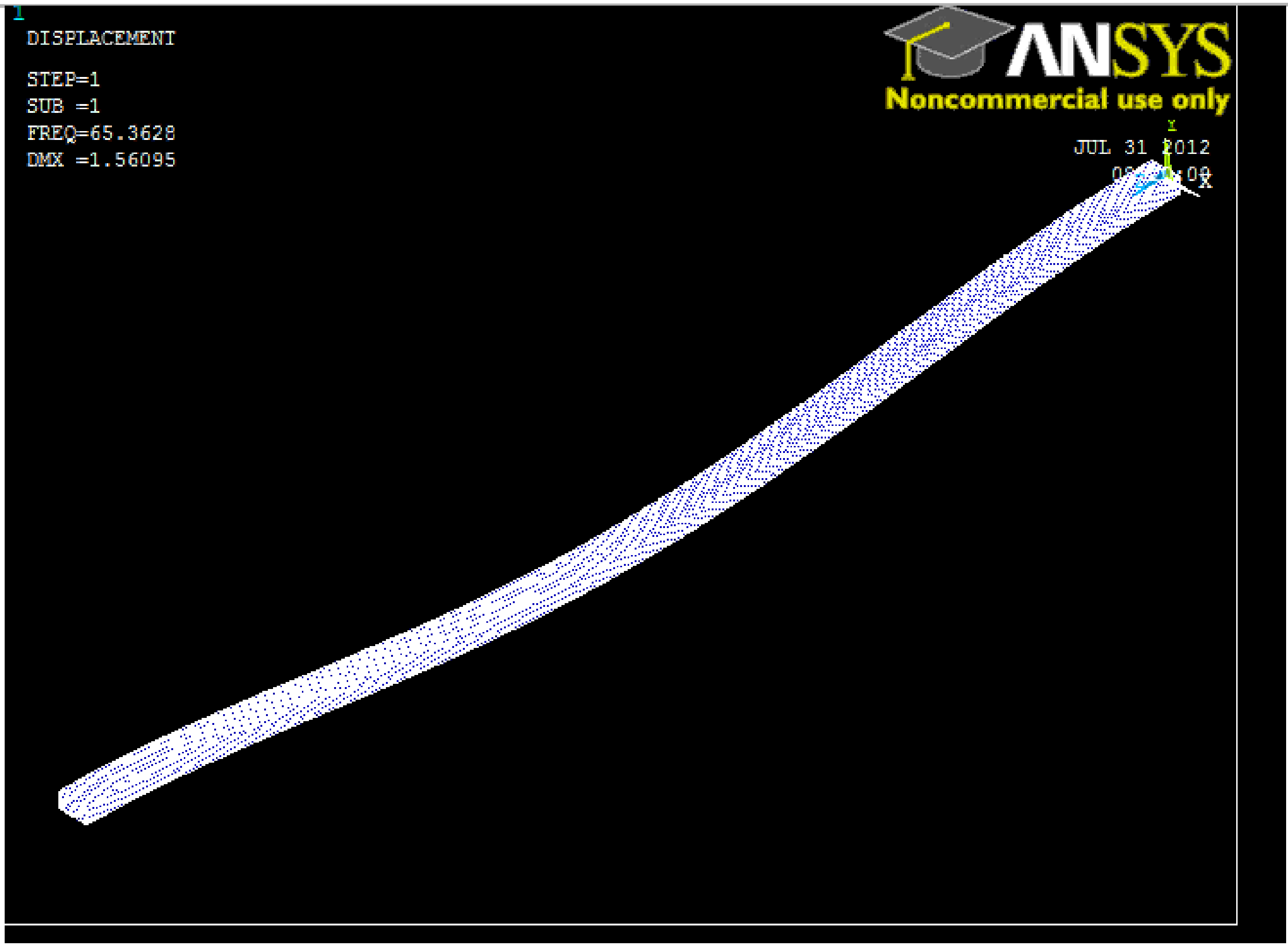
Klystron phase and amplitude control	Passive + active feed forward during 156 ns bunch train
Phase synchronisation (4.4 fs)	1)Same klystron drives both cavities, stabilized waveguide 2)Separate, stabilised klystrons for each cavity.
Phase measurement	Calibration stage and DBM. Down conversion to ~ 1 GHz, with digital phase detection.
Waveguide phase correction	DSP correction system with waveguide trombone phase shifters. (Choke mode flange).

Extra Slides

Waveguide Stability Model

Use ANSYS to find "dangerous" modes of vibration for a 1 m length of waveguide fixed at both ends.

Fundamental mode 65.4 Hz



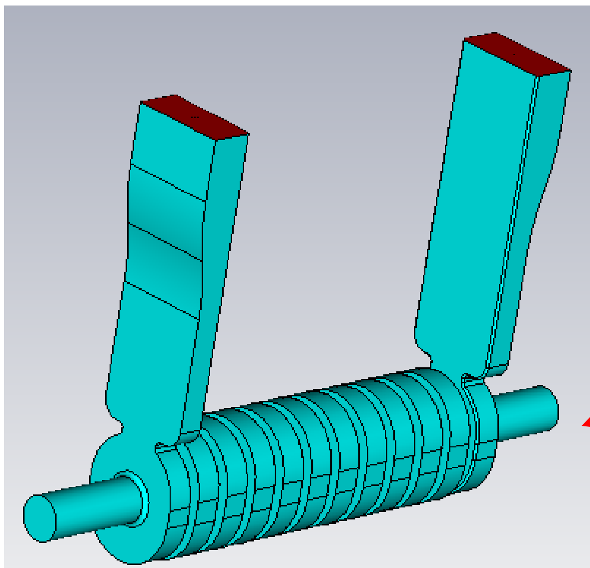
Planned CLIC crab high power tests

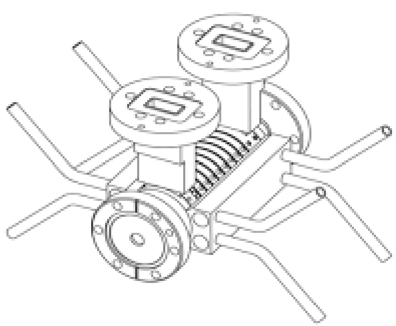
Travelling wave 11.9942 GHz

phase advance $2\pi/3$

TM110h mode

Input power ~ 14 MW





Test 1:
Middle Cell Testing – Low field coupler, symmetrical cells. Develop UK manufacturing.

Test 2:
Coupler and cavity test – Final coupler design, polarised cells, no dampers. Made with CERN to use proven techniques.

Test 3:
Damped Cell Testing – Full system prototype