High precision phase monitoring

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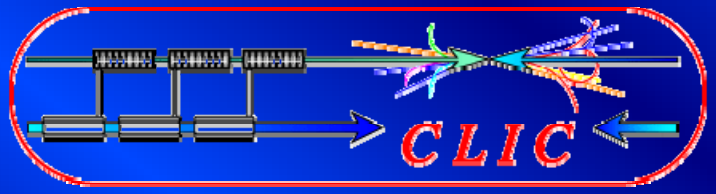

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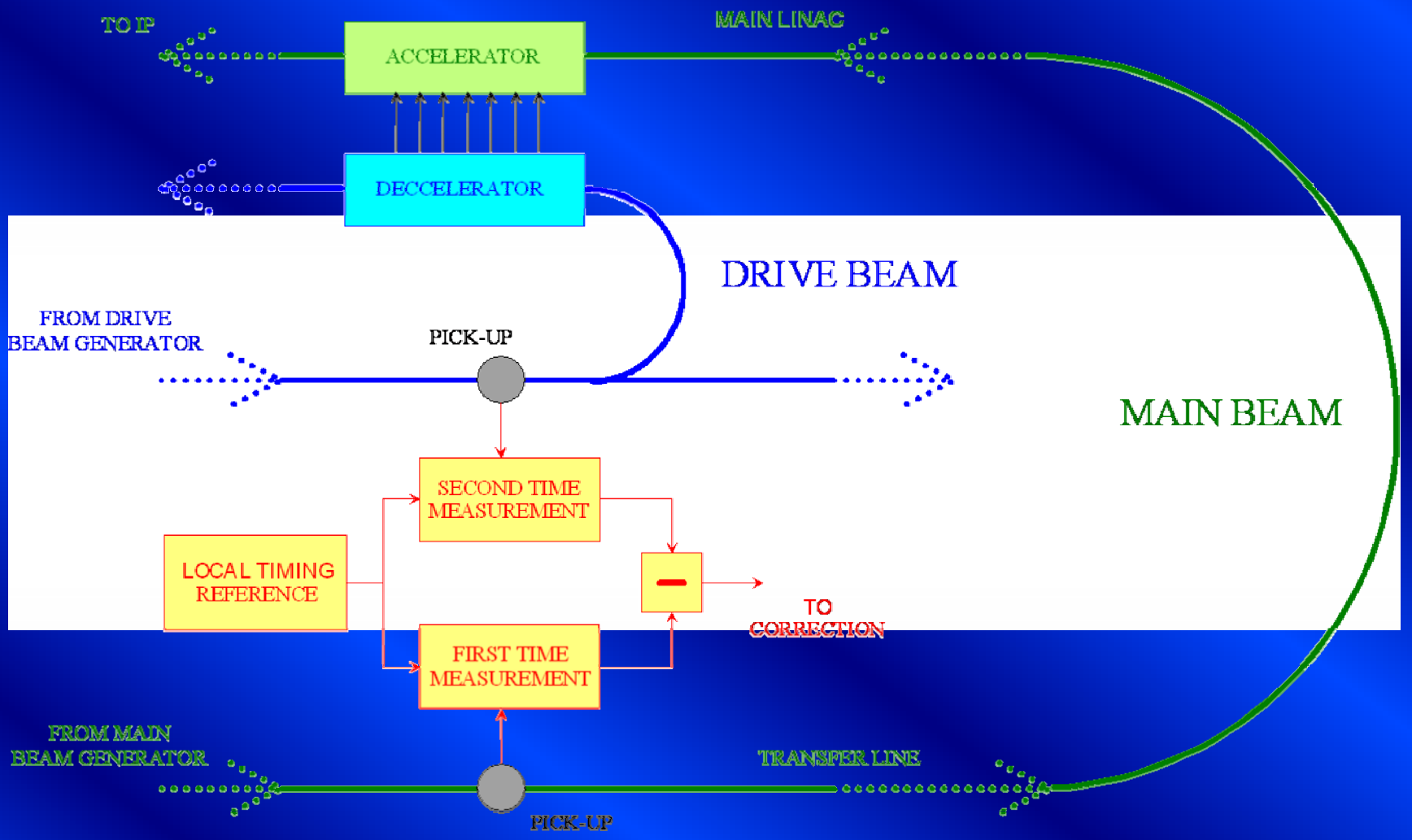
Phase errors

- Beam dynamics studies show that a phase error between the main beam and the accelerating RF of more than 0.1° will yield an unacceptable luminocity reduction
- A large quantity of phase jitter sources in the power production chain ensures that this limit will be well exceeded
- A need for phase error correction has been identified

Phase detection scheme in CLIC



Keeping time

- The local nature of the phase measurement obliterates the need for a global high-precision phase reference
- Due to the time difference of the passing of the two beams (92μs) the local oscillator must be stable to around 5fs for this duration

Low noise microwave source

- Jitter 10kHz to 50MHz from carrier:
  - Best commercial synthesizer 15fs
  - Best dielectric resonator 6fs
  - Sapphire loaded cavity oscillator 3fs
- For long term stability, locked to a reference:
  - Cesium standard
  - GPS-controlled quartz
  - CLIC master oscillator through reasonably stable distribution line

Phase detection

- Specifications
  - Single-shot
  - ± 50-100MHz bandwidth
  - 0.1 degree resolution
  - Limited linear range OK
  - Amplitude range 6dB?

Phase detection

- Mix down to some intermediate frequency and then
  - ADC
    - 2005 < 1 degree, 2007 < 0.25 degree
  - Analogue mixer
    - amplitude dependence very strong
    - (~ 0.1 degree for 1%)
  - Analogue multiplier
    - amplitude dependence
    - noisy (~ 0.2 degree RMS in 50 MHz)

Intermediary Frequency selection

- Devices tested at 250MHz and 750MHz as these frequencies are readily available in CTF3
- Devices found to have good performance at both frequencies
- 750MHz selected as downconversion is more easily implemented with a higher frequency

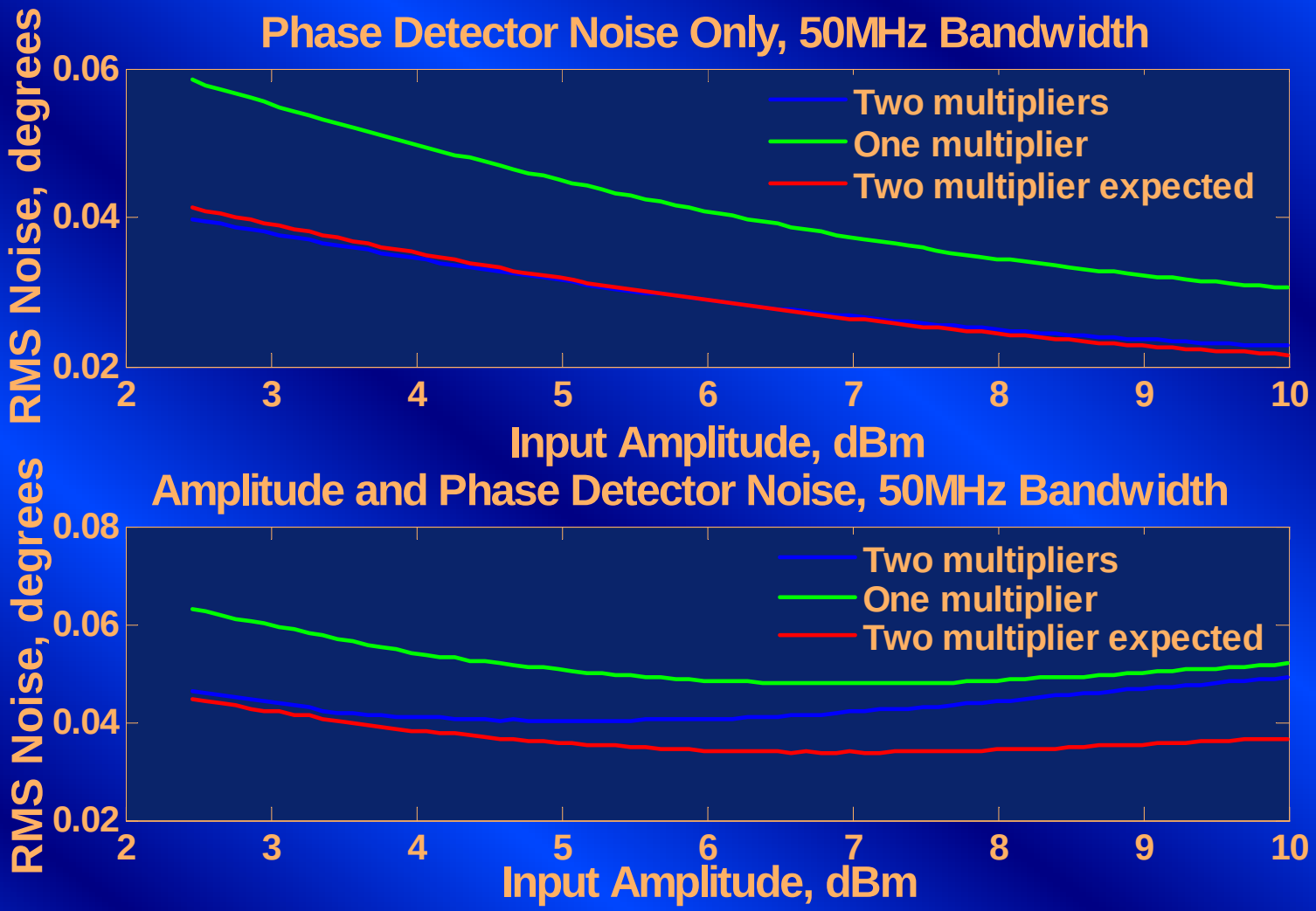
IF tests

- Two phase detectors:
  - Analog multiplier Analog Devices AD835
  - Double balanced mixer Mini-Circuits ZFM-2000
- Amplitude detector:
  - Analog devices AD8318
- Measure phase detector output and amplitude detector output
- Fit to input phase using polynomial of 3rd order in and first order in

Noise

- Two sources of noise, amplitude and phase detectors
- Averaging both amplitude and phase detectors necessary.
- Averaging 2 phase detectors yields the expected improvement

Noise plots


Phase Detector Noise Only, 50MHz Bandwidth
RMS Noise, degrees
0.06
0.04
0.02
2
3
4
5
6
7
8
9
10
Input Amplitude, dBm
Two multipliers
One multiplier
Two multiplier expected
Amplitude and Phase Detector Noise, 50MHz Bandwidth
RMS Noise, degrees
0.08
0.06
0.04
0.02
2
3
4
5
6
7
8
9
10
Input Amplitude, dBm
Two multipliers
One multiplier
Two multiplier expected

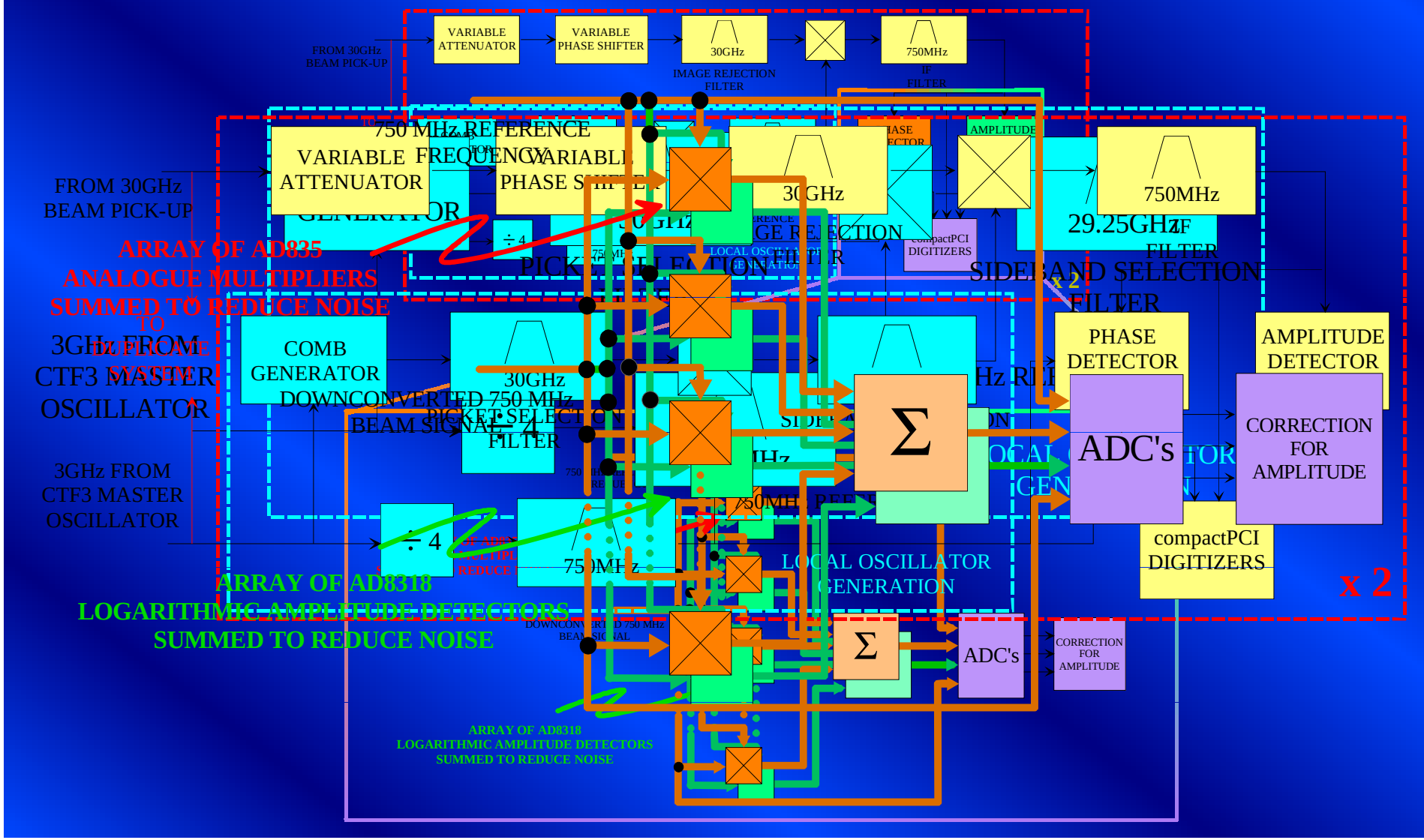
PCB

- More than two of both multipliers and amplitude detectors must be averaged for adequate noise reduction
- PCB has been designed 8 amplitude detectors, 8 multipliers in parallel.
- Need to use power splitters as input impedances are too low for direct parallelization

CTF test setup

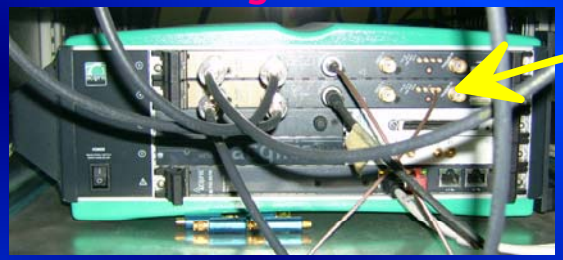
- 30GHz signal is mixed down to 750MHz
- CTF3 beam jitter greatly exceeds the required system accuracy
- Two system are built and compared with each other
- 30GHz reference is generated from CTF3 3GHz timing signal, which is common for both systems
- As the performance with standalone oscillator is not indicated to present a difficulty, the extreme price for such crystals prohibits their acquisition.

IF Downconversion

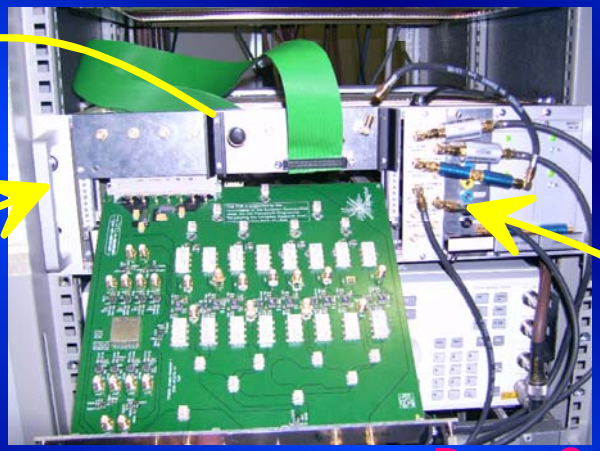


CTF3 installation

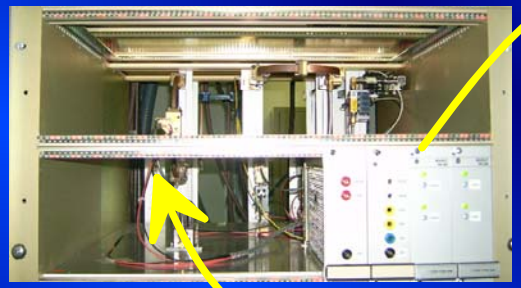
Digitiser



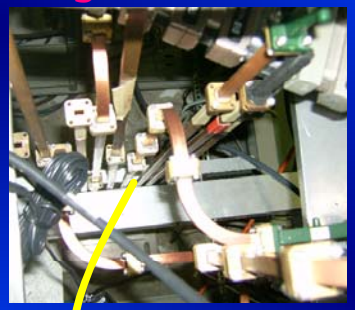
IF detectors



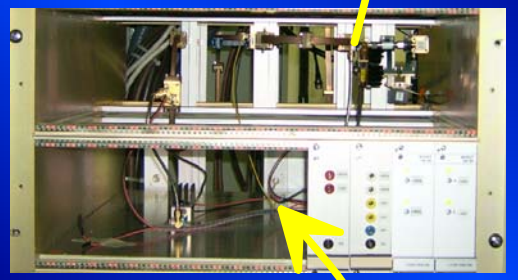
Down Converter



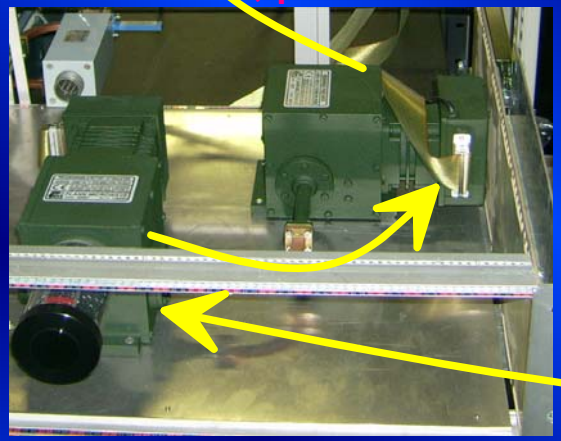
Waveguides from CTF3



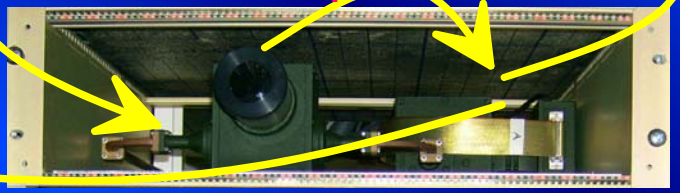
Down Converter



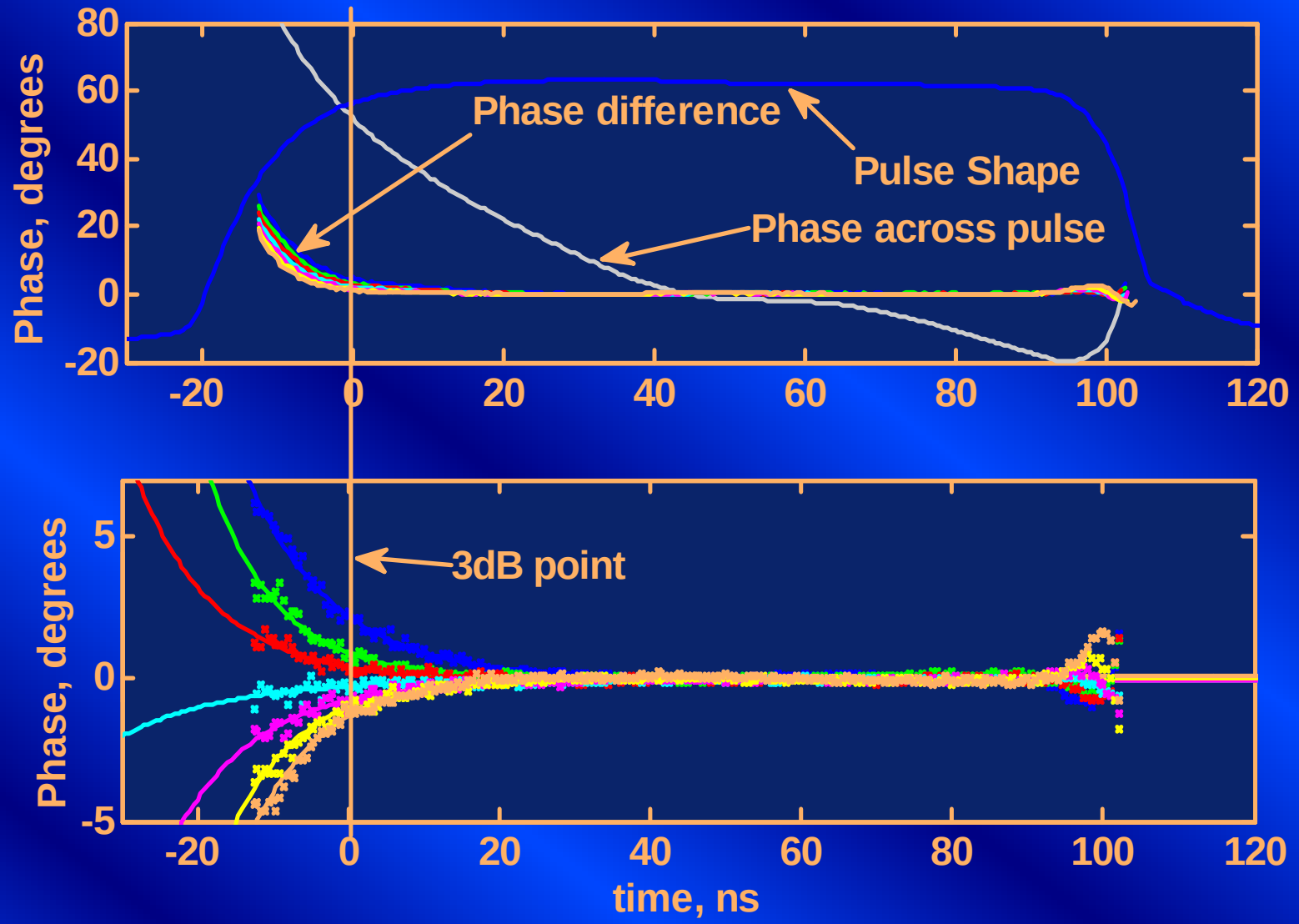
Attenuator, phase shifter



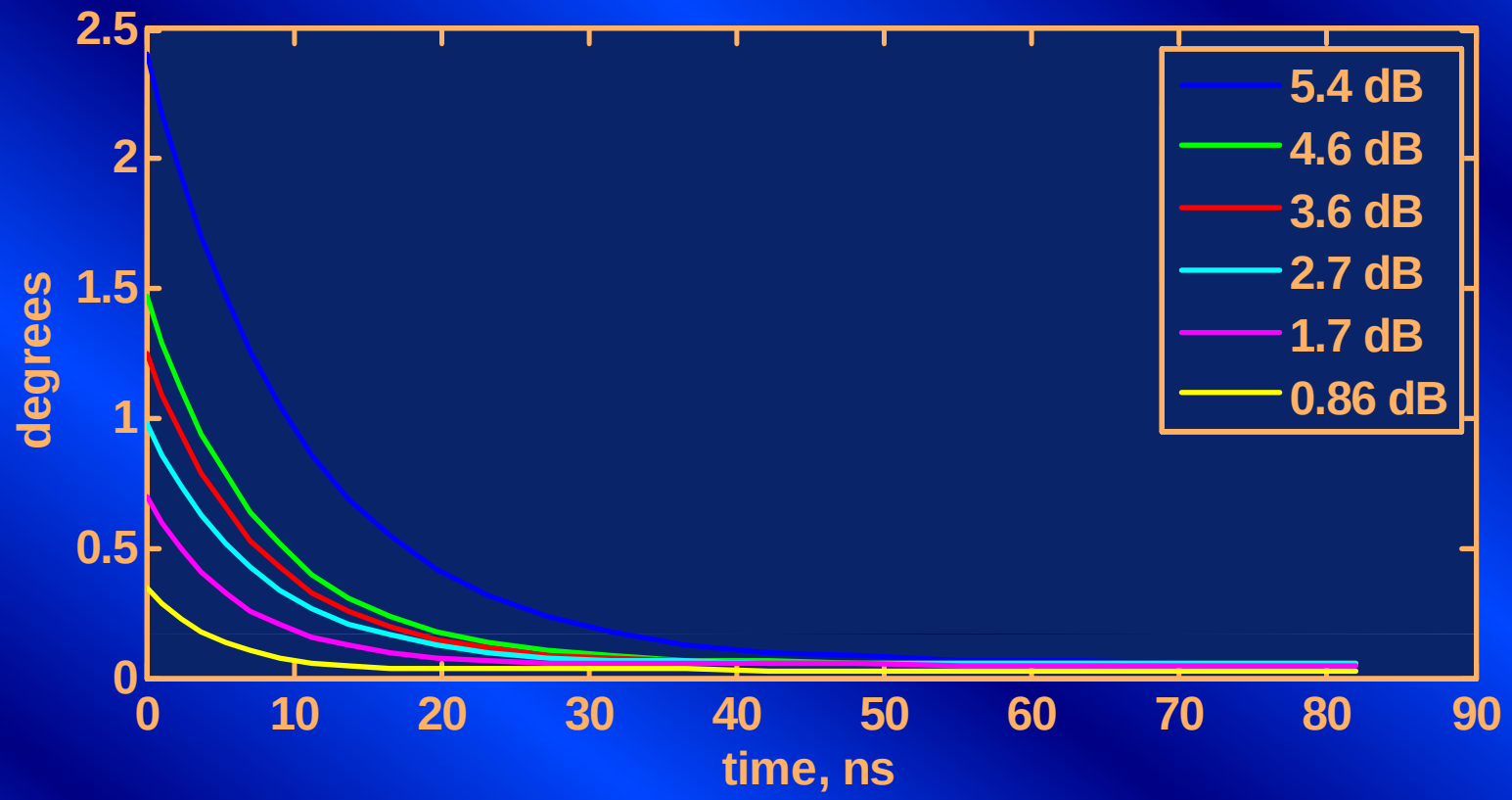
Attenuator, phase shifter



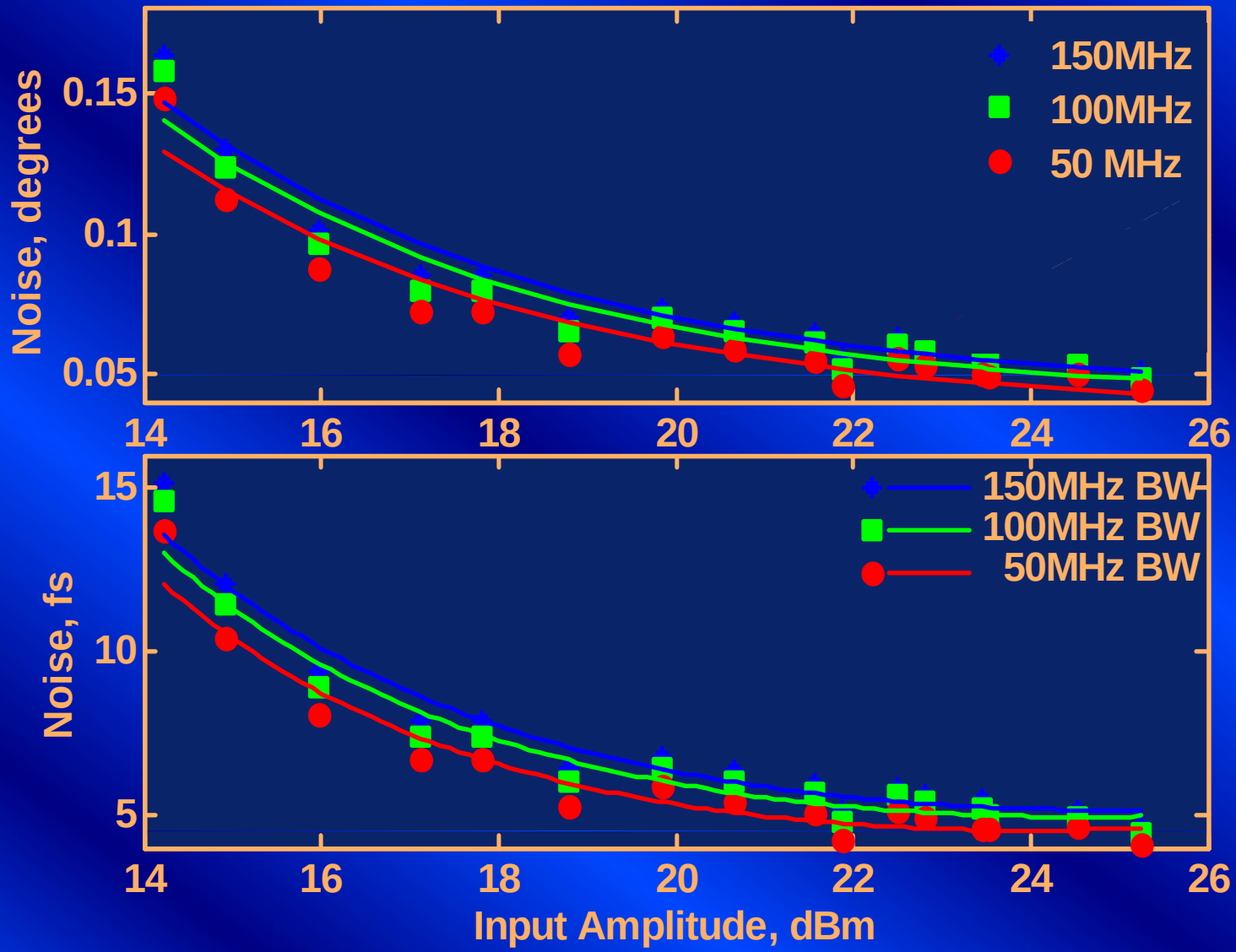
CTF3 measurements



CTF3 results
Pulse errors, by amplitude range



CTF3 results – Noise



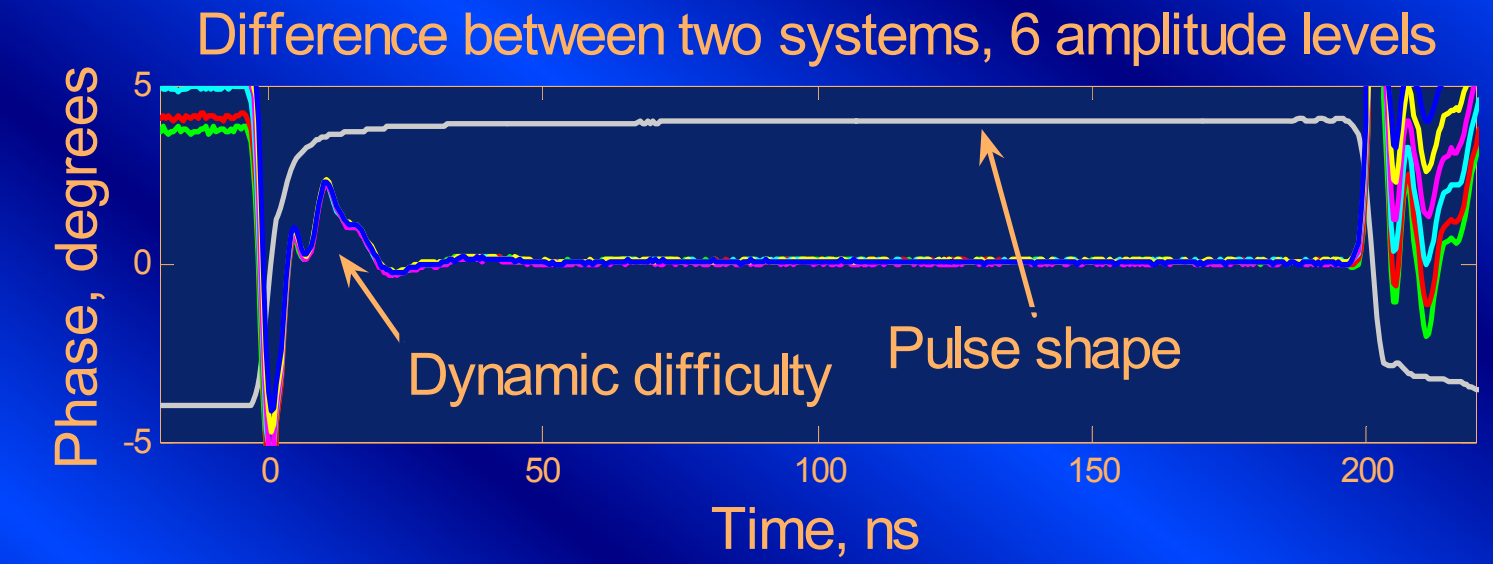
CTF3 results, conclusions

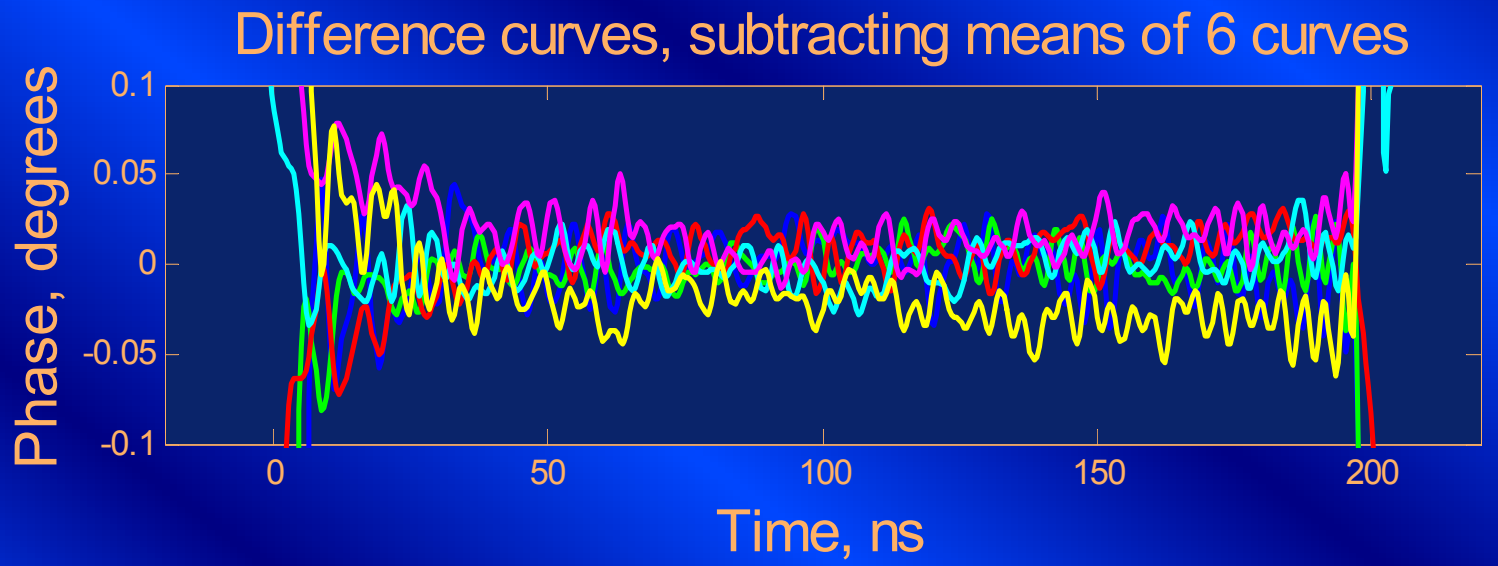
- The required low-noise performance as demanded by CLIC has been well demonstrated in CTF3 beam test.
- The two system's alignment has also been well shown, despite difficult beam conditions with phase variations across the pulse vastly exceeding the specifications of the system.
- Many thanks to CTF3 operations team for working to provide as good conditions as possible

‘Static’ Calibration

- Due to the amplitude dependence of the phase detector, a ‘static’ calibration must be performed to interpret results over a range of amplitudes
- This ‘static’ calibration is done with 100ns RF pulses over a range of amplitudes, using average values over a 30ns interval towards the end of the pulses
- It cannot be done in a non-pulsed system, due to discrepancies most likely due to device heating.
- The duty cycle of the calibration pulses must be sufficiently low to not alter the average device power too much

Static Calibration, results





Dynamic Calibration

- There is a difference between the two systems with a pulse input
- It will be necessary to characterize and correct this imperfection
- First (naïve) attempts to numerically compute a correction based on pulse shape have yielded a small improvement.
- Further study necessary

Dynamic modeling

- The main source of the problem is in the down converter (probably the mixer)
- Further work to localize the problem will be undertaken
- In order to fully characterize the dynamic limitations of the system, and possibilities for correction, modeling with a simulation program is necessary