High precision phase monitoring

Alexandra Andersson, CERN

Jonathan Sladen, CERN

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Timing jitter in CLIC [1]

Effects

- Drive beam phase and amplitude jitter give rise to main beam
  - Energy error
  - Emittance growth
- Leading to
  - Luminosity loss
  - Broadening of luminosity spectrum

Energy error from 0.15^0 coherent phase jitter gives 2% luminosity loss

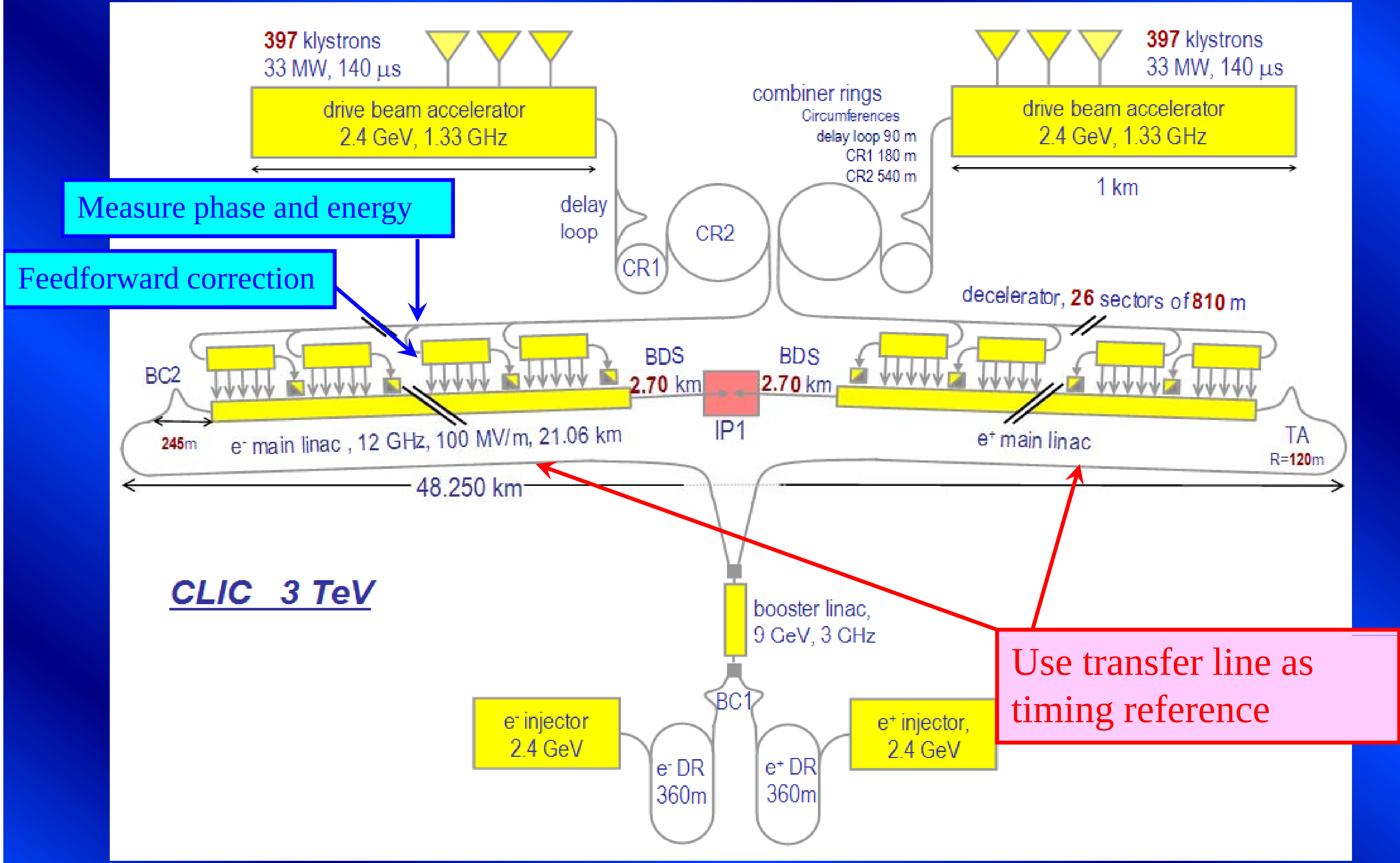
Drive beam phase jitter sources

- Injector timing
- Transverse jitter (→ time jitter by betatron motion)
- Path length changes
- Energy jitter (→ time jitter in pulse compressor)
- RF phase and amplitude stability
- Beam current

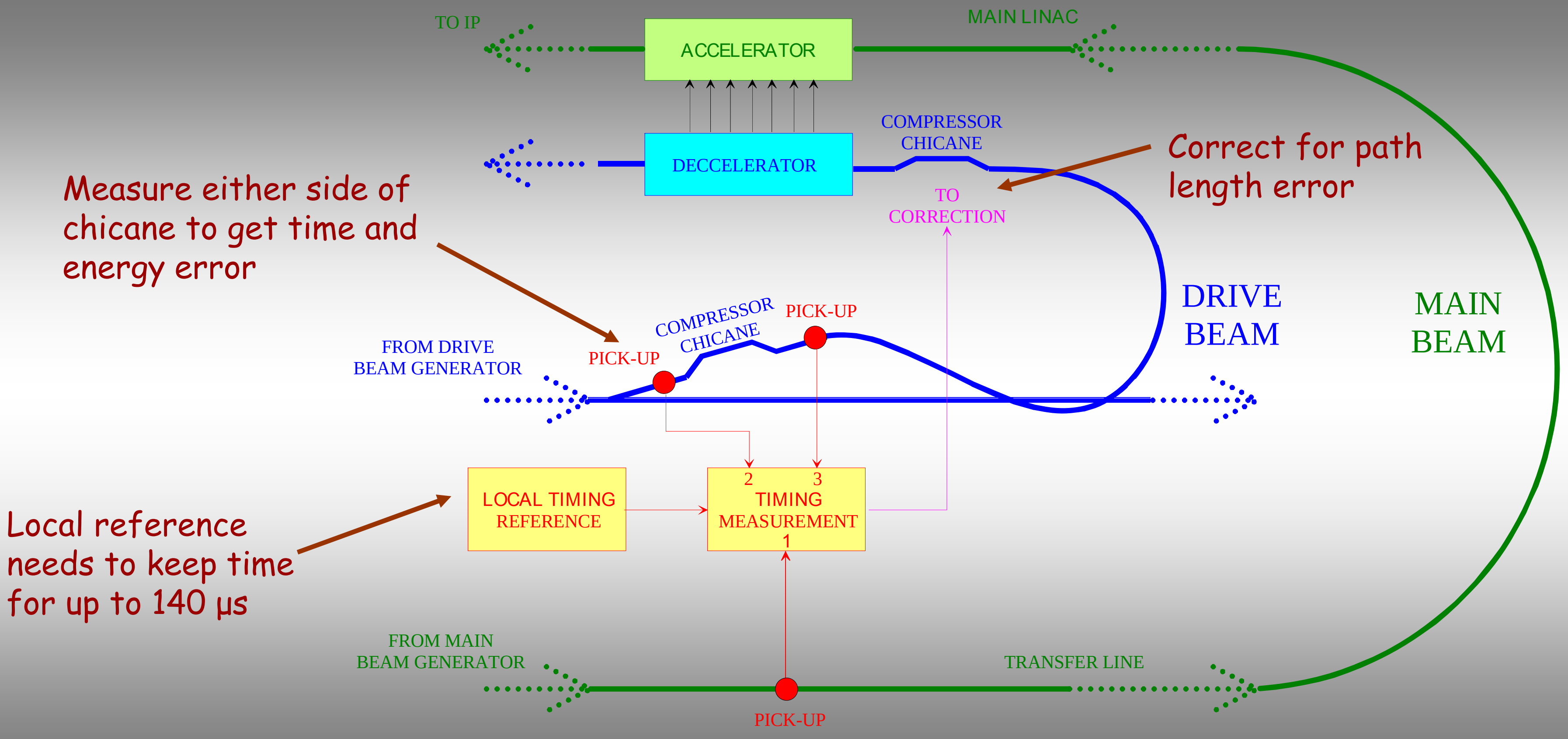
Need feedback and feedforward

[1] D. Schulte, E. J. N. Wilson, F. Zimmermann, "The impact of longitudinal drive beam jitter on the CLIC luminosity", CLIC Note 598, CERN

Need for stable reference line



Main beam as timing reference



- Can keep time locally with very good microwave oscillator to within 4 fs
- Local references should be locked to 'reasonably' stable reference line
- **Ability to measure beam with respect to reference is a key issue**

Developments for XFEL's

Jitter 10kHz to 50MHz from carrier:

- Best commercial synthesizer 15fs
- Best dielectric resonator 6fs
- Sapphire loaded cavity oscillator 3fs

Stabilized fibre links [1]

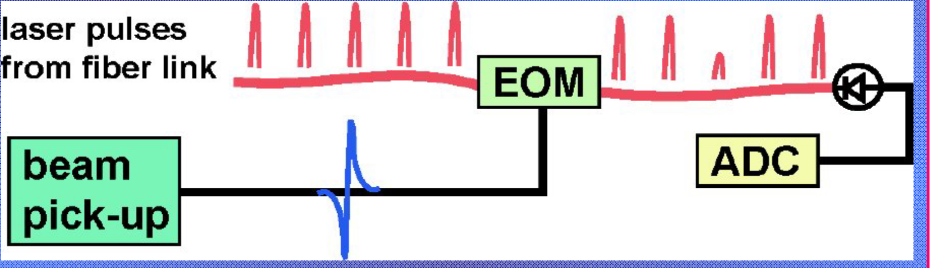
- 400m link, optical performance
  - 4.4fs short term jitter
  - 25fs drift in 24h

Optical to RF synchronization [2]

- 3fs (1Hz to 20MHz)

Electro-optical sampling [3]

- 30fs resolution



[1] 'Sub-10 femtosecond stabilization of a fiber link using a balanced optical cross correlator' J. Chen et al., PAC07
[2] 'Balanced optical–microwave phase detectors for optoelectronic phase-locked loops' J. Kim et al., Optics letters, 2006
[3] 'A Sub-50 fs bunch arrival time monitor system for FLASH', F. Loehl et al., DIPAC2007

Timing measurement at main linac frequency

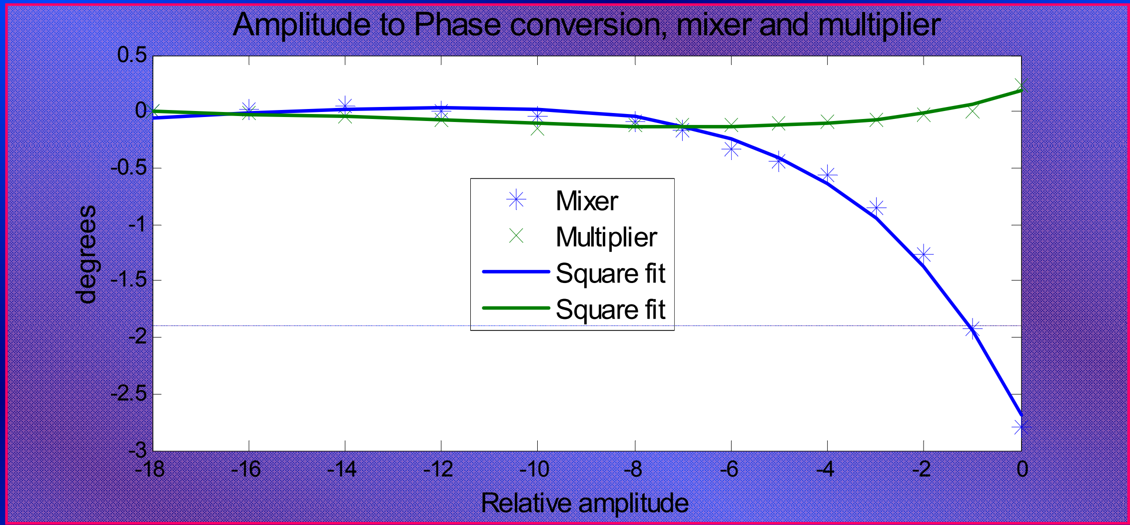
- ☺ Direct measurement of frequency component seen by main beam
- ☺ Will give precision measurement of drive beam amplitude
- ☹ Phase measurement challenging

Phase measurement requirements

- Single-shot
- Resolution
  - < 0.1 degrees for timing
  - < 0.03 degrees for energy measurement in drive beam bunch compressor
- Wideband (≥ ± 50MHz)
- Limited linear phase range OK (e.g. ± 5^0)
- Amplitude range? 6dB goal for development programme

Phase detection choices

Start by mixing down to a lower (intermediate) frequency (preserving phase) where suitable devices available.

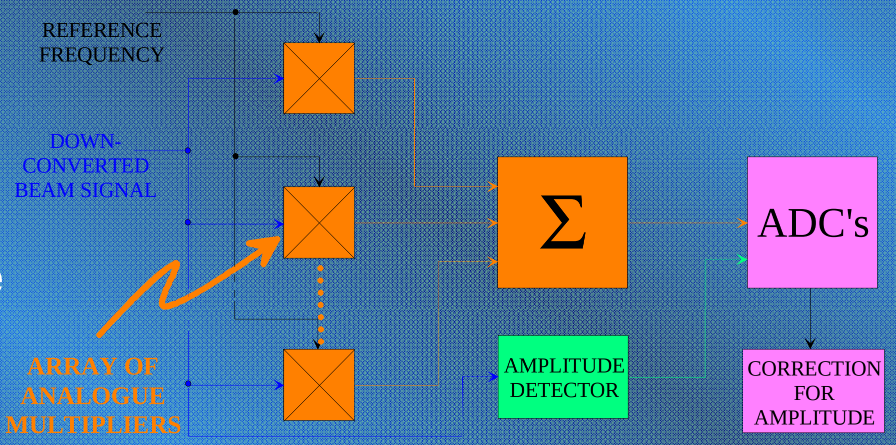


Analogue or digital detection

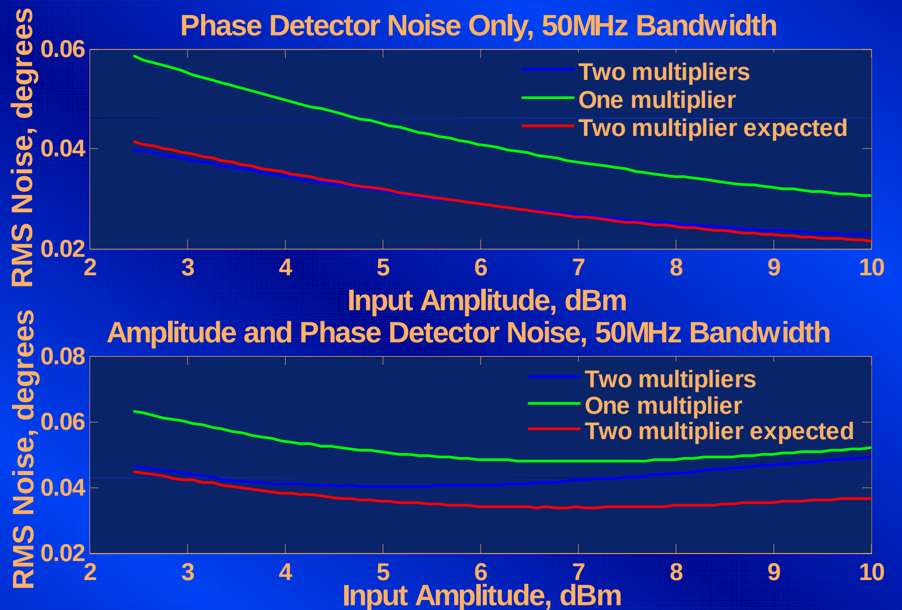
- Digital most convenient but too noisy for high bandwidth system
- Analogue mixer – very nonlinear
- Analogue multiplier – noisy but……….

Phase detection with summed multipliers...

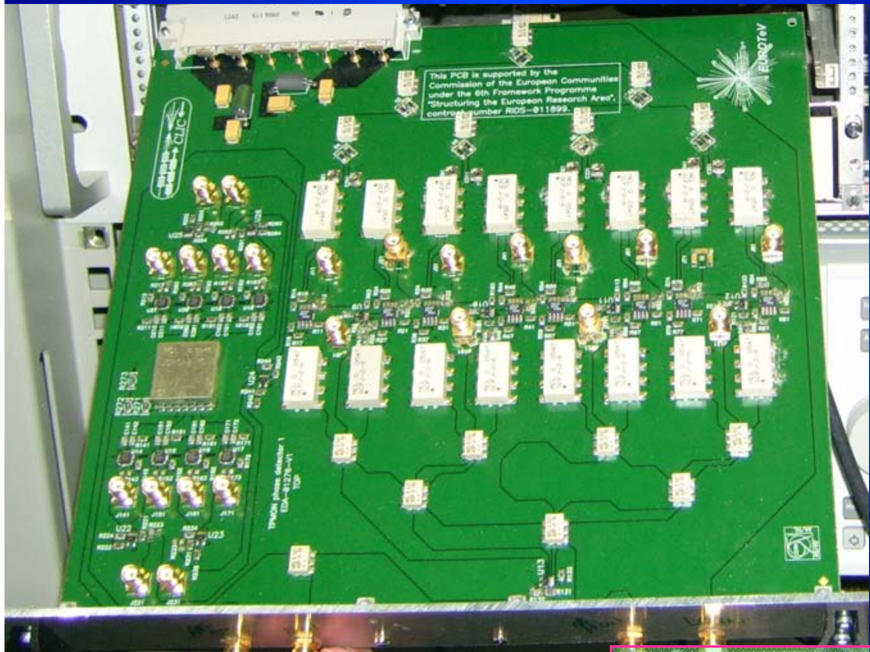
For better linearity, analogue multiplier chosen
Sum devices to reduce noise

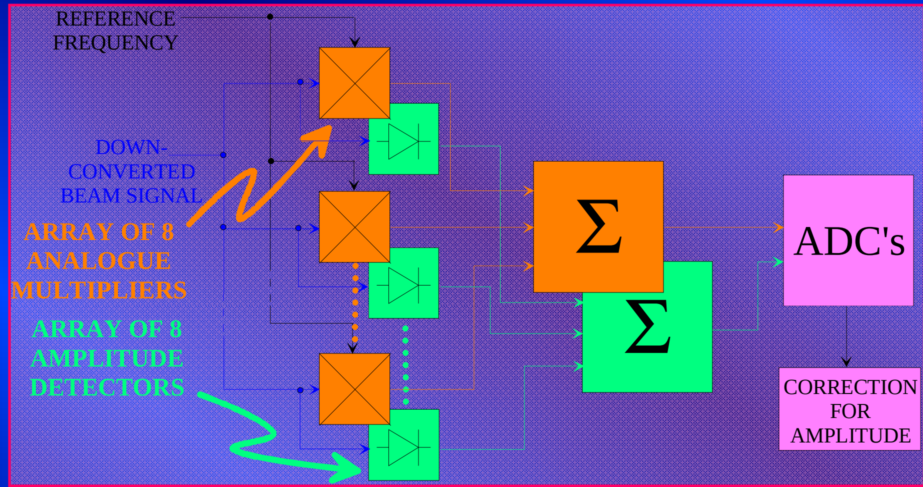


First tests were with two multipliers



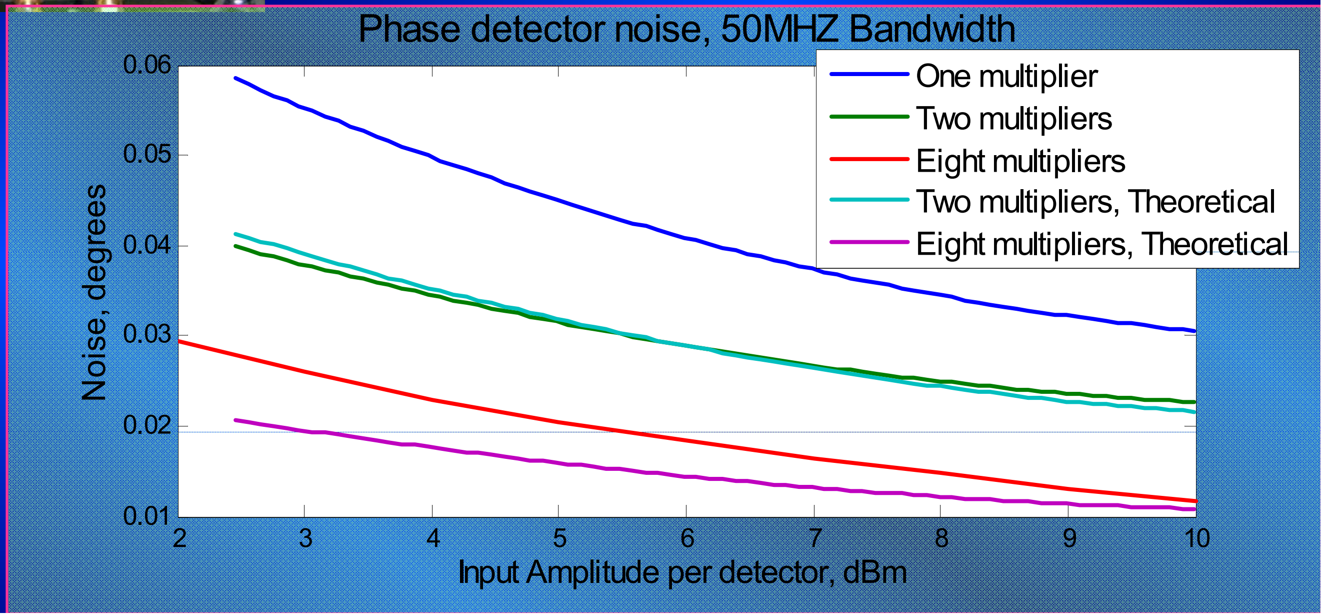
...but soon, more followed





Final version

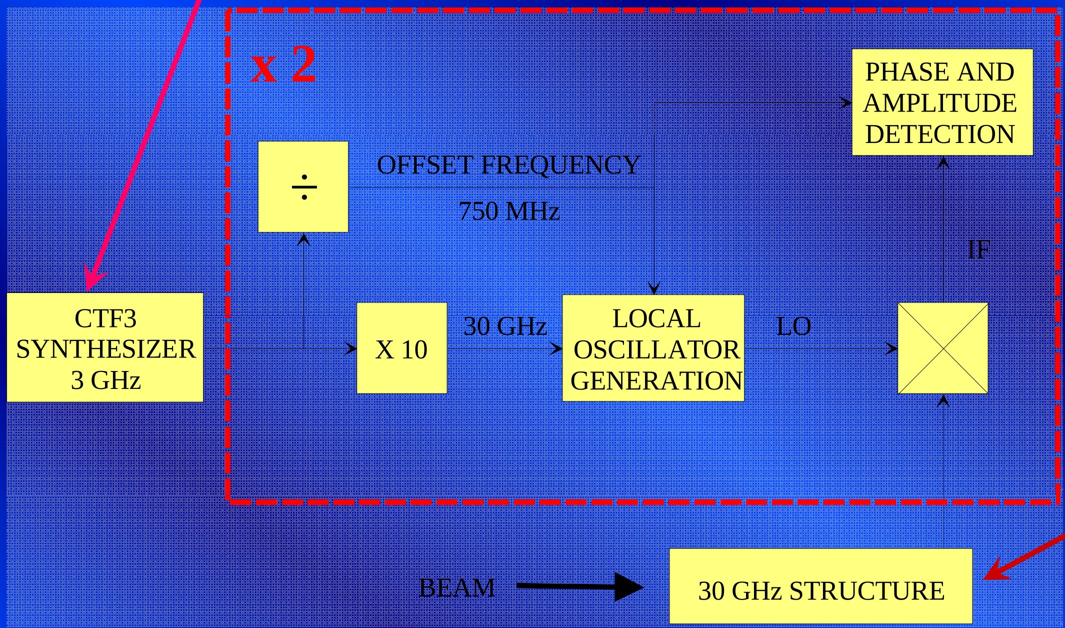
8 phase and 8 amplitude detectors summed on PCB



CTF test setup

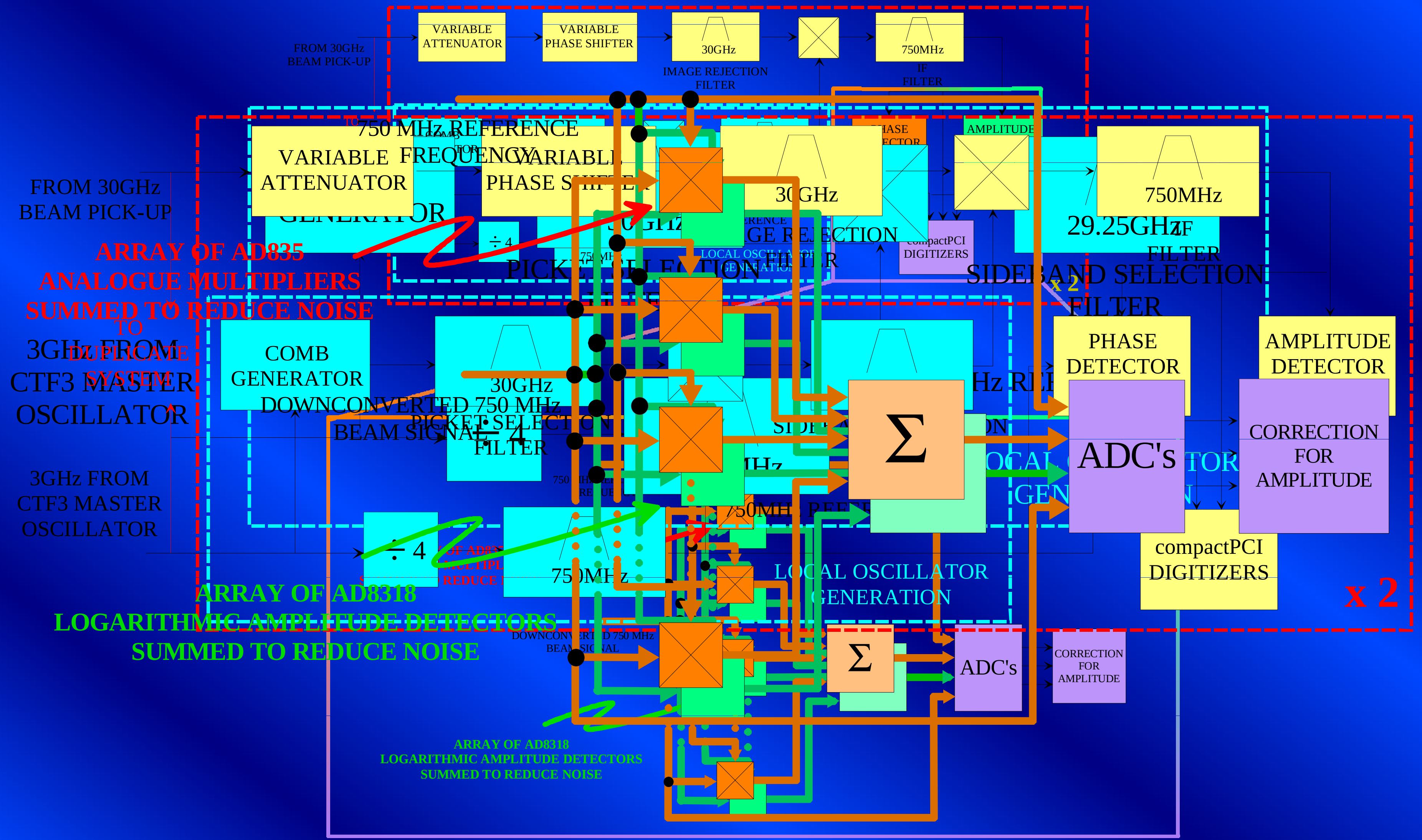
Common reference: obliterates the need for a prohibitively expensive crystal oscillator for prototype

- 30GHz signal is mixed down to 750MHz
- Because of CTF3 beam jitter two system are built and their outputs compared.

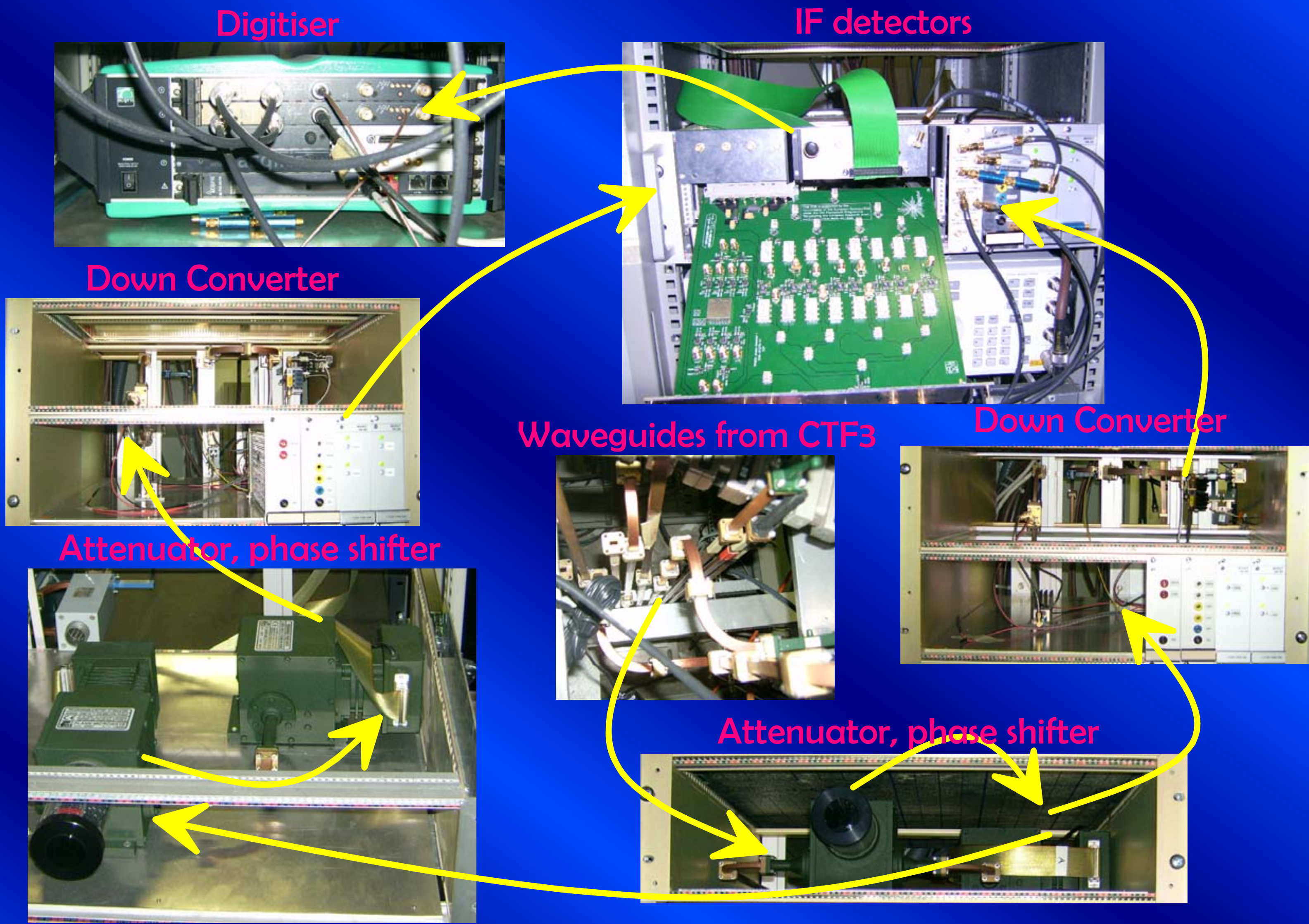


Pick-up: PETS structure

CTF test setup

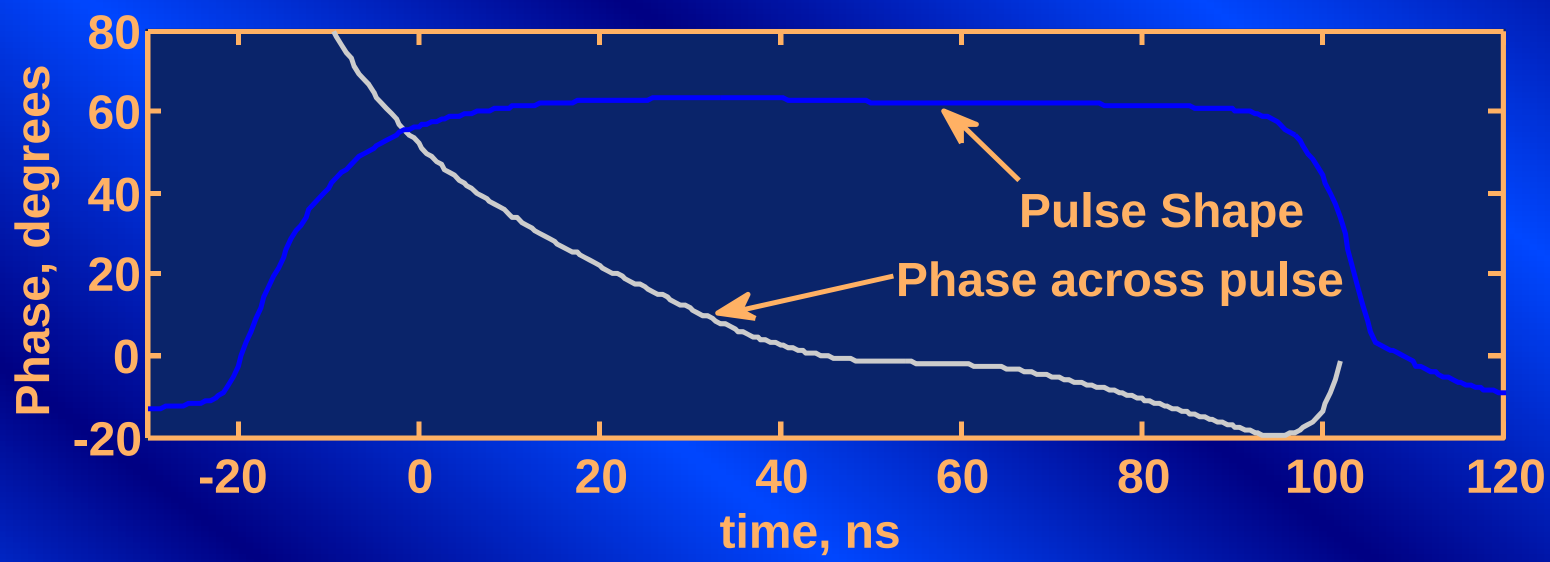


CTF3 installation

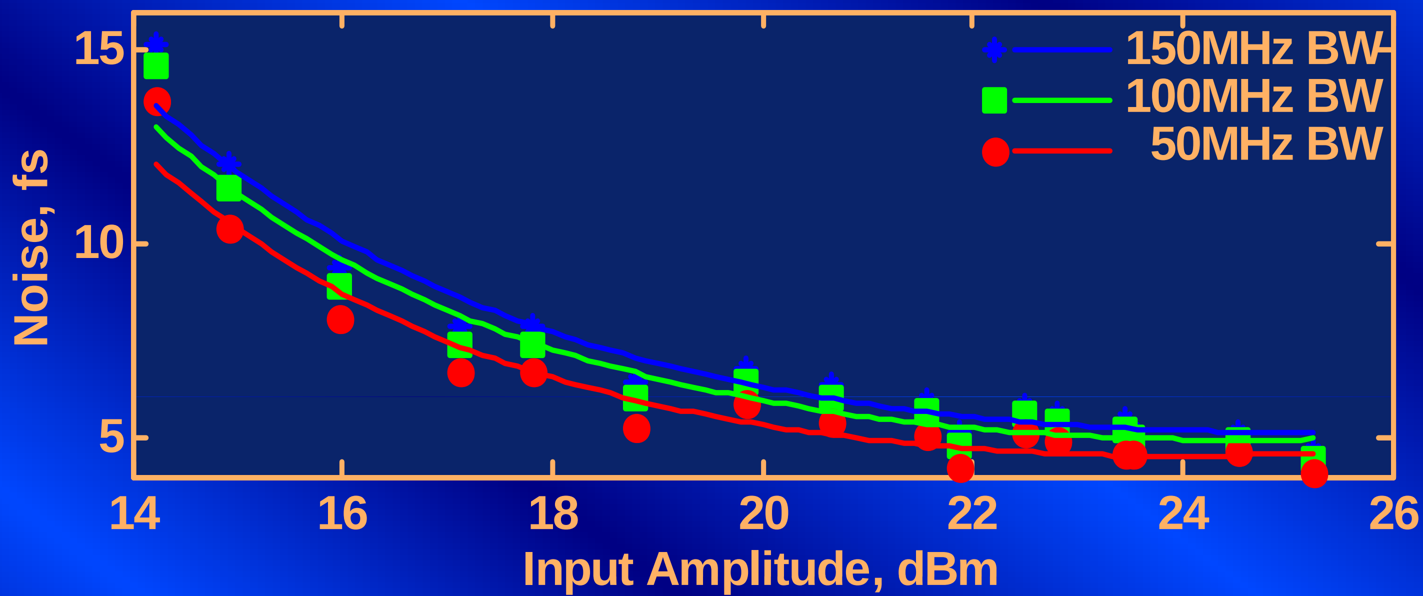


CTF3 measurements

- 100 ns long 3 GHz beam
- Large phase variation across pulse
- Jitter measurements over portion of pulse
- Pulse response data averaged
- Temperature drift (~110 fs /0C) removed from data

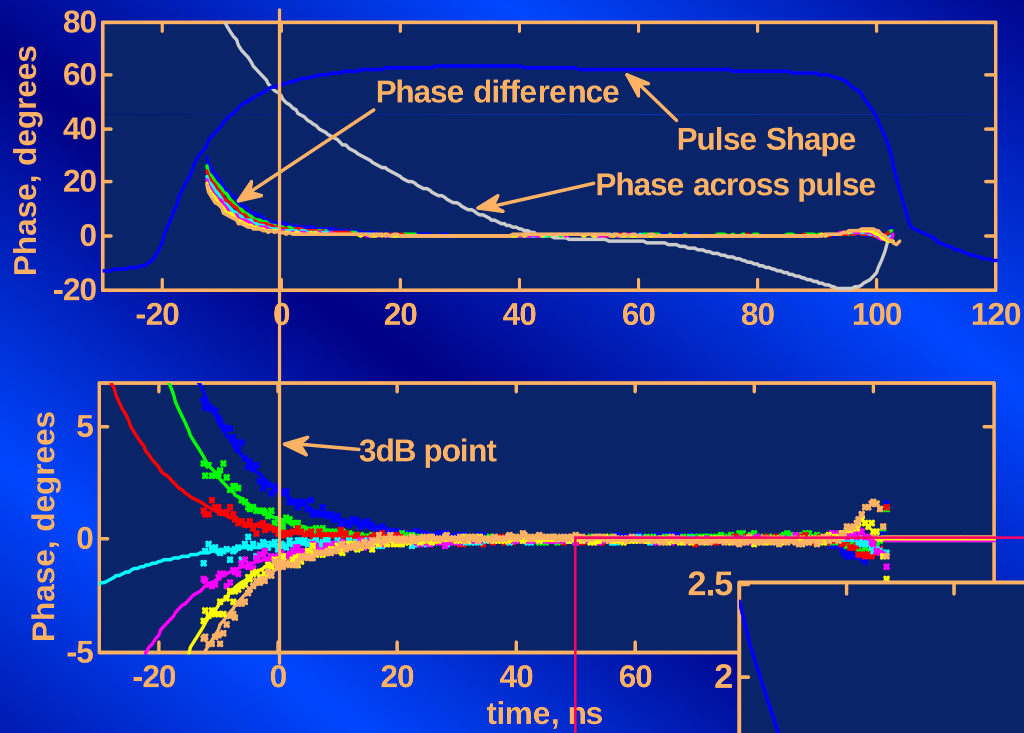


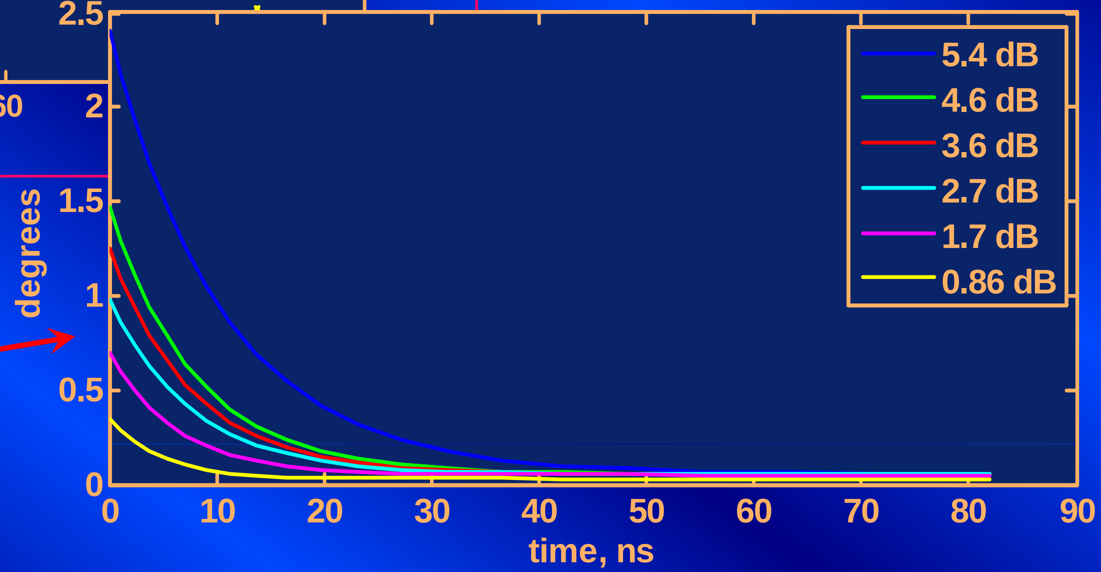
CTF3 results – Noise



- Shows 1/√2 jitter between two systems
- Includes noise from local oscillator, down conversion, phase detection, digitization and post-detection amplitude correction
- Common 3 GHz reference

CTF3 results: Pulse response





Alignment improves if amplitude range reduced

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 shown, despite difficult beam conditions.
- Many thanks to CTF3 operations team for working diligently and patiently to provide as good conditions as possible

Third order nonlinearities and AM to PM conversion

Instantaneous nonlinearity

$$V_{in}(t) = V_0 \sin(\omega_0 t + \phi(t))$$

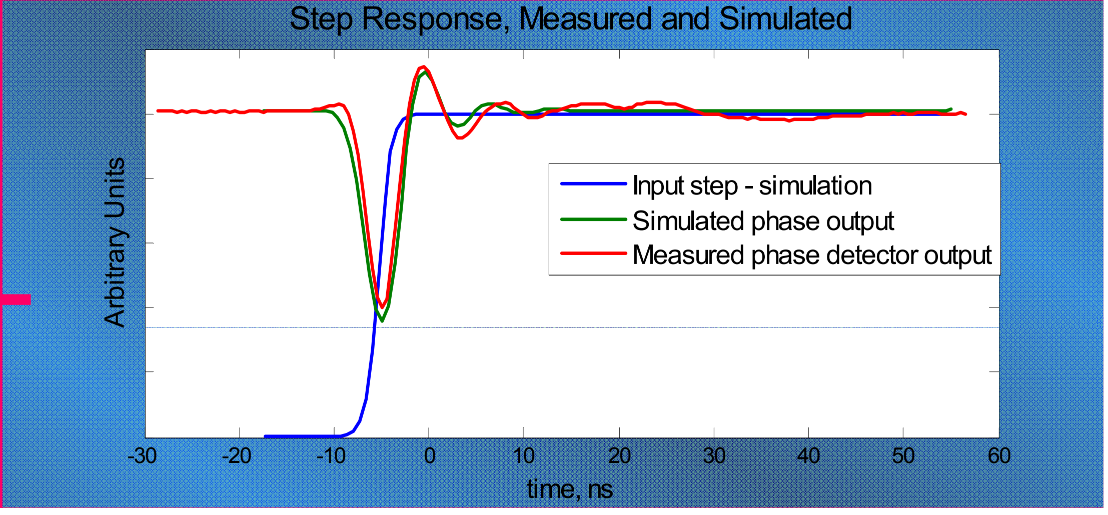
$$V_{out}(t) = V_{in}(t) + a_2 V_{in}(t)^2 + a_3 V_{in}(t)^3$$

– No phase shift

Reactive nonlinearity

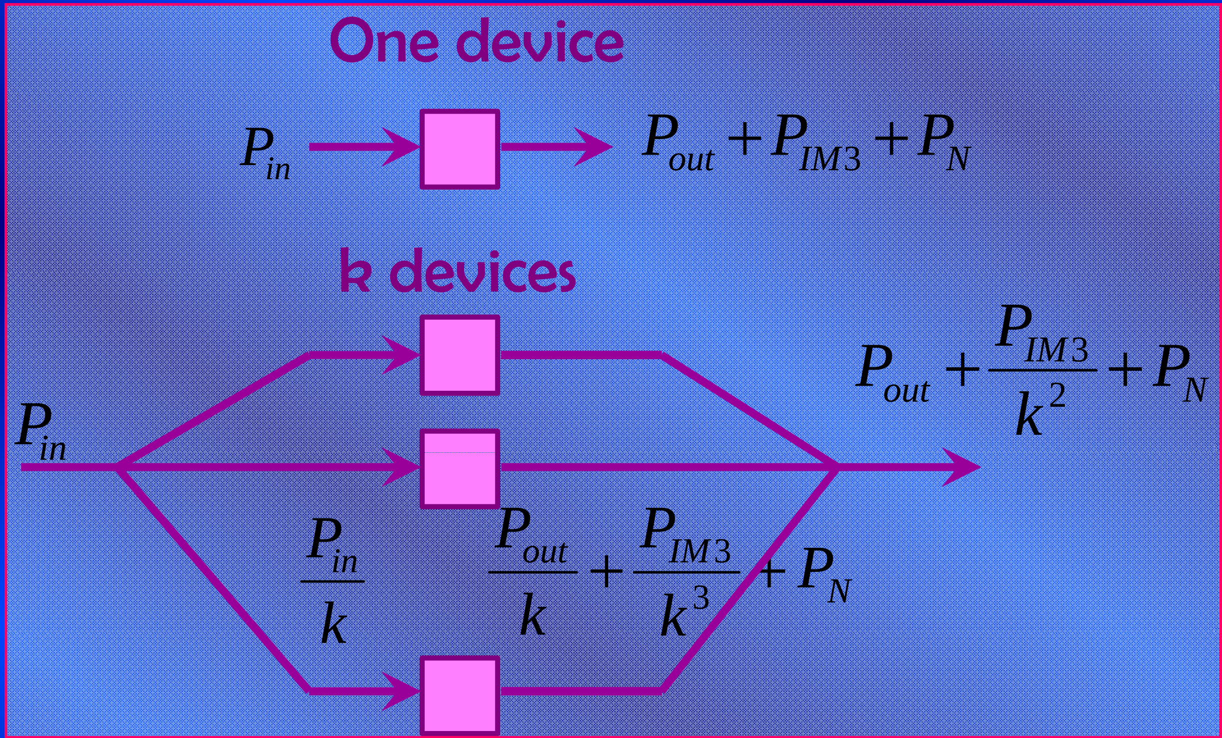
– a_3 is complex and frequency dependent
– Results in amplitude to phase conversion
– Assume:

$$\angle a_3 \propto \omega_1 + \omega_2 + \omega_3$$



Ongoing work

Third order nonlinearities – signal splitting and recombination

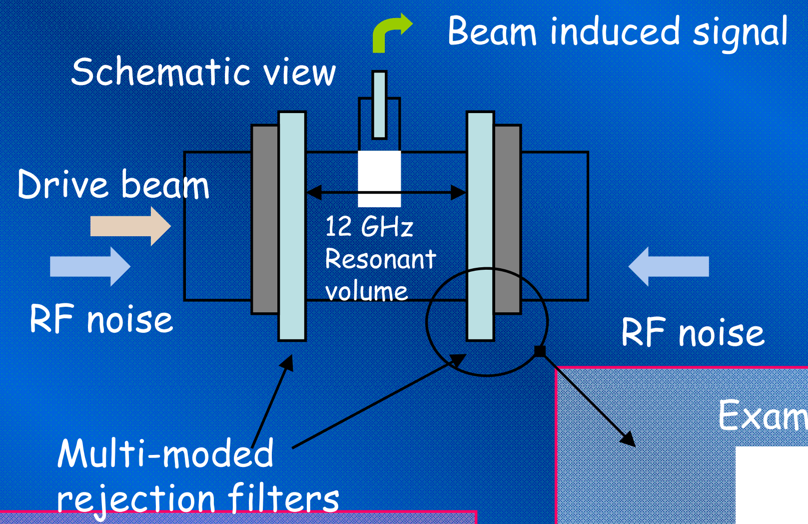


- Operating devices at lower power yields less distortion
- Can split on k devices, maintaining output power and noise constant
- Third order term decreases
- An operating point thus exist where distortion is low enough

Future development: FP7 plans

TPMON results have demonstrated feasibility of the electronics for a sub-10fs RF based beam timing measurement. So now need a dedicated beam pipe monitor!

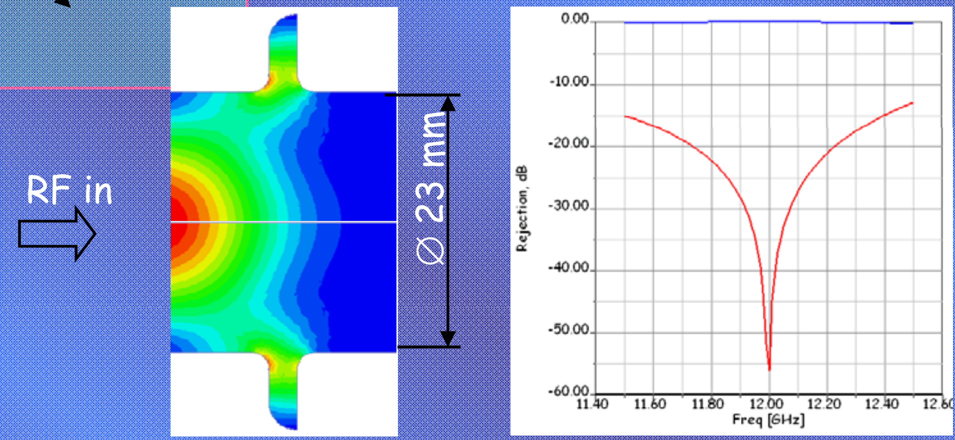
Monitor proposal by Igor Syratchev:



Special requirements

- Low impedance
- Immune to RF noise in beam pipe

Example: TM01 choke-type rejection filter



FP7

- Design and build monitors
- Convert electronics to 12 GHz and make improvements
- Test in CTF3

Conclusions

- Require ultra-stable phase reference line in CLIC
  - Propose using main beam in transfer line
  - Need to demonstrate an accurate beam timing measurement
- Electronics tested in CTF3 and demonstrated sub-10 fs resolution.
- Present and future work concentrating on
    - Characterization and improvement of electronics
    - Purpose-built monitor (FP7)