Latest Developments on Field Detection Using Automated Carrier Suppression in the Attosecond Regime for CW Signals .

2019 LLRF Workshop, Chicago

Sept. 29 - Oct. 03 2019

Louise Springer
Chicago, 2nd October 2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Agenda

01 Motivation

- Problem & Solutions

02 Carrier Suppression Interferometer & Development

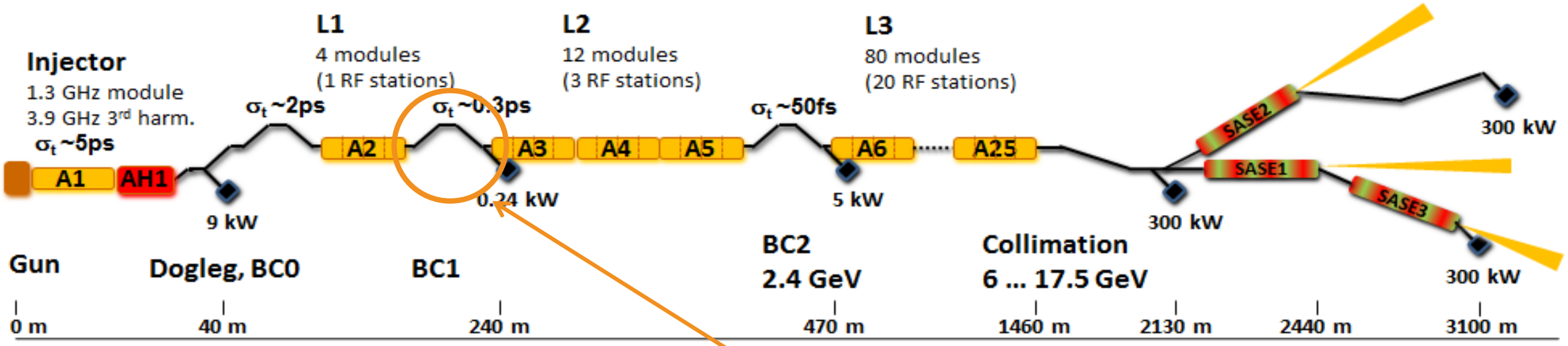
- Basic system – how it works
- Challenges – what to do
- Results

03 Application

- Current Work

04 Prospects & Summary

Motivation



Conclusions for 10fs bunch arrival time:

RF field control and reference distribution is critical
<0.01%, <0.01deg @ 1.3GHz

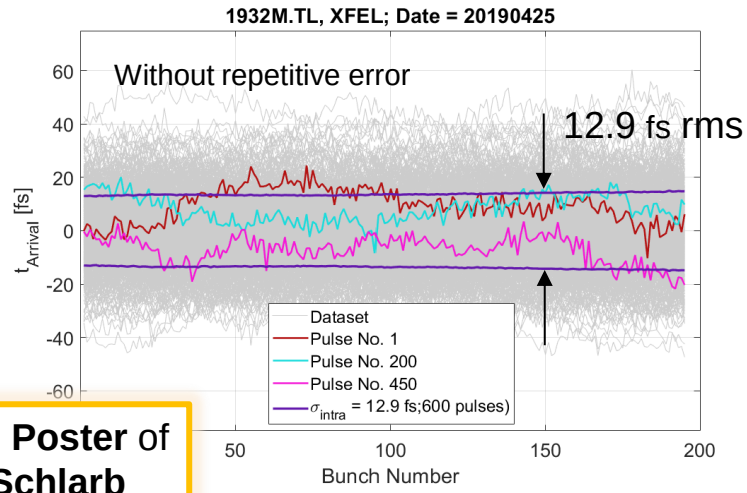
Amplitude | Phase | Init. arrival

$$t_{j,\mathrm{out}}^2 \approx \left(\frac{R_{56}}{c_0}\frac{\sigma_A}{A}\right)^2 + \left(\frac{C-1}{C}\right)^2\left(\frac{\sigma_\varphi}{c_0 k_{\mathrm{rf}}}\right)^2 + \left(\frac{1}{C}\right)^2 t_{j,\mathrm{in}}^2$$

EuropeanXFEL: 1.5ps/%
FLASH: 7.0ps/%

2 ps/deg
L-band

0.05 ps/ps
C=20

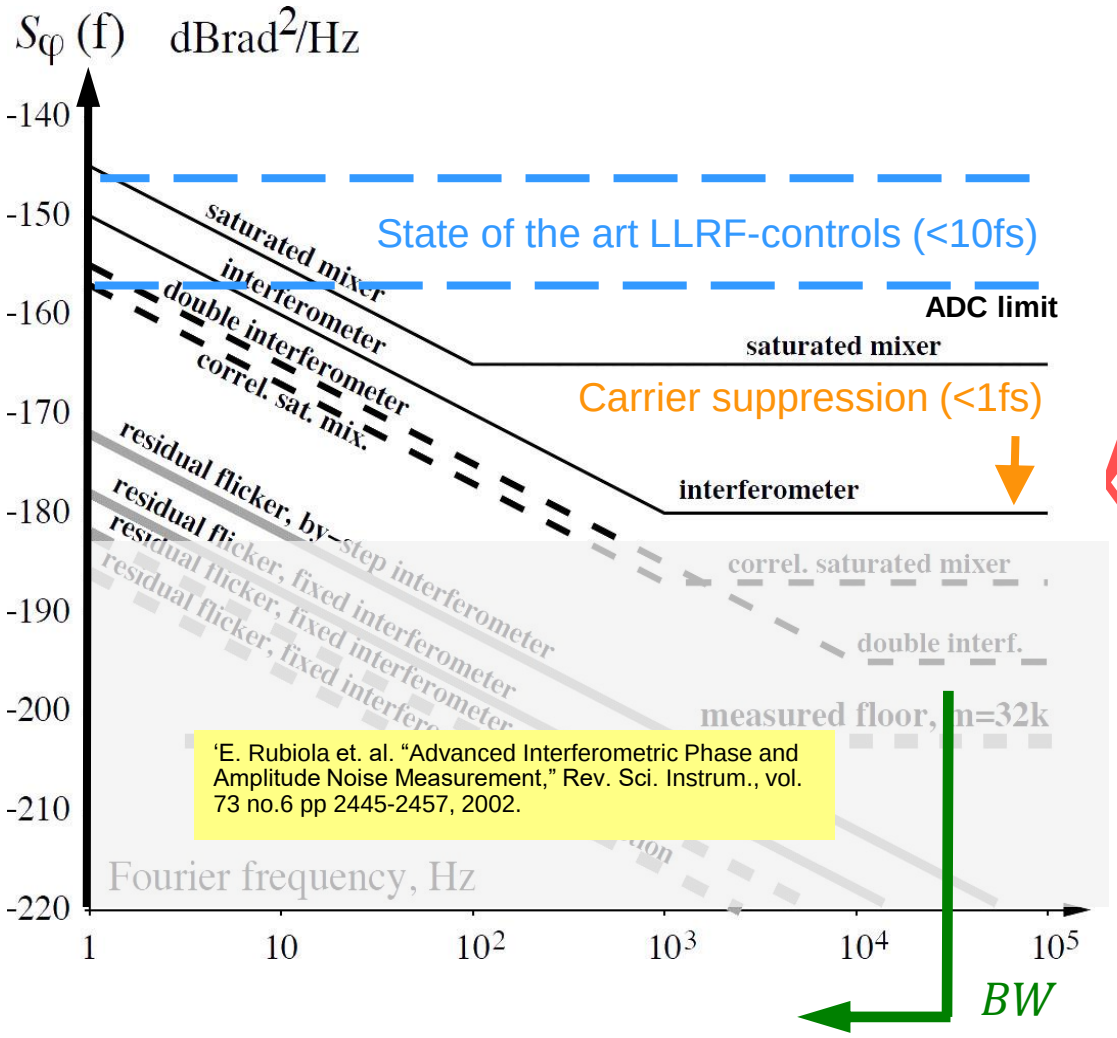


→ The integrated timing jitter in accelerators is mainly influenced by the RF acceleration fields.

see **Poster** of **H. Schlarb**

Motivation

Increasing the field detection resolution



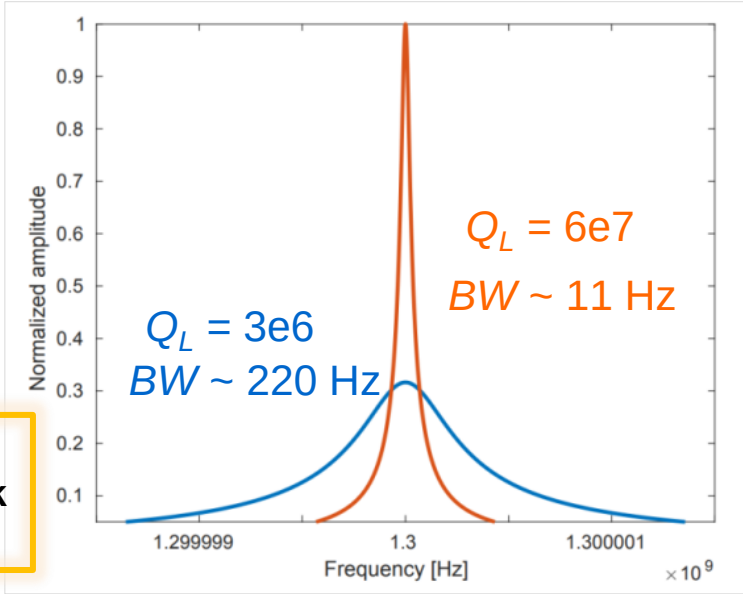
'E. Rubiola et. al. "Advanced Interferometric Phase and Amplitude Noise Measurement," Rev. Sci. Instrum., vol. 73 no.6 pp 2445-2457, 2002.

Decrease the noise contribution of the ADCs by parallelization or channel parallelization

Increase the RF input power or limit the carrier signal power

→ **Carrier Suppression Interferometer** (abbr.: CSI)

Increase the Q of the SRF cavities, lower the bandwidth



see **Poster & Student Grant Talk** of **A. Bellandi**

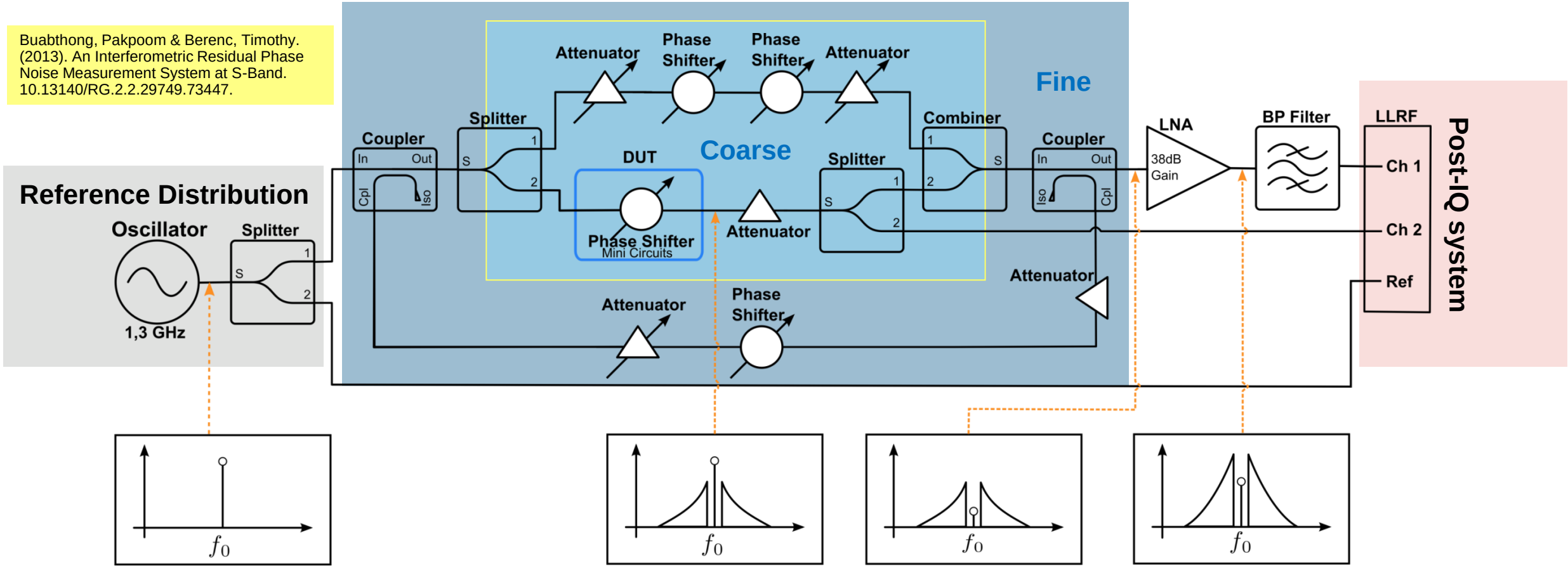
Carrier Suppression Interferometer & Development

The CSI System

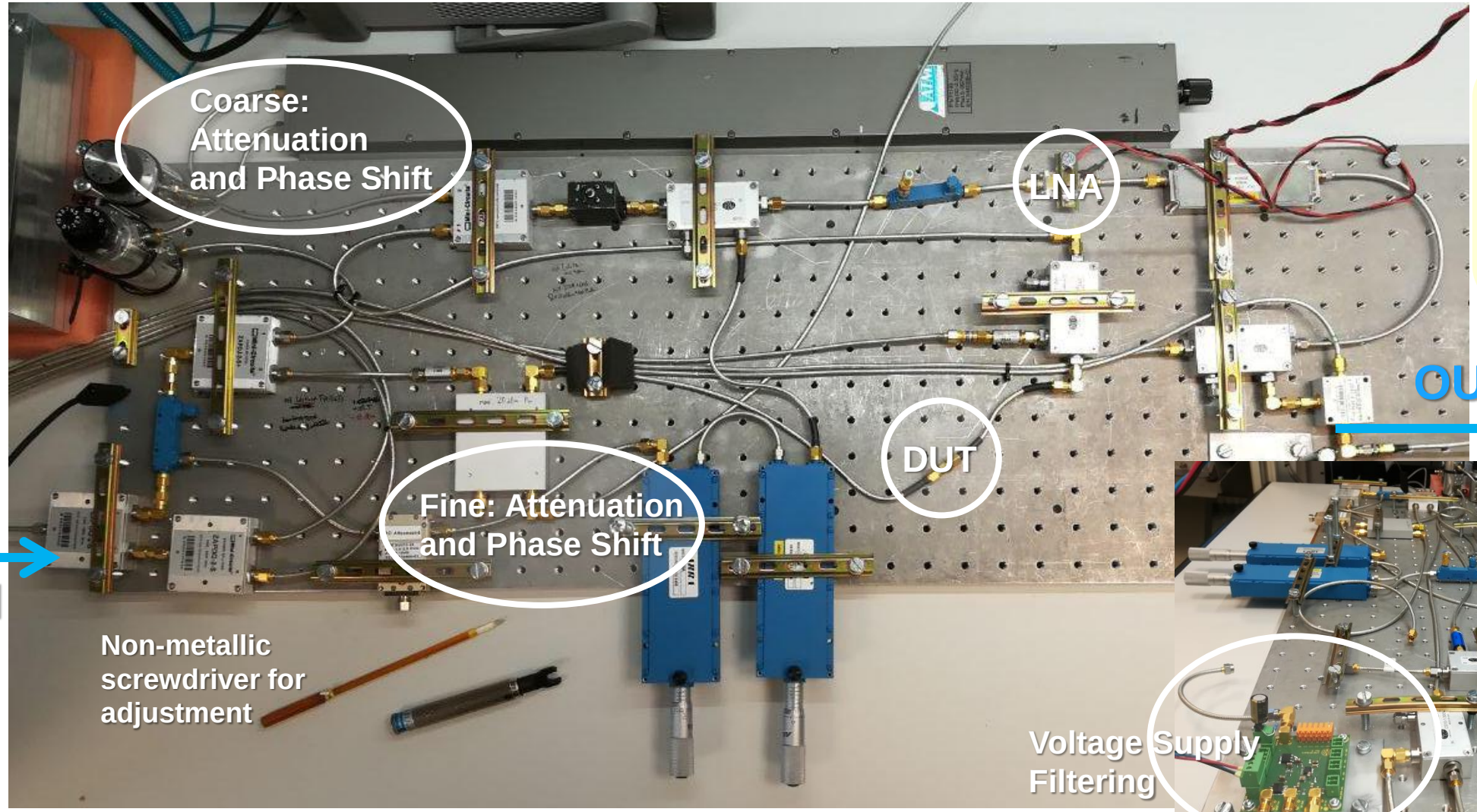
Front End of the LLRF System @DESY based on MicroTCA.4

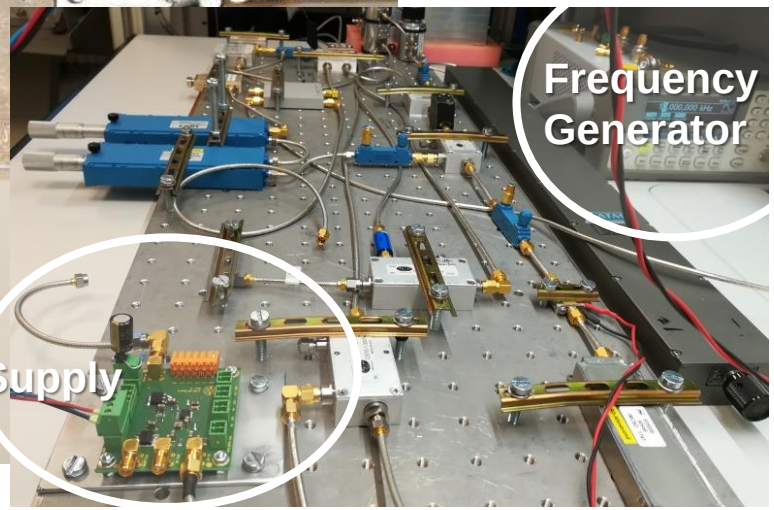
- PN, AN scales with RF-power
- Independent from the LNA performance by Friis
- Needs a carrier tracking for destructive interference
- Very low noise AM and PM stable signal source required

Buabthong, Pakpoom & Berenc, Timothy. (2013). An Interferometric Residual Phase Noise Measurement System at S-Band. 10.13140/RG.2.2.29749.73447.



The CSI System in Laboratory

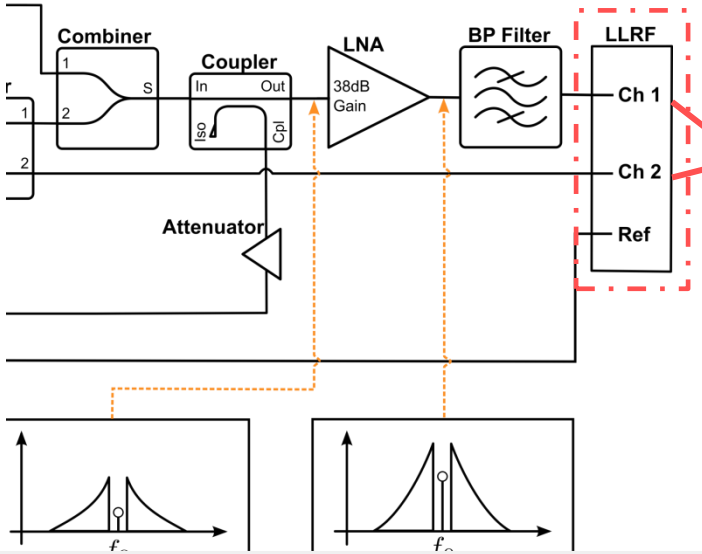


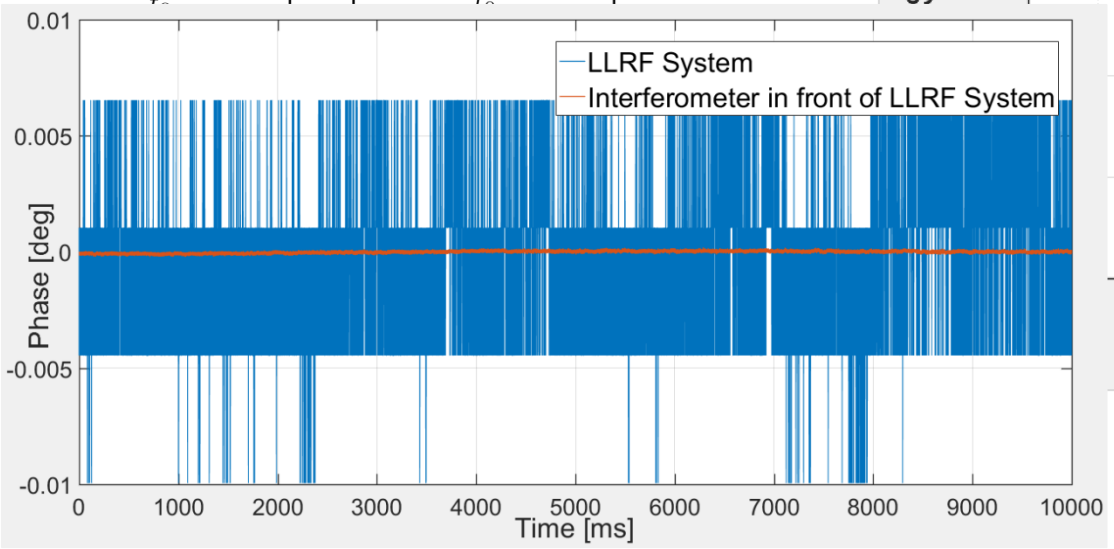


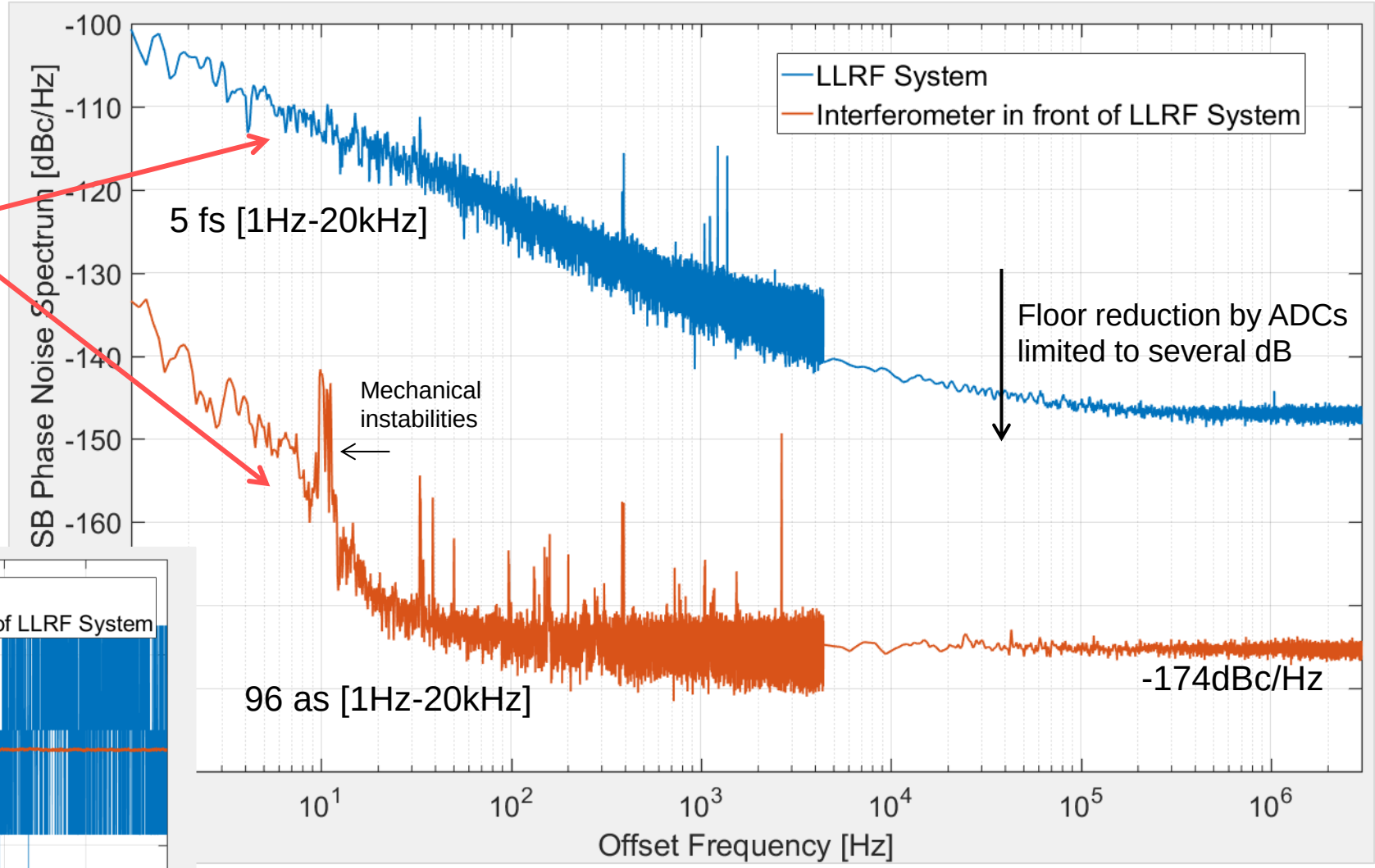
Motion-sensitive components need to be fixed on optical breadboard for measurements

The mechanical CSI System

First results



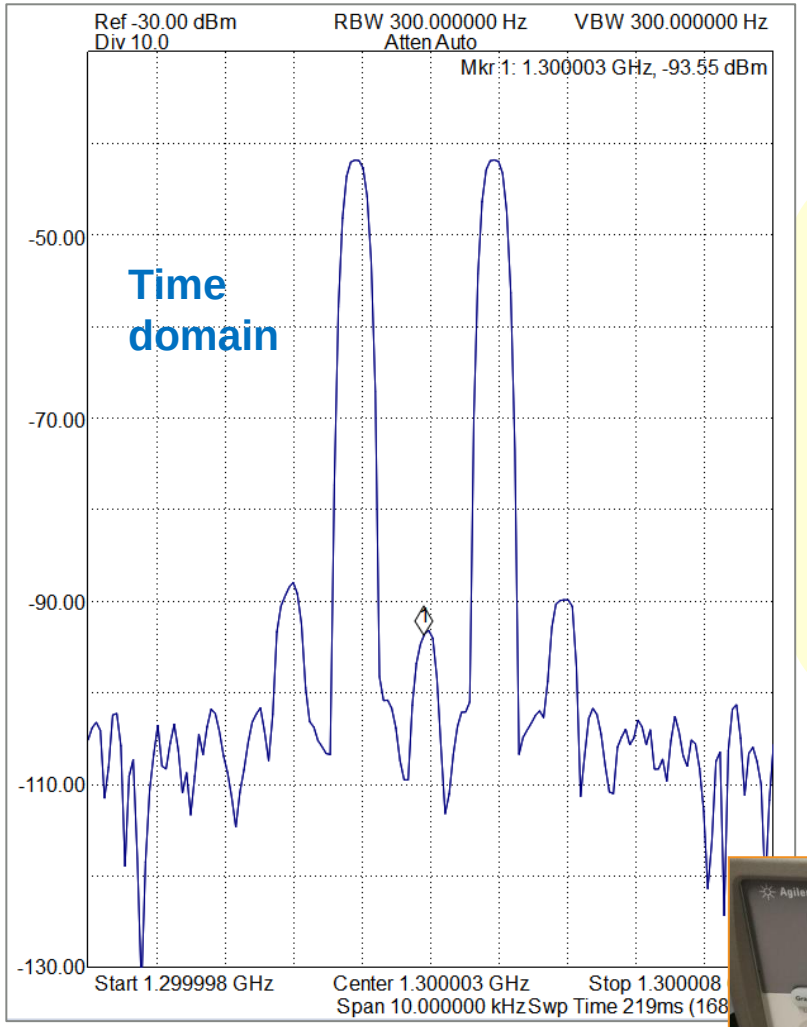




Effective number of bits ~6 bits higher by noise reduction of 40dB, precision increases by factor 100!

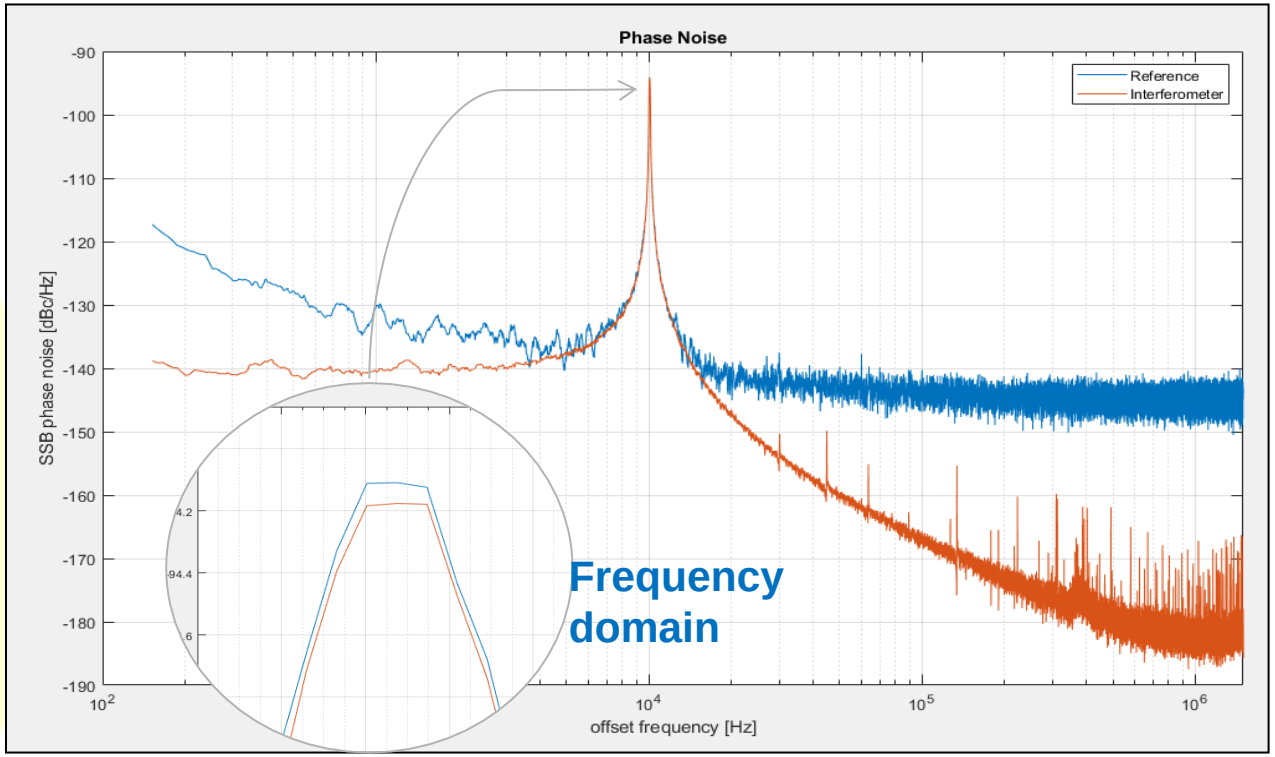
The Calibration of the CSI System

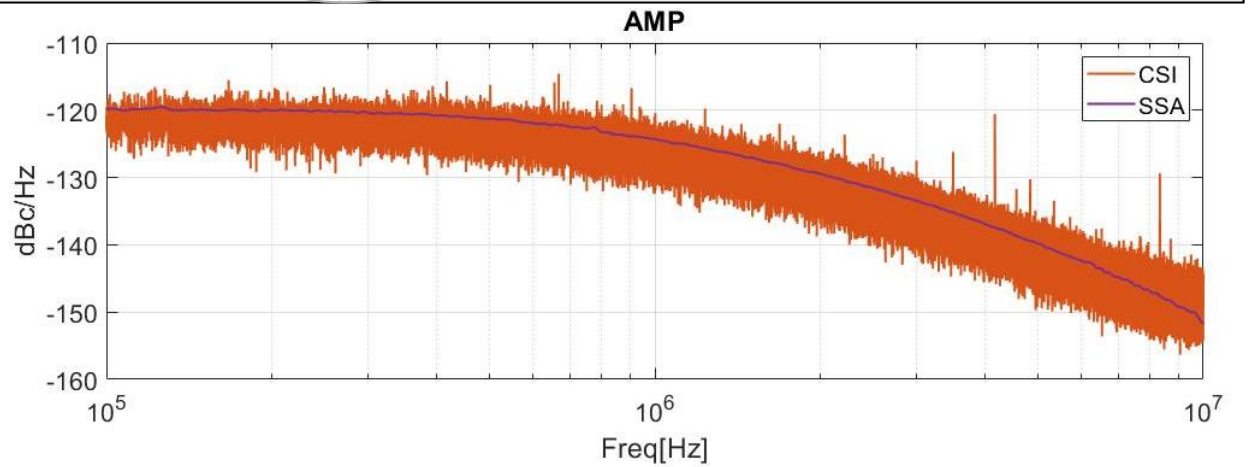
Proof of measuring the right numbers



1. MicroTCA.4 system calibrated to commercial SSA
2. CSI adapted to MicroTCA.4 system

$f_{mod} = 10\text{kHz}$
$\hat{u} = 10\text{mV}_{\text{pp}}$



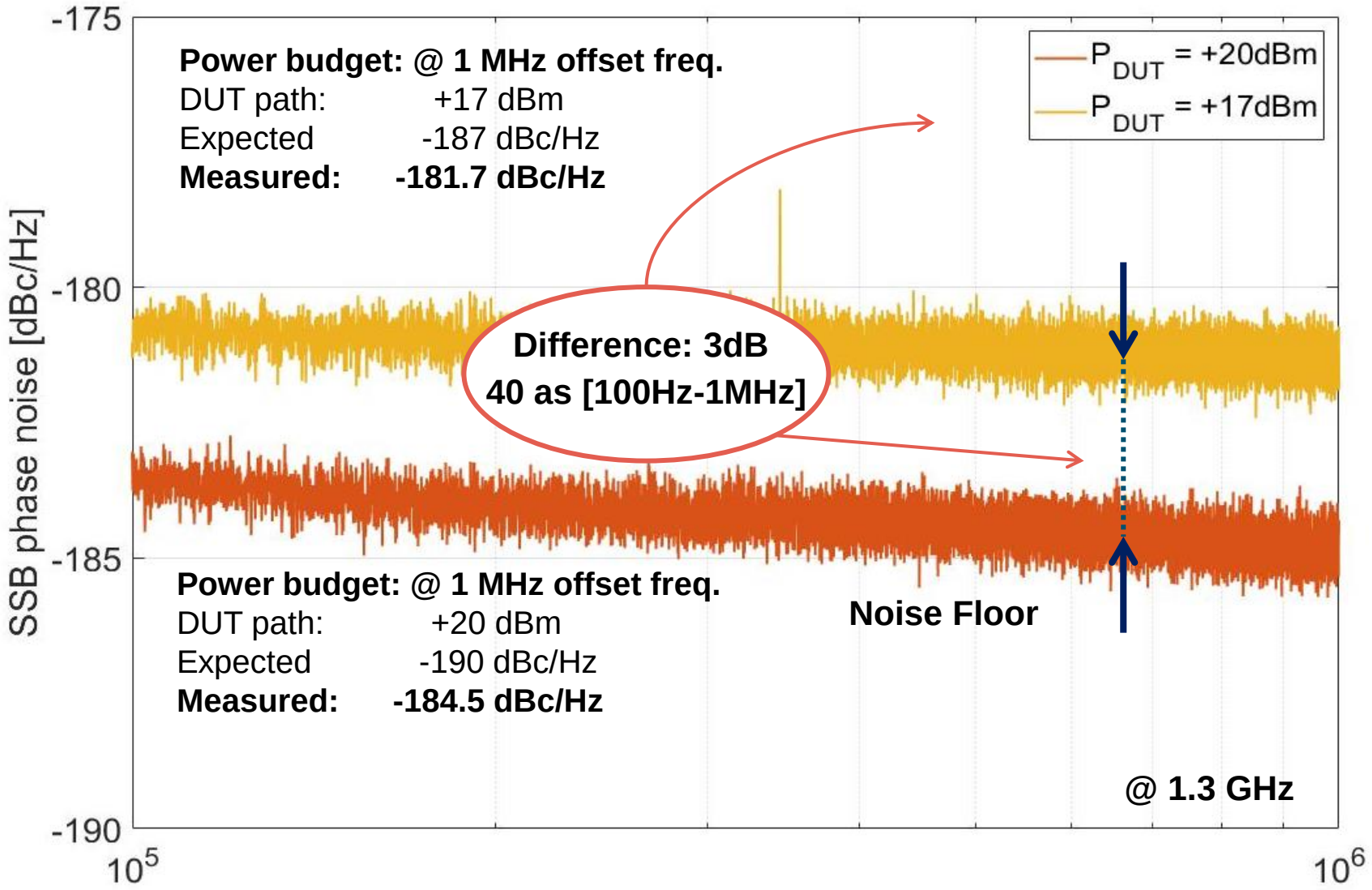


The mechanical CSI System

Amplitude and Phase Noise scales with increasing power

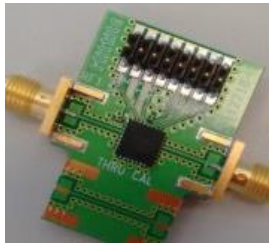
Typical commercial electronical RF components are limited to maximum input signal powers of +20 dBm.

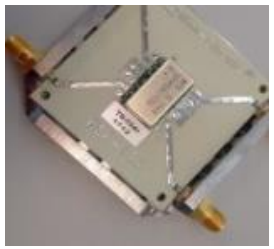
Development of low-noise RF components for high power levels required!

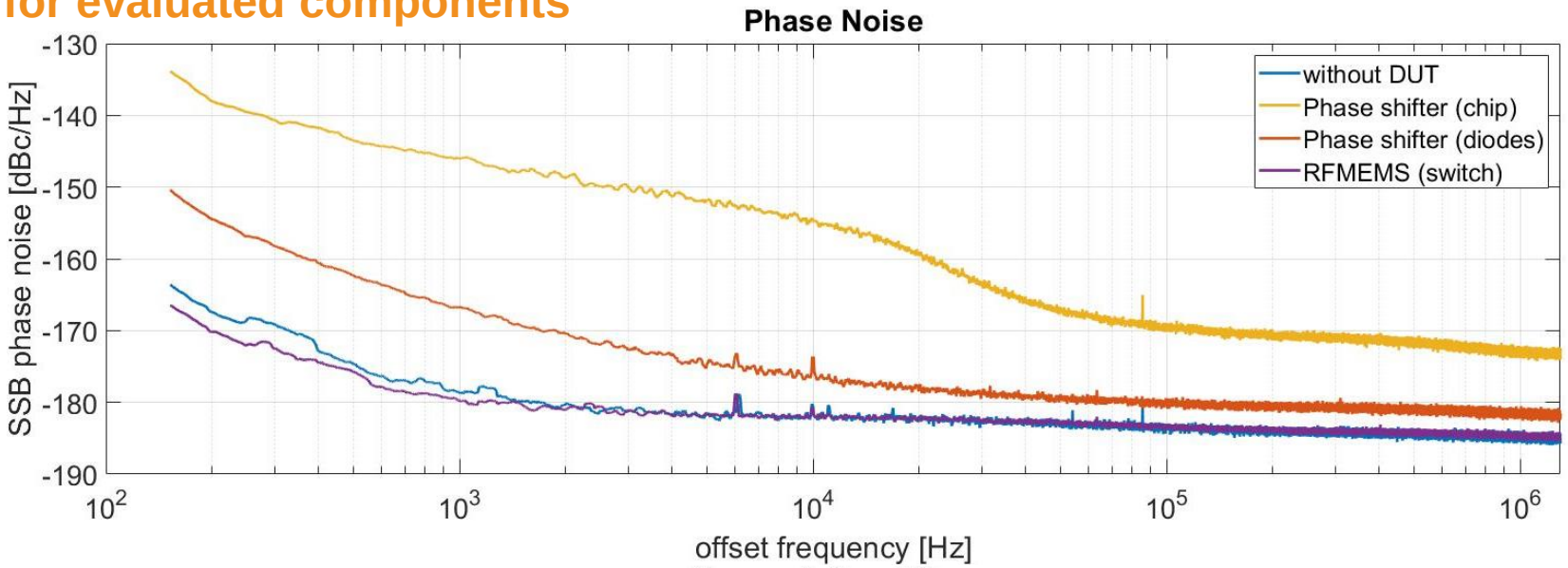


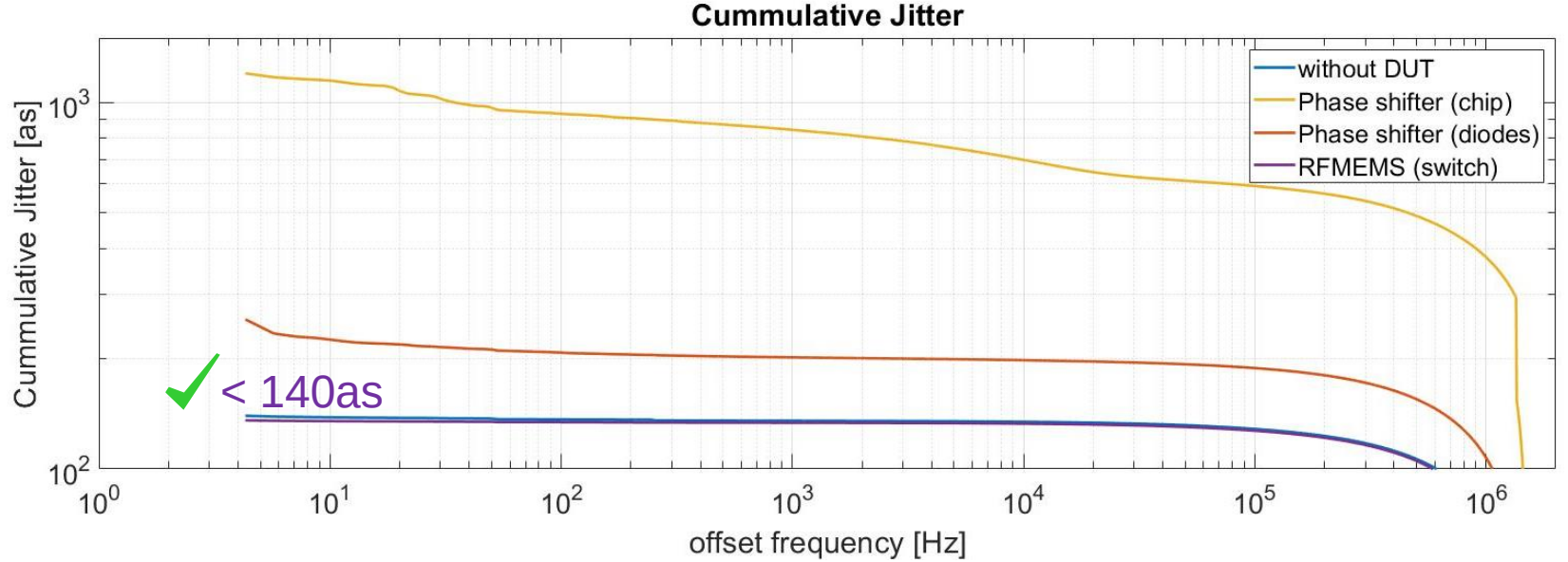
The electronical CSI System

Examples for evaluated components









→ Active Rf components involve 1/f noise (e.g. varactor diodes, transistors)

→ AM/PM conversion appears in RF components with higher input levels

RFMEMS* can be used for steppable phase shifters and attenuators!

Correlated setup for component characterization required!

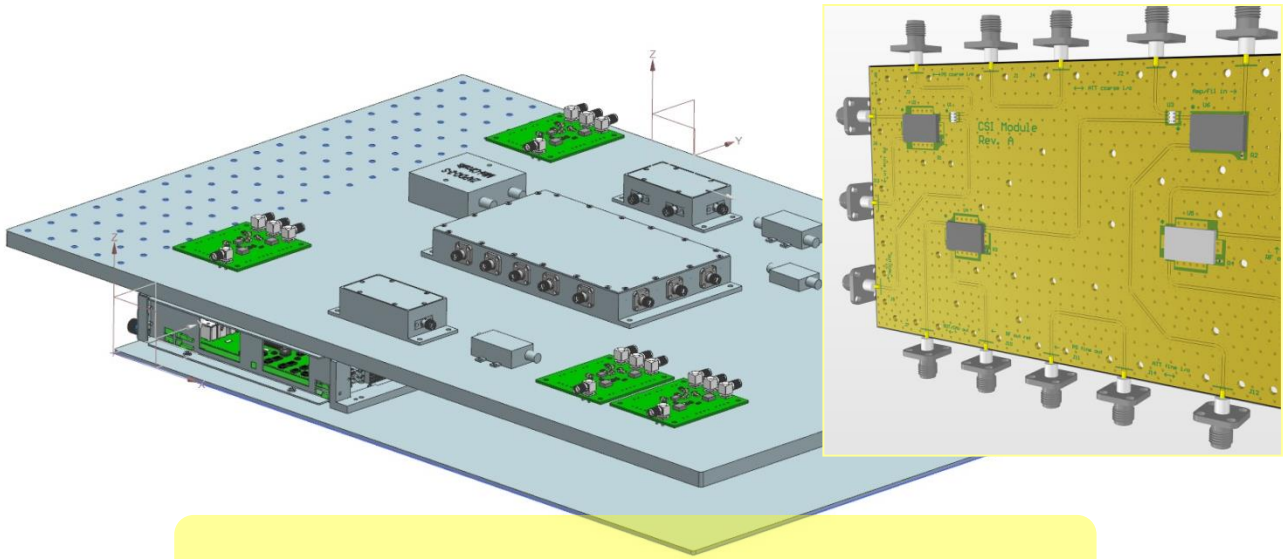
*RF MicroElectroMechanical System

Application

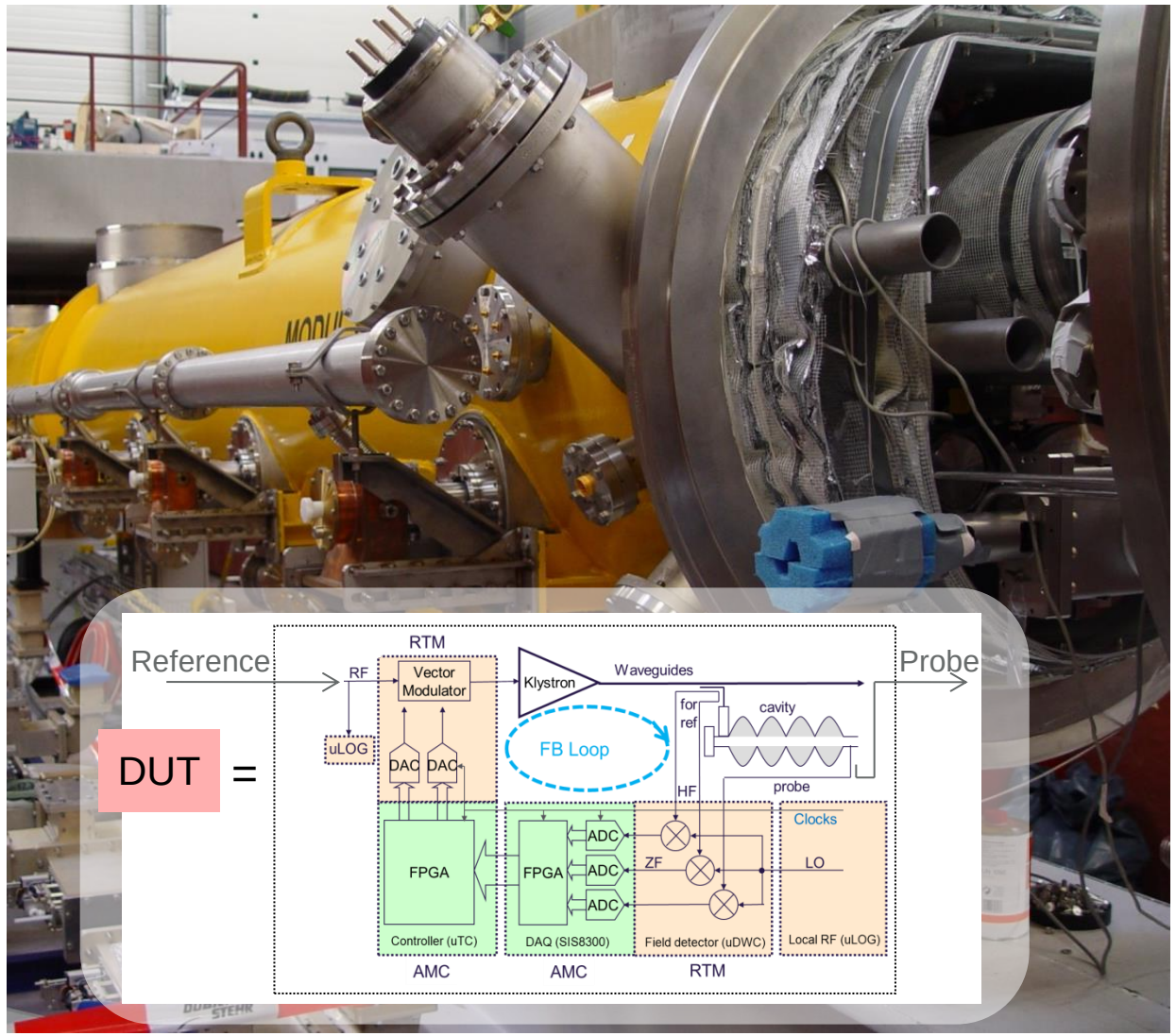
In Preparation: Frontend for the LLRF Detection System

Requirements:

- → electronical phase shifters and attenuators at very low noise level
- → PCB design for accelerator and laboratory environment
- → Packaging in 19“ box for accelerator environment
- → Automatic carrier suppression



First comissioning planned by end of 2019



Prospects & Summary

Prospects

Next steps

- Prepare the 19“ box for first tests at CMTB@DESY (CW research facility)
- Re-design active devices (phase shifter, attenuators) to ultra low-noise high power operation
- Design continous variable low-noise phase shifter
- Implement automatic carrier suppression
- Far future: cross-correllation CSI

Summary

- A mechanical CSI prototype in combination of a MicroTCA.4 LLRF system for AN and PN measurements at -180dBc/Hz with <90as [10Hz-1MHz] @1.3GHz is ready to use in laboratory
- Nevertheless, dynamic range is limited, only applicable to long pulses
- Major EMC and technical noise sources are identified and eliminated in the prototype setup
- First RF components for an automated CSI are characterized
- Working towards major improvements of a LLRF field detection system with <100as resolution

Thank you.

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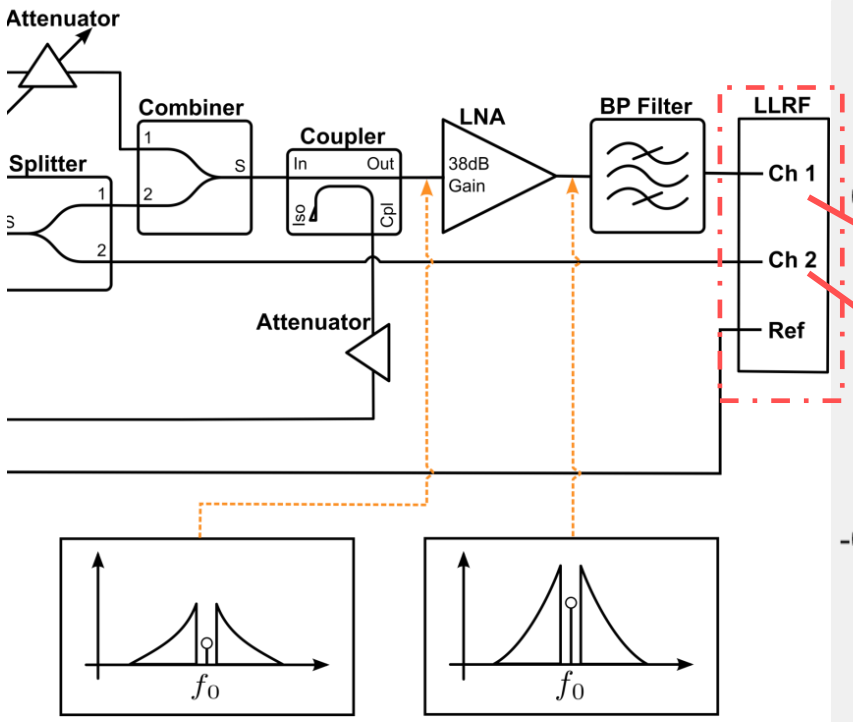
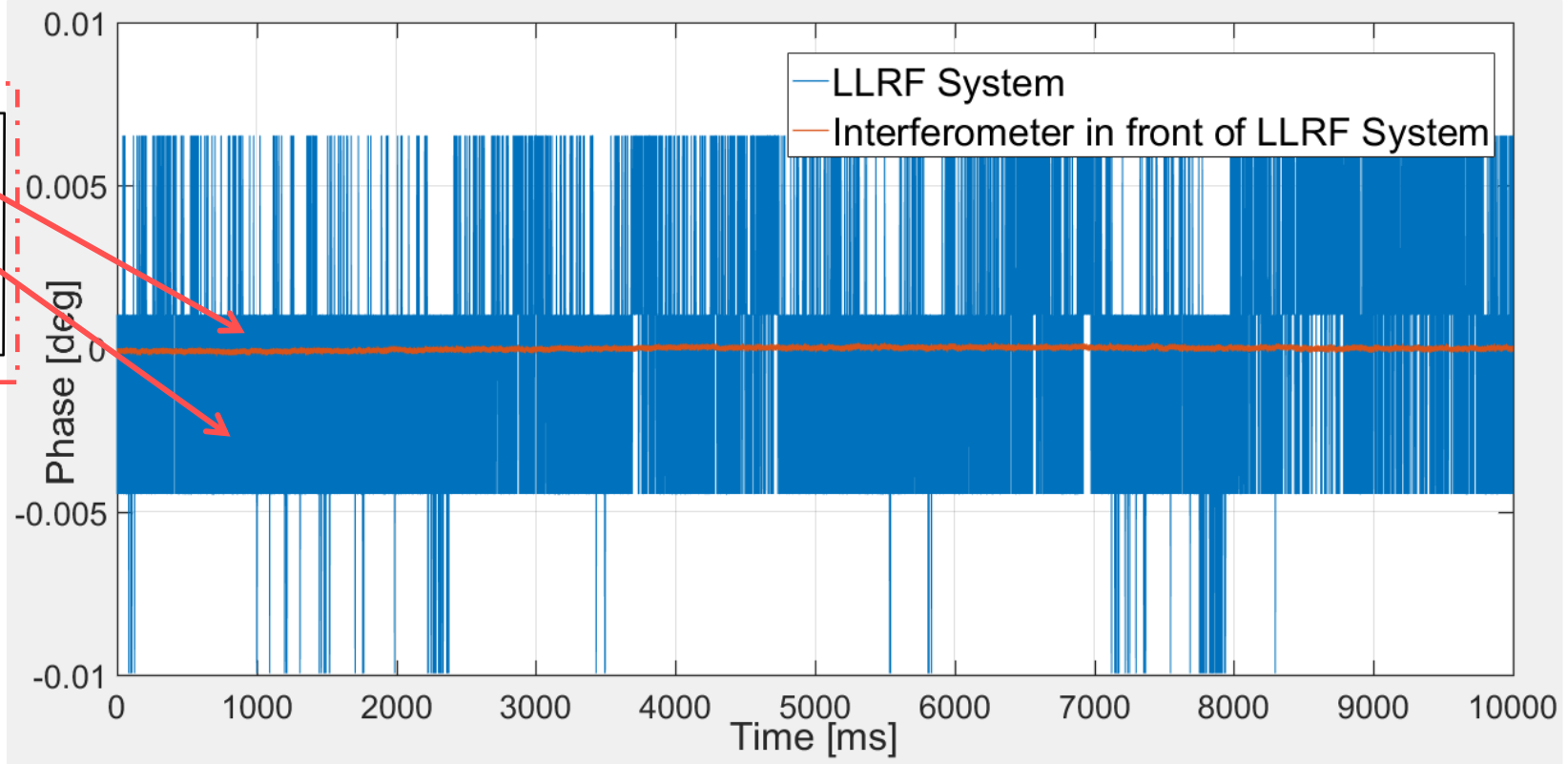
Back Up

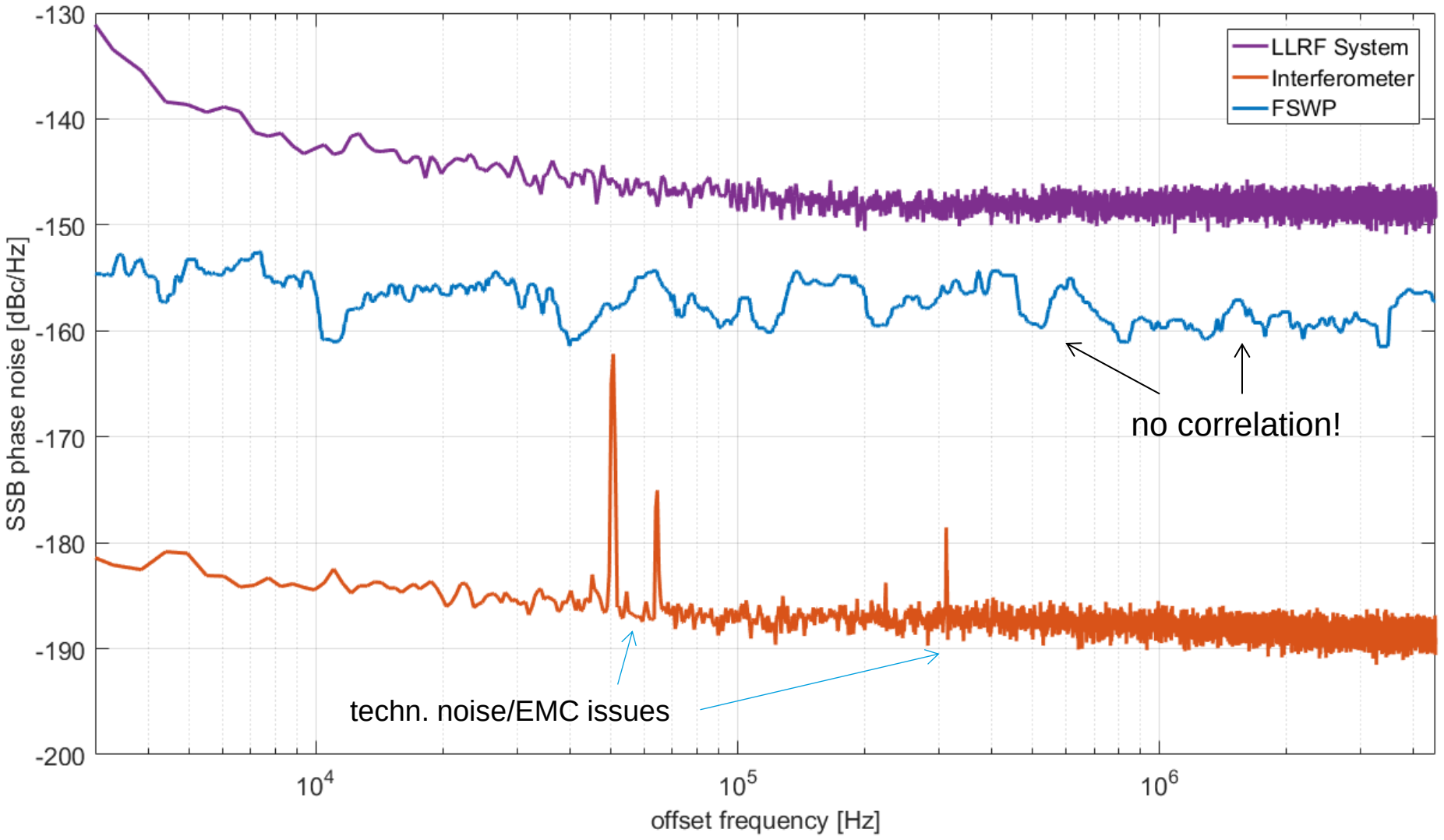
Measurements II





Measurements III

Measurement System Comparison



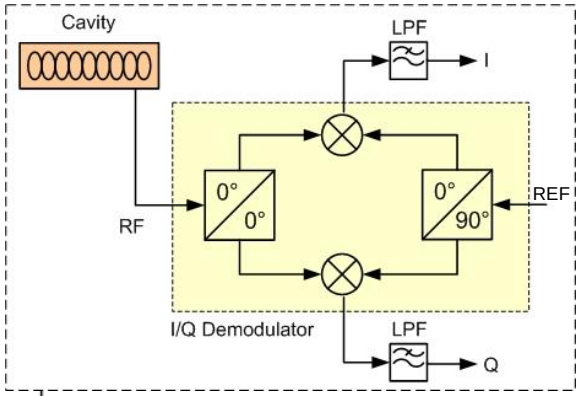
Integrated Timing Jitter

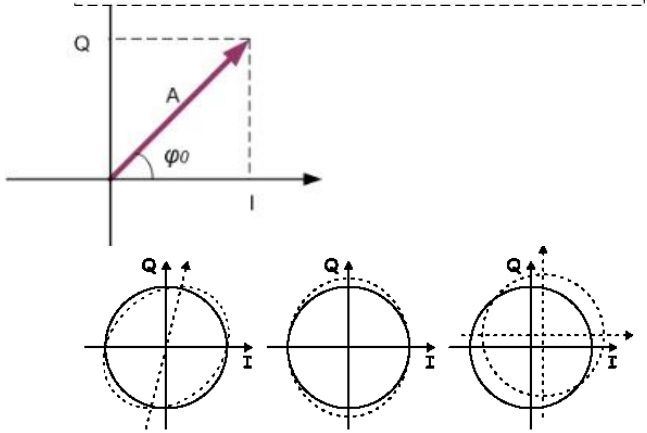
System/ Offset Frequency	CSI	FSWP
10kHz-100kHz	56 as	727 as
100kHz-1MHz	75 as	2241 as
1MHz-10MHz	374 as	6527 as

Settings: Additive Phase Noise Measurement/
Input Power 10dBm@1.3GHz/XCORR=1/no corr./
(2 channels)

Field Detectors – Modulation Schemes

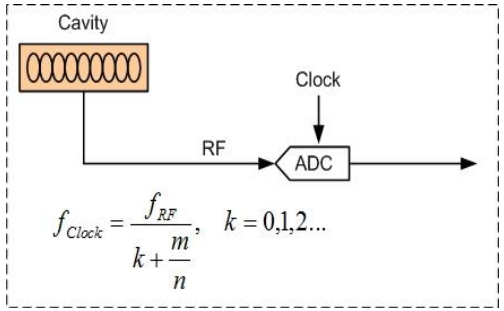
IQ-baseband Sampling:



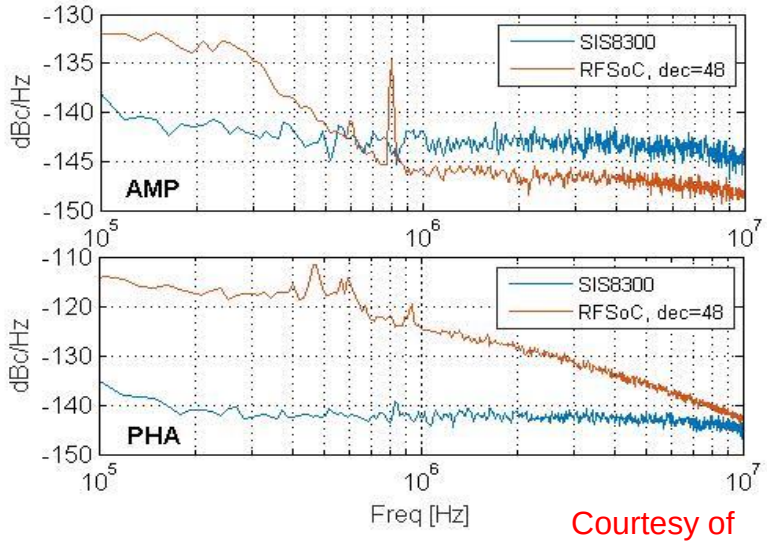


(+) No LO-Generation
(--) IQ-Errors in the % range
(--) PM to AM effects
(--) IQ-Calibration is needed

Direct Sampling:



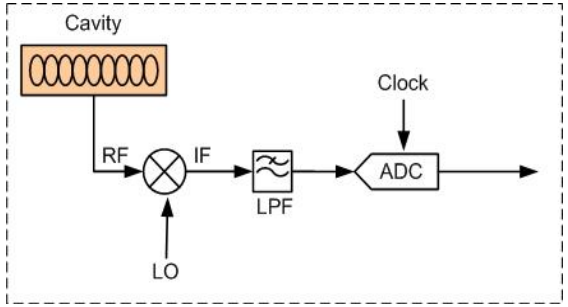
UltraScale RFSoC :
- 8 interleaved ADCs
- Spur Calibration

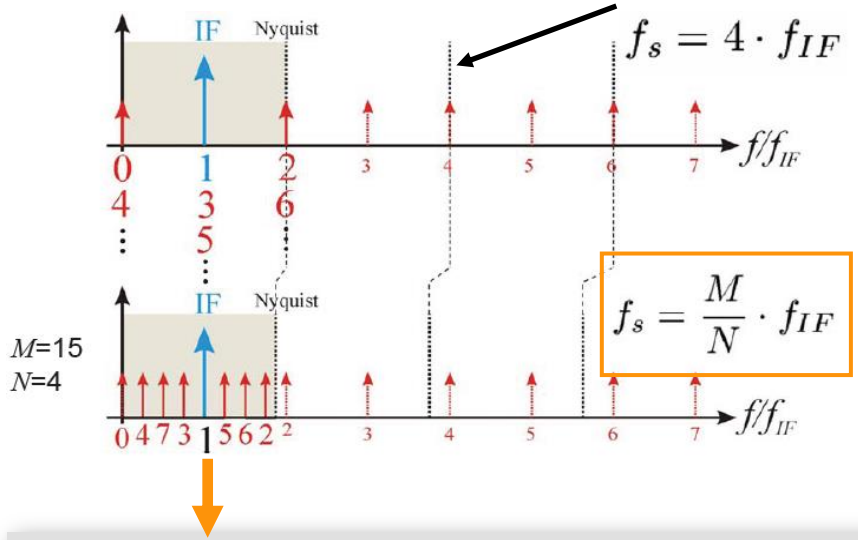


Courtesy of J.Marjanovic

(+) Wideband, flexible
(+) AM <0.005% @ 1.3GHz
(--) SNR sensitive to CLK jitter
due to high input frequency

Non-IQ Sampling (standard):



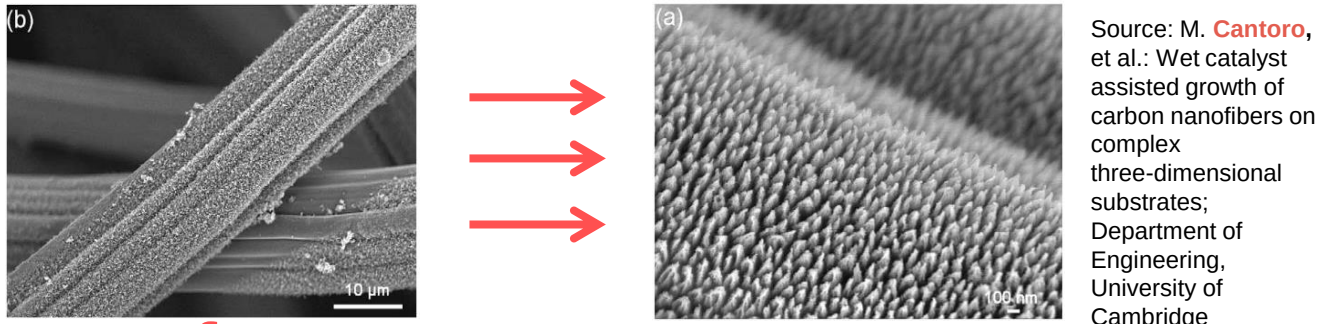


(+) Most harmonics do not alias into the signal
(+) No PM to AM effects
(+) Analog mixer ‘magnifies‘ the RF time jitter

Motivation

Main Interest

- Field detection for LLRF systems for SRF cavities in the attosecond range
- Implement more precise detection scheme based on carrier suppression
- Application in all accelerator types intended, CW preferred



Source: M. **Cantoro**, et al.: Wet catalyst assisted growth of carbon nanofibers on complex three-dimensional substrates; Department of Engineering, University of Cambridge