‚Beam Stability at FLASH - update‘

F.Ludwig - DESY

Content :

- Motivation
- RF Master-Reference Update
  (F.Ludwig, H.Weddig - DESY,
  K.Czuba - TU Warsaw)
- Beam Stability Update
  (C.Gerth, F.Ludwig, G.Möller - DESY,
  C.Schmidt - TU Hamburg Harburg)

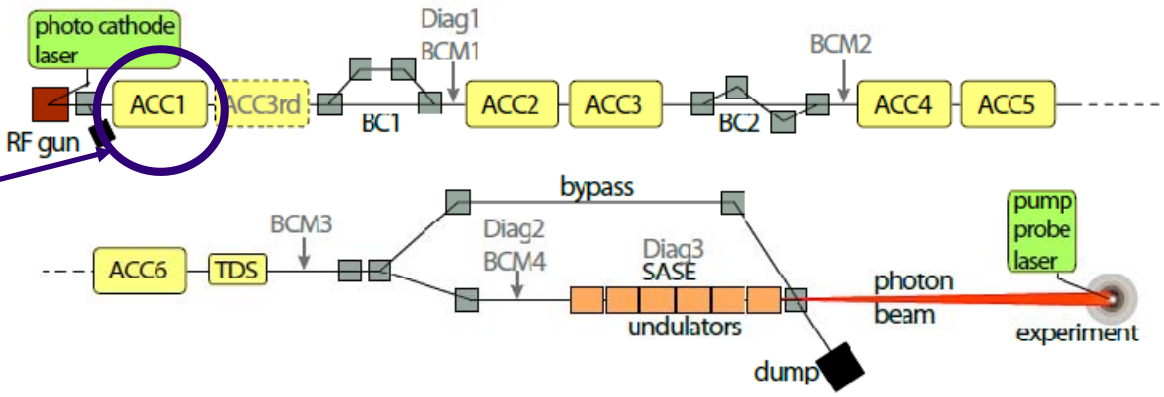
Motivation

- Schematic Layout of FLASH :

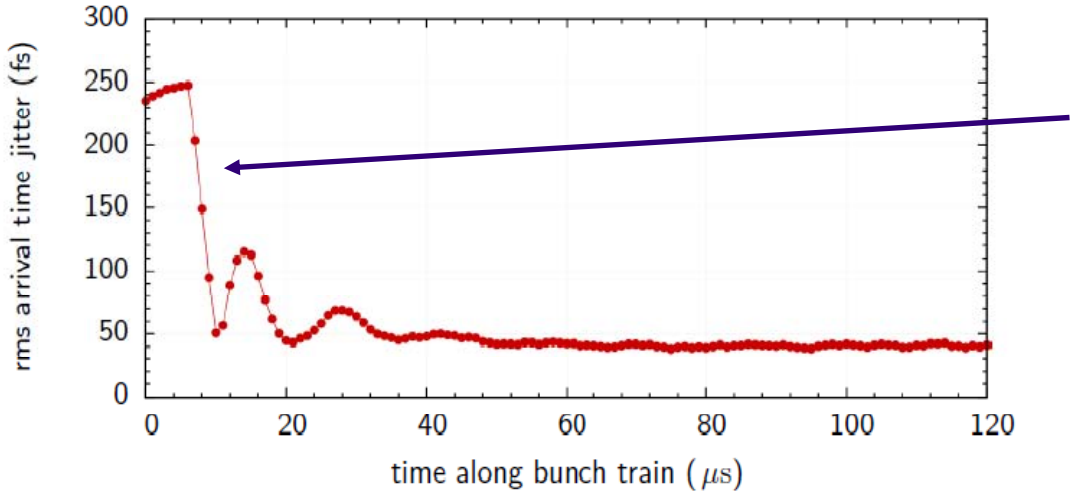
A cavity field fluctuation of 1% causes 6ps bunch arrival time:

0.0016% required for 10fs (without feedbacks)

F.Löhl, „Optical Synchronization of a Free-Electron Laser with Femtosecond Precision “, Hamburg 2009, Section 4.2



- Bunch arrival time stability with feedback :



Reduce number of „pilot“ bunches:

- Setpoints near to proper values
- Robust machine operation
- Reduce ACC1 cavity fluctuations (short-term and long-term)
- Stable RF-distribution system

RF-Master-Reference Update

- Drift in Poseidon PLL Module :

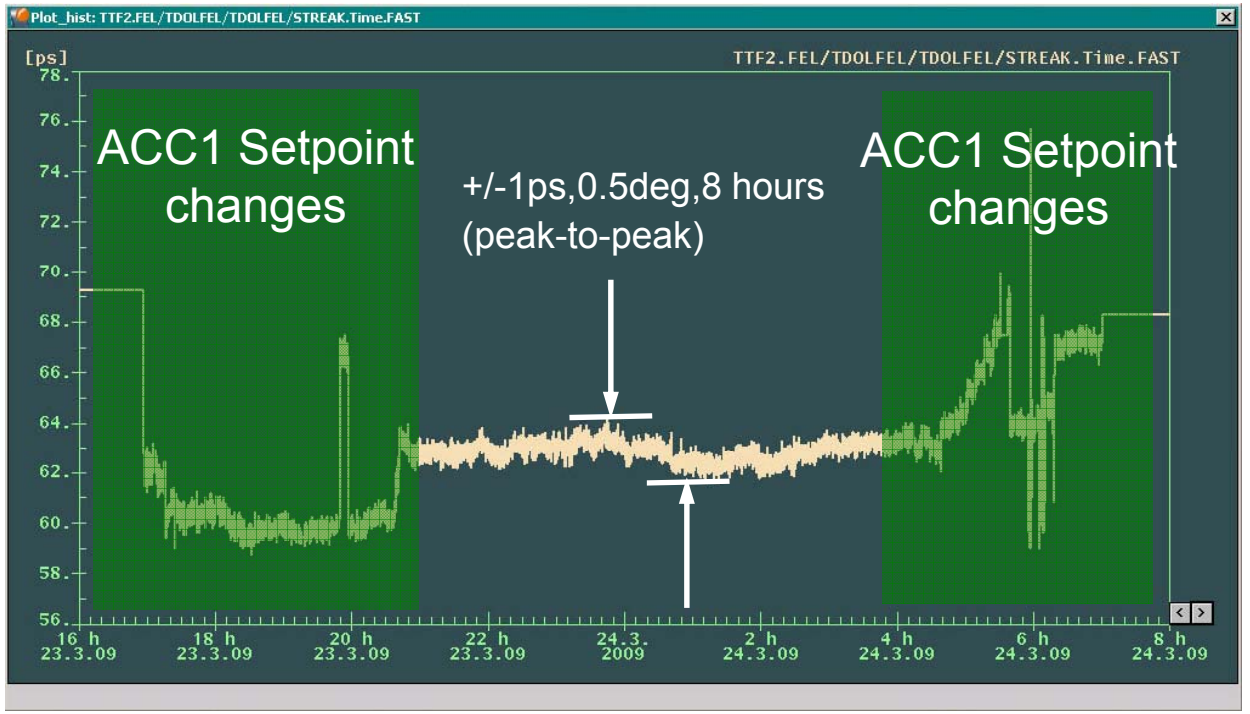
  - 3 Degree! over 9 hours (3 DUT Lab measurement), 0.1deg typical!

/TTFelog/data/2008/33/14.08_M timing drift between FEL(electrons) and PPLaser: 4ps drift, Streak
/TTFelog/data/2008/33/13.08_M phase relation 1.3 GHz / 9 MHz pplaser
TTFelog/data/2008/30/25.07_a 1.3GHz vs.108MHz (before new MO Installation) at Exp. Hall: 0.2 deg drift
/TTFelog/data/2008/30/25.07_a 1.3GHz vs.108MHz (after new MO Installation) at Exp. Hall: 2deg drift
/TTFelog/data/2008/30/25.07_a 1.3GHz vs. 9MHz (before new MO Installation) at Exp.Hall: 0.1 deg drift
/TTFelog/data/2008/30/25.07_a 1.3GHz vs. 81MHz (after new MO Installation) at Exp. Hall: 2deg drift

↷ Inhouse PLL.

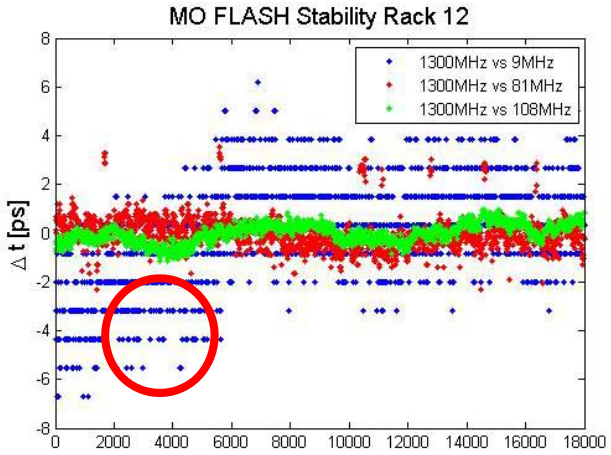
- Streak Camera :

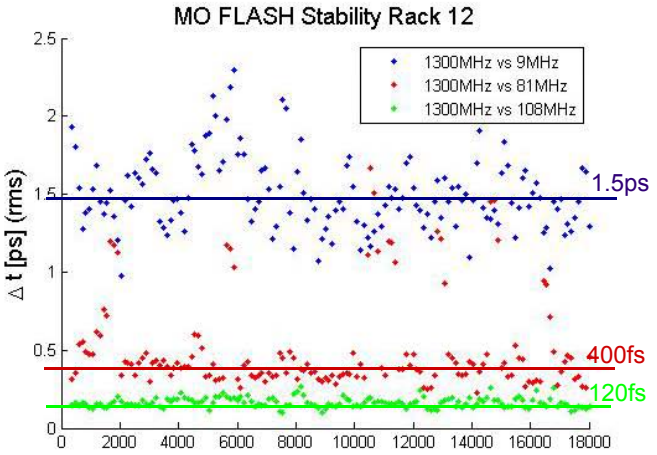
  Bunch arrival time

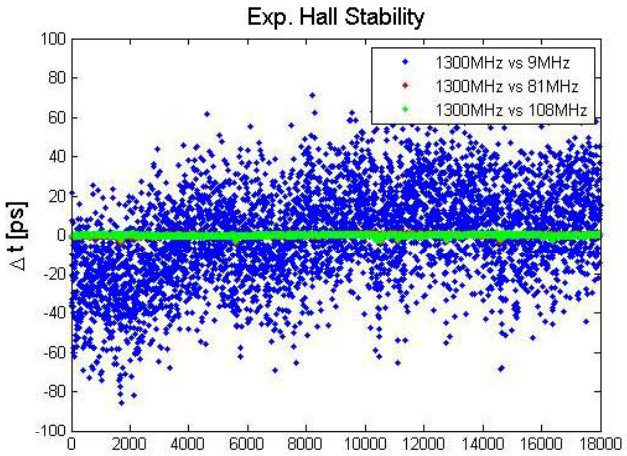


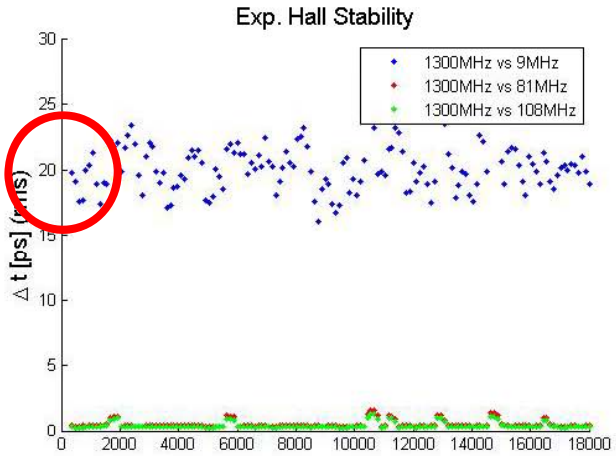
↷ Mainly caused from 1300MHz distribution cable (0.8ps (rms) using reflectometry methods) and ACC1 drifts.

- Long-term stability comparison between Injector and Exp. Hall :









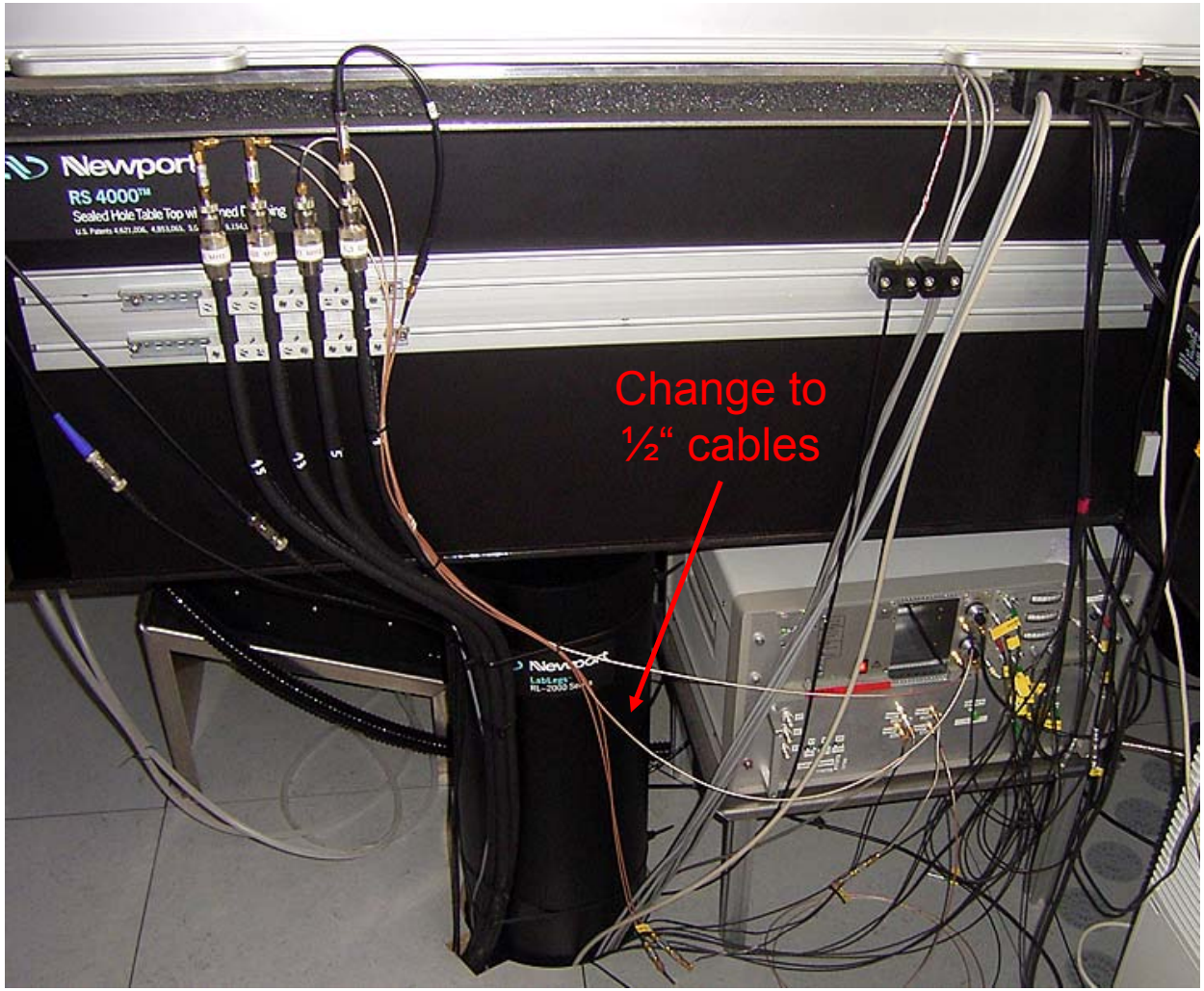
Detected problems:

- Phase detection is limited by 16-Bit ADCs and dividers
- Phase jumps are caused by ‚users'

- Upgrade FSB Box in Exp.Hall

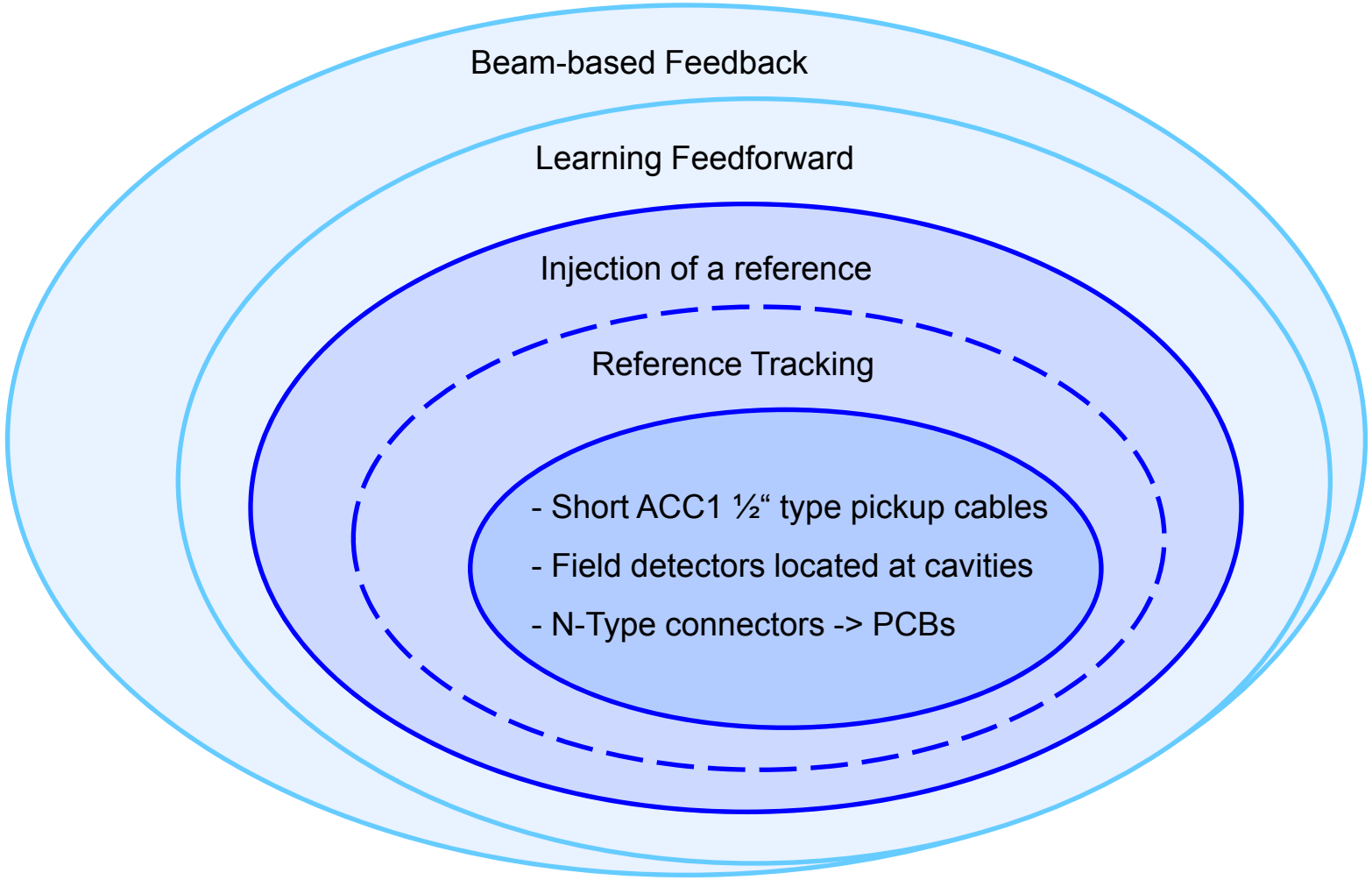
- Upgrade to 24-Bit ADCs
- Replace dividers by multipliers (limited upconversion frequencies!)
- Use driftfree phase detectors

- Upgrade FSB module in Exp. Hall, because of cabling.



Robust machine operation

- Proposal for a robust long-term stable machine operation :

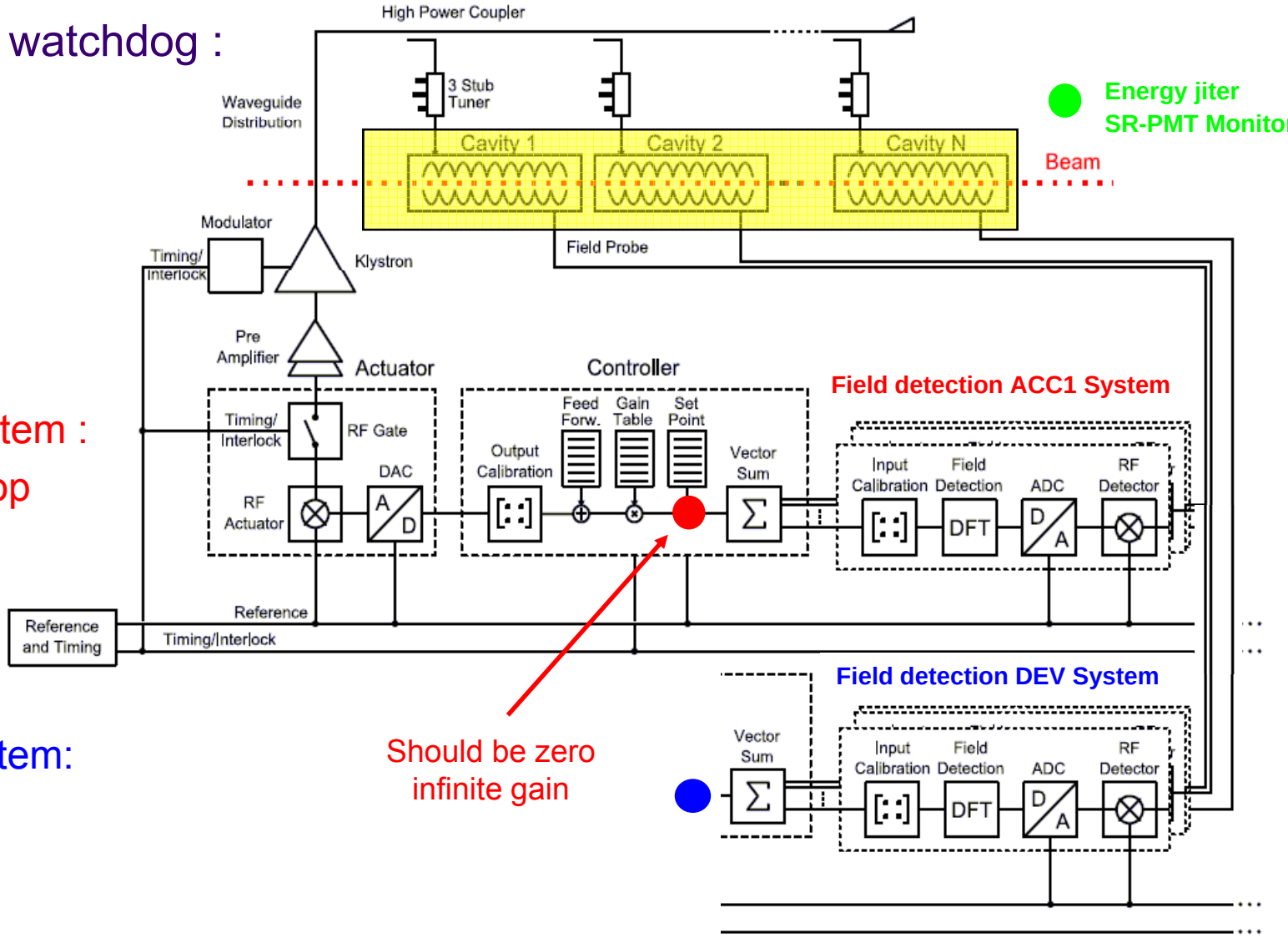


Beam Stability - Pulse-to-Pulse Fluctuations

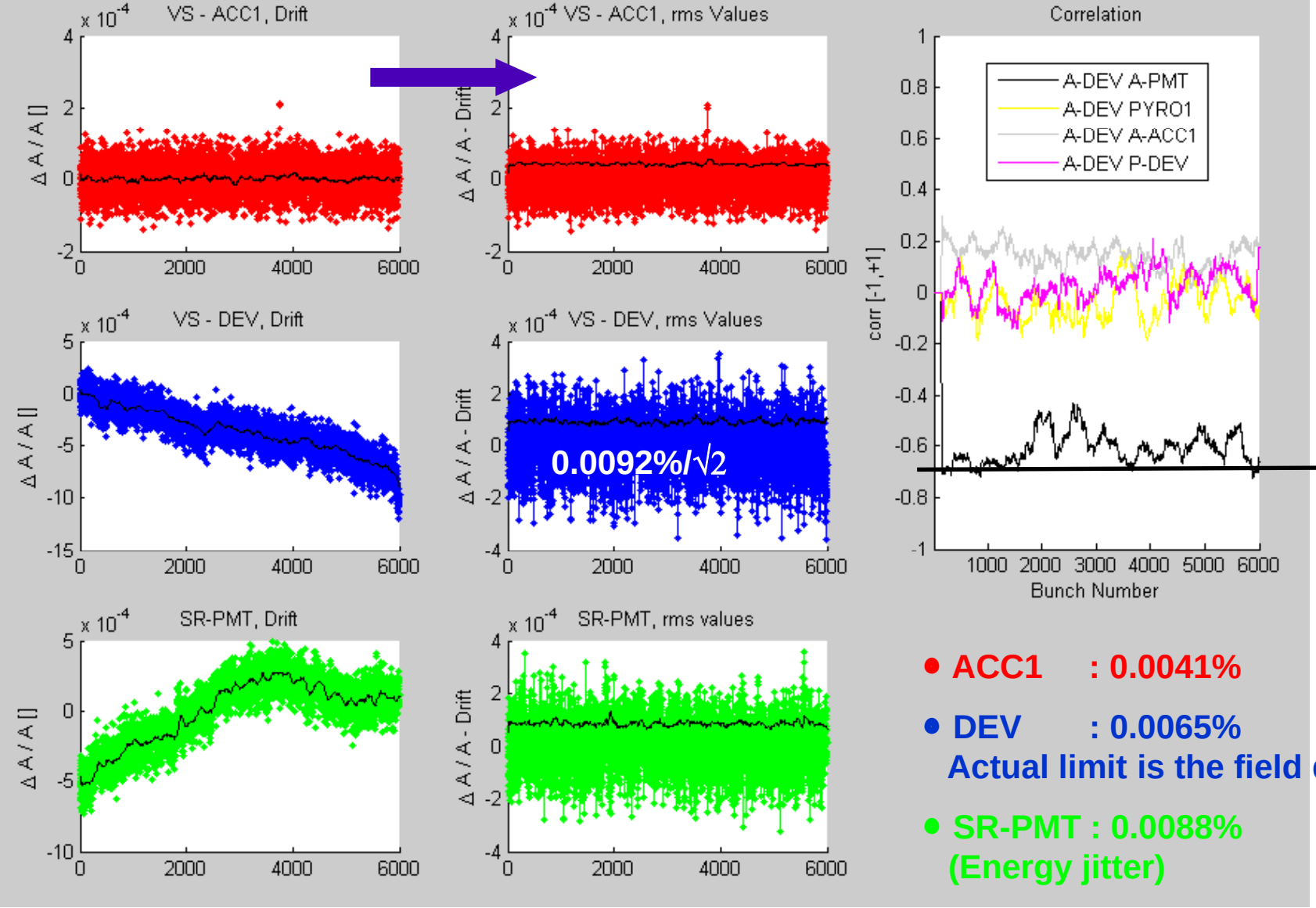
- ACC1 Noise watchdog :

- Regulation system :
  ACC1 close loop

- Regulation system:
  DEV open loop



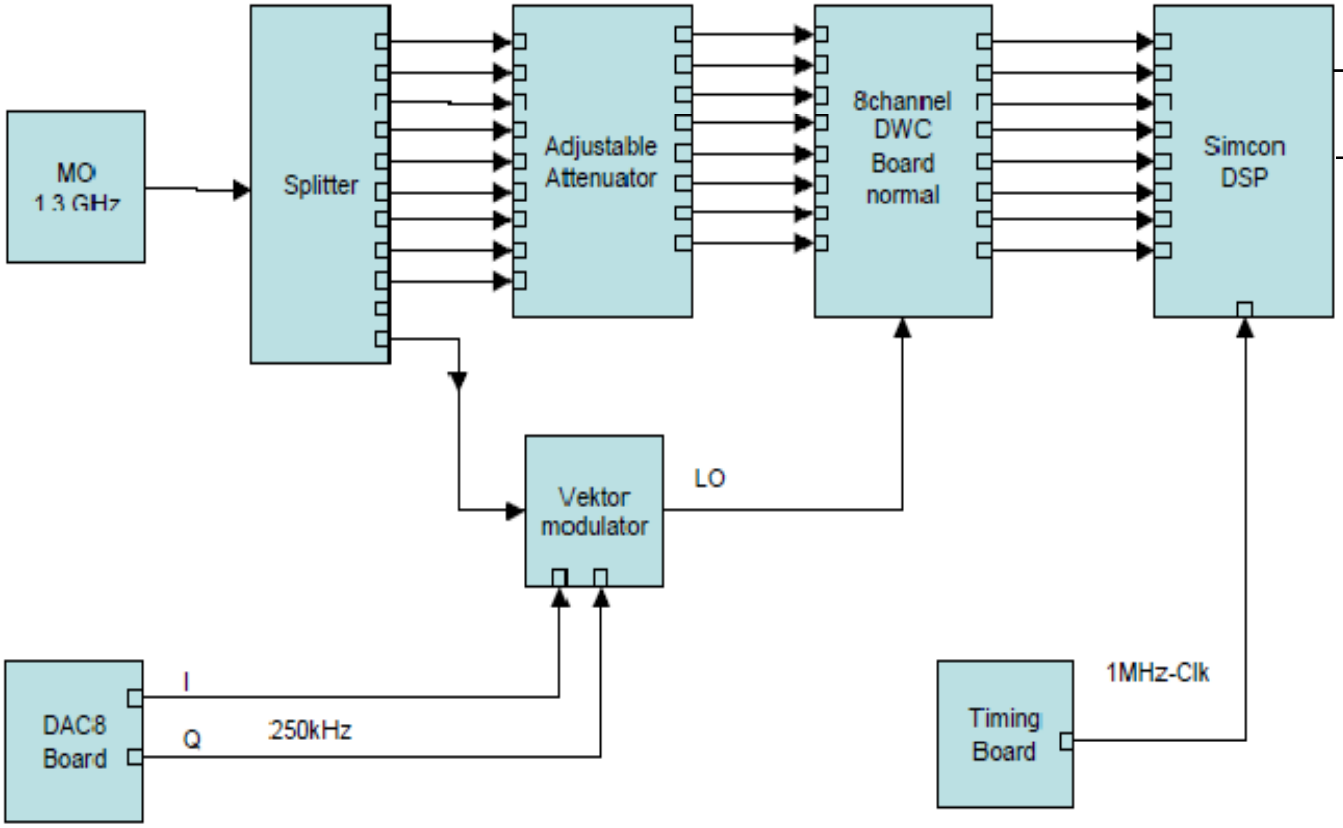
Beam Stability - Pulse-to-Pulse Fluctuations



Theoretical expectation $1/\sqrt{2}$

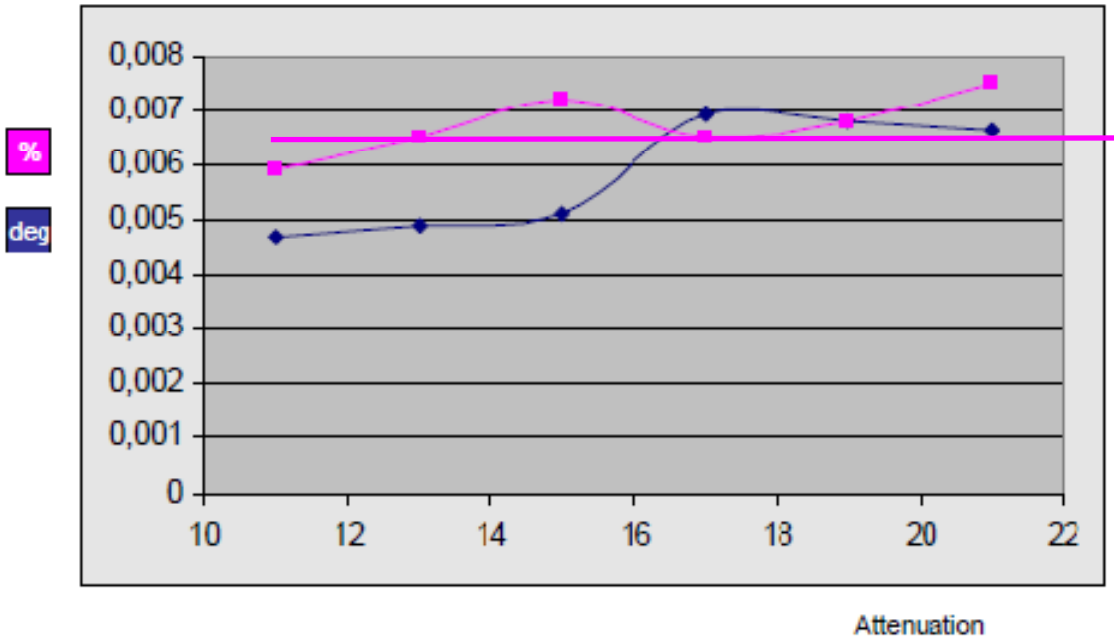
- **ACC1 : 0.0041%**
- **DEV : 0.0065%**
  Actual limit is the field detector
- **SR-PMT : 0.0088%**
  (Energy jitter)

- FLASH field detector performance test using the reference :



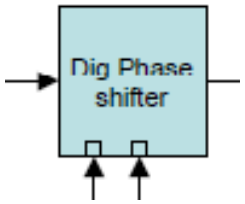
Field Detector – Performance Tests at FLASH

- FLASH field detector performance test using the reference :

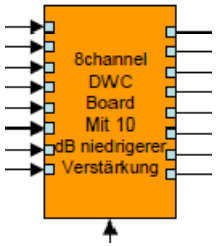


Limit determined by correlation measurement

- Improvement of field detection ? :



30fs -> 7fs

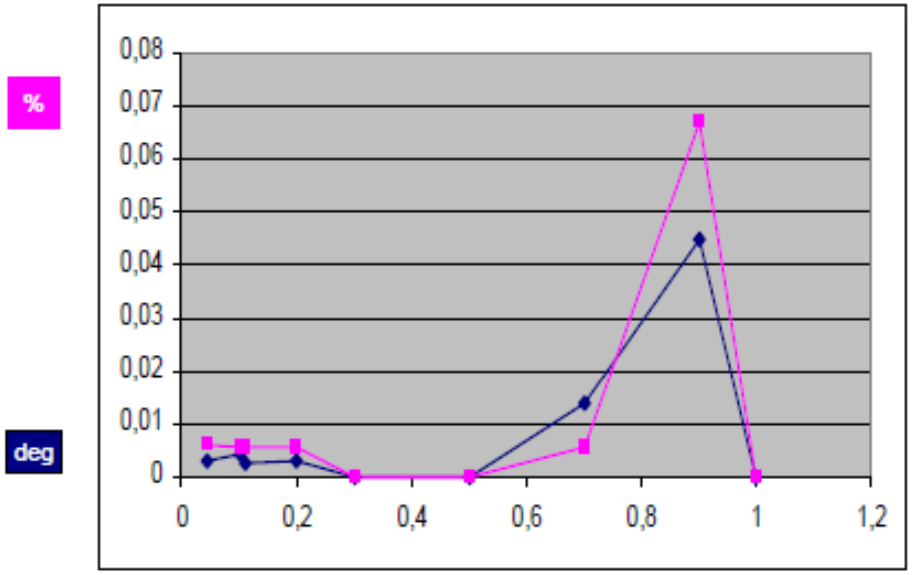


3x less noise

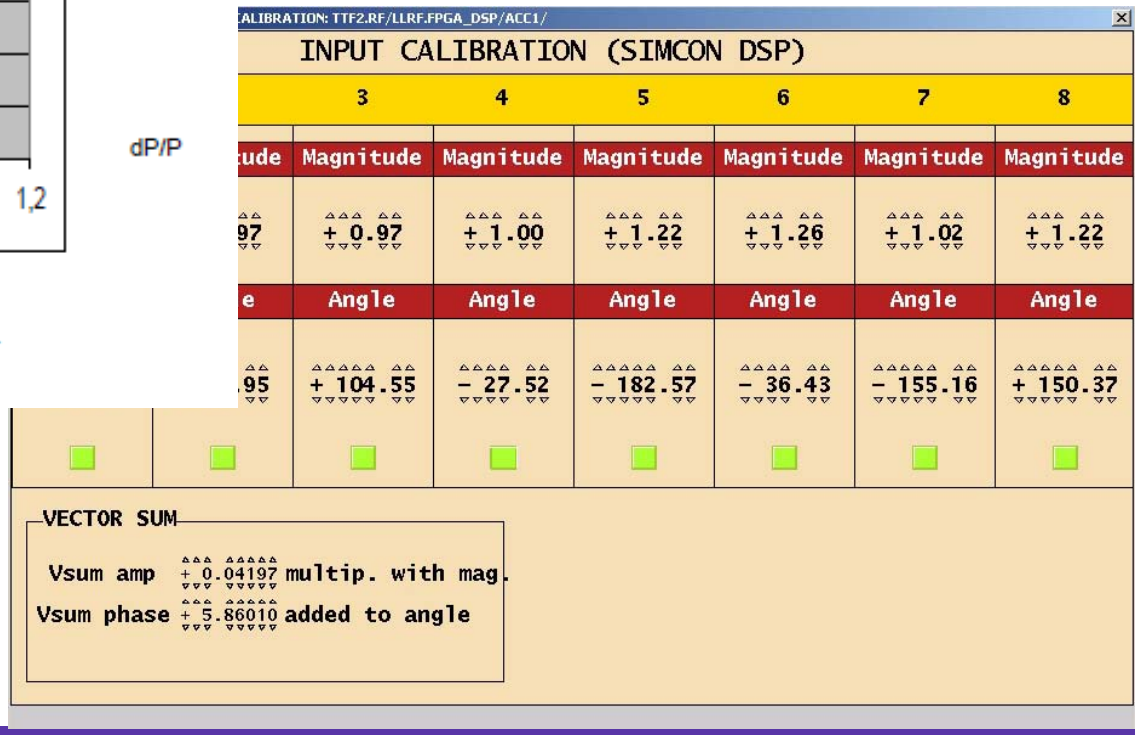
No improvement → **ADC noise limitation, MO (minor)** → **N parallel receiver channels (modular system, ATCA)**

Field Detector – Performance Tests at FLASH

- Improve strange FPGA behaviour for Vsum scaling :



Parameter
Calibration VS_multiplier



Field Detection Methods and Status 04/09

- Downconverter Noise and Drift Sources :
  - LO-Generation, ADC Noise, Receiver and FPGA IQ Detection
  - Cable drifts
  - Microphonics from Vector-Sum Calibration caused by non-linearity, cross-talk, field-flatness

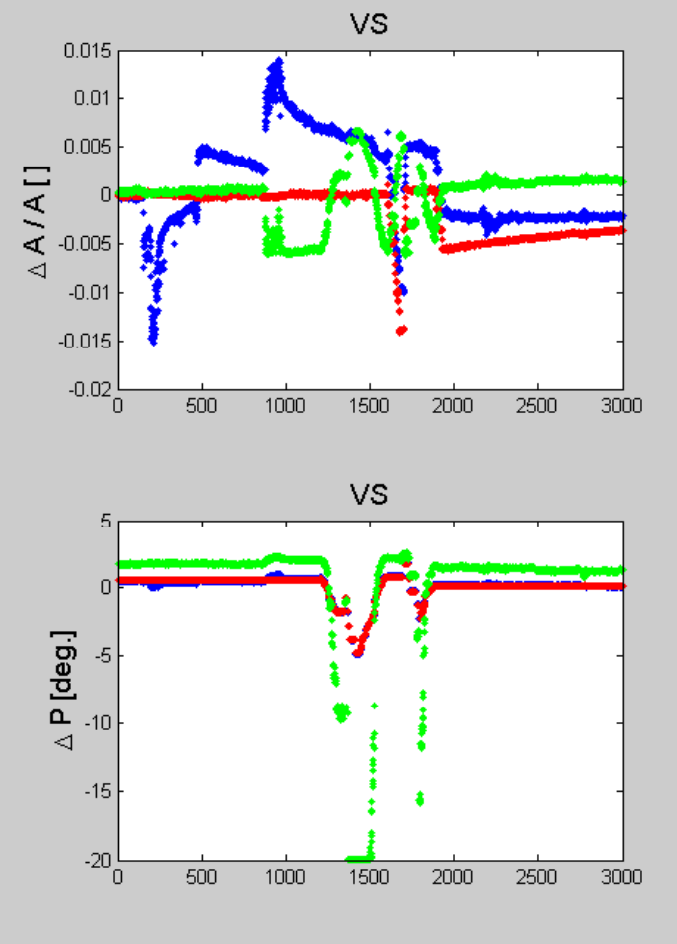
- Status of the Performance Evaluation

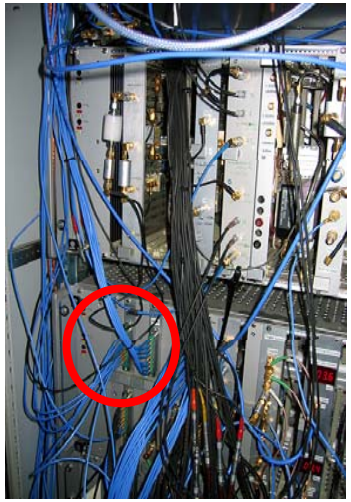
EUROFEL DS3.9, Delivery Report 01/2008 Section 1.5, F.Ludwig et.al.

Status of the Performance Evaluation: [10min, 1MHz]	Switched-modulation (existing at FLASH)	CW modulation (non-IQ-sampling)	Direct-sampling
Self test using the reference in Laboratory (Single channel, 8 channels to be done)	to be done	0.003% (PAC2007)[1]	to be done
Beam based in FLASH using SR-4BC2	0.016% (11/2008) [3]	0.022% (10/2007) [2]	to be done
2 DUT in FLASH using cavity probe splitting	0.016% (06/2008) [3]	to be done	to be done
Self test using the reference in FLASH (Single channel, 8 channels to be done)	**0.0065%**	0.016% (11/2007) [2]	0.022% (09/2008) [4]
Long-term operation at FLASH	YES	No	No
Calibration scheme tested in laboratory / FLASH	to be done	to be done	Reference tracking

Confguration: **1:** Passive Receiver, 16-bit ADC ACB 2.1, **2:** Active Receiver, 14-bit ADC SIMCON 3.1
3: Active Receiver, 14-bit ADC FLASH Boards, **4:** 12-bit ADC, 200Msps

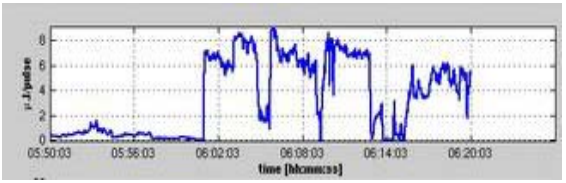
Beam Stability – Mechanical Distortions - Cables





Cable test in the injector, approx. 2mm motion!!!
ACC1,DEV1 LFF ON, Gain=50, Pyro Feedback OFF
Action:
6:01h: shot 130 DEV Injector door open (probe cable touch inner door)
6:02h: shot 200 DEV Probe cable bunch (Attenuator to DWC 1300MHz)
6:03h: shot 300 DEV IF cable bunch (baseband DWC to ADC)
6:04h: shot 400 DEV RF MO signal to VM
6:04h: shot 450 DEV Injector door close
6:05h: shot 700 ACC1 Probe cable bunch DWC input (sensitive,cause interlocks)
6:05h: shot 1200 ACC1 phase readjustment
6:11h: shot 1700 (approx) ACC1 Probe cable bunch 1/2" top rack, attenuator partly not fixed!
6:13h: shot 2500 New MO Main bunch distribution (right panel, middle rack 2)

SASE:



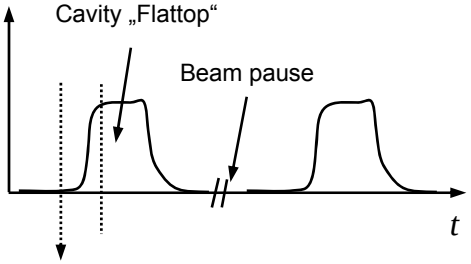
- Driftcalibration in phase and amplitude
- Short ACC1 ½“ type pickup cables
- Field detectors located at cavities
- N-Type connectors -> PCBs

Drift Calibration Schemes under Development

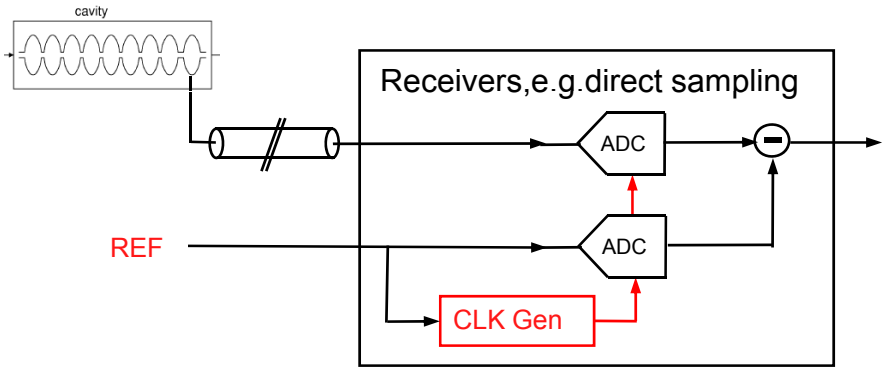
Is needed to eliminate pulse-to-pulse fluctuations and drifts from

- Cavity pickup cables (4 module) $5\ fs\ m^{-1}K^{-1}, \pm 125fs\ K^{-1}\ (\pm 25m), \Delta T \approx 1K$
- Downconverter (mixer) θ_A = 2e-3/°C, θ_P = 0.2°/°C (Injector)
- LO generation (dividers, amplifiers, filters)
- ADC CLK generation (timing system, less critical)

to have a robust machine operation.

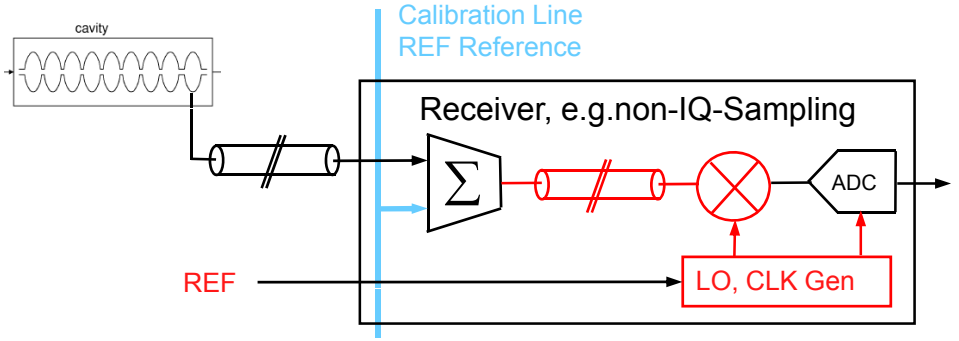


1) Tracking the reference :



+ Demonstrated, e.g. with direct sampling
+ High symmetric receivers
+ Low amplitude drifts

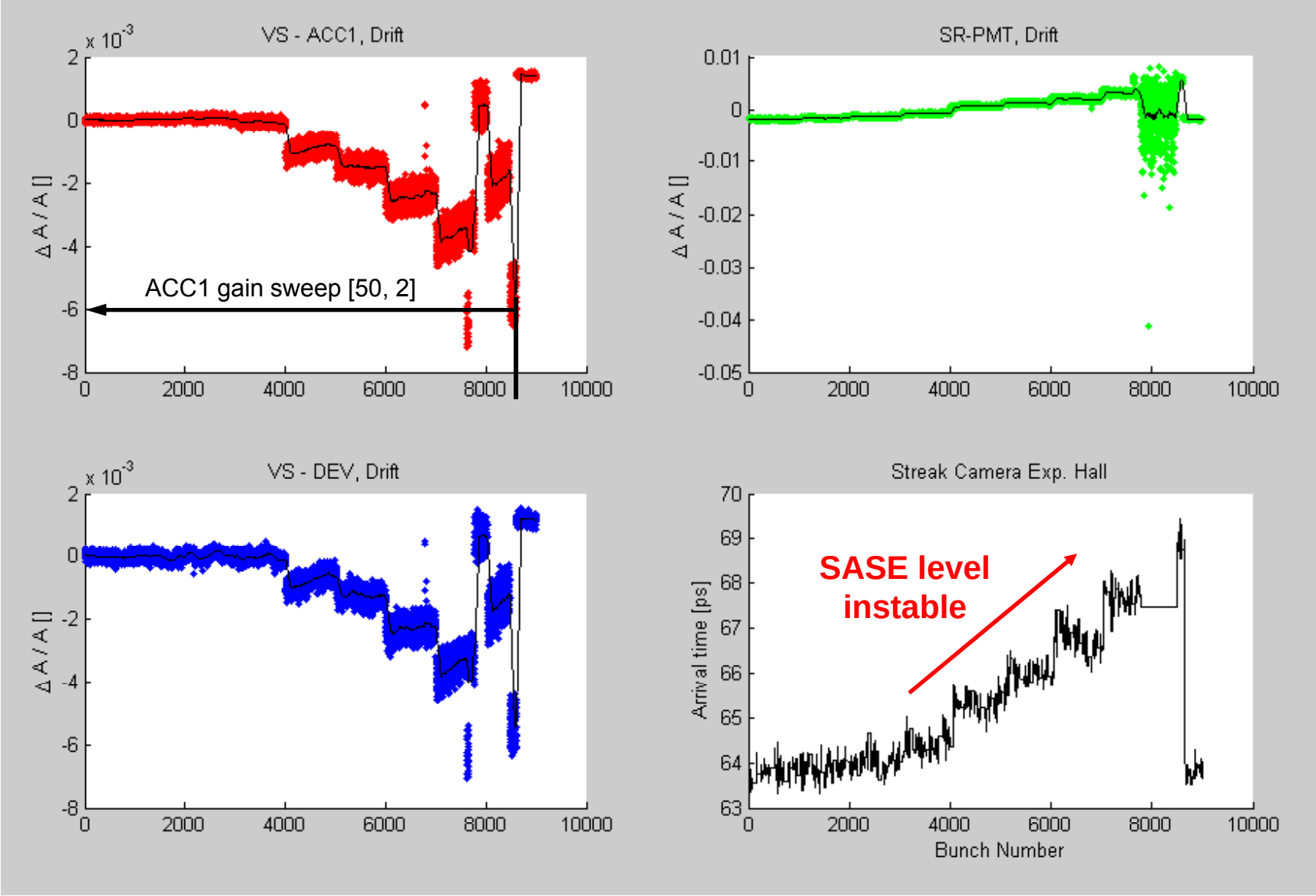
2) Injection of the reference signal :



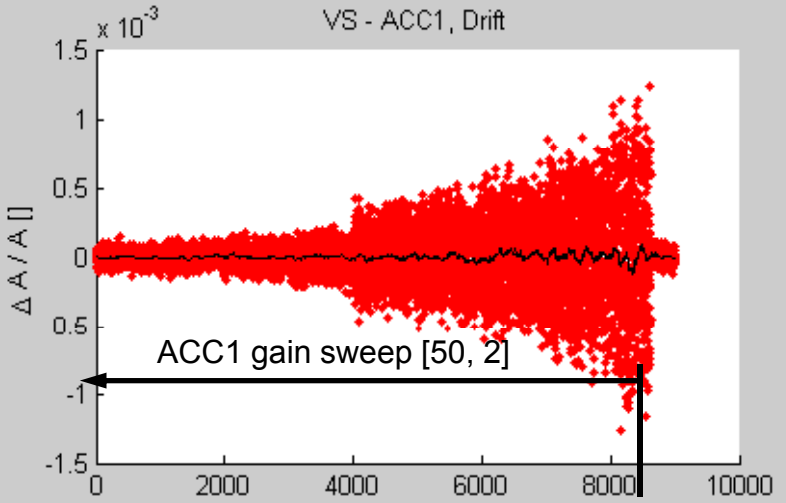
3) Reflection at the cavity :

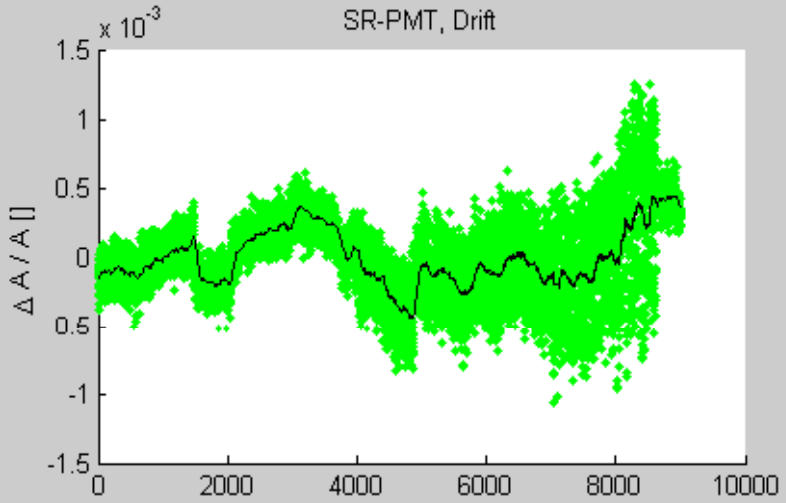
+ Compensates in addition antenna to cavity pickup

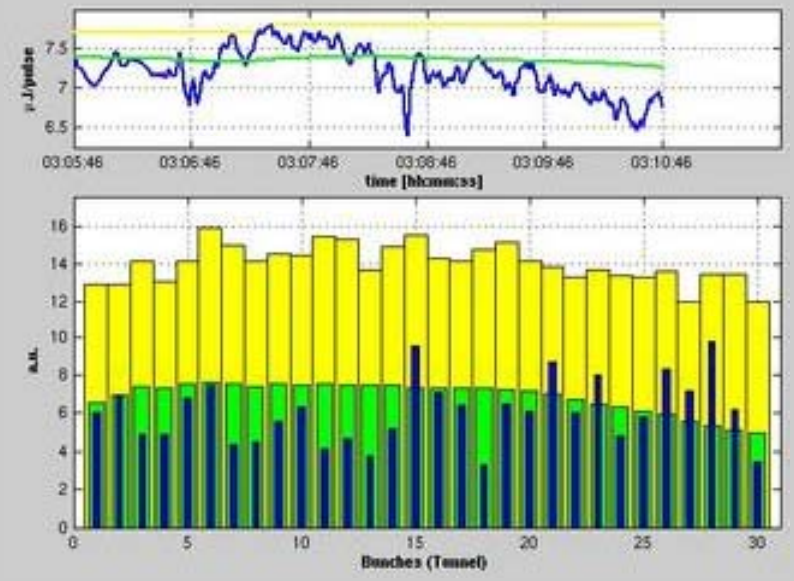
Cavity Field Flatness – Learning Feedforward OFF

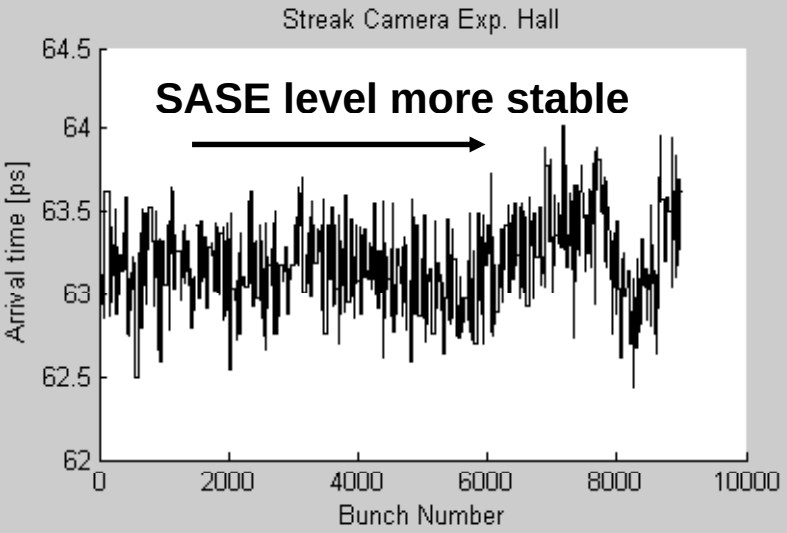


Cavity Field Flatness – Learning Feedforward ON









Summary

- Absolute phase noise of Master-Reference is improved.
- Bunch arrival time is limited by 1300 cable and ACC1 drifts.
- Phase detectors are limited for lower frequencies -> 24-Bit ADC, multipliers, driftfree detectors.
- ACC1 field detectors are the main reason for the the short-term and long-term energy jitter.
- A Learning feedforward makes SASE more stable.
- A proposal for a robust machine operation for ACC1 is presented.

Outlook

- Drift calibrated field detectors are needed.
- ADC noise will be overcome by parallel receiver channels in a modular system.
- Learning feedforward must be implemented into FLASH.
- Driftfree phase detectors.
- Exp. Hall FSB Upgrade.

Special thanks to

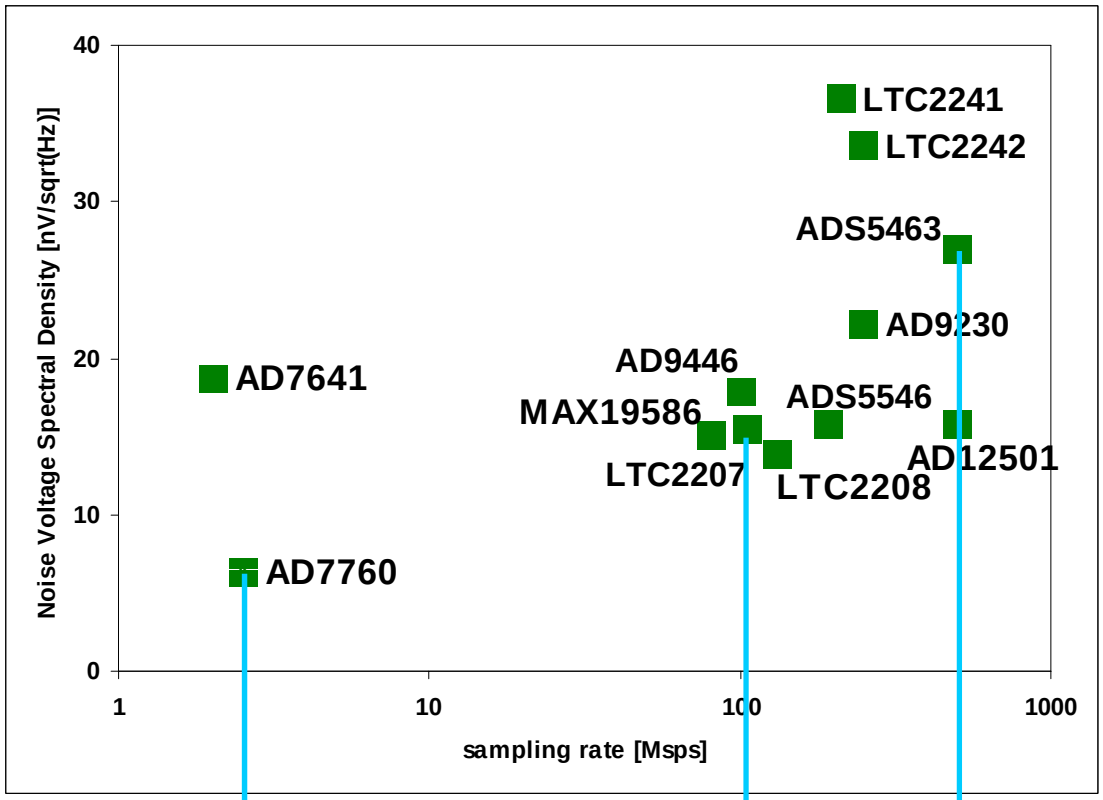
C.Schmidt, C.Gerth, G.Möller

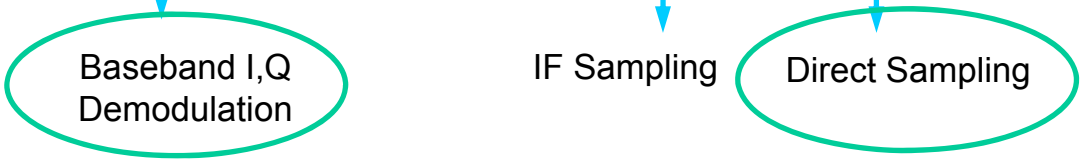
Thanks for your attention !

Backup Slides

Choice of the Modulation Scheme

- **ADC equilvalent noise spectral density :**





$$e_n = \frac{V_{FS,pp}}{\sqrt{8}} 10^{\frac{SNR(f_s,\varepsilon)}{20}} \sqrt{\frac{2}{f_s}}$$

Typ	Bits	$f_{s,max}$ [MSPS]	SNR [dBFS] 70 MHz	SFDR [dBc] 70 MHz	V_{FS} [V_{pp}]	t_j [fs]
LTC2207	16	105	77.5	90	2.25	80
LTC2208	16	130	77.5	90	2.25	70
AD6645	14	80	73.5	87	2.2	100
AD9461	16	130	77	84	3.4	60
AD9446	16	100	79	89	3.2	60
ADS5546	14	190	73.5	87	2.0	150

A lot of available ADCs have roughtly the same performance.