Electron Beam Timing Jitter And Energy Modulation Measurements At JLab ERL

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Outline

- motivation
- phase-noise measurements

  (technique, hardware, results)
- energy modulation measurements

  (cross check to the phase modulation measurements)
- outlook

Motivation

- operating JLab FEL we have observed reduction of the FEL efficiency when increasing the average beam current (bunch charge is kept constant 135 pC, bunch repetition rate increased)

- initial measurements were suggesting optics may not be the problem

- making measurements of the electron beam parameters we did not see any significant changes in:

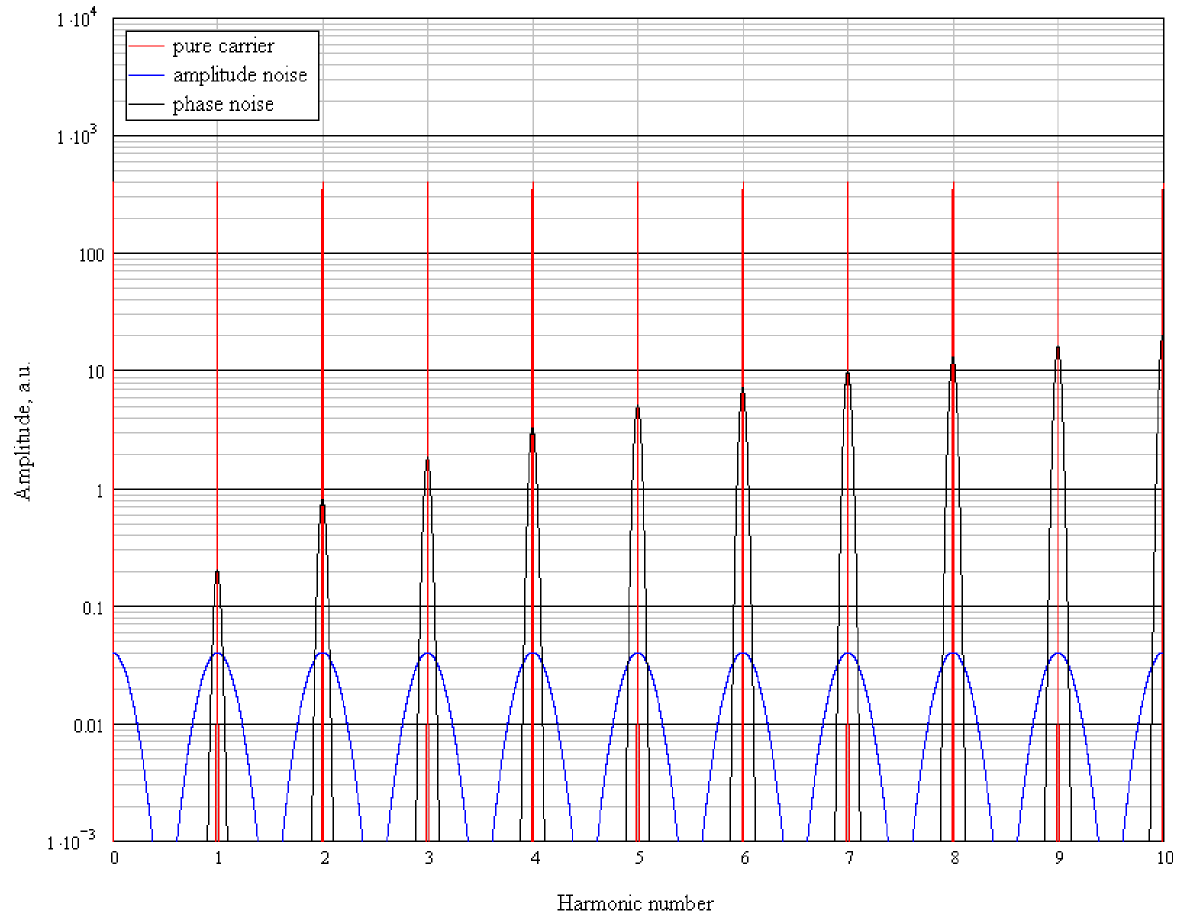
  bunch length, energy spread, orbit or betatron tune

- How do we know it is not due to the timing jitter of the electron beam? (routinely operating with 150 fs RMS bunch length)

- What are requirements of the FEL to the timing jitter? – develop instrumentation and techniques to determine experimentally the FEL sensitivity to the timing jitter.

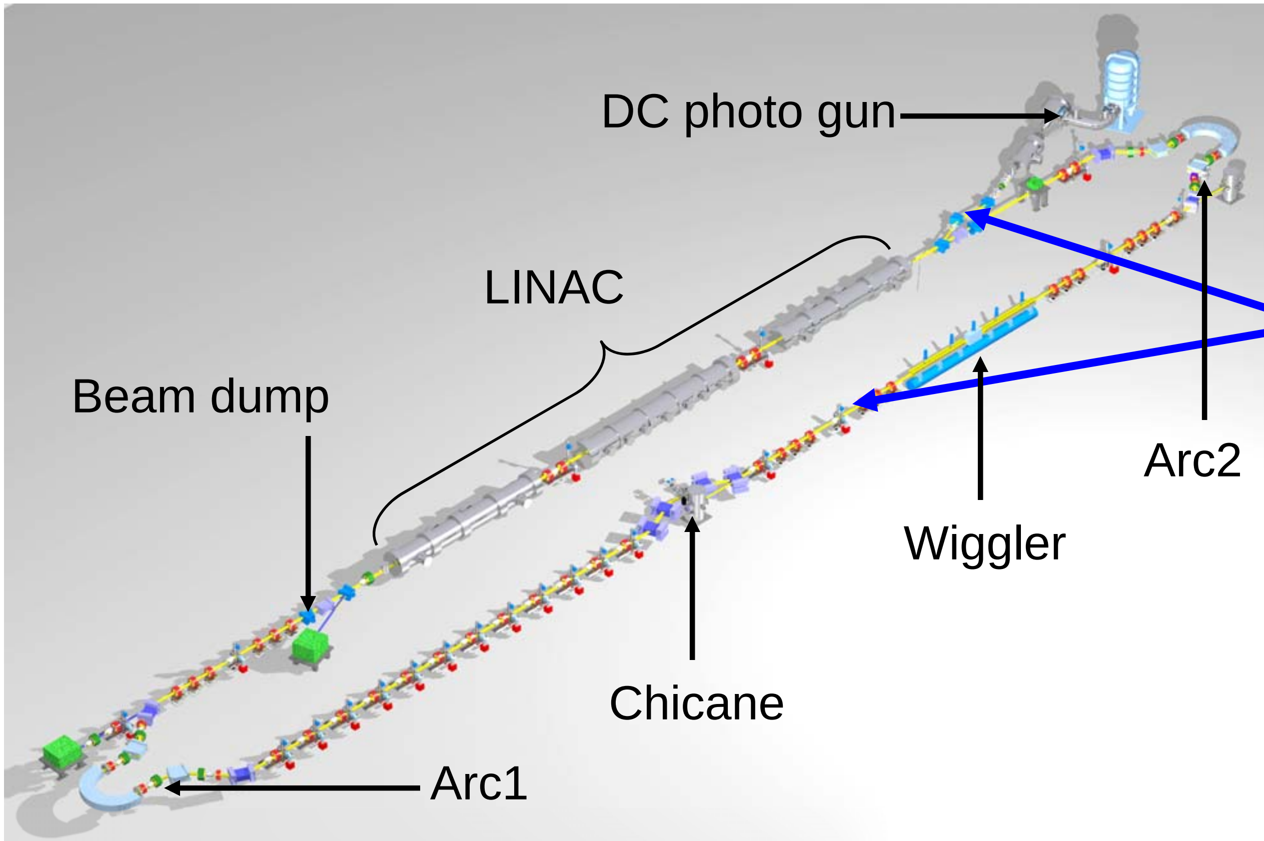
Phase noise measurements technique

- Originally developed for ultra fast lasers phase noise characterization
- Amplitude of phase modulation ~ N^2
  N - harmonic number
- Amplitude of amplitude noise is constant with N
- Power spectrum measure-ments at high N are used for phase noise measure-ments



D. Von der Linde Appl. Phys B 39, 201-217 (1986)

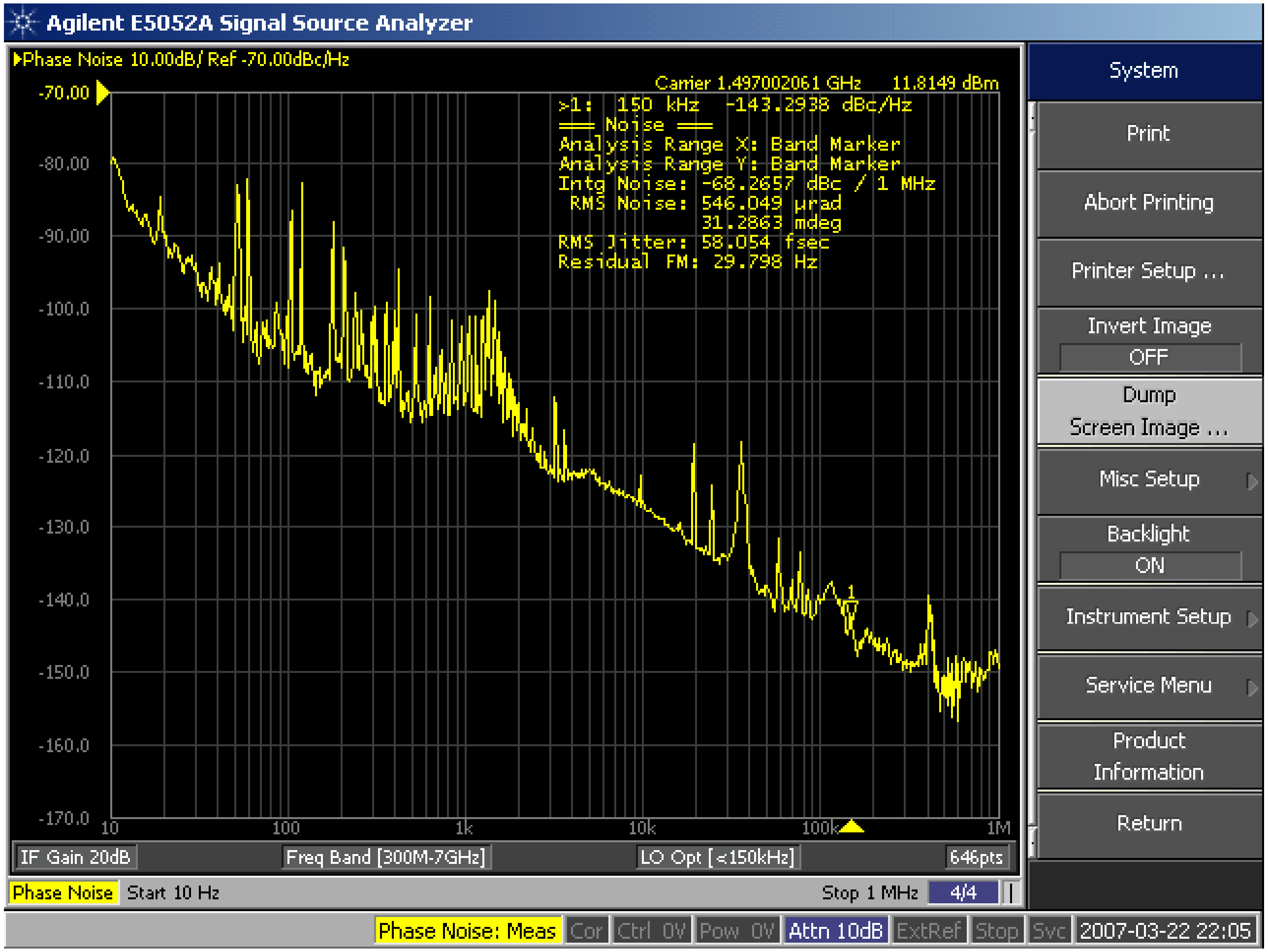
Beam phase and M_{55} measurements cavities



f_0=1497 MHz; $Q_L \approx 10^3$
N=20 for 74.85 MHz
N=320 for 4.678 MHz

Max. bunch repetition frequency (f_b) 1497MHz/20=74.85 MHz can be reduced by 2^n (n=1..8). Typically f_b=4.678125 MHz is used when start going from pulsed (diagnostic) mode to CW operation.

Phase noise spectrum



AM is still present in the sideband spectrum.

Without measurements of the spectrum around DC component must be careful with the interpretation.

The measurements are at least an upper estimate of the phase noise.

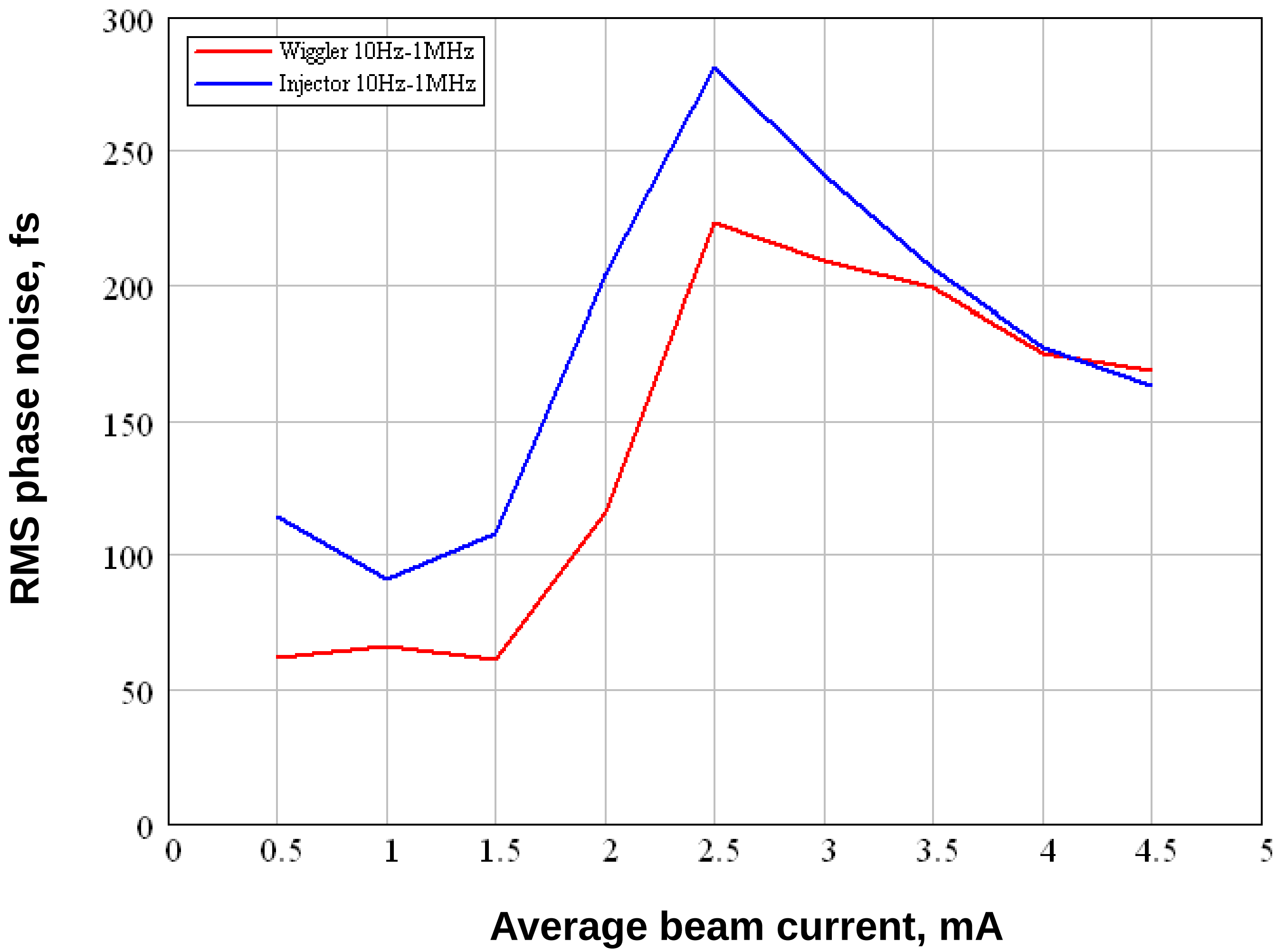
Dependence on the avr. beam current more was more important.

A wall current monitor can be used for the measurements at the DC

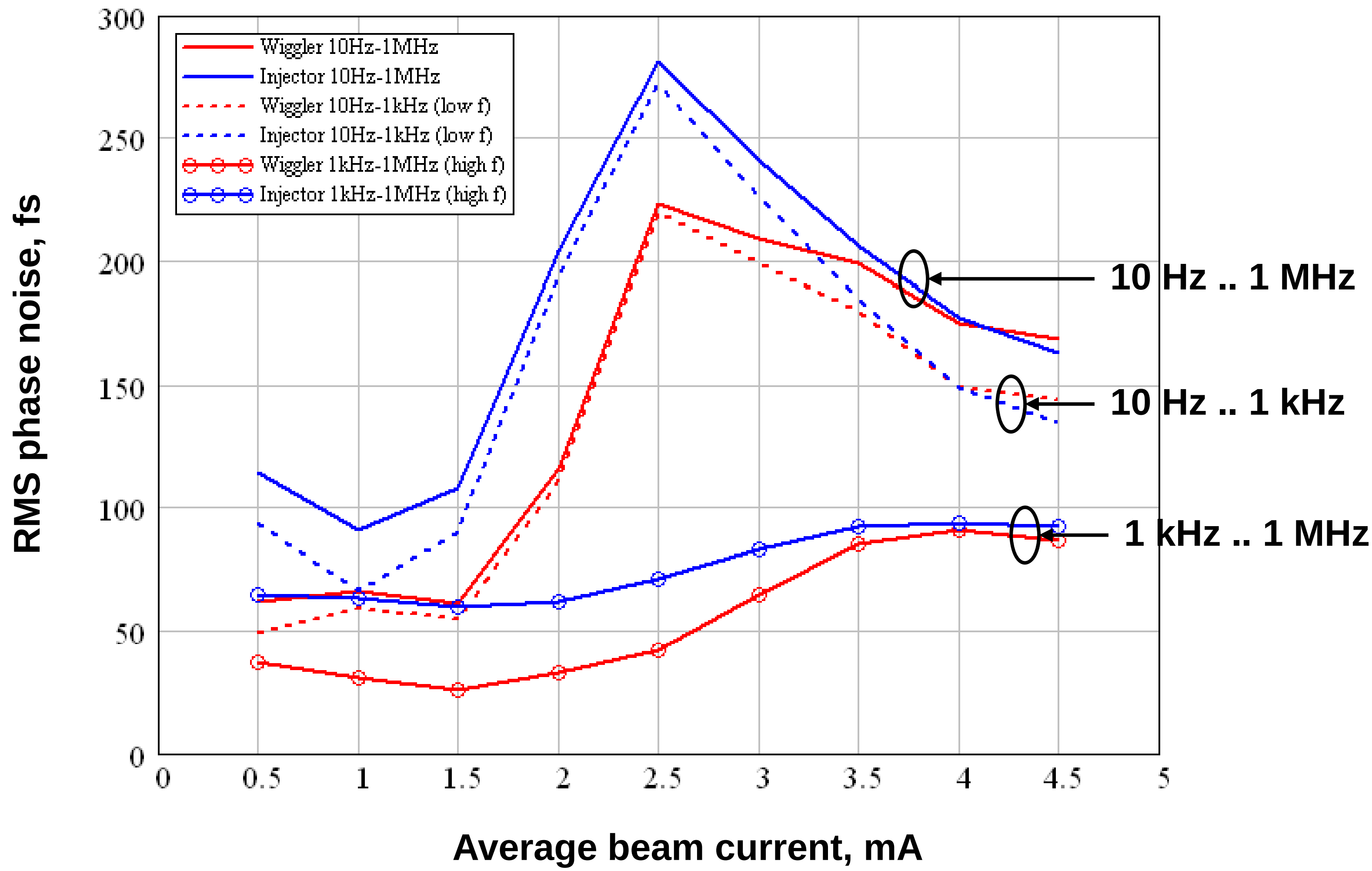
$$\frac{dBc}{Hz} = 10\log\left(L(f)\right)$$

$$\beta_{\varphi}[rad] = \sqrt{2\int_{f_{\min}}^{f_{\max}} 10^{\left(\frac{dBc(f)}{Hz}/10\right)} df}$$

RMS timing jitter vs. beam current



RMS timing jitter vs. beam current



FEL spec on timing jitter

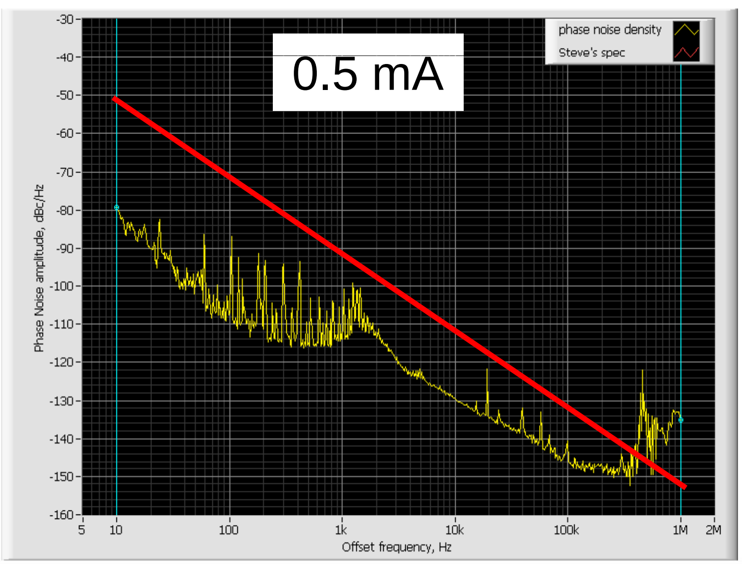
- Numerical simulations of pulse propagation in FELs indicate that in order to keep peak-to-peak power fluctuations below 10 % the optical cavity length should be kept stable to less than:

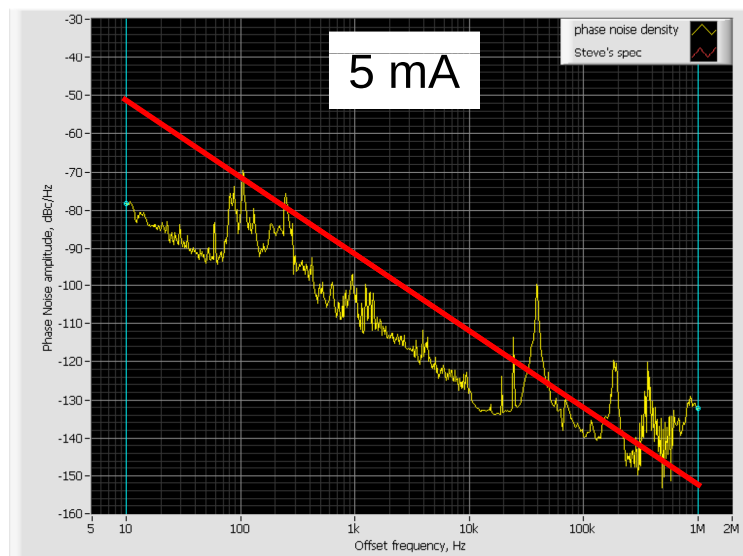
$$\Delta L_{cavity} < 0.05 \cdot G \cdot N \cdot \lambda$$

G–FEL gain, N–periods of wiggler λ-radiation wavelength

- Bunch time arrival variation effectively has the same effect as cavity length change.

$$\Delta t < \frac{6 \cdot 10^{-9}}{f_{\mathrm{mod.}}}$$

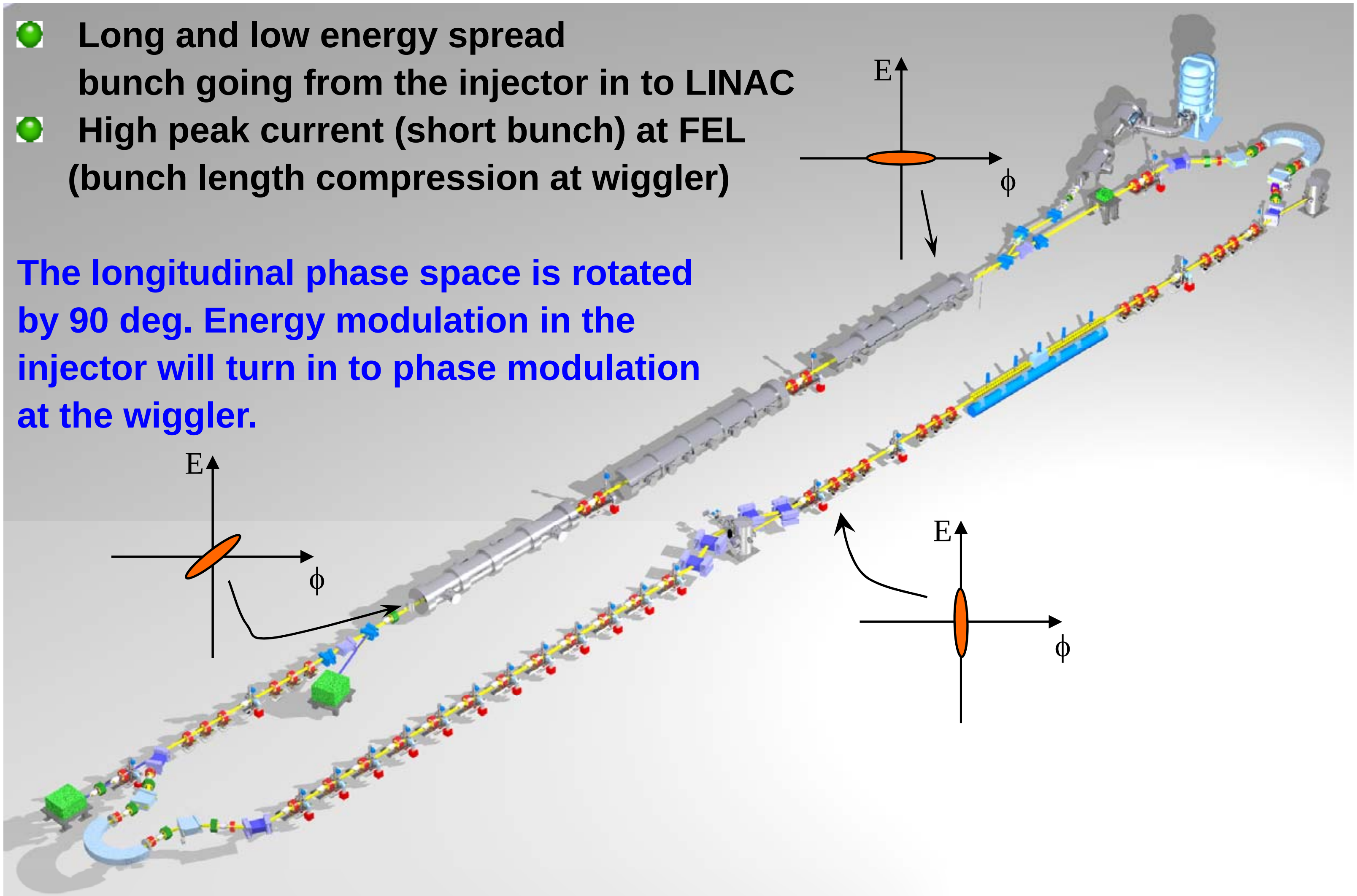




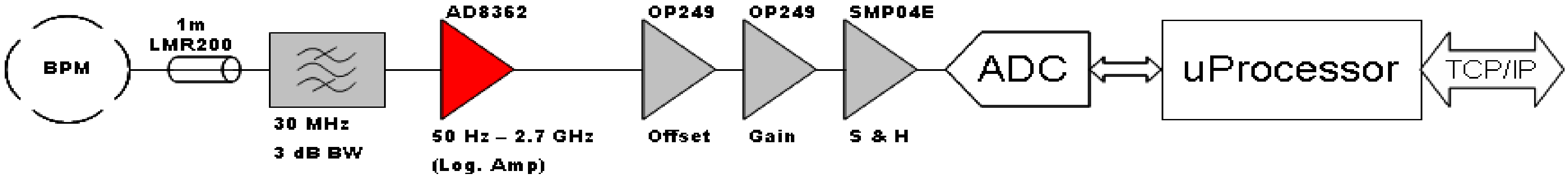
JLab FEL (layout and longitudinal matching)

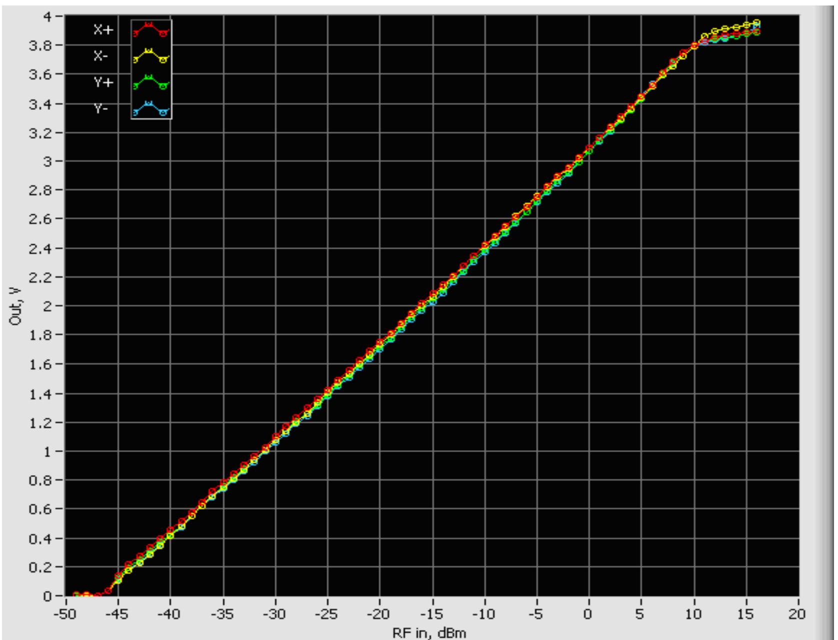
- Long and low energy spread bunch going from the injector in to LINAC
- High peak current (short bunch) at FEL (bunch length compression at wiggler)

The longitudinal phase space is rotated by 90 deg. Energy modulation in the injector will turn in to phase modulation at the wiggler.



Log amp based BPM electronics

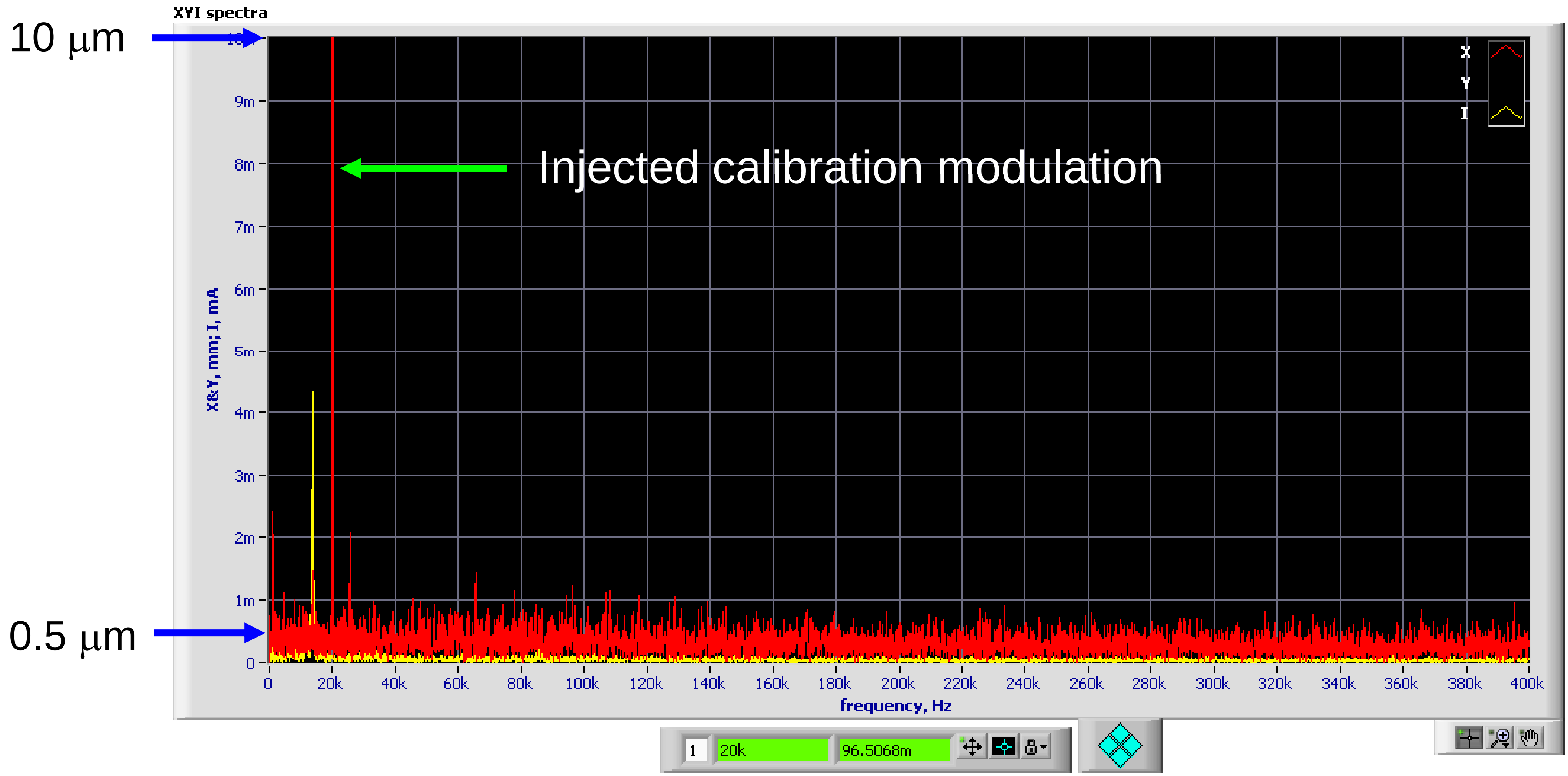




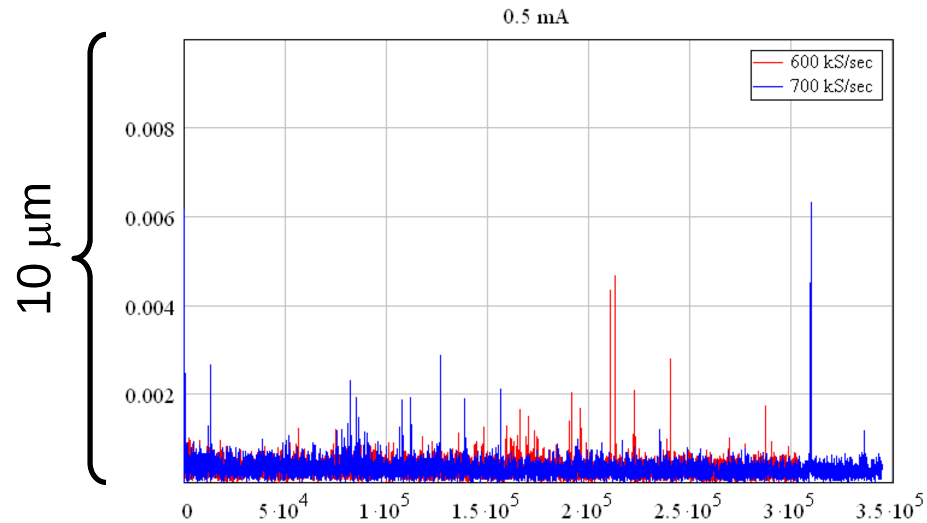
~ 60 dB dynamic range
with constant gain

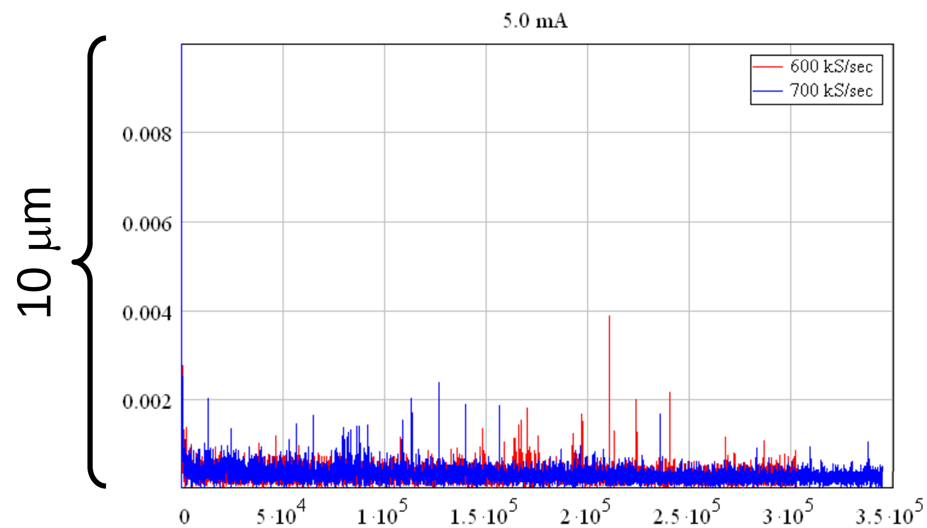
- Core element is a Logarithmic amplifier – RF to DC converter designed for measurements of an RF waveform envelope
- Detection bandwidth ~ 10 MHz, i.e., if the amplitude of the RF waveform is modulated with frequency up to 10 MHz it will be measured properly
- Used in a combination with high performance ADC:
  2.5 MS/sec (measures up to 1.25 MHz)
  14-bit resolution & 16 MSamples memory
  $\Rightarrow$ RBW 600 Hz

Log-amp BPM calibration and noise level



Energy stability in the injector





How much of the energy modulation in the injector would be too much?

$\delta\varphi_w = M_{55} \cdot \delta\varphi_{inj} + M_{56} \cdot \delta E_{inj}$

$M_{55} = \approx 0$
$M_{56} = -0.2\text{m}$

Let's say δt_w equivalent to the $\delta\varphi_w$ should be less than σ_z (150 fs)

$\delta x = (D \cdot \sigma_z \cdot c)/M_{56}$ $\quad D \approx 0.2\text{m}$

$\delta x \approx 90\ \mu\text{m}$

- Did not observe anything close to this.
- Also did not see any dramatic changes with average beam current

Conclusion

- made electron beam phase noise measurements as a function of the average beam current

  (at least upper limit of that)

- convinced our self that the phase noise was not the reason for the FEL efficiency decrease (presence of the AM makes this part difficult) add wall current monitor for DC measurements

- used energy stability measurements as a cross-check of the phase stability (possible due to $M_{56}\neq0$)

- Is the spec accurate enough? Planning to measure the spec experimentally.