Fast Electron Beam and FEL Diagnostics at the ALICE IR-FEL at Daresbury Laboratory

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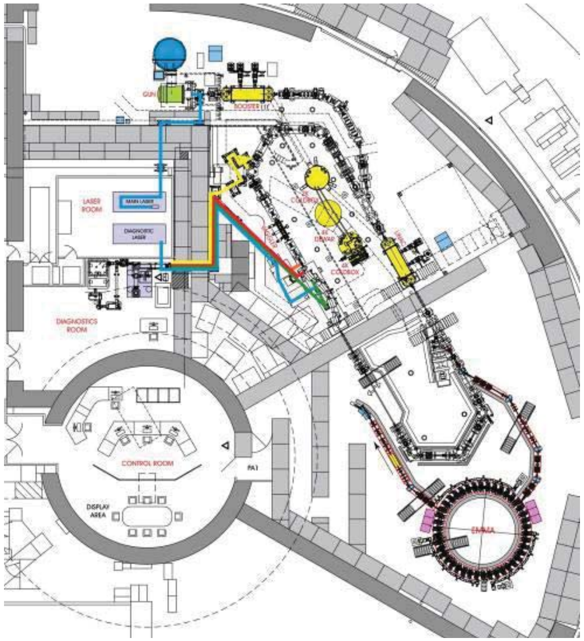
The ALICE Facility @ Daresbury Laboratory

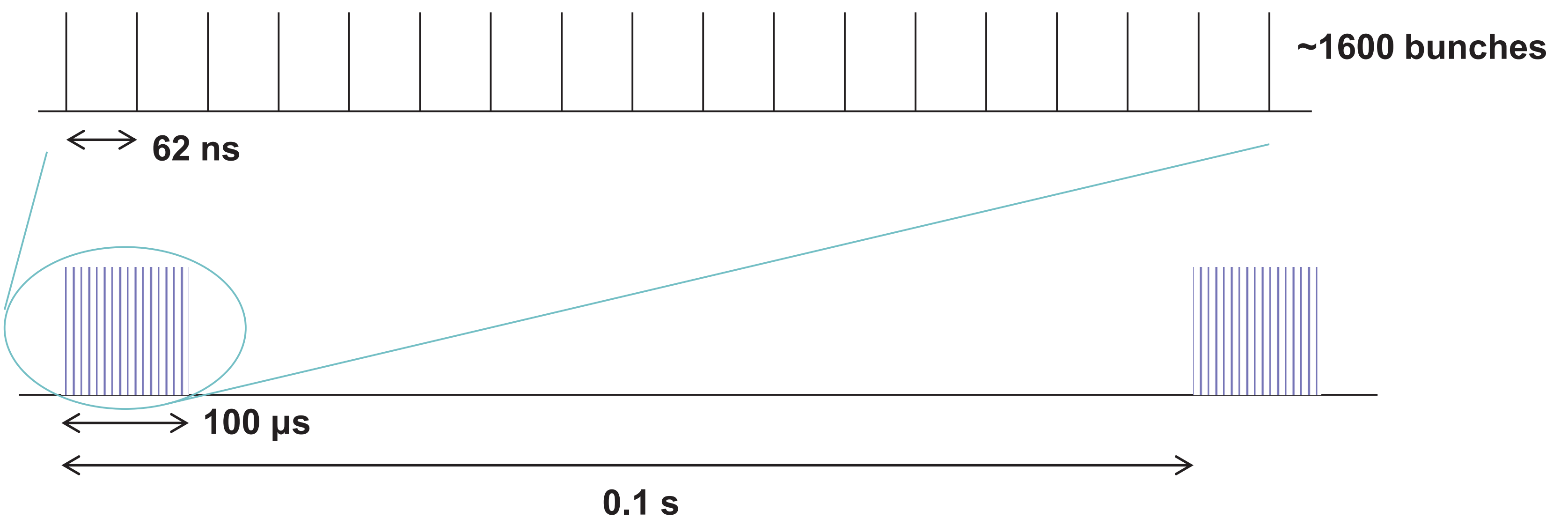
Accelerators and **L**asers **I**n **C**ombined **E**xperiments



- **An accelerator R&D facility based on a superconducting energy recovery linac**
- **DC Gun (325 kV), SC Booster (~ 7 MeV), SC Linac (~30 MeV), oscillator IR-FEL.**
- **History of construction, commissioning and operation ~ 10 years.**
- **Various applications over the years – used as injector to EMMA ns-FFAG**

ALICE parameters/beam structure

- Runs at 0.1% duty factor, or trains of 100 μs at 10 Hz
- 60 pC bunches at 16.25 MHz within train, i.e. one bunch every 62 nsec, ~1600 bunches in one train.



ALICE Fast Diagnostics

- Fast photo electromagnetic detector (PEM) to measure individual FEL pulse intensity – showed fast FEL instability quite soon after first lasing.
- Fast BPMs originally developed for EMMA ring (orbit period approximately 55 ns), to measure turn-by-turn beam position.
  - BPM electronics transferred to ALICE BPMs, to measure bunch-by-bunch position.
- High resolution time-of-arrival detectors also being developed for ASTeC's other projects and fundamental technology development
- Capabilities for synchronised FEL and e-beam fast diagnostics put to use on ALICE.

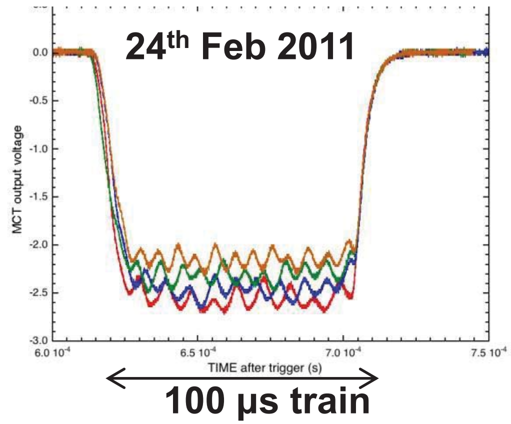
ALICE Diagnostics Details

- Please see the following references for more information
- BPMs
  - A. Kalinin et al ‘Application of EMMA BPMs to the ALICE ERL’, IBIC 2012, Tsukuba.
  - I. Kirkman et al ‘Calibration of EMMA BPMs …’, IPAC 2012, New Orleans
- TOA
  - T.T. Ng et al ‘Optical Clock Distribution System at the ALICE ERL’, IPAC 2011, San Sebastian
  - T.T. Thakker et al, ‘Bunch Train Characterisation for an IR-FEL driven by an ERL’, IPAC 2013, Shanghai.
- FEL
  - Photoelectromagnetic detector (PEM-10.6-1x1 from VIGO Systems S. A.) which has a time constant of <1 ns.

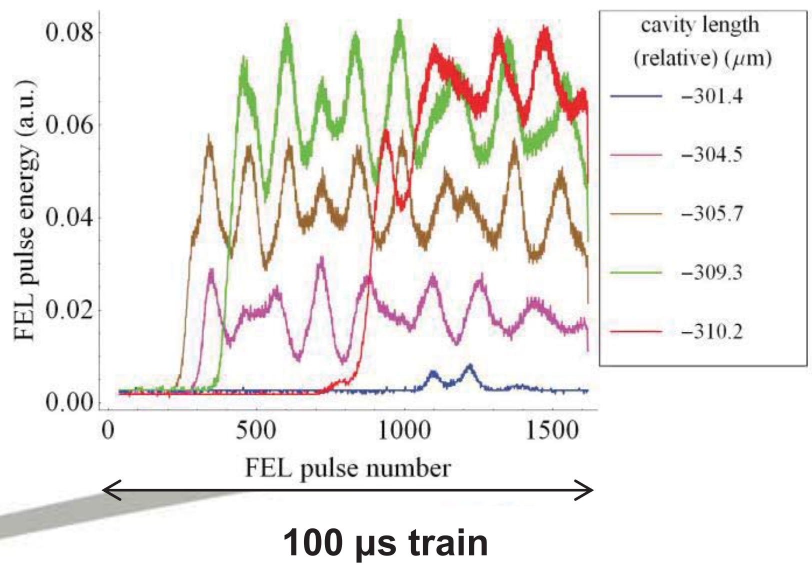
FEL output instability

- The shot-to-shot (macropulse) FEL power stability is estimated at *O*(1%)
  - FEL used mainly for microscopy experiments (SNOM)
- But there is also variation in the FEL micropulse power, within a shot, on the μs timescale.
- Observed in first weeks after first FEL lasing. ~100 kHz variation quite obvious
- Cause not immediately obvious and remained a curiosity rather than a problem

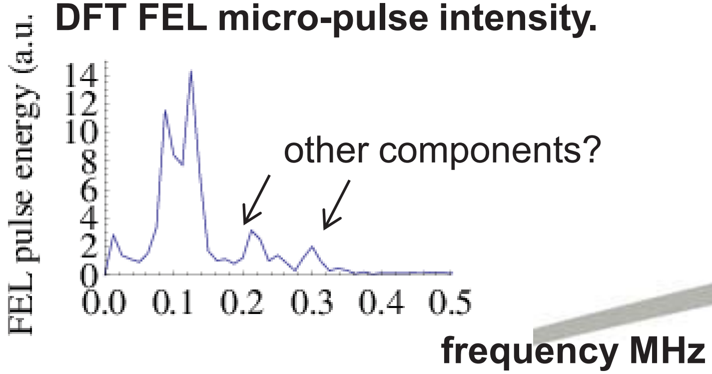
FEL micropulse intensity, first observation



FEL micropulse power at various FEL cavity tunings

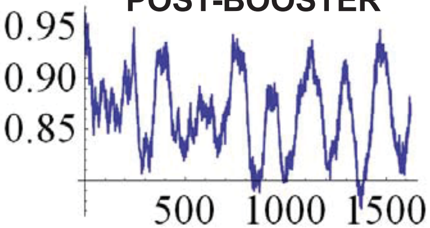


DFT FEL micro-pulse intensity.

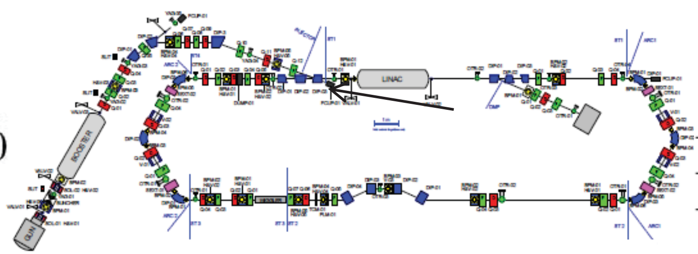


Bunch Position Instability

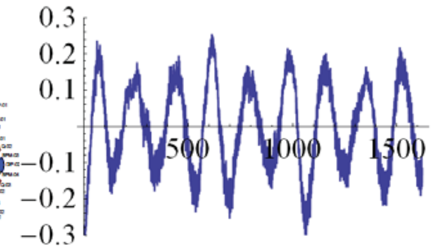
INJECTOR, POST-BOOSTER



Bunch x-position

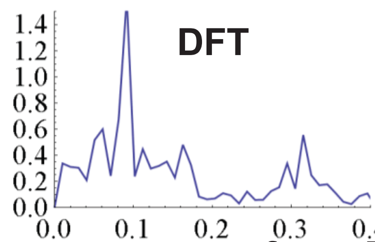


UPSTREAM ARC



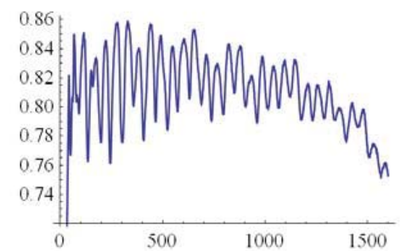
INJECTOR, PRE-BOOSTER

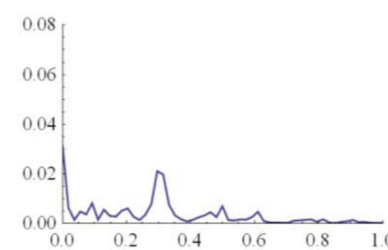
DFT



freq. MHz

Bunch charge (i.e. sum BPM signal)
typical appearance at all locations



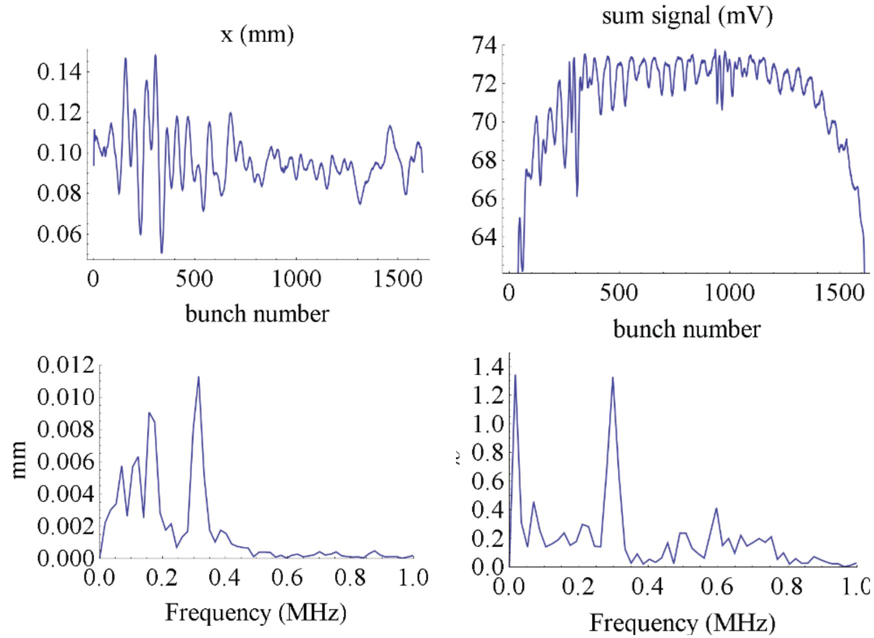


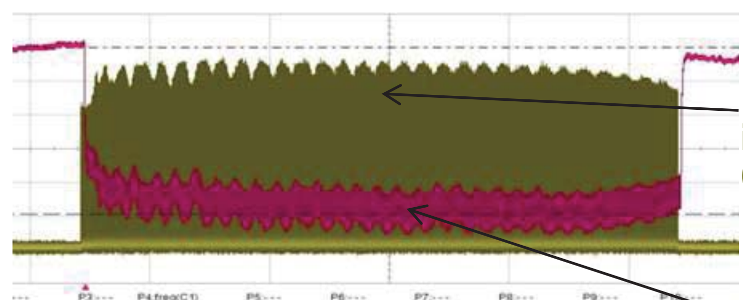
- Fast BPM reveal instability also in the bunch-by-bunch position (greater in x, the ‘machine plane’), in dispersive and non- dispersive regions
- Pronounced instability at 100-200 kHz throughout machine of ~ 0.1 mm magnitude
  - Less pronounced in gun-booster beamline
- Bunch charge variation (BPM sum-signal) visible at 300 KHz
  - Leaks through to x/y computation/measurement.

Photo Injector Laser Instabilities

- Has been seen as a cause of FEL instability at FLASH@DESY*
- Studied instability of laser pulses with quadrant photodiode on virtual cathode.
- 300 kHz laser pulse intensity instability is clear and confirmed by several independent measurements
  - And transfers to x, y position instability
- Some evidence of 100-200 kHz laser position instability, but much less clear than bunch position instability in post-linac lattice

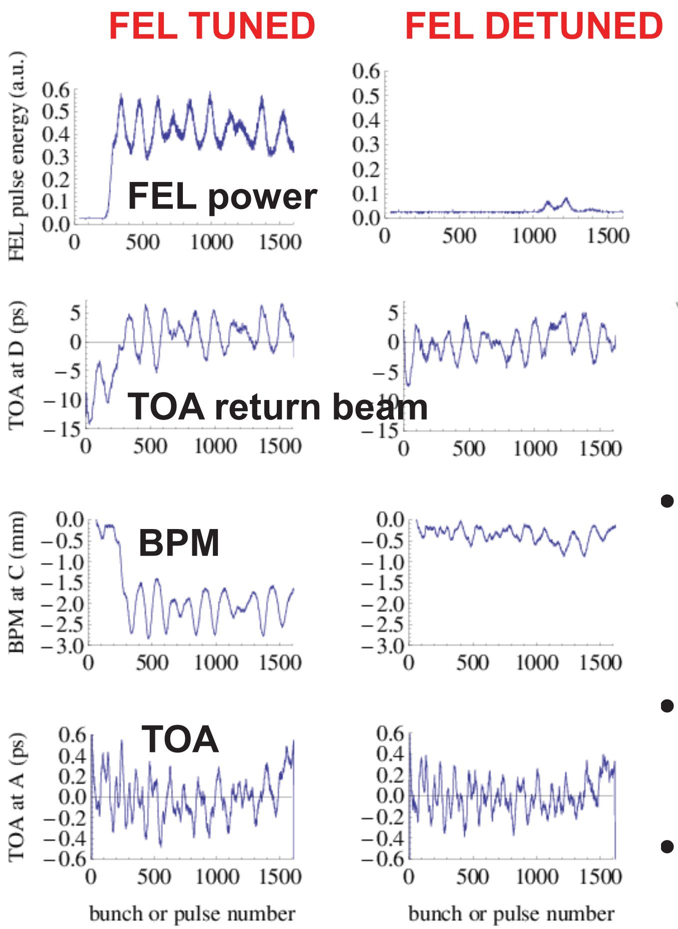
PI laser virtual cathode QPD measurements

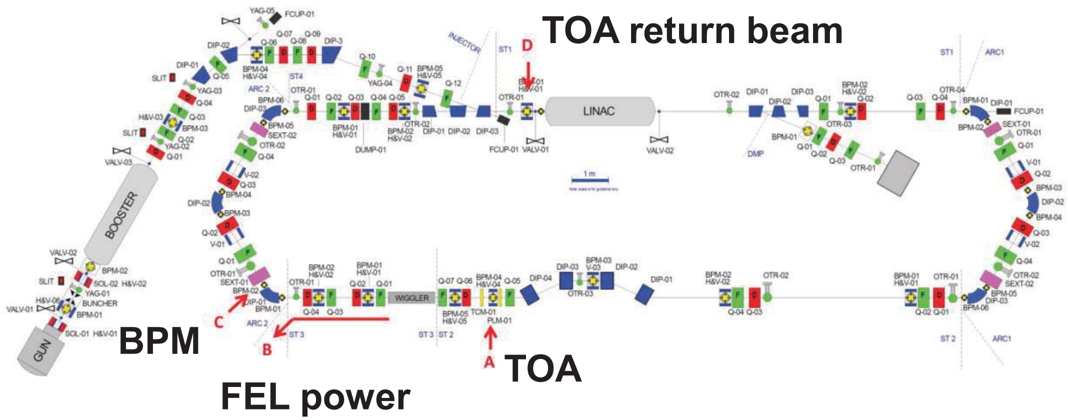




* W.Koprek et al, FEL 2010, Malmo

ALICE synchronised fast diagnostics





- Study was test-bed for optical TOA diagnostics and to gain more information on instabilities
- The same shot could be analysed on several different diagnostics
- Clear correlation between observed instabilities in bunch position, TOA, FEL power.

Conclusions

- 100-200 kHZ instability in the ALICE-FEL power, caused by bunch position instability
  - Not a significant problem for present applications
- 300 kHz instability sometimes seen in FEL power, usually seen in bunch position (but much smaller than 100-200 kHz).
- PI laser certainly responsible for 300 kHz, and may be responsible for the 100-200 kHz. Needs more study to determine evolution of instabilities and role of other factors – RF, magnets.

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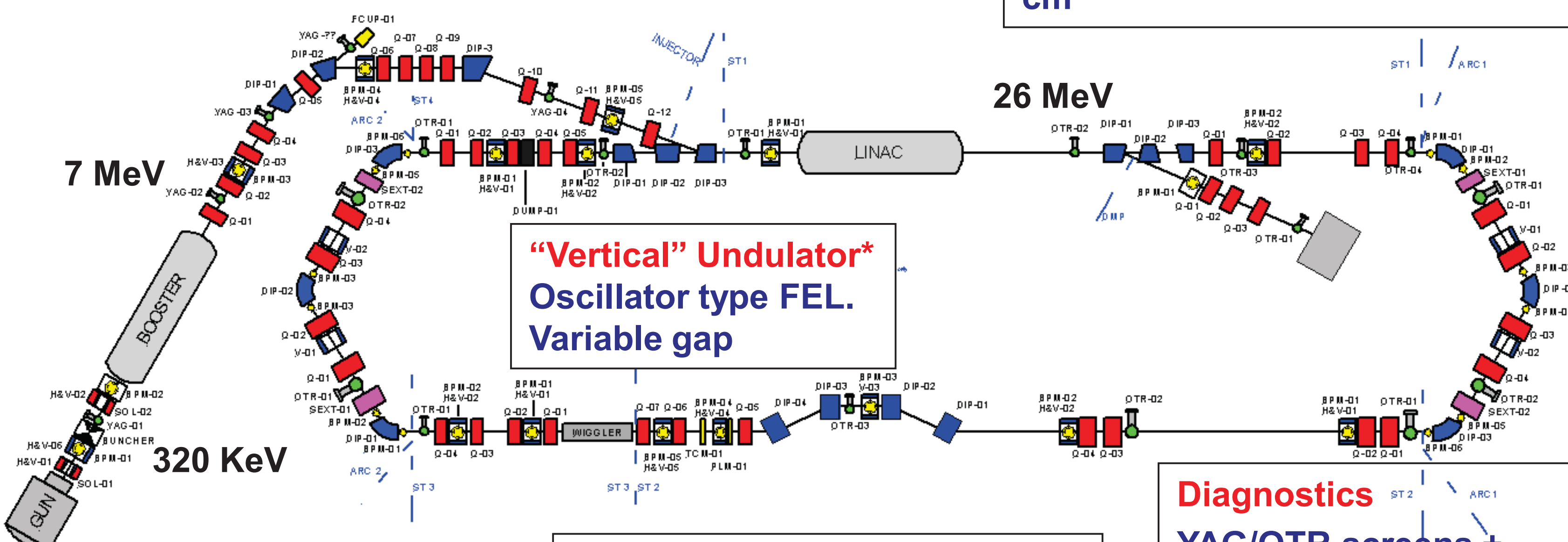
Extra information

Extra Slides

ALICE Machine Description

RF System
Superconducting booster + linac
9-cell cavities. 1.3 GHz, ~10 MV/m.
Pulsed up to 10 Hz, 100 μS bunch trains

Beam transport system.
Triple bend achromatic arcs.
First arc isochronous
Bunch compression chicane R_{56} = 28 cm



"Vertical" Undulator*
Oscillator type FEL.
Variable gap

DC Gun + Photo Injector Laser
230 kV
GaAs cathode
Up to 100 pC bunch charge
Up to 81.25 MHz rep rate

TW laser
For Compton Backscattering
And EO
~70 fS duration, 10 Hz
Ti Sapphire

Diagnostics
YAG/OTR screens + stripline BPMs
Electro-optic bunch profile monitor

*ALICE wiggler is "wrong way round" i.e. the electrons wiggle in the vertical plane (y-direction).

Laser 300 KHz

- SSB phase noise measurement

SSB phase noise measurement of PI laser

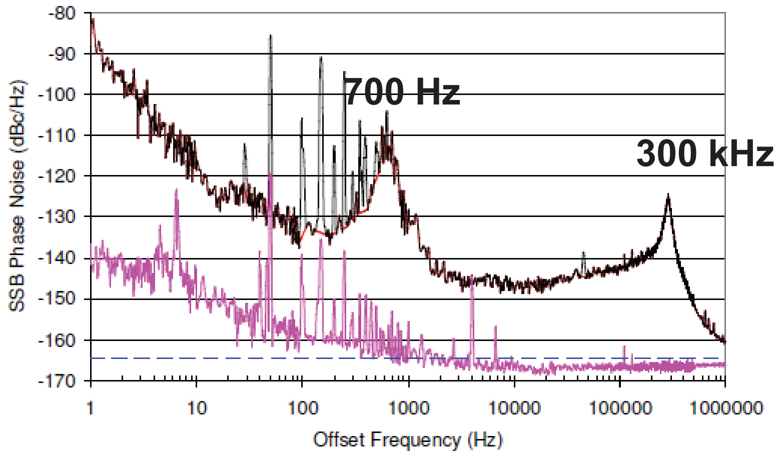
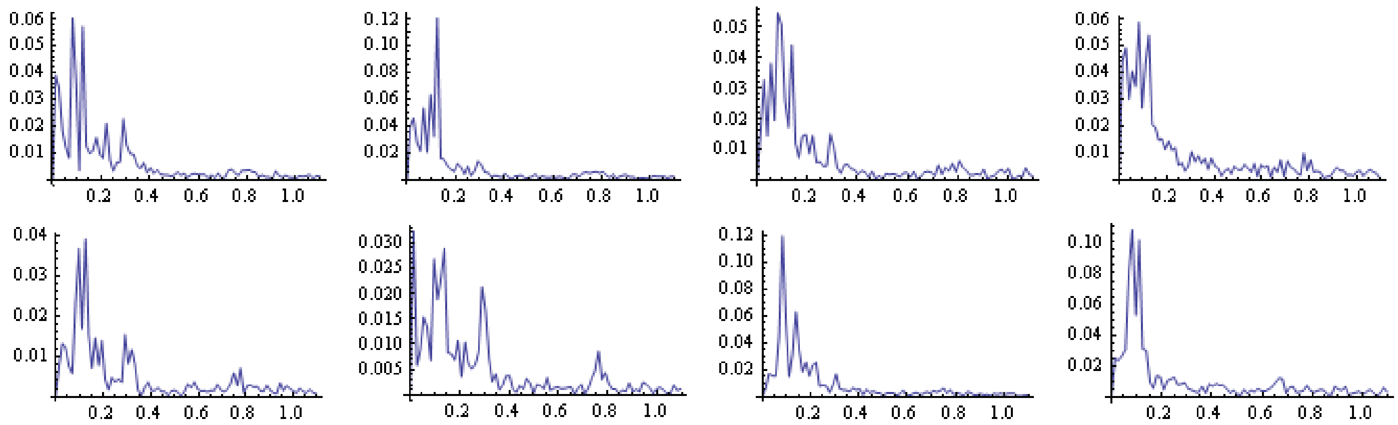


Figure 11: SSB phase noise of the ERLP photoinjector laser with spur data normalised to the spectrum analyser bandwidth (black) and with spur data removed (red interpolations). The pink trace shows the measured instrumental noise floor and the dashed blue line the calculated photodiode shot noise.

G J Hirst and L B Jones,
EUROTEV-Report-2007-DS3-057

FEL pulse frequency spectra

- # 3281 Period 14 data\AP_period13and14\FEL_AP
- Shots taken while varying buncher phase
- 300 kHZ not always visible



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FEL Instability – ‘limit cycle’ effect?

- In this process sub-pulses evolve in the main FEL radiation pulses due to slippage effects. This leads to the modulation of the macropulse power envelope.
- Seen at FELIX (Netherlands) IR-FEL

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Experimental Observation of Limit-Cycle Oscillations in a Short-Pulse Free-Electron Laser

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(Received 10 March 1992)

The first experimental observation of limit-cycle power oscillations in a short-pulse free-electron laser is presented. These are due to a nonlinear modulation of the optical micropulse shape and phase by the electrons, which leads to the formation of a train of subpulses. Experimentally, the oscillations have been found to depend on the slippage distance and on the desynchronism between optical pulses and electron bunches, comparing well with theoretical predictions.

PACS numbers: 41.60.Cr

- Frequency of modulation $\propto$ detuning. For ALICE parameters, we expect that if detuning changes by 10 μm, the modulation frequency changes by 800 kHz
- NO EVIDENCE FOR THIS IN ALICE DATA