ARD-ST3 at ELBE \ HZDR …*Update*

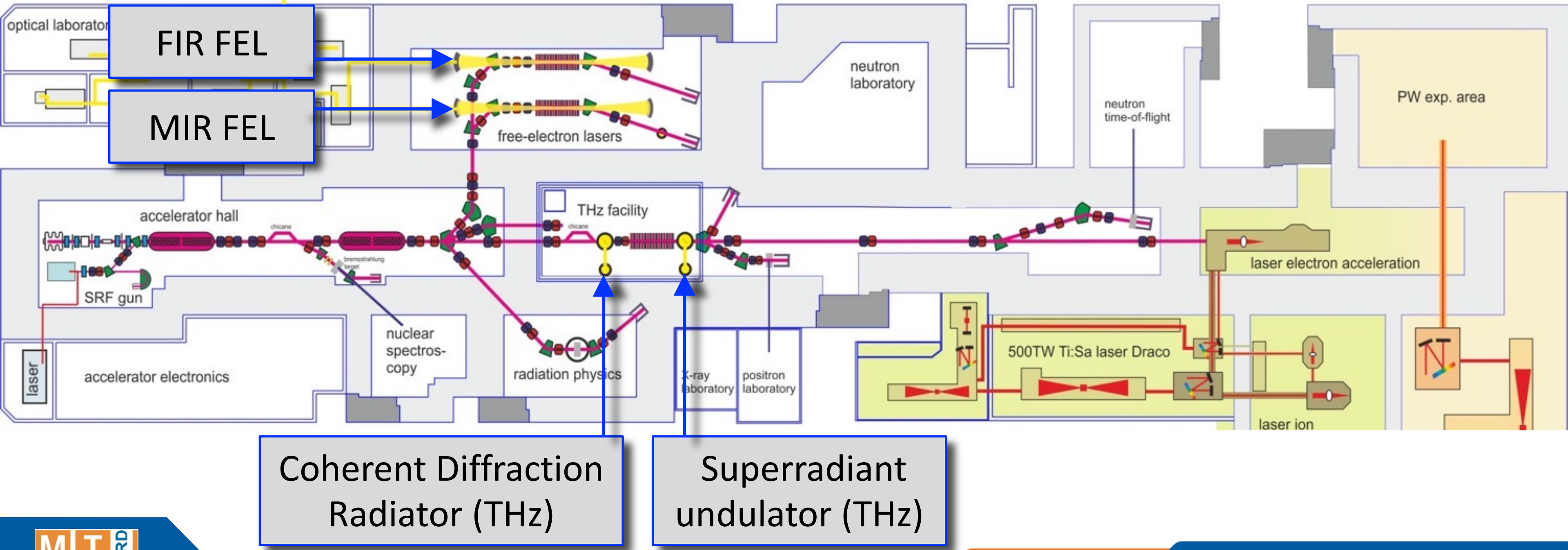
M. Chen, S. Kovalev, M. Kuntzsch, M. Klopf, C. Schneider, and P. Evtushenko (HZDR)
S. Bielawski, C. Hanoun, S. Szwaj (Lille Univeristy)

OUTLINE

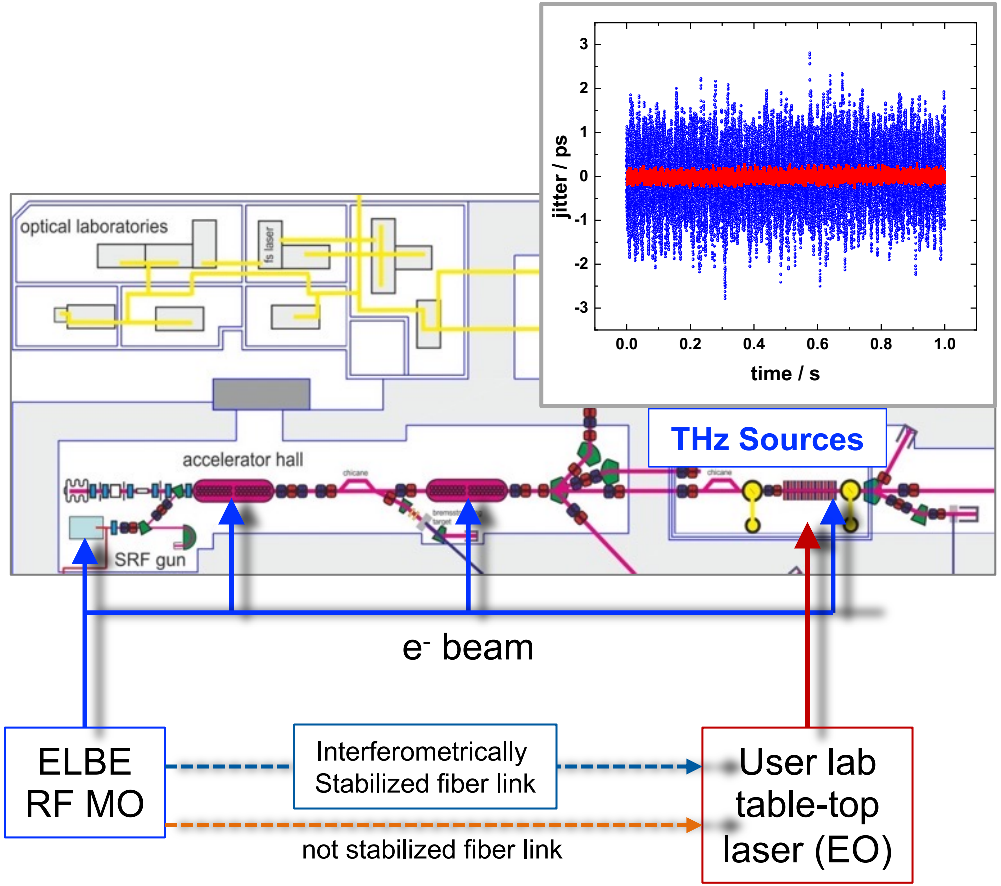
- Radiation Source ELBE (reminder)
- TELBE synchronization improvements
- FEL oscillators intensity stability; phase measurements
- EO time-stretch + phase diversity
- GigE Vision camera system for beam profile measurements
- Fast scanning slit emittance measurements / SRF gun

RADIATION SOURCE ELBE

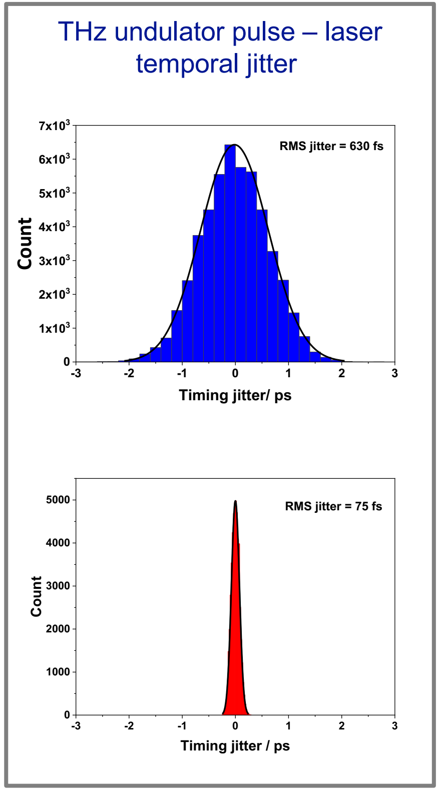
- SRF linac-based, CW, 40 MeV, 1 mA (13 MHz); User facility (~ 6000 hour/year for users)
- two e- sources: #1 thermionic cathode DC gun, #2 SRF gun photocathode gun (~ 25 % of user ops.)
- ST3 relevance: ps, sub-ps bunch length, linac and SRF gun LLRF, table top lasers synchronization

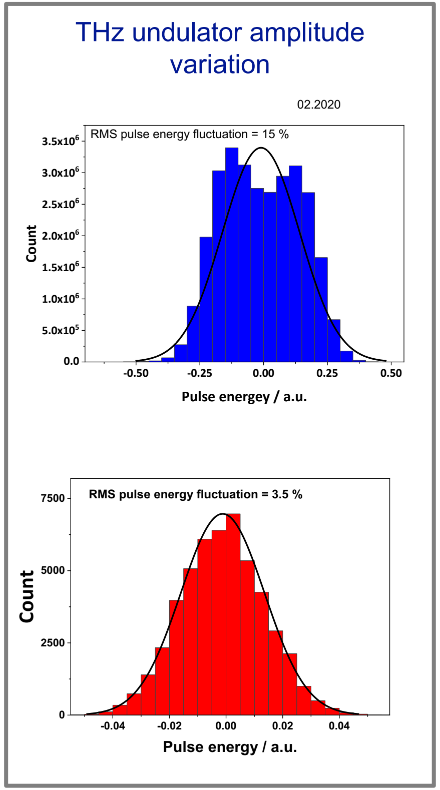


THZ SOURCE – LAB LASERS SYNCHRONIZATION



Red – before (not stabilized link)
Blue – after (stabilized link)





M. Kuntzsch, S. Kovalev

FEL STABILITY MEASUREMENTS

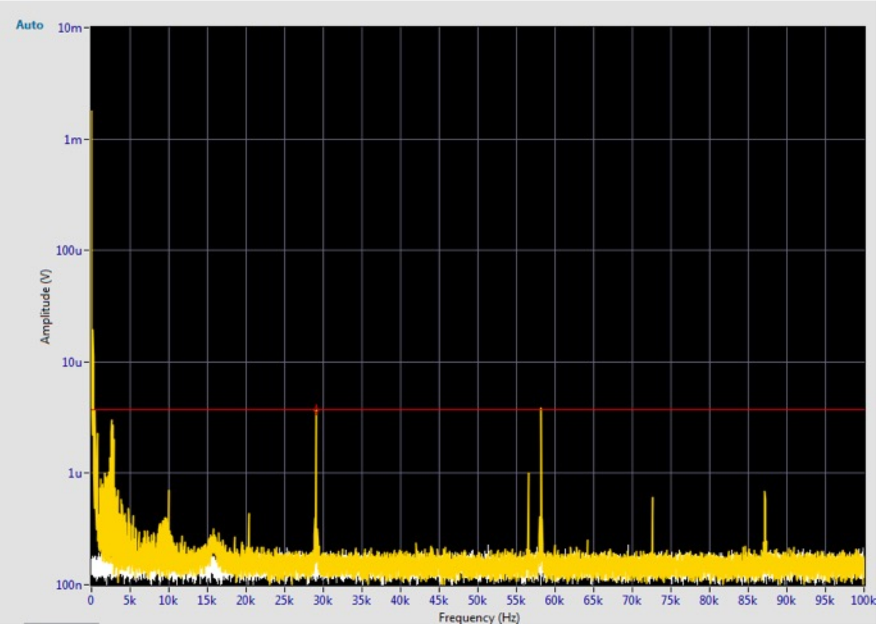
- Better FEL pulse energy stability is desired by users

- Commissioned a new detector (Scontel Type 2)
  - superconducting transition edge hot electron bolometer
  - high sensitivity - NEP < 20x10^{-12} $W/\sqrt{Hz}$
  - fast response - 200 MHz BW
  - covers full FEL tuning range (1.2 – 60 THz / 5 – 250 µm)

- Non-invasive (pickoff) to FEL user operations
  - 77.5mm x 30mm optical grade CVD diamond
  - set near Brewster's angle reflects 0.01% beam
  - ~ 5° C temp rise with 20 W beam power

- NI PXI ADC + LV spectrum analyzer program
  - reduce signal bandwidth to improve digitization (LPF)
  - synchronize ADC to ELBE 10 MHz clock
  - 5 Hz FFT resolution
  - signal >1 mV with 100 nV noise

Single sideband spectrum at 13 MHz



P. Evtushenko, M. Klopf

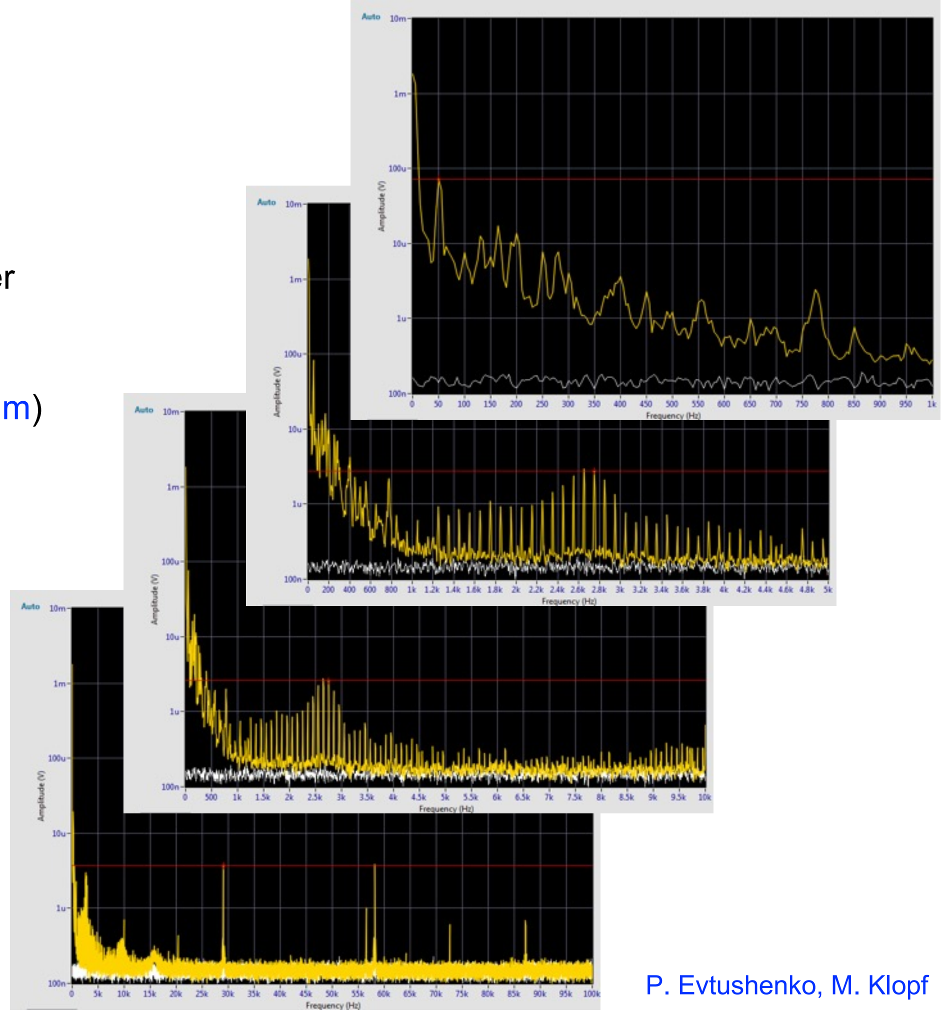
FEL STABILITY MEASUREMENTS

- Better FEL pulse energy stability is desired by users

- Commissioned a new detector (Scontel Type 2)
  - superconducting transition edge hot electron bolometer
  - high sensitivity - NEP < 20x10^{-12} $W/\sqrt{Hz}$
  - fast response - 200 MHz BW
  - covers full FEL tuning range (1.2 – 60 THz / 5 – 250 μm)

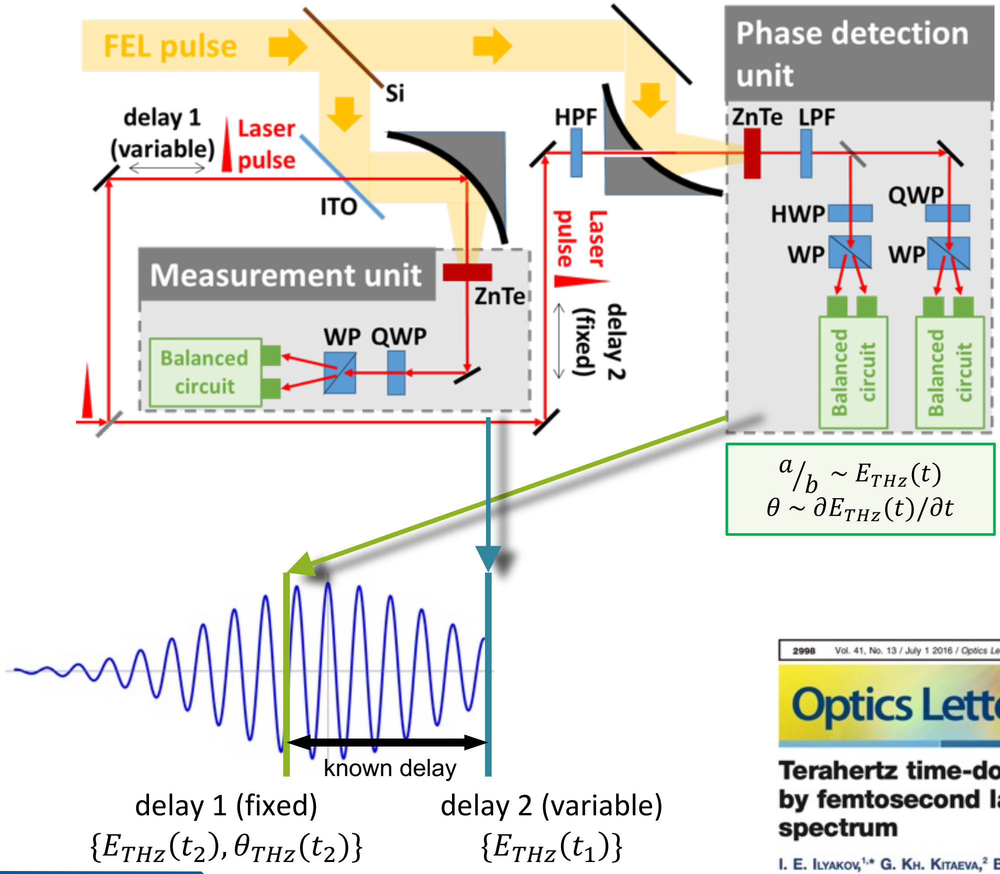
- Non-invasive (pickoff) to FEL user operations
  - 77.5mm x 30mm optical grade CVD diamond
  - set near Brewster's angle reflects 0.01% beam
  - ~ 5° C temp rise with 20 W beam power

- NI PXI ADC + LV spectrum analyzer program
  - reduce signal bandwidth to improve digitization (LPF)
  - synchronize ADC to ELBE 10 MHz clock
  - 5 Hz FFT resolution
  - signal >1 mV with 100 nV noise

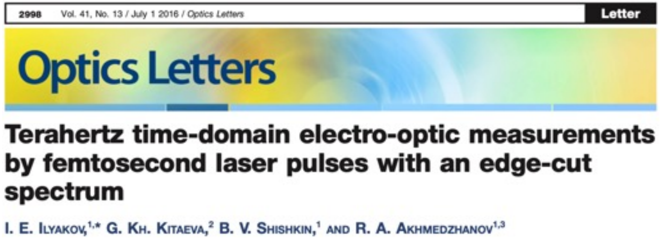


P. Evtushenko, M. Klopf

SUB-CYCLE TIME RESOLUTION WITH FEL OSCILLATORS



- ※ FEL oscillators are not CEP stable sources *(due to optical cavity length detuning; needed because in undulator $v_z^{e^-} < c$ is large effect)*
- ※ This limits time resolution of experiments with FEL oscillators
- ※ Now (2020-2021) it was demonstrated that **phase resolved measurements are possible** with FEL without CEP stability
- ※ Can allow new classes of experiments with FIR FEL oscillators
- ※ Better FEL diagnostics


2998 Vol. 41, No. 13 / July 1 2016 / Optics Letters

Letter

Optics Letters

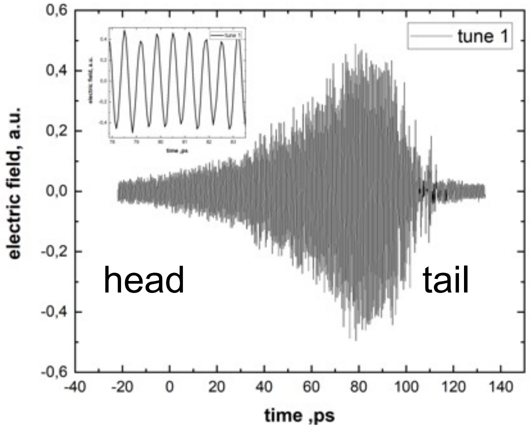
Terahertz time-domain electro-optic measurements by femtosecond laser pulses with an edge-cut spectrum

I. E. Ilyakov,[1,*] G. Kh. Kitaeva,[2] B. V. Shishkin,[1] and R. A. Akhmedzhanov[1,3]

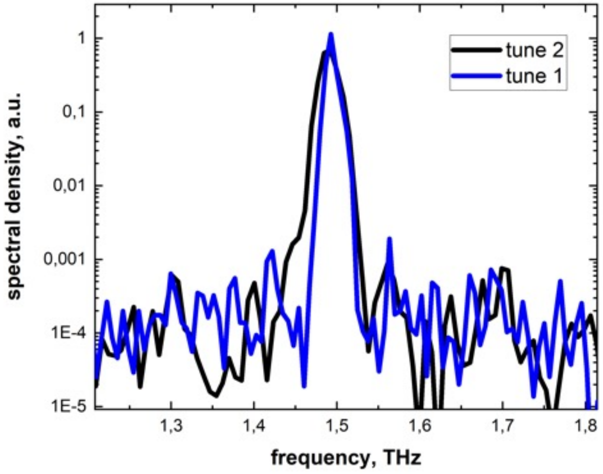
S. Kovalev, M. Klopf, I. Ilyakov

SUB-CYCLE TIME RESOLUTION WITH FEL OSCILLATORS (DATA)

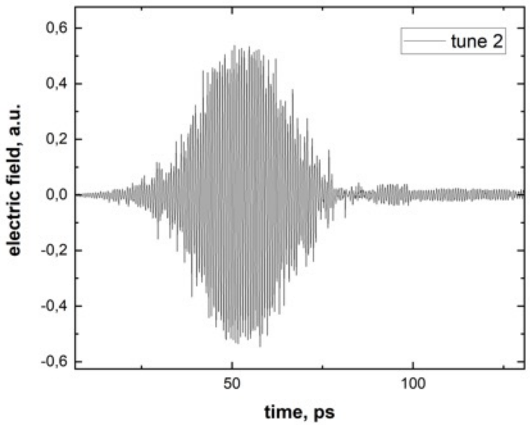
- **Tune 1 – large cavity detuning**
  - exponential front, Gaussian back
  - longer pulse
  - reduced spectral bandwidth



For more:
tutorial by Sergey Kovalev
Friday, 9am



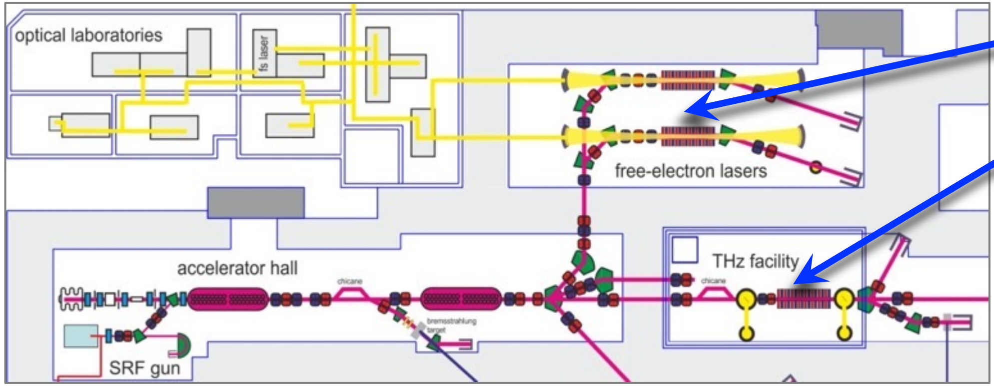
- **Tune 2 – near zero detuning**
  - Gaussian pulse profile
  - shorter pulse
  - wider spectral bandwidth



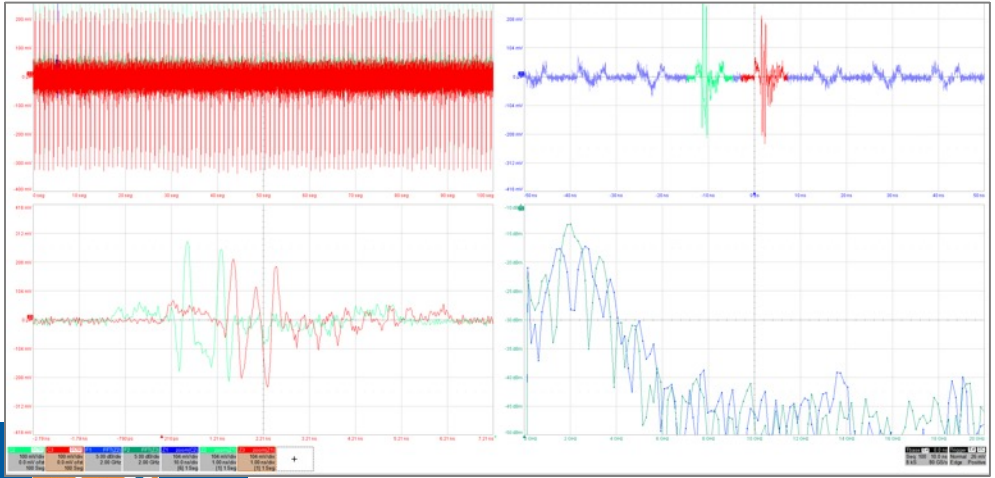
FEL pulse model
S. Regensburger, et al., IEEE Trans. Terahertz Sci. Technol., **9**, 262 (2019)

S. Kovalev, M. Klopf, I. Ilyakov

EO SAMPLING / TIME-STRETCH / PHASE DIVERSITY



Details in the talk by Christelle Hanoun (Lille Uni.)

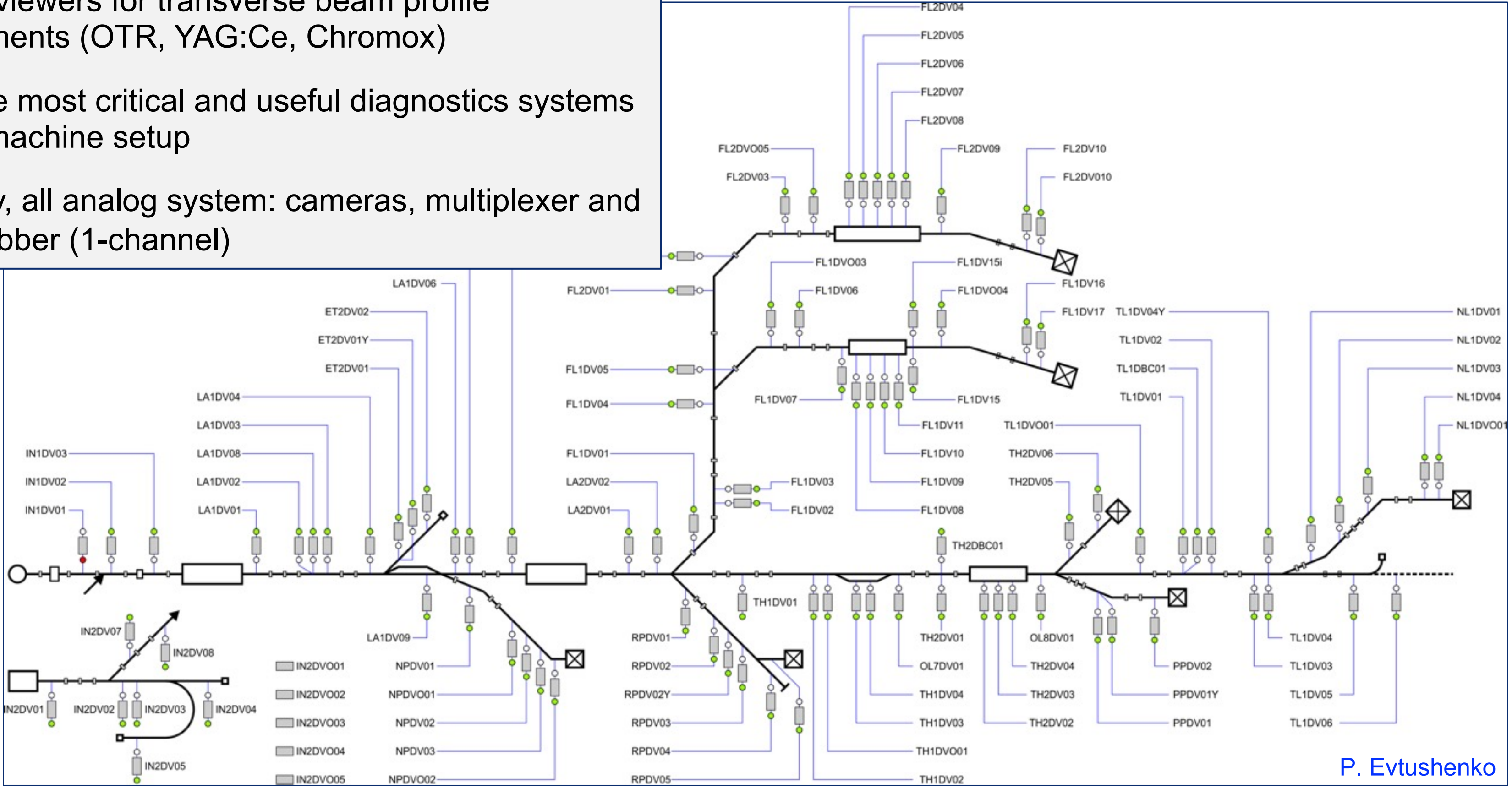


- FEL oscillators (FIR and MIR) operate with ps e- bunch length
- TELBE (THz superradiant undulator + CDR) operate with ~0.4 ps RMS bunch length
- Exiting bunch length measurements diagnostic – Martin-Puplett Interferometer (no spectral phase)
- EO measurements could be an improvement, but is very challenging with ELBE parameters for direct bunch (Coulomb) field measurements
  # low energy; # bunch charge 60 – 200 pC
- Single-shot measurements big advantages
  # pulse length stability measurements
  # less affected by beam ⇔ laser jitter
- **Spectral decoding + time-stretch + phase diversity (Lille University Collaboration)**
- Strategy: test setup(s) in TELBE user lab, transfer to accelerator vault

ELBE + PhLAM Lab. Lille University

ELBE / Beam Profile / Beam Viewers

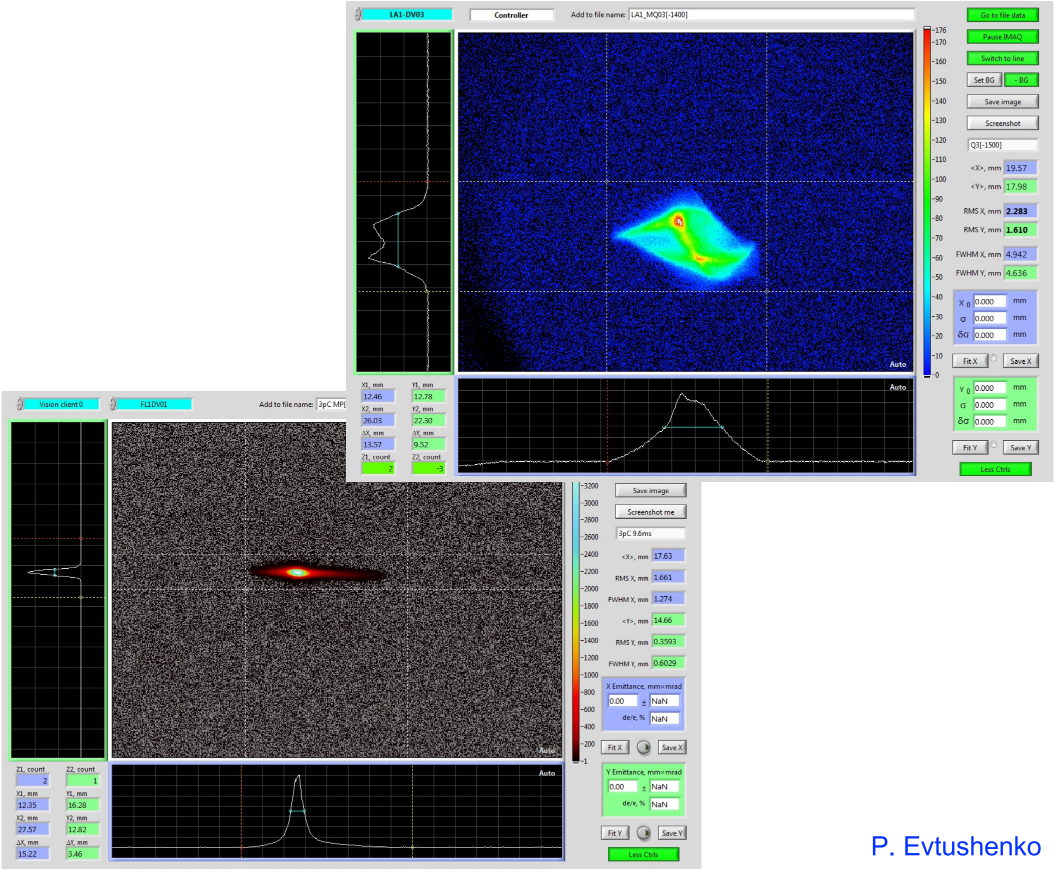
- 90 beam-viewers for transverse beam profile measurements (OTR, YAG:Ce, Chromox)
- One of the most critical and useful diagnostics systems used for machine setup
- Previously, all analog system: cameras, multiplexer and frame grabber (1-channel)



P. Evtushenko

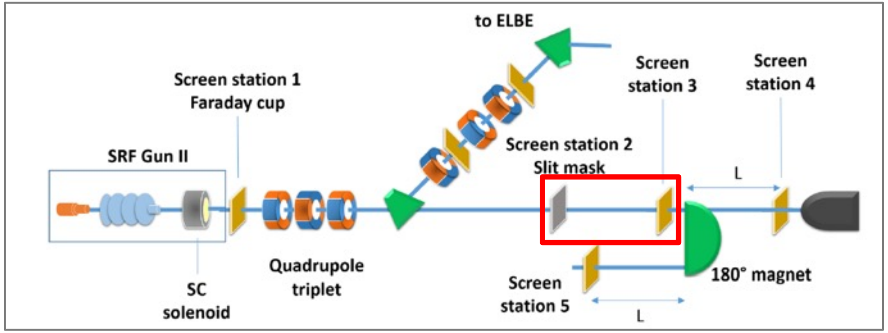
ELBE / Transverse Beam Profile Measurements

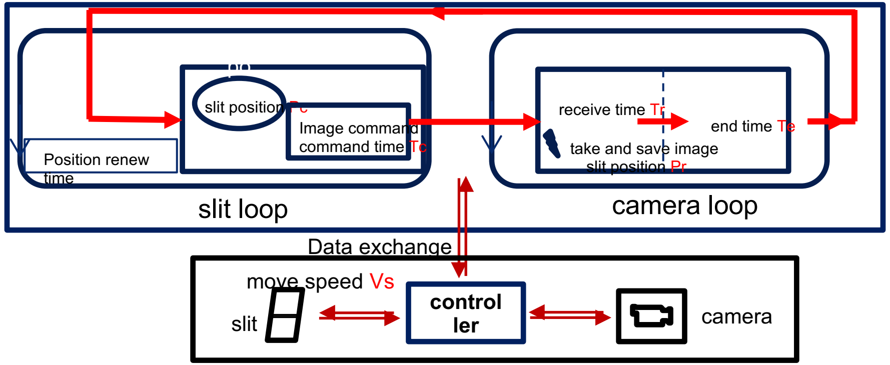
- ※ Analog cameras not available (almost)
- ※ Only one video channel
- ※ Practically - poor SNR
- ※ **Upgrade: digital (Ethernet) GigE Vision system, and a set of new software tools**
- ※ **2/3 of beam-viewer converted to the new camera system**
- ※ **Multiple video sources and client are supported**
- ※ **New system provides on-line beam size and position measurements at ~ 20 Hz**
- ※ **Provides a lot of high SNR data – pathway to ML learning applications for better (easier) machine setup and beam dynamics understanding**



P. Evtushenko

FAST SLIT-SCAN EMITTANCE MEASUREMENTS / SRF GUN

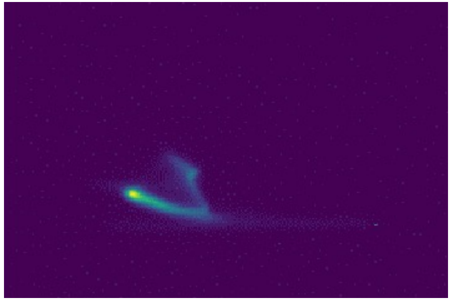




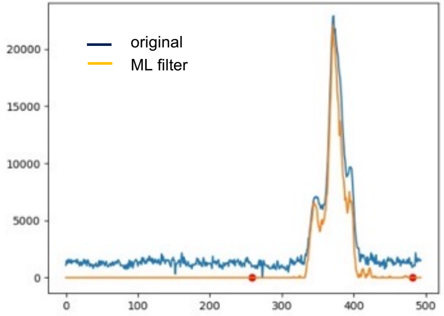
Slit motor velocity: 0 to 25 mm/s;
Camera frame rate: 0 to ~75 fps;
Images processing time: ~100 images/min.

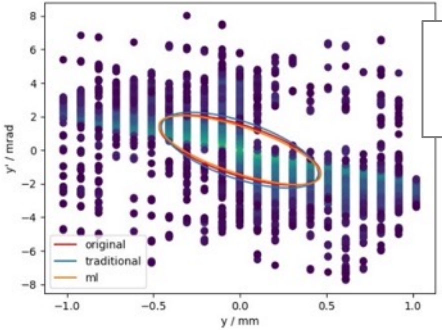
Deep leaning algorithms: convolutional neural network and auto-encoder network, are used to improve efficiency and accuracy in image processing.

Beamlet image



Beamlet vertical projection





Simulation of the slit-scan measurements system, with the ML filters test

Shuai Ma

Thank you