SLAC UED Laser Timing Synchronization and LLRF Upgrade

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U.S. DEPARTMENT OF ENERGY Stanford University SLAC NATIONAL ACCELERATOR LABORATORY

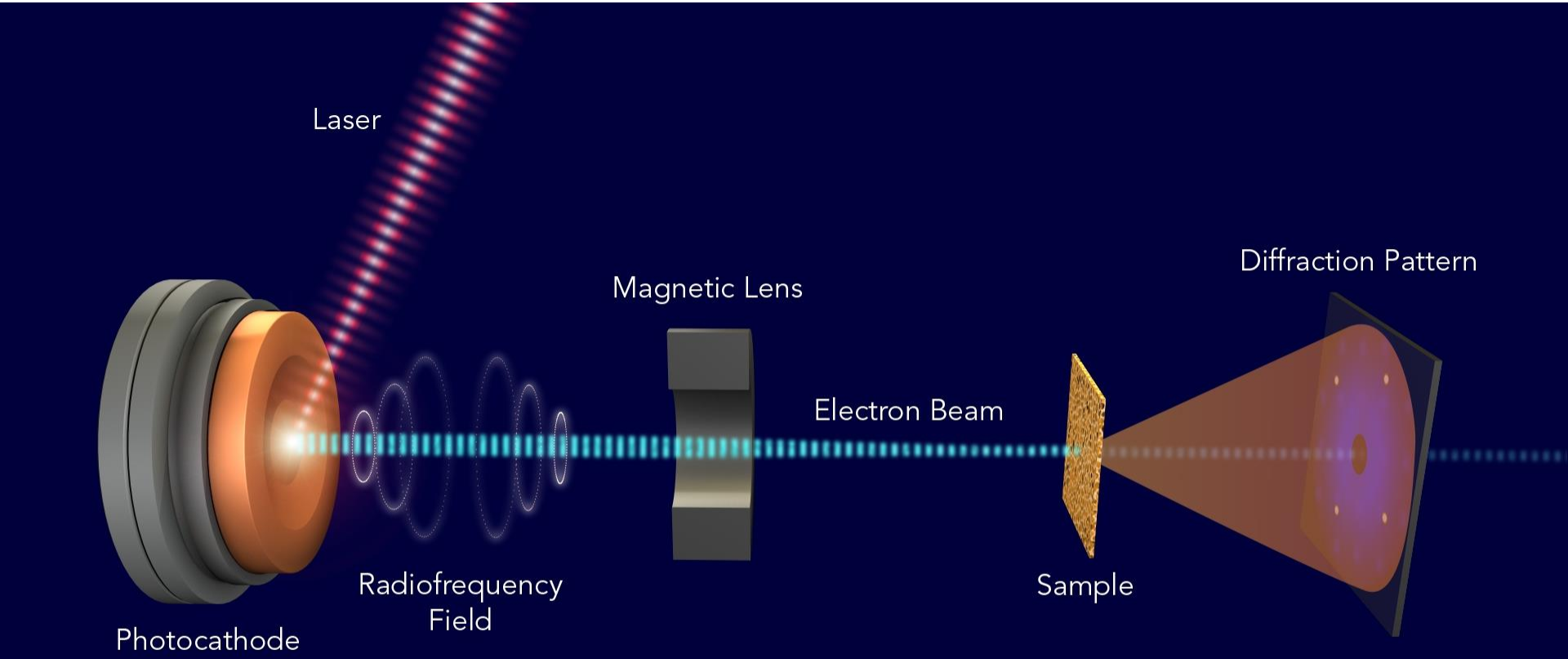
Outline

- Overview of SLAC Ultrafast Electron Diffraction Instrument
- SLAC UED Laser Timing and Gun LLRF Stability Requirements
- ATCA Based Femtosecond Laser Timing System
- ATCA Based RF Gun Control System

SLAC Ultrafast Electron Diffraction Instrument

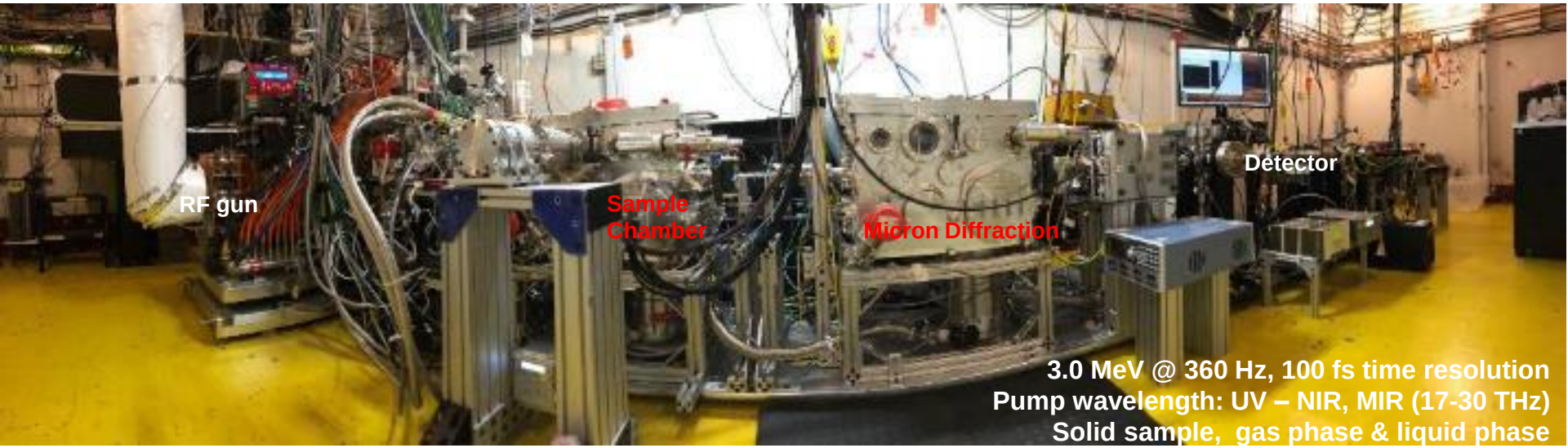
- A powerful "electron camera" for the study of time-resolved, ultrafast atomic & molecular dynamics in chemical and solid-state systems.
- Similar to X-ray light, highly energetic electrons can take snapshots of the interior of materials as they pass through them. Yet, electrons interact differently with materials and “see” different things.
- Complement ultrafast studies with SLAC’s X-ray free-electron laser.
- Help researchers better understand and possibly control important ultrafast processes.

SLAC Ultrafast Electron Diffraction Instrument



Source : ref [1]

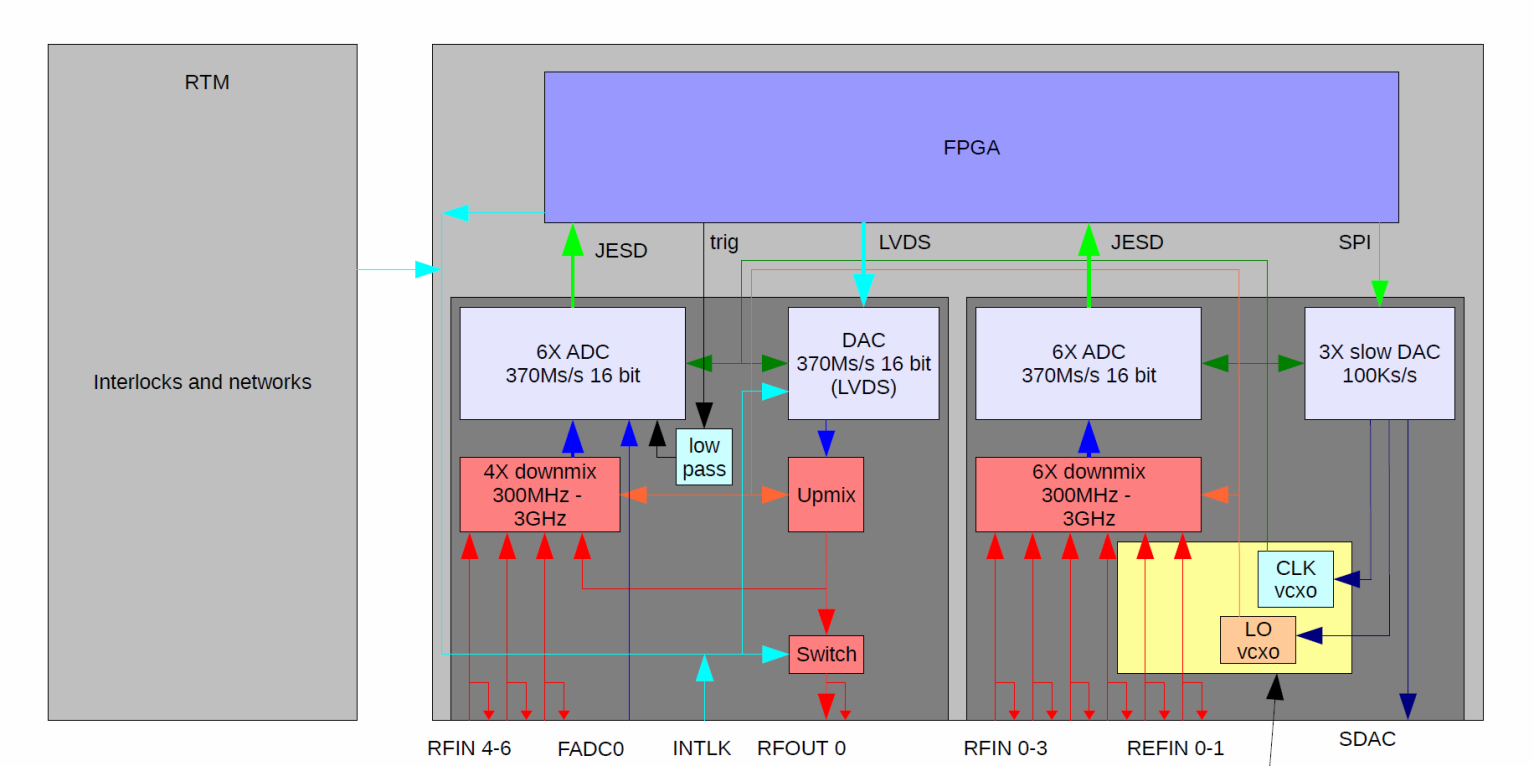
SLAC Ultrafast Electron Diffraction Instrument



SLAC UED Laser Timing & LLRF Upgrade Requirements

- Laser timing jitter – as good as possible
- Gun cavity amplitude & phase stability – as good as possible
- Beam operation rate, 180 Hz to 360 Hz
- Easy maintenance and capability for further upgrade to KHz operation
- Fit into existing UED infrastructure
  - Laser motor control
  - Laser pulse bucket jump recovery system
  - RF interlock system, timing system
  - Booster, Klystron

SLAC ATCA LLRF Platform



Application specific daughter card

RF inputs: 300MHz – 3GHz
RF output: 300MHz – 3GHz
Analog input: DC – 100MHz
Slow DAC outputs: DC -100KHz

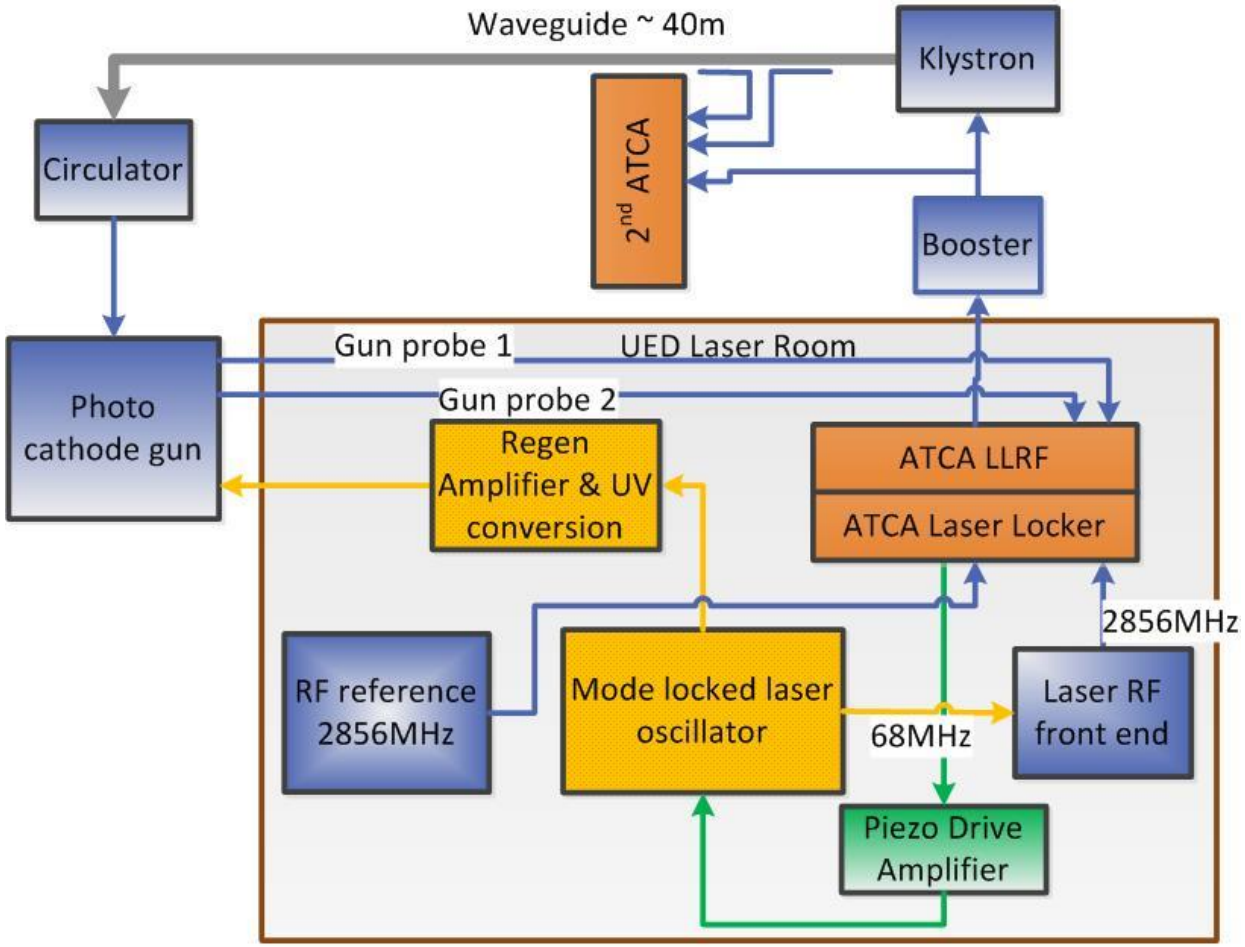
Source : ref [5]

SLAC ATCA LLRF System Specifications

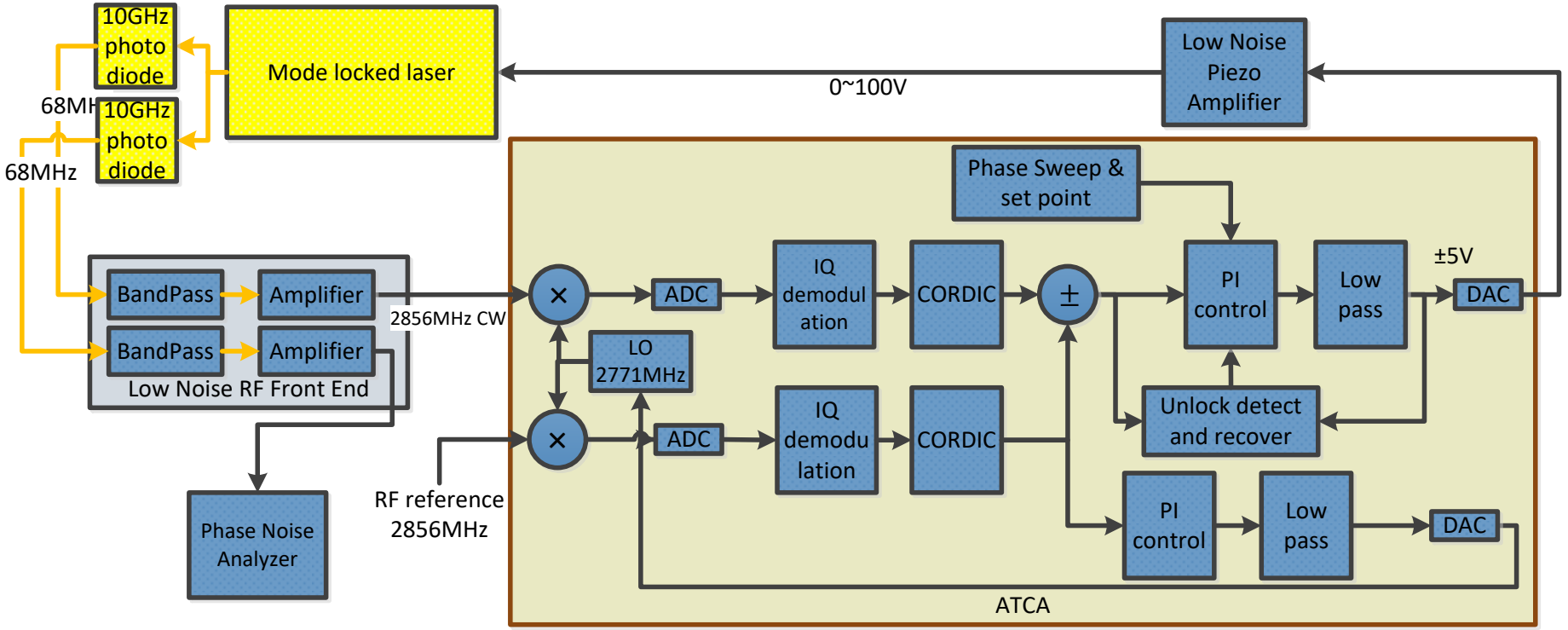
- Noise (phase): < 0.01 degrees 1 MHz BW
- Noise (amplitude): < 0.01% 1 MHz BW
- Drift (phase): 0.1 degrees
- Drift (amplitude): 0.1% (1min) (2 degrees C)
- RF Channel Bandwidth: >10 MHz
- RF Channel Resolution: 16 bit resolution
- Non-linearity: < 0.1 degrees for 6 dB change

SLAC ATCA LLRF Platform

SLAC UED ATCA Based Laser Timing & LLRF System Overview

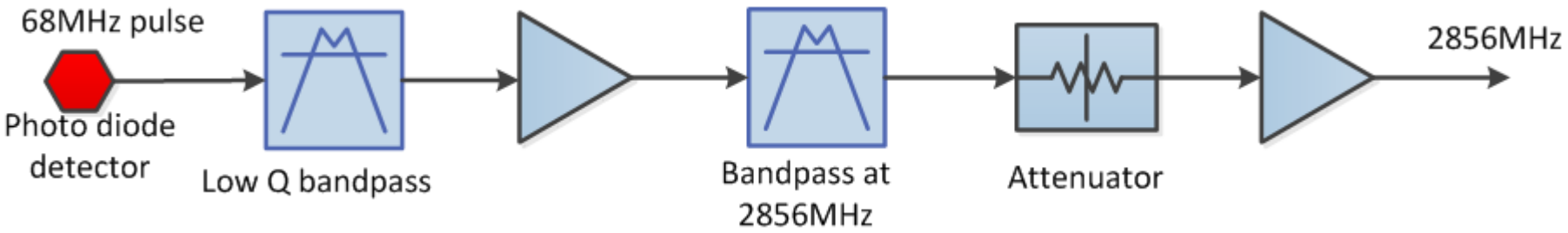


SLAC ATCA Based Femtosecond Laser Timing System



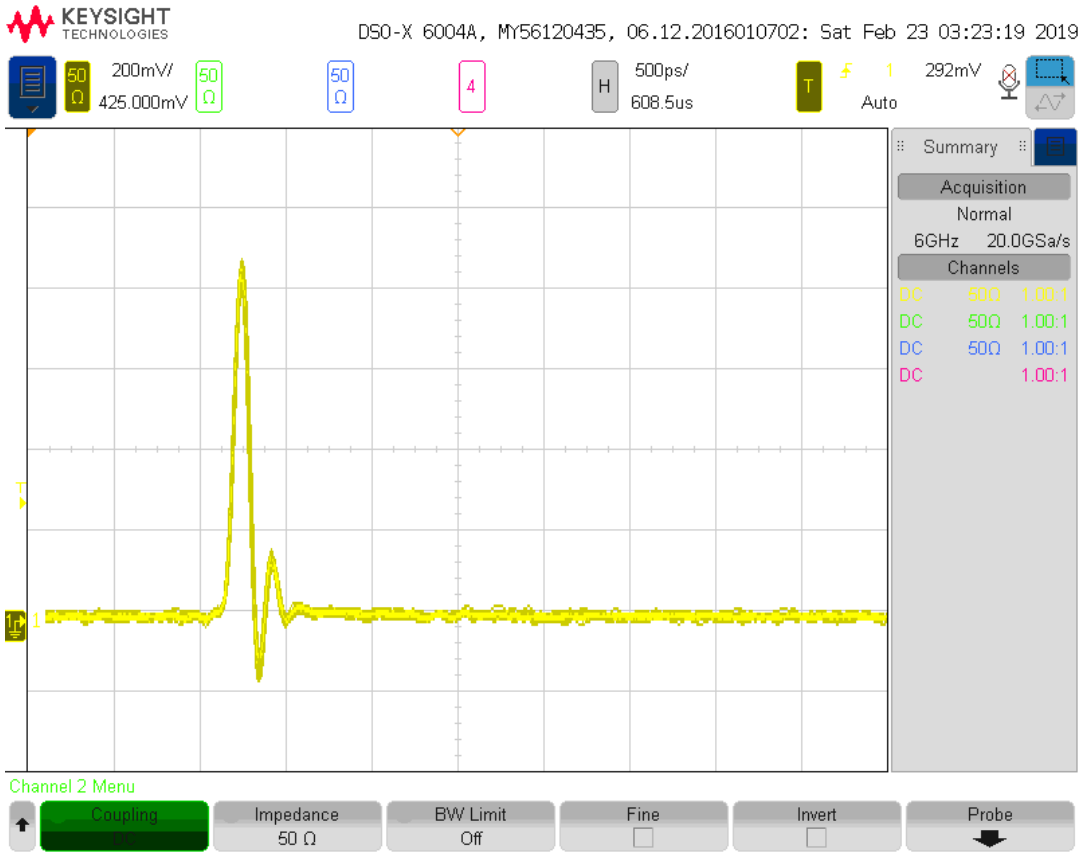
SLAC ATCA Based Femtosecond Laser Timing System - continued

- 10GHz photo diode detector
- Low noise RF front end picks up the 42th of laser harmonic at 2856MHz which is <-30dBm



RF front end designed by A. Young

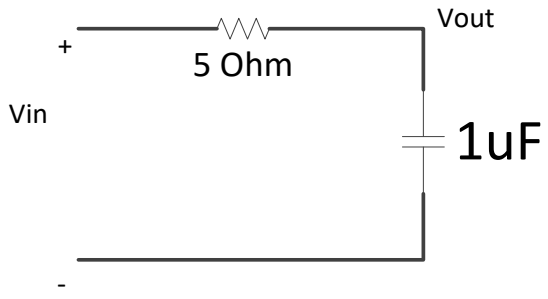
SLAC ATCA Based Femtosecond Laser Timing System – continued



- Keep photo diode detector in linear response range– proper positioning, power at photo diode <-12dBm .

SLAC ATCA Based Femtosecond Laser Timing System – continued

- Low noise Piezo amplifier, limited output current, ±50Volts output
- Piezo modulation bandwidth $\omega_{1/2} = \frac{1}{RC}$, BW=32 kHz



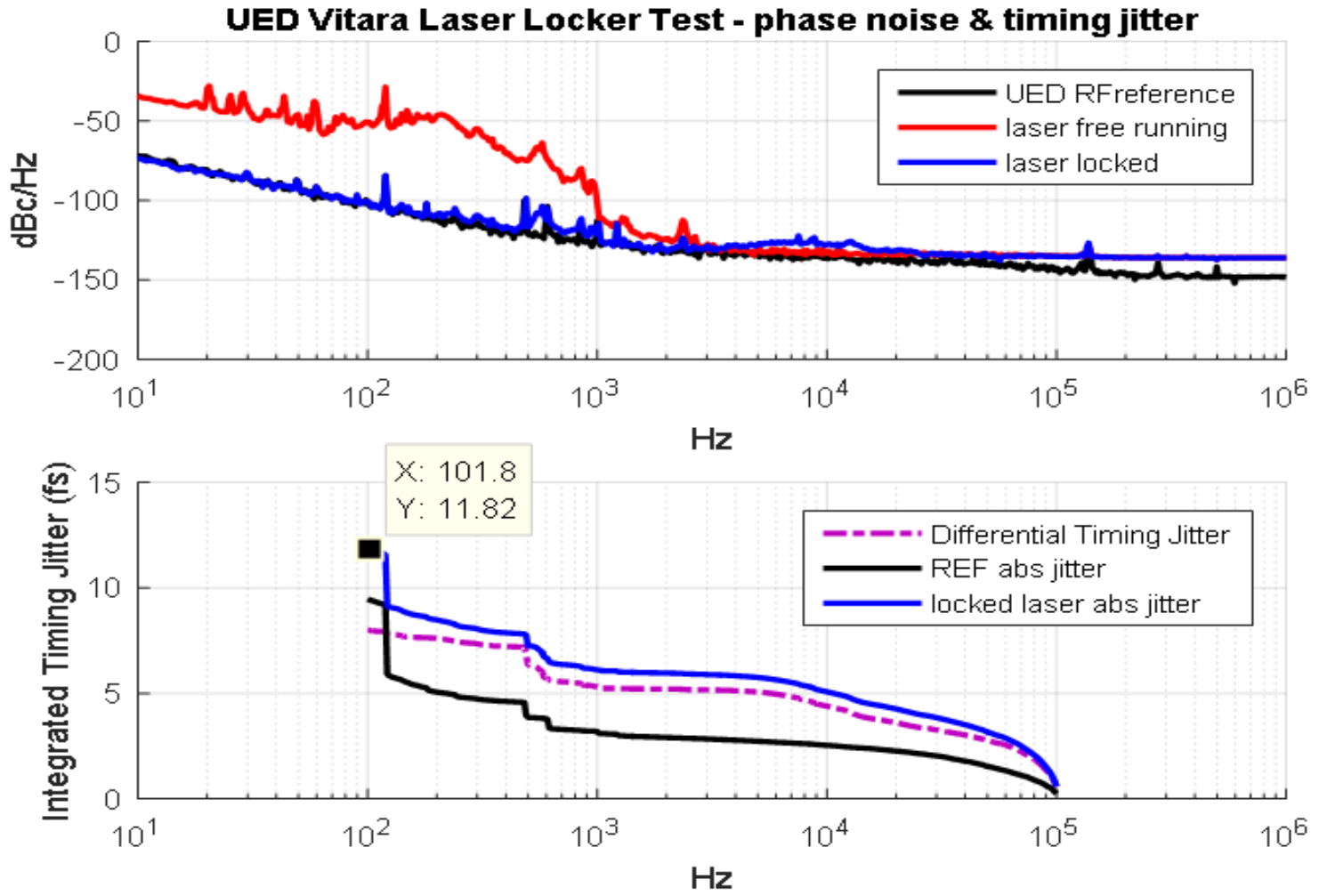
Low noise Piezo amplifier designed by D. Brown

SLAC ATCA Based Femtosecond Laser Timing System – continued

Firmware development features

- 2nd order integration of phase error
  - $H = K_p(1 + \frac{K_i}{s})^2 \frac{\omega_{lp}}{s+\omega_{lp}} \frac{K_{Piezo}}{s}$
- 20 KHz loop bandwidth, 10fs timing jitter
- Compatible with existing laser control infrastructures
  - motor control – move cavity back when laser oscillation is beyond Piezo control range.
  - laser pulse bucket detection system –selection of laser pulse at 360Hz rate relative to 68MHz RF bucket

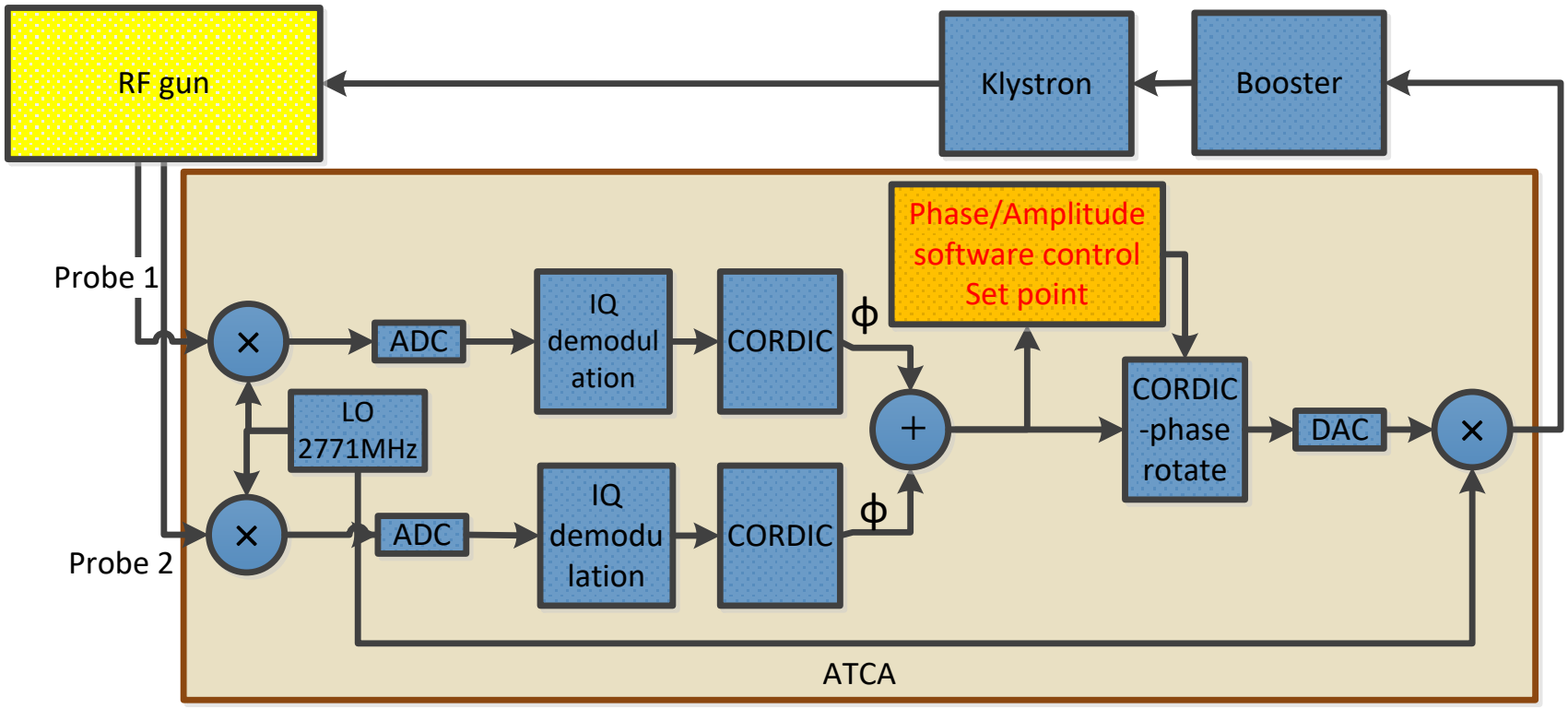
UED Laser Timing Jitter Measured with 2nd Photo Diode Detector (out of loop measurement)



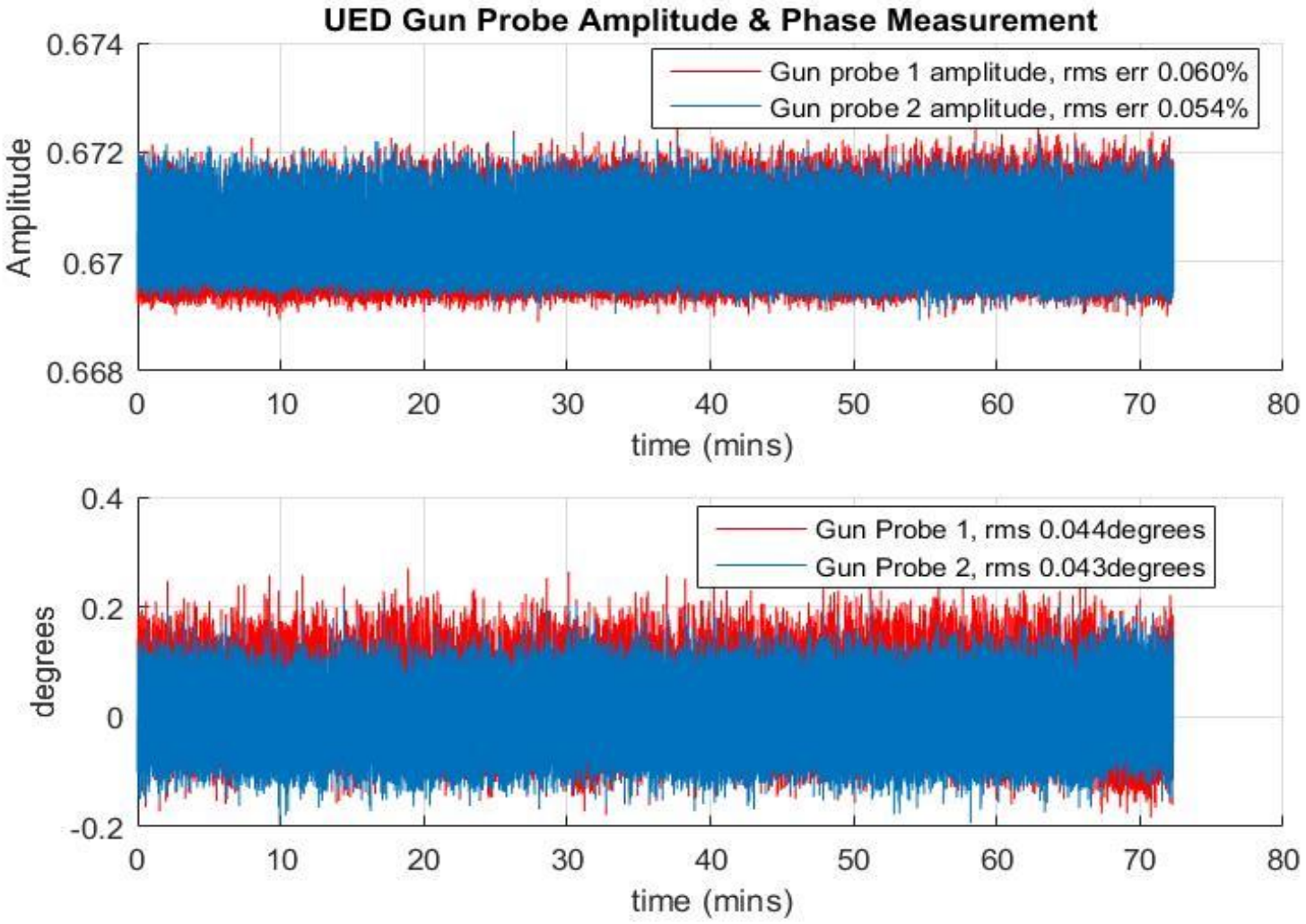
SLAC UED ATCA Based LLRF System

- The ATCA based LLRF system was first developed for LCLS Mission Readiness project.
- Compatible with existing UED timing event generation/receiving system.
- Compatible with existing UED interlock system
- Increase beam rate from 180 Hz to 360 Hz – the fastest UED instrument in the world. Further upgrade to KHz operation.
- Short pulse (2μs), low rate, very low loop bandwidth. Controller implemented in software.
- 6 feed back loop at 60 Hz rate

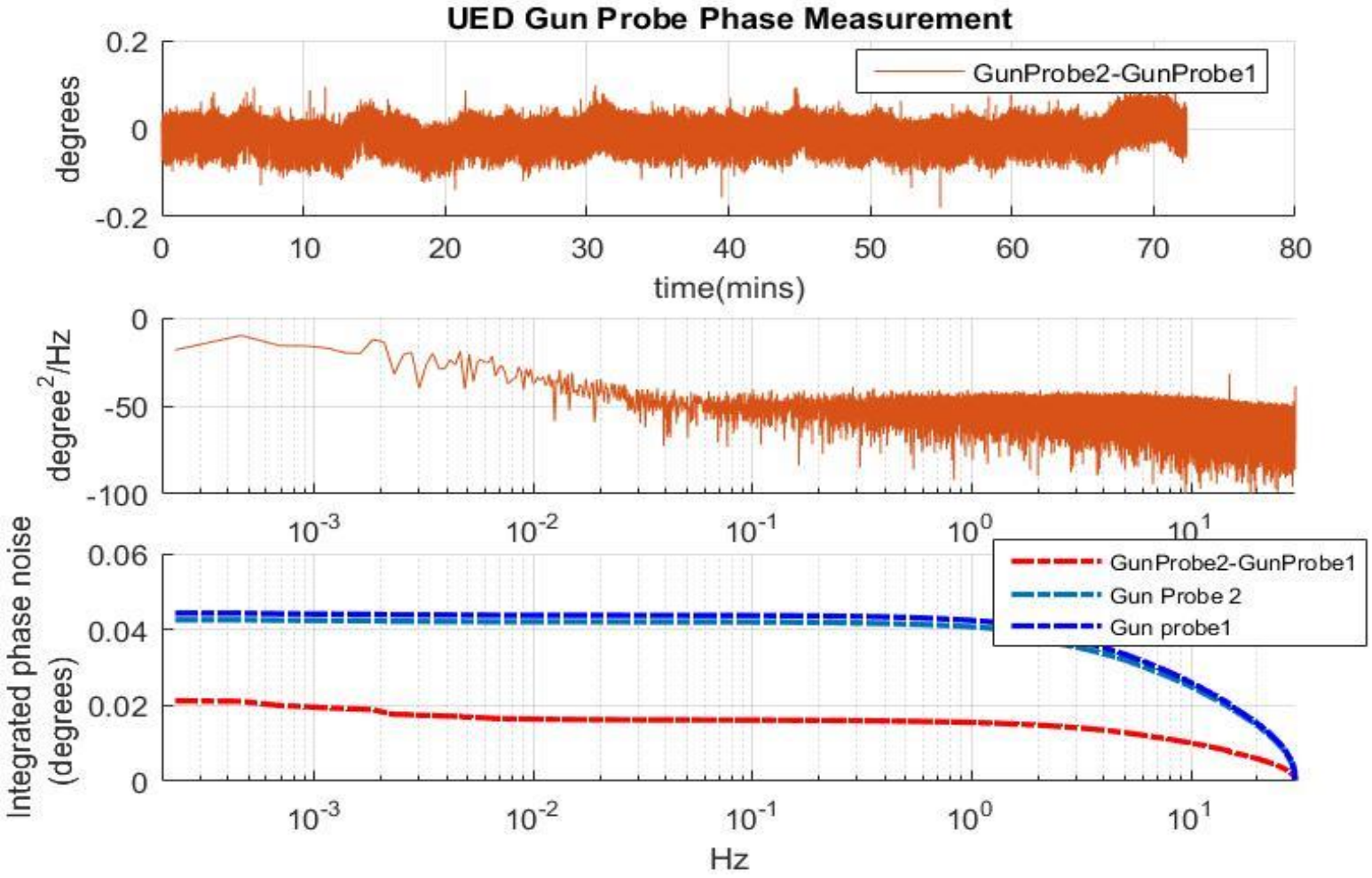
SLAC UED ATCA Based LLRF System



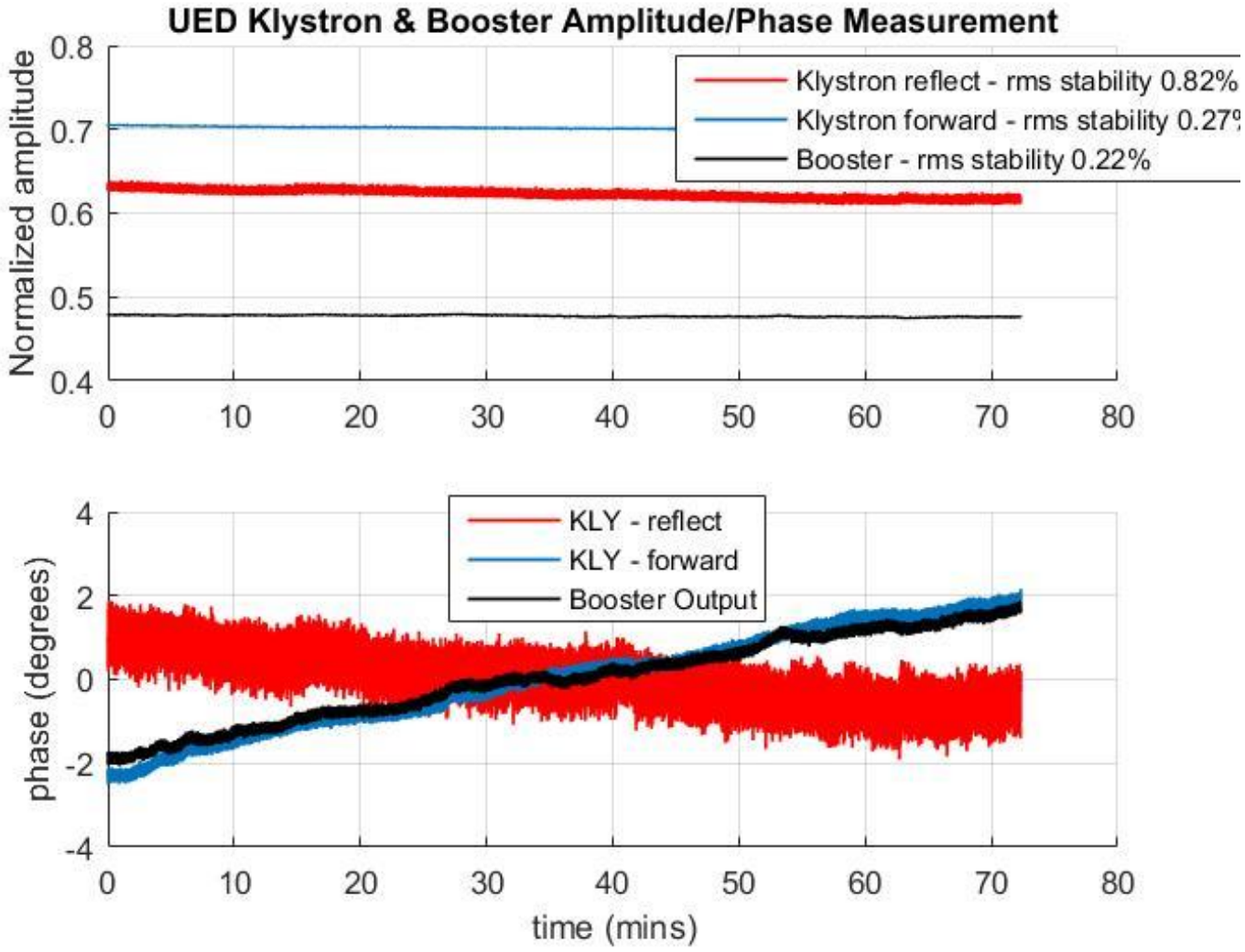
SLAC UED ATCA Based LLRF System – Gun Probes Amplitude & Phase Measurements



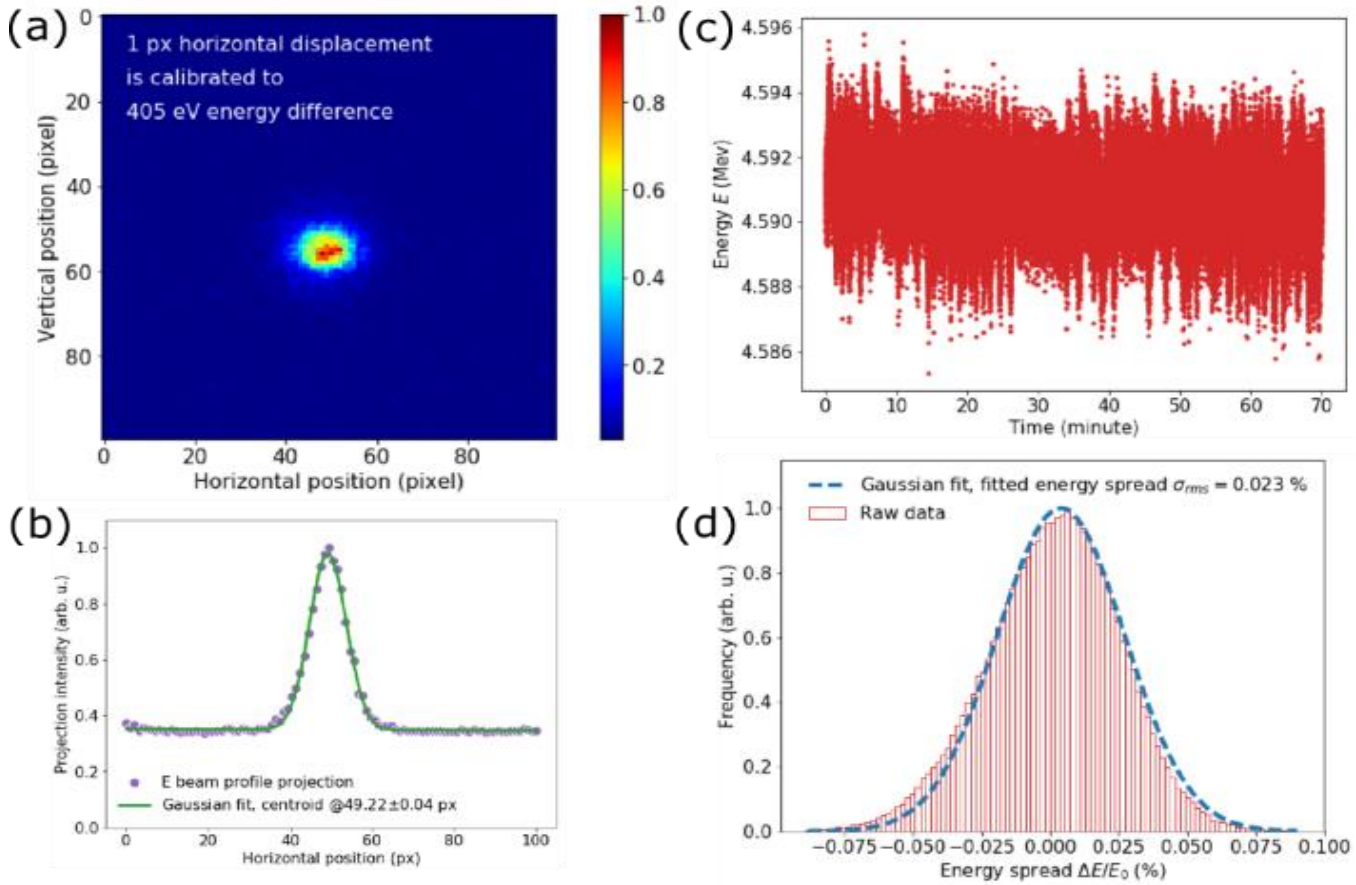
SLAC UED ATCA Based LLRF System – Phase Error between Two Gun Probes (0.02degrees)



2nd ATCA LLRF System at Klystron Area



UED Electron Beam Energy Measurement



Direct measurement of electron beam energy regulated by the new ATCA system shows a 0.023% energy stability, which is estimated to cause only 12 fs electron beam arrival time jitter.

Source : slide provided by X. Shen

Conclusion

- We have designed, installed and commissioned the ATCA based femtosecond laser timing control and gun cavity control system for SLAC Ultrafast Electron Diffraction instrument.
- The UED laser timing jitter is reduced to 10fs.
- UED beam operation rate is increased to 360 Hz.
- New system can support KHz beam operation.
- Gun cavity amplitude noise is 0.05%. Gun cavity phase noise is 0.04degrees.
- Has potential to further reduce gun amplitude/phase noise.

References

[1] SLAC Ultrafast Electron Diffraction Facility, https://lcls.slac.stanford.edu/instruments/mev-ued

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Thank you!