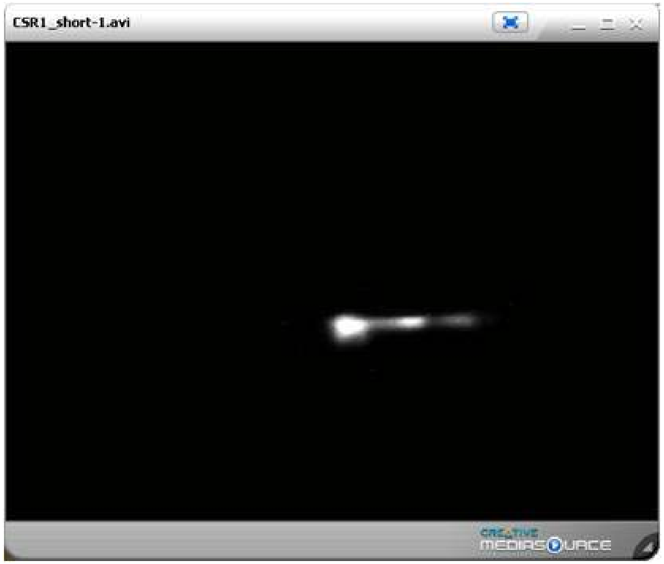
CSR/LSC/MBI Studies in FEL ERL

- Have significant theory/simulation capability in-house
- Have fully-instrumented test-bed exhibiting CSR/LSC (/MBI?) effects
- Provides opportunity to perform measurements
  - Characterize phenomena
    - Measure longitudinal and transverse beam quality (emittances & distributions) & energy loss as a function of compression ratio, bunch charge, and energy
  - Benchmark models
    - Cross-compare simulation of measurements on existing system with results of measurements

CSR/LSC in Jlab FEL Drivers

- 135 pC/0.35 psec bunch => I_{peak} ~400 A
- CSR/LSC effects evident
  - parasitic compression (Bates bend)
  - Irradiation of FEL outcoupler/THz heating
  - CSR enhancement ⇔ tuning cue
- Control of phase space through 2nd order (w/o harmonic RF)
  - Can change compression aspect ratio, run on either side of crest, etc
  - UV Driver ⇔ "chicaneless" compressor



CSR video courtesy K. Jordan

Full suite of instrumentation => detailed characterization of effects…

JTO-funded study underway

Program Plan

Measure beam quality/CSR power as a function of compression

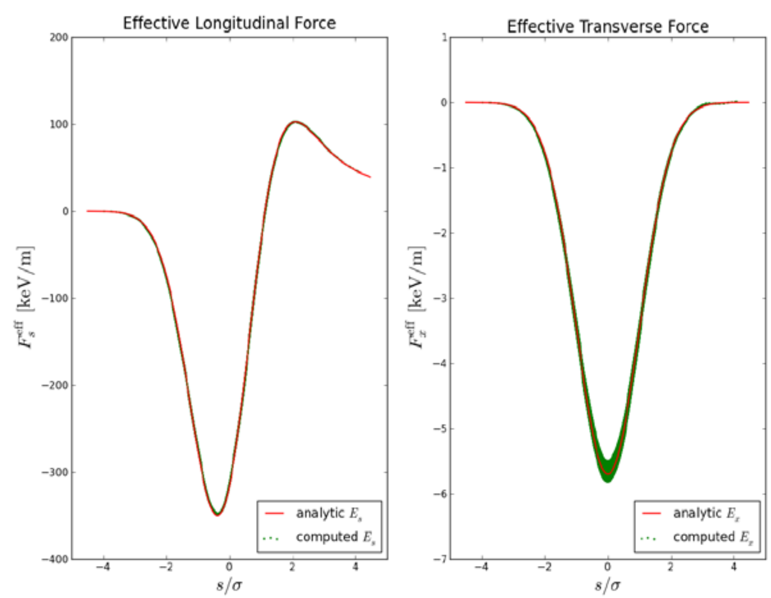
- Energy loss & transverse/longitudinal emittance measurement as function of compression, at
  - Linac phases -30^{o} ⇔ -5^{o}, $+5^{o}$ ⇔$+30^{o}$ in 2.5^{o} steps
  - 30, 60, 90, 120 pC
- 20 shifts setup/tuning/measurement development
- 80 measurements x ½ shift each =>

  total⇔60 shifts @30k$/shift=1.8M$
- 2 FTE simulation support/data analysis x 2 yrs

In-House Simulation Capability: New JLab 2D CSR Code ENCORE

- **ENCORE**: **E**lectro**N** **C**urved **OR**bit **E**ffect (Terzić & Li 2012, in preparation)
- Models beam's self-interaction modeled via *retarded potentials*
- Integration over beam's history: enormous memory and computational challenge
- Use advanced mathematical and computational methodologies to resolve these:
  - Particle-In-Cell: improved spatial resolution, better scaling of self-interaction
  - Wavelets: compress history, remove numerical noise, more efficient computations
  - CPU/GPU parallelization: harness parallel capabilities of both platforms
- Status:
  - All big pieces are in place
  - Established a proof-of-concept in 1D
  - Started CPU/GPU parallelization
- Next:
  - Benchmarking with semi-analytic 2D results
  - Benchmarking against existing 1D/2D codes
  - Modeling of the JLab FEL
  - Modeling other machines

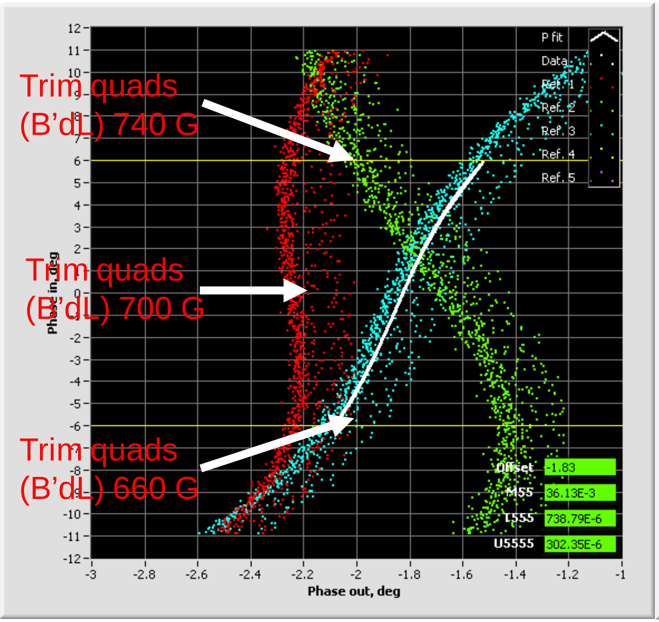
Proof-of-concept achieved:
Excellent agreement with 1D analytic results

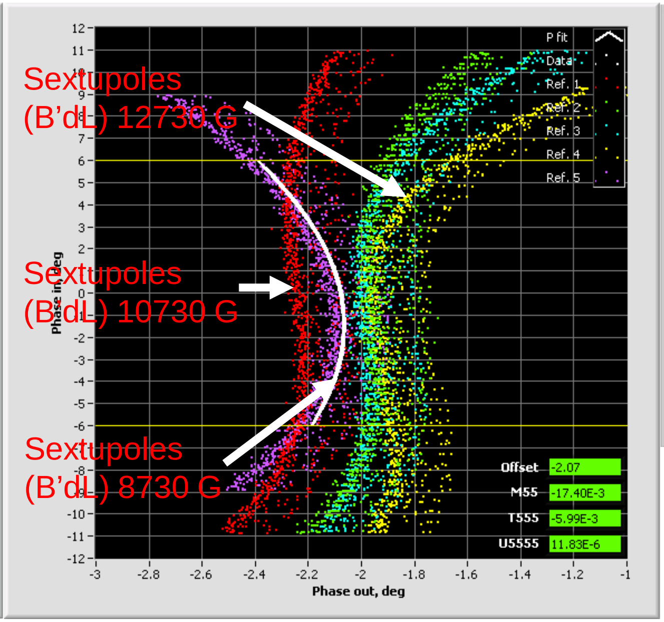


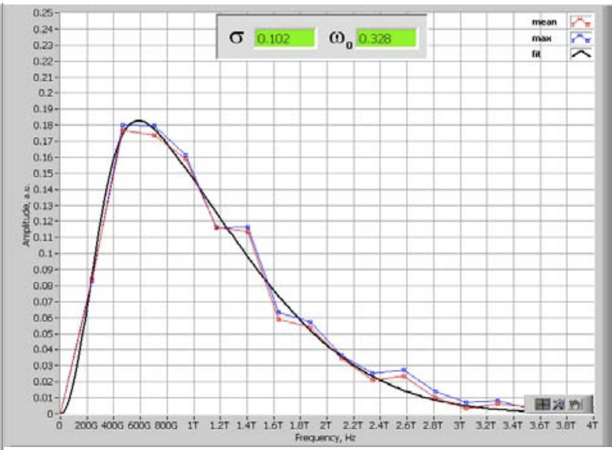
JLab FEL bunch compression and diagnostics

courtesy Pavel Evtushenko

- JLab IR/UV Upgrade FEL operates with bunch compression ration of 90-135 (cathode to wiggler); 17-25 (LINAC entrance to wiggler).
- To achieve this compression ratio nonlinear compression is used – compensating for LINAC RF curvature (up to 2nd order).
- The RF curvature compensation is made with multipoles installed in dispersive locations of 180° Bates bend with separate function magnets - D. Douglas design (no harmonic RF)
- Operationally longitudinal match relies on:
  - a. Bunch length measurements at full compression (Martin-Puplett Interferometer)
  - b. Longitudinal transfer function measurements R_{55}, T_{555}, U_{5555}
  - c. Energy spread measurements in injector and exit of the LINAC







Martin-Puplett Interferometer data in frequency domain – give upper limit on the RMS bunch length

BACKUP: Longitudinal Matching Scenario

Requirements on phase space:

- high peak current (short bunch) at FEL
  - bunch length compression at wiggler
    using quads and sextupoles to adjust compactions
- "small" energy spread at dump
  - energy compress while energy recovering
  - "short" RF wavelength/long bunch,
    large exhaust $\delta p/p$ (~10%)
  - $\Rightarrow$ get slope, curvature, *and* torsion right
    (quads, sextupoles, octupoles)