High Power Operation of the JLab IR FEL Driver Accelerator

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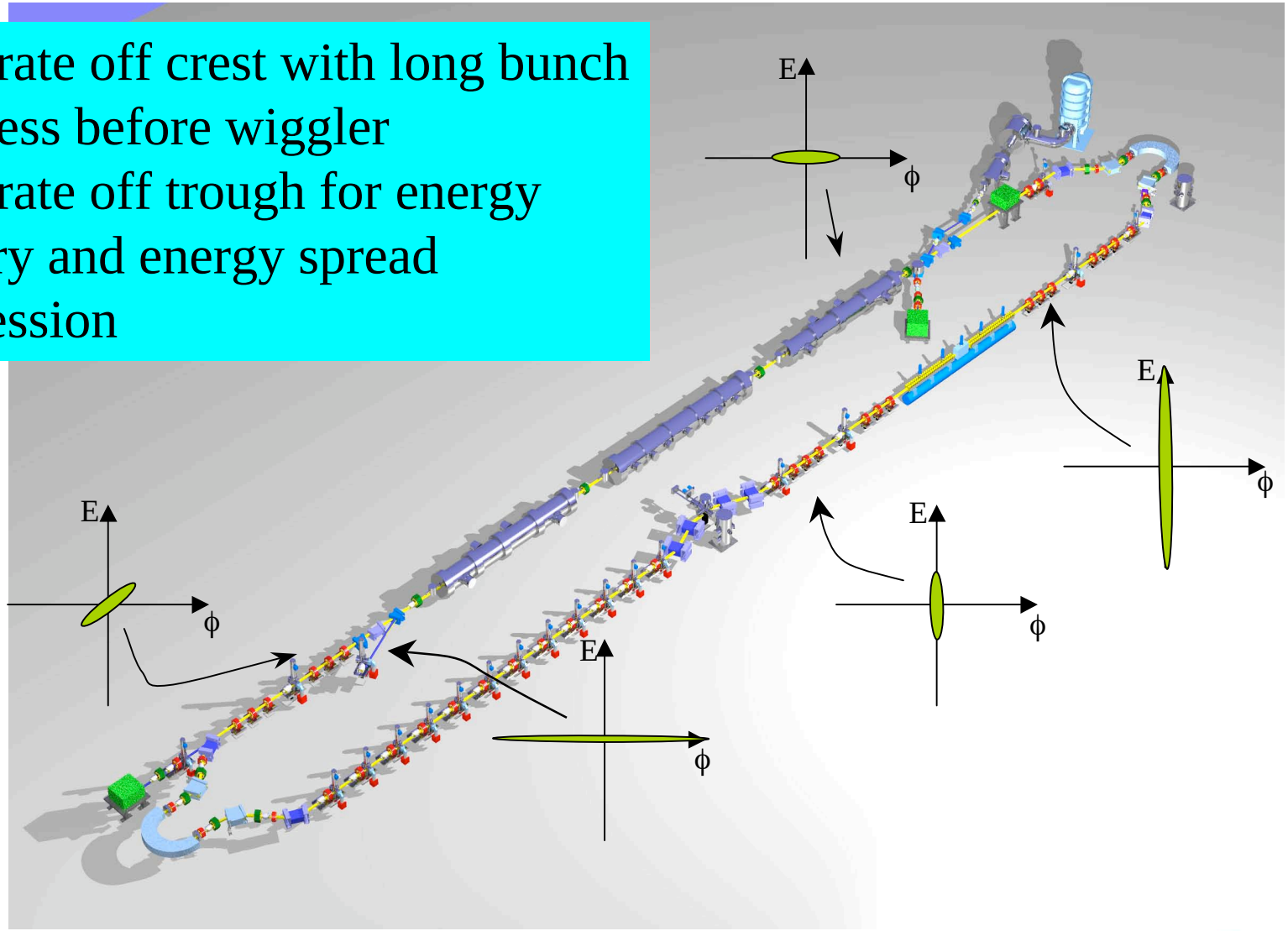
The IR Upgrade FEL

Accelerate off crest with long bunch
Compress before wiggler
Decelerate off trough for energy recovery and energy spread compression



IR Upgrade FEL Parameters

Wiggler&Resonator		Electron Beam	
λ_W(mm)	55	Energy(MeV)	115
N_W	30	Charge (pC)	<135
Max K^2_{rms}	8.4	Long. Emit.(keV-spec)	80
Max B(kG)	8.0	Trans. Emit.(mm-mrad)	10
Min. Gap (mm)	16.5	Pulse length(fs *rms*)	170
Cavity length(m)	32	Repetition rate(MHz)	<74.85
z_R(cm)	80	Wiggler β(m)	0.8

Limits to High Current Operations

- **Halo**
  - "the" operational limitation
  - Intensity several orders of magnitude below that of core beam (but still sufficient to destroy accelerator or wiggler)
  - Typically
    - from multiple sources (source, LSC, CSR…): can't fully model its generation
    - mismatched to core beam
    - difficult to control without adversely affecting core beam and laser performance
  - Need diagnostics with large dynamic range, excellent resolution, and tomographic algorithms

Transverse Charge Distribution is NOT Gaussian

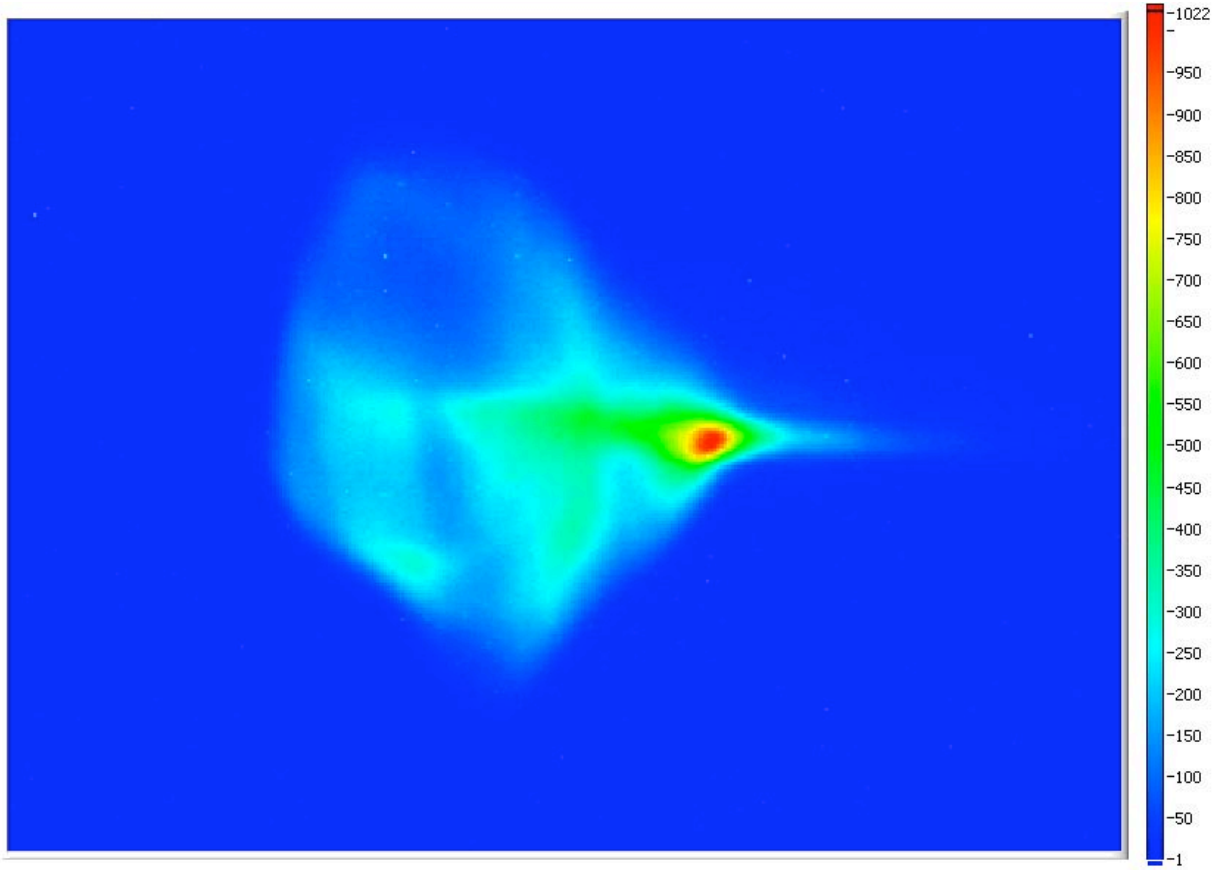
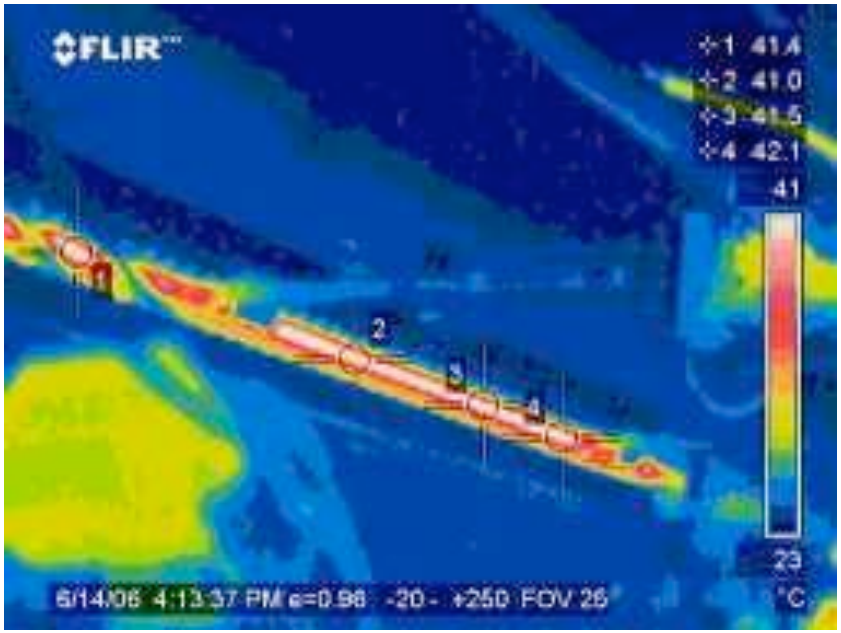


Figure 1. OTR image of the beam after a long drift before the final bunching chicane showing complicated phase space distribution

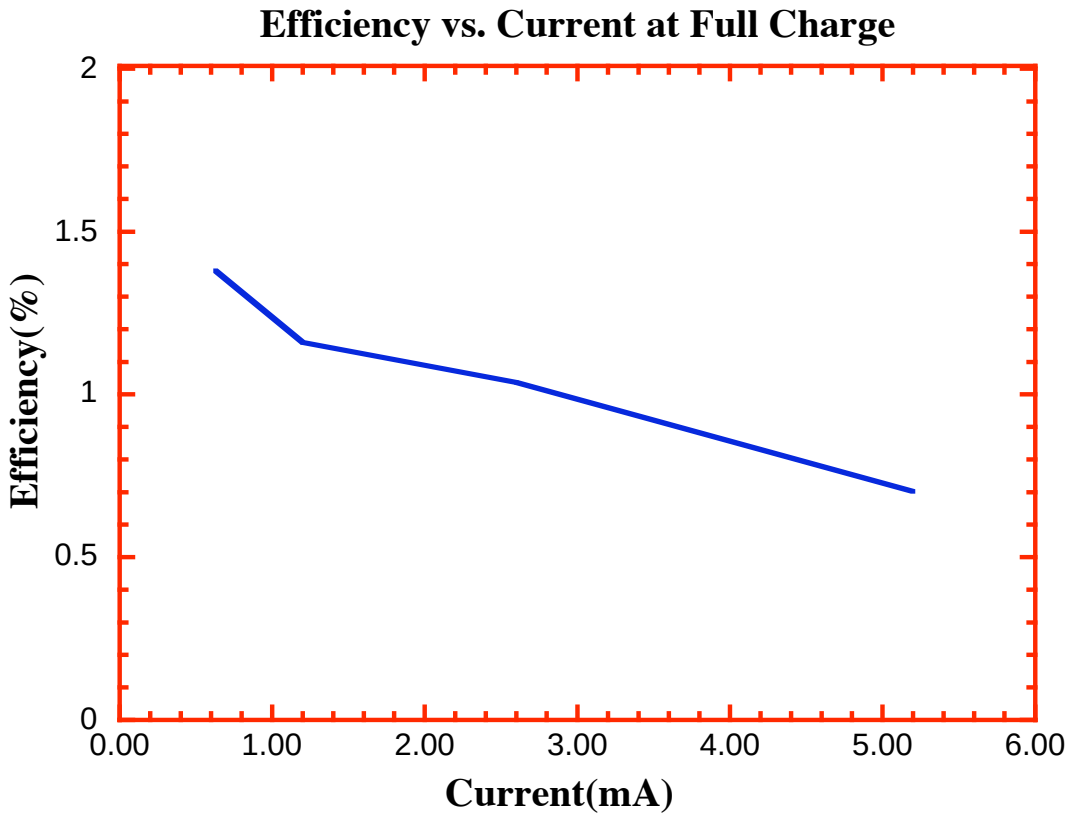
Resistive wall heating



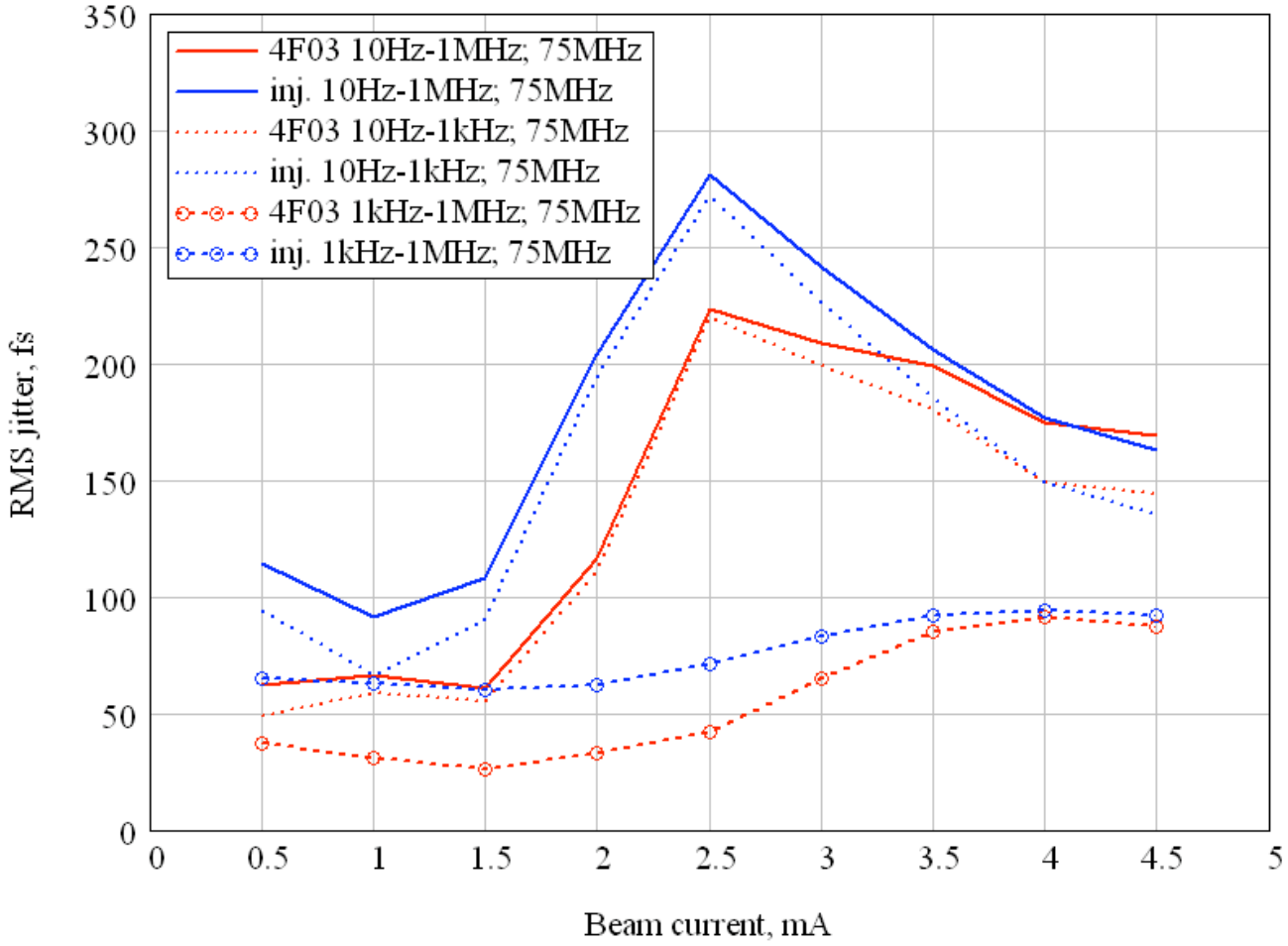
42ºC temperature with only 4.6 mA OOPS!

Efficiency Falls with Increasing Current

- With this 1.6 μm mirror set the efficiency was 1.7% with pulsed beam.
- The efficiency fell off sufficiently fast with increasing current that the power was clamped at 4.2 kW.
- Similar behavior was seen at 1.06, 2.8, and 5.8 μm



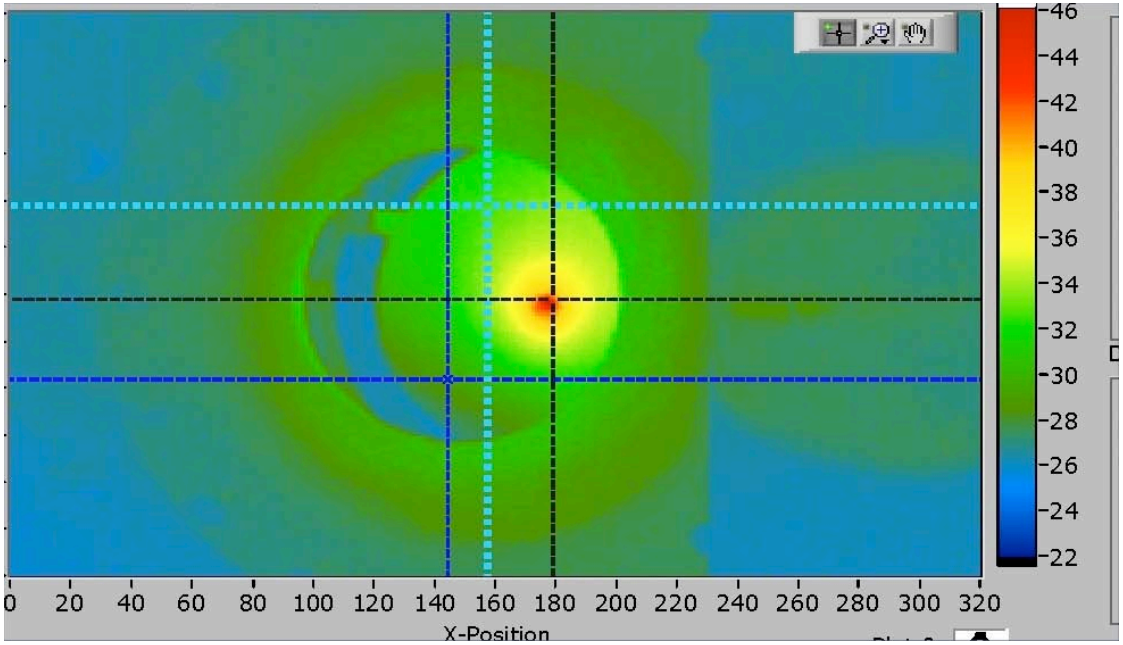
Phase Noise Cannot Explain Efficiency Fall-off



Any other High Current Effects?

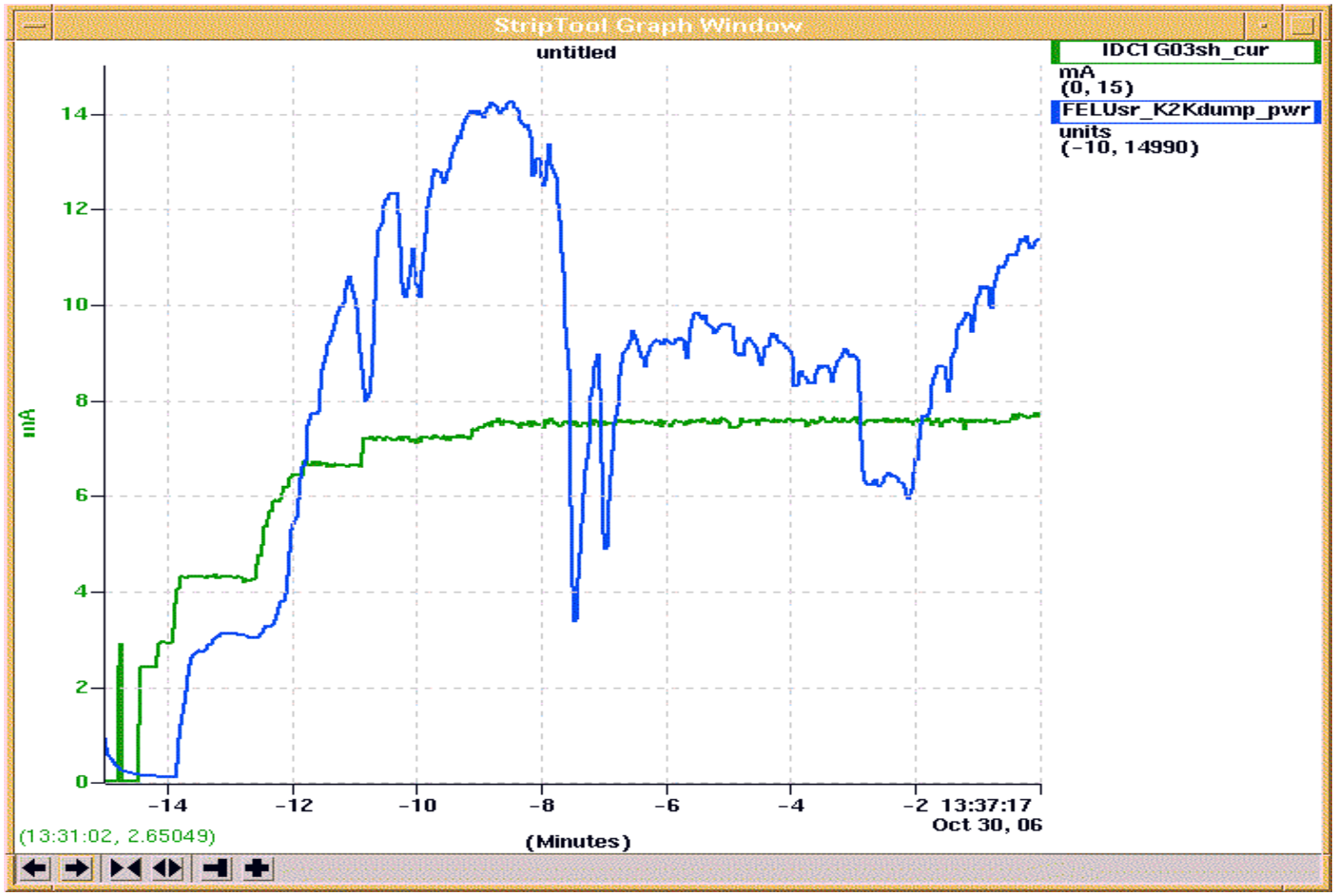
- Image electron beam in wiggler. No movement seen except for a shift due to beam loading.
- Phases shift due to beam loading but we can use CSR enhancement to reproduce low current phases.
- Pressure rises due to THz and wakefields limited operation at full current to about 1 hour.
- RF control loops have to be optimized for high current
- RF window heating in injector limited current to ~8mA
- BBU suppressed by beam rotation

Output Coupler Heating



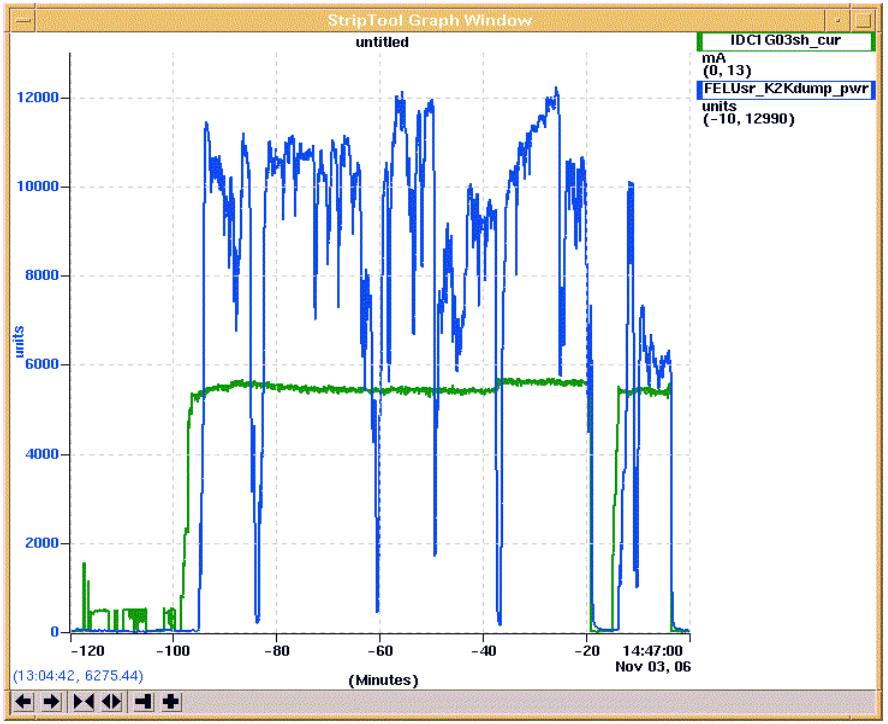
Large Temperature rise seen when operating at multi-kilowatt level

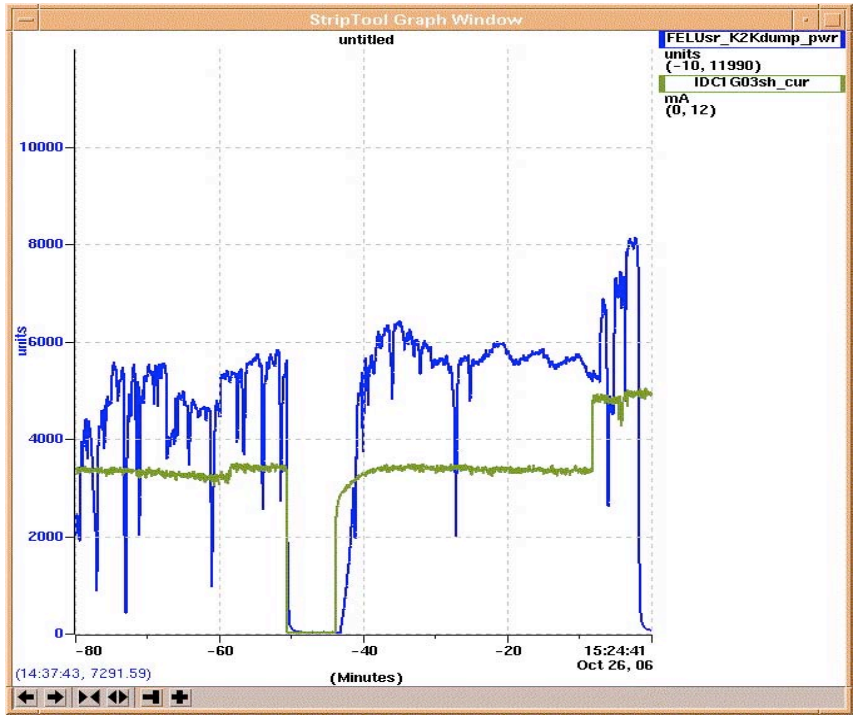
Cryo-Mirror Operation



Efficiency was 1.5% for this setup, 14.3 kW at 8 mA.

Endurance Runs

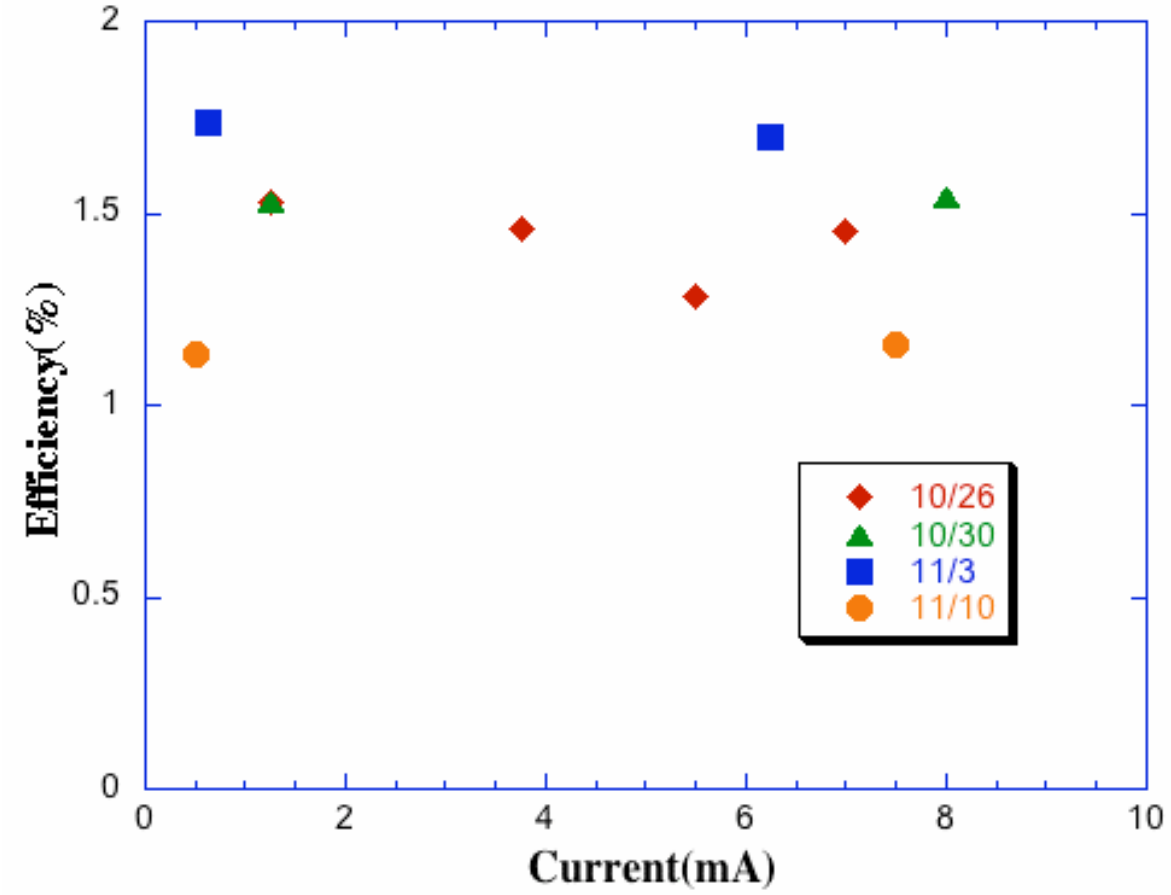




We could operate for long periods with the power above 10 kW but could not maintain the power steady for more than 10 minutes due to heating of the mirror mounts.

At lower power levels the laser was relatively stable running at 6 kW with no adjustments for an extended period.

Efficiency vs. Current with Cryo-Mirror



Efficiency of the FEL operating with the cryo- mirror as a function of current. Data was taken on four different days of operation

Conclusions

- The efficiency is independent of current when the mirrors do not distort. This supports, along with the diagnostics, the observation that the beam quality is high at high current.
- Beam loading can pull phases and steer the beam. These can be compensated.
- Current is now limited to 8 mA by injector cryo-unit RF windows (40 kW throughput).
- Even at 8 mA, vacuum chamber heating due to wakefields, resistive wall heating, and THz emission can limit operation time.