Commissioning Simulations Using GINGER

William M. Fawley
Lawrence Berkeley National Laboratory

Presented to the LCLS Undulator Diagnostics and Commissioning Workshop
19-20 January 2004

"An expert is someone who has already made all the mistakes"

(attributed to Edward Teller by LLNL folklore)

- LCLS commissioning should be based (in part) on previous TTF-1, LEUTL, VISA, *etc.*, experiences
- LCLS personnel should obtain operational experience on working FEL's (*e.g.* TTF-2, VISA-2, LEUTL, JLAB FEL, *etc.)*
- TTF-2 in particular may give invaluable pointers to LCLS, *partially* illuminating any "unknown unknowns" below 100-nm
- Continual and unavoidable problem of being forced by project scheduling pressure to make premature decisions while having insufficient information --- balancing the tradeoffs between future flexibility and cost is stressful

Information Numerical FEL Simulation can Provide During LCLS Commissioning

- Quick surveys of *P(z)*, L_{gain} sensitivity to e-beam properties
  - Sensitivity to *Q*, *I*, ε, $<x>$, $<y>$, $\Delta\gamma$, wakefields
  - Sensitivity to local and "global" (*i.e.* rms) $\Delta K/K$ (including both trajectory and longitudinal phase drift errors)
- Detailed predictions for coherent intensity *I(r,z,t)* or *I(x,y,z,t)*
  - Power spectra $P(\omega)$ and $\sigma_\omega(z)$
  - Far field opening angle
  - Autocorrelation functions, FROG/chirp details
  - Predictions for harmonics including (heightened) sensitivity to e-beam parameters
  - Statistical properties of SASE radiation, shot-to-shot and within a given shot for both power and spectrum

Close Collaboration Needed between Diagnosticians, Theorists/Simulationists, and Experimentalists

- Past efforts on obtaining deep agreement between simulation and experiment (e.g. VISA, TTF-1) has happened only after making good measurements and S2E simulation for both the e-beam and radiation output
- In commissioning experiment design, simulationists need to understand what is obtainable from the experiment and, conversely, experimentalists/diagnosticians should understand what measurements are meaningful for comparison with theory
- Just like voting in Chicago, "S2E dry run experiments" should be done early and often
  - Smooth interfaces needed between codes (and different owners/labs)
  - Diagnostic data formats should be publicized well in advance of actual commissioning

It's easy to do an experiment; it's hard to do a *meaningful one*

(Berkner's Second Law)

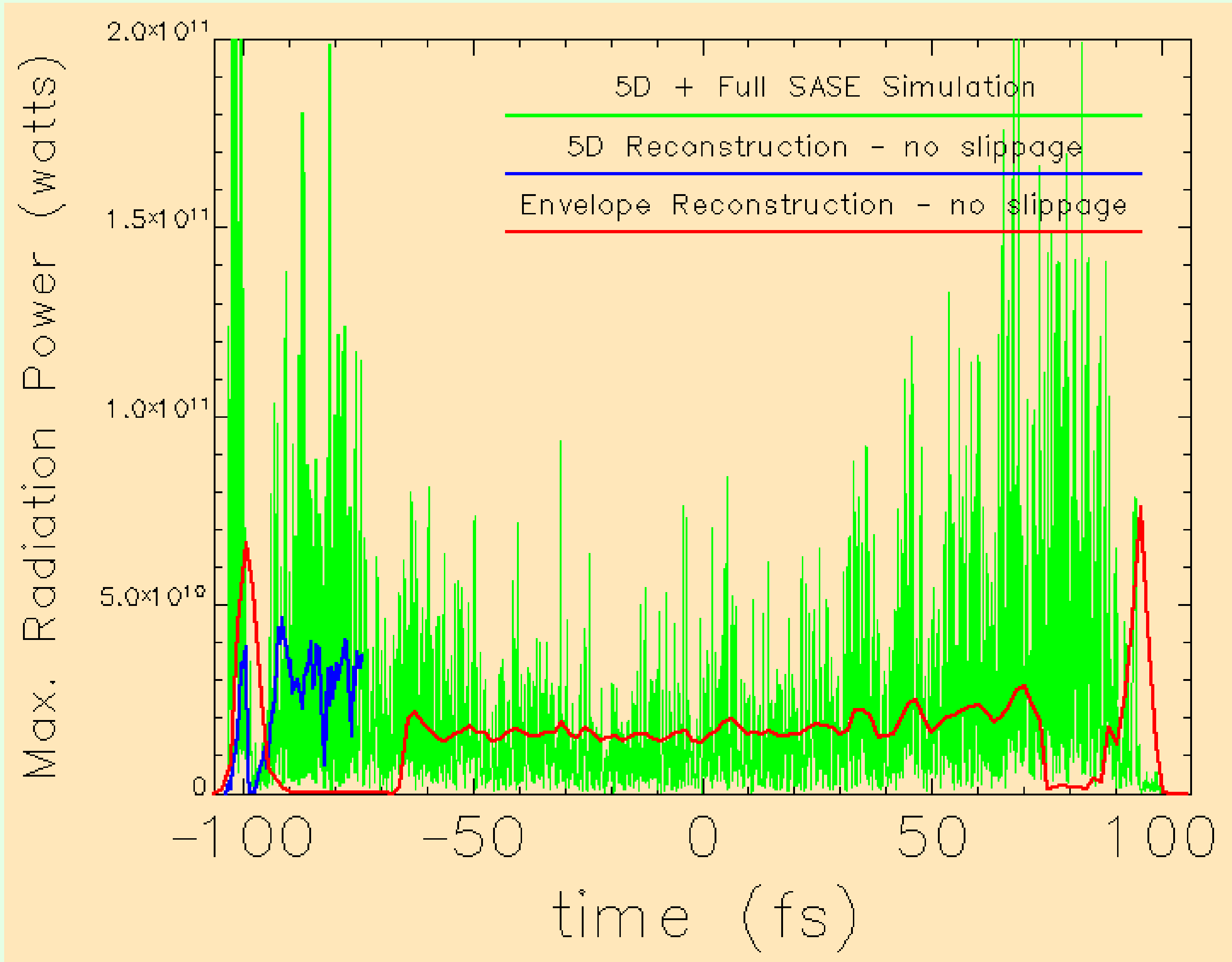
Current State of the GINGER Code

- Full 3D e-beam; axisymmetric radiation field
- Full SVEA time-dependence
- Can import ELEGANT data: both envelope parameters *and* macroparticles for highly detailed, time-dependent 5D phase space reconstruction
- Models for wakefield and wiggler error
- Can split full polychromatic simulation of “long” e-beam pulse into many separate runs via a “multi-segment” mode
- Fully parallel; runs efficiently on MPP machines (*e.g.* IBM-SP)
- Graphical, SDDS-formatted and simple ASCII table output all available from post-processor
- Up-to-date user manual *(new release late Jan. ’04)*

Full LCLS Pulse Simulation with GINGER

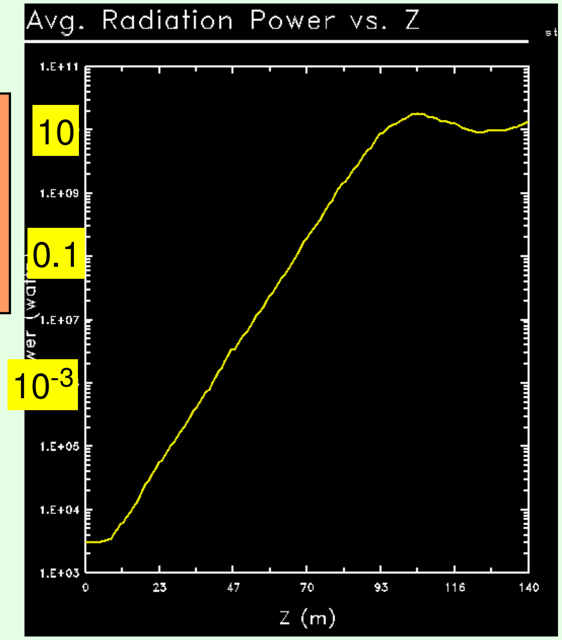
1-nC LCLS e-beam 5D phase space reconstructed from Emma'a ICFA03-S2E ELEGANT run with CSR

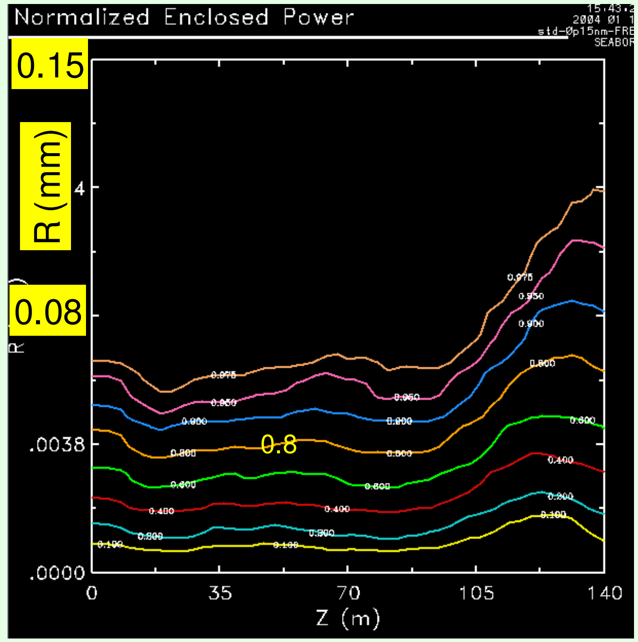
12-as temporal resolution ~20,000 slices for full SASE simulation --- run primarily in parallel mode on IBM-SP

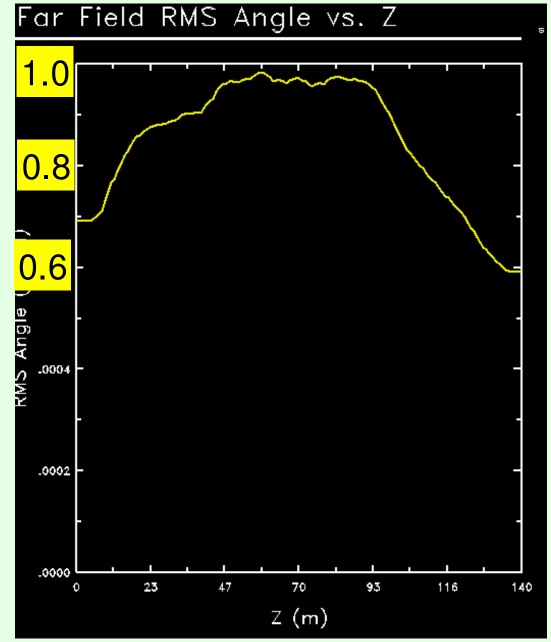


Monochromatic amplifier runs to *z=140* m for 0.15 nm & 1.5 nm with std. drift spaces

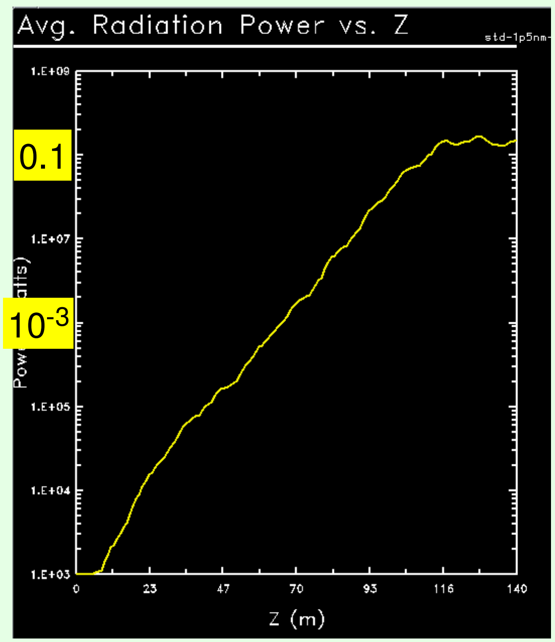
0.15 nm
1.2 mm-mrad
3.4 kA
14.35 GeV

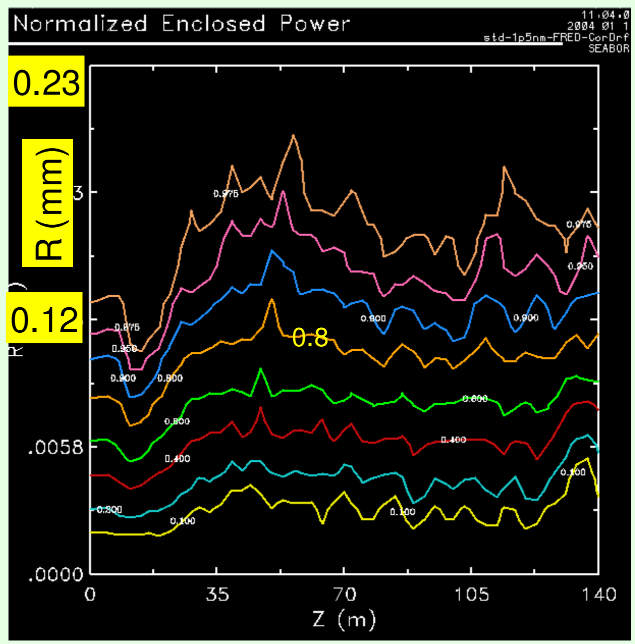


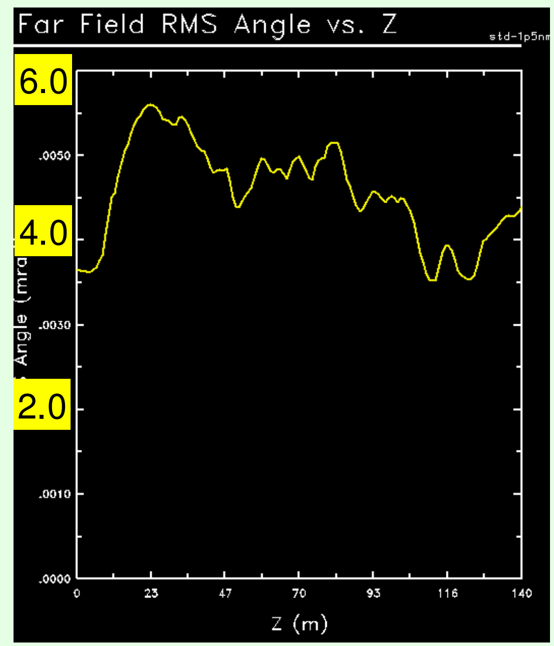




1.5 nm
4 mm-mrad
1.0 kA
GeV







Power (**GW**) vs. *z*

Enclosed Power Fraction as a function of radius

RMS Far Field Opening Angle (μRad)

Some (Likely) Near-to-Mid Term Improvements to GINGER

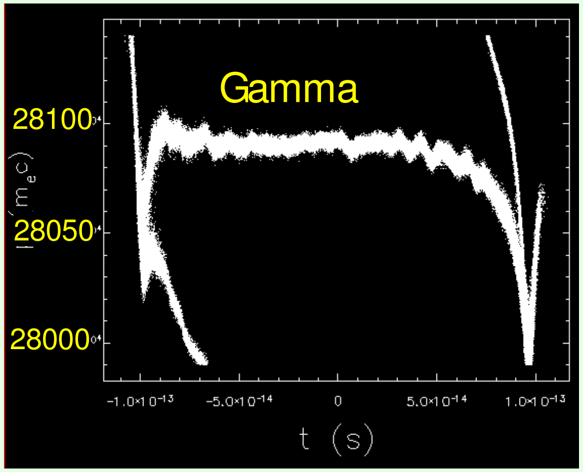
- Spontaneous emission energy losses
- Harmonic radiation emission
- 3-D radiation solver via azimuthal mode decomposition (*i.e.* r-θ-z-t)
- More generalized/robust treatment of optical & magnetic elements
  - Apertures, lenses, monochromators
  - *R*-matrix treatments of magnetic elements (*e.g.* chicanes, quads)
- More flexible/efficient format for GINGER disk output
  - Reduced file size
  - Self-describing (but not "classic" SDDS) format
- Some changes needed by LBNL/LUX, some by LCLS, some by others (*e.g.* MIT/BATES, Trieste/ELETTRA, *etc.)*

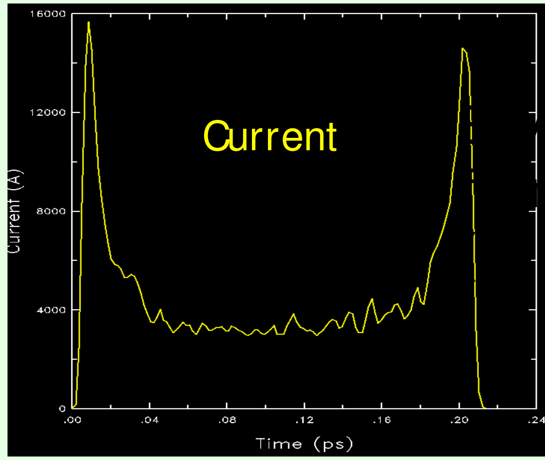
The Difficulties of Multiple Exponentials

- Even in the absence of undulator/quad/BPM and e-beam mismatch errors, L_{gain} will vary along the LCLS pulse
  - Different portions will have differing sensitivities to all different types of errors, especially in terms of saturation length
  - This was seen in the recent BNL UV HGHG experiment
- Without time-resolved power diagnostics, it may be very difficult to determine: (1) Is there a problem in L_{gain} or L_{sat} (or both) ?
  (2) If so, where in *z* did that problem arise?
- Commissioning the undulator in ≥3 stages may ease this difficulty
- It would be nice to have a temporally "isolated" pulse portion lase (with nearly constant e-beam properties)
  - similar to some LCLS short pulse ideas

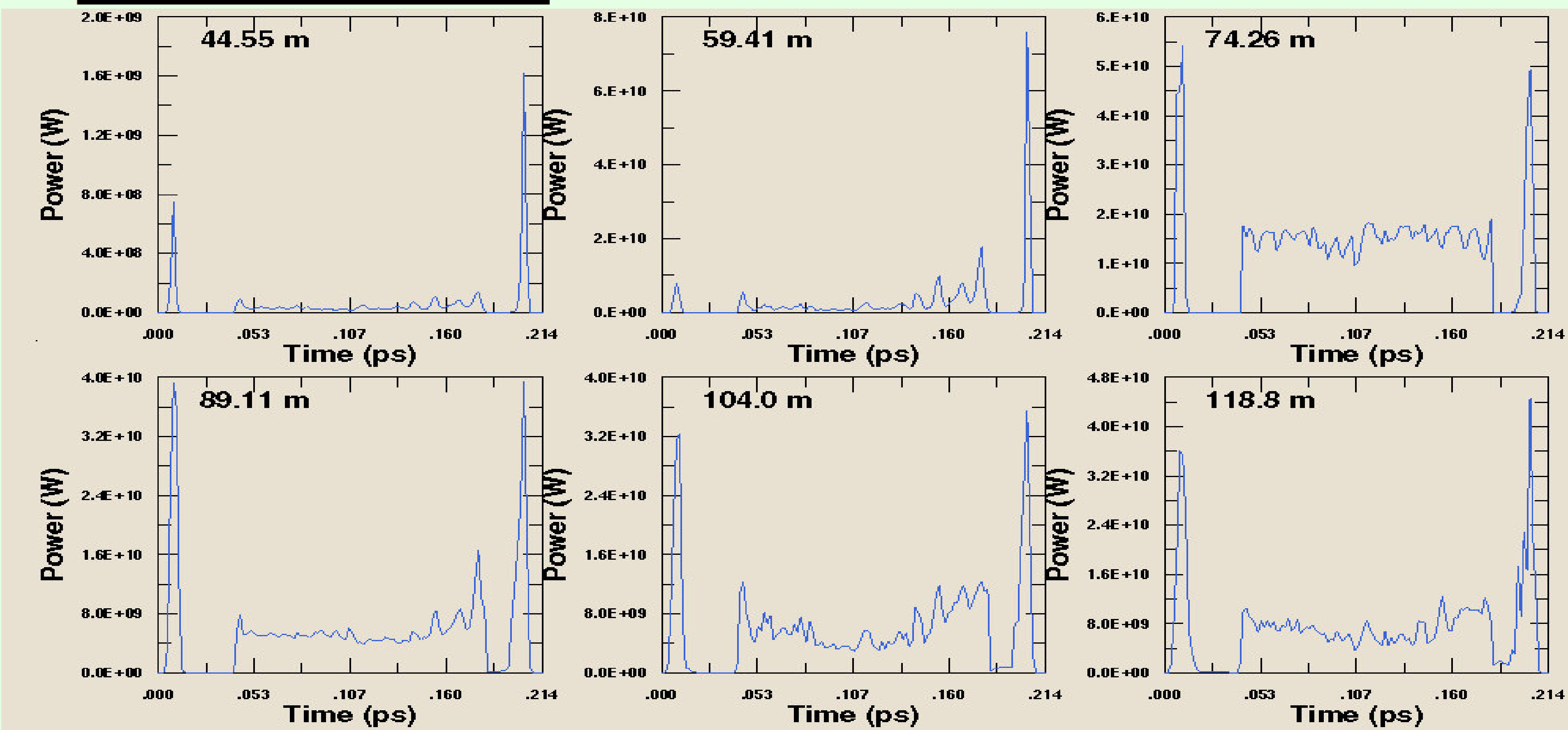
Systems should be brought on line systematically, or sometimes the tortoise beats the hare. *(Berkner's Fourth Law)*

Simple S2E Amplifier Run Illustrating *P(t)* Sensitivity to Variation in E-Beam Properties





elope reconstruction
n 1-nC ELEGANT results
Emma)



Some Errors Might Be (Infuriatingly) Difficult to Diagnose and Isolate

- Although trajectory errors diagnosis and correction via BBA seem to be well in hand, there may be other nasty errors out there
- Example: a ~150 micron vertical offset in 1 undulator segment
  - Sufficient to red-shift the local resonant λ by greater than $\rho\lambda$
  - Effect should reduce gain locally + increase L_{sat}
  - Not easily detectable in trajectory (quads dominate focusing)
  - Virtually undetectable in local P(z) growth in first 3-5 gain lengths
  - Probably non-localizable in latter half of undulator by looking for increase in gain length or shift in average wavelength
    - Alternate conclusions: mistuning in microtaper or slight emittance growth

One shouldn't jump to conclusions from preliminary data

(Berkner's Seventh Law)

Some additional suggestions/observations

- Workshops and informal semi-regular get-togethers are a good way to stimulate LCLS-related work from non-SLAC people
  - ~bi-monthly meeting on S2E and FEL ⇔ diagnostic issues/goals could vastly improve progress/communication
  - Team-building sounds corny but it's better than no team at all
- LCLS **must** be made to work or we may not see another DOE-funded FEL project in our working lifetimes
- Early commissioning/CD-4 (*i.e.* end of construction project) goals must be carefully thought out, especially in terms of diagnostic abilities

Assume nothing; trust no one *(Berkner's First Law)*