Update on Start−to−End Simulations

M. Borland
Operations Analysis Group
Argonne National Laboratory

Outline

- S2E jitter simulations
- CSR experimental results from APS
- Possibility of blocking CSR with ultrathin foils

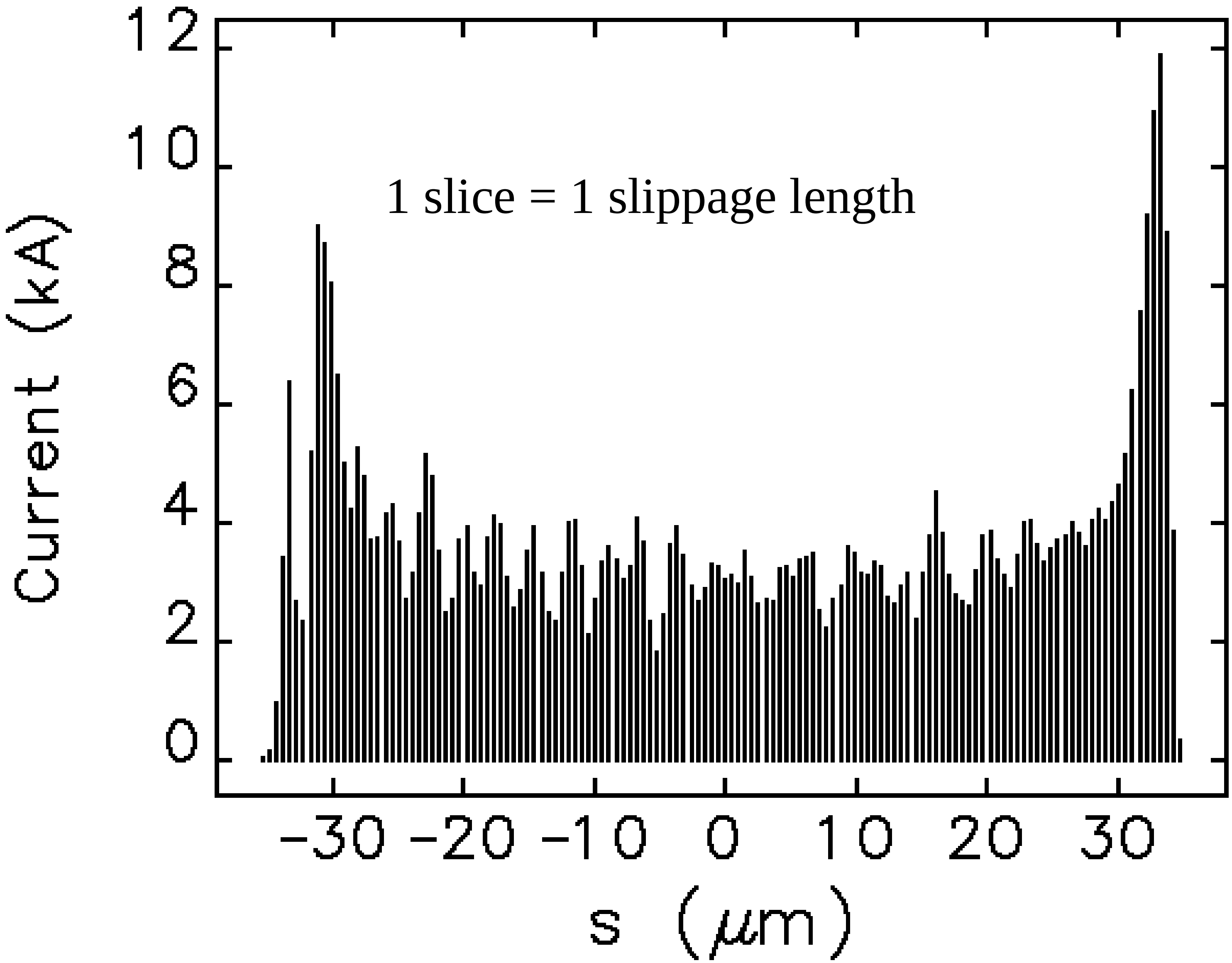
S2E Review

- Use PARMELA with 100K particles for photoinjector up to 150 MeV
- Track up to 14.35 GeV with **elegant**, including wakes and CSR
- Run GENESIS for many independent slices to simulate FEL
- Simulate pulse−to−pulse jitter about perfectly tuned condition

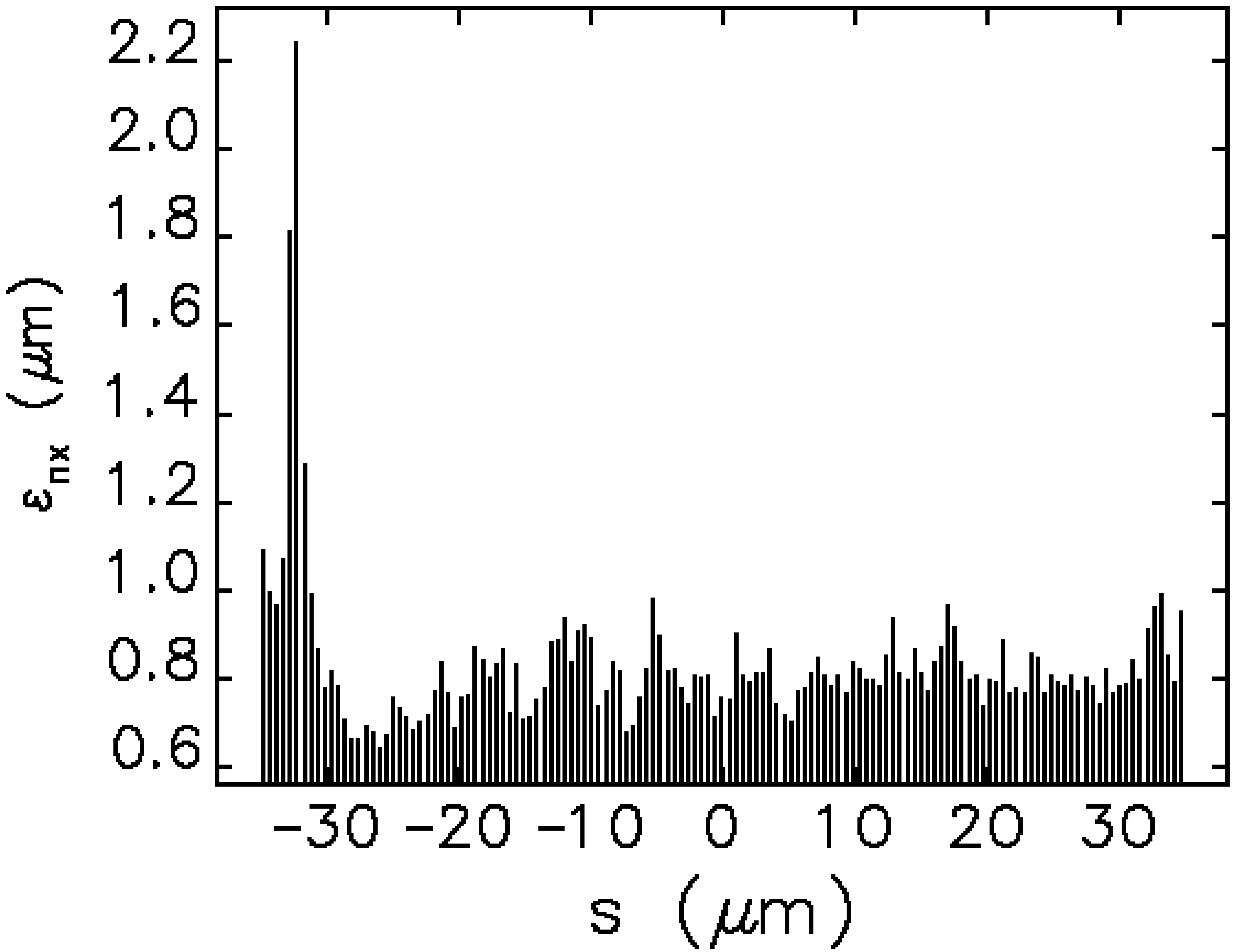
New Features Since Last TAC

- Jitter simulation starts with the photoinjector
- Use Stupakov’s formulae for CSR in drifts
- Simulation of emittance correction with "tweaker" quads
- CSR instability is no longer smoothed away
- CSR instability is properly reflected in FEL simulations

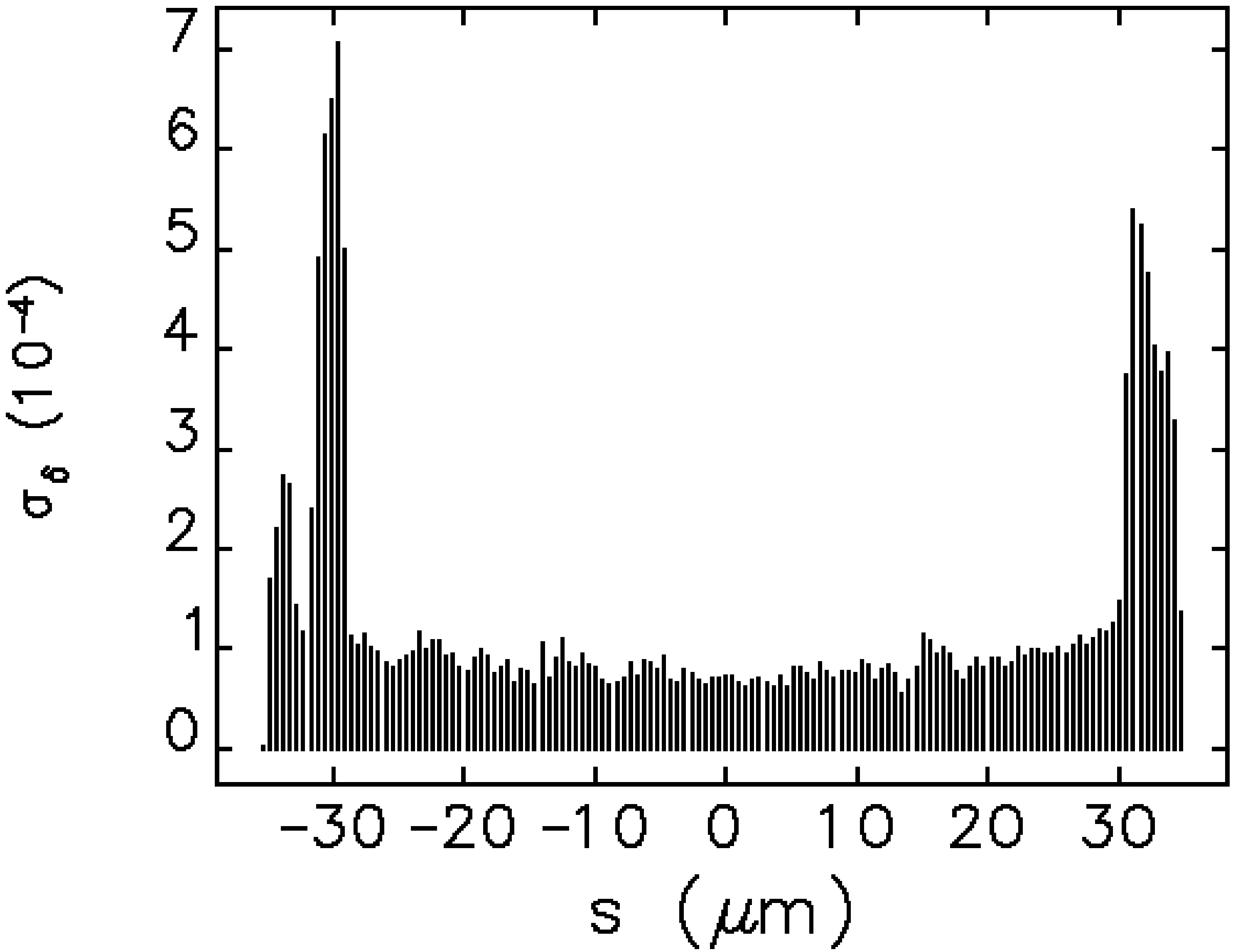
Slice Analysis for Ideal Case



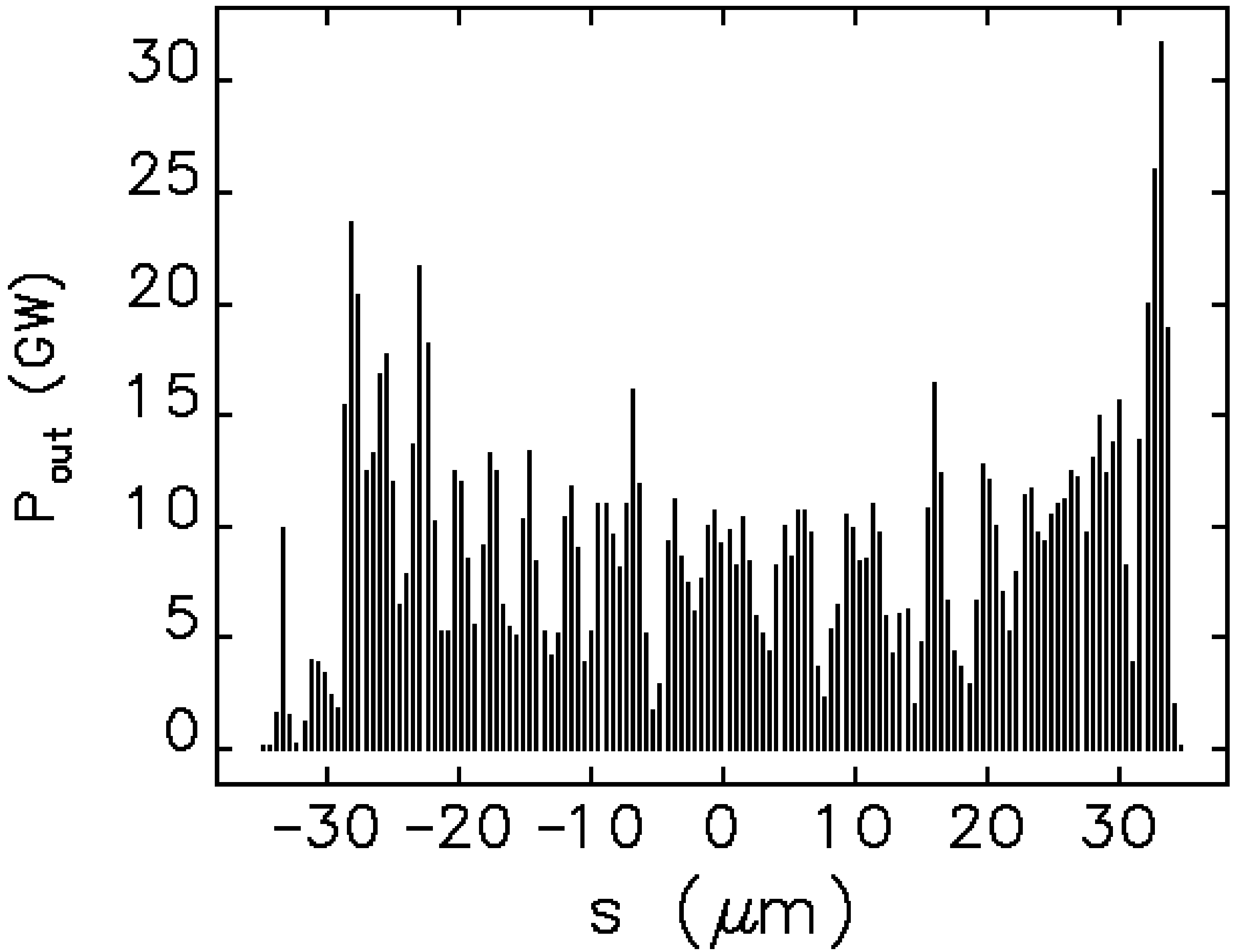
Slice Analysis for Ideal Case



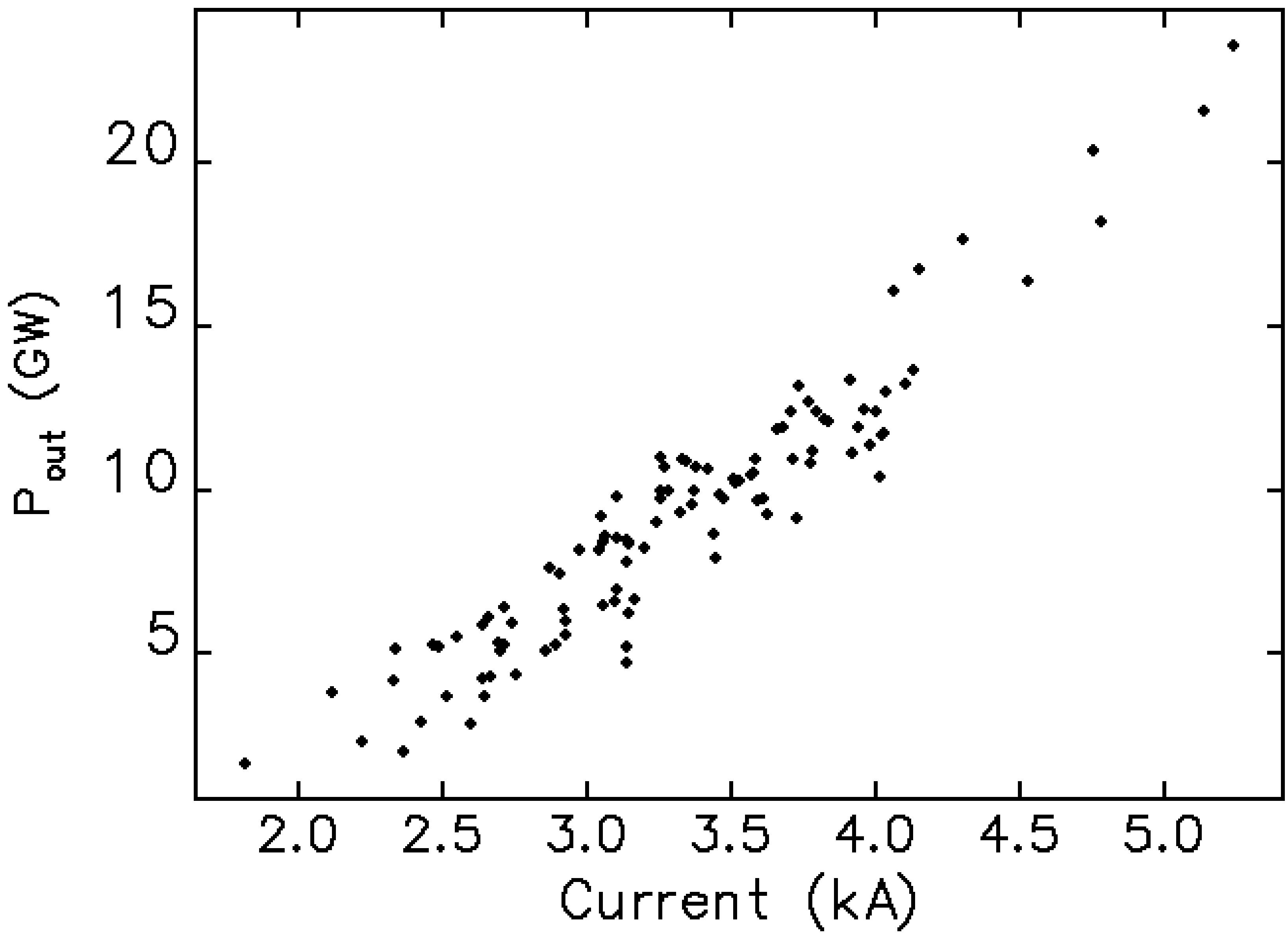
Slice Analysis for Ideal Case



Slice Result for Ideal Case



Slice Power and Slice Current



Predicted FEL Performance

- Results are averaged/summed over the central 80% "core slices"

Tweaker Quads ?	*Current (kA)*	*Bunch length (ps)*	*Frac. mom. spread (10^{-4})*	*Norm. x emit. (μm)*	*Gain length (m)*	*Output power (GW)*
on	3.321	0.184	0.847	0.798	3.433	7.345
off	3.320	0.186	0.837	0.793	3.501	6.970

S2E Jitter Simulations of LCLS

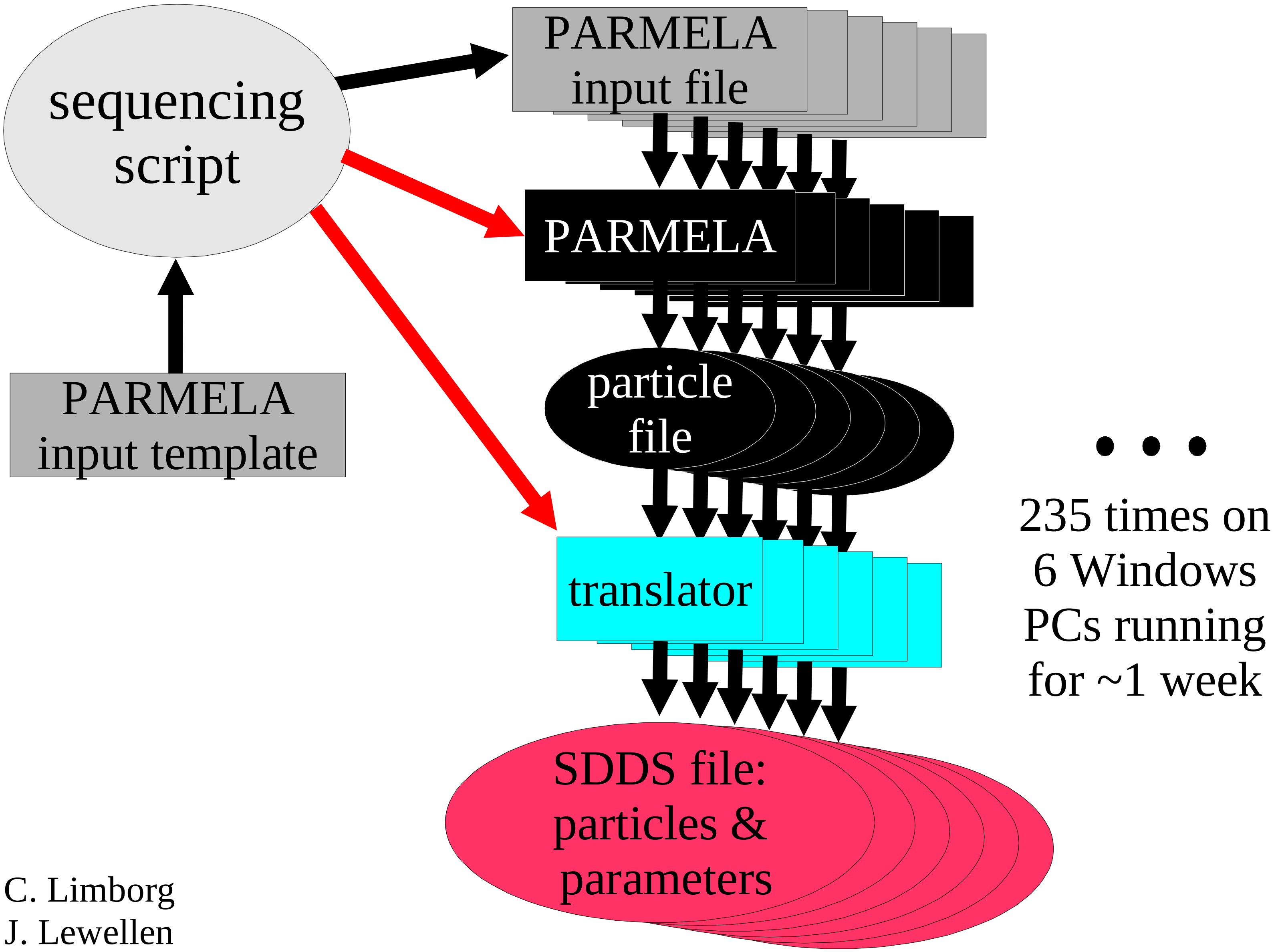
- "Jitter" refers to any error that we can’t correct with alignment, tuning, feedback, etc.
- We simulated jitter, including
  - drive laser timing and energy
  - photoinjector and linac rf voltages and phases
  - bunch compressor power supplies
- We assume that the machine is tuned to ideal performance on average

Jitter Levels for LCLS

Quantity	*Rms Jitter Level*
laser phase	0.5 deg−S
laser energy	1.00%
gun phase	reference
gun voltage	0.1%
L0 phase (1)	0.1 deg−S
L0 voltage (1)	0.10%
L1 phase (1)	0.1 deg−S
L1 voltage (1)	0.10%
X−band phase (1)	0.3 deg−X
X−band voltage (1)	0.25%

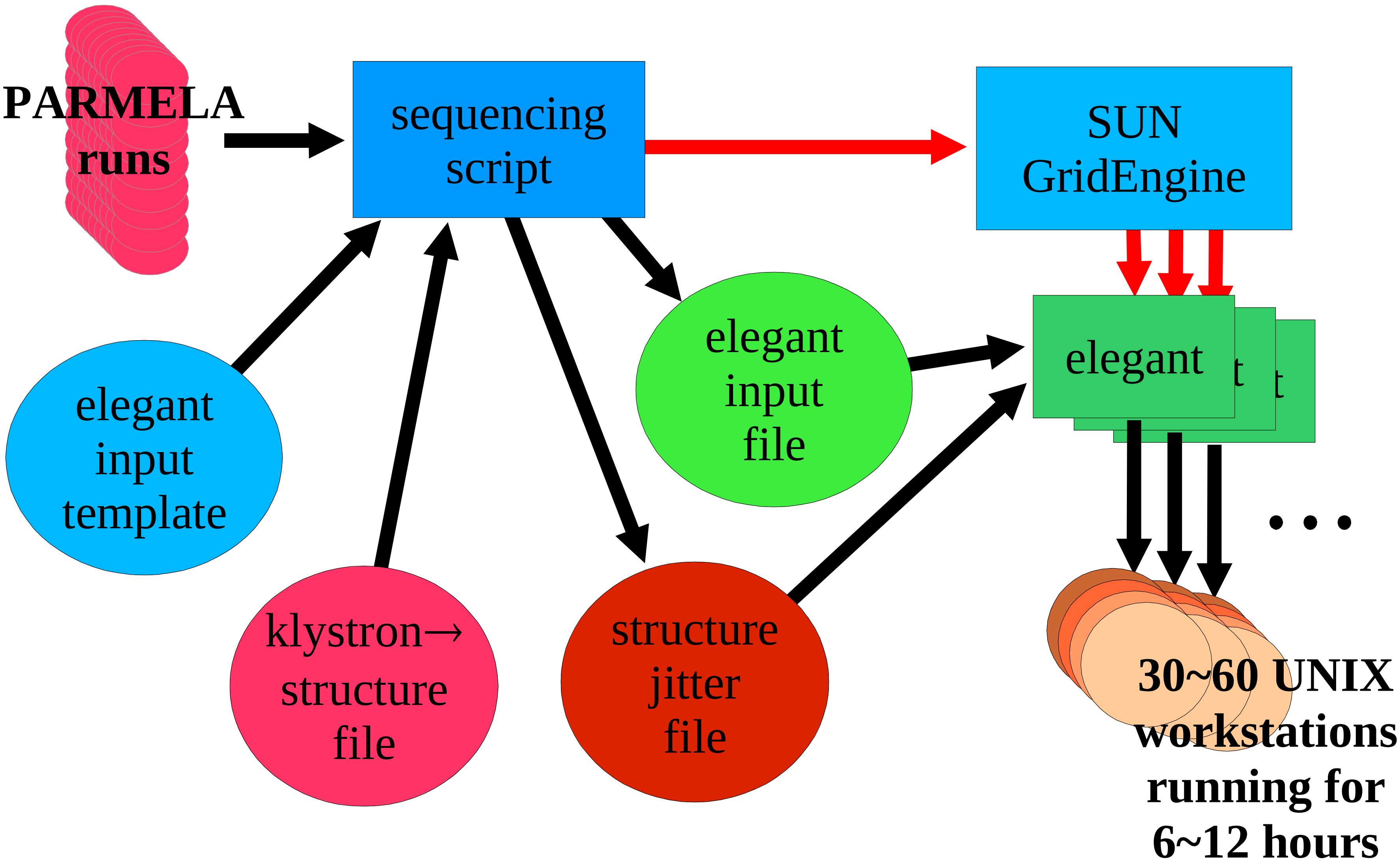
Quantity	*Rms Jitter Level*
L2 phases (28)	0.07 deg−S
L2 voltages (28)	0.07%
L3 phases (48)	0.07 deg−S
L3 voltages (48)	0.05%
BC1 dipoles	0.02%
BC2 dipoles	0.02%
DL dipoles	0.01%
Wiggler dipoles	0.02%
Tweaker quads (4)	0.1%

PARMELA Simulation Diagram



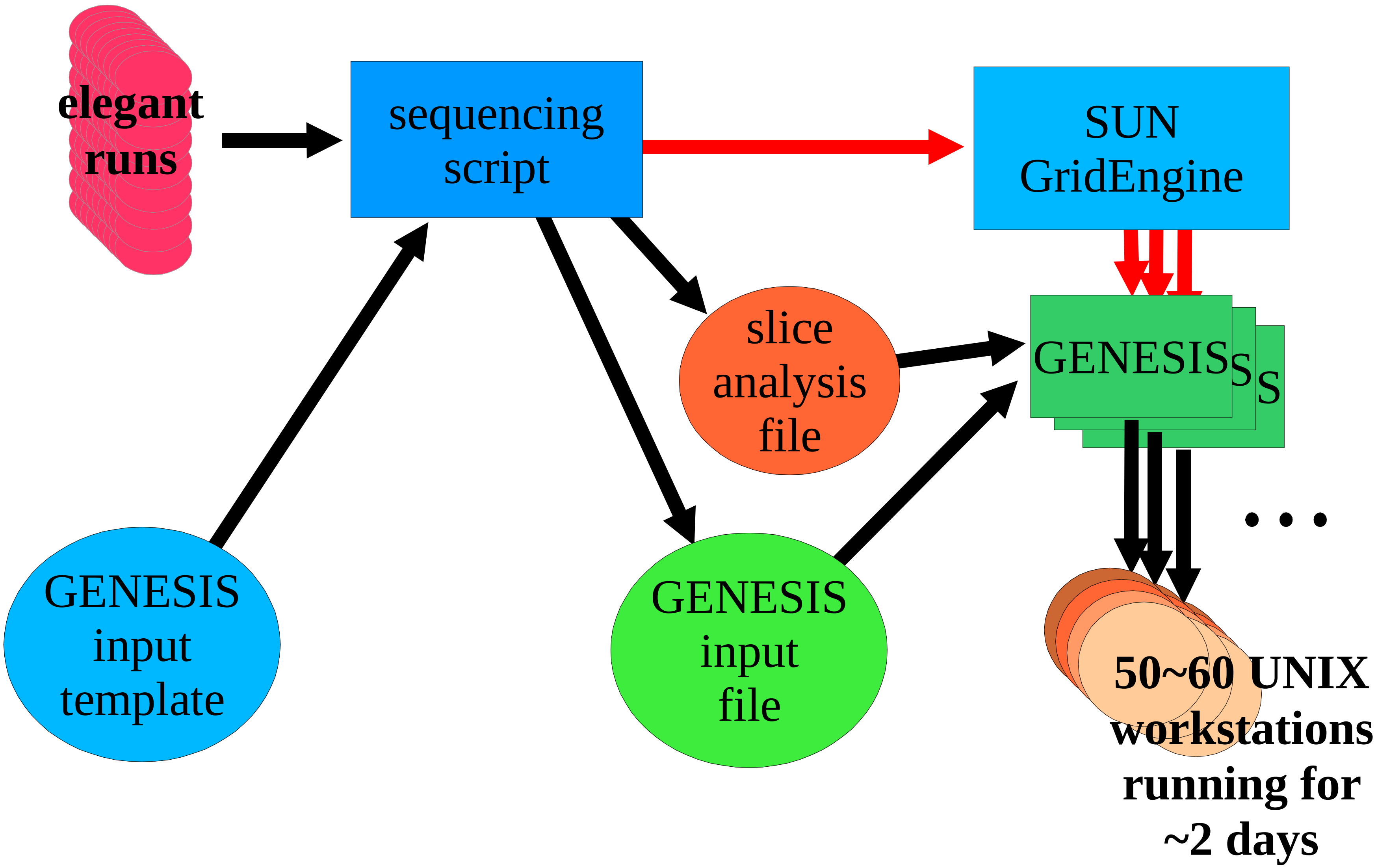
Lattice: C. Limborg
Scripts: J. Lewellen

elegant Simulation Diagram



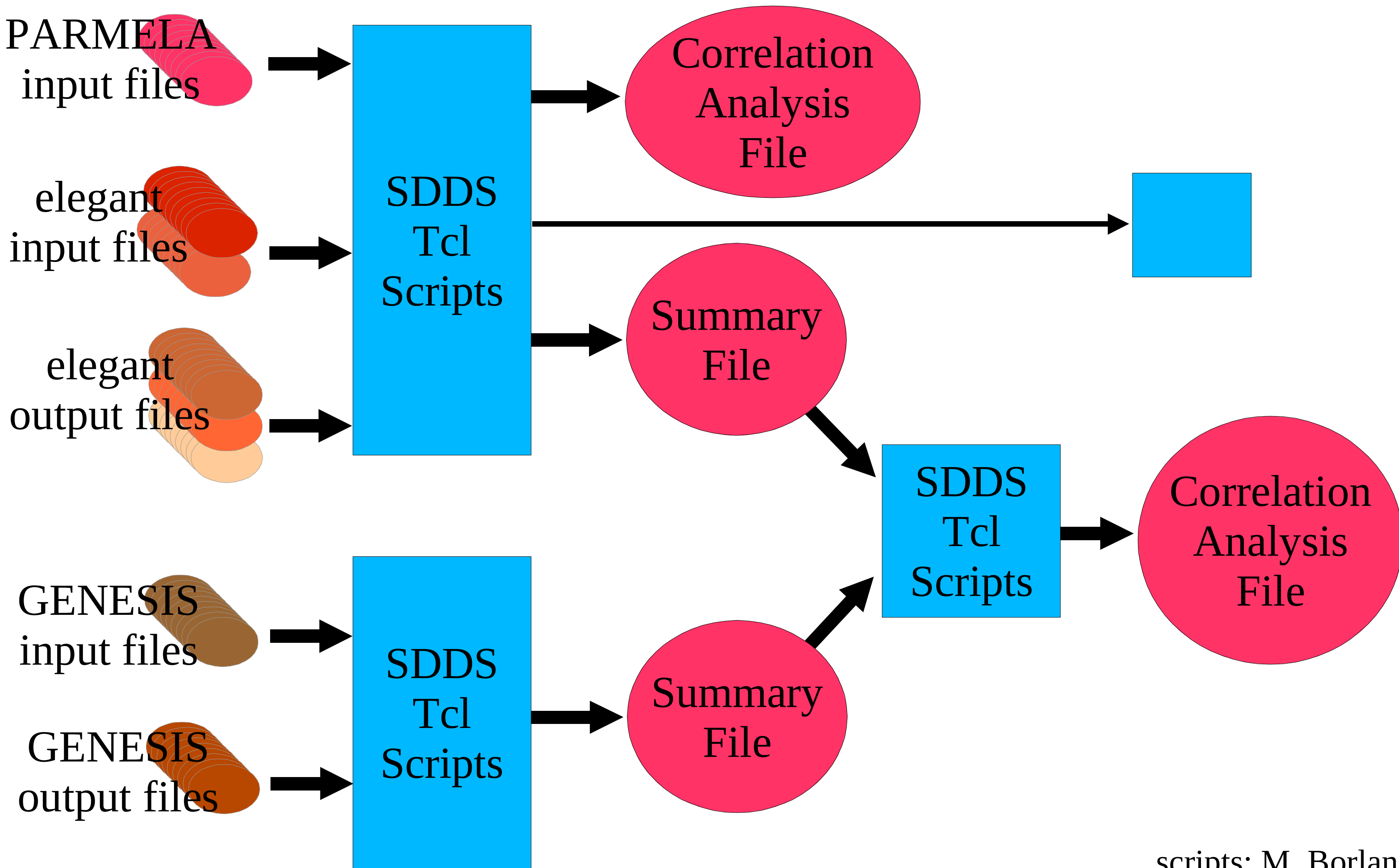
Lattice: P. Emma, M. Woodley
Scripts: M. Borland

GENESIS Simulation Diagram



Input template: Y.Chae
Scripts: M. Borland, Y. Chae, R. Soliday

Postprocessing Diagram



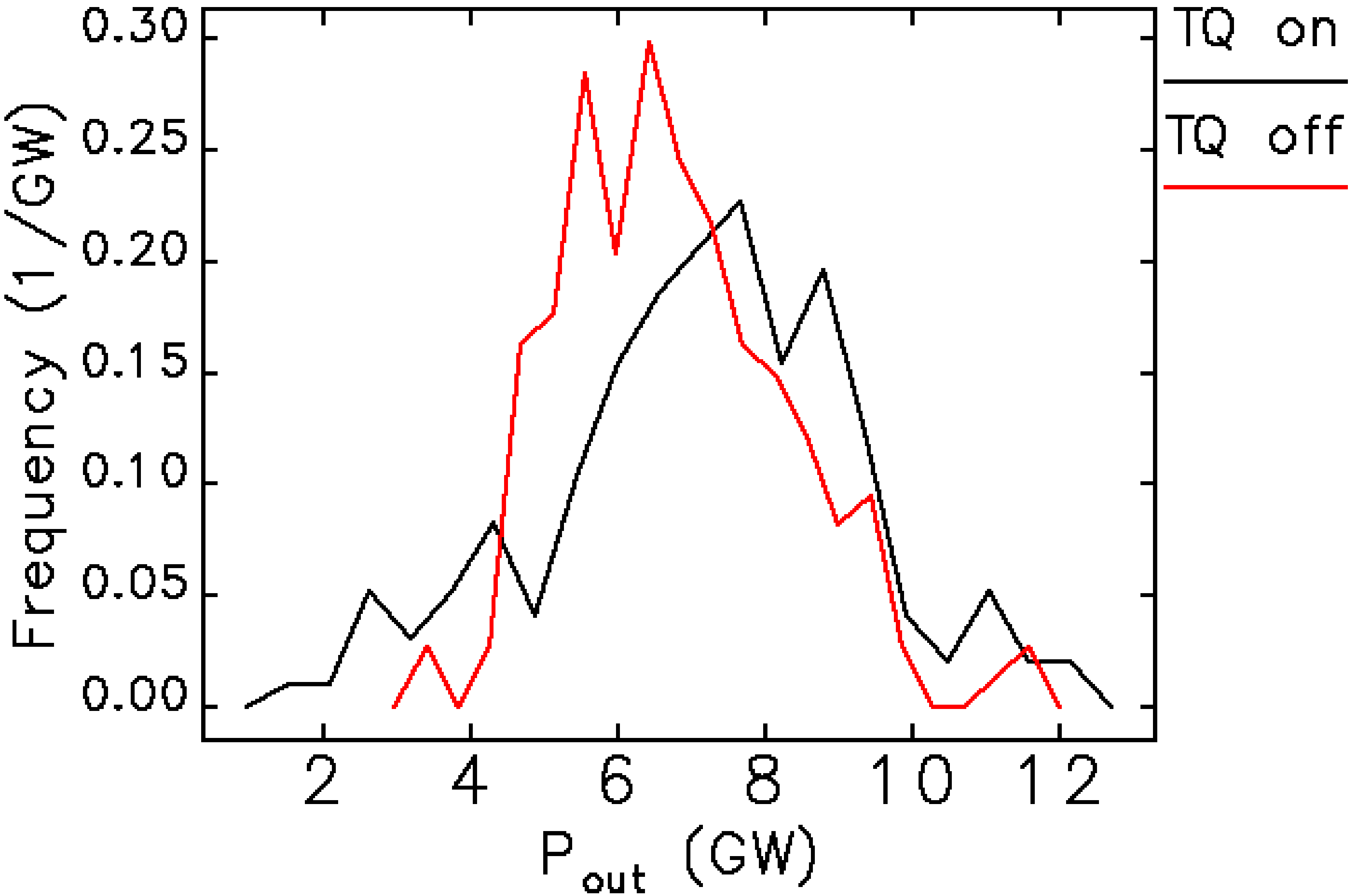
scripts: M. Borland

Results of Jitter Simulations

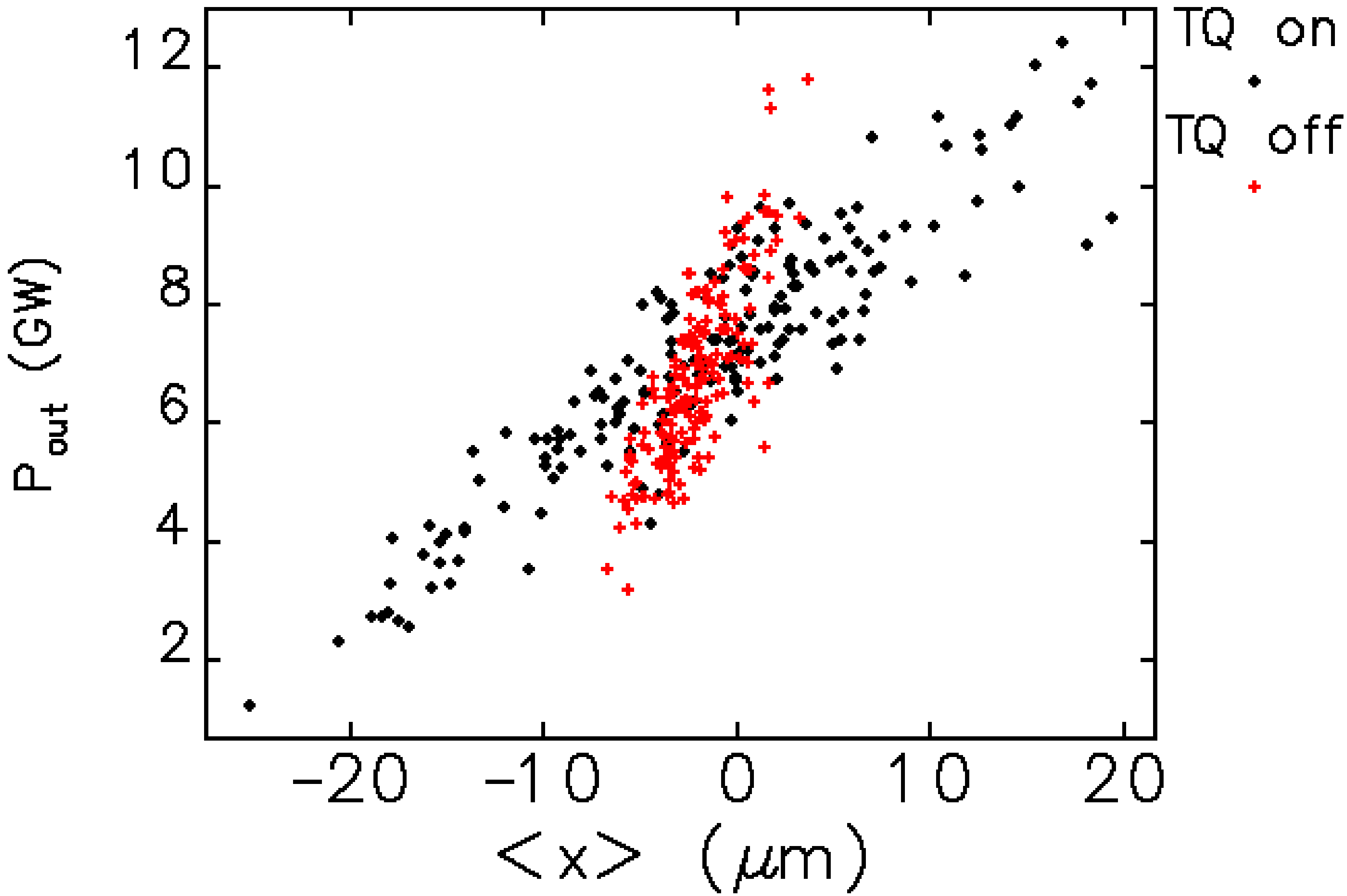
Tweaker Quads	*Current (kA)*	*Bunch length (ps)*	*Frac. mom. spread (10^{-4})*	*Norm. x emit. (μm)*	*Gain length (m)*	*Wavelength (A)*	*Output power (GW)*
on	3.32 ±0.18	0.185 ±0.013	0.819 ±0.040	0.793 ±0.012	3.44 ±0.16	1.4991 ±0.0013	7.33 ±1.35
off	3.28 ±0.17	0.188 ±0.014	0.814 ±0.031	0.792 ±0.012	3.53 ±0.14	1.4987 ±0.0012	6.60 ±1.00

- Values are medians.
- Error bars give half the quartile range.
- 170 seeds used.

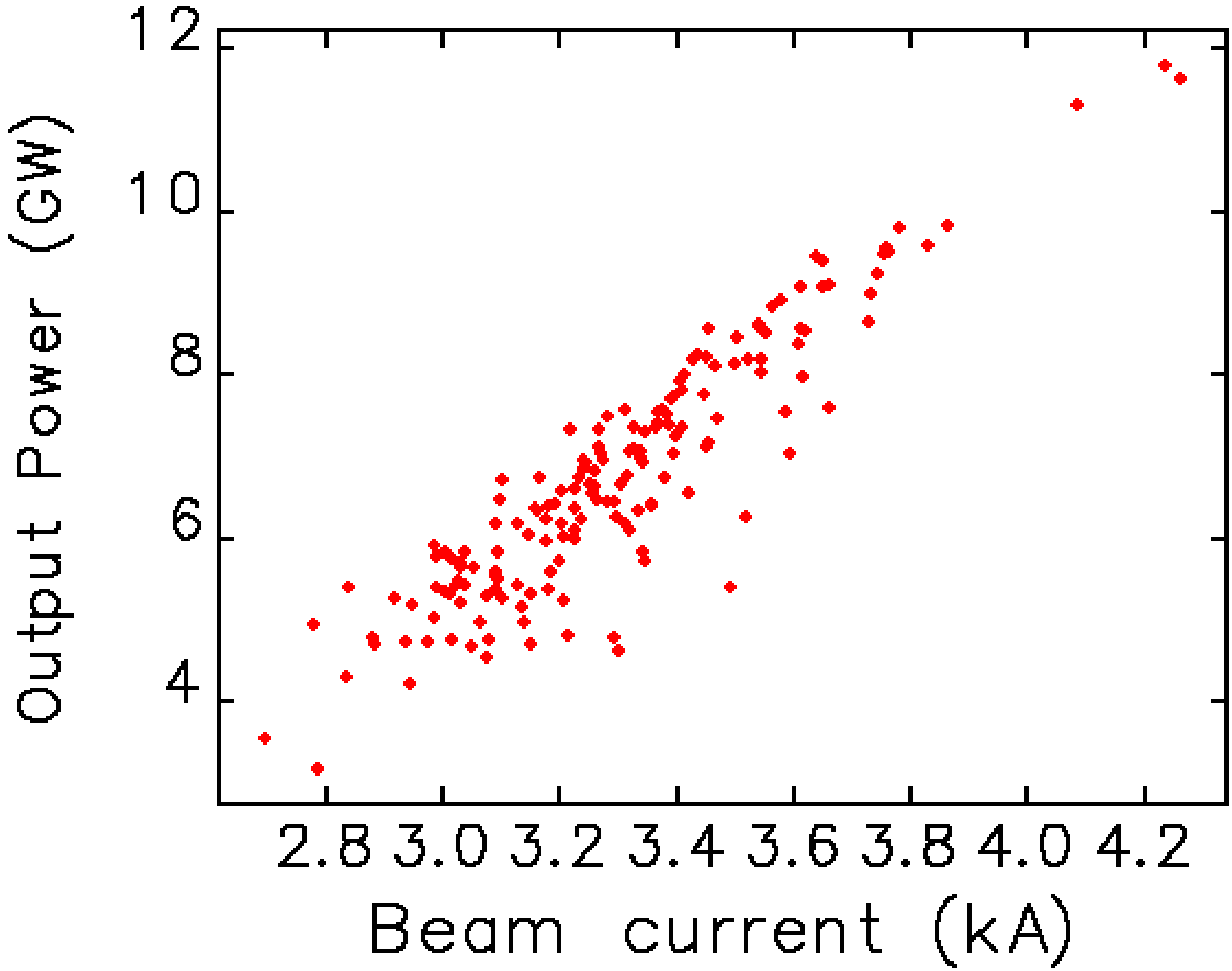
Results of Jitter Simulations



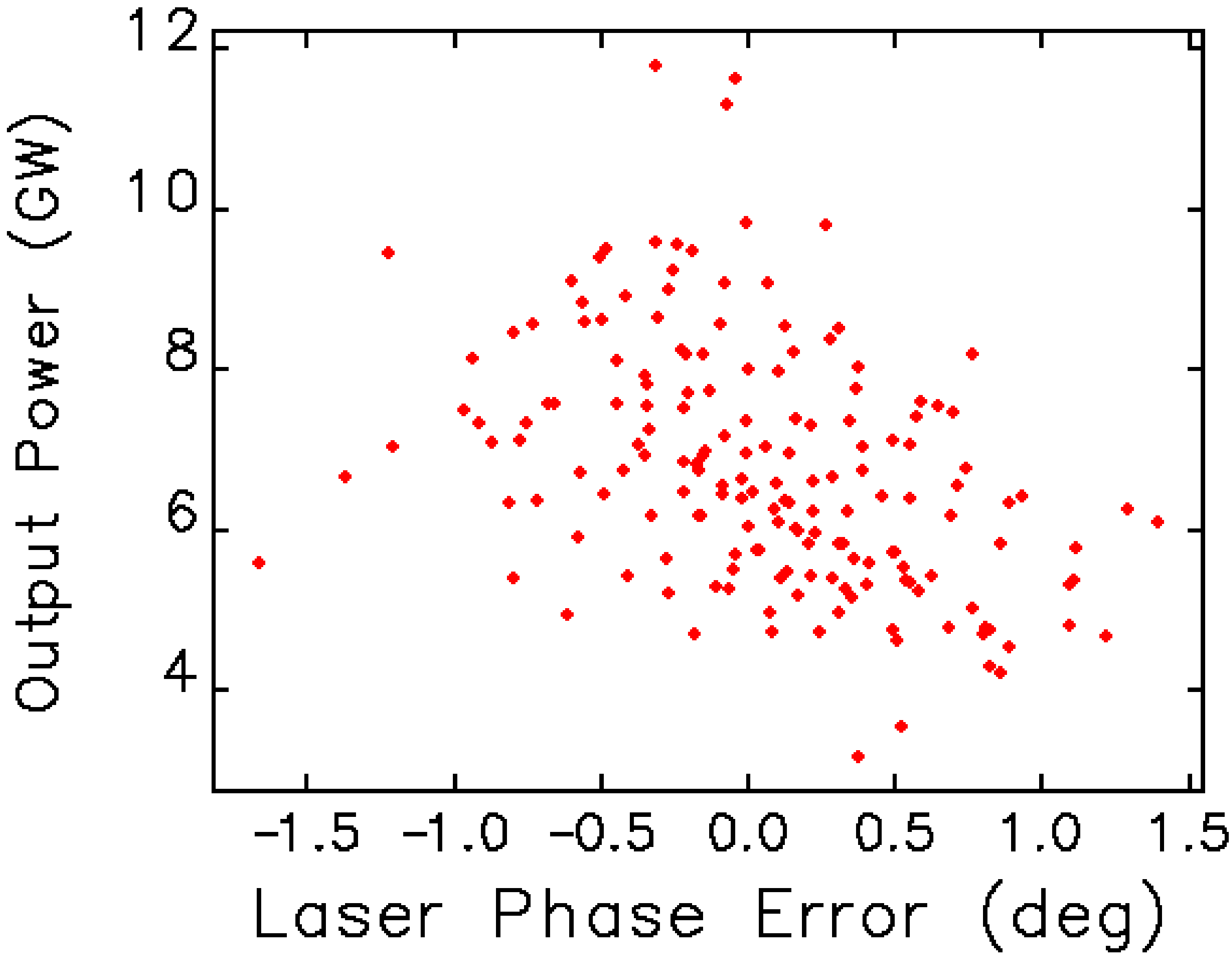
Results of Jitter Simulations



Results of Jitter Simulations



Jitter Correlation Plots



Correlation Analysis

- Computing correlation coefficients allows determining root causes of power variation

Quantity	***Responsibility (%)***
laser phase	22%
L1 phase	19%

- and wavelength variation

Quantity	***Responsibility (%)***
laser phase	17%
L1 phase	17%
L0 voltage	16%
L1 voltage	15%

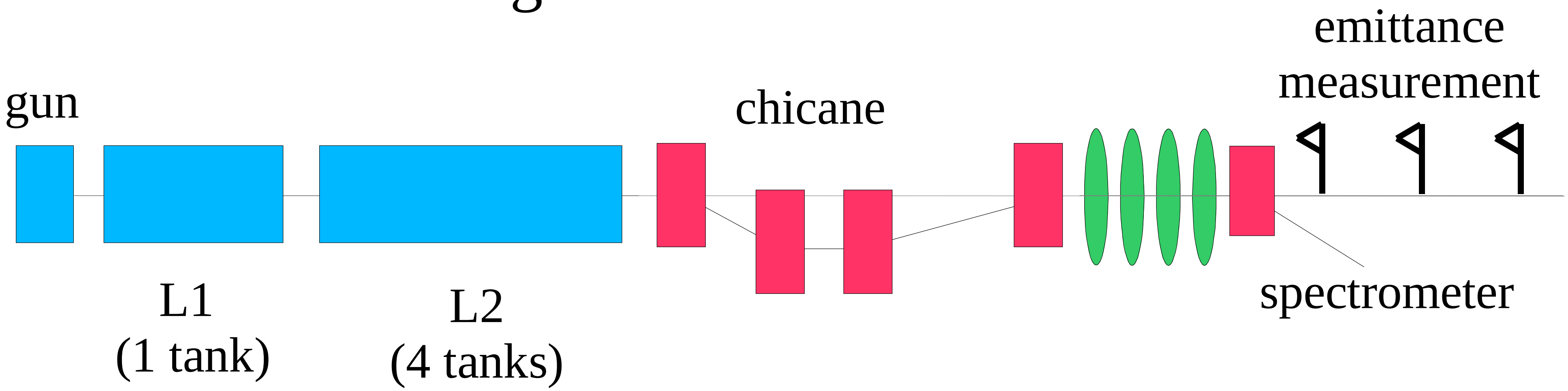
- "Responsibility" is the correlation coefficient squared.

Possibilities for Continuation of S2E

- Add a drive laser model
  - realistic spatial/temporal profiles
  - pulse−to−pulse profile jitter
  - pointing jitter
- Include simulation of "static" errors
  - cathode nonuniformity
  - misalignments and drifts, with correction
- Adopt a UNIX photoinjector code (ASTRA?) to make photoinjector simulations faster and easier

APS Bunch Compressor

- APS bunch compressor provides opportunity for benchmarking CSR codes

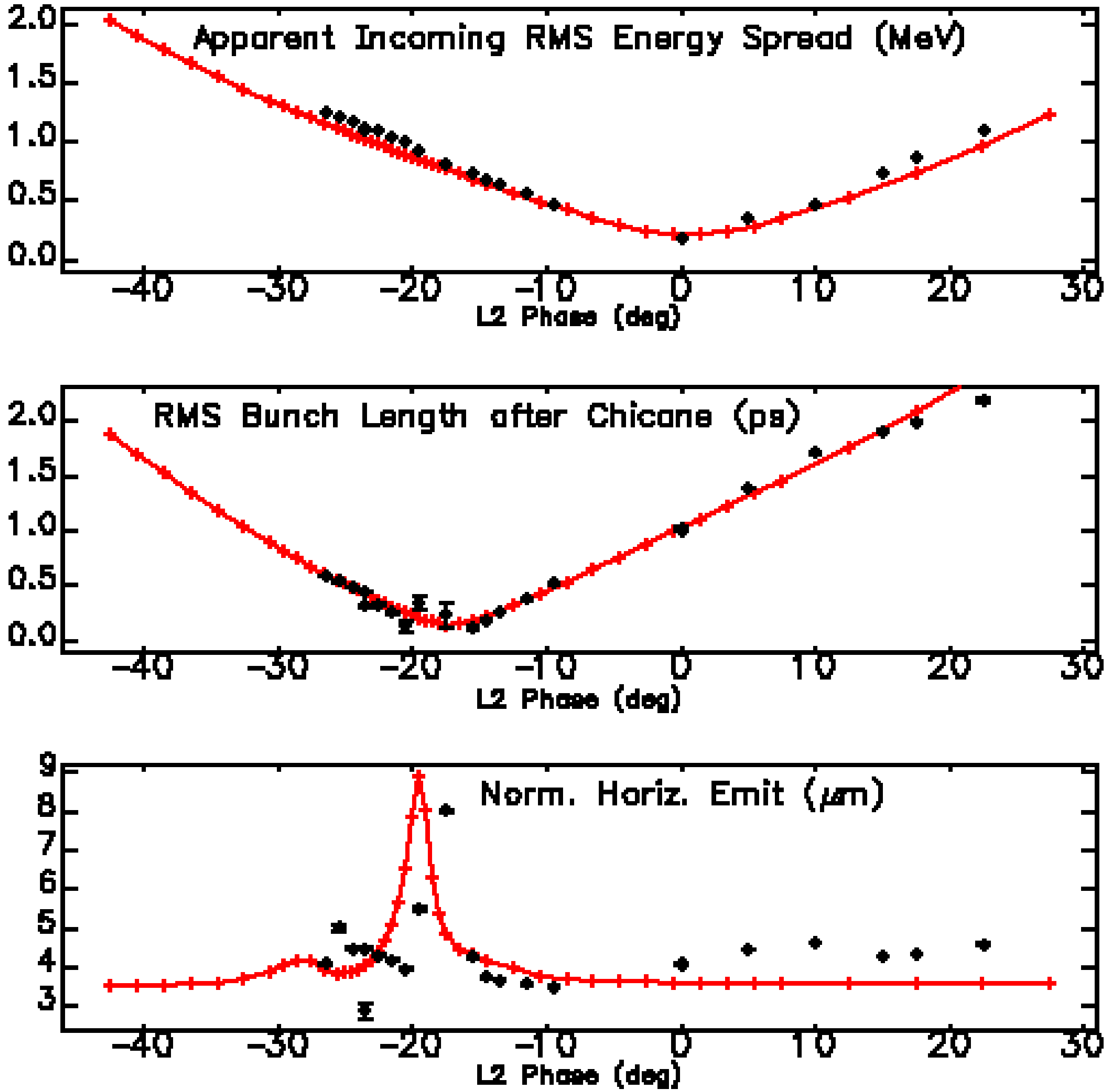


- Experimental time severely limited by use of injector for top−up and LEUTL

APS Bunch Compressor Experiment

- Vary L2 phase to vary energy chirp. Measure
  - emittance
  - energy spread at chicane center
  - bunch length
- Compare emittance with simulation using linearly-transformed PARMELA phase space data that matches
  - nominal emittance
  - bunch length and energy spread curves

Experimental Results



Fit

Fit

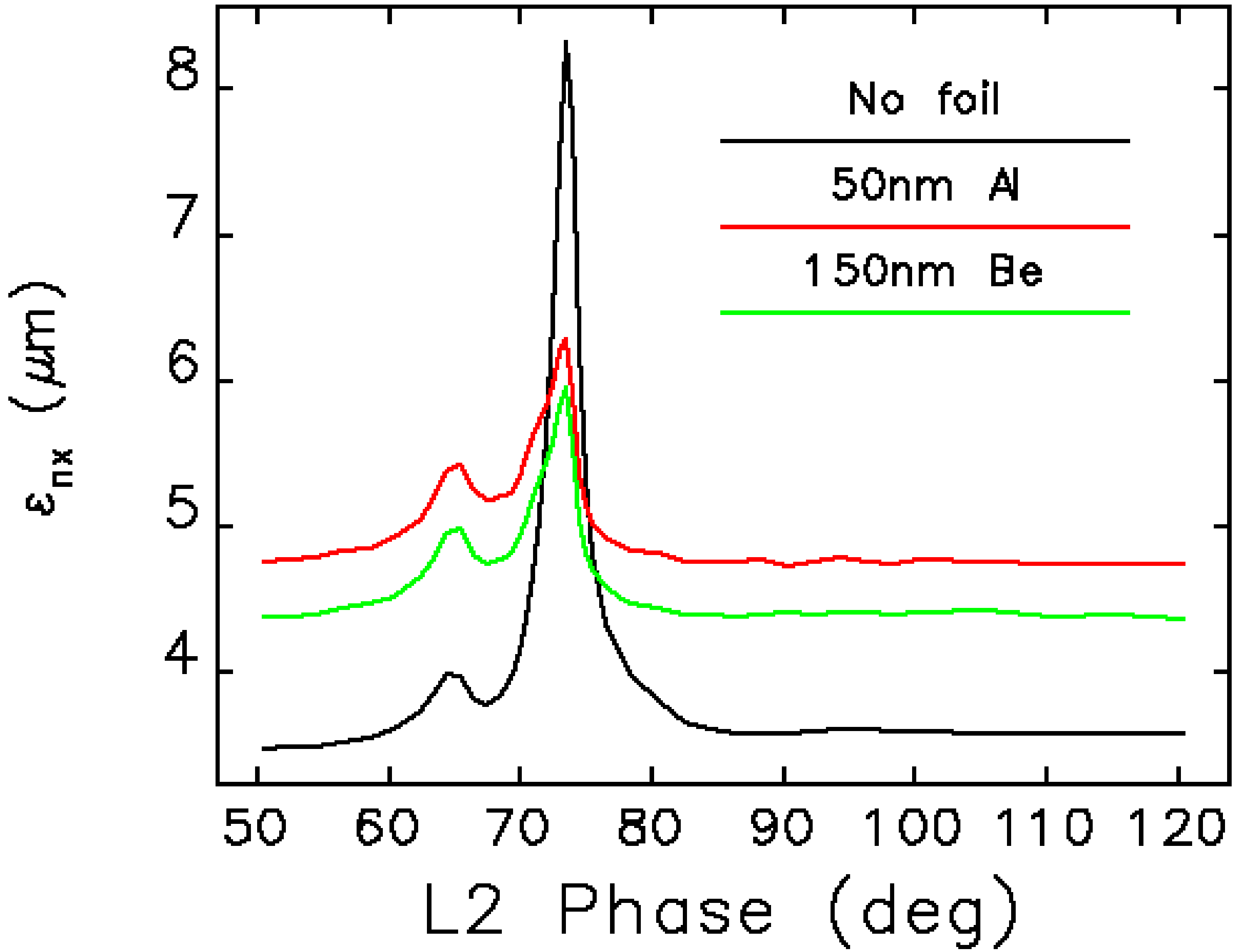
Suppressing CSR with Ultrathin Foils

- CSR in drifts is a major source of emittance degradation.
- An ultrathin metal foil at the dipole exit should block this radiation.
- APS has purchased a 50nm Al foil and a 150nm Be foil to test the concept.
- Cost of foils is negligible.

Simulation of Ultrathin Foils

- Just assume that all the radiation is blocked.
- Simulate "plural scattering" fairly rigorously
- Simulate energy straggling with a very conservative upper bound $(\Delta E)_{rms}=0.5*(\Delta E)_{ave}$
- *No* simulation of wakefield effects due to foils.

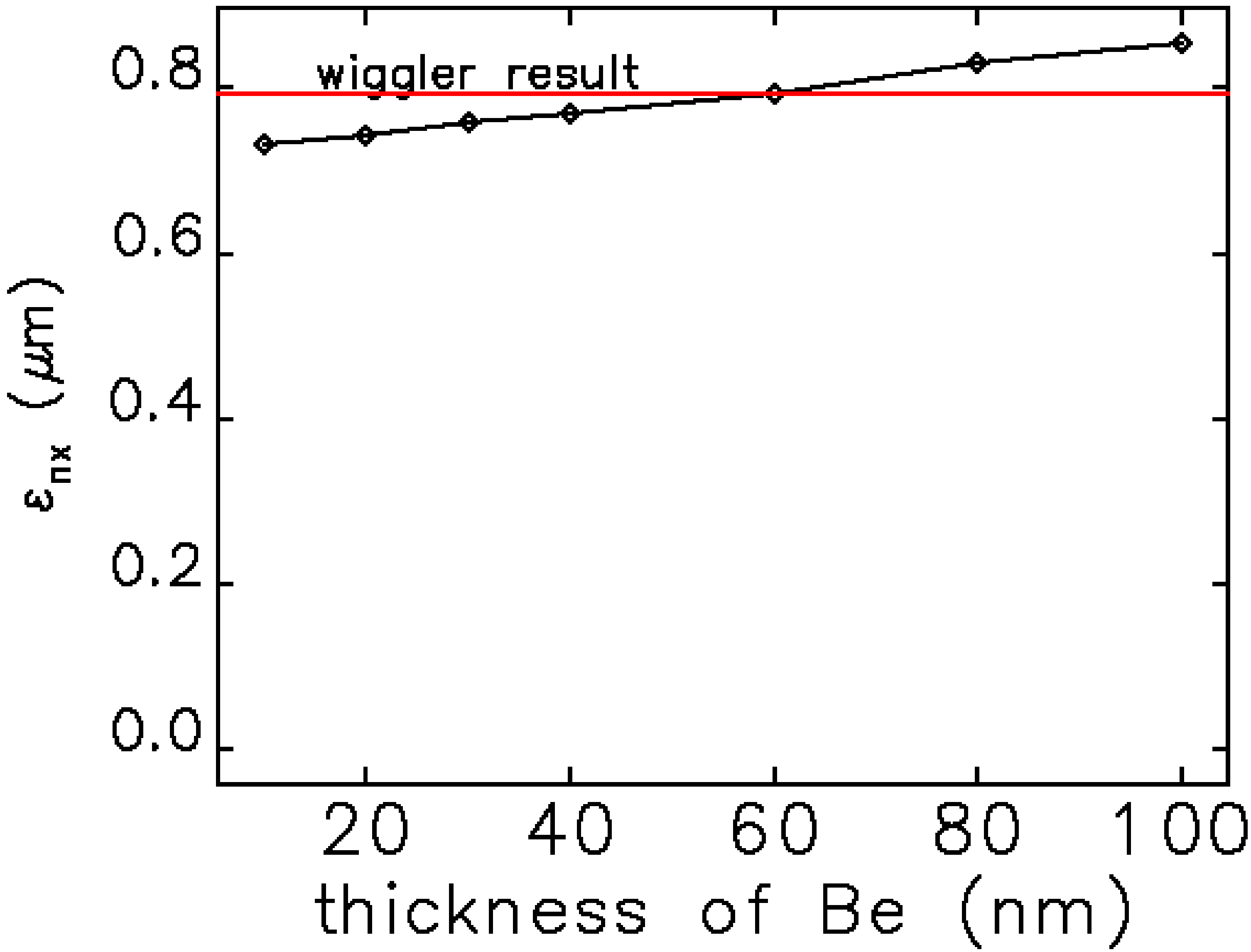
Predicted Foil Effects for APS Bunch Compressor



Foil Simulations for LCLS

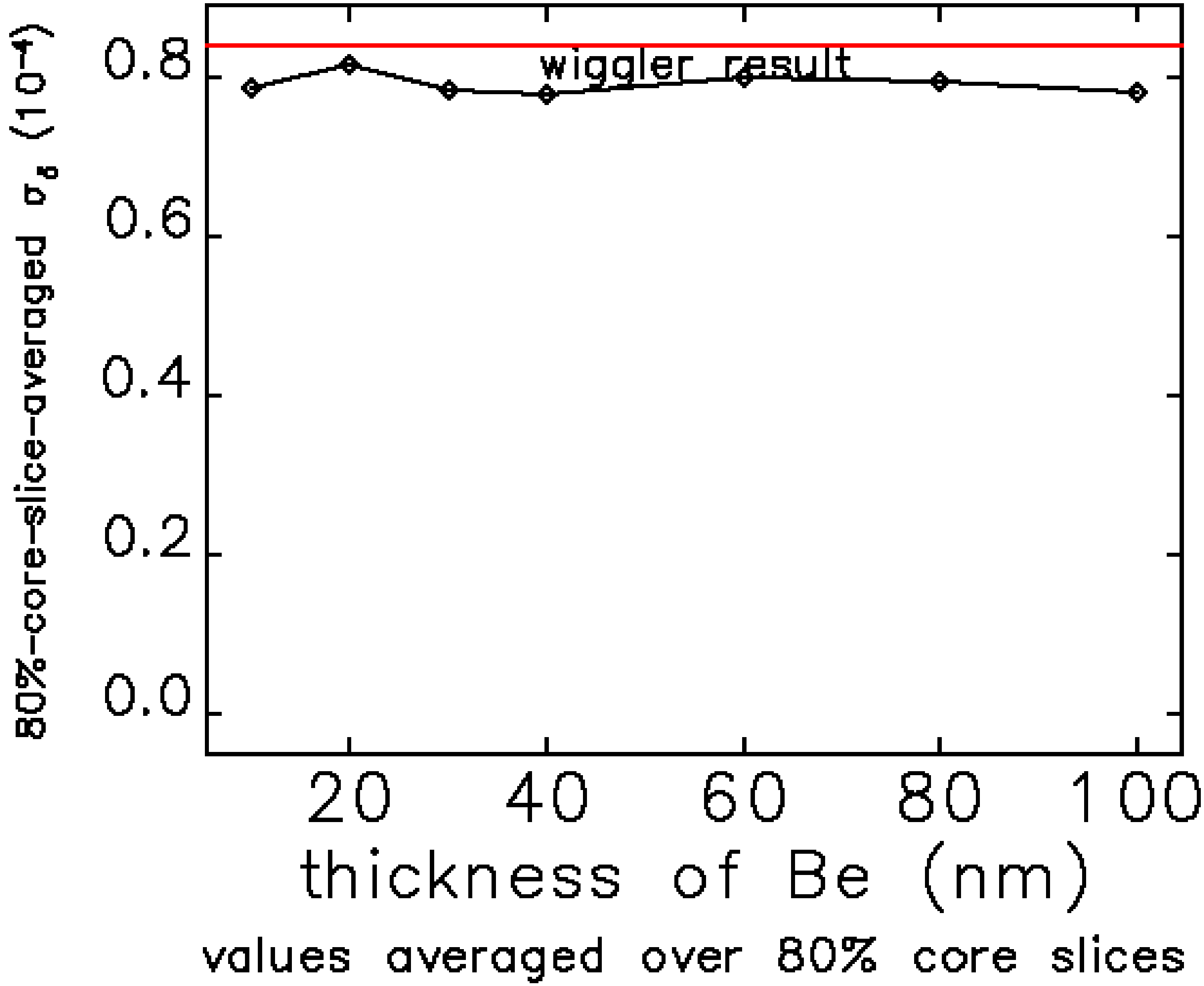
- Place Be foils at exit of all dipoles where beam is short:
  - exit of third and fourth dipole in BC2
  - exit of all dipoles in DL2
- Power density for a 100nm Be foil is 0.3 W/mm^2 for 1nC beam at 120 Hz
- Wiggler is modeled as a first−order optical element for these simulations

Predicted Foil Effects for LCLS

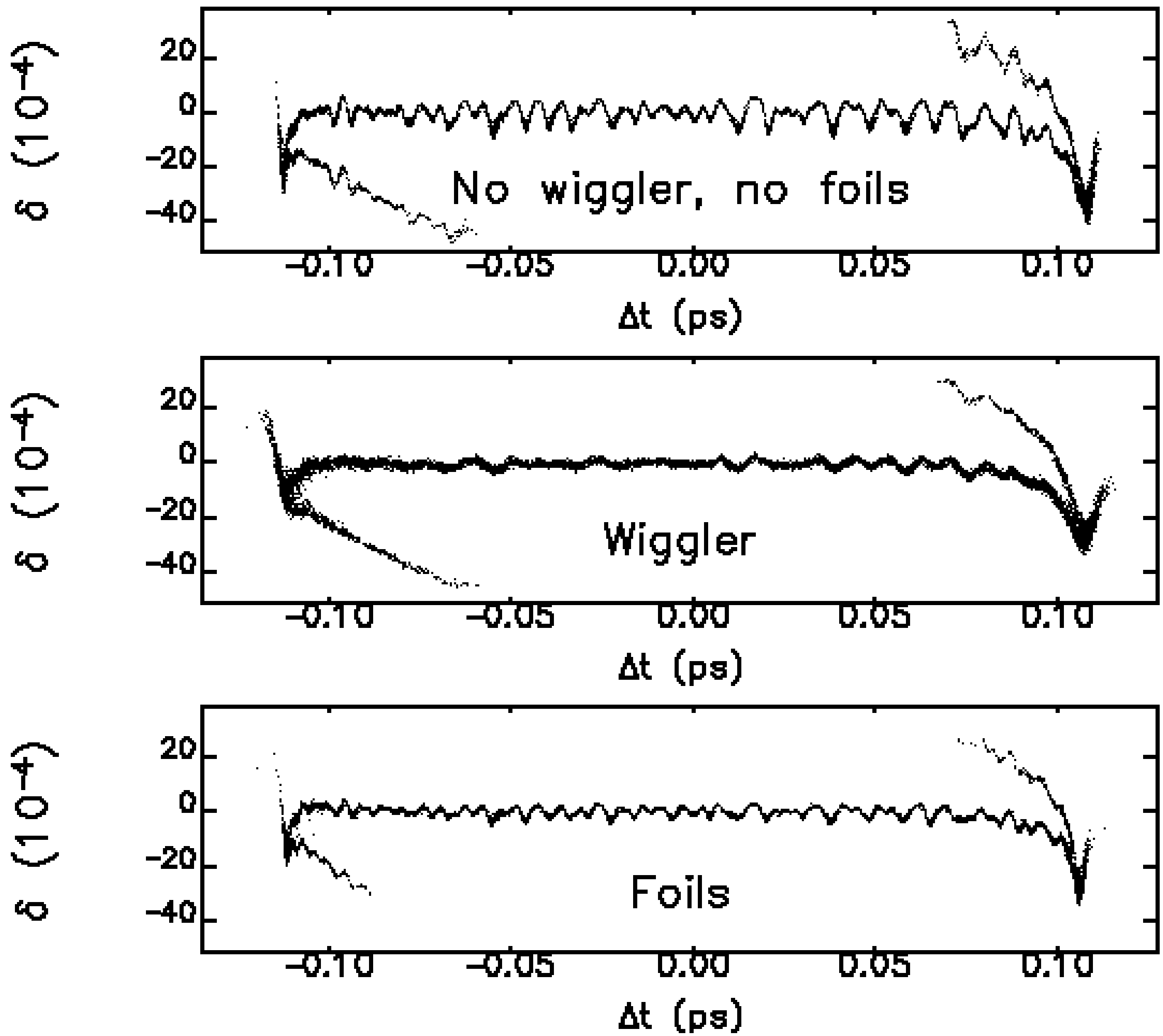


values averaged over 80% core slices

Predicted Foil Effects for LCLS



Comparison of Foils and Wiggler



Update on Start−to−End Jitter Simulations

M. Borland
Operations Analysis Group
Argonne National Laboratory