LCLS Start-to-End Simulations

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Outline

- Approach and goal of our start-to-end (S2E) simulations.
- Overview of LCLS S2E simulations.
- Impact of CSR instability.
- Jitter simulation.

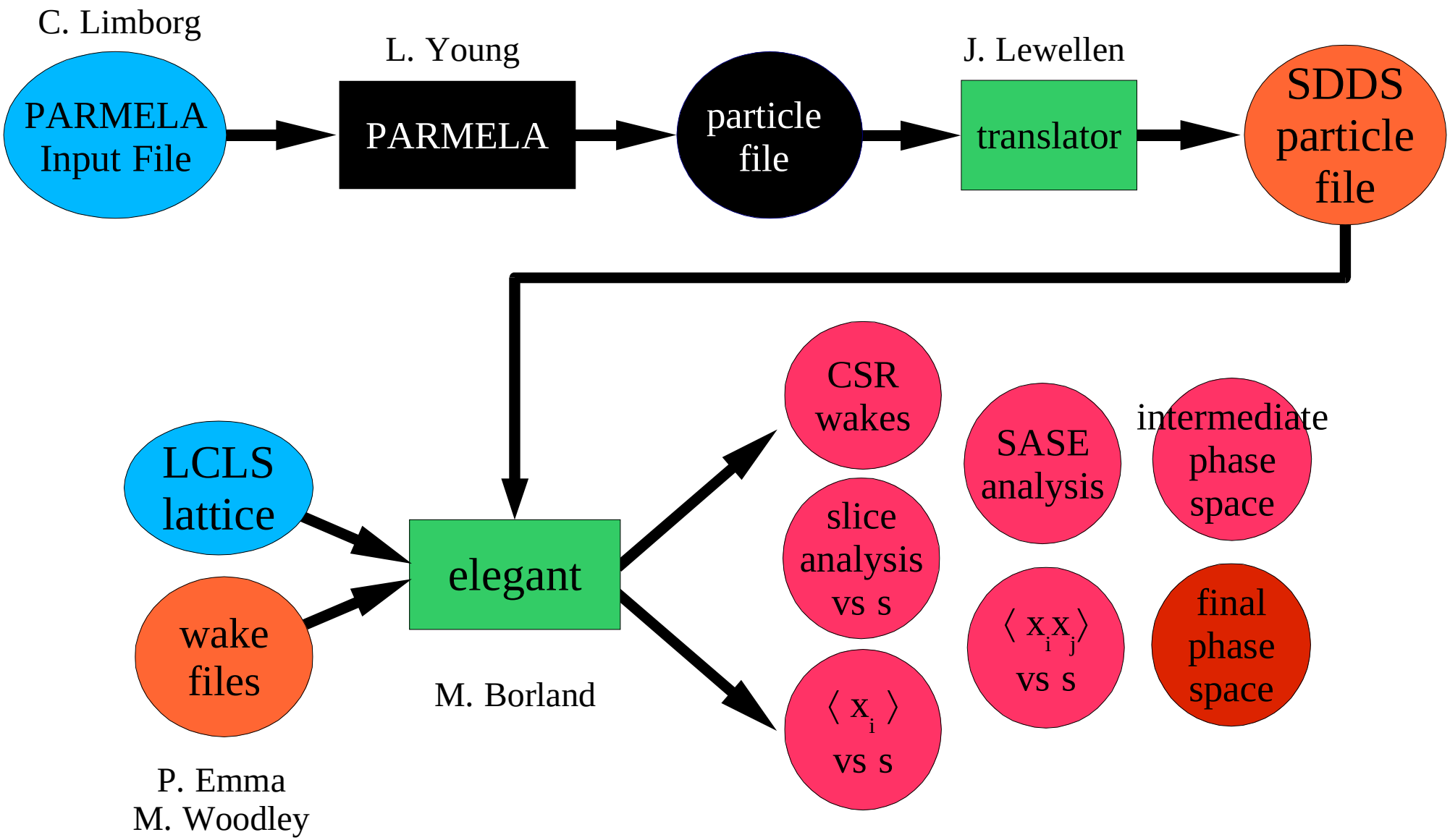
Approach and Goals

- Don't try to develop a single, all-encompassing code.
- Do standardize file formats to allow easily using data from many codes together.
- Try to employ at least two codes for each subsystem (e.g., photoinjector, linac, FEL)

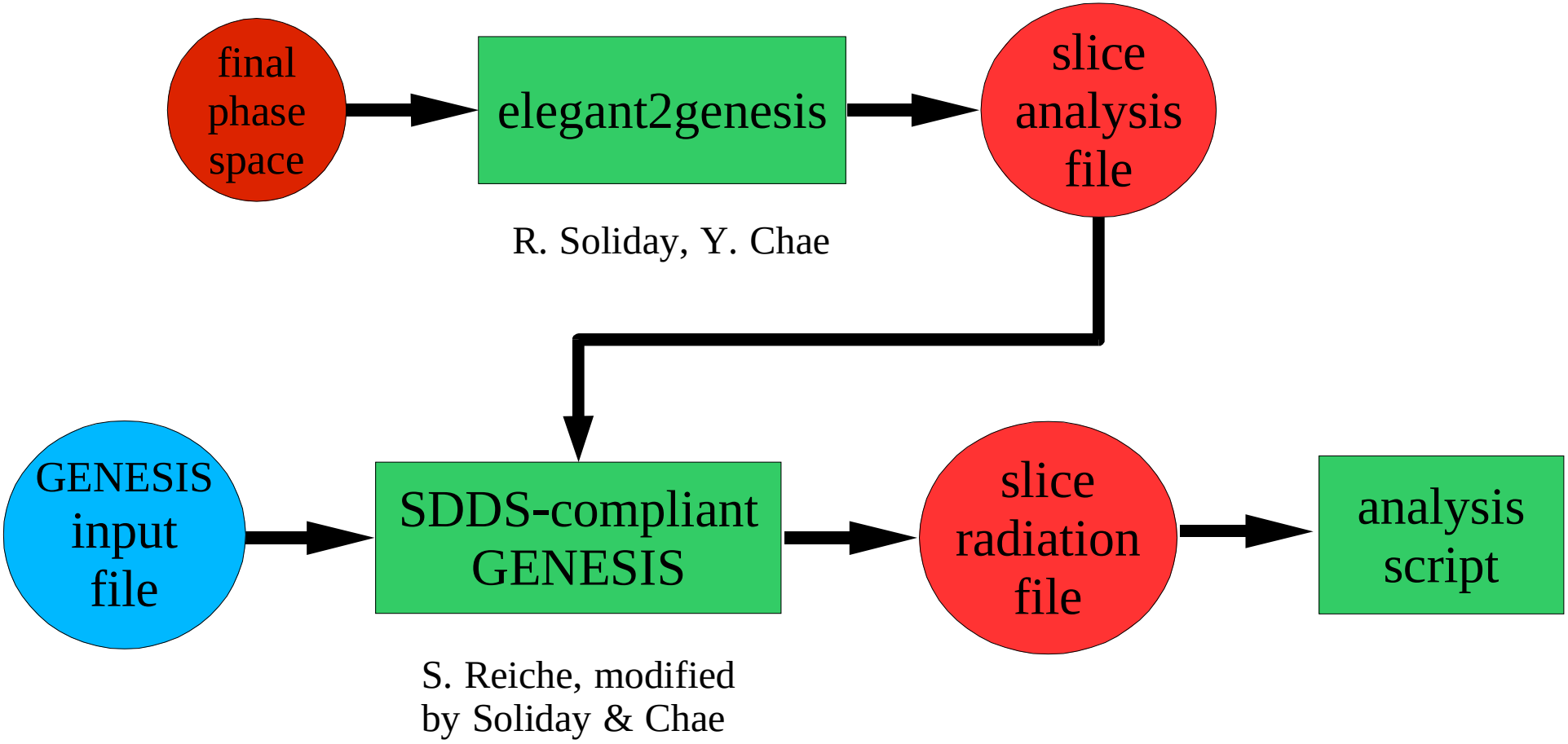
LCLS S2E Overview

- 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
- Use Self-Describing Data Sets (SDDS) for data exchange among codes

LCLS S2E Diagram



LCLS S2E Diagram

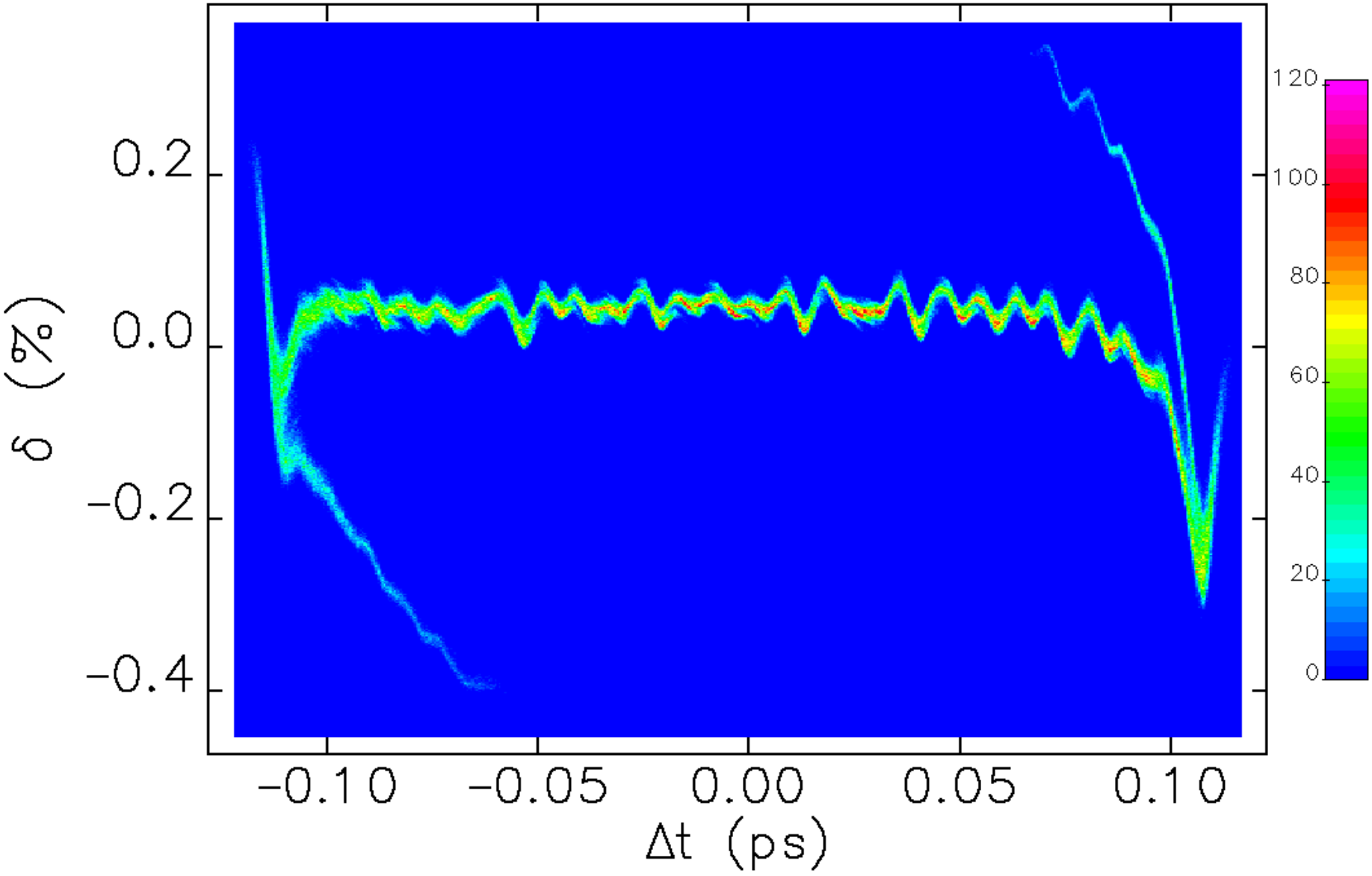


New Features of S2E Simulations

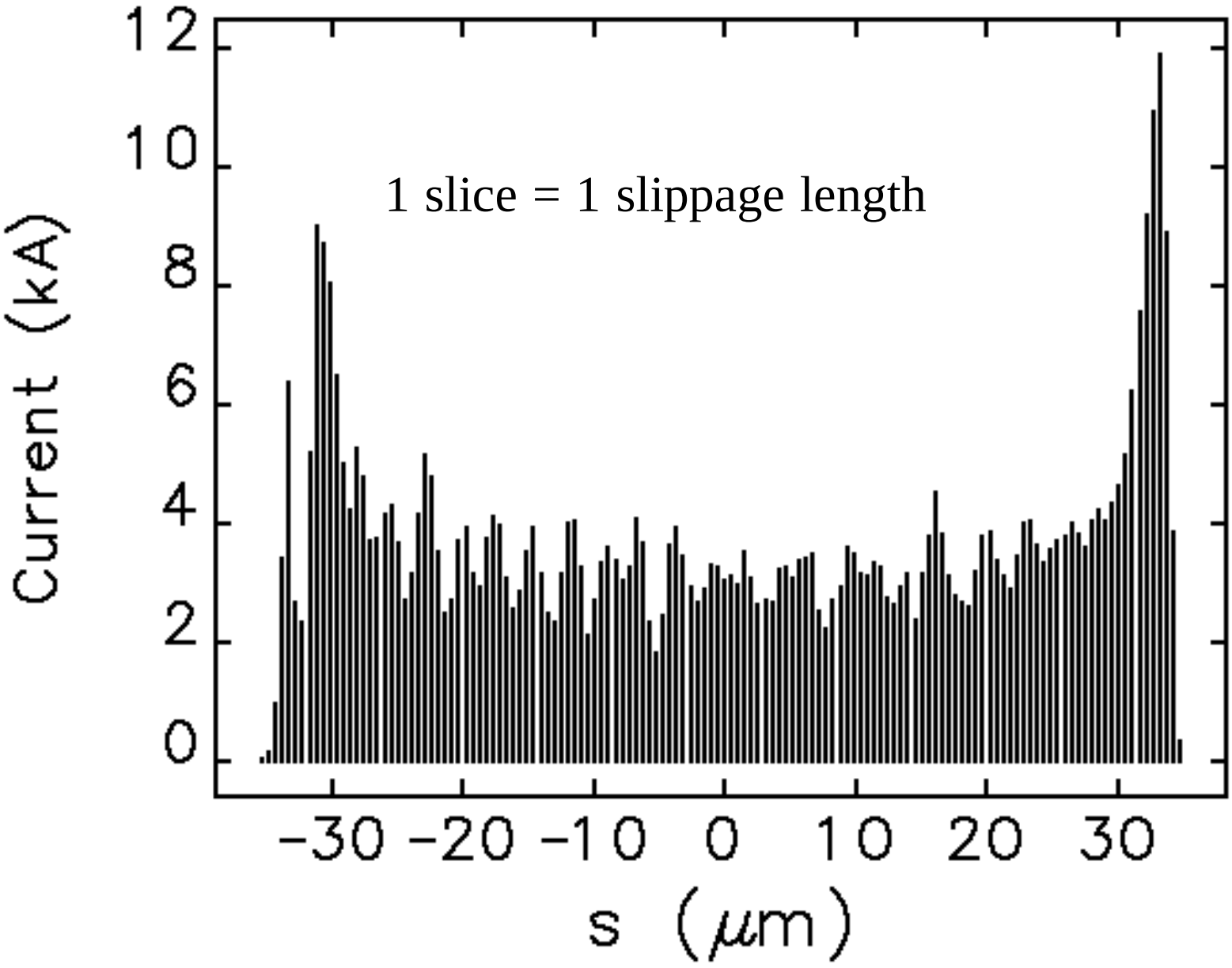
Since PAC2001 many improvements were made:

- Jitter simulation starts with the photoinjector
- Use Stupakov's formulae for CSR in drifts
- Simulation of emittance correction with "tweaker" quads
- CSR instability is properly reflected in FEL simulations
- New LCLS lattice is less affected by CSR

Longitudinal Phase Space for Ideal Case



Slice Analysis for Ideal Case



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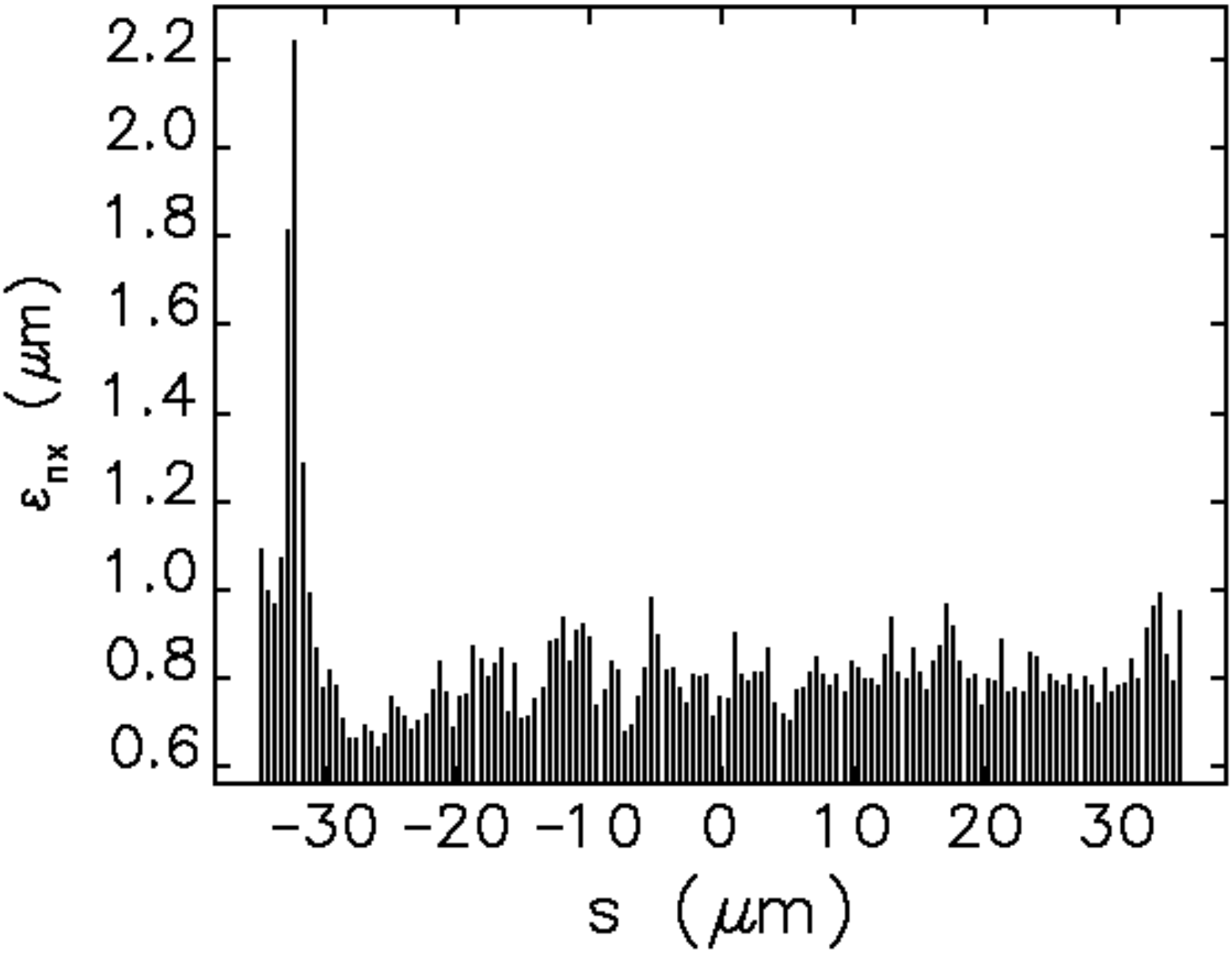

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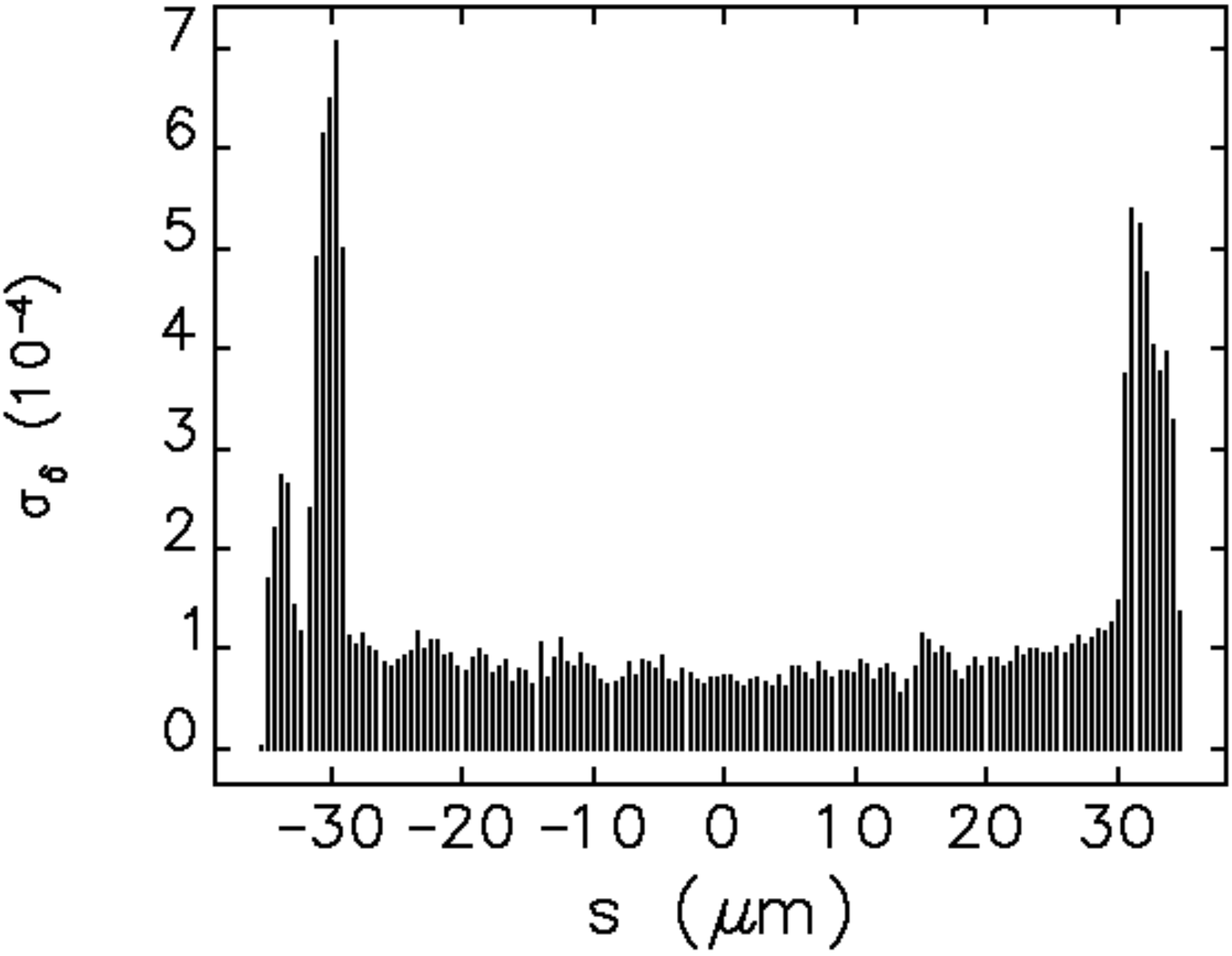
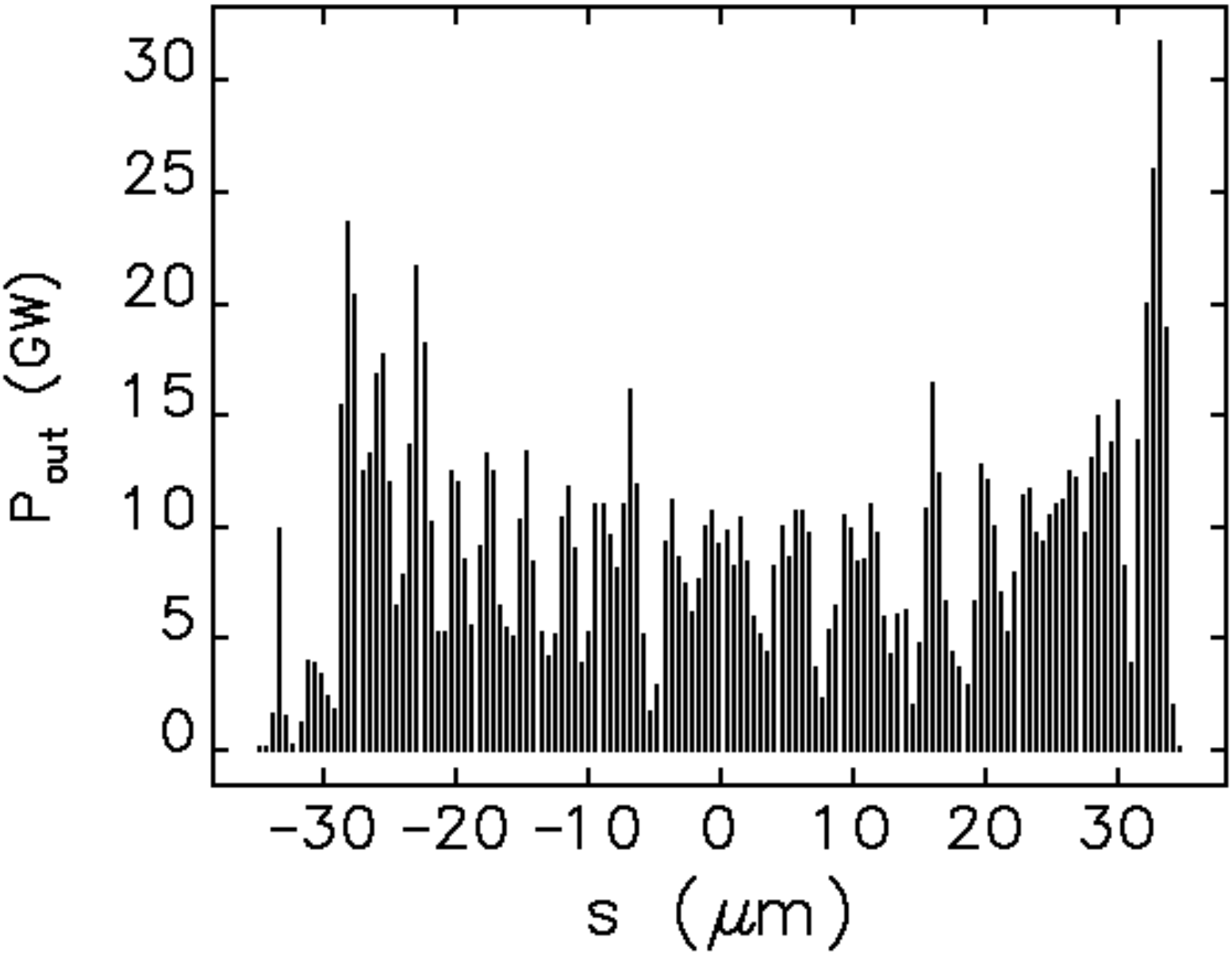
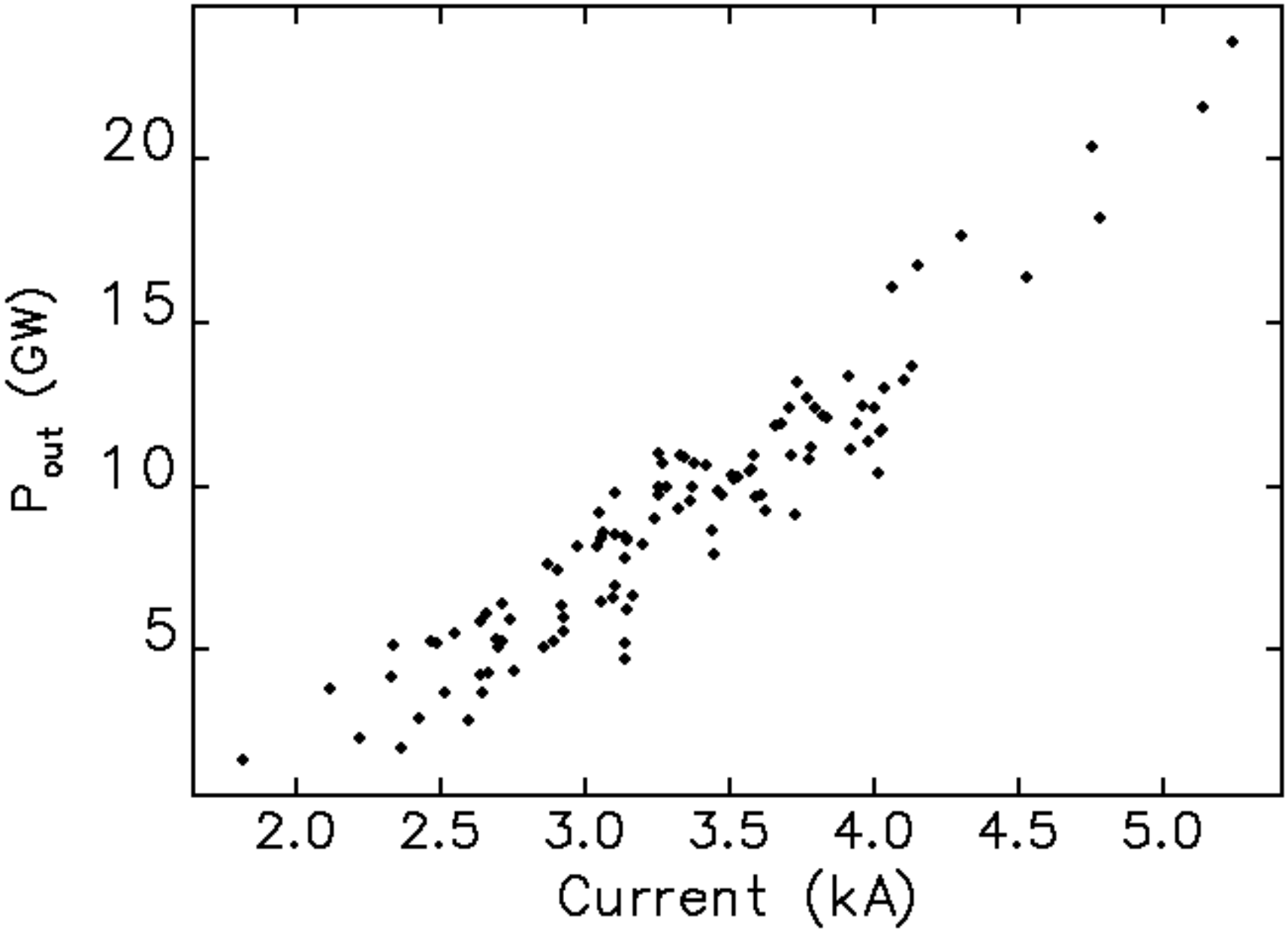


Slice Result for Ideal Case



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

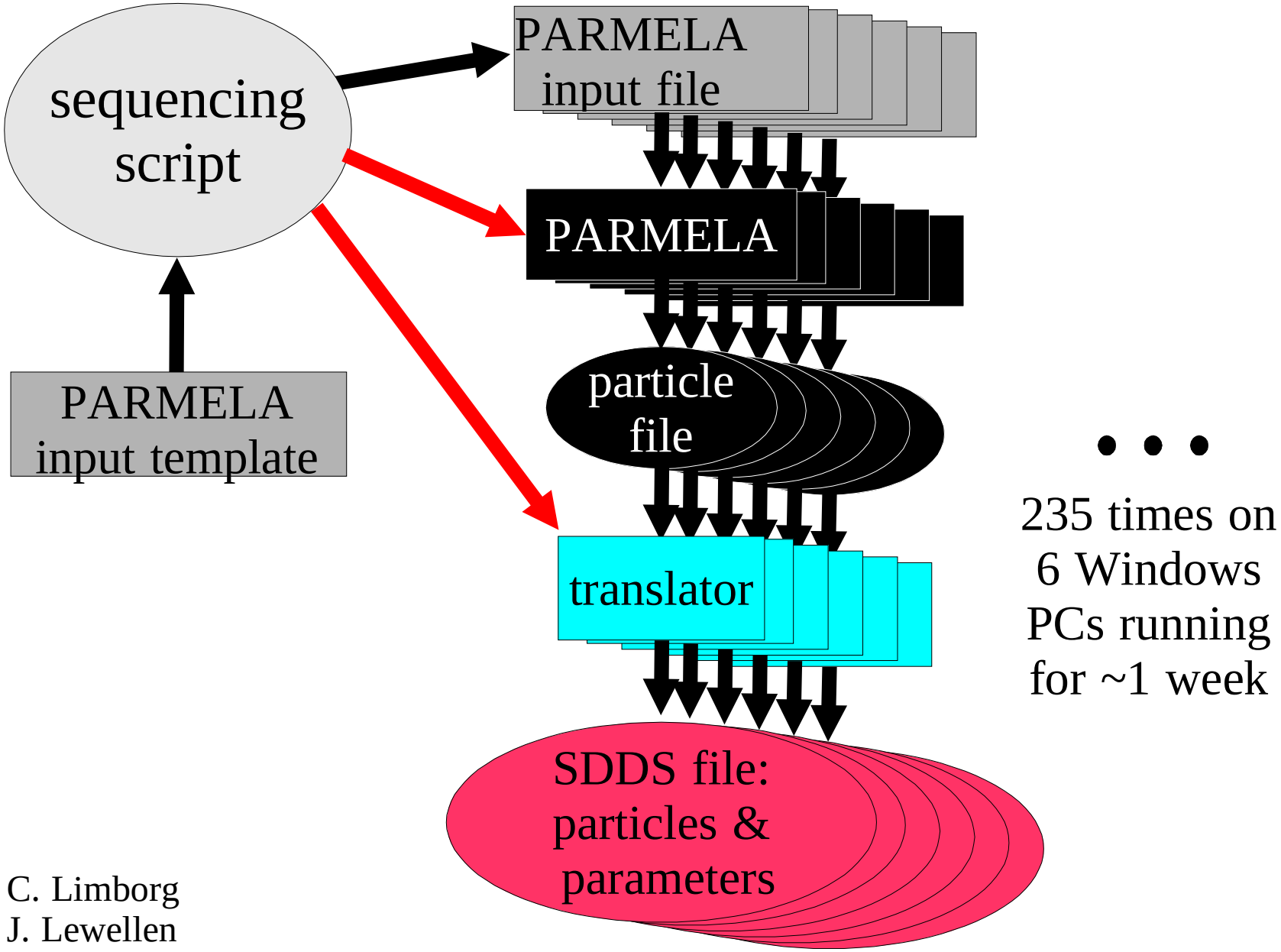
- "Jitter" refers to any error that we can't correct with alignment, tuning, feedback, etc.
- We simulated jitter, including
  - drive laser timing and energy
  - photoinjector and linac rf voltages and phases
  - bunch compressor power supplies
- We assume that the machine is tuned to ideal performance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

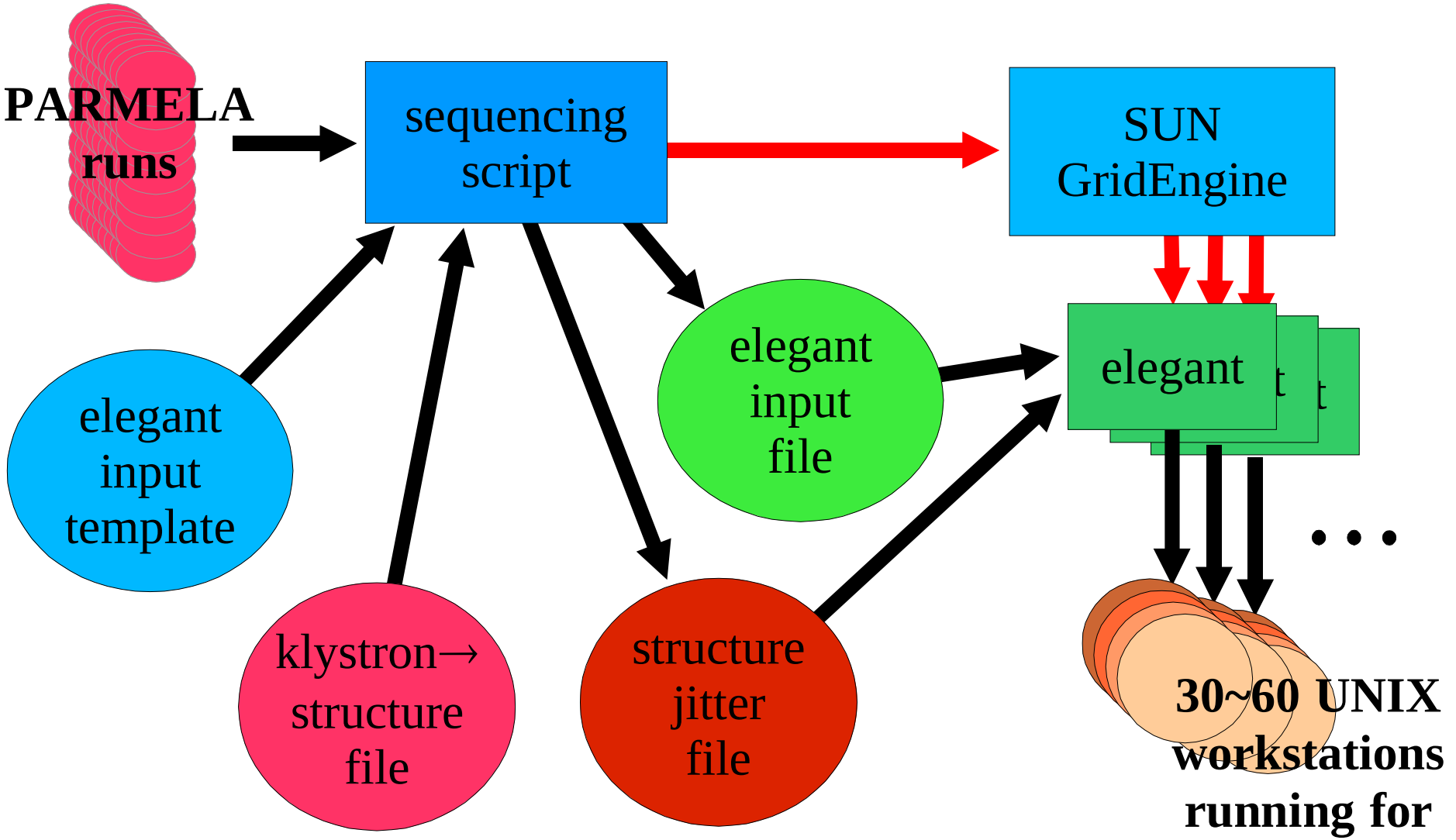
Quantity	*Rms Jitter Level*
L2 phases (28)	0.07 deg-S
L2 voltages (28)	0.07%
L3 phases (48)	0.07 deg-S
L3 voltages (48)	0.05%
BC1 dipoles	0.02%
BC2 dipoles	0.02%
DL dipoles	0.01%
Wiggler dipoles	0.02%
Tweaker quads (4)	0.1%

PARMELA Simulation Diagram



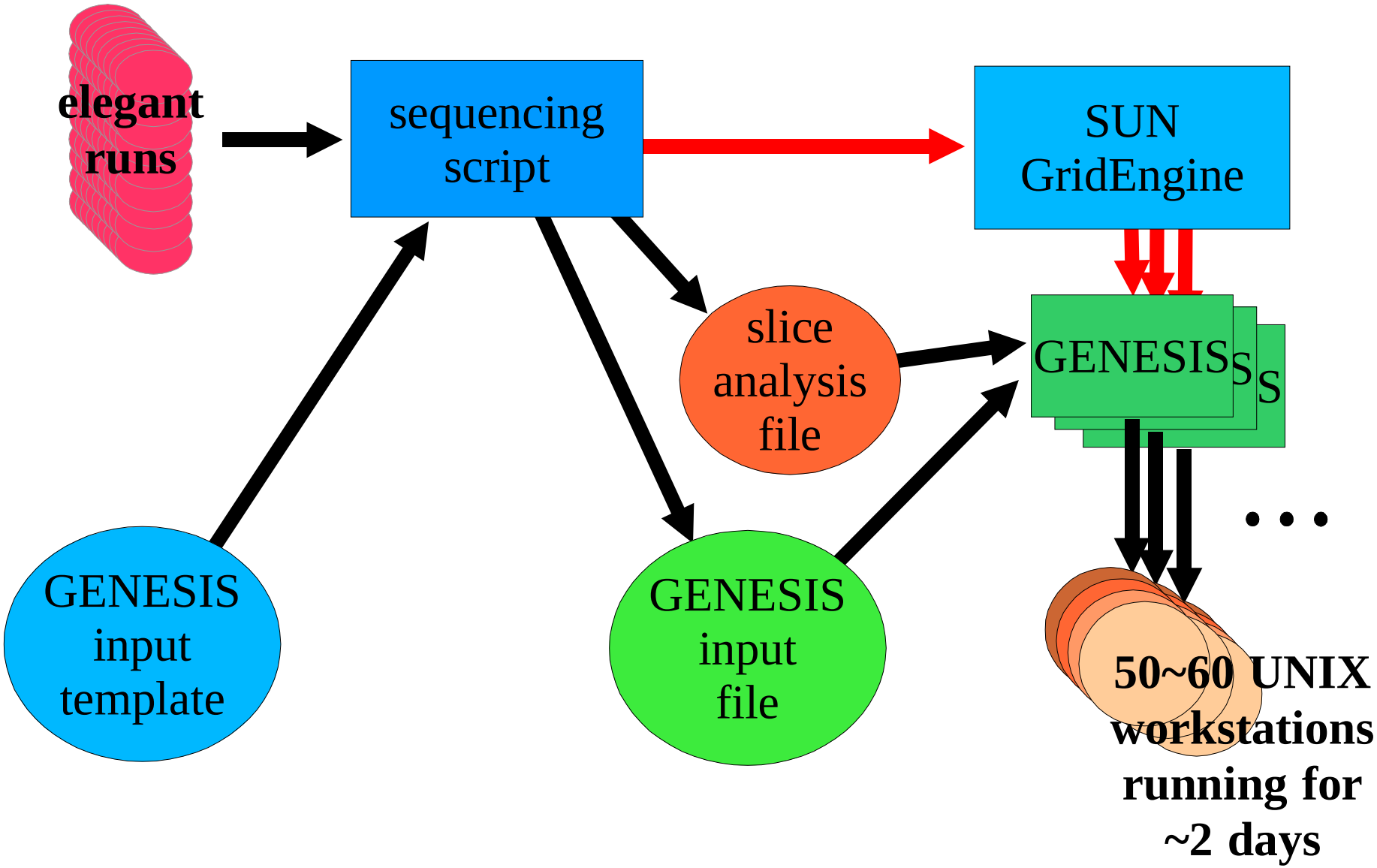
Lattice: C. Limborg
Scripts: J. Lewellen

elegant Simulation Diagram



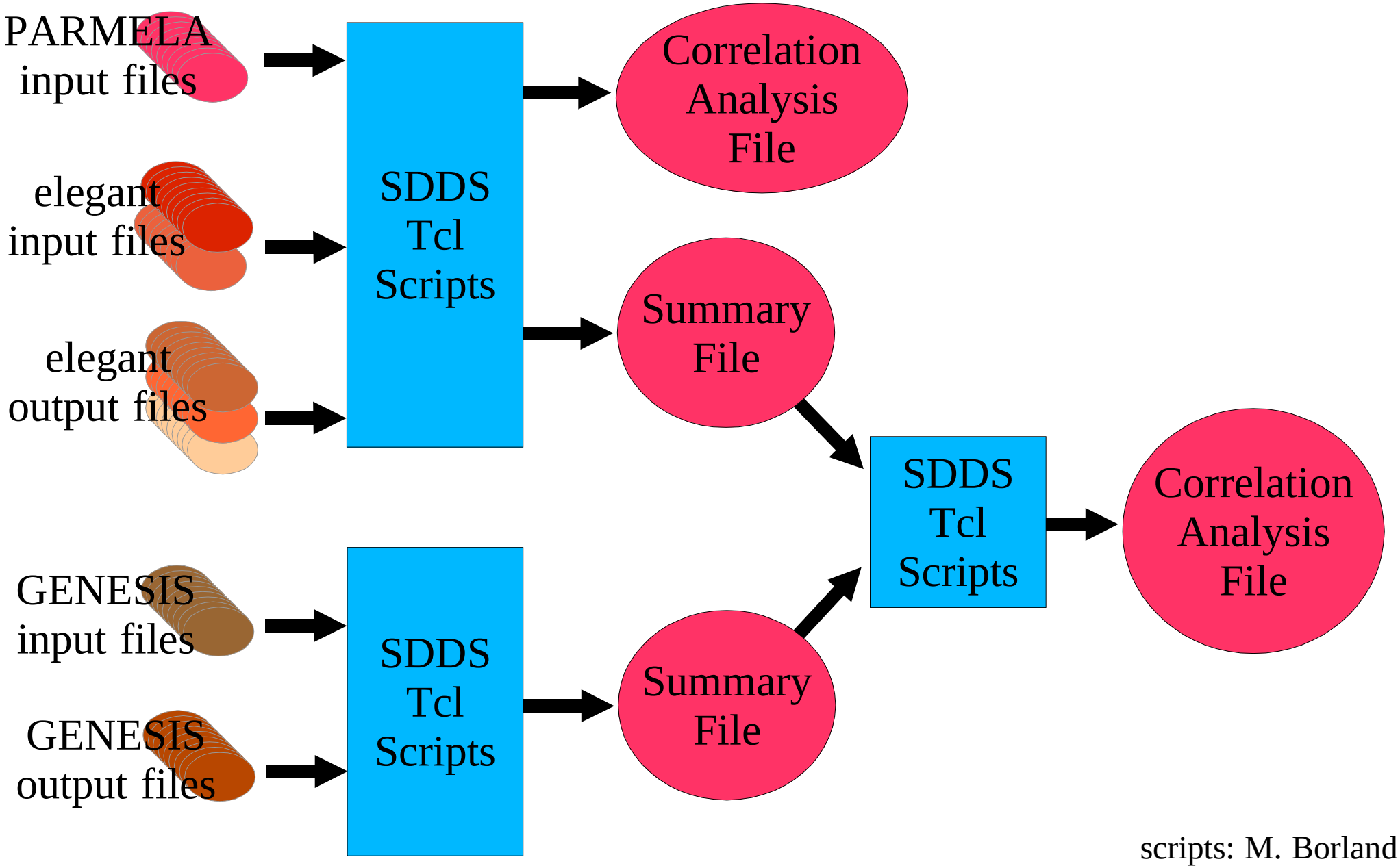
Lattice: P. Emma, M. Woodley
Scripts: M. Borland

GENESIS Simulation Diagram



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

Postprocessing Diagram



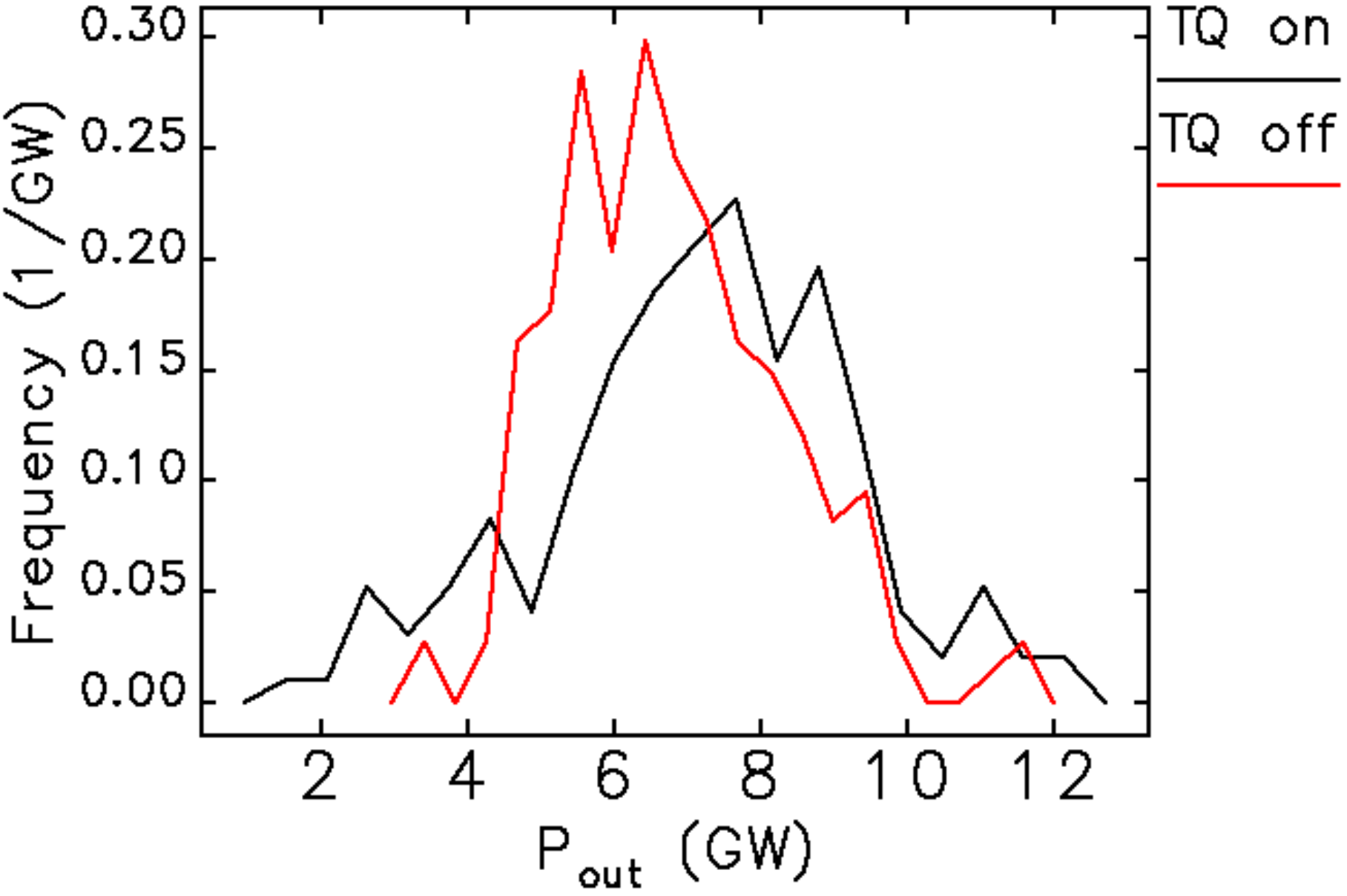
scripts: M. Borland

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



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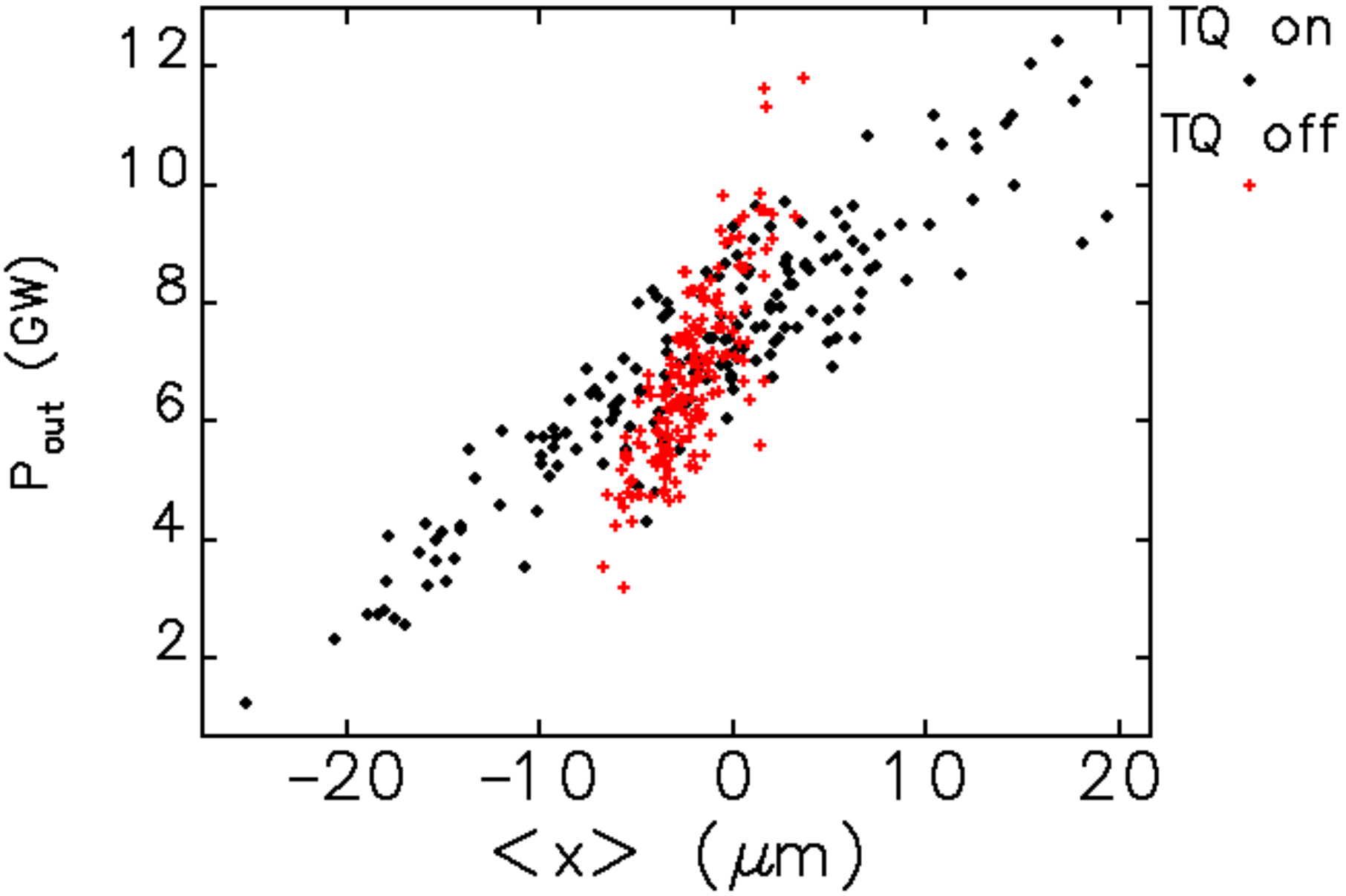

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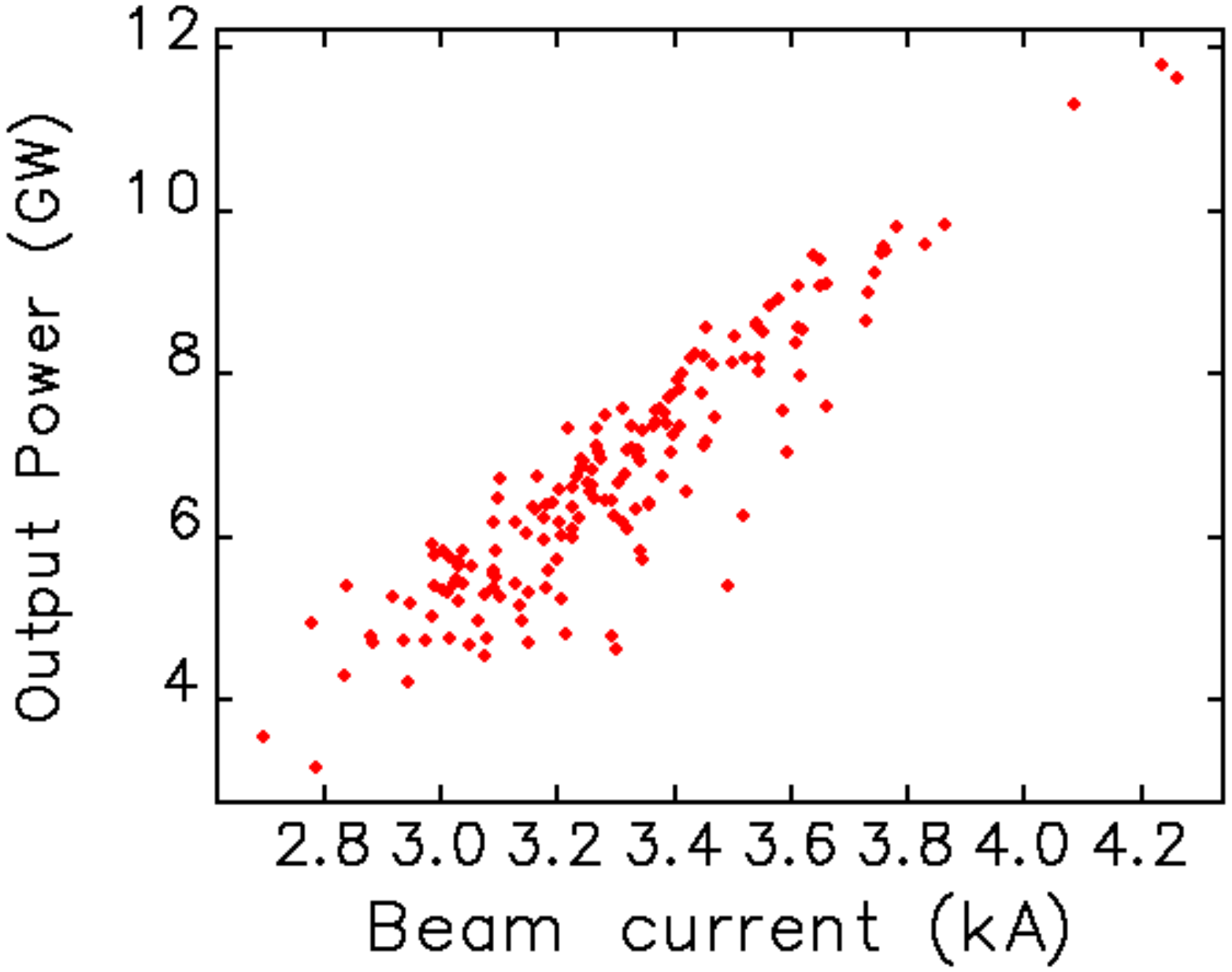
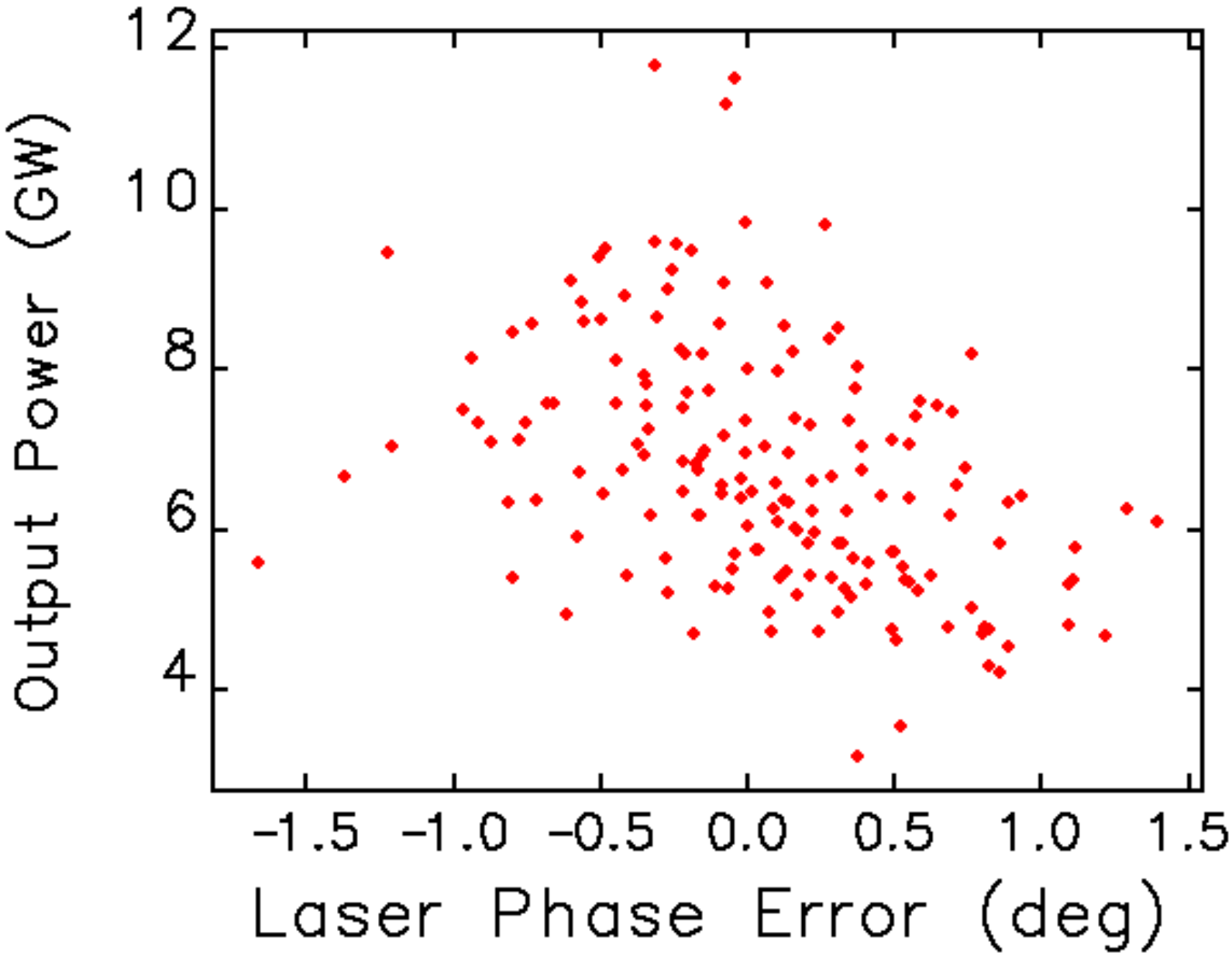


Jitter Correlation Plots



Correlation Analysis

- Correlation analysis may be used to determine the 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 and imperfections
  - cathode nonuniformity
  - misalignments and drifts, with correction
- Adopt a UNIX photoinjector code (e.g., ASTRA) to make simulations faster and easier