# Using elegant, SDDS, and DQS for High-Productivity Accelerator Design and Simulation

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# Acronym Dictionary

- **elegant**
  *ELEctron Generation ANd Tracking*
  An accelerator code developed (mostly) at APS and used for rings, transport lines, and linacs.

- SDDS
  *Self Describing Data Sets*
  An APS-developed file protocol and program toolkit used with **elegant** and other simulations.

- DQS
  *Distributed Queueing System*
  Free software that allows easily using multiple workstations as engines in a single batch queue.
  (See www.scri.fsu.edu/~pasko/dqs.html)

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# DQS at APS

- At APS, ~40 Sun workstations are in a DQS queue.
- DQS is load-sensitive.
- Several important projects have relied on 100's or 1000's of runs.
- DQS is easy to use and is used routinely.

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# Problems Using DQS

- How to prepare input for many jobs?
  - Problem for GUI-driven simulations.
- How to deal with the output from many jobs?
  - Simulation codes and postprocessors have a built-in one-run assumption.
  - Direct human-readable output doesn't work for 1000's of runs.
  - One prefers *not* to write a new postprocessing program for each project.

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# Making DQS Work

- Input preparation
  - Use file-driven programs.
  - Use “templates” and scripts to create individual input files.
- Output processing
  - Use SDDS files for output data.
  - Use generic, commandline SDDS toolkit for postprocessing.
  - Use scripts to remember/organize processing commands.

# SDDS Overview

- Used from 1994 for APS commissioning.
- Presently used by five accelerator labs for archiving and/or accelerator operations (APS, BESSY II, DESY, IPNS, RHIC).
- SDDS file protocol is relatively simple yet handles many types of data.
- The toolkit comprises ~90 programs
  - ~70 general-purpose data analysis and display programs
  - ~20 control system programs
- Runs on UNIX and Windows.
  Can be downloaded from our Web site.

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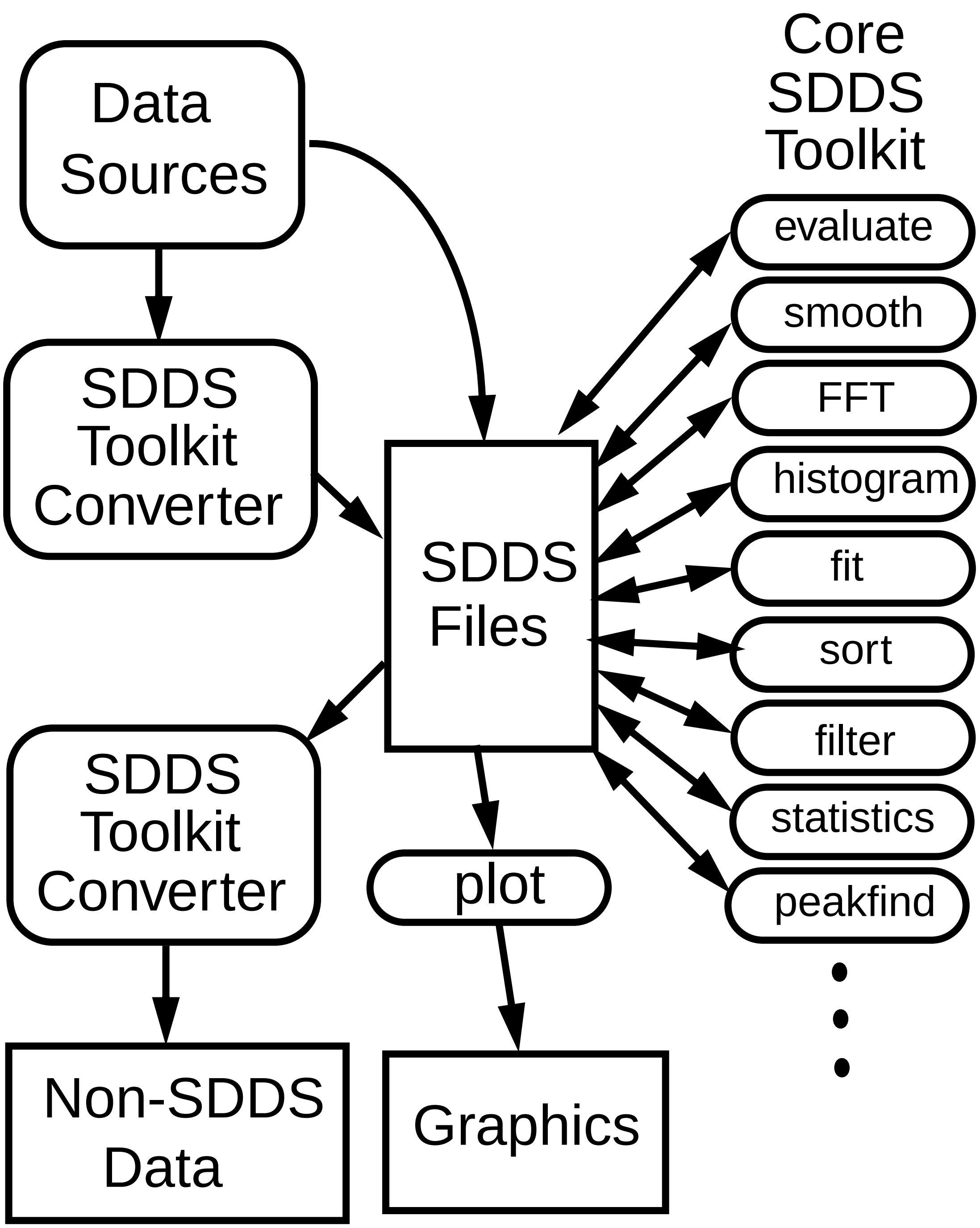
# SDDS File Protocol

- Self-describing data is created and accessed *by name only,* using a subroutine library.
- Files include meta-data about data, e.g., data type and units.
- Data may be ASCII or binary.
- No limits on the size or number of data elements.

# Some Advantages of SDDS Files and Programs

- Programs can't be broken by the addition of new data to a file.
- Robust input programming.
- Data is self-documenting.
- Programs can be generic and operate on *named* data.
- Any program's output is any other's input.

# SDDS Toolkit Paradigm



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# sddsplot: A Generic Graphics Program

- Simple plot of beta x:
  ```
  sddsplot -column=s,betax linac.twi
  ```
- Plot betas, dispersion, and magnet layout:
  ```
  sddsplot -graph=line,vary -legend
  -column=s,beta? linac.twi
  -column=s,etax linac.twi -yscales=id=etax
  -column=s,Profile linac.mag
  -overlay=xmode=norm,yfactor=0.04
  ```
- Plot 6D phase space:
  ```
  sddsplot -graph=dot -separate=1
  -layout=2,2 linac.out
  -column=x,xp -column=y,yp -column=t,p
  ```

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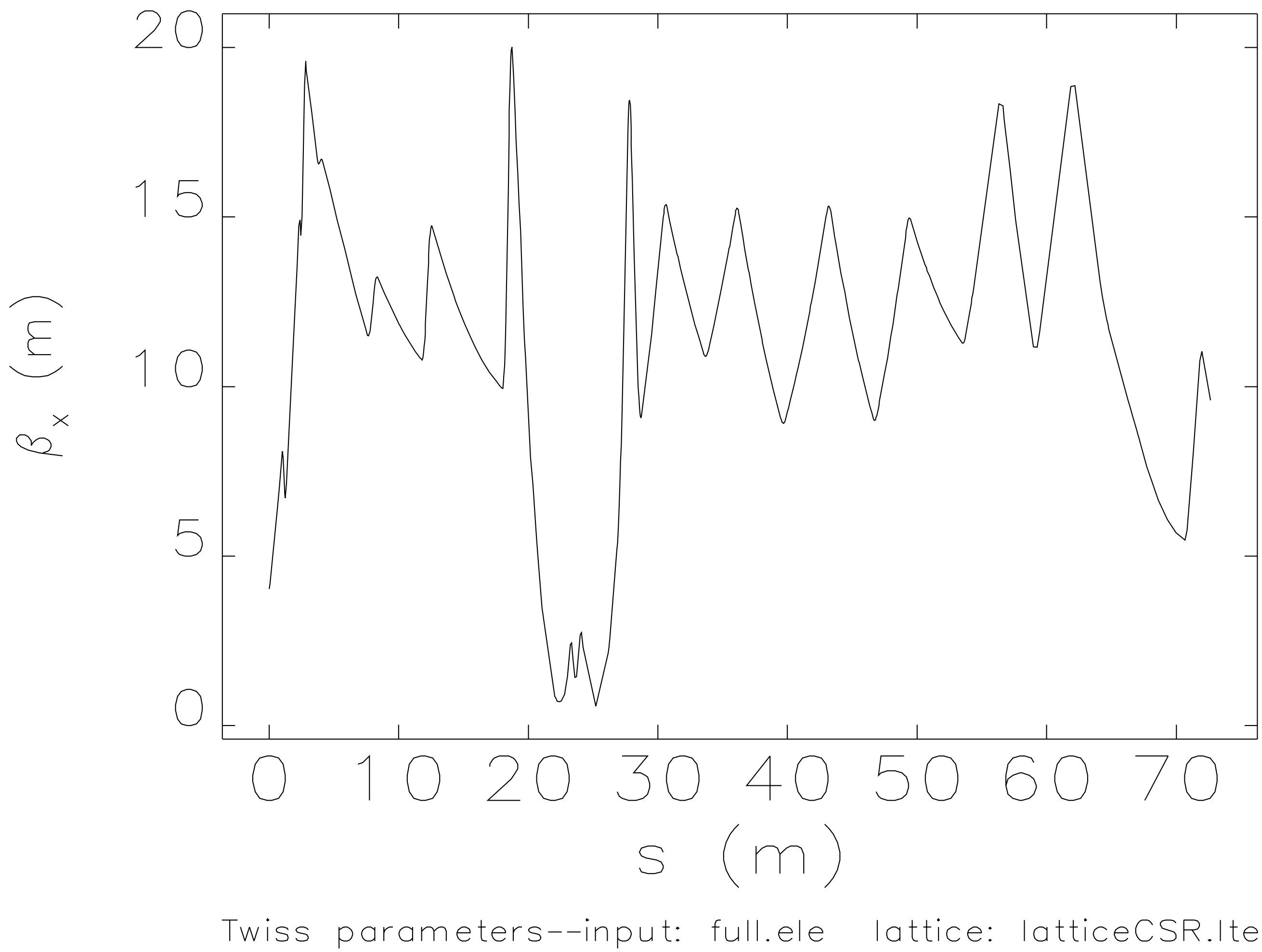
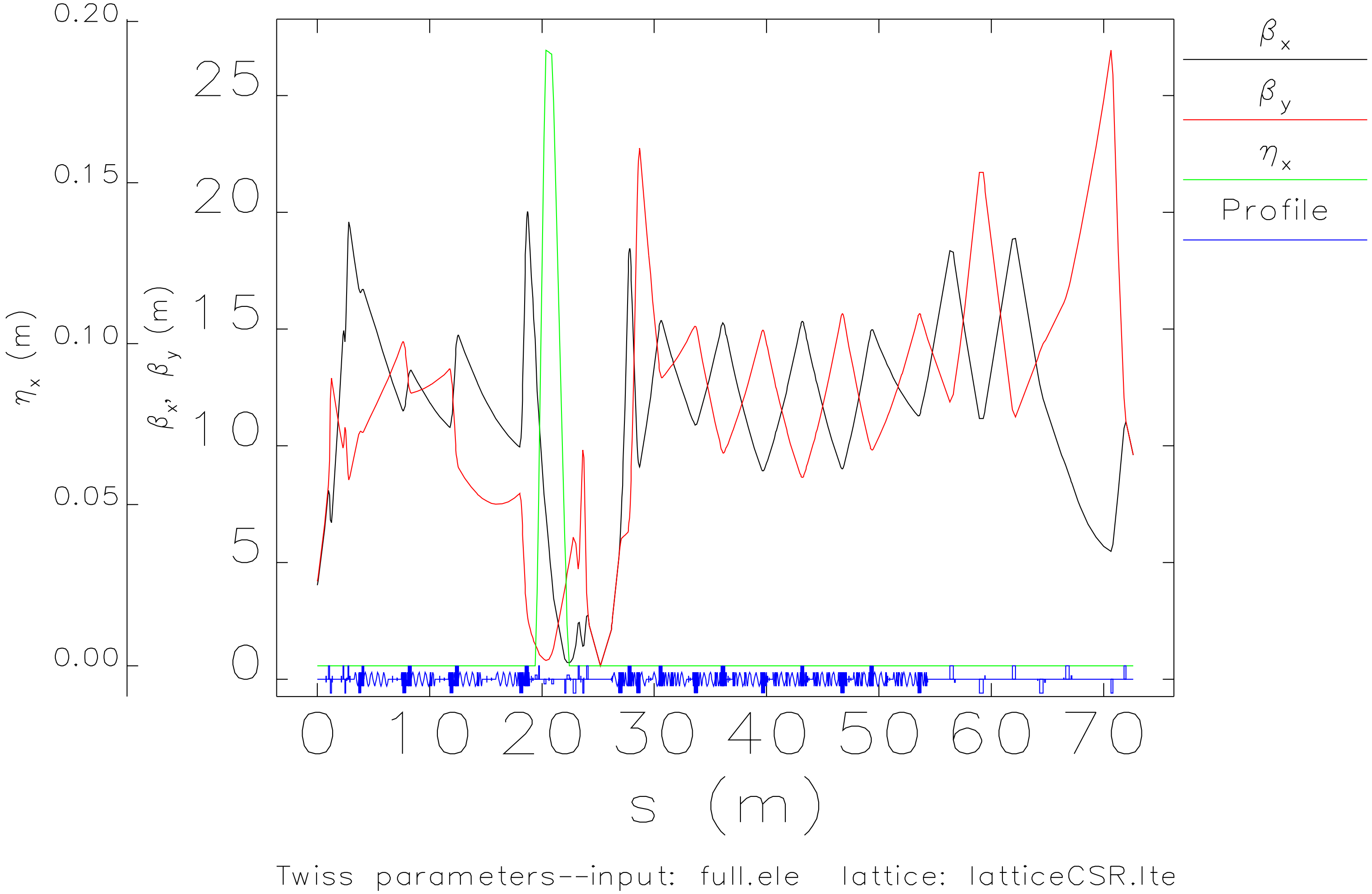
# sddsplot Example 1



# sddsplot Example 2



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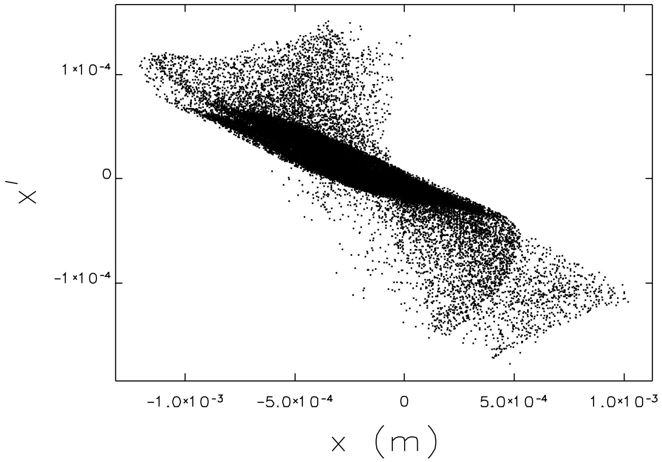
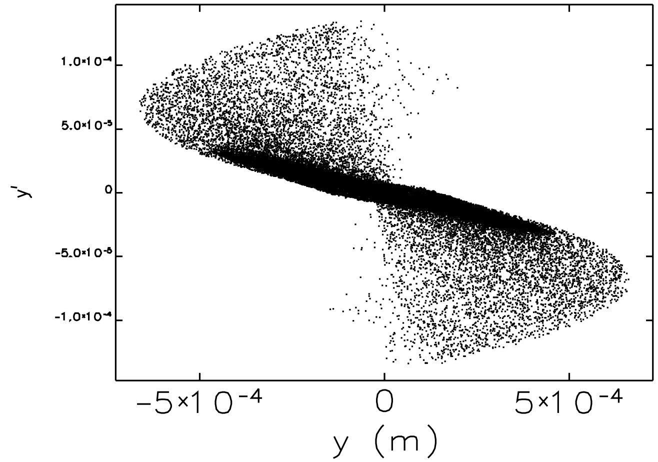
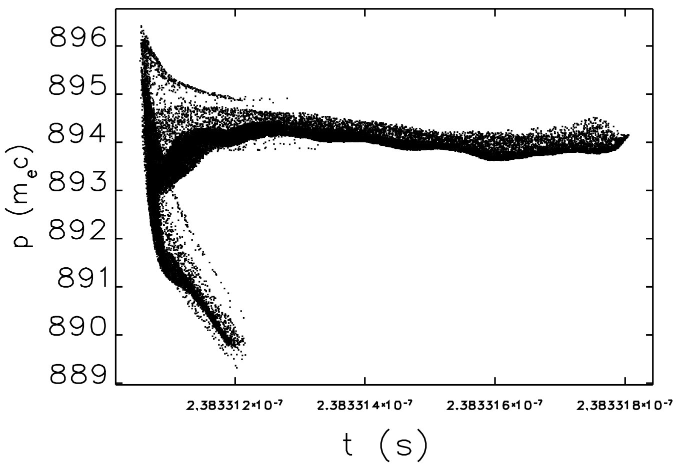
# sddsplot Example 3




output phase space--input: full.ele lattice: latticeCSR.lte




output phase space--input: full.ele lattice: latticeCSR.lte




output phase space--input: full.ele lattice: latticeCSR.lte

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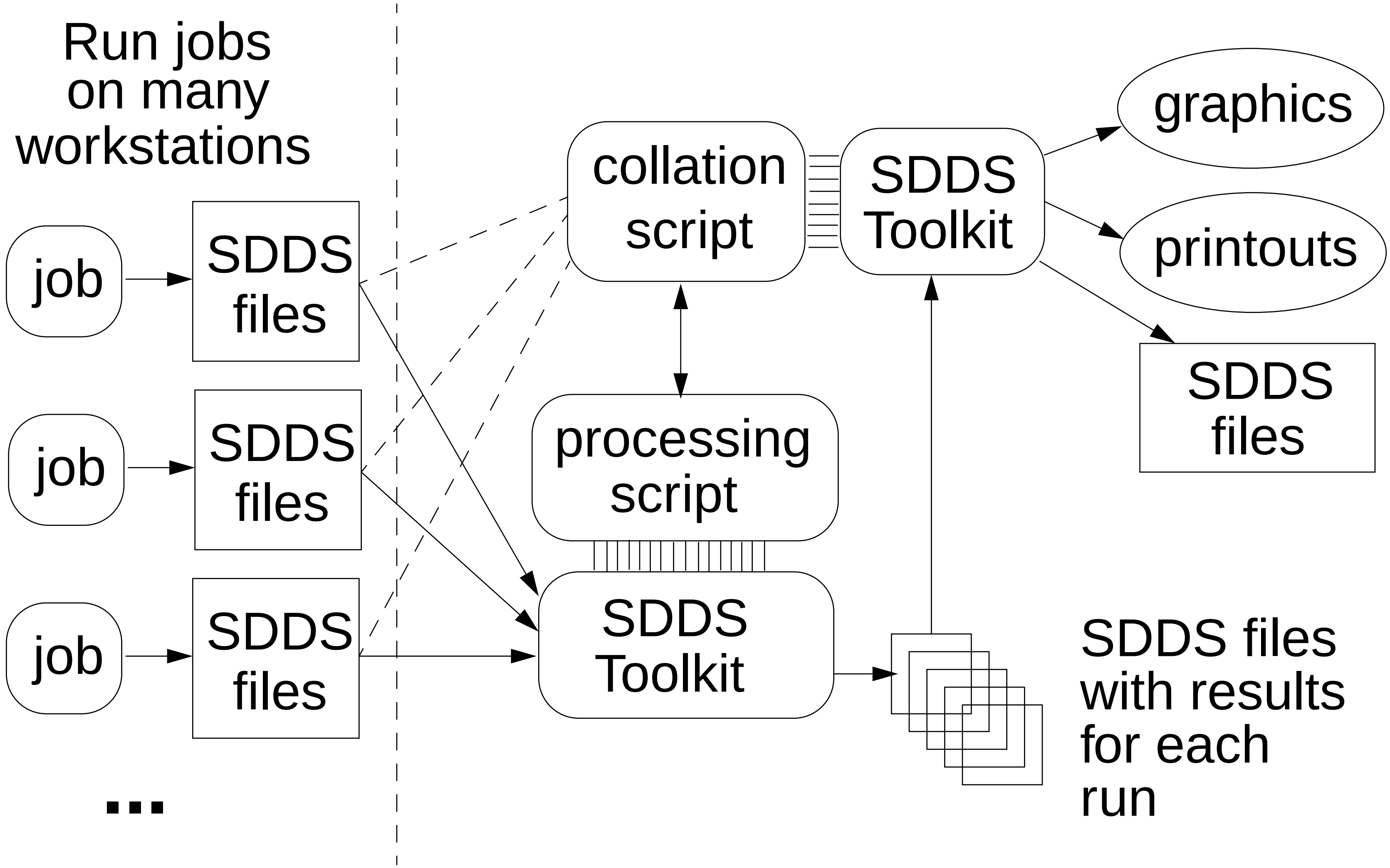
# Typical Example of Using SDDS and DQS



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# Overview of Features in elegant

- Uses SDDS files for input and output.✯
- Optimization of tracked and computed quantities.✯
- Variation of parameters in loops.✯
- 6 D tracking.
- Twiss parameters and radiation integrals.
- Addition of random errors, plus
  - orbit/trajectory correction
  - tune and chromaticity correction
  - load external perturbation values✯
- Closed orbit and response matrix.
- Dynamic aperture search.

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# Overview of Physics in elegant

- Track in 6D with matrices, canonical integration, numerical integration, or mixture.
- Time-dependent elements: rf cavity, kicker, deflectors, traveling wave linac, energy ramping, cavity ramping.
- Collective effects: wakes, impedances, resonant modes, CSR, IBS*.
  No space charge at this time.
- Collimators, scraper, momentum filter.
- Quantum excitation*, radiation damping*, material scattering.

*rings only.

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# Use of SDDS Files by elegant

- Input/output data:
  - particle coordinates
- Input data:
  - values for any element parameter
  - impedances and wake functions
  - cavity and energy ramps
  - kicker waveforms
- Output data:
  - turn-by-turn particle coordinates or statistics
  - FFTs of particle motion
  - beam moments vs s
  - transport matrix vs s
  - Twiss parameters and radiation integrals vs s
  - lattice parameters (chromaticities, emittance, etc.)
  - coordinates of lost particles
  - initial coordinates of transmitted particles
  - final beam parameters (size, energy, emittance, etc.)
  - amplification factors
  - orbits, corrector strengths, and statistics
  - magnet strengths after tune/chromaticity correction
  - internally-generated error values

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# Example: Checking the SPEAR III Lattice

- **elegant** was used to check the tolerance levels and dynamic aperture for the SPEAR III lattice.
- For lattice checks, 35 jobs were run for a total of 350 seeds.
  - Elapsed time: ~25 minutes.
  - Time saved: ~13 hours
- For dynamic aperture, 21 jobs were run for a total of 100 seeds.
  - Elapsed time: ~14 hours
  - Time saved: ~11 days

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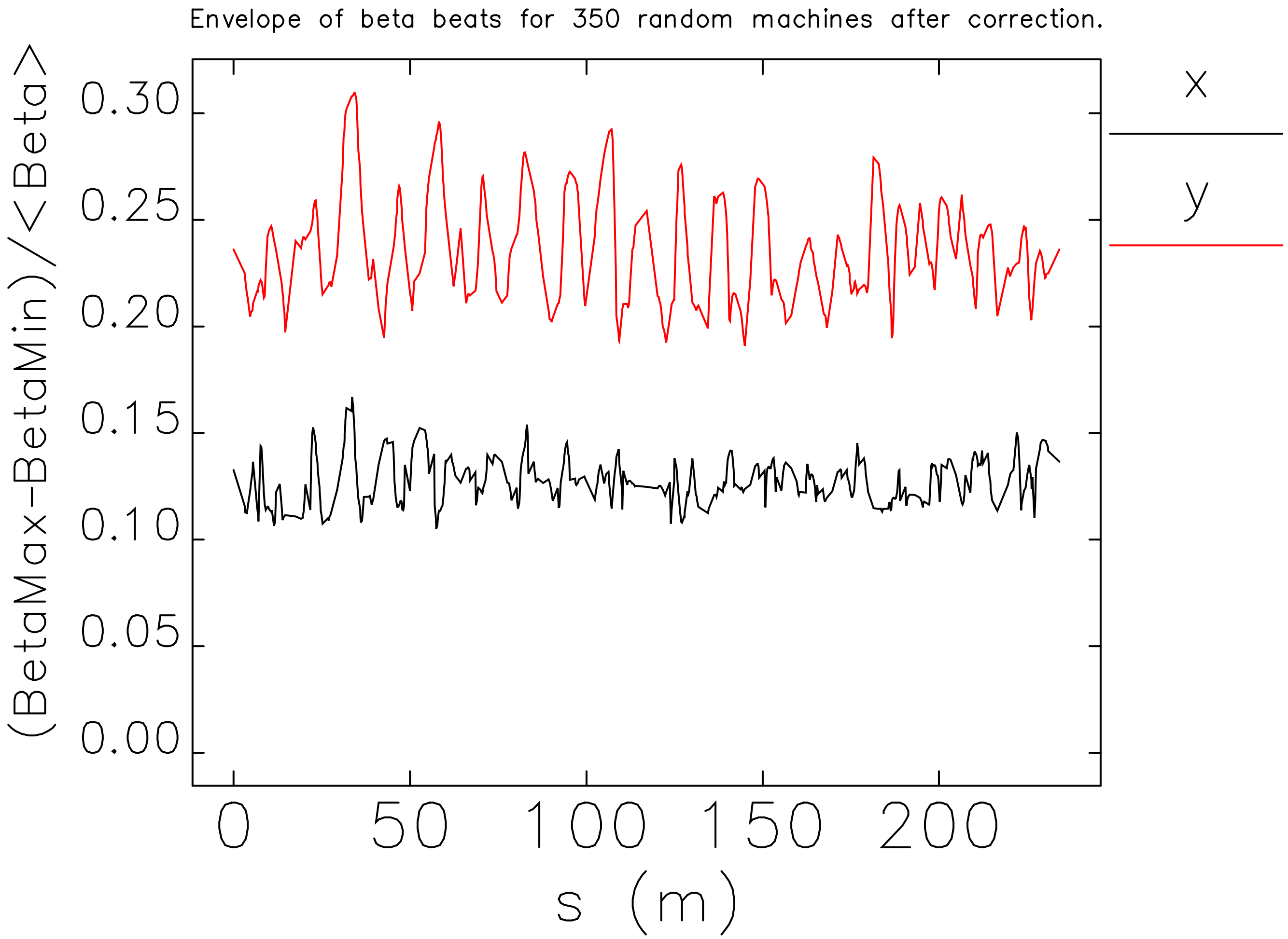
# SPEAR III Lattice with Errors



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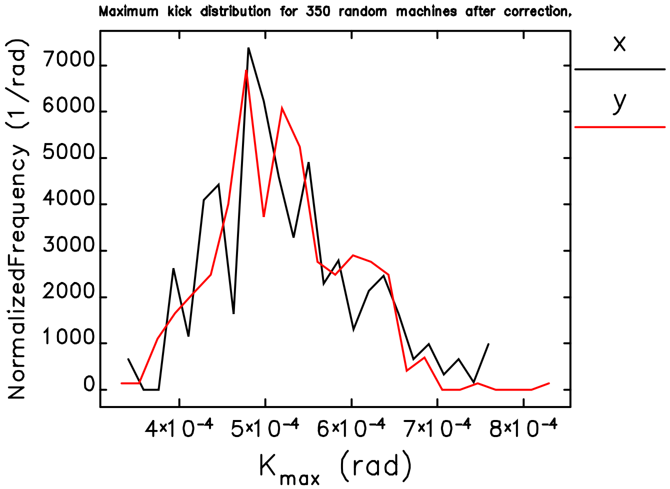
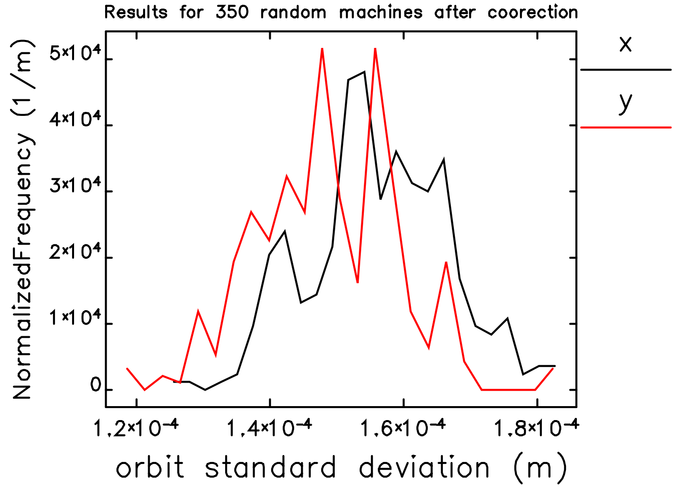
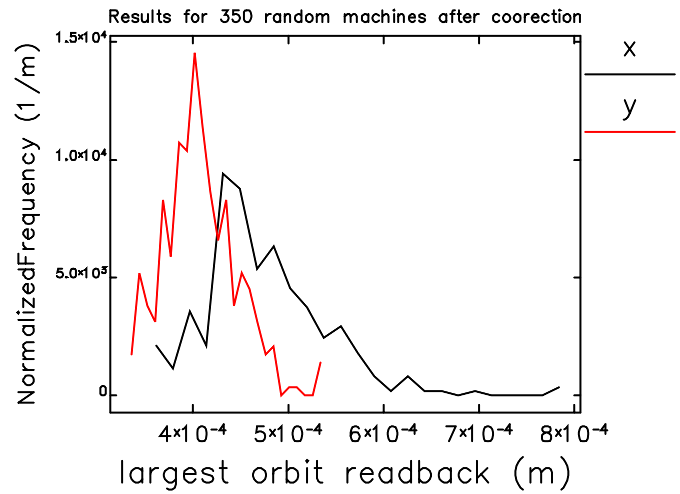
# SPEAR III Lattice with Errors



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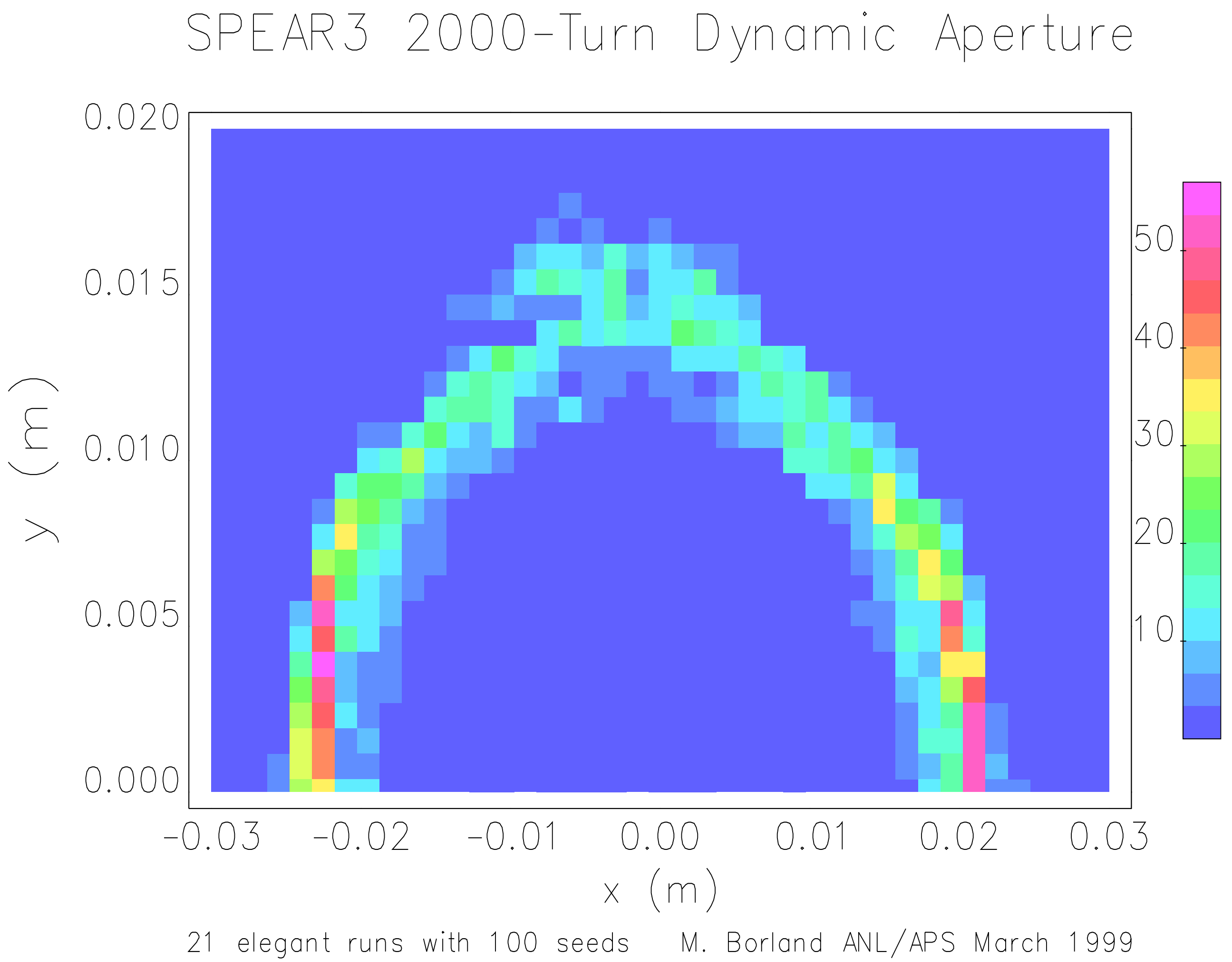
# SPEAR III Dynamic Aperture From 100 Seeds



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# APS Top-Up Safety Tracking

- “Top-up” refers to performing injection into a synchrotron light source with shutters open.
- Possible extraction of injected beam down a photon beamline is a concern.
- Question:
  Can a simple interlock on stored beam current protect against this?
- Approach:
  - Define a set of fault scenarios that might produce an accident.
  - Use tracking with detailed apertures to test whether an accident could occur.

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# Overview of Top-Up Simulations

- Fault scenarios include
  - shorted dipole
  - conspiratorial steering kicks
  - wrong tune due to any of 10 quadrupoles in a sector
  - 22 different lattices
- Scope of problem
  - ~1500 runs of **elegant**
  - ~13000 input and output files
  - elapsed time: ~2 days
  - time saved: ~11 weeks
- N.B: beamlines are *locked out* if applicable tracking isn't done!

# APS Bunch Compressor

- Bunch compressor under construction for APS Linac
  - improved gain from LEUTL FEL
  - test ideas for LCLS compressors
  - derived from concepts provided by V. Bharadwaj and P. Emma
- Issues
  - want a flexible design—variable $R_{56}$ and straight-through option.
  - what is best operating configuration?
  - what are tolerances?
  - what is likely performance?

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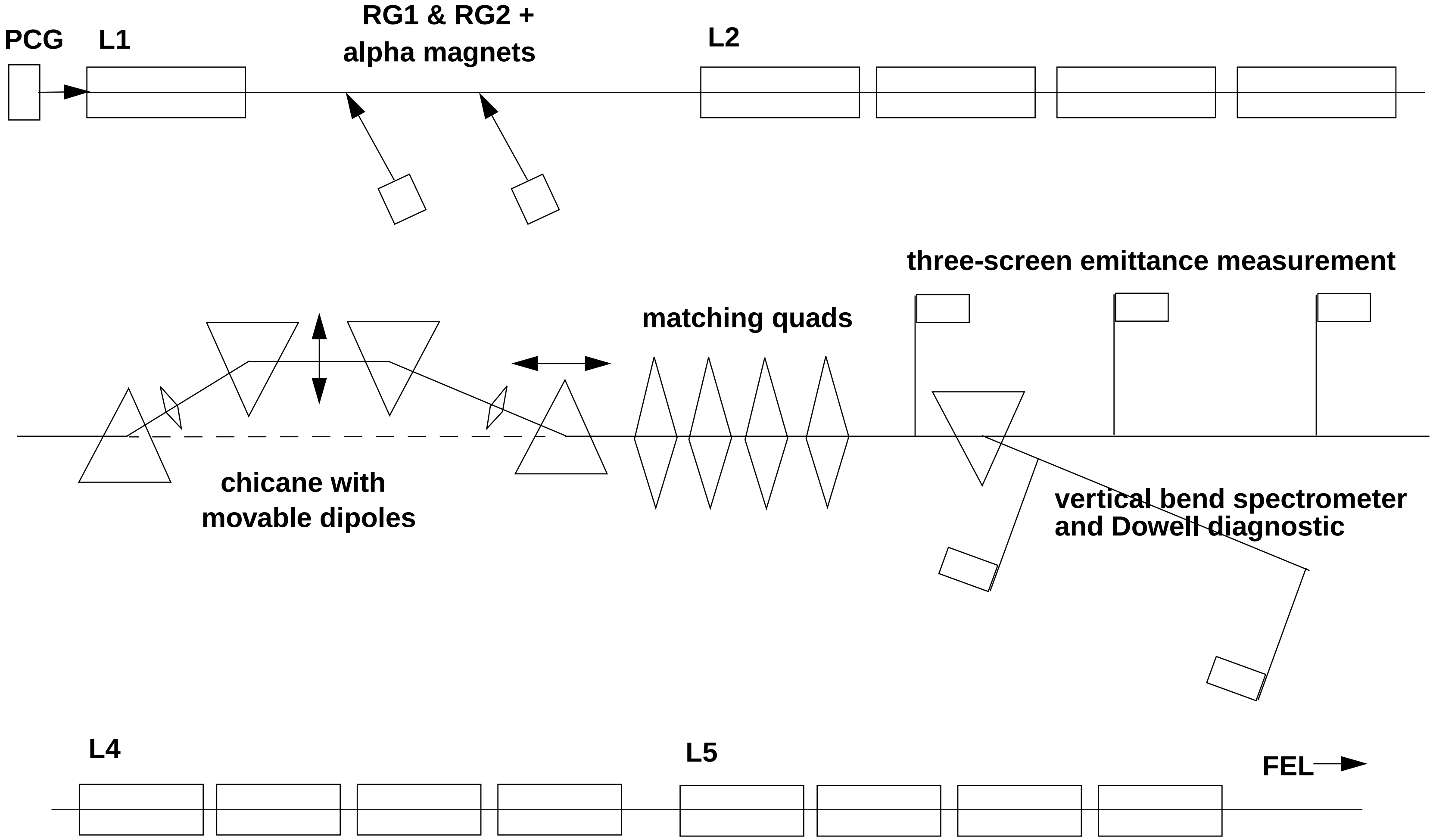
# APS Linac/Compressor Schematic



# Bunch Compressor Design Approach

- Use PARMELA to simulate PC gun to exit of L1 (J. Lewellen).
  Use **elegant** from L1 to undulators.
- Create a large number of configurations.
  - $R_{56}$ from -25mm to -65mm
  - symmetric and asymmetric chicane
  - various energy profiles
  - various final peak current
- Choose the best in terms of
  - emittance
  - energy spread
  - sensitivity to errors
- Provide specs and evaluate hardware limits

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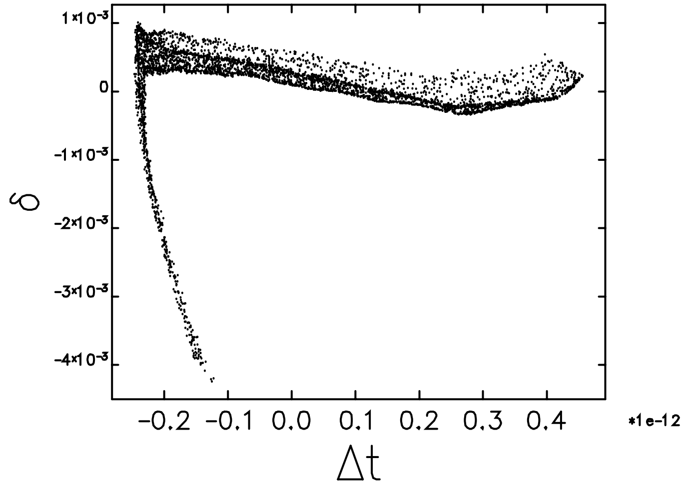
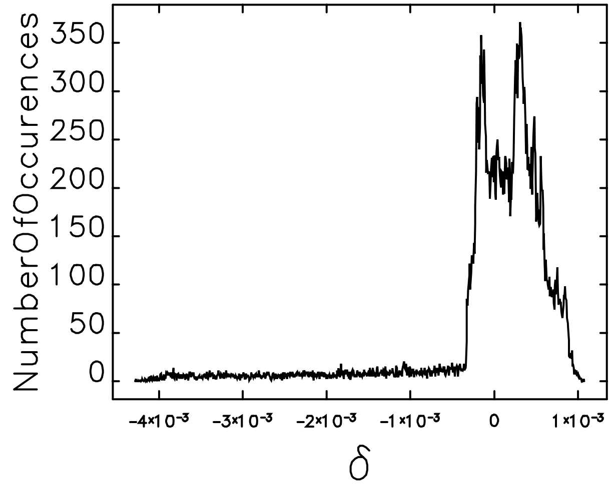
# Matching for the Bunch Compressor

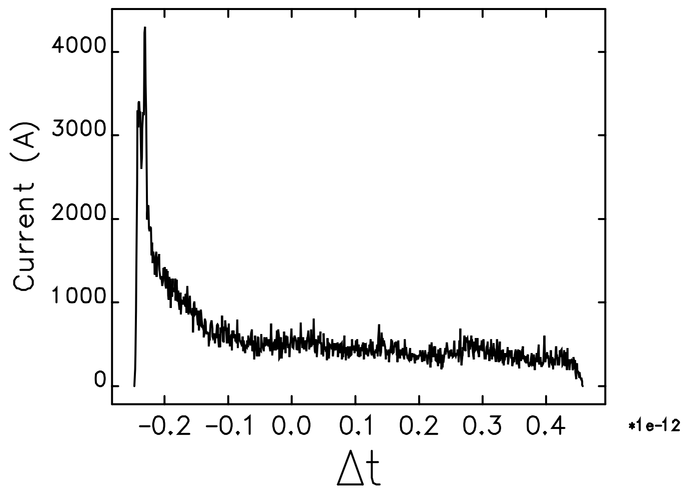
- Use matrix and floor coordinate optimization to get 80 chicane configurations for various $R_{56}$ and asymmetry.
- Use tracking optimization to optimize phase and voltage of L2, L4, and L5 for chosen chicane configuration
  - desired energy profile
  - target peak current
  - minimum energy spread
  - include longitudinal wakes

# Sample Longitudinal Phase Space




output phase space—input: 600A-185.457MeV-65mm2.ele lattice: compress.lte




600A-185.457MeV-65mm2

Charge: 4.185e-10C

Transmission: 0.900019

$\Delta t_{80}$: 5.55638e-13s

$\sigma_{\delta}$: 0.000791455

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# Matching for the Bunch Compressor —continued—

- Use Twiss parameter optimization to perform matching for each longitudinal configuration
  - four stages of matching work the solution down the linac
  - after matching, track with all wakes and CSR
- Typically 35-40 configurations are done
  - elapsed time: ~8 hours
  - time saved: ~11 days

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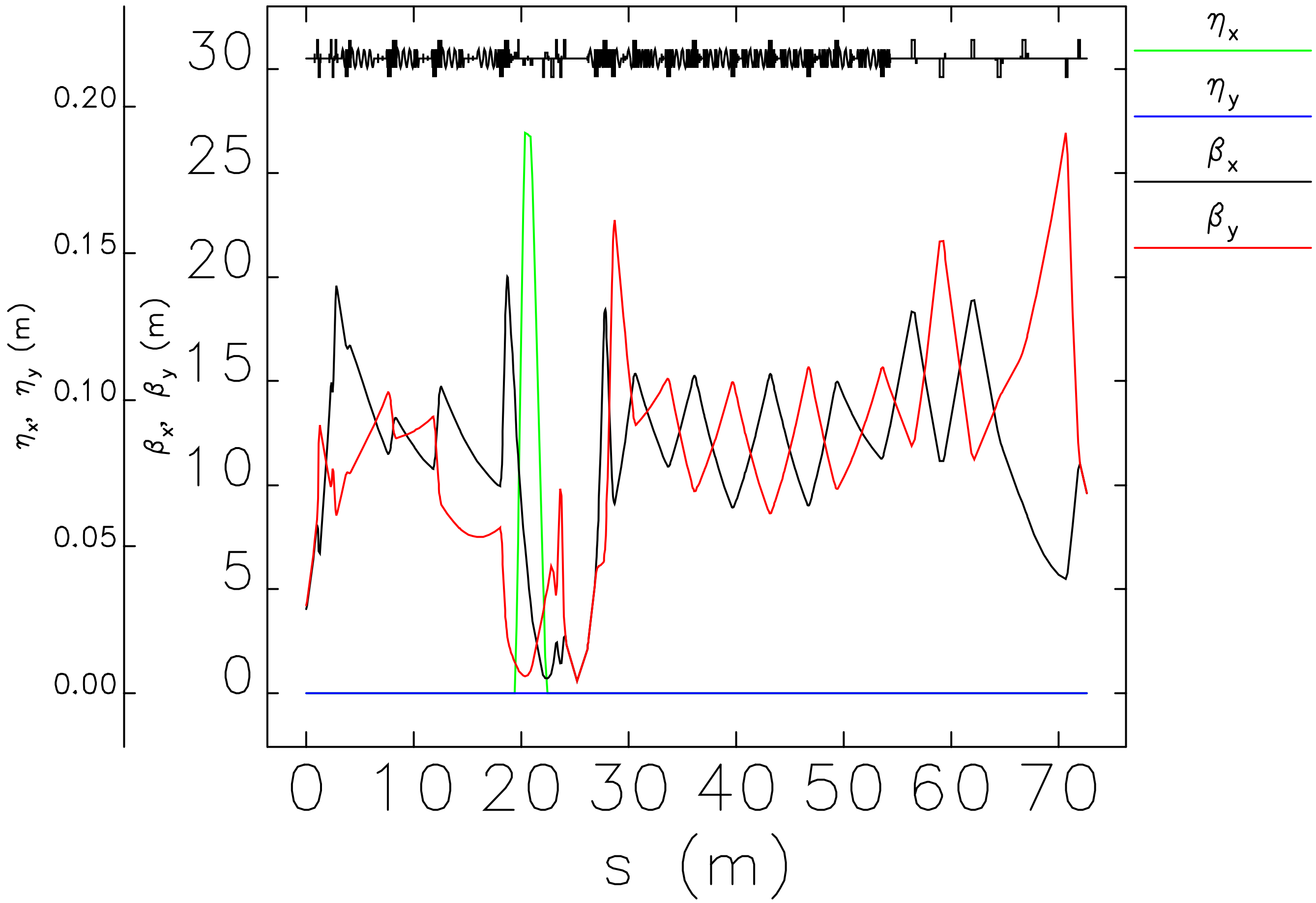
# Sample Lattice Functions




Twiss parameters for /home/oxygen26/BORLAND/aps/bunchComp/VaryL3/optics6.0/600A-185.457MeV-65mm2/full

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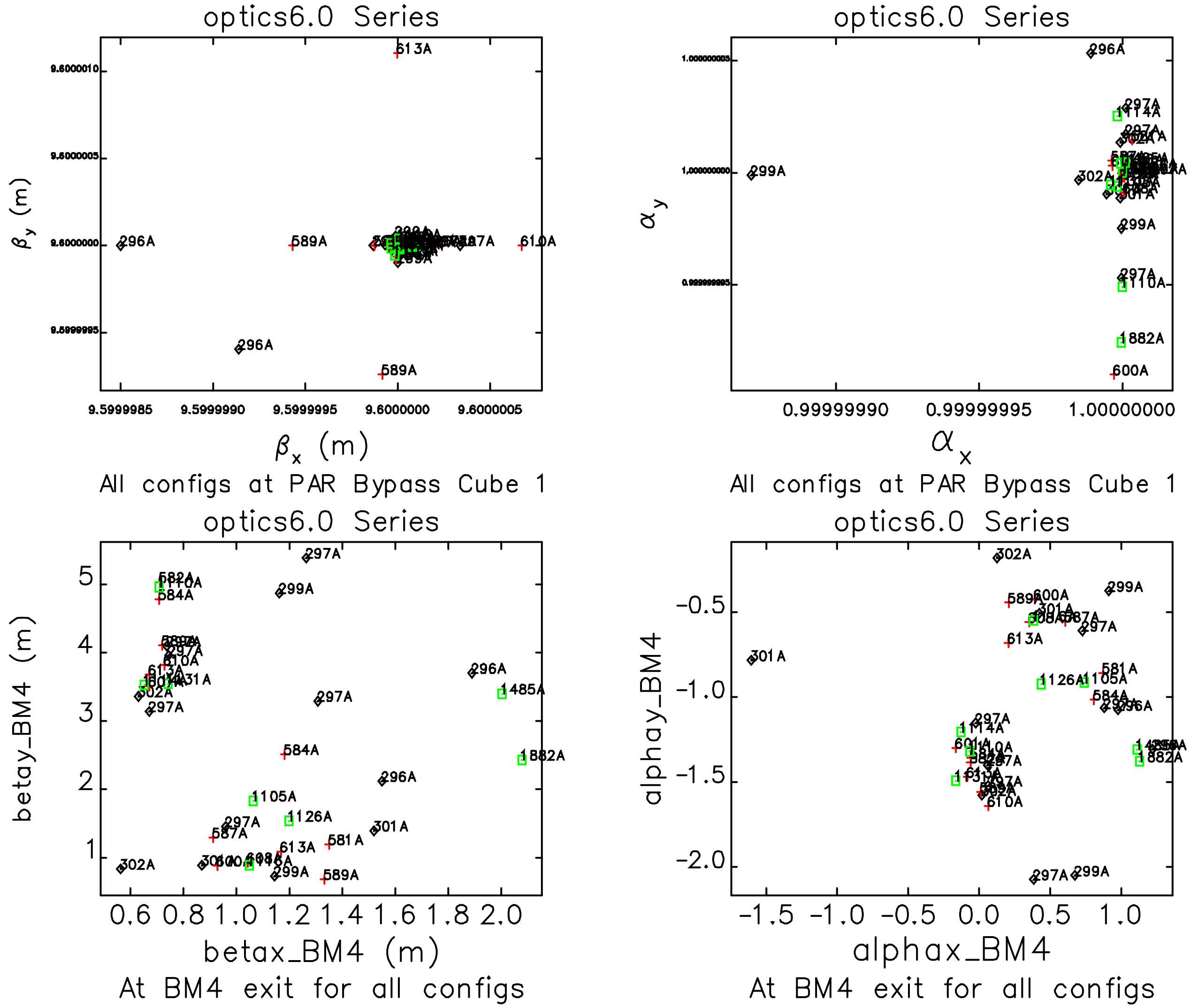
# Lattice Summary Plots for All Configurations



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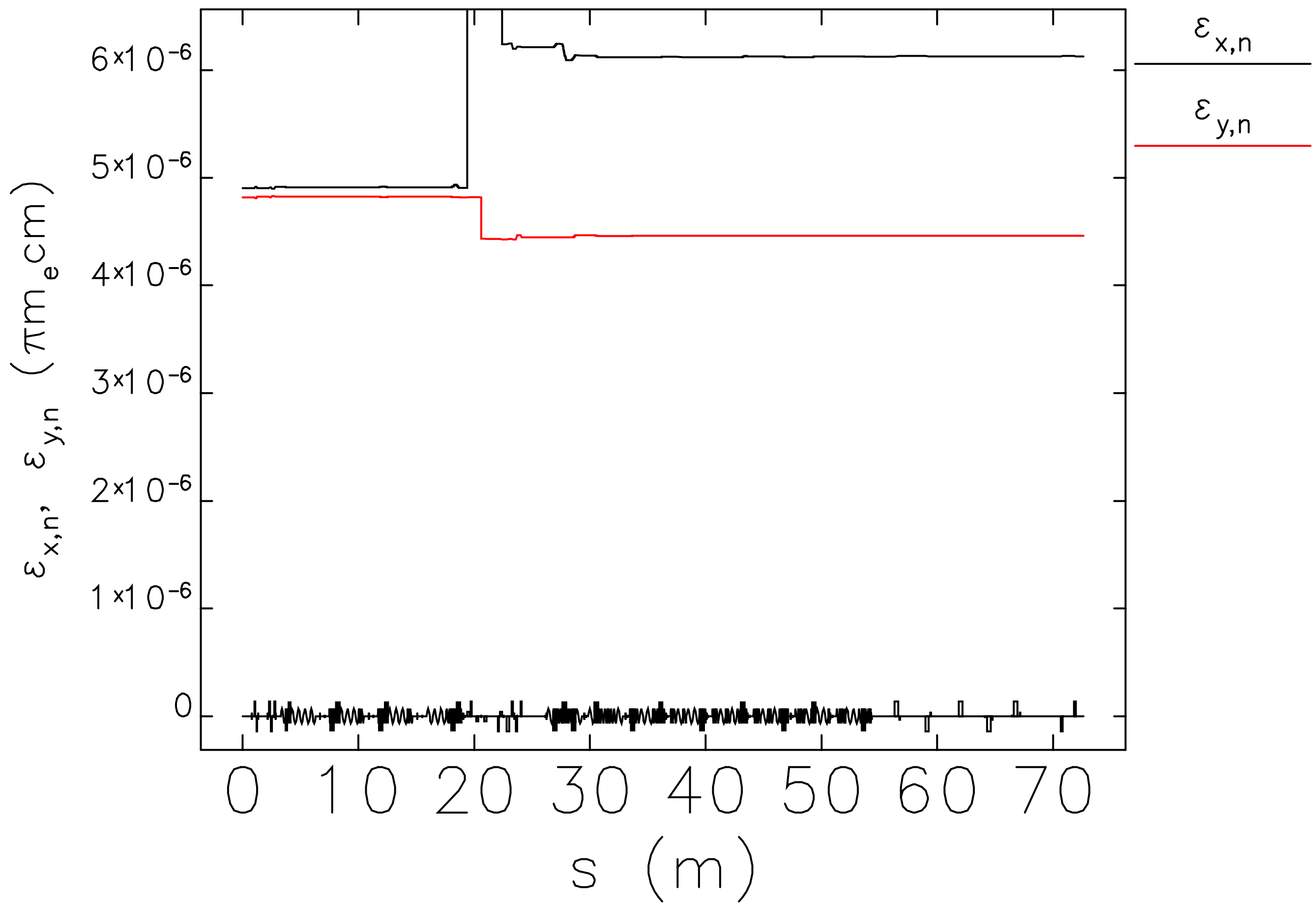
# Emittance Blow-up for 600A Case




600A-185.457MeV-65mm2/full

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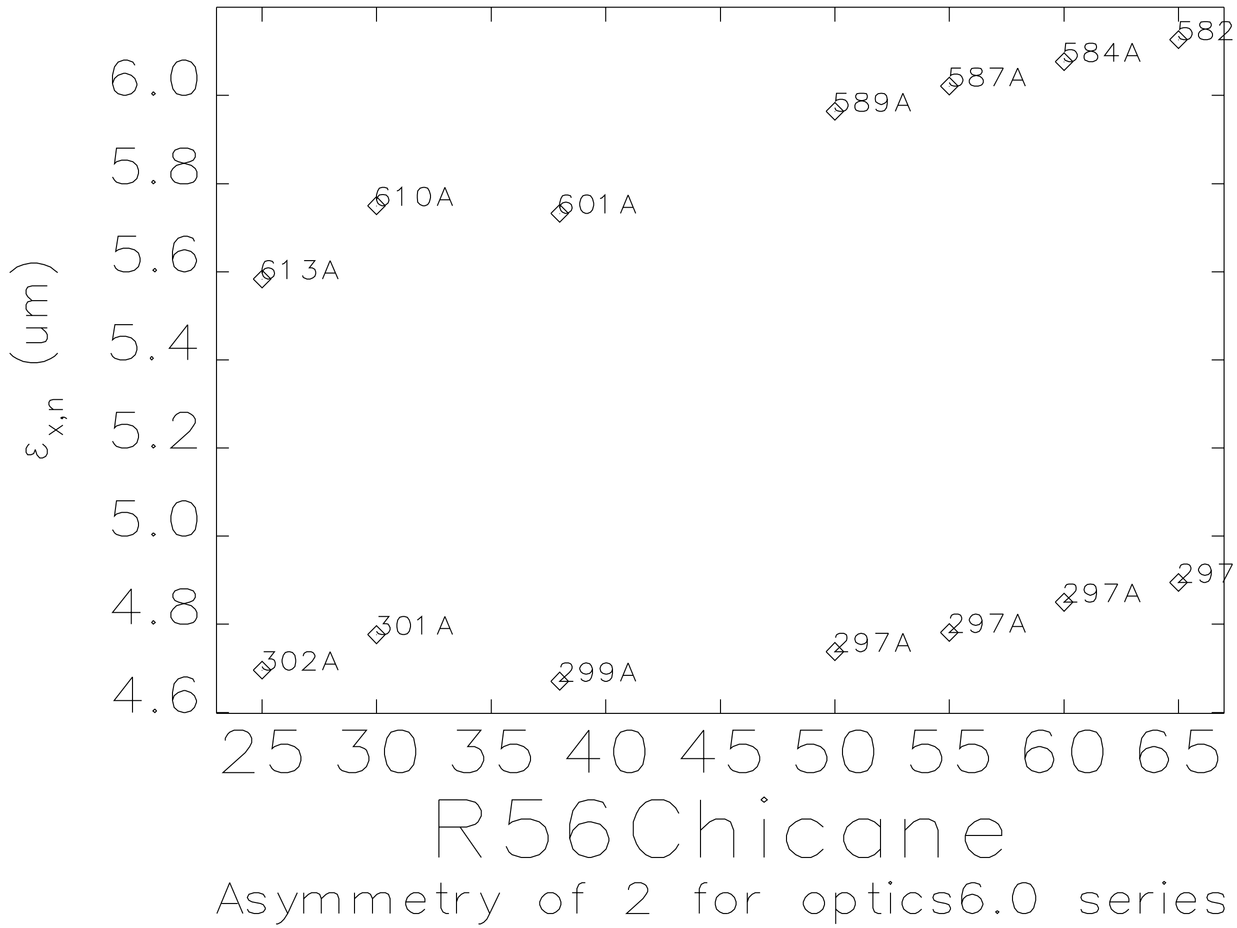
# Emittance Blow-up Variation



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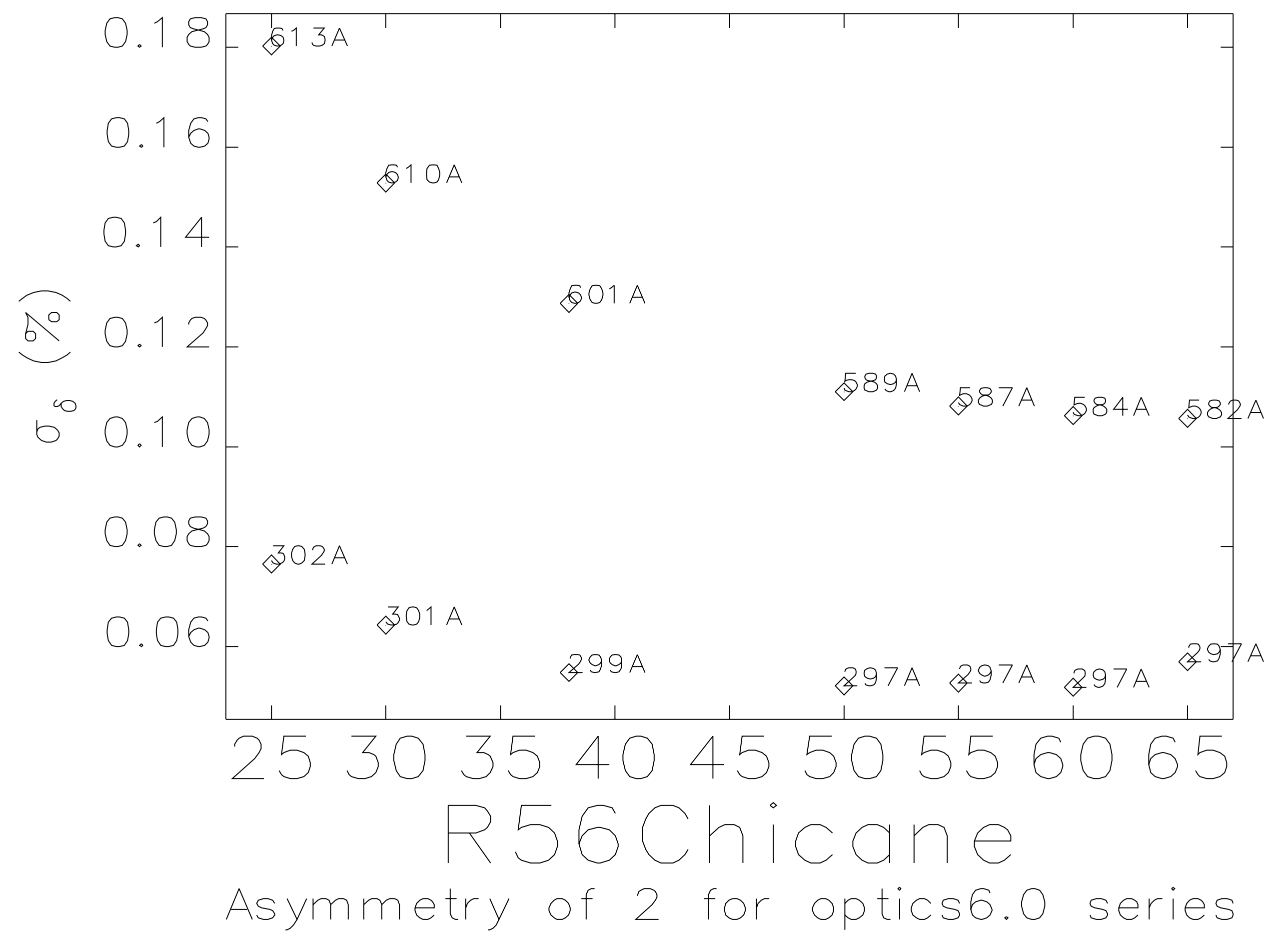
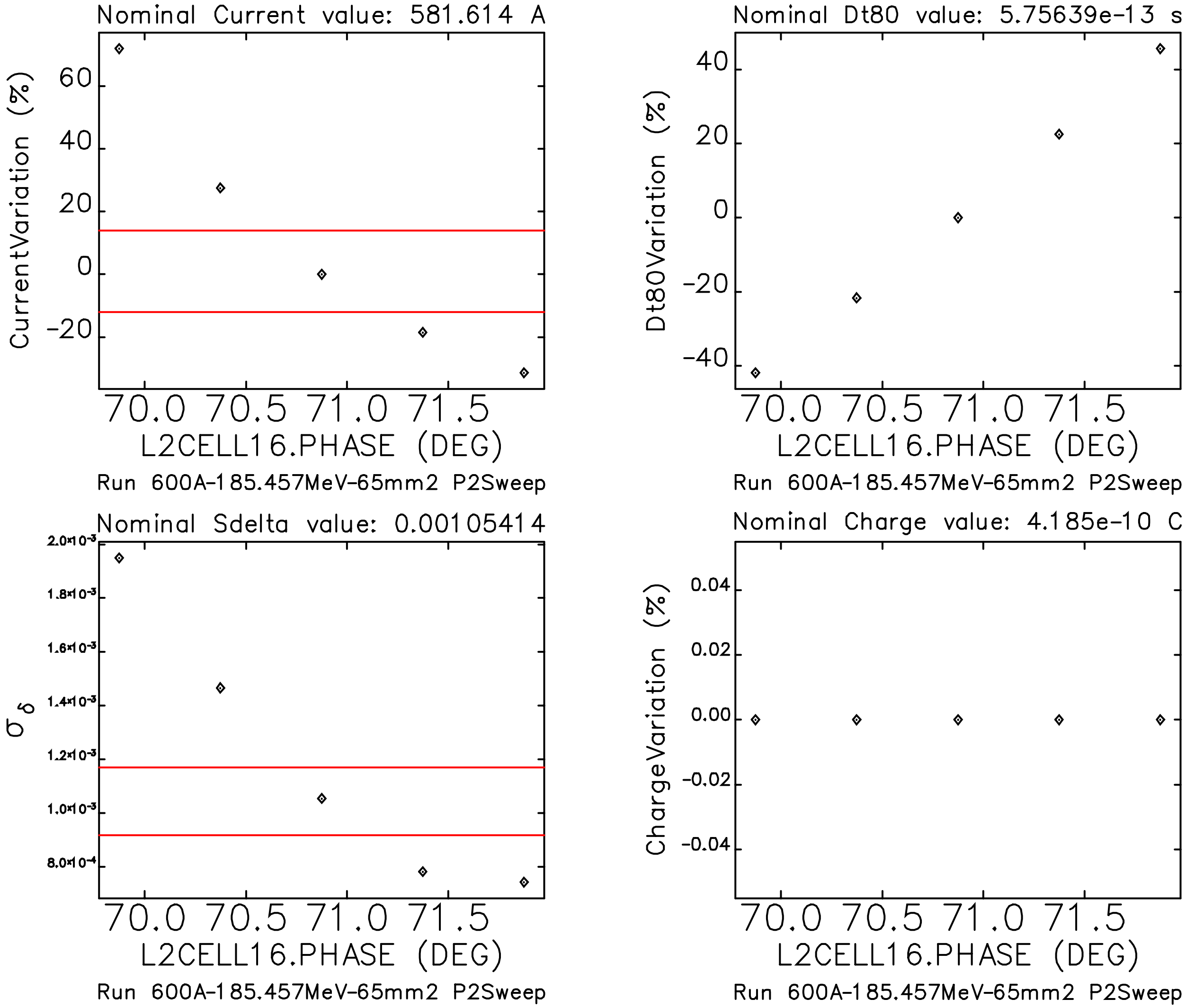
# Energy Spread Variation



# Establishing Tolerances for the Bunch Compressor

- Basic tolerance determination involves tracking for single-parameter “sweeps”
  - photoinjector timing, energy, charge
  - linac phase, voltage
  - chicane dipole strengths
  - chicane dipole positions
- A postprocessing script determines at what point the beam properties are unacceptable. This sets a “window” for each varied quantity.
- Divide by ~$\sqrt{N}$ to get RMS tolerances.
- Sweeps are done for many configurations to determine which are best.

# Example of Sweep Results



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# Example of Sweep Results

| ChangeLimit | ChangeLimit % | Cause | Run | VariableName |
|---|---|---|---|---|
| 0.126 | 0.246358 | Sdelta | 600A-185.457MeV-25mm2 | L2CELL1+2+4+8+12+14+16.PHASE |
| 1.18e+03 | 0.221417 | Energy | 600A-185.457MeV-25mm2 | L2CELL1+2+4+8+12+14+16.VOLT |
| 0.00204 | | Energy | 600A-185.457MeV-25mm2 | L3:BM1+2+3+4.FSE |
| 0.000588 | | Cxp | 600A-200.457MeV-55mm2 | L3:BM1+2.FSE |
| 0.000141 | | Cxp | 600A-185.457MeV-65mm2 | L3:BM1.FSE |
| 0.00179 | | Cxp | 600A-185.457MeV-65mm2 | L3:BM2+3.DX |
| 0.000186 | | Cxp | 600A-185.457MeV-65mm2 | L3:BM2.FSE |
| 0.00059 | | Cxp | 600A-200.457MeV-55mm2 | L3:BM3+4.FSE |
| 0.000447 | | Cxp | 600A-185.457MeV-65mm2 | L3:BM3.FSE |
| 0.000847 | | Cxp | 600A-200.457MeV-55mm2 | L3:BM4.DZ |
| 0.00085 | | Cx | 600A-185.457MeV-65mm2 | L3:BM4.FSE |
| 0.353 | 0.224547 | Energy | 600A-185.457MeV-25mm2 | L4CELL1+2+4+8+16.PHASE |
| 6.59e+03 | 1.46334 | Energy | 600A-185.457MeV-65mm2 | L4CELL1+2+4+8+16.VOLT |
| 0.354 | 0.225283 | Energy | 600A-185.457MeV-25mm2 | L5CELL1+2+4+8+16.PHASE |
| 6.59e+03 | 1.46442 | Energy | 600A-185.457MeV-65mm2 | L5CELL1+2+4+8+16.VOLT |
| 0.00734 | | Energy | 600A-185.457MeV-25mm2 | MALIN.DP |
| 1.21e-13 | | Sdelta | 600A-185.457MeV-25mm2 | MALIN.DT |
| 5.91e-16 | 5.91368 | Sdelta | 600A-185.457MeV-60mm2 | Q.PER_PARTICLE |

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# Establishing Tolerances for the Bunch Compressor —continued—

- Other tolerances are established by the "make an educated guess and try it" method.
  - quadrupole and corrector strength
  - positioning tolerances (magnets, accelerating structures, BPMs)
- Impact of relaxed tolerances can be evaluated readily.
- Typically 100-400 random seeds are used for randomized error work.

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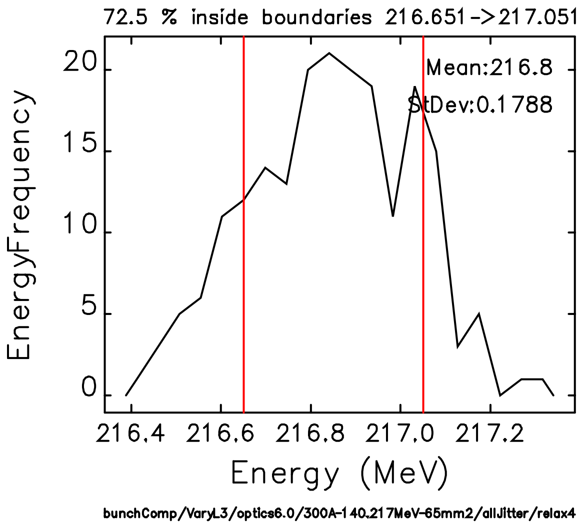
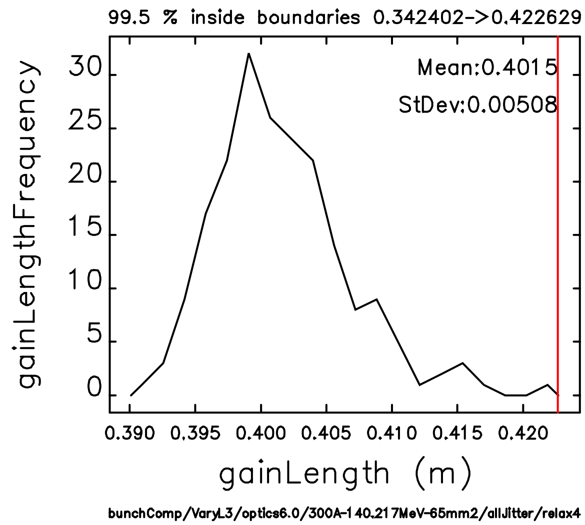
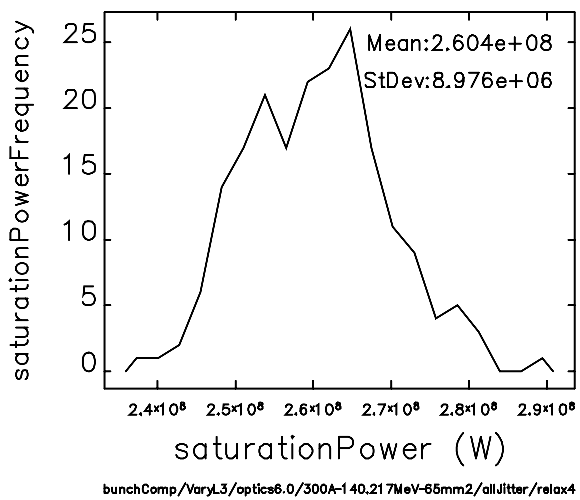
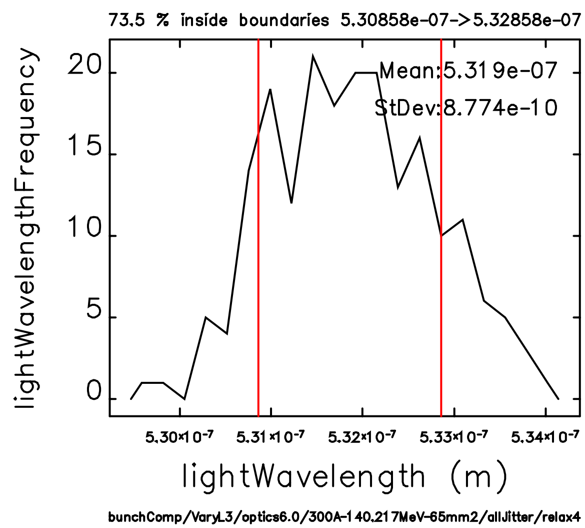
# Sample Results from Randomization Runs



# Codes That Use SDDS Files

- **elegant***
- **spiffe***
  A particle-in-cell code for rf guns.
- **shower***
  An EGS4-wrapper for electron-gamma shower simulation.
- GENESIS*
  FEL simulation by Sven Reiche.
- “Coming soon”:
  PARMELA
  GINGER

*Runs on UNIX and Windows. Can be downloaded from our Web site.

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# Using SDDS to Link Codes

- SDDS provides a robust link between codes.
- Tracking examples:
  - Gun and beamline simulation:
    **spiffe** > **elegant**
  - Start-to-end FEL:
    PARMELA > **elegant** > GENESIS
  - Positron production:
    **elegant** > **shower** > **elegant**

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# Summary

- DQS allows running many simulations concurrently in a routine manner.
- SDDS and scripts allow processing data from large numbers of runs in a flexible, efficient manner.
- **elegant** and other codes can be very effective on large projects when DQS and SDDS are used.