REALISTIC PREDICTION OF DYNAMIC APERTURE AND OPTICS PERFORMANCE FOR LEP

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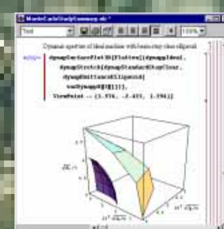
ABSTRACT: Over the two-decade lifetime of the LEP project, techniques for evaluating the quality of optical configurations have evolved considerably to exploit the growth in computer power and improved modelling of single-particle dynamics. These developments have culminated in a highly automated Monte-Carlo evaluation process whose stages include the generation of an ensemble of imperfect machines, simulation of the ***operational*** correction procedures, correlation studies of the optical functions and parameters of (both) beams, 4-dimensional dynamic aperture scans and tracking with quantum fluctuations to determine the beam core distribution. We outline the process, with examples, and explain why each step is necessary to realistically capture essential physics affecting performance. The mechanisms determining the vertical emittance, radial beam distribution and dynamic aperture are especially important. As a storage ring in which an unusual variety of optics have been tested, LEP provides a valuable test case for the predictive power of the methodology.

Optics evaluation procedure

- Ideal machine, no solenoids, no RF, no radiation
- → Install vacuum chambers to limit aperture in quads
- → Compute solenoid compensation with tilted quads
- → Compute 6D linear machine, RF, radiation $(x_n,p_n)_{1,2,3}, Q_{1,2,3}, U_0, \tau_{1,2,3}, \varepsilon_{1,2,3},\ldots$
- → 6D dynamic aperture scan in 4D (I_1,I_2,I_3,ϕ_3)

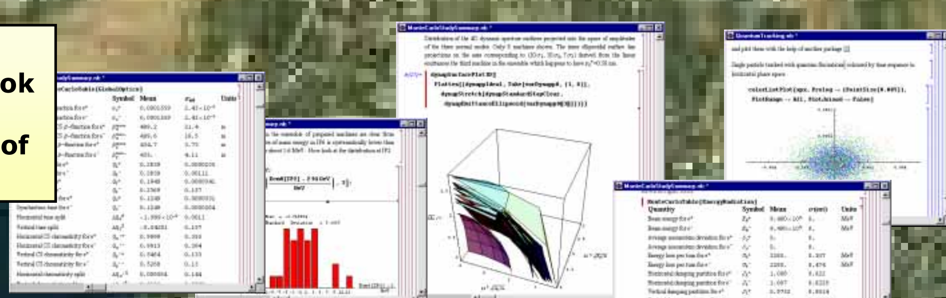


Generate ensemble of 30 imperfect machines (misalignments, tilts, field errors in all magnets)

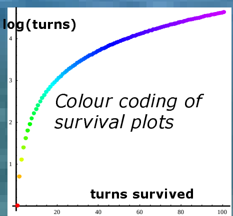
- Correct closed orbit without radiation $\sqrt{\langle x^2\rangle}=0.6\,\mathrm{mm}$, $\sqrt{\langle y^2\rangle}=0.4\,\mathrm{mm}$
- → Solenoids, RF, radiation on ⇒ **6D machine for e⁺** Correct β_y^*, tunes
- → Compute 6D linear machine, RF, radiation $(x_n,p_n)_{1,2,3}, Q_{1,2,3}, U_0, \tau_{1,2,3}, \varepsilon_{1,2,3},\ldots$
- → 6D dynamic aperture scan in 4D (I_1,I_2,I_3,ϕ_3)
- → Tracking with quantum fluctuations, >200 τ_I ⇒ higher order effects on emittances

From "Solenoids, RF, radiation on": Reverse element sequence, build **equivalent machine for e⁻** →

Process managed in Mathematica notebook interface.
Results as database of functions.



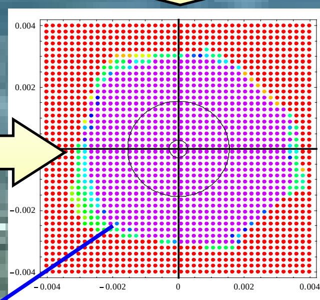
Shrinking of dynamic aperture at the ultimate energy accessible with available RF voltage

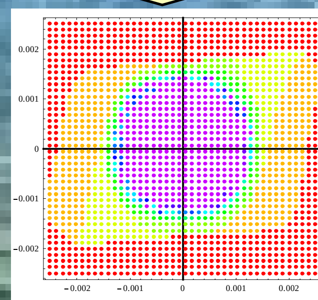


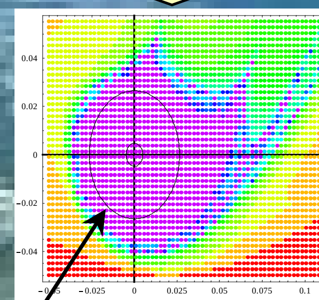
Survival plots of **initial conditions** in normal mode phase planes, units $\sqrt{m}$

Mode 1 "horizontal betatron"	Mode 2 "vertical betatron"	Mode 3 "synchrotron"

"Comfortable"
94 GeV,
Jx=1,
V_{RF}=2.96 GV





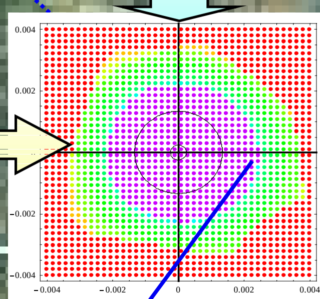


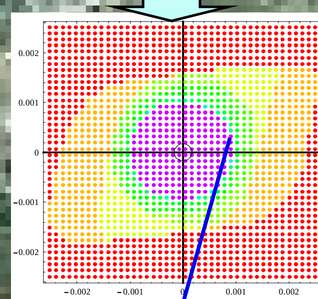
Integer resonance: $\frac{\partial Q_y}{\partial I_x}$

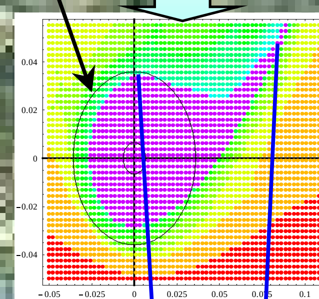
5.5 σ of notional gaussian distribution

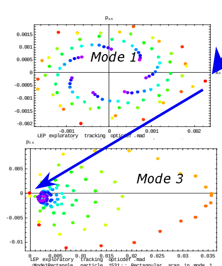
Reduction of DA by RBSC	Reduction of DA by RBSC	Reduced "bucket height"

"Just sufficient"
100 GeV,
Jx=1.5,
V_{RF}=3.265 GV









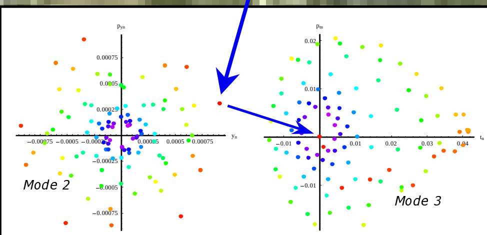
RBSC instability:

radiation in quadrupoles

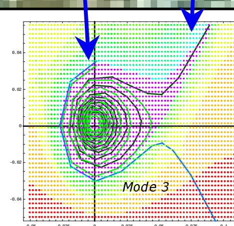
⇒ large amplitudes in mode 3

⇒ reduced dynamic aperture for modes 1 & 2

Example particle has zero initial amplitude in mode 3.



RBSC stronger closer to energy limit



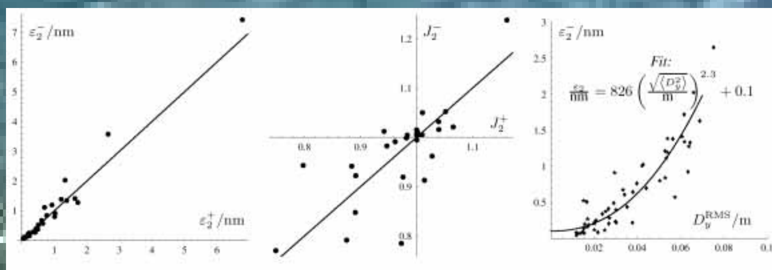
Strong damping

True shape of "RF bucket".

Orbits of 3 particles superposed on survival plot, 2 stable and 1 unstable.

Predicting vertical emittance

- Crucial parameter for luminosity performance.
- Need small emittance in absence of beam-beam effect.
- Determined entirely by imperfections via vertical dispersion (coupling usually well compensated).
- Can we predict it statistically?



- Predicted range typical of values in real operational life cycle.
- Differences between orbits and optics of e^+ and e^-

⇒Differences between damping partition numbers J_2.

- Operators select corrections that push it down.

CONCLUSIONS:

By carefully constructing ensembles of model machines, simulating the operational correction procedures and using a physically faithful model of single particle dynamics, it is possible to predict the distribution of beam parameters and their differences between the beams in LEP.

Dynamic aperture can be predicted to within about 10 % in a variety of optical configurations. (See references in paper!)

At the highest accessible energies, the dynamic aperture of LEP will be sharply reduced by the RBSC instability.

Copies of poster, paper and related material from

`http://wwwslap.cern.ch/~jowett/pac99.html`