Beam Physics Note 10

25 November 1998

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Effects of the sextupole configuration on the performance of the (102°,90°) optics in LEP

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Keywords: LEP, optics, dynamic aperture, emittance, detuning

Summary

The (102°,90°) optics used in LEP in 1998 had a new sextupole configuration. This led to a substantial increase of dynamic aperture. This note summarises the calculations and illustrates the physics behind this. It also discusses other beam parameters such as the vertical emittance.

Introduction

This note contains copies of transparencies shown at the LEP Studies Working Group meeting of 7 April 1998 where I discussed the effects of the new sextupole configuration adopted in 1998 on the expected performance of the (102°,90°) optics. It consists of a comparison of the old sextupole configuration (as used in 1997) and two versions of the new one proposed by A. Verdier. The second of these ("vrd3") corresponds to what was subsequently used in LEP during the 1998 run. The procedure followed was the usual systematic Monte-Carlo study of an ensemble of imperfect machines followed by exploratory tracking of particles to understand the physics of large-amplitude particle motion.

Although based on very extensive calculations, the presentation is brief and does not give the details expected in proper scientific text. However, as I think the information is quite important for our understanding of the performance of LEP and is not available elsewhere, I thought it useful to make it available informally in this series of notes.

If time allows, a version in proper form may be prepared later. Meanwhile, all the results are available in public files and databases. This is especially true for the exploratory tracking data where many cases have been treated. Please contact me for details if you are interested.

Finally, these transparencies made heavy use of colour. You can view them online at

`http://wwwslap.cern.ch/~jowett/JMJdocs.html#BPnotes`

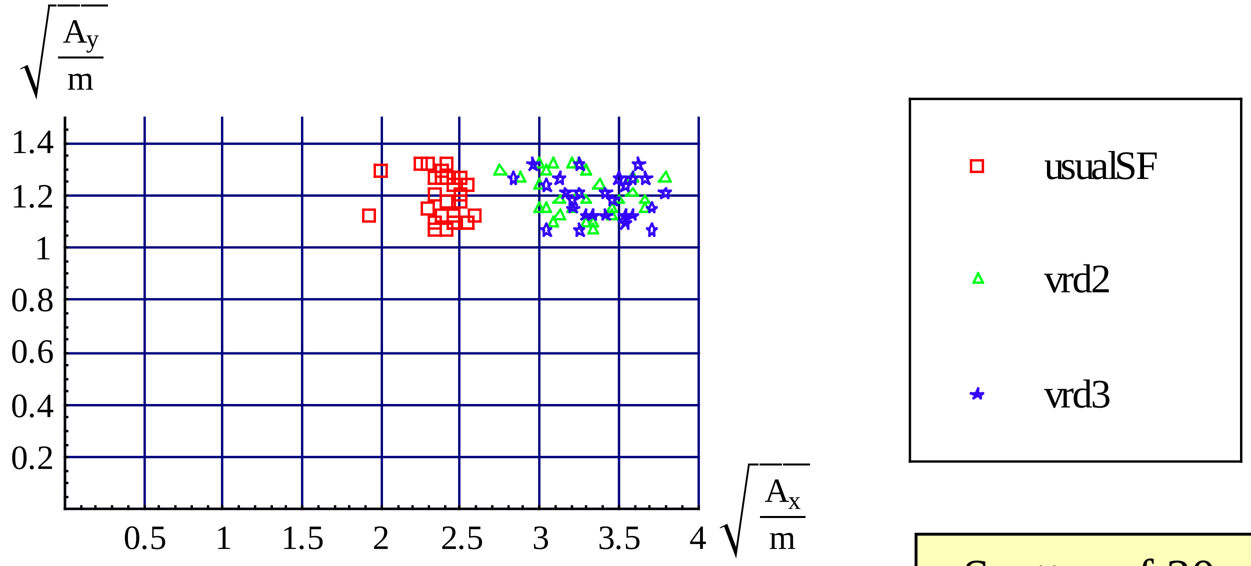
Evaluation of Sextupole Recabling for (102°,90°) Optics

- (102°,90°) optics, β_y^*=0.05 m, β_x^*=1.5 m, 94 GeV, 3 cases considered:
- usualSF: 1 horizontal sextupole family (as last year)
- vrd2: recabling into two families proposed by A. Verdier, reduces detuning with amplitude
- vrd3: recabling into two families proposed by A. Verdier, reduces detuning with amplitude, better chromatic behaviour

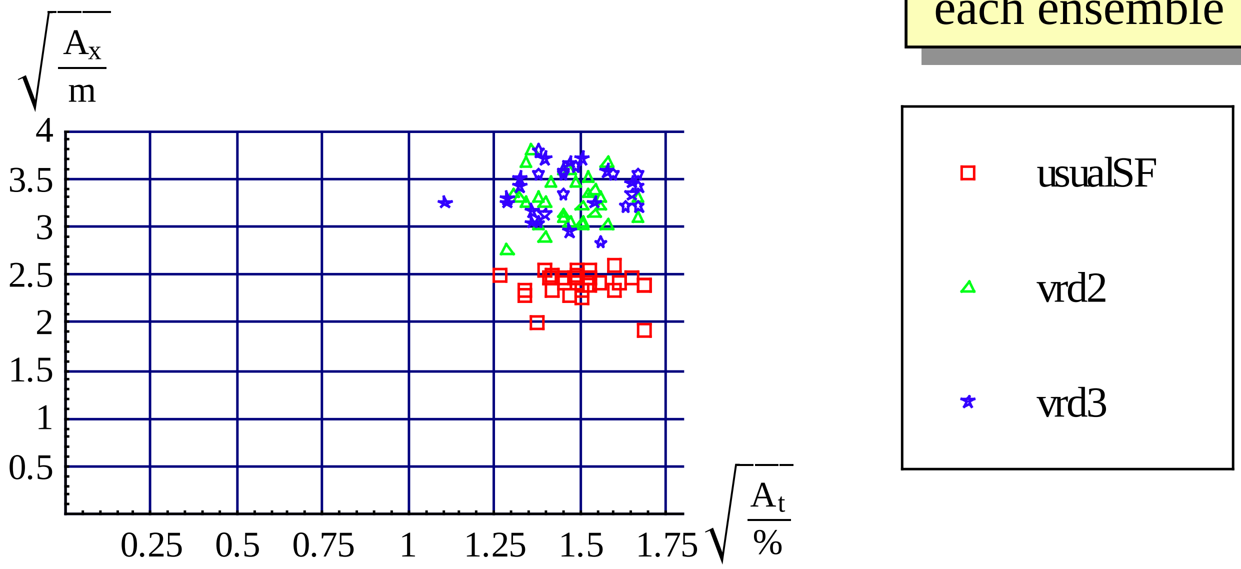
Optics Evaluation Procedure

- Optics, nominal beam energy, detailed RF configuration etc. define machine configuration.
- Correct linear coupling from solenoids.
- Ensemble of 30 imperfect machines generated:
  - Random field errors, tilts and misalignments applied to all magnetic elements. Realistic magnitudes.
  - Experimental solenoids and the sliced-up quadrupoles embedded in their fields are given special treatment to ensure the proper correlations among their random displacements and tilts.
  - "Collimators" are inserted in many elements in order to simulate the vacuum chamber for tracking.
  - Real RF. Electrostatic separators not excited.
- Corrections to each machine:
  - Orbit corrected to 0.6 mm RMS in x, 0.4 mm RMS in y.
  - The β_y* are corrected to nominal values at each IP (simulate operational method).
  - Tunes of positron beam corrected to nominal.
- *Physically equivalent* imperfect machines are constructed for the *positrons* and *electrons*.
- 4D dynamic aperture scan for each machine.
- Quantum tracking to get the “real” vertical emittance.

1D Dynamic aperture projections



Scatter of 30 machines in each ensemble



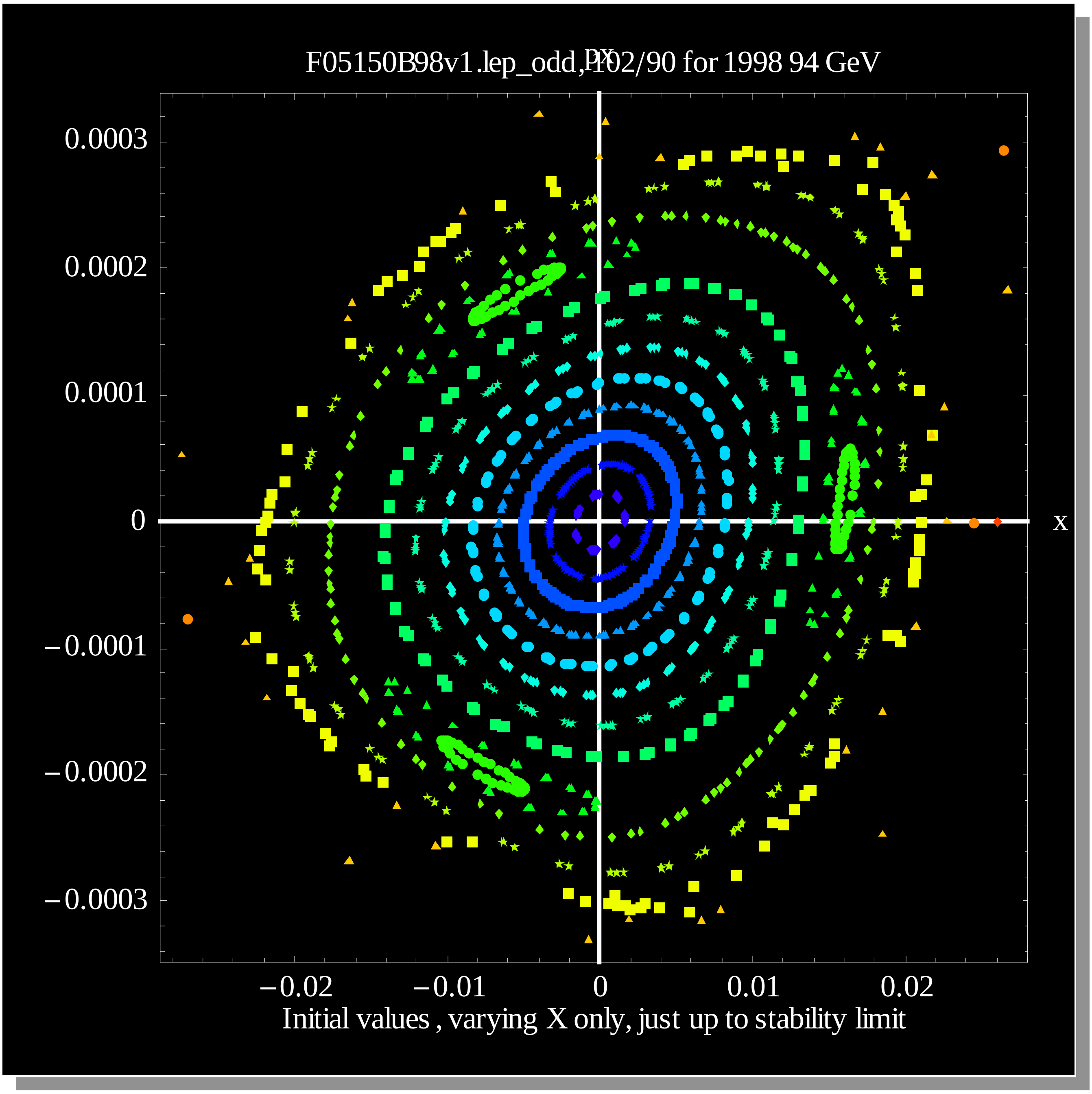
- Vrd2 OR vrd3 ⇒ improvement in *horizontal* dynamic aperture.
- Vertical dynamic aperture and momentum acceptance do not change significantly.

Tracking examples

- Compare the two cases 1m50usualSF and 1m50vrd3 by tracking on following slides
- Initial conditions mostly varying horizontal deviations from closed orbit at IP1, sometimes vertical
- Usually colours indicate increasing initial amplitude (blue is small, red is large)
- Tracking is either “symplectic with radiation” or with radiation damping (easy to distinguish)
- Look at the three phase planes and some Fourier spectra of the co-ordinates (shows detuning with amplitude)

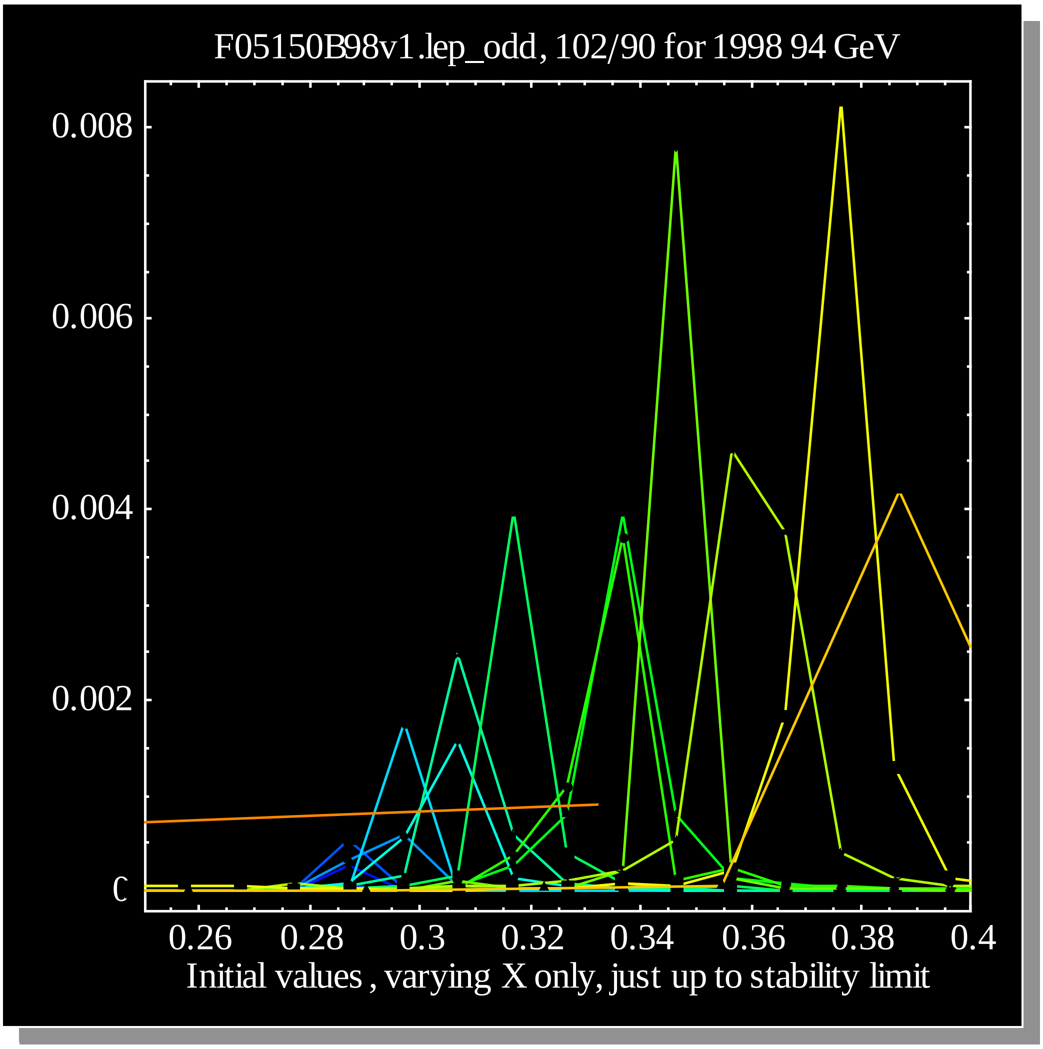
1m50usualSF

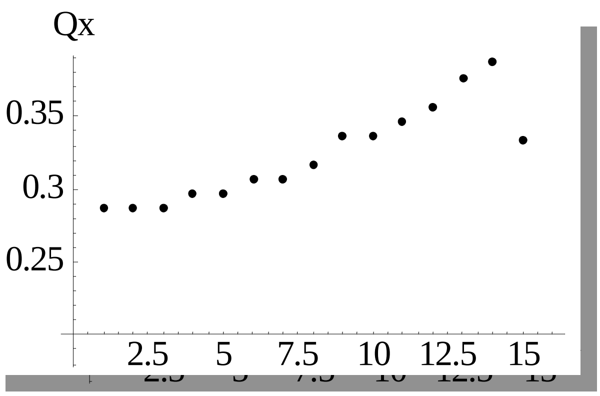
- Initial values, varying X only from closed orbit, just up to stability limit
  - 3rd order resonance visible, but does not cause instability directly



1m50usua lSF, detuning

- Spectra of horizontal motion as initial amplitude is increased

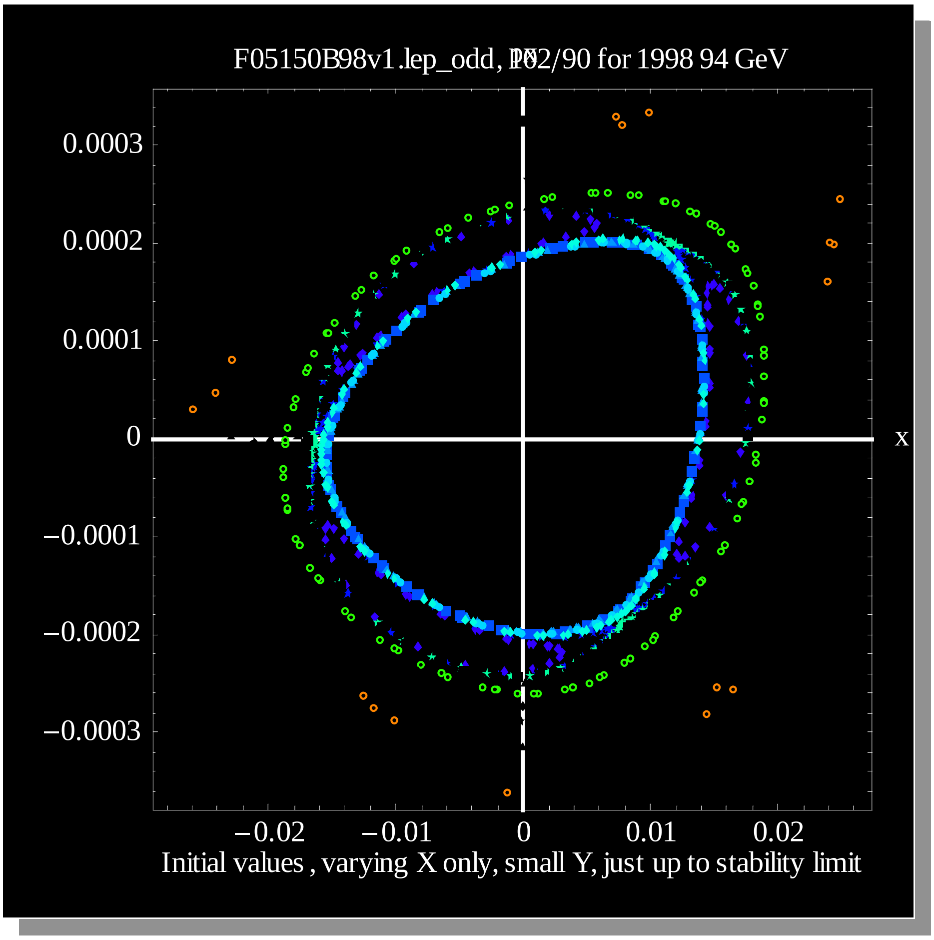


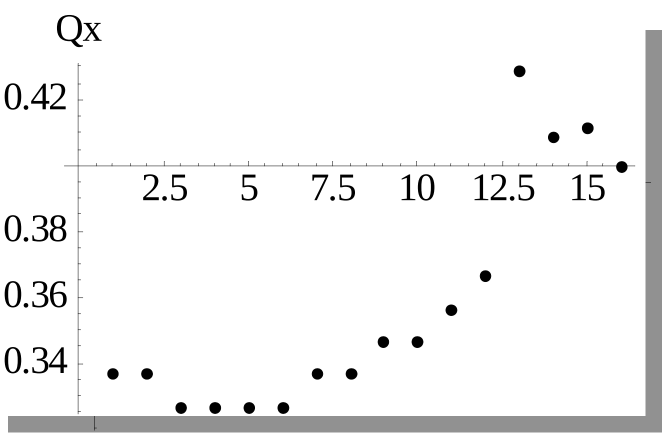


1m50usualSF

- Same again, except that all particles have *y*= 0.2mm initially

  Detuning with amplitude changes in character



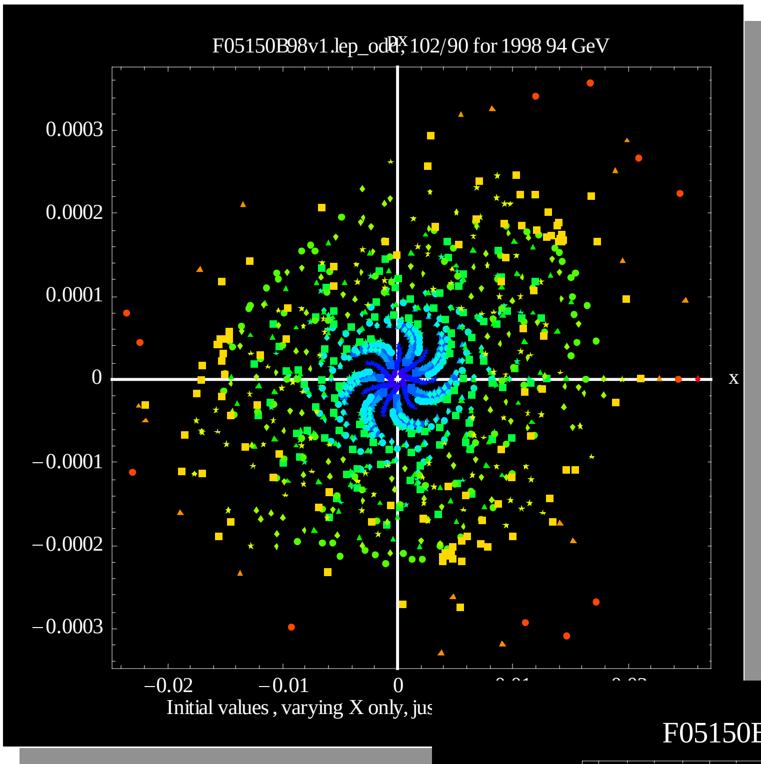


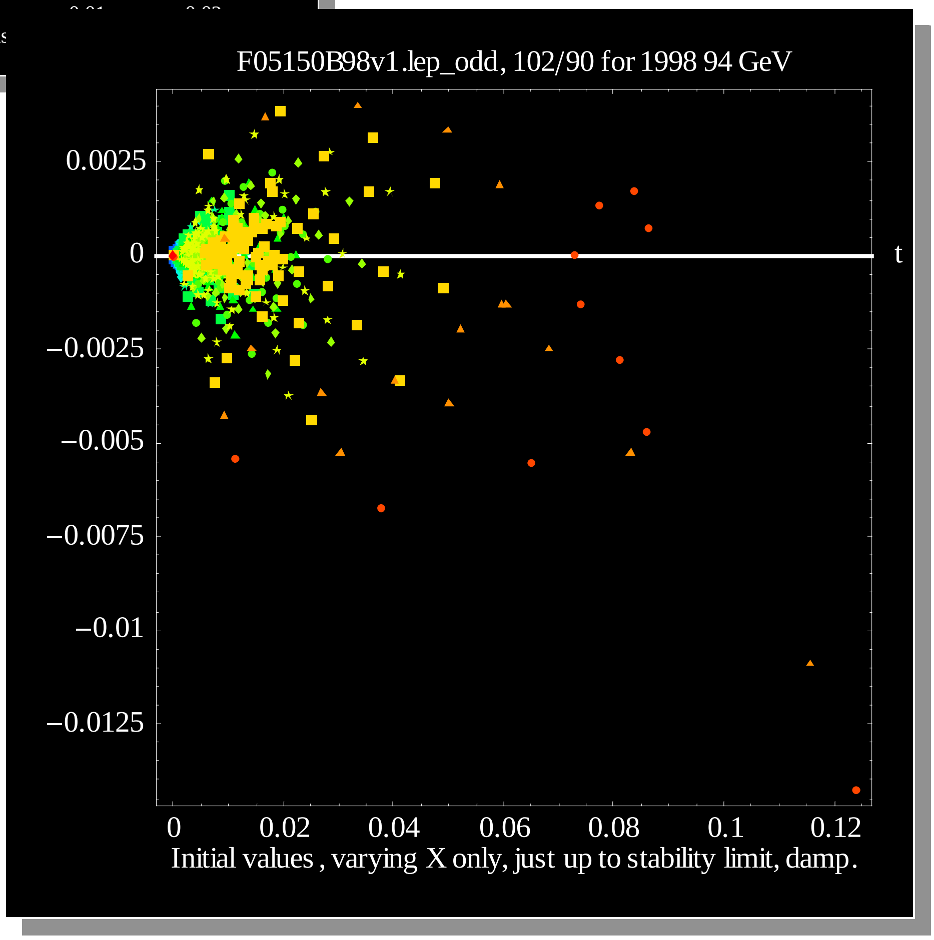
1m50usualSF, damping

- Same again, add radiation damping

  Harder to see effect of resonance …

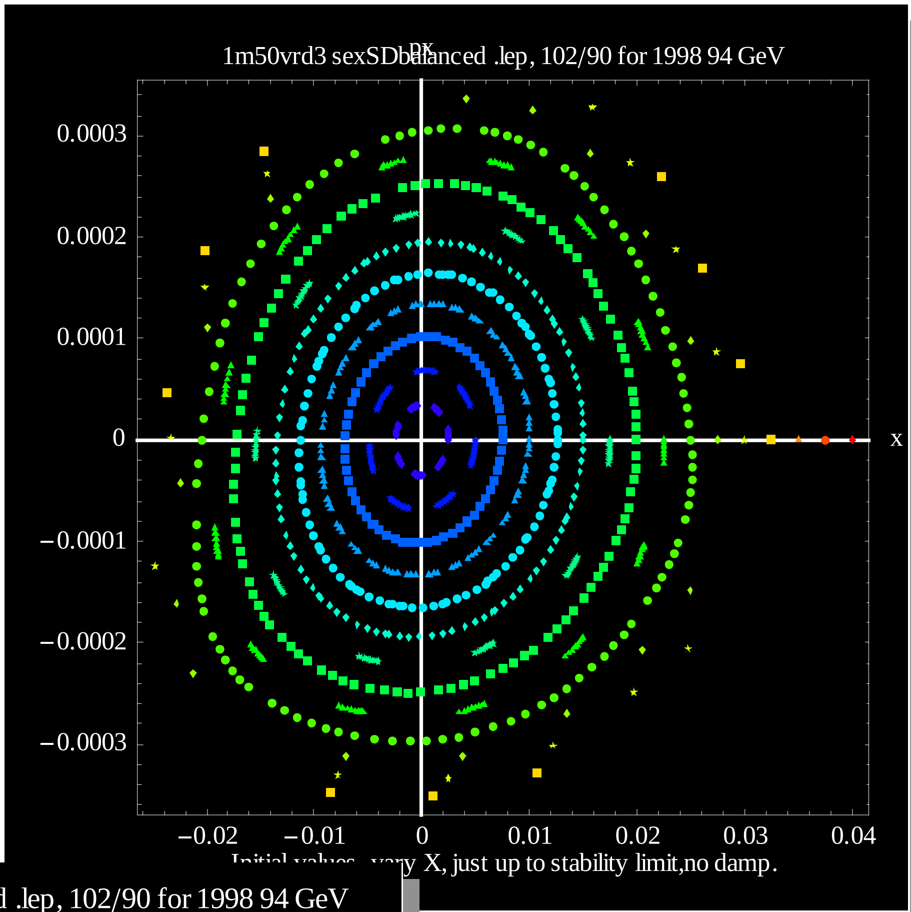
  RBSC effect in synchrotron phase space

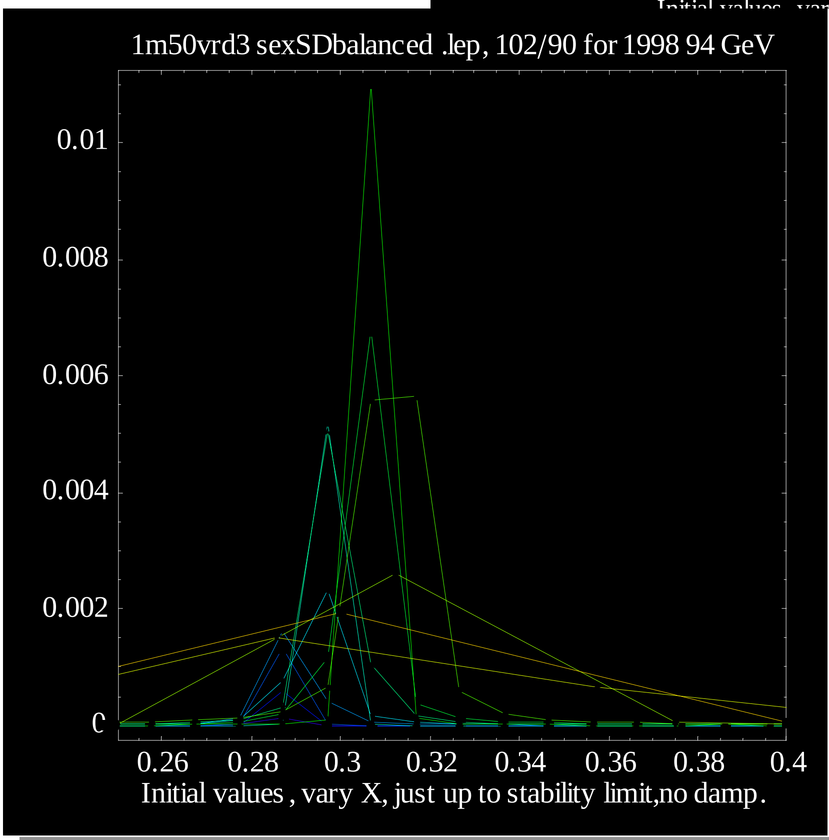




1m50vrd3, no damping

- Initial conditions now go to larger amplitude
  - 3rd order resonance no longer within dynamic aperture

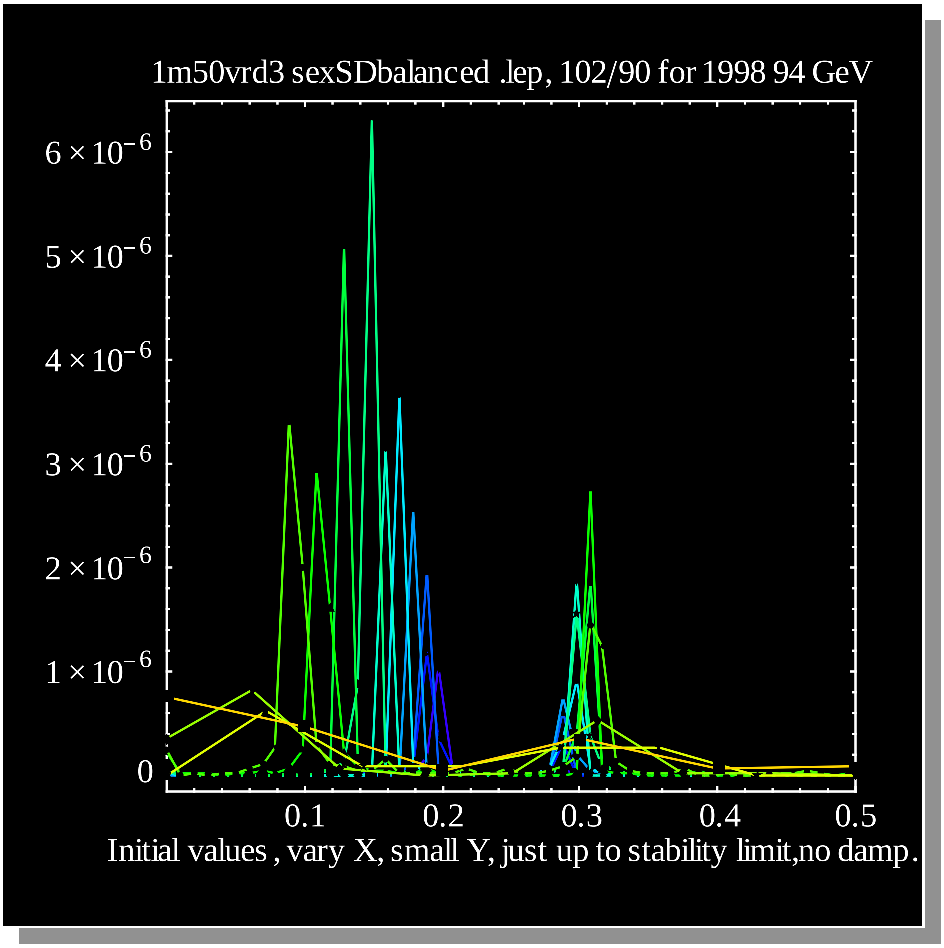




Fourier spectra of X motion do not reach 1/3

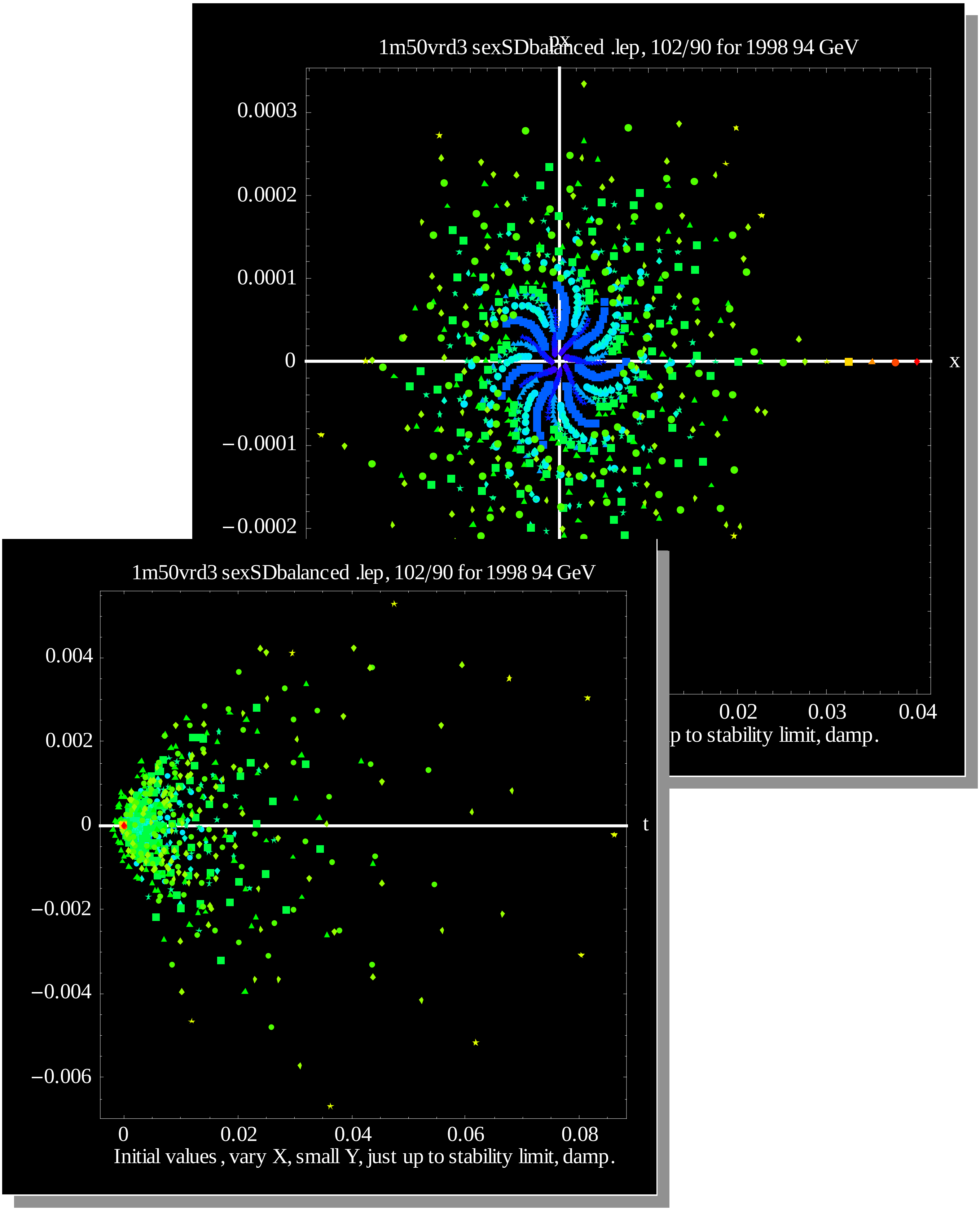
1m50vrd3, no damping

- Add initial vertical displacement, see effect of increasing *x* on vertical tune
  - Cross detuning may contribute to horizontal dynamic aperture limit



1m50vrd3, damping

- Qualitatively similar to 1m50usualSF but dynamic aperture is larger, RBSC again



Some Mean Parameters

- Mean values of a selection of global machine parameters over each ensemble.

  Standard deviations not shown here.

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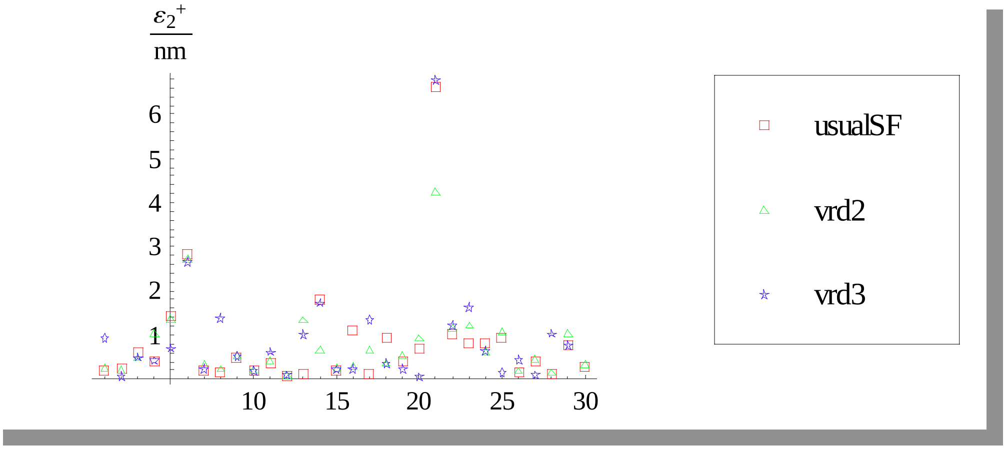
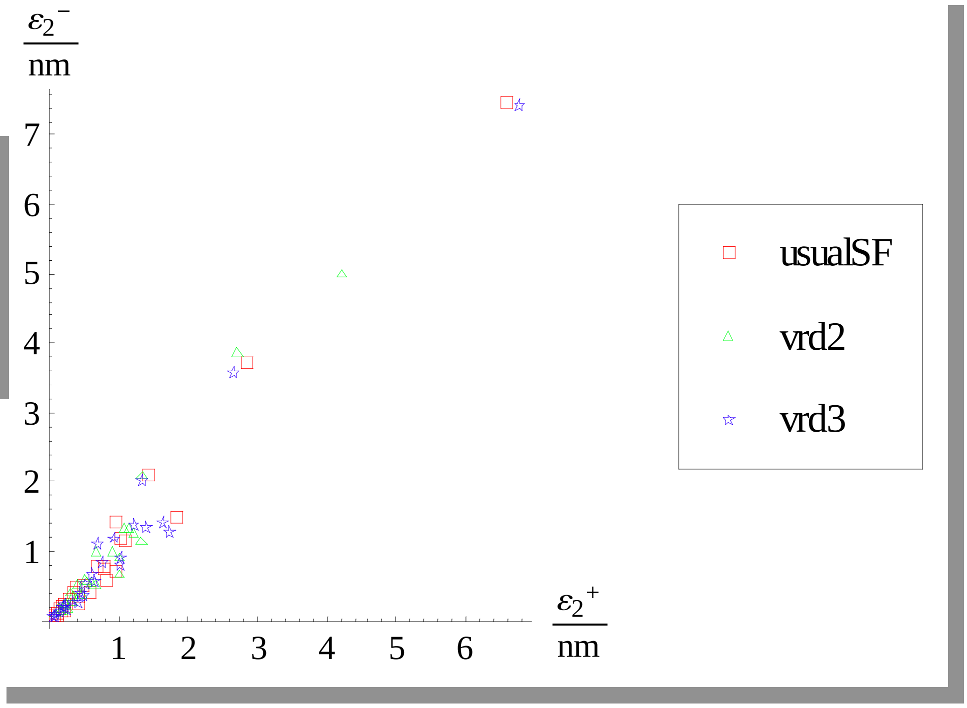
	usualSF	vrd2	vrd3
$\varepsilon_1{}^+$	40.5 nm	40.31 nm	40.02 nm
$\varepsilon_1{}^-$	40.44 nm	40.37 nm	40.07 nm
$Q_1{}^+$	0.2839	0.2839	0.2839
$Q_1{}^-$	0.2841	0.2841	0.2839
$\sqrt{\overline{D_y{}^2}}^{\,+}$	0.03728 m	0.03884 m	0.03976 m
$\sqrt{\overline{D_y{}^2}}^{\,-}$	0.03904 m	0.04027 m	0.03963 m
$J_2{}^+$	0.9734	0.9819	0.9752
$\varepsilon_2{}^+$	0.8131 nm	0.7609 nm	0.8975 nm
$J_2{}^-$	0.9744	0.9817	0.9738
$\varepsilon_2{}^-$	0.8884 nm	0.8489 nm	0.9614 nm
$Q_2{}^+$	0.1949	0.1949	0.1949
$Q_2{}^-$	0.2154	0.2153	0.2369
$\sigma_\epsilon{}^+$	0.001471	0.001473	0.001472
$\sigma_\epsilon{}^-$	0.001472	0.001473	0.001471

(Linear) Vertical Emittance



Correlation of positron and electron vertical emittances

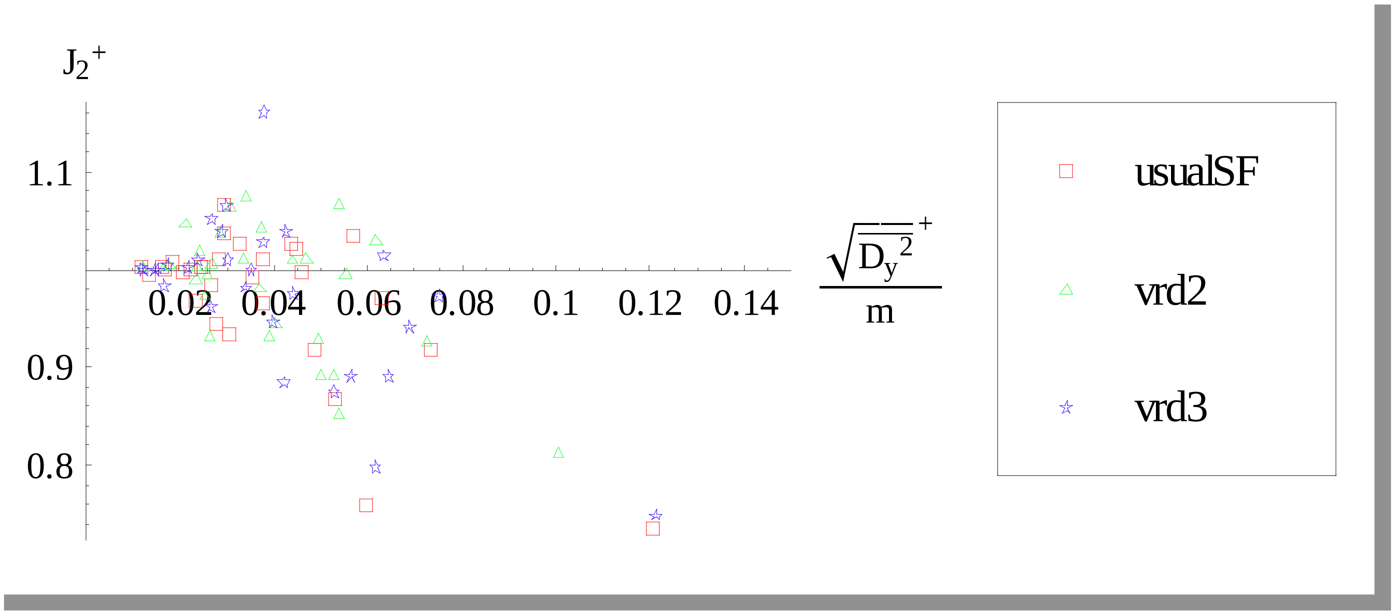


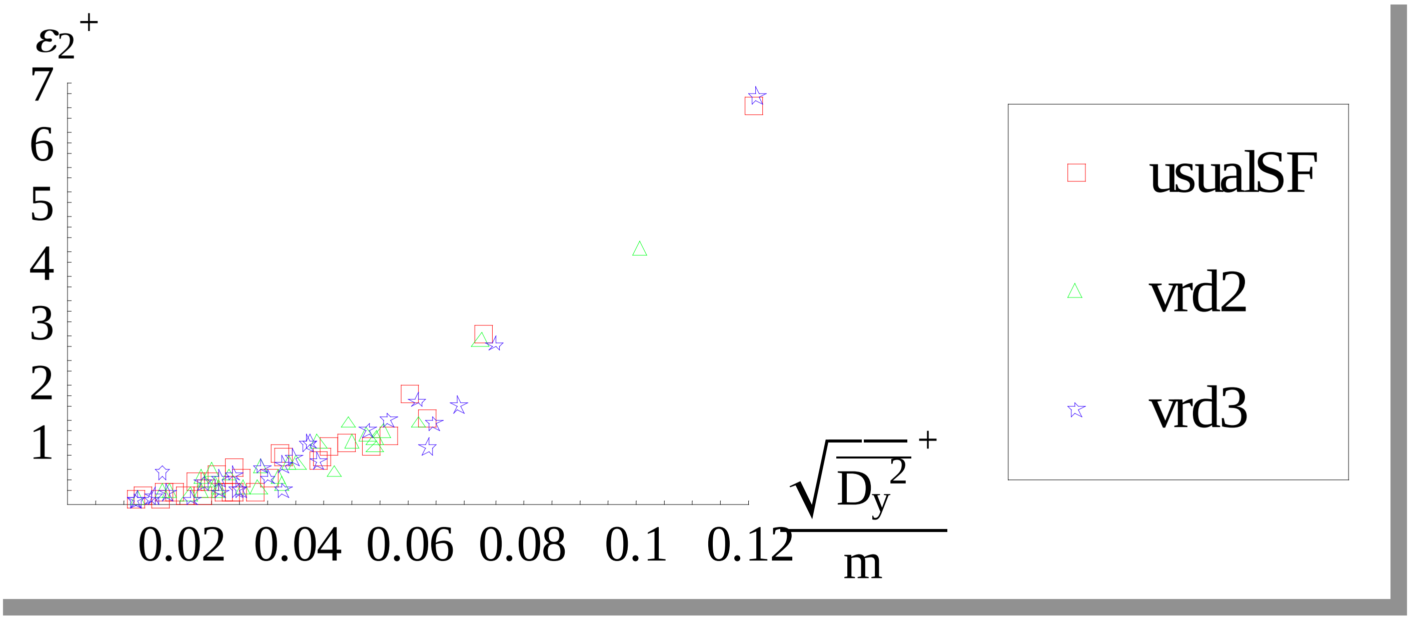
- High correlation among linear vertical emittances for the three configurations

  $\Rightarrow$ Vertical emittance does not depend much on the sextupole configuration

- Small vertical emittance remains attainable

Effects of vertical dispersion





- Vertical emittance generated by vertical quantum excitation (as usual)

No significant difference between configurations.

Conclusions

- Monte-Carlo comparison of the (102°,90°) optics with the usual sextupole cabling and the two proposals (1m50vrd2,1m50vrd3)
- Ensembles of 30 imperfect machines corrected as in operation.   Almost all machines stable.
- Sextupole re-cabling *increases the dynamic aperture.*
- Horizontal dynamic aperture is not determined by 3rd order resonance.
  - Actually combination of effects.
- Dynamic aperture of 1m50vrd3 determined by cross-detuning and RBSC
  - Similar to (90°,60°).
- Present understanding of development of beam tails (see Chamonix 1997) suggests that 1m50vrd3 may have less populated tails at large amplitude.
  - *This is semi-conjecture, not result of a calculation!*
- Linear vertical emittance remains small.
- Quantum tracking of 1m50vrd3 case (not presented here) looks similar to other optics.