Preparation and status of beam-beam tracking

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Preparation for tune scans at collision with triplet errors and correction

- triplet correction
  1. Thanks and references
  2. Theory (here with Lie algebra)
  3. found that MCX2 is badly positioned in V6.4
  4. how correction was tested with MadX
  5. comparison with Note 310 (ST tracking)
  6. FFT
- automatic finder of the chaos border
- the new ST environment and what was done this month
- Lie algebra on a notebook ("LieMath") if there is time

Triplet correction: Thanks

- Stephane for the Triplet and Coupling scripts
- Stephane and Andre for confirming my suspicions that the triplet corrector MCX2 CANNOT stay at a place where $\boldsymbol{\beta_x = \beta_y}$

  as this is the case in 6.4,
  but it is changed in 6.5

  (you get an independent study & discovery of this fact)

Triplet correction: References

1. Dynamic Aperture Limitations if the LHC in physics conditions due to low-beta Insertions, A. Faus-Golfe and A. Verdier, EPAC??.
2. A. Faus-Golfe and A. Verdier, Multipole compensation in the LHC low-beta insertions, LHC Pr Rep. 116
3. H. Grote, F. Schmidt, L.H.A. Leunissen, LHC Dynamic Aperture at Collision, LHC Project Note 197, August 1999
4. Y. Luo,F. Schmidt, Dynamic Aperture Studies for LHC Optics Version 6.2 at Collision, LHC Project Note 310, ⇐ we compare with this

Triplet correction:
the total multipole kick at location i is

$$\boldsymbol{X_{exit} = e^{:f_i^{kick}:} X_{|X \to X_i}},$$
$$\boldsymbol{X = (x, px, y, py)}$$
$$\boldsymbol{f_i^{kick}(x,y) = Re \sum_{n=1}^{Nord} \frac{1}{n+1} (\mathrm{KNL}[n]_i + i\ \mathrm{KSL}[n]_i)(x+iy)^{n+1}}$$

notations as in MadX

Lie factor map $e^{:F:}$ for a perfect IR

A beamline = kicks + linear elements. The map is:

$$:\mathcal{M}: = \prod_{k=1}^{N_{ele}} e^{:f_k:} = \cdots = \prod_{i=1}^{N_{kicks}} e^{:f_i^{kick}(\tilde{R}_i.X):} R_{tot}$$

Factors $f_i^{kick}(\tilde{R}_i.X)$ appear, where $\tilde{R}_i = \prod_k R_k$ is the 4x4 R-matrix from the entrance to the i-th kick and R_{tot} is the tot. matrix. Next one uses BCH to concatenate into one kick $e^{:F:}$

- the monomials $f_i^{kick}(X)$ do not contain p_x, p_y.
- perfect IR: phase adv. is constant left, or right of the IP and jumps by π at the IP.
- $\Rightarrow \tilde{R}_i.(x,0,y,0)^T$ just multiplies x by $\pm\sqrt{\frac{\beta_{x,i}}{\beta_{x,1}}}$ and the same for y

  $\Rightarrow$ all $f_i^{kick}(\tilde{R}_i.X)$ do not depend on px,py

  $\Rightarrow$ all Poisson brackets in the BCH disappear $\Rightarrow$ F is a sum over factors

$$F_n = \frac{x^l y^m}{(\sqrt{\beta_{x,1}})^l(\sqrt{\beta_{y,1}})^m} \sum_{i=1}^{N} \mathrm{KNL}[n]_i (\sqrt{\beta_{x,i}})^l (\sqrt{\beta_{y,i}})^m = 0$$

One should not place tripl. corrector at equal horiz. and vert. betas:

Take the b4 or a4 error and denote $\mathrm{KNL}[3]$ or $\mathrm{KSL}[3] = \mathrm{K}$

For a fixed IR, a linear system for the two (Left and Right) correctors K_L and K_R (minus sign for KSL):

$$\sum_L \tilde{\mathrm{K}}_L \tilde{\beta}^2_{x,L} + \mathrm{K}_L \beta^2_{x,L} \pm (\sum_R \tilde{\mathrm{K}}_R \tilde{\beta}^2_{x,R} + \mathrm{K}_R \beta^2_{x,R}) = 0$$

$$\sum_L \tilde{\mathrm{K}}_L \tilde{\beta}^2_{y,L} + \mathrm{K}_L \beta^2_{y,L} \pm (\sum_R \tilde{\mathrm{K}}_R \tilde{\beta}^2_{y,R} + \mathrm{K}_R \beta^2_{y,R}) = 0$$

The Det is (antisymmetry: $\beta_{x,L} \approx \beta_{y,R}$):

$$Det = \beta^2_{x,L}\beta^2_{y,R} - \beta^2_{y,L}\beta^2_{x,R} \approx \beta^4_{x,L} - \beta^4_{y,L} \approx \beta^4_{x,R} - \beta^4_{y,R}, \qquad (1)$$

$\beta_{x,L} \approx \beta_{y,L} \rightarrow Det \approx 0 \rightarrow$ large corr. strengths $\rightarrow$ **destroys optics**

Test it with MadX (measuring driving term x^4 with tracking)

1. apply only multipole error b4
2. track for one turn in the hor. plane
3. print out in trrun.F x_i and the total kick above quadrupole: $\Delta p_{x,i}$

   Since just one term is present, the kick at loc. i is: $\quad i = 1, \ldots, 144$

$$\Delta p_{x,i} = \frac{x_i^3}{6} \mathrm{KNL}[3]_i, \tag{2}$$

4. subst $\mathrm{KNL}[3]_i$ from (2) in the first sum (previous page)
5. check that these 4 sums are zero

$$\sum_{\text{i over each IR}} \frac{6\Delta p_{x,i}}{x_i^3} \, \beta_{x,i}^2 = 0$$

Compare with Note 310 (V6.2)
Conditions:

- V6.4 with MCX2 moved to where $\beta_x \neq \beta_y$
- collision; w.point = 64.31/59.32 ; 10^5 turns; 60 seeds
- with crossing at four IPs $\longrightarrow$ head on + long range
- with table 0210 and only MQX errors (of order > 2);
- with full triplet correction in all 4 insertions;
- the border of the chaotic region found with automatic script.

Compare with Note 310 (bottom right).
1) no beam-beam
top two: no tripl. correction   bottom two: with tripl. correction

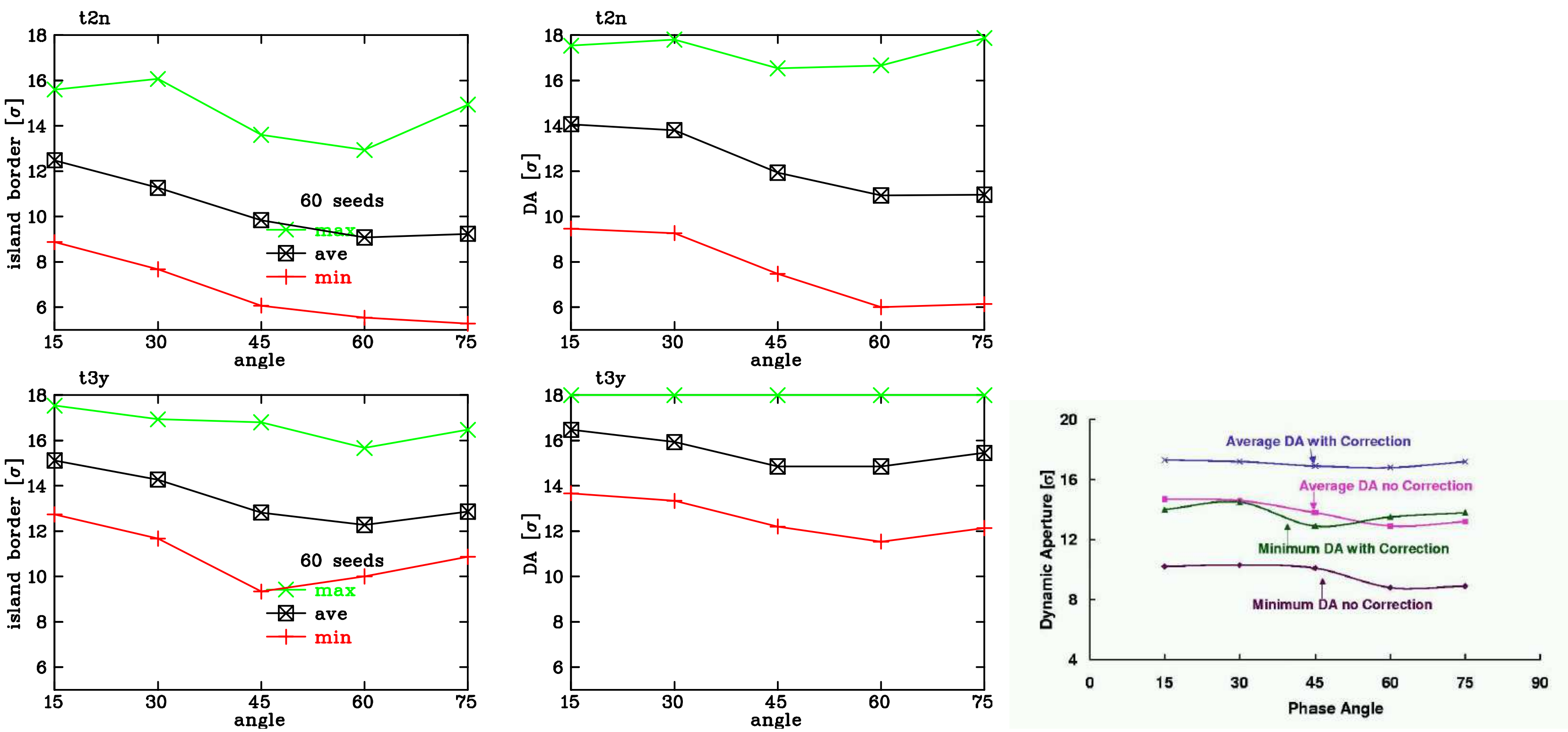


Figure 1: <u>No beam-beam</u>; green = max.; black = average; red = min. **Improvement of chaos border:** minimum by 3 sigma and average by more than 2 sigma; **of dynamic aperture**: minimum by 2-5 sigma and average by 2-4 sigma.

Compare with Note 310
2) with beam-beam

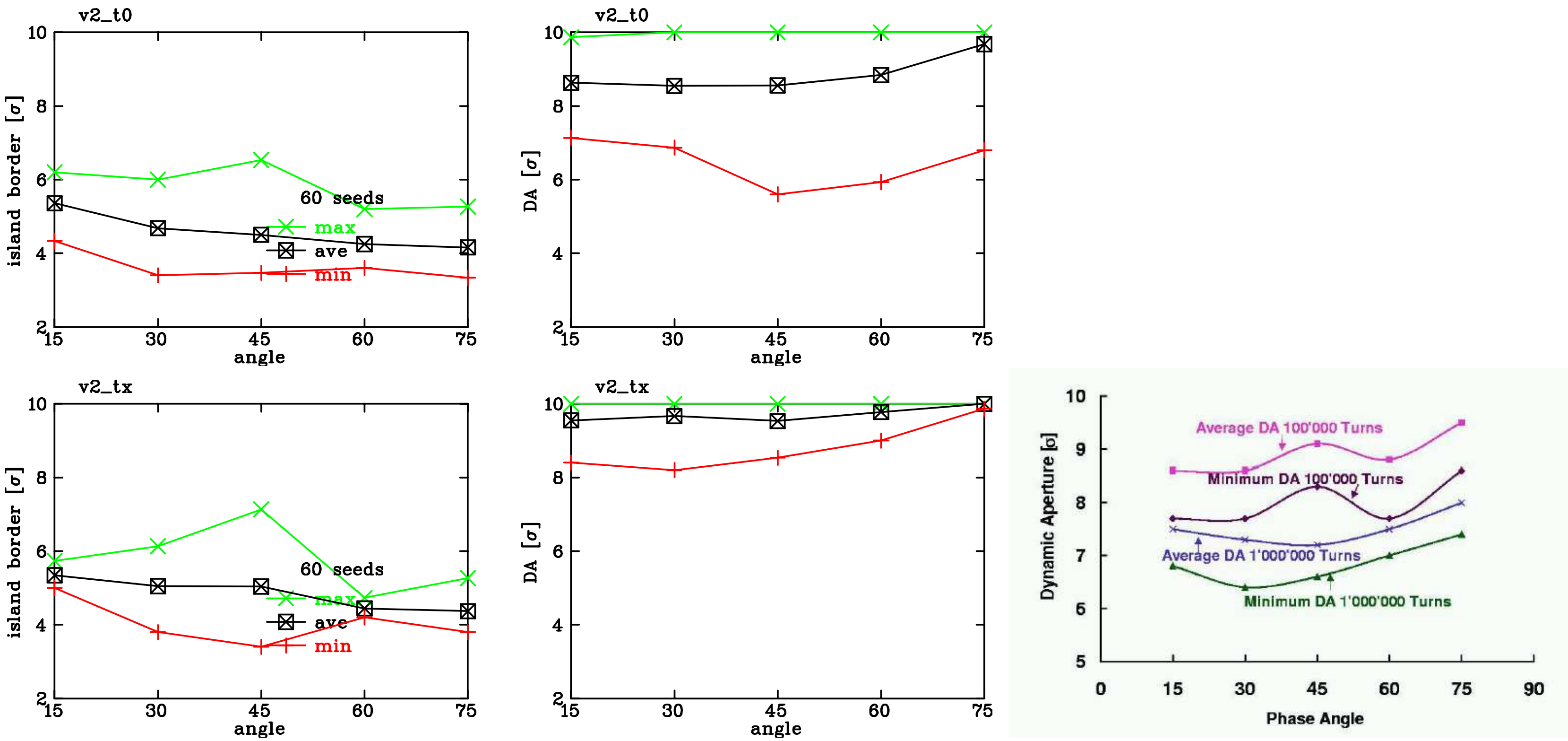
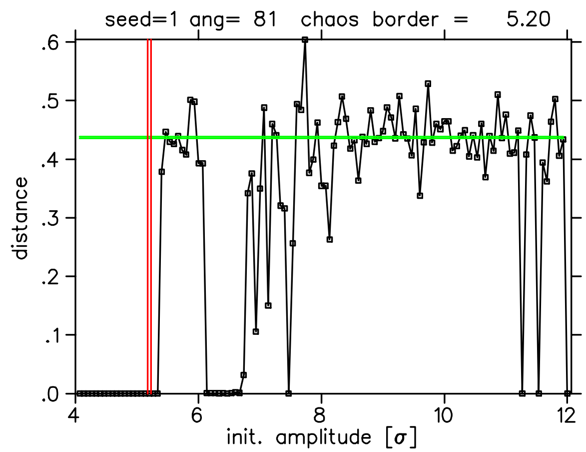
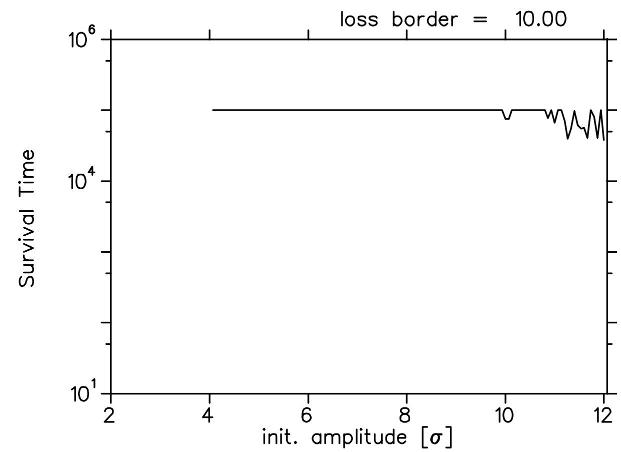
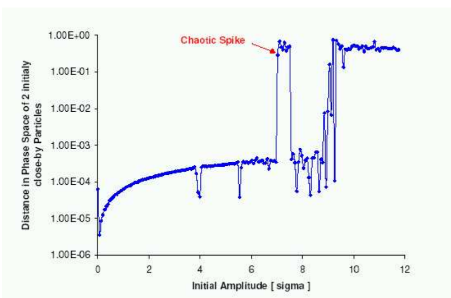


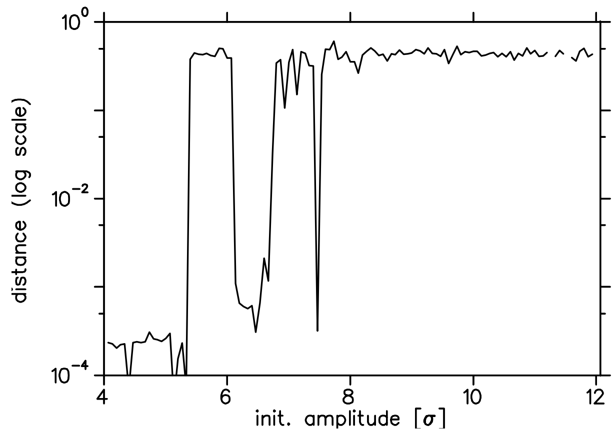
Figure 2: <u>With beam-beam</u>; **Improvement of island border:** minimum by 1-2 sigma and average by < 1 sigma; **of dynamic aperture**: minimum by 2-3 sigma and average by around 1 sigma.

Automatic search for the chaos border (vert. red line)

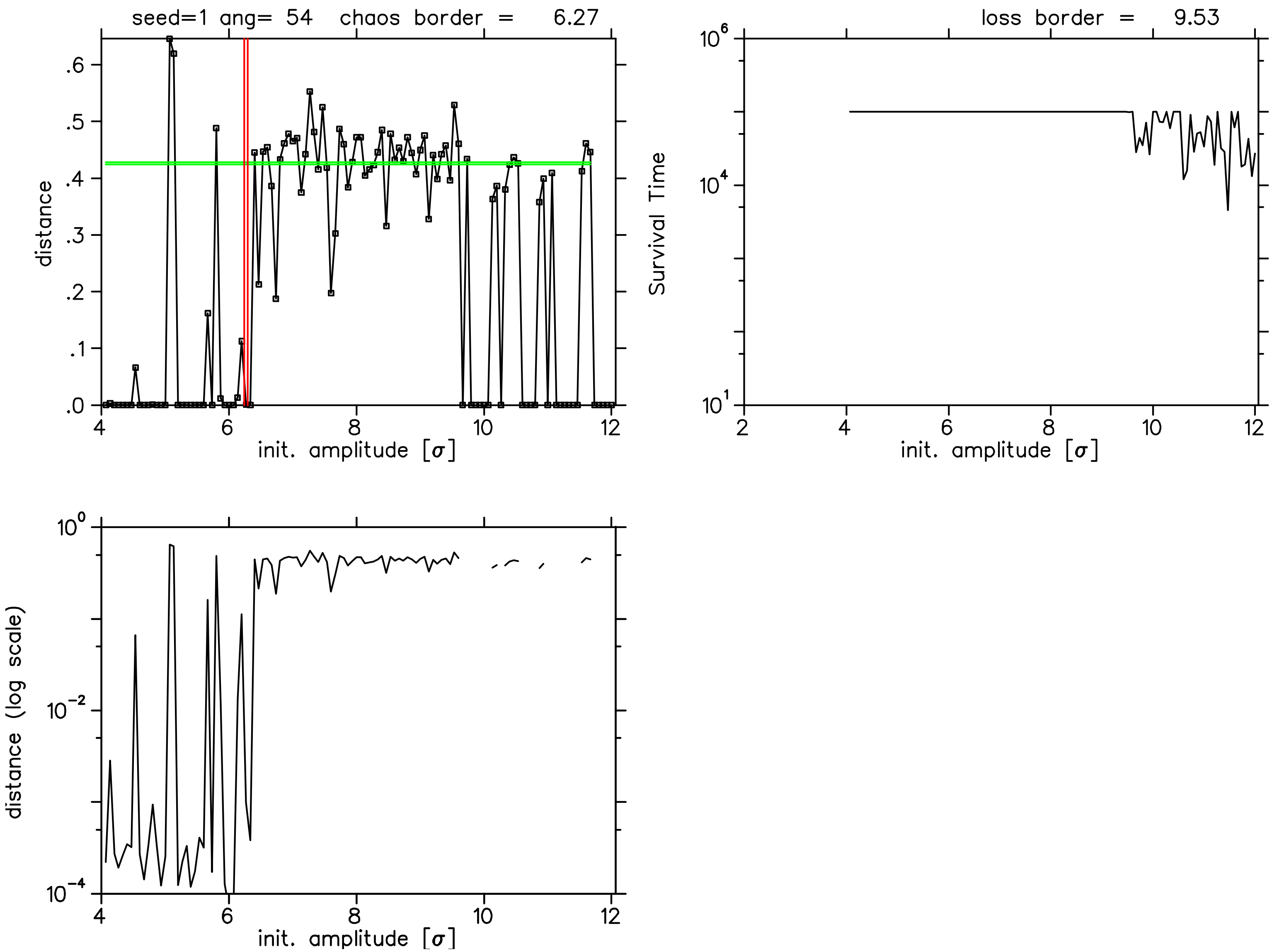






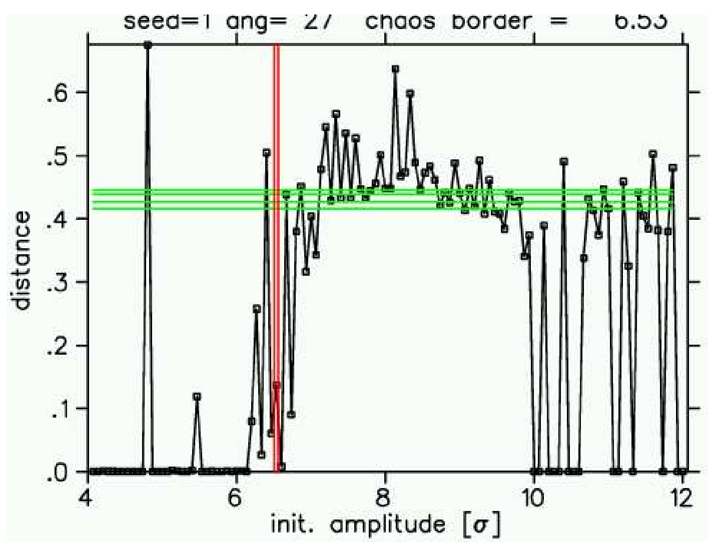


Automatic finder of chaotic-border (continued)



Method:

1. regular motion on the left (“sea”); chaos region on the right (“shore”)
2. find mean shore hight w.r.t. sea level $\rightarrow$ iterations (in green)
3. slide from left to right an amplitude window $0.3\ \sigma$ wide ($=$ 5 amplitudes)
4. sufficiently **both** tall ($> 1/2$ mean shore hight) and thick ($>$ 2 of the 5 points) islands are declared to be a part of the chaotic region



fft: with and without crossing in IP1 and IP5

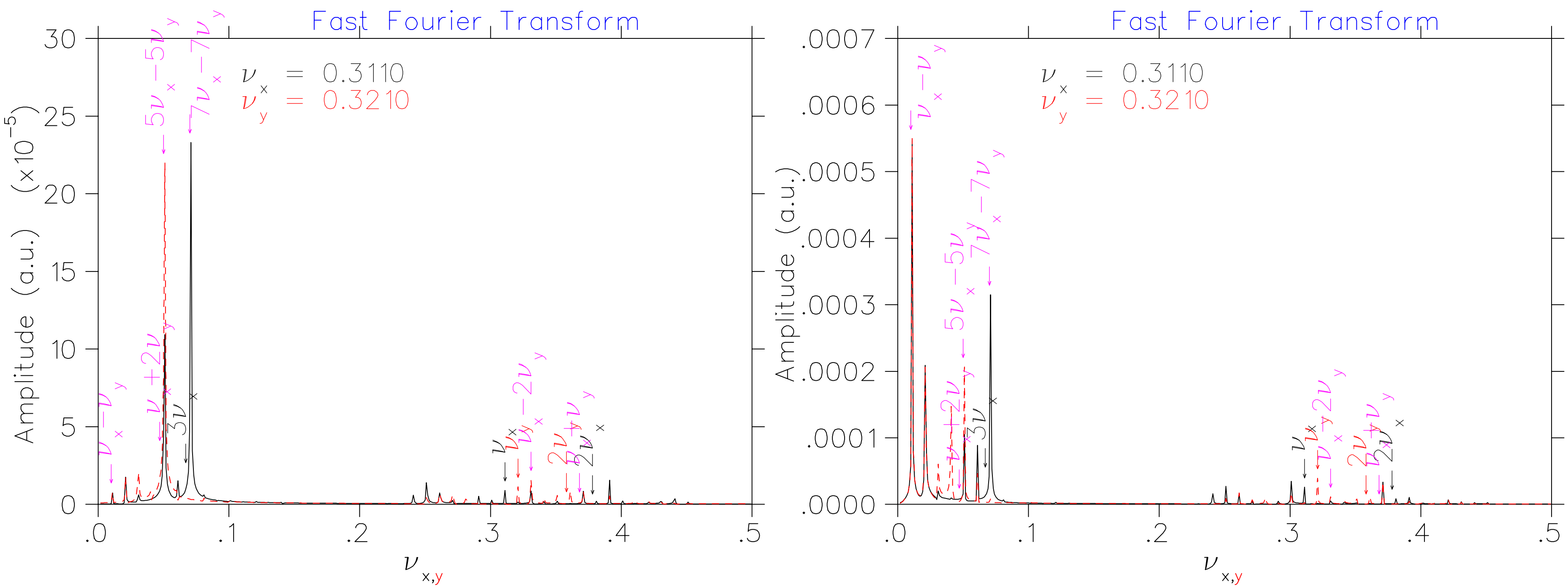


Figure 3: **Triplet errors are ON and correction is ON**. The two figures show FFT of transverse invariants: **left**: no X-ing ; **right**: with X-ing

fft: with and without triplet errors

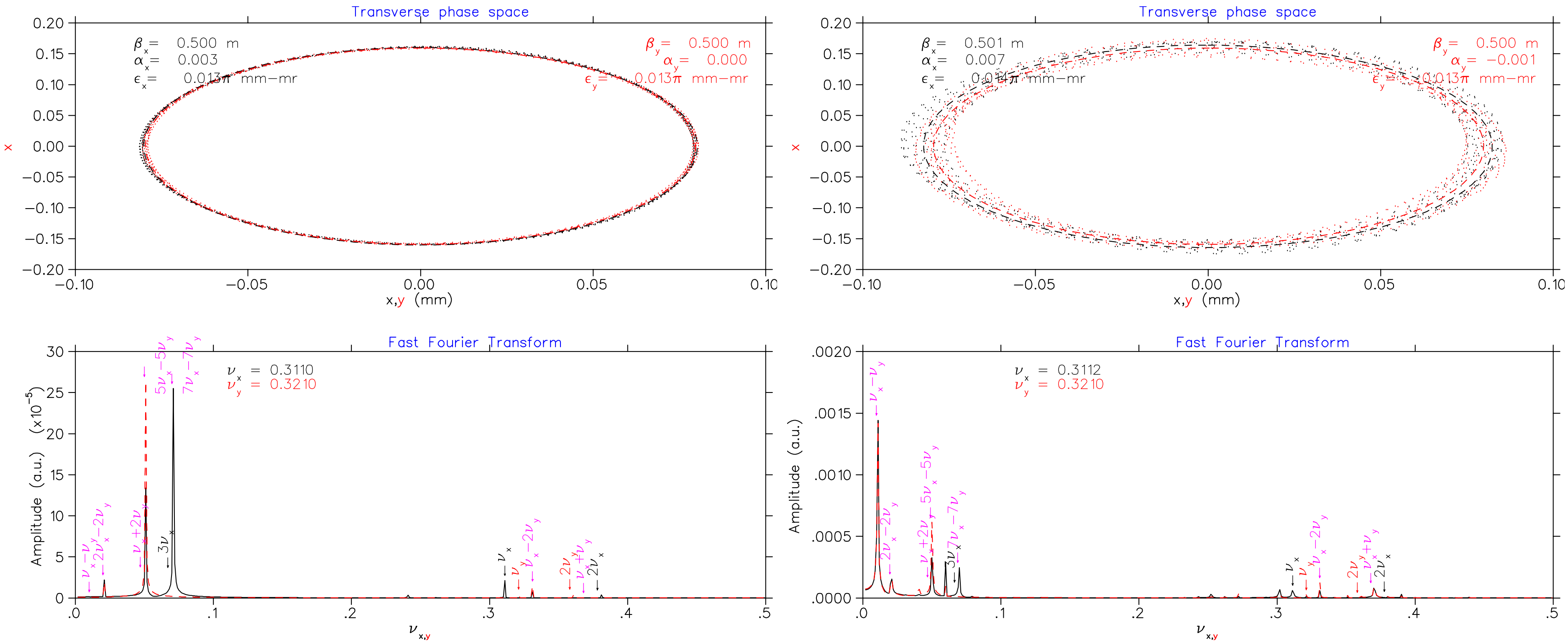


Figure 4: particle starts at x0=y0=5 σ (X-ing is on)

Left: no errors; **Right:** with errors.

... and with triplet correction

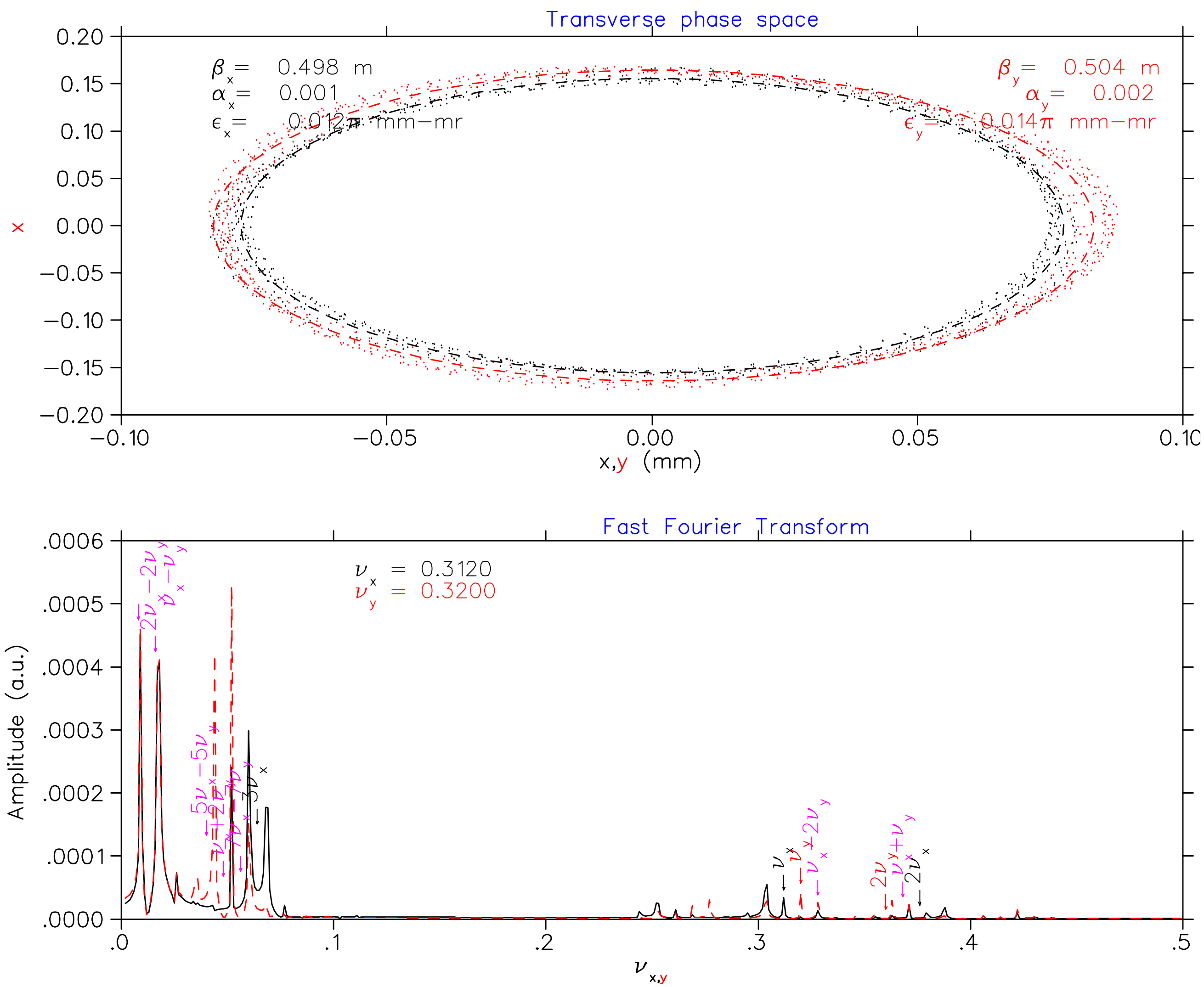


Figure 5: with tripl. errors **and correctors**

Status of the tune scans with the new ST environment

1. plans for total: 80 tunes; 4 cases; 5 two-sigma ampl. intervals; 10 angles; 60 seeds $\rightarrow \sim 1$ million jobs
2. what was done this month (Eric McIntosh)

   – finalized the new LSF environment (automatic tune scans)

   – thought me CPSS (nearly final) and Boinc

   – run 2 cases (Hor-Hor and Hor-Vert crossings) of scans over 6 tunes with triplet corr. $\rightarrow$ agrees with Werner's conclusions w.o. corr.

   – tests of the automatic chaos finder

   – my impressions of the new environment:

   wisely managed disk space; by the way: no more `COREHOME`

   improvement in `run_status` reports;
   `bjobs` in `run_status`

   `CPSS`, `BOINC` and soon LSF too will use `run_results`

LieMath

LieMath.nb

Coordnates: x, px, y, py, -E, τ or x, px, y, py,z,δ

Exact Hamiltonians: thick elements up to octupole

full expansion of the square root

Builds Factor Map Xfin = Exp[-:F:] Xini

and Taylor Map Xfin = M Xini

Normal form to 3 order (of F) chromaticity => OK

(C ijkl) anharmonicity => analyt. = OK with single sextupole

Closed orbit, but not in this demo.

More like a toy, but has solved:

-- Map of FFAG cell to 6th order (off-mom. c.o. = OK; tune wrt c.o. = OK)

-- helped to understand LHC triplet

-- Tijk agree with Mad and Dimad (Transport)

-- 4D map tracking agrees with MADX

Reference: A.Chao, http://www.slac.stanford.edu/~achao/lecturenotes.html

Dragt, Irwin, Forest,...

LieMath continued

Constants (here take relat βref)

Reading optics from MadX twiss output MathIn

Lie Algebra Tools

Expanded H

Linear optics analysis

Building the Taylor MAD to order Nord (main concatenation loop)

T-matrix (note: the diagonal elements in the Static output are divided by 2). The printout is as in Cosy.

Map iteration (4D)

Normal form -- expansion of the factor polynomial F in the resonance basis

MSC Tests