Guiding Lines for Computing and Reading a Frequency Map

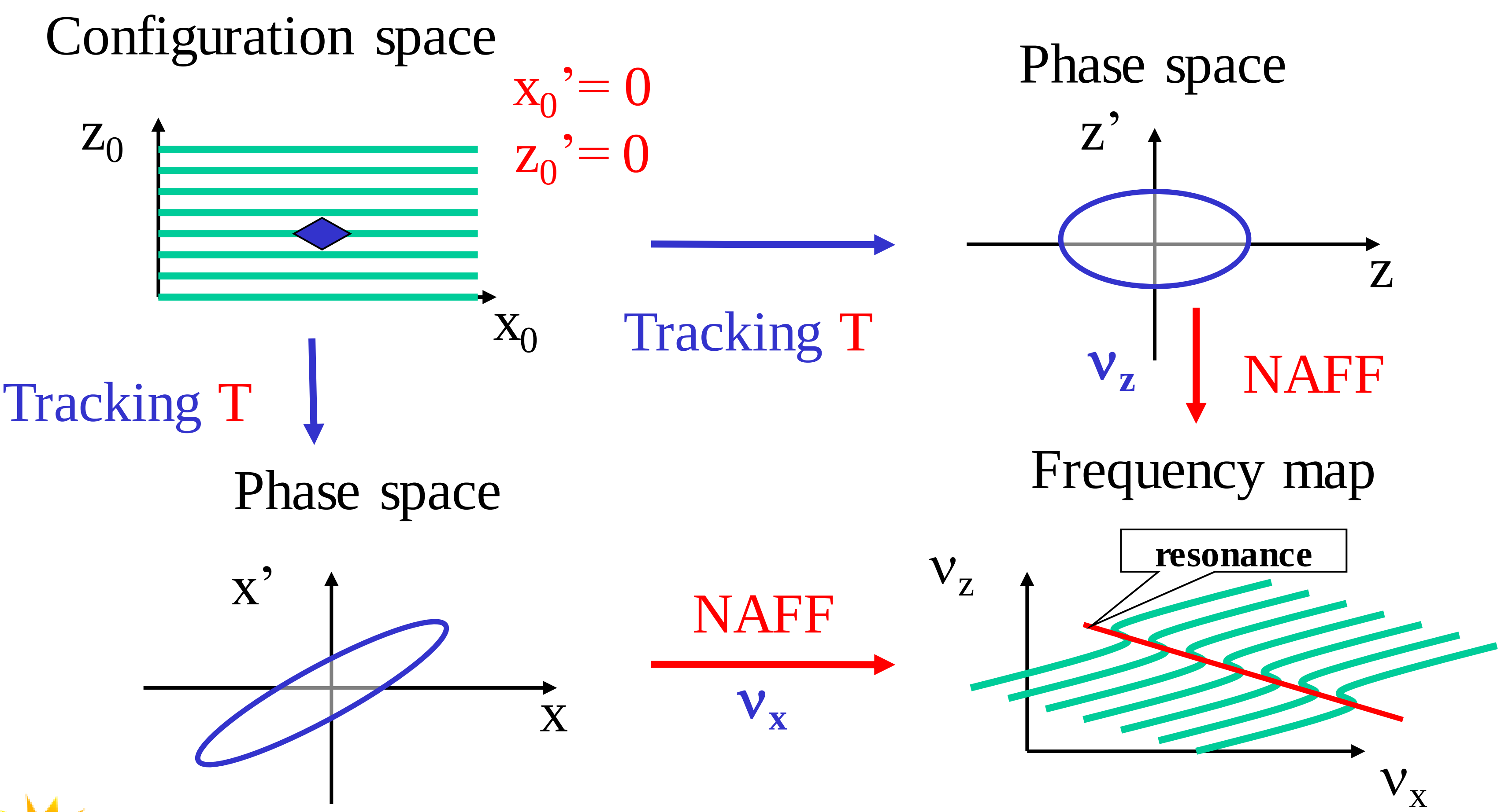
New FMA Calculations for SOLEIL including Insertion Device Effects

Laurent S. Nadolski

Pascale Brunelle and Amor Nadji

Computing a frequency map

Frequency map: $F^T : (x_0, z_0) \longrightarrow (\nu_x, \nu_z)$



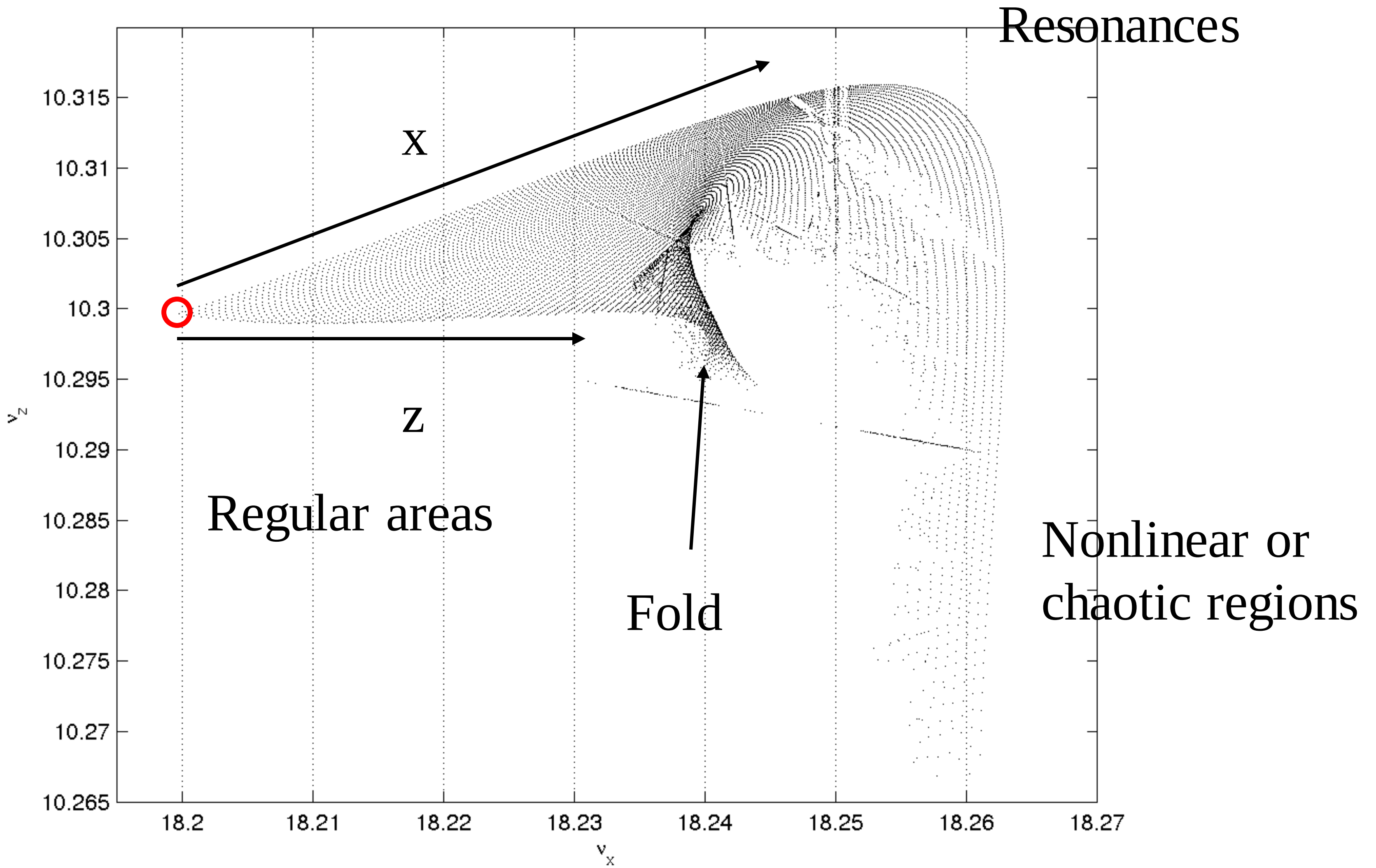
Tools

- Tracking codes
  - Simulation: Tracy II, Despot, MAD, AT, …
  - Nature: beam signal collected on BPM electrodes

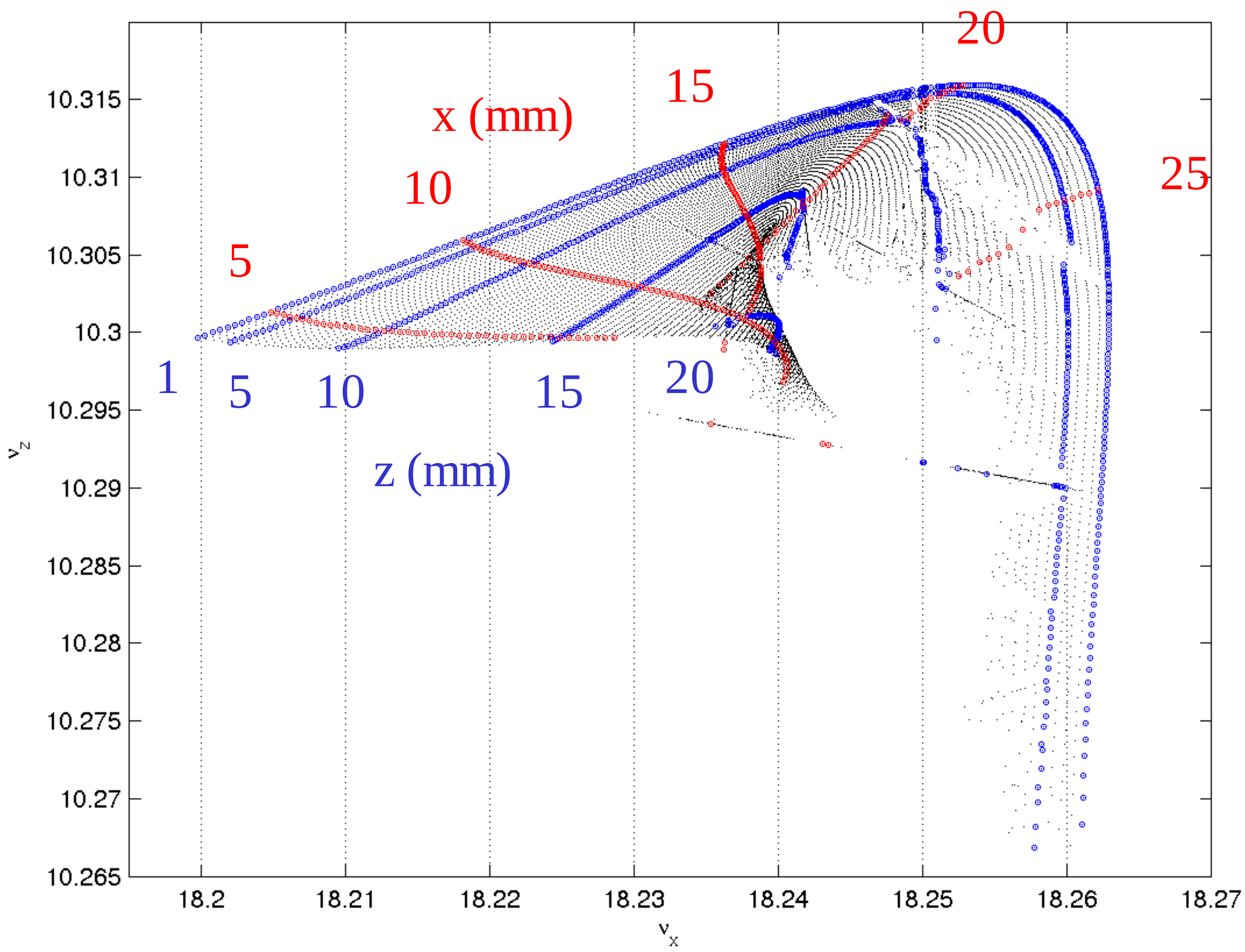
- NAFF package (C, fortran, matlab)

- Turn number Selections
  - Choice dictated by
    - Allows a good convergence near resonances
    - Beam damping times (electrons, protrons)
    - 4D/6D
  - AMD Opteron 2 GHz
    - 0.7 s for tracking a particle over 2 x 1026 turns
      - 1h00 for 100x50 (enough for getting main caracteristics)
      - 6h45 for 400x100 (next fmap)
    - Step size following a square root law (cf. Action)

Reading a FMA



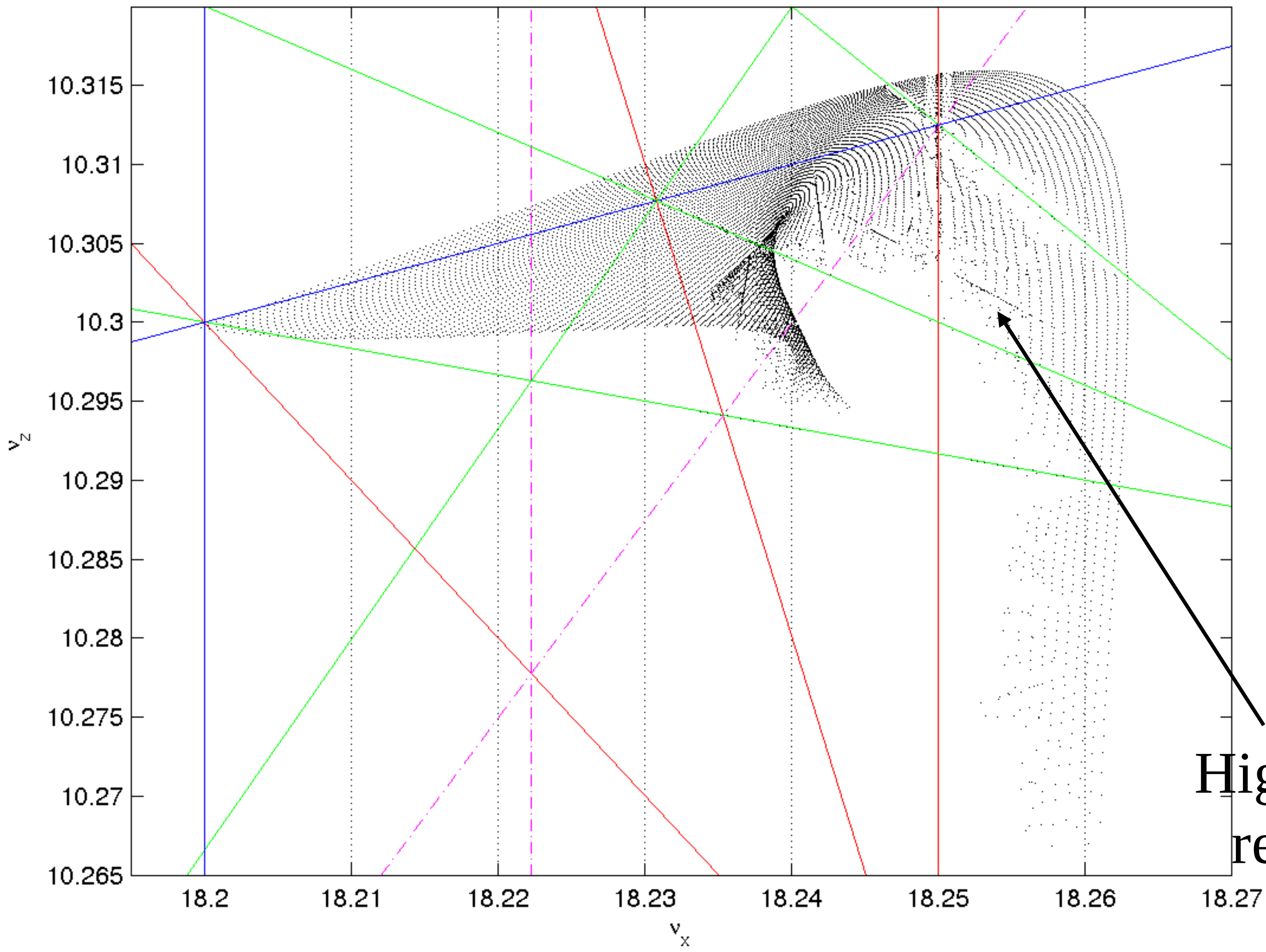
Mapping



20
15
x (mm)
10
5
25
1
5
10
15
20
z (mm)
10.315
10.31
10.305
10.3
10.295
10.29
10.285
10.28
10.275
10.27
10.265
ν_z
18.2
18.21
18.22
18.23
18.24
18.25
18.26
18.27
ν_x

Resonance network: $a\,\nu_x + b\,\nu_z = c$

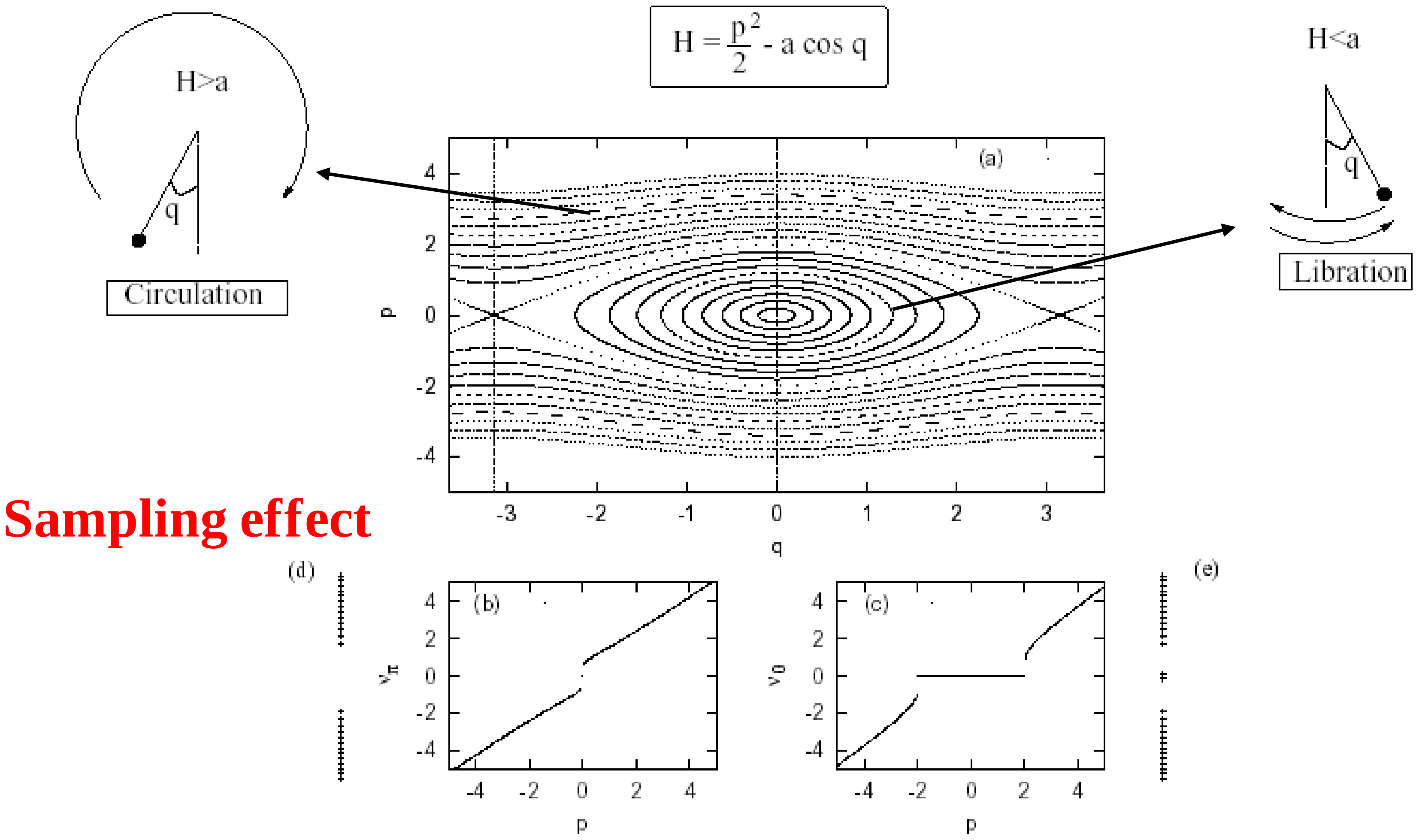
order = |a| + |b|



4th order
5th order
7th order
9th order

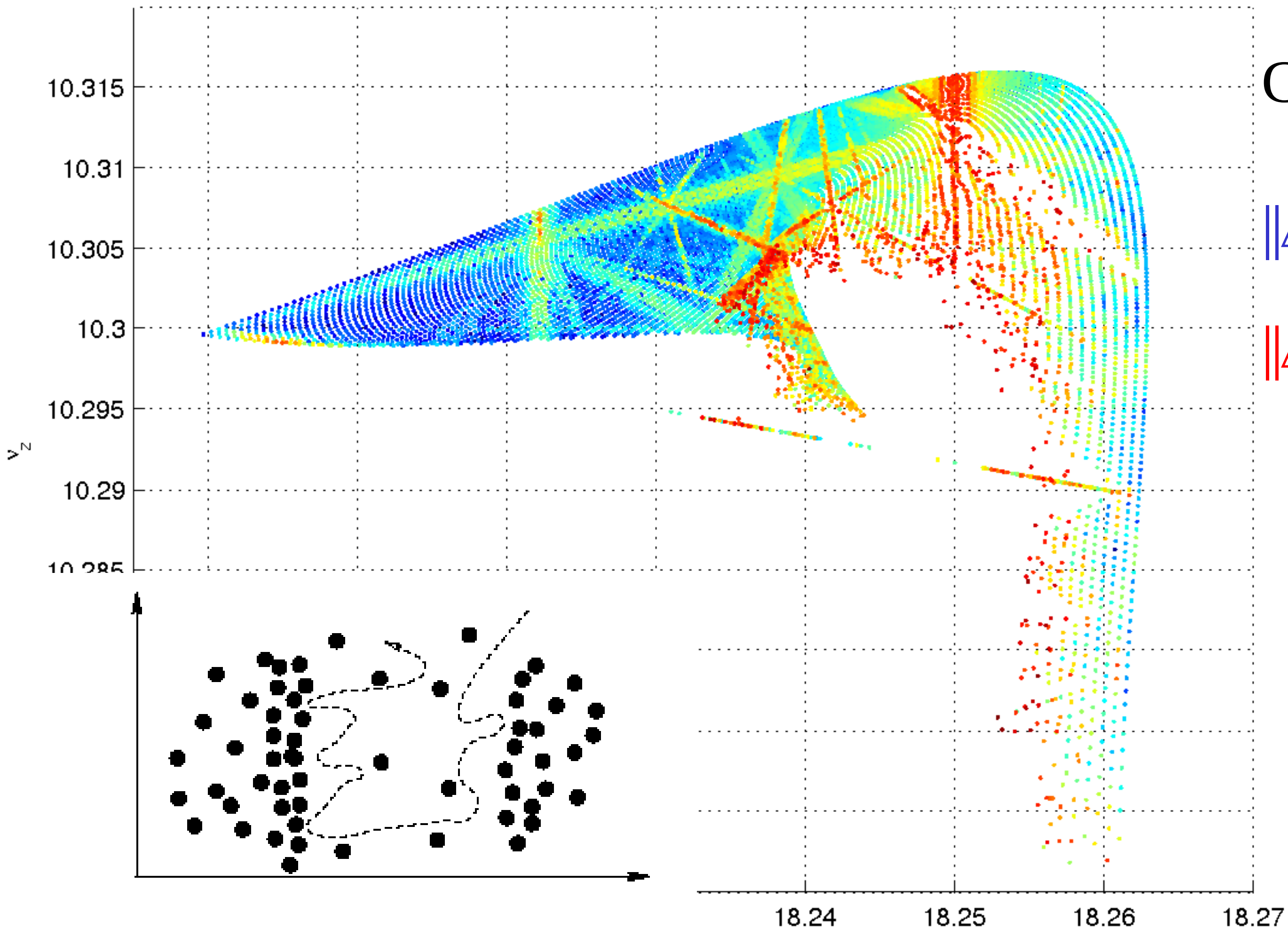
Higher order resonance

Rigid pendulum



Hyperbolic **Elliptic**

Diffusion $D = (1/N)*\log10(\|\Delta\nu\|)$



Color code:

$\|\Delta\nu\| < 10^{-10}$

$\|\Delta\nu\| > 10^{-2}$

Diffusion reveals as well slighted excited resonances

Soleil Beam Dynamics investigations using FMA

- Working point 18.20 10.30
  - Lattice: bare, errors, IDs
  - Optimization schemes

- Design of a new working point taking into account what was discovered through FMA

- Conclusions

Optimization Method

- Tuneshift w/ amplitude
- Tuneshift w/ energy
- Robustness to errors
  multipoles
  coupling
  IDs

Knobs
10 quadrupole families
10 sextupole families

Lattice design
Fine tuning

- 4D tracking
- 6D tracking

Tracking
NAFF

NAFF suggestions

- (x-z) fmap → injection eff.
- (x-δ) fmap → Lifetime
- Touschek computation

Dynamics analysis

Resonance identification

Improvement Needed

Yes

No

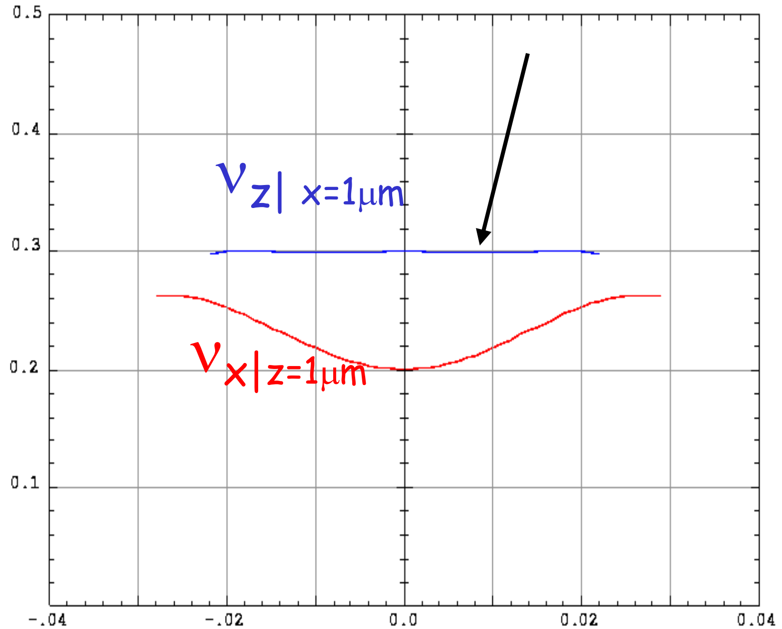
Good WP

Reference working point (18.2, 10.3)

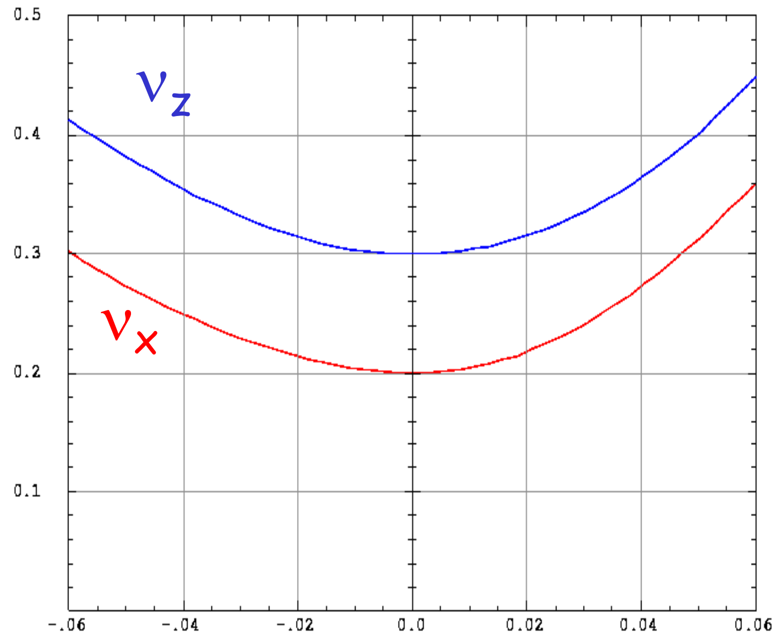
No coupling resonance crossing
$\nu_x - \nu_z = 8$ ($\Delta\nu = 0.1$).

Flat vertical tune

See M. Belgroune's talk



X or z (m)



δ

Just looking at these curves, it seems very clean …

On-momentum Dynamics --Working point: (18.2,10.3)

Bare lattice (no errors)

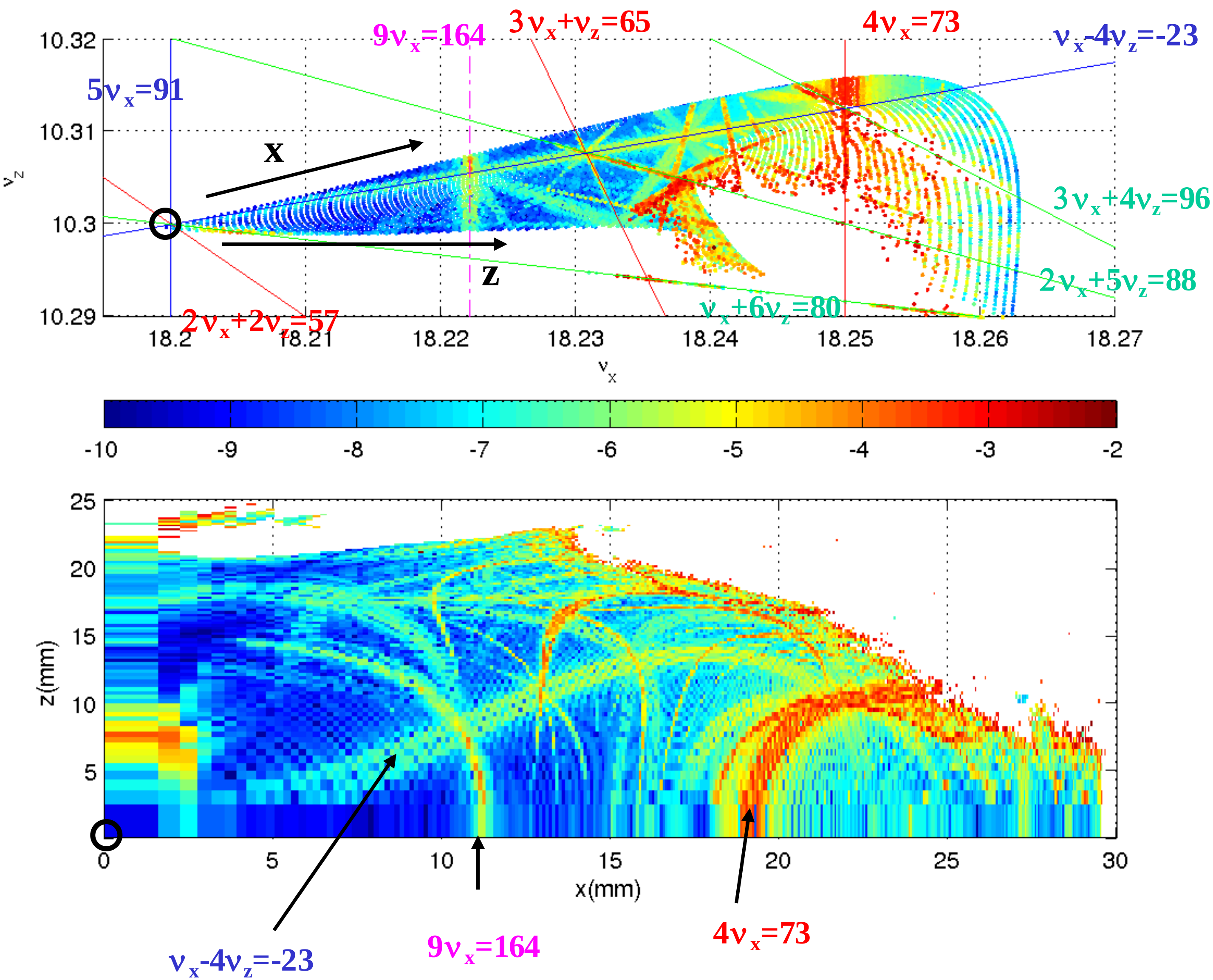
WP sitting on Resonance node

$\nu_x + 6\nu_z = 80$

$5\nu_x = 91$

$\nu_x - 4\nu_z = -23$

$2\nu_x + 2\nu_z = 57$



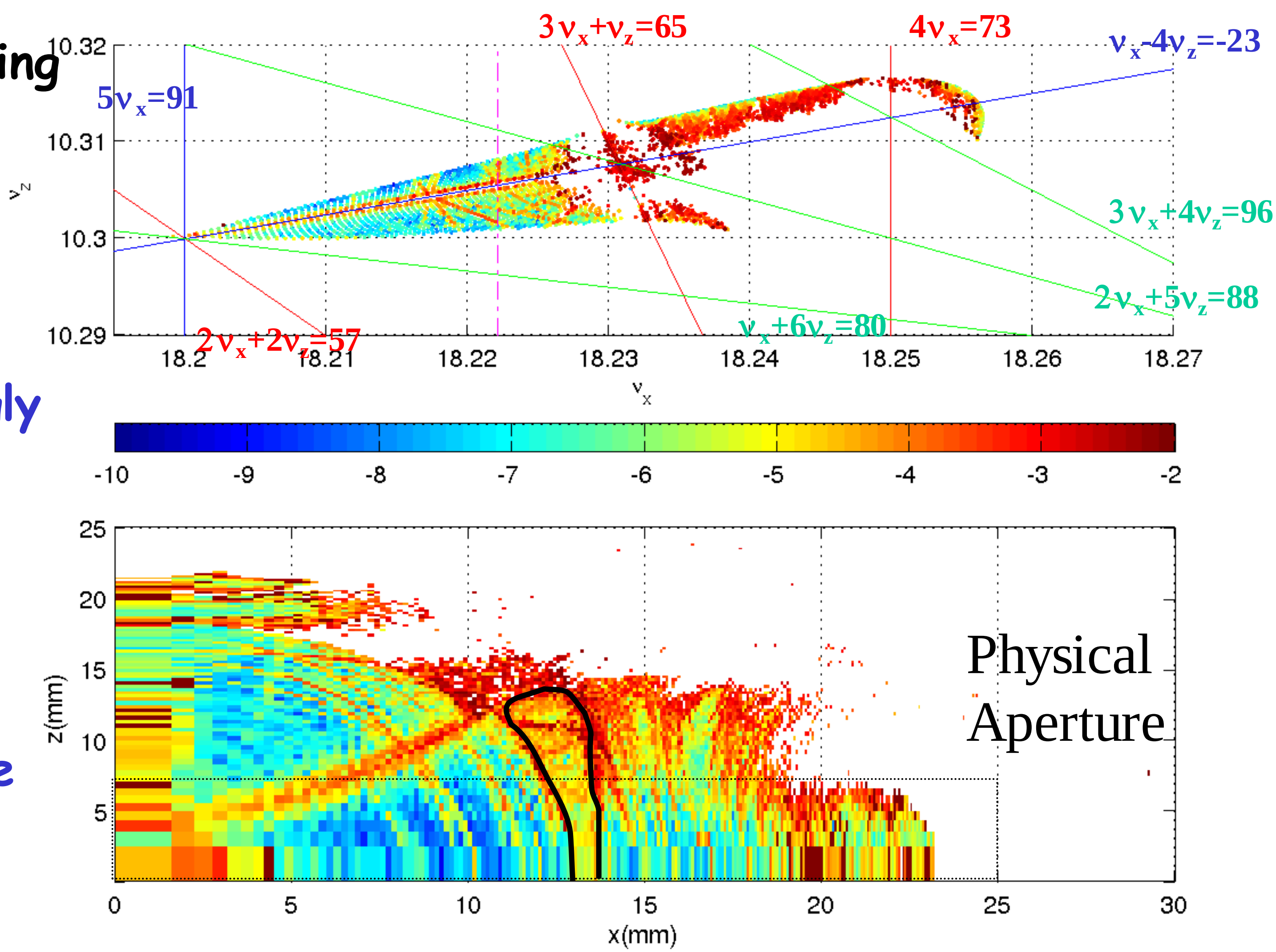
On-momentum dynamics with 1.9% coupling (18.2,10.3)

Randomly rotating 160 Quads

- Map fold Destroyed
- Coupling strongly impacts

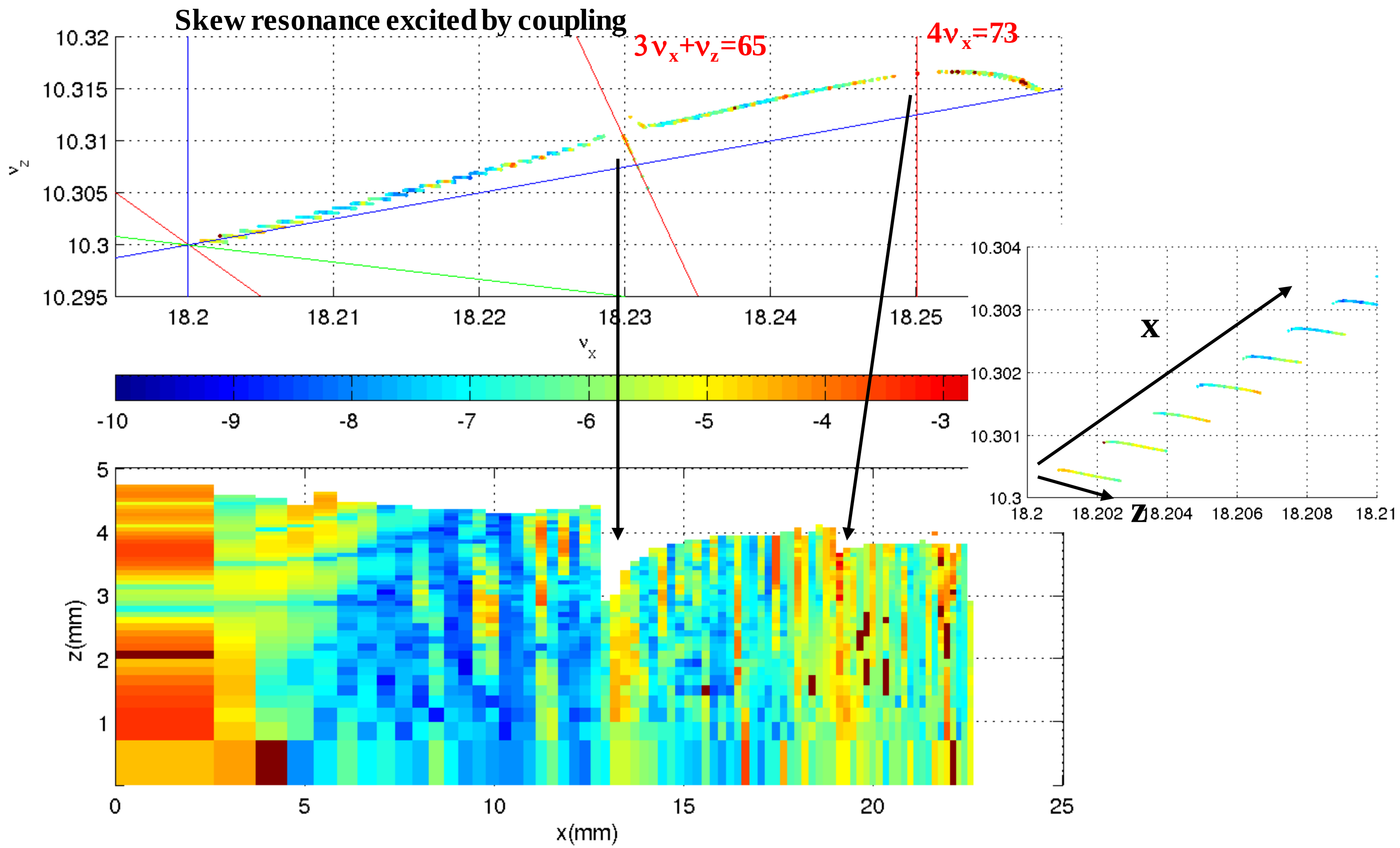
$3\nu_x + \nu_z = 65$

- Resonance node excited



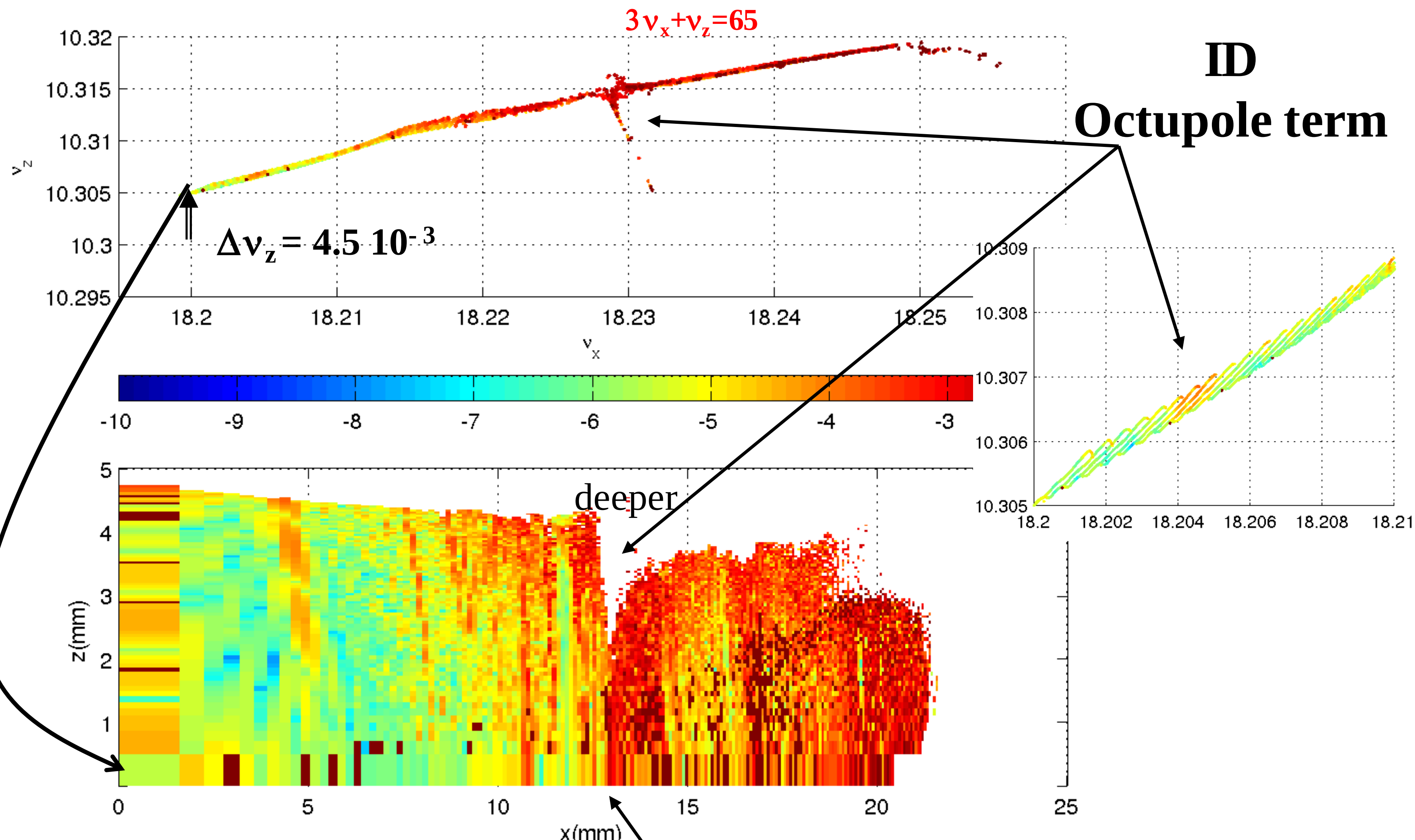
Resonance island
$3\nu_x+\nu_z=65$

Importance of including vaccum chamber



Injection @ 14mm

Adding effect of 3 in-vacuum IDs

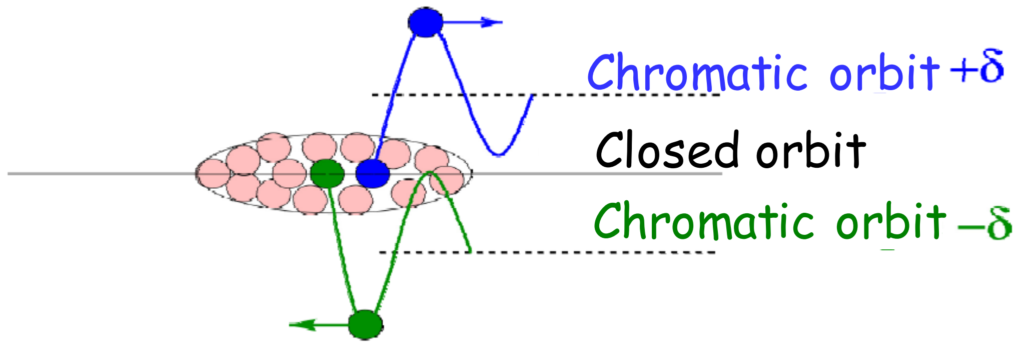


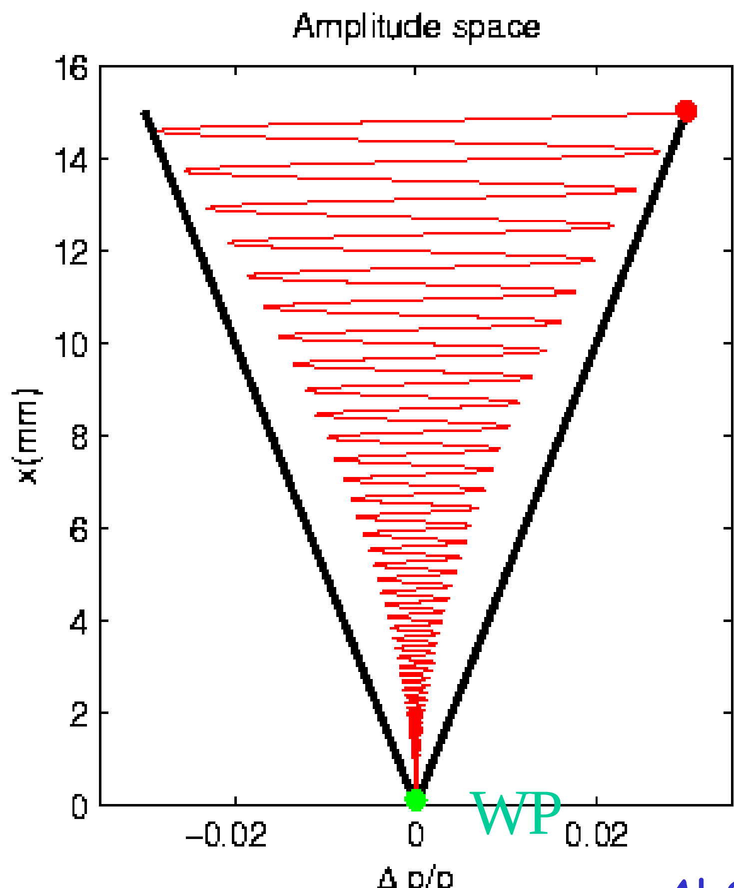
Injection trouble if stronger

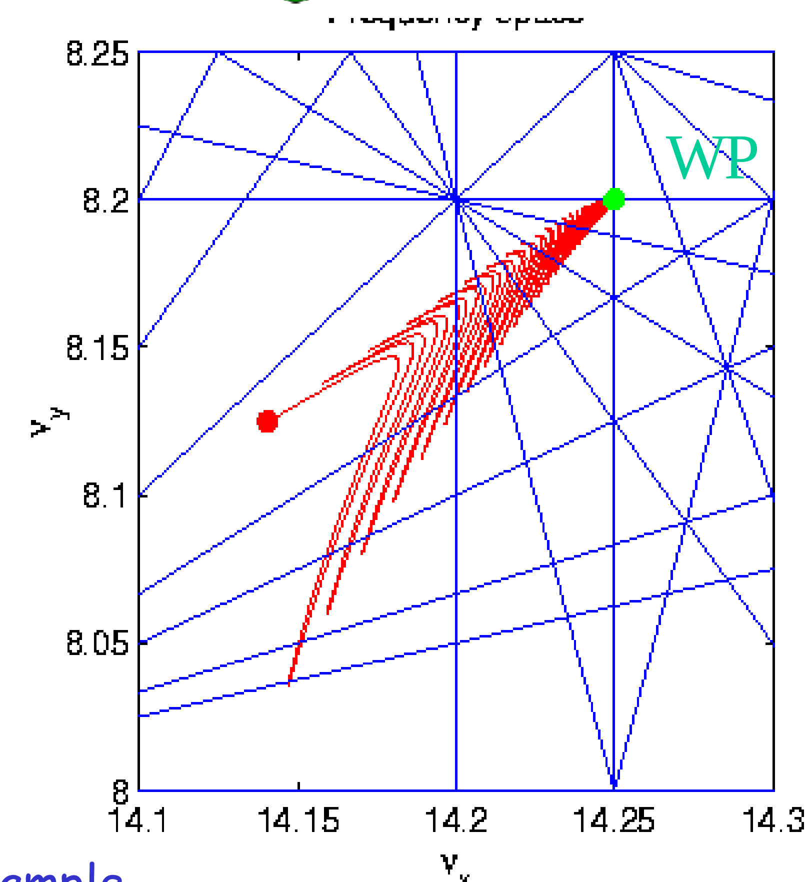
Particle behavior after Touschek scattering

$$x=\sqrt{A_x\beta_{x_1}}+\eta_0\delta$$

$$A_x=\gamma_{x_0}(\eta_0\delta)^2+2\alpha_{x0}(\eta_0\delta)(\eta_0'\delta)+\beta_{x0}(\eta_0'\delta)^2$$



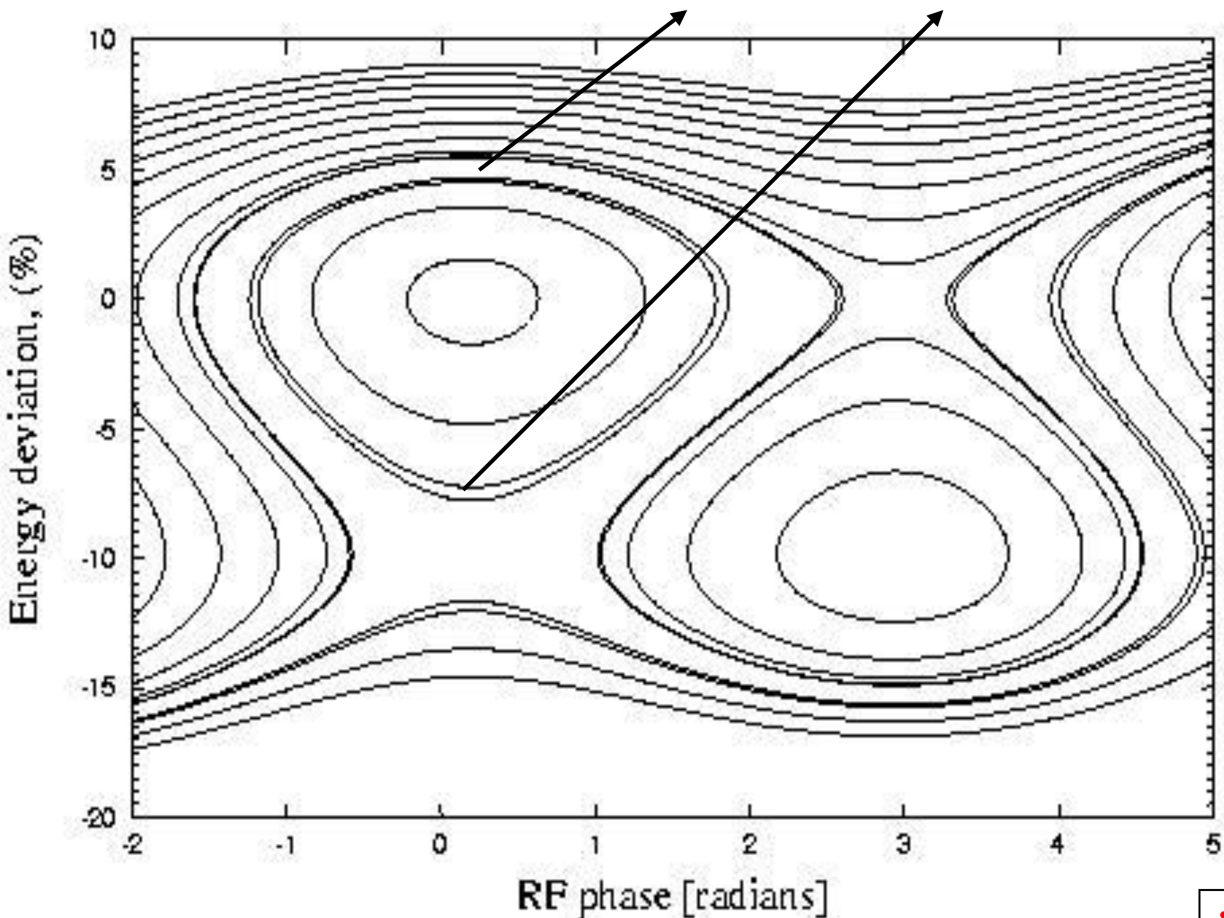




ALS Example

Non-linear synchrotron motion

+3.8% ↔ -6%



$\alpha_1 = 4.38\ 10^{-04}$

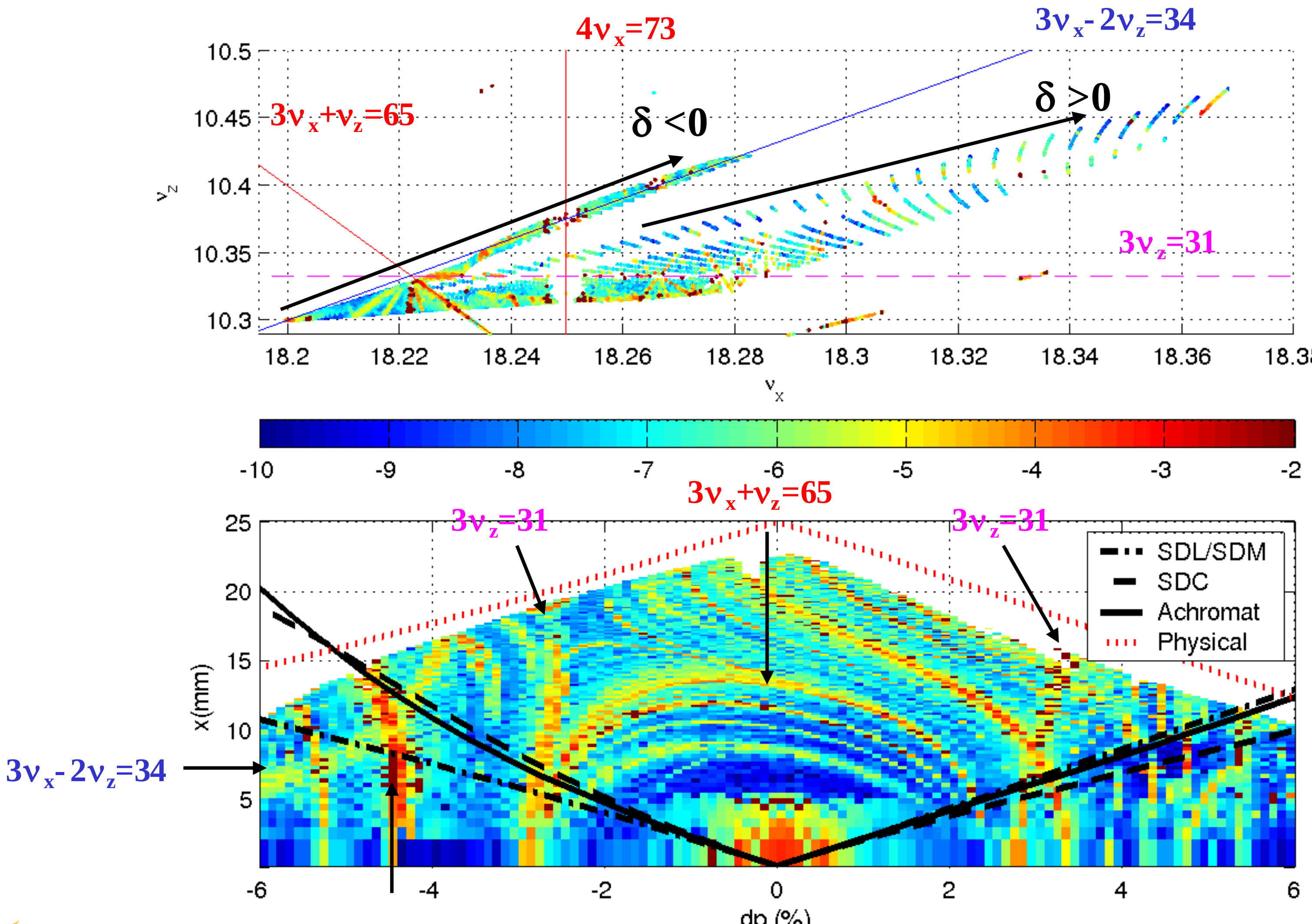
$\alpha_2 = 4.49\ 10^{-03}$

$$\alpha_1 = \oint \frac{\eta}{\rho} ds$$

$$\alpha_2 = \oint \left(\frac{\eta'^2}{2} - \frac{\eta_1}{\rho} \right) ds$$

Tracking 6D required

Off momentum dynamics w/o IDs



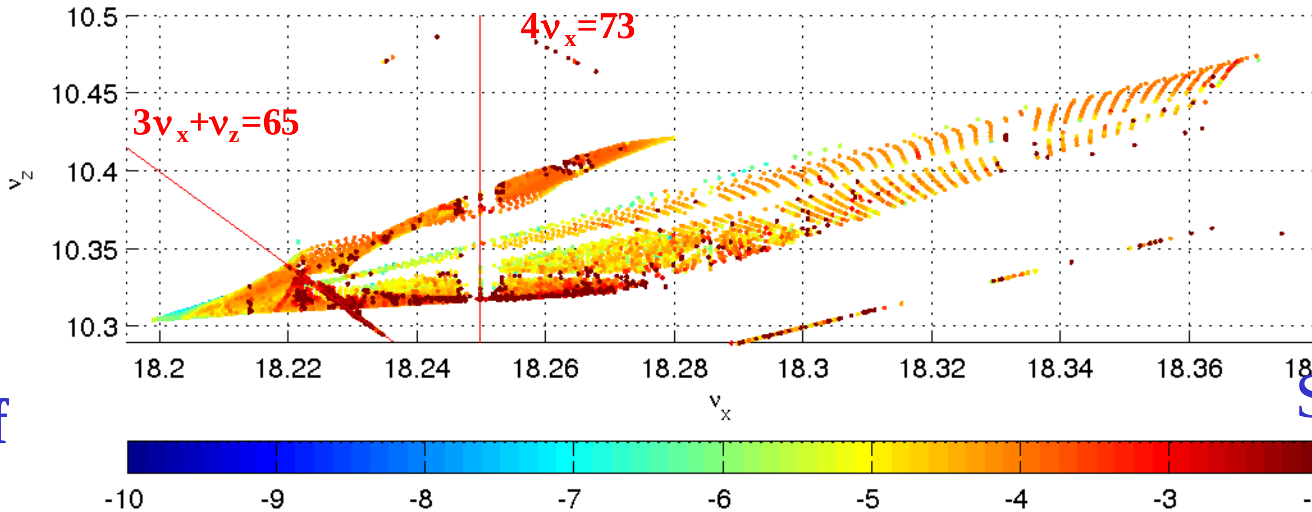
z_0 = 0.3mm

Off momentum dynamics w/ 3 x U20

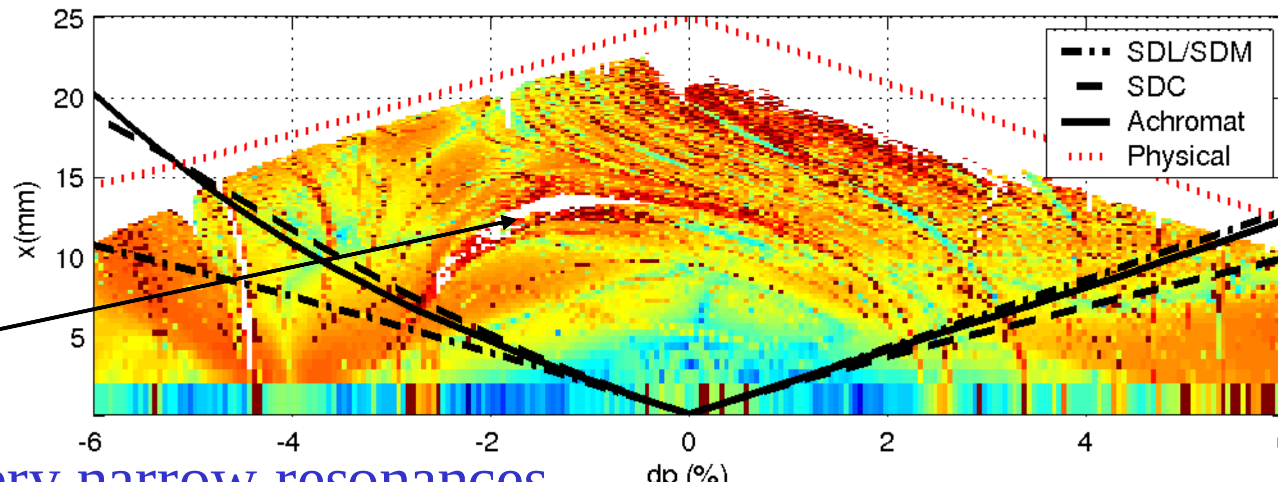
What's about Effect of synchrotron radiation and damping?

U20

B-Roll off
β_x = 18 m
g = 5mm



Synchrotron
140 turns

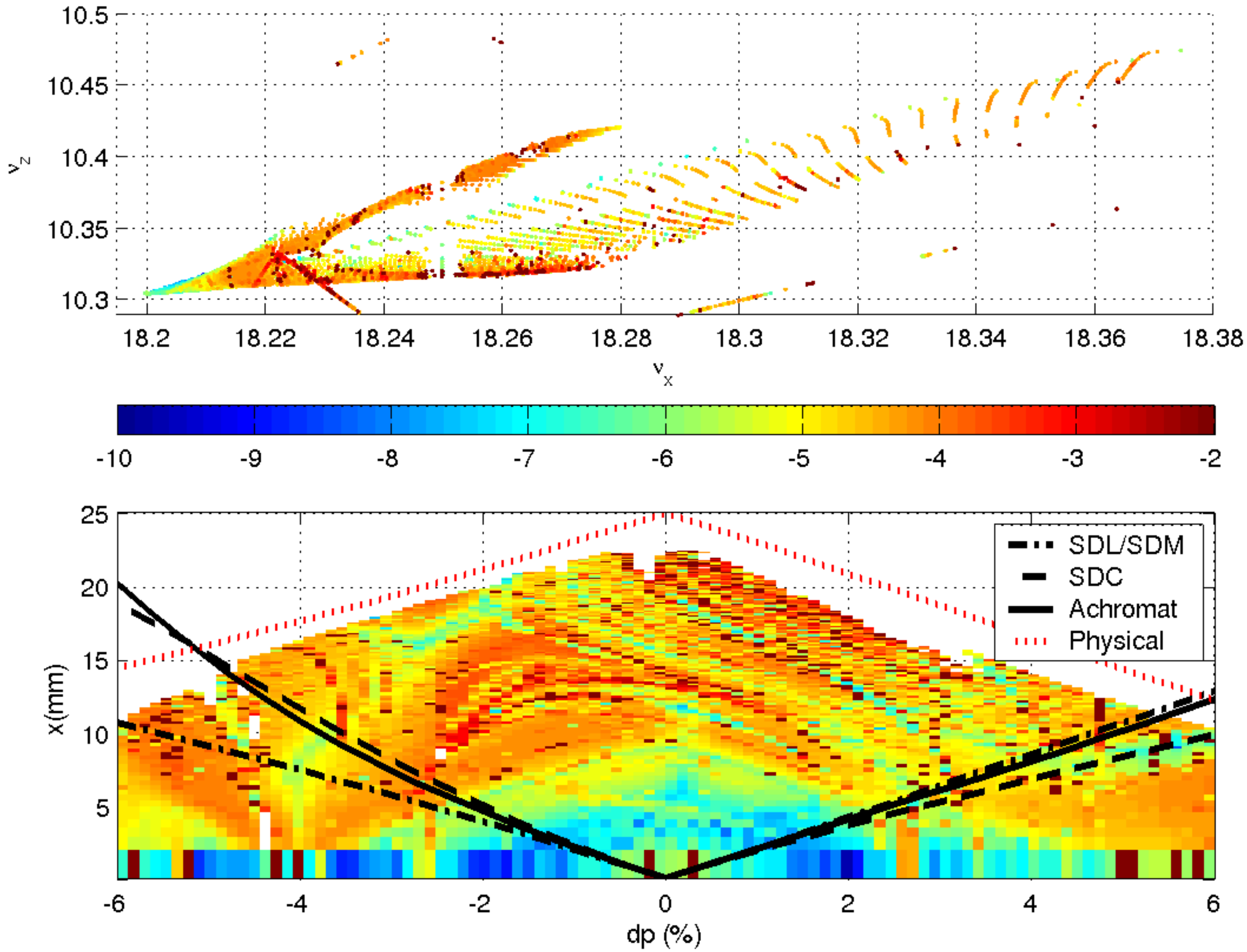


Damping
5600 turns

Loss over
>400 turns
Stable in 6D

Very narrow resonances

Coupling reduction by a factor 2 with 3 x U20



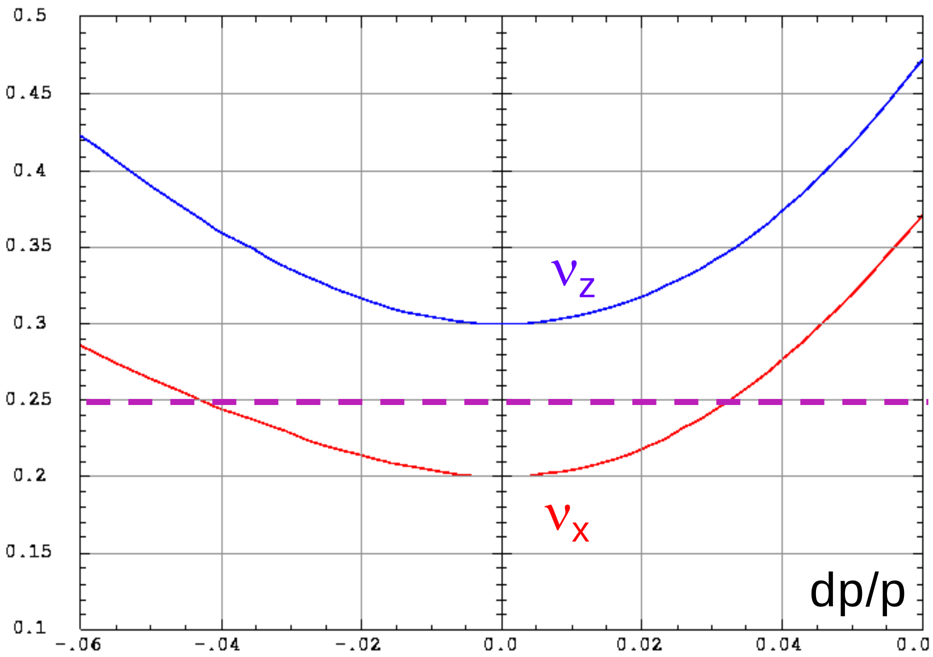
Optimization of a New Point
Enhanced philosophy

- On momentum
  - **$3\,\nu_x + \nu_z = 65$** to be avoided (not shown w/o fmap)
  - WP to be shifted from resonance node: locus of most particles
  - Control of tune shift with amplitude using sextupole knobs
    - $\nu_x(J_x, J_z) = a\,J_x + b\,J_z$
    - $\nu_z(J_x, J_z) = \mathbf{b}\,J_x + c\,J_z$

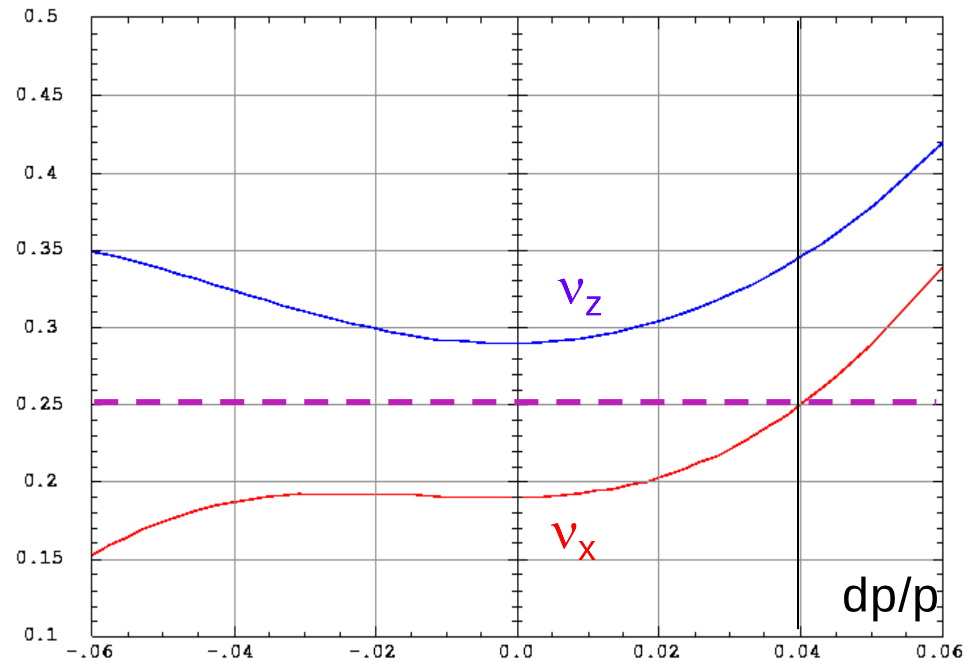
- Off momentum **$\nu_x(\delta)$**
    - Large energy acceptance
    - Control of the tune shift with energy using sextupoles
    - The $4\,\nu_x = 73$ resonance has to be avoided for insertion devices

Energy tune shift for the new WP 18.19 / 10.29

18.20 / 10.30

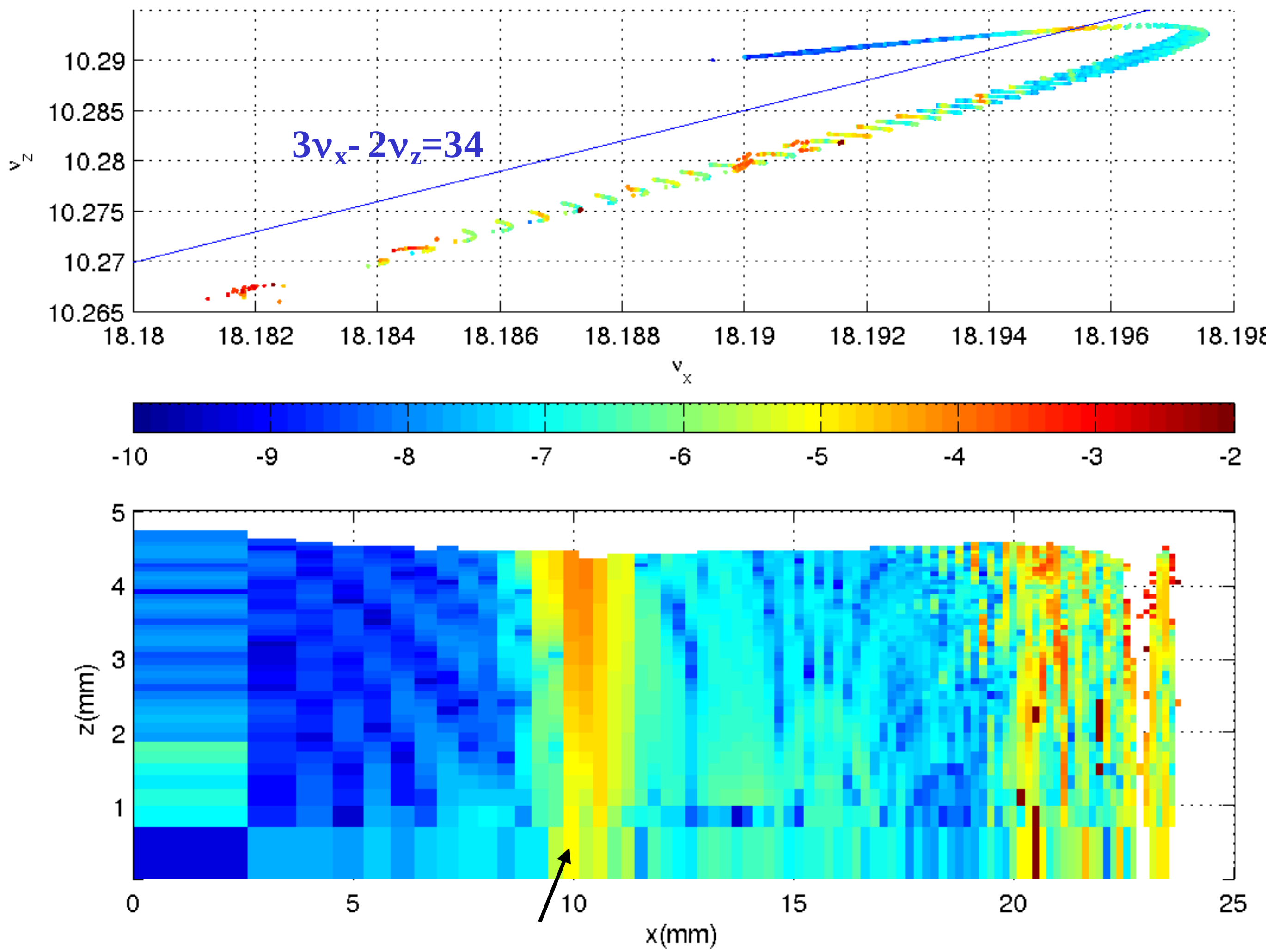


18.19 / 10.29



Tune shift w/ energy optimised with sextupoles to avoid in addition the $4\nu_x = 73$ resonance for negative energy offset

On momentum fmap for the WP 18.19 / 10.29



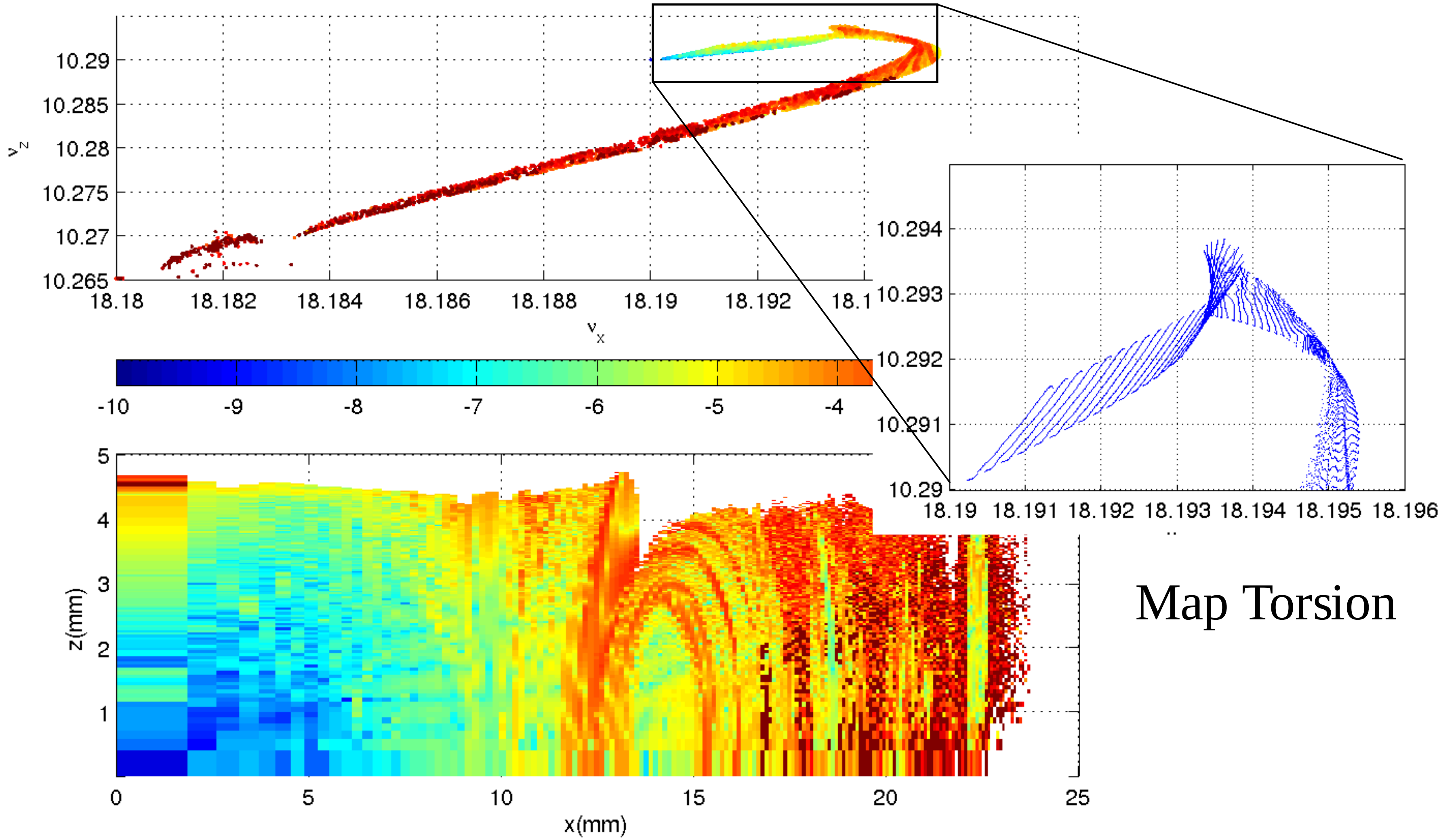
$3\nu_x - 2\nu_z = 34$

WP to be slightly shifted

1% coupling

Clean DA

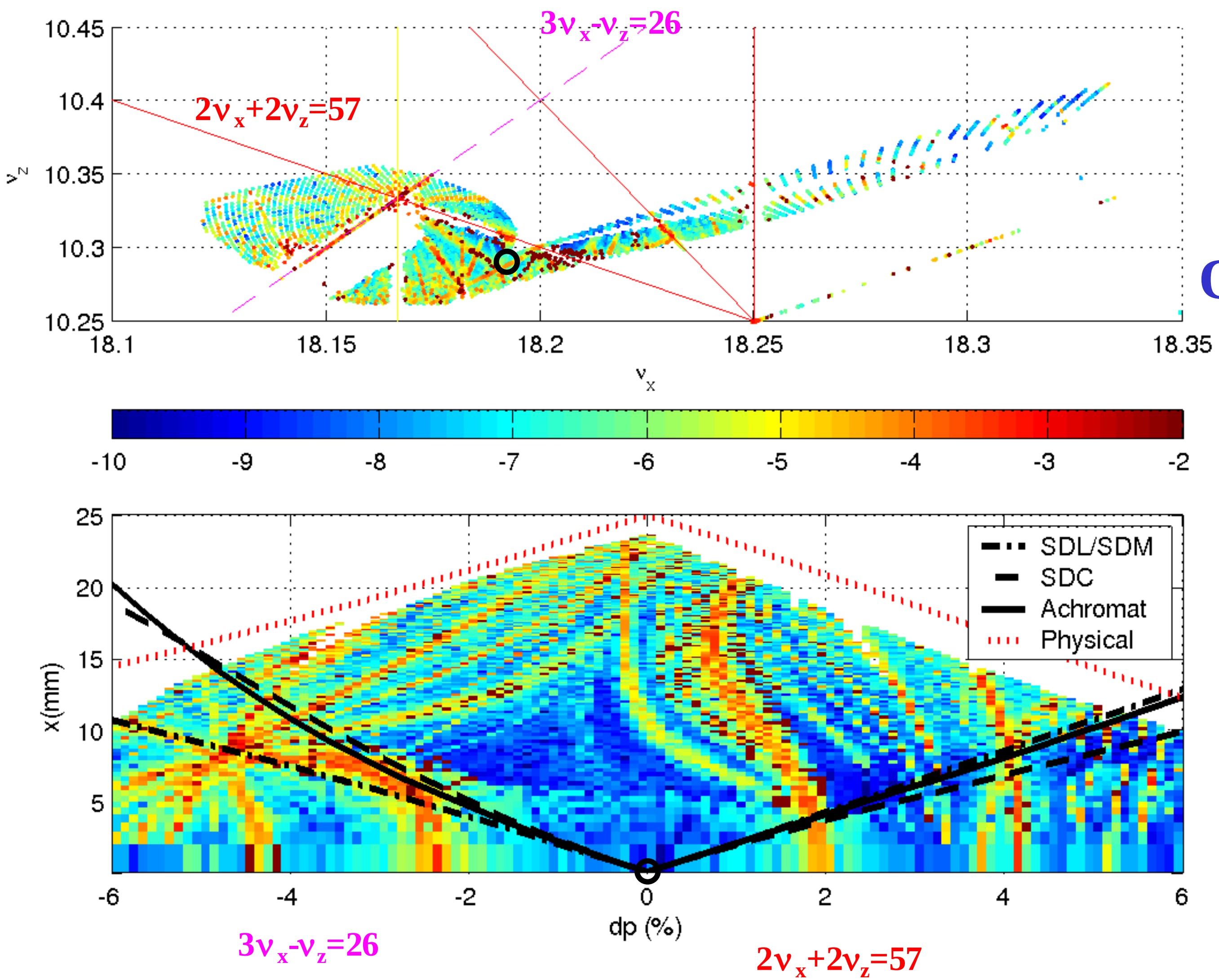
On momentum fmap for the WP 18.19 / 10.29 with 3 x U20



Map Torsion

Strong diffusion related to ID roll off

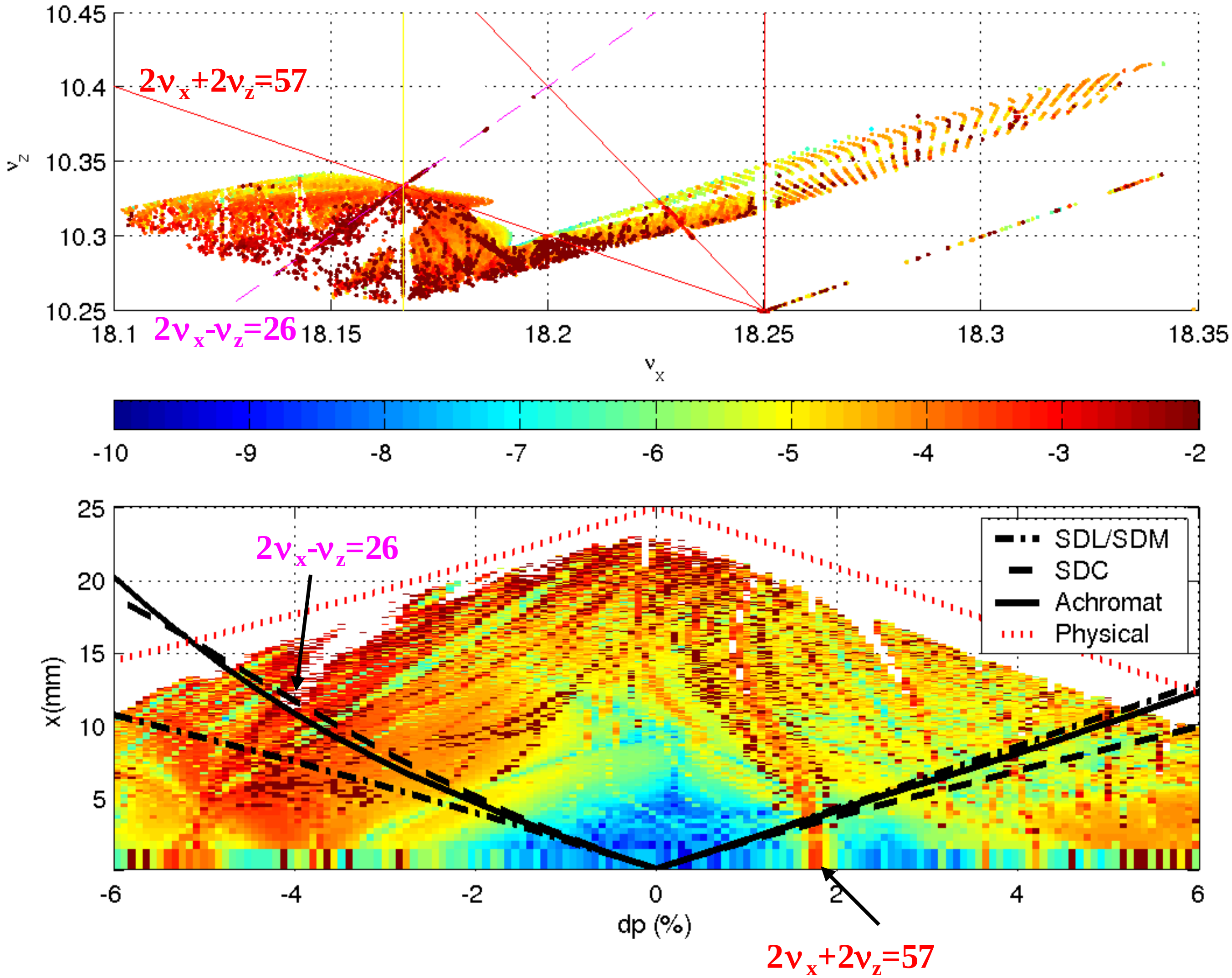
Off momentum fmap for the WP 18.19 / 10.29



1% coupling

Off-momentum map comparable to the nominal WP

Off momentum fmap for the WP 18.19 / 10.29 with 3 x U20



Effect of the $2\nu_x+2\nu_z=57$ resonance becomes « dangerous » with the 3xU20

Smoothing by synchrotron oscillations

Conclusions

FMA at design stage for the SOLEIL lattice

- Gives us a global view (footprint of the dynamics)
- Dynamics sensitiveness to quads, sextupoles and IDs
- Reveals nicely effect of coupled resonances, specially cross term $\nu_z(x)$
- Enables us to modify the working point to avoid resonances or regions in frequency space
- Importance of coupling correction to small values (below 1%)
- 4D/6D …

Aknowledgements and references

- Institutes
  - IMCCE, ALS, SOLEIL
- Codes
  - BETA (Loulergue -- SOLEIL)
  - Tracy II (Nadolski -- SOLEIL, Boege -- SLS)
  - AT (Terebilo http://www-ssrl.slac.stanford.edu/at/welcome.html)
- Papers
  - *Frequency map analysis and quasiperiodic decompositions*, J. Laskar, Proceedings of Porquerolles School, sept. 01
  - *Global Dynamics of the Advanced Light Source Revealed through Experimental Frequency Map Analysis*, D. Robin et al., PRL (85) 3
  - *Measuring and optimizing the momentum aperture in a particle accelerator*, C. Steier et al., Phys. Rev. E (65) 056506
  - *Review of single particle dynamics of third generation light sources through frequency map analysis*, L. Nadolski and J. Laskar, Phys. Rev. AB (6) 114801