

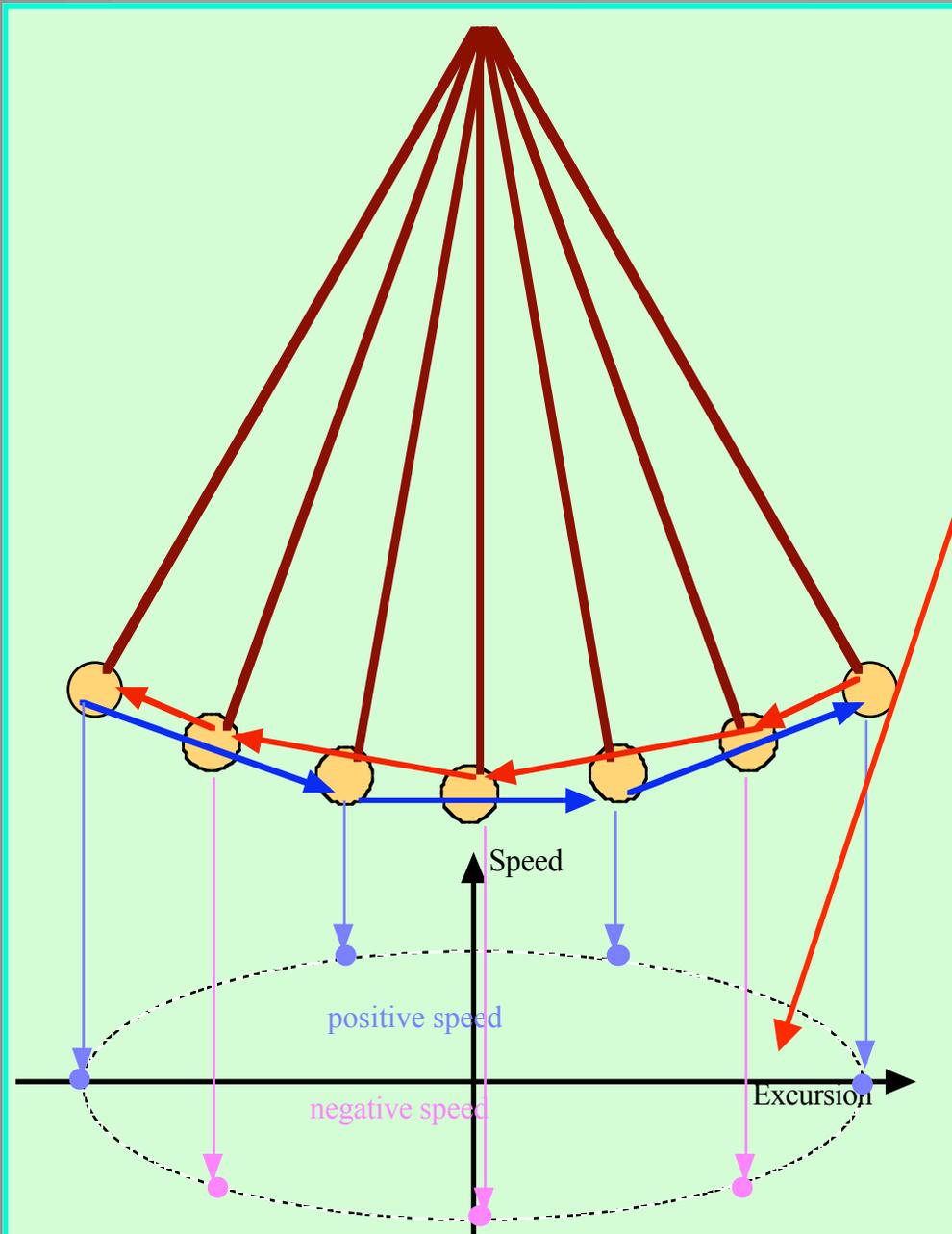
Why are we afraid of

RF noise ?



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CERN, AB-RF

Pendulum and phase space



For an **undamped** pendulum
its trace in this plane

(phase space)

will follow the ellipse
forever !!

‘pendulum is in prison’

The **size of the ellipse** is
linked to the total energy
in the pendulum

Beam in accelerator/collider has a certain (nominal) energy:

But:

Each real particle has (a little bit) more or less energy
than nominal energy

All (high energy) particles have nearly the same speed (+) about c

more energetic particles (*) make a ‘wider curve’ in bending field
—> **come later** back to RF after one turn.

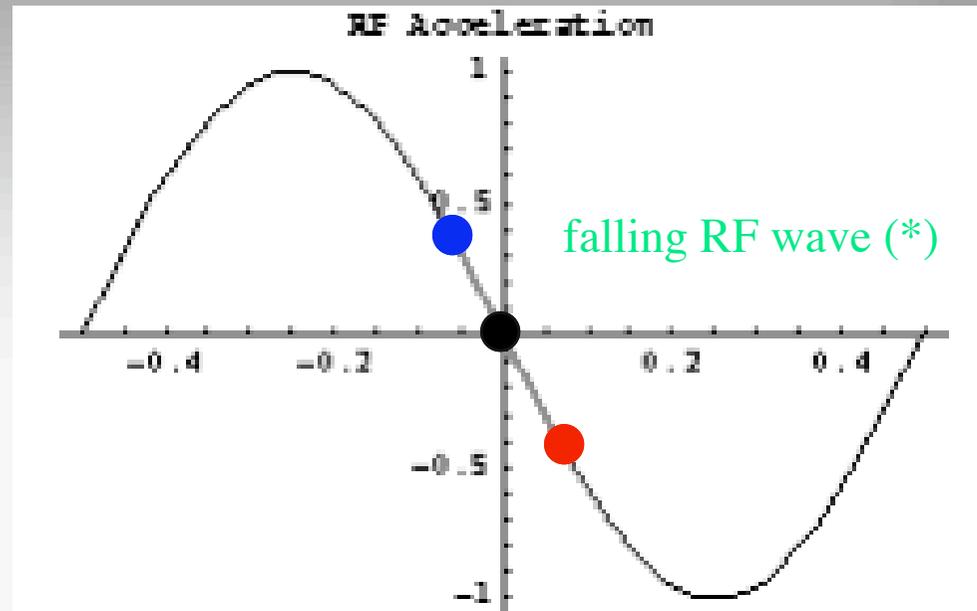
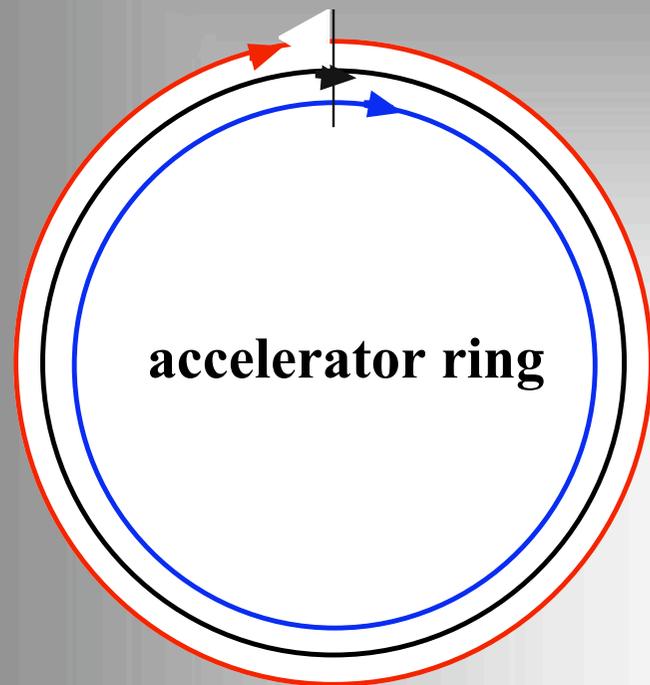
less energetic particles (*) make a ‘closer curve’ in bending field
—> **come earlier** back to RF after one turn.

Acceleration depends on when the particle arrives at cavity

(+) thanks to Albert Einstein (*) above transition energy of the accelerator

3

(in coast)



Nominal (E_0) particle: just in time \rightarrow no energy change

($E < E_0$) particle: early arrival \rightarrow acceleration (*)

($E > E_0$) particle: late arrival \rightarrow deceleration (*)

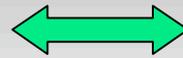
(*) above transition energy of the accelerator falling RF wave

Pendulum

Particle

dE =deviation from 'nominal' E_0

left-most excursion, $v=0$



most early arrival, $dE=0$

centre position, $v=+v_{\max}$



nominal arrival, $dE=+dE_{\max}$

Right-most excursion, $v=0$



most late arrival, $v=0$

centre position, $v=-v_{\max}$



nominal arrival, $dE=-dE_{\max}$

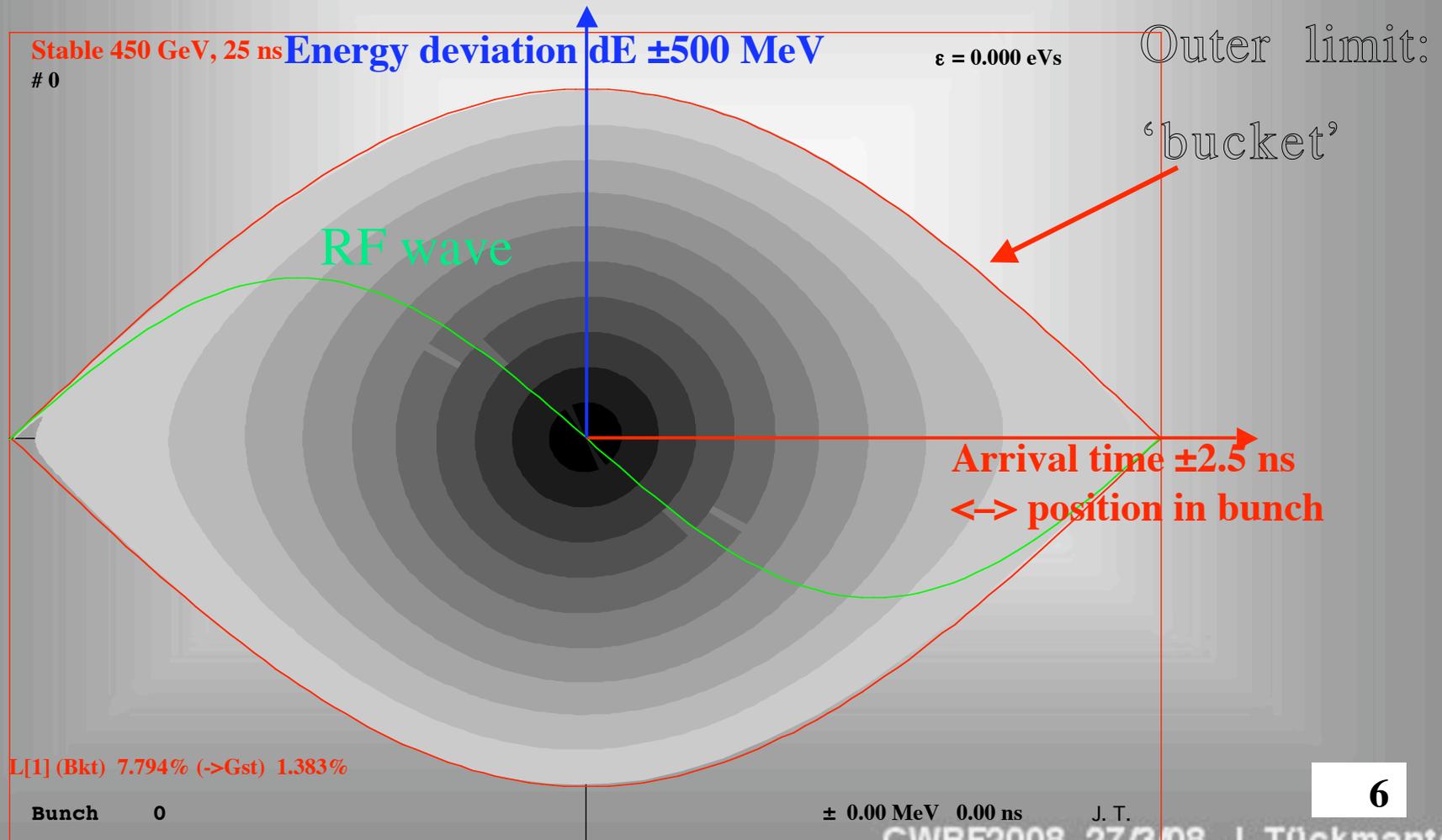
left-most excursion, $v=0$

most early arrival, $dE=0$

Synchrotron Oscillation
 f_s : synchrotron frequency

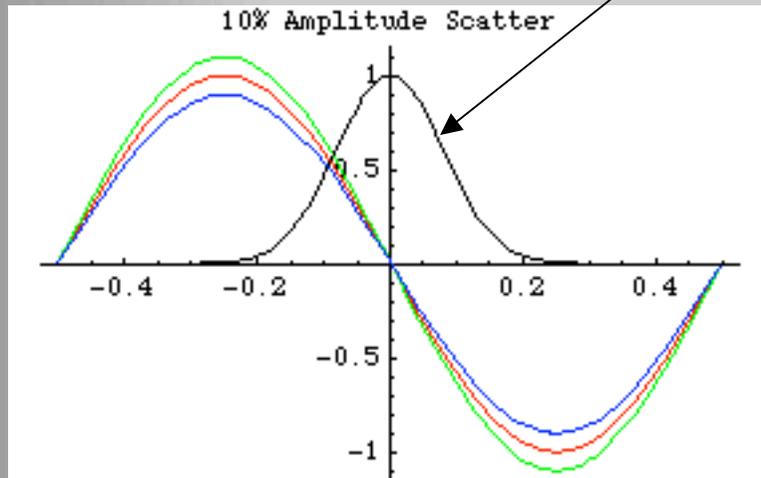
'restoring force' in RF is NOT linear but is the RF wave (-integral)
—> trace in phase space is not exactly elliptical
(but close to it for small oscillations)

particle phase-space: limited



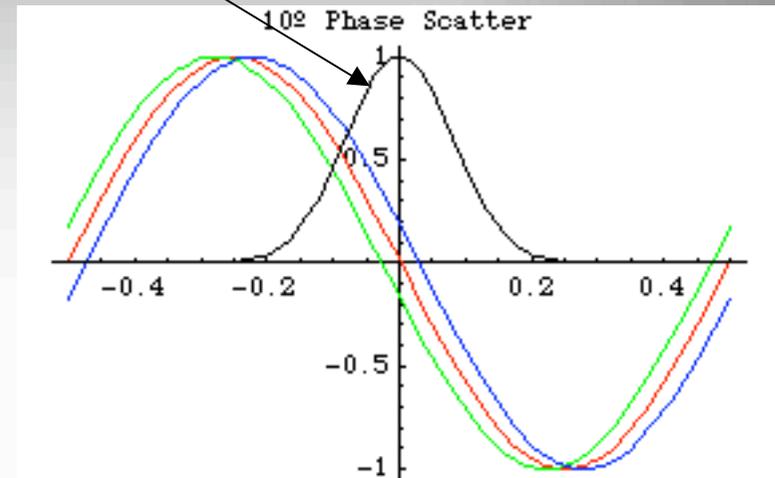
For **perfectly stable** RF: particles **stay on their 'ellipse' forever**

Particle density distribution \rightarrow arrival time



RF amplitude scatter 10%

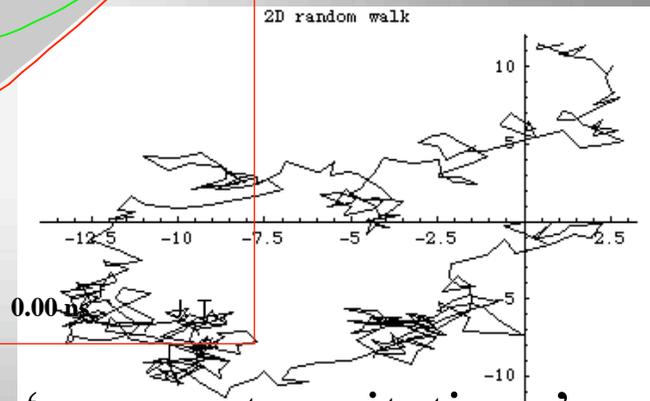
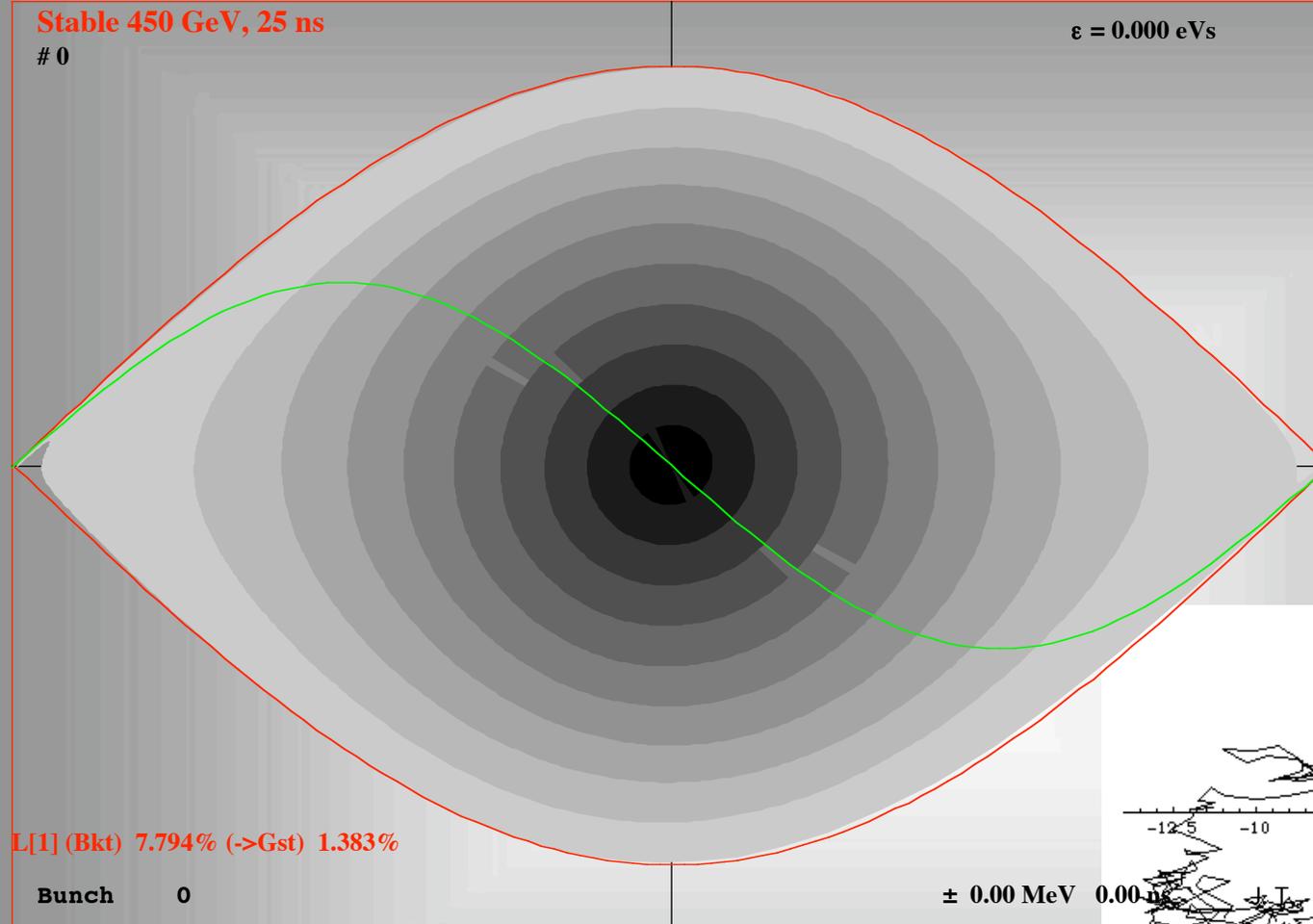
if $f_{A_{mod}} = 2 * f_s$: resonant excit.
(4*, 6*, .. : non-linearities)



RF phase scatter 10°

if $f_{\phi_{mod}} = 1 * f_s$: resonant excit.
(3*, 5*, .. : non-linearities)

particles can get scattered out of their 'prison'
 \rightarrow **tails** or **'out of bucket'**

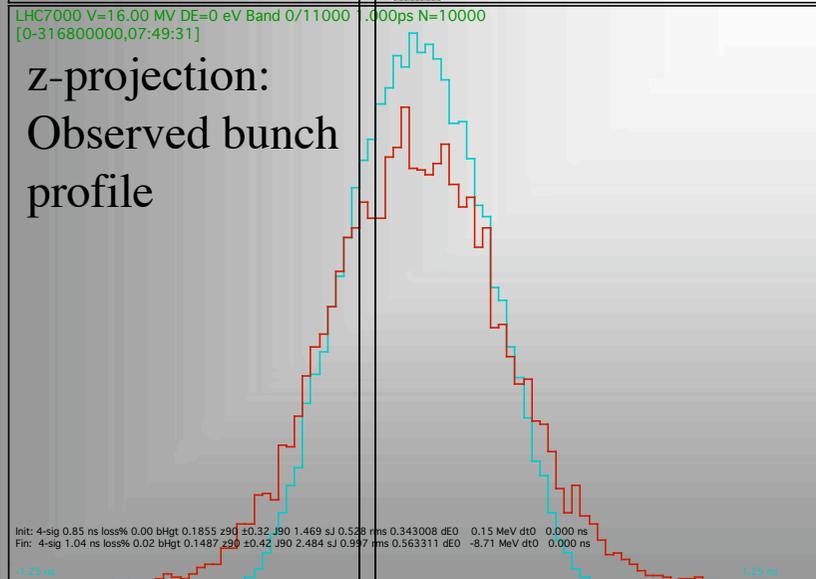
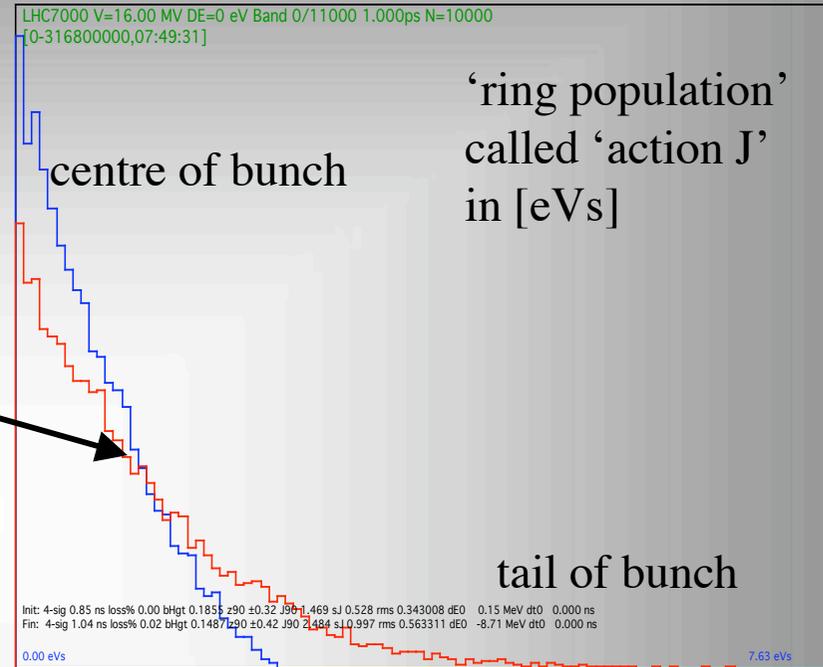
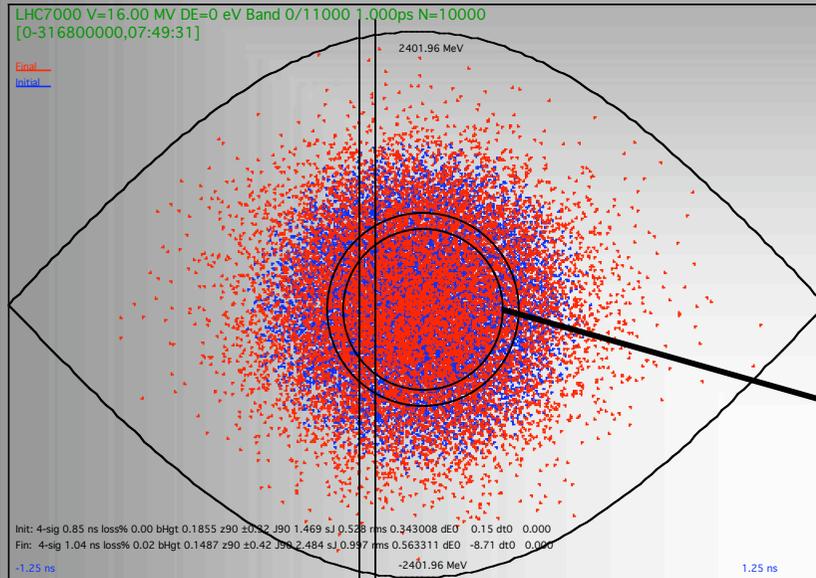


‘random walk’ -> contains frequencies with ‘resonant excitations’
 particles (can) move from one ‘ring’ to the other
‘natural tendency’: from high density to low density: *equalize*

LHC coast at 7TeV

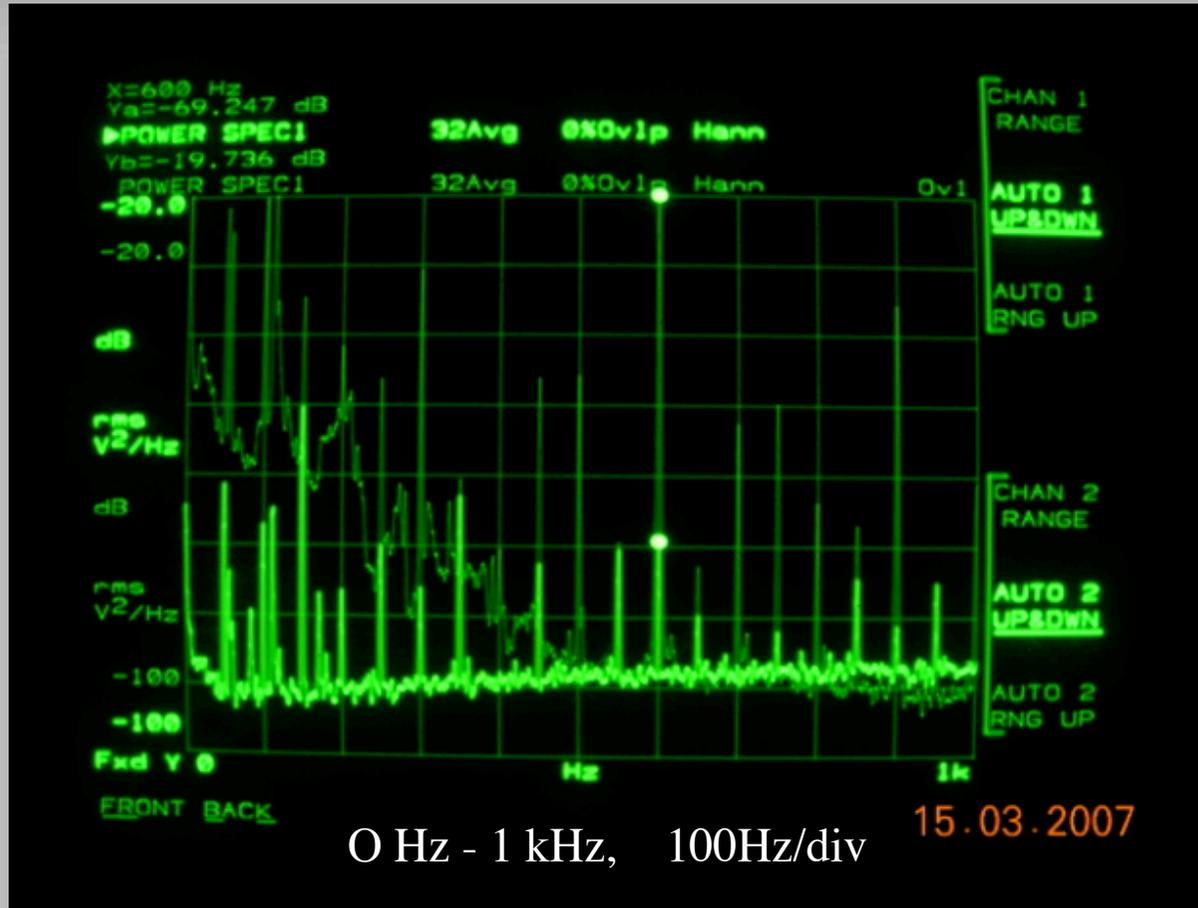
start ←—8h—→ end

$\langle \delta\phi \rangle = 0.023^\circ @ 400 \text{ MHz } (\rightarrow 1 \text{ ps})$



↑
without noise **blue**
and **red** would be
absolutely identical

50-Hz multiples (origin: power converter)



Phase noise spectrum as measured on the 400 MHz cavity field

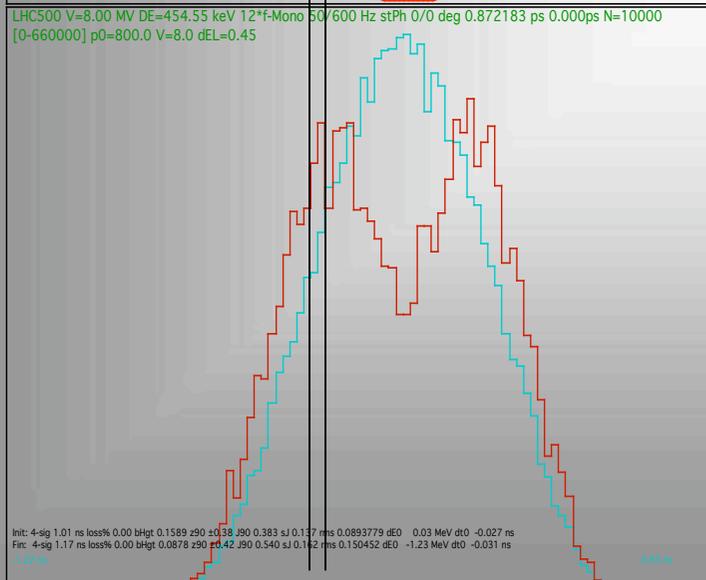
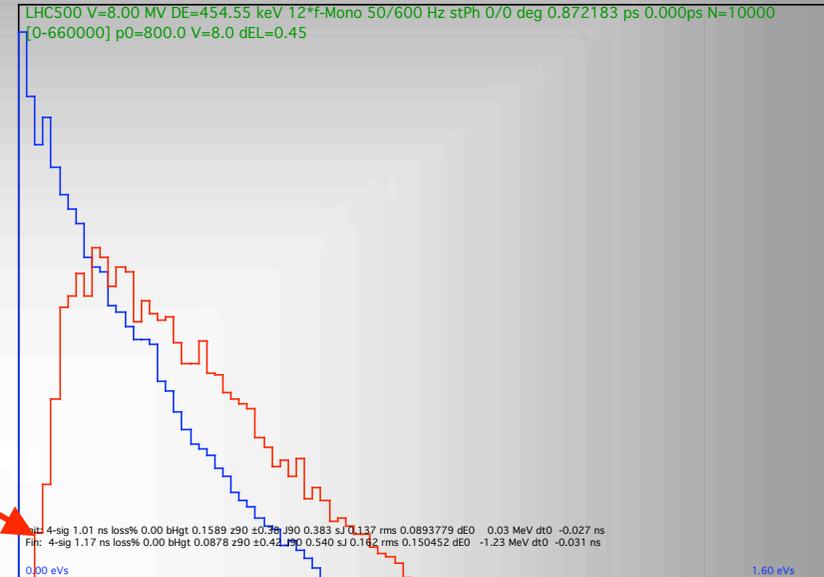
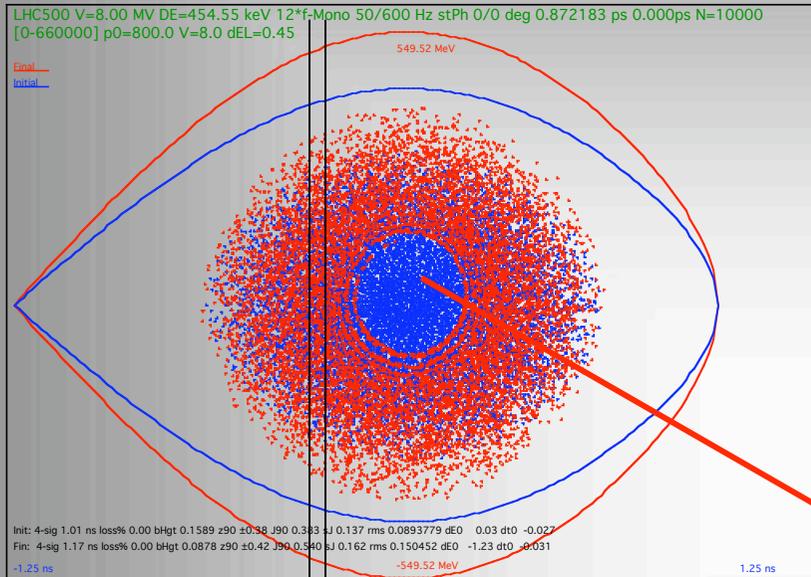
Thin line: no fast vector feedback (open loop)

Thick line: feedback loop closed (noise floor ‘instrumental’)

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During energy ramp **synchrotron frequencies pass 50-Hz line**
(for about 2 minutes)

Exaggerated by factor 30 in amplitude (30dB for ‘RF-guys’)



Bunch centre ‘blown apart’
but no large tails
nor ‘out of bucket’

(only small perturbation for ‘noise’
as is, **LHC OK**)



Thank you
for listening!