Control of Hamiltonian chaos in a Traveling Wave Tube

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Centre universitaire de St. Jérôme - Marseille

- beam - plasma system
- traveling wave tube
- trochoidal analyzer
- distribution function
- Hamiltonian chaos
- the beam-wave/s system
- the “devil’s staircase”
- control of chaos
- conclusion and perspectives

beam-plasma

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beam – plasma system

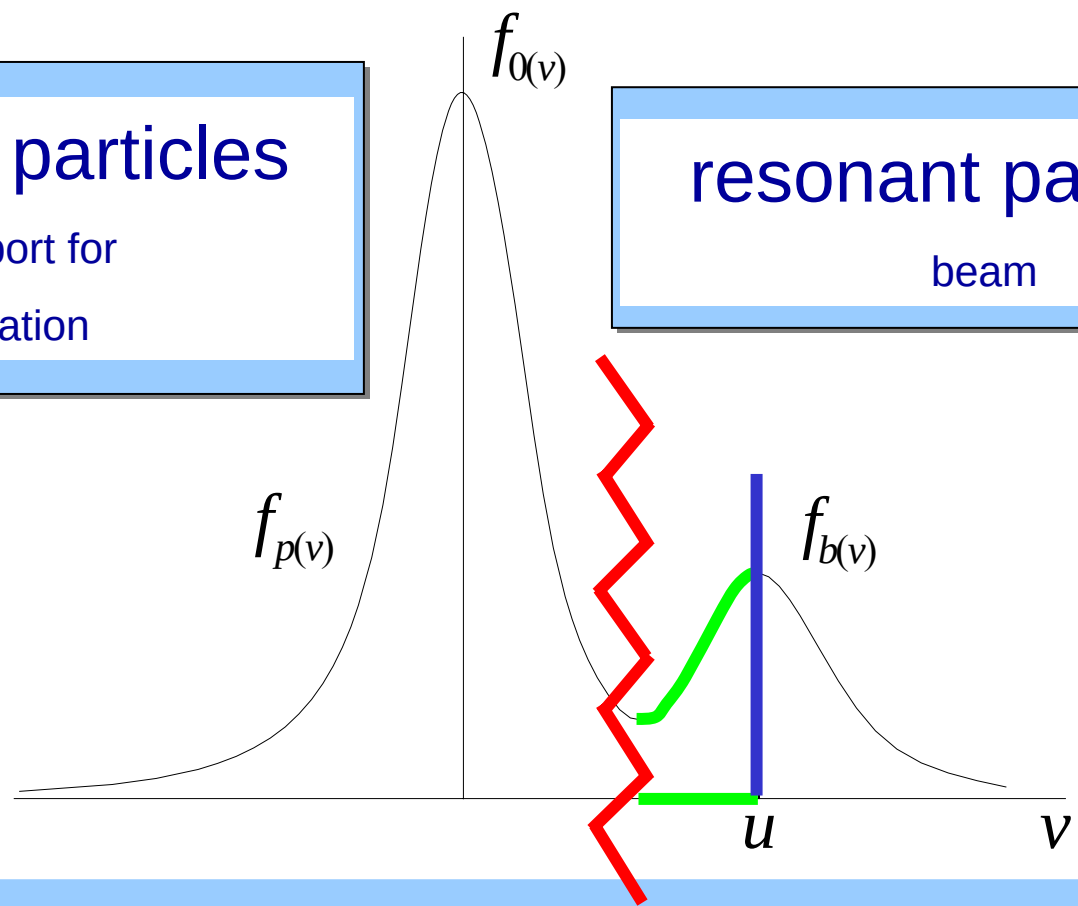
non resonant particles

Dielectric support for

wave propagation

resonant particles

beam



Velocity distribution function

- beam - plasma system

traveling wave tube

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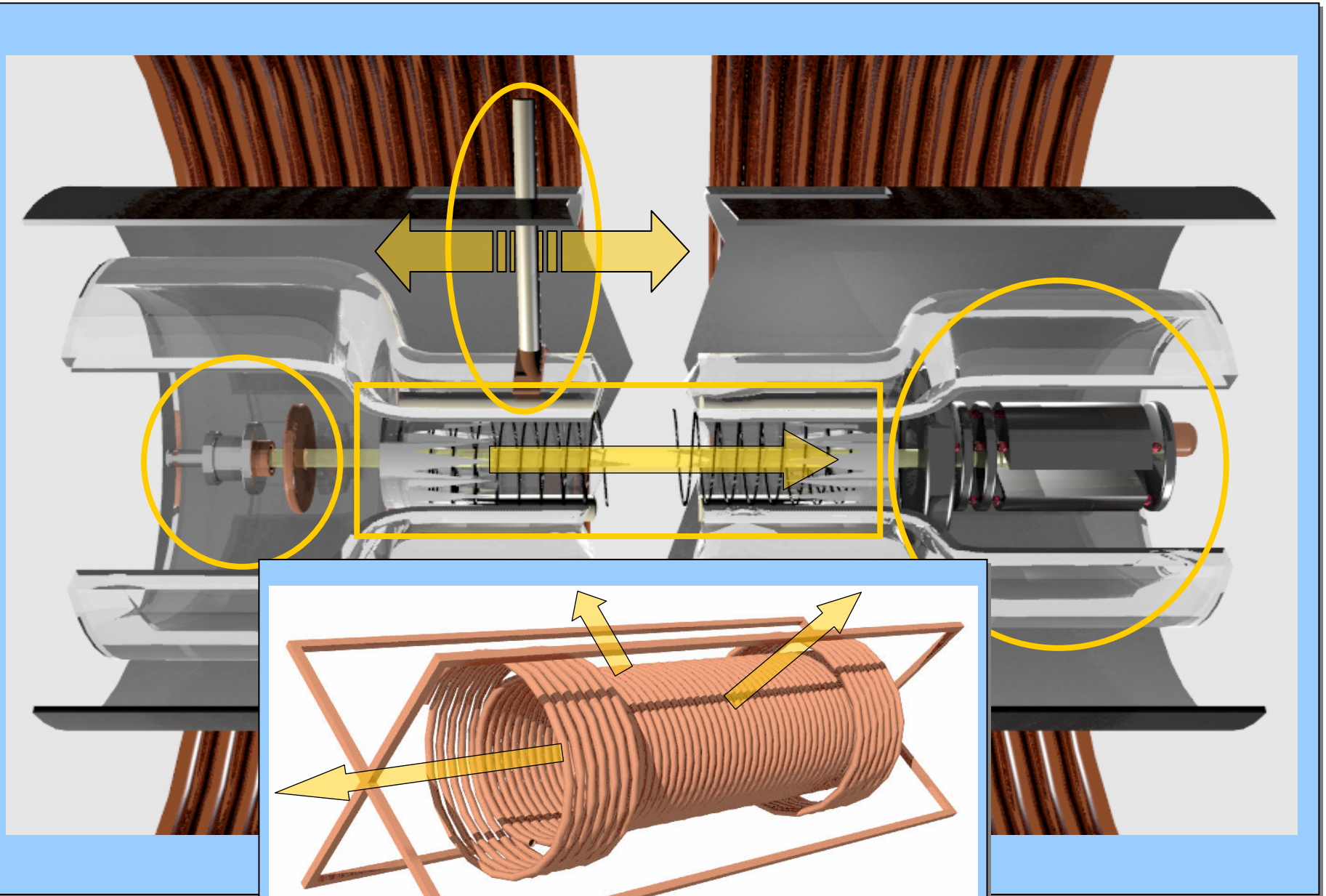

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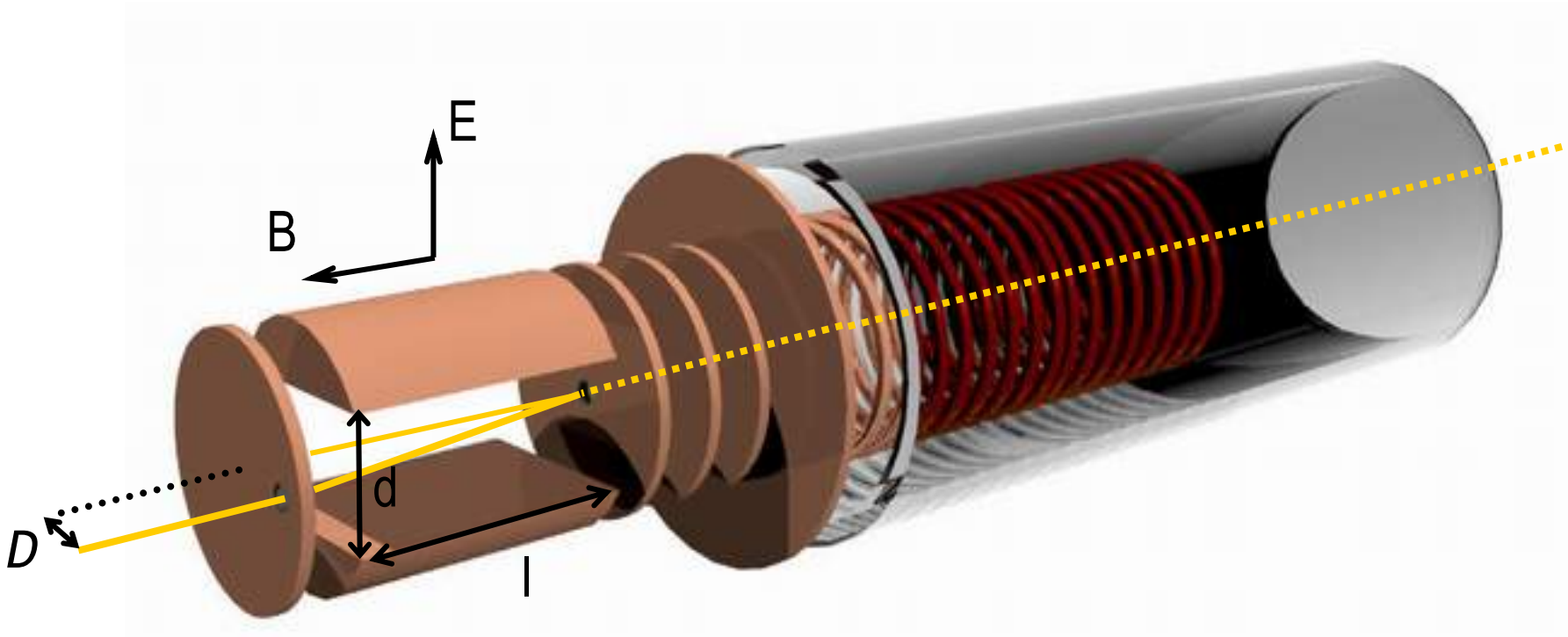
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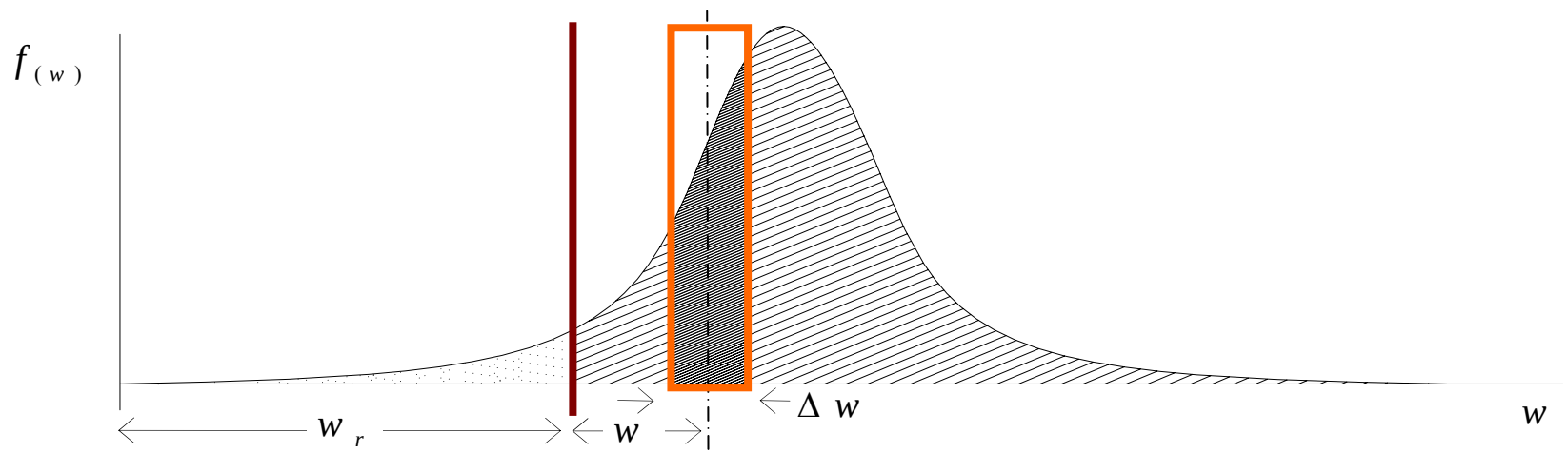
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w

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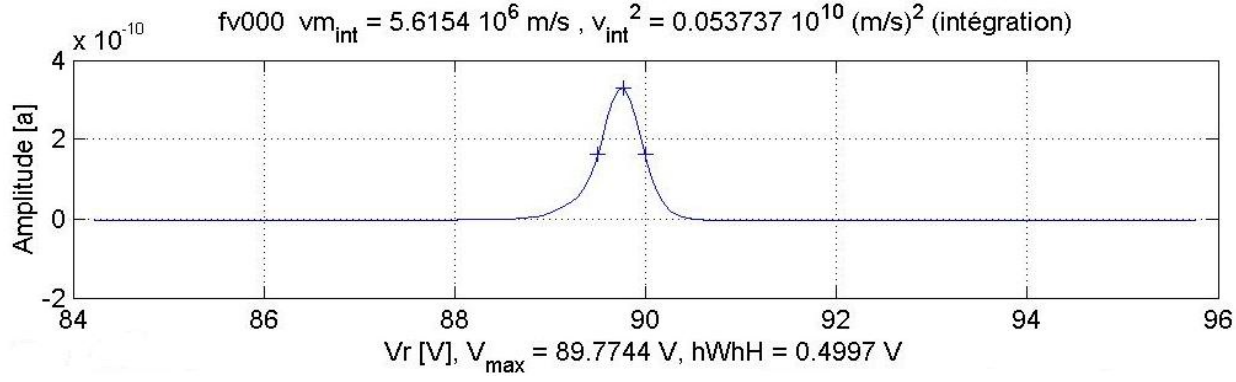
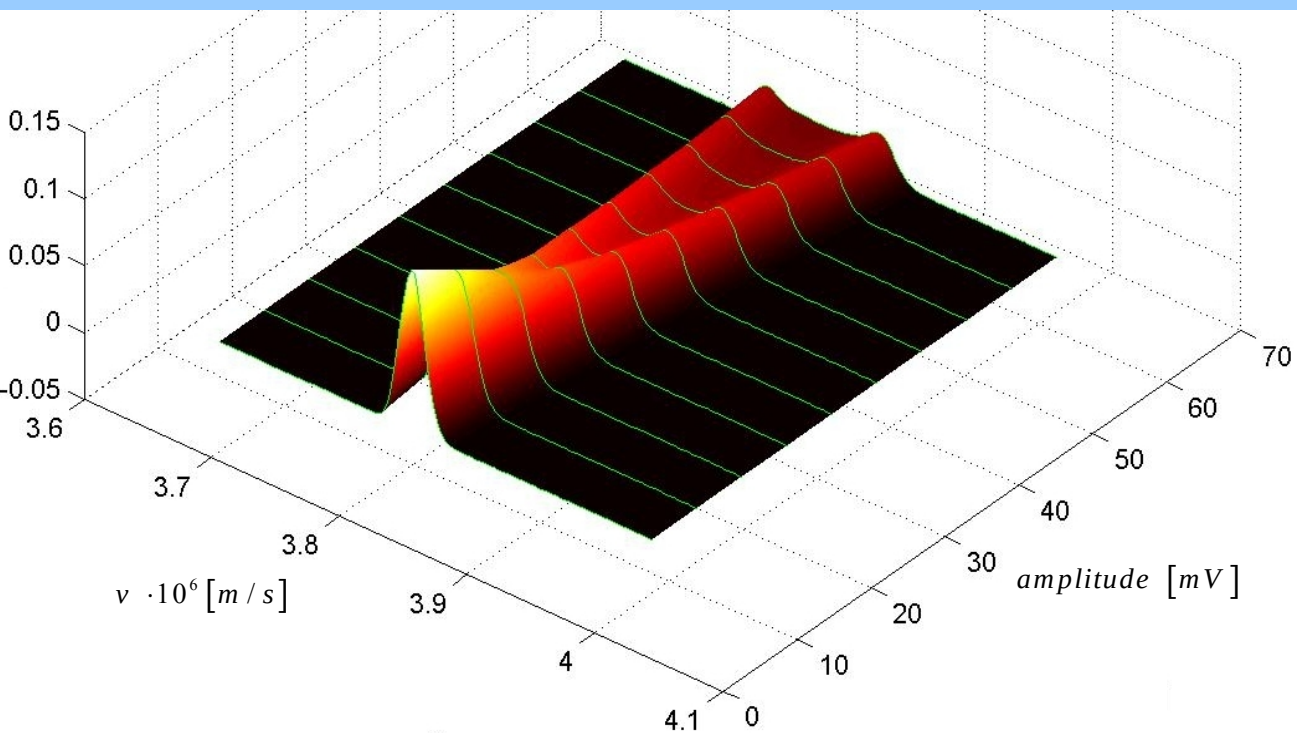


beam

$v_b \quad [m/s]$

$I \quad [nA]$



wave/s

$\begin{bmatrix} f_i & [MHz] \\ v_{\varphi_i} & [m/s] \end{bmatrix}$

$\phi_i \quad [V]$

$phases \ \alpha_i$

$l_{int} \quad [m]$

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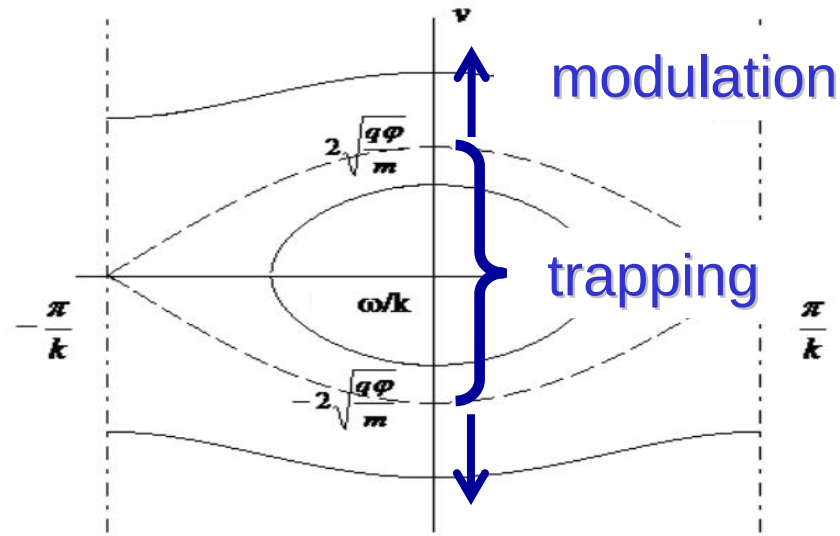
Integrable system

a particle in one wave

$$H_{(x,v)} = \frac{v^2}{2} - M\cos(x)$$

$$M = \frac{|e\varphi|}{m}$$



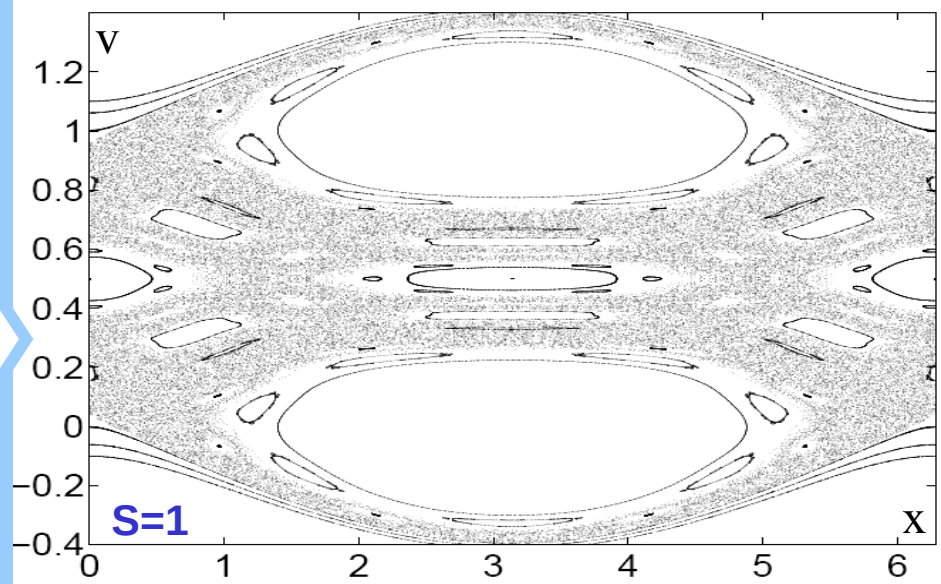
Non integrable system

a particle in two waves

$$H_{(v,x,t)} = \frac{v^2}{2} - M\cos(x) - P\cos(k(x-t))$$

Overlap parameter

$$s = \frac{2\left(\sqrt{\left|\frac{q\varphi_1}{m}\right|} + \sqrt{\left|\frac{e\varphi_2}{m}\right|}\right)}{\left|\frac{\omega_2}{k_2} - \frac{\omega_1}{k_1}\right|}$$



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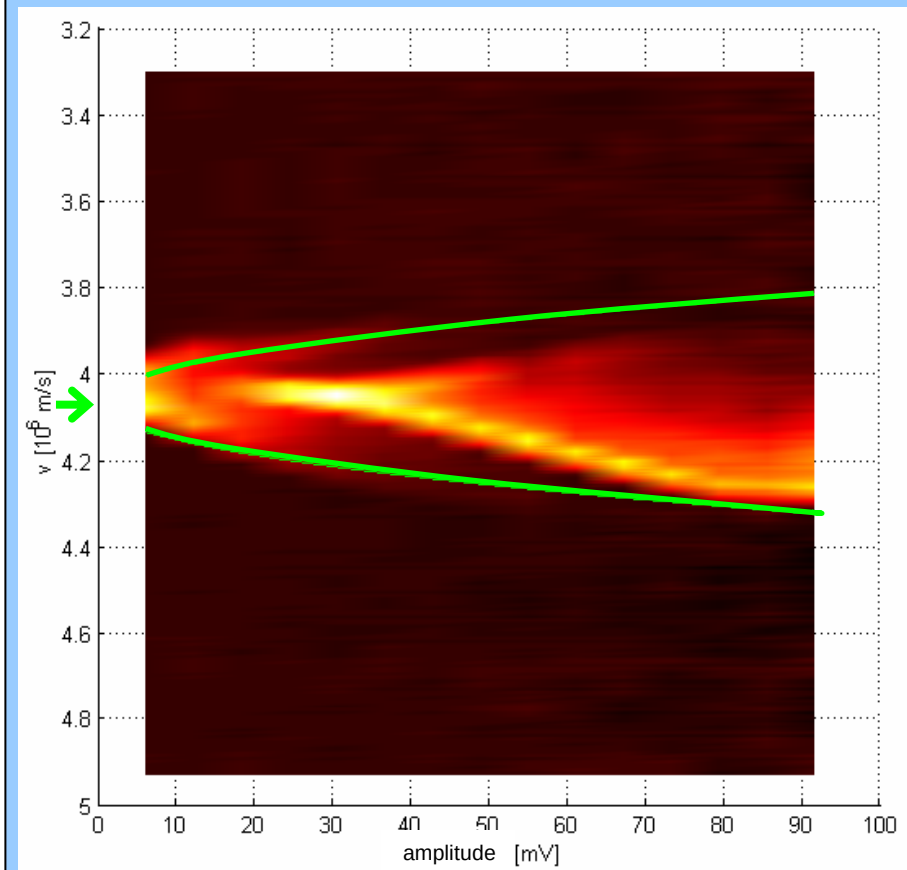


libration

f $30[MHz]$

v_φ $4,07 \cdot 10^6 [m/s]$

ϕ_S $6,1[mV]\,(C_{E_1} = 0,061)$

v_b $4,03 \cdot 10^6 [m/s]$

I $100\,[nA]$

l_{int} $400[cm]$

$$\omega_b = k\sqrt{\frac{|e|\phi}{m}}$$

$$L_b = \frac{2\pi v_\varphi}{\omega_b}$$

f $30[MHz]$

v_φ $4,07 \cdot 10^6 [m/s]$

ϕ_S $6,1[mV]\,(C_{E_1} = 0,061)$

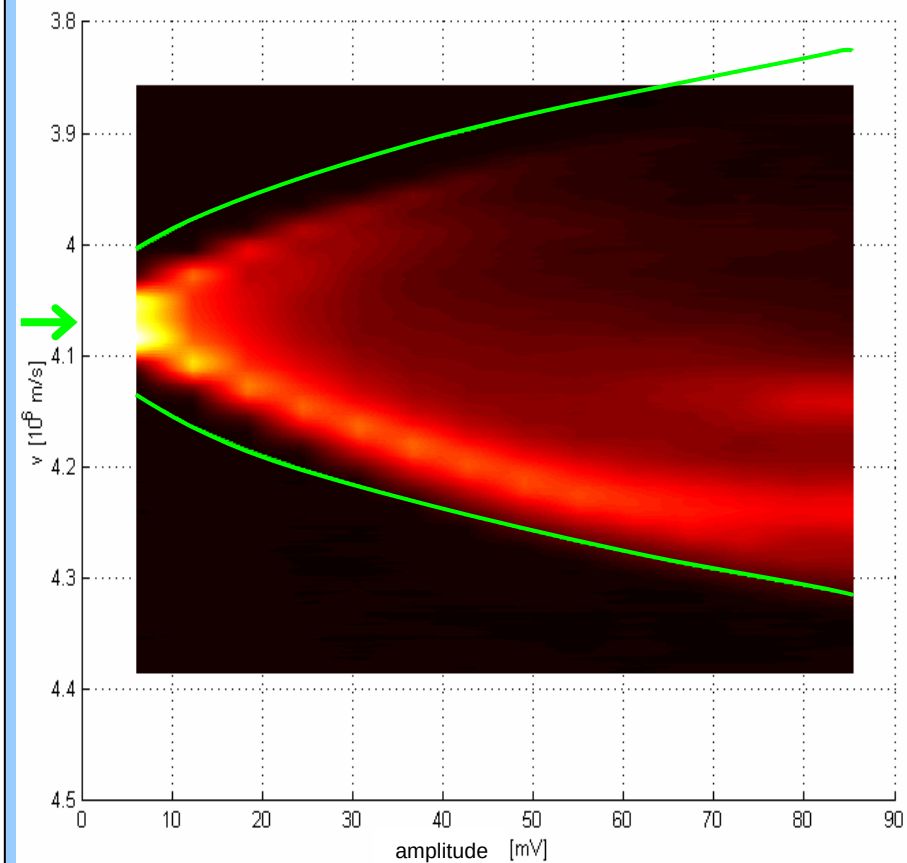
v_b $4,03 \cdot 10^6 [m/s]$

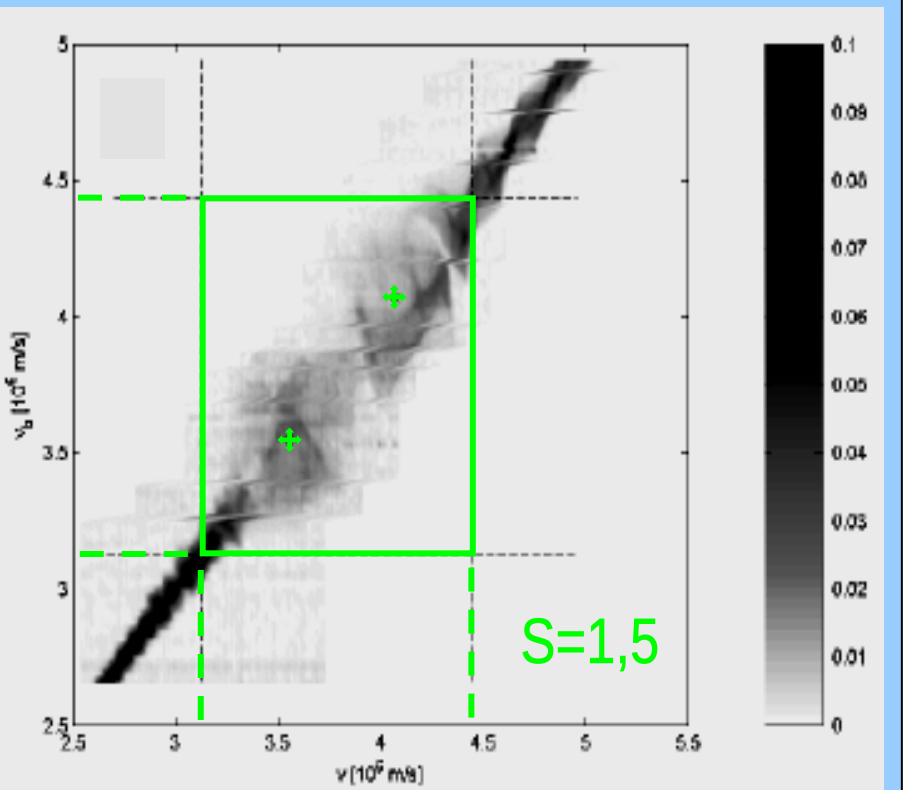
I $100\,[nA]$

l_{int} $260[cm]$

$$v_\pm = v_\varphi \pm 2\sqrt{\frac{e\phi}{m}}$$

trapping





beam-waves

f 30 *and* 40 $[MHz]$

v_φ $4,07 \cdot 10^6$ *e* $3,55 \cdot 10^6 [m/s]$

ϕ_{30} $195[mV]\,(C_{30} = 0,061)$

ϕ_{40} $250[mV]\,(C_{40} = 0,04)$

v_b $3,35 \cdot 10^6 \rightarrow 4,78 \cdot 10^6 [m/s] (step\, 0,42[m/s])$

I $50\,[nA]$

l_{int} $400[cm]$

f 30 *and / or* 40 $[MHz]$

v_φ $4,07 \cdot 10^6$ *and* $3,55 \cdot 10^6 [m/s]$

ϕ_{30} $144[mV]\,(C_{30} = 0,061)$

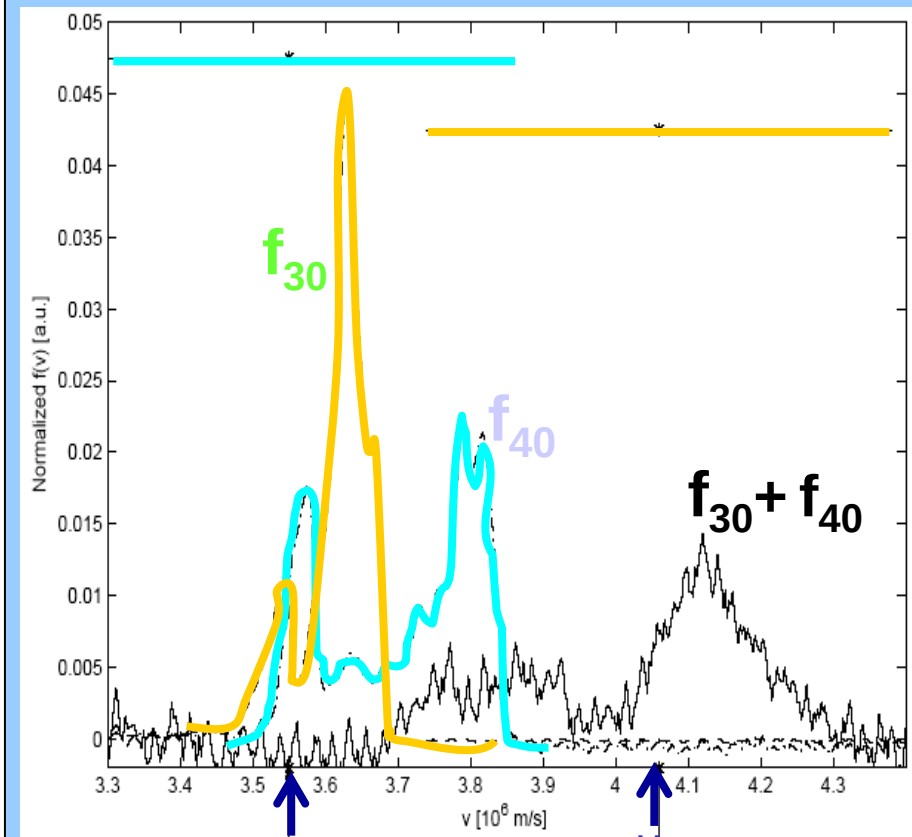
ϕ_{40} $136[mV]\,(C_{40} = 0,04)$

v_b $3,55 \cdot 10^6 [m/s]$

I $50\,[nA]$

l_{int} $400[cm]$

KAM tori breaking



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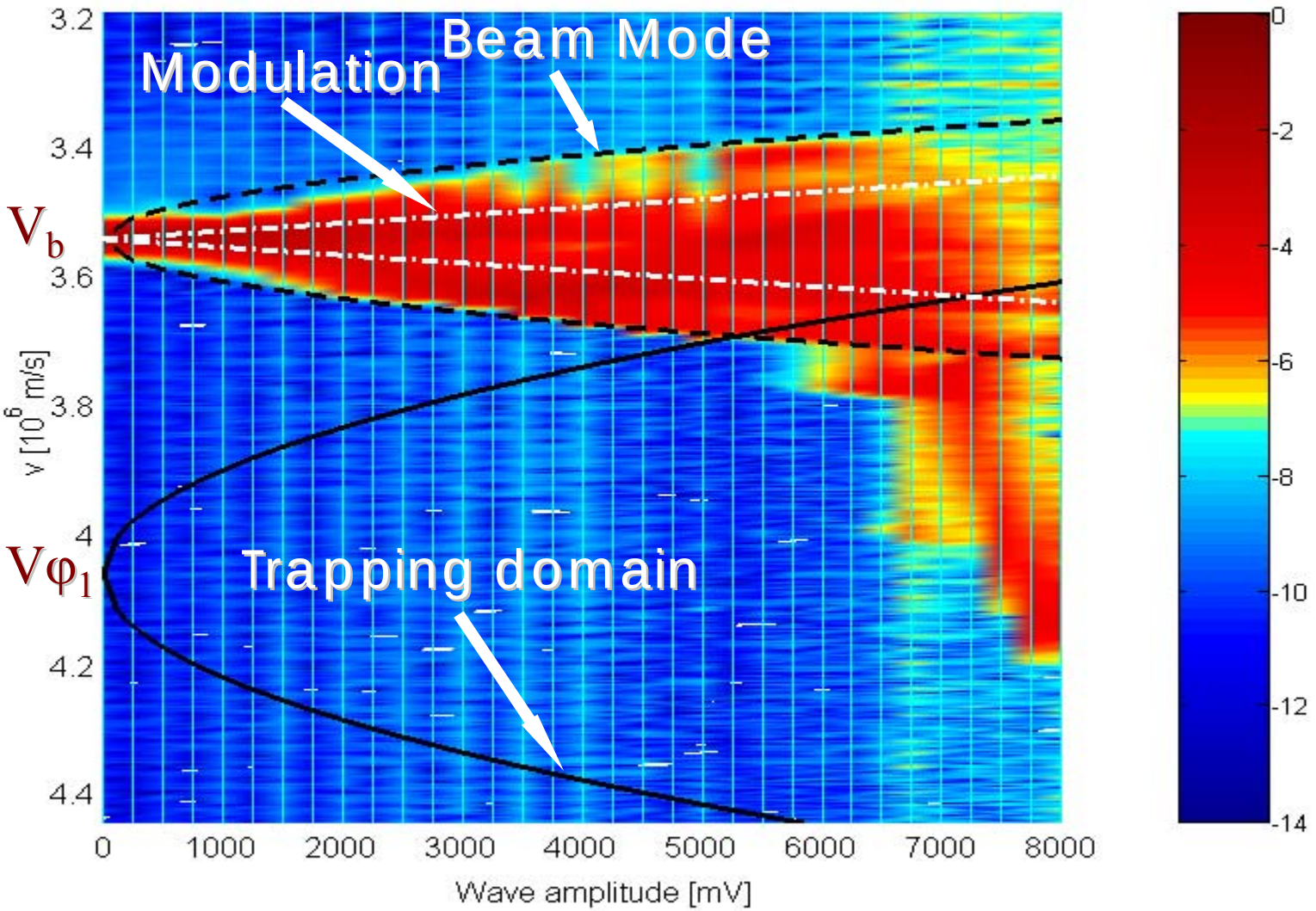
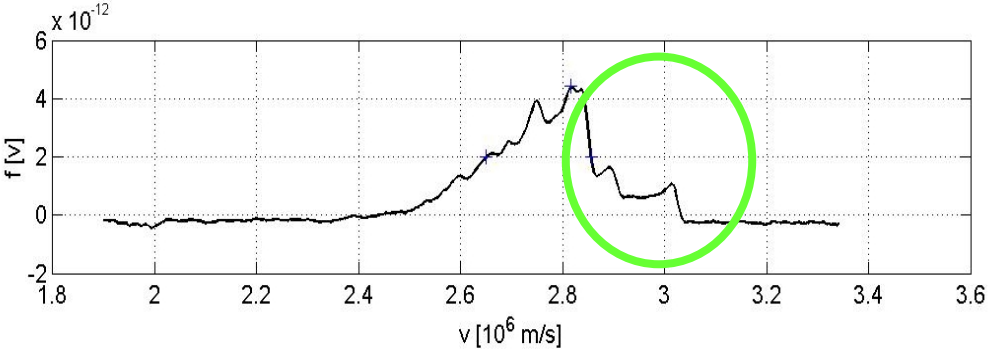
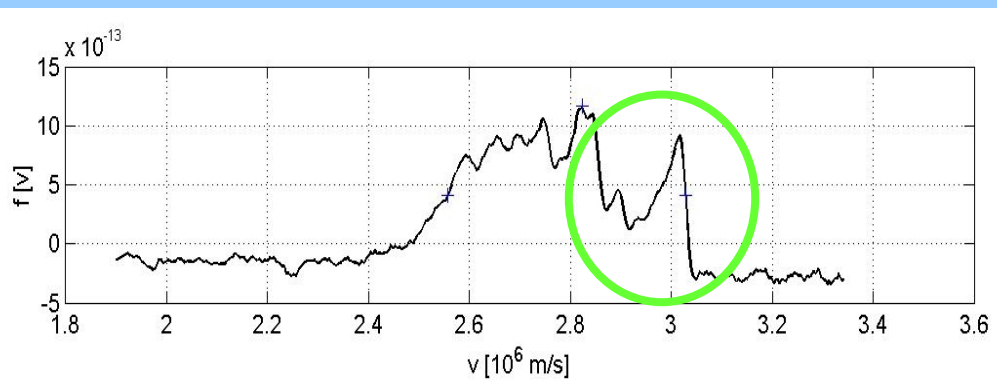
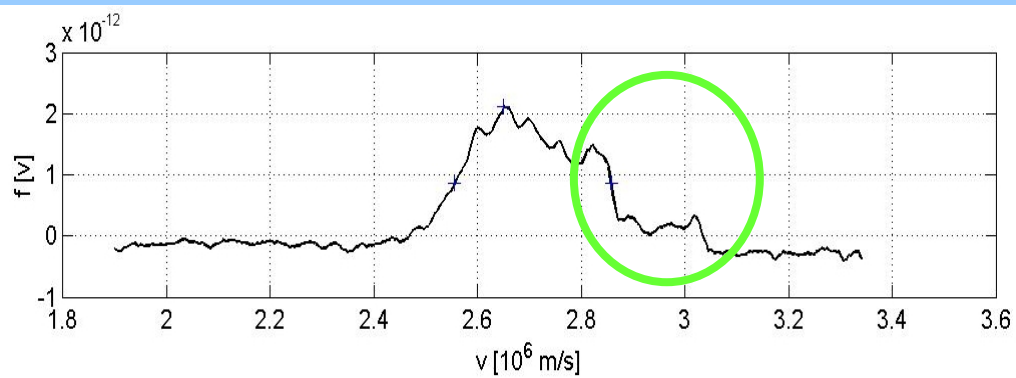
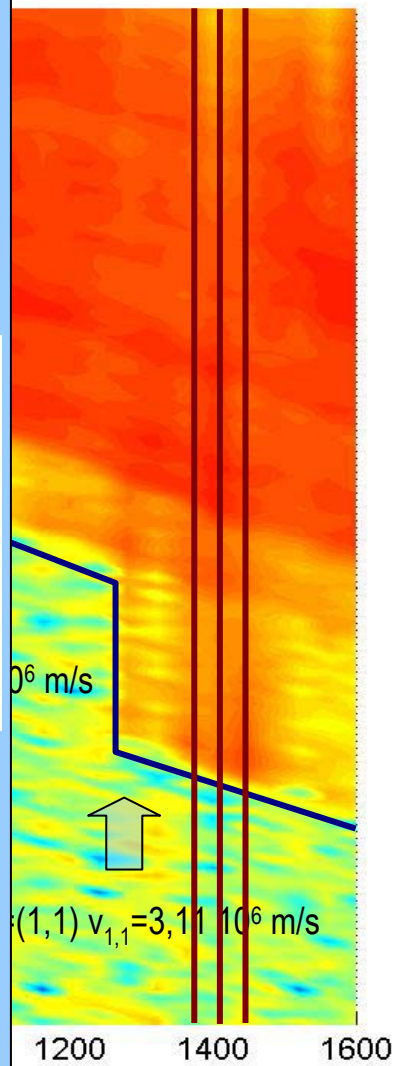
One excitation at 30 MHz

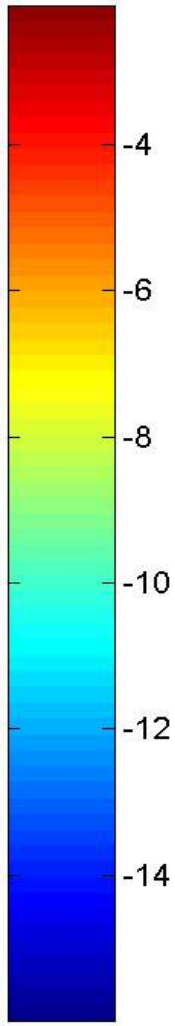



x 10^-12
f [v]
v [10^6 m/s]


x 10^-13
f [v]
v [10^6 m/s]


x 10^-12
f [v]
v [10^6 m/s]


0^6 m/s
(1,1) v1,1=3,11 10^6 m/s
1200
1400
1600


-4
-6
-8
-10
-12
-14

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$f \quad 30[MHz]$

$v_\varphi \quad 4,07 \cdot 10^6 [m/s]$

$\phi_\varphi \quad 2,332[V]\,(C_{E_2} = 0,088)$

$\phi_M \quad 0,168[V]\,(C_{E_2} = 0,088)$

$f_b \quad 30[MHz]$

$v_b \quad 2,51 \cdot 10^6 [m/s]$

$\alpha = \phi_b / \phi_\varphi = 0,072$

$I \quad 50\,[nA]$

$l_{\text{int}} \quad 400[cm]$

+

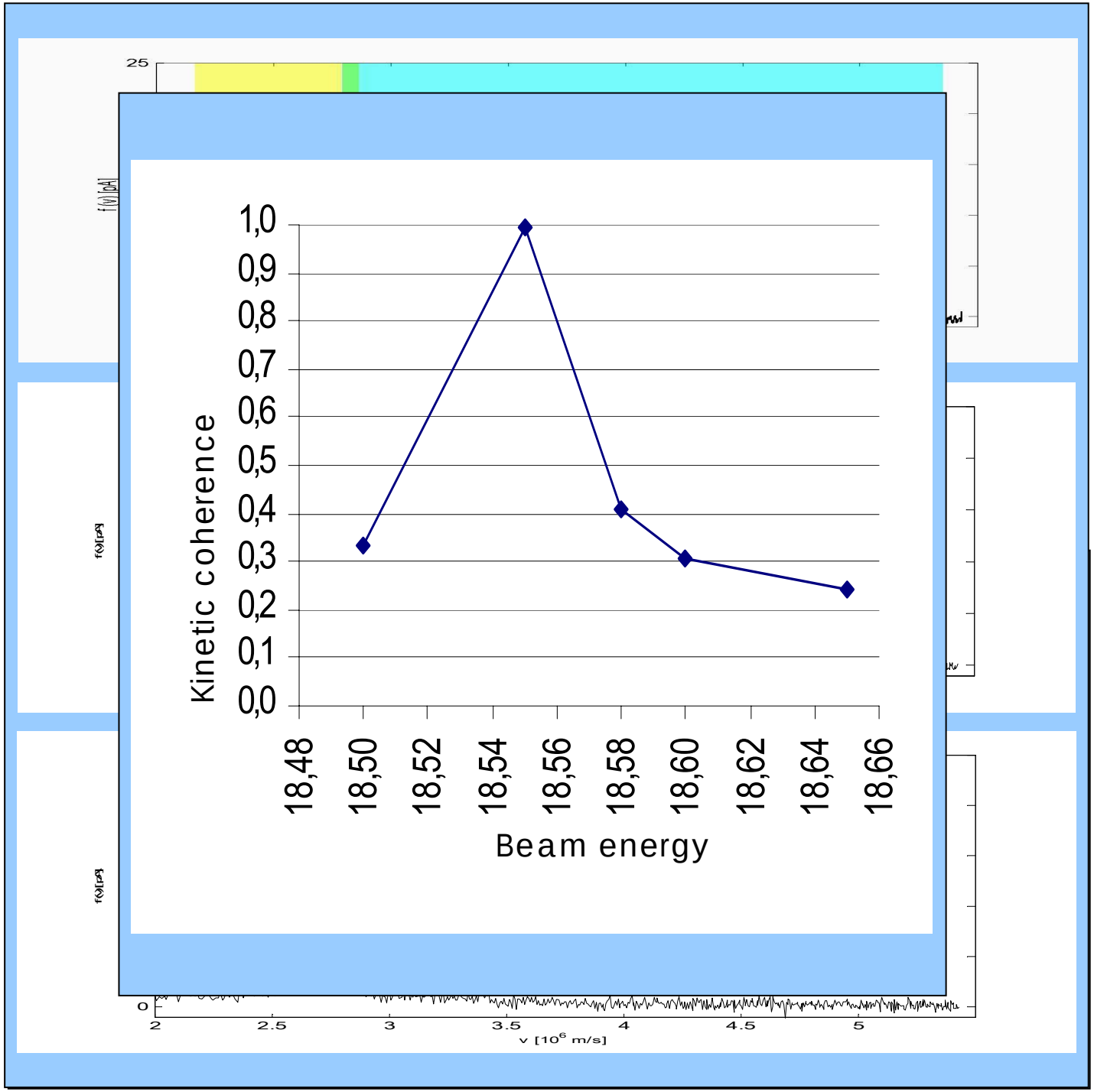
$f_c \quad 60[MHz]$

$v_c \quad 3,08 \cdot 10^6 [m/s]$

$\phi_c \quad 0,058[V]$

$(C_{E_2} = 0,00792)$

$$\frac{E_{contr}}{E_{sist}} \approx 0,1\%$$



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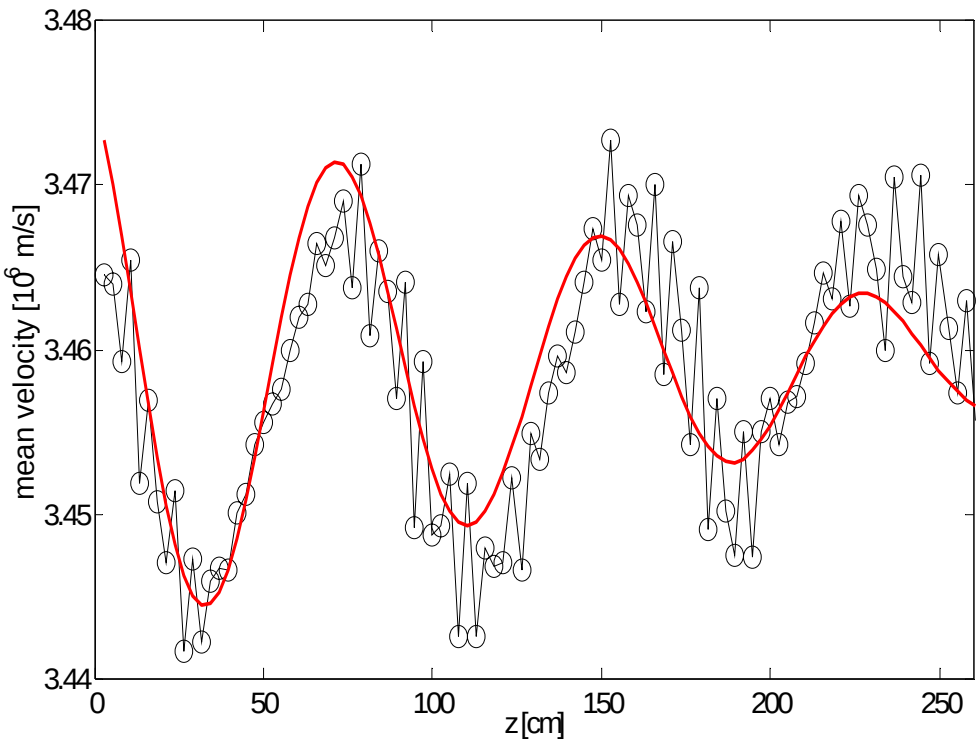
conclusion

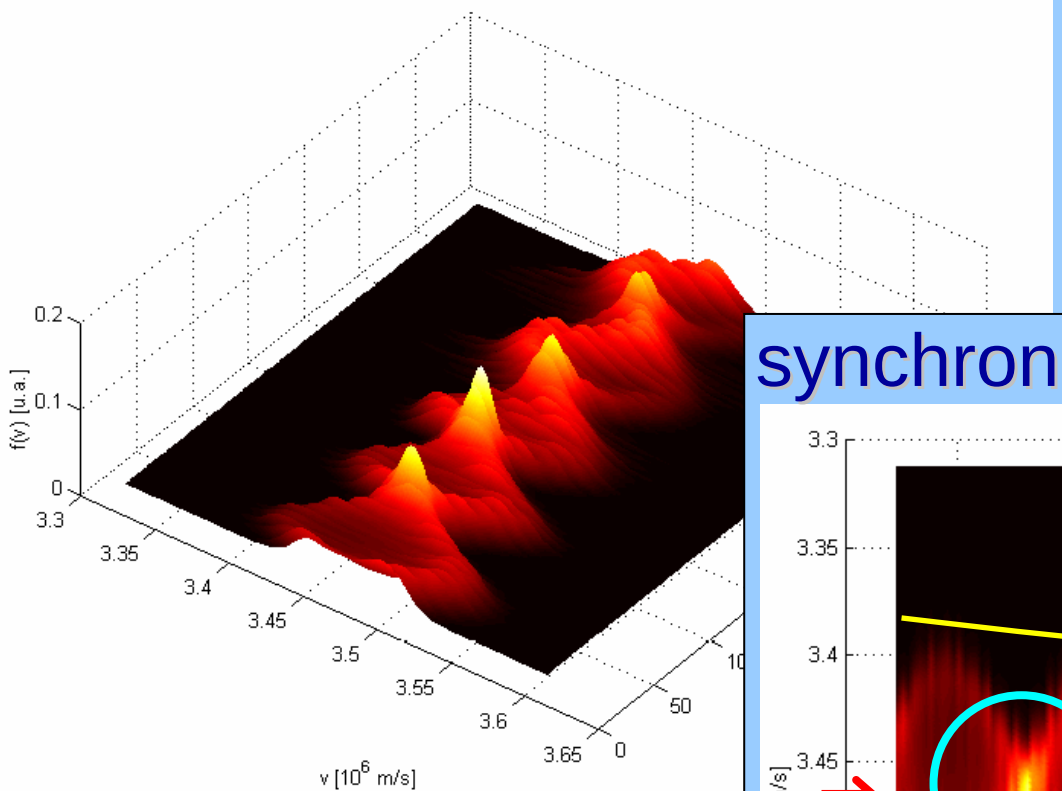
- trapping and modulation of test beam measured
- transition to large scale chaos observed
- secondary resonances observed
- new method of control of Hamiltonian chaos tested

perspectives

- detailed analysis of destruction of KAM barriers
- measure chaotic diffusion
- introduce self consistency
- injection of electron packets

Mean beam velocity of a modulated beam (2nd order perturbation theory)

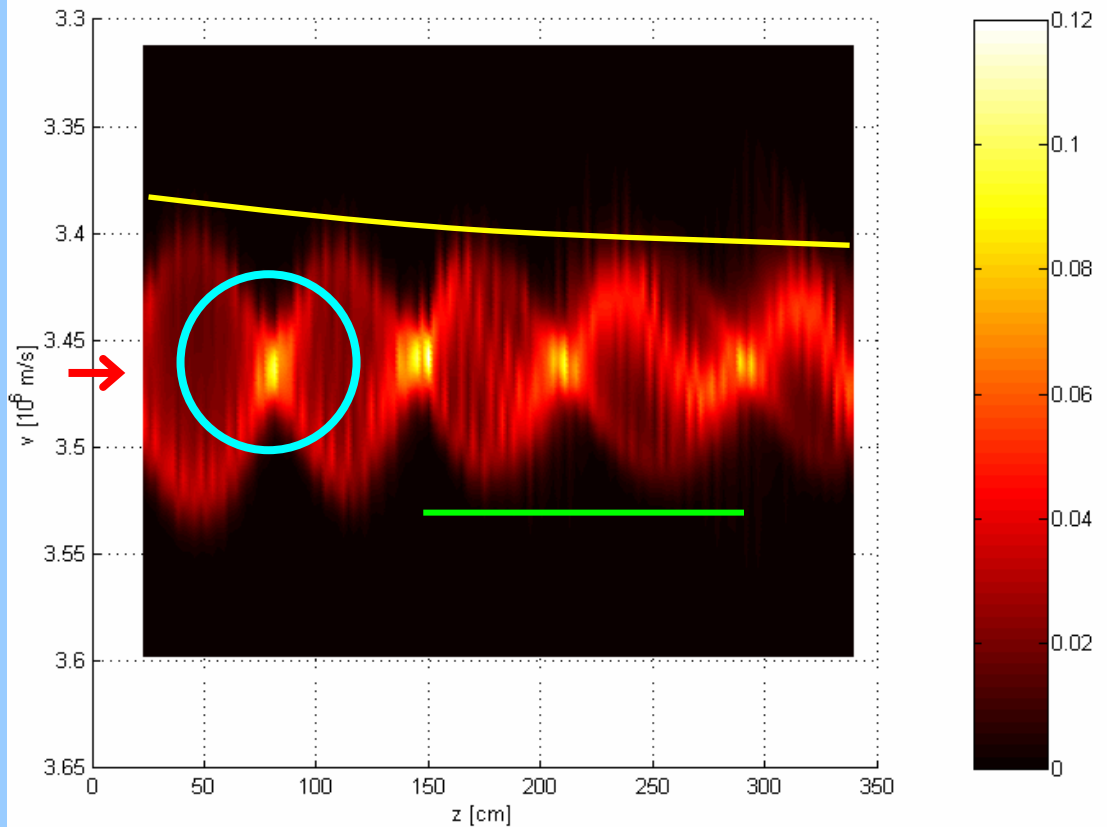




$$L_{batt} = \frac{2v_b v_\varphi}{f\left|v_b - v_\varphi\right|}$$

$$L_{port} = \frac{4v_b v_\varphi}{f\left|v_b + v_\varphi\right|}$$

synchronization and bunching



f $30[MHz]$

v_φ $4,07 \cdot 10^6 [m/s]$

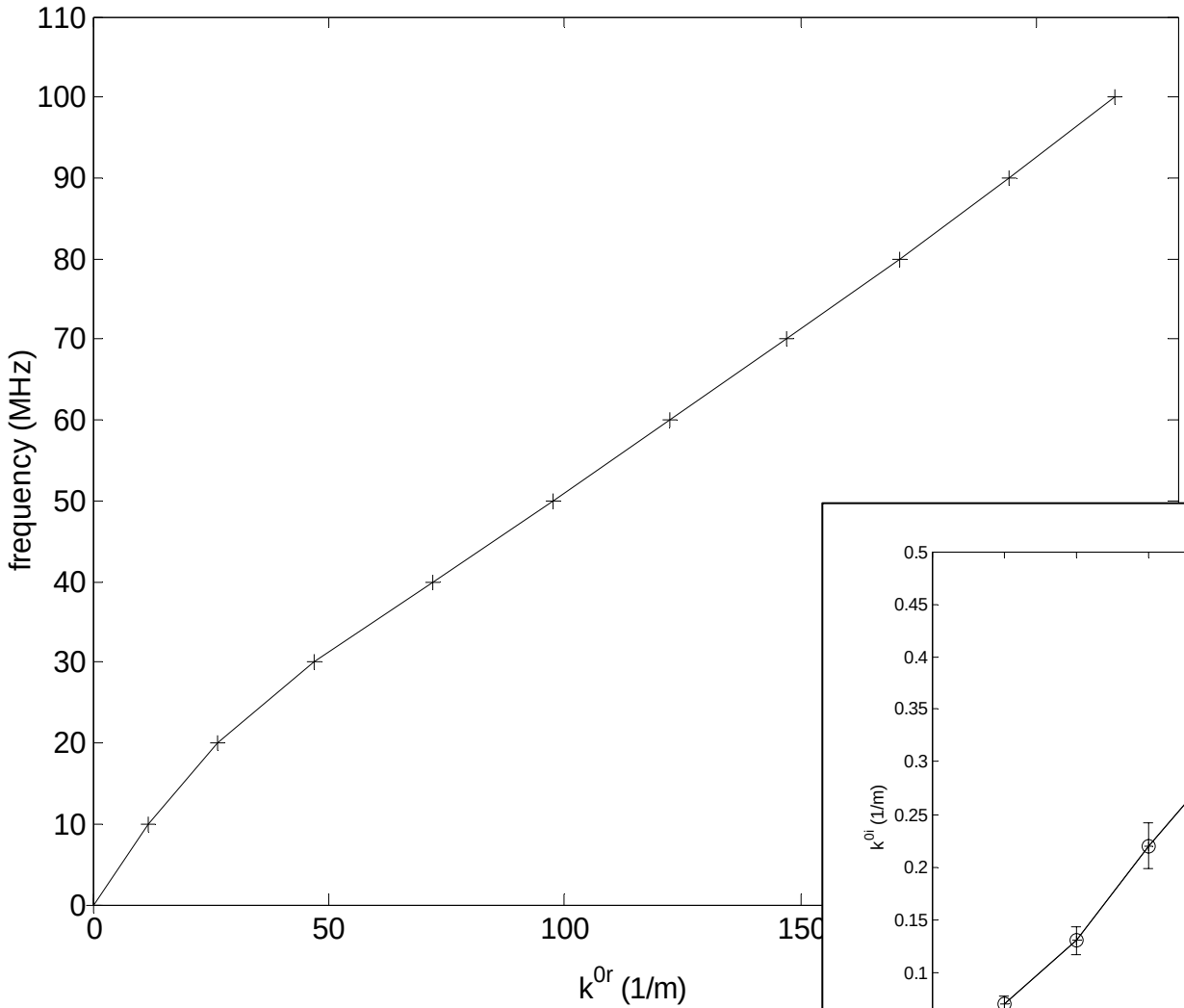
ϕ $18,3[mV]\,(C_{E_1} = 0,061)$

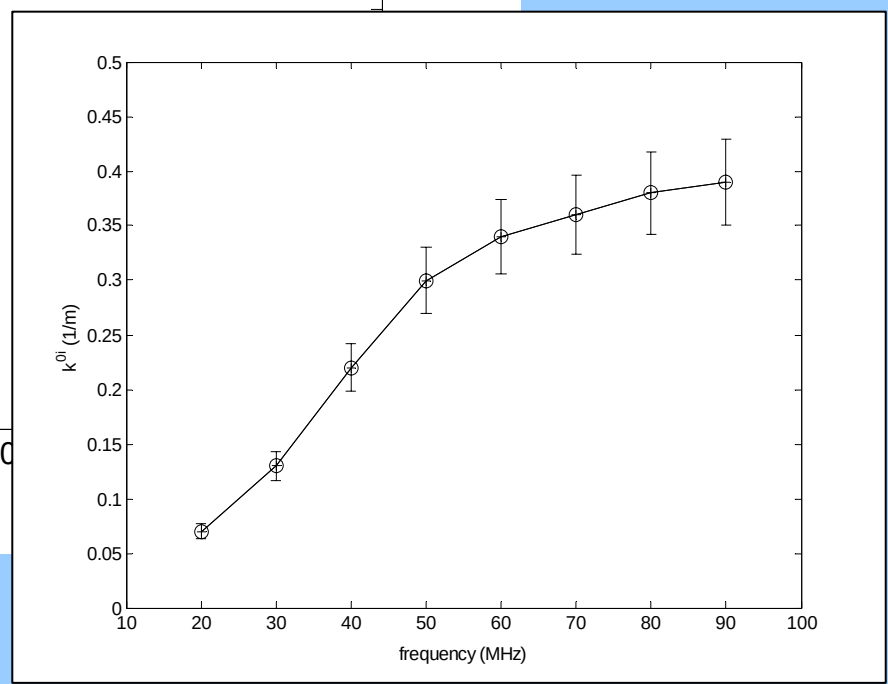
v_b $3,46 \cdot 10^6 [m/s]$

I $230\,[nA]$

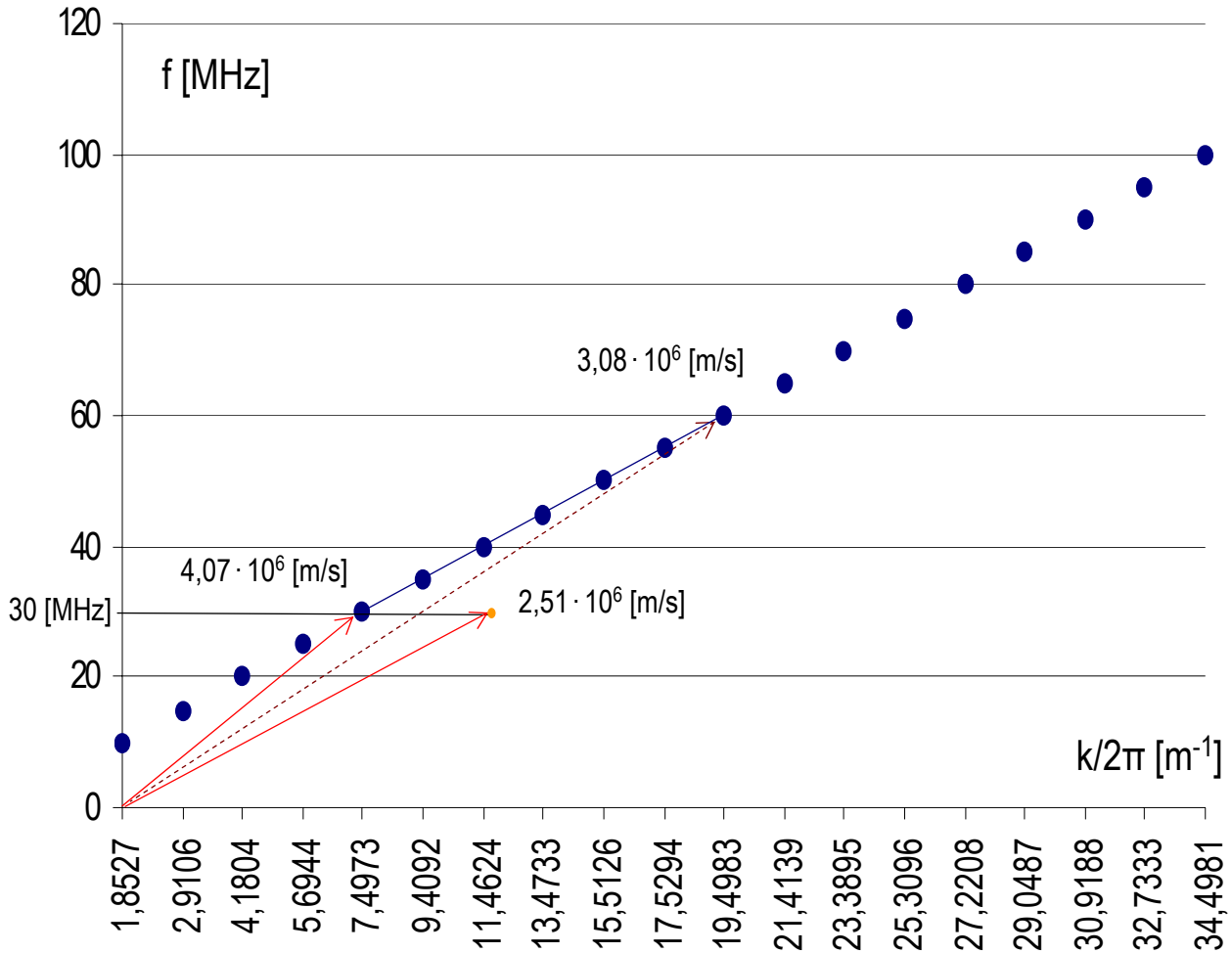
l_{int} $20 \rightarrow 351,5[cm]\,(126 step\,,\, 2,63\,[cm])$

Dispersion relation

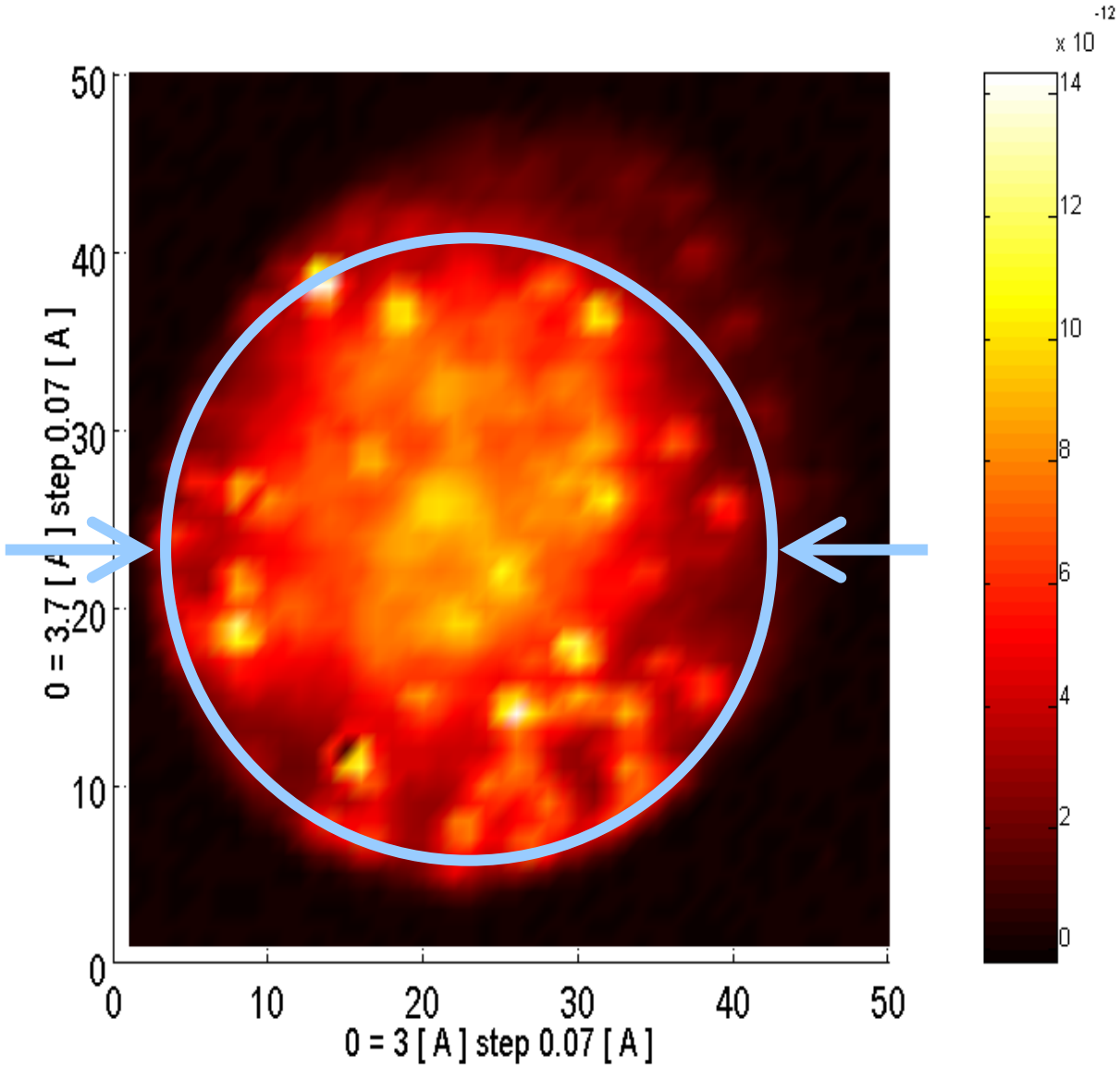




Resonance condition



Beam radial profile



Principle of measurement

Excited wave(s) (f_i, A_i , ϕ_i , $\iota = 1...N$)

Interaction length

Trochoidal analyser

Test Beam

V_b

Helix