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Storage Ring Free Electron Laser Dynamics: Longitudinal Detuning Study

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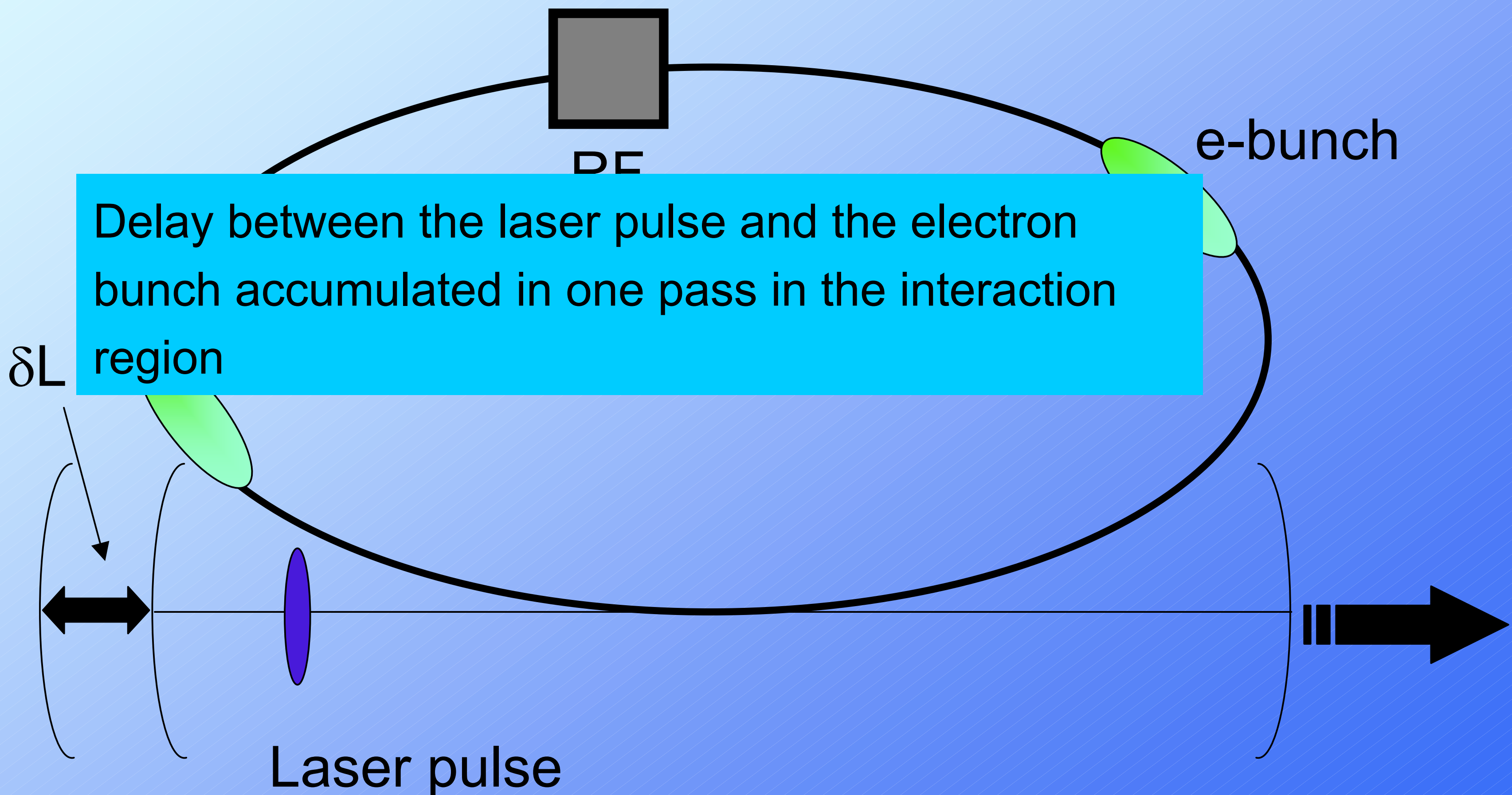
I. Experimental detuning curves

- Super ACO
- ELETTRA

II. Comparison Theory vs. Experiment:

- Numerical simulations

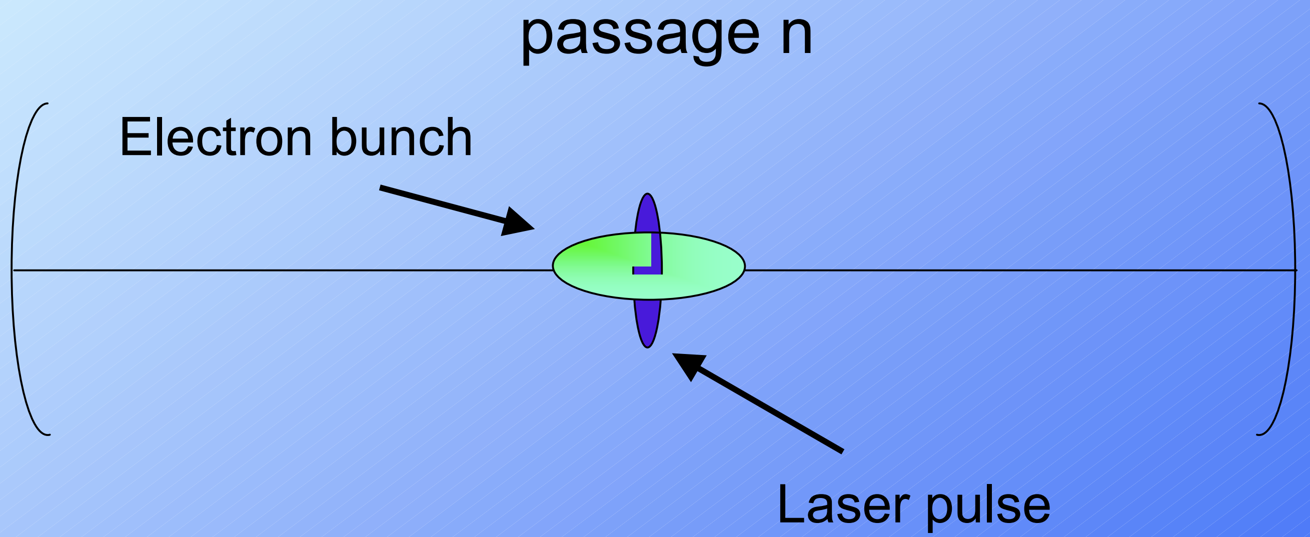
Detuning: definition



Delay between the laser pulse and the electron bunch accumulated in one pass in the interaction region

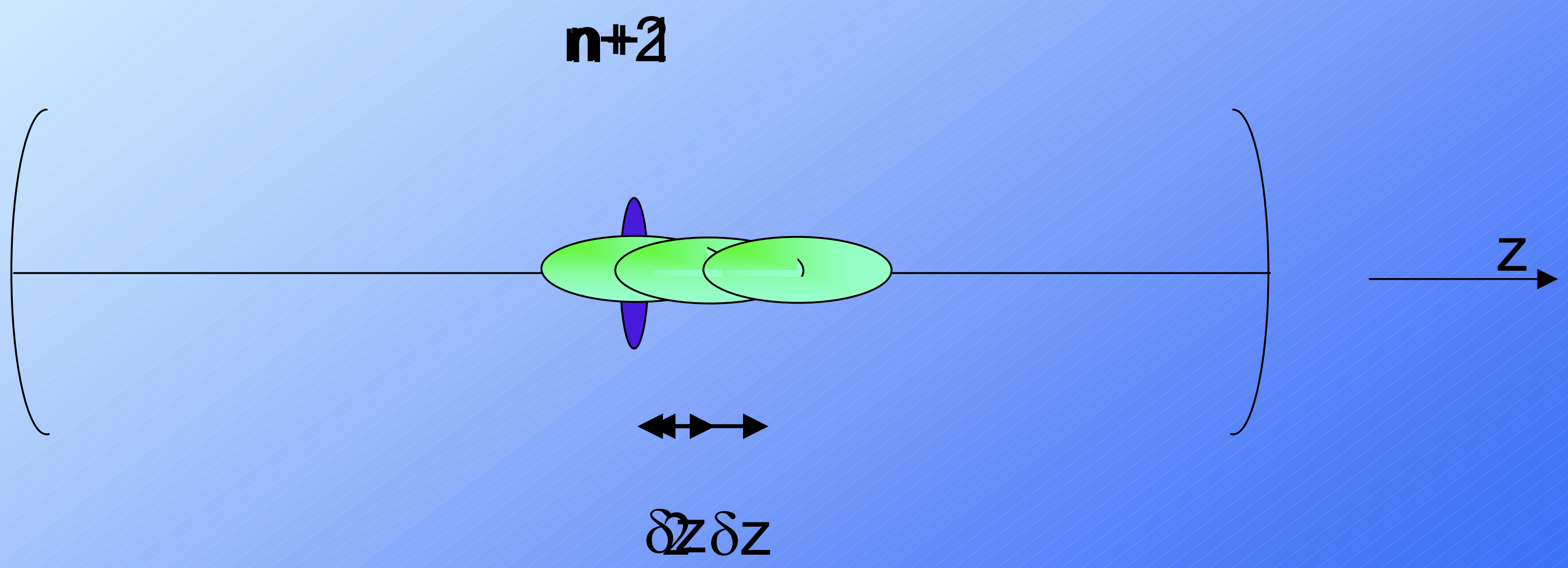
Detuning effect:

$\nu_{RF} \rightarrow T_{las} = T_b$



Detuning effect: $\nu_{RF} + \delta\nu_{RF}$ $\delta\nu_{RF} > 0$

$T_{las} > T_b$



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Why studying the detuning curves?

Detuning curves characteristics give information about FEL dynamical system properties

Importance: control the FEL source stability for user applications

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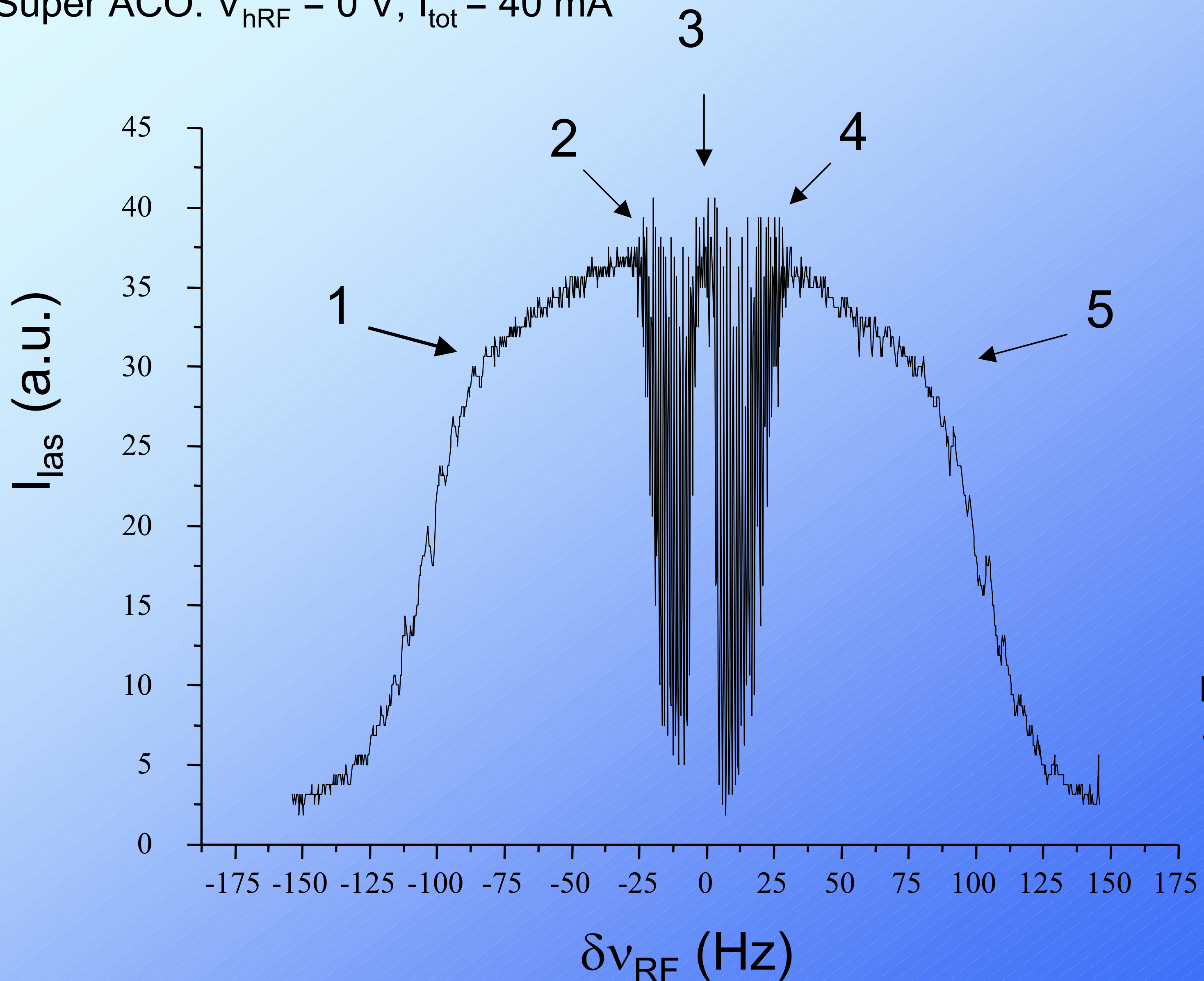
Detuning curve

Super ACO: V_{hRF} = 0 V, I_{tot} = 40 mA

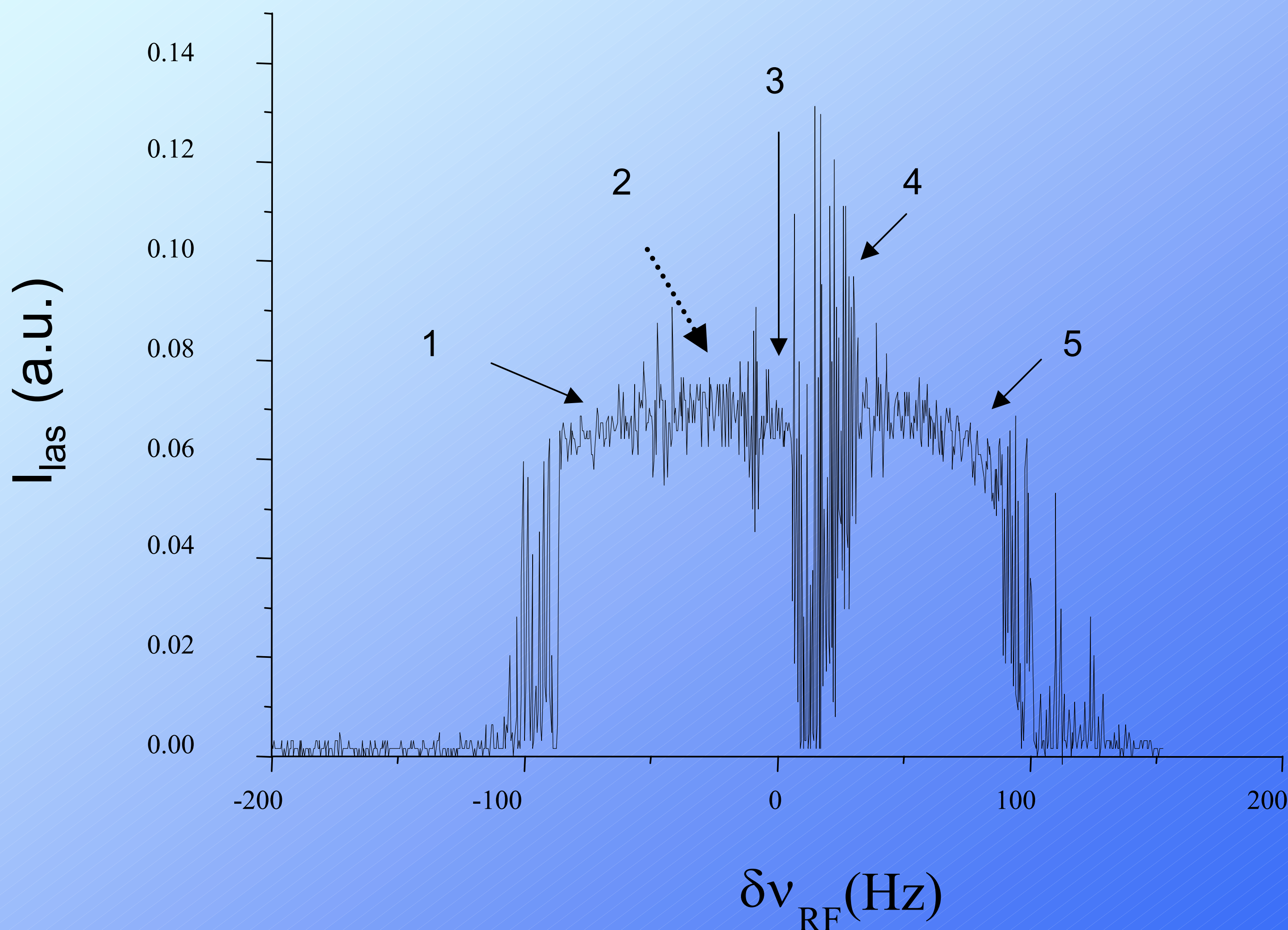


Delay:

1Hz ↔ 0.36 μm

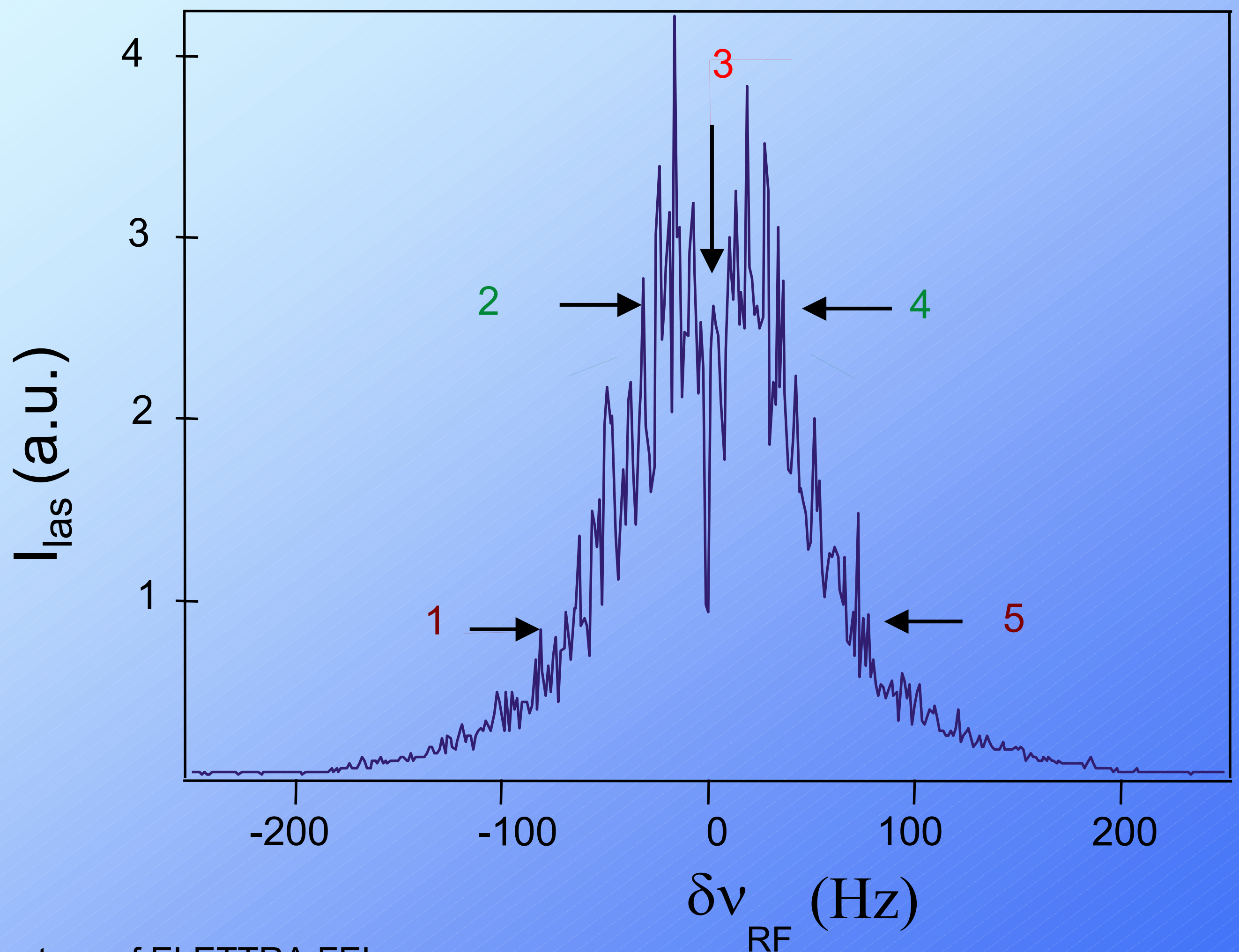
Detuning curve

Super ACO: V_{hrf} = 150 kV, I_{tot} = 25 mA



Detuning curve

ELETTRA: I_{tot} = 20 mA



Courtesy of ELETTRA FEL group

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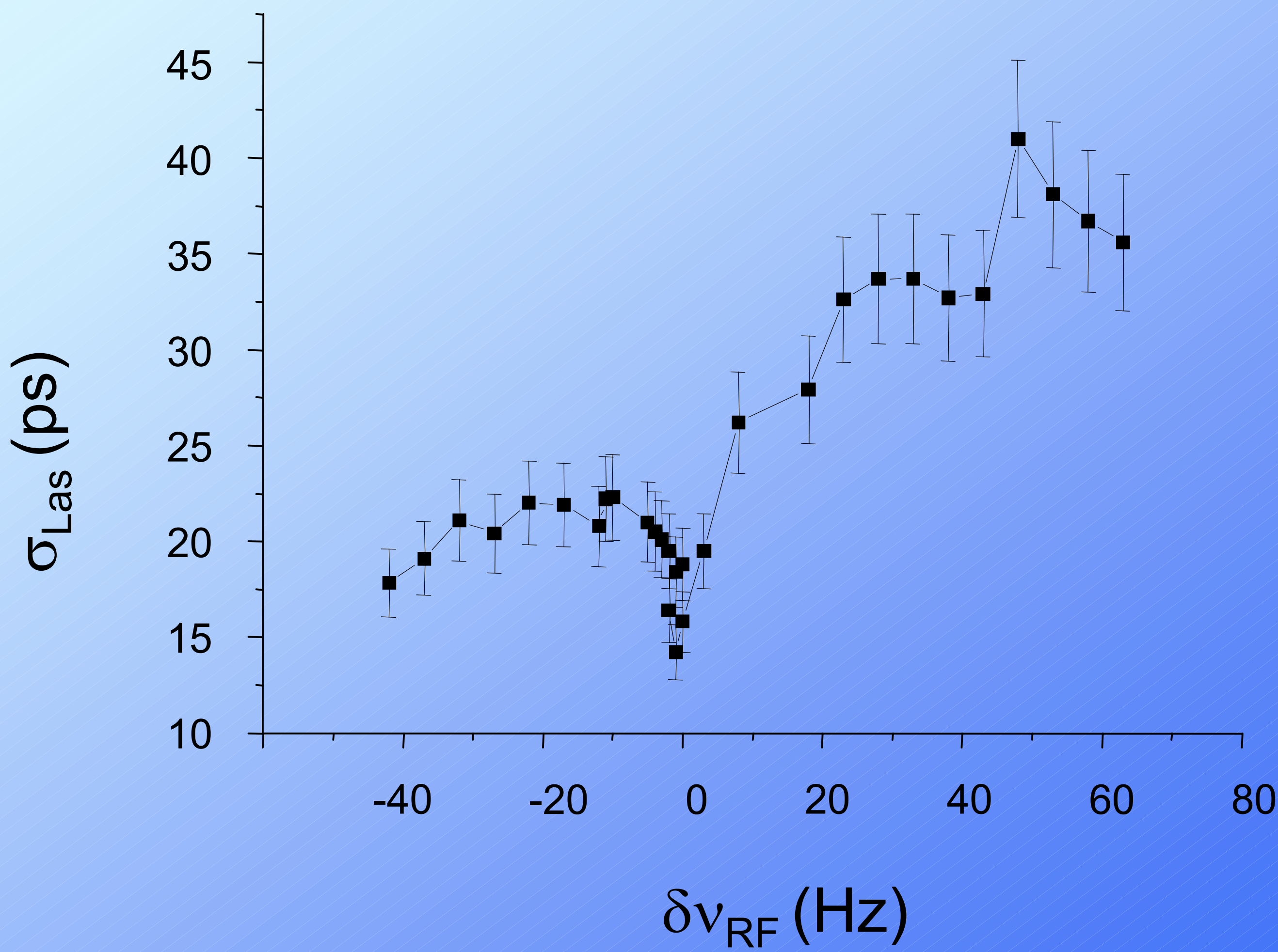
Laser pulse duration

Super ACO: V_{hRF} = 150 kV



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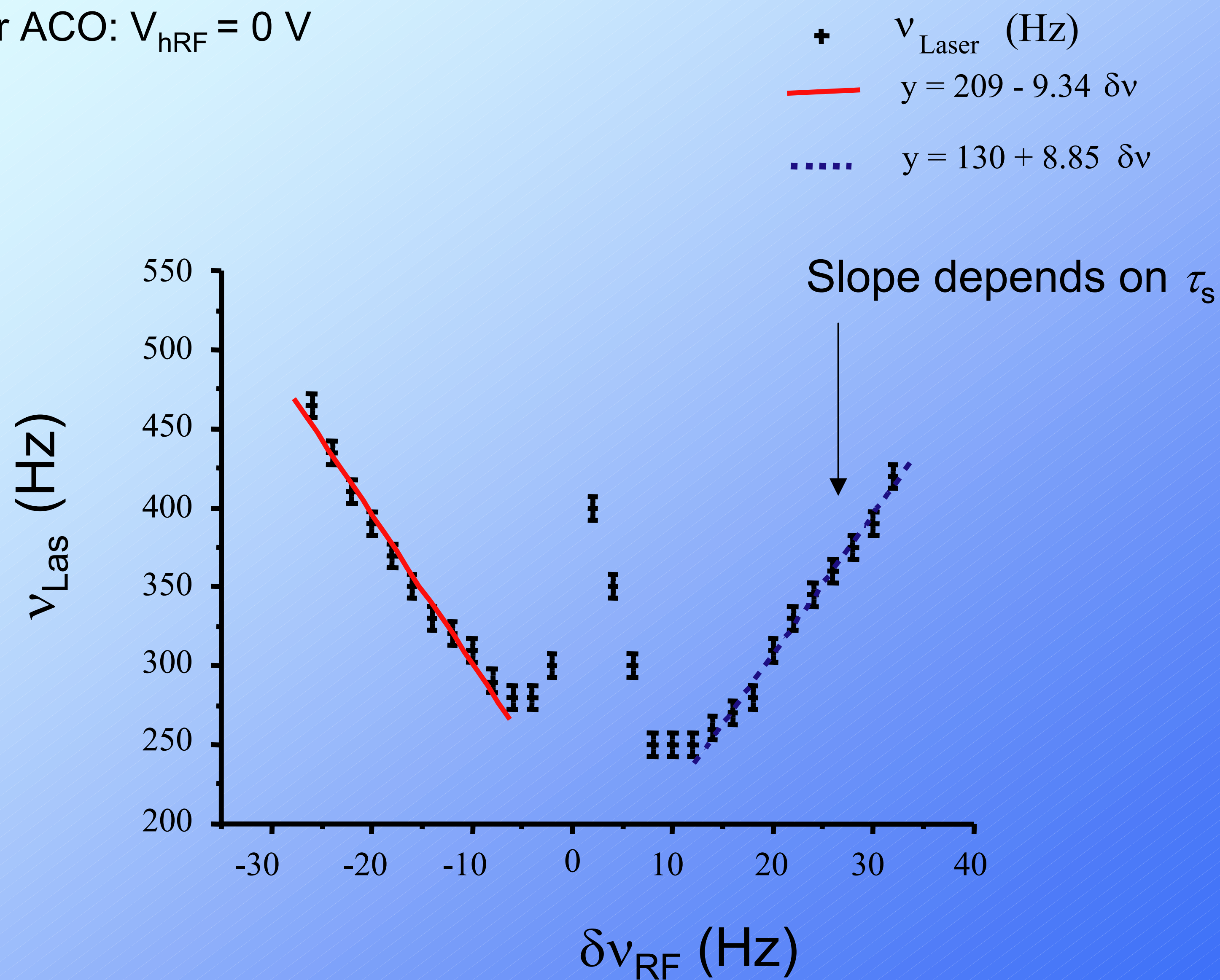
Pulsed behavior

Super ACO: $V_{hRF} = 0$ V



Numerical code: integrates differential equations

1-D model coupling:

- Laser electric field evolution
- Longitudinal phase space evolution
- Microwave instability

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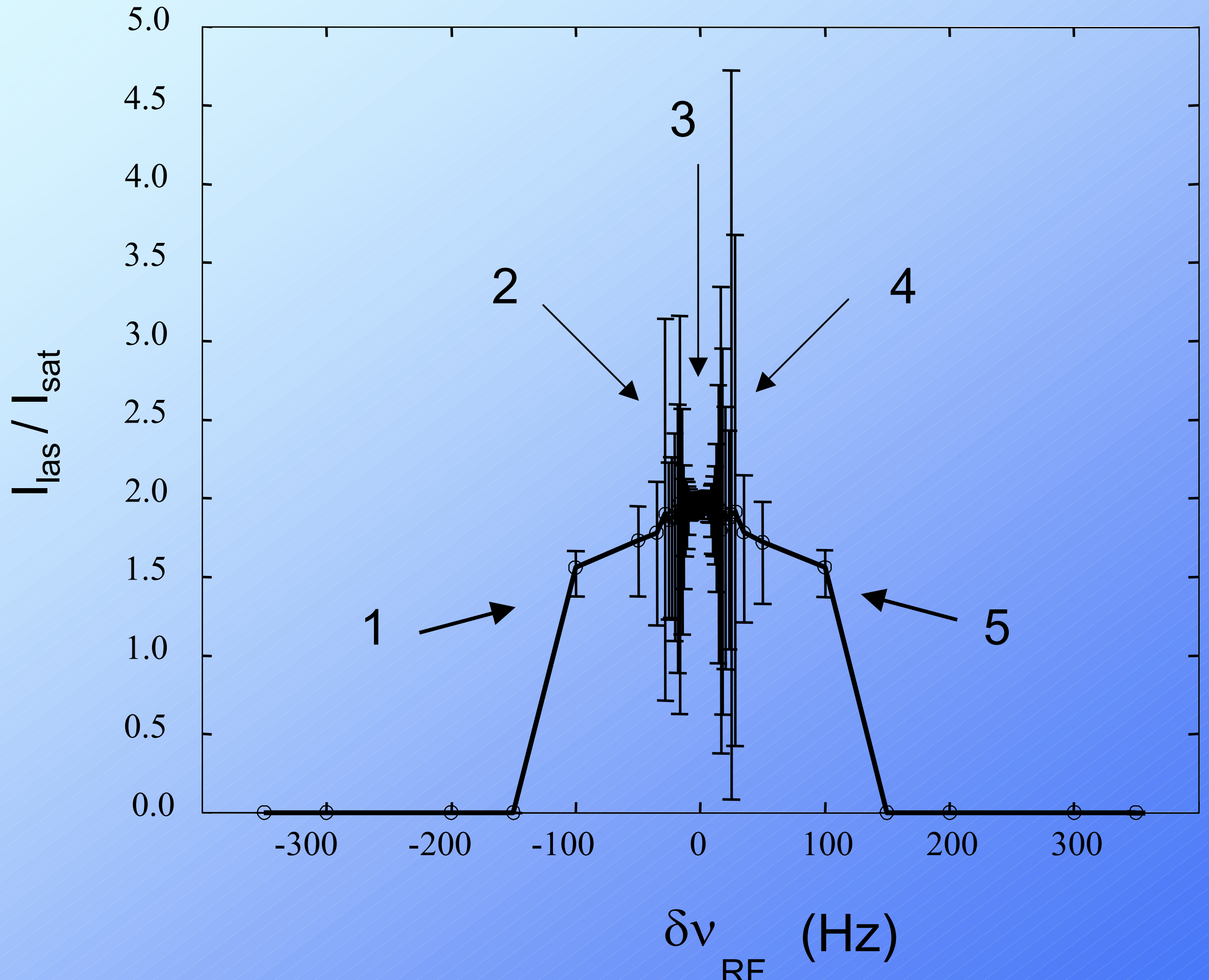
Numerical detuning curve: Super ACO



$g_0 \approx 2$ %

$|Z_n/n| \approx 5\ \Omega$

$I_{tot} = 40$ mA

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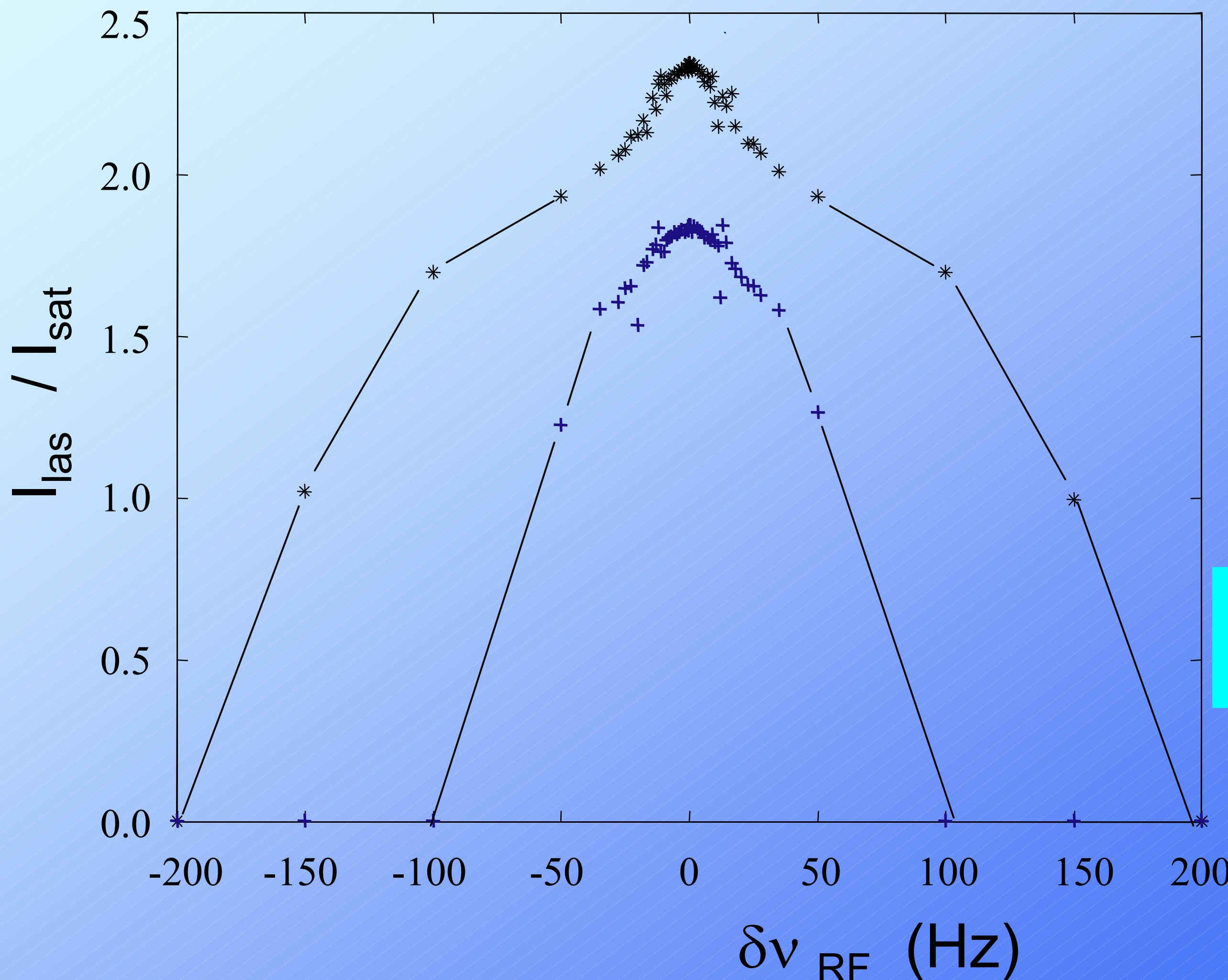
Super ACO, detuning curve for two gain values



$g_{0,eff}$ =1.4 %

$\Delta\nu$ = 350 Hz

$g_{0,eff}$ =1.3 %

$\Delta\nu$ = 200 Hz

Conclusion: width depends on the gain

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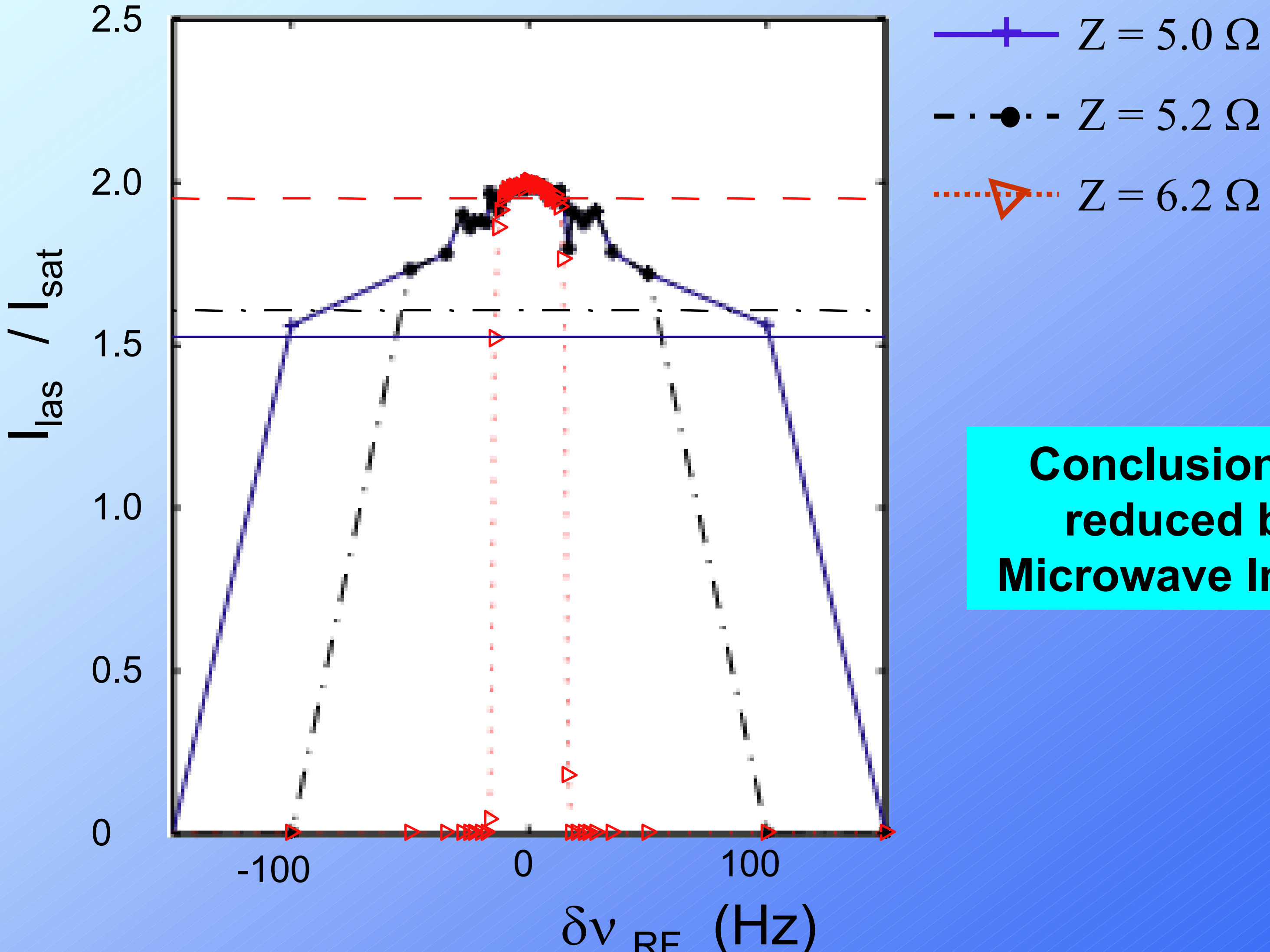
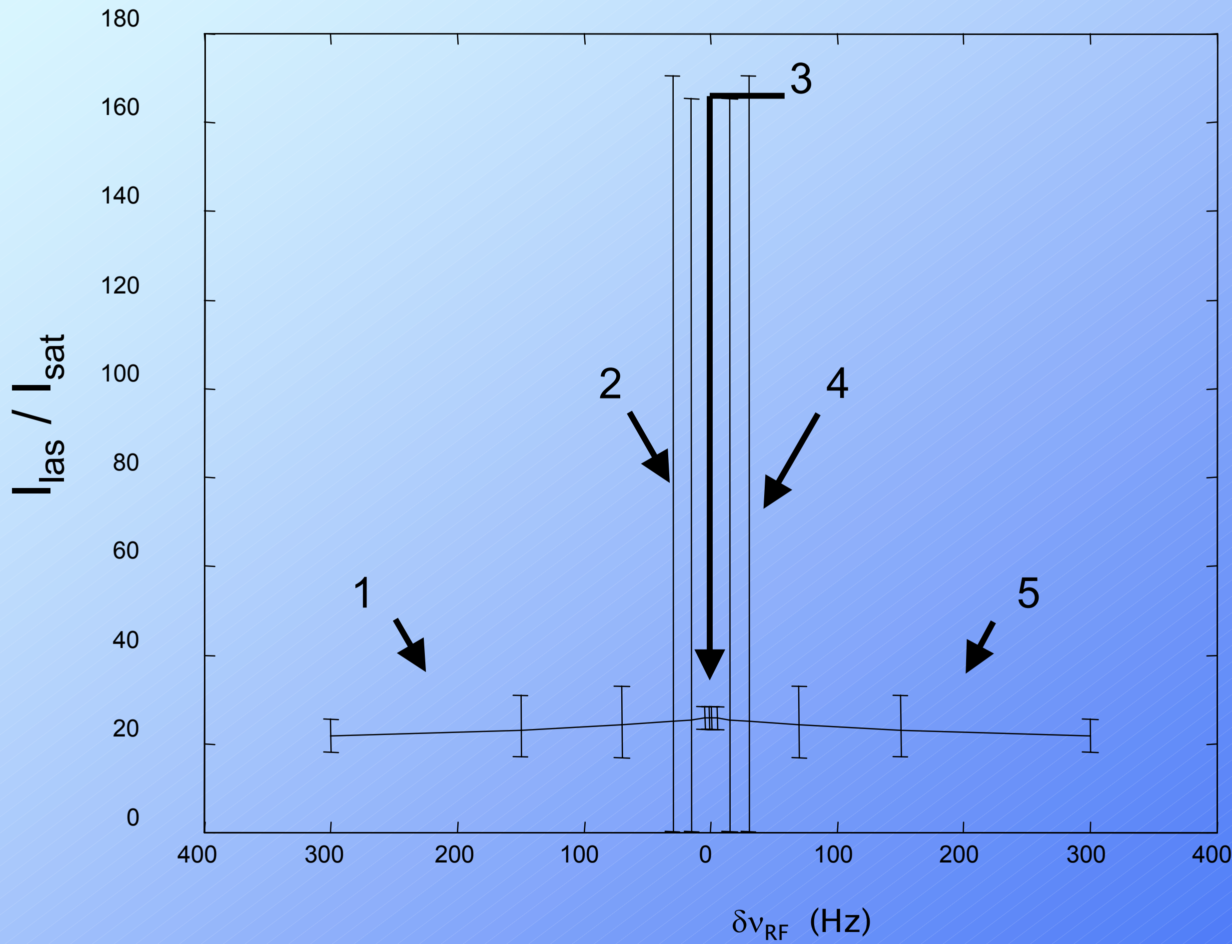
Super ACO



Conclusion: width reduced by the Microwave Instability

Numerical detuning curve: ELETTRA



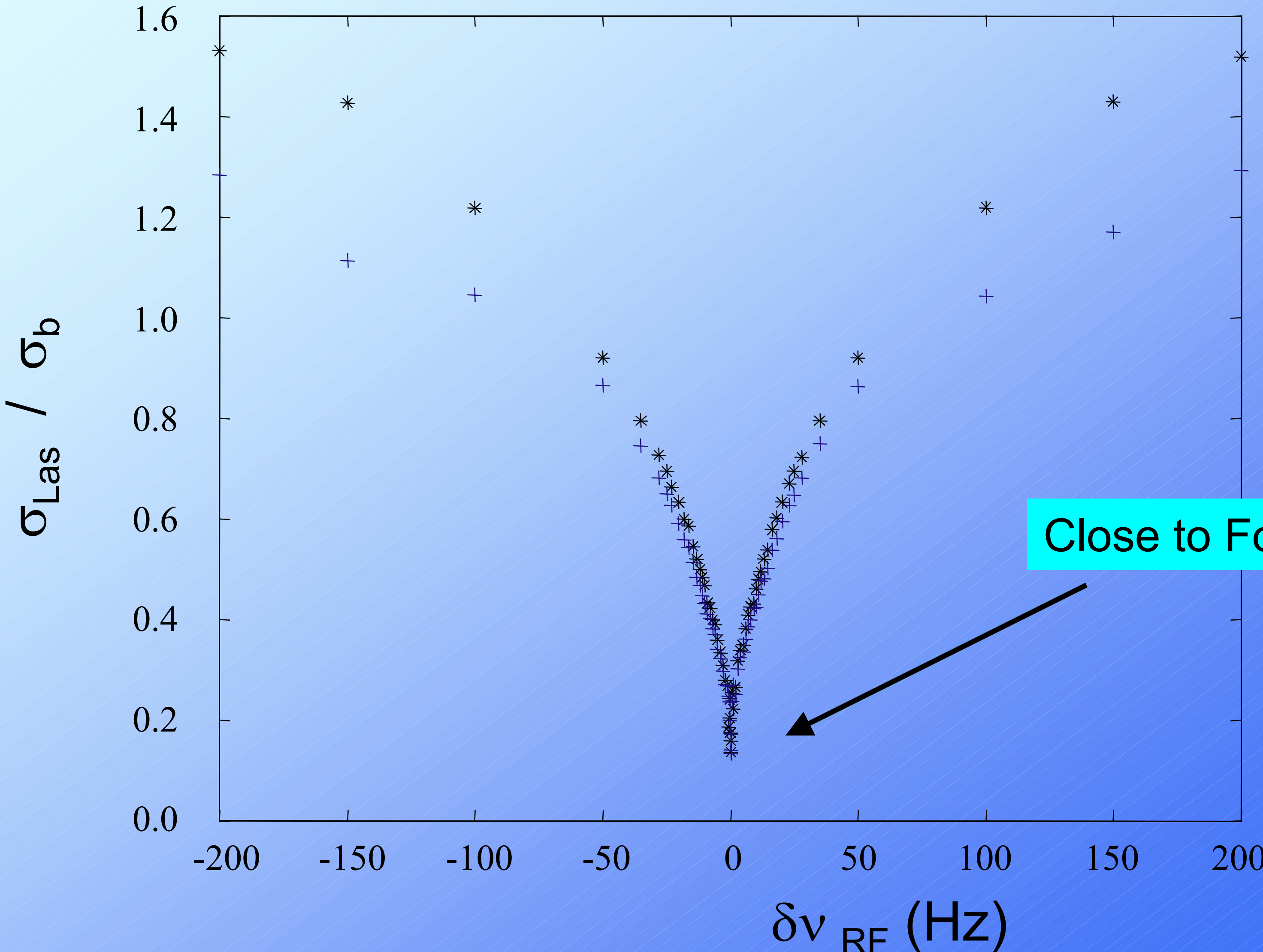
$g_0 \approx 30$ %

$|Z_n/n| \approx 0.5\ \Omega$

$I_{tot} = 20$ mA

Laser pulse duration

Numerical detuning curve: Super ACO



g_0 = 2.2 %

* $g_{0,eff}$ =1.4 %

+ $g_{0,eff}$ =1.3 %

σ_b = 150 ps

Close to Fourier limit

Conclusion:

- Detuning measurements done both at Super ACO and ELETTRA
- Numerical comparison performed
- Qualitative and quantitative agreements found
- Detuning curve study:
  - width given by the gain, and reduced by instabilities
  - five zones with characteristic laser behavior: cw and pulsed
  - narrow detuning central zone: laser near Fourier limit