Study of Coherence limits and chirp control in long pulse FEL oscillator

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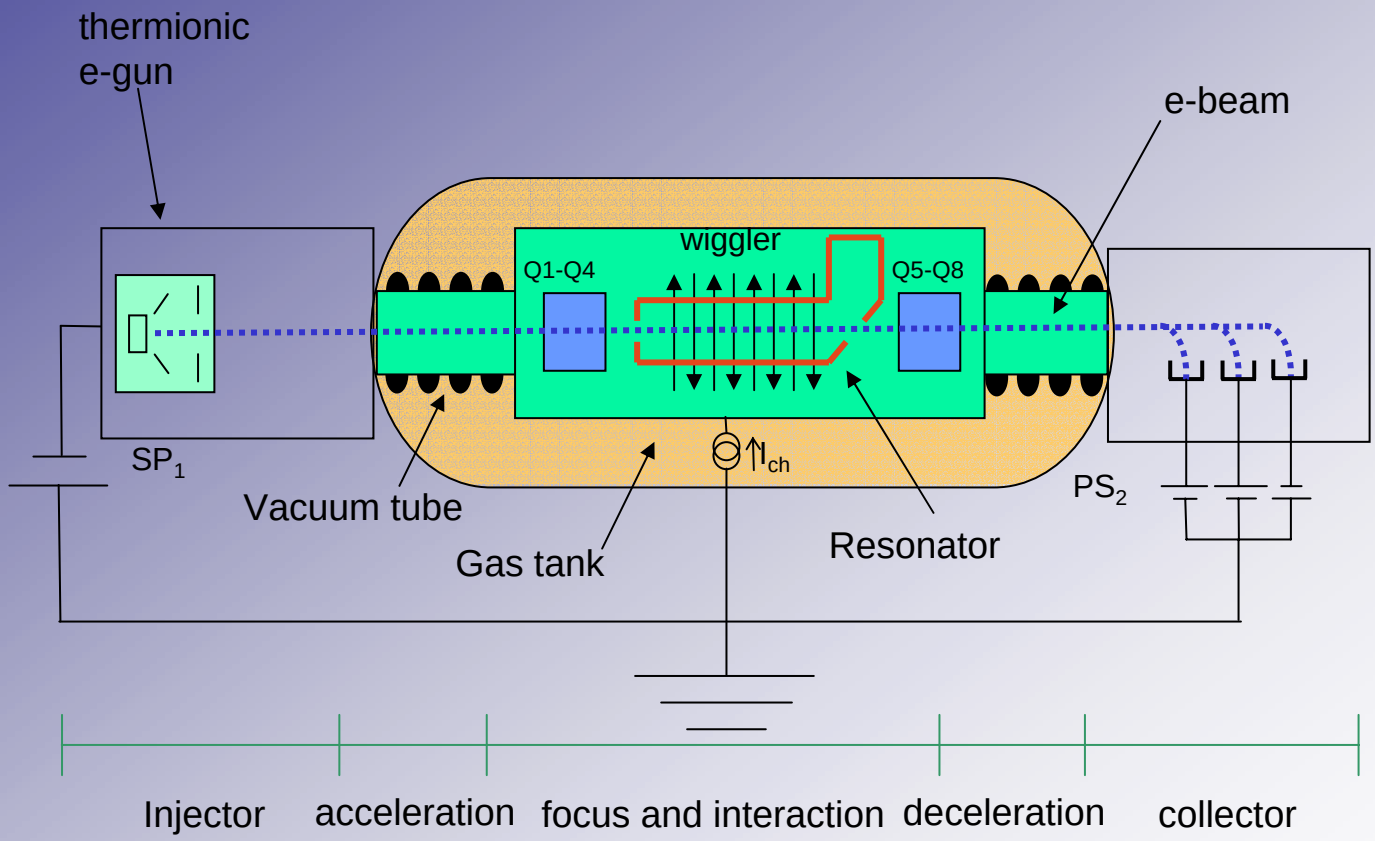
Inner Cavity Electrostatic Accelerator FEL Configuration



The Israeli FEL

Coherence Limits of FEL

Schawlow–Towns Equivalent Natural linewidth*:

$$\Delta f_{laser} = \frac{\left(\Delta f_{1/2}\right)^2}{I_0 / e}$$

$$\left(\Delta f_{laser} = 10^{-2}\, Hz,\ for \qquad I_0 = 2A, \quad \Delta f_{1/2} = 10MHz\right)$$

Technical noise frequency instability** :

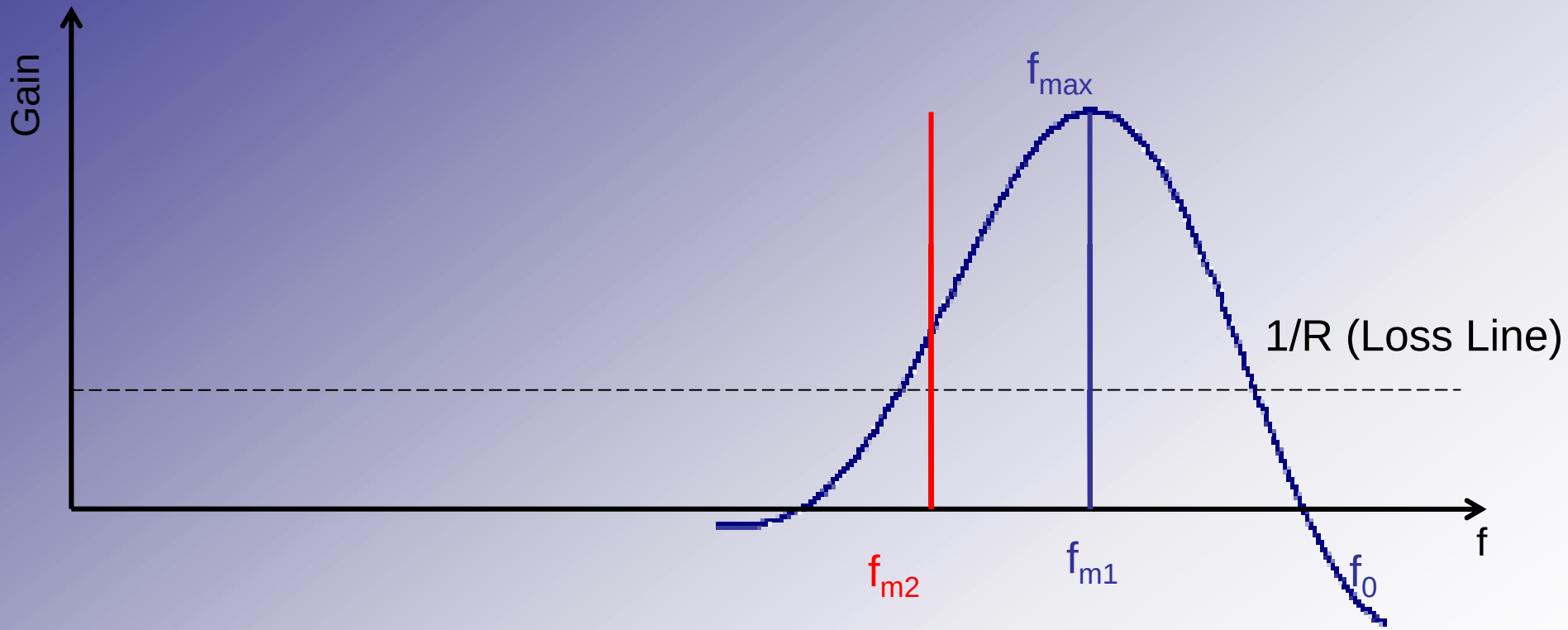
$$\Delta f_{tech} = \left[\left(\frac{\partial \varphi}{\partial V_b}\right)^2 \langle(\Delta V_b)^2 + \left(\frac{\partial \varphi}{\partial I_b}\right)^2 \langle(\Delta I_b)^2\rangle\right] \Delta f_{1/2} \qquad \left(\varphi = \delta k_r L_w\right)$$

$$\frac{\Delta f_{tech}}{f_0} = 5 \cdot 10^{-7} \quad \left(for \qquad \Delta V_{b\,rms} = 1kV, \quad \Delta I_{b\,rms} = 10mA\right)$$

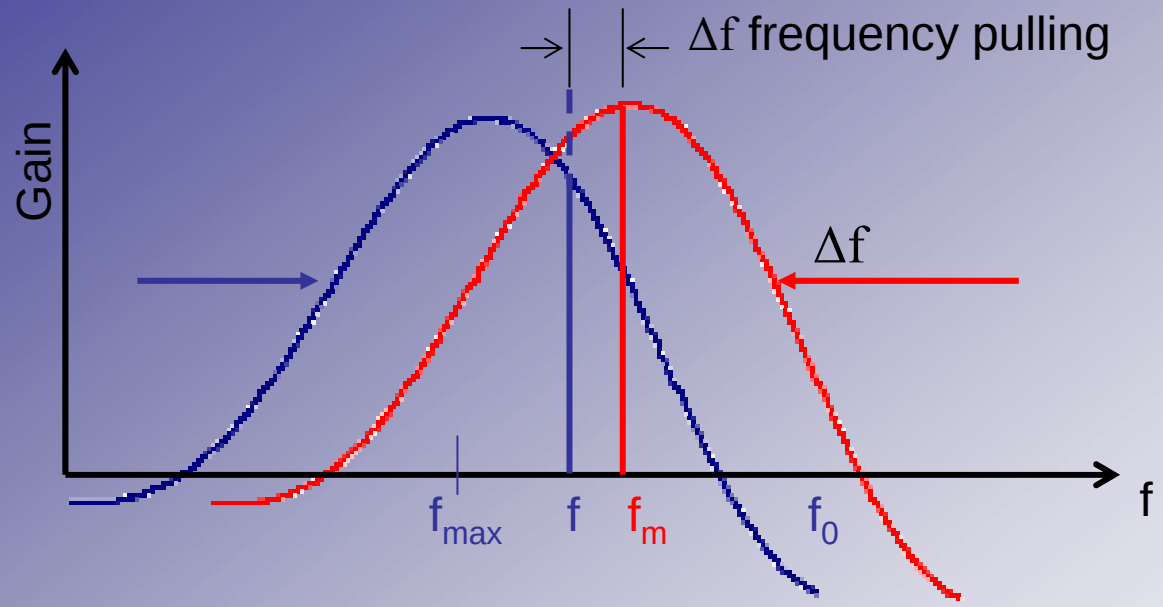
* A. Gover, A. Amir, L.R. Elias, PR A, 35, 164 (1987)

** A. Abramovich, M. Canter, A. Gover, J. Sokolowski, Y. Yakover, Y. Pinhasi, I. Schnitzer, J. Shiloh, PRL 82, 5257 (1997)

Effect of Voltage Drop: Mode Hopping



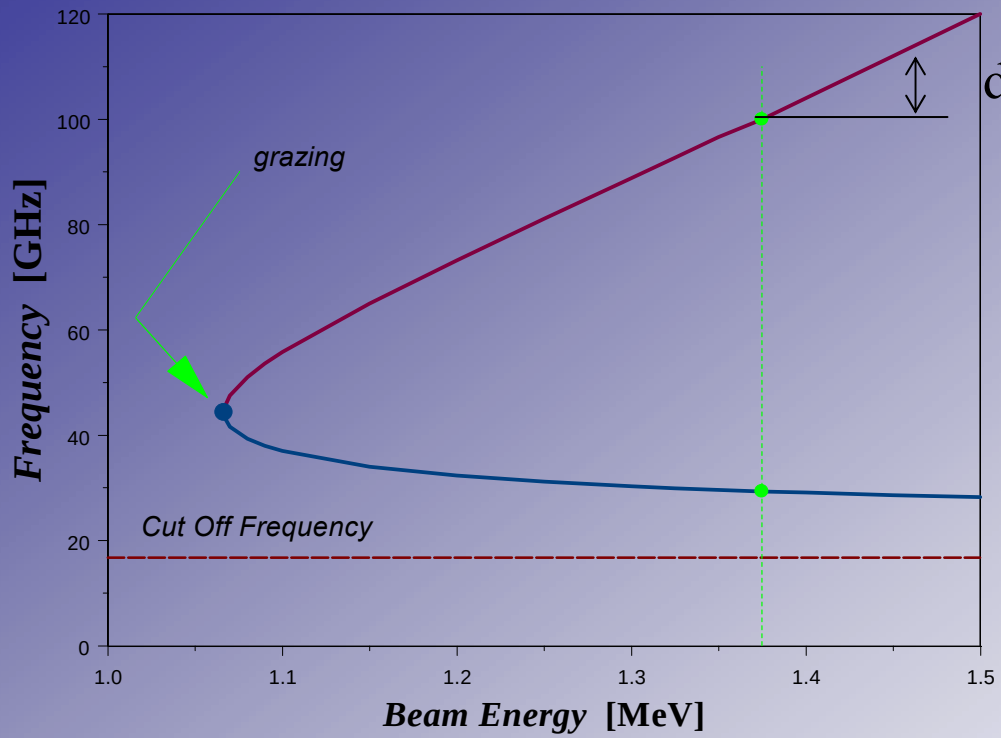
Effect of Voltage Drop: Chirp



$$f(t) - f_m = \left(f_{\max}(t) - f_m \right) \frac{\Delta f_{1/2}}{\Delta f}$$

$$\frac{df(t)}{dt} = \frac{df_{\max}}{d\gamma} \frac{d\gamma}{dt} \frac{\Delta f_{1/2}}{\Delta f}$$

FEL Frequency Dependence on in a Waveguide Dispersive



$df_{max}/d\gamma$

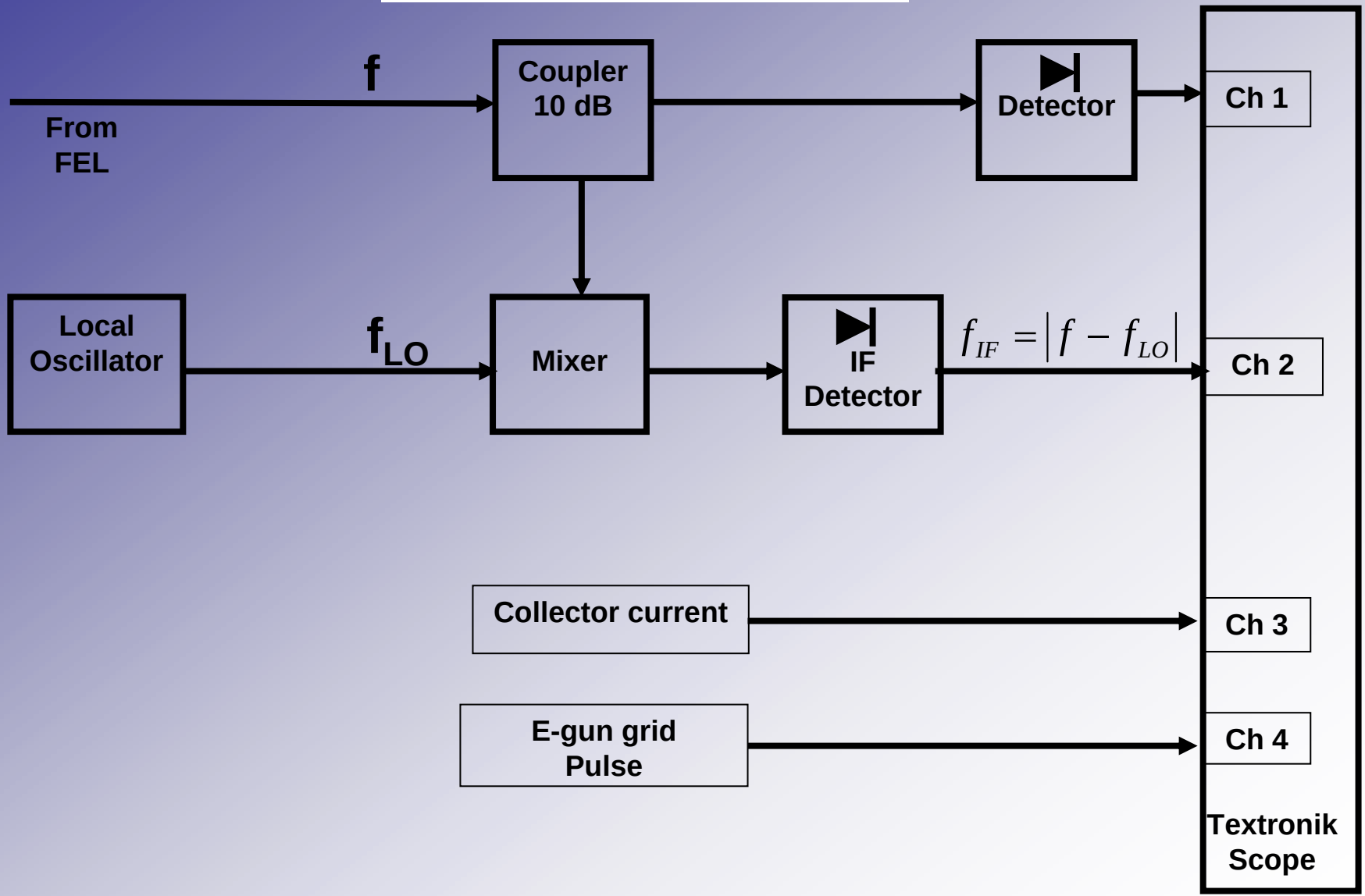
$$\frac{df(t)}{dt} = \frac{df_{max}}{d\gamma}\frac{d\gamma}{dt}\frac{\Delta f_{1/2}}{\Delta f}$$

$$For \quad f_{max} = 86GHz, \quad \Delta f = 6GHz, \quad \Delta f_{1/2} = 16MHz$$

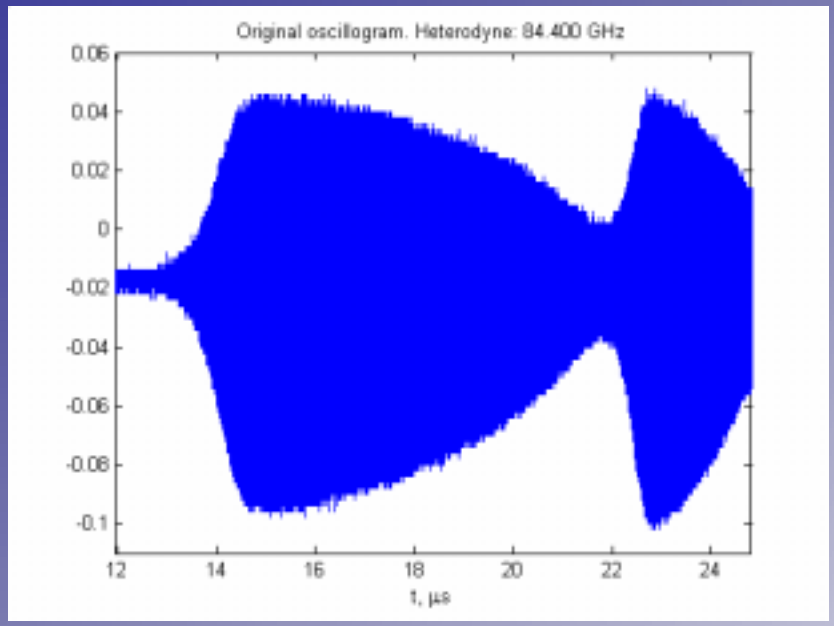
$$\frac{df_{max}}{dV} = 0.43\frac{MHz}{KV} \qquad \frac{dV}{dt} = 0.7\frac{KV}{\mu s} \Rightarrow$$

$$\boxed{\frac{df}{dt} = 0.3\frac{MHz}{\mu s}}$$

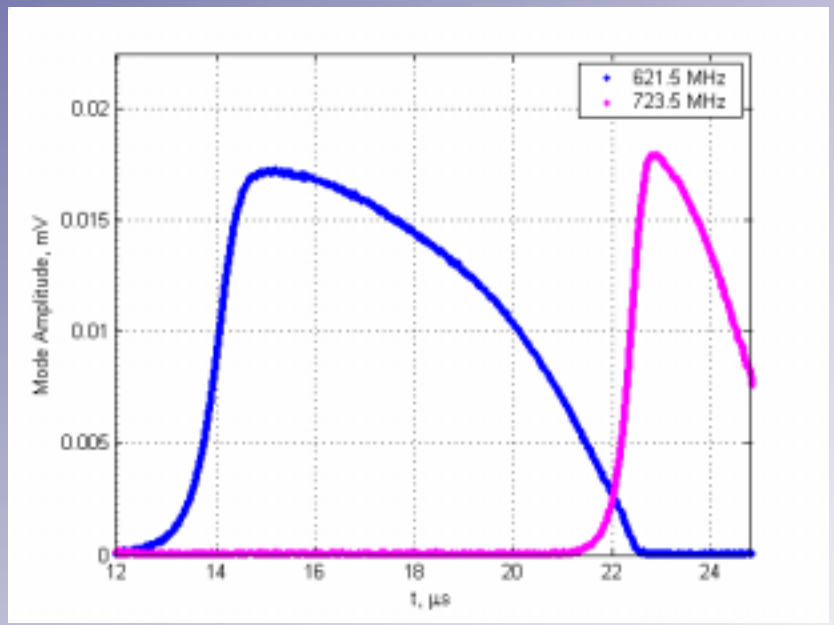
Block-Diagram RF Measurements of FEL Radiation



Voltage Drop Effect: Mode Hoping

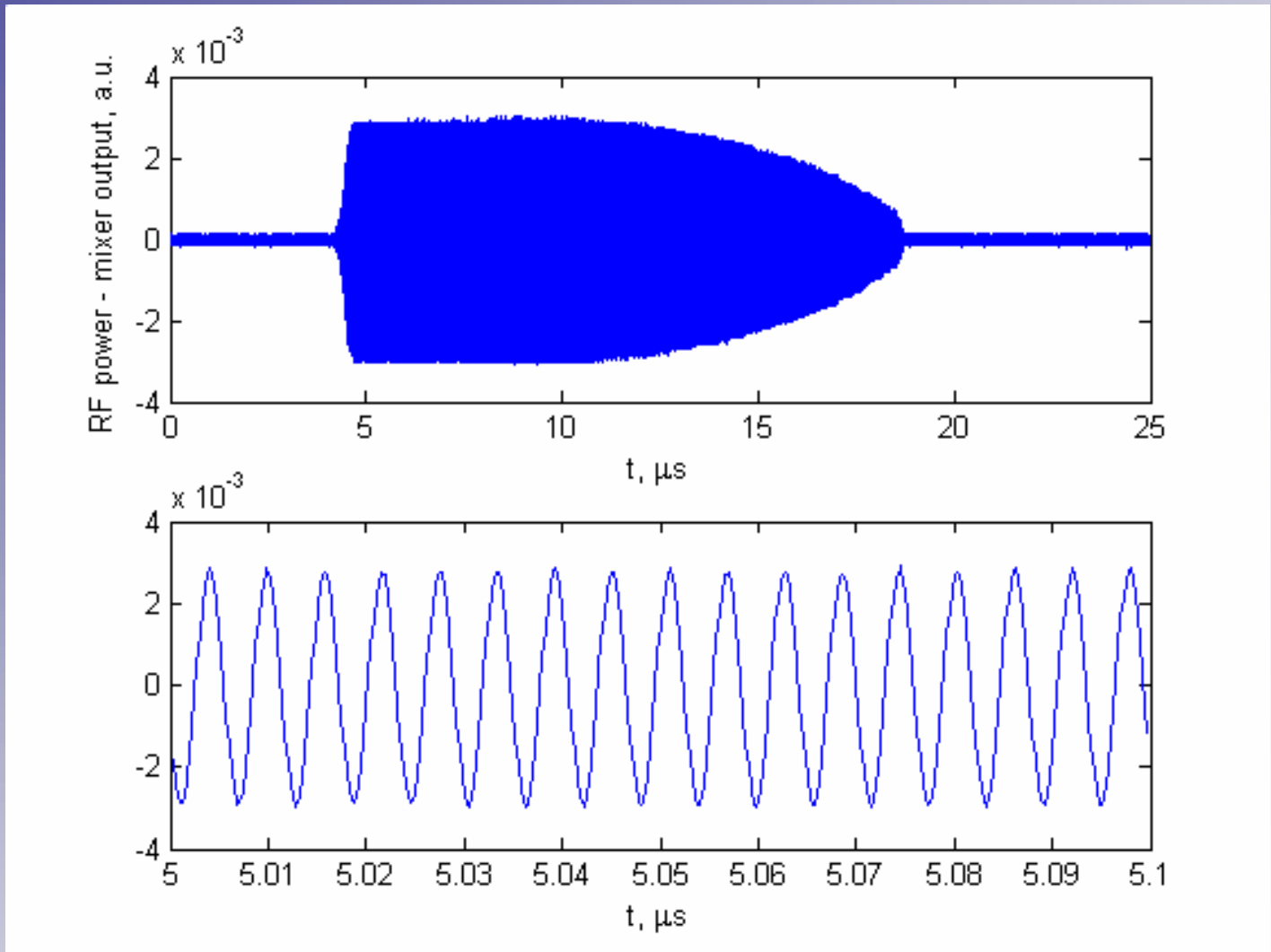


IF - signal



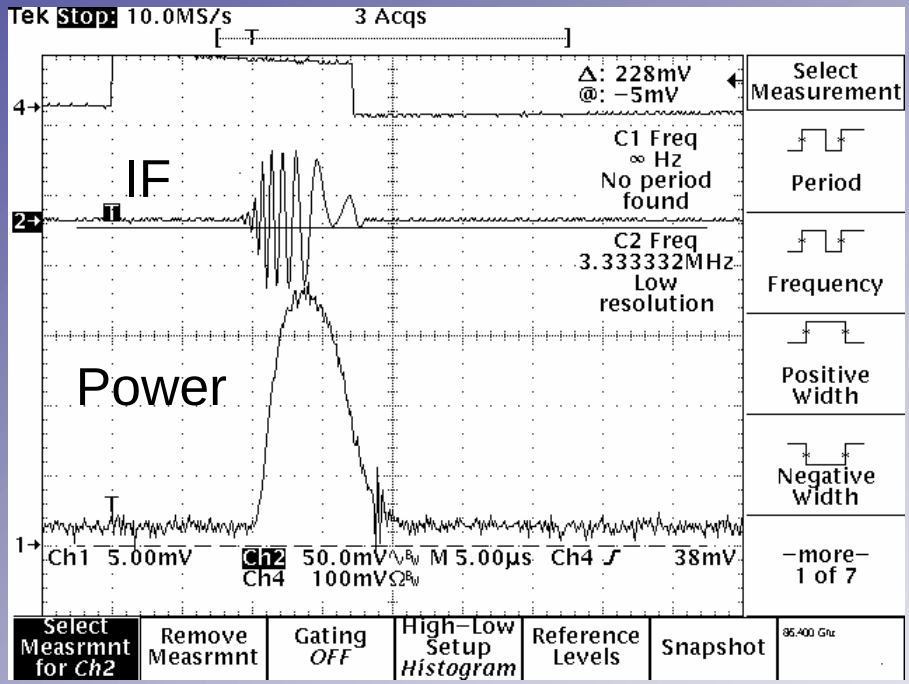
Numerically filtered IF signal amplitude

IF Signal at Single Mode Operation

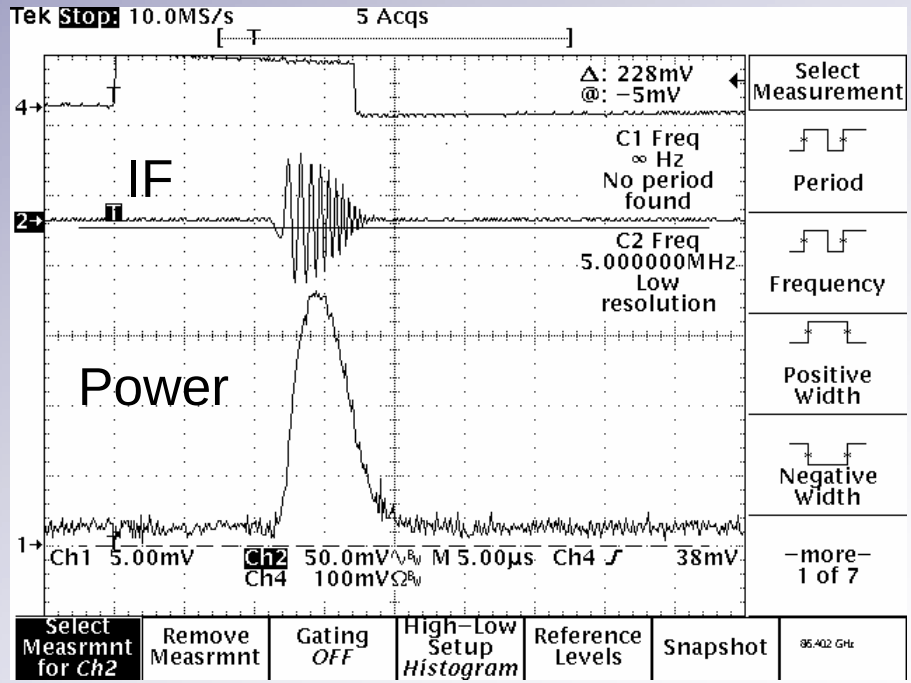


Measured IF Signal $f_{IF} = |f(t) - f_{LO}|$

f(t)>f_{LO}=86,4000 [MHz]

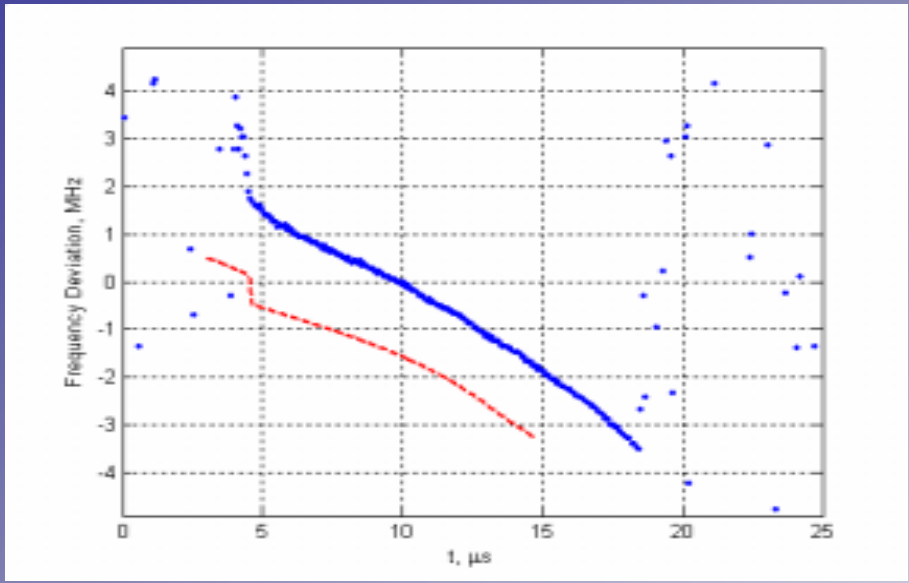


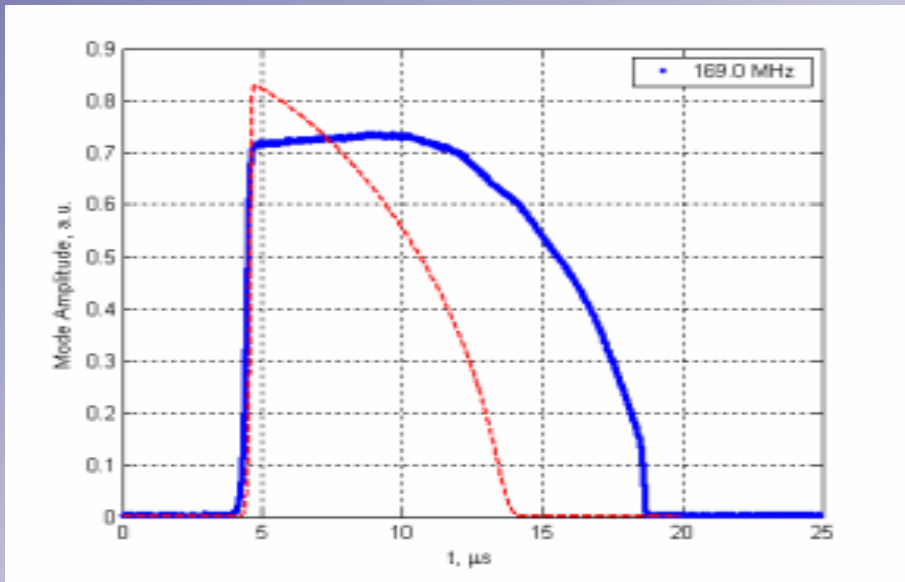
f(t)<f_{LO}=86,402 [MHz]



=> f(0)=86.401±1MHz

Frequency Chirp and Power Decay of a single mode during voltage drop

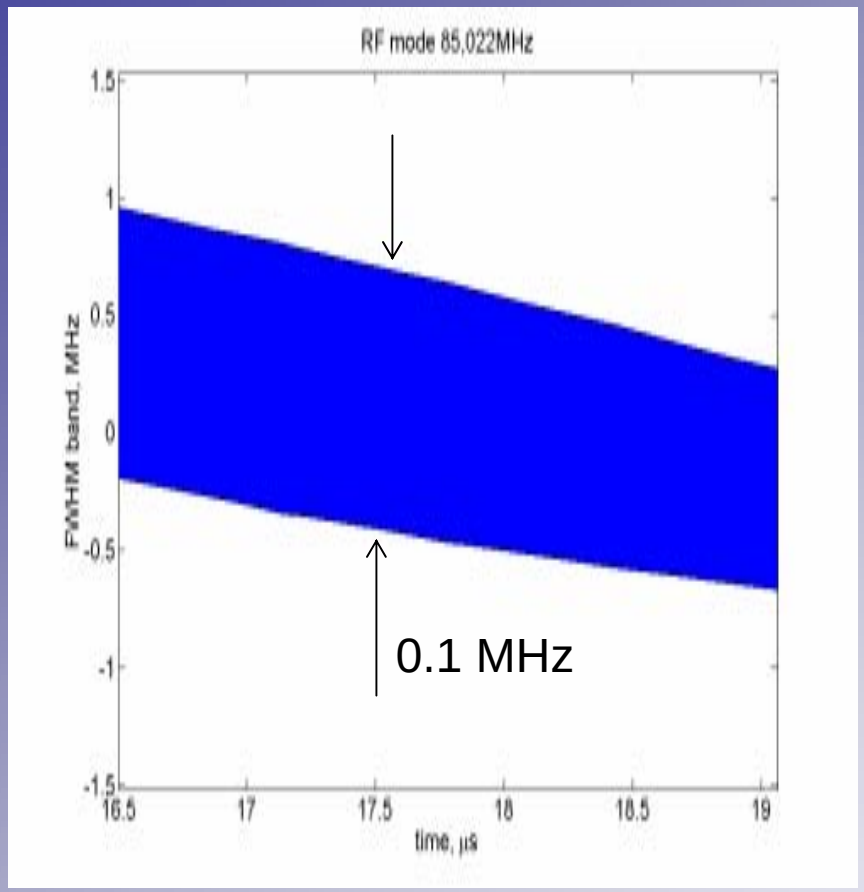




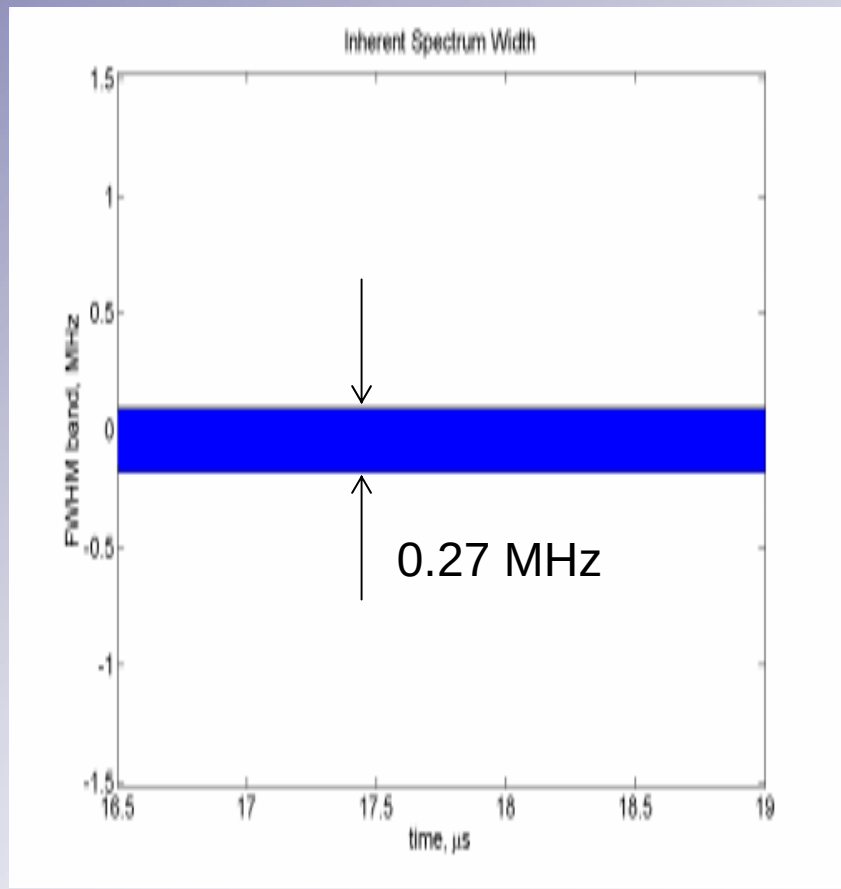
Measured

FEL3D Oscillator Simulation

Spectrum and Inherent Spectral Width

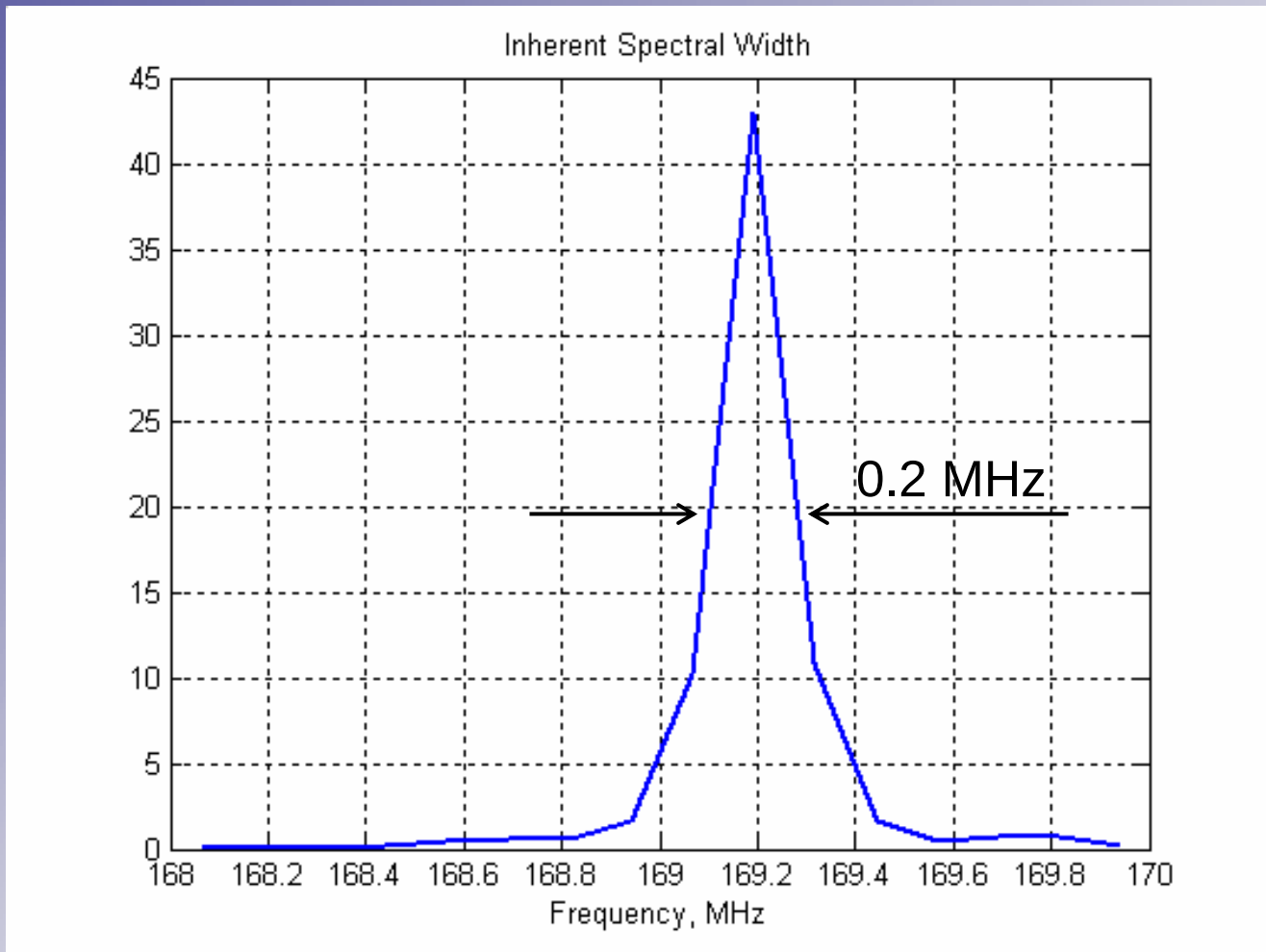


1μs window spectrogram

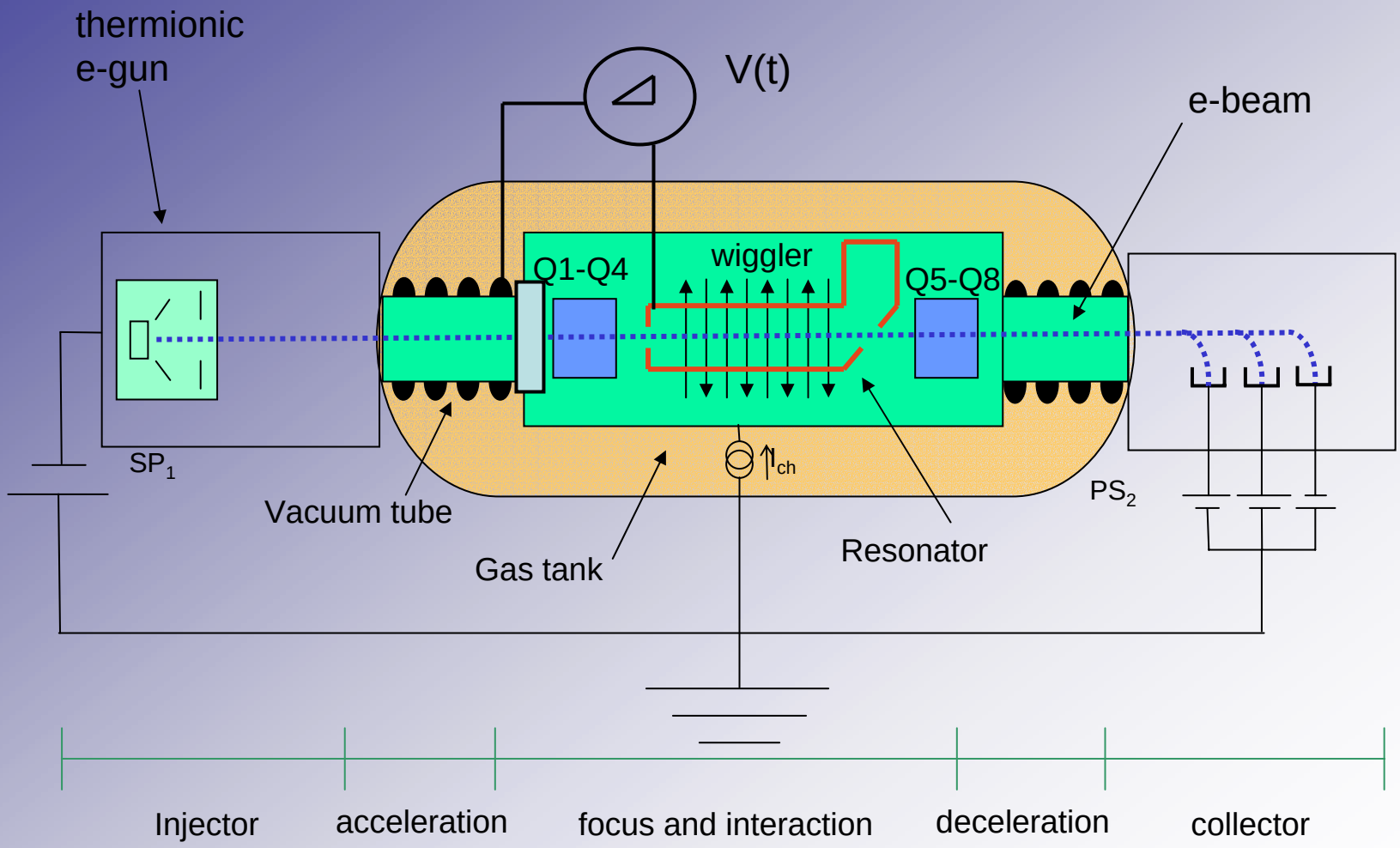


10μs window spectrogram after numerical elimination of linear chirp

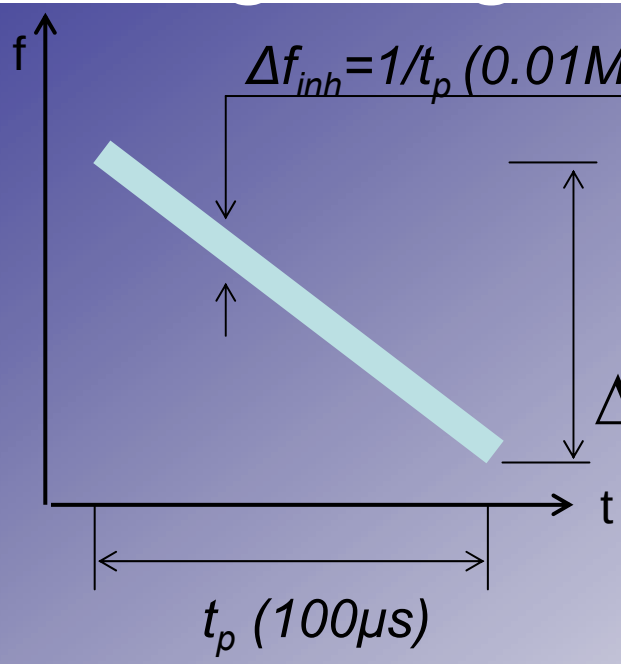
Inherent Spectral Width



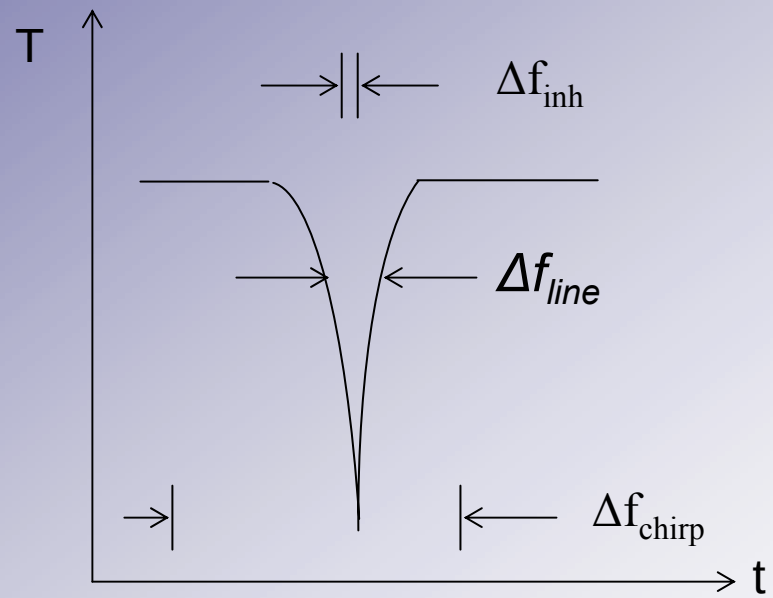
Planned Application of Controlled Chirp in Electrostatic Accelerator FEL



Scanning Single Pulse Spectroscopy

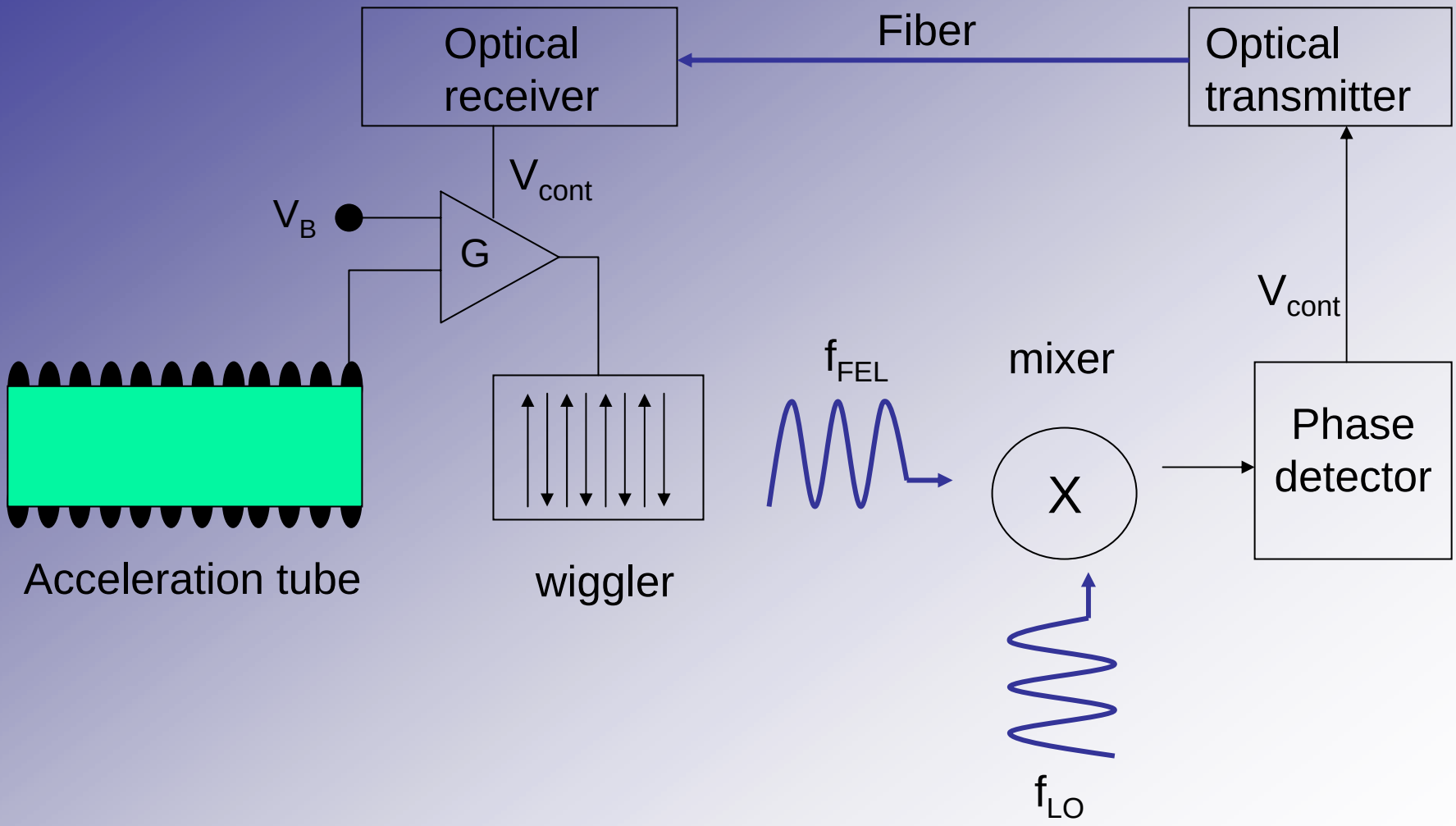


$$\Delta f_{chirp} = \frac{f_{\max} - f_0}{\Delta f} \Delta f_{1/2}(5MHz)$$



Transmission of Absorption Line

FEL Oscillator Frequency Stabilization



Conclusion

1. $\frac{df}{dt} = 0.3 \frac{MHz}{\mu s}$

2. $\left(\frac{\Delta f}{f}\right)_{\text{intrinsic}} = 2 \cdot 10^{-6}$

3. Plans to utilize chirp for :

   (a) Single pulse scanning spectroscopy

   (b) Phase locked loop frequency stabilization