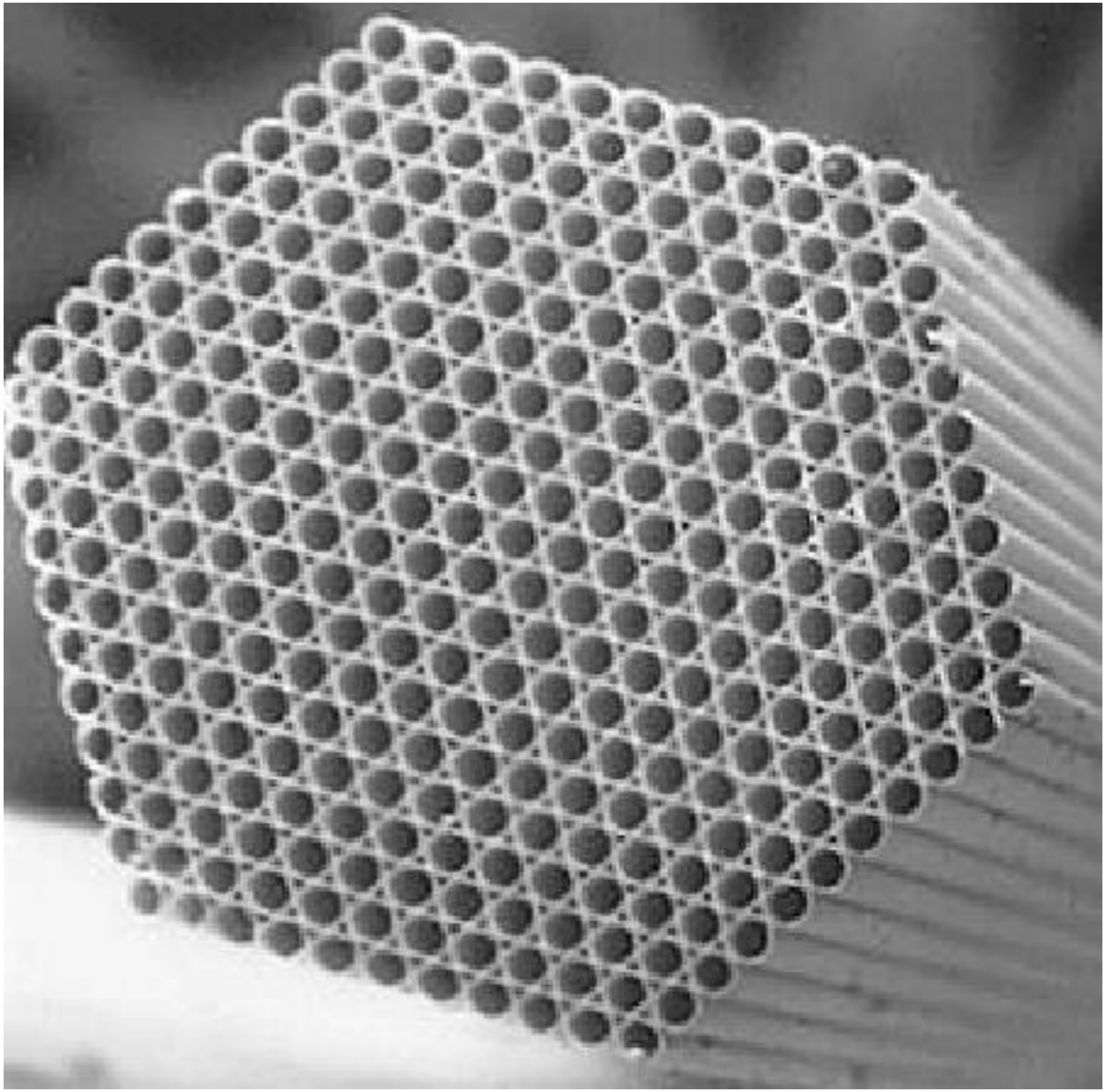
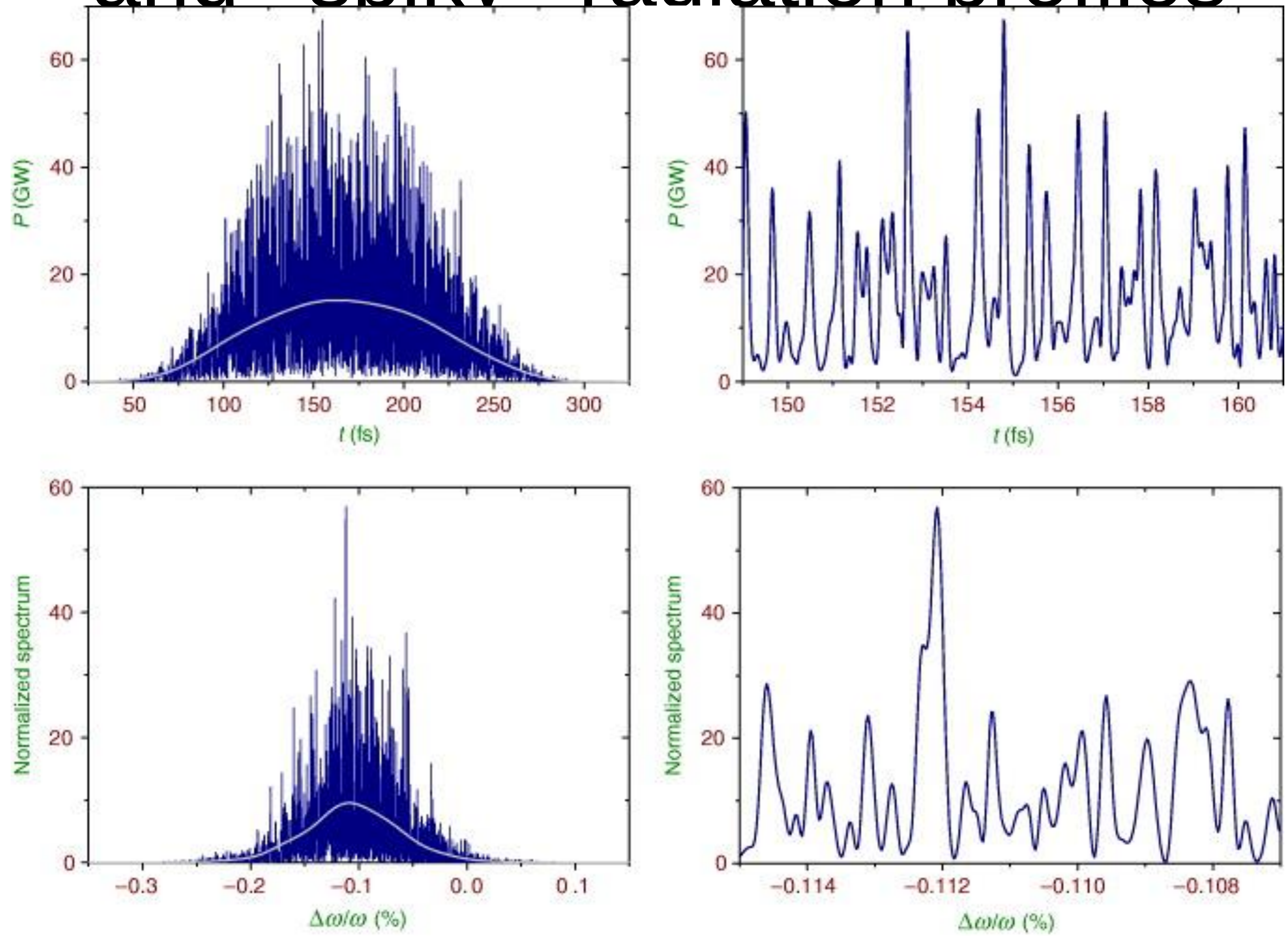
Reducing Noise of SASE FEL Start-up with a Monocapilllary Tube

Alexander Lin

UCLA Department of Physics & Astronomy

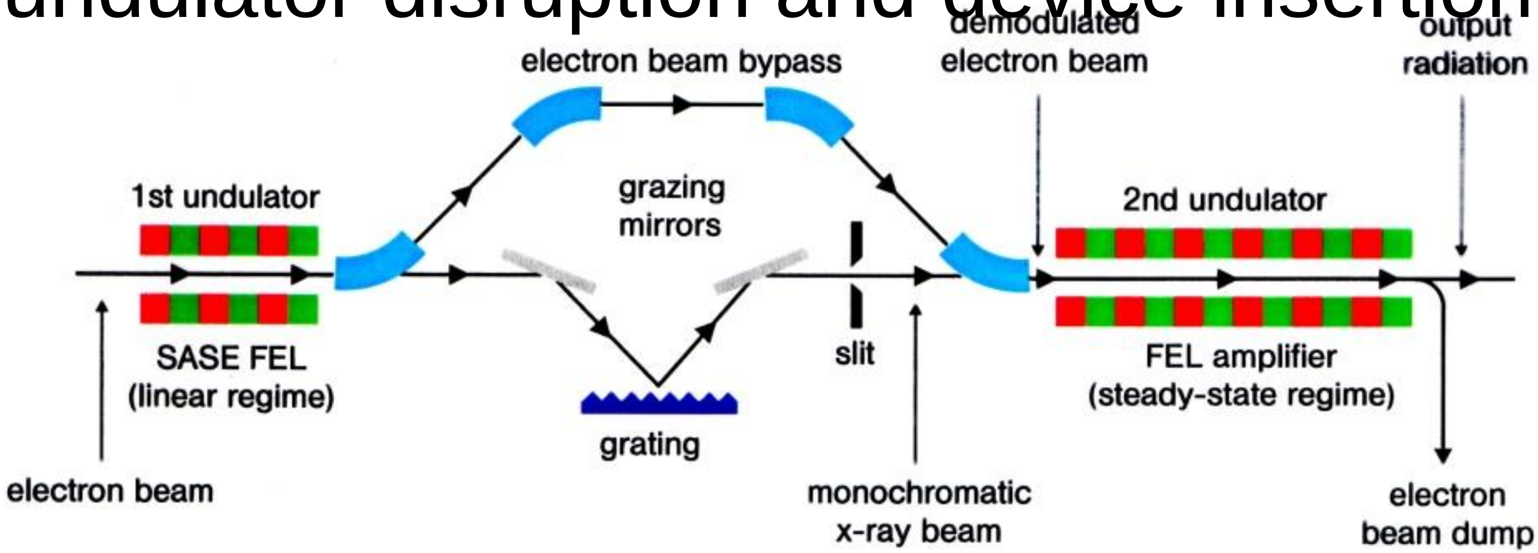


The SASE FEL process yields “noisy” and “spiky” radiation profiles

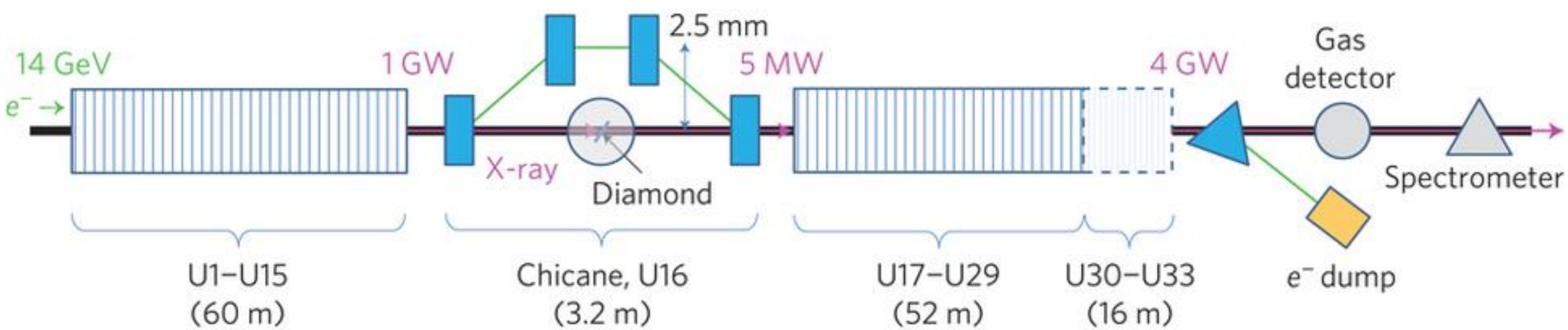


G. Geloni, et al., New J. Phys. **12** (2010) 035021

Current schemes to improve start-up involve undulator disruption and device insertion

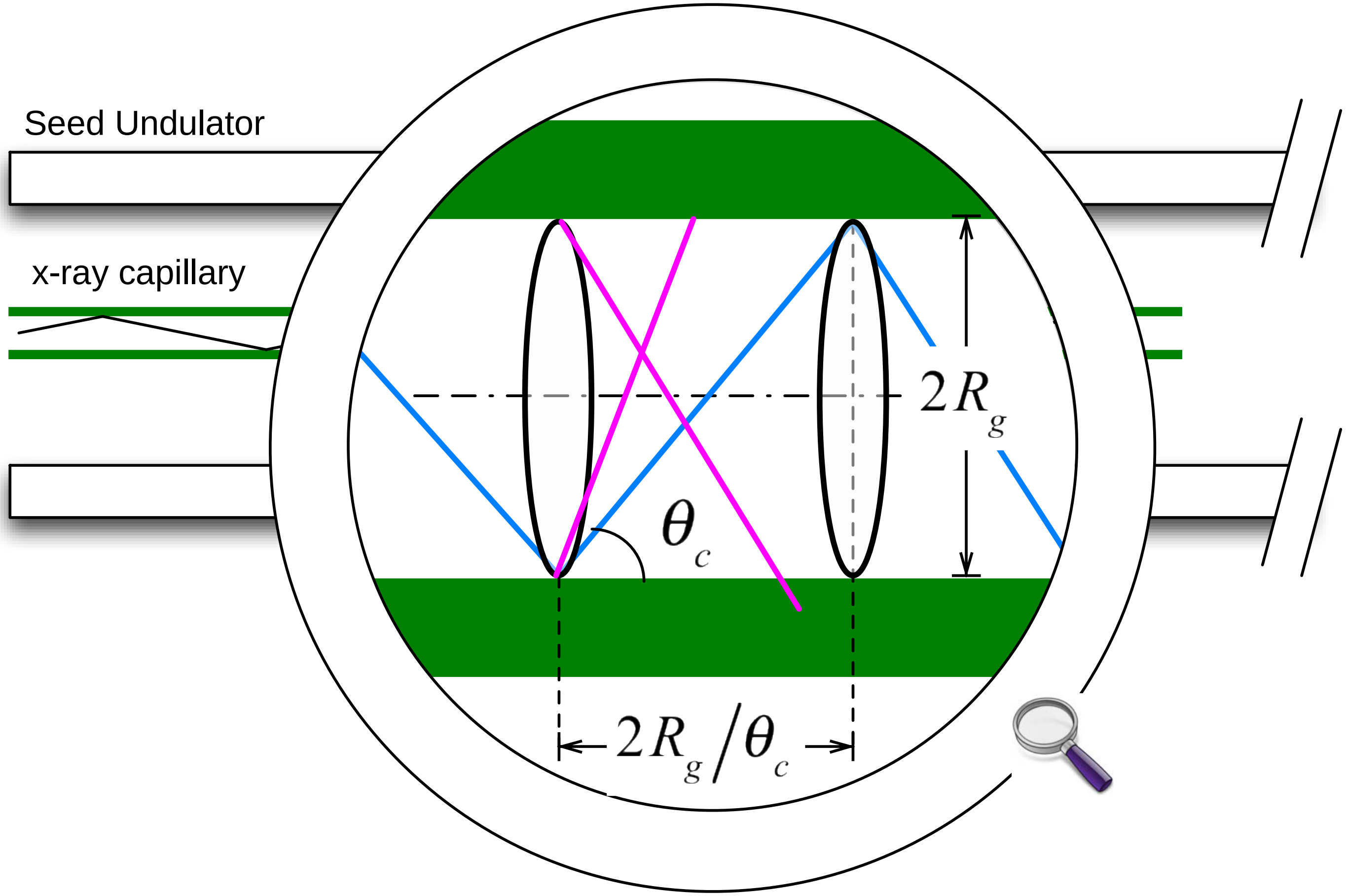


J. Feldhaus, et al., Opt. Commun. 140, 341 (1997).



LCLS, *Nature Photonics* (2012)

A monocapillary tube placed along the undulator can reduce noise without beam removal



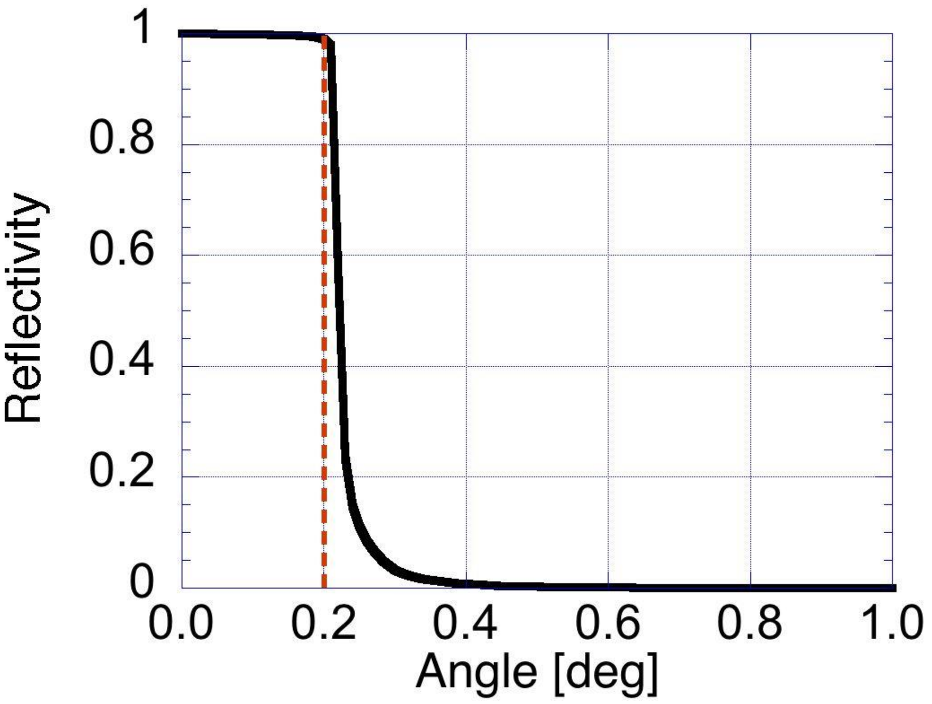
Monocapillary tubes are selective in frequency and angle, reducing on-axis spectral impurities

The index of refraction at X-ray wavelengths is given by the Drude model:

$$n(\omega)^2 = 1 - \frac{\omega_P^2}{\omega^2}$$

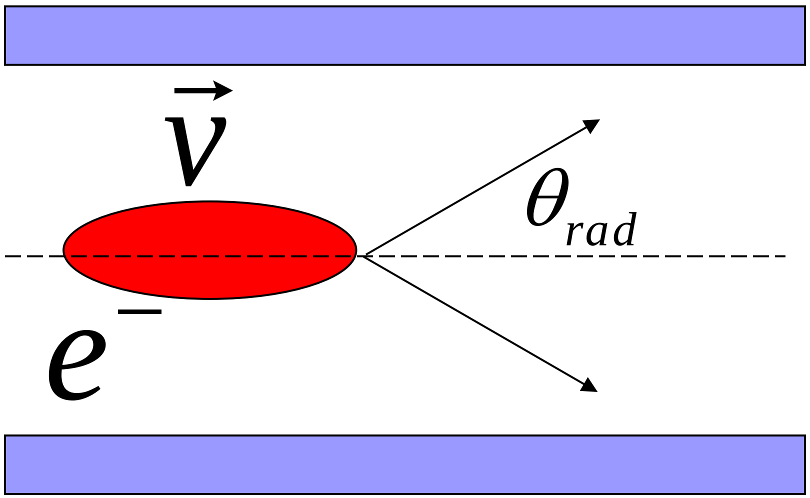
$$\omega_P^2 = \frac{e^2 n_e}{\varepsilon_0 m_e}$$

For most materials, this value is less than unity, so guiding occurs via total external reflection.



The **critical angle** at **8 KeV** occurs at **0.2 degrees (3.75 mrad)**.

LCLS-like case is used as a challenging trial



The diffraction angle of radiation is inversely proportional to the electron beam energy.

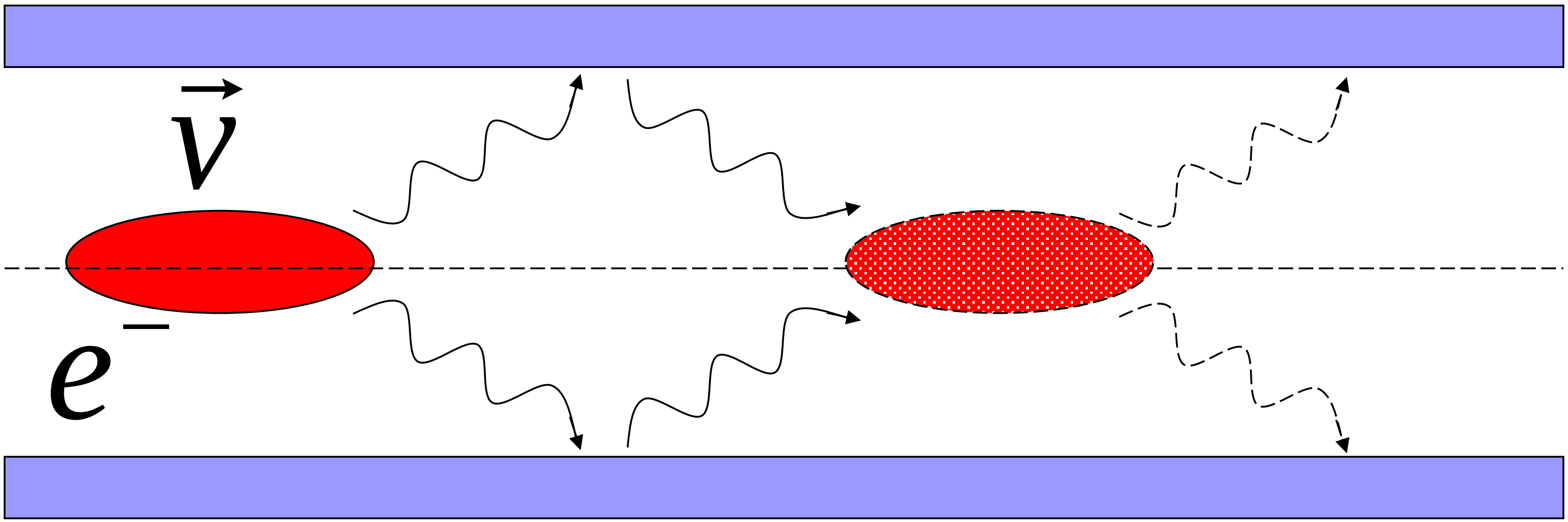
$$\theta_{rad} \propto \frac{1}{\gamma_{beam}}$$

Parameter	Value
Electron Beam Energy	14 GeV
Diffraction Angle	0.42 μrad

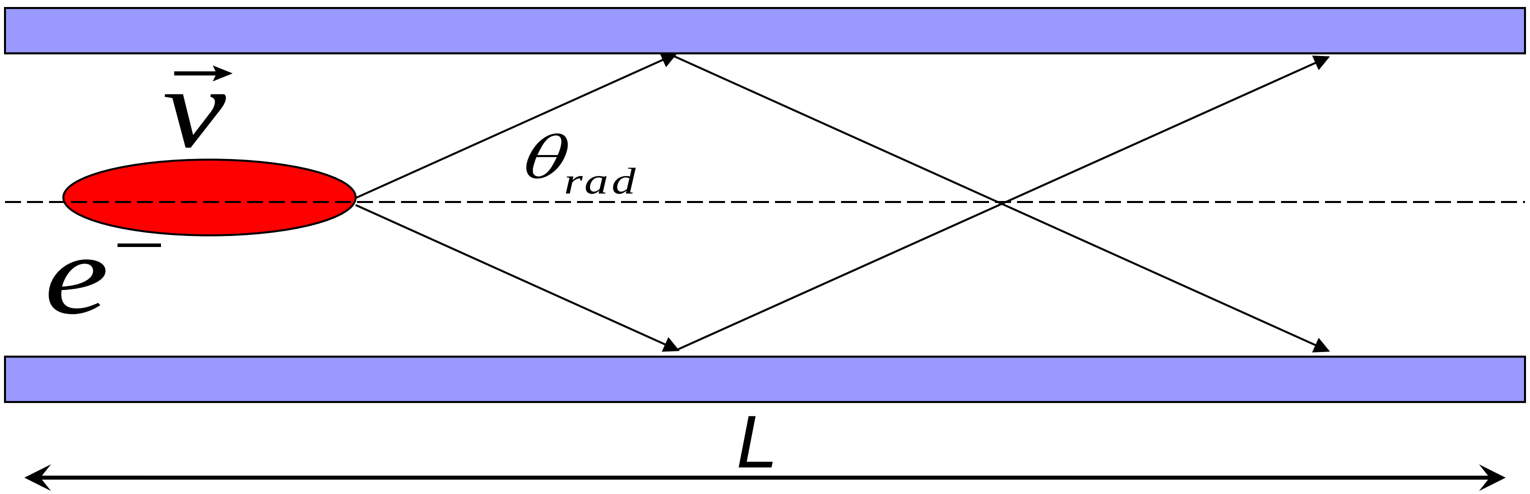
The tube acts as a non-intercepting monochrometer

Parameters of interest: **length**, **bandwidth**, and **radius**.

The tube also provides the effect of **"reverse" slippage**, which enhances the effect of bunching.



The tube's length must be on the order of the undulator gain length



For the monocapillary tube to have significant effect on the radiation, the power of the reflected radiation must be greater than the effective SASE power:

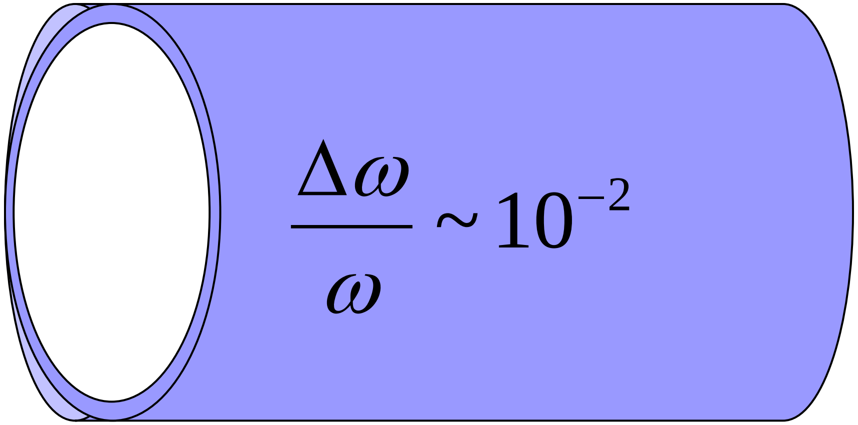
$$P(z) = P_0 e^{\frac{z}{Lg}} \geq P_{EFF}$$

$$\frac{z}{Lg} \geq 1$$

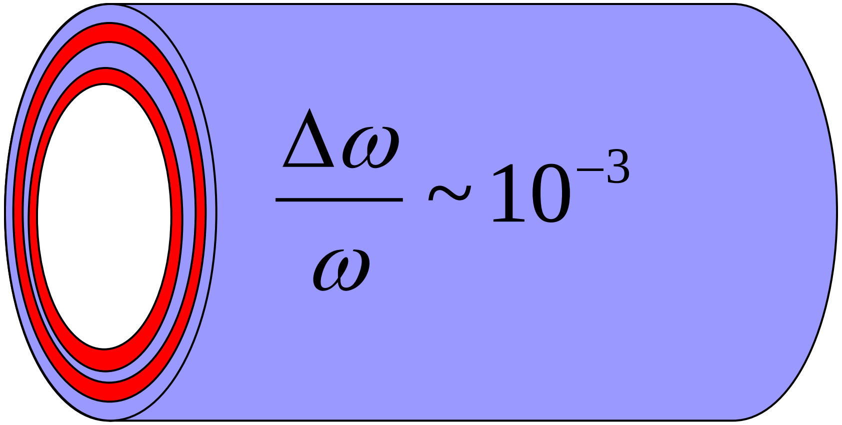
The bandwidth of the tube must be on the order of the FEL parameter

For SASE FEL, the bandwidth of radiation is near the FEL parameter:

$$\frac{\Delta\omega}{\omega} \sim \rho \approx 10^{-3}$$

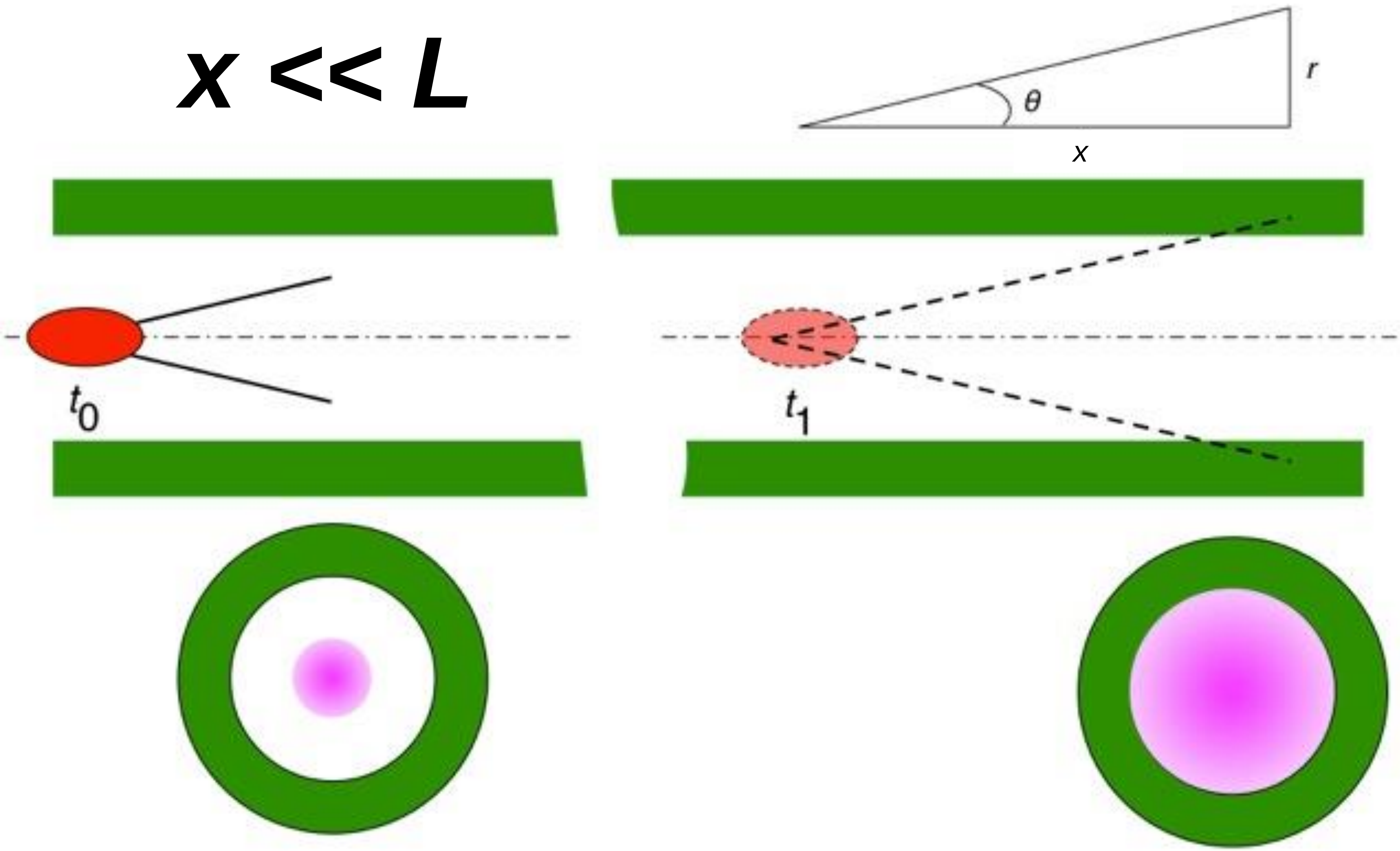


Single layered monocapillary tubes have bandwidths of ~10^{-2}, which is too small for proper effects. However, multilayered tubes can reach bandwidth of ~10^{-3}.

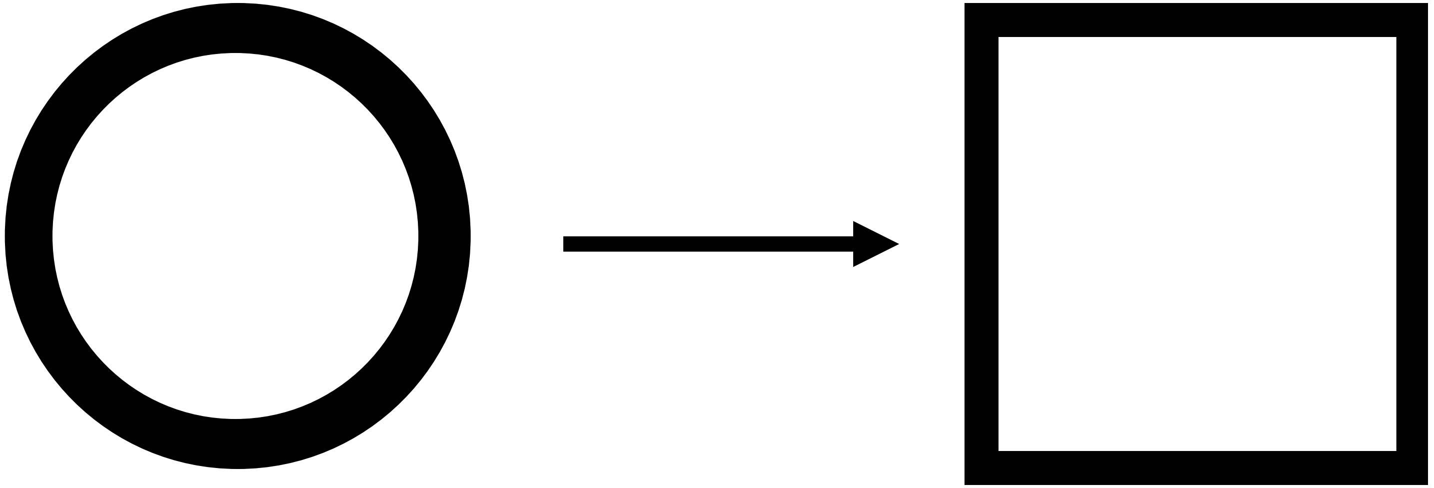


The radiation must intercept and reflect from the tube

x << L

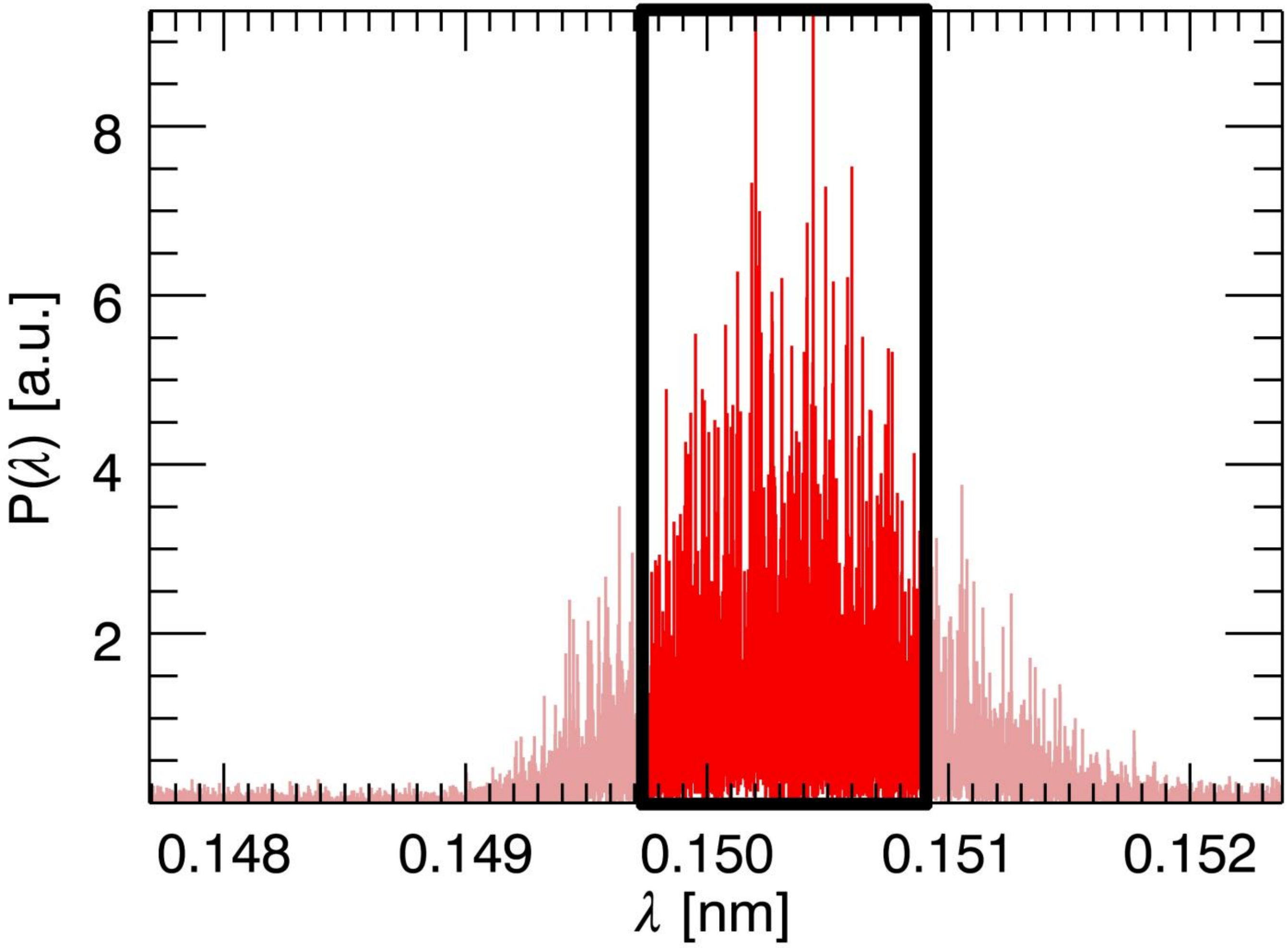


Our model of a monocapillary tube is a waveguide with imperfect boundaries



$$R = \begin{cases} 1 & \theta < \theta_c\,, \quad \omega = \omega_r \pm \frac{\Delta\omega}{\omega} \\ 0 & \theta \geq \theta_c\,, \quad \omega \neq \omega_r \pm \frac{\Delta\omega}{\omega} \end{cases}$$

We use a simple hard-edge frequency filter model



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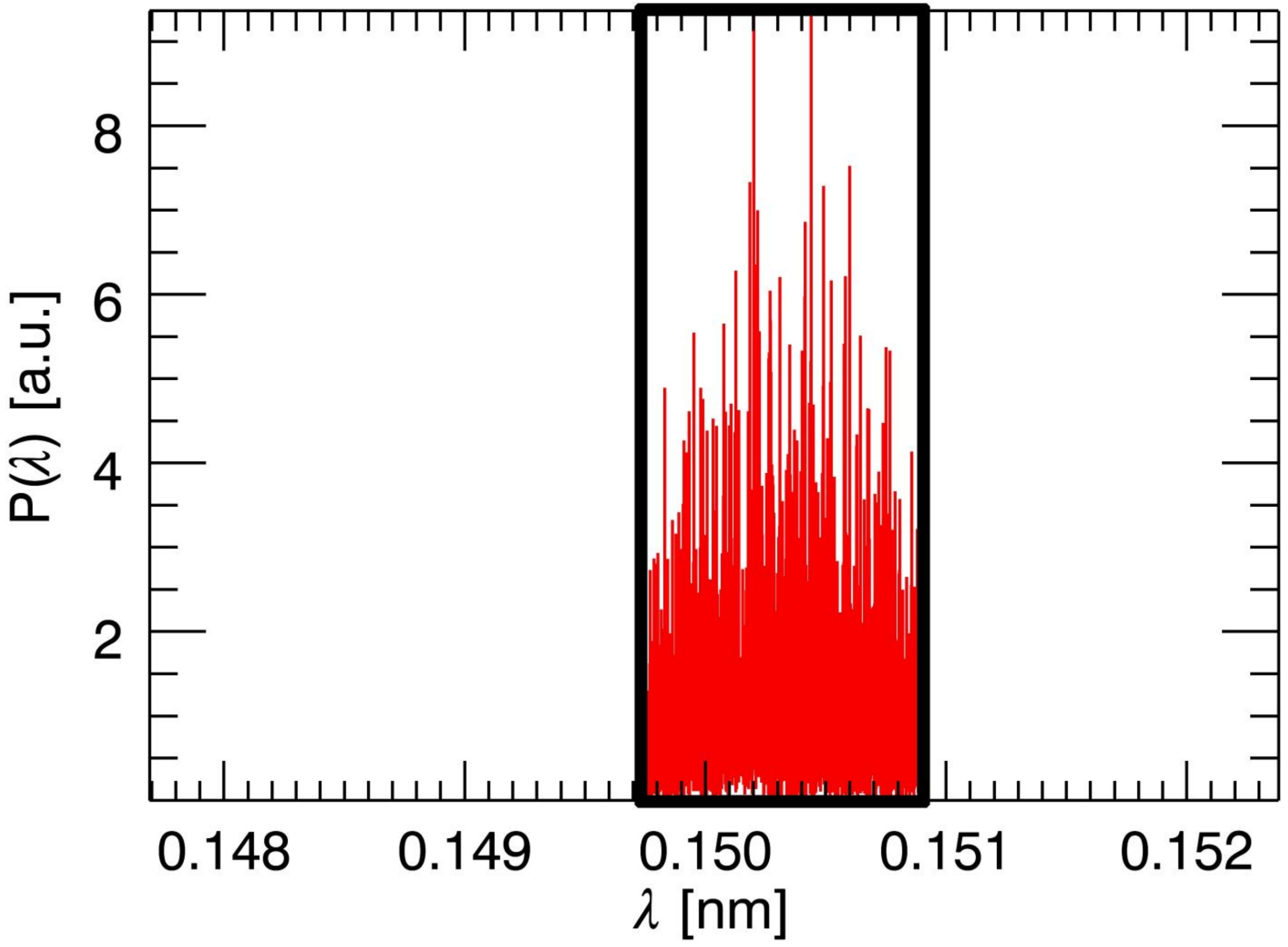
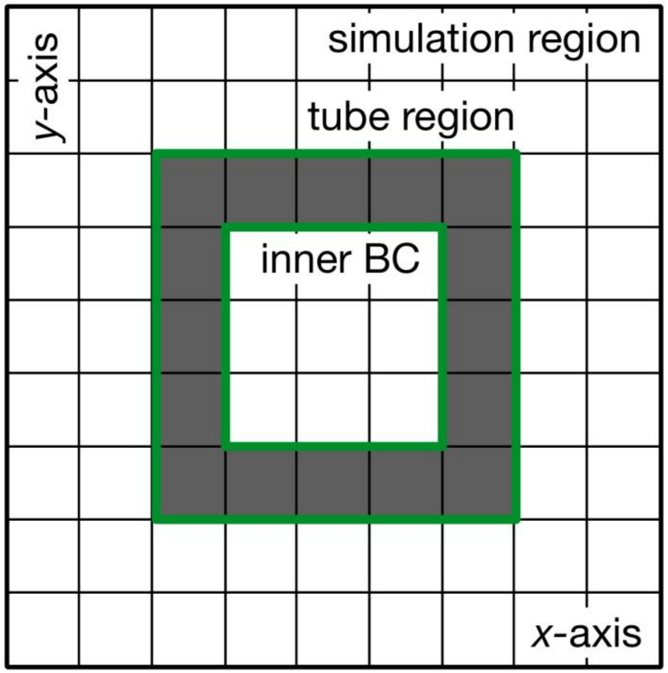
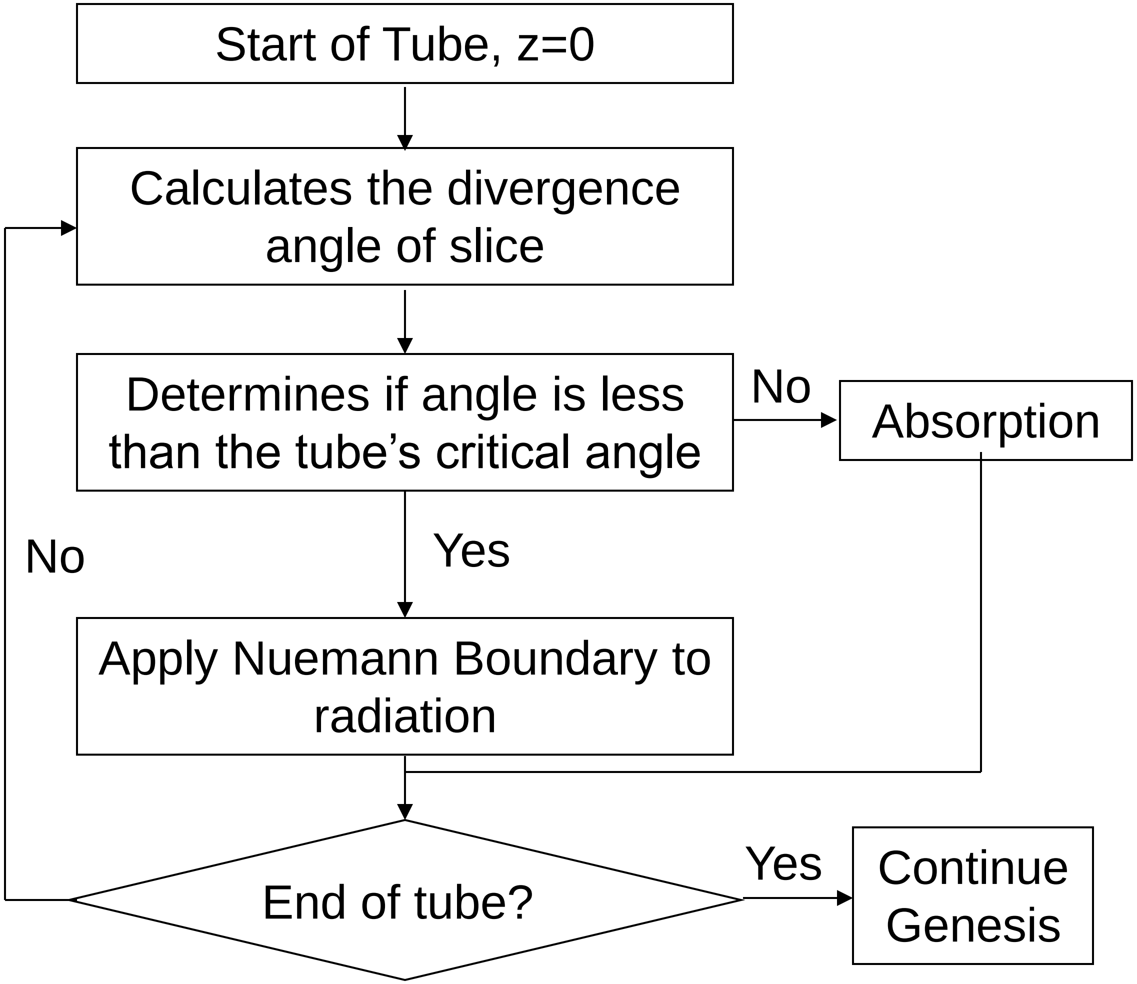


A modified version of Genesis 1.3 allows for modeling our scheme





The simple model requires an unachievable and unrealistic tube

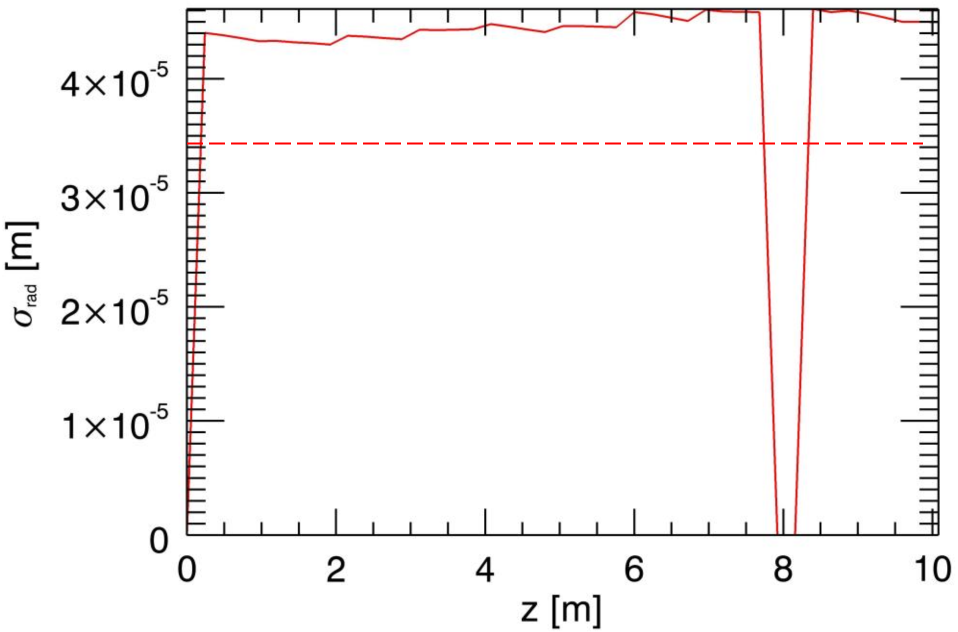
Table 1: Simulation Parameters

Parameter	Value
Undulator Type	Planar
Peak Current	3400 A
Undulator Period Length	3 cm
Radiation Wavelength	1.5 Å
Simulated Undulator Length	60 m
Electron Beam Energy	13.6 GeV
RMS Diffraction Angle	$\sim$6.8 μrad

Table 2: Tube Values

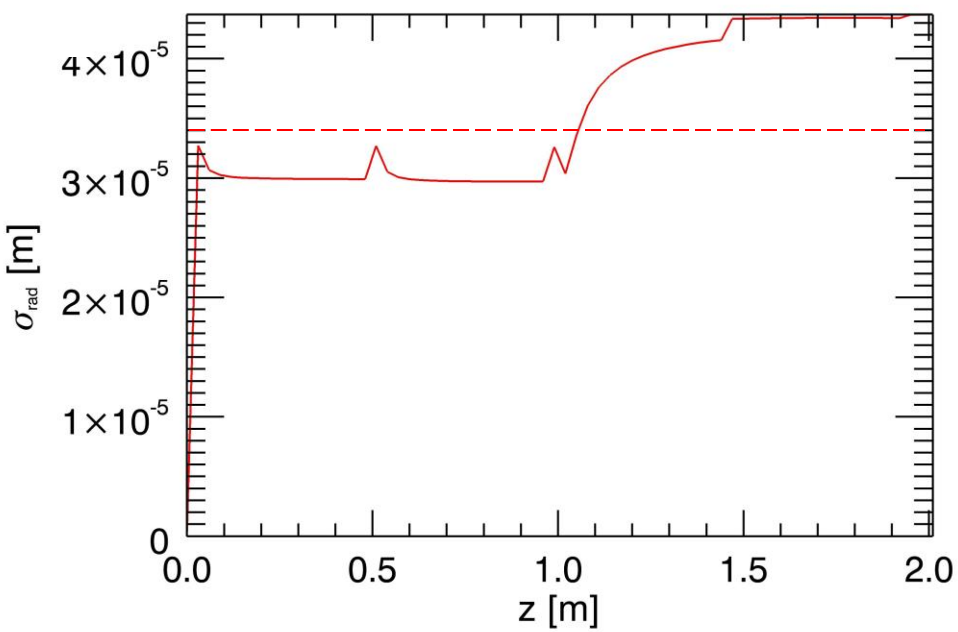
Parameter	Value
Width	34 μm
Height	34 μm
Length	20 m
Critical Angle	3.75 mrad

The spread of radiation is confined by the tube

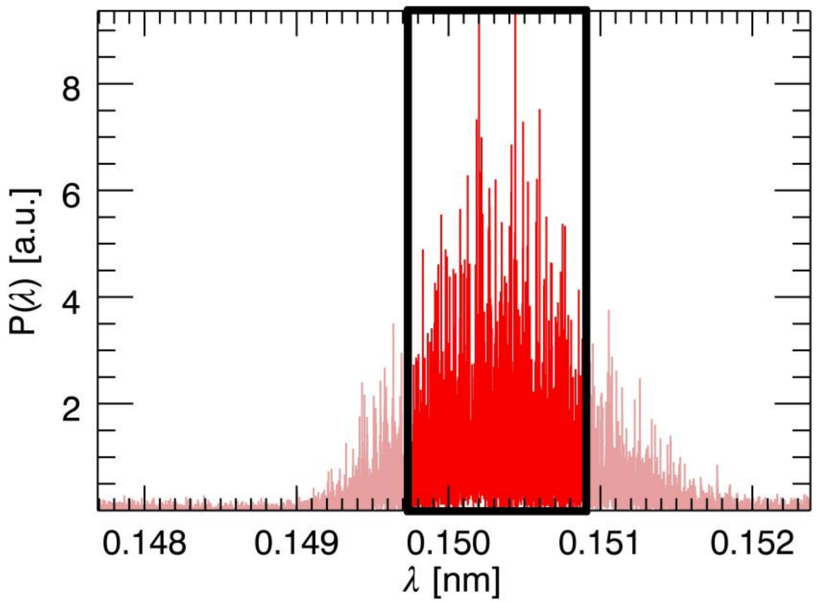


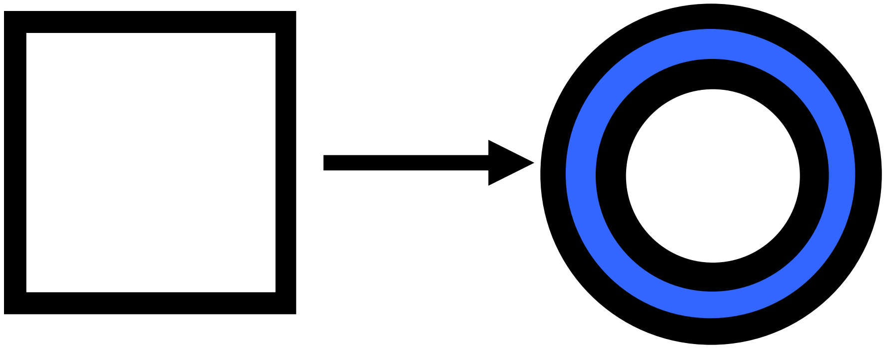
Simulation over 10 meters without the tube. Radiation rapidly grows and without restraint.

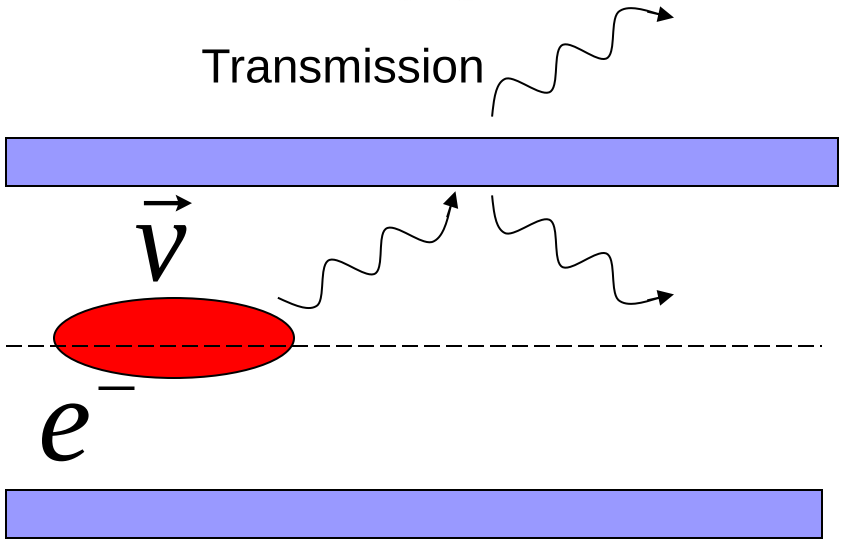
The effect of the tube (L=1) over a simulation length of 2 meters. Guiding and radiation confinement is observed.



Future Work







Simulate other FEL parameters:

- FLASH
- SACLA