Practical solutions for compact X-ray FEL laser based undulator

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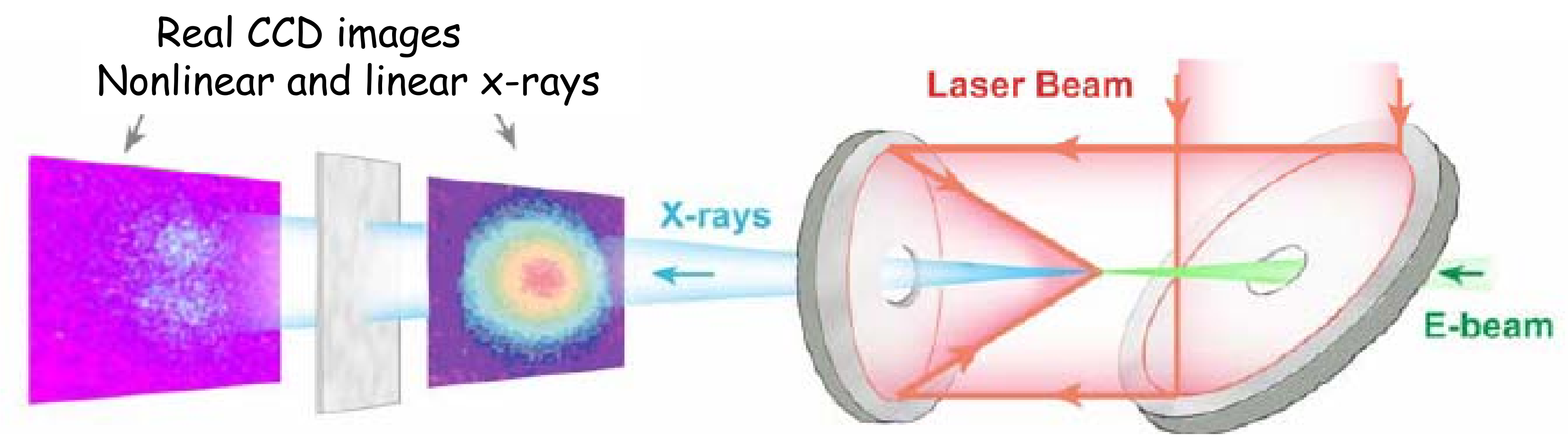
Idea:



N_X/N_{e-} ~ 0.35 in experiments at ATF/ no Coherence

Can the e-beam/laser interaction over few mm lead to electrons bunching and coherent interaction?

C. Pellegrini at SLAC FLS workshop: " yes, but e-beam brightness and lasers are very challenging"

Laser numbers

Wavelength:		$\lambda_{laser} := 10.6\mu m$
Energy		$E_{laser} := 30J$
Duration (e2e/flattop):		$\tau_{laser} := 30ps$
Duration (RMS):	$\sigma_{\tau laser} := 0.3 \cdot \tau_{laser}$	$\sigma_{\tau laser} = 9\,ps$
Power	$P_{laser} := \frac{E_{laser}}{\tau_{laser}}$	$P_{laser} = 1\,TW$
Rayleig length	$Z_R := 0.5 \tau_{laser} \cdot c$	$Z_R = 4.5\,mm$
Laser waist size:	$w(z) := \sqrt{\frac{Z_R \cdot \lambda_{laser}}{\pi}} \cdot \sqrt{1 + \left(\frac{z}{Z_R}\right)^2}$	$w(0mm) = 0.1\,mm$
Laser intencity	$I(z) := \frac{P_{laser}}{\pi \cdot w(z)^2}$	$I(0mm) = 2.1 \times 10^{15} \frac{W}{cm^2}$
Laser parameter	$a_0(z) := \sqrt{0.86 \cdot \frac{I(z)}{10^{18} \cdot \frac{W}{cm^2}} \cdot \frac{\lambda_{laser}^2}{\mu m^2}}$	$a_0(0mm) = 0.5$ $a_0(2.5mm) = 0.4$

X ray energy

Convirsion from Compton to Laser

$$\lambda_U := 2\lambda_{laser} \qquad \omega_U := 2\omega_{laser} \qquad K_U(z) := a_0(z)$$

Electron beam energy

$$\gamma := \frac{E_e}{m_e \cdot c^2} \qquad E_e := 77.3\,\text{MeV} \qquad \gamma = 151.2$$

FEL wavelength:

$$\lambda_X(z) := \frac{\lambda_{laser}}{4\cdot\gamma^2}\cdot\left(1 + \frac{K_U(z)^2}{2}\right) \qquad \lambda_X(3\text{mm}) = 0.1\,\text{nm}$$

X ray energy:

$$E_X(z) := h\cdot\frac{c}{\lambda_X(z)} \qquad E_X(3\text{mm}) = 10\,\text{KeV}$$

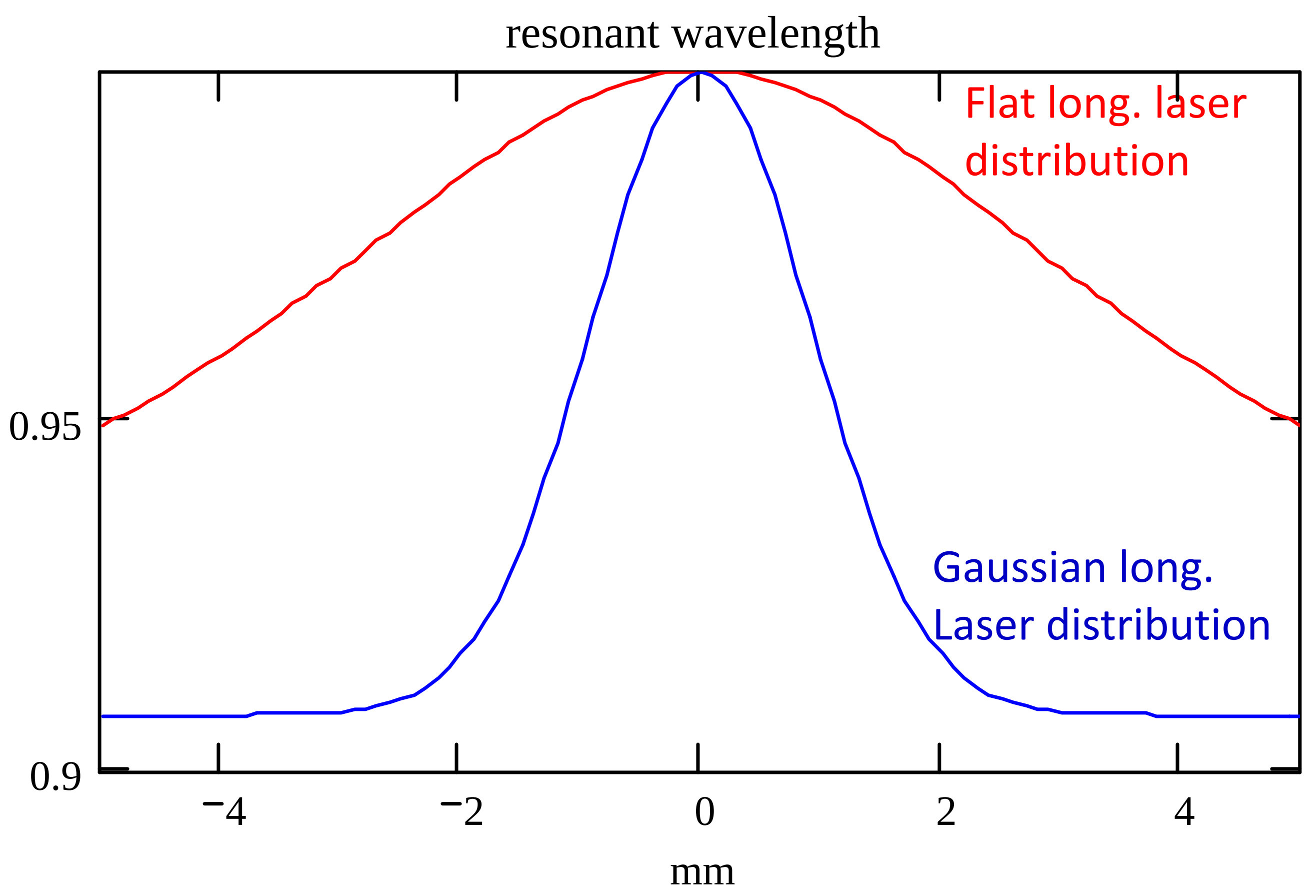
FEL calculations

Beam current		$I_e := 1.5\text{kA}$
Required diffraction emittance x20	$\varepsilon_N := \frac{\lambda_X(3\text{mm})\cdot\gamma}{4\pi}\cdot 20$	$\varepsilon_N = 29.8\text{nm}$
Transverse size	$\beta := Z_R \qquad \sigma_{re} := \sqrt{\beta\cdot\frac{\varepsilon_N}{\gamma}}$	$\sigma_{re} = 0.9\mu\text{m}$
Rho parameter:	$\rho(z) := \frac{1}{\gamma}\left(JJ(z)\cdot\frac{K_U(z)}{4}\cdot\frac{\omega_p}{\omega_U}\right)^{\frac{2}{3}}$	$\rho(3\text{mm}) = 1.1\times 10^{-3}$
Saturation length	$L_{sat}(z) := \frac{\lambda_{laser}}{2\rho(z)}$	$L_{sat}(0.5\text{mm}) = 4.2\text{mm}$ $L_{sat}(4.5\text{mm}) = 5.3\text{mm}$
Gain length:	$L_G := \frac{\lambda_{laser}}{4\cdot\sqrt{3}\cdot\pi\cdot\rho(3\text{mm})}$	$L_G = 0.4\text{mm}$
3D emittance	$\varepsilon_{nc} := \frac{\beta}{L_G}\cdot\frac{\gamma\cdot\lambda_X(3\text{mm})}{2\pi}$	$\varepsilon_{nc} = 30.7\text{nm}$

Summary of numbers

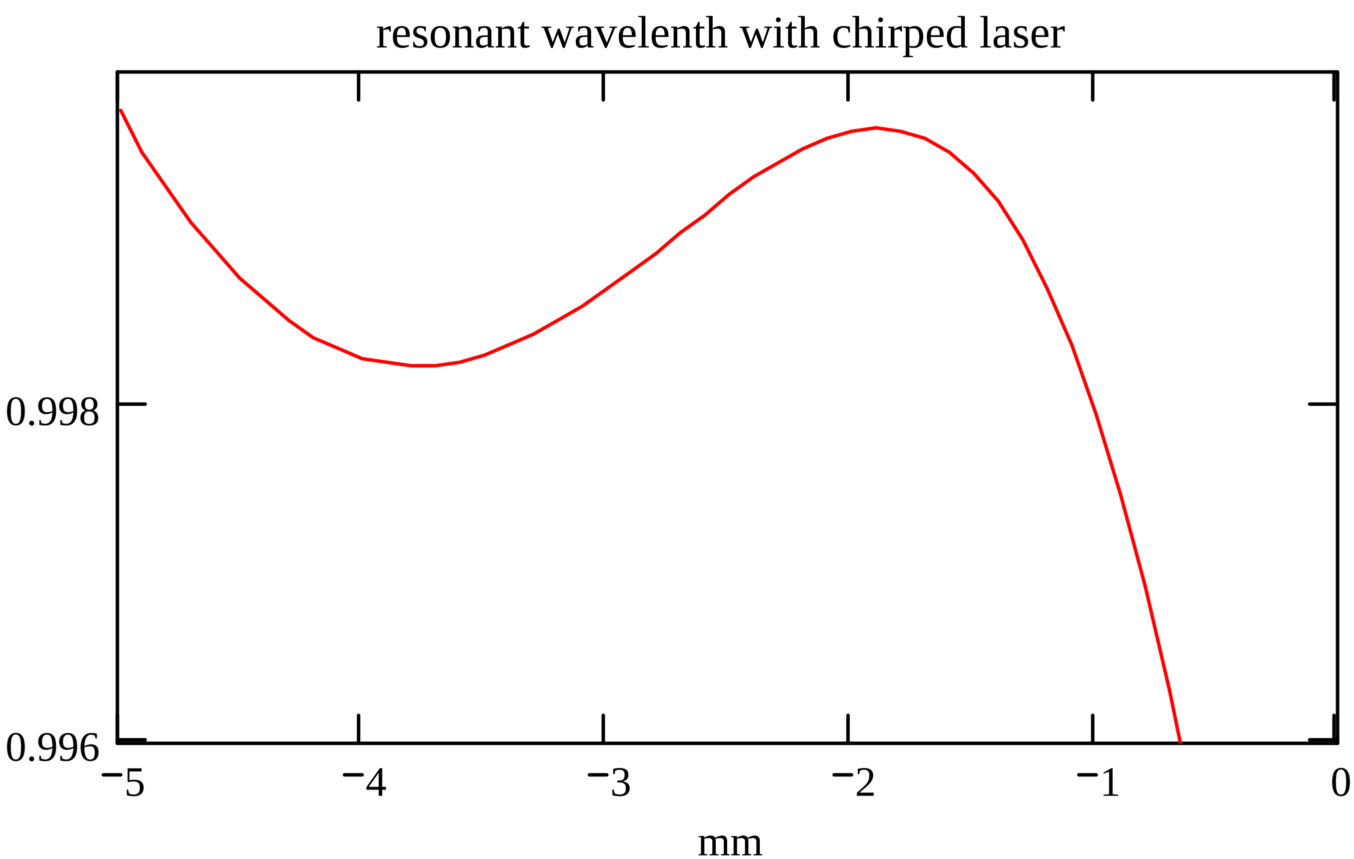
Electron beam energy	$E_e = 77.3\text{MeV}$
3D emittance	$\varepsilon_{nc} = 30.7\text{nm}$
Electron beam current	$I_e = 1.5\text{kA}$
Laser wavelength:	$\lambda_{laser} = 10.6\mu\text{m}$
Laser energy	$E_{laser} = 30\text{J}$
Laser duration (e2e flattop):	$\tau_{laser} = 30\text{ps}$
Saturation length	$L_{sat}(3\text{mm}) = 4.8\text{mm}$
Number of x rays per electron	$\dfrac{E_e}{E_X(3\text{mm})} \cdot \rho(3\text{mm}) = 8.6$
X ray energy:	$E_X(3\text{mm}) = 10\text{KeV}$

Resonant wavelength variation



~2% wavelength variation due to change in the laser intensity is not acceptable

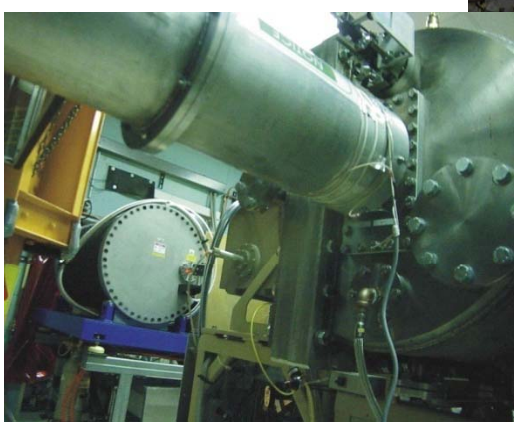
One can chirp the laser:

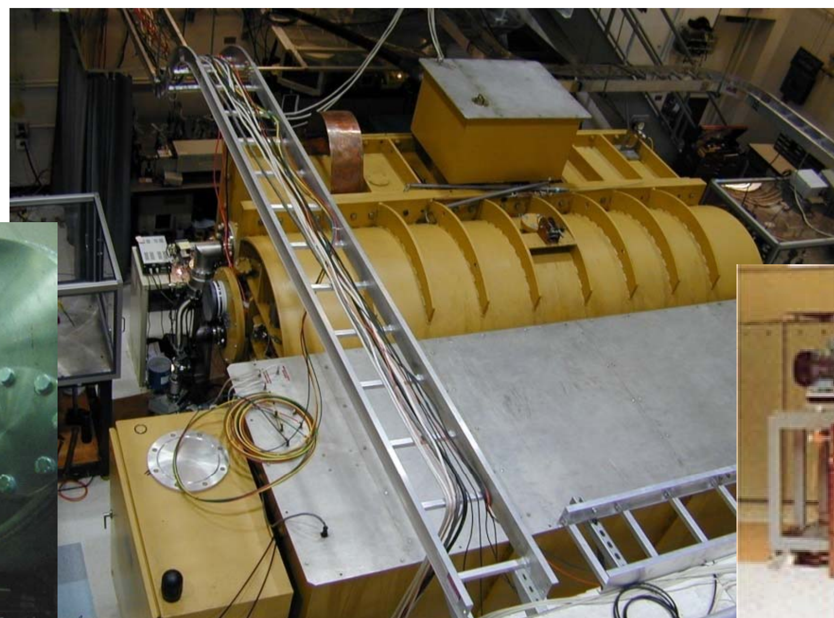


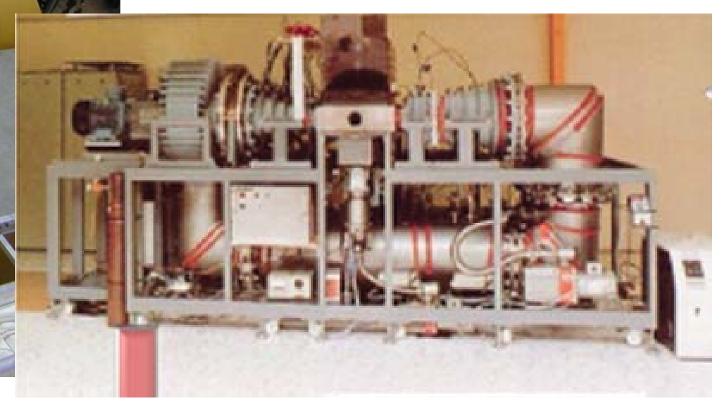
~6% laser chirp will keep wavelength within 0.1% over the gain length.
Combination of chirping and longitudinal shaping is needed.

CO2 laser as wiggler

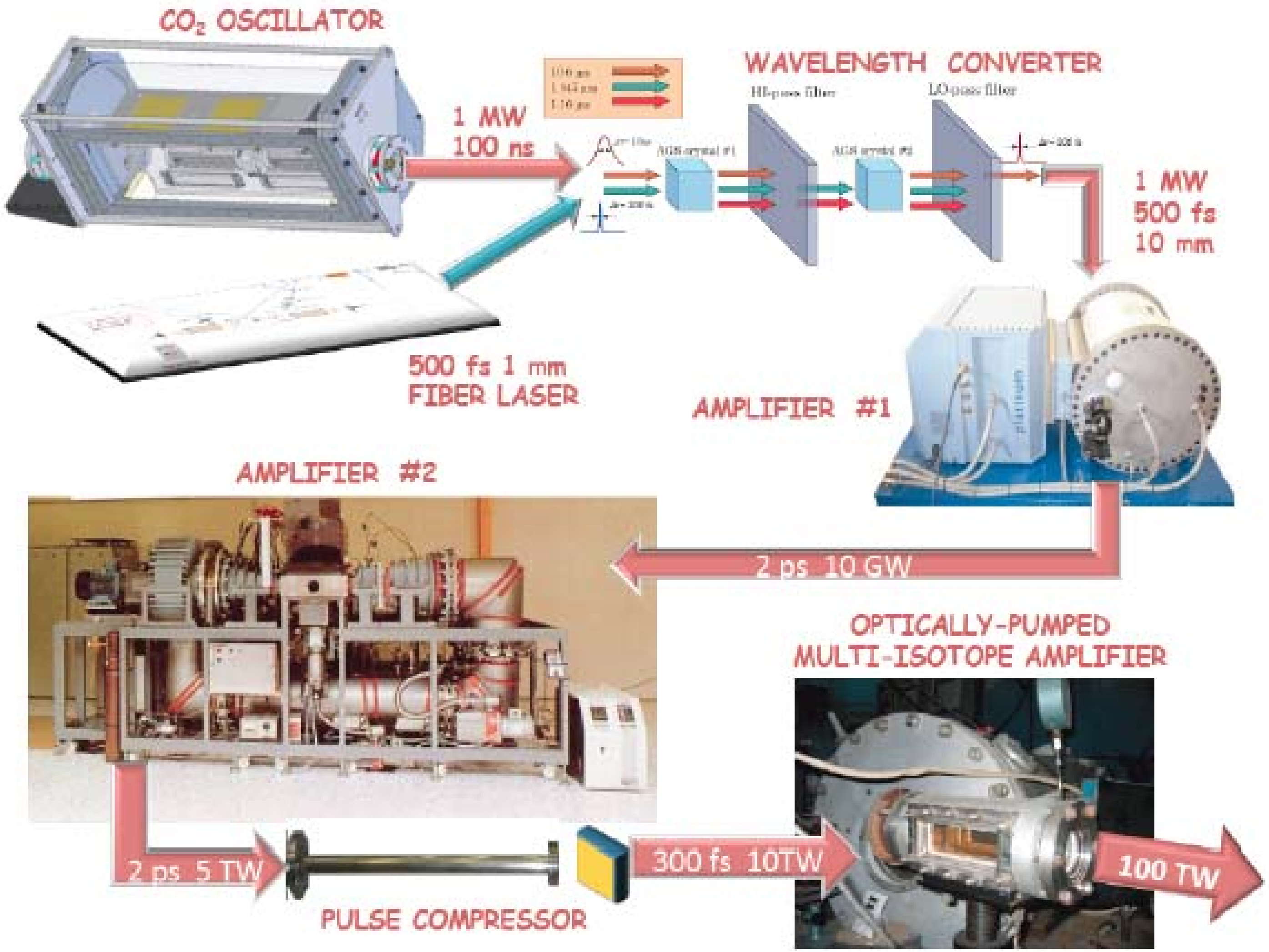
- ATF CO2 laser generates 5J / 3ps /~0.5% BW (upgrade pass to ~10-15J /~2% BW)
- UCLA Laser 150J in train of 3 3ps pulses
- Commercial Sopra laser is capable of ~10J /~2%BW at ~100Hz.







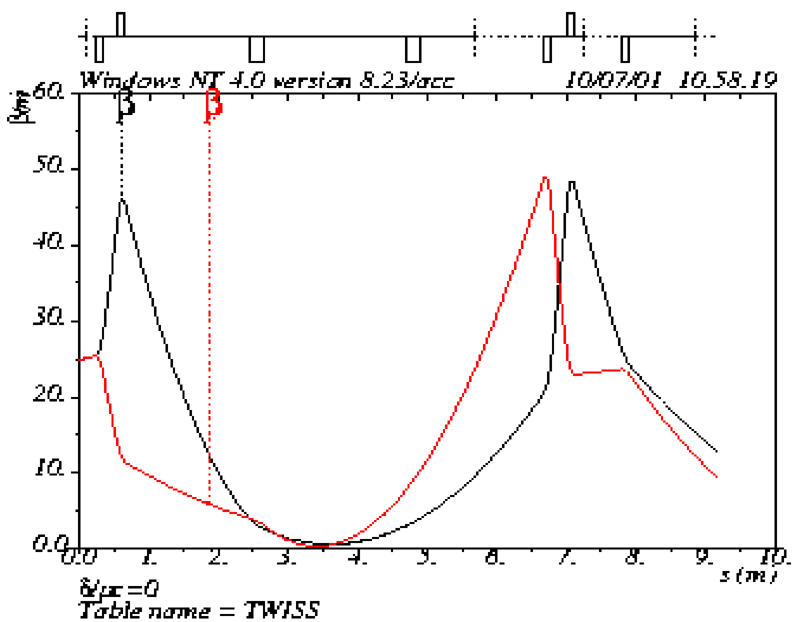
laser system based on realistic technology

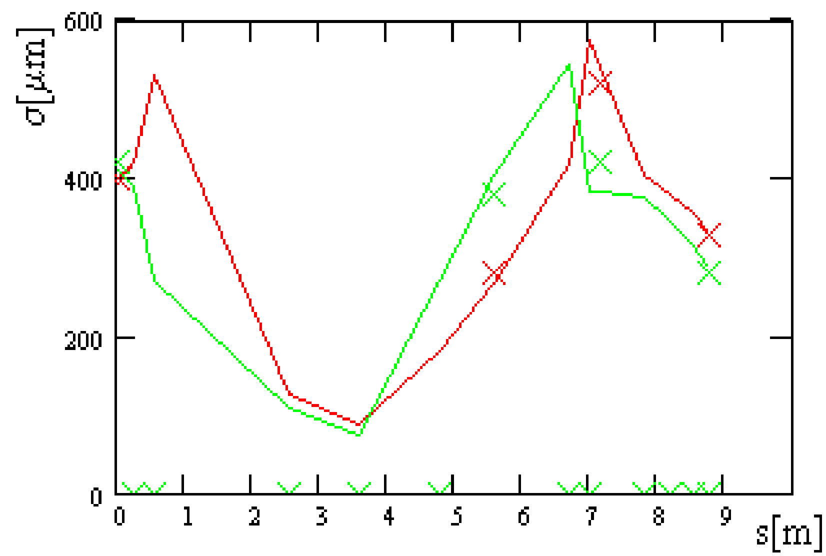


Fitting the beam size using multiple BPMs to resolve 0.6μm emittance

FEL 2001
23RD International Conference
Darmstadt
20TH to 24TH August 2001

BPMs were used to measure beam sizes >200 μm and quads for smaller sizes





Focusing properties of the transport line were extensively studied for the tomographic phase space rotation.

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BPM resolution limit

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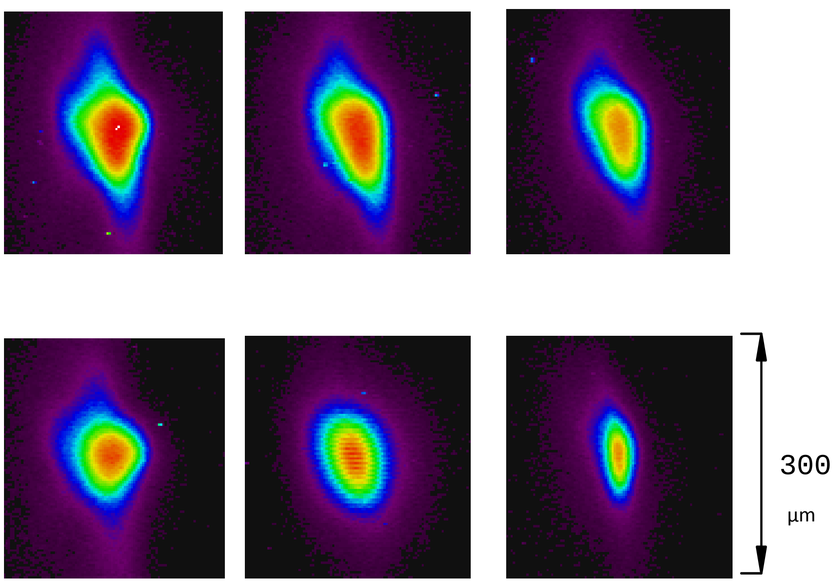

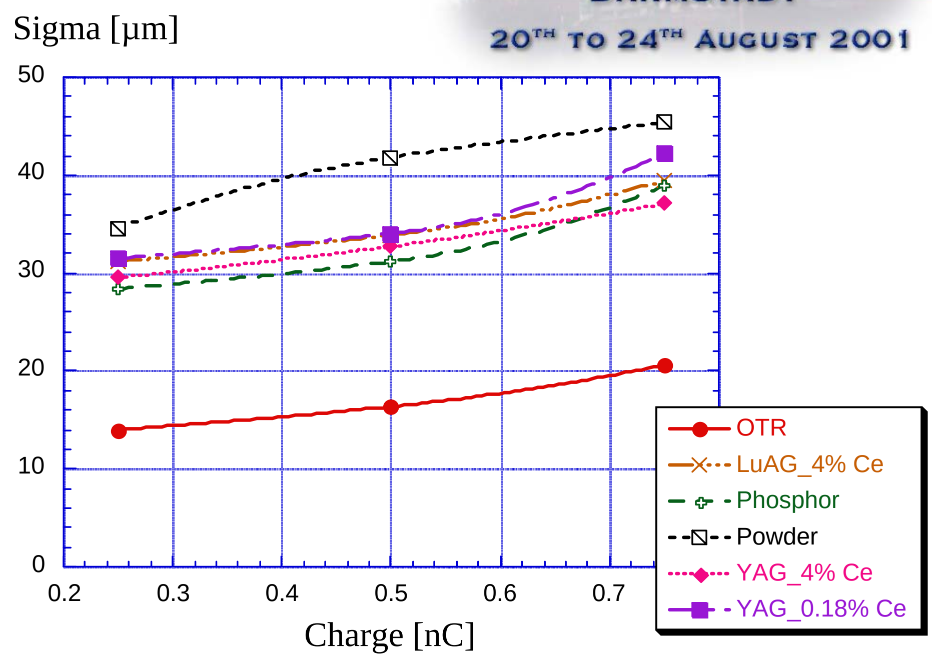

Beam images taken consequently with the six different diagnostics under stable experimental conditions (the charge Q ~ 500 pC).

Electron beam horizontal spot size as a function of charge, measured with the scintillating diagnostics and the OTR.

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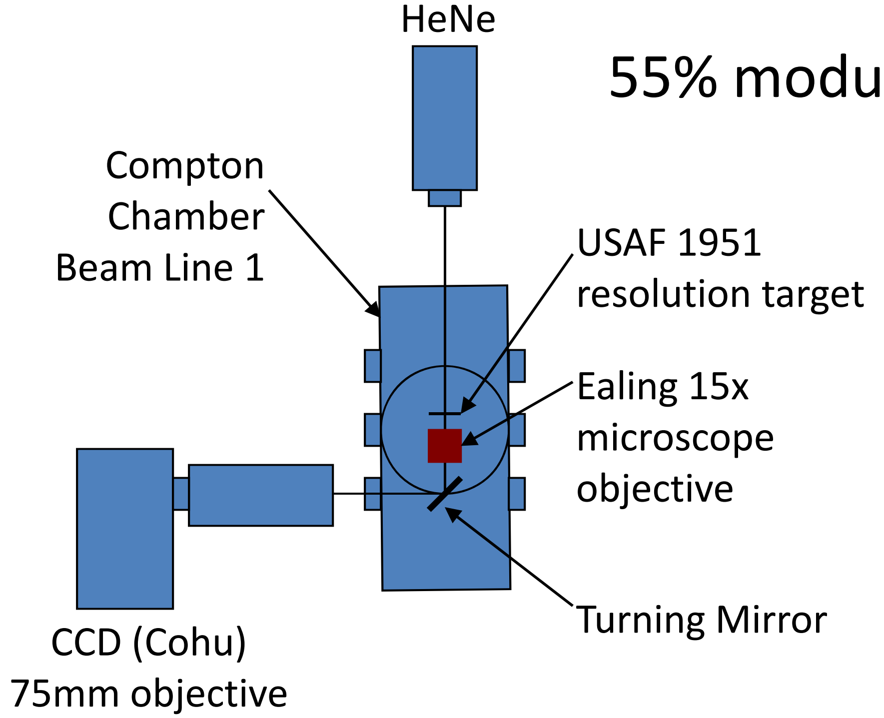
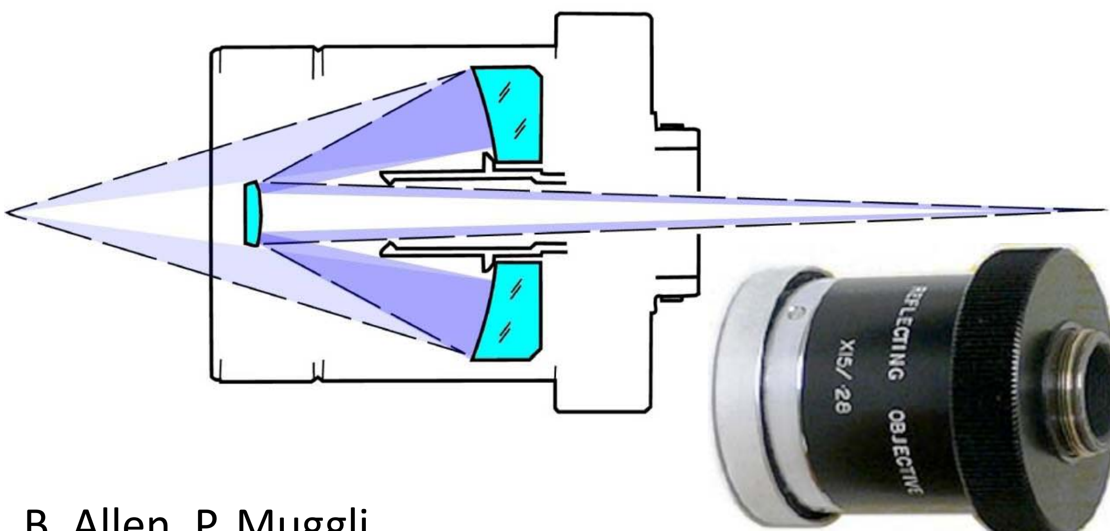
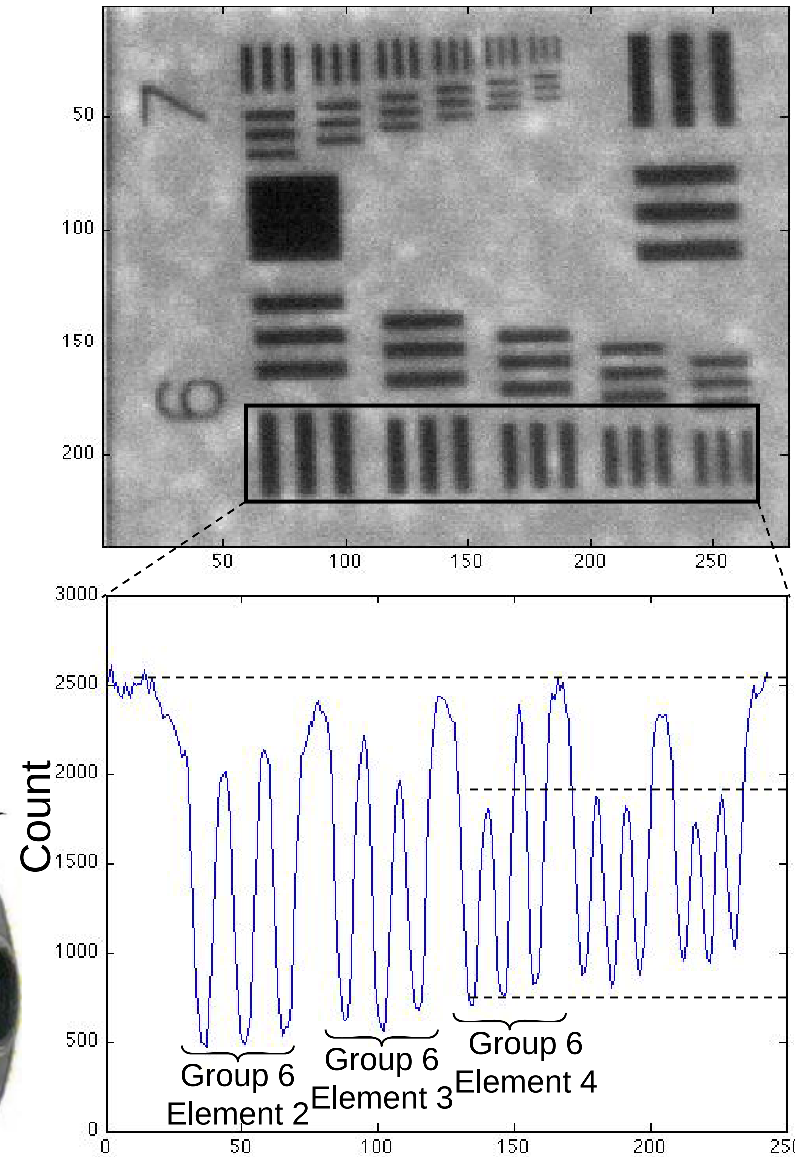
Resolution Analysis

55% modulation at 4.4 microns

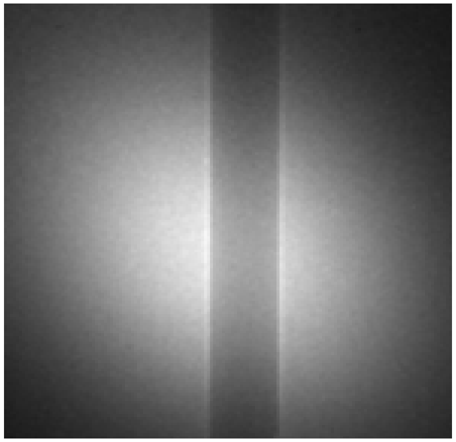






B. Allen, P. Muggli

Diagnostics



- Sub micron resolution is needed
- Compton scattering generated beam.
- P. Muggli, B. Allen (USC) testing in vacuum microscope imaging (TR) with 2μm optical resolution
- Measuring beam size at large β-function locations and fitting transport optics to deduct beams at waist.
- Number of photons could be an issue
- Second momentum cavities
- Combination of techniques / more ideas are needed

Conclusion

- Photoinjector
  - there are ideas (UCLA: X band bunching injector)
  - "twenty years after (1.6cell BNL/SLAC/UCLA gun)" team is needed
- CO_2 laser
  - technology is close
  - likely to be developed due to other applications
  - Self chirping in plasma and longitudinal shaping are not demonstrated
- Diagnostics
  - Development and testing is crucial

Inverse Free Electron Laser as a current buster