Atto-Second Electron Beam Generation and Characterization Experiment at the ATF

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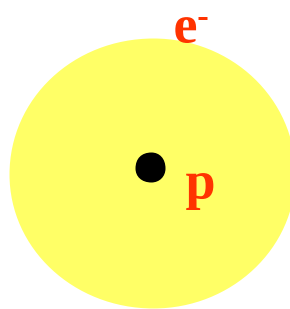
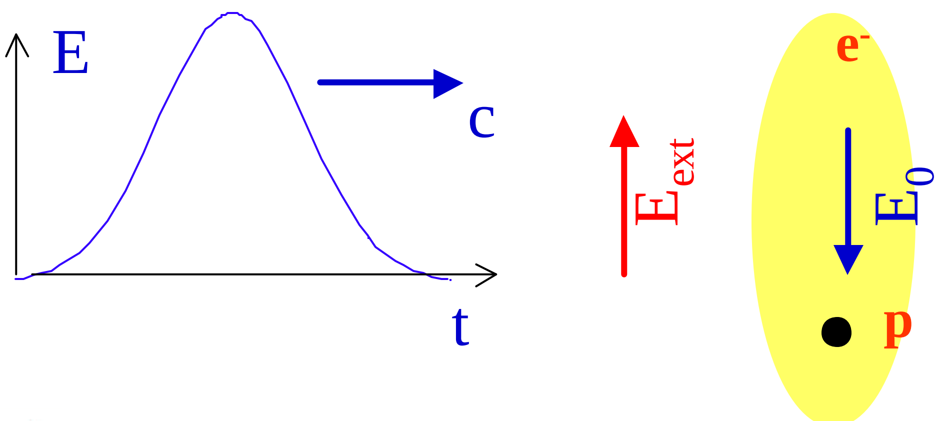
Motivation

Atom at rest

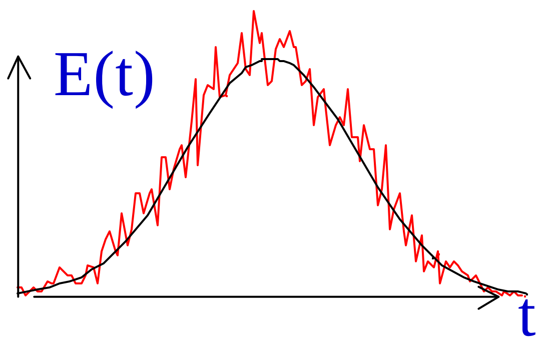


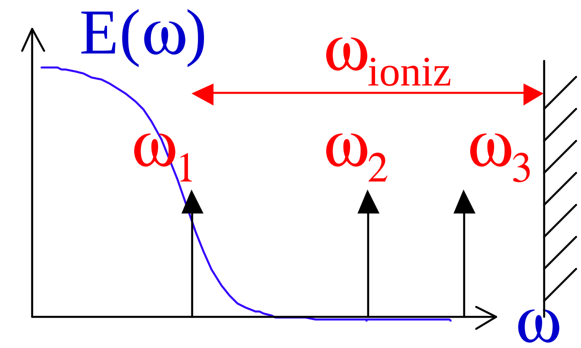
Atom affected by a slowly varying external field



Motivation cont'd

Real electron pulse
has shot noise fluctuations





ω_1, ω_2, ω_3 are atomic transition frequencies

Ionization losses are due to fluctuations that are responsible for high frequencies in the spectra, i. e. frequencies that are comparable with ω_{ioniz}

Therefore: $\delta P \sim \sqrt{N}$

$\delta E \sim N$

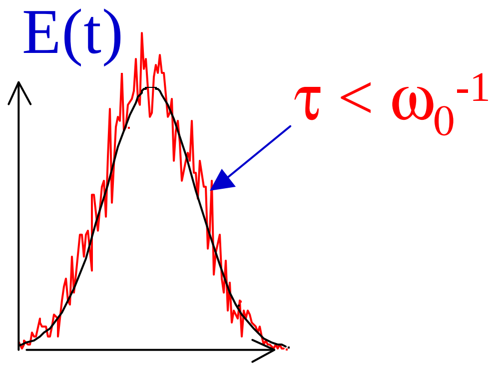
Momenta

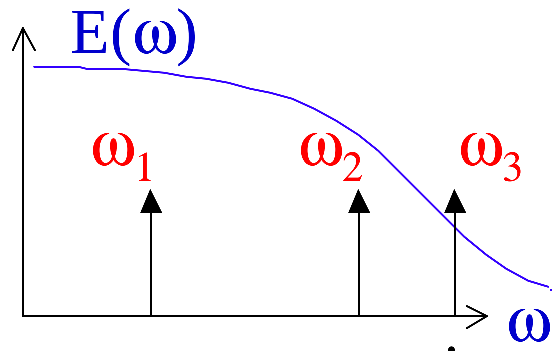
Energy loss

Total number of particles in the bunch

Motivation cont'd

Short pulses



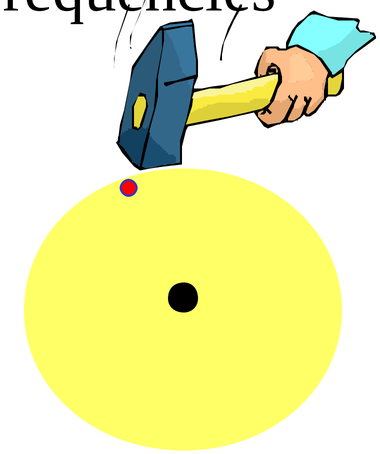


ω_0, ω_1, ω_2 are atomic transition frequencies

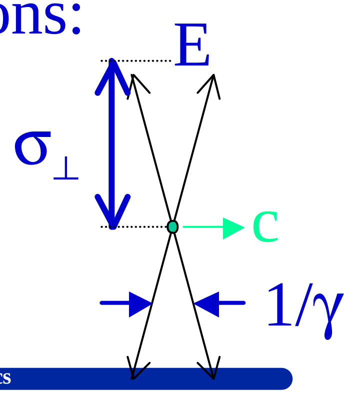
Now a collective field of all electrons in the bunch can drive the atomic electron. Therefore:

Momenta $\delta P \sim N$

Energy loss $\delta E \sim N^2$



Transverse limitations:



$$\frac{\sigma_\perp}{c\,\gamma} < \tau$$

Optimal condition for interaction

Simple model for media $\quad \epsilon - 1 = \dfrac{\omega_p^2}{\omega_0^2 - \omega^2}$, $\quad \omega_p^2 = 4\pi n r_e c^2$

For short pulse $\quad \dfrac{1}{\tau} \simeq \omega > \omega_0$ $\quad$ medium behaves like plasma and compensates electric field of the bunch

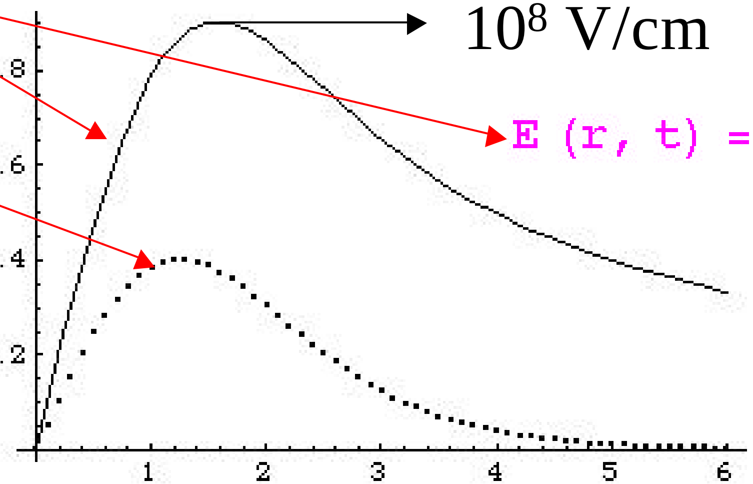
For Gaussian beam $\quad N_m^* = \left(\dfrac{d_{nm}}{e a_B}\right)^2 \dfrac{N^2}{16} \dfrac{a_B}{\epsilon_{tr}} e^{-\omega_{nm}^2 \tau^2} \Longrightarrow 4\ 10^9$

field in vacuum

field in media

$k_p \sigma_{tr} = 1$

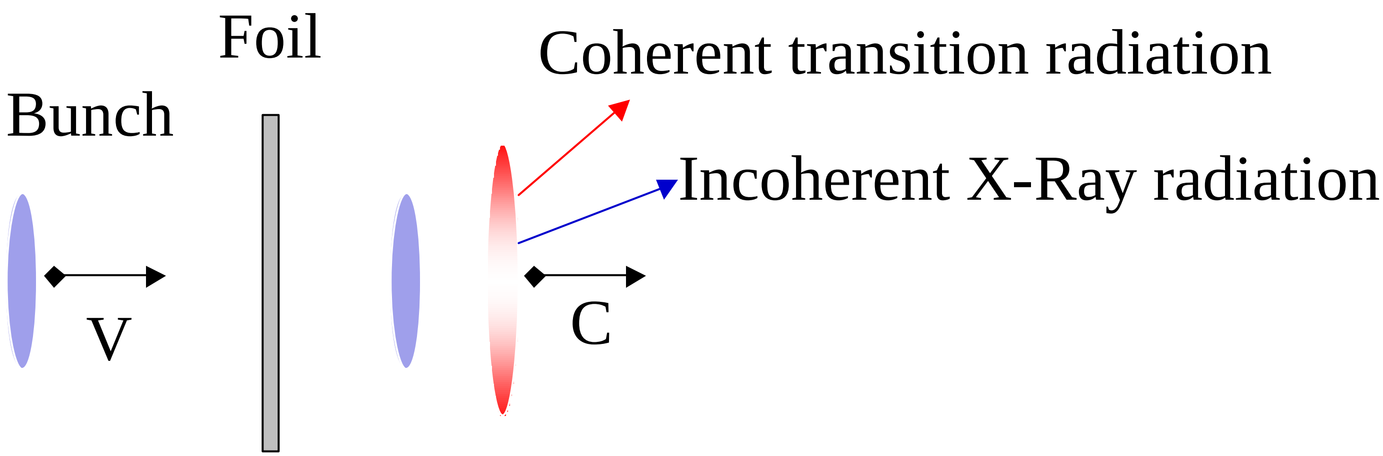
E(r)



10^8 V/cm

$$E(r,t) = \frac{2 q N e^{-\frac{t^2}{2\tau^2}}}{\sqrt{2\pi}\, c \tau r}\left(1 - e^{-\frac{r^2}{2\sigma_{tr}^2}}\right)$$

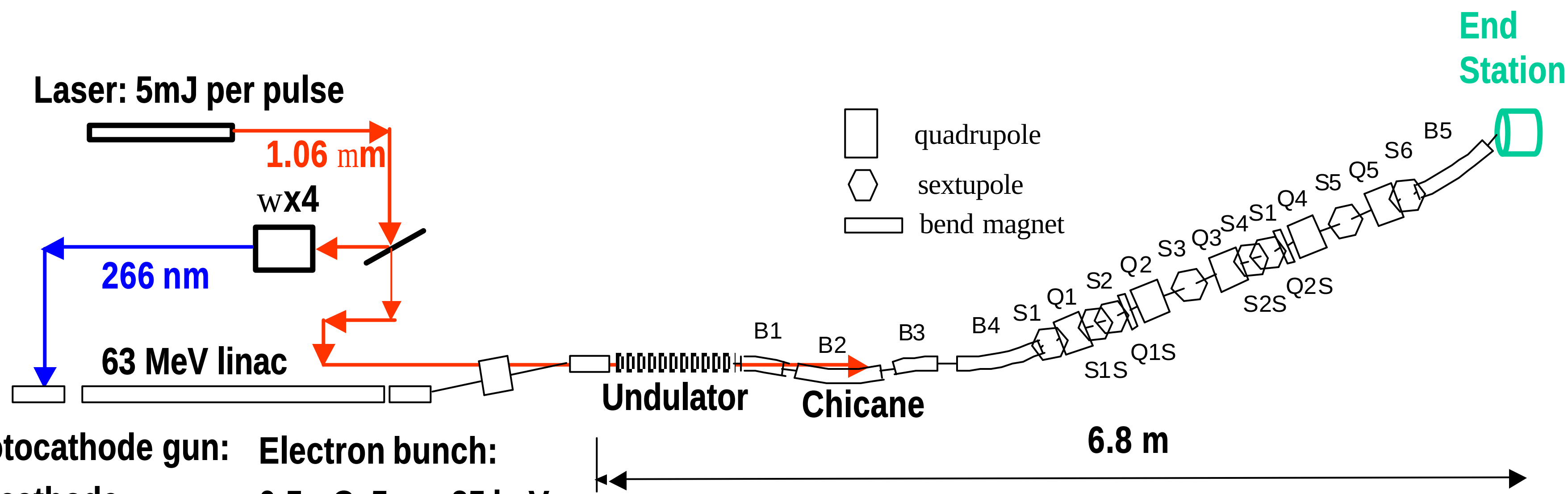
r $/\sigma_{tr}$



Electric field of coherent transition radiation very similar to collective field of the bunch (virtual photons became real)

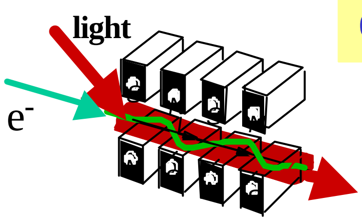
This kind of set up can be used for pump probe type of experiments Using X-Rays as probe opens the way for measurement of radial atomic wave functions

Method



Photocathode gun:
Mg cathode

Electron bunch:
0.5 nC, 5ps , 25 keV,
2 mm-mrad



e-beam-light interaction in the undulator

laser peak power

Bessel functions

undulator parameter

$$(\Delta g)^2 = 32p\ M \frac{P}{P_0} x \left[J_0(z\ /2) - J_1(z\ /2)\right]^2$$

$$x = \frac{K^2/2}{1+K^2/2}$$

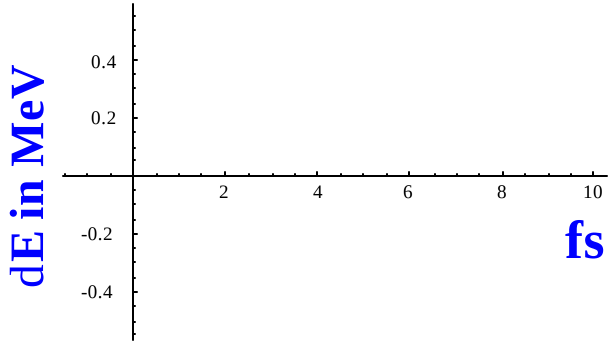
number of undulator periods

$8.7\text{x}10^9$ W

Method cont'd

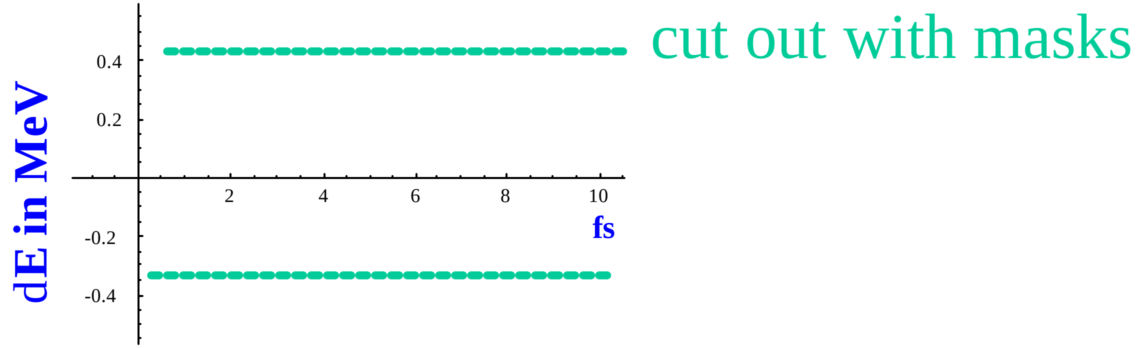
Estimate: δE=0.6 MeV for P=10 MW, K=1.28, M=55

Simulations (GINGER was used)



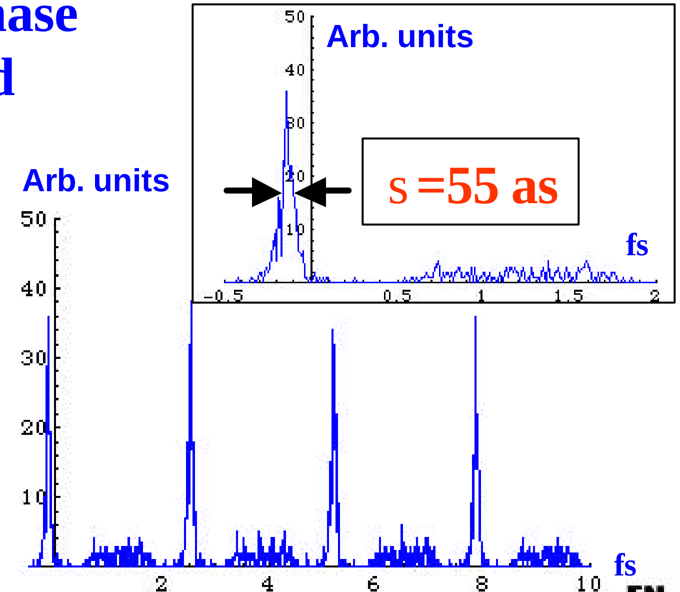
Longitudinal phase space at the exit of the undulator.

Modulation amplitude = 40 s_e



Longitudinal phase space at the End Station

Histogram of electron longitudinal density

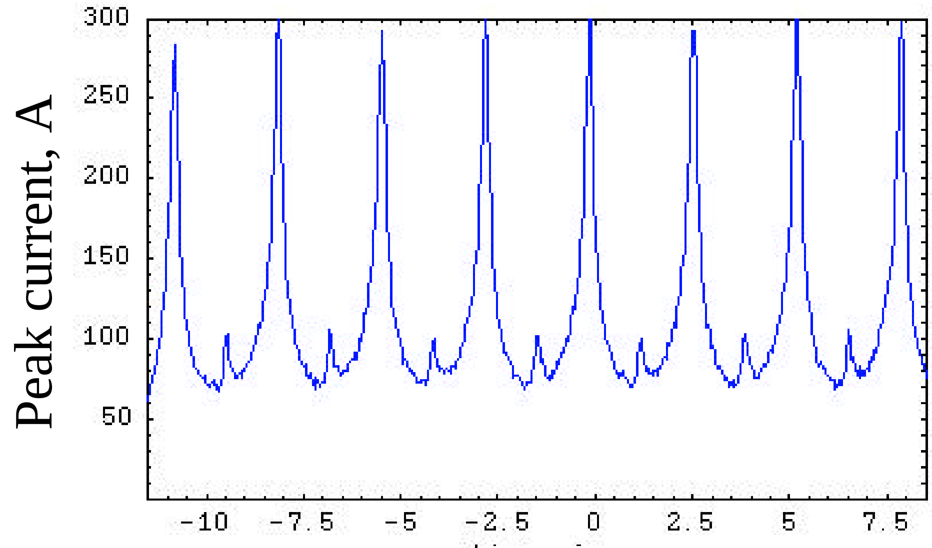


The feasibility of electron pulses of ~100 attosecond is demonstrated.

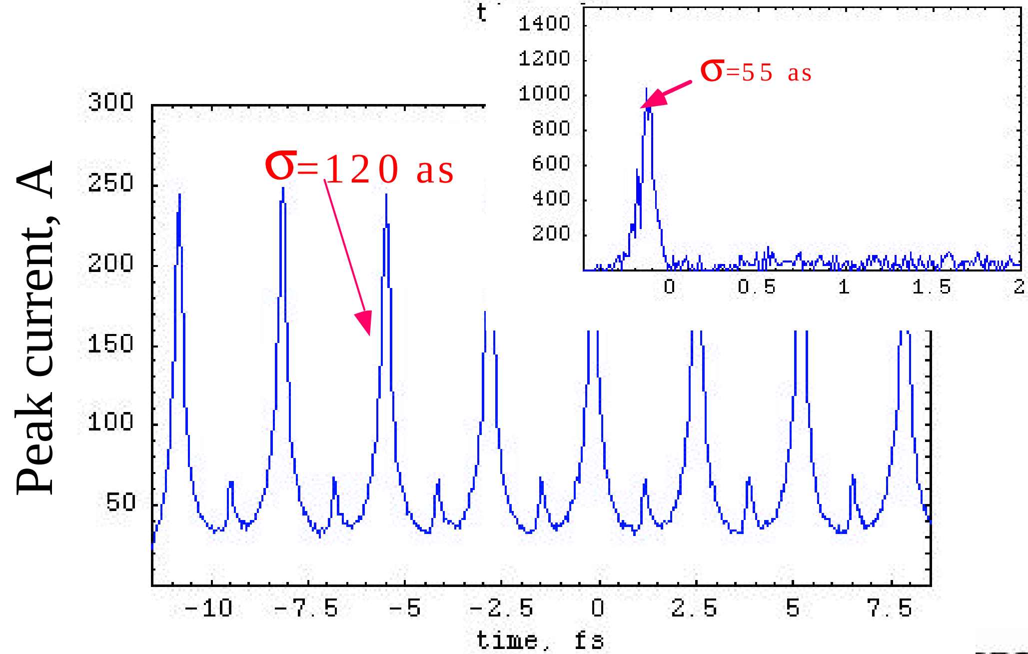
This attosecond electron pulses will open the way to a new class of experiments based on the interaction of atomic electrons in the medium with the *collective electric field* of electron bunch, this includes, for example the measurement of the *wavefunction of atoms*, or *coherent ionization losses* that are proportional to the square of the number of electrons in the microbunch.

Results

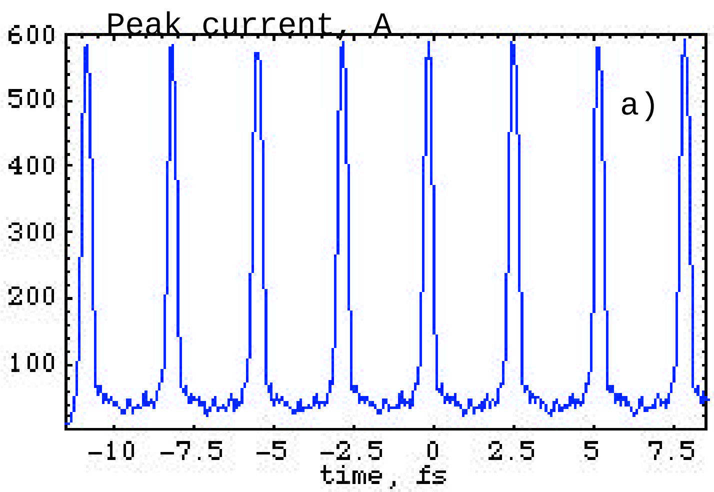
Particle tracking without errors and without cut of tails

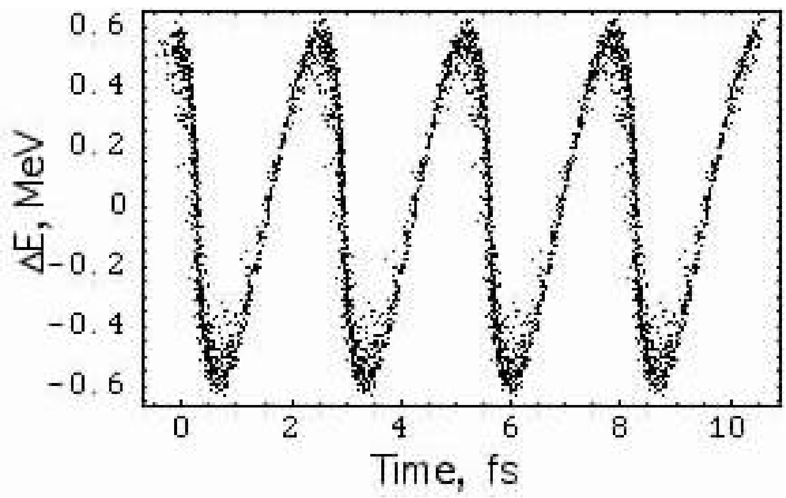


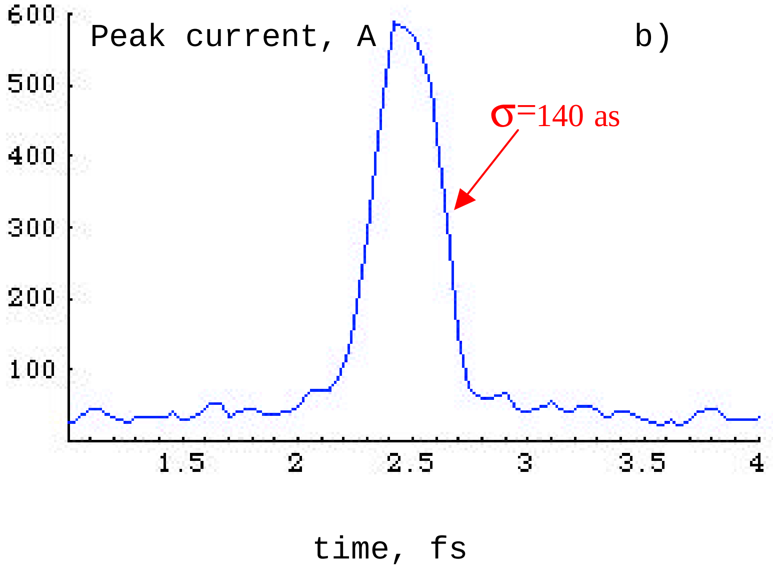
Particle tracking without errors and with cut of tails



Results for the ATF beam

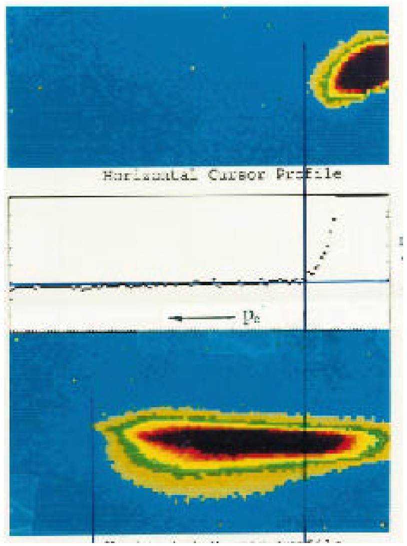


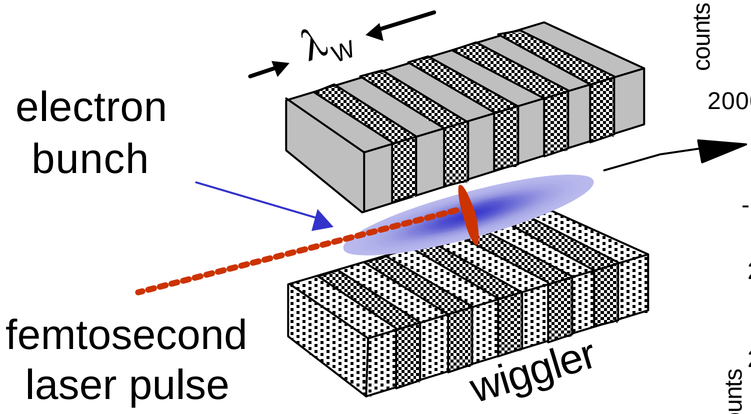


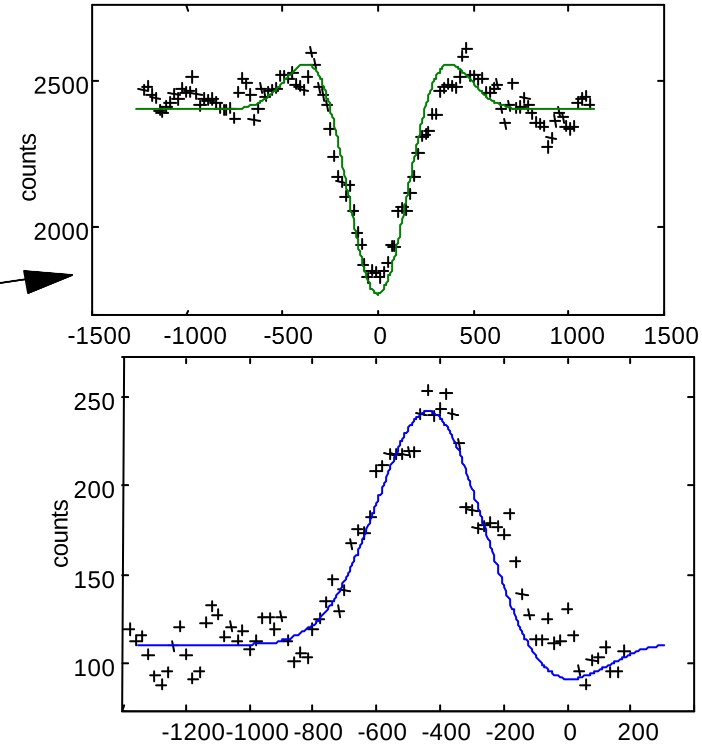


Why Atto-Second Pulse at the ATF

- Both LBNL and BNL has long a tradition in IFEL R&D.



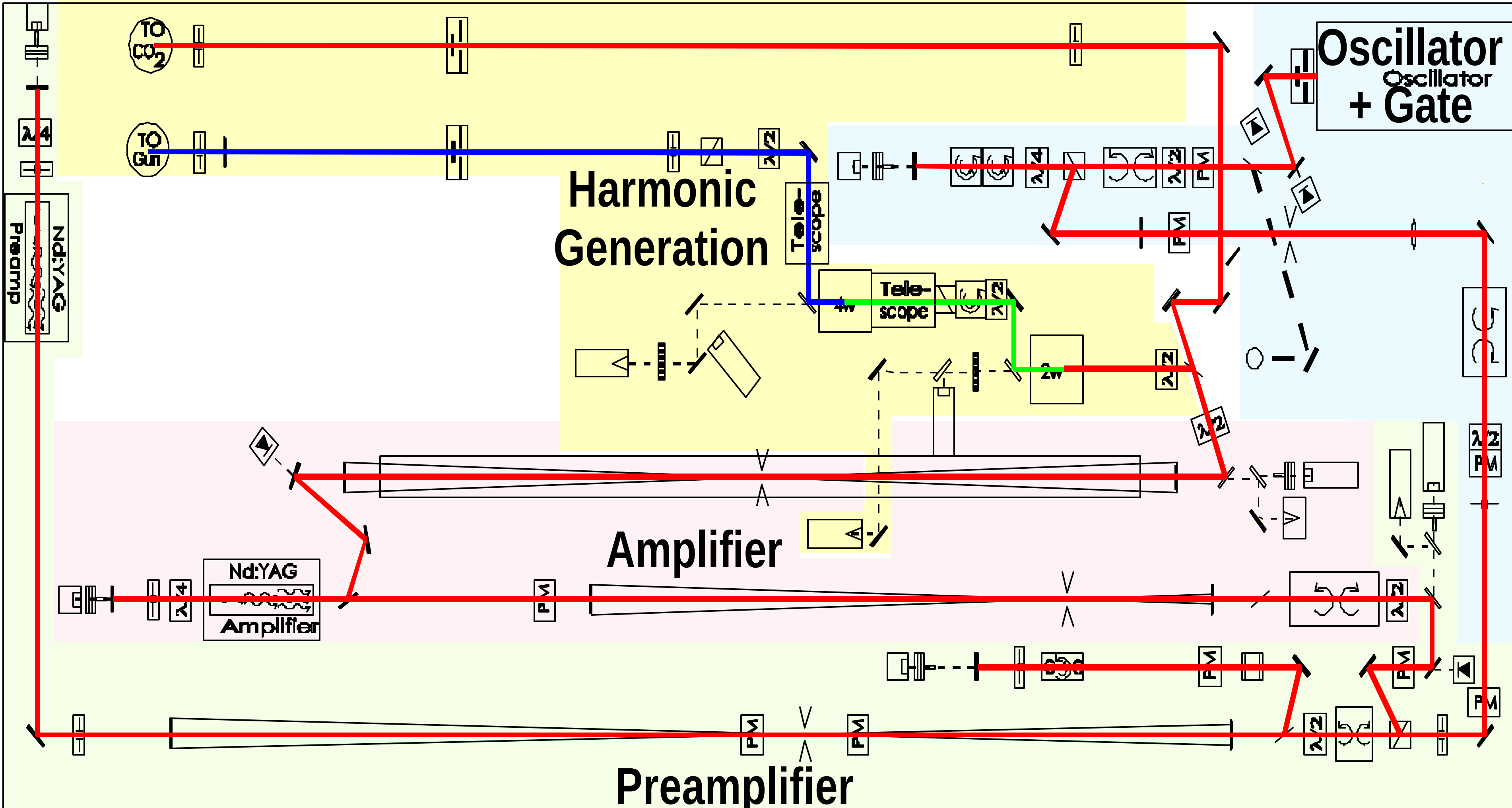


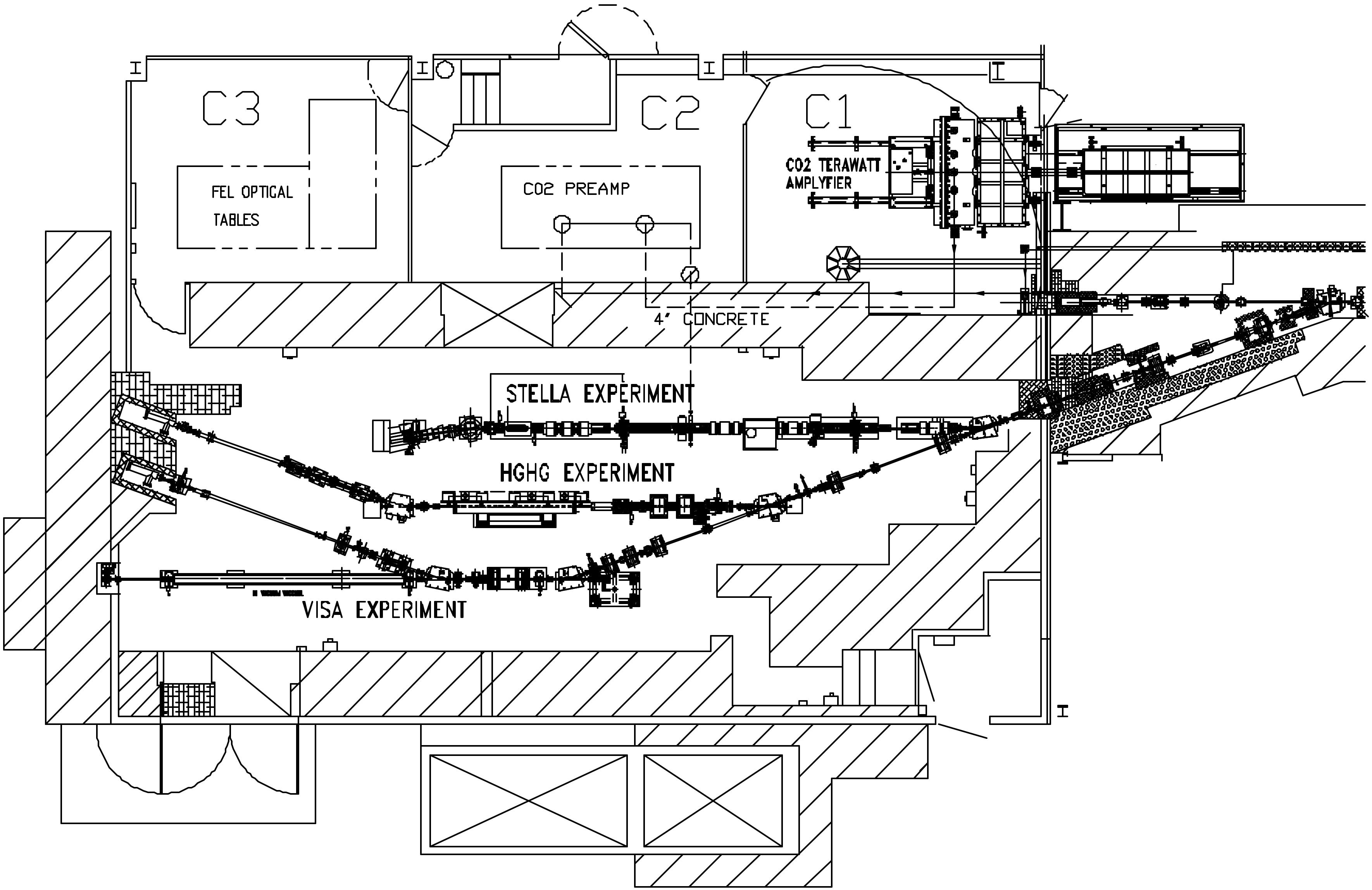


- The electron beam quality.
- The laser system.
- Most other hardware available with minimum investment.

ATF Nd:YAG Laser - functional units and beam path

To ATF experimental hall



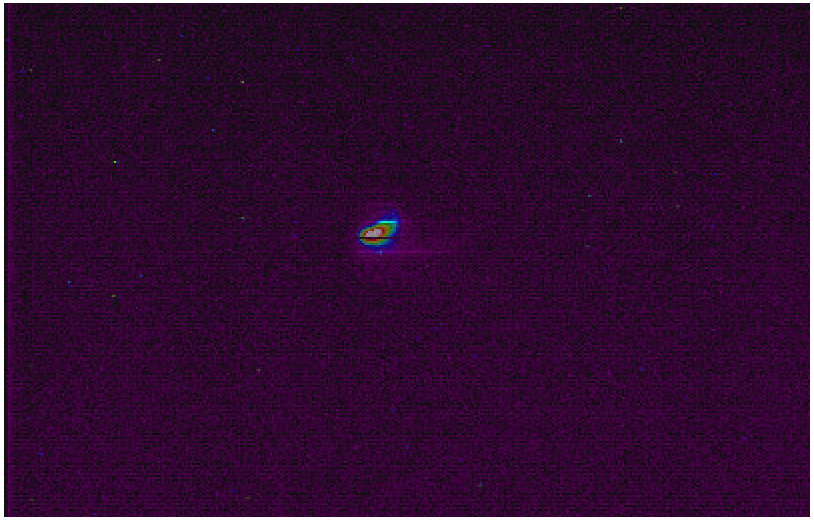

C3
C2
C1
FEL OPTICAL
TABLES
CO2 PREAMP
CO2 TERAWATT
AMPLYFIER
4' CONCRETE
STELLA EXPERIMENT
HGHG EXPERIMENT
VISA EXPERIMENT

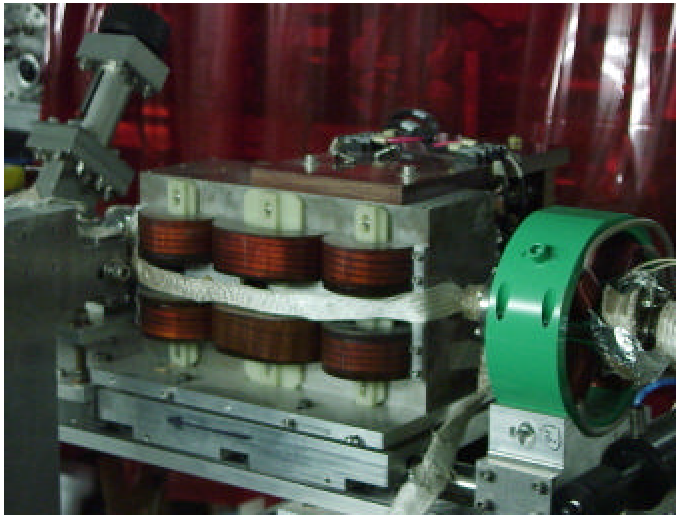
Hardware now available

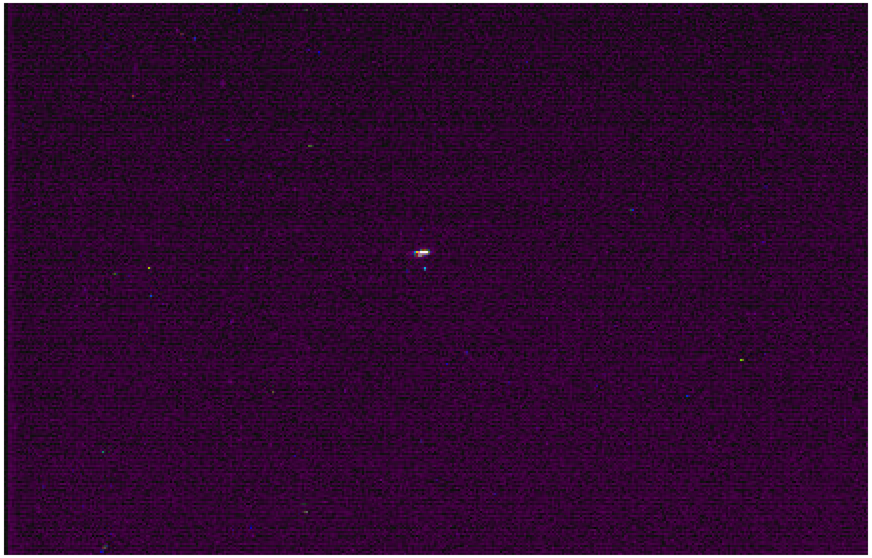
The VISA Undulator Section

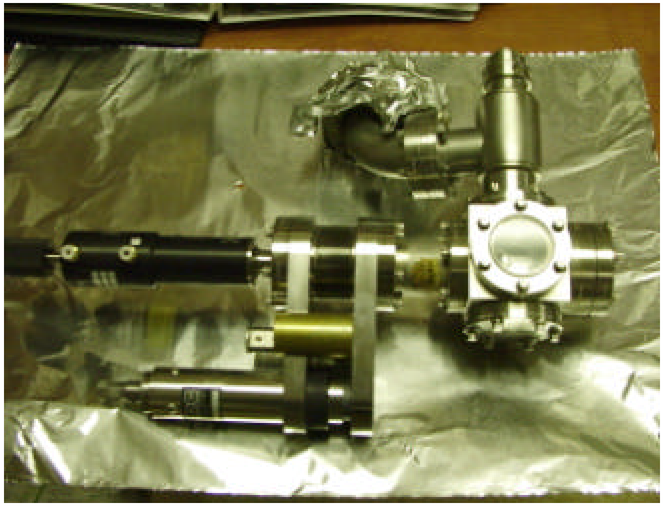
Period length	**18 mm**
Number of periods	**55 segment**
Magnetic gap *g*	**6.0 mm**
Maximum *B* field *B* max	**0.75 T**
***B* field error D *B* _ max**	**0.4%**
Undulator parameter *K*	**1.26**

Hardware now available









Coherent Transition Radiation

$$r(x,y,z) = \frac{eN\exp\left(-\frac{x^2}{2s_x^2}-\frac{y^2}{2s_y^2}-\frac{z^2}{2s_z^2}\right)}{(2p)^{3/2}s_x s_y s_z}\left[1+\sum_{n=1}^{\infty} b_n \cos(nk_r z)\right]$$

$$U_n = \frac{N^2 e^2 b_n^2}{8\sqrt{p}\, s_x s_y s_z}\left(\frac{g}{nk_r}\right)^4\left(\frac{1}{s_x^2}+\frac{1}{s_y^2}\right)$$

Work need to be done

- New vacuum chamber for the undulator.
- Design match laser transport line.
- Installation.

Schedule

If the proposed experiment approved:

1. funding ?
2. New single-shot spectrometer?
3. Design and construction of the undulator vacuum chamber and support. (March – June, 2002)
4. Tuning the undulator. (April – June, 2002).
5. Vacuum testing. (August)
6. Laser and electron beam diagnostics.
7. Install in Sept, 2002.
8. Beam time request: 5 runs, each run 2 to 3 days

Summary

- Attosecond Physics
- High Harmonic IFEL.
- High harmonic generation.
- CSR.
- New beam diagnostics techniques.

When such pulses become available, a new vista of applications will appear and add new vitality to the community.