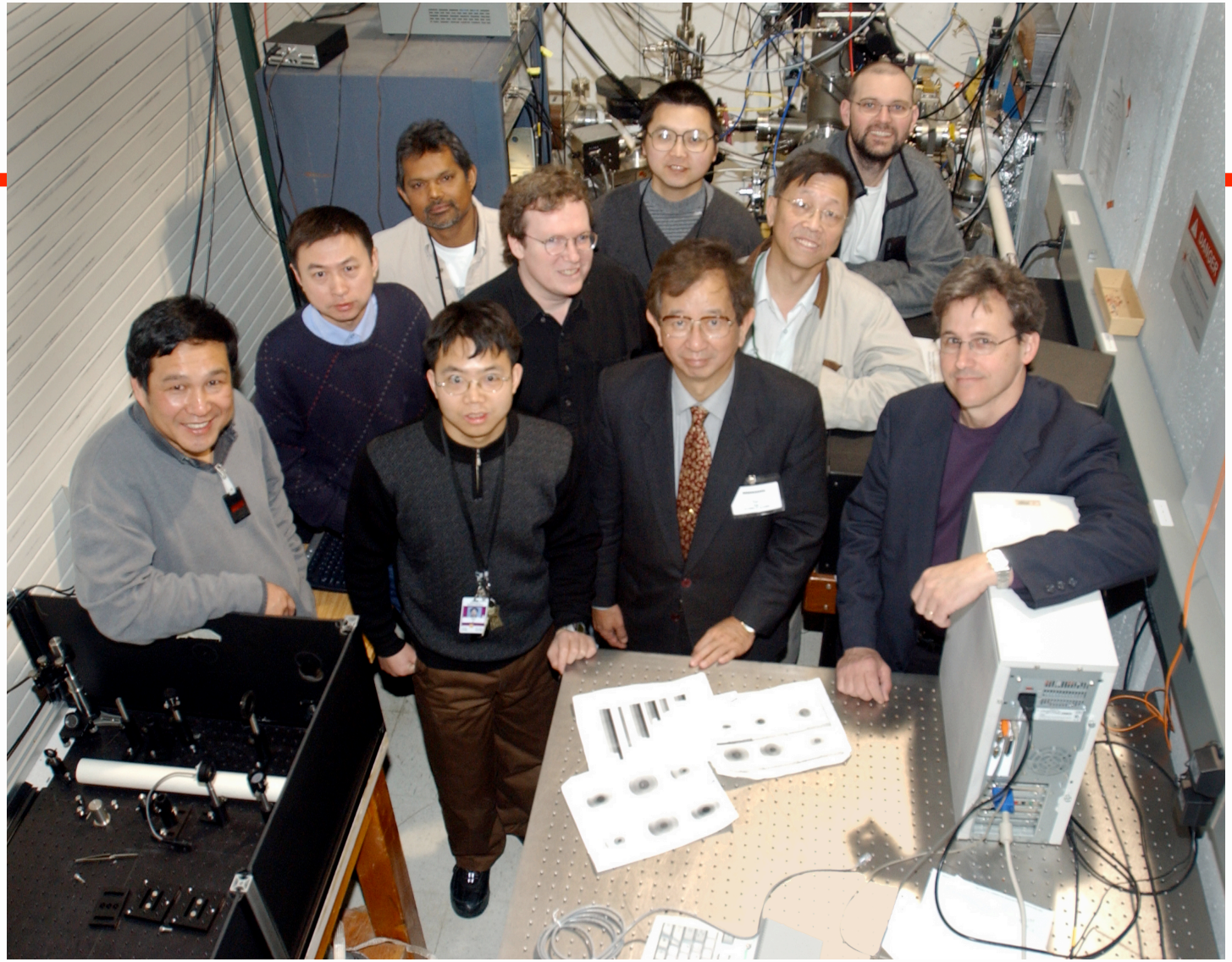
# The DUV-FEL Facility at NSLS

**X.J. Wang for DUV-FEL Team**
**National Synchrotron Light Source**

***Presented at the UltraFast X-Rays2004***
***April 30, 2004***



**Prof. Y. Lee with some of the DUV-FEL Colleague.**

# What Does the DUV-FEL Do ?

A *dedicated* platform for the development of single-pass FEL Science and Technology, and its applications.

The *only* short wavelength FEL project based on Laser Seeded High Gain Harmonic Generation

We are now fulfilling those promises:

1. High gain harmonic generation (HGHG) reach saturation at 266 nm (L.H. Yu et al, PRL 91, No. 7, 074801-1 [2003]).
2. First chemical science user experiment – ion pair imaging of methyl fluoride just published (W. Li *et al*, PRL 92, No. 8, 083002-1 [2004]).

# Outline

- Introduction – FEL R&D and The DUV-FEL
- The HGHG FEL and First user experiment

  1. HGHG Performance.

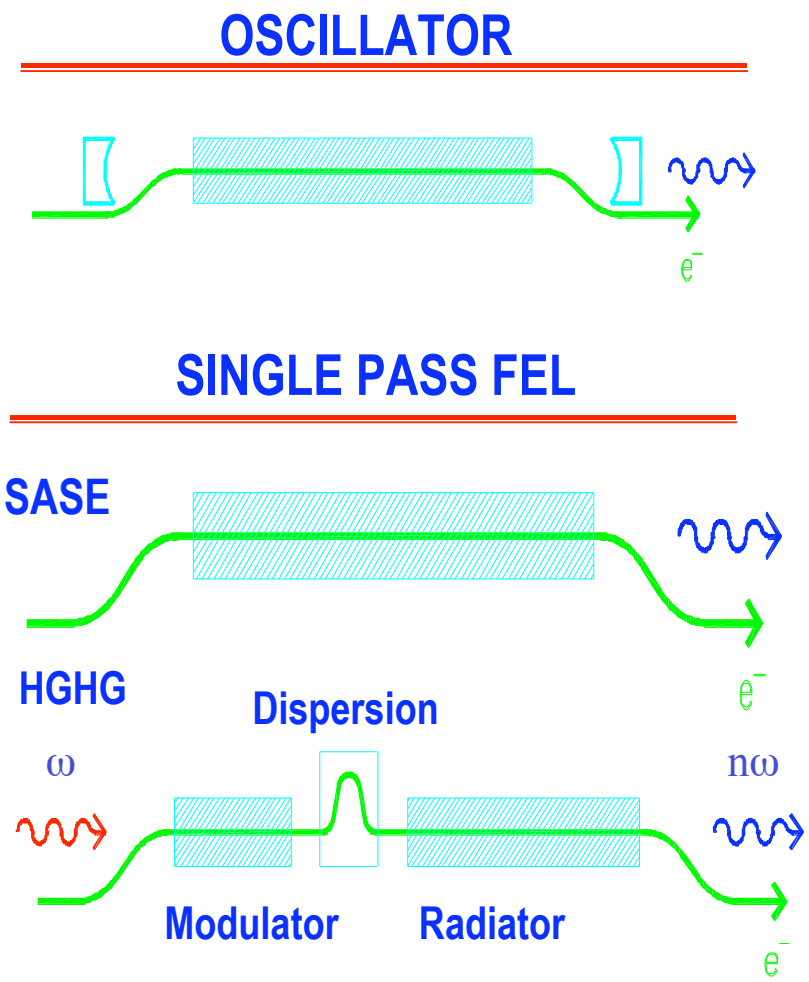
  2. Chemical science user experiment.

  3. Recent experimental results – FEL pulse length control, CPA HGHG, HGHG tuning et al

- Upgrade and Future FEL R&D
- Other ultra-fast R&D at the DUV-FEL:

  Coherent THz, Electro-optical bunch length detector, Laser Plasma X-ray source, and femto-second electron diffraction.
- Summary

# Free Electron Laser Configurations



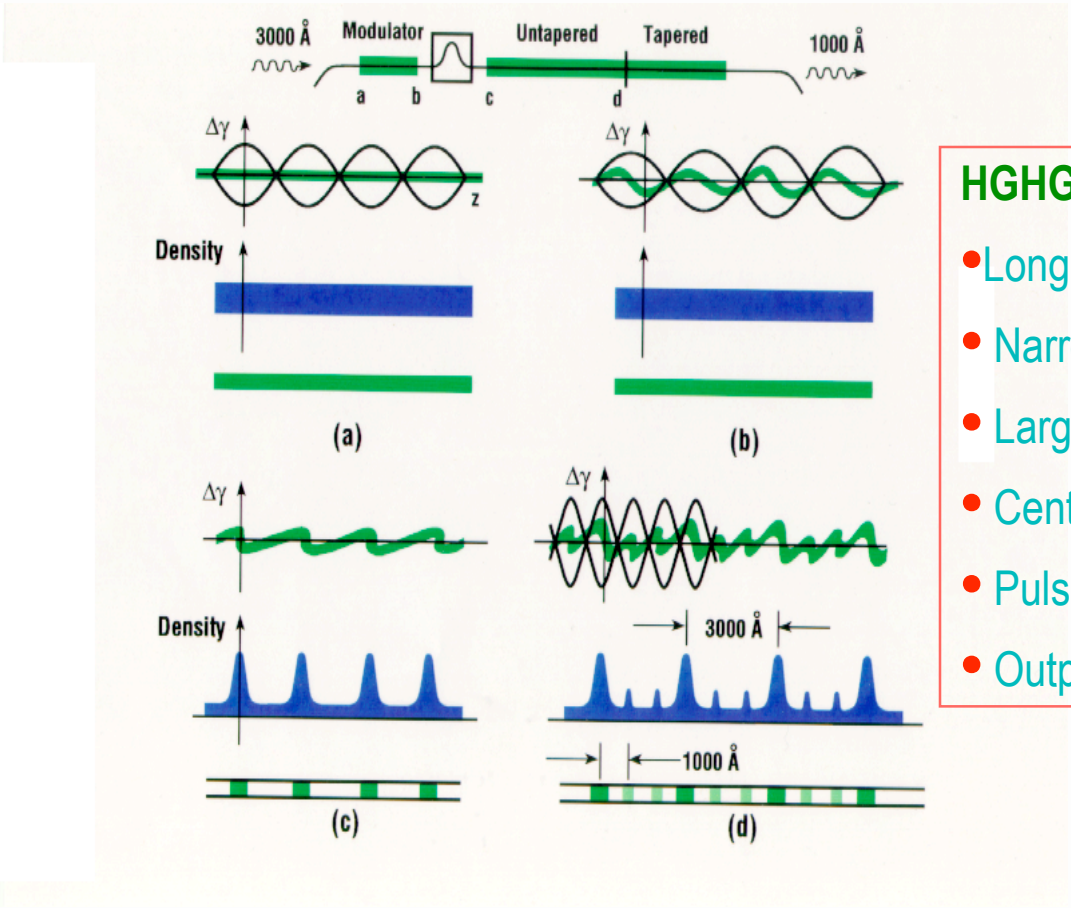

## Challenges:

1. Oscillator produces fully coherent output; but there is no High-quality mirrors in UV and X-ray range.

2. SASE output covers full spectrum, but it is only transverse coherent.

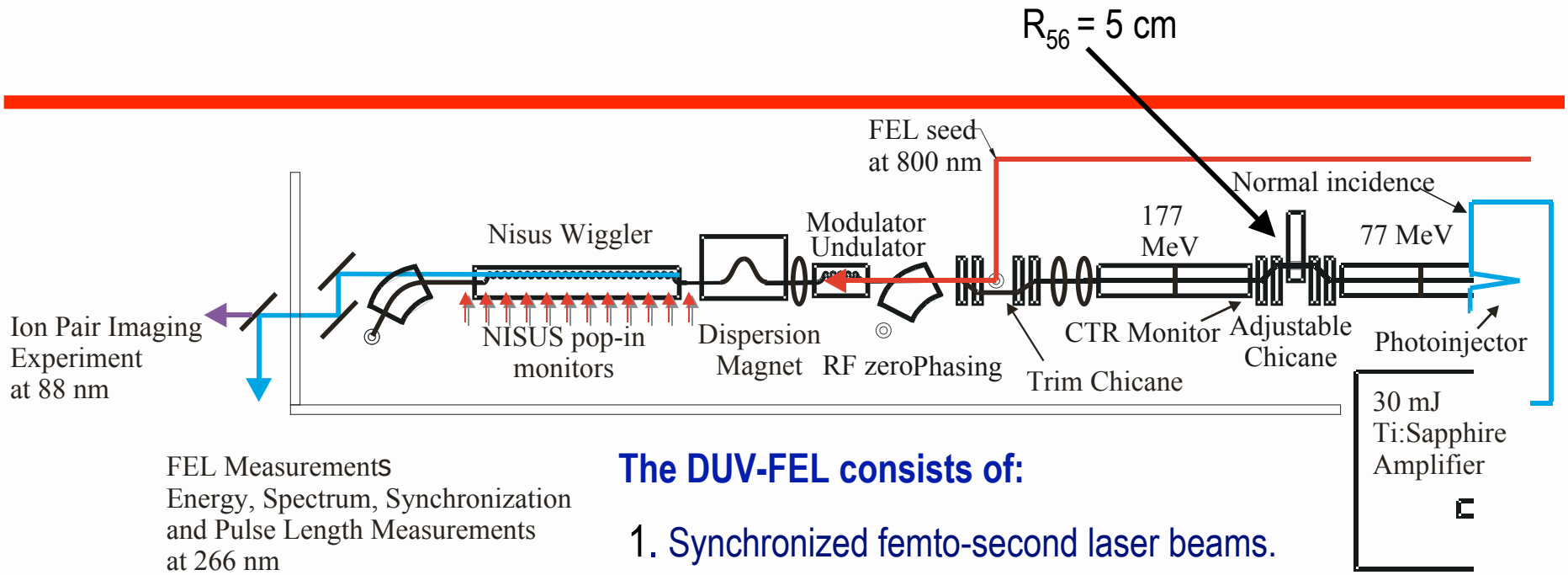
3. HGHG is capable of producing fully coherent output, seed laser limits its spectra coverage.

# High Gain Harmonic Generation (HGHG) Principle




**HGHG has the following advantages:**

- Longitudinally fully coherent
- Narrower bandwidth than SASE
- Larger ratio of output/spontaneous radiation
- Central wavelength is stable
- Pulse length is short & controllable (20 fs)
- Output fluctuations can be reduced




FEL Measurements
Energy, Spectrum, Synchronization
and Pulse Length Measurements
at 266 nm

**The DUV-FEL consists of:**

1. Synchronized femto-second laser beams.
2. High-Brightness femto-second electron beam.
3. 6-D electron beam diagnostics
4. Sophisticated optical instrumentations.
5. HGHG FEL
6. Chemical science user station.

# NISUS

DO NOT TOUCH OR LEAN ON
DO NOT TOUCH OR LEAN ON
HGHG Radiator - NISUS Undulator

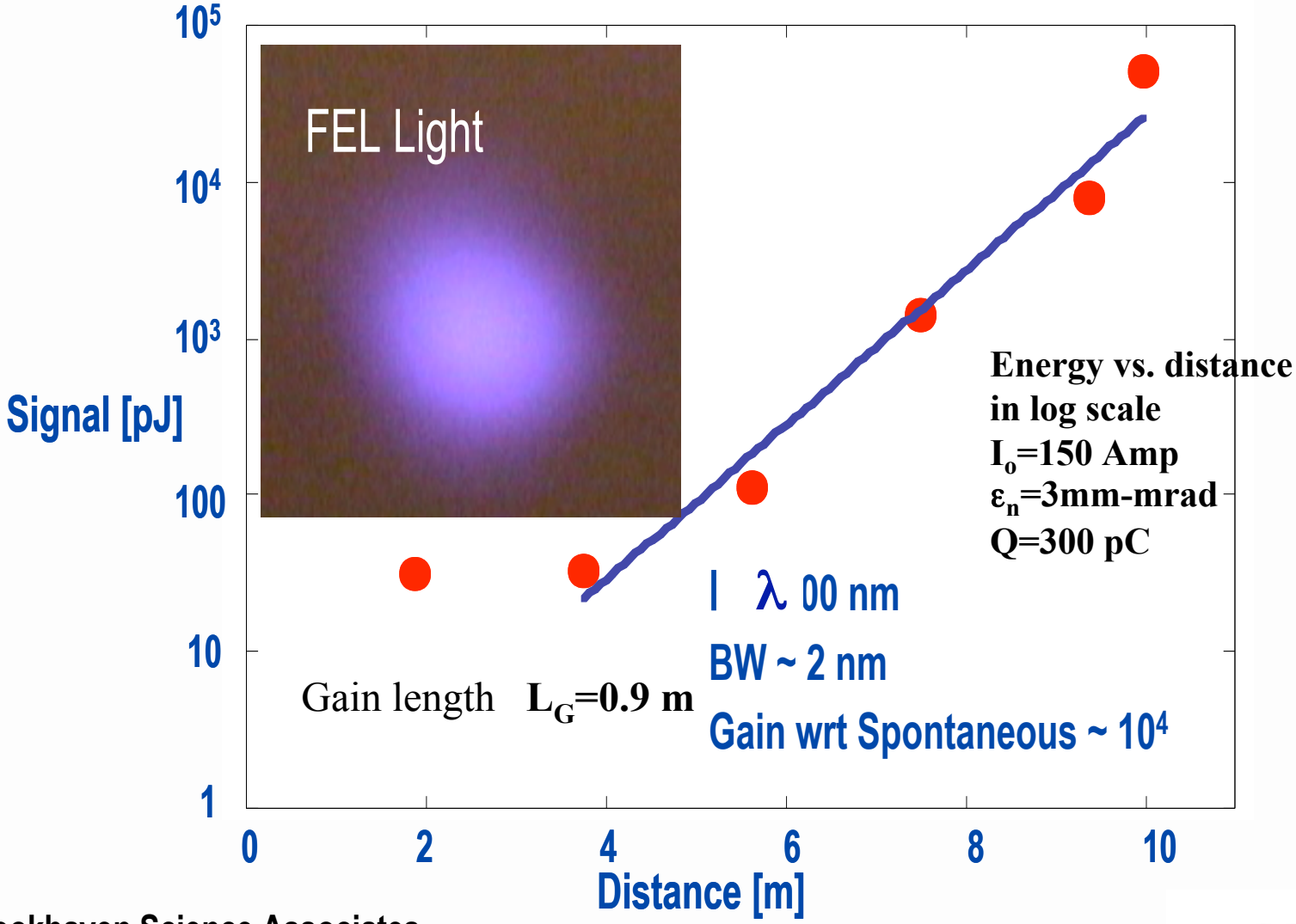
WT 1033 LBS
NUCLEAR LEAD CO. INC.
SDL - 505. 04 - 034 3A
DANGER
HGHG Seed Laser Table

DANGER

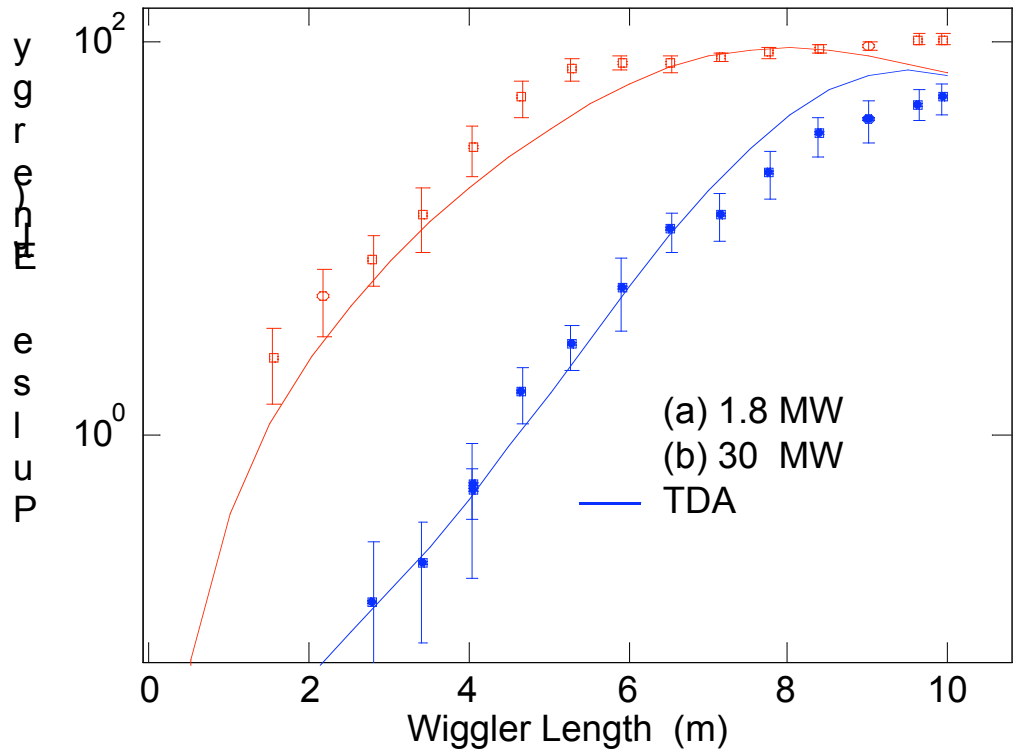
# HGHG FEL Performance

| | | | | |
|---|---|---|---|---|
| Electron Energy (MeV) | 174.5 | | Peak Current (A) | 300 |
| NISUS Period $\lambda_U$ (cm) | 8.0 | | NISUS length (m) | 10 |
| Seed laser $\lambda_S$ (nm) | 800 | | Seed laser pulse length ( FWHM) (ps) | 0.1 - 6 |
| **Energy/pulse at 266 nm (μJ)** | **100** | | **Energy/pulse at the 3rd harmonic 89 nm (μJ)** | **~ 1.0** |
| **HGHG pulse length (FWHM) (ps)** | **1 – 0.5** | | **HGHG spectrum width (%)** | **0.1** |
| **Spot size at 266 nm (rms, μm)** | **250** | | **Spot size at 89 nm (rms,μm)** | **150** |

# SASE Signal at DUV-FEL February 2002

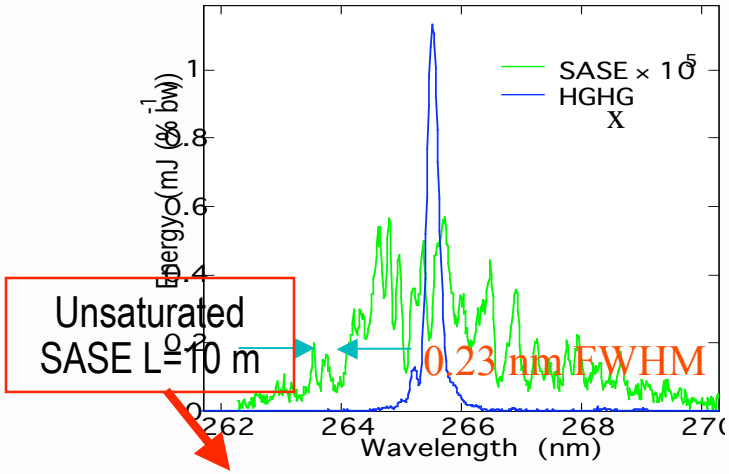


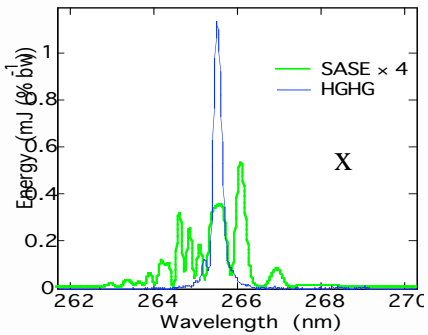
# 266 nm HGHG Power vs. Distance




Average output: 100 _J, 10% fluctuation

# Spectrum of HGHG and SASE at 266 nm

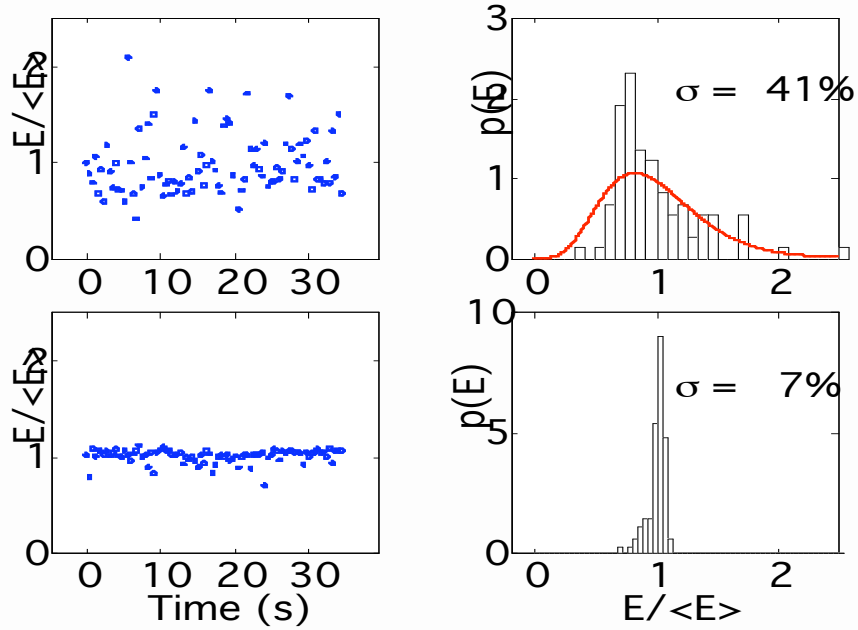


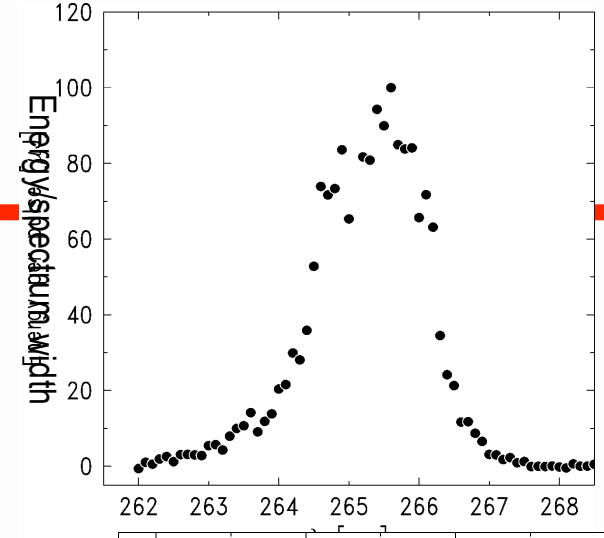

Saturated
SASE L=20 m

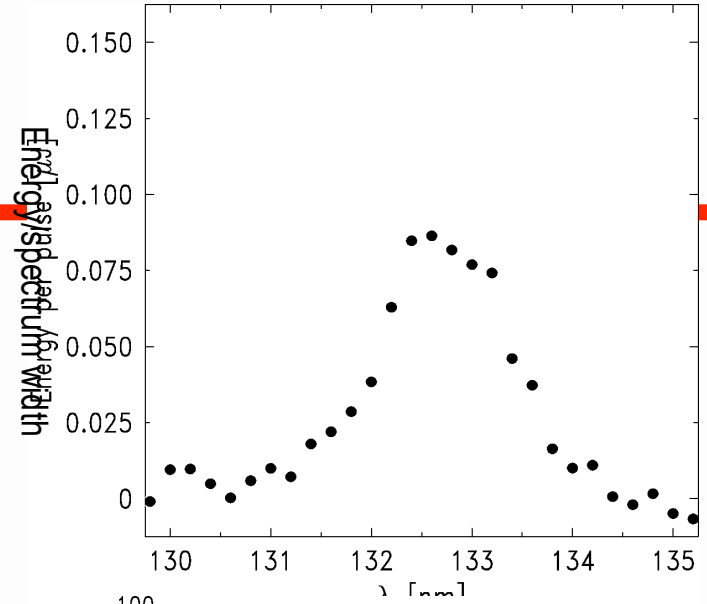
# Intensity Fluctuation of SASE and HGHG

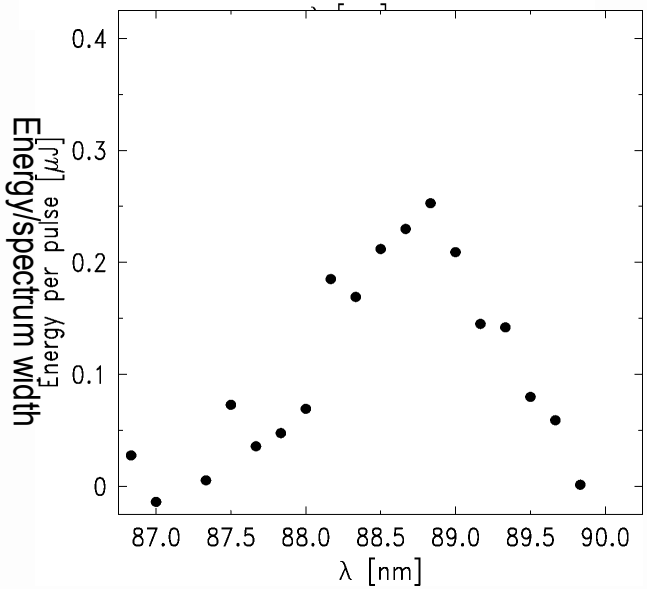
Unsaturated
SASE

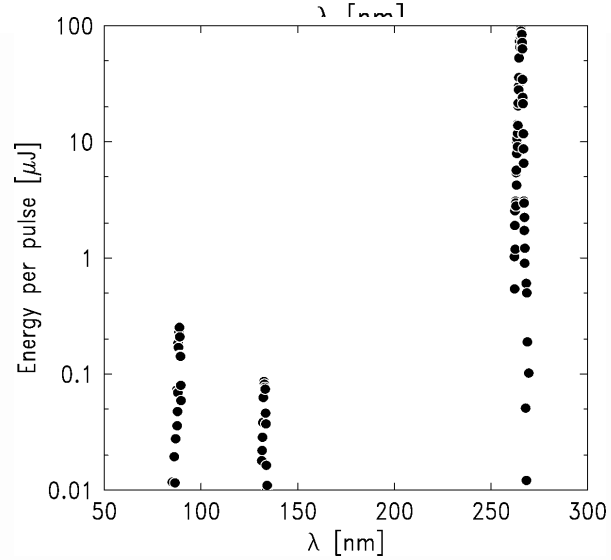



HGHG



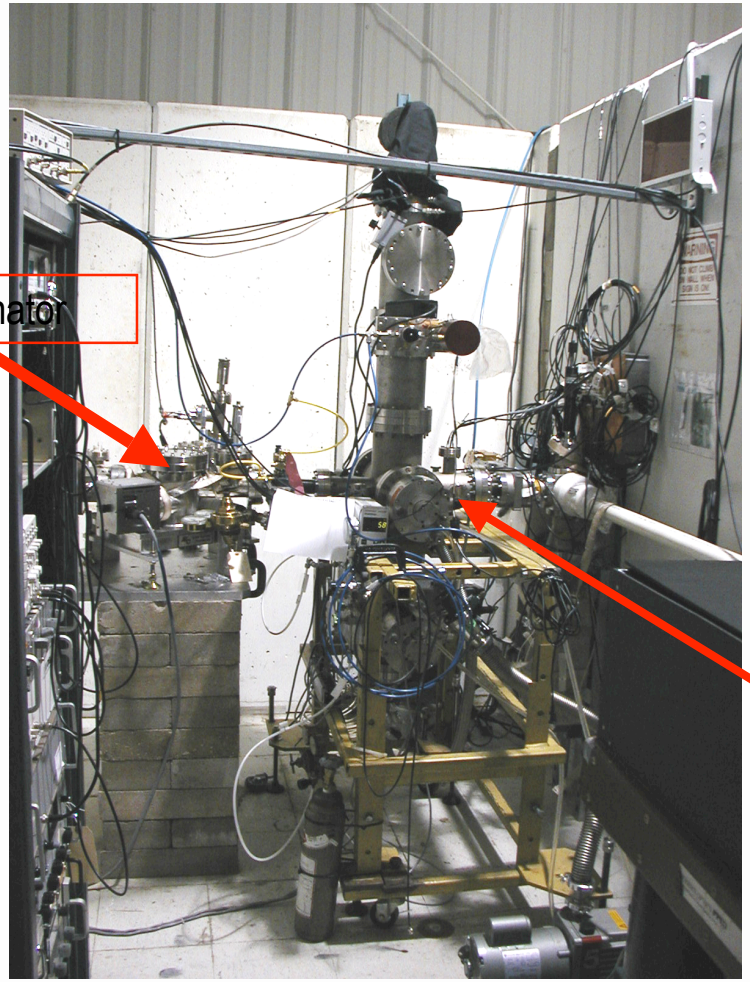



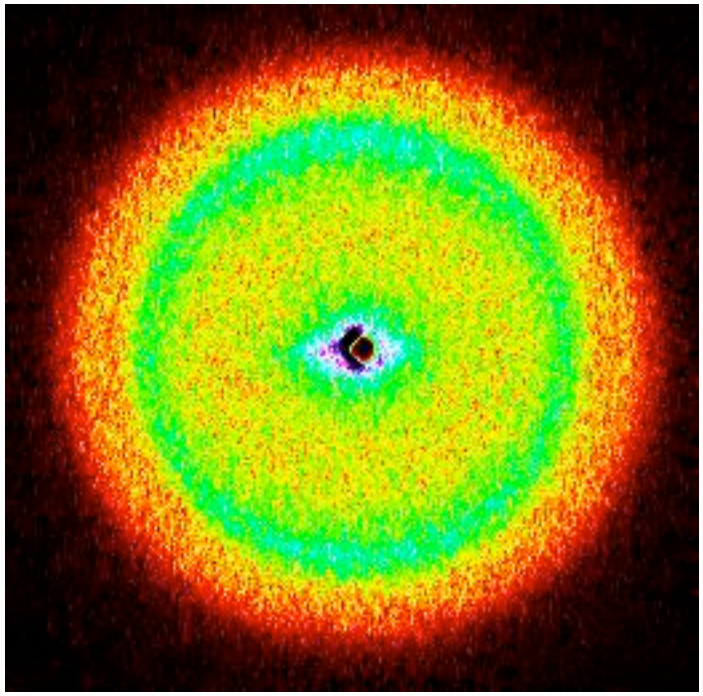



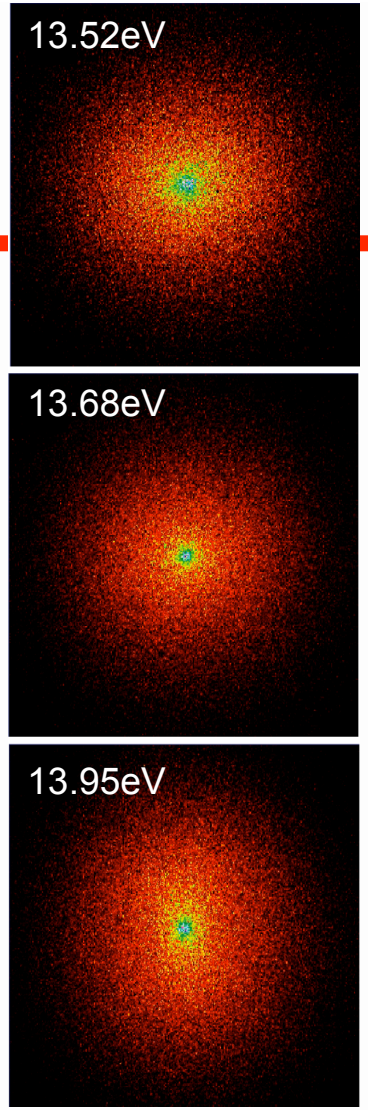



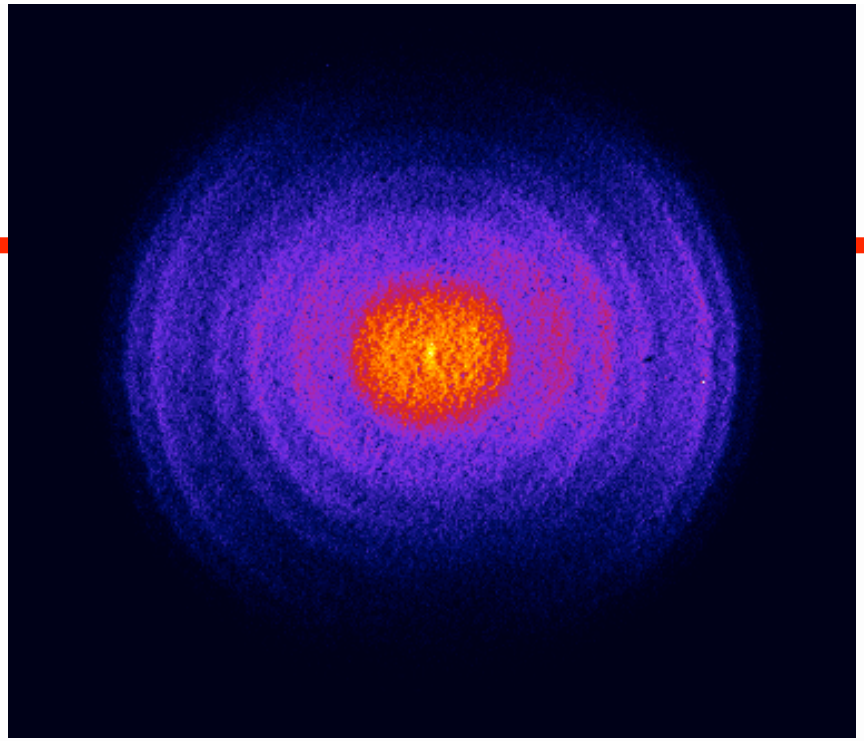

Scaled to 100 uJ for 266 nm, assumed mono has equal efficiency at 89 and 266 nm, and a factor of 2 greater at 133 nm.

# Installation of the first experiment – Dec, 2002





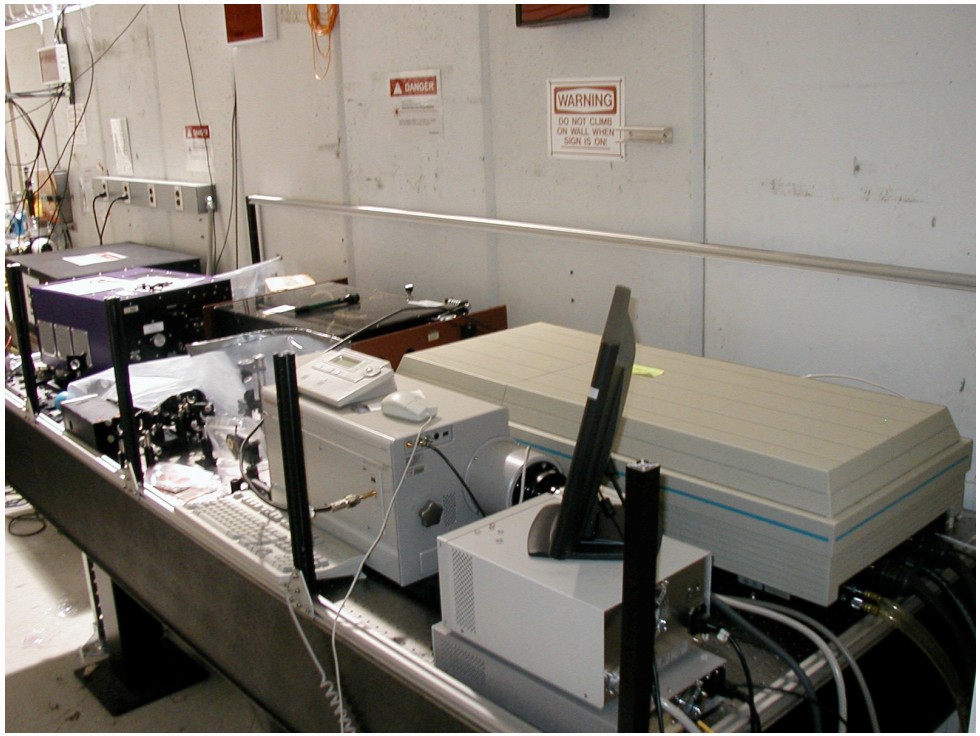



Photoelectron image shows photoionization of molecular oxygen at 13.92ev. Both kinetic energy and angular distribution are obtained. Different rings correspond to vibrational levels, which shows very strong non Franck-Condon feature. Data analysis is underway. Results could tell us the detail of quantum interchannel coupling of such system.

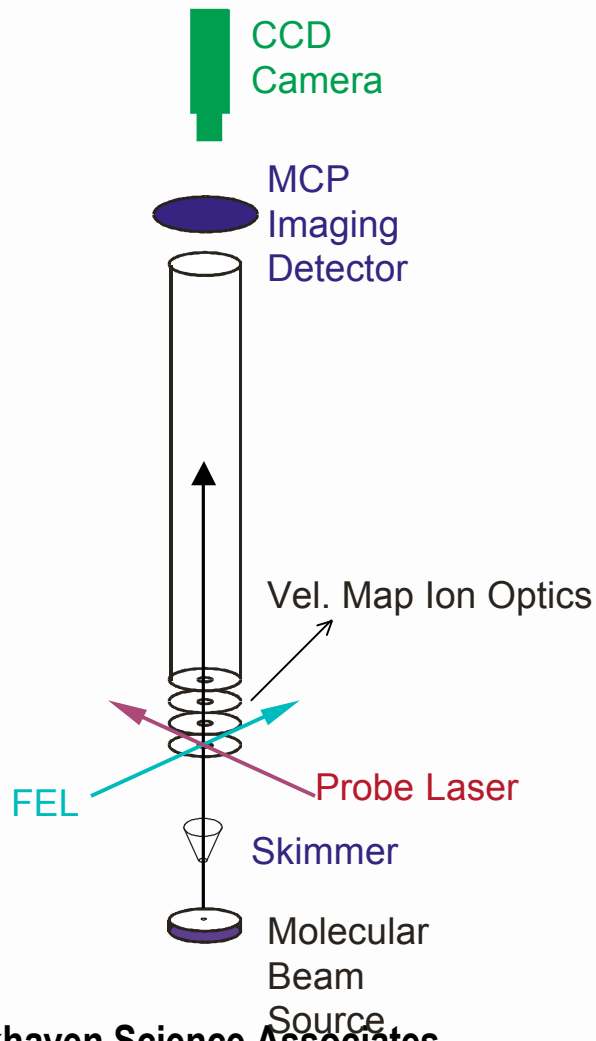
Images shows methyl fluoride ion pair dissociation at different photon energies. This study unravels the superexcited states decay dynamics.

# Photodissociation Dynamics

- Very little is known about product state distributions from deep VUV photodissociation of small molecules
- This information could help to characterize the excited states and their interactions with repulsive states
- Dissociation information particularly useful for studies of planetary atmospheres, including that of earth



# Experimental: Velocity Map Imaging




$$CO_2 \rightarrow CO + O$$

Dissociation by FEL (89 nm)

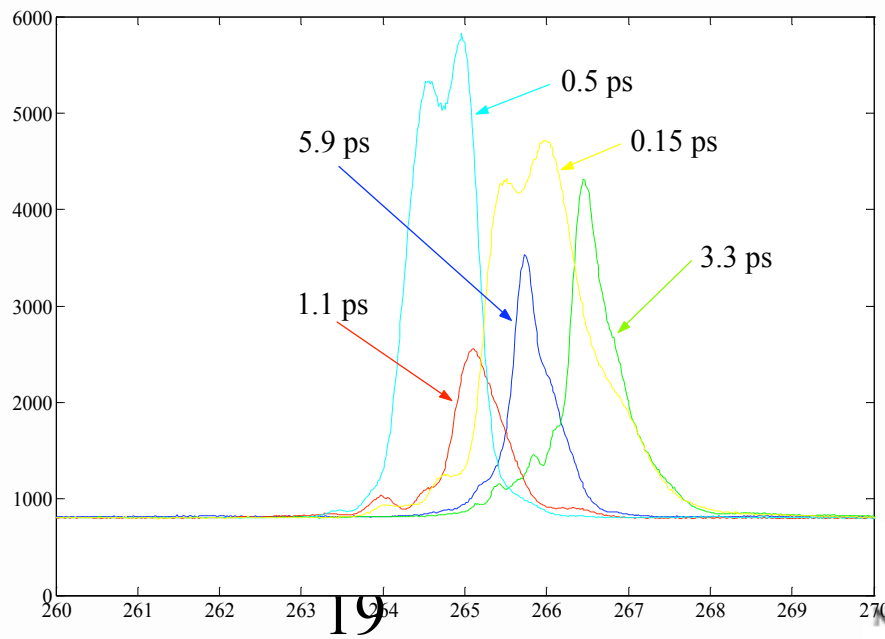
$$O \rightarrow O^+ + e^-$$

REMPI Ionization by Probe Laser

(203.7nm for $O(^1D)$)

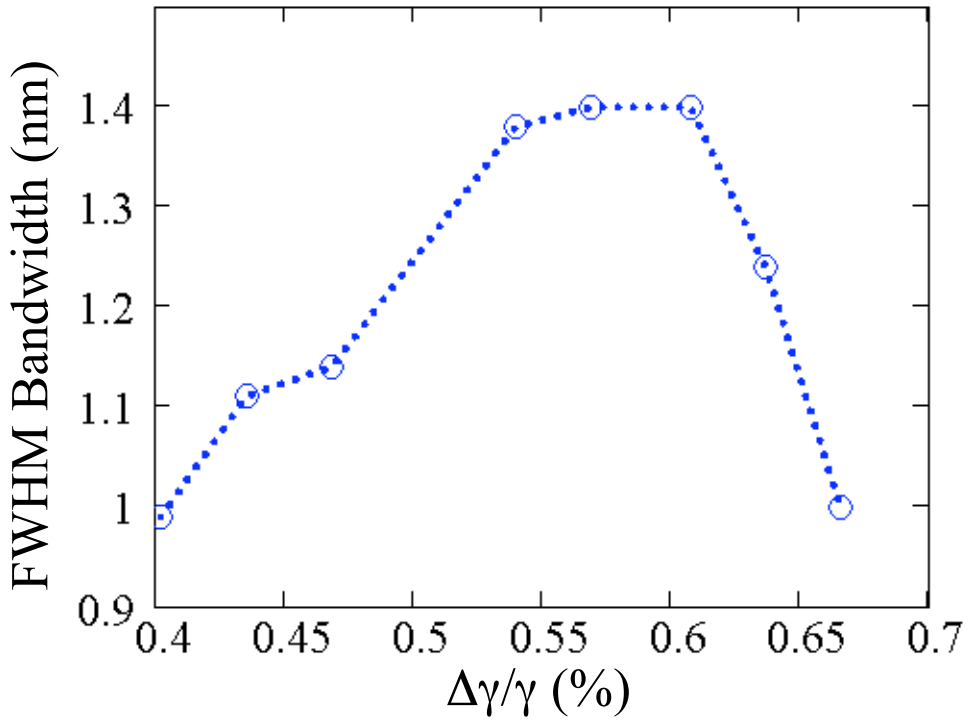
# Recent Results from DUV-FEL

**HGHG pulse length control by seed laser**

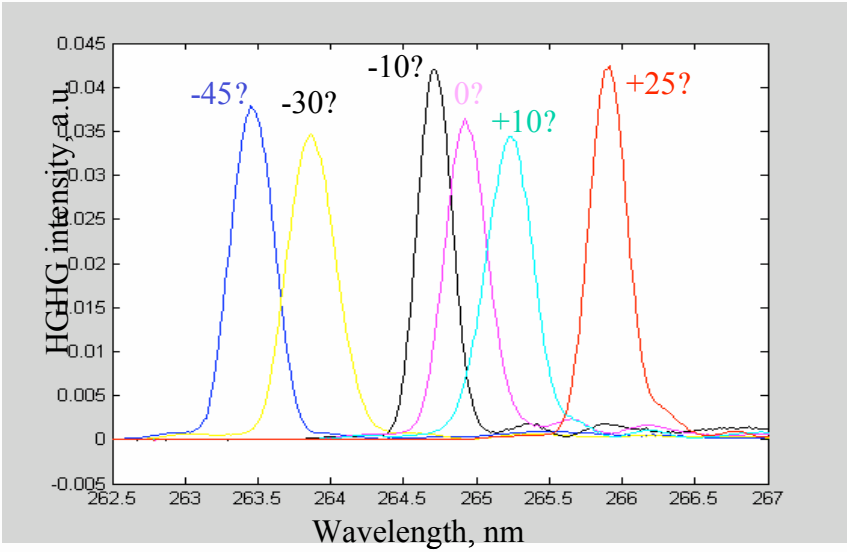


# Recent Results from DUV-FEL

## CPA HGHG




## HGHG tuning by e-beam energy chirp

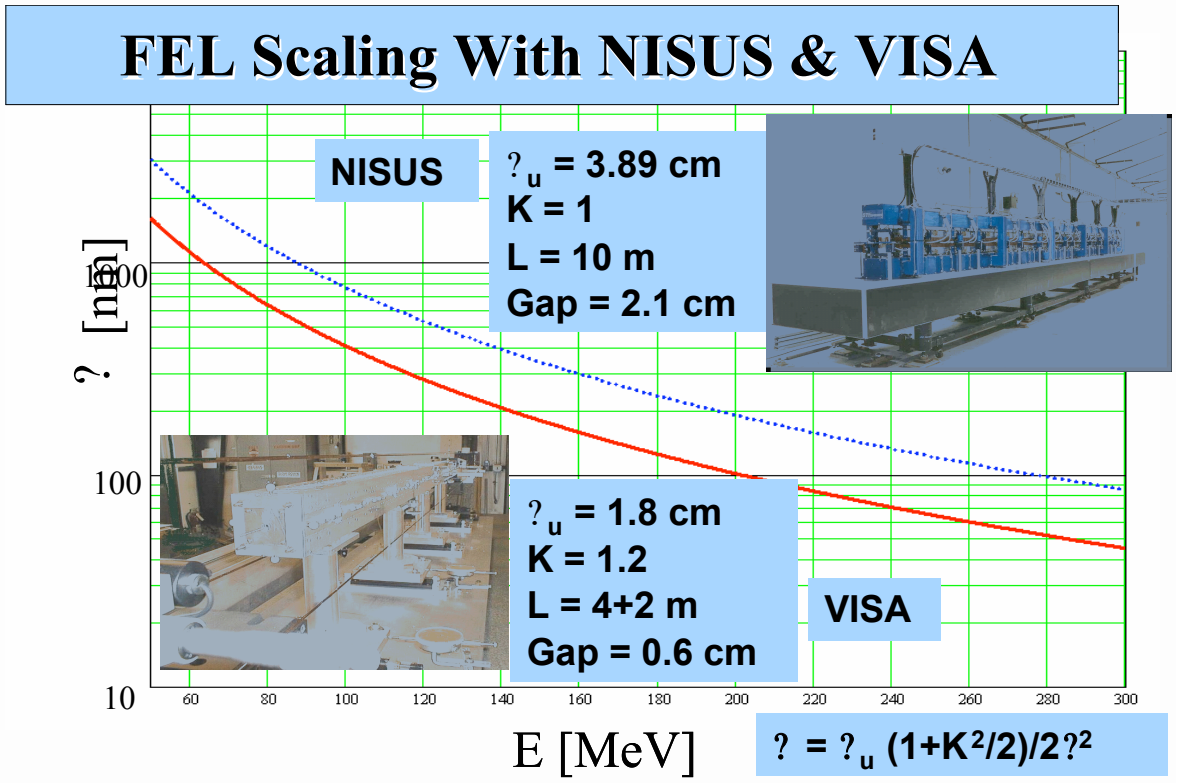


# DUV-FEL

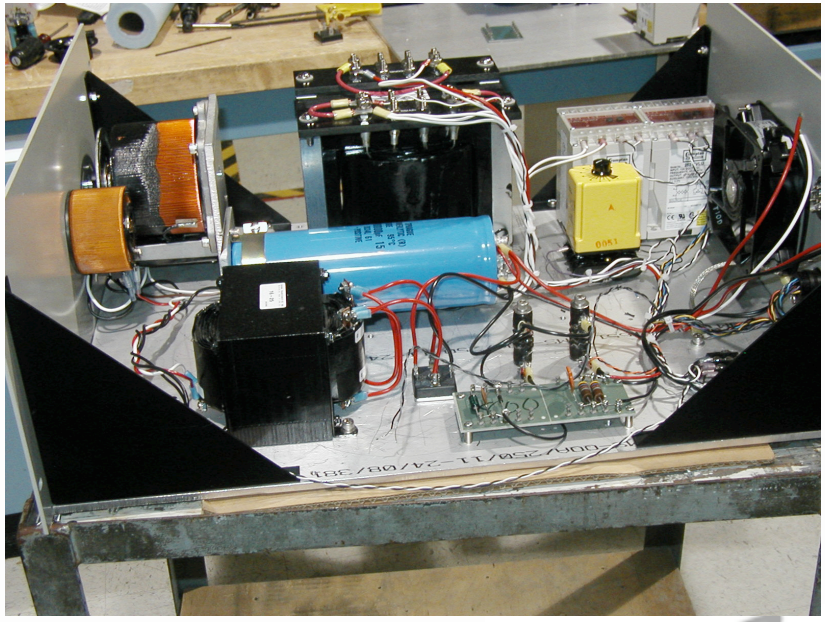
## A Fourth Generation Light Source User Facility

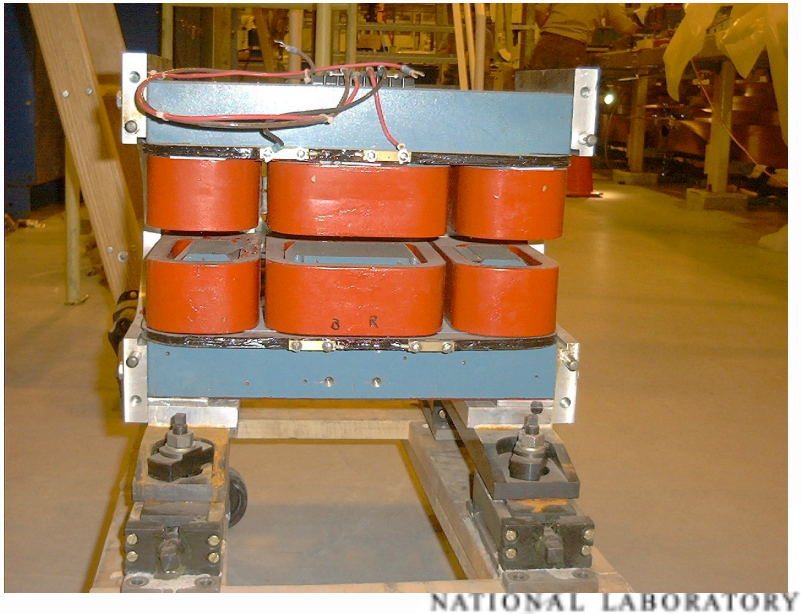
NSLS hosted a Chemical Science Workshop last July. Consensus reached is that, **a 100 nm 100 uJ** DUV-FEL will be a truly unique UV light source in the world, and will open new opportunities in:

1. Gas phase chemical dynamics
2. Nonlinear atomic and surface physics.
3. Quantum control.
4. Single molecule detection
5. Nano-science
6. Many others




$? = ?_u (1+K^2/2)/2?^2$





# Performance of The DUV-FEL

**Present**

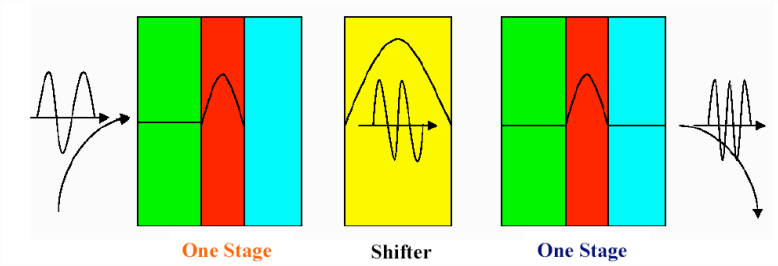
| | |
|---|---|
| Energy (MeV) | 200 |
| Charge (pC) | 300 |
| Normalized emittance(mm-mrad) | 4 |
| $R_{56}$(cm) | 5 |
| Compressed bunch length, RMS (ps) | 0.3-0.6 |
| Energy spread, RMS (%) | 0.3 |
| $\lambda_U$ (cm) | 3.89 |
| $\lambda_M$ (cm) | 8 |
| $R_{56}$ (HGHG, mm) | 0.35 |
| Seed laser (nm) | 800 |
| HGHG Wavelength | 266 nm |
| HGHG Output | 100 $\mu$J |

**Expected**

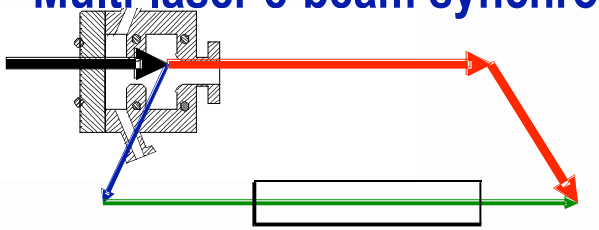
| | |
|---|---|
| Energy (MeV) | 300 |
| Charge (pC) | 500 |
| Normalized emittance(mm-mrad) | < 4 |
| $R_{56}$(cm) | 5 |
| Compressed bunch length, RMS (ps) | 0.3-0.6 |
| Energy spread, RMS (%) | 0.3 |
| $\lambda_U$ (cm) | 3.89 |
| $\lambda_M$ (cm) | 8 |
| $R_{56}$ (HGHG, mm) | 4.2 ? |
| Seed laser (nm) | 800,400 |
| HGHG Wavelength | 100 nm |
| HGHG Output | 100 $\mu$J |

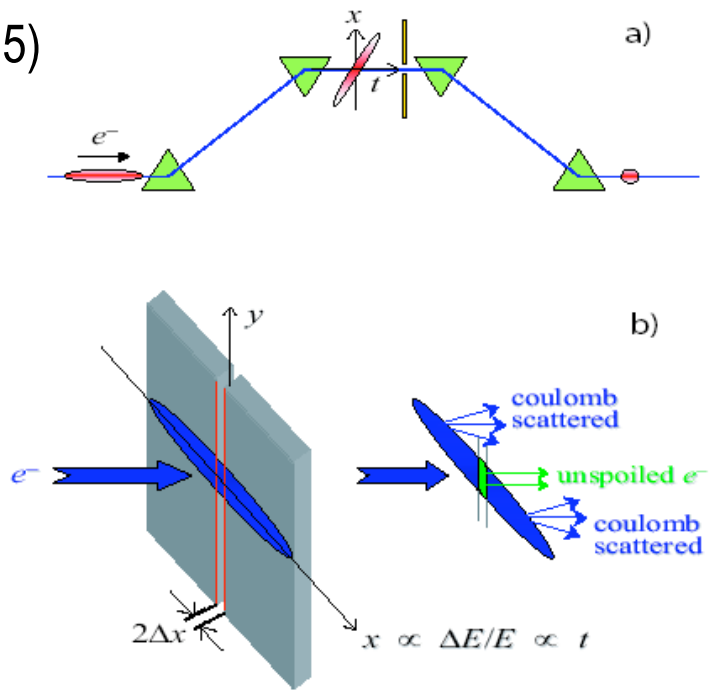
# FEL and Accelerator R&D at the DUV-FEL

- FEL R&D: cascaded HGHG; high harmonic HGHG (n>5)



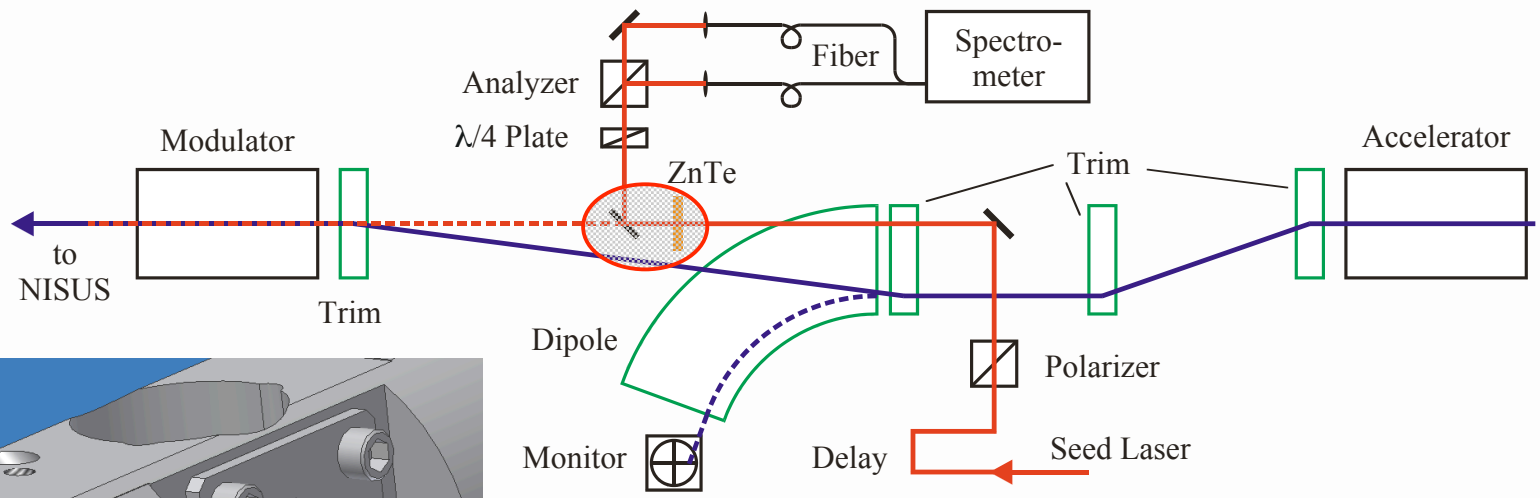

- Accelerator Physics R&D: emittance optimization by programmable laser control; beam physics during compression; femto-second E-O bunchlength detector; coherent THz generation; **Multi-laser e-beam synchronization.**

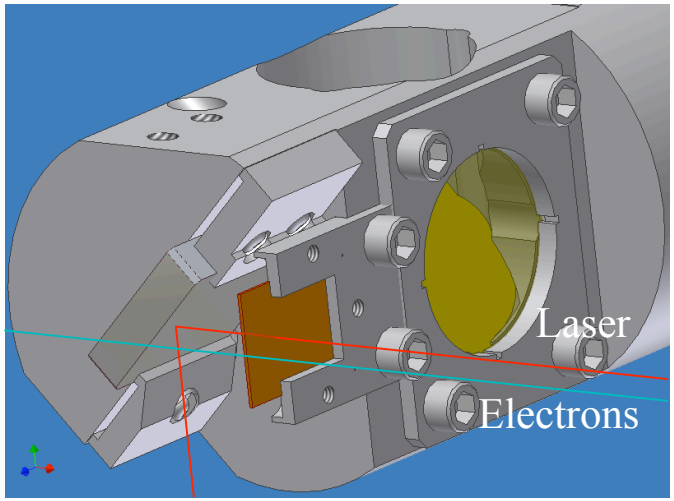





**Emittance spoiler**

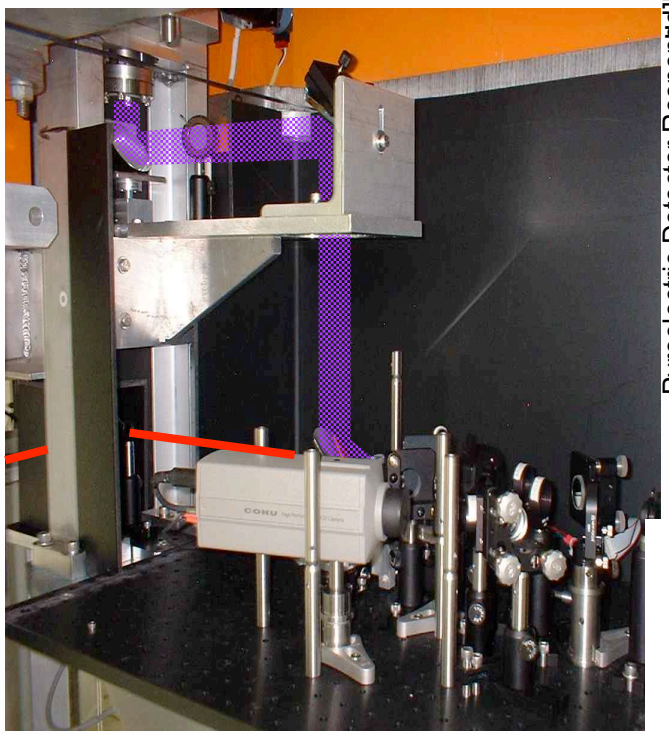
# Electro-optic Detector at the DUV-FEL

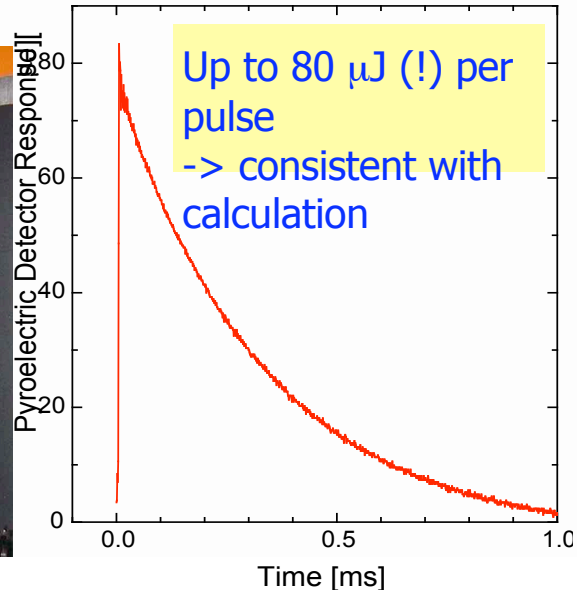


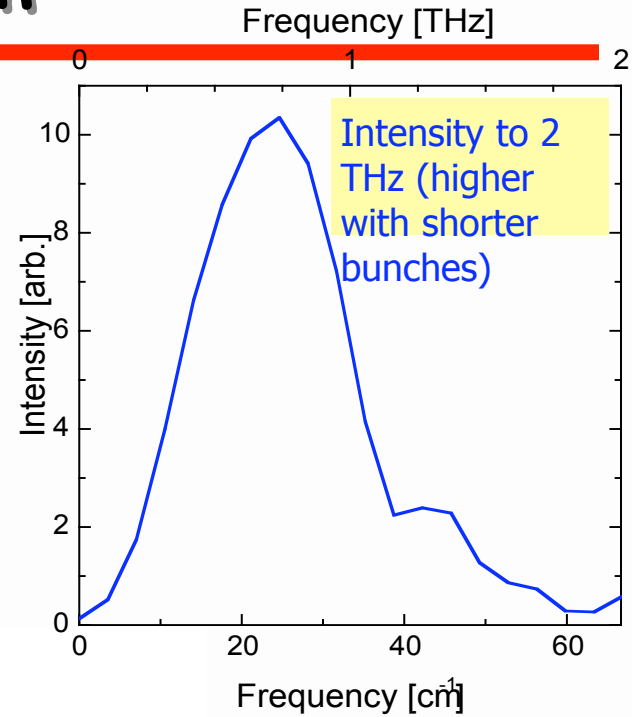



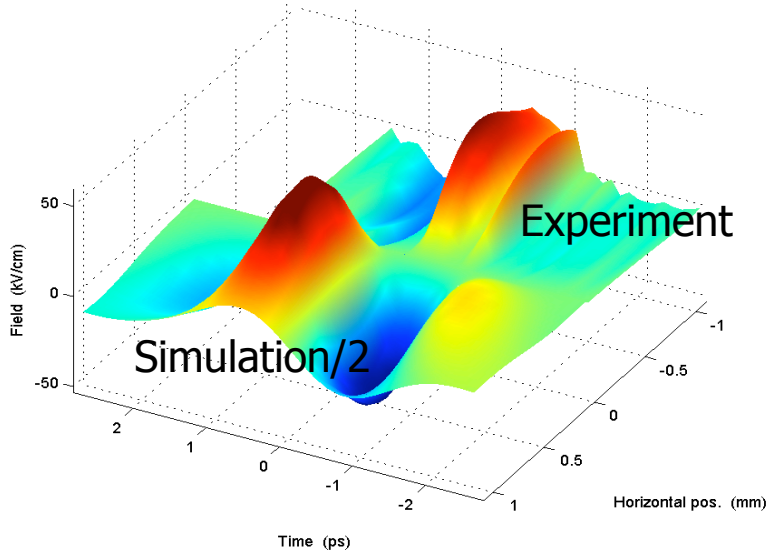

- **Temporal resolution 800 fs.**
- **Jitter within 20 seconds of 150 fs rms.**

# Coherent THz Generation and Characterization





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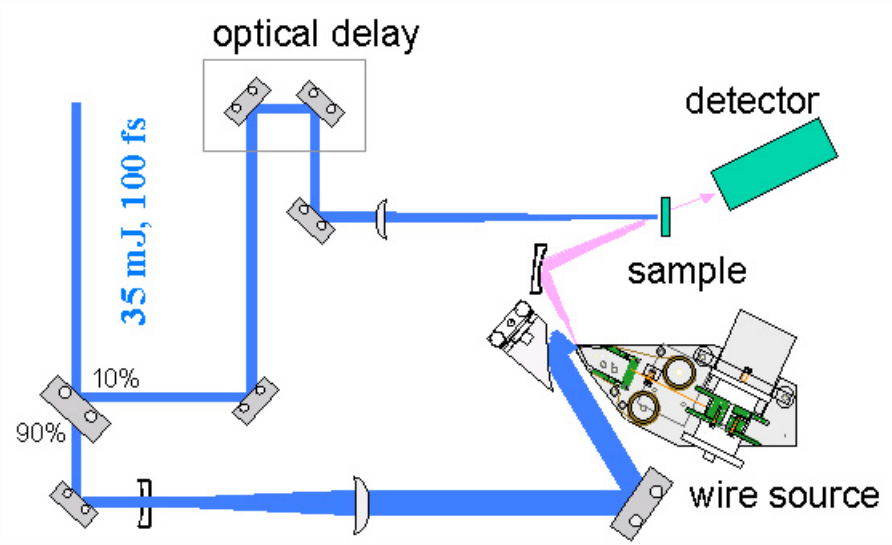
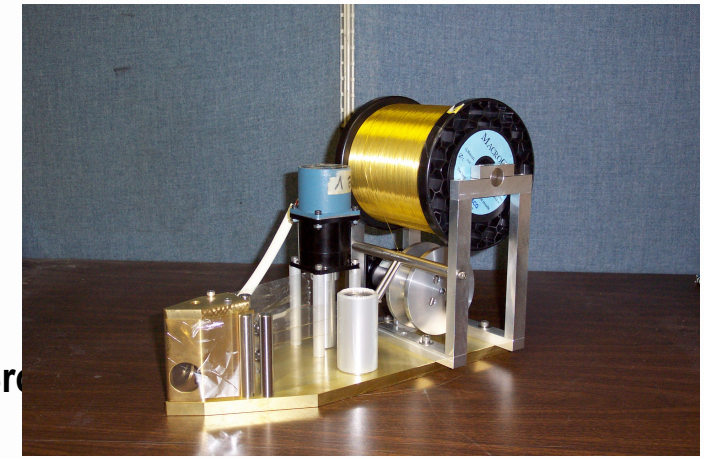
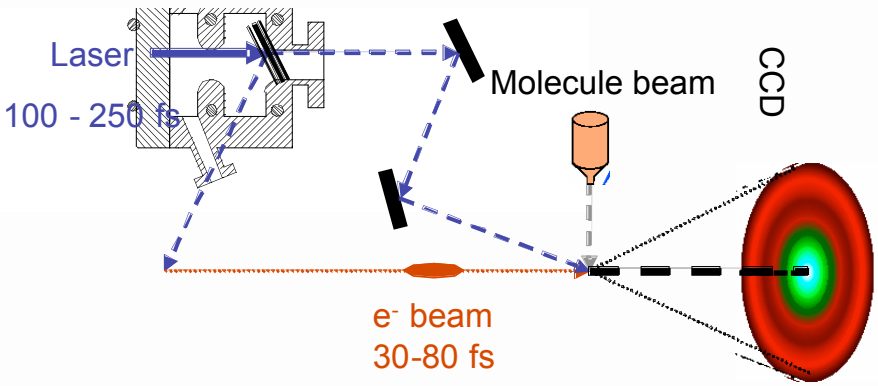
# Ultrafast Sources R&D at the NSLS

## Ultrafast Laser-driven Plasma X-ray Source



## Femto-second Electron Diffraction




BNL RF gun



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# Summary

Tremendous progress was made in DUV-FEL in the last couple years. The operation of the DUV-FEL facility in the last 12 months shows that, **it is ready to provide beam for users if funding for its operation is available.**

We are on the way of upgrading DUV-FEL to 300 MeV and reach 100 nm for DUV-FEL.

The support from BNL director office, NSLS and dedicated staff made all successes possible.

Thank You!