ICFA 17TH ADVANCED BEAM DYNAMICS WORKSHOP ON
FUTURE LIGHT SOURCES

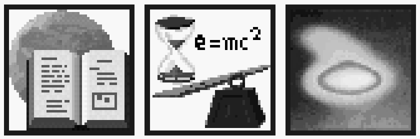
Advanced Photon Source
Conference Center
Argonne National Laboratory
Argonne, Illinois U.S.A.
April 6-9, 1999

THE DEMANDS OF FOURTH GENERATION UV SOURCES AND SCIENCE

Erik D. Johnson
Group Leader NSLS Experimental Systems Group
Project Manager Deep UV Free Electron Laser

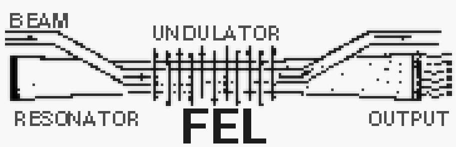
BROOKHAVEN NATIONAL LABORATORY

FEL Virtual Library



http://sbfel3.ucsb.edu/www/vl_fel.html

Free Electron Laser



The World Wide Web Virtual Library: Free Electron Laser research and applications.

Maintained by: G. Ramian (ramian@sbfel3.ucsb.edu)

TESLA FEL

A VUV Free Electron Laser at the TESLA Test Facility at DESY

Example Scientific Applications:

- Microscopy
- Single and Multiphoton Excitation Dynamics of Atoms and Ions
- Clusters and Radicals
- Reaction and Relaxation Dynamics in Photochemistry and Surface Science
- High Resolution Photoelectron Spectroscopy of Excited Solids
- Magnetic Materials and Dichroism
- Interaction of Electron Pulses from the TTF with Condensed Matter

http://www-mpy.desy.de/fel/conceptual_design_report/cdr-welcome.html

Essential characteristics of new sources

Review of requirements for atomic physics, chemical, biological, and materials sciences suggests need for

- Broad range of wavelengths
- High intensity, high duty factor
- Transform limited bandwidth
- Short pulses
- High stability
- Low harmonic content

DUV-FEL Research Opportunities

UV-VUV Photochemical Research

Fundamental problems addressed by direct excitation

Quantum Control

Fundamental study of energy transfer and distribution in chemical reactions

Non Linear Optics at Short Wavelengths

Fundamental test of Atom-Laser Interactions in high frequency region

FEL Technology Development

Fundamental contributions to pursuit of ‘Fourth Generation Light Sources’

Quantum Control

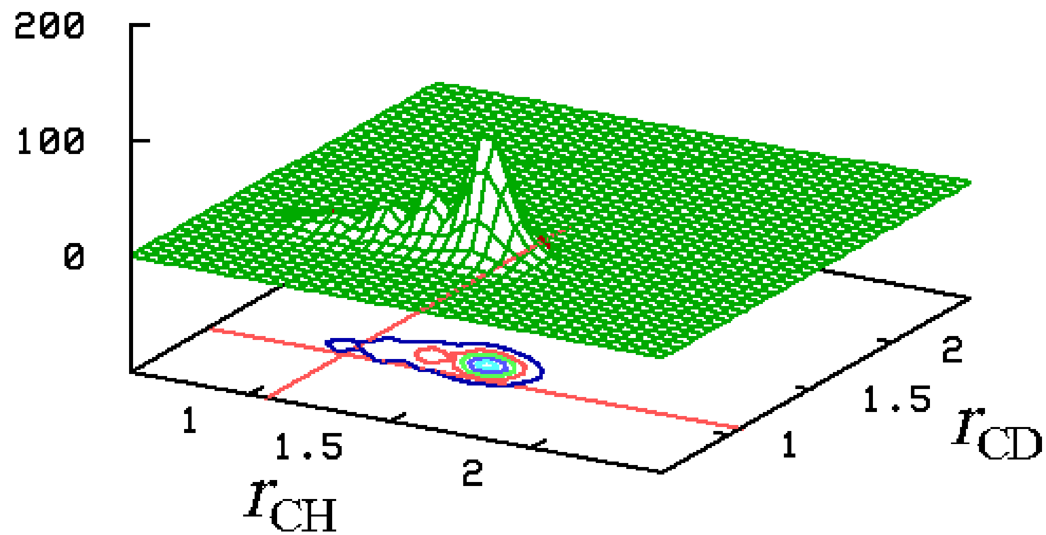
Study of energy transfer and distribution in chemical reactions

Manipulate Intramolecular Vibrational Energy-Redistribution Bottleneck

Enhanced Selectivity

Control of Reaction Pathways

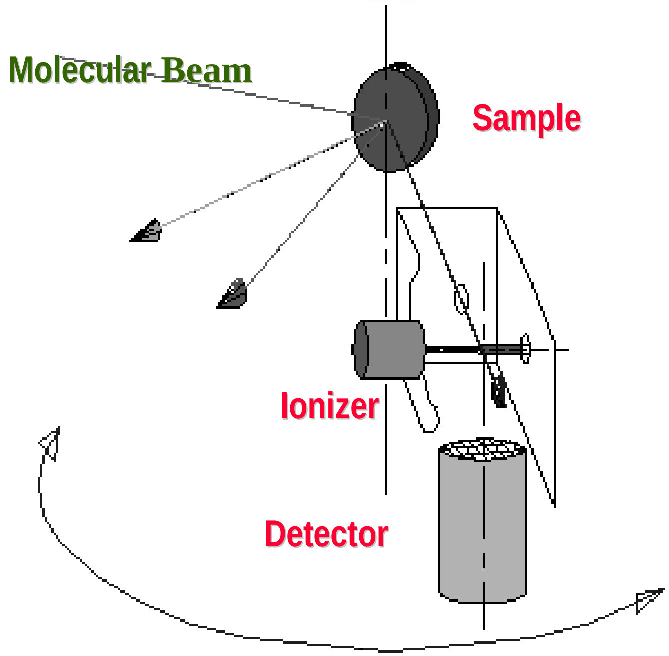
Bond lengths in HCCD 76 fs after excitation by 3186 cm^{-1} light. Muckerman *et al* show localization of excitation in the CH stretch. 2495 cm^{-1} light would excite CD stretch. DUV-FEL would provide probe light to produce parent ion at threshold.



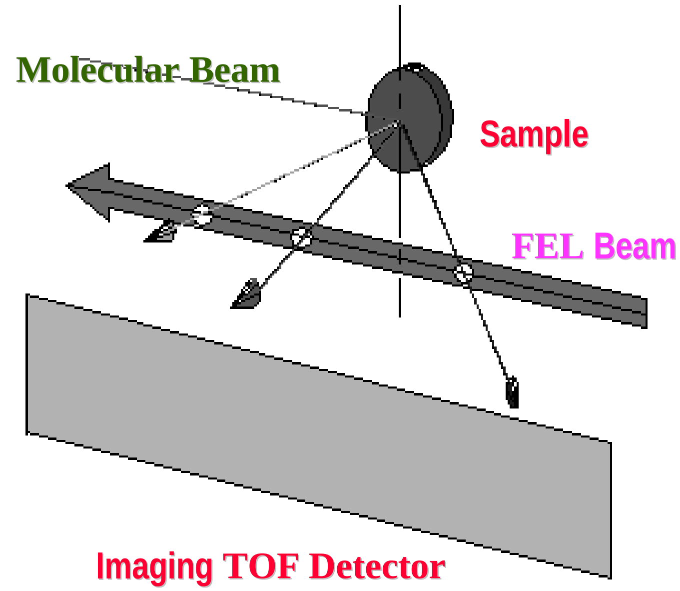
UV-VUV Photochemical Research:

Reactive Molecular Beam Scattering

Conventional Apparatus



FEL as State Selective Detector



Potential Gains to be had from:

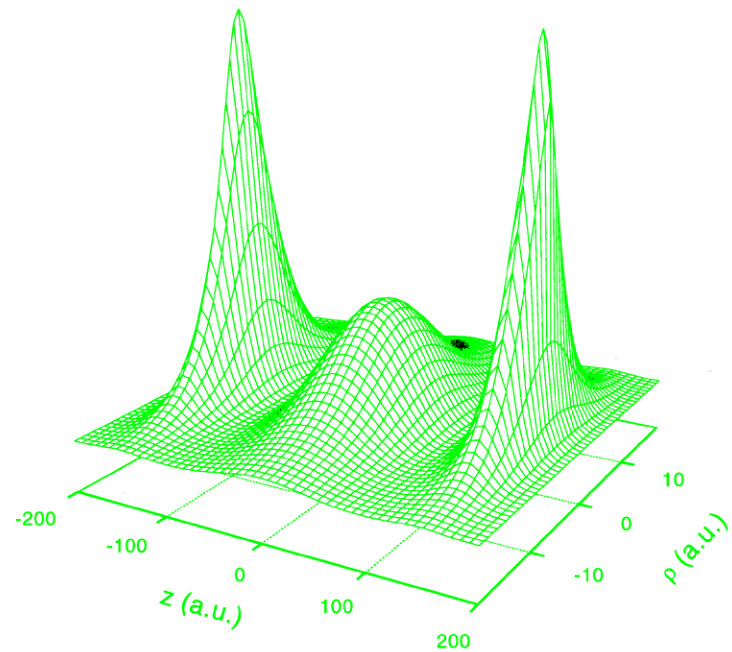
- Multi-beam detection
- Cold Background
- High Ionization Efficiency
- Proximity to Sample

Typical Experimental Parameters:

- Gain in Sensitivity ~ ***2500***
- **Neglecting benefits of State Selectivity!**

Non-Linear Optics at Short Wavelengths:
Atom-Laser Interactions in High Frequency Fields

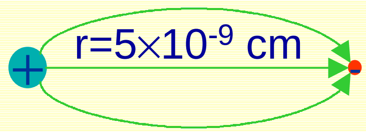
- Short Wavelength Metrology
- Atomic Stabilization
- Non-linear inner shell processes
- Coherent Transient Phenomena



Three electron wavefunction of H^{2-} in a linearly polarized laser field (Ernst van Duijn)

GAUGING THE INTERACTION

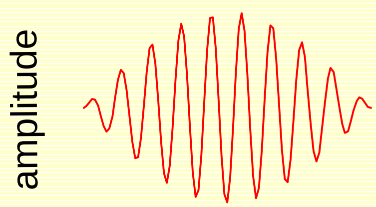
HYDROGEN ATOM IN GROUND STATE



Coulomb Law

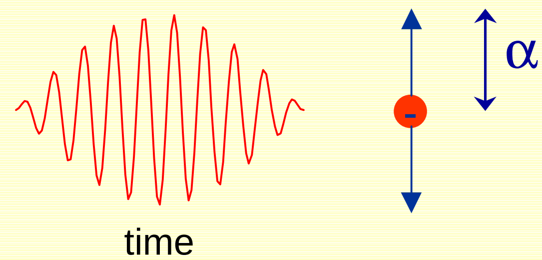
$E = q/r^2 \sim 5\times10^9$ V/cm $\equiv$ 1 au

What laser intensity ⇒ au field strength?



$$I_p = \frac{\varepsilon_o}{2} c E_p^2 \equiv 3\times10^{16} \, W/cm^2$$

MOTION OF A FREE ELECTRON



Displacement:

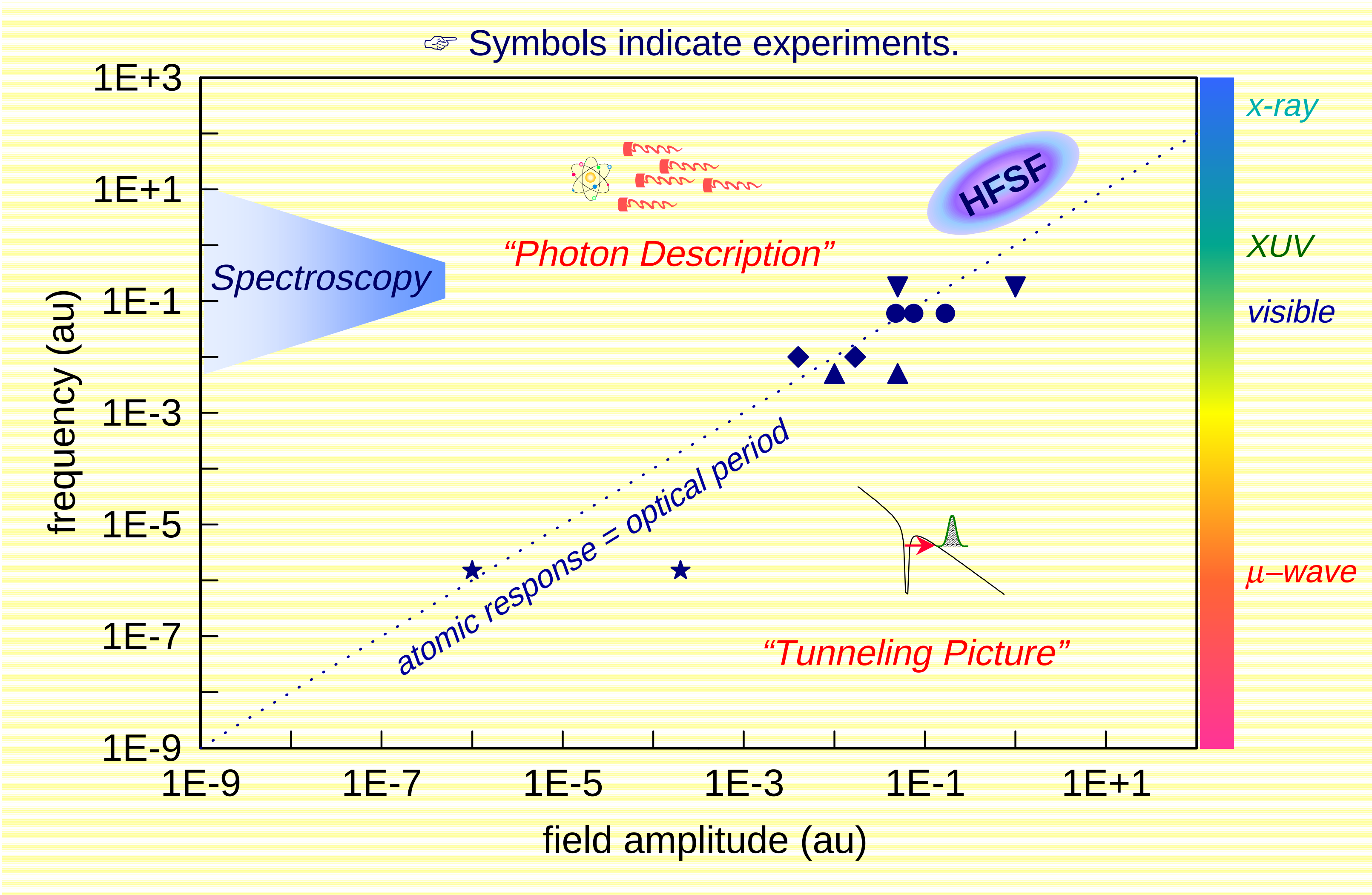
$$\alpha = E/\omega^2$$

✷ For 800 nm (red) laser at 10^{16} W/cm^2

$\alpha \sim 500$ au (250 A)

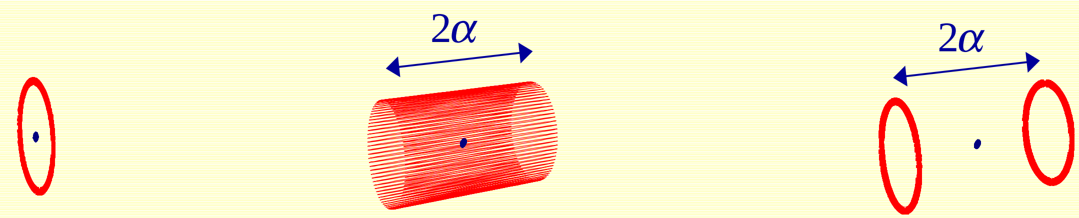
Courtesy L.F. DiMauro

MAP OF STRONG-FIELD PHYSICS

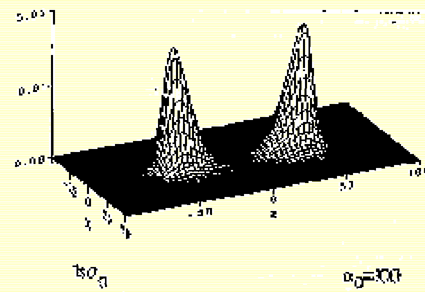


Courtesy L.F. DiMauro

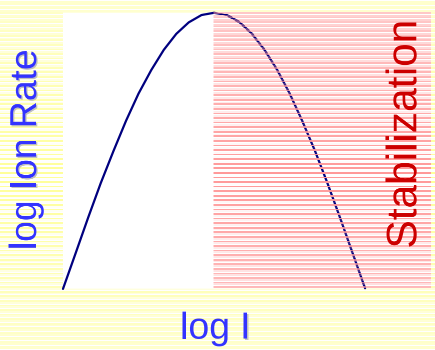
STRONG FIELD PHYSICS IN THE HIGH FREQUENCY LIMIT



- Conditions:
  $\omega_{laser} >> \omega_{atom}$
  $\gamma >> 1$ MPI
  $\alpha >> 1$ high intensity
- Wave function dichotomy



Pont & Gavrila, PRL **65**, 2362 (1990)



What would you see in an experiment?

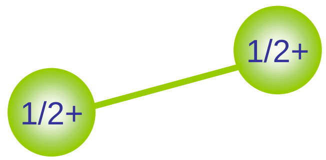
✝ *Many technical difficulties* !!

Courtesy L.F. DiMauro

PHYSICAL IMPLICATIONS OF THE DICHOTOMY

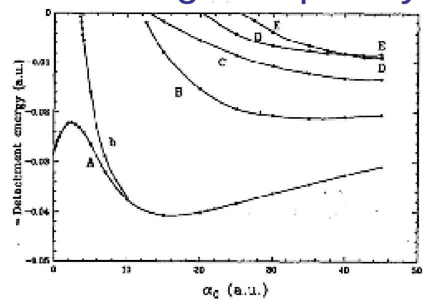
☞ "New" Field-Induced Atomic States

✓ Molecular-like potential induced by the dichotomy



In electron's rest frame the effective potential looks molecular.

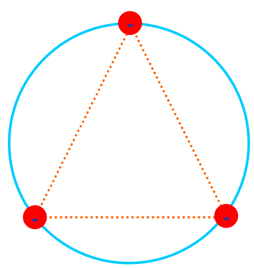
H^- at high frequency



✎ Muller and Gavrila, PRL **71**, 1693 (1993).

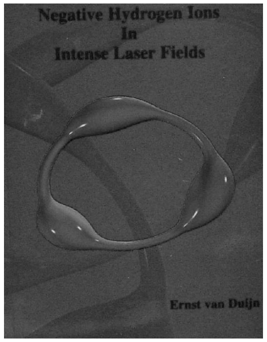
☞ "New" Forms of Matter

✓Binding of 3 or more electrons to a proton



H^{2-} in CP HF-field

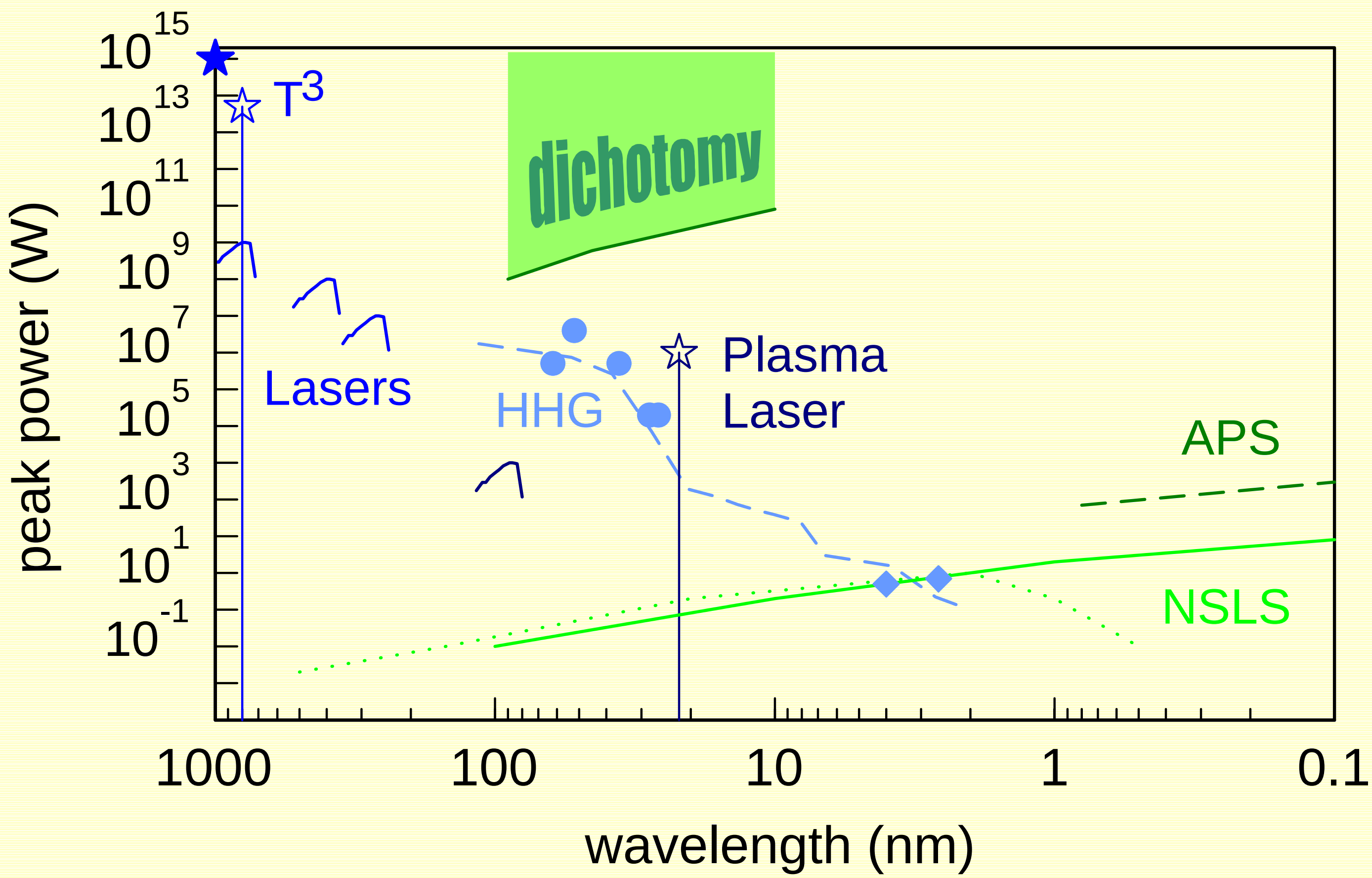
✎ E. van Duijn et al., PRL **77**, 3759 (1996).



FOM thesis

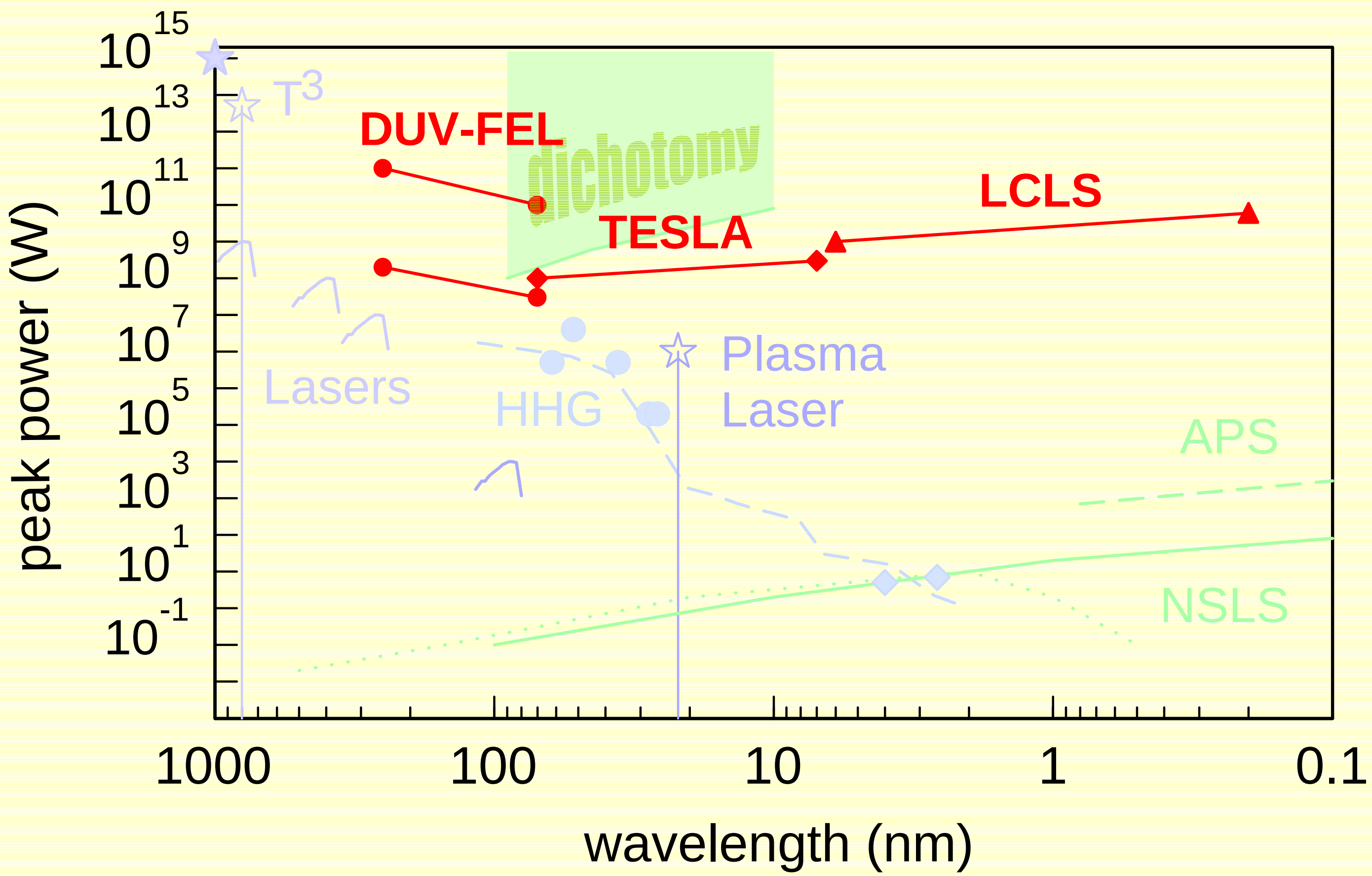
Courtesy L.F. DiMauro

PROSPECTS IN FOURTH GENERATION SOURCES



Courtesy L.F. DiMauro

PROSPECTS IN FOURTH GENERATION SOURCES



Courtesy L.F. DiMauro

Essential characteristics of new sources

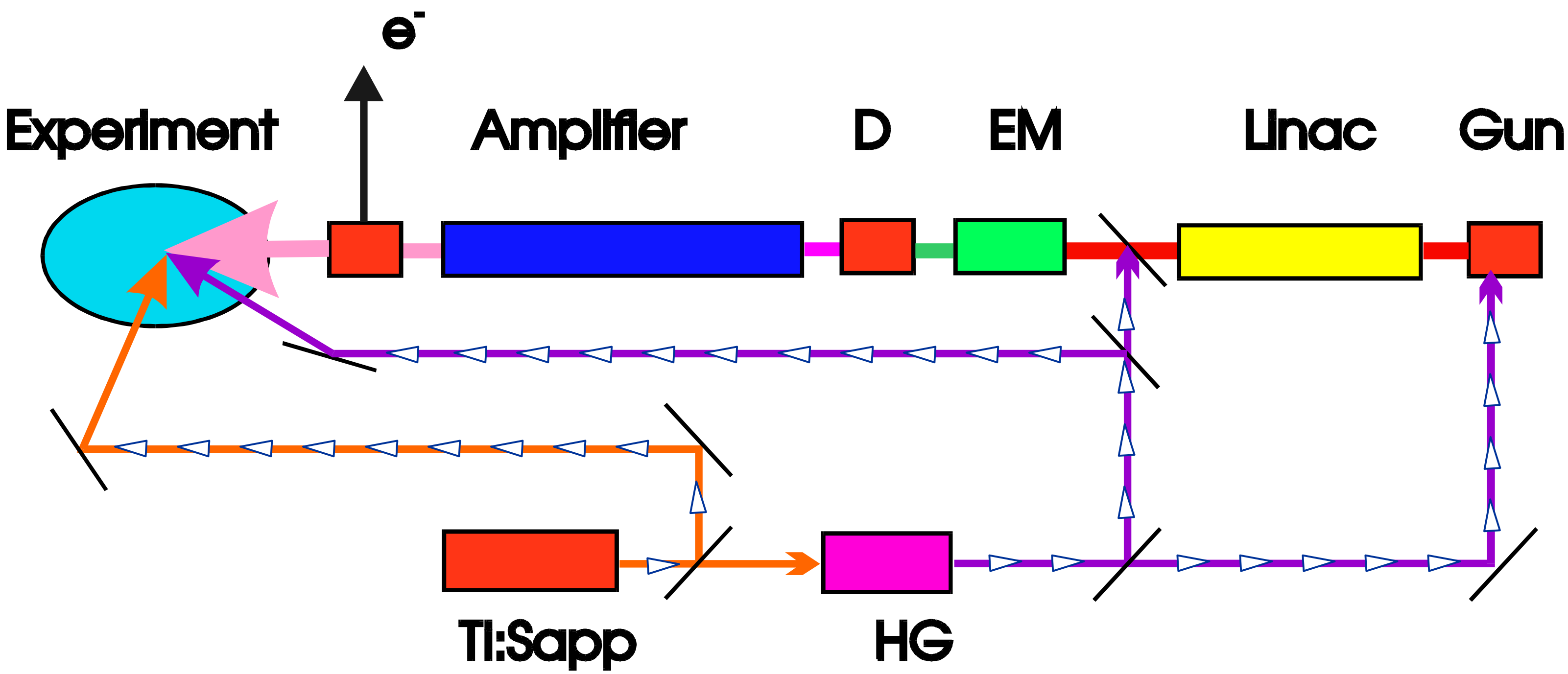
Review of requirements for atomic physics, chemical, biological, and materials sciences suggests need for

- Broad range of wavelengths
- High intensity, high duty factor
- Transform limited bandwidth
- Short pulses
- High stability
- Low harmonic content

Implications for a technology roadmap

- Sources will be lasers, accelerators, or a combination of the two.
- Technologies requiring development include:
  - Increased brightness electron guns
  - Improved electron beam diagnostics
  - E-beam bunch compression
  - Improved insertion device technology
  - Emittance control through entire system
  - Improved light metrology
  - Suite of enhanced laser/nlo technologies

The BNL Seeded Beam FEL



With Seeded Beam and High Gain Harmonic Generation:
THE PROPERTIES OF A LASER
WITH THE REACH OF AN ACCELERATOR

For the DUV-FEL:

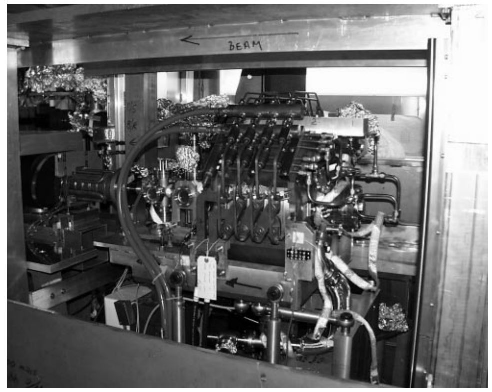
- Wavelengths down to 50 nm
- Pulse Lengths down to 4 fs
- Multi-color Experiments

Foundation technology for useful x-ray Free Electron Lasers

DUV-FEL well suited to:

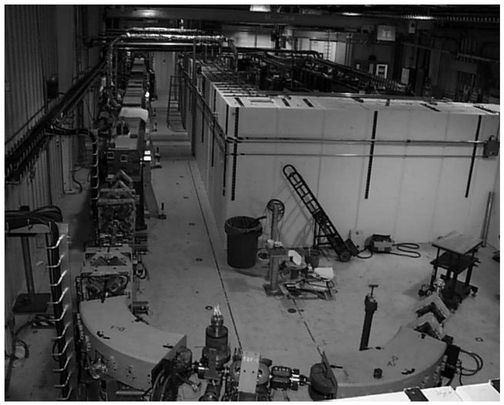
- **Dilute Samples**
  - Gas Phase
  - Surface Adsorbates
  - Transient Species (Radicals &c)
- **Resonant Processes**
  - Threshold spectroscopies
  - Excited States
- **Time Dependant Phenomena**
  - Relaxation and Excitation Processes
  - Coherent Control of Quantum Dynamics
- **Pump-Probe Capabilities**
  - Natural Extension of Seeded Beam Design

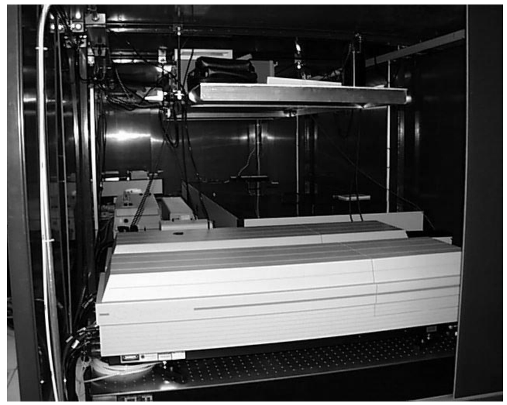
Recent Photographs at the DUV-FEL



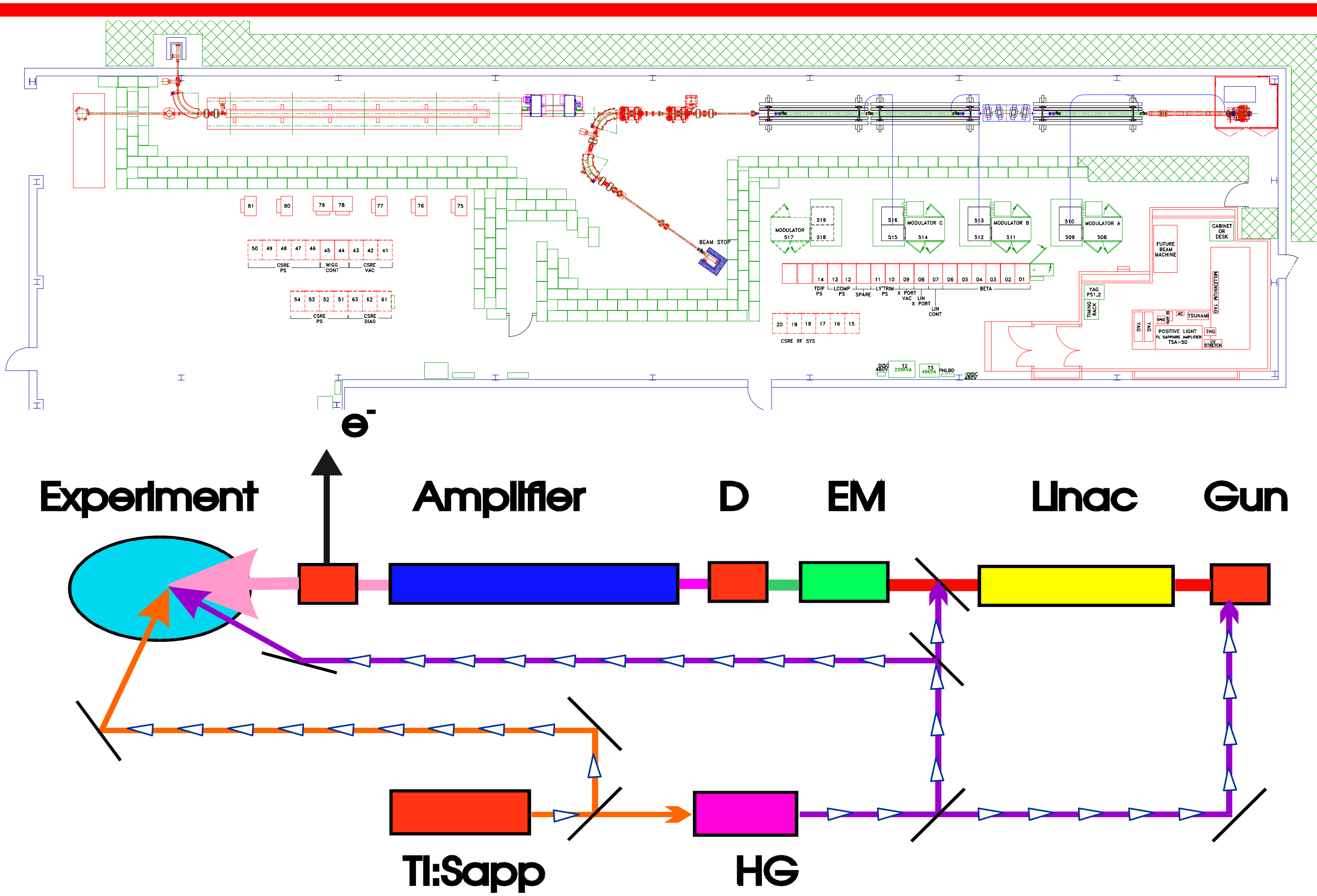
Linac Under Test | Pulse Compressor | Electron Gun

NISUS Undulator | Achromat | Laser System





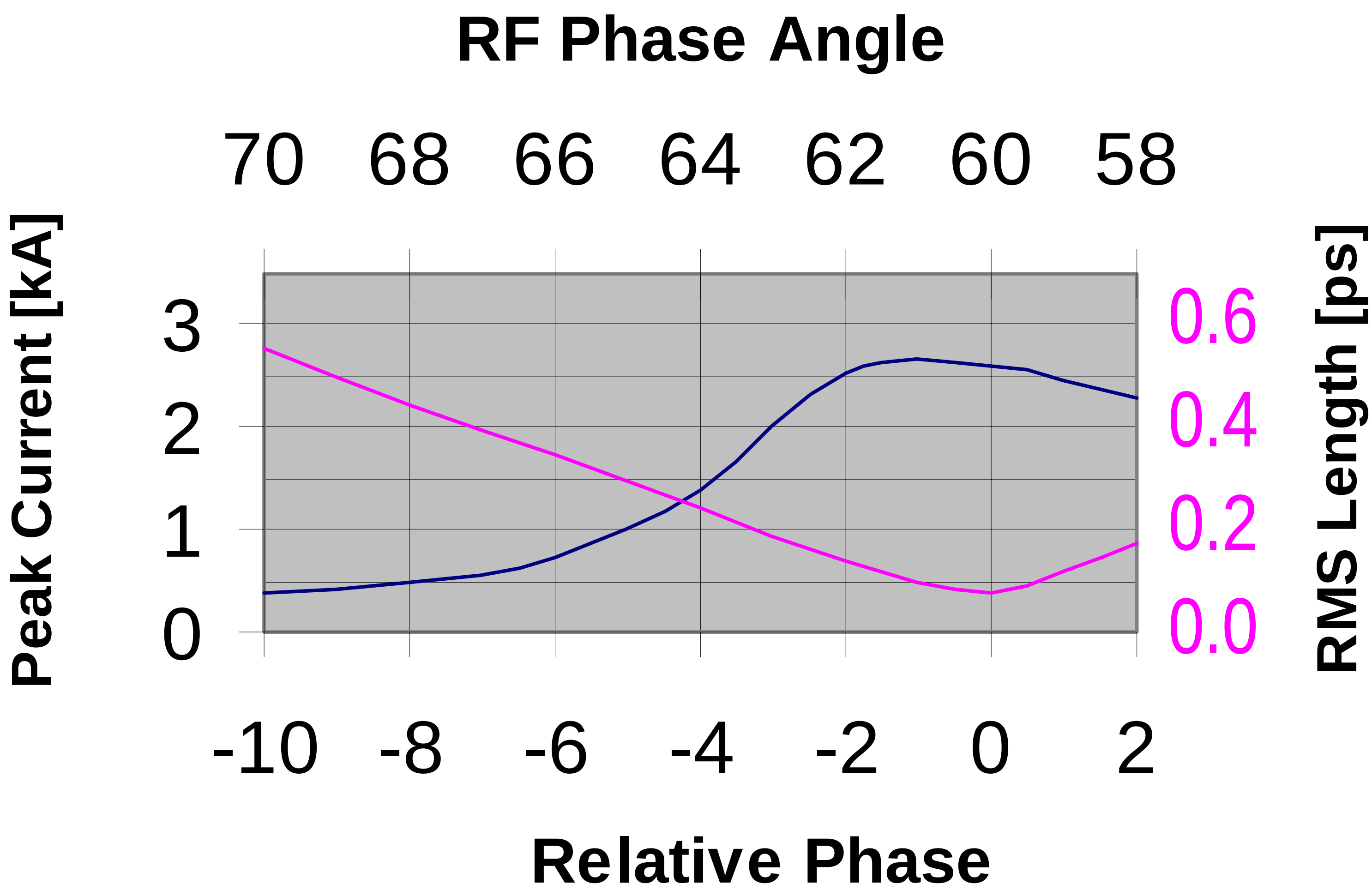
BNL Deep UltraViolet-Free Electron Laser



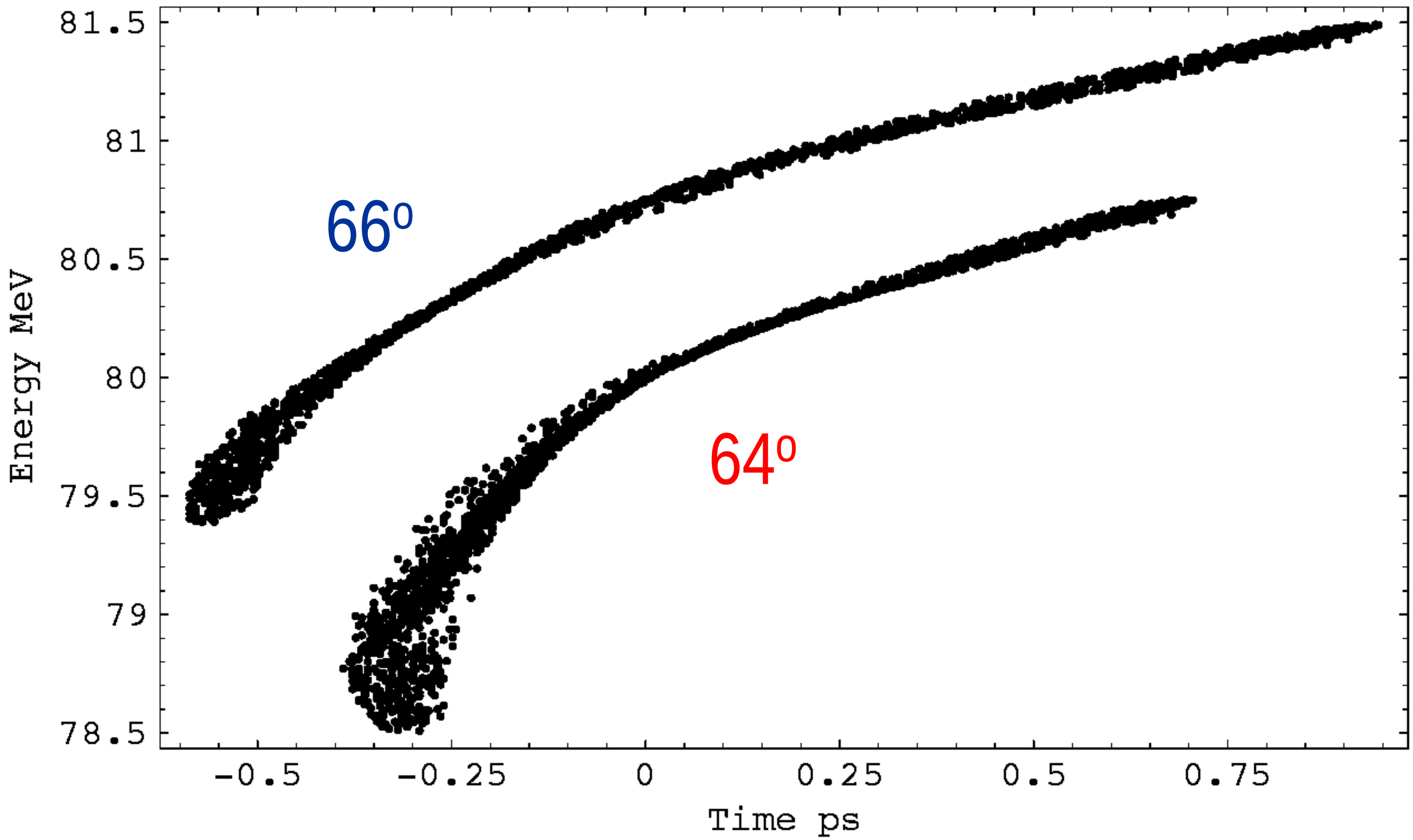
DUV-FEL: Challenges Ahead

- **Timing Stability**
  - Compressor Performance (Current and Energy)
  - Synchronization for Pump-Probe
- **Resonant Processes**
  - Threshold spectroscopies (Wavelength Stability)
  - Excited States (Harmonic Content)
- **Pump-Probe Capabilities**
  - Multi-color synchronization
  - Complimentary source matching
- **Cost & Performance Issues for Shorter Wavelengths**
  - Energy and Repetition Rate Upgrades
  - Amplifier Upgrades

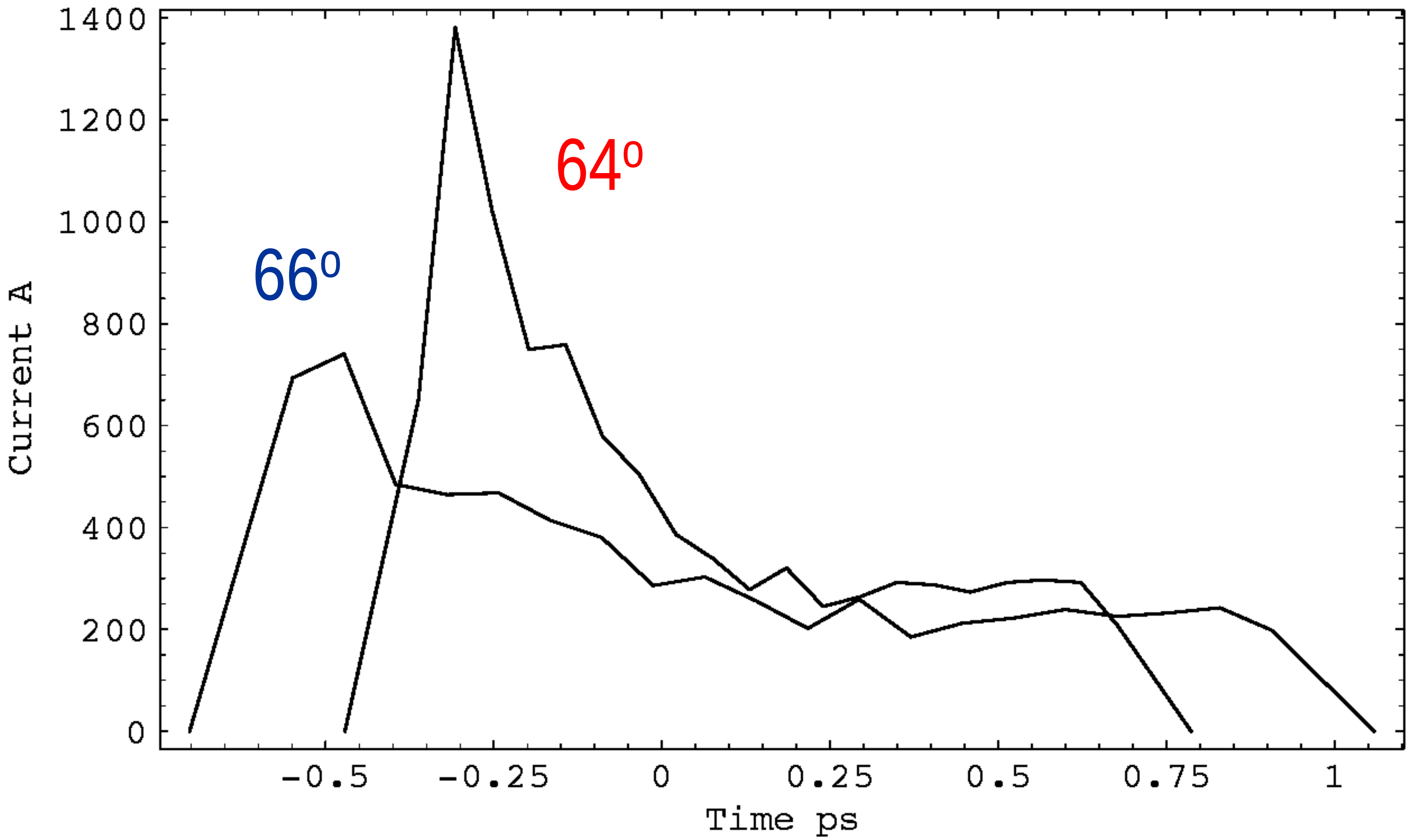
DUV-FEL Compressor Performance:



Compressor Performance:



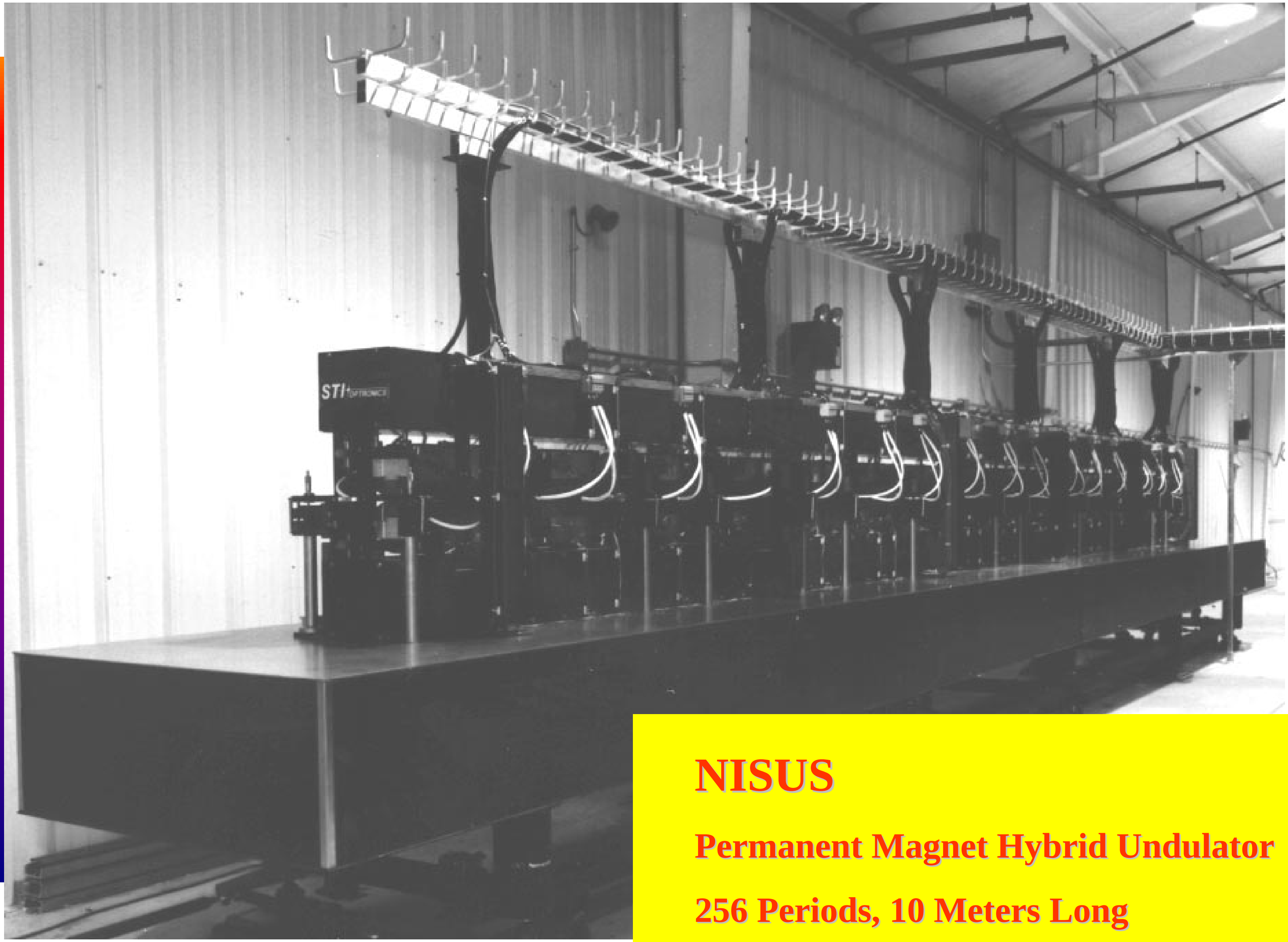
Compressor Performance



DUV-FEL Parameters

	DUV	DUV +
Rep. Rate [Hz]	10	10
Energy [MeV]	210	310
Wiggler	PM/T	PM/T?
Period [mm]	39	18
N	256	330
Wavelength [nm]	200-150	200-50
Pulse Length [ps]	10-0.01	10-0.01
Pulse Energy [mJ]	~0.2	~0.1
Ave Power [mW]	~2	~1

Evolving with Time, Budget, and Technical Achievements



NISUS

Permanent Magnet Hybrid Undulator

256 Periods, 10 Meters Long

VISA

http://www-ssrl.slac.stanford.edu/visa/

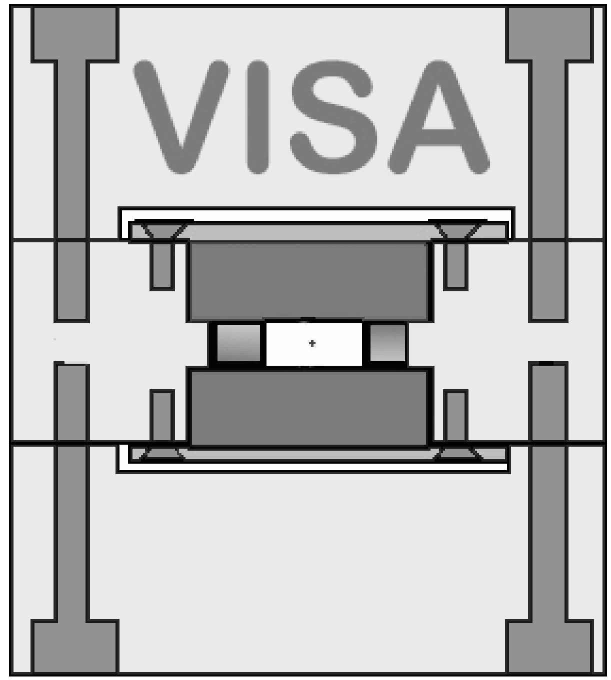
VISA Home

- Collaboration
- Experiment Description
- Status
- Schedule
- Parameter Table
- Publications

WEB site maintained by
Heinz-Dieter Nuhn, SLAC/SSRL

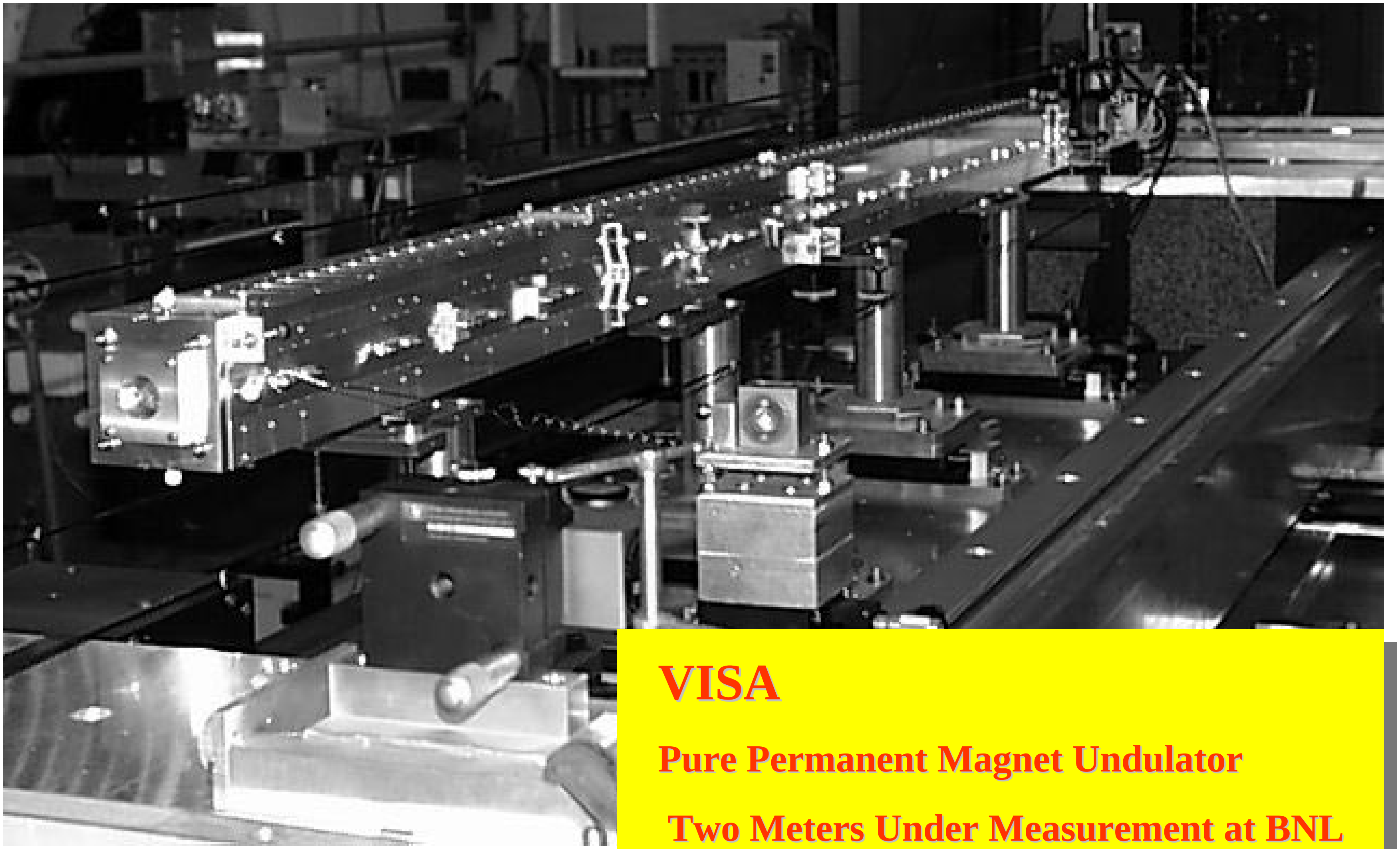
Visible to Infrared SASE Amplifier

Page updated on June 15, 1998



BNL, LLNL, LANL, SLAC/SSRL, UCLA Collaboration

Visible Light Proof-of-Principle for SASE



VISA

Pure Permanent Magnet Undulator

Two Meters Under Measurement at BNL
(330 Periods, 6 Meters Long)

Demands, Demands, Demands . . . .

- Combining Lasers with Accelerators ***is the*** Key in UV Applications
- Must develop new strategies for Experiments
- Must push frontier in Accelerator Technology