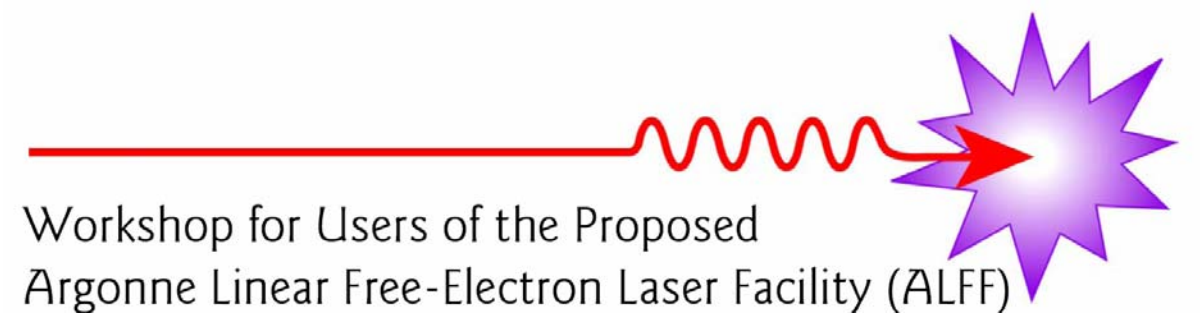
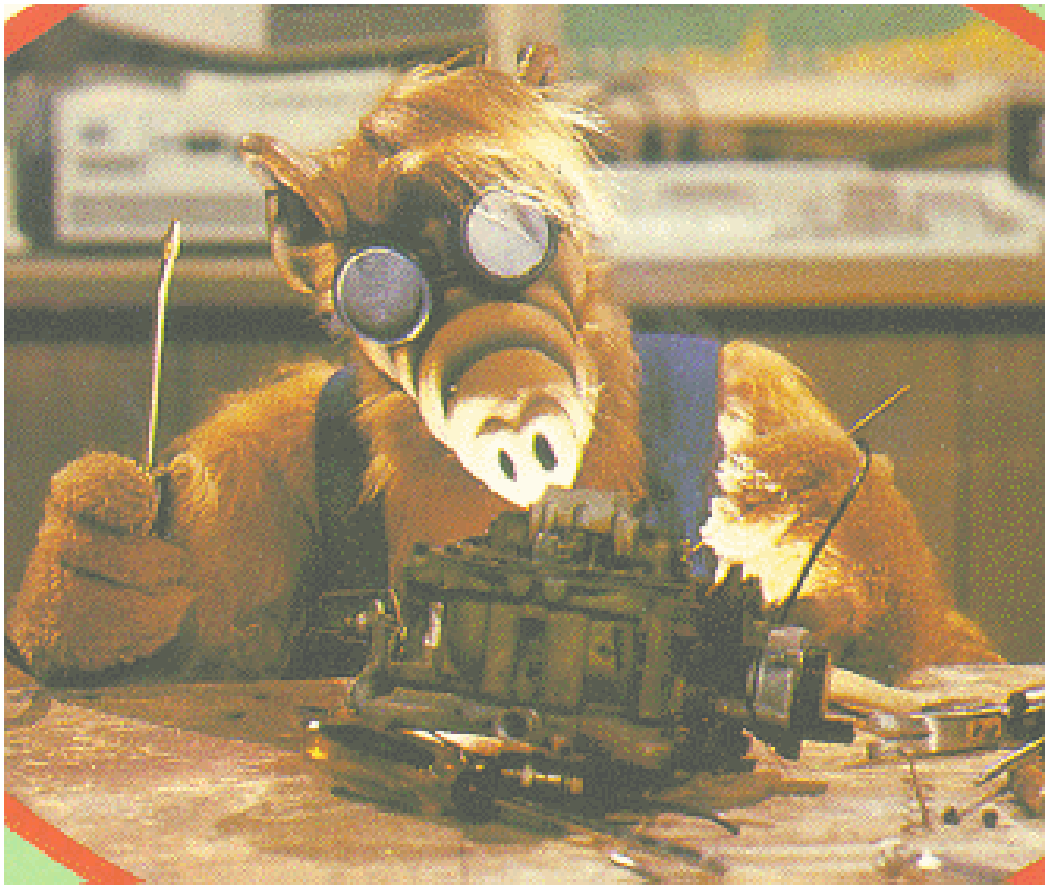


The FEL Project at the APS

Description and Status

ALFF Workshop 10/03 S. Milton

THE LEUTL* -> ALFF# Project



[* Low-Energy Undulator Test Line
Argonne Linear FEL Facility]

Stephen Milton 10/03

This Talk is About

- LEUTL
  - What it is
  - What has it done
    - Some FEL/Particle Beam Science
    - Some FEL User Science
  - What we want it to become

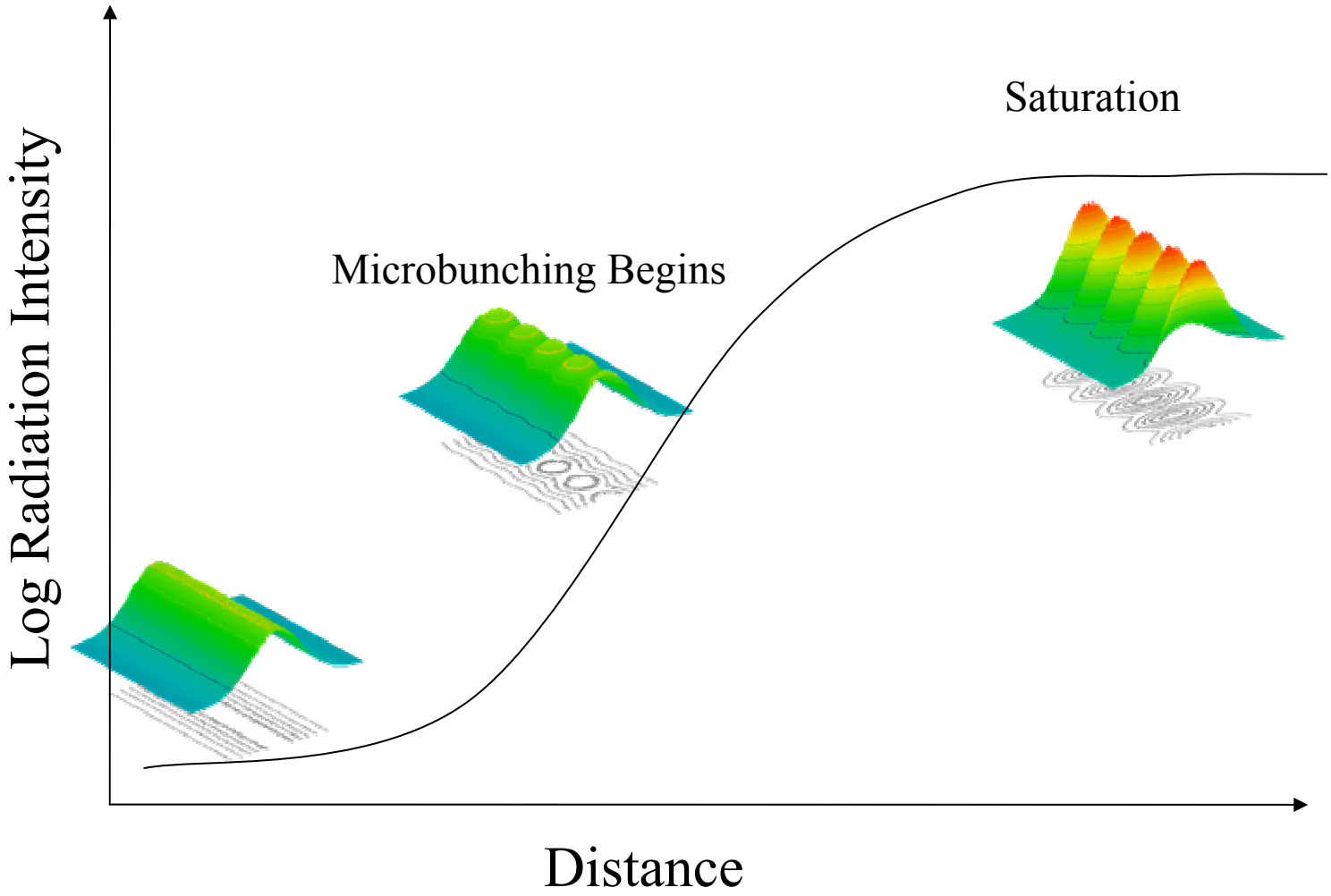
ALFF

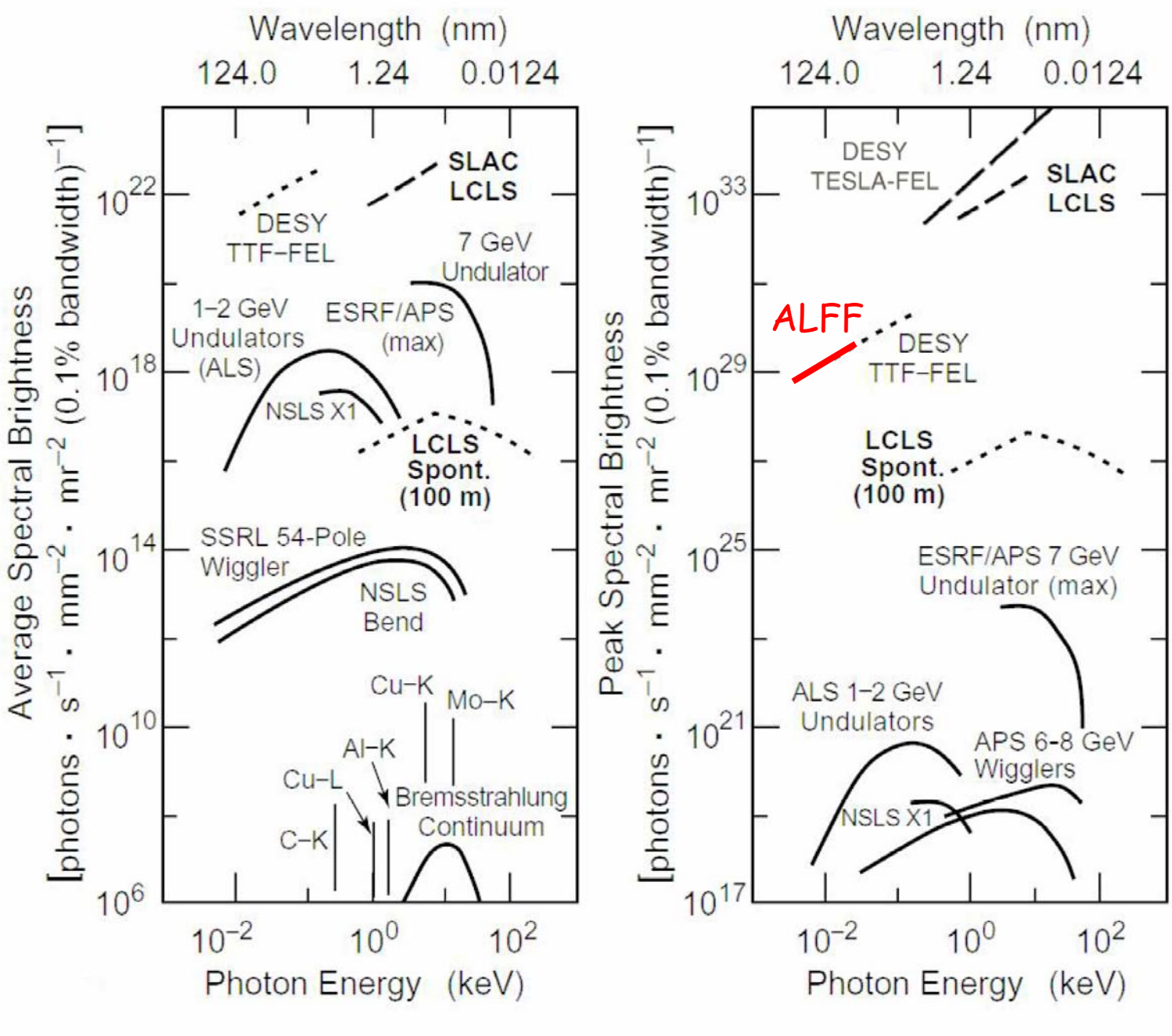
A user facility for both traditional users and for beam physicists

An Overview

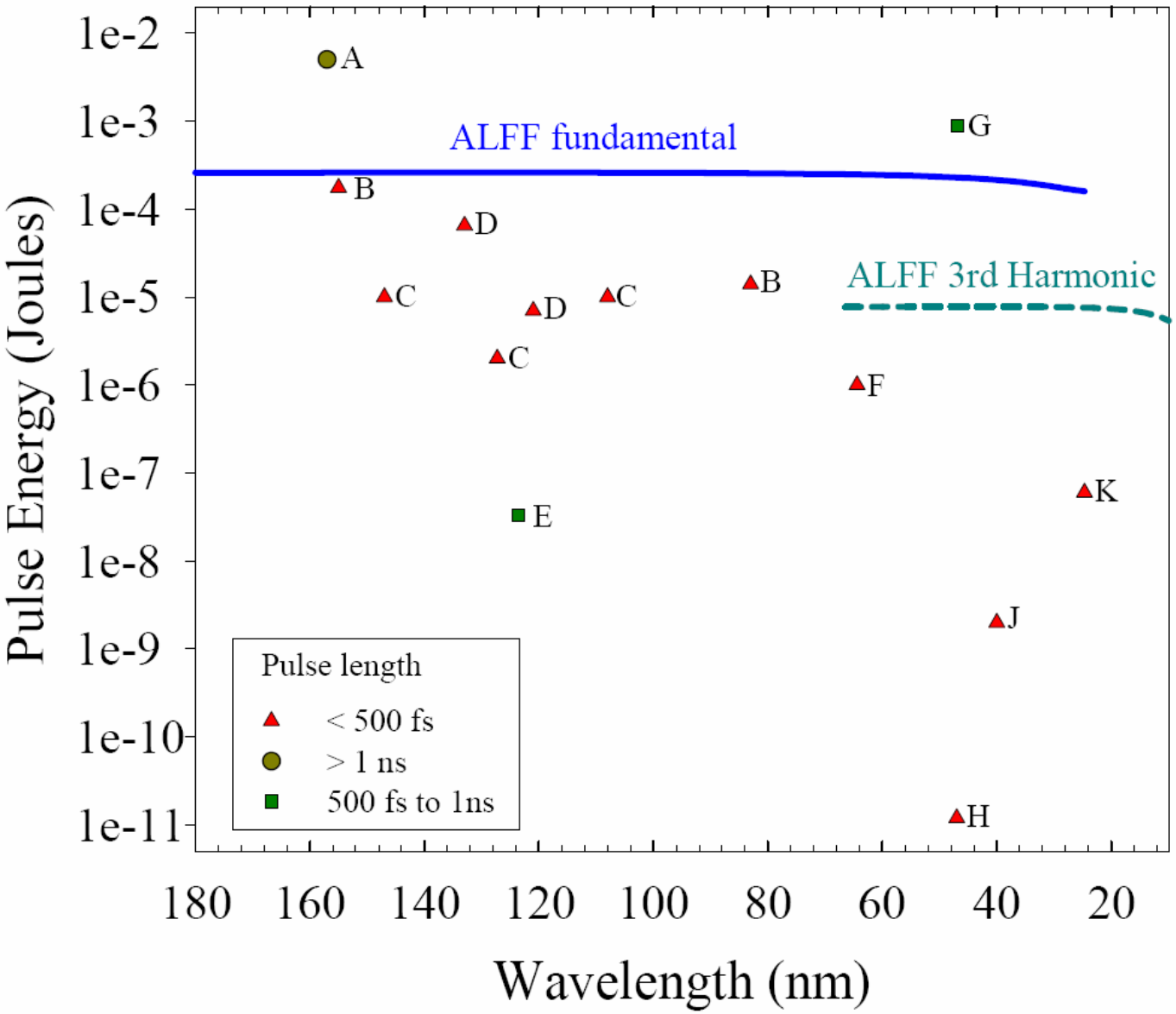
Exponential Growth

We call it SASE: Self-Amplified Spontaneous Emission




Wavelength (nm)
124.0
1.24
0.0124
Average Spectral Brightness
[photons · s⁻¹ · mm⁻² · mr⁻² (0.1% bandwidth)⁻¹]
10²²
10¹⁸
10¹⁴
10¹⁰
10⁶
SLAC LCLS
DESY TTF-FEL
7 GeV Undulator
1–2 GeV Undulators (ALS)
ESRF/APS (max)
NSLS X1
LCLS Spont. (100 m)
SSRL 54-Pole Wiggler
NSLS Bend
Cu–K
Mo–K
Al–K
Cu–L
Bremsstrahlung Continuum
C–K
10⁻²
10⁰
10²
Photon Energy (keV)
Wavelength (nm)
124.0
1.24
0.0124
Peak Spectral Brightness
[photons · s⁻¹ · mm⁻² · mr⁻² (0.1% bandwidth)⁻¹]
10³³
10²⁹
10²⁵
10²¹
10¹⁷
DESY TESLA-FEL
SLAC LCLS
ALFF
DESY TTF-FEL
LCLS Spont. (100 m)
ESRF/APS 7 GeV Undulator (max)
ALS 1–2 GeV Undulators
APS 6-8 GeV Wigglers
NSLS X1
10⁻²
10⁰
10²
Photon Energy (keV)

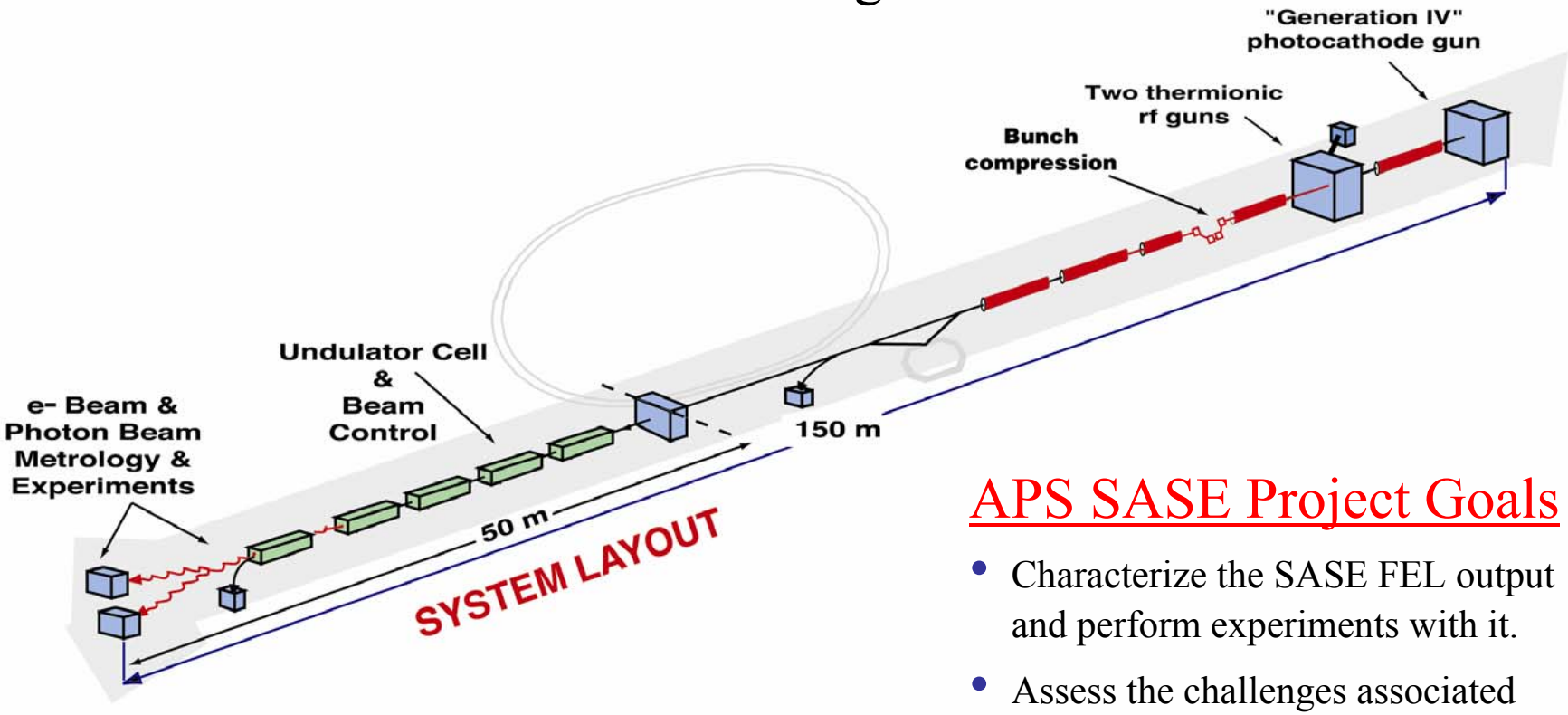
Argonne Linear FEL Facility:
Pulse Energy Compared to Laboratory Sources



See workshop handout for sources/references and explanation

The APS SASE FEL Schematic

The Low-Energy Undulator Test Line System
Present Configuration



APS SASE Project Goals

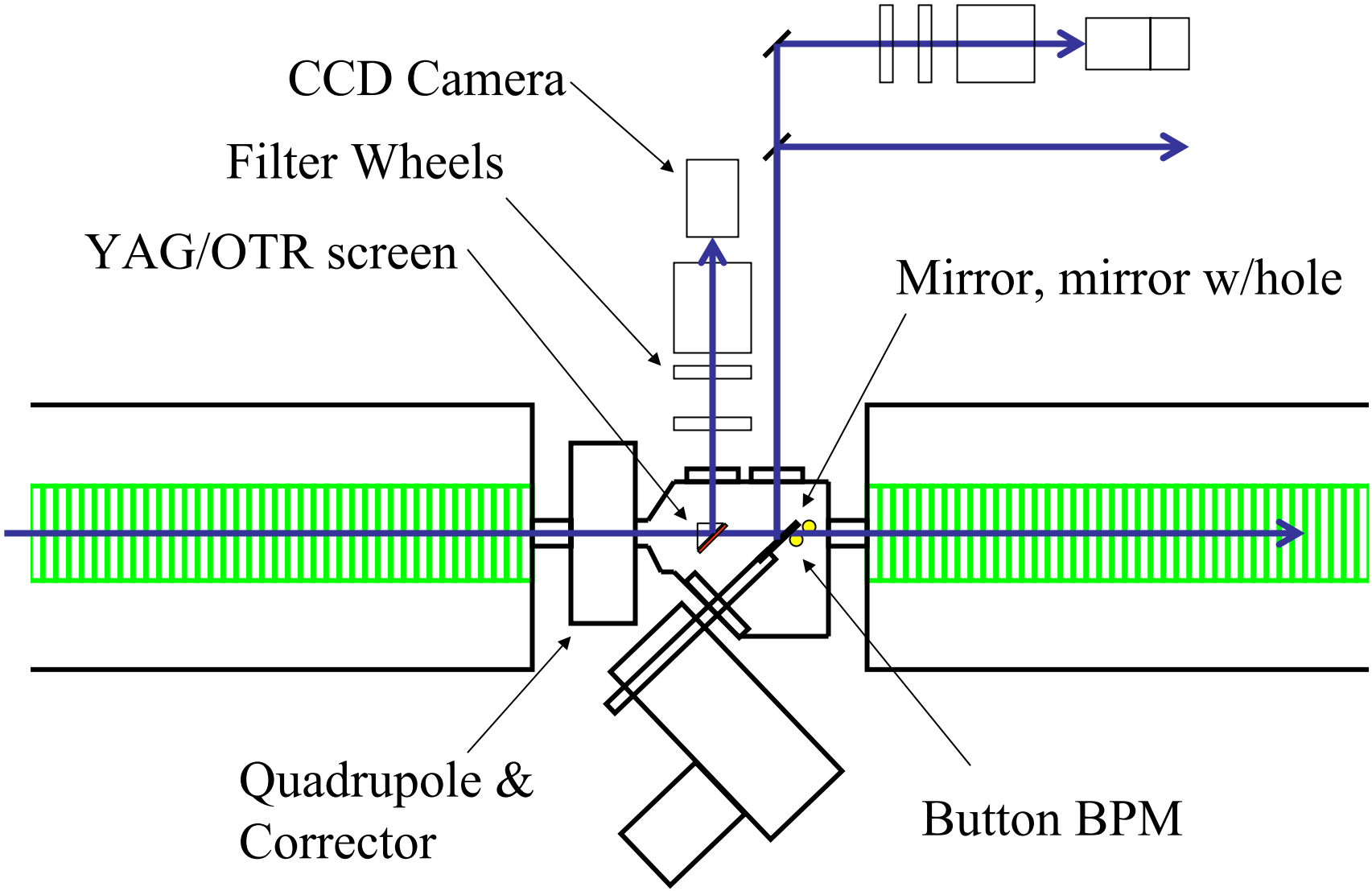
- Characterize the SASE FEL output and perform experiments with it.
- Assess the challenges associated with producing a SASE FEL in preparation for an x-ray regime machine.

Basic Parameters for the APS FEL

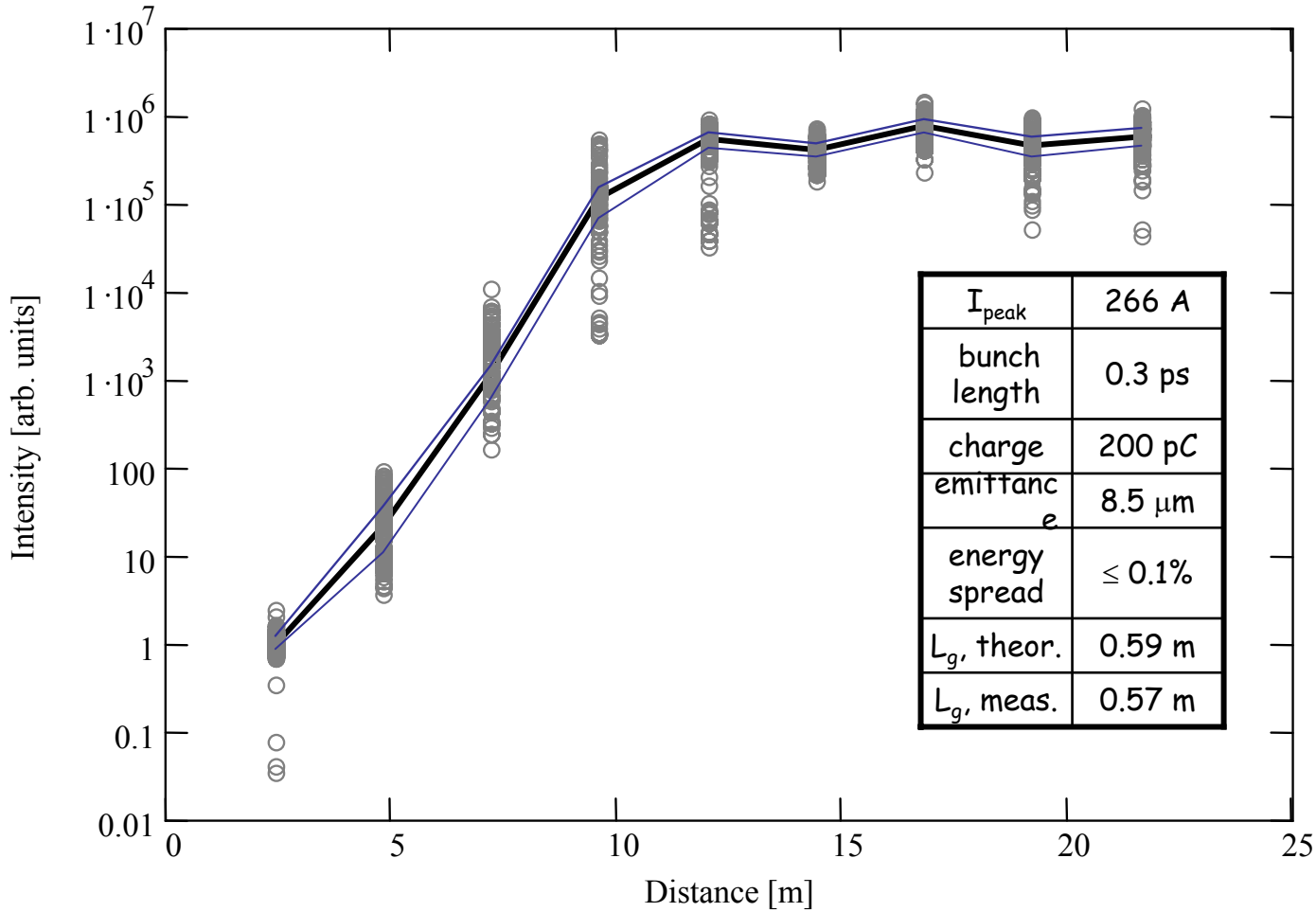
PARAMETERS			
Wavelength [nm]	**Regime 1 530**	**Regime 2 120**	**Regime 3 51**
Electron Energy [MeV]	**217**	**457**	**700**
Normalized rms Emittance (π mm-mrad)	**5**	**3**	**3**
Energy Spread [%]	**0.1**	**0.1**	**0.1**
Peak Current [A]	**100**	**300**	**500**
Undulator Period [mm]	**33**		
Magnetic Field [T]	**1.0**		
Undulator Gap [mm]	**9.3**		
Cell Length [m]	**2.73**		
Gain Length [m]	**0.81**	**0.72**	**1.2**
Undulator Length [m]	**5 x 2.4 then 9 x 2.4**	**9 x 2.4**	**10 x 2.4**

Some Measurements

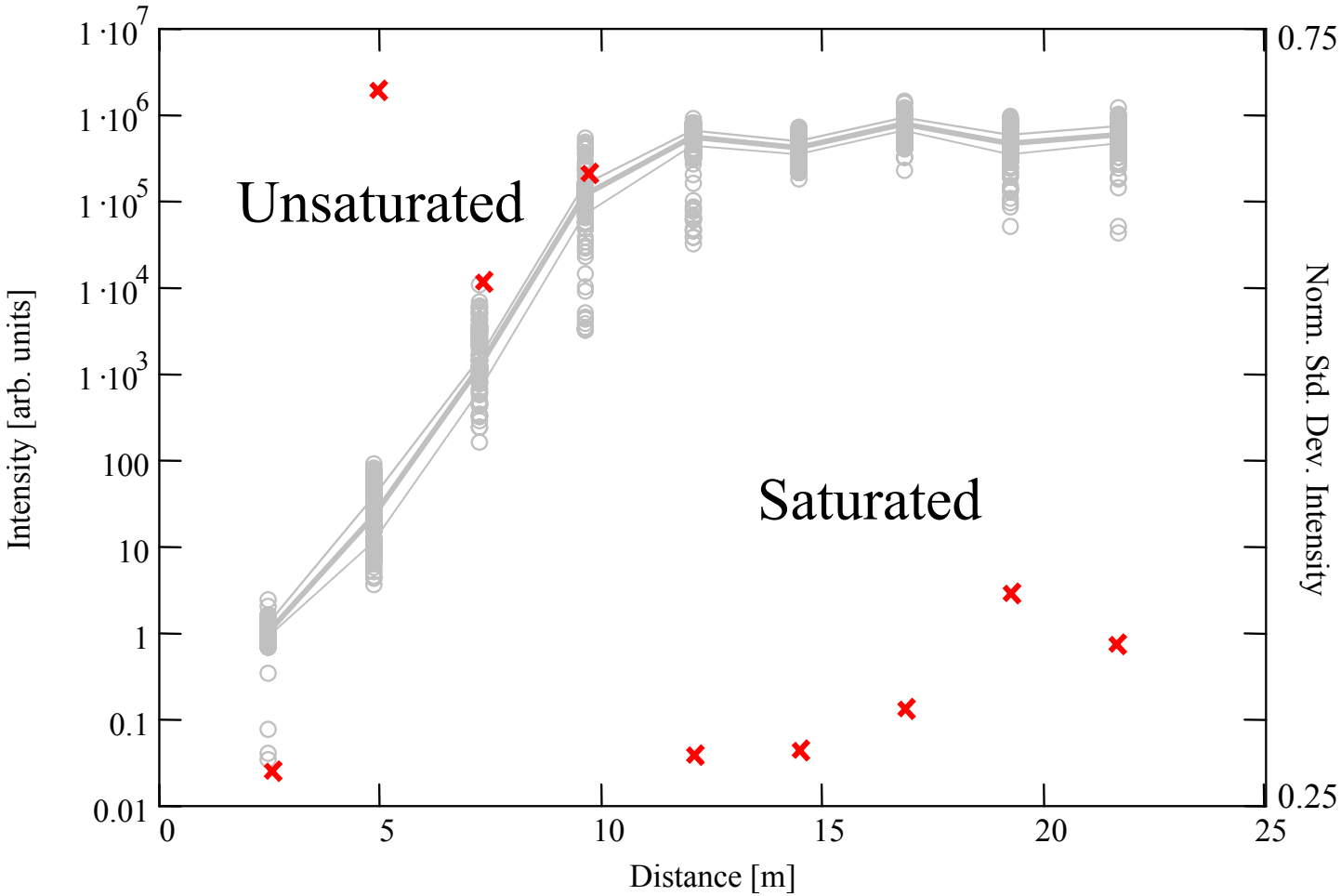
Undulator Line Diagnostics



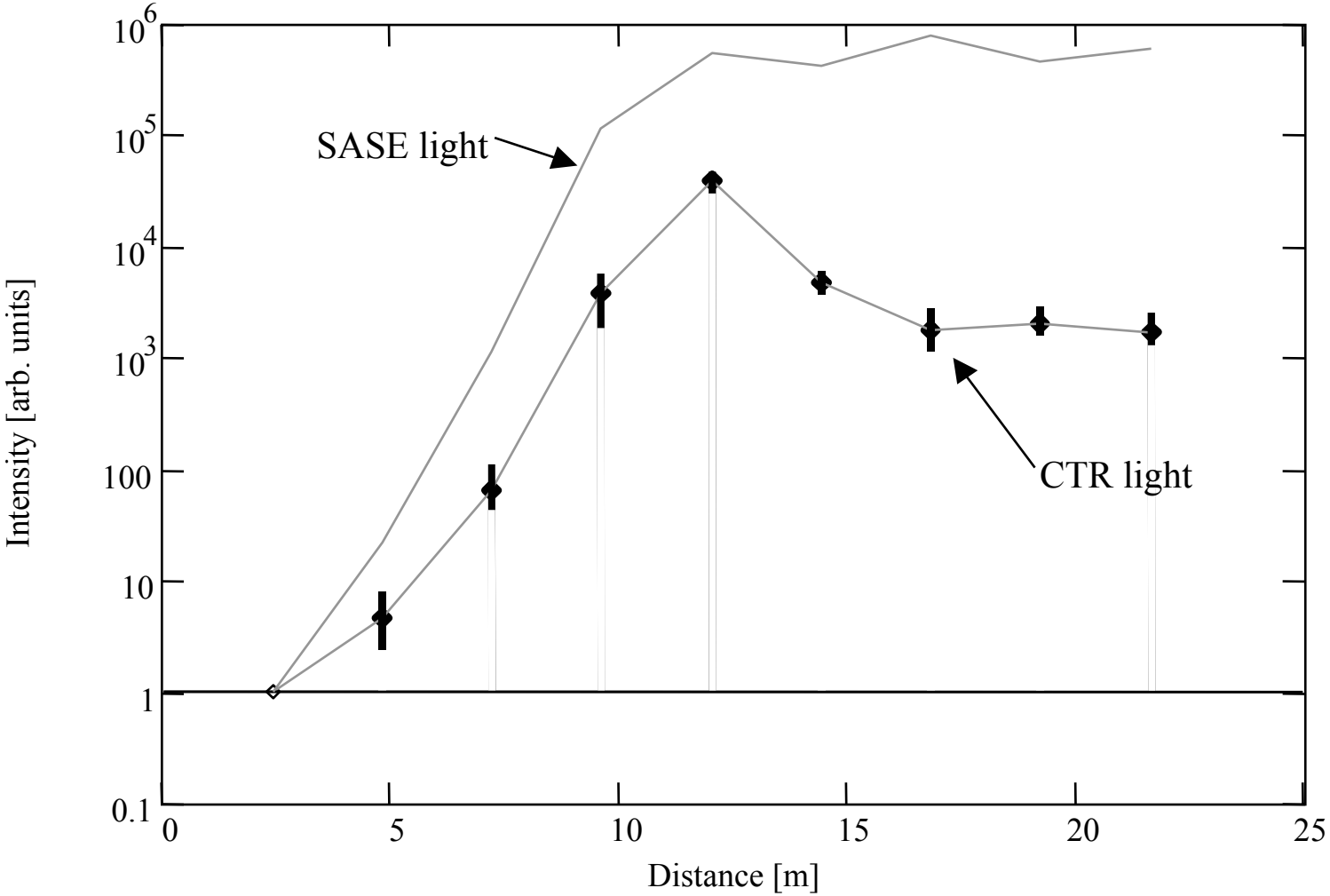
Optical Intensity vs. Distance: Gain



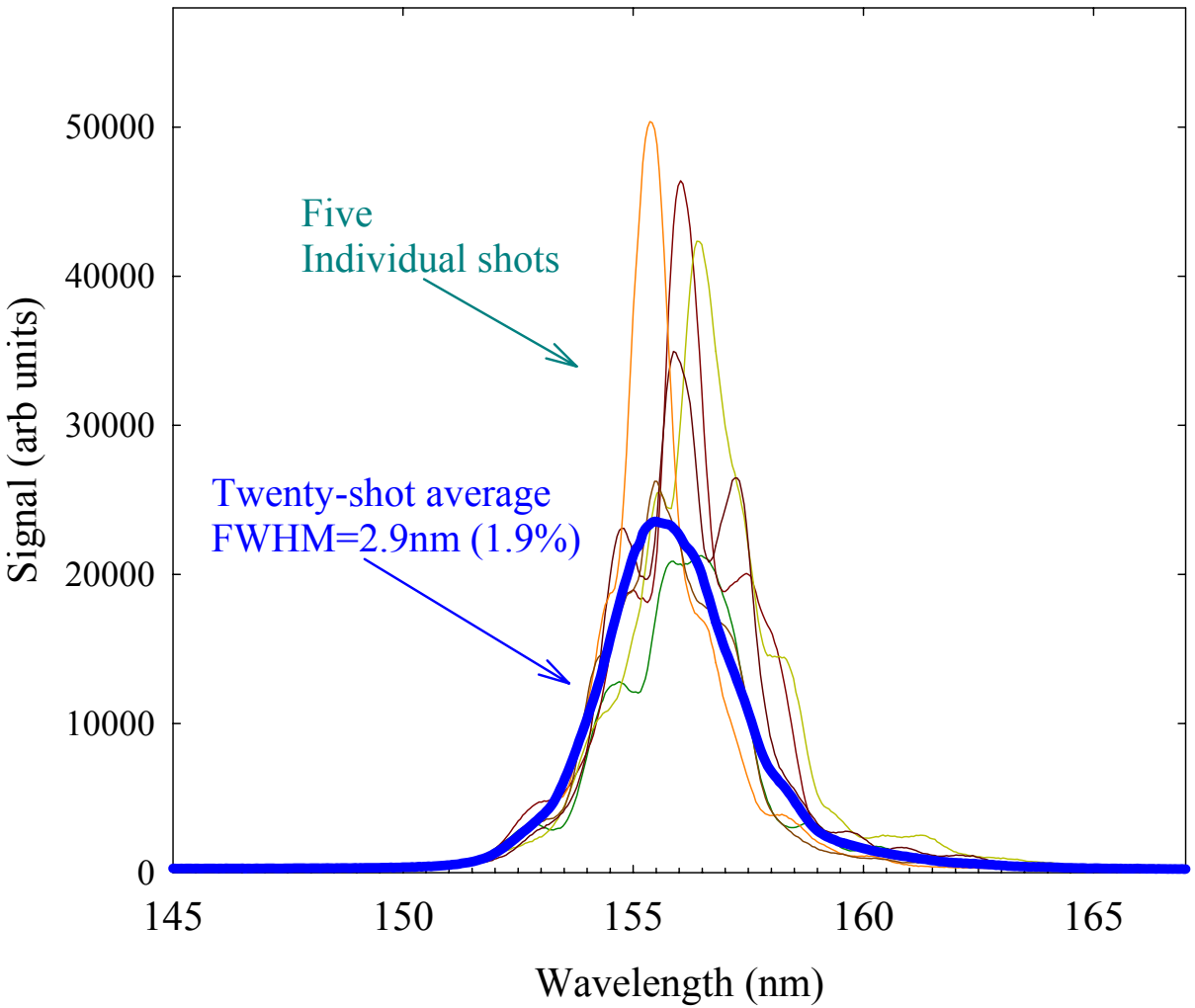
Optical Intensity Statistics



Microbunching Measurement



Typical Present Operations for Our Users



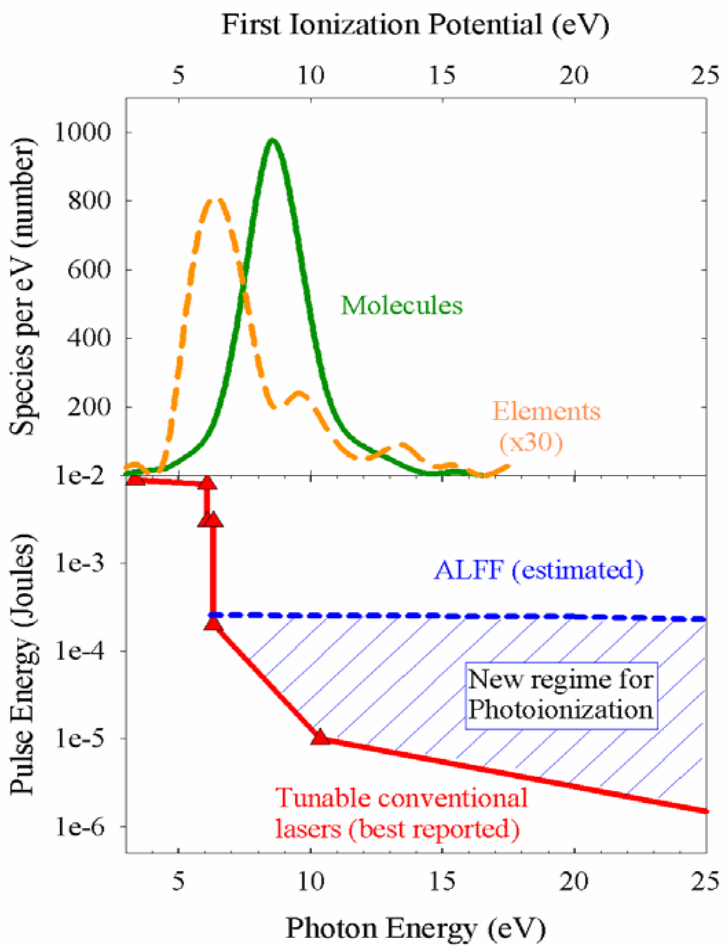
Wavelength
530 nm -> 120 nm
Quickly tunable to arbitrary values

Pulse Length
~ 200 -> 300 fs FWHM

Energy/Pulse
~ 10 microJoules
(This should be near 100 and is under investigation)

ALFF

Ionization Potentials



Just about everything loses electrons somewhere from a few eV (400 nm) to near 20 eV (50 nm) and molecules are no exception.

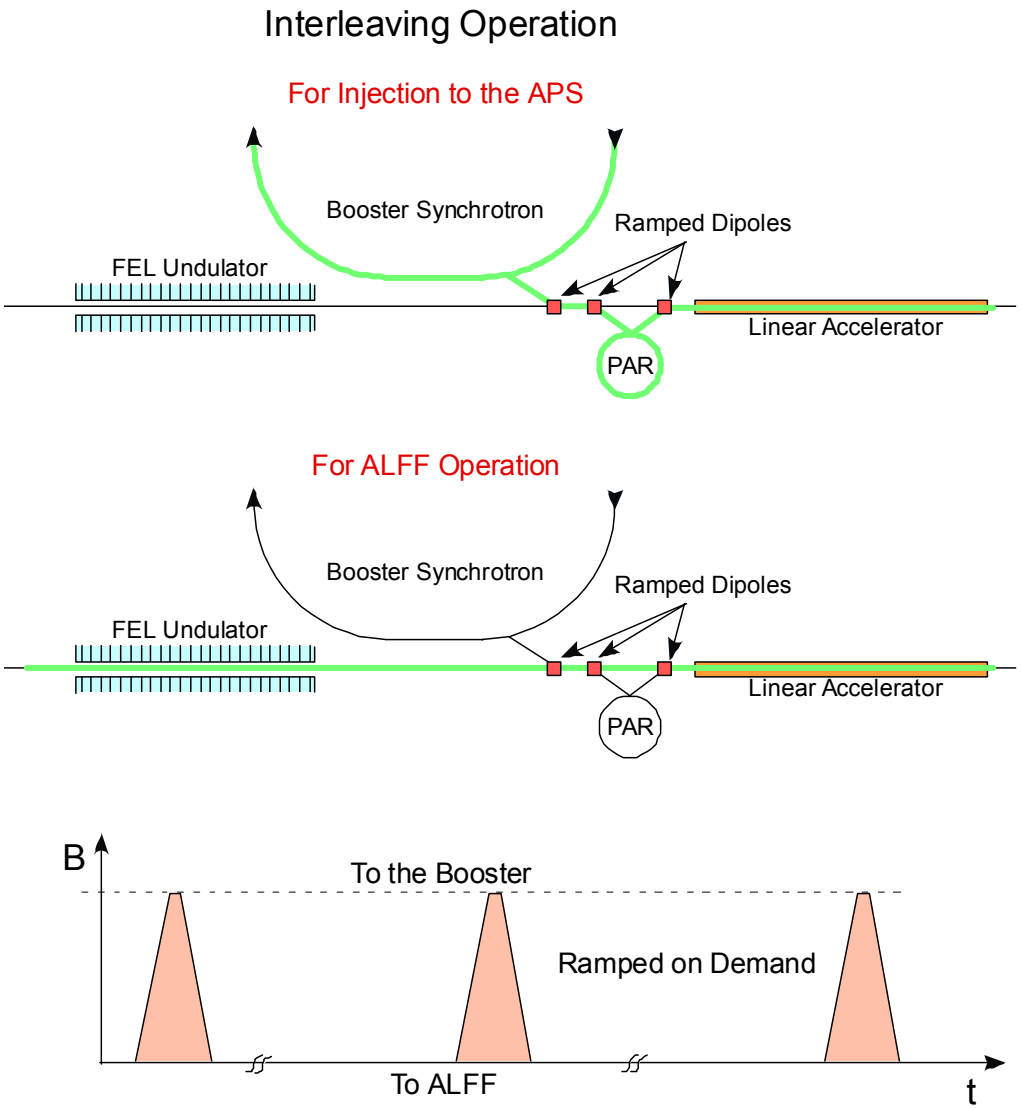
Improvements

Parameter	**Existing (LEUTL)**	**Proposed (ALFF)**
Photon Energy Fundamental Tuning Range (wavelength)	2-10 eV (600-120 nm)	2.8-22 eV (444-55 nm)
Bandwidth (FWHM)	≥ 0.4%	0.4-0.3%
Pulse Length (FWHM)	≤ 0.3 ps	≤ 0.3 ps
Photon Energy/Pulse Delivered to Experiment	5 μJ – 20 μJ	> 200 μJ
Saturation Length	< 18 m	< 18 m
Repetition Rate	6 Hz	30 Hz
User Beam Available (time relative to storage ring)	3%	96%
Availability (delivered time to scheduled time fraction)	NA	> 80%
Scheduled Time (1st operational year)	NA	1500 hrs

Enhancements

- New Photocathode RF Gun System
  - Laser System
  - High-Performance RF Gun
- Linac Improvements
  - New 1st accelerating structure
  - Improved and additional diagnositcs
- Transport Line Improvements
- Undulator VUV Diagnostics Improvements
- VUV Optical Transport Improvements
- Interleaving Capabilities

Interleaving

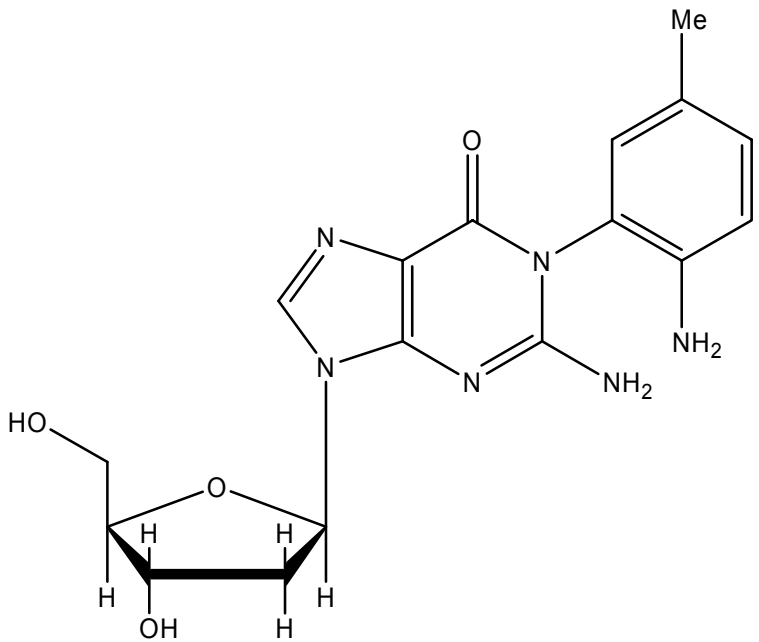


Our ability to make ALFF a success will be very dependent upon our ability to make interleaving a reality.

ALFF Scientific "Grand Challenges"

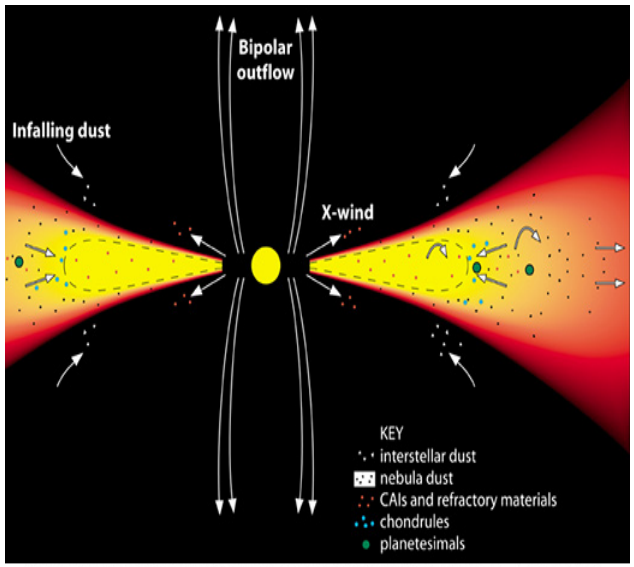
How Does Cancer Begin?

Molecular trace analysis suitable for cancer research has not been possible on samples from individuals. The new end station at ANL promises to be the most sensitive and discriminative instrument in the world and will enable these analyses.



The chemical structure of a possible alteration of guanosine by reaction with an aryl amine.

How Did Our Sun Evolve?



(PSRD graphic by Nancy Hulbirt, based on a conceptual drawing by Edward Scott, Univ. of Hawaii.)

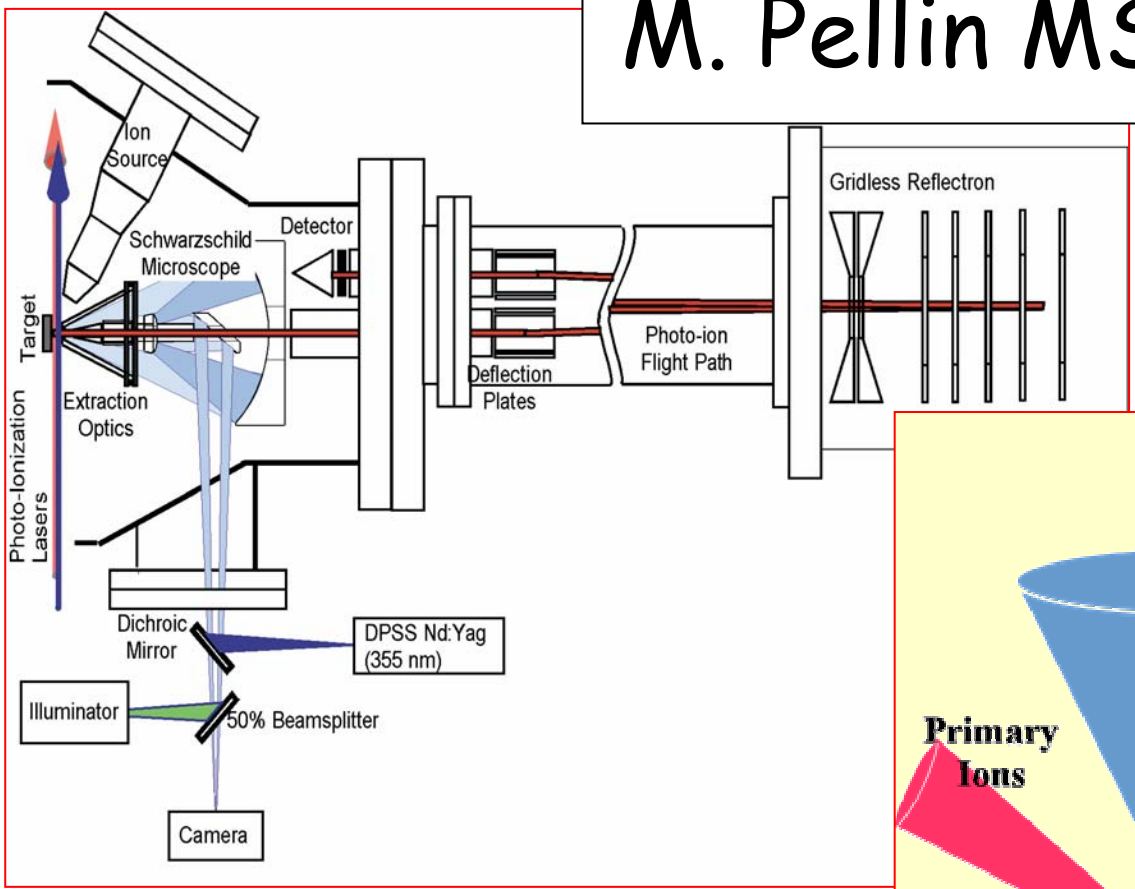
Schematic drawing of X-wind emanating from a young Stellar Object. This model for the evolution of our solar system explains many recent meteoritical discoveries and can now be tested using solar wind samples from the Genesis spacecraft and the SPIRIT end station on the ALFF.

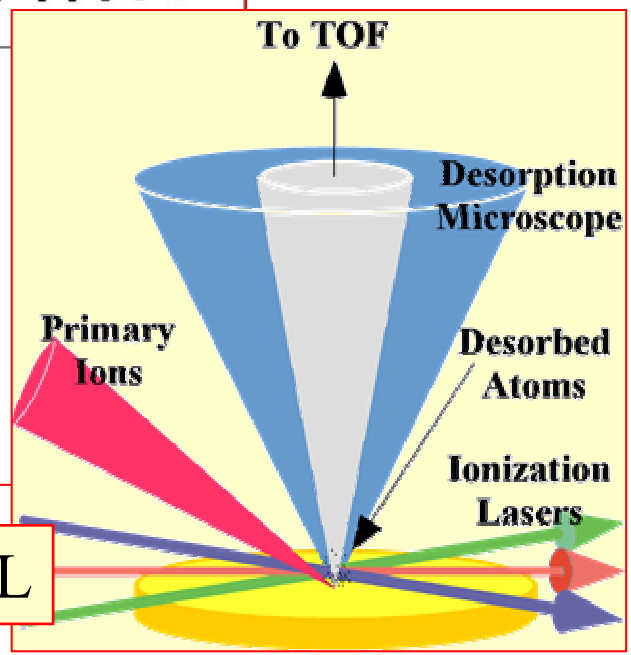
Determination of how our sun evolved by performing isotopic analysis on extraterrestrial material is now possible using resonant ionization mass spectroscopy; however, accurate measurement of light elements such as oxygen and nitrogen is only possible with a tunable laser capable of reaching VUV wavelengths and with sufficient energy per pulse. The ALFF, together with the SPIRIT apparatus, will be the most sensitive system in the world for this important measurement.

The First Experiment

The First APS FEL Experiment

M. Pellin MSD/ANL



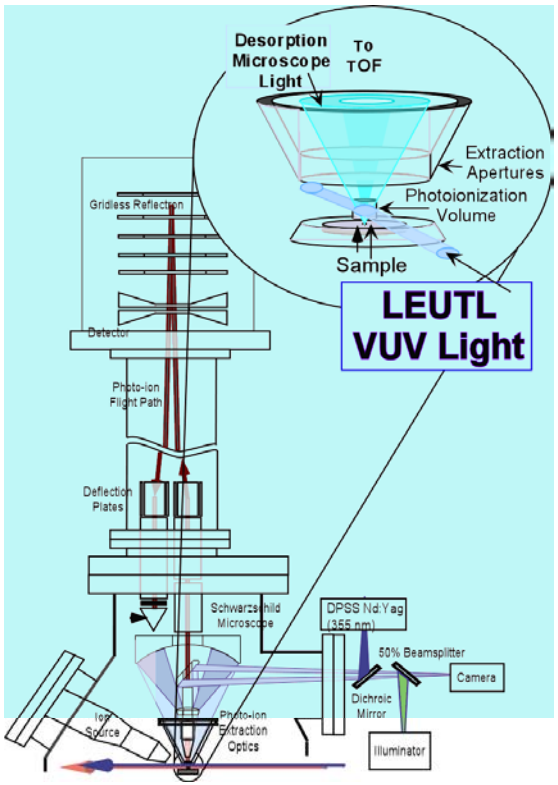


LEUTL

The First APS FEL Experiment

Single Photon Ionization / Resonant Ionization to Threshold (SPIRIT)

M. Pellin, Jerry Moore, Wally Callaway, and Others, ANL+



Operating Since 2002

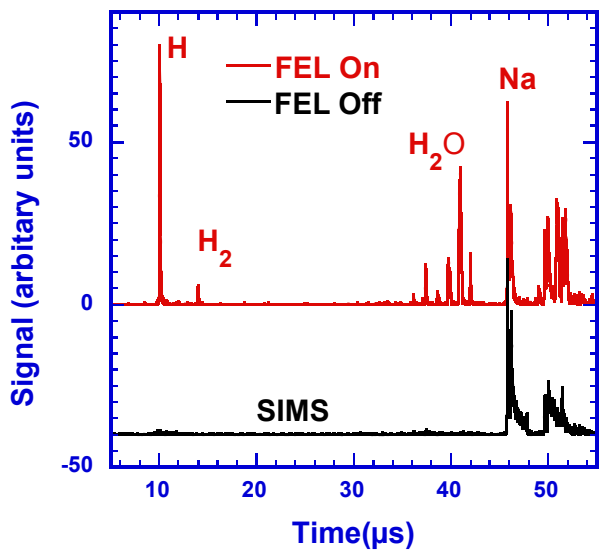
SPIRIT will use the high VUV pulse energy from LEUTL to uniquely study –

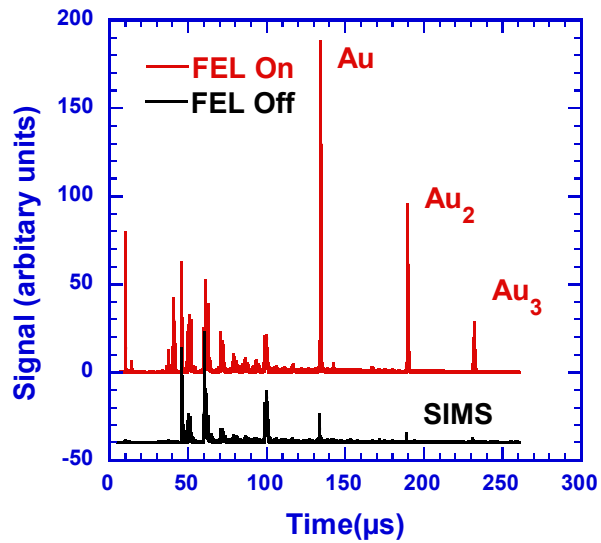
- **Trace quantities of light elements:**
  H, C, N, O in semiconductors with 100 times lower detection limit
- **Organic molecules with minimal fragmentation**
  cell mapping by mass becomes feasible
  polymer surfaces
  modified (carcinogenic) DNA
  photoionization thresholds
- **Excited states of molecules**
  cold wall desorption in accelerators
  sputtering of clusters

First Measurements

Photoionization of Gold and Gold clusters

- Only secondary ions below the ionization potential (IP) of Au
  - FEL wavelength 127 nm (9.8 eV)
  - IP of Au equals 9.2 eV
- Light atoms and molecules are also observed
  - H peak may be due to fragmentation of molecules.



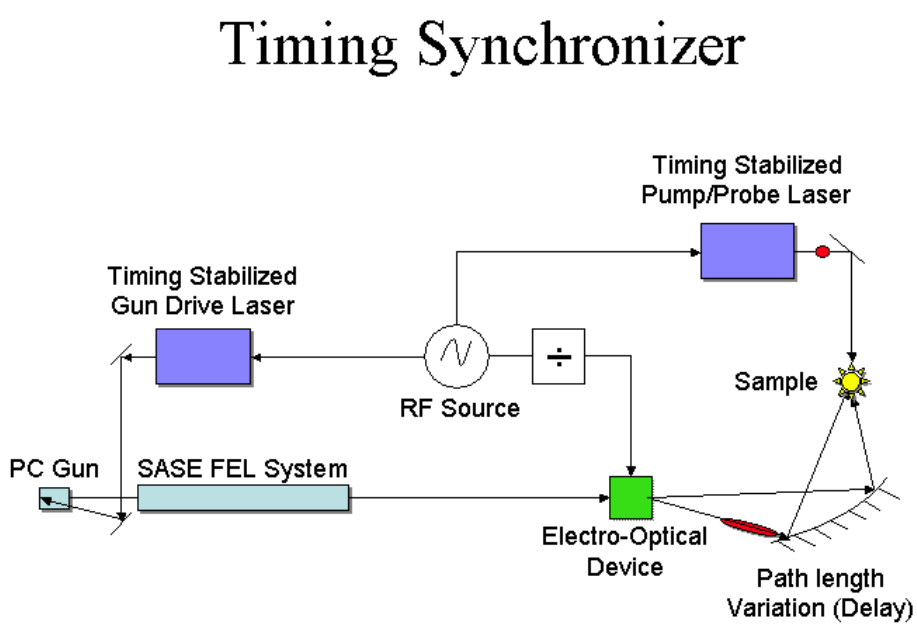


Challenges to Accelerator and FEL Development

Incomplete List

- Electron Beam Brightness Enhancement and Preservation
  - "Bread and Butter"
- Wavelength Extension
  - Exploitation of Harmonics
- Femtosecond/Attosecond Pulses
  - Capitalize on the tremendous bandwidth
- Other

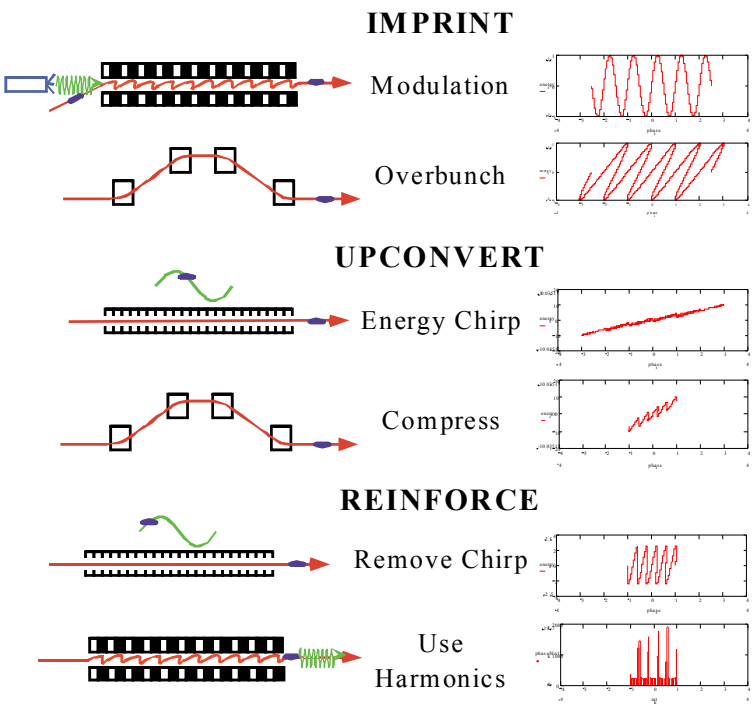
Multiple Arbitrary Wavelengths in a Single Pulse



A possible scheme to synchronize the SASE FEL pulse to an external laser operating at an independent wavelength.

Many experiments need precisely timed, multiple wavelengths to excite and then probe the sample under study. Although the SASE-FEL system will generate multiple wavelengths via nonlinear harmonics, completely arbitrary wavelength generation within a single bunch has yet to be accomplished.

Advanced Seeding



The concept of wavelength shifting.

There is tremendous interest in seeding the FEL process in order to stabilize the shot-to-shot fluctuations in optical power output and to narrow the bandwidth. With the exception of self-seeding techniques, however, there are no existing arbitrarily tunable wavelength sources suitable for generating seed pulses. If one could seed with a fixed wavelength and later shift that wavelength arbitrarily, this problem could be overcome.

Summarizing

- LEUTL to be Converted to a user facility: ALFF
  - Need DOE support
  - This workshop is being held to both develop and gauge the scientific case for ALFF
- ALFF Designed to
  - Support the traditional VUV scientist's needs
  - Also be available to beam physicists for exploration of FEL and beam brightness science (Not being addressed at this Workshop).