Research in Novel Coherent Light Sources in BES

Eric A. Rohlfing

BESAC Meeting

October 10, 2000

BES Synchrotron Light Sources

2nd Generation

Total Operating Budget: $189M (FY01 request)

3rd Generation

Next Generation Light Source

- **Workshops on Fourth Generation Light Sources began in 1992**
  - Converged upon linac driven free electron laser as best technology for increased brightness
  - Scientific applications discussed but case not made broadly
  - Material damage recognized as a critical issue
- **Proposal to use SLAC linac to drive x-ray FEL**
  Linac Coherent Light Source
  - LCLS Conceptual Design Report reviewed in November 1997 and published in April 1998
- **Office of Science facilities roadmap has a marker for a next generation light source**

BESAC's Role

- **Report of the BESAC Panel on DOE Synchrotron Radiation Sources and Science (November, 1997)**

  Examined operations, user support and science at four BES light sources and made specific funding recommendations

  Highest priority included funding exploratory research on fourth generation light sources (X-ray FEL) and recommended that another panel be convened to advise BES on development and applications

- **BESAC Panel on Novel, Coherent Light Sources**

  What new science can be done with new capabilities such as coherence, ultrashort pulses, high intensities, short wavelengths?

  What is a reasonable R&D plan, what would such sources look like and how would they serve the user community?

Novel Coherent Light Source Panel

◆ Chaired by Steve Leone, JILA/NIST/Univ. of Colorado

Paul Alivisatos, UC Berkeley
William Colson, NPGS
Raymond Jeanloz, UC Berkeley
Simon Mochrie, MIT
Geri Richmond, Oregon
Nora Berrah, West. Mich.
Richard Haight, IBM
Steve Laderman, HP
Keith Moffat, Chicago
Jochen Schneider, DESY
Phil Bucksbaum, Michigan
John Hepburn, Waterloo
Don Levy, Chicago
Yves Petroff, ESRF
Ron Shen, UC Berkeley

◆ Workshop held in January 1999

Presentations by each DOE national lab involved in light source development (including joint presentation by LCLS collaboration)

Invited presentations from table-top laser community:

Margaret Murnane, Michigan
Steve Harris, Stanford
Jorge Rocca, Colorado St.
Keith Nelson, MIT
Chris Barty, UCSD
Graham Fleming, UCB

Extensive meetings of panelists with liaisons from labs and invited speakers

◆ Report unanimously accepted by BESAC in February 1999

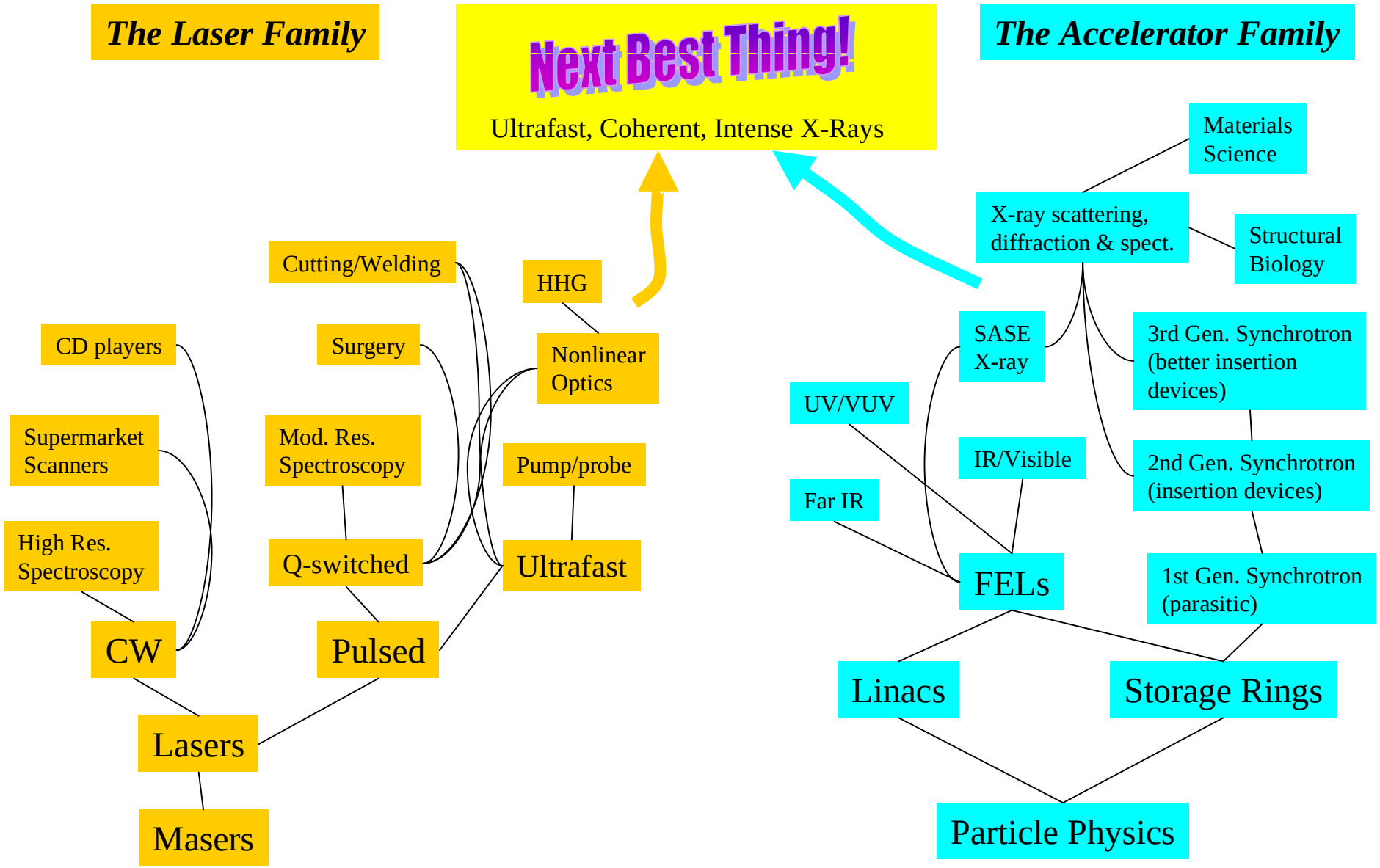
Leone Panel Recommendations/BES Actions

◆ Report of the BESAC Panel on Novel Coherent Light Sources

"The Panel recognized that there will be a symbiotic relationship between future accelerator-based sources and high-powered ultrafast lasers…. The state-of-the-art light source facility of the future will include a complete marriage of accelerator principles and laser art, which has not been previously recognized widely."

Recommendations:	**BES Actions:**
Emphasis on hard X-ray region Focused R&D program at DOE labs on linac-driven X-ray FEL	Linac Coherent Light Source Project (SLAC, ANL, BNL, LANL, LLNL, UCLA)
Support for laboratory scale laser sources Utilization of 3rd gen. synchrotron sources Improved X-ray detectors and optics	Novel X-Ray Light Source Initiative
Improved scientific case for coherent x-rays	Support for workshops

Light Source Family Trees



Linac Coherent Light Source (LCLS)

◆ R&D facility for coherent, intense x-rays

Proposed x-ray FEL (0.8 - 8.0 keV) designed to produce spatially coherent, sub-picosecond x-ray pulses with ~10 orders of magnitude greater peak brightness than 3rd generation synchrotrons

Key components: laser-driven photocathode RF electron gun, last 1 km of the SLAC linac, electron bunch compressors, 100-m long undulator, x-ray optics and detectors

Collaboration between SLAC, ANL, BNL, LANL, LLNL and UCLA

BES funding 4-yr. R&D project at $1.5M/yr. begun in FY99; highly leveraged by lab contributions; estimated construction cost $100M

A step toward an ultimate next generation user facility

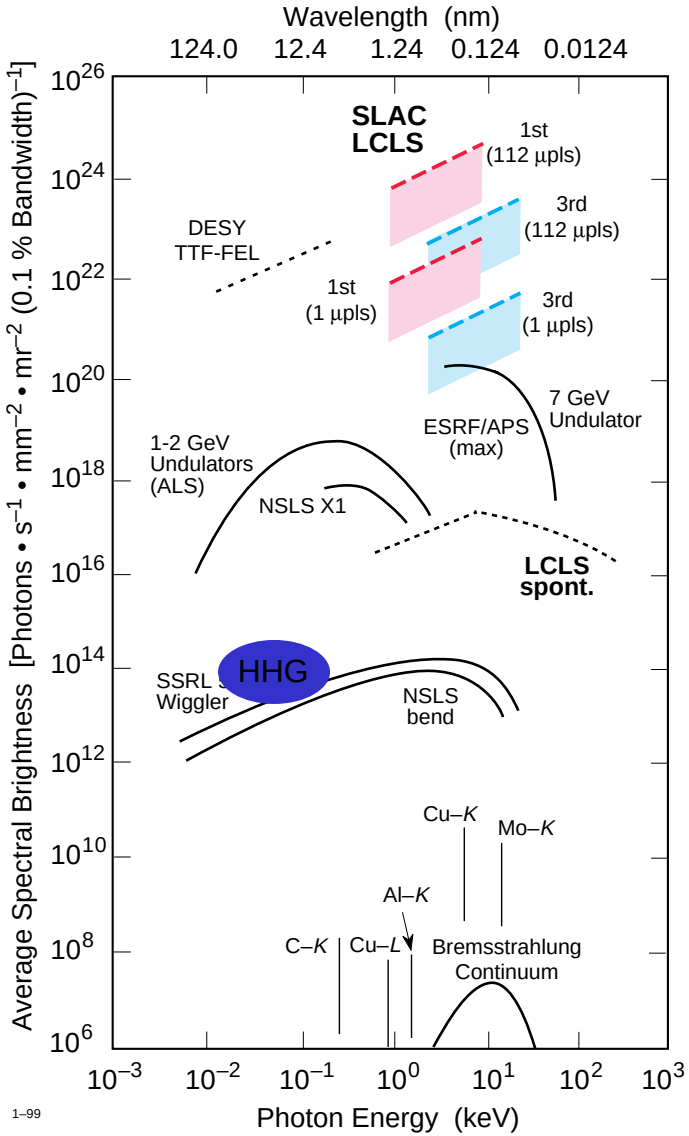
◆ R&D issues

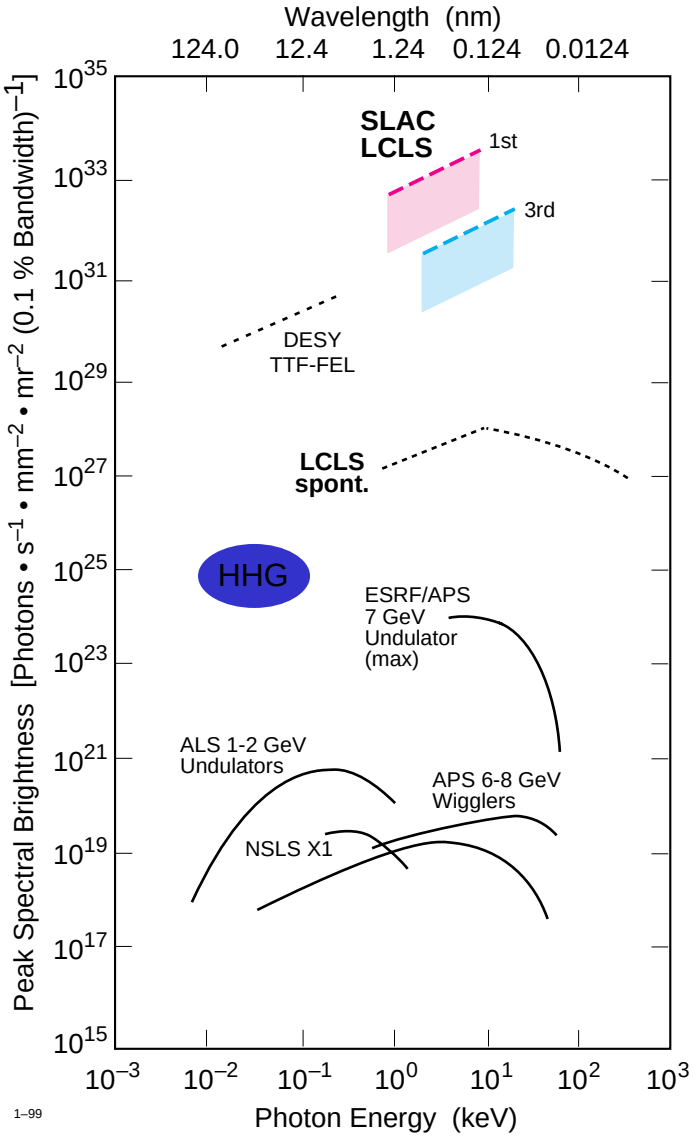
Photocathode gun development & emittance control
SASE physics in the x-ray region
Synchronization with ultrafast pump lasers
X-ray optics and ultrafast pulse characterization

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

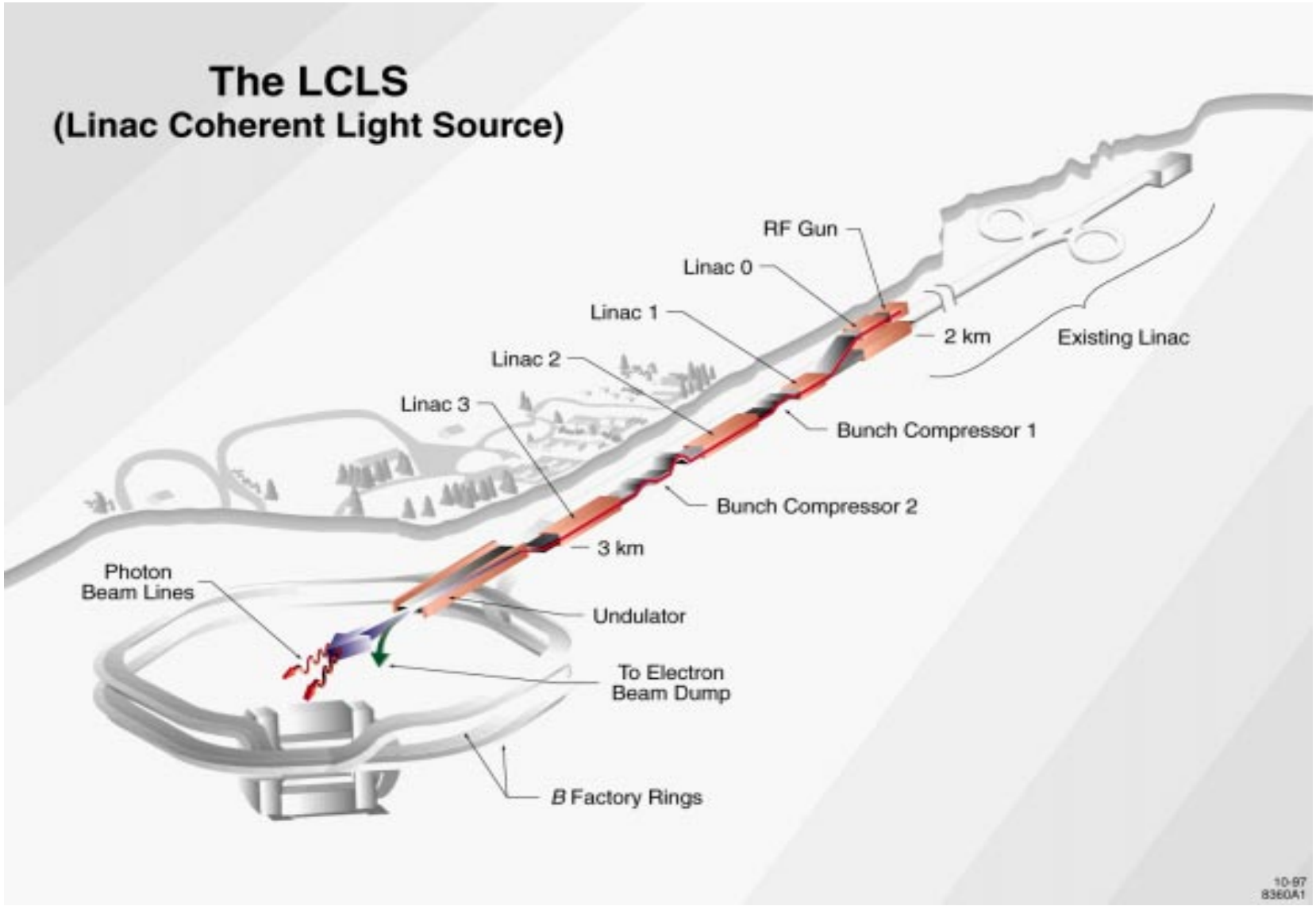
LCLS Performance Characteristics

- 1.5 - 15 Å
- 300 fs pulse width
- 100 Hz rep. rate
- 10^{12} ph./pulse
- full transverse coherence
- longitudinally incoherent





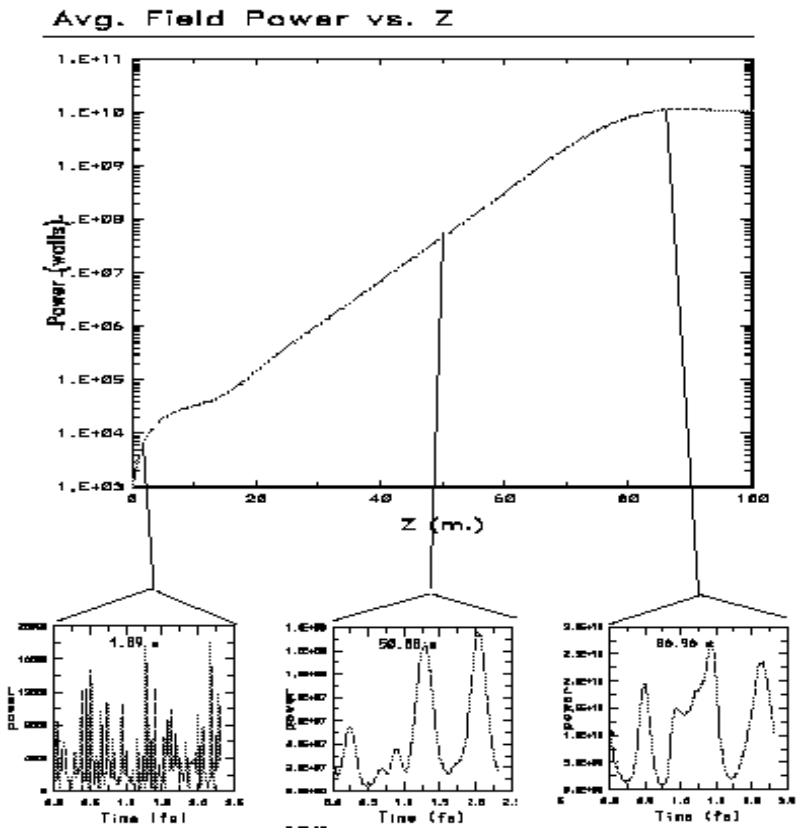
LCLS Conceptual View



Self-Amplifed Spontaneous Emission (SASE)

- SASE FEL theory well developed and used in simulations
- FEL starts from noise in spontaneous radiation
- Electric field modulates the energy and bunches the electrons within an optical wavelength
- Exponential build up of radiation along undulator
- Experimental verifications:
  - 12 μm at LANL (1998)
    - gain = 3 x 10^5; almost saturated
  - 490 & 530 nm at APS (1999)
    - not saturated
  - 110 nm at DESY (2000)
    - not saturated

Ginger Simulation



Linac Coherent Light Source (LCLS)

- **R&D Plan for FY1999-2002**

  Continue SASE experiments (VISA at BNL; LEUTL at APS)
  FEL simulations
  Photo-injector studies
  Studies of beam compression and effect of coherent synchrotron radiation
  Beam diagnostics
  Build and test a prototype undulator segment
  X-ray optics simulations and experiments
  Experimental program and instrumentation

- **Proposed Construction Plan**

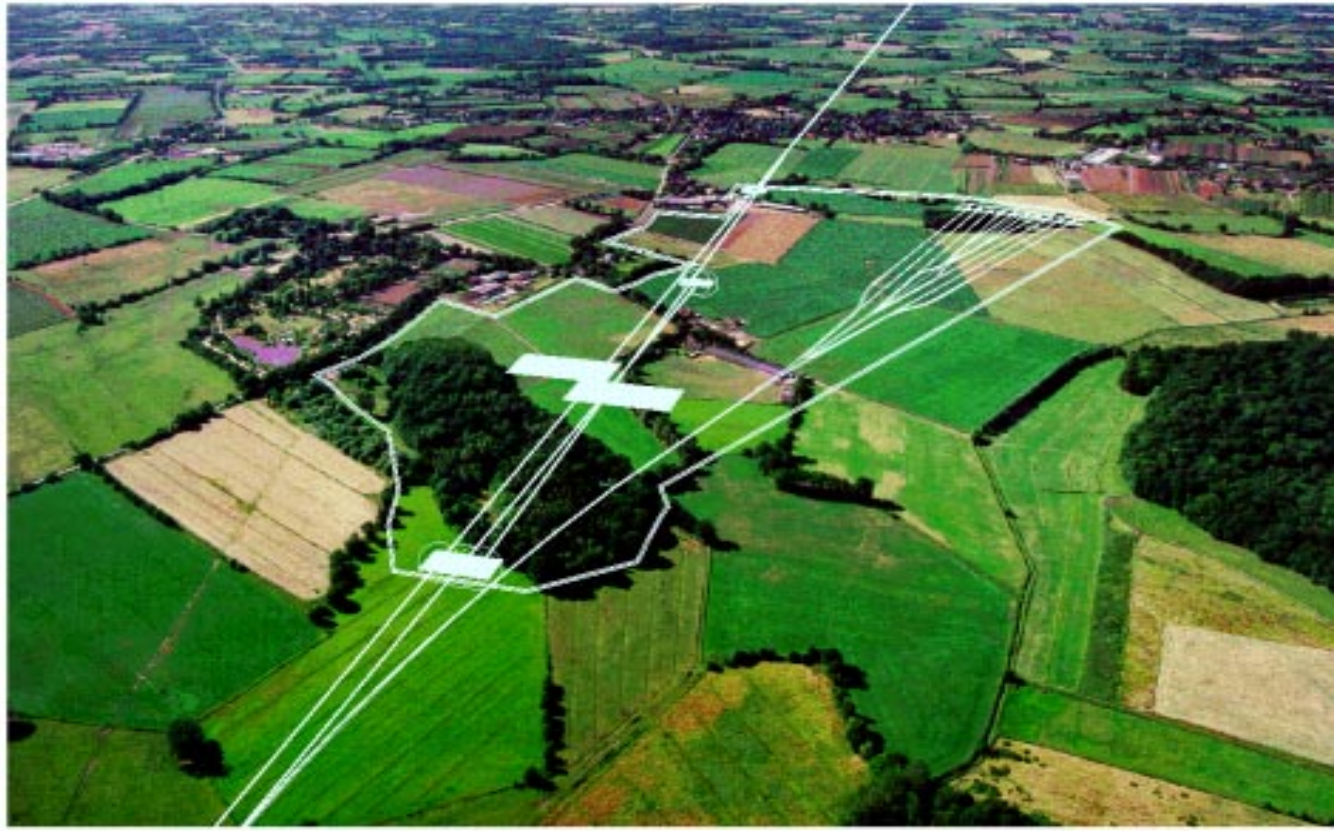
  Conceptual design completed in spring 2001
  Critical R&D completed and construction start in FY2003

X-FEL Facility at TESLA/DESY (Germany)

250 GeV linear collider
with
integrated FEL facility
for 20 - 1 Å wavelength

road map :

1999 - proof of principle
for SASE → 2/00
2001 - proposal
- evaluation by German
Science Council
2003 - decision
2010 - user operation



DESY

TESLA Test FEL Facility

Operational and achieved first lasing at 110 nm in February, 2000

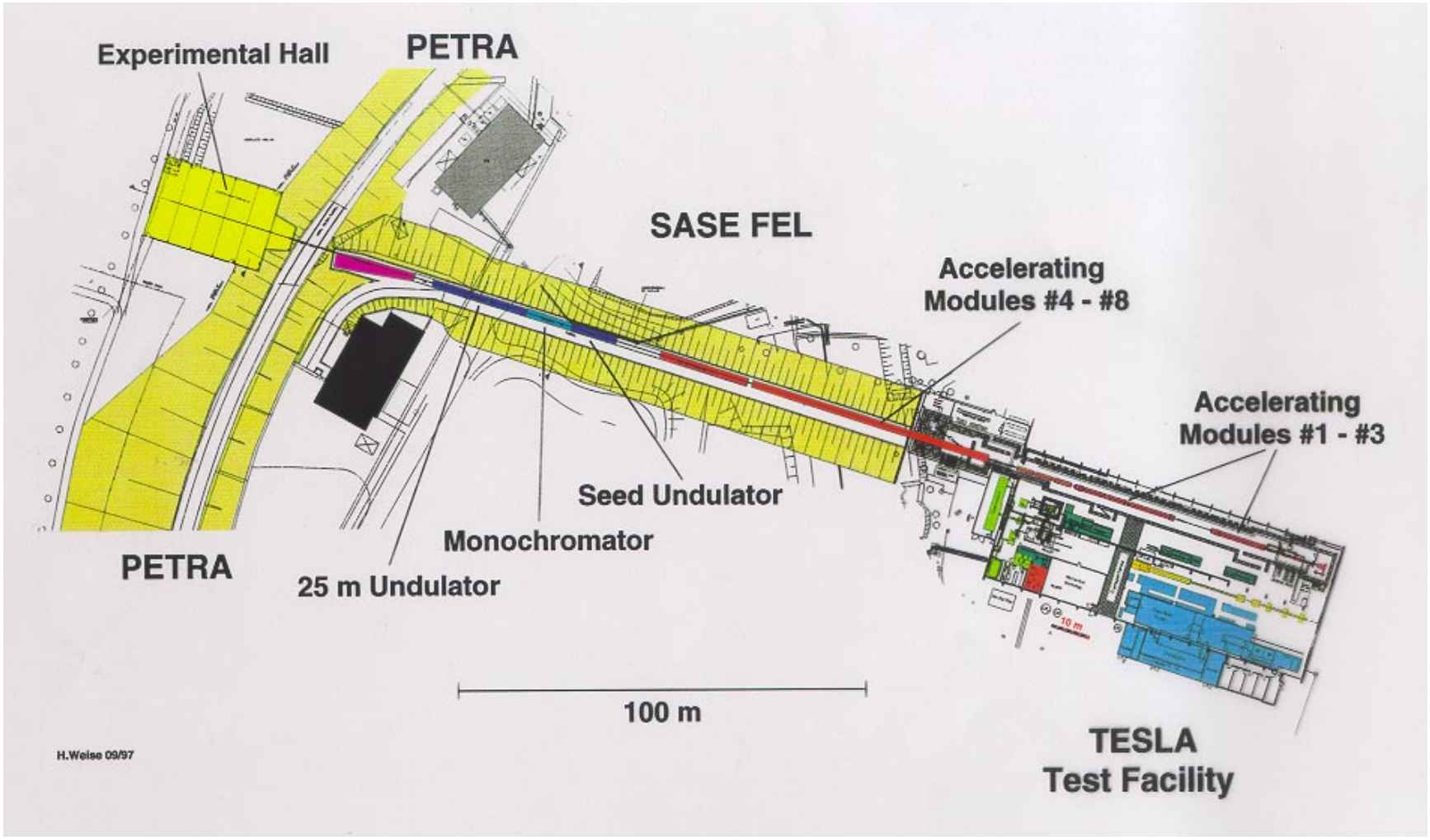
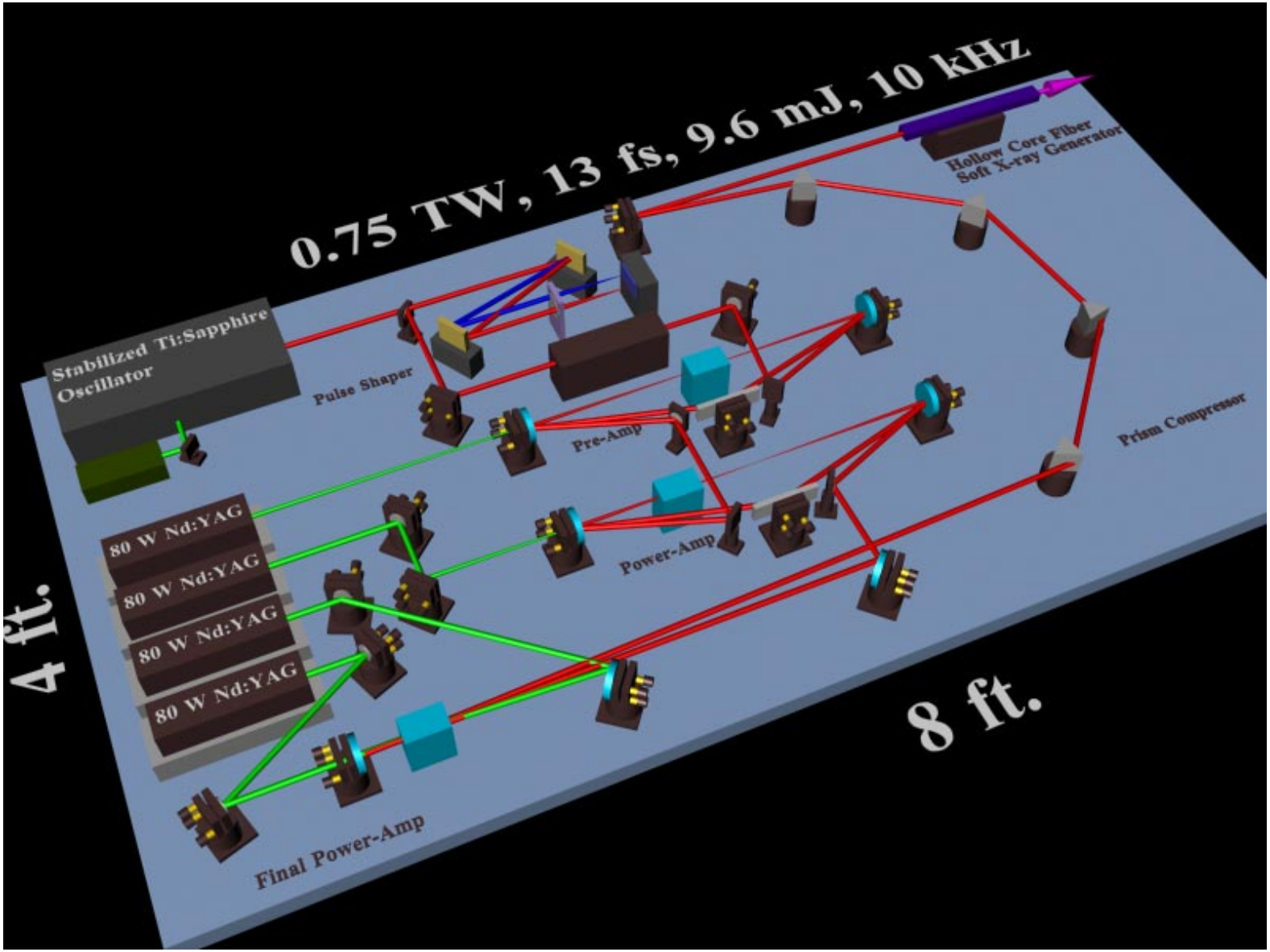


Table-top x-ray sources

Next generation ultrafast laser system

Margaret Murnane & Henry Kapteyn, JILA/Univ. of Colorado



Novel X-ray Light Source Initiative

- **Non-FEL recommendations of Leone panel**

  To support the development and application of table-top x-ray sources, the better utilization of existing third generation sources and to explore scientific applications using ultrafast x-ray pulses

  Both DOE labs and university solicitations for proposals in FY2000

- **New projects (total funding ~$1M/yr.)**

  1 new grant started in FY1999; 1 existing grant redirected

  HHG generation/optimization/utilization; coherent Thomson scattering

  5 new grants and 1 new lab project begun in FY2000

http://www.sc.doe.gov/production/grants/fr99_24.html

Novel X-ray Light Source Initiative

◆ Proposal solicitation, review and awards

18 proposals (12 university and 6 lab) grouped into 3 sets; each reviewed by panel of 5-6 reviewers

A. Fundamental Physics
B. Source Development and Applications (accelerator based)
C. Source Development and Applications (table-top lasers)

6 New awards ($940k in FY00):

"The Phonon Bragg Switch" by Phil Bucksbaum and Roberto Merlin, University of Michigan

"Multiphoton Quantum Dynamics & Optimal Generation of Coherent X-Ray Harmonic Emission" by Shih-I Chu, University of Kansas

Collaborative with Murnane/Kapteyn

"Development and Utilization of Bright Tabletop Sources of Coherent Soft X-Rays" by Jorge Rocca, Colorado State University

"Ultrafast Coherent Soft X-rays: A Novel Tool for Spectroscopy of Collective Behavior in Complex Materials" by Keith Nelson, MIT

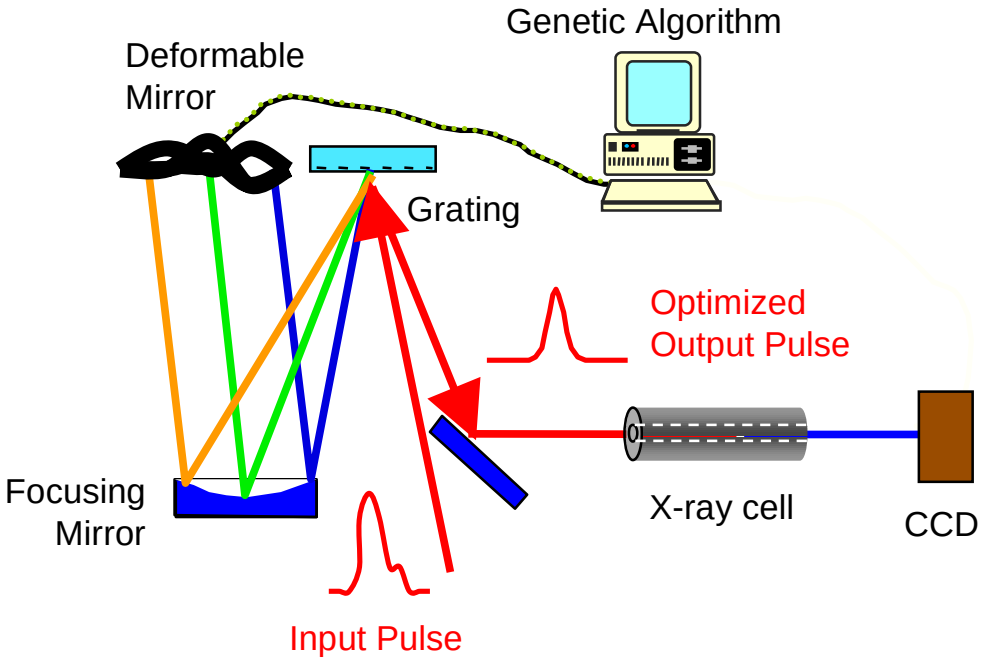
Collaboration

"100 fs X-Ray Detector" by Zenghu Chang, University of Michigan

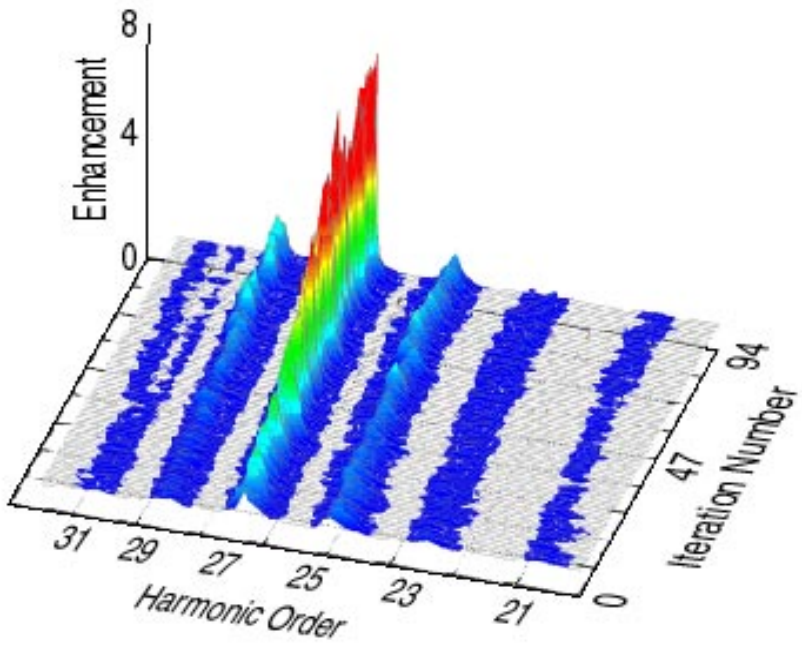
"Femtosecond X-ray Beamline for Probing Ultrafast Dynamics in Condensed Matter" by Robert Schoenlein et al., ALS

5 proposals held for possible funding in FY01; 7 proposals declined

Coherent Control of HHG for Soft X-Ray Production



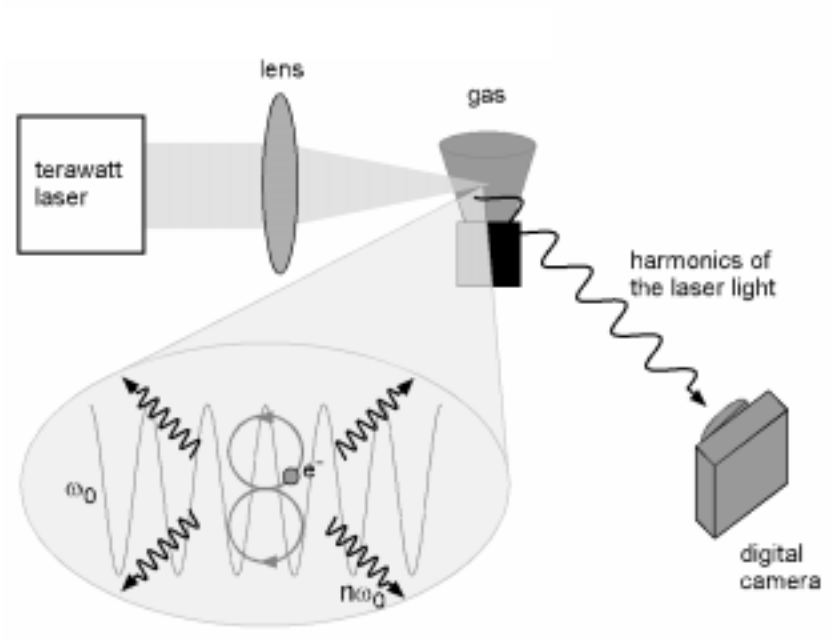
Nature, July 2000

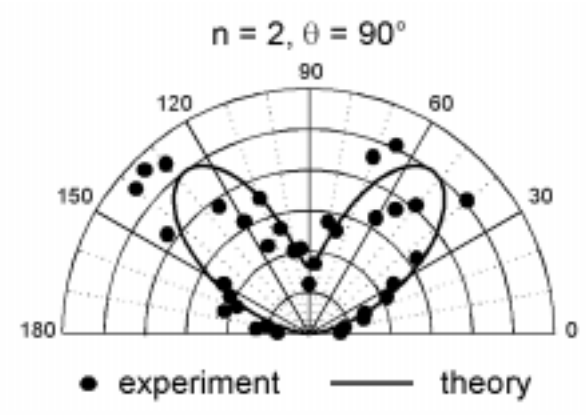


- **1st demonstration of feedback control of highly nonlinear system (HHG) using "survival of the fittest" genetic algorithm**
- **Optimizes SINGLE harmonic by controlling the wavefunction of the electron that rescatters off the ionic core**
- **10-fold increase in brightness of selected harmonic with improved energy resolution**

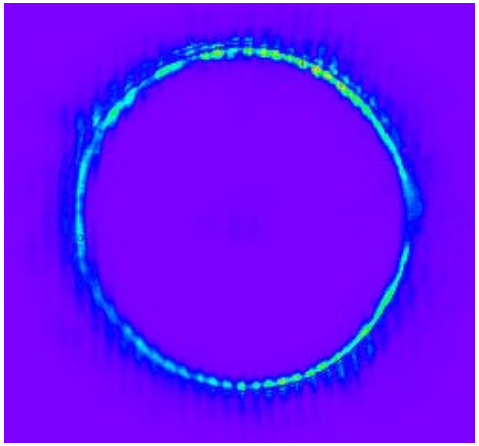
Margaret Murnane* and Henry Kapteyn
JILA/Univ. of Colorado
*2000 MacArthur Fellow

Coherent, Relativistic Thomson Scattering



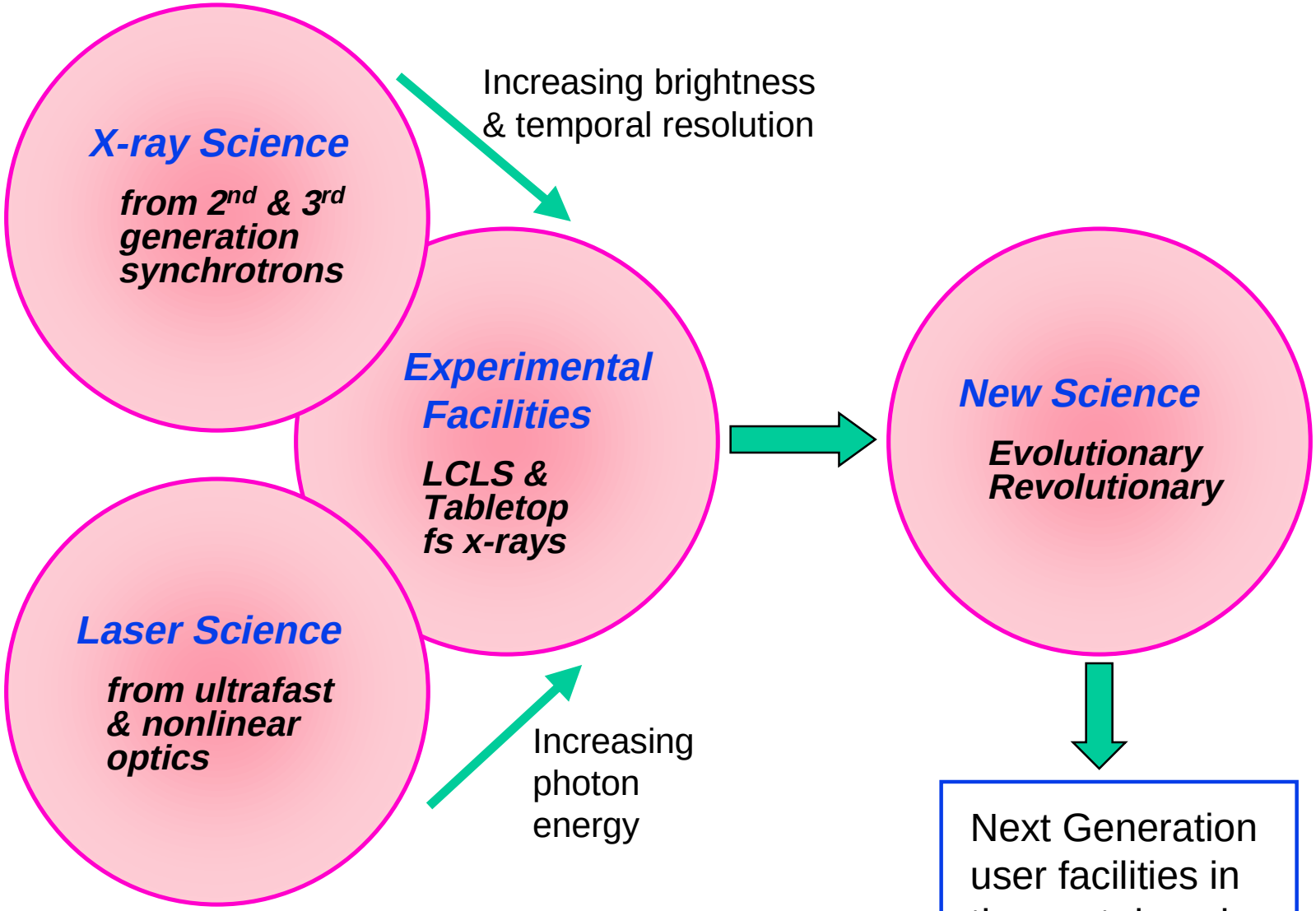


- **Relativistic Thomson scattering first observed in 1998**
- **Characterized by harmonic generation and angular distribution**
- **New work demonstrates process can be phase matched, giving coherent cone of 3rd harmonic**



Donald Umstadter et al.
Univ. of Michigan

What new science?



Scientific Case for Coherent X-rays

- **Leone panel recommendation:**

"The scientific case for coherent hard x-ray sources is in the formative stages and appears extremely promising, but must be improved to attain a more compelling and rigorous set of experiments that can be achieved only if such a new coherent light source becomes available."

Strong coupling of x-ray and laser community needed

Light source properties integral part of science

Major issue of sample degradation must be addressed

- **Strengthening the scientific case is a requirement for BES to proceed with the LCLS as a construction project**

Scientific Case for Coherent X-rays

- **Series of workshops to better define broad scientific case (with BES support)**
  - Chaired by Gopal Shenoy (APS) & Phil Bucksbaum (Michigan)
  - Goal is to produce document at same time as LCLS CDR
  - Several topical workshops held since 1999 - more coming
- **Separate scientific case document requested from LCLS by BES at last BESAC meeting (Feb. 2000)**
  - More directly tied to decision on proceeding with LCLS construction
  - Aimed at defining (in some detail) the first classes of experiments that would be mounted on the LCLS
  - Basis for experimental requirements for the LCLS CDR
  - Assembled through the LCLS Scientific Advisory Committee (Jo Stohr & Gopal Shenoy, co-chairs)