# THz experiments at the UCSB FELs and the THz Science and Technology Network.

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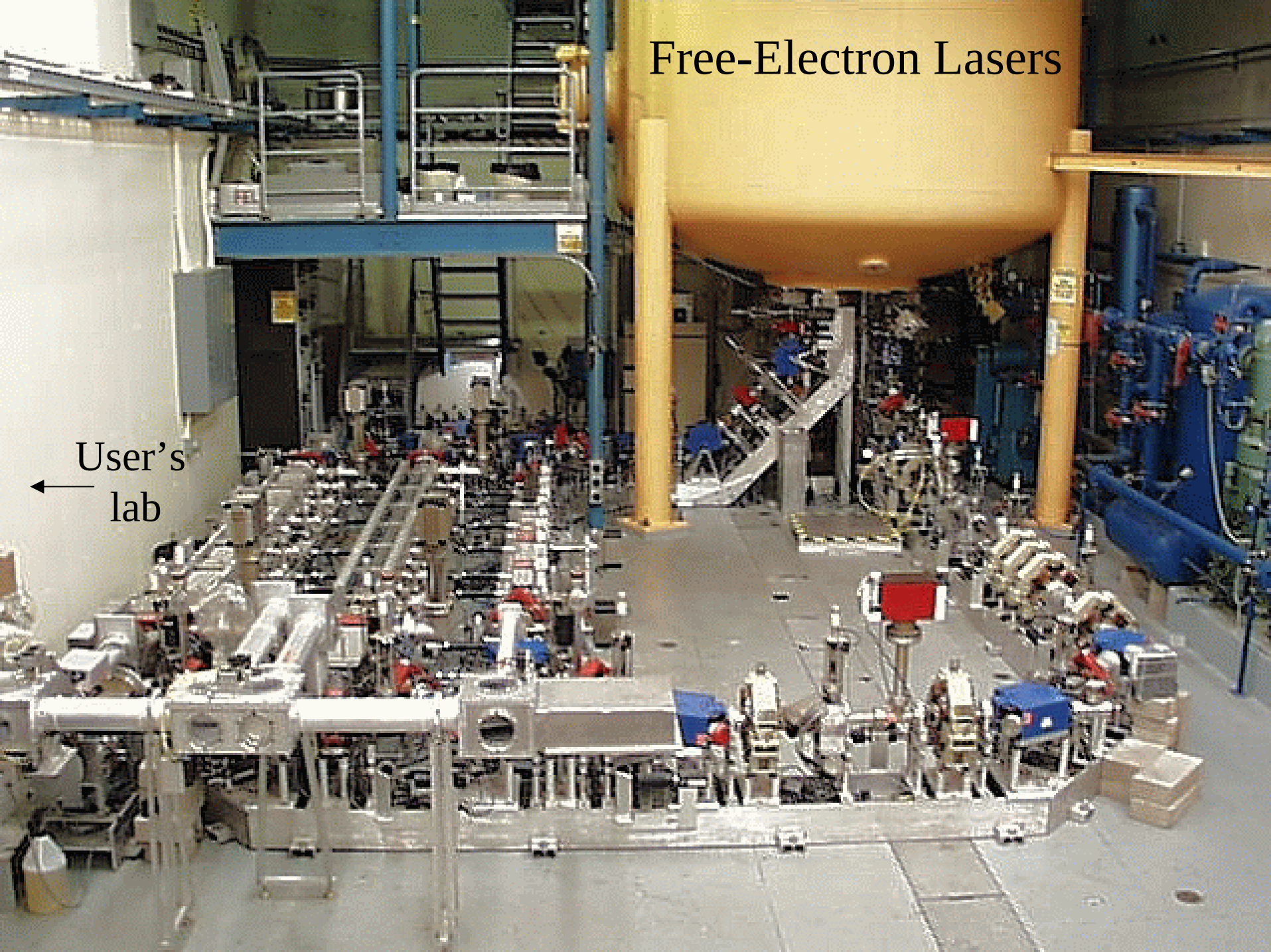
UCSB

*Physics Department*

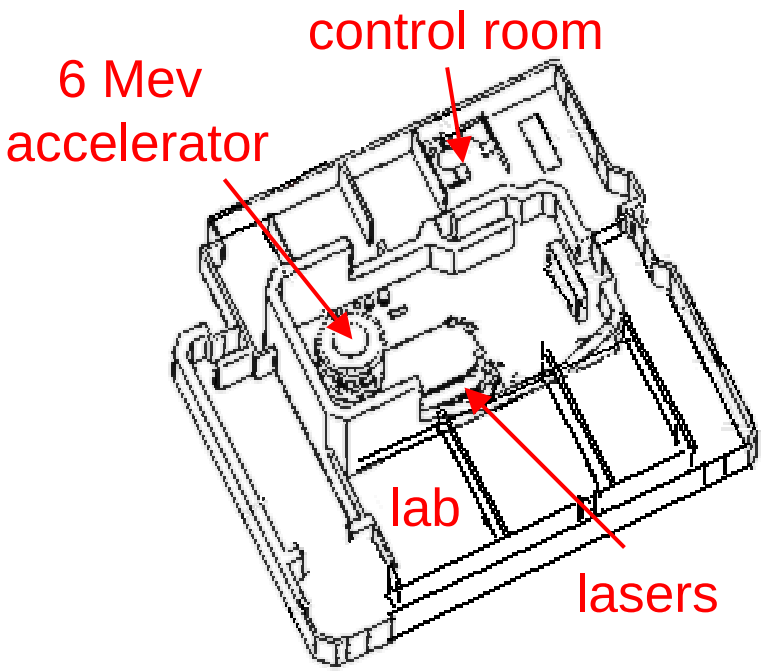
and

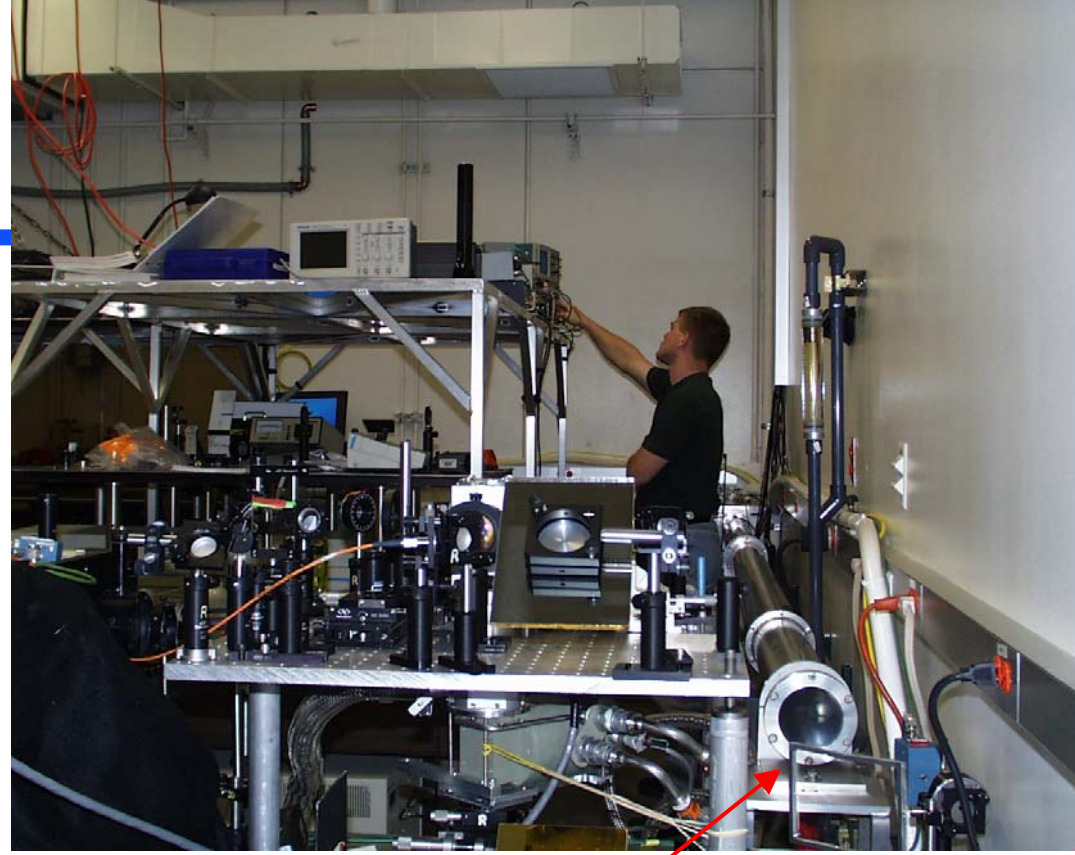
*Institute for Quantum and Complex Dynamics*

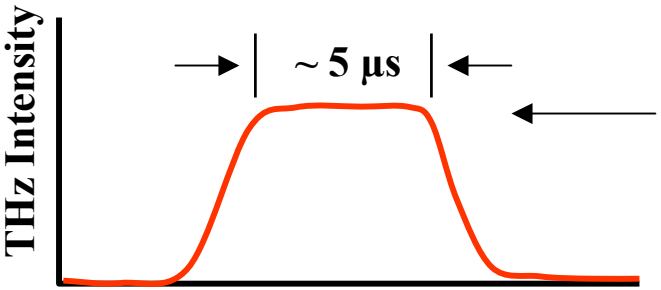

UCSB
Center for
Terahertz
Science and
Technology
UCSB
Free-
Electron
Lasers
Free-Electron Laser User's Labs


Free-Electron Lasers
User's lab

# User labs and output characteristics




**≤5 kW**

**0.12 - 4.8 × $10^{12}$ Hz (0.5-20 meV, 4-160 $cm^{-1}$)**

**Pulsed at ~ 1 Hz**

# Outline

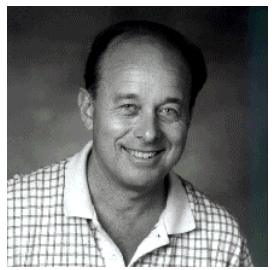
- High-field THz experiments at UCSB
  - Terahertz electro-optics in semiconductor quantum wells
  - Rabi oscillations of electrons bound to Hydrogenic donors in GaAs

Sam Carter

Victoria Ciulin

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Chad Wang



Larry Coldren

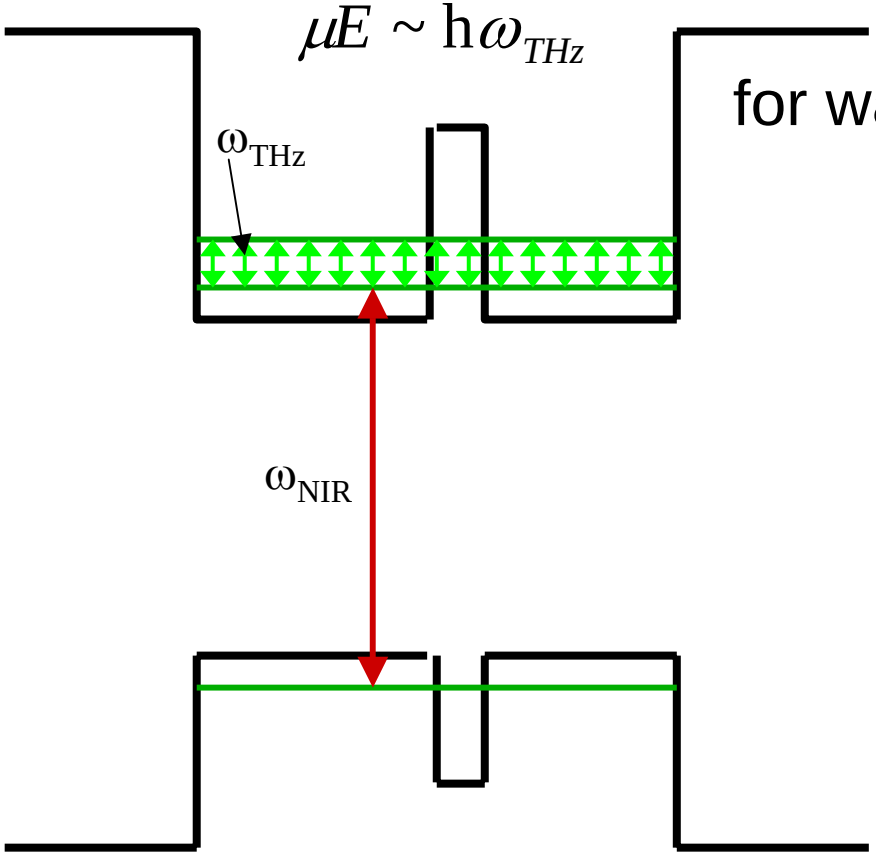
Alex Maslov, MSS

- Terahertz Science and Technology Network

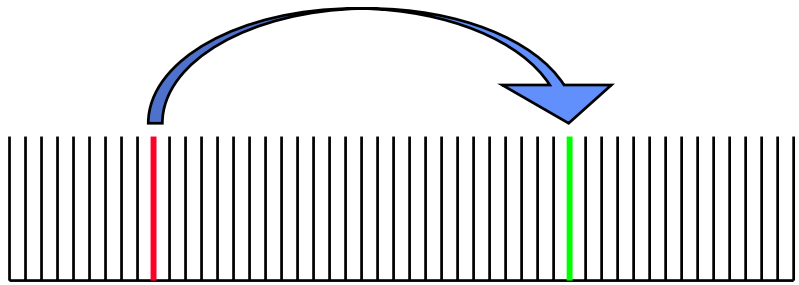
# Motivation for THz electro-optics

Spectroscopy of strongly-driven quantum system

$\mu E \sim \hbar\omega_{THz}$

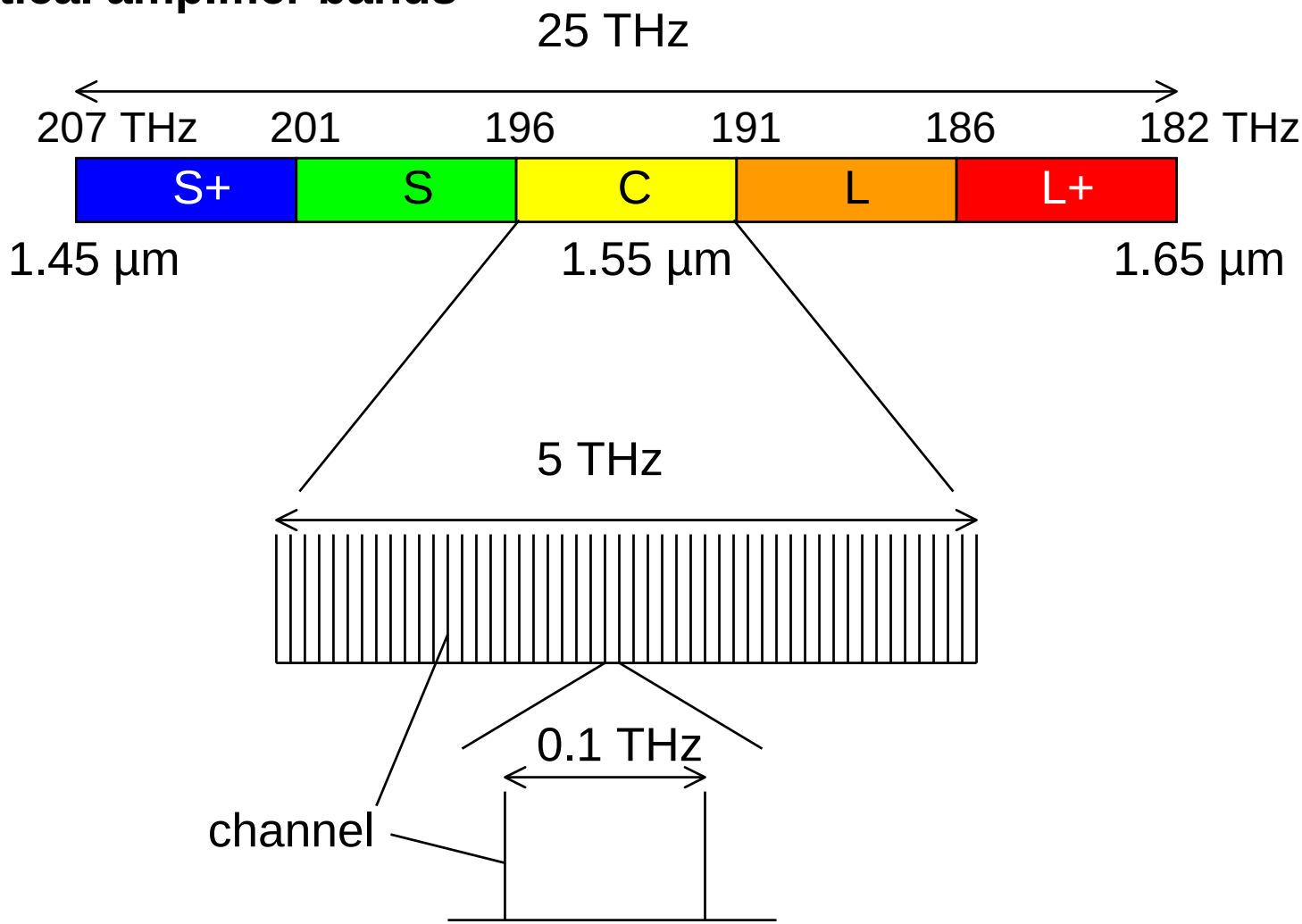



Voltage-controlled all-optical wavelength conversion for wavelength-division multiplexing

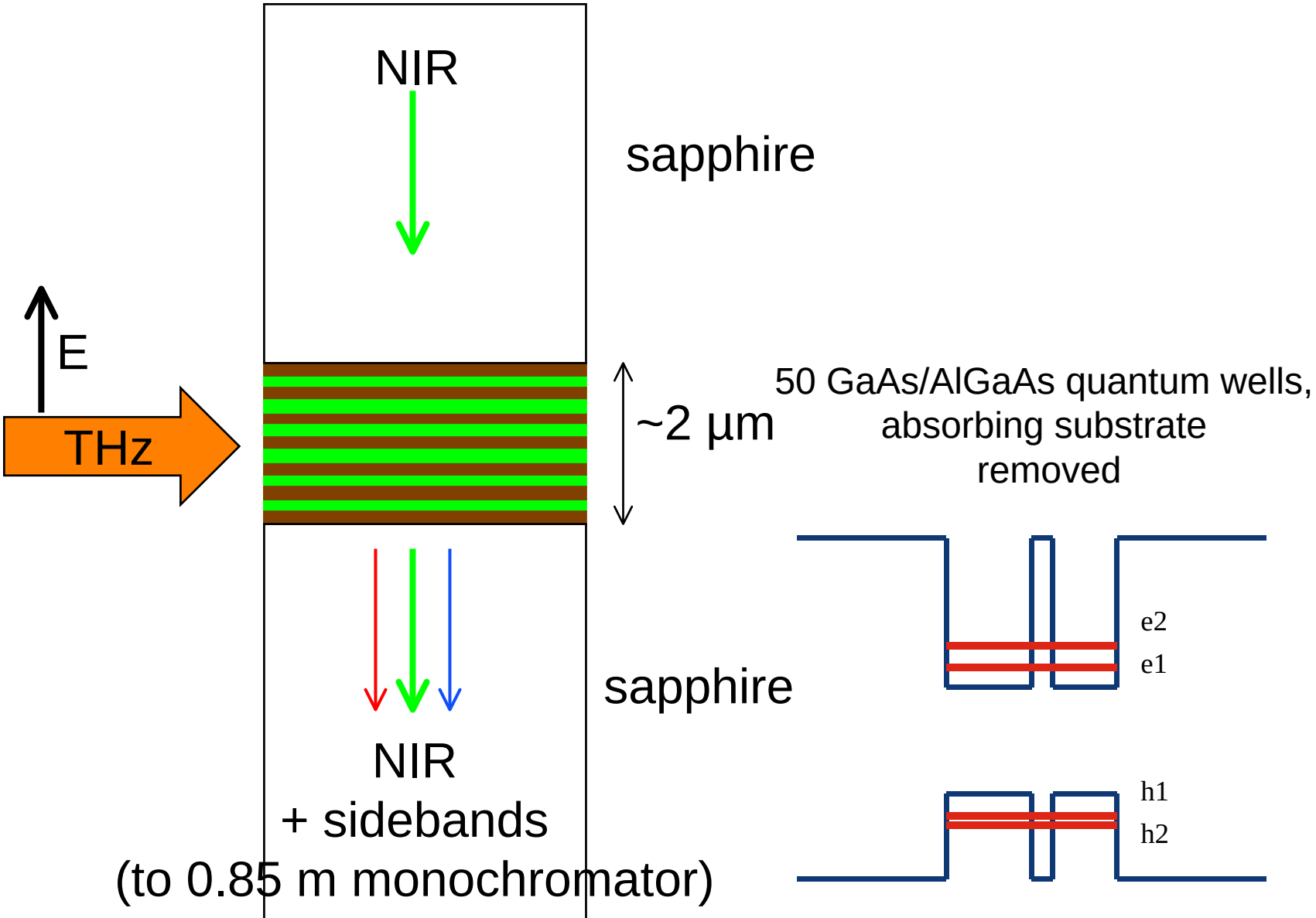


# The Terahertz in fiber-optic communications

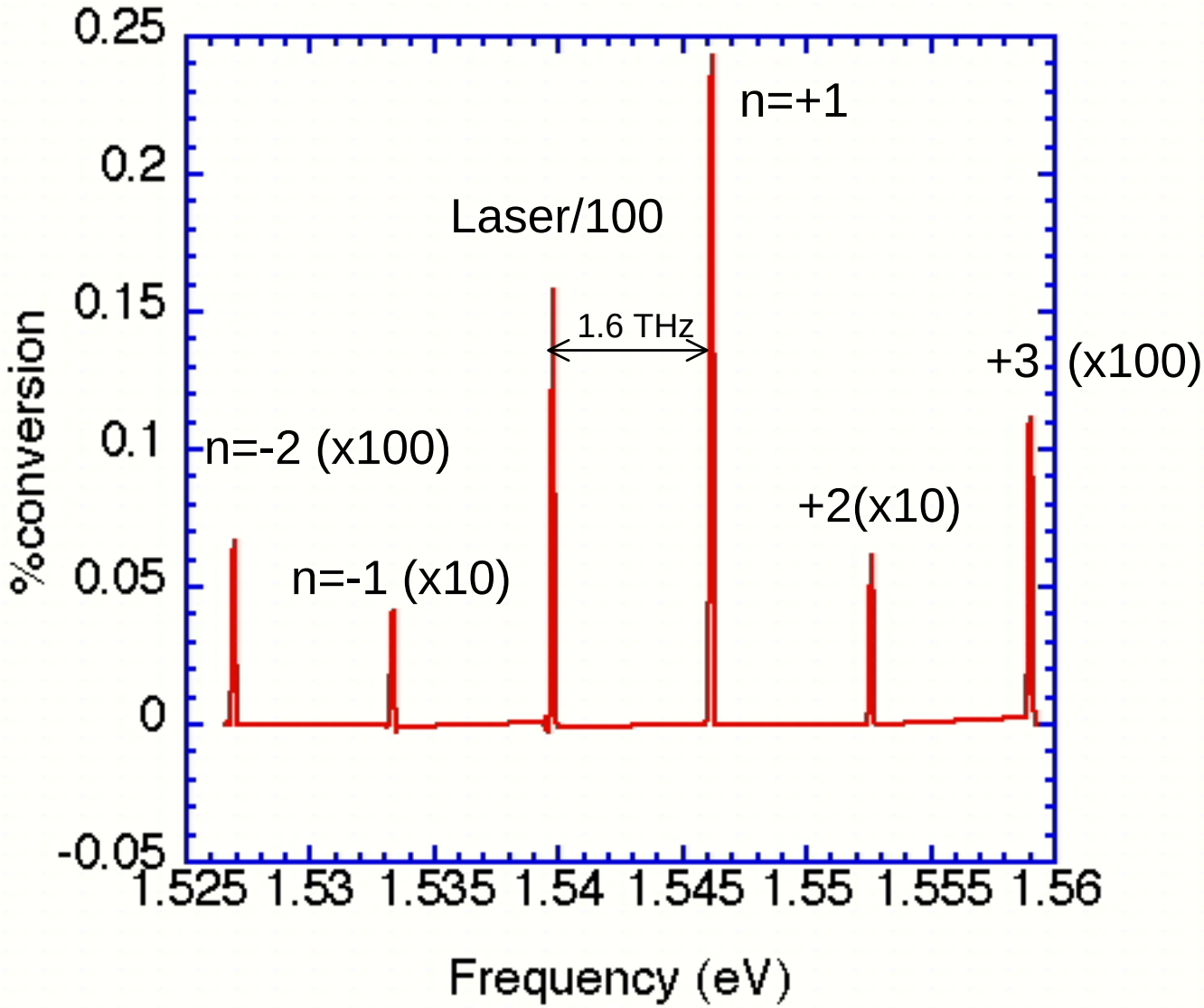
**Optical amplifier bands**



# Sample and experimental geometry



# THz modulation of optical properties: sidebands



# Conclusions for THz electro-optics

- THz sidebands:
  - easy to explore using high-power, accelerator-based FEL source
  - With careful engineering, can envision chip-based wavelength conversion with QCL source.

# Rabi oscillations of electrons bound to shallow donors

Bryan Cole
(now @ TeraVision)

Jon Williams
(now @ Caltech)

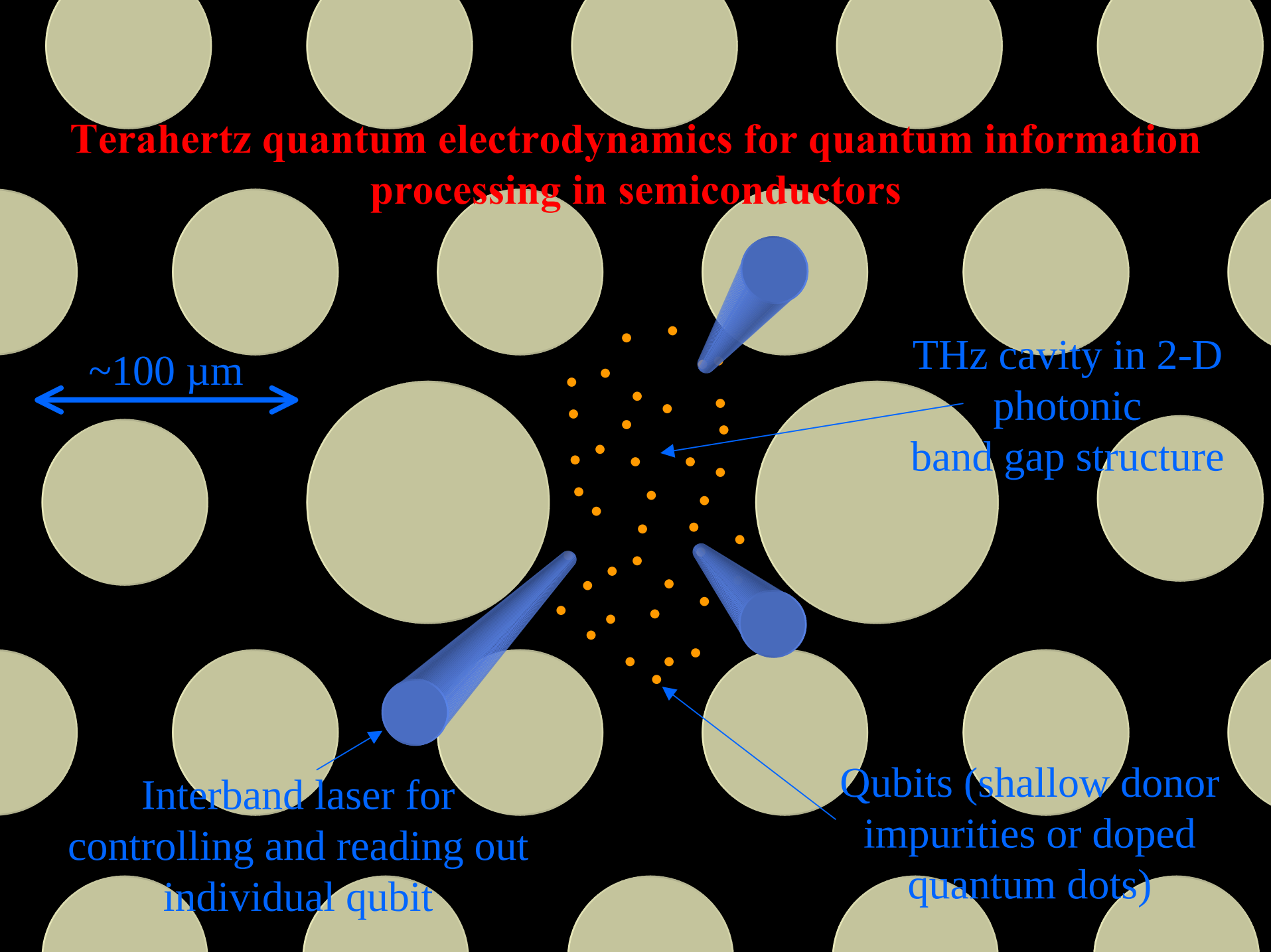
Tom King
(N. Zealand)

Matt Doty
Now@NRL


–Samples: Colin Stanley, U. of Glasgow

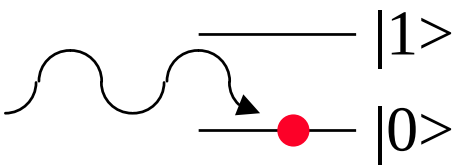
–Support: DARPA/QUIST

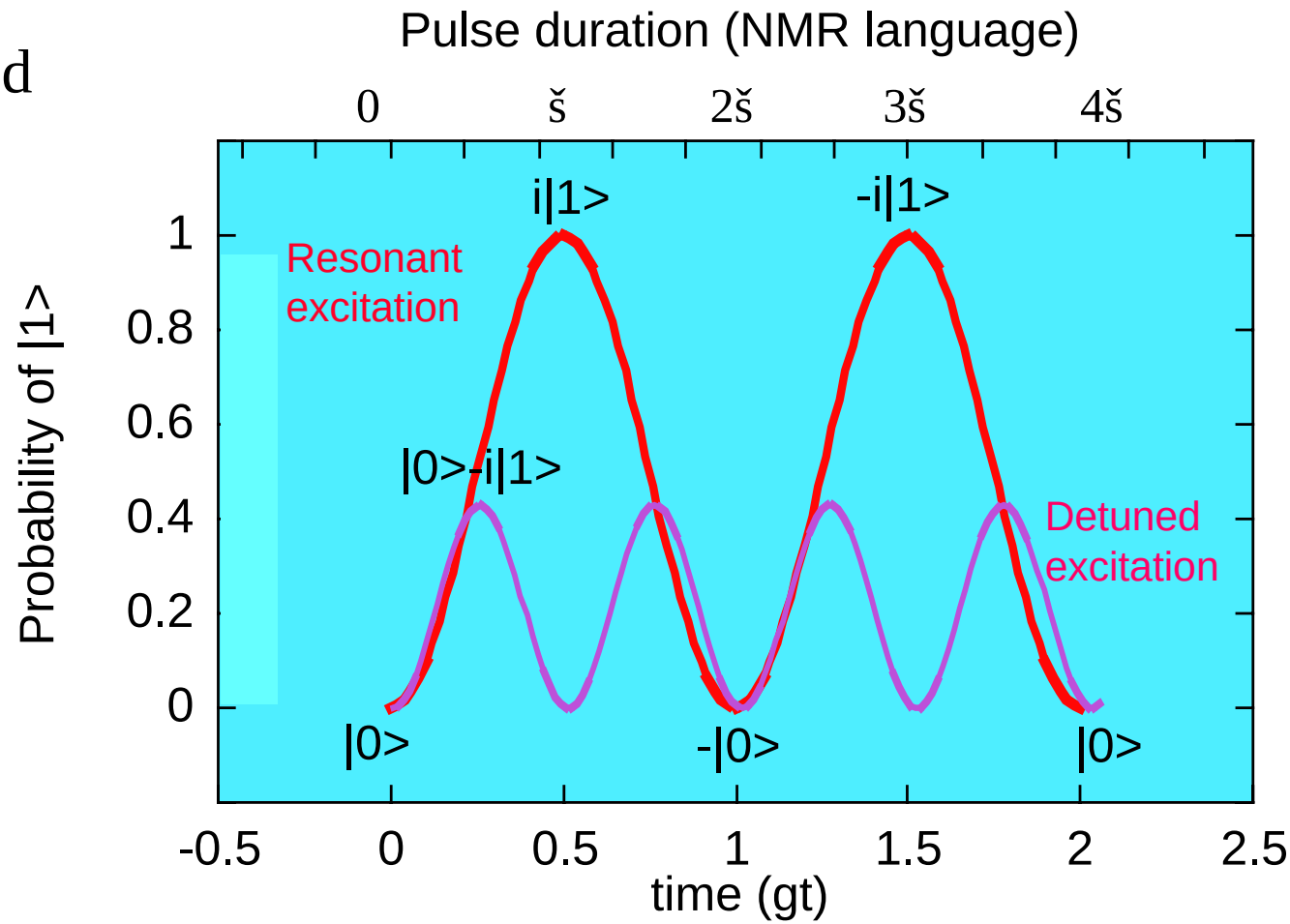
# Terahertz quantum electrodynamics for quantum information processing in semiconductors



# Two-state system in a resonant oscillating field

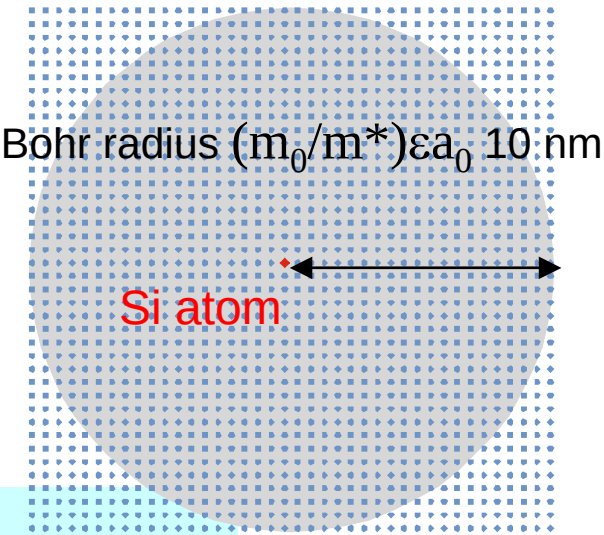
|1> and |0> coupled with strength g



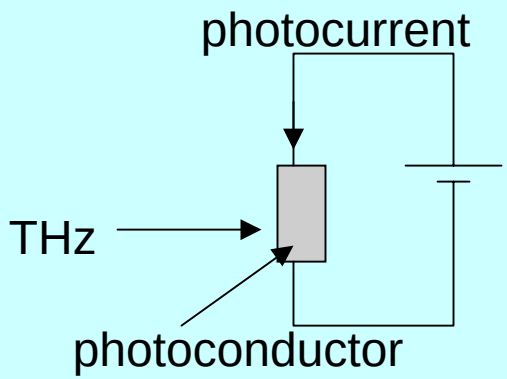



# Hydrogenic donors

- Example:  Si in GaAs
- Effective mass approx.:  H atom w.
  - m-> m*=0.067
  - Dielectric const. -> 13
  - Ry->Ry*~ $(m^*/m_0)\ (1/\varepsilon^2)13.6$ eV ~4 meV

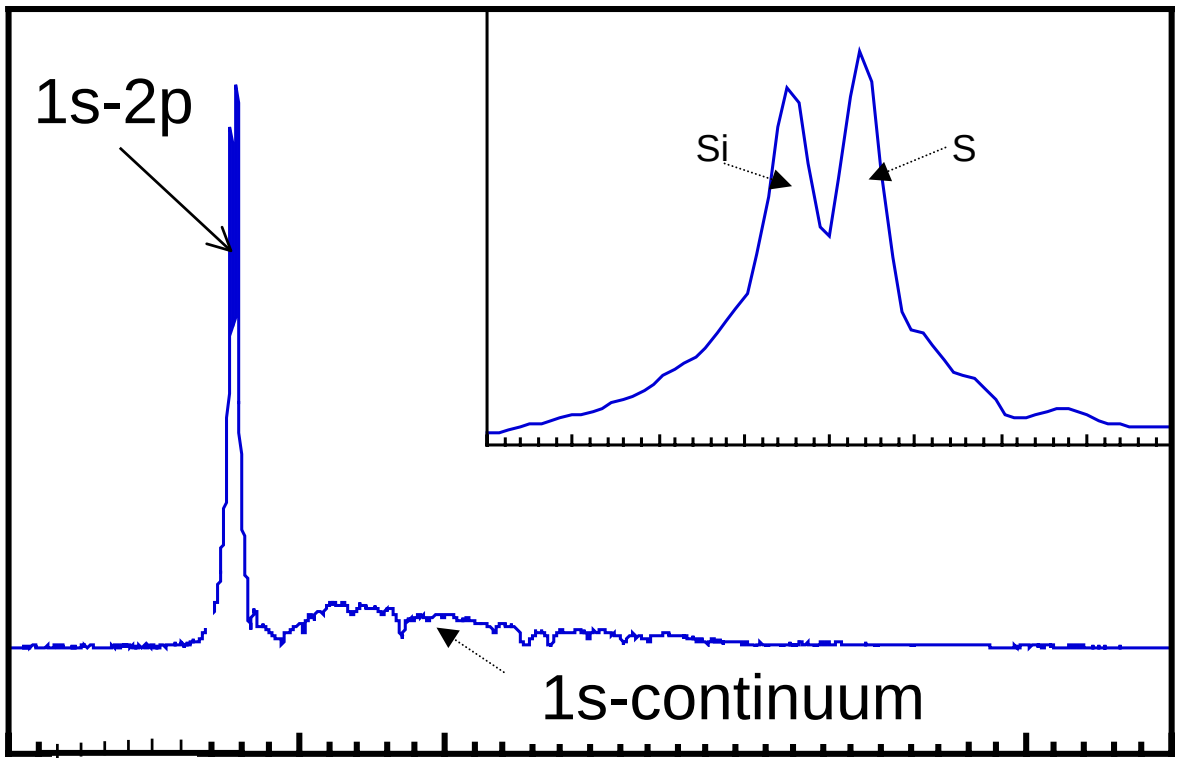



- Samples & experiment
  - Epitaxial GaAs, $N_D$-$N_A$=$10^{14}$ $cm^{-3}$
  - From Prof. Colin Stanley, U. Glasgow

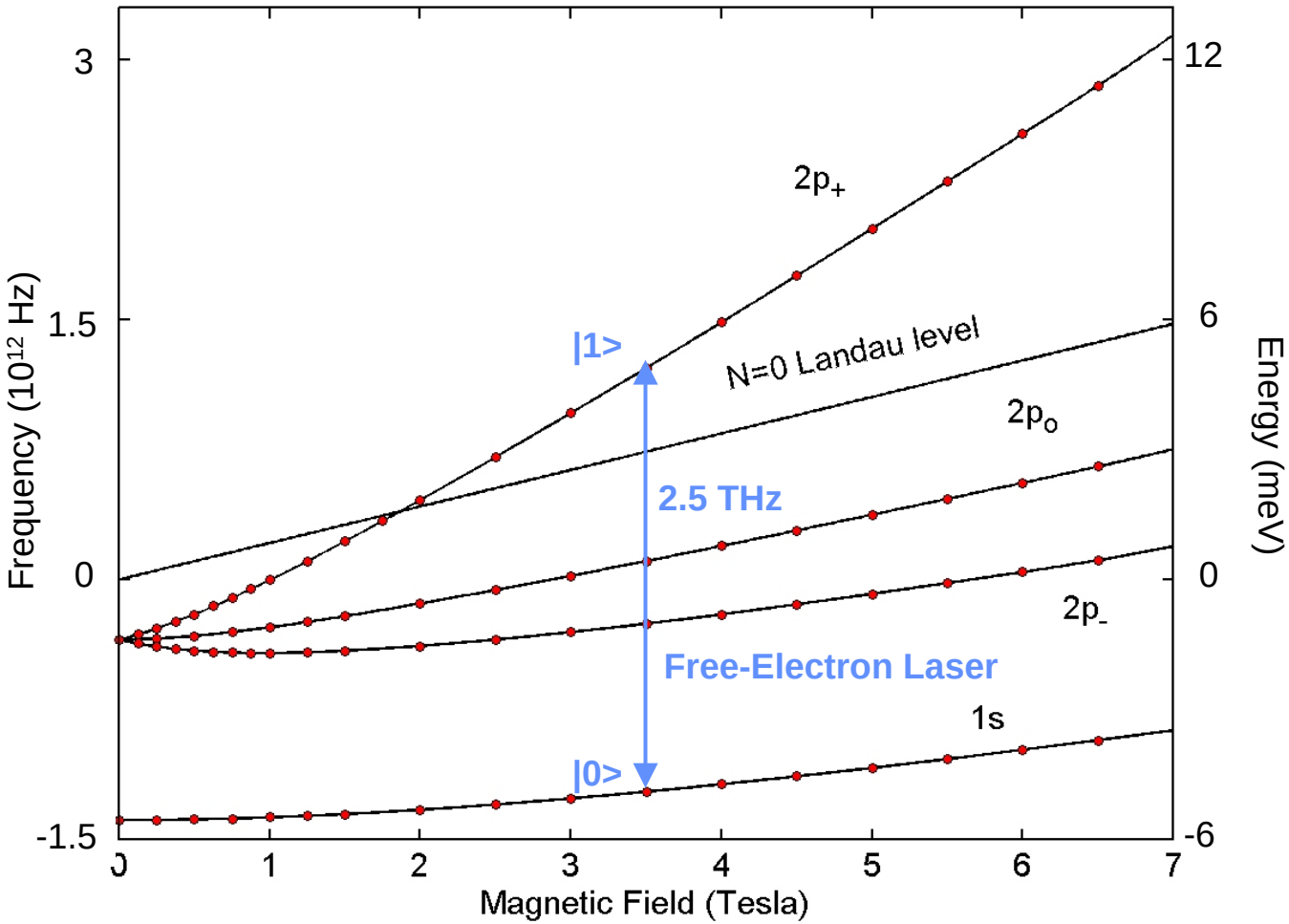


# Photocurrent spectrum (B=0)

Lines inhomogeneously-broadened



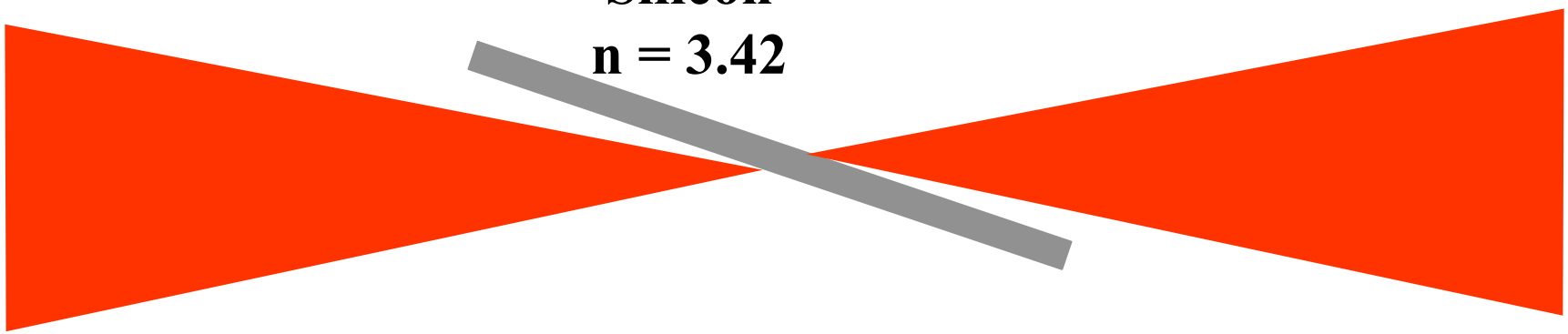
# B-dependence of Hydrogenic levels in GaAs



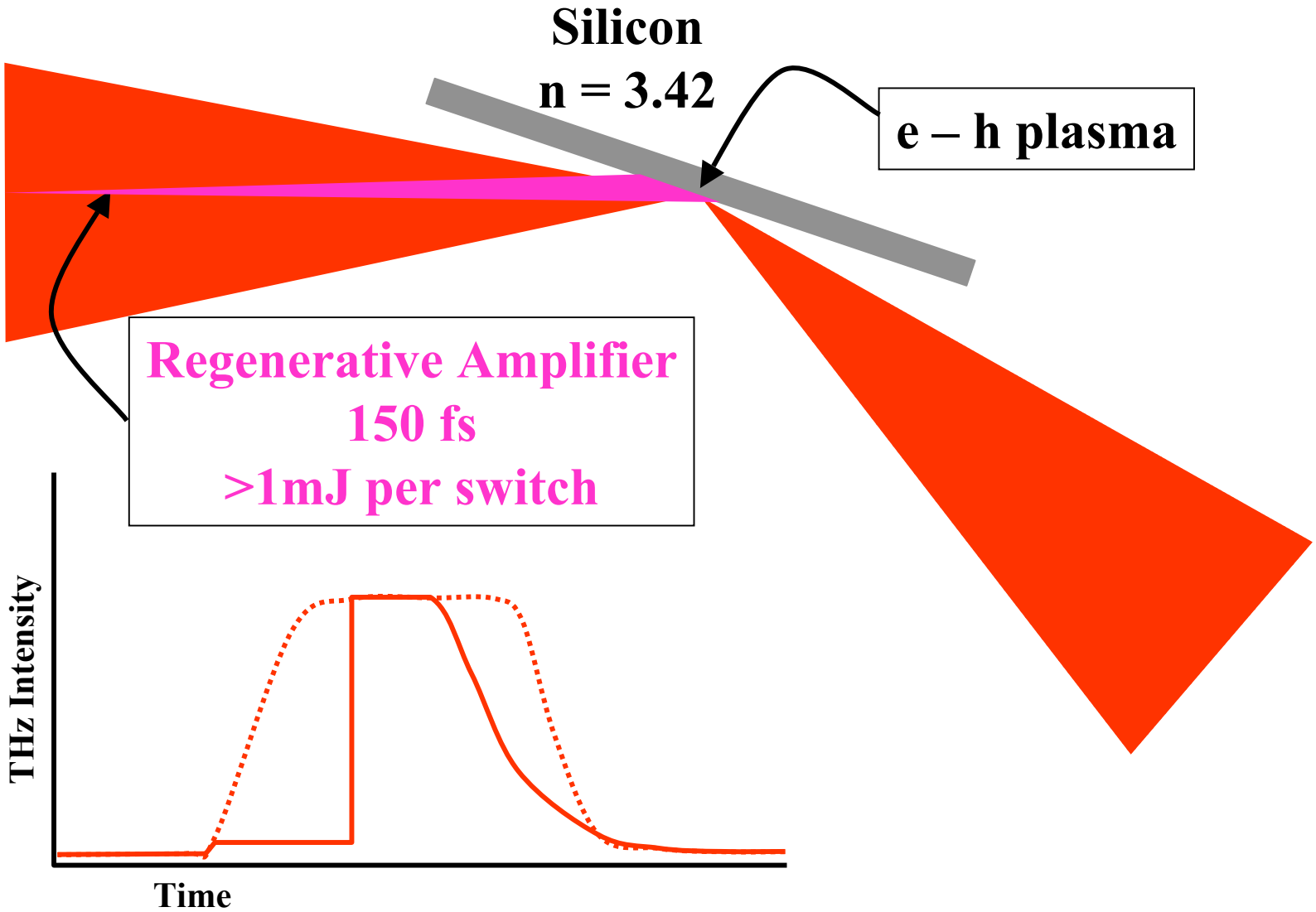

Data: Stillman and Wolfe, 1969

Calculations: B. Tom King (following Larsen, 1968)

# THz Switches



# THz Switches

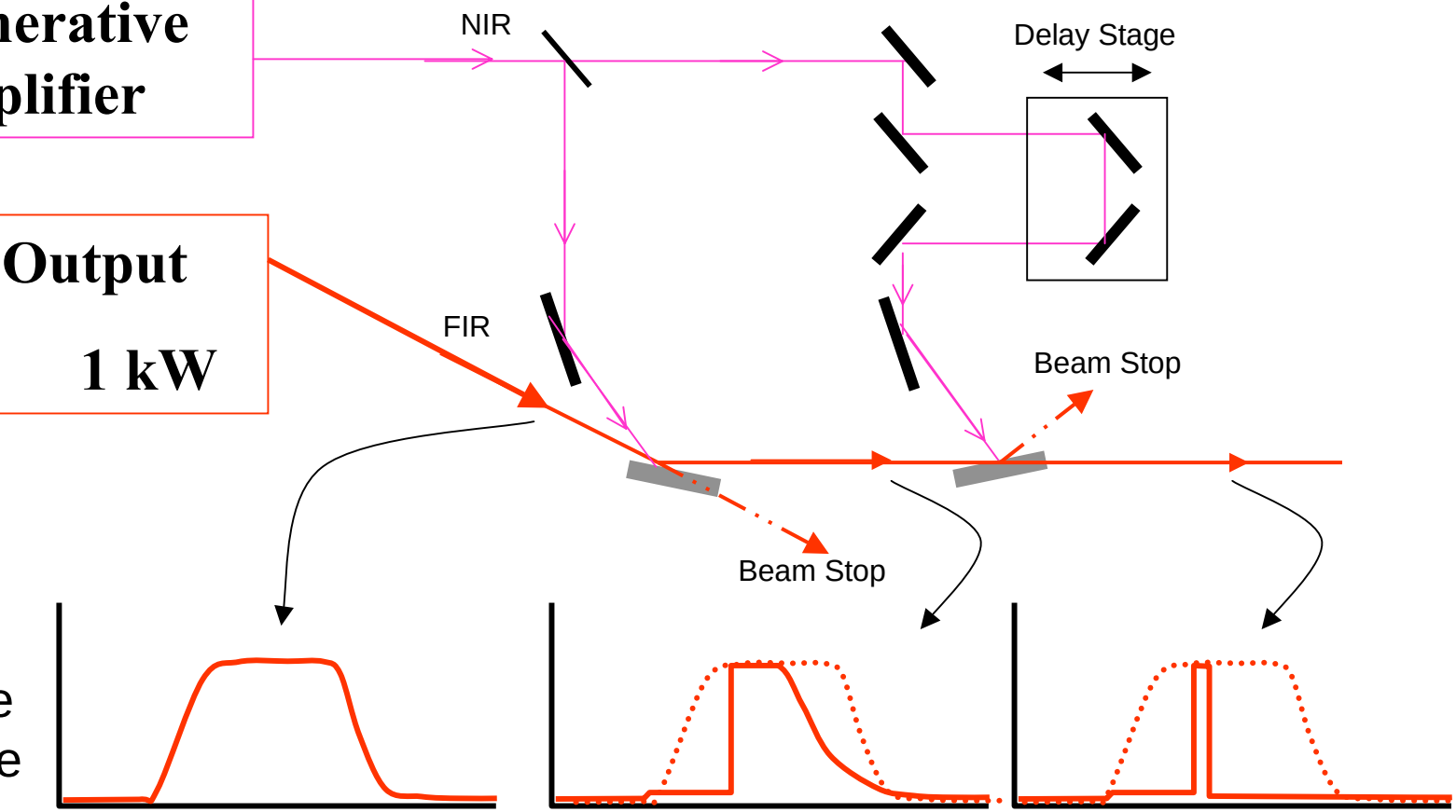


# Short THz Pulses:Pulse Slicer

**Regenerative Amplifier**

**FEL Output**

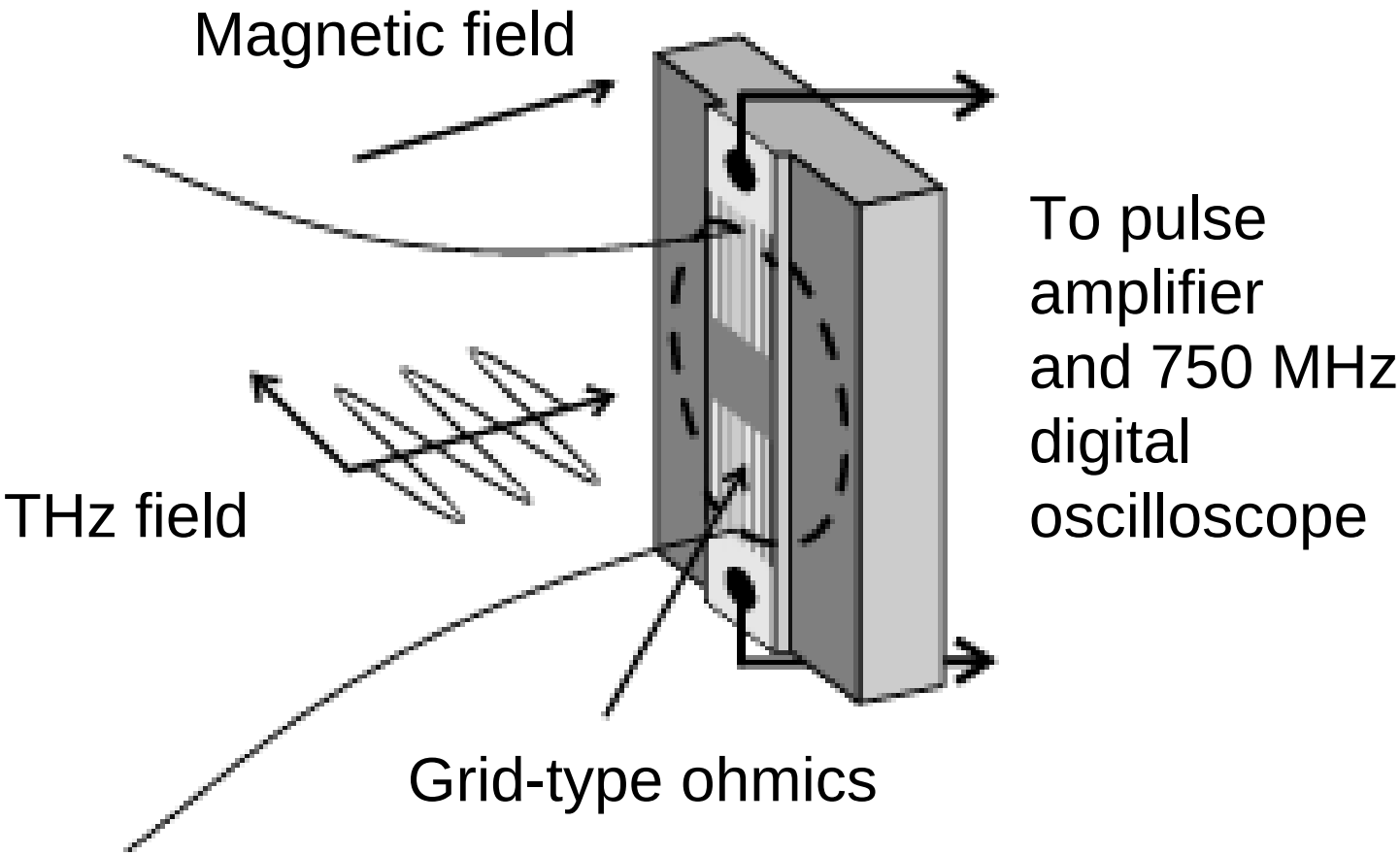
**~ 4 μs  1 kW**



# “Sliced” pulses

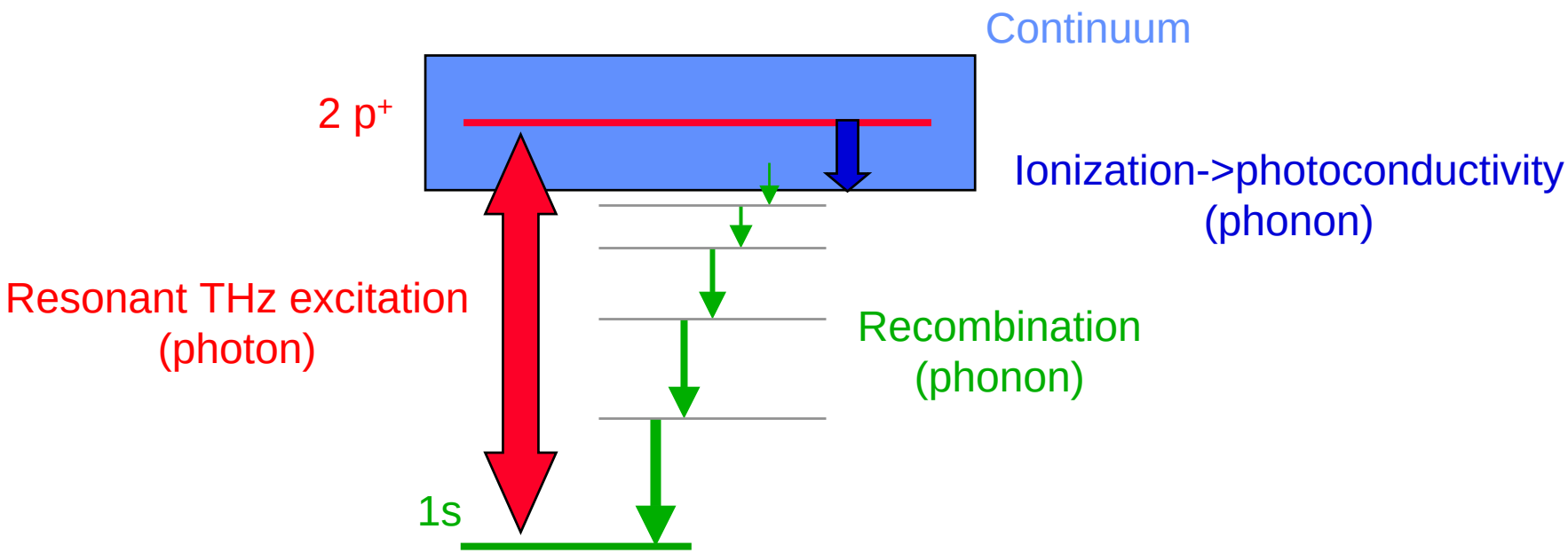

F. A. Hegmann, MSS et. al., Appl. Phys. Lett. **76**, 262 (2000)

# Sample geometry, RO in impurities

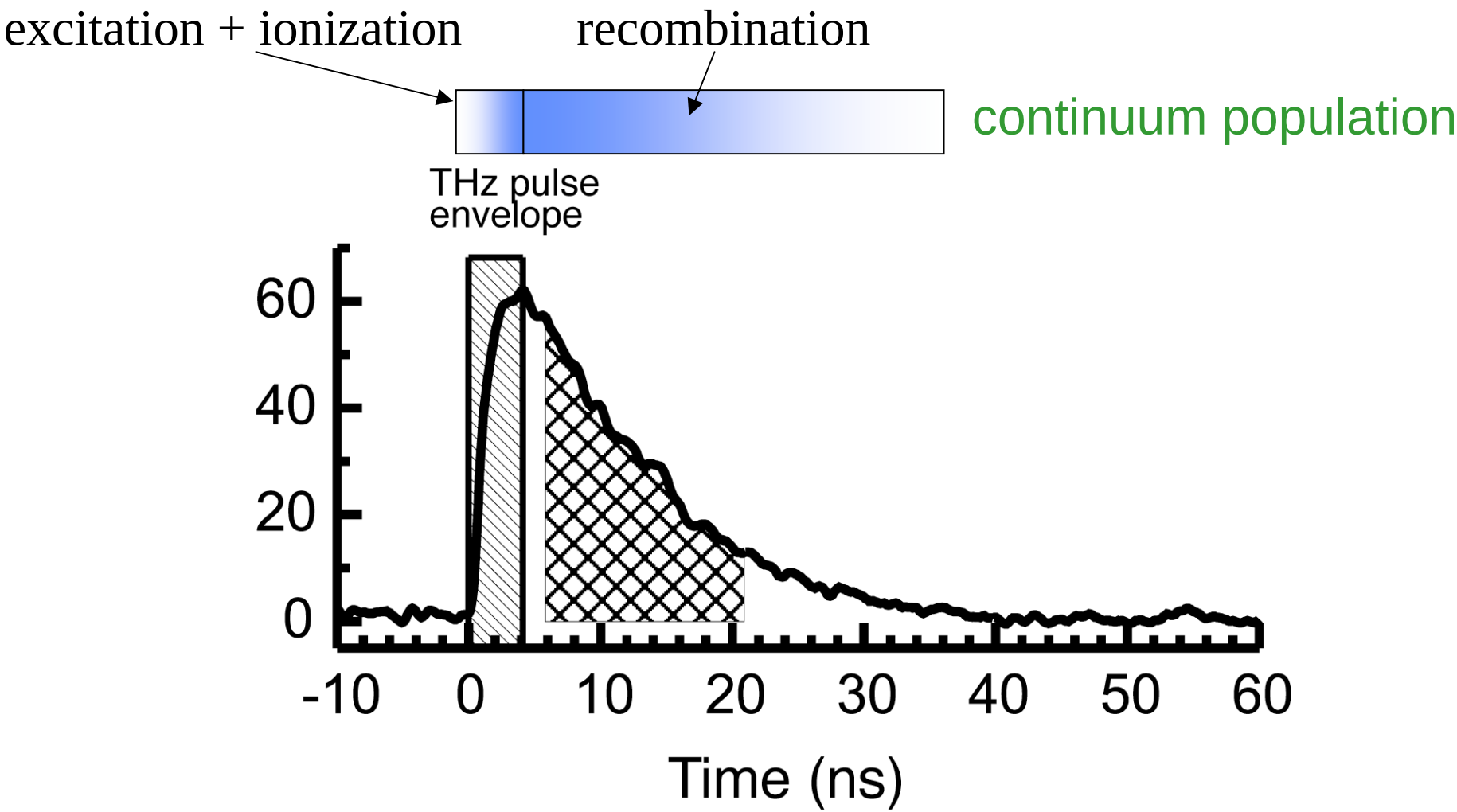



B. Cole, MSS et. al., Nature 410, 60 (2001)

# Mechanism for resonant photoresponse

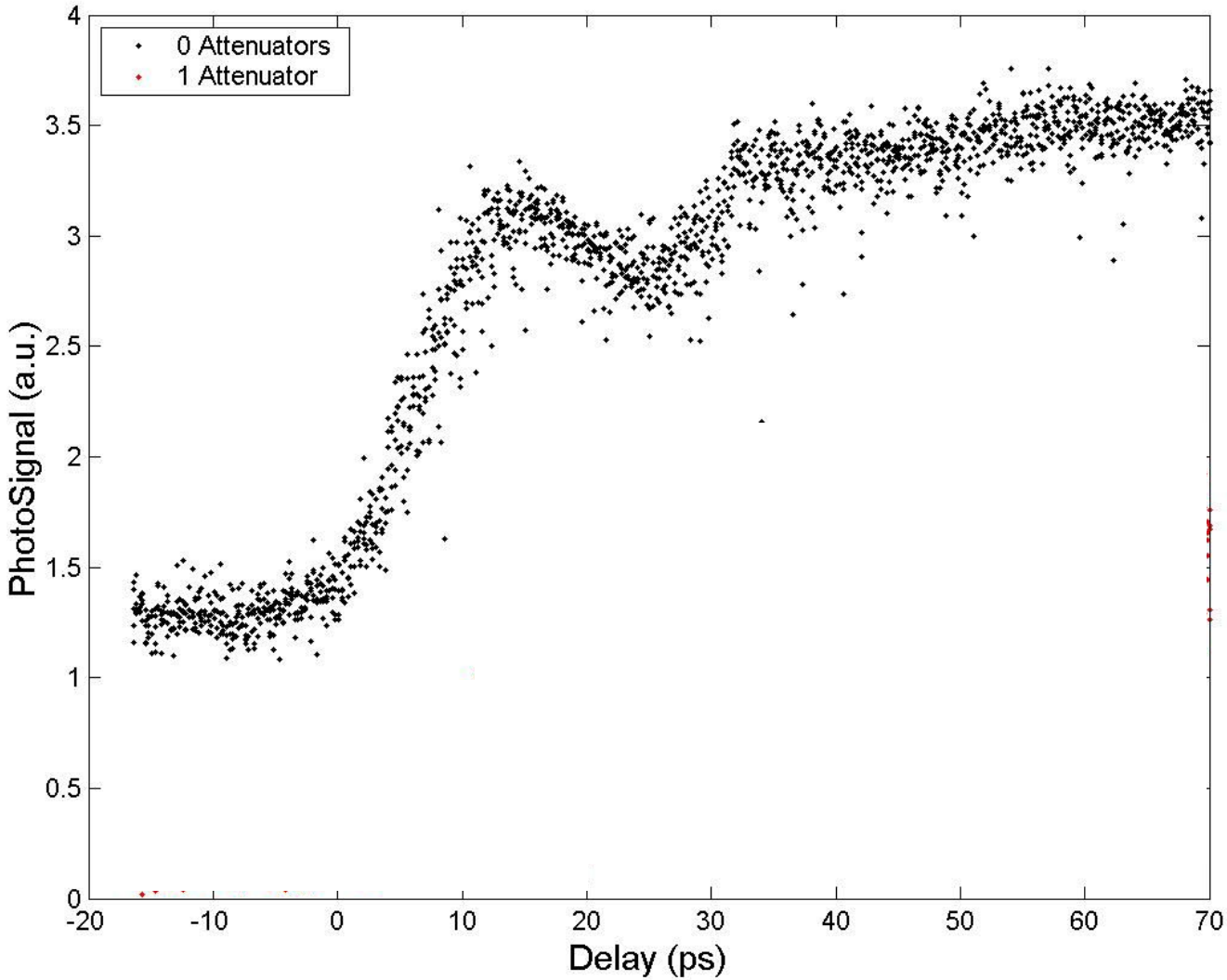


# Single photocurrent pulse



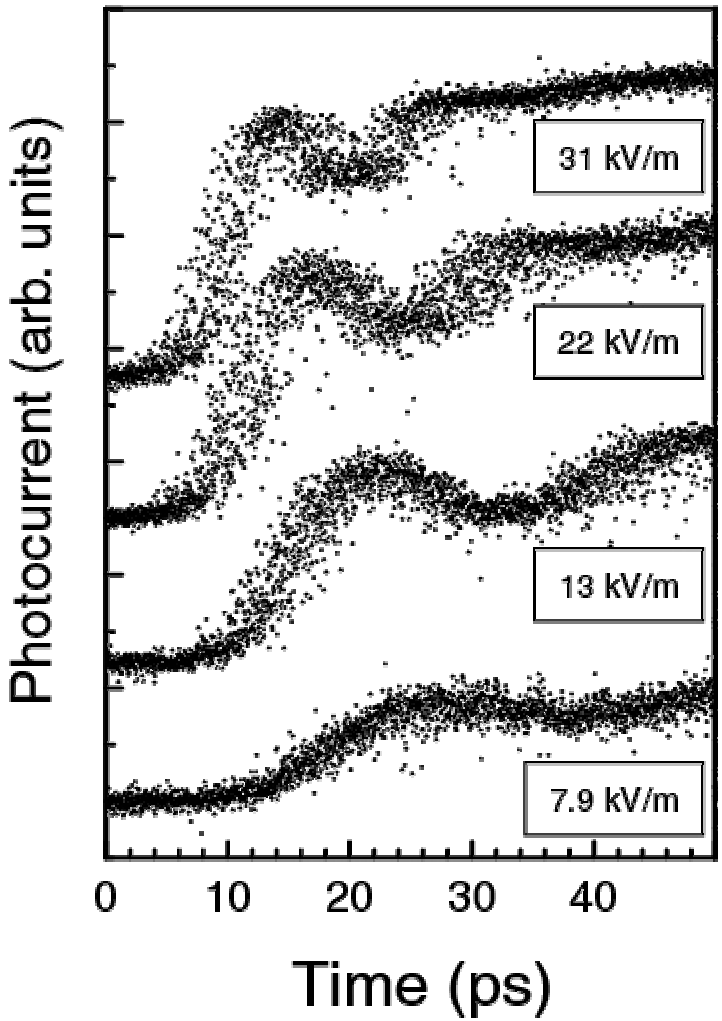

B. Cole, MSS et. al., Nature 410, 60 (2001)

# Rabi oscillation



# Rabi oscillation

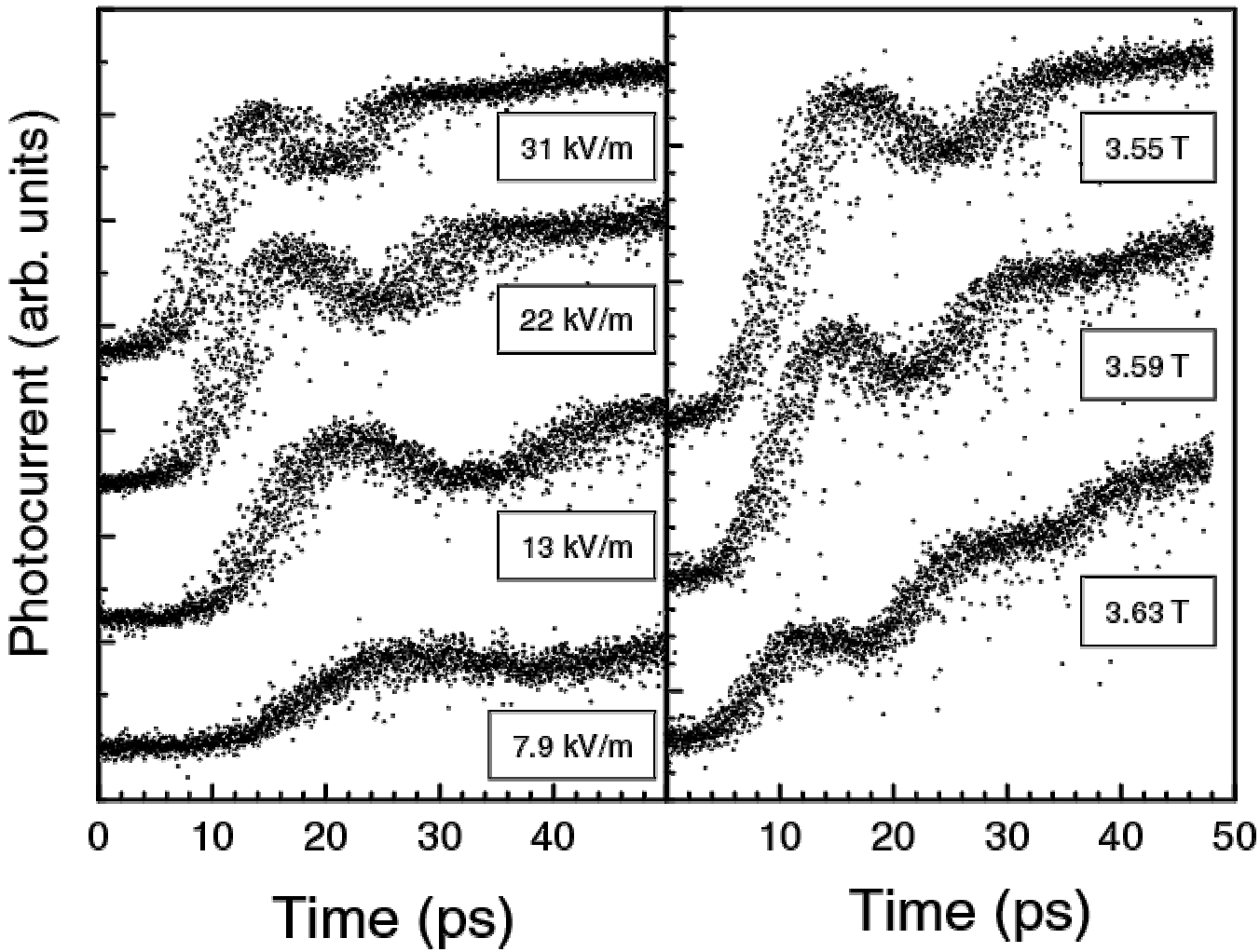
Dependence on THz electric field



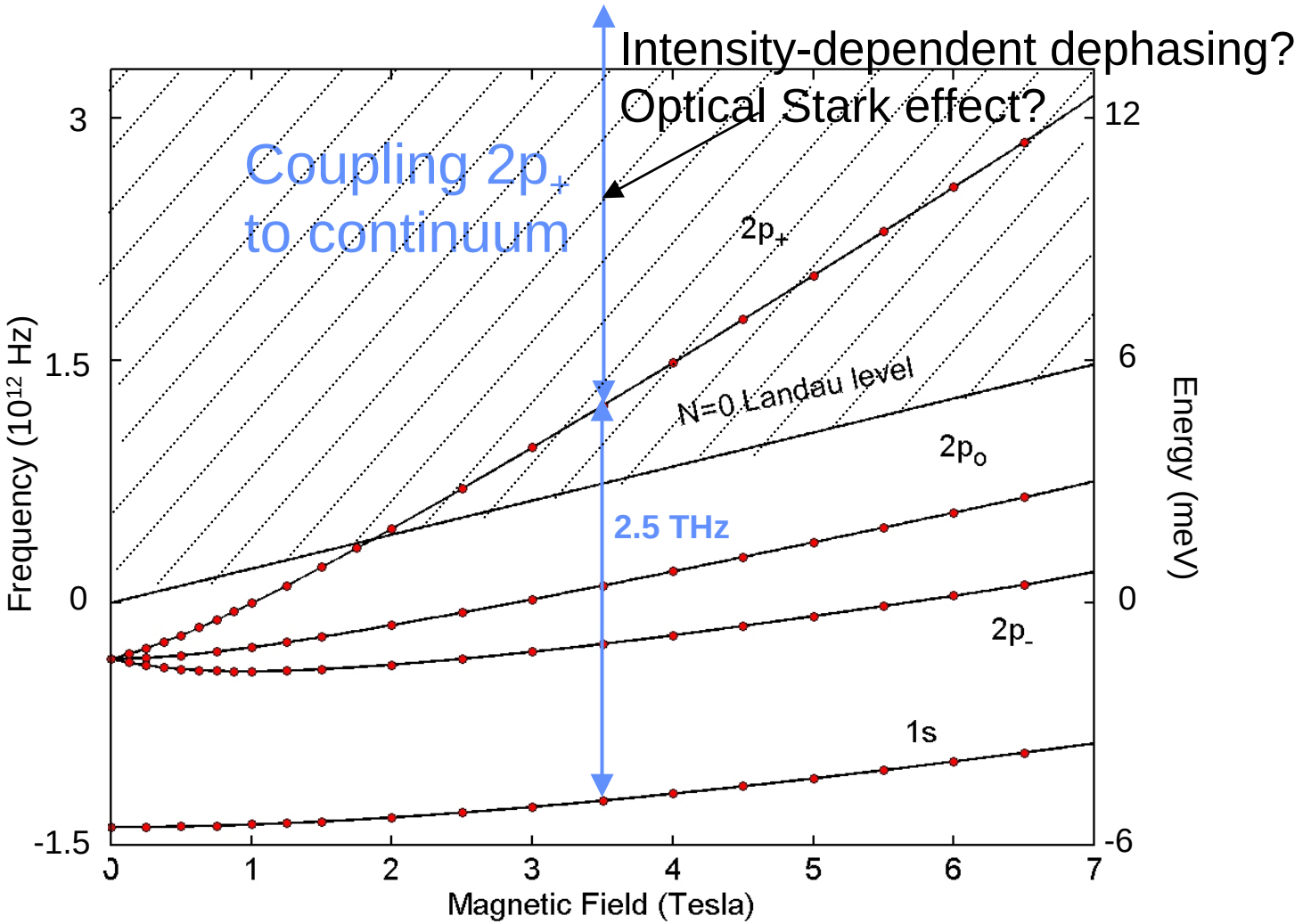
# Rabi oscillation

Dependence on detuning

Resonant



# Effect of continuum



# Outline

- High-field THz experiments at UCSB
  - Terahertz electro-optics in semiconductor quantum wells
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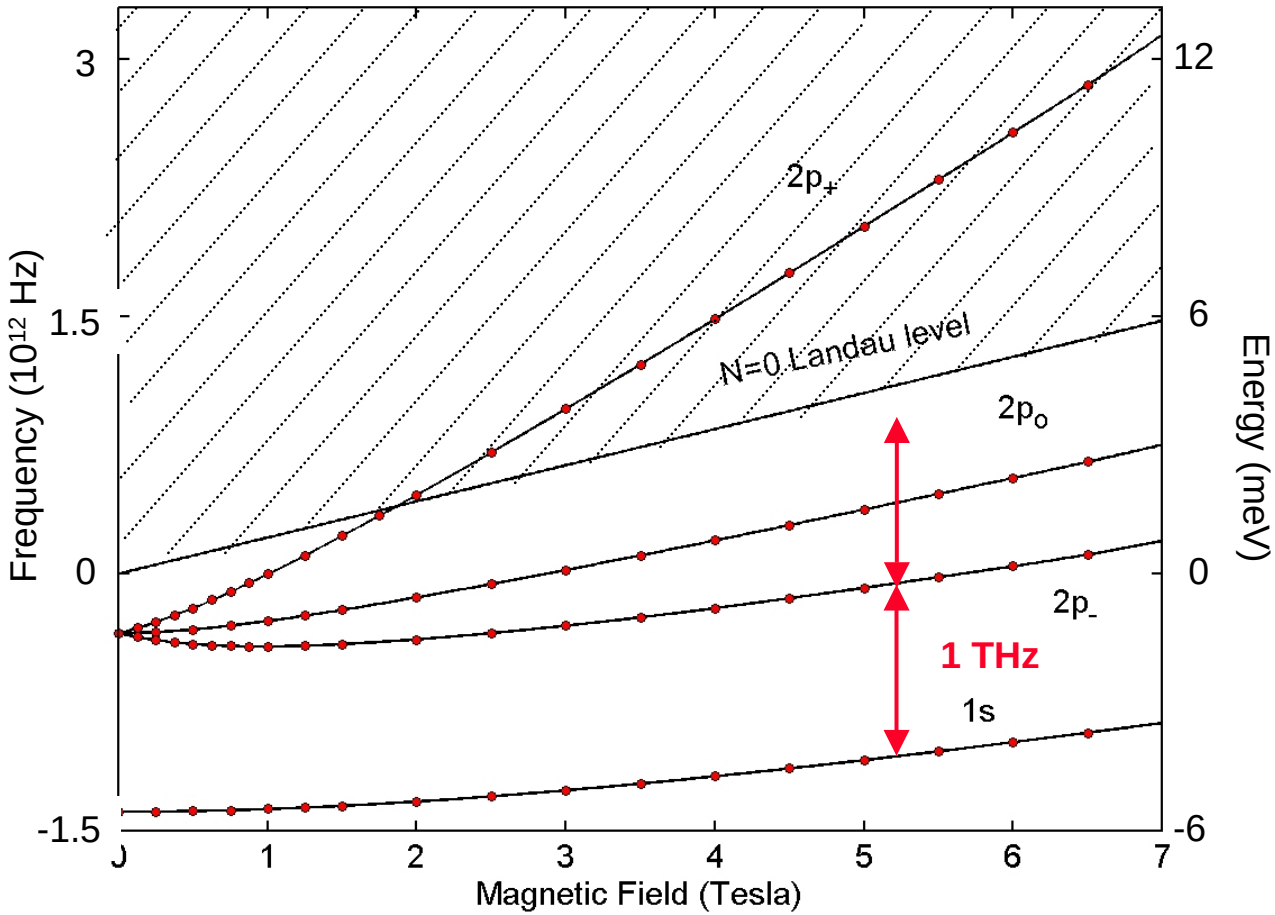
- Terahertz Science and Technology Network

# Experiments under way

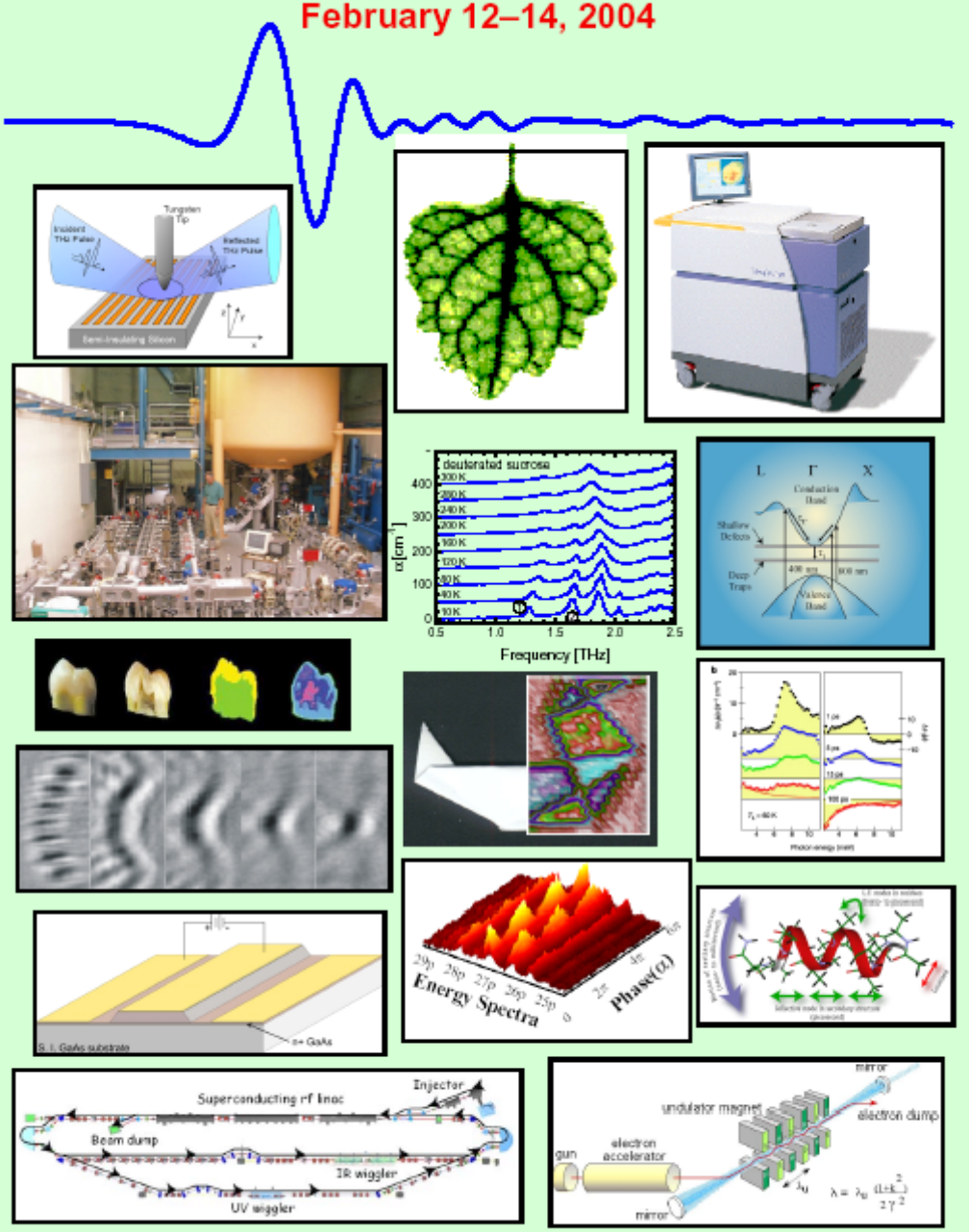



$2p_-$ state reduced THz-induced decoherence ->many Rabi oscillations

# THz Science and Technology Network

- Transparent organization.
- Lower barriers to entry into THz research.
- Connect researchers in academia, industry, government labs.
- Make appropriate technology available to researchers.
- Share and disseminate knowledge.
- Grow the field to realize its potential.

DOE-NSF-NIH Workshop on Opportunities in THz Science
February 12–14, 2004

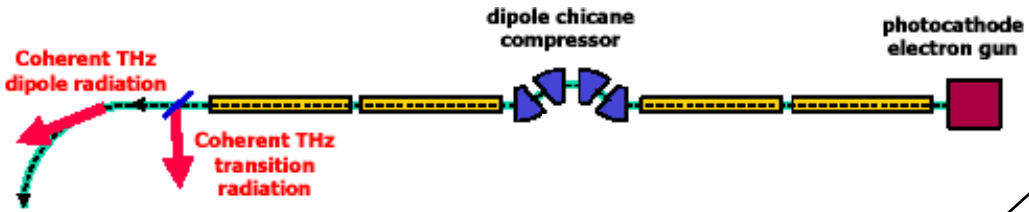


# THz sources

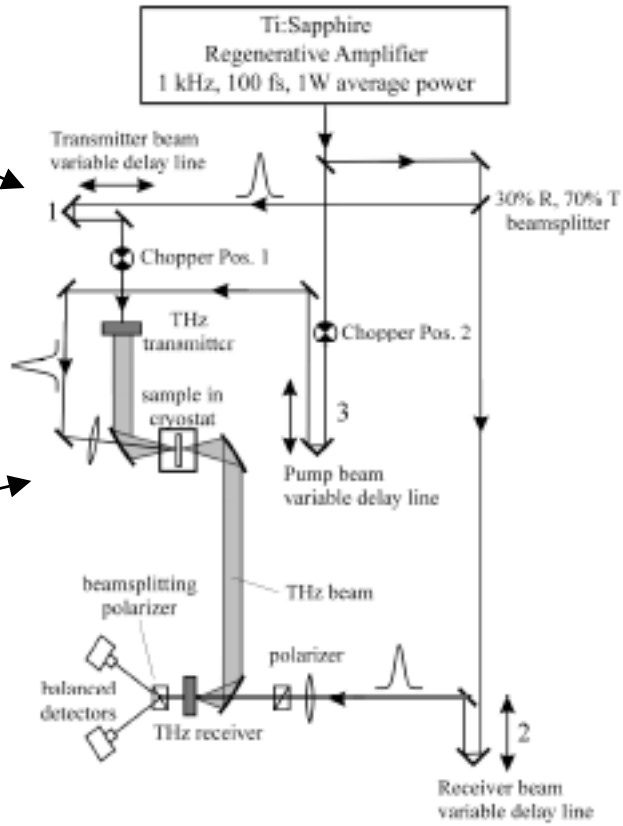
- Broad-band, low power
- Narrow-linewidth, low power.

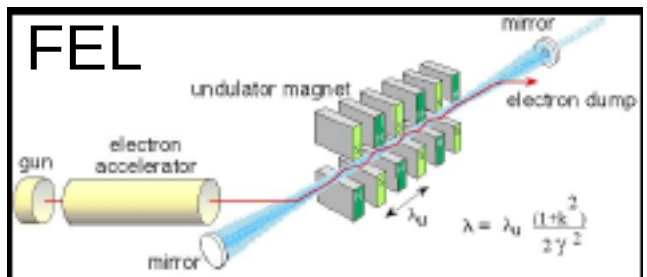
  –Molecular gas laser, multiplied microwave source, backward wave oscillator, photomixer, quantum cascade laser, …

- Broad-band, high power.

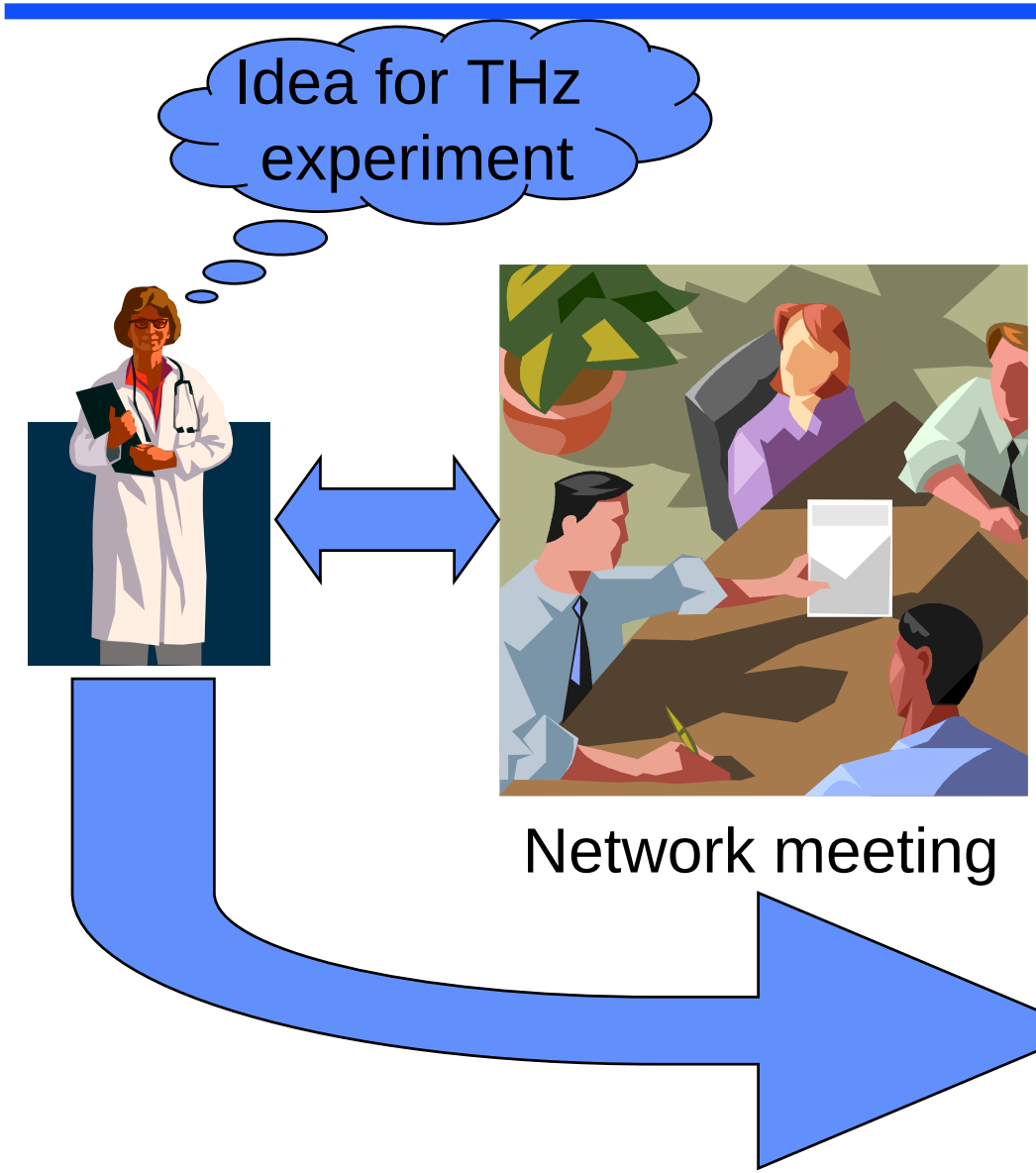



- Narrow-linewidth, high power.



# Network in operation




Oklahoma:Time-domain THz Spectroscopy

Ohio-State: High-resolution Spectroscopy.

UCSB: Narrow-linewidth high-power FEL radiation.

Jefferson Labs: Coherent Synchrotron Radiation.

# Immediate issues for Network

- Set up organization (by-laws, web-site, elected officers, . . . )
- Build up membership (esp. outside of physics)
  - Web site, word of mouth, presentations at professional society meetings.
- Acquire funding
  - network co-ordinator
  - travel funds
  - facility support funds
  - Funds for exploratory collaborations using table-top apparatus
- Potential sources of funds
  - Government
  - Industry
  - Membership dues (small)