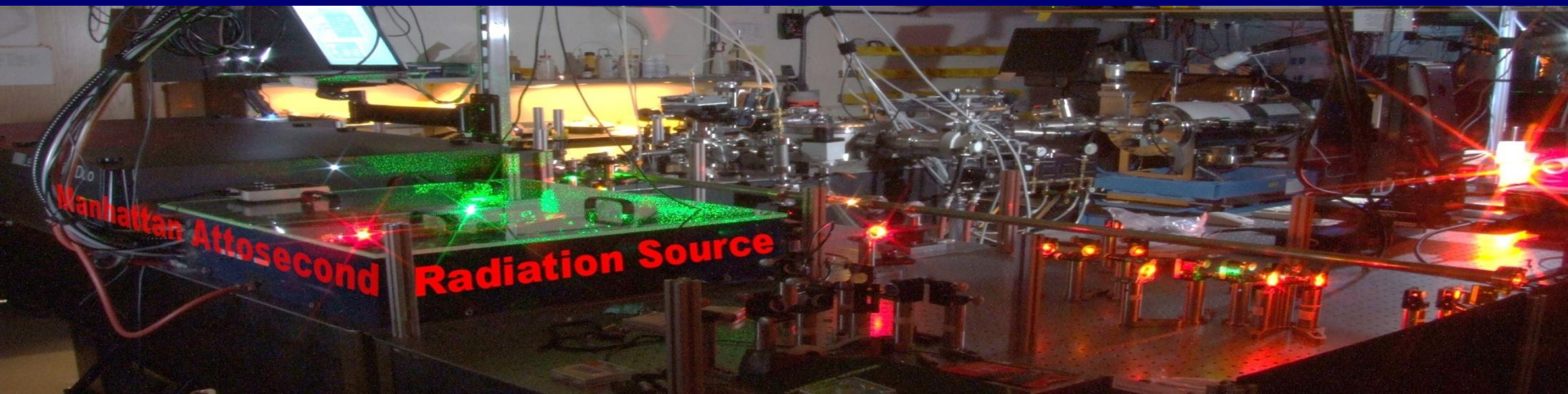
Overview:
Attosecond optical technology based on recollision and gating

Zenghu Chang

Kansas State University



Team members

- **Kansas State University**
  - Zenghu Chang (Dept. of Phys.)
  - Lew Cocke (Dept. of Phys.)
  - Shuting Lei (Dept. Industrial Eng.)
- **University of Ottawa and NRC**
  - Paul Corkum
- **Texas A&M**
  - Gerhard Paulus (Dept. Phys.)
  - Alexei Sokolov (Dept. Phys.)

Team members: students and postdocs

➢ Kansas State University

- PhD students:
  Mike Chini, Qiumei Bian, Steve Gilbertson,
  Sabih Khan, Yi Wu, Qi Zhang.

- Postdocs:
  Kamal Singh, Shouyuan Chen, Hiroki Mashiko.

➢ Texas A&M University

- Postdoc:
  Eugene Frumfer , Landan Arissian.

Time scale in atoms & molecules

as

10^{-18} s

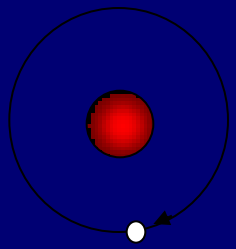
fs

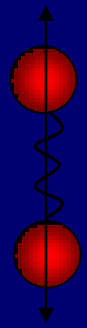
10^{-15} s

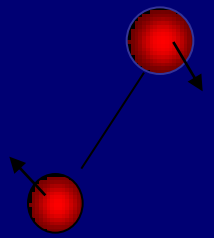
ps

10^{-12} s

Time





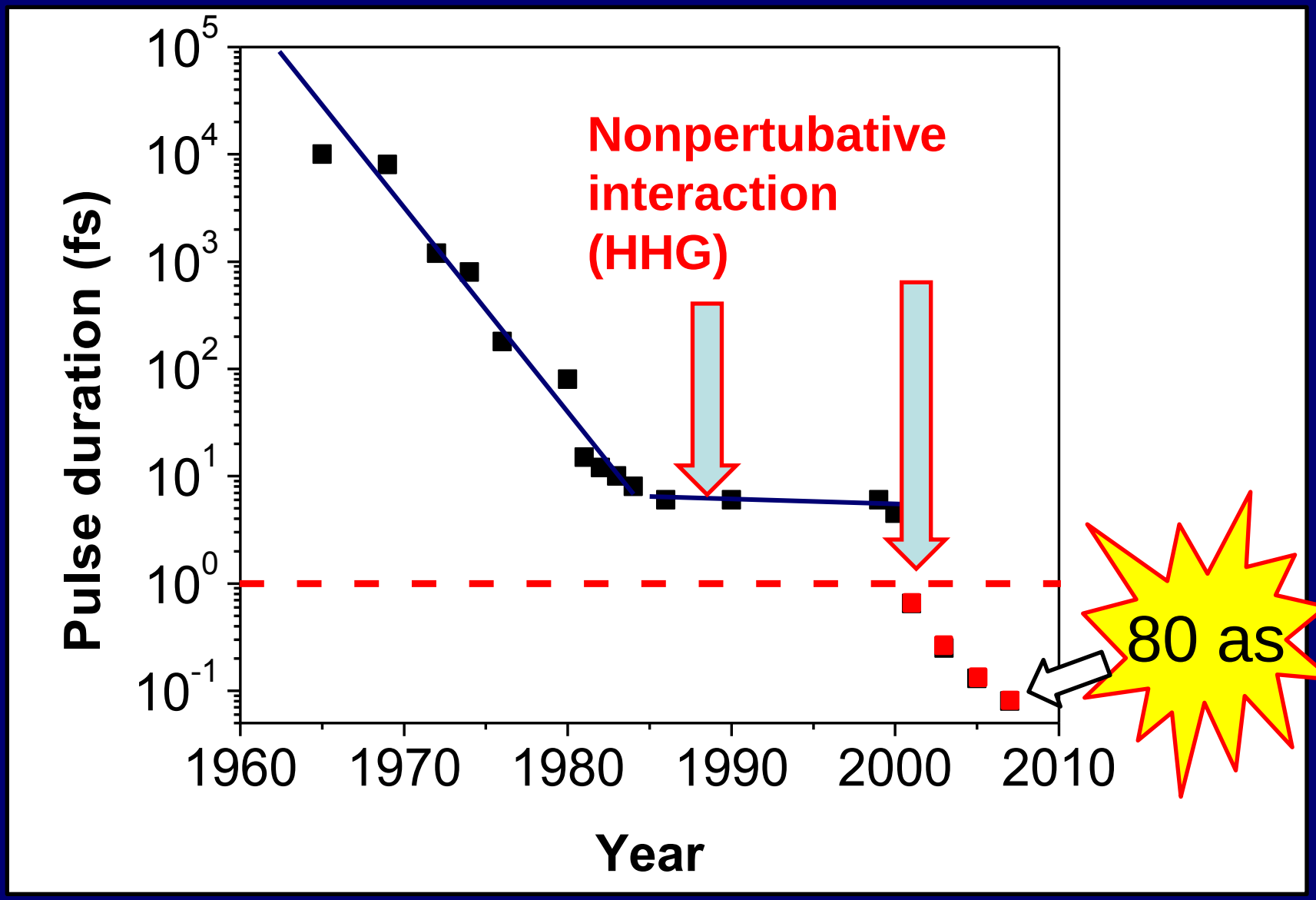


Circulation

Vibration

Rotation

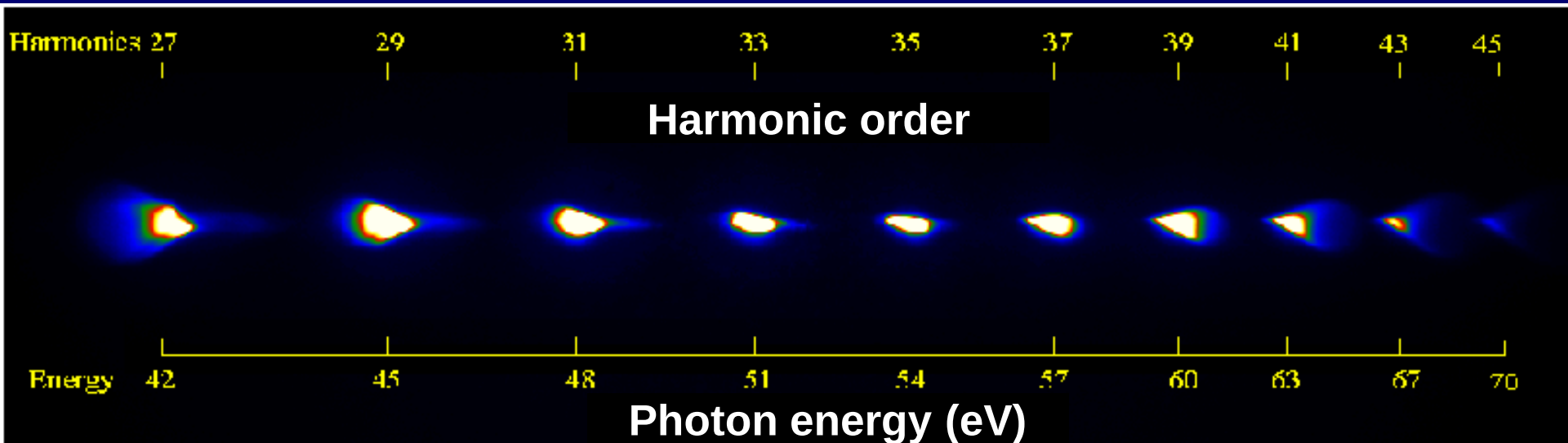
Attosecond revolution



Corkum & Chang, *Optics & Photonics News* **19**, 24 (2008).

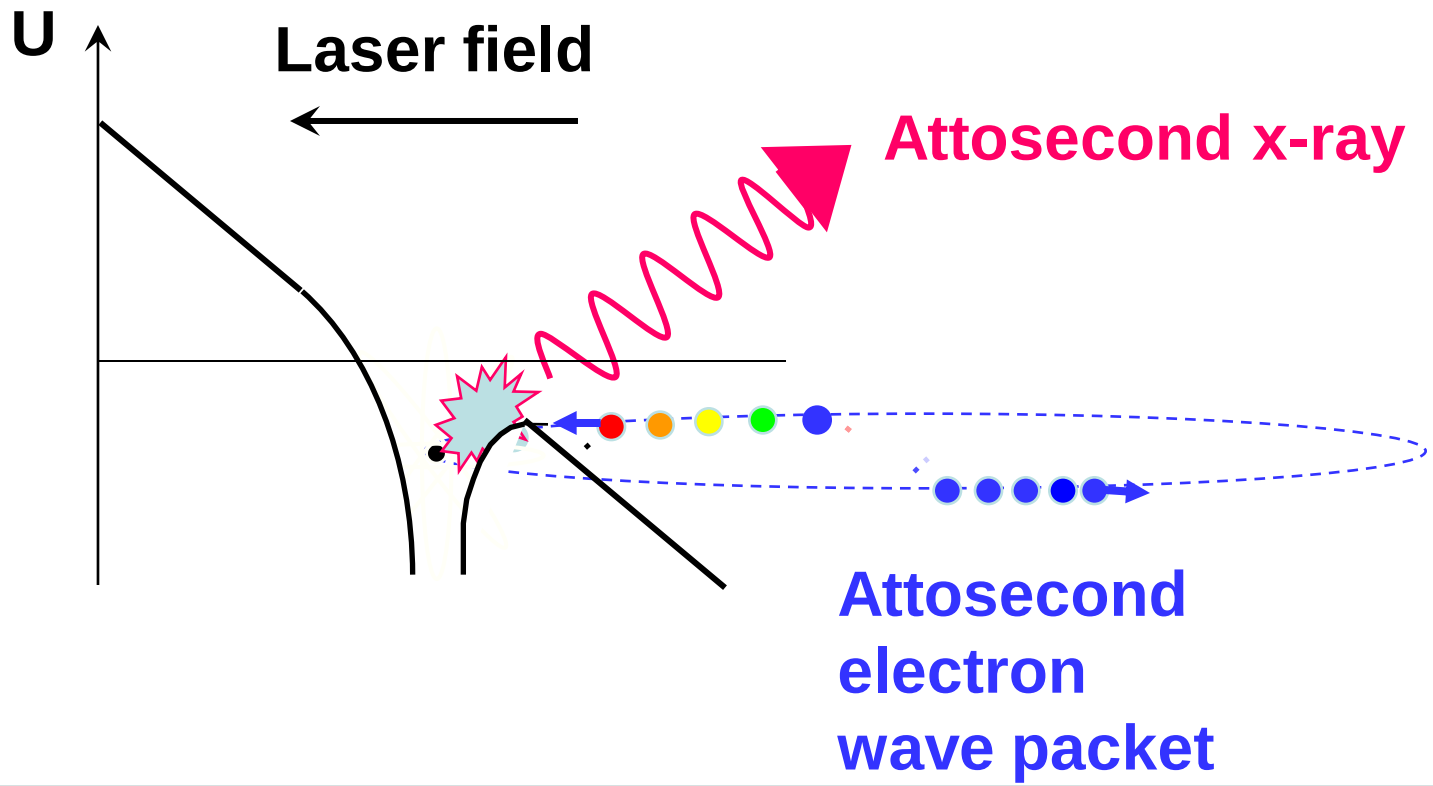
High order harmonic generation

Discovery by Rhodes & L'Huillier,1987



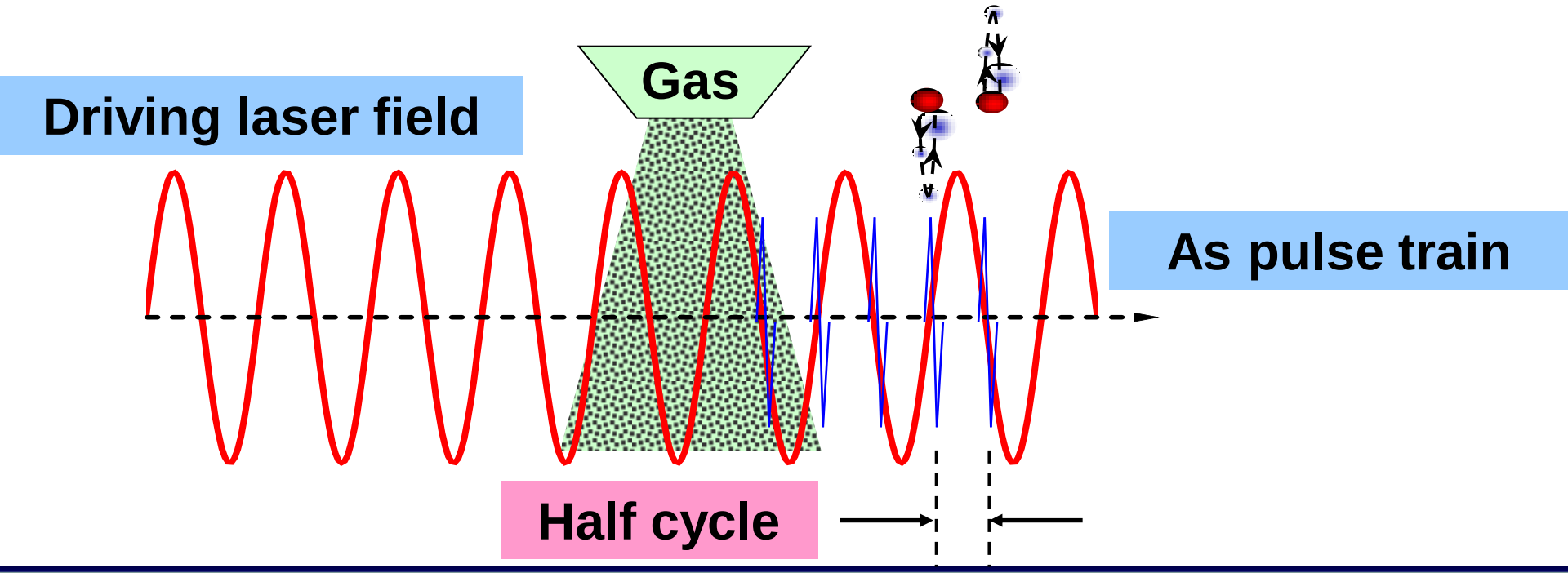
Three steps in one laser cycle

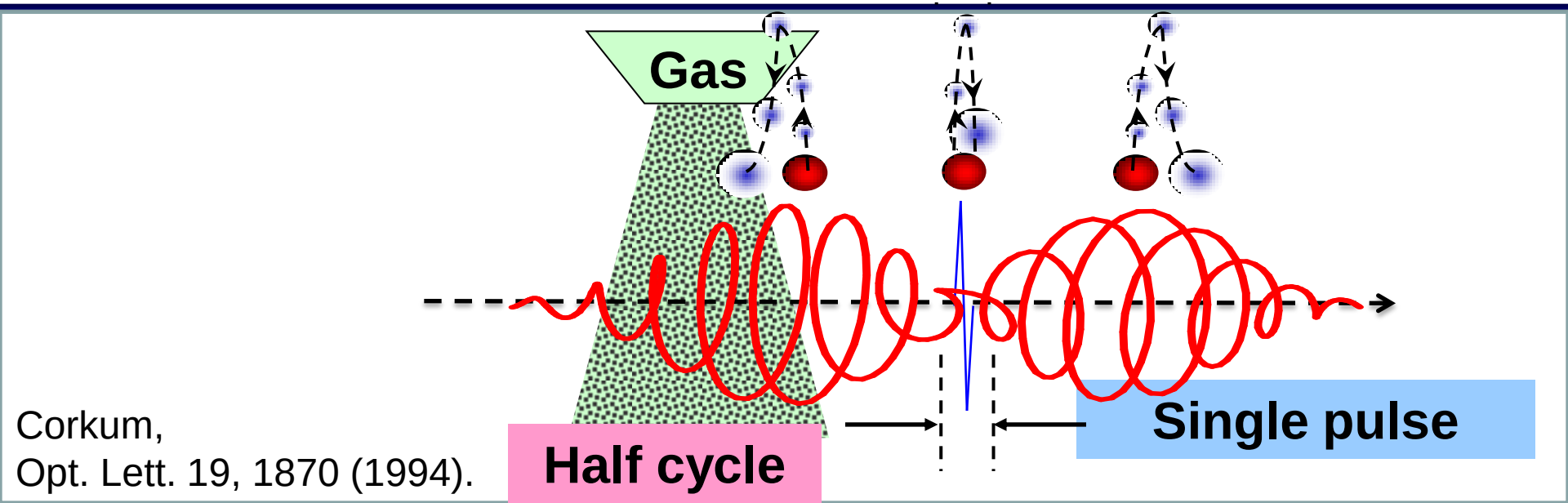
Proposed by Corkum & Kulander,1993



1. **Electron emission** (tunneling ionization).
2. **Acceleration** (in E field of laser).
3. **Attosecond emission** (recombination).

As pulse generation: recollision and gating





Corkum,
Opt. Lett. 19, 1870 (1994).

Our goals

- **Pulse duration: 25 as (1 atomic unit)**

  Based on recollision and gating.

- **Time domain applications**

  Pump-probe study of electron dynamics.

- **Spectrum domain applications**

  Absorption spectroscopy. Imaging of molecular orbital.

- **Laser applications**

  Nano machining.

Multidisciplinary approach

- **Kansas State University**

  High energy CE phase stabilized laser.

  Attosecond pulse generation.

  Reaction microscope (movie).

  Nano-machining.

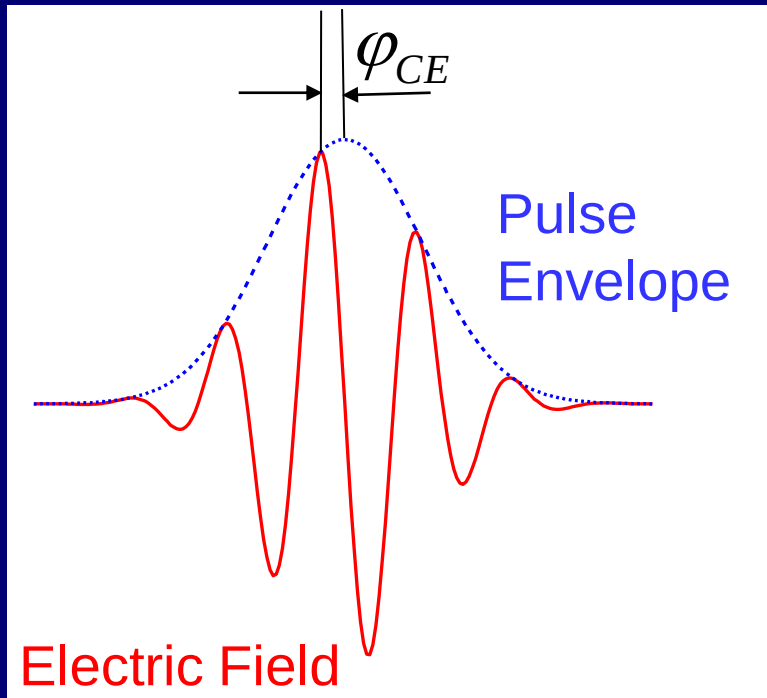
- **University of Ottawa/NRC**

  Spectrum domain applications.

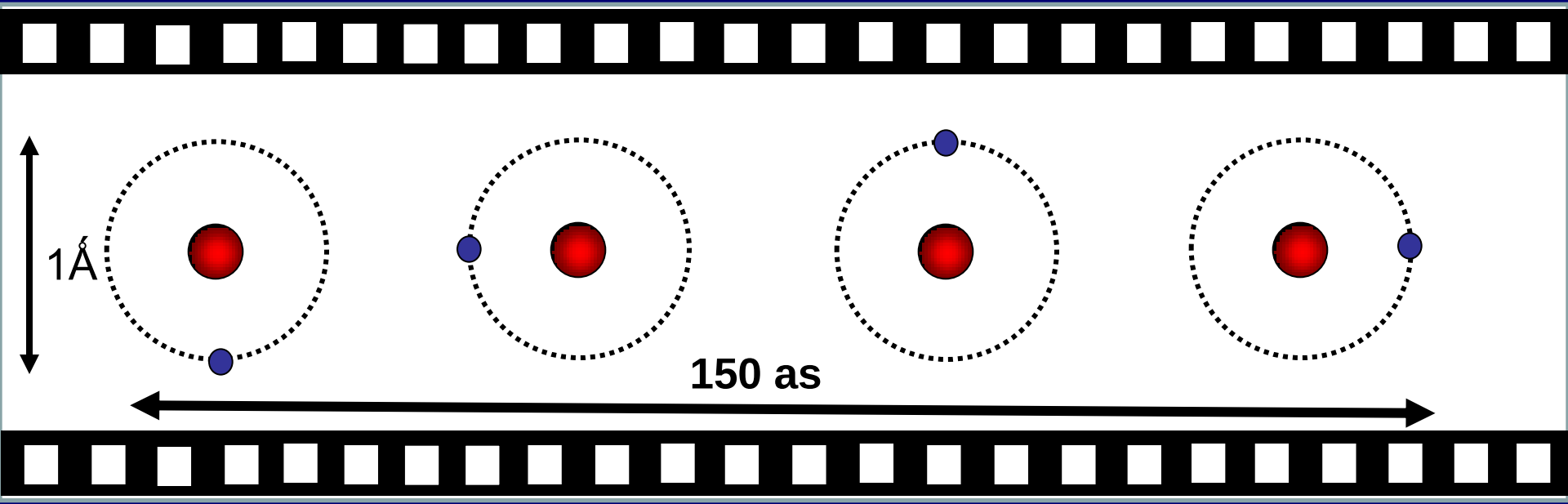
- **Texas A&M University**

  Stereo ATI CE phase meter.

  Molecular control.



Major challenges



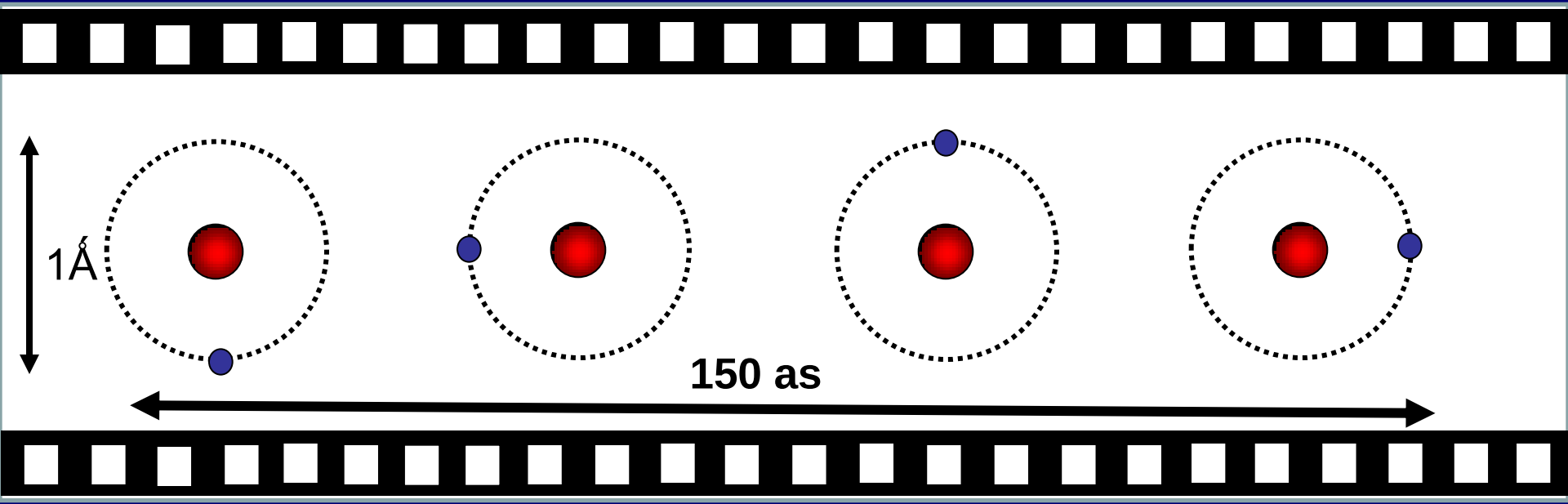
- How to reach 25 as pulses?
- How to achieve high flux (μJ to mJ)?
- How to use such pulses?

Corkum & Chang, *Optics & Photonics News* **19**, 24 (2008).

“One femtosecond is too long for us”

Kansas Attosecond Light Source Group

Major challenges



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Corkum & Chang, *Optics & Photonics News* **19**, 24 (2008).

Double Optical Gating: a new switch

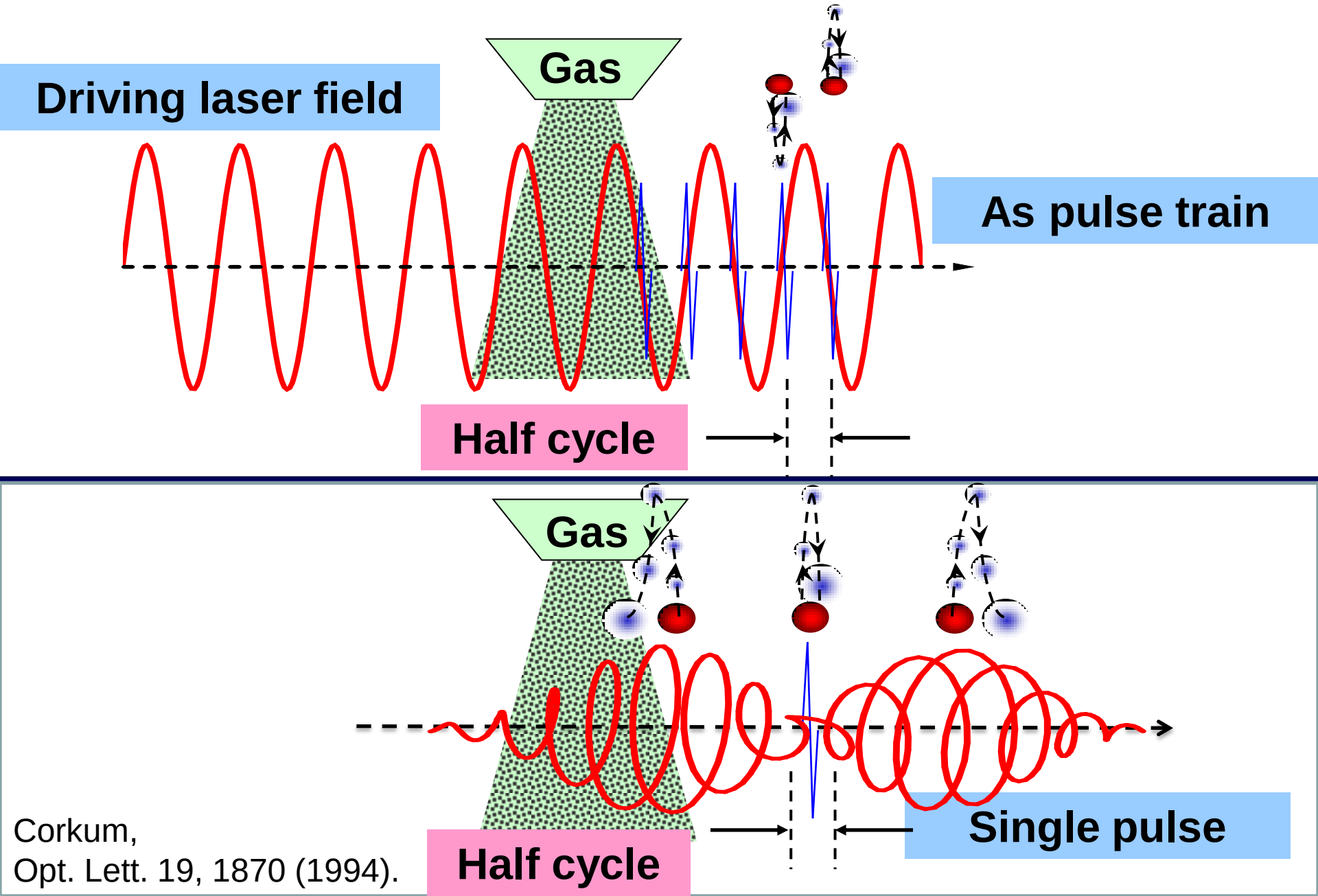
Our goals:

- Generation of 20 as pulses from multiple cycle pulses (~20 fs),
- Increase attosecond pulse intensity.

Our approach:
Double optical gating=
polarization gating + two color gating.

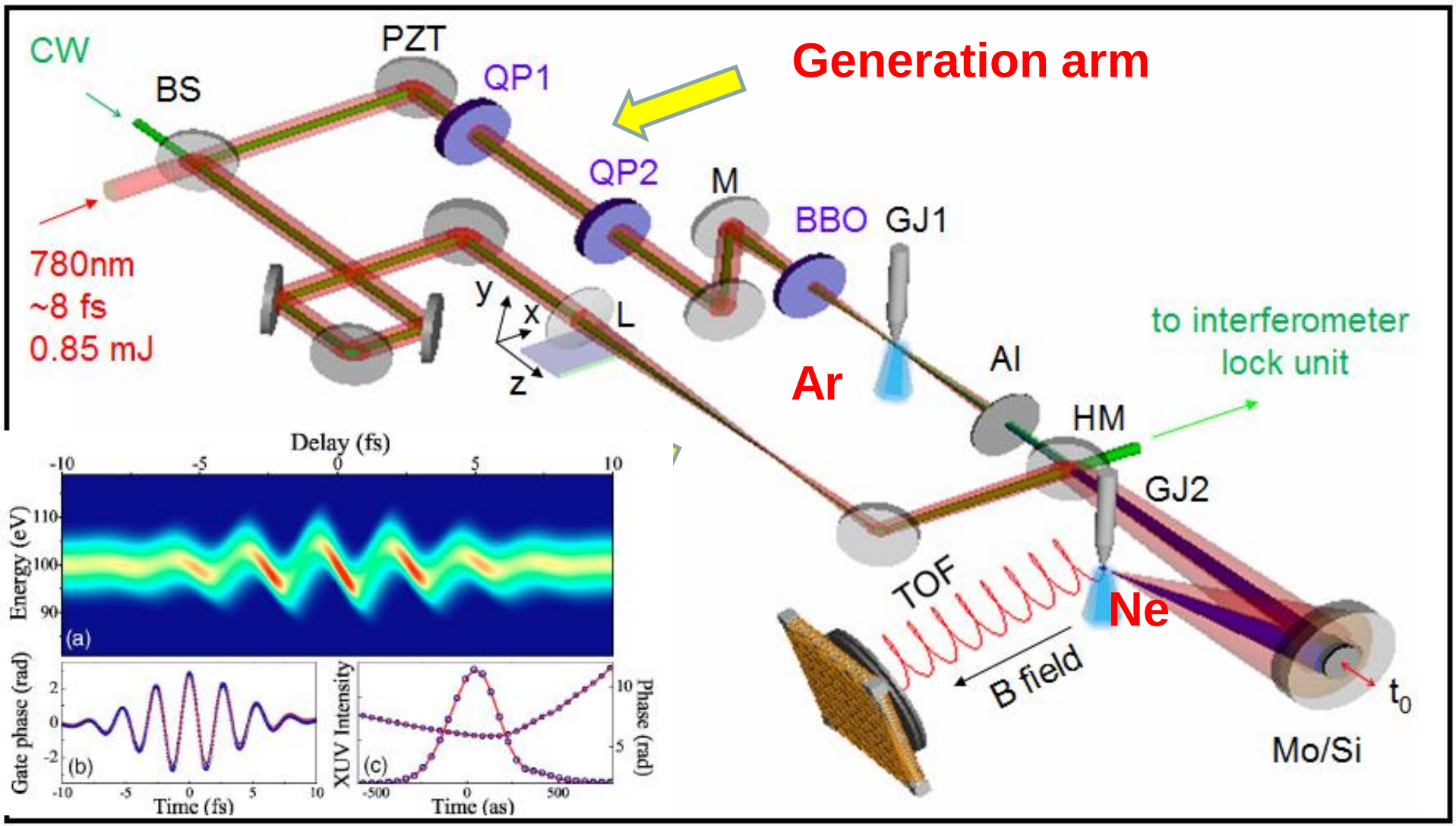
Chang, PRA **76**, 051403(R) (2007).
Mashiko et. al., PRL **100**, 103906 (2008),
Gilbertson et. al., APL **92**, 071109 (2008).

Double optical gating

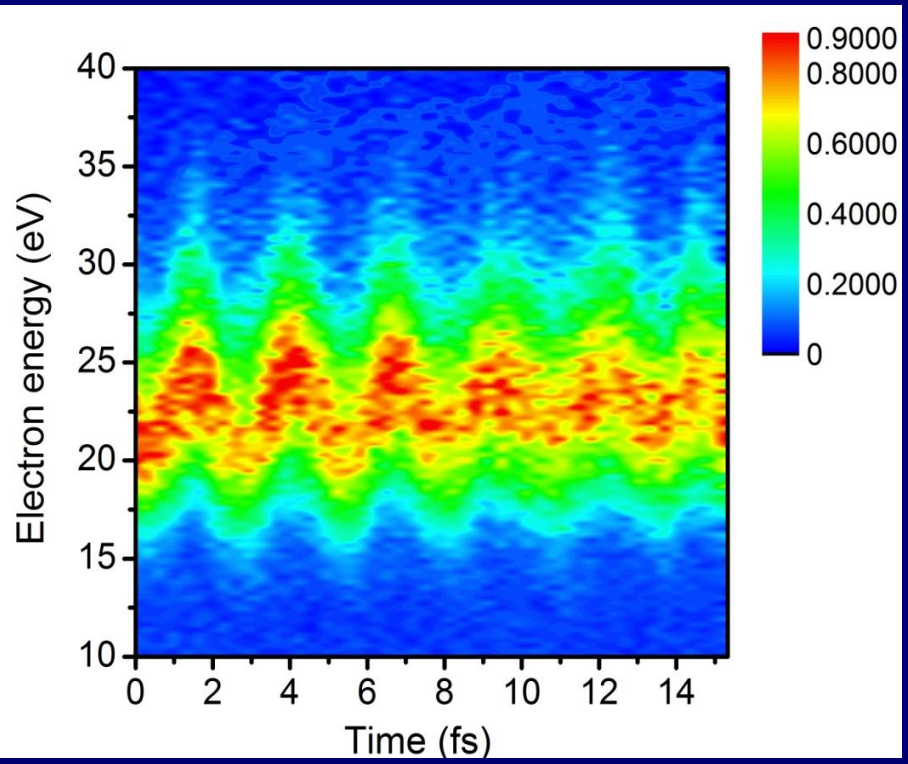


Corkum,
Opt. Lett. 19, 1870 (1994).

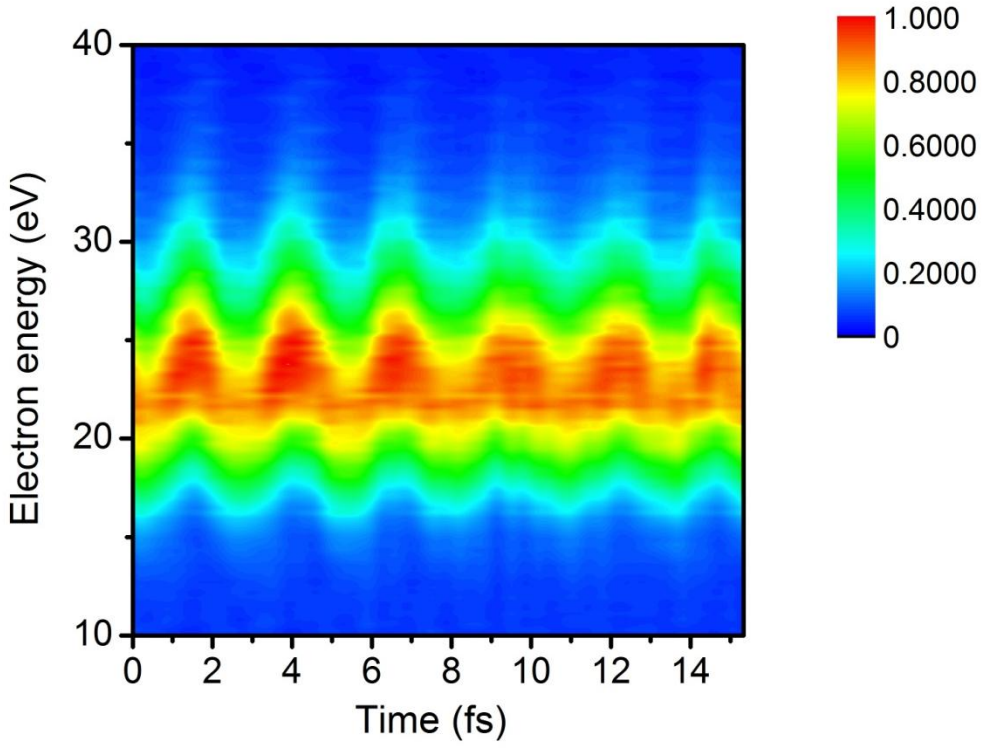
Attosecond streak camera



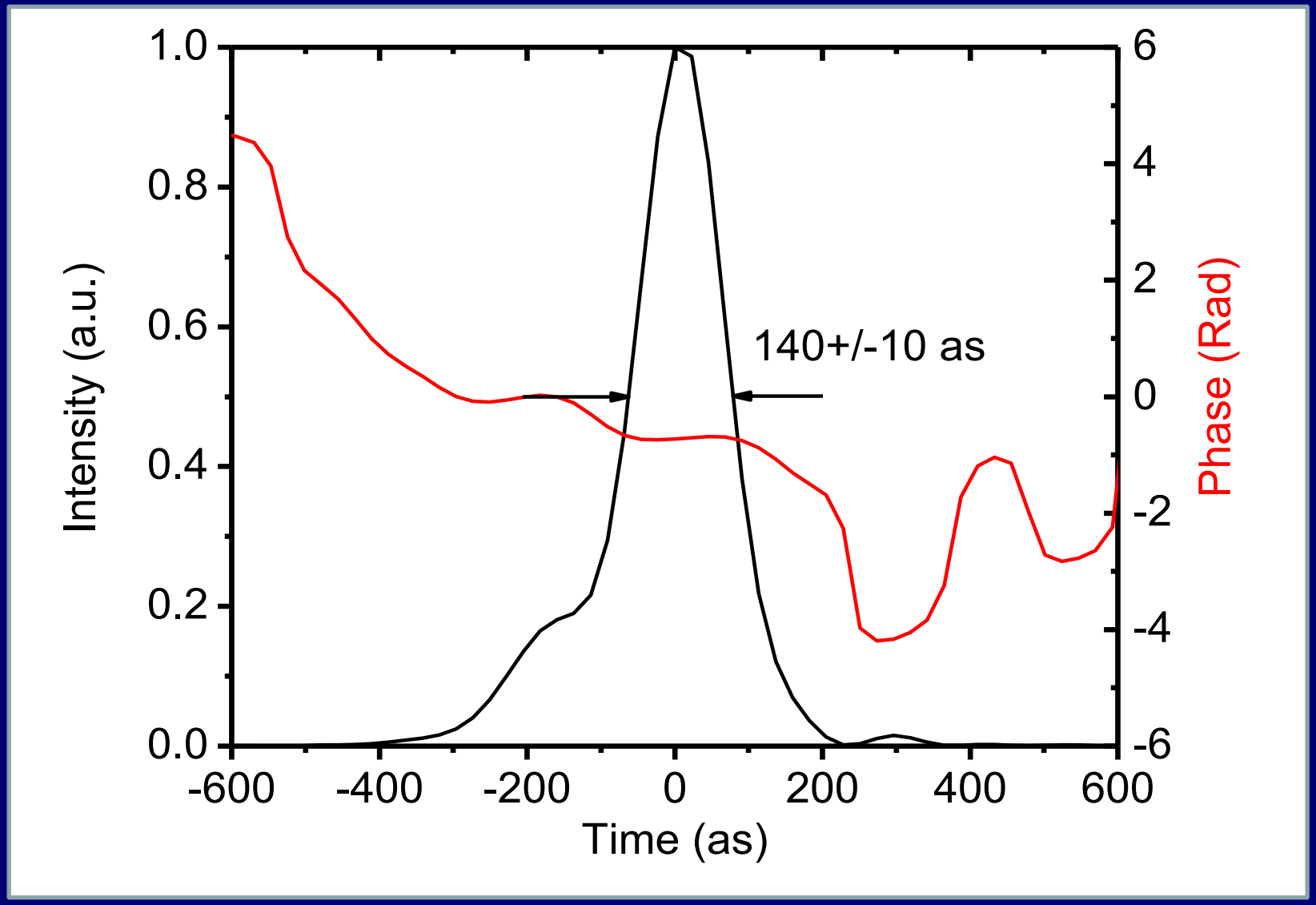
Experimental CRAB



Reconstructed CRAB



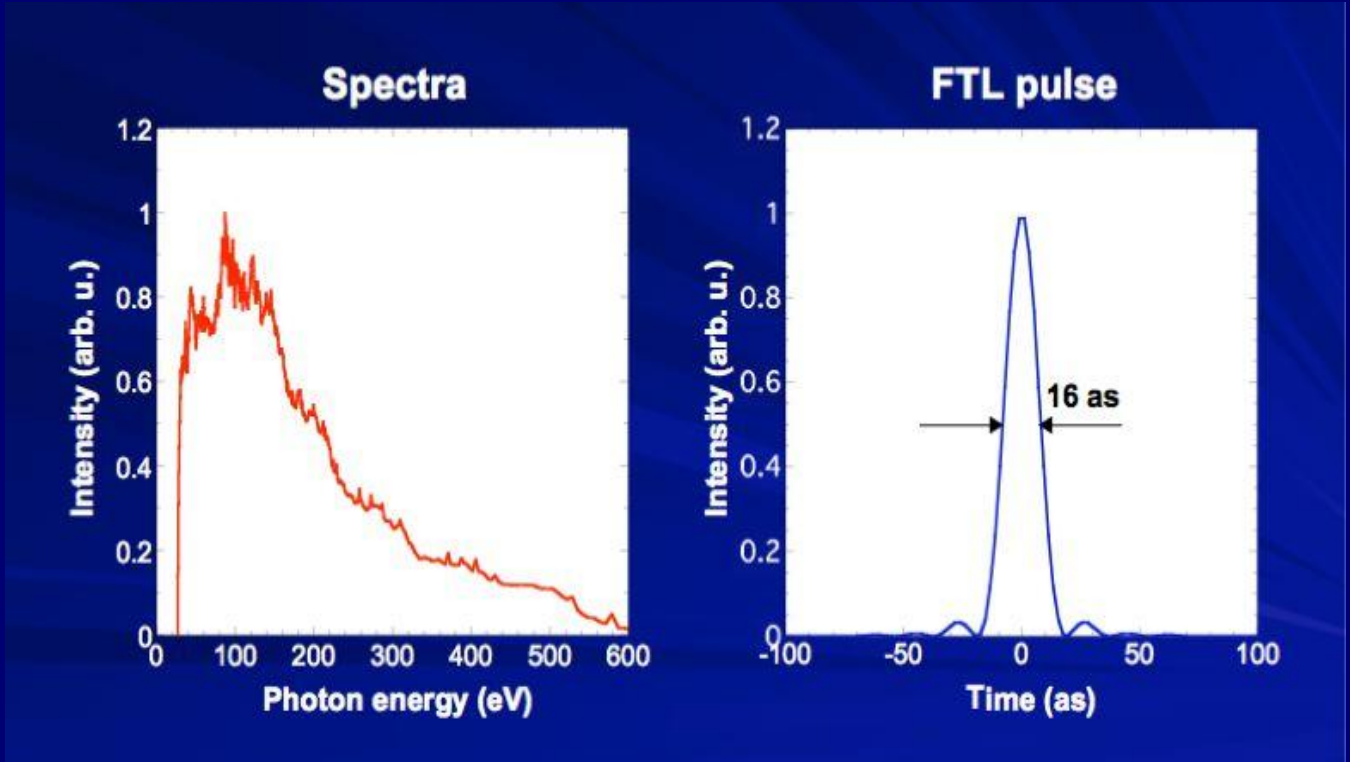
Measured attosecond pulse



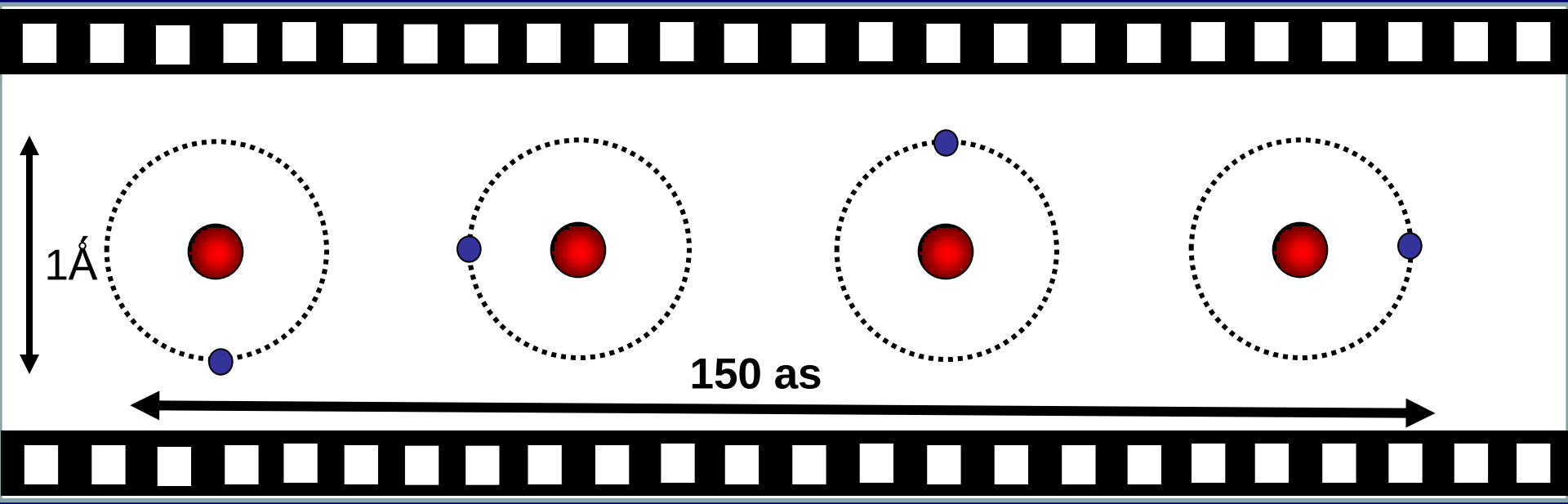
Wang *et al.*, J. Phys. B: At. Mol. Opt. Phys. **42**, 134007 (2009).

Potential breakthroughs

- Generation of the shortest soft x-ray pulse.
- High intensity for studying attosecond nonlinear processes.



Major challenges



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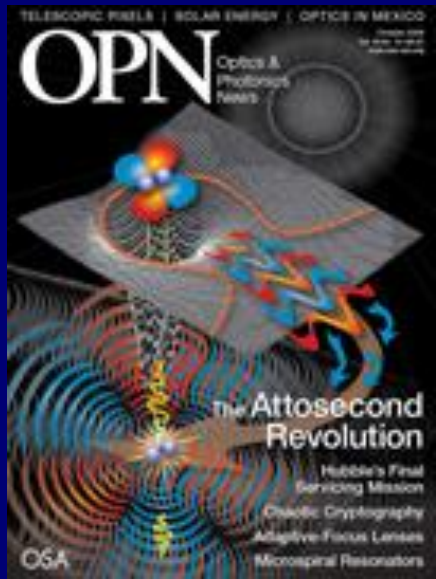
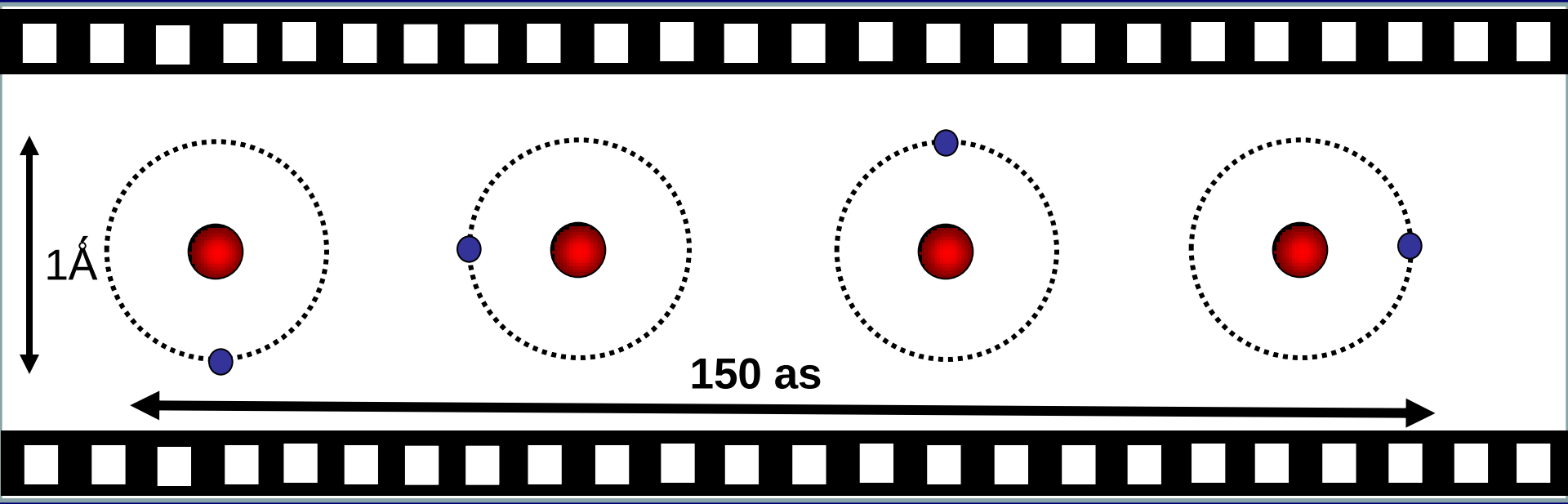


Corkum & Chang, *Optics & Photonics News* **19**, 24 (2008).

Major challenges



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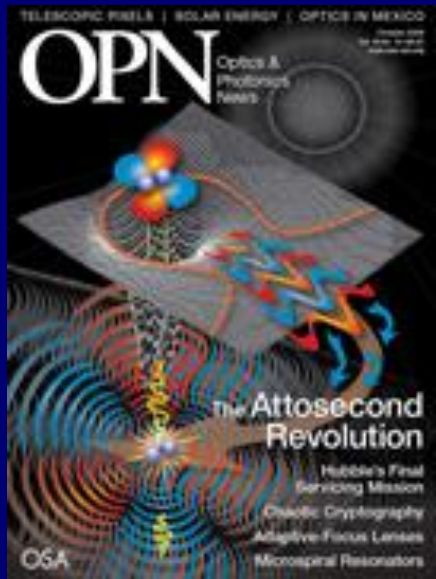
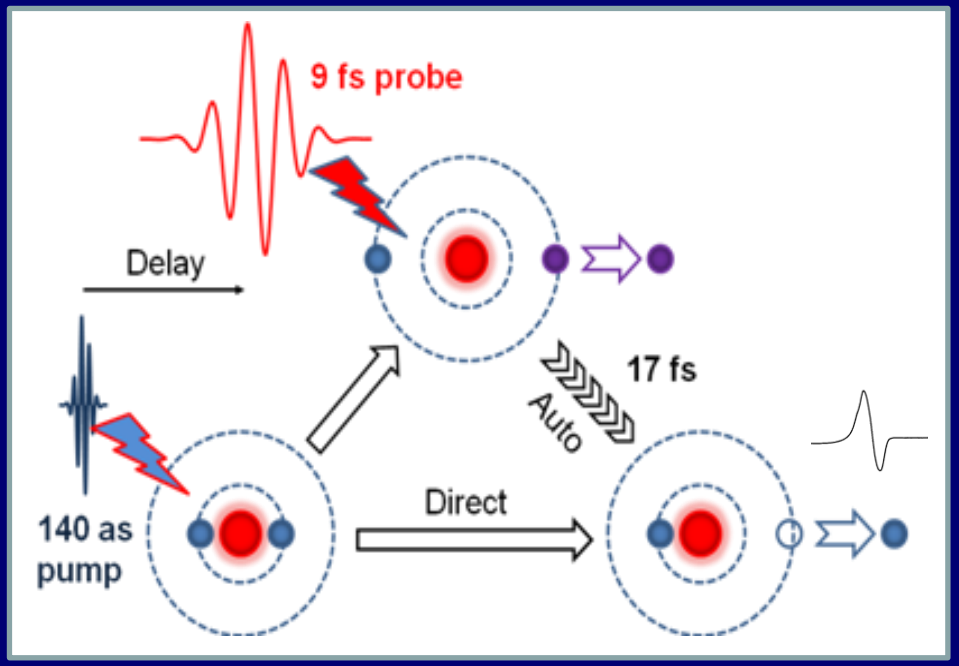
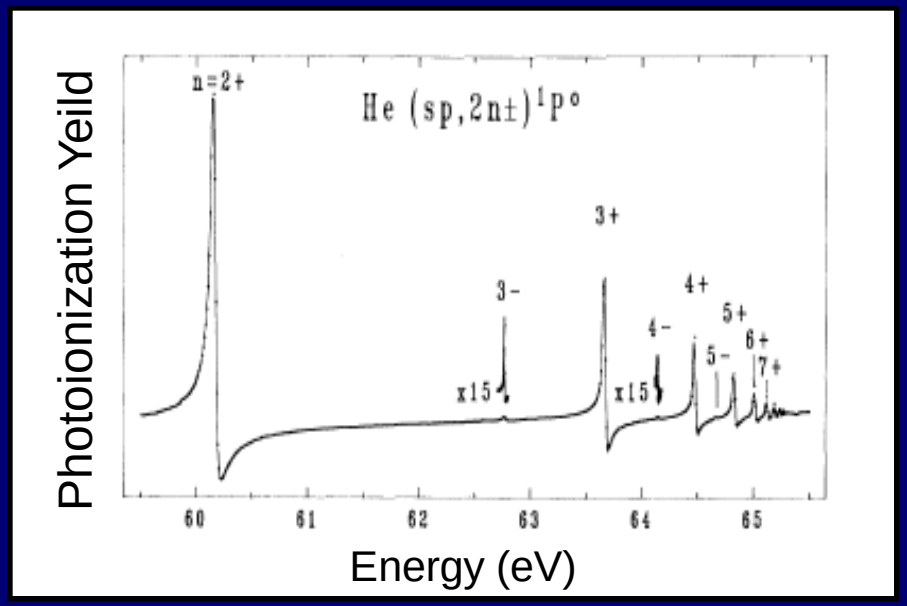


Corkum & Chang, *Optics & Photonics News* **19**, 24 (2008).

Controlling electron dynamics: Double excitation and autoionization

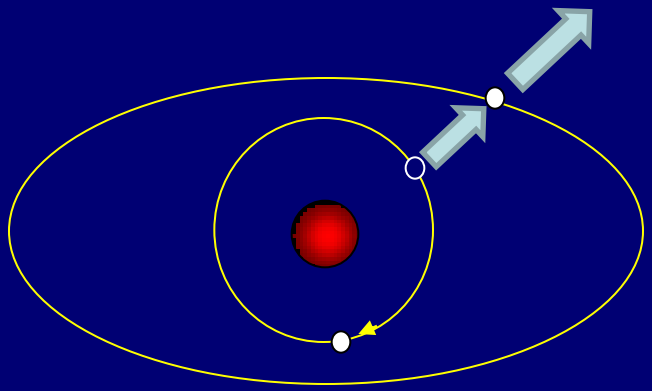


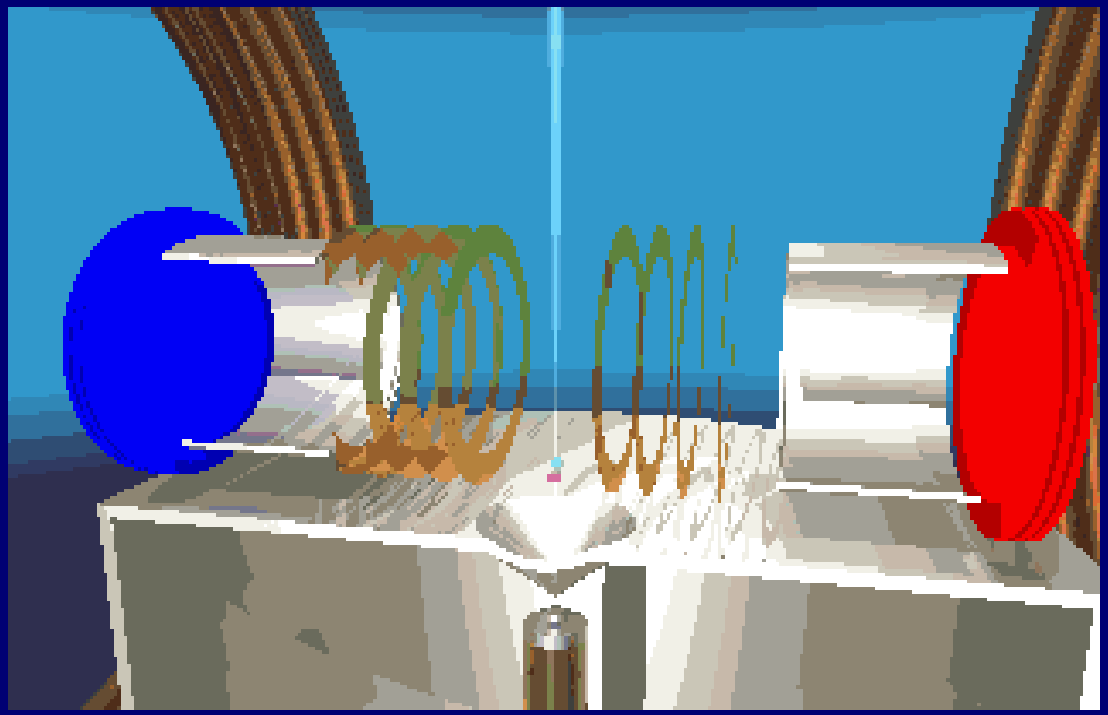


Previous work with synchrotrons (~100 ps XUV pulse):

- **Spectrum domain measurement (no dynamics).**
- **Could not control 2s2p decay and coupling strength.**

Study electron dynamics in He using attosecond pulse train

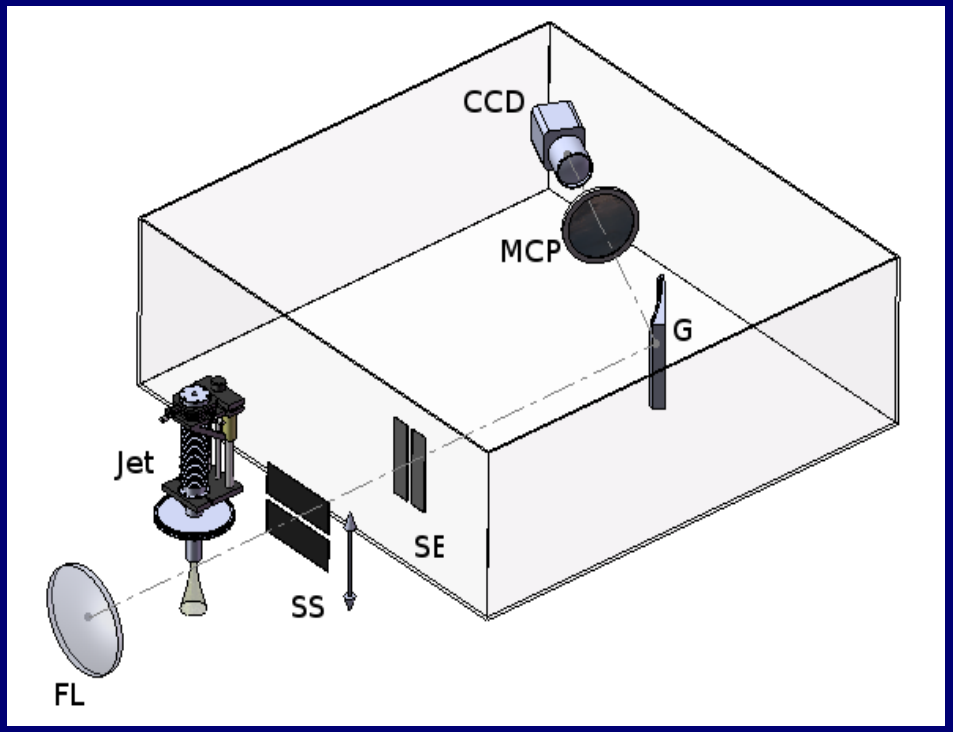


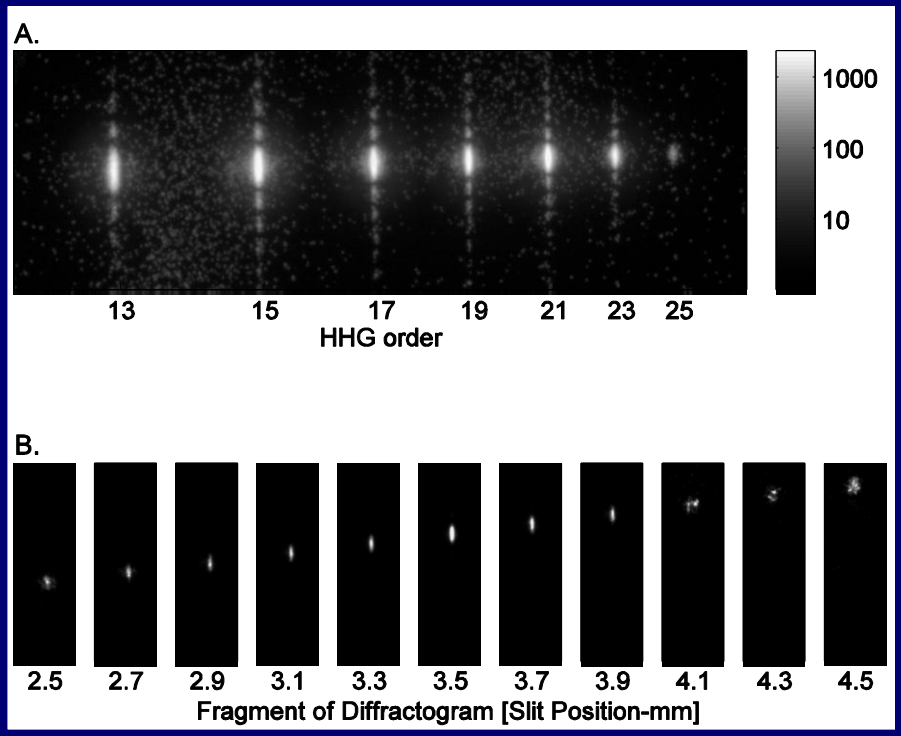


- **Excitation: attosecond pulse train.**
- **Ionization: NIR femtosecond laser.**
- **Reaction microscope: full momentum, ion/electron.**

L. Cocke's group at KSU, submitted to Nature Physics.

Frequency resolved high-harmonic wavefront characterization

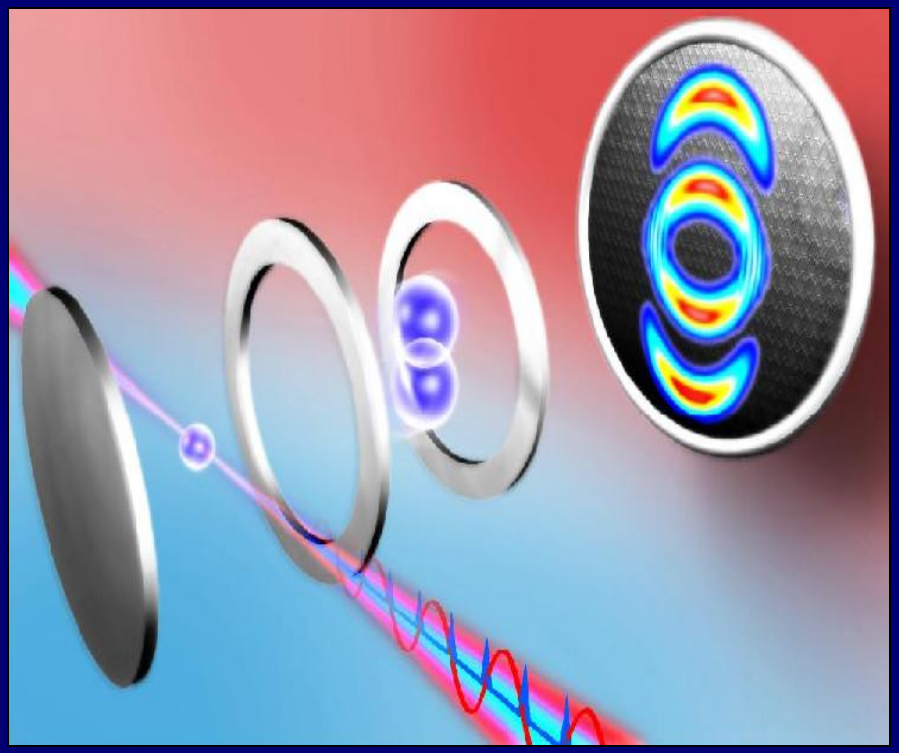


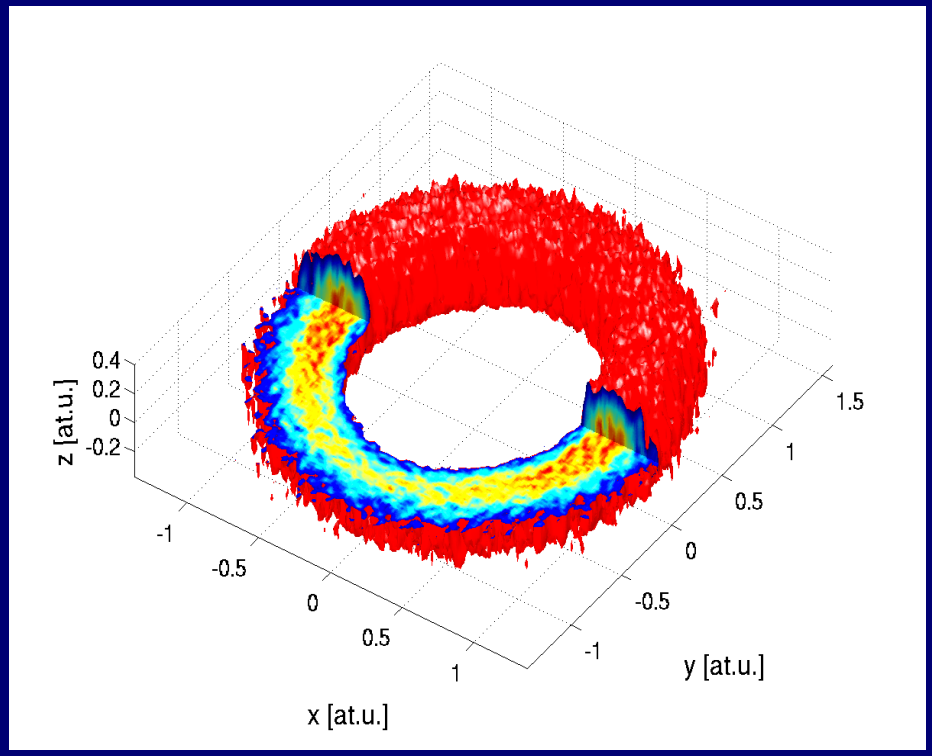


- Paves a new way to temporal-spatial coupling studies of high harmonic and attosecond pulses..

Corkum and Paulus' groups, Submitted to Optics Letters.

Tomographic imaging of 3D momentum distribution

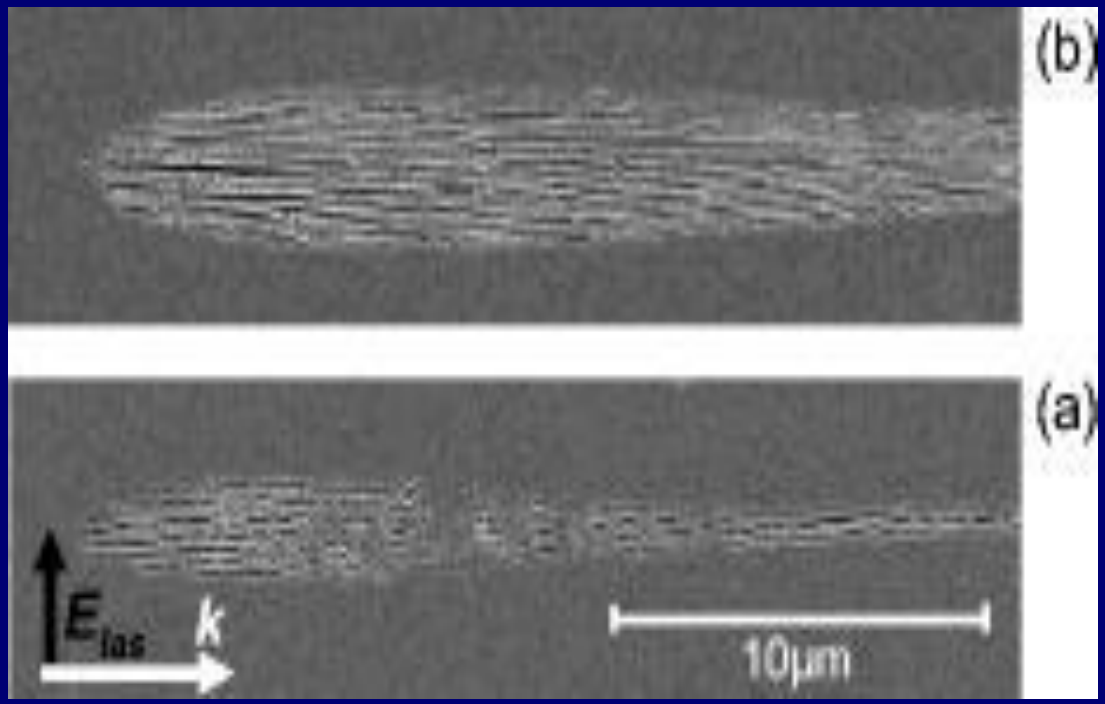




- Tunnelling is one of the most fundamental quantum mechanical process.
- Developing tools to measure tunnelling electron accurately.

Corkum and Sokolov's groups, submitted to Journal of Phys. B.

Nona structuring of materials by femtosecond lasers



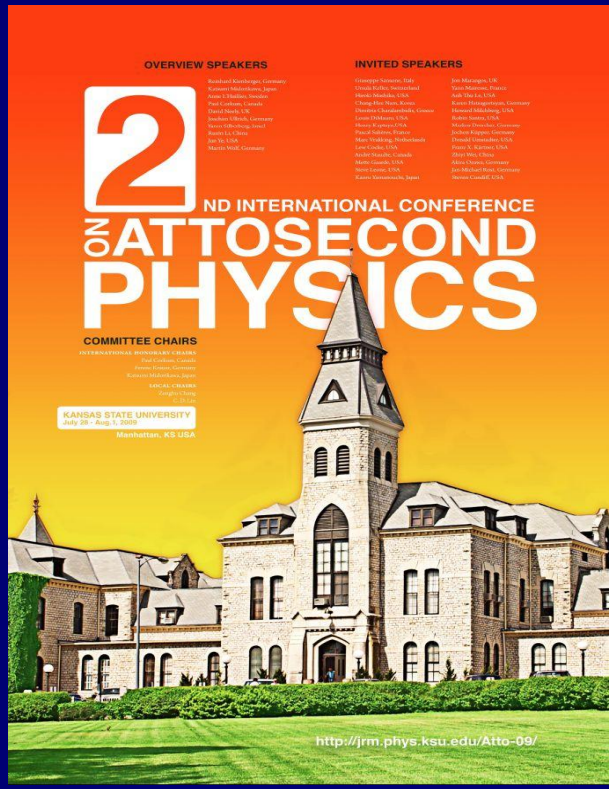
- The science behind laser surgery, laser machining and dielectric modification is light material interactions.

Corkum and Lei's groups, Appl. Phys. Lett. **93**, 243118 (2008).

Reviews and meetings

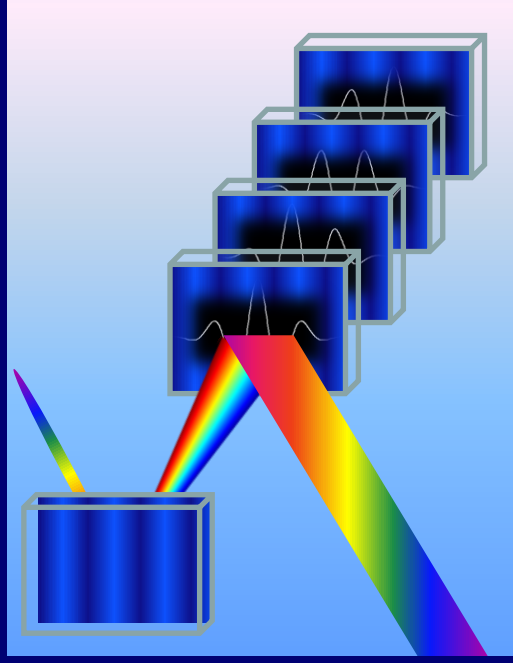
- **Kickoff meeting**
  5/22/2007,
  Kansas State University.

- **Annual meeting**
  8/14-15/2008,
  Texas A&M University.



- **The 2nd intentional conference on attosecond physics.**
  7/28-8/1, 2009, Manhattan, Kansas.

Publications



1. He Wang *et. al.,* Optics Express Optics Express **17**, 12082 (2009).

2. He Wang *et al.,* Applied Physics B DOI 10.1007/s00340-009-3639-0 (2009).

3. Eric Moon *et al.,* Laser and Photonics Reviews, (2009).

4. He Wang *et al.* J. Phys. B: At. Mol. Opt. Phys. **42**, 134007 (2009).

5. Michael Chini *et al.,* Appl. Phys. Lett. **94**, 161112 (2009).

6. Y. Wang *et al.,* Phys. Rev. A **79**, 023810, (2009).

7. (Invited) P. B. Corkum and Zenghu Chang, Optics and Photonics News **19**, 24 (2008).

8. He Wang, *et al.,* Optics Express **16**, 14448 **(**2008).

9. Steve Gilbertson *et al.,* Appl. Phys. Lett. **93**, 111105 (2008).

10. Hiroki Mashiko *et al.,*" Phys. Rev. A **77**, 063423 (2008).

11. Chengquan Li *et al.,* Appl. Phys. Lett. **92**, 191114 (2008).

12. Hiroki Mashiko *et al.,* Phys Rev. Lett. **100**, 103906 (2008).

13. Steve Gilbertson et al., Appl. Phys. Lett. **92**, 071109 (2008).

14 . Appl. Phys. Lett. **93**, 243118 (2008).

15. Zenghu Chang, PRA **76**, 051403(R) (2007).