# Multiple Ionisation of Clusters by intense soft X-rays from a Free-Electron Laser

Hamburg, November 7, 2002

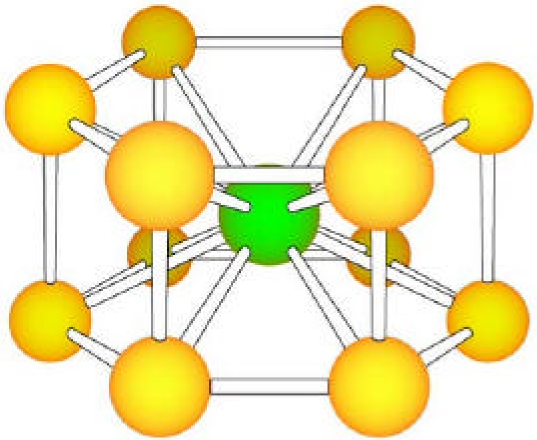
- **Introduction**
- **Interaction of intense pulses with clusters**

  **Coulomb explosion**

  **Multi-photon absorption**
- **Studies on clusters with short wavelength lasers**

# Why studies on clusters?

- **size dependent properties**
- **transition from isolated atoms to the solid**
- **new materials (fullerenes, nanotubes..)**



**Hexagonal silicon cage**
**around a tungsten atom**

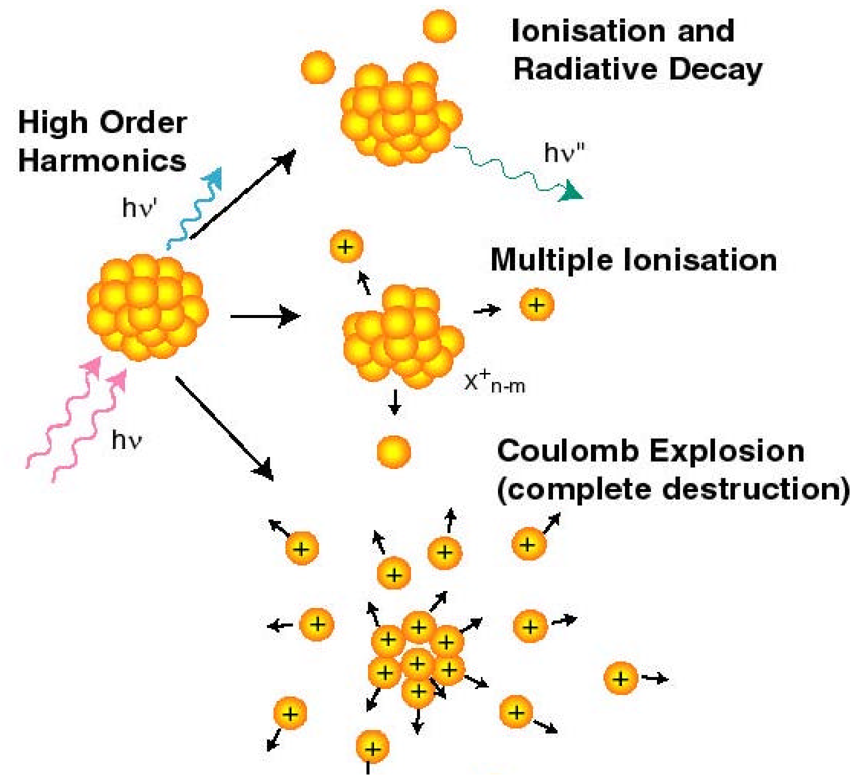
**Hiura et al PRL 86, 1733 (2001)**

- **interesting interaction with intense radiation**

**Ditmire, Rhodes**

# Idea of the experiment

## interaction of intense soft x-rays with matter

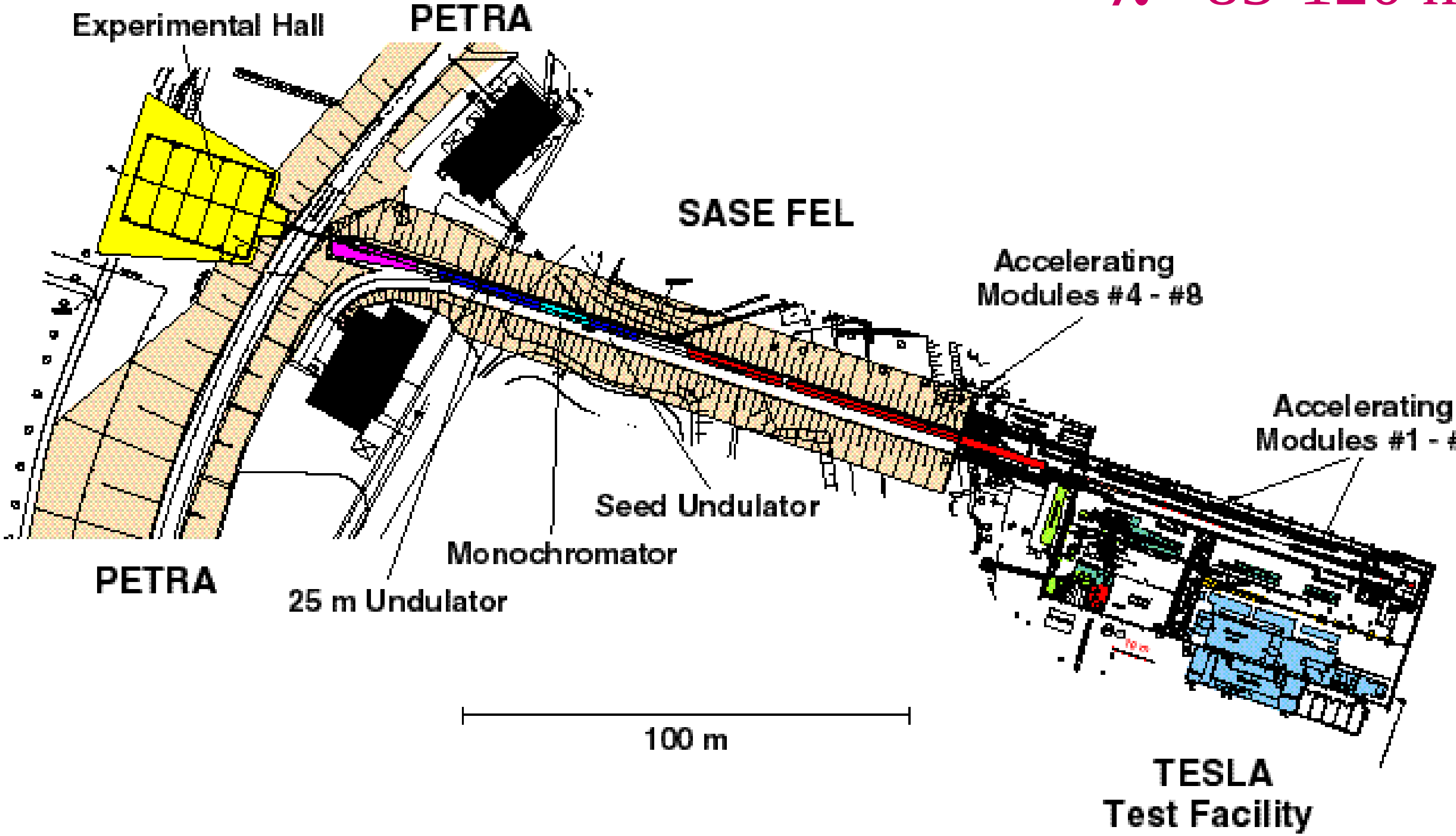



- **which multi-photon processes are observed**
- **which ions are prepared (charge state, electronically)**
- **absorption and ionisation mechanisms**

# VUV FEL at the TESLA Test Facility

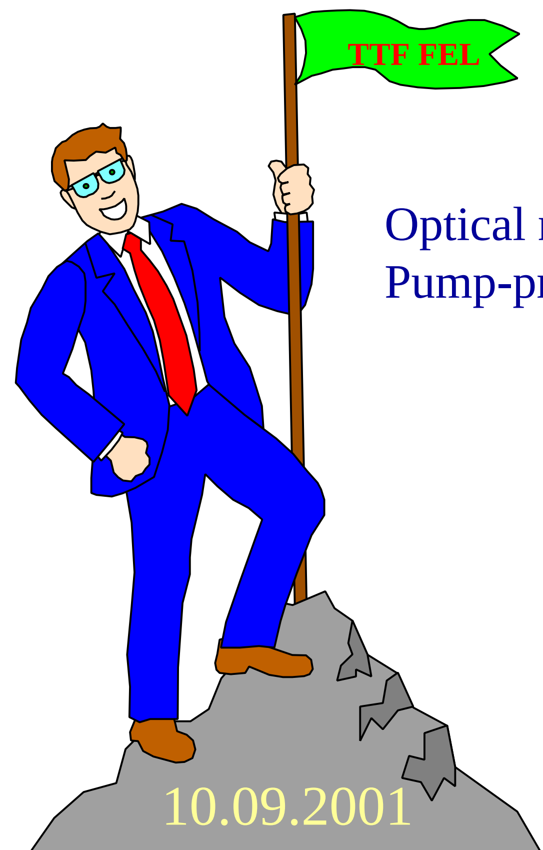
Phase II 2004
user facility λ > 6 nm

Phase I 2002
λ~ 85-120 nm



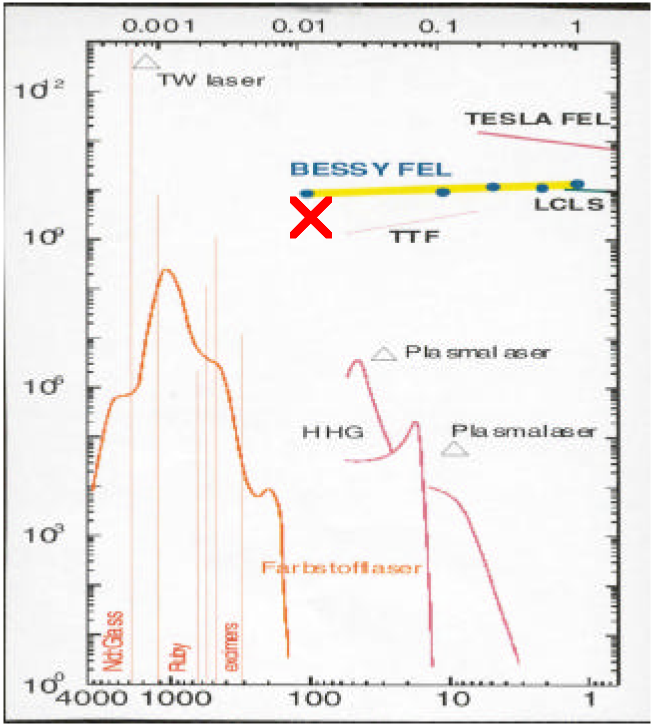
# The VUV-FEL is a unique light source

- Pulse length 30-100 fs
- Wavelength shorter than 100 nm
- Gigawatt peak power
- Fully coherent beam




Optical non-linear processes
Pump-probe experiments

## Peak power of different light sources



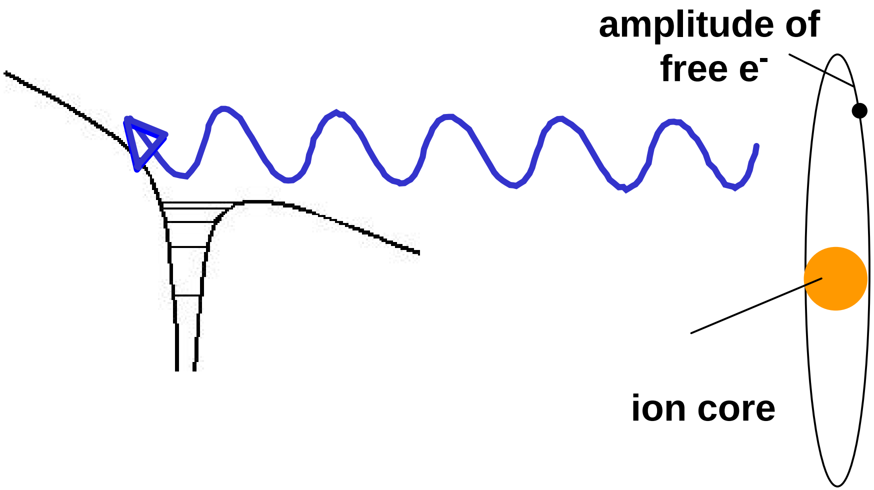

*✕ peak power achieved at TESLA FELin 2001*

**1000 times higher peak brilliance than any other source at this wavelength**

# Interaction of Intense Soft X-rays with Matter

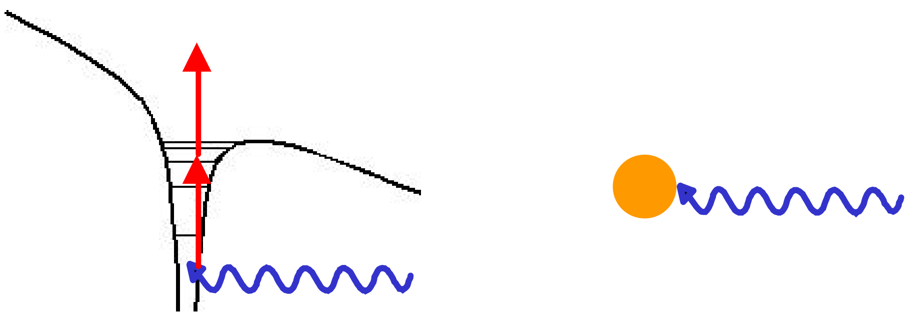
**laser-atom process at I ~ $10^{14}$ W/cm$^{2}$, ponderomotive energy 10-100 eV**

P. Bucksbaum et al



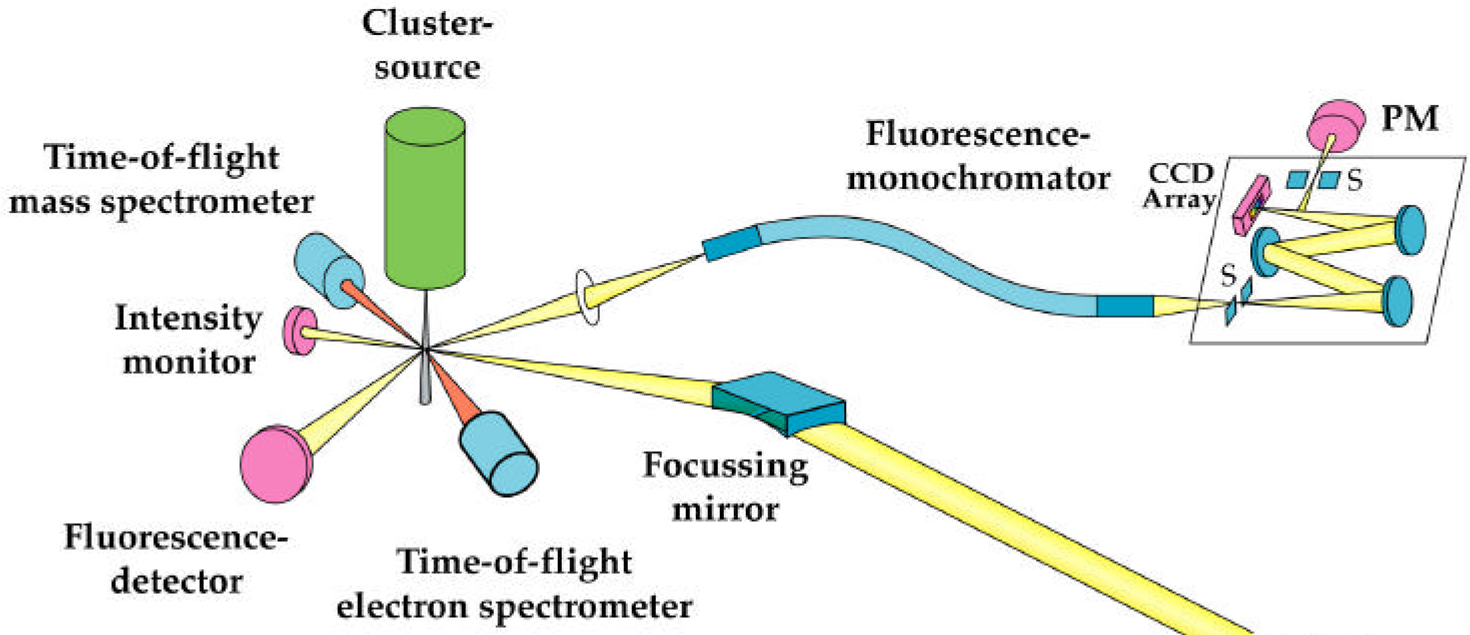

- **Field modulates the atomic potential at visible laser frequency**
- **Outer e$^{-}$ has time to tunnel or overcome the barrier: $2U_p > I_p$ where $U_p \sim I\, w^{-2}$**

**VUV FEL laser-atom process at I ~ $10^{14}$ W/cm$^{2}$, ponderomotive energy 10-100 meV**

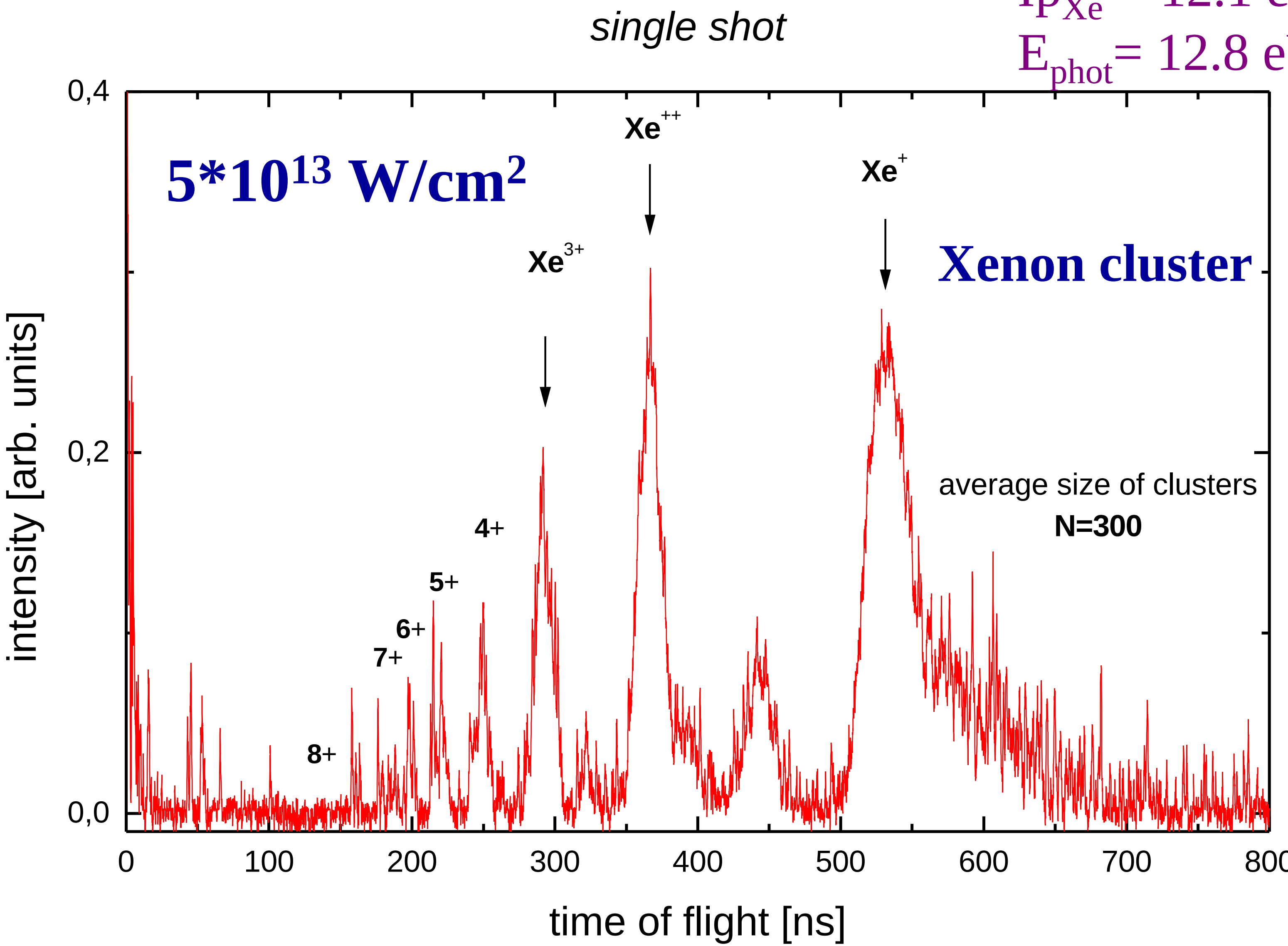


- **Field modulates the atomic potential at soft x-ray laser frequency**
- **e$^{-}$ do not have time to tunnel free**
- **multi photon process and innershell electrons are important**

# FEL Cluster-Experiment

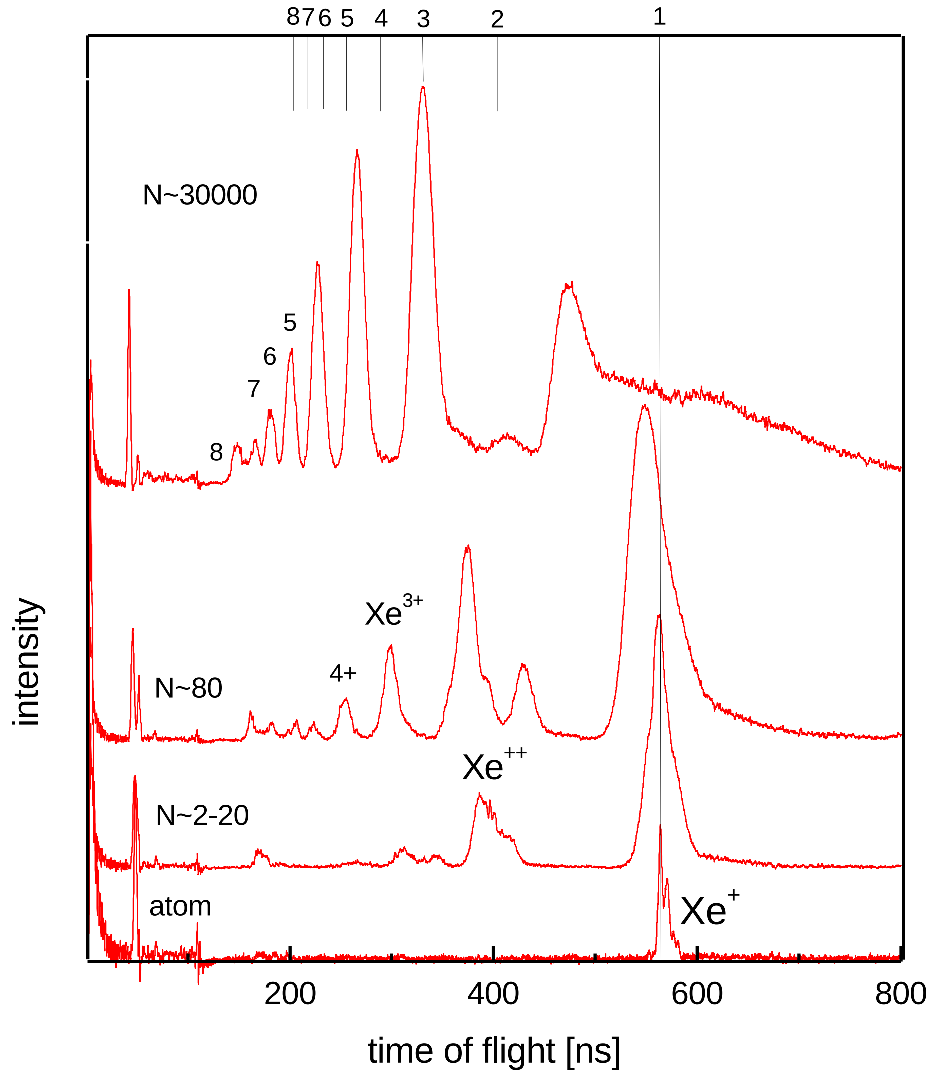


$Ip_{Xe} = 12.1$ eV
$E_{phot} = 12.8$ eV




σ = 50 Mbarn (single photon ionisation, 100 photons within σ)

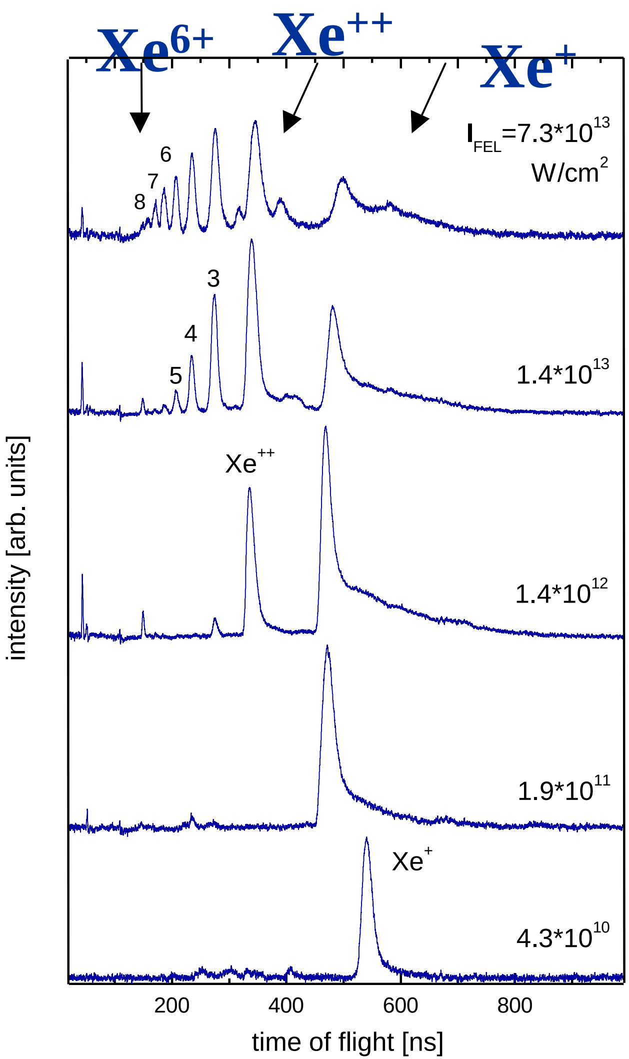
# Time of flight mass spectra of Xe atoms and clusters




- multiply charged ions from clusters
- singly charged atoms

$2*10^{13}$ W/cm$^2$

# Dependence on the power density



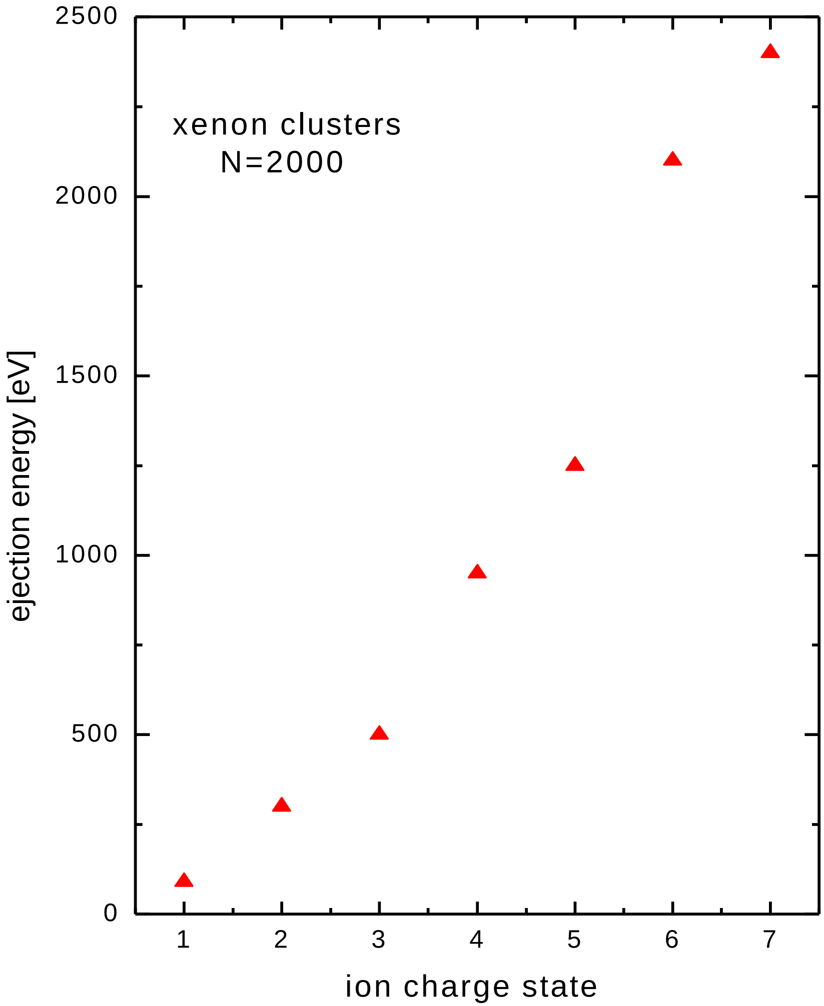

Time of flight [ns]

**Xenon clusters, 1500 atoms**

**$7*10^{13}$ Watt/cm$^2$**

**$4*10^{10}$ Watt/cm$^2$**

# Kinetic energy of the ejected ions




- Quadratic dependence on charge
- Coulomb explosion
- Up to 3 keV kinetic energy
- Each atom in the cluster absorbs 10-20 photons

# Questions and Answers

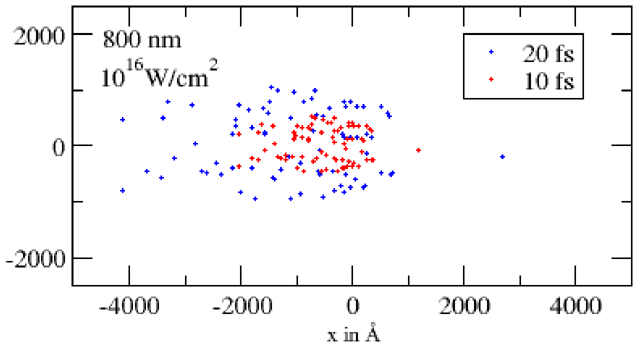
- **Which process allows the absorption of up to 20 photons/per atom?**

- **What is the ionisation mechanism?**

- **How can we explain the high charge states?**

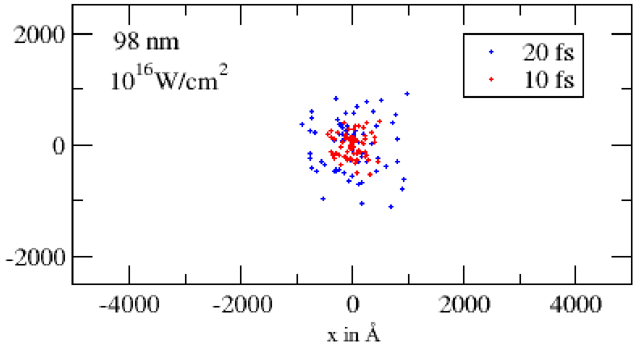
# Classical simulation of electron motion

## 78 electrons in $Xe_{13}$



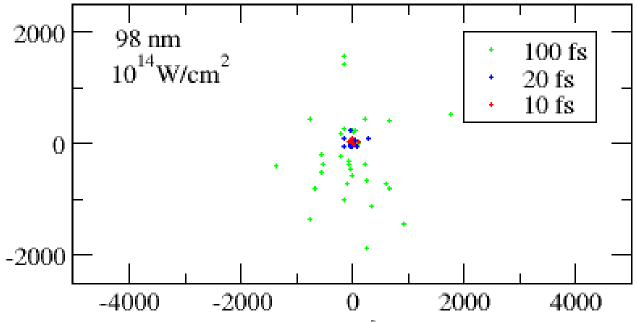

Infrared light (800 nm) $10^{16}$ W/cm$^2$
directed electron emission in the polarization plane

→ field ionization




VUV (98 nm) $10^{16}$ W/cm$^2$
isotropic electron emission

→ photon assistet thermionic electron emission



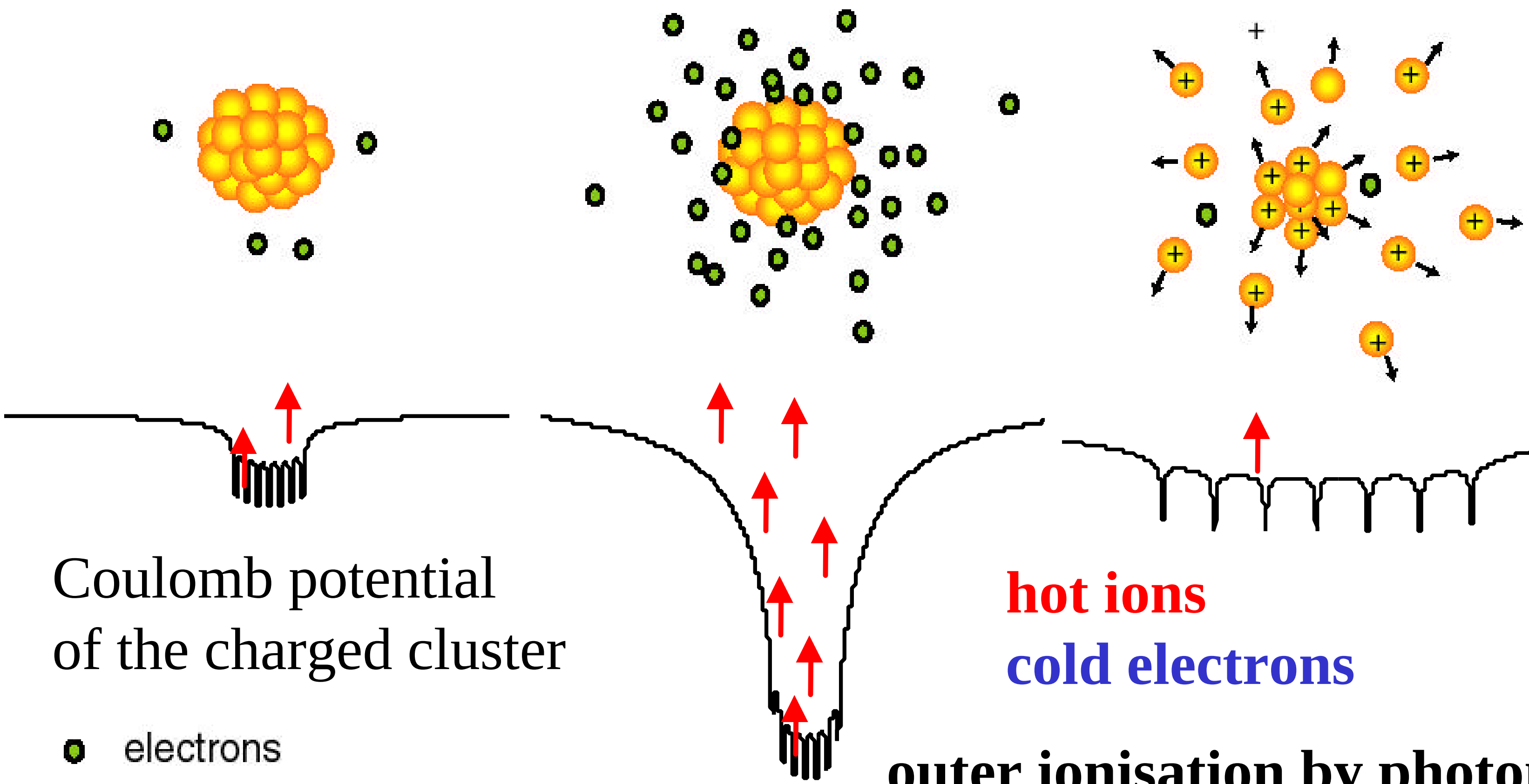

VUV (98 nm) $10^{14}$ W/cm$^2$

calculated cross section $\sigma$ = 0.3- 1Mbarn for Xe

experiment 10 Mbarn

# Coulomb explosion of clusters induced by multi-photon absorption

$t_0$ beginning of the pulse | $t_1$ maximum | $t_2$ end of the pulse

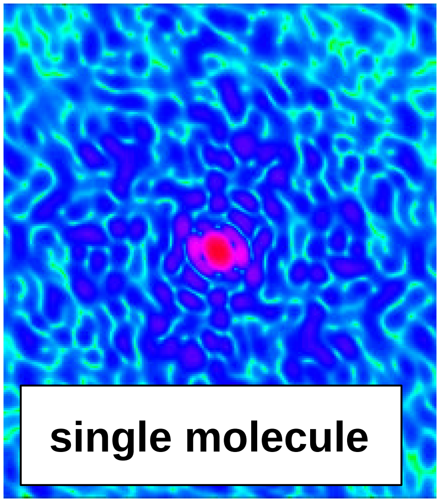


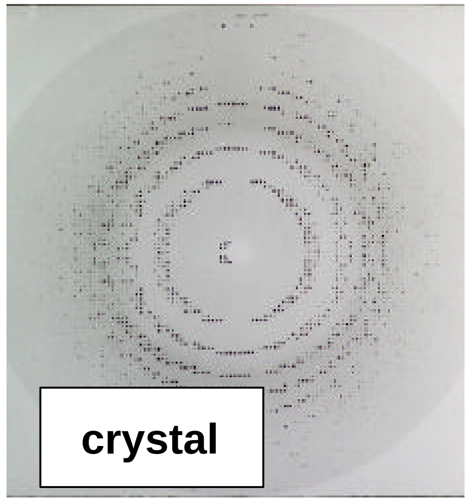

**Nanoplasma formation:**
**inner ionisation of all atoms**

**outer ionisation by photon assisted thermionc electron emission**

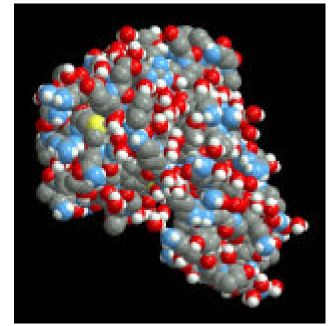
# Single molecule structure determination with X-rays from a FEL

**With atomic resolution**



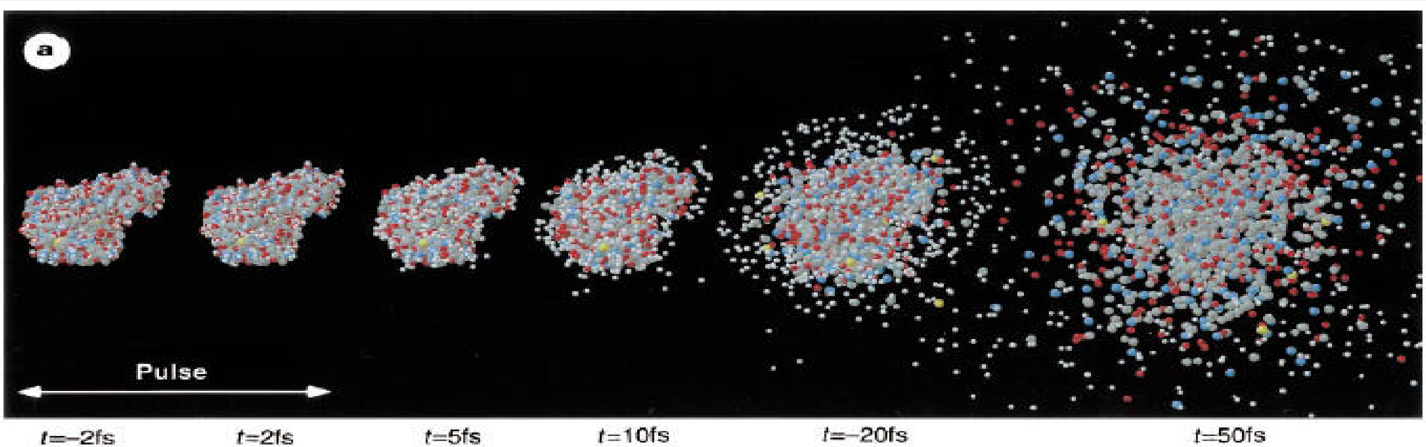




**Lysozyme**



R. Neutze, J. Haidu et al., Nature 406, 752 (2000)

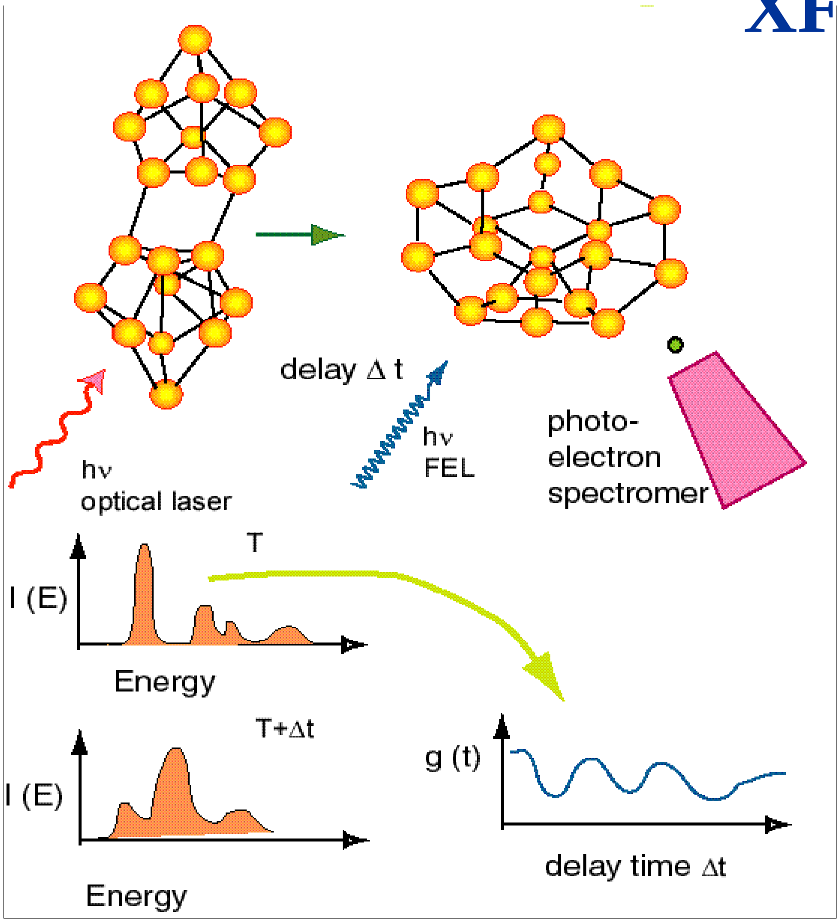
Radiation damage and Coulomb explosion



# Spectroscopy and structure determination of mass selected clusters

## TTF2: Electronic structure (photoelectron spectroscopy

## XFEL: Geometry (diffraction)




**Collaboration for TTF2**

**Rostock**
**Hamburg**
**Konstanz**
**Osnabrück**
**BESSY**
**HASYLAB**

# Summary and Outlook

- **VUV-FEL allows the study of non-linear processes in the VUV** **high power and short pulses (<100 fs)**

- **Coulomb explosion of clusters**

  **thermionic electron emission**

  **very efficient energy absorption**

- **Short wavelength free-electron lasers will open new and exciting sites for research on clusters**

  **electronic structure and geometry**

  **surface chemistry and catalytic reactions**

  **fs-dynamics**

**Hubertus Wabnitz**
**Joachim Schulz**
**Peter Gürtler**
**Wiebke Laasch** **Cluster experiment**
**Tim Laarmann**
**Anja Swiderski**
**Klaus von Haeften**

L**. Bittner, R. de Castro, R. Döhrmann, B. Faatz,**
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**and the TTF-team**