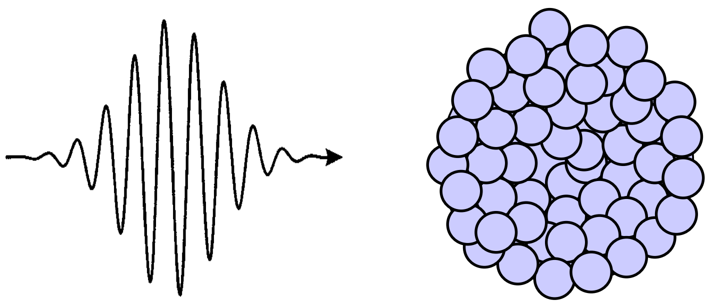
Interaction of Intense VUV-Radiation with Rare Gas Clusters



Outline

- Motivation
- Experimental set-up
- Coulomb explosion of Xe clusters
- Electron emission from Xe clusters
- Summary

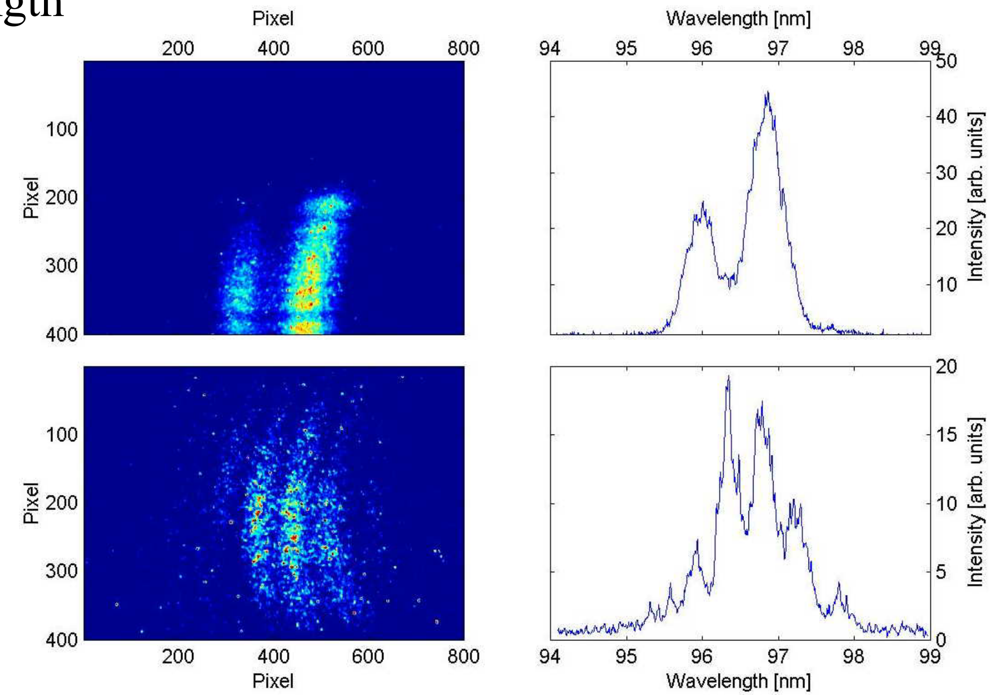
Hubertus Wabnitz *now: CEA-SPAM, Saclay*

FEL radiation

Photon
pulse length

50 fs

150 fs



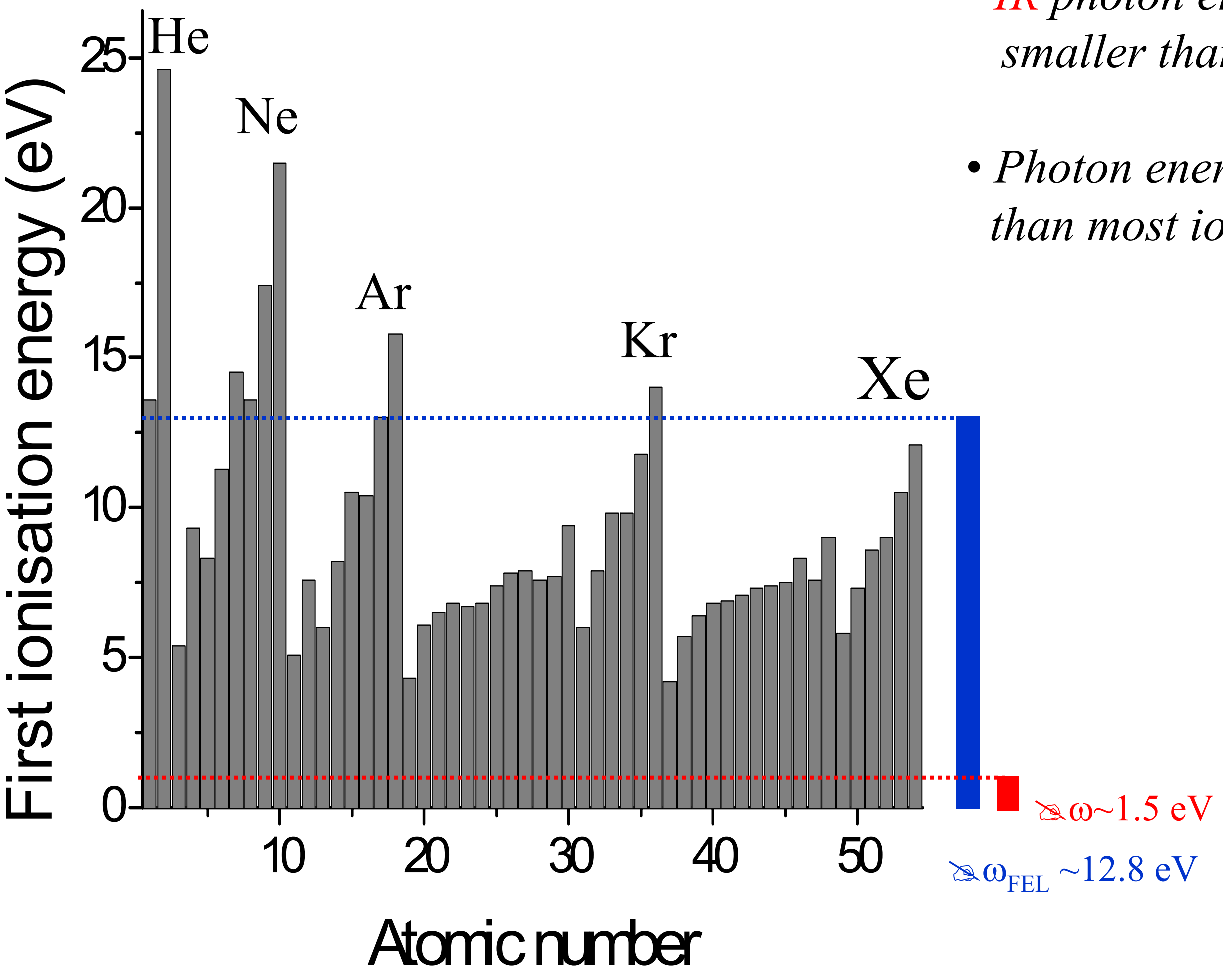
TTF1-FEL

Wavelength	80-120 nm
Pulse energy	≤ 100 μJ
Pulse duration	50-200 fs
Peak power	1GW
Spectral width	1 %

@ 12.8 eV
10^{12} photons/pulse

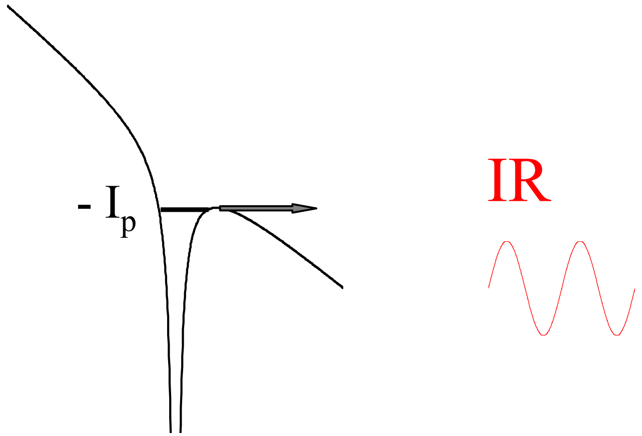
Pulse length determined from photon statistics
and by means of simulations
M. Yurkov et al.

Differences between IR- and VUV-Radiation



- *IR photon energy considerably smaller than ionisation potentials*
- *Photon energy of VUV-FEL larger than most ionisation potentials*

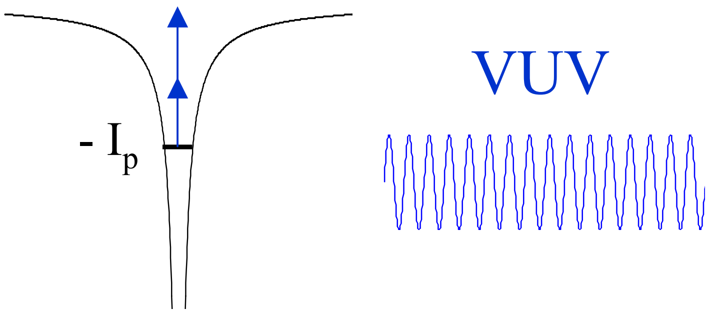
Interaction of IR-Laser with Atom at ~10^{15}W/cm^2 , ponderomotive energy 10-100 eV



Field Ionisation

- *Atomic potential is modulated with „slow" IR-frequency*
- *Outer e^- have time to tunnel or overcome the barrier*

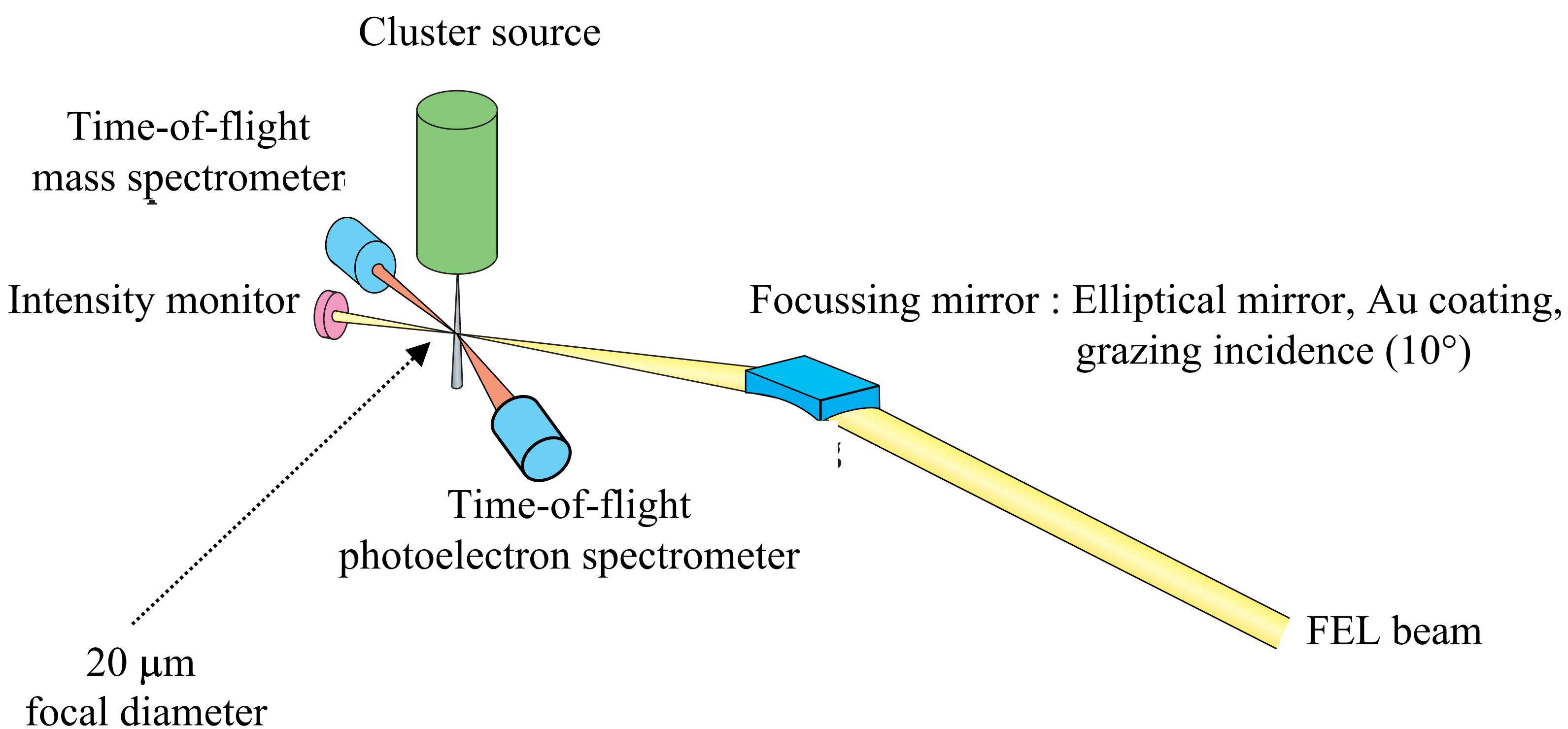
Interaction of VUV-FEL with Atom at ~10^{13}W/cm^2 , ponderomotive energy ~10 meV



Multiphoton Ionisation

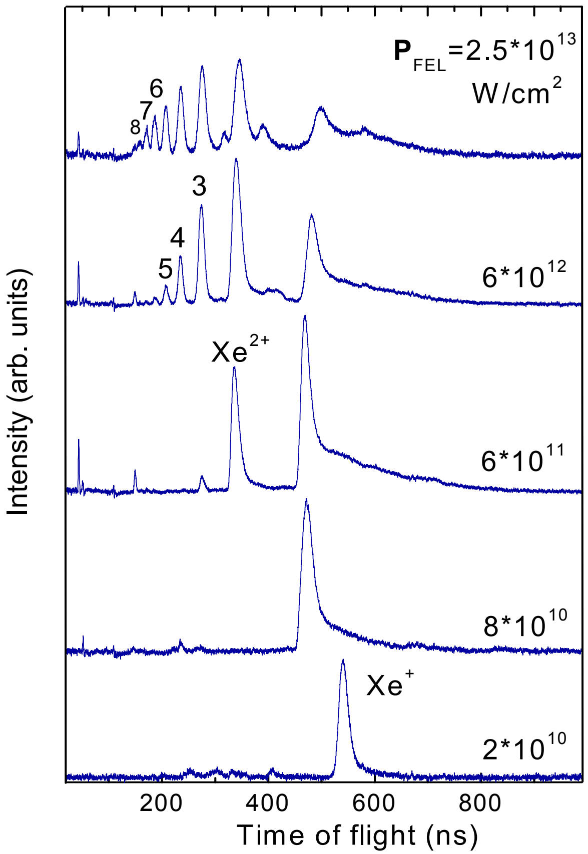
- *Atomic potential is modulated with „fast" VUV-frequency*
- *e^- do not have time to tunnel etc.*
- *Ionisation is governed by Multiphoton Processes*

Experimental set-up



Ionisation as a function of peak power density

Time-of-flight mass spectra



T_{puls}=50 fs
λ_{FEL}=98 nm

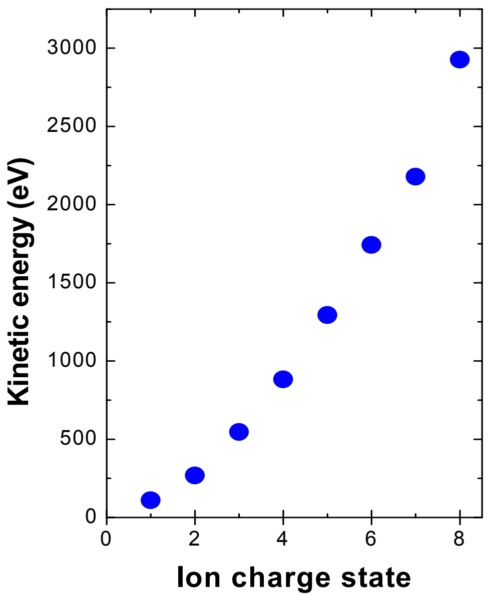
Cluster size 2500 atoms

- Multiply charged ions
- Only atomic fragments
- Strong dependence on power density

Non-linear optical processes dominate ionisation

- complete fragmentation at ~ 10^{10} W/cm^2

Expansion

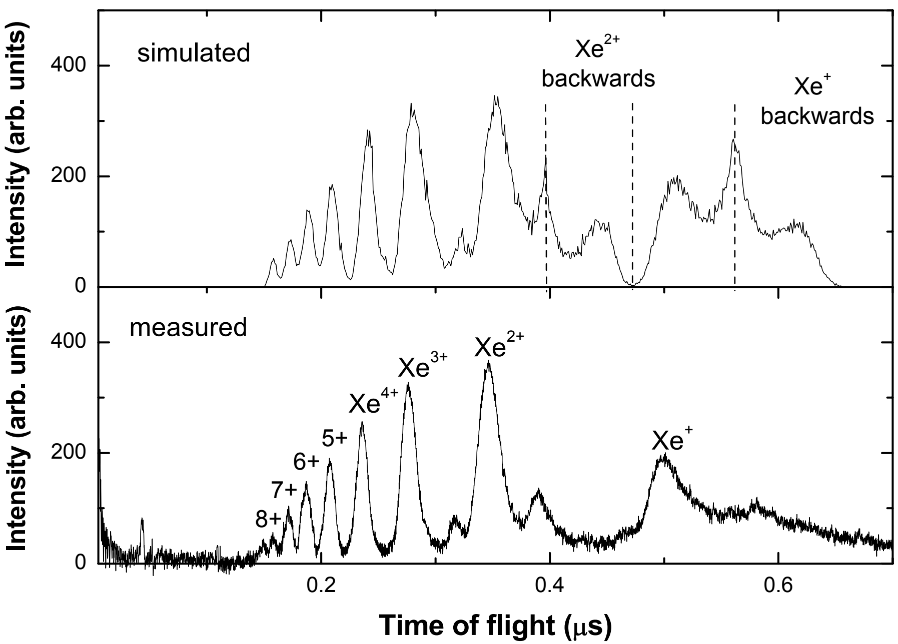


- high kinetic energies up to 3 keV
- $E_{kin} \sim z^2$

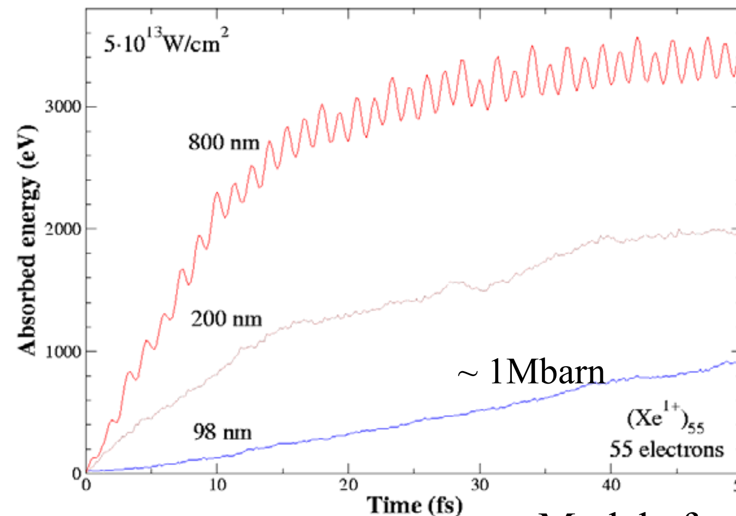
Coulomb explosion

Energy absorption

Average charge state	$\bar{z} = 3$
Average absorption	$\bar{E} = 550$ eV
	~ 43 FEL Photons
Average cross section	$\bar{\sigma} = 72 \pm 14$ Mbarn



Classical simulation



Model after I. Last, and J. Jortner

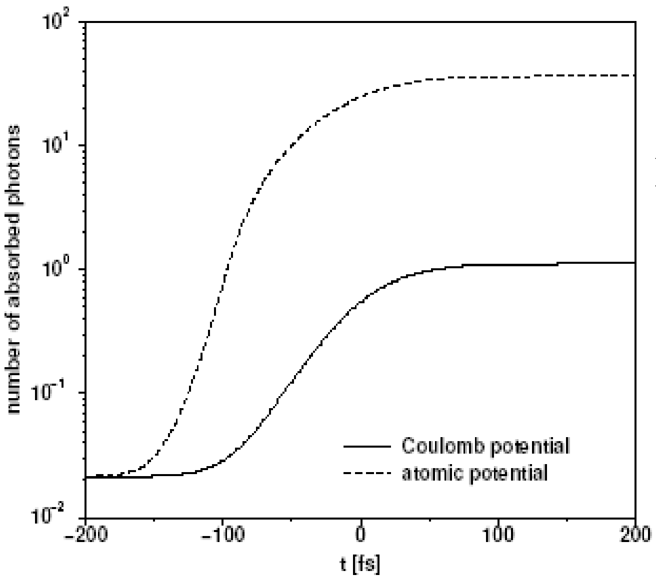
	$(Xe^{1+})_{13}$	$(Xe^{1+})_{55}$	$(Xe^{2+})_{55}$	$(Xe^{6+})_{55}$
Quasi-free e^-	13	55	110	330
Absorption	16 eV	26 eV	68 eV	374 eV

Classical heating can not account for high absorption in clusters

Recent theoretical work

Inverse bremsstrahlung with atomic potential

Robin Santra and Chris H. Green (Boulder),
PRL accepted



30 photons/atom

In good agreement with experiment (43 photons)

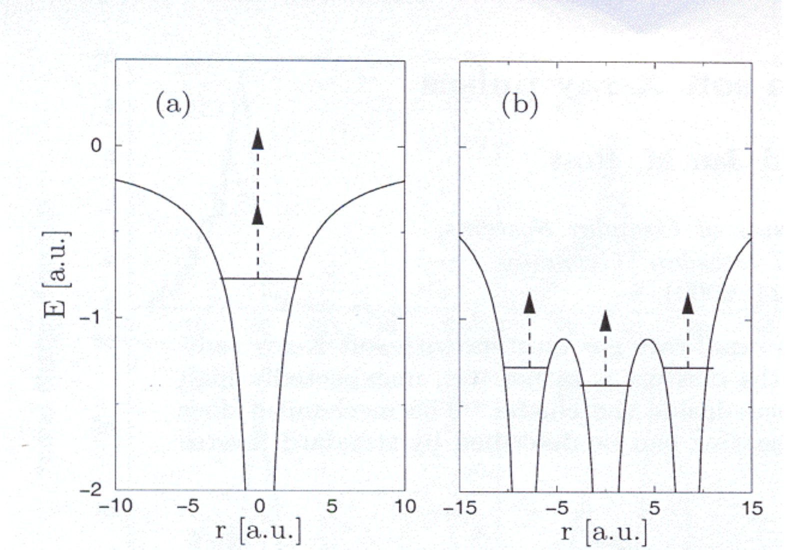
Atomic potential:

$$V_i(r) = -\frac{1}{r}\{i + [Z-i]\exp(-\alpha_i r)\}\exp(-r/\lambda_D)$$

Electron can penetrate deeper into ion core and sees charge up to q=5 instead of q=1

Mixed quantum-classcial model

Christian Siedschlag and Jan M. Rost
(MPI Dresden), PRL submitted

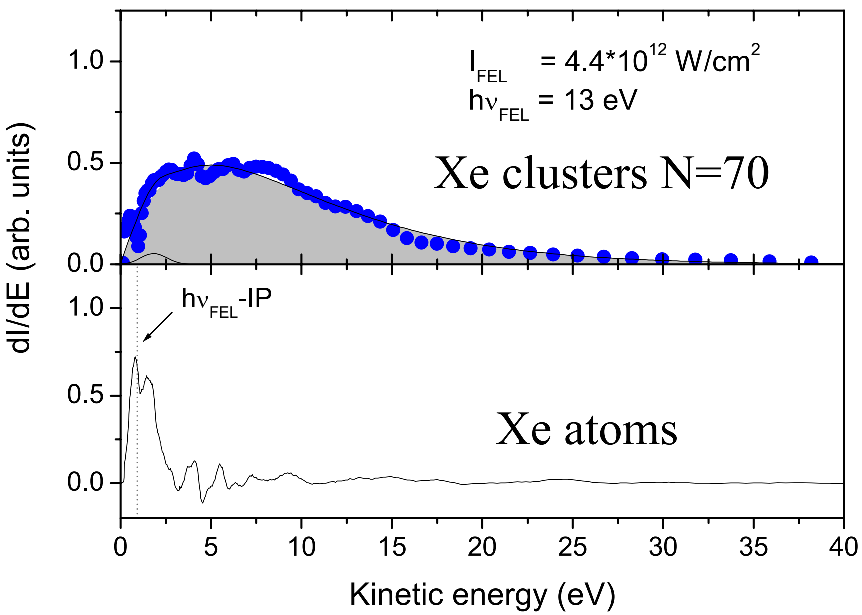


Barriers pulled down by surrounding charges

Much higher inner ionisation up to Xe^{7+}

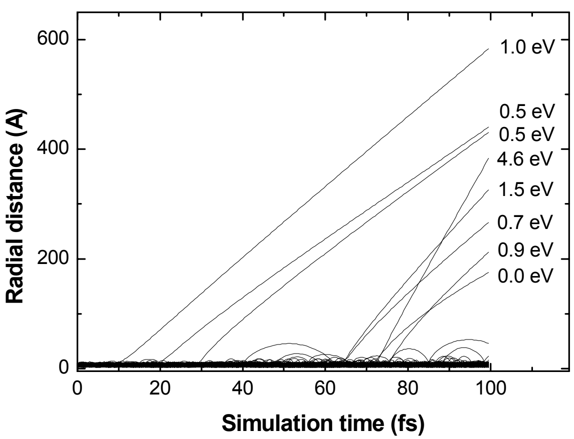
Photoelectrons

Experimental
time-of-flight spectra



- low energy electrons
- broad thermal distribution

Simulation
of electron trajectories



$(Xe^{3+})_{55}$
165 e^-

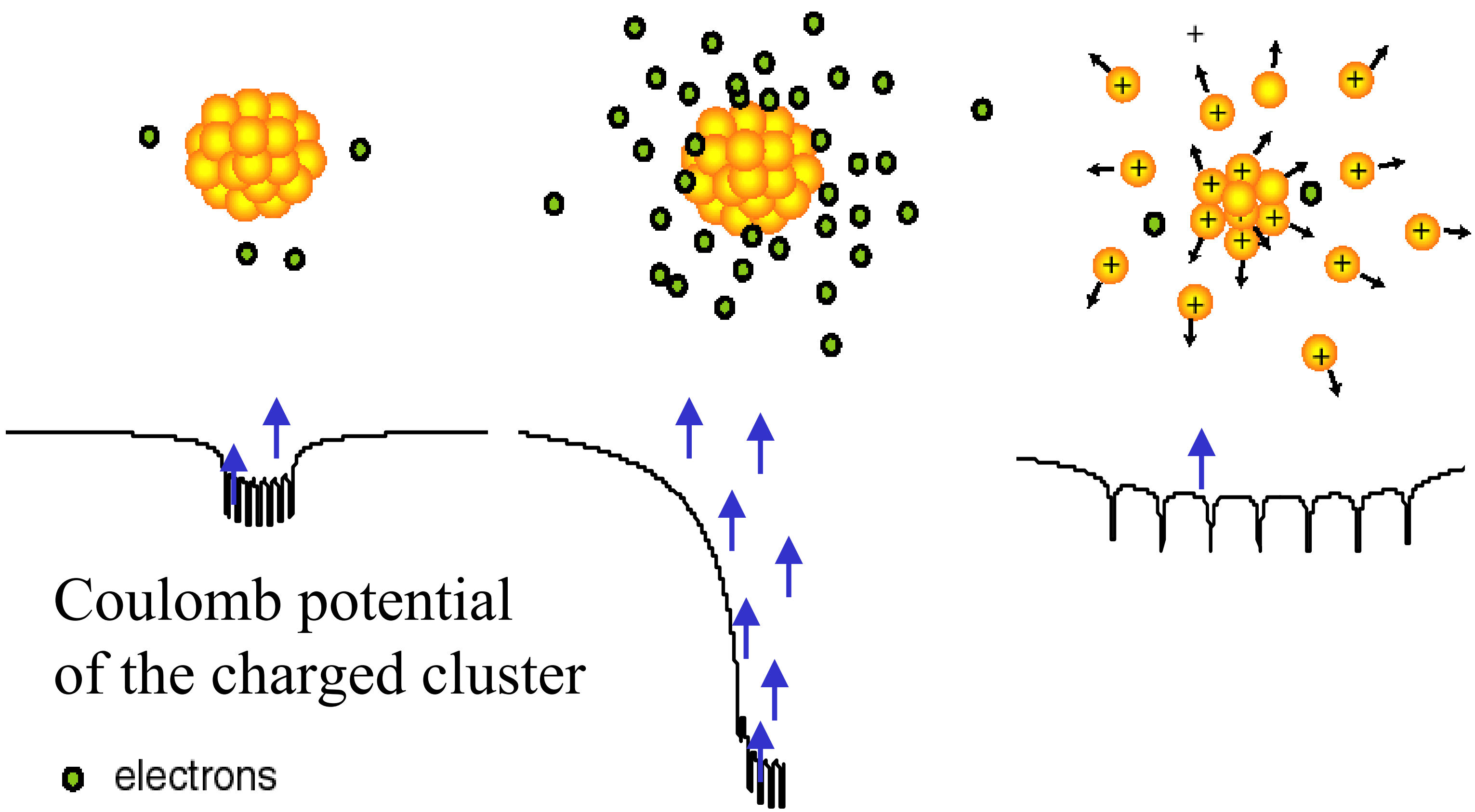
Delayed e^--emission
after many collisions

→ No field ionisation

Photoassisted
thermionic emission

Coulomb explosion of clusters induced by absorption of many photons

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



Summary

Xe clusters

- Coulomb explosion of clusters from $\sim 10^{10}$ W/cm^2
- Classical simulation of absorption gives 10 times smaller energy deposition than measured in FEL-experiment
- Photoelectron spectra give experimental evidence for thermionic electron emission

Cluster group and support

Cluster group @ HASYLAB

Thomas Möller
Tim Laarmann
Joachim Schulz
Anja Swiderski
Ralph Döhrmann
Peter Gürtler
Wiebke Laasch
Rubens de Castro

FEL @ DESY

Photon Diagnosis Team
and the TTF-Team

Hasylab and TTF

TTF1

80-120 nm, 30-100 µJ
1 GW_{peak}, 30-200 fs

Linac and FEL extension for TTF2

Experimental hall
(User Facility, starting 2004)

- 6 - ~100 nm
- 0.1 – 1 mJ
- 30 - 400 fs ?