Erste Experimente mit dem TESLA Freie-Elektronen Laser im VUV

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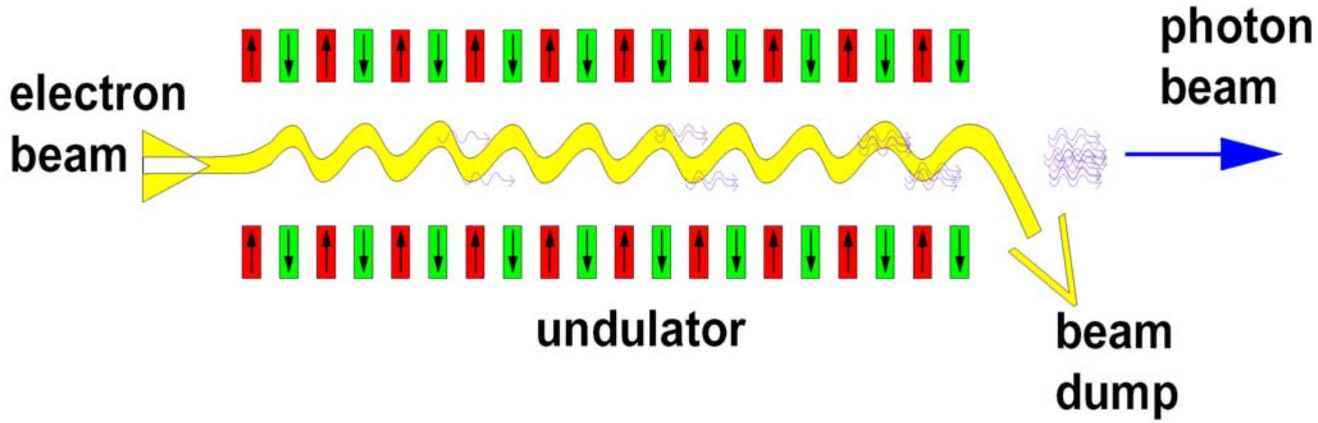
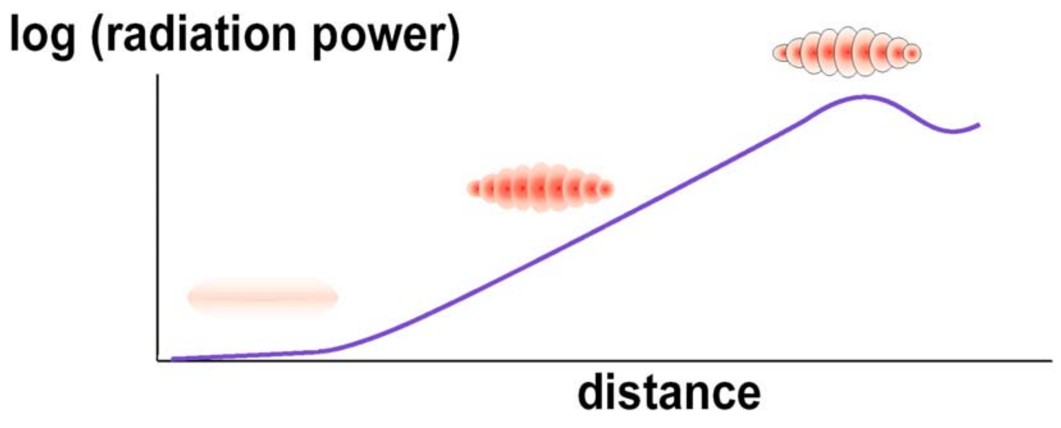
DESY/HASYLAB, Hamburg

- Strahleigenschaften
- Erste Experimente an Festkörpern
- Erste Experimente an Gasen
- Ausblick: FEL User Facility

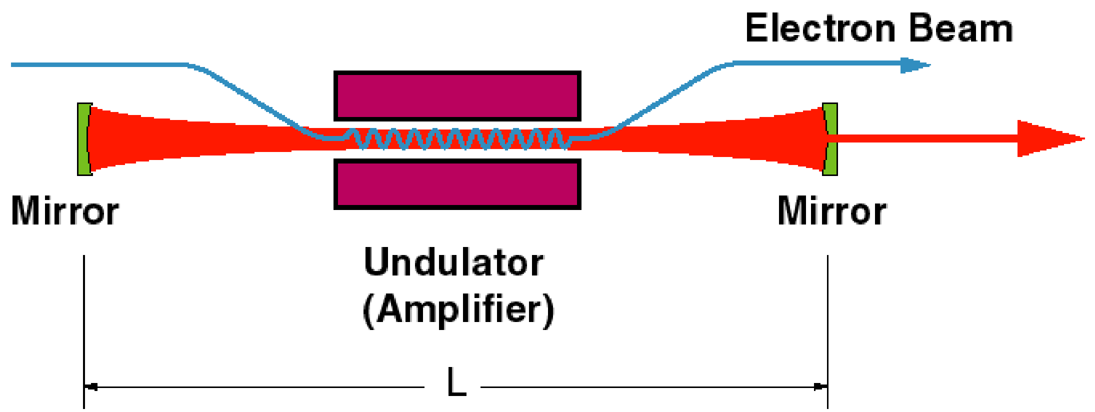
Self-Amplified Spontaneous Emission (SASE)





FEL Oscillator

used for FIR to UV,
$\lambda \sim 100$ to $0.2\ \mu m$



short pulses: ~mm (~ps)
small gain: many passes
electron bunch distance = 2L

Problems:
- **low reflectivity for short wavelengths**
- **radiation damage**

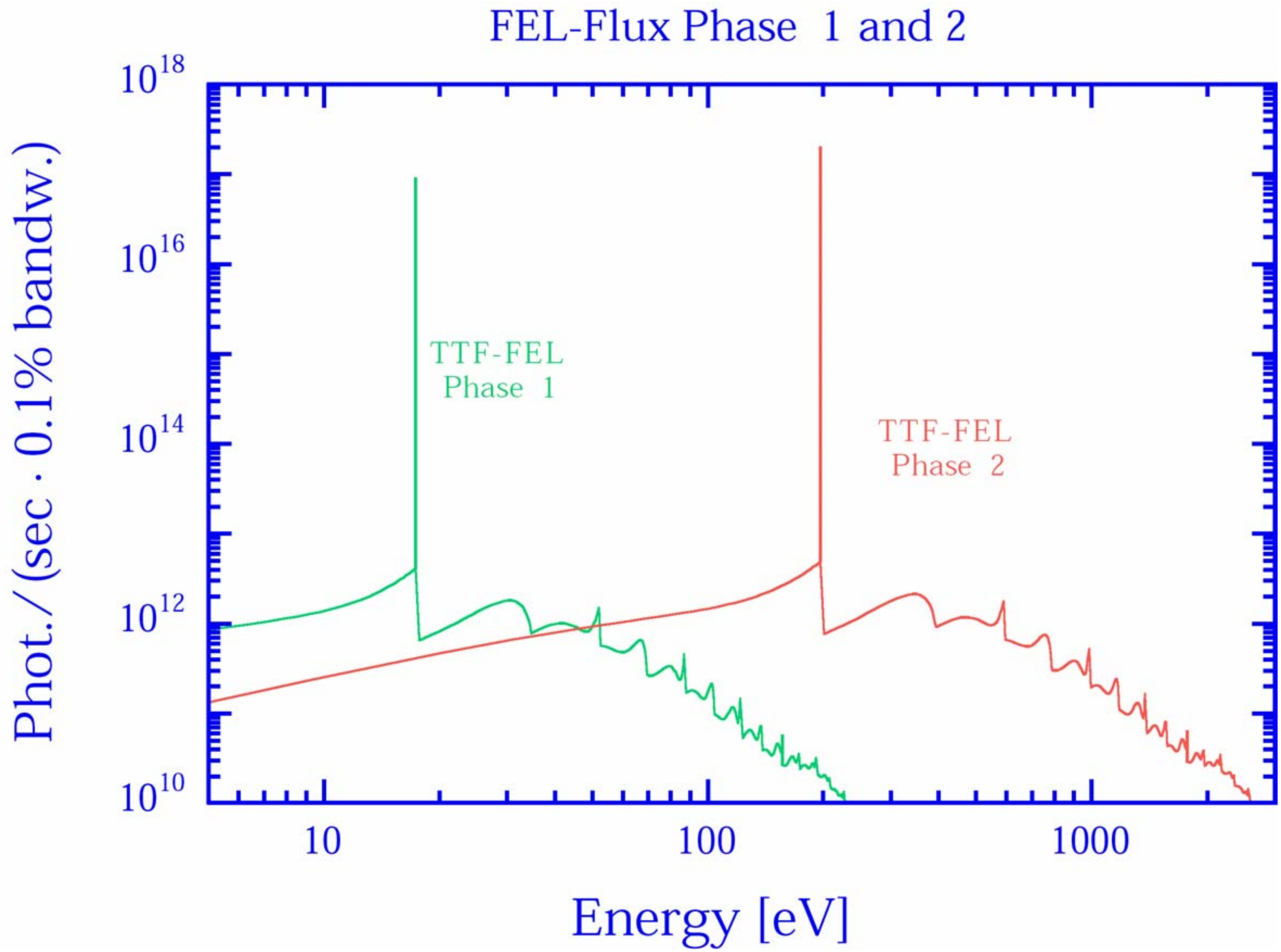
High gain, single pass: SASE

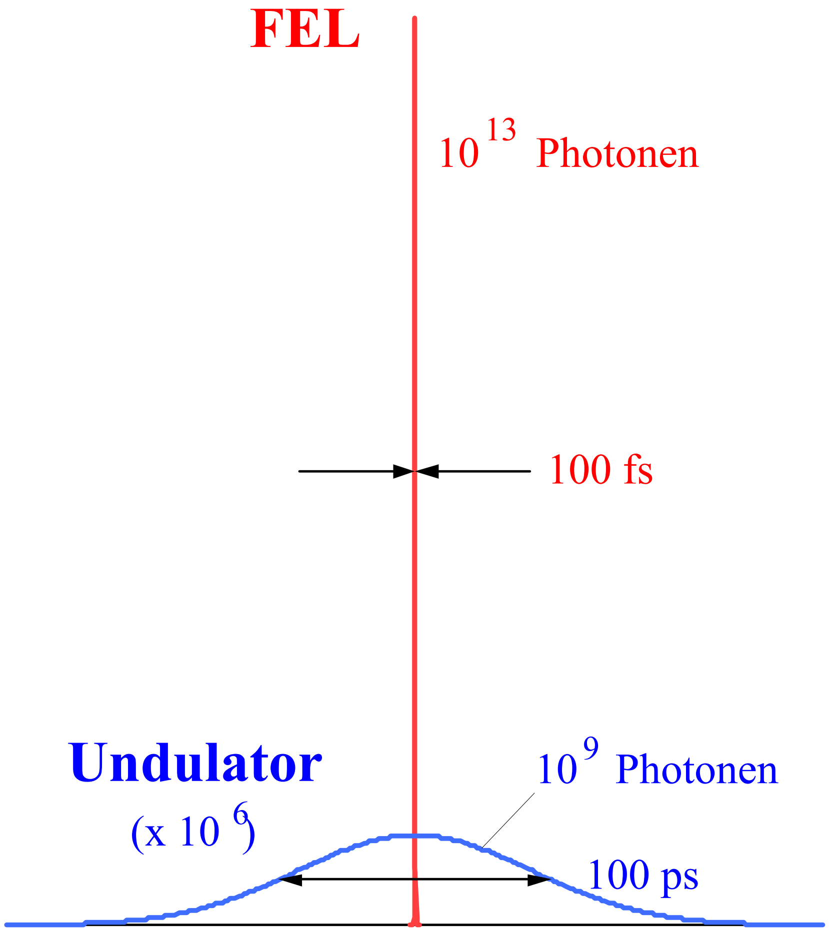
Meilensteine auf dem Weg zum Röntgenlaser

• 1998	UCLA/LANL	12 µm	10^5 Verstärkung
• 1999	LEUTL (APS)	530 nm	exp. Anstieg
• Feb. 2000	TTF (DESY)	109 nm	10^3 Verstärkung
• 2000	LEUTL (APS)	530 nm, 385 nm	exp. Anstieg
• Sep. 2001	TTF (DESY)	100 nm	Sättigung
• Jan. 2002	TTF (DESY)	82-125 nm	Sättigung
• 9/01-3/02	TTF (DESY)	85-120 nm	Experimente mit FEL-Strahlung

↓

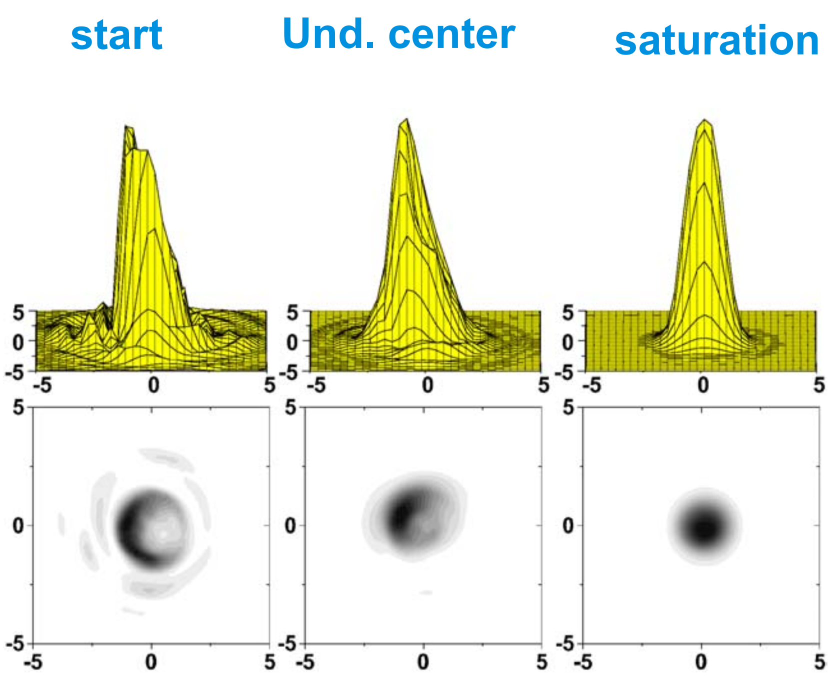
1 Å


FEL-Flux Phase 1 and 2
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
Phot./(sec · 0.1% bandw.)
TTF-FEL
Phase 1
TTF-FEL
Phase 2
10
100
1000
Energy [eV]

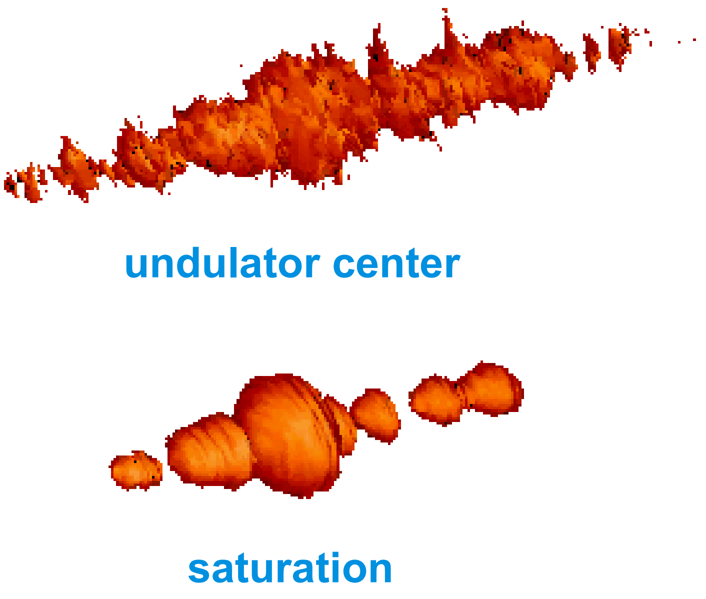


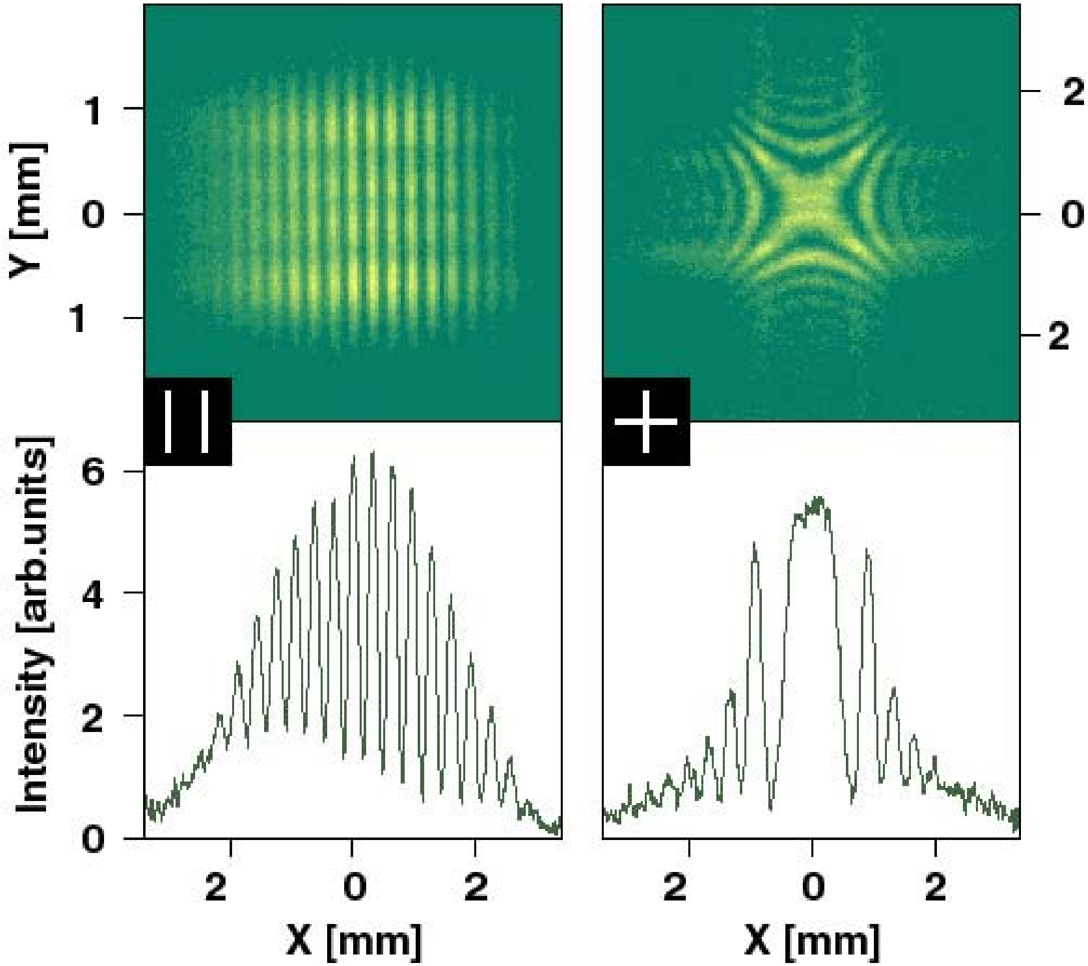
FEL
10^{13} Photonen
100 fs
Undulator
(x 10^6)
10^9 Photonen
100 ps

Development of transverse coherence (simulation)

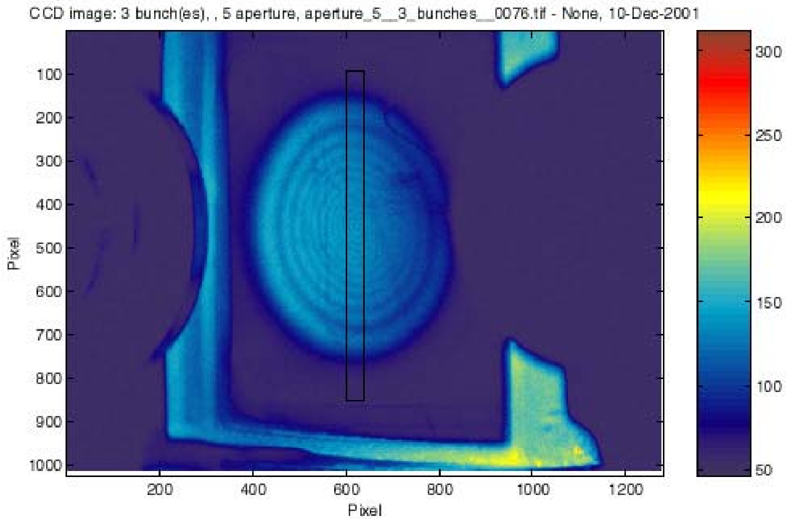


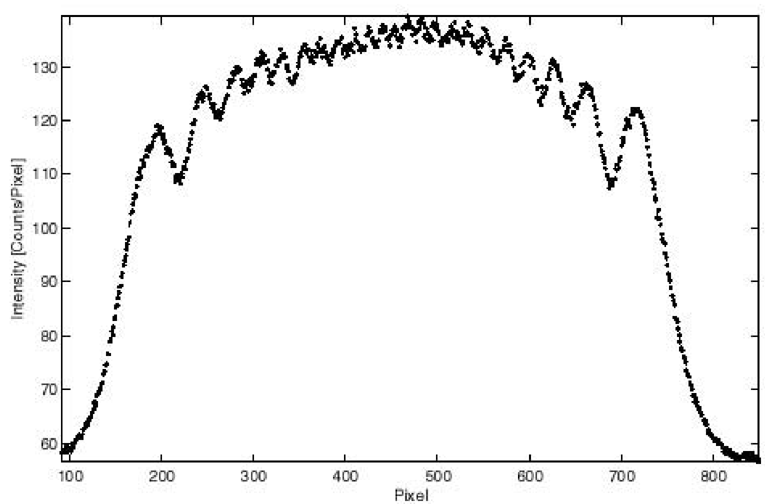
distribution along the bunch

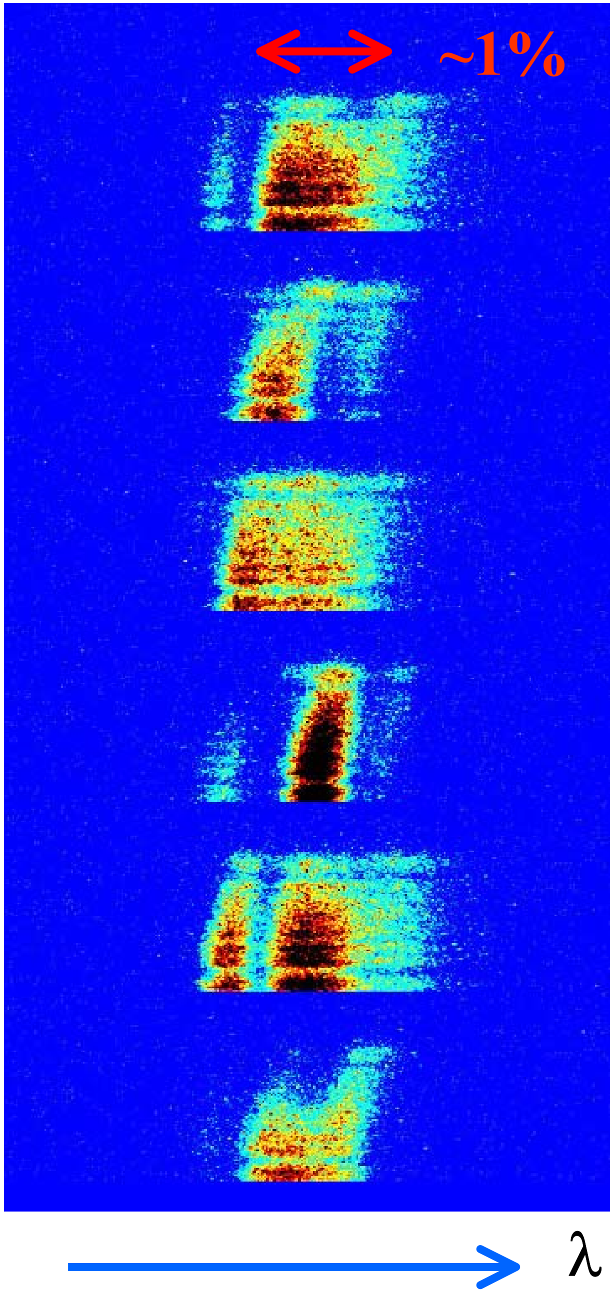




Diffraction of 95 nm FEL radiation from a pair of parallel slits, each 2mm long and 200 µm wide at a distance of 1 mm, and crossed slits, 100 µm wide and 4 mm long. The diffraction patterns were observed by a CCD camera on a Ce:YAG crystal 3 m behind the slits. Slit distance from the FEL ~12 m.


CCD image: 3 bunch(es), , 5 aperture, aperture_5__3_bunches__0076.tif - None, 10-Dec-2001
Pixel
Pixel


Intensity [Counts/Pixel]
Pixel



Spectral distribution of single FEL pulses at ~95 nm

Erste Experimente

an Festkörpern
J. Krzywinski et al.,
Poln. Akad. der Wiss.

an Gasen
Th. Möller et al.,
HASYLAB/DESY

Strahl-Durchmesser	10 – 100 µm
Wellenlänge	85 – 105 nm
Puls-Energie	10 – 100 µJ

→

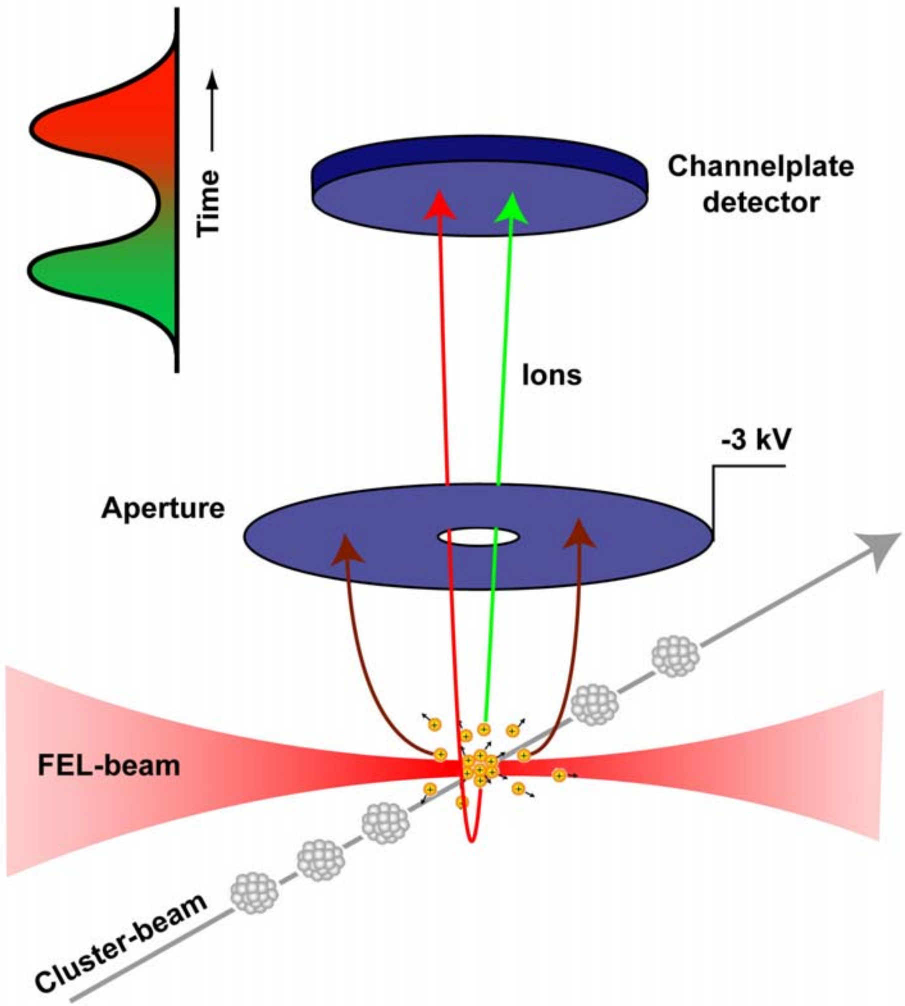
$\sim 10^{12}$	–	10^{14}	W/cm^2
$\sim 0{,}1$	–	10	J/cm^2
$\sim 5 \cdot 10^{17}$	–	$5 \cdot 10^{19}$	$Phot./cm^2$

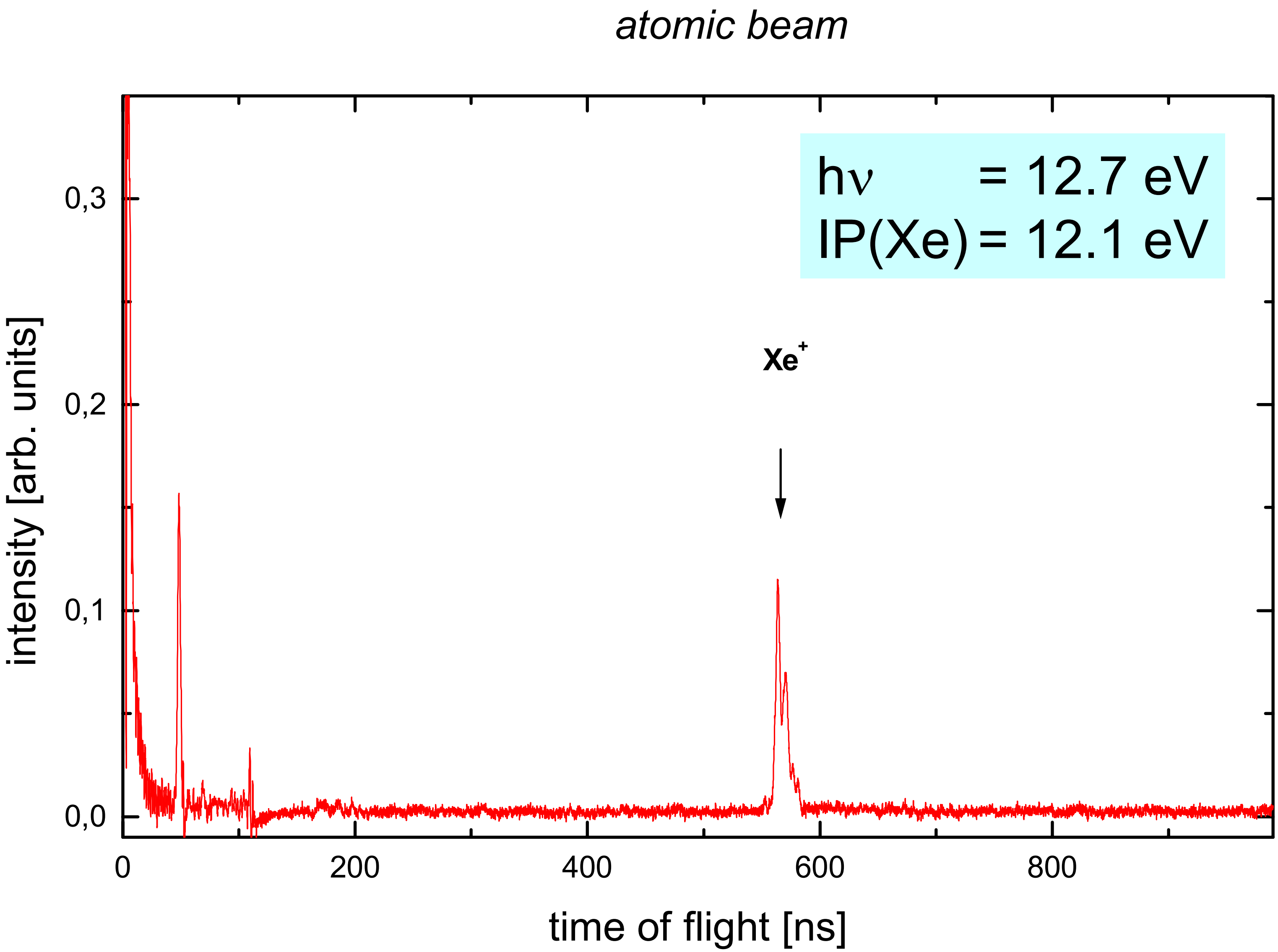
Ionisierungs-Wirkungsquerschnitt von Xe: $\sim 5 \cdot 10^{17}$ cm^2

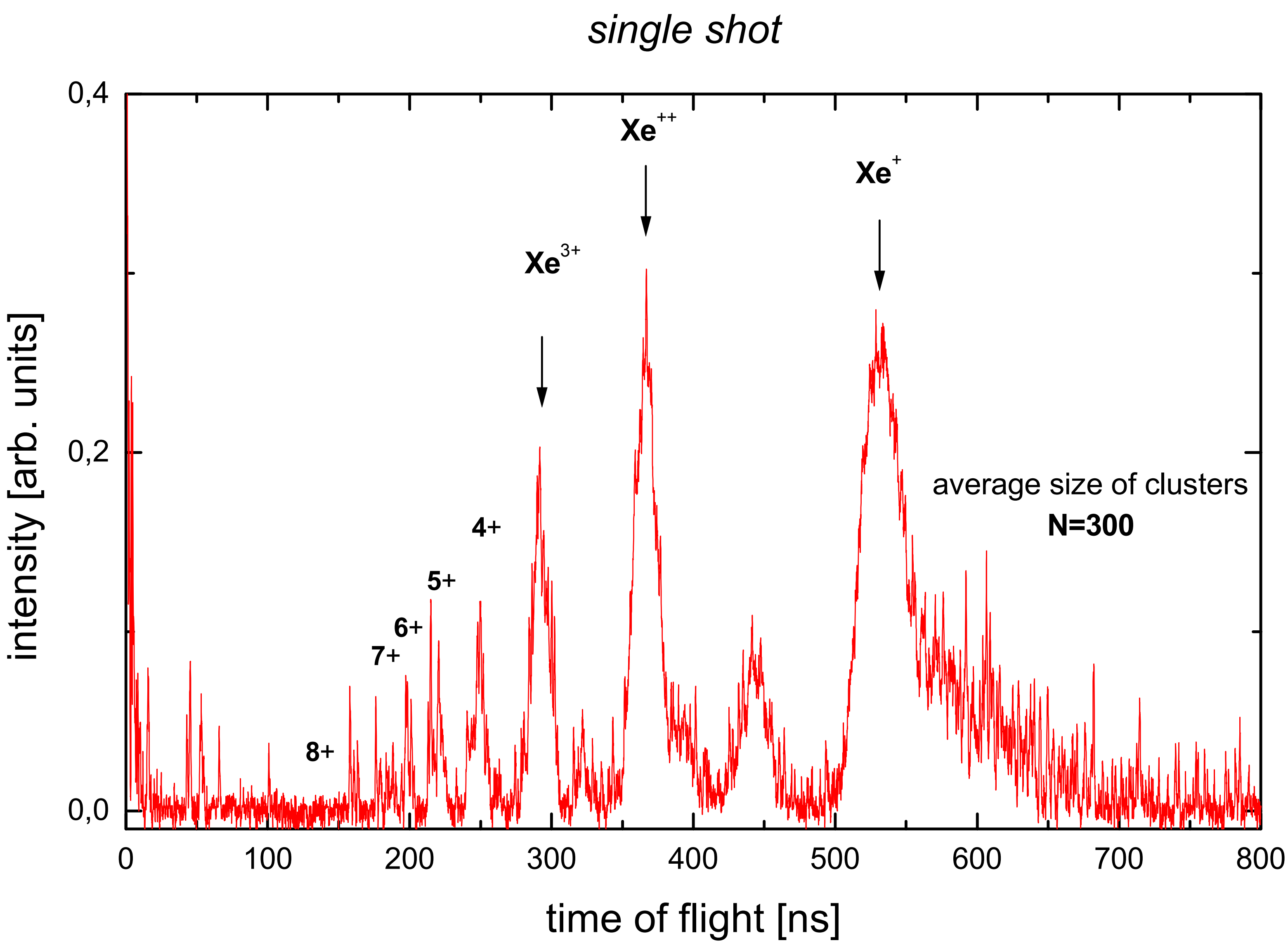
→ $\sim 2 \cdot 10^{16}$ $Phot./cm^2$ reichen, um jedes Xe- Atom zu ionisieren

Undulatorstrahlung bei 10 µm Fokus: $\sim 10^{13}$ $Phot./cm^2$

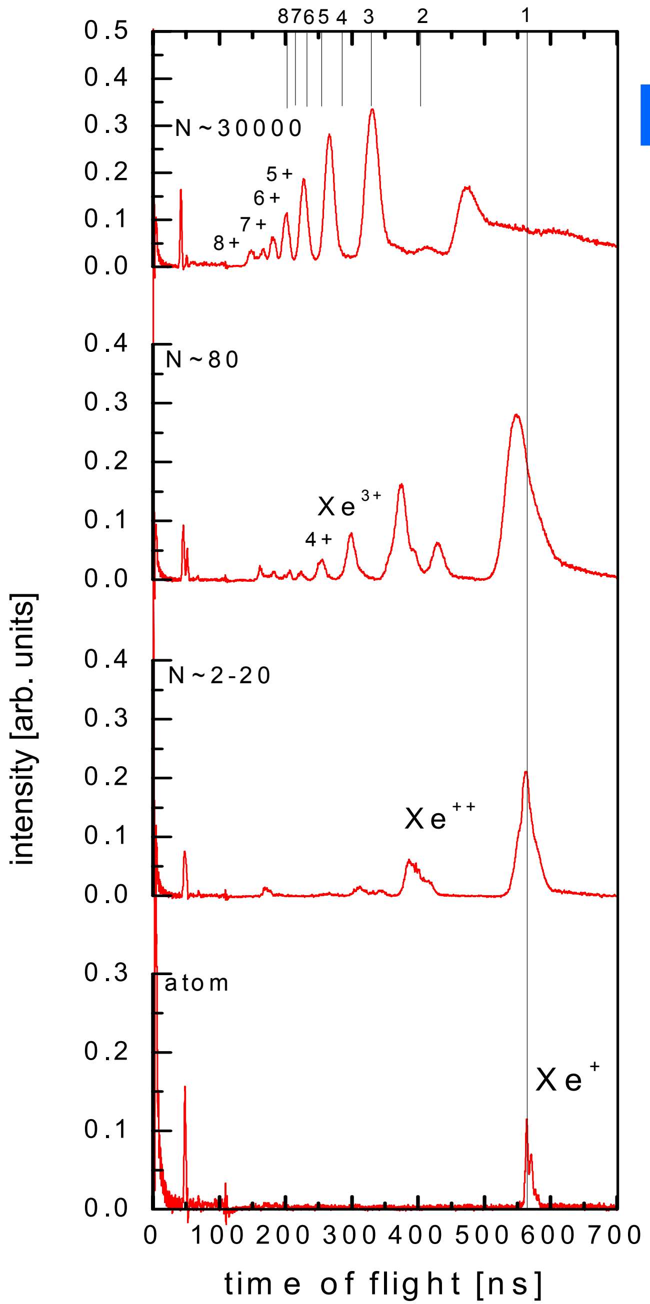
Cluster-Ion Detector




atomic beam
hν = 12.7 eV
IP(Xe) = 12.1 eV
Xe+
intensity [arb. units]
0,0
0,1
0,2
0,3
time of flight [ns]
0
200
400
600
800

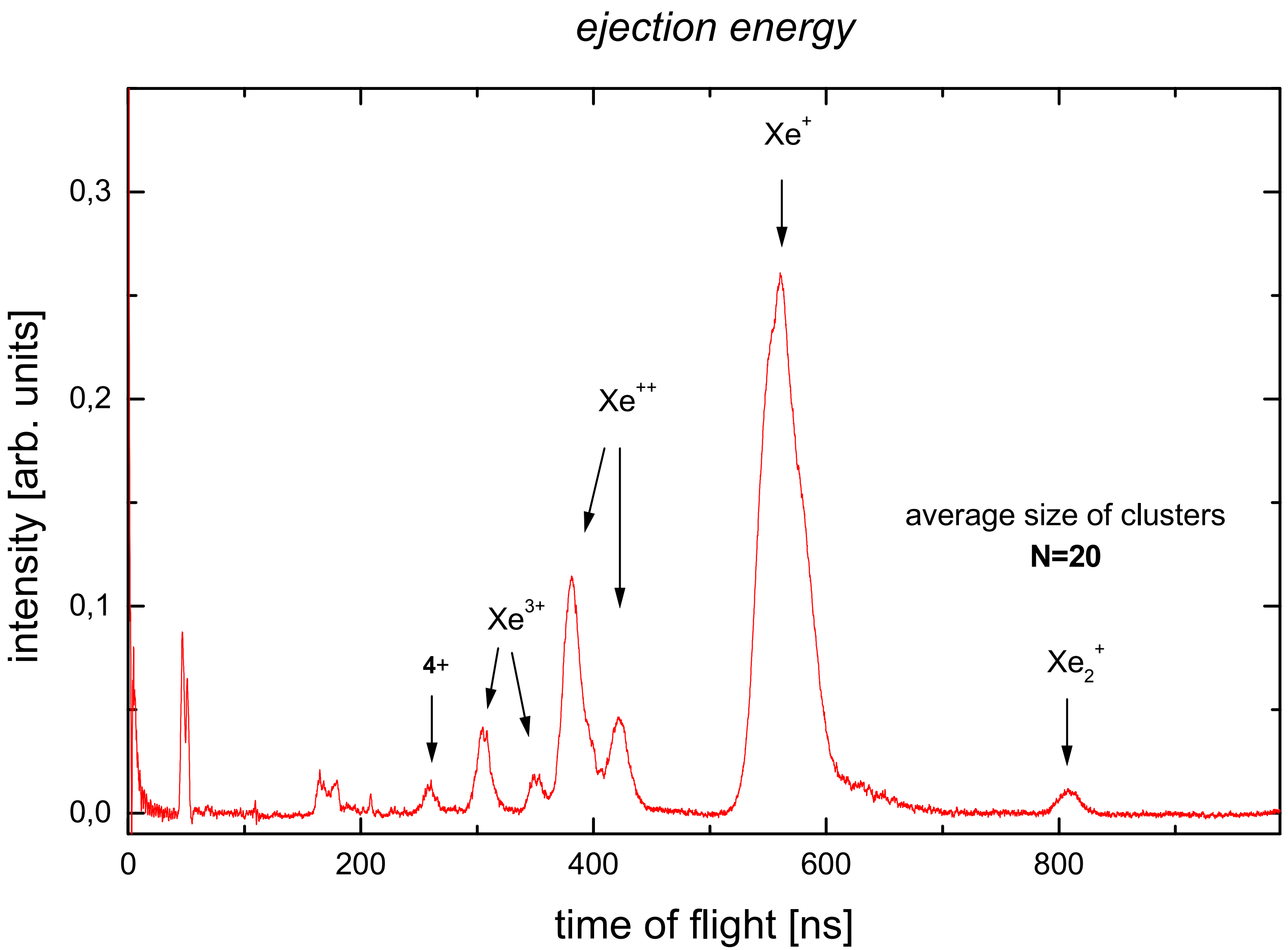


single shot
0,4
0,2
0,0
intensity [arb. units]
Xe++
Xe+
Xe3+
4+
5+
6+
7+
8+
average size of clusters
N=300
0
100
200
300
400
500
600
700
800
time of flight [ns]

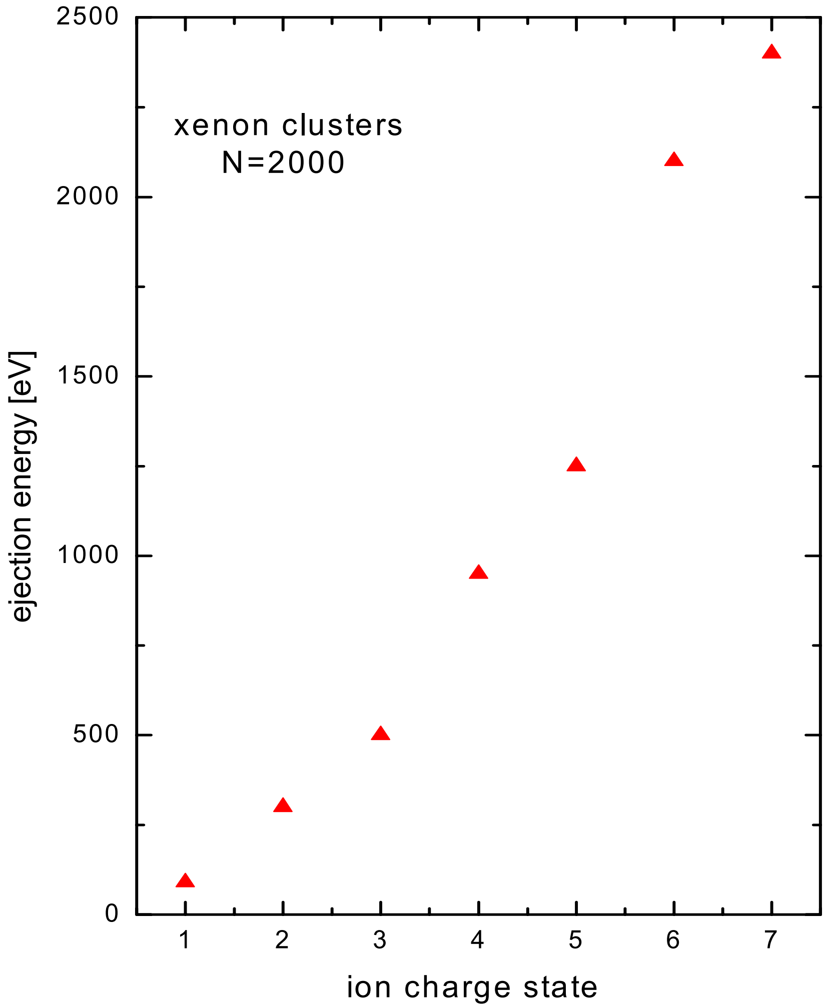


Dependence on cluster size

- single photon absorption in Xe atoms
- emission of highly charged ions from clusters (up to 8+)
- ions have high kinetic energy


ejection energy
intensity [arb. units]
0,0
0,1
0,2
0,3
0
200
400
600
800
time of flight [ns]
Xe+
Xe++
Xe3+
4+
Xe2+
average size of clusters
N=20

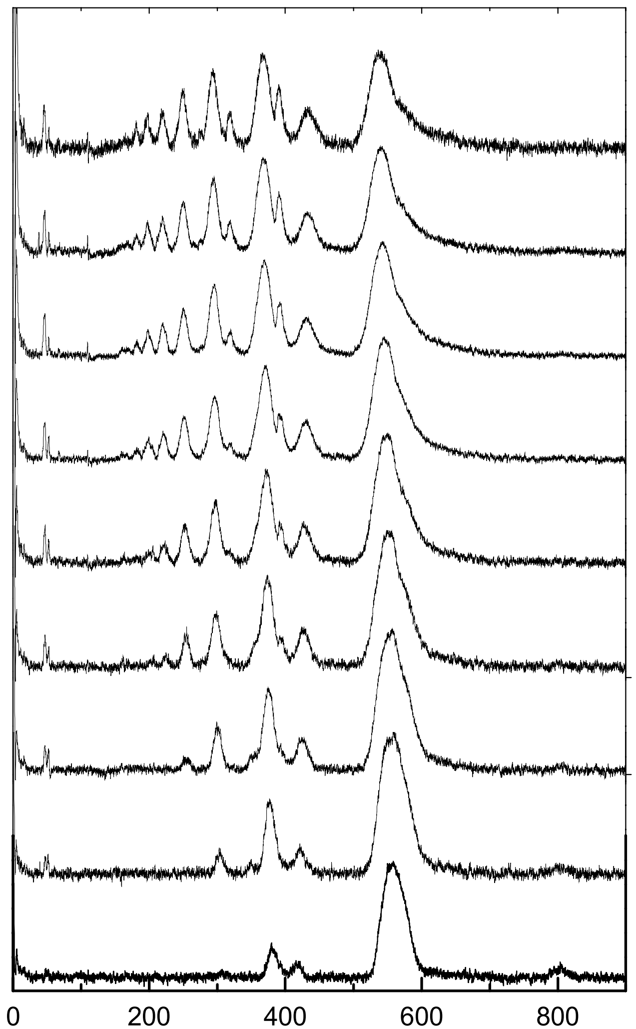
Kinetic energy of the ejected ions



- **Quadratic dependence on charge**
- **Coulomb explosion**

Dependence on power density

Xenon clusters, 50 atoms

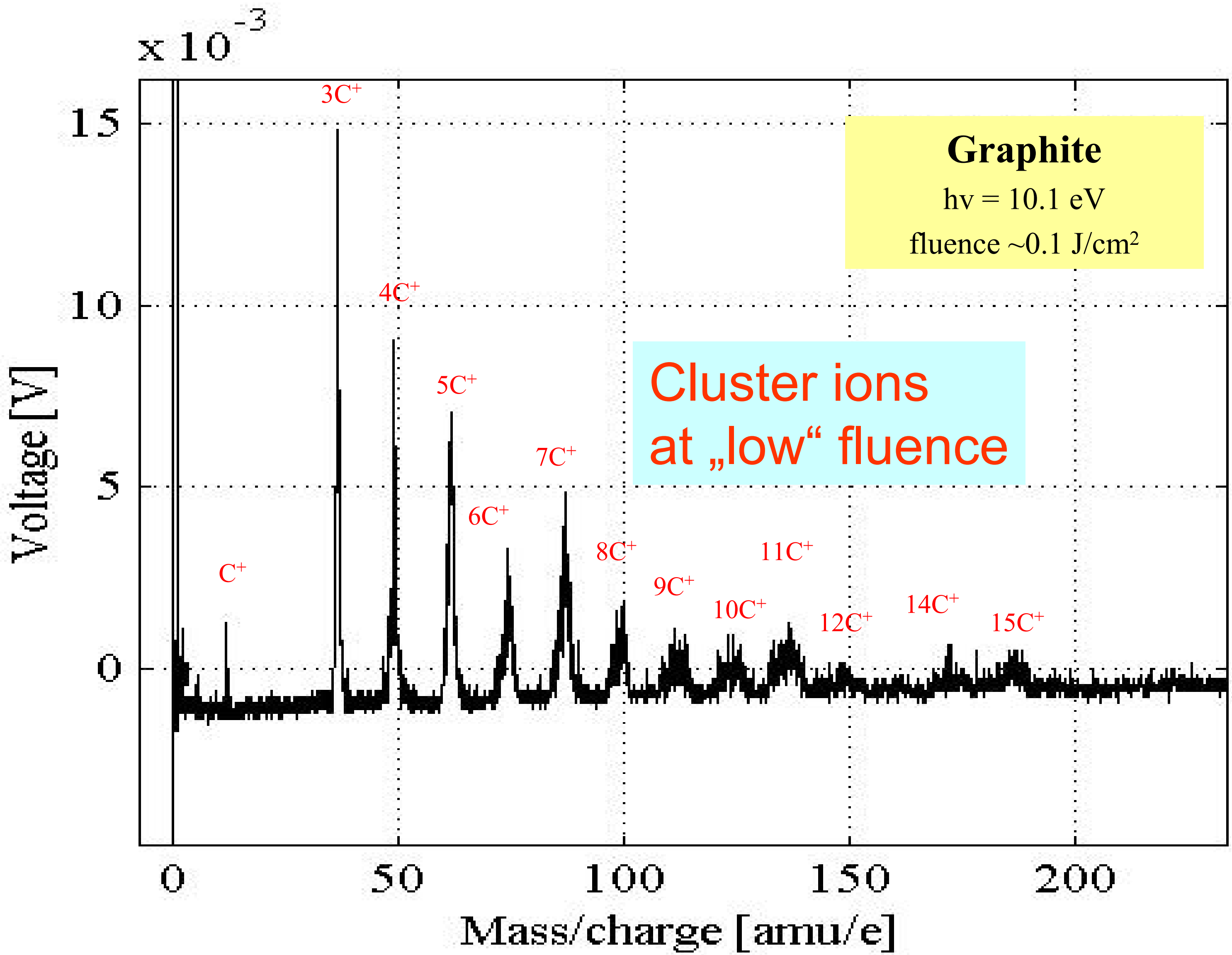


10^{13} Watt/cm^2

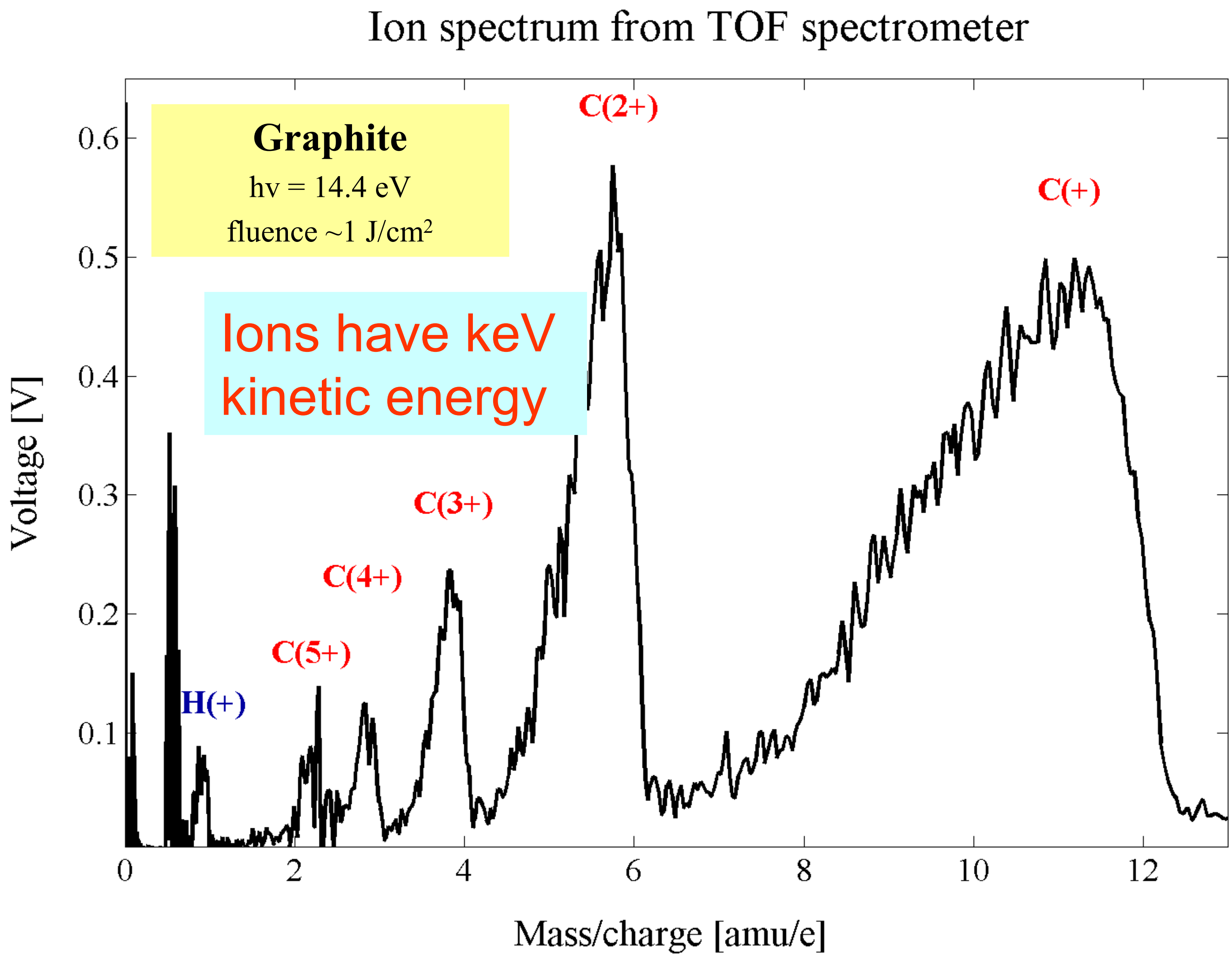
↑

$5*10^{11}$ Watt/cm^2

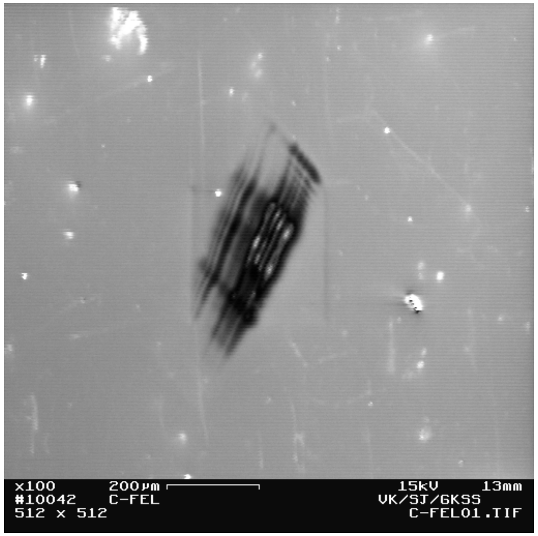
FELIS Jan. 2002



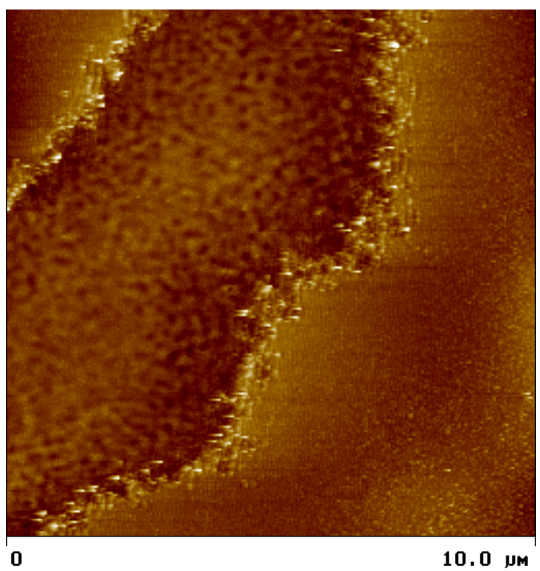
FELIS Jan. 2002



Damage of C coatings

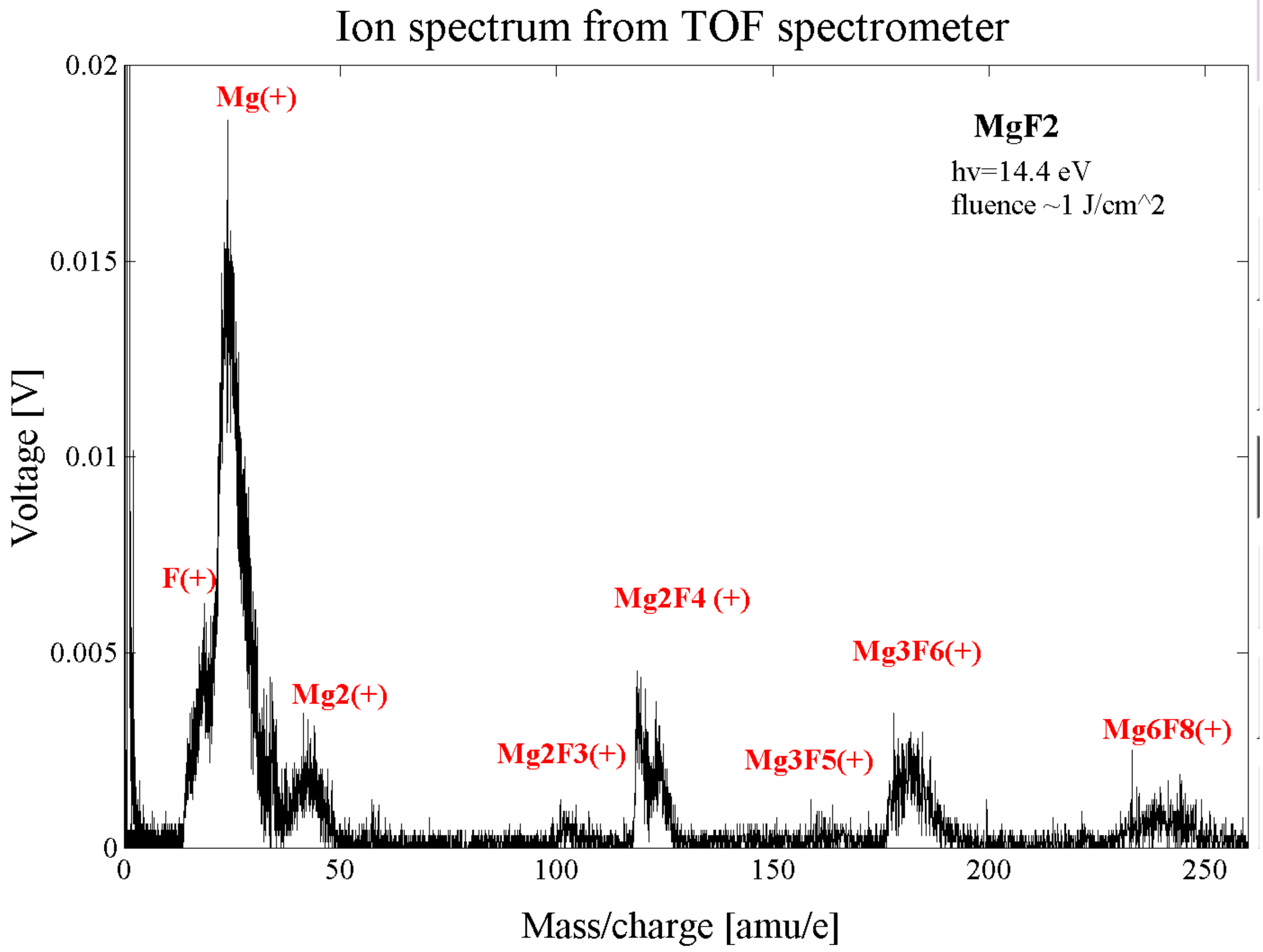


SEM
V. Küstner, GKSS

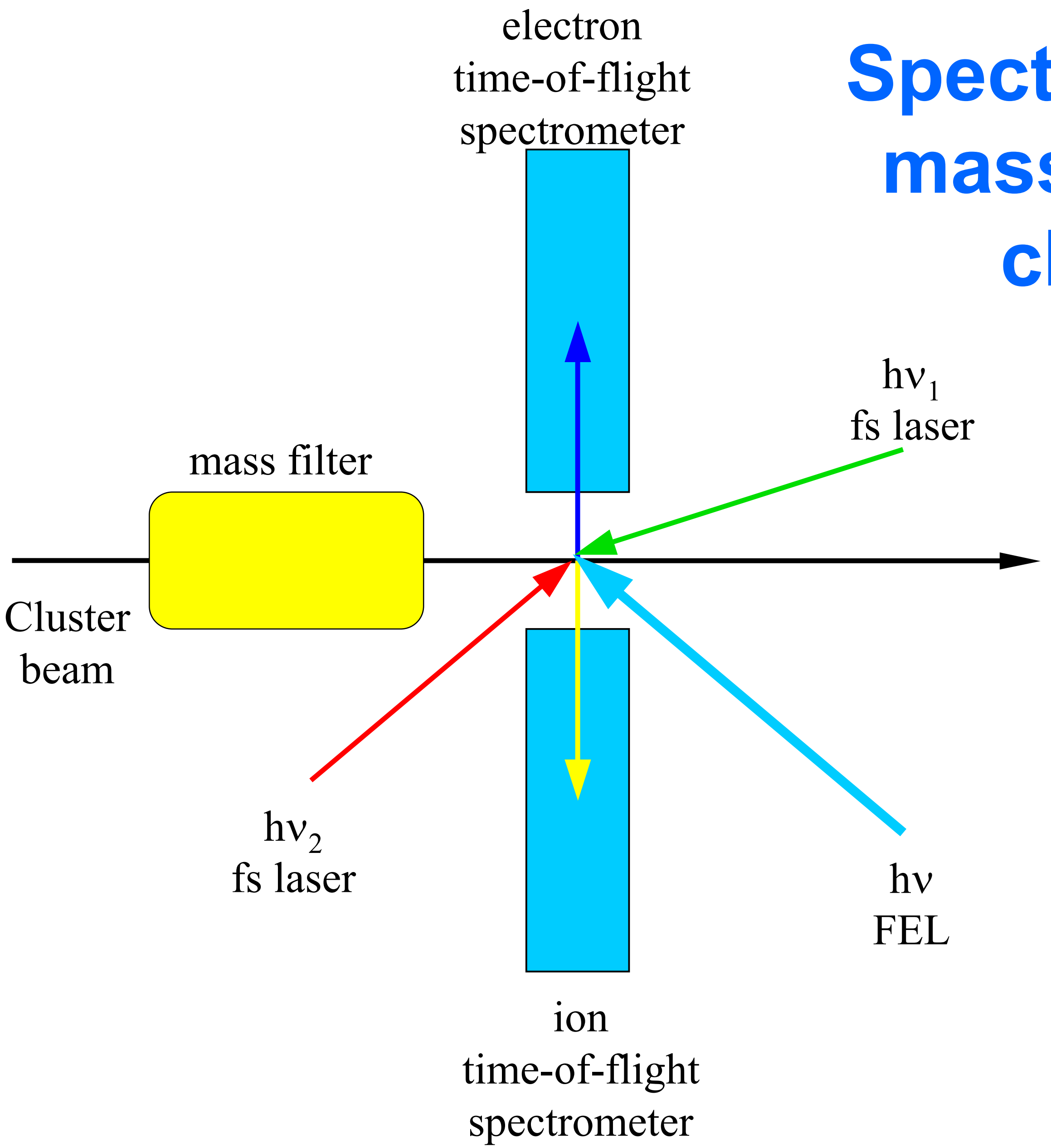


AFM
F. Felten, TU HH

FELIS Jan. 2002

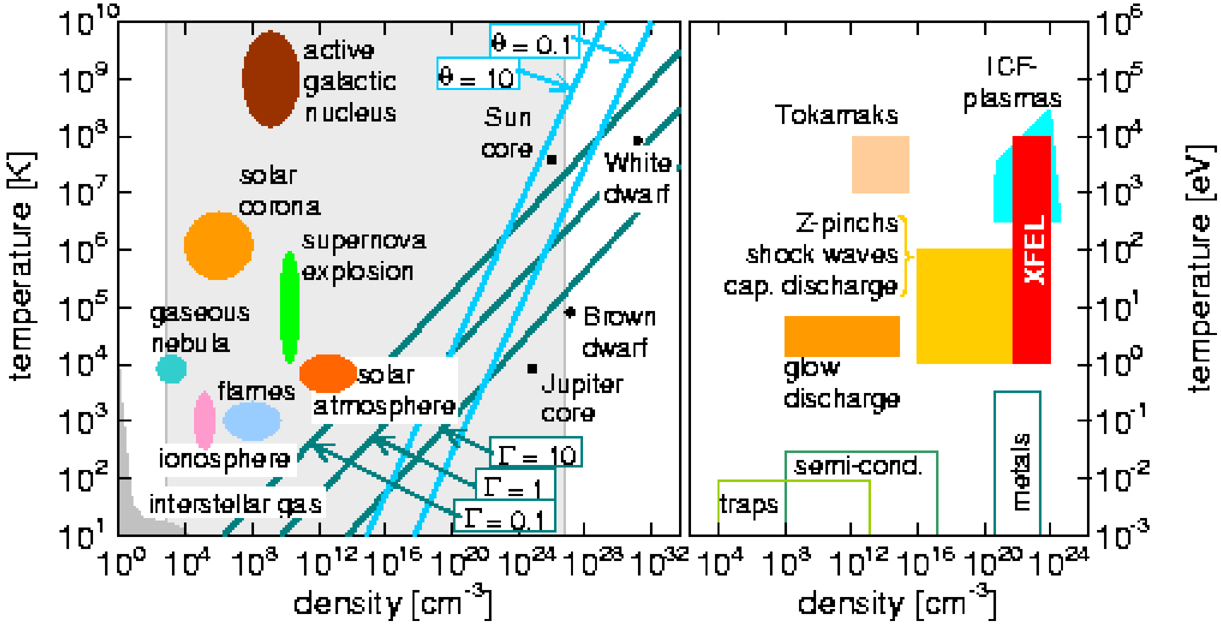


Spectroscopy of mass-selected clusters



Plasma physics

Generation and investigation of plasma states

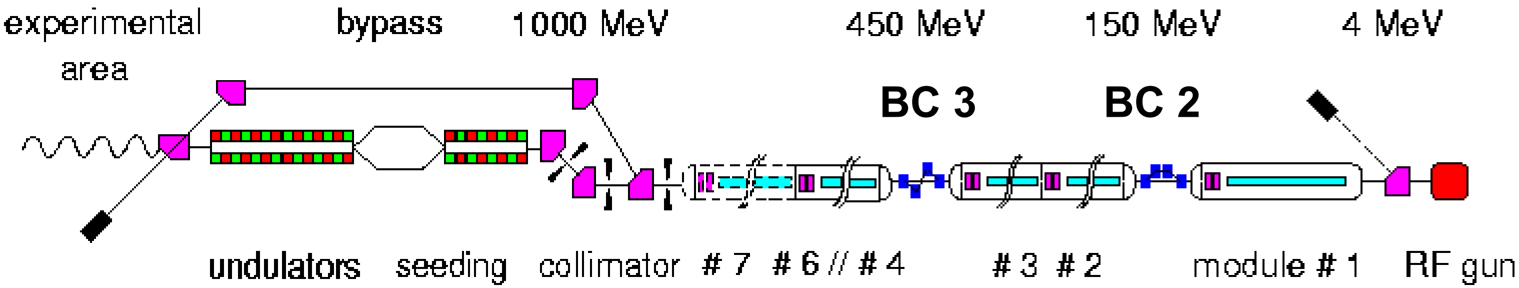


- high penetration power ⇒ volume interaction
- smooth energy deposition

⇒ isochoric heating will enable investigation of density-of-states in a wide plasma regime

- direct excitation of ground-state electrons
- non-relativistic regime

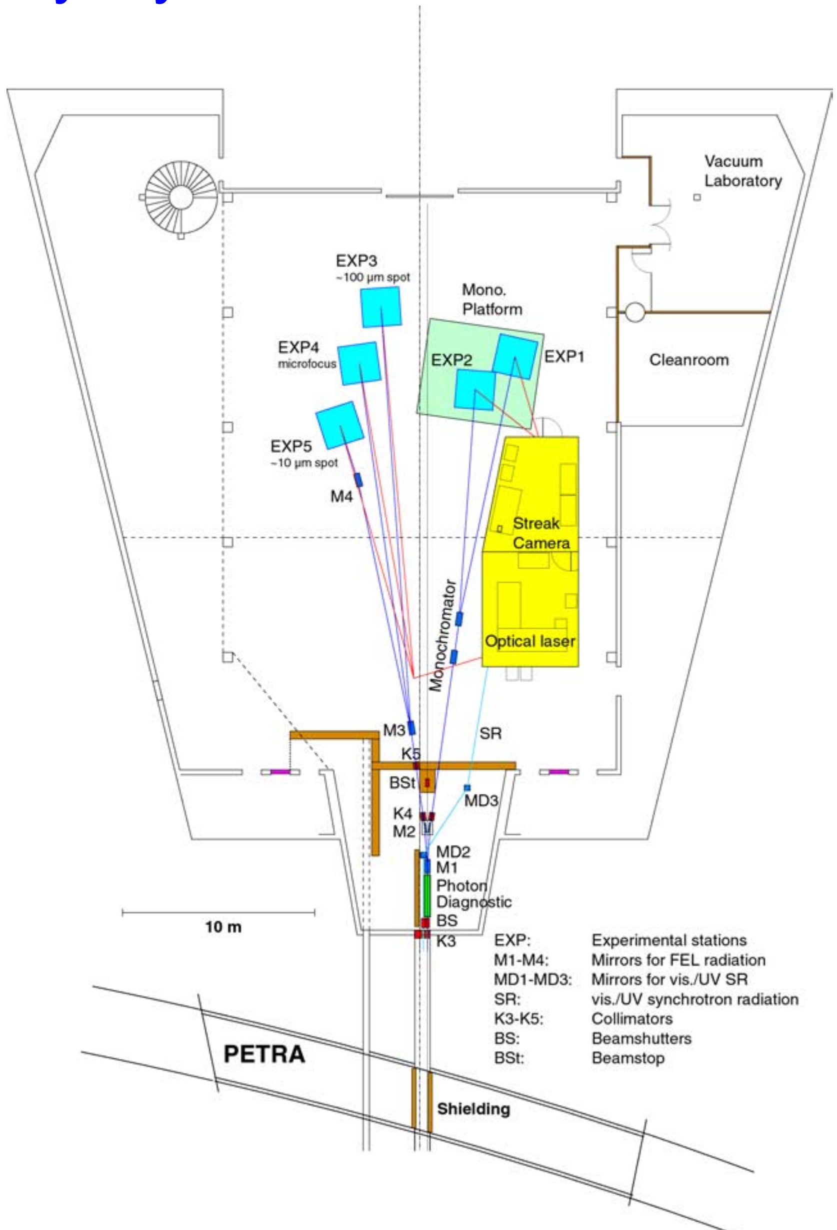
TTF Phase 2



experimental
area
bypass
1000 MeV
450 MeV
150 MeV
4 MeV
BC 3
BC 2
undulators
seeding
collimator
7
6 // # 4
3
2
module # 1
RF gun

The TESLA Test Facility (TTF)

Preliminary layout of the VUV FEL user facility



FEL – Licht der Zukunft?

- Es gibt keine prinzipiellen Zweifel, dass SASE FELs wie erwartet funktionieren.
- FELs werden komplementär sein zu Speicherringen und Lasern.
- Auf dem Weg zu einer XFEL Multi-User Facility liegen noch viele, spannende Herausforderungen vor uns, z.B.

  - Verkürzung der Wellenlänge um weiteren Faktor 1000
  - zeitlich kohärent (durch Seeding)
  - Pulslängen unter 50 fs
  - evtl. gleichmäßiges Pulsraster (~1 kHz – 1 MHz)
- Der Start einer FEL User Facility (TTF2) ist sehr wichtig für

  - die Entwicklung von Maschine und FEL,
  - die Entwicklung der Experimente und Methoden,
  - und das Entstehen neuer wissenschaftlicher Anwendungen.