Ultrafast electron kinetics in Aluminum irradiated with VUV-XUV femtosecond laser pulses (FLASH)

Nikita Medvedev*,[1] and Bärbel Rethfeld[2]

1) **Center for Free-Electron Laser Science at DESY**

Notkestr. 85, D-22607 Hamburg, Germany

2) **Technical University Kaiserslautern, Department of Physics**

and **OPTIMAS Research Center**

Erwin-Schroedinger-Str. 46, D-67663 Kaiserslautern, Germany

Outline

I. Introduction and motivation

II. Monte-Carlo method

- *Modeling*
- *Parameters*

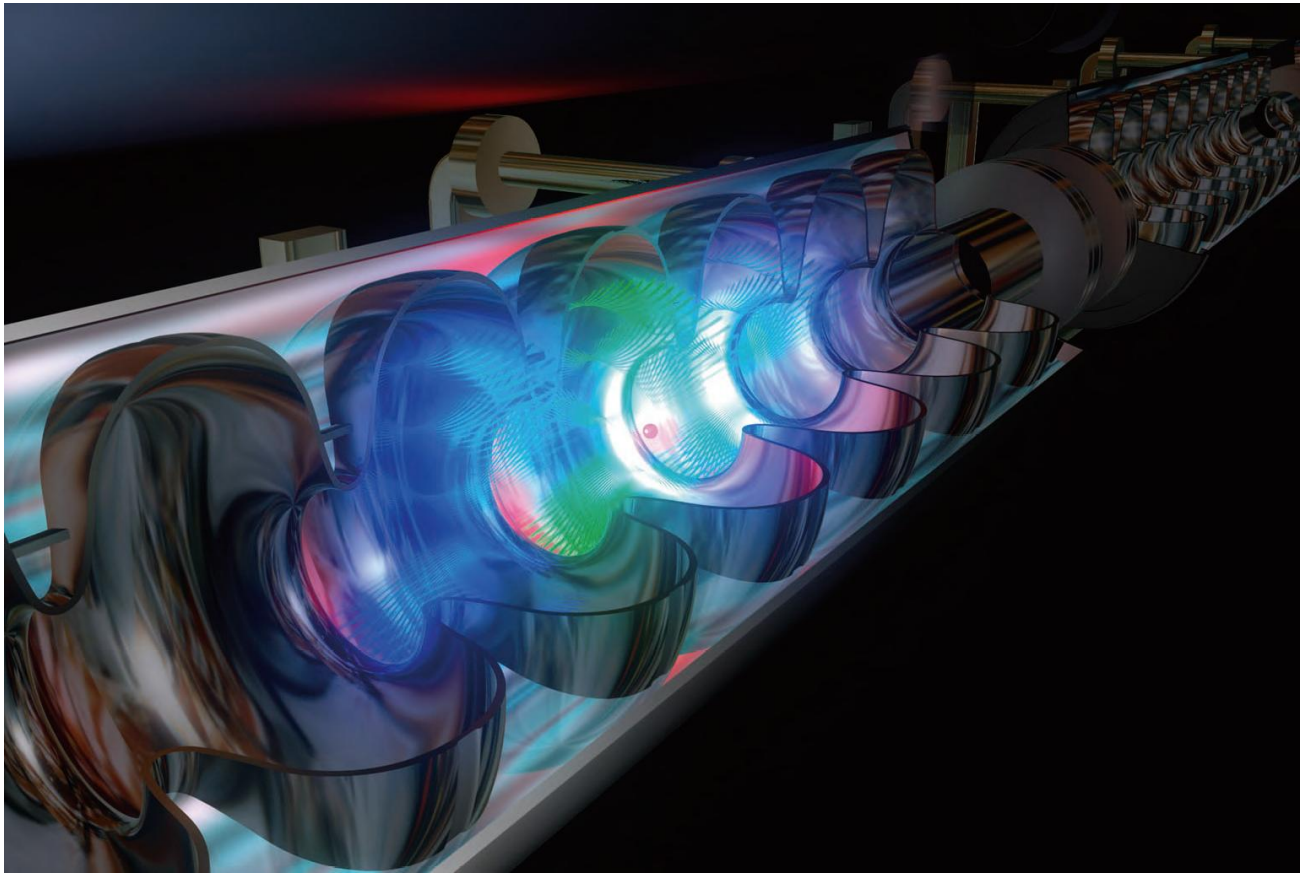
III. Results: FLASH excited Aluminum

- *electron kinetics*
- *comparison to experiments*

IV. Conclusions

Motivation

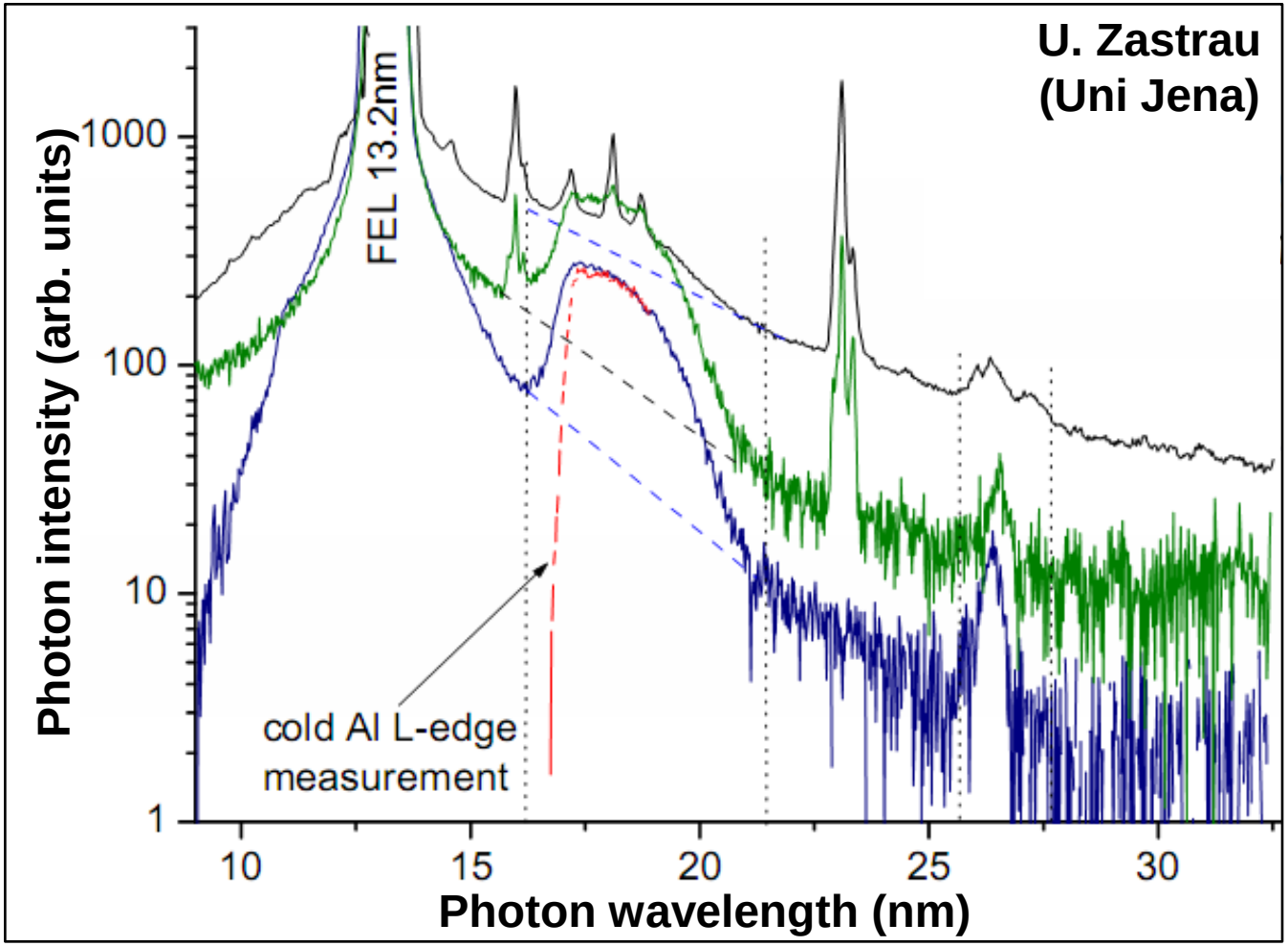
Free-electron Laser in Hamburg - FLASH



The new light source FLASH at DESY provides ultrashort (~ 10 fs) high intensity (~ 10^{14} W/cm^2) VUV-XUV laser pulses

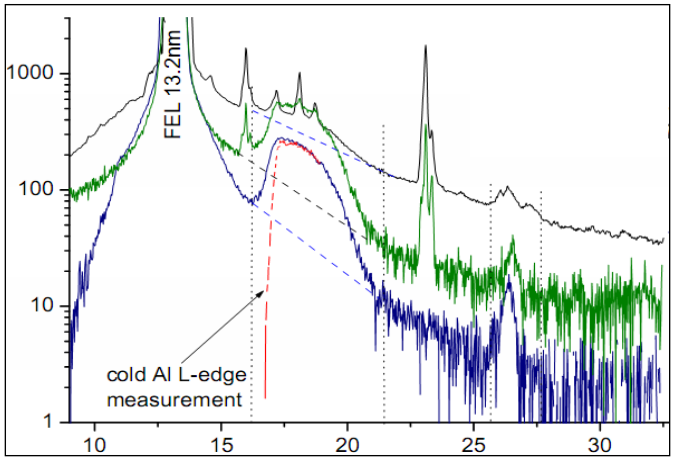
Motivation

Solid aluminum, irradiated with FLASH at DESY



Experimental measured spectra of emission of photons

Motivation



Experimental measured spectra of emission of photons

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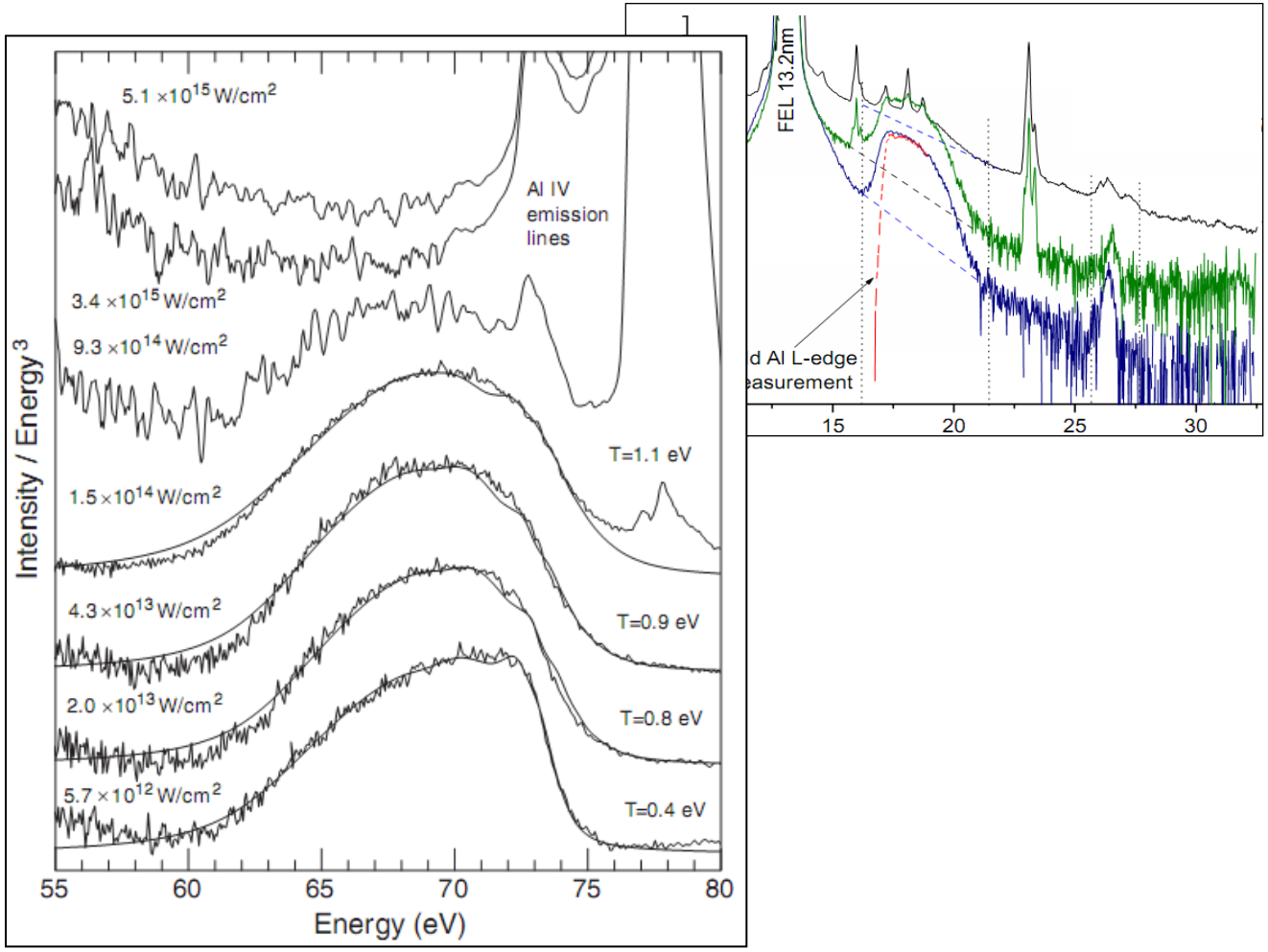
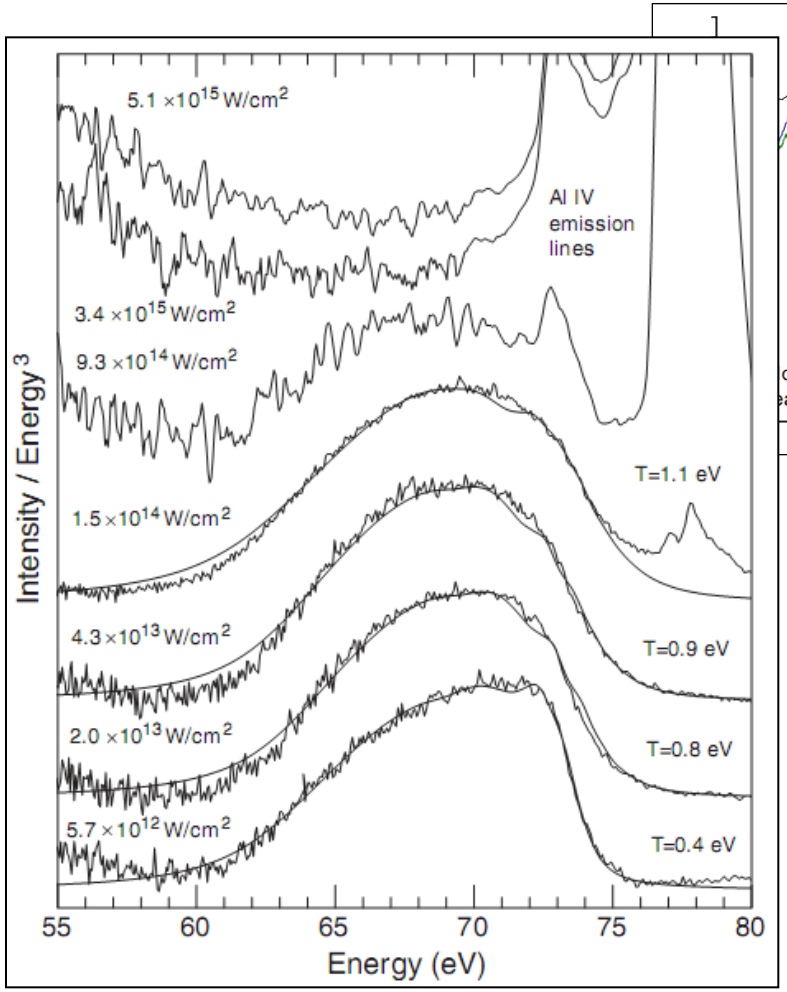


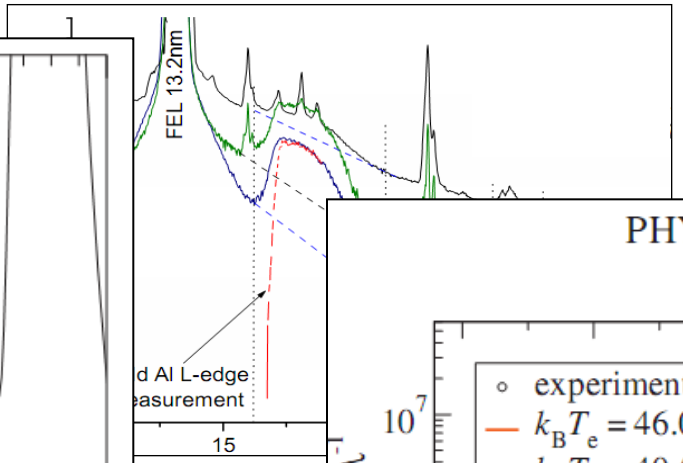
[S. Vinko *et al*, PRL 104, 225001 (2010)]

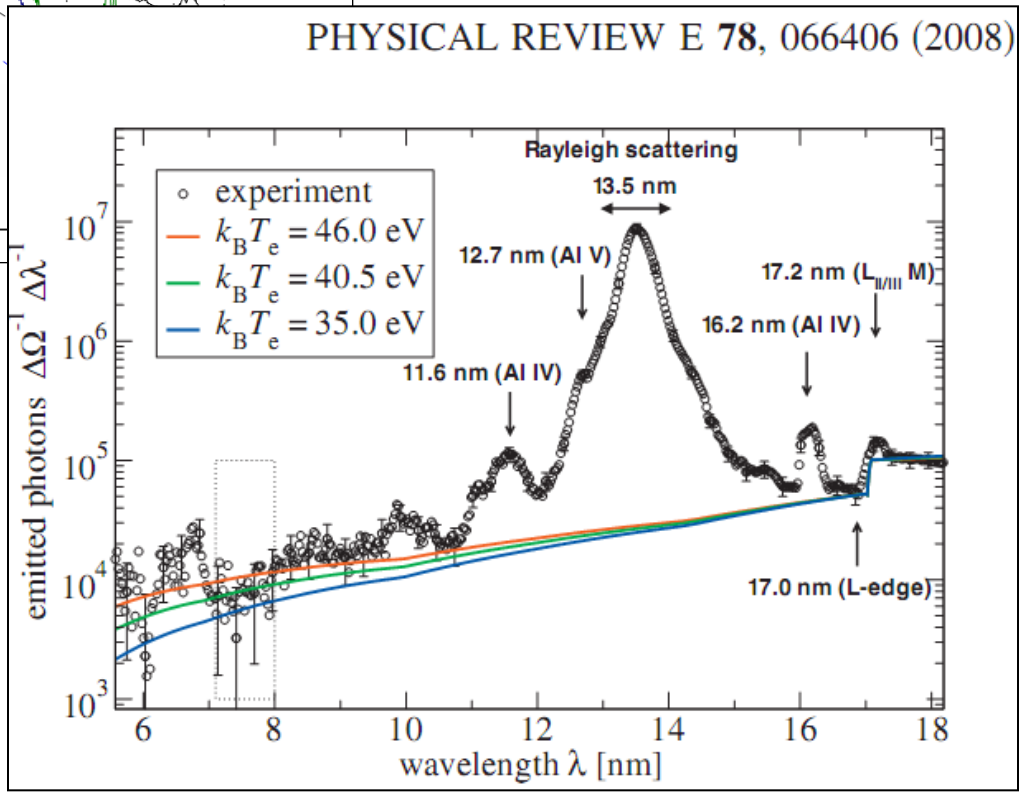
$T_e \sim 1$ eV

Motivation



[S. Vinko *et al*, PRL 104, 225001 (2010)]



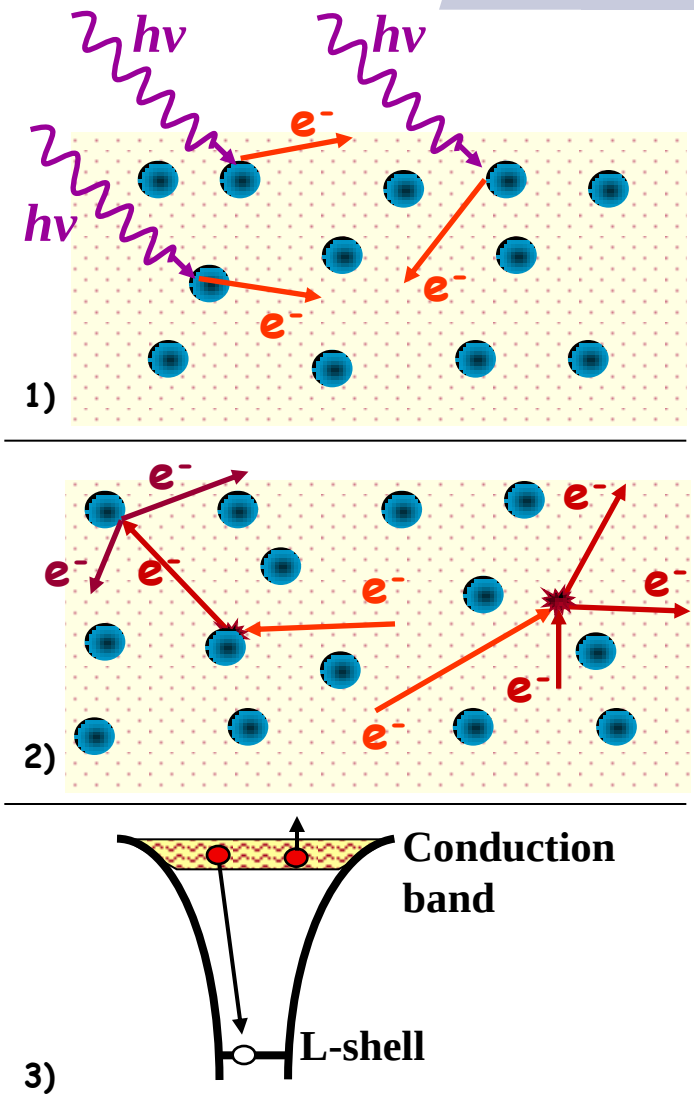


[U. Zastrau *et al*, PRE 78, 066406 (2008)]

$T_e \sim 1$ eV

$T_e \sim 40$ eV

Monte-Carlo method



1) Photo-absorption (10 fs, pulse)

2) Electron redistribution:
impact ionizations, elastic scattering, free-electron scattering

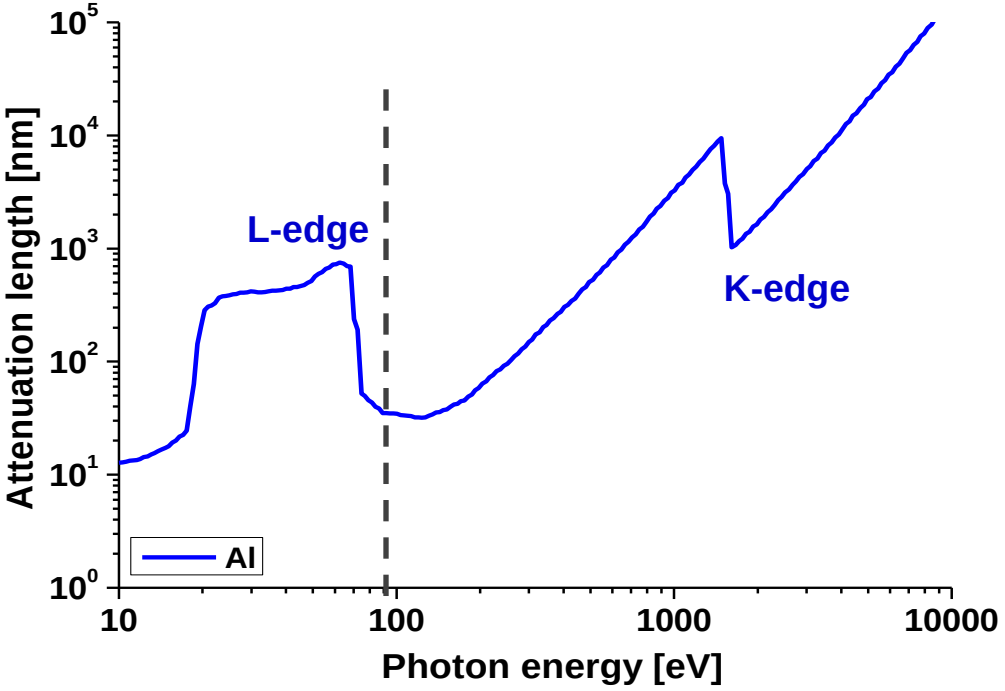
3) Auger-like transitions (~ 40 fs) to deep shells

Ultra short timescales => electronic processes only

Modeling

Photons:

L-shell absorption is dominant



[N.J. Carron, «An Introduction to the Passage of Energetic Particles through Matter», 2007]

Electrons:

free electron-electron scattering

$$\frac{d\sigma_e}{d\omega} = \frac{\hbar}{\pi a_0 E_e} \int_{q_1}^{q_2} \frac{1}{q} \mathrm{Im}\left(-\frac{1}{\varepsilon(q,\omega)}\right) dq$$

Mean free path:

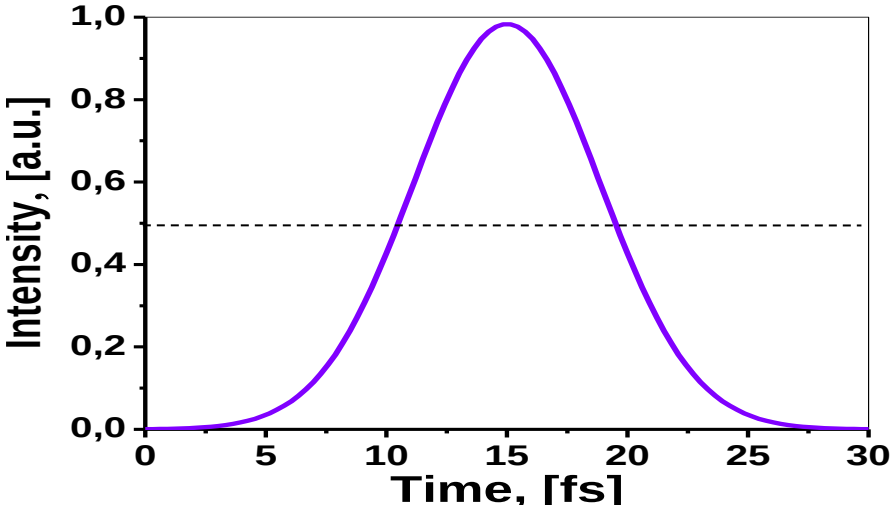
$$l_e^{-1} = n_e \int_0^{E_e - E_f} \left(\frac{d\sigma_e}{d\omega}\right) d\omega$$

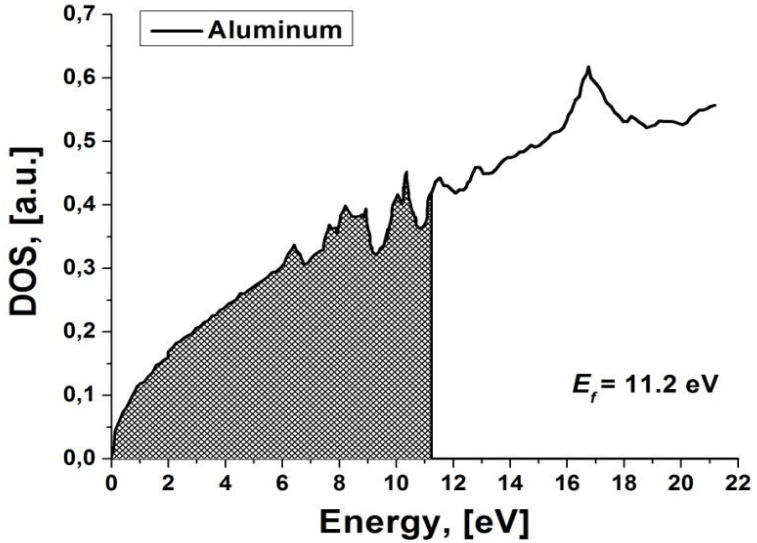
Lindhard Dielectric Function ε(q,ω) formalism gives dynamical screening

[A.Akkerman and J.Barak, IEEE Transact. on Nucl. Science 6 (2002) 3022]

All processes are described event by event

Parameters





[F.Ladstädter *et al*, Phys. Rev. B 70, 235125 (2004)]

Energy: $h\nu$ = 92 eV

FWHM: t_{pulse} ~ 10 fs

Fluence: J = 0.2 - 5 J/cm^2

Aluminum target:

ρ = 2.7 g/cm^3

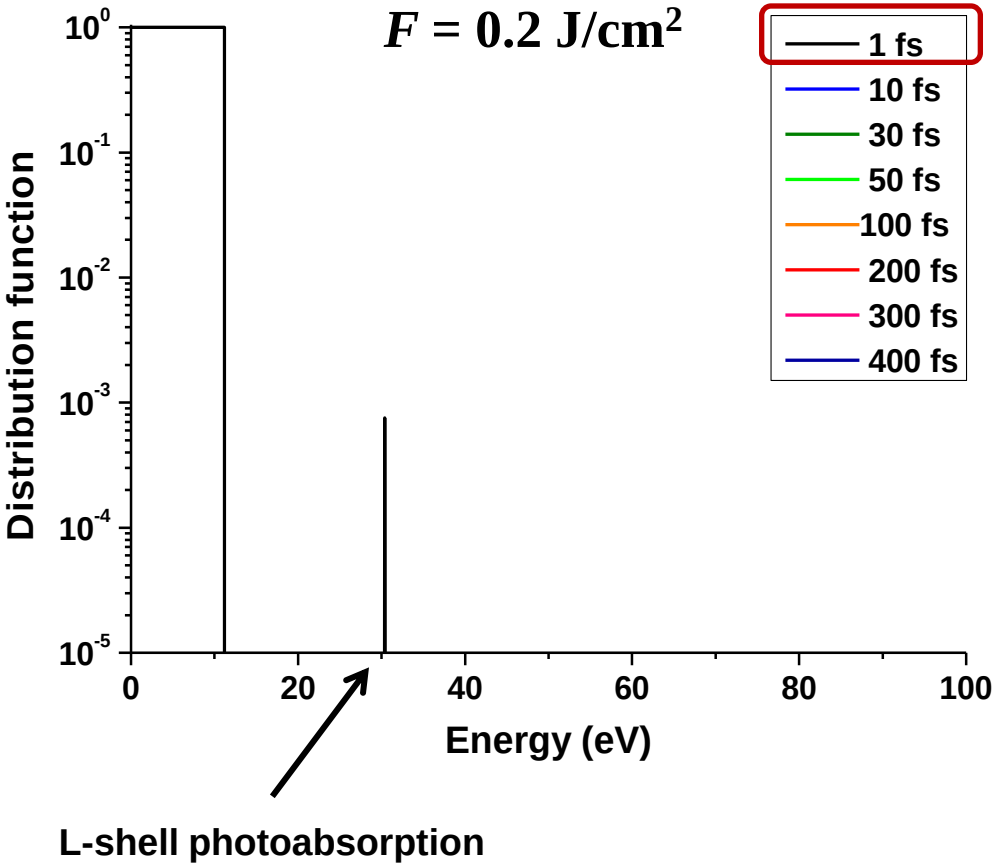
($n_{at} = 5.9 \cdot 10^{22}$ cm^{-3})

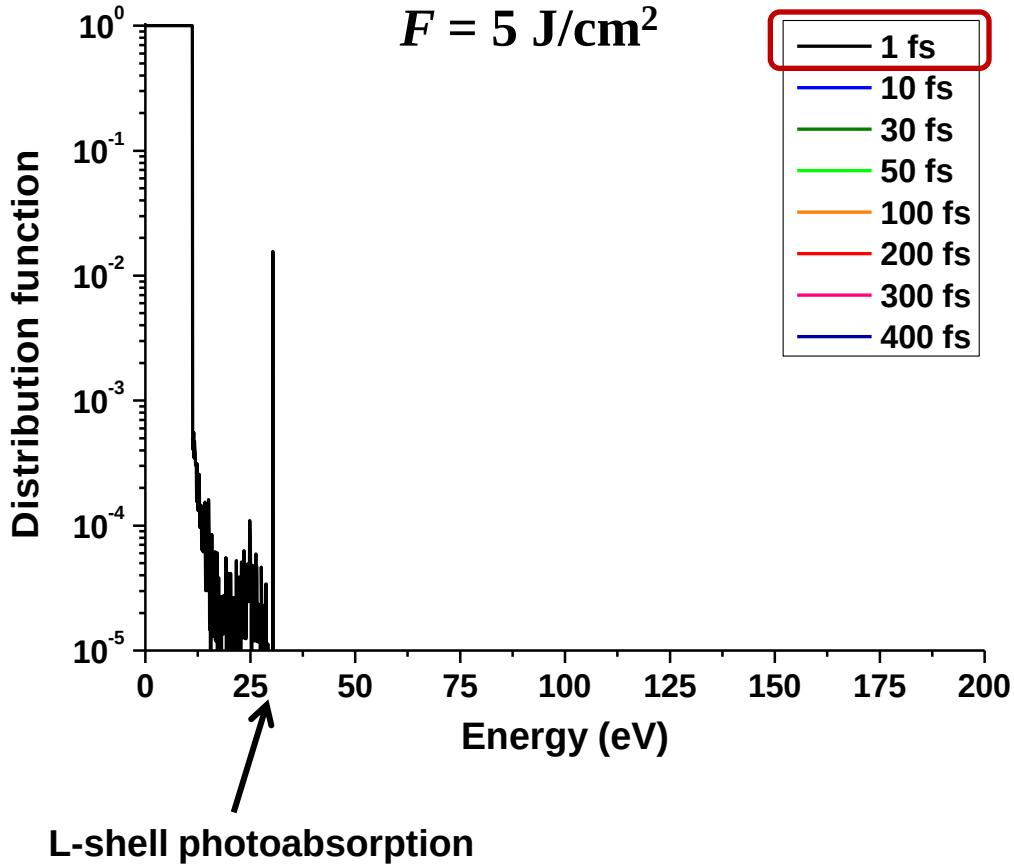
Density-of-States and Pauli's principle:

$$W \sim w\, f_v(1-f_c)\, g_c$$

Transient distribution

$h\nu$ = 92 eV, t_{pulse} ~ 10 fs





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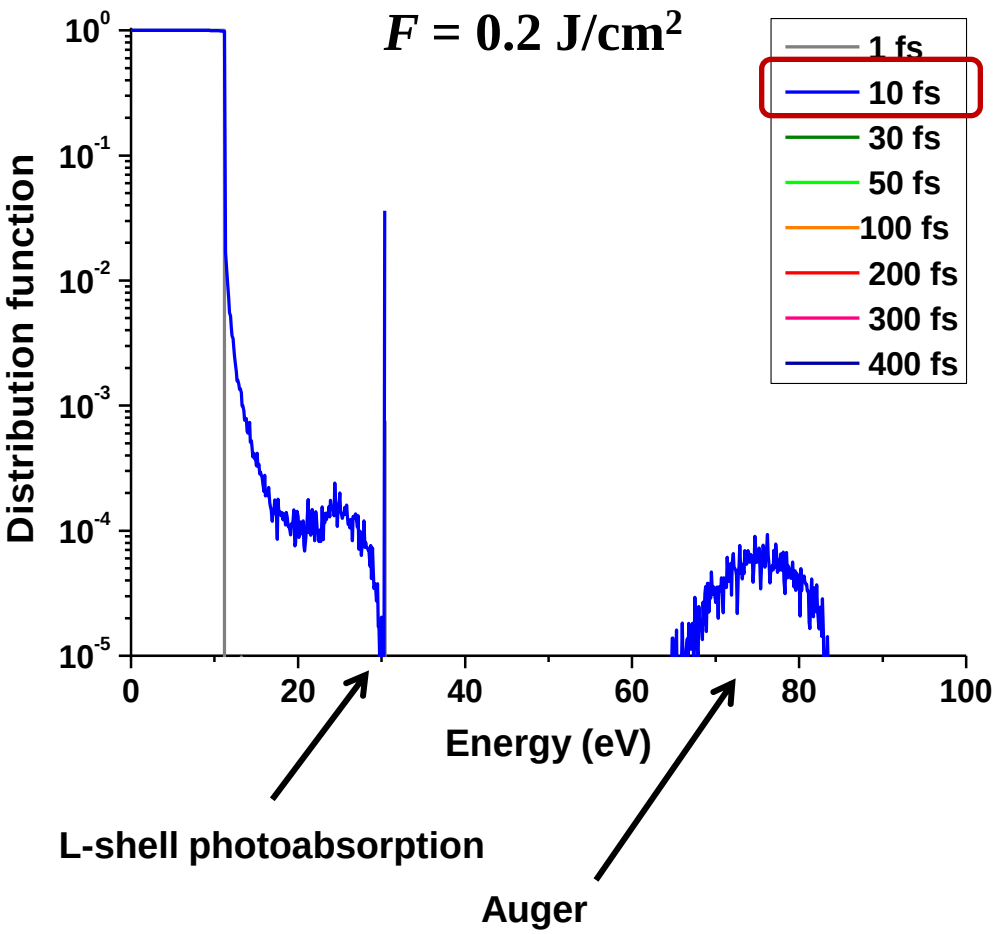

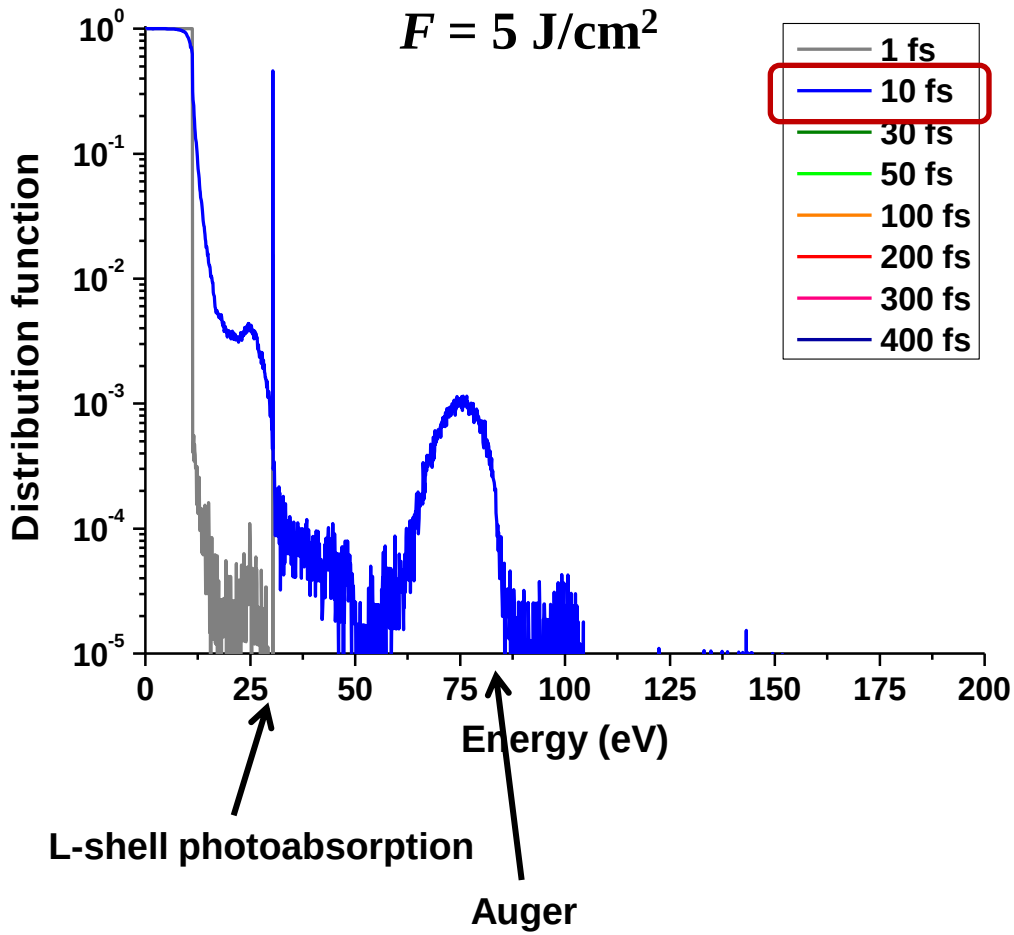

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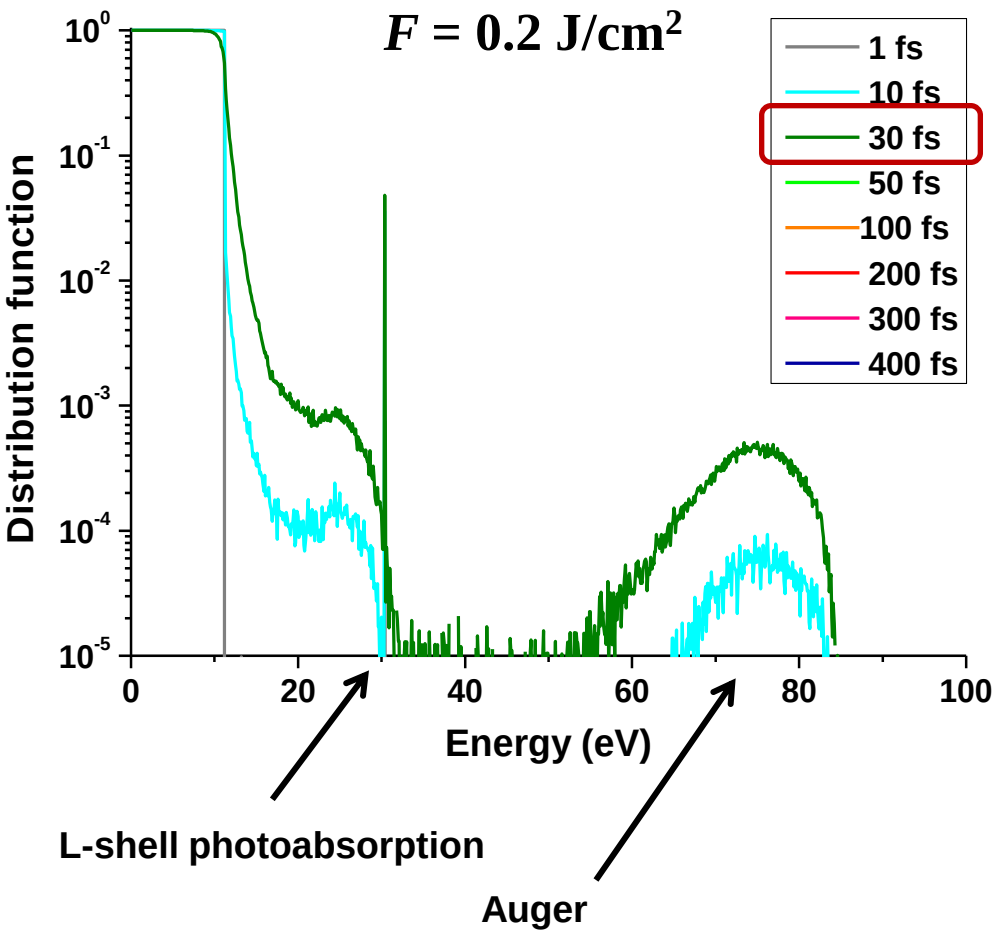

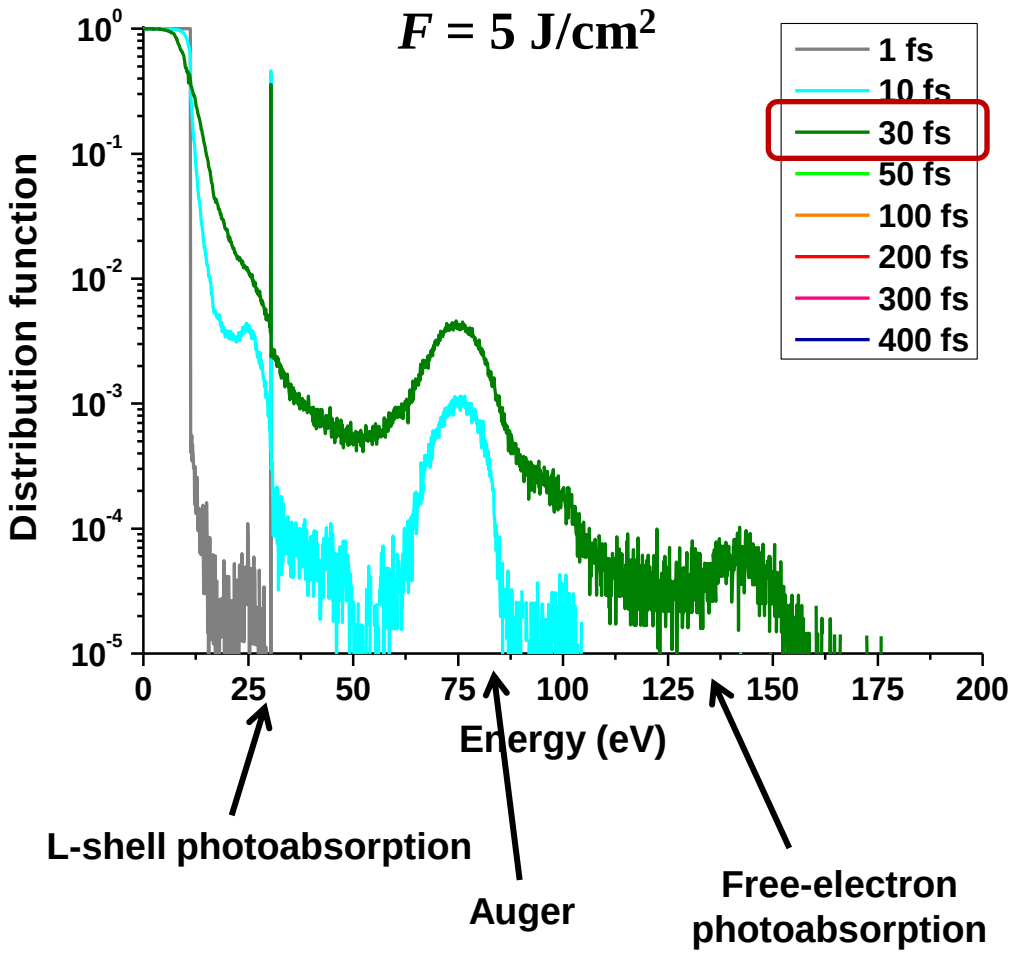

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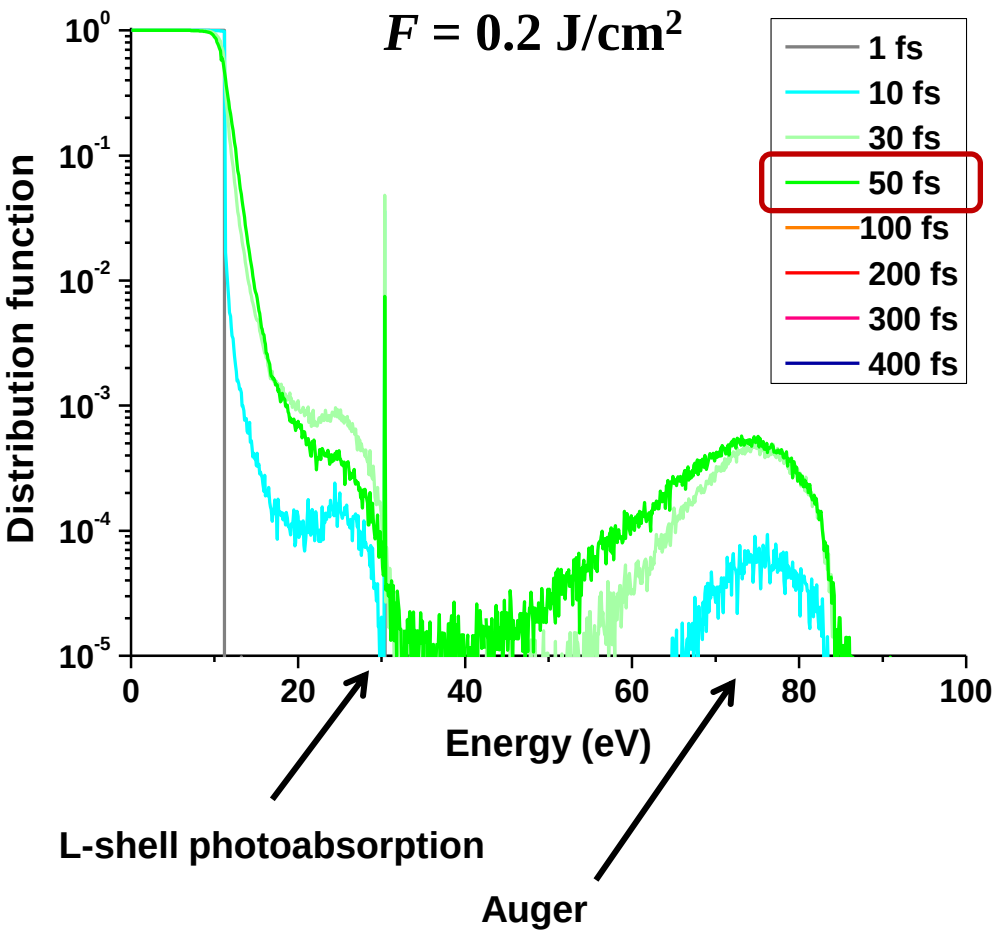

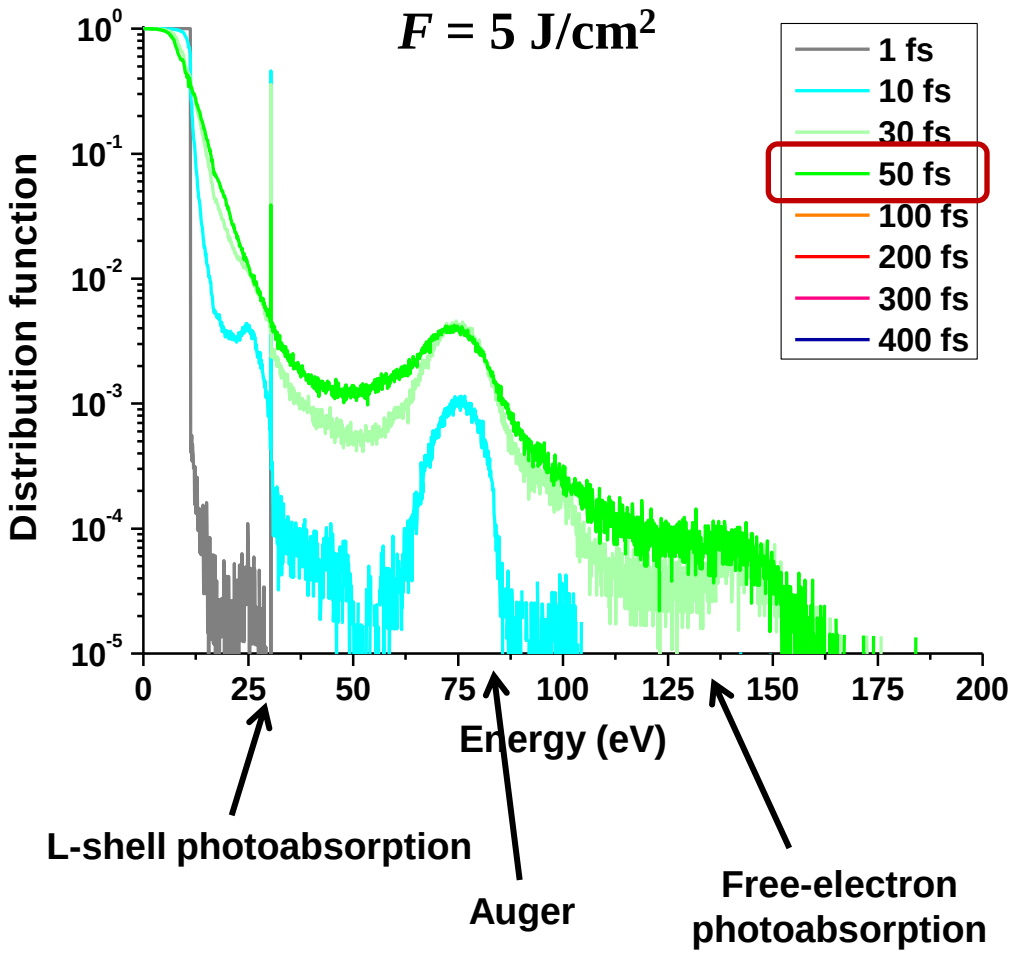

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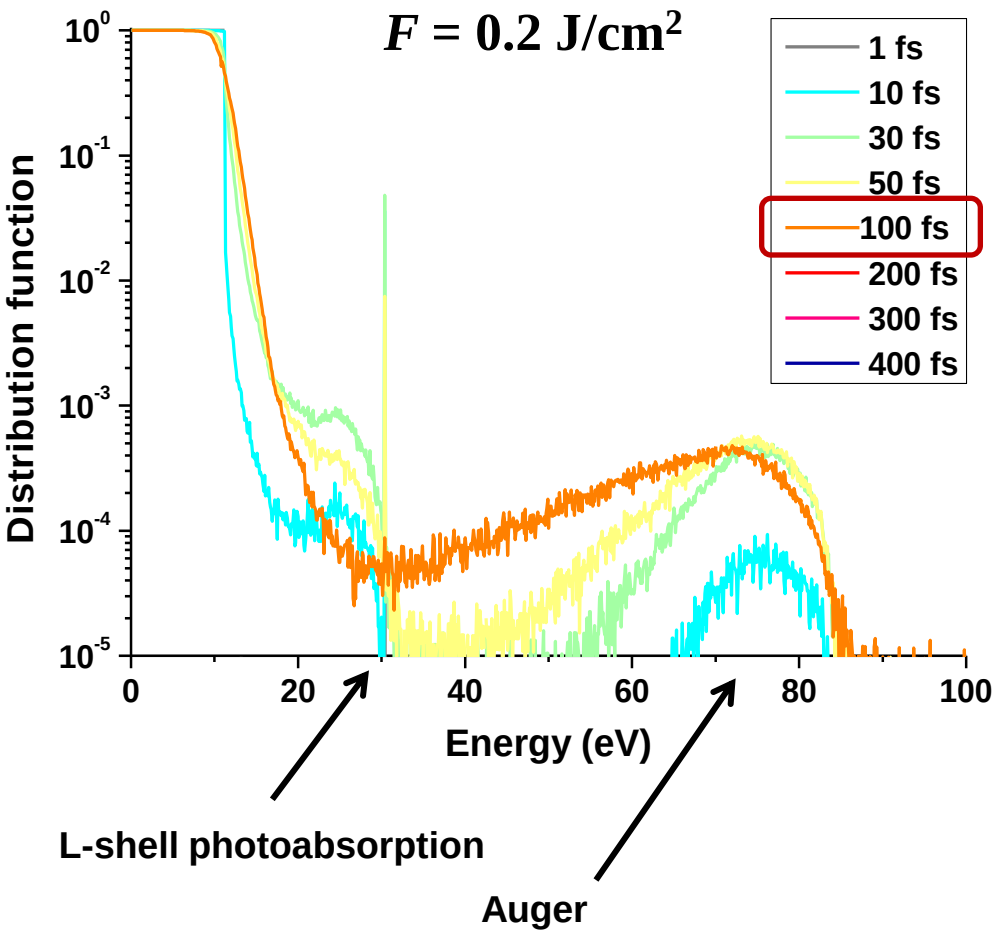

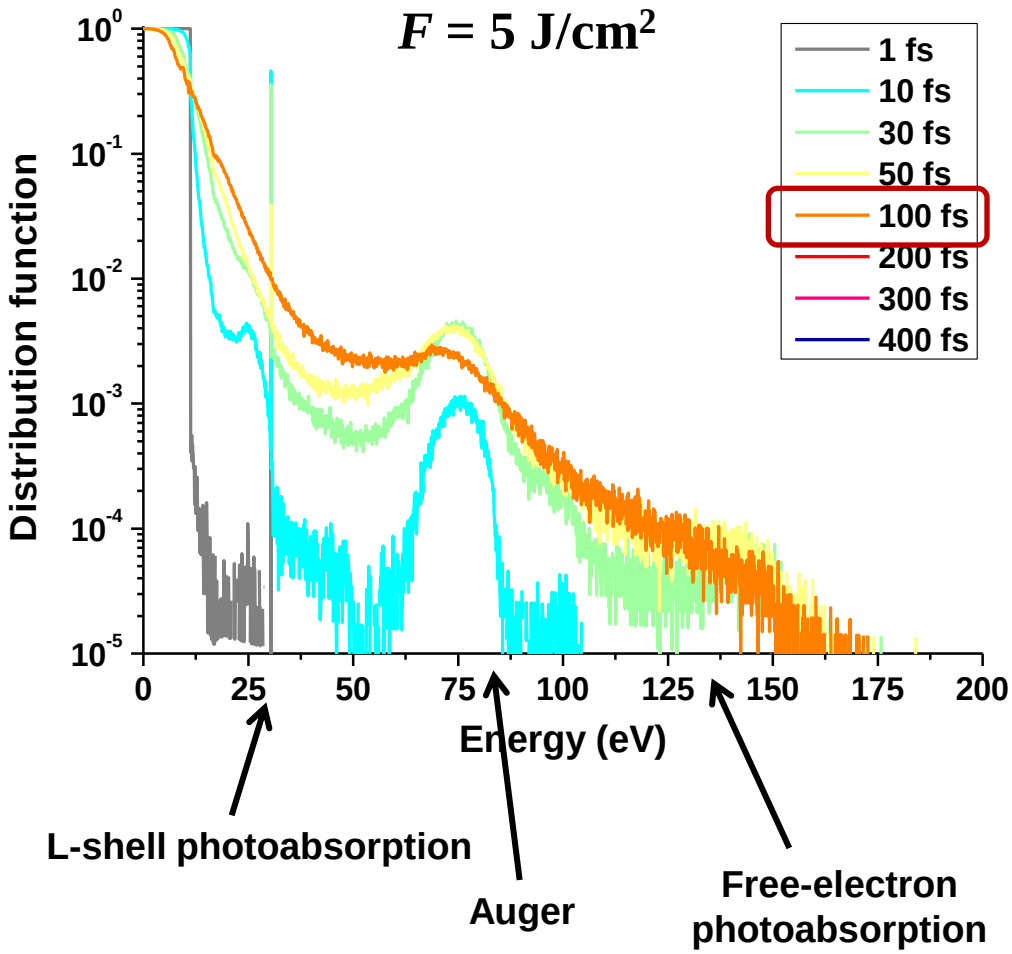

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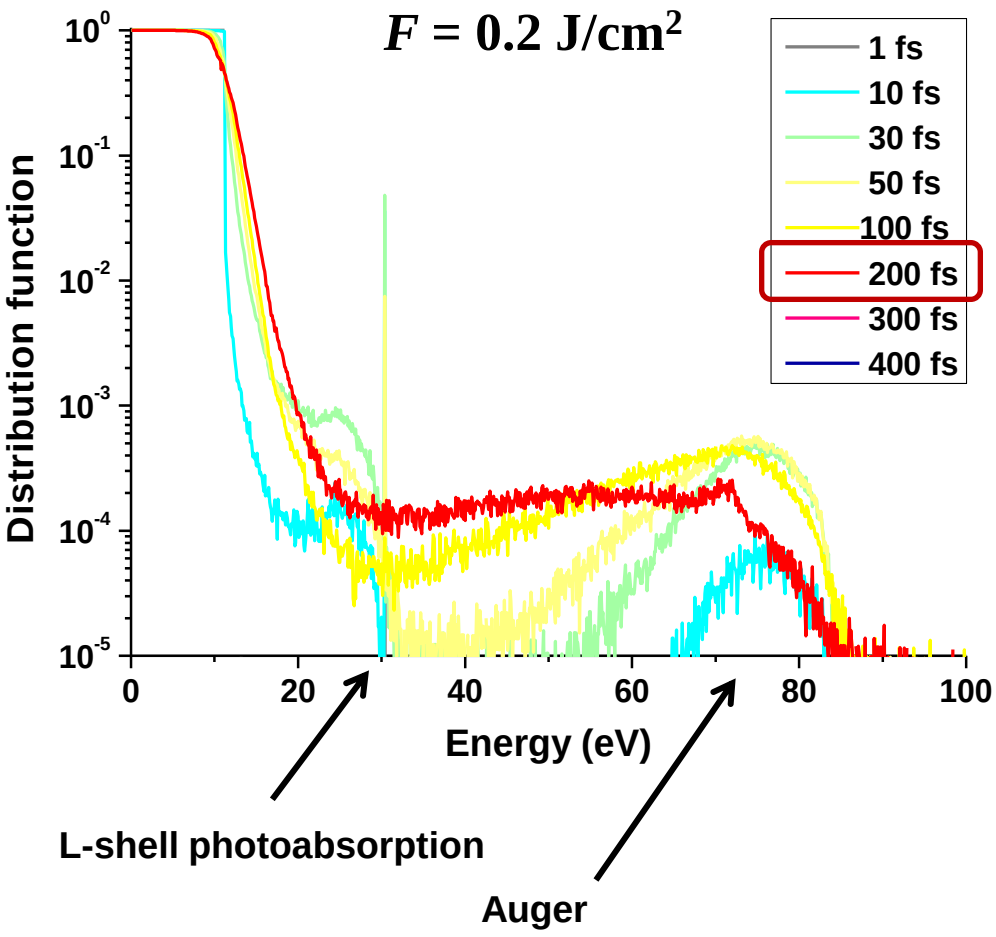

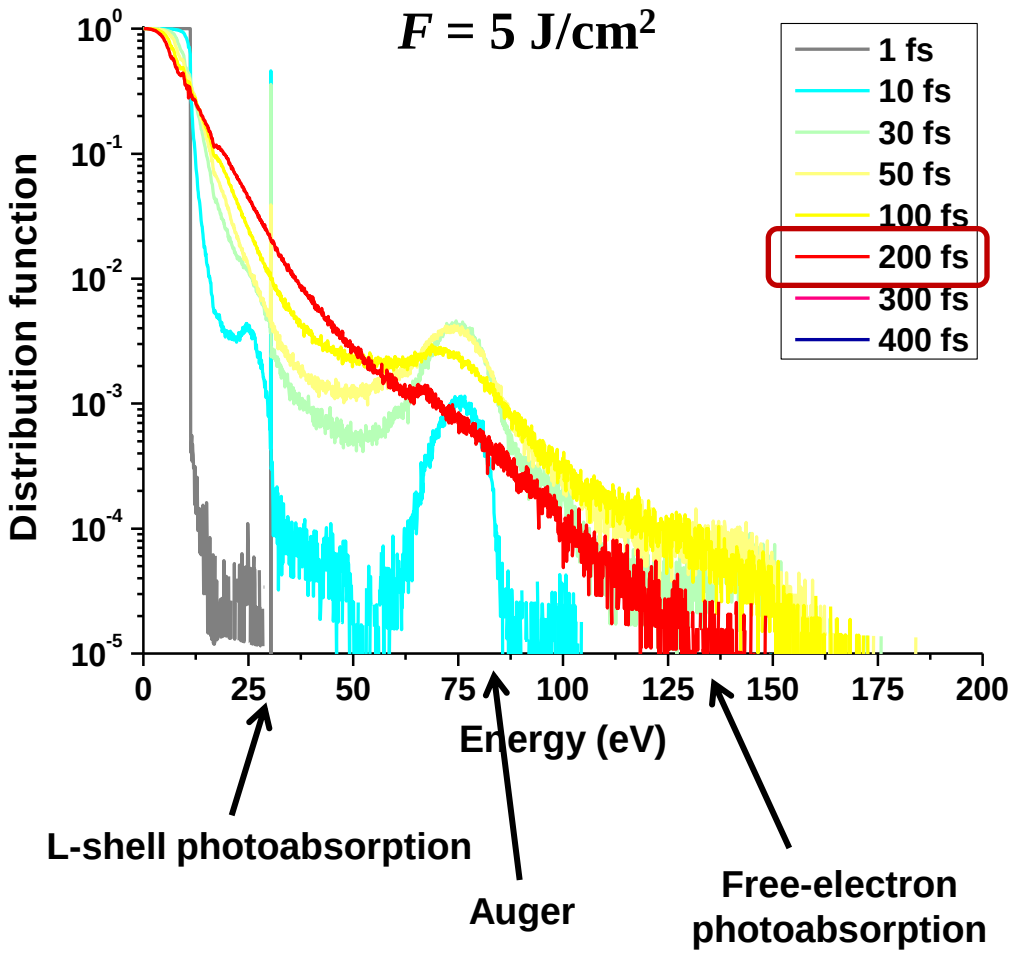

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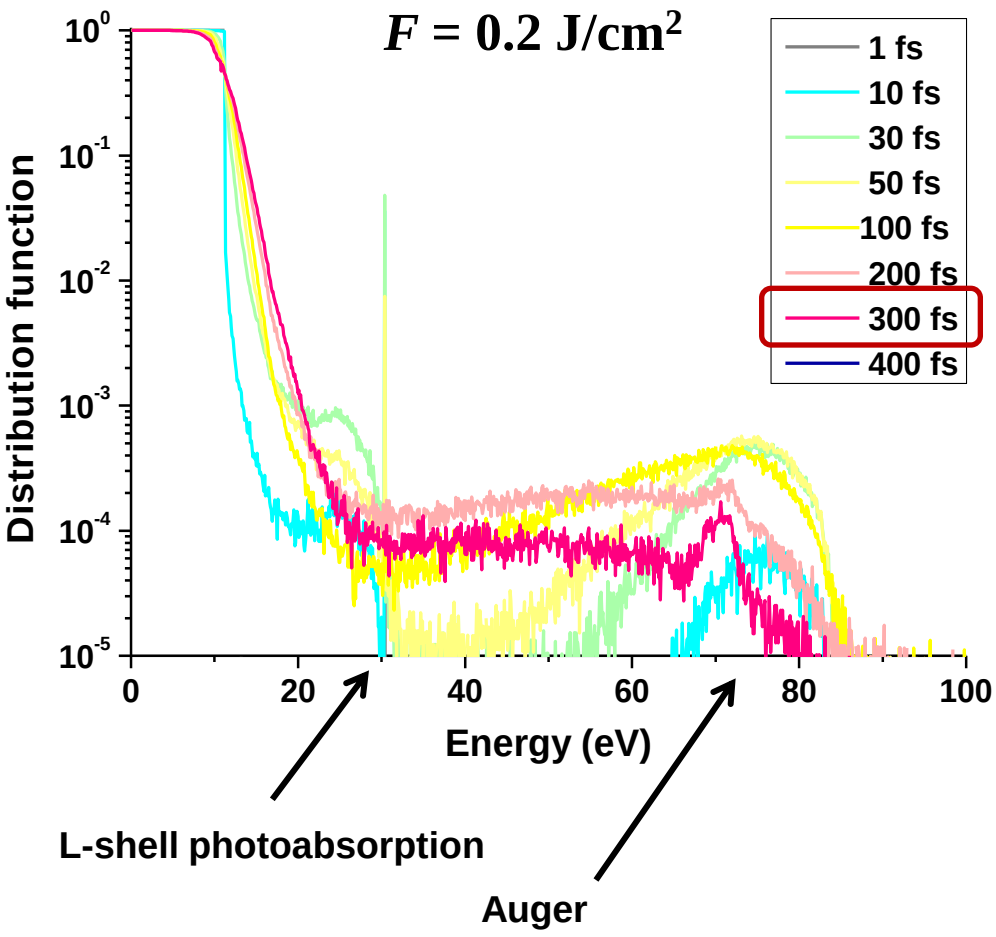

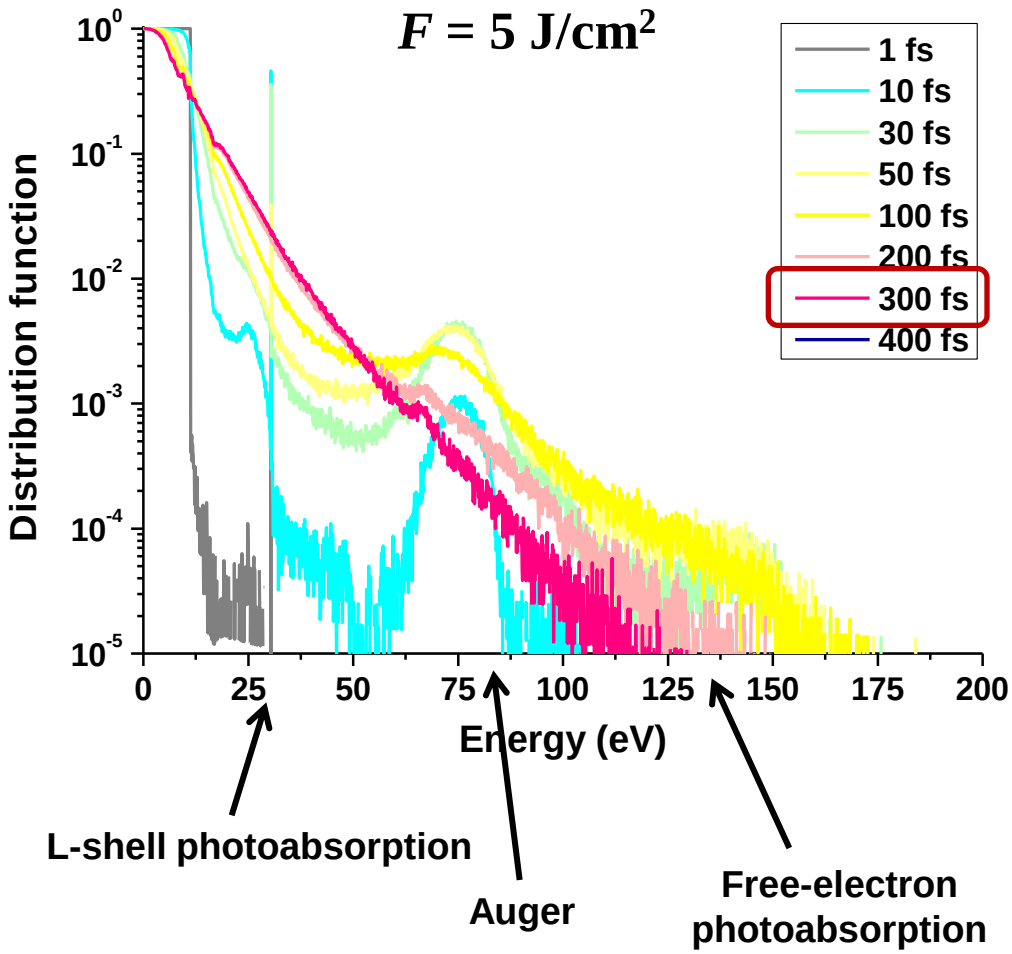

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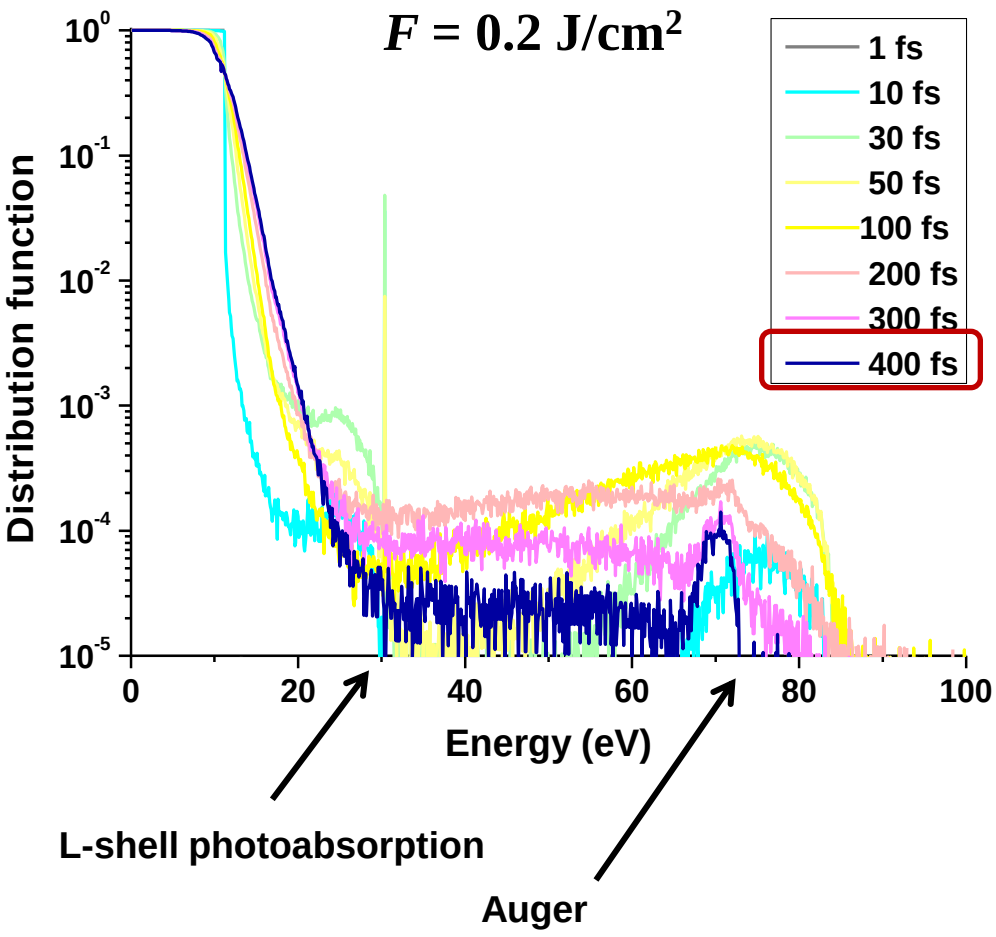
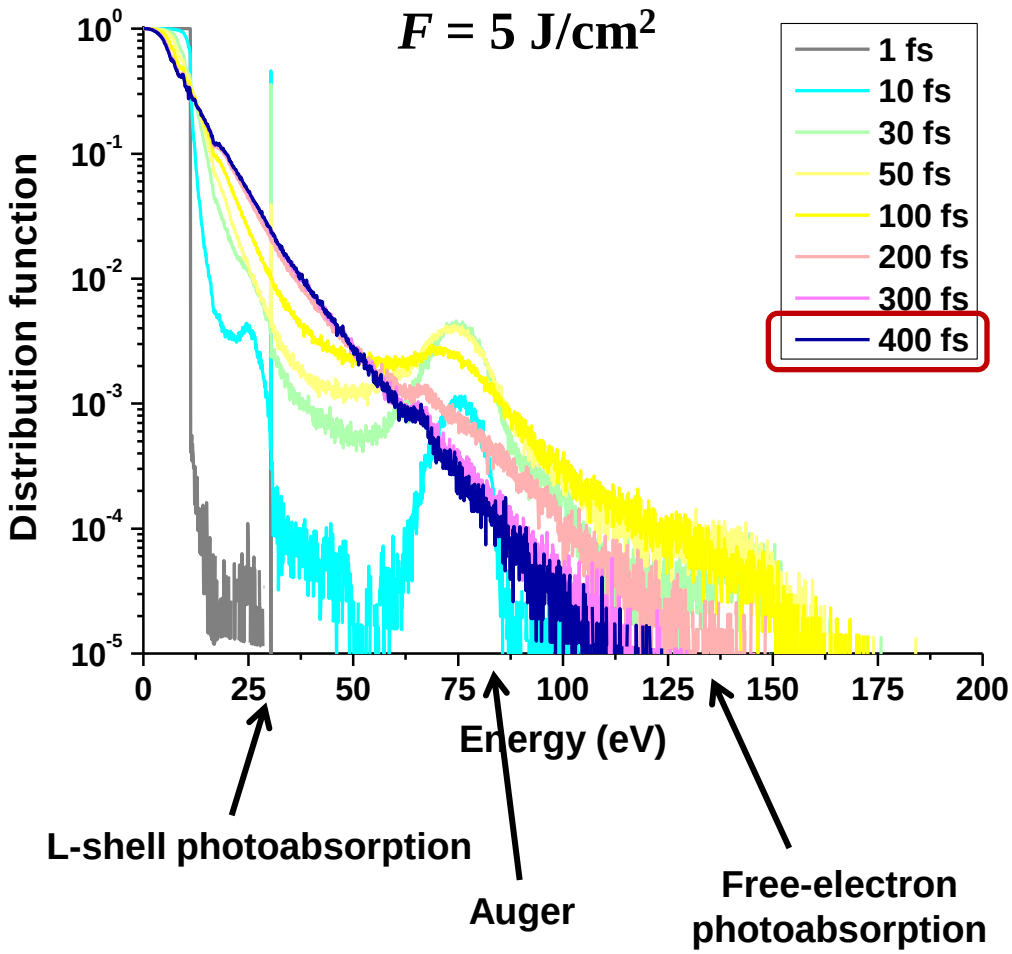
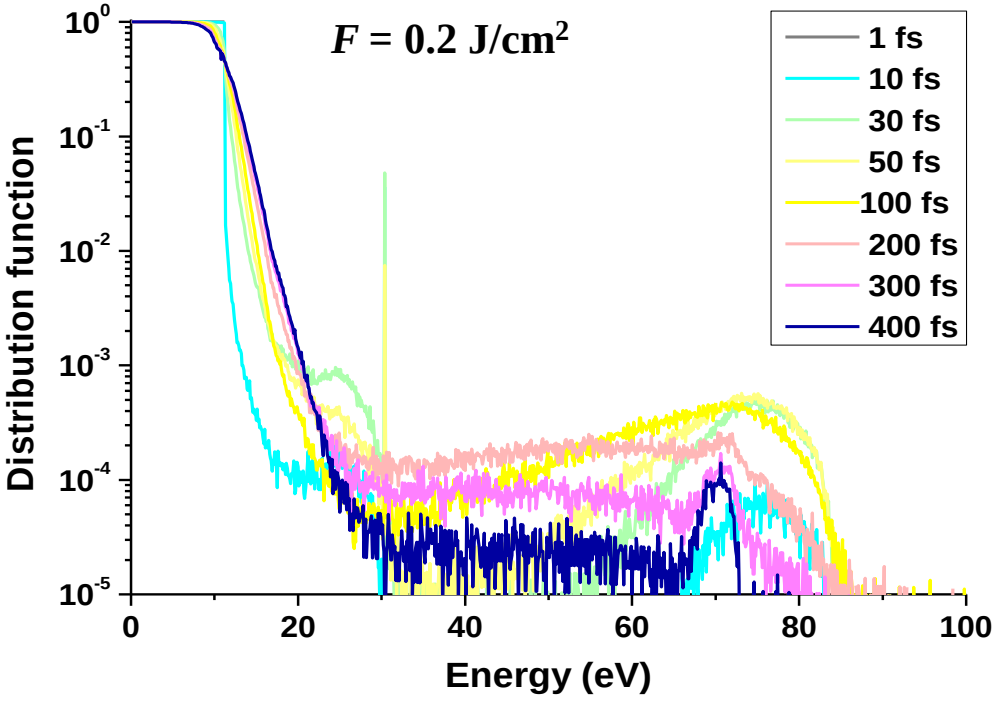
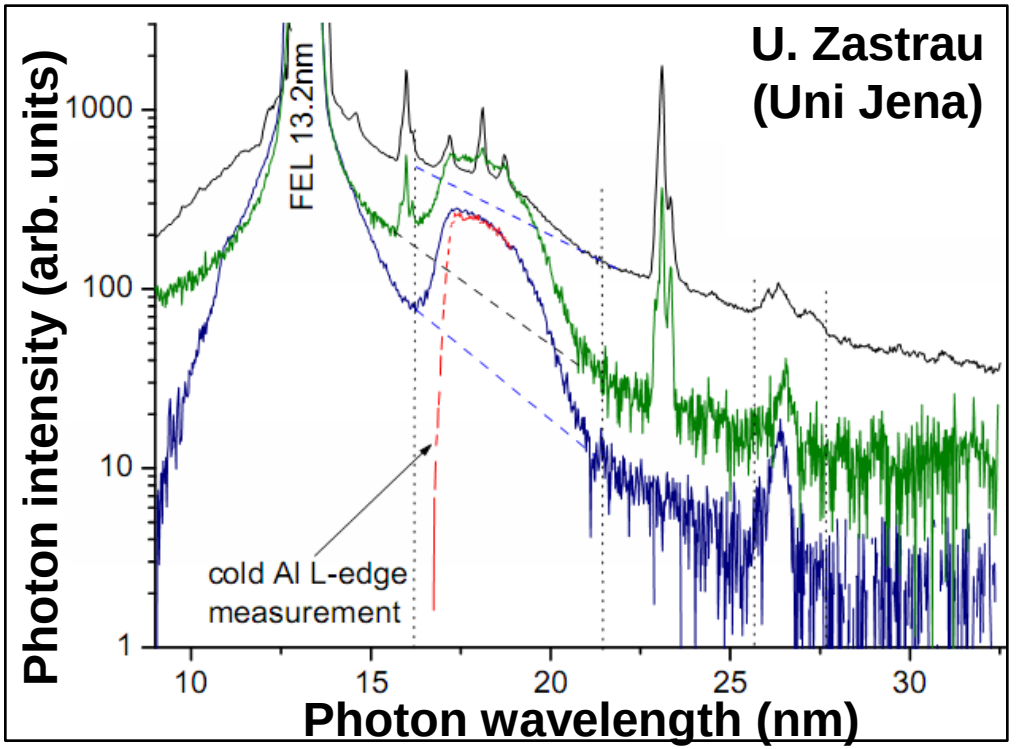




Qualitative comparison

Influence of different processes: photoabsorption, Auger, scattering

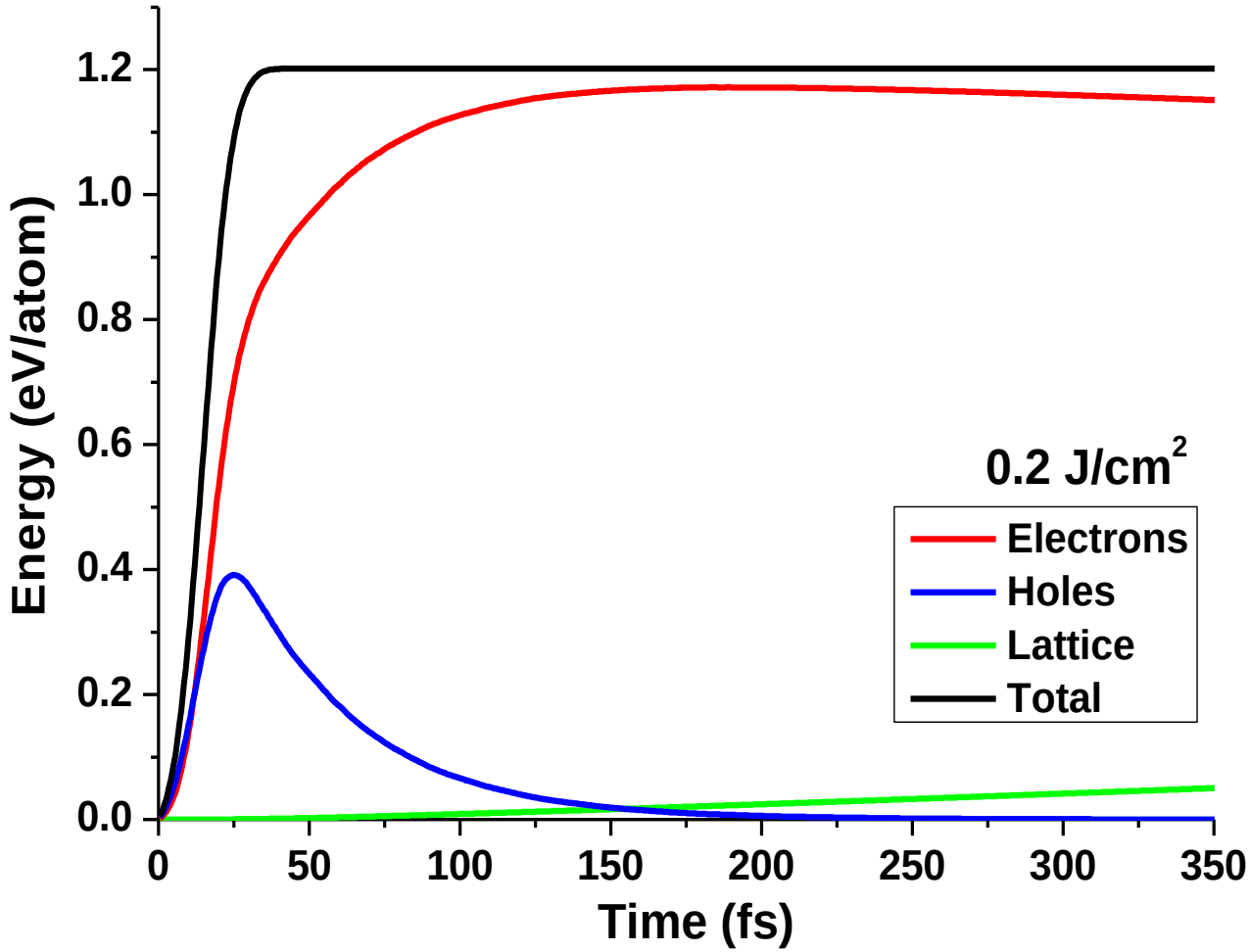




Two parts of distribution:
close to thermalized one + long nonthermalized tail

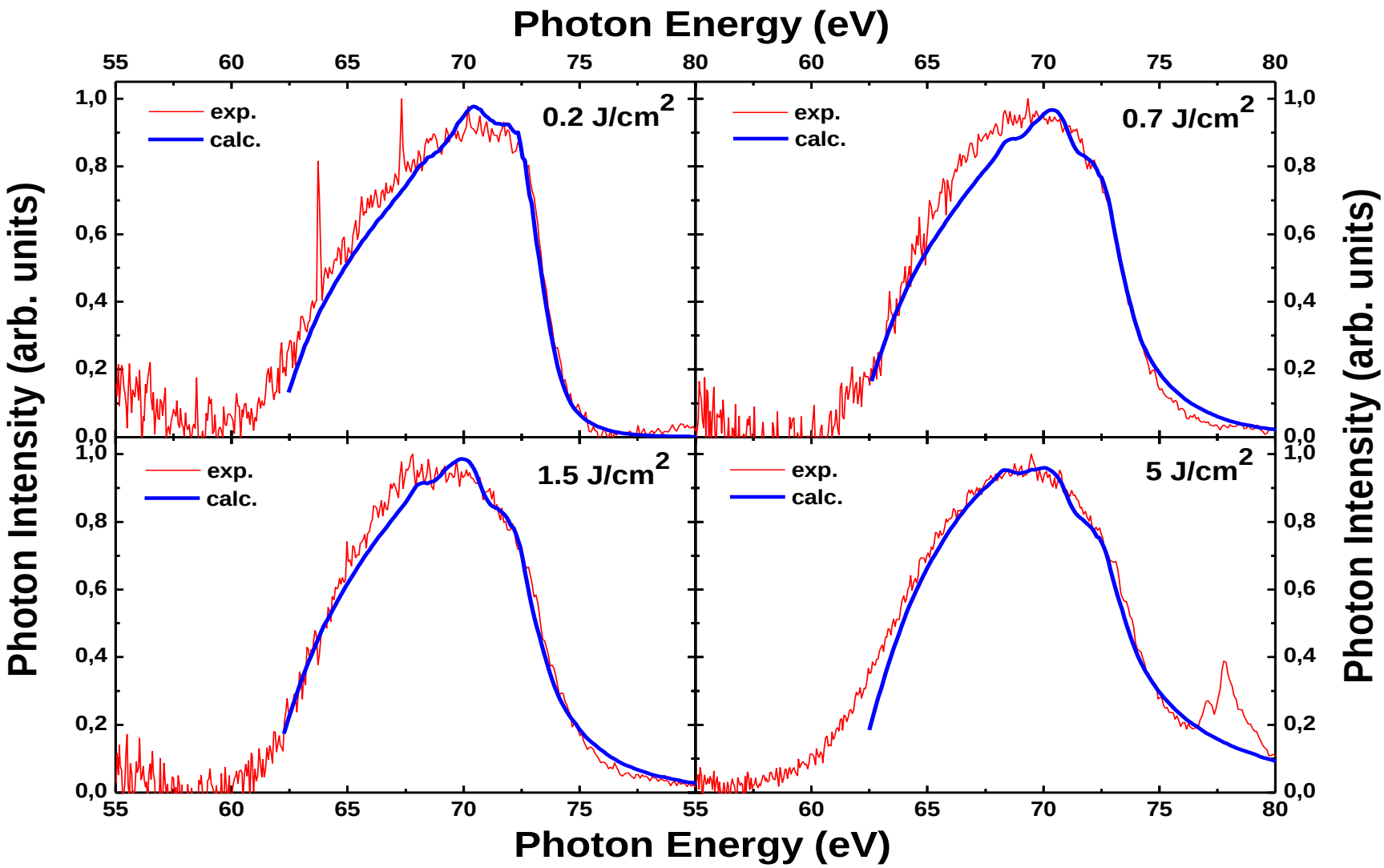
bump (~1 eV) **background (~20 eV)**

Energies



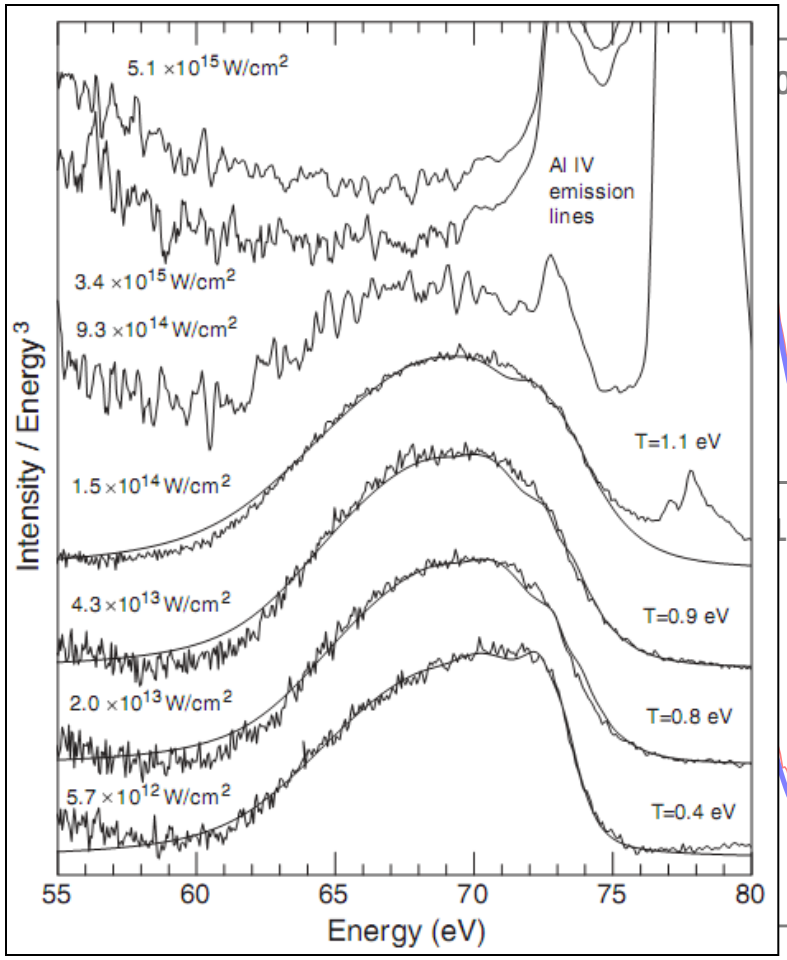
Experimental spectra are averaged over ~ 200 fs

Quantitative comparison

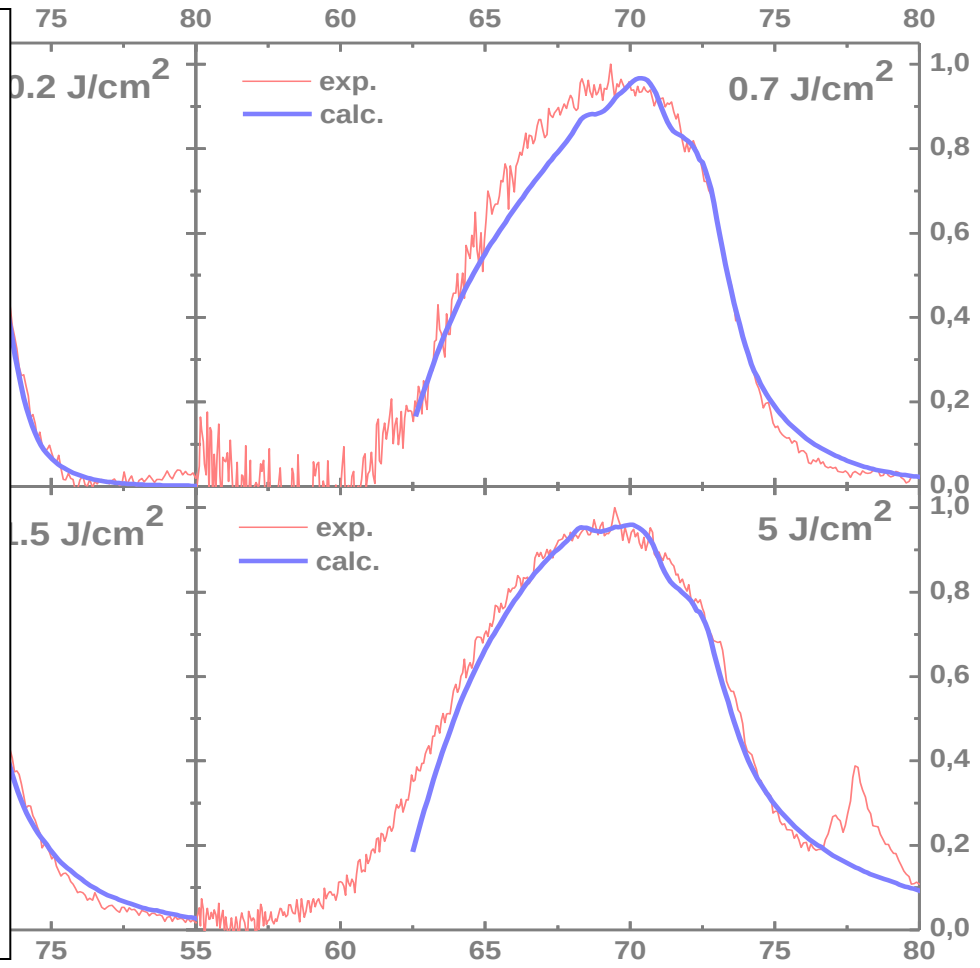


Good agreement with experiment

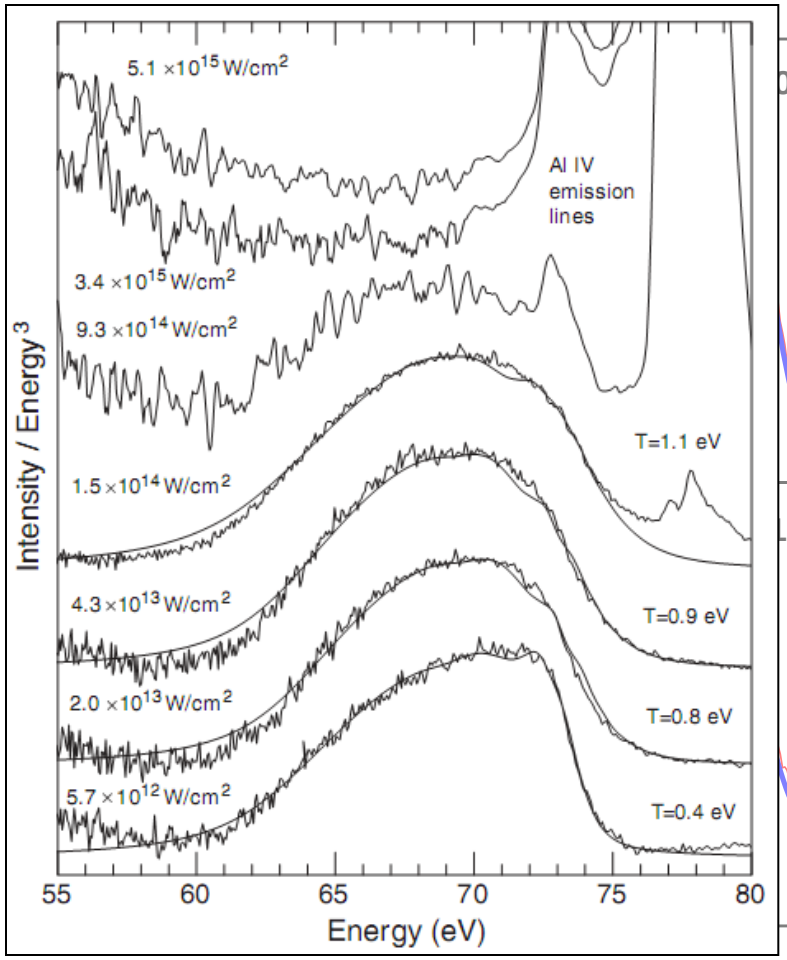
Quantitative comparison

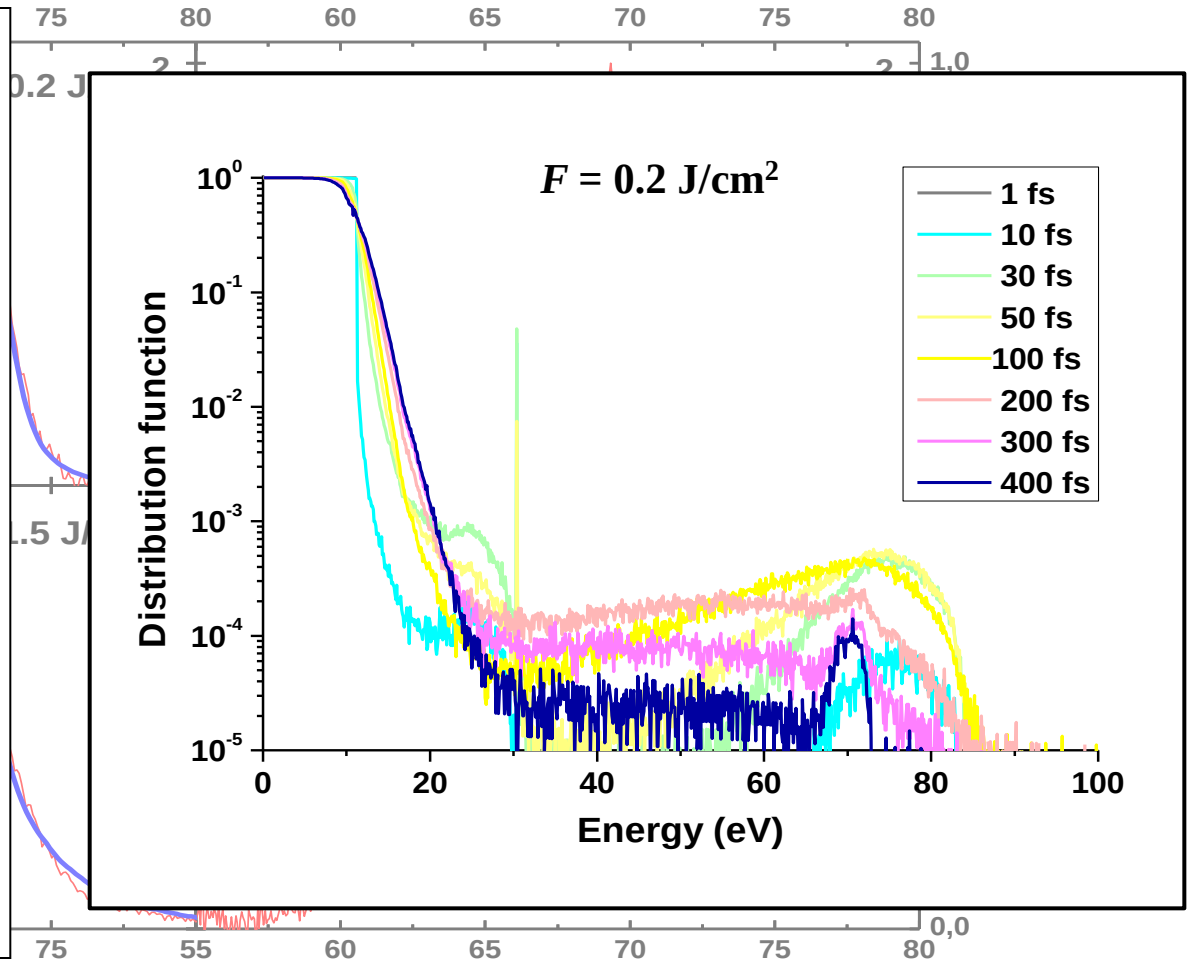


[S. Vinko *et al*, PRL 104, 225001 (2010)]



Quantitative comparison



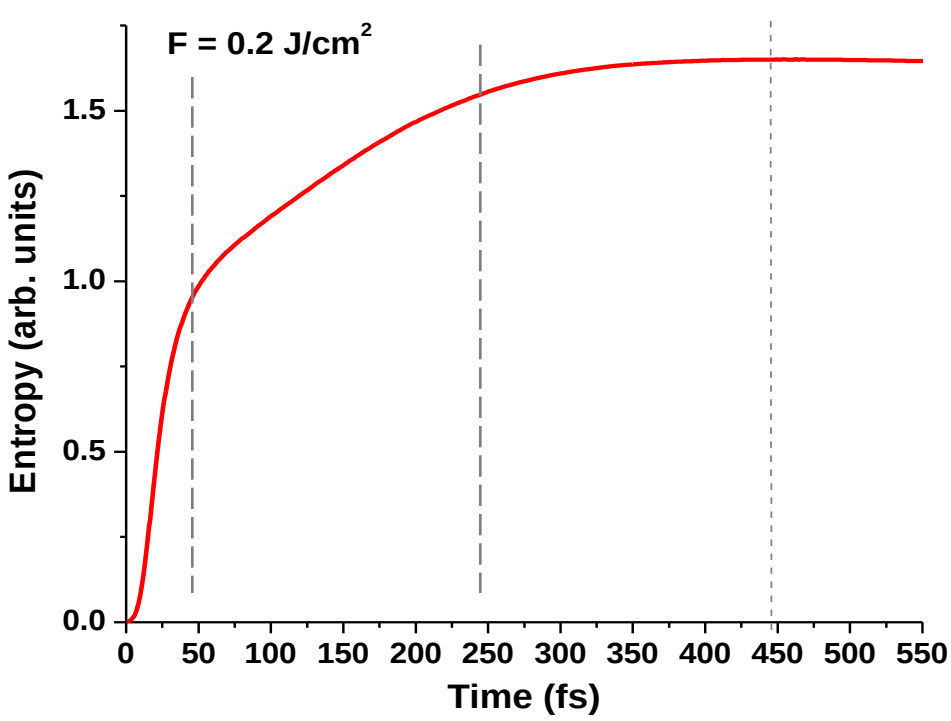


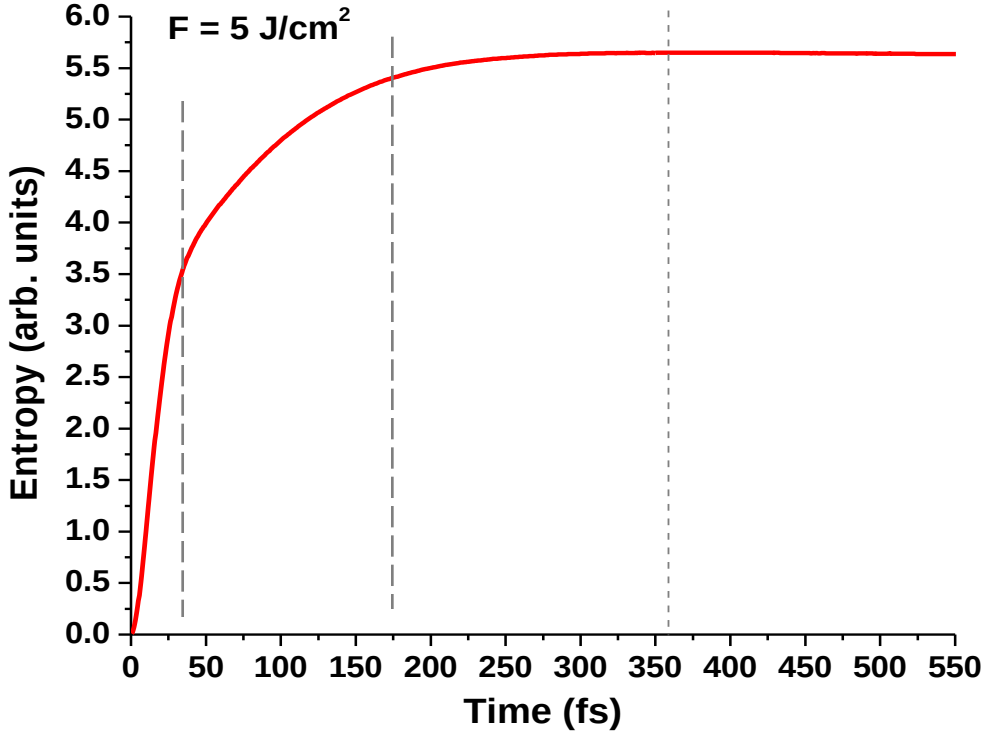
[S. Vinko *et al*, PRL 104, 225001 (2010)]

L-shell decays "sees" only low energy part of distribution

Electron thermalization

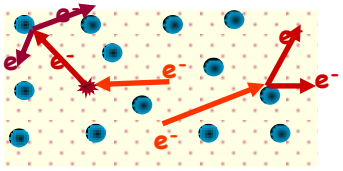
Electron entropy measures deviation from equilibrium



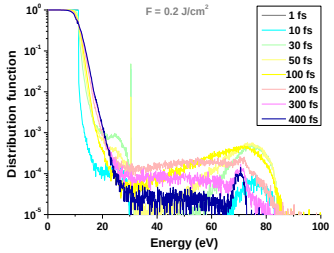


Thermalization times are ~ 400 fs

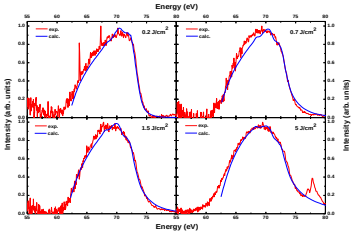
Conclusions



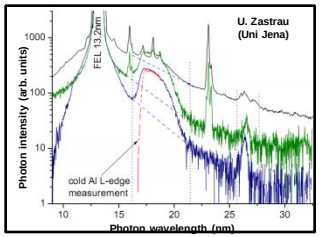
1. Monte-Carlo with electronic band structure



2. Electronic distribution of two parts:
   - Low energetic, close to fermi-distribution
   - High energetic, non-thermalized



3. Experiments with Auger/radiative-decay spectra reflect only low energy electrons



4. Bremsstrahlung spectra have access to high energy tail

Thank you for your attention!

References

[Medvedev and Rethfeld, *Europhys. Lett.* **88** (2009) 55001]

[Medvedev and Rethfeld, *New J. Phys.* **12** (2010) 073037]

[Medvedev and Rethfeld, *AIP conf. proc.* **1278** (2010) 250]

Acknowledgements

U. Zastrau, D.O. Gericke

FLASH-team