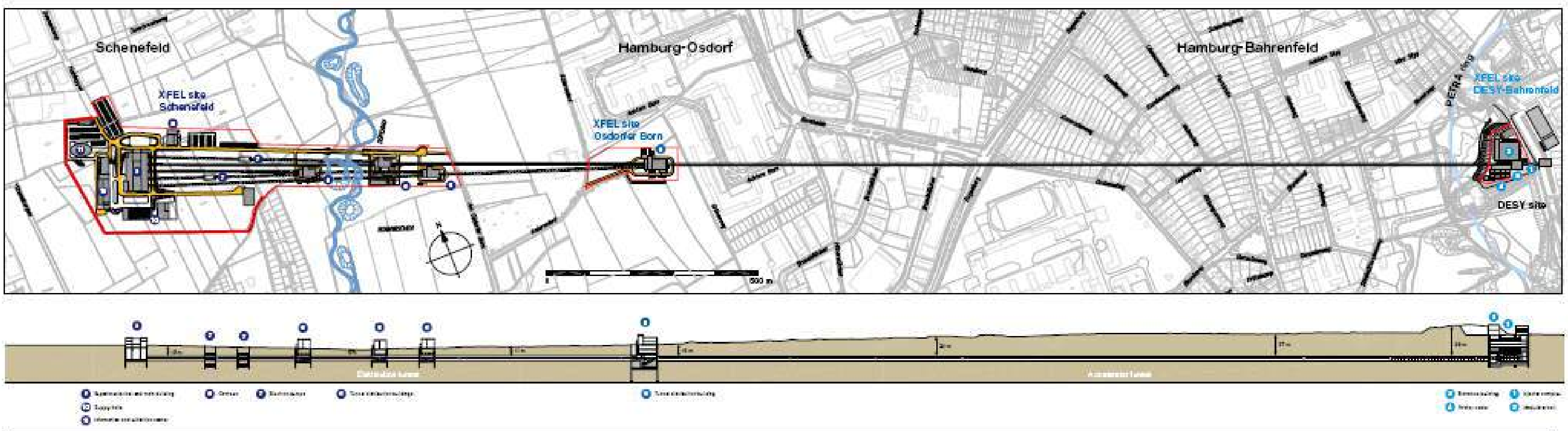
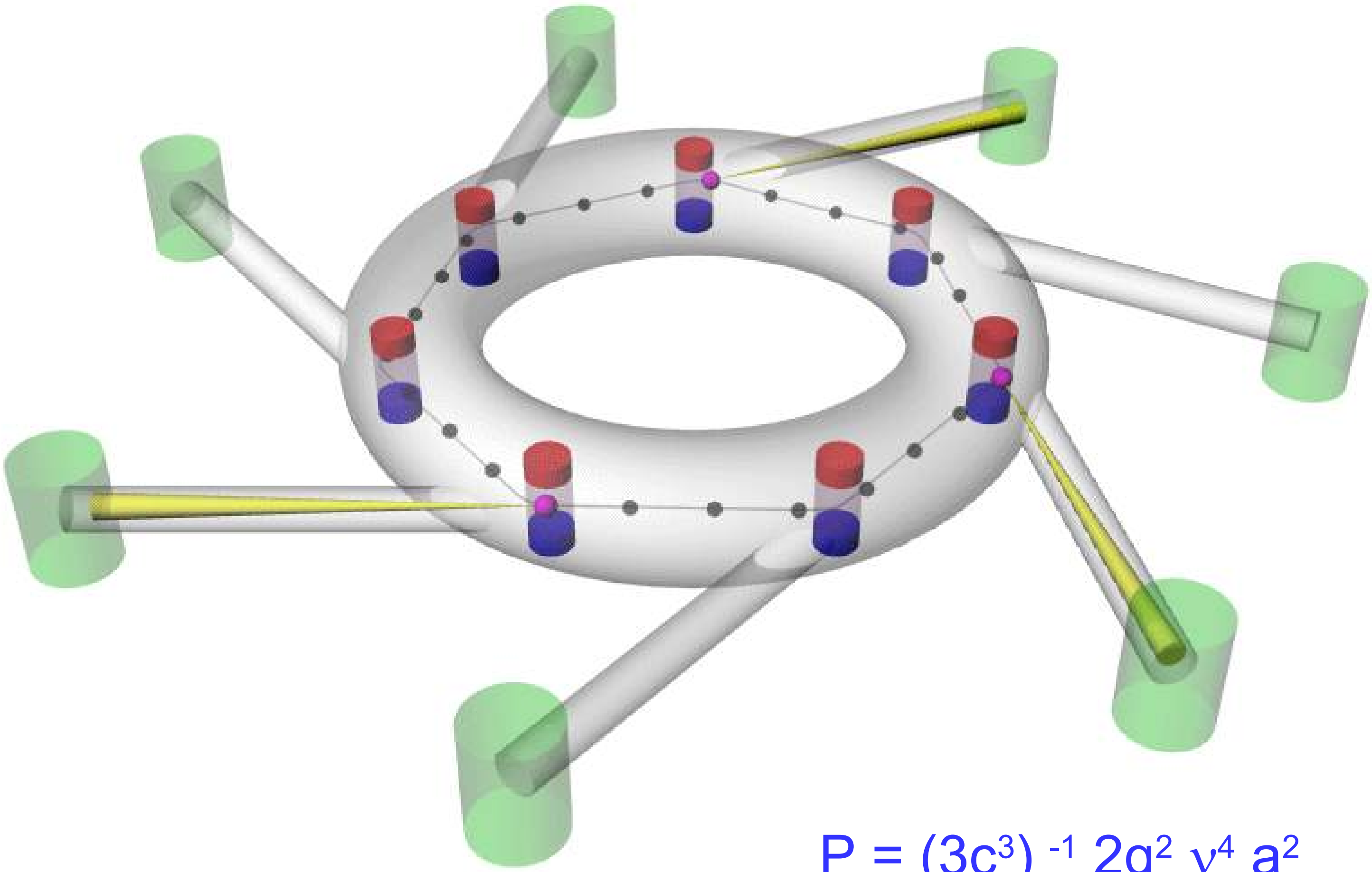
New Dimensions for Time- and Angle-Resolved PES at European XFEL

Serguei L. Molodtsov, European XFEL, Hamburg



Synchrotron radiation (dipoles)

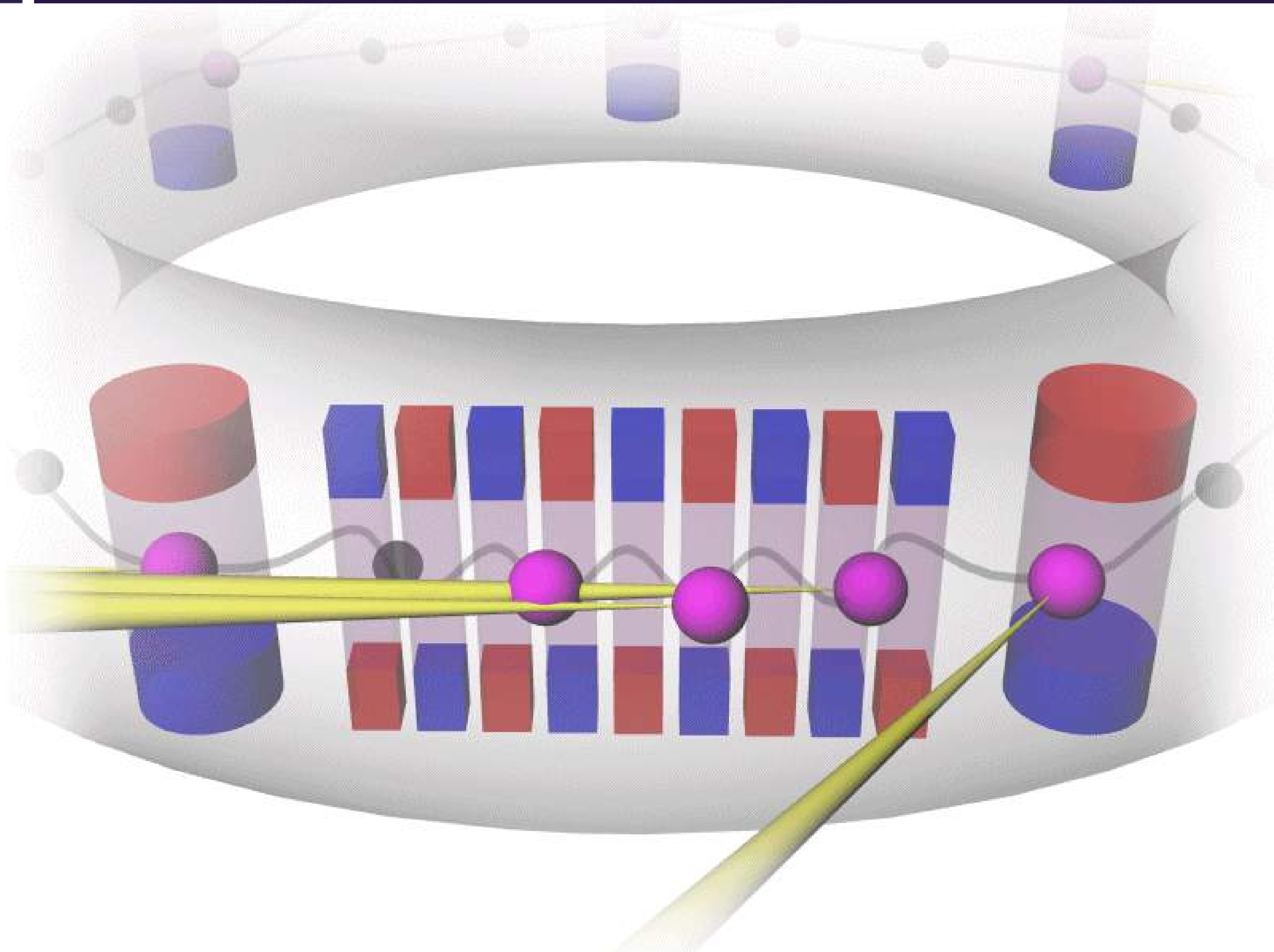


$$P = (3c^3)^{-1}\, 2q^2\, \nu^4\, a^2$$

P – radiated power; c – light velocity; q – particle charge; a – acceleration; ν - normalized ener

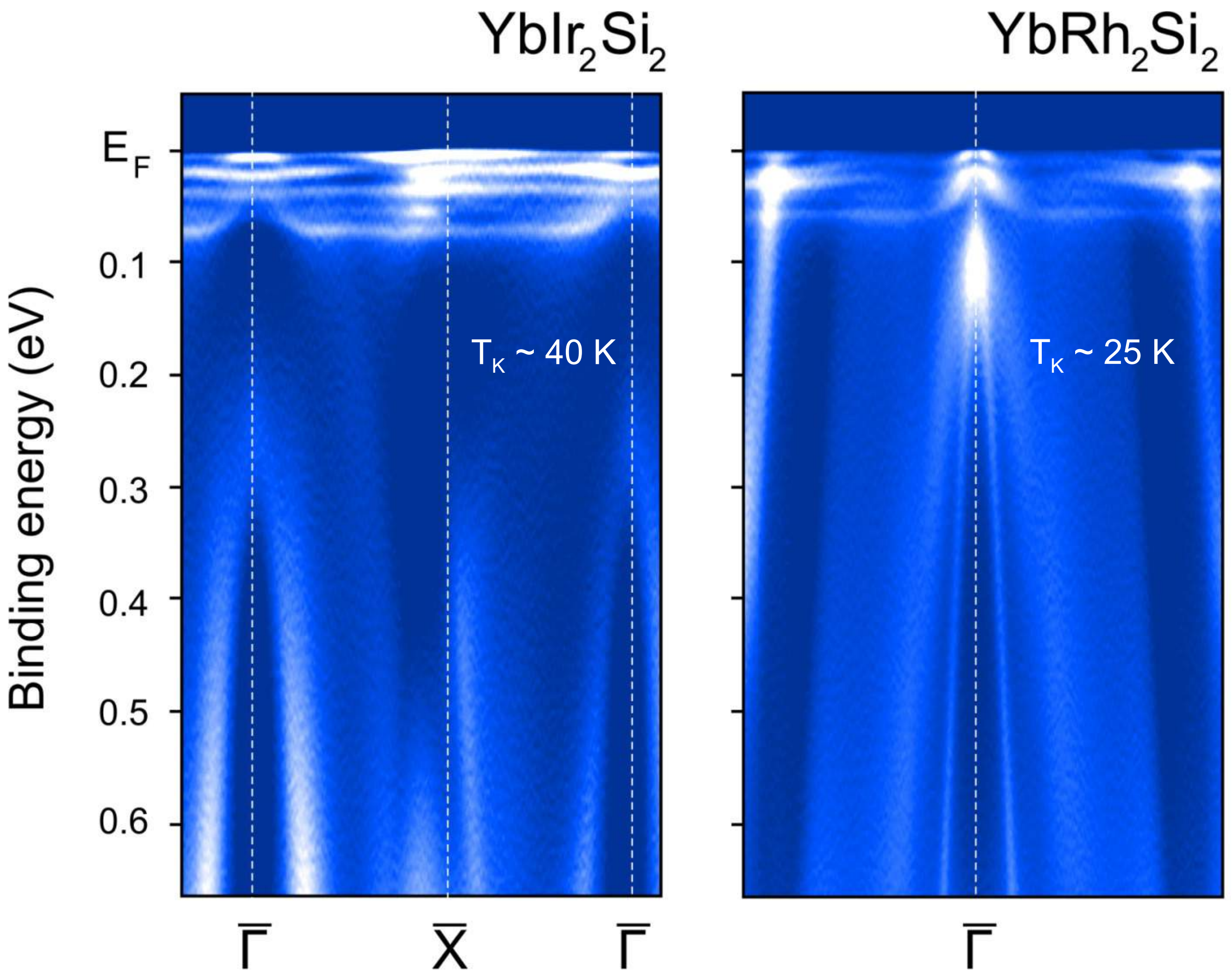
European XFEL

Synchrotron radiation (undulators)



What can be done at 3rd generation sources?

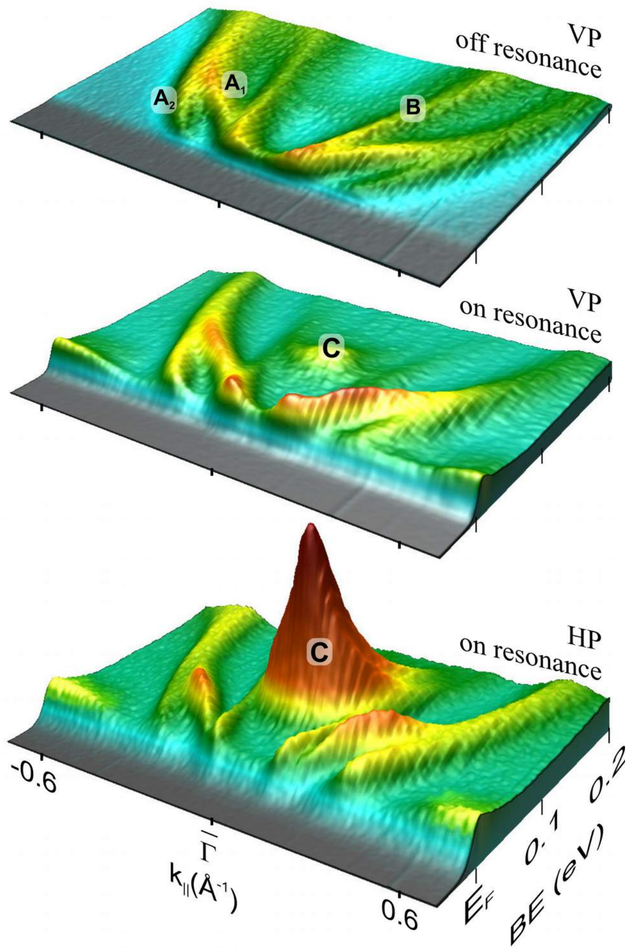
Kondo (heavy-fermion) systems (D. Vyalikh, TU Dresden)



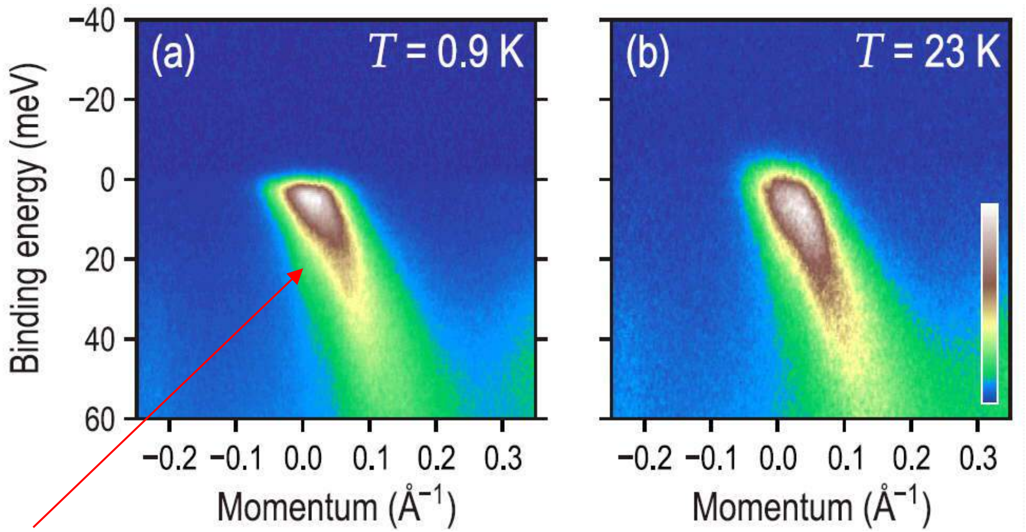
- effective mass mapping (transport phenomena)
- crystal field-split *4f* states probing (magnetic properties)
- strength of electron states correlation (Kondo behavior)

High-temperature superconductors (S. Borisenko, IFW)

CeFePO



LiFeAs



kink below T_c

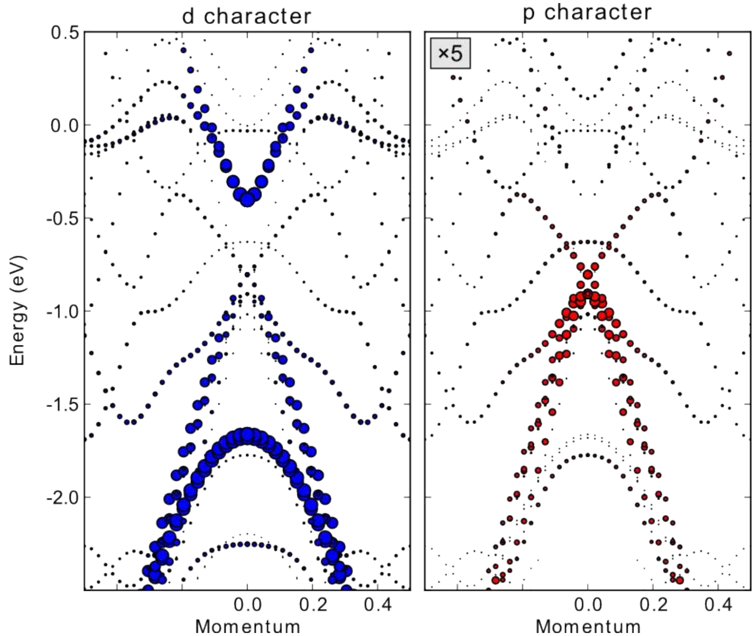
- which band is responsible for superconductivity?
- how large is superconducting gap?
- how strong is electron pairing (kink energy)?

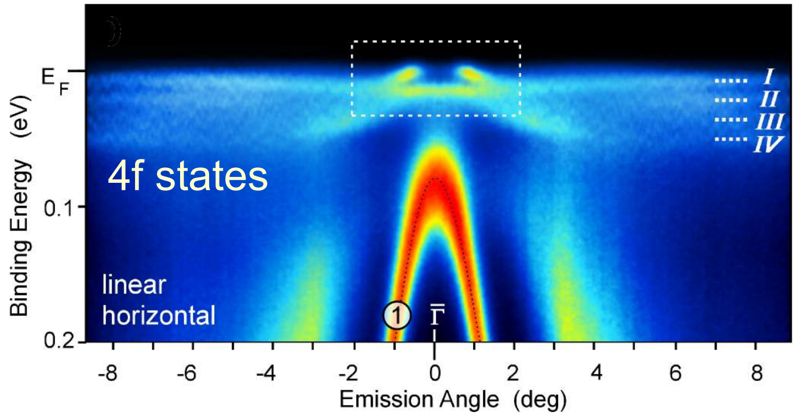
What is missing?

Electron system dynamics that is of the time scale order < 0.1 ps

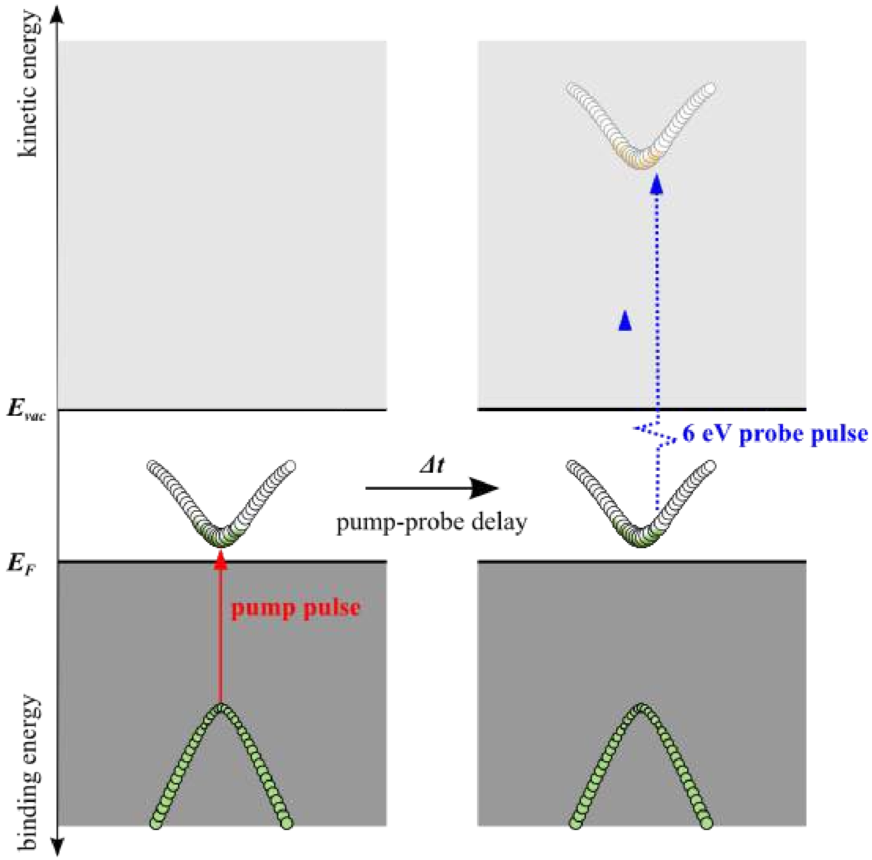
Probing dynamics one can decide, e.g. in favor of spin or phonon mediated mechanism of electron pairing both in superconducting and Kondo systems

Pump-probe experiment (K. Kummer, et al.)



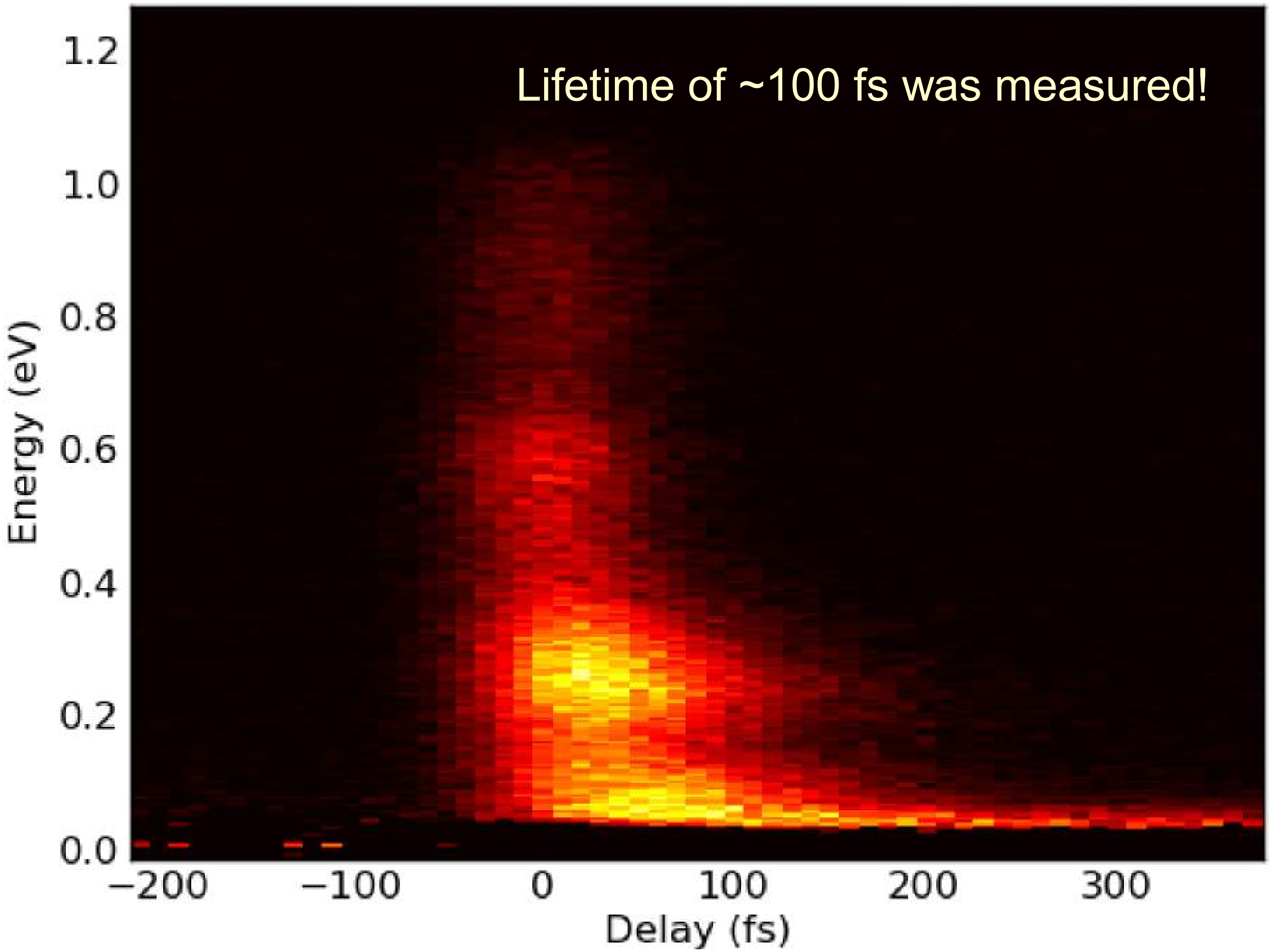


- $YbRh_2Si_2$

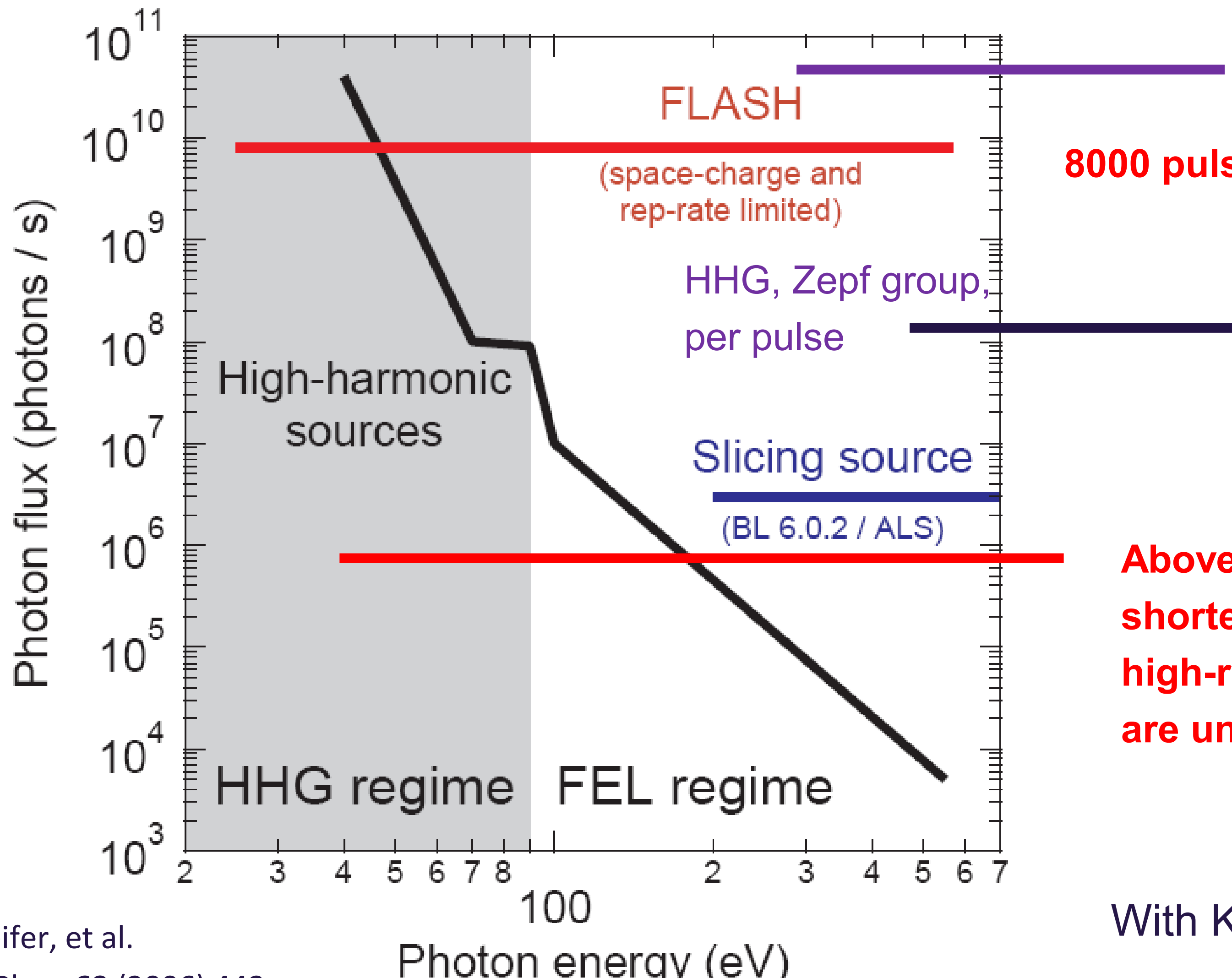


ARPES with MHz optical lasers

Proof of principle pump-probe experiment



Source comparison: Time-resolved PES



XFEL
27000 p/s

8000 pulses/s

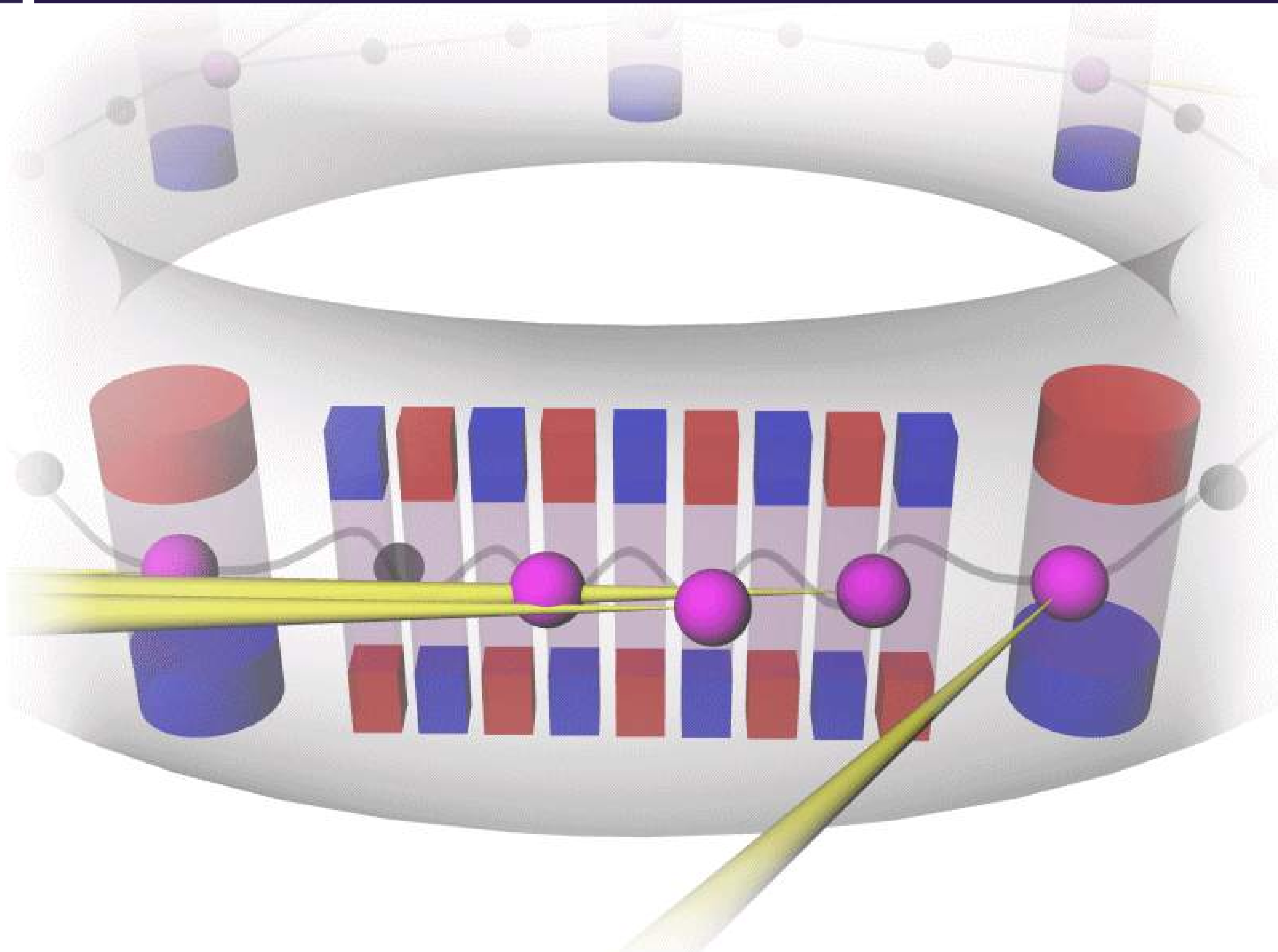
LCLS
120 Hz

Above 200 eV and shorter than 100 fs high-rep rate FEL's are unique!

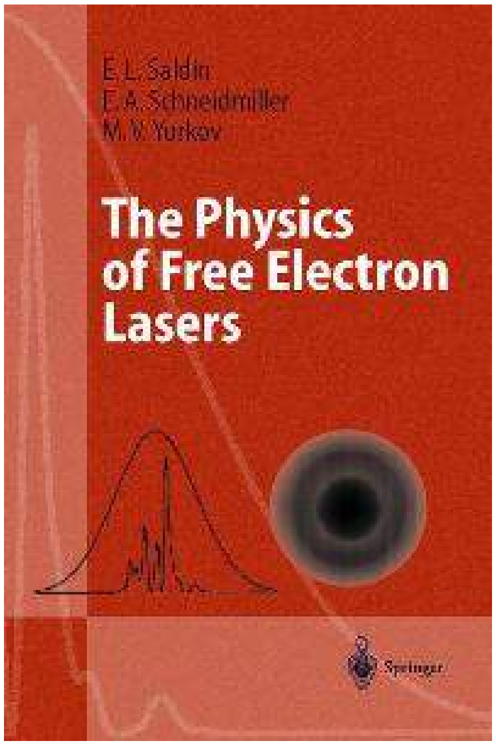
HHG, T. Pfeifer, et al.
Rep. Prog. Phys. **69** (2006) 443

With K. Rossnagel

Synchrotron radiation (undulators)

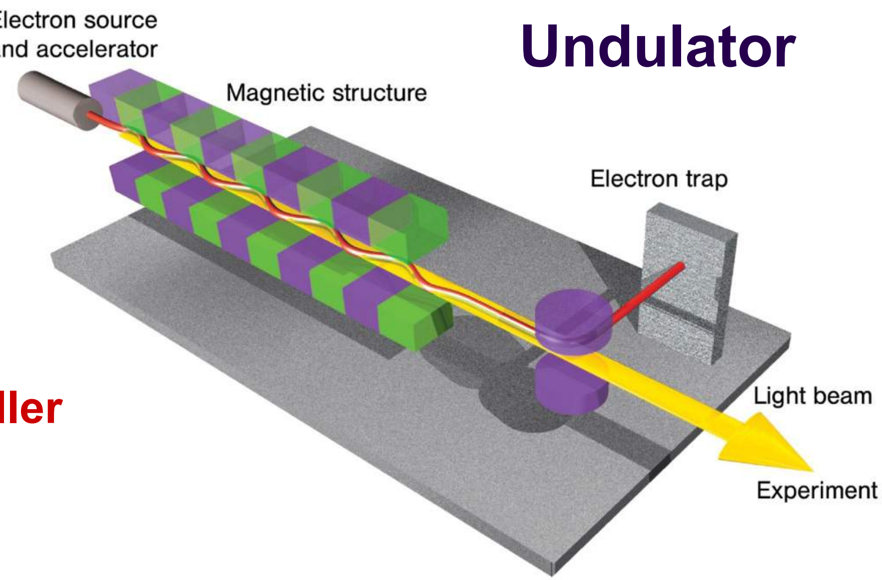


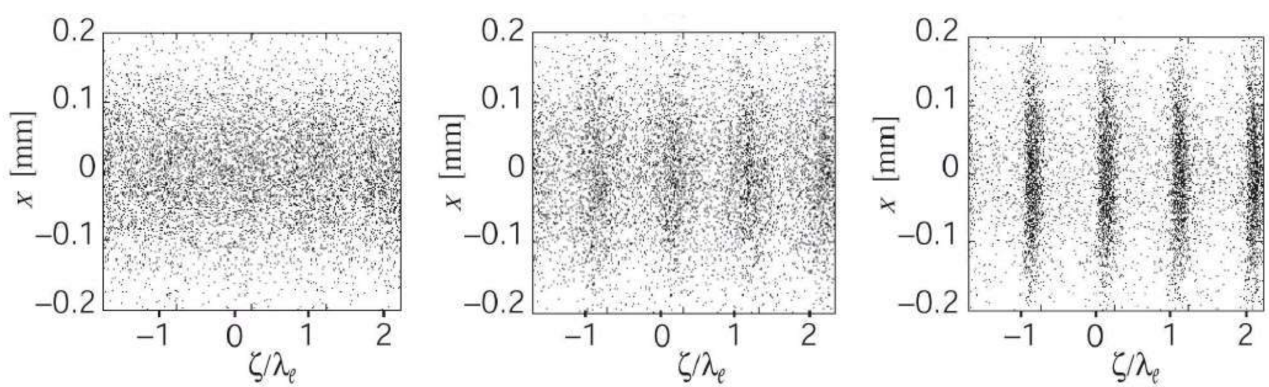
Basics of SASE FEL process



E.L. Saldin
E.A. Schneidmiller
M.V. Yurkov

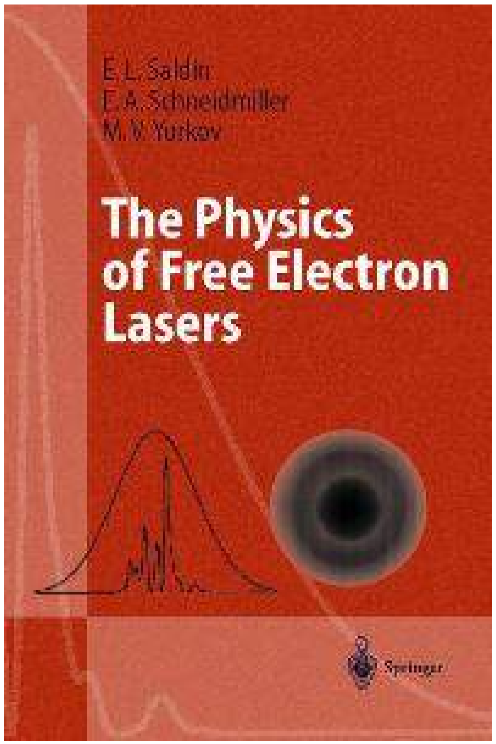
Undulator



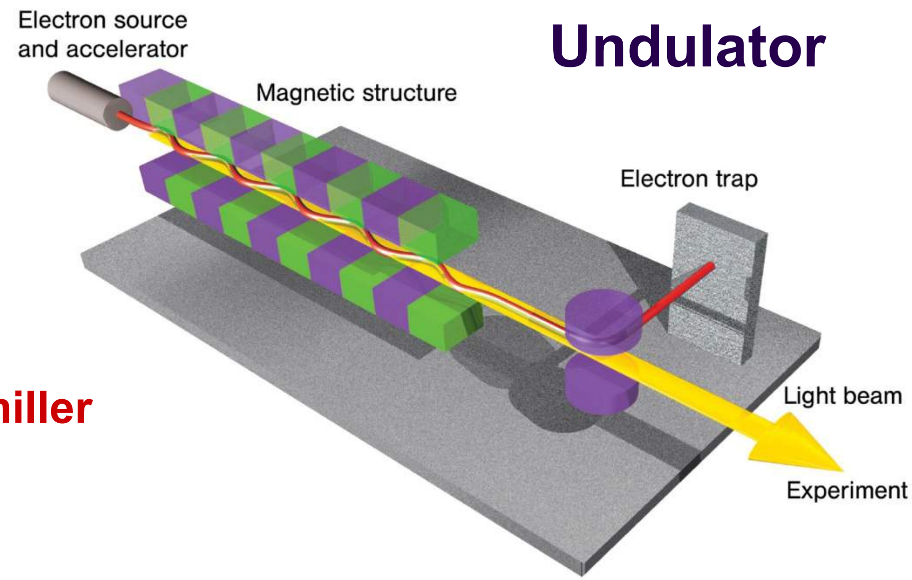


simulations at the radiation wavelength (λ_e), ζ – distance inside the undulator

Basics of SASE FEL process



Undulator



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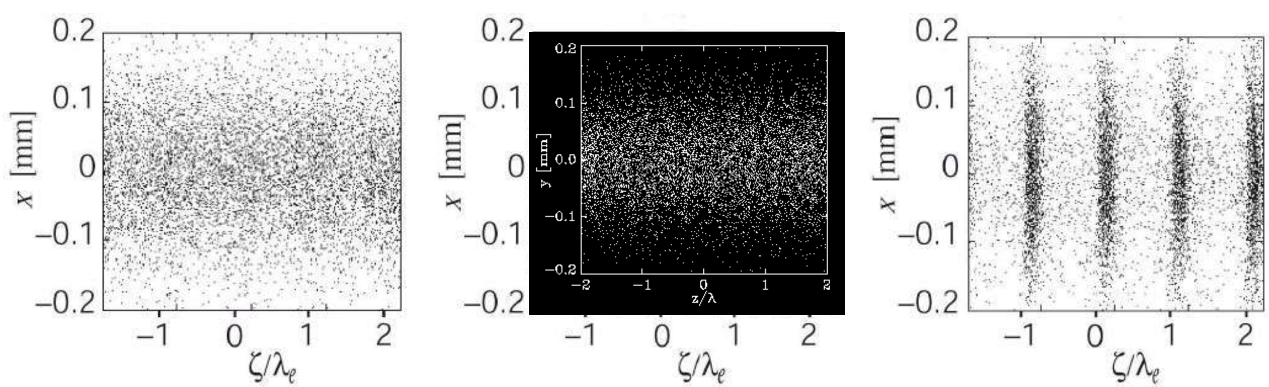
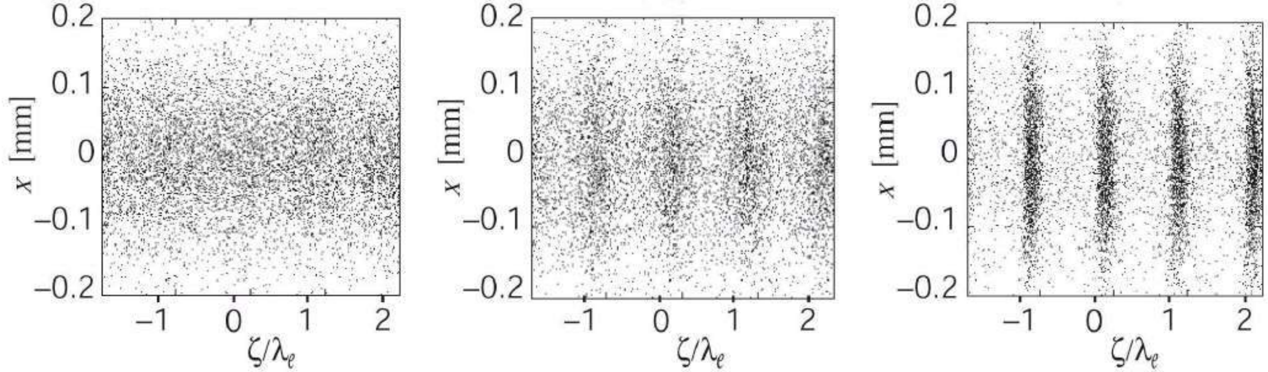
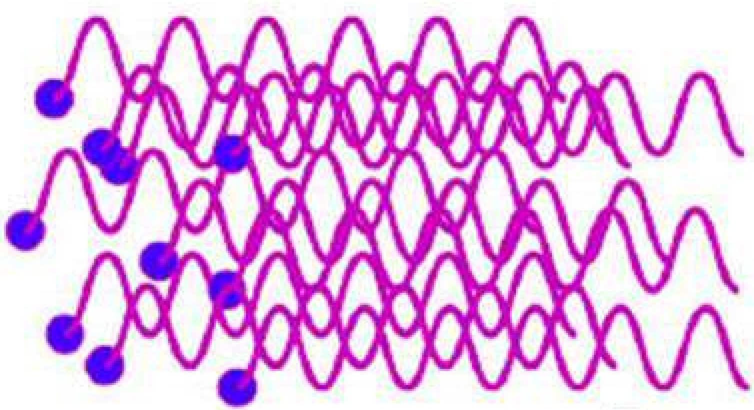


simulations at the radiation wavelength (λ_e), ζ – distance inside the undulator

Spontaneous vs. coherent radiation in undulators



Spontaneous Radiation

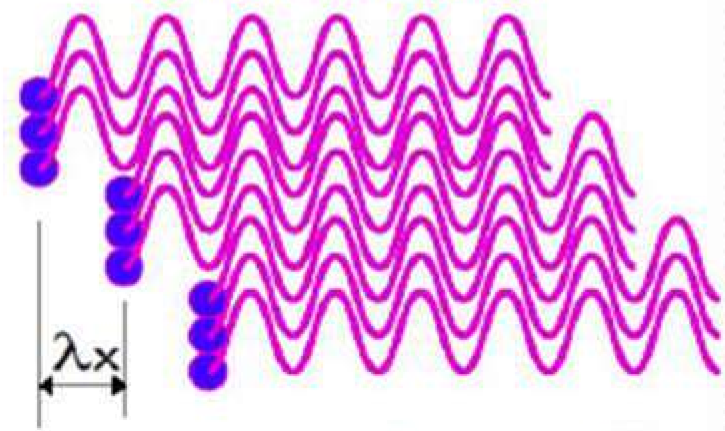


N-electrons random distribution

$E_{spt} \sim \sqrt{N}\, E_1$

$P_{spt} \sim N\, P_1$

Coherent Radiation



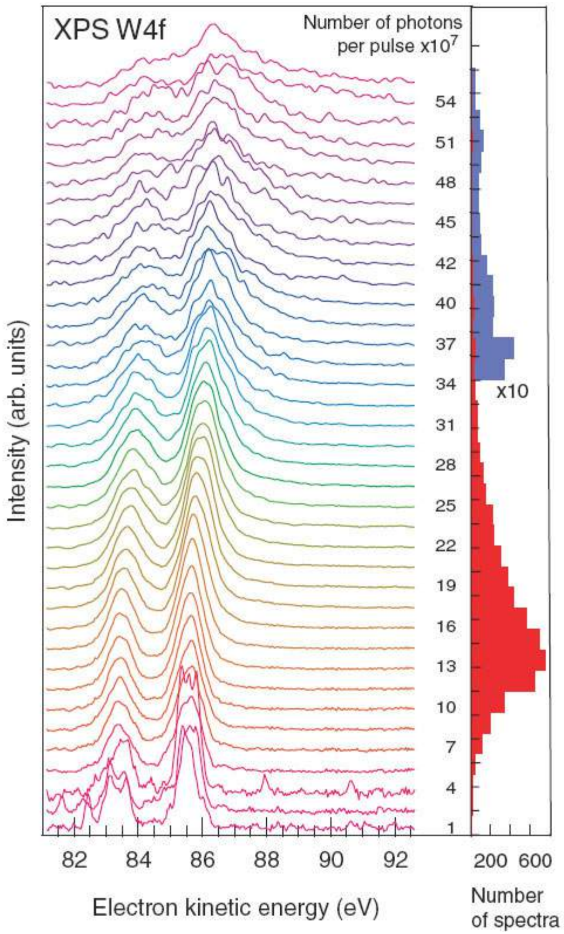
N-electrons micro-bunched

$E_{coherent} \sim N\, E_1$

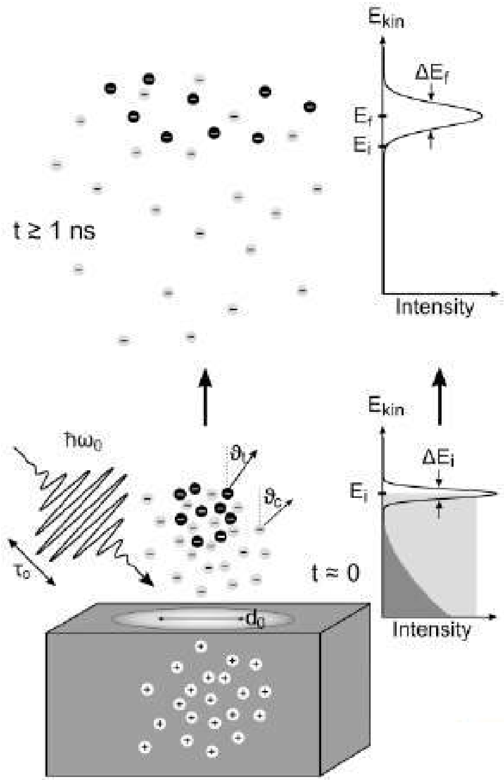
$P_{coherent} \sim N^2 P_1$

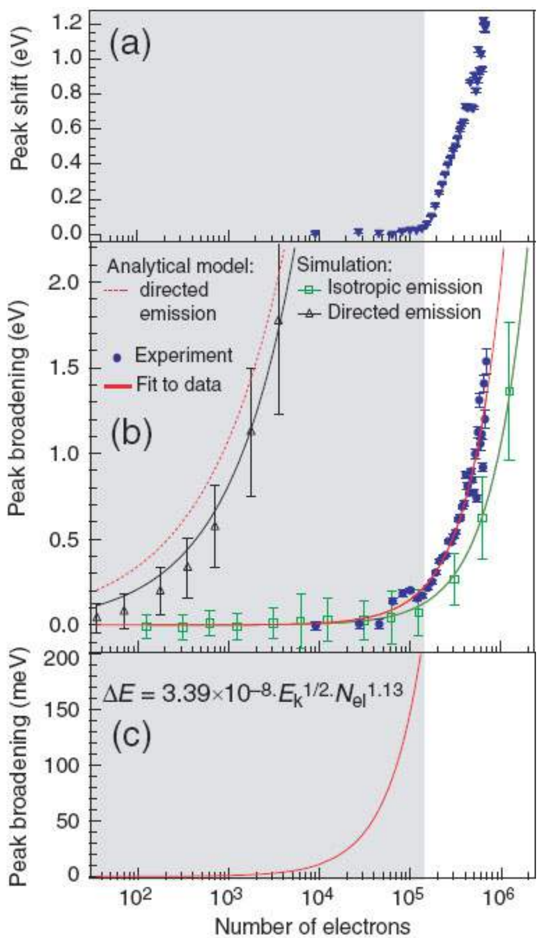
Core-level X-ray photoemission spectroscopy (XPS)

Core-level PE was proven to be extremely useful tool for time-resolved studies of, e.g. chemical interactions at FLASH and LCLS (W. Wurth, L. Kipp, A. Nilsson).

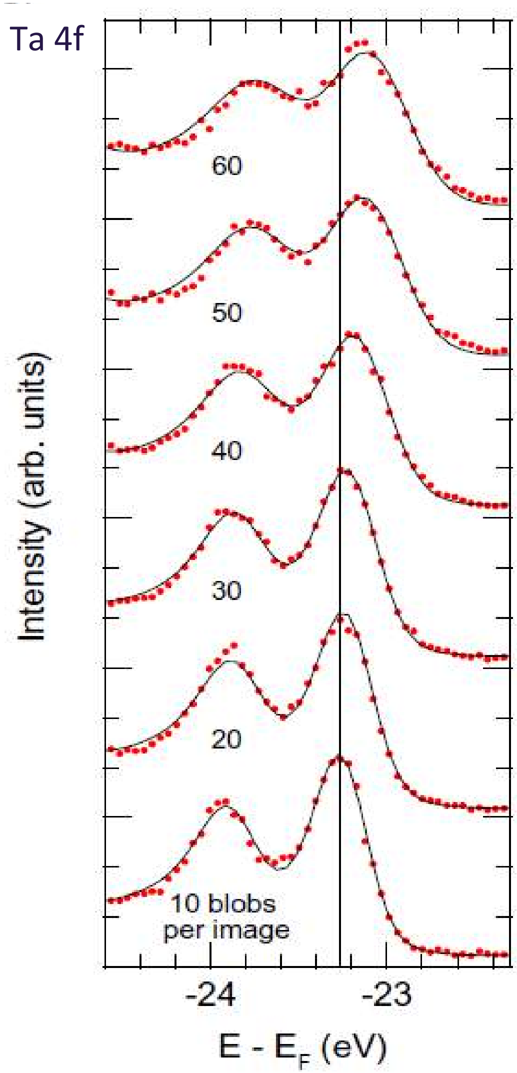


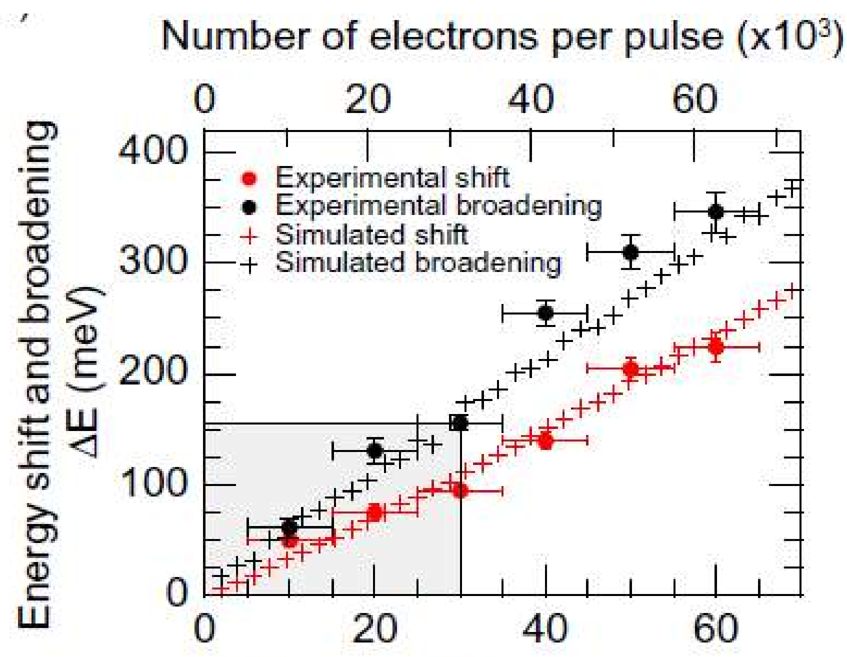
space charge (1mm spot)
> 10^8 phot/pulse
> 10^4 el/pulse





Challenges for time-resolved (tr) PES: Space charge





Number of events per image

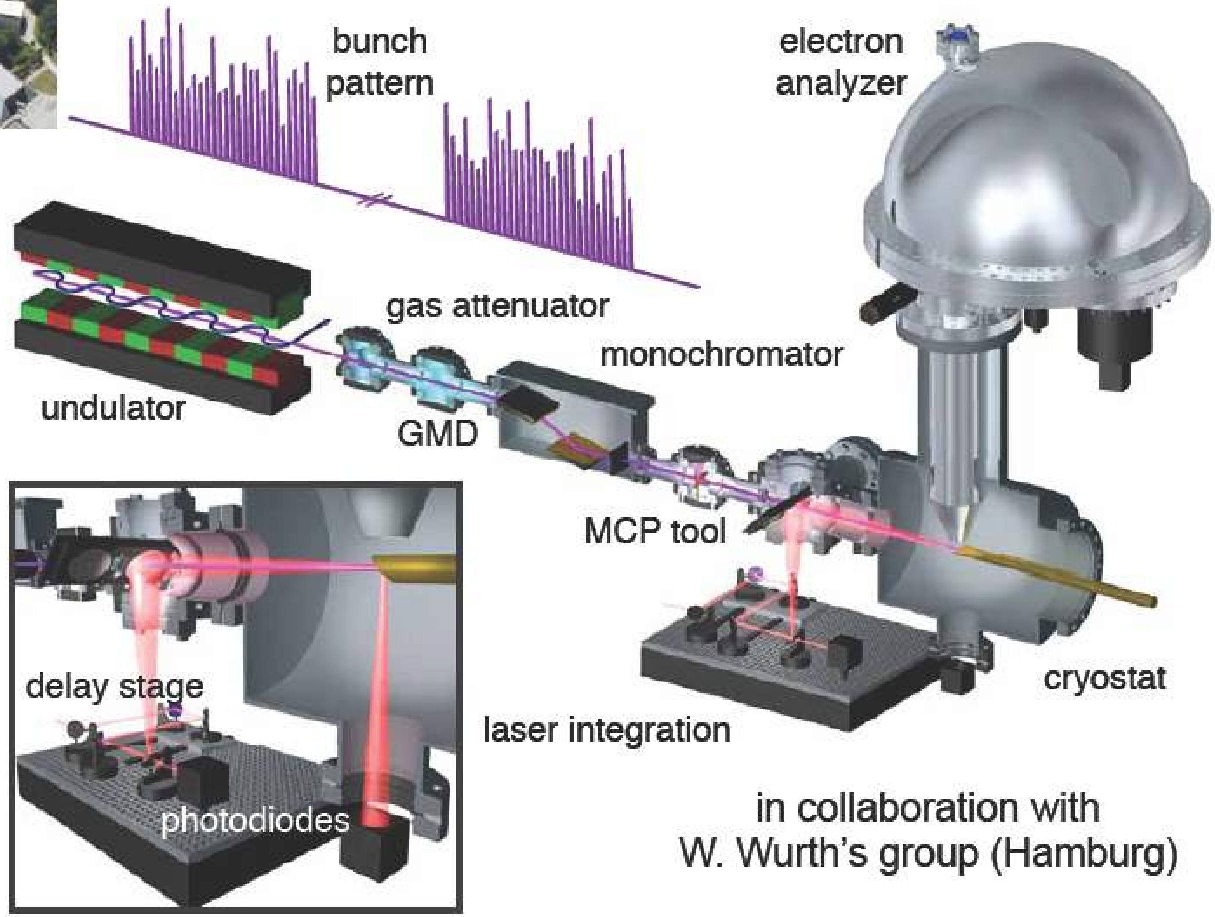
Poses physical limits on number of electrons per pulse

But can be controlled !

S. Hellmann et al.,

New Journal of Physics 14 (2012) 013062

Experimental set-up at FLASH (L. Kipp, Uni Kiel)



in collaboration with
W. Wurth's group (Hamburg)

Bundesministerium
für Bildung
und Forschung

1 *T*-TaSe2: tr-XPS using FLASH

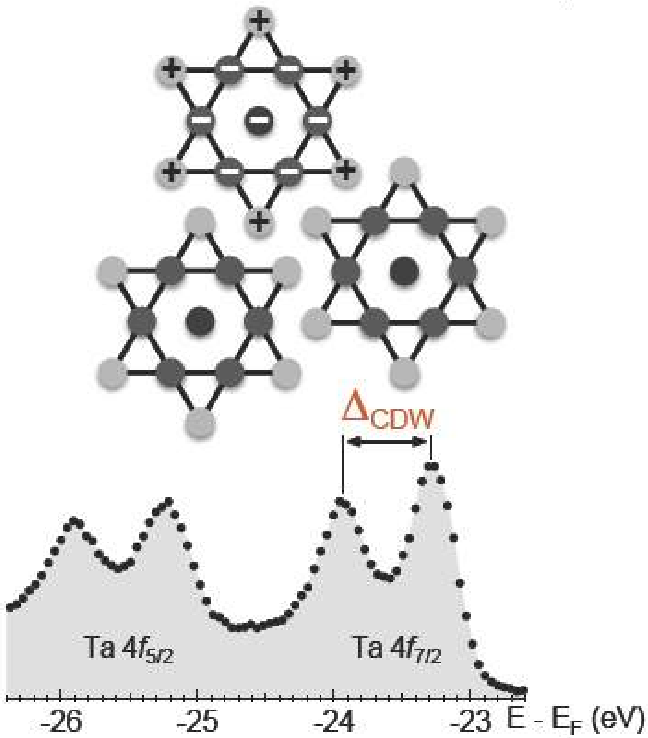
PRL **105**, 187401 (2010)

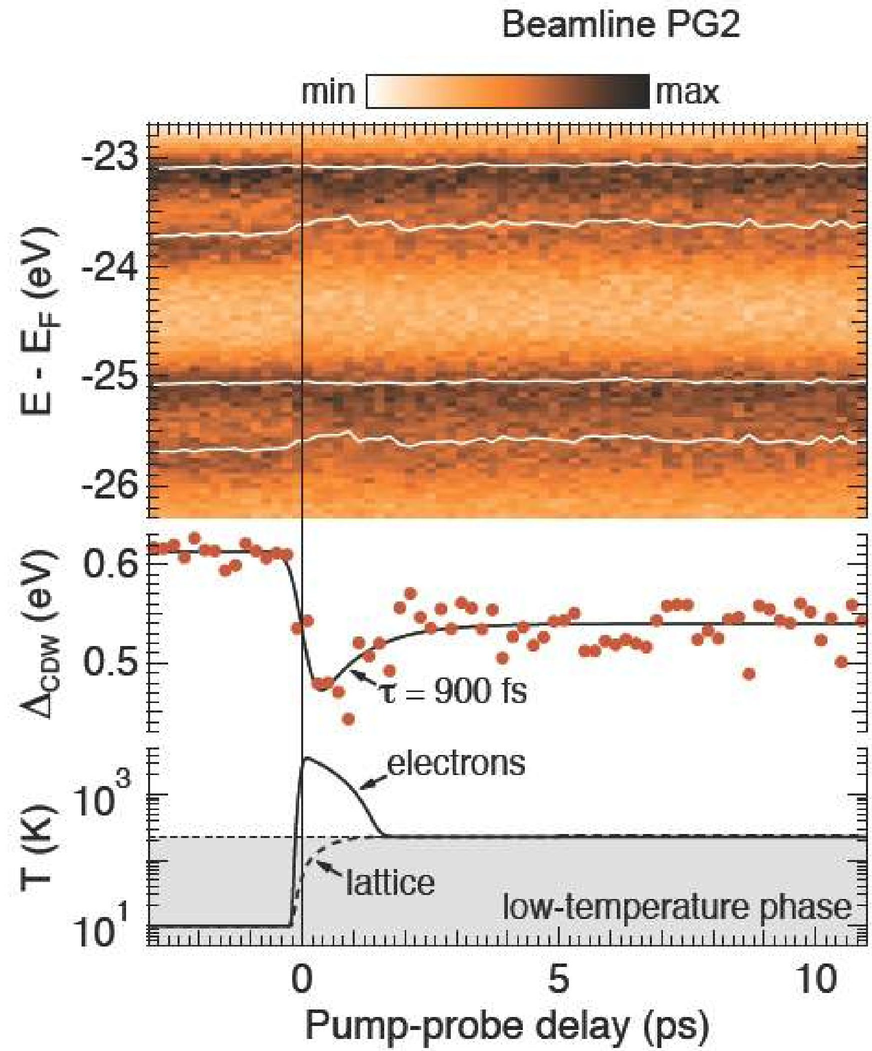
$$T = 10\ \mathrm{K}$$

$$h\nu_{pump} = 1.55\ \mathrm{eV}.\ \ h\nu_{probe} = 156\ \mathrm{eV}$$

$$\Delta E \approx 300\ \mathrm{meV}.\ \ \Delta t \approx 700\ \mathrm{fs}$$

$$F = 1.8\ \mathrm{mJ/cm^2}$$



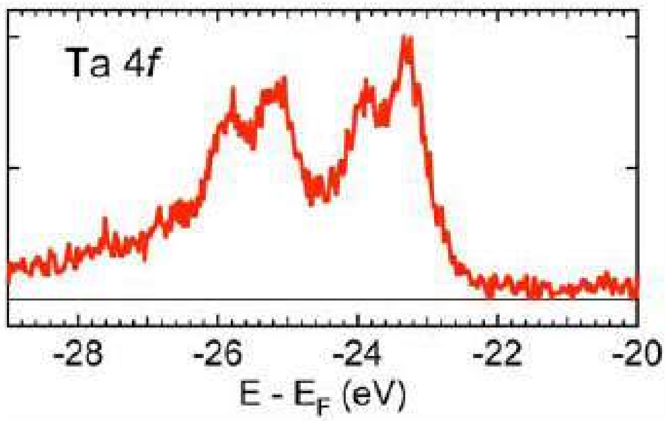


What is feasible at FLASH (L. Kipp)

- Energy resolution: **<100 meV**
- Time resolution: **<500 fs**
- Time per spectrum: **<10 min**

XPS

1*T*-TaS_2, $\hbar\omega$ = 115.5 eV (3rd harm.)

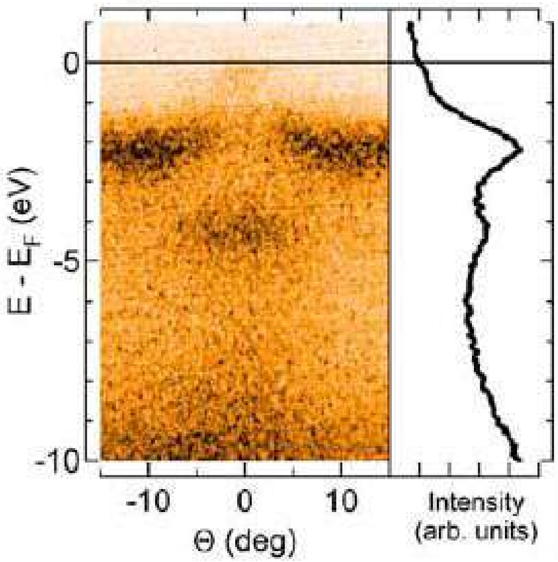


≈9 min

56347 pulses, 100 pulses/s (5 Hz)

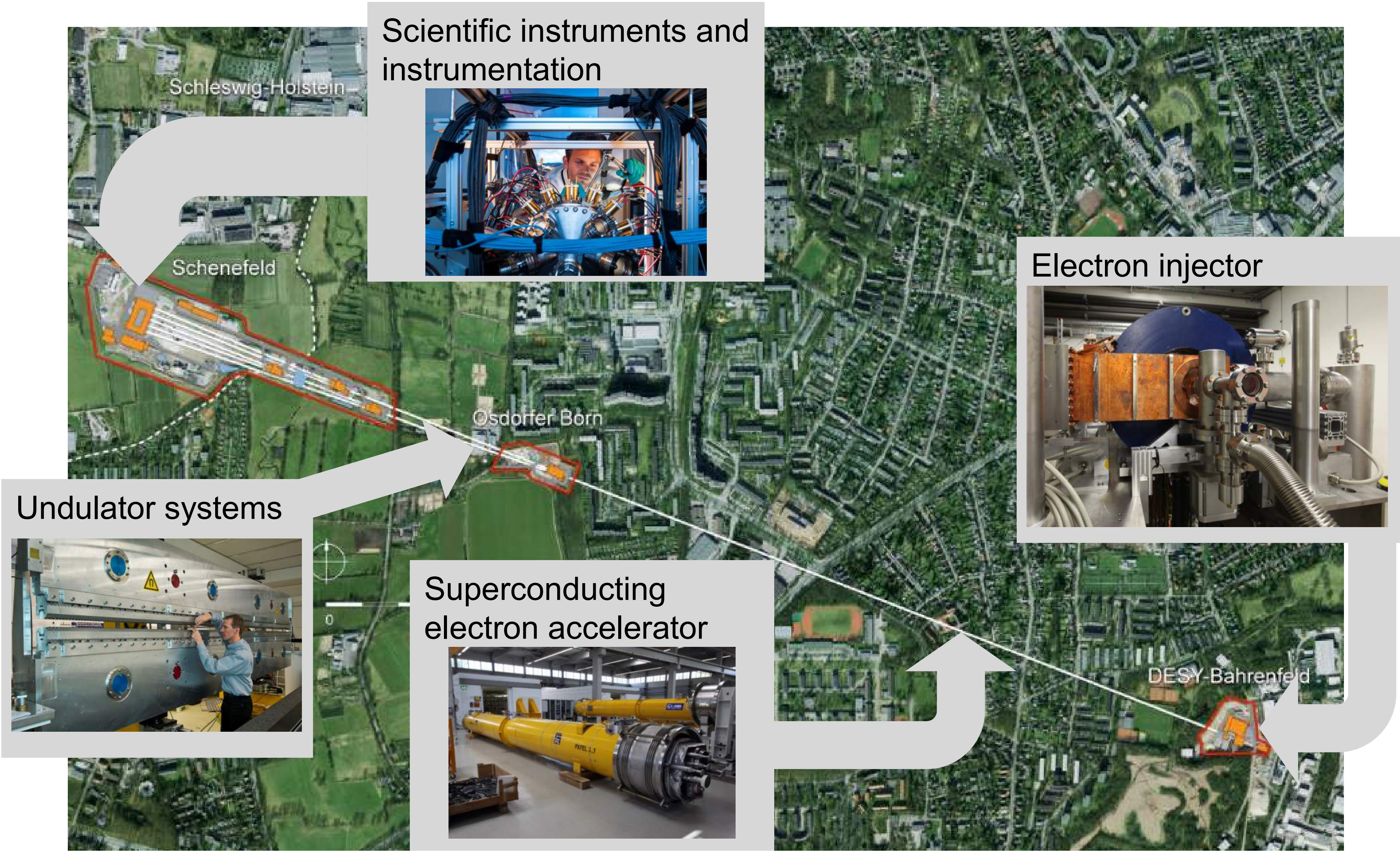
ARPES

1*T*-$TiTe_2$, $\hbar\omega$ = 38.3 eV (1st harm.)

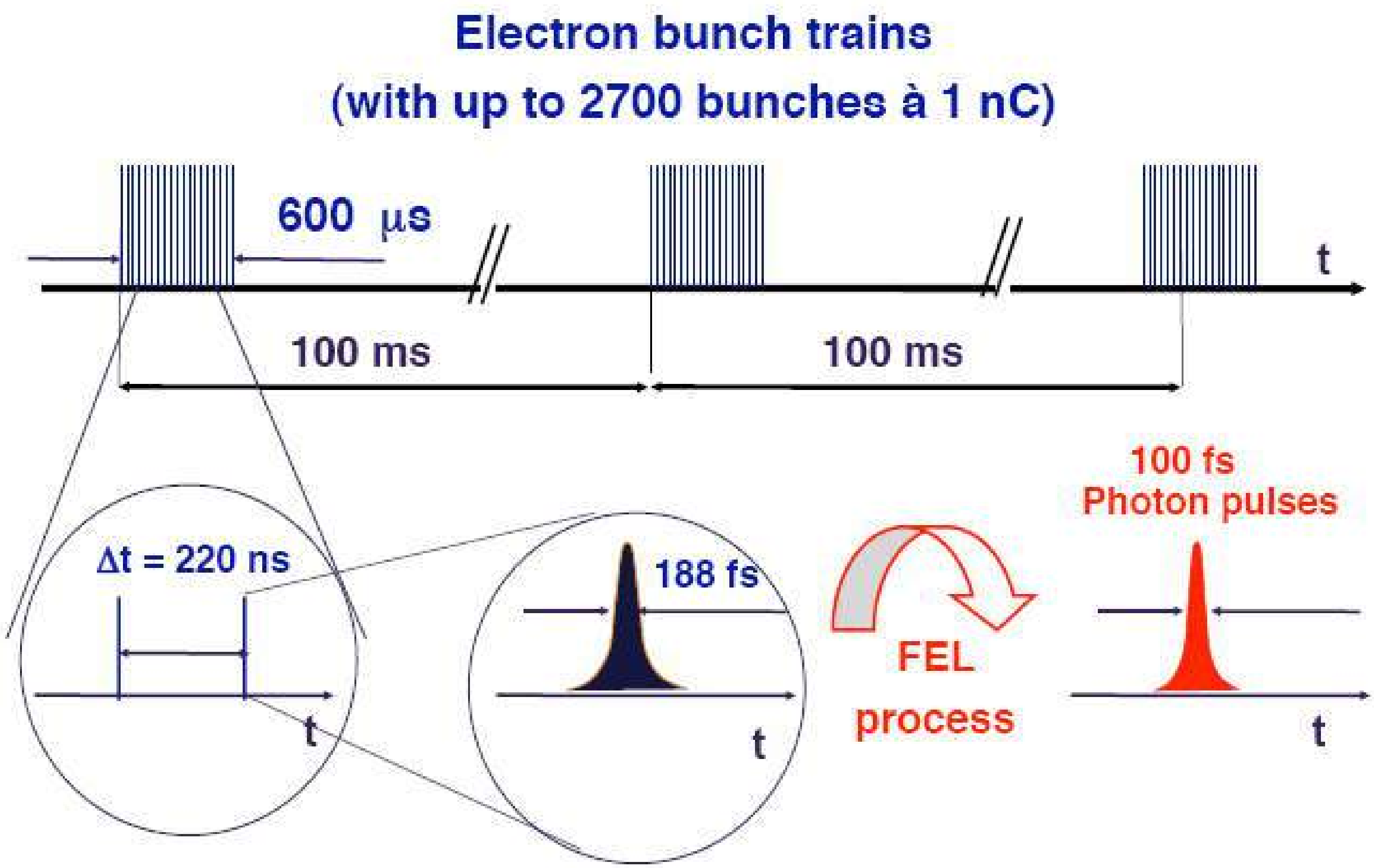


≈9 min
21440 pulses
40 pulses/s
(2 Hz)

How it works – a closer look at the facility

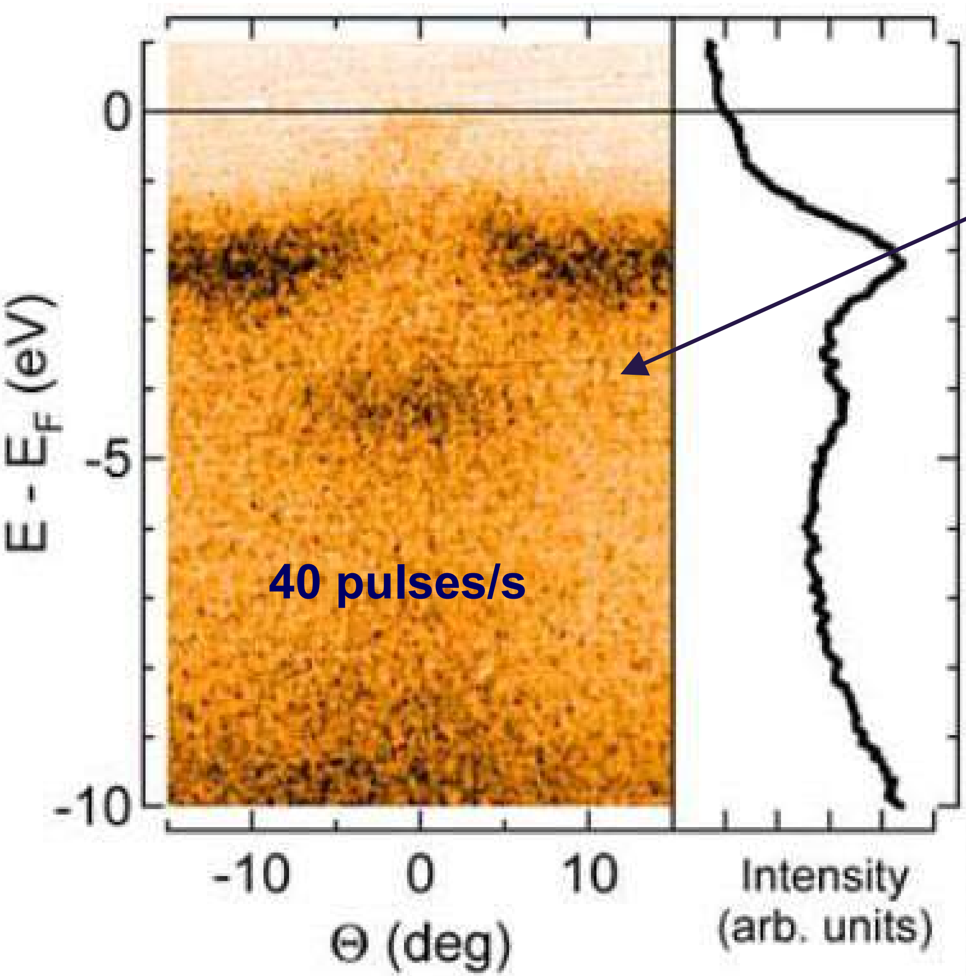


Time structure



Superconducting LINAC technology provides 27.000 light pulses/s in burst-like structure. It makes XFEL.EU attractive for photon-hungry experiments.

ARPES at European XFEL

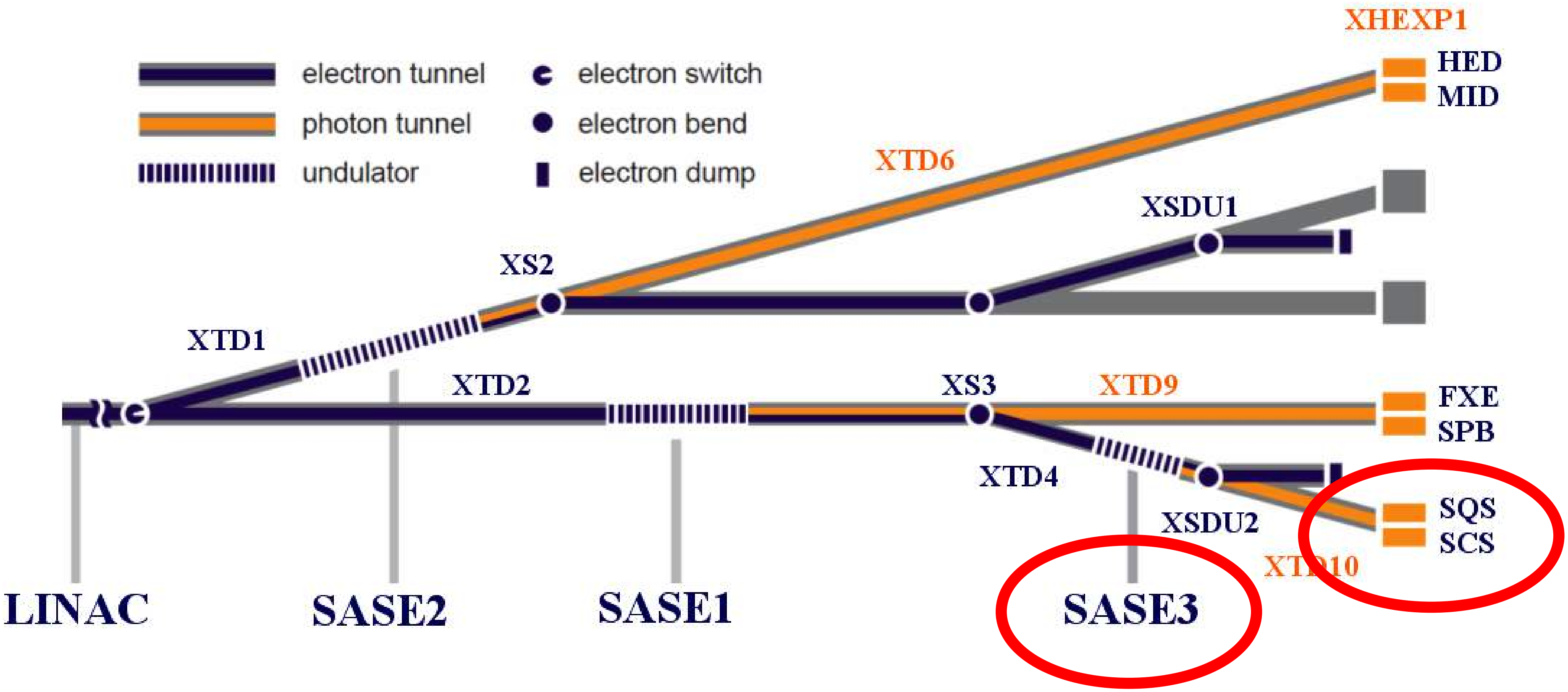


What you get at non-superconducting XFEL facilities (60 - 100 Hz rep. rate)

Due to unique rep. rate photoemission response at the European XFEL is about 10^3 higher (statistics)
→ strong case for ARPES:

- **two-color exp. (unfilled states)**
- **pump-probe (electron dynamics)**

Photon beam transport systems, soft X-rays



SCS: Spectroscopy & Coherent Scattering

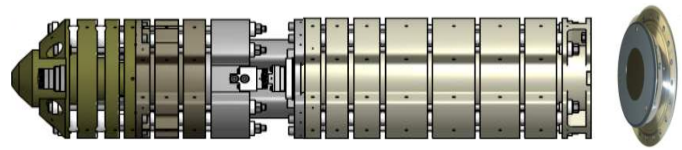
Users Consortium

-

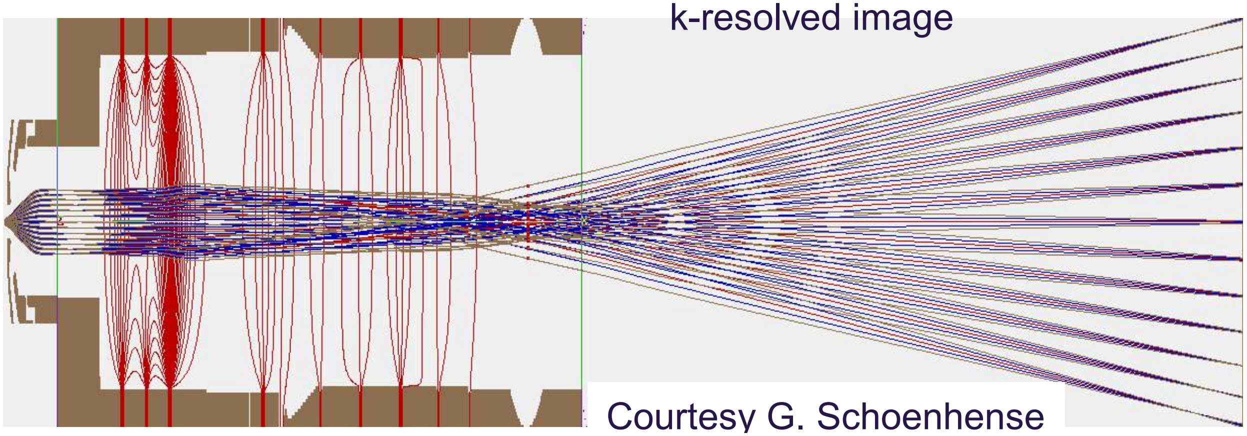
tr-XPS and tr-ARPES

Choice of spectrometers

1000eV Start energy

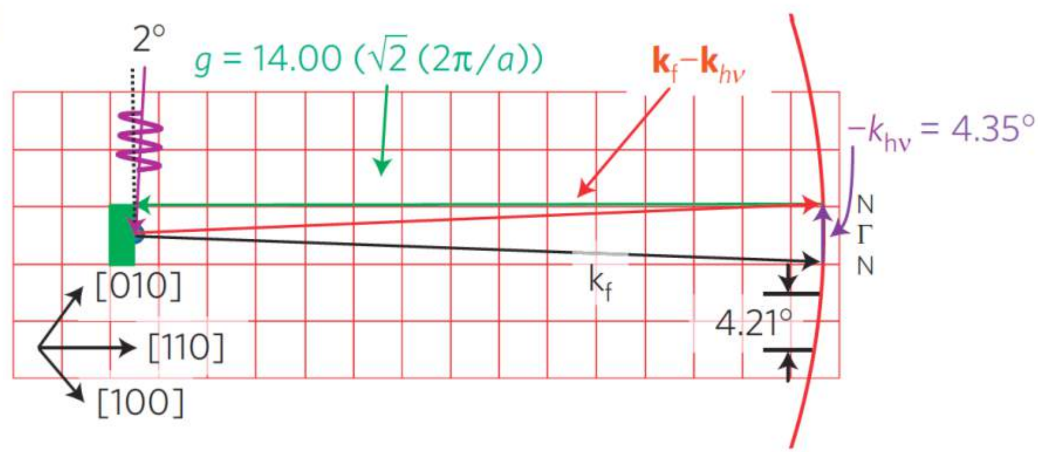


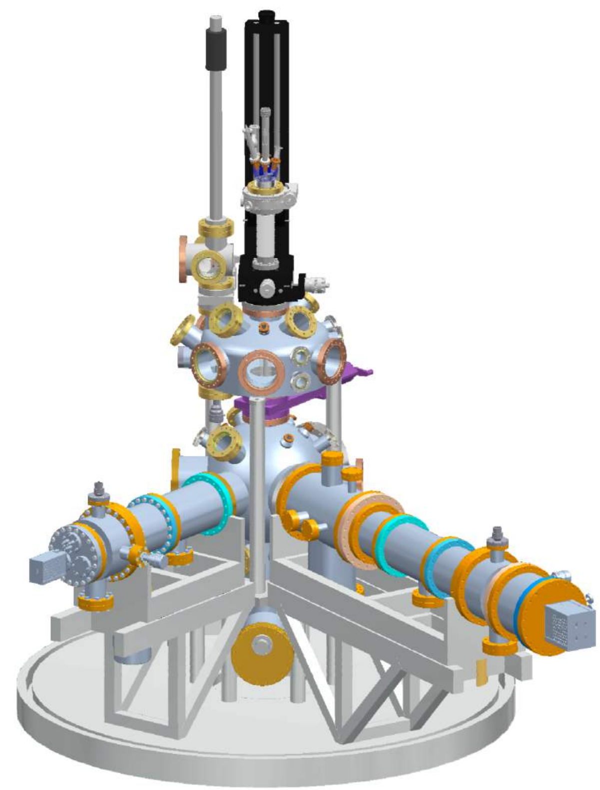
k-resolved image



Courtesy G. Schoenhense

High angular resolution required for HARPES

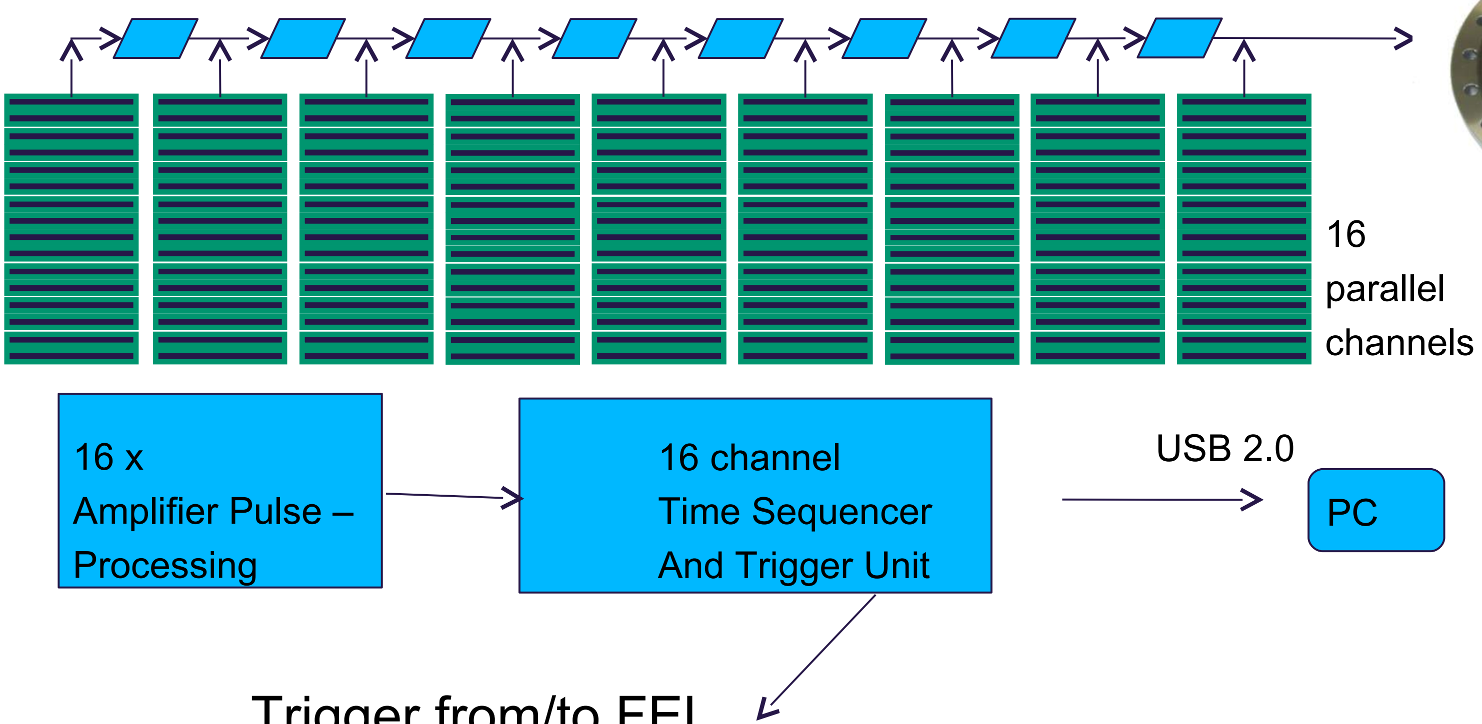




Gray, Ueda, Fadley et al, Nature Materials 10, 3089, (2011)

„Cluster DLD“: Capability for multiple event detection

16 x 8 delays of 12 ns integrated into detector anode in vacuum

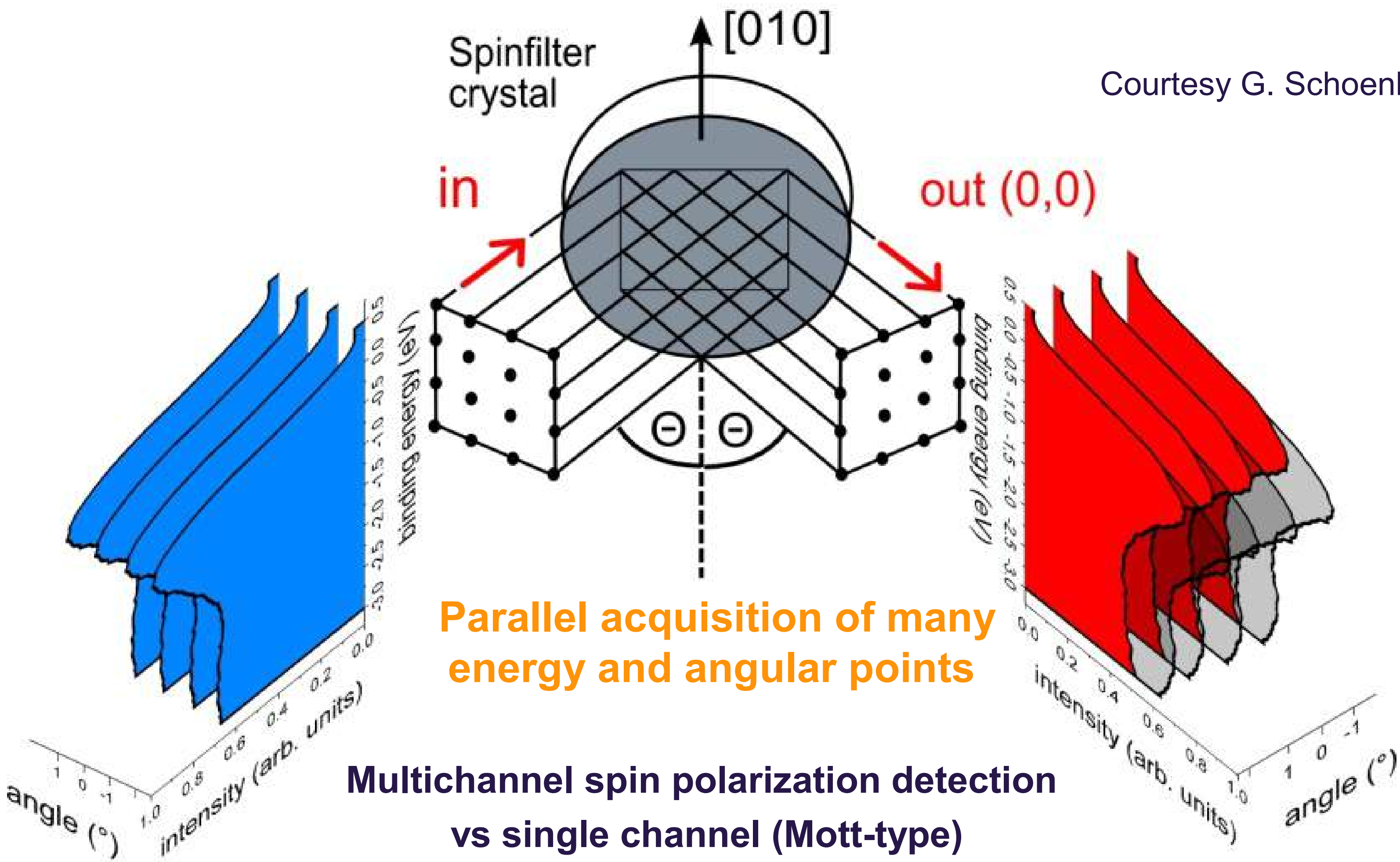


256 (may be 512) channel DLD in development (BMBF project with CFEL/UHH)

SURFACE CONCEPT

Spin detection

Courtesy G. Schoenhense



Parallel acquisition of many energy and angular points

Multichannel spin polarization detection vs single channel (Mott-type)

„Established“ for hemispherical analyzers – concepts for TOF spectrometers

Hamburg, 30.06.2010:
Christening of the boring machines and tunnels

100% of tunnels are excavated

Completion of underground construction (06.06.13)

Tunnels: Infrastructure installation

European XFEL, Campus

Experimental hall

Main building: Architect's view

Main building: Architect's view

Users' meeting 2014

Together with DESY Photon Sciences Users' Meeting:

822 registered participants, of which:

- 388 from Hamburg (DESY, XFEL.EU, University, CFEL,..)
- 434 from elsewhere than Hamburg

You are very welcome

to plan your experiments

at European XFEL