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High-Resolution Photoelectron Spectroscopy

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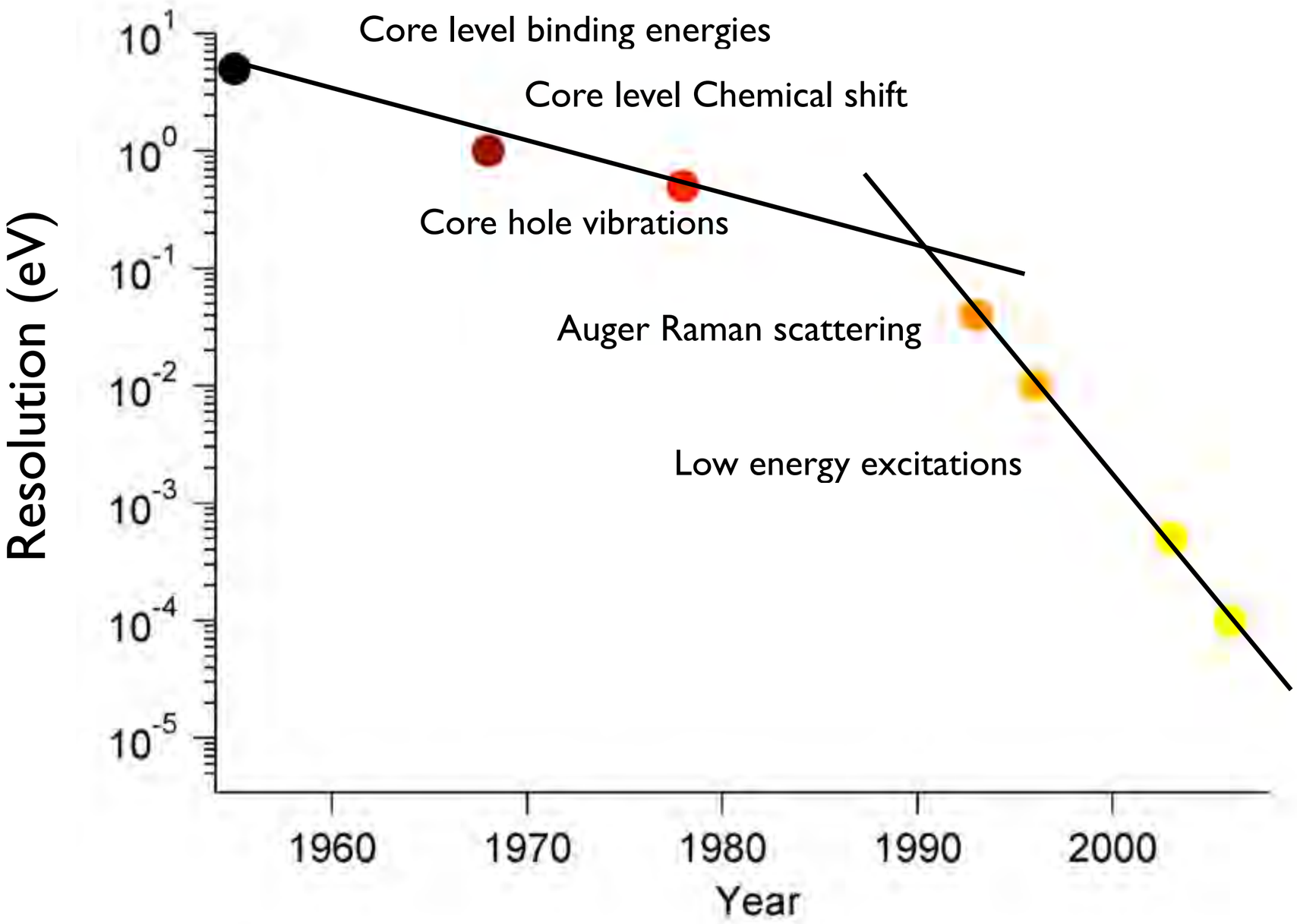
High-resolution photoelectron spectroscopy

How is high resolution defined ?



Hemispherical electron spectrometer

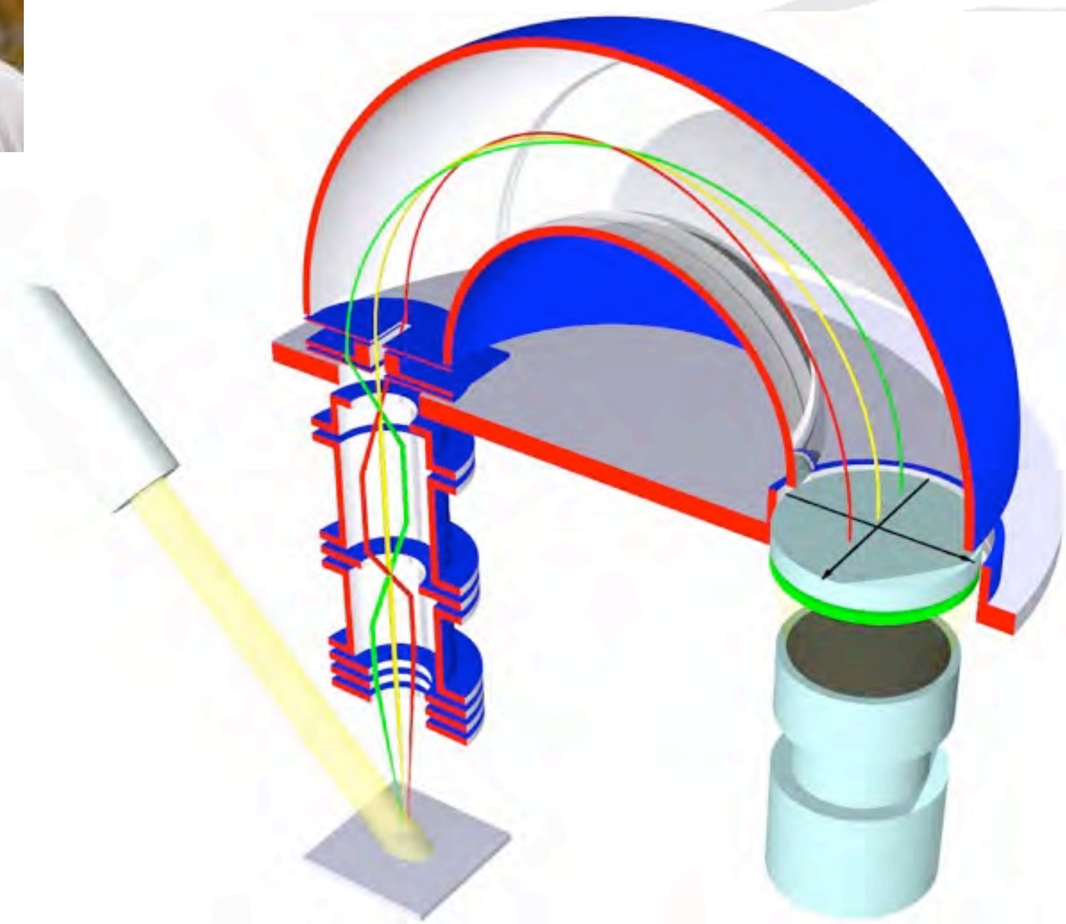
The Scienta SES spectrometers

Björn Wannberg

2008 APS Joseph F. Keithley Award for Advances in Measurement Science

A very high resolution electron spectrometer

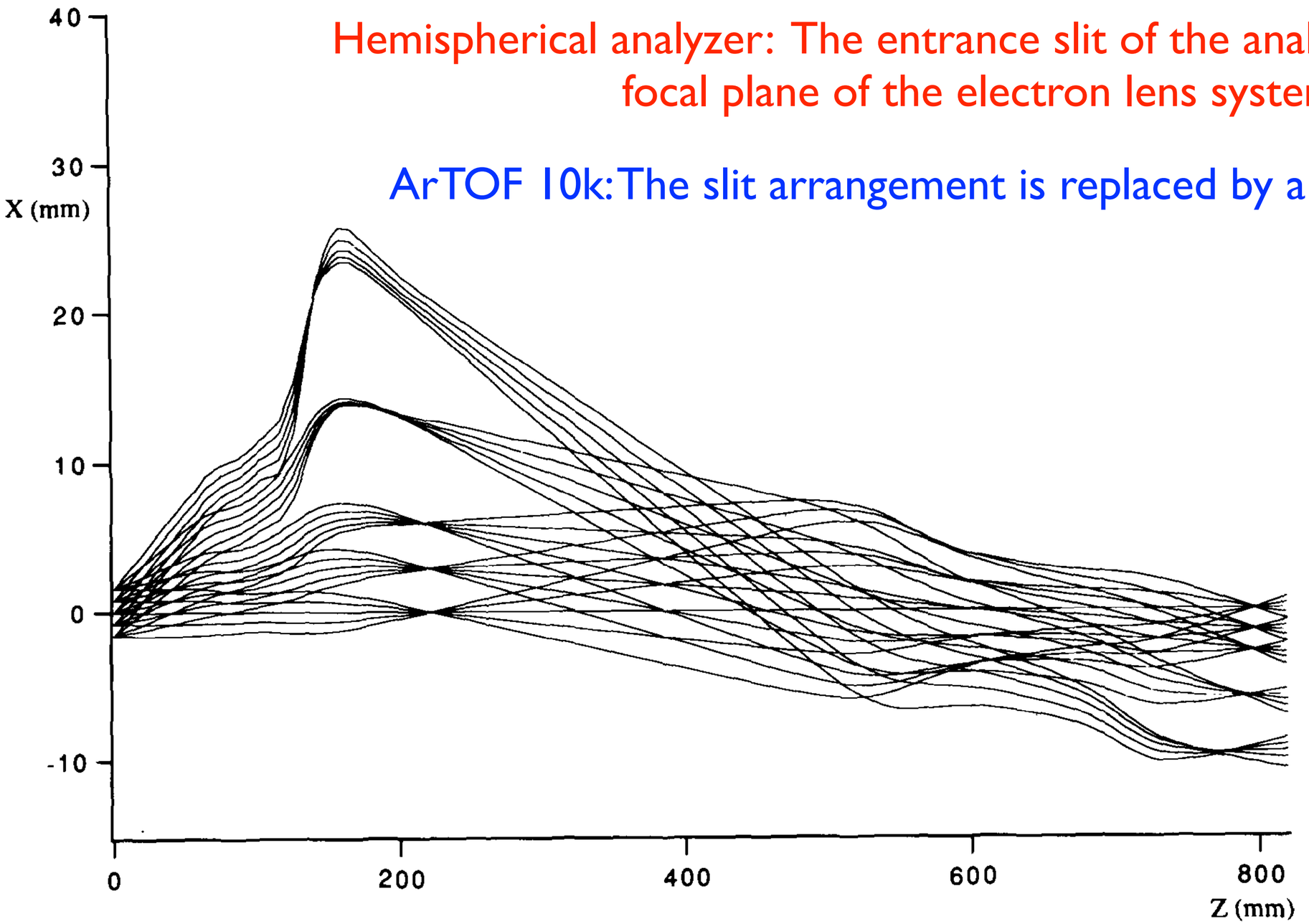
N. Mårtensson et al, J. Electron Spectosc. Relat. Phenom 70 (1994) 117

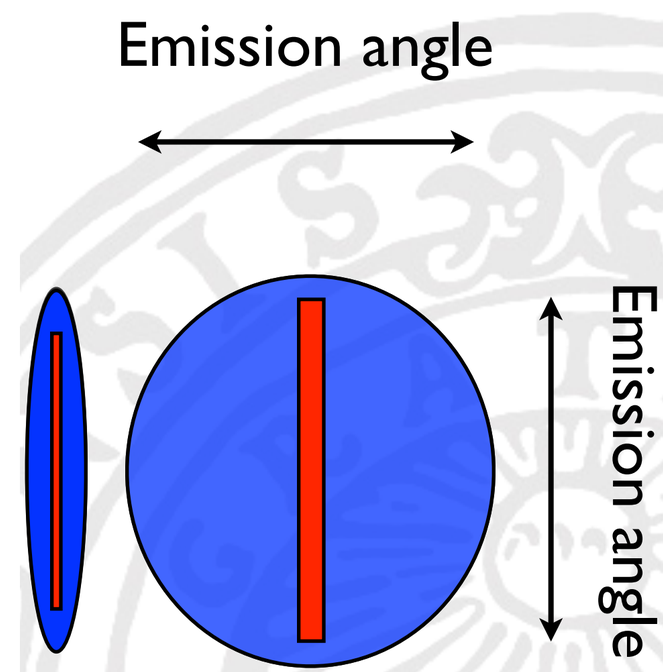


The electron lens - Angle resolved mode

Hemispherical analyzer: The entrance slit of the analyzer is put in the focal plane of the electron lens system

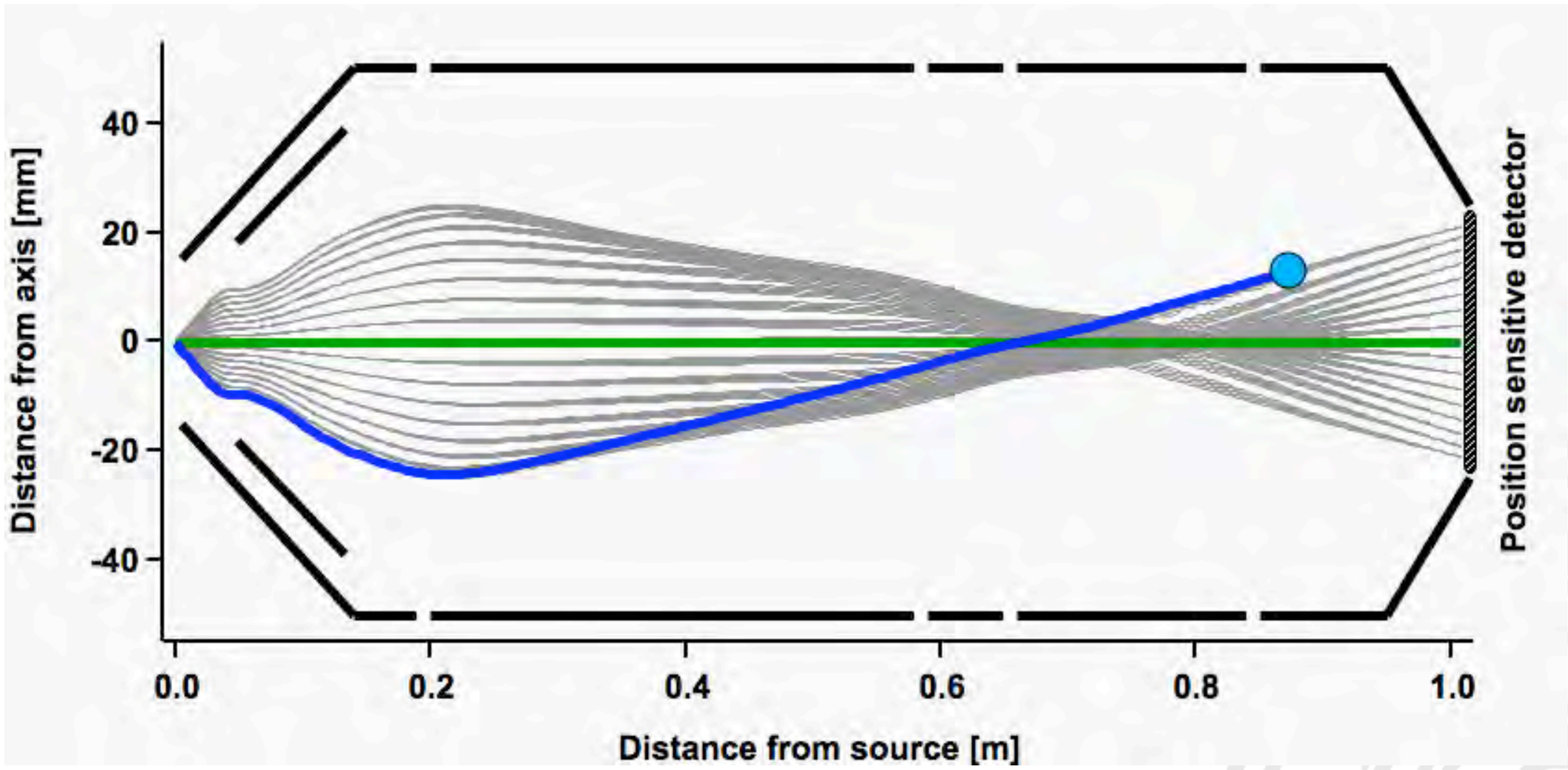
ArTOF 10k: The slit arrangement is replaced by a 2D detector





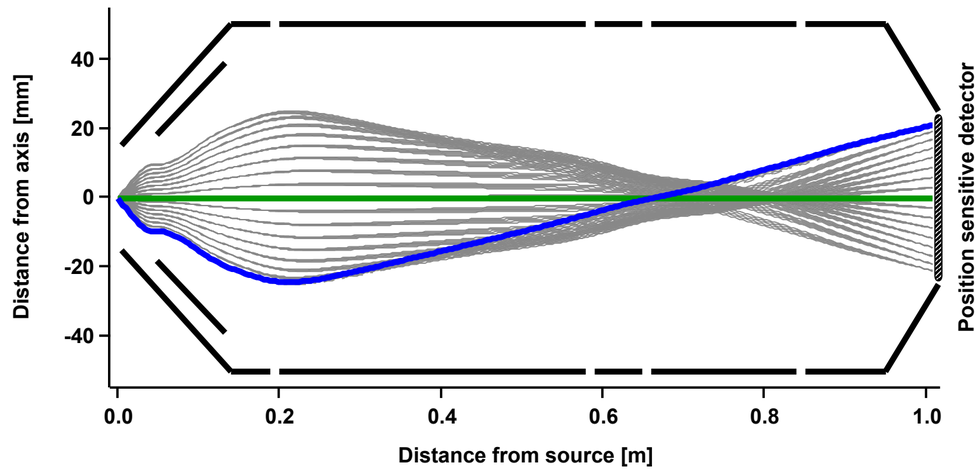
The energy has to be determined by time-of-flight

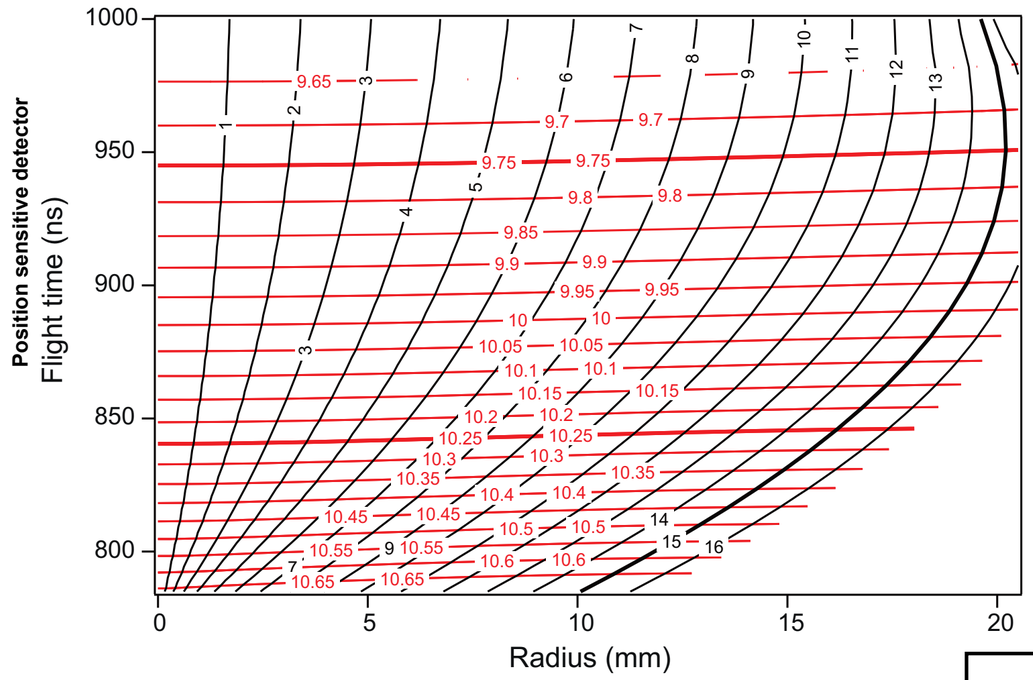
Principles of Angle-resolved Time Of Flight spectrometer (ArTOF)



Courtecy of R. Ovsyannikov

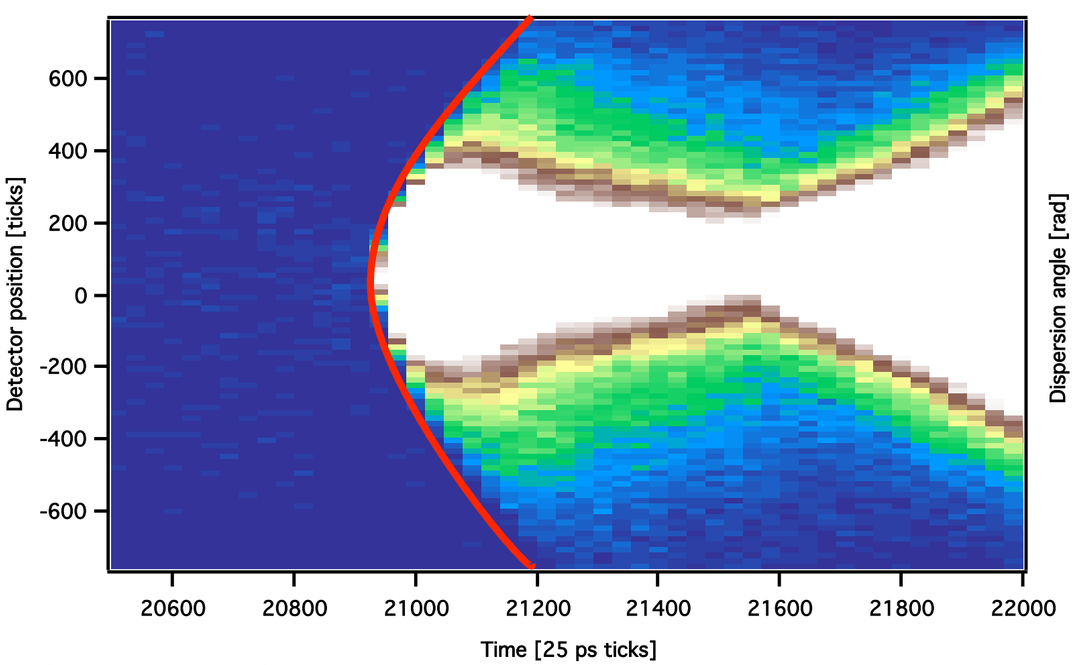
Principles of Angle-resolved Time Of Flight spectrometer (ArTOF)

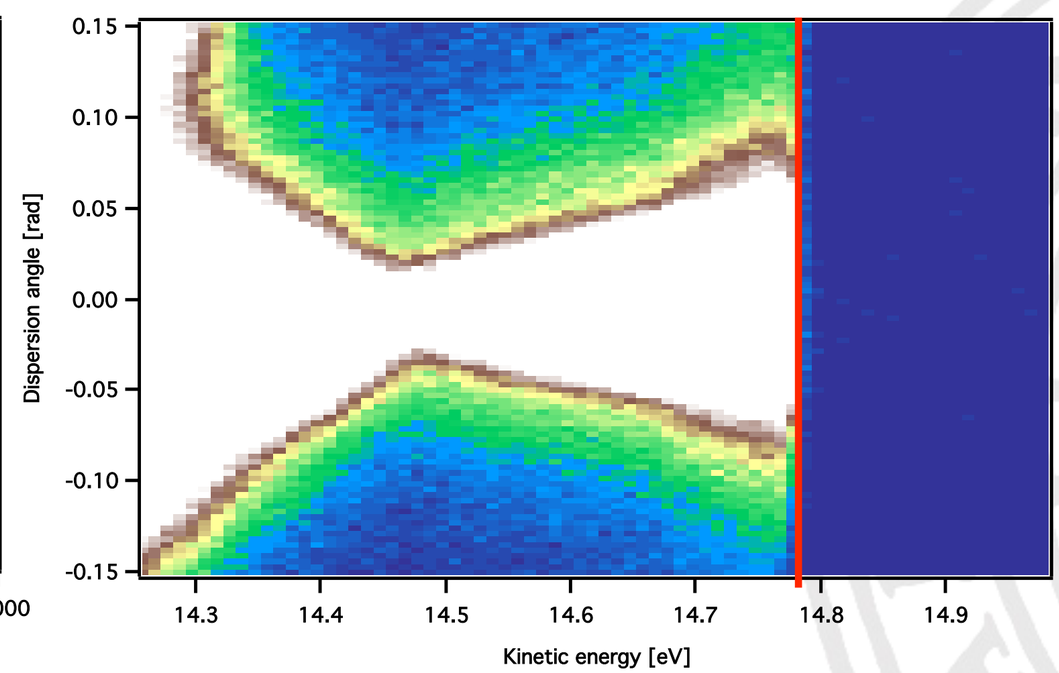




$$\begin{pmatrix} E_k \\ \Omega_1 \\ \Omega_2 \\ t_0 \end{pmatrix} = T \begin{pmatrix} t \\ x \\ y \\ t_0 \end{pmatrix}$$

1 TByte of data in 8 hours





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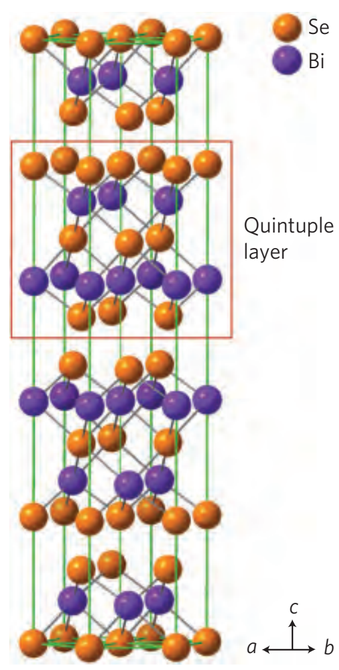
Angle-resolved photoemission
Probing the band structure

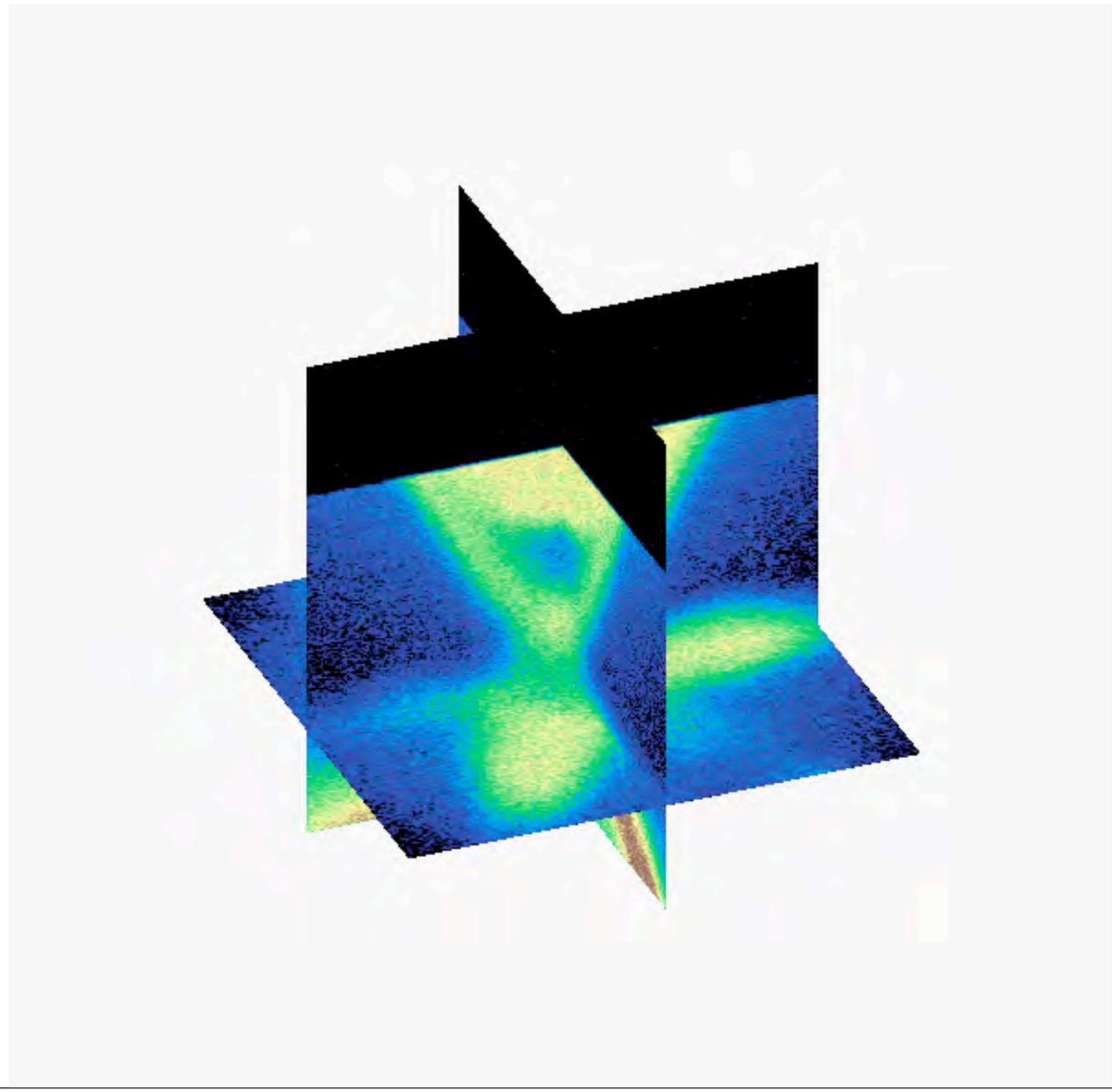
Bi_2Se_3 topological insulator: 3D band structure collected in 15 minutes

Fixed mode
No rotation of the sample



P.D.C. King et al., PRL 107, 096802 (2011)

Rapid recording of a complete data set



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Time resolved studies

High transmission
- All data stored as function of time (probe pulse)

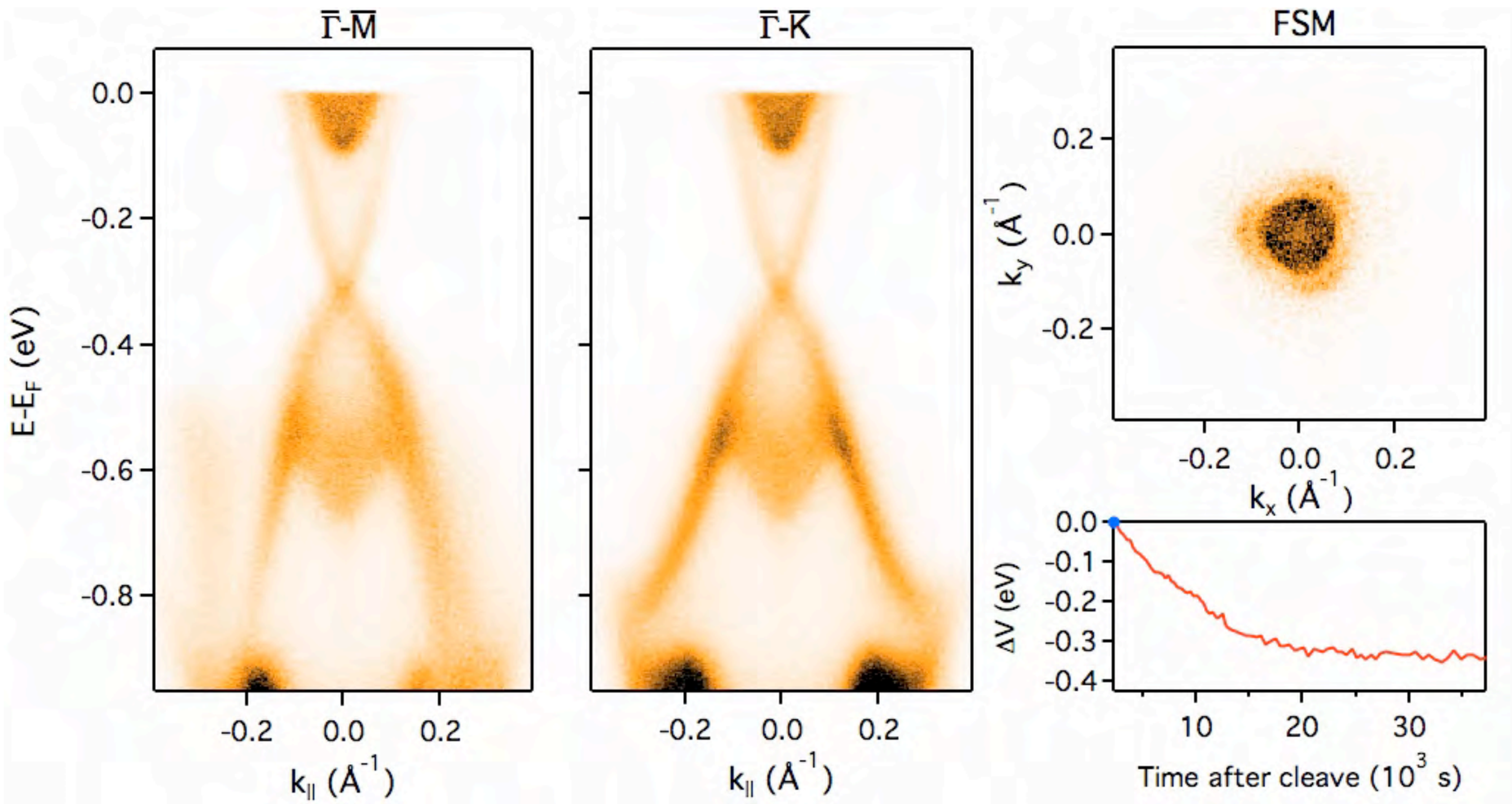
Broad range of time scales
- From s to fs

Slow processes
- Rapid measurements - Complete spectra in short time
- Chemical reactions
- Functionalization of surfaces

Rapid processes:
- Pump-probe measurements

Time evolution of the Bi_2Se_3 band structure

Effects of adsorption



P.D.C. King et al., PRL 107, 096802 (2011)

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Prospects for micro- and nano-focusing

A number of advantages of the ArTOF spectrometer

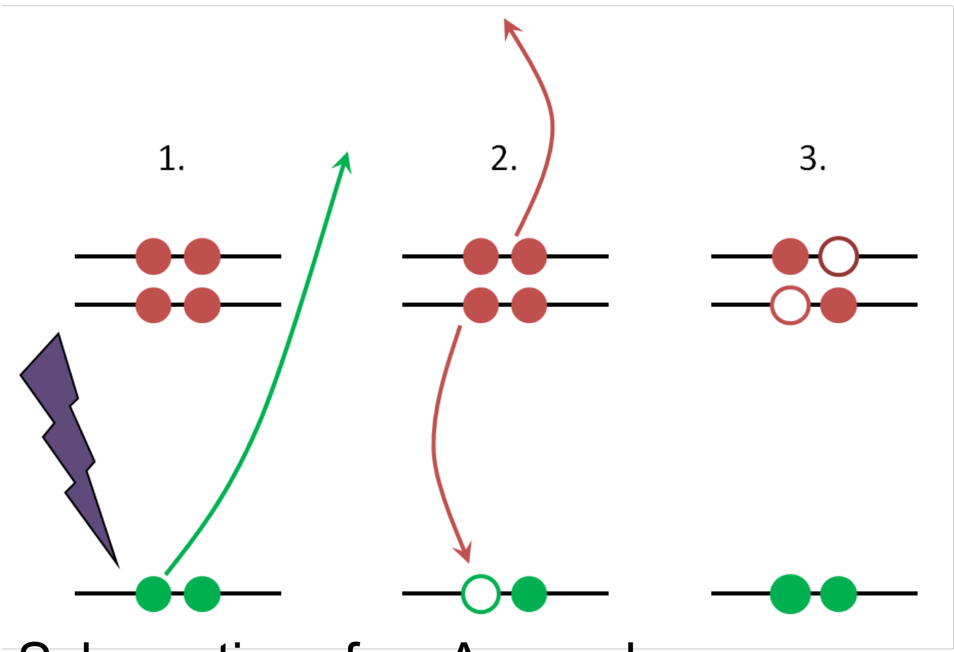
The ArTOF uses naturally a point focus

Angle resolved spectra can be obtained without moving the sample

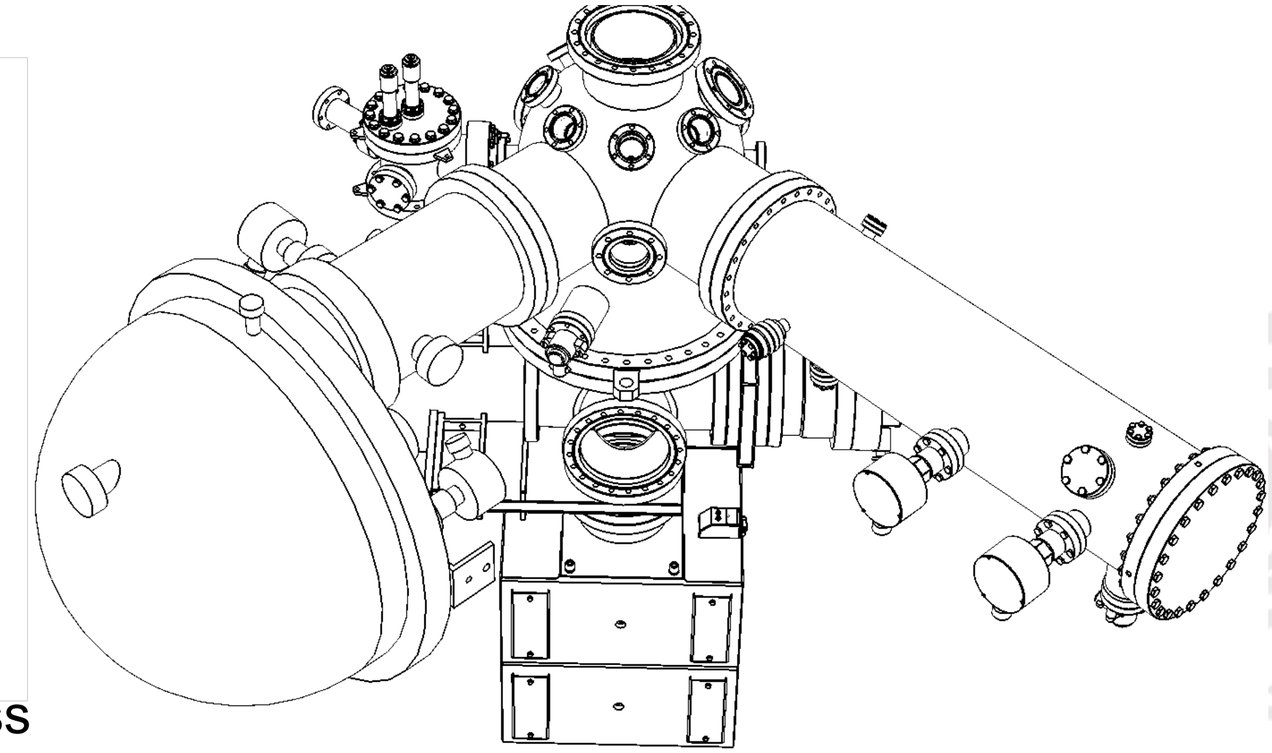
The large acceptance reduces space-charge effects
(Low-dose photoemission)

Coincidence spectroscopies

Photoelectron - Auger electron coincidences



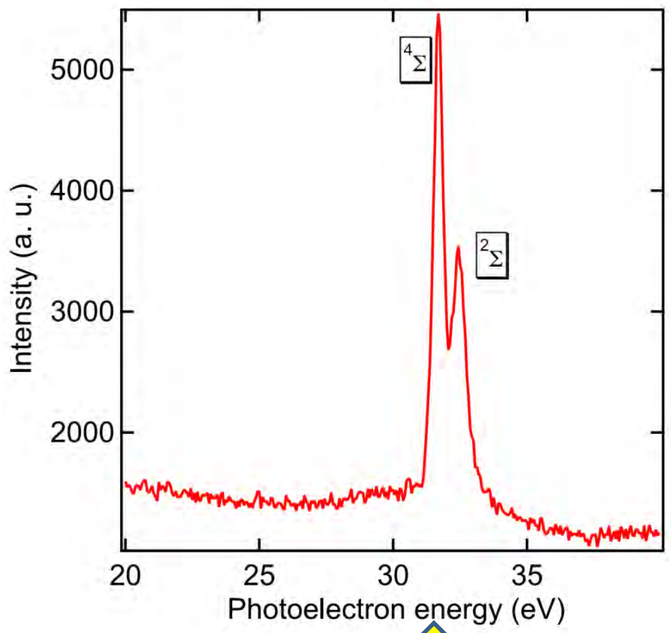
Schematics of an Auger decay process

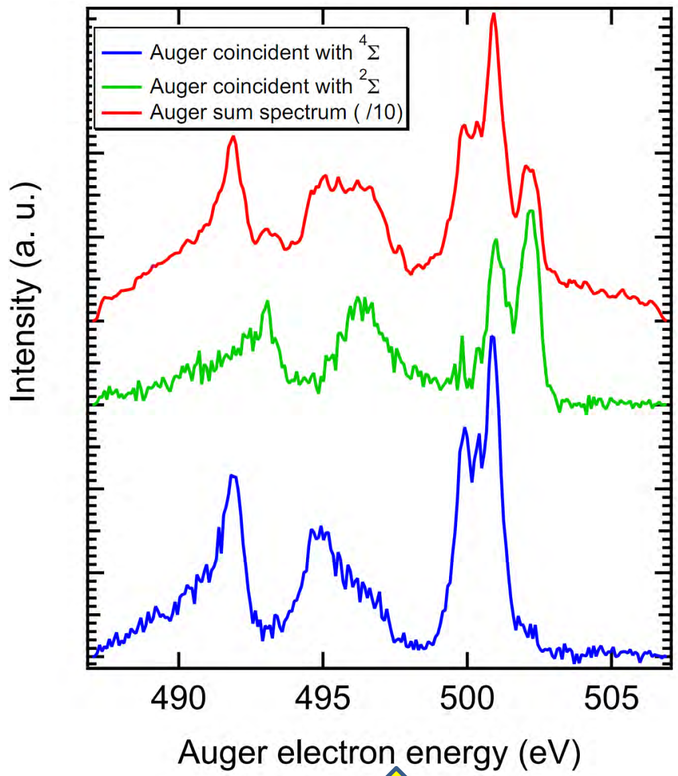


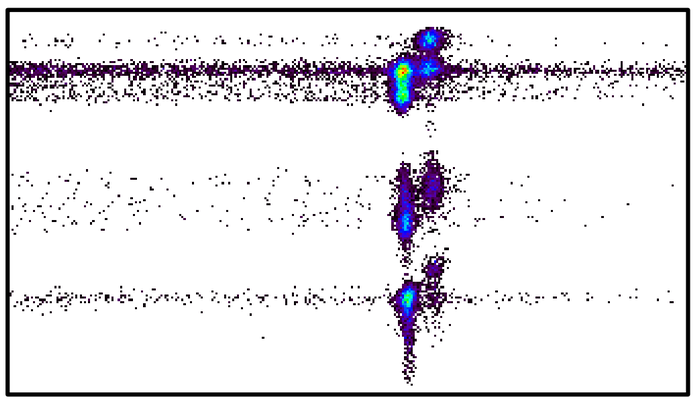
Provides information on the two-hole spectrum
Coincidense Auger spectra not broadened by the core-hole life-time

Gas phase measurements together with
Uwe Hergenhahn and Tiberiu Arion

Photoelectron - Auger electron coincidences





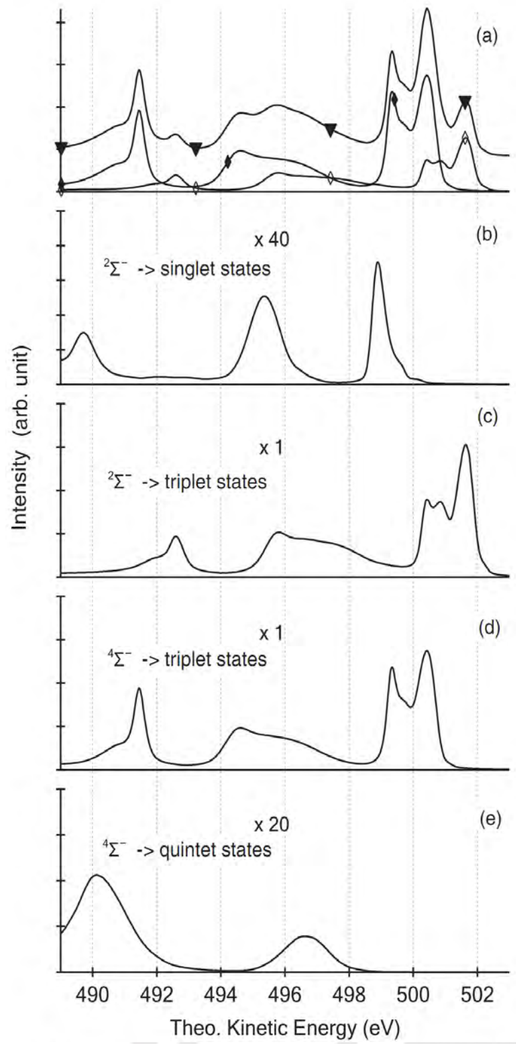


O_2 O 1s edge

$h\nu$=573.1 eV

U. Hergenhahn, T. Arion, et al.

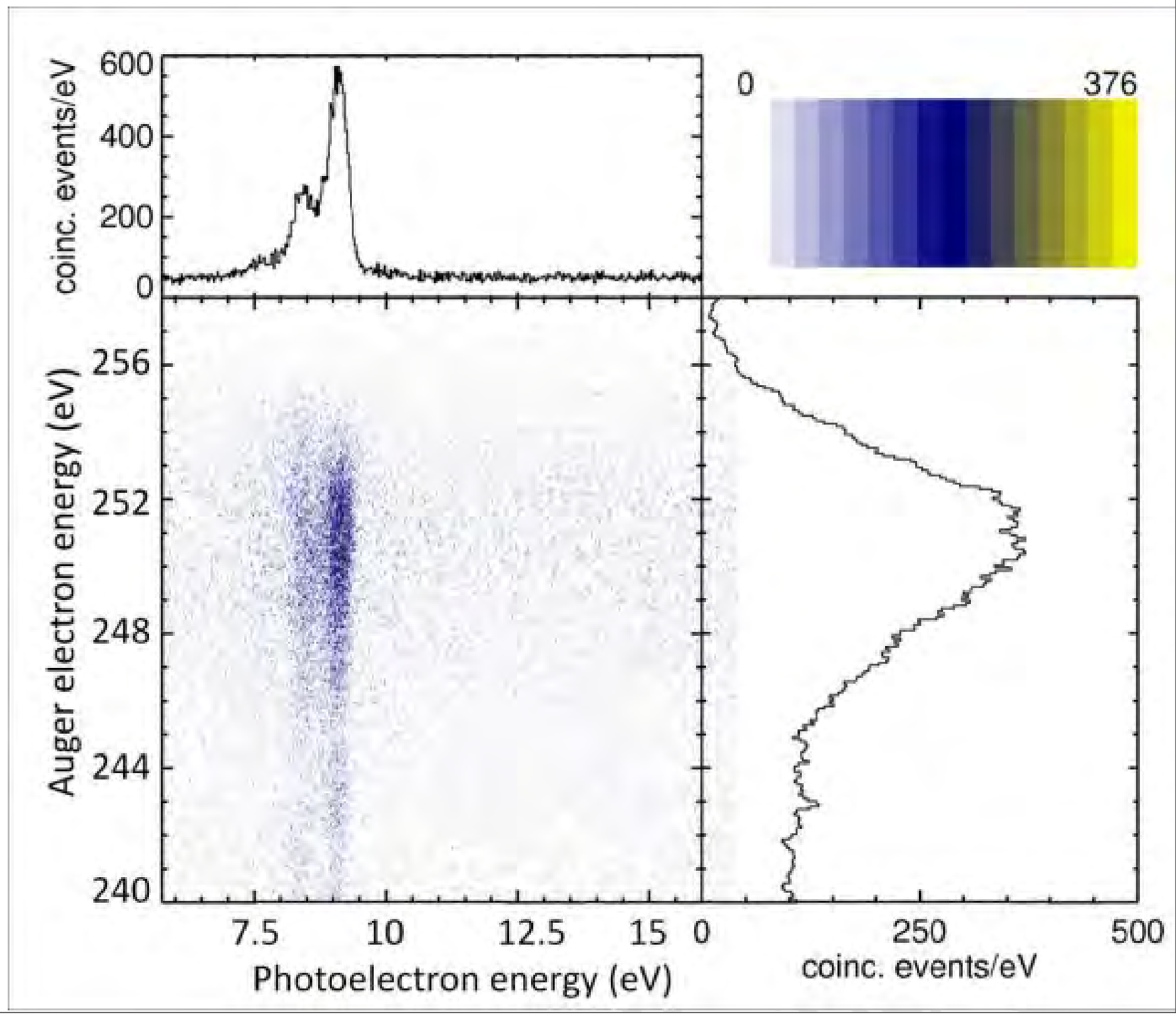
Theory



Z. Bao *et al.*, J. Phys. B: At. Mol. Opt. Phys. **41** (2008) 125101

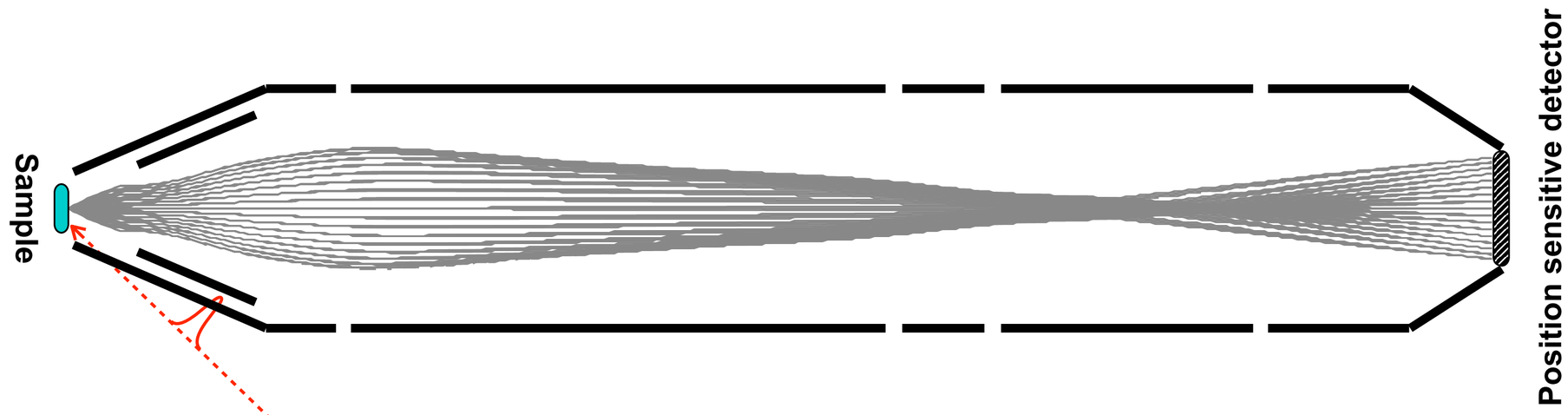
Vibrationally resolved coincidence spectra for CH_4

Coincidences between C1s core ionization and Auger electron emission



U. Hergenhahn, T. Arion, et al.

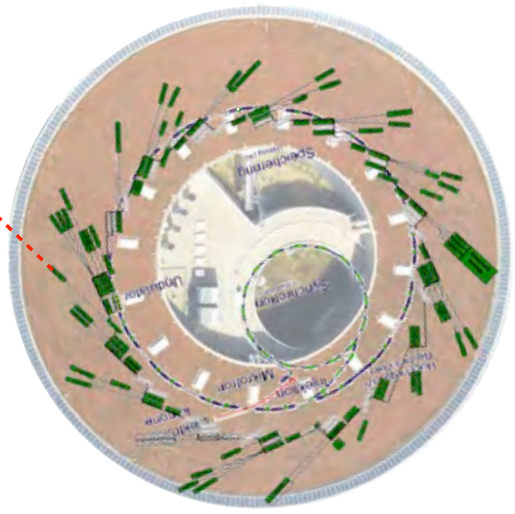
Requirement of single bunch operation



800

Single Bunch Operation

Photon pulse every 800 ns



Pulse duration ≤ 50 ps

BESSY II is today the ideal source for this research

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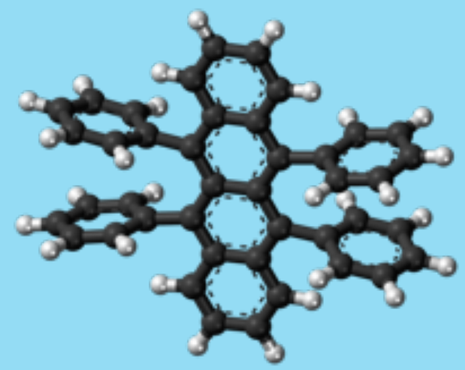
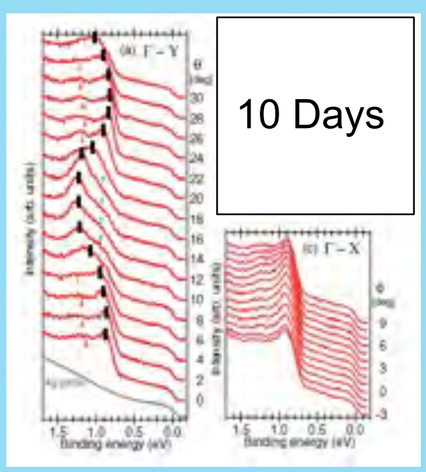
Low-dose photoemission

Organic single crystals: Rubrene

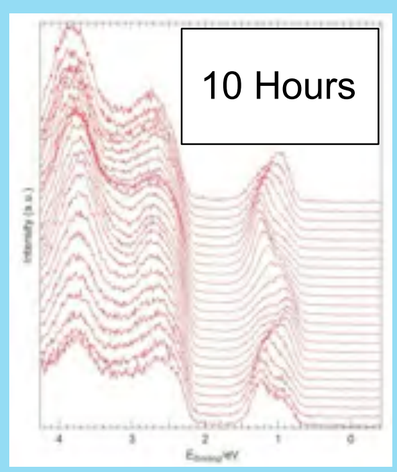
- hole mobility of over 15 cm^2/Vs at room temperature
- better than that of micro-crystalline Si-based transistors
- but: charge transport mechanisms in single crystalline organic semiconductors is still incomprehensive.
- but: highly sensitive to beam damage, exposure to x-rays has to be extremely small



A. Vollmer et al. in press



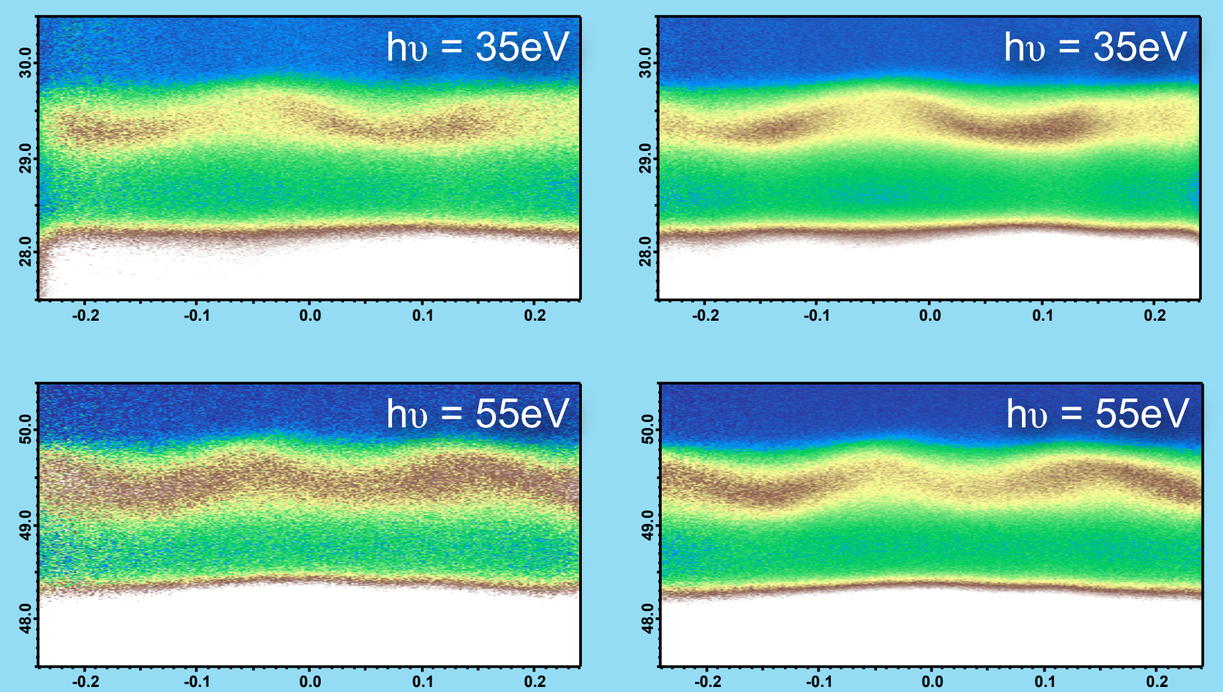
first report of angle–resolved photoemission spectroscopy to determine a full band structure of an organic single crystal in 2010 by Machida et al.



Our first measurement with ARTOF 10k analyzer. Flux during the experiment was less then 10^7 photons per second

Measurement time 20 minutes

Measurement time 2 hours



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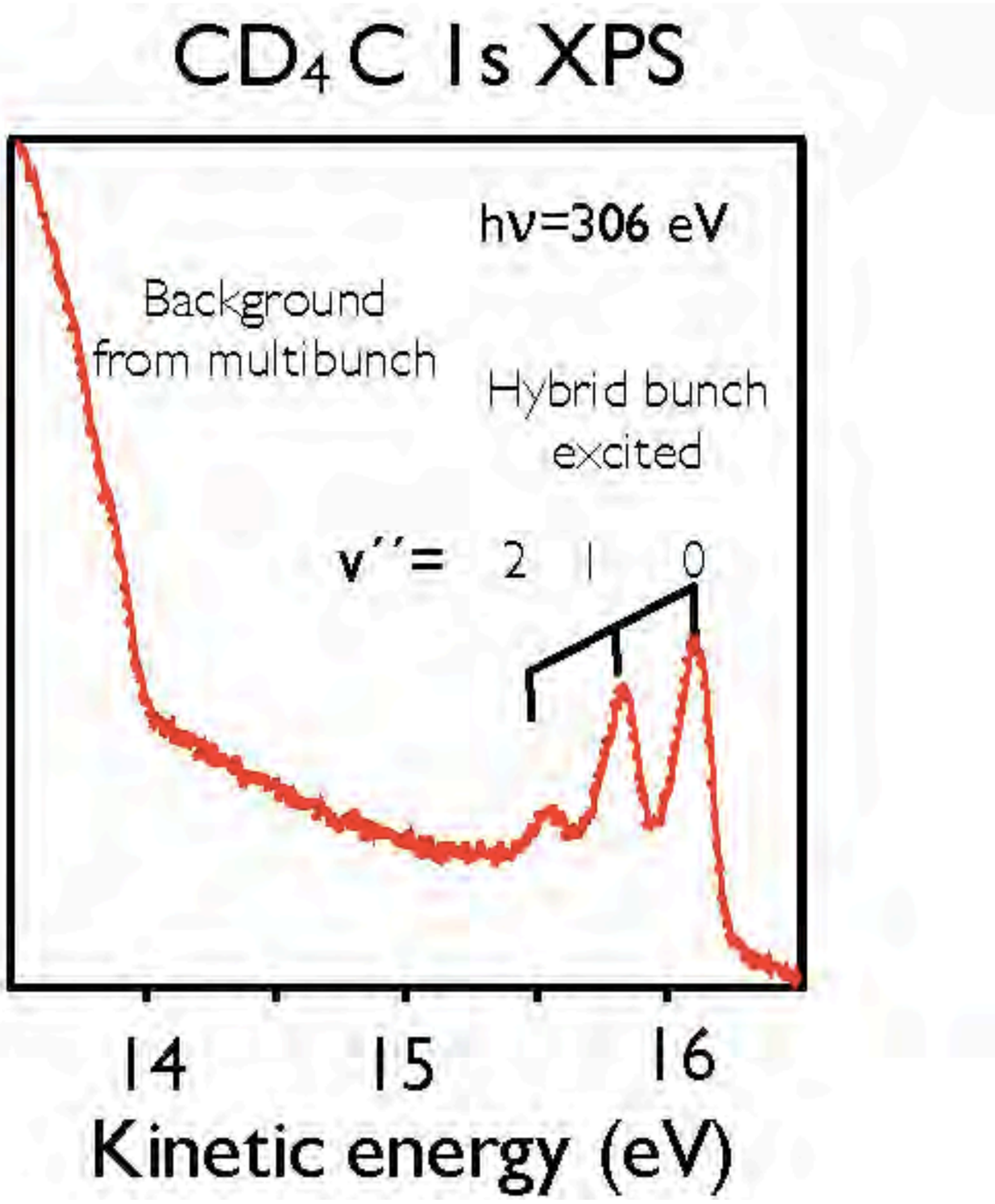
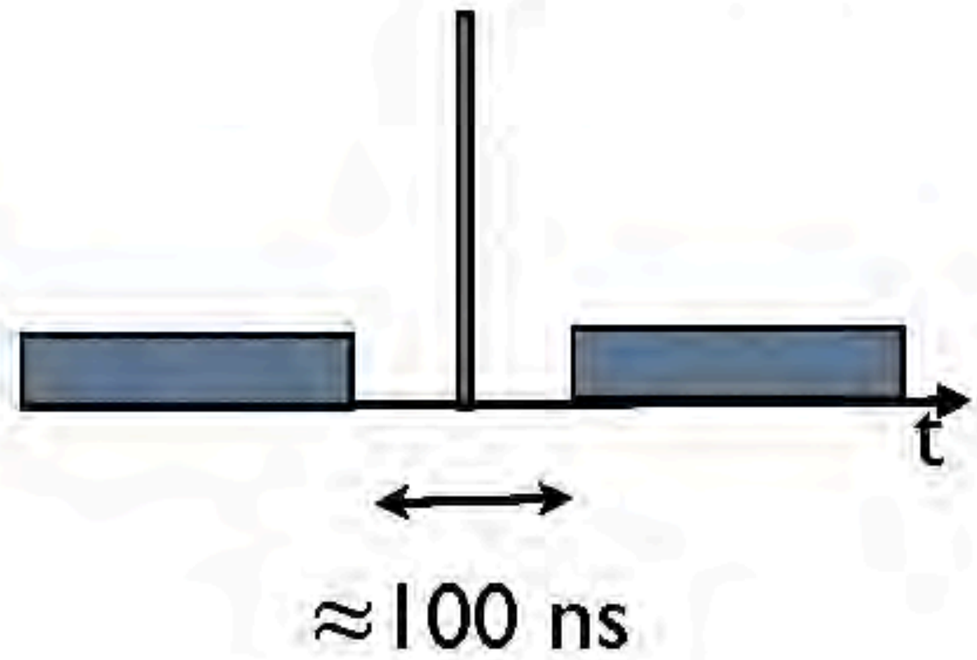
Hybrid mode

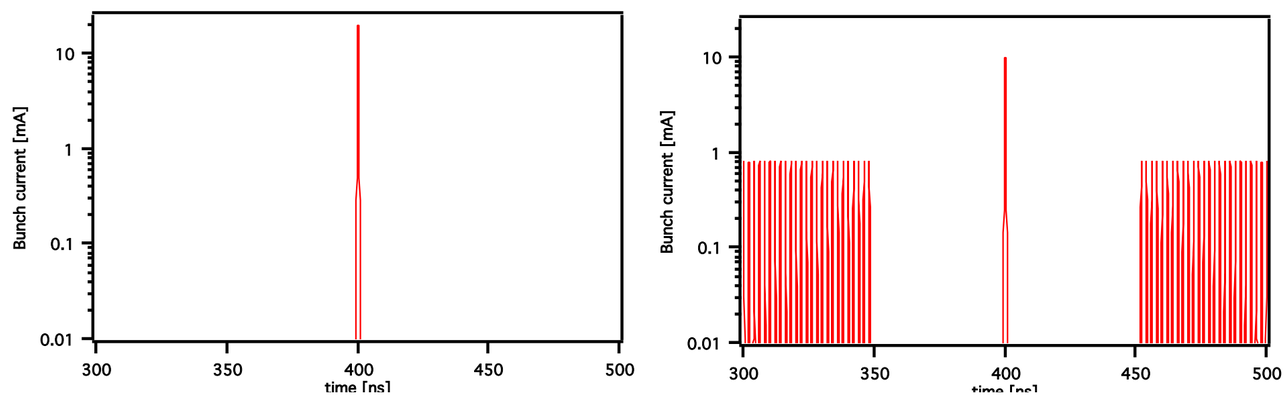


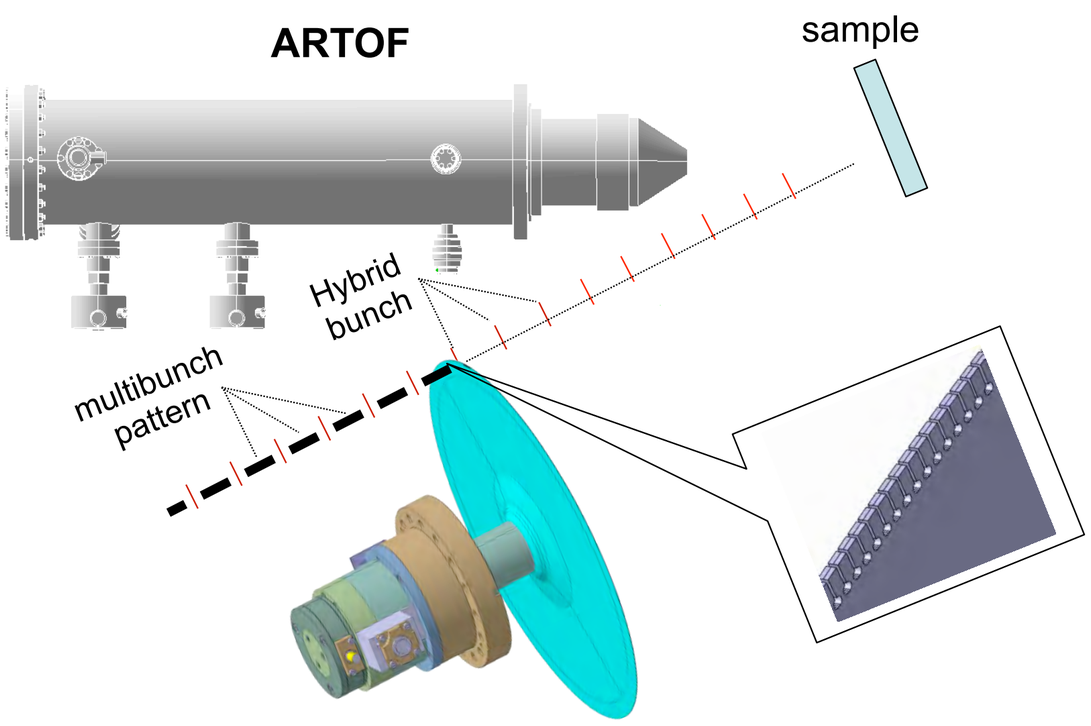
Hybrid filling mode of ring



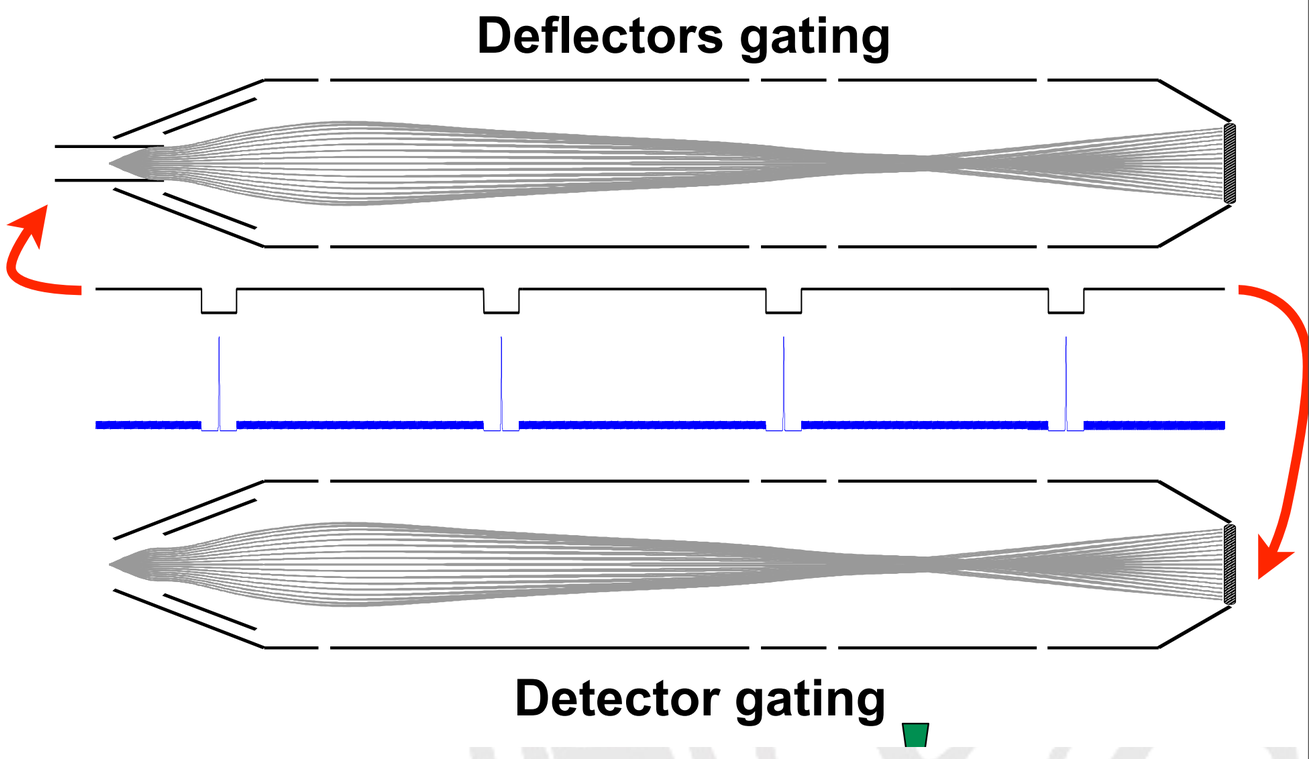
Next goal - Time-of-flight spectroscopy using the hybrid mode

There are only two weeks in each semester when BESSY operates in single bunch mode. We are working now on the possibility of using the hybrid mode, which is the standard operation mode of BESSY II





MHz Light Chopper



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Acknowledgements (incomplete list)

Uppsala University
Svante Svensson

VG Scienta, Uppsala
Patrik Karlsson
Mikael Wirde
Måns Lundqvist

Helmholtz-Zentrum Berlin
Ruslan Ovsyannikov
Mihaela Gorgoi
Antje Vollmer
Cosmin Lupulescu
Wolfgang Eberhardt
Alexander Föhlisch

Humboldt University Berlin
Stefan Krause
Norbert Koch