

Neubau Institut für Physik und Neubau Forschungsgebäude Leben, Licht und Materie





25.11.2011

lecture 25.11.2011

we had so far:

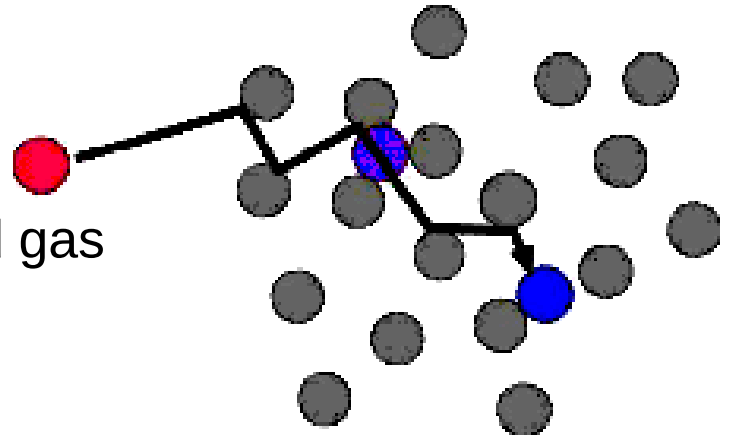
- continuation with trapping and cooling of ions
- ion crystals
- Fourier transform ion spectrometer

now:

- photoionization
- detection of correlated processes

buffer gas cooling:

- collisions with a cold gas
- final temperature is temp. of the cold gas
- good for all particles

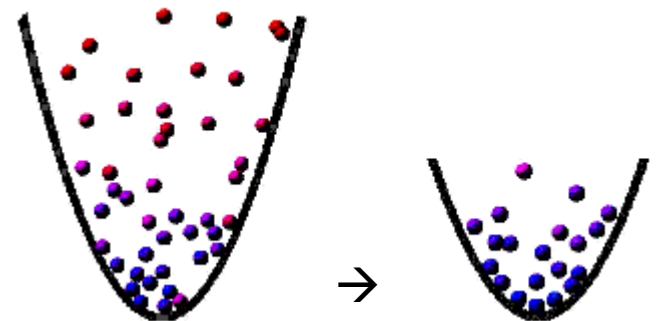


electron collisions cooling:

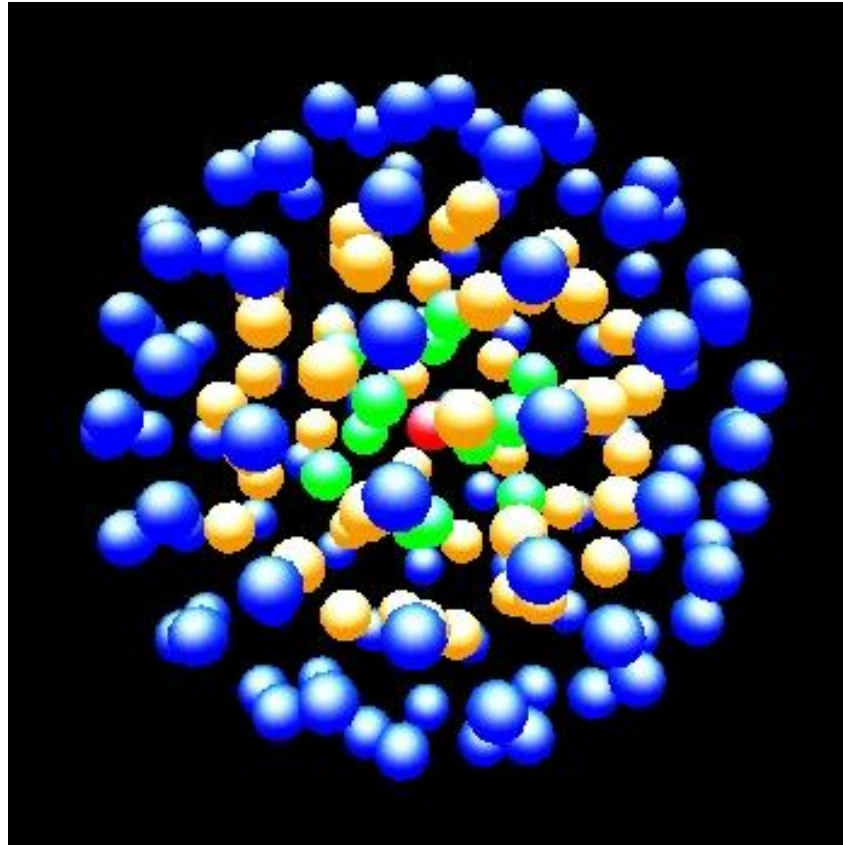
- co-propagating electron beam
 - ion velocity ultimately adapts the electron velocity
- monoenergetic ion beam with low divergence

evaporation cooling:

- hot atoms of the **Maxwell-Boltzmann distribution** will be removed

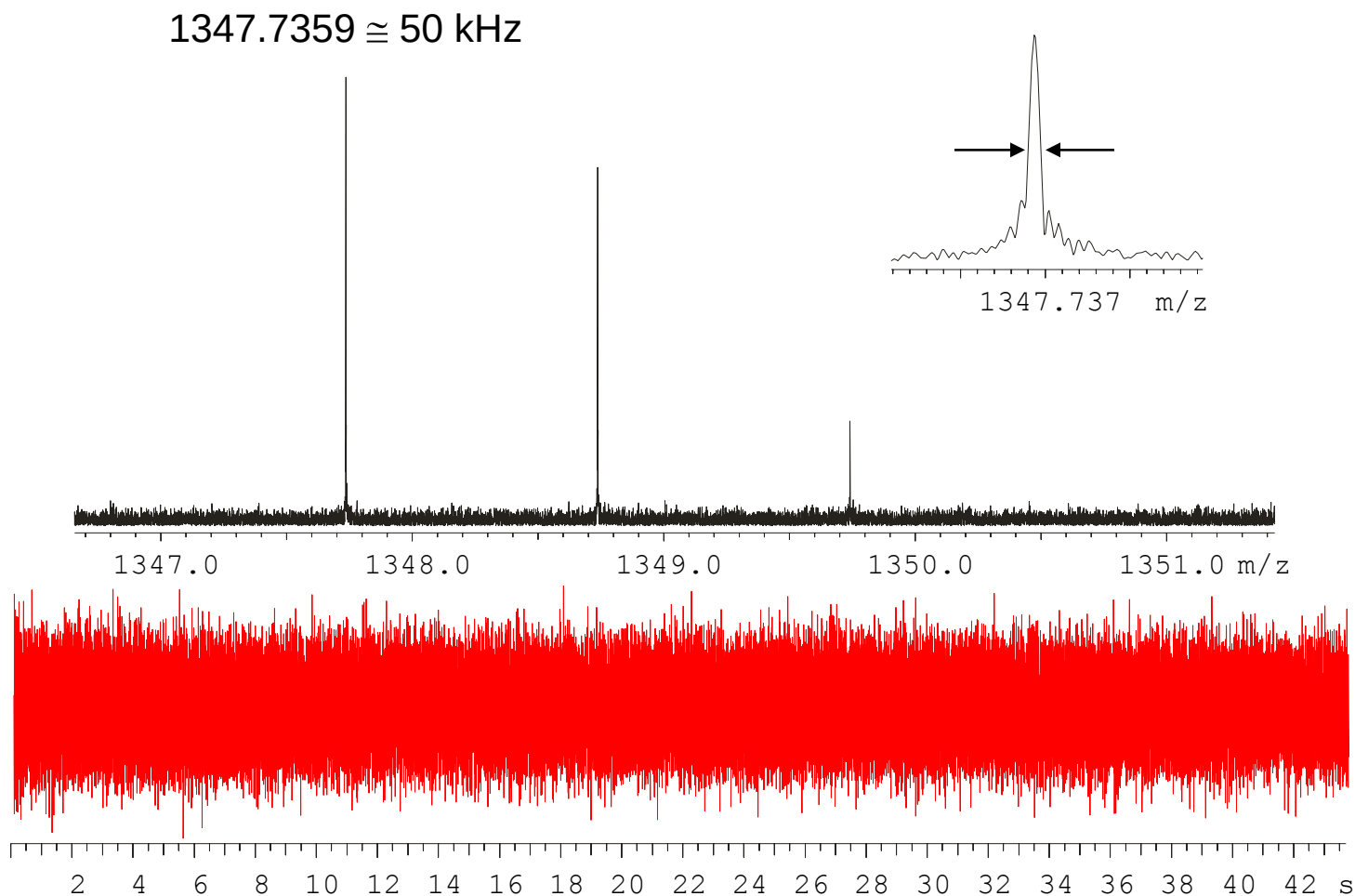


Wigner crystal



FT-ICR: resolution of substance P

Resolving Power = 1,800,000



extremely high mass resolution in a FT ion trap

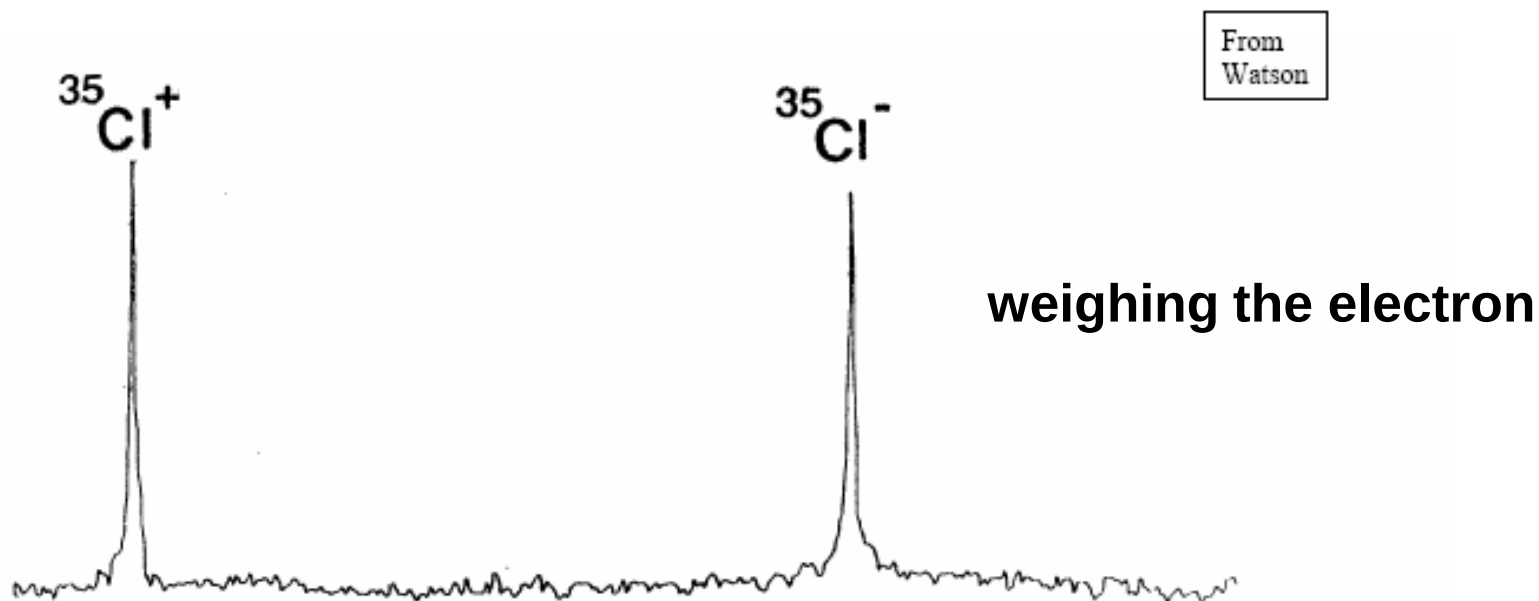
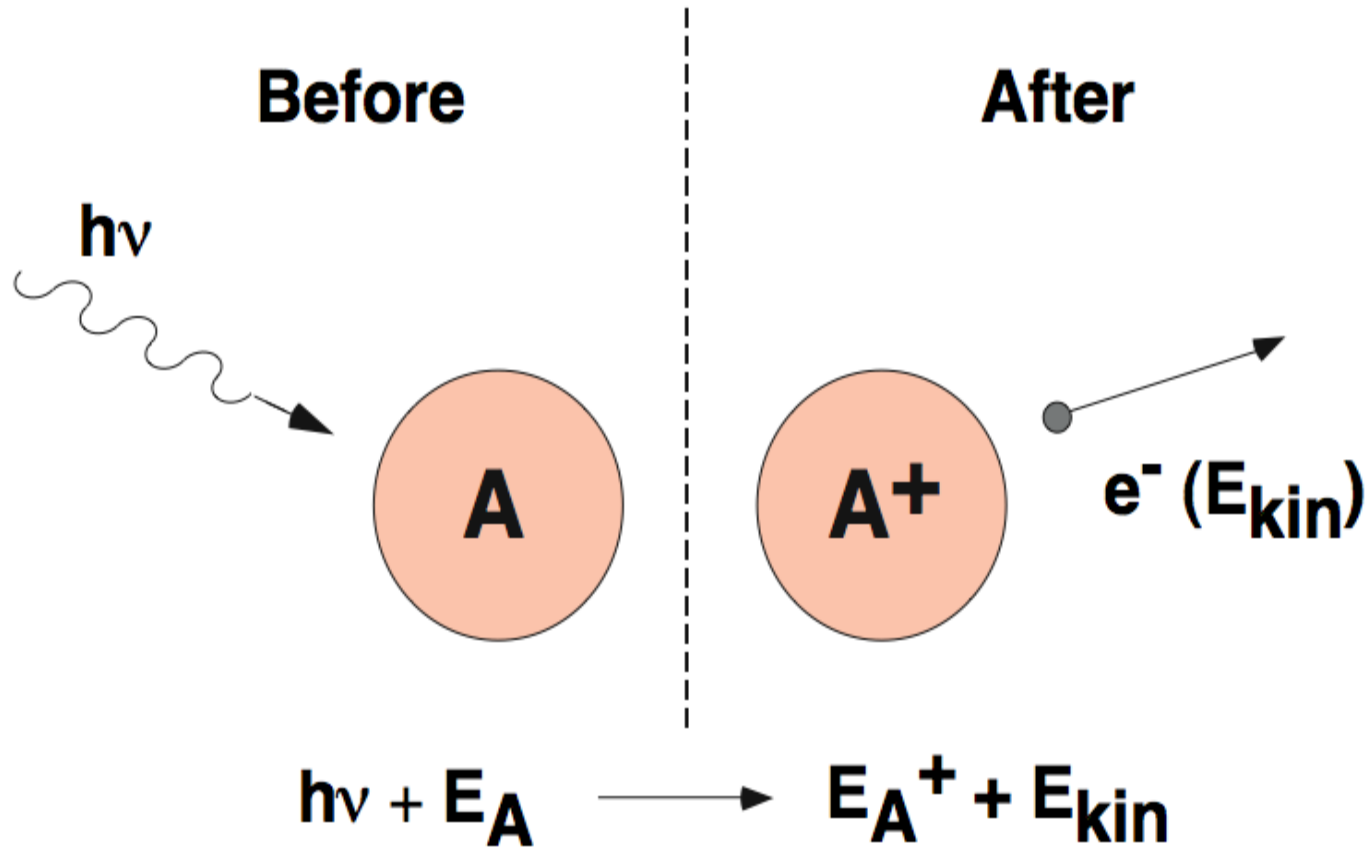


FIG. 4.22. Segment of mass spectrum in region of nominal mass 35 showing a resolution greater than 1,000,000 (FWHM definition) when using FT-MS. The peaks represent the positive and negative ions of ^{35}Cl that have a difference in mass equivalent to the mass of two electrons. The spectrum was obtained using a FT-ICR mass spectrometer with a superconducting magnet (4.7 tesla); the instrument was switched from the positive-ion-detection mode to the negative-ion-detection mode during the scan between the two peaks (Courtesy of Spectrospin AG.)

atomic photoionisation as correlated process

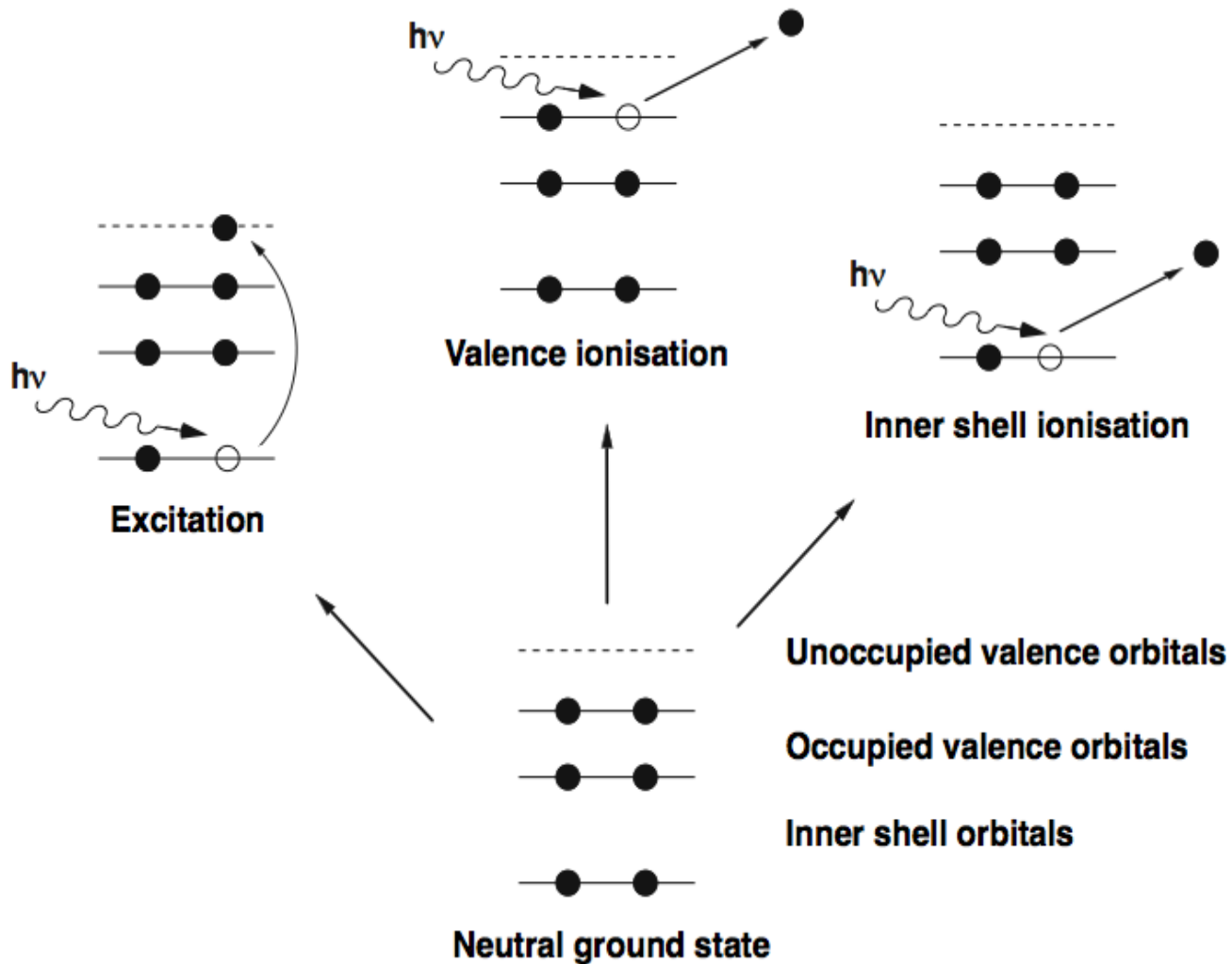


Photoelectric law, A. Einstein 1905:

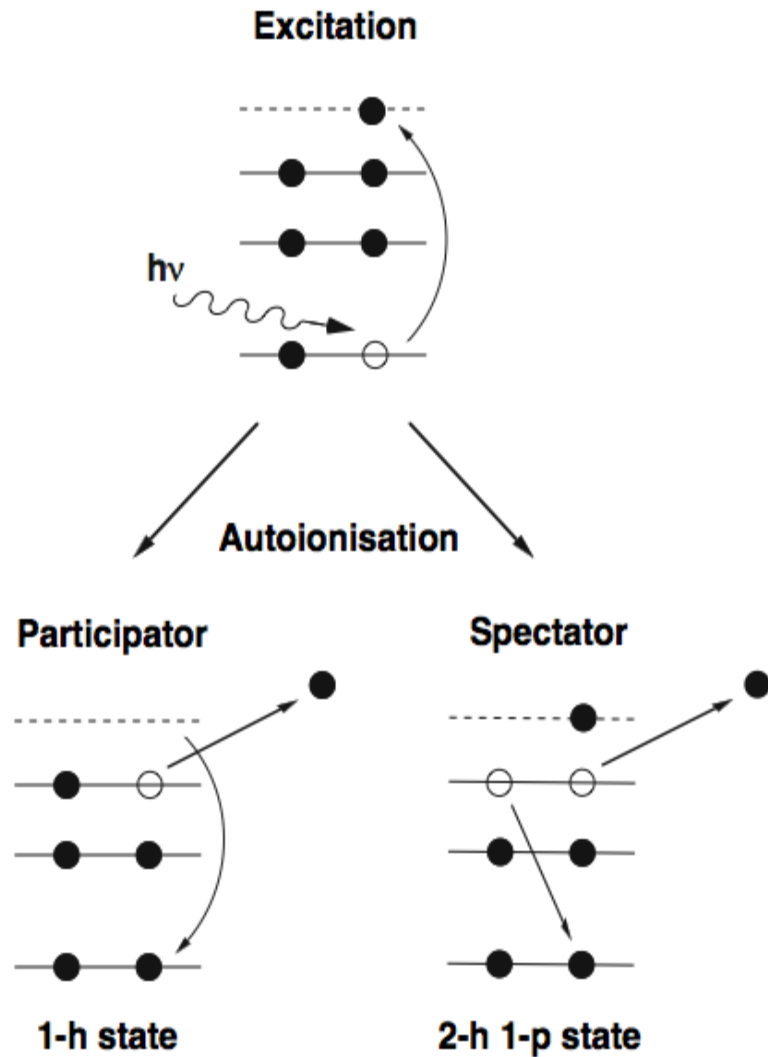
$$h\nu = E_{\text{kin}} + E_{\text{B}}$$

IP

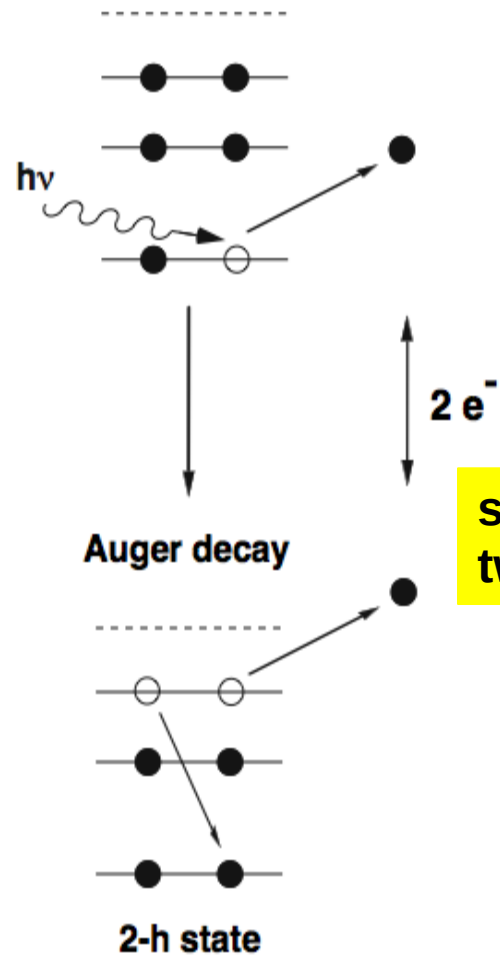
photoexcitation and ionisation processes



deexcitation processes

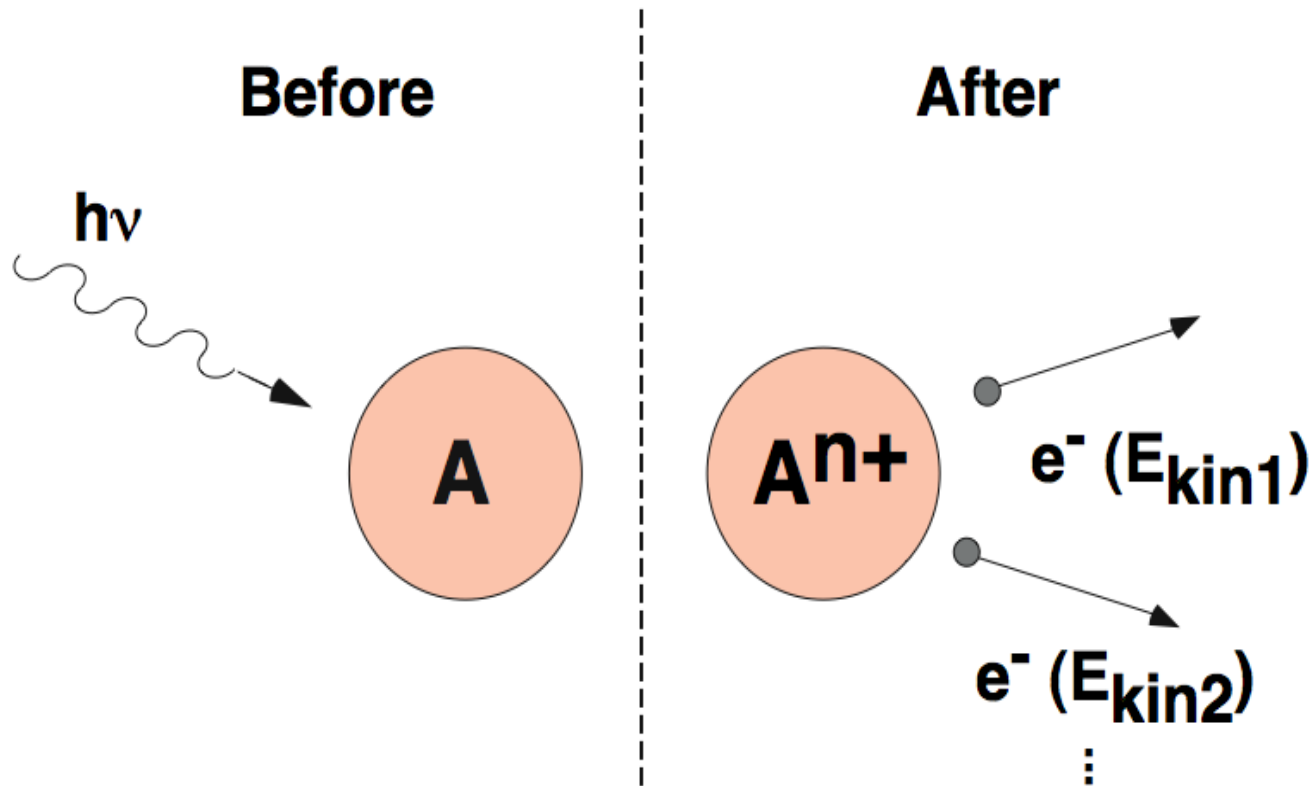


Inner shell ionisation



single photon
two electrons

single photon - multiple ionisation

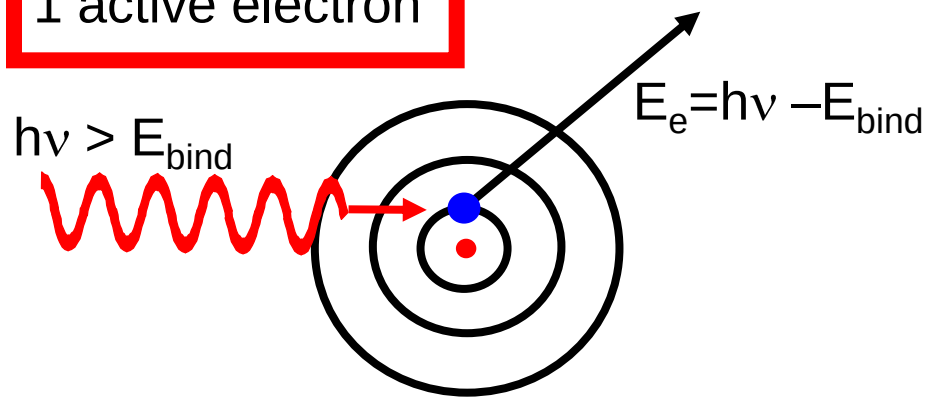


$$E_{B1} + E_{B2} (+ \dots) = h\nu - E_{kin1} - E_{kin2} (- \dots)$$

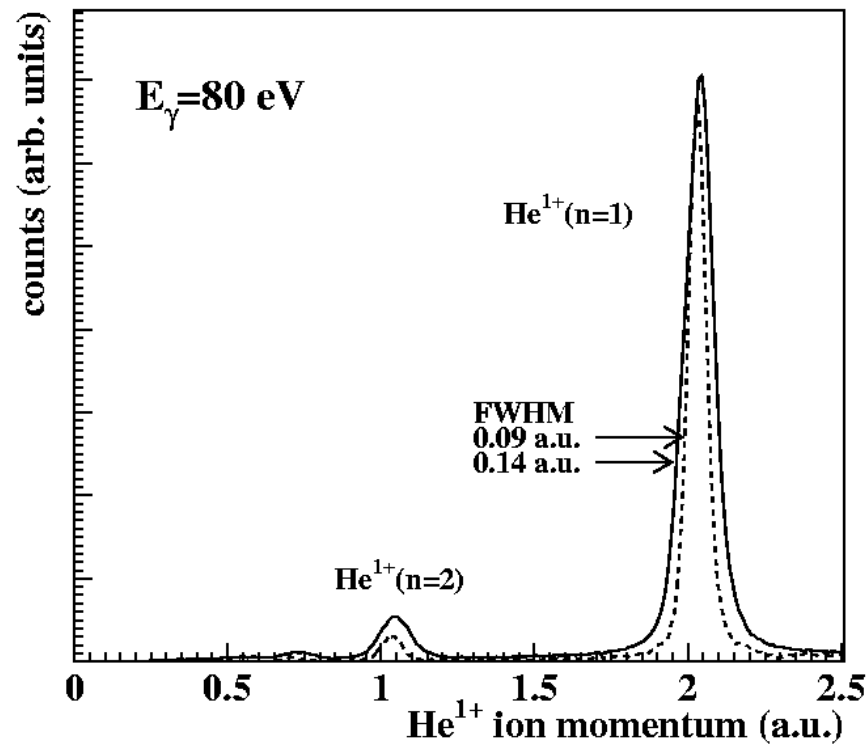
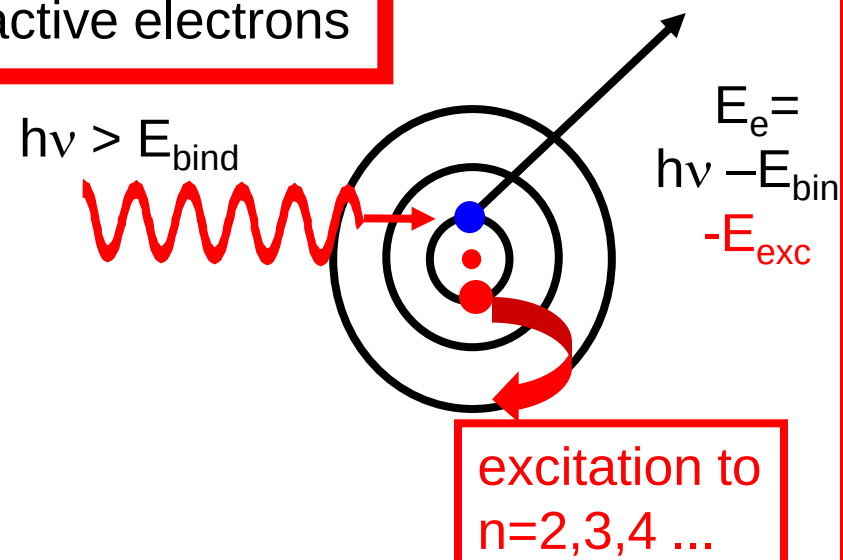
prominent example:
 $\text{He} \rightarrow \text{He}^{++}$

is the emission correlated?

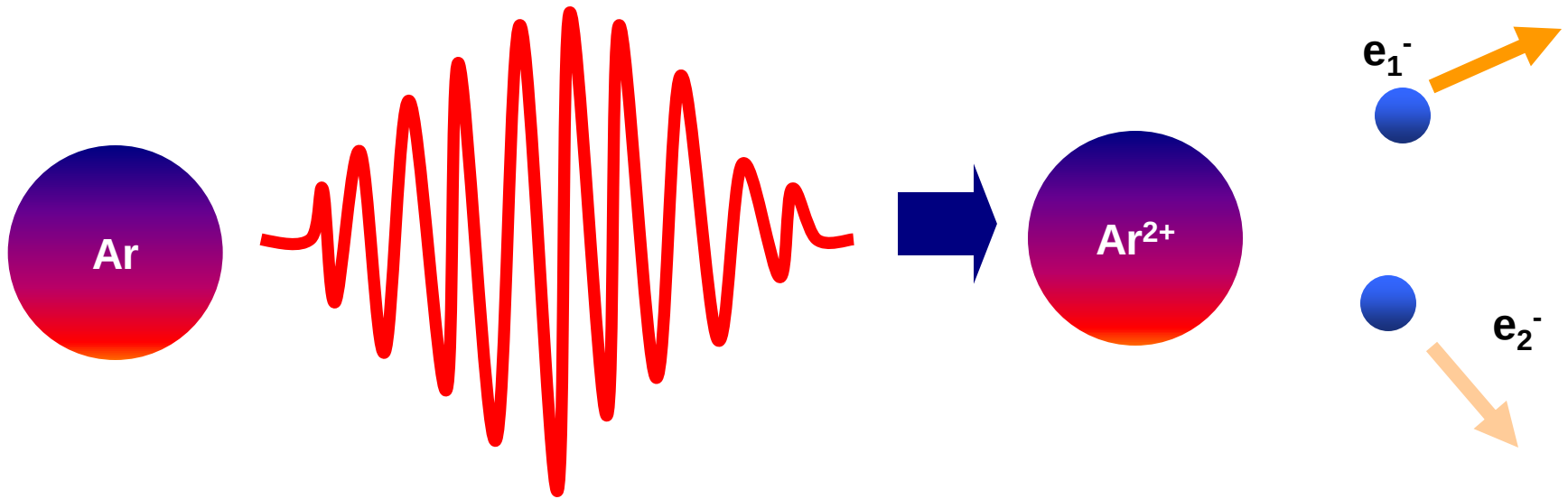
1 active electron



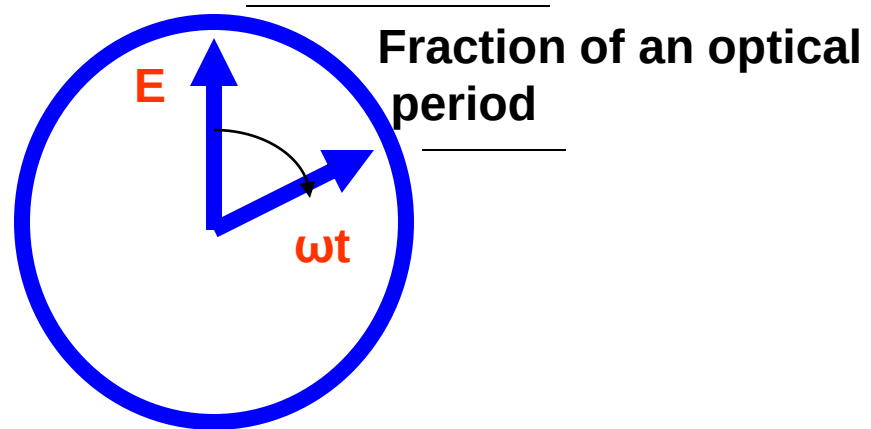
2 active electrons



One of the many current questions:
Correlation in the sequential release of two electrons from atomic
targets by short laser pulses



Sub femto-second
Electrons dynamics



Optical period=2.6 fs

in words

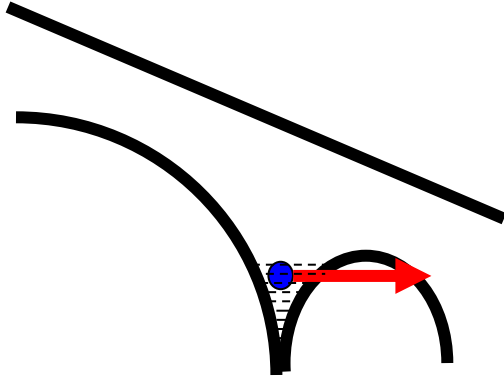
The Goal: to directly measure the time correlation between the two electrons and explore the clock that reads electronic dynamics of the system on sub-fs scale

Tool : Measure *in COINCIDENCE* the highly resolved momentum distributions of electrons and doubly-charged ions produced in the circularly polarized ultra short laser pulse.

What is achieved : the full vector momentum of the singly and doubly charged recoil ions (Ar and Ne) is measured. The ion momentum distributions can also be used to map the vector sum of the two emitted electrons' momenta.

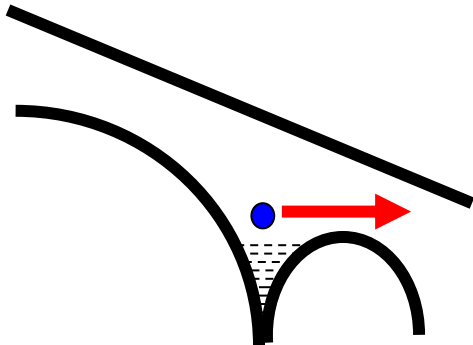
Mechanism????

Sequential ionization



Tunneling Ionization

At high laser intensities;

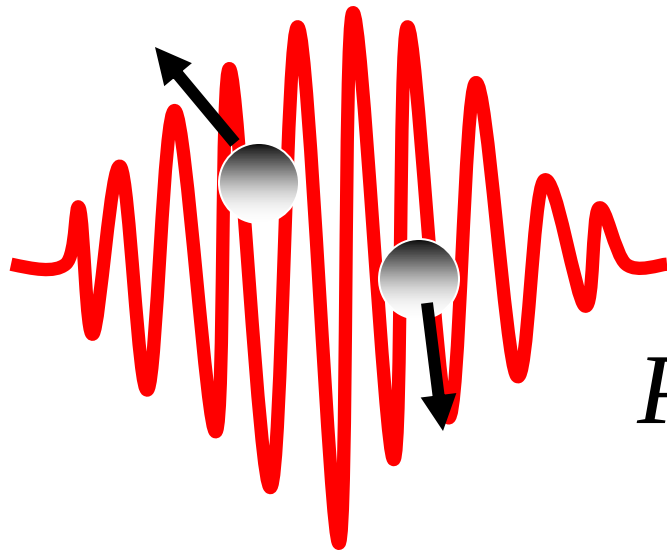


Over barrier ionization

$$E = I_p^2 / 4Z_{\text{eff}}$$

$$P = E / \omega$$

How electrons and ion gain momentum in laser field?



$$P(e) = \int_{t_0}^{\infty} E dt$$

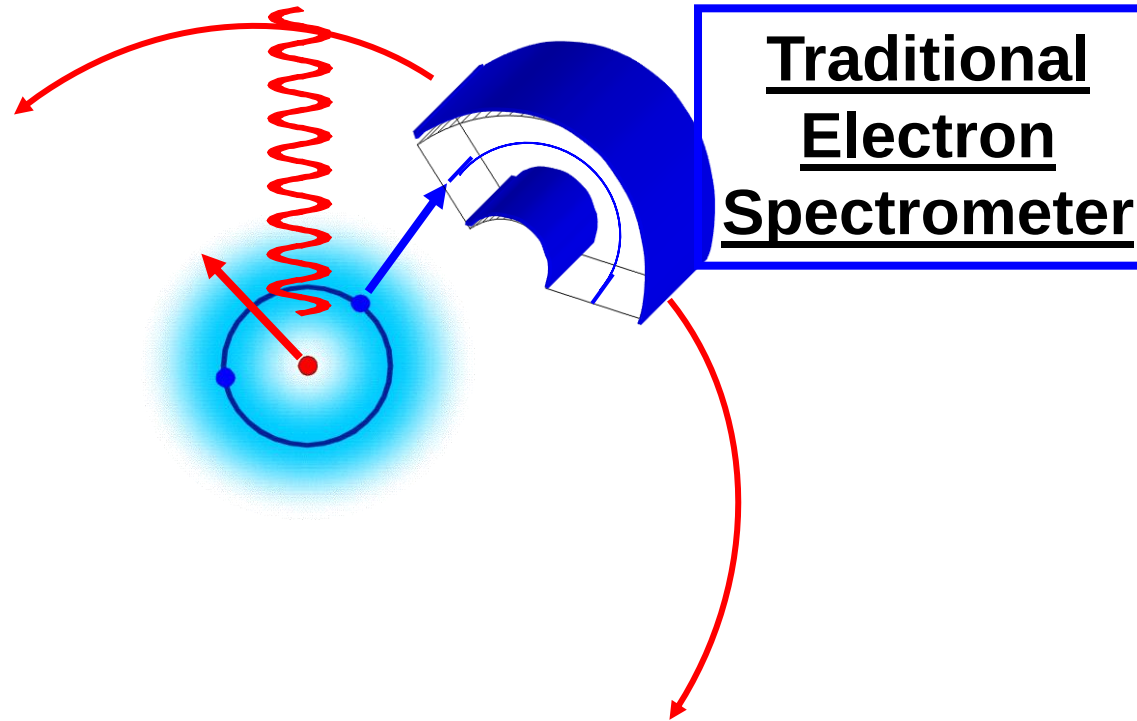
$$P_{Ar^{2+}} = \int_{t_0}^{t_1} E dt + 2 \int_{t_1}^{\infty} E dt$$

$$= \int_{t_0}^{\infty} E dt + \int_{t_1}^{\infty} E dt = P(e_1) + P(e_2)$$

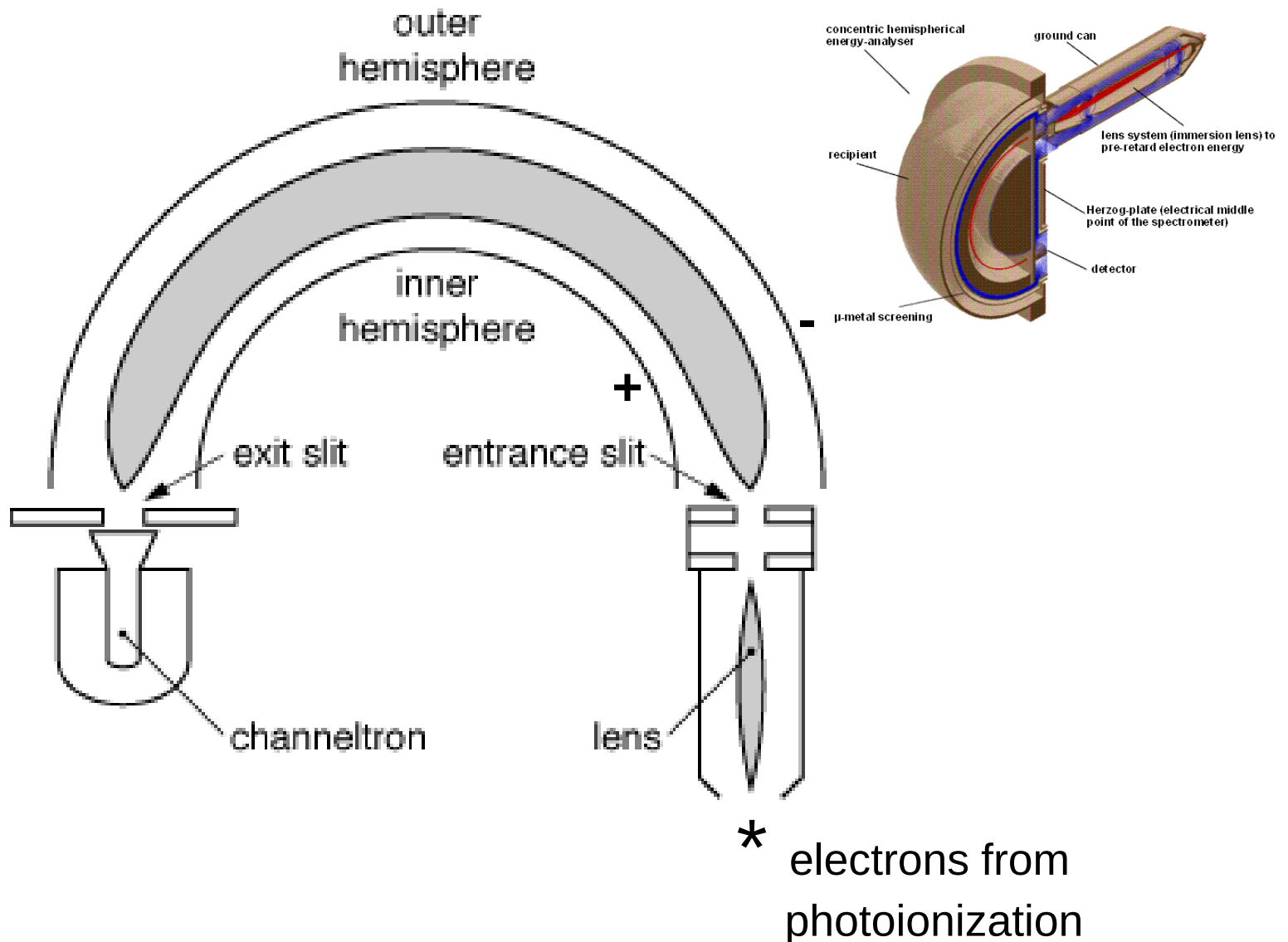
Momentum conservation.....

what can be measured:

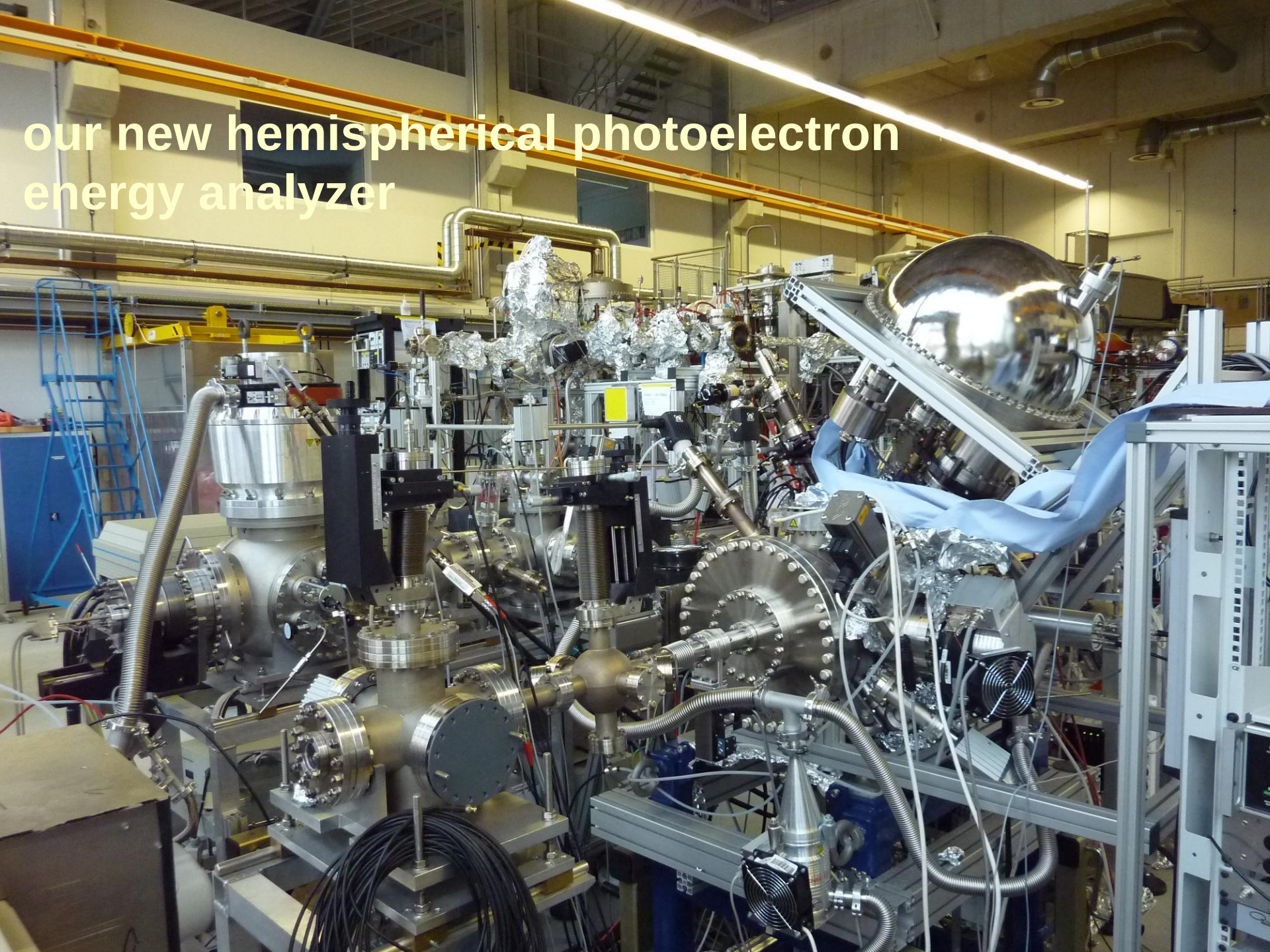
- Absorption
- Ion production
- Electron energy
- Electron angle



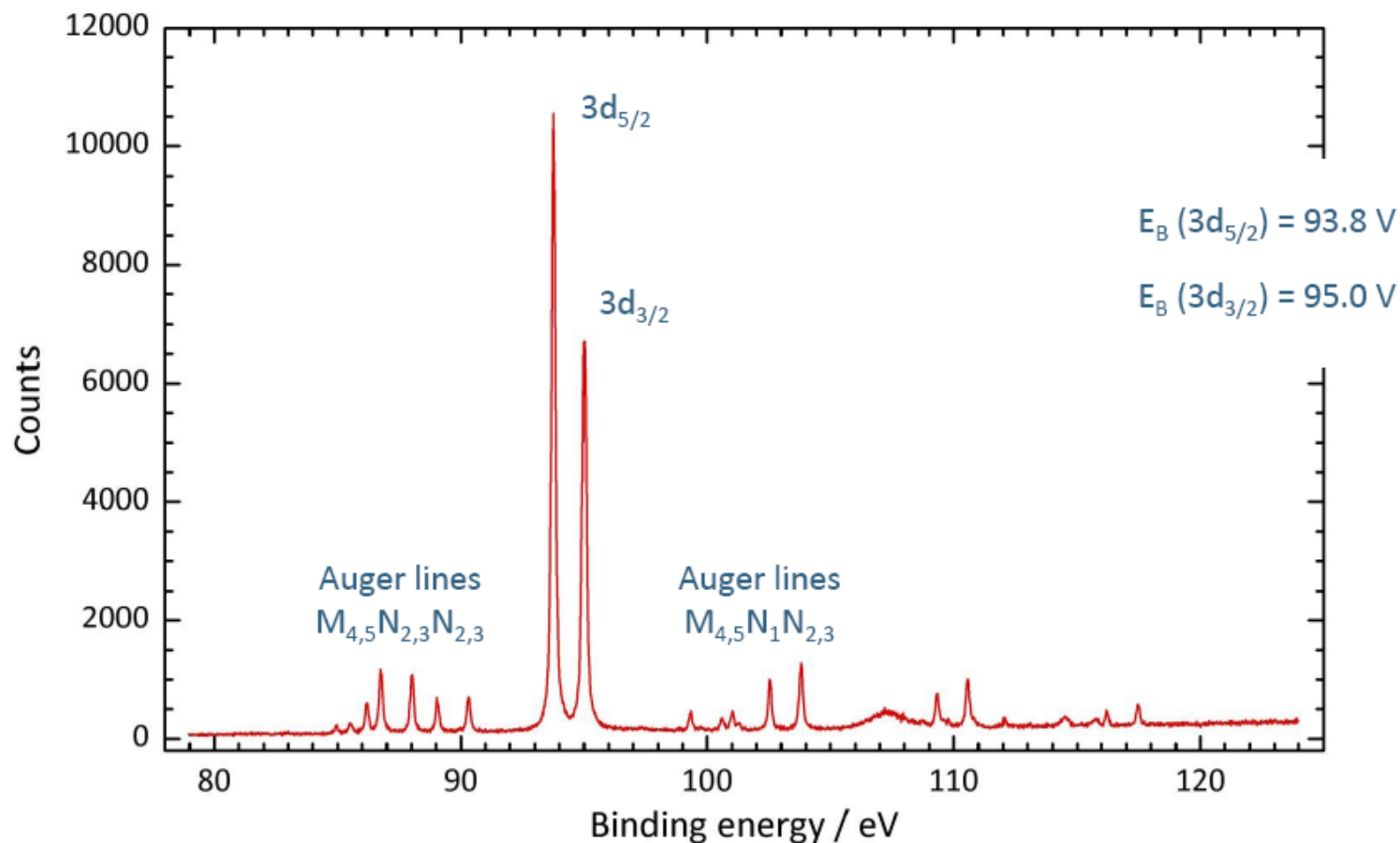
hemispherical electron analyser with a lens system



our new hemispherical photoelectron
energy analyzer



own measurement:
photoemission from Kr atoms at the synchrotron DORIS with a
hemispherical analyzer



DORIS BW3, $4.1 \cdot 10^{-6}$ mbar Kr, $E_{ph} = 142$ eV, $E_{pass} = 3.0$ eV

time-of-flight electron spectrometers

im principle: trivial

measure field-free time of flight, known mass $\rightarrow$ energy

problems:

intensity, loss in stray fields

with magnetic guidance: time information goes lost

solution: magnetic bottle electron spectroscopy

$$r_i = \frac{v \sin \theta_i}{\omega_i}, \quad \checkmark$$

$$\frac{\sin \theta_f}{\sin \theta_i} = \sqrt{\frac{B_f}{B_i}}$$

$$(2) \Rightarrow \frac{\Delta E}{E} \approx \frac{B_f}{B_i}$$

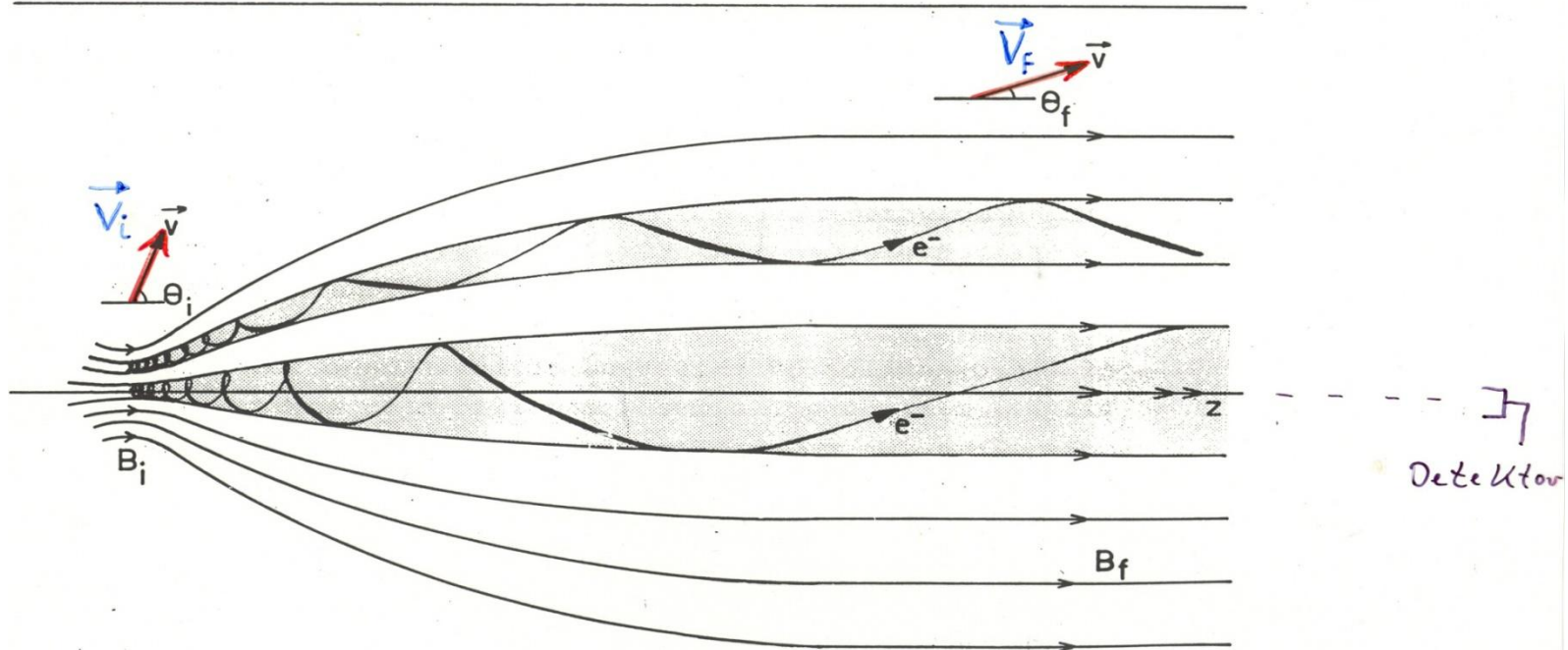


Figure 1

Schematic diagram showing the helical motion of an electron moving in a magnetic field that changes gradually from a strong field B_i to a weaker uniform field B_f .

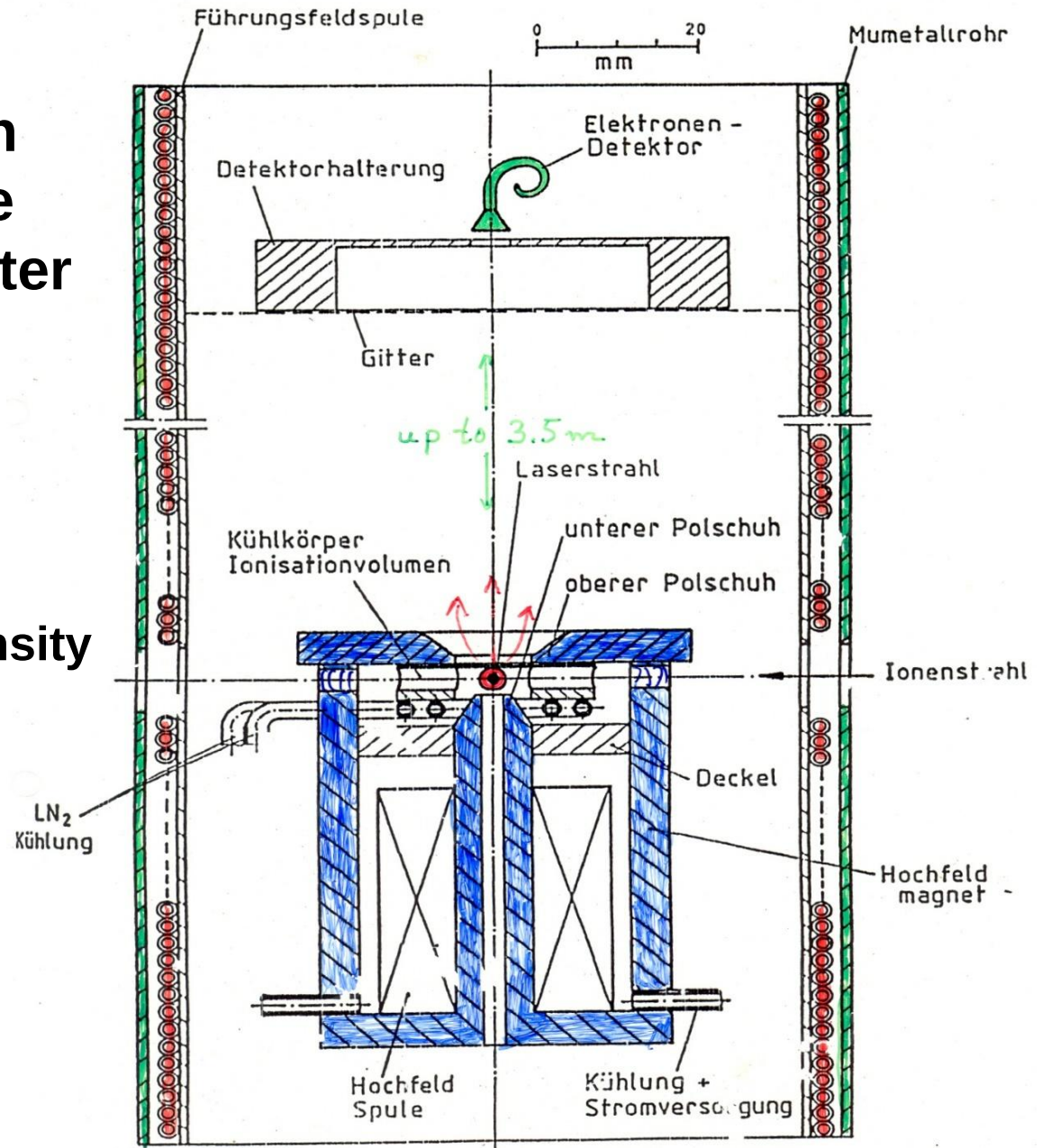
Kruit, Read

in the limit of a strong gradient and a long drift area, the flight times of electrons with the same energy are independent of the emission angle.
detection efficiency of about 50 %

technical realization of a magnetic-bottle electron spectrometer

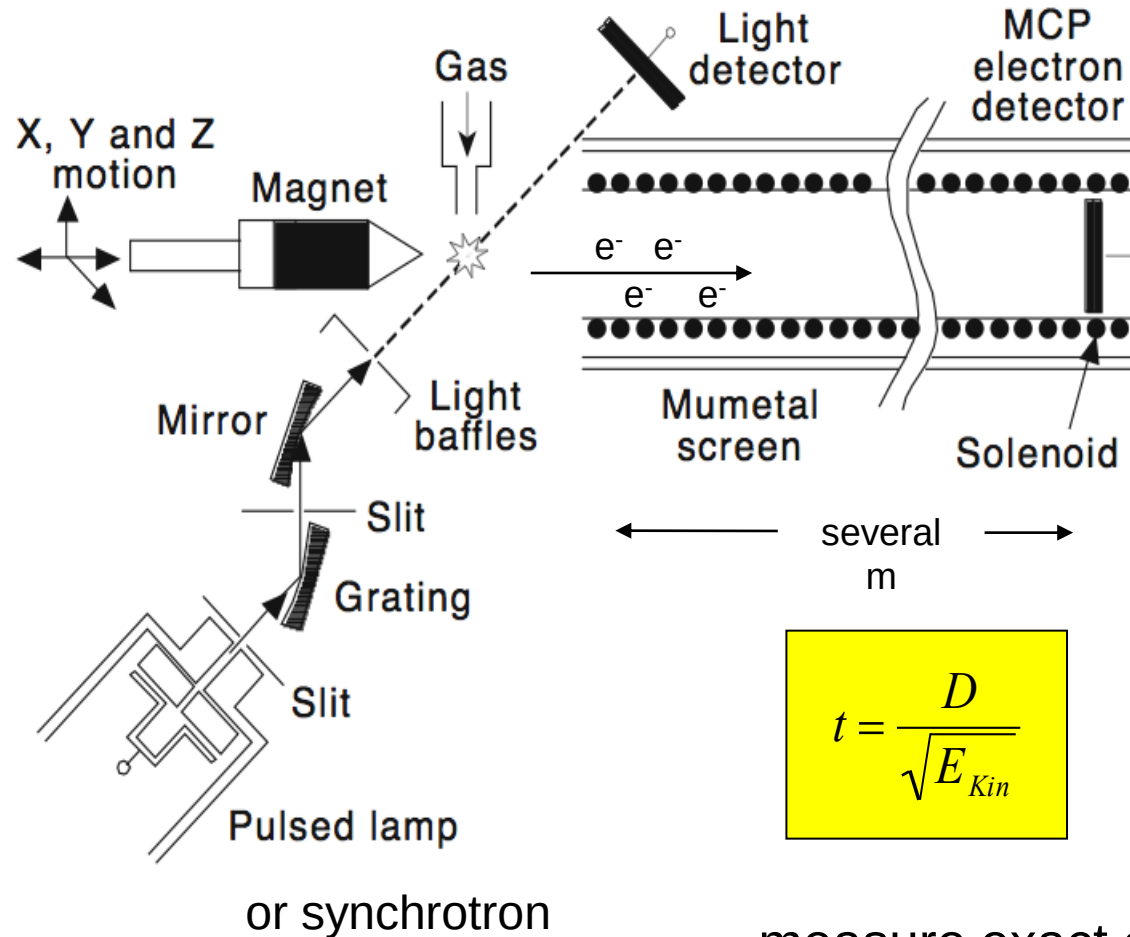
in particular well-suited
for low density targets

even good for low-intensity
charged cluster beams



Aobildung 11: Schnitt durch den neuen Hochfeldmagneten

open time of flight (TOF) electron spectrometer

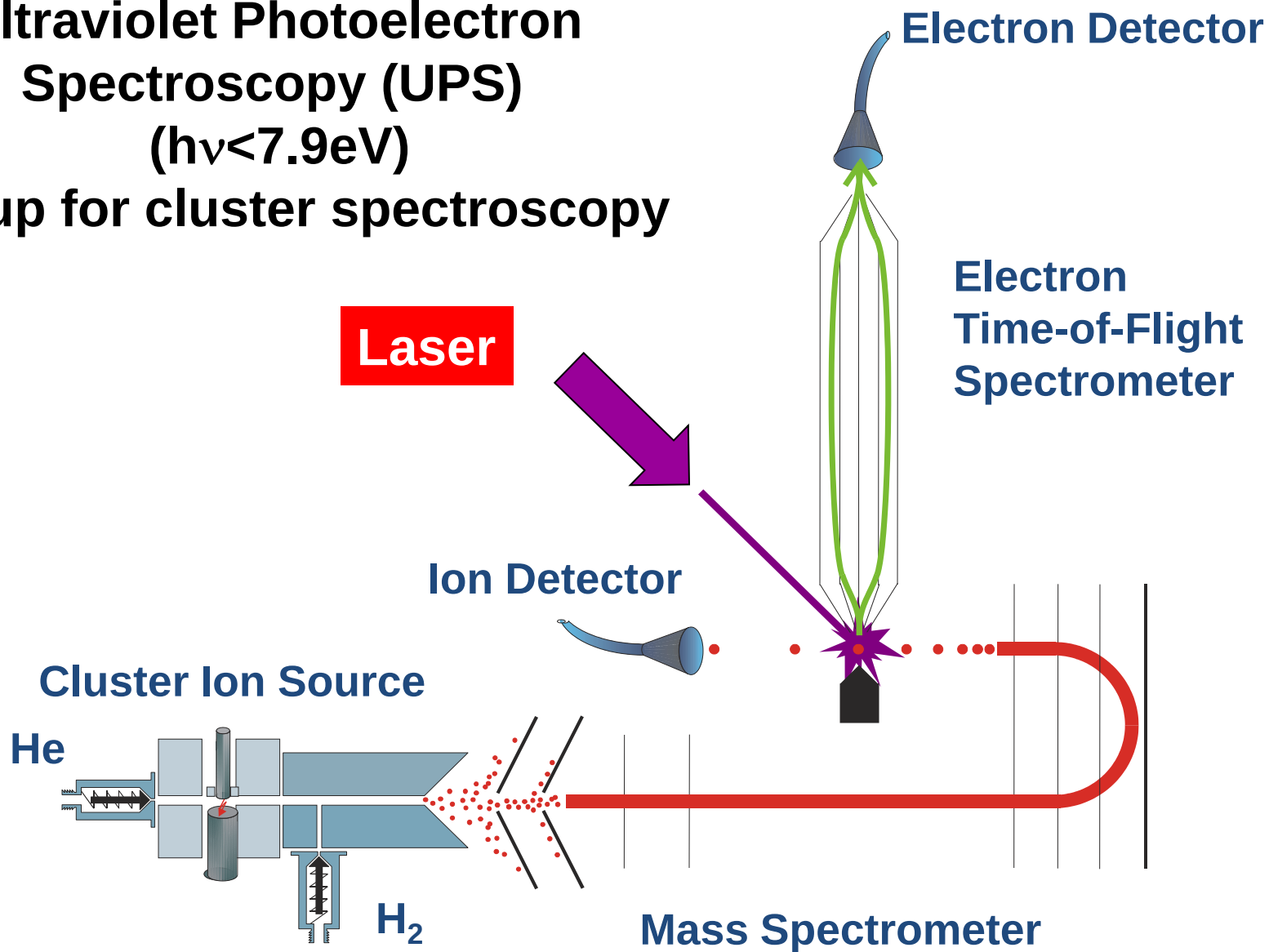


TOF spectrometer instrument...

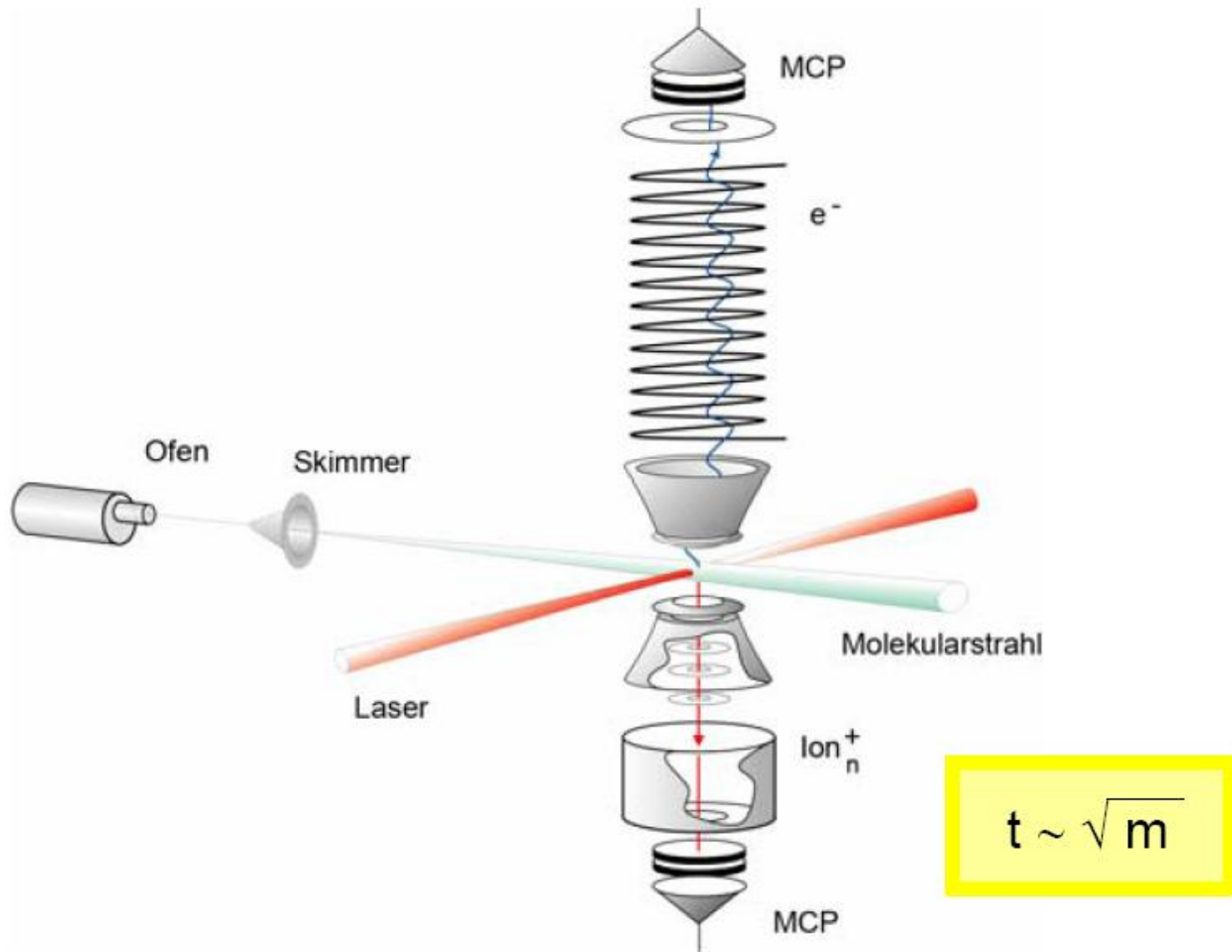


a long electron drift tube yields high resolution
World's longest electron time-of-flight electron spectrometer

Ultraviolet Photoelectron Spectroscopy (UPS) ($h\nu < 7.9\text{eV}$) set-up for cluster spectroscopy

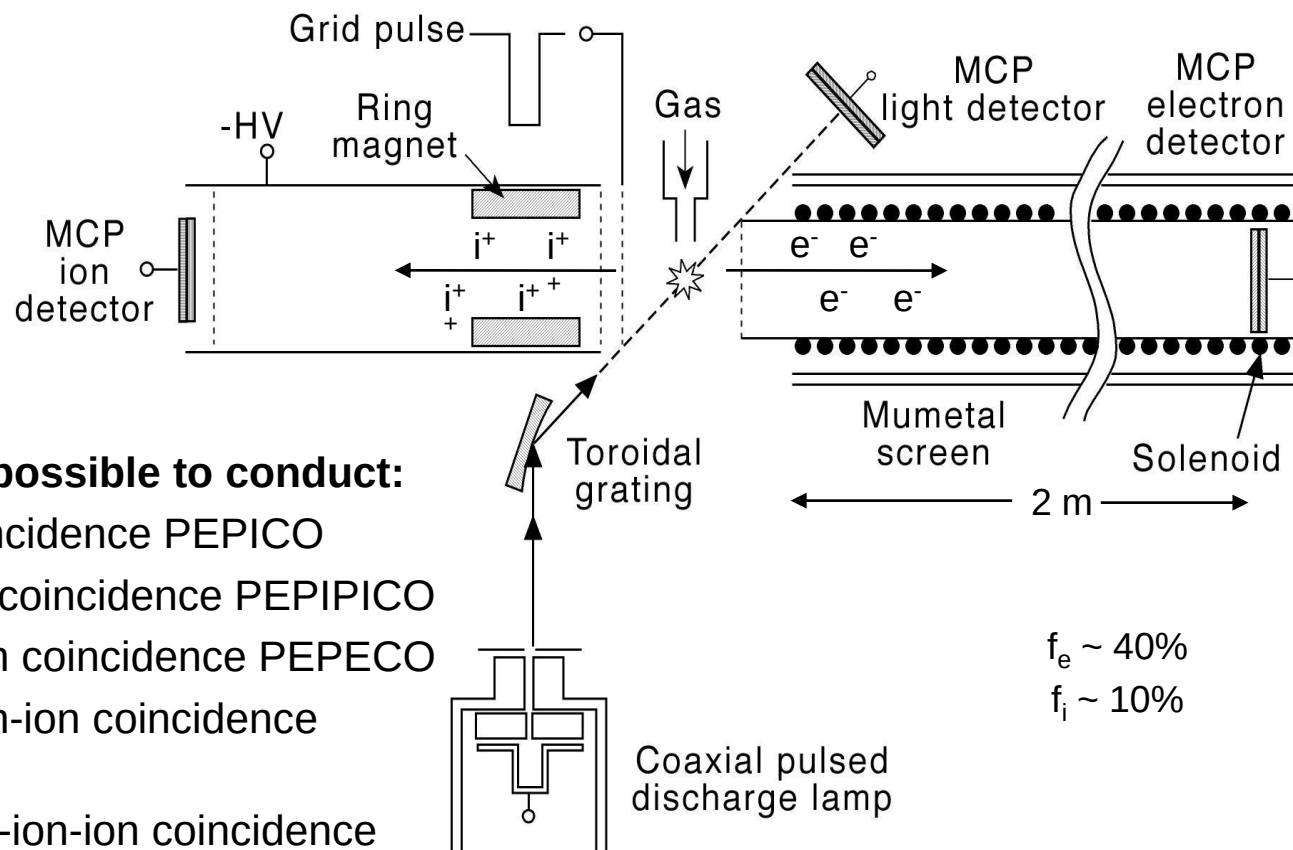


electron *and* ion time-of-flight coincidence spectroscopy



TOF photoelectron-photoion spectroscopy

TOF - PEPEPIPICO



Simultaneously possible to conduct:

- Electron-ion coincidence PEPICO
- Electron-ion-ion coincidence PEPIPICO
- Electron-electron coincidence PEPECO
- Electron-electron-ion coincidence (PEPEPICO)
- Electron-electron-ion-ion coincidence (PEPEPIPICO)

.....

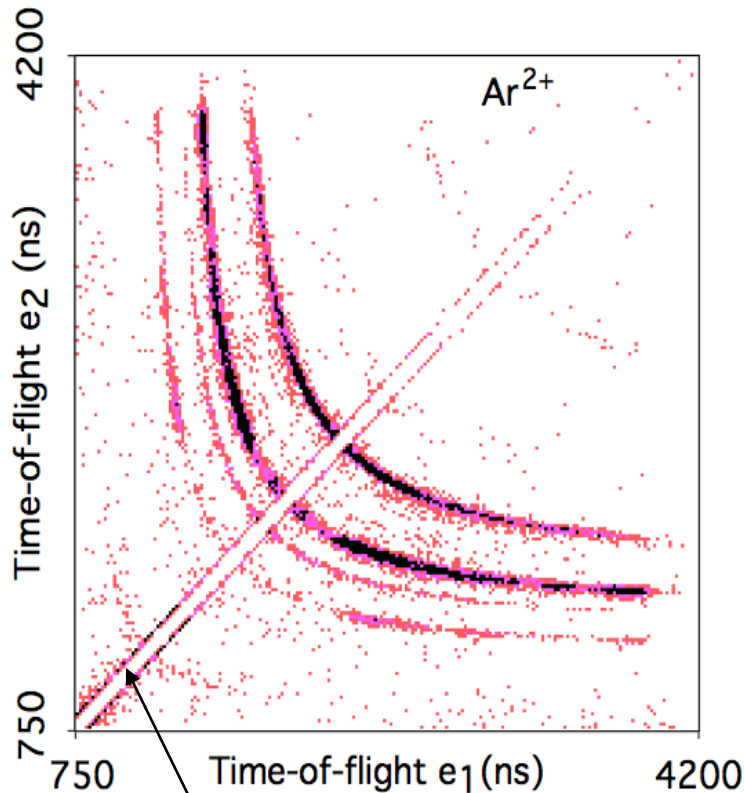
J.H.D Eland and R. Feifel Chem. Phys. 327 85 (2006)

R. Feifel *et al.*, J. Chem. Phys. 125, 194318 (2006)

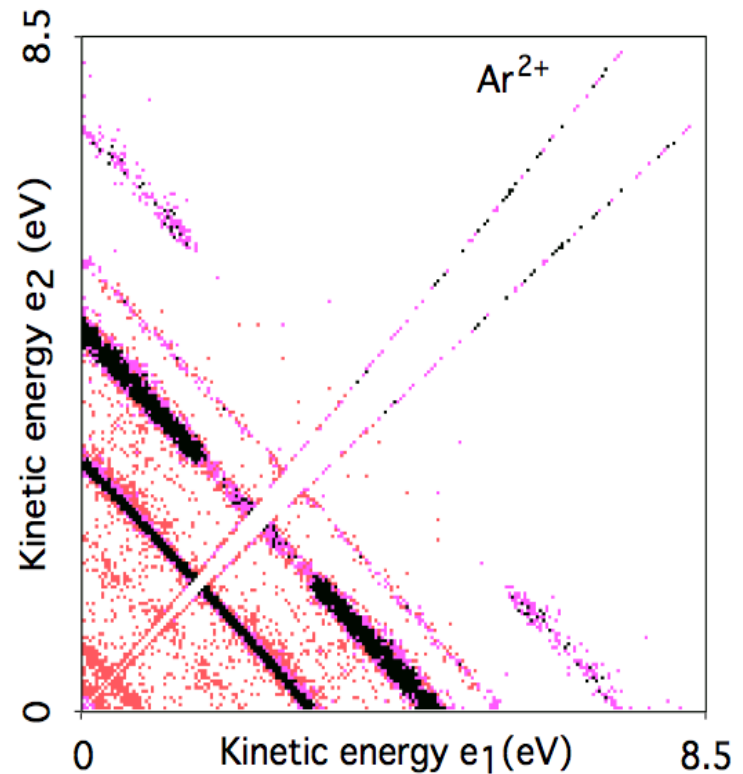
Single photon - double ionisation of Argon ($h\nu = 48.372$ eV)

measure the electrons in coincidence with Ar^{2+}

time spectra



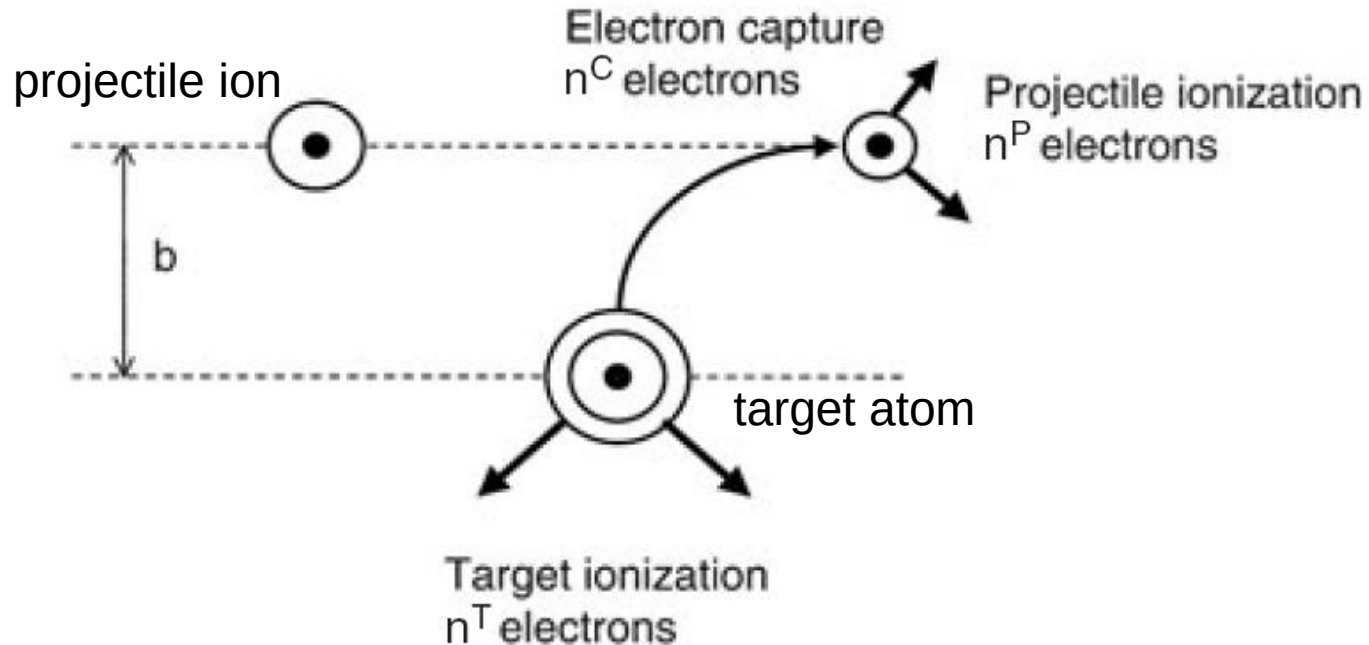
converted into energy space



from the diagonal lines we learn: all energies for e1 and e2 are possible, but their sum is constant, depending on the atomic level

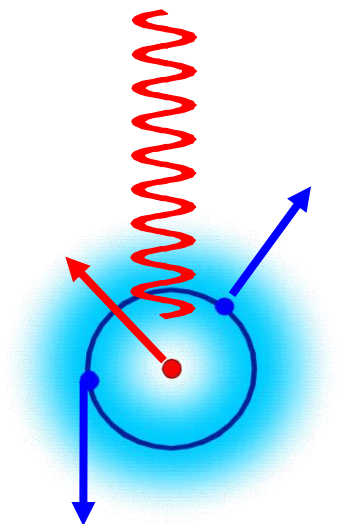
recoil-ion and electron momentum spectroscopy

need to measure ion momenta and several electrons



many different reaction channels

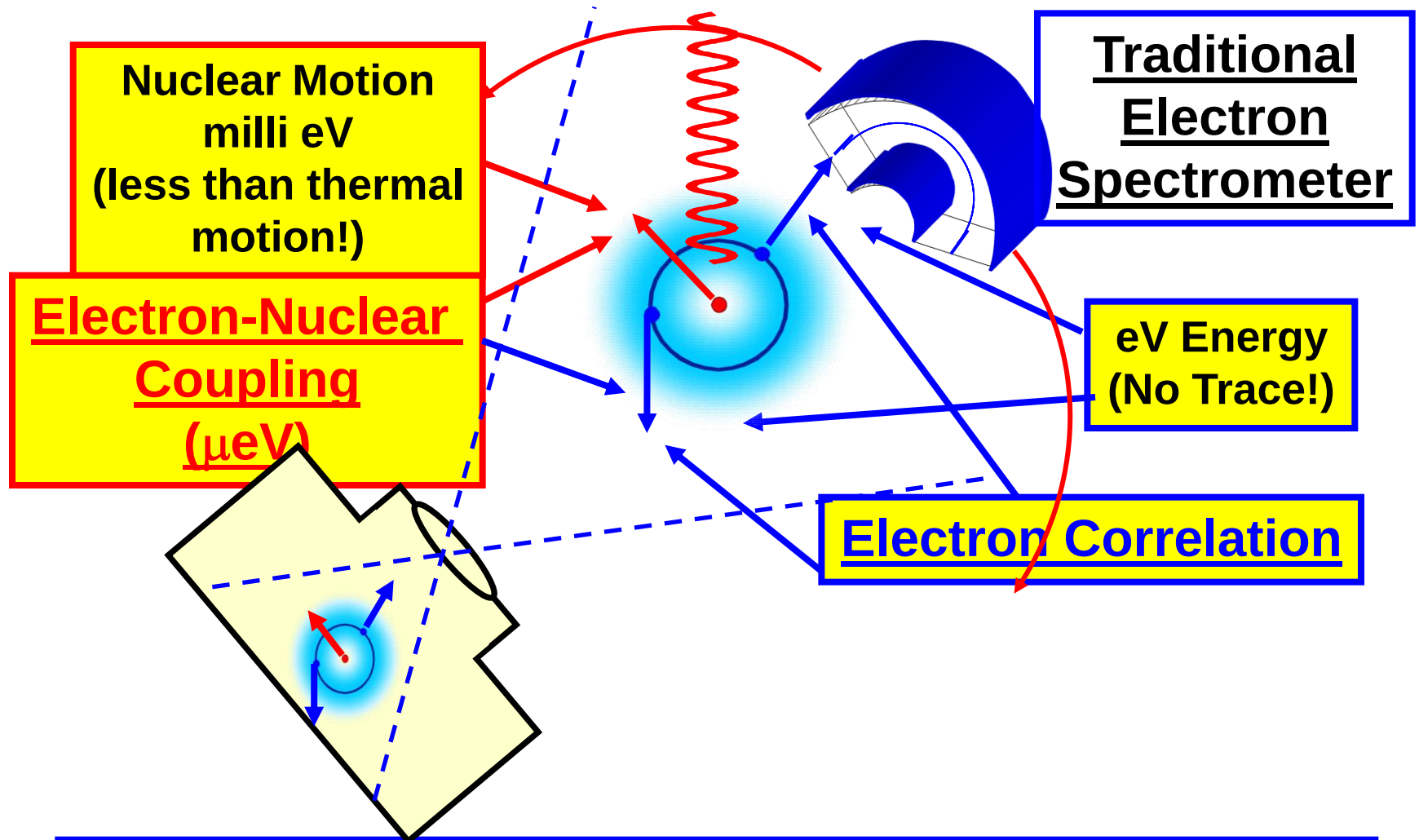
needs for a 'complete experiment'



Cloud Chamber and
its successors
Crystal ... Balls
TPC s

High energy Particles!





COLTRIMS:
Cloud Chamber for Atomic Physics
meV particles

COLTRIMS: A “Cloud Chamber” for μeV Particles:

Position
sensitive
multi-hit
ion
detector

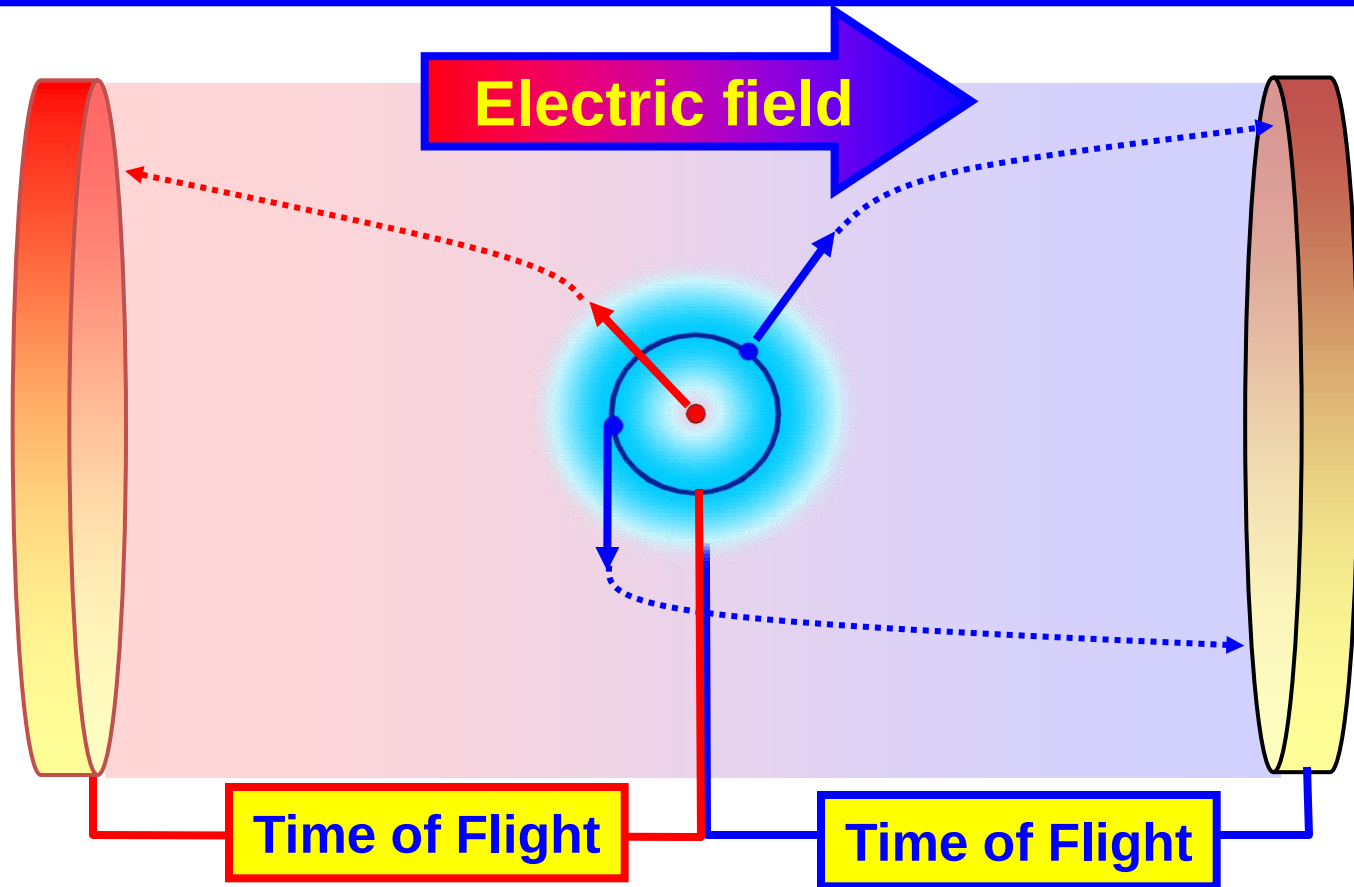
Electric field

Position
sensitive
multi-hit
electron
detector

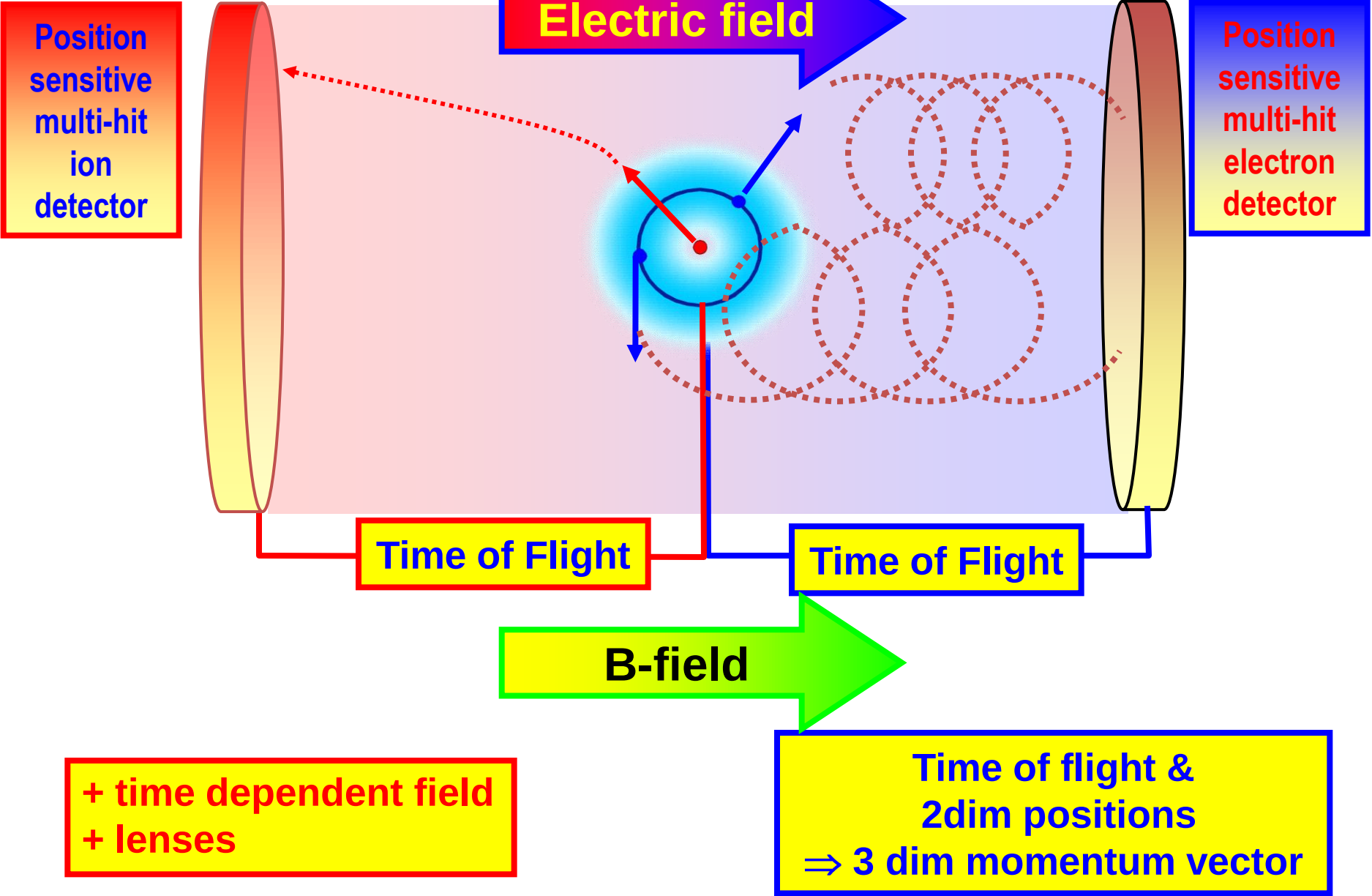
Time of Flight

Time of Flight

Time of flight &
2dim positions
 $\Rightarrow$ 3 dim momentum vector



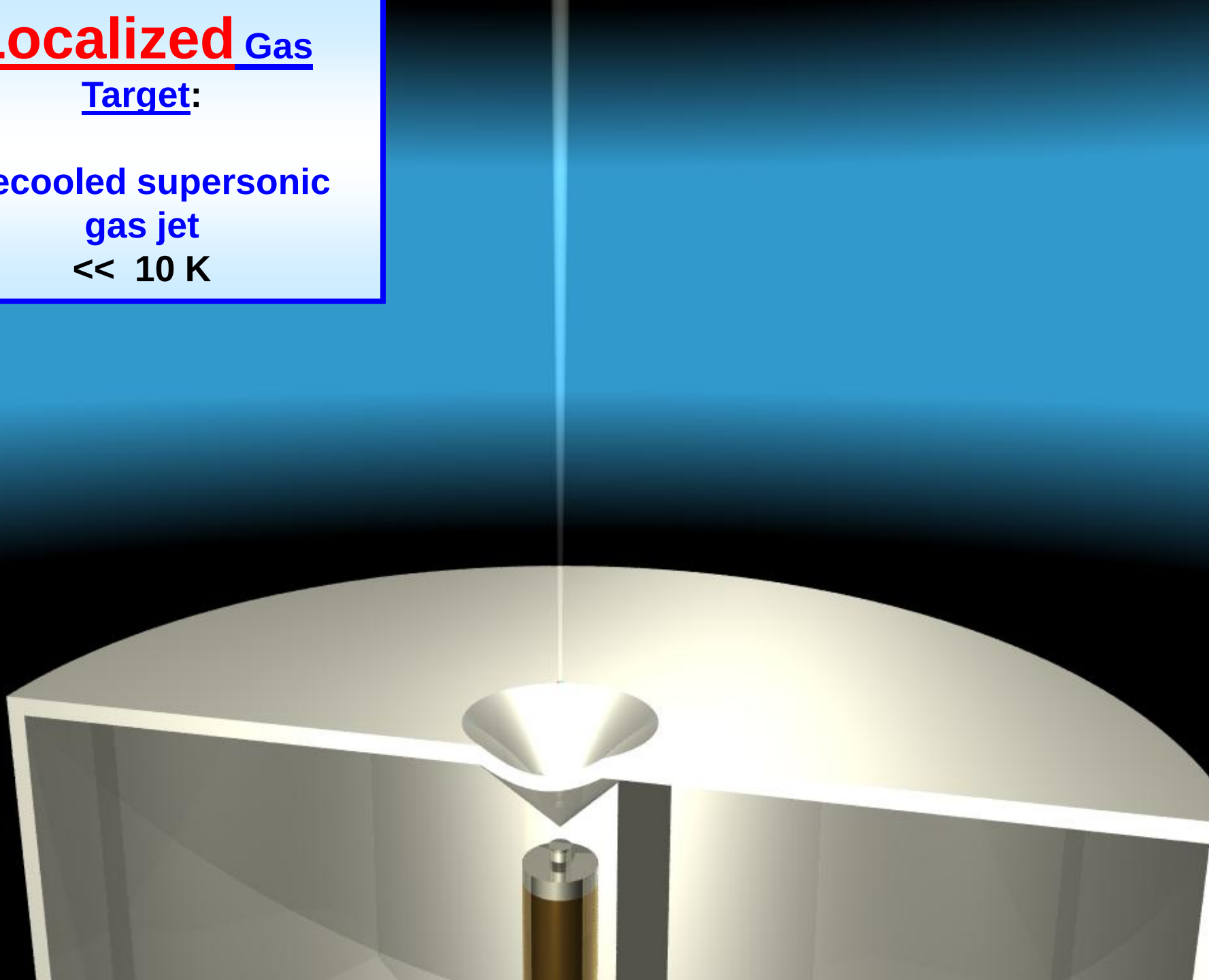
COLTRIMS: A “Cloud Chamber” for $\square$ eV Particles:



Localized Gas

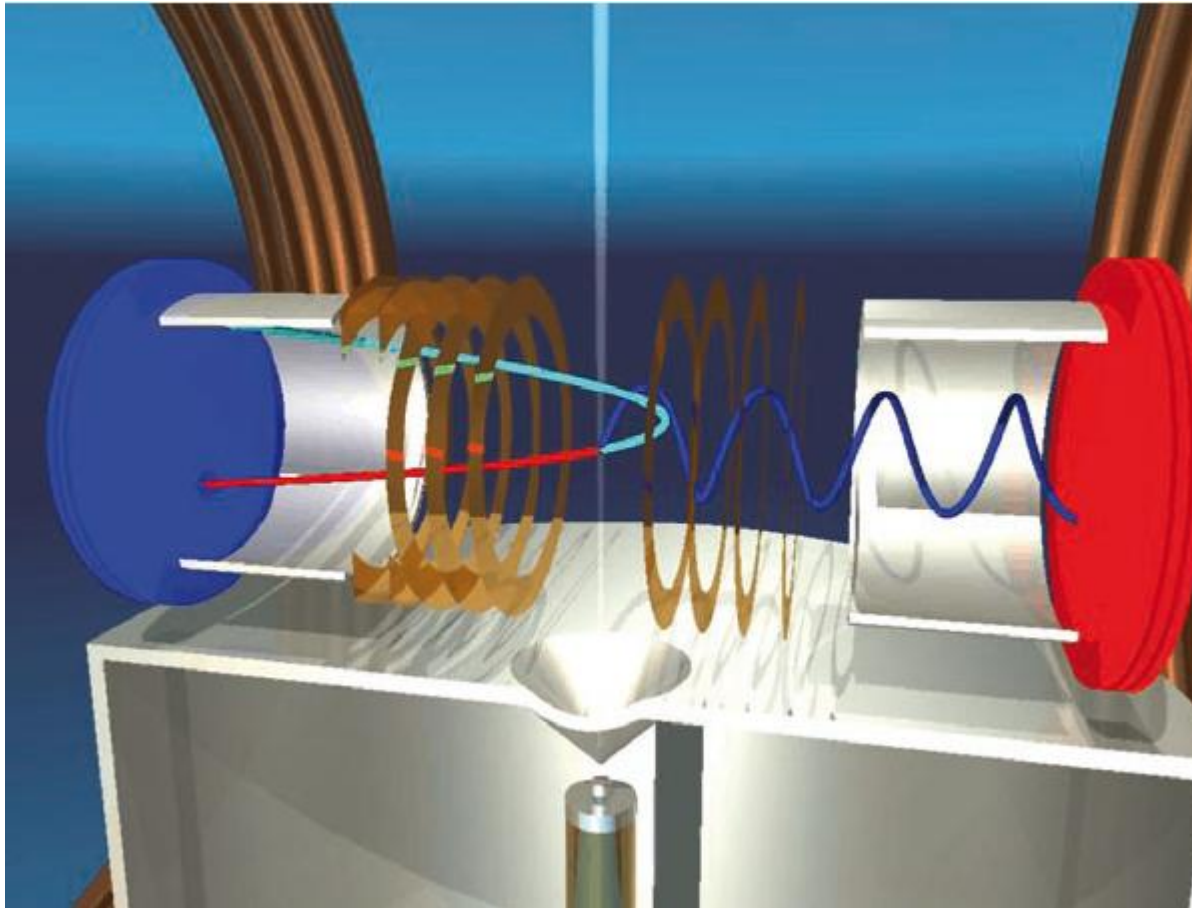
Target:

precooled supersonic
gas jet
 $\ll 10\text{ K}$



ion and electron momentum spectrometer COLTRIMS (Cold Target Recoil Ion Momentum Spectroscopy) the 'bubble chamber' of atomic physics

blue:
position and
time
sensitive
ion
detector

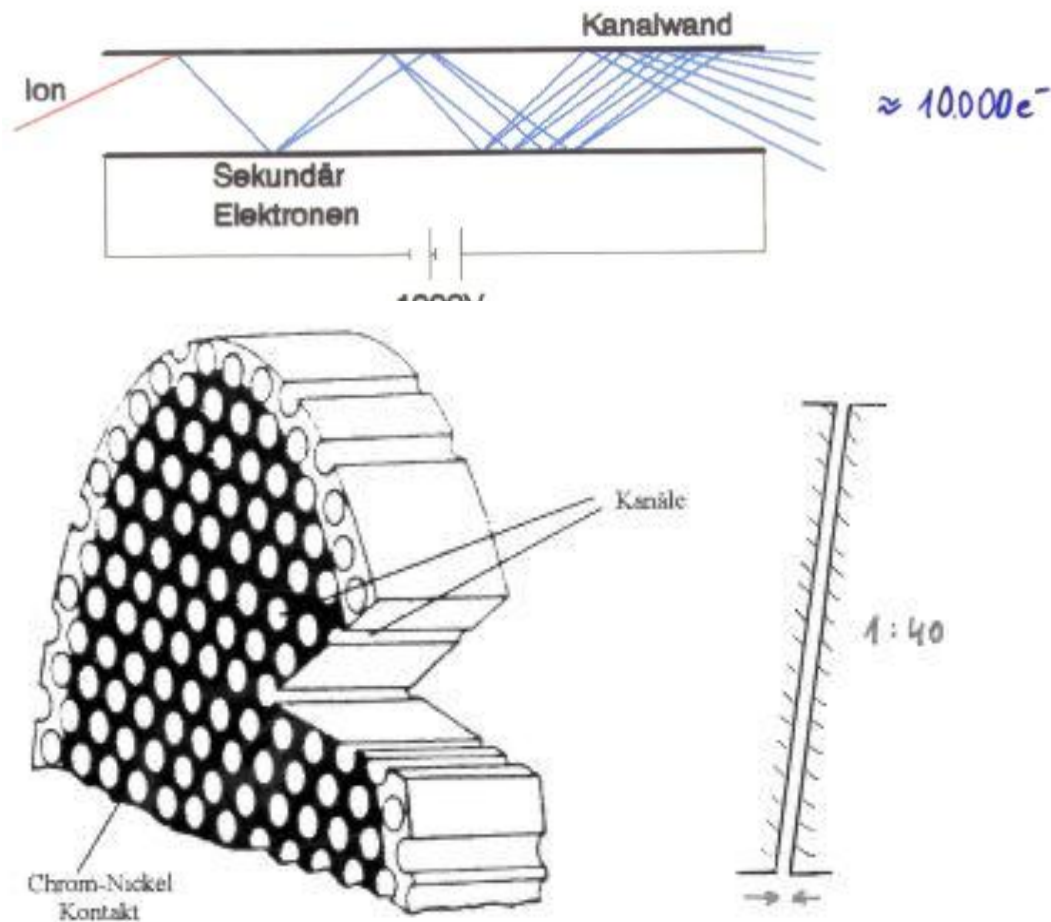


red:
position and
time
sensitive
electron
detector

Horst Schmidt-Böcking, Stern-Gerlach medal 2010
of the German Physical Society (DPG)

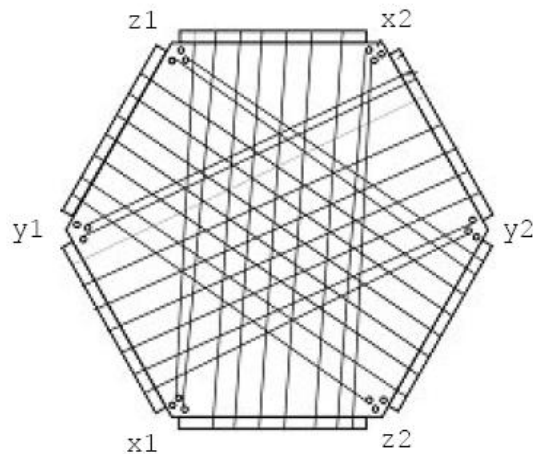
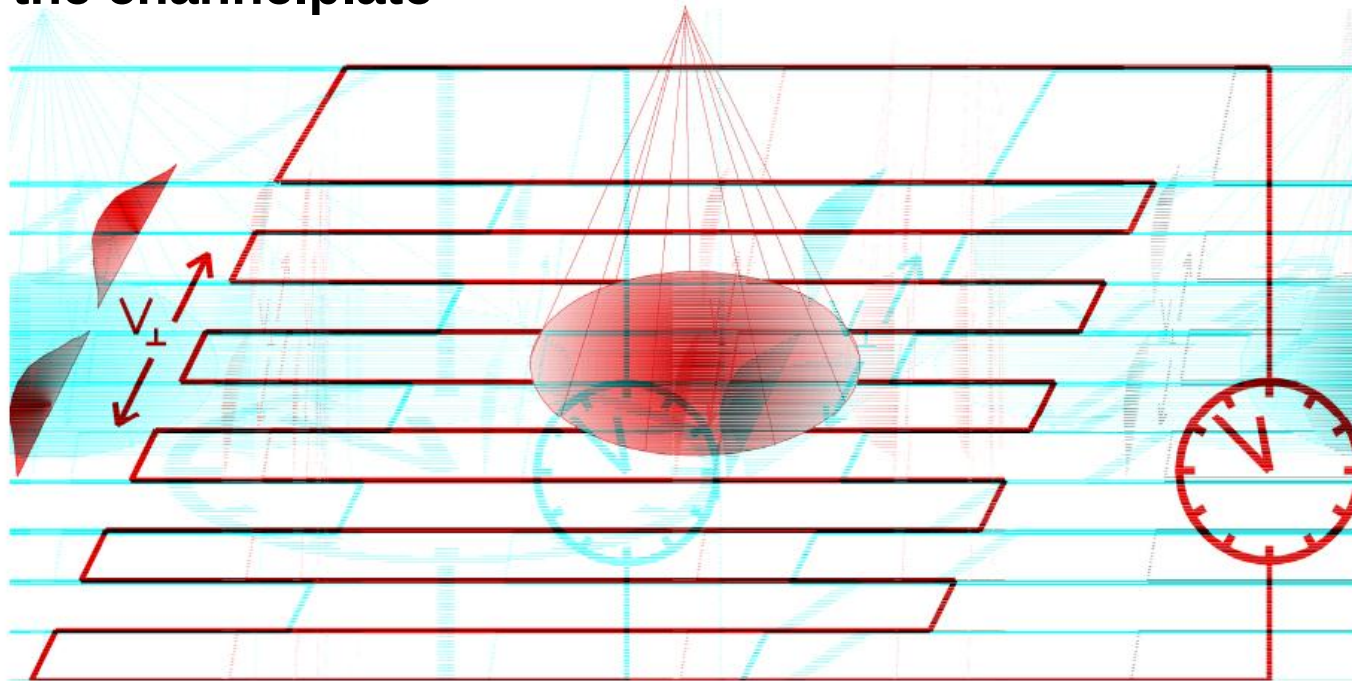
how to get time and spacially resolving detector?

important element: multichannel plate detector

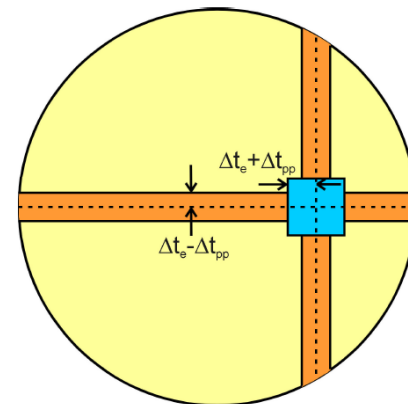


spatial resolution

with position-sensitive detection with the delay-line detector
behind the channelplate



high resolution
with the
Hexanode
detector

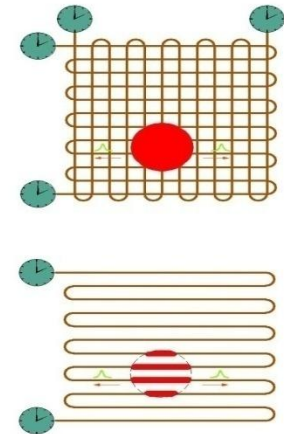
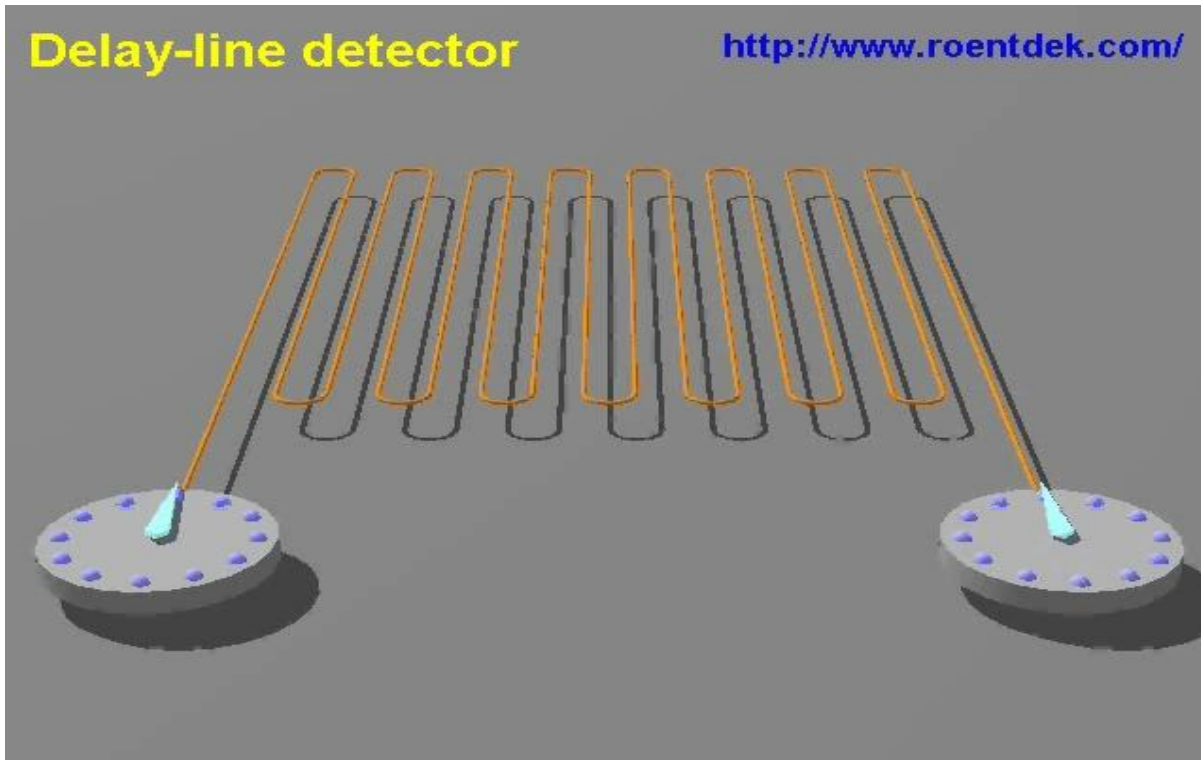


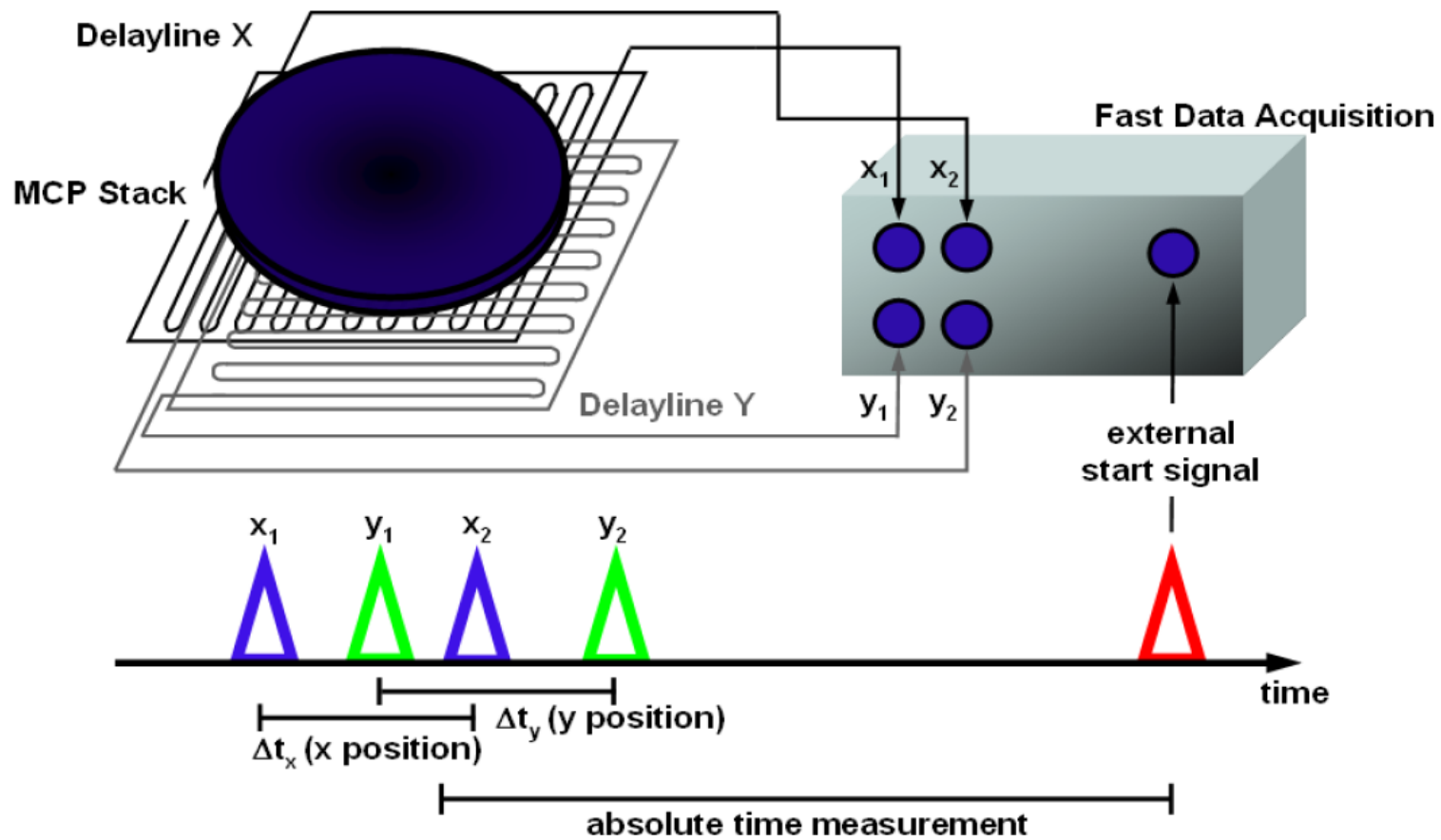
delay-line timing signals

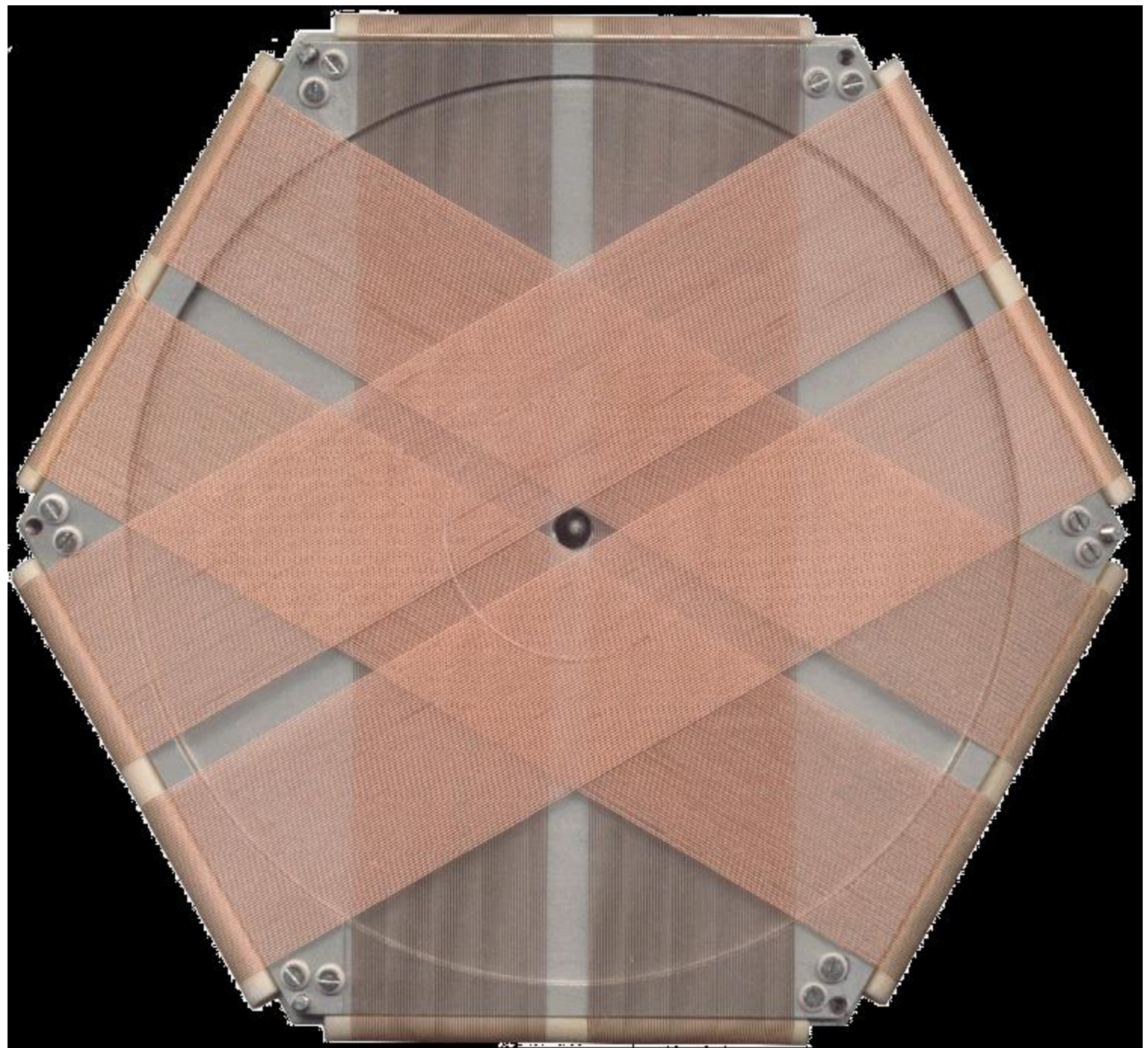
All times recorded in a time-to-digital converter on an event-by-event basis by computer

Delay-line detector

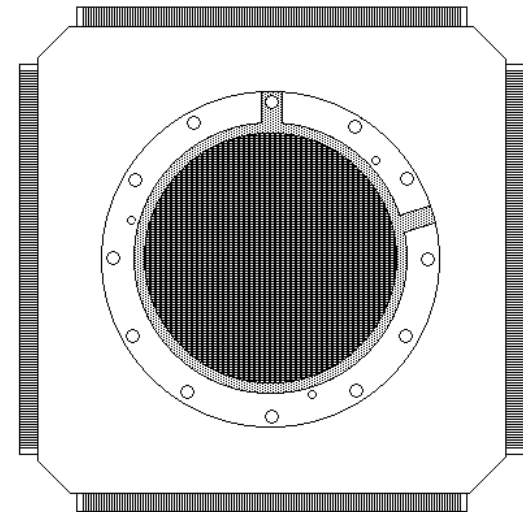
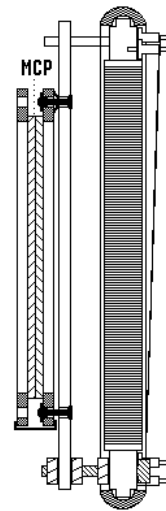
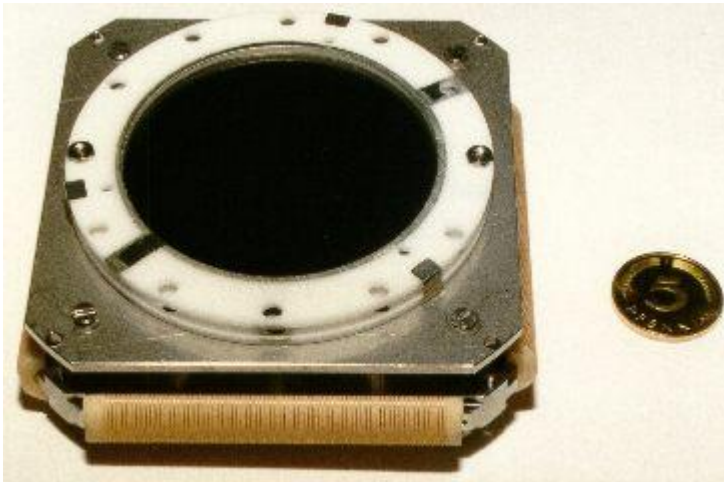
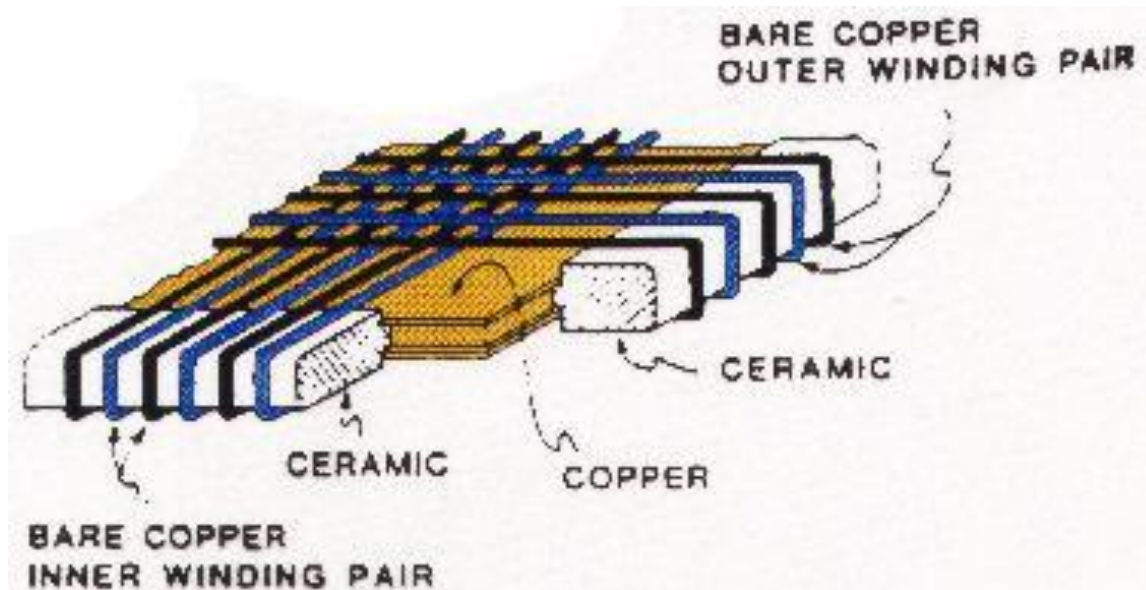
<http://www.roentdek.com/>



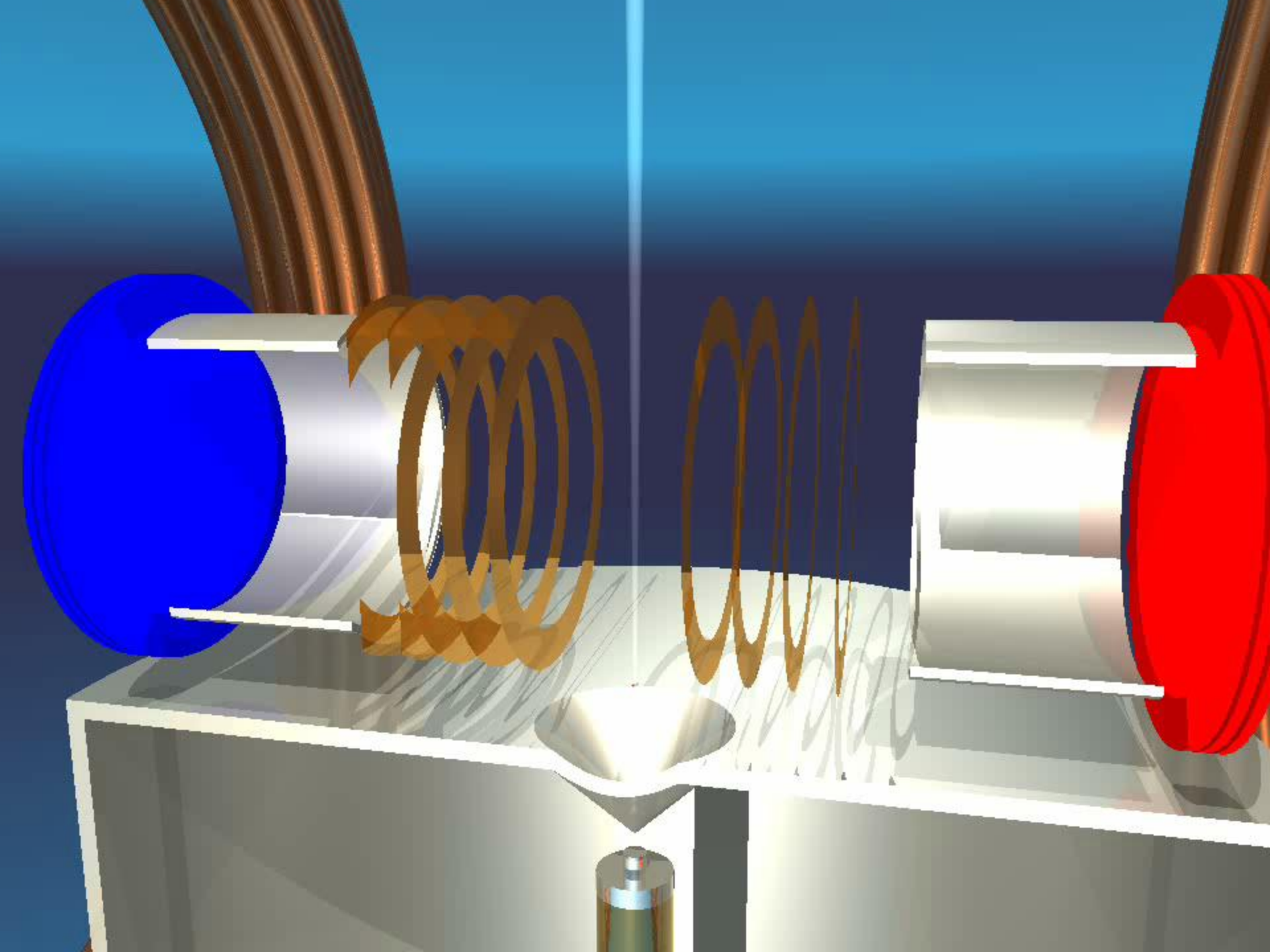


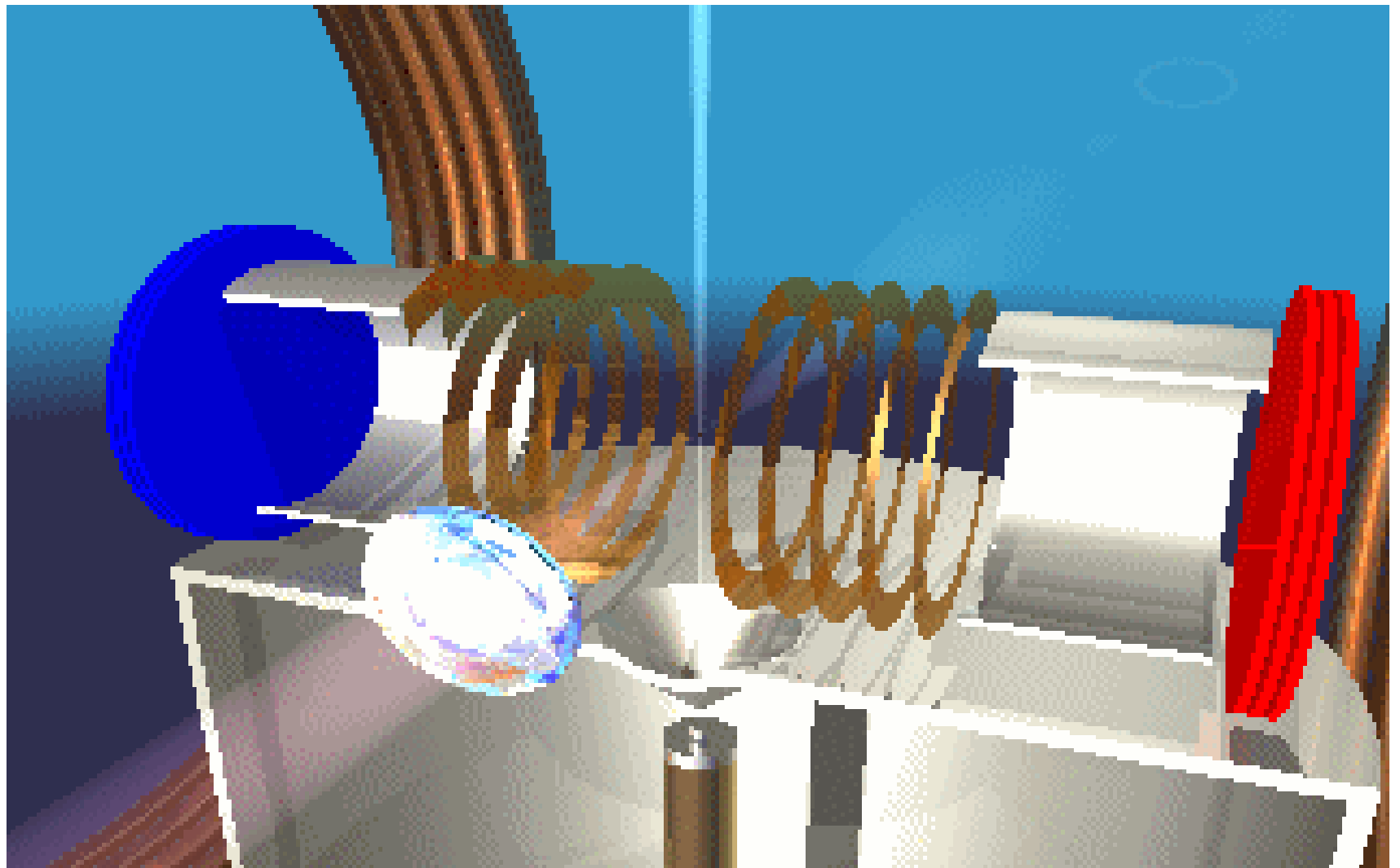


delay line detector

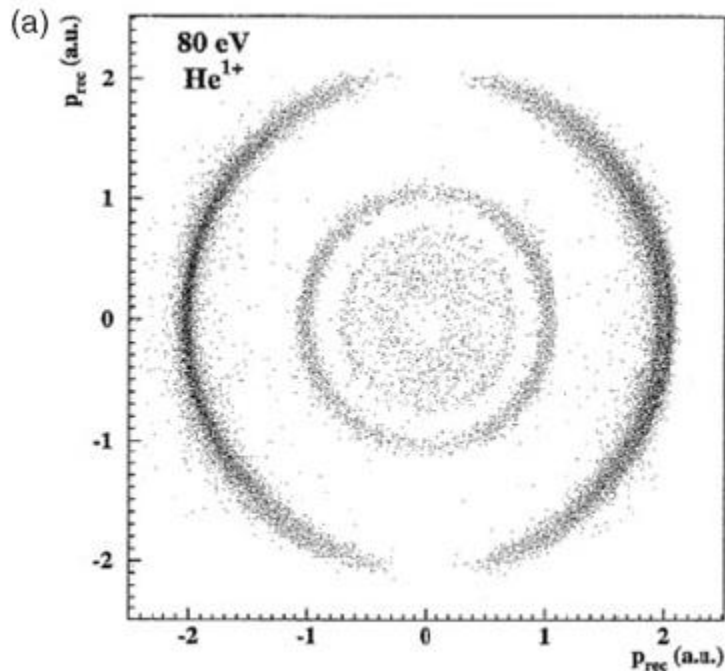


delay line detector with MCP

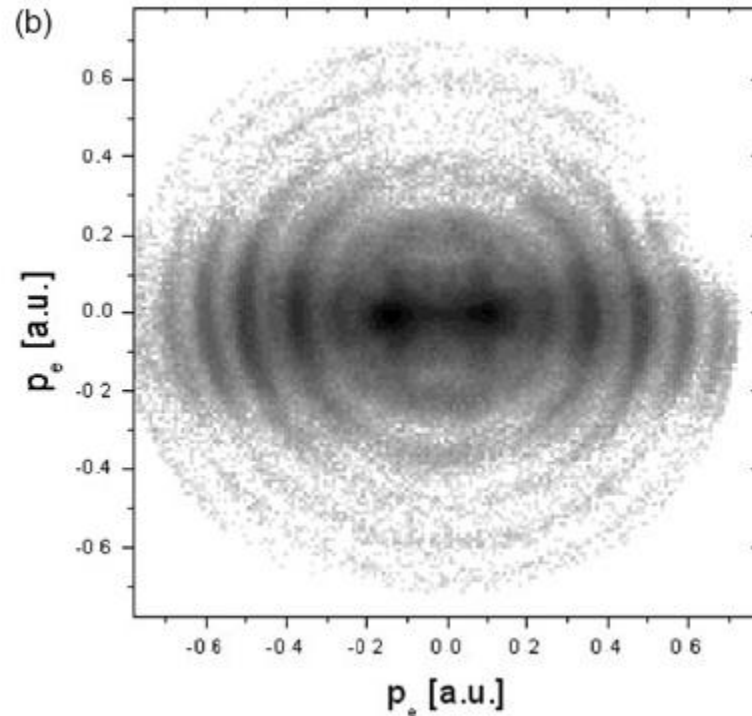




momentum distributions from He ionization



single ionization with 80 eV



multiphoton single ionization
with 25 fs at 800 nm
10exp15 W/cm²