

Beschleunigung von Molekülen

Not und Tugend

Beschleuniger-Massenspektrometrie

- Unterdrückung von molekularen Ionen
- “SuperSIMS”
- Die Geschichte mit den Sauriern

MeV Clusterionen

- Die Technik
- Coulomb-Explosion
- Energiedeposition
- Nanolithographie

6. Dezember 2001
M. Döbeli



PSI
Teilchen und Materie
(TEM)

ETHZ
Teilchenphysik
(IPP)

Labor für Ionenstrahlphysik

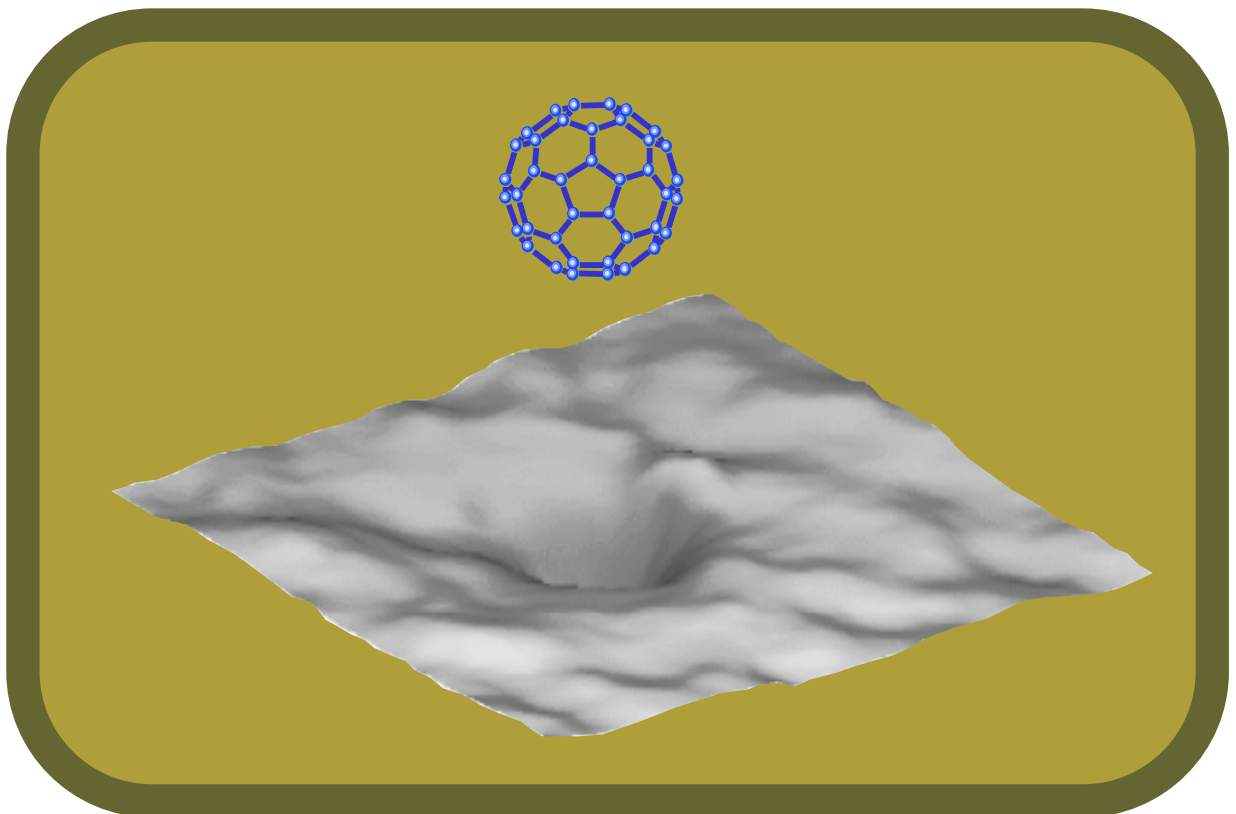


6 MV Tandem Van de Graaff, ETH-Hönggerberg

Beschleunigermassenspektrometrie (AMS)

Ionenstrahlanalyse

Ionenstrahlmodifikation



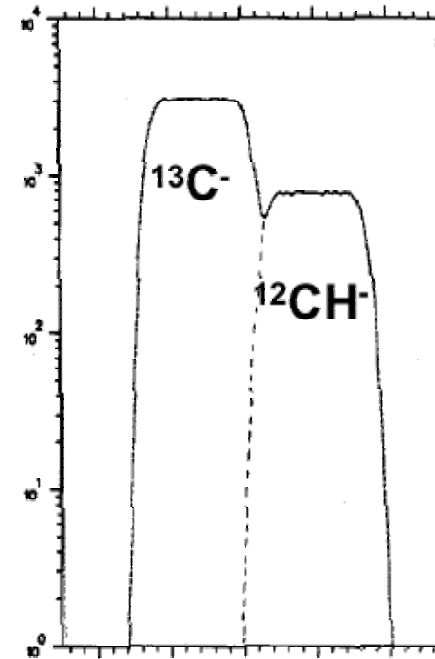
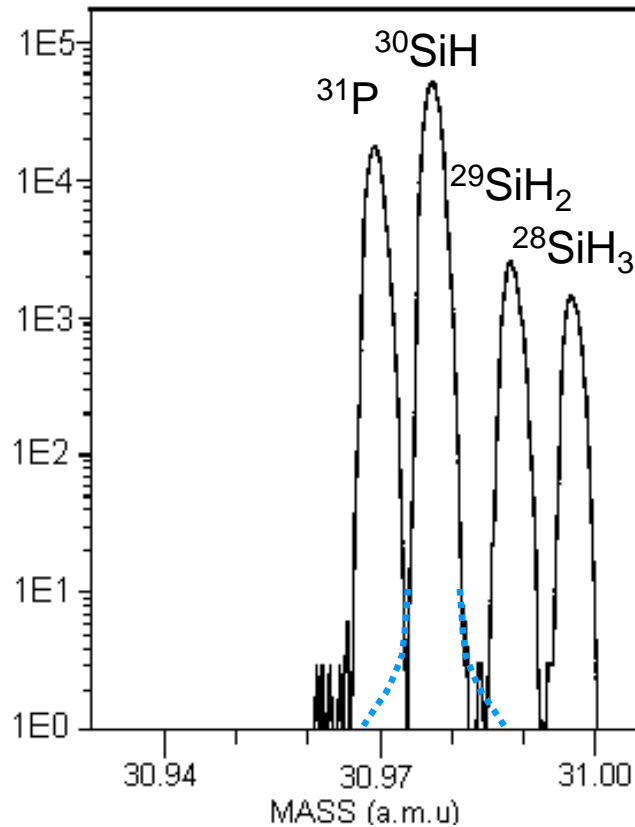
I. Teil

Zerstörung von Molekülen in Tandem- Beschleunigern

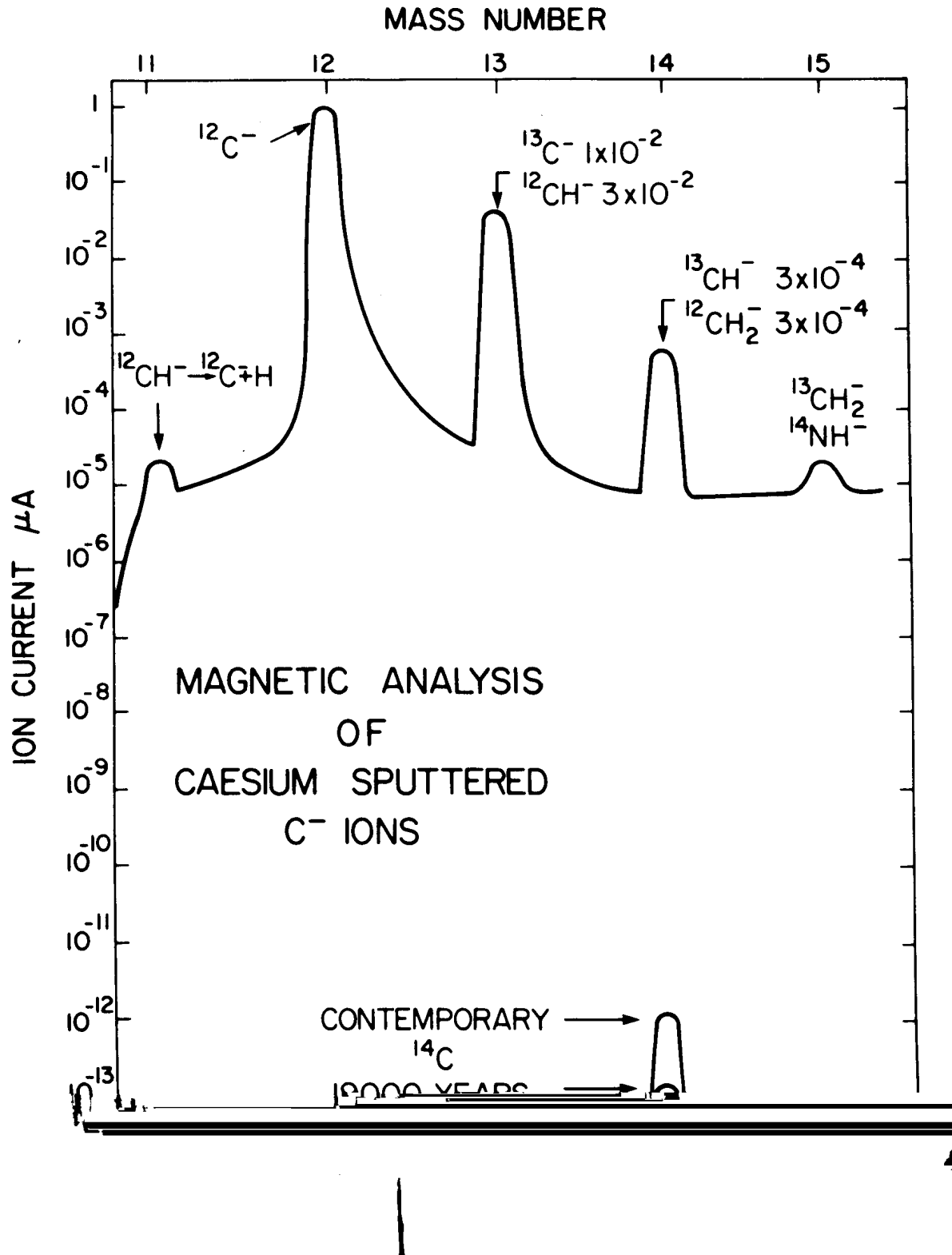
Grenzen der konventionellen Massenspektrometrie

Probenmaterial \longrightarrow Ionen \longrightarrow Massenspektrometer

Problem: molekulare Ionen!

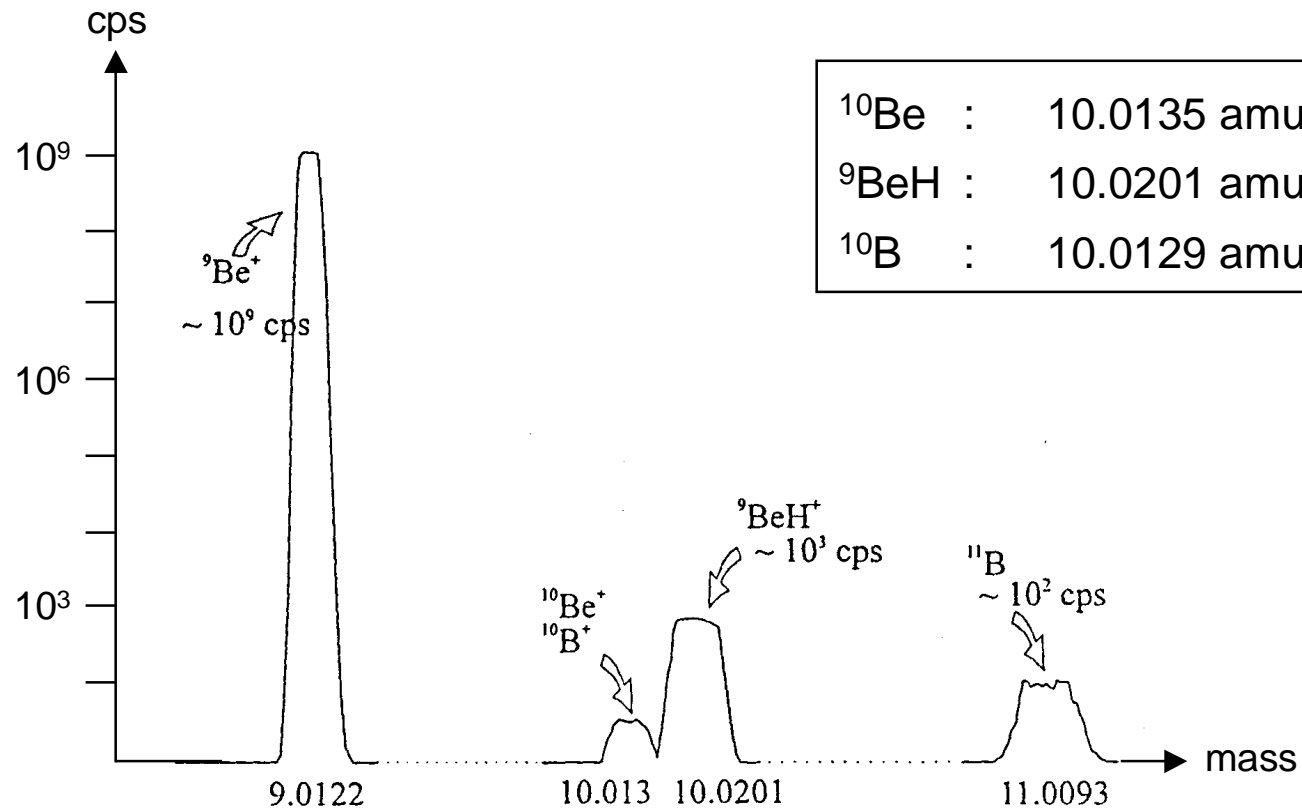


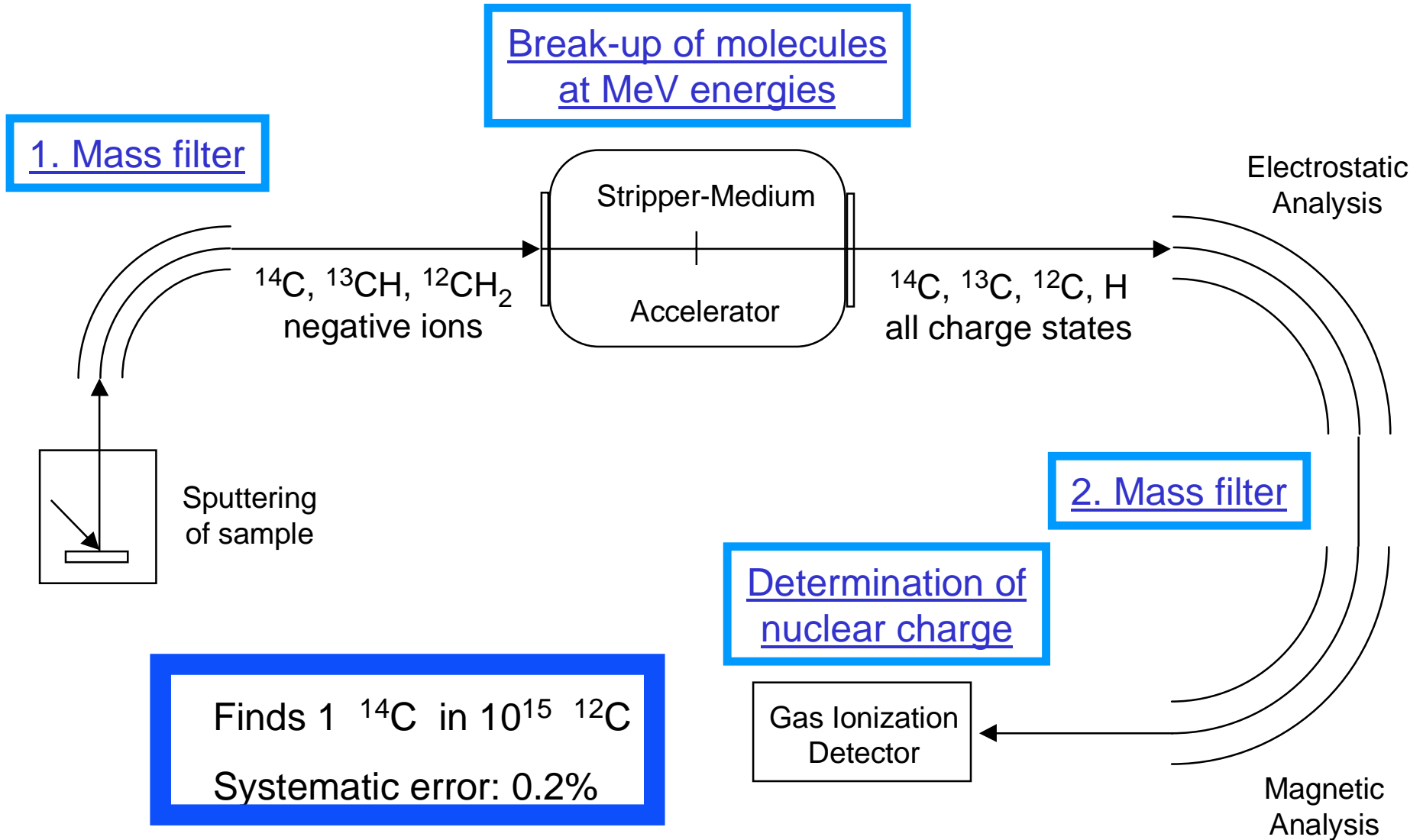
Selbst bei hoher Massenauflösung ($M/\Delta M = 10^4$) können benachbarte Peaks nur bis zu einem gewissen Niveau getrennt werden.



Detektion von ^{10}Be

Diskrimination gegen ^9BeH und ^{10}B





Beschleuniger-Massenspektrometrie

Accelerator Mass Spectrometry (AMS)

Nachweisgrenzen: 10^{-10} bis 10^{-15}

Hauptanwendung: kosmogene Radionuklide

^{14}C , ^{10}Be , ^{26}Al , ^{36}Cl , ^{41}Ca , ^{129}I , etc...

Unentbehrlich in

- Klimaforschung
- Archäologie
- Geologie
- Ozeanographie
- Biomedizin

Nachweis stabiler Isotope mit AMS

Kombination von **SIMS** (**S**econdary **I**on **M**ass **S**pectrometry) mit **AMS**

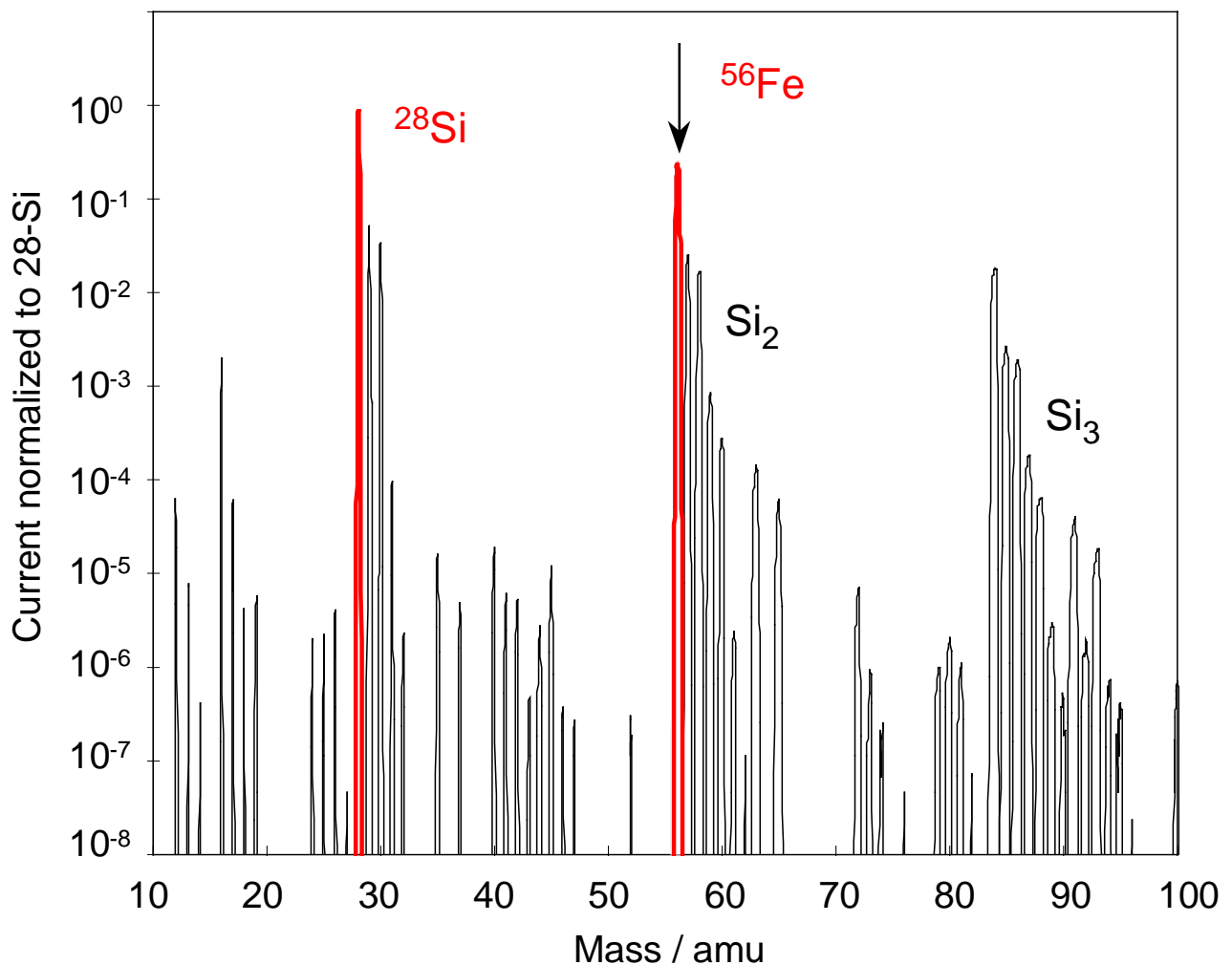
Super-SIMS (SSIMS)

Trace Element AMS (TEAMS)

- Molekularer Untergrund ca. um 12 Grössenordnungen unterdrückt
- Keine Dunkelzählrate
- Problem: Kontamination
- In einem beliebigen, makroskopischen Stück Materie kommen die meisten Elemente auf dem ppb-Niveau (10^{-9}) vor.

Beispiel: Nachweis von Fe in Si:

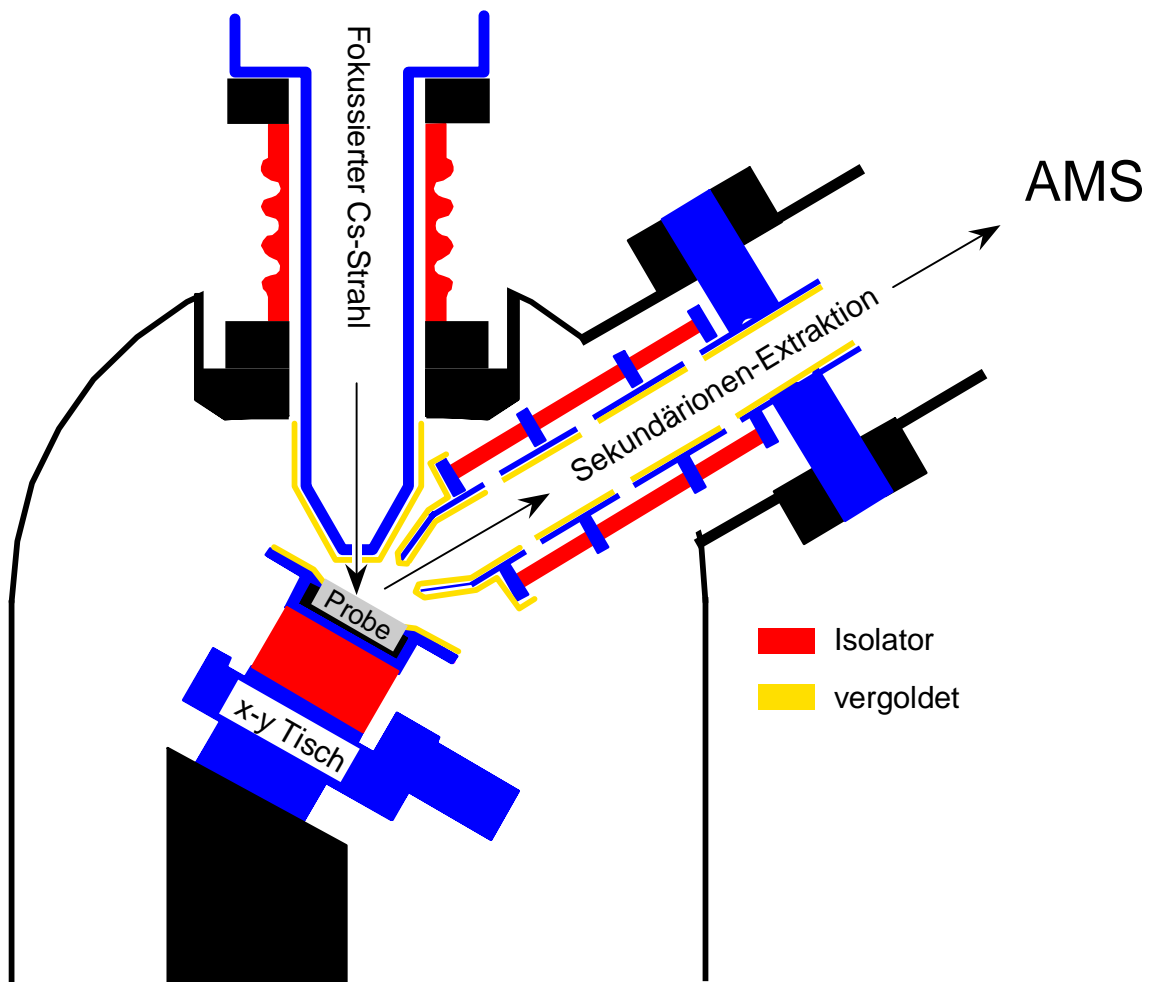
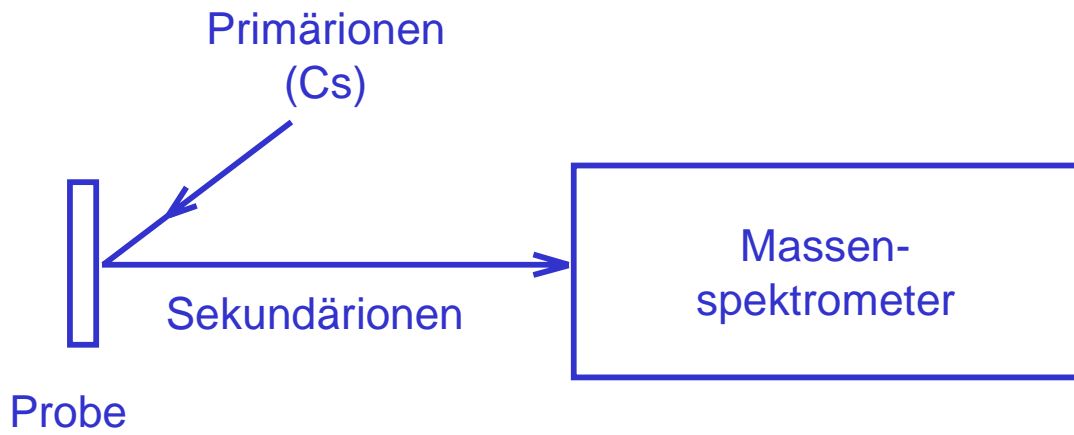
SIMS-Spektrum von reinem Si mit $M/\Delta M = 300$

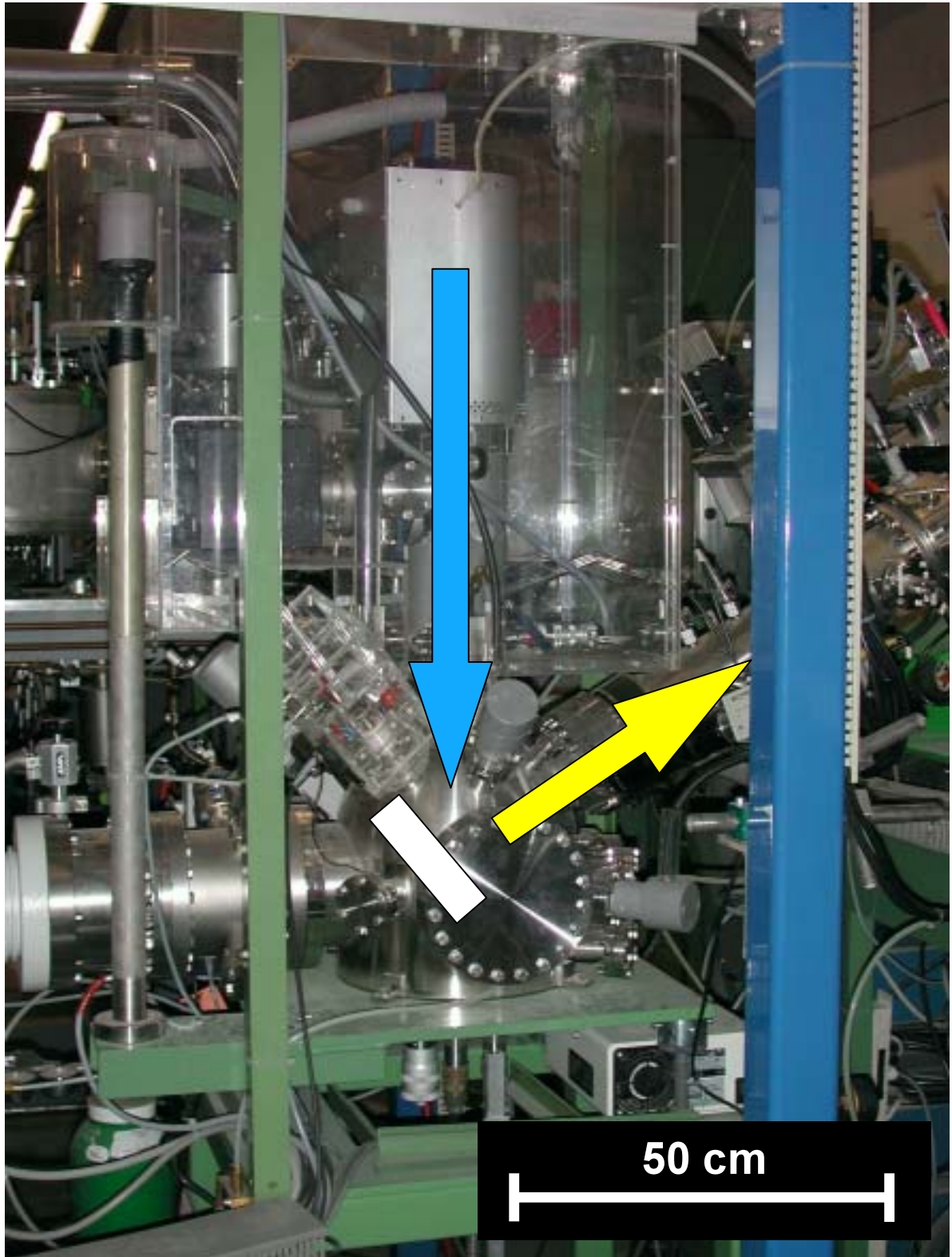


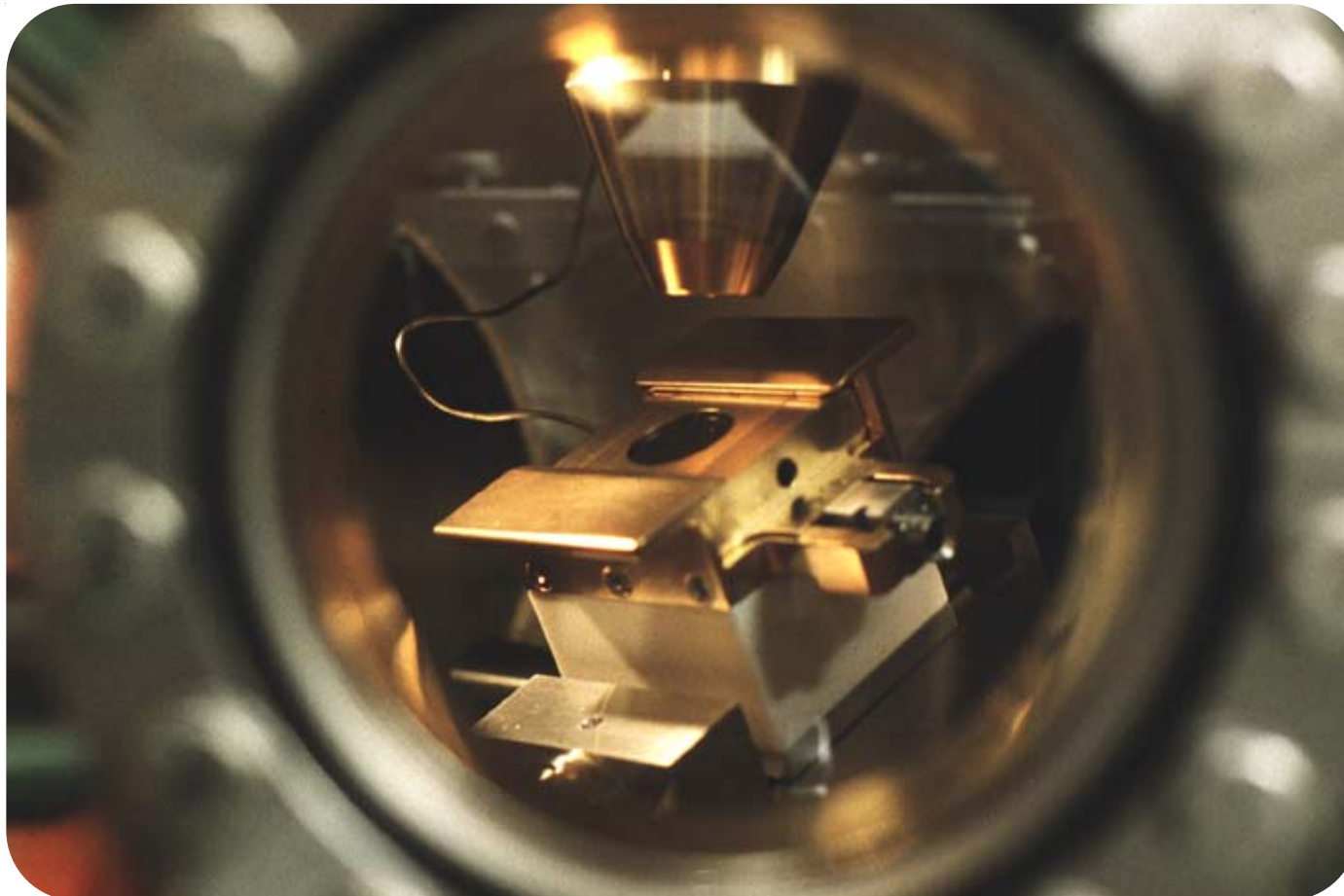
Si-Halbleitertechnologie:

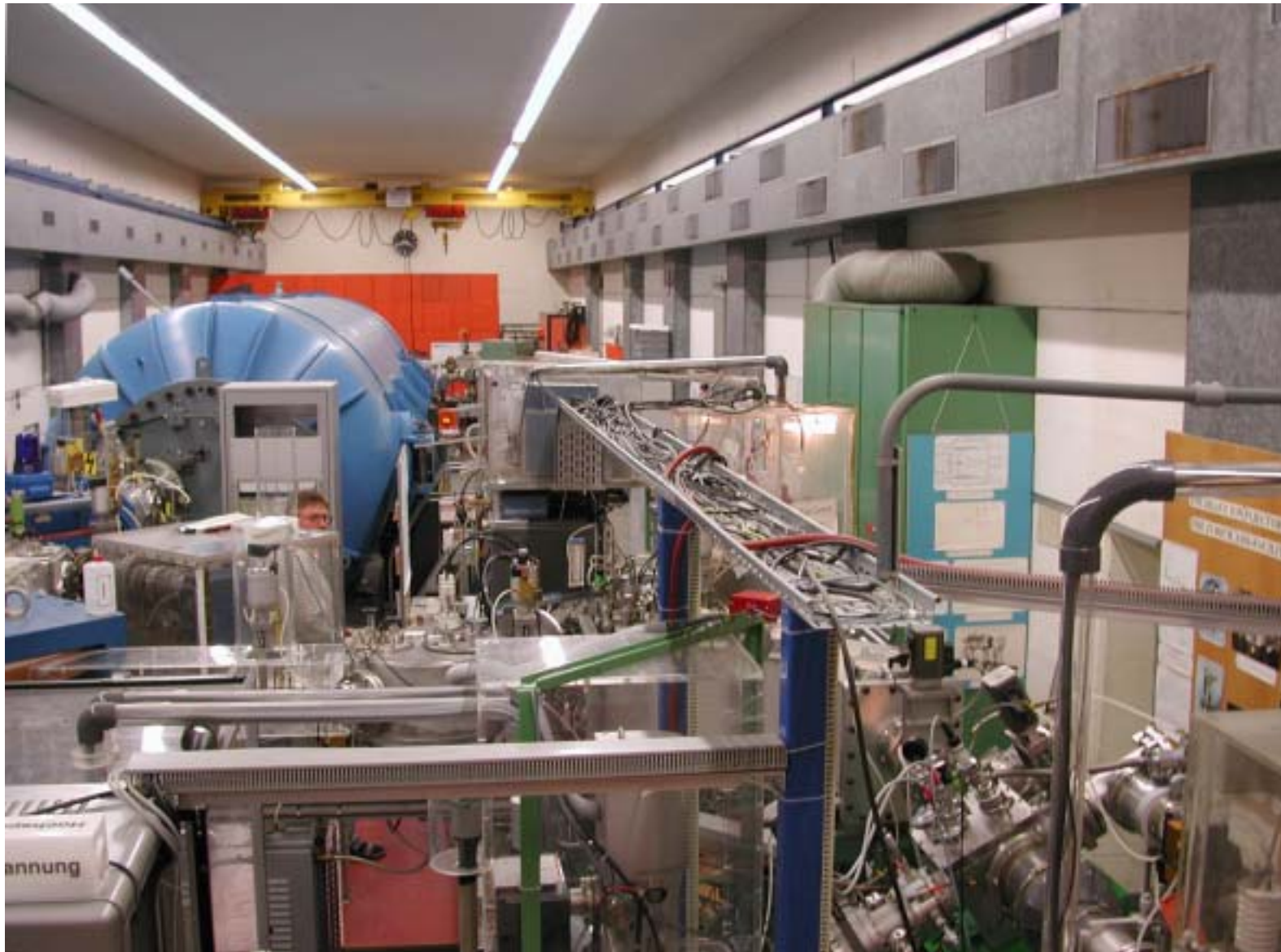
Konzentrationen von Übergangsmetallen $< 10^{-9}$ bis 10^{-12}

Experimenteller Aufbau



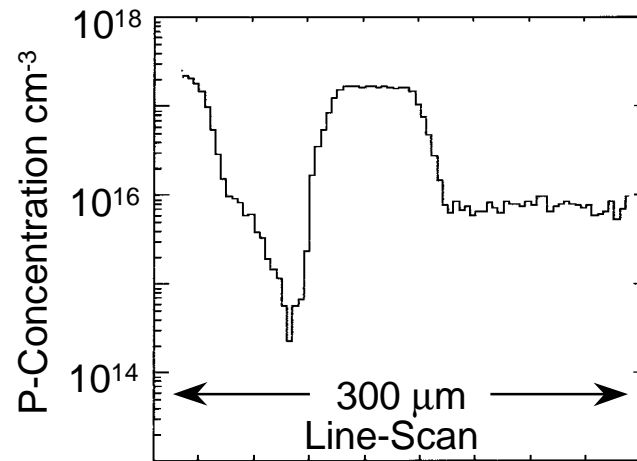
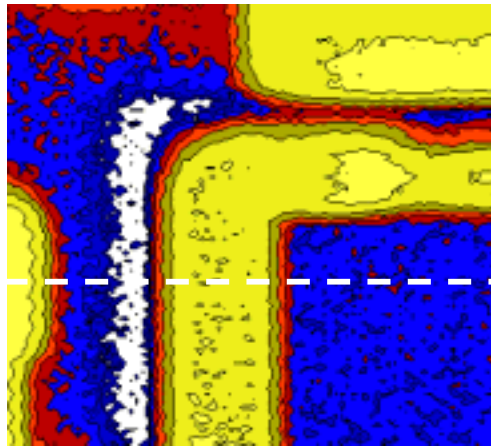
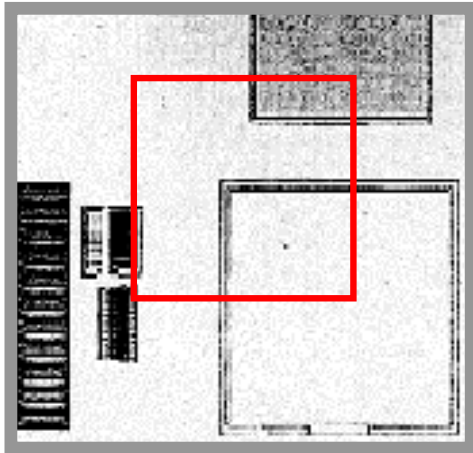






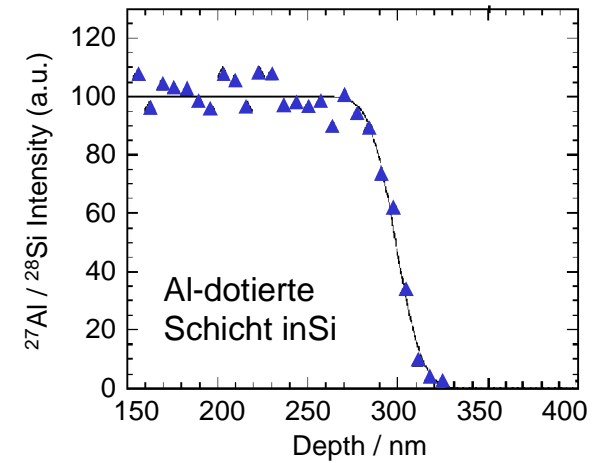
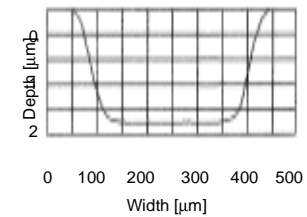
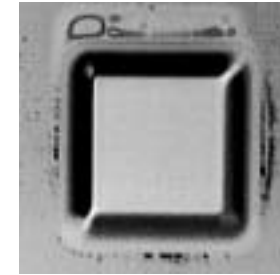
Rasterbild

2D Phosphorkonzentration



3 μm laterale Auflösung

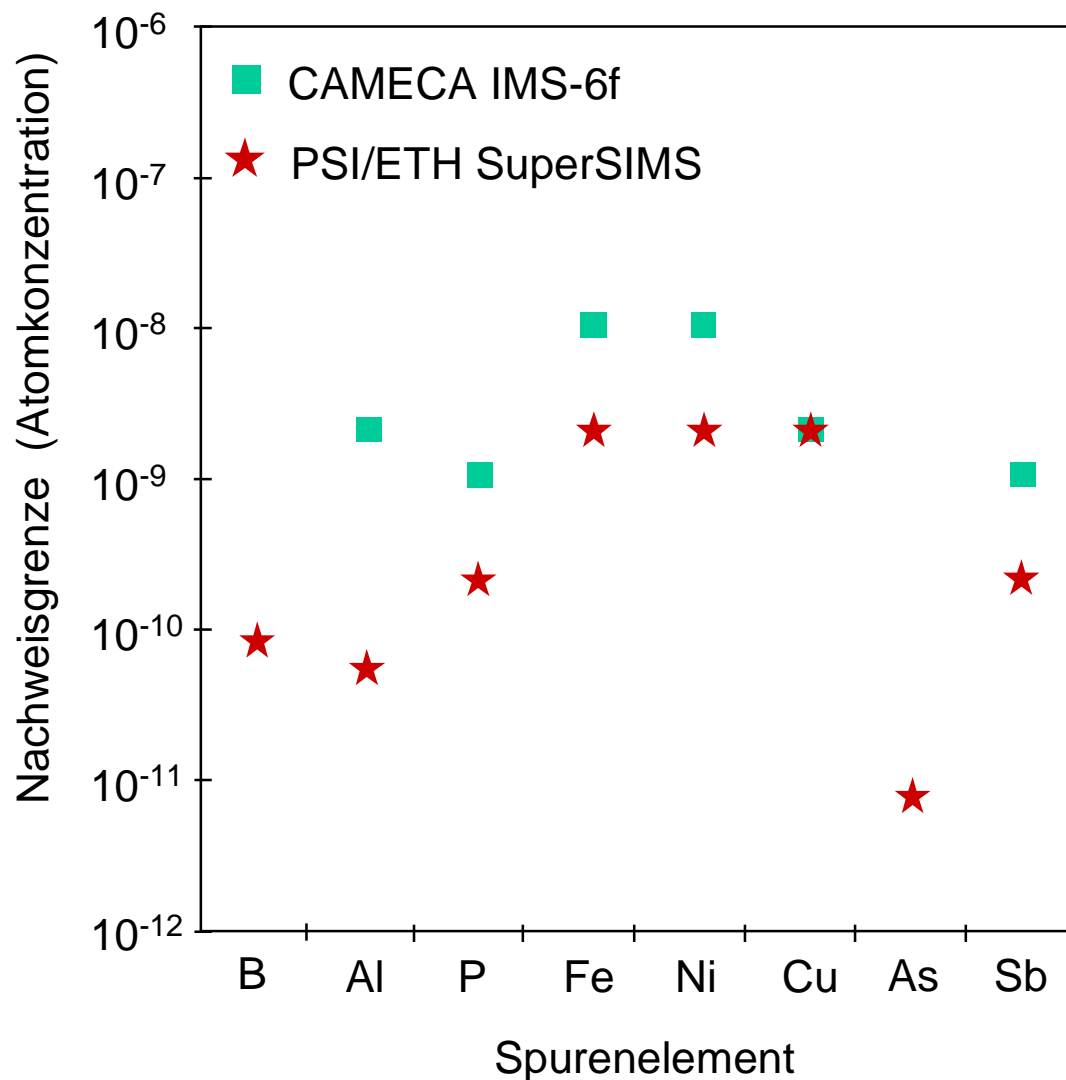
Tiefenprofil



Tiefenauflösung < 10 nm

SuperSIMS Nachweisgrenzen in Si:

B	$1 \cdot 10^{-10}$	$(5 \cdot 10^{12} \text{ cm}^{-3})$
Al	$7 \cdot 10^{-11}$	$(4 \cdot 10^{12} \text{ cm}^{-3})$
P	$2 \cdot 10^{-10}$	$(1 \cdot 10^{13} \text{ cm}^{-3})$
Fe	$2 \cdot 10^{-9}$	$(1 \cdot 10^{14} \text{ cm}^{-3})$
Ni	$2 \cdot 10^{-9}$	$(1 \cdot 10^{14} \text{ cm}^{-3})$
Cu	$2 \cdot 10^{-9}$	$(1 \cdot 10^{14} \text{ cm}^{-3})$
As	$9 \cdot 10^{-12}$	$(5 \cdot 10^{11} \text{ cm}^{-3})$
Sb	$2 \cdot 10^{-10}$	$(1 \cdot 10^{13} \text{ cm}^{-3})$



Das Ereignis an der KT-Grenze

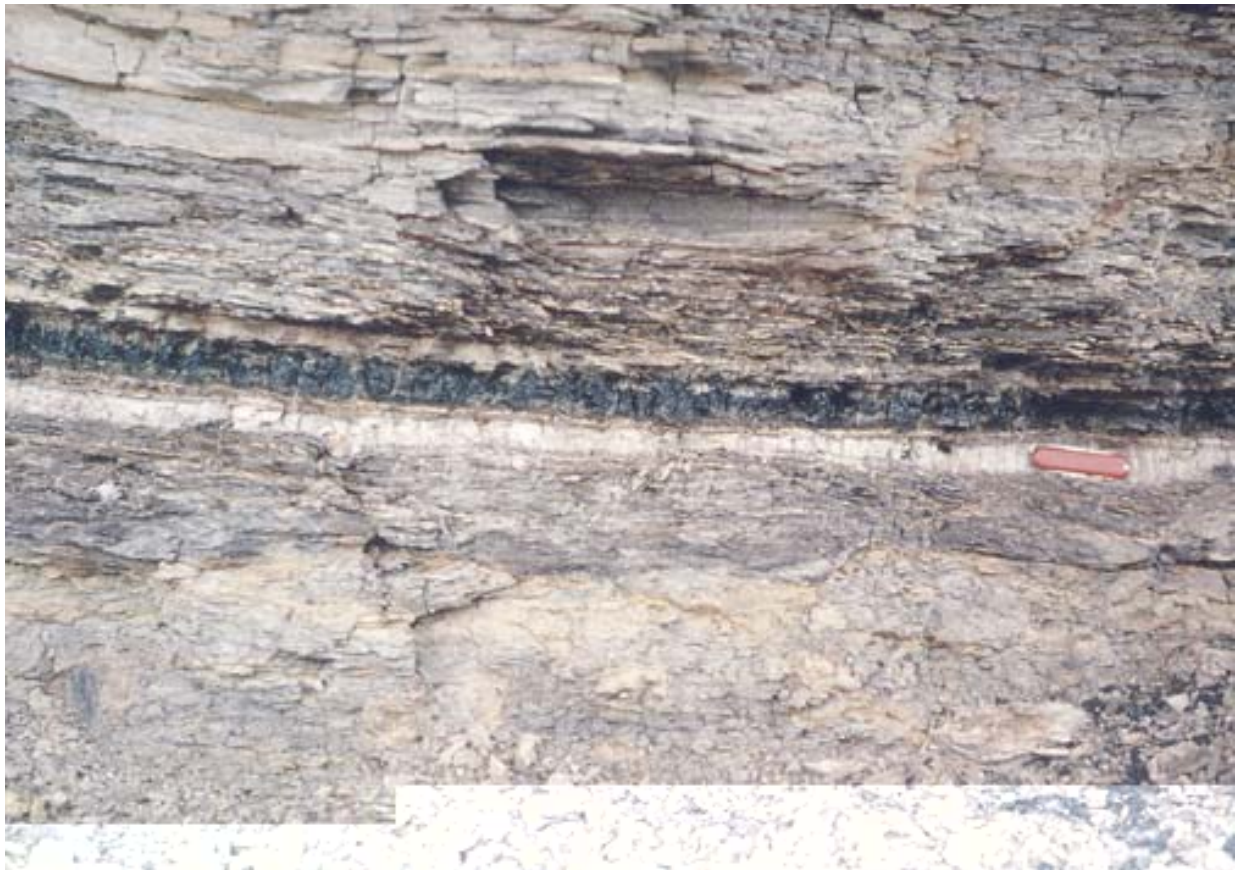
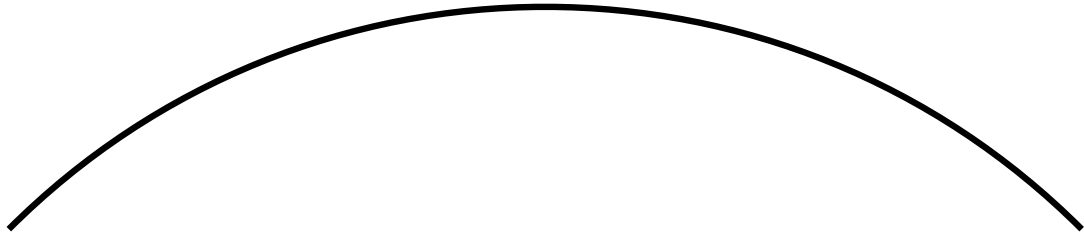
Massensterben am Übergang
Kreidezeit → Tertiär vor 65 Millionen Jahren.

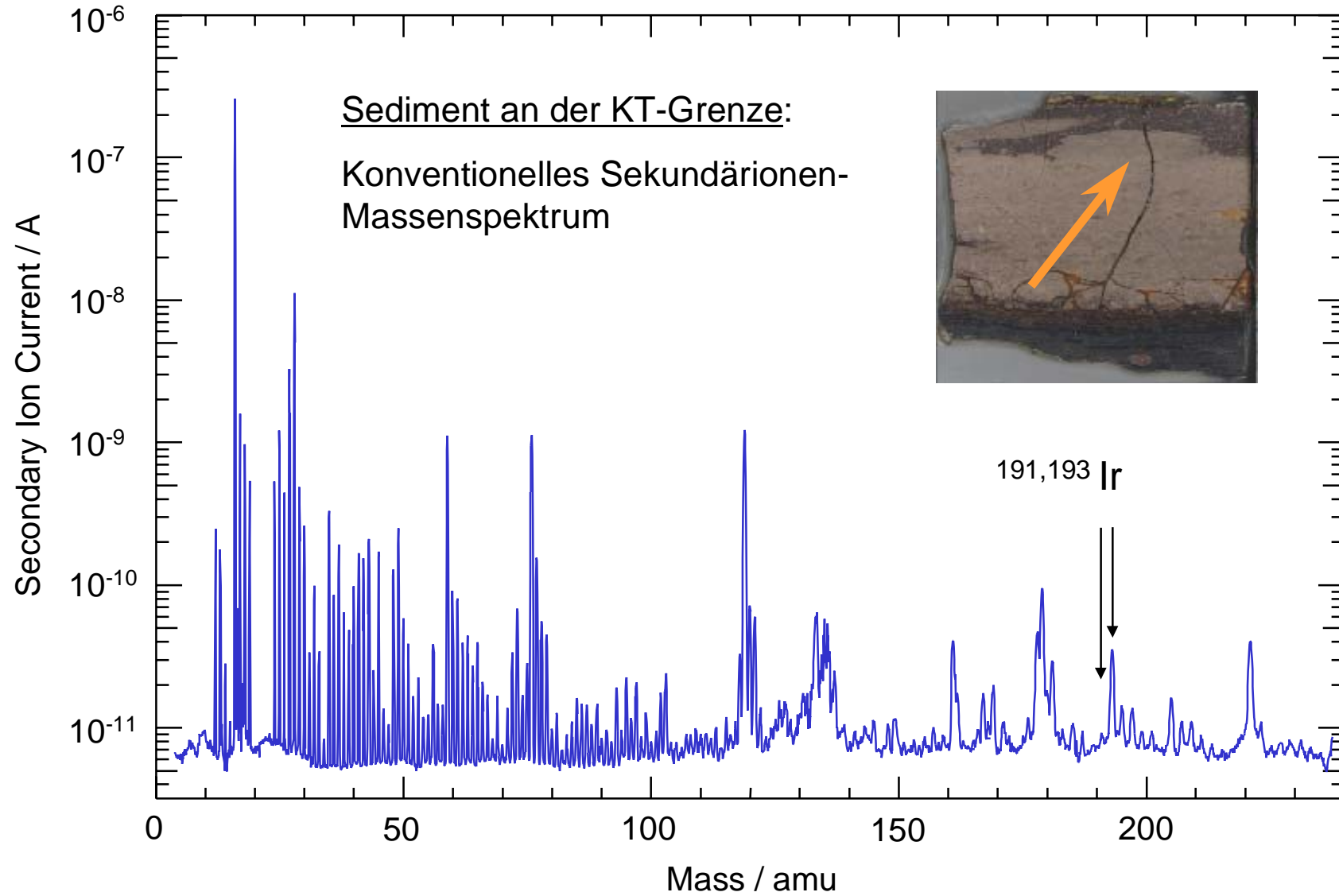
Weltweites 'KT-Sediment'

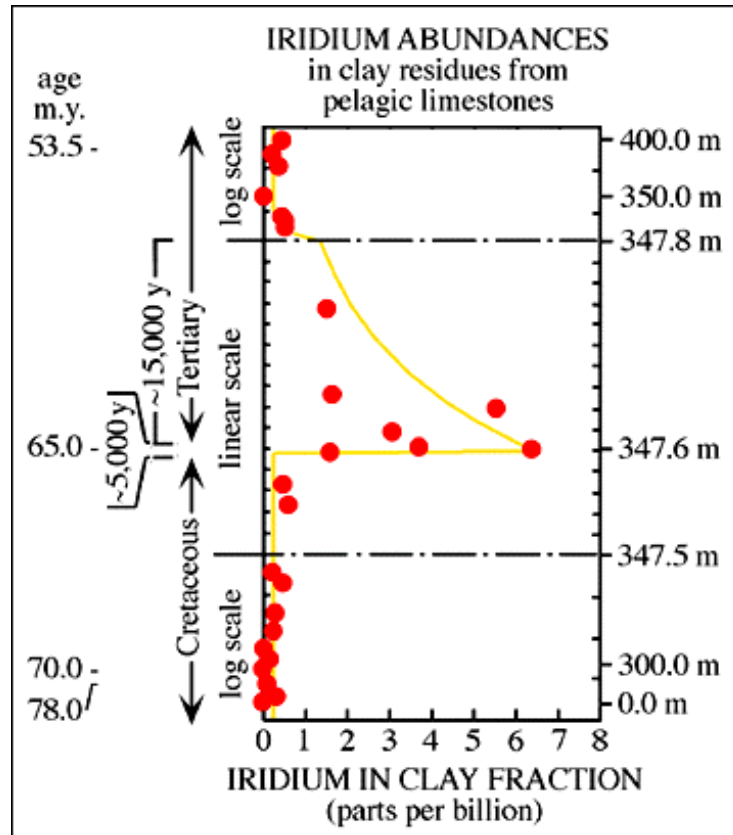
Alvarez (1980): Asteroideneinschlag

1991: Chicxulub Krater (Golf von Mexiko)

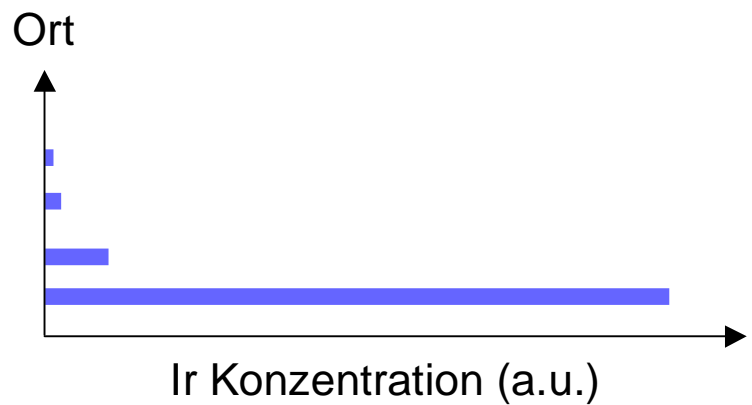
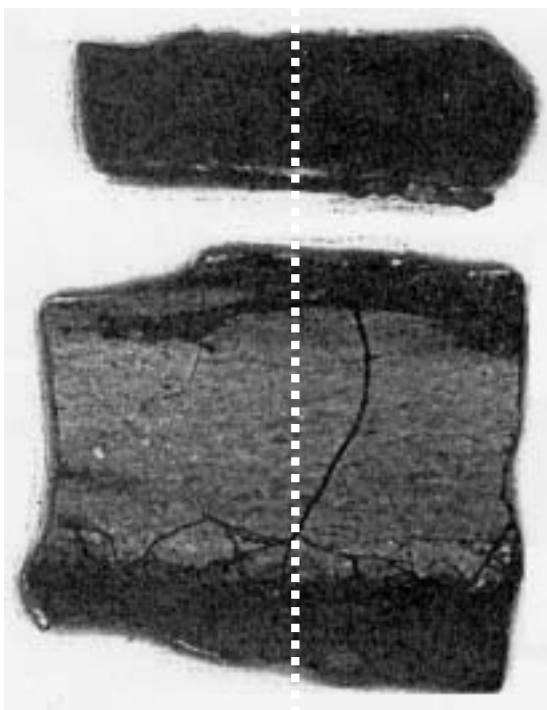






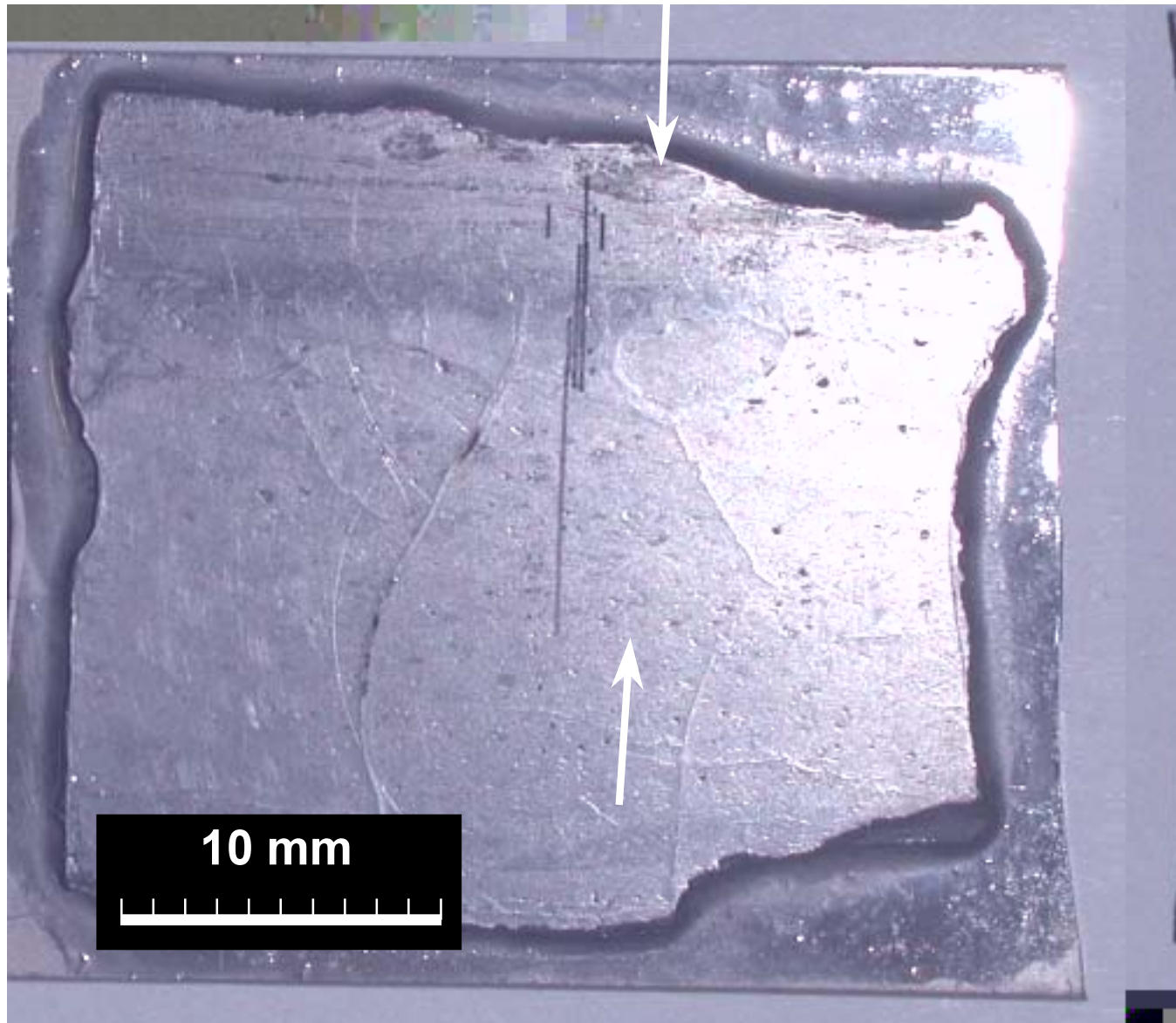


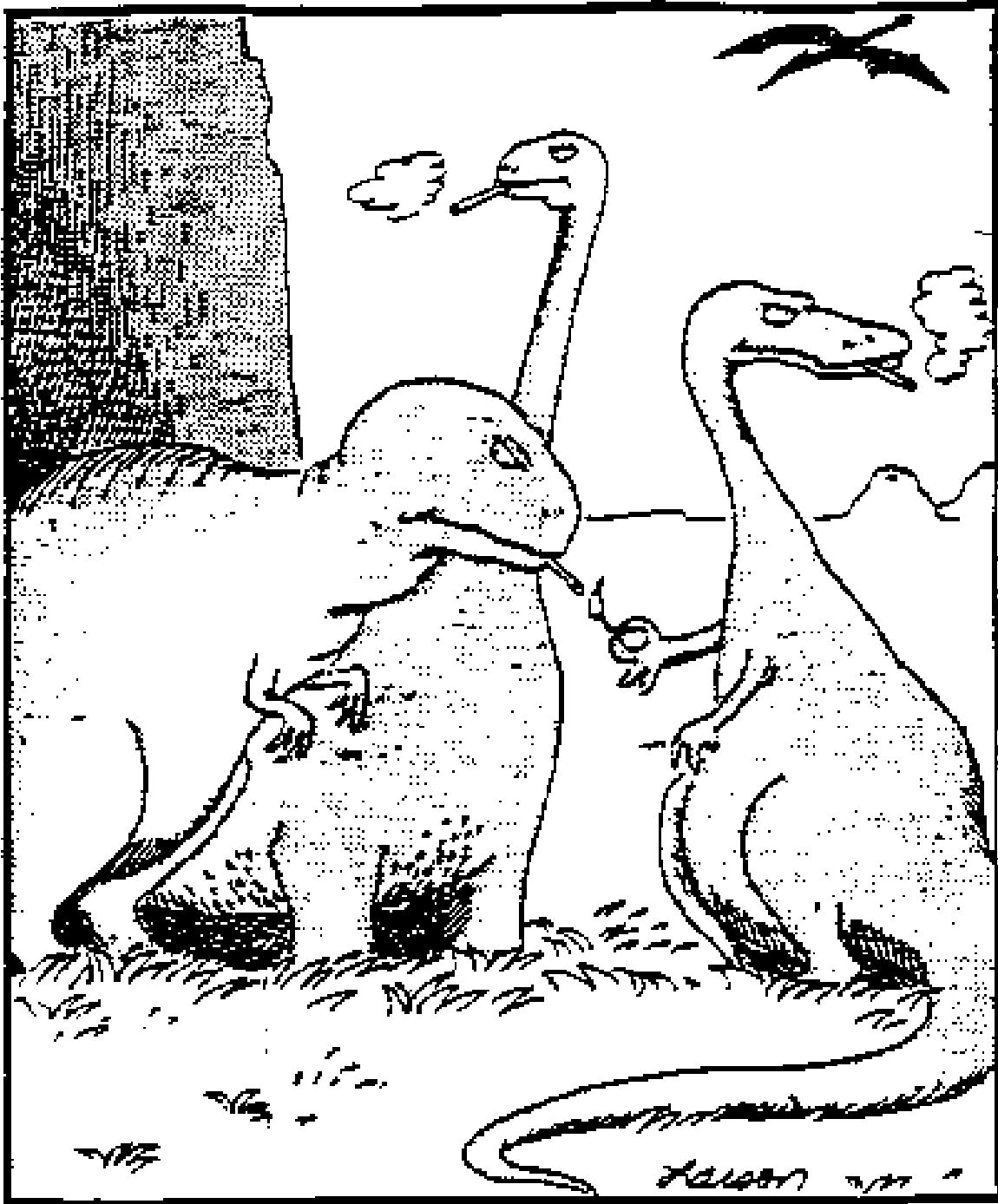
Alvarez
1980



KT-Sediment
Starkville, Colorado

B. Hofmann, NMBE



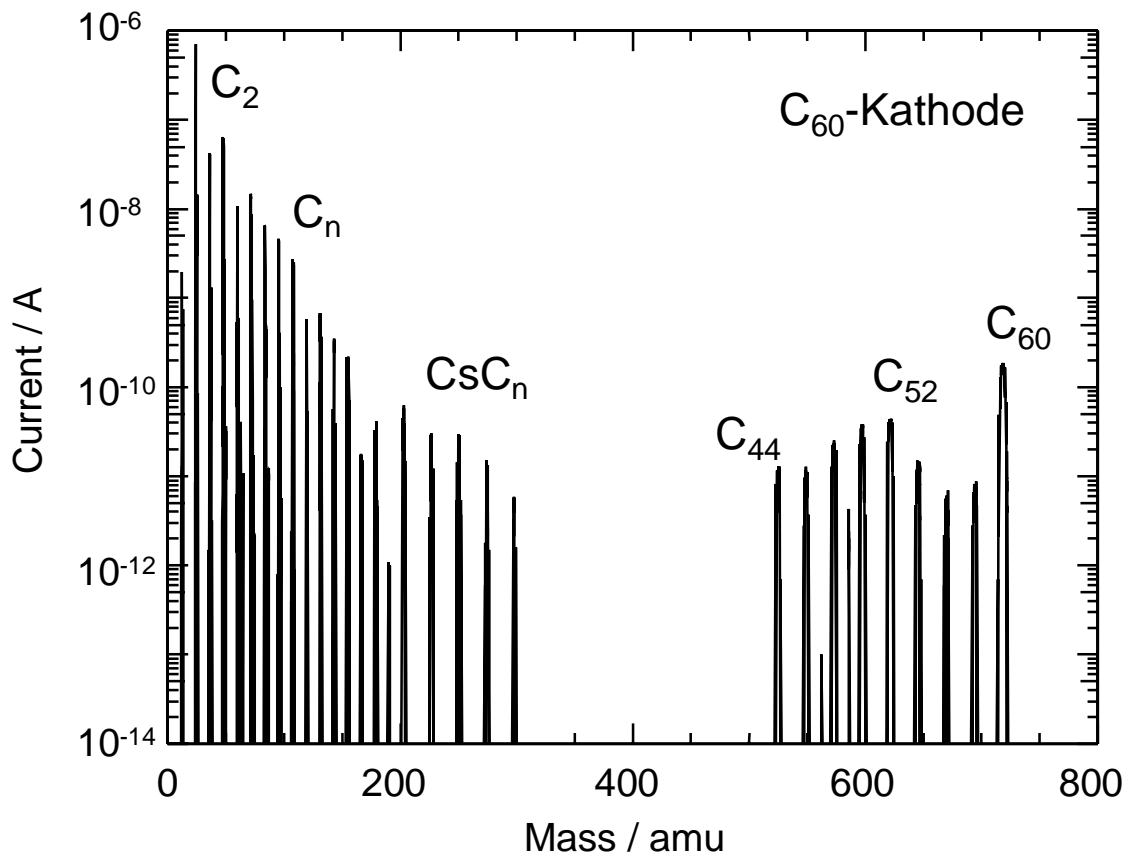
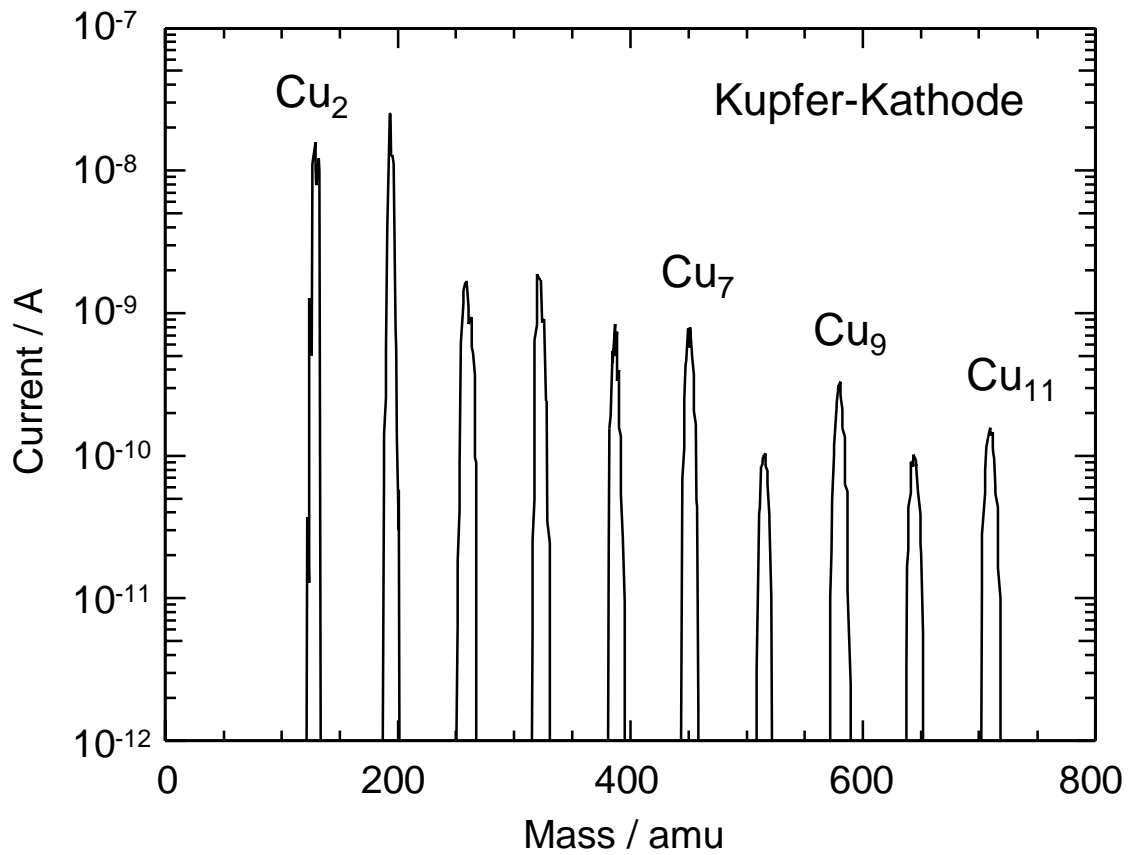


The real reason dinosaurs became extinct.

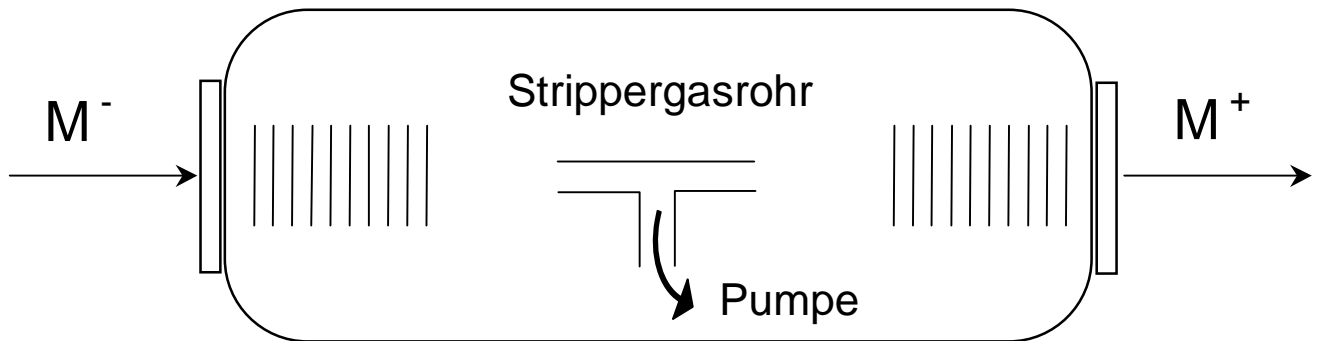
II. Teil

Beschleunigung von Molekülen auf MeV Energien

Massenspektren der Sputter-Ionenquelle



Tandem-Beschleunigung von Molekülen



Strippergasdruck sehr niedrig
Ladungszustand 1^+ (max. 2^+)

Ergebnisse:

C_2 C_3 C_4 C_5 C_6 C_7 C_8 C_{10} C_{60}
 Ge_2 Ge_3
 Cu_9 Cu_{11}

Ströme: 100 fA bis 200 nA

Tandem-Beschleunigung von Molekülen

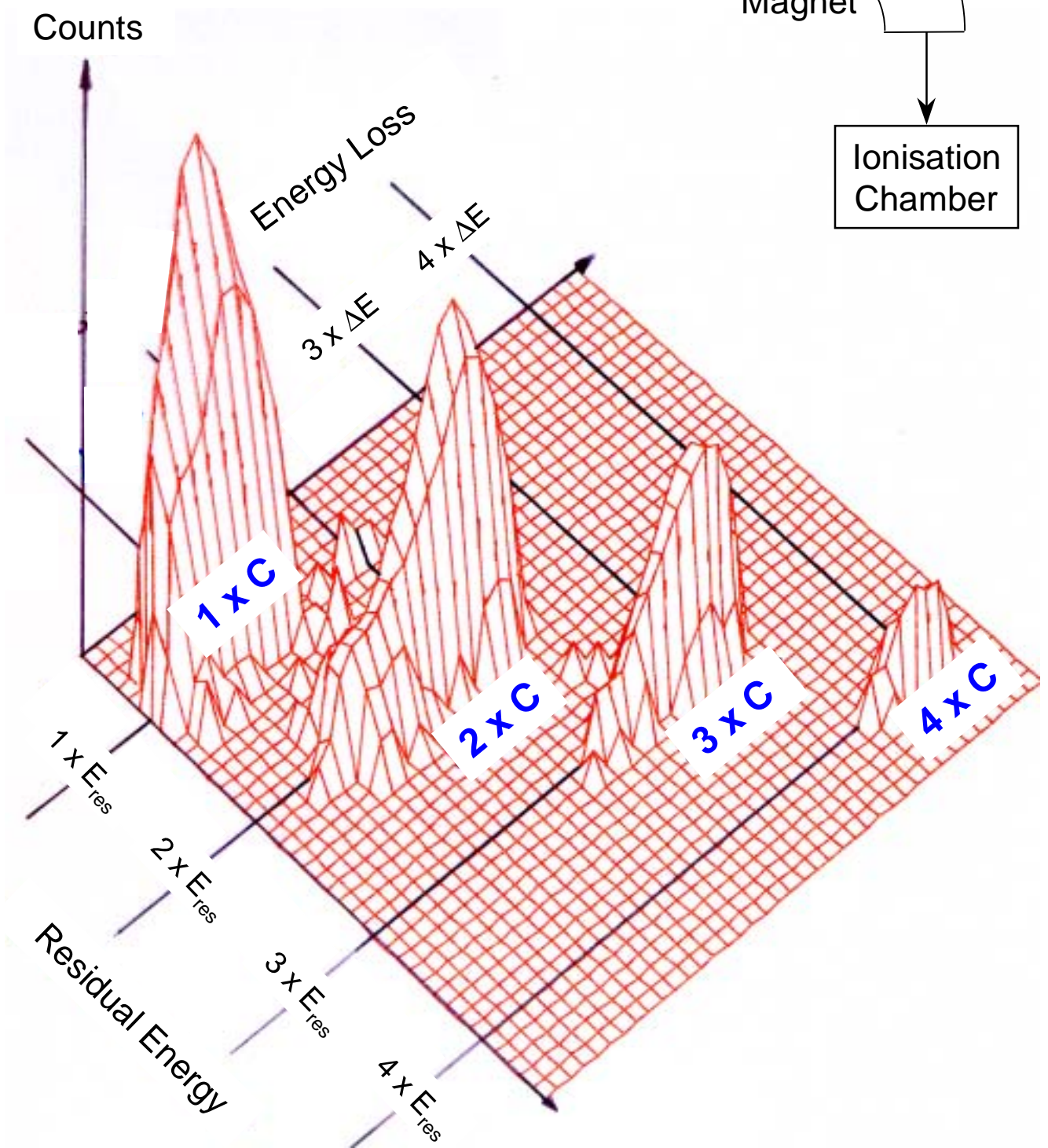
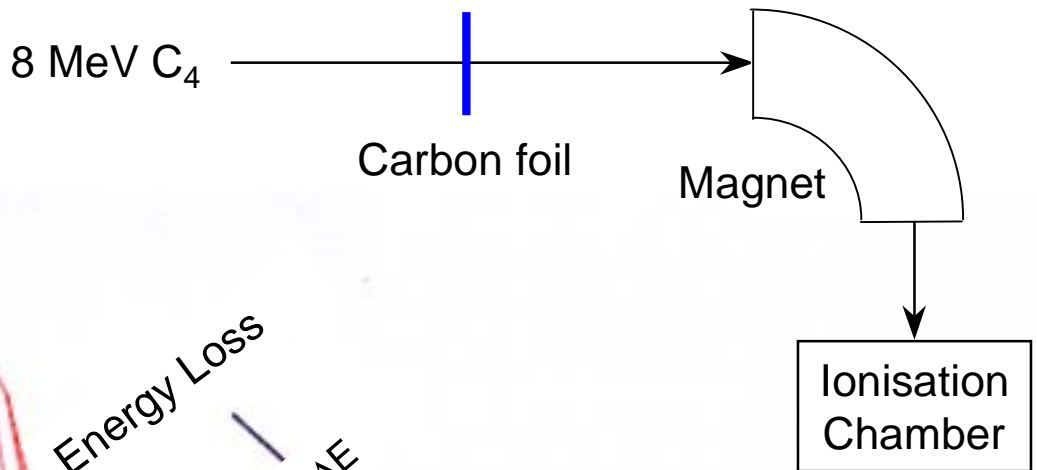
Strippergasdruck sehr niedrig

Ladungszustand 1^+ (max. 2^+)

Ergebnisse:

Teilchen	max. Energie	typ. Strom
C_2	8 MeV	200 nA
C_3	8 MeV	50 nA
C_4	8 MeV	20 nA
C_5	8 MeV	5 nA
C_6	8 MeV	10 nA
C_7	8 MeV	500 pA
C_8	8 MeV	2 nA
C_{10}	8 MeV	200 pA
C_{60}	15 MeV	300 fA
Ge_2	8 MeV	50 nA
Ge_3	8 MeV	5 nA
Cu_9	8 MeV	200 fA
Cu_{11}	8 MeV	100 fA

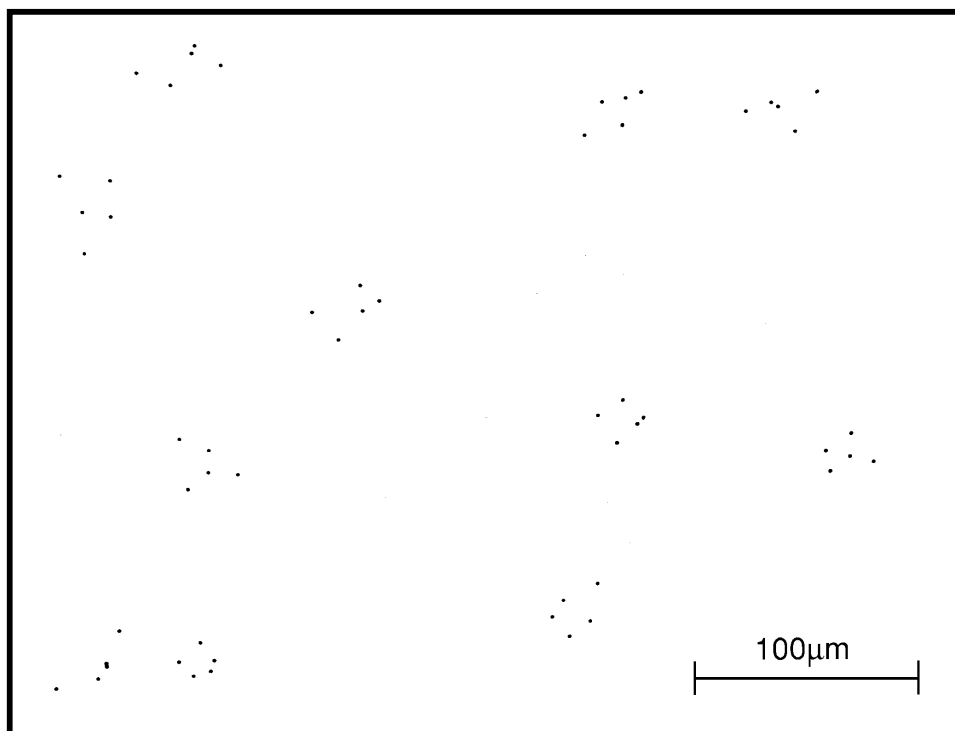
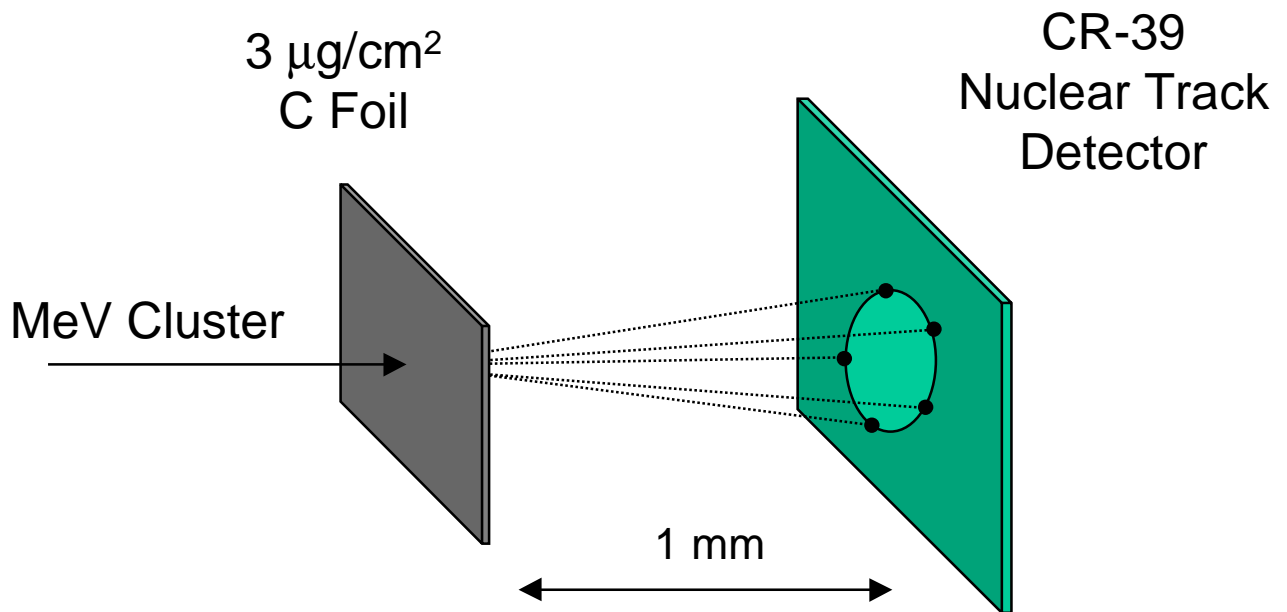
Is it a molecular ion?



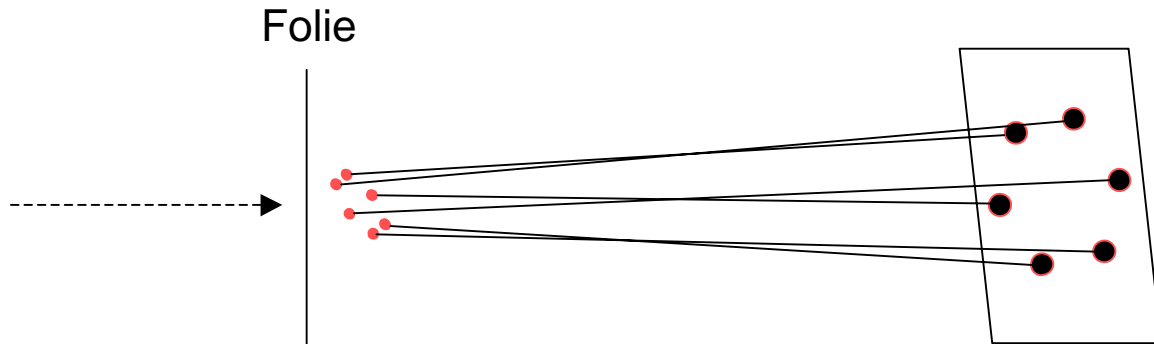
Untersuchungen mit MeV Molekülen

- ⊗ Abbildung der Coulomb-Explosion in Folien
- ⊗ Ionisations- und Zerstörungswirkungsquerschnitte in Gasen
- Coulomb-Explosion in Festkörperoberflächen
- Transmission von Molekülen durch Folien
- Nichtlineare Defekterzeugung in Si-Kristallen
- ⊗ Einschläge in Glimmer- und PMMA-Oberflächen
- ⊗ Nanolithographie mit molekularen Einzelionen

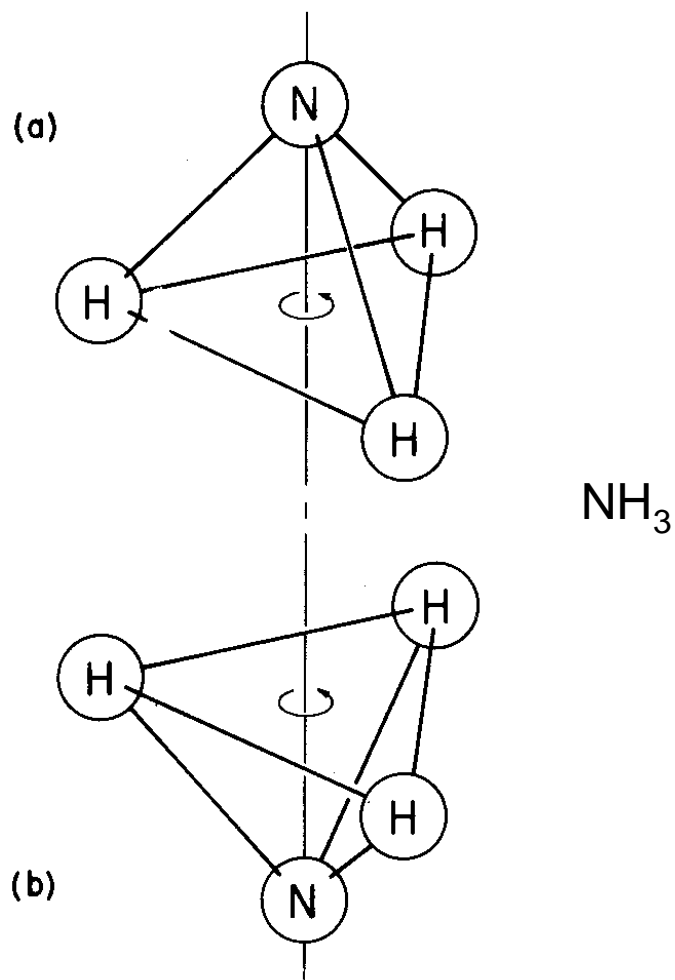
Observation of Coulomb-Explosion



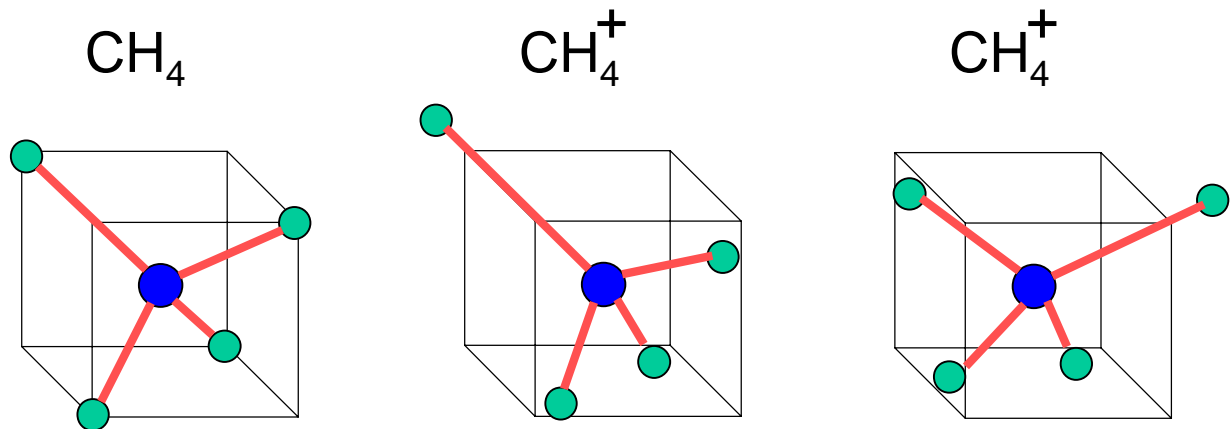
Coulomb Explosion Imaging (CEI)



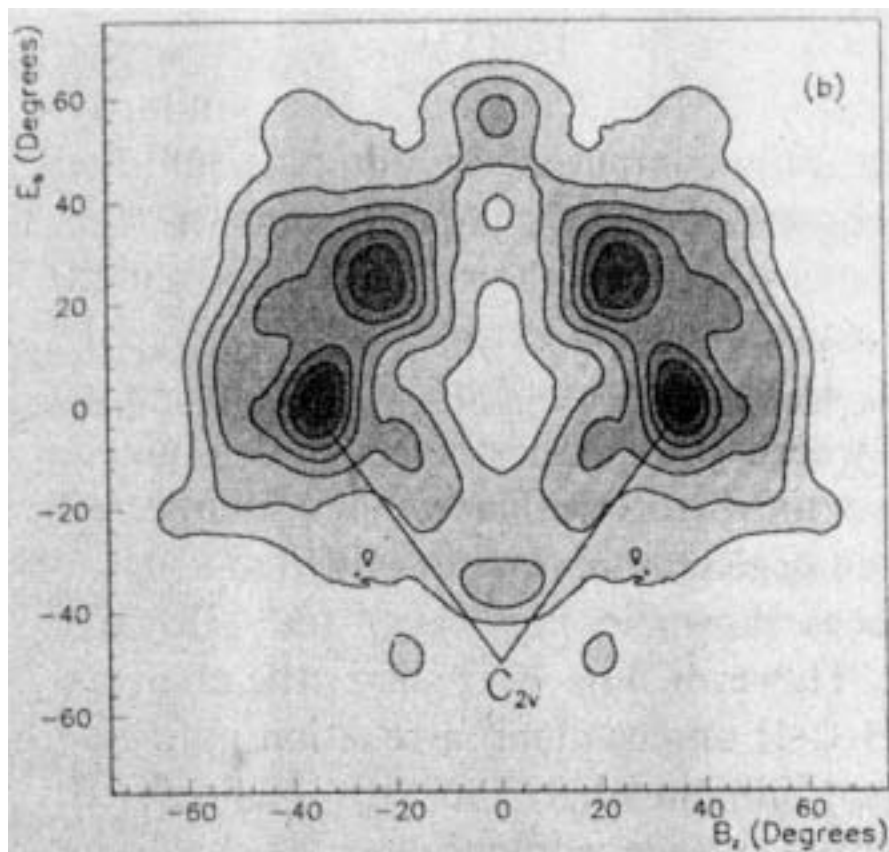
'Stripping Zeit' $\approx 10^{-16}$ sec (Momentaufnahme)

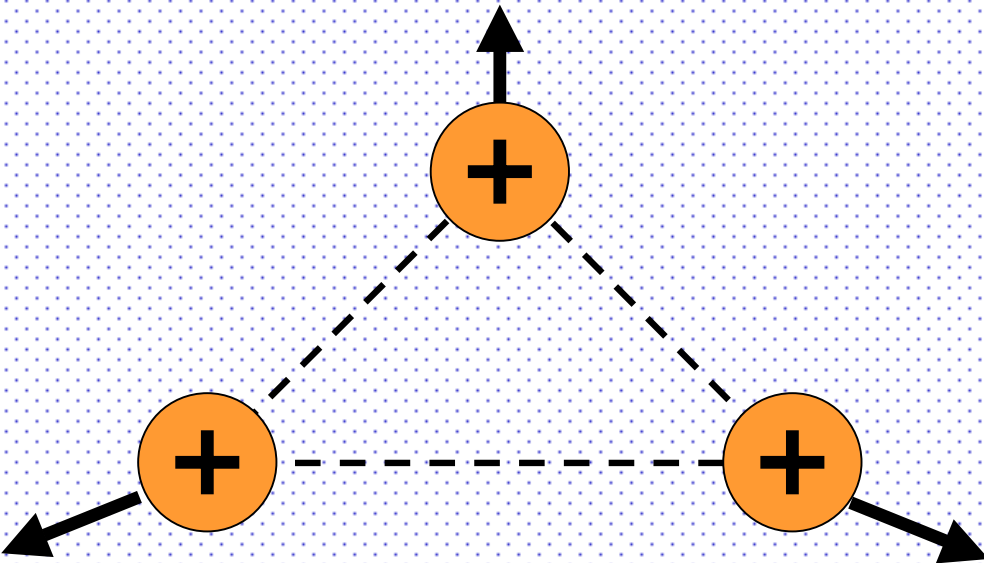
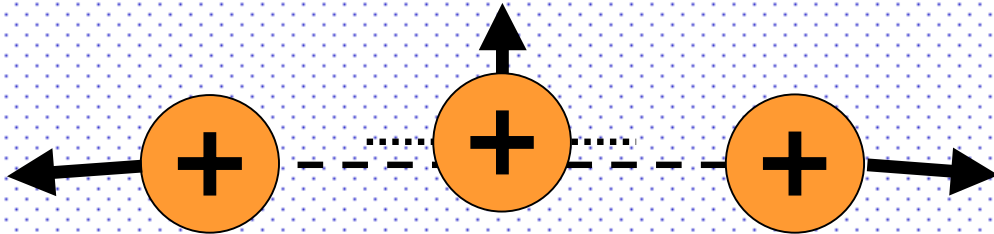
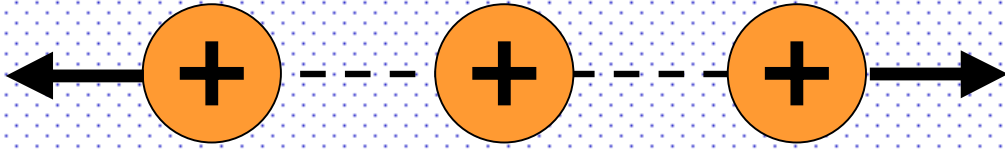


Beobachtung von chemischen Reaktionspfaden mit Coulomb-Explosion-Imaging (Weizmann Institut)



Konformationen

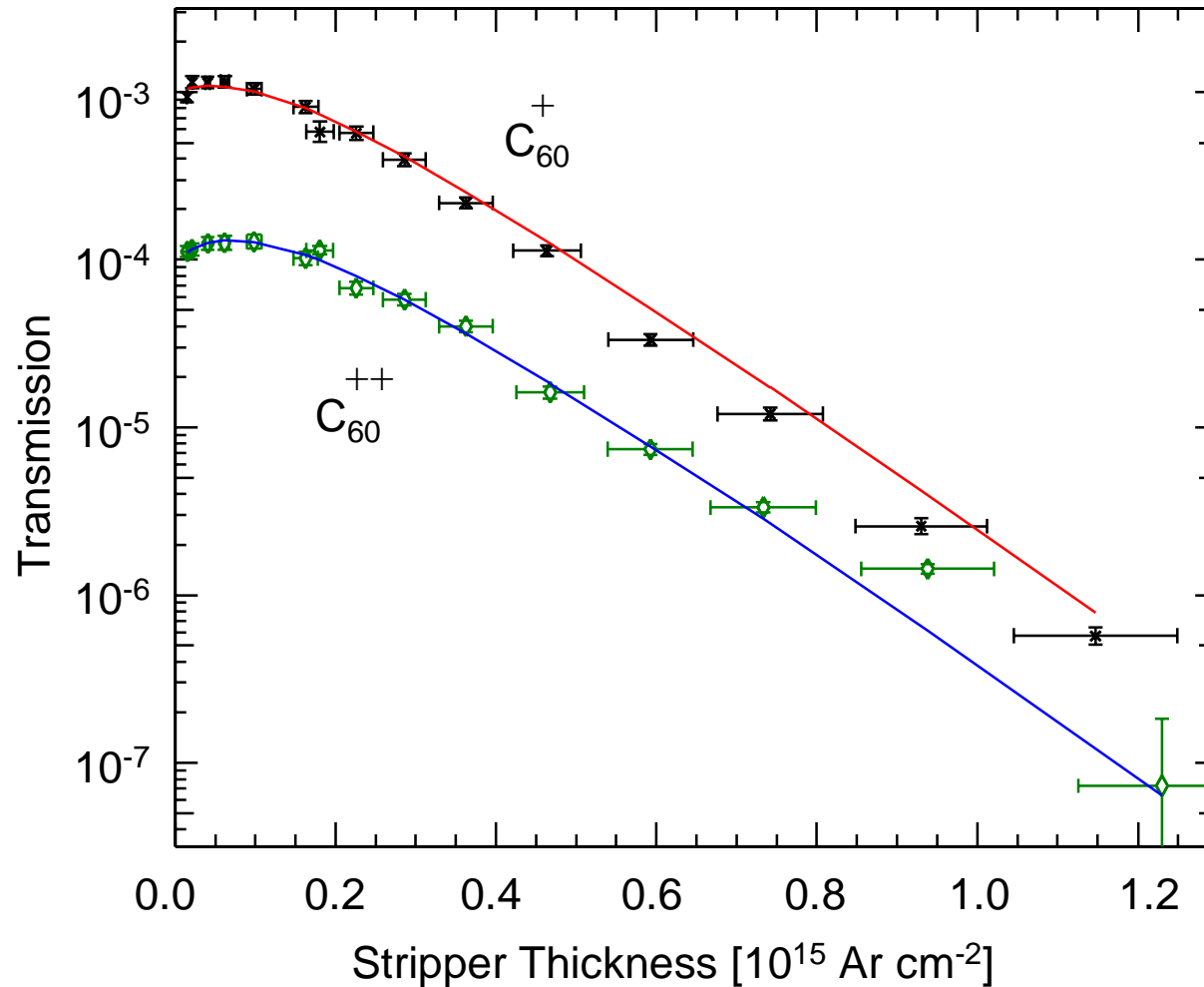




Accelerator Transmission

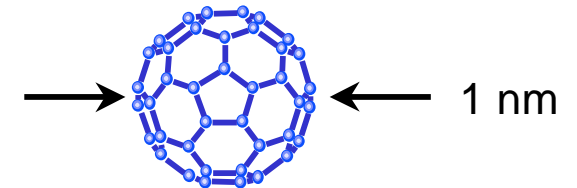
3.75 MV

Ar Stripper Gas



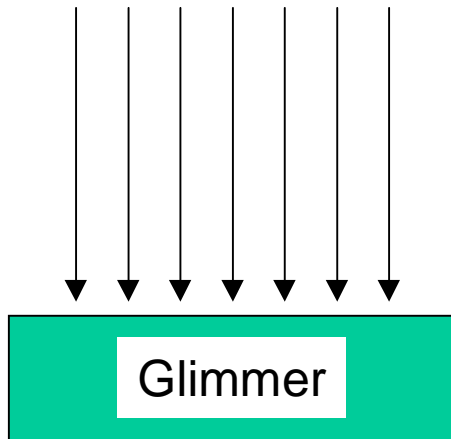
Destruction Cross Section

$$\sigma_d = (8.0 \pm 0.5) \cdot 10^{-15} \text{ cm}^2$$



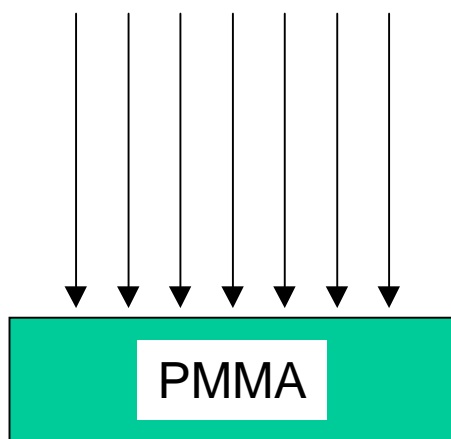
$$\text{Area} \approx 8 \cdot 10^{-15} \text{ cm}^2$$

Bestrahlungsexperimente



Einzelatome
Cluster

10 bis 100 Einschläge
pro μm^2

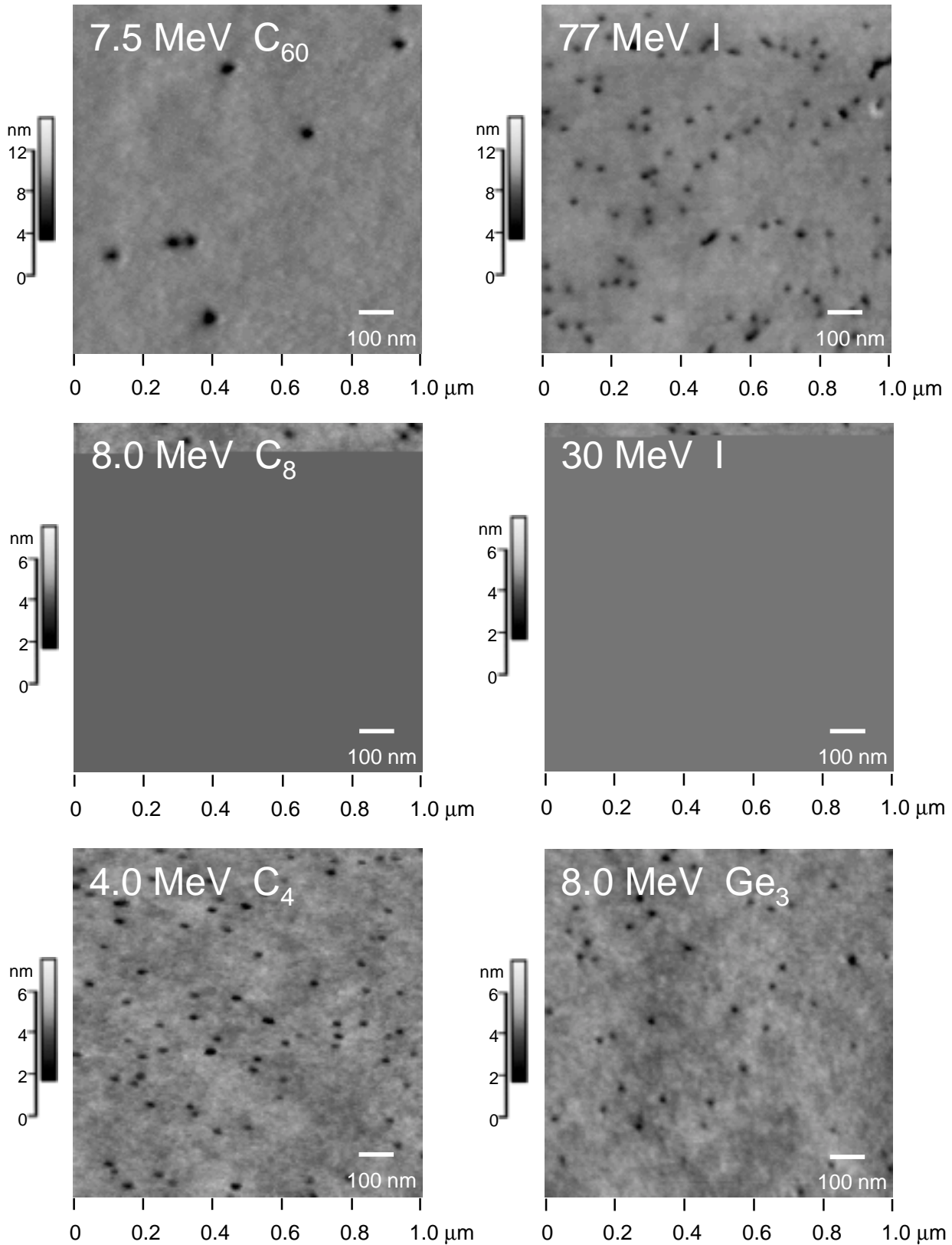


'Plexiglas'
Resist (Maske)



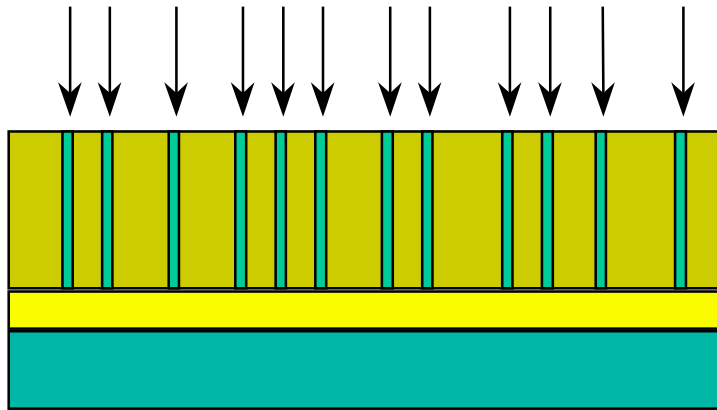
Abbildung mit dem Raster-Kraftmikroskop (AFM)

Irradiated and developed PMMA surface imaged by AFM



Production of Track Replica

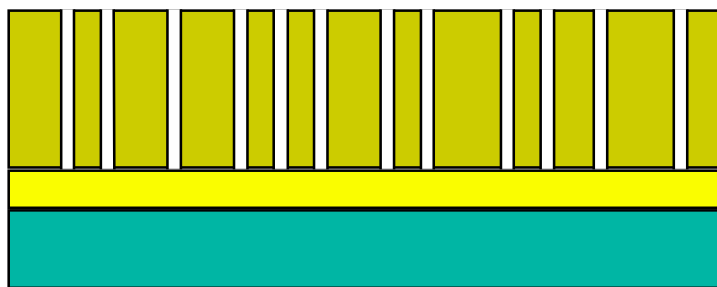
Ions



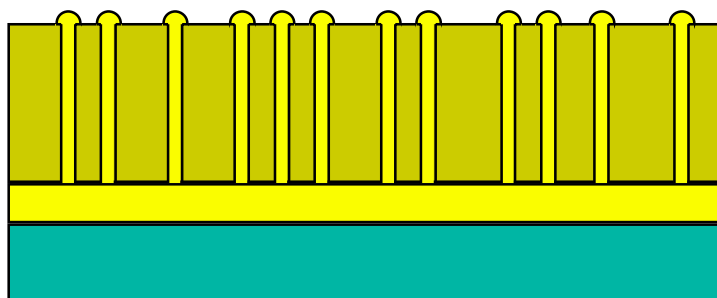
PMMA

Au

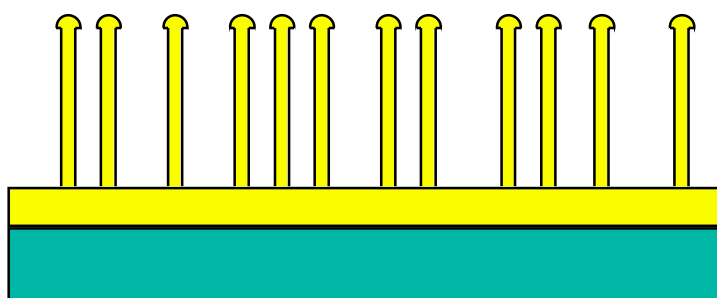
Si-substrate



Development
of PMMA



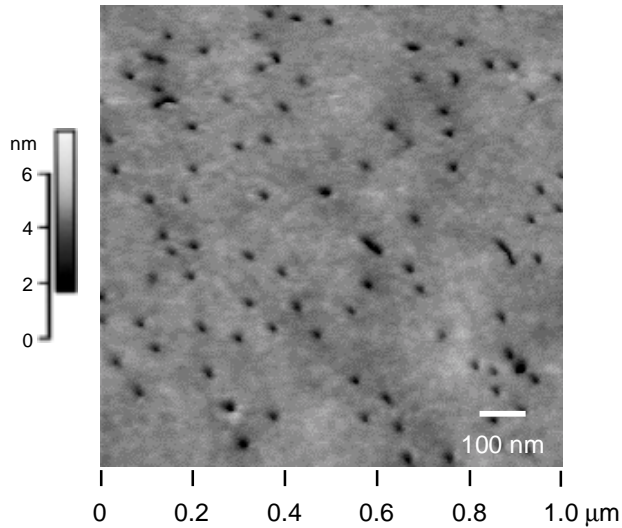
Nickel
galvanoforming



Stripping of
PMMA

**free standing
track replica**

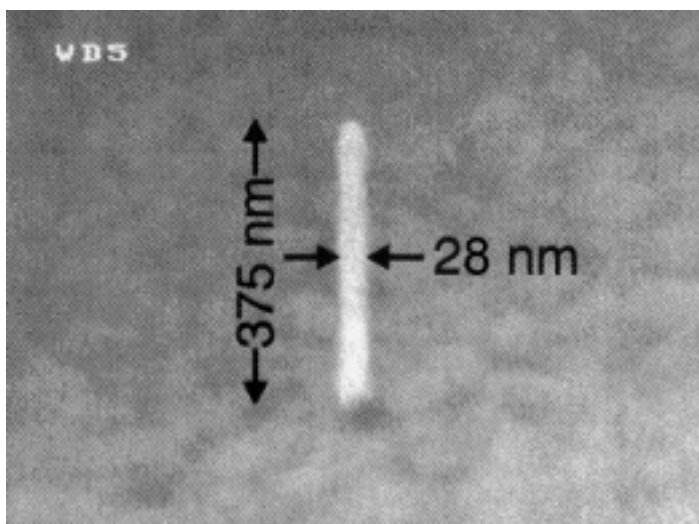
Nanowires produced by 77 MeV Iodine Tracks



Developed resist



After galvanofarming
and stripping



Ni nanowire
aspect ratio 1 : 13