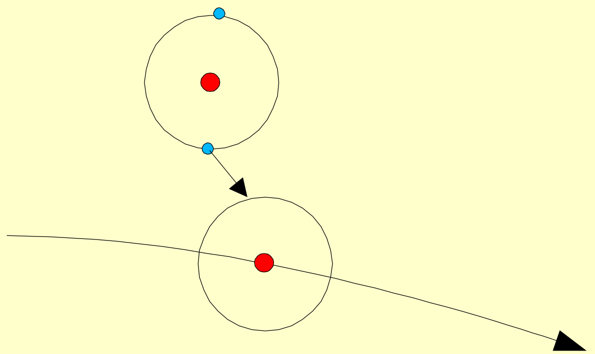
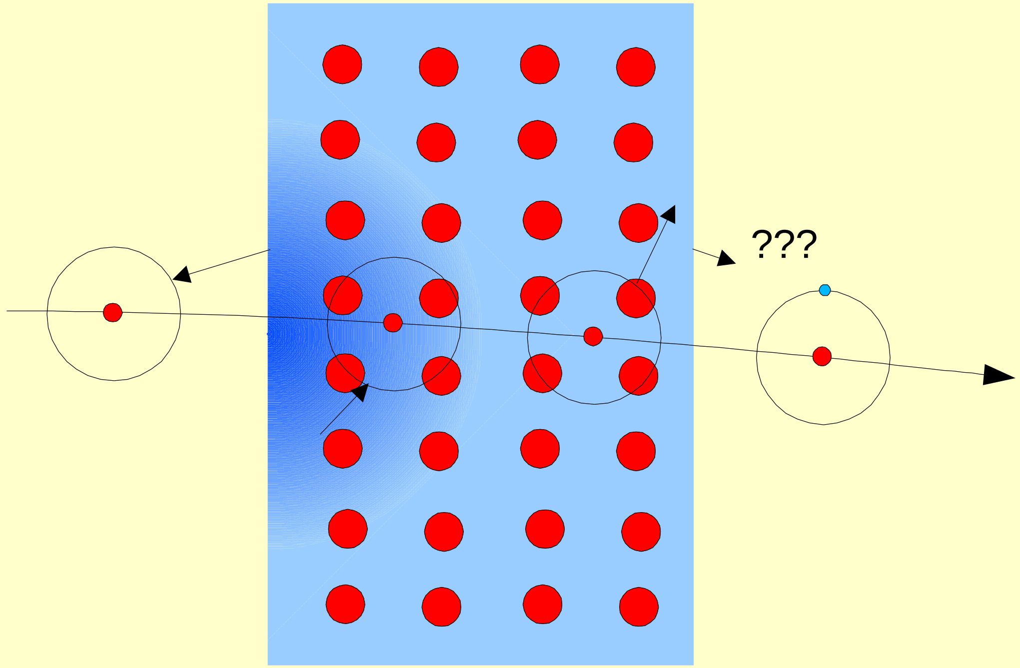
Multi−Electron Capture from Solid Targets into 46 MeV/u Pb^{81+} Ions

Harald Bräuning

single target



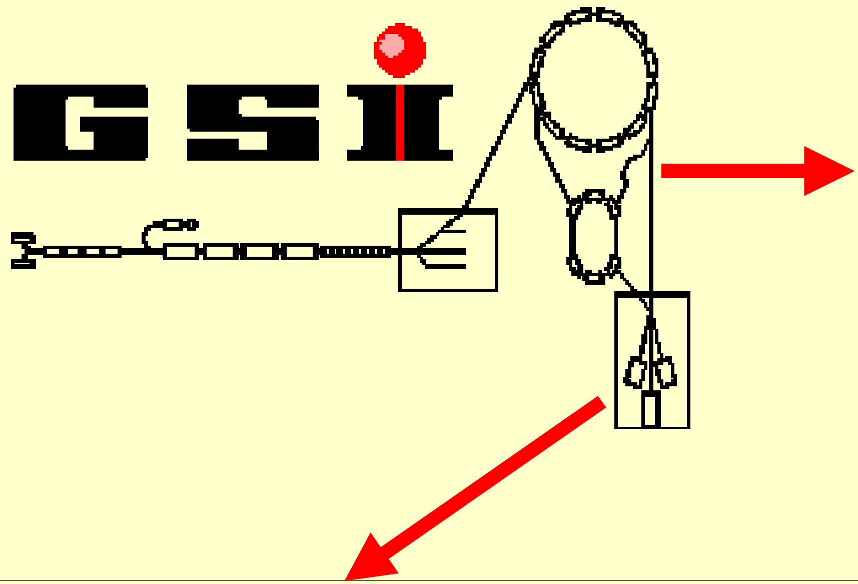
solid target



- pure ion − single atom collision
- few body process
- direct theoretical treatment
- no boundary conditions

- many body processes
- equilibrium charge state for thick targets
- capture from surfaces for very slow ions

GSI



SIS/ESR opens a new field in the study of highly charged heavy ion − solid target interactions

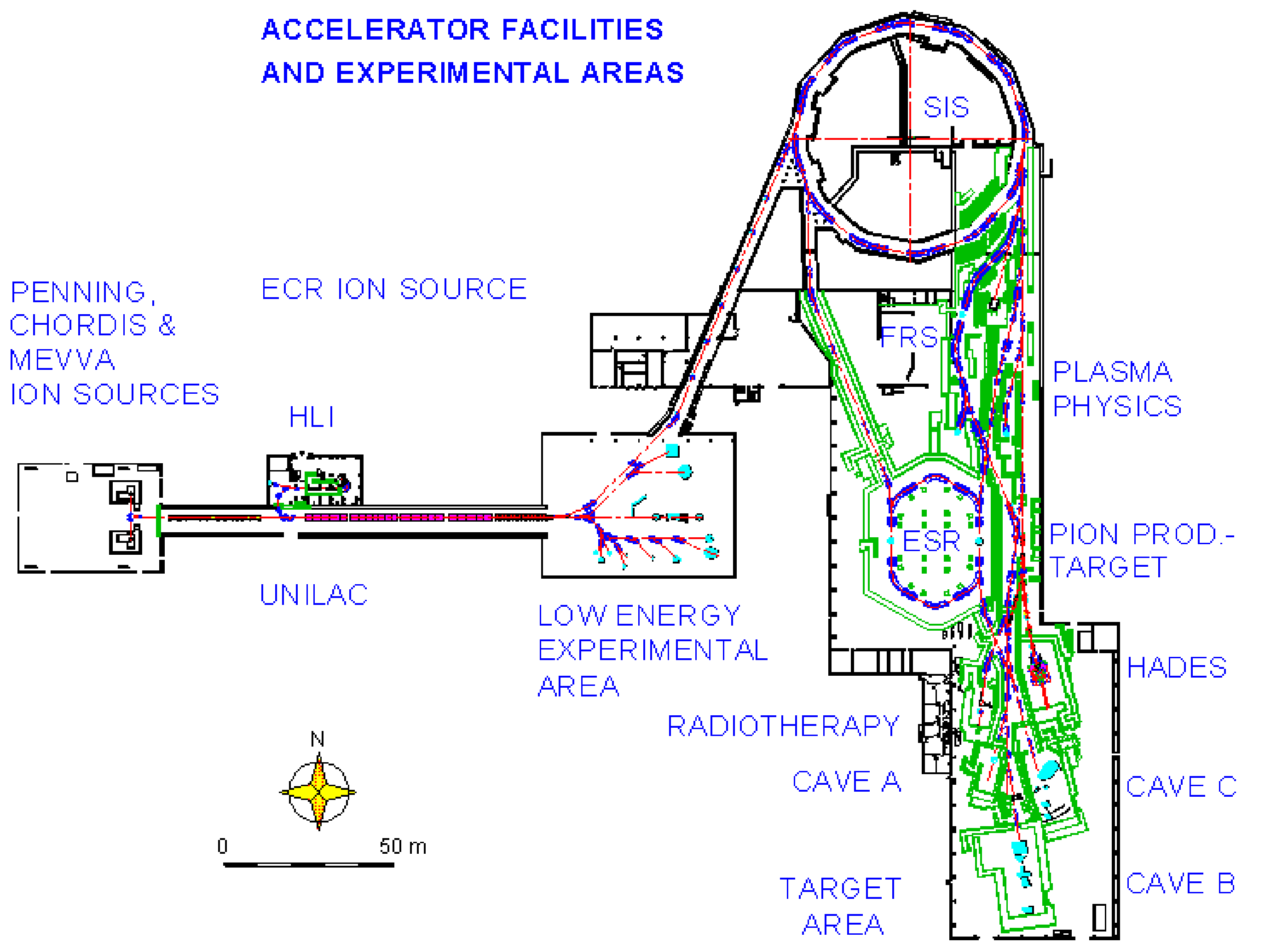
- **moderate velocities** — $v_{ion} / v_K < 1$
- **high charge states** — $q_{in} > q_{equilibrium}$
- **high Z** — fine structure splitting $\sim Z^4$

New experimental facility in **Cave A**

- **outgoing charge state** analysis with newly installed spectrometer
- **coincidence measurements** with x−rays
- **low beam emittance**

For the first time: measure (n,l)−differential transitions after ion−solid interactions with higher precision and in coincidence with the outgoing charge state.

Gesellschaft für Schwerionenforschung mbH



UNILAC:

1.4−14 MeV/u

SIS:

50−1000 MeV/u U

50−2000 MeV/u Ne

ESR:

3−560 MeV/u U

3−830 MeV/u Ne

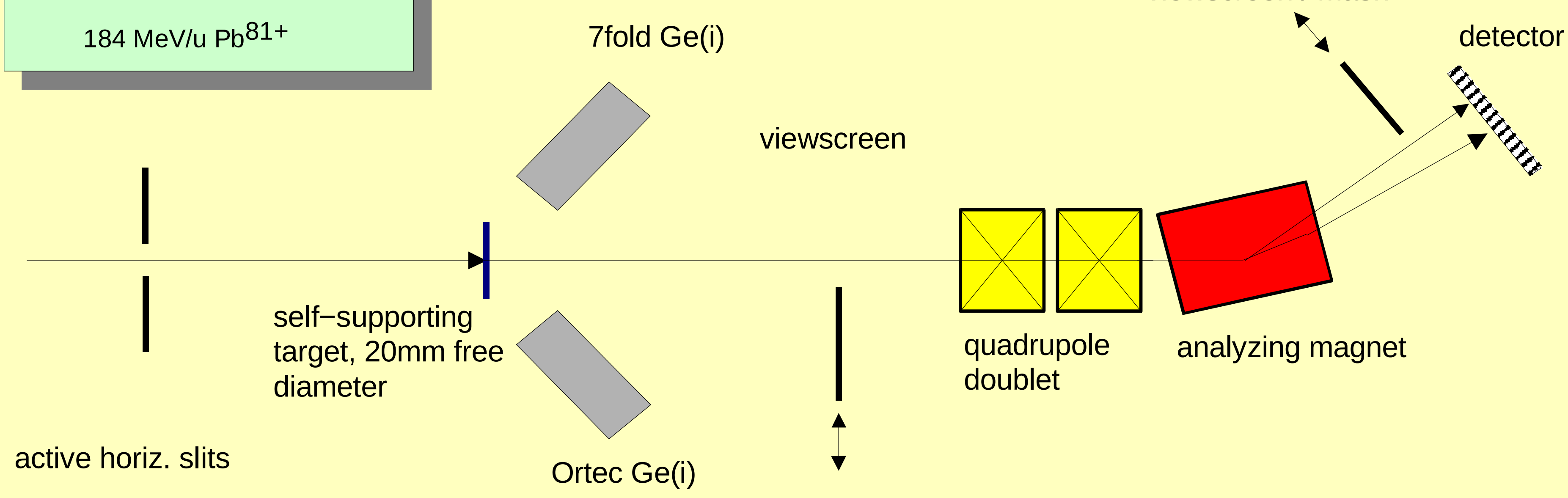
Alle Angaben wie immer ohne Gewähr. Der Rechts−weg ist ausgeschlossen.

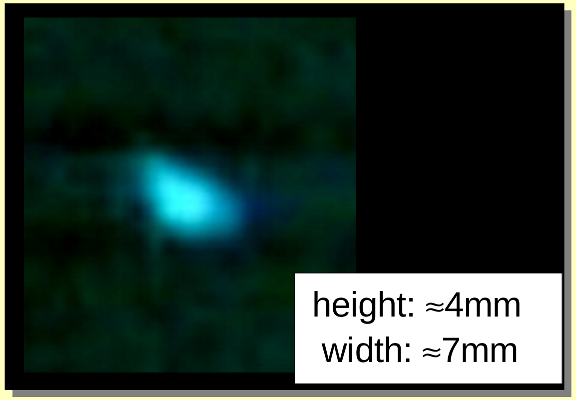
Experimental Setup

ESR: 46 MeV/u Pb^{81+}

SIS: 184 MeV/u Pb^{82+}

184 MeV/u Pb^{81+}





C: 11, 13, 19, 46 $\mu g/cm^2$

Al: 17, 105 $\mu g/cm^2$ Cu: 50, 95 $\mu g/cm^2$

Au: 80, 100 $\mu g/cm^2$

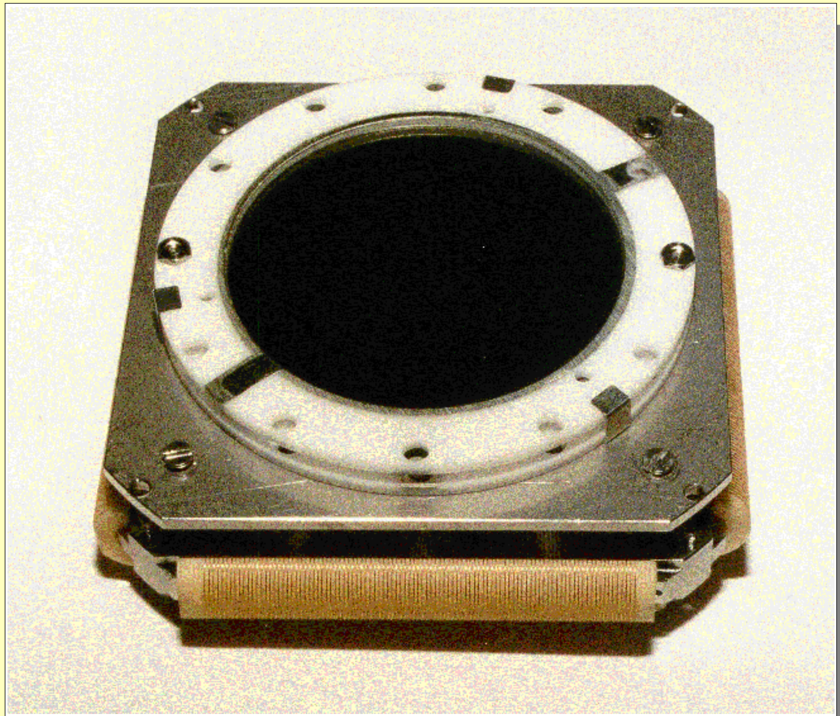
Charge State Spectrometer

Detector:

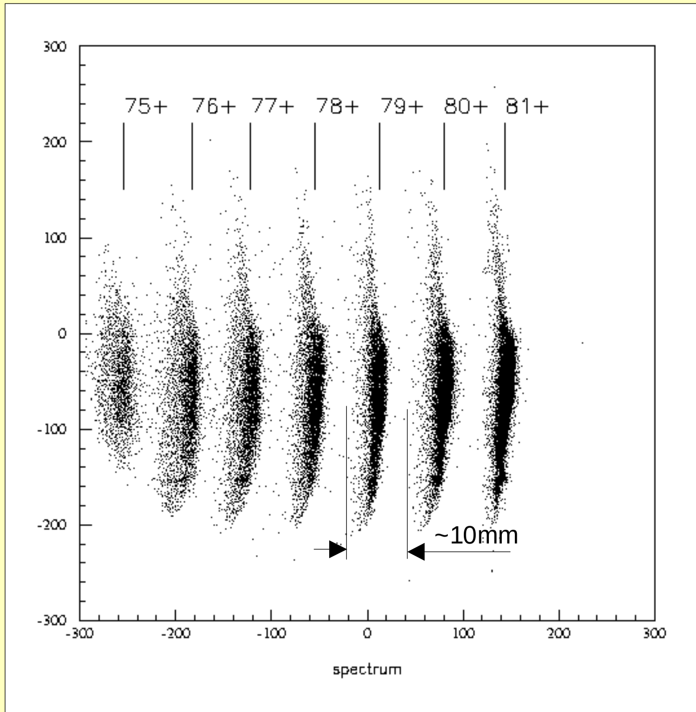
- MCP Chevron
- 80mm active diameter
- 2 dim. delay line readout
- overall count rate >1 MHz (homogenous illumination)

Spectrometer:

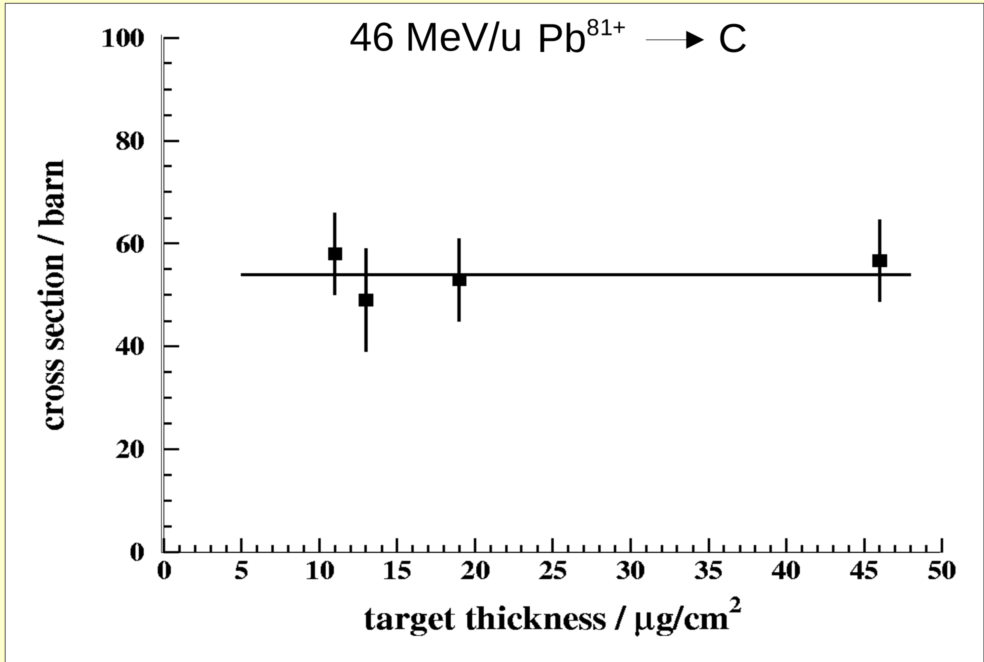
- 14.5° dipole magnet
- 10Tm rigidity
- up to 8 charge states simultaneously
- direct beam on detector
- max. 10 kHz rate in direct beam



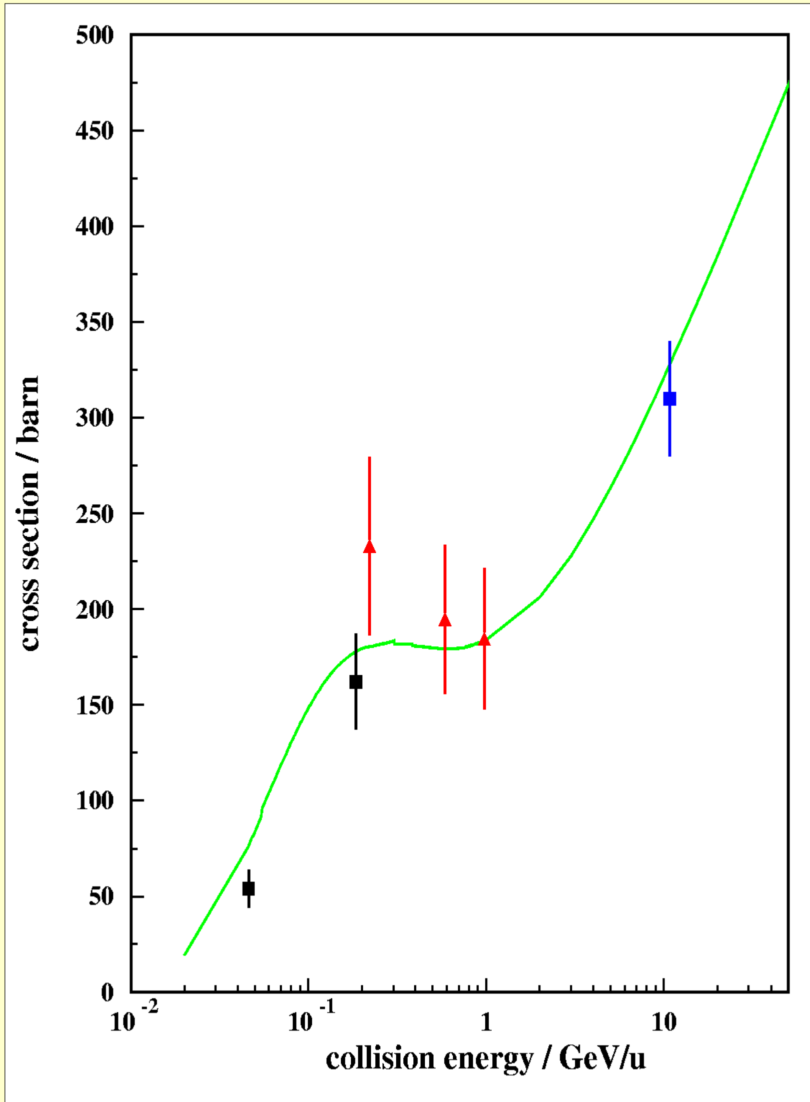
(mit freundlicher Unterstützung der Firma Roentdek)



Projectile Ionization

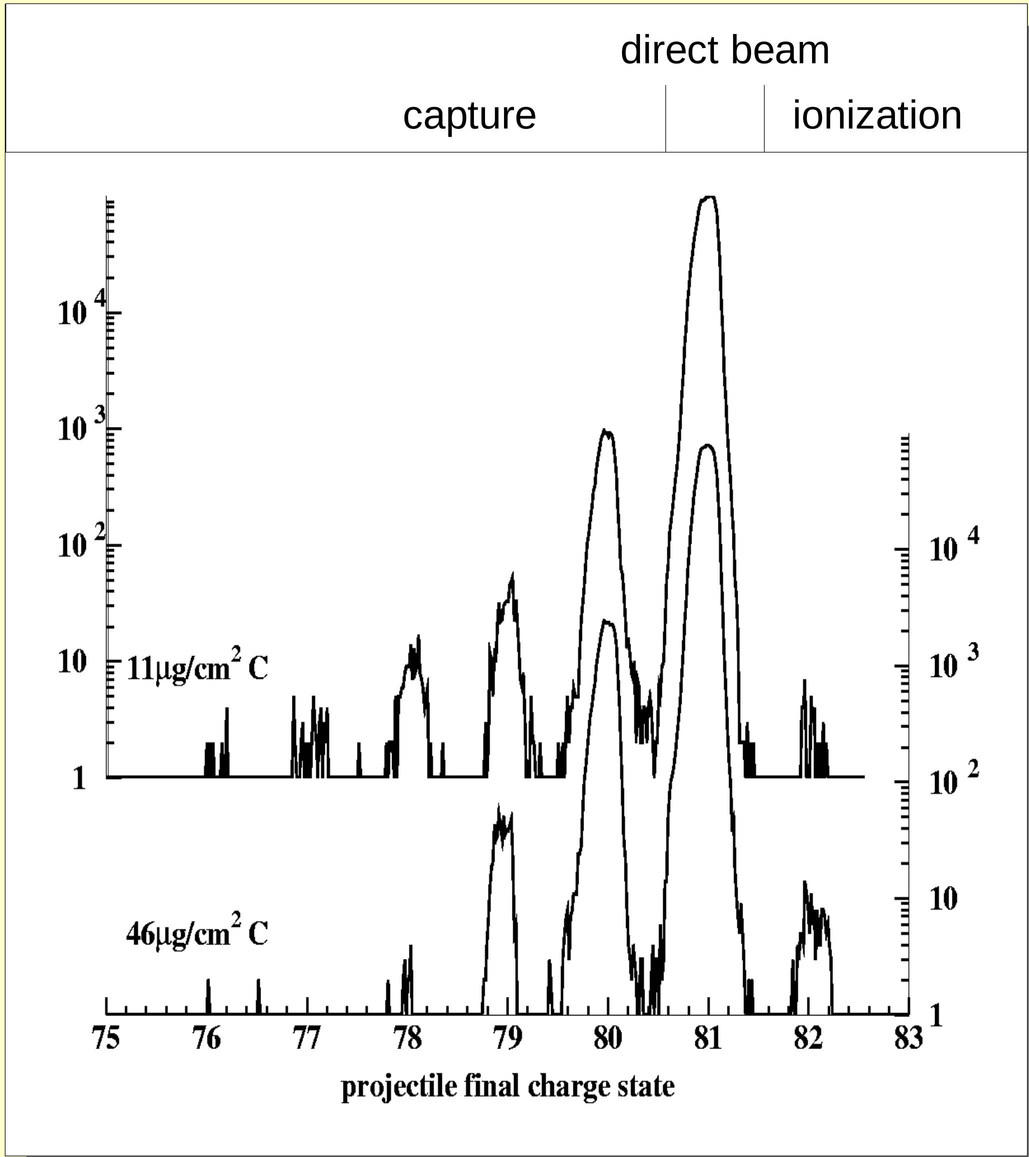


$\sigma_{ionization}$ = 54 ± 4 barn



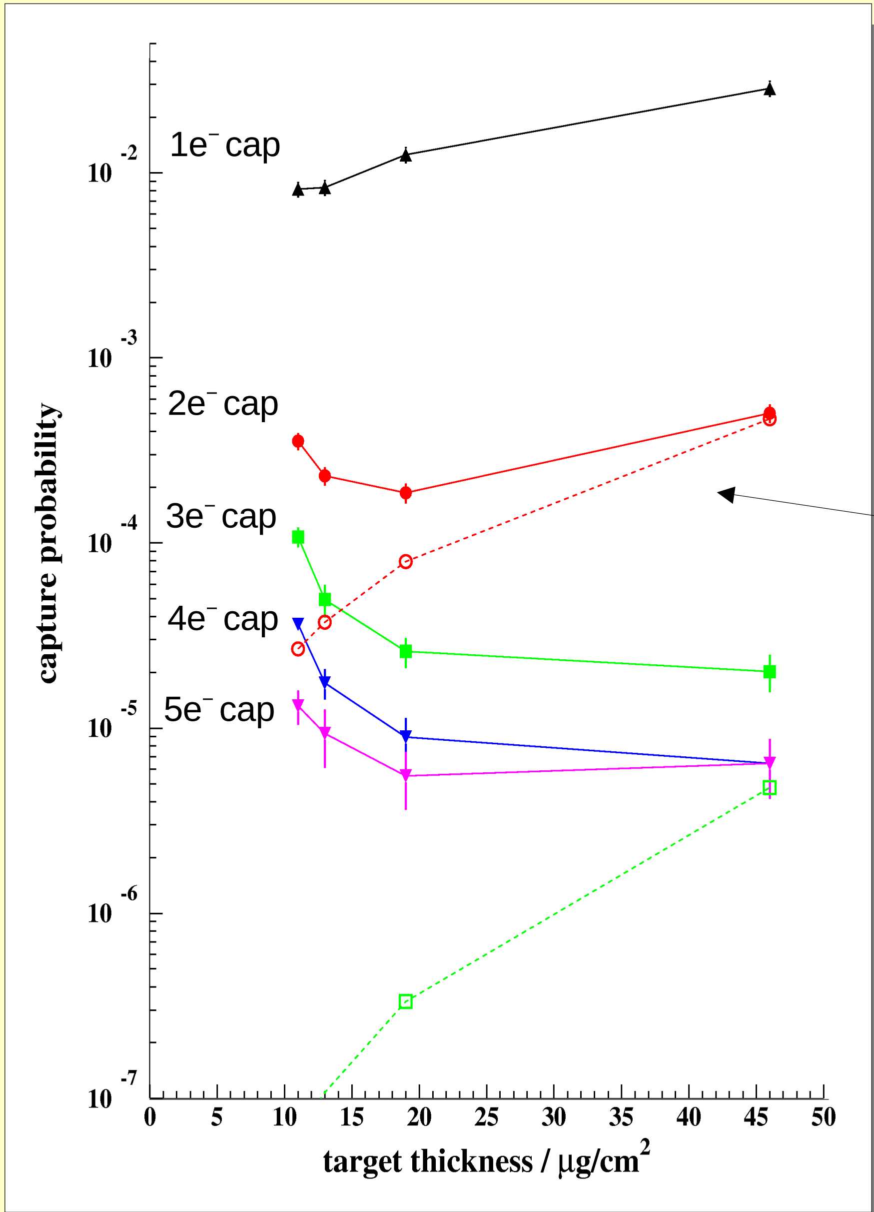
- ■ this data
- ■ Au^{78+} Claytor et al. PRA 55 (1997)
- ▲ Au^{78+} Stöhlker et al. NIM B124 (1997)
- — PWBA calculations

46 MeV/u Pb^{81+} → C



projectile charge state distribution on the position sensitive MCP detector

Electron Capture Probabilities



single electron capture cross section:

$$\sigma_{1-cap} = 13.3 \pm 0.7 \text{ kbarn}$$

Contribution from multiple electron capture via Auger decay: 4% at 46μg/cm²

multiple capture by subsequent single capture

$$P_n = P_1^{\,n} / n!$$

severely underestimates multiple capture probability, especially for <u>thin targets</u>!

decay length of competing processes:

- radiative decay to K−shell: ~10 nm
- Auger decay : ~1000 nm

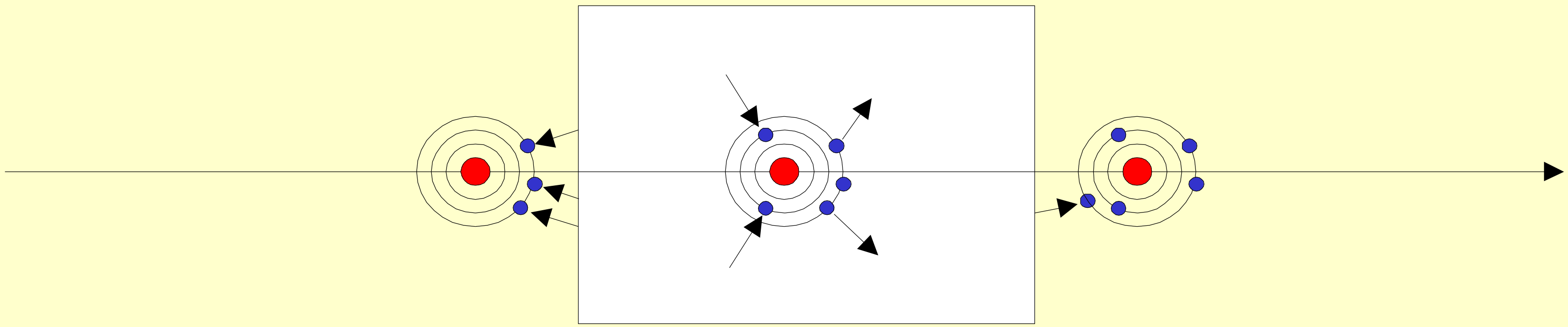
target thickness: ~45 − 225 nm

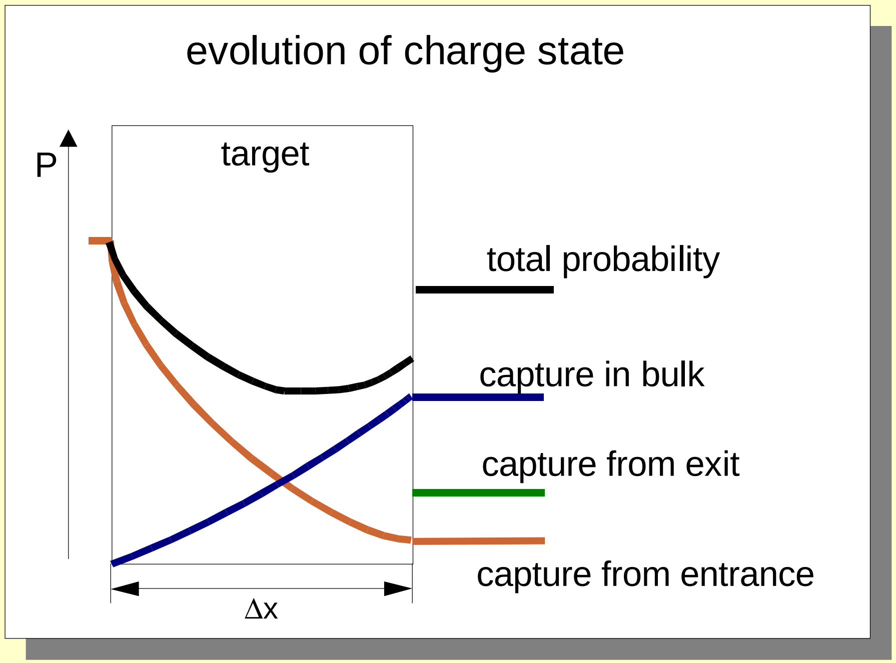
Model for Charge State Evolution with Target Thickness

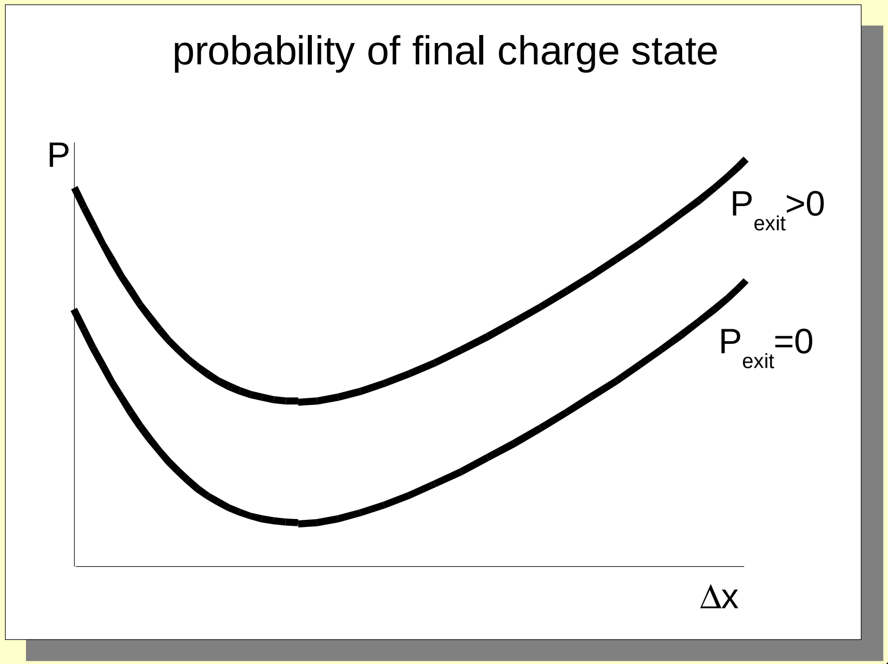
capture at the surface into high lying states

re−ionization and additional capture in the bulk
radiative decay to K−shell

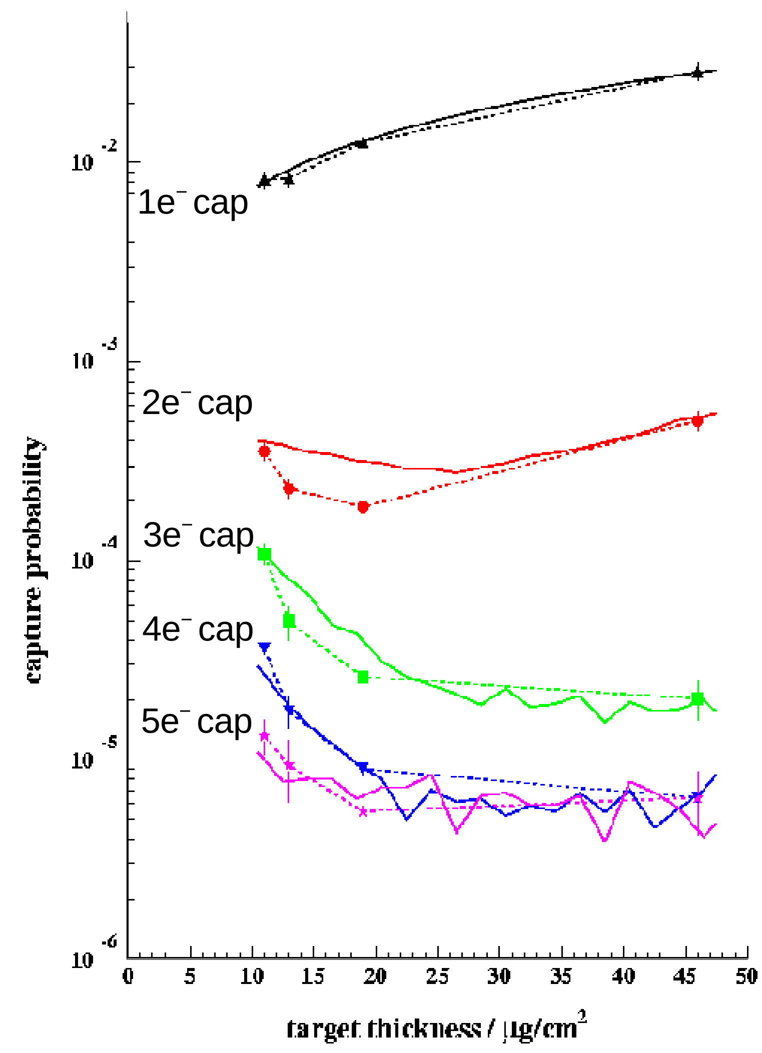
capture at the exit surface







Monte−Carlo Simulation in Comparison to the Experiment



Simulation Parameters

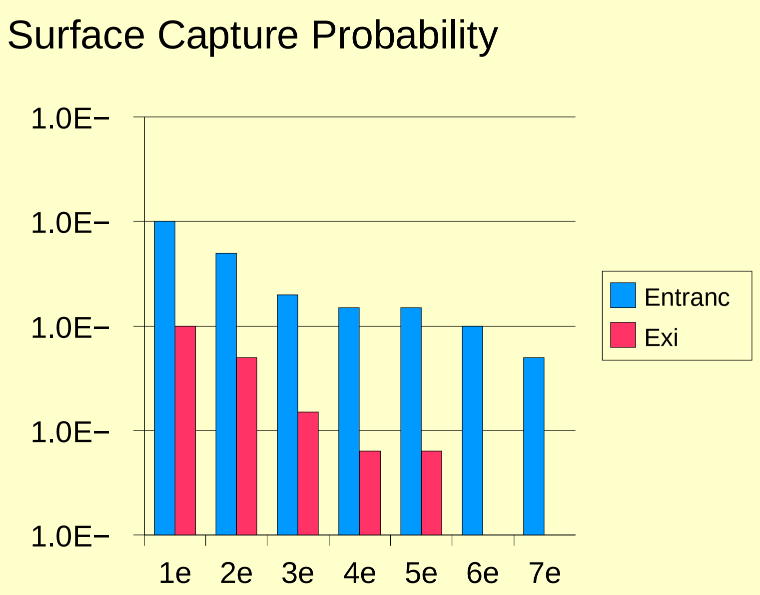
State II (bulk)

σ_{1e-cap} = 13.3 kbarn

$\sigma_{re-ionization}$ = 10 kbarn

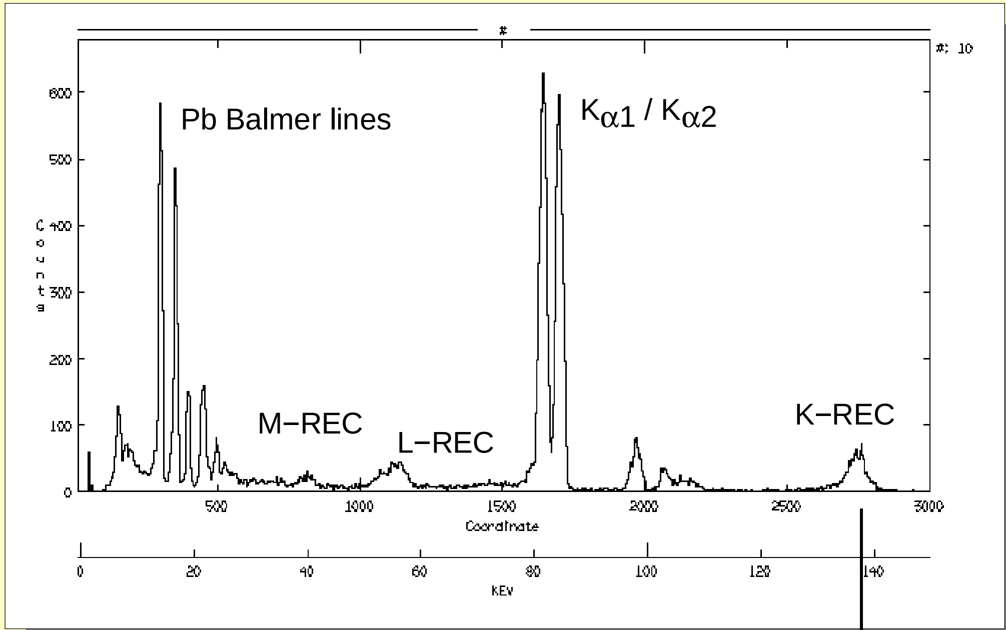
multiple capture by subsequent single capture

State III (surfaces)

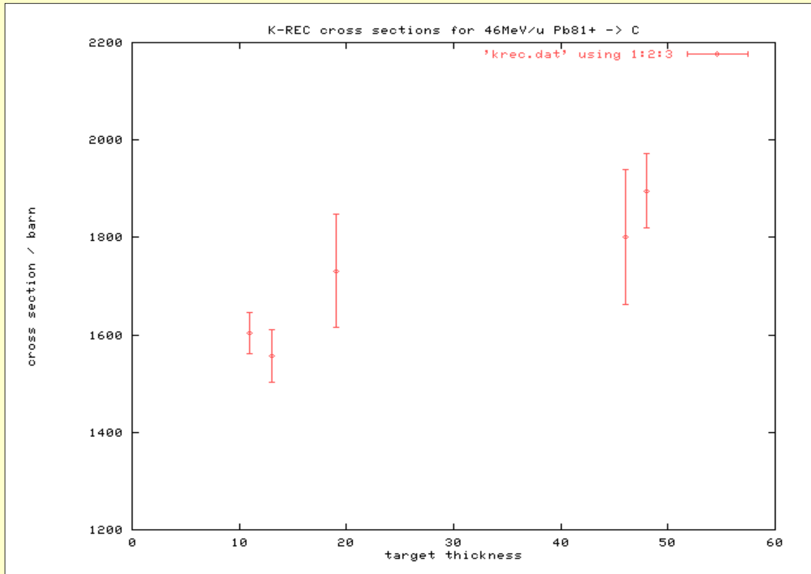


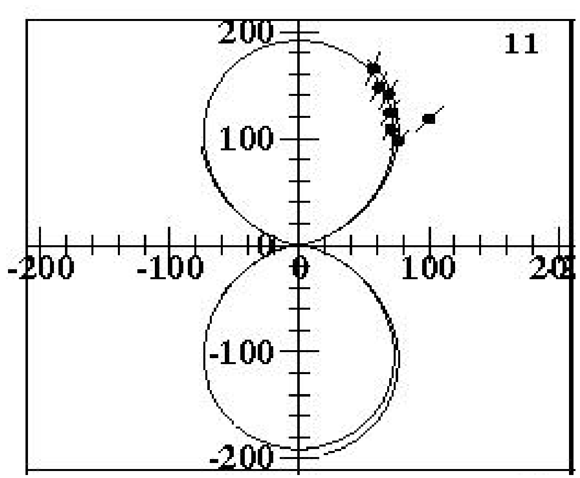
$\sigma_{re-ionization}$ = 2400 kbarn per electron

State Selective Electron Capture from Coincident X−Ray Spectra



46 MeV/u Pb^{81+} −> C





Coincident angle resolved x−ray spectra provide additional valuable information.

Future Experiments

Verification...

- repeat experiment at 46 MeV/u
- measure more target thicknesses
- obtain better control of target production and surface cleaness (diamond like carbon targets)

Extension...

- investigate dependence on projectile velocity (decelerate to 15 MeV/u)
- isolate surface effects
  - capillaries / nano tubes (channeling experiment)
  - fullerenes

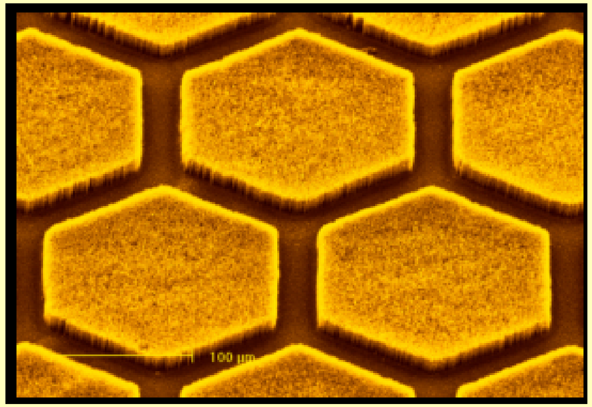
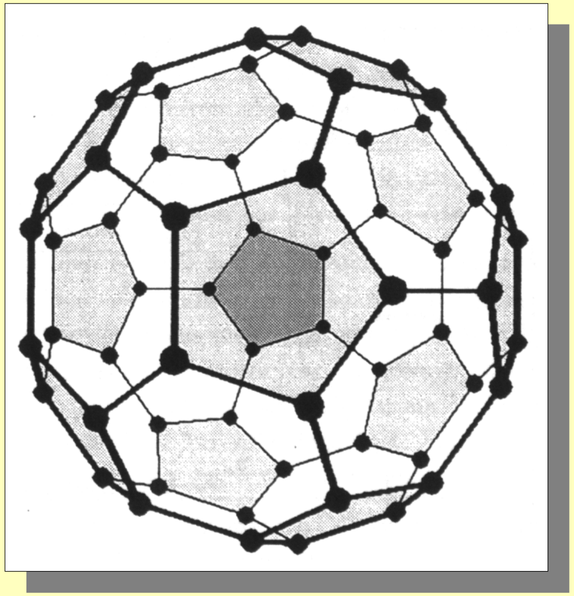


Photo: CSIRO, Australia

hexagonal bundles of nanotubes made by CSIRO, Australia

Fullerenes – the Missing Link ?

- radius 0.355 nm
- 120 core electrons
- 240 valence electrons
  - 180 tightly bound σ electrons
  - 60 loosely bound π electrons

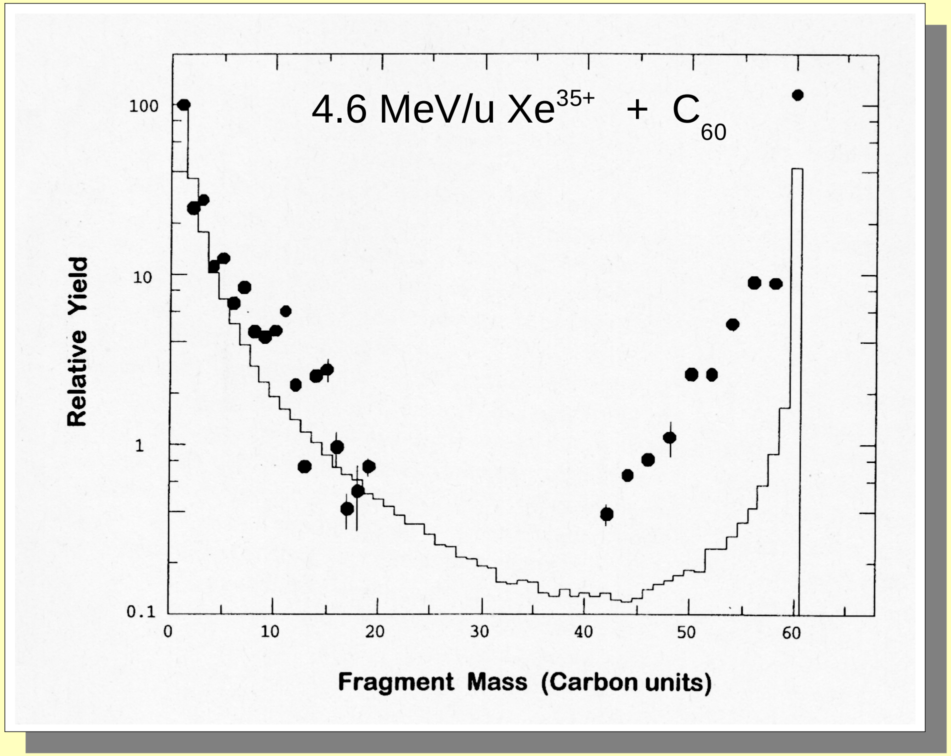


perspective view of a C_{60} fullerene

Can be treated as a 'jelliumlike' solid shell!

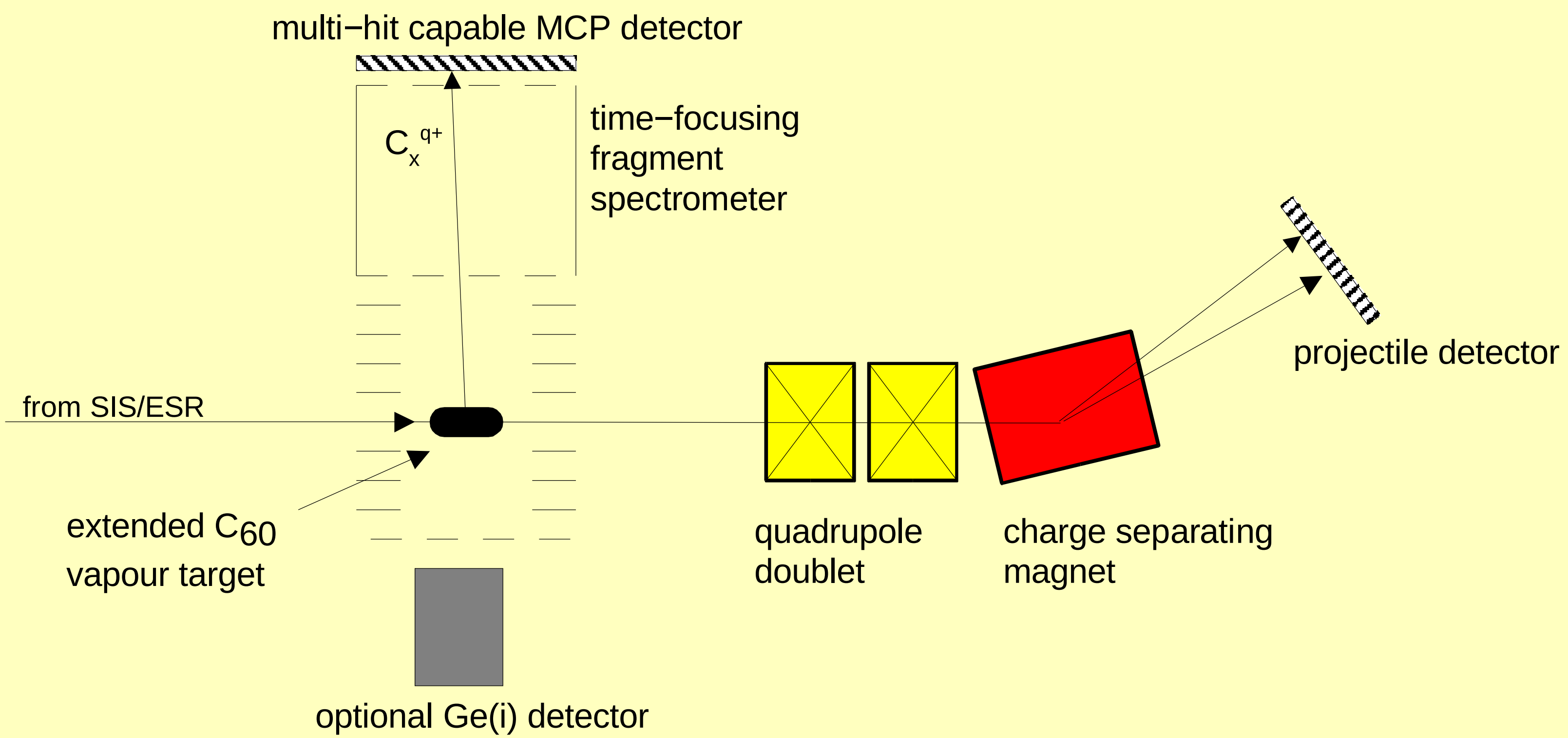
large impact parameters:
giant resonance excitation → heavy fragments

small impact parameters:
stopping power phenomenon → many light fragments



S.Cheng et al.: Phys. Rev. A 54 (1996) 3182

Planned Setup for Studying HCI − C_{60} Collisions in Cave A



C_{60} fragmentation may allow to differentiate between hard and soft collisions

Proposal E043 approved in Dec. 1999

Summary

We have found...

- an unexpected increase in the many electron capture probability with **decreasing** target thickness

A model to explain the data includes...

- a strong contribution from capture at the surface into highly excited states
- a significantly reduced capture probability at the exit surface as compared to the entrance surface

This may indicate...

- the formation of hollow ions
- polarization of the charge distribution in the bulk with respect to the approaching ion

Future experiments include...

- more data points
- extension towards thinner targets (diamond like carbon foils)
- Fullerenes

The People

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