Transmission of heavy ion beams in the AGOR cyclotron

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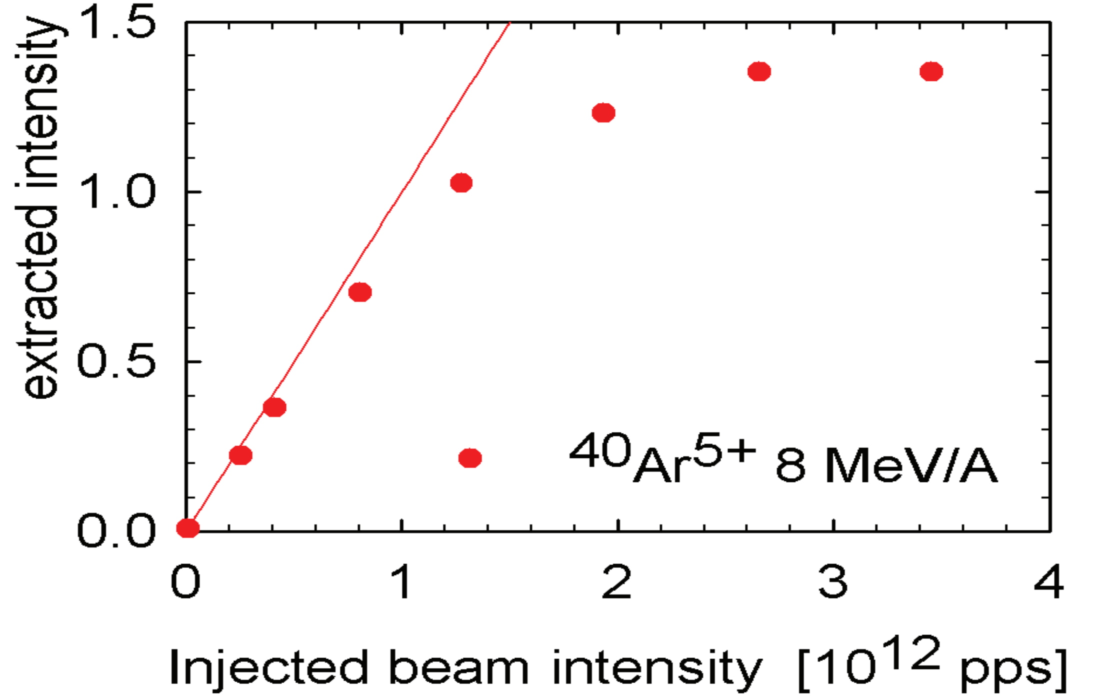
Problem Statement

Need maximum intensity of heavy ion beams such as ^{206}Pb at 8.5 MeV/amu

Observation: increased intensity → reduced transmission



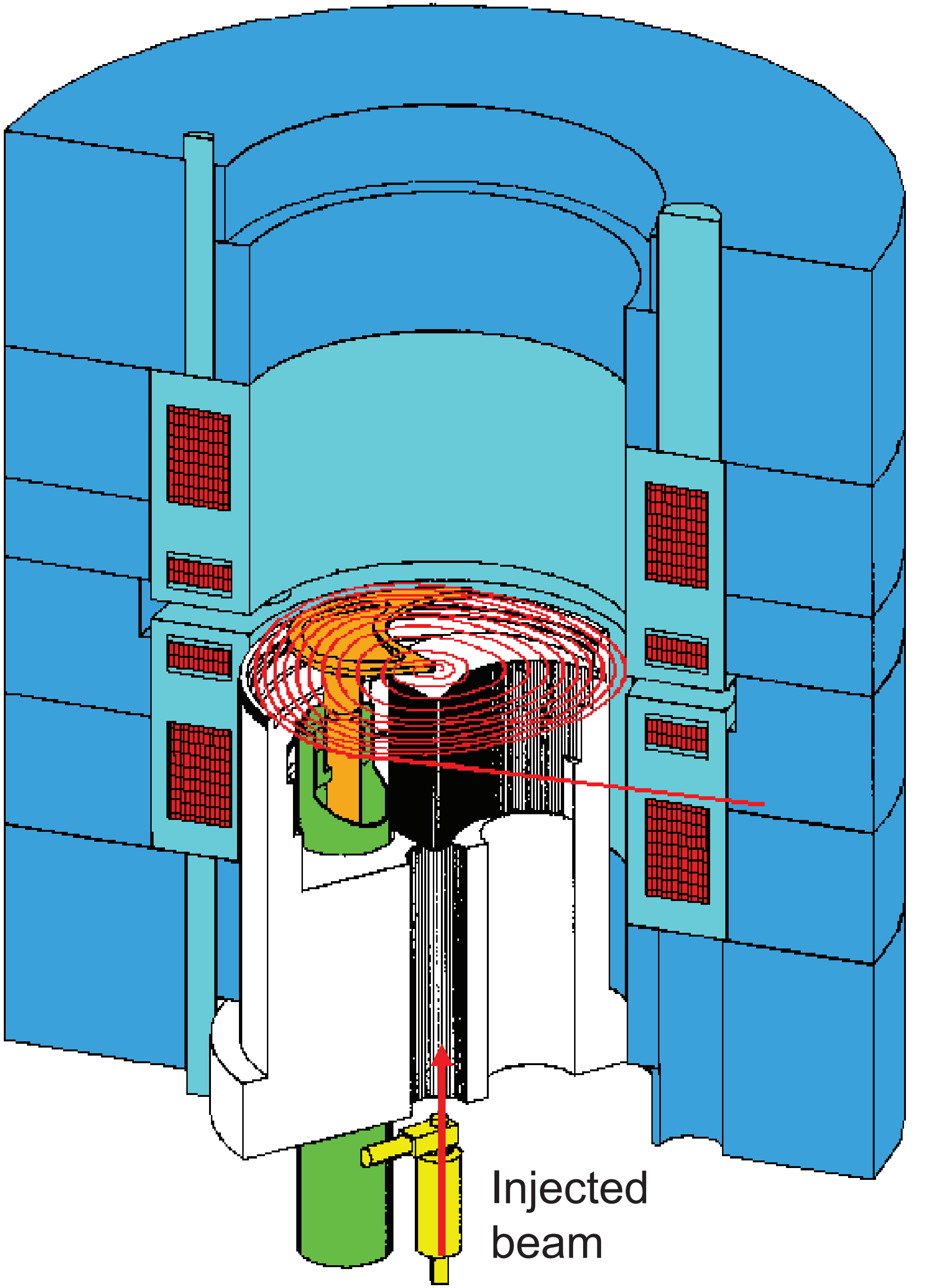
Lost particles hit the walls → Release particles from the walls (Desorption)

Feedback cycle for intensity dependent beamloss is not new !

- First observed in ISR (CERN) 1972
- Important issue in LHC (CERN) and SIS18 (GSI)

- Goal : Improve cyclotron transmission
- Understand beamloss process in the cyclotron

- Estimate the pressure rise and thereby transmission



AGOR

Pressure ~ 10^{-7} mbar

No of turns ~ 300

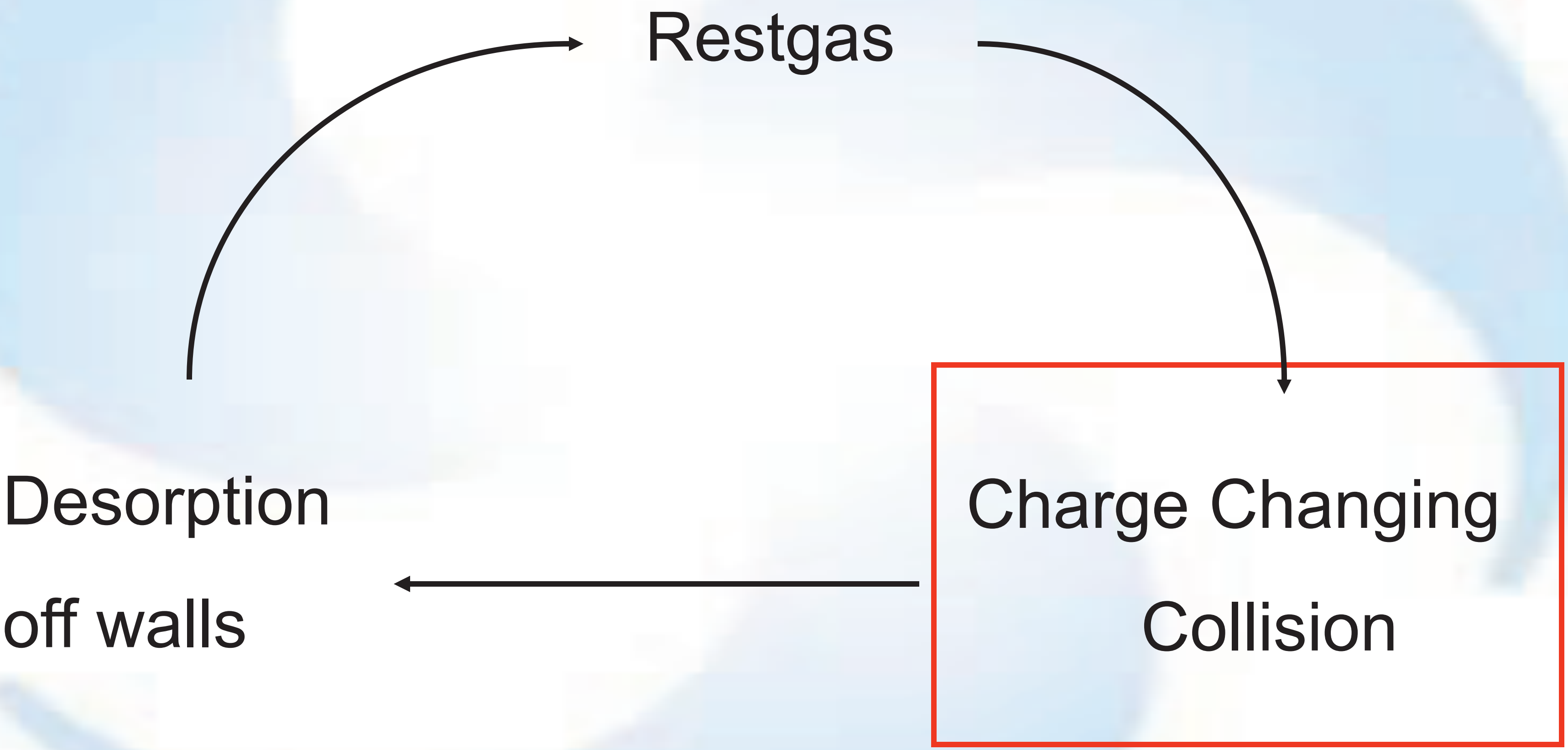
Pathlength ~ 1.5 km

Storage ring
(SIS18, GSI)

Pressure ~ 10^{-11} mbar

Pathlength ~216 m/turn

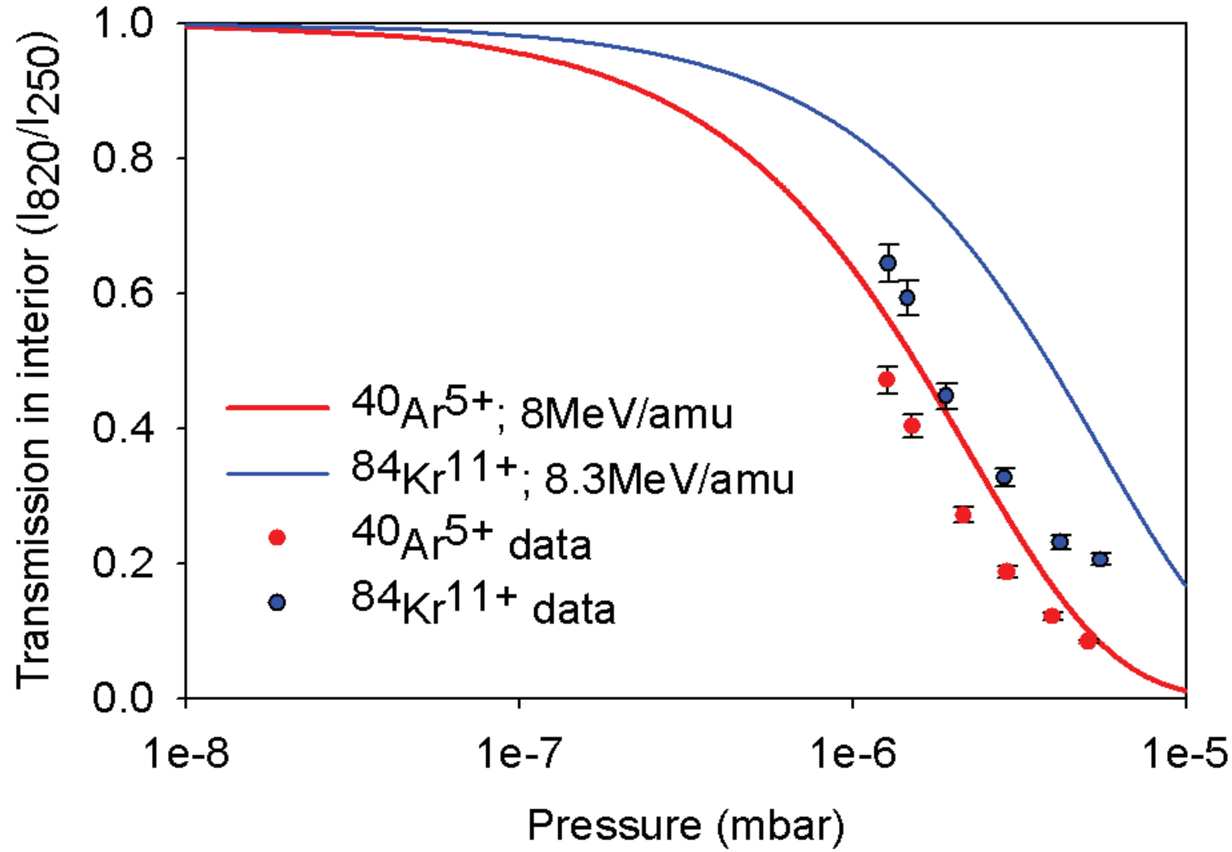
BeamLoss in Cyclotron



Charge Changing Collision & Transmission

Loss per turn $\delta N = N_0(r)\{1 - exp(-\sigma * 2\pi r * \eta * P)\}$

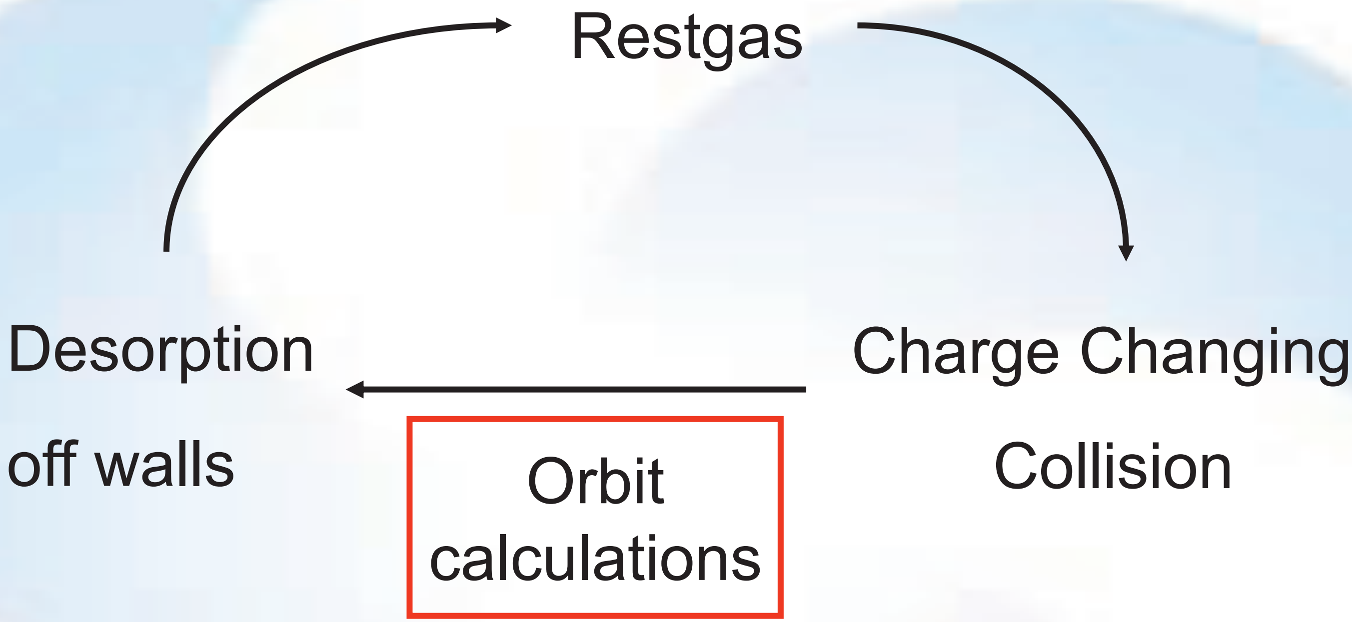
- Simulations done with semi-empirical models for σ
- Experiments done at low intensities – minimize feedback
- Pressure controlled with variable leak



Similar exponential dependence

Uncertainty in pressure

Orbit Calculations.



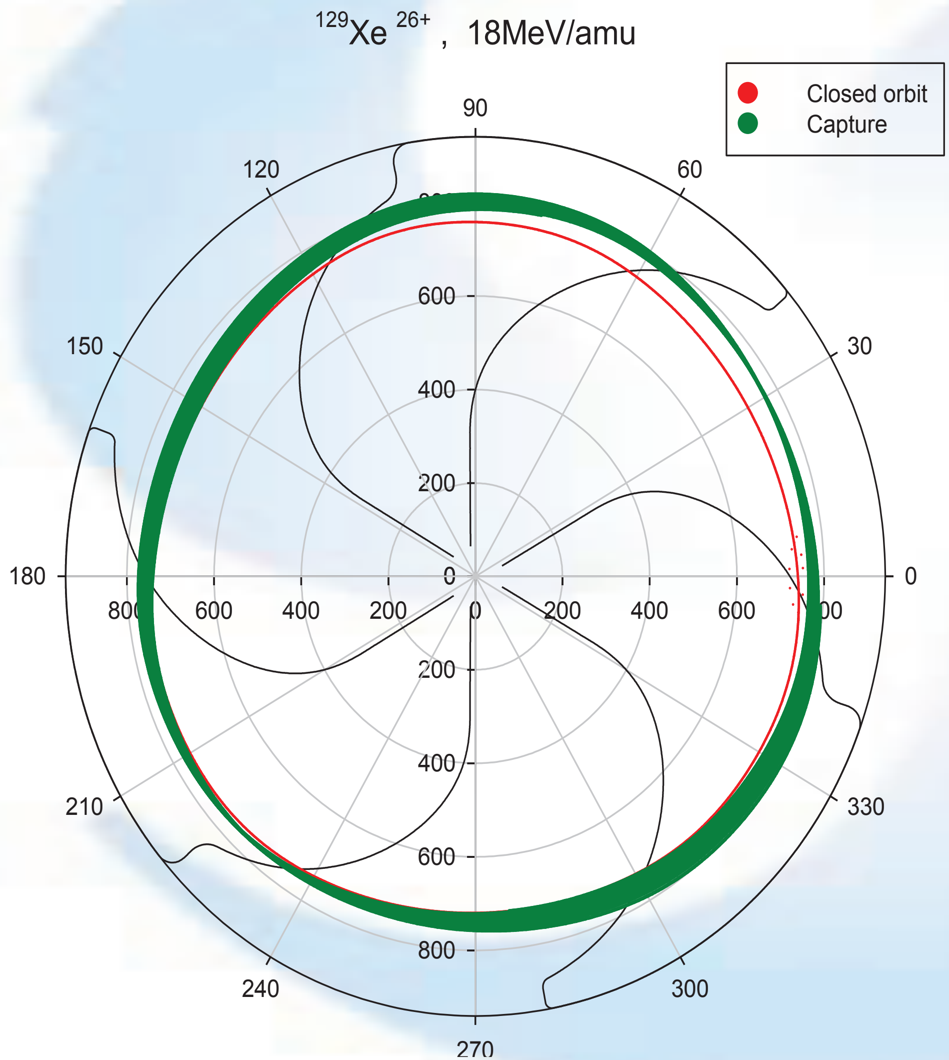
Track the beam particles after collision

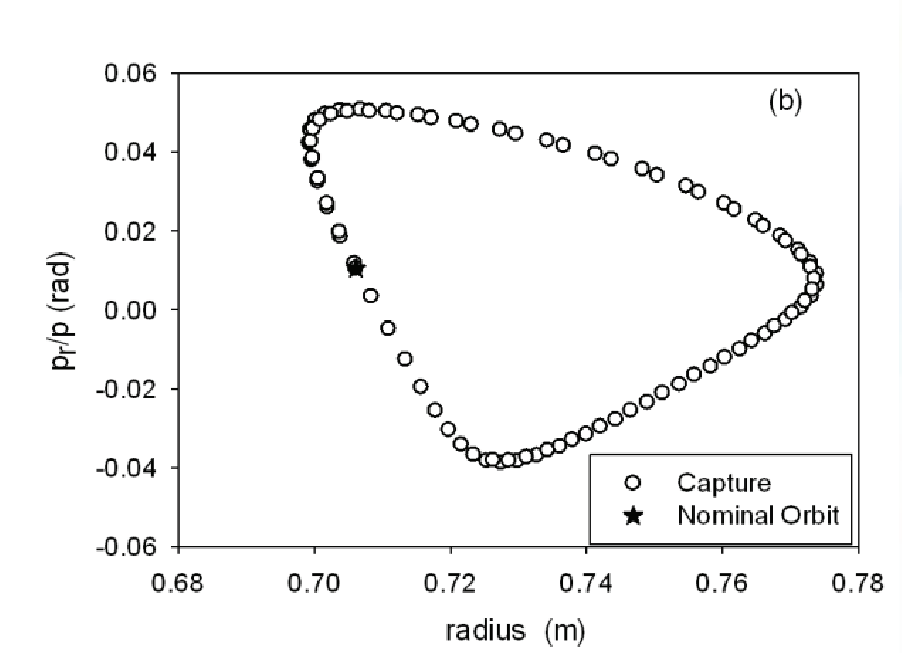
- unit change in charge
- negligible change in $\vec{p}$ for beam particle -*negligible effect on axial motion*

Consider radial motion:

- Energy on impact
- Angles of incidence
- Point of impact

Orbit Calculations

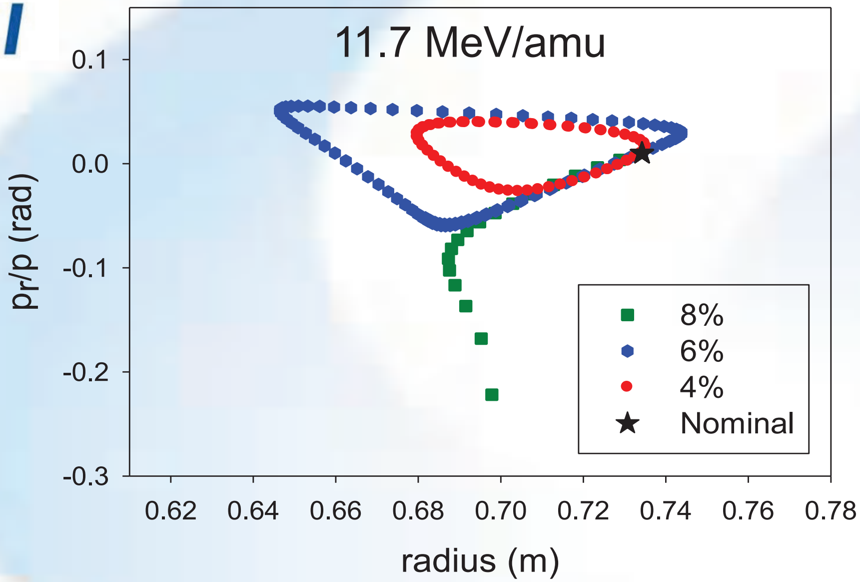


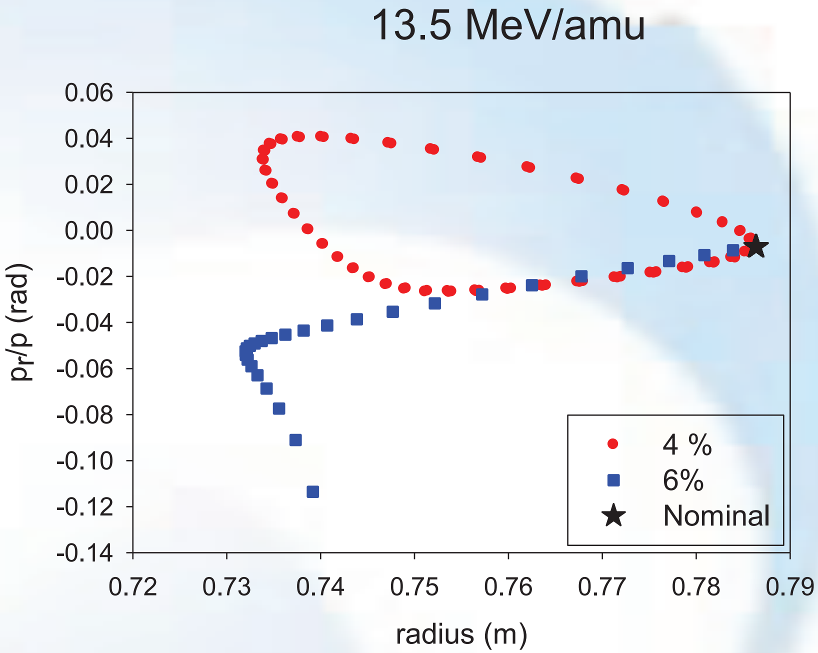


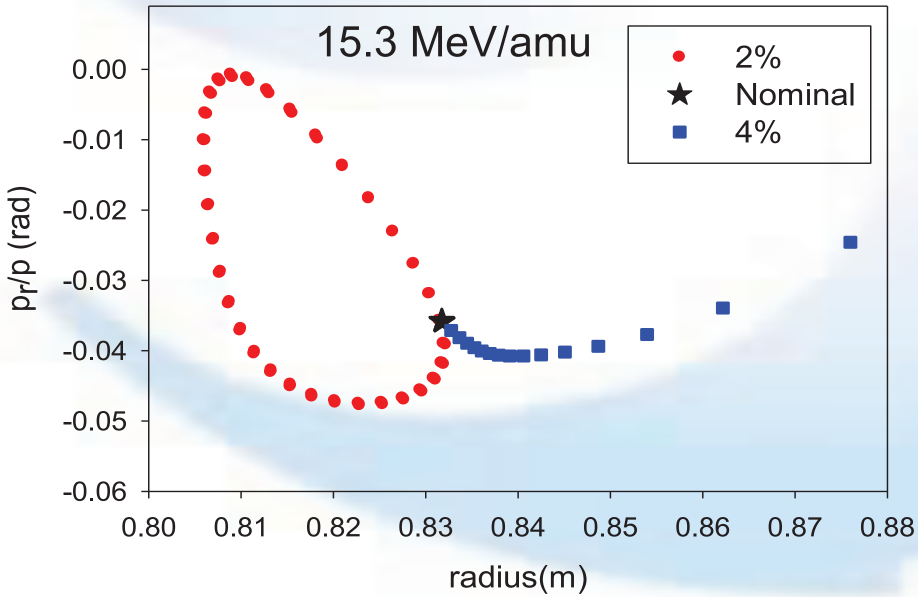
Track particles in phase space at an azimuth.

Radial stability -Energy dependence

$^{129}Xe^{26+}$ at different radii







Larger radius

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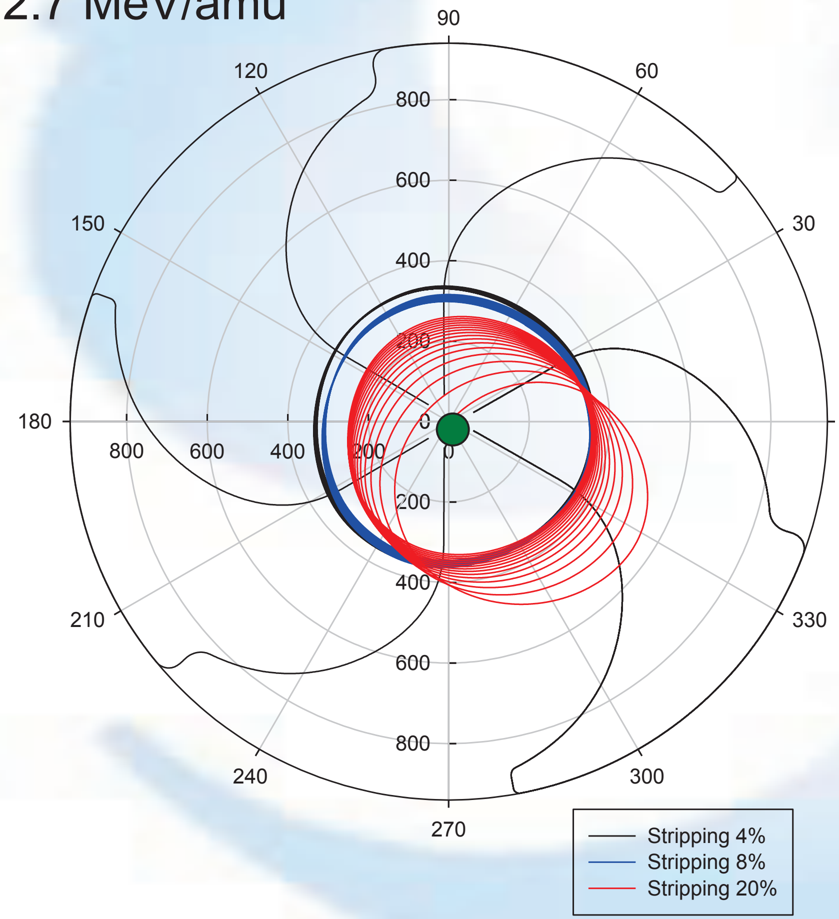
smaller stable ΔQ/Q range

Trajectory after charge change

$^{129}Xe^{26+}$ @ 18MeV/amu,

Near Center

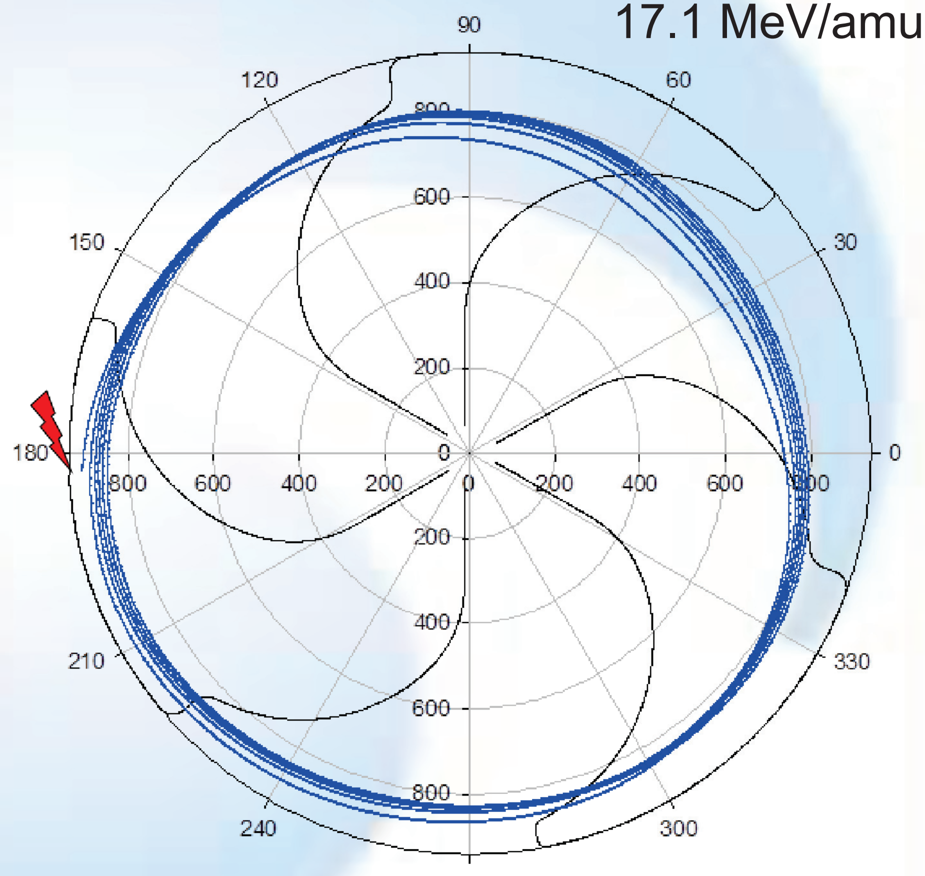
2.7 MeV/amu



High impact angle

Near Extraction

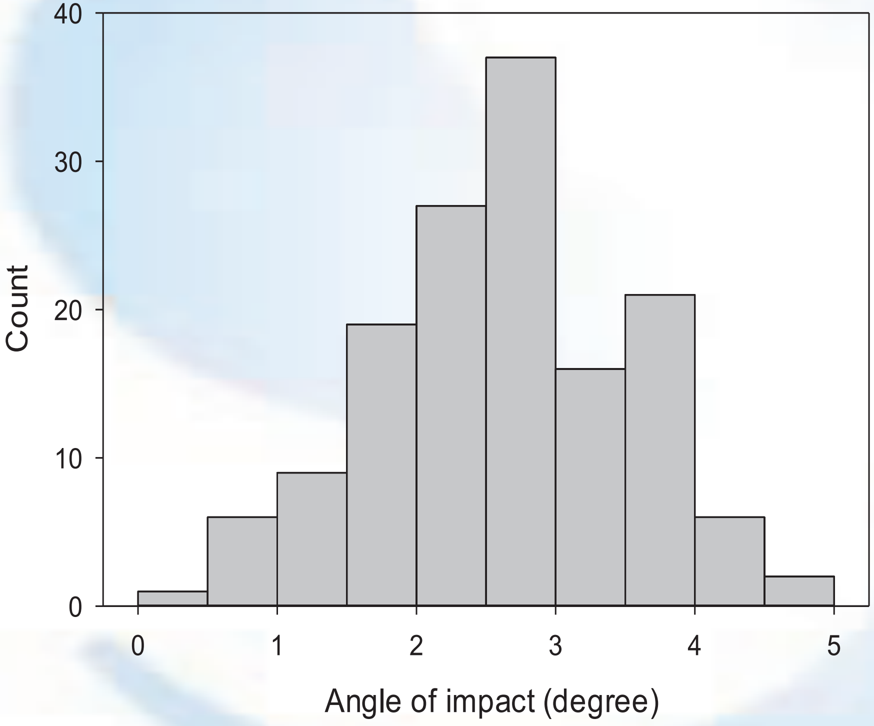
17.1 MeV/amu



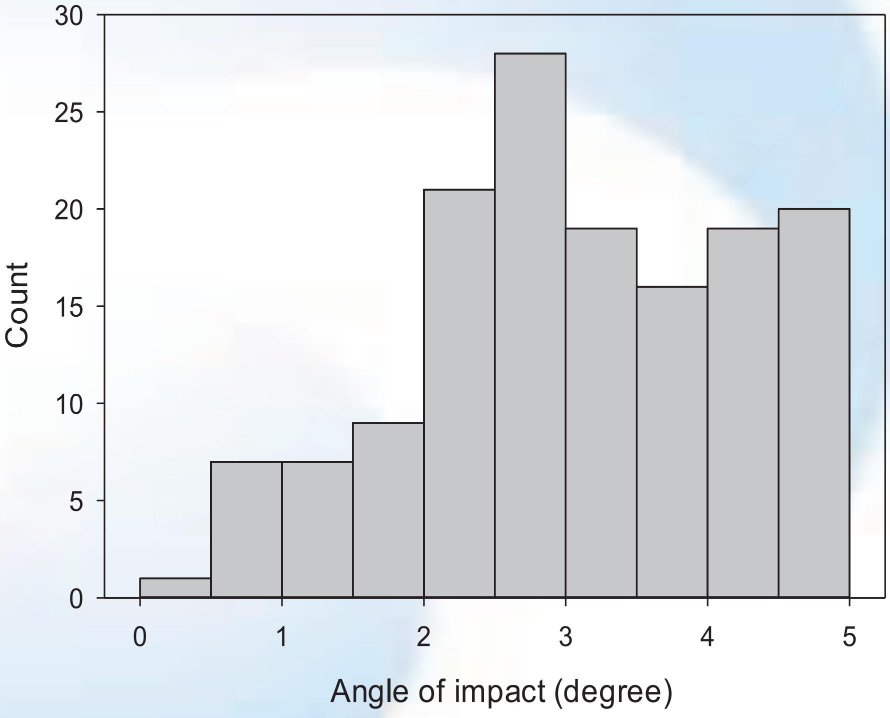
Small impact angle

Parameters of impact

Angle of impact of charge changed particles near extraction radius



Stripping

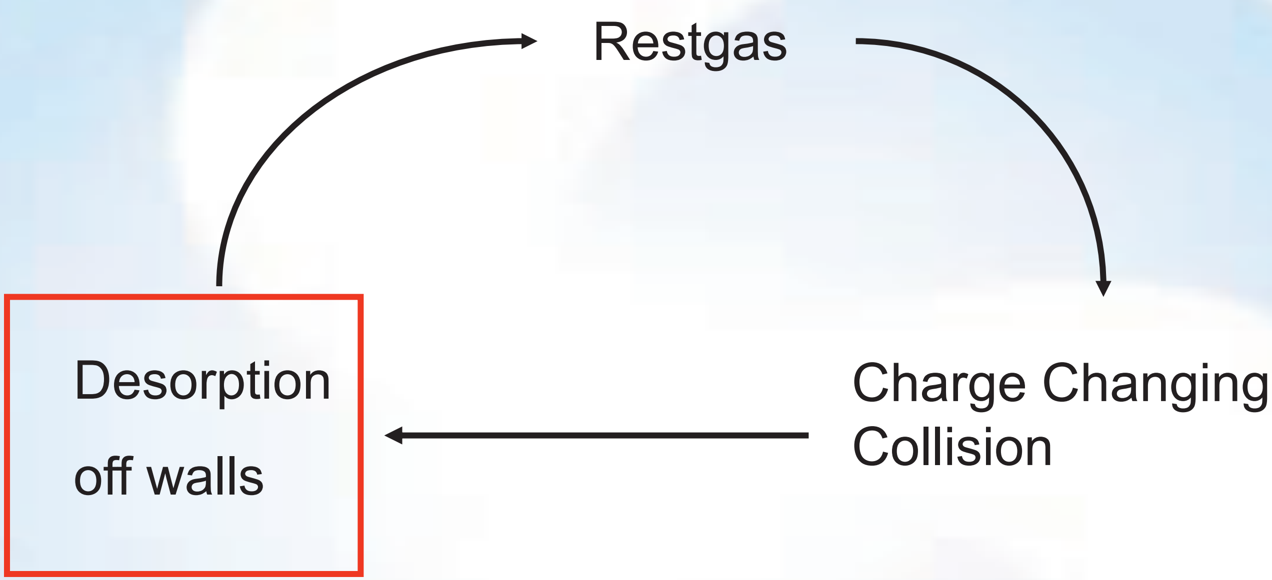


Capture

Orbit calculation - results

- A single charge change generally does not lead to radially unstable orbits.
- Most particles need multiple charge changes before they hit the walls of the cyclotron.
- Only particles changing charge near the extraction radius hit the walls at small angles (0° - 5°).
- Particles lost in the inner radii have a low energy and large impact angle.

Desorption

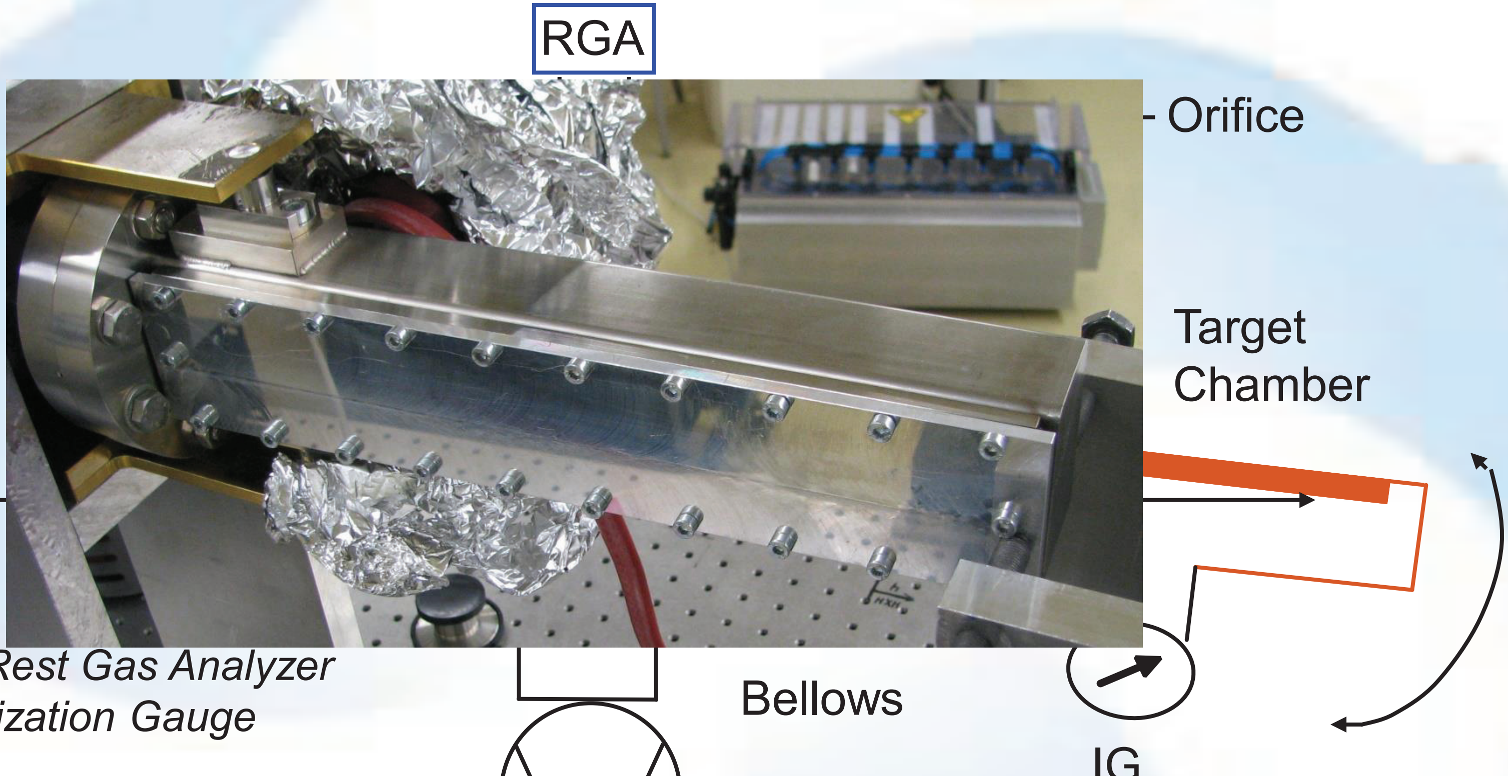


beam particles hit walls → release material

Depends on

- Energy
- Angle of incidence
- Z (beam)
- Surface material

Experiment to Measure Desorption



RGA – Rest Gas Analyzer
IG – Ionization Gauge

- Higher pressure
- Angle dependence
- Different energy

E. Mahner et al., "Ion-Stimulated gas desorption yields and their dependence on the surface preparation of stainless steel", EPAC 2002,

Beams

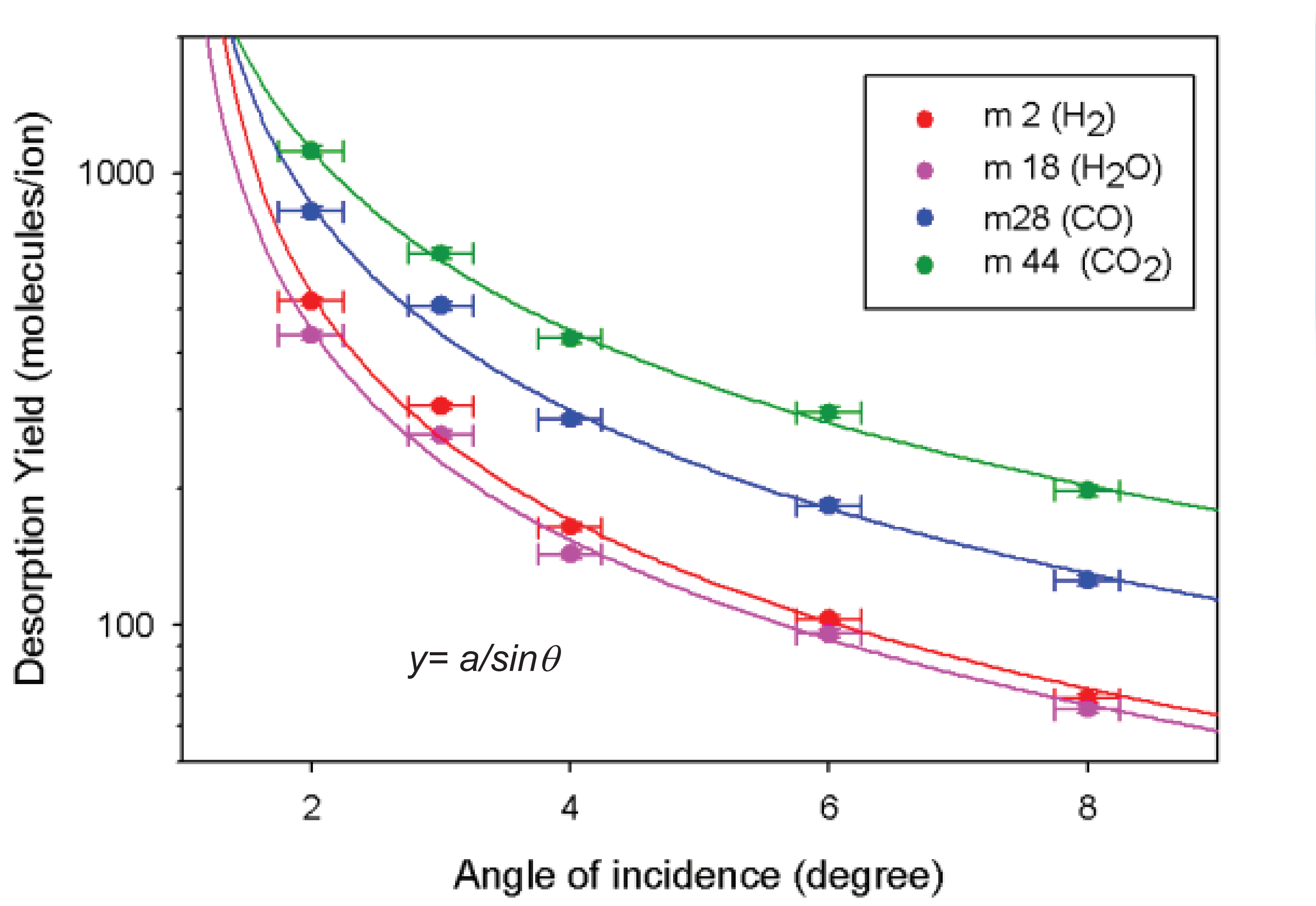
$^{16}O^{2+}$, $^{40}Ar^{5+}$, $^{84}Kr^{11+}$, $^{129}Xe^{16+}$ $^{206}Pb^{27+}$ @ 8 MeV/amu

Targets

Aluminum, Copper, Stainless Steel, Gold plated Copper

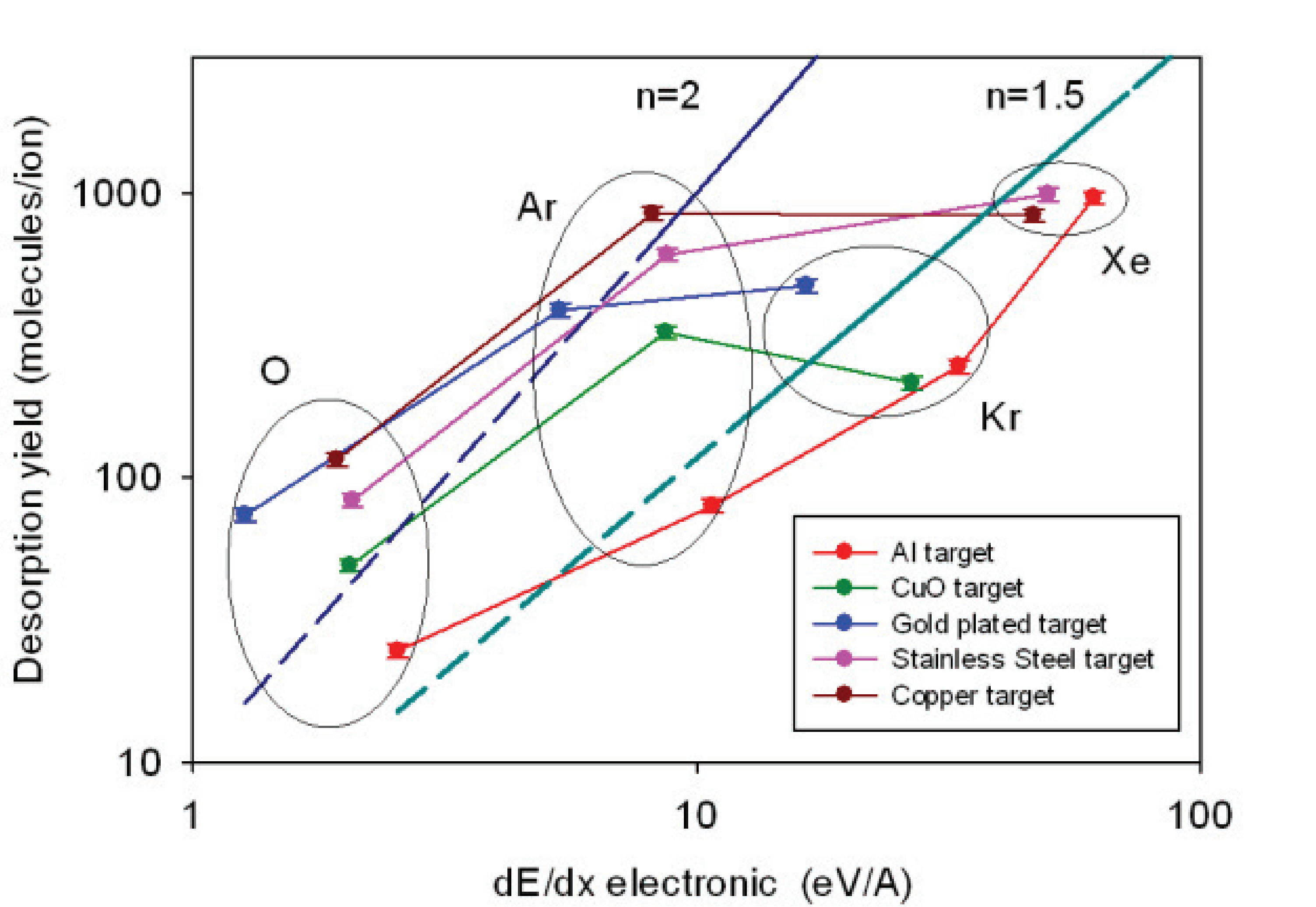
Angle dependence

$^{40}Ar^{5+}$ at 8 MeV/amu on Cu;



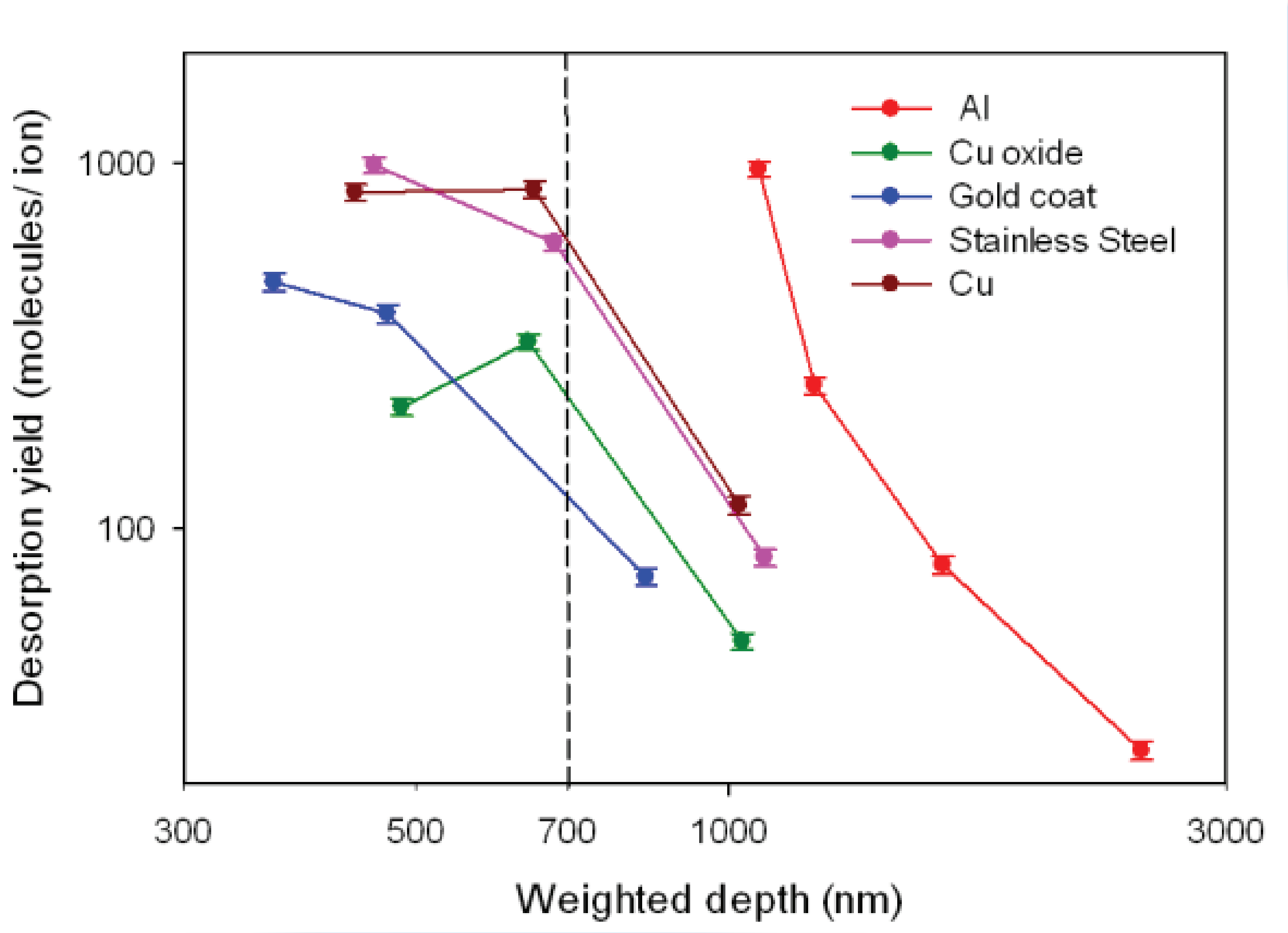
Dependence on $(dE/dx)^n$

All beams on target; at 2° angle of incidence, m 28(CO)



Dependence on weighted depth
(weighted with energy deposited)

All beams on target; at 2° angle of incidence, m 28(CO)



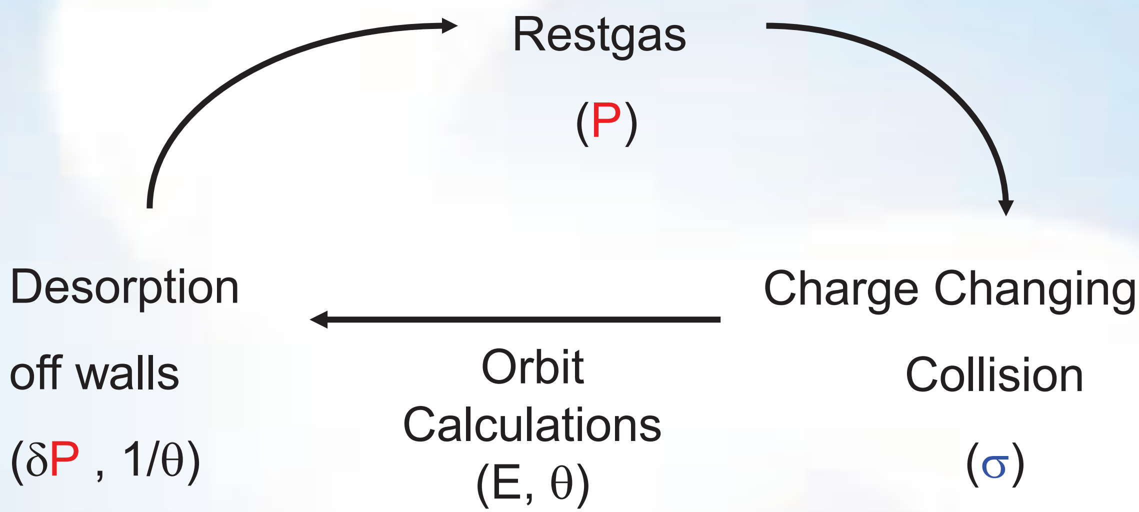
Desorption results

Ion	Energy (MeV/amu)	Angle	Target	Yield (1/ion)	Yield (KVI) (1/ion)
Ar^{9+}	9.7	90°	Copper	53	82 (Ar^{5+})
Pb^{27+}	4.2	4.2°	Stainless steel	1234	1575 (Pb^{27+})
Pb^{27+}	4.2	0.8°	Stainless steel	5575	8230 (Pb^{27+})
Ar^{10+}	40	90°	Stainless steel	47	55 (Ar^{5+})

- Linear dependence of desorption with beam intensity.
- Inverse dependence on angle of impact.
- Thermal spike model does not explain our observations.
- Introduce a “weighted depth” parameter to improve predictive power.

Summary

Estimation of the transmission of heavy ion beams



Improvement of transmission

- Scrapers (1/θ) -not practical.
- Surface coating (δP) - more investigation required.
- Beam induced cleaning (temporary).

Solutions offered are temporary -Effective ones should have been implemented during design.

Thank You