Lifetimes of Low-Charged Ion Beams

R.D. DuBois, A.C.F. Santos
University of Missouri-Rolla, Rolla, MO 65409, USA

Th. Stöhlker, F. Bosch, A. Bräuning-Demian, A. Gumberidze, S. Hagmann,C. Kozhuharov, R. Mann, A. Oršić Muthig, U. Spillmann, S. Tachenov
Atomic Physics Division, GSI, 64291 Darmstadt, Germany

W. Barth, L. Dahl, B. Franzke, J. Glatz, L. Gröning, S. Richter, D. Wilms, A. Krämer
Accelerator Division, GSI, 64291 Darmstadt, Germany
and
K. Ullmann and O. Jagutzki
Instutüt für Kernphysik der J.W. Geothe Universität Frankfurt, August-Euler-Str. 6, Frankfurt am Main, Germany

Work supported, by OFES DOE

Workshop on Atomic Physics Research at the Future GSI Facility
Dec. 9-10, 2002

Importance

GSI future facility: requires accelerating and storing intense beams of “low-to-medium” charge state ions for nuclear, atomic and dense plasma studies.

Heavy Ion Fusion program in USA: use intense beams of fast, singly charged, heavy ions (eg. 10 – 20 MeV/u Pb^+, Cs^+, K^+, or Ar^+) to induce DT fusion.

Problem: projectile stripping in background gases

- **Transport losses:**

  Ramifications include
  - loss of beam intensity and luminosity
  - erosion of walls, lenses, etc.
  - excessive heat loads
  - increased vacuum loads from heating, desorption
  - radiation buildup

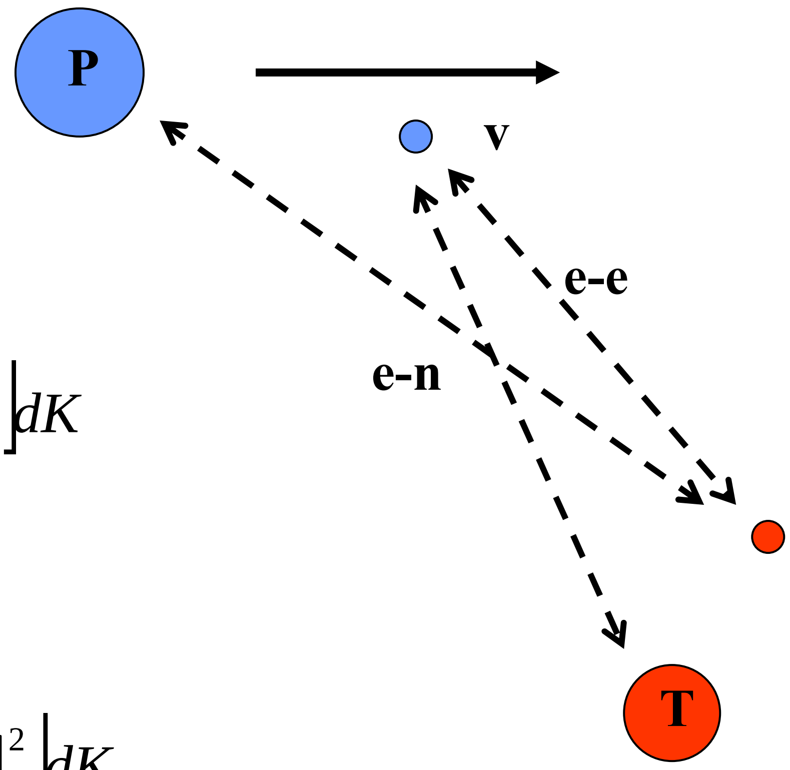
- **Shortened storage lifetimes:**

  Adequate to perform desired studies?

  Base vacuum required?

  (solutions limited by technology and €)

e-e and e-n Interactions

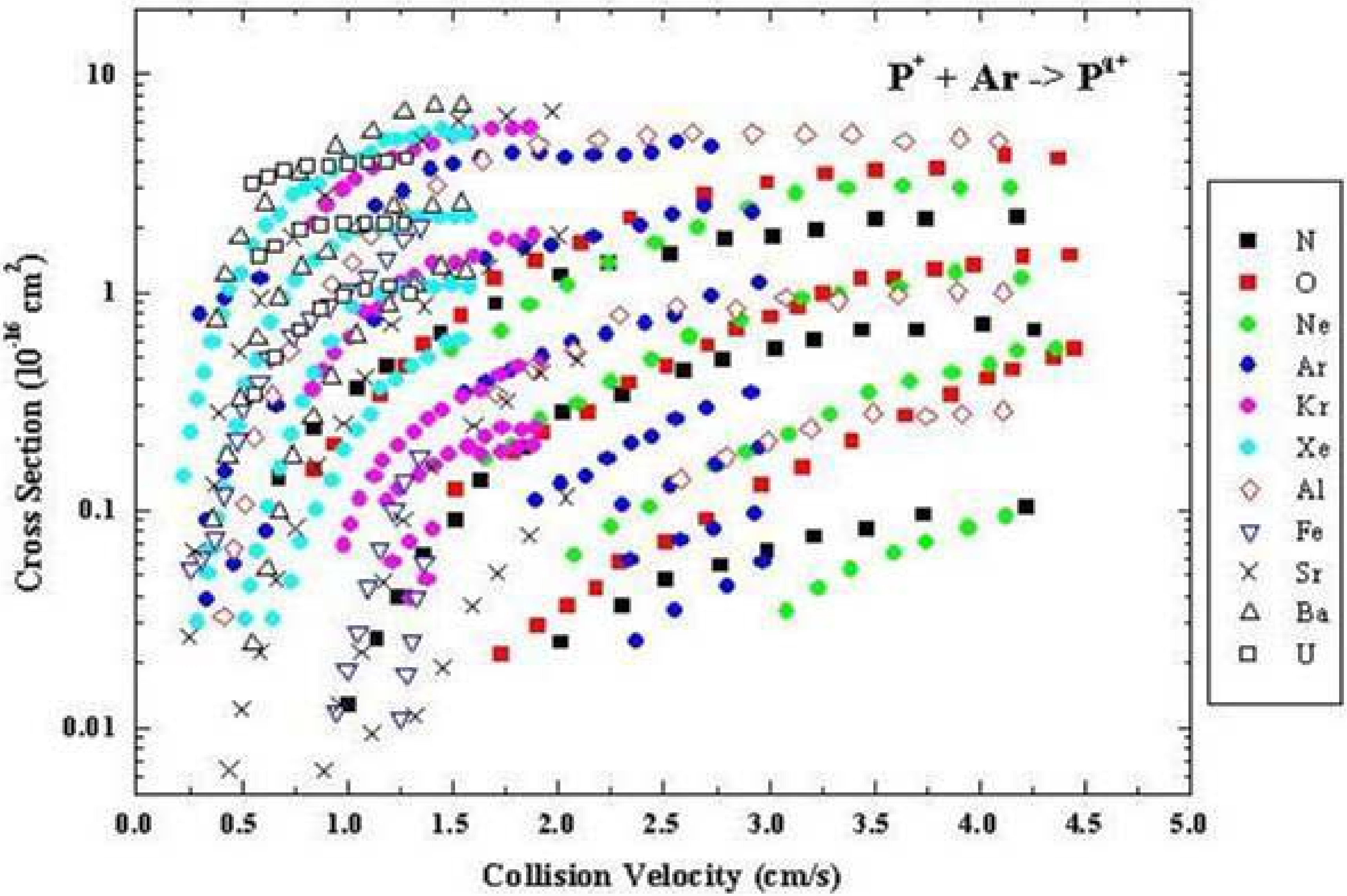


e-n

$$d^2\sigma(\varepsilon) = \int_{K\min} A(\varepsilon, K)\left[\left|Z - N\,F(K)\right|^2\right] dK$$

e-e

$$d^2\sigma(\varepsilon) = \int_{K'\min} A(\varepsilon, K)\left[N - N\left|F(K)\right|^2\right] dK$$


$P^+ + Ar \rightarrow P^{q+}$
Cross Section (10^{-16} cm^2)
10
1
0.1
0.01
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Collision Velocity (cm/s)
N
O
Ne
Ar
Kr
Xe
Al
Fe
Sr
Ba
U

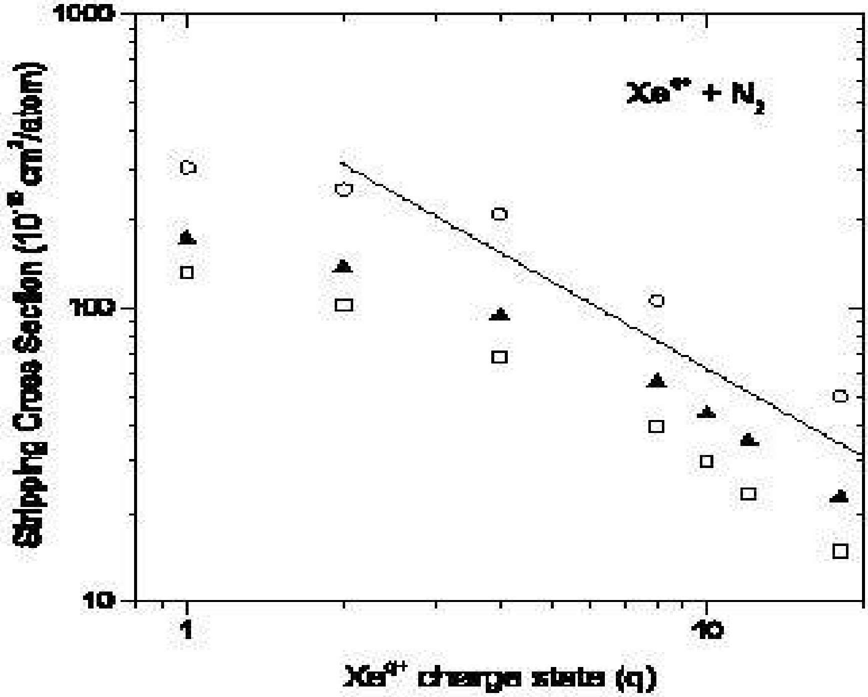


Figure 4. Calculated total projectile stripping cross sections as a function of incident c
for $Xe^{q+} + N_2$ at 2 MeV u^{-1} (open circles), 10 MeV u^{-1} (full triangles) and 20 MeV
squares). The full line indicates a q^{-1} dependence.

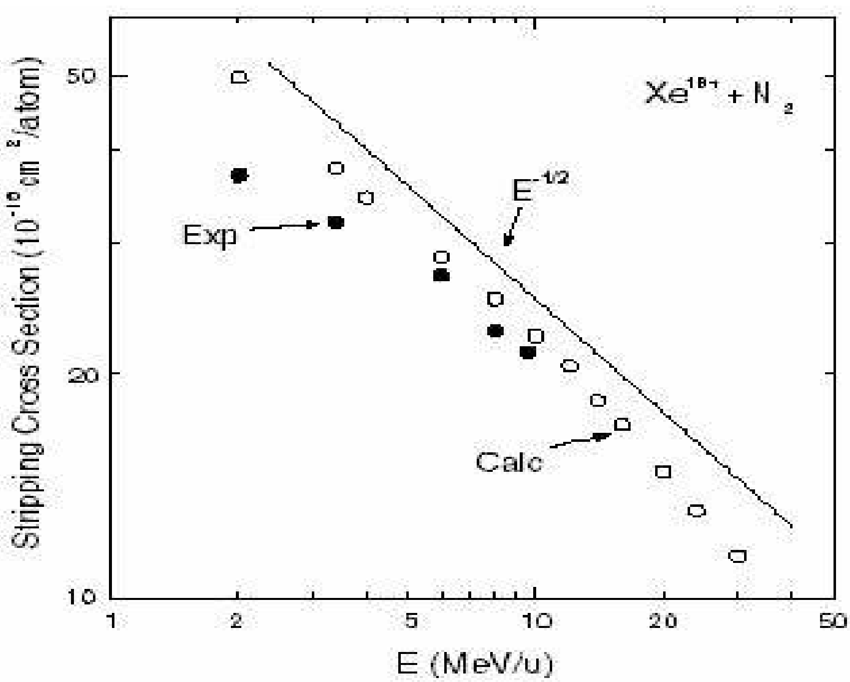


Figure 3. Total projectile stripping cross sections (cm^2/atom) for $Xe^{18+} + N_2$
Experimental results are displayed by full circles and the calculations by open circles.

From Olson et al. J. Phys. B 35, 1893 (2002)

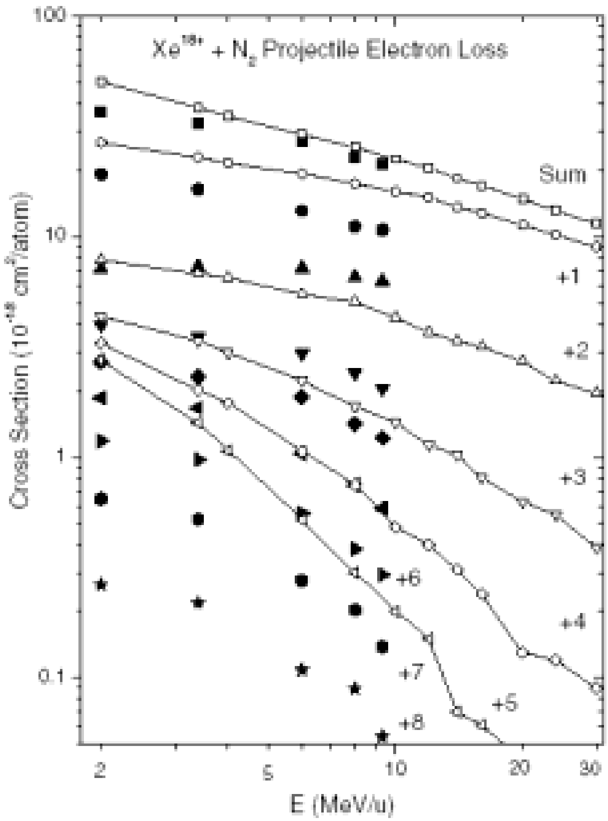


Figure 10. Single and multiple stripping cross sections for Xe^{18+} + N_2 collisions. The experimental data are given by full symbols and the calculations using a direct ionization model are displayed by open symbols.

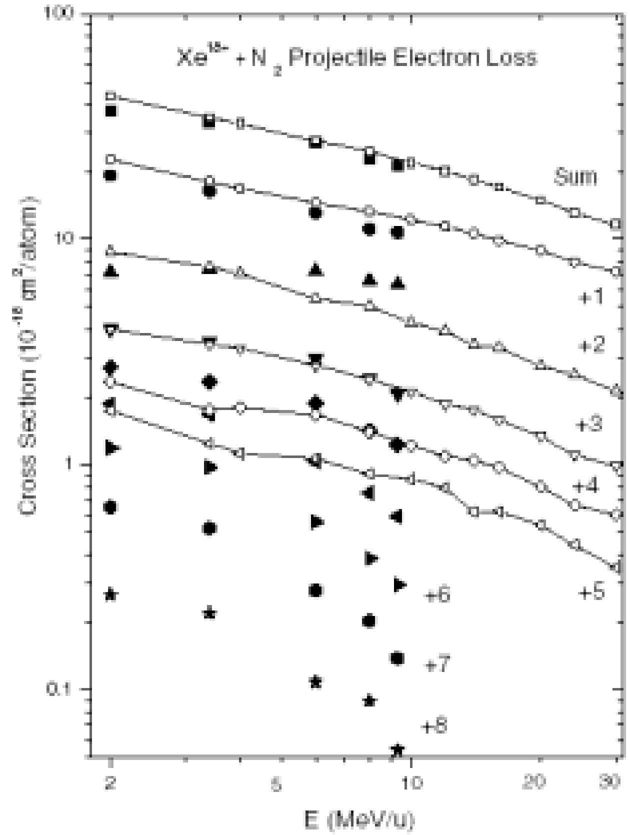
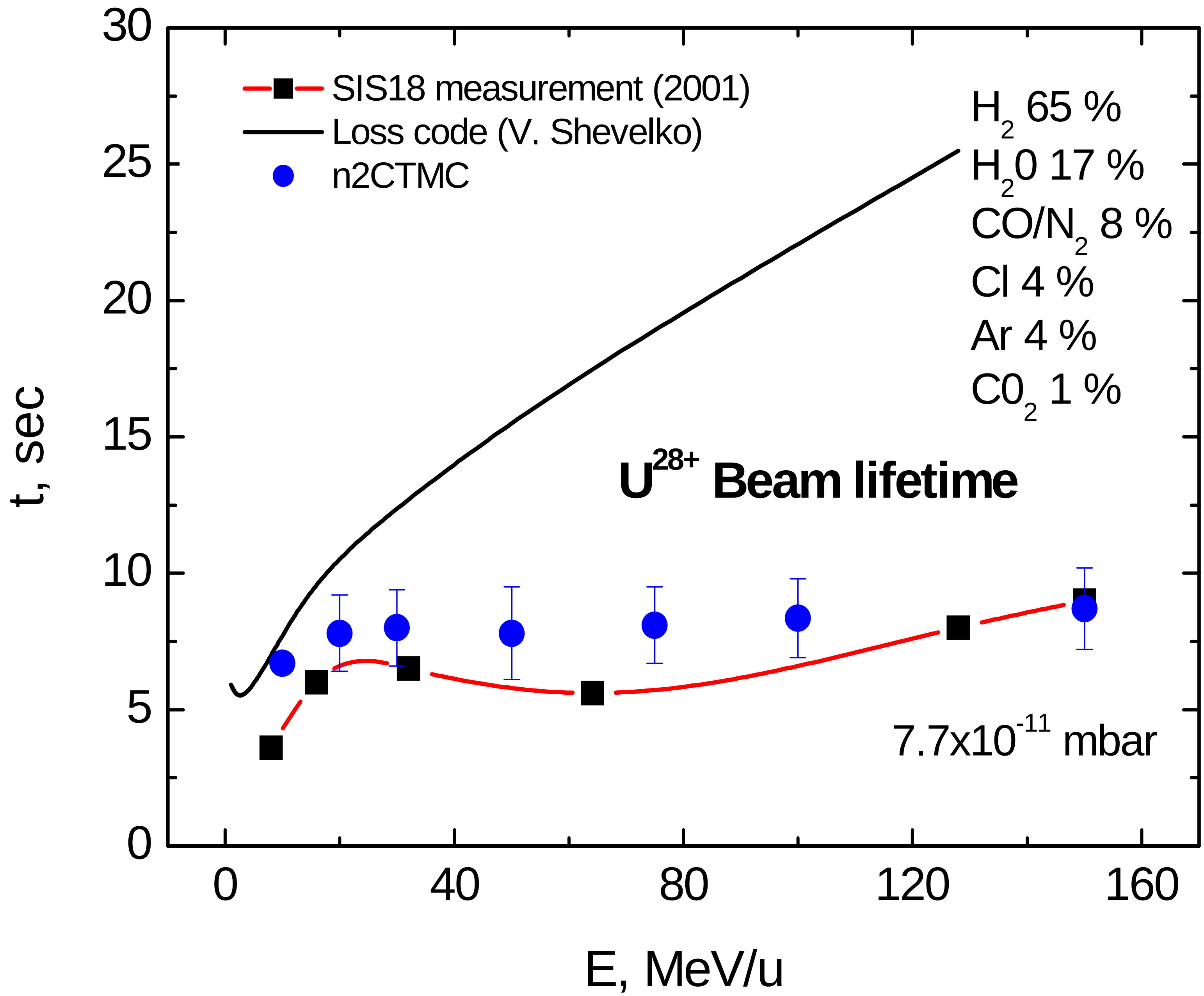


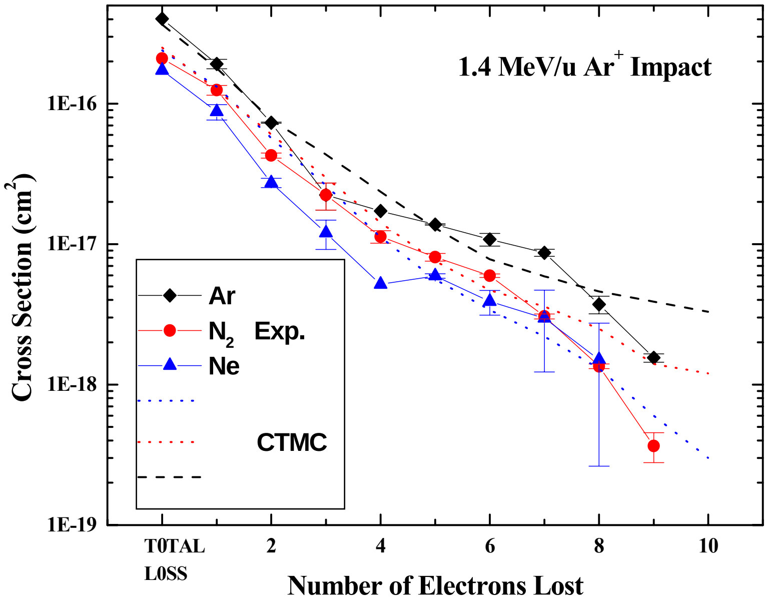
Figure 11. Experimental single and multiple stripping cross sections for Xe^{18+} + N_2 compared to calculated results obtained using the energy deposition model.

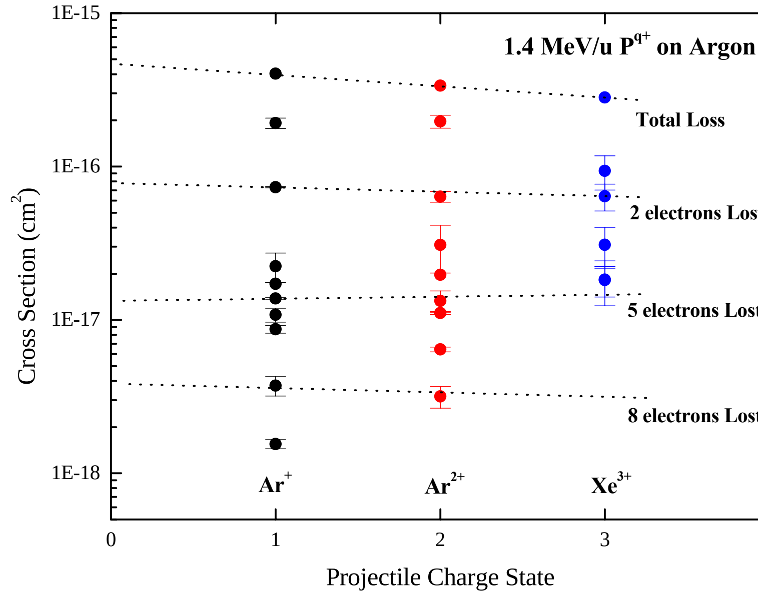
From Olson et al. J. Phys. B **35**, 1893 (2002)

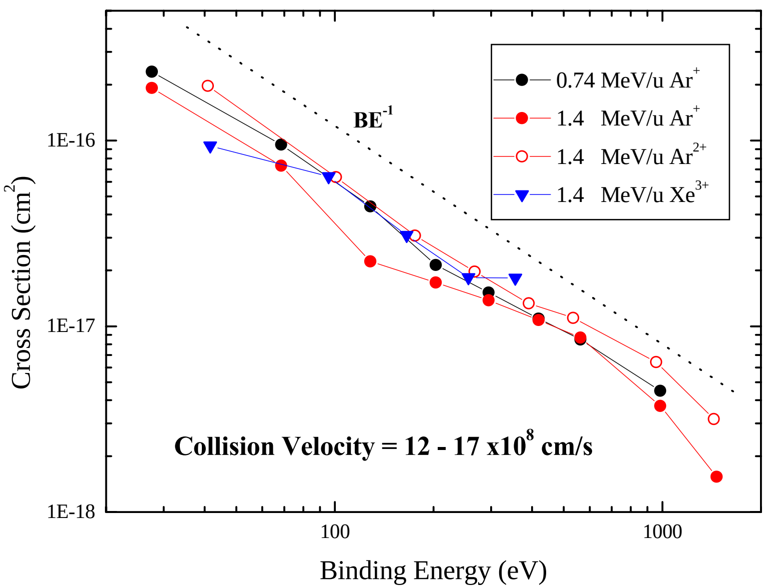


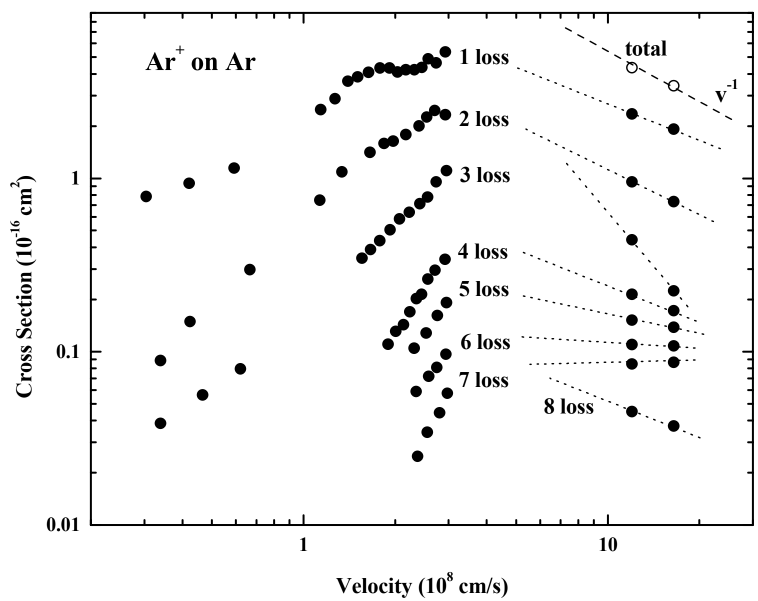
SIS18 measurement (2001)
Loss code (V. Shevelko)
n2CTMC
H2 65 %
H20 17 %
CO/N2 8 %
Cl 4 %
Ar 4 %
C02 1 %
U28+ Beam lifetime
7.7x10-11 mbar
t, sec
E, MeV/u
0
5
10
15
20
25
30
0
40
80
120
160

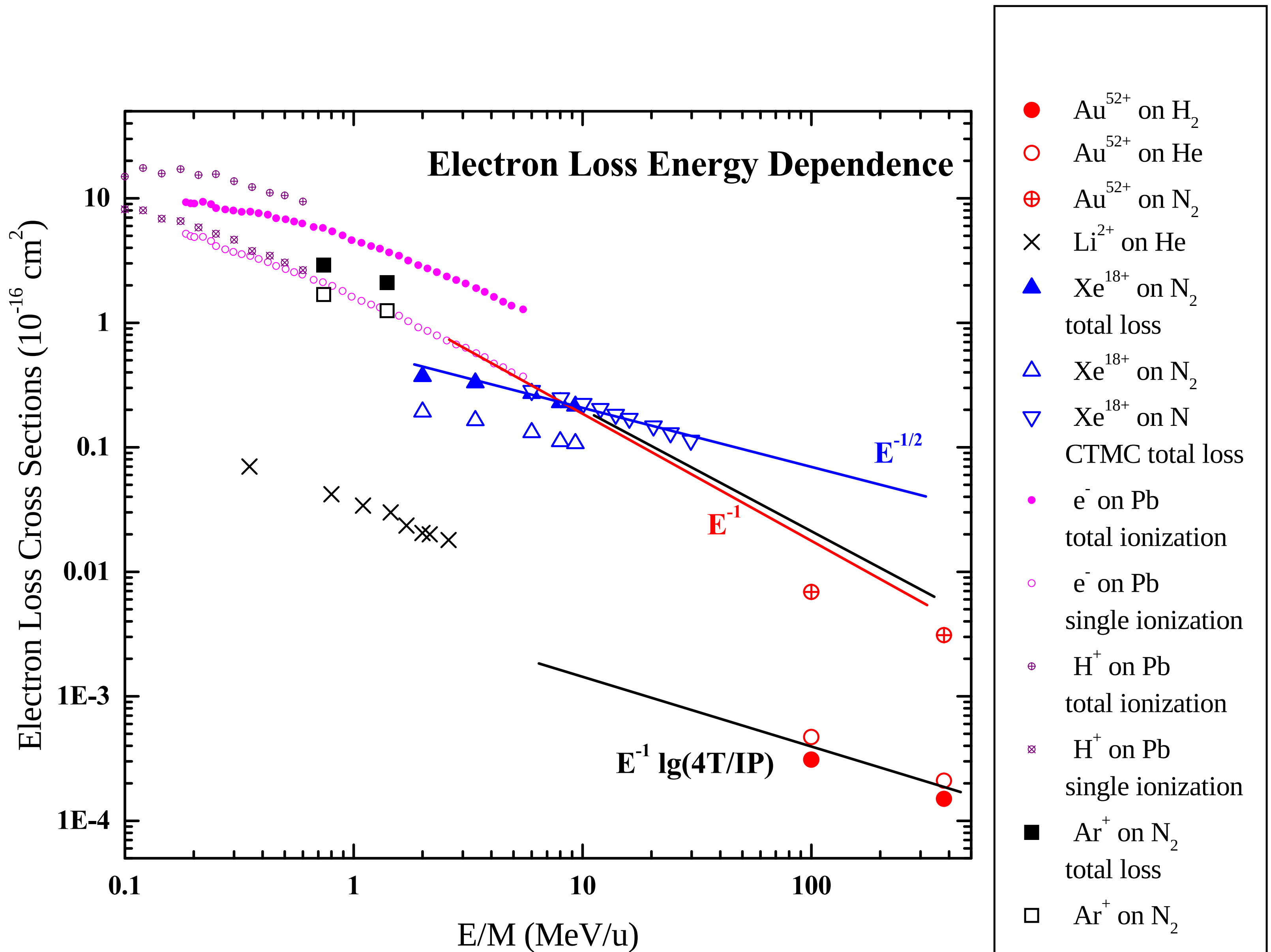
UNILAC Results



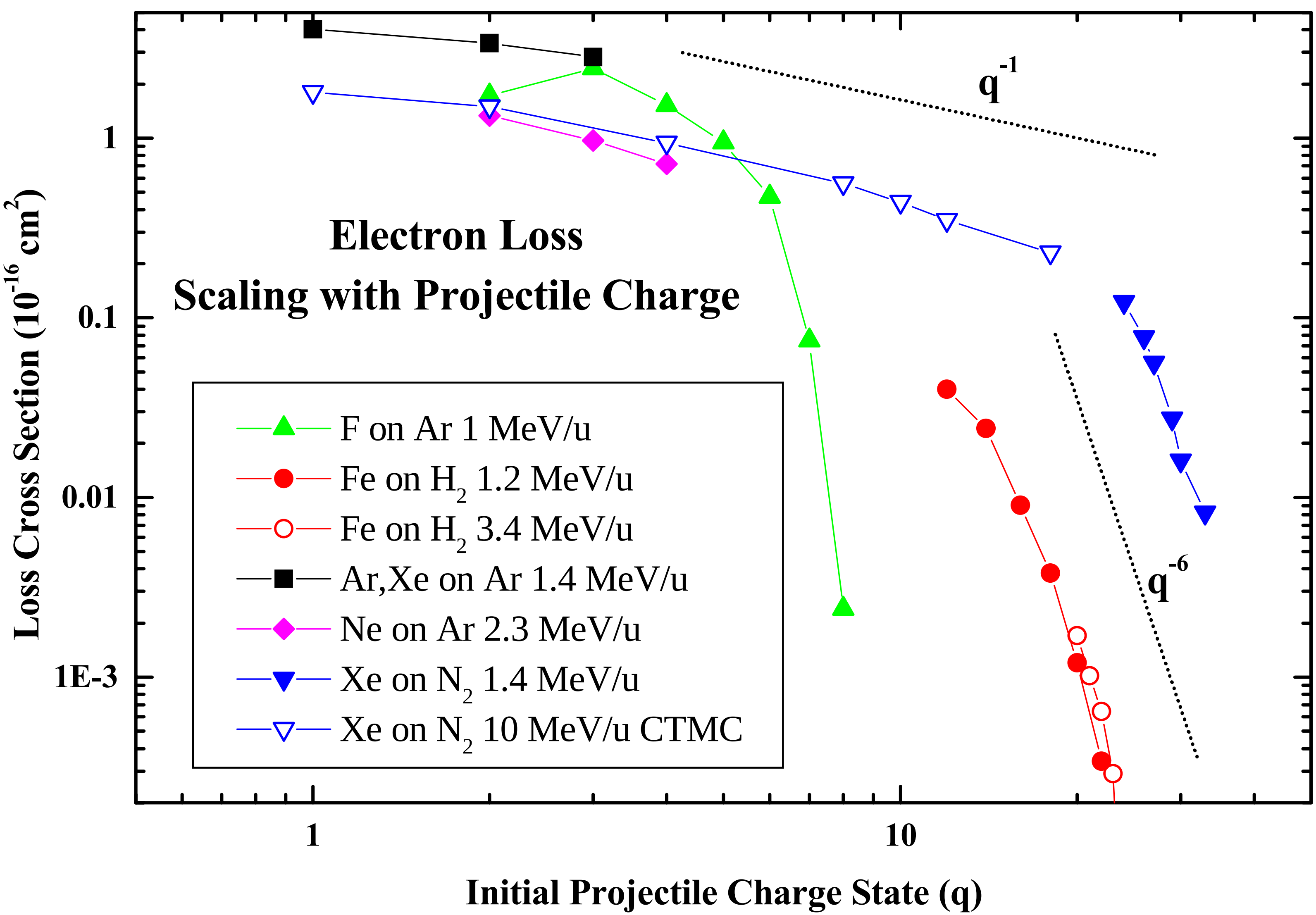




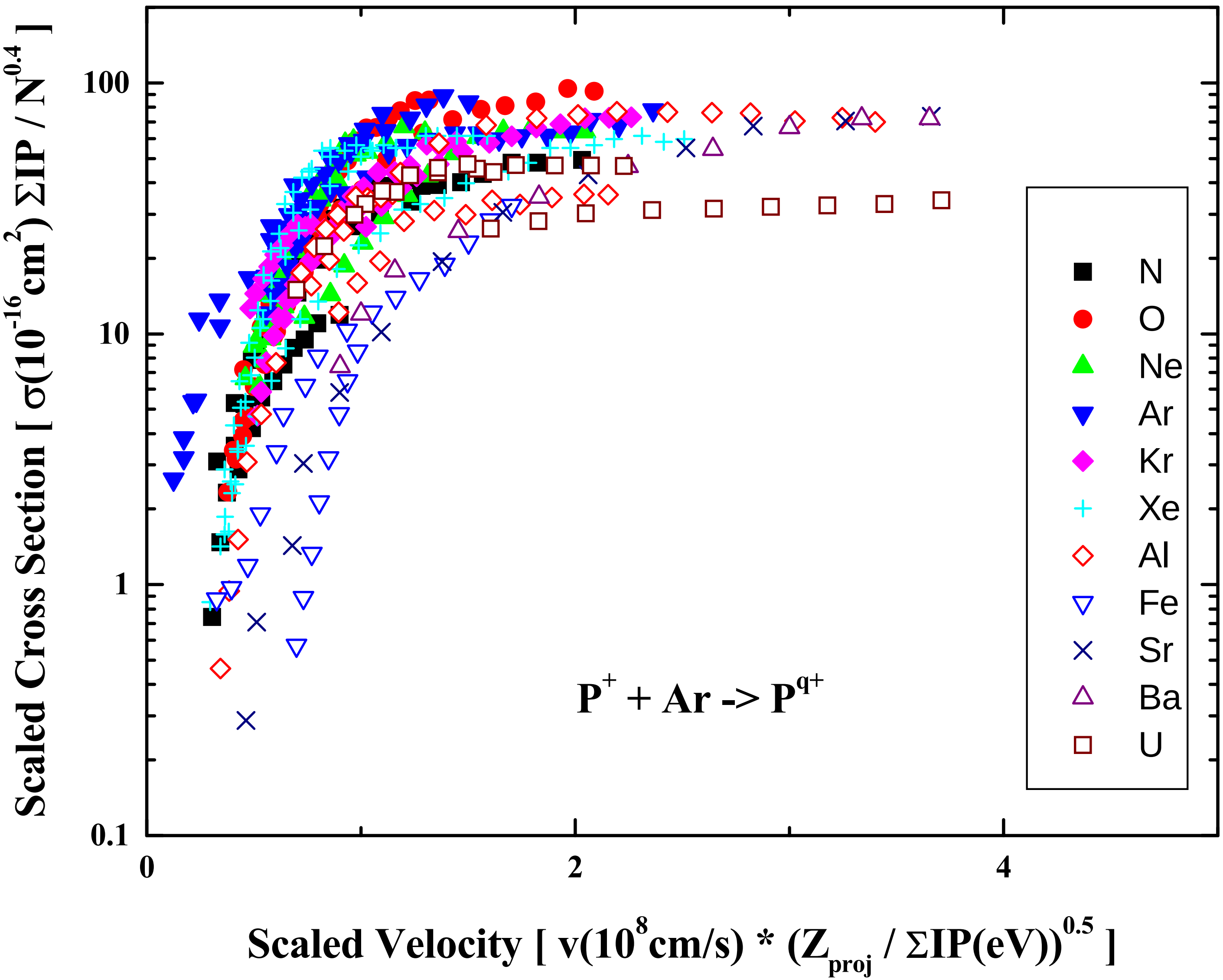


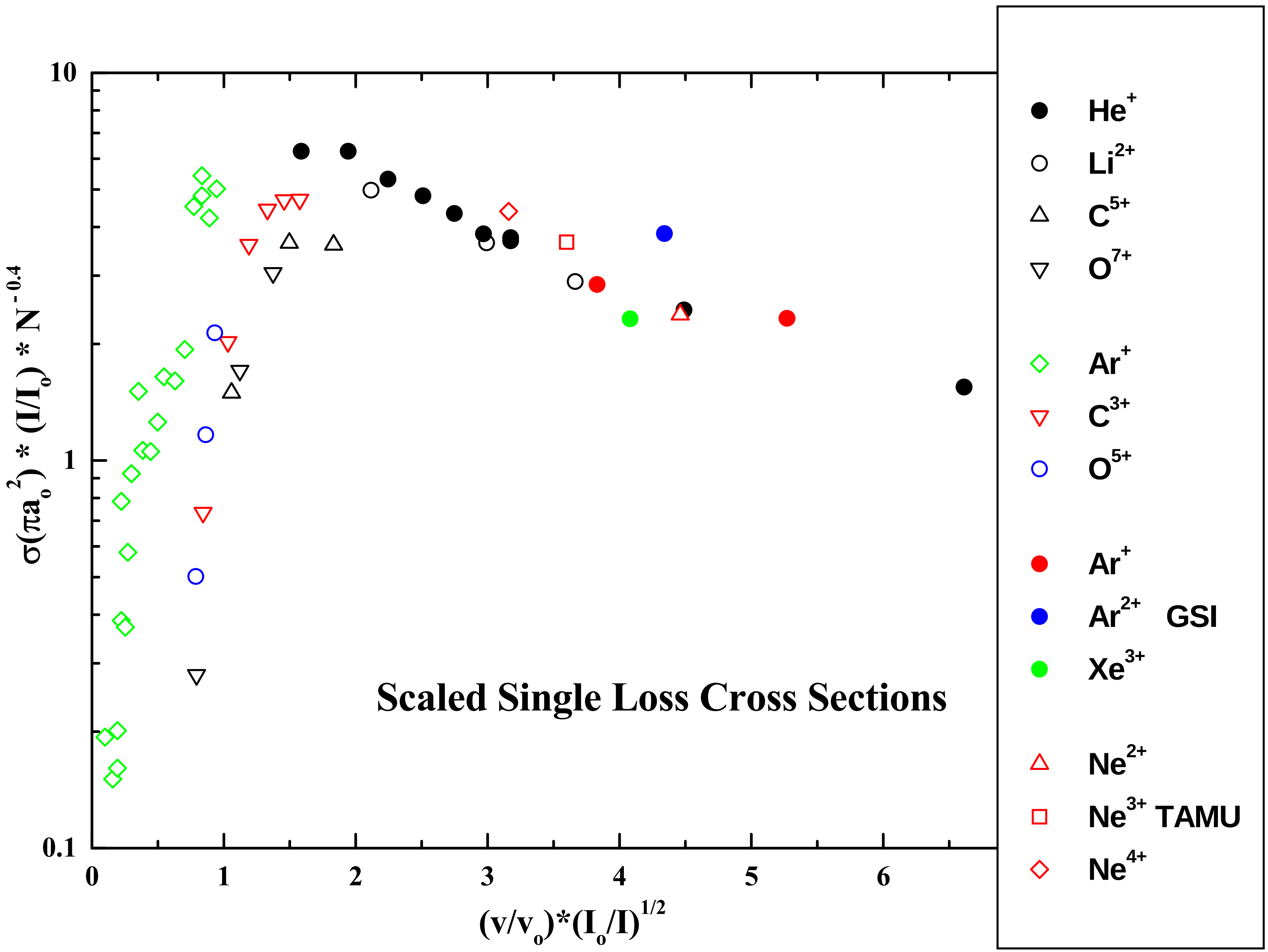


Electron Loss Energy Dependence
Electron Loss Cross Sections (10^{-16} cm^2)
E/M (MeV/u)
10
1
0.1
0.01
1E-3
1E-4
0.1
1
10
100
$E^{-1/2}$
E^{-1}
E^{-1} lg(4T/IP)
Au^{52+} on H_2
Au^{52+} on He
Au^{52+} on N_2
Li^{2+} on He
Xe^{18+} on N_2 total loss
Xe^{18+} on N_2
Xe^{18+} on N CTMC total loss
e^- on Pb total ionization
e^- on Pb single ionization
H^+ on Pb total ionization
H^+ on Pb single ionization
Ar^+ on N_2 total loss
Ar^+ on N_2



Electron Loss
Scaling with Projectile Charge
q^{-1}
q^{-6}
F on Ar 1 MeV/u
Fe on H_2 1.2 MeV/u
Fe on H_2 3.4 MeV/u
Ar,Xe on Ar 1.4 MeV/u
Ne on Ar 2.3 MeV/u
Xe on N_2 1.4 MeV/u
Xe on N_2 10 MeV/u CTMC
Loss Cross Section (10^{-16} cm^2)
1
0.1
0.01
1E-3
1
10
Initial Projectile Charge State (q)


Scaled Cross Section [σ(10^-16 cm^2) ΣIP / N^0.4]
100
10
1
0.1
0
2
4
Scaled Velocity [v(10^8 cm/s) * (Z_proj / ΣIP(eV))^0.5]
N
O
Ne
Ar
Kr
Xe
Al
Fe
Sr
Ba
U
P^+ + Ar -> P^q+


Scaled Single Loss Cross Sections
σ(πa_o^2) * (I/I_o) * N^-0.4
(v/v_o)*(I_o/I)^1/2
10
1
0.1
0
1
2
3
4
5
6
He+
Li2+
C5+
O7+
Ar+
C3+
O5+
Ar+
Ar2+ GSI
Xe3+
Ne2+
Ne3+ TAMU
Ne4+

Where do we stand?

- **1^{st} data for fast (.74, 1.4 MeV/u) low charge state heavy ions**
  - Systematic study
  - $\sim v^{-1}$ dependence
  - $\sigma_n \sim BE^{-1}$ (independent of target)
  - Approx. const. with proj. q
  - Target dependence ??
  - $\sigma_{totloss}$ good agreement with CTMC
  - CTMC very good for total loss, BUT classical calculation and requires testing since must model MANY body systems
  - Tried reverse collisions

- **Making progress on scaling formulae**
  - Success for all +1 ions and all σ_n
  - Looks promising for +q ions (low q ??) for single loss

- **Big questions**
  - Energy dependence v^{-1} or E^{-1} ; which, when???
  - Proj q scaling low q, $\sim q^{-1}$; high q, $\sim q^{-6}$; what defines low and high?
  - VERY high energies