Towards improvement of ETACHA for S3 ions

S3WS 09

Collaboration between
INSP (Paris), CNEA (Bariloche), IFR (Rosario)

- ETACHA was developed following experiments at the ALICE accelerator in Orsay to predict (and optimize) the production of highly stripped ions (bare and hydrogenlike).

- Our first model considered ions with only up to 10 e- (n=1 & 2 shells).

- In 1996, a new version for PC was elaborated, with several improvements such as an extension to up to 28 electrons (n=1,2,3 shells). This allows to consider ions such as 30 MeV/n $^{56+}$Pb as delivered by GANIL

- End of 2001, the code was further extended, with up to 60 e-, but much more remains to do to account for many electron ions …

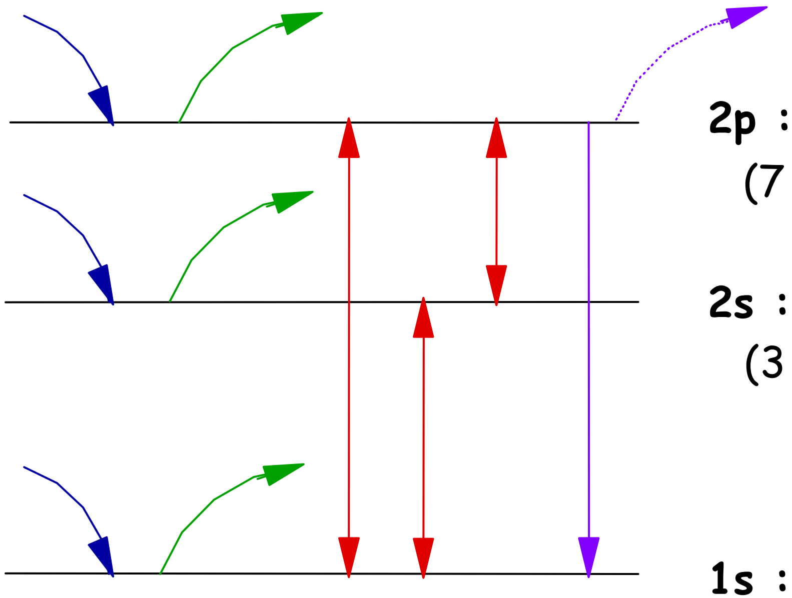
In any case, the starting point is a code that was well suited to **highly charged ions**

Basic considerations in the model

Atomic processes and charge states :

➢ each charge state results from the combination of various configurations with the same electron number

➢ the population of each configuration results from the competition between various atomic processes :



2p : 0,1,... 6 e-
(7 possibilities)

2s : 0,1 or 2 e-
(3 possibilities)

1s : 0,1 or 2 e-
(3 possibilities)

- **capture**
- **ionisation**
- **excitation**
- **radiative (and Auger) processes**

Basic considerations in the model

Atomic processes and charge states :

- each charge state results from the combination of various configurations with the same electron number

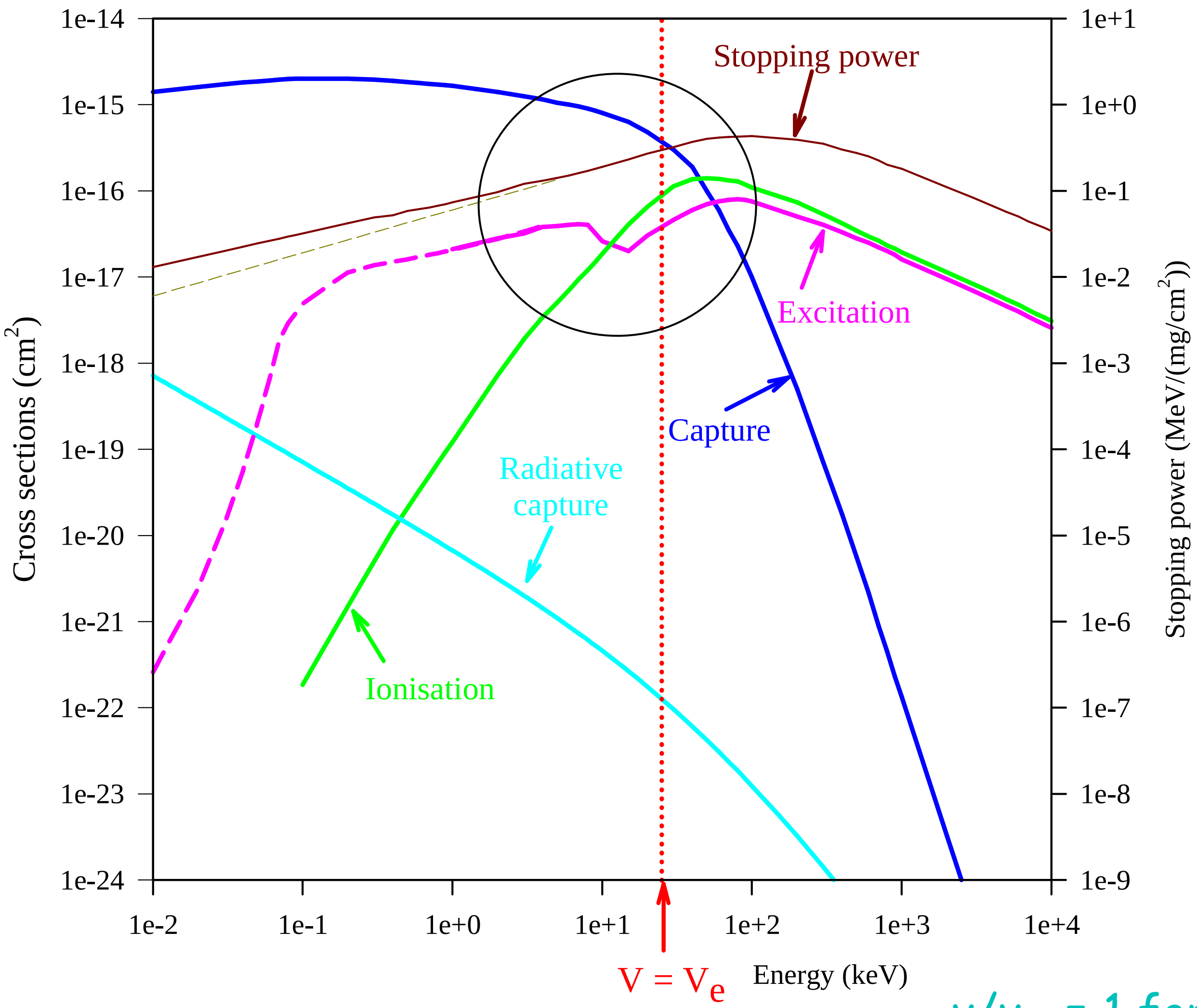
- 2 shell model : (10 electrons)
  Y(n1s).Y(n2s).Y(n2p) → 3+3+7=13 configurations or
  Y(n1s,n2s,n2p) → 3x3x7 = 63 correlated configurations
  (better results)

- 3 shell model : (28 electrons)
  Y(n1s,n2s,n2p,n3s,n3p,n3d) → 3x3x7x3x7x11 = 14553 (!) correlated configurations or
  Y(n1s,n2s,n2p,n3) → 3x3x7x19 = 1197 partially correlated +
  Y(n3s), Y(n3p), Y(n3d) calculated separately → 1218 equations or
  Y(n1s,n2s,n2p) then Y(n12,n3) → 63+21+11x19=293 equations

- 4 shell model : (60 electrons)
  Y(n1s,n2s,n2p,n3,n4) → 3x3x7x19x33 = 39501 (!) configurations or
  Y(n1s,n2s,n2p) then Y(n12,n3) then Y(n123,n4) →
  293+33+29*33=293+990=1283 coupled differential equations :

$$\frac{\mathrm{d}Y_i(x)}{\mathrm{d}x} = \sum_j Y_j(x)\,\sigma_{ji} - Y_i(x)\sum_j \sigma_{ij}$$

Cross sections (p → H system)



$$\bar{n}_{e-} = n_{max} \frac{\sigma_{gain}}{\sigma_{loss} + \sigma_{gain}}$$

v/v_{1s} = 1 for Ar at 8 MeV/u

v/v_{1s} = 1 for Kr at 34 MeV/u

v/v_{1s} = 1 for Pb at 230 MeV/u

Present status and objectives

➢ ETACHA has proved to be accurate in the high velocity regime, ie, for ions such as

- C ions, E ❍ 1 MeV/u
- Ar ions, E ❍ 8 MeV/u
- Kr ions, E ❍ 30 MeV/u
- Pb ions, E ❍ 200 MeV/u

$$K = \frac{Zc}{Zp} \times \frac{V_e}{V_p} << 1$$

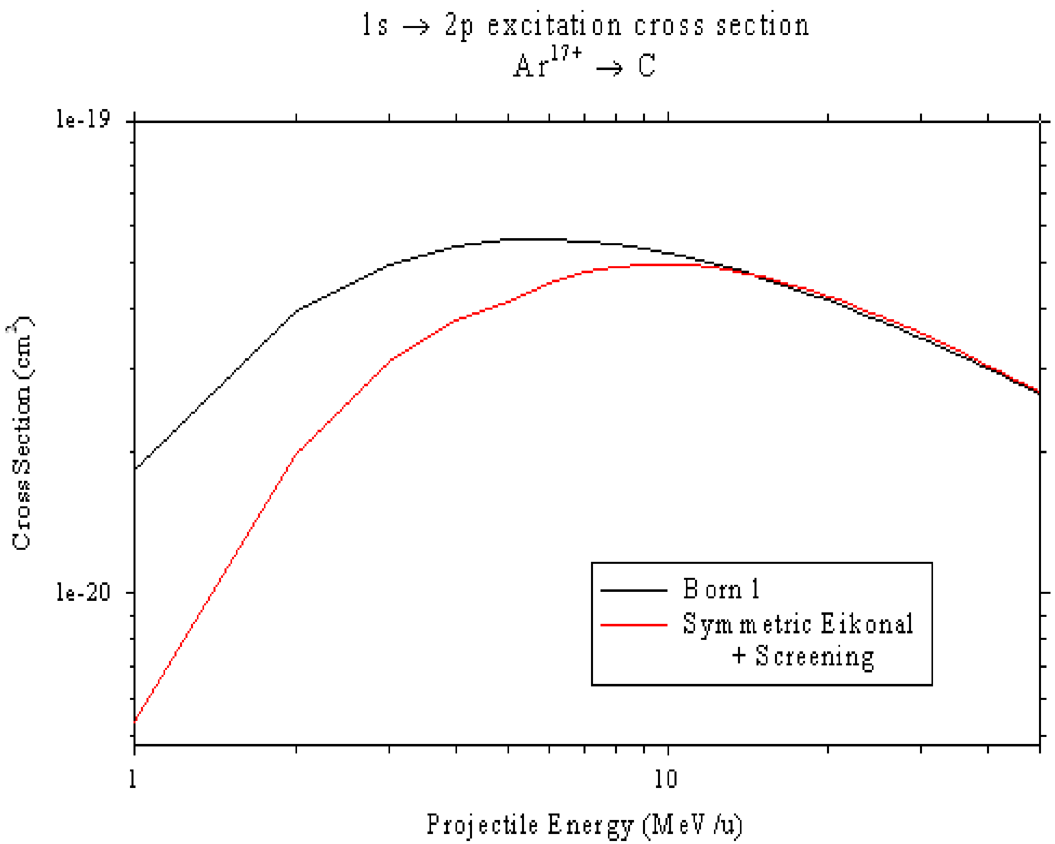
➢ Challenging systems need to be considered in the context of S3 :

- (Exotic) Sn ions, E ~ 1 Mev/u
- SHE ions, E ~ 3 – 0.1 Mev/u

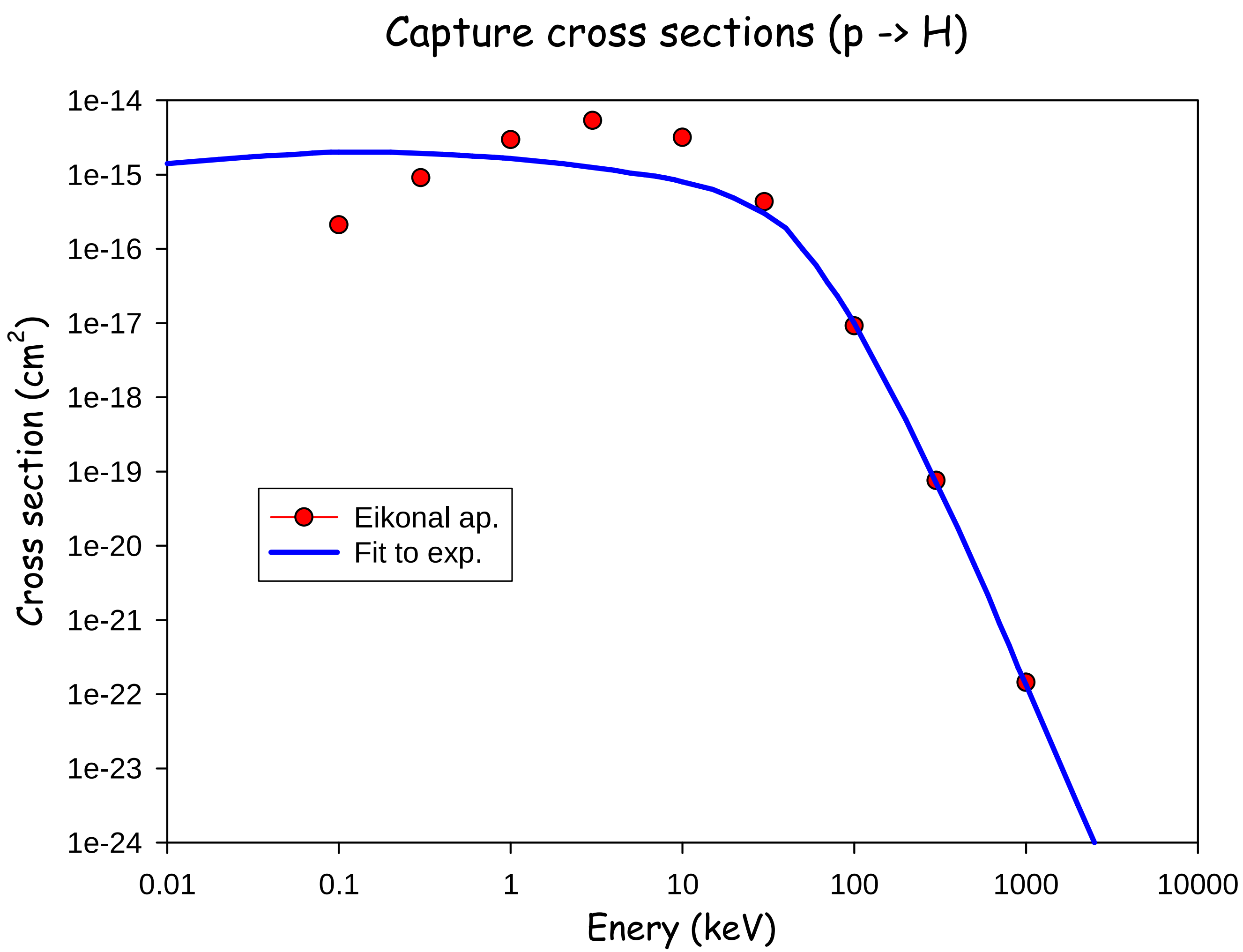
and probably many others …

Cross sections for strong perturbation

At low velocities, excitation and ionization cross sections strongly deviate from (simple) Born 1 theories



Cross sections : capture at low velocity



The CDW approximation appears to diverge at low velocity

Some results

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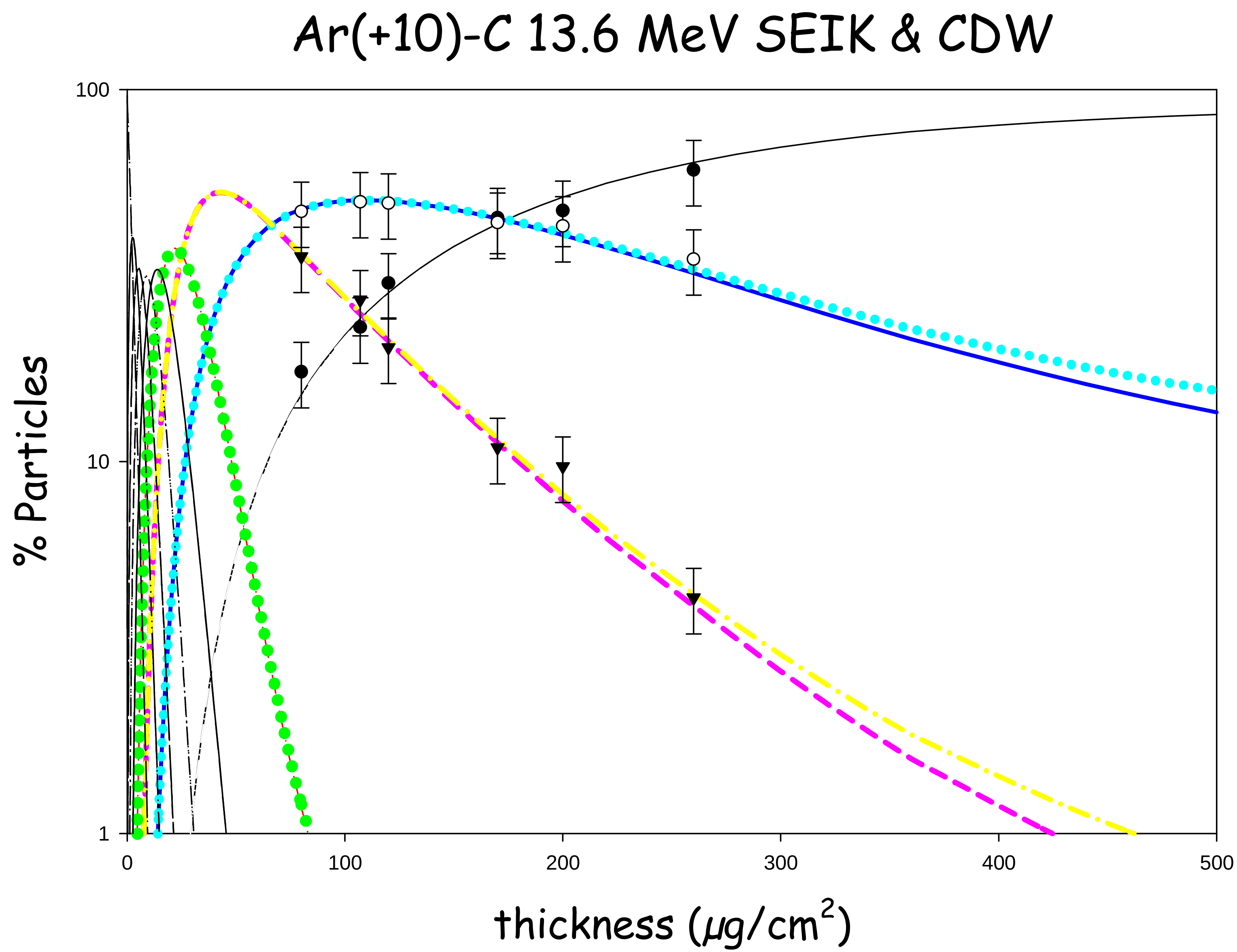
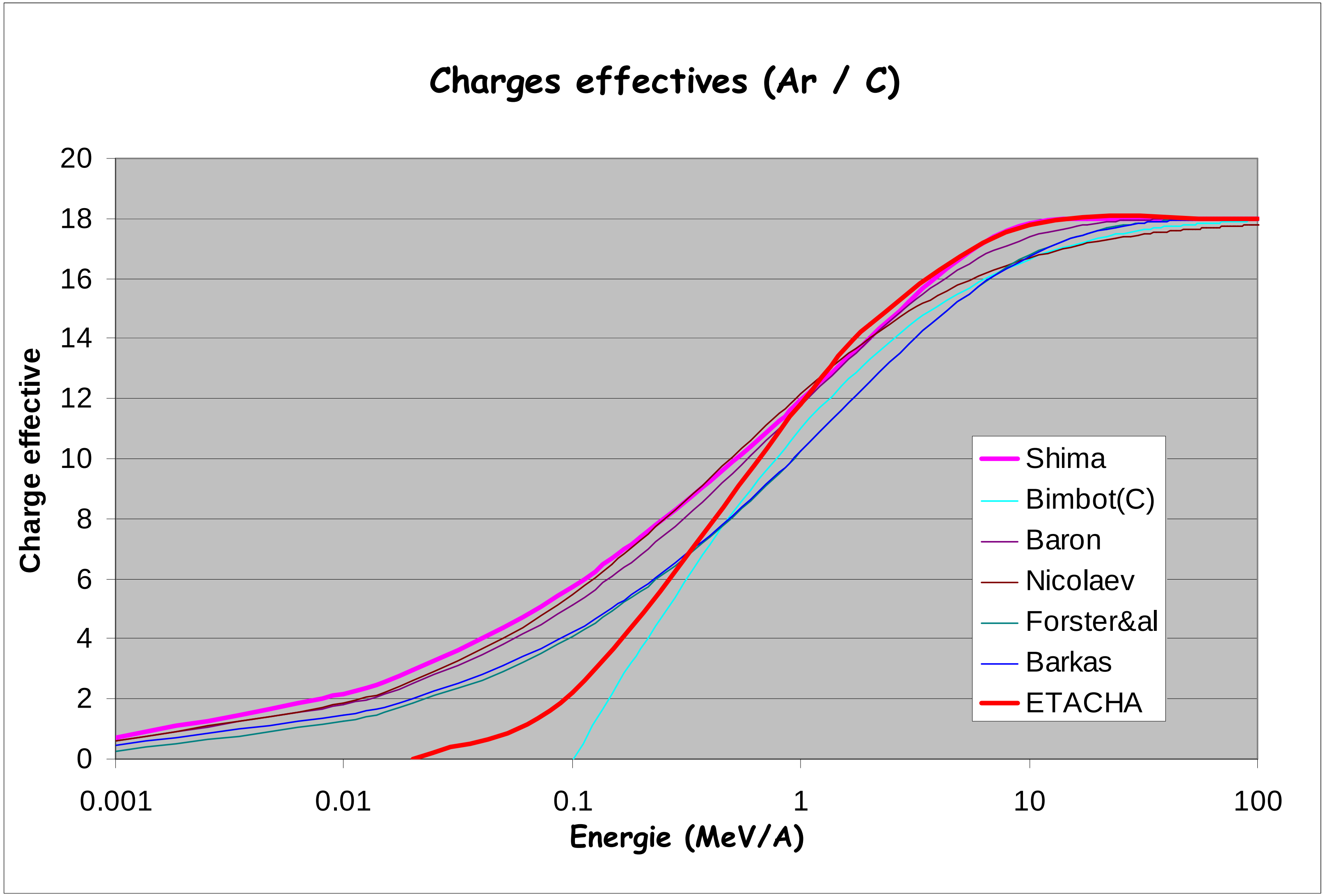


Some results



Some preliminary results

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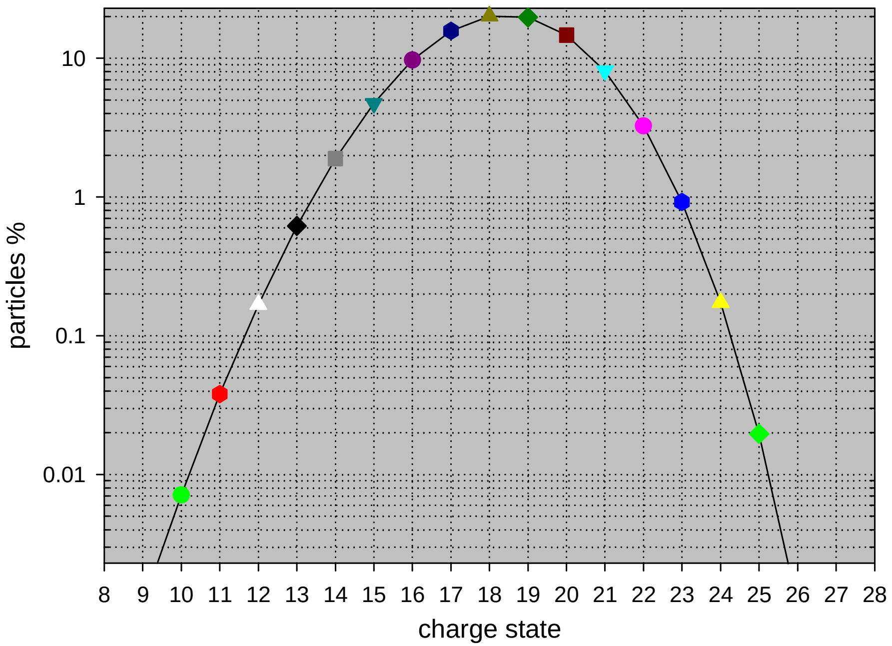
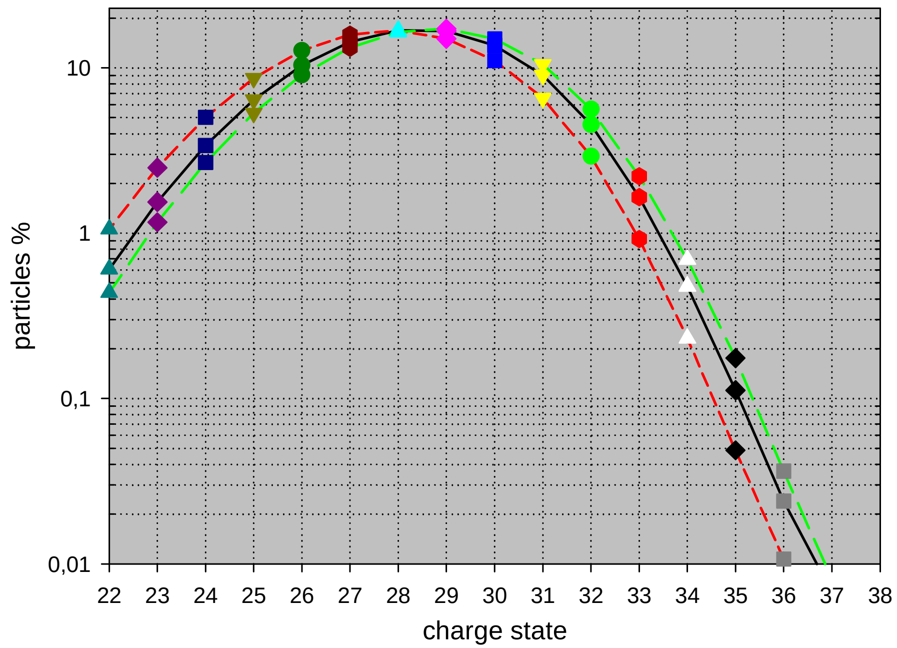
$^{58}Ni + ^{46}Ti \rightarrow ^{100}Sn + 4n$

Charge state distribution $^{58}Ni^{19+}$ on ^{46}Ti @ 3.15 MeV/u for 500 µg/cm^2 of Ti



$\langle Q \rangle_{Shima} = 23$

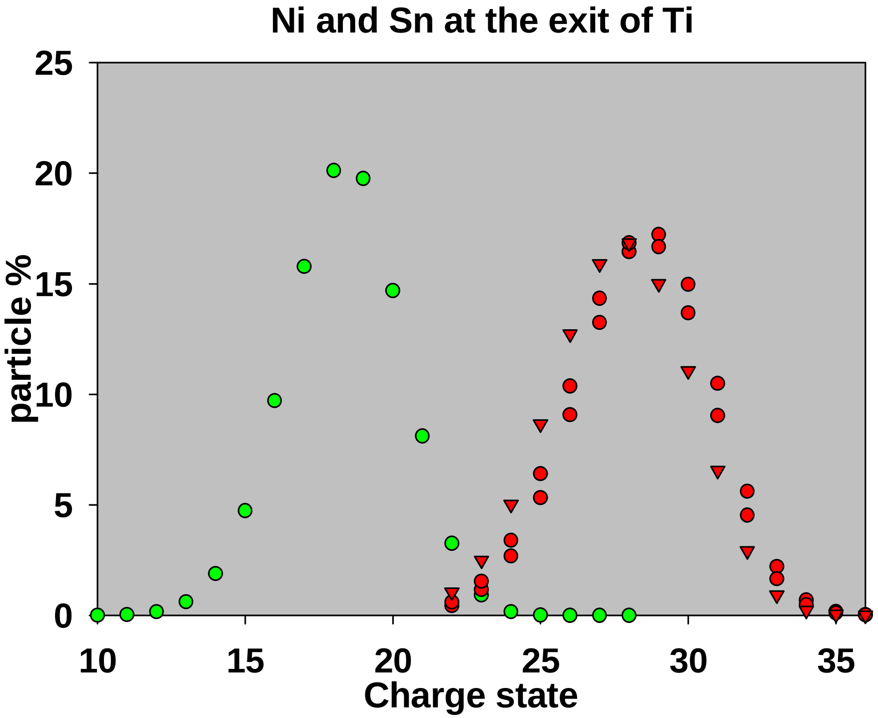
Charge state distribution $^{100}Sn^{50+}$ on ^{46}Ti @ 0.981 MeV/u for 100, 250 and 500 µg/cm^2 of Ti

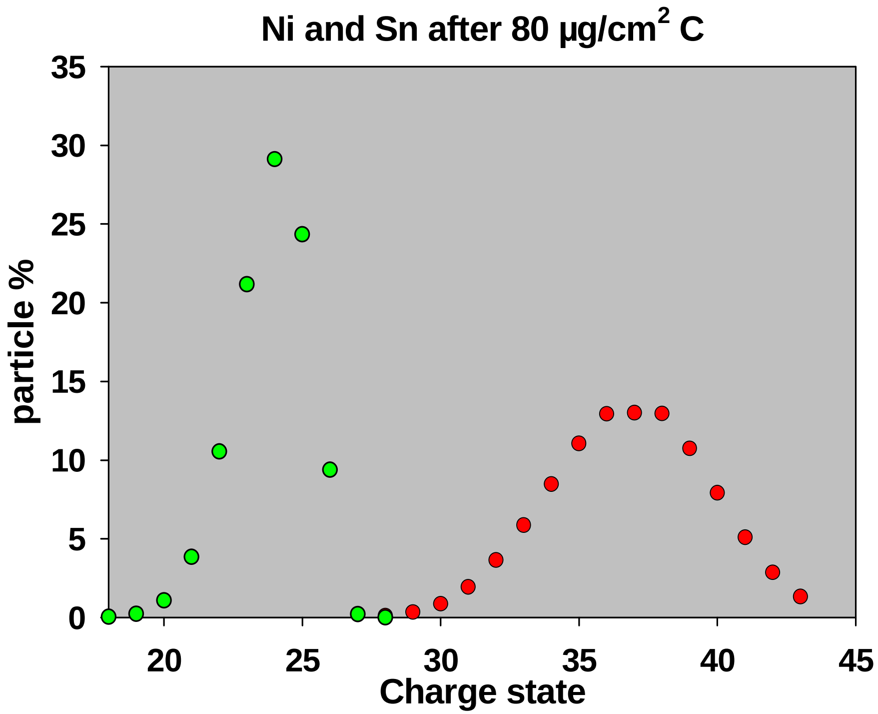


$\langle Q \rangle_{Shima} = 32$

Some preliminary results

$^{58}Ni + ^{46}Ti \rightarrow ^{100}Sn + 4n$





Forthcoming improvements

- Cross sections are supposed to be (independent electron model) :
  - proportional to the number of electrons in the initial state
  - Proportional to the number of vacancies in the final state

- This is probably a good enough approximation for the present purpose, provided not too much electrons or holes are involved. **Checks need to be done.**

- Cross sections, however, also depend on the effective (mean) charge of the projectile. ETACHA re-calculates cross sections each time the mean charge state (or projectile energy) has changed by more than a few %. Screening formula are used, that are valid as long as there is not too large a departure from hydrogenlike states : **for many electron ions, shell effects may need to be considered.**

- **For ions with more than 60 electrons, new "tricks" need to be found …**

Dynamical screening in solid targets

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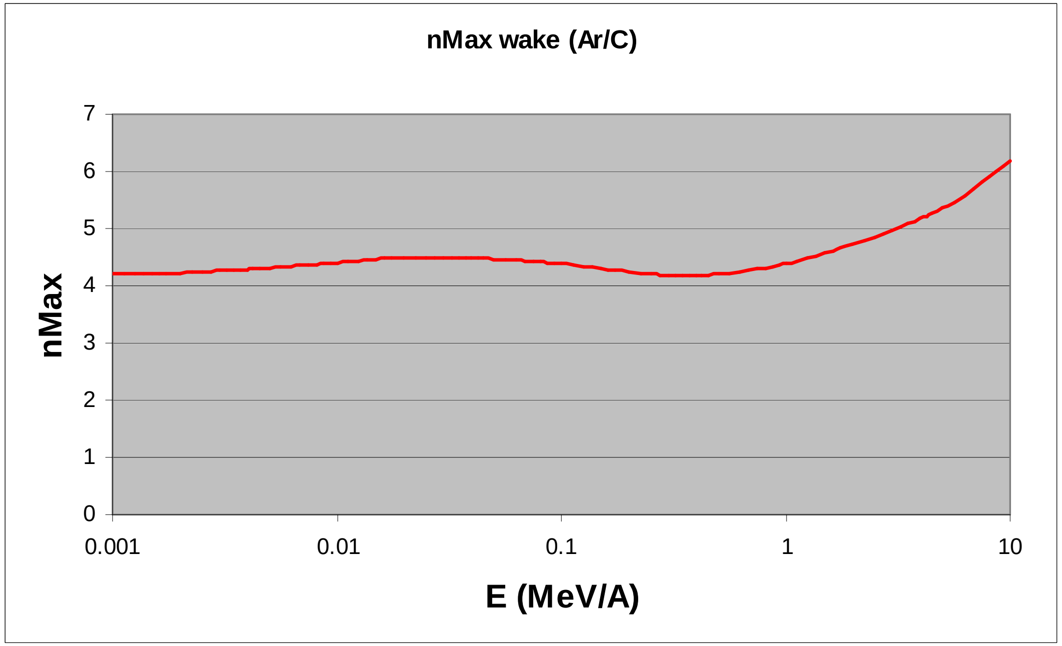

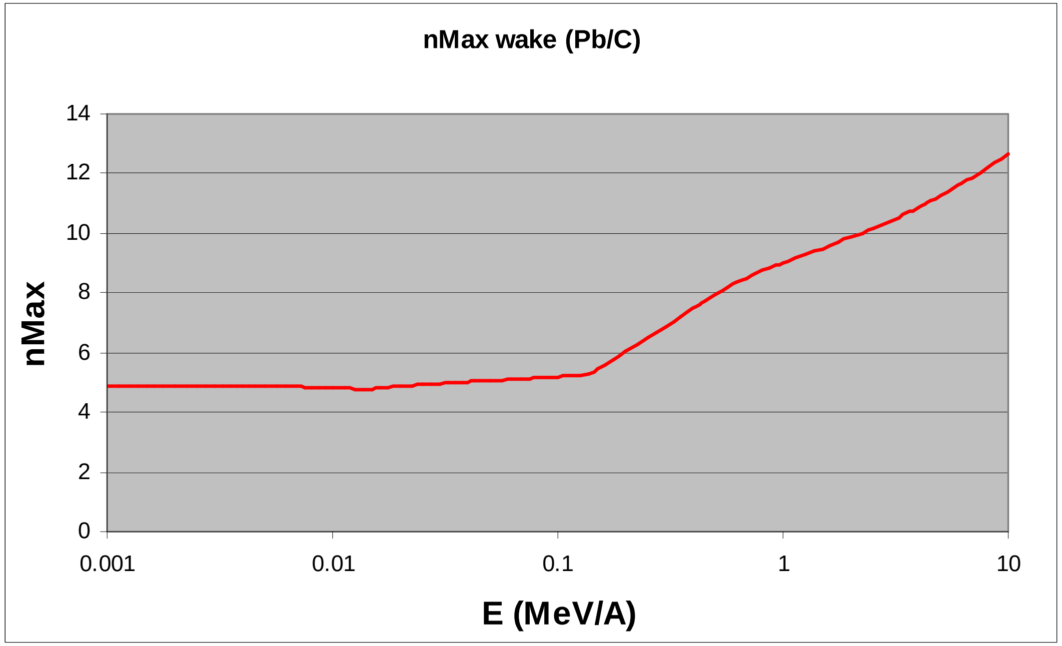

summary

- Cross sections for low velocity / strong perturbation are on the way to be under control

- The system of rate equations has to be revisited if calculations are to be done for more than 60 electron – ions

- Screening and shell effects need careful examination.