Open Quantum System Approach to Transient Coherence in Ion-Solid Transport

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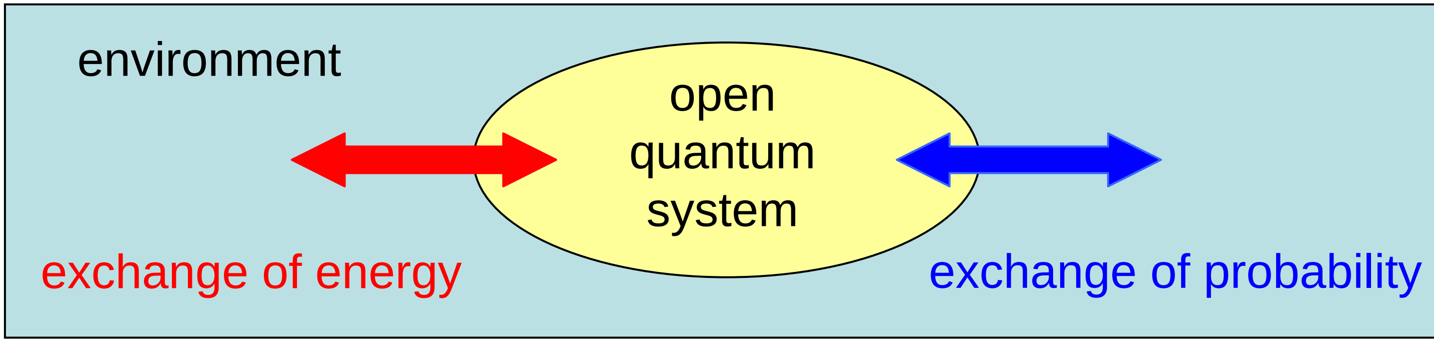
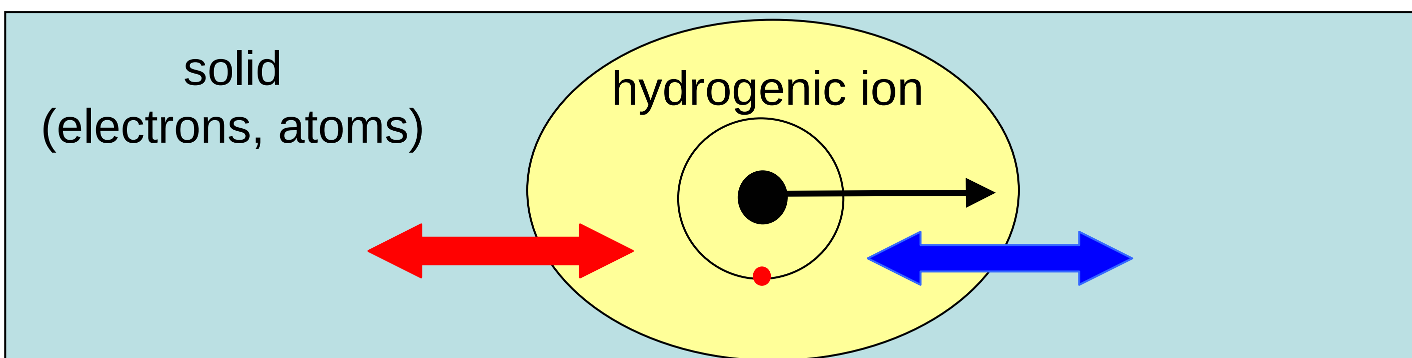
Open Quantum System



coherent control of Rydberg atoms
(quantum information)

coherent control of non-unitary systems
larger applicability:
quantum coherence in ion-solid transport

Application to Ion-Solid Transport



exchange of energy
in collisions

exchange of probability
in ionization and electron capture

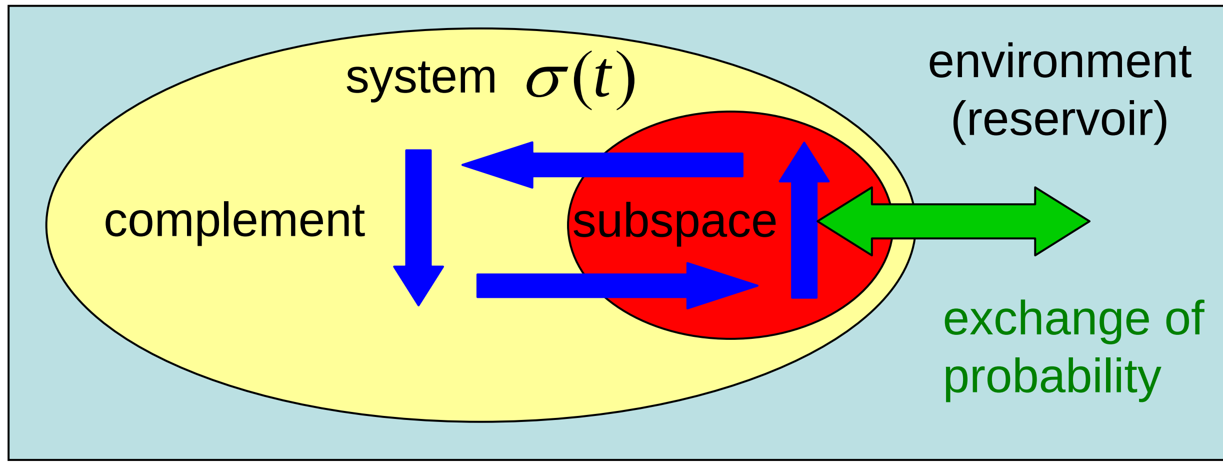
Outline

- The method:
  - Open quantum system approach
  - Generalization to exchange of probability
  - Solution by quantum trajectory Monte Carlo method
- Application to transport of fast highly charged ions:
  - $Krypton^{35+}$
  - $Argon^{18+}$
- Summary and conclusions

Open quantum system approach

Liouville equation $$\frac{\partial \rho_{total}(t)}{\partial t} = -i\left[H_{total}, \rho_{total}(t)\right]$$

$$\sigma(t) = \mathrm{Tr}_R\left[\rho_{total}(t)\right]$$



Born-Markov approx.

Master equation
of Lindblad form:

$$\frac{\partial \sigma(t)}{\partial t} = -i\left[H_S, \sigma(t)\right] + L\sigma(t)L^\dagger - \frac{1}{2}\left[L^\dagger L, \sigma(t)\right]_+$$

+ exchange of
probability

projection onto subspace: P P P P

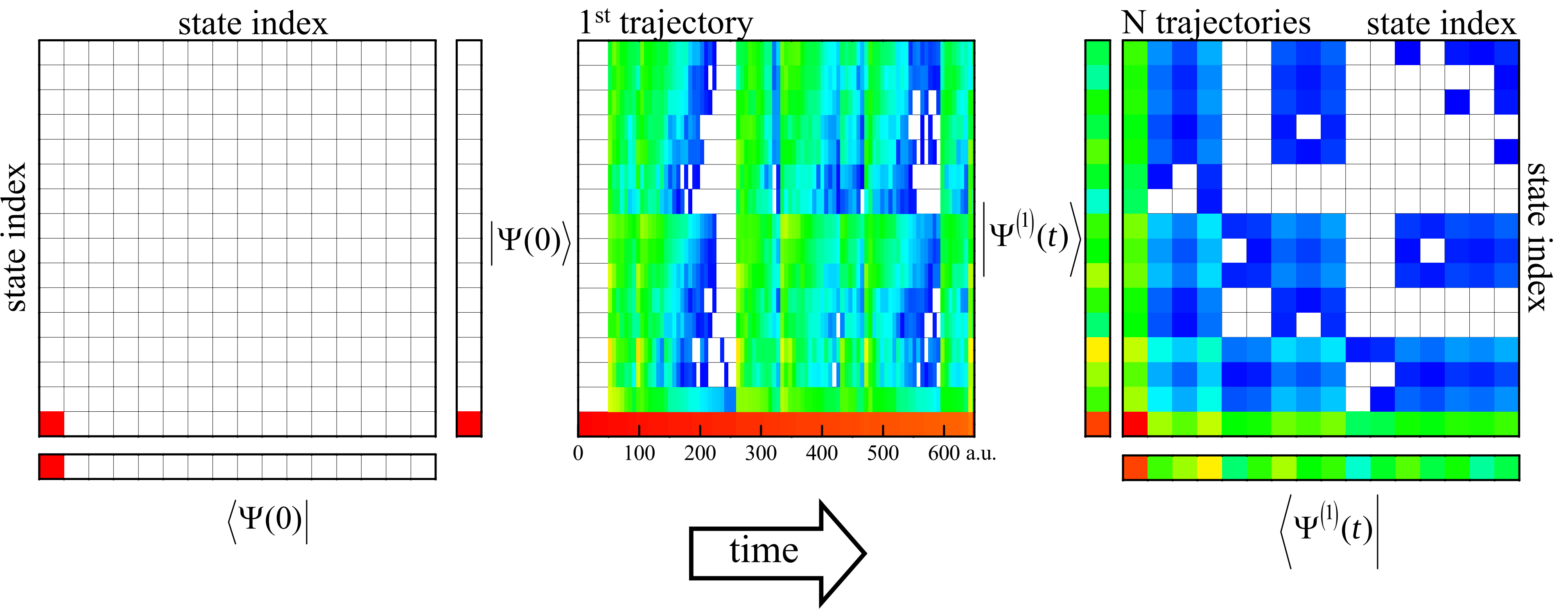
solve for large systems:

solved by "wavefunction" Monte Carlo method
(Mölmer, Dalibard, Zoller, Gardiner, et al 1990s)

Solving Lindblad master equation by Quantum Trajectory Monte Carlo Method

$$\frac{\partial \sigma(t)}{\partial t} = -i\left[H_S, \sigma(t)\right] + L\sigma(t)L^\dagger - \frac{1}{2}\left[L^\dagger L, \sigma(t)\right]_+$$

$$\sigma(0) = \left|\Psi(0)\right\rangle\left\langle\Psi(0)\right| \qquad \left|\Psi^{(2)}(t)\right\rangle \qquad \sigma(t) = \frac{1}{N}\sum_{\mu=1}^{N}\left|\Psi^{\mu}(t)\right\rangle\left\langle\Psi^{\mu}(t)\right|$$



stochastic realization = quantum trajectory

How do we propagate a quantum trajectory?

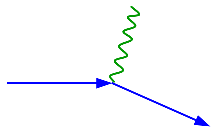
non-linear stochastic Schrödinger equation

$$\left|d\Psi^{\mu}(t)\right\rangle = [\text{jump}]\,\left|\Psi^{\mu}(t)\right\rangle + [\text{continuous}]\,dt\left|\Psi^{\mu}(t)\right\rangle$$

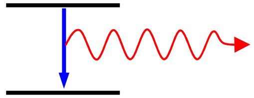
input:
- system Hamiltonian
- state-to-state transition operators
  for different environments:
  - scattering with:
    - electrons
    - atomic nuclei
  - radiative decay

[T. Minami et al. PRA 67, 022902 (2003)]

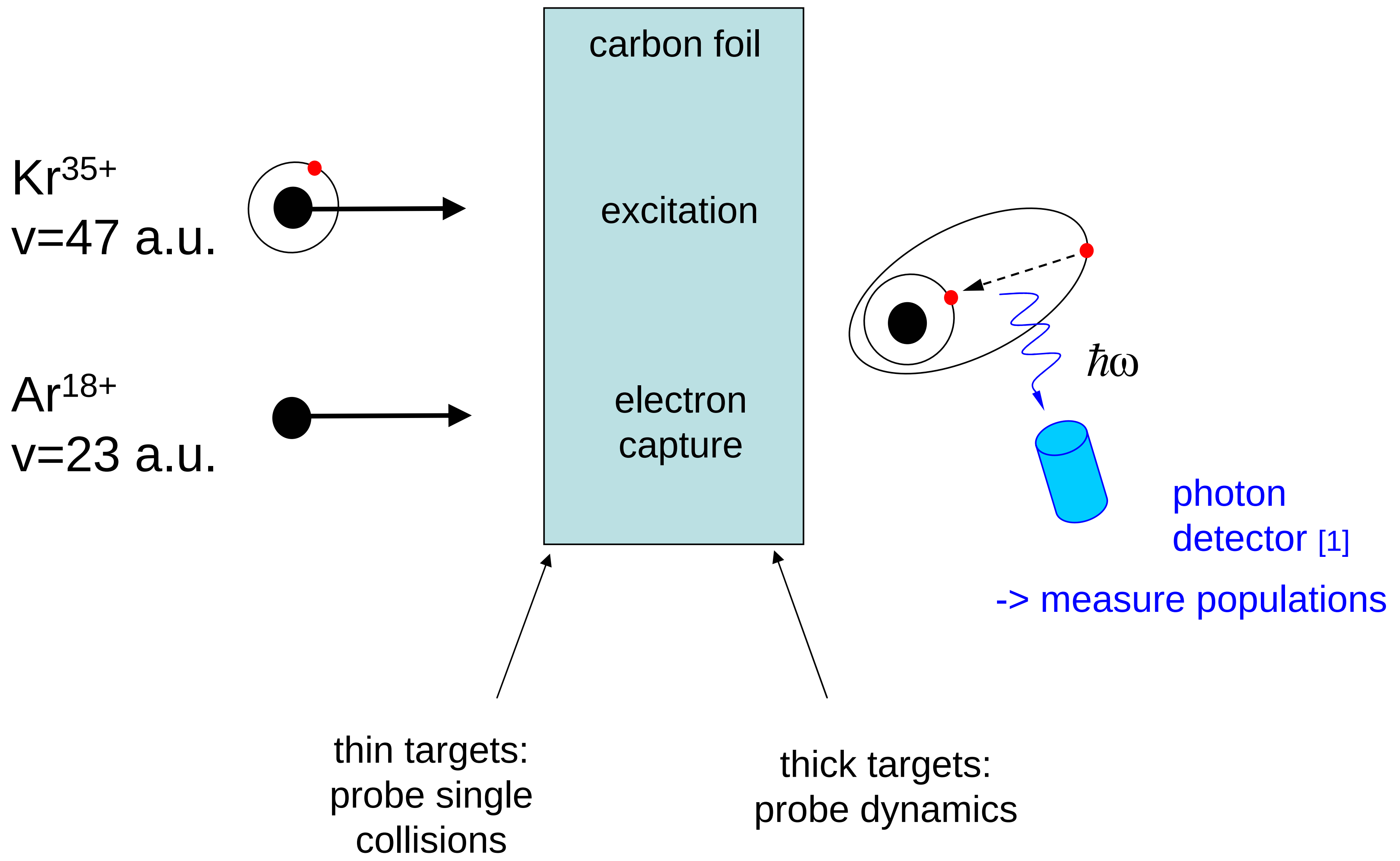
scattering



radiative decay



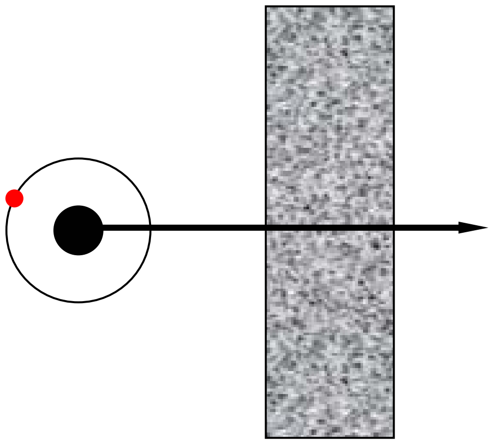
Experimental Observation

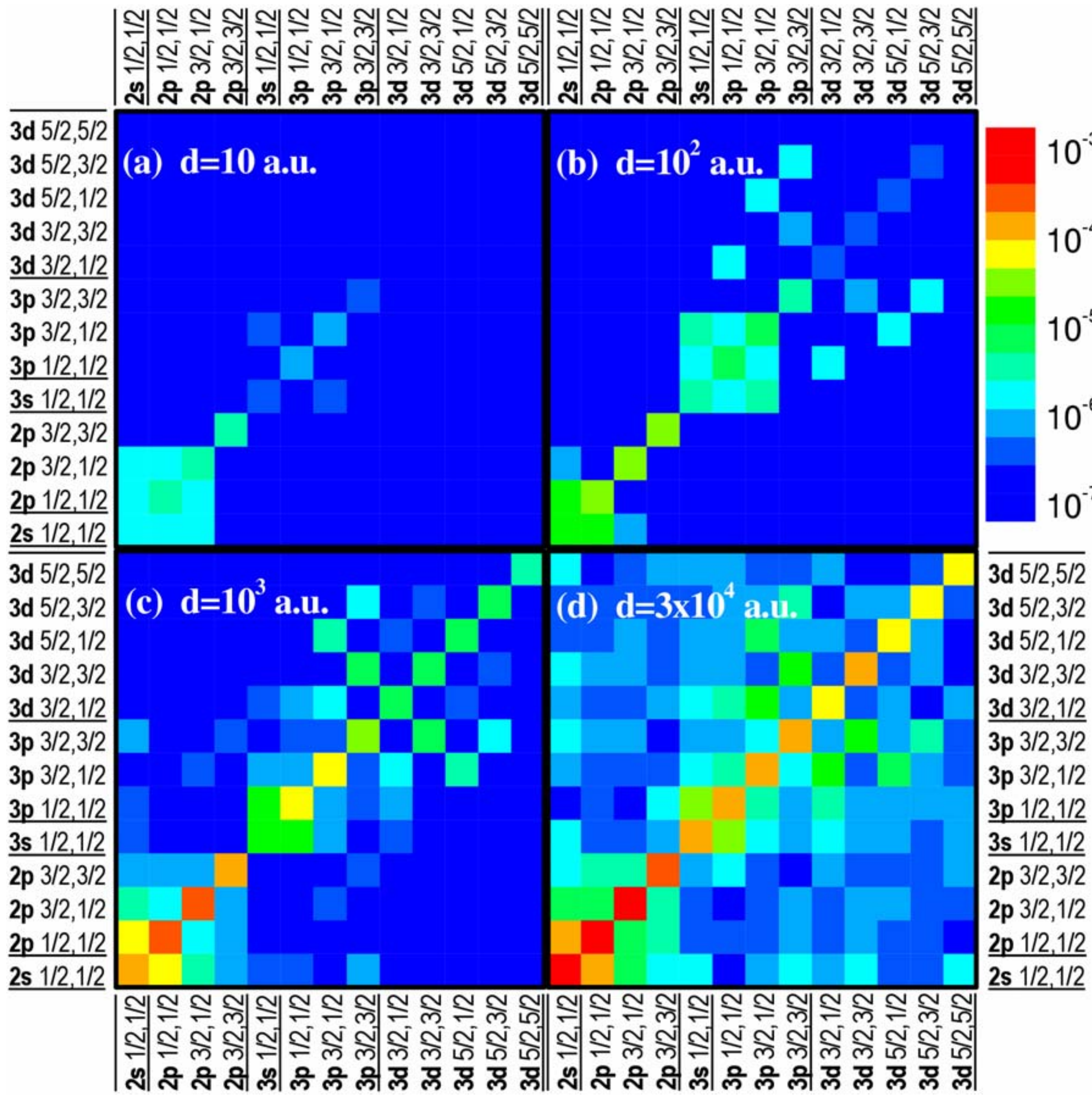


[1] D. Vernhet et.al., J. Phys. B 31, 177 (1998)

Application to Kr^{35+} transport: results for excited states density matrix

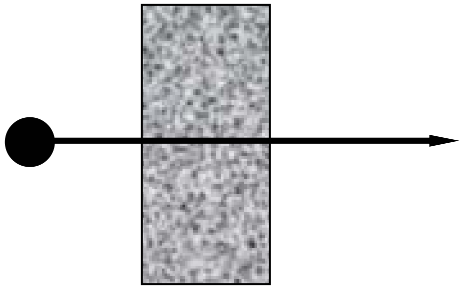
$Kr^{35+} \rightarrow$ C, v=47 a.u.



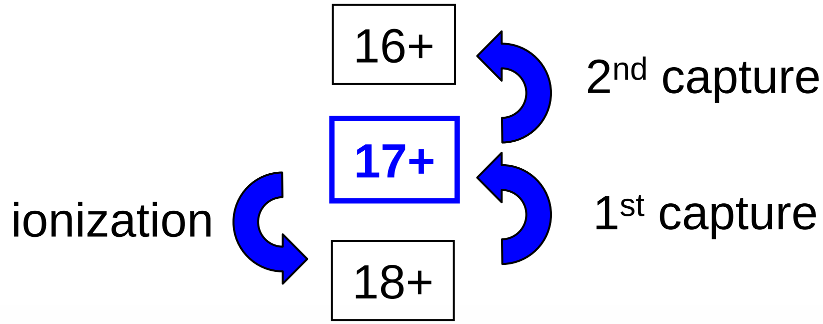


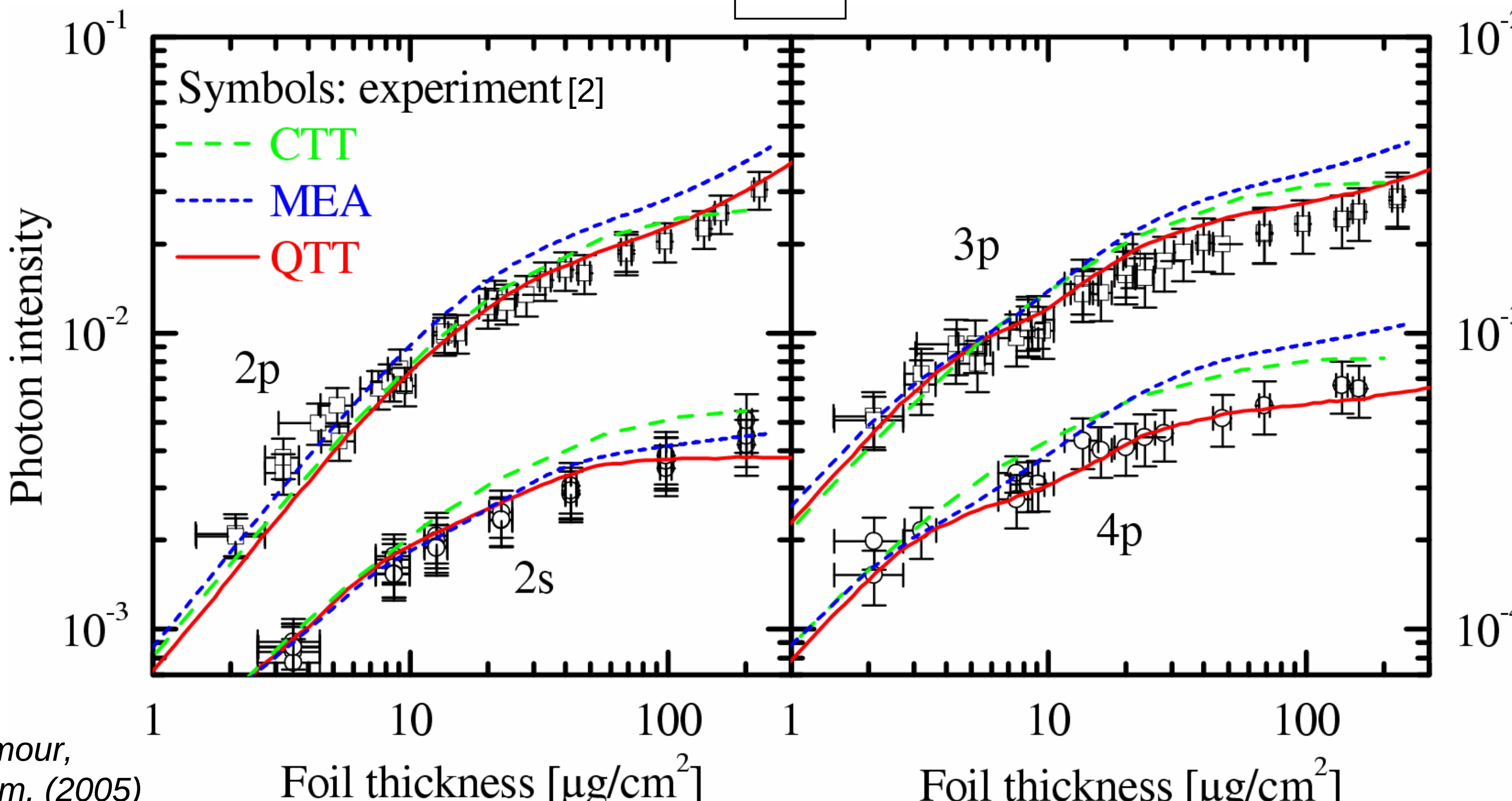
Application to Ar^{18+} transport

$Ar^{18+} \rightarrow C$, v=23 a.u.



population of excited states by electron capture





[2] E. Lamour, priv. comm. (2005)

Summary

- Generalization of the open quantum system approach
- Solution by means of a quantum trajectory Monte Carlo method
- Application to transport: overall good agreement with experiment

Outlook

- Application to other open quantum systems in quantum information
- Prediction of excited states population in stripping foils of high current GeV tandem accelerators

References:

T. Minami et al, PRA 67, 022902 (2003)

M. Seliger et al, PRA 71, 062901 (2005)

M. Seliger, PhD-thesis (2005)