Stochastic TDHF

➔ Goal

- Physics of large fluctuations, dissipative dynamics
- Fermi energy domain, low energy heavy-ion collisions

➔ Why a « new » theory ?

- Quantum mechanics
- Transparent derivation
- Robust numerics

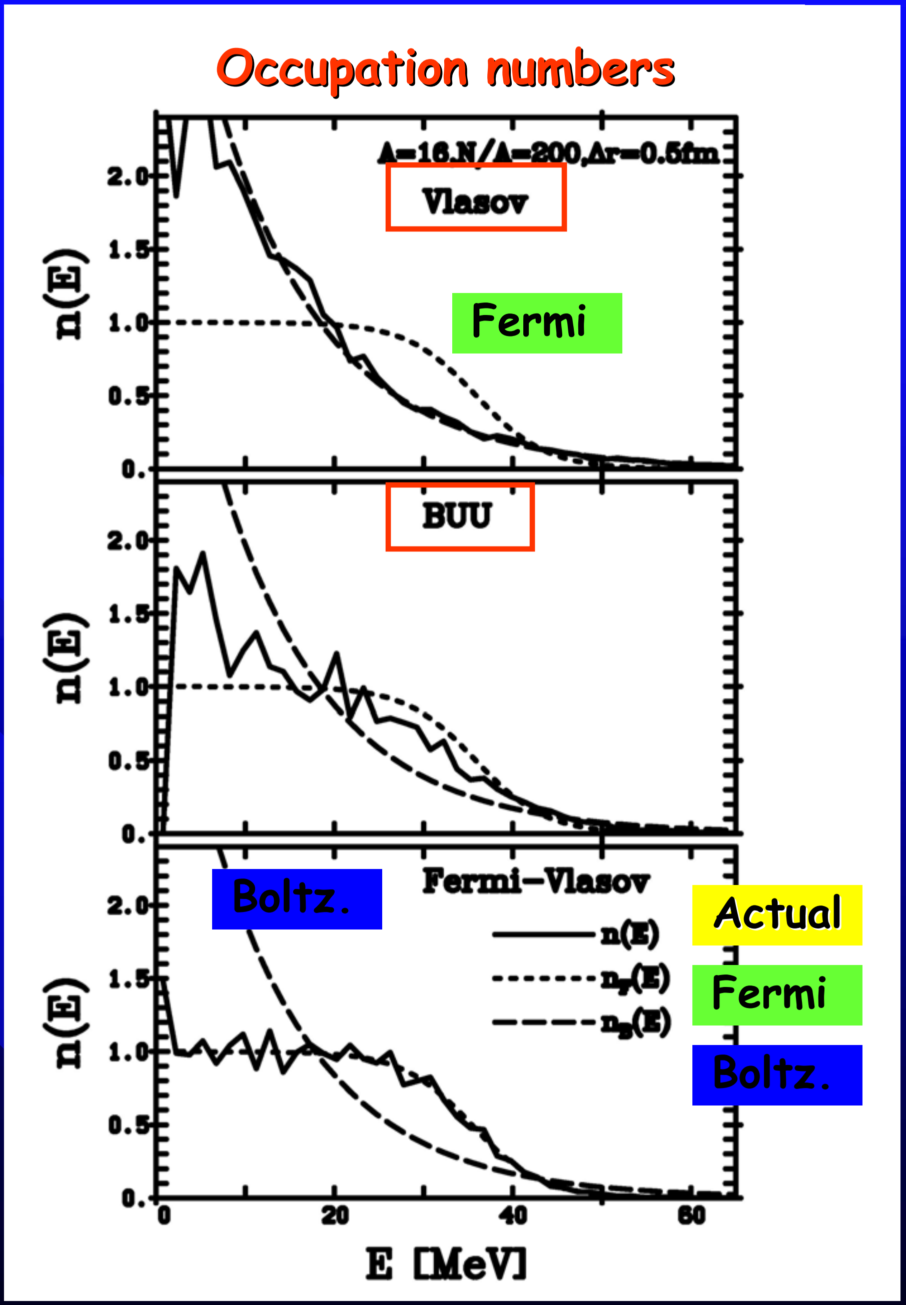
Toulouse-Erlangen collaboration (P. G. Reinhard)

The importance of quantum mechanics

- Pauli principle

Difficulties with BUU

MD (FMD, AMD)



The importance of quantum mechanics

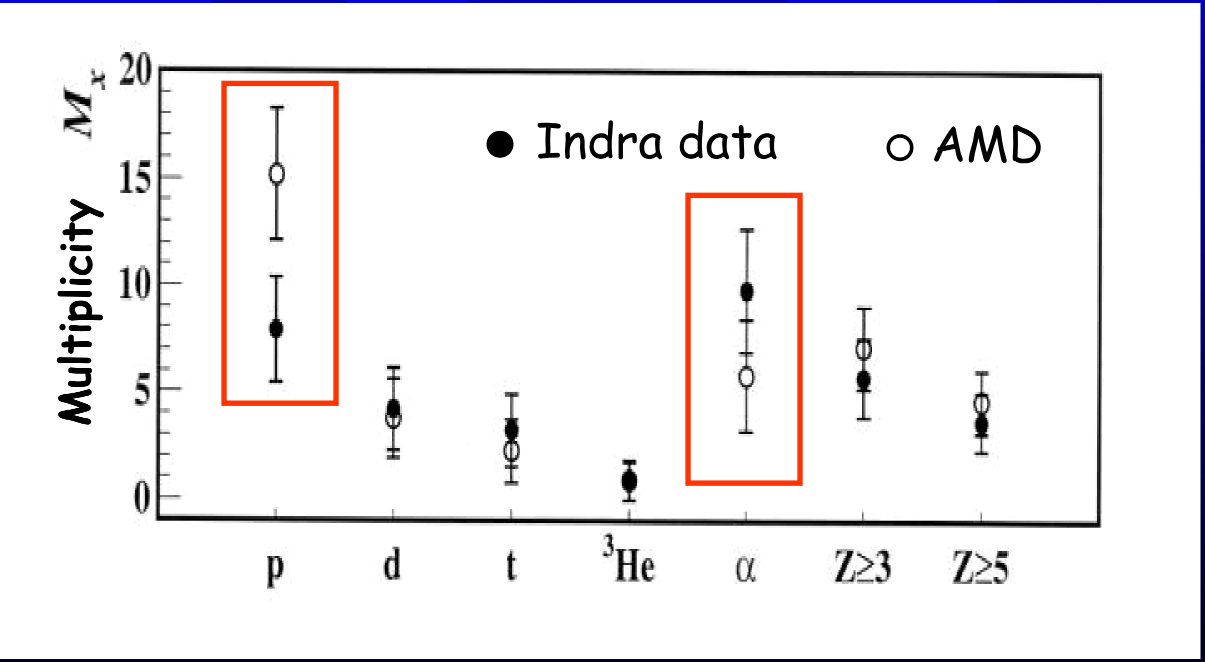
- Pauli principle

  Difficulties with BUU

  MD (FMD, AMD)

- Genuine effects in fragment production

Xe + Sn E = 50 MeV/A
central colls.



Deriving STDHF

- Framework

- TDHF basis states (Slater)

$$|\Phi_N >= \mathcal{A}(\Pi_i|\varphi^i_M >)$$

- Second order perturb. theory, correlation on a time step τ_{STDHF}
- Assumption of coherence loss between states : statistical picture

$$\tau_{coll} \ll \tau_{STDHF} \ll \tau_{m.f.}$$

Element. Coll. — STDHF — Mean field

- Elementary propagation of a Slater

$$D_N = |\Phi_N >< \Phi_N|$$

$$\underbrace{\mathcal{D}_N(\tau_{STDHF})}_{\text{correlated}} = \underbrace{\sum_M W_{MN}}_{\text{transition rate}} \underbrace{D_M(\tau_{STDHF})}_{\text{uncorrelated}}$$

W_{MN}

Fermi Golden rule

Deriving STDHF (cont'd)

- Ensemble description of the dynamics

$$\left\{ \begin{array}{lllll} D_N & \stackrel{\tau_{STDHF}}{\rightarrow} & \{D_M, W_M\} & & \\ & & D_{M_0} & \stackrel{\tau_{STDHF}}{\rightarrow} & \{D_L, W_{M_0 L}\} \\ & & & & \ldots \end{array} \right\}_{N=1,\ldots}$$

Deriving STDHF (cont'd)

- Ensemble description of the dynamics

$$\left\{ \begin{array}{lllll} D_N & \stackrel{\tau_{STDHF}}{\rightarrow} & \{D_M, W_M\} & & \\ & & D_{M_0} & \stackrel{\tau_{STDHF}}{\rightarrow} & \{D_L, W_{M_0 L}\} \\ & & & & \dots \end{array} \right\}_{N=1,\dots}$$

- Interest(s)
  - Fully quantal formulation (TDHF)
  - No a priori separation between average and fluctuations
  - Practical scheme

STDHF for practitioners

- TDHF propagation + stochastic jumps

$$|\Phi_N > \rightarrow |\Phi_M >$$

- How to do it ?

- Exploit sampling to « avoid » empty states (Cf BUU algorithm for collision integral)
  - Sampled two-body collisions (semi-classical collisions in k space)
  - Pauli principle + energy conservation + unitarity

- The unitarity problem
  - Unitary quantum collision term treated in Husimi picture
  - First attempt (1997) : global and local, but non unitary collisions
  - Fully unitary scheme : global (2003)

- Numerics

- Robust full 3D TDHF on a grid

STDHF vs TDHF and BUU

$^{16}O + ^{16}O$, b = 0, E = 50 MeV/A

First step :

average trends

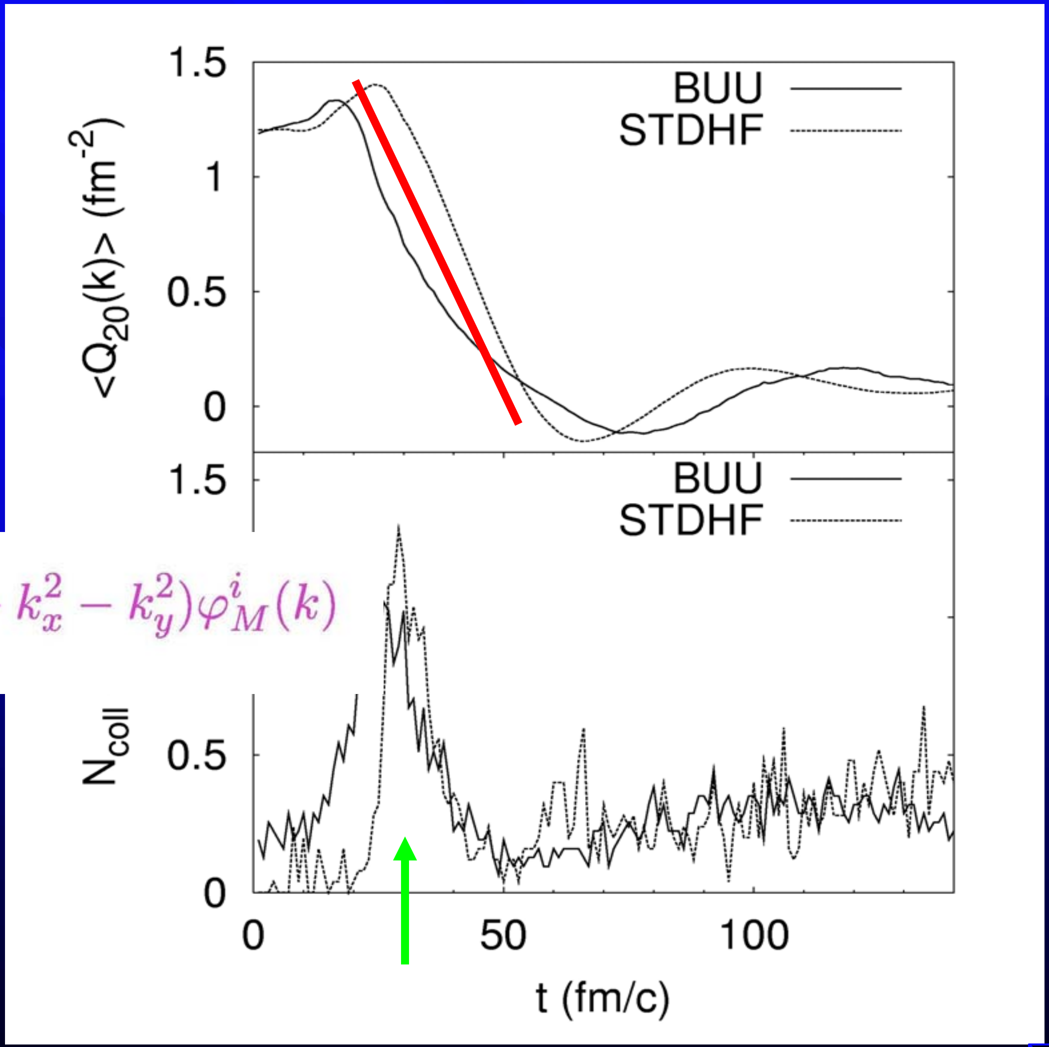
Quadrupole moment

in k space

$$Q_{20}^{k} = \sum_i \int d^3k \varphi_M^{i*}(k)(2k_z^2 - k_x^2 - k_y^2)\varphi_M^i(k)$$

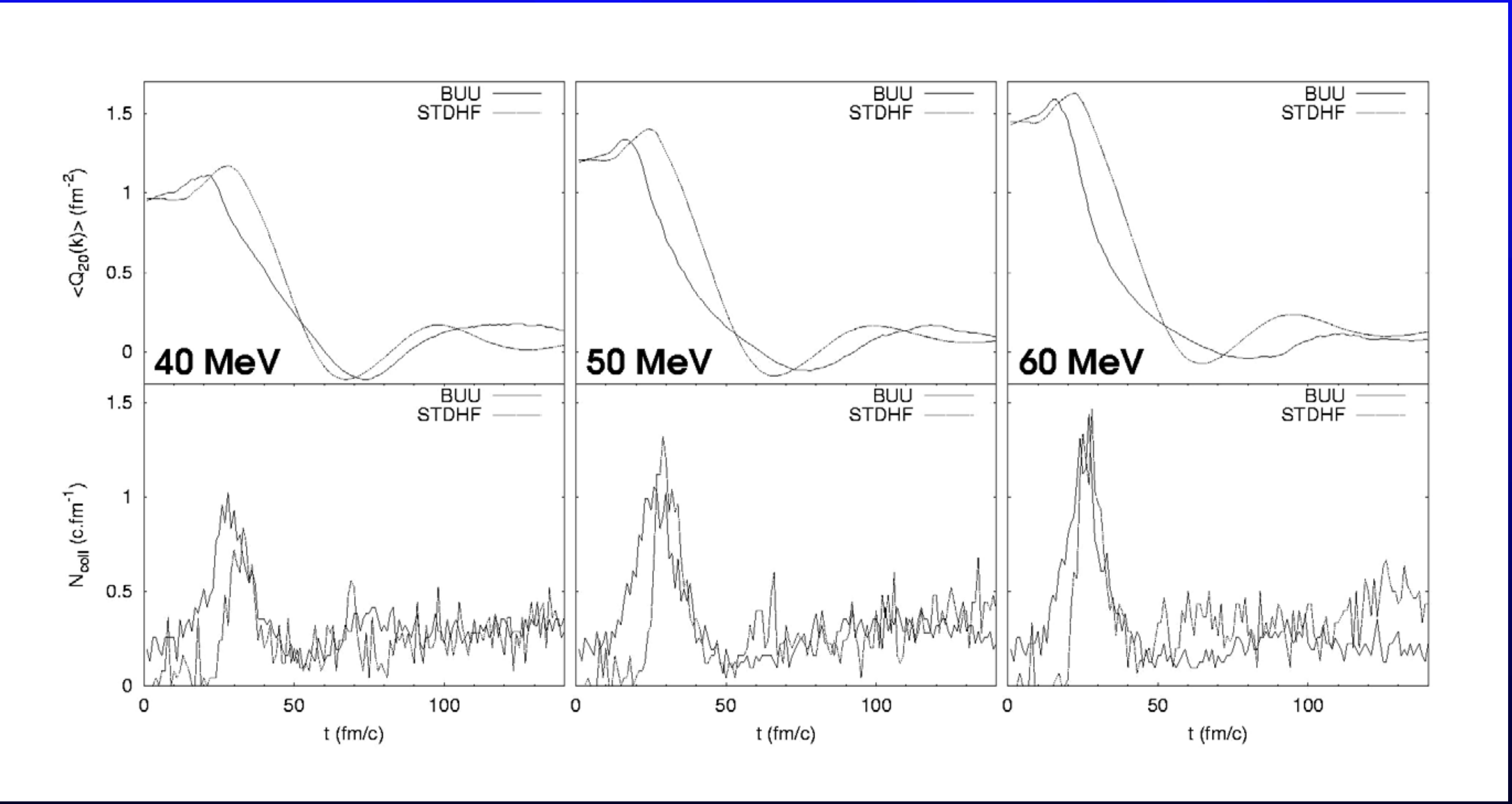
Number of

two-body collisions



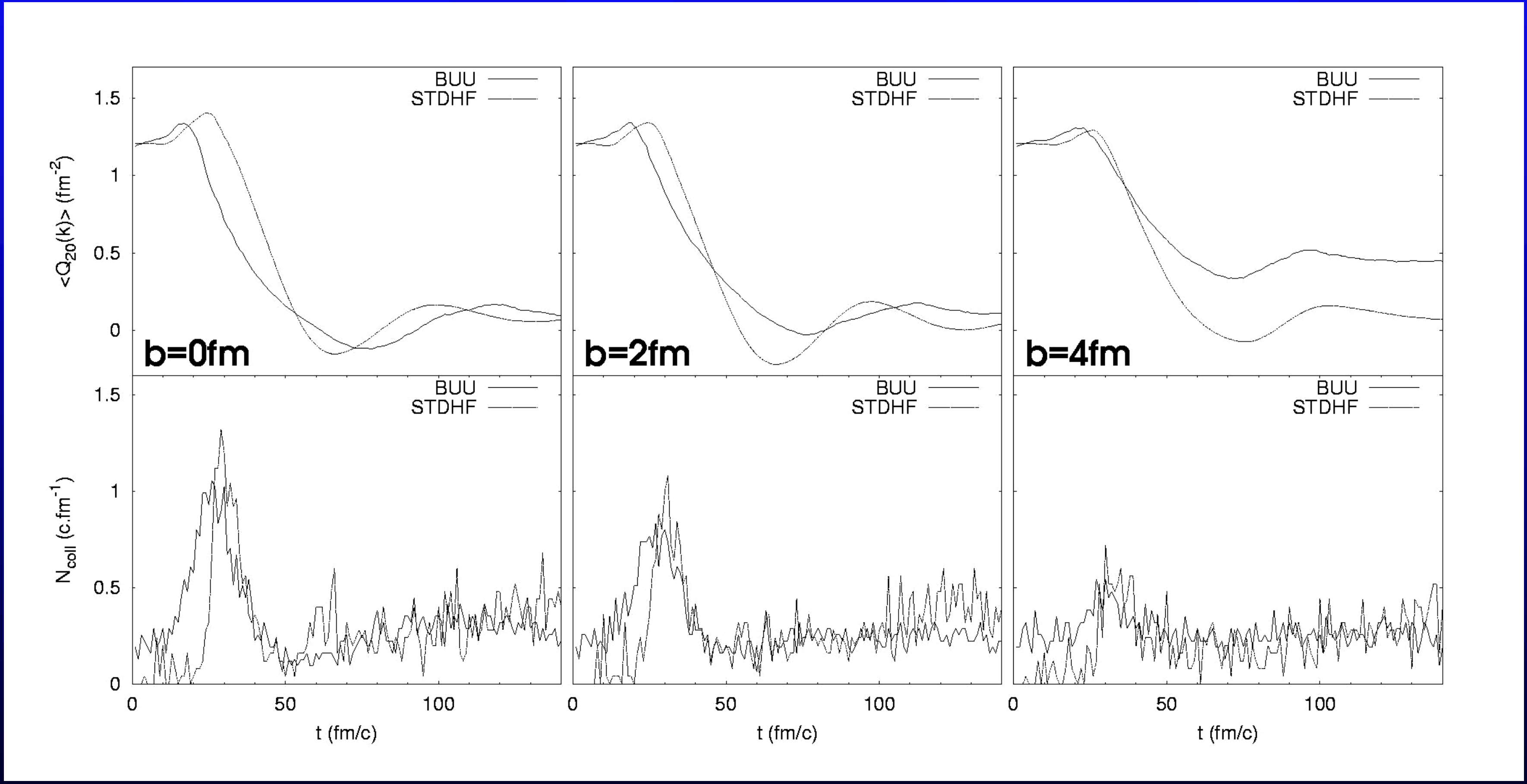
Average trends with beam energy

$^{16}O + ^{16}O$ b = 0, E = 50 MeV/A



Average trends with impact parameter

$^{16}O + ^{16}O$ b = 0, E = 50 MeV/A



Some conclusions and perspectives

- STDHF for heavy-ion collisions
  - Quantum framework
  - Transparent derivation including fluctuations
  - Scheme for practical calculations

- Future directions
  - Local scheme for nucleon-nucleon collisions
  - Examples of applications
  - Semi classical version of STDHF
  - Case of metal clusters (**Stochastic TDLDA**)