Summary on transport code descriptions
→ Remarks on the nature of discrepancies between transport codes

physical input (EOS, $\sigma_{inmed,}$ $\pi\Delta$ physics, ..) → transport code → observables

→ unique?, e.g. like 2N transfer
→ very complex, simulation of an equation rather than a solution
→ depends on the question you ask

Transport theory based on a chain of approximations

Martin-Schwinger hierachy in many body densities:
truncation, introduction of self energies (1-body quantities)

Quantum transport theory: Irreversibility, Kadanoff Baym theory

semiclassical approximation :
Wigner transform, not necc. Phase space probabilities
Gradient approximation (sep.of short and long scales)

Quasiparticle approximation
Spectral function→ delta function with effective quantities

→ BUU equation

$$\frac{\partial f}{\partial t} + \frac{\vec{p}}{m}\vec{\nabla}^{(r)} f - \vec{\nabla} U(r)\, \vec{\nabla}^{(p)} f(\vec{r},\vec{p};t) = \int d\vec{v}_2\, d\vec{v}_{1'}\, d\vec{v}_{2'}\, v_{21}\, \sigma_{12}(\Omega)\, (2\pi)^3 \delta(p_1 + p_2 - p_{1'} - p_{2'}) \left[f_{1'} f_{2'} (1 - f_1)(1 - f_2) - f_1 f_2 (1 - f_{1'})(1 - f_2{}') \right] + \delta f(r,p,t)$$

fluctuations
variance of 2b collisions
neglct of higher orders

6-dim integro-differential equation, non-linear
→ simulate solutions
introduces many technical details

methods of solutions:

$$\frac{\partial f}{\partial t} + \frac{\vec{p}}{m}\vec{\nabla}^{(r)} f - \vec{\nabla} U(r)\,\vec{\nabla}^{(p)} f(\vec{r},\vec{p};t) = \int d\vec{v}_2\, d\vec{v}_{1'}\, d\vec{v}_{2'}\, v_{21}\, \sigma_{12}(\Omega)\,(2\pi)^3\,\delta(p_1 + p_2 - p_{1'} - p_{2'})$$
$$\left[f_{1'} f_{2'} (1 - f_1)(1 - f_2) - f_1 f_2 (1 - f_{1'})(1 - f_2{}') \right]$$

Boltzmann-Vlasov-like (BUU)
solve as exactly as possible:
- test particle method
  exact in the limit of $N_{TP} \rightarrow \infty$
- deterministic, no fluctuations
  include fluctuations explicitely
- connection between U and σ
  by approx of self energy,
  e.g. Brueckner theory

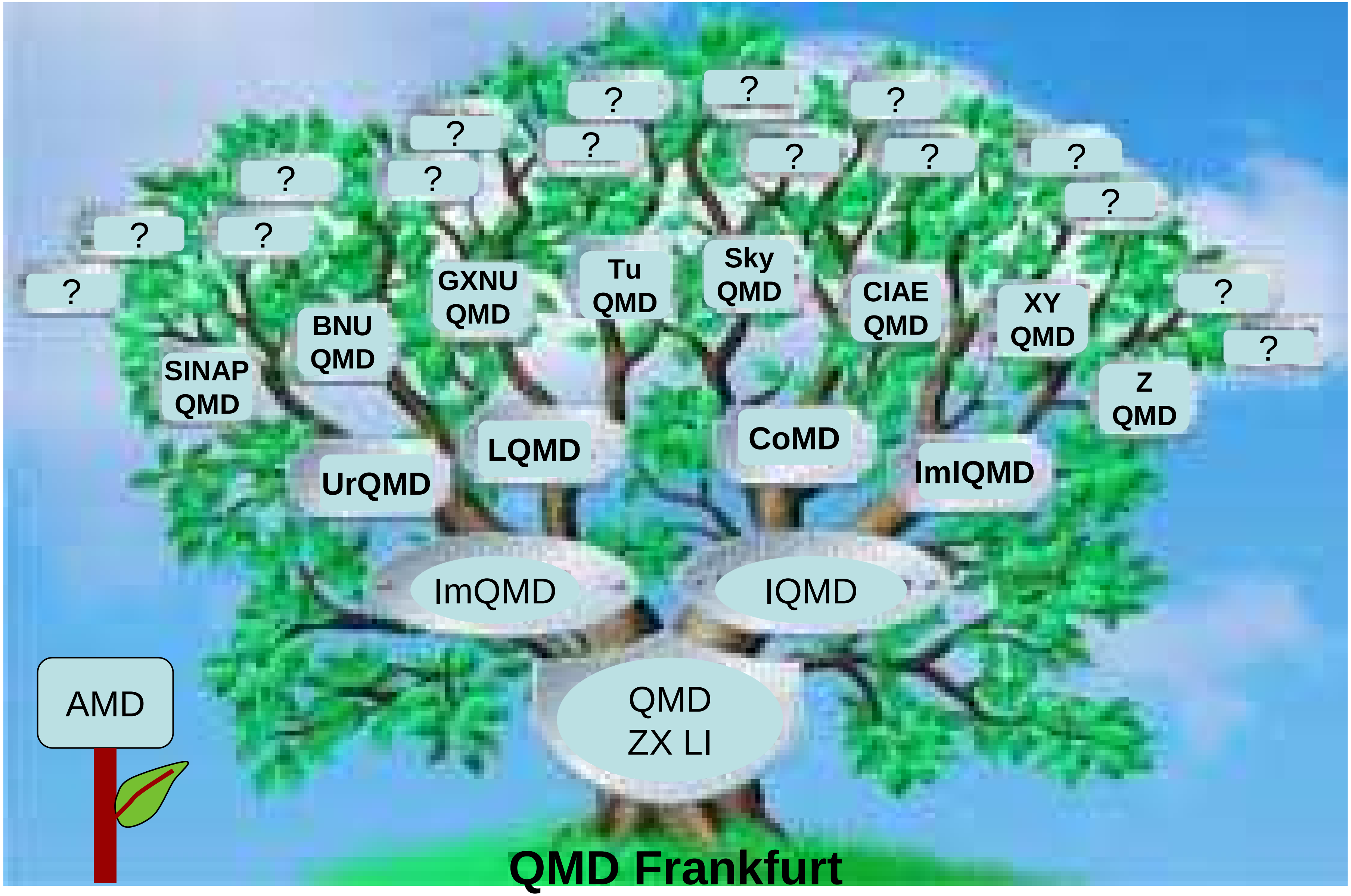
Molecular dynamic-like (QMD)
- inject classical flcuctuations
  and correlations (nucleon wave packet)
- damped (finite Gausians,
  averaging width Δx, parameter
+ Pauli correlations (AMD)
- relation between U and σ not so clear,

biggest difference:
role of fluctuations
fragmentation, correlation functions
but also affects Pauli blocking and collective excitations

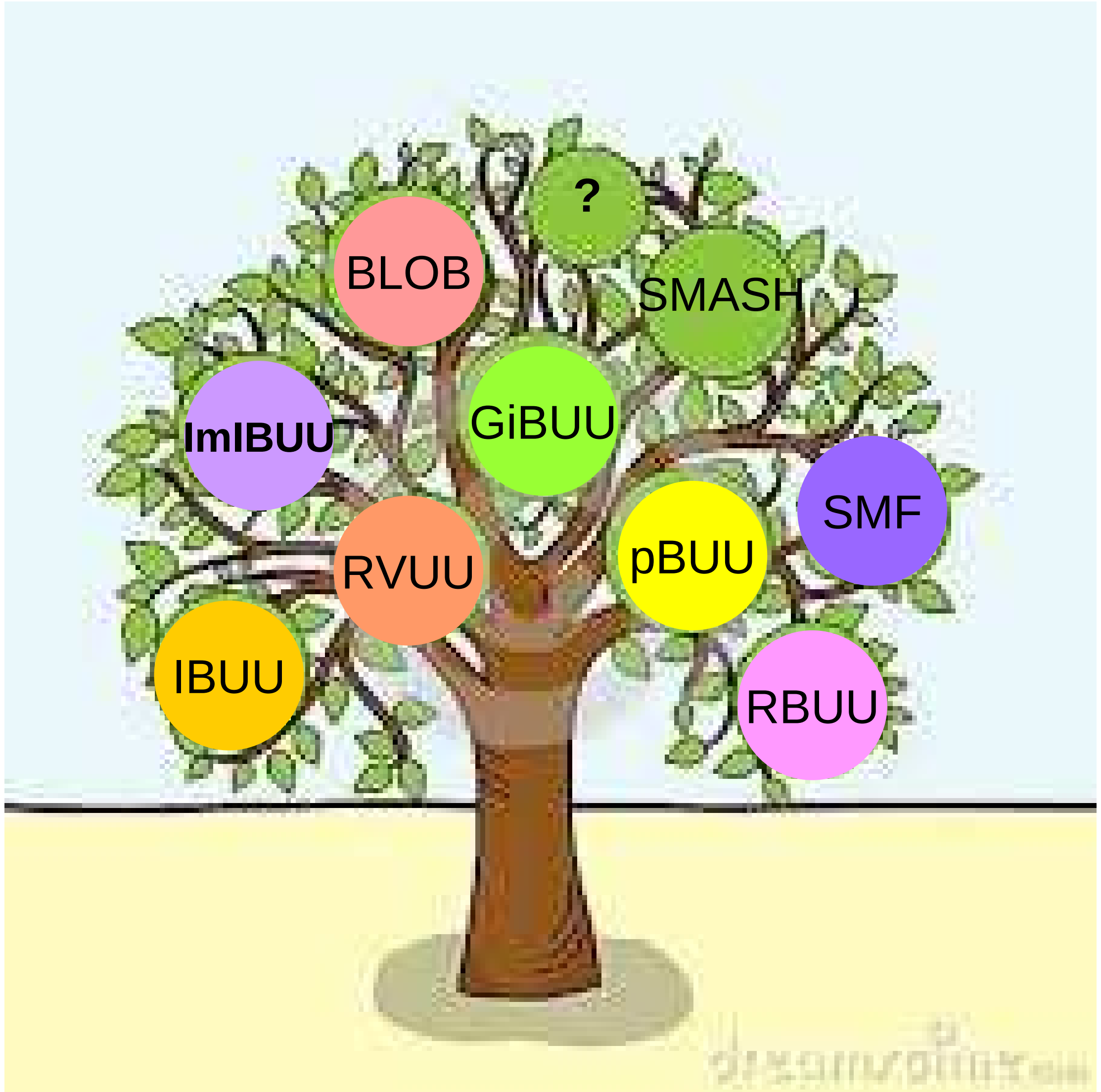
Fluctuations: almost a „fight“ between MD and Boltzmann models:

$$\boxed{\frac{df}{dt} = I_{coll} + I_{fluc}}$$

now discussed beyond ideological barriers



„.. in full bloom…“ – a good sign for the expanding activity,
but try to make realtion and changes transparent,



„…lots of individuals…“

Steps in solving transport simulation
- initialization
- propagation of (test) particles (Vlasov)
- Collision partners and probabilities, elastic (Boltzmann)
- Pauli blocking (Ühling-Uhlenbeck)
- inelastic collisions (new particles), often perturbative, dep. on energy

Code comparison:
- differences of results of codes, e.g. isospin duffusion, pion ratios
- 1. phase: comparison of HIC with controlled input
  - differences seen (talk of Betty)
  - indications of reasons (initialization, Pauli blocking)
  - but difficult to pin point
  - general systematic theoretical error (30% (100 MeV), 13% (400 MeV)
    how to improve?
- 2. phase: box calculations
  - better controlled conditions
  - exact limits often available
  - resolve differences because of strategies and of errors
    from inrinsic differences (like BUU vs. QMD)

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initialization: solvable,
- initialize consistent with density functional used in transport
  so that initial nucleus is a good approximation to the ground state
- more important than having identical density distributions

propagation: hamitonian eom, easy
but
fluctuation dampen critically collective motions
momentum dependence, energy conservation

Time evolution of Fourier transform ρ_k

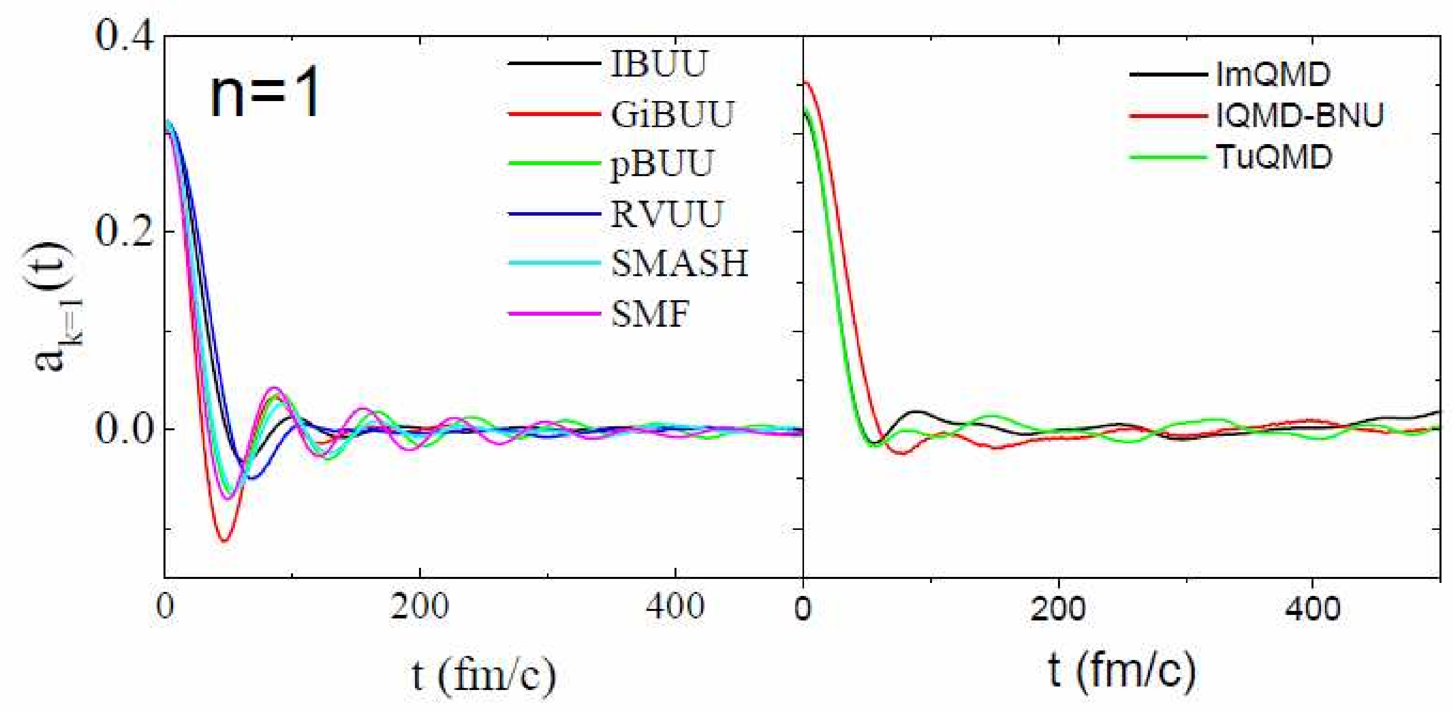
Second formulation of Homework #2:
Longer final time and results given each 0.5-1 fm/c

n = 1

$$\boxed{\rho_k(t) = \int dz \sin(kz)\, \rho(z,t)}$$ $k = n\, 2\pi/L$

Larger damping and structureless fluctuations In QMD-like

Different oscillation frequency in BUU-like



Collision probabilities:

Bertsch prescription: particles collide,

- if their distance is below the interaction length and
- if the reach the distance of closest approach in theis time step
- improve: the same nucleons should not colide again in the next time step

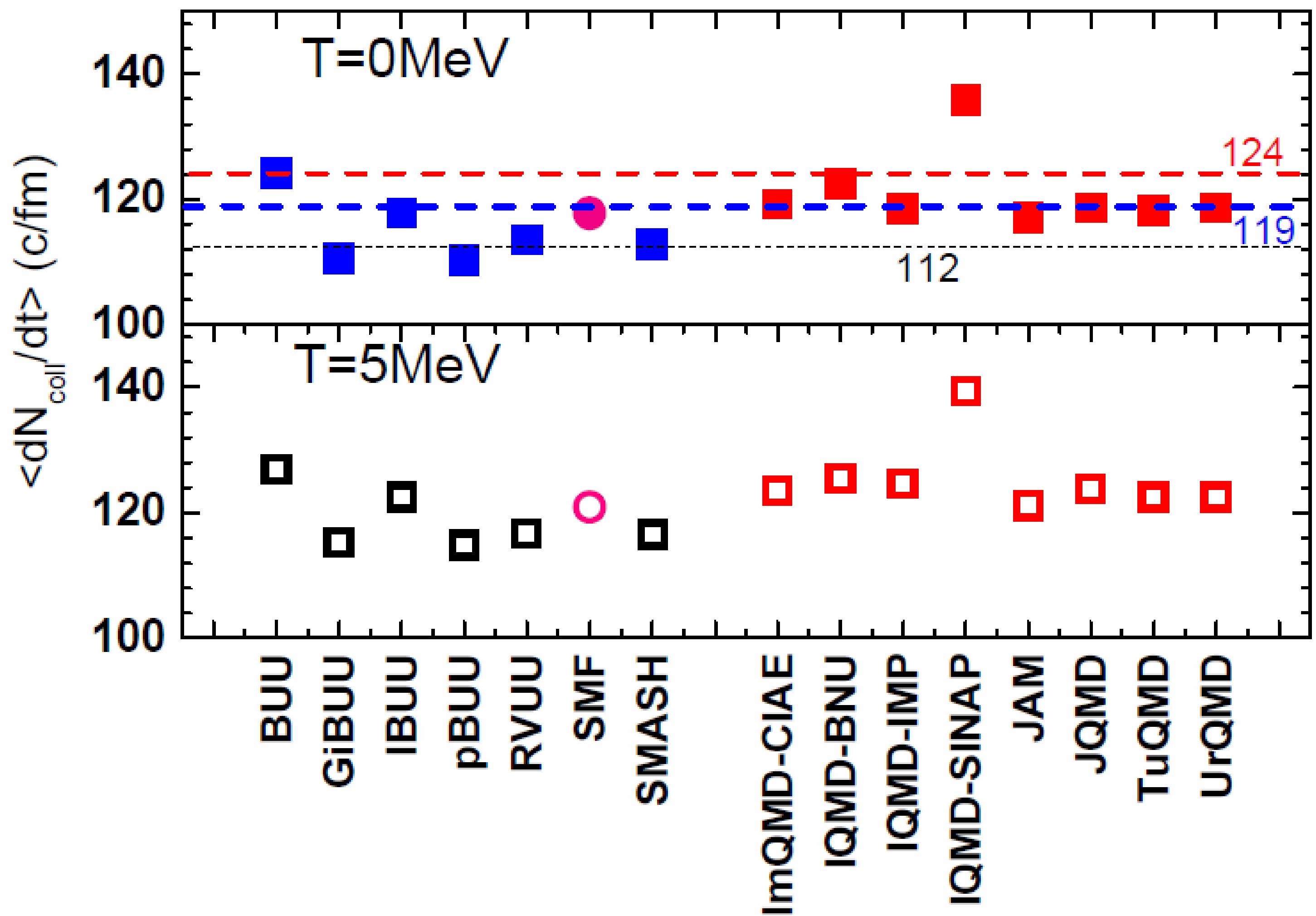
lesson: exact results come from kinetic theory, which makes assumtion
in complete independence of collisions and equilibrium

→ not so easy to follow in simulations (not always good)

mean free path description: assure mf path from kinetic theory
assure agreement limits put perhasp oversimplified in collisions (no equilibrium)

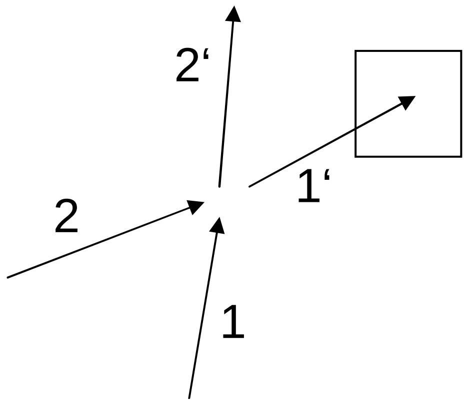
Theoretical results for CT0

Effect in dN_{coll}/dt for CT0: 124[1] (nonrelativistic) → 119 (relativistic);



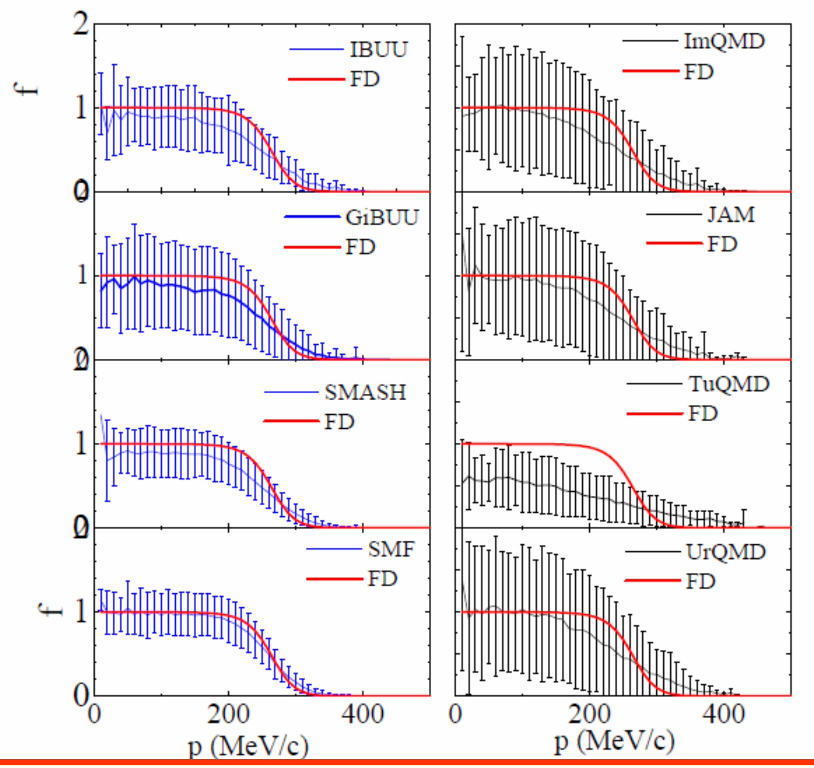
Ideal value for Boltzmann: 116.8 (nonrelativistic) → 112.6 (relativistic, by J. Xu)

Pauli blocking:

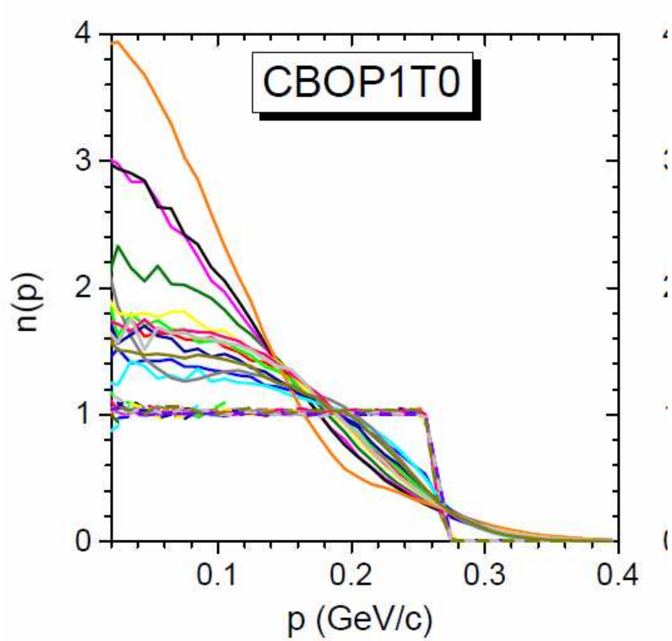


occupation probablity f(r,p,t)

local
- but realistically averaged over a volume
- often very large, non-localities
- fluctuations!



consequence: evolution to a MB distribution,
f(p) >1
prescription: f≤1

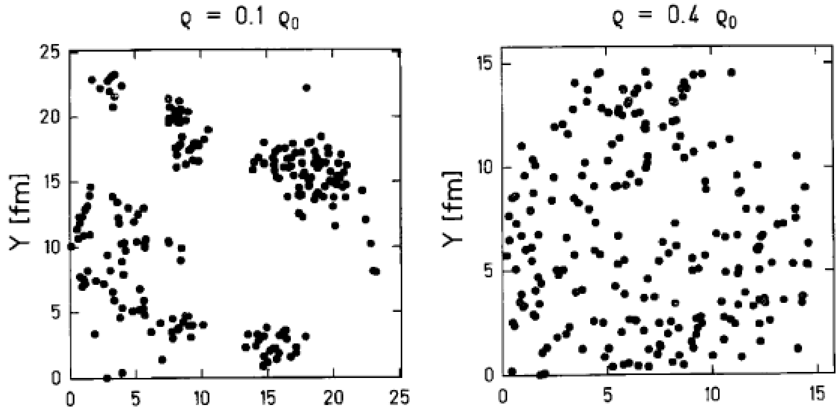


how much this affects a transport simulation not clear,
very likely in the initial stages, e.g. pre-eq emission

Fluctuations: biggest differences between families of codes
and implementation of codes

important: yes!
indirect: blocking, mf propagation
direct: fragments formation

test also fluctuations and fragmentation



how treated:

BV-like→ Boltzmann-Langevin eq.
realizations: BOB, SMF, BLOB

MD-like: damped classical fluctuations
parameter Dx of wave packets

light clusters: another problem, → tomorrow afternoon.

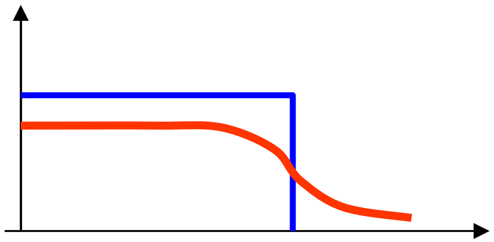
freeze out:

assumption of a completely equilibrated primary fragment is probably too naive

there is still collective motion: expansion

perhaps a differential freeze-out,
surface layer of an expanding source
→ see e.g. Natowitz experiments
check with transport models

short range correlations:



proposed treatments:

1. initialize momentum distribution
   - but has to active at every moment
2. calculate correlation energy in nuclear matter and use this as a part of the potential energy
   - does not generate high energy particles
3. three body collisions, to conserve energy
   - difficult