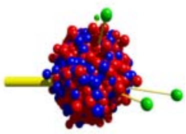
The GiBUU Model

A transport approach to hadronic reactions

O. Buss and the GiBUU group
Institut für Theoretische Physik, JLU Giessen

Overview



The **G**iessen **B**oltzmann-**U**ehling-**U**hlenbeck (GiBUU) project is aiming to provide an **unified transport framework** in the MeV and GeV energy regimes for elementary reactions on nuclei induced by electrons, neutrinos, photons and hadrons (in particular pions) and for heavy-ion collisions. The **flow of particles** being produced in those reactions is **simulated via BUU** where the relevant degrees of freedom are mesons and baryons. These propagate in mean fields and scatter according to cross sections which are tuned to the kinetic energy range of 30 MeV to more than 10 GeV.

The BUU equation

The BUU equation, which can be **derived from the Kadanoff-Baym-equations** [1], describes the time evolution of the so-called **Wigner transform** of the real time Green's function,

$$g^{<}(r,p) = \int d^4y \, e^{ipy} \langle \Psi^{\dagger}(r-y/2)\, \Psi(r+y/2) \rangle \;.$$

This Wigner transform represents a **quantum mechanical generalization of the classical phase-space density**. In Poisson-bracket notation, the BUU equation can be written as

$$[p_0 - H, g^{<}] + [\mathrm{Re}(g), \Sigma^{<}] = i\Sigma^{>} g^{<} - i\Sigma^{<} g^{>} \;,$$

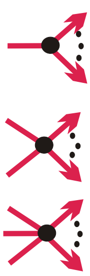
where g denotes the retarded Green's function and $g^{>}$ represents the density of hole-states in the phase-space. The $\Sigma^{>}$ and $\Sigma^{<}$ are the gain and loss terms which implement scattering processes. In general, we get **for each particle species one such equation**. All **equations are coupled through the gain and loss terms and also via the mean fields** being included in the Hamiltonian H, which may depend on all available phase space densities.

The GiBUU model

The GiBUU model includes 61 baryonic and 31 mesonic states. The necessary parameters (e.g. pole masses, life times in vacuum, branching ratios) are **based on the Manley analysis and the PDG compilation**.

The BUU equation is solved applying a **test-particle ansatz in a full ensemble scheme** which guarantees locality in the scattering processes of the test-particles.

Resonances are explicitly propagated, in particular off-shell. Hence an off-shell potential according to Effenberger et al. [2] is introduced which influences the time-development of the spectral functions.



The loss and gain terms include besides particle decays also **two and three-body reaction channels**. The low-energy two-body reaction rates are to a large extent given by **resonance excitations**. Whereas at higher center-of-mass energies (above 2 GeV for meson-baryon and above 2.6 GeV baryon-baryon scattering) an enhanced version of **Pythia** [3] is implemented to describe the reaction processes.

The Hamiltonian of the nucleon and baryonic resonances includes a **momentum-dependend Skyrme-like potential**. For the pion, we consider a low-energy potential based on the Δ-hole model and on pionic atom phenomenology. Also **Coulomb distortions** are taken into account.

The nuclear ground state is treated within a local **Thomas-Fermi approximation**. For this the nuclear density profiles are parametrized according to elastic electron-scattering data and Hartree-Fock nuclear-many-body calculations.

The GiBUU code is written **modular in Fortran 2003** and is being **developed in a multi-user environment** [4].

Applications

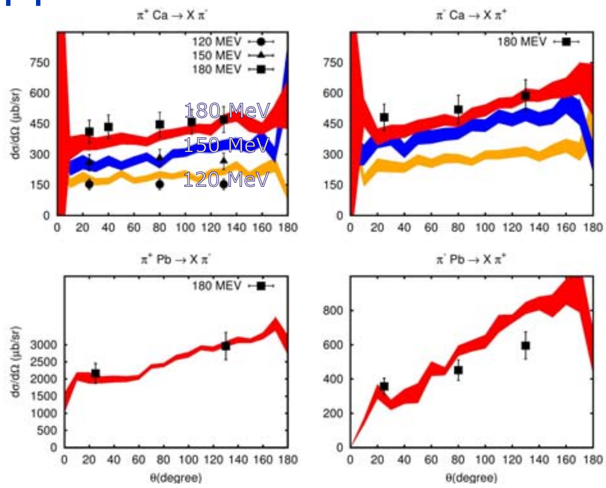


Fig 1: Pion Double Charge Exchange (DCX) is a crucial benchmark for pion dynamics. The upper panel shows the GiBUU results as bands which denote the statistical uncertainty for beam energies of 120, 150 and 180 MeV. The data points are from Wood et al. [PRC46 (1992), 1903].

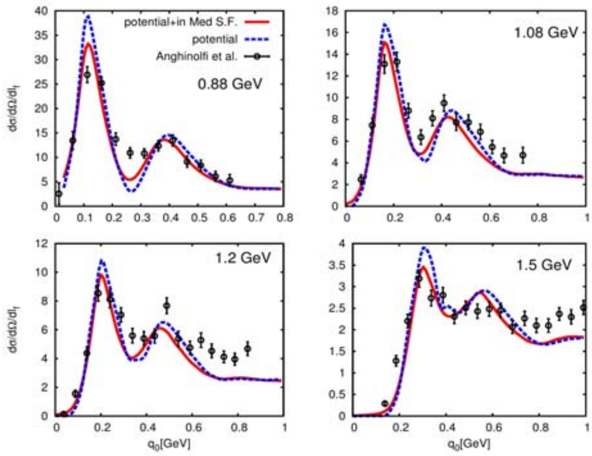


Fig 2: Inclusive electron scattering serves as a benchmark for ground state properties and the spectral functions [5]. The upper panel shows our results with an without in-medium spectral functions for an electron scattering angle of 32° and beam energies of 0.88-1.5 GeV. Data: Anghinolfi et al. [NPA602 (1996), 405].

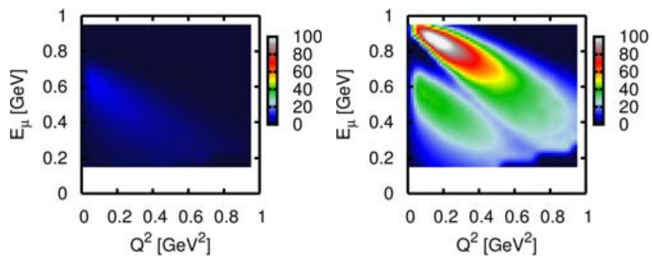


Fig 3: Double differential cross-section $d\sigma/dQ^2dE_\mu$ $[10^{-38}\mathrm{cm}^2/\mathrm{GeV}^3]$ for neutrino-induced neutron knockout on ^{56}Fe at 1 GeV beam energy. Comparing the left panel (no final-state interactions) to the right one (with FSI), one immediately notices the importance of a proper final-state treatment [6].

Major references

[1] Kadanoff and Baym: Quantum Statistical Mehanics, Perseus Books, Reading (1998)
[2] Effenberger et al., PRC 60 (1999), 051901
[3] Pythia Website: http://www.thep.lu.se/~torbjorn/Pythia.html
[4] GiBUU Website: http://GiBUU.physik.uni-giessen.de
[5] Buss et al., PRC 76 (2007), 035502
[6] Leitner et al., PRC 73 (2006), 065502

supported by DFG

Institut für Theoretische Physik
JLU Giessen