Strange and non-strange particle production in nucleus-nucleus collisions at $E_{\mathrm{kin}} = 0.4 - 2A\,\mathrm{GeV}$

Vinzent Steinberg[1,2], Ömür Erkiner[1,2], Dmytro Oliinychenko[1,4], Janus Weil[1], Hannah Petersen[1,2,3]

[1]Frankfurt Institute for Advanced Studies — [2]Institute for Theoretical Physics, Goethe University Frankfurt — [3]GSI Helmholtzzentrum für Schwerionenforschung — [4]Bogolyubov Institute for Theoretical Physics

Abstract

- New hadronic transport model SMASH [1] to describe heavy-ion collisions
- Reproduces cross sections, maintains detailed balance
- Comparison to observed pion and kaon production at low energies (FOPI, KaoS)
- Understand important physical effects for low-energy hadronic reactions
- Such reactions are also important for late stages of collisions at RHIC and LHC energies

SMASH

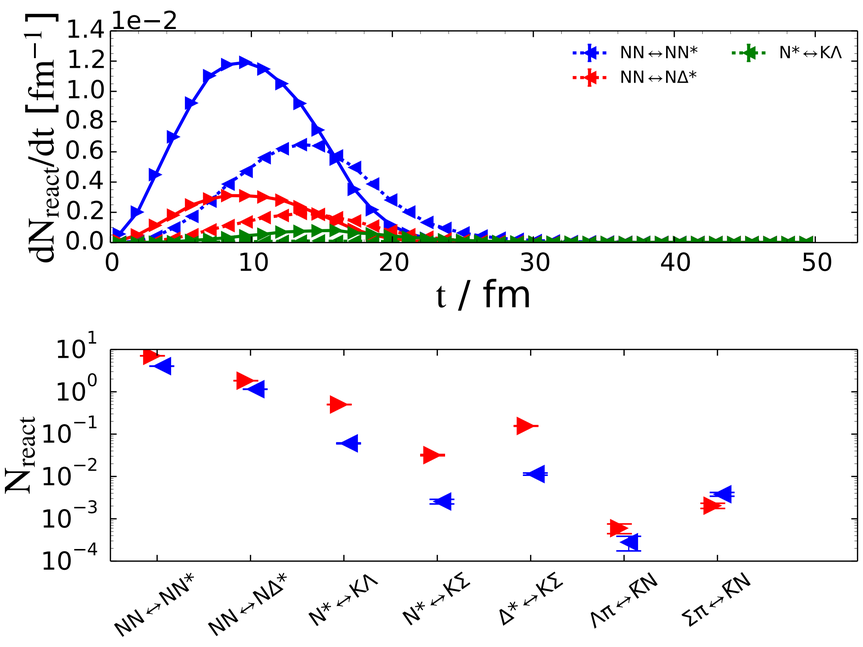
- New hadron transport approach for dilute non-equilibrium stages of heavy-ion collisions and low energy collisions
- **S**imulating **M**any **A**ccelerated **S**trongly-interacting **H**adrons
- Goal: Standard reference for hadronic systems with vacuum properties
- Modes: Nuclear collisions, infinite matter calculations, afterburner for hydrodynamic simulations
- Dileptons and photons

Transport approach

- Microscopic simulation of colliding particles
- Solve relativistic Boltzmann equation for particle species i

$$p^\mu \partial_\mu f_i(x,p) = C^i_{\mathrm{coll}}$$

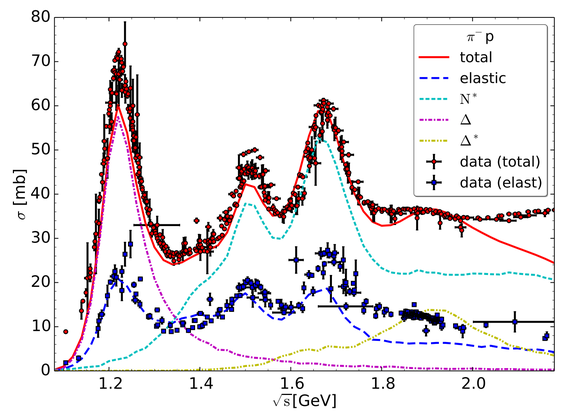
- Each particle represented by point-like test particles
- SMASH:
  - Geometric collision criterion
  - Only $2 \leftrightarrow 2$ and $2 \leftrightarrow 1$ hadronic reactions
  - 56 mesons and 60 baryons (+ anti particles)



- Reaction rates for strangeness production in Au+Au collisions at $E_{\mathrm{kin}} = 1.5A\,\mathrm{GeV}$
- N^*, Δ^* decays produce strangeness
- Strangeness exchange absorbs K^-

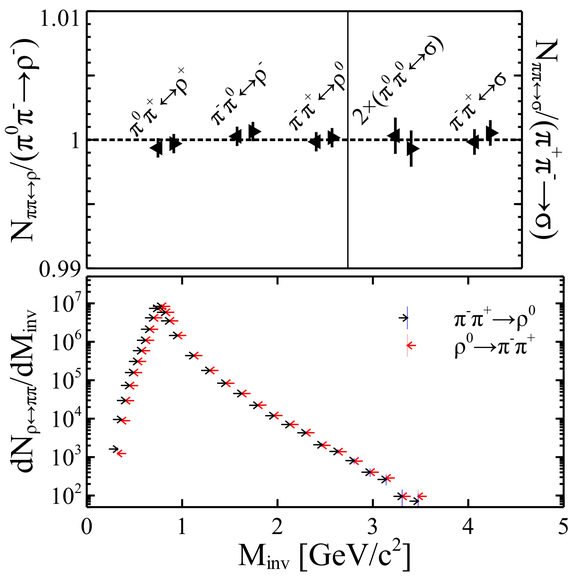
Cross section

- Calculated from resonance masses, decay widths and branching ratios
- Parametrization of some experimental cross sections



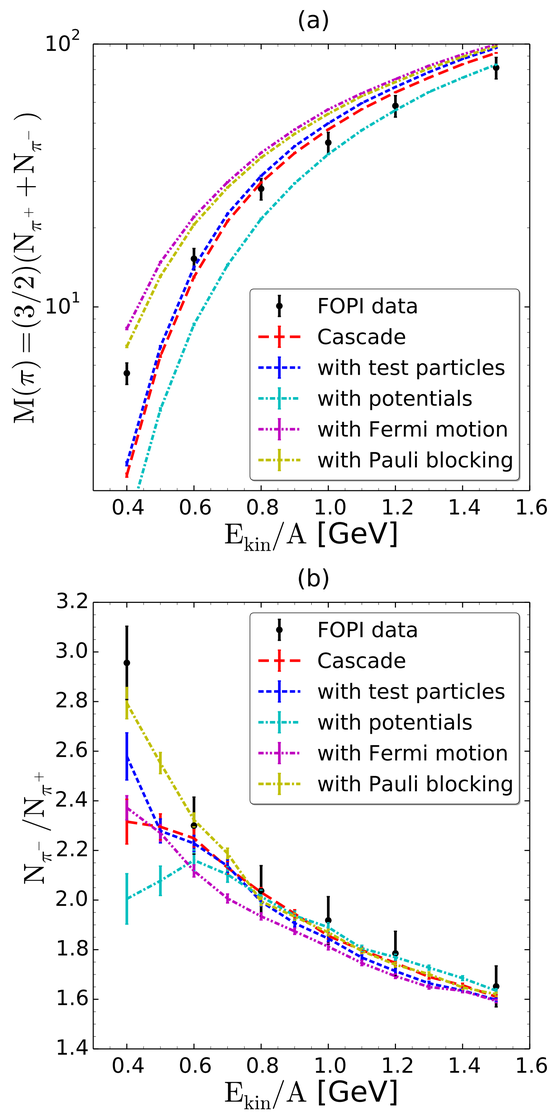
- Pion-proton cross section compared to data from the PDG
- Peaks of N^*, Δ, Δ^* resonances clearly visible
- For $\sqrt{s} \gg 2\,\mathrm{GeV}$: string fragmentation

Detailed balance



- Detailed balance for a $\pi - \rho - \sigma$ system in a box for $t > 20\,\mathrm{fm}$
- Equal forward and backward reactions for any invariant mass

Pion production



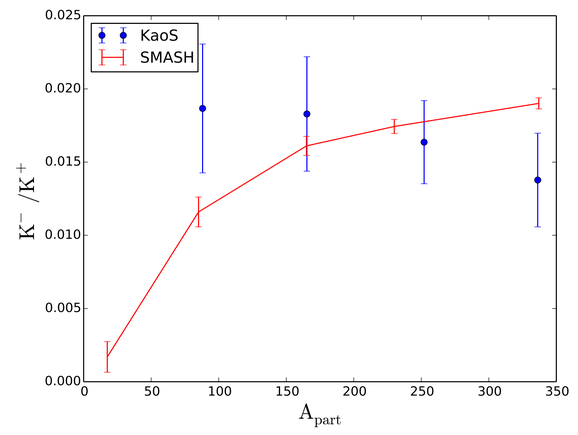
- Pion multiplicities in Au+Au collisions as measured by FOPI [2] (markers), in comparison with SMASH (lines)
- Physical features are successively added to a pure cascade simulation (see legend)
- Total pion multiplcity
  - Strongly enhanced by Fermi motion
  - Supressed by soft nucleon-nucleon potential
  - Overestimated
- π^-/π^+ ratio
  - Fermi motion, potentials and Pauli blocking important at low energies only
  - Well reproduced

Strangeness production

- Strangeness exclusively produced during collision ⇒ interesting probe for studying evolution of the reaction
- Production channels for strange particles ($Y \in \{\Lambda, \Sigma\}$):

$$NN \to NN^*, N\Delta^* \to NYK \quad (1)$$
$$\pi Y \leftrightarrow KN \quad (2)$$

- Kaons and 11 kaonic resonances (+ anti particles)
- Λ, Σ, Ξ, Ω and 28 resonances (+ anti particles)



- K^-/K^+ ratio measured by KaoS [3] in Au+Au collisions at $E_{\mathrm{kin}} = 1.5A\,\mathrm{GeV}$ as a function of the number of participants compared to SMASH
- Good agreement, but trend differs?

Conclusion

- Low-energy particle production can be modeled via resonances
- SMASH overstimates pions but reproduces π^-/π^+ and K^-/K^+ ratios
- Future work: String fragmentation (Pythia), many-particle reactions

References

[1] J. Weil et al., Phys. Rev. C **94**, 054905 (2016), 1606.06642

[2] W. Reisdorf et al. (FOPI), Nucl. Phys. A **781**, 459 (2007), nucl-ex/0610025

[3] A. Forster et al. (KaoS), J. Phys. G **31**, S693 (2005), nucl-ex/0411045

Acknowledgements

Computational resources have been provided by the Center for Scientific Computing at the Goethe University Frankfurt. The authors acknowledge funding of a Helmholtz Young Investigator Group VH-NG-822 from the Helmholtz Association and GSI. This work was supported by the Helmholtz International Center for the Facility for Antiproton and Ion Research within the framework of the Landes-Offensive zur Entwicklung Wissenschaftlich-Ökonomischer Exzellenz program launched by the State of Hesse. D.O. acknowledges support by the Deutsche Telekom Stiftung. D.O. and V.S acknowledge support by the Helmholtz Graduate School for Hadron and Ion Research.

HELMHOLTZ ASSOCIATION

HIC for FAIR Helmholtz International Center

FIAS Frankfurt Institute for Advanced Studies

Contact information

- Email: steinberg@fias.uni-frankfurt.de