Particle Production via Strings and Baryon Stopping in a Hadronic Transport Approach

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DPG Spring Meeting
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Investigate regions with high $\mu_B$ to search for a phase transition and a critical point.
Baryon Stopping

- Net proton number $N^p - \bar{p}$ to measure stopped protons from initial nuclei

- Shape of $dN^p - \bar{p}/dy$ is strongly energy dependent

- $\sqrt{s_{NN}} \approx 5$ GeV: Baryons are stopped around mid rapidity

- $\sqrt{s_{NN}} > 60$ GeV: Nuclei pass through each other

- First nucleon-nucleon interactions play most important role
Transport Model SMASH

- Hadronic degrees of freedom
- Geometric collision criterion:
  \[ d_{\text{trans}} < \sqrt{\frac{\sigma_{\text{tot}}}{\pi}} \]
- Established hadrons from PDG up to \( m \approx 2 \text{ GeV} \)
- Effectively solving relativistic Boltzmann equation
  J.Tindall et al. 10.1016/j.physletb.2017.04.080
- Inelastic processes via resonances, soft strings or Pythia directly, depending on energy
  J.Weil et al. 10.1103/PhysRevC.94.054905

Code available at https://smash-transport.github.io

Lead-lead collision at \( \sqrt{s_{NN}} = 17.3 \text{ GeV} \) in SMASH

J.Weil et al. 10.1103/PhysRevC.94.054905
Other SMASH Contributions

Damjan Mitrovic - HK 54.28
Nucleon-Nucleon correlations in SMASH

Natey Kübler - HK 54.19
Predictions for particle production in Ag+Ag collisions at $E_{\text{kin}} = 1.67A$ GeV from a hadronic transport approach

Anna Schäfer - HK 58.1
SMASH: A New Hadronic Transport Approach
Friday 2:00 pm

Jan Hammelmann - HK 58.5
Influence of the neutron skin effect on the isospin density in heavy ion collisions
Friday 3:30 pm
String Model

- Massless quarks with momentum $p_1$, $p_2$ and position $x_1$, $x_2$
- Motion according to:

$$H = |p_1| + |p_2| + \kappa |x_1 - x_2|$$

- $\kappa \approx 1$ GeV/fm: String tension
- New $q\bar{q}$ pairs are produced
- String fragments into hadrons
- Hadrons are formed around a constant proper time

B. Anderson et al. 10.1016/0370-1573(83)90080-7
Strings in SMASH

**Hard processes:**
- Dominate for high $\sqrt{s}$
- Pythia to excite and fragment strings
- Map colliding hadron species to nucleons and pions

**Soft processes:**
- Dominate at intermediate $\sqrt{s}$
- Excite strings and call Pythia only for fragmentation
- Contains single diffractive, double diffractive and non-diffractive processes
Proton-Proton Collisions
Fragmentation Function for Leading Baryons

- Fragmentation function for sampling light cone momentum fraction for each string fragment
- Green curve: Lund fragmentation function everywhere
- Blue curve: Different fragmentation function for leading baryons

\[ x_F = \frac{p_z}{p_{z,\text{beam}}} \]

\[ p \sqrt{s_{NN}} = 17.27 \text{ GeV} \]
Overview p+p Rapidity Spectra

Fragmentation function, strangeness suppression and diquark suppression tuned to data
Overview p+p mean $p_{T}$

- Transverse momentum transfer and transverse momentum production from string fragmentation tuned to data
Heavy Ion Collisions
Heavy Ion Collisions

- Good agreement with measured proton rapidity spectrum high SPS energies
- Overshoot proton multiplicity at low SPS energies but shape is reproduced
Heavy Ion Collisions

\[
\pi^-, \text{ Pb} + \text{Pb}
\]

\[
\begin{align*}
\sqrt{s_{NN}} &= 17.27 \text{ GeV} \\
\sqrt{s_{NN}} &= 8.765 \text{ GeV} \\
\sqrt{s_{NN}} &= 6.27 \text{ GeV}
\end{align*}
\]

- Overall reasonable agreement with measurement for pion production
- Slightly underestimate pion production at top SPS energies
- Overestimate pion production at low SPS energies

Summary and Outlook

Summary:
- String model is implemented for describing hadronic interactions at large $\sqrt{s}$
- Free parameters are tuned to reproduce the particle production in proton-proton collisions
- Dynamics of protons in p+p collisions not fully understood
- Good agreement with measured proton and pion rapidity spectra achieved in heavy ion collisions

Outlook:
- Further investigate transverse momentum production when using separate fragmentation function
- Calculate initial state of a heavy ion collision as starting point of a hydro simulation
Backup
Formation Times

\[ \text{Pb + Pb, } \sqrt{s_{NN}} = 17.27 \text{ GeV} \]

- Multiply formation times by a constant factor \( b_{\text{form}} \)
- Equivalent to changing string tension \( \kappa \)
- Short formation times reproduce shape best
- How does changing the formation time affect pions?
Formation Times

\[ \text{Pb + Pb, } \sqrt{s_{NN}} = 17.27 \text{ GeV} \]

- Pion multiplicity increases with longer formation times
- Use \( b_{\text{form}} = 1 \) to obtain a reasonable agreement for pions and protons
Cross Section Scaling Factors

- During formation time cross section is scaled down by factor $f_\sigma$
- By default use a Heavyside function in time for $f_\sigma$
- One can also have $f_\sigma$ grow with a given power $\alpha$ in time

Cross Section Scaling Factors

Pb + Pb, $\sqrt{s_{NN}} = 8.765$ GeV

- Vary power $\alpha$ with which the cross section grows in time
- $\alpha = -1$ stands for using a Heavyside function
- If the cross section grows too fast the dip cannot be reproduced at intermediate SPS energy