Can Baryon Stopping be understood within the String Model?

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Motivation
- Investigate reaction in QCD phase diagram, where phase transition and critical point might exist
- Understand how much the protons from initial nuclei are stopped
- Full non-equilibrium dynamical description of colliding hadrons in transport model
- Correct fluctuations in participant number $\rightarrow$ necessary for finding possible critical point

Transport Model SMASH
- Hadronic degrees of freedom
- Geometric collision criterion:
  \[ d_{\text{Hmax}} \leq \sqrt{\frac{2E}{\pi}} \]
- Well established hadrons from PDG
- Inelastic processes via resonances, soft strings or Pythia directly, depending on energy
- Photons and leptons treated perturbatively
- Effectively solving relativistic Boltzmann equation
- J. Tross et al. 10.1016/j.physrep.2017.04.001

String Model
- Describe particle production from excited quark antiquark or quark diquark pair
- Massless (di)quarks with momentum $p_1$, $p_2$ and position $x_1$, $x_2$
  \[ H = |p_1| + |p_2| + \kappa |x_1 - x_2| \]
- String tension $\kappa$
- New $qq$ or $qqqq$ pairs are produced
- Hadrons are formed around constant proper time

Soft String Excitation
Single diffractive $A + B \rightarrow A + X$ or $A + B \rightarrow X + B$
- Hadrons collide, exchange momentum and one of them is excited to a string
- String mass $M_X$ and transverse momentum exchange $p_T$ are sampled from
  \[ dN = N \frac{1}{M_X} \exp \left( -\frac{p_T^2}{\sigma_T^2} \right) \]
  G. Ingelman and P. E. Schlein 10.1006/0370-1573(83)90080-7

Double diffractive $A + B \rightarrow X + X$
- Hadrons exchange gluons and are both excited to a string
- Gluon light cone momentum fraction $x$ sampled from PDF for gluons
  \[ P_D^G \propto x^{\beta + 1} (1 - x)^{\beta + 1} \]
- Transverse momentum exchange also sampled from Gaussian

Non-diffractive
- Two hadrons exchange a valence quark and are both excited to a string
- Quark light cone momentum fraction $x$ sampled from PDF for quarks
  \[ P_D^q \propto x^{\beta + 1} (1 - x)^{\beta + 1} \]

Transverse Momentum Transfer
- Varying $\sigma_T$ in order to reproduce $p+p$ data at SPS energies
- Larger values of $\sigma_T$ lead to more ($p_T$)
- If more energy is transformed into $p_T$, protons are decelerated more
- Increasing $\sigma_T$ tightens rapidity distribution

Strangeness Suppression
- Strangeness suppression factor
  \[ \lambda = \frac{P(\bar{s}s)}{P(\bar{u}u)} = \frac{P(\bar{s}s)}{P(\bar{d}d)} \]
- Can be used to tune strange hadron multiplicities
- Only slightly varies non strange hadron multiplicities

Proton Mean Transverse Mass
- Mean transverse mass of protons agrees with data for $8 \text{GeV} < \sqrt{s} < 20 \text{GeV}$
- New measurement by NA61 provides constraints on transport approaches

Particle Spectra in $p+p$
- Reasonable agreement for rapidity spectra of produced hadrons

Outlook
- Find a set of parameters to reproduce $p+p$ data at SPS energies
- Investigate baryon stopping in heavy ion collisions
- Understand how the interaction between string fragments affects stopping (formation times, cross section scaling factors etc.)

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