The JETSCAPE collaboration: First X-SCAPE release and major hybrid hadronization updates

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In previous versions of this report we have discussed the continuing work of the JETSCAPE collaboration. The original product, the JETSCAPE framework, has the main task of providing a framework for comprehensive simulations of A+A collisions. It is now available in version 3.5x [1]. In addition, in 2020 the NSF has approved the X-SCAPE project as the follow-up to JETSCAPE. The new framework will allow users to simulate lower energy nuclear collisions as well as proton-nucleus and electron-nucleus collisions. Thus X-SCAPE will offer much needed capabilities to support experiments at the Electron-Ion Collider. The EIC is the next-generation nuclear physics experiment planned by the Department of Energy at Brookhaven National Laboratory for 2030 and beyond. Fig. 1 shows a schematic flow diagram for the X-SCAPE framework. In the current reporting period version 1.0 of the X-SCAPE framework has been published.

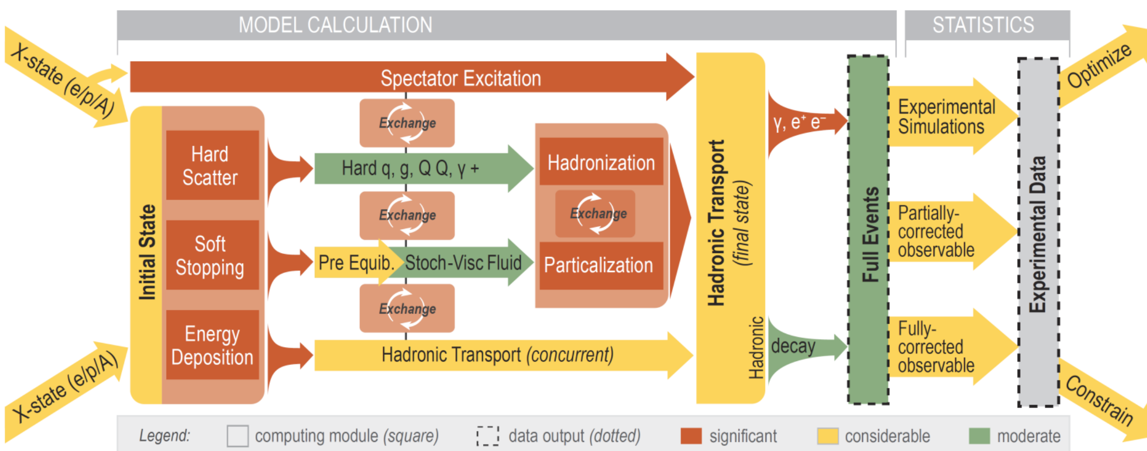

Fig. 1. Schematic Flow Diagram of the X-SCAPE event generator that will be able to simulate p+p, p+A, A+A, e+p and e+A collisions at high energies.

The JETSCAPE group at Texas A&M University maintains the Hybrid Hadronization module which will undergo a major update in the next versions of the JETSCAPE/X-SCAPE frameworks. Many of these updates were developed in collaboration with the JETSCAPE group of Hannah Elfner at the University in Frankfurt. These updates are briefly discussed below.

(i) There are several bug fixes to the handling of string junctions. String systems can get quite complex in Hybrid Hadronization, with multiple connected junctions carrying baryon number. Proper treatment of such string systems, taking into account the odds for PYTHIA 8 sucessfully fragmenting them, is important to accurately account for baryon number. Previous versions could lead to instances of PYTHIA 8 crashing or to violations of baryon number conservation. In the new version all junctions are given to PYTHIA separately to achieve excellent stability. (ii) There is now the option to force final hadrons onto the mass shell while preserving energy and momentum of the event. This is necessary for feeding hadrons in the hadronic afterburner SMASH, but it is optional if final state hadrons are instead given to PYTHIA 8 for decay. (iii) Energy and momentum conservation at the start of the module, when the initial parton list is prepared for recombination, e.g. by decaying gluons non-perturbatively, are more strictly enforced in the new version. (iv) The process of adding beam partons to events, which is necessary if the full underlying event is not read into the framework, e.g. in p+p, has also been improved to avoid adding too much energy to the event. (v) There are tantalizing hints, e.g. from Λ_c production, that making full use of the hadron spectrum and the pertinent feeddown are important for a correct description of hadronization (see also a companion report in this volume). The recombination into excited and highly excited meson states has been implemented in the new version following [2]. However, currently these states can only be decayed by PYTHIA 8 with additional particle information data, as they are not implemented in SMASH. For the future, it is planned to restructure the handling of cross-sections in SMASH, such that the addition of new particles and channels is easier. (vi) There is also a more precise determination of the position of hadrons from string fragmentation. Hadrons that can be identified as coming from a particular string segment are now distributed evenly along the string segment, hadrons connected to a junction are placed along the junction legs.

With these improvements, new physics capabilities have been unlocked, e.g. the study of hadronic final state interactions of hadrons from hard processes using SMASH.

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[1] The JETSCAPE 3.5x and X-SCAPE 1.0 packages, https://github.com/JETSCAPE
[2] M. Kordell II, R.J. Fries and C.M. Ko, Annals Phys. **443**, 168960 (2022).