Introduction to X-SCAPE

RHIC & AGS Users' Meeting 2024

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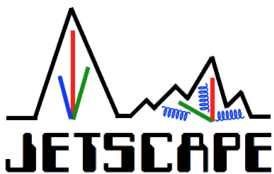
For the JETSCAPE Collaboration



VANDERBILT
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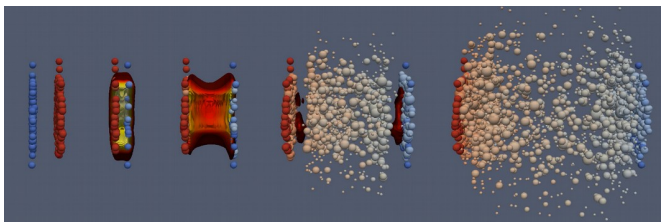
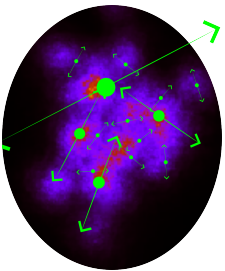
Motivation

- High energy nuclear physics is a broad field with varied expertise
- A necessity to bring it together for coherent phenomenology
- Provide a framework for community to have basic minimal tools to choose from
- Set up the background for Bayesian analysis and model comparisons





JETSCAPE framework

- Can be used to generate p-p or A-A collisions
- The framework controls the flow of information to different modules
- The modules themselves can be modified, replaced or added

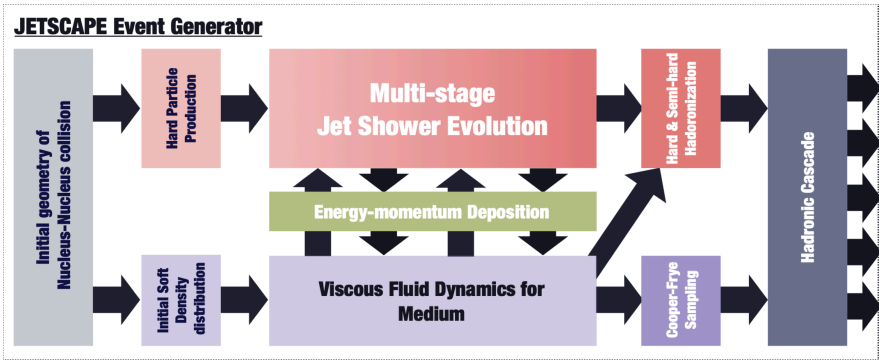
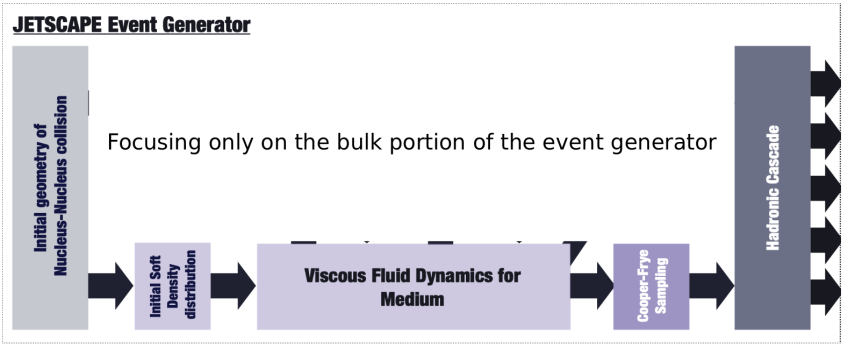


Illustration by Y. Tachibana

JETSCAPE framwork

- It can be run in pure soft, pure hard or interactive modes



X-SCAPE

- The X-ion collisions with a Statistically and Computationally Advanced Program Envelope (X-SCAPE) is the second project of the JETSCPAE collaboration
- The framework is extended to include
  1. Small systems (p-p and p-A)
  2. Lower energy collisions
  3. Electron - Ion collisions
- The clock can go forward and backward
- Multiple bulk event generators can run concurrently
- Fully backwards compatible and can be run in the JETSCAPE mode

X-SCAPE framework

- User can determine the order of modules, i.e. time can go forward and backward
- Helps with implementation of initial state radiation

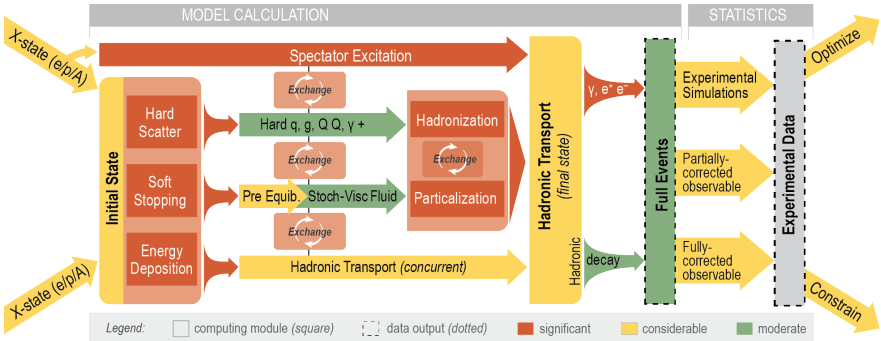
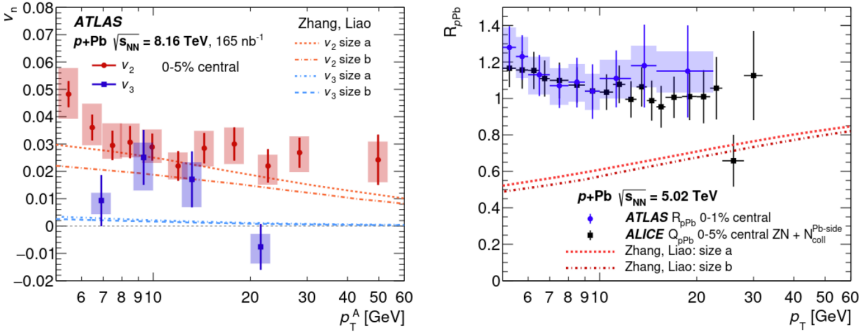


Illustration by R. Soltz

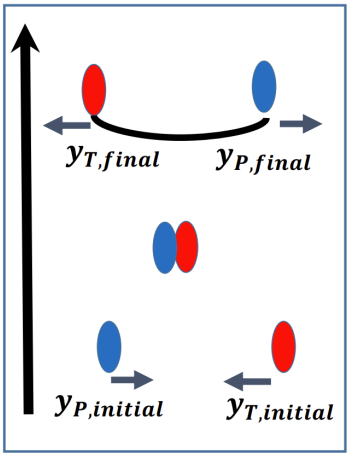
Small systems

- Simultaneous description of R_{AA} and v_2 in small systems has been a challenge



ATLAS Eur.Phys.J.C 80 (2020)
ALICE Phys. Rev. C 91 (2015)
X. Zhang and J. Liao arXiv: 1311.5463 (2013)

3D Glauber



- Nucleon positions are sampled from Woods-Saxon distribution
- Hotspots are associated with valence quarks which are sampled from PDFs
- Incoming partons are decelerated by a string with a classical string

$$\frac{dE}{dz} = -\sigma \qquad \frac{dp_z}{dt} = -\sigma$$

C. Shen and B. Schenke Phys. Rev. C 97 (2018), Phys. Rev. C,105 (2022)

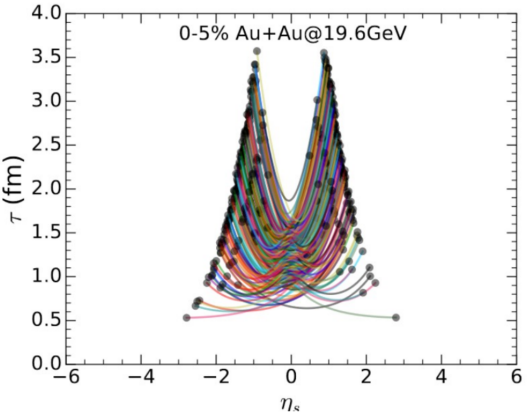
3D Glauber

- Energy deposited with the string is added as source terms in hydro-equations

$$\partial_\mu T^{\mu\nu} = J^\nu_{\text{Source}}$$

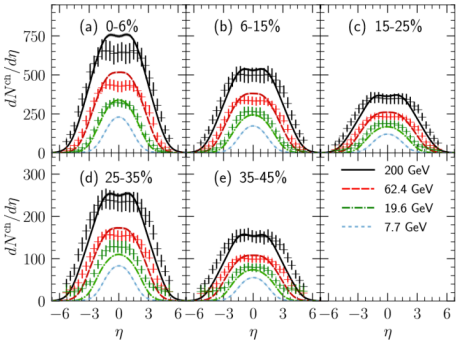
$$\partial_\mu J^\mu = \rho_{\text{Source}}$$

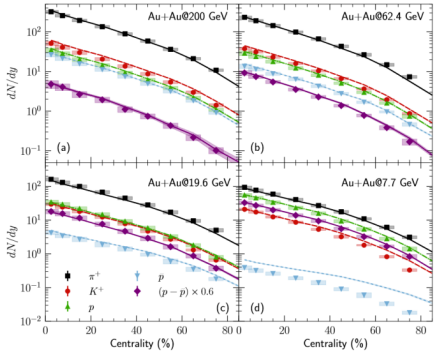
- Remaining energy in the partons is added at the string ends



C. Shen and B. Schenke Phys. Rev. C 97 (2018)

3D Glauber + MUSIC + UrQMD for low energies



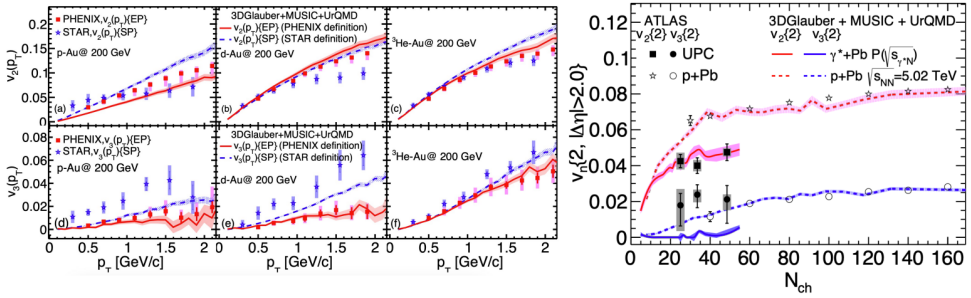


C. Shen and B. Schenke Phys. Rev. C 97 (2018), Phys. Rev. C,105 (2022)
STAR Phys. Rev. C 79 (2009), Phys. Rev. C 96 (2017)

RHOBOS Phys. Rev. C 74 (2006)

- The model works well for a range of collision energies for bulk medium

3D Glauber + MUSIC + UrQMD for small systems



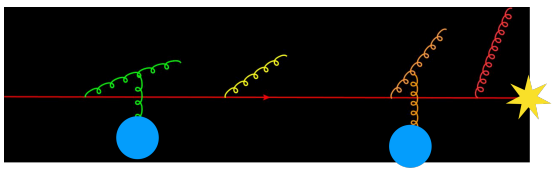
W.Zhao, C. Shen and B. Schenke Phys. Rev. Lett. 129 (2022)
W.Zhao, S. Ryu, C. Shen and B. Schenke Phys. Rev. C 107 (2023)
ATLAS Phys. Rev. C 104 (2021), Phys. Rev. C 96 (2017)
PHENIX Nat. Phys. 15 (2019)

STAR Nucl. Phys. A 1005 (2021))

- It can also describe p-Au, d-Au, He^3-Au, p-Pb and γ^*-Pb

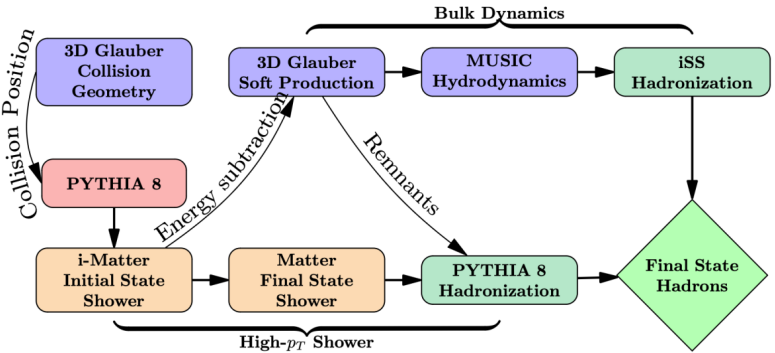
I-MATTER

- Calling Pythia (ISR-FSR-OFF) generates MPI scatterings
- Start each parton at high and negative $\mathbb{Q}^2$ and evolve back to $Q^2 = -1$ GeV^2
- i-MATTER runs parton shower backwards in time and the final parton at most negative time is the parent
- Parent energy can be subtracted from 3D Glauber making it unavailable for bulk medium
- Brings non-trivial soft-hard correlations from the earliest stages
- A strictly energy-conserving initial state model



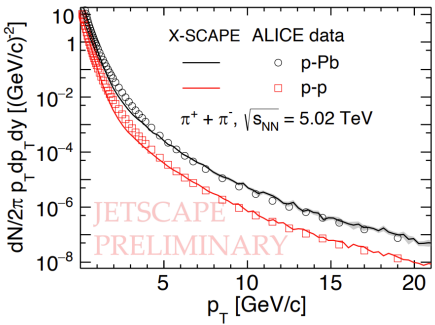
Consistent Hard + Soft Description

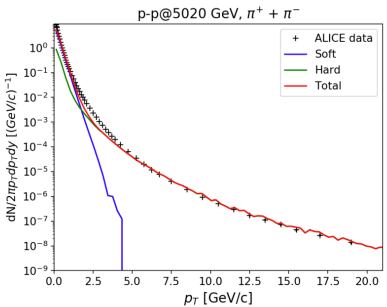
- The hard and soft sector can be modelled concurrently using the 3D Glauber + i-MATTER framework



Hadron spectra from low to high p_T

- X-SCAPE can describe the pion spectra from low to high p_T as a combination of soft and hard pions
- There is still some tension at intermediate p_T. Coalescence? Medium response?

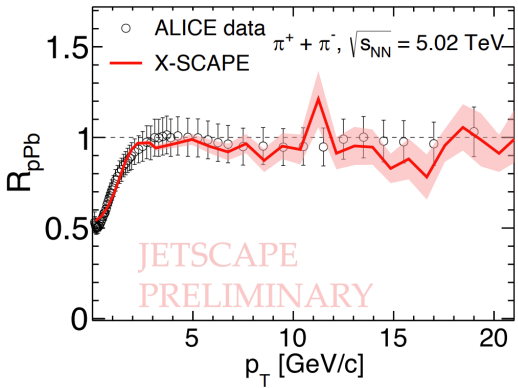




ALICE Phys. Lett. B 760 (2016)

Hadron spectra from low to high p_T

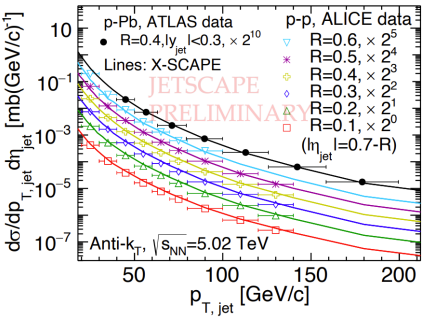
- R_{pPb} is also well described. Suppression at low p_T is reproduced

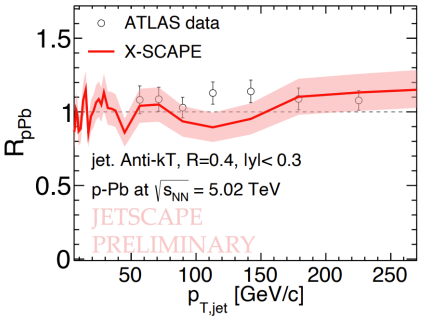


ALICE Phys. Lett. B 760 (2016)

Jets in small systems

- Jet R_{pPb} is also well described
- Simple background subtraction. Only fragmentation hadrons used in jet clustering

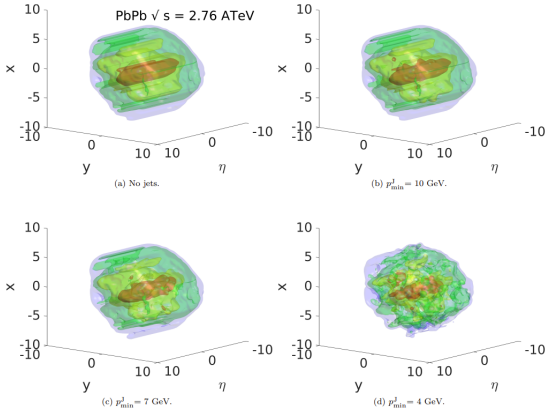




ATLAS Phys. Lett. B 748 (2015)
ALICE Phys. Rev. C 101 (2020)

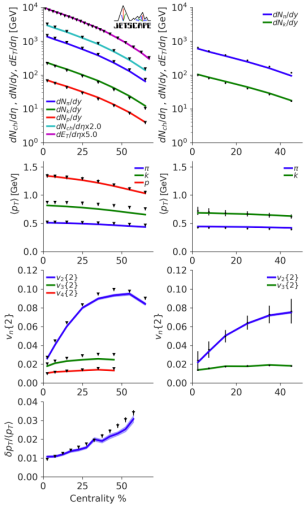
Towards simultaneous Hard+Soft evolution

- The framework is well suited to do a concurrent jet+medium evolution
- No initial-state normalization factor needed
- Will be helpful in constraining the non-flow features effects in small-systems



D. Pablos, M. Singh, S. Jeon and C. Gale Phys. Rev. C 106 (2022)

Bayesian analysis: Soft sector

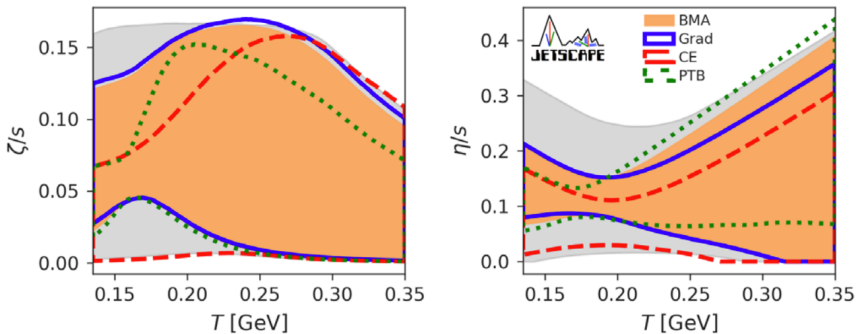


- The framework can be leveraged to use Bayesian analysis to simultaneously explain RHIC and LHC data using same model parameters
- A wide range of mid-rapidity soft observables described
- Provides a bulk-physics tune for studying jets and heavy-flavor

JETSCAPE Phys. Rev. Lett. 126 (2021), Phys.Rev.C 103 (2021)

Bayesian analysis: Soft sector

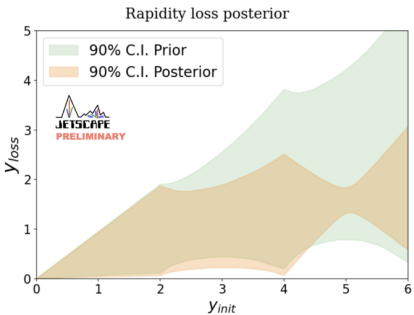
- Did comparison of different non-equilibrium corrections at Cooper-Frye

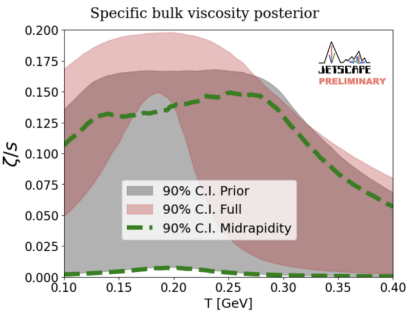


JETSCAPE Phys. Rev. Lett. 126 (2021), Phys.Rev.C 103 (2021)

3D Bayesian calibration

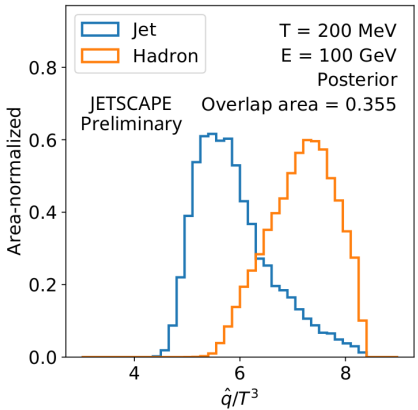
- With 3D Glauber + MUSIC framework, we are moving towards a 3D calibration
- Removes energy normalization parameterization. Rapidity dependence provides additional constraints





Andi Mankolli, Quark Matter 2023

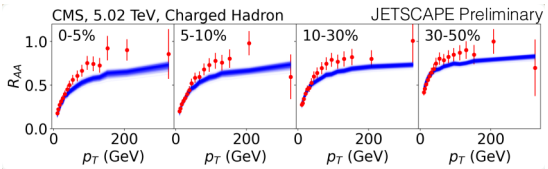
Bayesian analysis: Hard sector



Yi (Luna) Chen, Hard Probes 2023

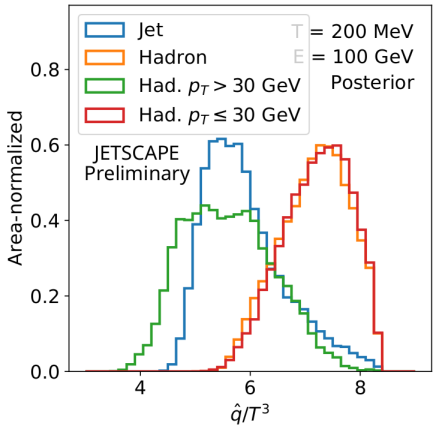
Raymond Ehlers, Quark Matter 2023

- There appears to be some tension in $\hat{q}$ extracted from jets vs hadrons
- Charged hadron R_{AA} being dominated by low-p_T where the experimental uncertainty is smallest
- Jets are naturally at higher p_T



CMS JHEP 04 039 (2017)

Bayesian analysis: Hard sector



- Agreement is much better when only high-p_T hadrons are included in analysis
- Important to carefully account for experimental and theoretical uncertainties
- The framework is a great tool for model studies and helps pinpoint where the model needs improvement

Yi (Luna) Chen, Hard Probes 2023

Raymond Ehlers, Quark Matter 2023

Summary

- X-SCAPE is constructed to be to be a computational envelope for developing complete event generators for any collision energy, any collision system
- Fully backwards compatible with JETSCAPE
- Can simultaneously describe hard and soft observable by using 3D Glauber + i-MATTER framework
- No overall energy normalization parameter. Energy either goes to jets or to the soft medium
- The framework can be leveraged to do Bayesian extraction of all model parameters

The JETSCAPE Collaboration