Studying small systems using a multi-stage approach

Ismail Soudi

Wayne State University

For the JETSCAPE Collaboration

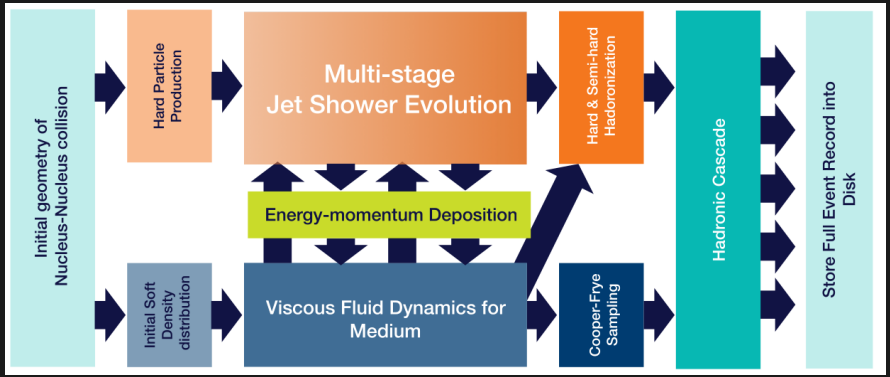
CIPANP 2022, Lake Buena Vista, Florida: Sept 3, 2022

Table of contents

Introduction

Multi-Stage Approach In Heavy-ion Collisions I

- Modular Framework for studying jets and bulk dynamics of HIC
- Latest version 3.5 available: github.com/JETSCAPE

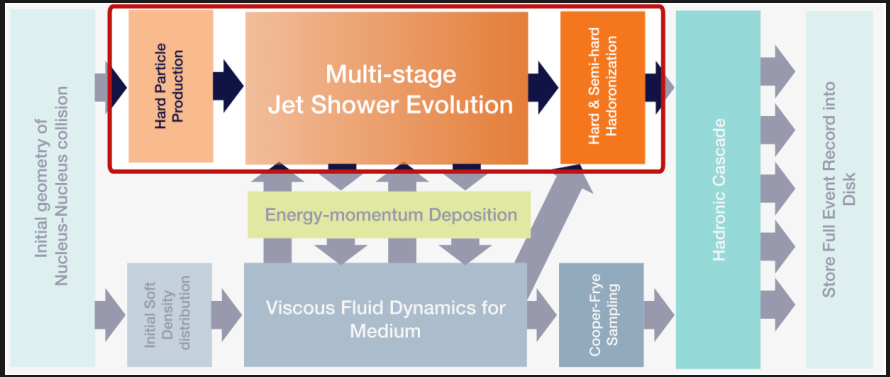


See also HIC Talks:
A. Majumder
Thu 17
&
W. Zhao
Sat 15:30

Diagram by
Y. Tachibana

Multi-Stage Approach In Heavy-ion Collisions I

- Modular Framework for studying jets and bulk dynamics of HIC
- Latest version 3.5 available: github.com/JETSCAPE



See also HIC Talks:
A. Majumder
Thu 17
&
W. Zhao
Sat 15:30

Diagram by
Y. Tachibana

Multi-Stage Approach In Heavy-ion Collisions II

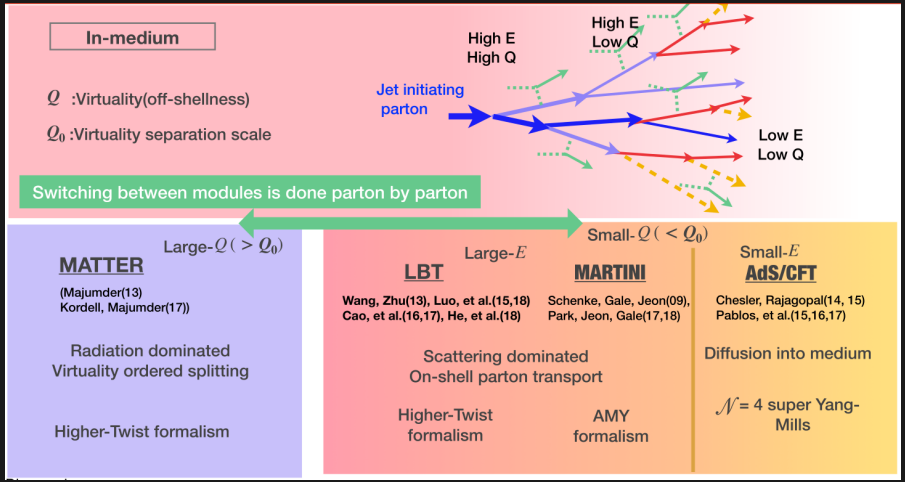


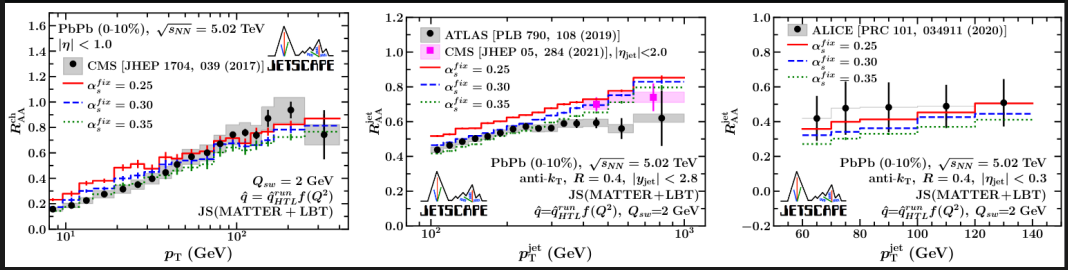
Diagram by
Y. Tachibana

Multi-Stage Approach In Heavy-ion Collisions III

Inclusive Jet and Hadron Suppression in a Multi-Stage Approach

JETSCAPE Collaboration • A. Kumar Show All(60)

Apr 3, 2022



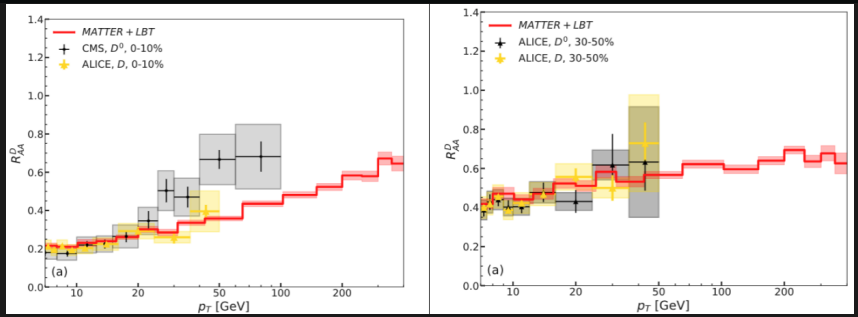
A. Kumar et al., 2204.01163 [hep-ph]

Multi-Stage Approach In Heavy-ion Collisions IV

Multi-scale evolution of charmed particles in a nuclear medium

JETSCAPE Collaboration • W. Fan Show All(59)

Aug 1, 2022



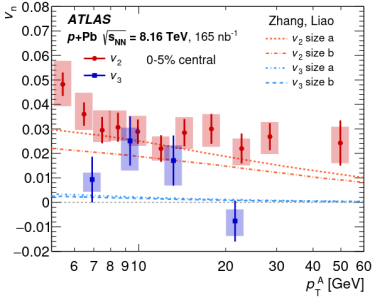
W. Fan, et al. e-Print: 2208.00983 [nucl-th] [hep-ph]

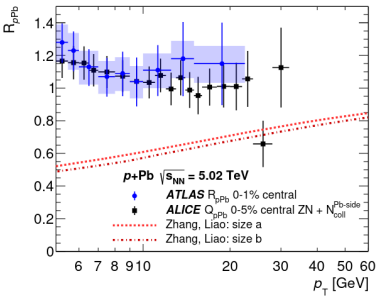
Multi-Stage Approach to small Systems

Jet quenching vs Flow

- Models of flow for high-p_T particles can lead to large supressions

Flow $v_{2,3}$ and supression R_{pPb}





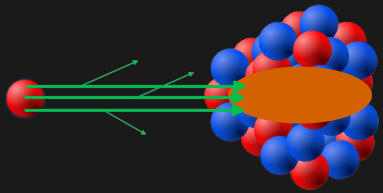
ATLAS Eur. Phys. J. C 80 (2020) 73

X. Zhang and J. Liao, arXiv: 1311.5463 [nucl-th]

Jets In Small Systems

- For Small systems:
  - Soft interactions may lead to thermalization of the medium

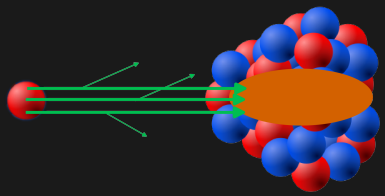
- Soft:



Jets In Small Systems

- For Small systems:
  - Soft interactions may lead to thermalization of the medium
  - Hard partons can interact with the nucleons before the hard scattering

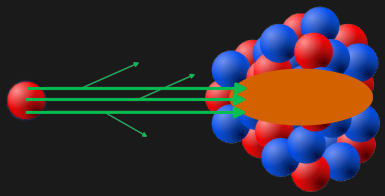
- Soft:



Jets In Small Systems

- For Small systems:
  - Soft interactions may lead to thermalization of the medium
  - Hard partons can interact with the nucleons before the hard scattering
  - May lead to modification of the initial state radiation

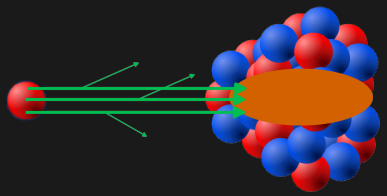
- Soft:



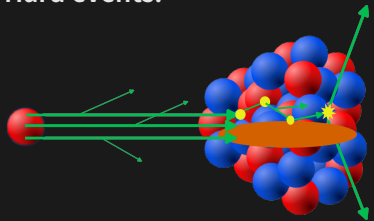
Jets In Small Systems

- For Small systems:
  - Soft interactions may lead to thermalization of the medium
  - Hard partons can interact with the nucleons before the hard scattering
  - May lead to modification of the initial state radiation
  - Correlation of Soft/Hard particle production, i.e. More hard scatterings $\Rightarrow$ less energy for soft-partons

- Soft:

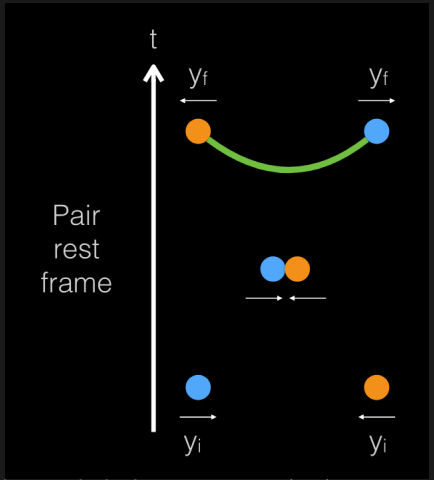


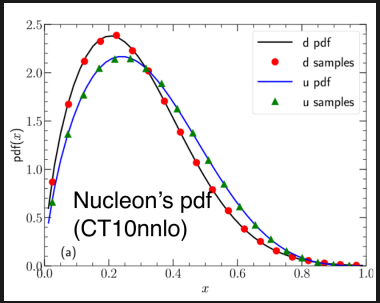
- Hard events:



3D MCGlauber

3D MCGlauber: W. Zhao, C. Shen & B. Schenke

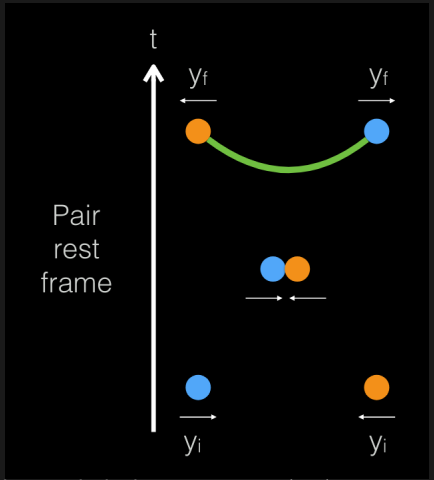


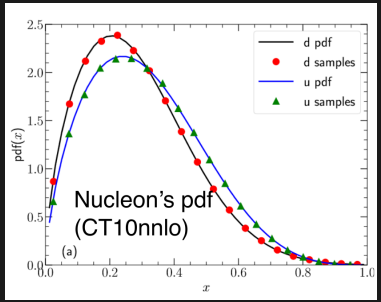


- **Collision geometry is determined by MC-Glauber model**

C. Shen & B. Schenke Phys. Rev. C 97, 024907 (2018).
C. Shen & B. Schenke, [arXiv:2203.04685 [nucl-th]].
W. Zhao, C. Shen & B. Schenke, [arXiv:2203.06094 [nucl-th]]

3D MCGlauber: W. Zhao, C. Shen & B. Schenke

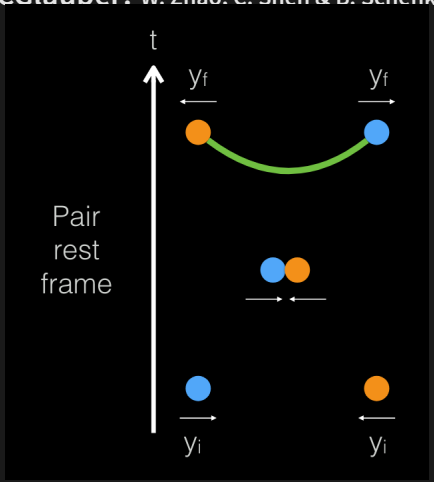


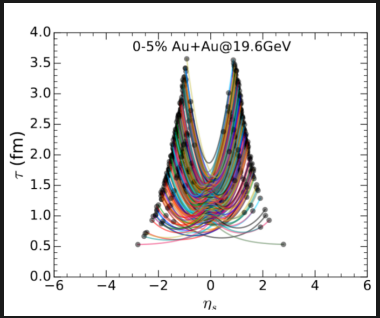


- Collision geometry is determined by MC-Glauber model
- 3 valence quarks sampled from PDF

C. Shen & B. Schenke Phys. Rev. C 97, 024907 (2018).
C. Shen & B. Schenke, [arXiv:2203.04685 [nucl-th]].
W. Zhao, C. Shen & B. Schenke, [arXiv:2203.06094 [nucl-th]]

3D MCGlauber: W. Zhao, C. Shen & B. Schenke



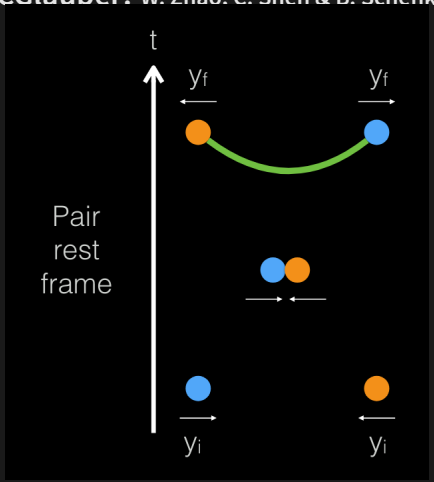


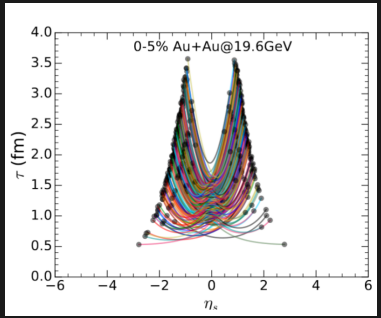
- **Incoming quarks are decelerated with a classical string tension.**

$$\frac{dE}{dz} = -\sigma \ , \qquad \frac{dp_z}{dt} = -\sigma \qquad (1)$$

C. Shen & B. Schenke Phys. Rev. C 97, 024907 (2018).
C. Shen & B. Schenke, [arXiv:2203.04685 [nucl-th]].
W. Zhao, C. Shen & B. Schenke, [arXiv:2203.06094 [nucl-th]]

3D MCGlauber: W. Zhao, C. Shen & B. Schenke





- Incoming quarks are decelerated with a classical string tension.

$$\frac{dE}{dz} = -\sigma \ , \qquad \frac{dp_z}{dt} = -\sigma \qquad (1)$$

- Conservations of energy, momentum, and net baryon density are imposed.

C. Shen & B. Schenke Phys. Rev. C 97, 024907 (2018).
C. Shen & B. Schenke, [arXiv:2203.04685 [nucl-th]].
W. Zhao, C. Shen & B. Schenke, [arXiv:2203.06094 [nucl-th]]

3D MCGlauber: W. Zhao, C. Shen & B. Schenke

- **Energy-momentum current and net baryon density are fed into hydrodynamic simulations as source terms**

$$\partial_\mu T^{\mu\nu} = J^\nu_{\text{Source}} \,, \qquad (2)$$

$$\partial_\mu J^\mu = \rho_{\text{Source}} \qquad (3)$$

3D MCGlauber: W. Zhao, C. Shen & B. Schenke

- Energy-momentum current and net baryon density are fed into hydrodynamic simulations as source terms

$$\partial_\mu T^{\mu\nu} = J^\nu_{\text{Source}} \,, \qquad (2)$$

$$\partial_\mu J^\mu = \rho_{\text{Source}} \qquad (3)$$

- Parameters callibrated with p+p at LHC

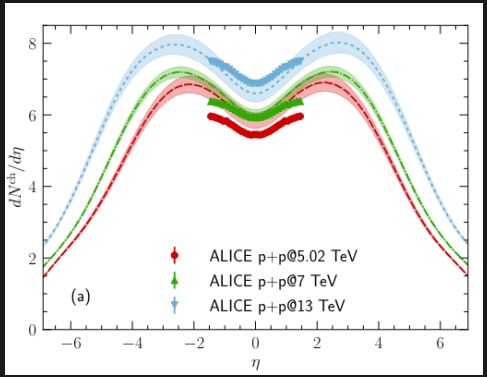


Figure 1: Charged hadron pseudo-rapidity distributions in p+p, experimental data from the ALICE Collaboration

3D MCGlauber: W. Zhao, C. Shen & B. Schenke

- Energy-momentum current and net baryon density are fed into hydrodynamic simulations as source terms

$$\partial_\mu T^{\mu\nu} = J^\nu_{\text{Source}}\,, \qquad (2)$$

$$\partial_\mu J^\mu = \rho_{\text{Source}} \qquad (3)$$

- Parameters callibrated with p+p at LHC
- **Good description of charged hadron distributions at Au+Au at RHIC after retuning of parameters**

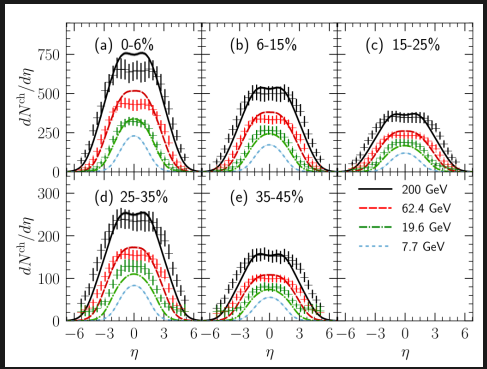
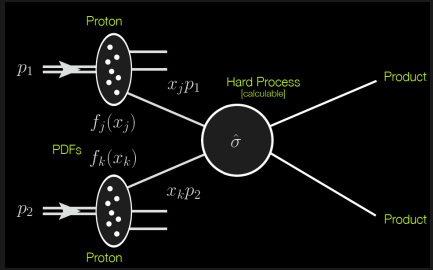


Figure 1: Centrality dependence of charged hadron pseudo-rapidity distributions in Au+Au, experimental data from the PHOBOS Collaboration

iMatter: Initial State Radiation

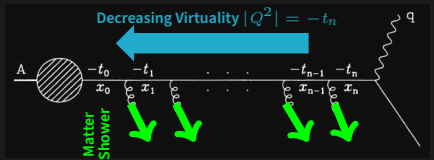
iMatter: Initial State Radiation

- **One firsts generates the hard $2 \leftrightarrow 2$ scatterings using PYTHIA**



iMatter: Initial State Radiation

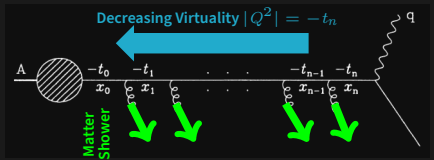
- One firsts generates the hard $2 \leftrightarrow 2$ scatterings using PYTHIA
- The initial state radiation is then generated in a backward shower, starting from the 2 partons that scatters:



T. Sjostrand, Phys. Lett. B157 (1985) 321.
G. Marchesini and B.R. Webber, Nucl Phys. B310 (1988) 461.
Ellis, R., Stirling, W., & Webber, B. (1996).

iMatter: Initial State Radiation

- One firsts generates the hard $2 \leftrightarrow 2$ scatterings using PYTHIA
- The initial state radiation is then generated in a backward shower, starting from the 2 partons that scatters:
- The Sudakov is dependent on the PDF which limits the energy of earlier partons



Sudakov

$$\Pi(t_1, t_2; x) = \frac{f(x,t_1)\Delta(t_2)}{f(x,t_2)\Delta(t_1)},$$

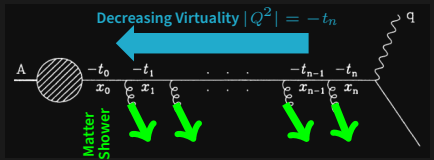
PDFs

Forward Sudakov

T. Sjostrand, Phys. Lett. B157 (1985) 321.
G. Marchesini and B.R. Webber, Nucl Phys. B310 (1988) 461.
Ellis, R., Stirling, W., & Webber, B. (1996).

iMatter: Initial State Radiation

- One firsts generates the hard $2 \leftrightarrow 2$ scatterings using PYTHIA
- The initial state radiation is then generated in a backward shower, starting from the 2 partons that scatters:
- The Sudakov is dependent on the PDF which limits the energy of earlier partons
- **Splitting probability also $\propto$ PDF**



Sudakov

$$\Pi(t_1, t_2; x) = \frac{f(x,t_1)\Delta(t_2)}{f(x,t_2)\Delta(t_1)} ,$$

PDFs

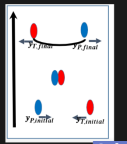
Forward Sudakov

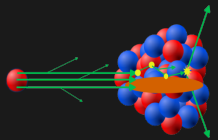
$$\Gamma(z) = \frac{\alpha_s}{2\pi} \frac{P(z)}{z} f(x_1 = x_2/z, t_1) ,$$

T. Sjostrand, Phys. Lett. B157 (1985) 321.
G. Marchesini and B.R. Webber, Nucl Phys. B310 (1988) 461.
Ellis, R., Stirling, W., & Webber, B. (1996).

Multi-Stage Approach To Small Systems

- Energy available for the hard shower is subtracted from the sodt sector (3D-MCGlauber)





Soft-hard Correlations

3D-MCGLauber

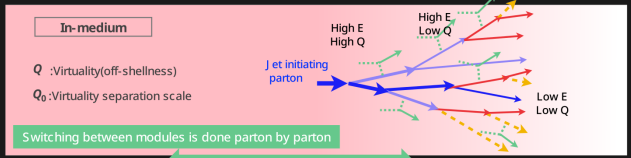
MCGlauber Collision geometry

String tension

iMATTER

Initial state radiation

Backward propagation of the cascade.



Large-Q (> Q_0)

MATTER

(Majumder(13)
Kordell, Majumder(17))

Radiation dominated
Virtuality ordered splitting

Higher-Twist formalism

Small-Q (< Q_0)

Large-E

LBT

Wang, Zhu(13), Luo, et al.(15,18)
Cao, et al.(16,17), He, et al.(18)

MARTINI

Schenke, Gale, Jeon(09),
Park, Jeon, Gale(17,18)

Scattering dominated
On-shell parton transport

Higher-Twist formalism

AMY formalism

Small-E

AdS/CFT

Chesler, Rajagopal(14, 15)
Pablos, et al.(15,16,17)

Diffusion into medium

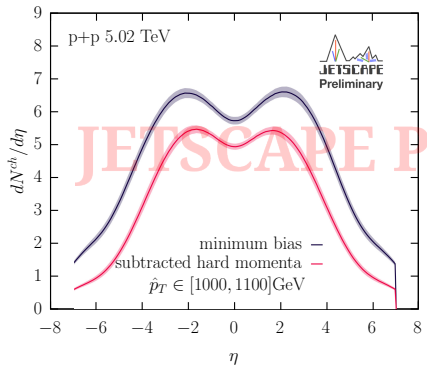
= 4 super Yang-Mills

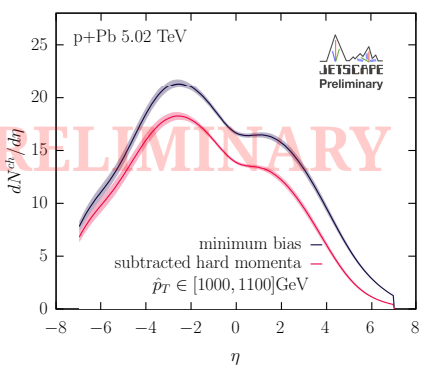
Correlation of soft-hard partons

Soft/Hard Correlation

- Soft particle production reduced in $p+p$ and $p+A$ due to the hard processes

Rapidity distribution





$\Rightarrow$ Hadronization still in development to look at the full spectrum (hard+soft)

Hard Hadron Correlation

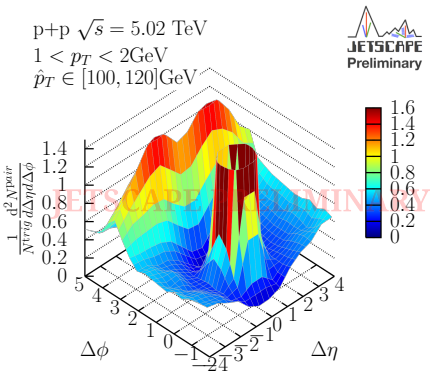
- Preliminary results of two-particle correations of the high-p_T hadrons
- Some correlation is oberserved

$$\frac{1}{N^{trig}}\frac{\mathrm{d}^2 N^{\mathrm{pair}}}{d\Delta\eta d\Delta\phi} \quad (4)$$

! Here we only consider the hadrons from the hard shower

WIP including hadrons from the soft sector

2 Particle correlations



Summary & Outlook

Summary & Outlook

- Small systems will lead to marginal jet quenching or modification
- While sizeable eleptic flow of high-p_T particles have been observed
- Understanding correlation between soft and hard particle production in small systems is crucial to understanding collectivity and jet modifications

Thank you for listening

And thanks to all collaborators !