Jet production at RHIC

In collaboration with Yang-Ting Chien, Daniel Reichelt and Steffen Schumann

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Introduction and Motivation

- The jet substructure studies allows to test fundamental predictions of QCD.
- Recently, CMS measured jet substructure for $Z + \mathrm{jet}$ and $\mathrm{jet} + \mathrm{jet}$ final states at $\sqrt{S} = 13$ TeV
- The resummed predictions for jet angularities λ_α^1 at $\mathrm{NLO} + \mathrm{NLL}'$ accuracy level are available as a plugin to SHERPA
- The RHIC experiment is now now taking data at $\sqrt{S} = 200$ GeV
- What is the difference between LHC and RHIC physics and how it will affect the jet substructure?
- We aim to use available $\mathrm{NLO} + \mathrm{NLL}'$ implementation to make pheomenological predictions for future RHIC measurements as well as impement some additional observables like angular decorrelation δ_ϕ.

The $\mathrm{NLO} + \mathrm{NLL}'$ predictios for jet angularities in the approximation of massless partons were obtained in collaboration with S. Caletti, S. Marzani, D. Reichelt, S. Schumann, G. Soyez, V. Theeuwes, see 2112.09545, 2104.06920

Introduction: CAESAR formalism

The cumulative cross section for a generic observable v can be written as a sum over partonic channels δ:

$$\Sigma_{\rm res}(v) = \sum_{\delta} \Sigma_{\rm res}^{\delta}(v)\,, \text{ with}$$

$$\Sigma_{\rm res}^{\delta}(v) = \int d\mathcal{B}_\delta \frac{d\sigma_\delta}{d\mathcal{B}_\delta} \exp\left[-\sum_{l\in\delta} R_l^{\mathcal{B}_\delta}(L)\right] \mathcal{P}^{\mathcal{B}_\delta}(L) \mathcal{S}^{\mathcal{B}_\delta}(L) \mathcal{F}^{\mathcal{B}_\delta}(L) \mathcal{H}^{\delta}(\mathcal{B}_\delta)\,,$$

where $L = -\ln(v)$, $\frac{d\sigma_\delta}{d\mathcal{B}_\delta}$ is the differential Born cross section, R_l is the collinear radiator for the hard legs l, $\mathcal{P}$ is the ratio of PDFs, $\mathcal{S}$ is the soft function, $\mathcal{F}$ is the multiple emission function and $\mathcal{H}$ stands for the corresponding kinematic cuts on the Born process. For more details on CAESAR approach, see hep-ph/0407286

For CAESAR implementation of jet angularities for $Z + jet$ and $jet + jet$ production see 2104.06920 and 2112.09545.

Observable definition

The jet angularity is defined as

$$\lambda_\alpha = \sum_{i\in\text{jet}} \frac{p_{t,i}}{p_{t,\text{jet}}} \left(\frac{\Delta R_{ij}}{R}\right)^\alpha , \quad \alpha > 0$$

The angular decorrelation is defined as

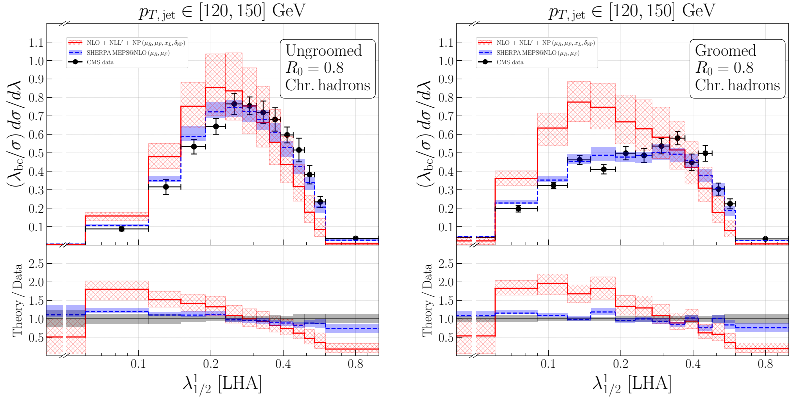
$$\Delta\phi_{\mathrm{p}_1,\mathrm{p}_2} = \text{arccos}\left(\frac{\vec{p}_1 \cdot \vec{p}_2}{|\vec{p}_1||\vec{p}_2|}\right)$$

SoftDrop grooming condition:

$$\frac{\min(p_{ti}, p_{tj})}{p_{ti} + p_{tj}} > z_{\text{cut}} \left(\frac{\Delta R_{ij}}{R}\right)^\beta$$

- The LHC measurements LHA ($\lambda_{1/2}$), Jet Width (λ_1), Jet Thrust (λ_2), see, for example, 2109.03340
- The theoretical predictions, see, for example 2112.09545, 2104.06920 and 2005.12279
- RHIC measurements?

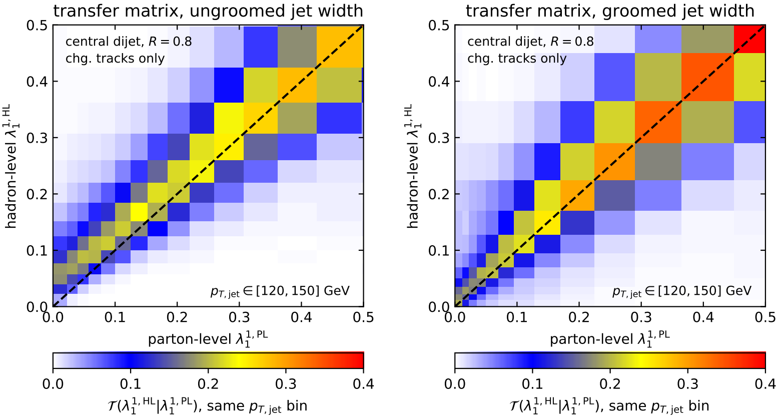
Previous results for $\lambda_\alpha = \sum_i z_i \left(\frac{\Delta_{i,jet}}{R}\right)^\alpha$



Comparison against recent CMS data for the Jet Thrust angularity, $p_{T,\mathrm{jet}} \in [120, 150]$ GeV. Magenta band correspond to transfer matrix approach.

Theory: 2112.09545, 2104.06920 (in collaboration with S. Caletti, S. Marzani, D. Reichelt, S. Schumann, G. Soyez, V. Theeuwes); CMS: 2109.03340

Parton to hadron level transition; credits G. Soyez



Transfer matrix $\mathcal{T}(\lambda_1^{1,\mathrm{HL}}|\lambda_1^{1,\mathrm{PL}})$ for the jet-width angularity for central dijet events with $R = 0.8$ and $p_{T,\mathrm{jet}} \in [120, 150]$ GeV.

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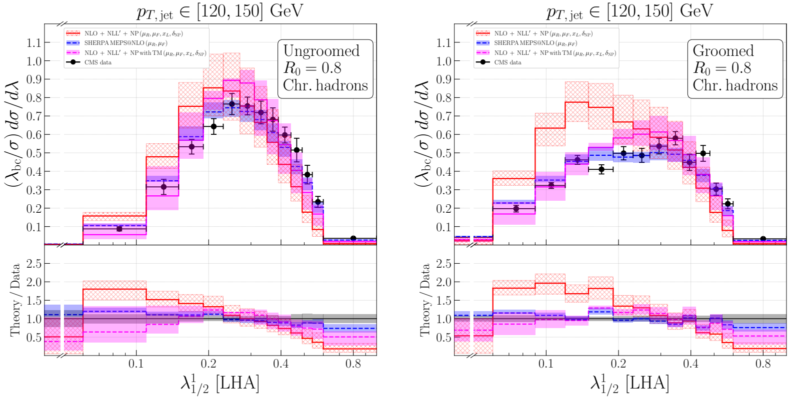

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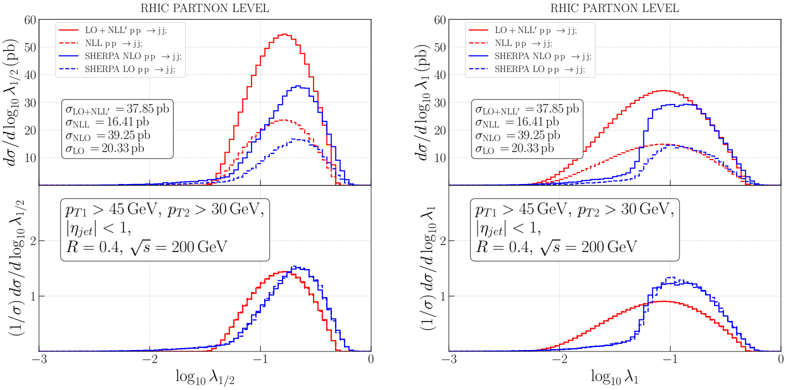
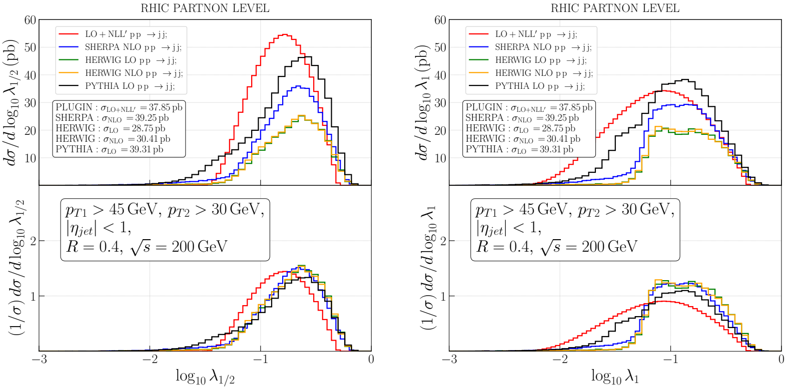
$\lambda_\alpha = \sum_i z_i \left(\frac{\Delta_{i,jet}}{R}\right)^\alpha$ at RHIC energy, SHERPA Res. + MC



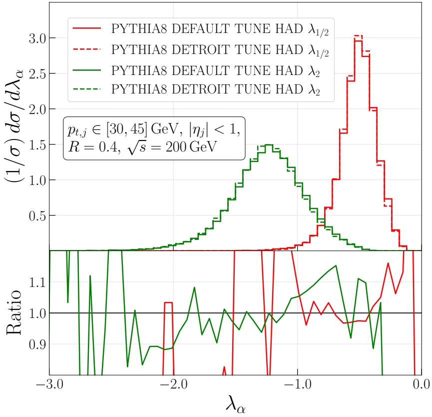
SHERPA: comparison bettween $\mathrm{LO}+\mathrm{NLL}'$ predictions, LO and NLO MC simulations. Mathcing to fixed order results and higher order corrections change cross section but do not affect shape of λ_α (preliminary).

$\lambda_\alpha = \sum_i z_i \left(\frac{\Delta_{i,jet}}{R}\right)^\alpha$ at RHIC energy, Res. vs. MC



Comparison between resummed predictions matched to fixed order results (SHERPA $\mathrm{LO} + \mathrm{NLL}'$ accuracy level) against MC simulations (preliminary)

$\lambda_\alpha = \sum_i z_i \left(\frac{\Delta_{i,jet}}{R}\right)^\alpha$ at RHIC energy, Detroit PYTHIA tune

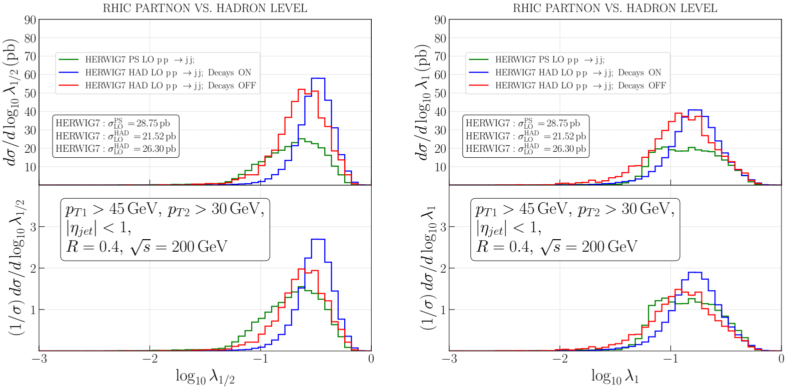


(preliminary)

Shall one make new tunes?

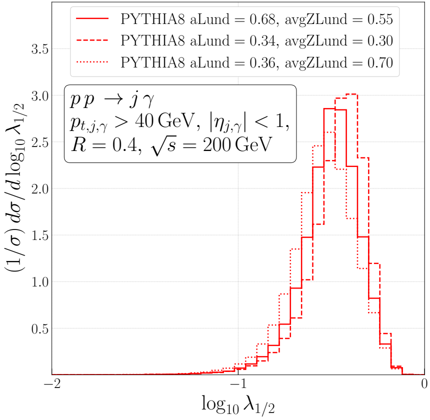
- There is a Detroit PYTHIA tune 2110.09447 for RHIC, but it mostly affect MPI
- However, MPI are almost absent at RHIC energies
- Main contribution comes from hadronization

$\lambda_\alpha = \sum_i z_i \left(\frac{\Delta_{i,jet}}{R}\right)^\alpha$ at RHIC energy, hadronisation and dacays



Angularities at RHIC energies are strongly affected by hadronization and decay of produced hadrons in case of jets containing a single hadron, see also Lee *et al* in 1901.09095. (preliminary)

Hadronization and Lund string model



(preliminary)

New tunes?

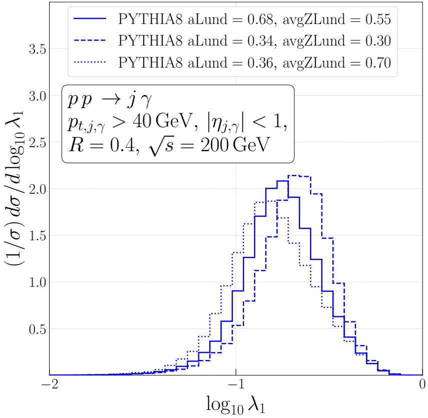
- There is a Detroit PYTHIA tune 2110.09447 designed to describe RHIC data, but it mostly affect MPI
- However, MPI are almost absent at RHIC energies $\sqrt{S}$ is too small.
- Lund symmetric fragmentation function

$$f(z) \sim \frac{(1-z)^a}{z} \exp\left(-bm^2/z\right)$$

- Hadron formation time

$$\langle \tau^2 \rangle = \frac{1+a}{b\kappa^2} \approx 2\,\mathrm{fm}$$

Hadronization and Lund string model



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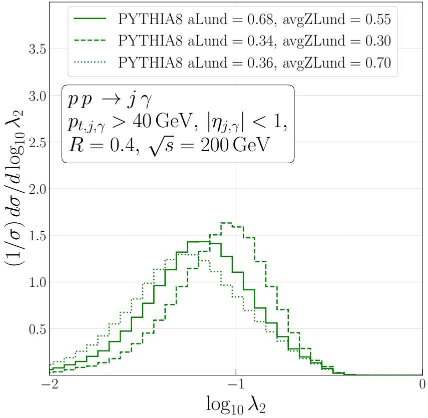

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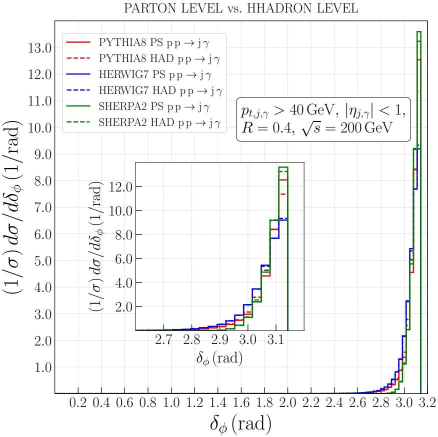
Is $\delta\phi$ affected by NP-corrections?

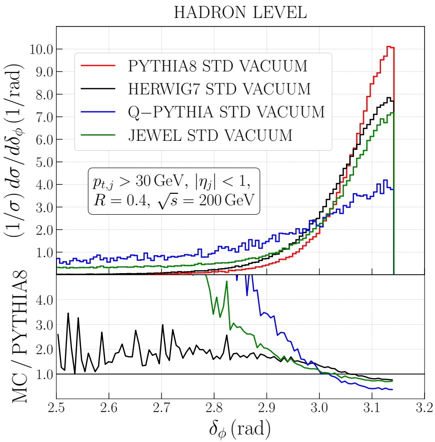


(preliminary)

Angular decorrelation

- $\Delta\phi$ is an azimthal angle between two most energetic jets (or between a leading jet and a leading photon)
- Unlike λ_α is more sensetive to radiation pattern
- Which PS-model would work better?

What about JEWEL and Q-PYTHIA without medium effects?

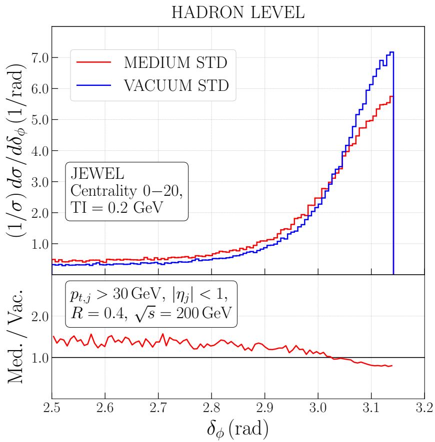


(preliminary)

Angular decorrelation

- Before studying medium effects better understanding of vaccum is needed
- Both Q-PYTHIA and JEWEL are based upon PYTHIA6 (officialy not supported any more)
- However, there is a huge distance between PYTHIA8 and PYTHIA6 (MPI, interleaved evolution, PS-model *etc*).

What is the role of medium effects?



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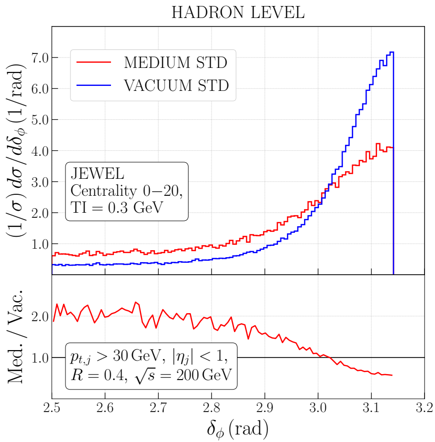

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Summary and next steps:

Current results

- Resummed predictions for both groomed and ungroomed angularities λ_α ($\alpha \in [1/2, 1, 2]$) at $\mathrm{LO} + \mathrm{NLL}'$ are ready, the $\mathrm{NLO} + \mathrm{NLL}'$ requires some more running
- We found that angularities λ_α at RHIC energies can be used to study hadronization and produce new MC tunes
- On the other hand, angular decorrelation δ_ϕ, can be used to test various parton shower models
- JEWEL and Q-PYTHIA with default parameter strongly differ from LHC MC applied to RHIC setup
- $\delta\phi$ simulated with JEWEL shows strong dependence on the medium temperature
- Correct the resummed predictions for non-perturbative effects using corresponding parton-to-hadron transition matrices
- What is the main source of the differences between Q-PYTHIA, JEWEL and LHC MC tools? What about Jetscape?
- RHIC data is needed!

Thank you for your attention!