Jet angularities for the Z+jet production at the LHC

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Introduction

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The studies of jet structure allow us:

- measure the value of the QCD coupling constant α_S
- perform efficient quark-gluon discrimination
- make high-precision tests of the Standard Model

To achieve best description one needs:

- high-precision theoretical computation at fixed order
- high-precision resummed predictions matched to the fix order results
- state-of-the-art Monte Carlo simulations
- a model for non-perturbative effects
- implementation of the obtained results into Monte Carlo tools (preferably)

We study jet angularities in Z+jet production

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The jet angularities are defined as

$$\lambda_\alpha^\kappa = \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{\sum_{j \in \text{jet}} p_{T,j}} \right)^\kappa \left(\frac{\Delta_i}{R_0} \right)^\alpha ,$$

where

$$\Delta_i = \sqrt{(y_i - y_{\text{jet}})^2 + (\phi_i - \phi_{\text{jet}})^2} ,$$

is the Euclidean azimuth-rapidity distance of particle i from the jet axis.

- The concept of infrared and collinear (IRC) safety requires $\kappa = 1$ and $\alpha > 0$.
- We consider $\lambda_{1/2}^1$ (LHA), λ_1^1 (Width) and λ_2^1 (Thrust) cases.
- For the grooming we use SoftDrop with $\beta = 0$ and $z_{\text{cut}} = 0.1$.

We study jet angularities in Z+jet production

We use the selection cuts from the preliminary CMS measurements:[2]

- We require all final state particles to have pseudo-rapidity $|\eta| < 5$
- Z-boson decays into muons. For both muon candidates we require $p_{T,\mu} > 26\ \mathrm{GeV}$, and $|\eta_\mu| < 2.4$
- The lepton pair has to pass the additional conditions $70\ \mathrm{GeV} < m_{\mu^+\mu^-} < 110\ \mathrm{GeV}$, and $p_{T,\mu^+\mu^-} > 30$ GeV
- The leading AK8 (AK4) jet has to satisfy $|y_{\text{jet}}| < 1.7$ and $p_{TJ} \in [50, 1500]$ GeV

Additionally, we impose the constraint

$$\Delta^{p_T}_{Z,\mathrm{jet}} \equiv \left| \frac{p_{T,\mathrm{jet}} - p_{T,\mu^+\mu^-}}{p_{T,\mathrm{jet}} + p_{T,\mu^+\mu^-}} \right| < 0.3\,.$$

and require the Z-boson and the leading jet to be well separated in azimuthal angle

$$\Delta^{\phi}_{Z,\mathrm{jet}} \equiv |\phi_Z - \phi_{\mathrm{jet}}| > 2\,.$$

[2] CMS-PAS-SMP-20-010

Monte Carlo result: K-factor

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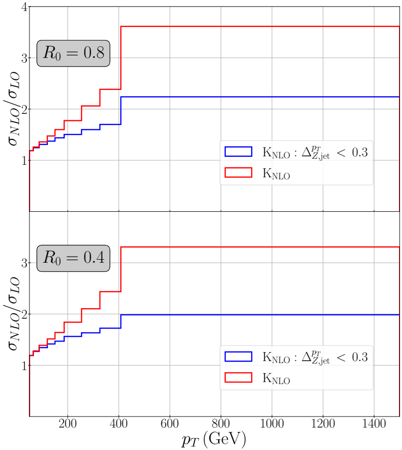

The NLO K-factor as a function of the p_{TJ} with and without $\Delta^{p_T}_{Z,\mathrm{jet}} = \left|(p_{T,\mathrm{jet}} - p_{T,\mu^+\mu^-})/(p_{T,\mathrm{jet}} + p_{T,\mu^+\mu^-})\right| < 0.3$ cut.

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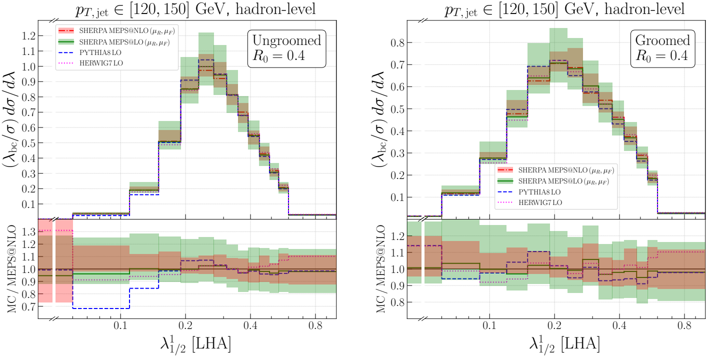
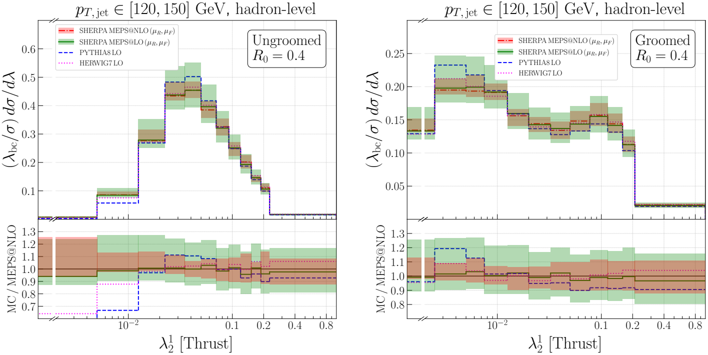


Comparison of hadron-level predictions for ungroomed and groomed jet-angularities in Zj production from Pythia and Herwig (both based on the LO Zj matrix element), and MEPS@LO as well as MEPS@NLO results from Sherpa. Here we use SoftDrop with $\beta = 0$ and $z_{\text{cut}} = 0.1$.

Monte Carlo results: Thrust



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Impact of NP-corrections

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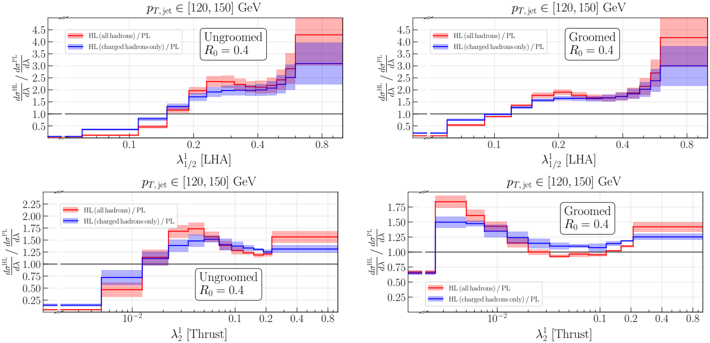
One can estimate the impact of non-perturbative corrections using Monte Carlo simulations



Hadron-to-parton-level ratios with associated uncertainties extracted from MC simulations (Pythia, Herwig and Sherpa).

CAESAR formalism

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

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

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

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.

CAESAR resummation plugin to Sherpa

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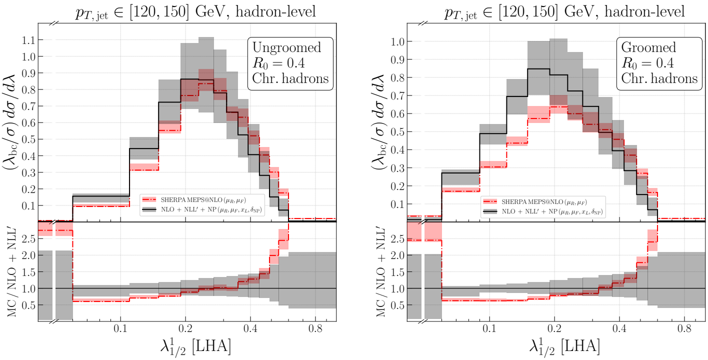
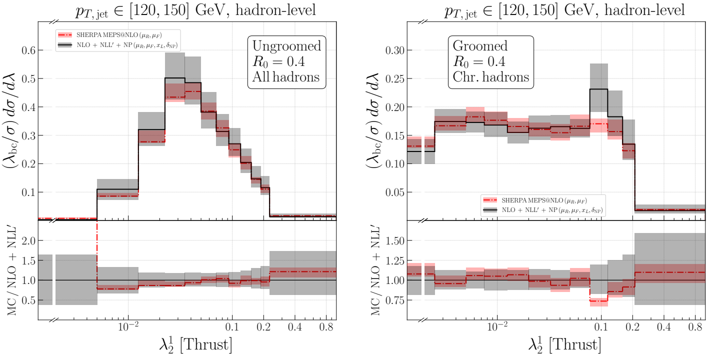
- Is using Comix matrix element generator as well as Sherpa machinery for phase-space integration and event generation
- The NLO computations are performed using Catani-Seymour dipole subtraction
- For the loop computations we use Recola and OpenLoops libraries
- The resummed results are matched to the fixed order NLO computations using the multiplicative matching scheme
- The final result is at NLO+NLL$'$ accuracy level + corrections for the non-perturbative effects

Final results: LHA



Comparison of hadron-level MEPS@NLO Sherpa results against NLO+NLL′+NP resummation. Here we use SoftDrop with $\beta = 0$ and $z_{\text{cut}} = 0.1$.

Final results: Thrust



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Theory vs. data (CMS-PAS-SMP-20-010)[3]

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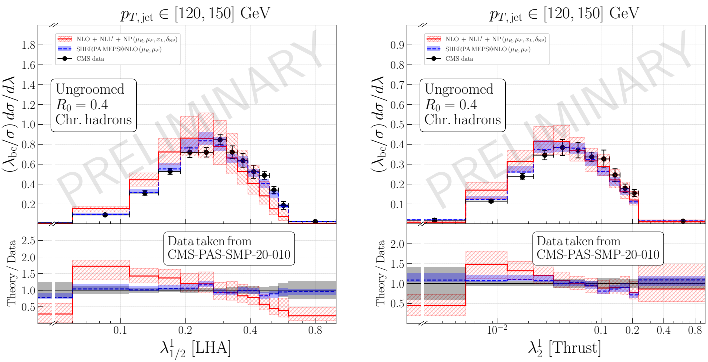

Comparison against preliminary CMS data. Also see the talk of Andreas Hinzmann and Benjamin Nachman at CERN-TH workshop: "Jets and their substructure from LHC data"

[3] See https://cds.cern.ch/record/2759616?ln=en

Summary

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- We performed computation of the ungroomed and groomed angularities for Z+jet production @ NLO+NLL$'$ accuracy level
- Our results are implemented in the resumation plugin to Sherpa (which is automated!) and can be easily applied for acceptance cuts different from the ones used by CMS
- Our study show the necessity to use state-of-the art Monte Carlo to describe jet substructure
- More detailed comparison against experimental data is coming soon
- Strong dependence on the non-perturbative effects at the low values of λ opens perspectives for tuning of Monte Carlo event generators