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Publication date
2015

Document Version
Final published version

Published in
Proceedings of the 6th International Workshop on Multiple Partonic Interactions at the LHC: MPI@LHC 2014

Proceedings of the

6th International Workshop on
Multiple Partonic Interactions at the LHC

MPI@LHC 2014

3-7 November, 2014
Kraków, Poland

Dissecting Soft Radiation with Factorization

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The modeling of soft hadronic activity at the LHC relies heavily on Monte Carlo programs. We scrutinize their theoretical basis, using field theory (specifically factorization) to quantify the effect of perturbative and nonperturbative primary soft radiation. This is motivated by the ambiguity between these effects and multiple parton interactions (MPI) in underlying event measurements. We compare our predictions to Pythia 8 and Herwig++ 2.7.

Instead of looking at the regions away from hard jets, we directly study the effect of various sources of soft hadronic activity on the jet invariant mass m_J, which is a benchmark observable at the LHC. We show how these sources can be separated by exploiting their different dependence on the jet radius R, jet momentum p_T^J, jet rapidity y_J, and partonic scattering process [1].

The *normalized* jet mass spectrum in $pp \to Z$+1-jet and $pp \to H$+1-jet events is given by [2]

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}m_J^2} \simeq \int \mathrm{d}k_S\, J_{\kappa_J}(m_J^2 - 2p_T^J k_S)\, S_\kappa(k_S, y_J, R)\,. \qquad (2)$$

Here, $\kappa = \{\kappa_a, \kappa_b, \kappa_J\}$ denotes the partonic channel, and k_S is the contribution of soft radiation to the jet mass measurement. The jet function J_{κ_J} describes energetic final-state radiation and the soft function S_κ initial and final-state soft radiation. Eq. (2) does not include MPI.

The soft function S_κ is sensitive to perturbative effects S_κ^{pert} and nonperturbative effects F_κ, which can be factorized $S_\kappa = S_\kappa^{\mathrm{pert}} \otimes F_\kappa$ [3]. In the tail of the jet mass spectrum, $k_S \gg \Lambda_{\mathrm{QCD}}$, S_κ can be expanded, $S_\kappa(k_S, y_J, R) = S_\kappa^{\mathrm{pert}}\big(k_S - \Omega_\kappa(R), y_J, R\big)$. The resulting shift of the jet mass $m_J^2 = (m_J^2)^{\mathrm{pert}} + 2p_T^J\,\Omega_\kappa(R)$ agrees with Pythia, as shown in the left panel of Fig. 11.

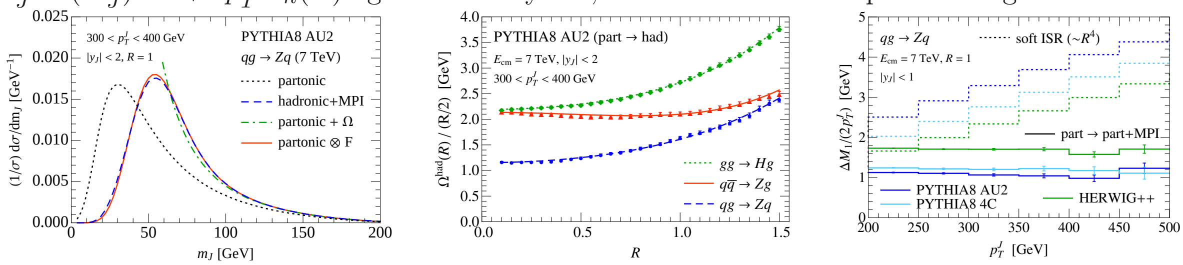

Figure 11: *Left:* The change in Pythia's jet mass spectrum from partonic to hadronic+MPI is described by a shift in the tail, and a simple convolution everywhere. *Center:* The R dependence of hadronization in Pythia agrees with factorization: it fits odd powers of R and for $R \ll 1$ only depends on whether the jet is initiated by a quark or gluon. *Right:* p_T^J dependence of the $\sim R^4$ contributions to the jet mass in Pythia and Herwig from MPI and soft ISR for $qg \to Zq$.

The field-theoretic definition of the nonperturbative parameter Ω_κ allows us to show that it is independent of y_J, only involves odd powers of R, and that the linear R term differs between quark and gluon jets but does not depend on the full partonic process [1]. Thus MPI cannot be part of $\Omega_\kappa(R)$ because they scale like R^4. Hadronization in Pythia agrees very well with our predictions for Ω_κ, as shown for the R dependence in the middle panel of Fig. 11.

The perturbative soft function contains a interference contribution from initial-state radiation (ISR) that scales like R^4 [1]. Current tunes do not address its potential degeneracy with MPI. As the right panel in Fig. 11 shows, these R^4 contributions differ much more between tunes than their sum, and can be separated by exploiting their different p_T^J and channel dependence.

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