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Proceedings of the  
**6<sup>th</sup> International Workshop on  
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# 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  $pp \rightarrow Z+1\text{-jet}$  and  $pp \rightarrow H+1\text{-jet}$  events is given by [2]

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

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  $J_{\kappa_J}$  describes energetic final-state radiation and the soft function  $S_{\kappa}$  initial and final-state soft radiation. Eq. (2) does not include MPI.

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

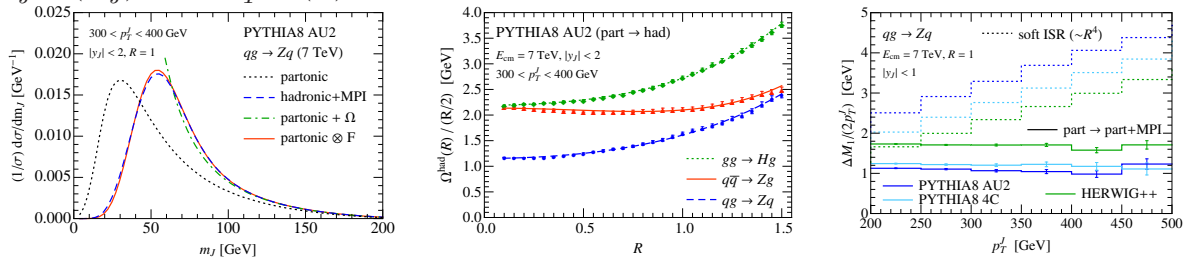


Figure 11: *Left:* The change in Pythia’s jet mass spectrum from partonic to hadronic+MPI is described by a shift in the tail, and a simple convolution everywhere. *Center:* The  $R$  dependence of hadronization in Pythia agrees with factorization: it fits odd powers of  $R$  and for  $R \ll 1$  only 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  $qg \rightarrow Zq$ .

The field-theoretic definition of the nonperturbative parameter  $\Omega_{\kappa}$  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  $\Omega_{\kappa}$ , 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.

## References

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