AUTOMATED RESUMMATION OF JET OBSERVABLES IN QCD*

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We build a computer code that fully automates the resummation of jet-observable distributions at next-to-leading logarithmic accuracy. As an application we present results for a jet shape in hadronic dijet production.

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1. Introduction

Understanding the physics of event shapes and jet rates (collectively *jet observables*) requires a deep knowledge of QCD dynamics. Their distributions (defined as the fraction of events $\Sigma(v)$ with the observable's value V less than v) explore a wide range of physical scales, from the more inclusive region $v = \mathcal{O}(1)$, well described by fixed order perturbative (PT) calculations, to the extreme exclusive region $v \to 0$ where the language of quarks and gluons is no longer applicable. Describing the intermediate region requires a resummation of logarithmic enhanced contributions that appear at all orders in the PT expansion [1]. Resummation can then be seen as the link between PT and NP physics. Given that interest, a number of event shapes have been introduced, and for most of them there exist both next-to-leading order (NLO) calculations as well as resummed predictions at next to-leading logarithmic (NLL) accuracy.

Unfortunately, while it is straightforward to compute a NLO distribution by just interfacing a fixed order Monte Carlo program with the observable definition in the form of a computer routine, for what concerns resummation a separate analytic calculation has to be performed for each observable.

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Together with Gavin Salam and Giulia Zanderighi we started then a project whose goal is the construction of a computer code that takes as input from the user the definition of an observable and returns its resummed distribution at NLL accuracy. The starting point of such a programme is the classification of LL and NLL effects.

2. Automated resummation

Consider a Born system consisting of n hard partons (*legs*) $\{p_i\}_{i=1,\dots,n}$ and an observable V that vanishes in the Born limit, *i.e.* $V(\{p\}) = 0$.

For most jet observables LL contributions can be addressed by computing $\Sigma(v)$ when a single soft gluon collinear to the hard legs is emitted and exponentiating the result.

For any of these *exponentiating* quantities, NL logarithms can have different origins:

- emission of gluons soft at large angles or hard and collinear. Such contributions can be resummed by exponentiating the single emission result for $\Sigma(v)$;

- *multiple emission* effects, which originate when, given a set of emitted partons $\{k_i\}$, all $V(k_i) < v$ but $V(\{k_i\}) > v$ (or vice versa), so that one has to take into account how all emissions contribute to build up the observable's value;

- *non-global* logarithms [2], that arise whenever V is sensitive to emissions only in a part of the phase space. Unfortunately such NLL contributions are known only in the large N_c limit, thus reducing the accuracy of resummed predictions for non-global observables.

Given the above classification we restrict ourselves to exponentiating global observables. Under the additional hypothesis that, after a soft emission collinear to leg ℓ, the observable's dependence on the emitted transverse momentum k_t, rapidity η and azimuthal angle ϕ (all with respect to ℓ) obeys the following parametrisation

$$V(k) = d_\ell \left(\frac{k_t}{Q}\right)^{a_\ell} \mathrm{e}^{-b_\ell \eta} g_\ell(\phi) \,, \tag{1}$$

at NLL accuracy $\Sigma(v)$ is given by the master formula [3]

$$\Sigma(v) = \mathrm{e}^{-R(v)} \mathcal{F}(R'(v)) \,, \qquad R'(v) = -v \frac{dR(v)}{dv} \,. \tag{2}$$

Here $R(v)$ embodies all LL contributions and the NLL contributions that can be taken into account by exponentiating the single emission result. This function, computed analytically, depends parametrically on a_ℓ, b_ℓ, d_ℓ as well as on the azimuthal average $\langle \ln g_\ell(\phi) \rangle$.

The NLL function $\mathcal{F}(R')$ represents the multiple emission correction factor. Its general expression is [4]

$$\mathcal{F}(R') = \left\langle \exp\left\{ -R' \ln \frac{V(k_1,\ldots,k_n)}{\max\{V(k_1),\ldots,V(k_n)\}} \right\} \right\rangle , \tag{3}$$

where the average is taken over all configuration of soft and collinear gluons such that, for fixed R', the probability density of emissions along leg ℓ is constant (the actual value of the constant depends on R' and on the colour factors of the hard legs, see [3]).

Although the above procedure is rather complicated, we were able to embody it a computer code, CAESAR, that completely automates the resummation of any exponentiating global jet-observable [3].

3. Event-shapes in hadronic dijet production

Let us show how the program works in the specific case of an event shape in hadronic dijet production. Given a unit vector $\vec{n}$ orthogonal to the beam axis we define the global transverse thrust:

$$\tau_{t,g} = 1 - \max_{\vec{n}} \frac{\sum_i |\vec{p}_{ti} \cdot \vec{n}|}{\sum_i |\vec{p}_{ti}|} , \tag{4}$$

where $\vec{p}_{ti}$ are the final state transverse momenta with respect to the beam.

The program chooses a reference Born event with two incoming and two outgoing hard partons and generates soft and collinear emissions. It first checks that a resummation in the $(2+2)$-jet limit is feasible and that the observable is global. It then verifies that the parametrisation (1) holds and determines for each leg a_ℓ, b_ℓ, d_ℓ. It recognises also whether $g_\ell(\phi) = |\sin\phi|^{c_\ell}$, with c_ℓ integer, otherwise tabulates the azimuthal dependence. The program then should determine whether the observable exponentiates and compute the function $\mathcal{F}(R')$ via a Monte Carlo procedure [4]. In this case it recognises that $\tau_{t,g}$ is additive, that is $V(k_1,\ldots,k_n) = V(k_1) + \cdots + V(k_n)$, which allows us to skip all the subsequent steps, since for additive observables exponentiation holds and $\mathcal{F}(R') = \mathrm{e}^{-\gamma_E R'}/\Gamma(1+R')$ [1].

These results are automatically tabulated (see Fig. 1), and used as inputs for the master formula (2) to compute the NLL resummed $\tau_{t,g}$ distribution. In Fig. 1 we see the differential distribution $D(\tau_{t,g}) = d\Sigma(\tau_{t,g})/d\ln\tau_{t,g}$ at the Tevatron run II c.o.m. energy $\sqrt{s} = 1.96$ TeV corresponding to selected dijets with $E_t > 50$ GeV and $|\eta| < 1$. We use the CTEQ6M pdf set [5] and set factorisation and renormalisation scales at the partonic c.o.m. energy. The plot shows a clean separation among the various partonic channels, information that can be exploited for fits of the parton densities.

Test	result
check number of jets	T
globalness	T
additivity	T
exponentiation	T

ℓ	a_ℓ	b_ℓ	$g_\ell(\phi)$	d_ℓ
1	1	0	tabulated	1.02062
2	1	0	tabulated	1.02062
3	1	1	$\sin^2\phi$	1.04167
4	1	1	$\sin^2\phi$	1.04167

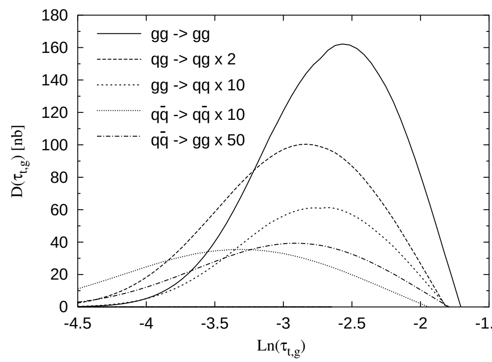

Fig. 1. A sample output of CAESAR: the results of the observable analysis (left) and the resummed distribution at NLL accuracy (right) for the global transverse thrust. The analysis has been performed with a reference Born configuration with the two outgoing partons back-to-back at an angle $\cos\theta = 0.2$ with respect to the beam. The final result does not depend on the chosen configuration, as the program can check automatically.

4. Conclusions and outlook

The main feature of our approach is that the output curves are pure NLL functions, without contamination with spurious subleading contributions, so that they can be straightforwardly matched with fixed order results, and any hadronisation model can be applied. At present our effort is concentrated in releasing the first version of the program. The next step will be including in the code an automated matching with NLO calculations [6], which will open the way to a vast amount of phenomenological analyses.

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REFERENCES

[1] S. Catani, L. Trentadue, G. Turnock, B.R. Webber, *Nucl. Phys.* **B407**, 3 (1993).

[2] M. Dasgupta, G.P. Salam, *Phys. Lett.* **B512**, 323 (2001).

[3] A. Banfi, G.P. Salam, G. Zanderighi, `hep-ph/0304148` and in preparation.

[4] A. Banfi, G.P. Salam, G. Zanderighi, *J. High Energy Phys.* **0201**, 018 (2002).

[5] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P. Nadolsky, W.K. Tung, *J. High Energy Phys.* **0207**, 012 (2002).

[6] Z. Nagy, *Phys. Rev.* **D68**, 094002 (2003).