Jet Observables at NNLL Accuracy

Fourth NExT Workshop, University of Southampton

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25.06.2014

Event shapes are collider observables measuring the geometric properties of energy-momentum flow in an event.

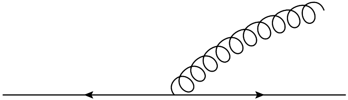
These observables allow for

- precision tests of QCD
- determination of the strong coupling, α_s
- insight into fundamental quark-gluon interactions

For example, **thrust** in e^+e^- annihilation
For dijet events:

two back-to-back particles, $\tau = 0$

In reality, soft and/or collinear gluon emission will occur, resulting in a value for the thrust $\tau \approx 0$:

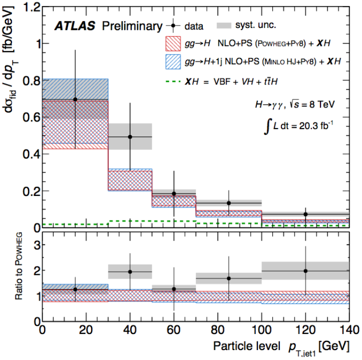


the quasi back-to-back region: a pair of hard quarks emit a soft/collinear gluon

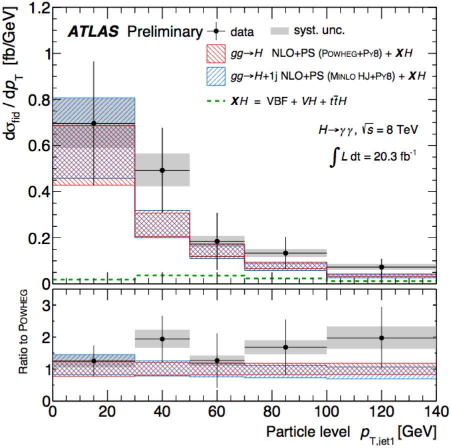
This is the region in which most events lie, and so the region in which we are interested.

Event shape distributions are observables which exhibit two widely separated kinematic scales.

An example from hadron-hadron collisions is the production of a heavy boson with additional jets - involving the mass of the boson and the jet transverse momentum.



(ATLAS-CONF-2013-072) Observed differential cross sections of the Higgs boson decaying into two isolated photons, for leading jet p_T.



The relevant event shape here is $\frac{p_{T,\text{jet1}}}{m_H}$.

Most events lie in the region $p_{T,\text{jet1}} \ll m_H$, i.e. the zero-jet cross section.

Logarithms of the ratio of the two scales, $v = \frac{Q_1}{Q_2}$,modify the effective coupling away from the usual α_s.

When $v \to 0$, the logarithms become large.

These large logs originate from soft and/or collinear gluon emission:

$$\sigma \propto \alpha_s \int_v \frac{dk_t}{k_t} \int_v \frac{d\theta}{\theta} = \alpha_s \log^2 \left(\frac{1}{v}\right)$$

$\alpha_s log(\frac{1}{v}) \approx 1$ is no longer a perturbative expansion parameter.

To restore calculability, we rearrange the series and resum it to all orders in α_s:

$$1+\alpha_s+\alpha_s^2+\alpha_s^3+\cdots\rightarrow$$

$$1+(\alpha_s L+\alpha_s L^2)+(\alpha_s^2 L+\alpha_s^2 L^2+\alpha_s^2 L^3+\cdots)+(\alpha_s^3 L+\alpha_s^3 L^2+\alpha_s^3 L^3\cdots)+\cdots$$

$$=e^{Lg_1(\alpha_s L)}(G_2(\alpha_s L)+\alpha_s G_3(\alpha_s L)+\alpha_s^2 G_4(\alpha_s L)+\cdots)$$

$$=e^L(1+\alpha_s+\alpha_s^2+\alpha_s^3+\cdots)$$

$$(L\equiv log(\tfrac{1}{v}))$$

g_1 resums all of the leading logarithmic terms (LL); G_2 the next-to-leading terms (NLL), and so on.

CAESAR (Computer Automated Semi-Analytical Resummer) [1] is a program which encodes the principles to perform NLL resummation.

Applicable for a generic observable in a range of processes:
$e^+e^- \to$ 2jets, $e^+e^- \to$ 3jets, hadron-hadron 2+2jets, and more.

The generic observable takes a **characteristic form** for events with soft/collinear emissions.

The observable in question must behave when emissions occur on **widely disparate scales**.

[1] Banfi, Salam, Zanderighi, arXiv:0407286v2

For an observable conforming to the CAESAR ‘simple observable’, its resummation has the following form:

$$f(v) = \exp\left(-\int_v [dk]|M^2(k)|\right)\mathcal{F}(R')$$

The Sudakov form factor, containing all the virtual corrections as double logs (a LL contribution).

The $\mathcal{F}$ function, containing single logs coming from real emissions that are widely separated in rapidity and independent from one another (an NLL contribution).

($R' = \alpha_s \log(\frac{1}{v})$ is the effective coupling)

NNLL resummation of event shapes is necessary:

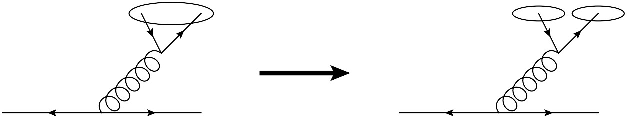
(in e^+e^- processes) to gain a **measurement of** α_s at ‰ level accuracy;

(in hadronic processes) to allow **uncertainty in theoretical predictions to match experimental uncertainty**.

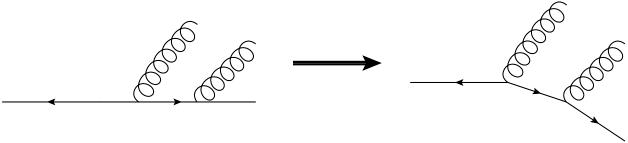
Start with the simplest case: well-understood event shapes in $e^+e^- \rightarrow$ 2jets.

New contributions to the $\mathcal{F}$ function at NNLL:

- emissions no longer widely separated in **rapidity** as they were at NLL
- **correlated** emissions: daughter emissions end up in different jets



- **recoil** corrections: proper treatment of recoil to hard partons



- treatment of one emission exactly (hard collinear; soft wide-angle)

General numerical method:

- Generate, using a Monte Carlo code, an arbitrary number of emissions
- Assign these emissions random kinematic values (k_t, η, ϕ)
- Feed the emissions into each correction procedure
- Manipulate the solution so it only contains terms of our desired logarithmic accuracy

y_{23} in e^+e^- annihilation

Jet algorithms are theoretical methods used to build the jets of hadrons seen at colliders, from the parton level.

General idea (sequential algorithm) :

- Cycle through pairs of particles
- Combine if they are closer than any other pair
- Also need to be smaller than the resolution parameter, y_{cut}

y_{23} is the value of y_{cut} for which a 2-jet event becomes a 3-jet event; the threshold value.

The 3-jet resolution parameter, y_{23} is an important observable to study:

It is almost free from hadronisation effects; the calculation using quarks and gluons will closely match the experimental result;

It provides one of the most precise determinations of α_s.

Resummation of event shapes in e^+e^- annihilation also provides a basis structure of calculations and computer code.

Build on this structure to implement NNLL resummation to jet rates in e^+e^- annihilation (also require clustering corrections);

Implement NNLL resummation to a range of hadronic processes (requiring treatment of initial-state radiation).

References:

[1] Banfi, Salam, Zanderighi, Principles of general final-state resummation and automated implementation, *JHEP* 0503 (2005) 073

[2] Catani, Trentadue, Turnock, Webber, Resummation of large logarithms in e+e- event shape distributions, *Nucl. Phys. B* 407 (1993) 3

[3] Salam, Towards jetography, *Eur. Phys. J.* C67 (2010) 637-686

[4] Banfi, Salam, Zanderighi, Semi-numerical resummation of event shapes, *JHEP* 0201 (2002) 018