Resummed Results for Hadron Collider Observables

Heather McAslan, University of Sussex

ISMD 2015, Wildbad Kreuth - 05.10.15

University of Sussex

Event Shapes

Measures of the hadronic energy-momentum flow of the final states particles in an event.
Used in e^+e^- annihilation, *h*-*h* collisions, and DIS, +more.

They allow for:
Determination of the strong coupling α_s.

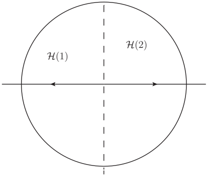
Tuning of Monte Carlo generators.

+ they are among the simplest observables to work with.

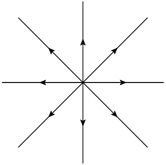
e^+e^- **Thrust**

$$\tau \equiv 1 - \max_{\vec{n}} \frac{\sum_i |\vec{p_i} \cdot \vec{n}|}{Q} \ ,$$

where the vector $\vec{n}$ maximised by the sum defines the thrust axis, $\vec{n}_T$.



$\tau = 0$



$\tau = 1$

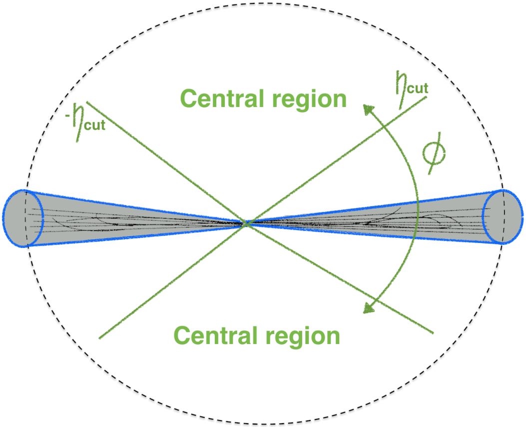
e^+e^- **Broadening**

$$B_T \equiv B_L + B_R,$$

$$B_L \equiv \sum_{i \in \mathcal{H}^{(1)}} \frac{|\vec{p_i} \times \vec{n_T}|}{2Q}, \quad B_R \equiv \sum_{i \in \mathcal{H}^{(2)}} \frac{|\vec{p_i} \times \vec{n_T}|}{2Q}.$$

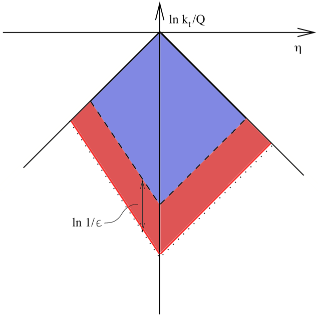
Globalness Issues in *h*-*h* Collisions

Experimentally, focus on the central region:
Make the most of information from detectors in this region.

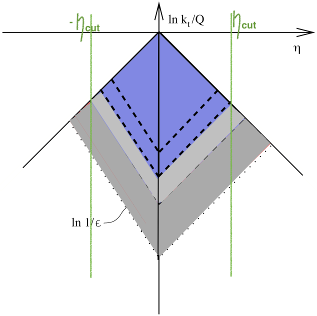


Globalness

Theoretically, want to avoid cutting on regions of phase space: this leads to non-global logs which pose difficulties to resummation.



Region of phase-space integration



Region is encroached upon by η_{cut}

Non-Global Logarithms

Recent progress:

Y. Hatta and T. Ueda, Nucl.Phys. B874 (2013) 808820, [hep-ph/1304.6930]
K. Khelifa-Kerfa and Y. Delenda, [hep-ph/1501.0047]
A. J. Larkoski, I. Moult, D. Neill, JHEP 1509 (2015) 143, [hep-ph/1501.04596]

Ways to get around the problem:

Enforcing measurement in the non-central regions suppresses non-global effects.

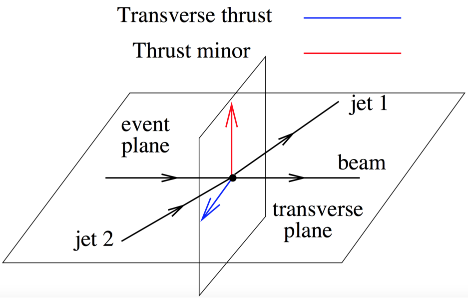
Q: How well can we measure be controlled in the forward/backward regions?
This would allow for globalness in the measurements.

Hadronic Event Shapes

Event shapes analogous to those defined for e^+e^- annihilation, but for use at hadron colliders. [1]

Measure in the transverse plane, for boost invariance.

$T_\perp \equiv \max_{\vec{n_T}} \frac{\sum_i |\vec{p}_{\perp i} \cdot \vec{n_T}|}{\sum_i |\vec{p}_{\perp i}|}$



[1] A. Banfi, G. P. Salam and G. Zanderighi, JHEP 0408 (2004) 62 [hep-ph/0407287]

Hadronic Event Shapes (in the central region)

$$T_{\perp} \equiv \max_{\vec{n_T}} \frac{\sum_i |\vec{p}_{\perp i} \cdot \vec{n_T}|}{\sum_i |\vec{p}_{\perp i}|} \ , \quad T_m \ \frac{\sum_i |\vec{p}_{\perp i} \times \vec{n_T}|}{\sum_i |\vec{p}_{\perp i}|} \ ,$$

$$B_T \equiv \frac{1}{2P_{\perp}^2} \left(\sum_{i \in \mathcal{C}^{(1)}} p_{\perp i} \sqrt{(\Delta\eta_{1,i})^2 + (\Delta\phi_{1,i})^2} + \sum_{i \in \mathcal{C}^{(2)}} p_{\perp i} \sqrt{(\Delta\eta_{2,i})^2 + (\Delta\phi_{2,i})^2} \right)$$

$$y_{23} = \frac{1}{P_{12,\perp}^2} \min \left(p_{3,\perp}^2, \min(p_{\perp,i}, p_{\perp,j}) \frac{\Delta R_{ij}^2}{R^2} \right)$$

Away From the Central Region

Supplement the observable with a piece sensitive to outside the central region. [2]

$$\eta_{\mathcal{C}} = \frac{1}{Q_{\perp,\mathcal{C}}} \sum_{i \in \mathcal{C}} p_{\perp i} \eta_i \,,$$

where

$$\varepsilon_{\bar{\mathcal{C}}} = \frac{1}{Q_{\perp,\mathcal{C}}} \sum_{i \notin \mathcal{C}} p_{\perp i} e^{-|\eta_i - \eta_{\mathcal{C}}|}$$

Then

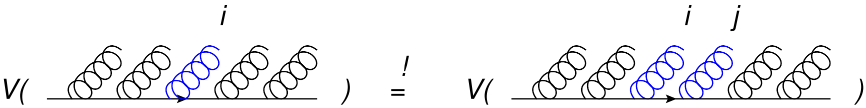
$$\tau_{\perp,\varepsilon} \equiv 1 - T_{\perp,\varepsilon} \equiv \tau_{\perp} + \varepsilon_{\bar{\mathcal{C}}}$$

N.B: '$i \in (\notin)\mathcal{C}$' can be replaced by 'anti-k_t jet $\in (\notin)\mathcal{C}$', for example.

[2] A. Banfi, G. P. Salam, G. Zanderighi, JHEP 1006 (2010) 038, [hep-ph/1001.4082]

IRC Safety

Event shapes are infra-red and collinear (IRC) safe.



Hence they are calculable via a perturbation expansion in the strong coupling, α_s.

$$\Sigma(v) = \frac{1}{\sigma}\int_0^v dv' \frac{d\sigma(v')}{dv'} = \Sigma_0(v) + \Sigma_1(v)\alpha_s + \Sigma_2(v)\alpha_s^2 + \cdots$$

But...

When the QCD radiation is constrained, remnant logarithms from the cancellation of real and virtual singularities dominate.

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

Each power of α_s is accompanied by up to two of these kinematic logarithms.

When this is the case, $\alpha_s \ln(\frac{1}{v}) \approx 1$, and 'leading' and 'higher-order' corrections become comparable.

Resummation

We re-order the series in terms of these dominant logs and resum to all orders in α_s.

Current state-of-the-art resummation for event shapes:

Generic event shapes to NLL order: CAESAR [3]
Transverse thrust (NNLL) using Soft Collinear Effective Theory (SCET). [4]
Beam thrust (NNLL) (SCET) [5]

N-jettiness (NNLL) (SCET) [6]

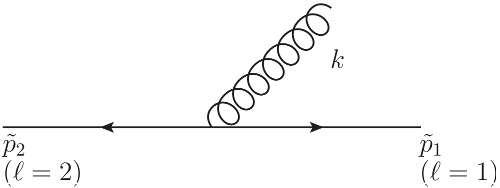
[3] A. Banfi, G. P. Salam and G. Zanderighi, JHEP 0503 (2005) 073 [hep-ph/0407286]
[4] T. Becher and X. G. i Tormo, JHEP 1506 (2015) 71 [hep-ph/1502.04136]
[5] I. W. Stewart, F. J. Tackmann, and W. J. Waalewijn, Phys. Rev. Lett. 106 (032001), [hep-ph/1005.4060]
[6] I. W. Stewart, F. J. Tackmann, and W. J. Waalewijn, Phys. Rev. Lett. 105, (092002) , [hep-ph/1004.2489]

Computer Automated Semi-Analytical Resummer

Generic observable:

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

($a = b_\ell = 1$ for thrust-type observables, and $a = 1, b_\ell = 0$ for broadening-type.)

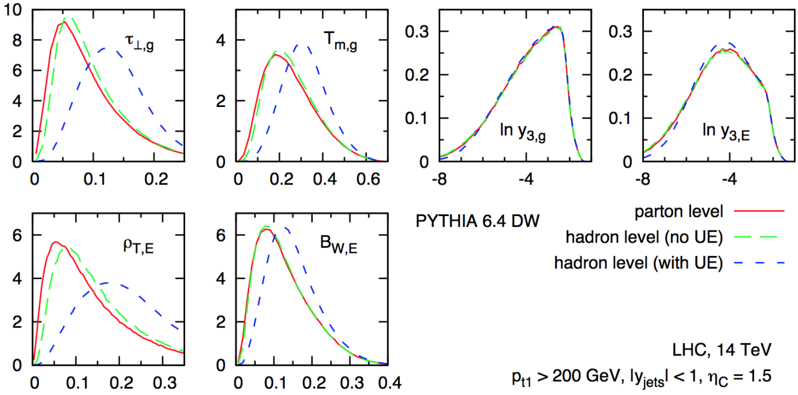


Further Requirements

CAESAR specifically requires that the observable being resummed satisfies:

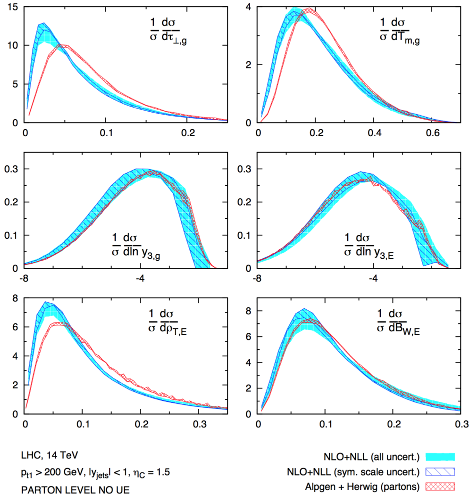
‘continuous globalness’
‘recursive infra-red and collinear (rIRC) safety’

These stipulate how the observable parametrisation must behave upon emission of several soft and collinear partons, and is **satisfied by event shapes** and jet rates.



Comparison of the effect of underlying event on different observables.
$\tau_\perp$ is significantly affected by UE, whereas y_{23} is very insensitive.

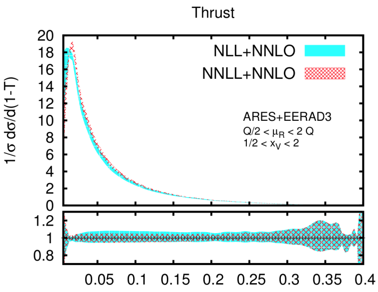
A. Banfi, G. P. Salam, G. Zanderighi, JHEP 1006 (2010) 038, [hep-ph/1001.4082]



Comparison of the resummation to different parton shower results

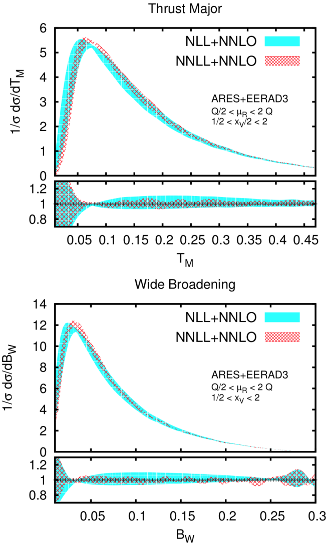
A. Banfi, G. P. Salam, G. Zanderighi, JHEP 1006 (2010) 038, [hep-ph/1001.4082]

In ARES [6] we have resummed generic event shapes to NNLL accuracy in e^+e^- using the method of CAESAR.



Reduction of scale uncertainties in going from NLL to NNLL.

[6] A. Banfi, HM, P. F. Monni, G. Zanderighi, JHEP 1505 (2015) 102, [hep-ph/1412.2126]


Thrust Major
NLL+NNLO
NNLL+NNLO
ARES+EERAD3
Q/2 < μR < 2 Q
1/2 < xV/2 < 2
1/σ dσ/dTM
TM
C parameter
ARES+EERAD3
Q/2 < μR < 2 Q
1/2 < xV/6 < 2
1/σ dσ/dC
C
Wide Broadening
ARES+EERAD3
Q/2 < μR < 2 Q
1/2 < xV < 2
1/σ dσ/dBW
BW
Total Broadening
ARES+EERAD3
Q/2 < μR < 2 Q
1/2 < xV < 2
1/σ dσ/dBT
BT

Hadronic event shapes in ARES

Event shapes from e^+e^- are analogous to hadronic event shapes: we can use the same techniques to resum them

Transverse thrust $\rightarrow$ Thrust in e^+e^- + beam thrust

Thrust minor $\rightarrow$ Thrust minor in e^+e^- + beam thrust

Jet broadening $\rightarrow$ Jet broadening in e^+e^- + beam thrust

$y_{23} \rightarrow y_{23}$ in e^+e^- + jet-veto

Jet rates in ARES

Jet rates have the advantage of insensitivity to non-perturbative (hadronisation) effects.

The three-jet resolution parameter has been resummed to NLL in e^+e^- using CAESAR.

Jet algorithms render this calculation sensitive to the rapidity of the particles, and the order of recombination, unlike with event shapes.

Current work on jet rates in ARES: this step will soon allow dealing with resummation of jet rates at hadronic colliders.