CKKW at NLO

Leif Lönnblad

Department of Astronomy
and Theoretical Physics
Lund University

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Introduction

- CKKW-L
- K-factors and $\bar{B}$
- Multi-jet merging to NLO

CKKW-L

Starting from Stefan's talk. . .

Take eg. W events generated with one extra parton using the *inclusive* $|\mathcal{M}_1|^2$, cut off at some merging scale, ρ_{MS}.

We make it *exclusive* by multiplying with Sudakov form factors and no-emission probabilities and get

$$x_1 f_1(x_1, \mu_F)\,|\mathcal{M}_1|^2\,\alpha_s(\mu_R)$$
$$\times \left[w_{\text{path}} \frac{\bar{\alpha}(\rho_1)}{\alpha_s(\mu_R)} \frac{x_0 f_0(x_0, \rho_F)}{x_1 f_1(x_1, \mu_F)} \frac{x_1 f_1(x_1, \rho_1)}{x_0 f_0(x_0, \rho_1)} \Pi_0(\rho_0, \rho_1) \Pi_1(\rho_1, \rho_{\text{MS}}) \right] d\phi_1$$

$$
\begin{aligned}
\Pi_i(\rho_i, \rho_{i+1}) &= \exp\left(-\int_{\rho_{i+1}}^{\rho_i} \frac{d\rho}{\rho} dz \frac{f_{i+1}(x_i/z, \rho)}{z f_i(x_i, \rho)} \bar{\alpha}(\rho) P_i(z) \right) \\
&= 1 - \int_{\rho_{i+1}}^{\rho_i} \frac{d\rho}{\rho} dz \frac{f_{i+1}(x_i/z, \rho)}{z f_i(x_i, \rho)} \bar{\alpha}(\rho) P_i(z) + \mathcal{O}(\alpha_s^2)
\end{aligned}
$$

Generalizes nicely for arbitrary jet multiplicities
Works very well now in PYTHIA8 (as of 8.157)

Dependence on ρ_{MS} is absent to parton shower precision.

Still, ρ_{MS} variations introduces unitarity violations.

Also, only shapes are described. To get reasonable cross sections, we need to go to NLO.

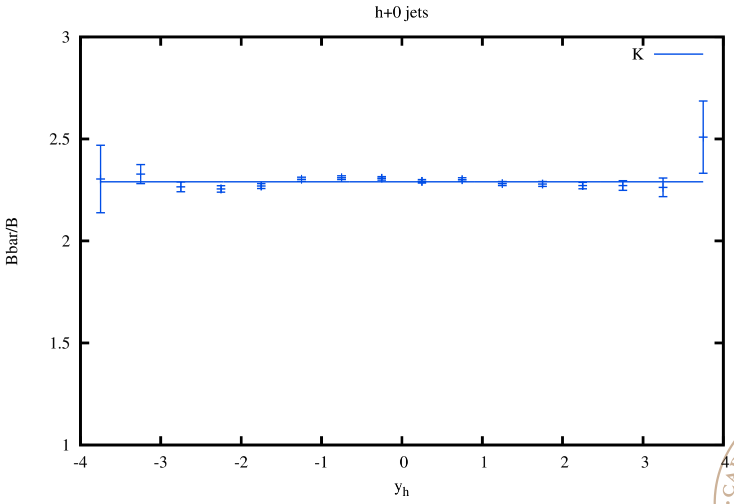
Unitarity violations comes from using full ME in real emissions, but having parton shower approximations in the no-emission probabilities (virtual corrections).

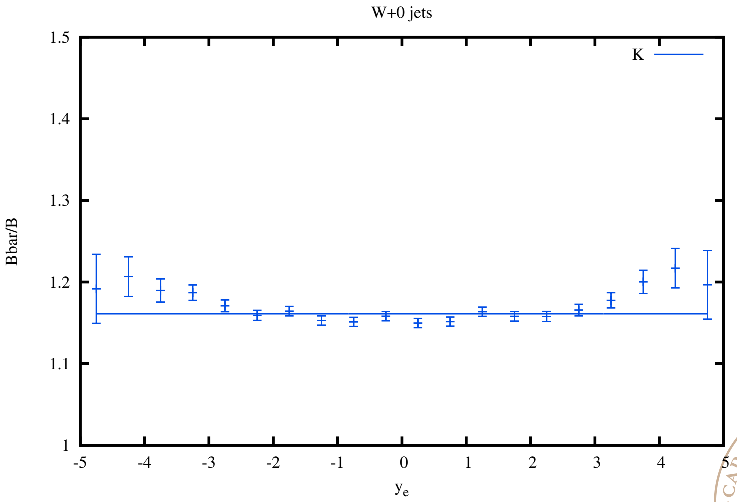
Let’s try to fix both of these.

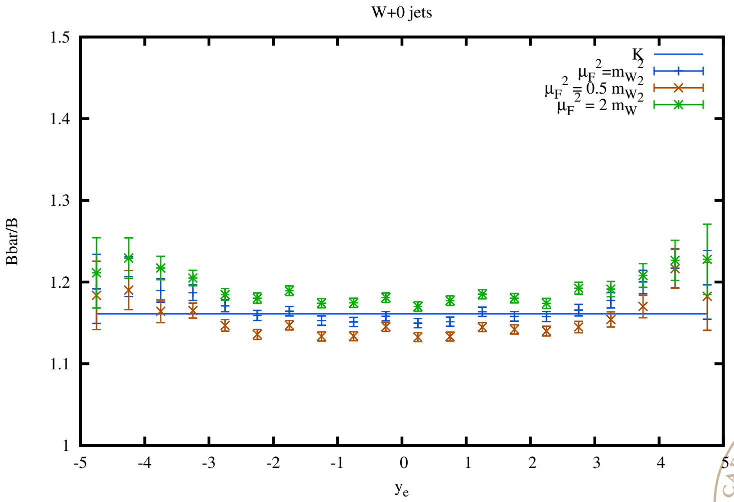
To get reasonable cross sections we could simply multiply by a K-factor. It will not be exactly correct to NLO, but it will be improved.

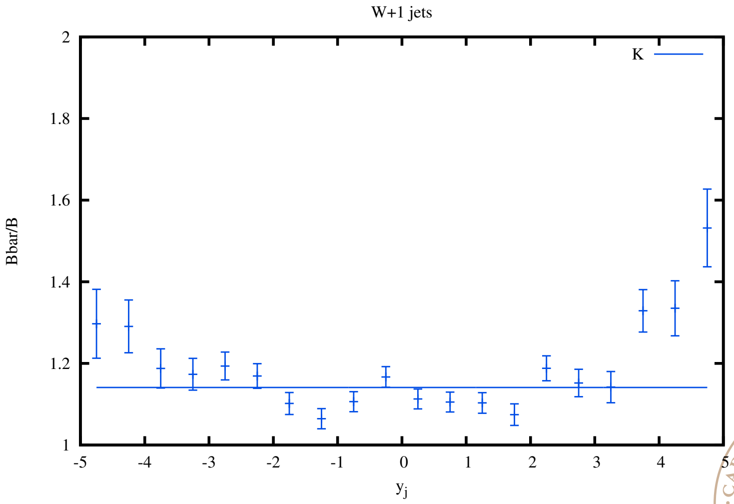
Instead of a K-factor, we could use $\bar{B}$ from Powheg, but it still wouldn't be NLO correct.
(Still have splitting functions rather than R/B in the Sudakovs)

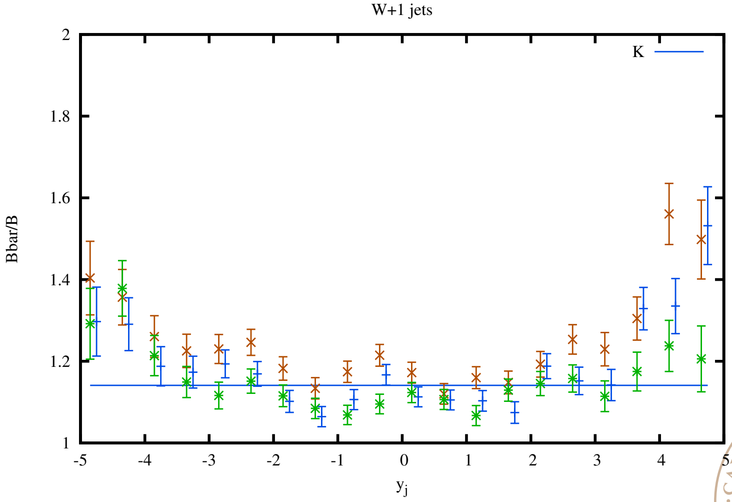
In many cases, the K-factor is not very different from the $\bar{B}$...

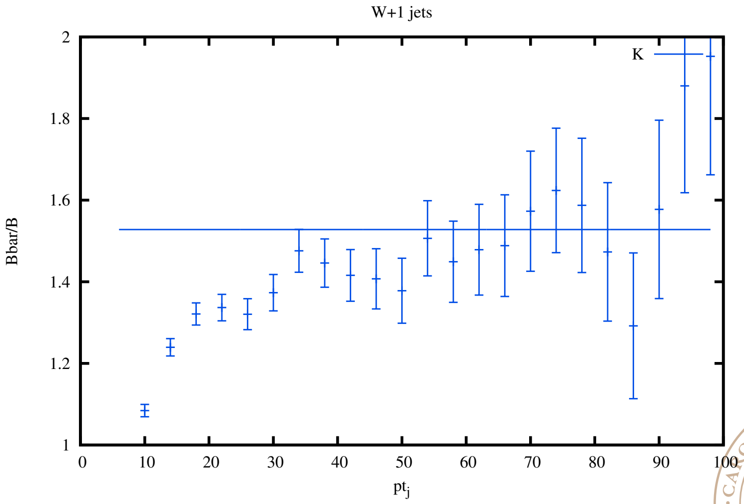

h+0 jets
K
Bbar/B
yh
3
2.5
2
1.5
1
-4
-3
-2
-1
0
1
2
3
4

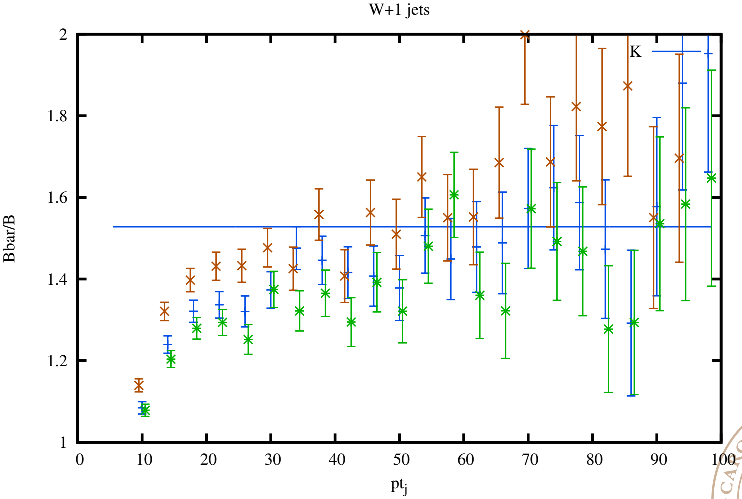

W+0 jets
1.5
1.4
1.3
1.2
1.1
1
Bbar/B
K
-5
-4
-3
-2
-1
0
1
2
3
4
5
y_e


W+0 jets
1.5
1.4
1.3
1.2
1.1
1
Bbar/B
-5
-4
-3
-2
-1
0
1
2
3
4
5
y_e
K
$\mu_F^2 = m_W^2$
$\mu_F^2 = 0.5\ m_W^2$
$\mu_F^2 = 2\ m_W^2$


W+1 jets
K
Bbar/B
2
1.8
1.6
1.4
1.2
1
-5
-4
-3
-2
-1
0
1
2
3
4
5
yj


W+1 jets
K
Bbar/B
2
1.8
1.6
1.4
1.2
1
-5
-4
-3
-2
-1
0
1
2
3
4
5
y_j


W+1 jets
K
Bbar/B
pt$_j$
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50
60
70
80
90
100


W+1 jets
K
Bbar/B
pt_j
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50
60
70
80
90
100

Multi-jet merging to NLO

We can generate events according to $\bar{B}_1$, corresponding to the NLO cross section for inclusive 1-jet production above ρ_{MS}.

How can we make this cross section exclusive (to be able to combine it with other jet multiplicities).

$$\left[\bar{B}_1(\phi_1) - \int d\left[\frac{\phi_2}{\phi_1}\right] R_2(\phi_2)\right] d\phi_1$$

We use the reconstructed parton shower paths of the 2-parton state to define the projection. We use both ordered and unordered paths.
(corresponding to the no-emission probability above and below the reclustered state).

Compare this to the born cross section made exclusive with the CKKW-L weight

$$x_1 f_1(x_1, \mu_F) \left|\mathcal{M}_1\right|^2 \alpha_s(\mu_R)$$
$$\times \left[K_1 \frac{\bar{\alpha}(\rho_1)}{\alpha_s(\mu_R)} \frac{x_0 f_0(x_0, \rho_F)}{x_1 f_1(x_1, \mu_F)} \frac{x_1 f_1(x_1, \rho_1)}{x_0 f_0(x_0, \rho_1)} \Pi_0(\rho_0, \rho_1) \Pi_1(\rho_1, \rho_{\text{MS}}) \right] d\phi_1$$

All the individual weight factors can be written as $1 + \text{blah} \times \alpha_s(\mu_R) + \text{duh} \times \alpha_s^2(\mu_R) + \ldots$

We want to remove the 1 and the blah from these weights, and simply add the NLO exclusive cross section, $\bar{B} - R^{\text{rec}}$.

Rather than exponentiating the R/B as in Powheg, We still exponentiate the PS splitting function, but replace with R/B for the leading α_s term.

This means that we will get smaller mismatch between the real emission and virtual terms, and we should get smaller unitarity violations.

It also means that all the higher orders in α_s are unchanged as compared to the parton shower.

In $e^+e^- \to$ jets, this works like a charm (already 3 years ago).

For initial-state showers we have been struggling with the fact that we have PDF ratios which are not easy to match up with the exclusive NLO cross section.

(Also we had to implement CKKW-L in PYTHIA8)

Now we think we know how to do this…

the results are a bit too preliminary to be shown

If we combine $W+0$, $W+1, \ldots, W+N-1$ jets to NLO in this way, and add tree-level $W+N$ jets, any observable for $n<N$-jets above ρ_{MS} will be correct to NLO+PS-resummation.

For this we need $N-1$ event samples generated according to $\bar{B}_n$ and N samples generated according to B_n.

We also get the resummed $n-1$ jet contribution to to n-jet observables.

Stay tuned!