Merging parton showers and matrix elements — back to basics

Nils Lavesson
in collaboration with Leif Lönnblad

Department of Theoretical Physics
Lund University

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Outline

Introduction

- Goal of Merging Algorithms: To improve the description of exclusive final states with several hard widely separated jets.
- The phase space for particle production at the LHC will be huge, which leads to a rather high production rate of multi-jet states.
- States with several hard jets generated by QCD is the main part of the irreducible background for many discovery channels for new physics.

Introduction cont.

- Thoroughly test the four main merging algorithms: CKKW, CKKW-L, Pseudo-Shower and MLM.
- Use the simplest possible case $e^+e^- \to q\bar{q}g$.
- Excludes complications due to higher order corrections, initial state shower, pdfs etc.
- "Correct" answer available by reweighting the first splitting function. (Implemented in most parton showers)

Merging ME and PS

- Parton showers give a description of the exclusive final states, but are unreliable for states with several hard widely separated jets.
- Tree-level matrix elements give a better description of several hards jets, but only describe inclusive quantities.

The two main tasks of merging algorithms:

- Clear split between the parton shower and the matrix element phase space to avoid dead regions and double counting. The scale that defines the border is called the merging scale.
- Including the effects of Sudakov form factors in the matrix element phase space to make the final states exclusive.

CKKW

1. Choose a merging scale according to the $k_\perp$-algorithm. Use the merging scale as cutoff and calculate all relevant cross sections using tree-level matrix elements.
2. Choose a parton multiplicity with a probability proportional to their respective total cross section and generate kinematics according to the matrix element.
3. Cluster the partons using the $k_\perp$-algorithm.
4. Keep the event with a probability equal to the product of analytical Sudakov form factors and the running α_s.
5. Start the shower from each leg using the scales calculated in the clustering and veto emissions if they are above the matrix element cutoff.

CKKW-L

1. Choose a merging scale, which can in principle be defined using any scale definition. Use the merging scale as cutoff and calculate all relevant cross sections using tree-level matrix elements.
2. Choose a parton multiplicity with a probability proportional to their respective total cross section and generate kinematics according to the matrix element.
3. Construct a shower history consisting of a set of intermediate states and emission scales, by constructing steps backwards in the shower.
4. For each intermediate state generate an emission and discard the event if the emission is above the next constructed scale. This works since the no emission probability of the shower is equal to the Sudakov form factor.
5. Start the shower using the lowest constructed scale and discard the event if the first emission is above the matrix element cutoff.

Pseudo-Shower

- Shower history is constructed using a jet clustering algorithm.
- The full shower is applied and jet clustered. The scales from the clustering are used to determine if the event should be kept.
- The use of single parton distances and clustered jets scale together result in a unclear split between ME and PS phase space. The differences are moderated by adding a fudge factor, δ, to the constructed shower history scales.

MLM

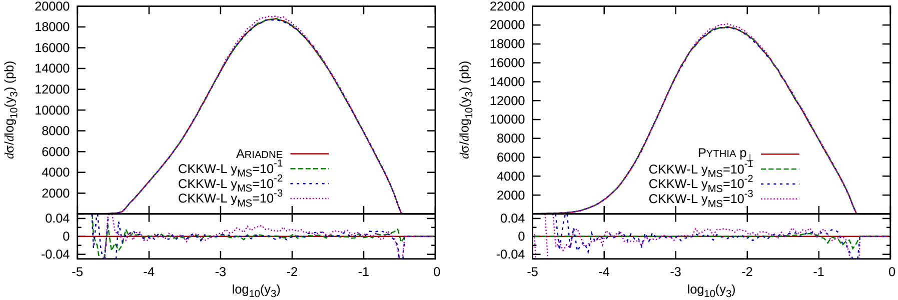
- Different values are used for the merging scale and the matrix element cutoff.
- No shower history is constructed.
- Shower started from maximum scale with no veto on emissions.
- Cluster jets and match them to the partons from the matrix element. Keep the event if all partons match and there are no extra jets.
- Simple to implement.
- To our knowledge no MLM results for e^+e^- have been published and no general algorithm presented. The results shown later are therefore based on our interpretation of the steps needed for implementing e^+e^- annihilation with MLM.

Overview of Results

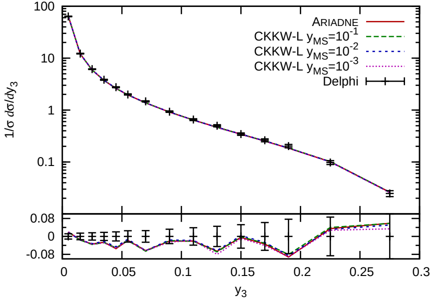
- The process studied is the simplest possible case of $e^+e^- \rightarrow q\bar{q}g$.
- All the matrix element events are generated using MADEVENT.
- The merging scale is defined according to the $k_\perp$-algorithm, except for the Pseudo-Shower results where a slightly different scale was used.
- The main distribution to be studied is the parton level $k_\perp$-value for the third jet, which should be the most sensitive.
- The same distribution is also shown for charge hadrons and compared to experimental data.
- The merging scale is varied to check the properties of the algorithms. Ideally only small variations should be present.

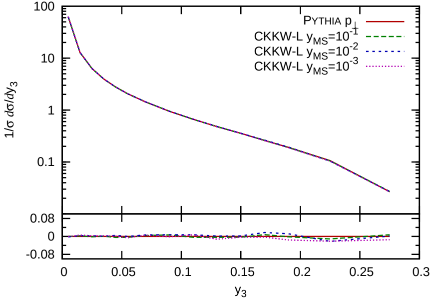
(The $k_\perp$-scale definition: $y_{ij} \equiv 2\min(E_i^2, E_j^2)(1 - cos\theta_{ij})/E_{\mathrm{CM}}^2$)

CKKW-L Parton Level y_3

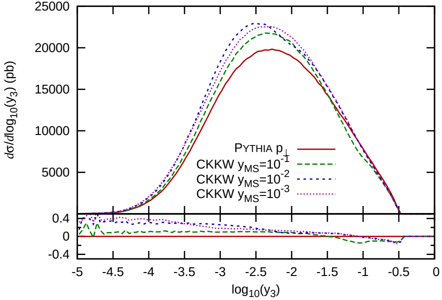


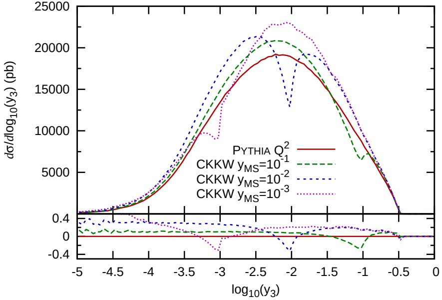
CKKW-L Charged Particle y_3



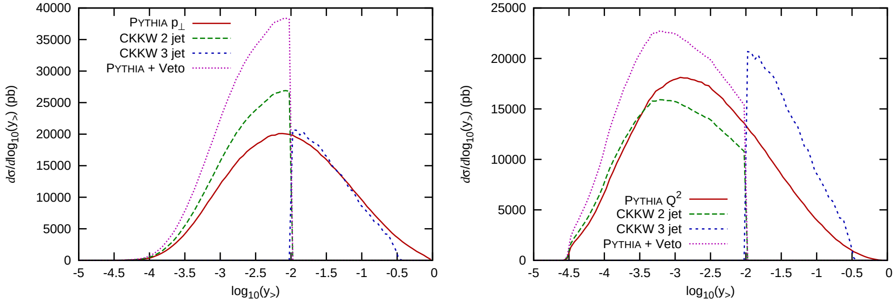


CKKW Parton Level y_3





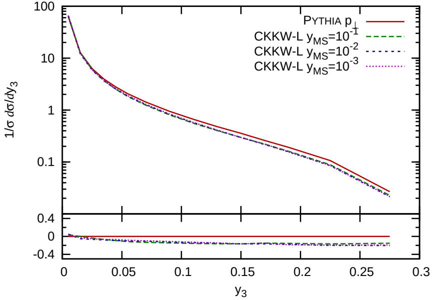
CKKW Maximum Emission y

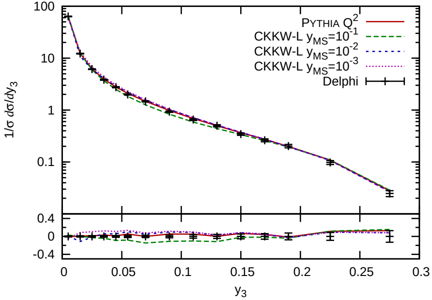


$$y \approx \min\left(\frac{z}{1-z}, \frac{1-z}{z}\right) \frac{Q^2}{E_{\mathrm{CM}}^2}$$

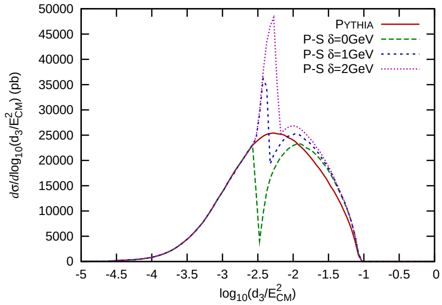
$$\approx \min\left(\frac{z}{1-z}, \frac{1-z}{z}\right) \frac{p_\perp^2}{z'(1-z')E_{\mathrm{CM}}^2}$$

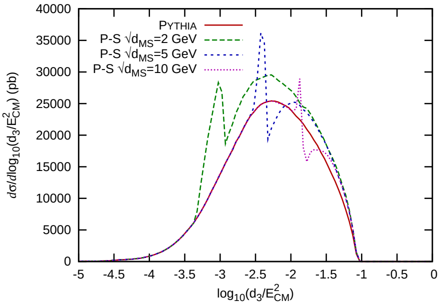
CKKW Charged Particle y_3





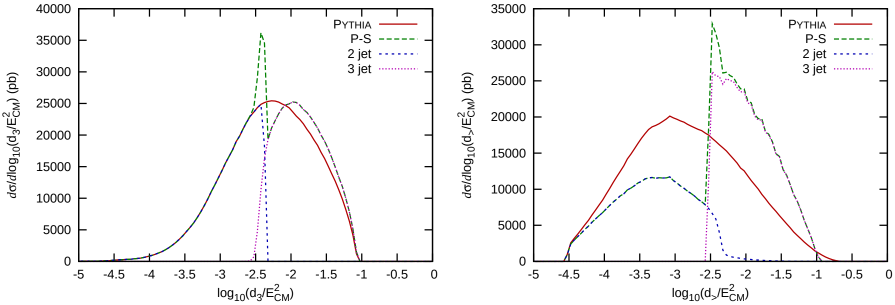
Pseudo-Shower Parton Level d_3



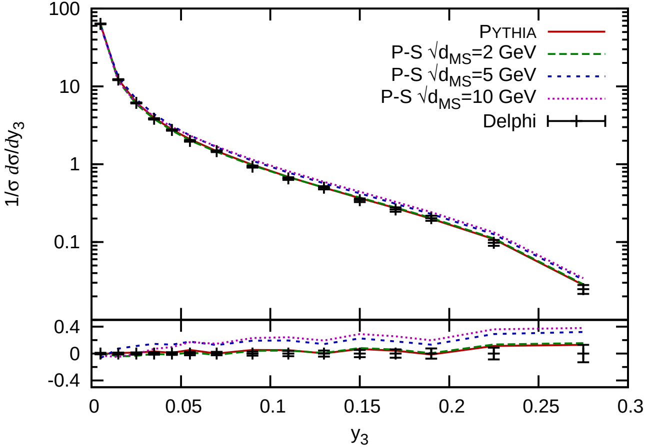


$$d_{ij} \equiv m_{ij}^2 E_i E_j / (E_i + E_j)^2$$

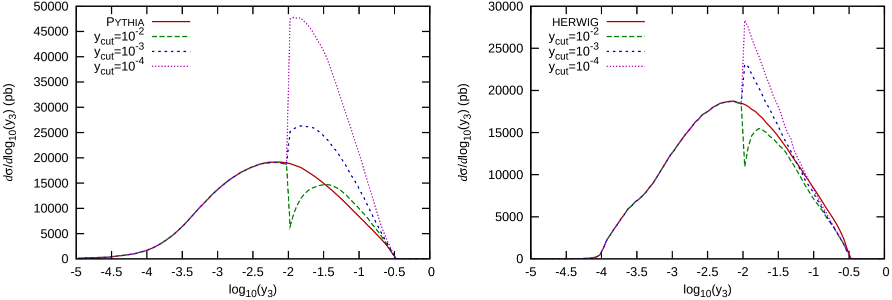
Pseudo-Shower Parton Level d_3 and $d_>$



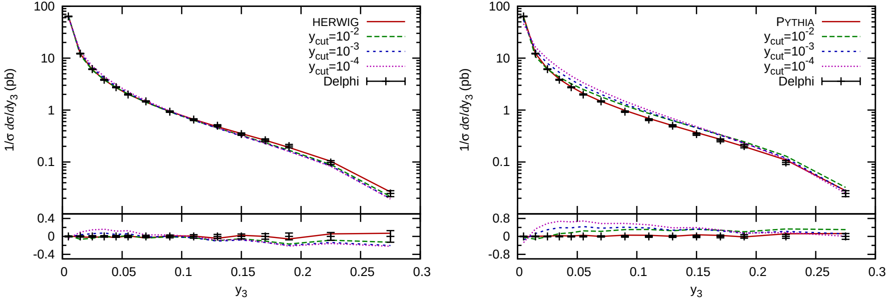
Pseudo-Shower Charged Particle y_3



MLM Parton Level y_3 with $y_{\mathrm{MS}} = 10^{-2}$



MLM Charged Particle y_3 with $y_{\rm MS} = 10^{-2}$



Summary

- Algorithms that work for the simple process studied needs further testing before they can be used for more complicated processes. On the other hand, problems that show up for this most simple case are likely to persist to more complicated processes.
- CKKW-L shows very small discrepancies. (CKKW-L is constructed to match perfectly for the studied process.)
- CKKW has some problems especially when using a virtuality ordered shower.
- Pseudo-Shower and MLM need to tune extra parameters and have potentially serious trouble achieving reasonable independence of the merging scale.