Comparison of Algorithms for the Merging of Matrix Elements and Parton Showers

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Outline

Steps for Generating Events

1. Hard Process
2. Parton Shower
3. Hadronization
4. Hadron Decay

(+ Underlying Event, Multiple Interactions etc.)

Parton Showers

Advantages

- Emissions are treated to all orders in the collinear and soft approximation
- Includes virtual corrections by Sudakov form factors
- Running coupling
- Generates exclusive final states

Disadvantages

- Based on strong ordering in virtuality
- Neglects some interference
- Poor description of several hard widely separated jets

Leading Order Matrix Elements

Advantages

- Correct treatment up to the given order
- Good description of several hard widely separated jets

Disadvantages

- Truncated at fixed order in α_s
- No virtual corrections
- Divergent in collinear and soft region (cutoff needed)
- Overestimates the cross section
- Complicated to calculate for high multiplicities
- Fixed coupling
- No exclusive final states

Combining ME and PS

Overall Goal: To improve the description of exclusive final states with several hard widely separated jets.

Specific things that needs to be included in the algorithm:

- Correct treatment of interferences from the ME
- Sudakov form factors from the PS
- Running coupling
- Clear split between the PS and the ME phase space to avoid dead regions and double counting
- Exclusive final states

General Algorithm for Merging ME and PS

1. Define a jet measure and calculate all relevant cross sections using leading order matrix elements.
2. Produce hard parton samples with a probability proportional to the respective total cross section and with kinematics according to the matrix element.
3. Accept or reject the individual configurations with a probability that includes both the effects of the running coupling constant and of the Sudakov form factors.
4. Invoke the parton shower with suitable initial conditions for each leg. Constrain the parton shower not to produce any extra jet.

Jet Algorithms

Cone

Defined by including all the partons within a cone

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < \Delta R_{cut},$$

if their total $\mathrm{E}_\perp > \mathrm{E}_{\perp cut}$ and $|\eta| < \eta_{cut}$.

KTCLUS

Defined by merging particles with a minimum value of $k_\perp$ (defined by some $k_\perp$-measure) with each other or the beam until a cutoff is reached. A typical $k_\perp$-measure would be

$$\begin{aligned} k_{\perp ij}^2 &= \min(p_{\perp i}, p_{\perp j})^2 \cdot \Delta R^2 \\ k_{\perp iB}^2 &= p_\perp^2. \end{aligned}$$

CKKW

1. Cluster the partons using the $k_\perp$-algorithm.
2. Keep the event with a probability equal to the product of analytical NLL Sudakov form factors.
3. Start the shower from each leg using the scales calculated in the clustering.
4. Veto emissions if they are above the matrix element cutoff.

CKKW-L

1. Construct a shower history consisting of a set of intermediate states and emission scales, by constructing steps backwards in the shower.
2. 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.
3. Start the shower using the lowest constructed scale.
4. Discard the event if the first emission is above the matrix element cutoff.

MLM

1. Run the cascade starting from the maximum scale of the process.
2. Apply the jet finding algorithm used for the ME cut.
3. Match the jets to the partons from the matrix element.
4. Keep the event if all partons match and there are no extra jets.

Current Study

Comparison of 5 programs using different algorithms.

Tevatron: $W^{+/-}+$ 4 jets
LHC: $W^{+}+$ 4 jets

Jets are defined by the cone algorithm GETJET with $E_{\perp} > 10(20)$ GeV, $\Delta R < 0.7(0.4)$ and $\eta < 2(4.5)$ for the Tevatron (LHC).

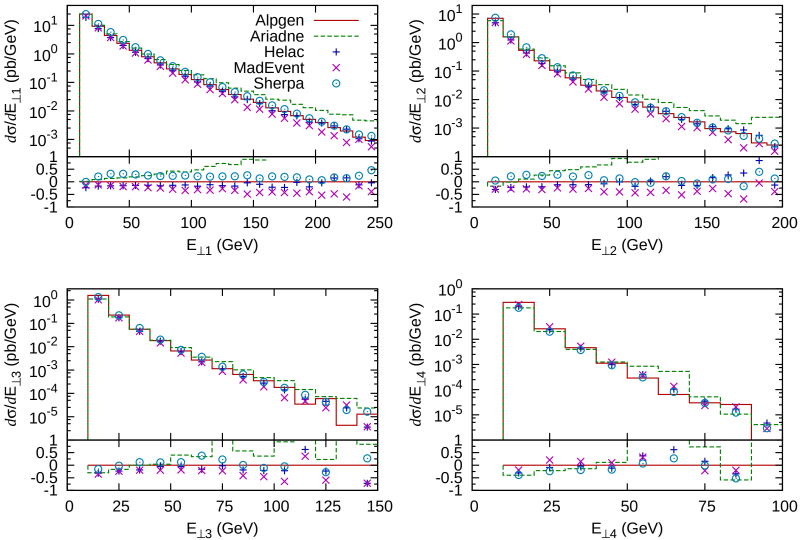
To be investigated:

- Consistency above the merging scale (should be dominated by the matrix elements)
- Properties near the merging scale
- Effects of varying the merging scale

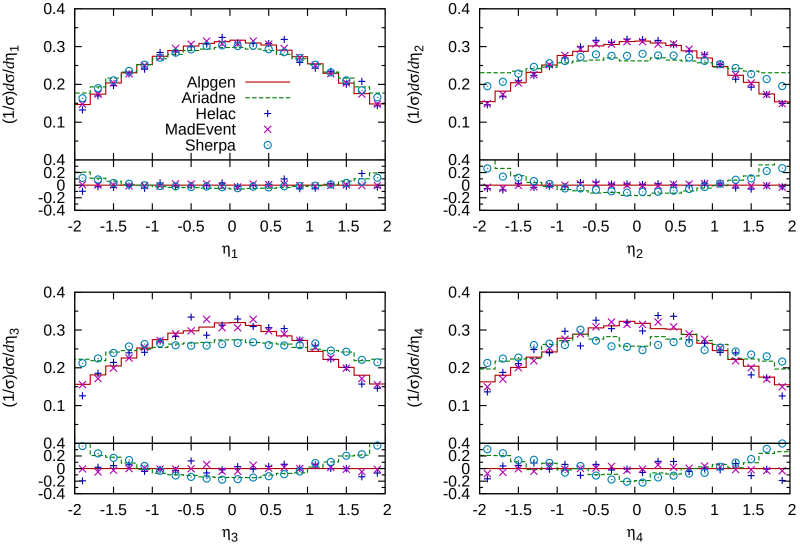
Overview of the Programs

Program	Algorithm	ME Cut	ME	PS	Hadronization
ALPGEN	MLM	Cone	ALPGEN	HERWIG	HERWIG
ARIADNE	CKKW-L	Cone	MADEVENT	ARIADNE	PYTHIA
HELAC	MLM	Cone	HELAC	PYTHIA	PYTHIA
MADEVENT	MLM	$k_{\perp}$	MADEVENT	PYTHIA	PYTHIA
SHERPA	CKKW	$k_{\perp}$	AMEGIC++	APACIC++	PYTHIA

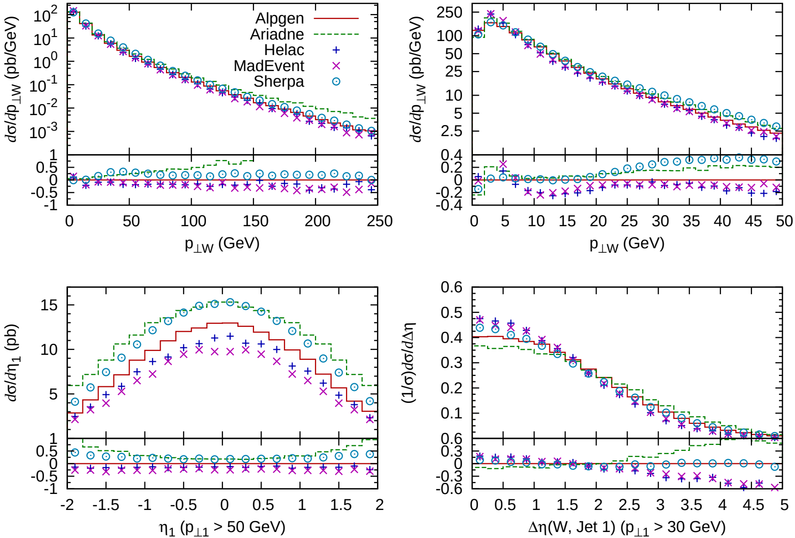
Tevatron Jet $E_\perp$



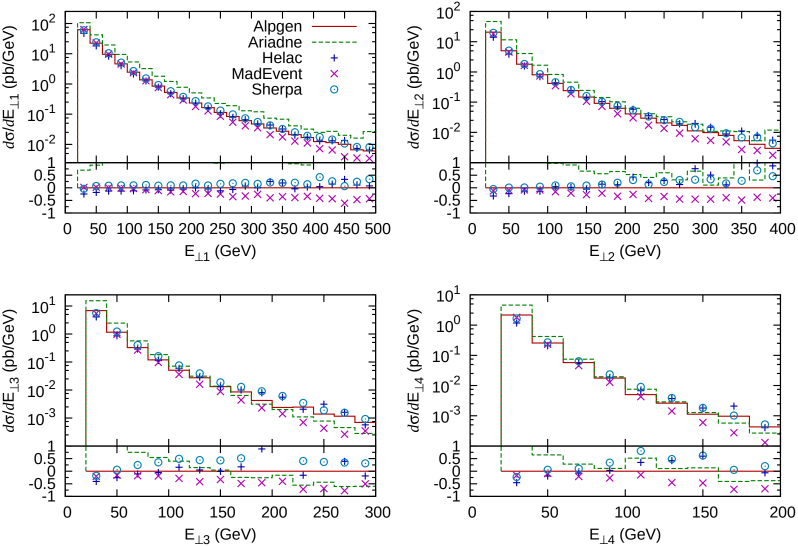
Tevatron Jet η



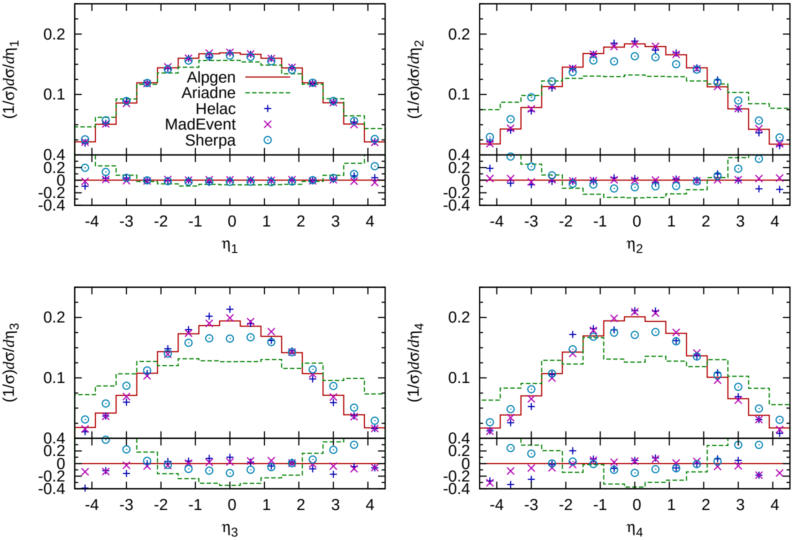
Tevatron $p_{\perp W}$, η_1 and $\Delta\eta(W, \text{Jet } 1)$



LHC Jet $E_\perp$

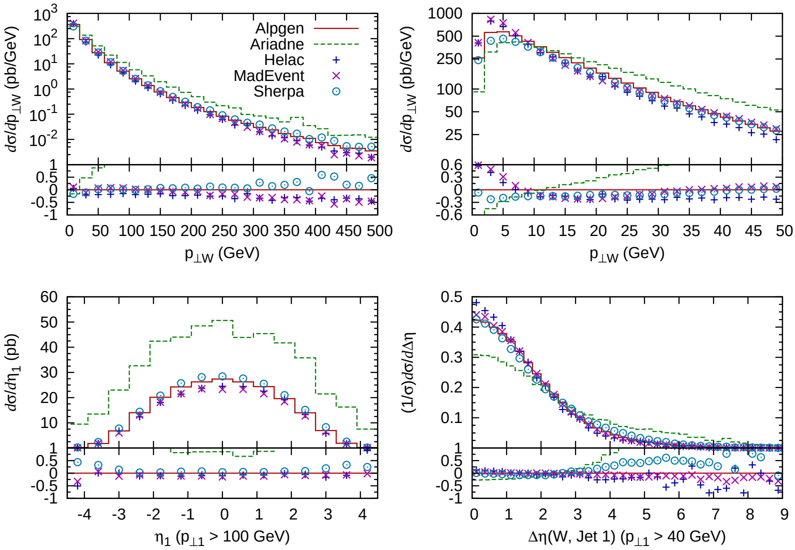


LHC Jet η

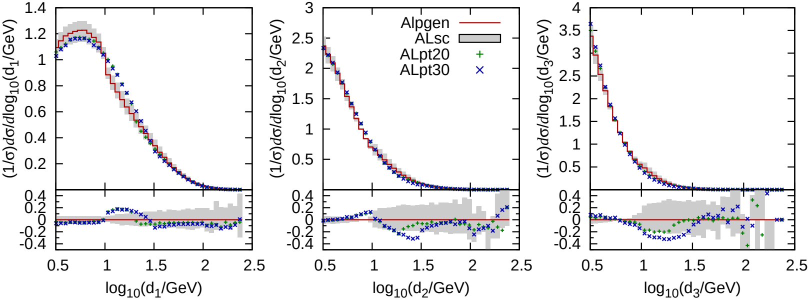


(1/σ)dσ/dη1
(1/σ)dσ/dη2
(1/σ)dσ/dη3
(1/σ)dσ/dη4
Alpgen
Ariadne
Helac
MadEvent
Sherpa
0.2
0.1
0.4
0.2
0
-0.2
-0.4
-4
-3
-2
-1
0
1
2
3
4
η1
η2
η3
η4

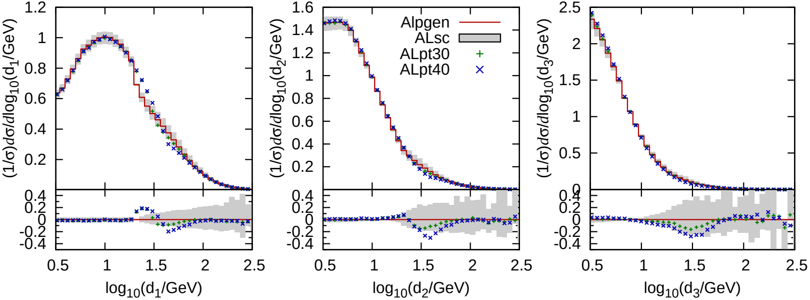
LHC $p_{\perp W}$, η and $\Delta\eta(W, \text{Jet } 1)$



ALPGEN Tevatron $k_\perp$ Jet Scales at Parton Level



ALPGEN LHC $k_\perp$ Jet Scales at Parton Level



Summary

- All programs are fairly consistent above the merging scale.
- Differences are mostly within what is expected from merging leading log parton showers and leading order matrix elements.
- Ariadne is significantly different due to a different treatment of initial state radiation.
- All programs show residual effects from varying the merging scale.

General Advice

General advise if you want to look at several hard widely separated jets.

- Don't rely on a parton shower based Monte Carlo event generator.
- Run several different programs that do matching.
- Try to choose observables that are not sensitive to the physics near the merging scale.
- Check the sensitivity be running with different merging scales.