LUND
UNIVERSITY

Matrix Element matching in ARIADNE

- Introduction
- ME matching in ARIADNE
- Preliminary results for DIS

DESY
2004.06.01
Leif Lönnblad

ME vs. PS

Parton shower generators are not good at describing more than one or two hard jets. If we want more we need to use Matrix Element generators. But we still need parton showers to be able to use hadronization models to get proper jets.

How do we combine ME and PS?

ME vs. PS

Parton shower generators are not good at describing more than one or two hard jets. If we want more we need to use Matrix Element generators. But we still need parton showers to be able to use hadronization models to get proper jets.

How do we combine ME and PS?

- Make a clean cut in phase space between ME and PS. No double counting and no under counting.
- PS uses Sudakovs to get exclusive states (MLLA resummation of virtual corrections or no-emission probabilities)
- PS has a definite ordering in the cascade, ME's does not.

A general fixed (second) order calculation

$$
\begin{aligned}
O_{+0\text{jet}} &= C_{0,0} + C_{0,1}\alpha_{\text{s}} + C_{0,2}\alpha_{\text{s}}^2 \\
O_{+1\text{jet}} &= C_{1,1}\alpha_{\text{s}} + C_{1,2}\alpha_{\text{s}}^2 \\
O_{+2\text{jet}} &= C_{2,2}\alpha_{\text{s}}^2
\end{aligned}
$$

But all the coefficients are divergent in the soft and collinear limit, so we need a cutoff.

When we add PS, we must not add radiation above this cutoff and also not leave out any phase space below it.

But if you add a PS below the cutoff to an N-jet state from an ME generator, the PS assumes there are no other emissions above.

Parton shower generators do things to all orders, summing up all virtual corrections to leading log into Sudakov form factors.

$$
\begin{aligned}
O_{+0\text{jet}} &= C^{\text{PS}}_{0,0}\Delta_{\text{S}0} \\
O_{+1\text{jet}} &= C^{\text{PS}}_{1,1}\alpha_{\text{s}}\Delta_{\text{S}1} \\
O_{+2\text{jet}} &= C^{\text{PS}}_{2,2}\alpha_{\text{s}}^2\Delta_{\text{S}2} \\
&\ldots
\end{aligned}
$$

$O_{+1\text{jet}} = C^{\text{PS}}_{1,1}\alpha_{\text{s}}\Delta_{\text{S}1}$ is the cross section for to producing one additional jet and nothing else. The Sudakov form factor is a no-emission probability.

Parton shower generators do things to all orders, summing up all virtual corrections to leading log into Sudakov form factors.

$$
\begin{aligned}
O_{+0\text{jet}} &= C^{\text{PS}}_{0,0}\Delta_{\text{S}0} = C^{\text{PS}}_{0,0} + C^{\text{PS}}_{0,1}\alpha_{\text{s}} + C^{\text{PS}}_{0,2}\alpha_{\text{s}}^2 + \ldots \\
O_{+1\text{jet}} &= C^{\text{PS}}_{1,1}\alpha_{\text{s}}\Delta_{\text{S}1} = C^{\text{PS}}_{1,1}\alpha_{\text{s}} + C^{\text{PS}}_{1,2}\alpha_{\text{s}}^2 + C^{\text{PS}}_{1,3}\alpha_{\text{s}}^3 + \ldots \\
O_{+2\text{jet}} &= C^{\text{PS}}_{2,2}\alpha_{\text{s}}^2\Delta_{\text{S}2} = C^{\text{PS}}_{2,2}\alpha_{\text{s}}^2 + C^{\text{PS}}_{2,3}\alpha_{\text{s}}^3 + C^{\text{PS}}_{2,4}\alpha_{\text{s}}^4 + \ldots \\
&\ldots
\end{aligned}
$$

$O_{+1\text{jet}} = C^{\text{PS}}_{1,1}\alpha_{\text{s}}\Delta_{\text{S}1}$ is the cross section for to producing one additional jet and nothing else. The Sudakov form factor is a no-emission probability.

Also these coefficients are divergent. But when summed to all orders the result is finite.

The CKKW strategy

$$\begin{array}{rcl} O_{+0\text{jet}} & = & C_{0,0}^{\text{ME}}\Delta_{\text{S}0} \\ O_{+1\text{jet}} & = & C_{1,1}^{\text{ME}}\alpha_{\text{s}}\Delta_{\text{S}1} \\ O_{+2\text{jet}} & = & C_{2,2}^{\text{ME}}\alpha_{\text{s}}^{2}\Delta_{\text{S}2} \\ & \ldots & \end{array}$$

Use tree-level ME generator with some cutoff. Make a jet reconstruction to find a sequence of ordered emissions. Reweight with the Sudakov form factors (and running α_{s}) and add a (vetoed) parton shower below the cutoff.

The dependence on the cutoff disappears to NNLL. But it is still visible and some tuning is needed.

Matching in ARIADNE

ARIADNE is special.

- The emissions are ordered in $p_\perp$.

- All partons are always on-shell in the cascade.

Matching in ARIADNE

ARIADNE is special.

- The emissions are ordered in $p_\perp$. The *inverse* of ARIADNE is a good jet algorithm (DICLUS).

- All partons are always on-shell in the cascade.

Matching in ARIADNE

ARIADNE is special.

- The emissions are ordered in $p_\perp$. The *inverse* of ARIADNE is a good jet algorithm (DICLUS). Instead of reconstructing intermediate scales with the $k_\perp$-algorithm we reconstruct a likely complete shower history with scales and intermediate states.

- All partons are always on-shell in the cascade.

Matching in ARIADNE

ARIADNE is special.

- The emissions are ordered in $p_\perp$. The *inverse* of ARIADNE is a good jet algorithm (DICLUS). Instead of reconstructing intermediate scales with the $k_\perp$-algorithm we reconstruct a likely complete shower history with scales and intermediate states.

- All partons are always on-shell in the cascade. The cascade can be started/stopped at any intermediate state.

Matching in Ariadne

Ariadne is special.

- The emissions are ordered in $p_\perp$. The *inverse* of Ariadne is a good jet algorithm (Diclus). Instead of reconstructing intermediate scales with the $k_\perp$-algorithm we reconstruct a likely complete shower history with scales and intermediate states.

- All partons are always on-shell in the cascade. The cascade can be started/stopped at any intermediate state. We can make trial emissions from any reconstructed intermediate state and by checking where it ends up we can get the no-emission probability for a phase space region which gives exactly the same Sudakov as Ariadne.

Matching in ARIADNE

ARIADNE is special.

- The emissions are ordered in $p_\perp$. The *inverse* of ARIADNE is a good jet algorithm (DICLUS). Instead of reconstructing intermediate scales with the $k_\perp$-algorithm we reconstruct a likely complete shower history with scales and intermediate states.

- All partons are always on-shell in the cascade. The cascade can be started/stopped at any intermediate state. We can make trial emissions from any reconstructed intermediate state and by checking where it ends up we can get the no-emission probability for a phase space region which gives exactly the same Sudakov as ARIADNE.

No dependence on the ME cutoff in $\mathrm{e}^+\mathrm{e}^-$

Incominging hadrons are even more special in ARIADNE

All gluon radiation is treated as final state emissions from colour dipoles between partons formed in the hard sub-process and between the partons and the hadron remnants.

Coherence effects suppresses radiation from remnant dipoles due to the extendedness of the remnants.

Initial-state $g \to \mathrm{q}\bar{\mathrm{q}}$ has to be added by hand as in standard backward evolution PS.

ARIADNE does not generate standard DGLAP evolution (small-x effects are included)

In ARIADNE the maximum scale is set by W^2, ie. emissions in the whole of phase space is allowed. For the standard CKKW the maximum scale would typically be Q^2 which is clearly not appropriate for HERA.

For ARIADNE the small-x effects would still be included in the matching since the Sudakovs still are the ARIADNE ones.

For CKKW the Sudakovs would be the standard DGLAP ones.

ME generators sample the PDF's at the cutoff scale. ARIADNE uses the scale of the leading order sub-process. Reweighting needed (Total cross section is still at leadingorder).

$$\frac{xf_i(x,Q^2)}{xf_j(x',E_{\text{cut}})}$$

ME generators sample the PDF's at the cutoff scale. ARIADNE uses the scale of the leading order sub-process. Reweighting needed (Total cross section is still at leadingorder).

$$\frac{xf_i(x,Q^2)}{xf_j(x',E_{\rm cut})}$$

In addition to the Sudakov and $\alpha_{\rm s}$ reweighting, each initial-state (or remnant) emission is reweighted by

$$\Theta_{\rm sup}(p_\perp,z)/z$$

for gluon emission and

$$\frac{xf_g(x/z,p_\perp^2)}{xf_q(x,p_\perp^2)}$$

for initial-state $g \to \mathrm{q\bar{q}}$.

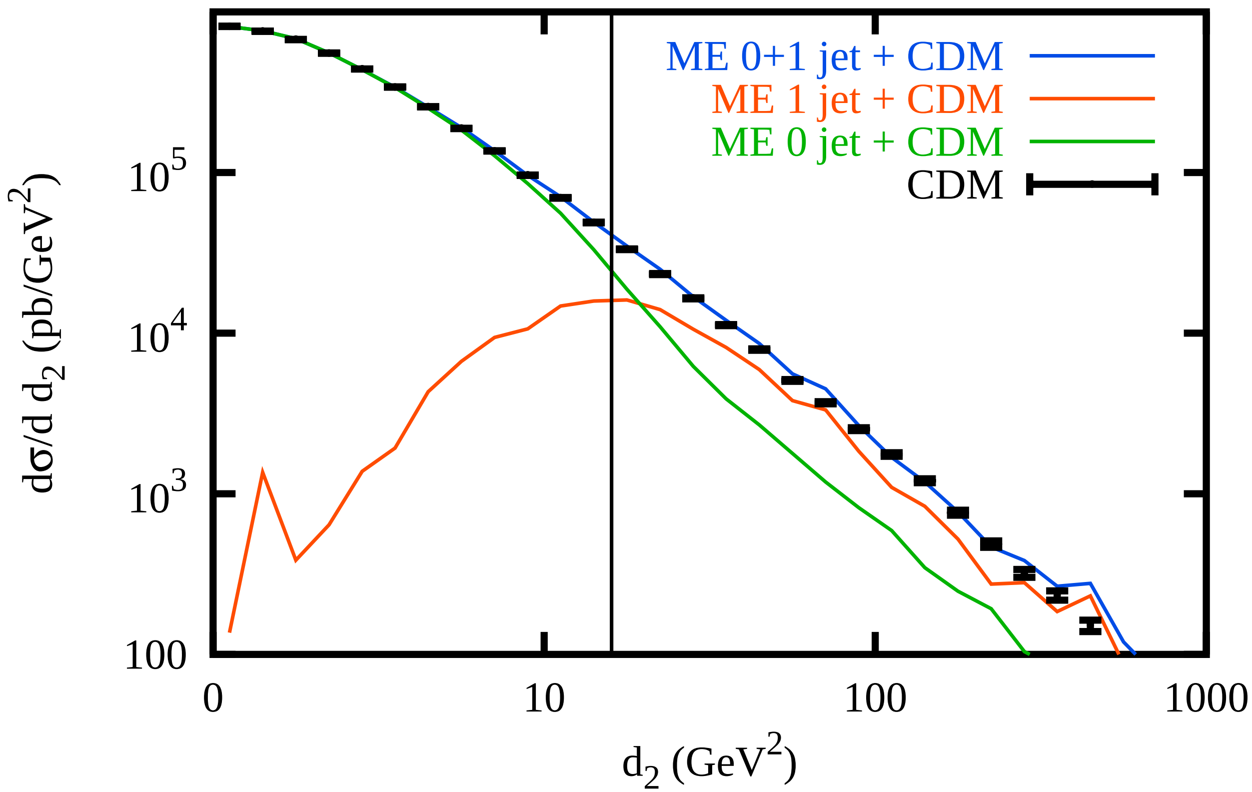
Preliminary results for DIS@HERA

Use MadGraph/MadEvent for Matrix element generation.

Not optimized for DIS. Make cut in Q^2 and the $k_\perp$-algorithm jet measure in the lab frame (4 GeV).

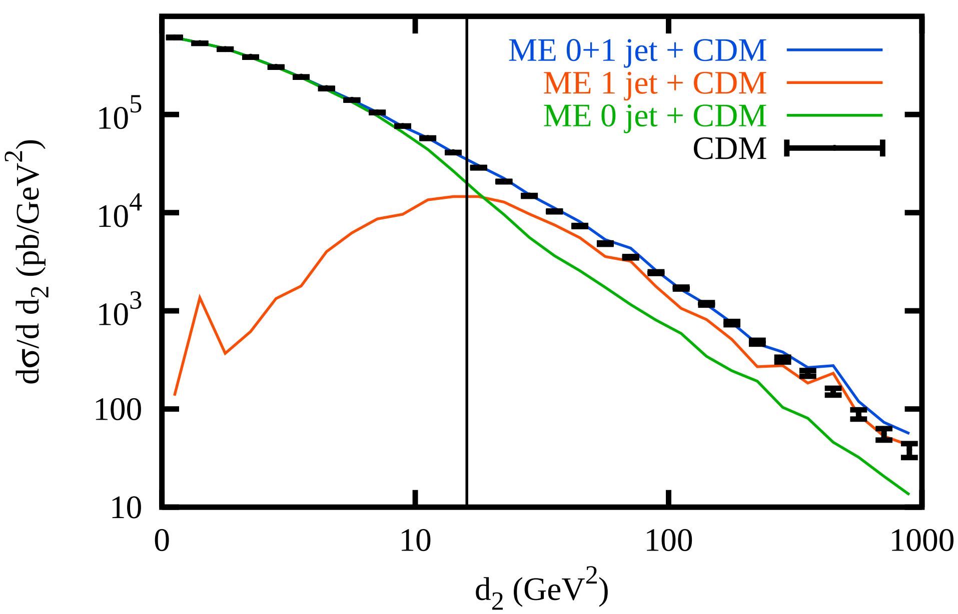
This is an initial study: Use the new matching procedure with $\mathcal{O}(\alpha_\mathrm{s})$ ME from MagGraph. Compare with slightly modified standard ARIADNE which already has ME correction for first emission. These should agree perfectly.

All events

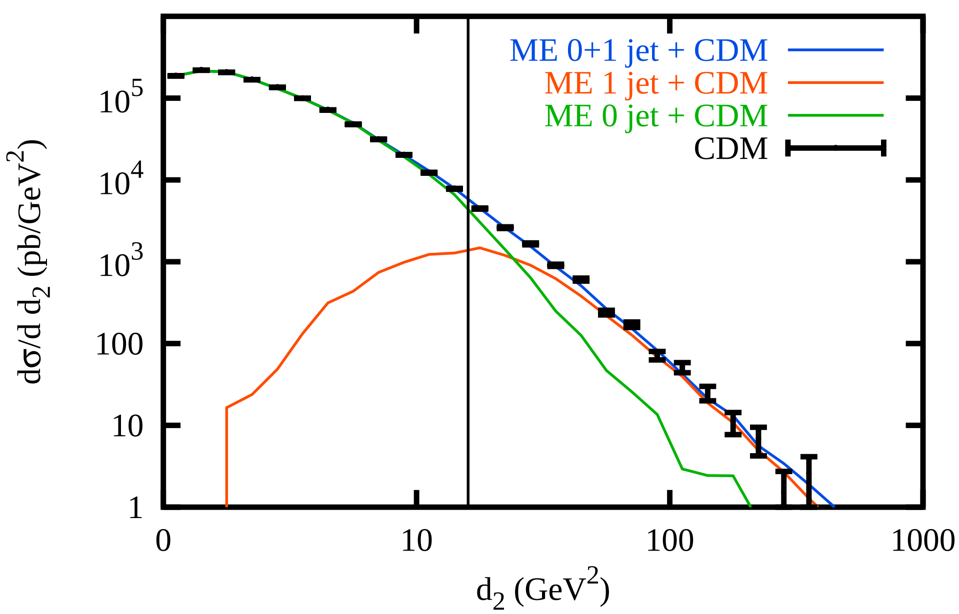


(preliminary)

QCD-C events



BGF events



Conclusions

- ME/PS matching is maturing.
- In ARIADNE the CKKW is greatly simplified
- DIS matching is in principle working in ARIADNE.