Overview of Matching Matrix Elements and Parton Showers

Peter Richardson
IPPP, Durham

- Introduction
- Traditional Approach
- NLO Simulation
- Multijet leading-order
- Conclusions

Introduction

- We are now interested in processes which produce may high p_T jets, for example:
  - Top pair production including the decay products of the top;
  - BSM processes with high p_T jets from the decay of new heavy particles.
- The backgrounds to these processes are typically the production of electroweak gauge bosons with additional QCD radiation.
- These processes are interesting in their own right of the study of QCD.
- We need better simulation of the backgrounds.
- This means better treatment of the emission of hard radiation in the parton shower.

Matching matrix elements and Parton Showers

- Parton Shower (PS) simulations use the soft/collinear approximation:
  - Good for simulating the internal structure of a jet;
  - Can't produce high p_T jets.

- Matrix Elements (ME) compute the exact result at fixed order:
  - Good for simulating many high p_T jets;
  - Can't give the structure of a jet.

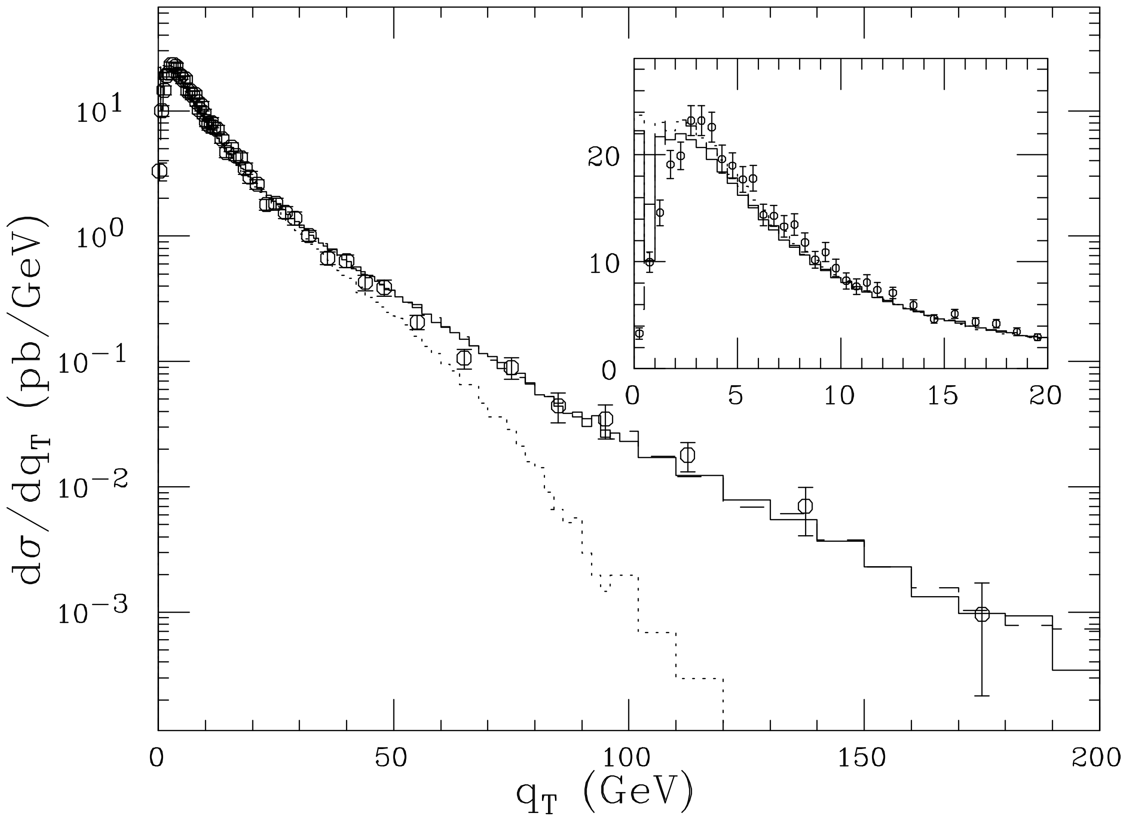
- We want to use both in a consistent way, *i.e.*
  - ME gives hard emission,
  - PS gives soft/collinear emission,
  - Smooth matching between the two,
  - No double counting of radiation.

Matching matrix elements and Parton Showers

- There have been a number of attempts to do this.
- The first attempts got the hardest emission correct for simple processes, for example:
  - $e^+e^- \to q\bar{q}$;
  - DIS;
  - Drell-Yan;
  - Top Decay.
- There were problems with this:
  - Only the hardest emission was correctly described;
  - The leading-order normalization was retained.

Matching matrix elements and Parton Showers

- Transverse momentum distribution of Z at the Tevatron (CDF) compared with HERWIG.



- Taken from Nucl. Phys. B565:227-244,2000, G. Corcella and M. H. Seymour.

Matching matrix elements and Parton Showers

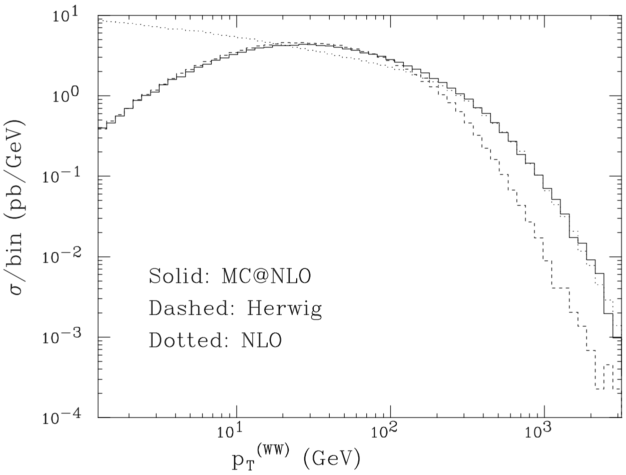
- Recently there has been renewed interest.
- Two types of approach have emerged.

1. NLO Simulation
   - NLO normalization of the cross section.
   - Gets the hardest emission correct.
   - Only programs by Frixione/Webber and Dobbs.
2. Multi-jet Leading Order
   - Still leading order.
   - Gets many hard emissions correct.
   - Programs by Krauss et. al. and Lonnblad for e^+e^-.

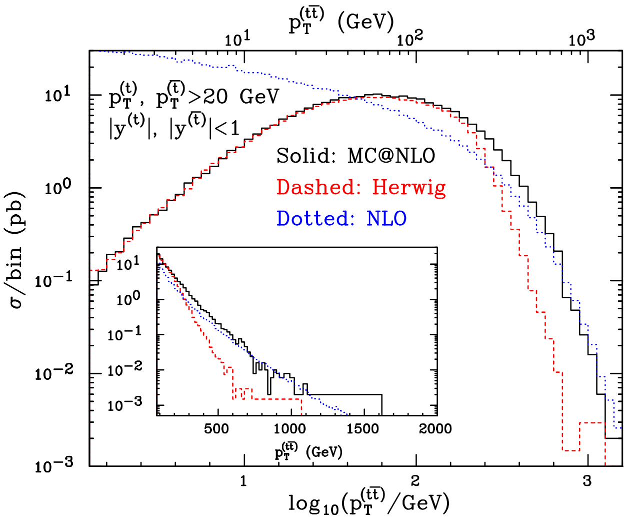
NLO Simulation

- These simulations are now available for a range of processes using the method of Frixione and Webber.

- Transverse momentum of W^+W^- pair at the LHC.



- Transverse momentum of $t\bar{t}$ pairs at the LHC.



Multi-Jet Leading Order Simulation

- While the NLO approach is good for one hard additional jet and the overall normalization can not be used to give many extra hard jets, at least at the moment.
- Therefore to simulate these processes use matching at leading order to get many hard emissions correct.

Procedure

- In order to match the ME and PS we need to separate the phase space:
  - One region should contain the soft/collinear region and be filled by the PS;
  - The other is filled by the matrix element.

- Most of the work is based on the work of Catani-Krauss-Kuhn-Webber (CKKW) with various modifications.

- In these approaches the phase-space is separated using a k_T-type jet algorithm.

- Radiation above a cut-off value of the jet measure is simulated by the matrix element and radiation below the cut-off by the parton-shower.

Procedure

1. Select the jet multiplicity with probability

$$P_n = \frac{\sigma_n}{\sum_{k=0}^{k=N} \sigma_k}$$

   where σ_n is the n-jet matrix element evaluated at resolution $d_{\rm ini}$ using $d_{\rm ini}$ as the scale for the P.D.F's and α_S, n is the number of additional jets.

2. Distribute the jet momenta according to the ME.

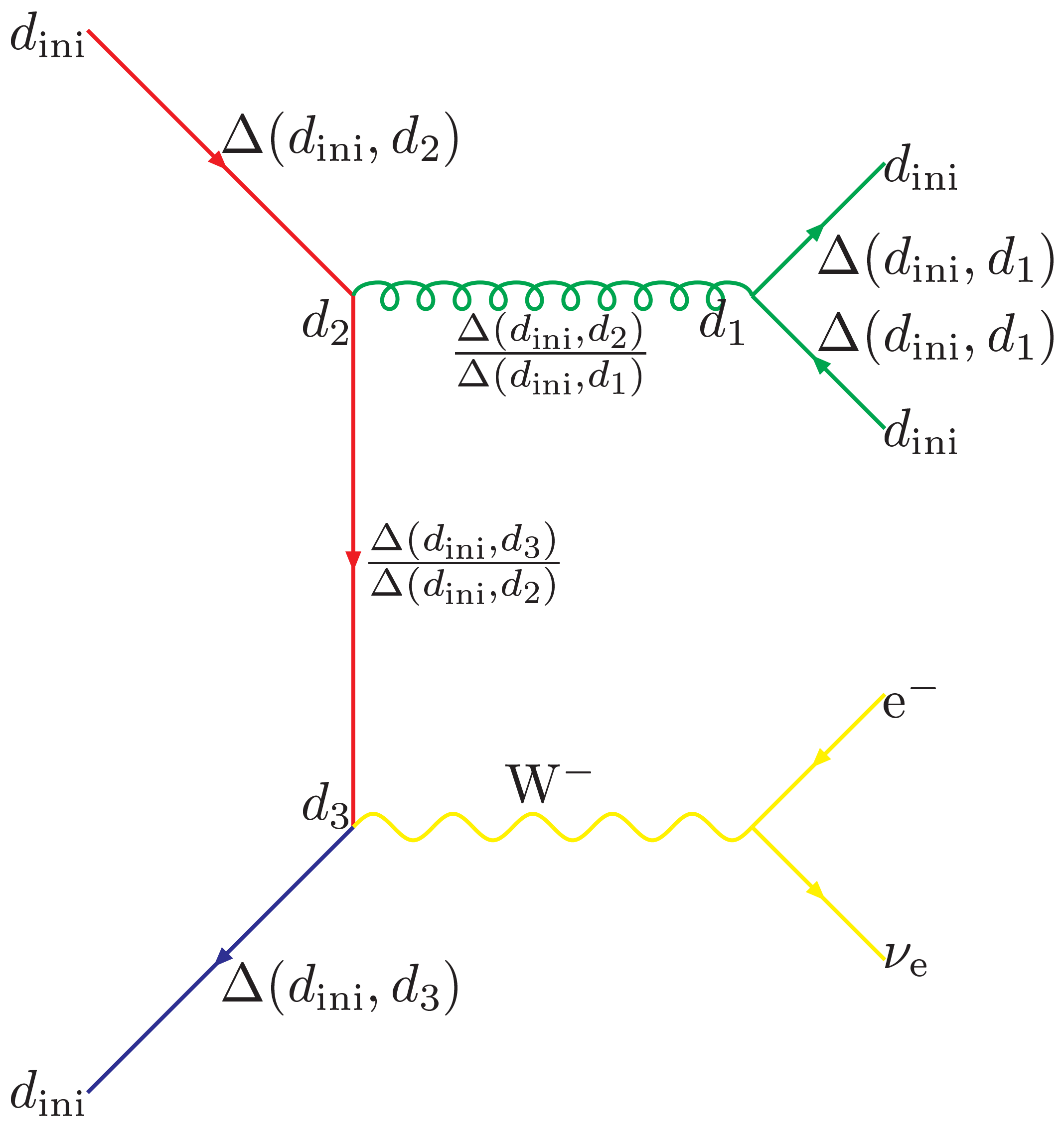
3. Cluster the partons to determine the values at which 1,2,..n-jets are resolved. These give the nodal scales for a tree diagram.

4. Apply a coupling-constant reweighting $\alpha_S(d_1)\alpha_S(d_2)..\alpha_S(d_n)/(\alpha_S(d_{\rm ini})^n \leq 1$.

5. Reweight the lines by a Sudakov factor $\Delta(d_{\rm ini}, d_j)/\Delta(d_{\rm ini}, d_k)$.

6. Accept the configuration if the product of the α_S and Sudakov weight is less the $\mathcal{R} \in [0, 1]$., otherwise return to step 1.

Procedure



7. Generate the parton shower from the event starting the evolution of each parton at the scale it was created and vetoing emission above the scale $d_{\rm ini}$

Variants

- Two variants of the approach have emerged.
  - Analytic Sudakovs
  - Pseudo-shower
- The first is closest in spirit to the original idea and uses an analytically calculated Sudakov.
- The second generates a trial parton-shower and uses this to calculate the Sudakovs numerically.
- There are pros and cons or both approaches.
- The first is faster
- The second includes recoil effects etc. from the shower.

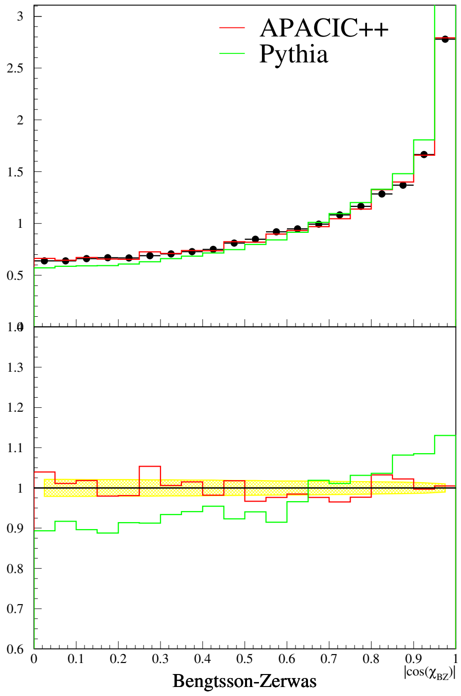
Results

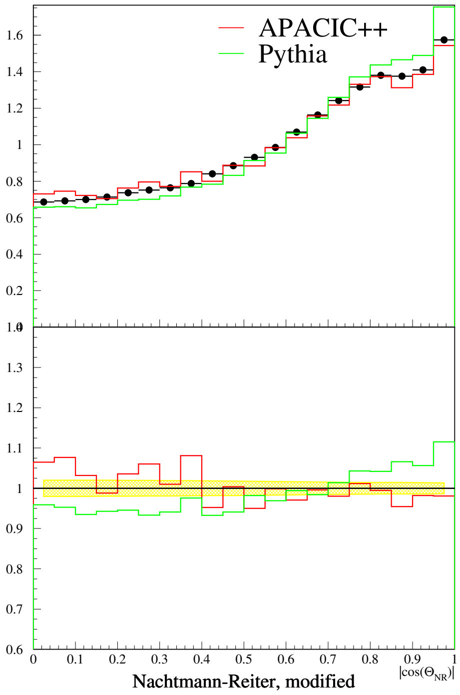
- So far all the results have been for e^+e^- collisions or hadron-hadron.
- To the best of my knowledge no work for DIS.
- I think this is a possible area for work in this workshop.
- Perhaps the accuracy of the approach can be proved for DIS as e^+e^- (F. Krauss)
- Certainly would be useful to test ideas when only one incoming hadron.
- Opportunity to compare with data.

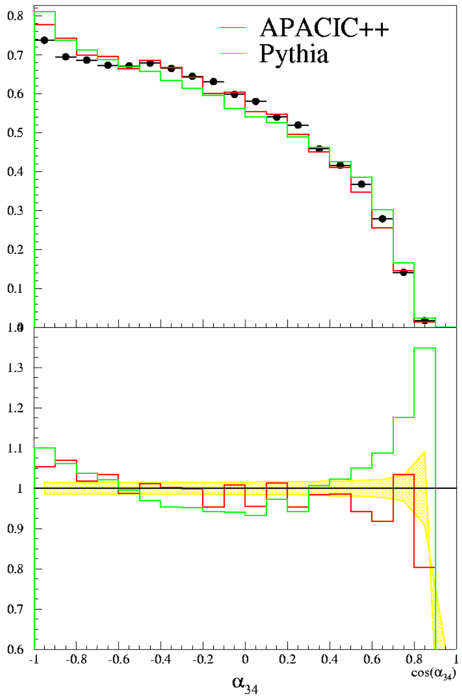
Results

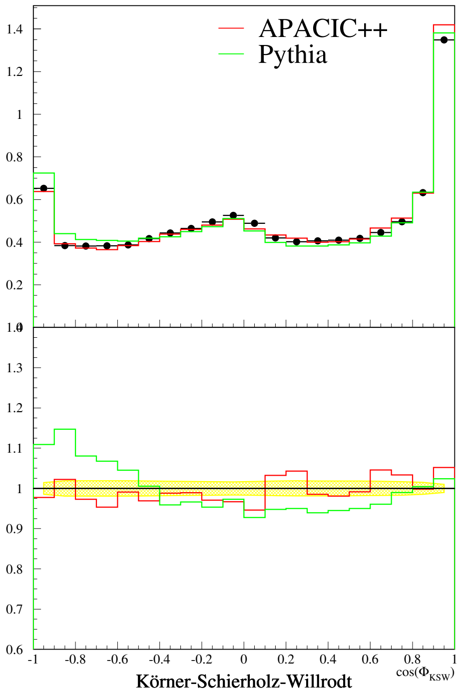
- A lot of work has been done in this area mainly by
  - Frank Krauss et. al. (SHERPA)
  - Leif Lonnblad (ARIADNE)
  - Steve Mrenna PYTHIA)
  - Peter Richardson (HERWIG)
- All have produced results, I will just show some results from SHERPA for e^+e^- and HERWIG for hadron collisions (this is just because these were the easiest plots to get hold of.)

e^+e^- results from SHERPA (four jet angles)



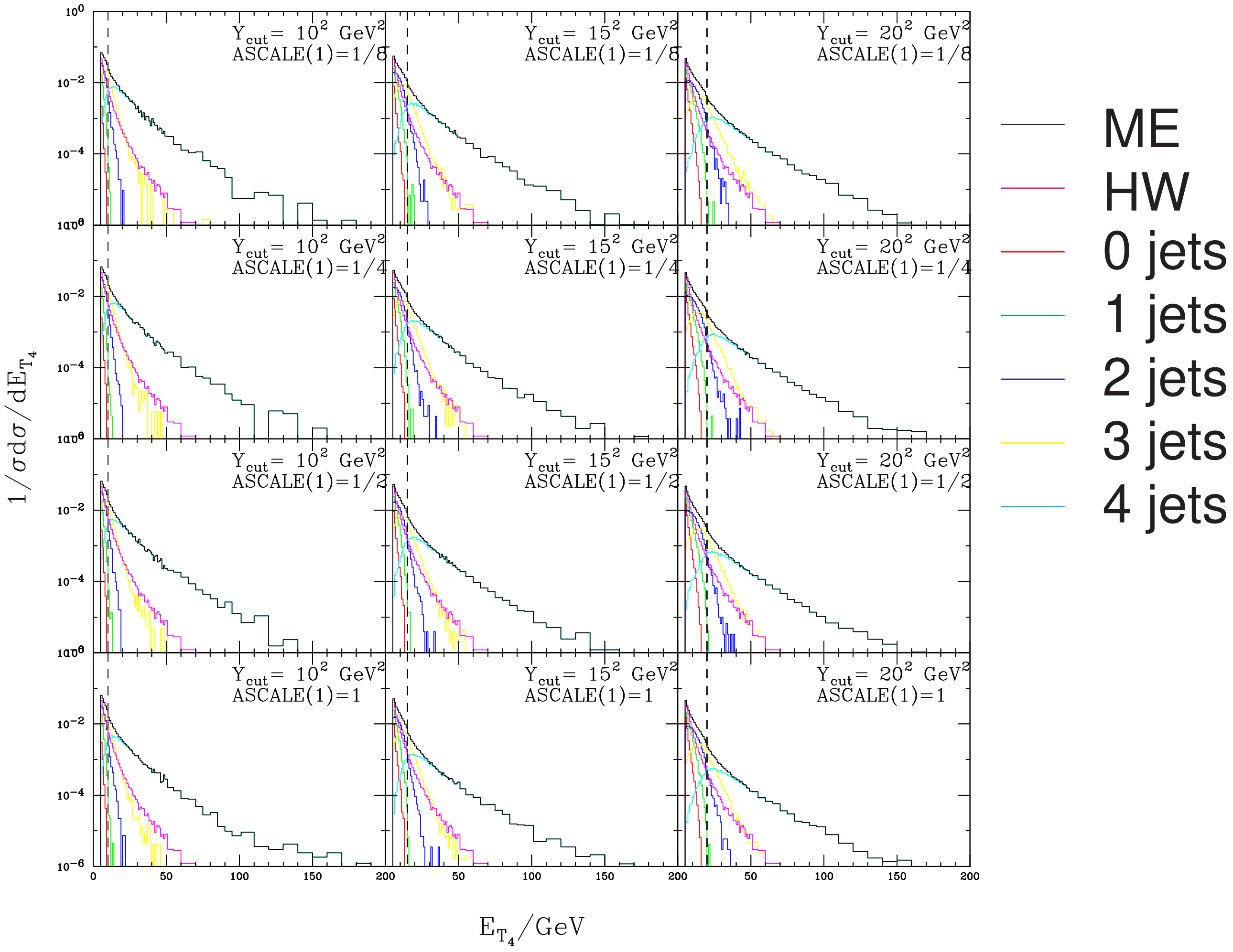






LHC results from HERWIG

- These results are the E_T for the fourth jet in $W+$ jets events.



Comclusions

- There has been a lot of progress in recent years improving hard radiation in the parton shower.
- Surprisingly little has been done for HERA.
- This offers an opportunity to explore these ideas within this workshop and the chance to compare with data.