Our aim for this workshop series: proving that the SHERPA MC is ready for LHC studies.

- validating the SHERPA (CKKW) approach against Tevatron data
- validating it against other ME PS merging approaches
- verifying that it gives reliable results in new (so far untested) channels
- making predictions: extrapolation to LHC energies
- MI model of SHERPA has been shown to work well (HERA/LHC proceedings)

Sorry...!!! SHERPA is still not a MC event generator for DIS scenarios.

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\( a \) SHERPA authors: T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann, J. W.
Sherpa vs. DØ in Z + jets

Challenge: future (and present) hadron collider experiments.

- LHC: first re-discover SM physics
- LHC: these signals will be tomorrow’s backgrounds
- LHC: tremendously large phase space for QCD radiation
- LHC: is a QCD machine → Multijets
- LHC physics: need to understand SM backgrounds

Model...!!!

Jet production → Jet evolution → Hadronization

SHERPA: AMEGIC++’s MEs ← CKKW → APACIC++ Shower →

SHERPA: → PYTHIA (phenomenological) Models
Scope of this talk

Central part: DØ analysis and its preliminary results
- Brief description of the analysis
- SHERPA version used in the analysis
- The results

A brief comment: detailed merging comparison has started
- 1st results in proceedings hep-ph/0601012,13
- Go for a second round.

Status of SHERPA.
The $Z/\gamma^*$+jet-production DØ analysis

Names related with this analysis:

**Henrik Nilsen**
under supervision of Prof. Karl Jacobs, DØ group Freiburg.

Scope:
- Study accuracy of modelling associated jet production in $Z/\gamma^*$ events
- MCs: PYTHIA and SHERPA
- Data: Fermilab Tevatron Run II, Oct 2002 - Nov 2005, int lum 950 pb$^{-1}$

Some details:
- $e^-, e^+ \text{ with } p_T > 25 \text{ GeV, } |\eta| < 2.5$, one central $\ell \text{ with } |\eta| < 1.1$
- variety of single and di-electron triggers, optimized likelihood function to separate real electrons from QCD jet production BG
- $70 \text{ GeV} \leq m^2(e^-, e^+) \leq 100 \text{ GeV}$
- jets according to DØ Run II cone algorithm, $p_T > 15 \text{ GeV, } \Delta R_{\ell j} > 0.5$
- some more work to suppress fake jets and to avoid electron contamination
- Gaussian smearing of jet energies in MC events
- + data zero bias events overlayed to account for other $p\bar{p}$ in same beam crossing
The $Z/\gamma^*$+jet-production DØ analysis

PYTHIA:
- version 6.319 using CTEQ6L1 PDF
- tuned to match a ME prediction for $Z/\gamma^* + 1$ jet production
- UE model: TUNE A parameter set

SHERPA:
- version 1.0.6 with CTEQ6L PDF
- inclusive $Z/\gamma^* + 3$ jet sample, i.e. ME’s up to 3 jets included
- internal separation cut $k_{T,0} = 20$ GeV
- UE model: default (set up according to data used for R. Field’s TUNE A)

Processing:
- full DØ detector simulation and reconstruction chain
- normalization is to total number of $Z/\gamma^*$ events found in data sample
- systematic uncertainties: main contributions arise from jet energy scale and smearing of jet energies
SHERPA version 1.0.6 has been used:

- ME generator AMEGIC++
  (at tree level, provides HP and HD in SM, MSSM, ADD)
SHERPA in the Z+jet-production DØ analysis


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  - Simulation of multiple parton interactions
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Sherpa is the event generation framework:
- initialization of the different phases
- interplay of the various stages
- steering the event generation
Brief note: CKKW is implemented within SHERPA in full generality.

Strategy:

- Divide multijet phase space into two regimes.
  - apply cut $Q_{sep}$ on MEs to regularize divergencies.
  - implies large, unphysical $Q_{sep}$ dependence for fixed multiplicity.
  - jet production through the tree level MEs.
  - jet evolution down to fragmentation scale through the PS.
- Reweight MEs by a combined coupling and Sudakov weight to get exclusive samples at given resolution scale $Q_{sep}$.
- Veto on PS configurations that are already included through higher order ME.
- Reweighting and vetoing eliminate/sizeably reduce the $Q_{sep}$ dependence.
SHERPA in the Z+jet-production DØ analysis

Brief note: CKKW is implemented within SHERPA in full generality.

Visualization:

\[
W = \frac{\Delta g(Q_{\text{jet}}, Q_2)[\Delta q(Q_{\text{jet}}, Q_1)]^2}{\alpha_s(Q_2)} \frac{\alpha_s(Q_{\text{jet}})}{\Delta q(Q_{\text{jet}}, Q_2)}
\]
Brief note: SHERPA uses MI model mainly based on Sjöstrand/Zijl ansatz.

1st results have been presented in the “HERA and the LHC” proceedings: hep-ph/0601012,13

AMISIC++ has been set up to also work with the CKKW merging of SHERPA.

HPs with FS multiplicities different from two require unique definition of the MI start scale.

Employ $k_T$ jet clustering algorithm to identify the last QCD node of the HP that needs to be clustered.

Its $p_T^2$ defines the start scale for the MI evolution, and also the veto scale for the subsequent PS,

since PSs are attached to the secondary interactions initiated at the QCD scale

$\mu^2_{QCD} = 2stu / (s^2 + t^2 + u^2)$. 

Multiple Parton Interactions

Proton

PT(hard)

Underlying Event

Outgoing Parton
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

The transverse momentum of the $e^+e^-$ system.

![Graphs showing data vs. PYTHIA and SHERPA simulations for $p_T$ of Z boson and di-electron system.](image)

- Data vs. PYTHIA
- Data vs. SHERPA

Shaded ranges: MC statistics, central value $\pm 1\sigma$.

Di-electron system has to balance the $p_T$ of the jet system.
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

Jet multiplicity, data vs. PYTHIA (left) and SHERPA (right).

MC predictions are normalized to total number of events observed in data.

large systematic uncertainties arise from low $p_T$ jets $\Rightarrow$ both predictions are in agreement with data.
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

Jet spectra: 1st jet, data vs. PYTHIA (left) and SHERPA (right).

- PYTHIA: clear, positive slope in the ratio; lack of hard jets
- SHERPA: for most bins, prediction consistent with data if syst. errors included
- SHERPA: predictions are too hard around 80 GeV

Jan Winter
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

Jet spectra: 2nd jet, data vs. PYTHIA (left) and SHERPA (right).

- PYTHIA: slope in the ratio gets increased.
- SHERPA: as before, nearly consistent with data, the 80 GeV problem!
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

Jet spectra: 3rd jet, data vs. PYTHIA (left) and SHERPA (right).

With the same pattern as before.
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

→ Eta difference between the two hardest jets in incl \(Z/\gamma^* + 2\) jets.

Studying angular correlations; these should fall into the domain of ME.

Both predictions are consistent with the data.
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

Phi difference between the two hardest jets in incl $Z/\gamma^* + 2$ jets.

Overall normalization is still in agreement with data within the errors.

SHERPA predicts shape that allows for consistency with straight line at 1.

PYTHIA has problems in the lowest and highest (their UE model?) $\Delta \phi$ bins.
Central-jet studies according to Zeppenfeld ideas:

$|\eta_1 - \eta_2| > 2.0$ and $\eta_{1,2} < \eta_3 < \eta_{2,1}$. 
The DØ collaboration, DØ note 5066-CONF

Eta of third jet using the Zeppenfeld definition.

Number of events passing tagging criteria might be too low, for PYTHIA even worse.

\[ \eta^* = \eta_3 - \frac{\eta_1 + \eta_2}{2} \]
Conclusions from our point of view:

- First of all, many thanks go to ...
- SHERPA has been passed through a full detector simulation and it worked.
- Our implemented MI model reasonably/smoothly fits into the CKKW machinery of SHERPA.
- For characteristics,
  - multijets $\Rightarrow$ jet multiplicities and spectra,
  - angular correlations,
  - we have been expected to describe them well, we succeeded.
- Global normalization seems to be sufficient.
Merging approach comparison between ... the MLM, LL and SHERPA ME-PS-merging has started: hep-ph/0602031.

**$E_T$ jet spectra at Tevatron Run II**

$E_T$ jet spectra at Tevatron Run II and the LHC

Impact of scale variation, a 1st estimate of scale uncertainties similar pattern wrt Tevatron broadening of jet in ARIADNE again similar pattern wrt Tevatron once tuned to Tevatron data, same extrapolation to LHC can be expected exploring differences of the merging approaches is essential to assess systematic uncertainties of multijet calculations

2nd round: more observ. (correlations, intrajet ch.), scale variat., residual param. depend.
Merging approach comparison between the MLM, LL and SHERPA ME-PS-merging has started: hep-ph/0602031.

$E_T$ jet spectra at Run II

Alpgen $\mu_R \times 0.5$

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$E_T$ jet spectra at the LHC

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$\eta$ jet spectra at Tevatron Run II

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Merging approach comparison between ... the MLM, LL and SHERPA ME-PS-merging has started: hep-ph/0602031.

- $\eta$ jet spectra at the LHC
- Impact of scale variation, a 1st estimate of scale uncertainties
- Similar pattern wrt Tevatron
- Broadening of jet $\eta s$ in ARIADNE
- Again similar pattern wrt Tevatron
- Once tuned to Tevatron data, same extrapolation to LHC can be expected

Jan Winter
HERA/LHC workshop at CERN, Geneva, June 7, 2006 – p.20
Merging approach comparison between ...

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\[ p_T(W) \] and $\Delta \eta$ spectra at Tevatron Run II

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\( p_T(W) \) and \( \Delta \eta \) spectra at the LHC

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Once tuned to Tevatron data, same extrapolation to LHC can be expected

Exploring differences of the merging approaches is essential to assess systematic uncertainties of multijet calculations

2nd round: more observ. (correlations, intrajet ch.), scale variat., residual param. depend.
SHERPA version 1.0.8 has been released recently:

- ME generator AMEGIC++
- IS/FS shower module APACIC++
- Combination of ME and PS according to CKKW
- Multiple interactions module AMISIC++
- Interface to PYTHIA’s string hadronization
- Interface to PYTHIA’s hadron decays
  Own hadron-decay framework and tau decay library

More new features:

- revised SUSY sector (SUSY comparison: K. Hagiwara et al., Phys. Rev. D73, 055005 (2006)), including SLHA interface
- decay chain treatment for heavy unstable particles in MEs
- revised CKKW sector (QCD jets, VBF) simply a number of bug fixings