SUMMARY OF THE HADRONIC FINAL STATE WORKING GROUP

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The contributions to the Hadronic Final State Working Group sessions are summarised.

EXPERIMENTAL TALKS

1. Jets in DIS

Jet production in neutral current DIS at not too low Q^2 allows for precision test of QCD already with NLO predictions. Hadronisation corrections are generally small at medium to high jet E_t. High precision data from HERA is being used for $\alpha_s(m_Z)$ determinations with competitive uncertainties.

Inclusive jet cross sections at high Q^2 were investigated by H1 (S.Maxfield). The data, presented double differentially in Q^2 and E_t are corrected for hadronisation and are well described over the whole phasespace by the NLOJET++ prediction. This allow for a fit of $\alpha_s(m_Z)$ using the CTEQ4A pdf series. The procedure was performed separately for all bins, the consistent results were combined into an average value which is consistent with the world average and previous H1 determinations.

A determination of $\alpha_s(m_Z)$ using inclusive jets was shown by ZEUS (M.Jimenez). The Q^2 and E_t distributions of the jets are reproduced by NLO using DISENT and MRST99 pdfs when corrections for hadronisation are applied. For the determination of $\alpha_s(m_Z)$ the phasespace was restricted to the highest Q^2, where theoretical uncertainties are smallest. This yields a very precise total uncertainty.

ZEUS (T.Schoerner-Sadenius) presented new measurements of inclusive and dijet cross sections at high Q^2. The dijets are presented single differentially in quantities like the dijet mass and are an extension of former results by ZEUS. The very precise data are well described by pQCD within the experimental uncertainties and give constraints on the gluon density. Consequently, this data will be used in future QCD fits.

2. Jets in Photo Production

The larger cross section for photo production allows for the extension of jet analyses to higher E_t ranges. Resolved contributions need the inclusion of parton density functions of the photon, however it is also possible to enrich direct contributions. Resolved photo production shares several properties with p-(anti)p collisions, like the importance of the underlying event.

H1 (K.Krüger) presented a recent measurement of dijet production at high transverse momenta. The cross sections are determined differentially in E_t and x, separated in direct and resolved enriched subsamples. NLO calculations corrected for hadronisation effects provide a good description over the full phase space. Direct enriched distributions will be included in future QCD fits of the proton density functions and the strong coupling. On the other hand, the resolved subsamples are suitable to provide further constraints on the photon pdfs.

A measurement of three and four jet cross sections in photo production was shown by ZEUS (T.Namsoo). It was found that at low invariant 3- and 4-jet masses the predictions by PYTHIA and HERWIG significantly underestimate the data. An improvement is achieved when including multi parton interactions (MPI), given that the MPI parameters are tuned to the data. An open issue is that the inclusion of MPI appears to deteriorate the distribution of the kinematic variable y.

An investigation of dijets in photo production, where the dijets are separated by a large gap in rapidity, was presented by ZEUS (P.Ryan). A large rapidity gap can be generated due to a fluctuation of the particle flow as well as the exchange of a hard scale color singlet object, the pomeron.

The new data can only be described by the addition of a color singlet exchange.

3. Parton Dynamics

Jet data at HERA are over a large range in phase space well described by calculations using the DGLAP evolution equations. At low x and Q^2 terms proportional to $\alpha_s \log(1/x)$ (corresponding to gluon emission unordered in k_t) may lead to a break down of DGLAP. It is interesting whether CCFM or BFKL like dynamics give an improved description in this phasespace.

Forward jet production in DIS at low x and low Q^2 has been investigated by H1 (C.Risler). In order to suppress the phase space for DGLAP evolution, forward jets are selected with transverse momenta similar to the photon virtuality. Contrary, the phase space for BFKL evolution is favoured by requiring that the forward jet takes a large fraction of the proton momentum. In addition event configurations with a dijet system on top of the forward jet are measured. Single and triple differential cross sections are extracted, where DGLAP alone is found to be not sufficient to reproduce the data, however CCFM (as implemented in CASCADE) provides a not good as well. Best results are obtained by models with parton emission employing a breaking of k_t ordering, namely the color dipole model and inclusion of resolved photons.

Another investigation by H1 (C.Werner) concentrates on 3-jet cross sections. A DGLAP based prediction at LO proves to be not sufficient, especially at low Bjorken x and in the forward region. NLOJET++ provides a NLO DGLAP calculation, which improves the description significantly, still the cross section are underestimated. The color dipole model, as implemented in ARIADNE, is found to be particularly suitable. In consequence, unordered gluon emission appears to play an important role at low x. H1 (M.Hansson) presented a measurement of dijets angular decorrelations in DIS at low x. At LO and with DGLAP parton dynamics the dijets are forced to be back to back in the hadronic center of mass frame. Higher orders are needed to obtain deviations from this configuration, quantified by $\Delta\phi \neq 180°$. The k_t ordering of DGLAP restricts artificially the available phase space for additional gluon emission at low x. The DGLAP calculation with the highest order available is NLOJET++ with 3-jet at NLO. In the presented analysis this prediction is found to be not sufficient to describe the $\Delta\phi$ spectrum, which gives a hint that higher orders are needed. CASCADE (CCFM) gives a good description, however depending on the

unintegrated pdfs used. Thus the measurement of $\Delta\phi$ can be used in the future to constrain the unintegrated pdfs.

4. Event Shapes

Event shape variables play an important role in QCD studies of the hadronic final state since a long time. There are several differences compared to jet cross sections: larger statistics due to the semi-inclusive nature of event shapes, reduced experimental systematic uncertainties from hadronic energy scales and larger hadronisation effects. For differential distributions, fixed order calculations alone proved to be not sufficient, hence soft gluon resummations are supplementing the NLO predictions.

The LEP experiments (M.Tasevky) have measured a variety of event shape variables at different center of mass energies of LEP. Observables may be distinguished by how many partons (jets) are needed in the final state for non trivial results: e.g. 3-jet and 4-jet variables. In general the 3-jet distributions measured by the LEP experiments are well described by event generators like PYTHIA. Problems arise at extreme 2-jet regions and for 4-jet observables at low scales (LEP1). ALEPH obtained a good description as well using NLO+resummed calculations, corrected for hadronisation using models. This event shape as well as jet rate data have been used by the LEP experiments (T.Wengler) to determine $\alpha_s(m_Z)$, using NLO+NLLA resummed calculations. Regions for fits were selected where the theory is well behaved. The dominating uncertainty is the theory error, which is around 5%. An especially good precision is obtained using the 4-jet rate, however rather few measurements are available for this kind ob observable, hence less cross checks are possible, compared to 3-jet observables. Overall, a very consistent picture for the different methods in determining $\alpha_s(m_Z)$ at e^+e^- arises.

H1 (J.Turnau) presented recently published distributions of five 2-jet event shape variables. For the first time, this distributions are compared to calculations based on fixed order and matched resummed parts. To take into account hadronisation Dokshitzer/Webber power corrections (PC) have been used. Simultaneous fits of $\alpha_s(m_Z)$ and the power correction parameter α_0 yield results consistent to the world mean of $\alpha_s(m_Z)$. The results support the assumption of an universal value of α_0 around 0.5 at the 10% level. This holds for distributions as well as for mean values of the event shape variables. Moreover, the fits were performed separately for all scales covered by the data, where asymptotic freedom of QCD is clearly

demonstrated.

ZEUS (A.Savin) presented an analysis of the same event shape variables, which was recently published as well. The data appear to be consistent with H1 the results, on the theory side very similar calculations have been used. For the simultaneous fits of $\alpha_s(m_Z)$ and the power correction parameter α_0 a large dependence of the results on fit intervals was found. Large theory errors due to neglected higher orders and degrees of freedom in some parameters are observed. In addition to the 2-jet variables also 3-jet event shapes were measured, however the theory for this is not that far developed, as NLO+NLLA+PC is not yet available.

5. Production of prompt photons

Prompt-photon production in hadron-induced reactions probes the partonic content of the proton in a cleaner way than jet production; prompt photons emerge directly from the hard scattering, in contrast to quarks and gluons, which undergo fragmentation into hadrons. New results on prompt-photon production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV from the DØ Collaboration were presented by A. Kumar. The large statistics available by using an integrated luminosity of 326 pb^{-1} has allowed an extension of previous measurements to significantly higher values of the transverse momentum of the photon (p_T^γ). The cross-section $d\sigma/dp_T^\gamma d\eta$ for the production of prompt photons with pseudorapidities in the range $|\eta| < 0.9$ and transverse momenta in the range $23 < p_T^\gamma < 300$ GeV has been compared to NLO QCD calculations using current parametrisations of the proton PDFs. These calculations, in which the dominant contribution to the region $p_T^\gamma < 150$ GeV arises from the Compton process $qg \to q\gamma$, agree with the data.

In the photoproduction regime of ep collisions at HERA, prompt-photon production is sensitive to both the partonic content of the proton (e.g. $q\gamma \to q\gamma$) and of the photon (e.g. $qg \to q\gamma$). Requiring the presence of a jet in addition to the prompt photon provides a handle on the production mechanism. New measurements of prompt photons with associated jets using an integrated luminosity of 77 pb^{-1} and, for the first time, a preshower detector, were presented by E. Brownson on behalf of the ZEUS Collaboration. The differential cross section for the production of prompt photons with $5 < E_T^\gamma < 16$ GeV and jets with $6 < E_T^{jet} < 17$ GeV were measured as a function of the prompt photon and jet variables. Leading-logarithmic parton-shower calculations disagree with the data. NLO QCD calculations provide an improved description, but they still underestimate the data at

low values of E_T^γ and E_T^{jet}.

Prompt-photon production in neutral current DIS at HERA allows the study of the underlying dynamics without the uncertainties associated to the photon structure and offers the potential to constrain the fragmentation function of quarks into photons. New measurements of inclusive prompt-photon production in the kinematic region $Q^2 > 4\,\mathrm{GeV}^2$ using an integrated luminosity of 71 pb^{-1} were presented by C. Schmitz on behalf of the H1 Collaboration. The cross section for the inclusive production of prompt photons was measured differentially in η^γ over the region $-1.2 < \eta^\gamma < 1.8$; at large η^γ, the dominant contribution comes from photon radiation off the quark line, whereas in the region $\eta^\gamma < -0.6$ the dominant contribution arises from photon radiation off the electron line. A new perturbative LO $\mathcal{O}(\alpha^3)$ calculation reasonably describes the data.

6. Jet and W production in hadron-hadron collisions

Jet production in $p\bar{p}$ collisions at Tevatron probes the dynamics of quark and gluon interactions at the smallest distances. The production of jets also probes the partonic content of the proton. To disentangle possible deviations arising from new physics from those due to poorly known proton PDFs, measurements of jet production have been made in different regions of the jet rapidity; forward (central) jet production is particularly sensitive to the proton PDFs (new physics). Preliminary results on inclusive-jet production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV based on an integrated luminosity of 1 fb^{-1} from the CDF Collaboration were presented by O. Norniella. The increased center-of-mass energy in Run II, the highly upgraded CDF detector and the large statistics accumulated have allowed measurements in an extended region of jet transverse momentum (p_T^{jet}) and rapidity (y^{jet}). Results were presented of the inclusive-jet cross section using the k_T-cluster algorithm with $D = 0.7$ for jets with $p_T^{jet} > 54$ GeV/c in five jet rapidity regions up to $|y^{jet}| = 2.1$. NLO QCD calculations using the CTEQ6M1 parametrisations of the proton PDFs describe the data well in all rapidity regions. In the forward region, the experimental uncertainties are smaller than the sensitivity to the proton PDFs and, therefore, these measurements will provide a better understanding of the gluon density in the proton at high x.

New preliminary measurements of inclusive-jet production from the DØ Collaboration using an integrated luminosity of 0.8 fb^{-1} were presented by M. Voutilainen. Results were presented in two central rapidity regions,

$|y^{jet}| < 0.4$ and $0.4 < |y^{jet}| < 0.8$, using an iterative cone algorithm with radius $R_{cone} = 0.7$. The measurement at $p_T^{jet} = 100$ GeV/c for $|y^{jet}| < 0.4$ was normalised to the theoretical prediction to avoid the uncertainty associated to the luminosity determination. NLO QCD calculations supplemented with threshold corrections in the two-loop approximation and using the CTEQ6M1 parametrisations of the proton PDFs describe the data well.

The production of W bosons in association with jets in $p\bar{p}$ collisions represents a testbed of new approaches to perturbative QCD calculations for multi-parton final states. Furthermore, understanding the production of W + jets will be useful to reduce the uncertainty on the background to top pair production and to improve the searches for new particles at the Tevatron and LHC. New measurements on the inclusive production of W bosons in association with up to four or more jets in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV from the CDF Collaboration using an integrated luminosity of 320 pb^{-1} were presented by A. Messina. Results were presented as functions of the relevant jet kinematic variables. W boson candidates were identified by the leptonic decay $W \to e\nu$ and jets were reconstructed using an iterative seed-based cone algorithm with a cone radius $R = 0.4$. Calculations based on ALPGEN plus PYTHIA describe well the shape of the measured distributions as functions of the jet transverse energy in each jet multiplicity sample as well as the dijet invariant mass and the jet angular correlations in the $W+ \geq 2$ jets sample.

Jet production in polarised proton-proton collisions at RHIC opens a new window into the dynamics of quark and gluon interactions. Preliminary measurements of the inclusive-jet cross section in polarised proton-proton collisions at $\sqrt{s} = 200$ GeV from the STAR Collaboration using an integrated luminosity of 0.16 pb^{-1} were presented by M.L. Miller. The cross section for inclusive-jet production has been measured over the range $5 < p_T^{jet} < 50$ GeV/c using an implementation of the midpoint-cone algorithm. The cross section as a function of p_T^{jet} shows a steep fall-off of seven order of magnitudes and is reasonably described by NLO QCD calculations.

Prospects for top pair production in the fully hadronic channel in pp collisions at LHC with the CMS detector were presented by C. Ciocca. With an integrated luminosity of 10 fb^{-1}, 8 million $t\bar{t}$ events are expected at the LHC, making this machine a top factory in which to measure the top-quark properties with precision. The fully hadronic channel $t\bar{t} \to WWb\bar{b} \to qqqqb\bar{b}$ has the largest branching fraction and allows full reconstruction of the kinematics, but suffers from a very large background from QCD multijet production and difficulties in triggering. Big efforts have been

invested in the definition of an specific trigger, the use of an optimized kinematical selection to enhance the signal over the background and b-tagging techniques. These developments provide a way to isolate a sample of $t\bar{t}$ events in the fully hadronic channel with an efficiency of 2.7% and a signal to background ratio of $S/B = 1/5$ for the case of two b tags; the use of a neural net improves S/B to $1/2$, making possible precision measurements of the top-pair production cross section and the top-quark mass in this channel.

7. Particle production

Measurements of the scaled momentum distributions of charged final-state hadrons in the Breit frame of neutral current DIS from the H1 Collaboration were presented by D. Traynor. The large statistics available has made possible an extension to higher Q^2 than before and to the full range in the scaled momentum variable $x_p = 2p_h^{\pm}/Q$, where $p_h^{\pm}$ is the momentum of a charged track in the current region of the Breit frame. The predictions of Monte Carlo programs which implement parton radiation either via the colour-dipole model or the parton-shower approach supplemented with hadronisation using the string model describe the data. The results have been compared with measurements in one hemisphere of e^+e^- annihilation and found to be in good agreement, demonstrating the universality of quark fragmentation.

Measurements of K_S^0, Λ and $\bar{\Lambda}$ production in neutral current DIS and photoproduction at HERA from the ZEUS Collaboration were presented by A.A. Savin. The baryon-antibaryon asymmetry, $A = (N(\Lambda) - N(\bar{\Lambda}))/(N(\Lambda) + N(\bar{\Lambda}))$, is found to be small in agreement with the predictions of Monte Carlo generators in both NC DIS and photoproduction. The baryon to meson ratio $R = (N(\Lambda) + N(\bar{\Lambda}))/N(K_S^0)$ at fixed x_{Bj} increases as Q^2 increases, a trend which is reasonably described by the models. In photoproduction, the measured R is larger for resolved- than for direct-photon processes; whereas PYTHIA describes the measurements in the direct-photon enriched region, it underestimates the data in the resolved-photon enriched region. This disagreement is due to the contribution of those events in which the jet with the highest transverse energy carries at most 30% of the total transverse energy (fireball type of events).

Results on the production of (anti)deuterons and (anti)protons in DIS at HERA from the ZEUS Collaboration were presented by T. Matsumoto. The measurements are based on an integrated luminosity of 120 pb^{-1}. It

was reported that it constitutes the first observation of antideuterons in DIS at HERA. For comparison with other experiments, the ratios $\bar{d}/\bar{p}$ and $\bar{p}/p$ were measured for $0.3 < p_T/M < 0.7$ in the rapidity region $|y| < 0.4$. The measured rate of antideuterons is about three to four orders of magnitude smaller than that of antiprotons, in broad agreement with other experiments. The measured ratio of $\bar{p}/p$ is consistent with unity.

Photoproduction cross sections of $\Lambda(1520)$ and $\bar{\Lambda}(1520)$ from the HERMES Collaboration using an integrated luminosity of 209 pb^{-1} were presented by S. Wang. The candidates were reconstructed using the decay channels $\Lambda(1520) \to pK^-$ and $\bar{\Lambda}(1520) \to \bar{p}K^+$. Measurements were reported of the photoproduction cross sections for hyperons with longitudinal momentum above 6 GeV, $\sigma_{\Lambda(1520)}$ and $\sigma_{\bar{\Lambda}(1520)}$, as well as of its ratio. Such measurements represent useful information to understand the production mechanism of nearby resonances, such as the exotic Θ^+.

Recent results on the observation of new particles produced in e^+e^- collision at the $\Upsilon(4S)$ from the Belle Collaboration were reported by A. Kuzmin. The decay $B \to D^{(*)}\pi\pi$ has allowed the study of D^{**} production: the first observation of the states D_0^{*0} and $D_1^{\prime 0}$ as well as measurements of their masses, widths and branching fractions. A new charmonium state, $X(3872)$, was observed using the decay $B^+ \to K^+\pi^+\pi^- J/\Psi$. Evidence of the decays $X(3872) \to \gamma J/\Psi$ and $X(3872) \to \pi^+\pi^-\pi^0 J/\Psi$ have been found. The increased statistics strongly favors a 1^{++} assignment for the $X(3872)$. Additional new resonance states were reported demonstrating the unique capabilities of the Belle experiment.

Measurements of particle production inside jets in $p\bar{p}$ collisions at Tevatron from the CDF Collaboration were reported by A. Korytov. Results were presented on the momentum distributions of particles in jets, on multiplicity of charged particles in jets as well as on momentum correlations of particles in jets. The results were compared with perturbative QCD calculations in the MLLA framework supplemented with the hypothesis of local parton-hadron duality. The measured particle distributions are reasonably described by the perturbative QCD calculations for partons.

THEORY TALKS

8. Fix order calculations

8.1. *Born level cross sections*

Calculating the hard-scattering cross section with multi-particle final state is already a challenging task at Born level. Fortunately we don't have to

deal with ultraviolet (UV) and infrared (IR) singularities but the complexity of the calculations grows factorial with the number of external legs.

Malgorzata Worek presented the HELAC fully automated program for generating matrix elements at Born level within the Standard Model and perform the phase space integral efficiently. The advantage of the HELAC project is that the program generates basic building blocks according to the Dyson-Schwinger recursive relations instead of generating the Feynman graphs separately. Furthermore the helicity and color sum of the external partons are perform by Monte Carlo summation. With this technics the computational efficiency is $\mathcal{O}(N^3)$.

Johan Alwhall presented the MadGraph program for generating any multi-particle matrix elements automatically for Standard Model and MSSM processes. However this program generates Feynman graphs directly that can worse the performance but the $2 \to 6, 7$ process are still feasible. The MADGRAPH has several good feature: i) It comes user friendly graphical and web interface. ii) It is interfaced to parton shower programs according to the Les Houches Accord. iii) Interfaced to the CKKW method to combine multi-parton hard matrix element and parton shower. iv) A general interface implemented to add other theories such as two Higgs doublet model or extended super-symmetric model.

8.2. *Next-to-leading and higher order calculations*

Since the strong coupling is relatively large the leading order calculations completely fails in most of the cases. The Born results strongly depend of the unphysical renormalization and factorization scales. In order to fix this strong scale uncertainty we must calculate the cross section at least at next-to-leading order (NLO) level.

The multi-particle NLO computations are usually very complicated and require enormous amount of CPU time. Since the current jet data are accurate enough to use them for parton distribution function (PDF) fit but the speed of the NLO computation is a serious issue. Marcus Wobisch presented the FASTNLO project. This is a complementary tool for the existing NLO computation. The basic idea is to expand the PDFs on a suitable set of basis functions and calculate the cross sections on this basis once. This step is very time consuming but once it is done a new calculation with another PDF set takes only nanoseconds. However the authors of the FASTNLO project encourage the NLO community to make them NLO program ready for FASTNLO, at the moment only the NLOJET++ can

cooperate with the FASTNLO interface.

One of the main complication in the NLO calculation is the 1-loop amplitudes. With the current analytic techniques we can basically calculate any $2 \to 3$ processes. It is clear at the LHC we need more complicated process at NLO level and the automatization of the NLO calculation is necessary. One possible solution could be the numerical evaluation of the loop integral. Alejandro Daleo presented a numerical method for loop integrals based on the Mellin-Barnes representation of the Feynman integral.

Since the automated NLO program is not available yet, we have to do the NLO calculation process by process for the most interesting cases. Carlo Oleari presented NLO result for Higgs and vector boson production in vector boson fusion. Bern Kniehl talked about one-hadron inclusive NLO level cross section in deep inelastic scattering.

Where the NLO fails to do its job we need NNLO computation. For example in the measurement of the strong coupling the main uncertainty is theoretical or in Higgs production where the NLO correction is huge ($> 100\%$). Vittorio Del Duca gave a status report on the progress of NNLO calculations.

9. Resummation and all order calculations

In some phase space regions the fix order calculations fail. This regions are dominated by large logarithms and their resummation is needed.

In the high energy limit the cross section can be approximated by the solution of the BFKL equation. Jeppe R. Andersen presented a Monte Carlo method for solving the BFKL equation at next-to-leading logarithmic (NLL) accuracy. The advantage of this method that the events are fully exclusive and one can calculate the cross section in the high energy limit all order for any jet observable. The method is also applicable for small-x studies at NLL accuracy.

Nicolaos Kidonakis presented a method for calculating soft gluon corrections in hard processes through NNNLO. Large logarithms enhance QCD cross sections when the scattering energy is barely above the threshold in the considered particle production channel. The process independent master formula has been derived, and its application to top quark production was described.

Feng Yuan presented a method for resumming soft gluons using effective field theory and its application for Higgs production. Mrinal Dasgupta discussed some theoretical difficulties of the resummation of the interjet

transverse energy flow with $k_\perp$ jet algorithm.

10. Jet algorithms

The systematically defined jet algorithm is very important for the current and future collider experiments. A well defined jet algorithm must be collinear and infrared safe otherwise we are not able to do theoretical predictions in the perturbative framework.

At lowest order in the perturbative calculation every parton in the final state correspond to a jet. At higher order level one jet can contains more partons. One can address the question if it is possible to define the jet flavor. In the leading order calculation it is certainly possible and the physical meaning of the jet flavor is obvious but with the current jet algorithms the sum of the parton flavors in the jet is infrared unsafe quantity. We have problem when a soft gluon splits to quark antiquark pair with large angle and they are clustered into two different jets. Gavin Salam presented a solution for this problem and defined a modified $k_\perp$ jet algorithm in such a way that the jet flavor is infrared safe quantity.

The jet clustering algorithm are very time consuming procedures. For example clustering 2000 particles into jets takes about 10 seconds with any jet algorithm. Naively the $k_\perp$ algorithm scales like $\mathcal{O}(N^3)$ with number of the particles. The main problem of the implementation is to find the nearest neighbor to a particle. Matteo Cacciari talked about the FASTJET algorithm which is a new implementation of the $k_\perp$ algorithm that is based on the Voronoi diagram. The idea is to store the clustering informations in a clever way and the minimum finding problem of the $k_\perp$ algorithm can be translated to a geometrical problem. This implementation scales like $\mathcal{O}(N \log N)$ with the number of particles. With FASTJET clustering 2000 particles takes about 0.01 second.

11. Parton shower

The parton shower algorithms simulate multi-parton final state in particle collision processes. These are essential tools for the experimentalist especially in detector simulation but we cannot consider their results as QCD prediction. There are two way two improve our Monte Carlo tools; one is to make the parton shower more precise by building in more and more QCD information, the other is to combine the parton shower algorithm with exact hard matrix elements at LO and NLO level.

Leif Lönnblad talked about current progress on development of shower

Monte Carlo programs. He developed a general purpose C++ library (ThePeg) for implementing parton shower algorithms. This computes a framework at very abstract level and provides useful tools such as lorentz vector, memory management and tools for CKKW matching. Ariadne++, Pythia7 and Herwig++ are already in this framework.

11.1. *Matching parton showers and NLO computations*

One way to improve the shower Monte Carlo programs is to add higher order contributions to the hard part. It is not an easy task because the next-to-leading corrections contains some contributions which are already provided in the first step of the shower, thus one has to deal with the so called double counting problem.

Stefano Frixione gave a status report on MC@NLO program. This program can calculate several processes at NLO level with shower correction those are mainly $2 \to 0$ or $2 \to 1$ type processes like $pp \to ZZ$ or $pp \to H, Z, W^{\pm}$ but it can also deal with heavy quark pair in the final state. The MC@NLO program is based on the Herwig parton shower algorithm but in principle the matching procedure is applicable for any parton shower implementation.

Paolo Nason presented a new matching procedure that can be interfaced to any parton shower implementation and it provides only positive weights. The idea is to treat the first emission as part of the NLO calculation and the rest of the emissions are managed by the parton shower program. Some preliminary results were shown for $pp \to ZZ$ process.

12. Conclusion, outlook

This short article does not attempt to give more than a flavour of the diverse topics presented during the Hadronic Final State sessions of the conference. The reader can find the full details of each presentation within the individual contributions. Several conclusions can be drawn from this overview, which of course do not cover the whole span of important topics discussed in many interesting talks.

Acknowledgments

We would like to thank the organizers of the conference for a well prepared conference and for providing a warm atmosphere that led to many lively physics discussions.