

Measurements of jet rates with the anti- k_T and SiScone algorithms at LEP with the OPAL detector

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We study jet production in e^+e^- annihilation to hadrons with data recorded by the OPAL experiment at LEP at centre-of-mass energies between 90 GeV and 207 GeV. The jet e^+e^- production rates were measured for the first time with the anti- k_T and SiScone jet clustering algorithms. We compare the data with predictions by modern Monte Carlo event generators.

1 Introduction

The strong interactions in the Standard Model are described with Quantum Chromodynamics (QCD). The verification of the predictions of QCD is essential for the understanding of Standard Model and is instrumental for searches of the physics beyond the Standard Model. One of the precise QCD predictions, which depends strongly on the only theory parameter, the constant of strong interaction α_s , is the topology of the $e^+e^- \rightarrow$ hadrons events, i.e. multi-jet events.

Recent theoretical developments allow to make predictions for this process even more precise than before. In the same time, these events can be studied for the first time with the recently developed jet clustering algorithms. The presented analysis aims to provide such measurements.

2 Jet algorithms

A jet clustering algorithm is a way to simplify the high energy collision event topology and exhibit the underlying physics at the parton level. The main goal of such a procedure is to reconstruct the kinematic variables of the partons produced during the primary hard interaction. The energy and the momenta of the partons are reconstructed by combining momenta and energy of the charged and neutral particles which are clustered into jets. Several jet algorithms are used to perform the combination in different environments – e^+e^- , pp or $e^\pm p$ collisions. A detailed overview of their properties can be found elsewhere¹. Basically, the contemporary algorithms can be divided in two groups: the sequential recombination algorithms and the cone algorithms.

The jets clustered with the sequential recombination algorithms are defined with the clustering procedure. The objects in the event are sequentially recombined into jets taking into account a pairwise distance measure between them. The definition of the distance measure, the order of recombination, the recombination scheme and the criteria to stop the procedure are the intrinsic properties of the algorithm.

The cone algorithms use a concept of cone object, which is defined as a set of considered objects with some given properties, e.g. having the jet energy above the defined threshold E_{cut} .

In this analysis two new jet algorithms, SiScone^{2,3,4} and anti- k_T ^{5,3} are applied to $e^+e^- \rightarrow$ hadrons events. For both algorithms the used value of the R parameter, the angular jet size (radius) was equal to 0.7 for the basic studies. The maximal fraction of the energy shared

between jets was set to 0.75. For a comparison with previously published results a PxCone algorithm was used⁶.

3 The OPAL detector

A detailed description of the OPAL detector can be found elsewhere^{7,8}. Briefly OPAL is a multi-purpose detector with 93% solid angle coverage. Tracking of charged particles was performed by a central detector, enclosed in a solenoid which provided a uniform axial magnetic field. The solenoid coil was surrounded by a time-of-flight counter array and a barrel lead-glass electromagnetic calorimeter with a presampler. Outside the electromagnetic calorimetry, the magnet return yoke was instrumented with streamer tubes to form a hadronic calorimeter. The detector was completed with muon detectors outside the magnet return yoke. The integrated luminosity was evaluated using small angle Bhabha scattering events observed in the forward calorimeters⁹.

4 Data and Monte Carlo samples

The analysis is based on the data samples obtained between 1995 and 2001 at the centre-of-mass energies close to $\sqrt{s} = 91, 130, 136, 161, 172, 183, 189, 192, 196, 200, 202, 205, 207$ GeV (see a summary elsewhere¹⁰). For presentation purposes the results were combined into four samples with the average energies $\sqrt{s} = 91, 133, 177, 197$ GeV.

For the correction of the reconstructed events to the hadron (particle) level Monte Carlo samples with simulation of $e^+e^- \rightarrow$ hadrons events were produced with KK2f¹¹ and hadronised with Pythia 6.1¹² or Herwig 6.2¹³ generators. For the reconstruction of the events at the particle level all undecayed particles were used.

For the estimation of background from $e^+e^- \rightarrow W^+W^- \rightarrow qq\bar{q}\bar{q}$ and $e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}l\bar{l}$ processes, the Monte Carlo samples were produced with the grc4f2.1¹⁴ and KORALW1.42¹⁵ generators and hadronised with JETSET¹⁵. The samples above were passed through the Geant3-based¹⁶ OPAL detector simulation¹⁷ and reconstructed in the same way as the data.

5 Event selection and reconstruction

The performed event selection is identical to the one used in the previous jet analyses¹⁰. Briefly, the events were rejected if the tracking system, electromagnetic calorimeter or the trigger system were inoperational, less than five tracks were reconstructed or the event had energetic initial state radiation^{9,10}.

The events were required to have $|\cos\theta| < 0.95$, where the θ is the polar angle of the thrust axis calculated from all track and cluster objects. The events with a high probability to contain $e^+e^- \rightarrow W^+W^- \rightarrow qq\bar{q}\bar{q}$ or $e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}l\bar{l}$ processes¹⁸ were rejected.

The input for the reconstruction procedure at the (simulated) detector level was a set of tracks and the electromagnetic calorimeter clusters. To avoid double counting of the clustered objects an energy-flow algorithm^{19,20}, matching tracks to the clusters in the electromagnetic calorimeter was applied.

The measured distributions of the jet rates were obtained in the following way. To take into account the presence of $e^-e^+ \rightarrow W^-W^+$ background events the simulated detector level distributions of the $e^+e^- \rightarrow W^+W^-$ events weighted to the same luminosity as the data were subtracted from the detector level distributions. The obtained distributions were corrected bin-by-bin to the detector effects. The corrections were obtained as a ratio of the simulated detector level distributions and the particle level distributions of the same events. Finally, the distributions were normalised to the number of weighted entries.

The systematic uncertainties on the obtained results had several sources. The procedure of systematic uncertainties estimation is exactly the same as in the previous analyses¹⁰. The dominant systematic effects are the hadronisation modelling uncertainties.

6 Results and discussion

The results obtained with the SiScone and anti- k_T jet algorithms are shown^a in Fig. 1.

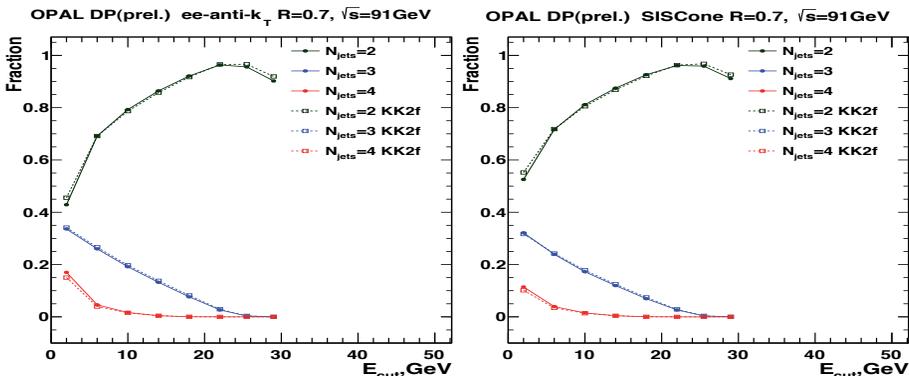


Figure 1 – The 2-,3- and 4-jet rates distributions with anti- k_T $R = 0.7$ (left) and SiScone $R = 0.7$ (right) jet clustering algorithms for $\sqrt{s} = 91$ GeV. The data is corrected to the particle level. The KK2f Monte Carlo samples are hadronised with Pythia6.

As the results of the clustering procedures strongly depend on the value of cone radius R this dependence was studied, see Fig. 2.

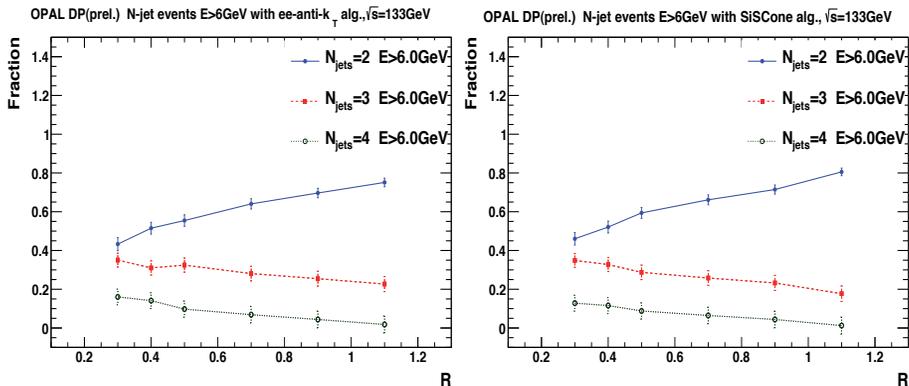


Figure 2 – The fraction of 2-, 3- and 4-jet rates with energy $E_{\text{cut}} > 6$ GeV versus R for anti- k_T (left) and SiScone (right) jet clustering algorithm for $\sqrt{s} = 133$ GeV. The data is corrected to the particle level.

The measurements obtained in the previous sections were compared to the predictions of three Monte Carlo generators: Herwig++²¹, Pythia8.2²² and SHERPA2.2²³. For the Herwig++ and SHERPA2.2 the default setups without specific hadronisation tunings were used. The Pythia8 events were generated with the setup tuned to the LEP1 data²². All the Monte Carlo simulated distributions describe the data well, see Fig. 3.

For these generators the hadronisation corrections were computed, see Fig. 4.

^aOnly a part of results is shown.

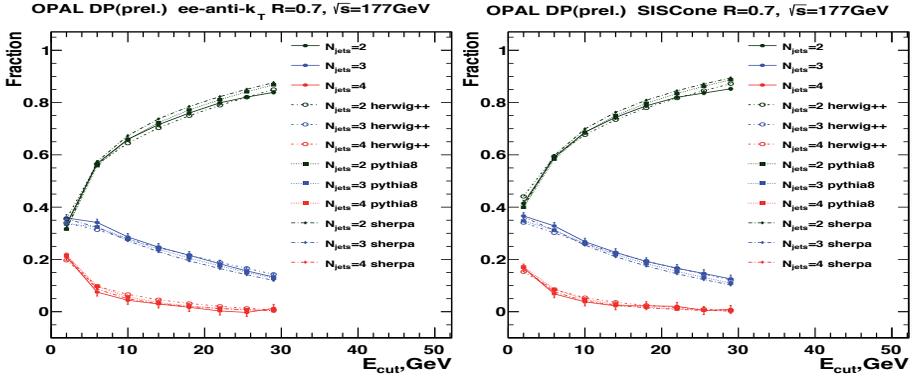


Figure 3 – The fraction of 2-, 3- and 4-jet rates distributions with anti- k_T $R = 0.7$ (left) and SiScone $R = 0.7$ (right) jet clustering algorithms for $\sqrt{s} = 177$ GeV for Monte Carlo predictions on the particle level.

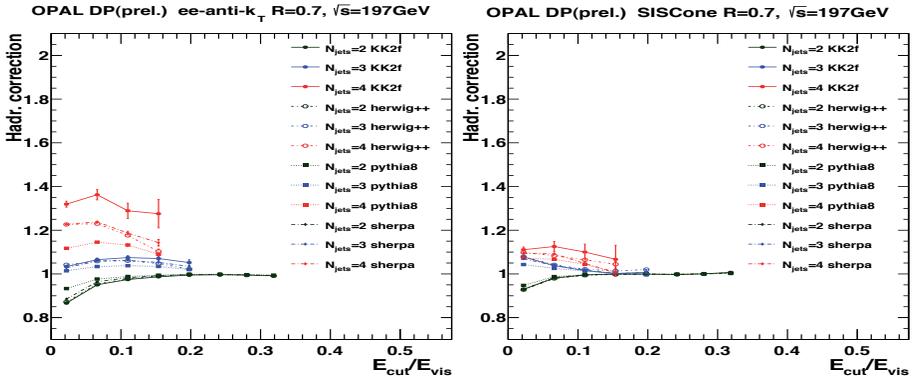


Figure 4 – The hadronisation corrections to fraction of 2-, 3- and 4-jet rates with anti- k_T $R = 0.7$ (left) and SiScone $R = 0.7$ (right) jet clustering algorithms for $\sqrt{s} = 197$ GeV with different Monte Carlo generators. The E_{vis} stands for the visible energy in the event.

7 Summary

The jet rate observables in e^+e^- annihilations to hadrons were measured with various clustering procedures. The new results obtained with clustering algorithms used earlier are consistent with the previously published measurements. The results obtained with the recently developed clustering algorithms provide an input for the validation of QCD and possibly precise estimation of α_s .

References

1. A. Ali and G. Kramer, Eur. Phys. J. **H36**, 245 (2011), 1012.2288
2. M. Cacciari and P.G. Salam, Phys. Lett. **B641**, 57 (2006), hep-ph/0512210
3. M. Cacciari et al., Eur. Phys. J. **C72**, 1896 (2012), 1111.6097
4. S. Weinzierl, Comp. Phys. Comm. **183**, 813 (2012), 1108.1934
5. M. Cacciari et al., JHEP **04**, 063 (2008), 0802.1189
6. M.H. Seymour and C. Tevlin, JHEP **11**, 052 (2006), hep-ph/0609100

7. K. Ahmet et al. (OPAL Coll.), Nucl. Instrum. Meth. **A305**, 275 (1991)
8. S. Anderson et al. (OPAL Coll.), Nucl. Instrum. Meth. **A403**, 326 (1998)
9. G. Abbiendi et al. (OPAL Coll.), Eur. Phys. J. **C33**, 173 (2004), [hep-ex/0309053](#)
10. G. Abbiendi et al. (OPAL Coll.), Eur. Phys. J. **C40**, 287 (2005), [hep-ex/0503051](#)
11. S. Jadach et al., Comp. Phys. Comm. **130**, 260 (2000), [hep-ph/9912214](#)
12. T. Sjostrand et al., Comp. Phys. Comm. **135**, 238 (2001), [hep-ph/0010017](#)
13. G. Corcella et al., JHEP **01**, 010 (2001), [hep-ph/0011363](#)
14. J. Fujimoto et al., Comp. Phys. Comm. **100**, 128 (1997), [hep-ph/9605312](#)
15. M. Skrzypek et al., Comp. Phys. Comm. **94**, 216 (1996)
16. R. Brun et al. (GEANT3 Coll.), CERN-DD-EE-84-1 (1987)
17. J. Allison et al. (OPAL Coll.), Nucl. Instrum. Meth. **A317**, 47 (1992)
18. G. Abbiendi et al (OPAL Coll.), Phys. Lett. **B493**, 249 (2000), [hep-ex/0009019](#)
19. K. Ackerstaff et al. (OPAL Coll.), Eur. Phys. J. **C2**, 213 (1998), [hep-ex/9708018](#)
20. G. Abbiendi et al. (OPAL Coll.), Eur. Phys. J. **C12**, 567 (2000), [hep-ex/9908002](#)
21. J. Bellm et al., Eur. Phys. J. **C76**, 196 (2016), [1512.01178](#)
22. T. Sjostrand et al., Comp. Phys. Comm. **178**, 852 (2008), [0710.3820](#)
23. T. Gleisberg et al., JHEP **02**, 007 (2009), [0811.4622](#)

