EVENT SHAPE DISTRIBUTIONS AT LEP

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The LEP experiments have measured distributions of the event shape observables and their moments from e^+e^- annihilation data at centre-of-mass energies from 91 to 209 GeV. The measured distributions are compared with predictions of Monte Carlo event generators.

1. Data samples

The e^+e^- data at center-of-mass energies $\sqrt{s}$ ranging from 91 to 209 GeV have been recorded by the four LEP experiments between 1989 and 2000. At $\sqrt{s} = 91$ GeV, each experiment has collected several million hadronic events. At higher energies, thousand events have been recorded at every energy point. After a standard hadronic event selection, no significant background remains at $\sqrt{s} = 91$ GeV. At $\sqrt{s} > M_Z$ several sources of background exist. The majority of events are radiative events in which the initial-state radiation reduces the original c.m.s. energy of the hadronic system. They are rejected by requiring $\sqrt{s} - \sqrt{s}' < 10$ GeV where $\sqrt{s}'$ is the effective c.m.s. energy determined by taking possible multiple photon radiation into account. At $\sqrt{s} > 2M_W$ the production of W^+W^- or ZZ pairs with hadronic or semi-leptonic decays (4-fermion final states) is an additional source of background. After applying a special procedure, the residual 4-fermion background is 10–15% and is subtracted bin-by-bin from the data. Data are then corrected for detector effects using models which describe well the uncorrected data.

2. Event shape observables

To make experimental tests of perturbative QCD and to measure its free parameter, α_S, we need to define physical observables that are sensitive to the high energy process but little sensitive to the subsequent non-perturbative hadronization and decays. Inclusive quantities, called event shapes, were shown to fulfil these requirements. Event shapes are functions of the momenta and energies of all particles detected in the final state and do not require identification of particle types. They characterize geometry of event: its shape may vary from 2-jet (or pencil-like) through 3-jet (or planar) and 4-jet up to many-jet (or spherical) nature. Perturbative QCD is applicable only to quantities which are infra-red safe (i.e. not affected by soft gluon emissions) and collinear safe (i.e. not affected by replacing a parton by collinear partons with the same total 4-momentum). In almost all cases, larger (smaller) values indicate the region dominated by the radiation of hard (soft) gluons. All quantities approach zero in the 2-jet limit. Experimentally, however, pure zero is never reached due to hadronization. Most of the quantities receive contributions from 3-jet configurations — these are then called 3-jet observables. Those vanishing in the 3-jet limit are called 4-jet observables. The event shape observables measured at LEP are:

- **Thrust *T*:** defined by the expression
$$T = \max_{\vec{n}} \left(\frac{\sum_i |p_i \cdot \vec{n}|}{\sum_i |p_i|} \right) , \tag{1}$$
where p_i is the three-momentum of particle i. The thrust axis $\vec{n}_T$ is the direction $\vec{n}$ which maximises the expression in parentheses. A plane through the origin and perpendicular to $\vec{n}_T$ divides the event into two hemispheres H_1 and H_2.
- **Thrust major $T_{\mathrm{maj.}}$:** The maximization in Eq. (1) is performed subject to the constraint that $\vec{n}$ must lie in the plane perpendicular to $\vec{n}_T$. The resulting vector is called $\vec{n}_{T_{\mathrm{maj.}}}$.
- **Thrust minor $T_{\mathrm{min.}}$:** The expression in parentheses in Eq. (1) is evaluated for the vector $\vec{n}_{T_{\mathrm{min.}}}$ which is perpendicular to both $\vec{n}_T$ and $\vec{n}_{T_{\mathrm{maj.}}}$.
- **Oblateness *O*:** This observable is defined by $O = T_{\mathrm{maj.}} - T_{\mathrm{min.}}$.

$T_{\mathrm{maj.}}$ and $T_{\mathrm{min.}}$ are both zero for a perfect 2-jet event since all particle momenta are parallel to $\vec{n}_T$ and hence orthogonal to $\vec{n}_{T_{\mathrm{min.}}}$ and $\vec{n}_{T_{\mathrm{maj.}}}$. $T_{\mathrm{min.}}$ is a 4-jet observable. For a spherical event, both $T_{\mathrm{maj.}}$ and $T_{\mathrm{min.}}$ approach a maximal value of 1/2. O is unusual, in that it vanishes for both, 2-jet and spherical events.

- **Sphericity *S* and Aplanarity *A*:** These observables are based on the momentum tensor
$$S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i p_i^2} , \quad \alpha, \beta = 1, 2, 3 , \tag{2}$$

where the sum runs over particles, i, and α and β denote the cartesian coordinates of the momentum vector. Three eigenvalues Q_j of $S^{\alpha\beta}$ are ordered such that $Q_1 < Q_2 < Q_3$ and define S and A by

$$S = \frac{3}{2}(Q_1 + Q_2) \quad \text{and} \quad A = \frac{3}{2}Q_1 \; . \tag{3}$$

A is a 4-jet observable. Since $S^{\alpha\beta}$ is quadratic in $p_i^{\alpha,\beta}$, it is not infrared safe; S neither A can be predicted reliably in perturbation theory.

- **C- and D-parameters:** The tensor $S^{\alpha\beta}$ is modified to become

$$\Theta^{\alpha\beta} = \frac{\sum_i (p_i^\alpha p_i^\beta)/|p_i|}{\sum_i |p_i|} \quad , \quad \alpha, \beta = 1, 2, 3 \; . \tag{4}$$

The three eigenvalues λ_j of this tensor define C through

$$C = 3(\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1) \tag{5}$$

and D through

$$D = 27\lambda_1\lambda_2\lambda_3 \; . \tag{6}$$

C and D parameters reach their maximal values for an isotropic event with $\lambda_1 = \lambda_2 = \lambda_3 = 1/3$. In the case of a planar event, one of λ will be zero. D-parameter is therefore a 4-jet observable.

- **Jet Masses M_{H} and M_{L}:** The hemisphere invariant masses are calculated using the particles in the two hemispheres H_1 and H_2. M_{H} is the heavier and M_{L} the lighter mass, both divided by $\sqrt{s}$.

M_{L} vanishes in a 3-particle system, since one of the hemispheres contain only a single particle.

- **Jet Broadening observables B_{T}, B_{N} and B_{W}:** These are defined by computing the quantity

$$B_k = \left(\frac{\sum_{i \in H_k} |p_i \times \vec{n}_T|}{2\sum_i |p_i|} \right) \tag{7}$$

for each of the two event hemispheres.

$$B_{\mathrm{T}} = B_1 + B_2 \; , \; B_{\mathrm{N}} = \min(B_1, B_2) \; \text{ and } \; B_{\mathrm{W}} = \max(B_1, B_2) \tag{8}$$

where B_{T} is the total, B_{N} is the narrow and B_{W} is the wide jet broadening.

The broadenings all vanish in the 2-jet limit, while for a spherical event $B_{\mathrm{T}}= \pi/8$ and $B_{\mathrm{W}}=B_{\mathrm{N}}= \pi/16$. B_{N} is a 4-jet observable.

- **Transition value between 2 and 3 jets y_{23}^{D}**: The value of the jet resolution parameter, y_{cut}, at which the number of resolved jets changes from two to three for the Durham jet finding scheme [1].

For events with three or more jets, we expect $y_{23}^{\mathrm{D}}$to be large, while for 2-jet events at LEP energies, $y_{23}^{\mathrm{D}}\lesssim 10^{-3}$. The maximum possible value of 1/3 is reached for events with three identical jets 120° apart.

Some of the distributions measured by the LEP experiments [2,3,4,5] are shown in Fig1. In general, the agreement between data and models is good.

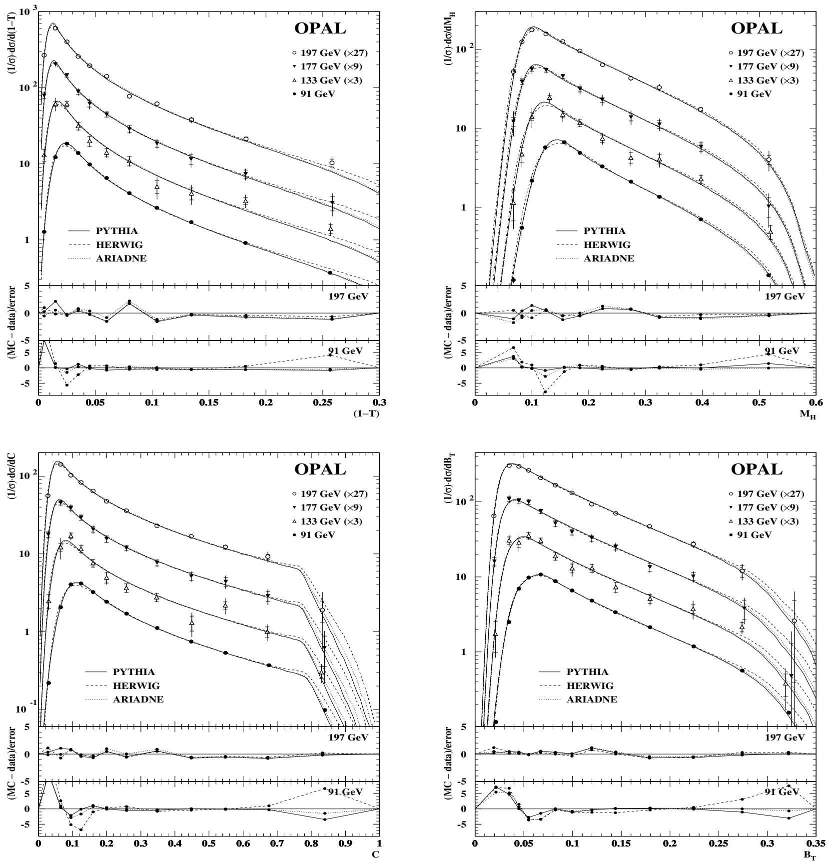

Figure 1. Comparisons of measured distributions of 1-T, M_{H}, C-parameter, and B_{T} at $\sqrt{s} = 91$ GeV, 133 GeV, 161–183 GeV and 189–209 GeV with predictions of PYTHIA, HERWIG and ARIADNE.

References

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