BOSE-EINSTEIN AND OTHER CORRELATIONS IN HADRONIC Z DECAY

W.J. METZGER
University of Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands

In hadronic Z decays, Bose-Einstein correlations in π^0 pairs are compared to those in identical charged pion pairs. Bose-Einstein correlations are also measured in triplets of identical charged pions, and comparison with those in pairs of pions indicates that pion production is completely incoherent. Further, factorial cumulants are used to compare correlations among like-sign as well as among all particles with those of several Monte Carlo models.

1 3-particle BEC

Bose-Einstein correlations (BEC) among n identical particles are usually studied in terms of

$$R_n(Q_n) = \frac{\rho_n(Q_n)}{\rho_{n0}(Q_n)} \tag{1}$$

where $\rho_n(Q_n)$ is the n-particle number density as a function of Q_n and ρ_{n0} is the density that would occur in the absence of BEC. Here, $Q_2^2 = M_{12}^2 - 4m_\pi^2$ is the four-momentum difference of a pair of particles, and $Q_3^2 = M_{123}^2 - 9m_\pi^2 = Q_{12}^2 + Q_{23}^2 + Q_{13}^2$ with Q_{ij} the four-momentum difference between the two pions i and j of the triplet. In the simplest case of a Gaussian-shaped source of radius R, R_2 can be parametrized as

$$R_2(Q) = \mathcal{N}(1 + \alpha Q)(1 + \lambda e^{-Q^2 R^2}) \tag{2}$$

where $\mathcal{N}(1+\alpha Q)$ serves as normalization, taking into account some long-range correlation in Q. The density, ρ_{n0}, of the so-called reference sample is usually taken from unlike-sign pairs, mixed events, or Monte Carlo. The use of unlike-sign pairs is problematic because of the presence of many resonances. The studies reported here do not use unlike-sign pairs as reference sample.

The parameter, λ, is equal to unity if pion production is incoherent and all pions come from the hypothesized source. The latter is certainly not the case because of long-lived resonances,

Table 1: Results of 2-particle BEC studies for charged and for neutral pions.

Charges	Experiment	R (fm)	λ
$\pm\pm$	ALEPH[4]	0.52 ± 0.02	0.30 ± 0.01
	DELPHI[5]	0.47 ± 0.03	0.24 ± 0.02
	OPAL[7]	0.79 ± 0.02	0.58 ± 0.01
	L3[1]	0.65 ± 0.04	0.45 ± 0.07
	L3[1] (3-π)	0.65 ± 0.07	0.47 ± 0.08
	L3[2] $E_\pi < 6\,\mathrm{GeV}$	0.46 ± 0.01	0.29 ± 0.03
00	L3[2] $E_\pi < 6\,\mathrm{GeV}$	0.31 ± 0.10	0.16 ± 0.09
	OPAL[3] $p_\pi > 1\,\mathrm{GeV}$, 2-jet	0.59 ± 0.09	0.55 ± 0.14

and usually λ is found to be less than unity. Whether production is indeed incoherent can be investigated by comparing 2- and 3-particle BEC. This was done by L3, and agreement with the hypothesis of complete incoherence was observed.[1] This is rather surprizing within a string picture of hadronization, since particles produced close to each other along the string should be rather coherent. The question is whether resonances would be sufficient to destroy this coherence.

2 2-particle BEC: $\pi^0\pi^0$ and $\pi^\pm\pi^\pm$

Measurement of BEC between neutral pions is quite rare, for obvious experimental reasons. In e^+e^- interactions this has only been done by L3[2] and, more recently, by OPAL.[3] Experimental exigencies result in quite different analyses. For example, OPAL requires 2-jet events (thrust, $T > 0.9$) and $p_{\pi^0} > 1\,\mathrm{GeV}$, whereas L3 uses all topologies and requires $E_{\pi^0} < 6\,\mathrm{GeV}$. The results of both experiments are shown in Fig. 1 and, together with those for charged pions from previous experiments, in Table 1.

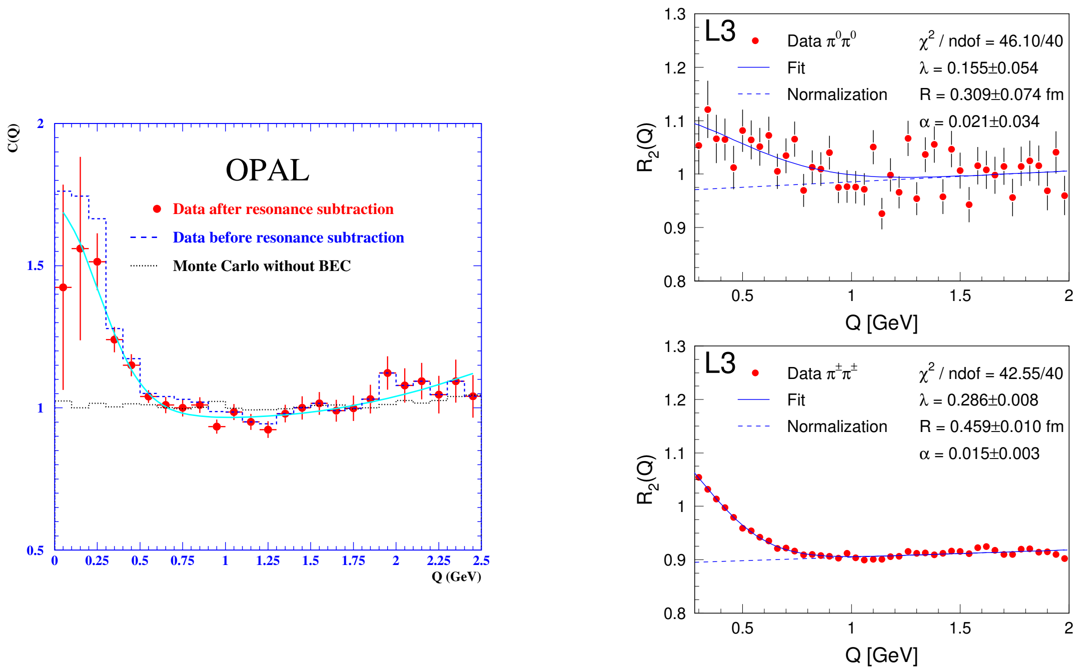

Figure 1: Distribution of R_2 for π^0 pairs in OPAL and L3, as well as that for identical charged pion pairs in L3 subject to selections analogous to the π^0 case.

The L3 values of both λ and R are about 1.5 standard deviations lower for neutral than for charged pions. Such a result would seem expected in fragmentation models with local charge compensation, such as a string, since two π^0's could be produced next to each other while two π^+'s could not. However, resonances would dilute this effect. And OPAL does not confirm it,[3] preferring to compare their π^0 result to the LEP average rather than to their own previous charged-π result.[7]

In fact, at first glance, the π^0 results of L3 and OPAL disagree, both for λ and R, by about 2 standard deviations. However, we note that the L3 values for charged pions are lower when cuts are imposed analogous to those for the neutral pion analysis. The question is then whether the apparent L3-OPAL disagreement is not due to the different cuts applied in the analyses. One hopes that OPAL will do a charged-pion analysis using the same cuts as in their neutral-pion analysis.

3 BEC and intermittency

Factorial cumulants have been used by OPAL to investigate correlations among charged particles[6] and among like-sign charged particles.[8] The factorial cumulant, K_q, of order q measures the genuine correlations among q particles.

The OPAL results are shown in Fig. 2 for binning in rapidity, y, and azimuthal angle, ϕ, with respect to the sphericity axis. The data are compared to various Bose-Einstein models[9] available in PYTHIA.[10]

There is good agreement between the data and the BE_{32} model, while PYTHIA without BE agrees less well. Quite remarkably, this is true not only for K_2 but also for K_3 and K_4 even though BE_{32} contains no explicit 3- or 4-particle correlations. Other BE models agree less well.

However, a recent preliminary L3 analysis with respect to the thrust axis, shown in Fig. 3, presents a less optimistic picture. While BE_{32} agrees better, overall, with the data, While overall agreement with the data is best for BE_{32}, the agreement for $K_2(y)$ cannot be deemed good, and none of the models gives good agreement in ϕ.

It must be pointed out that these comparisons may be quite sensitive not only to the details and the values of parameters of the Bose-Einstein model, but also to the fragmentation parameters of PYTHIA. The comparisons suggest, however, that it might be useful to include these cumulants in the tuning of fragmentation and BE-model parameters.

Acknowledgments

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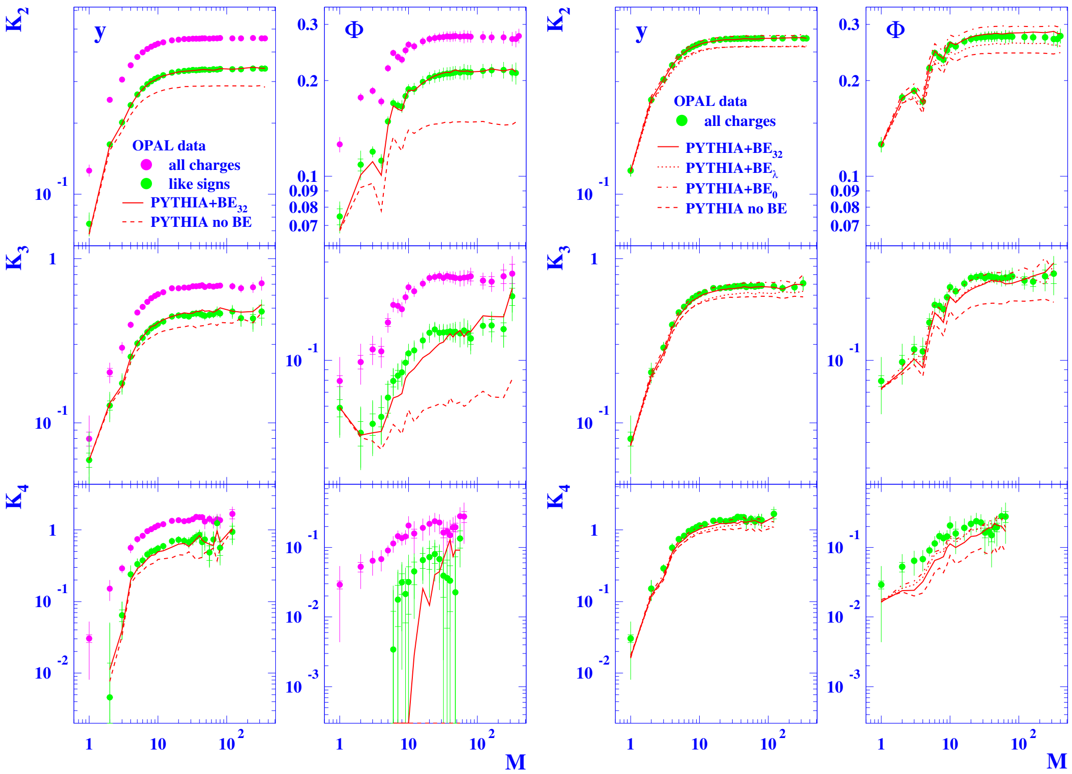

Figure 2: Factorial cumulants compared to PYTHIA Bose-Einstein models..

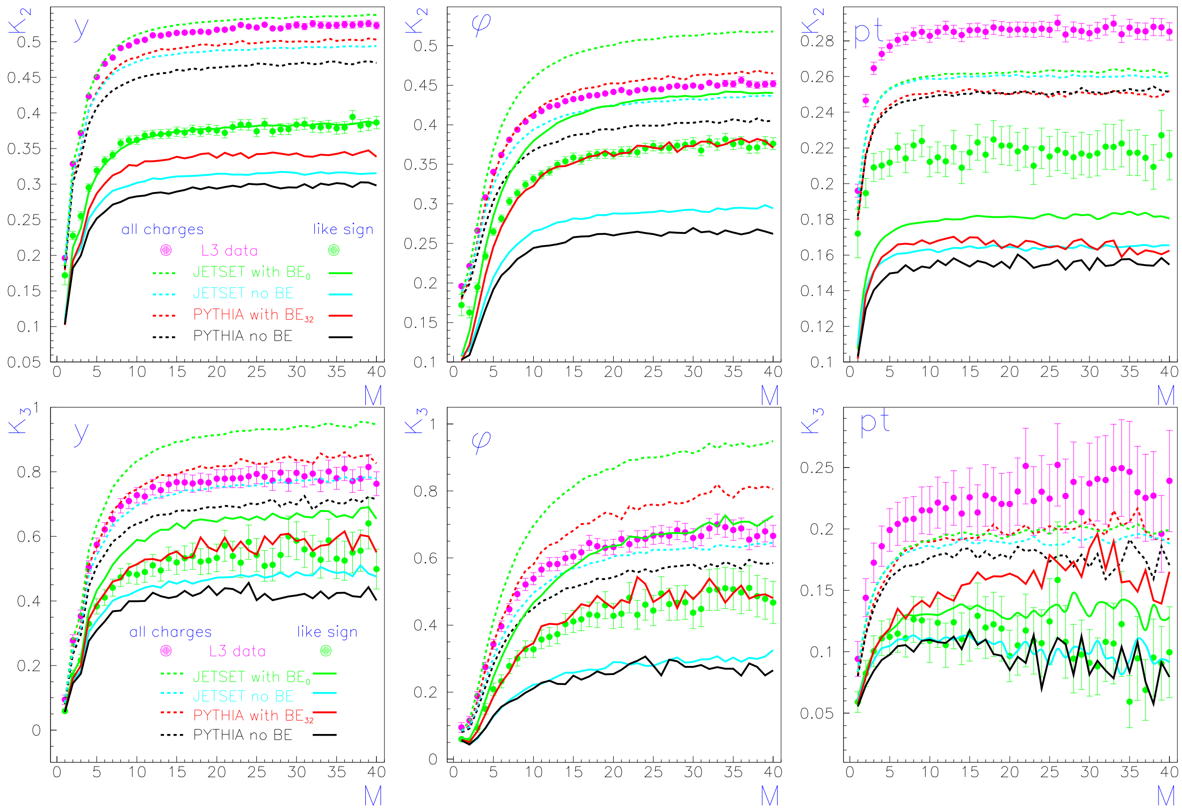

Figure 3: Factorial cumulants compared to PYTHIA Bose-Einstein models..