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Comment on the CERN ISR π^0-π^0 azimuthal correlation data

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The π^0-π^0 azimuthal-angle distributions measured at CERN ISR are described in terms of standard large-$p_\perp$ two-jet and three-jet contributions in combination with a background obtained by superimposing two uncorrelated π^0 spectra (one at high $p_\perp$, the other at low $p_\perp$). The main characteristics of the data can be fitted suprisingly well by a simple analytic expression. We emphasize the importance of having azimuthal-angle correlation data at higher values of the transverse-momentum cut.

The azimuthal-angle distributions of large-transverse-momentum pions produced in hadron-hadron collisions are expected to receive contributions from the production of both two and three large-$p_\perp$ jets. In particular, at very high transverse momenta these processes must give the dominant contributions. Obviously it is important to define quantitatively the kinematical regions where possible background effects are efficiently suppressed.

The π^0-π^0 azimuthal correlation data from the CERN ISR (Ref. 1) are analyzed with a transverse-momentum cutoff such that both the π^0's have $p_\perp > 1.2$ GeV/c; the data are plotted for various transverse-energy bins from $E_\perp = 6$ GeV up to $E_\perp = 20$ GeV. The transverse energy in this experiment has been defined as

$$E_\perp = |\vec{p}_{1\perp}| + |\vec{p}_{2\perp}| + |\vec{p}_{1\perp} + \vec{p}_{2\perp}| , \qquad (1)$$

where $\vec{p}_{1\perp}, \vec{p}_{2\perp}$ denote the transverse momenta of the π^0's. The results (Fig. 1) are characterized by a "same-side" ($\Delta\phi = 20°$) and an "opposite-side" ($\Delta\phi \approx 180°$) enhancement. Increasing the transverse energy causes the broad same-side peak to gradually disappear, while the opposite-side peak becomes more pronounced.

It has been pointed out[2] that the same-side peak in the ϕ distribution cannot be interpreted by the contribution of quantum-chromodynamic two-jet and three-jet production, even if $p_\perp$ smearing and jet broadening are taken into account. Typically the data near the region $\phi = 180°$ (or acoplanarity angle $\psi \equiv \pi - \phi = 0°$) are nicely described by two-jet processes; as ψ increases these two-jet contributions are suppressed leaving only the three-jet processes; but these jet contributions lie below the data near $\psi = 90°$ by factors of 5–20 and exhibit no significant enhancement in the region $\psi = 100°$–$160°$. However, the transverse-momentum cut used for the pions is dangerously small ($p_\perp > 1.2$ GeV/c). Therefore large contributions might still be present due to π^0's belonging to the background of the beam fragments.

In this short comment we point out that indeed the data can be described surprisingly well by adding a third component in which the π^0 (π_2^0) with lower $p_\perp$ comes from the background due to the beam and target fragments while the higher-$p_\perp$ π^0 (π_1^0) is produced according to the usual single-particle high-$p_\perp$ spectrum. This choice is motivated by the fact that the beam- and target-fragmentation background is expected to decrease exponentially while the large-$p_\perp$ pion spectrum drops according to a power law.

Fixing the transverse energy defined by Eq. (1), a kinematical correlation is introduced. At a given transverse energy $E_\perp$ and transverse momentum of one of the pions ($p_{2\perp}$) the transverse momentum of the other pion ($p_{1\perp}$) is determined

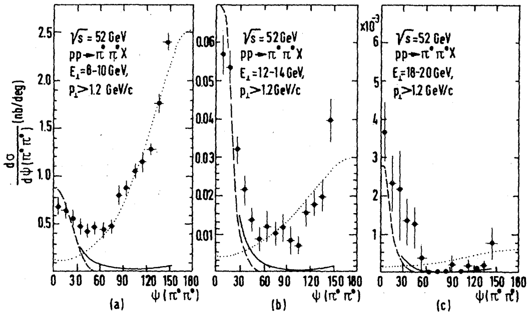

FIG. 1. Kinematical background (dotted lines), smeared three-jet (solid lines) contributions to the π^0-π^0 acoplanarity angle distribution ($\psi = \pi - \phi$) measured in proton-proton collisions at $\sqrt{s} = 52$ GeV. The unnormalized data are scaled to the smeared two-jet distribution predicted near $\psi = 0°$ at $E_\perp = 12$–14 GeV, see (b). The kinematical-background curves are then normalized to the data points in the region $\psi = 120°$–$160°$ at $E_\perp = 8$–10 GeV.

by the relation

$$p_{1\perp}=\frac{E_\perp'^2-p_{2\perp}^2}{2(E_\perp'+p_{2\perp}\cos\phi)}\,,\quad E_\perp'=E_\perp-p_{2\perp} \tag{2}$$

where ϕ is the azimuthal angle between π_1^0 and π_2^0. We fix $p_{2\perp}$ at the value of the transverse-momentum cut $p_{2\perp}=1.2$ GeV/c and $p_{1\perp}$ varies with ϕ as in (2). When the transverse energy is not too large the ϕ dependence given by Eq. (2) is sizable. For example, at $E_\perp=8$ GeV and $p_{2\perp}=1.2$ GeV/c we obtain for the parallel and antiparallel configuration the values $p_{1\perp}=2.8$ and 4.0 GeV/c, respectively. Since in this transverse-momentum region the one-particle inclusive cross section falls approximately as $p_\perp^{-8.5}$, the same-side ($\phi=0°$) configuration is strongly enhanced with respect to the opposite-side ($\phi=180°$) configuration. This effect, however, becomes less significant at higher values of the transverse energy.

To be more precise we require a fit to the single-π^0 spectrum. According to the same group,[3] the π^0 inclusive cross section can be described by the formula

$$E\frac{d^3\sigma}{d^3p}=C\frac{(1-x_\perp)^{9.5}}{p_\perp^{n_{\text{eff}}(x_\perp)}}\,, \tag{3a}$$

where $x_\perp=2p_\perp/\sqrt{s}$. In the region $x_\perp=0.1$–0.3, $n_{\text{eff}}(x_\perp)$ can be fitted approximately by

$$n_{\text{eff}}(x_\perp)=a-bx_\perp \tag{3b}$$

with $a=9.3\pm0.4$, $b=4.8\pm0.5$. Using Eqs. (1) and (2) and assuming that both the low-$p_\perp$ (π_2^0) and high-$p_\perp$ (π_1^0) spectra depend negligibly on rapidity we can derive from Eq. (3a) the formula

$$\frac{d^3\sigma}{dE_\perp d\phi}\propto\frac{C'(1-x_{1\perp})^{9.5}}{p_{1\perp}(\phi)^{n_{\text{eff}}(x_{1\perp})}}\left(\frac{dE_\perp}{dp_{1\perp}}\right)^{-1}\Bigg|_{p_{2\perp}\,\text{fixed}}\,, \tag{4}$$

where $x_{1\perp}=2p_{1\perp}/\sqrt{s}$. At fixed $E_\perp$ the ϕ dependence is completely given via $p_{1\perp}(\phi)$ [see Eq. (2)].

In Fig. 1 we plot the ϕ distribution determined by this expression at transverse energies $E_\perp=8$, 12, 18 GeV, with $p_\perp=1.2$ GeV/c and $\sqrt{s}=52$ GeV. For $n_{\text{eff}}(x_\perp)$ we use the values $a=9.3$ and $b=5.0$. The parameter C' was fixed by fitting the distribution to the same-side enhancement of the data at $E_\perp=8$ GeV. The agreement with the measured distributions, both in shape and normalization, is remarkably good. In the same figure we also plot the smeared two-jet and three-jet contributions calculated in Ref. 2.

It is clear that the background is too large to try to draw any conclusion concerning the importance of the three-jet contributions.

We have checked the validity of the analytic approximation (4) by a Monte Carlo program, in which the kinematical conditions of the data are taken into account precisely. Assuming a Gaussian distribution with $\langle\vec{q}_\perp^{\,2}\rangle\approx(0.7$–$0.8\text{ GeV}/c)^2$ for the background contributions, we found azimuthal-angle correlations in agreement with the dotted curves of Fig. 1 determined by Eq. (4).

The background considered here can be easily suppressed by increasing the value of the transverse-momentum cut above 1.2 GeV/c; for example, if we require $p_\perp>2.5$ GeV/c and use an even larger Gaussian width, $\langle\vec{q}_\perp^{\,2}\rangle\approx(1\text{ GeV}/c)^2$, the background will be suppressed by a factor of 5–10 with respect to the more interesting and fundamental three-jet contributions. Thus it would be extremely interesting to have data with larger $p_\perp$ cuts ($p_\perp>2.0$, 2.5 GeV/c e.g.), so that it would be possible to study the gradual suppression of the kinematical background correlation discussed here and the emergence of the three-jet contribution.

Finally we remark that the p_{out} distributions with $p_1>5$ GeV and $x_e>0.4$ (Ref. 4) published by the same group[1] are free from this kinematical background.

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[2] Z. Kunszt and E. Pietarinen, Nucl. Phys. B (to be published).

[3] C. Kourkoumelis *et al.*, Phys. Lett. 84B, 271 (1979) and D. Lissauer, private communication.

[4] Here p_1 denotes the transverse momentum of the trigger pion and x_e is defined as $x_e=-(\vec{p}_{1\perp}\cdot\vec{p}_{2\perp})/(|\vec{p}_{1\perp}||\vec{p}_{2\perp}|)$.