FINITE SIZE OF HADRONS AND BOSE-EINSTEIN CORRELATIONS

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WARNING

CORRELATION BETWEEN MOMENTA OF TWO IDENTICAL HADRONS

$$C(p_1, p_2) \equiv \frac{N(p_1, p_2)}{N(p_1)N(p_2)} - 1 \tag{1}$$

IS USUALLY ANALYZED USING THE STANDARD FORMULA

$$C(p_1, p_2) = \frac{\tilde{w}(P_{12}; Q)\tilde{w}(P_{12}; -Q)}{w(p_1)w(p_2)} = \frac{|\tilde{w}(P_{12}, Q)|^2}{w(p_1)w(p_2)} \tag{2}$$

WHERE $w(p.x)$ IS THE SINGLE-PARTICLE MOMENTUM-SPACE DISTRIBUTION;

$$\tilde{w}(P_{12}; Q) = \int dx\; e^{iQx} w(P_{12}; x); \quad w(p) = \int dx\; w(p; x)$$
$$P_{12} = (p_1 + p_2)/2; \quad Q = p_1 - p_2,$$

THIS PROCEDURE IS - IN GENERAL - ***INCORRECT*****.**

TWO PARTICLE CORRELATIONS

LET $W(p_1, p_2; x_1, x_2)$ **BE THE MOMENTUM AND SPACE "DISTRIBUTION" OF TWO PARTICLES ("SOURCE FUNCTION"). IF PARTICLES ARE IDENTICAL, THE OBSERVED MOMENTUM DISTRIBUTION IS**

$$\Omega(p_1, p_2) = \int dx_1 dx_2 W(p_1, p_2; x_1, x_2) + \\ + \int dx_1 dx_2 e^{i(x_1 - x_2)Q} W(P_{12}, P_{12}; x_1, x_2) \equiv \\ \equiv \Omega_0(p_1, p_2)\left[1 + C(p_1, p_2)\right] \quad (3)$$

WHERE $P_{12} = (p_1 + p_2)/2$**,** $Q = p_1 - p_2,$ **AND**

$$\Omega_0(p_1, p_2) = \int dx_1 dx_2 W(p_1, p_2; x_1, x_2) \quad (4)$$

ONE SEES THAT $C(p_1, p_2)$ **CONTAINS INFORMATION ONLY ON THE DISTRIBUTION OF** $x_1 - x_2$**.**

NO MOMENTUM-SPACE CORRELATIONS

IF THERE ARE NO MOMENTUM AND SPACE CORRELATIONS,

$$W(p_1, p_2; x_1, x_2) = w(p_1, x_1)w(p_2, x_2)$$

THEN $\Omega(p_1, p_2) = w(p_1)w(p_2) + |\tilde{w}(P_{12}, Q)|^2]$**,**

WHERE $\tilde{w}(P_{12}, Q) = \int dx w(P_{12}, x)e^{ixQ}$.

THUS THE CORRELATION FUNCTION IS

$$C_2(p_1, p_2) = \frac{|\tilde{w}(P_{12}, Q)|^2}{w(p_1)w(p_2)} \geq 0!!!! \quad (5)$$

THIS IS THE COMMONLY USED FORMULA.

FROM $\tilde{w}(P_{12}, Q)$ **ONE CAN RECOVER** $w(P_{12}, x)$**.**

BUT: *THIS IS VALID ONLY IF THERE ARE NO MOMENTUM AND SPACE CORRELATIONS.*

CORRELATIONS IN SPACE

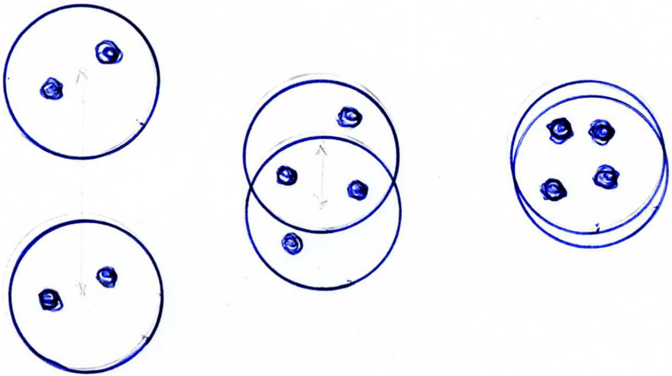
IDEA: WHEN PIONS ARE TOO CLOSE TO EACH OTHER THEY ARE *NOT* PIONS ANYMORE!!!
(BECAUSE THEIR CONSTITUENTS ARE MIXING AND THEIR WAVE FUNCTIONS ARE NOT WELL-DETERMINED).

SINCE HBT EXPERIMENTS MEASURE QUANTUM INTERFERENCE BETWEEN THE WAVE FUNCTIONS OF PIONS THEY CANNOT SEE PIONS TOO CLOSE TO EACH OTHER.

THEREFORE $W(P_{12}, P_{12}; x_1, x_2)$ **MUST VANISH AT SMALL** $|x_1 - x_2|$**, IMPLYING CORRELATION BETWEEN POSITIONS OF TWO PIONS.**

PICTURE

MIXING OF QUARKS



CORRELATIONS IN SPACE

Repeat: $W(P_{12}, P_{12}; x_1, x_2)$ **MUST VANISH AT** $|x_1 - x_2| = 0$**, IMPLYING CORRELATION BETWEEN POSITIONS OF TWO PIONS. THIS IS THE** ***NECESSARY*** **CONSEQUENCE OF THE FUNDAMENTAL PROPERTY OF HADRONS: THEY ARE** ***NOT*** **POINT-LIKE.**

THUS THE TWO-PION DISTRIBUTION IS OF THE FORM

$$W(P_{12}, P_{12}; x_1, x_2) = w(P_{12}; x_1) w(P_{12}; x_2)[1 - \Delta(x_1 - x_2)]. \quad (6)$$

THE CORRELATION FUNCTION:

$$C(p_1, p_2) = \frac{|\tilde{w}(P_{12}, Q)|^2}{w(p_1) w(p_2)} - C_{corr}(p_1, p_2);$$

$$C_{corr} = \frac{\int dx_1 dx_2 e^{i(x_1 - x_2)Q} w(P_{12}; x_1) w(P_{12}; x_2) \Delta(x_1 - x_2)}{w(p_1) w(p_2)} \quad (7)$$

EXAMPLE

FOR ILLUSTRATION, TAKE

$$\Delta(x_1 - x_2) = \Theta[r^2 - |\vec{x}_1 - \vec{x}_2|^2 - (t_1 - t_2)^2];$$

$$w(P, x) = e^{-|\vec{x}|^2/R^2} e^{-t^2/\tau^2} f(P)$$

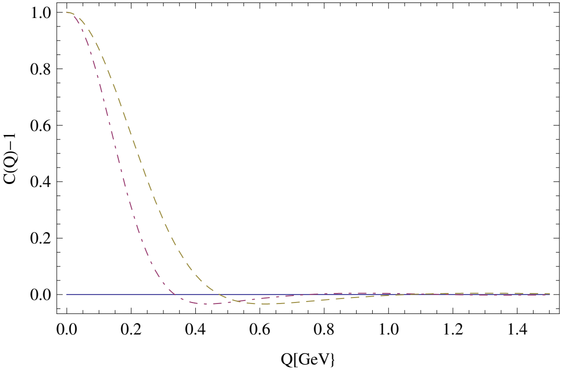


Figure: Oscillating two-pion correlation function. $R = r = \tau = 1$ fm.

DATA L3

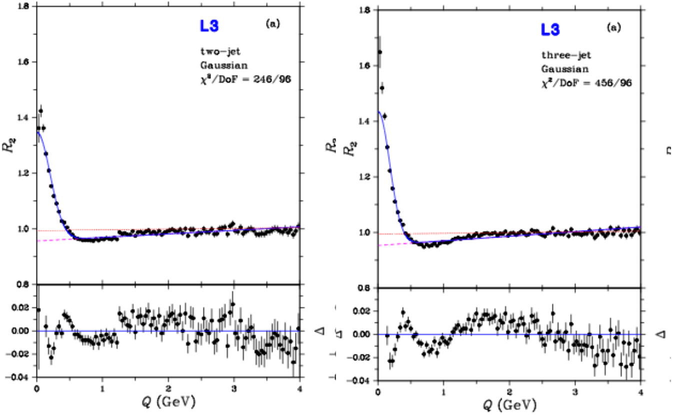


Figure: L3 data for two-jet and three-jet events.

DATA CMS 1

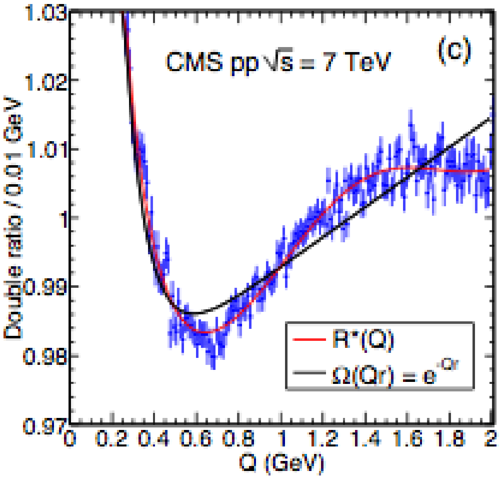


Figure: Two-pion correlation function from CMS (pp at 7 TeV)

DATA CMS 2

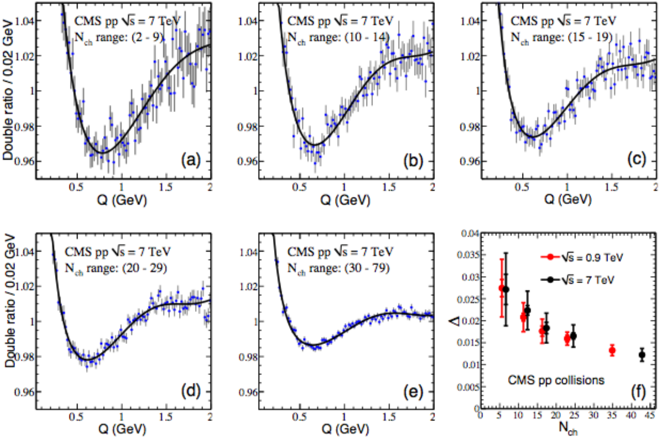


Figure: Two-pion correlation function for various multiplicities from CMS (pp at 7 TeV)

COMMENTS

(i) Our qualitative argument shows that the observed oscillations of the HBT correlation function are not accidental but reflect the fundamental fact that hadrons are not point-like. Therefore they deserve more attention in data analysis. It seems that the effect simply MUST BE THERE and the real experimental challenge is to determine its size.

(ii) More serious calculations, as well as a detailed comparison with data is clearly needed and are in progress (together with W.Florkowski)

(a) It is necessary to formulate a consistent phenomenological framework where the measured HBT radii are correctly described.

(b) Including other space correlations (e.g. clusters) may also be of interest.