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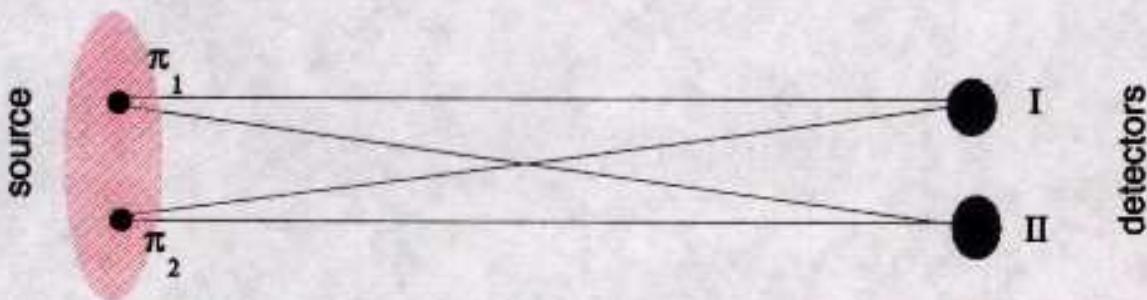
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Bose-Einstein Multidimensional Analysis in Z^0 decays

- Introduction
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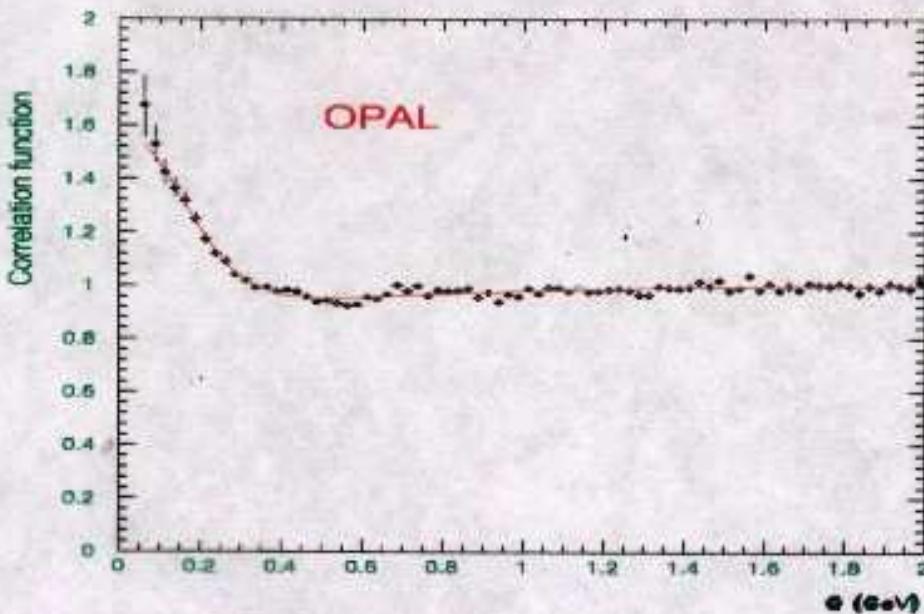
Bose-Einstein Correlations

Bose - Einstein correlations are a quantum mechanical phenomenon which manifests itself as an enhanced probability for identical bosons to be emitted with small relative four-momenta Q , as compared with non identical bosons under similar conditions. The effect arises from the ambiguity of path between source and detectors. From the magnitude of the effect it is possible to determine the space-time dimensions of the boson source.



A study of Bose-Einstein correlations for charged pions has been performed by OPAL. Assuming that the correlation function of the two pions has the following form: $C(Q) = [1 + \lambda \exp(-R^2 Q^2)]$, the measured radius of the emitting source is:

$$R = (0.928 \pm 0.019 \pm 0.150) \text{ fm}$$



Introduction

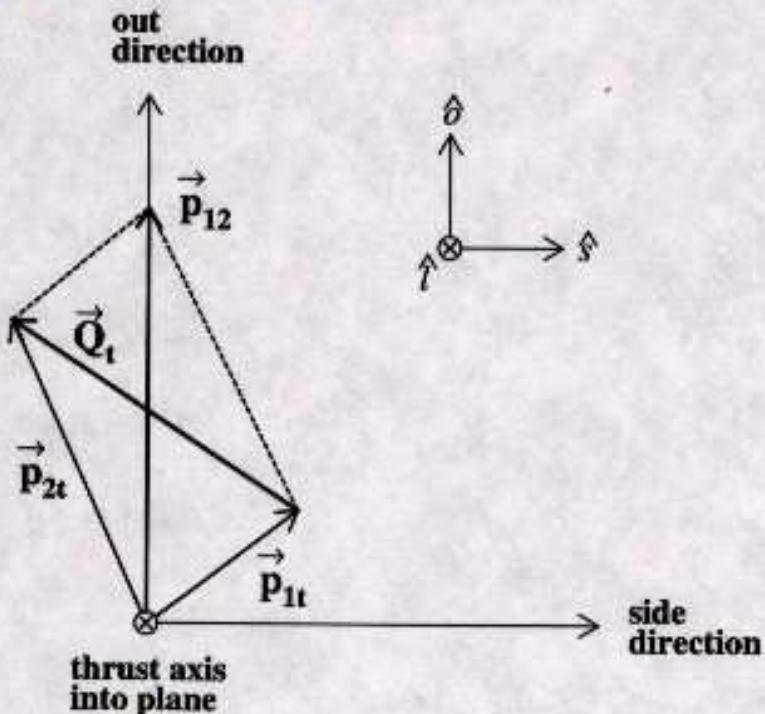
Study two-particle BECs in more than one dimension in order to obtain information on the shape of the source emitting pions during hadronization

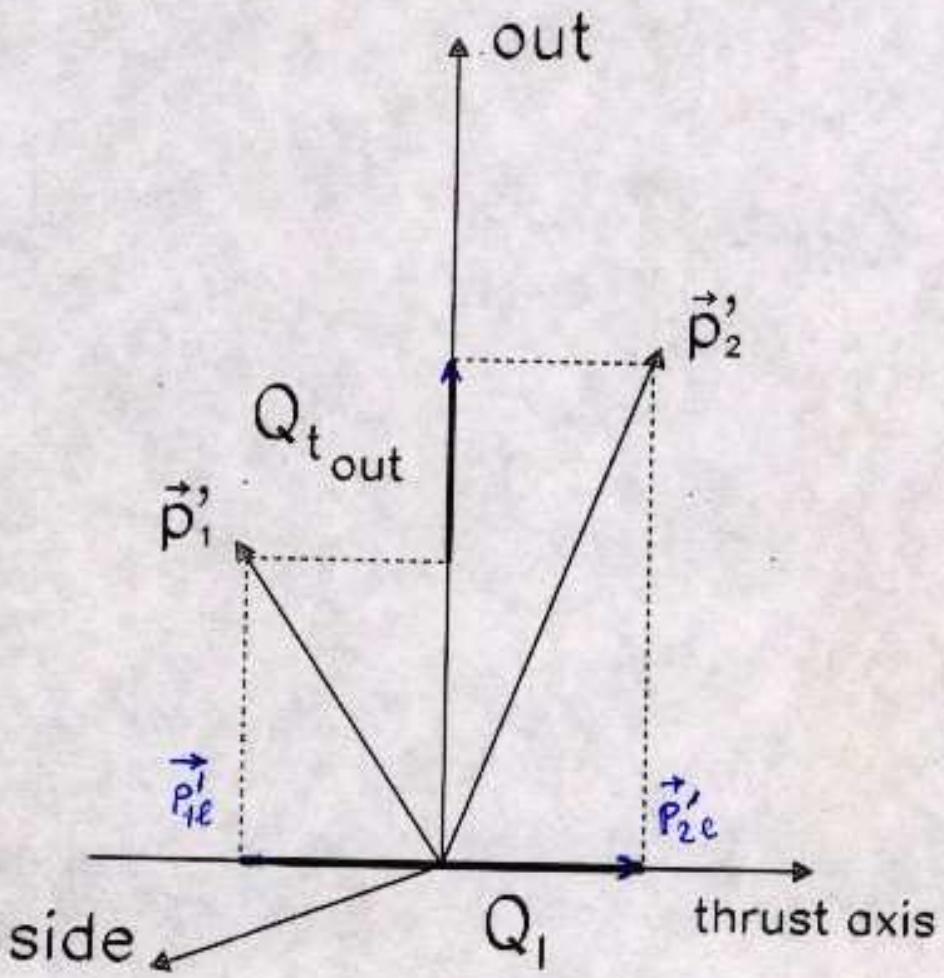
- ➡ Analyses performed at lower energies (TPC, Tasso, Mark II) ➡ results not conclusive.
- ➡ Test the string model prediction that the transverse size of the source is smaller than the longitudinal one (B.Andersson and M.Ringner, Phys. Lett. B421 (1998) 283)
- ➡ Test the assumption of spherical symmetry made in Monte Carlo generators.

The LCMS

Boost each pair along the thrust axis in order to have $\vec{p}'_{1P} + \vec{p}'_{2P} = \mathbf{0}$.

Resolve $\vec{Q} = \vec{p}'_2 - \vec{p}'_1$ into components longitudinal \vec{Q}_t and transverse \vec{Q}_\perp w.r.t. the thrust axis, and \vec{Q}_\perp into out $\vec{Q}_{t, \text{out}}$ and side $\vec{Q}_{t, \text{side}}$ components.





LONGITUDINALLY COMOVING SYSTEM (LCMS)

$$Q_t^2 = (p'_{t,out2} - p'_{t,out1})^2 + (p'_{t,side2} - p'_{t,side1})^2$$

$$Q_e^2 = (p'_{e2} - p'_{e1})^2$$

Advantage of the three-dimensional analysis in the LCMS

$$Q = [(E_2 - E_1), (\vec{p}_2 - \vec{p}_1)]$$

$$P = [(E_2 + E_1), (\vec{p}_2 + \vec{p}_1)]$$

In the LCMS

$$Q \cdot P = (E'_2 - E'_1)(E'_2 + E'_1) - Q_{t, \text{out}} p_{12}$$

Therefore

$$Q^2 = ((\frac{p_{12}}{E'_2 + E'_1})^2 - 1)Q_{t, \text{out}}^2 - Q_{t, \text{side}}^2 - Q_t^2$$

→ $Q_{t, \text{side}}$ and Q_t yield information on
the geometrical dimensions of the
source emitting pions.

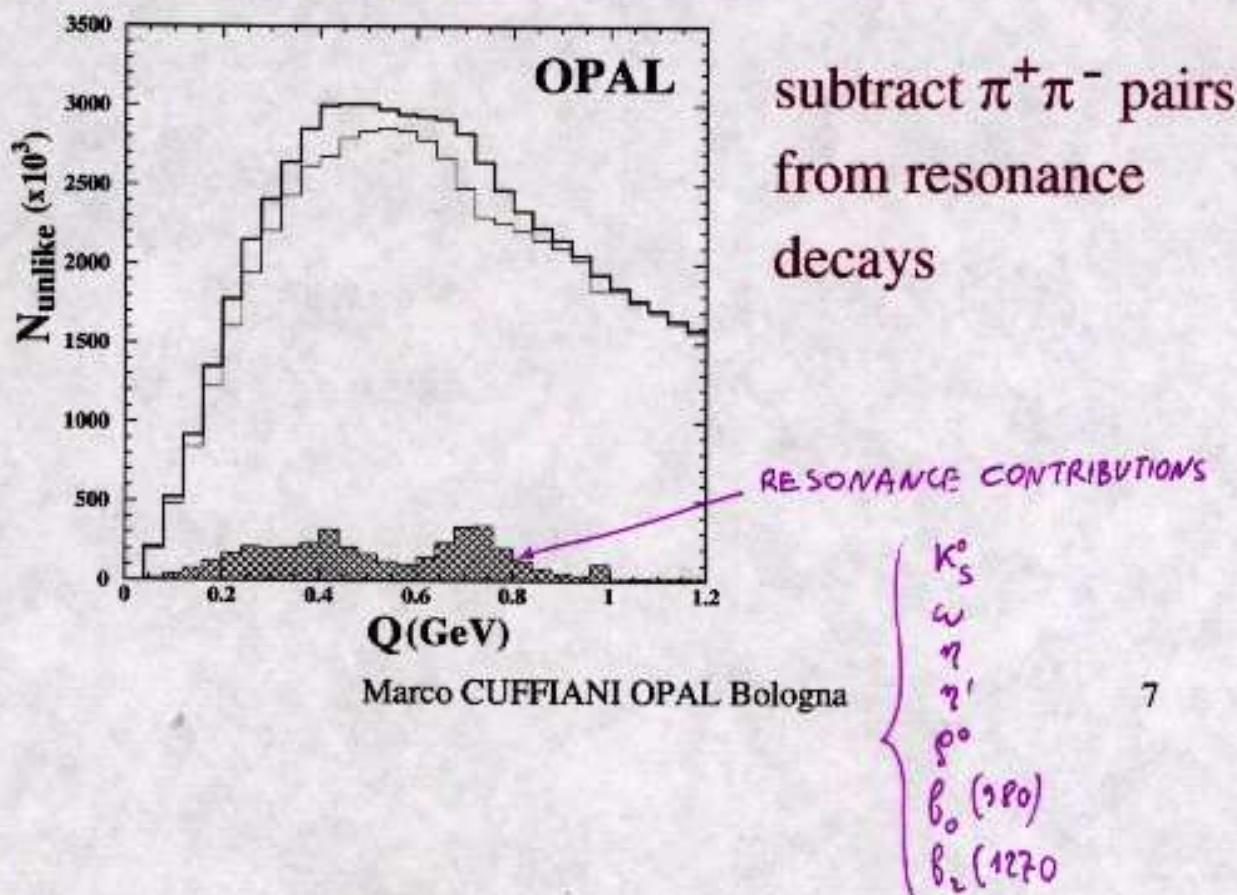
The Correlation Function

$$C(p_1, p_2) = \frac{\rho(p_1, p_2)}{\rho(p_1)\rho(p_2)}$$

OPAL

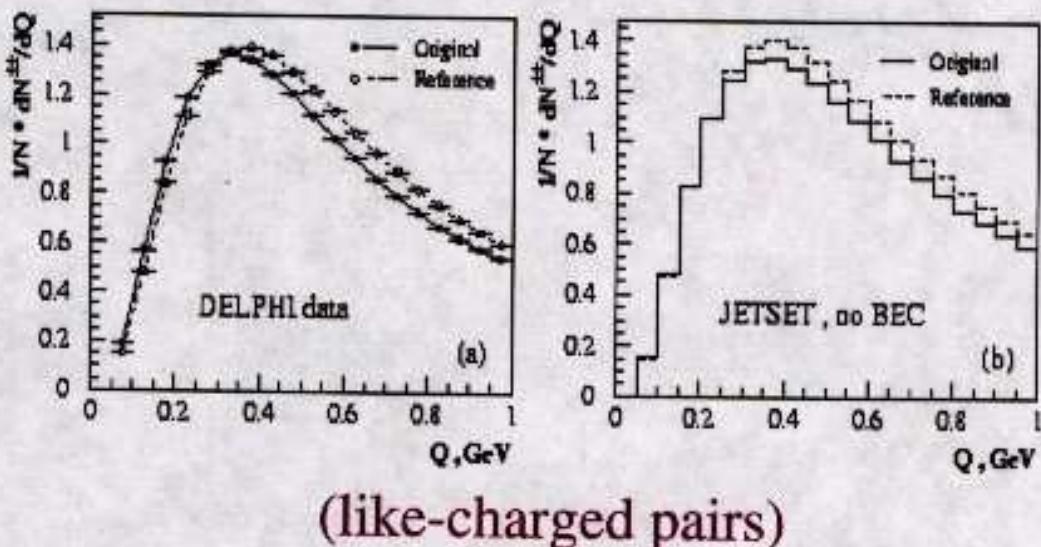
$$C'(Q_{t,\text{out}}; Q_{t,\text{side}}; Q_l) = \left(\frac{N_{\text{like}}}{N_{\text{unlike}}} \right)_{\text{DATA}} / \left(\frac{N_{\text{like}}}{N_{\text{unlike}}} \right)_{\text{MC}}$$

Divided by the same ratio computed using
Jetset (noBE) events
correction for Coulomb interactions



DELPHI and L3

get the reference sample by mixing particles from different data events

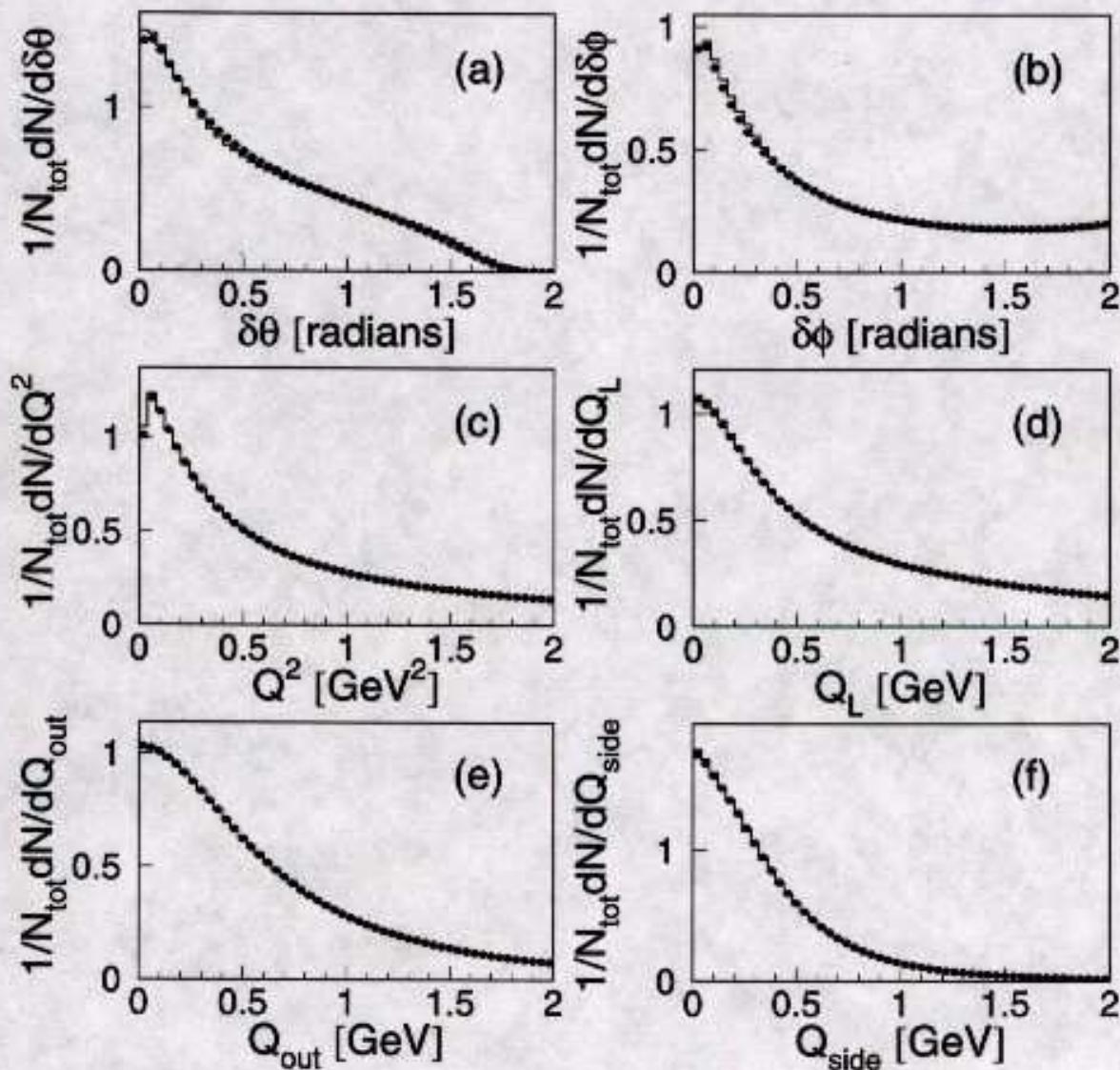


Correction factors for

- acceptance and detector resolution (with MonteCarlos BE/noBE)
- removal of correlations other than BE (with a MonteCarlo noBE)

LUBOEI

comparison data-Jetset (with BE) at the detector level after the selections L3



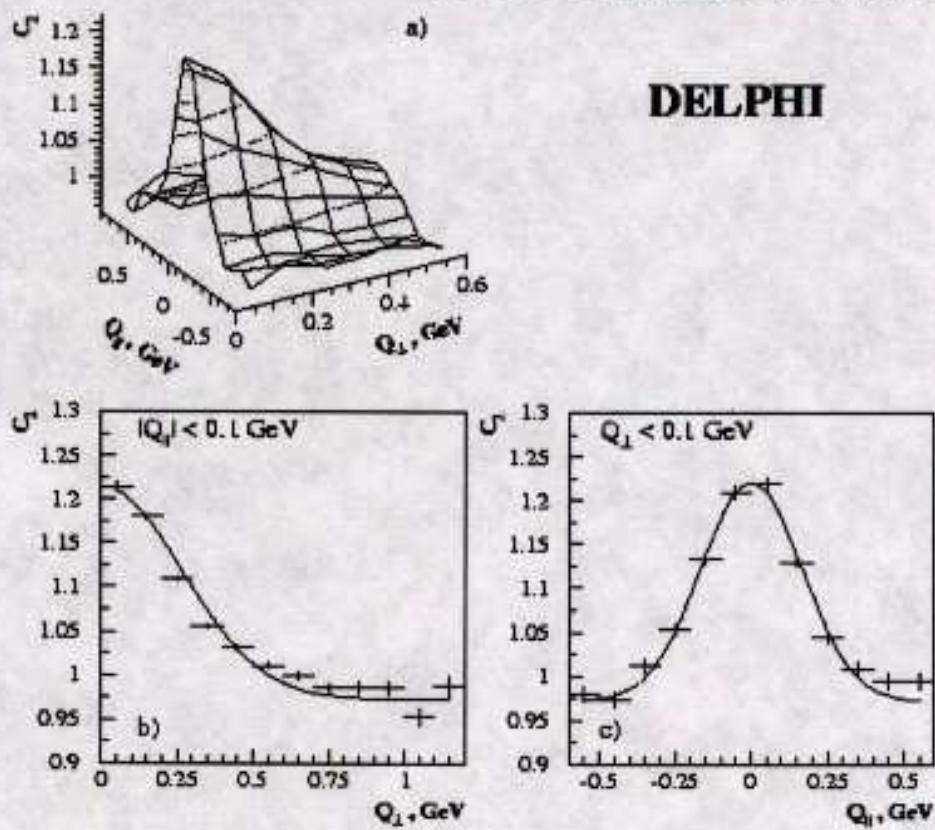
The Parametrization

“Extended” Goldhaber

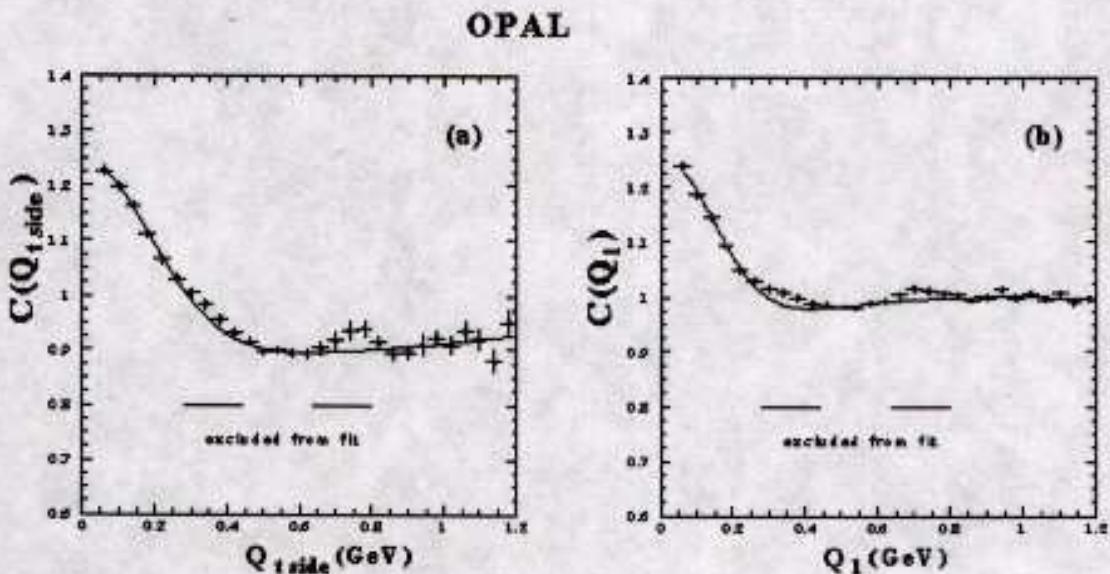
$$C(Q_{t,\text{out}}; Q_{t,\text{side}}; Q_l) =$$

$$= N [1 + \lambda \exp(-Q_{t,\text{out}}^2 R_{t,\text{out}}^2 - Q_{t,\text{side}}^2 R_{t,\text{side}}^2 - Q_l^2 R_l^2)] \quad F$$

the possible off-diagonal term $Q_l - Q_{t,\text{out}}$ found
to be consistent with zero

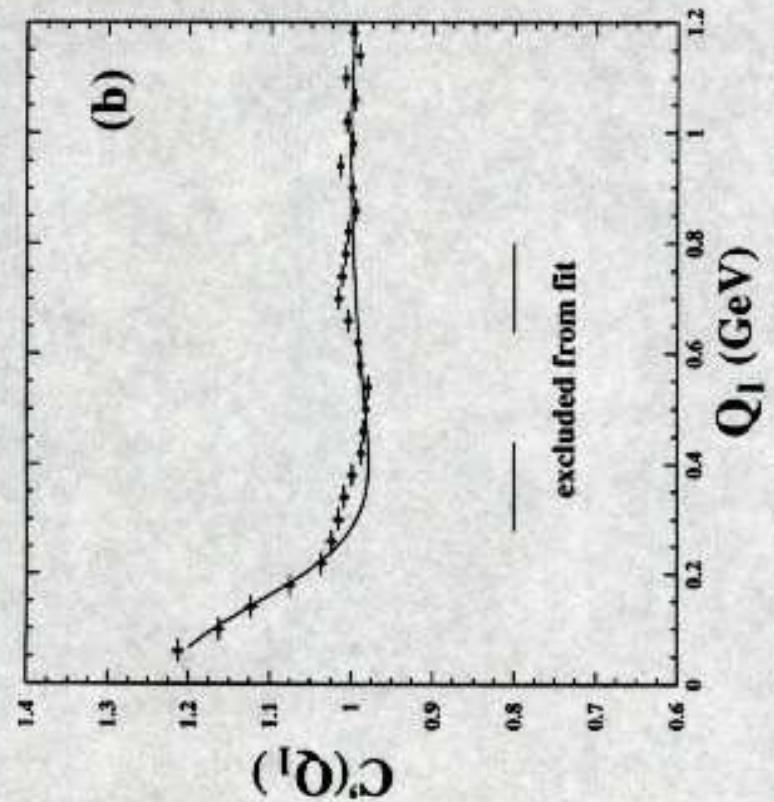
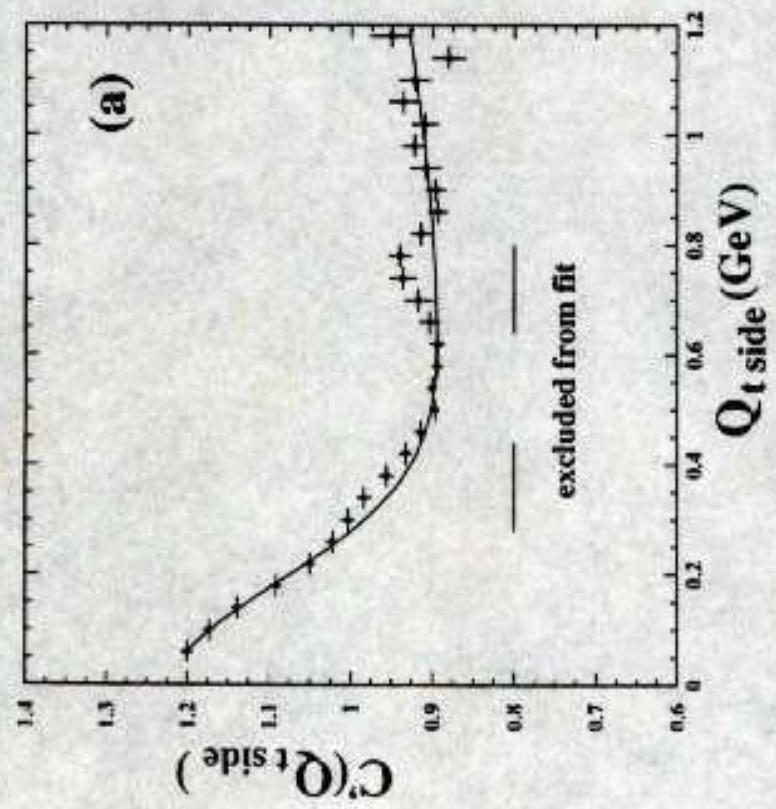


EXTENDED GOLDHABER
 $C(Q_{t,0}, Q_{t,1}, Q_e) = N [1 + \lambda e^{-(Q_{t,0}^2 R_{t,0}^2 + Q_{t,1}^2 R_{t,1}^2 + Q_e^2 R_e^2)}] F$
 $F(Q_{t,out}, Q_{t,in}, Q_e) = (1 + \delta_0 Q_{t,0} + \delta_1 Q_{t,1} + \delta_e Q_e + \varepsilon_0 Q_{t,0}^2 + \varepsilon_1 Q_{t,1}^2 + \varepsilon_e Q_e^2)$ OPAL
 F factor = $(1 + \delta Q_I + \varepsilon Q_{t,out} + \xi Q_{t,side})$ (L3) with
 Q_i^2 terms (OPAL) to take into account long-range correlations due to energy, momentum and charge conservation.



residual effects of pairs from resonance decays \rightarrow regions excluded from the fit range

OPAL



Results

FOR 2-jet EVENTS
USING $y_{\text{cut}} = 0.04$

OPAL

$$R_{t,\text{out}} = (0.647 \pm 0.011_{\text{stat}} \pm 0.024_{0.124}^{\text{syst}}) \text{ fm}$$

$$R_{t,\text{side}} = (0.809 \pm 0.009_{\text{stat}} \pm 0.019_{0.032}^{\text{syst}}) \text{ fm}$$

$$R_I = (0.989 \pm 0.011_{\text{stat}} \pm 0.030_{0.015}^{\text{syst}}) \text{ fm}$$

$$\frac{R_I}{R_{t,\text{side}}} = 1.222 \pm 0.027_{\text{stat}} \pm 0.075_{0.012}^{\text{syst}}$$

corresponding to

$$\frac{R_{t,\text{side}}}{R_I} = 0.818 \pm 0.018_{\text{stat}} \pm 0.008_{0.050}^{\text{syst}}$$

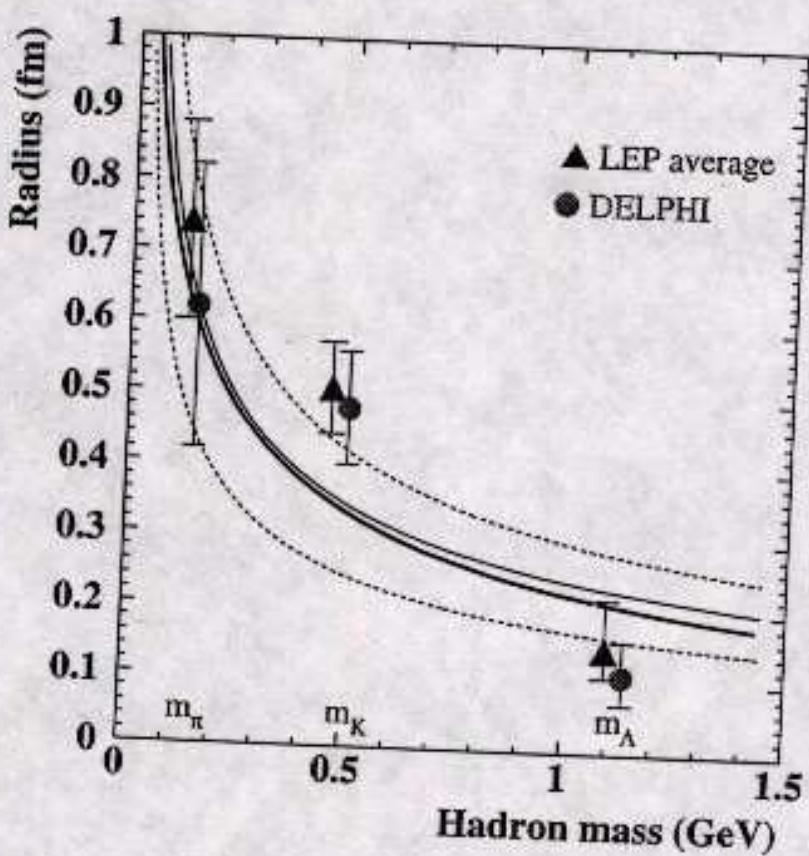
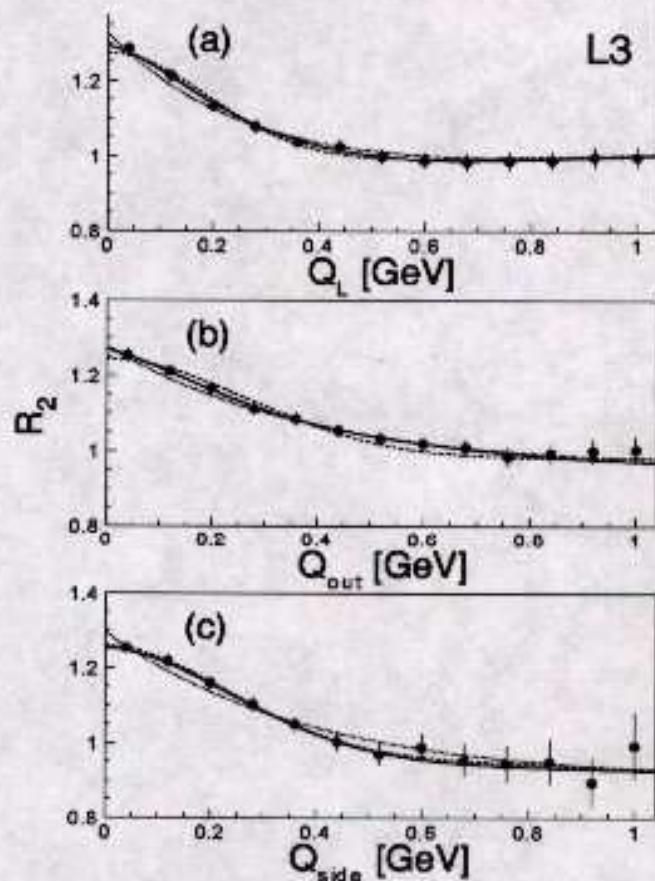


Figure 3: The measured emitter radius r as a function of the hadron mass m compared to some theoretical predictions (see text).

L3 fit the corr.
function to an
exponential and
to an expansion
(Edgeworth) of
the gaussian



$$R_{t,out} = (0.44 \pm 0.02 \text{ (stat)} \pm \frac{0.05}{0.06} \text{ (syst)}) \text{ fm}$$

$$R_{t,side} = (0.56 \pm 0.02 \text{ (stat)} \pm \frac{0.03}{0.12} \text{ (syst)}) \text{ fm}$$

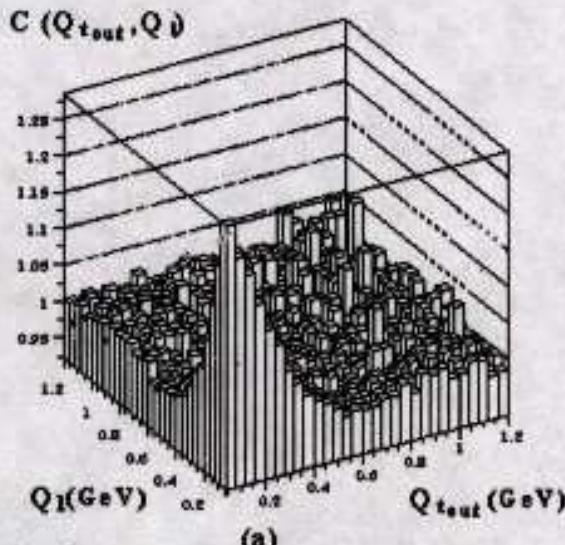
$$R_l = (0.69 \pm 0.02 \text{ (stat)} \pm \frac{0.04}{0.03} \text{ (syst)}) \text{ fm}$$

$$\frac{R_{t,side}}{R_l} = 0.81 \pm 0.02 \text{ (stat)} \pm \frac{0.03}{0.19} \text{ (syst)}$$

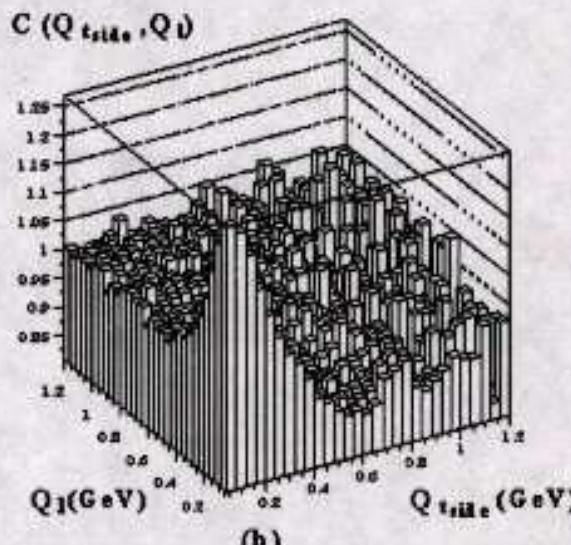
DURHAM $y_{cut} = 0.04$

OPAL (two-jets)

OPAL



(a)



(b)

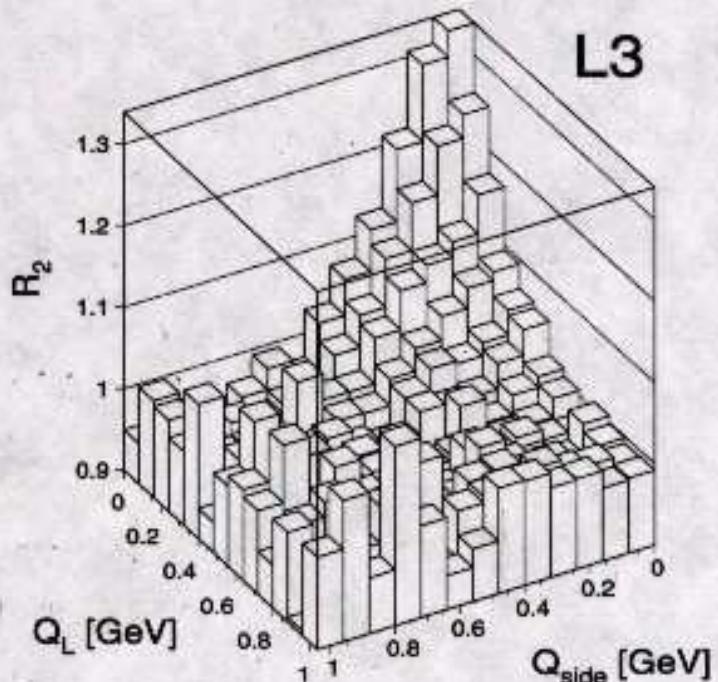
$Q_{t\text{out}}$ DEPENDS ALSO ON THE DIFFERENCE IN EMISSION TIME

DEPENDS ONLY ON THE DIFFERENCE IN EMISSION SPACE

L3

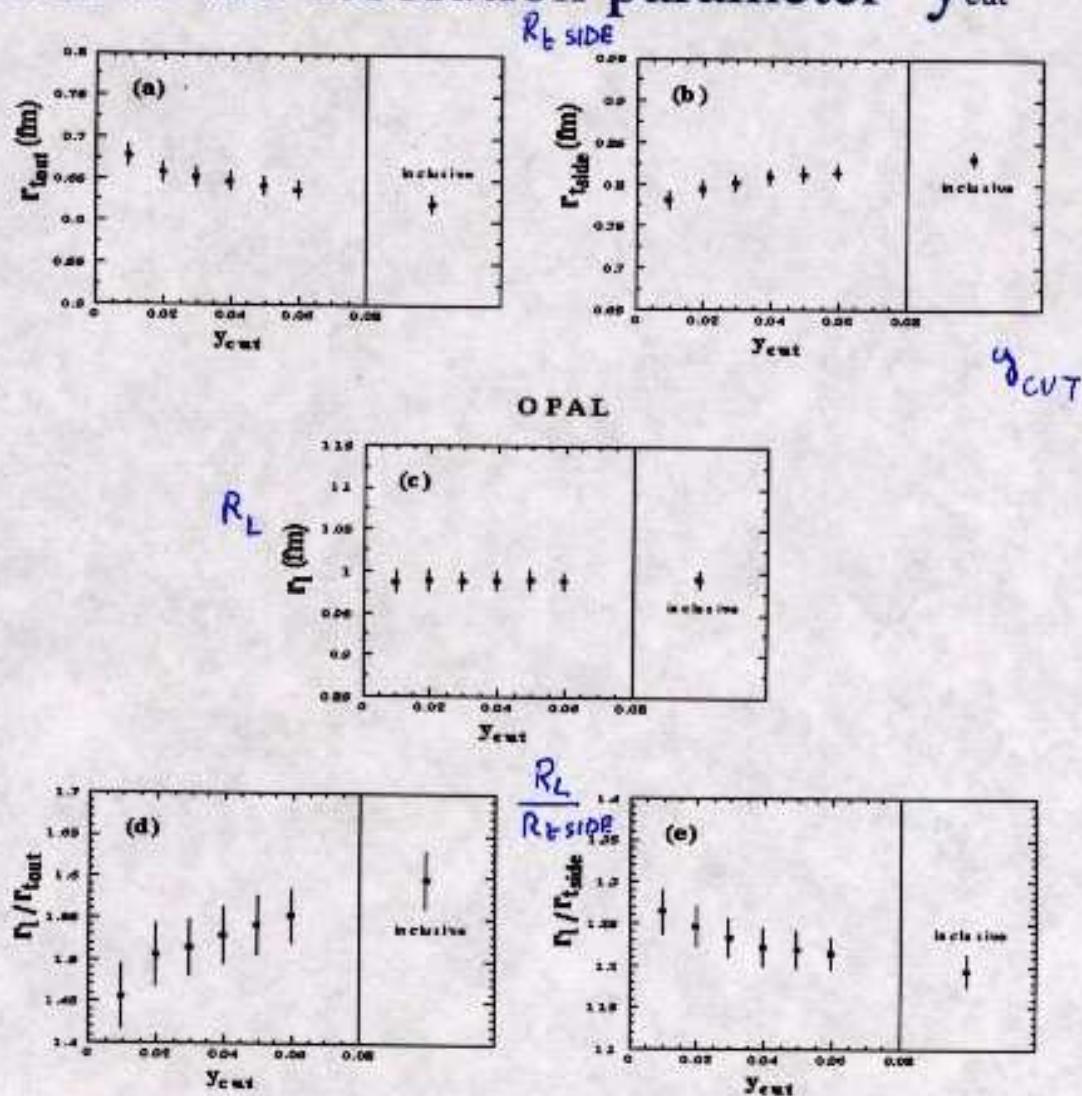
(inclusive)

the component Q_i
not plotted is
restricted to values
 < 200 (240) MeV

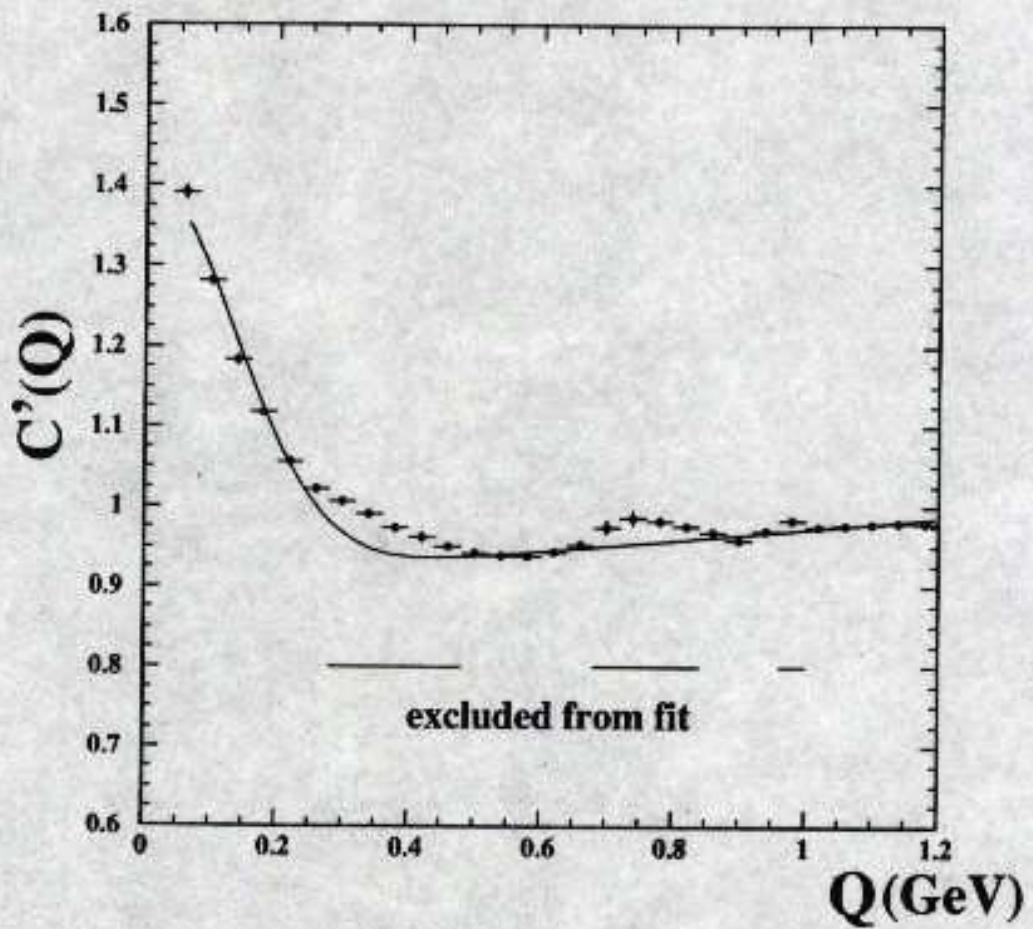


Dependence on y_{cut}

OPAL → select two-jet events with
the Durham algorithm and different
values of the resolution parameter y_{cut}



OPAL



$$C'(Q) = N \left(1 + \lambda e^{-Q^2 \tau^2}\right) \left(1 + \delta Q + \varepsilon Q^2\right)$$

$$\tau = 1.036 \pm 0.019_{\text{STAT}} \pm 0.026_{\text{SYST}} \quad \text{fm}$$

$$\lambda = 0.544$$

$$\chi^2_{\text{DOF}} = \frac{67}{45} = 4.5$$

1-DIMENSIONAL FIT

Conclusions

**Two- and three-dimensional analyses of
Bose-Einstein correlations between pairs of
like-charged pions produced in Z^0 hadronic
events show that the transverse radius
(correlation length) of the source is about
20% smaller than the longitudinal radius.**

**The value of the ratio $R_{t,\text{side}}/R_l$ measured
in the inclusive sample of events is slightly
larger than the value of the same ratio
measured in subsamples of two-jet events.**