Two Pion Correlations

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Results from EG2 experiment

Introduction

Bose-Einstein Correlations (BEC) arise from the interference between the symmetrized wave functions of identical bosons, in this case pions.
Using BEC it is possible to obtain information about the particle source or the emission duration.

Continuous source

In a continuous distribution of sources this correlation is defined in terms of:

$$R(p_1, p_2) = \frac{D(p_1, p_2)}{D(p_1) \cdot D(p_2)} \tag{1}$$

where p_1 and p_2 are the pion 4-momentum and D are the probability densities from two and one-particle.

Example

For example, one may consider the case of two pions generated from two point sources α and β. The total wave function of this system must be symmetric under permutation:

$$\varPsi = \frac{1}{\sqrt{2}}(\Psi_{1\alpha}\Psi_{2\beta} + \Psi_{2\alpha}\Psi_{1\beta}) \tag{2}$$

Assuming plane waves one may obtain

$$|\Psi|^2 = 1 + cos((\vec{k_1} - \vec{k_2}) \cdot (\vec{r_\alpha} - \vec{r_\beta})) \tag{3}$$

The correlation function will therefore have the form:

$$R(\vec{k_1}, \vec{k_2}) \propto 1 + cos((\vec{k_1} - \vec{k_2}) \cdot (\vec{r_\alpha} - \vec{r_\beta})) \tag{4}$$

Experimental definition

Experimentally the correlation is calculated using a background distribution $D_b(p_1, p_2)$ that doesn't have correlations instead of using the two single particle distributions. The correlation function used in this analysis is defined:

$$R(p_1, p_2) = \frac{D(p_1, p_2)}{D_b(p_1, p_2)} \tag{5}$$

Results from other Experiments

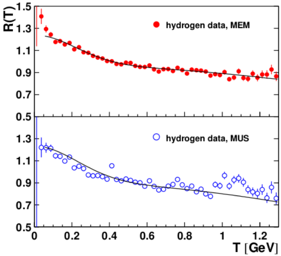

Fig. 4. Double ratio correlation function for like-sign hadron pairs obtained with *MEM* and *MUS* based on hydrogen target data.

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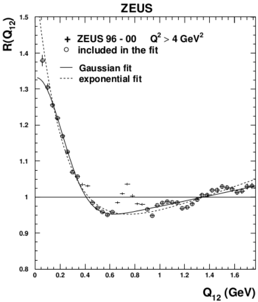

Figure 2: *The measured Bose-Einstein correlation function, $R(Q_{12})$, together with the Gaussian and the exponential fits. The error bars show the statistical uncertainties. The data points included in the fit are marked with the circles.*

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Results from other Experiments

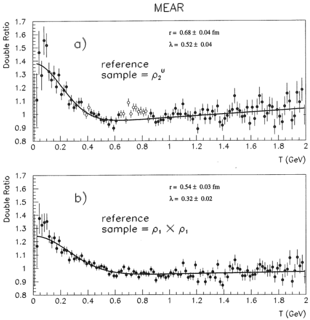

Figure 6.14: Double ratio $R'(T) = R^{\mathrm{data}}(T)/R^{\mathrm{MC}}(T)$ for $R(T) = \rho_2(T)/\rho_2^u(T)$ in (a) and for $R(T) = \rho_2(T)/\rho_1 \otimes \rho_1(T)$ in (b), here displayed as function of the variable $T = \sqrt{M^2 - 4m_\pi^2}$. The fitted values for r and λ corresponds to the "Goldhaber Parameterization" 2.16.

H1

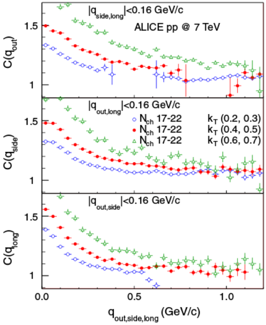

FIG. 4 (color online). Projections of the three-dimensional Cartesian representations of the correlation functions onto the q_{out}, q_{side}, and q_{long} axes, for events with $17 \leq N_{\mathrm{ch}} \leq 22$, for three k_{T} ranges. To project onto one q component, the others are integrated over the range 0–0.16 GeV/c.

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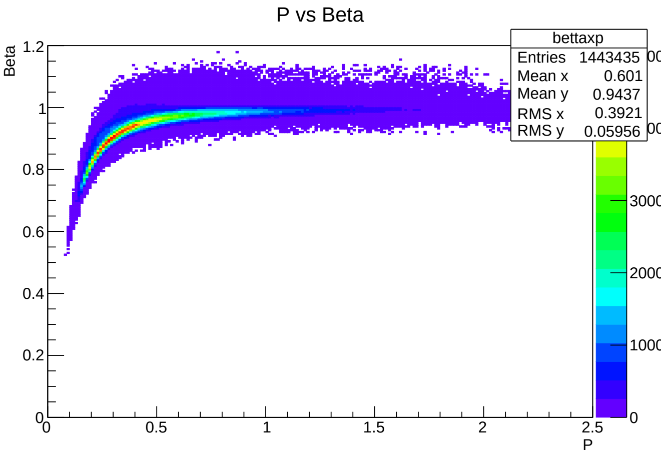
Pion Selection

Pions are identified using time of flight cuts for different momentum ranges. Pion pairs are selected from events with at least 2 positive pions within the momentum range: $0.2[Gev] < P < 2.5[Gev]$.
For different steps of the analysis, results from Iron Target are shown.
Final results are presented for four different targets:

- Deuterium
- Carbon
- Iron
- Lead

Pions Selected



Background Distribution

There are different methods for the construction of the background distribution. Two of these methods are:

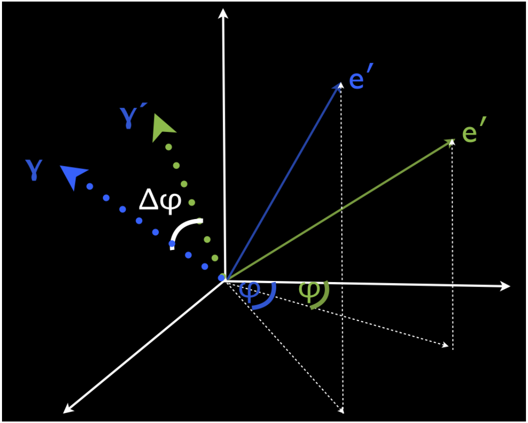
- Method of event mixing.
- Method of unlike sign pairs.

In this analysis we used the method of event mixing.

Mixing Pairs

Pions pairs for the background distribution are created taking random positive pions from two different events with at least 2 pions.
We have to conserve collinearity of the virtual photon from these two different events. To achieve this, the momenta of particles in the second event is rotated to align both virtual photons.
For both, real and mixed pairs $Q_{12} = \sqrt{-(p_1 - p_2)^2}$ is calculated.
(Where p_1 and p_2 are the four-momenta from pions.)

Rotation



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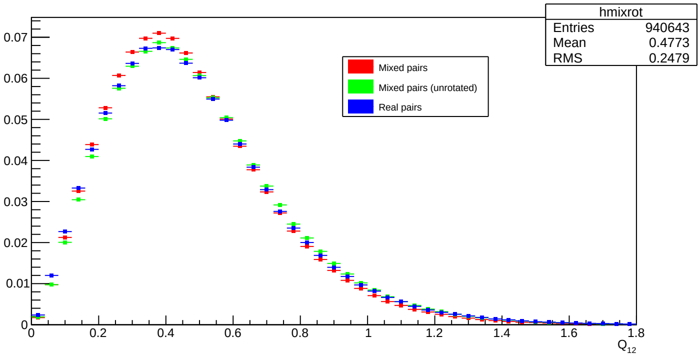
[1]**Hadronization Studies via pi 0 Electroproduction off D, C, Fe, and Pb, Taisiya Mineeva (2013)**.

Mixing problem

The main problem with this method is the violation of momentum and energy conservation.
Empirically this leads to a bias at high Q_{12} and can be solved using a Mixing Correction based in simulations.

Pair distributions

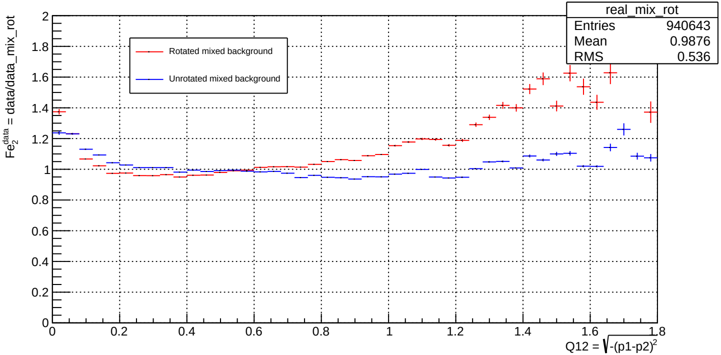


Each is normalized to 1.0

Correlation function

Correlation Function is calculated:

$$R(Q_{12}) = \frac{Q_{12} \text{ distribution from pairs of the same event (real data)}}{Q_{12} \text{ background distribution (mixed data)}}$$



Corrections

Two different corrections are made:

- Mixing Correction because of the energy-momentum conservation problem in mixed events pairs.
- Efficiency Correction because of the close track efficiency of the pions at low momenta difference[2].

[2] **K. Mikhailov**, **A. Stavinsky**, **A. Vlassov**, **CLAS NOTE 2002-02.**

Mixing Correction

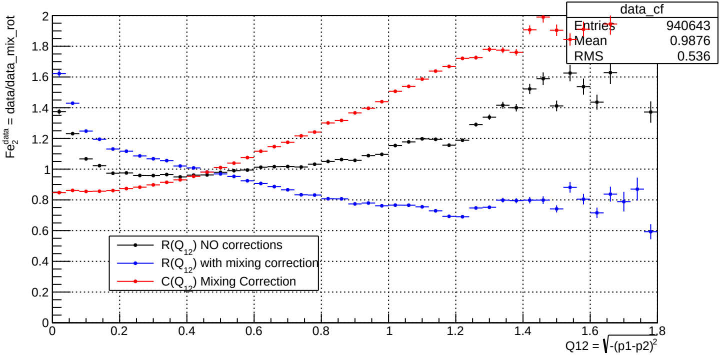
In order to estimate the mixing correction, the correlation function is calculated for generated pions in simulations $C(Q_{12})$.
This ratio from simulations should not present correlations but it should present the same bias at high Q_{12}.
Dividing the experimental ratio by the simulated one is applied to reduce this behavior.
The correlation function $R(Q_{12})$ is corrected by $C(Q_{12})$:

$$R(Q_{12})_{corr} = R(Q_{12})/C(Q_{12}) \tag{6}$$

Mixing Correction

The corrected correlation function is:

$$R_{corr}(Q_{12}) = \frac{Q12 \text{ distribution from real pairs}}{Q_{12} \text{ background distribution } / \ \mathrm{C}(Q_{12})} \qquad (7)$$



Efficiency Correction

For low 3-momentum difference $\vec{q} = \vec{p_1} - \vec{p_2}$, the tracks of the pions from the same event are very close in angle. This lead to the identification of only 1 particle instead of 2.
This close-track efficiency could be measured using 3 different methods.

- Experimental data on different particle mass pairs.
- Simulations of like-sign hadron pairs.
- Merging events.

Efficiency Correction (Experimental Data)

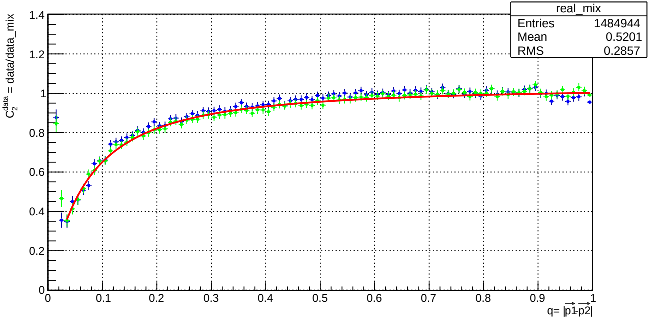
The dependence of the correlation function using different particles on the relative momentum $\vec{q}$ can be interpreted as a dependence of the efficiency on $\vec{q}$.
The particles selected were pion and protons.
Pions selected are in the momentum range $0.15 < P < 0.60$ GeV.
Protons selected are in the momentum range $0.3 < P < 1.0$ GeV.
Pion and Protons are selected using time of flight in different momentum ranges.

Efficiency Correction (Data)

Efficiency is fitted using a logarithmic function that presents a similar shape.

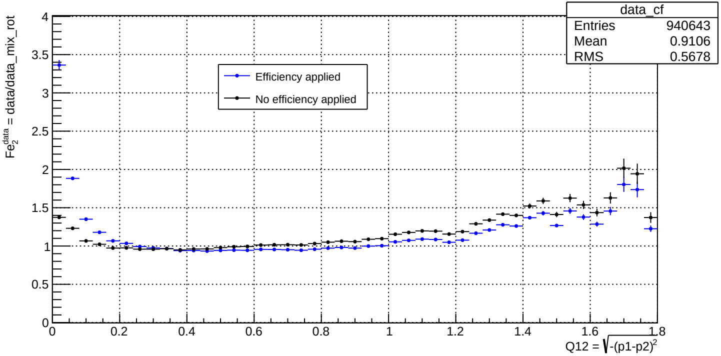
$$\varepsilon = a\frac{log(1+bq)}{1+log(1+cq)} \tag{8}$$

With a, b, c parameters.



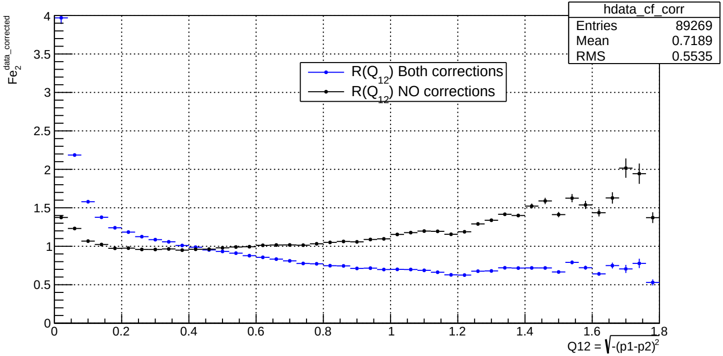
Efficiency Correction (Data)

The correlation function is corrected using the close-track efficiency by weighting each real pair depending on $\vec{q}$:



Correlation function with both corrections

Correlation function applying mixing and efficiency corrections.



Target Comparison

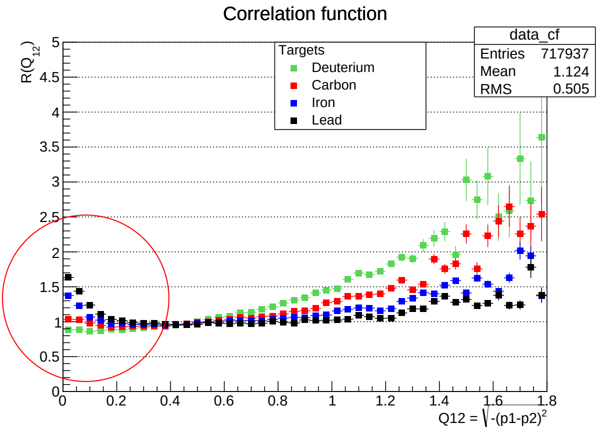
This procedure was applied for four different targets:

- Deuterium
- Carbon
- Iron
- Lead

With different targets we could obtain information about: current vs target fragmentation or nuclear effects vs intrinsic hadronization effects.

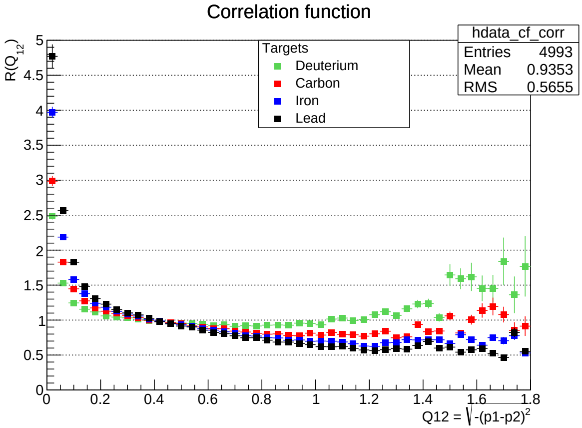
C vs Fe vs Pb vs D2 without corrections

Correlation function comparison using rotated events



C vs Fe vs Pb vs D2 with both correction

Correlation function comparison with Efficiency and Mixing Corrections



Things to do

- Apply Mixing unlike sign pairs method for background distribution.
- Use and compare results with different efficiency method.
- Calculate BEC for different kinematics ranges.
- Include final state corrections as Coulomb corrections.
- Include systematic errors.
- Fit results with the model.
- Compare results with other experiments.

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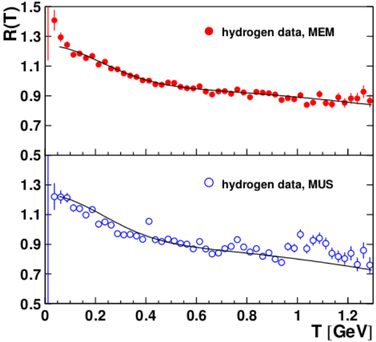

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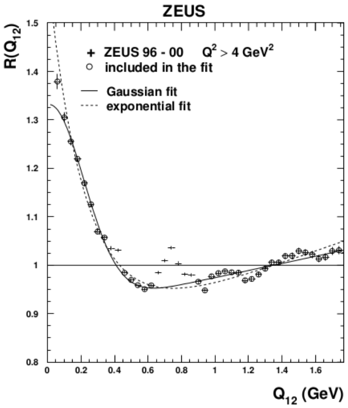

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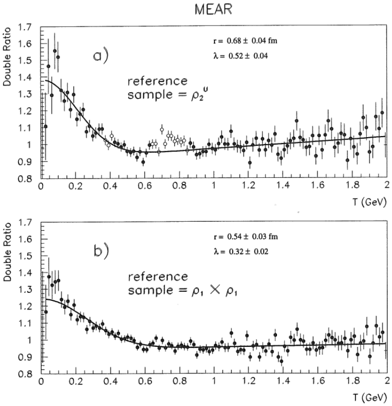

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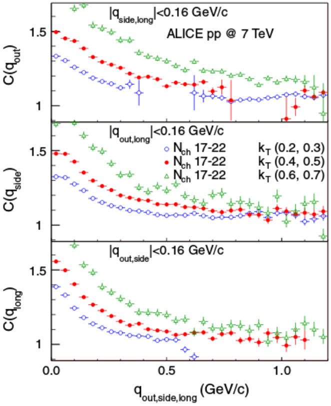

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