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Charm production in DIS using HERA II data

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Abstract

Production of D mesons in deep inelastic scattering has been measured with the ZEUS experiment at HERA-II using the silicon microvertex detector. The vertex detector was installed during the HERA upgrade to improve the tracking and vertexing. It is demonstrated that the resolution of the vertex detector allows charm to be selected by measuring the secondary vertex from the D meson decay.

1 Introduction

The recently commissioned ZEUS microvertex detector has been used to tag $D^{\pm}$ mesons in both photoproduction and deep inelastic scattering (DIS) at HERA. The methods developed in this paper will be extended in future to tag many other charm and beauty hadrons, with the aim of gaining further understanding of the production dynamics of heavy quarks in electron-proton interactions.

2 Experimental setup

The data presented in this analysis were collected with the ZEUS detector at HERA during the 2003-2004 running periods, with a positron beam energy $E_e = 27.5\,\text{GeV}$ colliding with protons with a beam energy $E_p = 920\,\text{GeV}$. The data sample used corresponds to an integrated luminosity of $15\,\text{pb}^{-1}$.

A detailed description of the ZEUS detector can be found elsewhere [1]. A brief outline of the components that are most relevant for this analysis is given below.

Charged particles are tracked in the central tracking detector (CTD) [2], which operates in a magnetic field of $1.43\,\text{T}$ provided by a thin superconducting coil. The CTD consists of 72 cylindrical drift chamber layers, organised in 9 superlayers covering the polar-angle[1] region $15^\circ < \theta < 164^\circ$. In 2001 a silicon microvertex detector (MVD) [3] was installed inside the CTD. The MVD is organised into a barrel with 3 cylindrical layers and a forward section with four planar layers perpendicular to the HERA beam direction. The barrel contains 600 single-sided silicon strip sensors each having 512 120 μm wide strips; the forward section contains 112 sensors each of which has 480 120 μm wide strips. Currently, without final corrections for alignment, the hit resolution is 40 μm in the $R-Z$ and 65 μm in the $R-\phi$ plane. The resulting resolution of the primary vertex is around 100 μm both in the transverse and in the longitudinal planes.

The high-resolution uranium–scintillator calorimeter (CAL) [4] consists of three parts: the forward (FCAL), the barrel (BCAL) and the rear (RCAL) calorimeters. Each part is subdivided transversely into towers and longitudinally into one electromagnetic section (EMC) and either one (in RCAL) or two (in BCAL and FCAL) hadronic sections (HAC). The smallest subdivision of the calorimeter is called a cell. The CAL energy res-

[1] The ZEUS coordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, referred to as the "forward direction", and the X axis pointing left towards the centre of HERA. The nominal interaction point is shifted by +1.75 cm in X with respect to the coordinate origin.

olutions, as measured under test-beam conditions, are $\sigma(E)/E = 0.18/\sqrt{E}$ for electrons and $\sigma(E)/E = 0.35/\sqrt{E}$ for hadrons (E in GeV).

3 Analysis

3.1 Event selection

In this paper two event samples are selected:

A. Inclusive selection
All events were analysed. This event sample is dominated by photoproduction events and is predominantly triggered by algorithms that reconstruct the $D^{\pm}$ mesons online.

B. DIS selection
The DIS selection ($Q^2 > 4\,\mathrm{GeV}^2$) is based by the identification of a clearly measured scattered positron in the CAL. The selection follows a similar strategy as in the inclusive neutral current analysis of the HERA-I data [5]. Events were triggered by requiring a scattered electron to be found. To give a well defined sample, the following cuts were applied: the scattered positron energy $E_e > 8\,\mathrm{GeV}$, the difference of the total energy and the longitudinal component of the total momentum, $E - p_Z$, satisfied $38 < E - p_Z < 65\,\mathrm{GeV}$, and a "box-cut" was made on the position of the scattered positron on the RCAL front face of $|X| > 13\,\mathrm{cm}$ and $|Y| > 10\,\mathrm{cm}$. The data used is a subsample corresponding to an integrated luminosity of $9.8\,\mathrm{pb}^{-1}$.

3.2 $D^{\pm}$ selection

The strategy to tag the $D^{\pm}$ is the same for both event selections. The cuts given below are for the inclusive selection. Where the DIS selection differs, the cut values are indicated in parentheses.

In each event, all combinations of three tracks with net charge $\pm$ 1 are combined to form the $D^{\pm}$ meson candidates. To ensure that only well-measured tracks were considered, the tracks were required to have hits in at least 3 CTD superlayers, and 4 (1 for the DIS selection) MVD hits. Only tracks with a transverse momentum greater than 0.8 (0.4) GeV were used for the inclusive (DIS) samples. The pion mass was assigned to the two tracks with equal charges while the kaon mass was assigned to the third track. Subsequently, the $D^{\pm}$-candidate invariant mass, $M(K\pi\pi)$ was calculated.

The following selections reduced the combinatorial background:

- $\cos\theta^*(K) > -0.75$
  where $\theta^*(K)$ is the angle between the kaon in the $K\pi\pi$ rest frame and the $K\pi\pi$ line-of-flight in the laboratory;

- $p_T(D^\pm) > 3.7\,\text{GeV}$ for the inclusive sample ; $p_T(D^\pm) > 2.0\,\text{GeV}$ for the DIS sample;

- $|\eta(D^\pm)| < 1.5$, where η is the pseudorapidity.

The three decay tracks were refitted to a secondary vertex for candidates in the invariant-mass region between 1.6 GeV and 2.2 GeV. The $D^\pm$ invariant mass was redetermined from the tracks refitted to the secondary vertex. The remaining tracks were also refitted to a new primary vertex, using the run-average vertex position as an initial seed. The distance between the $D^\pm$ vertex and the new primary vertex was then used to tag $D^\pm$ decays.

The signed decay length L is defined as:

$$L = |\boldsymbol{L}|\mathrm{sign}(\boldsymbol{L} \cdot \boldsymbol{p_{D^\pm}}), \tag{1}$$

with $\boldsymbol{L} = \boldsymbol{s} - \boldsymbol{P}$, where $\boldsymbol{P}$ is the primary vertex position and $\boldsymbol{s}$ is the secondary vertex position. The refitted momentum vector of the $D^\pm$ is $\boldsymbol{p_{D^\pm}}$. In the case that L is positive, the decay was downstream of the primary interaction in the direction of the $D^\pm$; if L is negative, the decay occurred upstream of the primary vertex, i.e. in the opposite direction to that of the $D^\pm$. The error on the decay length, σ_L, was calculated from the covariance matrices of the primary vertex and $D^\pm$ candidate vertex. The decay length significance is then defined as:

$$s_L = L/\sigma_L. \tag{2}$$

To reduce the fraction of background from badly reconstructed secondary vertices, the following cuts were applied:

- the $D^\pm$ decay-length error $\sigma_{D^\pm}$ should be less than 0.5 mm.

- the χ^2 probability of the secondary vertex $P(\chi^2)$ should be greater than 0.05 (DIS selection only).

- the radial decay length, $|L_{XY}|$ should be less than 4 mm, where $L_{XY} = L\sin\theta$, and θ is the polar angle of the $D^\pm$ candidate (DIS selection only).

A heavy-meson decay with a large decay length would lead to an excess at higher positive values of the significance. The negative values of significance can therefore be used as an estimate of the resolution.

4 Results

4.1 Inclusive selection

Figure 1 shows the invariant-mass distribution $M(K\pi\pi)$ for the inclusive data selection, before the cuts on the decay-length significance were applied. A small excess is observed in the mass region expected for the $D^{\pm}$ meson, over a huge combinatorial background. In all cases below, the data is fitted with a Gaussian for the signal and a first-order polynomial for the background. The fit gave a signal of 417 $\pm$ 195 $D^{\pm}$'s.

Figure 2 shows the significance distribution for the track combinations in the mass range around the nominal mass of the $D^{\pm}$ meson, $1.845 < M(K\pi\pi) < 1.905$ GeV. An excess can be observed on the positive side of the distribution, indicating the presence of long-lived decays.

Figure 3 shows the mass distribution after the significance cut of $s_L > 7.0$ is applied. A clear peak corresponding to 151 $\pm$ 28 $D^{\pm}$ mesons is observed at the $D^{\pm}$ mass with a width compatible with the detector resolution.

4.2 DIS selection

The DIS signal selection takes advantage of being able to apply much looser signal selection cuts than for the inclusive case, due to the lower average track multiplicity in DIS events and there being no preselection on $D^{\pm}$ mesons in the DIS trigger, in contrast to the inclusive selection which is predominantly triggered by algorithms that reconstruct the $D^{\pm}$ mesons online. Figure 4 shows the result from the DIS sample before and after a significance cut is applied. Without a significance cut, the fit gives 712 $\pm$ 260 $D^{\pm}$ candidates. After a significance cut of 6 is applied, again a clear peak corresponding to 191 $\pm$ 33 $D^{\pm}$ mesons is observed at the correct mass and with a width compatible with the detector resolution. This cut reduces the combinatorial background by a factor of 45, whilst reducing the signal by a factor of 2.7.

Figure 5 shows an example DIS event from the $D^{\pm}$ candidate sample. The scattered positron is separated from the other tracks. The three tracks that fit to the secondary vertex combine to make a D^{+} candidate with $\mathrm{p}_T(D^{+}) = 5.1$ GeV.

5 Summary

$D^{\pm}$ mesons in the three-body decay $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ have been tagged in the ZEUS microvertex detector, establishing that these new techniques can be used to select clean samples of such mesons in order to pin down the production dynamics of heavy quarks at HERA.

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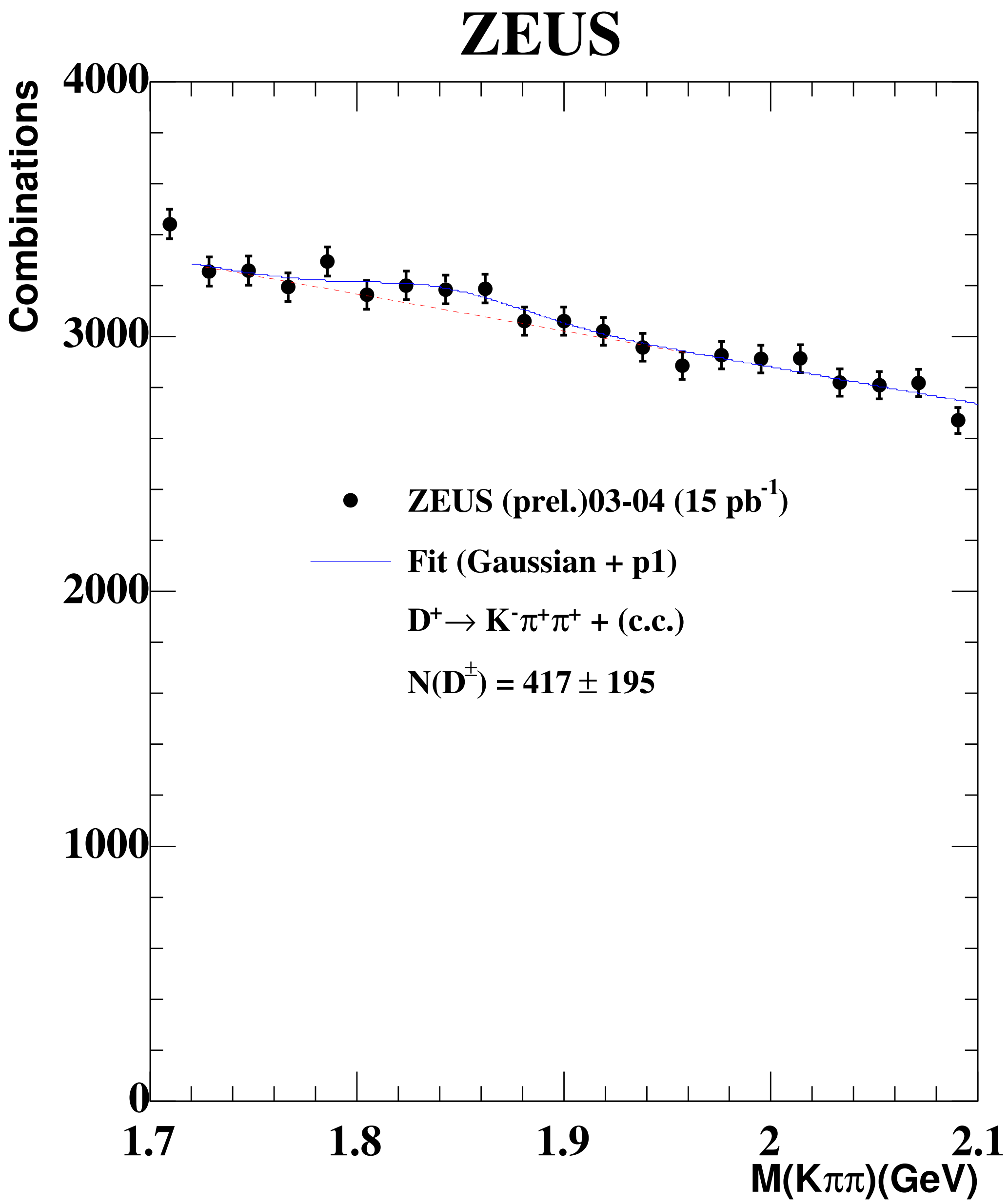

Figure 1: *$M(K\pi\pi)$ invariant-mass distribution prior to the decay-length significance cut from the inclusive event sample. The number of events displayed results from a Gaussian fit to the signal and a first-order polynomial for the background.*

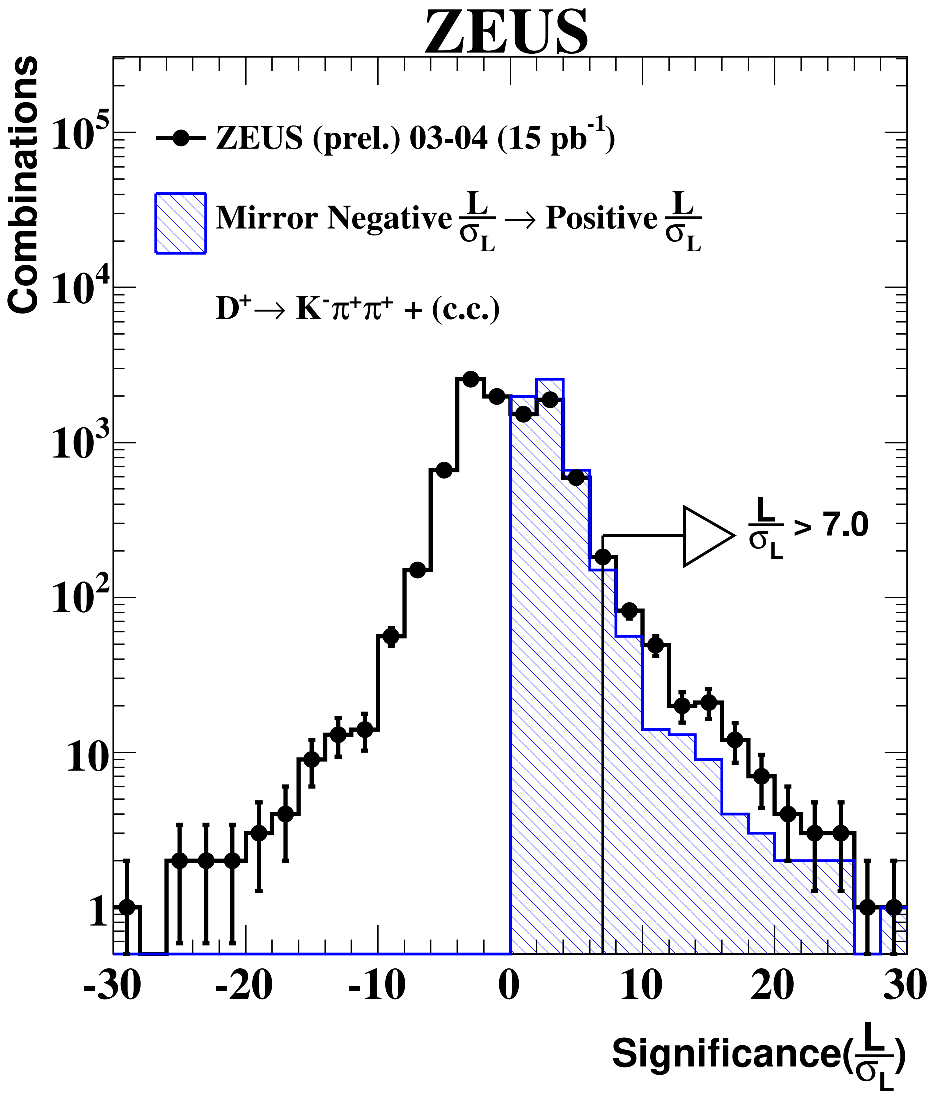

Figure 2: *Significance* $s_L = \frac{L}{\sigma_L}$ *distribution for events satisfying* $1.845 < M(D^{\pm}) < 1.905$ *GeV for the inclusive event sample. The selection cut subsequently used* ($s_L > 7$) *is indicated in the figure. The shaded area represents the negative part of the distribution reflected around* s_L=0.

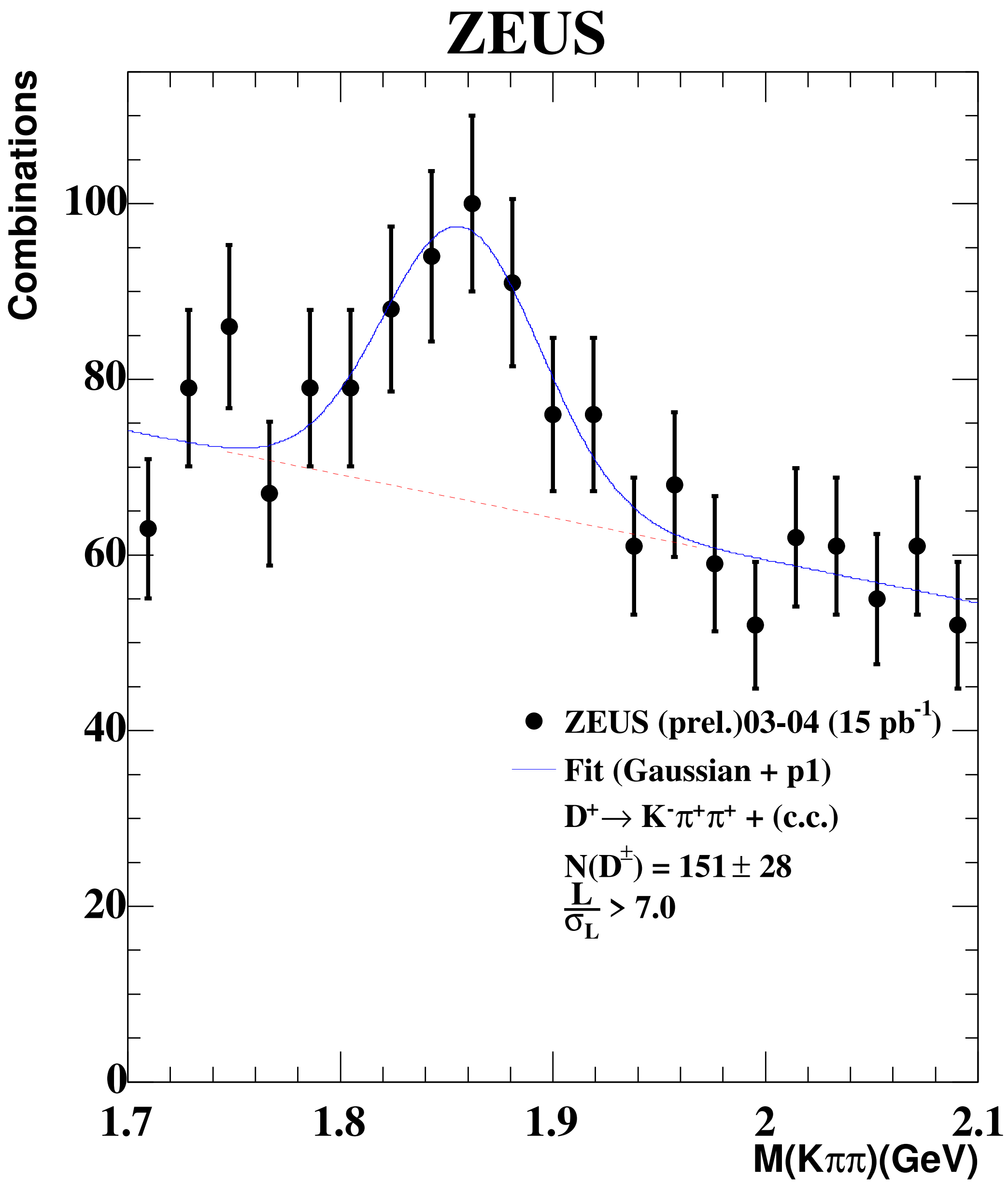

Figure 3: *$M(K\pi\pi)$ invariant-mass distribution with decay length significance $L/\sigma_L > 7$ for the inclusive event sample. The curve shows a fit to the data with a Gaussian for the signal and a first-order polynomial for the background.*

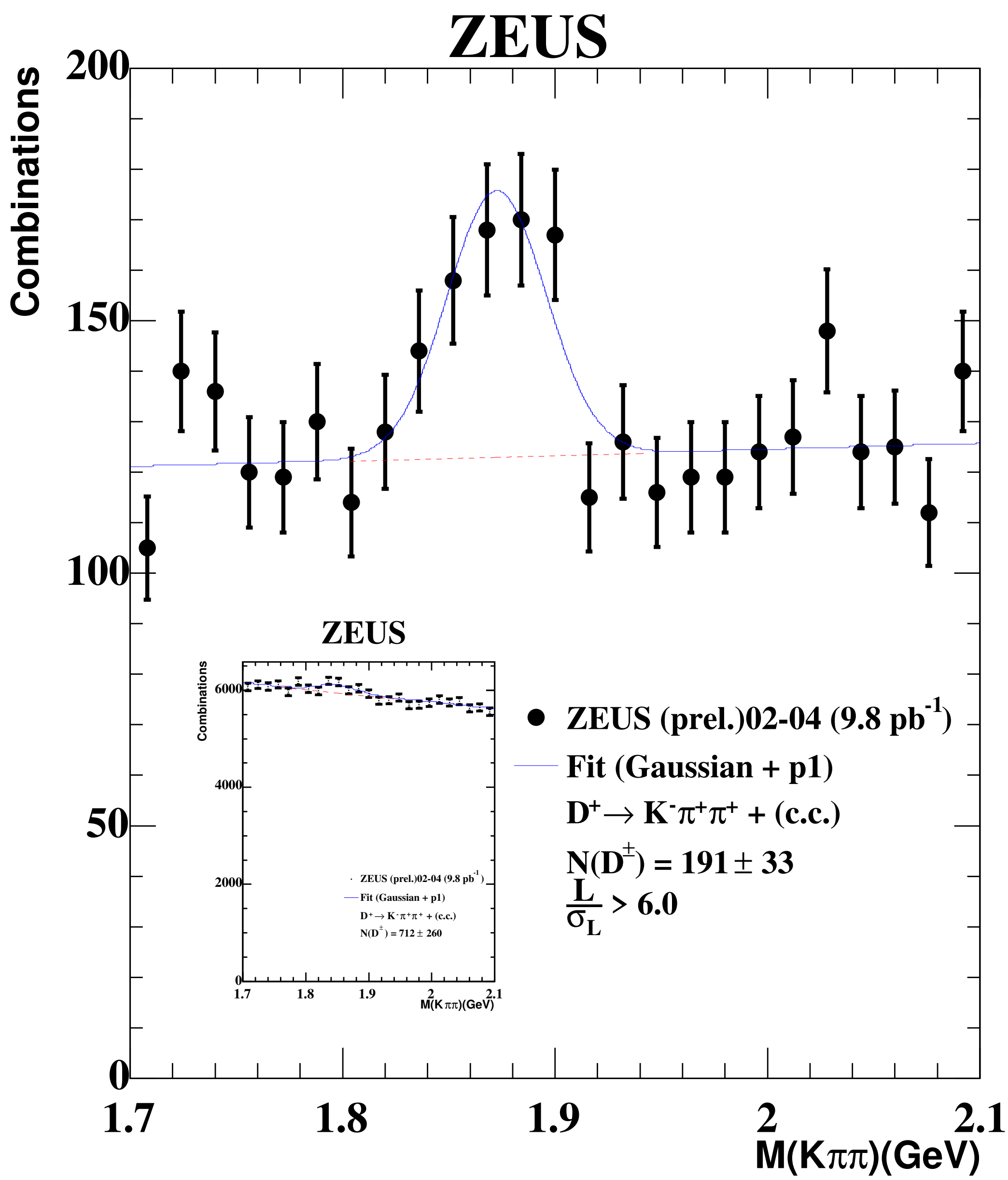

Figure 4: *$M(K\pi\pi)$ invariant-mass distribution for DIS events with decay-length significance $L/\sigma_L > 6$. The curve shows a fit to the data with a Gaussian for the signal and a first-order polynomial for the background. The invariant mass distribution prior to the decay length significance cut is shown in the insert.*

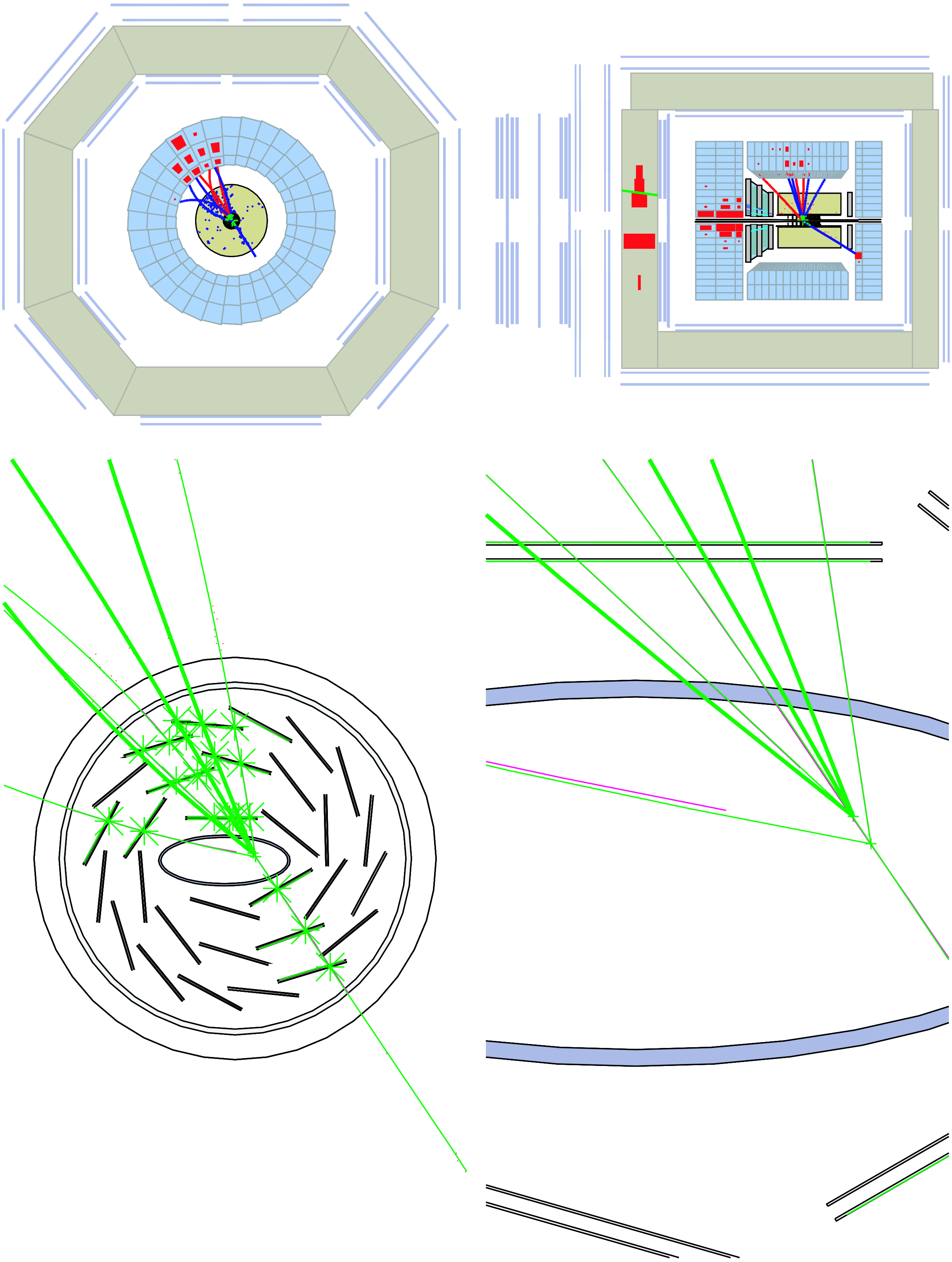

Figure 5: *Event display of a DIS D^+ candidate event ($Q^2 = 160\ GeV^2$). Three of the tracks combine to a form a D^+ candidate with $p_T(D^+) = 5.1\ GeV$, emanating from a secondary vertex.*