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Abstract

FNAL experiment 711 has investigated proton-nucleus collisions in which two high transverse momentum hadrons are produced forming high mass $++$, $+-$ and $--$ charged states, using an 800 GeV/c proton beam on targets of beryllium, aluminium, iron and tungsten. Our data cover the range in dihadron mass from 6 to 15 GeV/c^2. We show here that the dependence of the cross-section on atomic weight, A, can be parameterised as A^{α} where $\alpha = 1.043 \pm 0.011(stat) \pm 0.025(syst)$, and is independent of the charge state of the dihadron system.

Since its discovery in 1972[1], high transverse momentum hadronic production has been used to study QCD[2]. The interpretation of data on the production of a single high p_t particle is complicated, however, by effects due to the intrinsic motion of the partons. Data from nuclear targets[3] may be further complicated both by collective nuclear effects on the intrinsic motion of the partons[4], and by interactions of the scattered partons with the nuclear matter. While data on leptonic hadron production from nuclear targets[5] suggest that for leading particles the latter effect is small, experiments using jet-like triggers[6] have found large nuclear effects. When the cross sections are parameterised in the form $\sigma(A) = \sigma_o A^{\alpha}$, one of these experiments[7] finds α to be about 1.45 for their two-jet data. A technique which may avoid these effects is to select events in which two high transverse momentum hadrons are produced roughly back to back, to form a high mass state[8]. The present experiment was designed to test the hard scattering predictions of QCD in hadronic collisions by observing such high mass dihadron events in proton-nucleus collisions. As the first step, we present data taken between November 1987 and February 1988, on the dependence of the cross section with atomic weight (A) for the production of pairs of charged hadrons on four nuclear targets covering the mass range between 6 and 15 GeV/c^2.

The apparatus (Figure 1) was a double arm spectrometer, triggered calorimetrically, and with a high resolution magnetic momentum measurement. The detector[9] was designed to have a large acceptance for all charge states in both the polar angle defined in the rest frame of the massive state ($|cos\theta^*| < 0.5$), and in the central rapidity region in the proton-nucleon centre of mass ($|Y_{pN}| < 0.5$). The apparatus had very little matter in the path of the beam, enabling it to tolerate a beam intensity of 10^8 protons per second. A narrow (1mm) 10% interaction-length target was placed just upstream of two large aperture analysis magnets, which provided a momentum kick of 1.16 GeV/c in the horizontal plane. Downstream of the magnets were 5 stations of wire chambers (4 views per station) to reconstruct the particle tracks and four planes of hodoscopes and two calorimeters used for triggering. The calorimeters were comprised each of 16 horizontal segments and covered the azimuthal range $\pm 25^\circ$ about the vertical. To avoid any sensitivity to the beam and other particles in the median plane, the chambers were deadened across a central horizontal band, $\theta_y < 20\ mrad$.

The experiment trigger was provided by the calorimeters and required a localised energy deposition in each calorimeter with a transverse energy of greater than 2 GeV, and total transverse energy sum of the two arms greater than 6 GeV. The trigger selected charged hadrons by requiring signals from the hodoscopes in front of the energy clusters.

Triggering on scatters in the vertical plane and measuring momenta by bending in the horizontal plane minimised the effect of the magnetic bending on the trigger. This allowed the use of a high magnetic field and a long lever arm, thus improving the track momentum resolution. To allow the experiment to operate at high rates, a narrow target was used, thus defining the production vertex and obviating the need for track measurements upstream of the magnet, where the particle flux density was highest. The wire-chambers were designed to operate with small collection times and equipped with pre-amplifiers to reduce the operating gain required. The hodoscopes and calorimeters were constructed with fast scintillator and photomultipliers and low dispersion cables to avoid pile-up effects.

The determination of α relies critically on the measurement of the relative luminosity for each nuclear target. The total beam flux was measured by an ion chamber placed upstream of the experimental hall which was calibrated with scintillator counters at low beam intensity. The fraction of beam hitting the target, typically 90%, was measured by four independent sets of triple coincidence scintillator telescopes placed symmetrically around the target and at 90° to the beam. The counts from the four telescopes, gated by the beam time and live time of the experiment, were recorded at the end of each 20 second beam pulse, along with the ion chamber information. The monitoring system was calibrated by scanning the beam horizontally across the target and measuring the count rate divided by beam intensity as a function of the distance between the centre of the beam and the target. The distributions from all four telescopes were consistent with a Gaussian beam profile convoluted with the target profile plus a background proportional to the total beam flux. This background rate was independent of the target, and was equal to what was seen during beam scans when the target was removed. The constancy of the background limits the uncertainty in the relative luminosity to be less than 2%. Target scan data was recorded periodically in order to account for the effect of the changing beam conditions on the measurement of the luminosity. After subtracting the individual backgrounds, the luminosities as given by the four telescopes agreed to within 3%. The overall error in the luminosity due to counting statistics was negligible. The only significant error arose from uncertainties in the beam shape. Run to run variations of the luminosity monitor calibration were less than 4% for the Be target and less than 2% for the Al, Fe and W targets. The integrated luminosities for each target type are listed in Table 1.

The track reconstruction algorithm[10] was written in vectorised code, and the data was processed by an ETA-10 supercomputer. Due to changes in the chamber operating conditions over the course of the run, the reconstruction efficiency had to be evaluated as a function of time and (hence) target. The overall event reconstruction efficiency was found to vary between 0.585 and 0.711. The systematic error is estimated to be 8%.

The particle momenta are calculated from the downstream trajectory assuming that the interaction occurred at the centre of the target. The uncertainty in the momentum is due to the size of the target and the chamber resolution. Above $p = 20\ GeV/c$ the momentum resolution is dominated by the target width, and can be expressed as $\delta p/p = kp$, where k takes a value between 2.5×10^{-4} and 2.8×10^{-4} $(GeV/c)^{-1}$ for the four targets. The resolution function was also calculated by superimposing Monte Carlo tracks onto data events and comparing the momentum of the generated track with that found by the tracking algorithm. This technique gave a result in agreement with the direct calculation and was used to determine the mass resolution. In practice, corrections due to the mass resolution, including the non-gaussian tails, were negligible over the range of the data.

The high mass dihadrons were selected from the initial data sample by requiring:

- a loose cut on the vertical (non-bend view) position of the tracks at the target;
- the requirement that the dihadron alone satisfied the trigger;
- consistency between the track momentum and the associated calorimeter energy;

In order to use a purely geometrical calculation of acceptance, the fiducial volume was restricted in the calorimeter to ensure shower containment, and the range of rapidity and CM polar angle restricted to be $-0.4 < Y_{pN} < 0.2$ and $|cos\theta^*| < 0.2$. The acceptance was between 0.1 and 0.2, and variations within any mass bin of width 1 GeV/c^2 were less than 2%. The lower mass limit of 6 GeV/c^2 was determined from the measurement of the efficiency of the hardware trigger. This efficiency was found to be independent of target type.

The two backgrounds which have been considered are from proton interactions in material other than the target and from coincidental hadrons from two proton interactions within the trigger gate. Several runs were taken with the target removed and the data were analysed in exactly the same method as the target data. Normalising the number of events found by the beam flux, the fractions of this background in the data samples were found to be 2.7% for Be, 1.4% for Al, 1.2% for Fe and 1.0% for W. Both calculation and measurement of uncorrelated hadrons shows the latter background to be negligible ($< 1\%$).

The dependence of the event yield per unit luminosity on atomic weight has been parameterised in the form $ln[\sigma(A)] = \alpha ln A + ln \sigma_\circ$, for each dihadron mass range, p_t range and charge state. The results of the fits for α are shown as a function of mass for the three different charge states in Figures 2 ($p_t < 1$ GeV/c) and 3 ($p_t < 2$ GeV/c). The numerical values with their statistical errors are presented in Tables 2 and 3. The average values for $p_t < 1$ and < 2 GeV/c are 1.043 ± 0.011 and 1.049 ± 0.007 respectively. The 12% systematic error in the cross-section corresponds to an average systematic error in α of 0.025.

The fit of the form $\sigma(A) = \sigma_\circ A^\alpha$ shows that α is very close to unity for $p_t < 1$ and < 2 GeV/c and is in good agreement with most published results of unlike sign dihadrons[11]. We observe no significant variation over the available mass range or with charge state. Where the statistical uncertainties are small, α is always slightly larger than unity. These results are consistent with the multiple scattering hypothesis of Lev and Petersson[12], however the increase of α with p_t predicted by this model would be too small to be seen with this data.

We have presented the first results from E711, and shown the dependence of the massive dihadron production with the atomic weight of the target. Given the consistency of the value of α with expectations of phenomenological QCD calculations, and its measured value being near unity, we believe that the study of symmetric dihadrons will yield data that can serve as a reliable test of QCD. We anticipate the publication of those tests (mass cross sections and angular distributions) in the the coming months.

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Table 1 Integrated Luminosity of Data Summary

material	$\mathbf{L}_n$ *per nucleus* (nb^{-1})	$\mathbf{L}_N$ *per nucleon* $(pb^{-1}) \equiv \mathbf{L}_n \times \mathbf{A}$
Beryllium (Be)	1774.	15.98
Aluminium (Al)	225.8	6.090
Iron (Fe)	275.6	15.39
Tungsten (W)	35.34	6.497

Table 2 Results of Fits for α $p_t < 1$ GeV/c

Mass range (GeV/c^2)	$++$	$+-$	$--$
$6.0 < M < 6.5$	1.130 ± 0.040	1.034 ± 0.019	1.043 ± 0.049
$6.5 < M < 7.0$	1.054 ± 0.051	1.033 ± 0.024	1.111 ± 0.064
$7.0 < M < 7.5$	1.117 ± 0.061	0.988 ± 0.035	1.079 ± 0.086
$7.5 < M < 8.5$	1.041 ± 0.072	1.015 ± 0.037	0.944 ± 0.102
$8.5 < M < 10.5$	1.130 ± 0.102	1.101 ± 0.059	0.916 ± 0.147
$10.5 < M < 15.$	$0.553^* \pm 0.256$	1.091 ± 0.127	1.087 ± 0.790
average	1.093 ± 0.025	1.029 ± 0.012	1.049 ± 0.033

* To maintain constant vertical scales, this point is not shown in Figure 2.

Table 3 Results of Fits for α $p_t < 2$ GeV/c

Mass range (GeV/c^2)	$++$	$+-$	$--$
$6.0 < M < 6.5$	1.125 ± 0.022	1.035 ± 0.012	1.060 ± 0.029
$6.5 < M < 7.0$	1.052 ± 0.028	1.042 ± 0.016	1.051 ± 0.041
$7.0 < M < 7.5$	1.030 ± 0.036	1.030 ± 0.022	1.069 ± 0.053
$7.5 < M < 8.5$	1.045 ± 0.042	1.045 ± 0.023	1.059 ± 0.056
$8.5 < M < 10.5$	1.025 ± 0.059	1.025 ± 0.037	0.992 ± 0.093
$10.5 < M < 15.$	0.976 ± 0.126	0.976 ± 0.093	1.407 ± 0.274
average	1.087 ± 0.013	1.066 ± 0.005	1.087 ± 0.013

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Figure Captions

Figure 1

Plan view of the apparatus.

Figure 2

Variation of α with mass $p_t < 1$ GeV/c, $h+$ and $h-$ refer to positive and negative hadrons.

Figure 3

Variation of α with mass $p_t < 2$ GeV/c, $h+$ and $h-$ refer to positive and negative hadrons.

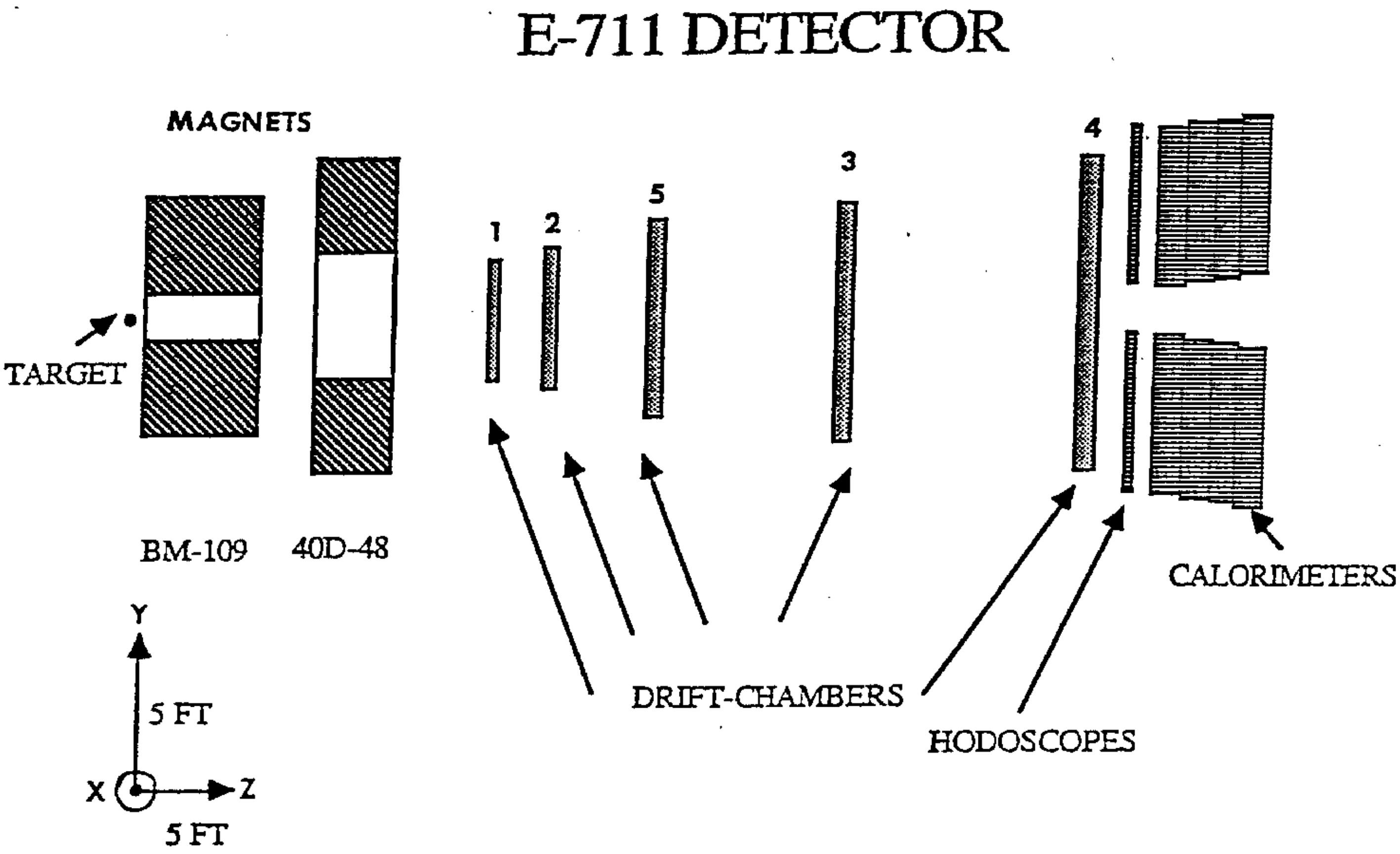

Figure 1

Plan view of the apparatus.

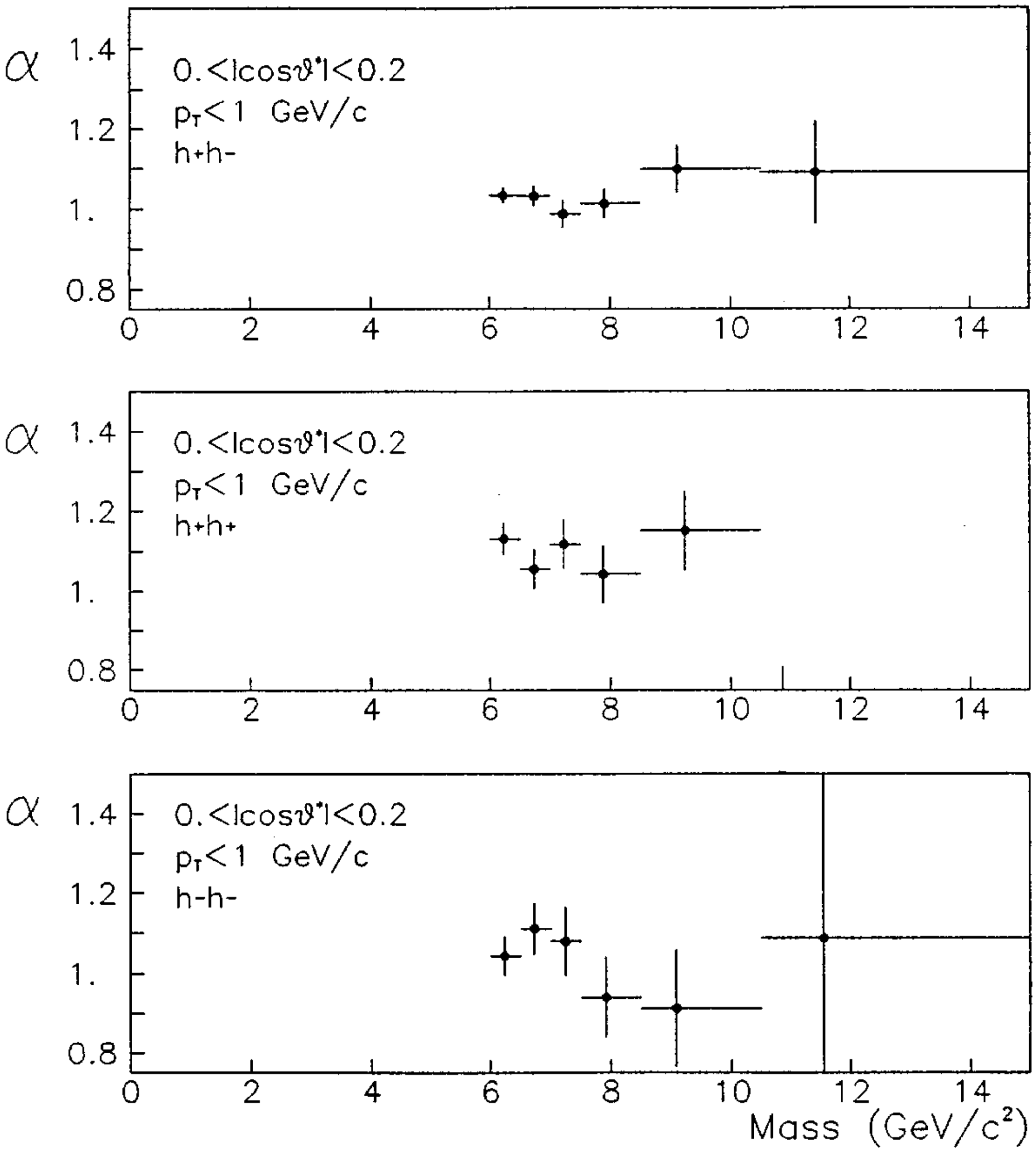

Figure 2

Variation of α with mass $p_t < 1$ GeV/c, $h+$ and $h-$ refer to positive and negative hadrons.

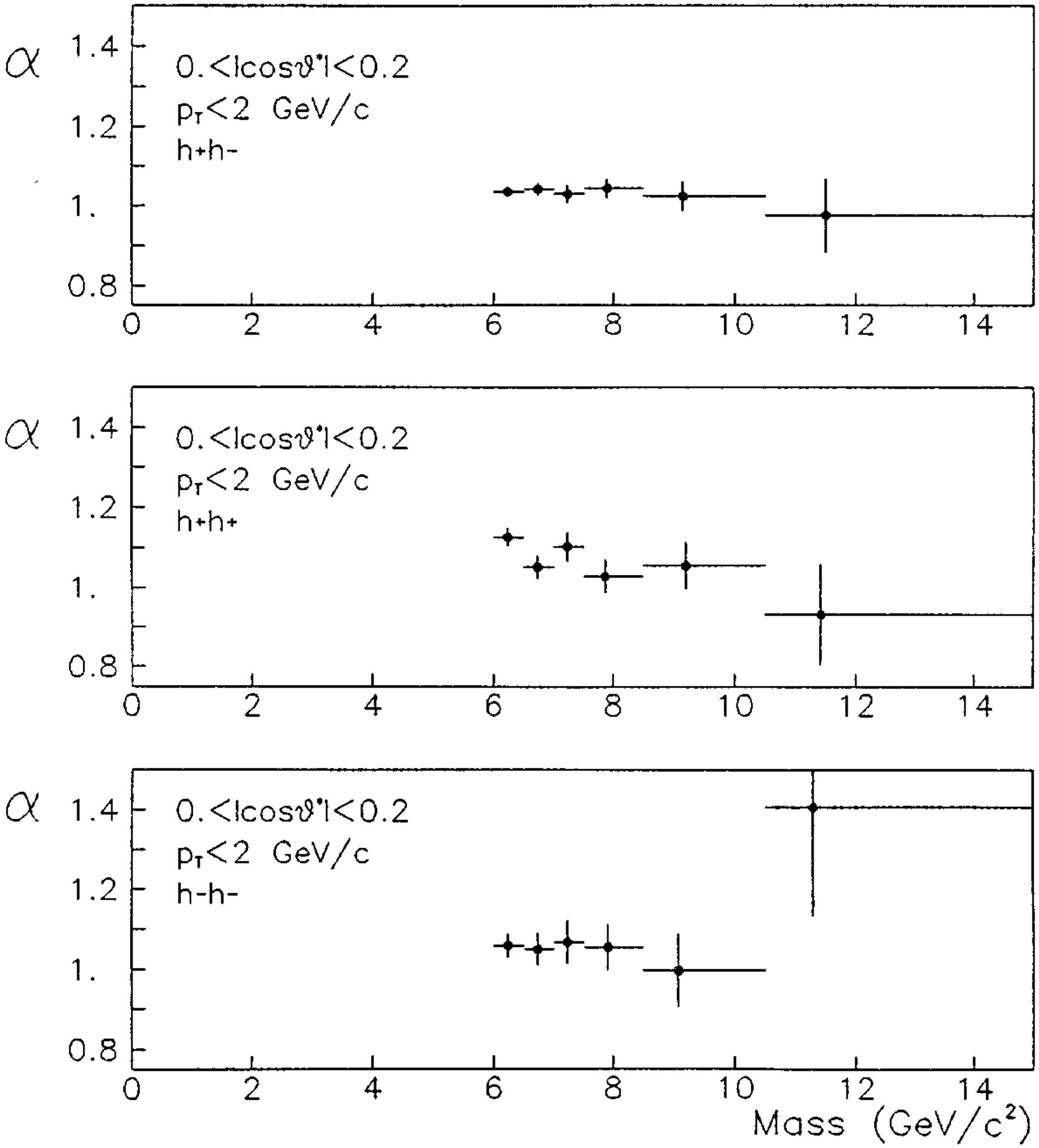

Figure 3

Variation of α with mass $p_t < 2$ GeV/c, $h+$ and $h-$ refer to positive and negative hadrons.