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INCLUSIVE ANTI-DEUTERON PHOTOPRODUCTION AT HERA

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Anti-deuteron photoproduction ($Q^2 < 10^{-2}$ GeV^2) has been measured, by the H1 Collaboration, at a mean centre-of-mass energy of $W_{\gamma p} = 200$ GeV. The numbers of anti-deuterons per event are found to be similar to those in central proton-proton collisions but much lower than those in high energy heavy nuclear collisions. The coalescence parameter B_2, which characterizes the likelihood of anti-deuteron production, is measured in photoproduction to be $0.010 \pm 0.002 \pm 0.001$, which is much higher than in heavy nuclear collisions at a similar nucleon-nucleon centre-of-mass energy.

Measurements of anti-deuteron production are described from data taken by the H1 Collaboration [1] using a minimum bias trigger with a total integrated luminosity of 5.5 pb^{-1}. The data are of particular interest in the context of recent studies of heavy ion collisions [2]. Deuteron and anti-deuteron production in particle collisions is thought to depend on a coalescence process [3]. In heavy ion collisions, the production rate depends on the size of the collision "fireball" at the stage at which the hadrons decouple [4], i.e. when final state interactions become unimportant. This is the so-called "thermal freeze-out" region.

In H1, particles are identified using their energy loss, dE/dx, measured in the central jet chamber. Anti-deuterons are measured in the range $0.2 < p_T/M < 0.7$ and laboratory frame rapidity $|y| < 0.4$, corresponding to a centre-of-mass rapidity of between 1.6 and 2.4 units[a]. In this range, the multiplicity distributions are on the central plateau [5] and they are compared to data in central pp collisions [6,7] and heavy ion collisions [8,9]. There have been several other measurements of anti-deuteron production in proton-proton (pp) [10], proton-nucleus (pA) [11], nucleus-nucleus (AA) [9] and electron-positron [12] collisions. These measurements are either for non-central production or at a centre-of-mass energy below 50 GeV.

The H1 data show a clear signal consisting of 45 anti-deuterons with negligible background, from which the inclusive cross sections are measured. Corrections for track efficiencies are determined from the data [1]. The total cross section for anti-deuteron production is found to be $2.7 \pm 0.5 \pm 0.2$ nb in the kinematic range defined. The ratio of the number of anti-deuterons to anti-protons in the range $|y| < 0.4$ and $0.3 < p_T/M < 0.7$ is measured to be $(5.0 \pm 1.0 \pm 0.5) \cdot 10^{-4}$. Figure 1 shows the measurements of the invariant cross section, normalised to the relevant total cross section, taken to be $165 \pm 11 \mu$b for photoproduction [13], as a function of p_T/M.

[a] The rapidity and pseudorapidity are defined by $y = 0.5 \ \ln[(E + p_z)/(E - p_z)]$ and $\eta = -\ln(\tan\theta/2)$ for a particle with total energy E, z component of momentum p_z and polar angle θ. The $+z$-axis (forward direction) is taken to be along the incident proton beam direction.

Figure 1 also shows the measured ratio of the corrected numbers of anti-deuterons to anti-protons versus p_T/M.

Measurements of the normalised invariant anti-deuteron cross section and the ratio of the anti-deuteron to anti-proton production rates performed by other high energy experiments in the central region are also shown in figure 1. The normalised cross section and ratio measurements obtained in pp collisions [6,7] and the photoproduction results are in good agreement, suggesting that the anti-deuteron formation processes are similar. The data on Au-Au collisions show a ratio which is slightly larger than that in pp collisions and photoproduction. However, the normalised invariant cross section is over two orders of magnitude larger than that in photoproduction or pp collisions, reflecting the more copious production of anti-nucleons in heavy ion collisions.

The coalescence parameter B_2 is given by,

$$B_2 = \frac{\frac{1}{\sigma}\frac{E_{\bar{d}}\mathrm{d}^3\sigma_{\bar{\mathrm{d}}}}{\mathrm{d}^3\mathrm{P}}}{\left(\frac{1}{\sigma}\frac{E_{\bar{p}}\mathrm{d}^3\sigma_{\bar{\mathrm{p}}}}{\mathrm{d}^3\mathrm{p}}\right)^2} = \frac{M_{\bar{p}}^4}{M_{\bar{d}}^2}\frac{R^2}{\left(\frac{1}{\sigma}\frac{\gamma_{\bar{d}}\mathrm{d}^3\sigma_{\bar{\mathrm{d}}}}{\mathrm{d}^3(\mathrm{P}/\mathrm{M}_{\bar{\mathrm{d}}})}\right)}. \tag{1}$$

Here, $M_{\bar{p}}$ and $M_{\bar{d}}$ are the masses of the $\bar{p}$ and $\bar{d}$ and σ, $\sigma_{\bar{p}}$ and $\sigma_{\bar{d}}$ are the total interaction cross section and the partial cross sections for $\bar{p}$ and $\bar{d}$ production, respectively. The quantity, R, is the measured ratio of the number of anti-deuterons to anti-protons from direct production in each bin of p_T/M, corrected for anti-protons formed remotely from the source by weak decays. In the coalescence model, only anti-nucleons produced directly from the source can form anti-deuterons. The number of $\bar{p}$ from direct production is taken to be $78 \pm 8\%$ of the number observed. This is estimated using the PYTHIA Monte Carlo [14], the accuracy being determined by the uncertainty in the strangeness suppression factor in this model. Hence, there is an overall theoretical uncertainty of about 20% in the determination of B_2. The weak decay correction is somewhat larger for heavy ion collisions [8] which is thought to be due to enhanced strangeness production [15].

The average value of B_2 in photoproduction at $W_{\gamma p} = 200$ GeV is determined to be $0.010 \pm 0.002 \pm 0.001 \pm 0.002$, where the first uncertainty is statistical, the second systematic from the errors in the efficiencies and the third the theoretical error from the weak decay correction. Figure 2 shows the mean value of B_2 in photoproduction, compared with the values obtained from the data of a variety of other experiments as a function of centre-of-mass energy. The value of B_2 measured in photoproduction is similar in magnitude to the values deduced at lower centre-of-mass energies in pp and pA interactions (labelled "elementary" in figure 2). However, this value of B_2 is over an order of magnitude larger than that observed in Au-Au collisions at RHIC at a similar nucleon-nucleon centre-of-mass energy. Comparison of the heavy ion data with the data from more elementary targets shows that this discrepancy grows with centre-of-mass energy. To avoid confusion associated with the A dependence of the colliding ions, the heavy ion data in figure 2 are restricted to very heavy ions. They are also restricted, at centre-of-mass energy below 50 GeV, to measurements of inclusive deuteron and proton production to avoid threshold effects in anti-deuteron production. The Bevelac data, at which energy the A dependence is weak, are the Ne-Au measurements of [16]. The AGS data are the Au-Pt measurements of the

E886 experiment [17], the SPS data are the Pb-Pb measurements of NA44 [18] and NA52 [19] and the RHIC data are from the Au-Au measurements of the STAR Collaboration [8]. The "elementary" data are the pA data of [16,17,20], the pp data at the ISR [6,7] and the photoproduction data presented here.

In the coalescence model for heavy ion collisions, the parameter B_2, varies inversely with both the volume of the fireball at freeze-out and the absolute rate of anti-nucleon production when both the spatial and momentum dependence are included in the model [4]. The $\bar{d}$ to $\bar{p}$ ratio is observed in pp and γp collisions to be close to that in Au-Au collisions, yet there is a much larger anti-nucleon production rate, and a smaller value of B_2 in Au-Au collisions. These facts can be reconciled in the coalescence model if the size of the fireball at freeze-out in pp and γp collisions is much smaller than that in Au-Au collisions.

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References

1. H1 Collaboration, to appear in Eur. Phys. J. (arXiv:hep-ex/0403056).
2. R.P. Duperray, K.V. Protasov and A.Yu. Voronin, Eur. Phys. J. **A16** (2003) 27 (nucl-th/0209078).
3. S.T. Butler and C.A. Pearson, Phys. Rev. **129** (1963) 836;
   A. Schwarzschild and C. Zupancic, Phys. Rev. **129** (1963) 854;
   H.H. Gutbrod et al., Phys. Rev. Lett. **37** (1976) 667;
   H. Sato and K. Yazaki, Phys. Lett. **B98** (1981) 153;
   L.P. Csernai and J.I. Kapusta, Phys. Rep. **131** (1985) 223.
4. R. Scheibl and U. Heinz, Phys. Rev. **C59** (1999) 1585 (nucl/th/9809092);
   A. Polleri, R. Mattiello, I.N. Mishustin and J.P. Bondorf, Phys. Lett. **B473** (2000) 193 (nucl-th/9904012).
5. See figure 39.4, Particle Data Group, K. Hagiwara et al., Phys. Rev. **66** (2002) 1.
6. B. Alper et al., Phys. Lett. **B46** (1973) 265.
7. W.M. Gibson et al., Lett. Nuov. Cim. **21** (1978) 189.
8. The STAR Collaboration, C. Adler et al., Phys.Rev.Lett. **87** (2001) 262301-1, (nucl-ex/0108022).
9. For a review of the lower energy data see A.G. Hansen Ph.D. Thesis (Niels Bohr Institute) available at http://www.nbi.dk/na44/publications.html.
10. V.V. Abramov et al., Sov. J. Nucl. Phys. **45** (1987) 845;
    CHLM collaboration, M.G. Albrow et al., Nucl. Phys. **B97** (1975) 189.
11. V.V. Abramov et al., reference [10];
    F. Binon et al., Phys. Lett.**B30**(1969) 510;
    Yu.M. Antipov et al., ibid., **B34**(1969)164;
    J.W. Cronin et al., Phys. Rev. **D11** (1975) 3105;
    A. Aoki et al., Phys. Rev. Lett. **69** (1992) 2345;
    T.A. Armstrong et al., Phys. Rev. **C59** (1999) 2699.

12. ARGUS Collaboration, H. Albrecht et al., Phys. Lett. **B236** (1990) 102.
13. H1 Collaboration, S. Aid et al., Z. Phys. **C69** (1995) 27;
ZEUS Collaboration, S. Chekanov et al., Nucl. Phys. **B627** (2002) 3.
14. T. Sjöstrand et al., Comp. Phys. Commun. **135** (2001) 238.
15. D. Hardtke, private communication.
16. S. Nagamiya et al., Phys. Rev. **C24** (1981) 971.
17. E886 Collaboration, G. Diebold et al., Phys. Rev. **C48** (1993) 2984.
18. NA44 Collaboration, I. G. Bearden et al., EPJ **C23** (2002) 237.
19. NA52 Collaboration, G. Appelquist et al., Phys. Lett. **B376** (1996) 245.
20. NA44 Collaboration, H. Boggild et al., Nuclear Physics **A590** (1995) 483c.

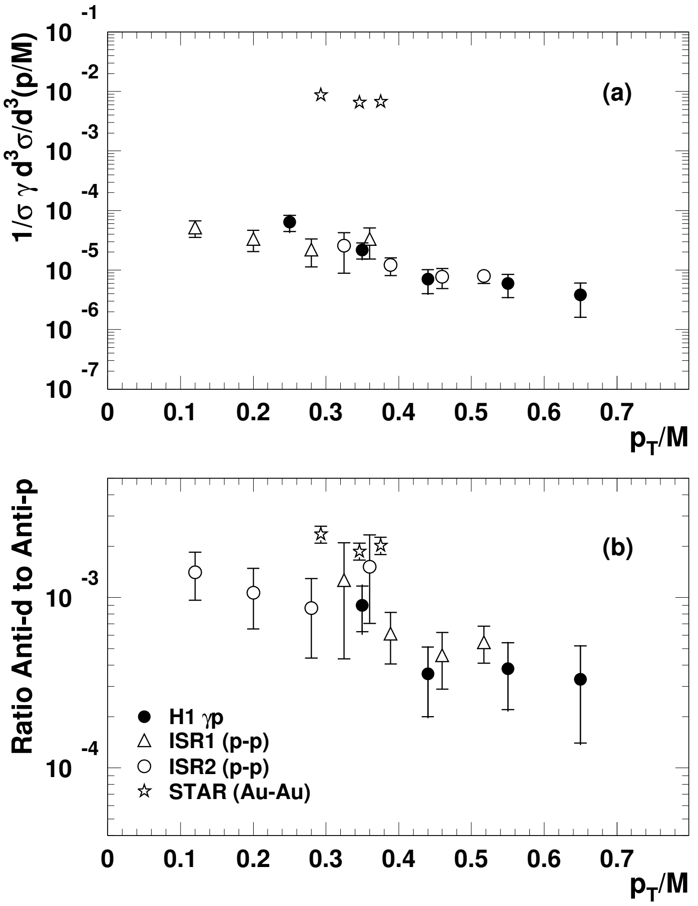

Figure 1. a) The measured invariant cross section (normalised to the relevant total cross sections) for inclusive $\bar{d}$ production, compared with the pp and Au-Au data. b) The measured $\bar{d}$ to $\bar{p}$ production ratio as a function of p_T/M (solid points) compared with pp data from the ISR at $\sqrt{s} = 53$ GeV in the central region [6,7] and RHIC data on Au-Au collisions [8].

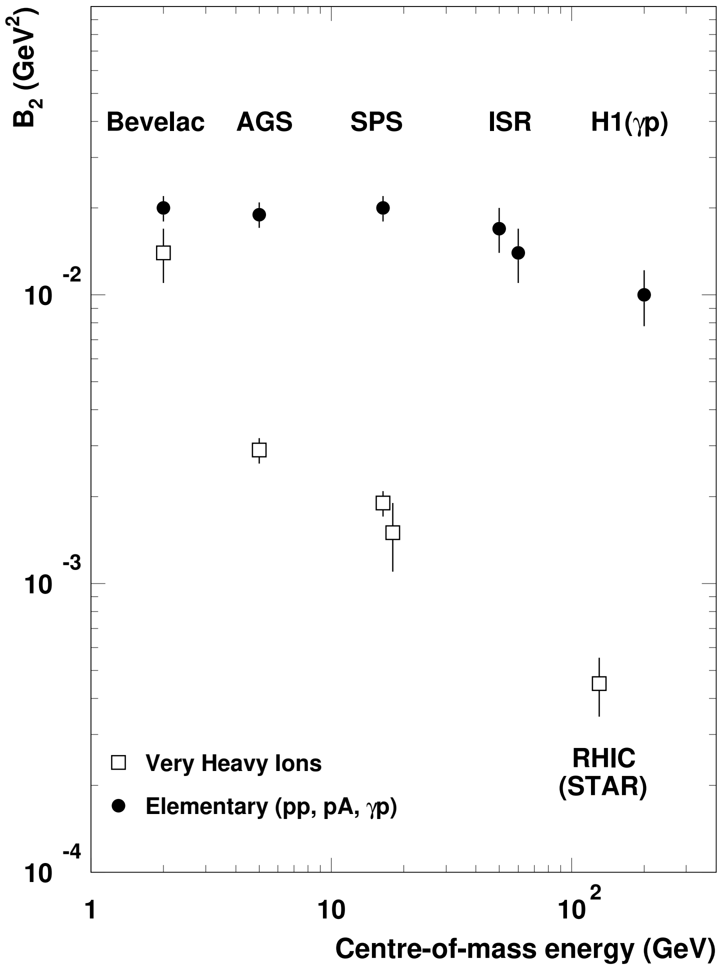

Figure 2. The dependence of B_2 on centre-of-mass energy for very heavy ion collisions (open squares) and interactions of more elementary particles (closed circles). The heavy ion data are the Ne-Au data at the Bevelac [16], the E886 Au-Pt data at the AGS [17], the Pb-Pb data of NA44 [18] and NA52 [19] at the SPS and the Au-Au data of STAR [8] at RHIC. The "elementary" data are the pA data of [16,17,20], the pp xdata at the ISR [6,7] and the photoproduction data presented here. In the latter the error bar represents the total uncertainty i.e. the sum in quadrature of the systematic and statistical uncertainties.