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HADRONIC FINAL STATES AND SPECTROSCOPY IN EP COLLISIONS AT HERA

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Recent results on spectroscopy and the measurement of hadronic final states in *ep* collisions from the H1 and ZEUS collaborations are presented using data sets with an integrated luminosity between 44 and 121 pb^{-1} collected during the HERA I running period. Besides a search for resonant states which could be interpreted as pentaquarks, a study of charged particle momentum spectra in the Breit frame and a measurement of neutral strange hadron production is shown. Furthermore two recent measurements of prompt photons are presented and compared with pQCD calculations. The measurements are performed in photoproduction (γp) with a four-momentum transfer squared $Q^2 \sim 0\,\mathrm{GeV}^2$ or in deep inelastic scattering (DIS) at $Q^2 > 1\,\mathrm{GeV}^2$.

Keywords: pentaquark, prompt photon, charged particle multiplicity, spectroscopy, HERA.

1 Spectroscopy

1.1 Measurement of K^0_S, Λ and $\bar{\Lambda}$ Production

The production of the neutral strange hadrons K^0_S, Λ and $\bar{\Lambda}$ has been measured[1] by the ZEUS collaboration. In addition to differential cross sections, further measurements are presented, such as the baryon-antibaryon asymmetry, baryon-to-meson ratio, ratio of strange-to-light hadrons, and the Λ ($\bar{\Lambda}$) transverse spin polarisation.

The ARIADNE Monte Carlo program can describe the differential cross sections in transverse momentum P_T and pseudorapidity $\eta = -\ln\tan(\theta/2)$ of the hadrons reasonably well when adjusting the strangeness-suppression factor to $\lambda_s = 0.3$, although the cross section at high Q^2 is overestimated. ARIADNE adjusted to $\lambda_s = 0.22$ is giving less satisfactory results.

The baryon-to-meson ratio $\mathcal{R} = (N(\Lambda) + N(\bar{\Lambda}))/N(K^0_S)$ varies between 0.2 and 0.5 in DIS, which is in agreement with measurements at e^+e^- colliders[2], where $\mathcal{R}$ ranges between 0.2 and 0.4. $\mathcal{R}$ is described by ARIADNE ($\lambda_s = 0.3$) to better than 10–20%. In γp a dijet sample is compared to the PYTHIA event generator. At large values of $x_\gamma^{\rm OBS} > 0.75$, where $x_\gamma^{\rm OBS}$ is a measure of the fraction of the photon energy transferred to the dijet system, $\mathcal{R}$ is found to be roughly 0.4, which is in agreement with the PYTHIA prediction and also corresponds to the values seen in DIS as discussed above. For low values of $x_\gamma^{\rm OBS}$, $\mathcal{R}$ rises to a value of about 0.7, while PYTHIA predicts a flat $x_\gamma^{\rm OBS}$ dependence.

The measured ratio of strange-to-light hadrons $\mathcal{T} = N(K^0_S)/(N(\pi^\pm)+N(K^\pm)+N(p)+N(\bar{p}))$ lies between 0.05 and 0.1 varying with P_T. A comparison with ARIADNE suggests a strangeness-suppression factor $\lambda_s < 0.3$.

1.2 Search for Baryonic States Decaying to $\Xi\pi$ in Deep Inelastic Scattering

A search for narrow baryonic resonances decaying into $\Xi^-\pi^-$ or $\Xi^-\pi^+$ and their antiparticles is carried out[3] with the H1 detector in DIS. No signal is observed for a new baryonic state in the mass range 1600–2300 MeV in neither the doubly charged ($\Xi^-\pi^-$, $\bar{\Xi}^+\pi^+$) nor the neutral ($\Xi^-\pi^+$, $\bar{\Xi}^+\pi^-$) decay channels. In the neutral charged combinations there is a clear signal of the well-known $\Xi(1530)^0$ resonance with 170 signal events. The NA49 collaboration[4] observed two baryonic resonances with masses around 1.86 GeV, which can be interpreted as pentaquark states. The observation can not be confirmed by the H1 measurement.

Mass dependent upper limits at 95% confidence level relative to the $\Xi(1530)^0$ signal $R_{u.l.}(M)$ are derived making use of a modified frequentist approach. The limits vary between 0.15 and 0.6 with values of $R_{u.l.}(1860) \sim 0.2(0.5)$ for the doubly (neutral) charged combinations. The sum of all charged combinations yields an upper limit of $R_{u.l.}(1860) \sim 0.5$, which is in agreement with the upper limit of 0.29 derived by the ZEUS collaboration[5].

1.3 Charged Particle Production in high Q^2 Deep Inelastic Scattering

The process of parton fragmentation and hadronisation has been studied[6] by H1 using charged particle momentum spectra at high Q^2. The measurement is performed in the current region of the Breit frame with an energy scale given by $Q/2$. Observables in the current region of the Breit frame can be compared with similar observables measured in one hemisphere of e^+e^- annihilation events, where the energy scale is half the centre-of-mass energy $E^*/2$. In the Breit frame the scaled momentum variable x_p is defined as $p_h^\pm/(Q/2)$, where $p_h^\pm$ is the momentum of a charged track. In e^+e^- annihilations the corresponding observable is $2p_h^\pm/E^*$.

The inclusive, event normalised charged particle scaled momentum spectrum defined as $D(x_p, Q) = (1/N_{event})dn^\pm/dx_p$ is shown in Fig. 1 as a function of Q for different bins of x_p and is compared with results from e^+e^- annihilation events. The ep and e^+e^- data are in broad agreement supporting the concept of quark fragmentation universality. The spectra become softer when moving from low to high Q, which implies a substantial increase in the number of hadrons with a small share of the initial parton's momentum. These scaling violations are assumed to be caused by parton splitting in QCD, i.e. the same effect that causes the scaling violations observed in deep inelastic structure functions. The parton shower model as implemented in RAPGAP gives the best description of the charged particle momentum spectra over the full range of x_p.

1.4 Measurement of $\bar{d}$ and $\bar{p}$ Production in Deep Inelastic Scattering

The production of (anti)deuterons, $d(\bar{d})$, and (anti)protons, $p(\bar{p})$, has been studied[7] in DIS with the ZEUS detector and represents the first measurement of $\bar{d}$ production in DIS. The

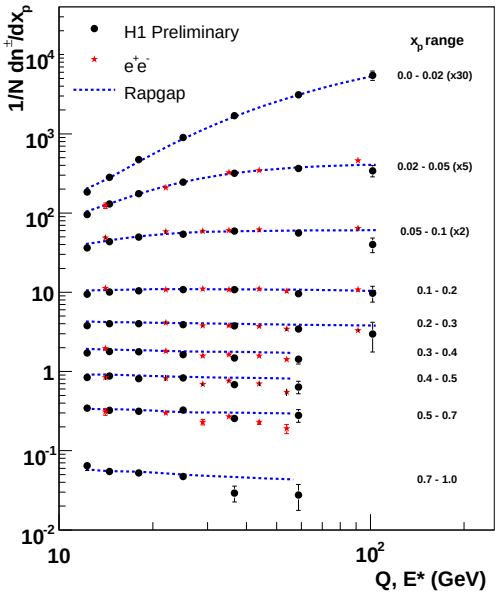

Figure 1: H1 data for the event normalised inclusive scaled momentum spectrum as function of Q for nine different x_p regions compared to data from e^+e^- annihilation events. Also shown is the prediction by the RAPGAP Monte Carlo program.

(anti)deuterons and (anti)protons are identified by means of the energy-loss measurement dE/dx in the central tracking detector.

The corrected $\bar{d}$ production rate is found to be 3–4 orders of magnitude lower than the corrected $\bar{p}$ yield, which is in agreement with the H1 published data[8] in γp. Furthermore the measured $\bar{p}/p$ ratio is consistent with unity. Within the given statistics antitritons have not been observed.

2 Prompt Photon Production

2.1 Inclusive Prompt Photon Production in Deep Inelastic Scattering

A measurement of prompt photons in DIS[9] has been presented by the H1 collaboration. Compared to the previous measurement[10] of prompt photons in DIS, the total cross section expectation is increased by roughly a factor of 10 due to a markedly extended phase space. The photon's transverse energy and pseudorapidity range is given by $3 < E_T^\gamma < 10\,\mathrm{GeV}$ and $-1.2 < \eta^\gamma < 1.8$.

Photons are identified by a compact electromagnetic cluster in the main calorimeter with no track pointing to it. The major background due to neutral hadrons inducing multi-photon clusters is considerably reduced by an infrared-safe isolation criteria. The extraction of the photon content from the remaining neutral hadron background is done by a fit to the output of a multivariate shower shape analysis. The measured differential cross sections $d\sigma/dE_T^\gamma$ and $d\sigma/d\eta^\gamma$ are compared to a LO(α^3) calculation[11]. The differential cross section $d\sigma/dE_T^\gamma$ is well described in shape, though the calculation is too low in normalisation. The underestimation is most visible at central pseudorapidities as can be seen in Fig. 2 a).

At large pseudorapidities the dominant contribution is photon radiation by the quark, while at low pseudorapidities, close to the scattered electron, the contribution of photon radiation from the electron is dominant.

2.2 Measurement of Prompt Photons with Associated Jets in Photoproduction

The photoproduction of prompt photons, together with a separate jet in addition to the photon, has been studied[12] with the ZEUS detector at HERA.

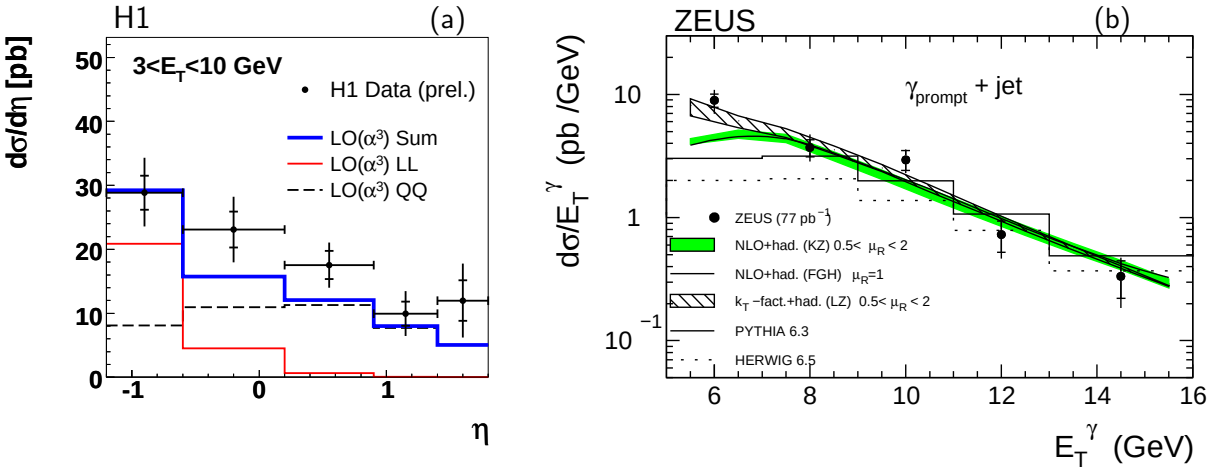

Figure 2: Inclusive prompt photon differential cross section $d\sigma/d\eta^\gamma$ in DIS as measured by H1 (a) and the photon plus accompanying jet differential cross section $d\sigma/dE_T^\gamma$ in γp as measured by the ZEUS collaboration (b). The measurements are compared to various pQCD calculations.

The photon identification is based on the conversion probability of photons to e^+e^- in front of a preshower detector (BPRE). The photon kinematics is restricted to $5 < E_T^\gamma < 16\,\text{GeV}$ and $-0.7 < \eta^\gamma < 1.1$, while the accompanying jet is selected in the kinematic range $6 < E_T^{\text{jet}} < 17\,\text{GeV}$ and $-1.6 < \eta^{\text{jet}} < 2.4$. A similar infrared-safe isolation criteria as in the above H1 analysis is used. Differential cross sections as functions of E_T^γ and η^γ are compared to two NLO calculations (cf. references in[12]). As visible in Fig. 2 b) both calculations describe the data rather well, however underestimate the data at low E_T^γ. Another calculation (cf. reference in[12]) based on a k_T factorisation approach yields the best description of the cross sections, particularly at low E_T^γ. When raising the minimum transverse energy to $E_T^\gamma > 7\,\text{GeV}$, the data is well described by all three predictions.

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