Shedding Light on Photons with HERA, Or: Three Glimpses at a γ - Remnant

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- Photoproduction of Neutral Pions in the Backward Region
  - Or: The Expected.
- Production of Light Complex Nuclei, Namely Antideuterons
  - Or: The Non - Unexpected.
- Proton - Antiproton Asymmetry in the Central Region: Baryon Number Travels Down the Rapidity Highway
  - Or: The (Rather) Unexpected.
- H1 Preliminary Results!

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The Stage:

⇒ All this happens in the “Photon Hemisphere”, in $Q^2 \approx 0$ electron - proton collisions (that is: Photoproduction) in H1 at HERA:

- $\gamma - p$ events are selected through the Electron Tagger which ensures $Q^2 < 0.01$ GeV^2, at an average $\gamma - p$ CM energy of 200 GeV.

I) $\boldsymbol{\pi^0}$ Production in the Backward Region:

- Neutral pions are identified through the decay $\pi^0 \to \gamma\gamma$ (BR = 98.8 %).
  Detection of photons in the electromagnetic calorimeters Liquid Argon (central) and SpaCal (backward) ⇒
- Access to single particle inclusive cross section in a phase space region where the charged particle measuring capability of H1 is reduced ⇒ a new piece of evidence.
- Extension of previous inclusive measurement performed with charged particles in the Central Region (- 1.5 < y < + 1.5).
- Kinematical range explored by SpaCal: $-3.5 < y_{LS} < -1.4$

$\boldsymbol{\pi^0}$ Production, Results:

- Shape of two - photon invariant mass distribution well described by a Gaussian on top of a phenomenological background. Position of peak consistent with PDG value of π^0 mass within calorimeters' scale uncertainties. Width of Gaussian reflects calorimeter resolution.
- Cross section given as a function of LS rapidity and transverse momentum.
- The shape of the $p_\perp$ distribution (integrated over the SpaCal rapidity range) is well described by the famous "power law" fit

$$d\sigma/dp_\perp^2 \propto (1 + p_\perp/p_{\perp,0})^{-n}$$

with the exponent $n = (8.3 \pm 0.2)$.

This is in agreement with the "classical" value $n = 8$, see e.g. R. Blankenbecler, S. J. Brodsky, J. F. Gunion, PR D18 (1978) 900, observed in many hadron - hadron collisions.

II) Production of Anti - Deuterons:

- Matter - in the form of charged and neutral elementary particles - is created in any high energy reaction. Do we also produce "complex" nuclei, i.e. nuclei heavier than light hydrogen?

  ⇒

  look for heavy charged particles and identify them by simultaneous measurement of momentum and velocity:

  $$dE/dx = f(\beta\gamma)$$

  (Bethe - Bloch !)

  The knowledge of a particle's momentum and velocity (from the dE/dx measurement) leads to its mass and thus to its identity.

Procedure:

- Utilize the dE/dx- and momentum measurement capabilities of the H1 central drift chambers CJC.
- Select an interval in the (dE/dx vs. momentum) - plane where particle identification is unproblematic.
- Look for Anti- nuclei because nuclei (p, d, t, ...) are copiously produced in beam - wall interactions.
- Suppress background by selecting tracks originating from the main event vertex, in a polar angular range where track reconstructioin efficiency is high.

Antideuterons, Results:

- Count the number of genuine antideuterons in the momentum interval under consideration, namely $(0.55 < p_{\bar{d}} < 1.0$ GeV/c), and find:

$$N(\bar{d})/event = (13 \pm 4) \cdot 10^{-6}.$$

- This is consistent with findings of other experiments, e.g. pp and e^+e^-. For example: ARGUS at DORIS investigated electron - positron annihilation processes at CMS energies around 10 GeV. They find

$$N(\bar{d}) = (6.0 \pm 2.0 \pm 0.6) \cdot 10^{-5}$$

  per direct $\Upsilon(1S)$ hadronic decay.

- No antideuteron production has so far been observed at LEP energies. Lund theorists (G. Gustafson and J. Häkkinen, Z. Phys. C61 (1994) 683) predict a rate of $5 \cdot 10^{-5}$ per event at the Z resonance, i.e. the same rate as at the $\Upsilon(1S)$.

Limits on Heavy Particle Production:

- A by - product of the antideuteron analysis is the search for "heavy charged particles", i.e. (semi -) stable particles with any non - zero charge, and heavier than the proton.

  Here the H1 result is:

  $$\mathrm{N(“exotic”)/event} < 1.5 \cdot 10^{-6}\ (90\ \%\ \mathrm{CL})$$

  in an interval of scaled momentum

  $$0.30 < \frac{p}{M_x \cdot q} < 0.52$$

  for γp interactions at 200 GeV.

III) Proton - Antiproton Asymmetry, or: How Does Baryon Number Travel through Phase Space?

- In (very) high energy collisions with nucleons we expect to find the baryon number in the final state in the neighbourhood (in phase space) of the incoming baryon ⇒ “leading baryon”.

Proton - Antiproton Asymmetry, Continued:

- Is that true, or can (net!) baryon number travel into phase space regions far away from the leading baryon?
- If YES, then one expects an asymmetry of baryons over antibaryons e.g. in rapidity regions far away from the incoming proton.

  H1 look for the asymmetry:

$$A = 2 \cdot \frac{\#p - \#\bar{p}}{\#p + \#\bar{p}}$$

  in the Central Region, i.e. ≈ 8 units in rapidity away from the incoming proton.

Procedure / Results:

- Go - as was done in the $\bar{d}$ case - to a region in (dE/dx vs. momentum) - space where particle separation is unproblematic. Remove background carefully ⇒
- Count numbers of protons and antiprotons and find:

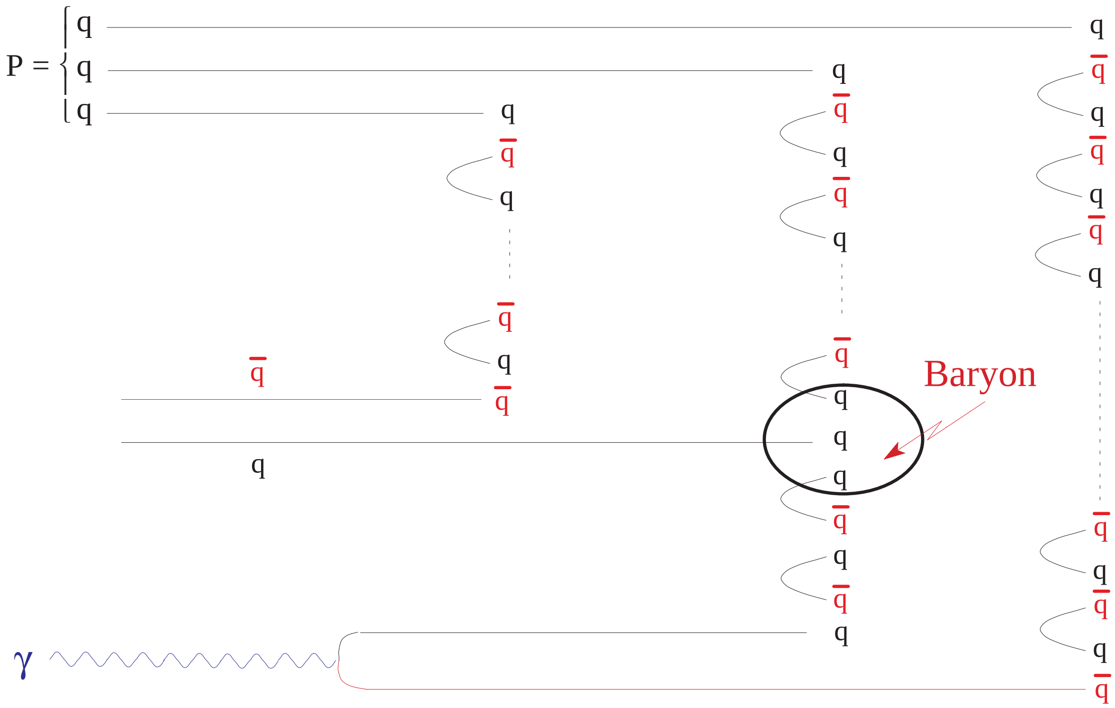
  $$A = (8.0 \pm 1.0 \pm 2.5)\%$$

  For comparison: Asymmetry for charged pions is zero ⇒.
- Apparently, baryon number CAN travel down the rapidity highway. HOW?

  The problem is under investigation by theorists. One novel idea by Kopeliovich and Povh (PL B446 (1999) 321) reads as follows:

Travelling Baryon Number:

- The incoming proton is “dissolved” by antiquarks from the fragmentation chain, while a new baryon emerges from the (“sea” + fragmentation) quarks:



- (Rather) new field of research, no final answer yet - BUT: Baryon number DOES travel!

Summary:

- Photoproduced π^0's fit in the picture taken with charged particles and are well described by models

  $\Rightarrow$ "The Expected".

- Light complex nuclei (= (anti-) deuterons) are produced in high energy $\gamma - p$ reactions at a small rate (as e.g. in e^+e^- annihilations at 10 GeV)

  $\Rightarrow$ "The Non - Unexpected".

- Baryon number does travel into phase space regions far away from the incoming proton

  $\Rightarrow$ "The (Rather) Unexpected".