

Hadron production in ep collisions at HERA

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on behalf of ZEUS collaboration

Presented results were obtained analysing data collected by the ZEUS detector at the HERA ep collider during the running period 1996-2000. The data correspond to an integrated luminosity of 121 pb^{-1} of which 82 pb^{-1} were collected at the ep centre-of-mass energy of 318 GeV (the electron or positron beam energy was 27.5 GeV and the proton beam energy was 920 GeV) and 39 pb^{-1} at the centre-of-mass energy of 300 GeV (where the proton beam energy was 820 GeV)

Outline of the presentation

The following results will be presented:

Measurement of K_s^0 , Lambda, Antilambda Production at HERA
European Physical Journal C51 (2007) 1-23

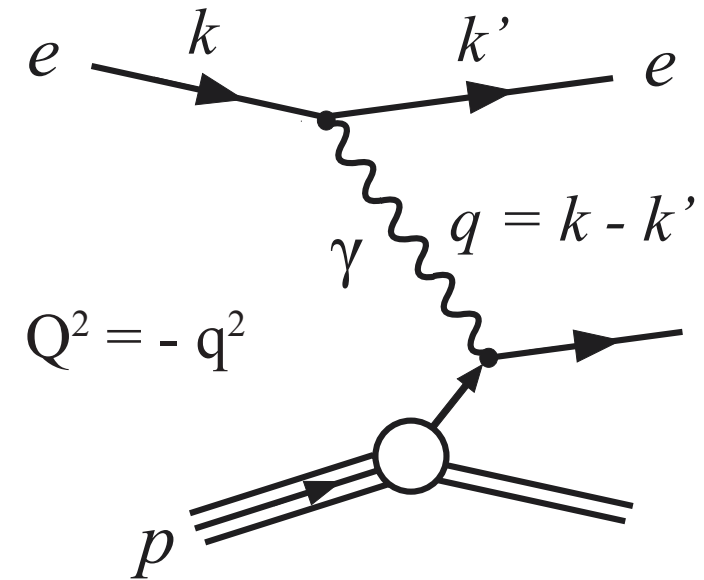
Three kinematic regions: DIS: $Q^2 > 25 \text{ GeV}^2$,
DIS: $5 < Q^2 < 25 \text{ GeV}^2$,
and photoproduction: $Q^2 \approx 0$. In photoproduction the presence of two hadronic jets, each with at least 5 GeV transverse energy, was required.

Measurement of (anti)deuteron and (anti)proton production in DIS at HERA
DESY-07-070 (May 2007), published online in Nuclear Physics B

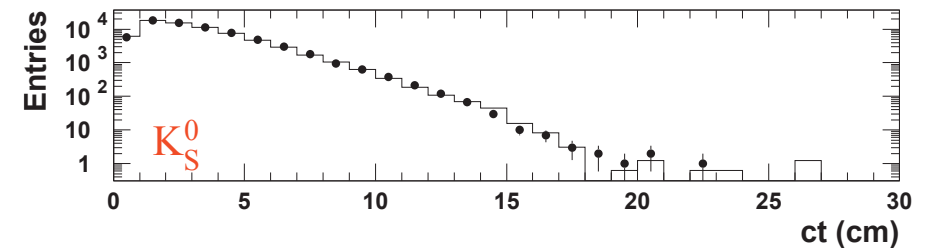
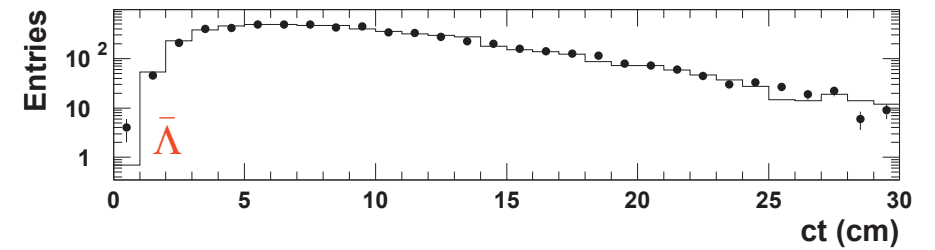
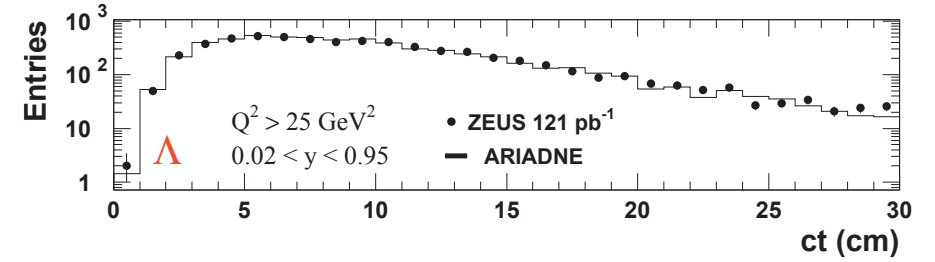
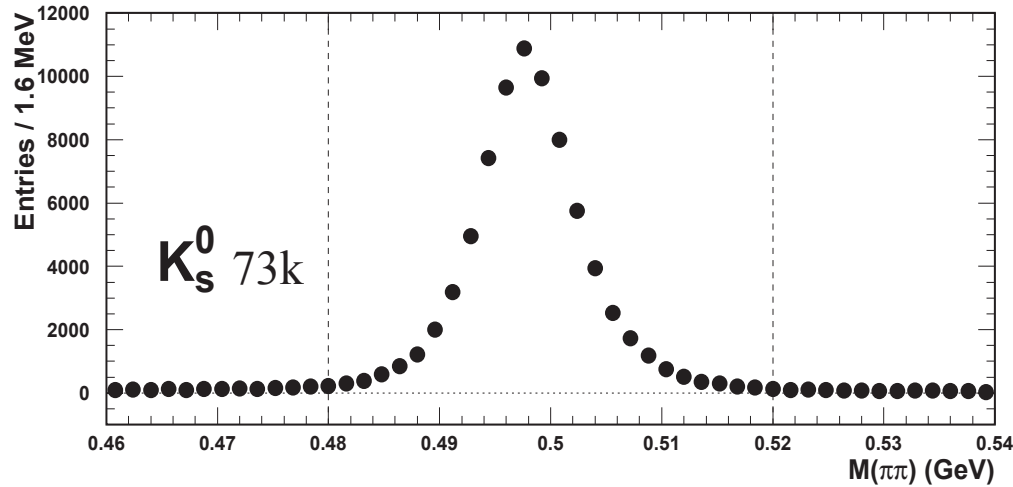
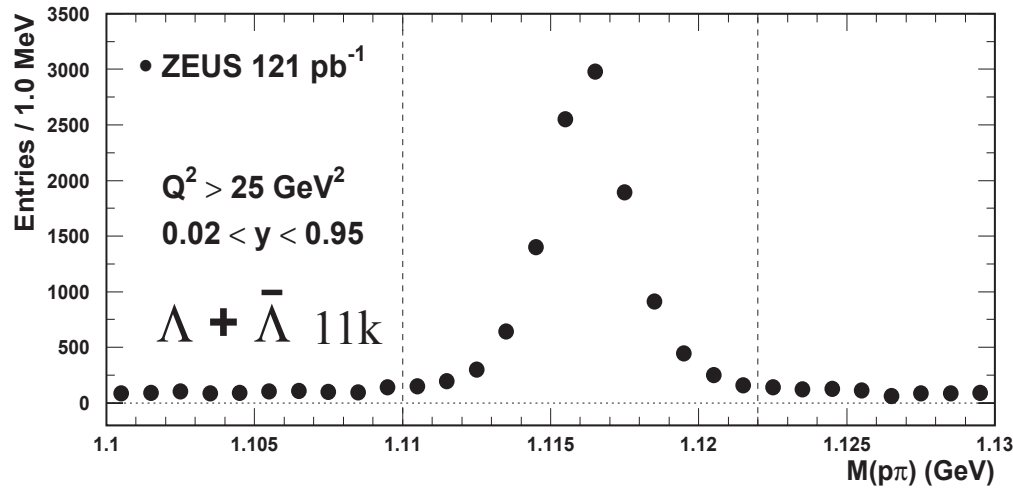
DIS: $Q^2 > 1 \text{ GeV}^2$

Bose-Einstein Correlations of Charged and Neutral Kaons in Deep Inelastic Scattering at HERA
DESY-07-069 (May 2007), published online in Physics Letters B

DIS: $2 < Q^2 < 15000 \text{ GeV}^2$

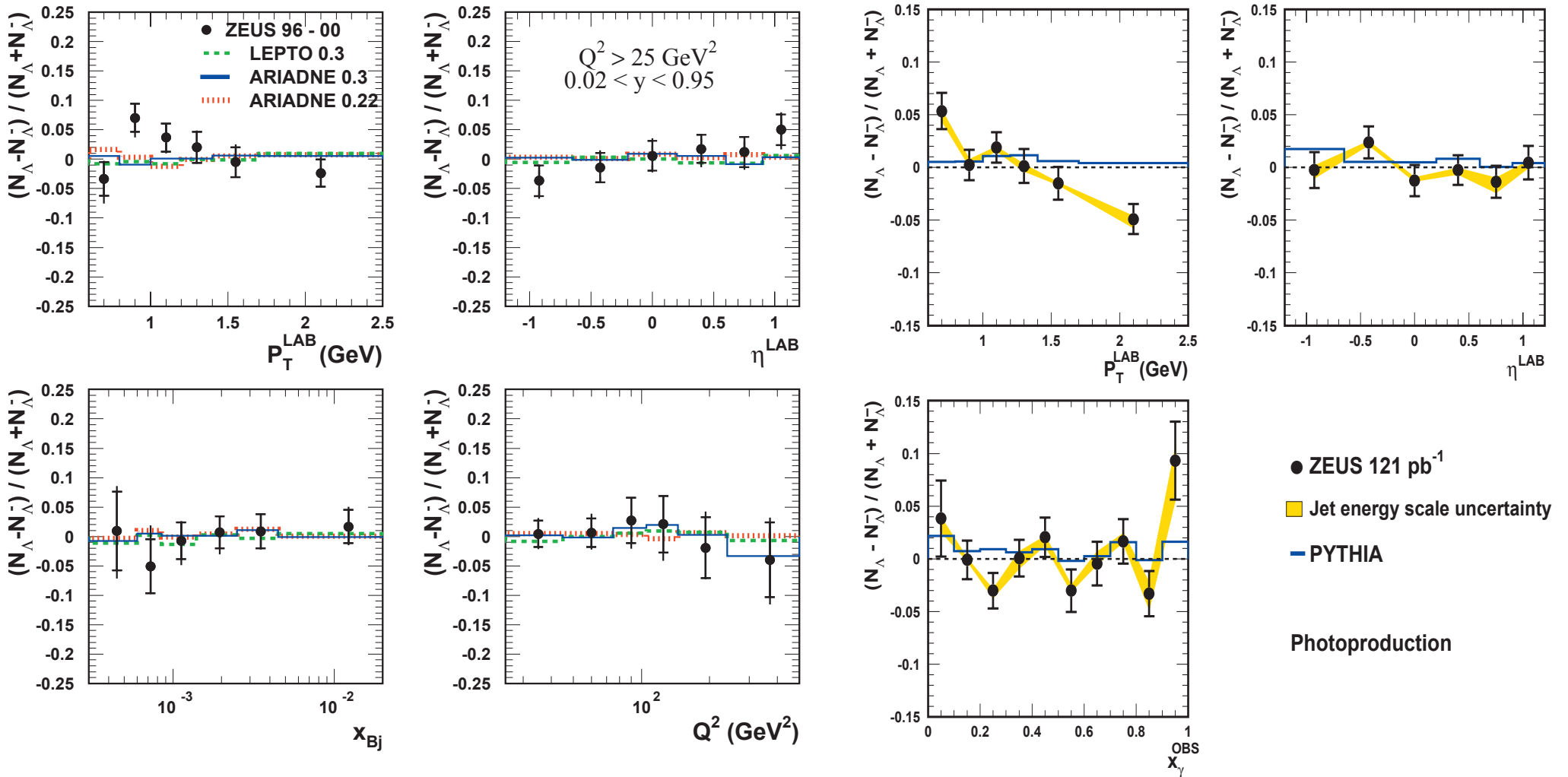


Quality of the data and quality of the detector-level description of the data by ARIADNE model



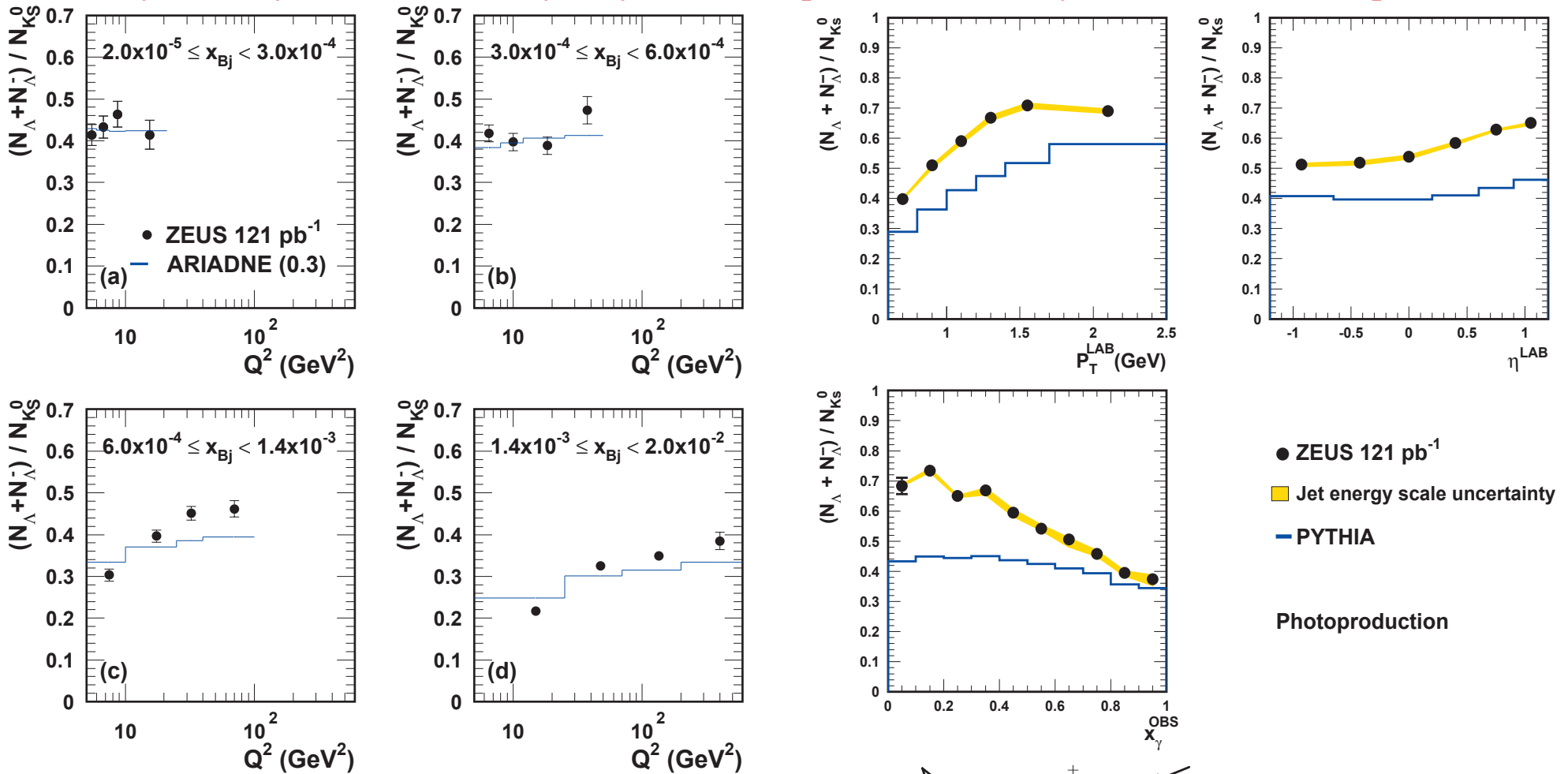
Detector-level distributions of the reconstructed proper lifetime t .

Number of lambdas = Number of antilambdas



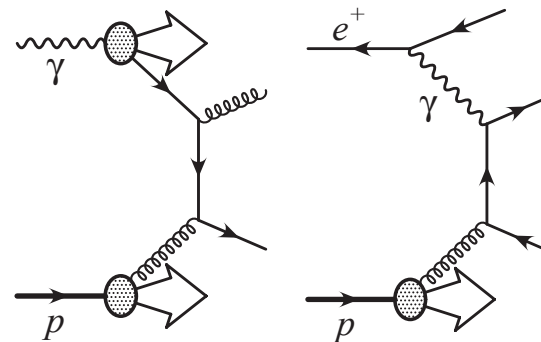
The numbers of lambda and antilambda baryons are consistent with being equal (with about 1% accuracy for the whole data sample). It is difficult for the “baryon number to travel” several units of rapidity.

Too many antibaryons and too many baryons where photon effectively acts as a source of partons

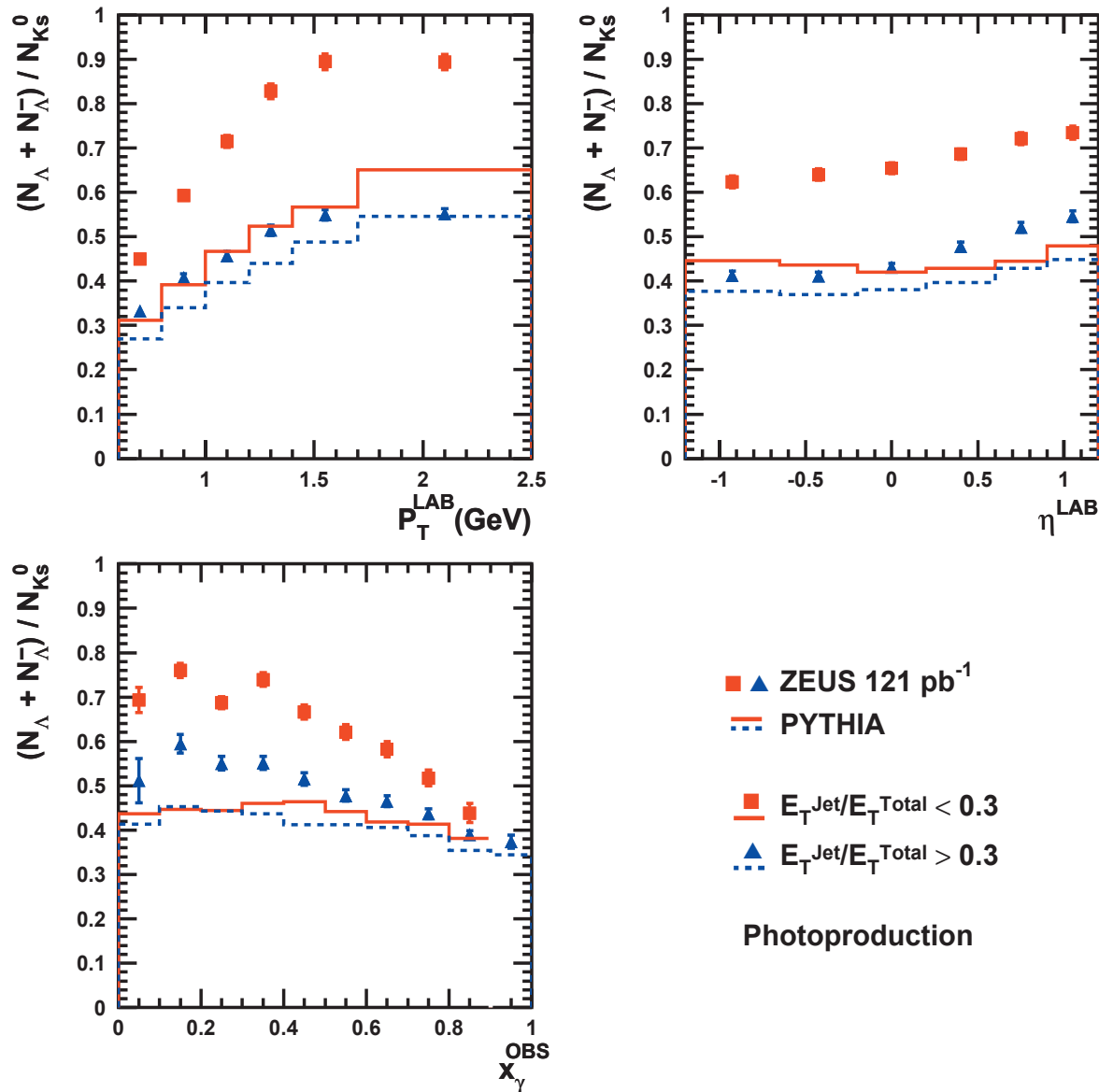


Except for the resolved photon interactions, the measured ratio of antibaryons (and baryons) to mesons is described by ARIADNE and PYTHIA models but in many cases, the agreement with the data is only at the 10 to 20% level. In the resolved photon region, the measured ratio is significantly larger than the PYTHIA prediction.

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Does large α_s prefer antibaryons and baryons ?



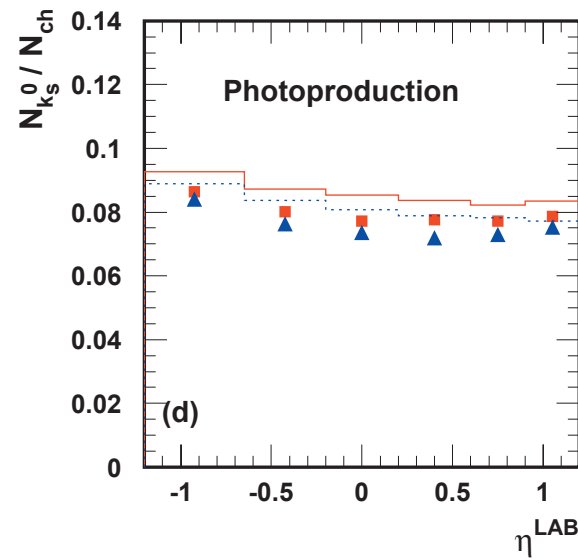
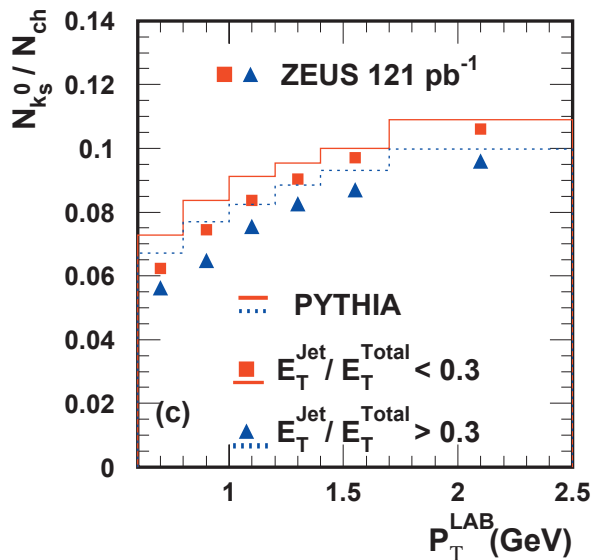
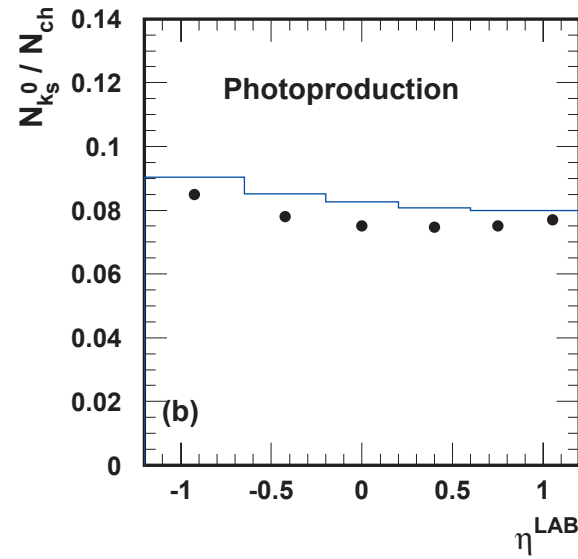
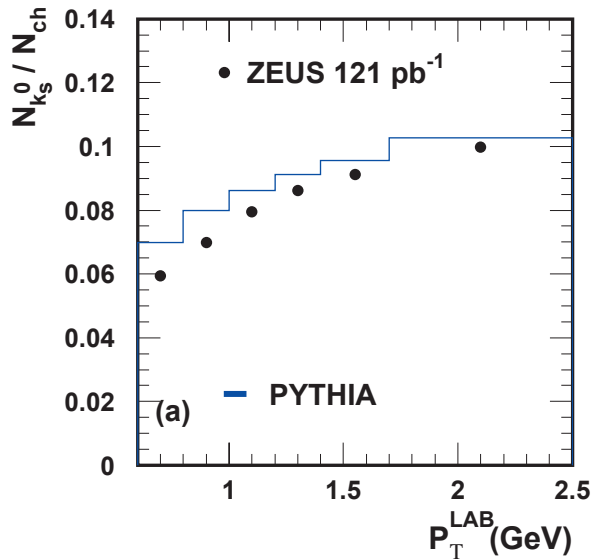
The enhancement of antibaryon and baryon production is observed in events with largely isotropic, fireball like, transverse energy flow. This effect is not described by PYTHIA model.

As typical transverse energy is low, α_s is large for fireball events. Does it mean that when α_s is growing, like on the way to confinement, antibaryons and baryons are getting some preference in comparison to mesons ? Could it be a feature of confinement ?

Is this enhancement hadronization problem ? Suppose the hadronization model is perfect but the input parton distribution wrong, then the hadron distribution would be wrong. Isn't it ?

No indication of any unusual yield of strange hadrons

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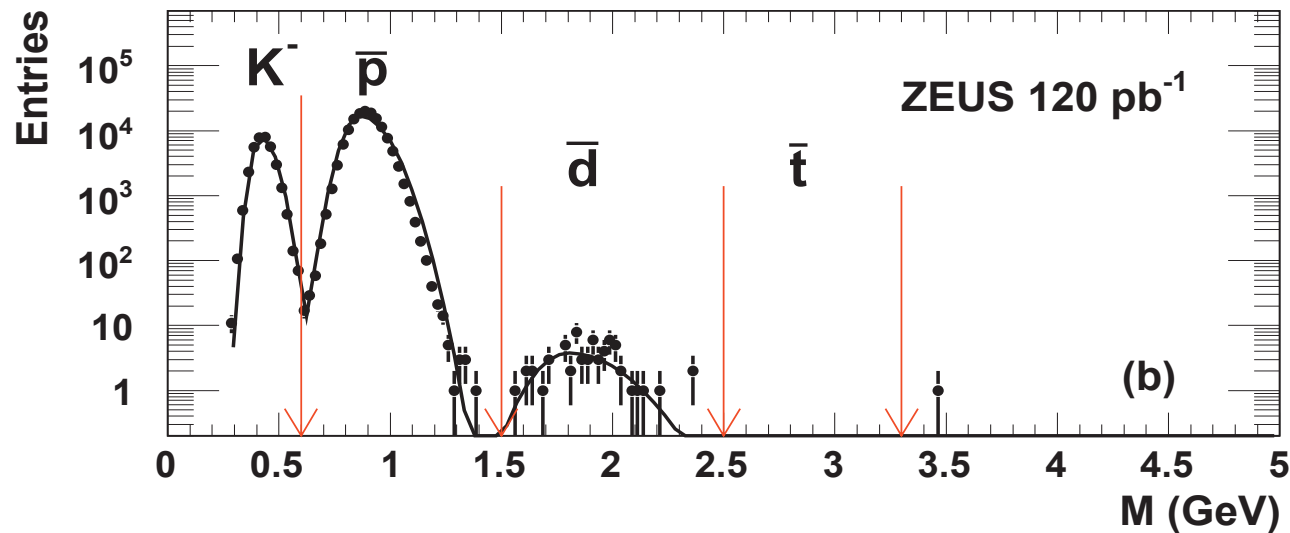
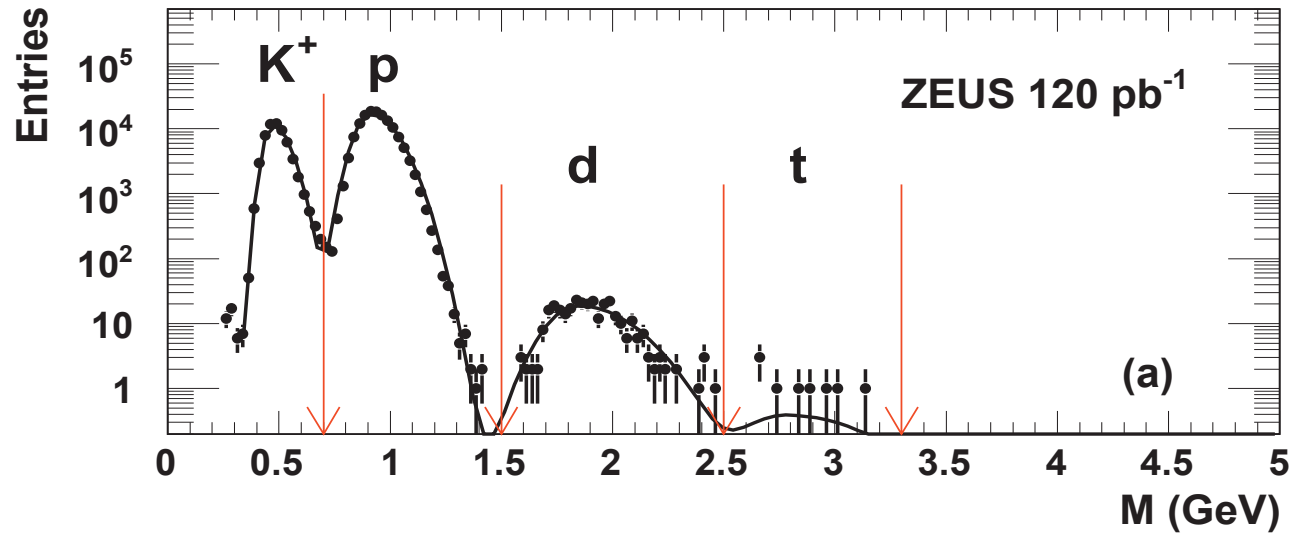
The ratio of strange-to-light hadrons is compatible with measurements at other colliders and is described by ARIADNE and PYTHIA models for all investigated samples of events.

There is no indication of any unusual yield of strange hadrons in the fireball like events with largely isotropic transverse energy flow, as would be expected had there been a significant contribution from QCD instantons.

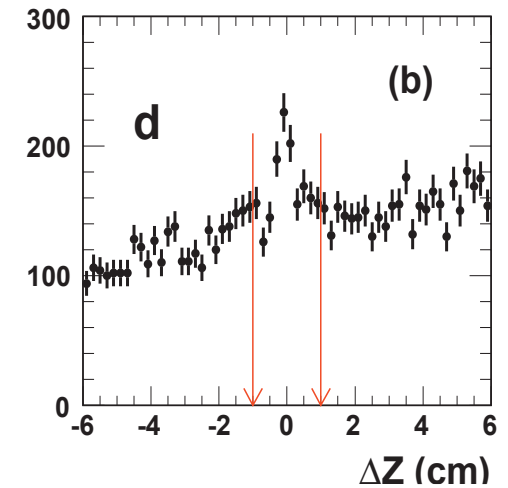
No evidence has been found for non-zero transverse polarization in inclusive lambda or antilambda production (at 5% accuracy level).

More antideuterons than deuterons

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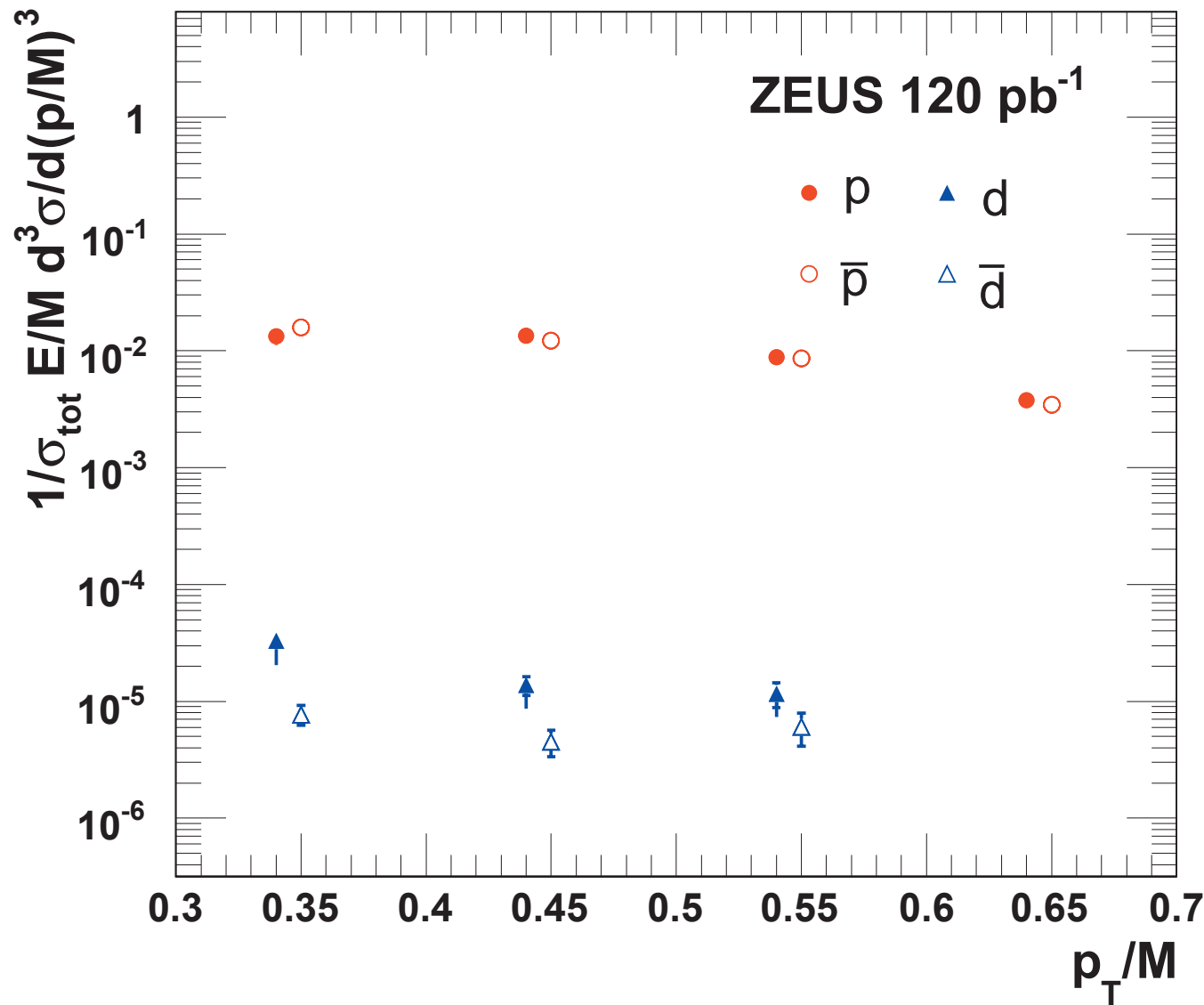
The masses were calculated from the measured track momentum and energy loss using Bethe-Bloch formula



ΔZ is the distance of the Z-component of the track helix to the Z component of the ep vertex.

$\approx 10^5$ proton and antiproton candidates,
 177 ± 17 deuteron and 53 ± 7 antideuteron candidates were found.

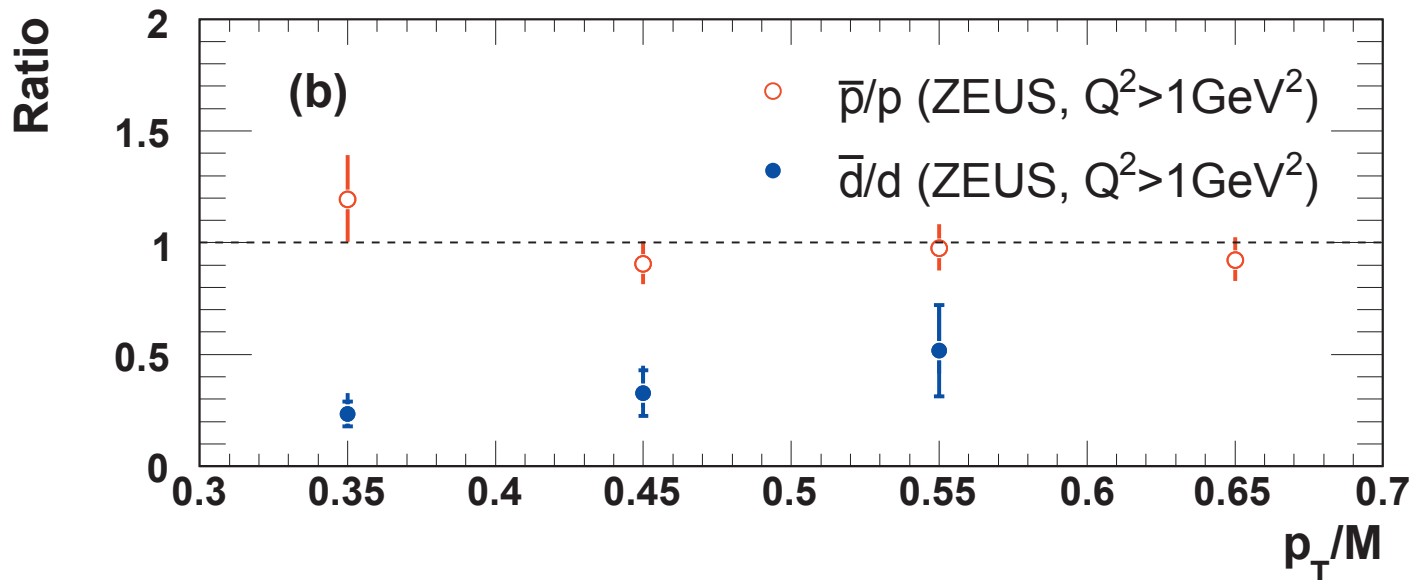
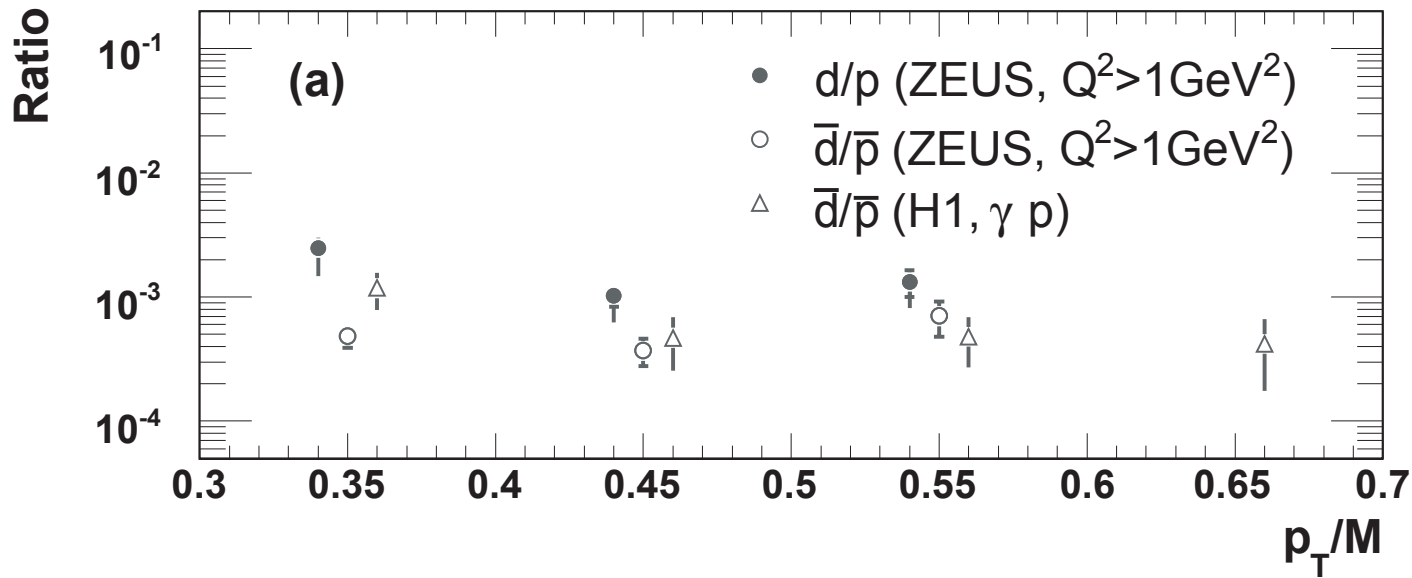
Difficult to predict the number of antideuterons and deuterons from the number of antiprotons and protons



The invariant differential cross sections for deuterons and antideuterons are approximately three orders of magnitude smaller than those of protons and antiprotons. According to the coalescence model, one would expect that deuteron and antideuteron cross sections would be similar as proton and antiproton cross sections are similar.

Why there are so few antideuterons in comparison to deuterons ?

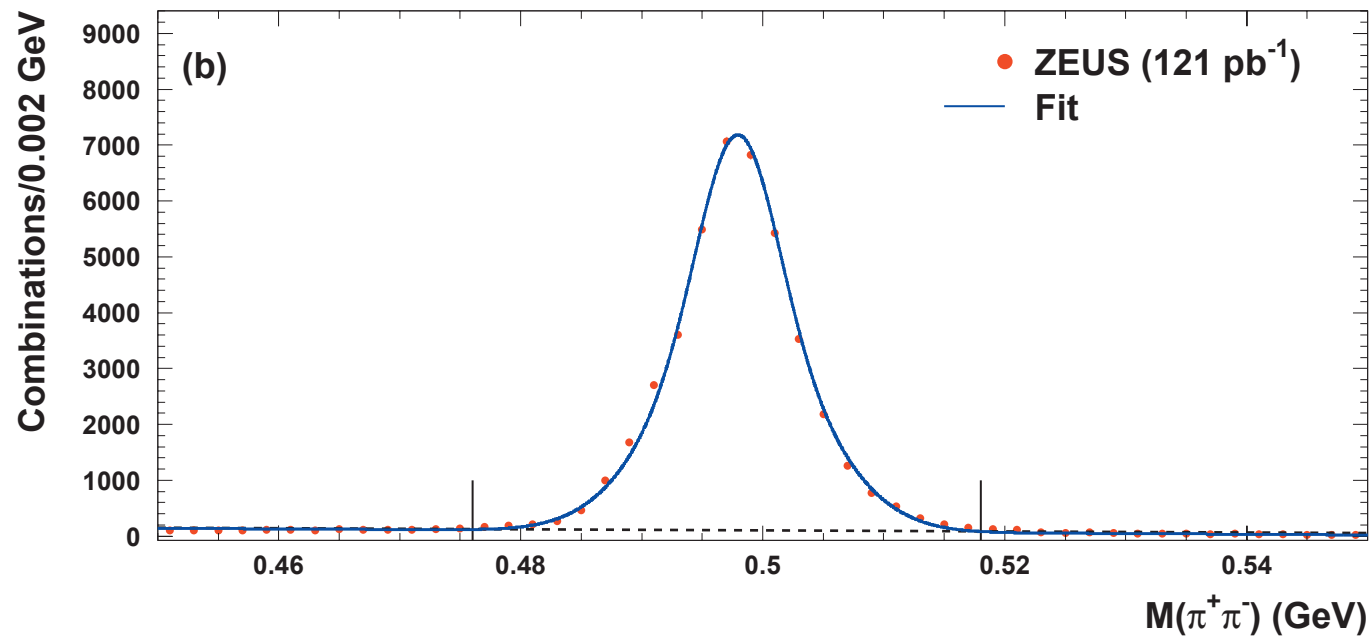
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The ratios of numbers of antideuterons to antiprotons are similar to those measured by H1 in photo-production.

As numbers of protons and antiprotons are similar and numbers of lambdas and anti-lambdas are similar, in gluon dominated DIS, **one would expect that the number of antideuterons would be similar to the number of deuterons. This expectation is surprisingly wrong ! WHY ?**

Clean and large samples of $K_s^0 K_s^0$, $K^+ K^+$ and $K^- K^-$ pairs



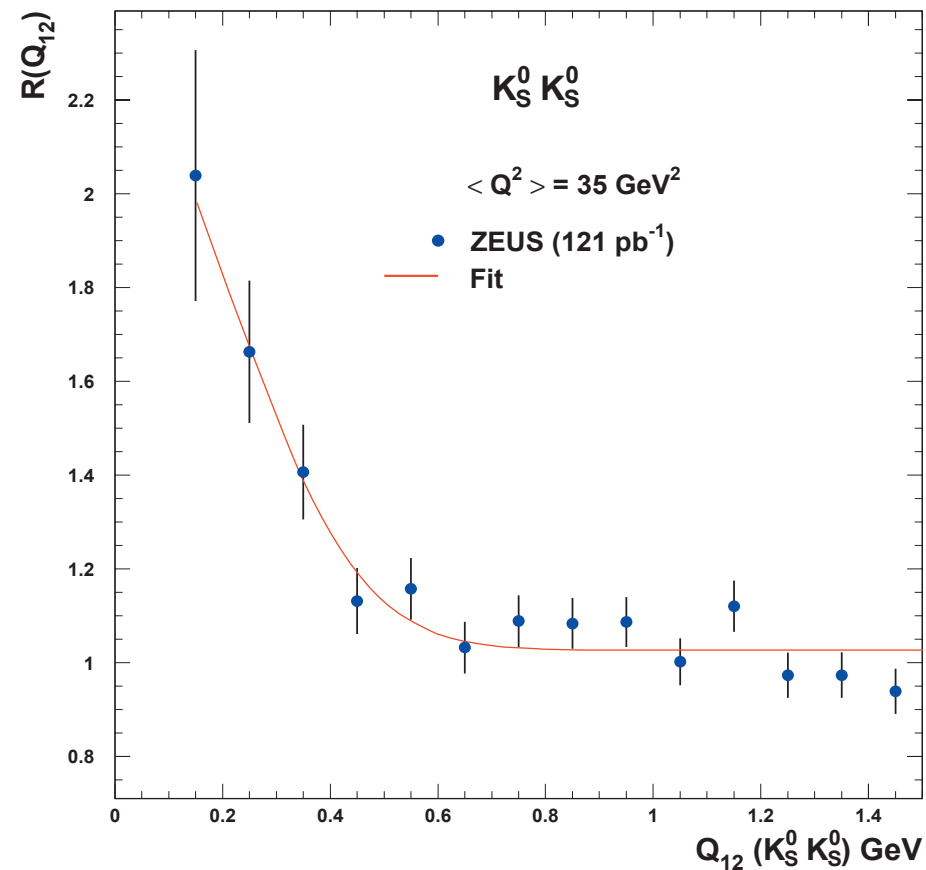
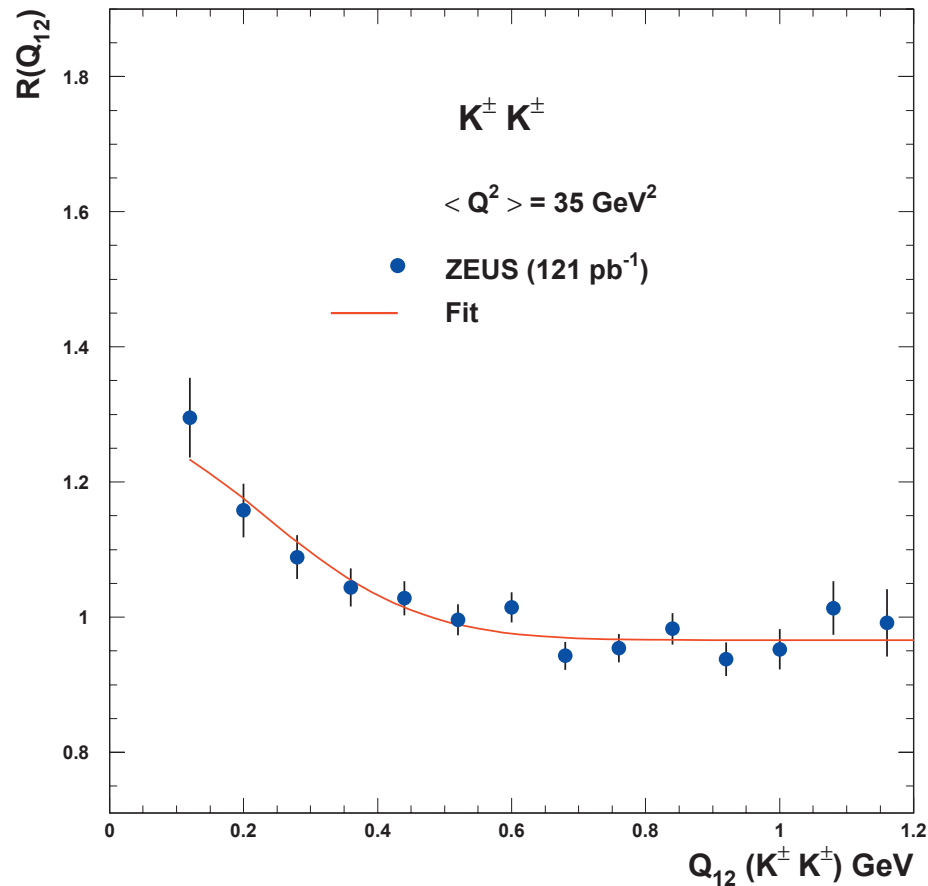
K_s^0 candidates were selected from within the mass window indicated by vertical lines.

Out of 725 505 K_s^0 candidates, 19 494 K_s^0 pairs and 400 triples were selected

K^+ and K^- candidates were selected using a measurement of their energy loss in the central tracking chamber.

The resulting data sample contained 55 522 kaon pairs.

Bose-Einstein Correlations demonstrated



$$Q_{12} = \sqrt{-(p_1 - p_2)^2}$$

$$R(Q_{12}) = \frac{P(Q_{12})}{P_0(Q_{12})}$$

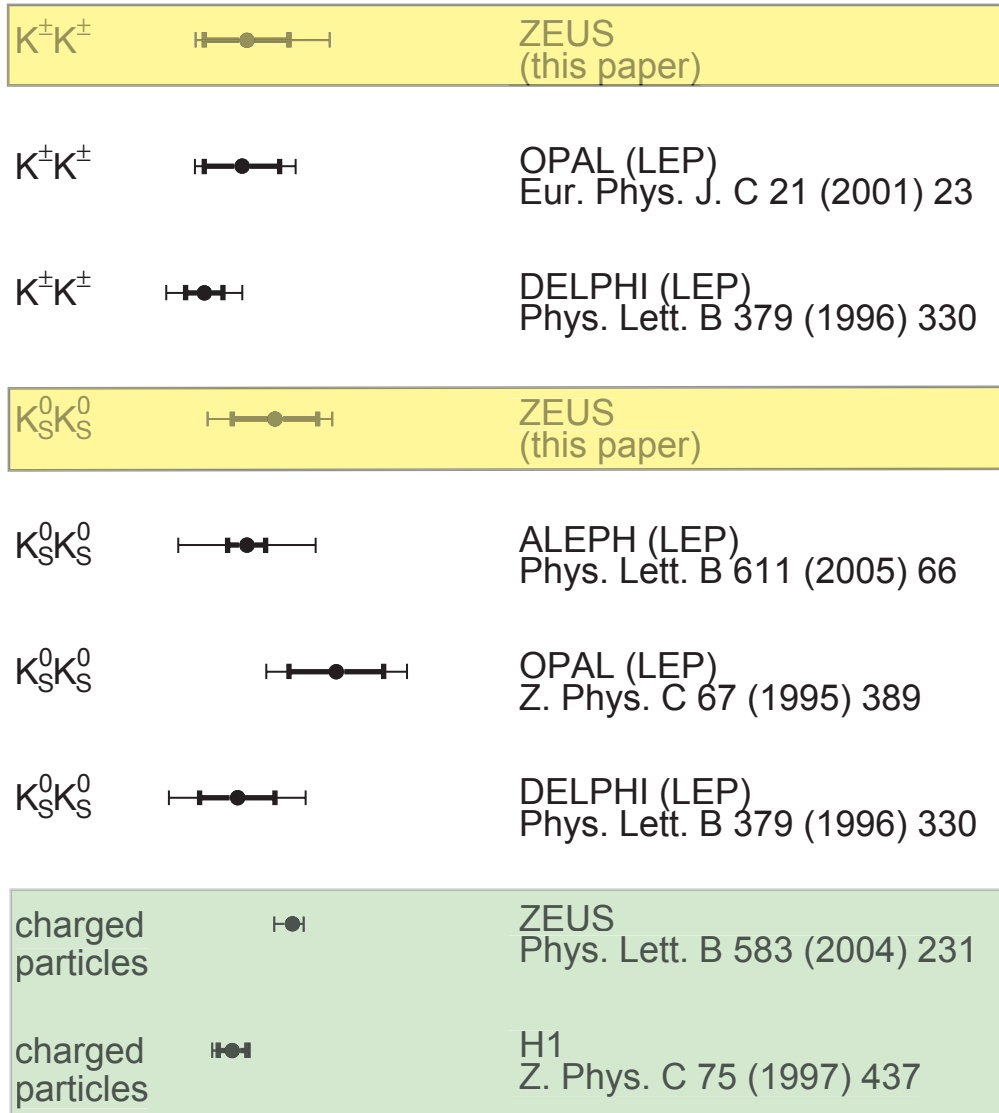
$R(Q_{12}) = 1 + \lambda \exp(-r^2 Q_{12})$ was fitted to the data. The parameter r is related to the size of the source and λ to the strength of the source. For a completely coherent source, λ is zero, while for a completely incoherent source, λ is one.

Experimentally, $R(Q_{12})$ is measured as a ratio of the two-particle density distribution

$$P(Q_{12}) = (1/N)(dn_{KK}/dQ_{12}) \text{ and } P_0(Q_{12})$$

where $P_0(Q_{12})$ is the two-particle density in the absence of Bose-Einstein Correlations.

The size r and the strength λ of the kaon source were extracted from the data



$K^\pm K^\pm$

$$\lambda = 0.37 \pm 0.07^{+0.09}_{-0.08}$$

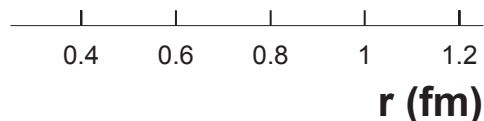
$$r = 0.57 \pm 0.09^{+0.15}_{-0.08} \text{ fm}$$

$K_S^0 K_S^0$

$$\lambda = 0.70 \pm 0.19^{+0.28+0.38}_{-0.08-0.52}$$

$$r = 0.63 \pm 0.09^{+0.07+0.09}_{-0.08-0.02} \text{ fm}$$

the second contribution to the systematic error comes from $f_0(980)$ resonance.



Outlook

Can we complete the path from partons to hadrons ?

partons at high Q^2



$Q^2 \approx 0$ but high E_t jets

parton fragmentation into hadrons like in e^+e^- annihilation but too few antibaryon molecules like antideuterons relative to baryon molecules. Why ? Are baryons produced first and baryonic molecules at the next step ?



$Q^2 \approx 0$ and low E_t jets but high total transverse energy, fireball like events

enhancement of antibaryon and baryon production relative to mesons. Why ? What about heavy baryons ? What is the size of the hadron source ? What about antideuterons ?



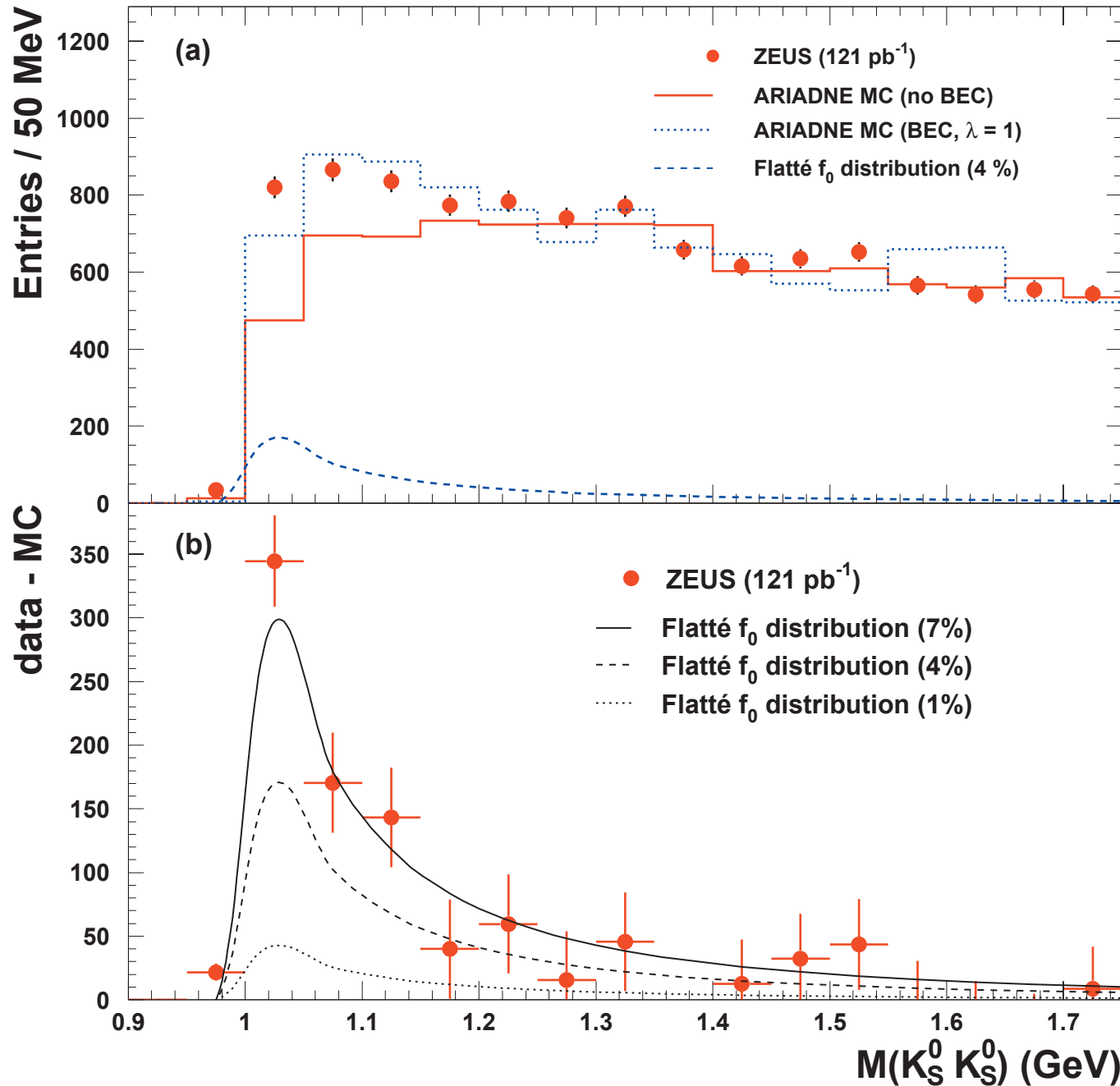
$Q^2 \approx 0$ and no jets, low total transverse energy but high particle multiplicity

are partonic degrees of freedom frozen already here ? How can we tell ?



$Q^2 \approx 0$ and no jets and low particle multiplicity → hadron physics

$f_0(980)$ contributes where Bose-Einstein Correlation is expected in $K_s^0 K_s^0$ case



The main difficulty to extract Bose-Einstein Correlation parameters in $K_s^0 K_s^0$ case is the existence of $f_0(980)$ resonance which contributes to small Q_{12} . The most probable contribution of $f_0(980)$ was found to be 4% but 1 sigma limit extends from 1 to 7%, making extraction of the λ parameter difficult. The extraction of the r parameter is almost not affected by this.

Figure (b) shows the difference between data and ARIADNE model without Bose-Einstein Correlation, compared to different $f_0(980)$ contributions.